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Combination of searches for Higgs boson decays into a photon and a massless dark photon using pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

ATLAS EXPERIMENT

The ATLAS collaboration

E-mail: atlas.publications@cern.ch

Abstract: A combination of searches for Higgs boson decays into a visible photon and a massless dark photon ($H \to \gamma\gamma_{\rm d}$) is presented using 139 fb^{-1} of proton-proton collision data at a centre-of-mass energy of $\sqrt{s} = 13$ TeV recorded by the ATLAS detector at the Large Hadron Collider. The observed (expected) 95% confidence level upper limit on the Standard Model Higgs boson decay branching ratio is determined to be $\mathcal{B}(H \to \gamma\gamma_{\rm d}) < 1.3\%$ (1.5)%. The search is also sensitive to higher-mass Higgs bosons decaying into the same final state. The observed (expected) 95% confidence level limit on the cross-section times branching ratio ranges from 16 fb (20 fb) for $m_H = 400$ GeV to 1.0 fb (1.5 fb) for $m_H = 3$ TeV. Results are also interpreted in the context of a minimal simplified model.

Keywords: Hadron-Hadron Scattering , Higgs Physics

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JHEP08(2024)153

Contents

1 Introduction

The existence of dark matter is supported by a series of astrophysical observations [1–8], but its unknown fundamental nature remains one of the central questions in particle physics. The discovery of a Higgs boson (H) [9, 10] with a mass of 125 GeV at the Large Hadron Collider (LHC) [11] has initiated an extensive effort aimed at investigating its possible connection with physics beyond the Standard Model (BSM). In particular, an upper limit of the order of 10% on the undetected Higgs boson decay branching ratio [12, 13] motivates searches for elusive BSM dark sector particles coupled to the Higgs boson. One example of such particles is an undetectable, massless dark photon (γ_{d}), which acts as the force carrier of an extra $\mathrm{U}(1)_{\mathrm{d}}$ gauge group of the dark sector. Dark photons may introduce dark matter self-interactions that can potentially solve the small-scale structure formation problem [14] and the PAMELA-Fermi-AMS2 anomaly [15]. They may also play a role in enhancing the light dark matter annihilation rate to reach the required phenomenological threshold, thereby making asymmetric dark matter scenarios phenomenologically viable [16]. A potential approach to search for this particle is through the Higgs boson decaying into a visible photon and a massless dark photon ($H \to \gamma\gamma_{\mathrm{d}}$) [17–23]. This scenario can involve either the Standard Model (SM) Higgs boson (H_{125}) or additional high-mass Higgs bosons predicted in some BSM theories (H_{BSM}). As the produced γ_{d} is invisible to the detector, its signature is characterised by missing transverse momentum, whose magnitude is denoted $E_{\mathrm{T}}^{\mathrm{miss}}$. The same behaviour is also exhibited by ultra-light dark photons with masses below the threshold to decay into SM particles or by the lightest supersymmetry particles in a cascaded Higgs-boson decay [24, 25]. In this paper, the Higgs boson is assumed to be produced via three different processes, including gluon-gluon fusion (ggF), vector-boson fusion (VBF), and in association with a Z boson (ZH), with the SM-like production cross-sections [26]. Their leading-order Feynman diagrams, including the Higgs boson decay, are shown in figure 1.

The CMS experiment reported searches for such Higgs boson decays exploiting the ZH production mechanism, with an integrated luminosity of 137 fb^{-1} [27], or via VBF production

JHEP08(2024)153

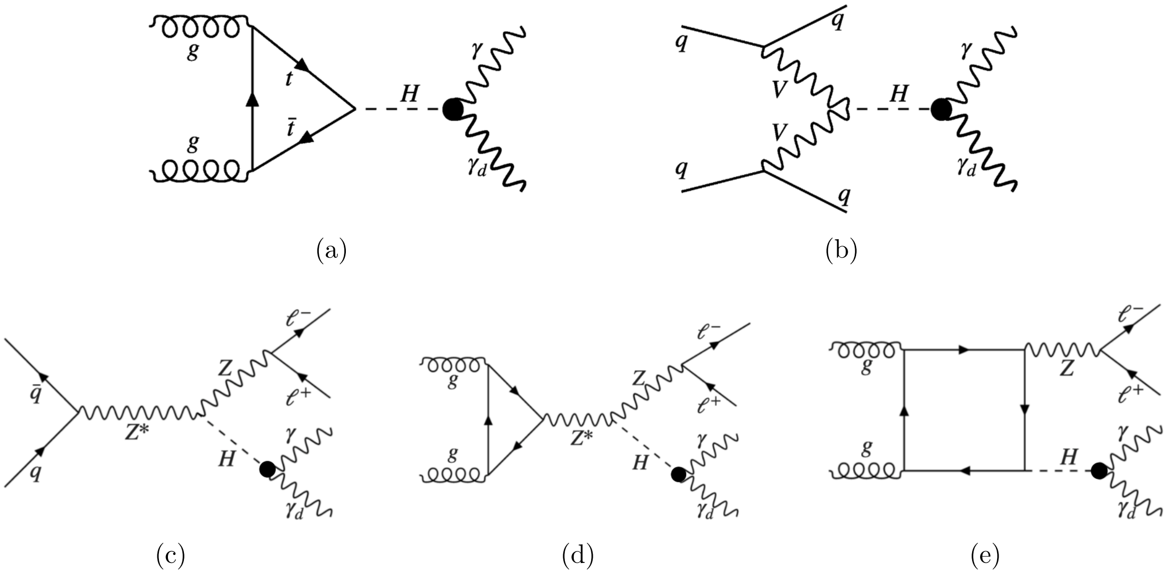


Figure 1. Leading-order Feynman diagrams for Higgs boson production decaying into a visible photon and a massless dark photon. The Higgs boson is produced via different processes: (a) ggF, (b) VBF, (c) $q\bar{q} \to ZH$ and (d) and (e) $gg \to ZH$.

with an integrated luminosity of $130\,\text{fb}^{-1}$ [28], where a combination of the two searches is also performed. Using the 8 TeV collision data, the ATLAS and CMS collaborations also reported various searches targeting the same $\gamma + E_{\text{T}}^{\text{miss}}$ final states [29–31].

This paper presents a combined search for $H \to \gamma\gamma_{\text{d}}$ produced in three distinct final-state signatures: $\gamma + E_{\text{T}}^{\text{miss}}$ + VBF jets (VBF channel[1]), $\gamma + E_{\text{T}}^{\text{miss}} + Z(\to \ell\ell, \ell = e, \mu)$ (ZH channel) and $\gamma + E_{\text{T}}^{\text{miss}}$ (ggF channel). The searches under consideration use the full LHC Run 2 data sample corresponding to an integrated luminosity of $139\,\text{fb}^{-1}$ [32, 33] of proton-proton (pp) collision data recorded with the ATLAS detector at a centre-of-mass energy of $\sqrt{s} = 13$ TeV. The results from the VBF channel are derived based on the analysis described in ref. [34], with an extension to higher-mass Higgs bosons and the inclusion of the ggF process contributions. The results for the ZH channel are taken from ref. [35]. The results for the ggF channel are based on the reinterpretation of the mono-γ results in ref. [36] using the RECAST technique [37]. Using the available results in the individual publications, the VBF and ZH channels are combined under the SM Higgs boson assumption, and the VBF and ggF channels are combined under the additional high-mass Higgs boson hypothesis in the narrow width approximation. The range of the H_{BSM} masses probed starts at 400 GeV, as the sensitivity of the ggF channel decreases for lower masses, and goes up to 3 TeV.

The ATLAS detector [38] is a multipurpose particle detector with cylindrical geometry. It consists of an inner tracking detector surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadronic sampling calorimeters, and a muon spectrometer with three toroidal superconducting magnets, providing a near

[1]In this paper, the term 'channel' is used to refer to the final-state signature that defines the event selections. The term 'process' refers to the production mode of the Higgs boson. Events from multiple processes can contribute to a given channel and they are all treated as signal events.

4π coverage in solid angle.[2] An extensive software suite [39] is used in data simulation, in the reconstruction and analysis of real and simulated data, in detector operations, and in the trigger [40] and data acquisition systems of the experiment.

Monte Carlo (MC) samples of simulated signal events for the ggF, VBF, and ZH via both the $q\bar{q} \to ZH$ and $gg \to ZH$ processes were generated at next-to-next-to-leading order (NNLO) for ggF, next-to-leading order (NLO) for VBF and $q\bar{q} \to ZH$ or leading order (LO) for $gg \to ZH$ in quantum chromodynamics (QCD) using POWHEG v2 [41–44], interfaced to PYTHIA 8 [45] for parton showering, hadronisation, and underlying event modelling, with the AZNLO set of tuned parameters [46]. The signal predictions from these MC samples were normalised to the NNLO (VBF and ZH) or next-to-NNLO (ggF) cross-section in QCD plus electroweak corrections at NLO [26, 47–56]. The Higgs boson mass was set to 125 GeV for the SM scenario. For the additional higher-mass Higgs boson scenarios, the mass takes values in the 400 GeV–1000 GeV range, in steps of 200 GeV, and in the 1000 GeV–3000 GeV range, in steps of 500 GeV. For the BSM Higgs boson samples, the detector response was simulated using a fast parameterised simulation of the ATLAS calorimeters and the full GEANT4 [57, 58] simulation was used for the SM Higgs boson samples. Additional pp collisions simulated using PYTHIA 8 [59] with the A3 set of tuned parameters [60] were overlaid to simulate the effect of multiple interactions in the same and neighbouring bunch crossings (pile-up). The simulated events are weighted to reproduce the distribution of the pile-up observed in the data. These samples are used to check the orthogonality of the channels and produce the final results. Descriptions of the data and simulation samples used to model backgrounds from SM processes can be found in refs. [34–36].

2 Description of the input analyses

The detailed information about the reconstruction, identification and calibration of physics objects used for analysis selections described below is given in refs. [34–36, 61–69]. A brief overview of the already published Run 2 searches relevant to the combination performed here is given below. The $H_{125} \to \gamma\gamma_{\mathrm{d}}$ search is performed in the VBF and ZH channels while $H_{\mathrm{BSM}} \to \gamma\gamma_{\mathrm{d}}$ is probed in the VBF and ggF channels. No significant deviation from the SM prediction is observed in any of these studies. All searches utilise the signature of an isolated photon and $E_{\mathrm{T}}^{\mathrm{miss}}$, with variations on the number of selected leptons and jets.

Events in the VBF channel were selected with the $E_{\mathrm{T}}^{\mathrm{miss}}$ trigger algorithm [70]. They are further required to have $E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV and two VBF jets. The VBF jets are the leading and subleading transverse momentum (p_{T}) jets, denoted j_1 and j_2, satisfying $p_{\mathrm{T}}^{j_1} > 60$ GeV and $p_{\mathrm{T}}^{j_2} > 50$ GeV, respectively. In addition, they are required to have a large pseudorapidity separation ($|\Delta\eta_{j_1 j_2}| > 3$, $\eta_{j_1} \cdot \eta_{j_2} < 0$), a large invariant mass ($m_{j_1 j_2} > 250$ GeV) and not be back-to-back in azimuthal angle ($\Delta\phi_{j_1 j_2} < 2$). An additional jet is allowed with $p_{\mathrm{T}}^{j_3} > 25$ GeV

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

JHEP08(2024)153

and a centrality[3] of $C_{j_3} < 0.7$. Events with a reconstructed lepton ($\ell = e, \mu$) are rejected. The photon must be isolated and lie in the electromagnetic calorimeter acceptance $|\eta^\gamma| < 2.37$ but not in the transition region ($1.37 < |\eta^\gamma| < 1.52$) between the barrel and endcap. These isolation and η requirements on the photon are used in all three analyses in addition to energy-related criteria specific to the different analyses. In the VBF analysis discussed here, the photon is required to have $15\,\text{GeV} < E_\text{T}^\gamma < \max(110\,\text{GeV}, 0.733 \times m_\text{T})$, where the transverse mass m_T is defined as $m_\text{T}(\gamma, E_\text{T}^\text{miss}) = \sqrt{2E_\text{T}^\gamma E_\text{T}^\text{miss}\left[1 - \cos(\phi_\gamma - \phi_{E_\text{T}^\text{miss}})\right]}$, bounded above by the Higgs boson mass. The centrality of the photon is required to be $C_\gamma > 0.4$. To increase the sensitivity of the search, events are categorised in ten signal regions (SRs) based on m_{jj} and m_T. The dominant backgrounds are $W(\to \ell\nu)\gamma +$jets events, in which the lepton from the W boson decay is lost if it falls outside of the acceptance, and $Z(\to \nu\nu)\gamma +$jets events. Four dedicated control regions (CRs) are designed to capture the background contributions from $W(\to e\nu)\gamma +$jets, $W(\to \mu\nu)\gamma +$jets, $Z(\to \nu\nu)\gamma +$jets and processes where electrons are misidentified as fake photons. Backgrounds due to jets misidentified as fake photons are estimated by using a data-driven method. Contribution from the ggF process was not considered in the original analysis [34] but is included for this combination. All SRs and CRs are simultaneously fitted using the profile likelihood fit method to constrain the background contributions and to extract the signal contribution.

In the ZH channel, $Z \to \ell^+\ell^-$ events were selected with single-lepton and dilepton triggers [71, 72]. Events are required to contain two same-flavour, oppositely charged (SFOC) leptons with invariant mass $76\,\text{GeV} < m_{\ell\ell} < 116\,\text{GeV}$. Furthermore, they are required to have $E_\text{T}^\text{miss} > 60\,\text{GeV}$ and a photon with $E_\text{T}^\gamma > 25\,\text{GeV}$ satisfying the isolation and η selections. The selected objects are required to satisfy $\Delta\phi(E_\text{T}^\text{miss}, p_\text{T}^{\ell\ell\gamma}) > 2.4$ and $m_{\ell\ell\gamma} > 100\,\text{GeV}$. Events with a third lepton with $p_\text{T} > 10\,\text{GeV}$ or any b-tagged jet (77% working point [73]) are rejected. To enhance the sensitivity of the search, a boosted decision tree (BDT) algorithm is applied to separate the signal from the backgrounds. The dominant background contribution comes from E_T^miss mismeasurement in mainly $Z\gamma +$jets and $Z +$jets processes due to undetected particles or hadronic jets not fully contained in the detector acceptance. Another major background is from electrons misidentified as photons in the SM diboson processes. Both of these backgrounds are estimated with data-driven techniques. The irreducible $VV\gamma$ ($V = W, Z$) background with both V decaying leptonically is constrained in the fit by a dedicated CR. Backgrounds from top quark and Higgs boson production are found to be minor and estimated from MC simulations. Contributions from ggF and VBF produced Higgs boson processes to the ZH channel are assumed to be negligible and therefore not considered. A simultaneous fit exploiting the distribution of the BDT discriminant and the single bin $VV\gamma$ CR is performed.

Events in the ggF channel were selected with a single photon trigger with a threshold of $E_\text{T}^\gamma > 140\,\text{GeV}$ [71]. Events are required to have $E_\text{T}^\text{miss} > 200\,\text{GeV}$ and at least one photon satisfying the isolation and η selections. The leading photon in the events is required to fulfil the following criteria: the transverse energy $E_\text{T}^\gamma > 150\,\text{GeV}$, the separation between its

[3]The centrality of an object i in this channel is defined as $C_i = \exp\left[-\frac{4}{(\eta_{j_1}-\eta_{j_2})^2}\left(\eta_i - \frac{\eta_{j_1}+\eta_{j_2}}{2}\right)^2\right]$. When the object i is centred between the two jets, C_i reaches the maximum value of 1. When the object i is aligned with one of the two jets, C_i decreases to $1/e$.

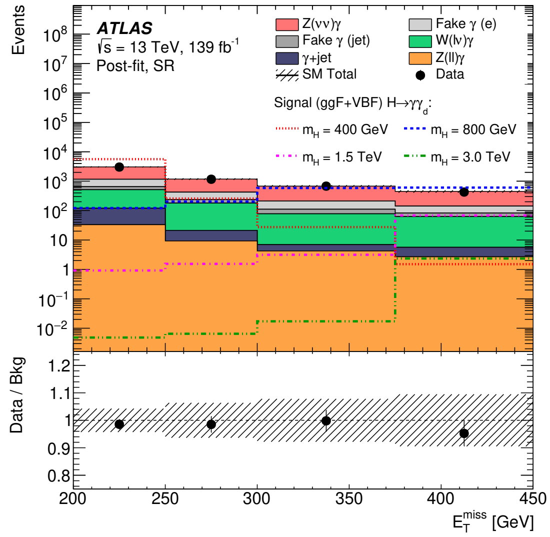


Figure 2. Number of events in each $E_{\mathrm{T}}^{\mathrm{miss}}$ bin in the SR of the ggF channel after a background-only fit. The signals $H_{\mathrm{BSM}} \to \gamma\gamma_{\mathrm{d}}$ are superimposed onto the observed data and the expected SM background. The ggF and VBF processes are considered, assuming $\mathcal{B}(H_{\mathrm{BSM}} \to \gamma\gamma_{\mathrm{d}}) = 5\%$ and the production cross-sections from ref. [26]. The error bars on data represent the statistical uncertainty, and the shaded band includes statistical and systematic uncertainties determined from the fit. The lower panel shows the ratio of observed data to expected SM background yields. The last bin includes the overflow. This analysis is reinterpreted from the mono-γ results in ref. [36].

extrapolated origin and primary vertex of the event along the beam axis $|\Delta z_\gamma| < 250\,\mathrm{mm}$ and $\Delta\phi(\gamma, E_{\mathrm{T}}^{\mathrm{miss}}) > 0.4$. At most one jet is allowed in the selection if $p_{\mathrm{T}}^{j} > 30\,\mathrm{GeV}$, $|\eta_j| < 4.5$ and $\Delta\phi(j, E_{\mathrm{T}}^{\mathrm{miss}}) > 0.4$. Events that contain leptons ($\ell = e, \mu$, hadronically decaying τ) are rejected. To improve the sensitivity, four SRs are defined corresponding to different $E_{\mathrm{T}}^{\mathrm{miss}}$ ranges. The SM background arises from several processes with either true photons or fake photons from misidentified electrons or jets. The background with true photons is dominated by the SM $Z(\to \nu\nu)\gamma$ process. Secondary contributions come from $\gamma +$jets events and from $W(\to \ell\nu)\gamma$ and $Z(\to \ell\ell)\gamma$ production with unidentified electrons, muons or with hadronically decaying τ-leptons. Four CRs are defined to estimate the contributions of these true-photon processes in the SRs through the profile likelihood fit. The fake photon backgrounds are estimated with control samples that contain electrons or jets, scaled by misidentification rates determined from data. Signal contributions from both the ggF and VBF Higgs boson processes are considered. Figure 2 shows the $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution in the SR after a background-only fit to data. Signals with higher mass tend to have larger $E_{\mathrm{T}}^{\mathrm{miss}}$. The highest $E_{\mathrm{T}}^{\mathrm{miss}}$ SR captures about 30% of the events for signal benchmarks with $m_H \geq 1.0\,\mathrm{TeV}$.

Theoretical uncertainties due to the QCD factorisation and renormalisation scales, and the choice of parton distribution functions are included. Uncertainties in initial- and final-state radiation due to the choice of parton shower parameters are estimated through simulations with alternative sets of tuned parameters.

The event selections for the input channels are summarised in table 1. To perform the combination, a few adjustments are made. In the VBF channel, the contribution of the ggF

JHEP08(2024)153

Channels	VBF	ZH	ggF
Trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$	Lepton(s)	Photon
Photons	$= 1$, $C_\gamma > 0.4$	$= 1$	≥ 1
E_{T}^{γ} [GeV]	$\in (15, \max(110, 0.733 \times m_{\mathrm{T}}))$	> 25	> 150
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 150	> 60	> 200
Jets	2 or 3, $m_{j_1 j_2} > 250\,\mathrm{GeV}$, $\lvert\Delta\eta_{j_1 j_2}\rvert > 3$	≤ 2	≤ 1
	$\eta_{j_1} \cdot \eta_{j_2} < 0$, $\Delta\phi_{j_1 j_2} < 2$, $C_{j_3} < 0.7$		
Leptons	$= 0$ (e, μ)	$= 2$, SFOC	$= 0$ (e, μ, τ)
		$m_{\ell\ell} \in (76, 116)$ GeV	
Disc. variables	m_{jj} and m_{T} in SR and 4 CRs	BDT score and 1 CR	$E_{\mathrm{T}}^{\mathrm{miss}}$
Reference	[34]	[35]	[36]
Processes considered in the combination	VBF, ggF	ZH	ggF, VBF
Combination scenario	SM, BSM	SM	BSM

Table 1. Summary of the main event selections, discriminating variables and processes considered in the input channels. The definition of the variables is provided in the text.

process to the BSM Higgs boson decay search is included using the RECAST technique. The contribution to the signal yields is up to 30% for the low masses and decreases to 1% for the high masses. Additional BSM Higgs boson signal samples are generated to align with the masses probed in the ggF analysis. The fit regions used in the three analyses are either orthogonal due to variations in the number and type of physics objects required in their final states or have a negligible number of overlapping events due to different jet algorithms being used. They are therefore treated as statistically independent.

3 Statistical combination

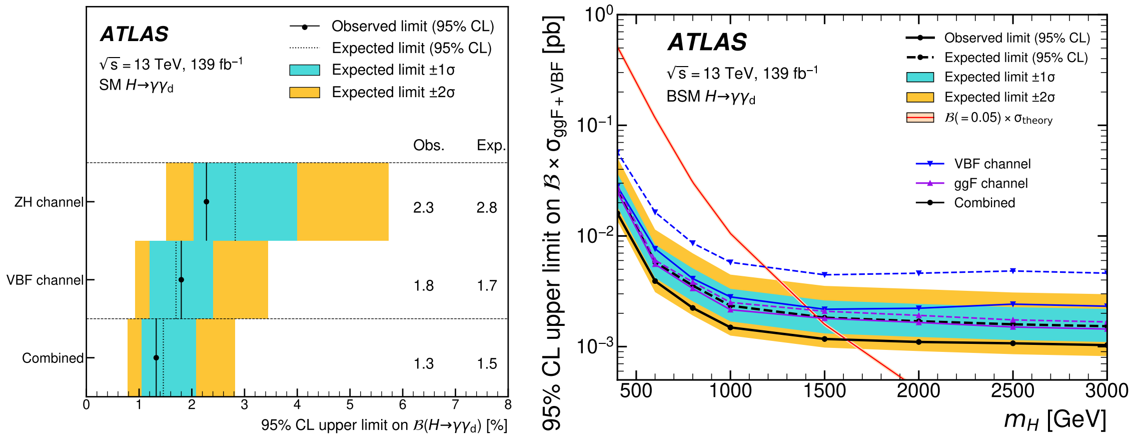
The results of the combination presented in this paper are obtained from a likelihood function $L(\mu, \vec{\theta})$, where μ denotes the parameter of interest (POI) of the model, and $\vec{\theta}$ constitutes a set of nuisance parameters, encoding the systematic uncertainty contributions and background normalisation factors that are constrained by CRs in data. The final likelihood function $L(\mu, \vec{\theta})$ is the product of the likelihoods from individual channels within the combination, which are themselves products of likelihoods computed from the final observables in various categories in a single analysis. To derive upper limits on the POI, the profile-likelihood-ratio test statistic is used with the $\mathrm{CL_s}$ method [74] following the asymptotic formulae [75].

All systematic uncertainties that are considered in the individual analyses are included in the combination and those that stem from common sources are treated as correlated among the input searches. A complete discussion of their sources can be found in the individual channel publications [34–36]. Systematic uncertainties related to the data-taking conditions, such as those associated with the integrated luminosity and the modelling of pile-up, are treated as correlated. Experimental uncertainties related to physics objects used by multiple searches are treated as correlated where appropriate, with the following exceptions. Uncertainties related to the same object but implemented with different reduced uncertainty schemes are treated as uncorrelated. In addition, uncertainties that were heavily constrained or pulled in the original input channel are treated as uncorrelated, and the impact on the final upper limits would be $\leq 3\%$ if they were correlated. These constraining powers come from the special phase space probed in certain channels and therefore passing these constraints to the other channels should be avoided. Uncertainties related to background modelling are considered as uncorrelated since the composition and phase space of the backgrounds are different. Uncertainties related to signal modelling, stemming from the choice of parton distribution functions and QCD calculations, have minor impact on the final results and are treated as uncorrelated. Ignoring correlations of the systematic uncertainties between the input channels is found to impact the upper limits by $\leq 2\%$. The $H_{125} \to \gamma\gamma_{\rm d}$ search has similar impacts from the data statistical (66%) and systematic (75%) uncertainties, where the values are relative to the total uncertainty. The dominant contributions to the systematic uncertainties stem from the background modelling (47%), jet and $E_{\rm T}^{\rm miss}$ calibration (40%), followed by the MC statistical uncertainty (36%) and fake-background estimate (35%). All of these impacts are evaluated from the quadratic differences of the fitted errors in the POI before and after fixing the considered nuisance parameters to their best-fit values. In the $H_{\rm BSM} \to \gamma\gamma_{\rm d}$ search, the statistical uncertainty increases from 75% to 86% for the higher Higgs boson mass assumptions. The dominant contributions come from the fake-background estimate, which decreases from 52% to 29% depending on the mass, and background modelling uncertainty, ranging from 27%–38%. The uncertainties related to jet and $E_{\rm T}^{\rm miss}$, leptons, and MC sample size share a similar $\sim 20\%$ impact each.

4 Results and interpretation

This combination yields an observed (expected) 95% confidence level (CL) upper limit on the branching ratio $\mathcal{B}(H_{125} \to \gamma\gamma_{\rm d})$ is 1.3% (1.5%). Relative to the most stringent result from the VBF analysis, this combination brings an improvement of 29% (14%) in the sensitivity. The limits are displayed in figure 3(a). The observed (expected) 95% CL upper limits on the BSM Higgs boson production cross-section times $\mathcal{B}(H_{\rm BSM} \to \gamma\gamma_{\rm d})$ as a function of the BSM Higgs boson mass m_H, obtained from this combination, are shown in figure 3(b). The observed (expected) limit ranges from 16 fb (26 fb) for $m_H = 400$ GeV to 1.0 fb (1.5 fb) for $m_H = 3000$ GeV. Assuming a branching ratio $\mathcal{B}(H_{\rm BSM} \to \gamma\gamma_{\rm d})$ of 5% and theoretically predicted cross-sections for $H_{\rm BSM}$ production from ref. [26], masses of $H_{\rm BSM}$ below around 1600 GeV (1500 GeV) are excluded. Relative to the leading ggF channel, the combination with the VBF channel yields an improvement of 33% (14%) on the cross-section times $\mathcal{B}(H_{\rm BSM} \to \gamma\gamma_{\rm d})$ at $m_H = 1500$ GeV.

Additionally, the results on $\mathcal{B}(H_{125} \to \gamma\gamma_{\rm d})$ are interpreted under a minimal simplified model described in refs. [17, 76]. The model assumes the SM prediction for the cross-section and its systematic uncertainties for all Higgs boson production modes. It introduces a generic



(a) (b)

Figure 3. Observed and expected 95% CL upper limits on (a) the branching ratio $\mathcal{B}(H_{125} \to \gamma\gamma_{\rm d})$ and (b) $\mathcal{B}(H_{\rm BSM} \to \gamma\gamma_{\rm d})$ times the BSM Higgs boson ggF + VBF production cross-section $\sigma_{\rm ggF+VBF}$ as a function of the Higgs boson mass m_H. Results obtained from the input channels are overlaid. The expected limit and the corresponding error bands are derived assuming the absence of the $H \to \gamma\gamma_{\rm d}$ process and with all nuisance parameters profiled to the observed data. The theory predictions and their error band are taken from ref. [26] assuming a branching ratio $\mathcal{B}(H_{\rm BSM} \to \gamma\gamma_{\rm d}) = 5\%$.

messenger sector consisting of one left-doublet and one right-singlet of the $\mathrm{SU}(2)_{\rm L}$ gauge group connecting the dark and the observable sectors. A minimal scenario can be realised under mass universality in the left and right messenger sector with a mixing parameter ξ. Under this scenario, the messenger sector couples to both U(1) and $\mathrm{U}(1)_{\rm d}$ gauge fields, allowing three Higgs boson decay modes: $\gamma\gamma_{\rm d}$, $\gamma_{\rm d}\gamma_{\rm d}$ and $\gamma\gamma$. Their branching ratios are all interconnected and can be expressed using two free, dimensionless parameters: ξ and the fine structure constant $\alpha_{\rm d}$ associated with the $\mathrm{U}(1)_{\rm d}$ gauge group [76], whose values are zero in the SM. Hence, setting upper limits on, or measuring the value of the branching ratio of the Higgs boson decaying into $\gamma\gamma$, $\gamma\gamma_{\rm d}$, and $\gamma_{\rm d}\gamma_{\rm d}$ can be translated into restrictions on the allowed parameter space in the $(\alpha_{\rm d}, \xi)$ plane. The range $0 < \alpha_{\rm d} < 1$ and $0 \leq \xi < 1$ is explored in this study. An extra parameter $\chi = \pm 1$ accounts for the relative sign of the new physics and SM contributions in the amplitudes of the $H_{125} \to \gamma\gamma$ and $H_{125} \to gg$ decays. It provides two scenarios with either constructive ($\chi = +1$) or destructive ($\chi = -1$) interference between the messenger sector and the SM particles affecting the $\mathcal{B}(H_{125} \to \gamma\gamma)$.

Figure 4 shows the observed exclusion limits derived from the combination of the VBF and ZH channels for $H_{125} \to \gamma\gamma_{\rm d}$ and from the reinterpretation of the ATLAS search for $H_{125} \to$ invisible [77]. In addition, the ATLAS measurement of $\mathcal{B}(H_{125} \to \gamma\gamma) = 0.247^{+0.022}_{-0.020}\%$ [12] provides a one standard deviation (σ) upper bound. The SM predicted $\mathcal{B}(H_{125} \to \gamma\gamma)$ defines a region in the $(\alpha_{\rm d}, \xi)$ parameter space of the minimal model that is not allowed when assuming a positive interference from the messenger sector in the $\gamma\gamma$ final state ($\chi = +1$).

From the reinterpretation of the $\mathcal{B}(H_{125} \to \text{invisible})$ result in terms of a $H_{125} \to \gamma_{\rm d}\gamma_{\rm d}$ signal, values down to about $\xi \simeq 0.7$ at $\alpha_{\rm d} = 1$ are excluded for $\chi = +1$. The $H_{125} \to \gamma\gamma_{\rm d}$ combination presented here provides additional sensitivity in the low $\alpha_{\rm d}$ region, which is also disfavoured by the $\mathcal{B}(H_{125} \to \gamma\gamma)$ measurement. The $\chi = -1$ scenario has also been investigated but no constraints can be placed in this case.

JHEP08(2024)153

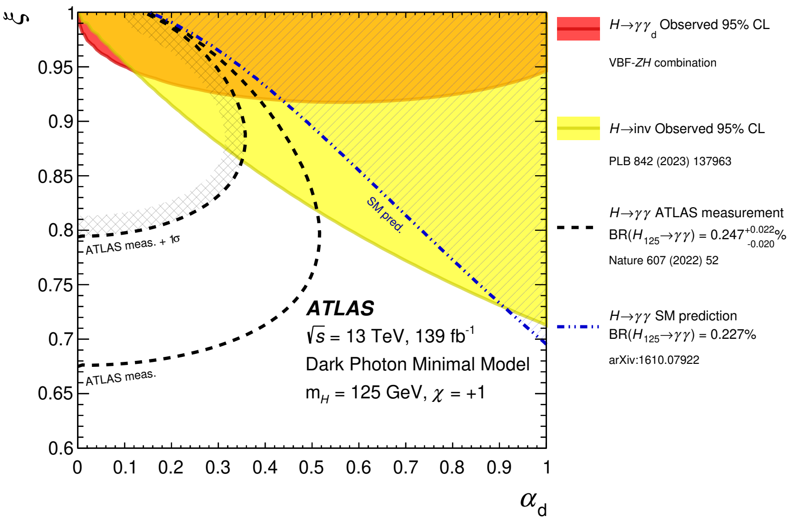


Figure 4. Observed 95% CL exclusion regions in the (α_d, ξ) parameter space from the VBF-ZH combination of $H_{125} \to \gamma\gamma_\mathrm{d}$ searches (dark coloured area) and the reinterpretation of the ATLAS measured limit of $\mathcal{B}(H_{125} \to \text{invisible})$ as $H_{125} \to \gamma_\mathrm{d}\gamma_\mathrm{d}$ (light coloured area). Both the central value (dashed line) and the $+1\sigma$ upper bound (dashed-hashed line) show the less favoured (α_d, ξ) plane obtained from the current ATLAS measurement of $\mathcal{B}(H_{125} \to \gamma\gamma)$. The dash-dotted line and the associated dashed area show the parameter space that is not allowed by the SM $\mathcal{B}(H_{125} \to \gamma\gamma)$ predictions assuming positive interference with the minimal messenger sector. The parameter $\chi = +1$ parameterises the relative sign of the new physics and SM contributions in the amplitudes of the $H_{125} \to \gamma\gamma$ and $H_{125} \to gg$ decays.

5 Conclusion

In conclusion, this paper reports a combined search for $H \to \gamma\gamma_\mathrm{d}$ produced in ggF, VBF, and ZH processes using $139\,\mathrm{fb}^{-1}$ of pp collision data at $\sqrt{s} = 13\,\mathrm{TeV}$ collected by the ATLAS detector at the LHC. Various Higgs boson mass assumptions are probed including the SM value of 125 GeV and higher values ranging from 400 GeV to 3 TeV. The combined analysis sets an observed (expected) 95% CL upper limit on $\mathcal{B}(H_{125} \to \gamma\gamma_\mathrm{d})$ at 1.3 (1.5)%. The observed (expected) 95% confidence level limit on the cross-section times branching ratio ranges from 16 fb (26 fb) for $m_H = 400\,\mathrm{GeV}$ to 1.0 fb (1.5 fb) for $m_H = 3\,\mathrm{TeV}$. This study provides the most stringent constraints on Higgs bosons decaying into a photon and a massless dark photon to date. The results are also interpreted in the context of a minimal simplified model, providing complementary exclusion in the parameter space obtained from other searches for this model.

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JHEP08(2024)153

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JHEP08(2024)153

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References

[1] E. Corbelli and P. Salucci, *The Extended Rotation Curve and the Dark Matter Halo of M33*, *Mon. Not. Roy. Astron. Soc.* **311** (2000) 441 [astro-ph/9909252] [INSPIRE].

[2] V.C. Rubin, N. Thonnard and W.K. Ford Jr., *Rotational properties of 21 SC galaxies with a large range of luminosities and radii, from NGC 4605 ($R = 4$ kpc) to UGC 2885 ($R = 122$ kpc)*, *Astrophys. J.* **238** (1980) 471 [INSPIRE].

[3] K.G. Begeman, A.H. Broeils and R.H. Sanders, *Extended rotation curves of spiral galaxies: Dark haloes and modified dynamics*, *Mon. Not. Roy. Astron. Soc.* **249** (1991) 523 [INSPIRE].

[4] WMAP collaboration, *Nine-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Cosmological Parameter Results*, *Astrophys. J. Suppl.* **208** (2013) 19 [arXiv:1212.5226] [INSPIRE].

[5] Planck collaboration, *Planck 2018 results. Part I. Overview and the cosmological legacy of Planck*, *Astron. Astrophys.* **641** (2020) A1 [arXiv:1807.06205] [INSPIRE].

[6] V. Trimble, *Existence and Nature of Dark Matter in the Universe*, *Ann. Rev. Astron. Astrophys.* **25** (1987) 425 [INSPIRE].

[7] G. Bertone, D. Hooper and J. Silk, *Particle dark matter: Evidence, candidates and constraints*, *Phys. Rep.* **405** (2005) 279 [hep-ph/0404175] [INSPIRE].

[8] J.L. Feng, *Dark Matter Candidates from Particle Physics and Methods of Detection*, *Ann. Rev. Astron. Astrophys.* **48** (2010) 495 [arXiv:1003.0904] [INSPIRE].

[9] ATLAS collaboration, *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, Phys. Lett. B **716** (2012) 1 [arXiv:1207.7214] [INSPIRE].

[10] CMS collaboration, *Observation of a New Boson at a Mass of* 125 *GeV with the CMS Experiment at the LHC*, Phys. Lett. B **716** (2012) 30 [arXiv:1207.7235] [INSPIRE].

[11] L. Evans and P. Bryant, *LHC Machine*, 2008 *JINST* **3** S08001 [INSPIRE].

[12] ATLAS collaboration, *A detailed map of Higgs boson interactions by the ATLAS experiment ten years after the discovery*, Nature **607** (2022) 52 [*Erratum ibid.* **612** (2022) E24] [arXiv:2207.00092] [INSPIRE].

[13] CMS collaboration, *A portrait of the Higgs boson by the CMS experiment ten years after the discovery*, Nature **607** (2022) 60 [arXiv:2207.00043] [INSPIRE].

[14] J.J. Fan, A. Katz, L. Randall and M. Reece, *Dark-Disk Universe*, Phys. Rev. Lett. **110** (2013) 211302 [arXiv:1303.3271] [INSPIRE].

[15] N. Arkani-Hamed, D.P. Finkbeiner, T.R. Slatyer and N. Weiner, *A Theory of Dark Matter*, Phys. Rev. D **79** (2009) 015014 [arXiv:0810.0713] [INSPIRE].

[16] K.M. Zurek, *Asymmetric Dark Matter: Theories, Signatures, and Constraints*, Phys. Rep. **537** (2014) 91 [arXiv:1308.0338] [INSPIRE].

[17] E. Gabrielli, M. Heikinheimo, B. Mele and M. Raidal, *Dark photons and resonant monophoton signatures in Higgs boson decays at the LHC*, Phys. Rev. D **90** (2014) 055032 [arXiv:1405.5196] [INSPIRE].

[18] S. Biswas, E. Gabrielli, M. Heikinheimo and B. Mele, *Dark-Photon searches via Higgs-boson production at the LHC*, Phys. Rev. D **93** (2016) 093011 [arXiv:1603.01377] [INSPIRE].

[19] E. Gabrielli and M. Raidal, *Exponentially spread dynamical Yukawa couplings from nonperturbative chiral symmetry breaking in the dark sector*, Phys. Rev. D **89** (2014) 015008 [arXiv:1310.1090] [INSPIRE].

[20] K.J. Kelly and Y.-D. Tsai, *Proton fixed-target scintillation experiment to search for millicharged dark matter*, Phys. Rev. D **100** (2019) 015043 [arXiv:1812.03998] [INSPIRE].

[21] J. Jaeckel, M. Jankowiak and M. Spannowsky, *LHC probes the hidden sector*, Phys. Dark Univ. **2** (2013) 111 [arXiv:1212.3620] [INSPIRE].

[22] H. Beauchesne and C.-W. Chiang, *Observability of the Higgs boson decay to a photon and a dark photon*, Phys. Rev. D **108** (2023) 015018 [arXiv:2304.04165] [INSPIRE].

[23] H. Beauchesne and C.-W. Chiang, *Is the Decay of the Higgs Boson to a Photon and a Dark Photon Currently Observable at the LHC?*, Phys. Rev. Lett. **130** (2023) 141801 [arXiv:2205.10976] [INSPIRE].

[24] A. Djouadi and M. Drees, *Higgs boson decays into light gravitinos*, Phys. Lett. B **407** (1997) 243 [hep-ph/9703452] [INSPIRE].

[25] C. Petersson, A. Romagnoni and R. Torre, *Higgs Decay with Monophoton + MET Signature from Low Scale Supersymmetry Breaking*, JHEP **10** (2012) 016 [arXiv:1203.4563] [INSPIRE].

[26] LHC Higgs Cross Section Working Group, *Handbook of LHC Higgs Cross Sections. Part 4. Deciphering the Nature of the Higgs Sector*, arXiv:1610.07922 [DOI:10.23731/CYRM-2017-002] [INSPIRE].

[27] CMS collaboration, *Search for dark photons in decays of Higgs bosons produced in association with Z bosons in proton-proton collisions at $\sqrt{s} = 13$ TeV*, JHEP **10** (2019) 139 [arXiv:1908.02699] [INSPIRE].

[28] CMS collaboration, *Search for dark photons in Higgs boson production via vector boson fusion in proton-proton collisions at $\sqrt{s} = 13$ TeV*, JHEP **03** (2021) 011 [arXiv:2009.14009] [INSPIRE].

[29] ATLAS collaboration, *Search for new phenomena in events with a photon and missing transverse momentum in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector*, Phys. Rev. D **91** (2015) 012008 [*Erratum ibid.* **92** (2015) 059903] [arXiv:1411.1559] [INSPIRE].

[30] CMS collaboration, *Search for new phenomena in monophoton final states in proton-proton collisions at $\sqrt{s} = 8$ TeV*, Phys. Lett. B **755** (2016) 102 [arXiv:1410.8812] [INSPIRE].

[31] CMS collaboration, *Search for exotic decays of a Higgs boson into undetectable particles and one or more photons*, Phys. Lett. B **753** (2016) 363 [arXiv:1507.00359] [INSPIRE].

[32] ATLAS collaboration, *Luminosity determination in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector at the LHC*, Eur. Phys. J. C **83** (2023) 982 [arXiv:2212.09379] [INSPIRE].

[33] G. Avoni et al., *The new LUCID-2 detector for luminosity measurement and monitoring in ATLAS*, 2018 JINST **13** P07017 [INSPIRE].

[34] ATLAS collaboration, *Observation of electroweak production of two jets in association with an isolated photon and missing transverse momentum, and search for a Higgs boson decaying into invisible particles at* 13 TeV *with the ATLAS detector*, Eur. Phys. J. C **82** (2022) 105 [arXiv:2109.00925] [INSPIRE].

[35] ATLAS collaboration, *Search for dark photons from Higgs boson decays via ZH production with a photon plus missing transverse momentum signature from pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, JHEP **07** (2023) 133 [arXiv:2212.09649] [INSPIRE].

[36] ATLAS collaboration, *Search for dark matter in association with an energetic photon in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, JHEP **02** (2021) 226 [arXiv:2011.05259] [INSPIRE].

[37] K. Cranmer and I. Yavin, *RECAST: Extending the Impact of Existing Analyses*, JHEP **04** (2011) 038 [arXiv:1010.2506] [INSPIRE].

[38] ATLAS collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, 2008 JINST **3** S08003 [INSPIRE].

[39] ATLAS collaboration, *Software and computing for Run 3 of the ATLAS experiment at the LHC*, arXiv:2404.06335 [INSPIRE].

[40] ATLAS collaboration, *Performance of the ATLAS Trigger System in 2015*, Eur. Phys. J. C **77** (2017) 317 [arXiv:1611.09661] [INSPIRE].

[41] P. Nason and C. Oleari, *NLO Higgs boson production via vector-boson fusion matched with shower in POWHEG*, JHEP **02** (2010) 037 [arXiv:0911.5299] [INSPIRE].

[42] S. Alioli, P. Nason, C. Oleari and E. Re, *A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX*, JHEP **06** (2010) 043 [arXiv:1002.2581] [INSPIRE].

[43] P. Nason, *A New method for combining NLO QCD with shower Monte Carlo algorithms*, JHEP **11** (2004) 040 [hep-ph/0409146] [INSPIRE].

[44] S. Frixione, P. Nason and C. Oleari, *Matching NLO QCD computations with Parton Shower simulations: the POWHEG method*, JHEP **11** (2007) 070 [arXiv:0709.2092] [INSPIRE].

JHEP08(2024)153

[45] T. Sjöstrand et al., *An introduction to PYTHIA 8.2*, *Comput. Phys. Commun.* **191** (2015) 159 [arXiv:1410.3012] [INSPIRE].

[46] ATLAS collaboration, *Measurement of the Z/γ^* boson transverse momentum distribution in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector*, *JHEP* **09** (2014) 145 [arXiv:1406.3660] [INSPIRE].

[47] C. Anastasiou et al., *High precision determination of the gluon fusion Higgs boson cross-section at the LHC*, *JHEP* **05** (2016) 058 [arXiv:1602.00695] [INSPIRE].

[48] C. Anastasiou, C. Duhr, F. Dulat, F. Herzog and B. Mistlberger, *Higgs Boson Gluon-Fusion Production in QCD at Three Loops*, *Phys. Rev. Lett.* **114** (2015) 212001 [arXiv:1503.06056] [INSPIRE].

[49] F. Dulat, A. Lazopoulos and B. Mistlberger, *iHixs 2 — Inclusive Higgs cross sections*, *Comput. Phys. Commun.* **233** (2018) 243 [arXiv:1802.00827] [INSPIRE].

[50] R.V. Harlander and K.J. Ozeren, *Finite top mass effects for hadronic Higgs production at next-to-next-to-leading order*, *JHEP* **11** (2009) 088 [arXiv:0909.3420] [INSPIRE].

[51] R.V. Harlander and K.J. Ozeren, *Top mass effects in Higgs production at next-to-next-to-leading order QCD: Virtual corrections*, *Phys. Lett. B* **679** (2009) 467 [arXiv:0907.2997] [INSPIRE].

[52] R.V. Harlander, H. Mantler, S. Marzani and K.J. Ozeren, *Higgs production in gluon fusion at next-to-next-to-leading order QCD for finite top mass*, *Eur. Phys. J. C* **66** (2010) 359 [arXiv:0912.2104] [INSPIRE].

[53] A. Pak, M. Rogal and M. Steinhauser, *Finite top quark mass effects in NNLO Higgs boson production at LHC*, *JHEP* **02** (2010) 025 [arXiv:0911.4662] [INSPIRE].

[54] S. Actis, G. Passarino, C. Sturm and S. Uccirati, *NLO Electroweak Corrections to Higgs Boson Production at Hadron Colliders*, *Phys. Lett. B* **670** (2008) 12 [arXiv:0809.1301] [INSPIRE].

[55] S. Actis, G. Passarino, C. Sturm and S. Uccirati, *NNLO computational techniques: The cases $H \to \gamma\gamma$ and $H \to gg$*, *Nucl. Phys. B* **811** (2009) 182 [arXiv:0809.3667] [INSPIRE].

[56] M. Bonetti, K. Melnikov and L. Tancredi, *Higher order corrections to mixed QCD-EW contributions to Higgs boson production in gluon fusion*, *Phys. Rev. D* **97** (2018) 056017 [*Erratum ibid.* **97** (2018) 099906] [arXiv:1801.10403] [INSPIRE].

[57] GEANT4 collaboration, *GEANT4 — a simulation toolkit*, *Nucl. Instrum. Meth. A* **506** (2003) 250 [INSPIRE].

[58] ATLAS collaboration, *The ATLAS Simulation Infrastructure*, *Eur. Phys. J. C* **70** (2010) 823 [arXiv:1005.4568] [INSPIRE].

[59] T. Sjostrand, S. Mrenna and P.Z. Skands, *A Brief Introduction to PYTHIA 8.1*, *Comput. Phys. Commun.* **178** (2008) 852 [arXiv:0710.3820] [INSPIRE].

[60] ATLAS collaboration, *The Pythia 8 A3 tune description of ATLAS minimum bias and inelastic measurements incorporating the Donnachie-Landshoff diffractive model*, ATL-PHYS-PUB-2016-017 (2016).

[61] ATLAS collaboration, *Electron and photon performance measurements with the ATLAS detector using the 2015–2017 LHC proton-proton collision data*, 2019 *JINST* **14** P12006 [arXiv:1908.00005] [INSPIRE].

[62] ATLAS collaboration, *Tools for estimating fake/non-prompt lepton backgrounds with the ATLAS detector at the LHC*, 2023 *JINST* **18** T11004 [arXiv:2211.16178] [INSPIRE].

[63] ATLAS collaboration, *Electron and photon energy calibration with the ATLAS detector using LHC Run 2 data*, 2024 *JINST* **19** P02009 [arXiv:2309.05471] [INSPIRE].

[64] ATLAS collaboration, *Electron and photon efficiencies in LHC Run 2 with the ATLAS experiment*, *JHEP* **05** (2024) 162 [arXiv:2308.13362] [INSPIRE].

[65] 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] [INSPIRE].

[66] ATLAS collaboration, *Studies of the muon momentum calibration and performance of the ATLAS detector with pp collisions at* $\sqrt{s} = 13$ *TeV*, *Eur. Phys. J. C* **83** (2023) 686 [arXiv:2212.07338] [INSPIRE].

[67] ATLAS collaboration, *Jet reconstruction and performance using particle flow with the ATLAS Detector*, *Eur. Phys. J. C* **77** (2017) 466 [arXiv:1703.10485] [INSPIRE].

[68] 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] [INSPIRE].

[69] 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*, arXiv:2402.05858 [INSPIRE].

[70] ATLAS collaboration, *Performance of the missing transverse momentum triggers for the ATLAS detector during Run-2 data taking*, *JHEP* **08** (2020) 080 [arXiv:2005.09554] [INSPIRE].

[71] ATLAS collaboration, *Performance of electron and photon triggers in ATLAS during LHC Run 2*, *Eur. Phys. J. C* **80** (2020) 47 [arXiv:1909.00761] [INSPIRE].

[72] ATLAS collaboration, *Performance of the ATLAS muon triggers in Run 2*, 2020 *JINST* **15** P09015 [arXiv:2004.13447] [INSPIRE].

[73] ATLAS collaboration, *ATLAS b-jet identification performance and efficiency measurement with* $t\bar{t}$ *events in pp collisions at* $\sqrt{s} = 13$ *TeV*, *Eur. Phys. J. C* **79** (2019) 970 [arXiv:1907.05120] [INSPIRE].

[74] A.L. Read, *Presentation of search results: The* CL_s *technique*, *J. Phys. G* **28** (2002) 2693 [INSPIRE].

[75] G. Cowan, K. Cranmer, E. Gross and O. Vitells, *Asymptotic formulae for likelihood-based tests of new physics*, *Eur. Phys. J. C* **71** (2011) 1554 [*Erratum ibid.* **73** (2013) 2501] [arXiv:1007.1727] [INSPIRE].

[76] S. Biswas, E. Gabrielli and B. Mele, *Dark Photon Searches via Higgs Boson Production at the LHC and Beyond*, *Symmetry* **14** (2022) 1522 [arXiv:2206.05297] [INSPIRE].

[77] ATLAS collaboration, *Combination of searches for invisible decays of the Higgs boson using* $139\,fb^{-1}$ *of proton–proton collision data at* $\sqrt{s} = 13$ *TeV collected with the ATLAS experiment*, *Phys. Lett. B* **842** (2023) 137963 [arXiv:2301.10731] [INSPIRE].

[78] ATLAS collaboration, *ATLAS Computing Acknowledgements*, ATL-SOFT-PUB-2023-001 (2023).

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G. Aad[104], E. Aakvaag[17], B. Abbott[123], S. Abdelhameed[119a], K. Abeling[56], N.J. Abicht[50], S.H. Abidi[30], M. Aboelela[45], A. Aboulhorma[36e], H. Abramowicz[154], H. Abreu[153], Y. Abulaiti[120], B.S. Acharya[70a,70b,k], A. Ackermann[64a], C. Adam Bourdarios[4], L. Adamczyk[87a], S.V. Addepalli[27], M.J. Addison[103], J. Adelman[118], A. Adiguzel[22c], T. Adye[137], A.A. Affolder[139], Y. Afik[40], M.N. Agaras[13], J. Agarwala[74a,74b], A. Aggarwal[102], C. Agheorghiesei[28c], F. Ahmadov[39,x], W.S. Ahmed[106], S. Ahuja[97], X. Ai[63e], G. Aielli[77a,77b], A. Aikot[166], M. Ait Tamlihat[36e], B. Aitbenchikh[36a], M. Akbiyik[102], T.P.A. Åkesson[100], A.V. Akimov[38], D. Akiyama[171], N.N. Akolkar[25], S. Aktas[22a], K. Al Khoury[42], G.L. Alberghi[24b], J. Albert[168], P. Albicocco[54], G.L. Albouy[61], S. Alderweireldt[53], Z.L. Alegria[124], M. Aleksa[37], I.N. Aleksandrov[39], C. Alexa[28b], T. Alexopoulos[10], F. Alfonsi[24b], M. Algren[57], M. Alhroob[170], B. Ali[135], H.M.J. Ali[93,r], S. Ali[32], S.W. Alibocus[94], M. Aliev[34c], G. Alimonti[72a], W. Alkakhi[56], C. Allaire[67], B.M.M. Allbrooke[149], J.F. Allen[53], C.A. Allendes Flores[140f], P.P. Allport[21], A. Aloisio[73a,73b], F. Alonso[92], C. Alpigiani[141], Z.M.K. Alsolami[93], M. Alvarez Estevez[101], A. Alvarez Fernandez[102], M. Alves Cardoso[57], M.G. Alviggi[73a,73b], M. Aly[103], Y. Amaral Coutinho[84b], A. Ambler[106], C. Amelung[37], M. Amerl[103], C.G. Ames[111], D. Amidei[108], B. Amini[55], K.J. Amirie[158], S.P. Amor Dos Santos[133a], K.R. Amos[166], D. Amperiadou[155], S. An[85], V. Ananiev[128], C. Anastopoulos[142], T. Andeen[11], J.K. Anders[37], A.C. Anderson[60], S.Y. Andrean[48a,48b], A. Andreazza[72a,72b], S. Angelidakis[9], A. Angerami[42], A.V. Anisenkov[38], A. Annovi[75a], C. Antel[57], E. Antipov[148], M. Antonelli[54], F. Anulli[76a], M. Aoki[85], T. Aoki[156], M.A. Aparo[149], L. Aperio Bella[49], C. Appelt[19], A. Apyan[27], S.J. Arbiol Val[88], C. Arcangeletti[54], A.T.H. Arce[52], J-F. Arguin[110], S. Argyropoulos[55], J.-H. Arling[49], O. Arnaez[4], H. Arnold[148], G. Artoni[76a,76b], H. Asada[113], K. Asai[121], S. Asai[156], N.A. Asbah[37], R.A. Ashby Pickering[170], K. Assamagan[30], R. Astalos[29a], K.S.V. Astrand[100], S. Atashi[162], R.J. Atkin[34a], M. Atkinson[165], H. Atmani[36f], P.A. Atmasiddha[131], K. Augsten[135], S. Auricchio[73a,73b], A.D. Auriol[21], V.A. Austrup[103], G. Avolio[37], K. Axiotis[57], G. Azuelos[110,ac], D. Babal[29b], H. Bachacou[138], K. Bachas[155,o], A. Bachiu[35], F. Backman[48a,48b], A. Badea[40], T.M. Baer[108], P. Bagnaia[76a,76b], M. Bahmani[19], D. Bahner[55], K. Bai[126], J.T. Baines[137], L. Baines[96], O.K. Baker[175], E. Bakos[16], D. Bakshi Gupta[8], L.E. Balabram Filho[84b], V. Balakrishnan[123], R. Balasubramanian[4], E.M. Baldin[38], P. Balek[87a], E. Ballabene[24b,24a], F. Balli[138], L.M. Baltes[64a], W.K. Balunas[33], J. Balz[102], I. Bamwidhi[119b], E. Banas[88], M. Bandieramonte[132], A. Bandyopadhyay[25], S. Bansal[25], L. Barak[154], M. Barakat[49], E.L. Barberio[107], D. Barberis[58b,58a], M. Barbero[104], M.Z. Barel[117], T. Barillari[112], M-S. Barisits[37], T. Barklow[146], P. Baron[125], D.A. Baron Moreno[103], A. Baroncelli[63a], A.J. Barr[129], J.D. Barr[98], F. Barreiro[101], J. Barreiro Guimarães da Costa[14], U. Barron[154], M.G. Barros Teixeira[133a], S. Barsov[38], F. Bartels[64a], R. Bartoldus[146], A.E. Barton[93], P. Bartos[29a], A. Basan[102], M. Baselga[50], A. Bassalat[67,b], M.J. Basso[159a], S. Bataju[45], R. Bate[167], R.L. Bates[60], S. Batlamous[101], B. Batool[144], M. Battaglia[139], D. Battulga[19], M. Bauce[76a,76b], M. Bauer[80], P. Bauer[25], L.T. Bazzano Hurrell[31], J.B. Beacham[52], T. Beau[130], J.Y. Beaucamp[92], P.H. Beauchemin[161], P. Bechtle[25], H.P. Beck[20,n],

JHEP08(2024)153

K. Becker[170], A.J. Beddall[83], V.A. Bednyakov[39], C.P. Bee[148], L.J. Beemster[16], T.A. Beermann[37], M. Begalli[84d], M. Begel[30], A. Behera[148], J.K. Behr[49], J.F. Beirer[37], F. Beisiegel[25], M. Belfkir[119b], G. Bella[154], L. Bellagamba[24b], A. Bellerive[35], P. Bellos[21], K. Beloborodov[38], D. Benchekroun[36a], F. Bendebba[36a], Y. Benhammou[154], K.C. Benkendorfer[62], L. Beresford[49], M. Beretta[54], E. Bergeaas Kuutmann[164], N. Berger[4], B. Bergmann[135], J. Beringer[18a], G. Bernardi[5], C. Bernius[146], F.U. Bernlochner[25], F. Bernon[37,104], A. Berrocal Guardia[13], T. Berry[97], P. Berta[136], A. Berthold[51], S. Bethke[112], A. Betti[76a,76b], A.J. Bevan[96], N.K. Bhalla[55], S. Bhatta[148], D.S. Bhattacharya[169], P. Bhattarai[146], K.D. Bhide[55], V.S. Bhopatkar[124], R.M. Bianchi[132], G. Bianco[24b,24a], O. Biebel[111], R. Bielski[126], M. Biglietti[78a], C.S. Billingsley[45], Y. Bimgdi[36f], M. Bindi[56], A. Bingul[22b], C. Bini[76a,76b], G.A. Bird[33], M. Birman[172], M. Biros[136], S. Biryukov[149], T. Bisanz[50], E. Bisceglie[44b,44a], J.P. Biswal[137], D. Biswas[144], I. Bloch[49], A. Blue[60], U. Blumenschein[96], J. Blumenthal[102], V.S. Bobrovnikov[38], M. Boehler[55], B. Boehm[169], D. Bogavac[37], A.G. Bogdanchikov[38], L.S. Boggia[130], C. Bohm[48a], V. Boisvert[97], P. Bokan[37], T. Bold[87a], M. Bomben[5], M. Bona[96], M. Boonekamp[138], C.D. Booth[97], A.G. Borbély[60], I.S. Bordulev[38], G. Borissov[93], D. Bortoletto[129], D. Boscherini[24b], M. Bosman[13], J.D. Bossio Sola[37], K. Bouaouda[36a], N. Bouchhar[166], L. Boudet[4], J. Boudreau[132], E.V. Bouhova-Thacker[93], D. Boumediene[41], R. Bouquet[58b,58a], A. Boveia[122], J. Boyd[37], D. Boye[30], I.R. Boyko[39], L. Bozianu[57], J. Bracinik[21], N. Brahimi[4], G. Brandt[174], O. Brandt[33], F. Braren[49], B. Brau[105], J.E. Brau[126], R. Brener[172], L. Brenner[117], R. Brenner[164], S. Bressler[172], G. Brianti[79a,79b], D. Britton[60], D. Britzger[112], I. Brock[25], G. Brooijmans[42], E.M. Brooks[159b], E. Brost[30], L.M. Brown[168], L.E. Bruce[62], T.L. Bruckler[129], P.A. Bruckman de Renstrom[88], B. Brüers[49], A. Bruni[24b], G. Bruni[24b], M. Bruschi[24b], N. Bruscino[76a,76b], T. Buanes[17], Q. Buat[141], D. Buchin[112], A.G. Buckley[60], O. Bulekov[38], B.A. Bullard[146], S. Burdin[94], C.D. Burgard[50], A.M. Burger[37], B. Burghgrave[8], O. Burlayenko[55], J. Burleson[165], J.T.P. Burr[33], J.C. Burzynski[145], E.L. Busch[42], V. Büscher[102], P.J. Bussey[60], J.M. Butler[26], C.M. Buttar[60], J.M. Butterworth[98], W. Buttinger[137], C.J. Buxo Vazquez[109], A.R. Buzykaev[38], S. Cabrera Urbán[166], L. Cadamuro[67], D. Caforio[59], H. Cai[132], Y. Cai[14,114c], Y. Cai[114a], V.M.M. Cairo[37], O. Cakir[3a], N. Calace[37], P. Calafiura[18a], G. Calderini[130], P. Calfayan[69], G. Callea[60], L.P. Caloba[84b], D. Calvet[41], S. Calvet[41], M. Calvetti[75a,75b], R. Camacho Toro[130], S. Camarda[37], D. Camarero Munoz[27], P. Camarri[77a,77b], M.T. Camerlingo[73a,73b], D. Cameron[37], C. Camincher[168], M. Campanelli[98], A. Camplani[43], V. Canale[73a,73b], A.C. Canbay[3a], E. Canonero[97], J. Cantero[166], Y. Cao[165], F. Capocasa[27], M. Capua[44b,44a], A. Carbone[72a,72b], R. Cardarelli[77a], J.C.J. Cardenas[8], G. Carducci[44b,44a], T. Carli[37], G. Carlino[73a], J.I. Carlotto[13], B.T. Carlson[132,p], E.M. Carlson[168,159a], J. Carmignani[94], L. Carminati[72a,72b], A. Carnelli[138], M. Carnesale[76a,76b], S. Caron[116], E. Carquin[140f], I.B. Carr[107], S. Carrá[72a], G. Carratta[24b,24a], A.M. Carroll[126], T.M. Carter[53], M.P. Casado[13,h], M. Caspar[49], F.L. Castillo[4], L. Castillo Garcia[13], V. Castillo Gimenez[166], N.F. Castro[133a,133e], A. Catinaccio[37], J.R. Catmore[128], T. Cavaliere[4], V. Cavaliere[30], N. Cavalli[24b,24a], L.J. Caviedes Betancourt[23b], Y.C. Cekmecelioglu[49], E. Celebi[83], S. Cella[37],

F. Celli[129], M.S. Centonze[71a,71b], V. Cepaitis[57], K. Cerny[125], A.S. Cerqueira[84a], A. Cerri[149], L. Cerrito[77a,77b], F. Cerutti[18a], B. Cervato[144], A. Cervelli[24b], G. Cesarini[54], S.A. Cetin[83], D. Chakraborty[118], J. Chan[18a], W.Y. Chan[156], J.D. Chapman[33], E. Chapon[138], B. Chargeishvili[152b], D.G. Charlton[21], M. Chatterjee[20], C. Chauhan[136], Y. Che[114a], S. Chekanov[6], S.V. Chekulaev[159a], G.A. Chelkov[39,a], A. Chen[108], B. Chen[154], B. Chen[168], H. Chen[114a], H. Chen[30], J. Chen[63c], J. Chen[145], M. Chen[129], S. Chen[89], S.J. Chen[114a], X. Chen[63c], X. Chen[15,ab], Y. Chen[63a], C.L. Cheng[173], H.C. Cheng[65a], S. Cheong[146], A. Cheplakov[39], E. Cheremushkina[49], E. Cherepanova[117], R. Cherkaoui El Moursli[36e], E. Cheu[7], K. Cheung[66], L. Chevalier[138], V. Chiarella[54], G. Chiarelli[75a], N. Chiedde[104], G. Chiodini[71a], A.S. Chisholm[21], A. Chitan[28b], M. Chitishvili[166], M.V. Chizhov[39], K. Choi[11], Y. Chou[141], E.Y.S. Chow[116], K.L. Chu[172], M.C. Chu[65a], X. Chu[14,114c], Z. Chubinidze[54], J. Chudoba[134], J.J. Chwastowski[88], D. Cieri[112], K.M. Ciesla[87a], V. Cindro[95], A. Ciocio[18a], F. Cirotto[73a,73b], Z.H. Citron[172], M. Citterio[72a], D.A. Ciubotaru[28b], A. Clark[57], P.J. Clark[53], N. Clarke Hall[98], C. Clarry[158], J.M. Clavijo Columbie[49], S.E. Clawson[49], C. Clement[48a,48b], Y. Coadou[104], M. Cobal[70a,70c], A. Coccaro[58b], R.F. Coelho Barrue[133a], R. Coelho Lopes De Sa[105], S. Coelli[72a], B. Cole[42], J. Collot[61], P. Conde Muiño[133a,133g], M.P. Connell[34c], S.H. Connell[34c], E.I. Conroy[129], F. Conventi[73a,ad], H.G. Cooke[21], A.M. Cooper-Sarkar[129], F.A. Corchia[24b,24a], A. Cordeiro Oudot Choi[130], L.D. Corpe[41], M. Corradi[76a,76b], F. Corriveau[106,w], A. Cortes-Gonzalez[19], M.J. Costa[166], F. Costanza[4], D. Costanzo[142], B.M. Cote[122], J. Couthures[4], G. Cowan[97], K. Cranmer[173], L. Cremer[50], D. Cremonini[24b,24a], S. Crépé-Renaudin[61], F. Crescioli[130], M. Cristinziani[144], M. Cristoforetti[79a,79b], V. Croft[117], J.E. Crosby[124], G. Crosetti[44b,44a], A. Cueto[101], H. Cui[98], Z. Cui[7], W.R. Cunningham[60], F. Curcio[166], J.R. Curran[53], P. Czodrowski[37], M.J. Da Cunha Sargedas De Sousa[58b,58a], J.V. Da Fonseca Pinto[84b], C. Da Via[103], W. Dabrowski[87a], T. Dado[37], S. Dahbi[151], T. Dai[108], D. Dal Santo[20], C. Dallapiccola[105], M. Dam[43], G. D'amen[30], V. D'Amico[111], J. Damp[102], J.R. Dandoy[35], D. Dannheim[37], M. Danninger[145], V. Dao[148], G. Darbo[58b], S.J. Das[30,ae], F. Dattola[49], S. D'Auria[72a,72b], A. D'avanzo[73a,73b], C. David[34a], T. Davidek[136], I. Dawson[96], H.A. Day-hall[135], K. De[8], R. De Asmundis[73a], N. De Biase[49], S. De Castro[24b,24a], N. De Groot[116], P. de Jong[117], H. De la Torre[118], A. De Maria[114a], A. De Salvo[76a], U. De Sanctis[77a,77b], F. De Santis[71a,71b], A. De Santo[149], J.B. De Vivie De Regie[61], J. Debevc[95], D.V. Dedovich[39], J. Degens[94], A.M. Deiana[45], F. Del Corso[24b,24a], J. Del Peso[101], L. Delagrange[130], F. Deliot[138], C.M. Delitzsch[50], M. Della Pietra[73a,73b], D. Della Volpe[57], A. Dell'Acqua[37], L. Dell'Asta[72a,72b], M. Delmastro[4], P.A. Delsart[61], S. Demers[175], M. Demichev[39], S.P. Denisov[38], L. D'Eramo[41], D. Derendarz[88], F. Derue[130], P. Dervan[94], K. Desch[25], C. Deutsch[25], F.A. Di Bello[58b,58a], A. Di Ciaccio[77a,77b], L. Di Ciaccio[4], A. Di Domenico[76a,76b], C. Di Donato[73a,73b], A. Di Girolamo[37], G. Di Gregorio[37], A. Di Luca[79a,79b], B. Di Micco[78a,78b], R. Di Nardo[78a,78b], K.F. Di Petrillo[40], M. Diamantopoulou[35], F.A. Dias[117], T. Dias Do Vale[145], M.A. Diaz[140a,140b], F.G. Diaz Capriles[25], A.R. Didenko[39], M. Didenko[166], E.B. Diehl[108], S. Díez Cornell[49], C. Diez Pardos[144], C. Dimitriadi[164], A. Dimitrievska[21], J. Dingfelder[25], T. Dingley[129], I-M. Dinu[28b], S.J. Dittmeier[64b], F. Dittus[37], M. Divisek[136], B. Dixit[94], F. Djama[104],

T. Djobava[152b], C. Doglioni[103,100], A. Dohnalova[29a], J. Dolejsi[136], Z. Dolezal[136], K. Domijan[87a], K.M. Dona[40], M. Donadelli[84d], B. Dong[109], J. Donini[41], A. D'Onofrio[73a,73b], M. D'Onofrio[94], J. Dopke[137], A. Doria[73a], N. Dos Santos Fernandes[133a], P. Dougan[103], M.T. Dova[92], A.T. Doyle[60], M.A. Draguet[129], E. Dreyer[172], I. Drivas-koulouris[10], M. Drnevich[120], M. Drozdova[57], D. Du[63a], T.A. du Pree[117], F. Dubinin[38], M. Dubovsky[29a], E. Duchovni[172], G. Duckeck[111], O.A. Ducu[28b], D. Duda[53], A. Dudarev[37], E.R. Duden[27], M. D'uffizi[103], L. Duflot[67], M. Dührssen[37], I. Duminica[28g], A.E. Dumitriu[28b], M. Dunford[64a], S. Dungs[50], K. Dunne[48a,48b], A. Duperrin[104], H. Duran Yildiz[3a], M. Düren[59], A. Durglishvili[152b], B.L. Dwyer[118], G.I. Dyckes[18a], M. Dyndal[87a], B.S. Dziedzic[37], Z.O. Earnshaw[149], G.H. Eberwein[129], B. Eckerova[29a], S. Eggebrecht[56], E. Egidio Purcino De Souza[84e], L.F. Ehrke[57], G. Eigen[17], K. Einsweiler[18a], T. Ekelof[164], P.A. Ekman[100], S. El Farkh[36b], Y. El Ghazali[63a], H. El Jarrari[37], A. El Moussaouy[36a], V. Ellajosyula[164], M. Ellert[164], F. Ellinghaus[174], N. Ellis[37], J. Elmsheuser[30], M. Elsawy[119a], M. Elsing[37], D. Emeliyanov[137], Y. Enari[85], I. Ene[18a], S. Epari[13], P.A. Erland[88], D. Ernani Martins Neto[88], M. Errenst[174], M. Escalier[67], C. Escobar[166], E. Etzion[154], G. Evans[133a], H. Evans[69], L.S. Evans[97], A. Ezhilov[38], S. Ezzarqtouni[36a], F. Fabbri[24b,24a], L. Fabbri[24b,24a], G. Facini[98], V. Fadeyev[139], R.M. Fakhrutdinov[38], D. Fakoudis[102], S. Falciano[76a], L.F. Falda Ulhoa Coelho[37], F. Fallavollita[112], G. Falsetti[44b,44a], J. Faltova[136], C. Fan[165], K.Y. Fan[65b], Y. Fan[14], Y. Fang[14,114c], M. Fanti[72a,72b], M. Faraj[70a,70b], Z. Farazpay[99], A. Farbin[8], A. Farilla[78a], T. Farooque[109], S.M. Farrington[53], F. Fassi[36e], D. Fassouliotis[9], M. Faucci Giannelli[77a,77b], W.J. Fawcett[33], L. Fayard[67], P. Federic[136], P. Federicova[134], O.L. Fedin[38,a], M. Feickert[173], L. Feligioni[104], D.E. Fellers[126], C. Feng[63b], Z. Feng[117], M.J. Fenton[162], L. Ferencz[49], R.A.M. Ferguson[93], S.I. Fernandez Luengo[140f], P. Fernandez Martinez[13], M.J.V. Fernoux[104], J. Ferrando[93], A. Ferrari[164], P. Ferrari[117,116], R. Ferrari[74a], D. Ferrere[57], C. Ferretti[108], D. Fiacco[76a,76b], F. Fiedler[102], P. Fiedler[135], S. Filimonov[38], A. Filipčič[95], E.K. Filmer[1], F. Filthaut[116], M.C.N. Fiolhais[133a,133c,c], L. Fiorini[166], W.C. Fisher[109], T. Fitschen[103], P.M. Fitzhugh[138], I. Fleck[144], P. Fleischmann[108], T. Flick[174], M. Flores[34d,z], L.R. Flores Castillo[65a], L. Flores Sanz De Acedo[37], F.M. Follega[79a,79b], N. Fomin[33], J.H. Foo[158], A. Formica[138], A.C. Forti[103], E. Fortin[37], A.W. Fortman[18a], M.G. Foti[18a], L. Fountas[9,i], D. Fournier[67], H. Fox[93], P. Francavilla[75a,75b], S. Francescato[62], S. Franchellucci[57], M. Franchini[24b,24a], S. Franchino[64a], D. Francis[37], L. Franco[116], V. Franco Lima[37], L. Franconi[49], M. Franklin[62], G. Frattari[27], Y.Y. Frid[154], J. Friend[60], N. Fritzsche[37], A. Froch[55], D. Froidevaux[37], J.A. Frost[129], Y. Fu[63a], S. Fuenzalida Garrido[140f], M. Fujimoto[104], K.Y. Fung[65a], E. Furtado De Simas Filho[84e], M. Furukawa[156], J. Fuster[166], A. Gaa[56], A. Gabrielli[24b,24a], A. Gabrielli[158], P. Gadow[37], G. Gagliardi[58b,58a], L.G. Gagnon[18a], S. Gaid[163], S. Galantzan[154], J. Gallagher[1], E.J. Gallas[129], B.J. Gallop[137], K.K. Gan[122], S. Ganguly[156], Y. Gao[53], F.M. Garay Walls[140a,140b], B. Garcia[30], C. García[166], A. Garcia Alonso[117], A.G. Garcia Caffaro[175], J.E. García Navarro[166], M. Garcia-Sciveres[18a], G.L. Gardner[131], R.W. Gardner[40], N. Garelli[161], D. Garg[81], R.B. Garg[146], J.M. Gargan[53], C.A. Garner[158], C.M. Garvey[34a], V.K. Gassmann[161], G. Gaudio[74a], V. Gautam[13],

JHEP08(2024)153

P. Gauzzi[76a,76b], J. Gavranovic[95], I.L. Gavrilenko[38], A. Gavrilyuk[38], C. Gay[167], G. Gaycken[126], E.N. Gazis[10], A.A. Geanta[28b], C.M. Gee[139], A. Gekow[122], C. Gemme[58b], M.H. Genest[61], A.D. Gentry[115], S. George[97], W.F. George[21], T. Geralis[47], P. Gessinger-Befurt[37], M.E. Geyik[174], M. Ghani[170], K. Ghorbanian[96], A. Ghosal[144], A. Ghosh[162], A. Ghosh[7], B. Giacobbe[24b], S. Giagu[76a,76b], T. Giani[117], A. Giannini[63a], S.M. Gibson[97], M. Gignac[139], D.T. Gil[87b], A.K. Gilbert[87a], B.J. Gilbert[42], D. Gillberg[35], G. Gilles[117], L. Ginabat[130], D.M. Gingrich[2,ac], M.P. Giordani[70a,70c], P.F. Giraud[138], G. Giugliarelli[70a,70c], D. Giugni[72a], F. Giuli[37], I. Gkialas[9,i], L.K. Gladilin[38], C. Glasman[101], G.R. Gledhill[126], G. Glemža[49], M. Glisic[126], I. Gnesi[44b], Y. Go[30], M. Goblirsch-Kolb[37], B. Gocke[50], D. Godin[110], B. Gokturk[22a], S. Goldfarb[107], T. Golling[57], M.G.D. Gololo[34g], D. Golubkov[38], J.P. Gombas[109], A. Gomes[133a,133b], G. Gomes Da Silva[144], A.J. Gomez Delegido[166], R. Gonçalo[133a], L. Gonella[21], A. Gongadze[152c], F. Gonnella[21], J.L. Gonski[146], R.Y. González Andana[53], S. González de la Hoz[166], R. Gonzalez Lopez[94], C. Gonzalez Renteria[18a], M.V. Gonzalez Rodrigues[49], R. Gonzalez Suarez[164], S. Gonzalez-Sevilla[57], L. Goossens[37], B. Gorini[37], E. Gorini[71a,71b], A. Gorišek[95], T.C. Gosart[131], A.T. Goshaw[52], M.I. Gostkin[39], S. Goswami[124], C.A. Gottardo[37], S.A. Gotz[111], M. Gouighri[36b], V. Goumarre[49], A.G. Goussiou[141], N. Govender[34c], R.P. Grabarczyk[129], I. Grabowska-Bold[87a], K. Graham[35], E. Gramstad[128], S. Grancagnolo[71a,71b], C.M. Grant[1,138], P.M. Gravila[28f], F.G. Gravili[71a,71b], H.M. Gray[18a], M. Greco[71a,71b], M.J. Green[1], C. Grefe[25], A.S. Grefsrud[17], I.M. Gregor[49], K.T. Greif[162], P. Grenier[146], S.G. Grewe[112], A.A. Grillo[139], K. Grimm[32], S. Grinstein[13,s], J.-F. Grivaz[67], E. Gross[172], J. Grosse-Knetter[56], L. Guan[108], J.G.R. Guerrero Rojas[166], G. Guerrieri[37], R. Gugel[102], J.A.M. Guhit[108], A. Guida[19], E. Guilloton[170], S. Guindon[37], F. Guo[14,114c], J. Guo[63c], L. Guo[49], Y. Guo[108], R. Gupta[132], S. Gurbuz[25], S.S. Gurdasani[55], G. Gustavino[76a,76b], P. Gutierrez[123], L.F. Gutierrez Zagazeta[131], M. Gutsche[51], C. Gutschow[98], C. Gwenlan[129], C.B. Gwilliam[94], E.S. Haaland[128], A. Haas[120], M. Habedank[49], C. Haber[18a], H.K. Hadavand[8], A. Hadef[51], S. Hadzic[112], A.I. Hagan[93], J.J. Hahn[144], E.H. Haines[98], M. Haleem[169], J. Haley[124], J.J. Hall[142], G.D. Hallewell[104], L. Halser[20], K. Hamano[168], M. Hamer[25], G.N. Hamity[53], E.J. Hampshire[97], J. Han[63b], K. Han[63a], L. Han[114a], L. Han[63a], S. Han[18a], Y.F. Han[158], K. Hanagaki[85], M. Hance[139], D.A. Hangal[42], H. Hanif[145], M.D. Hank[131], J.B. Hansen[43], P.H. Hansen[43], D. Harada[57], T. Harenberg[174], S. Harkusha[38], M.L. Harris[105], Y.T. Harris[25], J. Harrison[13], N.M. Harrison[122], P.F. Harrison[170], N.M. Hartman[112], N.M. Hartmann[111], R.Z. Hasan[97,137], Y. Hasegawa[143], F. Haslbeck[129], S. Hassan[17], R. Hauser[109], C.M. Hawkes[21], R.J. Hawkings[37], Y. Hayashi[156], D. Hayden[109], C. Hayes[108], R.L. Hayes[117], C.P. Hays[129], J.M. Hays[96], H.S. Hayward[94], F. He[63a], M. He[14,114c], Y. He[49], Y. He[98], N.B. Heatley[96], V. Hedberg[100], A.L. Heggelund[128], N.D. Hehir[96,*], C. Heidegger[55], K.K. Heidegger[55], J. Heilman[35], S. Heim[49], T. Heim[18a], J.G. Heinlein[131], J.J. Heinrich[126], L. Heinrich[112,aa], J. Hejbal[134], A. Held[173], S. Hellesund[17], C.M. Helling[167], S. Hellman[48a,48b], R.C.W. Henderson[93], L. Henkelmann[33], A.M. Henriques Correia[37], H. Herde[100], Y. Hernández Jiménez[148], L.M. Herrmann[25], T. Herrmann[51], G. Herten[55], R. Hertenberger[111], L. Hervas[37], M.E. Hesping[102], N.P. Hessey[159a], M. Hidaoui[36b], N. Hidic[136], E. Hill[158], S.J. Hillier[21], J.R. Hinds[109], F. Hinterkeuser[25], M. Hirose[127], S. Hirose[160], D. Hirschbuehl[174], T.G. Hitchings[103], B. Hiti[95], J. Hobbs[148], R. Hobincu[28e], N. Hod[172], M.C. Hodgkinson[142], B.H. Hodkinson[129], A. Hoecker[37], D.D. Hofer[108], J. Hofer[166], T. Holm[25], M. Holzbock[37], L.B.A.H. Hommels[33], B.P. Honan[103], J.J. Hong[69], J. Hong[63c], T.M. Hong[132], B.H. Hooberman[165], W.H. Hopkins[6], M.C. Hoppesch[165], Y. Horii[113], M.E. Horstmann[112], S. Hou[151], A.S. Howard[95], J. Howarth[60], J. Hoya[6], M. Hrabovsky[125], A. Hrynevich[49], T. Hryn'ova[4], P.J. Hsu[66], S.-C. Hsu[141], T. Hsu[67], M. Hu[18a], Q. Hu[63a], S. Huang[65b], X. Huang[14,114c], Y. Huang[142], Y. Huang[102], Y. Huang[14], Z. Huang[103], Z. Hubacek[135], M. Huebner[25], F. Huegging[25], T.B. Huffman[129], C.A. Hugli[49], M. Huhtinen[37], S.K. Huiberts[17], R. Hulsken[106], N. Huseynov[12,f], J. Huston[109], J. Huth[62], R. Hyneman[146], G. Iacobucci[57], G. Iakovidis[30], L. Iconomidou-Fayard[67], J.P. Iddon[37], P. Iengo[73a,73b], R. Iguchi[156], Y. Iiyama[156], T. Iizawa[129], Y. Ikegami[85], N. Ilic[158], H. Imam[84c], G. Inacio Goncalves[84d], M. Ince Lezki[57], T. Ingebretsen Carlson[48a,48b], J.M. Inglis[96], G. Introzzi[74a,74b], M. Iodice[78a], V. Ippolito[76a,76b], R.K. Irwin[94], M. Ishino[156], W. Islam[173], C. Issever[19,49], S. Istin[22a,ag], H. Ito[171], R. Iuppa[79a,79b], A. Ivina[172], J.M. Izen[46], V. Izzo[73a], P. Jacka[134], P. Jackson[1], C.S. Jagfeld[111], G. Jain[159a], P. Jain[49], K. Jakobs[55], T. Jakoubek[172], J. Jamieson[60], W. Jang[156], M. Javurkova[105], P. Jawahar[103], L. Jeanty[126], J. Jejelava[152a,y], P. Jenni[55,e], C.E. Jessiman[35], C. Jia[63b], J. Jia[148], X. Jia[14,114c], Z. Jia[114a], C. Jiang[53], S. Jiggins[49], J. Jimenez Pena[13], S. Jin[114a], A. Jinaru[28b], O. Jinnouchi[157], P. Johansson[142], K.A. Johns[7], J.W. Johnson[139], F.A. Jolly[49], D.M. Jones[149], E. Jones[49], K.S. Jones[8], P. Jones[33], R.W.L. Jones[93], T.J. Jones[94], H.L. Joos[56,37], R. Joshi[122], J. Jovicevic[16], X. Ju[18a], J.J. Junggeburth[105], T. Junkermann[64a], A. Juste Rozas[13,s], M.K. Juzek[88], S. Kabana[140e], A. Kaczmarska[88], M. Kado[112], H. Kagan[122], M. Kagan[146], A. Kahn[131], C. Kahra[102], T. Kaji[156], E. Kajomovitz[153], N. Kakati[172], I. Kalaitzidou[55], C.W. Kalderon[30], N.J. Kang[139], D. Kar[34g], K. Karava[129], M.J. Kareem[159b], E. Karentzos[55], O. Karkout[117], S.N. Karpov[39], Z.M. Karpova[39], V. Kartvelishvili[93], A.N. Karyukhin[38], E. Kasimi[155], J. Katzy[49], S. Kaur[35], K. Kawade[143], M.P. Kawale[123], C. Kawamoto[89], T. Kawamoto[63a], E.F. Kay[37], F.I. Kaya[161], S. Kazakos[109], V.F. Kazanin[38], Y. Ke[148], J.M. Keaveney[34a], R. Keeler[168], G.V. Kehris[62], J.S. Keller[35], A.S. Kelly[98], J.J. Kempster[149], P.D. Kennedy[102], O. Kepka[134], B.P. Kerridge[137], S. Kersten[174], B.P. Kerševan[95], L. Keszeghova[29a], S. Ketabchi Haghighat[158], R.A. Khan[132], A. Khanov[124], A.G. Kharlamov[38], T. Kharlamova[38], E.E. Khoda[141], M. Kholodenko[133a], T.J. Khoo[19], G. Khoriauli[169], J. Khubua[152b,*], Y.A.R. Khwaira[130], B. Kibirige[34g], D. Kim[6], D.W. Kim[48a,48b], Y.K. Kim[40], N. Kimura[98], M.K. Kingston[56], A. Kirchhoff[56], C. Kirfel[25], F. Kirfel[25], J. Kirk[137], A.E. Kiryunin[112], S. Kita[160], C. Kitsaki[10], O. Kivernyk[25], M. Klassen[161], C. Klein[35], L. Klein[169], M.H. Klein[45], S.B. Klein[57], U. Klein[94], P. Klimek[37], A. Klimentov[30], T. Klioutchnikova[37], P. Kluit[117], S. Kluth[112], E. Kneringer[80], T.M. Knight[158], A. Knue[50], D. Kobylianskii[172], S.F. Koch[129], M. Kocian[146], P. Kodyš[136], D.M. Koeck[126], P.T. Koenig[25], T. Koffas[35], O. Kolay[51], I. Koletsou[4], T. Komarek[88], K. Köneke[55], A.X.Y. Kong[1], T. Kono[121], N. Konstantinidis[98], P. Kontaxakis[57], B. Konya[100], R. Kopeliansky[42], S. Koperny[87a],

JHEP08(2024)153

K. Korcyl[88], K. Kordas[155,d], A. Korn[98], S. Korn[56], I. Korolkov[13], N. Korotkova[38], B. Kortman[117], O. Kortner[112], S. Kortner[112], W.H. Kostecka[118], V.V. Kostyukhin[144], A. Kotsokechagia[37], A. Kotwal[52], A. Koulouris[37], A. Kourkoumeli-Charalampidi[74a,74b], C. Kourkoumelis[9], E. Kourlitis[112,aa], O. Kovanda[126], R. Kowalewski[168], W. Kozanecki[126], A.S. Kozhin[38], V.A. Kramarenko[38], G. Kramberger[95], P. Kramer[102], M.W. Krasny[130], A. Krasznahorkay[37], A.C. Kraus[118], J.W. Kraus[174], J.A. Kremer[49], T. Kresse[51], L. Kretschmann[174], J. Kretzschmar[94], K. Kreul[19], P. Krieger[158], M. Krivos[136], K. Krizka[21], K. Kroeninger[50], H. Kroha[112], J. Kroll[134], J. Kroll[131], K.S. Krowpman[109], U. Kruchonak[39], H. Krüger[25], N. Krumnack[82], M.C. Kruse[52], O. Kuchinskaia[38], S. Kuday[3a], S. Kuehn[37], R. Kuesters[55], T. Kuhl[49], V. Kukhtin[39], Y. Kulchitsky[38,a], S. Kuleshov[140d,140b], M. Kumar[34g], N. Kumari[49], P. Kumari[159b], A. Kupco[134], T. Kupfer[50], A. Kupich[38], O. Kuprash[55], H. Kurashige[86], L.L. Kurchaninov[159a], O. Kurdysh[67], Y.A. Kurochkin[38], A. Kurova[38], M. Kuze[157], A.K. Kvam[105], J. Kvita[125], T. Kwan[106], N.G. Kyriacou[108], L.A.O. Laatu[104], C. Lacasta[166], F. Lacava[76a,76b], H. Lacker[19], D. Lacour[130], N.N. Lad[98], E. Ladygin[39], A. Lafarge[41], B. Laforge[130], T. Lagouri[175], F.Z. Lahbabi[36a], S. Lai[56], J.E. Lambert[168], S. Lammers[69], W. Lampl[7], C. Lampoudis[155,d], G. Lamprinoudis[102], A.N. Lancaster[118], E. Lançon[30], U. Landgraf[55], M.P.J. Landon[96], V.S. Lang[55], O.K.B. Langrekken[128], A.J. Lankford[162], F. Lanni[37], K. Lantzsch[25], A. Lanza[74a], M. Lanzac Berrocal[166], J.F. Laporte[138], T. Lari[72a], F. Lasagni Manghi[24b], M. Lassnig[37], V. Latonova[134], A. Laurier[153], S.D. Lawlor[142], Z. Lawrence[103], R. Lazaridou[170], M. Lazzaroni[72a,72b], B. Le[103], H.D.M. Le[109], E.M. Le Boulicaut[175], L.T. Le Pottier[18a], B. Leban[24b,24a], A. Lebedev[82], M. LeBlanc[103], F. Ledroit-Guillon[61], S.C. Lee[151], S. Lee[48a,48b], T.F. Lee[94], L.L. Leeuw[34c], H.P. Lefebvre[97], M. Lefebvre[168], C. Leggett[18a], G. Lehmann Miotto[37], M. Leigh[57], W.A. Leight[105], W. Leinonen[116], A. Leisos[155,q], M.A.L. Leite[84c], C.E. Leitgeb[19], R. Leitner[136], K.J.C. Leney[45], T. Lenz[25], S. Leone[75a], C. Leonidopoulos[53], A. Leopold[147], R. Les[109], C.G. Lester[33], M. Levchenko[38], J. Levêque[4], L.J. Levinson[172], G. Levrini[24b,24a], M.P. Lewicki[88], C. Lewis[141], D.J. Lewis[4], L. Lewitt[142], A. Li[30], B. Li[63b], C. Li[63a], C-Q. Li[112], H. Li[63a], H. Li[63b], H. Li[114a], H. Li[15], H. Li[63b], J. Li[63c], K. Li[14], L. Li[63c], M. Li[14,114c], S. Li[14,114c], S. Li[63d,63c], T. Li[5], X. Li[106], Z. Li[129], Z. Li[156], Z. Li[14,114c], Z. Li[63a], S. Liang[14,114c], Z. Liang[14], M. Liberatore[138], B. Liberti[77a], K. Lie[65c], J. Lieber Marin[84e], H. Lien[69], H. Lin[108], K. Lin[109], R.E. Lindley[7], J.H. Lindon[2], J. Ling[62], E. Lipeles[131], A. Lipniacka[17], A. Lister[167], J.D. Little[69], B. Liu[14], B.X. Liu[114b], D. Liu[63d,63c], E.H.L. Liu[21], J.B. Liu[63a], J.K.K. Liu[33], K. Liu[63d], K. Liu[63d,63c], M. Liu[63a], M.Y. Liu[63a], P. Liu[14], Q. Liu[63d,141,63c], X. Liu[63a], X. Liu[63b], Y. Liu[114b,114c], Y.L. Liu[63b], Y.W. Liu[63a], S.L. Lloyd[96], E.M. Lobodzinska[49], P. Loch[7], T. Lohse[19], K. Lohwasser[142], E. Loiacono[49], M. Lokajicek[134,*], J.D. Lomas[21], J.D. Long[165], I. Longarini[162], R. Longo[165], I. Lopez Paz[68], A. Lopez Solis[49], N.A. Lopez-canelas[7], N. Lorenzo Martinez[4], A.M. Lory[111], M. Losada[119a], G. Löschcke Centeno[149], O. Loseva[38], X. Lou[48a,48b], X. Lou[14,114c], A. Lounis[67], P.A. Love[93], G. Lu[14,114c], M. Lu[67], S. Lu[131], Y.J. Lu[66], H.J. Lubatti[141], C. Luci[76a,76b], F.L. Lucio Alves[114a], F. Luehring[69], O. Lukianchuk[67], B.S. Lunday[131], O. Lundberg[147], B. Lund-Jensen[147,*], N.A. Luongo[6], M.S. Lutz[37], A.B. Lux[26], D. Lynn[30], R. Lysak[134], E. Lytken[100], V. Lyubushkin[39], T. Lyubushkina[39], M.M. Lyukova[148], M.Firdaus M. Soberi[53], H. Ma[30], K. Ma[63a], L.L. Ma[63b], W. Ma[63a], Y. Ma[124], J.C. MacDonald[102], P.C. Machado De Abreu Farias[84e], R. Madar[41], T. Madula[98], J. Maeda[86], T. Maeno[30], H. Maguire[142], V. Maiboroda[138], A. Maio[133a,133b,133d], K. Maj[87a], O. Majersky[49], S. Majewski[126], N. Makovec[67], V. Maksimovic[16], B. Malaescu[130], Pa. Malecki[88], V.P. Maleev[38], F. Malek[61,m], M. Mali[95], D. Malito[97], U. Mallik[81], S. Maltezos[10], S. Malyukov[39], J. Mamuzic[13], G. Mancini[54], M.N. Mancini[27], G. Manco[74a,74b], J.P. Mandalia[96], S.S. Mandarry[149], I. Mandić[95], L. Manhaes de Andrade Filho[84a], I.M. Maniatis[172], J. Manjarres Ramos[91], D.C. Mankad[172], A. Mann[111], S. Manzoni[37], L. Mao[63c], X. Mapekula[34c], A. Marantis[155,q], G. Marchiori[5], M. Marcisovsky[134], C. Marcon[72a], M. Marinescu[21], S. Marium[49], M. Marjanovic[123], A. Markhoos[55], M. Markovitch[67], E.J. Marshall[93], Z. Marshall[18a], S. Marti-Garcia[166], J. Martin[98], T.A. Martin[137], V.J. Martin[53], B. Martin dit Latour[17], L. Martinelli[76a,76b], M. Martinez[13,s], P. Martinez Agullo[166], V.I. Martinez Outschoorn[105], P. Martinez Suarez[13], S. Martin-Haugh[137], G. Martinovicova[136], V.S. Martoiu[28b], A.C. Martyniuk[98], A. Marzin[37], D. Mascione[79a,79b], L. Masetti[102], J. Masik[103], A.L. Maslennikov[38], P. Massarotti[73a,73b], P. Mastrandrea[75a,75b], A. Mastroberardino[44b,44a], T. Masubuchi[127], T.T. Mathew[126], T. Mathisen[164], J. Matousek[136], J. Maurer[28b], T. Maurin[60], A.J. Maury[67], B. Maček[95], D.A. Maximov[38], A.E. May[103], R. Mazini[151], I. Maznas[118], M. Mazza[109], S.M. Mazza[139], E. Mazzeo[72a,72b], C. Mc Ginn[30], J.P. Mc Gowan[168], S.P. Mc Kee[108], C.C. McCracken[167], E.F. McDonald[107], A.E. McDougall[117], J.A. Mcfayden[149], R.P. McGovern[131], R.P. Mckenzie[34g], T.C. Mclachlan[49], D.J. Mclaughlin[98], S.J. McMahon[137], C.M. Mcpartland[94], R.A. McPherson[168,w], S. Mehlhase[111], A. Mehta[94], D. Melini[166], B.R. Mellado Garcia[34g], A.H. Melo[56], F. Meloni[49], A.M. Mendes Jacques Da Costa[103], H.Y. Meng[158], L. Meng[93], S. Menke[112], M. Mentink[37], E. Meoni[44b,44a], G. Mercado[118], S. Merianos[155], C. Merlassino[70a,70c], L. Merola[73a,73b], C. Meroni[72a,72b], J. Metcalfe[6], A.S. Mete[6], E. Meuser[102], C. Meyer[69], J-P. Meyer[138], R.P. Middleton[137], L. Mijović[53], G. Mikenberg[172], M. Mikestikova[134], M. Mikuž[95], H. Mildner[102], A. Milic[37], D.W. Miller[40], E.H. Miller[146], L.S. Miller[35], A. Milov[172], D.A. Milstead[48a,48b], T. Min[114a], A.A. Minaenko[38], I.A. Minashvili[152b], L. Mince[60], A.I. Mincer[120], B. Mindur[87a], M. Mineev[39], Y. Mino[89], L.M. Mir[13], M. Miralles Lopez[60], M. Mironova[18a], M.C. Missio[116], A. Mitra[170], V.A. Mitsou[166], Y. Mitsumori[113], O. Miu[158], P.S. Miyagawa[96], T. Mkrtchyan[64a], M. Mlinarevic[98], T. Mlinarevic[98], M. Mlynarikova[37], S. Mobius[20], P. Mogg[111], M.H. Mohamed Farook[115], A.F. Mohammed[14,114c], S. Mohapatra[42], G. Mokgatitswane[34g], L. Moleri[172], B. Mondal[144], S. Mondal[135], K. Mönig[49], E. Monnier[104], L. Monsonis Romero[166], J. Montejo Berlingen[13], A. Montella[48a,48b], M. Montella[122], F. Montereali[78a,78b], F. Monticelli[92], S. Monzani[70a,70c], A. Morancho Tarda[43], N. Morange[67], A.L. Moreira De Carvalho[49], M. Moreno Llácer[166], C. Moreno Martinez[57], J.M. Moreno Perez[23b], P. Morettini[58b], S. Morgenstern[37], M. Morii[62], M. Morinaga[156], F. Morodei[76a,76b], L. Morvaj[37], P. Moschovakos[37], B. Moser[129], M. Mosidze[152b], T. Moskalets[45], P. Moskvitina[116], J. Moss[32,j], P. Moszkowicz[87a], A. Moussa[36d], E.J.W. Moyse[105], O. Mtintsilana[34g], S. Muanza[104], J. Mueller[132],

JHEP08(2024)153

D. Muenstermann[93], R. Müller[37], G.A. Mullier[164], A.J. Mullin[33], J.J. Mullin[131],
D.P. Mungo[158], D. Munoz Perez[166], F.J. Munoz Sanchez[103], M. Murin[103],
W.J. Murray[170,137], M. Muškinja[95], C. Mwewa[30], A.G. Myagkov[38,a], A.J. Myers[8],
G. Myers[108], M. Myska[135], B.P. Nachman[18a], O. Nackenhorst[50], K. Nagai[129],
K. Nagano[85], J.L. Nagle[30,ae], E. Nagy[104], A.M. Nairz[37], Y. Nakahama[85],
K. Nakamura[85], K. Nakkalil[5], H. Nanjo[127], E.A. Narayanan[115], I. Naryshkin[38],
L. Nasella[72a,72b], M. Naseri[35], S. Nasri[119b], C. Nass[25], G. Navarro[23a],
J. Navarro-Gonzalez[166], R. Nayak[154], A. Nayaz[19], P.Y. Nechaeva[38], S. Nechaeva[24b,24a],
F. Nechansky[134], L. Nedic[129], T.J. Neep[21], A. Negri[74a,74b], M. Negrini[24b], C. Nellist[117],
C. Nelson[106], K. Nelson[108], S. Nemecek[134], M. Nessi[37,g], M.S. Neubauer[165],
F. Neuhaus[102], J. Neundorf[49], J. Newell[94], P.R. Newman[21], C.W. Ng[132], Y.W.Y. Ng[49],
B. Ngair[119a], H.D.N. Nguyen[110], R.B. Nickerson[129], R. Nicolaidou[138], J. Nielsen[139],
M. Niemeyer[56], J. Niermann[56], N. Nikiforou[37], V. Nikolaenko[38,a], I. Nikolic-Audit[130],
K. Nikolopoulos[21], P. Nilsson[30], I. Ninca[49], G. Ninio[154], A. Nisati[76a], N. Nishu[2],
R. Nisius[112], J-E. Nitschke[51], E.K. Nkadimeng[34g], T. Nobe[156], T. Nommensen[150],
M.B. Norfolk[142], B.J. Norman[35], M. Noury[36a], J. Novak[95], T. Novak[95], L. Novotny[135],
R. Novotny[115], L. Nozka[125], K. Ntekas[162], N.M.J. Nunes De Moura Junior[84b],
J. Ocariz[130], A. Ochi[86], I. Ochoa[133a], S. Oerdek[49,t], J.T. Offermann[40], A. Ogrodnik[136],
A. Oh[103], C.C. Ohm[147], H. Oide[85], R. Oishi[156], M.L. Ojeda[37], Y. Okumura[156],
L.F. Oleiro Seabra[133a], I. Oleksiyuk[57], S.A. Olivares Pino[140d], G. Oliveira Correa[13],
D. Oliveira Damazio[30], J.L. Oliver[162], Ö.O. Öncel[55], A.P. O'Neill[20], A. Onofre[133a,133e],
P.U.E. Onyisi[11], M.J. Oreglia[40], G.E. Orellana[92], D. Orestano[78a,78b], N. Orlando[13],
R.S. Orr[158], L.M. Osojnak[131], R. Ospanov[63a], G. Otero y Garzon[31], H. Otono[90],
P.S. Ott[64a], G.J. Ottino[18a], M. Ouchrif[36d], F. Ould-Saada[128], T. Ovsiannikova[141],
M. Owen[60], R.E. Owen[137], V.E. Ozcan[22a], F. Ozturk[88], N. Ozturk[8], S. Ozturk[83],
H.A. Pacey[129], A. Pacheco Pages[13], C. Padilla Aranda[13], G. Padovano[76a,76b],
S. Pagan Griso[18a], G. Palacino[69], A. Palazzo[71a,71b], J. Pampel[25], J. Pan[175], T. Pan[65a],
D.K. Panchal[11], C.E. Pandini[117], J.G. Panduro Vazquez[137], H.D. Pandya[1], H. Pang[15],
P. Pani[49], G. Panizzo[70a,70c], L. Panwar[130], L. Paolozzi[57], S. Parajuli[165], A. Paramonov[6],
C. Paraskevopoulos[54], D. Paredes Hernandez[65b], A. Pareti[74a,74b], K.R. Park[42],
T.H. Park[158], M.A. Parker[33], F. Parodi[58b,58a], E.W. Parrish[118], V.A. Parrish[53],
J.A. Parsons[42], U. Parzefall[55], B. Pascual Dias[110], L. Pascual Dominguez[101],
E. Pasqualucci[76a], S. Passaggio[58b], F. Pastore[97], P. Patel[88], U.M. Patel[52], J.R. Pater[103],
T. Pauly[37], C.I. Pazos[161], J. Pearkes[146], M. Pedersen[128], R. Pedro[133a],
S.V. Peleganchuk[38], O. Penc[37], E.A. Pender[53], S. Peng[15], G.D. Penn[175], K.E. Penski[111],
M. Penzin[38], B.S. Peralva[84d], A.P. Pereira Peixoto[141], L. Pereira Sanchez[146],
D.V. Perepelitsa[30,ae], G. Perera[105], E. Perez Codina[159a], M. Perganti[10], H. Pernegger[37],
S. Perrella[76a,76b], O. Perrin[41], K. Peters[49], R.F.Y. Peters[103], B.A. Petersen[37],
T.C. Petersen[43], E. Petit[104], V. Petousis[135], C. Petridou[155,d], T. Petru[136],
A. Petrukhin[144], M. Pettee[18a], A. Petukhov[38], K. Petukhova[37], R. Pezoa[140f],
L. Pezzotti[37], G. Pezzullo[175], A.J. Pfleger[37], T.M. Pham[173], T. Pham[107],
P.W. Phillips[137], G. Piacquadio[148], E. Pianori[18a], F. Piazza[126], R. Piegaia[31],
D. Pietreanu[28b], A.D. Pilkington[103], M. Pinamonti[70a,70c], J.L. Pinfold[2],

B.C. Pinheiro Pereira[133a], J. Pinol Bel[13], A.E. Pinto Pinoargote[138,138], L. Pintucci[70a,70c], K.M. Piper[149], A. Pirttikoski[57], D.A. Pizzi[35], L. Pizzimento[65b], A. Pizzini[117], M.-A. Pleier[30], V. Pleskot[136], E. Plotnikova[39], G. Poddar[96], R. Poettgen[100], L. Poggioli[130], I. Pokharel[56], S. Polacek[136], G. Polesello[74a], A. Poley[145,159a], A. Polini[24b], C.S. Pollard[170], Z.B. Pollock[122], E. Pompa Pacchi[76a,76b], N.I. Pond[98], D. Ponomarenko[69], L. Pontecorvo[37], S. Popa[28a], G.A. Popeneciu[28d], A. Poreba[37], D.M. Portillo Quintero[159a], S. Pospisil[135], M.A. Postill[142], P. Postolache[28c], K. Potamianos[170], P.A. Potepa[87a], I.N. Potrap[39], C.J. Potter[33], H. Potti[150], J. Poveda[166], M.E. Pozo Astigarraga[37], A. Prades Ibanez[77a,77b], J. Pretel[168], D. Price[103], M. Primavera[71a], L. Primomo[70a,70c], M.A. Principe Martin[101], R. Privara[125], T. Procter[60], M.L. Proffitt[141], N. Proklova[131], K. Prokofiev[65c], G. Proto[112], J. Proudfoot[6], M. Przybycien[87a], W.W. Przygoda[87b], A. Psallidas[47], J.E. Puddefoot[142], D. Pudzha[55], D. Pyatiizbyantseva[38], J. Qian[108], D. Qichen[103], Y. Qin[13], T. Qiu[53], A. Quadt[56], M. Queitsch-Maitland[103], G. Quetant[57], R.P. Quinn[167], G. Rabanal Bolanos[62], D. Rafanoharana[55], F. Raffaeli[77a,77b], F. Ragusa[72a,72b], J.L. Rainbolt[40], J.A. Raine[57], S. Rajagopalan[30], E. Ramakoti[38], L. Rambelli[58b,58a], I.A. Ramirez-Berend[35], K. Ran[49,114c], D.S. Rankin[131], N.P. Rapheeha[34g], H. Rasheed[28b], V. Raskina[130], D.F. Rassloff[64a], A. Rastogi[18a], S. Rave[102], S. Ravera[58b,58a], B. Ravina[56], I. Ravinovich[172], M. Raymond[37], A.L. Read[128], N.P. Readioff[142], D.M. Rebuzzi[74a,74b], G. Redlinger[30], A.S. Reed[112], K. Reeves[27], J.A. Reidelsturz[174], D. Reikher[126], A. Rej[50], C. Rembser[37], M. Renda[28b], F. Renner[49], A.G. Rennie[162], A.L. Rescia[49], S. Resconi[72a], M. Ressegotti[58b,58a], S. Rettie[37], J.G. Reyes Rivera[109], E. Reynolds[18a], O.L. Rezanova[38], P. Reznicek[136], H. Riani[36d], N. Ribaric[52], E. Ricci[79a,79b], R. Richter[112], S. Richter[48a,48b], E. Richter-Was[87b], M. Ridel[130], S. Ridouani[36d], P. Rieck[120], P. Riedler[37], E.M. Riefel[48a,48b], J.O. Rieger[117], M. Rijssenbeek[148], M. Rimoldi[37], L. Rinaldi[24b,24a], P. Rincke[56,164], T.T. Rinn[30], M.P. Rinnagel[111], G. Ripellino[164], I. Riu[13], J.C. Rivera Vergara[168], F. Rizatdinova[124], E. Rizvi[96], B.R. Roberts[18a], S.S. Roberts[139], S.H. Robertson[106,w], D. Robinson[33], M. Robles Manzano[102], A. Robson[60], A. Rocchi[77a,77b], C. Roda[75a,75b], S. Rodriguez Bosca[37], Y. Rodriguez Garcia[23a], A. Rodriguez Rodriguez[55], A.M. Rodríguez Vera[118], S. Roe[37], J.T. Roemer[37], A.R. Roepe-Gier[139], O. Røhne[128], R.A. Rojas[105], C.P.A. Roland[130], J. Roloff[30], A. Romaniouk[38], E. Romano[74a,74b], M. Romano[24b], A.C. Romero Hernandez[165], N. Rompotis[94], L. Roos[130], S. Rosati[76a], B.J. Rosser[40], E. Rossi[129], E. Rossi[73a,73b], L.P. Rossi[62], L. Rossini[55], R. Rosten[122], M. Rotaru[28b], B. Rottler[55], C. Rougier[91], D. Rousseau[67], D. Rousso[49], A. Roy[165], S. Roy-Garand[158], A. Rozanov[104], Z.M.A. Rozario[60], Y. Rozen[153], A. Rubio Jimenez[166], A.J. Ruby[94], V.H. Ruelas Rivera[19], T.A. Ruggeri[1], A. Ruggiero[129], A. Ruiz-Martinez[166], A. Rummler[37], Z. Rurikova[55], N.A. Rusakovich[39], H.L. Russell[168], G. Russo[76a,76b], J.P. Rutherfoord[7], S. Rutherford Colmenares[33], M. Rybar[136], E.B. Rye[128], A. Ryzhov[45], J.A. Sabater Iglesias[57], H.F-W. Sadrozinski[139], F. Safai Tehrani[76a], B. Safarzadeh Samani[137], S. Saha[1], M. Sahinsoy[83], A. Saibel[166], M. Saimpert[138], M. Saito[156], T. Saito[156], A. Sala[72a,72b], D. Salamani[37], A. Salnikov[146], J. Salt[166], A. Salvador Salas[154], D. Salvatore[44b,44a], F. Salvatore[149], A. Salzburger[37], D. Sammel[55],

E. Sampson[93], D. Sampsonidis[155,d], D. Sampsonidou[126], J. Sánchez[166], V. Sanchez Sebastian[166], H. Sandaker[128], C.O. Sander[49], J.A. Sandesara[105], M. Sandhoff[174], C. Sandoval[23b], L. Sanfilippo[64a], D.P.C. Sankey[137], T. Sano[89], A. Sansoni[54], L. Santi[37,76b], C. Santoni[41], H. Santos[133a,133b], A. Santra[172], E. Sanzani[24b,24a], K.A. Saoucha[163], J.G. Saraiva[133a,133d], J. Sardain[7], O. Sasaki[85], K. Sato[160], C. Sauer[64b], E. Sauvan[4], P. Savard[158,ac], R. Sawada[156], C. Sawyer[137], L. Sawyer[99], C. Sbarra[24b], A. Sbrizzi[24b,24a], T. Scanlon[98], J. Schaarschmidt[141], U. Schäfer[102], A.C. Schaffer[67,45], D. Schaile[111], R.D. Schamberger[148], C. Scharf[19], M.M. Schefer[20], V.A. Schegelsky[38], D. Scheirich[136], M. Schernau[162], C. Scheulen[56], C. Schiavi[58b,58a], M. Schioppa[44b,44a], B. Schlag[146,l], K.E. Schleicher[55], S. Schlenker[37], J. Schmeing[174], M.A. Schmidt[174], K. Schmieden[102], C. Schmitt[102], N. Schmitt[102], S. Schmitt[49], L. Schoeffel[138], A. Schoening[64b], P.G. Scholer[35], E. Schopf[129], M. Schott[25], J. Schovancova[37], S. Schramm[57], T. Schroer[57], H-C. Schultz-Coulon[64a], M. Schumacher[55], B.A. Schumm[139], Ph. Schune[138], A.J. Schuy[141], H.R. Schwartz[139], A. Schwartzman[146], T.A. Schwarz[108], Ph. Schwemling[138], R. Schwienhorst[109], F.G. Sciacca[20], A. Sciandra[30], G. Sciolla[27], F. Scuri[75a], C.D. Sebastiani[94], K. Sedlaczek[118], S.C. Seidel[115], A. Seiden[139], B.D. Seidlitz[42], C. Seitz[49], J.M. Seixas[84b], G. Sekhniaidze[73a], L. Selem[61], N. Semprini-Cesari[24b,24a], D. Sengupta[57], V. Senthilkumar[166], L. Serin[67], M. Sessa[77a,77b], H. Severini[123], F. Sforza[58b,58a], A. Sfyrla[57], Q. Sha[14], E. Shabalina[56], A.H. Shah[33], R. Shaheen[147], J.D. Shahinian[131], D. Shaked Renous[172], L.Y. Shan[14], M. Shapiro[18a], A. Sharma[37], A.S. Sharma[167], P. Sharma[81], P.B. Shatalov[38], K. Shaw[149], S.M. Shaw[103], Q. Shen[63c], D.J. Sheppard[145], P. Sherwood[98], L. Shi[98], X. Shi[14], S. Shimizu[85], C.O. Shimmin[175], J.D. Shinner[97], I.P.J. Shipsey[129], S. Shirabe[90], M. Shiyakova[39,u], M.J. Shochet[40], D.R. Shope[128], B. Shrestha[123], S. Shrestha[122,af], I. Shreyber[38], M.J. Shroff[168], P. Sicho[134], A.M. Sickles[165], E. Sideras Haddad[34g], A.C. Sidley[117], A. Sidoti[24b], F. Siegert[51], Dj. Sijacki[16], F. Sili[92], J.M. Silva[53], I. Silva Ferreira[84b], M.V. Silva Oliveira[30], S.B. Silverstein[48a], S. Simion[67], R. Simoniello[37], E.L. Simpson[103], H. Simpson[149], L.R. Simpson[108], N.D. Simpson[100], S. Simsek[83], S. Sindhu[56], P. Sinervo[158], S. Singh[158], S. Sinha[49], S. Sinha[103], M. Sioli[24b,24a], I. Siral[37], E. Sitnikova[49], J. Sjölin[48a,48b], A. Skaf[56], E. Skorda[21], P. Skubic[123], M. Slawinska[88], V. Smakhtin[172], B.H. Smart[137], S.Yu. Smirnov[38], Y. Smirnov[38], L.N. Smirnova[38,a], O. Smirnova[100], A.C. Smith[42], D.R. Smith[162], E.A. Smith[40], J.L. Smith[103], R. Smith[146], M. Smizanska[93], K. Smolek[135], A.A. Snesarev[38], H.L. Snoek[117], S. Snyder[30], R. Sobie[168,w], A. Soffer[154], C.A. Solans Sanchez[37], E.Yu. Soldatov[38], U. Soldevila[166], A.A. Solodkov[38], S. Solomon[27], A. Soloshenko[39], K. Solovieva[55], O.V. Solovyanov[41], P. Sommer[51], A. Sonay[13], W.Y. Song[159b], A. Sopczak[135], A.L. Sopio[98], F. Sopkova[29b], J.D. Sorenson[115], I.R. Sotarriva Alvarez[157], V. Sothilingam[64a], O.J. Soto Sandoval[140c,140b], S. Sottocornola[69], R. Soualah[163], Z. Soumaimi[36e], D. South[49], N. Soybelman[172], S. Spagnolo[71a,71b], M. Spalla[112], D. Sperlich[55], G. Spigo[37], B. Spisso[73a,73b], D.P. Spiteri[60], M. Spousta[136], E.J. Staats[35], R. Stamen[64a], A. Stampekis[21], E. Stanecka[88], W. Stanek-Maslouska[49], M.V. Stange[51], B. Stanislaus[18a], M.M. Stanitzki[49], B. Stapf[49], E.A. Starchenko[38], G.H. Stark[139], J. Stark[91], P. Staroba[134], P. Starovoitov[64a], S. Stärz[106], R. Staszewski[88], G. Stavropoulos[47], P. Steinberg[30], B. Stelzer[145,159a], H.J. Stelzer[132],

O. Stelzer-Chilton[159a], H. Stenzel[59], T.J. Stevenson[149], G.A. Stewart[37], J.R. Stewart[124], M.C. Stockton[37], G. Stoicea[28b], M. Stolarski[133a], S. Stonjek[112], A. Straessner[51], J. Strandberg[147], S. Strandberg[48a,48b], M. Stratmann[174], M. Strauss[123], T. Strebler[104], P. Strizenec[29b], R. Ströhmer[169], D.M. Strom[126], R. Stroynowski[45], A. Strubig[48a,48b], S.A. Stucci[30], B. Stugu[17], J. Stupak[123], N.A. Styles[49], D. Su[146], S. Su[63a], W. Su[63d], X. Su[63a], D. Suchy[29a], K. Sugizaki[156], V.V. Sulin[38], M.J. Sullivan[94], D.M.S. Sultan[129], L. Sultanaliyeva[38], S. Sultansoy[3b], T. Sumida[89], S. Sun[173], O. Sunneborn Gudnadottir[164], N. Sur[104], M.R. Sutton[149], H. Suzuki[160], M. Svatos[134], M. Swiatlowski[159a], T. Swirski[169], I. Sykora[29a], M. Sykora[136], T. Sykora[136], D. Ta[102], K. Tackmann[49,t], A. Taffard[162], R. Tafirout[159a], J.S. Tafoya Vargas[67], Y. Takubo[85], M. Talby[104], A.A. Talyshev[38], K.C. Tam[65b], N.M. Tamir[154], A. Tanaka[156], J. Tanaka[156], R. Tanaka[67], M. Tanasini[148], Z. Tao[167], S. Tapia Araya[140f], S. Tapprogge[102], A. Tarek Abouelfadl Mohamed[109], S. Tarem[153], K. Tariq[14], G. Tarna[28b], G.F. Tartarelli[72a], M.J. Tartarin[91], P. Tas[136], M. Tasevsky[134], E. Tassi[44b,44a], A.C. Tate[165], G. Tateno[156], Y. Tayalati[36e,v], G.N. Taylor[107], W. Taylor[159b], R. Teixeira De Lima[146], P. Teixeira-Dias[97], J.J. Teoh[158], K. Terashi[156], J. Terron[101], S. Terzo[13], M. Testa[54], R.J. Teuscher[158,w], A. Thaler[80], O. Theiner[57], T. Theveneaux-Pelzer[104], O. Thielmann[174], D.W. Thomas[97], J.P. Thomas[21], E.A. Thompson[18a], P.D. Thompson[21], E. Thomson[131], R.E. Thornberry[45], C. Tian[63a], Y. Tian[56], V. Tikhomirov[38,a], Yu.A. Tikhonov[38], S. Timoshenko[38], D. Timoshyn[136], E.X.L. Ting[1], P. Tipton[175], A. Tishelman-Charny[30], S.H. Tlou[34g], K. Todome[157], S. Todorova-Nova[136], S. Todt[51], L. Toffolin[70a,70c], M. Togawa[85], J. Tojo[90], S. Tokár[29a], K. Tokushuku[85], O. Toldaiev[69], M. Tomoto[85,113], L. Tompkins[146,l], K.W. Topolnicki[87b], E. Torrence[126], H. Torres[91], E. Torró Pastor[166], M. Toscani[31], C. Tosciri[40], M. Tost[11], D.R. Tovey[142], I.S. Trandafir[28b], T. Trefzger[169], A. Tricoli[30], I.M. Trigger[159a], S. Trincaz-Duvoid[130], D.A. Trischuk[27], B. Trocmé[61], A. Tropina[39], L. Truong[34c], M. Trzebinski[88], A. Trzupek[88], F. Tsai[148], M. Tsai[108], A. Tsiamis[155], P.V. Tsiareshka[38], S. Tsigaridas[159a], A. Tsirigotis[155,q], V. Tsiskaridze[158], E.G. Tskhadadze[152a], M. Tsopoulou[155], Y. Tsujikawa[89], I.I. Tsukerman[38], V. Tsulaia[18a], S. Tsuno[85], K. Tsuri[121], D. Tsybychev[148], Y. Tu[65b], A. Tudorache[28b], V. Tudorache[28b], A.N. Tuna[62], S. Turchikhin[58b,58a], I. Turk Cakir[3a], R. Turra[72a], T. Turtuvshin[39], P.M. Tuts[42], S. Tzamarias[155,d], E. Tzovara[102], F. Ukegawa[160], P.A. Ulloa Poblete[140c,140b], E.N. Umaka[30], G. Unal[37], A. Undrus[30], G. Unel[162], J. Urban[29b], P. Urrejola[140a], G. Usai[8], R. Ushioda[157], M. Usman[110], F. Ustuner[53], Z. Uysal[83], V. Vacek[135], B. Vachon[106], T. Vafeiadis[37], A. Vaitkus[98], C. Valderanis[111], E. Valdes Santurio[48a,48b], M. Valente[159a], S. Valentinetti[24b,24a], A. Valero[166], E. Valiente Moreno[166], A. Vallier[91], J.A. Valls Ferrer[166], D.R. Van Arneman[117], T.R. Van Daalen[141], A. Van Der Graaf[50], P. Van Gemmeren[6], M. Van Rijnbach[37], S. Van Stroud[98], I. Van Vulpen[117], P. Vana[136], M. Vanadia[77a,77b], W. Vandelli[37], E.R. Vandewall[124], D. Vannicola[154], L. Vannoli[54], R. Vari[76a], E.W. Varnes[7], C. Varni[18b], T. Varol[151], D. Varouchas[67], L. Variale[166], K.E. Varvell[150], M.E. Vasile[28b], L. Vaslin[85], G.A. Vasquez[168], A. Vasyukov[39], L.M. Vaughan[124], R. Vavricka[102], T. Vazquez Schroeder[37], J. Veatch[32], V. Vecchio[103], M.J. Veen[105], I. Veliscek[30], L.M. Veloce[158], F. Veloso[133a,133c], S. Veneziano[76a], A. Ventura[71a,71b], S. Ventura Gonzalez[138], A. Verbytskyi[112], M. Verducci[75a,75b],

JHEP08(2024)153

C. Vergis[96], M. Verissimo De Araujo[84b], W. Verkerke[117], J.C. Vermeulen[117], C. Vernieri[146], M. Vessella[105], M.C. Vetterli[145,ac], A. Vgenopoulos[102], N. Viaux Maira[140f], T. Vickey[142], O.E. Vickey Boeriu[142], G.H.A. Viehhauser[129], L. Vigani[64b], M. Vigl[112], M. Villa[24b,24a], M. Villaplana Perez[166], E.M. Villhauer[53], E. Vilucchi[54], M.G. Vincter[35], A. Visibile[117], C. Vittori[37], I. Vivarelli[24b,24a], E. Voevodina[112], F. Vogel[111], J.C. Voigt[51], P. Vokac[135], Yu. Volkotrub[87b], J. Von Ahnen[49], E. Von Toerne[25], B. Vormwald[37], V. Vorobel[136], K. Vorobev[38], M. Vos[166], K. Voss[144], M. Vozak[117], L. Vozdecky[123], N. Vranjes[16], M. Vranjes Milosavljevic[16], M. Vreeswijk[117], N.K. Vu[63d,63c], R. Vuillermet[37], O. Vujinovic[102], I. Vukotic[40], I.K. Vyas[35], S. Wada[160], C. Wagner[105], J.M. Wagner[18a], W. Wagner[174], S. Wahdan[174], H. Wahlberg[92], J. Walder[137], R. Walker[111], W. Walkowiak[144], A. Wall[131], E.J. Wallin[100], T. Wamorkar[6], A.Z. Wang[139], C. Wang[102], C. Wang[11], H. Wang[18a], J. Wang[65c], P. Wang[98], R. Wang[62], R. Wang[6], S.M. Wang[151], S. Wang[63b], S. Wang[14], T. Wang[63a], W.T. Wang[81], W. Wang[14], X. Wang[114a], X. Wang[165], X. Wang[63c], Y. Wang[63d], Y. Wang[114a], Y. Wang[63a], Z. Wang[108], Z. Wang[63d,52,63c], Z. Wang[108], A. Warburton[106], R.J. Ward[21], N. Warrack[60], S. Waterhouse[97], A.T. Watson[21], H. Watson[53], M.F. Watson[21], E. Watton[60,137], G. Watts[141], B.M. Waugh[98], J.M. Webb[55], C. Weber[30], H.A. Weber[19], M.S. Weber[20], S.M. Weber[64a], C. Wei[63a], Y. Wei[55], A.R. Weidberg[129], E.J. Weik[120], J. Weingarten[50], C. Weiser[55], C.J. Wells[49], T. Wenaus[30], B. Wendland[50], T. Wengler[37], N.S. Wenke[112], N. Wermes[25], M. Wessels[64a], A.M. Wharton[93], A.S. White[62], A. White[8], M.J. White[1], D. Whiteson[162], L. Wickremasinghe[127], W. Wiedenmann[173], M. Wielers[137], C. Wiglesworth[43], D.J. Wilbern[123], H.G. Wilkens[37], J.J.H. Wilkinson[33], D.M. Williams[42], H.H. Williams[131], S. Williams[33], S. Willocq[105], B.J. Wilson[103], P.J. Windischhofer[40], F.I. Winkel[31], F. Winklmeier[126], B.T. Winter[55], J.K. Winter[103], M. Wittgen[146], M. Wobisch[99], T. Wojtkowski[61], Z. Wolffs[117], J. Wollrath[162], M.W. Wolter[88], H. Wolters[133a,133c], M.C. Wong[139], E.L. Woodward[42], S.D. Worm[49], B.K. Wosiek[88], K.W. Woźniak[88], S. Wozniewski[56], K. Wraight[60], C. Wu[21], M. Wu[114b], M. Wu[116], S.L. Wu[173], X. Wu[57], Y. Wu[63a], Z. Wu[4], J. Wuerzinger[112,aa], T.R. Wyatt[103], B.M. Wynne[53], S. Xella[43], L. Xia[114a], M. Xia[15], M. Xie[63a], S. Xin[14,114c], A. Xiong[126], J. Xiong[18a], D. Xu[14], H. Xu[63a], L. Xu[63a], R. Xu[131], T. Xu[108], Y. Xu[15], Z. Xu[53], Z. Xu[114a], B. Yabsley[150], S. Yacoob[34a], Y. Yamaguchi[85], E. Yamashita[156], H. Yamauchi[160], T. Yamazaki[18a], Y. Yamazaki[86], J. Yan[63c], S. Yan[60], Z. Yan[105], H.J. Yang[63c,63d], H.T. Yang[63a], S. Yang[63a], T. Yang[65c], X. Yang[37], X. Yang[14], Y. Yang[45], Y. Yang[63a], Z. Yang[63a], W-M. Yao[18a], H. Ye[114a], H. Ye[56], J. Ye[14], S. Ye[30], X. Ye[63a], Y. Yeh[98], I. Yeletskikh[39], B.K. Yeo[18b], M.R. Yexley[98], T.P. Yildirim[129], P. Yin[42], K. Yorita[171], S. Younas[28b], C.J.S. Young[37], C. Young[146], C. Yu[14,114c], Y. Yu[63a], J. Yuan[14,114c], M. Yuan[108], R. Yuan[63d,63c], L. Yue[98], M. Zaazoua[63a], B. Zabinski[88], E. Zaid[53], Z.K. Zak[88], T. Zakareishvili[166], S. Zambito[57], J.A. Zamora Saa[140d,140b], J. Zang[156], D. Zanzi[55], O. Zaplatilek[135], C. Zeitnitz[174], H. Zeng[14], J.C. Zeng[165], D.T. Zenger Jr[27], O. Zenin[38], T. Ženiš[29a], S. Zenz[96], S. Zerradi[36a], D. Zerwas[67], M. Zhai[14,114c], D.F. Zhang[142], J. Zhang[63b], J. Zhang[6], K. Zhang[14,114c], L. Zhang[63a], L. Zhang[114a], P. Zhang[14,114c], R. Zhang[173], S. Zhang[108], S. Zhang[91], T. Zhang[156], X. Zhang[63c], X. Zhang[63b], Y. Zhang[63c], Y. Zhang[98],

JHEP08(2024)153

Y. Zhang[114a], Z. Zhang[18a], Z. Zhang[63b], Z. Zhang[67], H. Zhao[141], T. Zhao[63b], Y. Zhao[139], Z. Zhao[63a], Z. Zhao[63a], A. Zhemchugov[39], J. Zheng[114a], K. Zheng[165], X. Zheng[63a], Z. Zheng[146], D. Zhong[165], B. Zhou[108], H. Zhou[7], N. Zhou[63c], Y. Zhou[15], Y. Zhou[114a], Y. Zhou[7], C.G. Zhu[63b], J. Zhu[108], X. Zhu[63d], Y. Zhu[63c], Y. Zhu[63a], X. Zhuang[14], K. Zhukov[69], N.I. Zimine[39], J. Zinsser[64b], M. Ziolkowski[144], L. Živković[16], A. Zoccoli[24b,24a], K. Zoch[62], T.G. Zorbas[142], O. Zormpa[47], W. Zou[42], L. Zwalinski[37]

[1] *Department of Physics, University of Adelaide, Adelaide, Australia*
[2] *Department of Physics, University of Alberta, Edmonton AB, Canada*
[3] [(a)] *Department of Physics, Ankara University, Ankara;* [(b)] *Division of Physics, TOBB University of Economics and Technology, Ankara, Türkiye*
[4] *LAPP, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy, France*
[5] *APC, Université Paris Cité, CNRS/IN2P3, Paris, France*
[6] *High Energy Physics Division, Argonne National Laboratory, Argonne IL, United States of America*
[7] *Department of Physics, University of Arizona, Tucson AZ, United States of America*
[8] *Department of Physics, University of Texas at Arlington, Arlington TX, United States of America*
[9] *Physics Department, National and Kapodistrian University of Athens, Athens, Greece*
[10] *Physics Department, National Technical University of Athens, Zografou, Greece*
[11] *Department of Physics, University of Texas at Austin, Austin TX, United States of America*
[12] *Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan*
[13] *Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona, Spain*
[14] *Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China*
[15] *Physics Department, Tsinghua University, Beijing, China*
[16] *Institute of Physics, University of Belgrade, Belgrade, Serbia*
[17] *Department for Physics and Technology, University of Bergen, Bergen, Norway*
[18] [(a)] *Physics Division, Lawrence Berkeley National Laboratory, Berkeley CA;* [(b)] *University of California, Berkeley CA, United States of America*
[19] *Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany*
[20] *Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland*
[21] *School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom*
[22] [(a)] *Department of Physics, Bogazici University, Istanbul;* [(b)] *Department of Physics Engineering, Gaziantep University, Gaziantep;* [(c)] *Department of Physics, Istanbul University, Istanbul, Türkiye*
[23] [(a)] *Facultad de Ciencias y Centro de Investigaciónes, Universidad Antonio Nariño, Bogotá;* [(b)] *Departamento de Física, Universidad Nacional de Colombia, Bogotá, Colombia*
[24] [(a)] *Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna;* [(b)] *INFN Sezione di Bologna, Italy*
[25] *Physikalisches Institut, Universität Bonn, Bonn, Germany*
[26] *Department of Physics, Boston University, Boston MA, United States of America*
[27] *Department of Physics, Brandeis University, Waltham MA, United States of America*
[28] [(a)] *Transilvania University of Brasov, Brasov;* [(b)] *Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest;* [(c)] *Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi;* [(d)] *National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca;* [(e)] *National University of Science and Technology Politechnica, Bucharest;* [(f)] *West University in Timisoara, Timisoara;* [(g)] *Faculty of Physics, University of Bucharest, Bucharest, Romania*
[29] [(a)] *Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava;* [(b)] *Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic*
[30] *Physics Department, Brookhaven National Laboratory, Upton NY, United States of America*
[31] *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*

JHEP08(2024)153

[32] *California State University, CA, United States of America*
[33] *Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*
[34] [(a)] *Department of Physics, University of Cape Town, Cape Town;* [(b)] *iThemba Labs, Western Cape;* [(c)] *Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg;* [(d)] *National Institute of Physics, University of the Philippines Diliman (Philippines);* [(e)] *University of South Africa, Department of Physics, Pretoria;* [(f)] *University of Zululand, KwaDlangezwa;* [(g)] *School of Physics, University of the Witwatersrand, Johannesburg, South Africa*
[35] *Department of Physics, Carleton University, Ottawa ON, Canada*
[36] [(a)] *Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca;* [(b)] *Faculté des Sciences, Université Ibn-Tofail, Kénitra;* [(c)] *Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech;* [(d)] *LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda;* [(e)] *Faculté des sciences, Université Mohammed V, Rabat;* [(f)] *Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir, Morocco*
[37] *CERN, Geneva, Switzerland*
[38] *Affiliated with an institute covered by a cooperation agreement with CERN*
[39] *Affiliated with an international laboratory covered by a cooperation agreement with CERN*
[40] *Enrico Fermi Institute, University of Chicago, Chicago IL, United States of America*
[41] *LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand, France*
[42] *Nevis Laboratory, Columbia University, Irvington NY, United States of America*
[43] *Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark*
[44] [(a)] *Dipartimento di Fisica, Università della Calabria, Rende;* [(b)] *INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Italy*
[45] *Physics Department, Southern Methodist University, Dallas TX, United States of America*
[46] *Physics Department, University of Texas at Dallas, Richardson TX, United States of America*
[47] *National Centre for Scientific Research "Demokritos", Agia Paraskevi, Greece*
[48] [(a)] *Department of Physics, Stockholm University;* [(b)] *Oskar Klein Centre, Stockholm, Sweden*
[49] *Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen, Germany*
[50] *Fakultät Physik, Technische Universität Dortmund, Dortmund, Germany*
[51] *Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany*
[52] *Department of Physics, Duke University, Durham NC, United States of America*
[53] *SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom*
[54] *INFN e Laboratori Nazionali di Frascati, Frascati, Italy*
[55] *Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany*
[56] *II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany*
[57] *Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland*
[58] [(a)] *Dipartimento di Fisica, Università di Genova, Genova;* [(b)] *INFN Sezione di Genova, Italy*
[59] *II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany*
[60] *SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom*
[61] *LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble, France*
[62] *Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA, United States of America*
[63] [(a)] *Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei;* [(b)] *Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao;* [(c)] *School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai;* [(d)] *Tsung-Dao Lee Institute, Shanghai;* [(e)] *School of Physics and Microelectronics, Zhengzhou University, China*
[64] [(a)] *Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg;* [(b)] *Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
[65] [(a)] *Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong;* [(b)] *Department of Physics, University of Hong Kong, Hong Kong;* [(c)] *Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China*
[66] *Department of Physics, National Tsing Hua University, Hsinchu, Taiwan*

JHEP08(2024)153

[67] IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay, France
[68] Centro Nacional de Microelectrónica (IMB-CNM-CSIC), Barcelona, Spain
[69] Department of Physics, Indiana University, Bloomington IN, United States of America
[70] [(a)] INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine; [(b)] ICTP, Trieste; [(c)] Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine, Italy
[71] [(a)] INFN Sezione di Lecce; [(b)] Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
[72] [(a)] INFN Sezione di Milano; [(b)] Dipartimento di Fisica, Università di Milano, Milano, Italy
[73] [(a)] INFN Sezione di Napoli; [(b)] Dipartimento di Fisica, Università di Napoli, Napoli, Italy
[74] [(a)] INFN Sezione di Pavia; [(b)] Dipartimento di Fisica, Università di Pavia, Pavia, Italy
[75] [(a)] INFN Sezione di Pisa; [(b)] Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
[76] [(a)] INFN Sezione di Roma; [(b)] Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy
[77] [(a)] INFN Sezione di Roma Tor Vergata; [(b)] Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
[78] [(a)] INFN Sezione di Roma Tre; [(b)] Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy
[79] [(a)] INFN-TIFPA; [(b)] Università degli Studi di Trento, Trento, Italy
[80] Universität Innsbruck, Department of Astro and Particle Physics, Innsbruck, Austria
[81] University of Iowa, Iowa City IA, United States of America
[82] Department of Physics and Astronomy, Iowa State University, Ames IA, United States of America
[83] Istinye University, Sariyer, Istanbul, Türkiye
[84] [(a)] Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora; [(b)] Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; [(c)] Instituto de Física, Universidade de São Paulo, São Paulo; [(d)] Rio de Janeiro State University, Rio de Janeiro; [(e)] Federal University of Bahia, Bahia, Brazil
[85] KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
[86] Graduate School of Science, Kobe University, Kobe, Japan
[87] [(a)] AGH University of Krakow, Faculty of Physics and Applied Computer Science, Krakow; [(b)] Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland
[88] Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland
[89] Faculty of Science, Kyoto University, Kyoto, Japan
[90] Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka, Japan
[91] L2IT, Université de Toulouse, CNRS/IN2P3, UPS, Toulouse, France
[92] Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
[93] Physics Department, Lancaster University, Lancaster, United Kingdom
[94] Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
[95] Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia
[96] School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom
[97] Department of Physics, Royal Holloway University of London, Egham, United Kingdom
[98] Department of Physics and Astronomy, University College London, London, United Kingdom
[99] Louisiana Tech University, Ruston LA, United States of America
[100] Fysiska institutionen, Lunds universitet, Lund, Sweden
[101] Departamento de Física Teorica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid, Spain
[102] Institut für Physik, Universität Mainz, Mainz, Germany
[103] School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
[104] CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France
[105] Department of Physics, University of Massachusetts, Amherst MA, United States of America
[106] Department of Physics, McGill University, Montreal QC, Canada
[107] School of Physics, University of Melbourne, Victoria, Australia
[108] Department of Physics, University of Michigan, Ann Arbor MI, United States of America
[109] Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States of America
[110] Group of Particle Physics, University of Montreal, Montreal QC, Canada

JHEP08(2024)153

[111] Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
[112] Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
[113] Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan
[114] [a] Department of Physics, Nanjing University, Nanjing; [b] School of Science, Shenzhen Campus of Sun Yat-sen University; [c] University of Chinese Academy of Science (UCAS), Beijing, China
[115] Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, United States of America
[116] Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen, The Netherlands
[117] Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, The Netherlands
[118] Department of Physics, Northern Illinois University, DeKalb IL, United States of America
[119] [a] New York University Abu Dhabi, Abu Dhabi; [b] United Arab Emirates University, Al Ain, United Arab Emirates
[120] Department of Physics, New York University, New York NY, United States of America
[121] Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo, Japan
[122] Ohio State University, Columbus OH, United States of America
[123] Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States of America
[124] Department of Physics, Oklahoma State University, Stillwater OK, United States of America
[125] Palacký University, Joint Laboratory of Optics, Olomouc, Czech Republic
[126] Institute for Fundamental Science, University of Oregon, Eugene, OR, United States of America
[127] Graduate School of Science, Osaka University, Osaka, Japan
[128] Department of Physics, University of Oslo, Oslo, Norway
[129] Department of Physics, Oxford University, Oxford, United Kingdom
[130] LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris, France
[131] Department of Physics, University of Pennsylvania, Philadelphia PA, United States of America
[132] Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States of America
[133] [a] Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa; [b] Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa; [c] Departamento de Física, Universidade de Coimbra, Coimbra; [d] Centro de Física Nuclear da Universidade de Lisboa, Lisboa; [e] Departamento de Física, Universidade do Minho, Braga; [f] Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain); [g] Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
[134] Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic
[135] Czech Technical University in Prague, Prague, Czech Republic
[136] Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic
[137] Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
[138] IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
[139] Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States of America
[140] [a] Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; [b] Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago; [c] Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, y Departamento de Física, Universidad de La Serena; [d] Universidad Andres Bello, Department of Physics, Santiago; [e] Instituto de Alta Investigación, Universidad de Tarapacá, Arica; [f] Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
[141] Department of Physics, University of Washington, Seattle WA, United States of America
[142] Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
[143] Department of Physics, Shinshu University, Nagano, Japan
[144] Department Physik, Universität Siegen, Siegen, Germany
[145] Department of Physics, Simon Fraser University, Burnaby BC, Canada
[146] SLAC National Accelerator Laboratory, Stanford CA, United States of America

JHEP08(2024)153

[147] Department of Physics, Royal Institute of Technology, Stockholm, Sweden
[148] Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY, United States of America
[149] Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
[150] School of Physics, University of Sydney, Sydney, Australia
[151] Institute of Physics, Academia Sinica, Taipei, Taiwan
[152] [(a)] E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi; [(b)] High Energy Physics Institute, Tbilisi State University, Tbilisi; [(c)] University of Georgia, Tbilisi, Georgia
[153] Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel
[154] Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
[155] Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
[156] International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan
[157] Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
[158] Department of Physics, University of Toronto, Toronto ON, Canada
[159] [(a)] TRIUMF, Vancouver BC; [(b)] Department of Physics and Astronomy, York University, Toronto ON, Canada
[160] Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan
[161] Department of Physics and Astronomy, Tufts University, Medford MA, United States of America
[162] Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States of America
[163] University of Sharjah, Sharjah, United Arab Emirates
[164] Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
[165] Department of Physics, University of Illinois, Urbana IL, United States of America
[166] Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Valencia, Spain
[167] Department of Physics, University of British Columbia, Vancouver BC, Canada
[168] Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada
[169] Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany
[170] Department of Physics, University of Warwick, Coventry, United Kingdom
[171] Waseda University, Tokyo, Japan
[172] Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot, Israel
[173] Department of Physics, University of Wisconsin, Madison WI, United States of America
[174] Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany
[175] Department of Physics, Yale University, New Haven CT, United States of America

[a] Also Affiliated with an institute covered by a cooperation agreement with CERN
[b] Also at An-Najah National University, Nablus, Palestine
[c] Also at Borough of Manhattan Community College, City University of New York, New York NY, United States of America
[d] Also at Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki, Greece
[e] Also at CERN, Geneva, Switzerland
[f] Also at CMD-AC UNEC Research Center, Azerbaijan State University of Economics (UNEC), Azerbaijan
[g] Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland
[h] Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona, Spain
[i] Also at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece
[j] Also at Department of Physics, California State University, Sacramento, United States of America
[k] Also at Department of Physics, King's College London, London, United Kingdom
[l] Also at Department of Physics, Stanford University, Stanford CA, United States of America
[m] Also at Department of Physics, Stellenbosch University, South Africa
[n] Also at Department of Physics, University of Fribourg, Fribourg, Switzerland
[o] Also at Department of Physics, University of Thessaly, Greece
[p] Also at Department of Physics, Westmont College, Santa Barbara, United States of America

JHEP08(2024)153

[q] Also at Hellenic Open University, Patras, Greece
[r] Also at Imam Mohammad Ibn Saud Islamic University, Saudi Arabia
[s] Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain
[t] Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany
[u] Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria
[v] Also at Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir, Morocco
[w] Also at Institute of Particle Physics (IPP), Canada
[x] Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
[y] Also at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia
[z] Also at National Institute of Physics, University of the Philippines Diliman (Philippines), Philippines
[aa] Also at Technical University of Munich, Munich, Germany
[ab] Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing, China
[ac] Also at TRIUMF, Vancouver BC, Canada
[ad] Also at Università di Napoli Parthenope, Napoli, Italy
[ae] Also at University of Colorado Boulder, Department of Physics, Colorado, United States of America
[af] Also at Washington College, Chestertown, MD, United States of America
[ag] Also at Yeditepe University, Physics Department, Istanbul, Türkiye
[*] Deceased

JHEP08(2024)153