



Letter

Search for quantum black holes in lepton + jet final states using proton–proton collisions at $\sqrt{s} = 13.6$ TeV with the ATLAS detectorThe ATLAS Collaboration¹

ARTICLE INFO

Editor: Dr. M. Doser

Keywords:

Quantum black holes
 pp collisions
 Lepton + jet
 Extra dimensions
 BSM decay
 ATLAS Experiment
 Large Hadron Collider

ABSTRACT

A search for quantum black holes in electron + jet or muon + jet final states with high invariant mass is performed. The analysis uses data from $\sqrt{s} = 13.6$ TeV pp collisions recorded by the ATLAS detector between 2022 and 2024 during Run 3 of the Large Hadron Collider, corresponding to an integrated luminosity of 164 fb^{-1} . This search is strongly motivated by a dramatic increase of the production cross-section by up to an order of magnitude for the highest masses considered, thanks to the small increase of 0.6 TeV in centre-of-mass energy between Run 2 and Run 3. No significant excess above the Standard Model background is observed, and 95% CL upper limits are set on the production cross-section times branching ratio in several benchmark models, reaching a mass scale of 9.4 TeV. These represent the strongest exclusion limits to date on quantum black hole production.

1. Introduction

The hierarchy problem—the immense gulf between the electroweak scale and Planck scale—may be resolved by theories with extra dimensions (EDs) that lower the fundamental D -dimensional scale of gravity, M_D , to the TeV range. In the Arkani-Hamed, Dimopoulos, and Dvali (ADD) model [1,2], gravity propagates through n flat EDs (where $D = 4 + n$), while Standard Model (SM) fields are restricted to four-dimensional space-time. Alternatively, the Randall–Sundrum (RS) model [3] employs one warped extra dimension to generate this scale hierarchy. These theories predict a plethora of new phenomena, some of which are accessible at the Large Hadron Collider (LHC). One such prediction is the production of quantum black holes (QBHs) [4–8] at threshold masses $M_{\text{th}} \sim M_D$. In this benchmark framework, it is postulated that the QBH parton–parton cross-section follows a power-law increase with partonic centre-of-mass energy, with the power determined by the number of extra dimensions. For higher proton-beam energy, the suppression of the partonic cross-section arising from the parton distribution functions (PDF) at high Bjorken- x (the fraction of the proton's momentum carried by the interacting parton) is reduced, resulting in a significant increase in the QBH production cross-section, σ_{QBH} . Unlike semi-classical black holes, which decay thermally via Hawking radiation into high-multiplicity final states [9–14], these QBHs decay into two-particle final states, where lepton- and baryon-number conservation may be violated. This search focuses on diquark production of QBHs that can decay to lepton + antiquark ($\ell + \bar{q}$) final states:

$$uu \rightarrow \text{QBH}^{4/3} \rightarrow \bar{d}\ell^+, \quad ud \rightarrow \text{QBH}^{1/3} \rightarrow \bar{u}\ell^+, \quad dd \rightarrow \text{QBH}^{-2/3} \rightarrow \bar{d}\ell^-, \quad (1)$$

where the superscript indicates the QBH electric charge and the processes are sorted by descending σ_{QBH} , left-to-right. The notation u and d marks the up-type and down-type quarks. The branching ratios for the processes ordered as in Eq. (1) are 11%, 5.6% and 6.7%, to each lepton flavour [4].

A key feature that sets this model apart from virtually all other new-physics scenarios, and motivates this search already with a partial run dataset, is the production cross-section's strong dependence on the proton–proton centre-of-mass energy, $\sqrt{s}$. This dependence causes the increase in $\sqrt{s}$ from Run 2 of the LHC (13 TeV) to Run 3 (13.6 TeV) to enhance σ_{QBH} by approximately 100% at $M_{\text{th}} = 6$ TeV up to about 1000% at $M_{\text{th}} = 10.5$ TeV [4].

This analysis succeeds the previous ATLAS search performed at $\sqrt{s} = 13$ TeV using the full 140 fb^{-1} Run 2 dataset [15]. The same search was done by ATLAS at $\sqrt{s} = 8$ TeV with 20.3 fb^{-1} of data [16]. Complementary searches were also performed in dijet, dilepton and photon + jet final states by ATLAS [17–22] and CMS [23–26]. In comparison with the other final states, the lepton + jet ones benefit from significantly lower backgrounds, which compensates for their smaller cross-section times branching ratio. Lepton + jet final states are of course not unique to QBH production, and other searches probing similar regions of phase space do not necessarily provide an explicit interpretation in terms of QBHs. For example, ATLAS has published a lepton + jet search for leptoquarks

Contact: atlas.publications@cern.ch.

¹ Authors are listed at the end of this paper.

with a combination of the full Run 2 dataset and a partial (56 fb^{-1}) Run 3 dataset [27].

The present search uses 164 fb^{-1} of $\sqrt{s} = 13.6 \text{ TeV}$ proton–proton collision data, recorded by the ATLAS detector during the 2022–2024 period of Run 3. Even with a Run 3 dataset similar in size to the full Run 2 dataset, this analysis yields considerably higher QBH exclusion limits thanks to the significant increase in σ_{QBH} . Electron + jet and muon + jet final states with an invariant mass above 3 TeV are targeted separately in this search. Explicit contributions from QBH decays with τ -leptons are not considered, since they are expected to be negligible compared to those from the other two lepton + jet final states, owing to the $\tau \rightarrow \ell \bar{\nu}_\ell \nu_\tau$ branching ratio and the softer electron and muon transverse momentum (p_T) spectra due to the presence of neutrinos in τ decays. The main background processes include V + jets ($V = W, Z$), VV and events with top quarks. These are modelled using Monte Carlo (MC) simulations. Events containing non-prompt electrons, or electrons from photon conversions or jets misidentified as electrons, collectively referred to as “fakes”, are estimated using data-driven techniques. This is the dominant background in the electron channel, while W + jets production contributes the most background in the muon channel.

2. ATLAS detector

The ATLAS experiment [28,29] 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 tracking detector surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadronic calorimeters, and a muon spectrometer (MS). 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 MS 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 MS 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 detector which is located close to the beam pipe [30]. A two-level trigger system was used to select events [31,32]. The first-level trigger is implemented in hardware and used 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 reduced the accepted rate of complete events to 3 kHz on average, depending on the data-taking conditions. A software suite [33] 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 simulation

Data and simulated event samples used in this study must satisfy a requirement that all detector systems operate normally [34]. The data were collected with single-electron or single-muon triggers [32]. The

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 $y = (1/2) \ln[(E + p_z)/(E - p_z)]$ in the relativistic limit. Angular distance is measured in units of $\Delta R \equiv \sqrt{(\Delta y)^2 + (\Delta \phi)^2}$.

p_T threshold is 26 (24) GeV for isolated electron (muon) triggers and 60 (50) GeV for non-isolated triggers. As the analysis targets very high mass QBHs whose decays produce a lepton with $p_T > 150 \text{ GeV}$, virtually all events were triggered by high- p_T lepton triggers without isolation requirements whose p_T threshold is 140 (50) GeV for electrons (muons). The application of data-quality requirements [34] results in a sample corresponding to an integrated luminosity of $164 \pm 3 \text{ fb}^{-1}$.

QBH MC signal samples were generated using the QBH v3.02 generator [7] to compute the production cross-sections and model the hard-scatter process, assuming zero angular momentum. Events were then interfaced to PYTHIA 8 [35] to model parton showering and hadronisation. As in previous iterations of searches for QBHs, the CTEQ6L1 [36] PDF set was used and the QCD factorisation scale set to the inverse gravitational radius [7]. Requiring the QBH mass to be in the range $(1-3)M_{\text{th}}$ (with $M_{\text{th}} = M_D$) ensures that QBHs are produced in a region where quantum effects are significant, excluding thermal decays. In the ADD model, $n = 2, 4$, or 6 EDs are assumed, whereas $n = 1$ is used in the RS model. The kinematic distributions of the decay products are governed by the QBH mass; consequently, the signal acceptance and reconstruction efficiency are found to be independent of the specific model type or the number of extra dimensions. The production cross-section is significantly lower for the RS model than for the ADD model. Samples were produced in 0.5 TeV steps through threshold mass ranges of $M_{\text{th}} \in [6, 8.5] \text{ TeV}$ and $[8, 10.5] \text{ TeV}$ for the RS and ADD models, respectively.

Background events from W + jets, Z + jets and VV (WW, ZZ, WZ) production were modelled with the SHERPA 2.2.14 generator [37] using the NNPDF3.0NNLO PDF set [38]. The $t\bar{t}$ and single-top processes were modelled using the POWHEGBOX v2 [39–42] generator at NLO with the NNPDF3.0NNLO [38] PDF set. The $t\bar{t}W$ process was modelled using SHERPA 2.2.14, while other $t\bar{t}V$ samples were produced with MADGRAPH5_AMC@NLO 2.3.3 [43] interfaced to PYTHIA 8 [44]. Dijet MC samples were produced with PYTHIA 8 [35]. EVTGEN 2.1.1 [45] was used to perform bottom- and charm-quark decays except for the backgrounds modelled using SHERPA, for which the decays were performed internally. Non-prompt electrons are removed from all MC samples to avoid double-counting their contribution, which is obtained from data. For the muon channel, this background, estimated from dijet MC events, is negligible. The same dijet MC sample is used in the electron channel to cross-check the data-driven fake-background estimate. All generated MC events undergo the full ATLAS detector simulation [46] using GEANT4 [47]. The fully simulated MC events are reconstructed in the same manner as the data events and corrected to match the number of interactions per bunch crossing (in-time pile-up) observed in data. The effect of multiple interactions in the same and neighbouring bunch crossings (pile-up) was modelled by overlaying [48] the simulated hard-scattering event with inelastic proton–proton events generated from a mix of EPOS 2.0.1.4 [49] and PYTHIA 8.308 [35].

4. Event selection and background estimation

The physics objects used to reconstruct the lepton + jet final states in this analysis include electrons, muons, jets, and missing transverse momentum. The definitions of these objects as well as the event selection criteria are given below.

Signal electron candidates are reconstructed from energy clusters in the electromagnetic (EM) calorimeter that are matched to an inner-detector track. They are required to have $|\eta| < 2.47$, excluding the transition region $1.37 < |\eta| < 1.52$ between the barrel and endcap EM calorimeters. To ensure that these electrons originate from the primary vertex, the longitudinal impact parameter z_0 of their track relative to the primary vertex must satisfy $|z_0 \sin \theta| < 0.5 \text{ mm}$, where θ is the track’s polar angle. Similarly, their transverse impact parameter d_0 must have a significance satisfying $|d_0|/\sigma(d_0) \leq 5$, where $\sigma(d_0)$ is the uncertainty in d_0 . Electrons are required to have $p_T > 150 \text{ GeV}$ and satisfy the *Tight*

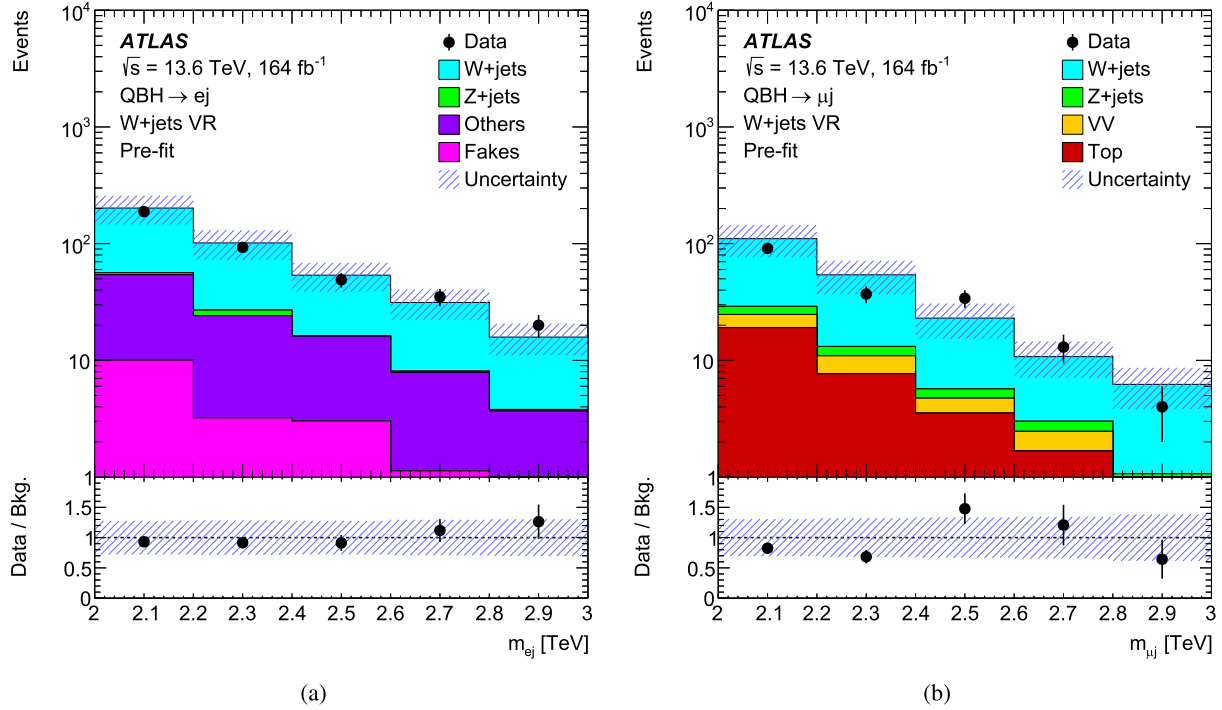


Fig. 1. Invariant mass of the lepton-jet pair in the W + jets validation region for (a) the electron channel and (b) the muon channel. The data-to-background ratio is shown in the bottom panels, and hatched bands indicate the total statistical and systematic uncertainty. In (a), “Others” denotes subdominant backgrounds including top and diboson processes. The MC contributions are normalised based on their expected cross-section, prior to the likelihood fit.

identification and *HighPtCaloOnly* isolation criteria [50,51]. They must also match the corresponding trigger-level electron object.

Signal muon candidates are reconstructed by matching inner-detector tracks in the region $|\eta| < 2.5$ to tracks reconstructed in the MS. For muons, the transverse impact parameter requirement is tightened to $|d_0|/\sigma(d_0) \leq 3$, whereas the longitudinal one is the same as for electrons. Muons must satisfy $p_T > 150$ GeV and also the *High- p_T* identification criterion and *PflowTightVarRad* isolation requirement [52]. This identification criterion is used to ensure optimal muon momentum resolution at high p_T . It requires at least three hits in each of three layers of precision tracking chambers in the MS, while specific regions of the MS where the alignment is suboptimal are vetoed. Selected muons are also required to match the trigger-level muon objects.

Jets are reconstructed from particle-flow objects [53] using the anti- k_t algorithm [54,55] with a radius parameter of $R = 0.4$. All jets are required to have $|\eta| < 2.5$. Signal jets must satisfy $p_T > 130$ GeV. To resolve ambiguities between reconstructed objects, a standard overlap-removal procedure is applied to leptons and jets to avoid the double-counting of energy deposits [27].

The missing transverse momentum, p_T^{miss} , is defined as the magnitude of the negative vectorial sum of the transverse momenta of all selected and calibrated physics objects and other inner-detector tracks from the primary vertex that are not associated with any of these objects [56]. For the p_T^{miss} calculation, the identification criteria for electrons and muons are relaxed. Additionally, an object-based missing transverse momentum significance $S(p_T^{\text{miss}})$ measures the likelihood that the reconstructed p_T^{miss} originates from real invisible particles rather than detector effects. It is defined as $S(p_T^{\text{miss}}) = p_T^{\text{miss}} / \sqrt{\sigma_L^2(1 - \rho_{LT}^2)}$, where σ_L is the resolution longitudinally to p_T^{miss} and ρ_{LT} the correlation between the transverse and longitudinal resolutions relative to p_T^{miss} [56]. To suppress contributions from pile-up, a jet vertex-tagging [57] requirement is applied to jets with $p_T < 60$ GeV, which may still enter the analysis via the overlap removal or the calculation of p_T^{miss} .

All reconstructed objects in simulations have their reconstruction efficiency, energy scale and energy resolution corrected to data, where the

corrections discussed in Refs. [50–53,56,57] are updated to the Run 3 conditions. Moreover, all events are required to contain a primary vertex built from at least two associated tracks with $p_T > 0.5$ GeV. If more than one such vertex is present, the primary vertex is the one with the highest sum of squared transverse momenta Σp_T^2 of its associated tracks [58].

Candidate events in the signal region (SR) require exactly one signal lepton and at least one signal jet with invariant mass $m_{\ell j} > 3$ TeV. The angular separation between the lepton and the jet is required to satisfy $\Delta\phi_{\ell j} > 2.8$ and $\Delta\eta_{\ell j} < 3.25$ to exploit the back-to-back topology of the QBH decay. To estimate the shape and/or normalisation of the dominant backgrounds, the analysis defines several control and validation regions (CRs and VRs, respectively). The normalisation of contributions from W and Z events is estimated in single-bin CRs (W CR and Z CR), while their shapes are taken from MC simulation, following confirmation that no shape correction from data is needed. These estimates are validated in the respective validation regions (W VR and Z VR), by examining the ratios of the total background to data and checking that they are within the uncertainty. Smaller backgrounds from $t\bar{t}$, single-top, VV and $t\bar{t}V$ events are estimated directly from MC simulation. The background due to fake/non-prompt electrons is estimated from data by using the matrix method (MM) [59]; the rates determined in a dedicated fake-enriched CR (f CR) are applied to all other analysis regions to obtain the fake-electron background contribution there. The behaviour of this background is examined in a corresponding VR (f VR). In the muon channel, the corresponding contribution is estimated from the dijet MC sample and found to be negligible. All CRs and VRs are orthogonal to the SRs and to each other via selections on the $m_{\ell j}$ and $S(p_T^{\text{miss}})$ variables. The region definitions and event selection are summarised in Table 1. The final background estimate is obtained from a simultaneous fit to data in the aforementioned regions. The fit procedure is described in Section 6.

The W CR is designed to be maximally pure in the W + jets background component by requiring $S(p_T^{\text{miss}}) > 5.0$ (3.0) for the electron (muon) channel. The different selection values originate from the need to accommodate the f CR in the electron channel, as discussed below.

Table 1

Analysis regions definitions. The control (validation) regions used to estimate the leading backgrounds, fake electrons and V + jets, are indicated. The label $ej(\mu j)$ refers to the electron (muon) channel. The “signal” subscript denotes the different lepton and jet signal definitions in the text. The dash (—) indicates a selection criterion not applied, where N/A indicates a criterion cannot be applied, in regions which require exactly one signal lepton. Selections on $m_{\ell j}$ and $S(p_T^{\text{miss}})$ orthogonalise analysis regions from one another. The $f\text{CR}$ and $f\text{VR}$ are only relevant in the context of the electron channel. The $m_{\ell\ell}$ criterion in the $f\text{CR}$ is only applied in the presence of a second electron.

Variable	$W\text{CR}$ ($W\text{VR}$)	$f\text{CR}$ ($f\text{VR}$) (electron channel only)	$Z\text{CR}$ ($Z\text{VR}$)	SR
N_{signal}^j	≥ 1	≥ 1	≥ 1	≥ 1
N_{signal}^e	1	1	2	1
$m_{\ell j}$ [TeV]	1.0–2.0 (2.0–3.0)	1.0–3.0	1.0–2.0 (2.0–3.0)	> 3.0
p_T^e [GeV]	> 150	> 150	> 150	> 150
p_T^j [GeV]	> 130	> 130	> 130	> 130
$S(p_T^{\text{miss}})_{ej, \mu j}$	$> 5.0, 3.0$	< 3.0 (3.0–5.0)	—	—
$m_{\ell\ell}$ [GeV]	N/A	> 120	60–120	N/A
$\Delta\eta_{\ell j}$	< 3.25	—	—	< 3.25
$\Delta\phi_{\ell j}$	> 2.8	—	—	> 2.8

Similarly, the $Z\text{CR}$ is made maximally pure in the Z + jets component by requiring a second same-flavour lepton, with the dilepton invariant mass constrained to the range 60–120 GeV. These two CRs are defined in the $m_{\ell j}$ range from 1 to 2 TeV, while the respective VRs cover the 2 to 3 TeV range. Distributions in the $W\text{VR}$ s are shown in Fig. 1, where it is shown that data and background predictions agree well within the assigned uncertainties.

In the electron channel, the dominant background in the SR arises from fakes, estimated via the MM. The MM requires the definition of “real” and “fake” rates, r and f , respectively. These probabilities are defined as the ratio of events coming from two different electron populations: signal and baseline. The signal criteria are defined above. The baseline criteria are defined by relaxing the electron identification from *Tight* to *Medium* and removing the isolation requirement [50,51]. These criteria are only used in order to (i) estimate f in $f\text{CR}$, and (ii) build the respective background template in the different regions. The estimation of r is performed in a “real”-enriched region using $Z(\rightarrow e^+e^-)$ +jets MC events. The estimation of f is performed in a “fake”-enriched region that is both orthogonal to the SR and contains a high-enough event yield. This is achieved by requiring that $m_{\ell j}$ be in the range 1–3 TeV. To increase the fakes’ purity in that region, contributions from the dominant W + jets and Z + jets backgrounds are reduced by placing a requirement on $S(p_T^{\text{miss}})$ or m_{ee} , respectively. The resulting fraction of events with fakes in the $f\text{CR}$ ranges from 60% to 90% (30% to 45%) for the baseline (signal) population. Both r and f are calculated as a function of the electron p_T in the range 150–2000 GeV and $|\eta|$ in four bins within the range 0–2.47, excluding the transition region mentioned above. In the calculation of f , the prompt-electron contributions found in MC simulation are subtracted from the data in the $f\text{CR}$, for both populations separately. Using the MM, r and f are combined into weights that are applied to data events meeting the baseline criteria. This operation yields the fakes background template in the different regions. The result is validated in the $f\text{VR}$, defined in Table 1. The $m_{\ell j}$ distribution in the $f\text{VR}$ is shown in Fig. 2, where the data and background predictions are seen to be in agreement within the assigned uncertainties. As can be seen, the fakes component is subdominant in this region, roughly 2–3 times smaller than the W + jets component. Nevertheless, this still allows to assess the modelling of the fakes background estimation there.

In the electron channel prior to the fit, the fakes component constitutes approximately 56% of the total SR background, followed by W + jets at 32%, with Z + jets, top, and diboson processes contributing the remaining 12%. In the muon channel, W + jets dominates at approximately 80%, with Z + jets, top, and diboson processes accounting for

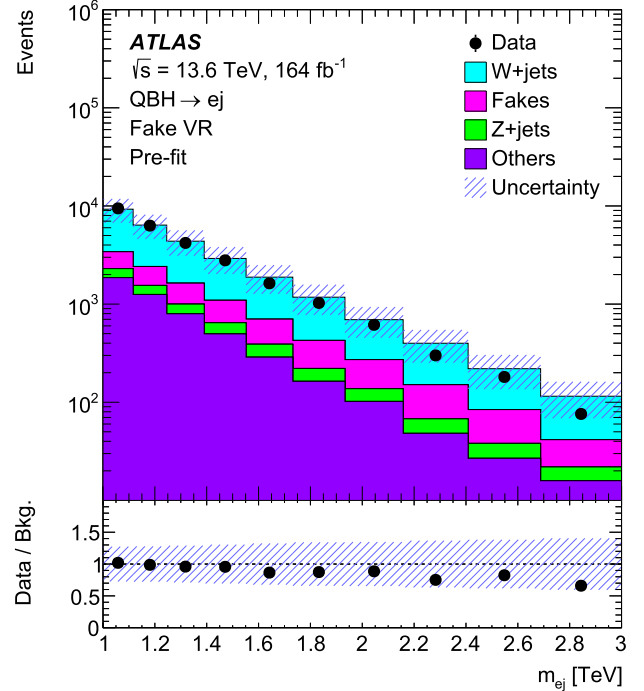


Fig. 2. Invariant mass of the lepton-jet pair in the fakes validation region. The data-to-background ratio is shown in the bottom panel, and hatched bands indicate the total statistical and systematic uncertainty. “Others” denotes subdominant backgrounds including top and diboson processes. The MC contributions are normalised based on their expected cross-section, prior to the likelihood fit.

the remaining 20%. The signal acceptance times efficiency ranges from 76% to 86% (52% to 58%) for the electron (muon) channel, for the signals considered in this analysis. The factors responsible for the difference in yield between the two channels are the lepton acceptance times efficiency and the lepton momentum resolution. The muon trigger has a lower geometric coverage than the electron counterpart. Furthermore, very tight identification requirements are necessary to maintain a reasonable muon momentum resolution at high p_T . Uncertainties associated with the modelling of high- p_T muon identification are taken into account as discussed in Ref. [52]. The limited momentum resolution leads to a significantly worse muon + jet mass resolution as compared to the electron + jet case and thus broader signal shapes. The lepton + jet mass resolution in the electron channel is consistently below 5% for all signal M_{th} points considered in the analysis. The muon-channel mass resolution varies between 25% and 30% for signal M_{th} values between 6 TeV and 10 TeV, respectively. The resolution is obtained from the quadrature sum of the standard deviation and the small bias in the mean of the respective lepton + jet mass reconstruction response distribution.

5. Systematic uncertainties

Systematic uncertainties affecting the signal and background expectations arise from various experimental and theoretical sources and are evaluated using the methods described below. Theoretical uncertainties are only calculated for the two leading MC backgrounds, W + jets and Z + jets, since the others are significantly smaller and their uncertainties have negligible impact on the analysis. These uncertainties, which originate from missing higher-order corrections, contribute via the choice of QCD renormalisation and factorisation scales, strong coupling constant and PDFs [38]. These sources are collectively referred to as “theory uncertainties” and amount to ~30% of the V + jets background yield in the SR. Following previous publications, no theoretical uncertainties are assigned to the QBH benchmark signals. This choice is related to

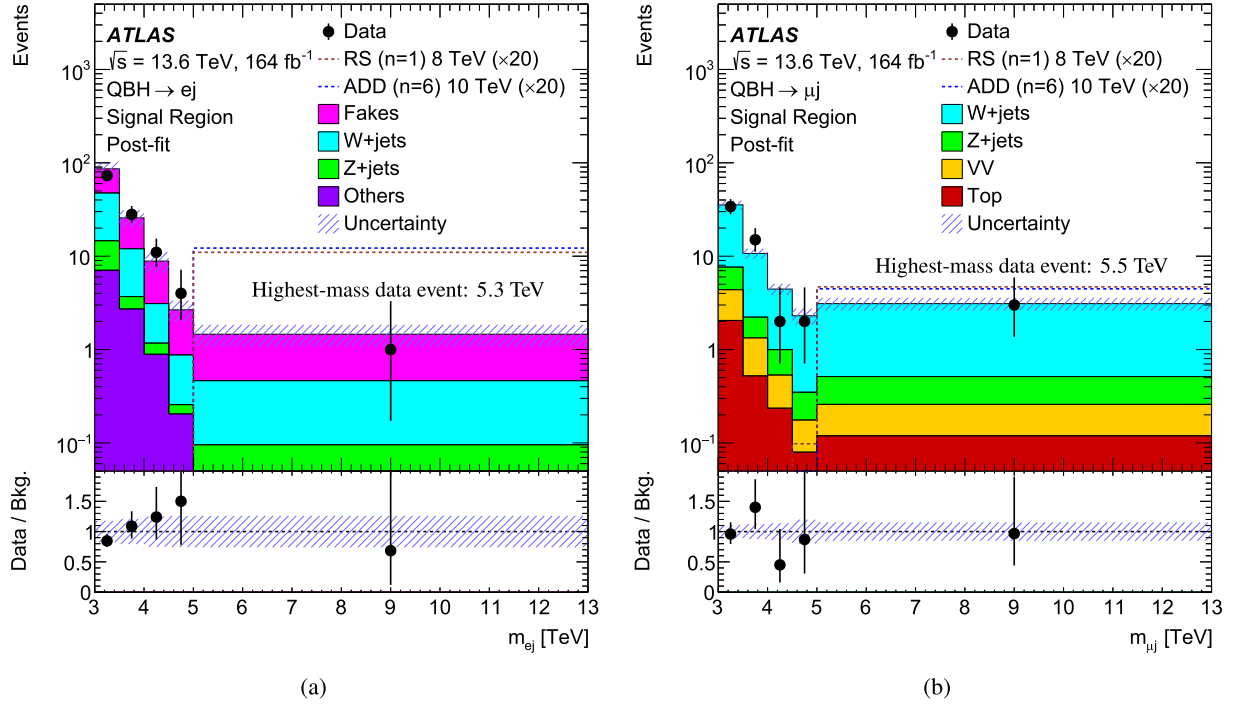


Fig. 3. Distribution of the lepton + jet invariant mass for events passing the full signal selection for (a) the electron channel and (b) the muon channel. Benchmark signals for the RS and ADD models with $n = 1, 6$ extra dimensions at $M_{\text{th}} = 8, 10$ TeV, respectively, are scaled by a factor of 20 for presentation purposes and overlaid on the total background estimate. The uncertainty band includes the statistical and systematic uncertainties. The highest-mass data events observed in the last bin have $m_{\ell j}$ values of 5.3 (5.0, 5.1, 5.5) TeV in the electron (muon) channel, and are plotted at the bin's centre. In (a), “Others” denotes subdominant backgrounds including top and diboson processes. The MC contributions are normalised based on the likelihood fit.

the unclarity in the application of these uncertainties to QBH production. It originates from the lack of an established quantum theory for the interaction between gravity and partons. Experimental uncertainties are evaluated for all MC signal and background samples. These uncertainties include those estimated by varying the reconstruction, identification, isolation and trigger efficiencies, and the energy/momentum calibration of electrons [60], muons [52], jets [61] and $p_{\text{T}}^{\text{miss}}$ [56], as well as uncertainties in the integrated luminosity [62] and pile-up. The theory and experimental uncertainties are propagated to the fakes background through the prompt-electron MC event yield that is subtracted from data in the $f\text{CR}$, as explained in the previous section. Collectively, they correspond to an uncertainty of approximately 18% of the fakes background in the SR, with the dominant contribution being from QCD scale uncertainties. Additionally, a separate normalisation uncertainty due to the fakes in the $f\text{CR}$ and SR not having the same mix of origins is considered. In this analysis, almost all fakes originate from light-flavour decays or photon conversions, according to the dijet MC sample. The two origins populate the $f\text{CR}$ and SR differently. Light-flavour decays account for 92% (71%) of fakes in the $f\text{CR}$ (SR), whereas photon conversions account for 8% (29%). The corresponding uncertainty is found by calculating the weighted average of the difference in the two origins between the $f\text{CR}$ and SR, as follows: let $g_{u,v}^{i,j}$ be the fraction of electrons of origin {light-flavour decays, photon conversion} in region { $f\text{CR}$, SR}, where LF denotes light-flavour decays and $\gamma\text{-conv}$ denotes photon conversions, and $g_{\text{SR}}^{\text{LF}} + g_{\text{SR}}^{\gamma\text{-conv}} = 1$. The uncertainty is therefore $g_{\text{SR}}^{\text{LF}} |g_{f\text{CR}}^{\text{LF}} - g_{\text{SR}}^{\text{LF}}| + g_{\text{SR}}^{\gamma\text{-conv}} |g_{f\text{CR}}^{\gamma\text{-conv}} - g_{\text{SR}}^{\gamma\text{-conv}}|$. This uncertainty amounts to 22% on the yield of the fakes background. By considering the difference in origin between the $f\text{CR}$ and $f\text{VR}$, the same uncertainty, computed in the same manner, is found to be 17% in the $f\text{VR}$. Lastly, the limited size of the data and MC samples in the $f\text{CR}$ is accounted for via a separate systematic uncertainty, which is then propagated as a function of electron p_{T} and $|\eta|$ to the SR, where it amounts to about 16%.

Table 2

Expected and observed exclusion limits at 95% confidence level on the QBH mass threshold M_{th} for RS and ADD models with different number of extra dimensions n , in the electron and muon channels, using Run 3 data at a centre-of-mass energy of 13.6 TeV.

Model	RS		ADD					
	n		1		2		4	
Channel	$e + j$	$\mu + j$	$e + j$	$\mu + j$	$e + j$	$\mu + j$	$e + j$	$\mu + j$
Exclusion limit	Expected							
M_{th} [TeV]	7.1	6.6	8.5	8.1	9.1	8.7	9.4	9.0
Exclusion limit	Observed							
M_{th} [TeV]	7.2	6.6	8.6	8.2	9.1	8.7	9.4	9.0

6. Results

A signal-plus-background model is used to fit the observed $m_{\ell j}$ spectra simultaneously in the SR, $W\text{CR}$ and $Z\text{CR}$ using the profile-likelihood method [63]. The expected and observed event counts in each $m_{\ell j}$ bin are described by Poisson-distributed variables, where the uncertainties are accounted for via nuisance parameters. The SR bins are chosen such that all have a background expectation of $\geq \mathcal{O}(1)$ events and are coarser than the detector resolution. The sensitivity of the analysis is driven by the highest $m_{\ell j}$ bin of the SR, 5–13 TeV. Contributions above 13 TeV are included in this bin. In that bin, the number of background events in the electron channel is predicted to be $1.46 \pm 0.65_{\text{stat.}} \pm 0.38_{\text{syst.}}$, where the leading systematic uncertainty is from the fakes estimation. In the muon channel, the number of background events in the highest bin is predicted to be $3.10 \pm 0.95_{\text{stat.}} \pm 0.47_{\text{syst.}}$, where the leading systematic uncertainty is due to the modelling of the $W + \text{jets}$ background. Normalisation factors for the leading MC backgrounds, $W + \text{jets}$ and $Z + \text{jets}$, are found to be 1.2 ± 0.5 and 1.1 ± 0.4 (1.1 ± 0.5 and 1.0 ± 0.3) for $W + \text{jets}$

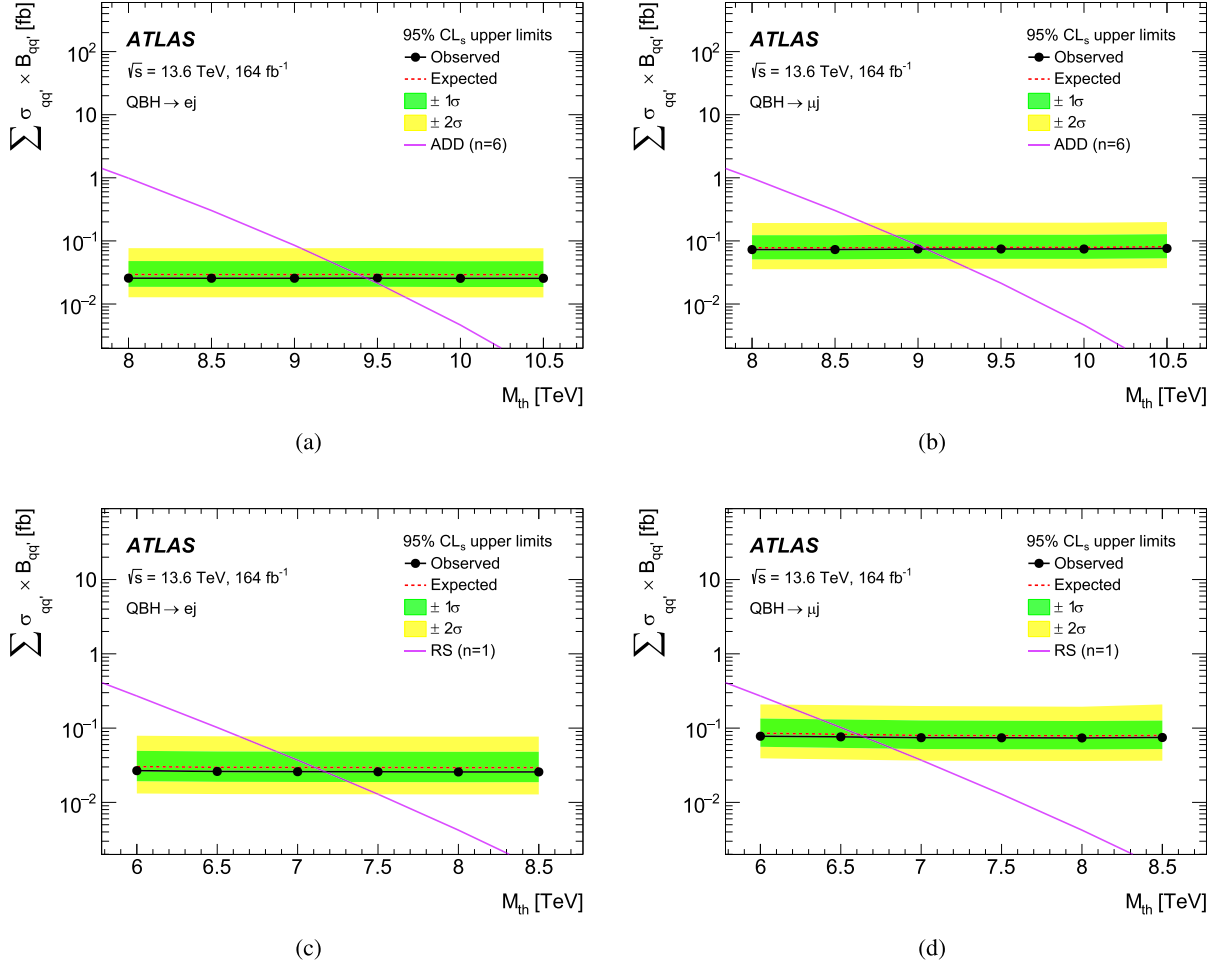


Fig. 4. Exclusion limits at 95% confidence level (CL) on the sum of the production cross-section times branching ratio of quantum black holes in the ADD model with $n = 6$ extra dimensions for the (a) electron and (b) muon channels, and in the RS model with $n = 1$ extra dimension for the (c) electron and (d) muon channels. The $\pm 1\sigma$ and $\pm 2\sigma$ uncertainty bands around the expected limit are shown. The central theoretical values are overlaid. The summation subscript qq' corresponds to the three relevant production channels of the quantum black hole. The branching fraction used is per lepton flavour.

and Z + jets in the electron (muon) channel, respectively. A moderate 20% (25%) non-closure is observed in the ZVR in the electron (muon) channel; given the small Z + jets fraction of 5% (12%) in the SR, the potential impact on the background yield in the SR is at most 1%–2% and is negligible. It is therefore not included in the fit as a separate uncertainty.

No significant excess of data is observed above the SM background. The $m_{\ell j}$ distributions in the electron channel SR and muon channel SR after the fit are shown in Fig. 3. Benchmark signal MC predictions corresponding to the RS and ADD models are overlaid for reference. The signals considered in this search are generally expected to populate the $m_{\ell j}$ region above 6 TeV, while the background shape falls steeply between 3 and 6 TeV in both channels. In the electron channel, the highest-mass event observed in data corresponds to $m_{\ell j} = 5.3$ TeV. This event features an electron with $(p_T, \eta) = (1.2 \text{ TeV}, 1.55)$, a jet with $(p_T, \eta) = (1.2 \text{ TeV}, -1.29)$, and a low $S(p_T^{\text{miss}})$ of 2.80. The objects are nearly back-to-back in the transverse plane with $\Delta\phi(\ell, j) = 3.05$, with a large pseudorapidity separation $\Delta\eta(\ell, j) = 2.84$. In the muon channel, the event with the highest invariant mass corresponds to $m_{\ell j} = 5.5$ TeV. This event features a muon with $(p_T, \eta) = (5.2 \text{ TeV}, 1.33)$, a jet with $(p_T, \eta) = (1.2 \text{ TeV}, 0.39)$, and a low $S(p_T^{\text{miss}})$ of 1.43. The objects are nearly back-to-back in the transverse plane with $\Delta\phi(\ell, j) = 3.11$, with a relatively small pseudorapidity separation of $\Delta\eta(\ell, j) = 0.94$ indicating a centrally produced system.

Upper limits on the QBH production cross-section times branching ratio are set at 95% CL using the CL_s method in the asymptotic approximation, as shown in Fig. 4. The limits set using the asymptotic approximation are validated against those obtained with pseudo-experiments, showing per-mille-level agreement on the cross-section limit for a variety of tested mass hypotheses.

The RS model is excluded at 95% CL for signals with $M_{th} < 7.2$ TeV. Depending on the number of EDs, ADD models with M_{th} below 8.6–9.4 TeV are excluded at 95% CL. The observed and expected M_{th} exclusion limits at 95% CL for the signal models considered are detailed in Table 2. The electron channel surpasses the muon channel in sensitivity by a factor of ~ 3 , due to better momentum resolution for electrons and its impact on the acceptance times efficiency, as well as the lower background in the SR. Hence, the two channels are not combined.

7. Conclusion

This ATLAS analysis is performed using 164 fb⁻¹ of data collected from $\sqrt{s} = 13.6$ TeV pp collisions at the LHC. The search for QBH-like signals yields no evidence of an excess in the lepton + jet invariant mass distribution in electron + jet or muon + jet final states. Exclusion limits are placed on the production cross-section times branching ratio in a few ADD and RS QBH scenarios. The experimental sensitivity is driven by the statistical uncertainty. The highest exclusion limits are for ADD

QBH scenarios with six extra dimensions, observed at 9.4 TeV (9.0 TeV) in the electron (muon) channel. Owing to the much better momentum resolution and larger acceptance times efficiency in the electron channel, the sensitivity is significantly higher. This analysis extends the mass-exclusion reach of the previous ATLAS search performed at $\sqrt{s} = 13$ TeV using the full 140 fb^{-1} Run 2 dataset [15] by 0.8 (0.4) TeV in the electron (muon) channel for QBHs in the ADD model with $n = 6$ extra dimensions. These limits represent the world-best sensitivity for the signals considered.

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. [64].

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, NSFC and FRFCU, China; Minciencias, Colombia; MEYS CR, Czech Republic; DNRF and DNSRC, Denmark; IN2P3-CNRS and CEA-DRF/IRFU, France; SRNSFG, Georgia; BMFT, HGF and MPG, Germany; GSRI, Greece; RGC and Hong Kong SAR, China; ICHEP and Academy of Sciences and Humanities, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MNiSW, Poland; FCT, Portugal; MNE/IFA, Romania; MSTDI, Serbia; MSSR, Slovakia; ARIS and MVZI, Slovenia; DSI/NRF, South Africa; MICIU/AEI, 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, FORTE and PRIMUS, Czech Republic; COST, ERC, ERDF, Horizon 2020 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 cofinanced by EU-ESF and the Greek NSRF, Greece; BSF-NSF and MINERVA, Israel; NCN and NAWA, Poland; La Caixa Banking Foundation, CERCA and AGAUR programs from Generalitat de Catalunya and PROMETEO and GenT Programmes Generalitat Valenciana, Spain; Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom; Eric and Wendy Schmidt Fund for Strategic Innovation, United States of America.

In addition, individual members wish to acknowledge support from Chile: Agencia Nacional de Investigación y Desarrollo (ANID FONDECYT reg. 1230987, FONDECYT 1230812, FONDECYT 1240864, Fondecyt 3240661, Fondecyt Regular 1240721); China: Fundamental Research Funds for the Central Universities (010-63263105), Chinese Ministry of Science and Technology (MOST-2023YFA1605700, MOST-2023YFA1609300), National Natural Science Foundation of China (NSFC 12275265, NSFC-W2543005); Czech Republic: Czech Science Foundation (GACR - 24-11373S), Ministry of Education Youth and Sports (ERC-CZ-LL2327, FORTE CZ.02.01.01/00/22_008/0004632),

PRIMUS Research Programme (PRIMUS/21/SCI/017); EU: H2020 European Research Council (ERC - 101002463); European Union: European Research Council (BARD No. 101116429, ERC - 101219398, ERC - 948254, ERC 101089007), European Regional Development Fund (HE COFUND GA No.101081355, ERDF), Marie Skłodowska-Curie Actions (GAP-101168829); France: Agence Nationale de la Recherche (ANR-21-CE31-0013, ANR-22-EDIR-0002, ANR-24-CE31-0504-01); Germany: Deutsche Forschungsgemeinschaft (DFG - 469666862); China: Research Grants Council (GRF); Italy: Istituto Nazionale di Fisica Nucleare (LHC-MIUR - 28003/2025), Ministero dell'Università e della Ricerca (NextGenEU 153D23001490006 M4C2.1.1, NextGenEU I53D23000820006 M4C2.1.1, NextGenEU I53D23001490006 M4C2.1.1, SOE2024_0000023); Japan: Japan Society for the Promotion of Science (JSPS KAKENHI JP25H0063, JSPS KAKENHI JP22H01227, JSPS KAKENHI JP22H04944, JSPS KAKENHI JP22KK0227, JSPS KAKENHI JP24K23939, JSPS KAKENHI JP24KK0251, JSPS KAKENHI JP25H00650, JSPS KAKENHI JP25H01291, JSPS KAKENHI JP25K01011, JSPS KAKENHI JP25K01023); Poland: Polish National Science Centre (NCN 2021/42/E/ST2/00350, NCN OPUS 2023/51/B/ST2/02507, NCN OPUS nr 2022/47/B/ST2/03059, NCN UMO-2019/34/E/ST2/00393, UMO-2022/47/O/ST2/00148, UMO-2023/49/B/ST2/04085, UMO-2023/51/B/ST2/00920, UMO-2024/53/N/ST2/00869); Spain: Agència de Gestió d'Ajuts Universitaris i de Recerca (AGAUR - 2023 BP 00141), Ministry of Science and Innovation (RYC2019-028510-I, RYC2020-030254-I, RYC2021-031273-I, RYC2022-038164-I), Ministerio de Ciencia, Innovación y Universidades/Agencia Estatal de Investigación (EU NextGenerationEU (PRTR-C17.I1), PID2022-142604OB-C22); Sweden: Carl Trygger Foundation (Carl Trygger Foundation CTS 22:2312), Swedish Research Council (Swedish Research Council 2023-04654, VR 2021-03651, VR 2022-03845, VR 2022-04683, VR 2023-03403, VR 2024-05451, VR 2025-05940), Knut and Alice Wallenberg Foundation (KAW 2023.0366); Switzerland: Swiss National Science Foundation (SNSF - PCEFP2_194658); United Kingdom: The Binks Trust, Royal Society (NIF-R1-231091); United States of America: U.S. Department of Energy (ECA DE-AC02-76SF00515), John Templeton Foundation (John Templeton Foundation 63206), Neubauer Family Foundation.

Data availability

The public release of data supporting the findings of this article will follow the CERN Open Data Policy [65]. The values of relevant plots and tables associated with this article are stored in <https://www.hepdata.net/record/ins3147718>.

The ATLAS Collaboration

G. Aad¹⁵⁴, E. Aakvaag¹⁸, B. Abbott¹⁷⁷, S. Abdelhameed¹³², K. Abeling⁸³, N.J. Abicht⁷⁷, S.H. Abidi⁴³, M. Aboelela⁷², A. Aboulhorma⁶², H. Abramowicz²²⁵, B.S. Acharya^{XIII,101,102}, A. Ackermann⁹², C. Adam Bourdarios⁵, L. Adamczyk¹³⁶, S.V. Addepalli²¹⁵, M. J. Addison¹⁵³, J. Adelman¹⁷³, A. Adiguzel²⁶, T. Adye¹⁹⁷, A.A. Affolder¹⁹⁹, Y. Afik⁶⁶, M.N. Agaras¹⁴, A. Aggarwal¹⁵², C. Agheorghiesei³⁶, A. Ahmad¹³¹, F. Ahmadov^{XXX,65}, S. Ahuja¹⁴⁷, S. Ahuja²³⁷, X. Ai¹⁶⁹, G. Aielli^{116,117}, A. Aikot²³⁷, M. Ait Tamlihat⁶², T.P.A. Åkesson¹⁵⁰, D. Akiyama²⁴², N.N. Akolkar³¹, S. Akts²⁴⁰, G.L. Alberghi³⁰, J. Albert²³⁹, U. Alberti²², P. Albicocco⁸¹, S. Alderdeldt⁸⁰, Z.L. Alegria¹⁷⁸, M. Aleksa⁶⁴, I.N. Aleksandrov⁶⁵, C. Alexa³⁵, T. Alexopoulos¹¹, F. Alfonsi³⁰, M. Algren⁸⁴, M. Alhroob²⁴¹, B. Ali¹⁹⁵, H. M. J. Ali^{XXII,143}, S. Ali⁴⁵, S.W. Alibocus¹⁴⁴, M. Aliev⁴⁹, G. Alimonti¹⁰⁶, C. Allaire⁹⁸, B.M.M. Allbrooke²¹⁸, D.R. Allen¹⁷⁸, J.S. Allen¹⁵³, J.F. Allen⁸⁰, C.S. Alley¹, E.R. Almazan¹⁹⁹, A. Aloisio^{108,109}, F. Alonso¹⁴², C. Alpigiani²⁰⁸, A. Alvarez Fernandez¹⁵², M. Alves Cardoso⁸⁴, M.G. Alviggi^{108,109}, M. Aly¹⁵³, Y. Amaral Coutinho¹²⁶, C. Amelung⁶⁴, M. Amerl¹⁵³,

T. Amezza¹⁸⁴, B. Amini⁸², K. Amirie²²⁹, A. Amirkhanov⁶⁵, D. Amperiadou²²⁶, S. An¹³⁰, C. Anastopoulos²¹¹, T. Andeen¹², J.K. Anders¹⁴⁴, A.C. Anderson⁸⁸, A. Andreazza^{106,107}, S. Angelidakis¹⁰, A. Angerami⁶⁸, A.V. Anisenkov⁶⁵, A. Annovi¹¹², C. Antel⁶⁴, E. Antipov²¹⁷, M. Antonelli⁸¹, F. Anulli¹¹⁴, M. Aoki¹³⁰, T. Aoki²²⁷, M.A. Aparo¹⁴, L. Aperio Bella⁷⁶, M. Apicella⁴⁴, C. Appelt²²⁵, A. Apyan³³, M. Arampatzis¹¹, S.J. Arbiol Val¹³⁸, C. Arcangeletti⁸¹, A.T.H. Arce⁷⁹, M. Arcuri^{71,70}, J-F. Arguin¹⁶⁰, S. Argyropoulos²²⁶, J.-H. Arling⁷⁶, O. Arnaez⁵, H. Arnold²¹⁷, G. Artoni^{114,115}, H. Asada¹⁶³, S. Asatryan²⁴⁷, N.A. Asbah⁶⁴, R.A. Ashby Pickering²⁴¹, A.M. Aslam¹⁴⁷, J. Assahsah¹⁷⁷, K. Assamagan⁴³, R. Astalos⁴¹, K.S.V. Astrand¹⁵⁰, S. Atashi²³⁴, R.J. Atkin⁴⁷, H. Atmani⁶³, P.A. Atmasiddha¹⁸⁵, K. Augsten¹⁹⁵, A.D. Aurio⁶⁷, V.A. Austrup¹⁵³, A.S. Avad¹⁴⁶, G. Avolio⁶⁴, A. Azzam¹⁴, D. Babal⁴², H. Bachacou¹⁹⁸, K. Bachas^{XVI,226}, A. Bachi⁵⁷, E. Bachmann⁷⁸, M.J. Backes⁹², A. Badea⁶⁶, T.M. Baer¹⁵⁸, M. Bahmani²¹, D. Bahner⁸², K. Bai¹⁸⁰, L. Baines¹⁴⁶, O.K. Baker²⁴⁶, D. Bakshi Gupta⁹, L.E. Balabram Filho¹²⁶, V. Balakrishnan¹⁷⁷, R. Balasubramanian⁵, P. Balek¹³⁶, E. Ballabene^{30,29}, F. Balli¹⁹⁸, L.M. Baltes⁹², W.K. Balunas¹⁸³, I. Bamwidhi¹³³, E. Banas¹³⁸, M. Bandieramonte¹⁸⁶, A. Bandyopadhyay³¹, S. Bansal³¹, L. Barak²²⁵, M. Barakat⁷⁶, E.L. Barberio¹⁵⁷, D. Barberis²⁰, M. Barbero¹⁵⁴, M.Z. Barel¹⁷², T. Barillari¹⁶², M-S. Barisits⁶⁴, T. Barklow²¹⁵, P. Baron¹⁹⁶, D.A. Baron Moreno¹⁵³, A. Baroncelli⁹¹, A.J. Barr¹⁸³, J.D. Barr¹⁴⁸, F. Barreiro¹⁵¹, J. Barreiro Guimarães da Costa¹⁵, M.G. Barros Teixeira¹⁸⁷, F. Bartels⁹², R. Bartoldus²¹⁵, A.E. Barton¹⁴³, P. Bartos⁴¹, M. Baselga⁷⁷, S. Bashiri¹³⁸, A. Bassalat^{II,98}, M.J. Basso²³⁰, S. Bataju⁷², R. Bate²³⁸, R.L. Bates⁸⁸, S. Batlamous¹⁵¹, M. Battaglia¹⁹⁹, D. Battulga²¹, M. Bause^{114,115}, L. Bauckhage⁷⁶, P. Bauer³¹, L.T. Bayer⁷⁶, L.T. Bazzano Hurrell⁴⁴, T. Beau¹⁸⁴, J.Y. Beauchamp¹⁴², S. Beauceron¹⁸⁴, P.H. Beauchemin²³³, P. Bechtel³¹, H.P. Beck^{XV,22}, K. Becker²⁴¹, A.J. Beddall¹²⁴, V.A. Bednyakov⁶⁵, C.P. Bee²¹⁷, L.J. Beemster¹⁷, M. Begalli¹²⁸, M. Begel⁴³, J.K. Behr⁷⁶, J.F. Beirer⁶⁴, F. Beisiegel³¹, M. Belfkir¹³³, G. Bella²²⁵, L. Bellagamba³⁰, A. Bellerive⁵⁷, C.D. Bellgraph¹⁰⁰, P. Bellos²³, I. Benaoumeur²³, D. Benckekroun⁵⁸, F. Bendebba⁵⁸, Y. Benhammou²²⁵, K.C. Benkendorfer²³⁹, L. Beresford⁷⁶, M. Beretta⁸¹, E. Bergeas Kuutmann²³⁵, N. Berger⁵, B. Bergmann¹⁹⁵, J. Beringer¹⁹, M. Berkat¹⁹⁸, G. Bernardi⁶, C. Bernius²¹⁵, F.U. Bernlochner³¹, A. Berrocal Guardia¹⁴, T. Berry¹⁴⁷, P. Berta¹⁹⁶, A. Berti¹⁸⁷, R. Bertrand¹⁵⁴, S. Bethke¹⁶², A. Betti^{114,115}, T.F. Beumker²⁴⁵, A.J. Bevan¹⁴⁶, L. Bezio⁸⁴, N.K. Bhalla⁸², S. Bharthuar¹⁶², S. Bhatta²¹⁷, P. Bhattarai²¹⁵, Z.M. Bhatti¹⁷⁴, K.D. Bhide⁸², V.S. Bhopatkar¹⁷⁸, R.M. Bianchi¹⁸⁶, G. Bianco^{30,29}, O. Biebel¹⁶¹, M. Biglietti¹¹⁸, P. Bijl⁸², C.S. Billingsley⁷², Y. Bimgdi⁶³, M. Bindi⁸³, A. Bingham²⁴⁵, A. Bingul²⁵, C. Bini^{114,115}, G.A. Bird⁴⁶, M. Biros¹⁹⁶, S. Biryukov²¹⁸, T. Bisanz⁷⁷, E. Bisceglie^{30,29}, J.P. Biswal¹⁹⁷, D. Biswas²¹³, M. Biyabi¹⁵, I. Bloch⁷⁶, A. Blue⁸⁸, U. Blumenschein¹⁴⁶, V.S. Bobrovnikov⁶⁵, L. Boccardo^{86,85}, M. Boehler⁸², B. Boehm²⁴⁰, D. Bogavac¹⁴, L.S. Boggia¹⁸⁴, V. Boisvert¹⁴⁷, P. Bokan²³⁵, T. Bold¹³⁶, M. Bomben⁶, M. Bona¹⁴⁶, M. Boonekamp¹⁹⁸, A.G. Borbély⁸⁸, G. Borissov¹⁴³, A. Borkar²⁴⁰, D. Bortoletto¹⁸³, M. Borysova²⁴³, D. Boscherini³⁰, M. Bosman¹⁴, K. Bouaouda⁵⁸, L. Boudet¹⁹⁸, J. Boudreau¹⁸⁶, E.V. Bouhova-Thacker¹⁴³, D. Boumediene⁶⁷, R. Bouquet^{86,85}, A. Boveia¹⁷⁶, D. Boyle⁴³, I.R. Boyko⁶⁵, L. Bozianu⁸⁴, J. Bracinik²³, N. Brahimi⁹, G. Brandt²⁴⁵, O. Brandt⁴⁶, B. Brau¹⁵⁵, R. Brenne²⁴³, L. Brenner¹⁷², R. Brenner²³⁵, S. Bressler²⁴³, M. Brettell¹⁴⁸, G. Brianti¹⁷², D. Britton⁸⁸, D. Britzger¹⁶², I. Brock³¹, R. Brock¹⁵⁹, H. Bronson¹⁸⁵, G. Brooijmans⁶⁸, A.J. Brooks¹⁰⁰, E.M. Brooks²³¹, E. Brost⁴³, L.M. Brown^{239,230}, L.E. Bruce⁹⁰, T.L. Bruckler¹⁸³, P.A. Bruckman de Renstrom¹³⁸, B. Brüers⁷⁶, A. Bruni³⁰, G. Bruni³⁰, D. Brunner^{74,75}, M. Bruschini³⁰, N. Bruscino^{114,115}, T. Buanes¹⁸, Q. Bua²⁰⁸, D. Buchin¹⁶², A.G. Buckley⁸⁸, J. Bucko¹⁹⁶, M. Buhring⁷⁸, O. Bulekov¹²⁴, B.A. Bullard²¹⁵, T.O. Buratovich¹⁴², S. Burdin¹⁴⁴, C.D. Burgard⁷⁷, A.M. Burger¹⁴¹, B. Burghgrave⁹, O.

Burlayenko⁸², J. Bursleson²³⁶, J.C. Burzynski¹⁷⁷, V. Büscher¹⁵², P.J. Bussey⁸⁸, O. But³¹, J.M. Butler³², C.M. Buttar⁸⁸, J.M. Butterworth¹⁴⁸, P. Butti⁶⁴, W. Buttinger¹⁹⁷, C.J. Buxo Vazquez¹⁵⁹, A.R. Buzykaev⁶⁵, S. Cabrera Urbán²³⁷, L. Cadamuro⁹⁸, H. Cai⁶⁴, Y. Cai^{30,166,29}, Y. Cai¹⁶⁴, M.A. Cairo¹⁸⁵, V.M.M. Cairo⁶⁴, O. Kakir³, N. Calace⁶⁴, P. Calafiura¹⁹, G. Calderini¹⁸⁴, P. Calfayan⁵⁷, L. Calic¹⁵⁰, G. Callea⁸⁸, L.P. Caloba¹²⁶, D. Calvet⁶⁷, S. Calvet⁶⁷, R. Camacho Toro¹⁸⁴, S. Camarda⁶⁴, D. Camarero Munoz³³, P. Camarri^{116,117}, C. Camincher⁶⁴, M. Campanelli¹⁴⁸, A. Camplani⁶⁹, V. Canale^{108,109}, A.C. Canbay³, E. Canonero¹⁴⁷, J. Cantero²³⁷, F. Capocasa³³, P. Cappelli³³, M. Capua^{71,70}, A. Carbone^{106,107}, R. Cardarelli¹¹⁶, J.C.J. Cardenas⁹, M.P. Cardiff³³, G. Carducci^{71,70}, T. Carli⁶⁴, G. Carlino¹⁰⁸, J.I. Carlotto¹⁴, B.T. Carlson^{XVII,186}, E.M. Carlson²³⁹, L. Carminati^{106,107}, A. Carnelli⁵, M. Carnesale⁶⁴, S. Caron¹⁷¹, E. Carquin²⁰⁶, I.B. Carr¹⁵⁷, S. Carrà^{110,111}, G. Carratta^{30,29}, C. Carrion Martinez²³⁷, A.M. Carroll¹⁸⁰, N. Cartalade⁶⁷, M.P. Casado^{108,109}, P. Casolaro^{108,109}, M. Caspar⁷⁶, F. Cassinese¹⁴², W.R. Castiglioni⁶⁶, F.L. Castillo⁵, V. Castillo Gimenez²³⁷, N.F. Castro^{187,191}, A. Catinaccio⁶⁴, J.R. Catmore¹⁸², T. Cavaliere⁵, V. Cavaliere⁴³, E. Celebi¹²⁴, S. Cella⁴³, V. Cepaitis⁸⁴, K. Cerny¹⁷⁹, A.S. Cerqueira¹²⁵, A. Cerr^{XIII,112}, L. Cerrito^{116,117}, F. Cerutti¹⁹, B. Cervato^{106,107}, A. Cervelli³⁰, G. Cesarini⁸¹, S.A. Cetin¹²⁴, V.C. Chabalala⁵⁶, P.M. Chabrilat¹⁸⁴, R. Chakkappa⁹⁸, S. Chakraborty²⁴¹, A. Chambers⁹⁰, J. Chan¹⁹, J.D. Chapman⁴⁶, E. Chapon¹⁹⁸, D.G. Charlton²³, C. Chauhan¹⁹⁴, Y. Che¹⁶⁴, S. Chekanov⁷, G.A. Chelkov^{I,65}, H. Chen⁴³, J. Chen²⁰⁹, J. Chen²¹⁴, M. Chen⁸⁹, S. Chen¹³⁹, S.J. Chen¹⁶⁴, X. Chen²⁰⁹, X. Chen^{XXXV,16}, Z. Chen⁹¹, C.L. Cheng²¹⁵, H.C. Cheng⁹⁴, S. Cheong²¹⁵, A. Cheplakov⁶⁵, E. Cherepanova¹⁷², E. Cheu⁸, K. Cheung⁹⁷, L. Chevalier¹⁹⁸, G. Chiarelli¹¹², G. Chiodini¹⁰⁴, A.S. Chisholm²³, J.L. Chisholm²³⁸, A. Chitan³⁵, M. Chitishvili²³⁷, M.V. Chizhov^{XVIII,65}, K. Choi¹², Y. Chou²⁰⁸, E.Y.S. Chow¹⁷¹, G. Christou⁸⁰, K.L. Chu²⁴³, M.C. Chu⁹⁴, Z. Chubinidze⁸¹, J. Chudoba¹⁹⁴, J.J. Chwastowski¹³⁸, D. Cieri¹⁶², K.M. Ciesla¹³⁶, V. Cindro¹⁴⁵, A. Ciochio¹⁹, F. Ciotto^{108,109}, Z.H. Citron²⁴³, M. Citterio¹⁰⁶, D.A. Ciubotaru³⁵, A. Clark⁸⁴, P.J. Clark⁸⁰, N. Clarke Hall¹⁴⁸, C. Clarry²²⁹, S.E. Clawson⁷⁶, C. Clement^{74,75}, L. Clissa^{30,29}, Y. Coadou¹⁵⁴, M. Cobal^{101,103}, A. Coccaro⁸⁶, M. G. Cochran Branson²⁰⁸, R.F. Coelho Barrue¹⁸⁷, R. Coelho Lopes De Sa¹⁵⁵, S. Coelli¹⁰⁶, M.M. Cohen¹⁸⁵, L.S. Colangeli²²⁹, B. Cole⁶⁸, P. Collado Soto¹⁵¹, J. Collot⁸⁹, M.R. Colucci¹⁰⁴, I. Combes⁹⁸, P. Conde Muino^{187,193}, L.H.J. Condren²³⁴, M.P. Connell⁴⁹, S.H. Connell⁴⁹, E.I. Conroy¹⁸³, M. Contreras Cossio¹², F. Conventi^{XXXVII,108}, A.M. Cooper-Sarkar¹⁸³, L. Corazzina^{114,115}, F.A. Corchia^{30,29}, A. Cordeiro Oudot Choi²⁰⁸, L.D. Corpe⁶⁷, M. Corradi^{114,115}, F. Corriveau^{XXVIII,156}, A. Cortes-Gonzalez²²⁷, M.J. Costa²³⁷, F. Costanza⁵, D. Costanzo²¹¹, J. Couthures⁵, G. Cowan¹⁴⁷, K. Cranmer²⁴⁴, L. Cremer⁷⁷, D. Cremonini^{30,29}, S. Crépe-Renaudin⁸⁹, F. Crescioli¹⁸⁴, T. Cresta^{110,111}, M. Cristinziani²¹³, M. Cristoforetti^{120,121}, T.M. Critchley⁸⁴, E. Critelli¹⁴⁸, A. Cueto¹⁵¹, H. Cui¹⁴⁸, Z. Cui⁸, B.M. Cunnett²¹⁸, W.R. Cunningham⁸⁸, E. Cuppini¹⁶², F. Curcio²³⁷, J.R. Curran⁸⁰, M.J. Da Cunha Sargedass De Sousa^{86,85}, J.V. Da Fonseca Pinto¹²⁶, C. Da Via¹⁵³, W. Dabrowski¹³⁶, T. Dado⁶⁴, S. Dahbi²²⁰, T. Dai¹⁵⁸, D. Dal Santo²², C. Dallapiccola¹⁵⁵, M. Dam⁶⁹, G. D'amen⁴³, V. D'Amico¹⁶¹, J.R. Dandoy⁵⁷, M. D'Andrea^{86,85}, D. Dannheim⁶⁴, G. D'Annibale^{112,113}, M. Danninger²¹⁴, V. Dao²¹⁷, G. Darbo⁸⁶, F. Dattola⁷⁶, S. D'Auria^{106,107}, A. D'Avanzo^{108,109}, T. Davidek¹⁹⁶, J. Davidson²⁴¹, I. Dawson¹⁴⁶, K. De⁹, C. De Almeida Rossi²²⁹, N. De Biase⁷⁶, S. De Castro^{30,29}, N. De Groot¹⁷¹, P. de Jong¹⁷², H. De la Torre¹⁷³, A. De Maria¹⁶⁴, S. De Miranda Rimes¹²⁸, A. De Salvo¹¹⁴, U. De Sanctis^{116,117}, F. De Santis^{104,105}, A. De Santo²¹⁸, J.B. De Vivie De Regie⁸⁹, K.G. De Vries¹⁷², J. Debevc¹⁴⁵, D.V. Dedovich⁶, J. Degens¹⁴⁴, A.M. Deiana⁷², J. Del Peso¹⁵¹, L. Delagrangé³³, F. Deliot¹⁹⁸, C.M. Delitzsch⁷⁷, M. Della Pietra^{108,109}, D. Della Volpe⁸⁴, A. Dell'Acqua⁶⁴, L. Dell'Asta^{106,107},

M. Delmastro⁵, C.C. Delogu^{86,85}, P.A. Delsart⁸⁹, S. Demers²⁴⁶, M. Demichev⁶⁵, H. Denizli^{XII,24}, M.G. Depala¹⁴⁴, L. D'Eramo⁶⁷, D. Derendarz¹³⁸, L. Derin^{86,85}, F. Derue¹⁸⁴, P. Dervan^{XIV,144}, A.M. Desai¹, K. Desch³¹, F.A. Di Bello^{112,113}, A. Di Ciaccio^{116,117}, L. Di Ciaccio⁵, D. Di Croce⁶⁴, C. Di Donato^{108,109}, A. Di Girolamo⁶⁴, G. Di Gregorio⁹⁸, A. Di Luca^{120,121}, B. Di Micco^{118,119}, R. Di Nardo^{118,119}, K.F. Di Petrillo⁶⁶, M. Diamantopoulou⁵⁷, F.A. Dias¹⁷², M.A. Diaz^{200,201}, A.R. Didenko⁶⁵, M. Didenko²³⁷, S.D. Diefenbacher¹⁹, E.B. Diehl¹⁵⁸, S. Díez Cornell⁷⁶, C. Diez Pardos²¹³, C. Dimitriadis²¹⁶, A. Dimitrievska²³, A. Dimri²¹⁷, Y. Ding⁹¹, J. Dingfelder³¹, T. Dingley¹⁸³, I.M. Dinu³⁵, S.J. Dittmeier⁹³, F. Dittus⁶⁴, M. Divisek¹⁹⁶, B. Dixit¹⁴⁴, F. Djama¹⁵⁴, T. Djobava²²², C. Doglioni^{153,150}, A. Dohnalova⁴¹, Z. Dolezal¹⁹⁶, K. Domijan¹³⁶, K.M. Dona⁶⁶, M. Donadelli¹²⁸, B. Dong¹⁵⁹, J. Donini⁶⁷, A. D'Onofrio^{108,109}, M. D'Onofrio¹⁴⁴, J. Dopke¹⁹⁷, A. Doria¹⁰⁸, N. Dos Santos Fernandes¹⁸⁷, I.A. Dos Santos Luz¹²⁹, P. Dougan⁷², M.T. Dova¹⁴², A.T. Doyle⁸⁸, M.P. Drescher⁸³, E. Dreyer²⁴³, I. Drivas-koulouris¹¹, M. Drnevich¹⁷⁴, D. Du⁹¹, T. Du⁶⁶, T.A. du Pree¹⁷², Z. Duan¹⁶⁴, M. Dubau⁵, F. Dubinin⁶⁵, M. Dubovsky⁴¹, E. Duchovni²⁴³, G. Duckeck¹⁶¹, P.K. Duckett¹⁴⁸, O.A. Ducu³⁵, D. Duda⁸⁰, A. Dudarev⁶⁴, M.M. Dudek¹³⁸, E.R. Duden³³, M. D'uffizi¹⁵³, L. Duflo⁹⁸, M. Dührssen⁶⁴, I. Duminica⁴⁰, A.E. Dumitriu³⁵, M. Dunford⁹², T. Duong⁵, A. Duperrin¹⁵⁴, A.F. Duque Bran⁶⁷, H. Duran Yildiz³, A. Durglishvili²²², G.I. Dyckes¹⁹, M. Dyndal¹³⁶, B.S. Dziedzic⁶⁴, G.H. Eberwein¹⁸³, B. Eckerova⁴¹, J.C. Egan¹⁴⁸, S. Eggbrecht⁸³, E. Egidio Purcino De Souza¹²⁹, G. Eigen¹⁸, K. Einsweiler¹⁹, T. Ekelof²³⁵, P.A. Ekman¹⁵⁰, S. El Farkh⁵⁹, Y. El Ghazali⁹¹, H. El Jarrari¹⁵⁶, A. El Moussaouy⁵⁸, I. Elbaz²²⁵, D. Elitez⁶⁴, M. Ellert²³⁵, F. Ellinghaus²⁴⁵, T.A. Elliot¹⁴⁷, J. Elmsheuser⁴³, M. Elsayy¹³², M. Elsing⁶⁴, D. Emeliyanov¹⁹⁷, Y. Enari¹³⁰, S. Epari¹⁶⁰, D. Ernani Martins Neto¹³⁸, F. Ernst⁶⁴, M. Escalier⁹⁸, C. Escobar²³⁷, R. Estevam De Paula¹²⁷, E. Etzion²²⁵, G. Evans^{187,188}, H. Evans¹⁰⁰, L.S. Evans⁷⁶, S. Ezzarqtouni⁵⁸, F. Fabbri^{30,29}, L. Fabbri^{30,29}, G. Facini¹⁴⁸, V. Fadeyev¹⁹⁹, D. Fakoudis¹⁵², S. Falciano¹¹⁴, L.F. Falda Ulhoa Coelho³³, F. Fallavollita¹⁶², G. Falsetti^{71,70}, J. Faltova¹⁹⁶, C. Fan²³⁶, K.Y. Fan⁹⁵, Y. Fan¹⁵, Y. Fang^{15,166}, M. Fanti^{106,107}, M. Faraj^{101,103}, Z. Farazpay¹⁴⁹, A. Farbin⁹, A. Farilla¹¹⁸, K. Farman²²⁰, J.N. Farr²⁴⁶, M.S. Farrington⁹⁰, S.M. Farrington^{197,80}, F. Fassi⁶², D. Fassouliotis¹⁰, L. Fayard⁹⁸, G. Fazzino⁹³, P. Federic¹⁹⁶, P. Federicova¹⁹⁴, M. Feickert²⁴⁴, L. Feligioni¹⁵⁴, D.E. Fellers¹⁹, C. Feng¹⁶⁸, Y. Feng¹⁵, Z. Feng⁹⁸, B. Fernandez Barbadillo¹⁴³, P. Fernandez Martinez⁹⁹, C. Fernandez Ruiz⁴⁶, J. Ferrando¹⁴³, A. Ferrari²³⁵, P. Ferrari^{172,171}, R. Ferrari¹¹⁰, D. Ferrere⁸⁴, C. Ferretti¹⁵⁸, M.P. Fewell¹, D. Fiacco^{114,115}, F. Fiedler¹⁵², P. Fiedler¹⁹⁵, S. Filimonov⁶⁵, M.S. Filip^{XIX,35}, A. Filipčić¹⁴⁵, E.K. Filmer²³⁰, F. Filthaut¹⁷¹, M.C.N. Fiolhais^{III,187,189}, L. Fiorini²³⁷, W.C. Fisher¹⁵⁹, T. Fitschen¹⁵³, I. Fleck²¹³, P. Fleischmann¹⁵⁸, T. Flick²⁴⁵, M. Flores^{XXXIII,50}, L.R. Flores Castillo⁹⁴, M. Foll¹⁸², F.M. Follega^{120,121}, N. Fomin⁴⁶, J.H. Foo²²⁹, A. Formica¹⁹⁸, M. Fornasiero²¹⁸, A.C. Forti¹⁵³, N. Forti^{30,29}, E. Fortin¹⁵⁴, A.W. Fortman¹⁹, L. Foster¹⁹, L. Fountas¹⁰, H. Fox¹⁴³, P. Francavilla^{112,113}, S. Francescato⁹⁰, S. Franchellucci²², M. Franchini^{30,29}, S. Franchino⁹², D. Francis⁶⁴, L. Franco⁷⁶, L. Franconi⁷⁶, M. Franklin⁹⁰, G. Frattari⁶⁴, Y.Y. Fri²²⁵, N. Fritzsche⁶⁴, A. Froch⁸⁴, D. Froidevaux⁶⁴, J.A. Frost¹⁹⁷, Y. Fu¹⁵⁹, S. Fuenzalida Garrido²⁰⁶, Y.C. Fujikake¹⁹⁹, M. Fujimoto²¹⁷, K.Y. Fung⁹⁴, E. Furtado De Simas Filho¹²⁹, M. Furukawa²²⁷, M. Fuste Costa⁷⁶, P. Fuste Martin¹⁴, J. Fuster²³⁷, A. Gaa⁸³, A. Gabrielli^{30,29}, A. Gabrielli²²⁹, G. Gagliardi^{86,85}, L.G. Gagnon¹⁹, S. Galantzan²²⁵, J. Gallagher¹, E.J. Gallas¹⁸³, A.L. Gallen²³⁵, B.J. Gallop¹⁹⁷, K.K. Gan¹⁷⁶, Y. Gao⁸⁰, Z. Gao¹⁶⁴, A. Garabaglu²⁰⁸, F.M. Garay Walls^{200,201}, C. García²³⁷, A. Garcia Alonso¹⁷², A.G. Garcia Caffaro²⁴⁶, J.E. Garcia Navarro²³⁷, M.A. Garcia Ruiz²⁸, M. Garcia-Sciveres¹⁹, G.L. Gardner¹⁸⁵, R.W. Gardner⁶⁶, N. Garelli²³³, R.B. Garg²¹⁵, J.M. Gargan⁴⁶, C.A. Garner²²⁹, C.M. Garvey⁴⁷, V.K. Gassmann²³³, G. Gaudio¹¹⁰, A.J. Gavin¹⁴⁶, J. Gavrancovic¹⁴⁵, I.L. Gavrilenco¹⁸⁷, C. Gay²³⁸, G. Gaycken¹⁸⁰, A. Gekow¹⁷⁶, C. Gemme⁸⁶, M.H. Genest⁸⁹, A.D. Gentry¹⁷⁰, S. George¹⁴⁷, T. Gerasis⁷³, A.A. Gerwin¹⁷⁷, P. Gessinger-Befurt⁶⁴, M. Ghani²⁴¹, K. Ghorbanian¹⁴⁶, A. Ghosal²¹³, A. Ghosh²³⁴, A. Ghosh⁸, B. Giacobbe³⁰, S. Giagu^{114,115}, A. Giannini⁹¹, S.M. Gibson¹⁴⁷, D.T. Gil¹³⁷, B.J. Gilbert⁶⁸, D. Gillberg⁵⁷, G. Gilles¹⁷², D.M. Gingrich^{XXXVI,2}, M.P. Giordani^{101,103}, P.F. Giraud¹⁹⁸, G. Giugliarelli^{101,103}, D. Giugni¹⁰⁶, F. Giuli^{XXXVIII,116,117}, I. Gkialas^{IX,10}, B.C. Gladwyn¹⁸³, C. Glasman¹⁵¹, M. Glazewska²², R.M. Gleason²³⁴, G. Glemža⁷⁶, I. Gnesi^{XXXIX,30,29}, Y. Go⁴³, M. Goblirsch-Kolb⁶⁴, B. Gocke⁷⁷, D. Godin¹⁶⁰, B. Gokturk²⁴, S. Goldfarb¹⁵⁷, T. Golling⁸⁴, M.G.D. Gololo⁴⁹, A. Golub²⁰⁸, J.P. Gombas¹⁵⁹, A. Gomes^{187,188}, G. Gomes Da Silva²¹³, A.J. Gomez Delegido⁶⁴, R. Gonçalves¹⁸⁷, A. Gongadze²²³, F. Gonnella²³, J.L. Gonski²¹⁵, R.Y. González Andana⁸⁰, S. González de la Hoz²³⁷, M.V. Gonzalez Rodrigues⁷⁶, R. Gonzalez Suarez²³⁵, S. Gonzalez-Sevilla⁸⁴, L. Goossens⁶⁴, B. Gorini⁶⁴, E. Gorini^{104,105}, A. Gorišek¹⁴⁵, T.C. Gosari¹⁸⁵, A.T. Goshaw⁷⁹, M.I. Gostkin⁶⁵, S. Goswami¹⁷⁸, C.A. Gottardo⁶⁴, S.A. Gotz¹⁶¹, M. Goughri⁵⁹, A.G. Goussiou²⁰⁸, N. Govender⁴⁹, R.P. Grabarczyk¹⁸³, I. Grabowska-Bold¹³⁶, K. Graham⁵⁷, E. Gramstad¹⁸², S. Grancagnolo^{104,105}, C.M. Grant¹, P.M. Gravila³⁹, F.G. Gravili^{104,105}, H.M. Gray¹⁹, M. Greco¹⁶², M.J. Green¹, C. Greife³¹, A.S. Grefsrud¹⁸, I.M. Gregor⁷⁶, K.T. Greif²³⁴, P. Grenier²¹⁵, S.G. Grewe¹⁶², K. Grimm⁴⁵, S. Grinstein^{XXIV,14}, E. Gross²⁴³, J. Grosse-Knetter⁸³, L.H. Grossman²⁰, L. Guan¹⁵⁸, G. Guerrieri⁶⁴, R. Guevara¹⁸², R. Gugel¹⁵², J.A.M. Guhit¹⁵⁸, A. Guida²¹, E. Guillon²⁴¹, S. Guindon⁶⁴, F. Guo^{15,166}, J. Guo²⁰⁹, L. Guo⁷⁶, L. Guo^{XXI,165}, Y. Guo¹⁵⁸, Y. Guo⁶⁸, A. Gupta⁷⁷, R. Gupta¹⁸⁶, S. Gupta³³, S. Gurbuz³¹, S.S. Gurdasani⁷⁶, G. Gustavino^{114,115}, P. Gutierrez¹⁷⁷, L.F. Gutierrez Zagazeta¹⁸⁵, M. Gutsche⁷⁸, C. Gutsche¹⁴⁸, W. Guérin¹⁴¹, C. Gwenlan¹⁸³, C.B. Gwilliam¹⁴⁴, E.S. Haaland¹⁸², A. Haas¹⁷⁴, M. Habadank⁸⁸, C. Haber¹⁹, R.J. Haberle²⁴³, H.K. Hadavand⁹, A. Haddad⁶⁷, A. Hader⁷⁸, A.I. Hagan¹⁴³, J.J. Hahn²¹³, M. Haleem²⁴⁰, J. Haley¹⁷⁸, G.D. Hallowell¹⁵⁴, J.A. Hallford⁷⁶, K. Hamano²³⁹, H. Hamdaoui²³⁵, M. Hamer³¹, S.E.D. Hammoud⁹⁸, E.J. Hampshire¹⁴⁷, L. Han¹⁶⁴, L. Han⁹¹, S. Han¹⁵, K. Hanagaki¹³⁰, M. Hance¹⁹⁹, D.A. Hangal⁶⁸, H. Hani²¹⁴, M.D. Hank¹⁸⁵, J.B. Hansen⁶⁹, P.H. Hansen⁶⁹, T. Harenberg²⁴⁵, S. Harkusha²⁴⁷, M.L. Harris¹⁵⁵, Y.T. Harris³¹, J. Harrison¹⁴, P.F. Harrison²⁴¹, M.L.E. Hart¹⁴⁸, N.M. Hartman¹⁶², N.M. Hartmann¹⁶¹, R.Z. Hasan^{147,197}, Y. Hasegawa²¹², D. Hashimoto¹⁶³, F. Haslbeck⁶⁴, S. Hassan¹⁸², R. Hauser¹⁵⁹, M. Haviernik¹⁹⁶, C.M. Hawkes²³, R.J. Hawkins⁶⁴, Y. Hayashi²²⁷, D. Hayden¹⁵⁹, R.L. Hayes¹⁷², C.P. Hays¹⁸³, J.M. Hays¹⁴⁶, H.S. Hayward¹⁴⁴, M. He^{15,166}, Y. He⁷⁶, Y. He¹⁴⁸, N.B. Heatley¹⁴⁶, V. Hedberg¹⁵⁰, J. Heilman⁵⁷, S. Heim⁷⁶, T. Heim¹⁹, J.J. Heinrich¹⁸⁰, L. Heinrich¹⁶², J. Hejbal¹⁹⁴, M. Helbig⁷⁸, A. Held²⁴⁴, S. Hellesund¹⁸, C.M. Helling²³⁸, F.N.E. Henry⁸⁸, H. Herde¹⁵⁰, Y. Hernández Jiménez²¹⁷, G. Herten⁸², R. Hertenberger¹⁶¹, L. Hervas⁶⁴, M.E. Hespings¹⁵², N.P. Hessey²³⁰, J. Hessler¹⁶², R. Hicks¹⁸⁵, M. Hidaoui⁵⁹, N. Hidir¹⁹⁶, E. Hill²²⁹, T.S. Hillersoy¹⁸, S.J. Hillier²³, J.R. Hinds¹⁵⁹, F. Hinterkeuser³¹, M. Hirose¹⁸¹, S. Hirose²³², D. Hirschbuehl²⁴⁵, B. Hiti¹⁴⁵, J. Hobbs²¹⁷, R. Hobincu³⁸, N. Hod²⁴³, A.M. Hodges²³⁶, M.C. Hodgkinson²¹¹, B.H. Hodgkinson¹⁸³, A. Hoecker⁶⁴, D.D. Hofer¹⁵⁸, J. Hofer²³⁷, J. Hofner¹⁵², M. Holzbock⁶⁴, L.B.A.H. Hommels⁴⁶, V. Homsak¹⁸³, J.J. Hong¹⁰⁰, T.M. Hong¹⁸⁶, B.H. Hooberman²³⁶, W.H. Hopkins⁷, M.C. Hoppesch²³⁶, Y. Horii¹⁶³, M.E. Horstmann¹⁶², M.M. Horzela⁸³, S. Hou²²⁰, M.R. Housenga²³⁶, J. Howarth⁸⁸, J. Hoya⁷, M. Hrabovsky¹⁷⁹, T. Hryn'ova⁵, P.J. Hsu⁹⁷, S.-C. Hsu²⁰⁸, T. Hsu⁹⁸, M. Hu¹⁹, P. Hu⁹⁵, Q. Hu⁹¹, S. Huang⁴⁶, X. Huang^{15,166}, Y. Huang¹⁹⁶, Y. Huang¹⁶⁵, Y. Huang¹⁵, Z. Huang⁹⁸, Z. Hubacek¹⁹⁵, F. Huegging³¹, T.B. Huffman¹⁸³, M. Hufnagel Maranha De Faria¹²⁵, C.A. Hugli⁷⁶, M. Huhtinen⁶⁴, S.K. Huiberts¹⁸, R. Hulsken¹⁵⁶, C.E.

Hultquist¹⁹, D.L. Humphreys¹⁵⁵, N. Huseynov¹³, J. Huston¹⁵⁹, B. Huth⁶⁴, J. Huth⁹⁰, L. Huth⁷⁶, R. Hyneman⁸, G. Iacobucci⁸⁴, G. Iakovidis⁴³, L. Iaconidou-Fayard⁹⁸, J.P. Iddon⁶⁴, P. Iengo^{108,109}, Y. Iiyama²²⁷, T. Iizawa²²⁷, Y. Ikegami¹³⁰, D. Iliadis²²⁶, N. Ilic²²⁹, H. Imam⁵⁸, G. Inacio Goncalves¹²⁸, S.A. Infante Cabanas²⁰², T. Ingebrechtsen Carlson^{74,75}, J.M. Inglis¹⁴⁶, G. Introzzi^{110,111}, M. Iodice¹¹⁸, V. Ippolito^{114,115}, R.K. Irwin¹⁴⁴, M. Ishino²²⁷, W. Islam²⁴⁴, C. Issever²¹, S. Istin^{XLIV,24}, K. Itabashi¹⁸¹, H. Ito²⁴², R. Iuppa^{120,121}, A. Ivina²⁴³, F. Ivone⁶⁴, S. Izumiyama¹⁶³, V. Izzo¹⁰⁸, P. Jacka¹⁹⁵, P. Jackson¹, P.R. Jacobson⁷⁹, P. Jain⁷⁶, K. Jakobs⁸², J. Jamieson⁸⁸, W. Jang²²⁷, S. Jankovych¹⁷², B.K. Jashal¹⁹⁷, M. Javurkova¹⁵⁵, P. Jawahar¹⁵³, L. Jeanty¹⁸⁰, J. Jejelava^{XXI,221}, P. Jenni^{VI,82}, L. Jerala¹⁴⁵, C.E. Jessiman⁵⁷, H. Jia²³⁸, J. Jia²¹⁷, X. Jia^{162,166}, C. Jiang⁸⁰, Q. Jiang⁹⁵, S. Jiggins⁷⁶, M. Jimenez Ortega²³⁷, J. Jimenez Pena¹⁴, S. Jio¹⁶⁴, A. Jinaru³⁵, O. Jinnouchi²⁰⁷, P. Johansson²¹¹, K.A. Johns⁸, J.W. Johnson¹⁹⁹, F.A. Jolly⁷⁶, D.M. Jones²¹⁸, E. Jones⁷⁶, K.S. Jones⁹, P. Jones⁴⁶, R.W.L. Jones¹⁴³, T.J. Jones¹⁴⁴, H.L. Joos⁶⁴, R. Joshi¹⁷⁶, J. Jovicevic¹⁷, X. Ju¹⁹, J.J. Junggeburth⁶⁴, T. Junkermann⁹², A. Juste Rozas^{XXIV,14}, M.K. Juzek¹³⁸, S. Kabana²⁰⁵, A. Kaczmarska¹³⁸, S.A. Kadir²¹⁵, M. Kado¹⁶², H. Kagan¹⁷⁶, M. Kagan²¹⁵, A. Kahn¹⁸⁵, C. Kahra¹⁵², T. Kaj²²⁷, E. Kajomovitz²²⁴, N. Kakati²⁴³, N. Kakoty¹⁴, S. Kandel⁹, E. Kanellaki⁷³, N. Kanellos¹¹, D. Kar^{XLV,56}, E. Karentzos³¹, K. Karki⁹, O. Karkout¹⁷², S.N. Karpov⁶⁵, Z.M. Karpova⁶⁵, V. Kartvelishvili^{143,222}, E. Kasimi²²⁶, J. Katzy⁷⁶, S. Kaur⁵⁷, R. Kavak²³⁶, K. Kawade²¹², M.P. Kawale¹⁷⁷, C. Kawamoto¹³⁹, E.F. Kay⁶⁴, S. Kazakos¹⁵⁹, K. Kazakova¹⁵⁴, J.M. Keaveney⁴⁷, R. Keeler²³⁹, G.V. Kehris⁹⁰, J.S. Keller⁵⁷, J.M. Kelly²³⁹, J.J. Kempster²¹⁸, O. Kepka¹⁹⁴, J. Kerr²³¹, B.P. Kerridge¹⁹⁷, B.P. Kerševan¹⁴⁵, L. Keszeghova⁴¹, R.A. Khan¹⁸⁶, A. Khanov¹⁷⁸, M. Kholodenko¹⁸⁷, T.J. Khoo²¹, G. Khorauli²⁴⁰, Y. Khouli⁵⁸, Y.A.R. Khwaira¹⁸⁴, D. Kim⁷, D.W. Kim²⁰, Y.K. Kim⁶⁶, N. Kimura¹⁴⁸, M.K. Kingston⁸³, F. Kirfel³¹, J. Kirk¹⁹⁷, A.E. Kiryunin¹⁶², S. Kita²³², O. Kivernyk³¹, M. Klassen²³³, C. Klein⁵⁷, L. Klein²⁴⁰, M.H. Klein⁷², S.B. Klein⁸⁴, U. Klein¹⁴⁴, A. Klimentov⁴³, P. Kluit¹⁷², S. Kluth¹⁶², E. Kneringer¹²², T.M. Knight²²⁹, A. Knue⁷⁷, M. Kobel⁷⁸, D. Kobylanski²⁴³, S.F. Koch⁶⁴, M. Kocian²¹⁵, P. Kodyš¹⁹⁶, D.M. Koeck¹⁸⁰, T. Koffas⁵⁷, K. Kojima¹³⁰, O. Kolay⁷⁸, I. Koletsou⁵, T. Komarek¹³⁸, S. Kondo²²⁷, K. Köneke⁸³, A.X.Y. Kong¹, T. Kono¹⁷⁵, N. Konstantinidis¹⁴⁸, P. Kontaxakis⁸⁴, B. Konya¹⁵⁰, R. Kopeliansky⁶⁸, S. Koperny¹³⁶, R. Koppenhofer⁸², K. Korcyl¹³⁸, K. Kordas^{IV,226}, A. Korn¹⁴⁸, S. Korn⁸³, I. Korolkov¹⁴, B. Kortman¹⁷², O. Kortner¹⁶², S. Kortner¹⁶², W.H. Kostecka¹⁷³, M. Kostov⁴¹, V.V. Kostyukhin²¹³, A. Kotskechagia⁶⁴, A. Kotwal⁷⁹, A. Koulouris⁶⁴, A. Kourkoulis-Charalampidi^{110,111}, O. Kovanda¹⁸⁰, R. Kowalewski²³⁹, W. Kozanecki¹⁸⁰, G. Kramberger¹⁴⁵, P. Kramer³¹, A. Krasznahorkay¹⁵⁵, A.C. Kraus¹⁷³, J.W. Kraus²⁴⁵, J.A. Kremer⁷⁶, N.B. Krenkel²¹³, T. Kresse²²⁹, L. Kretschmann²⁴⁵, J. Kretschmar¹⁴⁴, P. Krieger²²⁹, K. Krizka²³, K. Kroeninger⁷⁷, H. Kroha¹⁶², J. Kroll¹⁹⁴, J. Kroll¹⁸⁵, K.S. Krowpman¹⁵⁹, U. Kruchonak⁶⁵, H. Krüger³¹, N. Krumnack¹²³, J. Krupa²¹⁵, M.C. Kruse⁷⁹, O. Kuchinskaya⁶⁵, S. Kuday³, S. Kuehn⁶⁴, R. Kuesters⁸², T. Kuhl⁷⁶, V. Kukhtin⁶⁵, Y. Kulchitsky⁶⁵, S. Kuleshov^{203,201}, J. Kull¹, E.V. Kumar¹⁶¹, M. Kumar⁵⁶, N. Kumari⁷⁶, P. Kumari²³¹, A. Kupco¹⁹⁴, O. Kuprash⁸², H. Kurashige¹³⁵, L.L. Kurchaninov²³⁰, O. Kurdysh⁵, M. Kuze²⁰⁷, A.K. Kvam¹⁵⁵, J. Kvita¹⁷⁹, N.G. Kyriacou²⁰⁸, M. Laassiri⁴³, C. Lacasta²³⁷, H. Lacker²¹, D. Lacour¹⁸⁴, E. Ladygin⁶⁵, A. Lafarge⁶⁷, B. Laforge¹⁸⁴, T. Lagouri²⁴⁶, F.Z. Lahbabi⁵⁸, S. Lai⁸³, W.S. Lai¹⁴⁸, I.K. Lakomic⁸³, J.E. Lambert²³⁹, S. Lammers¹⁰⁰, W. Lamp⁸, C. Lampoudis²²⁶, G. Lamprinoudis²⁴⁰, A.N. Lancaster¹⁷³, U. Landgraf⁸², M.P.J. Landon¹⁴⁶, V.S. Lang⁸², A.J. Lankford²³⁴, F. Lanni⁶⁴, C.S. Lantz²³⁶, K. Lantzsch³¹, A. Lanza¹¹⁰, M. Lanzac Berrocal²³⁷, T. Lari¹⁰⁶, D. Larsen¹⁸, L. Larson¹², F. Lasagni Manghi³⁰, M. Lassnig⁶⁴, H.C. Lau²³⁹, S.D. Lawlor²¹¹, R. Lazaridou²³⁴, M. Lazzaroni^{106,107}, E.T.T. Le²³⁴, H.D.M. Le¹⁵⁹, E.M. Le Boulicaut²⁴⁶, D.O. Le Guennec¹⁹⁸, L.T. Le Pottier¹⁹, B. Leban^{30,29}, F. Ledroit-Guillon⁸⁹, T.F. Lee²³¹, L.L. Leeuw⁵⁴, M. Lefebvre²³⁹, C. Leggett¹⁹, L.M. Lehmann¹⁷², G. Lehmann Miotto⁶⁴, M. Leigh⁸⁴, W.A. Leight¹⁵⁵, W. Leinonen¹⁷¹, A. Leisos^{XX,226}, M.A.L. Leite¹²⁷, C.E. Leitgeb²¹, R. Leitner¹⁹⁶, K.J.C. Leney⁷², T. Lenz³¹, S. Leone¹¹², C. Leonidopoulos⁸⁰, A. Leopold²¹⁶, J. LePage-Bourbonnais⁵⁷, R. Les¹⁵⁹, C.G. Lester⁴⁶, J. Levêque⁵, L.J. Levinson²⁴³, G. Levring^{30,29}, M.P. Lewicki¹³⁸, C. Lewis²⁰⁸, D.J. Lewis⁵, L. Lewitt²¹¹, A. Li⁴³, B. Li¹⁶⁸, C. Li¹⁵⁸, C.-Q. Li¹⁶², H. Li¹⁶⁸, H. Li¹⁵³, H. Li¹⁶, H. Li⁹¹, H. Li¹⁶⁸, J. Li²⁰⁹, L. Li²⁰⁹, R. Li²⁴⁶, S. Li^{210,209}, T. Li⁶, Y. Li¹⁵, Z. Li^{15,166}, Z. Li⁹¹, S. Liang^{15,166}, Z. Liang¹⁵, M. Liberatore¹⁹⁸, B. Liberti¹¹⁶, G. B. Libotte¹²⁸, K. Lie⁹⁶, J. Lieber Marin¹²⁹, H. Lien¹⁰⁰, H. Lin¹⁵⁸, S.F. Lin²¹⁷, L. Linden¹⁶¹, R.E. Lindley⁸, J.H. Lindon⁶⁴, J. Ling⁹⁰, E. Lipeles¹⁸⁵, A. Lipniacka¹⁸, A. Lister²³⁸, J.D. Little¹⁰⁰, B. Liu¹⁶⁷, B.X. Liu¹⁶⁵, D. Liu²²⁴, D. Liu¹⁹⁹, E.H.L. Liu²³, H. Liu¹⁶⁵, J.K.K. Liu¹⁷⁴, K. Liu²¹⁰, K. Liu²¹⁰, M. Liu⁹¹, M.Y. Liu⁹¹, P. Liu¹⁶⁸, Q. Liu²¹⁵, S. Liu²¹⁷, X. Liu¹⁶⁸, Y. Liu^{165,166}, Y. Liu²³⁶, Y.L. Liu¹⁶⁸, Y.W. Liu⁹¹, Z. Liu^{X,98}, S.L. Lloyd¹⁴⁶, E.M. Lobodzinska⁷⁶, P. Loch⁸, E. Lodhi²²⁹, K. Lohwasser²¹¹, E. Loiacono¹⁷⁸, J.D. Lomas²³, I. Longarini²³⁴, R. Longo^{XXXIX,30,29}, A. Lopez Solis¹⁴, N.A. Lopez-canelas⁸, N. Lorenzo Martinez⁵, A.M. Lory¹⁶¹, M. Losada¹³², G. Löschcke Centeno⁵, X. Lou^{15,166}, P.A. Love¹⁴³, M. Lu⁹⁸, S. Lu¹⁸⁵, Y.J. Lu²²⁰, H.J. Lubatti²⁰⁸, C. Luci^{114,115}, F.L. Lucio Alves¹⁶⁴, F. Luehring¹⁰⁰, B.S. Lunday¹⁸⁵, O. Lundberg²¹⁶, J. Lunde⁶⁴, N.A. Luongo⁷, M.S. Lutz²²⁹, A.B. Lux³², D. Lynn⁴³, R. Lysak¹⁹⁴, V. Lysenko¹⁹⁵, E. Lytken¹⁵⁰, V. Lyubushkin⁶⁵, T. Lyubushkina⁶⁵, M.M. Lyukova²¹⁷, H. Ma⁴³, K. Ma⁹¹, L.L. Ma¹⁶⁸, W. Ma⁹¹, Y. Ma¹⁶⁸, J.C. MacDonald¹⁵², P.C. Machado De Abreu Farias¹²⁹, D. Macina⁶⁴, R. Madar⁶⁷, T. Madula¹⁴⁸, J. Maeda¹³⁵, T. Maeno⁴³, P.T. Mafa⁵², H. Maguire²¹¹, M. Maheshwari⁴⁶, V. Maiboroda⁹⁸, G. Maineri^{106,107}, A. Maio^{187,188,190}, K. Maj¹³⁶, O. Majersky⁷⁶, S. Majewski¹⁸⁰, A. Makita²²⁷, N. Makovec⁹⁸, V. Maksimovic¹⁷, B. Malaescu¹⁸⁴, J. Malamant¹⁸², Pa. Malecki¹³⁸, F. Malek^{XIV,89}, M. Mali¹⁴⁵, D. Malito¹⁴⁷, A. Maloizel⁶, A. Malvezzi Lopes¹²⁸, S. Malyukov⁶⁵, J. Mamuzic¹⁴⁵, G. Mancini⁸¹, M.N. Mancini³³, G. Manco^{110,111}, S.S. Mandarri²¹⁸, I. Mandić¹⁴⁵, L. Manhaes de Andrade Filho¹²⁵, I.M. Maniatis²⁴³, J. Manjarres Ramos¹⁴¹, D.C. Mankad²⁴³, A. Mann¹⁶¹, T. Manoussos⁶⁴, M.N. Mantinan⁶⁶, S. Manzoni¹⁶⁴, L. Mao²⁰⁹, X. Maepkula⁴⁹, A. Marantis²²⁶, R.R. Marcelo Gregorio¹, G. Marchiori⁶, C. Marcon¹⁰⁶, E. Maricic¹⁷, M. Marinescu⁷⁶, S. Marium⁷⁶, M. Marjanovic¹⁷⁷, A. Markhoos⁸², M. Markovitch⁹⁸, M.K. Maroun¹⁵⁵, M.C. Marr²¹⁴, T.L. Marsault¹⁹⁸, G.T. Marsden¹⁵³, Z. Marshall¹⁹, S. Marti-Garcia²³⁷, J. Martin¹⁴⁸, T.A. Martin¹⁹⁷, V.J. Martin⁸⁰, B. Martin dit Latour¹⁸, L. Martinelli^{114,115}, V.I. Martinez Outschoorn¹⁵⁵, P. Martinez Suarez⁶⁴, S. Martin-Hauch¹⁹⁷, G. Martinovicova¹⁹⁶, V.S. Martoiu³⁵, A. Martone¹⁴¹, A.C. Martyniuk¹⁴⁸, A. Marzin⁶⁴, D. Mascione^{120,121}, L. Masetti¹⁵², J. Masik¹⁵³, A.L. Maslennikov⁶⁵, S.L. Mason⁶⁸, P. Massarotti^{108,109}, P. Mastrandrea^{112,113}, A. Mastroberardino^{71,70}, R. Mastrofrancesco^{110,111}, T. Masubuchi¹⁸¹, T.T. Mathew¹⁸⁰, J. Matousek¹⁹⁶, D.M. Mattern⁷⁷, K. Mauer⁷⁶, J. Maurer³⁵, T. Maurin⁸⁸, A.J. Maury⁹⁸, B. Maček¹⁴⁵, C. Mavungu Tsava¹⁵⁴, A.E. May¹⁵³, E. Mayer⁶⁷, R. Mazini⁵⁶, S.M. Mazza¹⁹⁹, E. Mazzeo⁶⁴, J.P. Mc Gowan²³⁹, S.P. Mc Kee¹⁵⁸, C.C. McCracken²³⁸, E.F. McDonald¹⁵⁷, L.F. Mcelhinney¹⁴³, J.A. Mcfayden²¹⁸, R.P. McGovern¹⁸⁵, R.P. Mckenzie⁵⁶, D.J. McLaughlin¹⁴⁸, S.J. McMahon¹⁹⁷, C.M. Mcpartland¹⁴⁴, R.A. McPherson^{XXVIII,239}, S. Mehlhase¹⁶¹, A. Mehta¹⁴⁴, D. Melini²³⁷, B.R. Mellado Garcia^{XXXIV,15}, A.H. Melo⁸³, F. Meloni⁷⁶, A.M. Mendes Jacques Da Costa¹⁵³, L. Meng¹⁴³, S. Menke¹⁶², M. Mentink⁶⁴, E. Meoni^{71,70}, G. Mercado¹⁷³, S. Merianos²²⁶, C. Merlassino^{101,103}, C. Meroni^{106,107}, J. Metcalfe⁷, A.S. Mete⁷, E. Meuser¹⁵², C. Meyer¹⁰⁰, J.-P. Meyer¹⁹⁸, Y. Miao¹⁶⁴, R.P. Middleton¹⁹⁷, M. Mihovilovic⁹⁸, L. Mijovic⁸⁰, G. Mikenberg²⁴³,

M. M. Mikstikova¹⁹⁴, M. Mikuž¹⁴⁵, H. Mildner¹⁵², A. Milic⁶⁴, D.W. Miller⁶⁶, E.H. Miller²¹⁵, A. Milov²⁴³, D.A. Milstead^{74,75}, T. Min¹⁶⁴, I.A. Minashvili²²², A.I. Mincer¹⁷⁴, B. Mindur¹³⁶, M. Mineev⁶⁵, Y. Mino¹³⁹, L.M. Mir¹⁴, M. Miralles Lopez⁸⁸, M. Mironova¹⁹, M. Missio⁶⁷, A. Mitra²⁴¹, V.A. Mitsou²³⁷, Y. Mitsumori¹⁶³, P.S. Miyagawa¹⁴⁶, R. Mizuhiki¹³⁵, T. Mkrtchyan⁶⁴, M. Mlinarevic¹⁴⁸, T. Mlinarevic¹⁴⁸, M. Mlynarikova¹⁹⁶, L. Mlynarska¹³⁶, C. Mo²⁰⁹, H. Möbius⁷⁶, S. Mobius²², M.H. Mohamed Farook¹⁷⁰, S. Mohapatra⁶⁸, M.F. Mohd Soberi⁸⁰, S. Mohiuddin¹⁷⁸, G. Mokgatitswane⁵⁶, R. Mole²³, L. Moleri²⁴³, U. Molinatti¹⁸³, L.G. Mollier²², L. Monaco^{64,88}, B. Mondal¹⁹⁴, S. Mondal¹⁹⁶, K. Mönig⁷⁶, E. Monnier¹⁵⁴, L. Monsonis Romero²³⁷, A. Montella^{74,75}, M. Montella¹⁷⁶, F. Montereali^{118,119}, F. Monticelli¹⁴², S. Monzani^{101,103}, M.E.E. Moors³¹, A. Moranco Tarda⁶⁹, N. Morange⁹⁸, M. Moreno Llacer²³⁷, C. Moreno Martinez⁸⁴, J.M. Moreno Perez²⁸, P. Morettini⁸⁶, S. Morgenstern⁹², M. Morii⁹⁰, M. Morinaga²²⁷, F. Morodei^{114,115}, P. Moschovakos⁶⁴, B. Moser⁸², M. Mosidze²²², T. Moskalets⁷², P. Moskvitina¹⁷¹, C.J. Mosomane⁴⁸, J. Moss⁴⁵, T. Motta Quirino¹²⁸, A. Moussa⁶¹, Y. Moyal^{11,243}, H. Moyano Gomez¹⁴, E.J.W. Moyse¹⁵⁵, T.G. Mroz¹³⁸, S. Muanza¹⁵⁴, M. Mucha³¹, J. Mueller¹⁸⁶, D. Muller²¹³, G.A. Mullier²³⁵, A.J. Mullin⁴⁶, J.J. Mullin⁷⁹, A.C. Mullins⁷², A.E. Mulski⁹⁰, D.P. Mungo²²⁹, D. Munoz Perez¹⁷⁸, F.J. Munoz Sanchez¹⁵³, W.J. Murray^{241,197}, E. Musajon⁹¹, M. Muškinja¹⁴⁵, C. Mwewa⁷⁶, A.J. Myers⁹, G. Myers¹⁵⁸, M. Myska¹⁹⁵, B.P. Nachman²¹⁵, K. Nagai¹⁸³, K. Nagano¹³⁰, R. Nagasaka²²⁷, J.L. Nagle^{11,43}, E. Nagy¹⁵⁴, A.M. Nairz⁶⁴, T. Nakagawa¹³⁹, Y. Nakahama¹³⁰, K. Nakamura¹³⁰, K. Nakkalil⁶, A. Nandi⁹³, H. Nanjo¹⁸¹, E.A. Narayanan⁷², Y. Narukawa²²⁷, L. Nasella^{106,107}, S. Nasri¹³³, C. Nass³¹, G. Navarro²⁷, A. Nayaz²¹, S. Nechaeva^{30,29}, F. Nechansky¹⁹⁴, L. Nedic¹⁸³, A. Negri^{110,111}, M. Negrini³⁰, C. Nellist¹⁷², C. Nelson¹⁵⁶, K. Nelson¹⁵⁸, S. Nemecek¹⁹⁴, M. Nessi^{7,64}, M.S. Neubauer²³⁶, J. Newell¹⁴⁴, P.R. Newman²³, Y.W.Y. Ng²³⁶, B. Ngair¹³², H.D.N. Nguyen¹⁶⁰, J.D. Nichols¹⁷⁷, R. Nicolaidou¹⁹⁸, J. Nielsen¹⁹⁹, M. Niemeyer⁸³, J. Niermann⁶⁴, N. Nikiforou⁶⁴, I. Nikolic-Audit¹⁸⁴, P. Nilsson⁴³, G. Ninio²²⁵, A. Nisati¹¹⁴, D. Nishimura²²⁷, R. Nisius¹⁶², N. Nitika²⁴³, E.K. Nkadameng⁴⁸, T. Nobe²²⁷, D. Noll²¹⁵, T. Nommensen²¹⁹, M.B. Norfolk²¹¹, B.J. Norman⁵⁷, L.C. Nosler¹⁹, M. Noury⁵⁸, J. Novak¹⁴⁵, T. Novak¹⁴⁵, P. Novotny²⁴³, R. Novotny¹⁹⁵, L. Nozka¹⁷⁹, K. Ntekas⁶⁴, D. Ntounis²¹⁵, N.M.J. Nunes De Moura Junior¹²⁶, R. Ocariz¹⁸⁴, I. Ochoa¹⁸⁷, A. Odella Rodriguez¹⁴, S. Oerdek⁷⁶, J.T. Offermann⁶⁶, A. Ogrodnik¹³⁸, A. Oh¹⁵³, C.C. Ohm²¹⁶, H. Oide¹³⁰, M.L. Ojeda⁶⁴, Y. Okumura²²⁷, L.F. Oleiro Seabra¹⁸⁷, I. Oleksiyuk⁸⁴, G. Oliveira Correa¹⁴, D. Oliveira Damazio⁴³, J.L. Oliver¹, R. Omar¹⁰⁰, A.P. O'Neill²², Y. Onoda²⁰⁷, A. Onofre^{1,187,191}, P.U.E. Onyisi¹², M.J. Oreglia⁶⁶, D. Orestano^{118,119}, R. Orlandini^{118,119}, R.S. Orr²²⁹, L.M. Osojnak⁶⁸, Y. Osumi¹⁶³, G. Otero y Garzón⁴⁴, H. Otono¹⁴⁰, M. Ouchrif⁶¹, F. Ould-Saada¹⁸², T. Ovsiannikova²⁰⁸, M. Owen⁸⁸, R.E. Owen¹⁹⁷, S.A. Oyeniran¹⁷⁰, V.E. Ozcan²⁴, F. Ozturk¹³⁸, N. Ozturk⁹, S. Ozturk¹²⁴, H.A. Pacey¹⁸³, K. Pachal²³⁰, A. Pacheco Pages¹⁴, C. Padilla Aranda¹⁴, G. Padovano^{114,115}, S. Pagan Griso¹⁹, L. Pagani^{116,117}, J. Pampel³¹, D.K. Panchal¹², C.E. Pandini⁸⁹, J.G. Panduro Vazquez¹⁹⁷, H.D. Pandya¹, H. Pang¹⁹⁸, P. Pani⁷⁶, G. Panizzo^{101,103}, L. Panwar^{XXIII,184}, L. Paolozzi²³, S. Parajuli²³⁶, A. Paramonov⁷, C. Paraskevopoulos⁸¹, D. Paredes Hernandez⁹⁵, S.R. Paredes Saenz⁸⁰, A. Pareti^{110,111}, K.R. Park⁶⁸, T.H. Park¹⁶², F. Parodi^{86,85}, J.A. Parsons⁶⁸, U. Parzefall⁸², B.A. Paschen¹⁹, B. Pascual Dias⁶⁷, L. Pascual Dominguez¹⁵¹, E. Pasqualucci¹¹⁴, S. Passaggio⁸⁶, F. Pastore¹⁴⁷, P. Patel¹³⁸, U.M. Patel⁷⁹, J.R. Pater¹⁵³, T. Pauly⁶⁴, A. Paunovic¹⁷, F. Pauwels¹⁹⁶, C.I. Pazos²³³, M. Pedersen¹⁸², R. Pedro¹⁸⁷, O. Penc¹⁹⁴, C.C. Penelaud¹⁸⁴, S. Peng¹⁶, G.D. Penn²⁴⁶, B.S. Peralva¹²⁸, A.P. Pereira Peixoto²⁰⁸, L. Pereira Sanchez²¹⁵, D.V. Perepelitsa^{11,43}, G. Perera¹⁵⁵, E. Perez Codina⁶⁴, M. Perganti¹¹, H. Pernegger⁶⁴, S. Perrella^{114,115}, K. Peters⁷⁶, R.F.Y. Peters¹⁵³, B.A. Petersen⁶⁴, T.C. Petersen⁶⁹, E. Petit¹⁵⁴, V. Petousis¹⁹⁵, A.R. Petri^{106,107}, T. Petru¹⁹⁶, M. Pettee¹⁹, A. Petukhov¹²⁴, K. Petukhova⁶⁴, R. Pezoa²⁰⁶, L. Pezzotti^{30,29}, G. Pezzullo²⁴⁶, L. Pfaffenbichler⁶⁴, A.J. Pflieger¹²², T.M. Pham²⁴⁴, T. Pham¹⁵⁷, P.W. Phillips¹⁹⁷, G. Piacquadio²¹⁷, E. Pianori¹⁹, F. Piazza¹⁸⁰, R. Piegai⁴⁴, D. Pietreanu³⁵, A.D. Pilkington¹⁵³, T. Pilusa⁵⁶, M. Pinamonti^{101,103}, J.L. Pinfold², G. Pinheiro Matos⁶⁸, B.C. Pinheiro Pereira¹⁸⁷, J. Pinol Bel¹⁴, A.E. Pinto Pinoargote¹⁸⁴, L. Pintucci^{101,103}, K.M. Piper²¹⁸, A. Pirttikoski⁸⁴, D.A. Pizzi⁵⁷, L. Pizzimento⁹⁵, A. Plebani⁴⁶, M.-A. Pleier⁴³, V. Pleskot¹⁹⁶, E. Plotnikova⁶⁵, G. Poddar¹⁴⁶, R. Poettgen¹⁵⁰, L. Poggioni¹⁸⁴, S. Polacek¹⁹⁶, G. Polesello¹¹⁰, A. Poley²¹⁴, A. Polini³⁰, C.S. Pollard²⁴¹, Z.B. Pollock¹⁷⁶, E. Pompa Pacchi¹⁷⁷, N.I. Pond¹⁴⁸, D. Ponomarenko¹⁰⁰, L. Pontecorvo⁶⁴, S. Popa³⁴, G.A. Popeneciu³⁷, A. Poreba⁶⁴, D.M. Portillo Quintero²³⁰, S. Pospisil¹⁹⁵, M.A. Postill²¹¹, P. Postolache³⁶, K. Potamianos²⁴¹, P.A. Potepa¹³⁶, I.N. Potrap⁶⁵, C.J. Potter⁴⁶, H. Potti²¹⁹, J. Poveda²³⁷, M.E. Pozo Astigarraga⁶⁴, R. Pozzi⁶⁴, A. Prades Ibanez^{116,117}, S.R. Pradhan²¹¹, J. Pretel²³⁹, D. Price¹⁵³, M. Primavera¹⁰⁴, L. Primomo^{101,103}, M.A. Principe Martin¹⁵¹, R. Privara¹⁷⁹, T. Procter¹³⁷, M.L. Proffitt²⁰⁸, N. Proklova¹⁸⁵, K. Prokofiev⁹⁶, G. Proto¹⁶², J. Proudfoot⁷, M. Przybycien¹³⁶, W.W. Przygoda¹³⁷, A. Psallidas⁷³, D. Pudza⁸¹, P. Puhl⁸⁷, H.I. Purnell¹, D. Pyatizbyantseva¹⁷¹, J. Qian¹⁵⁸, R. Qian¹⁵⁹, D. Qichen¹⁸³, Y. Qin¹⁴, T. Qiu⁸⁰, A. Quadt⁸³, M. Queitsch-Maitland¹⁵³, G. Quetant⁸⁴, R.P. Quinn²³⁸, D. Rafanoharana¹⁶², J.L. Rainbolt⁶⁶, S. Rajagopalan⁴³, E. Ramakoti⁶⁵, L. Rambelli^{86,85}, I.A. Ramirez-Berend⁵⁷, K. Ran^{158,166}, S.D. Randles¹⁴⁴, D.S. Rankin¹⁸⁵, N.P. Rapheeha⁵⁶, H. Rasheed³⁵, A. Rastogi¹⁹, S. Rave¹⁵², S. Ravera^{86,85}, B. Ravina⁶⁴, I. Ravinovich²⁴³, M. Raymond⁶⁴, A.L. Read¹⁸², N.P. Readoff²¹¹, D.M. Rebuszi^{110,111}, A.S. Reed⁸⁸, K. Reeves³³, D. Reikher⁶⁴, A. Rej⁷⁷, C. Rembser⁶⁴, H. Ren⁹¹, M. Renda³⁵, F. Renner⁷⁶, A.G. Rennie⁸⁸, M. Repik⁸⁴, A.L. Rescia^{86,85}, S. Resconi¹⁰⁶, M. Ressegotti⁸⁶, S. Rettie¹⁷², W.F. Rettie⁵⁷, M.M. Revering⁴⁶, O.L. Rezanova⁶⁵, P. Reznicek¹⁹⁶, H. Riani⁶¹, N. Ribaric⁷⁹, B. Ricci^{101,103}, E. Ricci^{120,121}, R. Richter¹⁶², E. Richter-Was¹³⁷, M. Ridel¹⁸⁴, S. Ridouani⁶¹, P. Riedler⁶⁴, E.M. Riefel^{74,75}, J.O. Rieger¹⁷², M. Rimoldi⁴⁹, L. Rinaldi^{30,29}, P. Rincke^{235,83}, G. Ripellino²³⁵, I. Riu¹⁴, J.C. Rivera Vergara²³⁹, F. Rizatdinova¹⁷⁸, E. Rizvi¹⁴⁶, B.R. Roberts⁶⁶, S.S. Roberts¹⁹⁹, D. Robinson⁴⁶, A. Robson⁸⁸, A. Rocchi^{116,117}, C. Roda^{112,113}, F.A. Rodriguez¹⁷³, S. Rodriguez Bosca⁶⁴, Y. Rodriguez Garcia²⁷, A.M. Rodriguez Vera¹⁷³, S. Roe⁶⁴, J.T. Roemer⁶⁴, O. Röhne¹⁸², R.A. Rojas⁶⁴, Z. Rokavec¹⁴⁵, C.P.A. Roland¹⁸⁴, A. Romanouk¹²², E. Romano^{110,111}, M. Romano³⁰, N. Rompotis¹⁴⁴, L. Roos¹⁸⁴, S. Rosati¹¹⁴, L. Roscher⁷⁶, B.J. Rosser⁶⁶, E. Rossi¹⁸³, E. Rossi^{108,109}, L.P. Rossi⁹⁰, L. Rossini⁸², R. Rosten¹⁷⁶, M. Rotaru³⁵, R. Roth⁶⁴, D. Rousseau⁹⁸, D. Rousso⁷⁶, S. Roy-Garand⁸⁴, A. Rozanov¹⁵⁴, Z.M.A. Rozario⁸⁸, Y. Rozen²²⁴, A. Rubio Jimenez²³⁷, V.H. Ruelas Rivera²¹, T.A. Ruggeri¹, A. Ruggiero¹⁸³, A. Ruiz-Martinez²³⁷, A. Rummler⁶⁴, G.B. Rupnik Boero⁶⁴, N.A. Rusakovich⁶⁵, S. Ruscelli⁷⁷, H.L. Russell²³⁹, G. Russo¹⁹⁹, J.P. Rutherford⁸, S. Rutherford Colmenares¹⁷⁴, M. Rybar¹⁹⁶, P. Rybczynski¹³⁶, A. Ryzhov⁷², F. Safai Tehrani¹¹⁴, S. Saha¹, B. Sahoo²⁴³, B.T. Saifuddin¹⁷⁷, M. Saimpert¹⁹⁸, I. Sainz Saenz Diez⁹², G.T. Saito¹²⁷, M. Saito²²⁷, T. Saito²²⁷, A. Sala^{106,107}, O.T. Salin⁹⁸, A. Salknikov²¹⁵, J. Salt²³⁷, A. Salvador Salas²²⁵, F. Salvatore²¹⁸, A. Salzburger⁶⁴, D. Sammel⁸², E. Sampson¹⁴³, D. Sampsonidis^{IV,226}, D. Sampsonidou¹⁸⁰, M.A.A. Samy⁸⁸, J. Sánchez²³⁷, V. Sanchez Sebastian²³⁷, H. Sandaker¹⁸², C.O. Sander⁷⁶, J.A. Sandesara²⁴⁴, M. Sandhoff²⁴⁵, C. Sandoval²⁸, L. Sanfilippo⁹², D.P.C. Sankey¹⁹⁷, T. Sano¹³⁹, A. Sansar²⁶, A. Sansoni⁸¹, M. Santana Queiroz²⁰, L. Santi⁶⁴, C. Santoni⁶⁷, H. Santos^{187,188}, L. Santos Pereira Trigo⁷⁶, E. Sanzani^{30,29}, K.A. Saoucha¹³⁴, J.G. Saraiva^{187,190}, J. Sardain⁸, S. Sarkar⁷⁹, O. Sasaki¹³⁰, K. Sato²³², C. Sauer⁶⁴, E. Sauvan⁵, P. Savard^{XXVI,229}, R. Sawada²²⁷, C. Sawyer¹⁹⁷, L. Sawyer¹⁴⁹, A.M. Sayed³³, C. Sbarra³⁰, A. Sbrizzi^{30,29}, R. Scaglioni^{110,111}, T.

Scanlon¹⁴⁸, J. Schaarschmidt²⁰⁸, U. Schäfer¹⁵², A.C. Schaffer^{98,72}, D. Schaile¹⁶¹, R.D. Schamberger²¹⁷, C. Scharf²¹, M.M. Schefer²², D. Scheirich¹⁹⁶, M. Schernau²⁰⁵, C. Scheulen⁸⁴, C. Schiavi^{86,85}, M. Schioppa^{71,70}, S. Schlenker⁶⁴, T. Schlomer⁸³, J. Schmeing²⁴⁵, C.R. Schmidt⁷⁸, E. Schmidt¹⁶², M.A. Schmidt²⁴⁵, K. Schmieden³¹, C. Schmitt¹⁵², N. Schmitt¹⁵², S. Schmitt⁷⁶, N.A. Schneider¹⁶¹, L. Schoeffel¹⁹⁸, A. Schoening⁹³, P.G. Scholer⁵⁷, E. Schopf²¹³, M. Schott³¹, S. Schramm⁸⁴, T. Schroer⁸⁴, H.-C. Schultz-Coulon⁹², M. Schumacher⁸², B.A. Schumm¹⁹⁹, Ph. Schune¹⁹⁸, H.R. Schwartz⁸, A. Schwartzman²¹⁵, T.A. Schwarz¹⁵⁸, Ph. Schwemling¹⁹⁸, R. Schwienhorst¹⁵⁹, F.G. Sciaccia²², A. Sciacca⁴³, G. Scialla³³, S.A. Scoville¹⁸⁶, F. Scuri¹¹², C.D. Sebastiani⁶⁴, K. Sedlaczek¹⁷³, A. Sehrawat²⁰¹, S.C. Seidel¹⁷⁰, B.D. Seidlitz⁶⁸, C. Seitz⁷⁶, J.M. Seixas¹²⁶, G. Sekhniaidze¹⁰⁸, L. Selem¹⁸⁴, N. Semprini-Cesari^{30,29}, A. Semushin²⁴⁷, V. Senthilkumar¹⁷², L. Serin⁹⁸, M. Sessa^{108,109}, H. Severini¹⁷⁷, F. Sforza^{86,85}, A. Sfyra⁸⁴, Q. Sha¹⁵, H. Shaddix¹⁷³, A.H. Shah⁴⁶, R. Shaheen²¹⁶, J.D. Shahinian¹⁸⁵, M. Shamim⁶⁴, L.Y. Shan¹⁵, M. Shapiro¹⁹, A. Sharma⁶⁴, A.S. Sharma²³⁸, P. Sharma⁴³, K. Shaw²¹⁸, S.M. Shaw¹⁵³, D. Shemyakin²⁴³, Q. Shen¹⁵, D.J. Sheppard²¹⁴, P. Sherwood¹⁴⁸, L. Shi¹⁶⁵, X. Shi¹⁵, S. Shimizu¹³⁰, S. Shirabe¹⁴⁰, M. Shiyakova^{XXVI,65}, M.J. Shochet⁶⁶, D.R. Shope¹⁸², B. Shrestha¹⁷⁷, S. Shrestha^{XLIII,176}, I. Shreyber⁶⁵, M.J. Shroff¹⁵⁶, P. Sicho¹⁹⁴, A.M. Sickles²³⁶, E. Sideras Haddad⁵⁶, A.C. Sidley¹⁷², A. Sidoti³⁰, F. Siegert⁷⁸, Dj. Sijacki¹⁷, F. Sili⁹¹, J.M. Silva⁸⁰, I. Silva Ferreira¹²⁶, M.V. Silva Oliveira⁴³, S.B. Silverstein⁷⁴, S. Simion⁹⁸, R. Simoniello⁶⁴, E.L. Simpson¹⁵³, H. Simpson²¹⁸, L.R. Simpson⁷, S. Simsek¹²⁴, S. Sindhu⁸³, S.N. Singh³³, S. Singh⁴³, S. Sinha⁷⁶, S. Sinha¹⁵³, M. Sioli^{30,29}, K. Sioulas¹⁰, I. Siral⁶⁴, E. Sitnikova⁷⁶, J. Sjölin^{74,75}, A. Skar⁸³, E. Skorda²³, P. Skubic¹⁷⁷, M. Slawinska¹³⁸, I. Slazyk¹⁸, I. Sliusar¹⁸², V. Smakhtin²⁴³, B.H. Smart¹⁹⁷, S.Yu. Smirnov²⁰¹, Y. Smirnov⁴⁹, O. Smirnova¹⁵⁰, J.L. Smith¹⁵³, M.B. Smith⁵⁷, R. Smith²¹⁵, H. Smitmanns¹⁵², M. Smizanska¹⁴³, K. Smolek¹⁹⁵, P. Smolyanskiy¹⁹⁵, A.A. Snasarev⁶⁵, H.L. Snoek¹⁷², R.M. Snyder⁷⁹, S. Snyder⁴³, R. Sobie^{XXVIII,239}, A. Soffer²²⁵, C.A. Solans Sanchez⁶⁴, E. Yu. Soldatov⁶⁵, U. Soldevila²³⁷, A.A. Solodkov⁵⁶, S. Solomon³³, A. Soloshenko⁶⁵, O.V. Solovyanov⁶⁷, P. Sommer⁷⁸, A. Sopczak¹⁹⁵, A.L. Sopio⁸⁰, F. Sopkova⁴², J.D. Sorenson¹⁷⁰, I.R. Sotarriva Alvarez²⁰⁷, V. Sothilingam⁹², O.J. Soto Sandoval^{202,201}, S. Sottocornola¹⁰⁰, R. Soualah¹³¹, D. South⁷⁶, N. Soybelman²⁴³, S. Spagnolo^{104,105}, A.S. Spellman¹⁸⁰, D. Sperlich⁸², B. Spisso^{108,109}, L. Splendori¹⁵⁴, M. Spousta¹⁹⁶, E.J. Staats⁵⁷, R. Stamen⁹², E. Stanecka¹³⁸, W. Stanek-Maslouska⁷⁶, M.V. Stange⁷⁸, B. Stanislaus¹⁹, M.M. Stanitzki⁷⁶, G.H. Stark¹⁹⁹, J. Stark¹⁴¹, P. Staroba¹⁹⁴, P. Starovoitov¹³⁴, R. Staszewski¹³⁸, C. Stauch¹⁶¹, G. Stavropoulos⁷³, A. Steff⁶⁴, A. Stein¹⁵², P. Steinberg⁴³, B. Stelzer^{214,230}, H.J. Stelzer¹⁸⁶, O. Stelzer²³⁰, H. Stenzel⁸⁷, T.J. Stevenson²¹⁸, G.A. Stewart⁷⁶, G. Stoicea³⁵, M. Stolarski¹⁸⁷, S. Stonjek¹⁶², A. Straessner⁷⁸, J. Strandberg²¹⁶, S. Strandberg^{74,75}, M. Stratmann²⁴⁵, M. Strauss¹⁷⁷, T. Streblor¹⁵⁴, P. Strizenec⁴², R. Ströhmer²⁴⁰, D.M. Strom¹⁸⁰, R. Stroynowski⁷², A. Strubig^{74,75}, S.A. Stucci⁴³, B. Stugu¹⁸, J. Stupak¹⁷⁷, N.A. Styles⁷⁶, D. Su²¹⁵, S. Su⁹¹, X. Su⁹¹, D. Suchy⁴¹, A.D. Sudhakar Ponnur⁸³, L. Sudit²⁴³, Y. Sue¹³⁰, K. Sugizaki¹⁸⁵, D.M.S. Sultan¹⁸³, L. Sultanaliyeva³¹, S. Sultansoy⁴, S. Sun²⁴⁴, W. Sun¹⁵, S. Sundar Raman²³⁸, N. Sur¹⁵⁰, J.P. Surdutovich¹⁷⁶, N. Suri Jr²⁴⁶, M.R. Sutton²¹⁸, M. Svatos¹⁹⁴, P.N. Swallow⁴⁶, S.N. Swatman⁶⁴, M. Swiatlowski²³⁰, A. Swoboda⁶⁴, I. Sykora⁴¹, M. Sykora¹⁹⁶, T. Sykora¹⁹⁶, D. Ta¹⁵², K. Tackmann^{XXV,76}, A. Taffard²³⁴, R. Tafirout²³⁰, Y. Takubo¹³⁰, M. Talby¹⁵⁴, N.M. Tamir²²⁵, A. Tanaka²²⁷, J. Tanaka²²⁷, R. Tanaka⁹⁸, M. Tanasini²¹⁷, Z. Tao²³⁸, S. Tapia Araya²⁰⁶, S. Tapprogge¹⁵², A. Tarek Abouelfadl Mohamed⁶⁴, S. Tarem²²⁴, K. Tariq¹⁵, G. Tarna⁶⁴, G.F. Tartarelli¹⁰⁶, M.J. Tartarin²¹⁰, P. Tas¹⁹⁶, M. Tasevsky¹⁹⁴, E. Tassi^{71,70}, A.C. Tate²³⁶, Y. Tayalati^{XXVII,62}, G.N. Taylor¹⁵⁷, W. Taylor²³¹, R.J. Taylor Vara²³⁷, A.S. Tegetmeier¹⁴¹, P. Teixeira-Dias¹⁴⁷, J.J. Teoh²²⁹, K. Terashi²²⁷, J. Terron¹⁵¹, S. Terzo¹⁴, M. Testa⁸¹, R.J. Teuscher^{XXVIII,229}, A. Thaler¹²², T. Theveniaux-Pelzer¹⁵⁴, J.P. Thomas²³, E.A. Thompson¹⁹, P.D. Thompson²³, E. Thomson¹⁸⁵, R.E. Thornberry⁴³, T.M. Thory-Rao²³, C.N. Thotamuna Wijewardhana²¹⁷, C. Tian⁹¹, Y. Tian⁸⁴, V. Tikhomirov¹²⁴, Yu.A. Tikhonov⁶⁵, D. Timoshyn¹⁹⁶, E.X.L. Ting¹, P. Tipton²⁴⁶, A. Tishelman-Charny⁴³, K. Todome²⁰⁷, S. Todorova-Nova¹⁹⁶, L. Toffolin^{101,103}, M. Togawa¹³⁰, J. Tojo¹⁴⁰, S. Tokár⁴¹, O. Toldaiev¹⁰⁰, G. Tolkachev¹⁵⁴, M. Tomoto¹³⁰, L. Tompkins²¹⁵, E. Torrence¹⁸⁰, H. Torres¹⁴¹, D.I. Torres Arza²⁰⁶, E. Torres Reoyo²³⁷, E. Torró Pastor²³⁷, M. Toscani⁴⁴, C. Toscirri⁶⁶, M. Tost¹², D.R. Tovey²¹¹, T. Trefzger²⁴⁰, P.M. Tricarico¹⁴, A. Tricoli⁴³, I.M. Trigger²³⁰, S. Trincas-Duvold¹⁸⁴, D.A. Trischuk²³⁹, A. Tropina⁶⁵, D. Truncali^{116,117}, L. Truong⁴⁹, M. Trzebinski¹³⁸, A. Trzupek¹³⁸, F. Tsai²¹⁷, A. Tsiamis²²⁶, P.V. Tsiarehsha⁶⁵, S. Tsigaridas²³⁰, A. Tsigotis^{XX,226}, V. Tsiskaridze²²¹, E.G. Tskhadadze²²¹, H.F. Tsoi¹⁸⁵, Y. Tsujikawa¹³⁹, V. Tsulaia¹⁹, K. Tsuru¹⁷⁵, D. Tsybychev²¹⁷, Y. Tu⁹⁵, A. Tudorache³⁵, V. Tudorache³⁵, S.B. Tuncay¹⁸³, S. Turchikhin^{86,85}, I. Turk Cakir³, R. Turra¹⁰⁶, T. Turtuvshin^{XXIX,65}, P.M. Tuts⁶⁸, Y. Uematsu¹³⁰, F. Ukegawa²³², P.A. Ulloa Poblete^{202,201}, G. Unal⁶⁴, A. Undrus⁴³, J. Urban⁴², P. Urrejola²⁰⁴, G. Usai⁹, R. Ushioda²²⁸, M. Usman¹⁶⁰, F. Ustuner⁸⁰, Z. Uysal¹²⁴, V. Vacek¹⁹⁵, B. Vachon¹⁵⁶, T. Vafeiadis⁶⁴, A. Vaitkus¹⁴⁸, C. Valderanis¹⁶¹, E. Valdes Santurio^{74,75}, M. Valente⁶⁴, S. Valentini^{30,29}, A. Valero²³⁷, E. Valiente Moreno²³⁷, A. Vallier¹⁴¹, J.A. Valls Ferrer²³⁷, D.R. Van Arneam¹⁷², R. Van Den Broucke¹⁸⁴, A. Van Der Graaf⁷⁷, H.Z. Van Der Schyf⁵⁶, P. Van Gemmeren⁷, M. Van Rijnbach⁶⁴, S. Van Stroud¹⁴⁸, I. Van Vulpen¹⁷², P. Vana¹⁹⁶, M. Vanadia^{116,117}, U.M. Vande Voorde²¹⁶, W. Vandelli⁶⁴, E.R. Vandewall²¹⁵, D. Vannicola²²⁵, R. Vari¹¹⁴, M. Varma²⁴⁶, E.W. Varnes⁸, C. Varni¹³⁶, D. Varouchas⁹⁸, L. Varriale²³⁷, K.E. Varvell²¹⁹, M.E. Vasile³⁵, A. Vasileiadou¹⁰, L. Vaslin¹³⁰, M.D. Vassilev²¹⁵, A. Vasyukov⁶⁵, L.M. Vaughan¹⁷⁸, R. Vavricka¹⁹⁶, T. Vazquez Schroeder¹⁴, J. Veatch⁴⁵, V. Vecchio¹⁵³, M.J. Veen¹⁵⁵, I. Veliscek⁴³, I. Velkovska¹⁴⁵, L.M. Veloce²²⁹, F. Veloso^{187,189}, A.G. Veltman⁸⁰, S.H. Venetianer²³³, S. Veneziano¹¹⁴, A. Ventura^{104,105}, A. Verbitskiy¹⁶², M. Verducci^{112,113}, C. Vergis¹⁴⁶, M. Verissimo De Araujo¹²⁶, W. Verkerke¹⁷², J.C. Vermeulen¹⁷², C. Vernieri²¹⁵, M. Vessella²³⁴, M.C. Vetterli^{XXXVI,214}, A. Vgenopoulos¹⁵², N. Viaux Maira^{XXXII,206}, L. Vicens¹⁹⁵, T. Vickey²¹¹, O.E. Vicky Boerui²¹¹, G.H.A. Viehhauser¹⁸³, L. Viganì⁹³, M. Vigi¹⁶², M. Villa^{30,29}, M. Villaplana Perez²³⁷, E.M. Villhauer⁶⁶, E. Vilucchi⁸¹, M. Vincent²³⁷, M.G. Vinciter⁵⁷, A. Visibile¹⁷², A. Visive¹⁷², C. Vittori²³³, I. Vivarelli^{30,29}, M.I. Vivas Albornoz⁷⁶, E. Voevodina¹⁶², F. Vogel¹⁶¹, J.C. Voigt⁷⁸, P. Vokac¹⁹⁵, Yu. Volkotrub¹³⁷, L. Vomberg³¹, E. Von Toerne³¹, B. Vormwald⁶⁴, K. Vorobev⁷⁹, M. Vos²³⁷, K. Voss²¹³, M. Vozak⁶⁴, L. Vozdecky¹⁷⁷, N. Vranjes¹⁷, M. Vranjes Milosavljevic¹⁷, M. Vreeswijk¹⁷², N.K. Vu¹⁶⁴, R. Vuillemet⁶⁴, O. Vujanovic¹⁵², I. Vukotic⁶⁶, I.K. Vyas⁵⁷, J.F. Wack⁴⁶, A. Wada¹⁶³, S. Wada²³², C. Wagner²¹⁵, J.M. Wagner¹⁹, W. Wagner²⁴⁵, S. Wahdan²⁴⁵, H. Wahlberg¹⁴², C.H. Waits¹⁷⁷, J. Walder¹⁹⁷, R. Walker¹⁶¹, K. Walkingshaw Pass⁸⁸, W. Walkowiak²¹³, A. Wall¹⁸⁵, E.J. Wallin¹⁵⁰, T. Wamorkar²¹⁵, K. Wandall-Christensen²³⁷, A. Wang⁹¹, A.Z. Wang¹⁹⁹, C. Wang⁷⁶, C. Wang¹², H. Wang¹⁹, J. Wang⁹⁶, P. Wang¹⁵³, P. Wang¹⁴⁸, R. Wang⁹⁰, R. Wang¹⁵⁸, R. Wang⁷, S.M. Wang²²⁰, S. Wang¹⁵, T. Wang¹⁷¹, T. Wang⁹¹, W.T. Wang¹⁸³, W. Wang¹⁶⁹, X. Wang²³⁶, X. Wang²⁰⁹, X. Wang⁷⁶, Y. Wang²¹⁷, Y. Wang¹⁷⁰, Z. Wang¹⁵⁸, Z. Wang¹⁵, Z. Wang⁹⁵, C. Wanotayaroj¹³⁰, A. Warburton¹⁵⁶, A.L. Warnerbring²¹³, S. Waterhouse¹⁴⁸, A.T. Watson²³, H. Watson⁸⁰, M.F. Watson²³, E. Watton⁶⁴, G. Watts²⁰⁸, B.M. Waugh¹⁴⁸, J.M. Webb⁸², C. Weber⁴³, M.S. Weber²², C. Wei⁹¹, Y. Wei⁸², A.R. Weidberg¹⁸³, E.J. Weik¹⁷⁴, J. Weingarten⁷⁷, C. Weiser⁸², C.J. Wells⁷⁶, P.S. Wells⁶⁴, T. Wenaus⁴³, T. Wengler⁶⁴, N.S. Wenke¹⁶², N. Wermes³¹, D. Werner⁷⁶, M. Wessels⁹², A.M. Wharton¹⁴³, A.S. White⁶⁴, A. White⁹, M.J. White¹, D. Whiteson²³⁴, L.

Wickremasinghe¹⁸¹, W. Wiedenmann²⁴⁴, M. Wielders¹⁹⁷, R. Wierda²¹⁶, C. Wiglesworth⁶⁹, H.G. Wilkens⁶⁴, J.J.H. Wilkinson⁴⁶, S. Williams⁴⁶, S. Willocq¹⁵⁵, D.J. Wilson¹⁵³, P.J. Windischhofer⁶⁶, F.I. Winkel⁴⁴, F. Winklmeier¹⁸⁰, B.T. Winter⁸², M. Wittgen²¹⁵, M. Wobisch¹⁴⁹, T. Wojtkowski⁸⁹, Z. Wolffs¹⁷², J. Wollrath⁶⁴, M.W. Wolter¹³⁸, H. Wolters^{187,189}, M.C. Wong¹⁹⁹, E.L. Woodward⁶⁸, S.D. Worm⁷⁶, B.K. Wosiek¹³⁸, K.A. Wozniak⁸⁴, K.W. Woźniak¹³⁸, S. Wozniowski⁸³, K. Wraight⁸⁸, C. Wu²²⁹, C. Wu²³, J. Wu²²⁷, M. Wu¹⁶⁵, M. Wu¹⁷¹, S.L. Wu²⁴⁴, S. Wu¹⁵, X. Wu⁹¹, Y.Q. Wu²²⁹, Y. Wu⁹¹, Z. Wu¹⁵⁴, Z. Wu¹⁶⁴, J. Wuerzinger¹⁶², T.R. Wyatt¹⁵³, B.M. Wynne⁸⁰, S. Xella⁶⁹, L. Xia¹⁶⁴, M. Xie⁹¹, A. Xiong¹⁸⁰, I. Xiotidis⁶⁴, D. Xu¹⁵, H. Xu⁹¹, L. Xu⁹¹, R. Xu¹⁸⁵, T. Xu¹⁵⁸, W. Xu¹⁶⁴, Y. Xu²⁰⁸, Z. Xu⁸⁰, R. Xue¹⁸⁶, B. Yabsley²¹⁹, S. Yacoub¹², Y. Yamaguchi¹³⁰, E. Yamashita²²⁷, H. Yamauchi²³², T. Yamazaki¹⁹, Y. Yamazaki¹³⁵, S. Yan⁸⁸, Z. Yan¹⁵⁵, C. Yang¹⁹, H.J. Yang²⁰⁹, H.T. Yang⁹¹, S. Yang⁹¹, X. Yang⁶⁴, X. Yang¹⁵, Y. Yang²²⁷, Y. Yang⁹¹, W.-M. Yao¹⁹, C.L. Yardley²¹⁸, J. Ye¹⁵, S. Ye⁴³, X. Ye⁹¹, I. Yeletskikh⁶⁵, B. Yeo²⁰, M.R. Yexley¹⁴⁸, T.P. Yildirim¹⁸³, K. Yorita²⁴², C.J.S. Young⁶⁴, C. Young²¹⁵, I.N.L. Young⁸⁸, N.D. Young¹⁸⁰, Y. Yu⁹¹, J. Yuan^{15,166}, M. Yuan¹⁵⁸, R. Yuan²¹⁰, L. Yue¹⁴⁸, M. Zaazoua⁹¹, B. Zabinski¹³⁸, I. Zahir⁵⁸, Q.U.A. Zahoor⁸⁰, A. Zaid^{86,85}, Z.K. Zak¹³⁸, T. Zakareishvili²³⁷, S. Zambito⁸⁴, J. Zang²²⁷, R. Zanzottera^{106,107}, O. Zaplatilek¹⁹⁵, E. Zaya²¹⁶, C. Zeitnitz²⁴⁵, H. Zeng¹⁵, D.T. Zenger Jr³³, T. Ženiš⁴¹, S. Zenz¹⁴⁶, D. Zerwas⁹⁸, W. Zhan⁹¹, B. Zhang²⁴¹, D.F. Zhang²¹¹, G. Zhang¹⁵, J. Zhang¹⁶⁸, J. Zhang⁷, L. Zhang⁹¹, L. Zhang¹⁶⁴, P. Zhang^{15,166}, R. Zhang¹⁶⁴, S. Zhang⁶², Y. Zhang²⁰⁸, Y. Zhang¹⁴⁸, Y. Zhang⁹¹, Y. Zhang¹⁶⁴, Z. Zhang¹⁹, Z. Zhang¹⁶⁸, Z. Zhang⁹⁸, H. Zhao²⁰⁸, T. Zhao¹⁶⁸, Y. Zhao⁵⁷, Z. Zhao⁹¹, Z. Zhao⁹¹, A. Zhemchugov⁶⁵, J. Zheng¹⁶⁴, K. Zheng²³⁶, L. Zheng¹⁶⁸, X. Zheng⁹¹, Z. Zheng²¹⁵, D. Zhong²³⁶, B. Zhou¹⁵⁸, B. Zhou^{210,209}, N. Zhou²⁰⁹, Y. Zhou¹⁶, Y. Zhou¹⁶⁴, Y. Zhou⁸, Z. Zhou⁹¹, J. Zhu¹⁵⁸, X. Zhu²¹⁰, Y. Zhu²⁰⁹, X. Zhuang¹⁵, K. Zhukov¹⁰⁰, P. Ziakas⁵, N.I. Zimine⁶⁵, J. Zinsser⁹³, M. Ziolkowski²¹³, L. Živković¹⁷, A. Zoccoli^{30,29}, K. Zoch⁶⁴, A. Zografos⁶⁴, T.G. Zorbas²¹¹, L. Zwalsinski⁶⁴

Affiliation Notes

^I Also at Affiliated with an institute formerly covered by a cooperation agreement with CERN

^{II} Also at An-Najah National University, Nablus, Palestine

^{III} Also at Borough of Manhattan Community College, City University of New York, New York NY, United States of America

^{IV} Also at Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki, Greece

^V Also at Centre of Physics of the Universities of Minho and Porto (CF-UM-UP), Portugal

^{VI} Also at CERN, Geneva, Switzerland

^{VII} Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland

^{VIII} Also at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona, Spain

^{IX} Also at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece

^X Also at Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, China

^{XI} Also at Department of Physics, Ben Gurion University of the Negev, Beer Sheva, Israel

^{XII} Also at Department of Physics, Bolu Abant İzzet Baysal University, Bolu, Türkiye

^{XIII} Also at Department of Physics, King's College London, London, United Kingdom

^{XIV} Also at Department of Physics, Stellenbosch University, South Africa

^{XV} Also at Department of Physics, University of Fribourg, Fribourg, Switzerland

^{XVI} Also at Department of Physics, University of Thessaly, Greece

^{XVII} Also at Department of Physics, Westmont College, Santa Barbara, United States of America

^{XVIII} Also at Faculty of Physics, Sofia University, 'St. Kliment Ohridski', Sofia, Bulgaria

^{XIX} Also at Faculty of Physics, University of Bucharest, Romania

^{XX} Also at Hellenic Open University, Patras, Greece

^{XXI} Also at Henan University, China

^{XXII} Also at Imam Mohammad Ibn Saud Islamic University, Saudi Arabia

^{XXIII} Also at Indian Institute of Technology (IIT), Jodhpur, India

^{XXIV} Also at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain

^{XXV} Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany

^{XXVI} Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria

^{XXVII} Also at Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir, Morocco

^{XXVIII} Also at Institute of Particle Physics (IPP), Canada

^{XXIX} Also at Institute of Physics and Technology, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia

^{XXX} Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan

^{XXXI} Also at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia

^{XXXII} Also at Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago, Chile

^{XXXIII} Also at National Institute of Physics, University of the Philippines Diliman (Philippines), Philippines

^{XXXIV} Also at School of Physics, University of the Witwatersrand, Johannesburg, South Africa

^{XXXV} Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing, China

^{XXXVI} Also at TRIUMF, Vancouver BC, Canada

^{XXXVII} Also at Università di Napoli Parthenope, Napoli, Italy

^{XXXVIII} Also at Università degli Studi Link, Italy

^{XXXIX} Also at University and INFN Torino, Torino, Italy

^{XL} Also at University of Chinese Academy of Sciences (UCAS), Beijing, China

^{XLI} Also at University of Colorado Boulder, Department of Physics, Colorado, United States of America

^{XLII} Also at University of Siena, Italy

^{XLIII} Also at Washington College, Chestertown, MD, United States of America

^{XLIV} Also at Yeditepe University, Physics Department, Istanbul, Türkiye

^{XLV} Deceased

Collaboration Institutes

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

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

³ Department of Physics, Ankara University, Ankara, Türkiye

⁴ Division of Physics, TOBB University of Economics and Technology, Ankara, Türkiye

⁵ LAPP, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy, France

⁶ APC, Université Paris Cité, CNRS/IN2P3, Paris, France

⁷ High Energy Physics Division, Argonne National Laboratory, Argonne IL, United States of America

⁸ Department of Physics, University of Arizona, Tucson, AZ, United States of America

⁹ Department of Physics, University of Texas at Arlington, Arlington, TX, United States of America

¹⁰ Physics Department, National and Kapodistrian University of Athens, Athens, Greece

- ¹¹ Physics Department, National Technical University of Athens, Zografou, Greece
- ¹² Department of Physics, University of Texas at Austin, Austin, TX, United States of America
- ¹³ Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
- ¹⁴ Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona, Spain
- ¹⁵ Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China
- ¹⁶ Physics Department, Tsinghua University, Beijing, China
- ¹⁷ Institute of Physics, University of Belgrade, Belgrade, Serbia
- ¹⁸ Department for Physics and Technology, University of Bergen, Bergen, Norway
- ¹⁹ Physics Division, Lawrence Berkeley National Laboratory, Berkeley, CA, United States of America
- ²⁰ University of California, Berkeley, CA, United States of America
- ²¹ Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany
- ²² Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland
- ²³ School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom
- ²⁴ Department of Physics, Bogazici University, Istanbul, Türkiye
- ²⁵ Department of Physics Engineering, Gaziantep, Gaziantep, Türkiye
- ²⁶ Department of Physics, Istanbul University, Istanbul, Türkiye
- ²⁷ Facultad de Ciencias y Centro de Investigaciones, Universidad Antonio Nariño, Bogotá, Colombia
- ²⁸ Departamento de Física, Universidad Nacional de Colombia, Bogotá, Colombia
- ²⁹ Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna, Italy
- ³⁰ INFN Sezione di Bologna, Italy
- ³¹ Physikalisches Institut, Universität Bonn, Bonn, Germany
- ³² Department of Physics, Boston University, Boston, MA, United States of America
- ³³ Department of Physics, Brandeis University, Waltham, MA, United States of America
- ³⁴ Transilvania University of Brasov, Brasov, Romania
- ³⁵ Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania
- ³⁶ Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi, Romania
- ³⁷ National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca, Romania
- ³⁸ National University of Science and Technology Politehnica, Bucharest, Romania
- ³⁹ West University in Timisoara, Timisoara, Romania
- ⁴⁰ Faculty of Physics, University of Bucharest, Bucharest, Romania
- ⁴¹ Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovak Republic
- ⁴² Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic
- ⁴³ Physics Department, Brookhaven National Laboratory, Upton, NY, United States of America
- ⁴⁴ 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
- ⁴⁵ California State University, CA, United States of America
- ⁴⁶ Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
- ⁴⁷ Department of Physics, University of Cape Town, Cape Town, South Africa
- ⁴⁸ iThemba Labs, Western Cape, South Africa
- ⁴⁹ Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, South Africa
- ⁵⁰ National Institute of Physics, University of The Philippines Diliman (Philippines), Philippines
- ⁵¹ Department of Physics, Stellenbosch University, Matieland, South Africa
- ⁵² University of KwaZulu-Natal School of Agriculture and Science, Mathematics, Westville, South Africa
- ⁵³ University of South Africa, Department of Physics, Pretoria, South Africa
- ⁵⁴ University of Pretoria Department of Mechanical and Aeronautical Engineering, Pretoria, South Africa
- ⁵⁵ University of Zululand, KwaDlangezwa, South Africa
- ⁵⁶ School of Physics, University of the Witwatersrand, Johannesburg, South Africa
- ⁵⁷ Department of Physics, Carleton University, Ottawa, ON, Canada
- ⁵⁸ Faculté des Sciences Ain Chock, Université Hassan II de Casablanca, Morocco
- ⁵⁹ Faculté des Sciences, Université Ibn-Tofail, Kénitra, Morocco
- ⁶⁰ Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Morocco
- ⁶¹ LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda, Morocco
- ⁶² Faculté des sciences, Université Mohammed V, Rabat, Morocco
- ⁶³ Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir, Morocco
- ⁶⁴ CERN, Geneva, Switzerland
- ⁶⁵ Affiliated with an international laboratory covered by a cooperation agreement with CERN
- ⁶⁶ Enrico Fermi Institute, University of Chicago, Chicago, IL, United States of America
- ⁶⁷ LPC, Université Clermont Auvergne CNRS/IN2P3, Clermont-Ferrand, France
- ⁶⁸ Nevis Laboratory, Columbia University, Irvington, NY, United States of America
- ⁶⁹ Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
- ⁷⁰ Dipartimento di Fisica, Università della Calabria, Rende, Italy
- ⁷¹ INFN Gruppo Collegato di Cosenza Laboratori Nazionali di Frascati, Italy
- ⁷² Physics Department, Southern Methodist University, Dallas, TX, United States of America
- ⁷³ National Centre for Scientific Research "Demokritos", Agia Paraskevi, Greece
- ⁷⁴ Department of Physics, Stockholm University, Sweden
- ⁷⁵ Oskar Klein Centre, Stockholm, Sweden
- ⁷⁶ Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen, Germany
- ⁷⁷ Fakultät Physik, Technische Universität Dortmund, Dortmund, Germany
- ⁷⁸ Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany
- ⁷⁹ Department of Physics, Duke University, Durham, NC, United States of America
- ⁸⁰ SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
- ⁸¹ INFN e Laboratori Nazionali di Frascati, Frascati, Italy
- ⁸² Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany
- ⁸³ II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany
- ⁸⁴ Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland
- ⁸⁵ Dipartimento di Fisica, Università di Genova, Genova, Italy
- ⁸⁶ INFN Sezione di Genova, Italy
- ⁸⁷ II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany

- ⁸⁸ SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
- ⁸⁹ LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble, France
- ⁹⁰ Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, MA, United States of America
- ⁹¹ Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, China
- ⁹² Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
- ⁹³ Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
- ⁹⁴ Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China
- ⁹⁵ Department of Physics, University of Hong Kong, Hong Kong, China
- ⁹⁶ Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China
- ⁹⁷ Department of Physics, National Tsing Hua University, Hsinchu, Taiwan
- ⁹⁸ JCLab, Université Paris-Saclay, CNRS/IN2P3, Orsay, 91405, France
- ⁹⁹ Centro Nacional de Microelectrónica (IMB-CNM-CSIC), Barcelona, Spain
- ¹⁰⁰ Department of Physics, Indiana University, Bloomington, IN, United States of America
- ¹⁰¹ INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, Italy
- ¹⁰² ICTP, Trieste, Italy
- ¹⁰³ Université Paris-Saclay Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine, Italy
- ¹⁰⁴ INFN Sezione di Lecce, Italy
- ¹⁰⁵ Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
- ¹⁰⁶ INFN Sezione di Milano, Italy
- ¹⁰⁷ Dipartimento di Fisica, Università di Milano, Milano, Italy
- ¹⁰⁸ INFN Sezione di Napoli, Italy
- ¹⁰⁹ Dipartimento di Fisica, Università di Napoli, Napoli, Italy
- ¹¹⁰ INFN Sezione di Pavia, Italy
- ¹¹¹ Dipartimento di Fisica, Università di Pavia, Pavia, Italy
- ¹¹² INFN Sezione di Pisa, Italy
- ¹¹³ Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
- ¹¹⁴ INFN Sezione di Roma, Italy
- ¹¹⁵ Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy
- ¹¹⁶ INFN Sezione di Roma Tor Vergata, Italy
- ¹¹⁷ Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
- ¹¹⁸ INFN Sezione di Roma Tre, Italy
- ¹¹⁹ Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy
- ¹²⁰ INFN-TIFPA, Italy
- ¹²¹ Università degli Studi di Trento, Trento, Italy
- ¹²² Universität Innsbruck Department of Astro and Particle Physics, Innsbruck, Austria
- ¹²³ Department of Physics and Astronomy, Iowa State University, Ames, IA, United States of America
- ¹²⁴ Istinye University, Sariyer, Istanbul, Türkiye
- ¹²⁵ Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora, Brazil
- ¹²⁶ Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil
- ¹²⁷ Instituto de Física, Universidade de São Paulo, São Paulo, Brazil
- ¹²⁸ Rio de Janeiro State University, Rio de Janeiro, Brazil
- ¹²⁹ Federal University of Bahia, Bahia, Brazil
- ¹³⁰ KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
- ¹³¹ Khalifa University of Science and Technology, Abu Dhabi, United Arab Emirates
- ¹³² New York University Abu Dhabi, Abu Dhabi, United Arab Emirates
- ¹³³ United Arab Emirates University, Al Ain, United Arab Emirates
- ¹³⁴ University of Sharjah, Sharjah, United Arab Emirates
- ¹³⁵ Graduate School of Science, Kobe University, Kobe, Japan
- ¹³⁶ AGH University of Krakow Faculty of Physics and Applied Computer Science, Krakow, Poland
- ¹³⁷ Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland
- ¹³⁸ Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland
- ¹³⁹ Faculty of Science, Kyoto University, Kyoto, Japan
- ¹⁴⁰ Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka, Japan
- ¹⁴¹ L2IT, Université de Toulouse CNRS/IN2P3, UPS, Toulouse, France
- ¹⁴² Instituto de Física La Plata Universidad Nacional de La Plata and CONICET, La Plata, Argentina
- ¹⁴³ Physics Department, Lancaster University, Lancaster, United Kingdom
- ¹⁴⁴ Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
- ¹⁴⁵ Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia
- ¹⁴⁶ Department of Physics and Astronomy, Queen Mary University of London, London, United Kingdom
- ¹⁴⁷ Department of Physics, Royal Holloway University of London, Egham, United Kingdom
- ¹⁴⁸ Department of Physics and Astronomy, University College London, London, United Kingdom
- ¹⁴⁹ Louisiana Tech University, Ruston, LA, United States of America
- ¹⁵⁰ Fysiska institutionen, Lunds universitet, Lund, Sweden
- ¹⁵¹ Departamento de Física Teórica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid, Spain
- ¹⁵² Institut für Physik, Universität Mainz, Mainz, Germany
- ¹⁵³ School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
- ¹⁵⁴ CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France
- ¹⁵⁵ Department of Physics, University of Massachusetts, Amherst, MA, United States of America
- ¹⁵⁶ Department of Physics, McGill University, Montreal, QC, Canada
- ¹⁵⁷ School of Physics, University of Melbourne, Victoria, Australia
- ¹⁵⁸ Department of Physics, University of Michigan, Ann Arbor, MI, United States of America
- ¹⁵⁹ Department of Physics and Astronomy, Michigan State University, East Lansing, MI, United States of America
- ¹⁶⁰ Group of Particle Physics, University of Montreal, Montreal, QC, Canada
- ¹⁶¹ Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
- ¹⁶² Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
- ¹⁶³ Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan
- ¹⁶⁴ Department of Physics, Nanjing University, Nanjing, China
- ¹⁶⁵ School of Science, Shenzhen Campus of Sun Yat-sen University, China
- ¹⁶⁶ University of Chinese Academy of Science (UCAS), Beijing, China
- ¹⁶⁷ School of Physics, Nankai University, Tianjin, China
- ¹⁶⁸ Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao, China
- ¹⁶⁹ School of Physics, Zhengzhou University, China
- ¹⁷⁰ Department of Physics and Astronomy, University of New Mexico, Albuquerque, NM, United States of America
- ¹⁷¹ Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen, Netherlands

- ¹⁷² Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
- ¹⁷³ Department of Physics, Northern Illinois University, DeKalb, IL, United States of America
- ¹⁷⁴ Department of Physics, New York University, New York NY, United States of America
- ¹⁷⁵ Ochanomizu University Otsuka, Bunkyo-ku, Tokyo, Japan
- ¹⁷⁶ Ohio State University, Columbus, OH, United States of America
- ¹⁷⁷ Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK, United States of America
- ¹⁷⁸ Department of Physics, Oklahoma State University, Stillwater, OK, United States of America
- ¹⁷⁹ Palacký University Joint Laboratory of Optics, Olomouc, Czech Republic
- ¹⁸⁰ Institute for Fundamental Science, University of Oregon, Eugene, OR, United States of America
- ¹⁸¹ Graduate School of Science, University of Osaka, Osaka, Japan
- ¹⁸² Department of Physics, University of Oslo, Oslo, Norway
- ¹⁸³ Department of Physics, Oxford University, Oxford, United Kingdom
- ¹⁸⁴ LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris, France
- ¹⁸⁵ Department of Physics, University of Pennsylvania, Philadelphia, PA, United States of America
- ¹⁸⁶ Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States of America
- ¹⁸⁷ Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa, Portugal
- ¹⁸⁸ Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal
- ¹⁸⁹ Departamento de Física, Universidade de Coimbra, Coimbra, Portugal
- ¹⁹⁰ Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal
- ¹⁹¹ Departamento de Física, Escola de Ciências, Universidade do Minho, Braga, Portugal
- ¹⁹² Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada, (Spain), Spain
- ¹⁹³ Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
- ¹⁹⁴ Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic
- ¹⁹⁵ Czech Technical University in Prague, Prague, Czech Republic
- ¹⁹⁶ Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic
- ¹⁹⁷ Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
- ¹⁹⁸ IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
- ¹⁹⁹ Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States of America
- ²⁰⁰ Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile
- ²⁰¹ Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago, Chile
- ²⁰² Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, y Departamento de Física, Universidad de La Serena, Chile
- ²⁰³ Universidad Andres Bello, Department of Physics, Santiago, Chile
- ²⁰⁴ Universidad San Sebastian, Recoleta, Chile
- ²⁰⁵ Instituto de Alta Investigación, Universidad de Tarapacá, Arica, Chile
- ²⁰⁶ Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
- ²⁰⁷ Department of Physics, Institute of Science, Tokyo, Japan
- ²⁰⁸ Department of Physics, University of Washington, Seattle, WA, United States of America
- ²⁰⁹ 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, China
- ²¹⁰ State Key Laboratory of Dark Matter Physics, Tsung-Dao Lee Institute, Shanghai Jiao Tong University, Shanghai, China
- ²¹¹ Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
- ²¹² Department of Physics, Shinshu University, Nagano, Japan
- ²¹³ Department Physik, Universität Siegen, Siegen, Germany
- ²¹⁴ Department of Physics, Simon Fraser University, Burnaby, BC, Canada
- ²¹⁵ SLAC National Accelerator Laboratory, Stanford, CA, United States of America
- ²¹⁶ Department of Physics, Royal Institute of Technology, Stockholm, Sweden
- ²¹⁷ Departments of Physics and Astronomy, Stony Brook University, Stony Brook, NY, United States of America
- ²¹⁸ Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
- ²¹⁹ School of Physics, University of Sydney, Sydney, Australia
- ²²⁰ Institute of Physics, Academia Sinica, Taipei, Taiwan
- ²²¹ E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia
- ²²² High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
- ²²³ University of Georgia, Tbilisi, Georgia
- ²²⁴ Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel
- ²²⁵ Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
- ²²⁶ Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
- ²²⁷ International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan
- ²²⁸ Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
- ²²⁹ Department of Physics, University of Toronto, Toronto, ON, Canada
- ²³⁰ TRIUMF, Vancouver, BC, Canada
- ²³¹ Department of Physics and Astronomy, York University, Toronto, ON, Canada
- ²³² Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan
- ²³³ Department of Physics and Astronomy, Tufts University, Medford, MA, United States of America
- ²³⁴ Department of Physics and Astronomy, University of California Irvine, Irvine, CA, United States of America
- ²³⁵ Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
- ²³⁶ Department of Physics, University of Illinois, Urbana, IL, United States of America
- ²³⁷ Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Valencia, Spain
- ²³⁸ Department of Physics, University of British Columbia, Vancouver, BC, Canada
- ²³⁹ Department of Physics and Astronomy, University of Victoria, Victoria, BC, Canada
- ²⁴⁰ Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany
- ²⁴¹ Department of Physics, University of Warwick, Coventry, United Kingdom
- ²⁴² Waseda University, Tokyo, Japan
- ²⁴³ Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot, Israel
- ²⁴⁴ Department of Physics, University of Wisconsin, Madison, WI, United States of America
- ²⁴⁵ Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany

²⁴⁶Department of Physics, Yale University, New Haven, CT, United States of America
²⁴⁷Yerevan Physics Institute, Yerevan, Armenia

References

- [1] N. Arkani-Hamed, S. Dimopoulos, G. Dvali, The hierarchy problem and new dimensions at a millimeter, *Phys. Lett. B* 429 (1998) 263–272. [arXiv:hep-ph/9803315](#), [https://doi.org/10.1016/S0370-2693\(98\)00466-3](https://doi.org/10.1016/S0370-2693(98)00466-3)
- [2] I. Antoniadis, N. Arkani-Hamed, S. Dimopoulos, G. Dvali, New dimensions at a millimeter to a Fermi and superstrings at a TeV, *Phys. Lett. B* 436 (1998) 257–263. [arXiv:hep-ph/9804398](#), [https://doi.org/10.1016/S0370-2693\(98\)00860-0](https://doi.org/10.1016/S0370-2693(98)00860-0)
- [3] L. Randall, R. Sundrum, Large mass hierarchy from a small extra dimension, *Phys. Rev. Lett.* 83 (1999) 3370–3373. [arXiv:hep-ph/9905221](#), <https://doi.org/10.1103/PhysRevLett.83.3370>
- [4] D.M. Gingrich, Quantum black holes with charge, color, and spin at the LHC, *J. Phys. G* 37 (2010) 105008. [arXiv:0912.0826](#) [hep-ph], <https://doi.org/10.1088/0954-3889/37/10/105008>
- [5] P. Meade, L. Randall, Black holes and quantum gravity at the LHC, *JHEP* 05 (2008) 003. [arXiv:0708.3017](#) [hep-ph], <https://doi.org/10.1088/1126-6708/2008/05/003>
- [6] J. Calmet, W. Gong, S.D.H. Hsu, Colorful quantum black holes at the LHC, *Phys. Lett. B* 668 (2008) 20–23. [arXiv:0806.4605](#) [hep-ph], <https://doi.org/10.1016/j.physletb.2008.08.011>
- [7] D.M. Gingrich, Monte Carlo event generator for black hole production and decay in proton-proton collisions — QBH version 1.02, *Comput. Phys. Commun.* 181 (2010) 1917–1924. [arXiv:0911.5370](#) [hep-ph], <https://doi.org/10.1016/j.cpc.2010.07.027>
- [8] D.M. Gingrich, Collider searches for non-perturbative low-scale gravity states, *Int. J. Mod. Phys. A* 30 (34) (2015) 1530061. [arXiv:1509.07180](#) [hep-ph], <https://doi.org/10.1142/S0217751X15300616>
- [9] L.A. Anchordoqui, J.L. Feng, H. Goldberg, A.D. Shapere, Black holes from cosmic rays: probes of extra dimensions and new limits on TeV-scale gravity, *Phys. Rev. D* 65 (2002) 124027. [arXiv:hep-ph/0112247](#), <https://doi.org/10.1103/PhysRevD.65.124027>
- [10] ATLAS Collaboration, Search for strong gravity in multijet final states produced in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector at the LHC, *JHEP* 03 (2016) 026. [arXiv:1512.02586](#) [hep-ex], [https://doi.org/10.1007/JHEP03\(2016\)026](https://doi.org/10.1007/JHEP03(2016)026)
- [11] ATLAS Collaboration, Search for heavy particles decaying into top-quark pairs using lepton-plus-jets events in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, *Eur. Phys. J. C* 78 (7) (2018) 565. [arXiv:1804.10823](#) [hep-ex], <https://doi.org/10.1140/epjc/s10052-018-5995-6>
- [12] CMS Collaboration, Search for black holes and other new phenomena in high-multiplicity final states in proton-proton collisions at $\sqrt{s} = 13$ TeV, *Phys. Lett. B* 774 (2017) 279–307. [arXiv:1705.01403](#) [hep-ex], <https://doi.org/10.1016/j.physletb.2017.09.053>
- [13] CMS Collaboration, Search for black holes and sphalerons in high-multiplicity final states in proton-proton collisions at $\sqrt{s} = 13$ TeV, *JHEP* 11 (2018) 042. [arXiv:1805.06013](#) [hep-ex], [https://doi.org/10.1007/JHEP11\(2018\)042](https://doi.org/10.1007/JHEP11(2018)042)
- [14] CMS Collaboration, A search for microscopic black holes, string balls, and sphalerons in proton-proton collisions at $\sqrt{s} = 13$ TeV (2026). Submitted to *JHEP*. [arXiv:2604.10732](#) [hep-ex]
- [15] ATLAS Collaboration, Search for quantum black hole production in lepton + jet final states using proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, *Phys. Rev. D* 109 (3) (2024) 032010. [arXiv:2307.14967](#) [hep-ex], <https://doi.org/10.1103/nrjw-qx33> Erratum: *Phys. Rev. D* 114 (2026) 039901
- [16] ATLAS Collaboration, Search for quantum black hole production in high-invariant-mass lepton+jet final states using pp collisions at $\sqrt{s} = 8$ TeV and the ATLAS detector, *Phys. Rev. Lett.* 112 (9) (2014) 091804. [arXiv:1311.2006](#) [hep-ex], <https://doi.org/10.1103/PhysRevLett.112.091804>
- [17] ATLAS Collaboration, Search for new phenomena in dijet mass and angular distributions from pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, *Phys. Lett. B* 754 (2016) 302–322. [arXiv:1512.01530](#) [hep-ex], <https://doi.org/10.1016/j.physletb.2016.01.032>
- [18] ATLAS Collaboration, Search for new phenomena in different-flavour high-mass dilepton final states in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, *Eur. Phys. J. C* 76 (10) (2016) 541. [arXiv:1607.08079](#) [hep-ex], <https://doi.org/10.1140/epjc/s10052-016-4385-1>
- [19] ATLAS Collaboration, Search for new resonances in mass distributions of jet pairs using 139 fb⁻¹ of pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, *JHEP* 03 (2020) 145. [arXiv:1910.08447](#) [hep-ex], [https://doi.org/10.1007/JHEP03\(2020\)145](https://doi.org/10.1007/JHEP03(2020)145)
- [20] ATLAS Collaboration, Search for new phenomena in photon + jet events collected in proton–proton collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector, *Phys. Lett. B* 728 (2014) 562–578. [arXiv:1309.3230](#) [hep-ex], <https://doi.org/10.1016/j.physletb.2013.12.029>
- [21] ATLAS Collaboration, Search for new phenomena with photon + jet events in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, *JHEP* 03 (2016) 041. [arXiv:1512.05910](#) [hep-ex], [https://doi.org/10.1007/JHEP03\(2016\)041](https://doi.org/10.1007/JHEP03(2016)041)
- [22] ATLAS Collaboration, Search for new phenomena in high-mass final states with a photon and a jet from pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, *Eur. Phys. J. C* 78 (2) (2018) 102. [arXiv:1709.10440](#) [hep-ex], <https://doi.org/10.1140/epjc/s10052-018-5553-2>
- [23] CMS Collaboration, Search for new physics with dijet angular distributions in proton-proton collisions at $\sqrt{s} = 13$ TeV, *JHEP* 07 (2017) 013. [arXiv:1703.09986](#) [hep-ex], [https://doi.org/10.1007/JHEP07\(2017\)013](https://doi.org/10.1007/JHEP07(2017)013)
- [24] CMS Collaboration, Search for lepton-flavor violating decays of heavy resonances and quantum black holes to $e\mu$ final states in proton-proton collisions at $\sqrt{s} = 13$ TeV, *JHEP* 04 (2018) 073. [arXiv:1802.01122](#) [hep-ex], [https://doi.org/10.1007/JHEP04\(2018\)073](https://doi.org/10.1007/JHEP04(2018)073)
- [25] CMS Collaboration, Search for heavy resonances and quantum black holes in $e\mu$, $e\tau$, and $\mu\tau$ final states in proton–proton collisions at $\sqrt{s} = 13$ TeV, *JHEP* 05 (2023) 227. [arXiv:2205.06709](#) [hep-ex], [https://doi.org/10.1007/JHEP05\(2023\)227](https://doi.org/10.1007/JHEP05(2023)227)
- [26] CMS Collaboration, Search for resonances in events with photon and jet final states in proton-proton collisions at $\sqrt{s} = 13$ TeV, *JHEP* 12 (2023) 189. [arXiv:2305.07998](#) [hep-ex], [https://doi.org/10.1007/JHEP12\(2023\)189](https://doi.org/10.1007/JHEP12(2023)189)
- [27] ATLAS Collaboration, Search for resonant leptoquark production via lepton-jet signatures in pp collisions at $\sqrt{s} = 13$ TeV and $\sqrt{s} = 13.6$ TeV with the ATLAS detector, *JHEP* 12 (2025) 180. [arXiv:2507.03650](#) [hep-ex], [https://doi.org/10.1007/JHEP12\(2025\)180](https://doi.org/10.1007/JHEP12(2025)180)
- [28] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, *JINST* 3 (2008) S08003. <https://doi.org/10.1088/1748-0221/3/08/S08003>
- [29] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider: a description of the detector configuration for Run 3, *JINST* 19 (2024) P05063. [arXiv:2305.16623](#) [physics.ins-det], <https://doi.org/10.1088/1748-0221/19/05/P05063>
- [30] G. Avoni, et al., The new LUCID-2 detector for luminosity measurement and monitoring in ATLAS, *JINST* 13 (2018) P07017. <https://doi.org/10.1088/1748-0221/13/07/P07017>
- [31] ATLAS Collaboration, Performance of the ATLAS trigger system in 2015, *Eur. Phys. J. C* 77 (2017) 317. [arXiv:1611.09661](#) [hep-ex], <https://doi.org/10.1140/epjc/s10052-017-4852-3>
- [32] ATLAS Collaboration, The ATLAS trigger system for LHC Run 3 and trigger performance in 2022, *JINST* 19 (2024) P06029. [arXiv:2401.06630](#) [hep-ex], <https://doi.org/10.1088/1748-0221/19/06/P06029>
- [33] ATLAS Collaboration, Software and computing for Run 3 of the ATLAS experiment at the LHC, *Eur. Phys. J. C* 85 (2025) 234. [arXiv:2404.06335](#) [hep-ex], <https://doi.org/10.1140/epjc/s10052-024-13701-w> Erratum: *Eur. Phys. J. C* 85 (2025) 907
- [34] ATLAS Collaboration, ATLAS data quality operations and performance for 2015–2018 data-taking, *JINST* 15 (2020) P04003. [arXiv:1911.04632](#) [physics.ins-det], <https://doi.org/10.1088/1748-0221/15/04/P04003>
- [35] C. Bierlich, S. Chakraborty, N. Desai, L. Gellersen, I. Helenius, P. Ilten, L. Lönnblad, S. Mrenna, S. Prestel, C.T. Preuss, T. Sjöstrand, P. Skands, M. Uthheim, R. Verheyen, A comprehensive guide to the physics and usage of PYTHIA 8.3, *SciPost Phys. Codebases* (2022) 8. [arXiv:2203.11601](#) [hep-ph], <https://doi.org/10.21468/SciPostPhysCodeB.8>
- [36] J. Pumplin, et al., New generation of parton distributions with uncertainties from global QCD analysis, *JHEP* 07 (2002) 012. [arXiv:hep-ph/0201195](#), <https://doi.org/10.1088/1126-6708/2002/07/012>
- [37] E. Bothmann, et al., Event generation with Sherpa 2.2, *SciPost Phys.* 7 (3) (2019) 034. [arXiv:1905.09127](#) [hep-ph], <https://doi.org/10.21468/SciPostPhys.7.3.034>
- [38] NNPDF Collaboration, R.D. Ball, et al., Parton distributions for the LHC run II, *JHEP* 04 (2015) 040. [arXiv:1410.8849](#) [hep-ph], [https://doi.org/10.1007/JHEP04\(2015\)040](https://doi.org/10.1007/JHEP04(2015)040)
- [39] S. Frixione, G. Ridolfi, P. Nason, A positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction, *JHEP* 09 (2007) 126. [arXiv:0707.3088](#) [hep-ph], <https://doi.org/10.1088/1126-6708/2007/09/126>
- [40] P. Nason, A new method for combining NLO QCD with shower Monte Carlo algorithms, *JHEP* 11 (2004) 040. [arXiv:hep-ph/0409146](#), <https://doi.org/10.1088/1126-6708/2004/11/040>
- [41] S. Frixione, P. Nason, C. Oleari, Matching NLO QCD computations with parton shower simulations: the POWHEG method, *JHEP* 11 (2007) 070. [arXiv:0709.2092](#) [hep-ph], <https://doi.org/10.1088/1126-6708/2007/11/070>
- [42] S. Alioli, P. Nason, C. Oleari, E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX, *JHEP* 06 (2010) 043. [arXiv:1002.2581](#) [hep-ph], [https://doi.org/10.1007/JHEP06\(2010\)043](https://doi.org/10.1007/JHEP06(2010)043)
- [43] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H.-S. Shao, T. Stelzer, P. Torrielli, M. Zaro, The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations, *JHEP* 07 (2014) 079. [arXiv:1405.0301](#) [hep-ph], [https://doi.org/10.1007/JHEP07\(2014\)079](https://doi.org/10.1007/JHEP07(2014)079)
- [44] T. Sjöstrand, S. Ask, J.R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C.O. Rasmussen, P.Z. Skands, An introduction to PYTHIA 8.2, *Comput. Phys. Commun.* 191 (2015) 159. [arXiv:1410.3012](#) [hep-ph], <https://doi.org/10.1016/j.cpc.2015.01.024>
- [45] D.J. Lange, The EvtGen particle decay simulation package, *Nucl. Instrum. Meth. A* 462 (2001) 152. [https://doi.org/10.1016/S0168-9002\(01\)00089-4](https://doi.org/10.1016/S0168-9002(01)00089-4)
- [46] ATLAS Collaboration, The ATLAS simulation infrastructure, *Eur. Phys. J. C* 70 (2010) 823. [arXiv:1005.4568](#) [physics.ins-det], <https://doi.org/10.1140/epjc/s10052-010-1429-9>
- [47] S. Agostinelli, et al., GEANT4 – a simulation toolkit, *Nucl. Instrum. Meth. A* 506 (2003) 250. [https://doi.org/10.1016/S0168-9002\(03\)01368-8](https://doi.org/10.1016/S0168-9002(03)01368-8)
- [48] ATLAS Collaboration, Emulating the impact of additional proton–proton interactions in the ATLAS simulation by presampling sets of inelastic Monte Carlo events, *Comput. Softw. Big Sci.* 6 (2022) 3. [arXiv:2102.09495](#) [hep-ex], <https://doi.org/10.1007/s41781-021-00062-2>
- [49] K. Werner, F.-M. Liu, T. Pierog, Parton ladder splitting and the rapidity dependence of transverse momentum spectra in deuteron–gold collisions at the BNL Relativistic Heavy Ion Collider, *Phys. Rev. C* 74 (2006) 044902. [arXiv:hep-ph/0506232](#), <https://doi.org/10.1103/PhysRevC.74.044902>

- [50] ATLAS Collaboration, Electron and photon efficiencies in LHC Run 2 with the ATLAS experiment, JHEP 05 (2024) 162. [arXiv:2308.13362](#) [hep-ex], [https://doi.org/10.1007/JHEP05\(2024\)162](https://doi.org/10.1007/JHEP05(2024)162)
- [51] ATLAS Collaboration, Electron and photon energy calibration with the ATLAS detector using LHC Run 2 data, JINST 19 (2024) P02009. [arXiv:2309.05471](#) [hep-ex], <https://doi.org/10.1088/1748-0221/19/02/P02009>
- [52] ATLAS Collaboration, Muon reconstruction and identification efficiency in ATLAS using the full Run 2 pp collision data set at $\sqrt{s} = 13$ TeV, Eur. Phys. J. C 81 (2021) 578. [arXiv:2012.00578](#) [hep-ex], <https://doi.org/10.1140/epjc/s10052-021-09233-2>
- [53] ATLAS Collaboration, Jet reconstruction and performance using particle flow with the ATLAS detector, Eur. Phys. J. C 77 (2017) 466. [arXiv:1703.10485](#) [hep-ex], <https://doi.org/10.1140/epjc/s10052-017-5031-2>
- [54] M. Cacciari, G.P. Salam, G. Soyez, The anti- k_t jet clustering algorithm, JHEP 04 (2008) 063. [arXiv:0802.1189](#) [hep-ph], <https://doi.org/10.1088/1126-6708/2008/04/063>
- [55] M. Cacciari, G.P. Salam, G. Soyez, FastJet user manual, Eur. Phys. J. C 72 (2012) 1896. [arXiv:1111.6097](#) [hep-ph], <https://doi.org/10.1140/epjc/s10052-012-1896-2>
- [56] ATLAS Collaboration, The performance of missing transverse momentum reconstruction and its significance with the ATLAS detector using 140 fb^{-1} of $\sqrt{s} = 13$ TeV pp collisions, Eur. Phys. J. C 85 (2025) 606. [arXiv:2402.05858](#) [hep-ex], <https://doi.org/10.1140/epjc/s10052-025-14062-8>
- [57] ATLAS Collaboration, Performance of pile-up mitigation techniques for jets in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector, Eur. Phys. J. C 76 (2016) 581. [arXiv:1510.03823](#) [hep-ex], <https://doi.org/10.1140/epjc/s10052-016-4395-z>
- [58] ATLAS Collaboration, Vertex Reconstruction Performance of the ATLAS Detector at $\sqrt{s} = 13$ TeV, ATL-PHYS-PUB-2015-026, 2015. <https://cds.cern.ch/record/2037717>
- [59] ATLAS Collaboration, Tools for estimating fake/non-prompt lepton backgrounds with the ATLAS detector at the LHC, JINST 18 (11) (2023) T11004. [arXiv:2211.16178](#) [hep-ex], <https://doi.org/10.1088/1748-0221/18/11/T11004>
- [60] ATLAS Collaboration, Electron and photon performance measurements with the ATLAS detector using the 2015–2017 LHC proton–proton collision data, JINST 14 (2019) P12006. [arXiv:1908.00005](#) [hep-ex], <https://doi.org/10.1088/1748-0221/14/12/P12006>
- [61] ATLAS Collaboration, Jet energy scale and resolution measured in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Eur. Phys. J. C 81 (2021) 689. [arXiv:2007.02645](#) [hep-ex], <https://doi.org/10.1140/epjc/s10052-021-09402-3>
- [62] ATLAS Collaboration, Preliminary luminosity calibration of the ATLAS 13.6 TeV data recorded in 2024 and combination with the 2022 and 2023 measurements, ATL-DAPR-PUB-2025-001, 2025. <https://cds.cern.ch/record/2948582>
- [63] 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], <https://doi.org/10.1140/epjc/s10052-011-1554-0> Erratum: Eur. Phys. J. C 73 (2013) 2501
- [64] ATLAS Collaboration, ATLAS Computing Acknowledgements, ATL-SOFT-PUB-2026-001, 2026. <https://cds.cern.ch/record/2952666>
- [65] CERN, CERN Open Data Policy for the LHC Experiments, Report Number CERN-OPEN-2020-013, 2020. <https://doi.org/10.17181/CERN.QXNK.8L2G>