



Letter

Search for a new scalar decaying into new spin-1 bosons in four-lepton final states with the ATLAS detector

The ATLAS Collaboration ^{*}

ARTICLE INFO

Editor: M. Doser

Dataset link: <https://www.hepdata.net/record/145171>

ABSTRACT

A search is conducted for a new scalar boson S , with a mass distinct from that of the Higgs boson, decaying promptly into four leptons ($\ell = e, \mu$) via an intermediate state containing two on-shell, promptly decaying new spin-1 bosons Z_d : $S \rightarrow Z_d Z_d \rightarrow 4\ell$, where the Z_d boson has a mass between 15 and 300 GeV, and the S boson has a mass between either 30 and 115 GeV or 130 and 800 GeV. The search uses proton–proton collision data collected with the ATLAS detector at the Large Hadron Collider with an integrated luminosity of 139 fb^{-1} at a centre-of-mass energy of $\sqrt{s} = 13 \text{ TeV}$. No significant excess above the Standard Model background expectation is observed. Upper limits at 95% confidence level are set on the production cross-section times branching ratio, $\sigma(gg \rightarrow S) \times \mathcal{B}(S \rightarrow Z_d Z_d \rightarrow 4\ell)$, as a function of the mass of both particles, m_S and m_{Z_d} .

1. Introduction

Notwithstanding its spectacular successes, the Standard Model (SM) is incomplete. In particular, the nature of dark matter is unknown. A potential framework for extending the SM to include dark matter is the Hidden Abelian Higgs Model (HAHM) [1–6], which posits a ‘hidden’ or ‘dark’ sector of particles and fields, including a field with a $U(1)_d$ symmetry that mixes kinetically with the SM $U(1)_Y$ hypercharge gauge field with some coupling strength ϵ . This results in an additional scalar S along with a new gauge boson Z_d or ‘dark photon’. The scalar S mixes with the SM Higgs boson with coupling κ , so all processes that can produce a SM Higgs boson also produce an S boson. Hence, the dominant production process for S in proton–proton (pp) collisions would be gluon–gluon fusion. The decays of the Z_d boson are determined by the gauge couplings and are independent of the mixings for $\epsilon, \kappa \ll 1$; the branching ratio of the Z_d boson into electron or muon pairs would therefore vary between 10% to 15% over the Z_d boson mass range $1 < m_{Z_d} < 300 \text{ GeV}$, except in the range $60 < m_{Z_d} < 135 \text{ GeV}$ where it is smaller, falling to about 4% at $m_{Z_d} = m_Z$ [1].

Previous studies [7–12] have searched for a resonantly produced SM Higgs boson mixing with a new scalar decaying into a $Z_d Z_d$ or a ZZ_d pair, with each Z_d or Z boson decaying into a pair of electrons or muons ($\ell \equiv e, \mu$) with opposite electric charge. Other simi-

lar searches, including searches for pairs of light bosons decaying into muons, τ -leptons, photons, and/or jets, as well as searches for a single light boson decaying into a pair of muons, using both $\sqrt{s} = 8 \text{ TeV}$ and $\sqrt{s} = 13 \text{ TeV}$ data, were performed at the Large Hadron Collider (LHC) by the ATLAS [13–17], CMS [18–21], and LHCb [22] experiments. Further searches for a SM Higgs boson decaying into undetected particles are reported in Refs. [23,24]. The present work extends the previous ATLAS $H \rightarrow Z_d Z_d \rightarrow 4\ell$ search [7], where the additional scalar S decaying into the $Z_d Z_d$ pair, $S \rightarrow Z_d Z_d \rightarrow 4\ell$, has a mass distinct from that of the SM Higgs boson. The search reported here is restricted to the region $m_S < 800 \text{ GeV}$ and $m_{Z_d} < 300 \text{ GeV}$. In the HAHM, the S and Z_d boson widths increase rapidly with mass, resulting in a loss of sensitivity above these masses. It is additionally restricted to regions of parameter space where all decays are prompt and further makes no use of information about any possible jets or missing transverse energy, so may also be sensitive to other signal processes that may produce extra particles in addition to four leptons.

2. The ATLAS detector

The ATLAS experiment [25] at the LHC is a multipurpose particle detector with a forward–backward symmetric cylindrical geometry and a near 4π coverage in solid angle.¹ It consists of an inner track-

^{*} E-mail address: atlas.publications@cern.ch.

¹ ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upwards. Polar coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z-axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$ and is equal to the rapidity $y = \frac{1}{2} \ln \left(\frac{E+p_z}{E-p_z} \right)$ in the relativistic limit. Angular distance is measured in units of $\Delta R \equiv \sqrt{(\Delta y)^2 + (\Delta \phi)^2}$.

ing detector surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadronic calorimeters, and a muon spectrometer. The inner tracking detector covers the pseudorapidity range $|\eta| < 2.5$. It consists of silicon pixel, silicon microstrip, and transition radiation tracking detectors. Lead/liquid-argon (LAr) sampling calorimeters provide electromagnetic (EM) energy measurements with high granularity within the region $|\eta| < 3.2$. A steel/scintillator-tile hadronic calorimeter covers the central pseudorapidity range ($|\eta| < 1.7$). The endcap and forward regions are instrumented with LAr calorimeters for EM and hadronic energy measurements up to $|\eta| = 4.9$. The muon spectrometer surrounds the calorimeters and is based on three large superconducting air-core toroidal magnets with eight coils each. The field integral of the toroids ranges between 2.0 and 6.0 Tm across most of the detector. The muon spectrometer includes a system of precision tracking chambers up to $|\eta| = 2.7$ and fast detectors for triggering up to $|\eta| = 2.4$. The luminosity is measured mainly by the LUCID-2 [26] detector, which is located close to the beam pipe. A two-level trigger system is used to select events [27]. The first-level trigger is implemented in hardware and uses a subset of the detector information to accept events at a rate close to 100 kHz. This is followed by a software-based trigger that reduces the accepted rate of complete events to 1.25 kHz on average depending on the data-taking conditions. A software suite [28] is used in data simulation, in the reconstruction and analysis of real and simulated data, in detector operations, and in the trigger and data acquisition systems of the experiment.

3. Data and simulated event samples

The data used in this search were recorded during the 2015–2018 LHC run with pp collisions at $\sqrt{s} = 13$ TeV. After requiring that all detector systems were operational [29] without excess calorimeter noise [30], this corresponds to an integrated luminosity of 139 fb^{-1} [31]. Events were selected by triggers requiring either one or two electron or muon candidates [32–34]. The trigger thresholds on transverse momentum p_T range from $p_T > 7$ GeV to $p_T > 60$ GeV, depending on lepton multiplicity and flavour. In either case, the trigger efficiency is above 95 % relative to the offline signal event selection criteria. Collision events are selected by requiring an identified primary vertex with at least two tracks [35] and at least four lepton candidates satisfying the requirements given in Section 4.

The expected contribution of the $S \rightarrow Z_d Z_d \rightarrow 4\ell$ ($\ell = e, \mu$) signal is determined from Monte Carlo (MC) simulations. Samples for this process are produced according to the HAHM implementation [36] for the gluon–gluon fusion production process at leading order (LO) using MADGRAPH5_aMC@NLO 2.2.2 [37] with the mixing parameters ϵ and κ both set to 10^{-4} so that decays of the Z_d boson are prompt [1]. Parton showers and decays are simulated using PYTHIA 8.186 [38], along with EVTGEN 1.2.0 [39] to decay heavy-flavour hadrons. The NNPDF2.3LO [40] set of parton distribution functions (PDFs) and the A14 tune [41] are used. The width of the scalar S is taken to vary with mass in the same way as the SM Higgs boson [42]. The signal samples cover different m_S and m_{Z_d} mass hypotheses, in two regions. In the first region, there are 32 samples with $30 \text{ GeV} \leq m_S \leq 110 \text{ GeV}$ and $15 \text{ GeV} \leq m_{Z_d} \leq 48 \text{ GeV}$ (the upper m_{Z_d} limit being chosen to avoid overlaps with the analyses of Ref. [7]; see Section 4), and in the second there are 49 samples with $150 \text{ GeV} \leq m_S \leq 800 \text{ GeV}$ and $15 \text{ GeV} \leq m_{Z_d} \leq 300 \text{ GeV}$. In both cases, $m_S > 2m_{Z_d}$. Detector effects are included using a GEANT4 [43] simulation of the ATLAS detector [44]. The effects of additional pp collisions in the same or a neighbouring bunch crossing (pile-up) are included in the simulation.

Most background processes are estimated by using MC simulations, which consider $\ell = e, \mu, \tau$, and thus include leptonic τ -lepton decays. The samples used are identical to those of Ref. [7] and are briefly summarized here. The non-resonant $q\bar{q} \rightarrow ZZ^* \rightarrow 4\ell$ and $gg \rightarrow ZZ^* \rightarrow 4\ell$ background processes are simulated using SHERPA 2.2.2 [45–51] at next-to-leading order (NLO) for up to one additional parton and at LO

for up to three additional partons. The $H \rightarrow ZZ^* \rightarrow 4\ell$ background is simulated with POWHEG BOX v2 [52–56] for the gluon–gluon fusion, vector–boson fusion, and $t\bar{t}H$ processes, with PYTHIA 8.186 for the VH process, and with MADGRAPH5_aMC@NLO for the $b\bar{b}H$ process. Higher-order electroweak processes, including triboson production (VVV) and vector–boson scattering (VBS), are simulated using SHERPA 2.2.2, while the process $t\bar{t} + (Z \rightarrow \ell\ell)$ is simulated with SHERPA 2.2.0. Other, reducible, backgrounds have fewer than four prompt leptons in the final state, but can be accepted by the event selection if there are additional leptons from, for example, heavy-flavour decay or jets misidentified as leptons. Backgrounds due to Z + jets and $t\bar{t}$ processes are estimated from data (see Section 5), but the method also requires simulations of these processes; the Z + jets process is simulated with SHERPA 2.2.1, while the $t\bar{t}$ process is simulated with POWHEG BOX v2. The WZ process was generated with POWHEG BOX at NLO. For processes simulated with MADGRAPH5_aMC@NLO and POWHEG BOX v2, PYTHIA is used to simulate parton showers and decays along with EVTGEN. For the portion of the $gg \rightarrow ZZ^* \rightarrow 4\ell$ sample with $m_{4\ell} > 130 \text{ GeV}$ (corresponding to a few percent of the total estimated background) and the VVV samples, detector effects are included using a fast simulation [44], of just the calorimeter response [57] component, which relies on a parameterization. All other samples use the full GEANT4 simulation.

In addition to the backgrounds mentioned above, numerous other simulated background processes were checked, including $t\bar{t}$ associated with a diboson pair, VH with the Higgs boson decaying into two W bosons, ZY , tH , tWH , and $q\bar{q} \rightarrow ZZ^*$ at low p_T . The contributions from these backgrounds were less than 0.1% of the total, so they were not included in the further background calculations.

4. Event selection

After reconstruction, electrons and muons are identified using the standard ATLAS ‘Loose’ criteria [58,59], defined to maximize the reconstruction and identification efficiencies while still providing good-quality candidates. Electron candidates must satisfy $p_T > 7$ GeV, $|\eta| < 2.47$, and must also have an additional associated hit in the innermost layer of the silicon detector. Longitudinal and transverse impact parameters with respect to the primary vertex must satisfy $|z_0 \sin \theta| < 0.5 \text{ mm}$ and $|d_0|/\sigma_{d_0} < 5$. Muon candidates must satisfy $p_T > 5$ GeV and $|\eta| < 2.5$, except that ‘calorimeter-tagged’ (CT) muons, identified by matching an inner-detector (ID) track (with no corresponding track in the muon system) with a deposit in the calorimeter consistent with a minimum-ionizing particle, must instead satisfy $p_T > 15$ GeV. Except for ‘stand-alone’ (SA) muons lacking a matching ID track, muon candidates must also have impact parameters satisfying $|z_0 \sin \theta| < 0.5 \text{ mm}$, $|d_0| < 1 \text{ mm}$, and $|d_0|/\sigma_{d_0} < 3$. Leptons must be isolated from other deposits in the calorimeter or ID tracks [58,59]. This rejects backgrounds in which leptons arise from the decay of heavy-flavour hadrons, or in which jets are misidentified as leptons [60]. For each lepton, the sum of the transverse energies of topological clusters [61] within a cone of $\Delta R = 0.2$ around it (excluding energy attributed to the lepton itself) must be less than 20% of its p_T for electrons, and less than 30% of its p_T for muons. The transverse momenta of tracks in a cone around the lepton are also summed, and must be less than 15% of its p_T . The radius of the cone depends on the momentum of the lepton. For electrons, it is $\Delta R = \min(0.2, 10 \text{ GeV}/p_T)$, while for muons it is $\Delta R = \min(0.3, 10 \text{ GeV}/p_T)$.

Quadruplets are then formed from two same-flavour, opposite-sign lepton pairs: either $4e$, $2e2\mu$, or 4μ . For the computation of isolation of a lepton in a quadruplet, tracks and energy clusters attributed to the other leptons in the same quadruplet are excluded from the sums. A quadruplet may contain no more than one CT or SA muon. In the case of four same-flavour leptons, two quadruplets are formed, one for each possible pairing. If there are more than four leptons then there may be additional quadruplets, depending on the flavours and signs of the leptons.

For each possible quadruplet, the invariant masses of the two pairs are denoted m_{ab} and m_{cd} , where $m_{ab} > m_{cd}$. If all four leptons have the same flavour, then the alternative pairing $m_{ad,bc}$ can be defined taking the positively charged lepton of the m_{ab} pair and the negatively charged lepton of the m_{cd} pair to make m_{ad} and the remaining two leptons to make m_{bc} .²

Each quadruplet must contain all the leptons corresponding to at least one of the triggers satisfied by the event. The three highest- p_T leptons must satisfy $p_{T\ell_1} > 20$ GeV, $p_{T\ell_2} > 15$ GeV, and $p_{T\ell_3} > 10$ GeV. To remove poorly-measured leptons and electrons from bremsstrahlung, all pairs of same-flavour leptons in the quadruplet must satisfy a separation requirement of $\Delta R(\ell, \ell') > 0.1$, while different-flavour pairs must satisfy $\Delta R(\ell, \ell') > 0.2$. At least one quadruplet per event is required. If more than one quadruplet passes these requirements, the one with the smallest mass difference between the two pairs, $\Delta m_{\ell\ell} = |m_{ab} - m_{cd}|$, is chosen.

All dilepton pair masses m_{ab} , m_{cd} , m_{ad} , and m_{bc} must be larger than 11.105 GeV, corresponding to $m_{Y(3S)} + 0.75$ GeV, where $m_{Y(3S)}$ is taken to be 10.355 GeV [62]. This removes events where the alternate pairing may be consistent with ZZ^* decay as well as events with lepton pairs consistent with J/ψ or Y decay.

Two signal regions are defined, each considering a scalar S with a mass different from that of the SM Higgs boson. The lower mass signal region (SR1) requires $m_{4\ell} < 115$ GeV and, to reject background from Z bosons, either $m_{ab} < 50$ GeV or $m_{ab} > 106$ GeV (this is the complement of one of the signal region requirements from the $H \rightarrow ZZ_d \rightarrow 4\ell$ search in Ref. [7], and was chosen to avoid overlap with that search). The higher mass signal region (SR2) requires $m_{4\ell} > 130$ GeV, and $|m_{ab,cd} - m_Z| > 8$ GeV and $|m_{ad,bc} - m_Z| > 4$ GeV, where the latter requirement on the alternative pairing applies only to the $4e$ and 4μ events. These pair mass requirements were set to optimize the expected significance.

Consistency between m_{ab} and m_{cd} is enforced by requiring $m_{cd}/m_{ab} > 0.85 - 0.1125f(m_{ab})$, where the modulating function f decreases monotonically from $f(m_{ab} \leq 10 \text{ GeV}) = 1$ to $f(m_{ab} \geq 50 \text{ GeV}) = 0$. It is the result of re-optimizing the analysis to allow for larger Z_d widths at lower lepton-pair invariant masses, where the background is low, and is fully described in Ref. [7].

Finally, if E'_{ab} is defined as the energy of the ab dilepton pair in the rest frame of the four-lepton system, then

$$\frac{E'_{ab}}{m_{4\ell}} = \frac{1}{2} \left(1 + \frac{m_{ab}^2 - m_{cd}^2}{m_{4\ell}^2} \right).$$

The additional requirement $|E'_{ab}/m_{4\ell} - 0.5| < 0.008$ reduces the dominant ZZ^* background by about a factor of 1.5, while reducing the efficiency for the signal by less than five percent over most of the explored (m_S, m_{Z_d}) range.

5. Background estimation

Backgrounds with four prompt leptons are estimated directly from simulation (see Section 3). The dominant background, comprising 90%–95% of the total, is the non-resonant process $ZZ^* \rightarrow 4\ell$. As described in Ref. [7], the prediction of this background was verified using background-dominated validation regions.³ The background from SM Higgs boson production is effectively suppressed by the requirement that the overall invariant mass $m_{4\ell}$ not be consistent with that of the SM Higgs boson. Other processes with four prompt leptons include

² These $m_{ab,cd}$ variables are distinct from the $m_{12,34}$ variables used in Ref. [7], which were chosen such that $|m_{12} - m_Z| < |m_{34} - m_Z|$. For $m_{4\ell} < 2m_Z$, $m_{ab,cd} = m_{12,34}$. For larger $m_{4\ell}$, either $m_{ab,cd} = m_{12,34}$ or $m_{ab,cd} = m_{34,12}$.

³ In particular, Validation Region 3 of Ref. [7] requires $m_{4\ell} < 115$ GeV or $m_{4\ell} > 130$ GeV and thus probes the $ZZ^* \rightarrow 4\ell$ background that is dominant for this analysis.

$t\bar{t}Z \rightarrow 4\ell + X$ and processes with three gauge bosons and are found to be small in comparison with the dominant ZZ^* background. The reducible background due to WZ production is similarly small.

Contributions from Z + jets and $t\bar{t}$ (including $t\bar{t}Z$ decays with fewer than four leptons) processes to the signal regions are estimated from data. They are estimated separately but with similar techniques. In both cases, the event sample is enlarged by relaxing the requirements on isolation and impact parameters for two of the lepton candidates. For the $t\bar{t}$ background, the two candidates with largest p_T must satisfy the nominal requirements. For the Z + jets background, the two candidates in the pair with invariant mass closest to that of the Z boson must satisfy the nominal requirements. In both cases, events are then classified into four regions based on the requirements satisfied by the other two candidates:

- Region A: The remaining two candidates both satisfy isolation and impact parameter requirements.
- Region B: The remaining two candidates both satisfy the isolation requirement, but at least one does not satisfy the impact parameter requirement.
- Region C: The remaining two candidates both satisfy the impact parameter requirement, but at least one does not satisfy the isolation requirement.
- Region D: All other events.

To obtain adequate statistics, event selections are applied only as far as the quarkonia veto, and the electron identification is also relaxed. Backgrounds other than the one being estimated are subtracted from the event counts in regions B, C, and D, using estimates from simulation. The number of background events in the signal region A can then be estimated as $N_A = \epsilon_{\text{sel}} N_B N_C / N_D$, where ϵ_{sel} is the efficiency of the remaining selections as determined from simulation. This assumes that the isolation and impact parameter requirements are uncorrelated. This is nearly the case for the $4e$ and $2e2\mu$ final states (correlation coefficient $r < 0.01$), but they are more correlated for the 4μ final state ($r \approx 0.4$). The effect of the correlation is taken into account as a systematic uncertainty assigned to the yields of the Z + jets and $t\bar{t}$ backgrounds.

6. Systematic uncertainties

The uncertainty in the integrated luminosity is 1.7% [31], obtained using the LUCID-2 detector [26]. Uncertainties in the yields and efficiencies of simulated samples due to pile-up arise from differences between the predicted and measured inelastic cross-sections and from the reweighting procedure. These uncertainties are approximately 1%.

The efficiency for events to satisfy the selection depends on the triggering, reconstruction, identification, and isolation efficiencies for leptons, as well as the determination of their momentum scale. Tag-and-probe techniques are applied to dilepton resonances, including $Z \rightarrow \ell^+ \ell^-$, $J/\psi \rightarrow \ell^+ \ell^-$, and $Y \rightarrow \mu^+ \mu^-$, to measure the efficiencies as well as momentum scales and resolutions for electrons and muons. This leads to corrections to account for differences between data and simulation along with an estimate of the residual uncertainty [58,59]. As there are four leptons in the final state, small single-lepton uncertainties can result in larger uncertainties in the final yields and efficiencies for simulated samples, up to 17%, dominated by the uncertainties on the electron reconstruction and identification efficiencies.

Uncertainties in the modelling of the simulated signal and background processes are estimated by varying the PDFs according to the prescription of Ref. [63] and the factorization and renormalization scales up and down by a factor of two. For the signal process, the resulting yield uncertainties are taken from the results for gluon-gluon fusion production of Ref. [64] and vary from 10%–19% depending on m_S , dominated by the uncertainty from factorization and renormalization scale variations. For the dominant $ZZ^* \rightarrow 4\ell$ background, these same sources result in an uncertainty in the yield of about 6%. Addition-

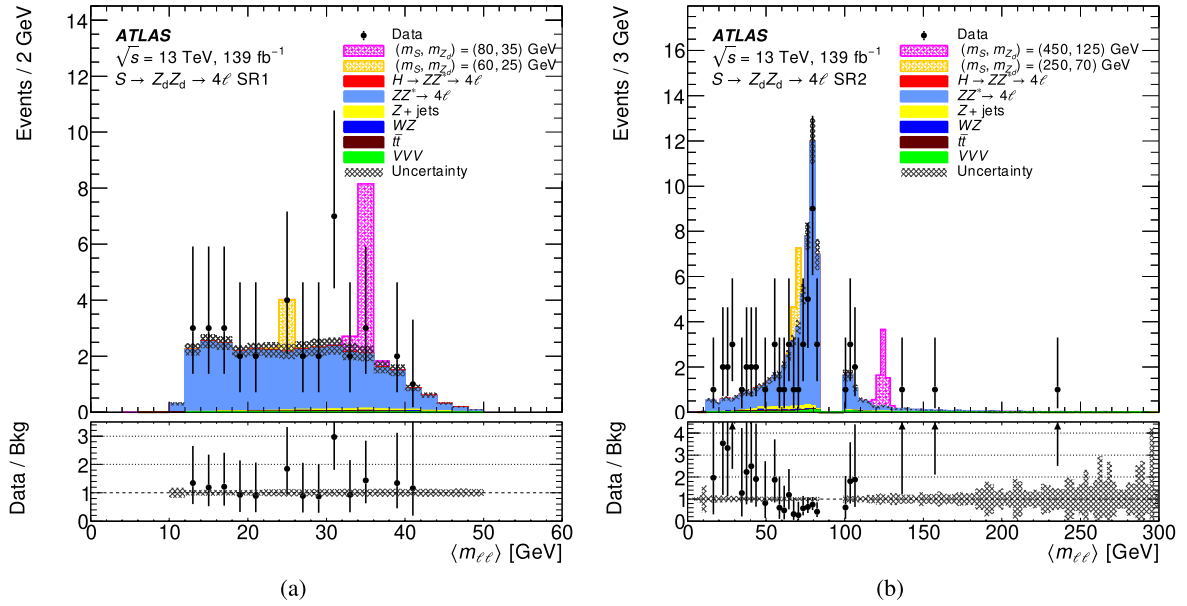


Fig. 1. Distributions of the average dilepton mass $\langle m_{\ell\ell} \rangle = \frac{1}{2}(m_{ab} + m_{cd})$ for the two signal regions (a) SR1 and (b) SR2. The hatched bands show the uncertainty in the background prediction. The uncertainties on the data points are asymmetric Poisson errors (Eqs. (40.82a) and (40.82b) of Ref. [62]). The lower panels show the ratio of the observed data to the background ('Bkg') predictions. The arrows at the upper edge indicate data points that fall outside of the y-axis range, and the plotted uncertainties include both the Poisson errors on the data and the uncertainty on the background prediction. Distributions for two example signal points are also shown. These are normalized to production cross sections of 0.5 fb for SR1 and 0.1 fb for SR2.

Table 1

Expected event yields of the SM background processes and observed data in the two signal regions SR1 and SR2. The first uncertainty is the statistical component of the total uncertainty and the second the systematic component.

Process	Yield ($\pm$ stat. $\pm$ syst.)	
	SR1	SR2
$ZZ^* \rightarrow 4\ell$	$30.9 \pm 0.5 \pm 3.2$	$62.0 \pm 0.5 \pm 7.9$
$H \rightarrow ZZ^* \rightarrow 4\ell$	$0.61 \pm 0.01 \pm 0.04$	$0.22 \pm 0.01 \pm 0.03$
WZ	$0.06 \pm 0.04 \pm 0.03$	$0.42 \pm 0.10 \pm 0.05$
VVV	$0.06 \pm 0.01 \pm 0.01$	$0.78 \pm 0.02 \pm 0.14$
$t\bar{t}$	$0.33 < 0.01 \pm 0.31$	$0.78 \pm 0.01 \pm 0.46$
$Z + \text{jets}$	$0.70 \pm 0.01 \pm 0.72$	$2.53 \pm 0.01 \pm 1.08$
Total	$32.6 \pm 0.5 \pm 3.3$	$66.8 \pm 0.6 \pm 8.0$
Data	36	55

ally, for this sample, the matrix element matching scale is varied from the nominal value of 20 GeV to 15 GeV and 30 GeV; the resummation scale is varied up and down by a factor of four; and the alternate recoil scheme of Ref. [65] (SHERPA parameter `CSS_KIN_SCHEME=1`) is compared. This results in an uncertainty in the yield of 6% in SR1 and 12% in SR2, dominated by the matrix element matching scale. The uncertainty in the yield for the $H \rightarrow ZZ^* \rightarrow 4\ell$ process is about 9% [66]. The uncertainty in the data-driven $Z + \text{jets}/t\bar{t}$ background estimate is 50%–100%.

7. Results

Table 1 reports the observed and expected yields in the signal regions. In SR1 ($m_{4\ell} < 115$ GeV), 36 events are observed with an estimated background of 32.6 ± 3.3 , while in SR2 ($m_{4\ell} > 130$ GeV), there are 55 events with an estimated background of 66.8 ± 8.0 . The distributions of $\langle m_{\ell\ell} \rangle = \frac{1}{2}(m_{ab} + m_{cd})$ for both signal regions are shown in Fig. 1, while Fig. 2 shows the overall invariant mass $m_{4\ell}$, which can also be interpreted as the mass of the scalar candidate. The selected events are represented in the $(m_{4\ell}, \langle m_{\ell\ell} \rangle)$ plane in Fig. 3, while the estimated

backgrounds and example signal shapes in SR1 and SR2 are shown in Fig. 4.

A two-dimensional interpolation procedure is used to obtain the shape of the $\langle m_{\ell\ell} \rangle$ distribution for the predicted signal at any point on the (m_S, m_{Z_d}) plane. For each generated signal MC sample, the $\langle m_{\ell\ell} \rangle$ distribution is fit. In SR1, these distributions are fit well by Gaussians, with three parameters. However, in SR2, the distributions are observed to be asymmetric, and a double-sided Crystal Ball distribution [67] is used instead, with seven parameters. For this interpolation, the S boson production cross-section and decay branching ratios are factored out, with the cross-section taken from Ref. [64] and the branching ratio set to one. Each fit parameter is then interpolated separately using the thin plate spline method [68–70], with the regularization parameter set to zero so that the interpolation passes smoothly through each control point. The interpolation procedure is validated by removing points from the interpolation one by one and then comparing the $\langle m_{\ell\ell} \rangle$ distribution for that point to what would be interpolated.

Exclusion limits on $\sigma(gg \rightarrow S) \times \mathcal{B}(S \rightarrow Z_d Z_d \rightarrow 4\ell)$ are set using frequentist significance testing of a statistic derived from a profile likelihood ratio that considers the data, the background model, and the signal model distributions for various hypothesized (m_S, m_{Z_d}) points [71–73]. To reduce the resources required, events are binned coarsely in $m_{4\ell}$ and limits set independently within each $m_{4\ell}$ bin as a function of $\langle m_{\ell\ell} \rangle$. Bins with a width of 1 GeV are used for $\langle m_{\ell\ell} \rangle$. In SR1 there are eight equal-sized bins in $m_{4\ell}$ in the range of 30 GeV to 110 GeV, and for SR2, there are 14 equal-sized bins in the range of 125 GeV to 825 GeV. These bin widths were chosen to have sufficient statistics while still being commensurate with the widths of the new scalar and the dark vector boson. Only signal MC events with $m_{4\ell}$ within one bin width of the generated m_S value are used to form the signal model distributions for this calculation. Limits are evaluated as described in Refs. [7–9] (using the `HypoTestInverter` component of the `ROOTSTATS` toolkit [74] and evaluating the test statistic distributions with MC pseudoexperiments taking into account both statistical and systematic uncertainties), resulting in CL_s frequentist upper limits at 95% confidence level (CL) on $\sigma(gg \rightarrow S) \times \mathcal{B}(S \rightarrow Z_d Z_d \rightarrow 4\ell)$ as a function of the m_{Z_d} parameter in each $m_{4\ell}$ bin. Expected and observed limits and their ratios are shown in Figs. 5(a) to 5(c) for SR1 and Figs. 5(d) to 5(f)

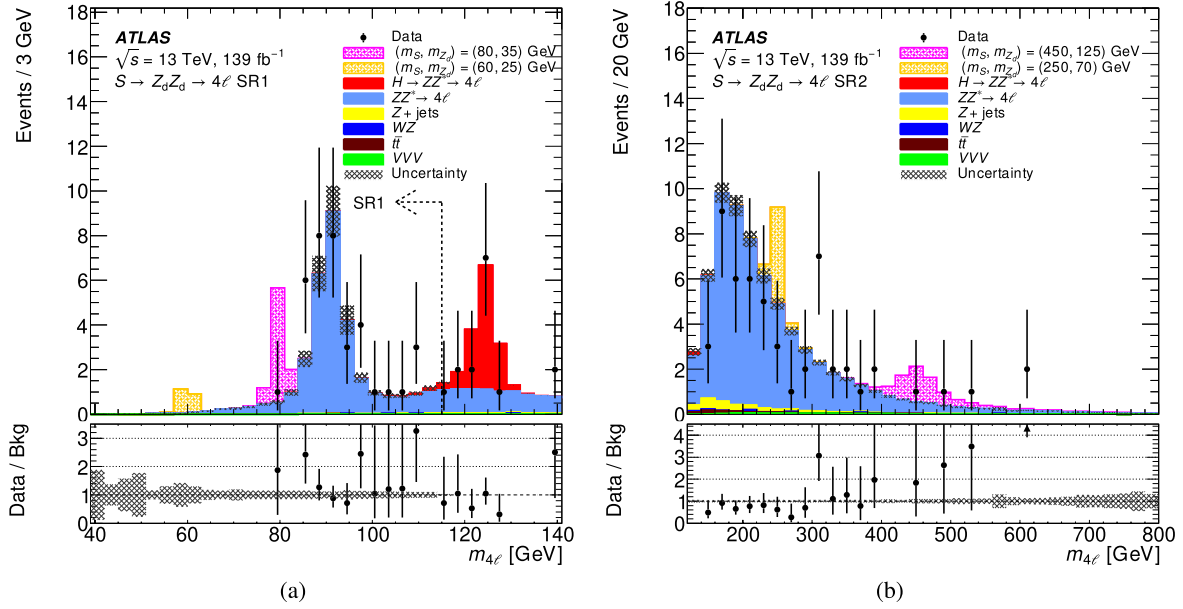


Fig. 2. Distributions of the total invariant mass $m_{4\ell}$ for the two signal regions (a) SR1 and (b) SR2. In (a), the requirement $m_{4\ell} < 115$ GeV is not applied, but is shown by the arrow. The hatched bands show the uncertainty in the background prediction; however, in (a), background uncertainties are not shown for $m_{4\ell} > 115$ GeV. The uncertainties on the data points are asymmetric Poisson errors (Eqs. (40.82a) and (40.82b) of Ref. [62]). The lower panels show the ratio of the observed data to the background ('Bkg') predictions. The arrows at the upper edge indicate data points that fall outside of the y-axis range, and the plotted uncertainties include both the Poisson errors on the data and the uncertainty on the background prediction. Distributions for two example signal points are also shown. These are normalized to production cross sections of 0.5 fb for SR1 and 0.1 fb for SR2.

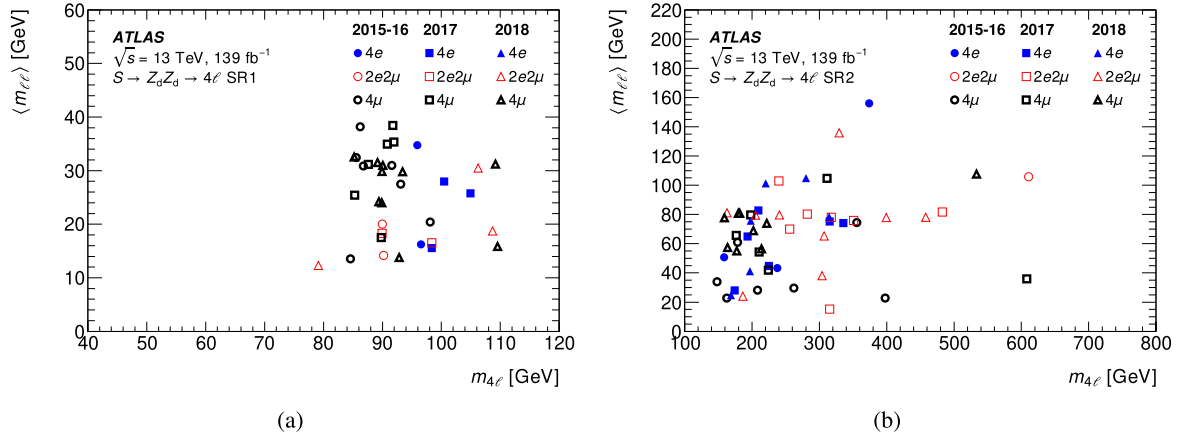


Fig. 3. Events selected in signal regions (a) SR1 and (b) SR2, represented in the $(m_{4\ell}, \langle m_{\ell\ell} \rangle)$ plane. The points are differentiated by final state (4e, 2e2 μ , and 4 μ) and by data-taking period (2015–2016, 2017, and 2018).

for SR2. The corresponding one-dimensional local p_0 -values are shown in Figs. 6(a) and 6(b). In SR1, the point with the smallest p_0 -value is at $(m_S, m_{Z_d}) = (110 \text{ GeV}, 30 \text{ GeV})$ with a local significance of 2.7σ , while in SR2 the smallest p_0 -value is at $(m_S, m_{Z_d}) = (350 \text{ GeV}, 75 \text{ GeV})$ with a local significance of 2.8σ . The local significance can be converted to a global significance by including the look-elsewhere effect using MC pseudo experiments as outlined in Ref. [75]. For SR2, the largest global significance is 0.5σ .

The local significance of the deviation in SR1 is re-evaluated using the same frequentist significance testing as described above but applied in the two-dimensional $(m_{4\ell}, \langle m_{\ell\ell} \rangle)$ plane with a binning of $\Delta m_{4\ell} \times \Delta \langle m_{\ell\ell} \rangle = 3 \text{ GeV} \times 1 \text{ GeV}$. The evaluation is done in a narrow window scanned over the plane with size set to contain at least 99% of the expected signal. The resulting local p_0 -value still corresponds to a significance of 2.7σ but for the mass point $(m_S, m_{Z_d}) = (109 \text{ GeV}, 31 \text{ GeV})$. Converting this to a global significance yields 1.6σ .

8. Conclusions

A search is presented for the decay of a new scalar S into two new spin-1 particles $S \rightarrow Z_d Z_d$, with each Z_d boson decaying promptly into a pair of electrons or muons, yielding an inclusive four-lepton final state. It is conducted in the plane of the reconstructed four-lepton mass and the average dilepton mass of the $Z_d \rightarrow \ell\ell$ candidates, and it uses 139 fb^{-1} of pp collision data at $\sqrt{s} = 13 \text{ TeV}$ recorded by the ATLAS experiment at the LHC during the period 2015–2018. Two different signal regions are studied, corresponding to $30 \text{ GeV} < m_S < 115 \text{ GeV}$ and $130 \text{ GeV} < m_S < 800 \text{ GeV}$. The data are found to be consistent with the Standard Model background expectation, and 95% CL upper limits are set on the total cross-section times branching ratio $\sigma(gg \rightarrow S) \times \mathcal{B}(S \rightarrow Z_d Z_d \rightarrow 4\ell)$ as a function of m_S and m_{Z_d} . In the first signal region, the limits range from 0.14 fb to 3.1 fb and in the second, from 0.05 fb to 0.60 fb. These constraints apply to the dark sector described by the Hidden Abelian

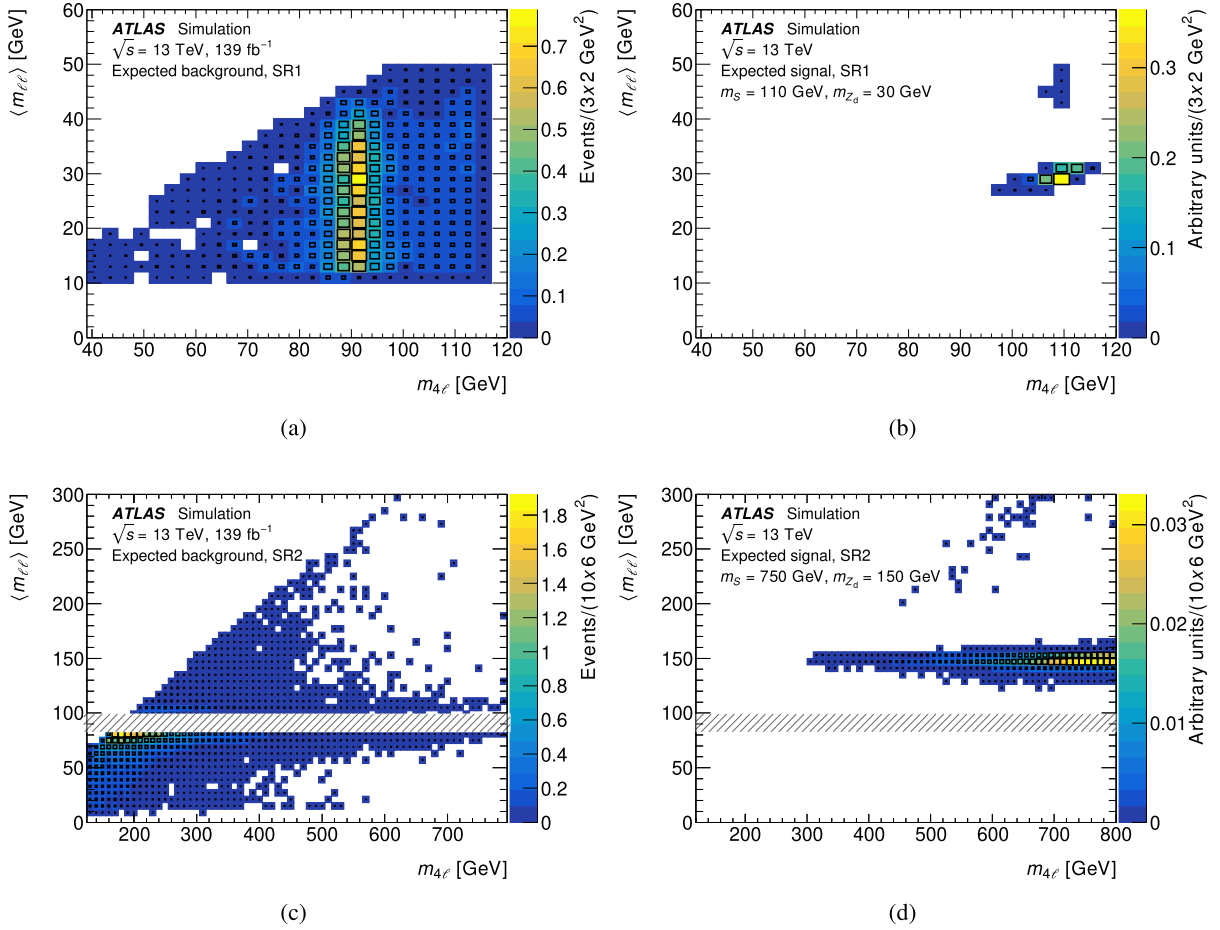


Fig. 4. (a) Estimated background and (b) expected signal shape for $(m_S, m_{Z_d}) = (110 \text{ GeV}, 30 \text{ GeV})$ in SR1 in the $(m_{4\ell}, \langle m_{\ell\ell} \rangle)$ plane, using both histograms and box representations. (c, d) The corresponding plots for SR2 with $(m_S, m_{Z_d}) = (750 \text{ GeV}, 150 \text{ GeV})$. The signal distributions are normalized to unit volume. Bins with less than 0.1% of the content of the largest bin are drawn as white.

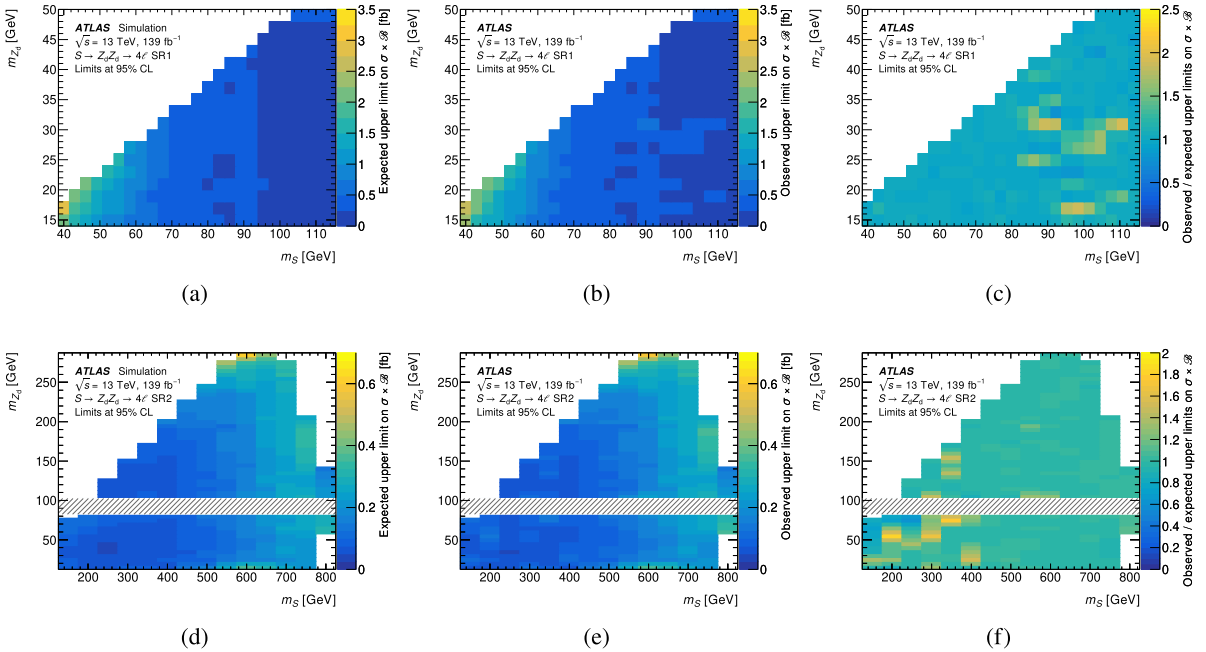


Fig. 5. 95% CL expected and observed limits on the total cross-section times branching ratio $\sigma(gg \rightarrow S) \times B(S \rightarrow Z_d Z_d \rightarrow 4\ell)$. (a) SR1 expected limit; (b) SR1 observed limit; (c) ratio of observed to expected limits in SR1; (d) SR2 expected limit; (e) SR2 observed limit; (f) ratio of observed to expected limits in SR2. The horizontal bands in the SR2 figures show the region excluded by the Z boson veto requirement, $|m_{ab,cd} - m_Z| > 8$ GeV.

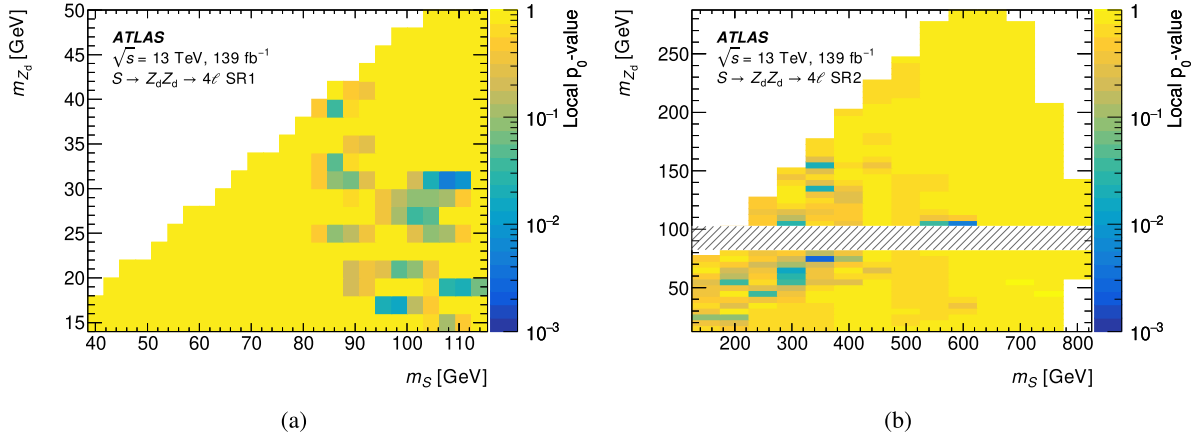


Fig. 6. Local p_0 -values in the $(m_{4\ell}, \langle m_{\ell\ell} \rangle)$ plane for (a) SR1 and (b) SR2, evaluated in slices in $m_{4\ell}$. The horizontal band in the SR2 figure shows the region excluded by the Z boson veto requirement, $|m_{ab,cd} - m_Z| > 8$ GeV.

Higgs Model, as well as to similar models resulting in a four-lepton final state.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank CERN for the very successful operation of the LHC and its injectors, as well as the support staff at CERN and at our institutions worldwide without whom ATLAS could not be operated efficiently.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF/SFU (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [76].

We gratefully acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; ANID, Chile; CAS, MOST and NSFC, China; Minciencias, Colombia; MEYS CR, Czech Republic; DNR and DNSRC, Denmark; IN2P3-CNRS and CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF and MPG, Germany; GSRI, Greece; RGC and Hong Kong SAR, China; ISF and Benozio Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MEiN, Poland; FCT, Portugal; MNE/IFA, Romania; MESTD, Serbia; MSSR, Slovakia; ARIS and MVZI, Slovenia; DSI/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; NSTC, Taipei; TENMAK, Türkiye; STFC/UKRI, United Kingdom; DOE and NSF, United States of America.

Individual groups and members have received support from BCKDF, CANARIE, CRC and DRAC, Canada; CERN-CZ, PRIMUS 21/SCI/017 and UNCE SCI/013, Czech Republic; COST, ERC, ERDF, Horizon 2020, ICSC-NextGenerationEU and Marie Skłodowska-Curie Actions, European Union; Investissements d'Avenir Labex, Investissements d'Avenir IDEX and ANR, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF, Greece; BSF-NSF and MINERVA, Israel; Norwegian Financial Mechanism 2014-2021, Norway; NCN and NAWA, Poland; La Caixa Banking Foundation, CERCA Programme Generalitat de Catalunya and PROMETEO and GenT Programmes Generalitat Valenciana, Spain;

Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom.

In addition, individual members wish to acknowledge support from Chile: Agencia Nacional de Investigación y Desarrollo (FONDECYT 1190886, FONDECYT 1210400); China: National Natural Science Foundation of China (NSFC-12175119, NSFC-12275265, NSFC-12075060); Czech Republic: PRIMUS Research Programme (PRIMUS/21/SCI/017); EU: H2020 European Research Council (ERC - 101002463, H2020-MSCA-IF-2020: HPOFHC - 10103); European Union: European Research Council (ERC - 948254), Horizon 2020 Framework Programme (MUCCA - CHIST-ERA-19-XAI-00), European Union, Future Artificial Intelligence Research (FAIR-NextGenerationEU PE00000013), Italian Center for High Performance Computing, Big Data and Quantum Computing (ICSC, NextGenerationEU), Marie Skłodowska-Curie Actions (EU H2020 MSC IF GRANT NO 101033496); France: Agence Nationale de la Recherche (ANR-20-CE31-0013, ANR-21-CE31-0013, ANR-21-CE31-0022), Investissements d'Avenir Idex (ANR-11-LABX-0012), Investissements d'Avenir Labex (ANR-11-LABX-0012); Germany: Baden-Württemberg Stiftung (BW Stiftung-Postdoc Eliteprogramme), Deutsche Forschungsgemeinschaft (DFG - CR 312/5-1); Italy: Istituto Nazionale di Fisica Nucleare (FELLINI G.A. n. 754496, ICSC, NextGenerationEU); Japan: Japan Society for the Promotion of Science (JSPS KAKENHI JP21H05085, JSPS KAKENHI JP22H01227, JSPS KAKENHI JP22H04944); Netherlands: Netherlands Organisation for Scientific Research (NWO Veni 2020 - VI.Veni.202.179); Norway: Research Council of Norway (RCN-314472); Poland: Polish National Agency for Academic Exchange (PPN/PPO/2020/1/00002/U/00001), Polish National Science Centre (NCN 2021/42/E/ST2/00350, NCN UMO-2019/34/E/ST2/00393, NCN & H2020 MSCA 945339, UMO-2020/37/B/ST2/01043, UMO-2021/40/C/ST2/00187); Slovenia: Slovenian Research Agency (ARIS grant J1-3010); Spain: BBVA Foundation (LEO22-1-603), Generalitat Valenciana (Artemisa, FEDER, ID-IFEDER/2018/048), La Caixa Banking Foundation (LCF/BQ/PI20/11760025), Ministry of Science and Innovation (MCIN & NextGenEU PCI2022-135018-2, MICIN & FEDER PID2021-125273NB, RYC2019-028510-I, RYC2020-030254-I, RYC2021-031273-I, RYC2022-038164-I), PROMETEO and GenT Programmes Generalitat Valenciana (CIDE-GENT/2019/023, CIDE-GENT/2019/027); Sweden: Swedish Research Council (VR 2018-00482, VR 2021-03651, VR 2022-03845, VR 2022-04683), Knut and Alice Wallenberg Foundation (KAW 2017.0100, KAW 2018.0157, KAW 2018.0458, KAW 2019.0447); Switzerland: Swiss National Science Foundation (SNSF - PCEFP2_194658); United Kingdom: Leverhulme Trust (Leverhulme Trust RPG-2020-004); United States of America: U.S. Department of Energy (ECA DE-AC02-76SF00515), Neubauer Family Foundation.

Data availability

The data that support the findings of this article are not publicly available. The values in the plots and tables associated with this article are stored in <https://www.hepdata.net/record/145171>.

References

- [1] D. Curtin, R. Essig, S. Gori, J. Shelton, Illuminating dark photons with high-energy colliders, *J. High Energy Phys.* 02 (2015) 157, arXiv:1412.0018 [hep-ph].
- [2] D. Curtin, R. Essig, S. Gori, P. Jaiswal, A. Katz, et al., Exotic decays of the 125 GeV Higgs boson, *Phys. Rev. D* 90 (2014) 075004, arXiv:1312.4992 [hep-ph].
- [3] H. Davoudiasl, H.-S. Lee, I. Lewis, W.J. Marciano, Higgs decays as a window into the dark sector, *Phys. Rev. D* 88 (2013) 015022, arXiv:1304.4935 [hep-ph].
- [4] H. Davoudiasl, H.-S. Lee, W.J. Marciano, “Dark” Z implications for parity violation, rare meson decays, and Higgs physics, *Phys. Rev. D* 85 (2012) 115019, arXiv:1203.2947 [hep-ph].
- [5] J.D. Wells, How to find a hidden world at the large hadron collider, arXiv:0803.1243 [hep-ph], 2008.
- [6] S. Gopalakrishna, S. Jung, J.D. Wells, Higgs boson decays to four fermions through an Abelian hidden sector, *Phys. Rev. D* 78 (2008) 055002, arXiv:0801.3456 [hep-ph].
- [7] ATLAS Collaboration, Search for Higgs bosons decaying into new spin-0 or spin-1 particles in four-lepton final states with the ATLAS detector with 139 fb^{-1} of pp collision data at $\sqrt{s} = 13\text{ TeV}$, *J. High Energy Phys.* 03 (2022) 041, arXiv:2110.13673 [hep-ex].
- [8] ATLAS Collaboration, Search for Higgs boson decays to beyond-the-standard-model light bosons in four-lepton events with the ATLAS detector at $\sqrt{s} = 13\text{ TeV}$, *J. High Energy Phys.* 06 (2018) 166, arXiv:1802.03388 [hep-ex].
- [9] ATLAS Collaboration, Search for new light gauge bosons in Higgs boson decays to four-lepton final states in pp collisions at $\sqrt{s} = 8\text{ TeV}$ with the ATLAS detector at the LHC, *Phys. Rev. D* 92 (2015) 092001, arXiv:1505.07645 [hep-ex].
- [10] CMS Collaboration, Dark sector searches with the CMS experiment, arXiv:2405.13778 [hep-ex], 2024.
- [11] CMS Collaboration, Search for low-mass dilepton resonances in Higgs boson decays to four-lepton final states in proton–proton collisions at $\sqrt{s} = 13\text{ TeV}$, *Eur. Phys. J. C* 82 (2022) 290, arXiv:2111.01299 [hep-ex].
- [12] CMS Collaboration, Search for a narrow resonance lighter than 200 GeV decaying to a pair of muons in proton–proton collisions at $\sqrt{s} = 13\text{ TeV}$, *Phys. Rev. Lett.* 124 (2020) 131802, arXiv:1912.04776 [hep-ex].
- [13] ATLAS Collaboration, Search for Higgs boson decays into two new low-mass spin-0 particles in the $4b$ channel with the ATLAS detector using pp collisions at $\sqrt{s} = 13\text{ TeV}$, *Phys. Rev. D* 102 (2020) 112006, arXiv:2005.12236 [hep-ex].
- [14] ATLAS Collaboration, Search for Higgs boson decays into pairs of light (pseudo)scalar particles in the $\gamma\gamma jj$ final state in pp collisions at $\sqrt{s} = 13\text{ TeV}$ with the ATLAS detector, *Phys. Lett. B* 782 (2018) 750, arXiv:1803.11145 [hep-ex].
- [15] ATLAS Collaboration, Search for the Higgs boson produced in association with a vector boson and decaying into two spin-zero particles in the $H \rightarrow aa \rightarrow 4b$ channel in pp collisions at $\sqrt{s} = 13\text{ TeV}$ with the ATLAS detector, *J. High Energy Phys.* 10 (2018) 031, arXiv:1806.07355 [hep-ex].
- [16] ATLAS Collaboration, Search for Higgs boson decays into a pair of light bosons in the $bb\mu\mu$ final state in pp collision at $\sqrt{s} = 13\text{ TeV}$ with the ATLAS detector, *Phys. Lett. B* 790 (2019) 1, arXiv:1807.00539 [hep-ex].
- [17] ATLAS Collaboration, Search for Higgs bosons decaying to aa in the $\mu\mu\tau\tau$ final state in pp collisions at $\sqrt{s} = 8\text{ TeV}$ with the ATLAS experiment, *Phys. Rev. D* 92 (2015) 052002, arXiv:1505.01609 [hep-ex].
- [18] CMS Collaboration, A search for pair production of new light bosons decaying into muons, *Phys. Lett. B* 752 (2016) 146, arXiv:1506.00424 [hep-ex].
- [19] CMS Collaboration, Search for light bosons in decays of the 125 GeV Higgs boson in proton–proton collisions at $\sqrt{s} = 8\text{ TeV}$, *J. High Energy Phys.* 10 (2017) 076, arXiv:1701.02032 [hep-ex].
- [20] CMS Collaboration, Search for a light pseudoscalar Higgs boson in the boosted $\mu\mu\tau\tau$ final state in proton–proton collisions at $\sqrt{s} = 13\text{ TeV}$, *J. High Energy Phys.* 08 (2020) 139, arXiv:2005.08694 [hep-ex].
- [21] CMS Collaboration, Search for long-lived particles decaying into muon pairs in proton–proton collisions at $\sqrt{s} = 13\text{ TeV}$ collected with a dedicated high-rate data stream, *J. High Energy Phys.* 04 (2022) 062, arXiv:2112.13769 [hep-ex].
- [22] LHCb Collaboration, Search for dark photons produced in 13 TeV pp collisions, *Phys. Rev. Lett.* 120 (2018) 061801, arXiv:1710.02867 [hep-ex].
- [23] ATLAS Collaboration, Combination of searches for invisible decays of the Higgs boson using 139 fb^{-1} of proton–proton collision data at $\sqrt{s} = 13\text{ TeV}$ collected with the ATLAS experiment, *Phys. Lett. B* 842 (2023) 137963, arXiv:2301.10731 [hep-ex].
- [24] CMS Collaboration, Search for invisible decays of the Higgs boson produced via vector boson fusion in proton–proton collisions at $\sqrt{s} = 13\text{ TeV}$, *Phys. Rev. D* 105 (2022) 092007, arXiv:2201.11585 [hep-ex].
- [25] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, *J. Instrum.* 3 (2008) S08003.
- [26] G. Avoni, et al., The new LUCID-2 detector for luminosity measurement and monitoring in ATLAS, *J. Instrum.* 13 (2018) P07017.
- [27] ATLAS Collaboration, Performance of the ATLAS trigger system in 2015, *Eur. Phys. J. C* 77 (2017) 317, arXiv:1611.09661 [hep-ex].
- [28] ATLAS Collaboration, Software and computing for Run 3 of the ATLAS experiment at the LHC, arXiv:2404.06335 [hep-ex], 2024.
- [29] ATLAS Collaboration, ATLAS data quality operations and performance for 2015–2018 data-taking, *J. Instrum.* 15 (2020) P04003, arXiv:1911.04632 [physics.ins-det].
- [30] ATLAS Collaboration, Selection of jets produced in 13 TeV proton–proton collisions with the ATLAS detector, ATLAS-CONF-2015-029, <https://cds.cern.ch/record/2037702>, 2015.
- [31] ATLAS Collaboration, Luminosity determination in pp collisions at $\sqrt{s} = 13\text{ TeV}$ using the ATLAS detector at the LHC, ATLAS-CONF-2019-021, <https://cds.cern.ch/record/2677054>, 2019.
- [32] ATLAS Collaboration, Performance of electron and photon triggers in ATLAS during LHC Run 2, *Eur. Phys. J. C* 80 (2020) 47, arXiv:1909.00761 [hep-ex].
- [33] ATLAS Collaboration, Performance of the ATLAS muon triggers in Run 2, *J. Instrum.* 15 (2020) P09015, arXiv:2004.13447 [physics.ins-det].
- [34] ATLAS Collaboration, The ATLAS inner detector trigger performance in pp collisions at 13 TeV during LHC Run 2, *Eur. Phys. J. C* 82 (2022) 206, arXiv:2107.02485 [hep-ex].
- [35] ATLAS Collaboration, Reconstruction of primary vertices at the ATLAS experiment in Run 1 proton–proton collisions at the LHC, *Eur. Phys. J. C* 77 (2017) 332, arXiv:1611.10235 [physics.ins-det].
- [36] D. Curtin, et al., SM + dark vector + dark Higgs Madgraph5 model, <https://feynrules.irmp.ucl.ac.be/wiki/HAHM>.
- [37] J. Alwall, et al., The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations, *J. High Energy Phys.* 07 (2014) 079, arXiv:1405.0301 [hep-ph].
- [38] T. Sjöstrand, S. Mrenna, P. Skands, A brief introduction to PYTHIA 8.1, *Comput. Phys. Commun.* 178 (2008) 852, arXiv:0710.3820 [hep-ph].
- [39] D.J. Lange, The EvtGen particle decay simulation package, *Nucl. Instrum. Methods A* 462 (2001) 152.
- [40] NNPDF Collaboration, R.D. Ball, et al., Parton distributions with LHC data, *Nucl. Phys. B* 867 (2013) 244, arXiv:1207.1303 [hep-ph].
- [41] ATLAS Collaboration, ATLAS PYTHIA 8 tunes to 7 TeV data, ATL-PHYS-PUB-2014-021, <https://cds.cern.ch/record/1966419>, 2014.
- [42] R. Contino, M. Ghezzi, C. Grojean, M. Mühlleitner, M. Spira, eHDECAY: an implementation of the Higgs effective Lagrangian into HDECAY, *Comput. Phys. Commun.* 185 (2014) 3412, arXiv:1403.3381 [hep-ph].
- [43] S. Agostinelli, et al., GEANT4 – a simulation toolkit, *Nucl. Instrum. Methods A* 506 (2003) 250.
- [44] ATLAS Collaboration, The ATLAS simulation infrastructure, *Eur. Phys. J. C* 70 (2010) 823, arXiv:1005.4568 [physics.ins-det].
- [45] E. Bothmann, et al., Event generation with SHERPA 2.2, *SciPost Phys.* 7 (2019) 034, arXiv:1905.09127 [hep-ph].
- [46] T. Gleisberg, S. Höche, COMIX, a new matrix element generator, *J. High Energy Phys.* 12 (2008) 039, arXiv:0808.3674 [hep-ph].
- [47] F. Cascioli, P. Maierhöfer, S. Pozzorini, Scattering amplitudes with Open Loops, *Phys. Rev. Lett.* 108 (2012) 111601, arXiv:1111.5206 [hep-ph].
- [48] S. Schumann, F. Krauss, A parton shower algorithm based on Catani–Seymour dipole factorisation, *J. High Energy Phys.* 03 (2008) 038, arXiv:0709.1027 [hep-ph].
- [49] S. Höche, F. Krauss, M. Schönherr, F. Siegert, QCD matrix elements + parton showers. The NLO case, *J. High Energy Phys.* 04 (2013) 027, arXiv:1207.5030 [hep-ph].
- [50] F. Caola, K. Melnikov, R. Röntsch, L. Tancredi, QCD corrections to ZZ production in gluon fusion at the LHC, *Phys. Rev. D* 92 (2015) 094028, arXiv:1509.06734 [hep-ph].
- [51] ATLAS Collaboration, Multi-boson simulation for 13 TeV ATLAS analyses, ATL-PHYS-PUB-2017-005, <https://cds.cern.ch/record/2261933>, 2017.
- [52] K. Hamilton, P. Nason, E. Re, G. Zanderighi, NNLOPS simulation of Higgs boson production, *J. High Energy Phys.* 10 (2013) 222, arXiv:1309.0017 [hep-ph].
- [53] K. Hamilton, P. Nason, G. Zanderighi, Finite quark-mass effects in the NNLOPS POWHEG+MiNLO Higgs generator, *J. High Energy Phys.* 05 (2015) 140, arXiv:1501.04637 [hep-ph].
- [54] S. Alioli, P. Nason, C. Oleari, E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX, *J. High Energy Phys.* 06 (2010) 043, arXiv:1002.2581 [hep-ph].
- [55] P. Nason, A new method for combining NLO QCD with shower Monte Carlo algorithms, *J. High Energy Phys.* 11 (2004) 040, arXiv:hep-ph/0409146.
- [56] S. Friexione, P. Nason, C. Oleari, Matching NLO QCD computations with parton shower simulations: the POWHEG method, *J. High Energy Phys.* 11 (2007) 070, arXiv:0709.2092 [hep-ph].
- [57] ATLAS Collaboration, The simulation principle and performance of the ATLAS fast calorimeter simulation FastCaloSim, ATL-PHYS-PUB-2010-013, <https://cds.cern.ch/record/1300517>, 2010.
- [58] ATLAS Collaboration, Electron and photon performance measurements with the ATLAS detector using the 2015–2017 LHC proton–proton collision data, *J. Instrum.* 14 (2019) P12006, arXiv:1908.00005 [hep-ex].
- [59] ATLAS Collaboration, Muon reconstruction and identification efficiency in ATLAS using the full Run 2 pp collision data set at $\sqrt{s} = 13\text{ TeV}$, *Eur. Phys. J. C* 81 (2021) 578, arXiv:2012.00578 [hep-ex].

- [60] ATLAS Collaboration, Tools for estimating fake/non-prompt lepton backgrounds with the ATLAS detector at the LHC, *J. Instrum.* **18** (2023) T11004, arXiv:2211.16178 [hep-ex].
- [61] ATLAS Collaboration, Topological cell clustering in the ATLAS calorimeters and its performance in LHC Run 1, *Eur. Phys. J. C* **77** (2017) 490, arXiv:1603.02934 [hep-ex].
- [62] Particle Data Group, S. Navas, et al., Review of particle physics, *Phys. Rev. D* **110** (2024) 030001.
- [63] J. Butterworth, et al., PDF4LHC recommendations for LHC Run II, *J. Phys. G* **43** (2016) 023001, arXiv:1510.03865 [hep-ph].
- [64] D. de Florian, et al., Handbook of LHC Higgs cross sections: 4. Deciphering the nature of the Higgs sector, arXiv:1610.07922 [hep-ph], 2017.
- [65] S. Höche, S. Schumann, F. Siegert, Hard photon production and matrix-element parton-shower merging, *Phys. Rev. D* **81** (2010) 034026, arXiv:0912.3501 [hep-ph].
- [66] S. Dittmaier, et al., Handbook of LHC Higgs cross sections: 1. Inclusive observables, CERN-2011-002, arXiv:1101.0593 [hep-ph], 2011.
- [67] M. Oreglia, A study of the reactions $\psi' \rightarrow \gamma\gamma\psi$, PhD thesis, SLAC, 1980, <http://www.slac.stanford.edu/pubs/slacreports/slac-r-236.html>.
- [68] J. Elonen, Thin plate spline editor — an example program in C++, <https://elonen.iki.fi/code/tpsdemo>.
- [69] J. Duchon, Interpolation des fonctions de deux variables suivant le principe de la flexion des plaques minces, *RAIRO. Anal. Numér.* **10** (1976) 5, http://www.numdam.org/item?id=M2AN.1976_10_3_5_0.
- [70] F.L. Bookstein, Principal warps: thin-plate splines and the decomposition of deformations, *IEEE Trans. Pattern Anal. Mach. Intell.* **11** (1989) 567.
- [71] G. Cowan, K. Cranmer, E. Gross, O. Vitells, Asymptotic formulae for likelihood-based tests of new physics, *Eur. Phys. J. C* **71** (2011) 1554, arXiv:1007.1727 [physics.data-an], Erratum: *Eur. Phys. J. C* **73** (2013) 2501.
- [72] A.L. Read, Presentation of search results: the CL_s technique, *J. Phys. G* **28** (2002) 2693.
- [73] K. Cranmer, A. Shibata, W. Verkerke, L. Moneta, G. Lewis, HistFactory: a tool for creating statistical models for use with RooFit and RooStats, *Tech. Rep.*, 2012, <https://cds.cern.ch/record/1456844>.
- [74] L. Moneta, et al., The RooStats project, PoS ACAT2010 (2010) 057, arXiv:1009.1003 [physics.data-an].
- [75] O. Vitells, E. Gross, Estimating the significance of a signal in a multi-dimensional search, *Astropart. Phys.* **35** (2011) 230, arXiv:1105.4355 [astro-ph].
- [76] ATLAS Collaboration, ATLAS computing acknowledgements, ATL-SOFT-PUB-2025-001, <https://cds.cern.ch/record/2922210>, 2025.

The ATLAS Collaboration

G. Aad^{102, }, B. Abbott^{120, }, K. Abeling^{55, }, N.J. Abicht^{49, }, S.H. Abidi^{29, }, A. Aboulhorma^{35e, }, H. Abramowicz^{152, }, H. Abreu^{151, }, Y. Abulaiti^{117,}, A.C. Abusleme Hoffman^{137a,}, B.S. Acharya^{69a,69b,},ⁿ, C. Adam Bourdarios^{4,}, L. Adamczyk^{86a,}, L. Adamek^{155,}, S.V. Addepalli^{26,}, M.J. Addison^{101,}, J. Adelman^{115,}, A. Adiguzel^{21c,}, T. Adye^{134,}, A.A. Affolder^{136,}, Y. Afik^{36,}, M.N. Agaras^{13,}, J. Agarwala^{73a,73b,}, A. Aggarwal^{100,}, C. Agheorghiesei^{27c,}, A. Ahmad^{36,}, F. Ahmadov^{38,},^{aa}, W.S. Ahmed^{104,}, S. Ahuja^{95,}, X. Ai^{62a,}, G. Aielli^{76a,76b,}, A. Aikot^{163,}, M. Ait Tamlihat^{35e,}, B. Aitbenchikh^{35a,}, I. Aizenberg^{169,}, M. Akbiyik^{100,}, T.P.A. Åkesson^{98,}, A.V. Akimov^{37,}, D. Akiyama^{168,}, N.N. Akolkar^{24,}, K. Al Khoury^{41,}, G.L. Alberghi^{23b,}, J. Albert^{165,}, P. Albicocco^{53,}, G.L. Albouy^{60,}, S. Alderweireldt^{52,}, M. Aleksa^{36,}, I.N. Aleksandrov^{38,}, C. Alexa^{27b,}, T. Alexopoulos^{10,}, A. Alfonsi^{114,}, F. Alfonsi^{23b,}, M. Algren^{56,}, M. Alhroob^{120,}, B. Ali^{132,}, H.M.J. Ali^{91,}, S. Ali^{149,}, S.W. Alibocus^{92,}, M. Aliev^{146,}, G. Alimonti^{71a,}, W. Alkakh^{55,}, C. Allaire^{66,}, B.M.M. Allbrooke^{147,}, J.F. Allen^{52,}, C.A. Allendes Flores^{137f,}, P.P. Allport^{20,}, A. Aloisio^{72a,72b,}, F. Alonso^{90,}, C. Alpigiani^{139,}, M. Alvarez Estevez^{99,}, A. Alvarez Fernandez^{100,}, M. Alves Cardoso^{56,}, M.G. Alviggi^{72a,72b,}, M. Aly^{101,}, Y. Amaral Coutinho^{83b,}, A. Ambler^{104,}, C. Amelung^{36,}, M. Amerl^{101,}, C.G. Ames^{109,}, D. Amidei^{106,}, S.P. Amor Dos Santos^{130a,}, K.R. Amos^{163,}, V. Ananiev^{125,}, C. Anastopoulos^{140,}, T. Andeen^{11,}, J.K. Anders^{36,}, S.Y. Andread^{47a,47b,}, A. Andreazza^{71a,71b,}, S. Angelidakis^{9,}, A. Angerami^{41,},^{ad} A.V. Anisenkov^{37,}, A. Annovi^{74a,}, C. Antel^{56,}, M.T. Anthony^{140,}, E. Antipov^{146,}, M. Antonelli^{53,}, D.J.A. Antrim^{17a,}, F. Anulli^{75a,}, M. Aoki^{84,}, T. Aoki^{154,}, J.A. Aparisi Pozo^{163,}, M.A. Aparo^{147,}, L. Aperio Bella^{48,}, C. Appelt^{18,}, A. Apyan^{26,}, N. Aranzabal^{36,}, C. Arcangeletti^{53,}, A.T.H. Arce^{51,}, E. Arena^{92,}, J-F. Arguin^{108,}, S. Argyropoulos^{54,}, J.-H. Arling^{48,}, O. Arnaez^{4,}, H. Arnold^{114,}, Z.P. Arrubarrena Tame^{109,}, G. Artoni^{75a,75b,}, H. Asada^{111,}, K. Asai^{118,}, S. Asai^{154,}, N.A. Asbah^{61,}, J. Assahsah^{35d,}, K. Assamagan^{29,}, R. Astalos^{28a,}, S. Atashi^{160,}, R.J. Atkin^{33a,}, M. Atkinson^{162,}, N.B. Atlay^{18,}, H. Atmani^{62b,}, P.A. Atmasiddha^{106,}, K. Augsten^{132,}, S. Auricchio^{72a,72b,}, A.D. Auriol^{20,}, V.A. Austrup^{101,}, G. Avolio^{36,}, K. Axiotis^{56,}, G. Azuelos^{108,},^{ah} D. Babal^{28b,}, H. Bachacou^{135,}, K. Bachas^{153,},^q A. Bachiu^{34,}, F. Backman^{47a,47b,}, A. Badea^{61,}, P. Bagnaia^{75a,75b,}, M. Bahmani^{18,}, A.J. Bailey^{163,}, V.R. Bailey^{162,}, J.T. Baines^{134,}, L. Baines^{94,}, C. Bakalis^{10,}, O.K. Baker^{172,}, E. Bakos^{15,}, D. Bakshi Gupta^{8,}, V. Balakrishnan^{120,}, R. Balasubramanian^{114,}, E.M. Baldin^{37,}, P. Balek^{86a,}, E. Ballabene^{23b,23a,}, F. Balli^{135,}, L.M. Baltes^{63a,}, W.K. Balunas^{32,}, J. Balz^{100,}, E. Banas^{87,}, M. Bandieramonte^{129,}, A. Bandyopadhyay^{24,}, S. Bansal^{24,}, L. Barak^{152,}, M. Barakat^{48,},^{id}

E.L. Barberio^{105, [id](#)}, D. Barberis^{57b,57a, [id](#)}, M. Barbero^{102, [id](#)}, G. Barbour⁹⁶, K.N. Barends^{33a, [id](#)}, T. Barillari^{110, [id](#)}, M.-S. Barisits^{36, [id](#)}, T. Barklow^{144, [id](#)}, P. Baron^{122, [id](#)}, D.A. Baron Moreno^{101, [id](#)}, A. Baroncelli^{62a, [id](#)}, G. Barone^{29, [id](#)}, A.J. Barr^{126, [id](#)}, J.D. Barr^{96, [id](#)}, L. Barranco Navarro^{47a,47b, [id](#)}, F. Barreiro^{99, [id](#)}, J. Barreiro Guimarães da Costa^{14a, [id](#)}, U. Barron^{152, [id](#)}, M.G. Barros Teixeira^{130a, [id](#)}, S. Barsov^{37, [id](#)}, F. Bartels^{63a, [id](#)}, R. Bartoldus^{144, [id](#)}, A.E. Barton^{91, [id](#)}, P. Bartos^{28a, [id](#)}, A. Basan^{100, [id](#)}, M. Baselga^{49, [id](#)}, A. Bassalat^{66, [id](#)}, M.J. Basso^{156a, [id](#)}, C.R. Basson^{101, [id](#)}, R.L. Bates^{59, [id](#)}, S. Batlamous^{35e, [id](#)}, J.R. Batley^{32, [id](#)}, B. Batool^{142, [id](#)}, M. Battaglia^{136, [id](#)}, D. Battulga^{18, [id](#)}, M. Bause^{75a,75b, [id](#)}, M. Bauer^{36, [id](#)}, P. Bauer^{24, [id](#)}, L.T. Bazzano Hurrell^{30, [id](#)}, J.B. Beacham^{51, [id](#)}, T. Beau^{127, [id](#)}, P.H. Beauchemin^{158, [id](#)}, F. Becherer^{54, [id](#)}, P. Bechtel^{24, [id](#)}, H.P. Beck^{19, [id](#)}, K. Becker^{167, [id](#)}, A.J. Beddall^{82, [id](#)}, V.A. Bednyakov^{38, [id](#)}, C.P. Bee^{146, [id](#)}, L.J. Beemster^{15, [id](#)}, T.A. Beermann^{36, [id](#)}, M. Begalli^{83d, [id](#)}, M. Begel^{29, [id](#)}, A. Behera^{146, [id](#)}, J.K. Behr^{48, [id](#)}, J.F. Beirer^{55, [id](#)}, F. Beisiegel^{24, [id](#)}, M. Belfkir^{159, [id](#)}, G. Bella^{152, [id](#)}, L. Bellagamba^{23b, [id](#)}, A. Bellerive^{34, [id](#)}, P. Bellos^{20, [id](#)}, K. Beloborodov^{37, [id](#)}, N.L. Belyaev^{37, [id](#)}, D. Benchekroun^{35a, [id](#)}, F. Bendebeba^{35a, [id](#)}, Y. Benhammou^{152, [id](#)}, M. Benoit^{29, [id](#)}, J.R. Bensinger^{26, [id](#)}, S. Bentvelsen^{114, [id](#)}, L. Beresford^{48, [id](#)}, M. Beretta^{53, [id](#)}, E. Bergeaas Kuutmann^{161, [id](#)}, N. Berger^{4, [id](#)}, B. Bergmann^{132, [id](#)}, J. Beringer^{17a, [id](#)}, G. Bernardi^{5, [id](#)}, C. Bernius^{144, [id](#)}, F.U. Bernlochner^{24, [id](#)}, F. Bernon^{36,102, [id](#)}, T. Berry^{95, [id](#)}, P. Berta^{133, [id](#)}, A. Berthold^{50, [id](#)}, I.A. Bertram^{91, [id](#)}, S. Bethke^{110, [id](#)}, A. Betti^{75a,75b, [id](#)}, A.J. Bevan^{94, [id](#)}, M. Bhamjee^{33c, [id](#)}, S. Bhatta^{146, [id](#)}, D.S. Bhattacharya^{166, [id](#)}, P. Bhattarai^{144, [id](#)}, V.S. Bhopatkar^{121, [id](#)}, R. Bi^{29, [aj](#)}, R.M. Bianchi^{129, [id](#)}, G. Bianco^{23b,23a, [id](#)}, O. Biebel^{109, [id](#)}, R. Bielski^{123, [id](#)}, M. Biglietti^{77a, [id](#)}, T.R.V. Billoud^{132, [id](#)}, M. Bindi^{55, [id](#)}, A. Bingul^{21b, [id](#)}, C. Bini^{75a,75b, [id](#)}, A. Biondini^{92, [id](#)}, C.J. Birch-sykes^{101, [id](#)}, G.A. Bird^{20,134, [id](#)}, M. Birman^{169, [id](#)}, M. Biros^{133, [id](#)}, T. Bisanz^{49, [id](#)}, E. Bisceglie^{43b,43a, [id](#)}, J.P. Biswal^{2, [id](#)}, D. Biswas^{142, [id](#)}, A. Bitadze^{101, [id](#)}, K. Bjørke^{125, [id](#)}, I. Bloch^{48, [id](#)}, C. Blocker^{26, [id](#)}, A. Blue^{59, [id](#)}, U. Blumenschein^{94, [id](#)}, J. Blumenthal^{100, [id](#)}, G.J. Bobbink^{114, [id](#)}, V.S. Bobrovnikov^{37, [id](#)}, M. Boehler^{54, [id](#)}, B. Boehm^{166, [id](#)}, D. Bogavac^{36, [id](#)}, A.G. Bogdanchikov^{37, [id](#)}, C. Bohm^{47a, [id](#)}, V. Boisvert^{95, [id](#)}, P. Boka^{48, [id](#)}, T. Bold^{86a, [id](#)}, M. Bomben^{5, [id](#)}, M. Bona^{94, [id](#)}, M. Boonekamp^{135, [id](#)}, C.D. Booth^{95, [id](#)}, A.G. Borbély^{59, [id](#)}, I.S. Bordulev^{37, [id](#)}, H.M. Borecka-Bielska^{108, [id](#)}, L.S. Borgna^{96, [id](#)}, G. Borissov^{91, [id](#)}, D. Bortoletto^{126, [id](#)}, D. Boscherini^{23b, [id](#)}, M. Bosman^{13, [id](#)}, J.D. Bossio Sola^{36, [id](#)}, K. Bouaouda^{35a, [id](#)}, N. Bouchhar^{163, [id](#)}, J. Boudreau^{129, [id](#)}, E.V. Bouhova-Thacker^{91, [id](#)}, D. Boumediene^{40, [id](#)}, R. Bouquet^{5, [id](#)}, A. Boveia^{119, [id](#)}, J. Boyd^{36, [id](#)}, D. Boye^{29, [id](#)}, I.R. Boyko^{38, [id](#)}, J. Bracinik^{20, [id](#)}, N. Brahimi^{62d, [id](#)}, G. Brandt^{171, [id](#)}, O. Brandt^{32, [id](#)}, F. Braren^{48, [id](#)}, B. Brau^{103, [id](#)}, J.E. Brau^{123, [id](#)}, R. Brenner^{169, [id](#)}, L. Brenner^{114, [id](#)}, R. Brenner^{161, [id](#)}, S. Bressler^{169, [id](#)}, D. Britton^{59, [id](#)}, D. Britzger^{110, [id](#)}, I. Brock^{24, [id](#)}, R. Brock^{107, [id](#)}, G. Brooijmans^{41, [id](#)}, W.K. Brooks^{137f, [id](#)}, E. Brost^{29, [id](#)}, L.M. Brown^{165,156a, [id](#)}, L.E. Bruce^{61, [id](#)}, T.L. Bruckler^{126, [id](#)}, P.A. Bruckman de Renstrom^{87, [id](#)}, B. Brüers^{48, [id](#)}, A. Bruni^{23b, [id](#)}, G. Bruni^{23b, [id](#)}, M. Bruschi^{23b, [id](#)}, N. Bruscino^{75a,75b, [id](#)}, T. Buanes^{16, [id](#)}, Q. Buat^{139, [id](#)}, D. Buchin^{110, [id](#)}, A.G. Buckley^{59, [id](#)}, M.K. Bugge^{125, [id](#)}, O. Bulekov^{37, [id](#)}, B.A. Bullard^{144, [id](#)}, S. Burdin^{92, [id](#)}, C.D. Burgard^{49, [id](#)}, A.M. Burger^{40, [id](#)}, B. Burghgrave^{8, [id](#)}, O. Burlayenko^{54, [id](#)}, J.T.P. Burr^{32, [id](#)}, C.D. Burton^{11, [id](#)}, J.C. Burzynski^{143, [id](#)}, E.L. Busch^{41, [id](#)}, V. Büscher^{100, [id](#)}, P.J. Bussey^{59, [id](#)}, J.M. Butler^{25, [id](#)}, C.M. Buttar^{59, [id](#)}, J.M. Butterworth^{96, [id](#)}, W. Buttinger^{134, [id](#)}, C.J. Buxo Vazquez^{107, [id](#)}, A.R. Buzykaev^{37, [id](#)}, S. Cabrera Urbán^{163, [id](#)}, L. Cadamuro^{66, [id](#)}, D. Caforio^{58, [id](#)}, H. Cai^{129, [id](#)}, Y. Cai^{14a,14e, [id](#)}, V.M.M. Cairo^{36, [id](#)}, O. Cakir^{3a, [id](#)}, N. Calace^{36, [id](#)}, P. Calafiura^{17a, [id](#)}, G. Calderini^{127, [id](#)}, P. Calfayan^{68, [id](#)}, G. Callea^{59, [id](#)}, L.P. Caloba^{83b, [id](#)}, D. Calvet^{40, [id](#)}, S. Calvet^{40, [id](#)}, T.P. Calvet^{102, [id](#)}, M. Calvetti^{74a,74b, [id](#)}, R. Camacho Toro^{127, [id](#)}, S. Camarda^{36, [id](#)}, D. Camarero Munoz^{26, [id](#)}, P. Camarri^{76a,76b, [id](#)}, M.T. Camerlingo^{72a,72b, [id](#)}, D. Cameron^{125, [id](#)}, C. Camincher^{165, [id](#)}, M. Campanelli^{96, [id](#)}, A. Camplani^{42, [id](#)}, V. Canale^{72a,72b, [id](#)}, A. Canesse^{104, [id](#)}, M. Cano Bret^{80, [id](#)}, J. Cantero^{163, [id](#)}, Y. Cao^{162, [id](#)}, F. Capocasa^{26, [id](#)}, M. Capua^{43b,43a, [id](#)}, A. Carbone^{71a,71b, [id](#)}, R. Cardarelli^{76a, [id](#)}, J.C.J. Cardenas^{8, [id](#)},

F. Cardillo ^{163, [ib](#)}, T. Carli ^{36, [ib](#)}, G. Carlino ^{72a, [ib](#)}, J.I. Carlotto ^{13, [ib](#)}, B.T. Carlson ^{129, [ib](#), [r](#)}, E.M. Carlson ^{165, 156a, [ib](#)},
L. Carminati ^{71a, 71b, [ib](#)}, A. Carnelli ^{135, [ib](#)}, M. Carnesale ^{75a, 75b, [ib](#)}, S. Caron ^{113, [ib](#)}, E. Carquin ^{137f, [ib](#)}, S. Carrá ^{71a, [ib](#)},
G. Carratta ^{23b, 23a, [ib](#)}, F. Carrio Argos ^{33g, [ib](#)}, J.W.S. Carter ^{155, [ib](#)}, T.M. Carter ^{52, [ib](#)}, M.P. Casado ^{13, [ib](#), [i](#)},
M. Caspar ^{48, [ib](#)}, E.G. Castiglia ^{172, [ib](#)}, F.L. Castillo ^{4, [ib](#)}, L. Castillo Garcia ^{13, [ib](#)}, V. Castillo Gimenez ^{163, [ib](#)},
N.F. Castro ^{130a, 130e, [ib](#)}, A. Catinaccio ^{36, [ib](#)}, J.R. Catmore ^{125, [ib](#)}, V. Cavaliere ^{29, [ib](#)}, N. Cavalli ^{23b, 23a, [ib](#)},
V. Cavasinni ^{74a, 74b, [ib](#)}, Y.C. Cekmecelioglu ^{48, [ib](#)}, E. Celebi ^{21a, [ib](#)}, F. Celli ^{126, [ib](#)}, M.S. Centonze ^{70a, 70b, [ib](#)},
K. Cerny ^{122, [ib](#)}, A.S. Cerqueira ^{83a, [ib](#)}, A. Cerri ^{147, [ib](#)}, L. Cerrito ^{76a, 76b, [ib](#)}, F. Cerutti ^{17a, [ib](#)}, B. Cervato ^{142, [ib](#)},
A. Cervelli ^{23b, [ib](#)}, G. Cesarini ^{53, [ib](#)}, S.A. Cetin ^{82, [ib](#)}, Z. Chadi ^{35a, [ib](#)}, D. Chakraborty ^{115, [ib](#)}, M. Chala ^{130f, [ib](#)},
J. Chan ^{170, [ib](#)}, W.Y. Chan ^{154, [ib](#)}, J.D. Chapman ^{32, [ib](#)}, E. Chapon ^{135, [ib](#)}, B. Chargeishvili ^{150b, [ib](#)}, D.G. Charlton ^{20, [ib](#)},
T.P. Charman ^{94, [ib](#)}, M. Chatterjee ^{19, [ib](#)}, C. Chauhan ^{133, [ib](#)}, S. Chekanov ^{6, [ib](#)}, S.V. Chekulaev ^{156a, [ib](#)},
G.A. Chelkov ^{38, [ib](#), [a](#)}, A. Chen ^{106, [ib](#)}, B. Chen ^{152, [ib](#)}, B. Chen ^{165, [ib](#)}, H. Chen ^{14c, [ib](#)}, H. Chen ^{29, [ib](#)}, J. Chen ^{62c, [ib](#)},
J. Chen ^{143, [ib](#)}, M. Chen ^{126, [ib](#)}, S. Chen ^{154, [ib](#)}, S.J. Chen ^{14c, [ib](#)}, X. Chen ^{62c, 135, [ib](#)}, X. Chen ^{14b, [ib](#), [ag](#)}, Y. Chen ^{62a, [ib](#)},
C.L. Cheng ^{170, [ib](#)}, H.C. Cheng ^{64a, [ib](#)}, S. Cheong ^{144, [ib](#)}, A. Cheplakov ^{38, [ib](#)}, E. Cheremushkina ^{48, [ib](#)},
E. Cherepanova ^{114, [ib](#)}, R. Cherkaoui El Moursli ^{35e, [ib](#)}, E. Cheu ^{7, [ib](#)}, K. Cheung ^{65, [ib](#)}, L. Chevalier ^{135, [ib](#)},
V. Chiarella ^{53, [ib](#)}, G. Chiarelli ^{74a, [ib](#)}, N. Chiedde ^{102, [ib](#)}, G. Chiodini ^{70a, [ib](#)}, A.S. Chisholm ^{20, [ib](#)}, A. Chitan ^{27b, [ib](#)},
M. Chitishvili ^{163, [ib](#)}, M.V. Chizhov ^{38, [ib](#), [s](#)}, K. Choi ^{11, [ib](#)}, A.R. Chomont ^{75a, 75b, [ib](#)}, Y. Chou ^{103, [ib](#)}, E.Y.S. Chow ^{114, [ib](#)},
T. Chowdhury ^{33g, [ib](#)}, K.L. Chu ^{169, [ib](#)}, M.C. Chu ^{64a, [ib](#)}, X. Chu ^{14a, 14e, [ib](#)}, J. Chudoba ^{131, [ib](#)}, J.J. Chwastowski ^{87, [ib](#)},
D. Cieri ^{110, [ib](#)}, K.M. Ciesla ^{86a, [ib](#)}, V. Cindro ^{93, [ib](#)}, A. Ciocio ^{17a, [ib](#)}, F. Ciotto ^{72a, 72b, [ib](#)}, Z.H. Citron ^{169, [ib](#), [l](#)},
M. Citterio ^{71a, [ib](#)}, D.A. Ciubotaru ^{27b}, B.M. Ciungu ^{155, [ib](#)}, A. Clark ^{56, [ib](#)}, P.J. Clark ^{52, [ib](#)},
J.M. Clavijo Columbie ^{48, [ib](#)}, S.E. Clawson ^{48, [ib](#)}, C. Clement ^{47a, 47b, [ib](#)}, J. Clercx ^{48, [ib](#)}, L. Clissa ^{23b, 23a, [ib](#)},
Y. Coadou ^{102, [ib](#)}, M. Cobal ^{69a, 69c, [ib](#)}, A. Coccaro ^{57b, [ib](#)}, R.F. Coelho Barrue ^{130a, [ib](#)}, R. Coelho Lopes De Sa ^{103, [ib](#)},
S. Coelli ^{71a, [ib](#)}, H. Cohen ^{152, [ib](#)}, A.E.C. Coimbra ^{71a, 71b, [ib](#)}, B. Cole ^{41, [ib](#)}, J. Collot ^{60, [ib](#)}, P. Conde Muiño ^{130a, 130g, [ib](#)},
M.P. Connell ^{33c, [ib](#)}, S.H. Connell ^{33c, [ib](#)}, I.A. Connelly ^{59, [ib](#)}, E.I. Conroy ^{126, [ib](#)}, F. Conventi ^{72a, [ib](#), [ai](#)}, H.G. Cooke ^{20, [ib](#)},
A.M. Cooper-Sarkar ^{126, [ib](#)}, A. Cordeiro Oudot Choi ^{127, [ib](#)}, F. Cormier ^{164, [ib](#)}, L.D. Corpe ^{40, [ib](#)}, M. Corradi ^{75a, 75b, [ib](#)},
F. Corriveau ^{104, [ib](#), [y](#)}, A. Cortes-Gonzalez ^{18, [ib](#)}, M.J. Costa ^{163, [ib](#)}, F. Costanza ^{4, [ib](#)}, D. Costanzo ^{140, [ib](#)},
B.M. Cote ^{119, [ib](#)}, G. Cowan ^{95, [ib](#)}, K. Cranmer ^{170, [ib](#)}, D. Cremonini ^{23b, 23a, [ib](#)}, S. Crépe-Renaudin ^{60, [ib](#)},
F. Crescioli ^{127, [ib](#)}, M. Cristinziani ^{142, [ib](#)}, M. Cristoforetti ^{78a, 78b, [ib](#)}, V. Croft ^{114, [ib](#)}, J.E. Crosby ^{121, [ib](#)},
G. Crosetti ^{43b, 43a, [ib](#)}, A. Cueto ^{99, [ib](#)}, T. Cuhadar Donszelmann ^{160, [ib](#)}, H. Cui ^{14a, 14e, [ib](#)}, Z. Cui ^{7, [ib](#)},
W.R. Cunningham ^{59, [ib](#)}, F. Curcio ^{43b, 43a, [ib](#)}, P. Czodrowski ^{36, [ib](#)}, M.M. Czurylo ^{63b, [ib](#)},
M.J. Da Cunha Sargedas De Sousa ^{57b, 57a, [ib](#)}, J.V. Da Fonseca Pinto ^{83b, [ib](#)}, C. Da Via ^{101, [ib](#)}, W. Dabrowski ^{86a, [ib](#)},
T. Dado ^{49, [ib](#)}, S. Dahbi ^{33g, [ib](#)}, T. Dai ^{106, [ib](#)}, D. Dal Santo ^{19, [ib](#)}, C. Dallapiccola ^{103, [ib](#)}, M. Dam ^{42, [ib](#)}, G. D'amen ^{29, [ib](#)},
V. D'Amico ^{109, [ib](#)}, J. Damp ^{100, [ib](#)}, J.R. Dandoy ^{128, [ib](#)}, M.F. Daneri ^{30, [ib](#)}, M. Danninger ^{143, [ib](#)}, V. Dao ^{36, [ib](#)},
G. Darbo ^{57b, [ib](#)}, S. Darmora ^{6, [ib](#)}, S.J. Das ^{29, [ib](#), [aj](#)}, S. D'Auria ^{71a, 71b, [ib](#)}, C. David ^{156b, [ib](#)}, T. Davidek ^{133, [ib](#)},
B. Davis-Purcell ^{34, [ib](#)}, I. Dawson ^{94, [ib](#)}, H.A. Day-hall ^{132, [ib](#)}, K. De ^{8, [ib](#)}, R. De Asmundis ^{72a, [ib](#)}, N. De Biase ^{48, [ib](#)},
S. De Castro ^{23b, 23a, [ib](#)}, N. De Groot ^{113, [ib](#)}, P. de Jong ^{114, [ib](#)}, H. De la Torre ^{107, [ib](#)}, A. De Maria ^{14c, [ib](#)},
A. De Salvo ^{75a, [ib](#)}, U. De Sanctis ^{76a, 76b, [ib](#)}, A. De Santo ^{147, [ib](#)}, J.B. De Vivie De Regie ^{60, [ib](#)}, D.V. Dedovich ³⁸,
J. Degens ^{114, [ib](#)}, A.M. Deiana ^{44, [ib](#)}, F. Del Corso ^{23b, 23a, [ib](#)}, J. Del Peso ^{99, [ib](#)}, F. Del Rio ^{63a, [ib](#)}, F. Deliot ^{135, [ib](#)},
C.M. Delitzsch ^{49, [ib](#)}, M. Della Pietra ^{72a, 72b, [ib](#)}, D. Della Volpe ^{56, [ib](#)}, A. Dell'Acqua ^{36, [ib](#)}, L. Dell'Asta ^{71a, 71b, [ib](#)},
M. Delmastro ^{4, [ib](#)}, P.A. Delsart ^{60, [ib](#)}, S. Demers ^{172, [ib](#)}, M. Demichev ^{38, [ib](#)}, S.P. Denisov ^{37, [ib](#)}, L. D'Eramo ^{40, [ib](#)},
D. Derendarz ^{87, [ib](#)}, F. Derue ^{127, [ib](#)}, P. Dervan ^{92, [ib](#)}, K. Desch ^{24, [ib](#)}, C. Deutsch ^{24, [ib](#)}, F.A. Di Bello ^{57b, 57a, [ib](#)},
A. Di Ciaccio ^{76a, 76b, [ib](#)}, L. Di Ciaccio ^{4, [ib](#)}, A. Di Domenico ^{75a, 75b, [ib](#)}, C. Di Donato ^{72a, 72b, [ib](#)}, A. Di Girolamo ^{36, [ib](#)},
G. Di Gregorio ^{5, [ib](#)}, A. Di Luca ^{78a, 78b, [ib](#)}, B. Di Micco ^{77a, 77b, [ib](#)}, R. Di Nardo ^{77a, 77b, [ib](#)}, C. Diaconu ^{102, [ib](#)},
M. Diamantopoulou ^{34, [ib](#)}, F.A. Dias ^{114, [ib](#)}, T. Dias Do Vale ^{143, [ib](#)}, M.A. Diaz ^{137a, 137b, [ib](#)}, F.G. Diaz Capriles ^{24, [ib](#)},

M. Didenko ^{163, [ib](#)}, E.B. Diehl ^{106, [ib](#)}, L. Diehl ^{54, [ib](#)}, S. Díez Cornell ^{48, [ib](#)}, C. Díez Pardos ^{142, [ib](#)}, C. Dimitriadi ^{161,24, [ib](#)}, A. Dimitrievska ^{17a, [ib](#)}, J. Dingfelder ^{24, [ib](#)}, I-M. Dinu ^{27b, [ib](#)}, S.J. Dittmeier ^{63b, [ib](#)}, F. Dittus ^{36, [ib](#)}, F. Djama ^{102, [ib](#)}, T. Djobava ^{150b, [ib](#)}, J.I. Djuvsland ^{16, [ib](#)}, C. Doglioni ^{101,98, [ib](#)}, J. Dolejsi ^{133, [ib](#)}, Z. Dolezal ^{133, [ib](#)}, M. Donadelli ^{83c, [ib](#)}, B. Dong ^{107, [ib](#)}, J. Donini ^{40, [ib](#)}, A. D’Onofrio ^{77a,77b, [ib](#)}, M. D’Onofrio ^{92, [ib](#)}, J. Dopke ^{134, [ib](#)}, A. Doria ^{72a, [ib](#)}, N. Dos Santos Fernandes ^{130a, [ib](#)}, M.T. Dova ^{90, [ib](#)}, A.T. Doyle ^{59, [ib](#)}, M.A. Dragnet ^{126, [ib](#)}, E. Dreyer ^{169, [ib](#)}, I. Drivas-koulouris ^{10, [ib](#)}, A.S. Drobac ^{158, [ib](#)}, M. Drozdova ^{56, [ib](#)}, D. Du ^{62a, [ib](#)}, T.A. du Pree ^{114, [ib](#)}, F. Dubinin ^{37, [ib](#)}, M. Dubovsky ^{28a, [ib](#)}, E. Duchovni ^{169, [ib](#)}, G. Duckeck ^{109, [ib](#)}, O.A. Ducu ^{27b, [ib](#)}, D. Duda ^{52, [ib](#)}, A. Dudarev ^{36, [ib](#)}, E.R. Duden ^{26, [ib](#)}, M. D’uffizi ^{101, [ib](#)}, L. Dufлот ^{66, [ib](#)}, M. Dührssen ^{36, [ib](#)}, C. Dülsen ^{171, [ib](#)}, A.E. Dumitriu ^{27b, [ib](#)}, M. Dunford ^{63a, [ib](#)}, S. Dungs ^{49, [ib](#)}, K. Dunne ^{47a,47b, [ib](#)}, A. Duperrin ^{102, [ib](#)}, H. Duran Yildiz ^{3a, [ib](#)}, M. Dören ^{58, [ib](#)}, A. Durglishvili ^{150b, [ib](#)}, B.L. Dwyer ^{115, [ib](#)}, G.I. Dyckes ^{17a, [ib](#)}, M. Dyndal ^{86a, [ib](#)}, S. Dysch ^{101, [ib](#)}, B.S. Dziedzic ^{87, [ib](#)}, Z.O. Earnshaw ^{147, [ib](#)}, G.H. Eberwein ^{126, [ib](#)}, B. Eckerova ^{28a, [ib](#)}, S. Eggebrecht ^{55, [ib](#)}, M.G. Eggleston ^{51, [ib](#)}, E. Egidio Purcino De Souza ^{127, [ib](#)}, L.F. Ehrke ^{56, [ib](#)}, G. Eigen ^{16, [ib](#)}, K. Einsweiler ^{17a, [ib](#)}, T. Ekelof ^{161, [ib](#)}, P.A. Ekman ^{98, [ib](#)}, S. El Farkh ^{35b, [ib](#)}, Y. El Ghazali ^{35b, [ib](#)}, H. El Jarrari ^{35e,149, [ib](#)}, A. El Moussaouy ^{35a, [ib](#)}, V. Ellajosyula ^{161, [ib](#)}, M. Ellert ^{161, [ib](#)}, F. Ellinghaus ^{171, [ib](#)}, A.A. Elliot ^{94, [ib](#)}, N. Ellis ^{36, [ib](#)}, J. Elmsheuser ^{29, [ib](#)}, M. Elsing ^{36, [ib](#)}, D. Emelianov ^{134, [ib](#)}, Y. Enari ^{154, [ib](#)}, I. Ene ^{17a, [ib](#)}, S. Epari ^{13, [ib](#)}, J. Erdmann ^{49, [ib](#)}, P.A. Erland ^{87, [ib](#)}, M. Errenst ^{171, [ib](#)}, M. Escalier ^{66, [ib](#)}, C. Escobar ^{163, [ib](#)}, E. Etzion ^{152, [ib](#)}, G. Evans ^{130a,130b, [ib](#)}, H. Evans ^{68, [ib](#)}, L.S. Evans ^{95, [ib](#)}, M.O. Evans ^{147, [ib](#)}, A. Ezhilov ^{37, [ib](#)}, S. Ezzarqtouni ^{35a, [ib](#)}, F. Fabbri ^{59, [ib](#)}, L. Fabbri ^{23b,23a, [ib](#)}, G. Facini ^{96, [ib](#)}, V. Fadeyev ^{136, [ib](#)}, R.M. Fakhrutdinov ^{37, [ib](#)}, S. Falciano ^{75a, [ib](#)}, L.F. Falda Ulhoa Coelho ^{36, [ib](#)}, P.J. Falke ^{24, [ib](#)}, J. Faltova ^{133, [ib](#)}, C. Fan ^{162, [ib](#)}, Y. Fan ^{14a, [ib](#)}, Y. Fang ^{14a,14c, [ib](#)}, M. Fanti ^{71a,71b, [ib](#)}, M. Faraj ^{69a,69b, [ib](#)}, Z. Farazpay ^{97, [ib](#)}, A. Farbin ^{8, [ib](#)}, A. Farilla ^{77a, [ib](#)}, T. Farooque ^{107, [ib](#)}, S.M. Farrington ^{52, [ib](#)}, F. Fassi ^{35e, [ib](#)}, D. Fassouliotis ^{9, [ib](#)}, M. Fauci Giannelli ^{76a,76b, [ib](#)}, W.J. Fawcett ^{32, [ib](#)}, L. Fayard ^{66, [ib](#)}, P. Federic ^{133, [ib](#)}, P. Federicova ^{131, [ib](#)}, O.L. Fedin ^{37, [ib](#)}, G. Fedotov ^{37, [ib](#)}, M. Feickert ^{170, [ib](#)}, L. Feligioni ^{102, [ib](#)}, D.E. Fellers ^{123, [ib](#)}, C. Feng ^{62b, [ib](#)}, M. Feng ^{14b, [ib](#)}, Z. Feng ^{114, [ib](#)}, M.J. Fenton ^{160, [ib](#)}, A.B. Fenyuk ^{37, [ib](#)}, L. Ferencz ^{48, [ib](#)}, R.A.M. Ferguson ^{91, [ib](#)}, S.I. Fernandez Luengo ^{137f, [ib](#)}, M.J.V. Fernoux ^{102, [ib](#)}, J. Ferrando ^{48, [ib](#)}, A. Ferrari ^{161, [ib](#)}, P. Ferrari ^{114,113, [ib](#)}, R. Ferrari ^{73a, [ib](#)}, D. Ferrere ^{56, [ib](#)}, C. Ferretti ^{106, [ib](#)}, F. Fiedler ^{100, [ib](#)}, A. Filipčič ^{93, [ib](#)}, E.K. Filmer ^{1, [ib](#)}, F. Filthaut ^{113, [ib](#)}, M.C.N. Fiolhais ^{130a,130c, [ib](#)}, L. Fiorini ^{163, [ib](#)}, W.C. Fisher ^{107, [ib](#)}, T. Fitschen ^{101, [ib](#)}, P.M. Fitzhugh ^{135, [ib](#)}, I. Fleck ^{142, [ib](#)}, P. Fleischmann ^{106, [ib](#)}, T. Flick ^{171, [ib](#)}, L. Flores ^{128, [ib](#)}, M. Flores ^{33d, [ib](#)}, L.R. Flores Castillo ^{64a, [ib](#)}, L. Flores Sanz De Acedo ^{36, [ib](#)}, F.M. Follega ^{78a,78b, [ib](#)}, N. Fomin ^{16, [ib](#)}, J.H. Foo ^{155, [ib](#)}, B.C. Forland ^{68, [ib](#)}, A. Formica ^{135, [ib](#)}, A.C. Forti ^{101, [ib](#)}, E. Fortin ^{36, [ib](#)}, A.W. Fortman ^{61, [ib](#)}, M.G. Foti ^{17a, [ib](#)}, L. Fountas ^{9, [ib](#)}, D. Fournier ^{66, [ib](#)}, H. Fox ^{91, [ib](#)}, P. Francavilla ^{74a,74b, [ib](#)}, S. Francescato ^{61, [ib](#)}, S. Franchellucci ^{56, [ib](#)}, M. Franchini ^{23b,23a, [ib](#)}, S. Franchino ^{63a, [ib](#)}, D. Francis ^{36, [ib](#)}, L. Franco ^{113, [ib](#)}, L. Franconi ^{48, [ib](#)}, M. Franklin ^{61, [ib](#)}, G. Frattari ^{26, [ib](#)}, A.C. Freegard ^{94, [ib](#)}, W.S. Freund ^{83b, [ib](#)}, Y.Y. Frid ^{152, [ib](#)}, J. Friend ^{59, [ib](#)}, N. Fritzsche ^{50, [ib](#)}, A. Froch ^{54, [ib](#)}, D. Froidevaux ^{36, [ib](#)}, J.A. Frost ^{126, [ib](#)}, Y. Fu ^{62a, [ib](#)}, M. Fujimoto ^{118, [ib](#)}, E. Fullana Torregrosa ^{163, [ib](#)}, K.Y. Fung ^{64a, [ib](#)}, E. Furtado De Simas Filho ^{83b, [ib](#)}, M. Furukawa ^{154, [ib](#)}, J. Fuster ^{163, [ib](#)}, A. Gabrielli ^{23b,23a, [ib](#)}, A. Gabrielli ^{155, [ib](#)}, P. Gadow ^{36, [ib](#)}, G. Gagliardi ^{57b,57a, [ib](#)}, L.G. Gagnon ^{17a, [ib](#)}, E.J. Gallas ^{126, [ib](#)}, B.J. Gallop ^{134, [ib](#)}, K.K. Gan ^{119, [ib](#)}, S. Ganguly ^{154, [ib](#)}, J. Gao ^{62a, [ib](#)}, Y. Gao ^{52, [ib](#)}, F.M. Garay Walls ^{137a,137b, [ib](#)}, B. Garcia ^{29, [ib](#)}, C. García ^{163, [ib](#)}, A. Garcia Alonso ^{114, [ib](#)}, A.G. Garcia Caffaro ^{172, [ib](#)}, J.E. García Navarro ^{163, [ib](#)}, M. Garcia-Sciveres ^{17a, [ib](#)}, G.L. Gardner ^{128, [ib](#)}, R.W. Gardner ^{39, [ib](#)}, N. Garelli ^{158, [ib](#)}, D. Garg ^{80, [ib](#)}, R.B. Garg ^{144, [ib](#)}, J.M. Gargan ^{52, [ib](#)}, C.A. Garner ^{155, [ib](#)}, S.J. Gasiorowski ^{139, [ib](#)}, P. Gaspar ^{83b, [ib](#)}, G. Gaudio ^{73a, [ib](#)}, V. Gautam ^{13, [ib](#)}, P. Gauzzi ^{75a,75b, [ib](#)}, I.L. Gavrilenko ^{37, [ib](#)}, A. Gavriluk ^{37, [ib](#)}, C. Gay ^{164, [ib](#)}, G. Gaycken ^{48, [ib](#)}, E.N. Gazis ^{10, [ib](#)}, A.A. Geanta ^{27b, [ib](#)}, C.M. Gee ^{136, [ib](#)}, C. Gemme ^{57b, [ib](#)}, M.H. Genest ^{60, [ib](#)}, S. Gentile ^{75a,75b, [ib](#)}, S. George ^{95, [ib](#)}, W.F. George ^{20, [ib](#)}, T. Gerasis ^{46, [ib](#)}, P. Gessinger-Befurt ^{36, [ib](#)}, M.E. Geyik ^{171, [ib](#)},

M. Ghani ^{167, [ib](#)}, M. Ghneimat ^{142, [ib](#)}, K. Ghorbanian ^{94, [ib](#)}, A. Ghosal ^{142, [ib](#)}, A. Ghosh ^{160, [ib](#)}, A. Ghosh ^{7, [ib](#)},
 B. Giacobbe ^{23b, [ib](#)}, S. Giagu ^{75a,75b, [ib](#)}, T. Giani ^{114, [ib](#)}, P. Giannetti ^{74a, [ib](#)}, A. Giannini ^{62a, [ib](#)}, S.M. Gibson ^{95, [ib](#)},
 M. Gignac ^{136, [ib](#)}, D.T. Gil ^{86b, [ib](#)}, A.K. Gilbert ^{86a, [ib](#)}, B.J. Gilbert ^{41, [ib](#)}, D. Gillberg ^{34, [ib](#)}, G. Gilles ^{114, [ib](#)},
 N.E.K. Gillwald ^{48, [ib](#)}, L. Ginabat ^{127, [ib](#)}, D.M. Gingrich ^{2, [ib](#), [ah](#)}, M.P. Giordani ^{69a,69c, [ib](#)}, P.F. Giraud ^{135, [ib](#)},
 G. Giugliarelli ^{69a,69c, [ib](#)}, D. Giugni ^{71a, [ib](#)}, F. Giuli ^{36, [ib](#)}, I. Gkialas ^{9, [ib](#), [j](#)}, L.K. Gladilin ^{37, [ib](#)}, C. Glasman ^{99, [ib](#)},
 G.R. Gledhill ^{123, [ib](#)}, G. Glemža ^{48, [ib](#)}, M. Glisic ^{123, [ib](#)}, I. Gnesi ^{43b, [ib](#), [f](#)}, Y. Go ^{29, [ib](#), [aj](#)}, M. Goblirsch-Kolb ^{36, [ib](#)},
 B. Gocke ^{49, [ib](#)}, D. Godin ^{108, [ib](#)}, B. Gokturk ^{21a, [ib](#)}, S. Goldfarb ^{105, [ib](#)}, T. Golling ^{56, [ib](#)}, M.G.D. Gololo ^{33g, [ib](#)},
 D. Golubkov ^{37, [ib](#)}, J.P. Gombas ^{107, [ib](#)}, A. Gomes ^{130a,130b, [ib](#)}, G. Gomes Da Silva ^{142, [ib](#)}, A.J. Gomez Delegido ^{163, [ib](#)},
 R. Gonçalo ^{130a,130c, [ib](#)}, G. Gonella ^{123, [ib](#)}, L. Gonella ^{20, [ib](#)}, A. Gongadze ^{150c, [ib](#)}, F. Gonnella ^{20, [ib](#)}, J.L. Gonski ^{41, [ib](#)},
 R.Y. González Andana ^{52, [ib](#)}, S. González de la Hoz ^{163, [ib](#)}, S. Gonzalez Fernandez ^{13, [ib](#)}, R. Gonzalez Lopez ^{92, [ib](#)},
 C. Gonzalez Renteria ^{17a, [ib](#)}, M.V. Gonzalez Rodrigues ^{48, [ib](#)}, R. Gonzalez Suarez ^{161, [ib](#)}, S. Gonzalez-Sevilla ^{56, [ib](#)},
 G.R. Gonzalvo Rodriguez ^{163, [ib](#)}, L. Goossens ^{36, [ib](#)}, B. Gorini ^{36, [ib](#)}, E. Gorini ^{70a,70b, [ib](#)}, A. Gorišek ^{93, [ib](#)},
 T.C. Gosart ^{128, [ib](#)}, A.T. Goshaw ^{51, [ib](#)}, M.I. Gostkin ^{38, [ib](#)}, S. Goswami ^{121, [ib](#)}, C.A. Gottardo ^{36, [ib](#)}, S.A. Gotz ^{109, [ib](#)},
 M. Goughri ^{35b, [ib](#)}, V. Goumarre ^{48, [ib](#)}, A.G. Goussiou ^{139, [ib](#)}, N. Govender ^{33c, [ib](#)}, I. Grabowska-Bold ^{86a, [ib](#)},
 K. Graham ^{34, [ib](#)}, E. Gramstad ^{125, [ib](#)}, S. Grancagnolo ^{70a,70b, [ib](#)}, M. Grandi ^{147, [ib](#)}, C.M. Grant ^{1,135, [ib](#)},
 P.M. Gravila ^{27f, [ib](#)}, F.G. Gravili ^{70a,70b, [ib](#)}, H.M. Gray ^{17a, [ib](#)}, M. Greco ^{70a,70b, [ib](#)}, C. Grefe ^{24, [ib](#)}, I.M. Gregor ^{48, [ib](#)},
 P. Grenier ^{144, [ib](#)}, C. Grieco ^{13, [ib](#)}, A.A. Grillo ^{136, [ib](#)}, K. Grimm ^{31, [ib](#)}, S. Grinstein ^{13, [ib](#), [u](#)}, J.-F. Grivaz ^{66, [ib](#)},
 E. Gross ^{169, [ib](#)}, J. Grosse-Knetter ^{55, [ib](#)}, C. Grud ^{106, [ib](#)}, J.C. Grundy ^{126, [ib](#)}, L. Guan ^{106, [ib](#)}, W. Guan ^{29, [ib](#)},
 C. Gubbels ^{164, [ib](#)}, J.G.R. Guerrero Rojas ^{163, [ib](#)}, G. Guerrieri ^{69a,69c, [ib](#)}, F. Guescini ^{110, [ib](#)}, R. Gugel ^{100, [ib](#)},
 J.A.M. Guhit ^{106, [ib](#)}, A. Guida ^{18, [ib](#)}, T. Guillemin ^{4, [ib](#)}, E. Guillon ^{167,134, [ib](#)}, S. Guindon ^{36, [ib](#)}, F. Guo ^{14a,14e, [ib](#)},
 J. Guo ^{62c, [ib](#)}, L. Guo ^{48, [ib](#)}, Y. Guo ^{106, [ib](#)}, R. Gupta ^{48, [ib](#)}, S. Gurbuz ^{24, [ib](#)}, S.S. Gurdasani ^{54, [ib](#)}, G. Gustavino ^{36, [ib](#)},
 M. Guth ^{56, [ib](#)}, P. Gutierrez ^{120, [ib](#)}, L.F. Gutierrez Zagazeta ^{128, [ib](#)}, C. Gutsche ^{96, [ib](#)}, C. Gwenlan ^{126, [ib](#)},
 C.B. Gwilliam ^{92, [ib](#)}, E.S. Haaland ^{125, [ib](#)}, A. Haas ^{117, [ib](#)}, M. Habedank ^{48, [ib](#)}, C. Haber ^{17a, [ib](#)}, H.K. Hadavand ^{8, [ib](#)},
 A. Hadeef ^{100, [ib](#)}, S. Hadzic ^{110, [ib](#)}, J.J. Hahn ^{142, [ib](#)}, E.H. Haines ^{96, [ib](#)}, M. Haleem ^{166, [ib](#)}, J. Haley ^{121, [ib](#)},
 J.J. Hall ^{140, [ib](#)}, G.D. Hallewell ^{102, [ib](#)}, L. Halser ^{19, [ib](#)}, K. Hamano ^{165, [ib](#)}, H. Hamdaoui ^{35e, [ib](#)}, M. Hamer ^{24, [ib](#)},
 G.N. Hamity ^{52, [ib](#)}, E.J. Hampshire ^{95, [ib](#)}, J. Han ^{62b, [ib](#)}, K. Han ^{62a, [ib](#)}, L. Han ^{14c, [ib](#)}, L. Han ^{62a, [ib](#)}, S. Han ^{17a, [ib](#)},
 Y.F. Han ^{155, [ib](#)}, K. Hanagaki ^{84, [ib](#)}, M. Hance ^{136, [ib](#)}, D.A. Hangal ^{41, [ib](#), [ad](#)}, H. Hanif ^{143, [ib](#)}, M.D. Hank ^{128, [ib](#)},
 R. Hankache ^{101, [ib](#)}, J.B. Hansen ^{42, [ib](#)}, J.D. Hansen ^{42, [ib](#)}, P.H. Hansen ^{42, [ib](#)}, K. Hara ^{157, [ib](#)}, D. Harada ^{56, [ib](#)},
 T. Harenberg ^{171, [ib](#)}, S. Harkusha ^{37, [ib](#)}, M.L. Harris ^{103, [ib](#)}, Y.T. Harris ^{126, [ib](#)}, J. Harrison ^{13, [ib](#)}, N.M. Harrison ^{119, [ib](#)},
 P.F. Harrison ^{167, [ib](#)}, N.M. Hartman ^{110, [ib](#)}, N.M. Hartmann ^{109, [ib](#)}, Y. Hasegawa ^{141, [ib](#)}, A. Hasib ^{52, [ib](#)}, S. Haug ^{19, [ib](#)},
 R. Hauser ^{107, [ib](#)}, C.M. Hawkes ^{20, [ib](#)}, R.J. Hawkins ^{36, [ib](#)}, Y. Hayashi ^{154, [ib](#)}, S. Hayashida ^{111, [ib](#)}, D. Hayden ^{107, [ib](#)},
 C. Hayes ^{106, [ib](#)}, R.L. Hayes ^{114, [ib](#)}, C.P. Hays ^{126, [ib](#)}, J.M. Hays ^{94, [ib](#)}, H.S. Hayward ^{92, [ib](#)}, F. He ^{62a, [ib](#)}, M. He ^{14a,14e, [ib](#)},
 Y. He ^{138, [ib](#)}, Y. He ^{127, [ib](#)}, N.B. Heatley ^{94, [ib](#)}, V. Hedberg ^{98, [ib](#)}, A.L. Heggelund ^{125, [ib](#)}, N.D. Hehir ^{94, [ib](#), [*](#)},
 C. Heidegger ^{54, [ib](#)}, K.K. Heidegger ^{54, [ib](#)}, W.D. Heidorn ^{81, [ib](#)}, J. Heilman ^{34, [ib](#)}, S. Heim ^{48, [ib](#)}, T. Heim ^{17a, [ib](#)},
 J.G. Heinlein ^{128, [ib](#)}, J.J. Heinrich ^{123, [ib](#)}, L. Heinrich ^{110, [ib](#), [af](#)}, J. Hejbal ^{131, [ib](#)}, L. Helary ^{48, [ib](#)}, A. Held ^{170, [ib](#)},
 S. Hellesund ^{16, [ib](#)}, C.M. Helling ^{164, [ib](#)}, S. Hellman ^{47a,47b, [ib](#)}, R.C.W. Henderson ^{91, [ib](#)}, L. Henkelmann ^{32, [ib](#)},
 A.M. Henriques Correia ^{36, [ib](#)}, H. Herde ^{98, [ib](#)}, Y. Hernández Jiménez ^{146, [ib](#)}, L.M. Herrmann ^{24, [ib](#)}, T. Herrmann ^{50, [ib](#)},
 G. Herten ^{54, [ib](#)}, R. Hertenberger ^{109, [ib](#)}, L. Hervas ^{36, [ib](#)}, M.E. Hesping ^{100, [ib](#)}, N.P. Hessey ^{156a, [ib](#)}, H. Hibi ^{85, [ib](#)},
 S.J. Hillier ^{20, [ib](#)}, J.R. Hinds ^{107, [ib](#)}, F. Hinterkeuser ^{24, [ib](#)}, M. Hirose ^{124, [ib](#)}, S. Hirose ^{157, [ib](#)}, D. Hirschbuehl ^{171, [ib](#)},
 T.G. Hitchings ^{101, [ib](#)}, B. Hiti ^{93, [ib](#)}, J. Hobbs ^{146, [ib](#)}, R. Hobincu ^{27e, [ib](#)}, N. Hod ^{169, [ib](#)}, M.C. Hodgkinson ^{140, [ib](#)},
 B.H. Hodgkinson ^{32, [ib](#)}, A. Hoecker ^{36, [ib](#)}, J. Hofer ^{48, [ib](#)}, T. Holm ^{24, [ib](#)}, M. Holzbock ^{110, [ib](#)}, L.B.A.H. Hommels ^{32, [ib](#)},
 B.P. Honan ^{101, [ib](#)}, J. Hong ^{62c, [ib](#)}, T.M. Hong ^{129, [ib](#)}, B.H. Hooberman ^{162, [ib](#)}, W.H. Hopkins ^{6, [ib](#)}, Y. Horii ^{111, [ib](#)},

S. Hou ^{149, [id](#)}, A.S. Howard ^{93, [id](#)}, J. Howarth ^{59, [id](#)}, J. Hoya ^{6, [id](#)}, M. Hrabovsky ^{122, [id](#)}, A. Hrynevich ^{48, [id](#)},
T. Hryn'ova ^{4, [id](#)}, P.J. Hsu ^{65, [id](#)}, S.-C. Hsu ^{139, [id](#)}, Q. Hu ^{41, [id](#)}, Y.F. Hu ^{14a, 14c, [id](#)}, S. Huang ^{64b, [id](#)}, X. Huang ^{14c, [id](#)},
Y. Huang ^{140, [id](#)}, Y. Huang ^{14a, [id](#)}, Z. Huang ^{101, [id](#)}, Z. Hubacek ^{132, [id](#)}, M. Huebner ^{24, [id](#)}, F. Huegging ^{24, [id](#)},
T.B. Huffman ^{126, [id](#)}, C.A. Hugli ^{48, [id](#)}, M. Huhtinen ^{36, [id](#)}, S.K. Huiberts ^{16, [id](#)}, R. Hulsken ^{104, [id](#)}, N. Huseynov ^{12, [id](#)},
J. Huston ^{107, [id](#)}, J. Huth ^{61, [id](#)}, R. Hyneman ^{144, [id](#)}, G. Iacobucci ^{56, [id](#)}, G. Iakovidis ^{29, [id](#)}, I. Ibragimov ^{142, [id](#)},
L. Iconomidou-Fayard ^{66, [id](#)}, P. Iengo ^{72a, 72b, [id](#)}, R. Iguchi ^{154, [id](#)}, T. Iizawa ^{84, [id](#)}, Y. Ikegami ^{84, [id](#)}, N. Ilic ^{155, [id](#)},
H. Imam ^{35a, [id](#)}, M. Ince Lezki ^{56, [id](#)}, T. Ingebretsen Carlson ^{47a, 47b, [id](#)}, G. Introzzi ^{73a, 73b, [id](#)}, M. Iodice ^{77a, [id](#)},
V. Ippolito ^{75a, 75b, [id](#)}, R.K. Irwin ^{92, [id](#)}, M. Ishino ^{154, [id](#)}, W. Islam ^{170, [id](#)}, C. Issever ^{18, 48, [id](#)}, S. Istin ^{21a, [id](#)}, ^{al},
H. Ito ^{168, [id](#)}, J.M. Iturbe Ponce ^{64a, [id](#)}, R. Iuppa ^{78a, 78b, [id](#)}, A. Ivina ^{169, [id](#)}, J.M. Izen ^{45, [id](#)}, V. Izzo ^{72a, [id](#)},
P. Jacka ^{131, 132, [id](#)}, P. Jackson ^{1, [id](#)}, R.M. Jacobs ^{48, [id](#)}, B.P. Jaeger ^{143, [id](#)}, C.S. Jagfeld ^{109, [id](#)}, P. Jain ^{54, [id](#)},
G. Jäkel ^{171, [id](#)}, K. Jakobs ^{54, [id](#)}, T. Jakoubek ^{169, [id](#)}, J. Jamieson ^{59, [id](#)}, K.W. Janas ^{86a, [id](#)}, A.E. Jaspan ^{92, [id](#)},
M. Javurkova ^{103, [id](#)}, F. Jeanneau ^{135, [id](#)}, L. Jeanty ^{123, [id](#)}, J. Jejelava ^{150a, [id](#)}, ^{ab}, P. Jenni ^{54, [id](#)}, ^g, C.E. Jessiman ^{34, [id](#)},
S. Jézéquel ^{4, [id](#)}, C. Jia ^{62b, [id](#)}, J. Jia ^{146, [id](#)}, X. Jia ^{61, [id](#)}, X. Jia ^{14a, 14c, [id](#)}, Z. Jia ^{14c, [id](#)}, Y. Jiang ^{62a, [id](#)}, S. Jiggins ^{48, [id](#)},
J. Jimenez Pena ^{13, [id](#)}, S. Jin ^{14c, [id](#)}, A. Jinaru ^{27b, [id](#)}, O. Jinnouchi ^{138, [id](#)}, P. Johansson ^{140, [id](#)}, K.A. Johns ^{7, [id](#)},
J.W. Johnson ^{136, [id](#)}, D.M. Jones ^{32, [id](#)}, E. Jones ^{48, [id](#)}, P. Jones ^{32, [id](#)}, R.W.L. Jones ^{91, [id](#)}, T.J. Jones ^{92, [id](#)},
R. Joshi ^{119, [id](#)}, J. Jovicevic ^{15, [id](#)}, X. Ju ^{17a, [id](#)}, J.J. Junggeburth ^{36, [id](#)}, T. Junkermann ^{63a, [id](#)}, A. Juste Rozas ^{13, [id](#)}, ^u,
M.K. Juzek ^{87, [id](#)}, S. Kabana ^{137c, [id](#)}, A. Kaczmarska ^{87, [id](#)}, M. Kado ^{110, [id](#)}, H. Kagan ^{119, [id](#)}, M. Kagan ^{144, [id](#)},
A. Kahn ^{41, [id](#)}, A. Kahn ^{128, [id](#)}, C. Kahra ^{100, [id](#)}, T. Kaji ^{168, [id](#)}, E. Kajomovitz ^{151, [id](#)}, N. Kakati ^{169, [id](#)}, I. Kalaitzidou ^{54, [id](#)},
C.W. Kalderon ^{29, [id](#)}, A. Kamenshchikov ^{155, [id](#)}, S. Kanayama ^{138, [id](#)}, N.J. Kang ^{136, [id](#)}, D. Kar ^{33g, [id](#)}, K. Karava ^{126, [id](#)},
M.J. Kareem ^{156b, [id](#)}, E. Karentzos ^{54, [id](#)}, I. Karkanias ^{153, [id](#)}, O. Karkout ^{114, [id](#)}, S.N. Karpov ^{38, [id](#)}, Z.M. Karpova ^{38, [id](#)},
V. Kartvelishvili ^{91, [id](#)}, A.N. Karyukhin ^{37, [id](#)}, E. Kasimi ^{153, [id](#)}, J. Katzy ^{48, [id](#)}, S. Kaur ^{34, [id](#)}, K. Kawade ^{141, [id](#)},
M.P. Kawale ^{120, [id](#)}, T. Kawamoto ^{135, [id](#)}, E.F. Kay ^{36, [id](#)}, F.I. Kaya ^{158, [id](#)}, S. Kazakos ^{107, [id](#)}, V.F. Kazanin ^{37, [id](#)},
Y. Ke ^{146, [id](#)}, J.M. Keaveney ^{33a, [id](#)}, R. Keeler ^{165, [id](#)}, G.V. Kehris ^{61, [id](#)}, J.S. Keller ^{34, [id](#)}, A.S. Kelly ^{96, [id](#)},
J.J. Kempster ^{147, [id](#)}, K.E. Kennedy ^{41, [id](#)}, P.D. Kennedy ^{100, [id](#)}, O. Kepka ^{131, [id](#)}, B.P. Kerridge ^{167, [id](#)}, S. Kersten ^{171, [id](#)},
B.P. Kerševan ^{93, [id](#)}, S. Keshri ^{66, [id](#)}, L. Keszeghova ^{28a, [id](#)}, S. Ketabchi Haghighat ^{155, [id](#)}, M. Khandoga ^{127, [id](#)},
A. Khanov ^{121, [id](#)}, A.G. Kharlamov ^{37, [id](#)}, T. Kharlamova ^{37, [id](#)}, E.E. Khoda ^{139, [id](#)}, T.J. Khoo ^{18, [id](#)}, G. Khorauli ^{166, [id](#)},
J. Khubua ^{150b, [id](#)}, ^{*}, Y.A.R. Khwaira ^{66, [id](#)}, A. Kilgallon ^{123, [id](#)}, D.W. Kim ^{47a, 47b, [id](#)}, Y.K. Kim ^{39, [id](#)}, N. Kimura ^{96, [id](#)},
A. Kirchhoff ^{55, [id](#)}, C. Kirfel ^{24, [id](#)}, F. Kirfel ^{24, [id](#)}, J. Kirk ^{134, [id](#)}, A.E. Kiryunin ^{110, [id](#)}, C. Kitsaki ^{10, [id](#)}, O. Kivernyk ^{24, [id](#)},
M. Klassen ^{63a, [id](#)}, C. Klein ^{34, [id](#)}, L. Klein ^{166, [id](#)}, M.H. Klein ^{106, [id](#)}, M. Klein ^{92, [id](#)}, ^{*}, S.B. Klein ^{56, [id](#)}, U. Klein ^{92, [id](#)},
P. Klimek ^{36, [id](#)}, A. Klimentov ^{29, [id](#)}, T. Klioutchnikova ^{36, [id](#)}, P. Kluit ^{114, [id](#)}, S. Kluth ^{110, [id](#)}, E. Kneringer ^{79, [id](#)},
T.M. Knight ^{155, [id](#)}, A. Knue ^{54, [id](#)}, R. Kobayashi ^{88, [id](#)}, M. Kobel ^{50, [id](#)}, D. Kobylanskii ^{169, [id](#)}, S.F. Koch ^{126, [id](#)},
M. Kocian ^{144, [id](#)}, P. Kodyš ^{133, [id](#)}, D.M. Koeck ^{123, [id](#)}, P.T. Koenig ^{24, [id](#)}, T. Koffas ^{34, [id](#)}, M. Kolb ^{135, [id](#)}, I. Koletsou ^{4, [id](#)},
T. Komarek ^{122, [id](#)}, K. Köneke ^{54, [id](#)}, A.X.Y. Kong ^{1, [id](#)}, T. Kono ^{118, [id](#)}, N. Konstantinidis ^{96, [id](#)}, B. Konya ^{98, [id](#)},
R. Kopeliansky ^{68, [id](#)}, S. Koperny ^{86a, [id](#)}, K. Korcyl ^{87, [id](#)}, K. Kordas ^{153, [id](#)}, ^e, G. Koren ^{152, [id](#)}, A. Korn ^{96, [id](#)},
S. Korn ^{55, [id](#)}, I. Korolkov ^{13, [id](#)}, N. Korotkova ^{37, [id](#)}, B. Kortman ^{114, [id](#)}, O. Kortner ^{110, [id](#)}, S. Kortner ^{110, [id](#)},
W.H. Kostecka ^{115, [id](#)}, V.V. Kostyukhin ^{142, [id](#)}, A. Kotskechagia ^{135, [id](#)}, A. Kotwal ^{51, [id](#)}, A. Koulouris ^{36, [id](#)},
A. Kourkouveli-Charalampidi ^{73a, 73b, [id](#)}, C. Kourkouvelis ^{9, [id](#)}, E. Kourlitis ^{110, [id](#)}, O. Kovanda ^{147, [id](#)},
R. Kowalewski ^{165, [id](#)}, W. Kozanecki ^{135, [id](#)}, A.S. Kozhin ^{37, [id](#)}, V.A. Kramarenko ^{37, [id](#)}, G. Kramberger ^{93, [id](#)},
P. Kramer ^{100, [id](#)}, M.W. Krasny ^{127, [id](#)}, A. Krasznahorkay ^{36, [id](#)}, J.W. Kraus ^{171, [id](#)}, J.A. Kremer ^{100, [id](#)}, T. Kresse ^{50, [id](#)},
J. Kretzschmar ^{92, [id](#)}, K. Kreul ^{18, [id](#)}, P. Krieger ^{155, [id](#)}, S. Krishnamurthy ^{103, [id](#)}, M. Krivos ^{133, [id](#)}, K. Krizka ^{20, [id](#)},
K. Kroeninger ^{49, [id](#)}, H. Kroha ^{110, [id](#)}, J. Kroll ^{131, [id](#)}, J. Kroll ^{128, [id](#)}, K.S. Krowpman ^{107, [id](#)}, U. Kruchonak ^{38, [id](#)},
H. Krüger ^{24, [id](#)}, N. Krumnack ^{81, [id](#)}, M.C. Kruse ^{51, [id](#)}, J.A. Krzysiak ^{87, [id](#)}, O. Kuchinskaia ^{37, [id](#)}, S. Kuday ^{3a, [id](#)},

S. Kuehn ^{36, [id](#)}, R. Kuesters ^{54, [id](#)}, T. Kuhl ^{48, [id](#)}, V. Kukhtin ^{38, [id](#)}, Y. Kulchitsky ^{37, [id](#), [a](#)}, S. Kuleshov ^{137d, 137b, [id](#)},
M. Kumar ^{33g, [id](#)}, N. Kumari ^{48, [id](#)}, A. Kupco ^{131, [id](#)}, T. Kupfer ⁴⁹, A. Kupich ^{37, [id](#)}, O. Kuprash ^{54, [id](#)},
H. Kurashige ^{85, [id](#)}, L.L. Kurchaninov ^{156a, [id](#)}, O. Kurdyshev ^{66, [id](#)}, Y.A. Kurochkin ^{37, [id](#)}, A. Kurova ^{37, [id](#)}, M. Kuze ^{138, [id](#)},
A.K. Kvam ^{103, [id](#)}, J. Kvita ^{122, [id](#)}, T. Kwan ^{104, [id](#)}, N.G. Kyriacou ^{106, [id](#)}, L.A.O. Laatu ^{102, [id](#)}, C. Lacasta ^{163, [id](#)},
F. Lacava ^{75a, 75b, [id](#)}, H. Lacker ^{18, [id](#)}, D. Lacour ^{127, [id](#)}, N.N. Lad ^{96, [id](#)}, E. Ladygin ^{38, [id](#)}, B. Laforge ^{127, [id](#)},
T. Lagouri ^{137e, [id](#)}, S. Lai ^{55, [id](#)}, I.K. Lakomic ^{86a, [id](#)}, N. Lalloue ^{60, [id](#)}, J.E. Lambert ^{165, [id](#)}, S. Lammers ^{68, [id](#)},
W. Lampl ^{7, [id](#)}, C. Lampoudis ^{153, [id](#), [e](#)}, A.N. Lancaster ^{115, [id](#)}, E. Lançon ^{29, [id](#)}, U. Landgraf ^{54, [id](#)}, M.P.J. Landon ^{94, [id](#)},
V.S. Lang ^{54, [id](#)}, R.J. Langenberg ^{103, [id](#)}, O.K.B. Langrekken ^{125, [id](#)}, A.J. Lankford ^{160, [id](#)}, F. Lanni ^{36, [id](#)},
K. Lantzsche ^{24, [id](#)}, A. Lanza ^{73a, [id](#)}, A. Lapertosa ^{57b, 57a, [id](#)}, J.F. Laporte ^{135, [id](#)}, T. Lari ^{71a, [id](#)}, F. Lasagni Manghi ^{23b, [id](#)},
M. Lassnig ^{36, [id](#)}, V. Latonova ^{131, [id](#)}, A. Laudrain ^{100, [id](#)}, A. Laurier ^{151, [id](#)}, S.D. Lawlor ^{95, [id](#)}, Z. Lawrence ^{101, [id](#)},
M. Lazzaroni ^{71a, 71b, [id](#)}, B. Le ¹⁰¹, E.M. Le Boulicaut ^{51, [id](#)}, B. Leban ^{93, [id](#)}, A. Lebedev ^{81, [id](#)}, M. LeBlanc ^{36, [id](#)},
F. Ledroit-Guillon ^{60, [id](#)}, A.C.A. Lee ⁹⁶, S.C. Lee ^{149, [id](#)}, S. Lee ^{47a, 47b, [id](#)}, T.F. Lee ^{92, [id](#)}, L.L. Leeuw ^{33c, [id](#)},
H.P. Lefebvre ^{95, [id](#)}, M. Lefebvre ^{165, [id](#)}, C. Leggett ^{17a, [id](#)}, G. Lehmann Miotto ^{36, [id](#)}, M. Leigh ^{56, [id](#)},
W.A. Leight ^{103, [id](#)}, W. Leinonen ^{113, [id](#)}, A. Leisos ^{153, [id](#), [r](#)}, M.A.L. Leite ^{83c, [id](#)}, C.E. Leitgeb ^{48, [id](#)}, R. Leitner ^{133, [id](#)},
K.J.C. Leney ^{44, [id](#)}, T. Lenz ^{24, [id](#)}, S. Leone ^{74a, [id](#)}, C. Leonidopoulos ^{52, [id](#)}, A. Leopold ^{145, [id](#)}, C. Leroy ^{108, [id](#)},
R. Les ^{107, [id](#)}, C.G. Lester ^{32, [id](#)}, M. Levchenko ^{37, [id](#)}, J. Levêque ^{4, [id](#)}, D. Levin ^{106, [id](#)}, L.J. Levinson ^{169, [id](#)},
M.P. Lewicki ^{87, [id](#)}, D.J. Lewis ^{4, [id](#)}, A. Li ^{5, [id](#)}, B. Li ^{62b, [id](#)}, C. Li ^{62a}, C-Q. Li ^{62c, [id](#)}, H. Li ^{62a, [id](#)}, H. Li ^{62b, [id](#)}, H. Li ^{14c, [id](#)},
H. Li ^{62b, [id](#)}, K. Li ^{139, [id](#)}, L. Li ^{62c, [id](#)}, M. Li ^{14a, 14c, [id](#)}, Q.Y. Li ^{62a, [id](#)}, S. Li ^{14a, 14c, [id](#)}, S. Li ^{62d, 62c, [id](#), [d](#)}, T. Li ^{5, [id](#)}, X. Li ^{104, [id](#)},
Z. Li ^{126, [id](#)}, Z. Li ^{104, [id](#)}, Z. Li ^{92, [id](#)}, Z. Li ^{14a, 14c, [id](#)}, S. Liang ^{14a, 14c, [id](#)}, Z. Liang ^{14a, [id](#)}, M. Liberatore ^{135, [id](#)},
B. Liberti ^{76a, [id](#)}, K. Lie ^{64c, [id](#)}, J. Lieber Marin ^{83b, [id](#)}, H. Lien ^{68, [id](#)}, K. Lin ^{107, [id](#)}, R.E. Lindley ^{7, [id](#)}, J.H. Lindon ^{2, [id](#)},
E. Lipeles ^{128, [id](#)}, A. Lipniacka ^{16, [id](#)}, A. Lister ^{164, [id](#)}, J.D. Little ^{4, [id](#)}, B. Liu ^{14a, [id](#)}, B.X. Liu ^{143, [id](#)}, D. Liu ^{62d, 62c, [id](#)},
J.B. Liu ^{62a, [id](#)}, J.K.K. Liu ^{32, [id](#)}, K. Liu ^{62d, 62c, [id](#)}, M. Liu ^{62a, [id](#)}, M.Y. Liu ^{62a, [id](#)}, P. Liu ^{14a, [id](#)}, Q. Liu ^{62d, 139, 62c, [id](#)},
X. Liu ^{62a, [id](#)}, Y. Liu ^{14d, 14c, [id](#)}, Y.L. Liu ^{62b, [id](#)}, Y.W. Liu ^{62a, [id](#)}, J. Llorente Merino ^{143, [id](#)}, S.L. Lloyd ^{94, [id](#)},
E.M. Lobodzinska ^{48, [id](#)}, P. Loch ^{7, [id](#)}, S. Loffredo ^{76a, 76b, [id](#)}, T. Lohse ^{18, [id](#)}, K. Lohwasser ^{140, [id](#)}, E. Loiacono ^{48, [id](#)},
M. Lokajicek ^{131, [id](#), [*](#)}, J.D. Lomas ^{20, [id](#)}, J.D. Long ^{162, [id](#)}, I. Longarini ^{160, [id](#)}, L. Longo ^{70a, 70b, [id](#)}, R. Longo ^{162, [id](#)},
I. Lopez Paz ^{67, [id](#)}, A. Lopez Solis ^{48, [id](#)}, J. Lorenz ^{109, [id](#)}, N. Lorenzo Martinez ^{4, [id](#)}, A.M. Lory ^{109, [id](#)},
G. Löschcke Centeno ^{147, [id](#)}, O. Loseva ^{37, [id](#)}, X. Lou ^{47a, 47b, [id](#)}, X. Lou ^{14a, 14c, [id](#)}, A. Lounis ^{66, [id](#)}, J. Love ^{6, [id](#)},
P.A. Love ^{91, [id](#)}, G. Lu ^{14a, 14c, [id](#)}, M. Lu ^{80, [id](#)}, S. Lu ^{128, [id](#)}, Y.J. Lu ^{65, [id](#)}, H.J. Lubatti ^{139, [id](#)}, C. Luci ^{75a, 75b, [id](#)},
F.L. Lucio Alves ^{14c, [id](#)}, A. Lucotte ^{60, [id](#)}, F. Luehring ^{68, [id](#)}, I. Luise ^{146, [id](#)}, O. Lukianchuk ^{66, [id](#)}, O. Lundberg ^{145, [id](#)},
B. Lund-Jensen ^{145, [id](#), [*](#)}, N.A. Luongo ^{123, [id](#)}, M.S. Lutz ^{152, [id](#)}, D. Lynn ^{29, [id](#)}, H. Lyons ⁹², R. Lysak ^{131, [id](#)},
E. Lytken ^{98, [id](#)}, V. Lyubushkin ^{38, [id](#)}, T. Lyubushkina ^{38, [id](#)}, M.M. Lyukova ^{146, [id](#)}, H. Ma ^{29, [id](#)}, K. Ma ^{62a, [id](#)},
L.L. Ma ^{62b, [id](#)}, Y. Ma ^{121, [id](#)}, D.M. Mac Donell ^{165, [id](#)}, G. Maccarrone ^{53, [id](#)}, J.C. MacDonald ^{100, [id](#)}, R. Madar ^{40, [id](#)},
J. Maeda ^{85, [id](#)}, T. Maeno ^{29, [id](#)}, M. Maerker ^{50, [id](#)}, H. Maguire ^{140, [id](#)}, V. Maiboroda ^{135, [id](#)}, A. Maio ^{130a, 130b, 130d, [id](#)},
K. Maj ^{86a, [id](#)}, O. Majersky ^{48, [id](#)}, S. Majewski ^{123, [id](#)}, N. Makovec ^{66, [id](#)}, V. Maksimovic ^{15, [id](#)}, B. Malaescu ^{127, [id](#)},
Pa. Malecki ^{87, [id](#)}, V.P. Maleev ^{37, [id](#)}, F. Malek ^{60, [id](#)}, M. Mali ^{93, [id](#)}, D. Malito ^{95, [id](#)}, U. Mallik ^{80, [id](#), [*](#)}, S. Maltezos ¹⁰,
S. Malyukov ³⁸, J. Mamuzic ^{13, [id](#)}, G. Mancini ^{53, [id](#)}, G. Manco ^{73a, 73b, [id](#)}, J.P. Mandalia ^{94, [id](#)}, I. Mandić ^{93, [id](#)},
L. Manhaes de Andrade Filho ^{83a, [id](#)}, I.M. Maniatis ^{169, [id](#)}, J. Manjarres Ramos ^{102, [id](#), [ac](#)}, D.C. Mankad ^{169, [id](#)},
A. Mann ^{109, [id](#)}, B. Mansoulie ^{135, [id](#)}, S. Manzoni ^{36, [id](#)}, A. Marantis ^{153, [id](#), [r](#)}, G. Marchiori ^{5, [id](#)}, M. Marcisovsky ^{131, [id](#)},
C. Marcon ^{71a, [id](#)}, M. Marinescu ^{20, [id](#)}, M. Marjanovic ^{120, [id](#)}, E.J. Marshall ^{91, [id](#)}, Z. Marshall ^{17a, [id](#)},
S. Marti-Garcia ^{163, [id](#)}, T.A. Martin ^{167, [id](#)}, V.J. Martin ^{52, [id](#)}, B. Martin dit Latour ^{16, [id](#)}, L. Martinelli ^{75a, 75b, [id](#)},
M. Martinez ^{13, [id](#), [u](#)}, P. Martinez Agullo ^{163, [id](#)}, V.I. Martinez Outschoorn ^{103, [id](#)}, P. Martinez Suarez ^{13, [id](#)},
S. Martin-Haugh ^{134, [id](#)}, V.S. Martoiu ^{27b, [id](#)}, A.C. Martyniuk ^{96, [id](#)}, A. Marzin ^{36, [id](#)}, D. Mascione ^{78a, 78b, [id](#)},

L. Masetti ^{100, [id](#)}, T. Mashimo ^{154, [id](#)}, J. Masik ^{101, [id](#)}, A.L. Maslennikov ^{37, [id](#)}, L. Massa ^{23b, [id](#)}, P. Massarotti ^{72a,72b, [id](#)}, P. Mastrandrea ^{74a,74b, [id](#)}, A. Mastroberardino ^{43b,43a, [id](#)}, T. Masubuchi ^{154, [id](#)}, T. Mathisen ^{161, [id](#)}, J. Matousek ^{133, [id](#)}, N. Matsuzawa ¹⁵⁴, J. Maurer ^{27b, [id](#)}, B. Maček ^{93, [id](#)}, D.A. Maximov ^{37, [id](#)}, R. Mazini ^{149, [id](#)}, I. Maznas ^{153, [id](#)}, M. Mazza ^{107, [id](#)}, S.M. Mazza ^{136, [id](#)}, E. Mazzeo ^{71a,71b, [id](#)}, C. Mc Ginn ^{29, [id](#)}, J.P. Mc Gowan ^{104, [id](#)}, S.P. Mc Kee ^{106, [id](#)}, E.F. McDonald ^{105, [id](#)}, A.E. McDougall ^{114, [id](#)}, J.A. Mcfayden ^{147, [id](#)}, R.P. McGovern ^{128, [id](#)}, G. Mchedlidze ^{150b, [id](#)}, R.P. McKenzie ^{33g, [id](#)}, T.C. McLachlan ^{48, [id](#)}, D.J. McLaughlin ^{96, [id](#)}, K.D. McLean ^{165, [id](#)}, S.J. McMahon ^{134, [id](#)}, P.C. McNamara ^{105, [id](#)}, C.M. Mcpartland ^{92, [id](#)}, R.A. McPherson ^{165, [id](#)}, S. Mehlhase ^{109, [id](#)}, A. Mehta ^{92, [id](#)}, D. Melini ^{151, [id](#)}, B.R. Mellado Garcia ^{33g, [id](#)}, A.H. Melo ^{55, [id](#)}, F. Meloni ^{48, [id](#)}, A.M. Mendes Jacques Da Costa ^{101, [id](#)}, H.Y. Meng ^{155, [id](#)}, L. Meng ^{91, [id](#)}, S. Menke ^{110, [id](#)}, M. Mentink ^{36, [id](#)}, E. Meoni ^{43b,43a, [id](#)}, C. Merlassino ^{126, [id](#)}, L. Merola ^{72a,72b, [id](#)}, C. Meroni ^{71a,71b, [id](#)}, G. Merz ¹⁰⁶, O. Meshkov ^{37, [id](#)}, J. Metcalfe ^{6, [id](#)}, A.S. Mete ^{6, [id](#)}, C. Meyer ^{68, [id](#)}, J-P. Meyer ^{135, [id](#)}, R.P. Middleton ^{134, [id](#)}, L. Mijović ^{52, [id](#)}, G. Mikenberg ^{169, [id](#)}, M. Mikestikova ^{131, [id](#)}, M. Mikuž ^{93, [id](#)}, H. Mildner ^{100, [id](#)}, A. Milic ^{36, [id](#)}, C.D. Milke ^{44, [id](#)}, D.W. Miller ^{39, [id](#)}, L.S. Miller ^{34, [id](#)}, A. Milov ^{169, [id](#)}, D.A. Milstead ^{47a,47b}, T. Min ^{14c}, A.A. Minaenko ^{37, [id](#)}, I.A. Minashvili ^{150b, [id](#)}, L. Mince ^{59, [id](#)}, A.I. Mincer ^{117, [id](#)}, B. Mindur ^{86a, [id](#)}, M. Mineev ^{38, [id](#)}, Y. Mino ^{88, [id](#)}, L.M. Mir ^{13, [id](#)}, M. Miralles Lopez ^{163, [id](#)}, M. Mironova ^{17a, [id](#)}, A. Mishima ¹⁵⁴, M.C. Missio ^{113, [id](#)}, T. Mitani ^{168, [id](#)}, A. Mitra ^{167, [id](#)}, V.A. Mitsou ^{163, [id](#)}, O. Miu ^{155, [id](#)}, P.S. Miyagawa ^{94, [id](#)}, Y. Miyazaki ⁸⁹, A. Mizukami ^{84, [id](#)}, T. Mkrtchyan ^{63a, [id](#)}, M. Mlinarevic ^{96, [id](#)}, T. Mlinarevic ^{96, [id](#)}, M. Mlynarikova ^{36, [id](#)}, S. Mobius ^{19, [id](#)}, K. Mochizuki ^{108, [id](#)}, P. Moder ^{48, [id](#)}, P. Mogg ^{109, [id](#)}, A.F. Mohammed ^{14a,14e, [id](#)}, S. Mohapatra ^{41, [id](#)}, G. Mokgatitswane ^{33g, [id](#)}, L. Moleri ^{169, [id](#)}, B. Mondal ^{142, [id](#)}, S. Mondal ^{132, [id](#)}, K. Mönig ^{48, [id](#)}, E. Monnier ^{102, [id](#)}, L. Monsonis Romero ¹⁶³, J. Montejo Berlingen ^{13,84, [id](#)}, M. Montella ^{119, [id](#)}, F. Montekali ^{77a,77b, [id](#)}, F. Monticelli ^{90, [id](#)}, S. Monzani ^{69a,69c, [id](#)}, N. Morange ^{66, [id](#)}, A.L. Moreira De Carvalho ^{130a, [id](#)}, M. Moreno Llácer ^{163, [id](#)}, C. Moreno Martinez ^{56, [id](#)}, P. Morettini ^{57b, [id](#)}, S. Morgenstern ^{36, [id](#)}, M. Morii ^{61, [id](#)}, M. Morinaga ^{154, [id](#)}, A.K. Morley ^{36, [id](#)}, F. Morodei ^{75a,75b, [id](#)}, L. Morvaj ^{36, [id](#)}, P. Moschovakos ^{36, [id](#)}, B. Moser ^{36, [id](#)}, M. Mosidze ^{150b, [id](#)}, T. Moskalets ^{54, [id](#)}, P. Moskvitina ^{113, [id](#)}, J. Moss ^{31, [id](#)}, E.J.W. Moyse ^{103, [id](#)}, O. Mtintsilana ^{33g, [id](#)}, S. Muanza ^{102, [id](#)}, J. Mueller ^{129, [id](#)}, D. Muenstermann ^{91, [id](#)}, R. Müller ^{19, [id](#)}, G.A. Mullier ^{161, [id](#)}, A.J. Mullin ³², J.J. Mullin ¹²⁸, D.P. Mungo ^{155, [id](#)}, D. Munoz Perez ^{163, [id](#)}, F.J. Munoz Sanchez ^{101, [id](#)}, M. Murin ^{101, [id](#)}, W.J. Murray ^{167,134, [id](#)}, A. Murrone ^{71a,71b, [id](#)}, J.M. Muse ^{120, [id](#)}, M. Muškinja ^{17a, [id](#)}, C. Mwewa ^{29, [id](#)}, A.G. Myagkov ^{37, [id](#)}, A.J. Myers ^{8, [id](#)}, A.A. Myers ¹²⁹, G. Myers ^{68, [id](#)}, M. Myska ^{132, [id](#)}, B.P. Nachman ^{17a, [id](#)}, O. Nackenhorst ^{49, [id](#)}, A. Nag ^{50, [id](#)}, K. Nagai ^{126, [id](#)}, K. Nagano ^{84, [id](#)}, J.L. Nagle ^{29, [id](#)}, E. Nagy ^{102, [id](#)}, A.M. Nairz ^{36, [id](#)}, Y. Nakahama ^{84, [id](#)}, K. Nakamura ^{84, [id](#)}, K. Nakkalil ^{5, [id](#)}, H. Nanjo ^{124, [id](#)}, R. Narayan ^{44, [id](#)}, E.A. Narayanan ^{112, [id](#)}, I. Naryshkin ^{37, [id](#)}, M. Naseri ^{34, [id](#)}, S. Nasri ^{159, [id](#)}, C. Nass ^{24, [id](#)}, G. Navarro ^{22a, [id](#)}, J. Navarro-Gonzalez ^{163, [id](#)}, R. Nayak ^{152, [id](#)}, A. Nayaz ^{18, [id](#)}, P.Y. Nechaeva ^{37, [id](#)}, F. Nechansky ^{48, [id](#)}, L. Nedic ^{126, [id](#)}, T.J. Neep ^{20, [id](#)}, A. Negri ^{73a,73b, [id](#)}, M. Negrini ^{23b, [id](#)}, C. Nellist ^{114, [id](#)}, C. Nelson ^{104, [id](#)}, K. Nelson ^{106, [id](#)}, S. Nemecek ^{131, [id](#)}, M. Nessi ^{36, [id](#)}, M.S. Neubauer ^{162, [id](#)}, F. Neuhaus ^{100, [id](#)}, J. Neundorff ^{48, [id](#)}, R. Newhouse ^{164, [id](#)}, P.R. Newman ^{20, [id](#)}, C.W. Ng ^{129, [id](#)}, Y.W.Y. Ng ^{48, [id](#)}, B. Ngair ^{35e, [id](#)}, H.D.N. Nguyen ^{108, [id](#)}, R.B. Nickerson ^{126, [id](#)}, R. Nicolaidou ^{135, [id](#)}, J. Nielsen ^{136, [id](#)}, M. Niemeyer ^{55, [id](#)}, J. Niermann ^{55,36, [id](#)}, N. Nikiforou ^{36, [id](#)}, V. Nikolaenko ^{37, [id](#)}, I. Nikolic-Audit ^{127, [id](#)}, K. Nikolopoulos ^{20, [id](#)}, P. Nilsson ^{29, [id](#)}, I. Ninca ^{48, [id](#)}, H.R. Nindhito ^{56, [id](#)}, G. Ninio ^{152, [id](#)}, A. Nisati ^{75a, [id](#)}, N. Nishu ^{2, [id](#)}, R. Nisius ^{110, [id](#)}, J-E. Nitschke ^{50, [id](#)}, E.K. Nkadimeng ^{33g, [id](#)}, S.J. Noacco Rosende ^{90, [id](#)}, T. Nobe ^{154, [id](#)}, D.L. Noel ^{32, [id](#)}, T. Nommensen ^{148, [id](#)}, M.B. Norfolk ^{140, [id](#)}, R.R.B. Norisam ^{96, [id](#)}, B.J. Norman ^{34, [id](#)}, J. Novak ^{93, [id](#)}, T. Novak ^{48, [id](#)}, L. Novotny ^{132, [id](#)}, R. Novotny ^{112, [id](#)}, L. Nozka ^{122, [id](#)}, K. Ntekas ^{160, [id](#)}, N.M.J. Nunes De Moura Junior ^{83b, [id](#)}, E. Nurse ⁹⁶, J. Ocariz ^{127, [id](#)}, A. Ochi ^{85, [id](#)}, I. Ochoa ^{130a, [id](#)}, S. Oerdek ^{48, [id](#)}, J.T. Offermann ^{39, [id](#)}, A. Ogrodnik ^{133, [id](#)}, A. Oh ^{101, [id](#)}, C.C. Ohm ^{145, [id](#)}, H. Oide ^{84, [id](#)}, R. Oishi ^{154, [id](#)}, M.L. Ojeda ^{48, [id](#)}, Y. Okazaki ^{88, [id](#)}, M.W. O'Keefe ⁹², Y. Okumura ^{154, [id](#)}, L.F. Oleiro Seabra ^{130a, [id](#)}, S.A. Olivares Pino ^{137d, [id](#)},

D. Oliveira Damazio ^{29, [id](#)}, D. Oliveira Goncalves ^{83a, [id](#)}, J.L. Oliver ^{160, [id](#)}, A. Olszewski ^{87, [id](#)}, Ö.O. Öncel ^{54, [id](#)}, D.C. O'Neil ^{143, [id](#)}, A.P. O'Neill ^{19, [id](#)}, A. Onofre ^{130a,130c, [id](#)}, P.U.E. Onyisi ^{11, [id](#)}, M.J. Oreglia ^{39, [id](#)}, G.E. Orellana ^{90, [id](#)}, D. Orestano ^{77a,77b, [id](#)}, N. Orlando ^{13, [id](#)}, R.S. Orr ^{155, [id](#)}, V. O'Shea ^{59, [id](#)}, L.M. Osojnak ^{128, [id](#)}, R. Ospanov ^{62a, [id](#)}, G. Otero y Garzon ^{30, [id](#)}, H. Otono ^{89, [id](#)}, P.S. Ott ^{63a, [id](#)}, G.J. Ottino ^{17a, [id](#)}, M. Ouchrif ^{35d, [id](#)}, J. Ouellette ^{29, [id](#)}, F. Ould-Saada ^{125, [id](#)}, M. Owen ^{59, [id](#)}, R.E. Owen ^{134, [id](#)}, K.Y. Oyulmaz ^{21a, [id](#)}, V.E. Ozcan ^{21a, [id](#)}, N. Ozturk ^{8, [id](#)}, S. Ozturk ^{82, [id](#)}, H.A. Pacey ^{32, [id](#)}, A. Pacheco Pages ^{13, [id](#)}, C. Padilla Aranda ^{13, [id](#)}, G. Padovano ^{75a,75b, [id](#)}, S. Pagan Griso ^{17a, [id](#)}, G. Palacino ^{68, [id](#)}, A. Palazzo ^{70a,70b, [id](#)}, S. Palestini ^{36, [id](#)}, J. Pan ^{172, [id](#)}, T. Pan ^{64a, [id](#)}, D.K. Panchal ^{11, [id](#)}, C.E. Pandini ^{114, [id](#)}, J.G. Panduro Vazquez ^{95, [id](#)}, H.D. Pandya ^{1, [id](#)}, H. Pang ^{14b, [id](#)}, P. Pani ^{48, [id](#)}, G. Panizzo ^{69a,69c, [id](#)}, L. Paolozzi ^{56, [id](#)}, C. Papadatos ^{108, [id](#)}, S. Parajuli ^{44, [id](#)}, A. Paramonov ^{6, [id](#)}, C. Paraskevopoulos ^{10, [id](#)}, D. Paredes Hernandez ^{64b, [id](#)}, T.H. Park ^{155, [id](#)}, M.A. Parker ^{32, [id](#)}, F. Parodi ^{57b,57a, [id](#)}, E.W. Parrish ^{115, [id](#)}, V.A. Parrish ^{52, [id](#)}, J.A. Parsons ^{41, [id](#)}, U. Parzefall ^{54, [id](#)}, B. Pascual Dias ^{108, [id](#)}, L. Pascual Dominguez ^{152, [id](#)}, F. Pasquali ^{114, [id](#)}, E. Pasqualucci ^{75a, [id](#)}, S. Passaggio ^{57b, [id](#)}, F. Pastore ^{95, [id](#)}, P. Pasuwan ^{47a,47b, [id](#)}, P. Patel ^{87, [id](#)}, U.M. Patel ^{51, [id](#)}, J.R. Pater ^{101, [id](#)}, T. Pauly ^{36, [id](#)}, J. Pearkes ^{144, [id](#)}, M. Pedersen ^{125, [id](#)}, R. Pedro ^{130a, [id](#)}, S.V. Peleganchuk ^{37, [id](#)}, O. Penc ^{36, [id](#)}, E.A. Pender ^{52, [id](#)}, H. Peng ^{62a, [id](#)}, K.E. Pensi ^{109, [id](#)}, M. Penzin ^{37, [id](#)}, B.S. Peralva ^{83d, [id](#)}, A.P. Pereira Peixoto ^{60, [id](#)}, L. Pereira Sanchez ^{47a,47b, [id](#)}, D.V. Perepelitsa ^{29, [id](#)}, E. Perez Codina ^{156a, [id](#)}, M. Perganti ^{10, [id](#)}, L. Perini ^{71a,71b, [id](#)}, H. Pernegger ^{36, [id](#)}, O. Perrin ^{40, [id](#)}, K. Peters ^{48, [id](#)}, R.F.Y. Peters ^{101, [id](#)}, B.A. Petersen ^{36, [id](#)}, T.C. Petersen ^{42, [id](#)}, E. Petit ^{102, [id](#)}, V. Petousis ^{132, [id](#)}, C. Petridou ^{153, [id](#)}, A. Petrukhin ^{142, [id](#)}, M. Pettee ^{17a, [id](#)}, N.E. Pettersson ^{36, [id](#)}, A. Petukhov ^{37, [id](#)}, K. Petukhova ^{133, [id](#)}, A. Peyaud ^{135, [id](#)}, R. Pezoa ^{137f, [id](#)}, L. Pezzotti ^{36, [id](#)}, G. Pezzullo ^{172, [id](#)}, T.M. Pham ^{170, [id](#)}, T. Pham ^{105, [id](#)}, P.W. Phillips ^{134, [id](#)}, G. Piacquadio ^{146, [id](#)}, E. Pianori ^{17a, [id](#)}, F. Piazza ^{71a,71b, [id](#)}, R. Piegai ^{30, [id](#)}, D. Pietreanu ^{27b, [id](#)}, A.D. Pilkington ^{101, [id](#)}, M. Pinamonti ^{69a,69c, [id](#)}, J.L. Pinfold ^{2, [id](#)}, B.C. Pinheiro Pereira ^{130a, [id](#)}, A.E. Pinto Pinoargote ^{135, [id](#)}, L. Pintucci ^{69a,69c, [id](#)}, K.M. Piper ^{147, [id](#)}, A. Pirttikoski ^{56, [id](#)}, C. Pitman Donaldson ^{96, [id](#)}, D.A. Pizzi ^{34, [id](#)}, L. Pizzimento ^{64b, [id](#)}, M.-A. Pleier ^{29, [id](#)}, V. Plesanovs ^{54, [id](#)}, V. Pleskot ^{133, [id](#)}, E. Plotnikova ^{38, [id](#)}, G. Poddar ^{4, [id](#)}, R. Poettgen ^{98, [id](#)}, L. Poggioli ^{127, [id](#)}, I. Pokharel ^{55, [id](#)}, S. Polacek ^{133, [id](#)}, G. Polesello ^{73a, [id](#)}, A. Poley ^{143,156a, [id](#)}, R. Polifka ^{132, [id](#)}, A. Polini ^{23b, [id](#)}, C.S. Pollard ^{167, [id](#)}, Z.B. Pollock ^{119, [id](#)}, V. Polychronakos ^{29, [id](#)}, E. Pompa Pacchi ^{75a,75b, [id](#)}, D. Ponomarenko ^{113, [id](#)}, L. Pontecorvo ^{36, [id](#)}, S. Popa ^{27a, [id](#)}, G.A. Popeneciu ^{27d, [id](#)}, A. Poreba ^{36, [id](#)}, D.M. Portillo Quintero ^{156a, [id](#)}, S. Pospisil ^{132, [id](#)}, M.A. Postill ^{140, [id](#)}, P. Postolache ^{27c, [id](#)}, K. Potamianos ^{167, [id](#)}, P.A. Potepa ^{86a, [id](#)}, I.N. Potrap ^{38, [id](#)}, C.J. Potter ^{32, [id](#)}, H. Potti ^{1, [id](#)}, T. Poulsen ^{48, [id](#)}, J. Poveda ^{163, [id](#)}, M.E. Pozo Astigarraga ^{36, [id](#)}, A. Prades Ibanez ^{163, [id](#)}, J. Pretel ^{54, [id](#)}, D. Price ^{101, [id](#)}, M. Primavera ^{70a, [id](#)}, M.A. Principe Martin ^{99, [id](#)}, R. Privara ^{122, [id](#)}, T. Procter ^{59, [id](#)}, M.L. Proffitt ^{139, [id](#)}, N. Proklova ^{128, [id](#)}, K. Prokofiev ^{64c, [id](#)}, G. Proto ^{110, [id](#)}, S. Protopopescu ^{29, [id](#)}, J. Proudfoot ^{6, [id](#)}, M. Przybycien ^{86a, [id](#)}, W.W. Przygoda ^{86b, [id](#)}, J.E. Puddefoot ^{140, [id](#)}, D. Pudzha ^{37, [id](#)}, D. Pyatiizbyantseva ^{37, [id](#)}, J. Qian ^{106, [id](#)}, D. Qichen ^{101, [id](#)}, Y. Qin ^{101, [id](#)}, T. Qiu ^{52, [id](#)}, A. Quadt ^{55, [id](#)}, M. Queitsch-Maitland ^{101, [id](#)}, G. Quetant ^{56, [id](#)}, R.P. Quinn ^{164, [id](#)}, G. Rabanal Bolanos ^{61, [id](#)}, D. Rafanoharana ^{54, [id](#)}, F. Ragusa ^{71a,71b, [id](#)}, J.L. Rainbolt ^{39, [id](#)}, J.A. Raine ^{56, [id](#)}, S. Rajagopalan ^{29, [id](#)}, E. Ramakoti ^{37, [id](#)}, K. Ran ^{48,14e, [id](#)}, N.P. Rapheeha ^{33g, [id](#)}, H. Rasheed ^{27b, [id](#)}, V. Raskina ^{127, [id](#)}, D.F. Rassloff ^{63a, [id](#)}, S. Rave ^{100, [id](#)}, B. Ravina ^{55, [id](#)}, I. Ravinovich ^{169, [id](#)}, M. Raymond ^{36, [id](#)}, A.L. Read ^{125, [id](#)}, N.P. Readioff ^{140, [id](#)}, D.M. Rebuzzi ^{73a,73b, [id](#)}, G. Redlinger ^{29, [id](#)}, A.S. Reed ^{110, [id](#)}, K. Reeves ^{26, [id](#)}, J.A. Reidelsturz ^{171, [id](#)}, D. Reikher ^{152, [id](#)}, A. Rej ^{142, [id](#)}, C. Rembser ^{36, [id](#)}, A. Renardi ^{48, [id](#)}, M. Renda ^{27b, [id](#)}, M.B. Rendel ^{110, [id](#)}, F. Renner ^{48, [id](#)}, A.G. Rennie ^{160, [id](#)}, A.L. Rescia ^{48, [id](#)}, S. Resconi ^{71a, [id](#)}, M. Ressegotti ^{57b,57a, [id](#)}, S. Rettie ^{36, [id](#)}, J.G. Reyes Rivera ^{107, [id](#)}, B. Reynolds ^{119, [id](#)}, E. Reynolds ^{17a, [id](#)}, O.L. Rezanova ^{37, [id](#)}, P. Reznicek ^{133, [id](#)}, N. Ribaric ^{91, [id](#)}, E. Ricci ^{78a,78b, [id](#)}, R. Richter ^{110, [id](#)}, S. Richter ^{47a,47b, [id](#)}, E. Richter-Was ^{86b, [id](#)}, M. Ridel ^{127, [id](#)}, S. Ridouani ^{35d, [id](#)}, P. Rieck ^{117, [id](#)}, P. Riedler ^{36, [id](#)},

M. Rijssenbeek ^{146, [id](#)}, A. Rimoldi ^{73a,73b, [id](#)}, M. Rimoldi ^{48, [id](#)}, L. Rinaldi ^{23b,23a, [id](#)}, T.T. Rinn ^{29, [id](#)},
M.P. Rinnagel ^{109, [id](#)}, G. Ripellino ^{161, [id](#)}, I. Riu ^{13, [id](#)}, P. Rivadeneira ^{48, [id](#)}, J.C. Rivera Vergara ^{165, [id](#)},
F. Rizatdinova ^{121, [id](#)}, E. Rizvi ^{94, [id](#)}, B.A. Roberts ^{167, [id](#)}, B.R. Roberts ^{17a, [id](#)}, S.H. Robertson ^{104, [id](#)},
D. Robinson ^{32, [id](#)}, C.M. Robles Gajardo ^{137f}, M. Robles Manzano ^{100, [id](#)}, A. Robson ^{59, [id](#)}, A. Rocchi ^{76a,76b, [id](#)},
C. Roda ^{74a,74b, [id](#)}, S. Rodriguez Bosca ^{63a, [id](#)}, Y. Rodriguez Garcia ^{22a, [id](#)}, A. Rodriguez Rodriguez ^{54, [id](#)},
A.M. Rodríguez Vera ^{156b, [id](#)}, S. Roe ³⁶, J.T. Roemer ^{160, [id](#)}, A.R. Roepe-Gier ^{136, [id](#)}, J. Roggel ^{171, [id](#)}, O. Røhne ^{125, [id](#)},
R.A. Rojas ^{103, [id](#)}, C.P.A. Roland ^{68, [id](#)}, J. Roloff ^{29, [id](#)}, A. Romanouk ^{37, [id](#)}, E. Romano ^{73a,73b, [id](#)}, M. Romano ^{23b, [id](#)},
A.C. Romero Hernandez ^{162, [id](#)}, N. Rompotis ^{92, [id](#)}, L. Roos ^{127, [id](#)}, S. Rosati ^{75a, [id](#)}, B.J. Rosser ^{39, [id](#)}, E. Rossi ^{126, [id](#)},
E. Rossi ^{72a,72b, [id](#)}, L.P. Rossi ^{57b, [id](#)}, L. Rossini ^{54, [id](#)}, R. Rosten ^{119, [id](#)}, M. Rotaru ^{27b, [id](#)}, B. Rottler ^{54, [id](#)},
C. Rougier ^{102, [id](#)}, ^{ac}, D. Rousseau ^{66, [id](#)}, D. Rousso ^{32, [id](#)}, A. Roy ^{162, [id](#)}, S. Roy-Garand ^{155, [id](#)}, A. Rozanov ^{102, [id](#)},
Y. Rozen ^{151, [id](#)}, X. Ruan ^{33g, [id](#)}, A. Rubio Jimenez ^{163, [id](#)}, A.J. Ruby ^{92, [id](#)}, V.H. Ruelas Rivera ^{18, [id](#)}, T.A. Ruggeri ^{1, [id](#)},
A. Ruggiero ^{126, [id](#)}, A. Ruiz-Martinez ^{163, [id](#)}, A. Rummler ^{36, [id](#)}, Z. Rurikova ^{54, [id](#)}, N.A. Rusakovich ^{38, [id](#)},
H.L. Russell ^{165, [id](#)}, G. Russo ^{75a,75b, [id](#)}, J.P. Rutherford ^{7, [id](#)}, S. Rutherford Colmenares ^{32, [id](#)}, K. Rybacki ⁹¹,
M. Rybar ^{133, [id](#)}, E.B. Rye ^{125, [id](#)}, A. Ryzhov ^{44, [id](#)}, J.A. Sabater Iglesias ^{56, [id](#)}, P. Sabatini ^{163, [id](#)}, L. Sabetta ^{75a,75b, [id](#)},
H.F-W. Sadrozinski ^{136, [id](#)}, F. Safai Tehrani ^{75a, [id](#)}, B. Safarzadeh Samani ^{147, [id](#)}, M. Safdari ^{144, [id](#)}, S. Saha ^{165, [id](#)},
M. Sahinsoy ^{110, [id](#)}, M. Saimpert ^{135, [id](#)}, M. Saito ^{154, [id](#)}, T. Saito ^{154, [id](#)}, D. Salamani ^{36, [id](#)}, A. Salnikov ^{144, [id](#)},
J. Salt ^{163, [id](#)}, A. Salvador Salas ^{13, [id](#)}, D. Salvatore ^{43b,43a, [id](#)}, F. Salvatore ^{147, [id](#)}, A. Salzburger ^{36, [id](#)}, D. Sammel ^{54, [id](#)},
D. Sampsonidis ^{153, [id](#)}, ^e, D. Sampsonidou ^{123, [id](#)}, J. Sánchez ^{163, [id](#)}, A. Sanchez Pineda ^{4, [id](#)},
V. Sanchez Sebastian ^{163, [id](#)}, H. Sandaker ^{125, [id](#)}, C.O. Sander ^{48, [id](#)}, J.A. Sandesara ^{103, [id](#)}, M. Sandhoff ^{171, [id](#)},
C. Sandoval ^{22b, [id](#)}, D.P.C. Sankey ^{134, [id](#)}, T. Sano ^{88, [id](#)}, A. Sansoni ^{53, [id](#)}, L. Santi ^{75a,75b, [id](#)}, C. Santoni ^{40, [id](#)},
H. Santos ^{130a,130b, [id](#)}, S.N. Santpur ^{17a, [id](#)}, A. Santra ^{169, [id](#)}, K.A. Saoucha ^{140, [id](#)}, J.G. Saraiva ^{130a,130d, [id](#)},
J. Sardain ^{7, [id](#)}, O. Sasaki ^{84, [id](#)}, K. Sato ^{157, [id](#)}, C. Sauer ^{63b}, F. Sauerburger ^{54, [id](#)}, E. Sauvan ^{4, [id](#)}, P. Savard ^{155, [id](#)}, ^{ah},
R. Sawada ^{154, [id](#)}, C. Sawyer ^{134, [id](#)}, L. Sawyer ^{97, [id](#)}, I. Sayago Galvan ¹⁶³, C. Sbarra ^{23b, [id](#)}, A. Sbrizzi ^{23b,23a, [id](#)},
T. Scanlon ^{96, [id](#)}, J. Schaarschmidt ^{139, [id](#)}, P. Schacht ^{110, [id](#)}, D. Schaefer ^{39, [id](#)}, U. Schäfer ^{100, [id](#)}, A.C. Schaffer ^{66,44, [id](#)},
D. Schaile ^{109, [id](#)}, R.D. Schamberger ^{146, [id](#)}, C. Scharf ^{18, [id](#)}, M.M. Schefer ^{19, [id](#)}, V.A. Schegelsky ^{37, [id](#)},
D. Scheirich ^{133, [id](#)}, F. Schenck ^{18, [id](#)}, M. Schernau ^{160, [id](#)}, C. Scheulen ^{55, [id](#)}, C. Schiavi ^{57b,57a, [id](#)},
E.J. Schioppa ^{70a,70b, [id](#)}, M. Schioppa ^{43b,43a, [id](#)}, B. Schlag ^{144, [id](#)}, K.E. Schleicher ^{54, [id](#)}, S. Schlenker ^{36, [id](#)},
J. Schmeing ^{171, [id](#)}, M.A. Schmidt ^{171, [id](#)}, K. Schmieden ^{100, [id](#)}, C. Schmitt ^{100, [id](#)}, S. Schmitt ^{48, [id](#)}, L. Schoeffel ^{135, [id](#)},
A. Schoening ^{63b, [id](#)}, P.G. Scholer ^{54, [id](#)}, E. Schopf ^{126, [id](#)}, M. Schott ^{100, [id](#)}, J. Schovancova ^{36, [id](#)}, S. Schramm ^{56, [id](#)},
F. Schroeder ^{171, [id](#)}, T. Schroer ^{56, [id](#)}, H-C. Schultz-Coulon ^{63a, [id](#)}, M. Schumacher ^{54, [id](#)}, B.A. Schumm ^{136, [id](#)},
Ph. Schune ^{135, [id](#)}, A.J. Schuy ^{139, [id](#)}, H.R. Schwartz ^{136, [id](#)}, A. Schwartzman ^{144, [id](#)}, T.A. Schwarz ^{106, [id](#)},
Ph. Schwemling ^{135, [id](#)}, R. Schwienhorst ^{107, [id](#)}, A. Sciandra ^{136, [id](#)}, G. Sciolla ^{26, [id](#)}, F. Scuri ^{74a, [id](#)},
C.D. Sebastiani ^{92, [id](#)}, K. Sedlaczek ^{115, [id](#)}, P. Seema ^{18, [id](#)}, S.C. Seidel ^{112, [id](#)}, A. Seiden ^{136, [id](#)}, B.D. Seidlitz ^{41, [id](#)},
C. Seitz ^{48, [id](#)}, J.M. Seixas ^{83b, [id](#)}, G. Sekhniaidze ^{72a, [id](#)}, S.J. Sekula ^{44, [id](#)}, L. Selem ^{60, [id](#)}, N. Semprini-Cesari ^{23b,23a, [id](#)},
D. Sengupta ^{56, [id](#)}, V. Senthilkumar ^{163, [id](#)}, L. Serin ^{66, [id](#)}, L. Serkin ^{69a,69b, [id](#)}, M. Sessa ^{76a,76b, [id](#)}, H. Severini ^{120, [id](#)},
F. Sforza ^{57b,57a, [id](#)}, A. Sfyrila ^{56, [id](#)}, E. Shabalina ^{55, [id](#)}, R. Shaheen ^{145, [id](#)}, J.D. Shahinian ^{128, [id](#)},
D. Shaked Renous ^{169, [id](#)}, L.Y. Shan ^{14a, [id](#)}, M. Shapiro ^{17a, [id](#)}, A. Sharma ^{36, [id](#)}, A.S. Sharma ^{164, [id](#)}, P. Sharma ^{80, [id](#)},
S. Sharma ^{48, [id](#)}, P.B. Shatalov ^{37, [id](#)}, K. Shaw ^{147, [id](#)}, S.M. Shaw ^{101, [id](#)}, A. Shcherbakova ^{37, [id](#)}, Q. Shen ^{62c,5, [id](#)},
P. Sherwood ^{96, [id](#)}, L. Shi ^{96, [id](#)}, X. Shi ^{14a, [id](#)}, C.O. Shimmin ^{172, [id](#)}, Y. Shimogama ^{168, [id](#)}, J.D. Shinner ^{95, [id](#)},
I.P.J. Shipsey ^{126, [id](#)}, ^{*}, S. Shirabe ^{56, [id](#)}, ^h, M. Shiyakova ^{38, [id](#)}, ^w, J. Shlomi ^{169, [id](#)}, M.J. Shochet ^{39, [id](#)}, J. Shojaii ^{105, [id](#)},
D.R. Shope ^{125, [id](#)}, B. Shrestha ^{120, [id](#)}, S. Shrestha ^{119, [id](#)}, ^{ak}, E.M. Shrif ^{33g, [id](#)}, M.J. Shroff ^{165, [id](#)}, P. Sicho ^{131, [id](#)},
A.M. Sickles ^{162, [id](#)}, E. Sideras Haddad ^{33g, [id](#)}, A. Sidoti ^{23b, [id](#)}, F. Siegert ^{50, [id](#)}, Dj. Sijacki ^{15, [id](#)}, R. Sikora ^{86a, [id](#)},

F. Sili^{90, [id](#)}, J.M. Silva^{20, [id](#)}, M.V. Silva Oliveira^{29, [id](#)}, S.B. Silverstein^{47a, [id](#)}, S. Simion⁶⁶, R. Simoniello^{36, [id](#)}, E.L. Simpson^{59, [id](#)}, H. Simpson^{147, [id](#)}, L.R. Simpson^{106, [id](#)}, N.D. Simpson⁹⁸, S. Simsek^{82, [id](#)}, S. Sindhu^{55, [id](#)}, P. Sinervo^{155, [id](#)}, S. Singh^{155, [id](#)}, S. Sinha^{48, [id](#)}, S. Sinha^{101, [id](#)}, M. Sioli^{23b,23a, [id](#)}, I. Siral^{36, [id](#)}, E. Sitnikova^{48, [id](#)}, S.Yu. Sivoklokov^{37, [id](#),*}, J. Sjölin^{47a,47b, [id](#)}, A. Skaf^{55, [id](#)}, E. Skorda^{20, [id](#)}, P. Skubic^{120, [id](#)}, M. Slawinska^{87, [id](#)}, V. Smakhtin¹⁶⁹, B.H. Smart^{134, [id](#)}, J. Smiesko^{36, [id](#)}, S.Yu. Smirnov^{37, [id](#)}, Y. Smirnov^{37, [id](#)}, L.N. Smirnova^{37, [id](#),a}, O. Smirnova^{98, [id](#)}, A.C. Smith^{41, [id](#)}, E.A. Smith^{39, [id](#)}, H.A. Smith^{126, [id](#)}, J.L. Smith^{92, [id](#)}, R. Smith¹⁴⁴, M. Smizanska^{91, [id](#)}, K. Smolek^{132, [id](#)}, A.A. Snesarev^{37, [id](#)}, S.R. Snider^{155, [id](#)}, H.L. Snoek^{114, [id](#)}, S. Snyder^{29, [id](#)}, R. Sobie^{165, [id](#),y}, A. Soffer^{152, [id](#)}, C.A. Solans Sanchez^{36, [id](#)}, E.Yu. Soldatov^{37, [id](#)}, U. Soldevila^{163, [id](#)}, A.A. Solodkov^{37, [id](#)}, S. Solomon^{26, [id](#)}, A. Soloshenko^{38, [id](#)}, K. Solovieva^{54, [id](#)}, O.V. Solovyanov^{40, [id](#)}, V. Solovyev^{37, [id](#)}, P. Sommer^{36, [id](#)}, A. Sonay^{13, [id](#)}, W.Y. Song^{156b, [id](#)}, J.M. Sonneveld^{114, [id](#)}, A. Sopczak^{132, [id](#)}, A.L. Soppio^{96, [id](#)}, F. Sopkova^{28b, [id](#)}, V. Sothilingam^{63a}, S. Sottocornola^{68, [id](#)}, R. Soualah^{116b, [id](#)}, Z. Soumami^{35e, [id](#)}, D. South^{48, [id](#)}, N. Soybelman^{169, [id](#)}, S. Spagnolo^{70a,70b, [id](#)}, M. Spalla^{110, [id](#)}, D. Sperlich^{54, [id](#)}, G. Spigo^{36, [id](#)}, M. Spina^{147, [id](#)}, S. Spinali^{91, [id](#)}, D.P. Spiteri^{59, [id](#)}, M. Spousta^{133, [id](#)}, E.J. Staats^{34, [id](#)}, A. Stabile^{71a,71b, [id](#)}, R. Stamen^{63a, [id](#)}, A. Stampekis^{20, [id](#)}, M. Standke^{24, [id](#)}, E. Stanecka^{87, [id](#)}, M.V. Stange^{50, [id](#)}, B. Stanislaus^{17a, [id](#)}, M.M. Stanitzki^{48, [id](#)}, B. Stapf^{48, [id](#)}, E.A. Starchenko^{37, [id](#)}, G.H. Stark^{136, [id](#)}, J. Stark^{102, [id](#),ac}, D.M. Starko^{156b}, P. Staroba^{131, [id](#)}, P. Starovoitov^{63a, [id](#)}, S. Stärz^{104, [id](#)}, R. Staszewski^{87, [id](#)}, G. Stavropoulos^{46, [id](#)}, J. Steentoft^{161, [id](#)}, P. Steinberg^{29, [id](#)}, B. Stelzer^{143,156a, [id](#)}, H.J. Stelzer^{129, [id](#)}, O. Stelzer-Chilton^{156a, [id](#)}, H. Stenzel^{58, [id](#)}, T.J. Stevenson^{147, [id](#)}, G.A. Stewart^{36, [id](#)}, J.R. Stewart^{121, [id](#)}, M.C. Stockton^{36, [id](#)}, G. Stoicea^{27b, [id](#)}, M. Stolarski^{130a, [id](#)}, S. Stonjek^{110, [id](#)}, A. Straessner^{50, [id](#)}, J. Strandberg^{145, [id](#)}, S. Strandberg^{47a,47b, [id](#)}, M. Strauss^{120, [id](#)}, T. Strebler^{102, [id](#)}, P. Strizenec^{28b, [id](#)}, R. Ströhmer^{166, [id](#)}, D.M. Strom^{123, [id](#)}, L.R. Strom^{48, [id](#)}, R. Stroynowski^{44, [id](#)}, A. Strubig^{47a,47b, [id](#)}, S.A. Stucci^{29, [id](#)}, B. Stugu^{16, [id](#)}, J. Stupak^{120, [id](#)}, N.A. Styles^{48, [id](#)}, D. Su^{144, [id](#)}, S. Su^{62a, [id](#)}, W. Su^{62d, [id](#)}, X. Su^{62a,66, [id](#)}, K. Sugizaki^{154, [id](#)}, V.V. Sulin^{37, [id](#)}, M.J. Sullivan^{92, [id](#)}, D.M.S. Sultan^{78a,78b, [id](#)}, L. Sultanaliyeva^{37, [id](#)}, S. Sultansoy^{3b, [id](#)}, T. Sumida^{88, [id](#)}, S. Sun^{106, [id](#)}, S. Sun^{170, [id](#)}, O. Sunneborn Gudnadottir^{161, [id](#)}, N. Sur^{102, [id](#)}, M.R. Sutton^{147, [id](#)}, H. Suzuki^{157, [id](#)}, M. Svatos^{131, [id](#)}, M. Swiatlowski^{156a, [id](#)}, T. Swirski^{166, [id](#)}, I. Sykora^{28a, [id](#)}, M. Sykora^{133, [id](#)}, T. Sykora^{133, [id](#)}, D. Ta^{100, [id](#)}, K. Tackmann^{48, [id](#),v}, A. Taffard^{160, [id](#)}, R. Tafirout^{156a, [id](#)}, J.S. Tafoya Vargas^{66, [id](#)}, E.P. Takeva^{52, [id](#)}, Y. Takubo^{84, [id](#)}, M. Talby^{102, [id](#)}, A.A. Talyshev^{37, [id](#)}, K.C. Tam^{64b, [id](#)}, N.M. Tamir^{152, [id](#)}, A. Tanaka^{154, [id](#)}, J. Tanaka^{154, [id](#)}, R. Tanaka^{66, [id](#)}, M. Tanasini^{57b,57a, [id](#)}, Z. Tao^{164, [id](#)}, S. Tapia Araya^{137f, [id](#)}, S. Tapprogge^{100, [id](#)}, A. Tarek Abouelfadl Mohamed^{107, [id](#)}, S. Tarem^{151, [id](#)}, K. Tariq^{14a, [id](#)}, G. Tarna^{102,27b, [id](#)}, G.F. Tartarelli^{71a, [id](#)}, P. Tas^{133, [id](#)}, M. Tasevsky^{131, [id](#)}, E. Tassi^{43b,43a, [id](#)}, A.C. Tate^{162, [id](#)}, G. Tateno^{154, [id](#)}, Y. Tayalati^{35e, [id](#),x}, G.N. Taylor^{105, [id](#)}, W. Taylor^{156b, [id](#)}, H. Teagle⁹², A.S. Tee^{170, [id](#)}, R. Teixeira De Lima^{144, [id](#)}, P. Teixeira-Dias^{95, [id](#)}, J.J. Teoh^{155, [id](#)}, K. Terashi^{154, [id](#)}, J. Terron^{99, [id](#)}, S. Terzo^{13, [id](#)}, M. Testa^{53, [id](#)}, R.J. Teuscher^{155, [id](#),y}, A. Thaler^{79, [id](#)}, O. Theiner^{56, [id](#)}, N. Themistokleous^{52, [id](#)}, T. Theveneaux-Pelzer^{102, [id](#)}, O. Thielmann^{171, [id](#)}, D.W. Thomas⁹⁵, J.P. Thomas^{20, [id](#)}, E.A. Thompson^{17a, [id](#)}, P.D. Thompson^{20, [id](#)}, E. Thomson^{128, [id](#)}, Y. Tian^{55, [id](#)}, V. Tikhomirov^{37, [id](#),a}, Yu.A. Tikhonov^{37, [id](#)}, S. Timoshenko³⁷, D. Timoshyn^{133, [id](#)}, E.X.L. Ting^{1, [id](#)}, P. Tipton^{172, [id](#)}, S.H. Tlou^{33g, [id](#)}, A. Tnourji^{40, [id](#)}, K. Todome^{23b,23a, [id](#)}, S. Todorova-Nova^{133, [id](#)}, S. Todt⁵⁰, M. Togawa^{84, [id](#)}, J. Tojo^{89, [id](#)}, S. Tokár^{28a, [id](#)}, K. Tokushuku^{84, [id](#)}, O. Toldaiev^{68, [id](#)}, R. Tombs^{32, [id](#)}, M. Tomoto^{84,111, [id](#)}, L. Tompkins^{144, [id](#),o}, K.W. Topolnicki^{86b, [id](#)}, E. Torrence^{123, [id](#)}, H. Torres^{102, [id](#),ac}, E. Torró Pastor^{163, [id](#)}, M. Toscani^{30, [id](#)}, C. Toscirì^{39, [id](#)}, M. Tost^{11, [id](#)}, D.R. Tovey^{140, [id](#)}, A. Traeet¹⁶, I.S. Trandafir^{27b, [id](#)}, T. Trefzger^{166, [id](#)}, A. Tricoli^{29, [id](#)}, I.M. Trigger^{156a, [id](#)}, S. Trincaz-Duvold^{127, [id](#)}, D.A. Trischuk^{26, [id](#)}, B. Trocmé^{60, [id](#)}, C. Troncon^{71a, [id](#)}, L. Truong^{33c, [id](#)}, M. Trzebinski^{87, [id](#)}, A. Trzupek^{87, [id](#)}, F. Tsai^{146, [id](#)}, M. Tsai^{106, [id](#)}, A. Tsiamis^{153, [id](#),e}, P.V. Tsiarehsha³⁷, S. Tsigaridas^{156a, [id](#)}, A. Tsirigotis^{153, [id](#),f},

V. Tsiskaridze^{155, [id](#)}, E.G. Tskhadadze^{150a, [id](#)}, M. Tsopoulou^{153, [id](#), [e](#)}, Y. Tsujikawa^{88, [id](#)}, I.I. Tsukerman^{37, [id](#)}, V. Tsulaia^{17a, [id](#)}, S. Tsuno^{84, [id](#)}, O. Tsur¹⁵¹, K. Tsurii^{118, [id](#)}, D. Tsybychev^{146, [id](#)}, Y. Tu^{64b, [id](#)}, A. Tudorache^{27b, [id](#)}, V. Tudorache^{27b, [id](#)}, A.N. Tuna^{36, [id](#)}, S. Turchikhin^{38, [id](#)}, I. Turk Cakir^{3a, [id](#)}, R. Turra^{71a, [id](#)}, T. Turtuvshin^{38, [id](#), [z](#)}, P.M. Tuts^{41, [id](#)}, S. Tzamarias^{153, [id](#), [e](#)}, P. Tzanis^{10, [id](#)}, E. Tzovara^{100, [id](#)}, K. Uchida¹⁵⁴, F. Ukegawa^{157, [id](#)}, P.A. Ulloa Poblete^{137c, 137b, [id](#)}, E.N. Umaka^{29, [id](#)}, G. Unal^{36, [id](#)}, M. Unal^{11, [id](#)}, A. Undrus^{29, [id](#)}, G. Unel^{160, [id](#)}, J. Urban^{28b, [id](#)}, P. Urquijo^{105, [id](#)}, G. Usai^{8, [id](#)}, R. Ushioda^{138, [id](#)}, M. Usman^{108, [id](#)}, Z. Uysal^{21b, [id](#)}, L. Vacavant^{102, [id](#)}, V. Vacek^{132, [id](#)}, B. Vachon^{104, [id](#)}, K.O.H. Vadla^{125, [id](#)}, T. Vafeiadis^{36, [id](#)}, A. Vaitkus^{96, [id](#)}, C. Valderanis^{109, [id](#)}, E. Valdes Santurio^{47a, 47b, [id](#)}, M. Valente^{156a, [id](#)}, S. Valentinetti^{23b, 23a, [id](#)}, A. Valero^{163, [id](#)}, E. Valiente Moreno^{163, [id](#)}, A. Vallier^{102, [id](#), [ac](#)}, J.A. Valls Ferrer^{163, [id](#)}, D.R. Van Arneman^{114, [id](#)}, T.R. Van Daalen^{139, [id](#)}, A. Van Der Graaf^{49, [id](#)}, P. Van Gemmeren^{6, [id](#)}, M. Van Rijnbach^{125, 36, [id](#)}, S. Van Stroud^{96, [id](#)}, I. Van Vulpen^{114, [id](#)}, M. Vanadia^{76a, 76b, [id](#)}, W. Vandelli^{36, [id](#)}, M. Vandenbroucke^{135, [id](#)}, E.R. Vandewall^{121, [id](#)}, D. Vannicola^{152, [id](#)}, L. Vannoli^{57b, 57a, [id](#)}, R. Vari^{75a, [id](#)}, E.W. Varnes^{7, [id](#)}, C. Varni^{17b, [id](#)}, T. Varol^{149, [id](#)}, D. Varouchas^{66, [id](#)}, L. Varriale^{163, [id](#)}, K.E. Varvell^{148, [id](#)}, M.E. Vasile^{27b, [id](#)}, L. Vaslin⁴⁰, G.A. Vazquez^{165, [id](#)}, A. Vasyukov^{38, [id](#)}, F. Vazeille^{40, [id](#)}, T. Vazquez Schroeder^{36, [id](#)}, J. Veatch^{31, [id](#)}, V. Vecchio^{101, [id](#)}, M.J. Veen^{103, [id](#)}, I. Veliscek^{126, [id](#)}, L.M. Veloce^{155, [id](#)}, F. Veloso^{130a, 130c, [id](#)}, S. Veneziano^{75a, [id](#)}, A. Ventura^{70a, 70b, [id](#)}, A. Verbytskyi^{110, [id](#)}, M. Verducci^{74a, 74b, [id](#)}, C. Vergis^{24, [id](#)}, M. Verissimo De Araujo^{83b, [id](#)}, W. Verkerke^{114, [id](#)}, J.C. Vermeulen^{114, [id](#)}, C. Vernieri^{144, [id](#)}, M. Vessella^{103, [id](#)}, M.C. Vetterli^{143, [id](#), [ah](#)}, A. Vgenopoulos^{153, [id](#), [e](#)}, N. Viaux Maira^{137f, [id](#)}, T. Vickey^{140, [id](#)}, O.E. Vickey Boeriu^{140, [id](#)}, G.H.A. Viehhauser^{126, [id](#)}, L. Vigani^{63b, [id](#)}, M. Villa^{23b, 23a, [id](#)}, M. Villaplana Perez^{163, [id](#)}, E.M. Villhauer⁵², E. Vilucchi^{53, [id](#)}, M.G. Vincter^{34, [id](#)}, G.S. Virdee^{20, [id](#)}, A. Vishwakarma^{52, [id](#)}, A. Visibile¹¹⁴, C. Vittori^{36, [id](#)}, I. Vivarelli^{147, [id](#)}, V. Vladimirov¹⁶⁷, E. Voevodina^{110, [id](#)}, F. Vogel^{109, [id](#)}, P. Vokac^{132, [id](#)}, J. Von Ahnen^{48, [id](#)}, E. Von Toerne^{24, [id](#)}, B. Vormwald^{36, [id](#)}, V. Vorobel^{133, [id](#)}, K. Vorobev^{37, [id](#)}, M. Vos^{163, [id](#)}, K. Voss^{142, [id](#)}, J.H. Vosseveld^{92, [id](#)}, M. Vozak^{114, [id](#)}, L. Vozdecky^{94, [id](#)}, N. Vranjes^{15, [id](#)}, M. Vranjes Milosavljevic^{15, [id](#)}, M. Vreeswijk^{114, [id](#)}, N.K. Vu^{62d, 62c, [id](#)}, R. Vuillermet^{36, [id](#)}, O. Vujinovic^{100, [id](#)}, I. Vukotic^{39, [id](#)}, S. Wada^{157, [id](#)}, C. Wagner¹⁰³, J.M. Wagner^{17a, [id](#)}, W. Wagner^{171, [id](#)}, S. Wahdan^{171, [id](#)}, H. Wahlberg^{90, [id](#)}, R. Wakasa^{157, [id](#)}, M. Wakida^{111, [id](#)}, J. Walder^{134, [id](#)}, R. Walker^{109, [id](#)}, W. Walkowiak^{142, [id](#)}, A. Wall^{128, [id](#)}, T. Wamorkar^{6, [id](#)}, A.Z. Wang^{170, [id](#)}, C. Wang^{100, [id](#)}, C. Wang^{62c, [id](#)}, H. Wang^{17a, [id](#)}, J. Wang^{64a, [id](#)}, R.-J. Wang^{100, [id](#)}, R. Wang^{61, [id](#)}, R. Wang^{6, [id](#)}, S.M. Wang^{149, [id](#)}, S. Wang^{62b, [id](#)}, T. Wang^{62a, [id](#)}, W.T. Wang^{80, [id](#)}, W. Wang^{14a, [id](#)}, X. Wang^{14c, [id](#)}, X. Wang^{162, [id](#)}, X. Wang^{62c, [id](#)}, Y. Wang^{62d, [id](#)}, Y. Wang^{14c, [id](#)}, Z. Wang^{106, [id](#)}, Z. Wang^{62d, 51, 62c, [id](#)}, Z. Wang^{106, [id](#)}, A. Warburton^{104, [id](#)}, R.J. Ward^{20, [id](#)}, N. Warrack^{59, [id](#)}, A.T. Watson^{20, [id](#)}, H. Watson^{59, [id](#)}, M.F. Watson^{20, [id](#)}, E. Watton^{59, 134, [id](#)}, G. Watts^{139, [id](#)}, B.M. Waugh^{96, [id](#)}, C. Weber^{29, [id](#)}, H.A. Weber^{18, [id](#)}, M.S. Weber^{19, [id](#)}, S.M. Weber^{63a, [id](#)}, C. Wei^{62a, [id](#)}, Y. Wei^{126, [id](#)}, A.R. Weidberg^{126, [id](#)}, E.J. Weik^{117, [id](#)}, J. Weingarten^{49, [id](#)}, M. Weirich^{100, [id](#)}, C. Weiser^{54, [id](#)}, C.J. Wells^{48, [id](#)}, T. Wenaus^{29, [id](#)}, B. Wendland^{49, [id](#)}, T. Wengler^{36, [id](#)}, N.S. Wenke¹¹⁰, N. Vermes^{24, [id](#)}, M. Wessels^{63a, [id](#)}, K. Whalen^{123, [id](#)}, A.M. Wharton^{91, [id](#)}, A.S. White^{61, [id](#)}, A. White^{8, [id](#)}, M.J. White^{1, [id](#)}, D. Whiteson^{160, [id](#)}, L. Wickremasinghe^{124, [id](#)}, W. Wiedenmann^{170, [id](#)}, C. Wiel^{50, [id](#)}, M. Wielers^{134, [id](#)}, C. Wiglesworth^{42, [id](#)}, D.J. Wilbern¹²⁰, H.G. Wilkens^{36, [id](#)}, D.M. Williams^{41, [id](#)}, H.H. Williams¹²⁸, S. Williams^{32, [id](#)}, S. Willocq^{103, [id](#)}, B.J. Wilson^{101, [id](#)}, P.J. Windischhofer^{39, [id](#)}, F.I. Winkel^{30, [id](#)}, F. Winklmeier^{123, [id](#)}, B.T. Winter^{54, [id](#)}, J.K. Winter^{101, [id](#)}, M. Wittgen¹⁴⁴, M. Wobisch^{97, [id](#)}, Z. Wolffs^{114, [id](#)}, R. Wölker^{126, [id](#)}, J. Wollrath¹⁶⁰, M.W. Wolter^{87, [id](#)}, H. Wolters^{130a, 130c, [id](#)}, A.F. Wongel^{48, [id](#)}, S.D. Worm^{48, [id](#)}, B.K. Wosiek^{87, [id](#)}, K.W. Woźniak^{87, [id](#)}, S. Wozniowski^{55, [id](#)}, K. Wraight^{59, [id](#)}, C. Wu^{20, [id](#)}, J. Wu^{14a, 14e, [id](#)}, M. Wu^{64a, [id](#)}, M. Wu^{113, [id](#)}, S.L. Wu^{170, [id](#)}, X. Wu^{56, [id](#)}, Y. Wu^{62a, [id](#)}, Z. Wu^{135, [id](#)}, J. Wuerzinger^{110, [id](#), [af](#)}, T.R. Wyatt^{101, [id](#)}, B.M. Wynne^{52, [id](#)}, S. Xella^{42, [id](#)}, L. Xia^{14c, [id](#)}, M. Xia^{14b, [id](#)}, J. Xiang^{64c, [id](#)}, X. Xiao^{106, [id](#)}, M. Xie^{62a, [id](#)}, X. Xie^{62a, [id](#)}, S. Xin^{14a, 14e, [id](#)}, J. Xiong^{17a, [id](#)},

D. Xu ^{14a, [id](#)}, H. Xu ^{62a, [id](#)}, L. Xu ^{62a, [id](#)}, R. Xu ^{128, [id](#)}, T. Xu ^{106, [id](#)}, Y. Xu ^{14b, [id](#)}, Z. Xu ^{52, [id](#)}, Z. Xu ^{14a, [id](#)},
 B. Yabsley ^{148, [id](#)}, S. Yacoub ^{33a, [id](#)}, N. Yamaguchi ^{89, [id](#)}, Y. Yamaguchi ^{138, [id](#)}, E. Yamashita ^{154, [id](#)},
 H. Yamauchi ^{157, [id](#)}, T. Yamazaki ^{17a, [id](#)}, Y. Yamazaki ^{85, [id](#)}, J. Yan ^{62c, [id](#)}, S. Yan ^{126, [id](#)}, Z. Yan ^{25, [id](#)}, H.J. Yang ^{62c, 62d, [id](#)},
 H.T. Yang ^{62a, [id](#)}, S. Yang ^{62a, [id](#)}, T. Yang ^{64c, [id](#)}, X. Yang ^{62a, [id](#)}, X. Yang ^{14a, [id](#)}, Y. Yang ^{44, [id](#)}, Y. Yang ^{62a, [id](#)},
 Z. Yang ^{62a, [id](#)}, W.-M. Yao ^{17a, [id](#)}, Y.C. Yap ^{48, [id](#)}, H. Ye ^{14c, [id](#)}, H. Ye ^{55, [id](#)}, J. Ye ^{44, [id](#)}, S. Ye ^{29, [id](#)}, X. Ye ^{62a, [id](#)},
 Y. Yeh ^{96, [id](#)}, I. Yeletsikh ^{38, [id](#)}, B. Yeo ^{17b, [id](#)}, M.R. Yexley ^{96, [id](#)}, P. Yin ^{41, [id](#)}, K. Yorita ^{168, [id](#)}, S. Younas ^{27b, [id](#)},
 C.J.S. Young ^{36, [id](#)}, C. Young ^{144, [id](#)}, Y. Yu ^{62a, [id](#)}, M. Yuan ^{106, [id](#)}, R. Yuan ^{62b, [id](#), [k](#)}, L. Yue ^{96, [id](#)}, M. Zaazoua ^{62a, [id](#)},
 B. Zabinski ^{87, [id](#)}, E. Zaid ⁵², T. Zakareishvili ^{150b, [id](#)}, N. Zakharchuk ^{34, [id](#)}, S. Zambito ^{56, [id](#)},
 J.A. Zamora Saa ^{137d, 137b, [id](#)}, J. Zang ^{154, [id](#)}, D. Zanzi ^{54, [id](#)}, O. Zaplatilek ^{132, [id](#)}, C. Zeitnitz ^{171, [id](#)}, H. Zeng ^{14a, [id](#)},
 J.C. Zeng ^{162, [id](#)}, D.T. Zenger Jr ^{26, [id](#)}, O. Zenin ^{37, [id](#)}, T. Ženiš ^{28a, [id](#)}, S. Zenz ^{94, [id](#)}, S. Zerradi ^{35a, [id](#)}, D. Zerwas ^{66, [id](#)},
 M. Zhai ^{14a, 14e, [id](#)}, B. Zhang ^{14c, [id](#)}, D.F. Zhang ^{140, [id](#)}, J. Zhang ^{62b, [id](#)}, J. Zhang ^{6, [id](#)}, K. Zhang ^{14a, 14e, [id](#)},
 L. Zhang ^{14c, [id](#)}, P. Zhang ^{14a, 14e, [id](#)}, R. Zhang ^{170, [id](#)}, S. Zhang ^{106, [id](#)}, T. Zhang ^{154, [id](#)}, X. Zhang ^{62c, [id](#)}, X. Zhang ^{62b, [id](#)},
 Y. Zhang ^{62c, 5, [id](#)}, Y. Zhang ^{96, [id](#)}, Z. Zhang ^{17a, [id](#)}, Z. Zhang ^{66, [id](#)}, H. Zhao ^{139, [id](#)}, P. Zhao ^{51, [id](#)}, T. Zhao ^{62b, [id](#)},
 Y. Zhao ^{136, [id](#)}, Z. Zhao ^{62a, [id](#)}, A. Zhemchugov ^{38, [id](#)}, J. Zheng ^{14c, [id](#)}, K. Zheng ^{162, [id](#)}, X. Zheng ^{62a, [id](#)}, Z. Zheng ^{144, [id](#)},
 D. Zhong ^{162, [id](#)}, B. Zhou ^{106, [id](#)}, H. Zhou ^{7, [id](#)}, N. Zhou ^{62c, [id](#)}, Y. Zhou ⁷, C.G. Zhu ^{62b, [id](#)}, J. Zhu ^{106, [id](#)}, Y. Zhu ^{62c, [id](#)},
 Y. Zhu ^{62a, [id](#)}, X. Zhuang ^{14a, [id](#)}, K. Zhukov ^{37, [id](#)}, V. Zhulanov ^{37, [id](#)}, N.I. Zimine ^{38, [id](#)}, J. Zinsser ^{63b, [id](#)},
 M. Ziolkowski ^{142, [id](#)}, L. Živković ^{15, [id](#)}, A. Zoccoli ^{23b, 23a, [id](#)}, K. Zoch ^{56, [id](#)}, T.G. Zorbas ^{140, [id](#)}, O. Zormpa ^{46, [id](#)},
 W. Zou ^{41, [id](#)}, L. Zwalinski ^{36, [id](#)}

¹ Department of Physics, University of Adelaide, Adelaide; Australia

² Department of Physics, University of Alberta, Edmonton AB; Canada

³ (a) Department of Physics, Ankara University, Ankara; (b) Division of Physics, TOBB University of Economics and Technology, Ankara; Türkiye

⁴ LAPP, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy; France

⁵ APC, Université Paris Cité, CNRS/IN2P3, Paris; France

⁶ High Energy Physics Division, Argonne National Laboratory, Argonne IL; United States of America

⁷ Department of Physics, University of Arizona, Tucson AZ; United States of America

⁸ Department of Physics, University of Texas at Arlington, Arlington TX; United States of America

⁹ Physics Department, National and Kapodistrian University of Athens, Athens; Greece

¹⁰ Physics Department, National Technical University of Athens, Zografou; Greece

¹¹ Department of Physics, University of Texas at Austin, Austin TX; United States of America

¹² Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan

¹³ Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona; Spain

¹⁴ (a) Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; (b) Physics Department, Tsinghua University, Beijing; (c) Department of Physics, Nanjing University, Nanjing; (d) School of Science, Shenzhen Campus of Sun Yat-sen University; (e) University of Chinese Academy of Science (UCAS), Beijing; China

¹⁵ Institute of Physics, University of Belgrade, Belgrade; Serbia

¹⁶ Department for Physics and Technology, University of Bergen, Bergen; Norway

¹⁷ (a) Physics Division, Lawrence Berkeley National Laboratory, Berkeley CA; (b) University of California, Berkeley CA; United States of America

¹⁸ Institut für Physik, Humboldt Universität zu Berlin, Berlin; Germany

¹⁹ Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern; Switzerland

²⁰ School of Physics and Astronomy, University of Birmingham, Birmingham; United Kingdom

²¹ (a) Department of Physics, Bogazici University, Istanbul; (b) Department of Physics Engineering, Gaziantep University, Gaziantep; (c) Department of Physics, Istanbul University, Istanbul; Türkiye

²² (a) Facultad de Ciencias y Centro de Investigaciones, Universidad Antonio Nariño, Bogotá; (b) Departamento de Física, Universidad Nacional de Colombia, Bogotá; Colombia

²³ (a) Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna; (b) INFN Sezione di Bologna; Italy

²⁴ Physikalisches Institut, Universität Bonn, Bonn; Germany

²⁵ Department of Physics, Boston University, Boston MA; United States of America

²⁶ Department of Physics, Brandeis University, Waltham MA; United States of America

²⁷ (a) Transilvania University of Brasov, Brasov; (b) Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest; (c) Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi; (d) National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca; (e) National University of Science and Technology Politehnica, Bucharest; (f) West University in Timisoara, Timisoara; (g) Faculty of Physics, University of Bucharest, Bucharest; Romania

²⁸ (a) Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava; (b) Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice; Slovak Republic

²⁹ Physics Department, Brookhaven National Laboratory, Upton NY; United States of America

³⁰ Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Física, y CONICET, Instituto de Física de Buenos Aires (IFIBA), Buenos Aires; Argentina

³¹ California State University, CA; United States of America

³² Cavendish Laboratory, University of Cambridge, Cambridge; United Kingdom

³³ (a) Department of Physics, University of Cape Town, Cape Town; (b) iThemba Labs, Western Cape; (c) Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg;

(d) National Institute of Physics, University of the Philippines Diliman (Philippines); (e) University of South Africa, Department of Physics, Pretoria; (f) University of Zululand, KwaDlangezwa;

(g) School of Physics, University of the Witwatersrand, Johannesburg; South Africa

³⁴ Department of Physics, Carleton University, Ottawa ON; Canada

³⁵ (a) Faculté des Sciences Ain Chock, Université Hassan II de Casablanca; (b) Faculté des Sciences, Université Ibn-Tofail, Kénitra; (c) Faculté des Sciences Semlalia, Université Cadi Ayyad,

LPHEA-Marrakech; (d) LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda; (e) Faculté des sciences, Université Mohammed V, Rabat; (f) Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco

³⁶ CERN, Geneva; Switzerland

³⁷ Affiliated with an institute covered by a cooperation agreement with CERN

- ³⁸ Affiliated with an international laboratory covered by a cooperation agreement with CERN
- ³⁹ Enrico Fermi Institute, University of Chicago, Chicago IL; United States of America
- ⁴⁰ LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand; France
- ⁴¹ Nevis Laboratory, Columbia University, Irvington NY; United States of America
- ⁴² Niels Bohr Institute, University of Copenhagen, Copenhagen; Denmark
- ⁴³ ^(a) Dipartimento di Fisica, Università della Calabria, Rende; ^(b) INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati; Italy
- ⁴⁴ Physics Department, Southern Methodist University, Dallas TX; United States of America
- ⁴⁵ Physics Department, University of Texas at Dallas, Richardson TX; United States of America
- ⁴⁶ National Centre for Scientific Research “Demokritos”, Agia Paraskevi; Greece
- ⁴⁷ ^(a) Department of Physics, Stockholm University; ^(b) Oskar Klein Centre, Stockholm; Sweden
- ⁴⁸ Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen; Germany
- ⁴⁹ Fakultät Physik, Technische Universität Dortmund, Dortmund; Germany
- ⁵⁰ Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden; Germany
- ⁵¹ Department of Physics, Duke University, Durham NC; United States of America
- ⁵² SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh; United Kingdom
- ⁵³ INFN e Laboratori Nazionali di Frascati, Frascati; Italy
- ⁵⁴ Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany
- ⁵⁵ II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen; Germany
- ⁵⁶ Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland
- ⁵⁷ ^(a) Dipartimento di Fisica, Università di Genova, Genova; ^(b) INFN Sezione di Genova; Italy
- ⁵⁸ II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen; Germany
- ⁵⁹ SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow; United Kingdom
- ⁶⁰ LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble; France
- ⁶¹ Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA; United States of America
- ⁶² ^(a) Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei; ^(b) Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao; ^(c) State Key Laboratory of Dark Matter Physics, School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai; ^(d) State Key Laboratory of Dark Matter Physics, Tsung-Dao Lee Institute, Shanghai Jiao Tong University, Shanghai; China
- ⁶³ ^(a) Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; ^(b) Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; Germany
- ⁶⁴ ^(a) Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong; ^(b) Department of Physics, University of Hong Kong, Hong Kong; ^(c) Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong; China
- ⁶⁵ Department of Physics, National Tsing Hua University, Hsinchu; Taiwan
- ⁶⁶ IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay; France
- ⁶⁷ Centro Nacional de Microelectrónica (IMB-CNM-CSIC), Barcelona; Spain
- ⁶⁸ Department of Physics, Indiana University, Bloomington IN; United States of America
- ⁶⁹ ^(a) INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine; ^(b) ICTP, Trieste; ^(c) Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine; Italy
- ⁷⁰ ^(a) INFN Sezione di Lecce; ^(b) Dipartimento di Matematica e Fisica, Università del Salento, Lecce; Italy
- ⁷¹ ^(a) INFN Sezione di Milano; ^(b) Dipartimento di Fisica, Università di Milano, Milano; Italy
- ⁷² ^(a) INFN Sezione di Napoli; ^(b) Dipartimento di Fisica, Università di Napoli, Napoli; Italy
- ⁷³ ^(a) INFN Sezione di Pavia; ^(b) Dipartimento di Fisica, Università di Pavia, Pavia; Italy
- ⁷⁴ ^(a) INFN Sezione di Pisa; ^(b) Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa; Italy
- ⁷⁵ ^(a) INFN Sezione di Roma; ^(b) Dipartimento di Fisica, Sapienza Università di Roma, Roma; Italy
- ⁷⁶ ^(a) INFN Sezione di Roma Tor Vergata; ^(b) Dipartimento di Fisica, Università di Roma Tor Vergata, Roma; Italy
- ⁷⁷ ^(a) INFN Sezione di Roma Tre; ^(b) Dipartimento di Matematica e Fisica, Università Roma Tre, Roma; Italy
- ⁷⁸ ^(a) INFN-TIFPA; ^(b) Università degli Studi di Trento, Trento; Italy
- ⁷⁹ Universität Innsbruck, Department of Astro and Particle Physics, Innsbruck; Austria
- ⁸⁰ University of Iowa, Iowa City IA; United States of America
- ⁸¹ Department of Physics and Astronomy, Iowa State University, Ames IA; United States of America
- ⁸² İstinye University, Sarıyer, Istanbul; Türkiye
- ⁸³ ^(a) Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora; ^(b) Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; ^(c) Instituto de Física, Universidade de São Paulo, São Paulo; ^(d) Rio de Janeiro State University, Rio de Janeiro; Brazil
- ⁸⁴ KEK, High Energy Accelerator Research Organization, Tsukuba; Japan
- ⁸⁵ Graduate School of Science, Kobe University, Kobe; Japan
- ⁸⁶ ^(a) AGH University of Krakow, Faculty of Physics and Applied Computer Science, Krakow; ^(b) Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow; Poland
- ⁸⁷ Institute of Nuclear Physics Polish Academy of Sciences, Krakow; Poland
- ⁸⁸ Faculty of Science, Kyoto University, Kyoto; Japan
- ⁸⁹ Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka; Japan
- ⁹⁰ Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata; Argentina
- ⁹¹ Physics Department, Lancaster University, Lancaster; United Kingdom
- ⁹² Oliver Lodge Laboratory, University of Liverpool, Liverpool; United Kingdom
- ⁹³ Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana; Slovenia
- ⁹⁴ Department of Physics and Astronomy, Queen Mary University of London, London; United Kingdom
- ⁹⁵ Department of Physics, Royal Holloway University of London, Egham; United Kingdom
- ⁹⁶ Department of Physics and Astronomy, University College London, London; United Kingdom
- ⁹⁷ Louisiana Tech University, Ruston LA; United States of America
- ⁹⁸ Fysiska institutionen, Lunds universitet, Lund; Sweden
- ⁹⁹ Departamento de Física Teórica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid; Spain
- ¹⁰⁰ Institut für Physik, Universität Mainz, Mainz; Germany
- ¹⁰¹ School of Physics and Astronomy, University of Manchester, Manchester; United Kingdom
- ¹⁰² CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille; France
- ¹⁰³ Department of Physics, University of Massachusetts, Amherst MA; United States of America
- ¹⁰⁴ Department of Physics, McGill University, Montreal QC; Canada
- ¹⁰⁵ School of Physics, University of Melbourne, Victoria; Australia
- ¹⁰⁶ Department of Physics, University of Michigan, Ann Arbor MI; United States of America
- ¹⁰⁷ Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America
- ¹⁰⁸ Group of Particle Physics, University of Montreal, Montreal QC; Canada
- ¹⁰⁹ Fakultät für Physik, Ludwig-Maximilians-Universität München, München; Germany
- ¹¹⁰ Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München; Germany
- ¹¹¹ Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya; Japan
- ¹¹² Department of Physics and Astronomy, University of New Mexico, Albuquerque NM; United States of America

- ¹¹³ Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen; Netherlands
¹¹⁴ Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam; Netherlands
¹¹⁵ Department of Physics, Northern Illinois University, DeKalb IL; United States of America
¹¹⁶ ^(a) New York University Abu Dhabi, Abu Dhabi; ^(b) University of Sharjah, Sharjah; United Arab Emirates
¹¹⁷ Department of Physics, New York University, New York NY; United States of America
¹¹⁸ Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo; Japan
¹¹⁹ Ohio State University, Columbus OH; United States of America
¹²⁰ Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK; United States of America
¹²¹ Department of Physics, Oklahoma State University, Stillwater OK; United States of America
¹²² Palacký University, Joint Laboratory of Optics, Olomouc; Czech Republic
¹²³ Institute for Fundamental Science, University of Oregon, Eugene, OR; United States of America
¹²⁴ Graduate School of Science, Osaka University, Osaka; Japan
¹²⁵ Department of Physics, University of Oslo, Oslo; Norway
¹²⁶ Department of Physics, Oxford University, Oxford; United Kingdom
¹²⁷ LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris; France
¹²⁸ Department of Physics, University of Pennsylvania, Philadelphia PA; United States of America
¹²⁹ Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA; United States of America
¹³⁰ ^(a) Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa; ^(b) Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa; ^(c) Departamento de Física, Universidade de Coimbra, Coimbra; ^(d) Centro de Física Nuclear da Universidade de Lisboa, Lisboa; ^(e) Departamento de Física, Escola de Ciências, Universidade do Minho, Braga; ^(f) Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain); ^(g) Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa; Portugal
¹³¹ Institute of Physics of the Czech Academy of Sciences, Prague; Czech Republic
¹³² Czech Technical University in Prague, Prague; Czech Republic
¹³³ Charles University, Faculty of Mathematics and Physics, Prague; Czech Republic
¹³⁴ Particle Physics Department, Rutherford Appleton Laboratory, Didcot; United Kingdom
¹³⁵ IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette; France
¹³⁶ Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA; United States of America
¹³⁷ ^(a) Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; ^(b) Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago; ^(c) Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, y Departamento de Física, Universidad de La Serena; ^(d) Universidad Andres Bello, Department of Physics, Santiago; ^(e) Instituto de Alta Investigación, Universidad de Tarapacá, Arica; ^(f) Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso; Chile
¹³⁸ Department of Physics, Institute of Science, Tokyo; Japan
¹³⁹ Department of Physics, University of Washington, Seattle WA; United States of America
¹⁴⁰ Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom
¹⁴¹ Department of Physics, Shinshu University, Nagano; Japan
¹⁴² Department Physik, Universität Siegen, Siegen; Germany
¹⁴³ Department of Physics, Simon Fraser University, Burnaby BC; Canada
¹⁴⁴ SLAC National Accelerator Laboratory, Stanford CA; United States of America
¹⁴⁵ Department of Physics, Royal Institute of Technology, Stockholm; Sweden
¹⁴⁶ Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY; United States of America
¹⁴⁷ Department of Physics and Astronomy, University of Sussex, Brighton; United Kingdom
¹⁴⁸ School of Physics, University of Sydney, Sydney; Australia
¹⁴⁹ Institute of Physics, Academia Sinica, Taipei; Taiwan
¹⁵⁰ ^(a) E. Andronikashvili Institute of Physics, Iv. Javakishvili Tbilisi State University, Tbilisi; ^(b) High Energy Physics Institute, Tbilisi State University, Tbilisi; ^(c) University of Georgia, Tbilisi; Georgia
¹⁵¹ Department of Physics, Technion, Israel Institute of Technology, Haifa; Israel
¹⁵² Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv; Israel
¹⁵³ Department of Physics, Aristotle University of Thessaloniki, Thessaloniki; Greece
¹⁵⁴ International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo; Japan
¹⁵⁵ Department of Physics, University of Toronto, Toronto ON; Canada
¹⁵⁶ ^(a) TRIUMF, Vancouver BC; ^(b) Department of Physics and Astronomy, York University, Toronto ON; Canada
¹⁵⁷ Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba; Japan
¹⁵⁸ Department of Physics and Astronomy, Tufts University, Medford MA; United States of America
¹⁵⁹ United Arab Emirates University, Al Ain; United Arab Emirates
¹⁶⁰ Department of Physics and Astronomy, University of California Irvine, Irvine CA; United States of America
¹⁶¹ Department of Physics and Astronomy, University of Uppsala, Uppsala; Sweden
¹⁶² Department of Physics, University of Illinois, Urbana IL; United States of America
¹⁶³ Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Valencia; Spain
¹⁶⁴ Department of Physics, University of British Columbia, Vancouver BC; Canada
¹⁶⁵ Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada
¹⁶⁶ Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg; Germany
¹⁶⁷ Department of Physics, University of Warwick, Coventry; United Kingdom
¹⁶⁸ Waseda University, Tokyo; Japan
¹⁶⁹ Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot; Israel
¹⁷⁰ Department of Physics, University of Wisconsin, Madison WI; United States of America
¹⁷¹ Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany
¹⁷² Department of Physics, Yale University, New Haven CT; United States of America

^a Also Affiliated with an institute covered by a cooperation agreement with CERN.

^b Also at An-Najah National University, Nablus; Palestine.

^c Also at Borough of Manhattan Community College, City University of New York, New York NY; United States of America.

^d Also at Center for High Energy Physics, Peking University; China.

^e Also at Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki; Greece.

^f Also at Centro Studi e Ricerche Enrico Fermi; Italy.

^g Also at CERN, Geneva; Switzerland.

^h Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.

ⁱ Also at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona; Spain.

^j Also at Department of Financial and Management Engineering, University of the Aegean, Chios; Greece.

^k Also at Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America.

^l Also at Department of Physics, Ben Gurion University of the Negev, Beer Sheva; Israel.

^m Also at Department of Physics, California State University, Sacramento; United States of America.

- ⁿ Also at Department of Physics, King's College London, London; United Kingdom.
- ^o Also at Department of Physics, Stanford University, Stanford CA; United States of America.
- ^p Also at Department of Physics, University of Fribourg, Fribourg; Switzerland.
- ^q Also at Department of Physics, University of Thessaly; Greece.
- ^r Also at Department of Physics, Westmont College, Santa Barbara; United States of America.
- ^s Also at Faculty of Physics, Sofia University, 'St. Kliment Ohridski', Sofia; Bulgaria.
- ^t Also at Hellenic Open University, Patras; Greece.
- ^u Also at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona; Spain.
- ^v Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg; Germany.
- ^w Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia; Bulgaria.
- ^x Also at Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco.
- ^y Also at Institute of Particle Physics (IPP); Canada.
- ^z Also at Institute of Physics and Technology, Mongolian Academy of Sciences, Ulaanbaatar; Mongolia.
- ^{aa} Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
- ^{ab} Also at Institute of Theoretical Physics, Ilia State University, Tbilisi; Georgia.
- ^{ac} Also at L2IT, Université de Toulouse, CNRS/IN2P3, UPS, Toulouse; France.
- ^{ad} Also at Lawrence Livermore National Laboratory, Livermore; United States of America.
- ^{ae} Also at National Institute of Physics, University of the Philippines Diliman (Philippines); Philippines.
- ^{af} Also at Technical University of Munich, Munich; Germany.
- ^{ag} Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing; China.
- ^{ah} Also at TRIUMF, Vancouver BC; Canada.
- ^{ai} Also at Università di Napoli Parthenope, Napoli; Italy.
- ^{aj} Also at University of Colorado Boulder, Department of Physics, Colorado; United States of America.
- ^{ak} Also at Washington College, Chestertown, MD; United States of America.
- ^{al} Also at Yeditepe University, Physics Department, Istanbul; Türkiye.
- ^{*} Deceased.