Search for New Phenomena in Two-Body Invariant Mass Distributions Using Unsupervised Machine Learning for Anomaly Detection at $\sqrt{s} = 13$ TeV with the ATLAS Detector

G. Aad *et al.*[*]
(ATLAS Collaboration)

(Received 10 July 2023; accepted 13 December 2023; published 20 February 2024)

Searches for new resonances are performed using an unsupervised anomaly-detection technique. Events with at least one electron or muon are selected from 140 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV recorded by ATLAS at the Large Hadron Collider. The approach involves training an autoencoder on data, and subsequently defining anomalous regions based on the reconstruction loss of the decoder. Studies focus on nine invariant mass spectra that contain pairs of objects consisting of one light jet or b jet and either one lepton (e, μ), photon, or second light jet or b jet in the anomalous regions. No significant deviations from the background hypotheses are observed. Limits on contributions from generic Gaussian signals with various widths of the resonance mass are obtained for nine invariant masses in the anomalous regions.

DOI: 10.1103/PhysRevLett.132.081801

Searches for new physics phenomena beyond those described by the standard model (SM) require advanced techniques to devise selections that involve a large number of variables characterizing collision events. Furthermore, limited understanding of how new physics would manifest itself has inspired the design of model-independent searches [1]. In traditional methods, event selections are optimized to target specific signatures of signals beyond the SM (BSM signals) and to maximize their separation from SM background processes. Alternatively, event selection criteria can be relaxed to target more general signatures, but this reduces the ability to suppress background.

Machine learning (ML) anomaly-detection methods [2–12] provide a new way to study collision events. One such approach uses an autoencoder (AE) [13–16], a neural network architecture that is commonly used in unsupervised learning. The AE is trained using mostly SM background events and is applied to identify collision events that display kinematic properties different from those of SM events. ATLAS previously used a weakly supervised learning technique for massive dijet final states [17] and an unsupervised machine-learning method to identify anomalous jets in a search for BSM resonances decaying into a Higgs boson and a generic new boson [18].

This Letter presents a generic search for resonances in various two-body final states that applies an anomaly detection method to the event topology, for the first time in ATLAS. Events are triggered by the presence of an isolated lepton to reduce contamination from QCD multijet events. The two-body final states consist of jet + Y, where the jet can be a light jet or a b jet (containing a b-hadron decay) while Y can be a lepton (electron or muon), a photon, or another light jet or b jet. The highest-p_{T} candidate for each kind of final-state object is used, except for final states with either two light jets or two b jets, where both the leading and subleading light jets or b jets are considered. Triggering on the lepton allows studies of invariant mass distributions below 1 TeV, which would be difficult to model because of trigger threshold effects if jet triggers were used [19].

The data correspond to 140 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV collected by the ATLAS experiment at the Large Hadron Collider (LHC). The ATLAS detector [20] is a multipurpose particle detector with cylindrical geometry [21]. It consists of an inner tracking detector (ID) surrounded by a superconducting solenoid, electromagnetic (EM) and hadronic sampling calorimeters, and a muon spectrometer with three toroidal superconducting magnets, providing a near 4π coverage in the solid angle. A two-level trigger system is used to select events for storage. Events used in this analysis were selected on-line by single-electron or single-muon triggers [22–24]. An extensive software suite [25] is used in data simulation, in the reconstruction and analysis of real and simulated data, in detector operations, and in the trigger and data acquisition systems of the experiment.

The interaction vertex with the highest sum of the squared transverse momenta (p_{T}^2) of all associated tracks with $p_{\mathrm{T}} > 500$ MeV is selected as the primary vertex [26].

---

[*] Full author list given at the end of the article.

Electrons are reconstructed from energy clusters in the EM calorimeter that match a reconstructed track [27]. Muons are reconstructed by combining a track from the ID with one from the muon spectrometer [28]. Electrons (muons) must have $E_{\mathrm{T}} > 20$ GeV ($p_{\mathrm{T}} > 20$ GeV) and pseudorapidity $|\eta| < 2.47$ ($|\eta| < 2.5$), excluding the region $1.37 < |\eta| < 1.52$ for electrons. To ensure that selected leptons originate from the primary vertex, their tracks must have $|d_0/\sigma(d_0)| < 5$ (3) for electrons (muons) and $|z_0 \sin(\theta)| < 0.5$ mm for both lepton flavors. Here d_0 and $\sigma(d_0)$ are the transverse impact parameter and its uncertainty, and z_0 is the longitudinal impact parameter along the beam line. Electrons must satisfy the “Tight” likelihood-based identification criterion defined in Ref. [27], and the “FCTight” isolation requirement defined in Ref. [23]. Muons must satisfy the “Medium” cut-based identification criterion and the particle-flow-based “PflowTight” isolation requirement [28]. Photons are reconstructed from energy deposits in the central EM calorimeter [27]. They must have $p_{\mathrm{T}} > 20$ GeV and pseudorapidity $|\eta| < 2.37$, excluding the region $1.37 < |\eta| < 1.52$. The “tight” identification requirement and the “tight” isolation requirement are applied, both defined in Ref. [27]. Jets are reconstructed using the anti-k_t algorithm [29,30] with a radius parameter of 0.4, applied to tracks in the ID and topological clusters [31] processed using a particle-flow algorithm [32]. To reduce the effect of additional collisions in the same and neighboring bunch crossings (pileup), jets with $p_{\mathrm{T}} < 60$ GeV and $|\eta| < 2.4$ must pass a jet-vertex-tagger requirement that has a 96% selection efficiency for hard-scattered jets [33]. Jets containing a b hadron are identified using the 77% efficiency working point of the DL1r b-tagging algorithm [34]. Jets failing to meet the b-tagging criteria are identified as light jets. An overlap-removal procedure detailed in Ref. [35] is applied to the selected objects.

The missing transverse energy, $E_{\mathrm{T}}^{\mathrm{miss}}$, is calculated from the vector sum of the transverse momenta of all reconstructed objects associated with the primary vertex. To account for soft hadronic activity, a term including tracks associated with the primary vertex, but not with any of the reconstructed objects, is included in the $E_{\mathrm{T}}^{\mathrm{miss}}$ calculation [36].

Following the reconstruction of these objects, events are first selected by requiring at least one lepton (e or μ, denoted by ℓ) with $p_{\mathrm{T}}^{\ell} > 60$ GeV, and at least one jet with $p_{\mathrm{T}} > 30$ GeV. A trigger matching requirement [22] is applied to ensure that the reconstructed lepton lies in the vicinity of the corresponding trigger-level object. Jets and b jets are required to have a pseudorapidity of $|\eta| < 2.4$. These requirements constitute the event *preselection*. Nine invariant mass distributions are studied in this analysis. The invariant mass distributions of m_{jj} and m_{bb} are reconstructed from the leading and subleading (b) jets in each event; m_{jb} is reconstructed from the leading jet and leading b jet; and m_{je} (m_{be}), $m_{j\mu}$ ($m_{b\mu}$), and $m_{j\gamma}$ ($m_{b\gamma}$) are reconstructed from the leading (b) jet and leading electron, muon, or photon, respectively. An event that contains multiple types of objects can contribute to multiple mass distributions.

Several Monte Carlo (MC) samples were simulated to validate the analysis procedure, although the anomaly detection relies only on data samples. All simulated SM samples, which are used to model the background, include a detailed ATLAS detector simulation [37] based on GEANT4 [38]. Samples for the benchmark BSM signal models instead include a faster, less detailed detector simulation [37]. Additional pp collisions generated using PYTHIA [39] with the A3 set of tuned parameters [40] were overlaid to simulate the effects of pileup interactions that match the multiplicity of additional collisions in data.

Kinematic features of the final-state objects in the preselected events are structured in a matrix called the rapidity-mass matrix (RMM) which is proposed as an input for machine learning [41]. The RMM was tested for an anomaly detection method using MC event generators and was found to produce more robust AE training than when four-momenta are used as input [42]. The RMM is a square matrix employed to represent a comprehensive picture of the event in terms of popular variables used for BSM searches, such as $E_{\mathrm{T}}^{\mathrm{miss}}$, transverse energies, transverse masses, Lorentz factors, two-particle invariant masses, and two-particle rapidity differences. In this analysis, the reconstructed final-state objects are light jets, b jets, muons, electrons, or photons. A maximum of ten light jets or b jets are considered, along with up to five electrons, muons, and photons. Together with $E_{\mathrm{T}}^{\mathrm{miss}}$, a total number of 36 final-state objects are used to define the RMM. The objects within each type are ordered in decreasing transverse energy. If the number of available objects for a particular type is less than the maximum allowed, the remaining elements in the corresponding row and column of the RMM are filled with zeros. This ensures that the input size is the same for every event.

By construction, all elements of the RMM are defined to be between 0 and 1, and most variables are Lorentz-invariant under boosts along the longitudinal axis. To reduce biases in the shapes of the jet + Y invariant mass spectra, the nine invariant mass variables are excluded from the RMM. The resulting input dimension is $36^2 - 9 = 1287$. The RMM matrix is then flattened to a one-dimensional input vector before being fed into the AE.

The AE is implemented using TensorFlow [43]. It comprises two sections, an encoder and a decoder. The encoder compresses the input to a latent dimensional space, whereas the decoder takes the data in the latent layer and decompresses it back to its original size. The network architecture for the encoder contains two hidden layers, with 800 and 400 neurons, respectively, and a latent layer of 200 neurons. The decoder reverses the structure of the encoder, using 400 and 800 neurons for the two hidden layers, and 1287 neurons for the output layer. The leaky ReLU [44] activation function is applied to the output in all hidden and output layers. The reconstruction loss is defined as the mean squared error between the input and reconstructed values of the dataset. The logarithm of the reconstruction loss, log(Loss), is defined as the anomaly score for each event. Artificial anomalous events with different characteristics were created and used as input to test the separation power of this architecture. The default AE outperforms (convolutional) variational AEs. Furthermore, the selected architecture has shown better separation between anomalous and nonanomalous events than AE architectures with other numbers of neurons. To form the training and validation datasets, 1% of the collision events are randomly selected after the preselection. They provide both a sufficient sample size and a good representation of typical collision events. The chance of finding BSM signal events in these datasets is considered to be negligible. Even if the training dataset is influenced by BSM physics, such contributions would alter the distribution of the log (Loss) of the AE and thus the shape of the mass spectra of the background but would not produce discernible bumps [42]. Therefore, the search for localized enhancements in the invariant mass distributions should not be affected significantly.

The training and validation sets are randomly split using a 7 : 3 ratio. The Adam optimizer [45] with a learning rate of 0.001 is used to train the network by minimizing the log (Loss) of the training sets. The batch size is 100 and all events in the training set are reshuffled at the beginning of each epoch. Training of the AE is monitored via the reconstruction loss of the validation set, and terminated if this value does not decrease within 30 epochs. To avoid selecting an overtrained model, the training is repeated 50 times with different network initialization and different random splits of the training and validation sets. The performance is found to be stable and the model that gives the median validation loss among these trials is used.

The distribution of the anomaly scores of the collision data is shown in Fig. 1. The data correspond to 140 fb^{-1} and include the 1% of data used in training. A peak is seen near $\log(\mathrm{Loss}) = -10.8$ from the total of 166 055 597 events after preselection. For comparison, several benchmark BSM models, studied in Refs. [46,47], are overlaid. These representative models are characterized by the presence of an isolated lepton in the final states. The models and their parameters are (1) charged Higgs boson production in association with a top quark, tbH^+ with $H^+ \to t\bar{b}$, with the mass of H^+ between 0.4 TeV and 2 TeV with a varying step size [48]. All top decays are enabled; (2) a Kaluza-Klein gauge boson, W_{KK}, with the SM W boson and a radion ϕ that decays into two gluons, with the mass of W_{KK} between 0.5 TeV and 6 TeV, and the mass difference of W_{KK} and the radion being 0.25 TeV [49]; (3) a model with a Z' boson and composite $\mathrm{SU}(2)_{\mathrm{L}}$ fermion doublets that breaks lepton-flavor universality ("composite lepton"), $Z' \to E\ell$, with the Z' boson mass of 0.5–4 TeV and various mass hypotheses for the composite lepton E decaying to $Z\ell$ with $Z \to q\bar{q}$ [50]; (4) the sequential standard model (SSM) $W' \to WZ' \to \ell\nu q\bar{q}$, with the mass of the W' boson ranging from 0.7 TeV to 6.2 TeV with a varying step size and the mass difference of the W' and Z' bosons being 0.25 TeV [51]; (5) a simplified dark-matter (DM) model $Z' \to q\bar{q}$, with an axial-vector mediator Z' boson whose mass ranges between 0.5 TeV and 6 TeV with a varying step size, where one of the quarks radiates a W boson which decays into $\ell\nu$ [52]. As can be seen in Fig. 1, the anomaly scores of the BSM processes tend to be larger than those of the collision events, which are all or mostly produced by SM processes. The SSM and DM model tend to have characteristics similar to those of the SM background from the event selection in this analysis, thus yielding lower anomaly scores. Although only one hypothetical mass is shown for each type of BSM model, it was found that events with larger hypothetical particle masses

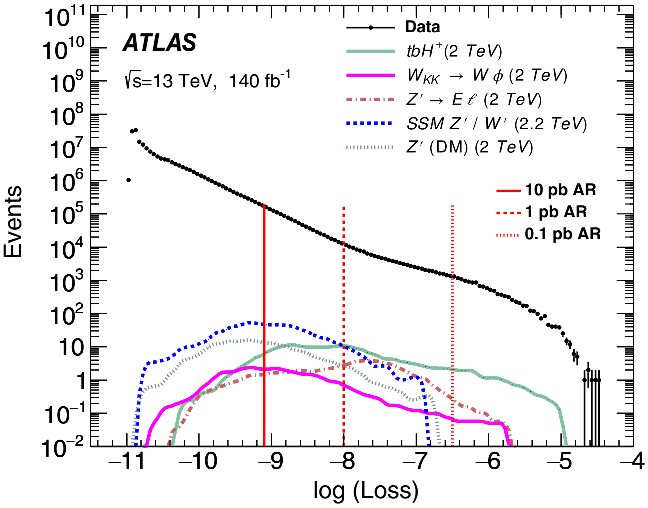

FIG. 1. Distributions of the anomaly score from the AE for data and five benchmark BSM models. Their legends, from top to bottom, are: (1) charged Higgs boson production in association with a top quark, tbH^+ with $H^+ \to t\bar{b}$; (2) a Kaluza-Klein gauge boson, W_{KK}, with the SM W boson and a radion ϕ; (3) a Z' boson decaying to a composite lepton E and ℓ, with $E \to Z\ell$ with a mass of 0.5 TeV; (4) the SSM $W' \to WZ' \to \ell\nu q\bar{q}$; (5) a simplified dark-matter model with an axial-vector mediator $Z' \to q\bar{q}$, where one of the quarks radiates a W boson decaying to $\ell\nu$. The BSM predictions represent the expected number of events from 140 fb^{-1} of data for heavy particle (H^+, W_{KK}, Z', W', and Z', respectively) masses around 2 TeV. The distributions for the BSM models are smoothed to remove fluctuations due to low MC event counts. The vertical lines indicate the start of the three anomaly regions (ARs). The labels of the three ARs indicate the visible cross section for hypothetical processes yielding the same number of events as observed in the 140 fb^{-1} dataset. The AE is applied to preselected events without any requirements on invariant mass distributions.

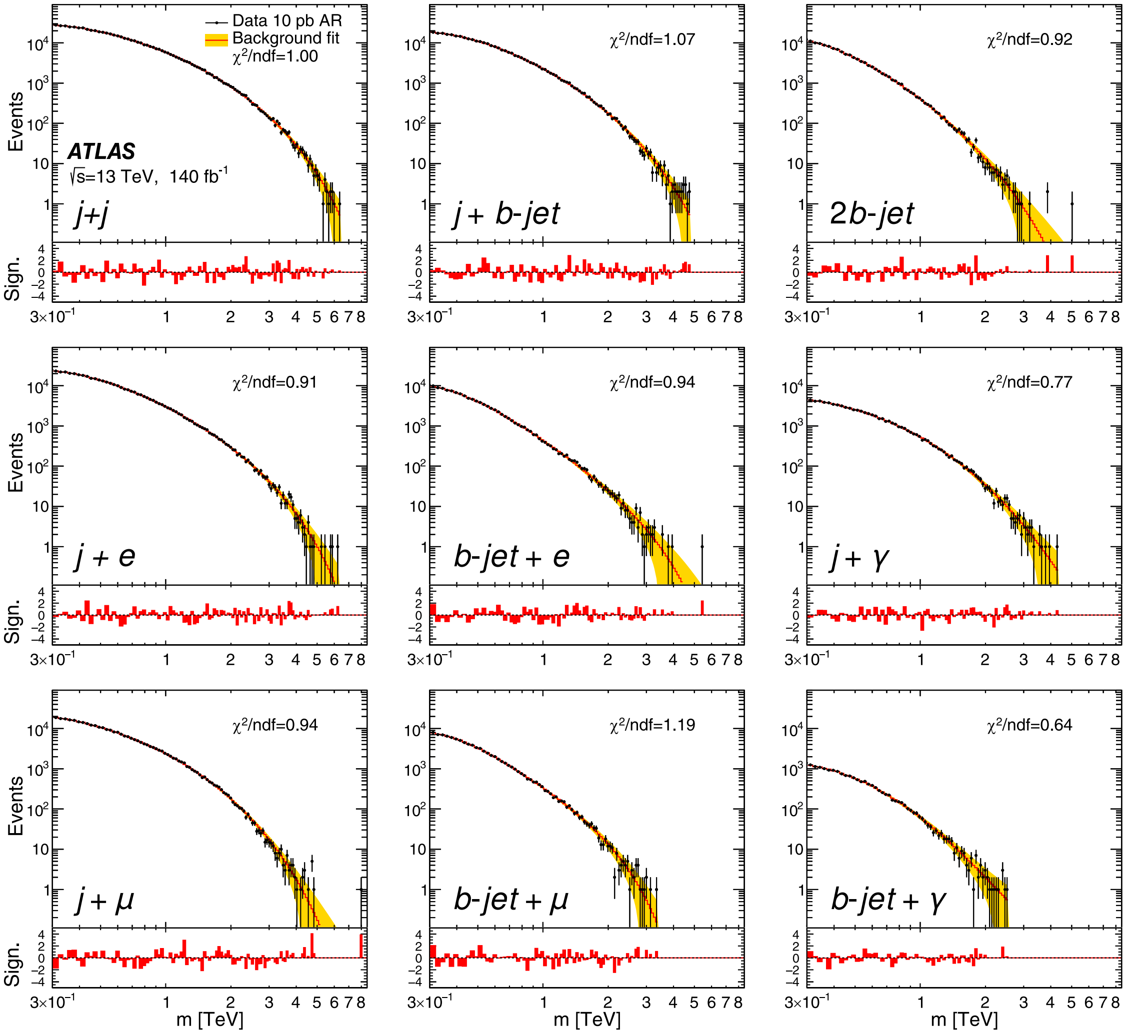

FIG. 2. Invariant mass distributions of jet + Y for $m_{jY} > 0.3$ TeV in the 10 pb AR along with the fit of Eq. (1). The fits are represented by the lines, while the associated statistical uncertainties are indicated by the shaded bands. The lower panels show the bin-by-bin significances of deviations from the fit, calculated as $(d_i - f_i)/\delta_i$, where d_i is the data yield, f_i is the fit value, and δ_i is the data uncertainty in the ith bin.

have larger anomaly scores. Furthermore, three anomaly regions (ARs) are chosen to maintain sensitivity to different BSM models. They are defined by $\log(\text{Loss}) > -9.1$, > -8.0, and > -6.5, respectively, as indicated by the vertical lines in Fig. 1. The labels for the three ARs indicate the visible cross section for hypothetical processes yielding the same number of events as observed in the 140 fb^{-1} dataset. The anomaly score distributions are consistent across the data-taking years, indicating that the AE training is robust against different pileup conditions and triggering criteria.

The nine invariant mass (m) spectra in each anomaly region are examined to search for any localized excesses above the background hypothesis. The bin widths chosen for the spectra increase from 16 GeV to 150 GeV over the mass range of 0.3–8 TeV to reflect the jet energy resolution of the ATLAS detector. As in the previous ATLAS searches based on the single-lepton requirement [46,47], the following analytic function is used to describe the shape of the smoothly falling background:

$$f(x) = p_1(1-x)^{p_2} x^{p_3 + p_4 \ln x + p_5 \ln^2 x}, \qquad (1)$$

where $x \equiv m/\sqrt{s}$ and p_i are free parameters.

To avoid any possible bias, the analysis was developed without looking at the signal mass distributions in the data. To verify that Eq. (1) can describe the background shape separately for each of the nine invariant mass distributions, fits are performed on the SM background. This background is estimated from the MC simulation samples, which are composed of W + jets, $t\bar{t}$ and single-top processes, and

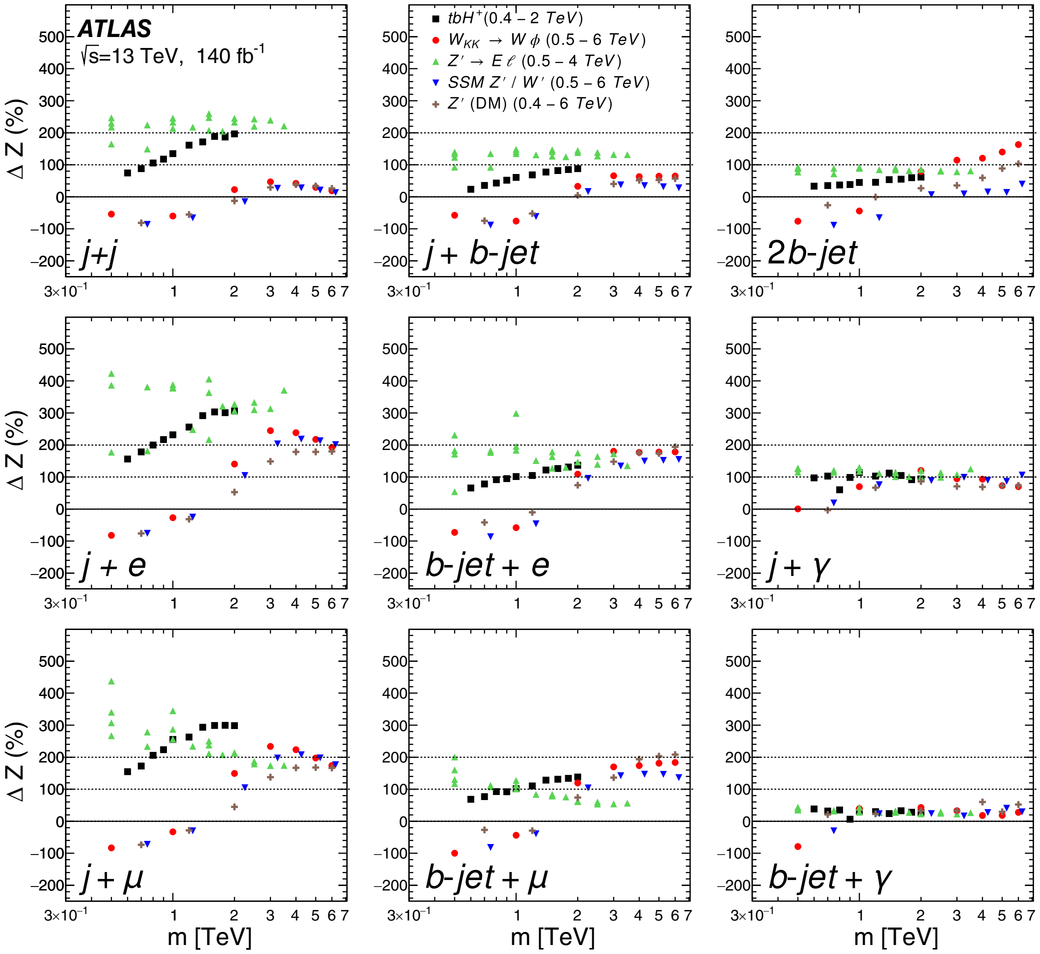

FIG. 3. Values of ΔZ for the discovery sensitivity, as defined in the text, as a function of the invariant mass m. The nine invariant mass distributions are calculated in the 10 pb AR. Positive percentages indicate improvements in sensitivity. Horizontal dashed lines are drawn at 100% and 200% to guide the eye. The five benchmark BSM models are (1) charged Higgs boson production in association with a top quark, tbH^+ with $H^+ \to t\bar{b}$; (2) a Kaluza-Klein gauge boson, W_{KK}, with the SM W boson and a radion ϕ; (3) a Z' boson decaying to a composite lepton E and ℓ, with $E \to Z\ell$; (4) the SSM $W' \to WZ' \to \ell\nu q\bar{q}$; (5) a simplified dark-matter model with an axial-vector mediator $Z' \to q\bar{q}$, where one of the quarks radiates a W boson decaying to $\ell\nu$. The multiple markers shown for the composite-lepton model at the same invariant mass values correspond to different composite lepton (E) masses between 0.25 and 3.5 TeV. The center positions of the markers are set to the masses of the corresponding heavy particles.

a “loose electron” control sample from data, which represents the QCD multijet events. Each event in the control sample must contain a leading electron that satisfies the “loose”, but not the “tight”, identification criteria [27], while also passing the anomaly region selections defined by the 1% data trained autoencoder. This ensures that the control sample is orthogonal to the signal sample. The fit results show that Eq. (1) can describe the shape of the nine invariant mass distributions in the anomaly regions, with the χ^2/ndf values ranging between 0.7 and 1.9. The distributions of the fit residuals are consistent with the normal distribution. More complex fit functions do not improve this description. These studies do not take into account systematic uncertainties in the SM simulations. The established functional form of the background hypothesis is then applied to data in the anomaly regions. Likelihood fits of Eq. (1) to the data are performed to determine the free parameters and are shown in Fig. 2 for the 10 pb AR. The data are well described by the fit, with the χ^2/ndf values ranging between 0.64 and 1.19 for all nine mass spectra. The lower panels show the fit significances, calculated as $(d_i - f_i)/\delta_i$, where d_i is the data yield, f_i is the fit value, and δ_i is the data uncertainty in the i th bin. The distributions of the significances are found to be consistent with normal distributions.

Each invariant mass spectrum is analyzed independently using the BumpHunter algorithm [53] to look for localized excesses without assumptions about BSM signal shapes. The uncertainty in the background shape is taken into account by using an alternative function that replaces the term $p_5 \ln^2 x$ with $p_5/\sqrt{x}$ in Eq. (1). The algorithm is used to search for statistically significant excesses, taking into

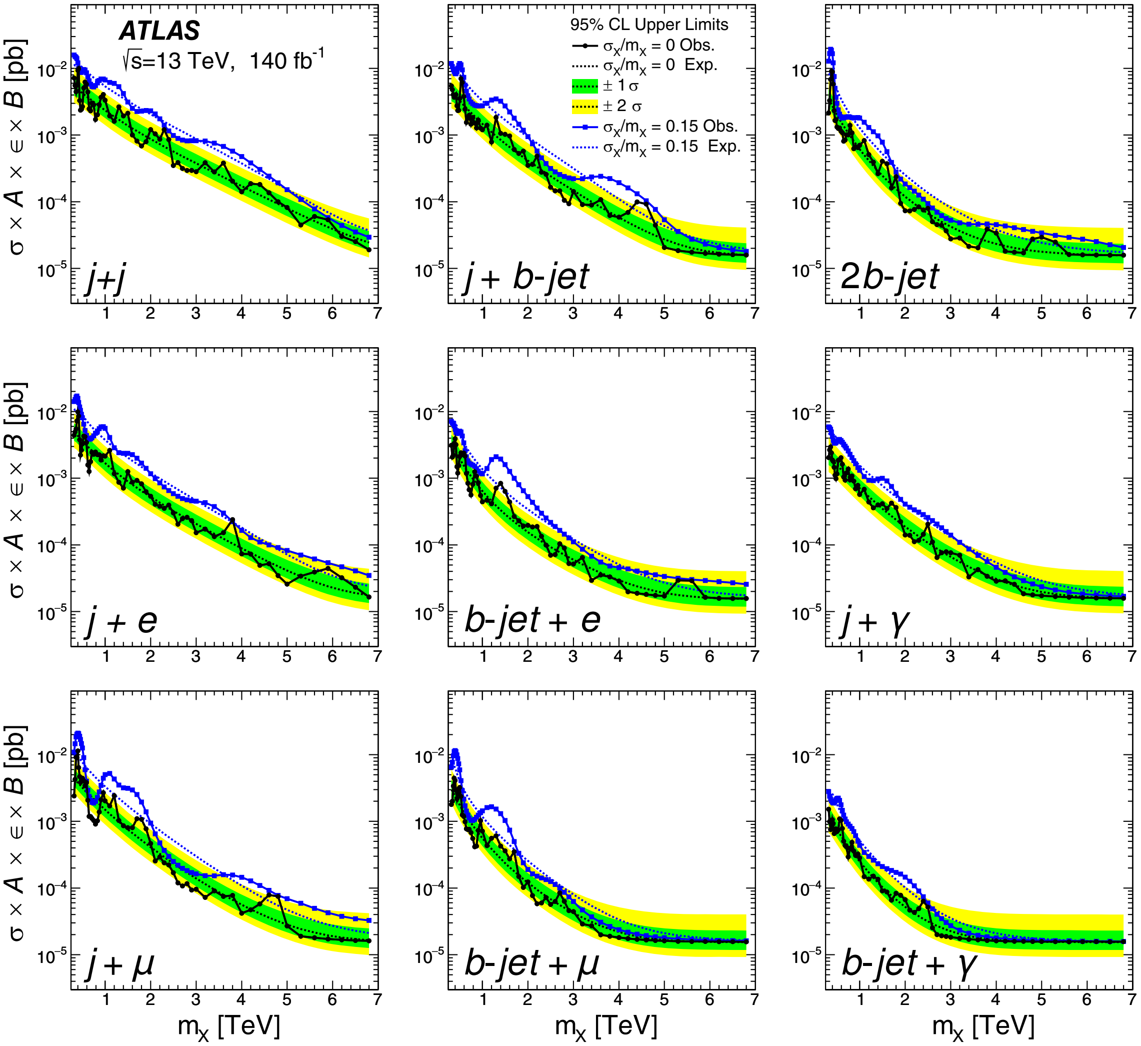

FIG. 4. The 95% C.L. upper limits on the cross section times acceptance (A), efficiency (ϵ), and branching ratio (B) for Gaussian-shaped signals with different signal widths. The limits are calculated for events with at least one lepton with $p_T^\ell > 60$ GeV in the 10 pb AR. Two width hypotheses are shown: $\sigma_X/m_X = 0$ and $\sigma_X/m_X = 0.15$. In both cases, the detector resolution for jets is included in the simulation of signal samples. The $\pm 1\sigma$ and $\pm 2\sigma$ bands around the expected limit are shown for $\sigma_X/m_X = 0$ signals. Mass points are spaced 5% apart, relative to the preceding point, starting at 0.3 TeV.

account the look-elsewhere effect [54] of the full mass spectrum under study and the uncertainty in the background shape. Among the nine invariant mass distributions in the 10 pb AR, BumpHunter finds the largest excess to be in the $m_{j\mu}$ spectrum near 4.8 TeV, and the second largest to be near 1.2 TeV, as shown in Fig. 2. Their statistical significances when including systematic uncertainties are discussed below.

Searches for localized excesses were also performed in the nine invariant mass distributions for the 1 pb and 0.1 pb ARs. No significant excesses were found. In particular, the 4.8 TeV region of the $m_{j\mu}$ spectra does not show any deviation from the background hypothesis in these two AR regions.

The anomaly region selection is expected to improve the discovery potential for BSM models. Figure 3 shows the improvements in discovery sensitivity for the five benchmark BSM models in the 10 pb AR. The improvement is defined as $\Delta Z = [(Z_{\mathrm{AE}}/Z) - 1] \times 100\%$, where Z_{AE} is the discovery sensitivity in the anomaly region and Z is that before any cut on the anomaly score. The discovery sensitivity is defined as $Z = \sqrt{2[(s + b)\ln(1 + s/b) - s]}$ [55], where s is the number of signal events and b the number of background events calculated from the fit of Eq. (1) to the data. Both are counted in a ± 1-standard-deviation region around the mean value of the reconstructed signal's mass distribution. The results show that using the AE trained on data improves the discovery sensitivity for most of the benchmark BSM models and mass points. The BSM hypotheses that do not show improvements in sensitivity correspond to models with low-mass hypothetical particles or models where the number of reconstructed objects and their kinematic-variable values in the RMM are closer to those of SM events. The 1 and 0.1 pb ARs show less improvements in the sensitivity compared to the 10 pb AR due to significant decrease in statistics.

In the absence of any significant resonant signals, upper limits on the cross section times acceptance, efficiency, and branching ratio are set for Gaussian-shaped signals using the $\mathrm{CL_s}$ method [56]. The effects of systematic uncertainties associated with the luminosity, jet energy scale, jet energy resolution, and object identification and reconstruction are included in the signal. These object-related uncertainties are derived from the SSM simulated signals. The uncertainty stemming from the choice of background fit function is taken from the difference of results obtained using Eq. (1) and the alternative background shape. An uncertainty included to account for a fit bias is computed using the spurious-signal method described in Ref. [57]. This is the dominant source of systematic uncertainty and it weakens the upper limits by approximately 10%. The stochastic fluctuations in the AE training also produce an uncertainty if the AE is retrained. It can cause a change of the observed limits by 4% on average [58].

Upper limits at 95% confidence level (C.L.) on the production cross section of resonant signals with an intrinsic width of 0% or 15% of the hypothetical mass in the 10 pb AR are presented in Fig. 4. For a 0% width, the Gaussian signals have widths consistent with the experimental resolutions. The limits are weaker for a 15% resonance width because the signals are spread over more bins. The local significance of a signal with a 0% width for $m_{j\mu} = 4.8$ TeV, where the largest excess was detected by BumpHunter, is found to be 2.9 standard deviations (2.9σ) using the asymptotic formulae [59]. A more stringent ("HighPT") identification criterion for muons [28] removes the event near $m_{j\mu} = 8$ TeV, but it does not reduce the significance of the excess at 4.8 TeV. The local significance at around $m_{j\mu} = 1.2$ TeV is 2.8σ.

The presented limits are more stringent than the limits on Gaussian signals presented in Ref. [46], which used the same preselected events. For example, the limits for m_{jj} below 1 TeV reported in this analysis show about a factor of 2–3 improvement compared to the results in Ref. [46]. The search sensitivity is comparable at high masses. Many BSM models with complex final states are expected to have high AE acceptances [60]. For example, the five benchmark BSM models shown in Fig. 3 have an average AE acceptance above 80% for m_{jj} masses around 0.5 TeV in the 10 pb AR. The trained AE rejects about 90% of the data in the same m_{jj} region. This illustrates the potential to set exclusion limits on heavy BSM particles with high AE acceptance.

In conclusion, model-independent searches for new phenomena in two-body invariant mass distributions are performed by applying an unsupervised anomaly-detection technique to 140 fb^{-1} of pp collision data at $\sqrt{s} = 13$ TeV recorded by the ATLAS detector at the LHC. Events are preselected to contain at least one lepton with $p_{\mathrm{T}}^{\ell} > 60$ GeV and at least one jet with $p_{\mathrm{T}} > 30$ GeV. An unsupervised machine-learning algorithm based on the AE architecture is trained with a randomly selected 1% sample of the preselected collision events, without targeting any specific BSM signal. Three anomaly regions are defined using the reconstruction loss of the AE. Nine two-body invariant mass spectra, m_{jY}, are studied, where j stands for a light jet or a b jet, and Y is a second light jet or b jet, a lepton, or a photon. No evidence of significant excesses is observed. The largest excess reported by BumpHunter is near 4.8 TeV in the $m_{j\mu}$ distribution for the 10 pb AR. Assuming a resonance with a width of 0%, the local significance of this excess is 2.9σ.

The discovery sensitivity shows a large improvement after the anomaly region selection, which is illustrated using several benchmark BSM models in the 10 pb AR. The analysis sets 95% C.L. upper limits on contributions from generic Gaussian signals to the studied invariant mass distributions in this AR. Compared to previous limits without anomaly region selections, the reported model-independent limits have a stronger potential to exclude generic heavy states with complex decay modes.

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently. We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; ANID, Chile; CAS, MOST and NSFC, China; Minciencias, Colombia; MEYS CR, Czech Republic; DNRF and DNSRC, Denmark; IN2P3-CNRS and CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF and MPG, Germany; GSRI, Greece; RGC and Hong Kong SAR, China; ISF and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MEiN, Poland; FCT, Portugal; MNE/IFA, Romania; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DSI/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TENMAK, Türkiye; STFC, United Kingdom; DOE and NSF, USA. In addition, individual groups and members have received support from BCKDF, CANARIE, Compute Canada and CRC, Canada; PRIMUS 21/SCI/017 and UNCE SCI/013, Czech Republic; COST, ERC, ERDF, Horizon 2020, ICSC-NextGenerationEU and Marie Skłodowska-Curie Actions, European Union; Investissements d'Avenir Labex, Investissements d'Avenir Idex and ANR, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF, Greece; BSF-NSF and MINERVA, Israel; Norwegian

Financial Mechanism 2014-2021, Norway; NCN and NAWA, Poland; La Caixa Banking Foundation, CERCA Programme Generalitat de Catalunya and PROMETEO and GenT Programmes Generalitat Valenciana, Spain; Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom. The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [61].

[1] ATLAS Collaboration, A strategy for a general search for new phenomena using data-derived signal regions and its application within the ATLAS experiment, Eur. Phys. J. C **79**, 120 (2019).

[2] J. H. Collins, K. Howe, and B. Nachman, Anomaly detection for resonant new physics with machine learning, Phys. Rev. Lett. **121**, 241803 (2018).

[3] R. T. D'Agnolo and A. Wulzer, Learning new physics from a machine, Phys. Rev. D **99**, 015014 (2019).

[4] A. De Simone and T. Jacques, Guiding new physics searches with unsupervised learning, Eur. Phys. J. C **79**, 289 (2019).

[5] J. Hajer, Y.-Y. Li, T. Liu, and H. Wang, Novelty detection meets collider physics, Phys. Rev. D **101**, 076015 (2020).

[6] T. Heimel, G. Kasieczka, T. Plehn, and J. M. Thompson, QCD or what?, SciPost Phys. **6**, 030 (2019).

[7] O. Cerri, T. Q. Nguyen, M. Pierini, M. Spiropulu, and J.-R. Vlimant, Variational autoencoders for new physics mining at the Large Hadron Collider, J. High Energy Phys. 05 (2019) 036.

[8] M. Farina, Y. Nakai, and D. Shih, Searching for New physics with deep autoencoders, Phys. Rev. D **101**, 075021 (2020).

[9] A. Blance, M. Spannowsky, and P. Waite, Adversarially-trained autoencoders for robust unsupervised new physics searches, J. High Energy Phys. 10 (2020) 206.

[10] B. M. Dillon, D. A. Faroughy, J. F. Kamenik, and M. Szewc, Learning the latent structure of collider events, J. High Energy Phys. 10 (2020) 206.

[11] T. Aarrestad *et al.*, The dark machines anomaly score challenge: Benchmark data and model independent event classification for the Large Hadron Collider, SciPost Phys. **12**, 043 (2022).

[12] G. Kasieczka *et al.*, The LHC Olympics 2020 a community challenge for anomaly detection in high energy physics, Rep. Prog. Phys. **84**, 124201 (2021).

[13] D. E. Rumelhart, G. E. Hinton, and R. J. Williams, Learning representations by back-propagating errors, Nature (London) **323**, 533 (1986).

[14] H. Bourlard and Y. Kamp, Auto-association by multilayer perceptrons and singular value decomposition, Biol. Cybern. **59**, 291 (1988).

[15] G. E. Hinton and R. S. Zemel, Autoencoders, minimum description length, and Helmholtz free energy, Adv. Neural Inf. Process. Syst. **6**, 3 (1994).

[16] G. E. Hinton and R. R. Salakhutdinov, Reducing the dimensionality of data with neural networks, Science **313**, 504 (2006).

[17] ATLAS Collaboration, Dijet resonance search with weak supervision using ($\sqrt{s} = 13$ TeV pp collisions in the ATLAS detector, Phys. Rev. Lett. **125**, 131801 (2020).

[18] ATLAS Collaboration, Anomaly detection search for new resonances decaying into a Higgs boson and a generic new particle X in hadronic final states using $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector, Report No. ATLAS-CONF-2022-045, 2022, https://cds.cern.ch/record/2816323.

[19] ATLAS Collaboration, Search for new resonances in mass distributions of jet pairs using 139 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, J. High Energy Phys. 03 (2020) 145.

[20] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, J. Instrum. **3**, S08003 (2008).

[21] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point in the center of the detector and the z axis along the beam pipe. The x axis points to the center of the LHC ring, and the y axis points upward. Cylindrical 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 $\eta = -\ln \tan(\theta/2)$. The distance between two objects in η-ϕ space is $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$. Transverse momentum is defined as $p_\mathrm{T} = p \cdot \sin\theta$.

[22] ATLAS Collaboration, Performance of the ATLAS trigger system in 2015, Eur. Phys. J. C **77**, 317 (2017).

[23] ATLAS Collaboration, Performance of electron and photon triggers in ATLAS during LHC Run 2, Eur. Phys. J. C **80**, 47 (2020).

[24] ATLAS Collaboration, Trigger menu in 2018, Report No. ATL-DAQ-PUB-2019-001, 2019, https://cds.cern.ch/record/2693402.

[25] ATLAS Collaboration, The ATLAS Collaboration software and firmware, Report No. ATL-SOFT-PUB-2021-001, 2021, https://cds.cern.ch/record/2767187.

[26] ATLAS Collaboration, Vertex reconstruction performance of the ATLAS detector at $\sqrt{s} = 13$ TeV, Report No. ATL-PHYS-PUB-2015-026, 2015, https://cds.cern.ch/record/2037717.

[27] ATLAS Collaboration, Electron and photon performance measurements with the ATLAS detector using the 2015-2017 LHC proton-proton collision data, J. Instrum. **14**, P12006 (2019).

[28] 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**, 578 (2021).

[29] M. Cacciari, G. P. Salam, and G. Soyez, The anti-k_t jet clustering algorithm, J. High Energy Phys. 04 (2008) 063.

[30] M. Cacciari, G. P. Salam, and G. Soyez, FastJet user manual, Eur. Phys. J. C **72**, 1896 (2012).

[31] ATLAS Collaboration, Topological cell clustering in the ATLAS calorimeters and its performance in LHC Run 1, Eur. Phys. J. C **77**, 490 (2017).

[32] ATLAS Collaboration, Jet reconstruction and performance using particle flow with the ATLAS detector, Eur. Phys. J. C **77**, 466 (2017).

[33] ATLAS Collaboration, Performance of pile-up mitigation techniques for jets in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector, Eur. Phys. J. C **76**, 581 (2016).

[34] ATLAS Collaboration, ATLAS flavour-tagging algorithms for the LHC Run 2 pp collision dataset, Eur. Phys. J. C **83**, 681 (2022).

[35] ATLAS Collaboration, Measurements of inclusive and differential fiducial cross-sections of $t\bar{t}\gamma$ production in leptonic final states at $\sqrt{s} = 13$ TeV in ATLAS, Eur. Phys. J. C **79**, 382 (2019).

[36] ATLAS Collaboration, $E_{\mathrm{T}}^{\mathrm{miss}}$ performance in the ATLAS detector using 2015-2016 LHC pp collisions, Report No. ATLAS-CONF-2018-023, 2018, https://cds.cern.ch/record/2625233.

[37] ATLAS Collaboration, The ATLAS simulation infrastructure, Eur. Phys. J. C **70**, 823 (2010).

[38] S. Agostinelli *et al.*, Geant4—a simulation toolkit, Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).

[39] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, and P. Z. Skands, An introduction to PYTHIA8.2, Comput. Phys. Commun. **191**, 159 (2015).

[40] ATLAS Collaboration, The PYTHIA8 A3 tune description of ATLAS minimum bias and inelastic measurements incorporating the Donnachie-Landshoff diffractive model, Report No. ATL-PHYS-PUB-2016-017, 2016, https://cds.cern.ch/record/2206965.

[41] S. V. Chekanov, Imaging particle collision data for event classification using machine learning, Nucl. Instrum. Methods Phys. Res., Sect. A **931**, 92 (2019).

[42] S. V. Chekanov and W. Hopkins, Event-based anomaly detection for searches for new physics, Universe **8**, 494 (2022).

[43] M. Abadi *et al.*, TensorFlow: A system for large-scale machine learning, *Proceedings of the 12th USENIX Conference on Operating Systems Design and Implementation* (2016); arXiv:1605.08695.

[44] B. Xu, N. Wang, T. Chen, and M. Li, Empirical evaluation of rectified activations in convolutional network, arXiv:1505.00853.

[45] D. P. Kingma and J. Ba, ADAM: A method for stochastic optimization, arXiv:1412.6980.

[46] ATLAS Collaboration, Search for dijet resonances in events with an isolated charged lepton using $\sqrt{s} = 13$ TeV proton-proton collision data collected by the ATLAS detector, J. High Energy Phys. 07 (2023) 202.

[47] ATLAS Collaboration, Search for new phenomena in multi-body invariant masses in events with at least one isolated lepton and two jets using $\sqrt{s} = 13$ TeV proton-proton collision data collected by the ATLAS detector, J. High Energy Phys. 07 (2023) 202.

[48] C. Degrande, M. Ubiali, M. Wiesemann, and M. Zaro, Heavy charged Higgs boson production at the LHC, J. High Energy Phys. 10 (2015) 145.

[49] K. S. Agashe *et al.*, LHC signals from cascade decays of warped vector resonances, J. High Energy Phys. 05 (05) 078.

[50] M. Chala and M. Spannowsky, Behavior of composite resonances breaking lepton flavor universality, Phys. Rev. D **98**, 035010 (2018).

[51] G. Altarelli, B. Mele, and M. Ruiz-Altaba, Searching for new heavy vector bosons in $p\bar{p}$ Colliders, Z. Phys. C **45**, 109 (1989); **47**, 676(E) (1990).

[52] D. Abercrombie *et al.*, Dark Matter benchmark models for early LHC Run-2 Searches: Report of the ATLAS/CMS dark matter forum, Phys. Dark Universe **27**, 100371 (2020).

[53] G. Choudalakis, On hypothesis testing, trials factor, hypertests and the BumpHunter, arXiv:1101.0390.

[54] E. Gross and O. Vitells, Trial factors for the look elsewhere effect in high energy physics, Eur. Phys. J. C **70**, 525 (2010).

[55] G. Cowan, Discovery sensitivity for a counting experiment with background uncertainty, https://www.pp.rhul.ac.uk/cowan/stat/notes/medsigNote.pdf (2012).

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

[57] ATLAS Collaboration, Measurements of Higgs boson properties in the diphoton decay channel with 36 fb^{-1} of pp collision data at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Rev. D **98**, 052005 (2018).

[58] This uncertainty is not included in the limits since the anomaly region selection can be treated as a fixed cut when using the trained AE model used in this study.

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

[60] The trained AE for evaluating the acceptances of BSM models is available in the HepData repository (record 144864).

[61] ATLAS Collaboration, ATLAS computing acknowledgements, Report No. ATL-SOFT-PUB-2023-001, 2023, https://cds.cern.ch/record/2869272.

G. Aad,[102] B. Abbott,[120] K. Abeling,[55] N. J. Abicht,[49] S. H. Abidi,[29] A. Aboulhorma,[35e] H. Abramowicz,[151]
H. Abreu,[150] Y. Abulaiti,[117] A. C. Abusleme Hoffman,[137a] B. S. Acharya,[69a,69b,b] C. Adam Bourdarios,[4]
L. Adamczyk,[86a] L. Adamek,[155] S. V. Addepalli,[26] M. J. Addison,[101] J. Adelman,[115] A. Adiguzel,[21c] T. Adye,[134]
A. A. Affolder,[136] Y. Afik,[36] M. N. Agaras,[13] J. Agarwala,[73a,73b] A. Aggarwal,[100] C. Agheorghiesei,[27c]
A. Ahmad,[36] F. Ahmadov,[38,c] W. S. Ahmed,[104] S. Ahuja,[95] X. Ai,[62a] G. Aielli,[76a,76b] A. Aikot,[163]
M. Ait Tamlihat,[35e] B. Aitbenchikh,[35a] I. Aizenberg,[169] M. Akbiyik,[100] T. P. A. Åkesson,[98] A. V. Akimov,[37]

D. Akiyama,[168] N. N. Akolkar,[24] K. Al Khoury,[41] G. L. Alberghi,[23b] J. Albert,[165] P. Albicocco,[53]
G. L. Albouy,[60] S. Alderweireldt,[52] M. Aleksa,[36] I. N. Aleksandrov,[38] C. Alexa,[27b] T. Alexopoulos,[10]
F. Alfonsi,[23b] M. Algren,[56] M. Alhroob,[120] B. Ali,[132] H. M. J. Ali,[91] S. Ali,[148] S. W. Alibocus,[92] M. Aliev,[145]
G. Alimonti,[71a] W. Alkakhi,[55] C. Allaire,[66] B. M. M. Allbrooke,[146] J. F. Allen,[52] C. A. Allendes Flores,[137f]
P. P. Allport,[20] A. Aloisio,[72a,72b] F. Alonso,[90] C. Alpigiani,[138] M. Alvarez Estevez,[99] A. Alvarez Fernandez,[100]
M. Alves Cardoso,[56] M. G. Alviggi,[72a,72b] M. Aly,[101] Y. Amaral Coutinho,[83b] A. Ambler,[104] C. Amelung,[36]
M. Amerl,[101] C. G. Ames,[109] D. Amidei,[106] S. P. Amor Dos Santos,[130a] K. R. Amos,[163] V. Ananiev,[125]
C. Anastopoulos,[139] T. Andeen,[11] J. K. Anders,[36] S. Y. Andrean,[47a,47b] A. Andreazza,[71a,71b] S. Angelidakis,[9]
A. Angerami,[41,d] A. V. Anisenkov,[37] A. Annovi,[74a] C. Antel,[56] M. T. Anthony,[139] E. Antipov,[145]
M. Antonelli,[53] F. Anulli,[75a] M. Aoki,[84] T. Aoki,[153] J. A. Aparisi Pozo,[163] M. A. Aparo,[146] L. Aperio Bella,[48]
C. Appelt,[18] A. Apyan,[26] N. Aranzabal,[36] C. Arcangeletti,[53] A. T. H. Arce,[51] E. Arena,[92] J-F. Arguin,[108]
S. Argyropoulos,[54] J.-H. Arling,[48] O. Arnaez,[4] H. Arnold,[114] G. Artoni,[75a,75b] H. Asada,[111] K. Asai,[118]
S. Asai,[153] N. A. Asbah,[61] J. Assahsah,[35d] K. Assamagan,[29] R. Astalos,[28a] S. Atashi,[160] R. J. Atkin,[33a]
M. Atkinson,[162] H. Atmani,[35f] P. A. Atmasiddha,[106] K. Augsten,[132] S. Auricchio,[72a,72b] A. D. Auriol,[20]
V. A. Austrup,[101] G. Avolio,[36] K. Axiotis,[56] G. Azuelos,[108,e] D. Babal,[28b] H. Bachacou,[135] K. Bachas,[152,f]
A. Bachiu,[34] F. Backman,[47a,47b] A. Badea,[61] P. Bagnaia,[75a,75b] M. Bahmani,[18] A. J. Bailey,[163] V. R. Bailey,[162]
J. T. Baines,[134] L. Baines,[94] C. Bakalis,[10] O. K. Baker,[172] E. Bakos,[15] D. Bakshi Gupta,[8] V. Balakrishnan,[120]
R. Balasubramanian,[114] E. M. Baldin,[37] P. Balek,[86a] E. Ballabene,[23b,23a] F. Balli,[135] L. M. Baltes,[63a]
W. K. Balunas,[32] J. Balz,[100] E. Banas,[87] M. Bandieramonte,[129] A. Bandyopadhyay,[24] S. Bansal,[24] L. Barak,[151]
M. Barakat,[48] E. L. Barberio,[105] D. Barberis,[57b,57a] M. Barbero,[102] K. N. Barends,[33a] T. Barillari,[110]
M-S. Barisits,[36] T. Barklow,[143] P. Baron,[122] D. A. Baron Moreno,[101] A. Baroncelli,[62a] G. Barone,[29] A. J. Barr,[126]
J. D. Barr,[96] L. Barranco Navarro,[47a,47b] F. Barreiro,[99] J. Barreiro Guimarães da Costa,[14a] U. Barron,[151]
M. G. Barros Teixeira,[130a] S. Barsov,[37] F. Bartels,[63a] R. Bartoldus,[143] A. E. Barton,[91] P. Bartos,[28a] A. Basan,[100]
M. Baselga,[49] A. Bassalat,[66,g] M. J. Basso,[156a] C. R. Basson,[101] R. L. Bates,[59] S. Batlamous,[35e] J. R. Batley,[32]
B. Batool,[141] M. Battaglia,[136] D. Battulga,[18] M. Bauce,[75a,75b] M. Bauer,[36] P. Bauer,[24] L. T. Bazzano Hurrell,[30]
J. B. Beacham,[51] T. Beau,[127] P. H. Beauchemin,[158] F. Becherer,[54] P. Bechtle,[24] H. P. Beck,[19,h] K. Becker,[167]
A. J. Beddall,[82] V. A. Bednyakov,[38] C. P. Bee,[145] L. J. Beemster,[15] T. A. Beermann,[36] M. Begalli,[83d] M. Begel,[29]
A. Behera,[145] J. K. Behr,[48] J. F. Beirer,[55] F. Beisiegel,[24] M. Belfkir,[159] G. Bella,[151] L. Bellagamba,[23b]
A. Bellerive,[34] P. Bellos,[20] K. Beloborodov,[37] N. L. Belyaev,[37] D. Benchekroun,[35a] F. Bendebba,[35a]
Y. Benhammou,[151] M. Benoit,[29] J. R. Bensinger,[26] S. Bentvelsen,[114] L. Beresford,[48] M. Beretta,[53]
E. Bergeaas Kuutmann,[161] N. Berger,[4] B. Bergmann,[132] J. Beringer,[17a] G. Bernardi,[5] C. Bernius,[143]
F. U. Bernlochner,[24] F. Bernon,[36,102] T. Berry,[95] P. Berta,[133] A. Berthold,[50] I. A. Bertram,[91] S. Bethke,[110]
A. Betti,[75a,75b] A. J. Bevan,[94] M. Bhamjee,[33c] S. Bhatta,[145] D. S. Bhattacharya,[166] P. Bhattarai,[143]
V. S. Bhopatkar,[121] R. Bi,[29,i] R. M. Bianchi,[129] G. Bianco,[23b,23a] O. Biebel,[109] R. Bielski,[123] M. Biglietti,[77a]
T. R. V. Billoud,[132] M. Bindi,[55] A. Bingul,[21b] C. Bini,[75a,75b] A. Biondini,[92] C. J. Birch-sykes,[101] G. A. Bird,[20,134]
M. Birman,[169] M. Biros,[133] S. Biryukov,[146] T. Bisanz,[49] E. Bisceglie,[43b,43a] J. P. Biswal,[134] D. Biswas,[141]
A. Bitadze,[101] K. Bjørke,[125] I. Bloch,[48] C. Blocker,[26] A. Blue,[59] U. Blumenschein,[94] J. Blumenthal,[100]
G. J. Bobbink,[114] V. S. Bobrovnikov,[37] M. Boehler,[54] B. Boehm,[166] D. Bogavac,[36] A. G. Bogdanchikov,[37]
C. Bohm,[47a] V. Boisvert,[95] P. Bokan,[48] T. Bold,[86a] M. Bomben,[5] M. Bona,[94] M. Boonekamp,[135]
C. D. Booth,[95] A. G. Borbély,[59] I. S. Bordulev,[37] H. M. Borecka-Bielska,[108] L. S. Borgna,[96] G. Borissov,[91]
D. Bortoletto,[126] D. Boscherini,[23b] M. Bosman,[13] J. D. Bossio Sola,[36] K. Bouaouda,[35a] N. Bouchhar,[163]
J. Boudreau,[129] E. V. Bouhova-Thacker,[91] D. Boumediene,[40] R. Bouquet,[5] A. Boveia,[119] J. Boyd,[36] D. Boye,[29]
I. R. Boyko,[38] J. Bracinik,[20] N. Brahimi,[62d] G. Brandt,[171] O. Brandt,[32] F. Braren,[48] B. Brau,[103] J. E. Brau,[123]
R. Brener,[169] L. Brenner,[114] R. Brenner,[161] S. Bressler,[169] D. Britton,[59] D. Britzger,[110] I. Brock,[24]
G. Brooijmans,[41] W. K. Brooks,[137f] E. Brost,[29] L. M. Brown,[165] L. E. Bruce,[61] T. L. Bruckler,[126]
P. A. Bruckman de Renstrom,[87] B. Brüers,[48] A. Bruni,[23b] G. Bruni,[23b] M. Bruschi,[23b] N. Bruscino,[75a,75b]
T. Buanes,[16] Q. Buat,[138] D. Buchin,[110] A. G. Buckley,[59] O. Bulekov,[37] B. A. Bullard,[143] S. Burdin,[92]
C. D. Burgard,[49] A. M. Burger,[40] B. Burghgrave,[8] O. Burlayenko,[54] J. T. P. Burr,[32] C. D. Burton,[11]
J. C. Burzynski,[142] E. L. Busch,[41] V. Büscher,[100] P. J. Bussey,[59] J. M. Butler,[25] C. M. Buttar,[59]

J. M. Butterworth,[96] W. Buttinger,[134] C. J. Buxo Vazquez,[107] A. R. Buzykaev,[37] S. Cabrera Urbán,[163]
L. Cadamuro,[66] D. Caforio,[58] H. Cai,[129] Y. Cai,[14a,14e] V. M. M. Cairo,[36] O. Cakir,[3a] N. Calace,[36]
P. Calafiura,[17a] G. Calderini,[127] P. Calfayan,[68] G. Callea,[59] L. P. Caloba,[83b] D. Calvet,[40] S. Calvet,[40]
T. P. Calvet,[102] M. Calvetti,[74a,74b] R. Camacho Toro,[127] S. Camarda,[36] D. Camarero Munoz,[26] P. Camarri,[76a,76b]
M. T. Camerlingo,[72a,72b] D. Cameron,[36] C. Camincher,[165] M. Campanelli,[96] A. Camplani,[42] V. Canale,[72a,72b]
A. Canesse,[104] J. Cantero,[163] Y. Cao,[162] F. Capocasa,[26] M. Capua,[43b,43a] A. Carbone,[71a,71b] R. Cardarelli,[76a]
J. C. J. Cardenas,[8] F. Cardillo,[163] T. Carli,[36] G. Carlino,[72a] J. I. Carlotto,[13] B. T. Carlson,[129,j]
E. M. Carlson,[165,156a] L. Carminati,[71a,71b] A. Carnelli,[135] M. Carnesale,[75a,75b] S. Caron,[113] E. Carquin,[137f]
S. Carrá,[71a] G. Carratta,[23b,23a] F. Carrio Argos,[33g] J. W. S. Carter,[155] T. M. Carter,[52] M. P. Casado,[13,k]
M. Caspar,[48] E. G. Castiglia,[172] F. L. Castillo,[4] L. Castillo Garcia,[13] V. Castillo Gimenez,[163] N. F. Castro,[130a,130e]
A. Catinaccio,[36] J. R. Catmore,[125] V. Cavaliere,[29] N. Cavalli,[23b,23a] V. Cavasinni,[74a,74b] Y. C. Cekmecelioglu,[48]
E. Celebi,[21a] F. Celli,[126] M. S. Centonze,[70a,70b] V. Cepaitis,[56] K. Cerny,[122] A. S. Cerqueira,[83a] A. Cerri,[146]
L. Cerrito,[76a,76b] F. Cerutti,[17a] B. Cervato,[141] A. Cervelli,[23b] G. Cesarini,[53] S. A. Cetin,[82] Z. Chadi,[35a]
D. Chakraborty,[115] J. Chan,[170] W. Y. Chan,[153] J. D. Chapman,[32] E. Chapon,[135] B. Chargeishvili,[149b]
D. G. Charlton,[20] T. P. Charman,[94] M. Chatterjee,[19] C. Chauhan,[133] S. Chekanov,[6] S. V. Chekulaev,[156a]
G. A. Chelkov,[38,l] A. Chen,[106] B. Chen,[151] B. Chen,[165] H. Chen,[14c] H. Chen,[29] J. Chen,[62c] J. Chen,[142]
M. Chen,[126] S. Chen,[153] S. J. Chen,[14c] X. Chen,[62c,135] X. Chen,[14b,m] Y. Chen,[62a] C. L. Cheng,[170]
H. C. Cheng,[64a] S. Cheong,[143] A. Cheplakov,[38] E. Cheremushkina,[48] E. Cherepanova,[114]
R. Cherkaoui El Moursli,[35e] E. Cheu,[7] K. Cheung,[65] L. Chevalier,[135] V. Chiarella,[53] G. Chiarelli,[74a]
N. Chiedde,[102] G. Chiodini,[70a] A. S. Chisholm,[20] A. Chitan,[27b] M. Chitishvili,[163] M. V. Chizhov,[38] K. Choi,[11]
A. R. Chomont,[75a,75b] Y. Chou,[103] E. Y. S. Chow,[114] T. Chowdhury,[33g] K. L. Chu,[169] M. C. Chu,[64a] X. Chu,[14a,14e]
J. Chudoba,[131] J. J. Chwastowski,[87] D. Cieri,[110] K. M. Ciesla,[86a] V. Cindro,[93] A. Ciocio,[17a] F. Cirotto,[72a,72b]
Z. H. Citron,[169,n] M. Citterio,[71a] D. A. Ciubotaru,[27b] B. M. Ciungu,[155] A. Clark,[56] P. J. Clark,[52]
J. M. Clavijo Columbie,[48] S. E. Clawson,[48] C. Clement,[47a,47b] J. Clercx,[48] L. Clissa,[23b,23a] Y. Coadou,[102]
M. Cobal,[69a,69c] A. Coccaro,[57b] R. F. Coelho Barrue,[130a] R. Coelho Lopes De Sa,[103] S. Coelli,[71a] H. Cohen,[151]
A. E. C. Coimbra,[71a,71b] B. Cole,[41] J. Collot,[60] P. Conde Muiño,[130a,130g] M. P. Connell,[33c] S. H. Connell,[33c]
I. A. Connelly,[59] E. I. Conroy,[126] F. Conventi,[72a,o] H. G. Cooke,[20] A. M. Cooper-Sarkar,[126]
A. Cordeiro Oudot Choi,[127] F. Cormier,[164] L. D. Corpe,[40] M. Corradi,[75a,75b] F. Corriveau,[104,p]
A. Cortes-Gonzalez,[18] M. J. Costa,[163] F. Costanza,[4] D. Costanzo,[139] B. M. Cote,[119] G. Cowan,[95] K. Cranmer,[170]
D. Cremonini,[23b,23a] S. Crépé-Renaudin,[60] F. Crescioli,[127] M. Cristinziani,[141] M. Cristoforetti,[78a,78b] V. Croft,[114]
J. E. Crosby,[121] G. Crosetti,[43b,43a] A. Cueto,[99] T. Cuhadar Donszelmann,[160] H. Cui,[14a,14e] Z. Cui,[7]
W. R. Cunningham,[59] F. Curcio,[43b,43a] P. Czodrowski,[36] M. M. Czurylo,[63b]
M. J. Da Cunha Sargedas De Sousa,[57b,57a] J. V. Da Fonseca Pinto,[83b] C. Da Via,[101] W. Dabrowski,[86a] T. Dado,[49]
S. Dahbi,[33g] T. Dai,[106] D. Dal Santo,[19] C. Dallapiccola,[103] M. Dam,[42] G. D'amen,[29] V. D'Amico,[109]
J. Damp,[100] J. R. Dandoy,[128] M. F. Daneri,[30] M. Danninger,[142] V. Dao,[36] G. Darbo,[57b] S. Darmora,[6]
S. J. Das,[29,i] S. D'Auria,[71a,71b] C. David,[156b] T. Davidek,[133] B. Davis-Purcell,[34] I. Dawson,[94] H. A. Day-hall,[132]
K. De,[8] R. De Asmundis,[72a] N. De Biase,[48] S. De Castro,[23b,23a] N. De Groot,[113] P. de Jong,[114] H. De la Torre,[115]
A. De Maria,[14c] A. De Salvo,[75a] U. De Sanctis,[76a,76b] A. De Santo,[146] J. B. De Vivie De Regie,[60] D. V. Dedovich,[38]
J. Degens,[114] A. M. Deiana,[44] F. Del Corso,[23b,23a] J. Del Peso,[99] F. Del Rio,[63a] F. Deliot,[135] C. M. Delitzsch,[49]
M. Della Pietra,[72a,72b] D. Della Volpe,[56] A. Dell'Acqua,[36] L. Dell'Asta,[71a,71b] M. Delmastro,[4] P. A. Delsart,[60]
S. Demers,[172] M. Demichev,[38] S. P. Denisov,[37] L. D'Eramo,[40] D. Derendarz,[87] F. Derue,[127] P. Dervan,[92]
K. Desch,[24] C. Deutsch,[24] F. A. Di Bello,[57b,57a] A. Di Ciaccio,[76a,76b] L. Di Ciaccio,[4] A. Di Domenico,[75a,75b]
C. Di Donato,[72a,72b] A. Di Girolamo,[36] G. Di Gregorio,[5] A. Di Luca,[78a,78b] B. Di Micco,[77a,77b] R. Di Nardo,[77a,77b]
C. Diaconu,[102] M. Diamantopoulou,[34] F. A. Dias,[114] T. Dias Do Vale,[142] M. A. Diaz,[137a,137b] F. G. Diaz Capriles,[24]
M. Didenko,[163] E. B. Diehl,[106] L. Diehl,[54] S. Díez Cornell,[48] C. Diez Pardos,[141] C. Dimitriadi,[161,24,161]
A. Dimitrievska,[17a] J. Dingfelder,[24] I-M. Dinu,[27b] S. J. Dittmeier,[63b] F. Dittus,[36] F. Djama,[102] T. Djobava,[149b]
J. I. Djuvsland,[16] C. Doglioni,[101,98] A. Dohnalova,[28a] J. Dolejsi,[133] Z. Dolezal,[133] K. M. Dona,[39]
M. Donadelli,[83c] B. Dong,[107] J. Donini,[40] A. D'Onofrio,[77a,77b] M. D'Onofrio,[92] J. Dopke,[134] A. Doria,[72a]
N. Dos Santos Fernandes,[130a] P. Dougan,[101] M. T. Dova,[90] A. T. Doyle,[59] M. A. Draguet,[126] E. Dreyer,[169]

I. Drivas-koulouris,[10] A. S. Drobac,[158] M. Drozdova,[56] D. Du,[62a] T. A. du Pree,[114] F. Dubinin,[37]
M. Dubovsky,[28a] E. Duchovni,[169] G. Duckeck,[109] O. A. Ducu,[27b] D. Duda,[52] A. Dudarev,[36] E. R. Duden,[26]
M. D'uffizi,[101] L. Duflot,[66] M. Dührssen,[36] C. Dülsen,[171] A. E. Dumitriu,[27b] M. Dunford,[63a] S. Dungs,[49]
K. Dunne,[47a,47b] A. Duperrin,[102] H. Duran Yildiz,[3a] M. Düren,[58] A. Durglishvili,[149b] B. L. Dwyer,[115]
G. I. Dyckes,[17a] M. Dyndal,[86a] S. Dysch,[101] B. S. Dziedzic,[87] Z. O. Earnshaw,[146] G. H. Eberwein,[126]
B. Eckerova,[28a] S. Eggebrecht,[55] E. Egidio Purcino De Souza,[127] L. F. Ehrke,[56] G. Eigen,[16] K. Einsweiler,[17a]
T. Ekelof,[161] P. A. Ekman,[98] S. El Farkh,[35b] Y. El Ghazali,[35b] H. El Jarrari,[35e,148] A. El Moussaouy,[35a]
V. Ellajosyula,[161] M. Ellert,[161] F. Ellinghaus,[171] A. A. Elliot,[94] N. Ellis,[36] J. Elmsheuser,[29] M. Elsing,[36]
D. Emeliyanov,[134] Y. Enari,[153] I. Ene,[17a] S. Epari,[13] J. Erdmann,[49] P. A. Erland,[87] M. Errenst,[171] M. Escalier,[66]
C. Escobar,[163] E. Etzion,[151] G. Evans,[130a] H. Evans,[68] L. S. Evans,[95] M. O. Evans,[146] A. Ezhilov,[37]
S. Ezzarqtouni,[35a] F. Fabbri,[59] L. Fabbri,[23b,23a] G. Facini,[96] V. Fadeyev,[136] R. M. Fakhrutdinov,[37] S. Falciano,[75a]
L. F. Falda Ulhoa Coelho,[36] P. J. Falke,[24] J. Faltova,[133] C. Fan,[162] Y. Fan,[14a] Y. Fang,[14a,14e] M. Fanti,[71a,71b]
M. Faraj,[69a,69b] Z. Farazpay,[97] A. Farbin,[8] A. Farilla,[77a] T. Farooque,[107] S. M. Farrington,[52] F. Fassi,[35e]
D. Fassouliotis,[9] M. Faucci Giannelli,[76a,76b] W. J. Fawcett,[32] L. Fayard,[66] P. Federic,[133] P. Federicova,[131]
O. L. Fedin,[37,l] G. Fedotov,[37] M. Feickert,[170] L. Feligioni,[102] D. E. Fellers,[123] C. Feng,[62b] M. Feng,[14b]
Z. Feng,[114] M. J. Fenton,[160] A. B. Fenyuk,[37] L. Ferencz,[48] R. A. M. Ferguson,[91] S. I. Fernandez Luengo,[137f]
M. J. V. Fernoux,[102] J. Ferrando,[48] A. Ferrari,[161] P. Ferrari,[114,113] R. Ferrari,[73a] D. Ferrere,[56] C. Ferretti,[106]
F. Fiedler,[100] A. Filipčič,[93] E. K. Filmer,[1] F. Filthaut,[113] M. C. N. Fiolhais,[130a,130c,q] L. Fiorini,[163]
W. C. Fisher,[107] T. Fitschen,[101] P. M. Fitzhugh,[135] I. Fleck,[141] P. Fleischmann,[106] T. Flick,[171] M. Flores,[33d,r]
L. R. Flores Castillo,[64a] L. Flores Sanz De Acedo,[36] F. M. Follega,[78a,78b] N. Fomin,[16] J. H. Foo,[155] B. C. Forland,[68]
A. Formica,[135] A. C. Forti,[101] E. Fortin,[36] A. W. Fortman,[61] M. G. Foti,[17a] L. Fountas,[9,s] D. Fournier,[66]
H. Fox,[91] P. Francavilla,[74a,74b] S. Francescato,[61] S. Franchellucci,[56] M. Franchini,[23b,23a] S. Franchino,[63a]
D. Francis,[36] L. Franco,[113] L. Franconi,[48] M. Franklin,[61] G. Frattari,[26] A. C. Freegard,[94] W. S. Freund,[83b]
Y. Y. Frid,[151] J. Friend,[59] N. Fritzsche,[50] A. Froch,[54] D. Froidevaux,[36] J. A. Frost,[126] Y. Fu,[62a] M. Fujimoto,[118,t]
E. Fullana Torregrosa,[163,a] K. Y. Fung,[64a] E. Furtado De Simas Filho,[83b] M. Furukawa,[153] J. Fuster,[163]
A. Gabrielli,[23b,23a] A. Gabrielli,[155] P. Gadow,[36] G. Gagliardi,[57b,57a] L. G. Gagnon,[17a] E. J. Gallas,[126]
B. J. Gallop,[134] K. K. Gan,[119] S. Ganguly,[153] J. Gao,[62a] Y. Gao,[52] F. M. Garay Walls,[137a,137b] B. Garcia,[29]
C. García,[163] A. Garcia Alonso,[114] A. G. Garcia Caffaro,[172] J. E. García Navarro,[163] M. Garcia-Sciveres,[17a]
G. L. Gardner,[128] R. W. Gardner,[39] N. Garelli,[158] D. Garg,[80] R. B. Garg,[143,u] J. M. Gargan,[52] C. A. Garner,[155]
S. J. Gasiorowski,[138] P. Gaspar,[83b] G. Gaudio,[73a] V. Gautam,[13] P. Gauzzi,[75a,75b] I. L. Gavrilenko,[37] A. Gavrilyuk,[37]
C. Gay,[164] G. Gaycken,[48] E. N. Gazis,[10] A. A. Geanta,[27b] C. M. Gee,[136] C. Gemme,[57b] M. H. Genest,[60]
S. Gentile,[75a,75b] A. D. Gentry,[112] S. George,[95] W. F. George,[20] T. Geralis,[46] P. Gessinger-Befurt,[36]
M. E. Geyik,[171] M. Ghani,[167] M. Ghneimat,[141] K. Ghorbanian,[94] A. Ghosal,[141] A. Ghosh,[160] A. Ghosh,[7]
B. Giacobbe,[23b] S. Giagu,[75a,75b] T. Giani,[114] P. Giannetti,[74a] A. Giannini,[62a] S. M. Gibson,[95] M. Gignac,[136]
D. T. Gil,[86b] A. K. Gilbert,[86a] B. J. Gilbert,[41] D. Gillberg,[34] G. Gilles,[114] N. E. K. Gillwald,[48] L. Ginabat,[127]
D. M. Gingrich,[2,e] M. P. Giordani,[69a,69c] P. F. Giraud,[135] G. Giugliarelli,[69a,69c] D. Giugni,[71a] F. Giuli,[36]
I. Gkialas,[9,s] L. K. Gladilin,[37] C. Glasman,[99] G. R. Gledhill,[123] G. Glemža,[48] M. Glisic,[123] I. Gnesi,[43b,v]
Y. Go,[29,i] M. Goblirsch-Kolb,[36] B. Gocke,[49] D. Godin,[108] B. Gokturk,[21a] S. Goldfarb,[105] T. Golling,[56]
M. G. D. Gololo,[33g] D. Golubkov,[37] J. P. Gombas,[107] A. Gomes,[130a,130b] G. Gomes Da Silva,[141]
A. J. Gomez Delegido,[163] R. Gonçalo,[130a,130c] G. Gonella,[123] L. Gonella,[20] A. Gongadze,[149c] F. Gonnella,[20]
J. L. Gonski,[41] R. Y. González Andana,[52] S. González de la Hoz,[163] S. Gonzalez Fernandez,[13]
R. Gonzalez Lopez,[92] C. Gonzalez Renteria,[17a] M. V. Gonzalez Rodrigues,[48] R. Gonzalez Suarez,[161]
S. Gonzalez-Sevilla,[56] G. R. Gonzalvo Rodriguez,[163] L. Goossens,[36] B. Gorini,[36] E. Gorini,[70a,70b] A. Gorišek,[93]
T. C. Gosart,[128] A. T. Goshaw,[51] M. I. Gostkin,[38] S. Goswami,[121] C. A. Gottardo,[36] S. A. Gotz,[109]
M. Gouighri,[35b] V. Goumarre,[48] A. G. Goussiou,[138] N. Govender,[33c] I. Grabowska-Bold,[86a] K. Graham,[34]
E. Gramstad,[125] S. Grancagnolo,[70a,70b] M. Grandi,[146] C. M. Grant,[1,135] P. M. Gravila,[27f] F. G. Gravili,[70a,70b]
H. M. Gray,[17a] M. Greco,[70a,70b] C. Grefe,[24] I. M. Gregor,[48] P. Grenier,[143] C. Grieco,[13] A. A. Grillo,[136]
K. Grimm,[31] S. Grinstein,[13,w] J.-F. Grivaz,[66] E. Gross,[169] J. Grosse-Knetter,[55] C. Grud,[106] J. C. Grundy,[126]
L. Guan,[106] W. Guan,[29] C. Gubbels,[164] J. G. R. Guerrero Rojas,[163] G. Guerrieri,[69a,69c] F. Guescini,[110]

R. Gugel,[100] J. A. M. Guhit,[106] A. Guida,[18] T. Guillemin,[4] E. Guilloton,[167,134] S. Guindon,[36] F. Guo,[14a,14e]
J. Guo,[62c] L. Guo,[48] Y. Guo,[106] R. Gupta,[48] S. Gurbuz,[24] S. S. Gurdasani,[54] G. Gustavino,[36] M. Guth,[56]
P. Gutierrez,[120] L. F. Gutierrez Zagazeta,[128] C. Gutschow,[96] C. Gwenlan,[126] C. B. Gwilliam,[92] E. S. Haaland,[125]
A. Haas,[117] M. Habedank,[48] C. Haber,[17a] H. K. Hadavand,[8] A. Hadef,[100] S. Hadzic,[110] J. J. Hahn,[141]
E. H. Haines,[96] M. Haleem,[166] J. Haley,[121] J. J. Hall,[139] G. D. Hallewell,[102] L. Halser,[19] K. Hamano,[165]
M. Hamer,[24] G. N. Hamity,[52] E. J. Hampshire,[95] J. Han,[62b] K. Han,[62a] L. Han,[14c] L. Han,[62a] S. Han,[17a]
Y. F. Han,[155] K. Hanagaki,[84] M. Hance,[136] D. A. Hangal,[41,d] H. Hanif,[142] M. D. Hank,[128] R. Hankache,[101]
J. B. Hansen,[42] J. D. Hansen,[42] P. H. Hansen,[42] K. Hara,[157] D. Harada,[56] T. Harenberg,[171] S. Harkusha,[37]
M. L. Harris,[103] Y. T. Harris,[126] J. Harrison,[13] N. M. Harrison,[119] P. F. Harrison,[167] N. M. Hartman,[110]
N. M. Hartmann,[109] Y. Hasegawa,[140] A. Hasib,[52] S. Haug,[19] R. Hauser,[107] C. M. Hawkes,[20] R. J. Hawkings,[36]
Y. Hayashi,[153] S. Hayashida,[111] D. Hayden,[107] C. Hayes,[106] R. L. Hayes,[114] C. P. Hays,[126] J. M. Hays,[94]
H. S. Hayward,[92] F. He,[62a] M. He,[14a,14e] Y. He,[154] Y. He,[48] N. B. Heatley,[94] V. Hedberg,[98] A. L. Heggelund,[125]
N. D. Hehir,[94] C. Heidegger,[54] K. K. Heidegger,[54] W. D. Heidorn,[81] J. Heilman,[34] S. Heim,[48] T. Heim,[17a]
J. G. Heinlein,[128] J. J. Heinrich,[123] L. Heinrich,[110,x] J. Hejbal,[131] L. Helary,[48] A. Held,[170] S. Hellesund,[16]
C. M. Helling,[164] S. Hellman,[47a,47b] R. C. W. Henderson,[91] L. Henkelmann,[32] A. M. Henriques Correia,[36] H. Herde,[98]
Y. Hernández Jiménez,[145] L. M. Herrmann,[24] T. Herrmann,[50] G. Herten,[54] R. Hertenberger,[109] L. Hervas,[36]
M. E. Hesping,[100] N. P. Hessey,[156a] H. Hibi,[85] S. J. Hillier,[20] J. R. Hinds,[107] F. Hinterkeuser,[24] M. Hirose,[124]
S. Hirose,[157] D. Hirschbuehl,[171] T. G. Hitchings,[101] B. Hiti,[93] J. Hobbs,[145] R. Hobincu,[27e] N. Hod,[169]
M. C. Hodgkinson,[139] B. H. Hodkinson,[32] A. Hoecker,[36] J. Hofer,[48] T. Holm,[24] M. Holzbock,[110]
L. B. A. H. Hommels,[32] B. P. Honan,[101] J. Hong,[62c] T. M. Hong,[129] B. H. Hooberman,[162] W. H. Hopkins,[6]
Y. Horii,[111] S. Hou,[148] A. S. Howard,[93] J. Howarth,[59] J. Hoya,[6] M. Hrabovsky,[122] A. Hrynevich,[48]
T. Hryn'ova,[4] P. J. Hsu,[65] S.-C. Hsu,[138] Q. Hu,[62a] Y. F. Hu,[14a,14e] S. Huang,[64b] X. Huang,[14c] Y. Huang,[139]
Y. Huang,[14a] Z. Huang,[101] Z. Hubacek,[132] M. Huebner,[24] F. Huegging,[24] T. B. Huffman,[126] C. A. Hugli,[48]
M. Huhtinen,[36] S. K. Huiberts,[16] R. Hulsken,[104] N. Huseynov,[12,l] J. Huston,[107] J. Huth,[61] R. Hyneman,[143]
G. Iacobucci,[56] G. Iakovidis,[29] I. Ibragimov,[141] L. Iconomidou-Fayard,[66] P. Iengo,[72a,72b] R. Iguchi,[153]
T. Iizawa,[126] Y. Ikegami,[84] N. Ilic,[155] H. Imam,[35a] M. Ince Lezki,[56] T. Ingebretsen Carlson,[47a,47b]
G. Introzzi,[73a,73b] M. Iodice,[77a] V. Ippolito,[75a,75b] R. K. Irwin,[92] M. Ishino,[153] W. Islam,[170] C. Issever,[18,48]
S. Istin,[21a,y] H. Ito,[168] J. M. Iturbe Ponce,[64a] R. Iuppa,[78a,78b] A. Ivina,[169] J. M. Izen,[45] V. Izzo,[72a] P. Jacka,[131,132]
P. Jackson,[1] R. M. Jacobs,[48] B. P. Jaeger,[142] C. S. Jagfeld,[109] P. Jain,[54] G. Jäkel,[171] K. Jakobs,[54]
T. Jakoubek,[169] J. Jamieson,[59] K. W. Janas,[86a] M. Javurkova,[103] F. Jeanneau,[135] L. Jeanty,[123] J. Jejelava,[149a,z]
P. Jenni,[54,aa] C. E. Jessiman,[34] S. Jézéquel,[4] C. Jia,[62b] J. Jia,[145] X. Jia,[61] X. Jia,[14a,14e] Z. Jia,[14c] Y. Jiang,[62a]
S. Jiggins,[48] J. Jimenez Pena,[13] S. Jin,[14c] A. Jinaru,[27b] O. Jinnouchi,[154] P. Johansson,[139] K. A. Johns,[7]
J. W. Johnson,[136] D. M. Jones,[32] E. Jones,[48] P. Jones,[32] R. W. L. Jones,[91] T. J. Jones,[92] H. L. Joos,[55,36]
R. Joshi,[119] J. Jovicevic,[15] X. Ju,[17a] J. J. Junggeburth,[103] T. Junkermann,[63a] A. Juste Rozas,[13,w] M. K. Juzek,[87]
S. Kabana,[137e] A. Kaczmarska,[87] M. Kado,[110] H. Kagan,[119] M. Kagan,[143] A. Kahn,[41] A. Kahn,[128] C. Kahra,[100]
T. Kaji,[153] E. Kajomovitz,[150] N. Kakati,[169] I. Kalaitzidou,[54] C. W. Kalderon,[29] A. Kamenshchikov,[155]
N. J. Kang,[136] D. Kar,[33g] K. Karava,[126] M. J. Kareem,[156b] E. Karentzos,[54] I. Karkanias,[152] O. Karkout,[114]
S. N. Karpov,[38] Z. M. Karpova,[38] V. Kartvelishvili,[91] A. N. Karyukhin,[37] E. Kasimi,[152] J. Katzy,[48] S. Kaur,[34]
K. Kawade,[140] M. P. Kawale,[120] T. Kawamoto,[135] E. F. Kay,[36] F. I. Kaya,[158] S. Kazakos,[107] V. F. Kazanin,[37]
Y. Ke,[145] J. M. Keaveney,[33a] R. Keeler,[165] G. V. Kehris,[61] J. S. Keller,[34] A. S. Kelly,[96] J. J. Kempster,[146]
K. E. Kennedy,[41] P. D. Kennedy,[100] O. Kepka,[131] B. P. Kerridge,[167] S. Kersten,[171] B. P. Kerševan,[93] S. Keshri,[66]
L. Keszeghova,[28a] S. Ketabchi Haghighat,[155] M. Khandoga,[127] A. Khanov,[121] A. G. Kharlamov,[37]
T. Kharlamova,[37] E. E. Khoda,[138] T. J. Khoo,[18] G. Khoriauli,[166] J. Khubua,[149b] Y. A. R. Khwaira,[66]
A. Kilgallon,[123] D. W. Kim,[47a,47b] Y. K. Kim,[39] N. Kimura,[96] M. K. Kingston,[55] A. Kirchhoff,[55] C. Kirfel,[24]
F. Kirfel,[24] J. Kirk,[134] A. E. Kiryunin,[110] C. Kitsaki,[10] O. Kivernyk,[24] M. Klassen,[63a] C. Klein,[34] L. Klein,[166]
M. H. Klein,[106] M. Klein,[92] S. B. Klein,[56] U. Klein,[92] P. Klimek,[36] A. Klimentov,[29] T. Klioutchnikova,[36]
P. Kluit,[114] S. Kluth,[110] E. Kneringer,[79] T. M. Knight,[155] A. Knue,[49] R. Kobayashi,[88] D. Kobylianskii,[169]
S. F. Koch,[126] M. Kocian,[143] P. Kodyš,[133] D. M. Koeck,[123] P. T. Koenig,[24] T. Koffas,[34] M. Kolb,[135]
I. Koletsou,[4] T. Komarek,[122] K. Köneke,[54] A. X. Y. Kong,[1] T. Kono,[118] N. Konstantinidis,[96] B. Konya,[98]

R. Kopeliansky,[68] S. Koperny,[86a] K. Korcyl,[87] K. Kordas,[152,bb] G. Koren,[151] A. Korn,[96] S. Korn,[55]
I. Korolkov,[13] N. Korotkova,[37] B. Kortman,[114] O. Kortner,[110] S. Kortner,[110] W. H. Kostecka,[115]
V. V. Kostyukhin,[141] A. Kotsokechagia,[135] A. Kotwal,[51] A. Koulouris,[36] A. Kourkoumeli-Charalampidi,[73a,73b]
C. Kourkoumelis,[9] E. Kourlitis,[110,x] O. Kovanda,[146] R. Kowalewski,[165] W. Kozanecki,[135] A. S. Kozhin,[37]
V. A. Kramarenko,[37] G. Kramberger,[93] P. Kramer,[100] M. W. Krasny,[127] A. Krasznahorkay,[36] J. W. Kraus,[171]
J. A. Kremer,[100] T. Kresse,[50] J. Kretzschmar,[92] K. Kreul,[18] P. Krieger,[155] S. Krishnamurthy,[103] M. Krivos,[133]
K. Krizka,[20] K. Kroeninger,[49] H. Kroha,[110] J. Kroll,[131] J. Kroll,[128] K. S. Krowpman,[107] U. Kruchonak,[38]
H. Krüger,[24] N. Krumnack,[81] M. C. Kruse,[51] J. A. Krzysiak,[87] O. Kuchinskaia,[37] S. Kuday,[3a] S. Kuehn,[36]
R. Kuesters,[54] T. Kuhl,[48] V. Kukhtin,[38] Y. Kulchitsky,[37,l] S. Kuleshov,[137d,137b] M. Kumar,[33g] N. Kumari,[48]
A. Kupco,[131] T. Kupfer,[49] A. Kupich,[37] O. Kuprash,[54] H. Kurashige,[85] L. L. Kurchaninov,[156a] O. Kurdysh,[66]
Y. A. Kurochkin,[37] A. Kurova,[37] M. Kuze,[154] A. K. Kvam,[103] J. Kvita,[122] T. Kwan,[104] N. G. Kyriacou,[106]
L. A. O. Laatu,[102] C. Lacasta,[163] F. Lacava,[75a,75b] H. Lacker,[18] D. Lacour,[127] N. N. Lad,[96] E. Ladygin,[38]
B. Laforge,[127] T. Lagouri,[137e] F. Z. Lahbabi,[35a] S. Lai,[55] I. K. Lakomiec,[86a] N. Lalloue,[60] J. E. Lambert,[165]
S. Lammers,[68] W. Lampl,[7] C. Lampoudis,[152,bb] A. N. Lancaster,[115] E. Lançon,[29] U. Landgraf,[54]
M. P. J. Landon,[94] V. S. Lang,[54] R. J. Langenberg,[103] O. K. B. Langrekken,[125] A. J. Lankford,[160] F. Lanni,[36]
K. Lantzsch,[24] A. Lanza,[73a] A. Lapertosa,[57b,57a] J. F. Laporte,[135] T. Lari,[71a] F. Lasagni Manghi,[23b] M. Lassnig,[36]
V. Latonova,[131] A. Laudrain,[100] A. Laurier,[150] S. D. Lawlor,[95] Z. Lawrence,[101] M. Lazzaroni,[71a,71b] B. Le,[101]
E. M. Le Boulicaut,[51] B. Leban,[93] A. Lebedev,[81] M. LeBlanc,[101] F. Ledroit-Guillon,[60] A. C. A. Lee,[96]
S. C. Lee,[148] S. Lee,[47a,47b] T. F. Lee,[92] L. L. Leeuw,[33c] H. P. Lefebvre,[95] M. Lefebvre,[165] C. Leggett,[17a]
G. Lehmann Miotto,[36] M. Leigh,[56] W. A. Leight,[103] W. Leinonen,[113] A. Leisos,[152,cc] M. A. L. Leite,[83c]
C. E. Leitgeb,[48] R. Leitner,[133] K. J. C. Leney,[44] T. Lenz,[24] S. Leone,[74a] C. Leonidopoulos,[52] A. Leopold,[144]
C. Leroy,[108] R. Les,[107] C. G. Lester,[32] M. Levchenko,[37] J. Levêque,[4] D. Levin,[106] L. J. Levinson,[169]
M. P. Lewicki,[87] D. J. Lewis,[4] A. Li,[5] B. Li,[62b] C. Li,[62a] C-Q. Li,[62c] H. Li,[62a] H. Li,[62b] H. Li,[14c] H. Li,[14b]
H. Li,[62b] K. Li,[138] L. Li,[62c] M. Li,[14a,14e] Q. Y. Li,[62a] S. Li,[14a,14e] S. Li,[62d,62c,dd] T. Li,[5] X. Li,[104] Z. Li,[126]
Z. Li,[104] Z. Li,[92] Z. Li,[14a,14e] S. Liang,[14a,14e] Z. Liang,[14a] M. Liberatore,[135] B. Liberti,[76a] K. Lie,[64c]
J. Lieber Marin,[83b] H. Lien,[68] K. Lin,[107] R. E. Lindley,[7] J. H. Lindon,[2] E. Lipeles,[128] A. Lipniacka,[16]
A. Lister,[164] J. D. Little,[4] B. Liu,[14a] B. X. Liu,[142] D. Liu,[62d,62c] J. B. Liu,[62a] J. K. K. Liu,[32] K. Liu,[62d,62c]
M. Liu,[62a] M. Y. Liu,[62a] P. Liu,[14a] Q. Liu,[62d,138,62c] X. Liu,[62a] Y. Liu,[14d,14e] Y. L. Liu,[62b] Y. W. Liu,[62a]
J. Llorente Merino,[142] S. L. Lloyd,[94] E. M. Lobodzinska,[48] P. Loch,[7] S. Loffredo,[76a,76b] T. Lohse,[18]
K. Lohwasser,[139] E. Loiacono,[48] M. Lokajicek,[131,a] J. D. Lomas,[20] J. D. Long,[162] I. Longarini,[160]
L. Longo,[70a,70b] R. Longo,[162] I. Lopez Paz,[67] A. Lopez Solis,[48] J. Lorenz,[109] N. Lorenzo Martinez,[4]
A. M. Lory,[109] G. Löschcke Centeno,[146] O. Loseva,[37] X. Lou,[47a,47b] X. Lou,[14a,14e] A. Lounis,[66] J. Love,[6]
P. A. Love,[91] G. Lu,[14a,14e] M. Lu,[80] S. Lu,[128] Y. J. Lu,[65] H. J. Lubatti,[138] C. Luci,[75a,75b] F. L. Lucio Alves,[14c]
A. Lucotte,[60] F. Luehring,[68] I. Luise,[145] O. Lukianchuk,[66] O. Lundberg,[144] B. Lund-Jensen,[144] N. A. Luongo,[123]
M. S. Lutz,[151] D. Lynn,[29] H. Lyons,[92] R. Lysak,[131] E. Lytken,[98] V. Lyubushkin,[38] T. Lyubushkina,[38]
M. M. Lyukova,[145] H. Ma,[29] K. Ma,[62a] L. L. Ma,[62b] Y. Ma,[121] D. M. Mac Donell,[165] G. Maccarrone,[53]
J. C. MacDonald,[100] P. C. Machado De Abreu Farias,[83b] R. Madar,[40] W. F. Mader,[50] T. Madula,[96] J. Maeda,[85]
T. Maeno,[29] M. Maerker,[50] H. Maguire,[139] V. Maiboroda,[135] A. Maio,[130a,130b,130d] K. Maj,[86a] O. Majersky,[48]
S. Majewski,[123] N. Makovec,[66] V. Maksimovic,[15] B. Malaescu,[127] Pa. Malecki,[87] V. P. Maleev,[37] F. Malek,[60]
M. Mali,[93] D. Malito,[95] U. Mallik,[80] S. Maltezos,[10] S. Malyukov,[38] J. Mamuzic,[13] G. Mancini,[53] G. Manco,[73a,73b]
J. P. Mandalia,[94] I. Mandić,[93] L. Manhaes de Andrade Filho,[83a] I. M. Maniatis,[169] J. Manjarres Ramos,[102,ee]
D. C. Mankad,[169] A. Mann,[109] B. Mansoulie,[135] S. Manzoni,[36] A. Marantis,[152,cc] G. Marchiori,[5]
M. Marcisovsky,[131] C. Marcon,[71a] M. Marinescu,[20] M. Marjanovic,[120] E. J. Marshall,[91] Z. Marshall,[17a]
S. Marti-Garcia,[163] T. A. Martin,[167] V. J. Martin,[52] B. Martin dit Latour,[16] L. Martinelli,[75a,75b] M. Martinez,[13,w]
P. Martinez Agullo,[163] V. I. Martinez Outschoorn,[103] P. Martinez Suarez,[13] S. Martin-Haugh,[134] V. S. Martoiu,[27b]
A. C. Martyniuk,[96] A. Marzin,[36] D. Mascione,[78a,78b] L. Masetti,[100] T. Mashimo,[153] J. Masik,[101]
A. L. Maslennikov,[37] L. Massa,[23b] P. Massarotti,[72a,72b] P. Mastrandrea,[74a,74b] A. Mastroberardino,[43b,43a]
T. Masubuchi,[153] T. Mathisen,[161] J. Matousek,[133] N. Matsuzawa,[153] J. Maurer,[27b] B. Maček,[93] D. A. Maximov,[37]
R. Mazini,[148] I. Maznas,[152] M. Mazza,[107] S. M. Mazza,[136] E. Mazzeo,[71a,71b] C. Mc Ginn,[29] J. P. Mc Gowan,[104]

S. P. Mc Kee,[106] E. F. McDonald,[105] A. E. McDougall,[114] J. A. Mcfayden,[146] R. P. McGovern,[128]
G. Mchedlidze,[149b] R. P. Mckenzie,[33g] T. C. Mclachlan,[48] D. J. Mclaughlin,[96] K. D. McLean,[165]
S. J. McMahon,[134] P. C. McNamara,[105] C. M. Mcpartland,[92] R. A. McPherson,[165,p] S. Mehlhase,[109] A. Mehta,[92]
D. Melini,[150] B. R. Mellado Garcia,[33g] A. H. Melo,[55] F. Meloni,[48] A. M. Mendes Jacques Da Costa,[101]
H. Y. Meng,[155] L. Meng,[91] S. Menke,[110] M. Mentink,[36] E. Meoni,[43b,43a] C. Merlassino,[126] L. Merola,[72a,72b]
C. Meroni,[71a,71b] G. Merz,[106] O. Meshkov,[37] J. Metcalfe,[6] A. S. Mete,[6] C. Meyer,[68] J-P. Meyer,[135]
R. P. Middleton,[134] L. Mijović,[52] G. Mikenberg,[169] M. Mikestikova,[131] M. Mikuž,[93] H. Mildner,[100] A. Milic,[36]
C. D. Milke,[44] D. W. Miller,[39] L. S. Miller,[34] A. Milov,[169] D. A. Milstead,[47a,47b] T. Min,[14c] A. A. Minaenko,[37]
I. A. Minashvili,[149b] L. Mince,[59] A. I. Mincer,[117] B. Mindur,[86a] M. Mineev,[38] Y. Mino,[88] L. M. Mir,[13]
M. Miralles Lopez,[163] M. Mironova,[17a] A. Mishima,[153] M. C. Missio,[113] A. Mitra,[167] V. A. Mitsou,[163]
Y. Mitsumori,[111] O. Miu,[155] P. S. Miyagawa,[94] T. Mkrtchyan,[63a] M. Mlinarevic,[96] T. Mlinarevic,[96]
M. Mlynarikova,[36] S. Mobius,[19] P. Moder,[48] P. Mogg,[109] A. F. Mohammed,[14a,14e] S. Mohapatra,[41]
G. Mokgatitswane,[33g] L. Moleri,[169] B. Mondal,[141] S. Mondal,[132] K. Mönig,[48] E. Monnier,[102]
L. Monsonis Romero,[163] J. Montejo Berlingen,[13] M. Montella,[119] F. Montereali,[77a,77b] F. Monticelli,[90]
S. Monzani,[69a,69c] N. Morange,[66] A. L. Moreira De Carvalho,[130a] M. Moreno Llácer,[163] C. Moreno Martinez,[56]
P. Morettini,[57b] S. Morgenstern,[36] M. Morii,[61] M. Morinaga,[153] A. K. Morley,[36] F. Morodei,[75a,75b] L. Morvaj,[36]
P. Moschovakos,[36] B. Moser,[36] M. Mosidze,[149b] T. Moskalets,[54] P. Moskvitina,[113] J. Moss,[31,ff] E. J. W. Moyse,[103]
O. Mtintsilana,[33g] S. Muanza,[102] J. Mueller,[129] D. Muenstermann,[91] R. Müller,[19] G. A. Mullier,[161] A. J. Mullin,[32]
J. J. Mullin,[128] D. P. Mungo,[155] D. Munoz Perez,[163] F. J. Munoz Sanchez,[101] M. Murin,[101] W. J. Murray,[167,134]
A. Murrone,[71a,71b] J. M. Muse,[120] M. Muškinja,[17a] C. Mwewa,[29] A. G. Myagkov,[37,l] A. J. Myers,[8] A. A. Myers,[129]
G. Myers,[68] M. Myska,[132] B. P. Nachman,[17a] O. Nackenhorst,[49] A. Nag,[50] K. Nagai,[126] K. Nagano,[84]
J. L. Nagle,[29,i] E. Nagy,[102] A. M. Nairz,[36] Y. Nakahama,[84] K. Nakamura,[84] K. Nakkalil,[5] H. Nanjo,[124]
R. Narayan,[44] E. A. Narayanan,[112] I. Naryshkin,[37] M. Naseri,[34] S. Nasri,[159] C. Nass,[24] G. Navarro,[22a]
J. Navarro-Gonzalez,[163] R. Nayak,[151] A. Nayaz,[18] P. Y. Nechaeva,[37] F. Nechansky,[48] L. Nedic,[126] T. J. Neep,[20]
A. Negri,[73a,73b] M. Negrini,[23b] C. Nellist,[114] C. Nelson,[104] K. Nelson,[106] S. Nemecek,[131] M. Nessi,[36,gg]
M. S. Neubauer,[162] F. Neuhaus,[100] J. Neundorf,[48] R. Newhouse,[164] P. R. Newman,[20] C. W. Ng,[129] Y. W. Y. Ng,[48]
B. Ngair,[35e] H. D. N. Nguyen,[108] R. B. Nickerson,[126] R. Nicolaidou,[135] J. Nielsen,[136] M. Niemeyer,[55]
J. Niermann,[55,36] N. Nikiforou,[36] V. Nikolaenko,[37,l] I. Nikolic-Audit,[127] K. Nikolopoulos,[20] P. Nilsson,[29]
I. Ninca,[48] H. R. Nindhito,[56] G. Ninio,[151] A. Nisati,[75a] N. Nishu,[2] R. Nisius,[110] J-E. Nitschke,[50]
E. K. Nkadimeng,[33g] T. Nobe,[153] D. L. Noel,[32] T. Nommensen,[147] M. B. Norfolk,[139] R. R. B. Norisam,[96]
B. J. Norman,[34] J. Novak,[93] T. Novak,[48] L. Novotny,[132] R. Novotny,[112] L. Nozka,[122] K. Ntekas,[160]
N. M. J. Nunes De Moura Junior,[83b] E. Nurse,[96] J. Ocariz,[127] A. Ochi,[85] I. Ochoa,[130a] S. Oerdek,[48nn]
J. T. Offermann,[39] A. Ogrodnik,[133] A. Oh,[101] C. C. Ohm,[144] H. Oide,[84] R. Oishi,[153] M. L. Ojeda,[48]
M. W. O'Keefe,[92] Y. Okumura,[153] L. F. Oleiro Seabra,[130a] S. A. Olivares Pino,[137d] D. Oliveira Damazio,[29]
D. Oliveira Goncalves,[83a] J. L. Oliver,[160] A. Olszewski,[87] Ö. O. Öncel,[54] A. P. O'Neill,[19] A. Onofre,[130a,130e]
P. U. E. Onyisi,[11] M. J. Oreglia,[39] G. E. Orellana,[90] D. Orestano,[77a,77b] N. Orlando,[13] R. S. Orr,[155] V. O'Shea,[59]
L. M. Osojnak,[128] R. Ospanov,[62a] G. Otero y Garzon,[30] H. Otono,[89] P. S. Ott,[63a] G. J. Ottino,[17a] M. Ouchrif,[35d]
J. Ouellette,[29] F. Ould-Saada,[125] M. Owen,[59] R. E. Owen,[134] K. Y. Oyulmaz,[21a] V. E. Ozcan,[21a] N. Ozturk,[8]
S. Ozturk,[82] H. A. Pacey,[32] A. Pacheco Pages,[13] C. Padilla Aranda,[13] G. Padovano,[75a,75b] S. Pagan Griso,[17a]
G. Palacino,[68] A. Palazzo,[70a,70b] S. Palestini,[36] J. Pan,[172] T. Pan,[64a] D. K. Panchal,[11] C. E. Pandini,[114]
J. G. Panduro Vazquez,[95] H. D. Pandya,[1] H. Pang,[14b] P. Pani,[48] G. Panizzo,[69a,69c] L. Paolozzi,[56] C. Papadatos,[108]
S. Parajuli,[44] A. Paramonov,[6] C. Paraskevopoulos,[10] D. Paredes Hernandez,[64b] T. H. Park,[155] M. A. Parker,[32]
F. Parodi,[57b,57a] E. W. Parrish,[115] V. A. Parrish,[52] J. A. Parsons,[41] U. Parzefall,[54] B. Pascual Dias,[108]
L. Pascual Dominguez,[151] E. Pasqualucci,[75a] S. Passaggio,[57b] F. Pastore,[95] P. Pasuwan,[47a,47b] P. Patel,[87]
U. M. Patel,[51] J. R. Pater,[101] T. Pauly,[36] J. Pearkes,[143] M. Pedersen,[125] R. Pedro,[130a] S. V. Peleganchuk,[37]
O. Penc,[36] E. A. Pender,[52] H. Peng,[62a] K. E. Penski,[109] M. Penzin,[37] B. S. Peralva,[83d] A. P. Pereira Peixoto,[60]
L. Pereira Sanchez,[47a,47b] D. V. Perepelitsa,[29,i] E. Perez Codina,[156a] M. Perganti,[10] L. Perini,[71a,71b,a]
H. Pernegger,[36] O. Perrin,[40] K. Peters,[48] R. F. Y. Peters,[101] B. A. Petersen,[36] T. C. Petersen,[42] E. Petit,[102]
V. Petousis,[132] C. Petridou,[152,bb] A. Petrukhin,[141] M. Pettee,[17a] N. E. Pettersson,[36] A. Petukhov,[37]

K. Petukhova,[133] R. Pezoa,[137f] L. Pezzotti,[36] G. Pezzullo,[172] T. M. Pham,[170] T. Pham,[105] P. W. Phillips,[134] G. Piacquadio,[145] E. Pianori,[17a] F. Piazza,[71a,71b] R. Piegaia,[30] D. Pietreanu,[27b] A. D. Pilkington,[101] M. Pinamonti,[69a,69c] J. L. Pinfold,[2] B. C. Pinheiro Pereira,[130a] A. E. Pinto Pinoargote,[100,135] L. Pintucci,[69a,69c] K. M. Piper,[146] A. Pirttikoski,[56] D. A. Pizzi,[34] L. Pizzimento,[64b] A. Pizzini,[114] M.-A. Pleier,[29] V. Plesanovs,[54] V. Pleskot,[133] E. Plotnikova,[38] G. Poddar,[4] R. Poettgen,[98] L. Poggioli,[127] I. Pokharel,[55] S. Polacek,[133] G. Polesello,[73a] A. Poley,[142,156a] R. Polifka,[132] A. Polini,[23b] C. S. Pollard,[167] Z. B. Pollock,[119] V. Polychronakos,[29] E. Pompa Pacchi,[75a,75b] D. Ponomarenko,[113] L. Pontecorvo,[36] S. Popa,[27a] G. A. Popeneciu,[27d] A. Poreba,[36] D. M. Portillo Quintero,[156a] S. Pospisil,[132] M. A. Postill,[139] P. Postolache,[27c] K. Potamianos,[167] P. A. Potepa,[86a] I. N. Potrap,[38] C. J. Potter,[32] H. Potti,[1] T. Poulsen,[48] J. Poveda,[163] M. E. Pozo Astigarraga,[36] A. Prades Ibanez,[163] J. Pretel,[54] D. Price,[101] M. Primavera,[70a] M. A. Principe Martin,[99] R. Privara,[122] T. Procter,[59] M. L. Proffitt,[138] N. Proklova,[128] K. Prokofiev,[64c] G. Proto,[110] S. Protopopescu,[29] J. Proudfoot,[6] M. Przybycien,[86a] W. W. Przygoda,[86b] J. E. Puddefoot,[139] D. Pudzha,[37] D. Pyatiizbyantseva,[37] J. Qian,[106] D. Qichen,[101] Y. Qin,[101] T. Qiu,[52] A. Quadt,[55] M. Queitsch-Maitland,[101] G. Quetant,[56] R. P. Quinn,[164] G. Rabanal Bolanos,[61] D. Rafanoharana,[54] F. Ragusa,[71a,71b] J. L. Rainbolt,[39] J. A. Raine,[56] S. Rajagopalan,[29] E. Ramakoti,[37] K. Ran,[48,14e] N. P. Rapheeha,[33g] H. Rasheed,[27b] V. Raskina,[127] D. F. Rassloff,[63a] S. Rave,[100] B. Ravina,[55] I. Ravinovich,[169] M. Raymond,[36] A. L. Read,[125] N. P. Readioff,[139] D. M. Rebuzzi,[73a,73b] G. Redlinger,[29] A. S. Reed,[110] K. Reeves,[26] J. A. Reidelsturz,[171] D. Reikher,[151] A. Rej,[141] C. Rembser,[36] A. Renardi,[48] M. Renda,[27b] M. B. Rendel,[110] F. Renner,[48] A. G. Rennie,[160] A. L. Rescia,[48] S. Resconi,[71a] M. Ressegotti,[57b,57a] S. Rettie,[36] J. G. Reyes Rivera,[107] E. Reynolds,[17a] O. L. Rezanova,[37] P. Reznicek,[133] N. Ribaric,[91] E. Ricci,[78a,78b] R. Richter,[110] S. Richter,[47a,47b] E. Richter-Was,[86b] M. Ridel,[127] S. Ridouani,[35d] P. Rieck,[117] P. Riedler,[36] M. Rijssenbeek,[145] A. Rimoldi,[73a,73b] M. Rimoldi,[48] L. Rinaldi,[23b,23a] T. T. Rinn,[29] M. P. Rinnagel,[109] G. Ripellino,[161] I. Riu,[13] P. Rivadeneira,[48] J. C. Rivera Vergara,[165] F. Rizatdinova,[121] E. Rizvi,[94] B. A. Roberts,[167] B. R. Roberts,[17a] S. H. Robertson,[104,p] D. Robinson,[32] C. M. Robles Gajardo,[137f] M. Robles Manzano,[100] A. Robson,[59] A. Rocchi,[76a,76b] C. Roda,[74a,74b] S. Rodriguez Bosca,[63a] Y. Rodriguez Garcia,[22a] A. Rodriguez Rodriguez,[54] A. M. Rodríguez Vera,[156b] S. Roe,[36] J. T. Roemer,[160] A. R. Roepe-Gier,[136] J. Roggel,[171] O. Røhne,[125] R. A. Rojas,[103] C. P. A. Roland,[68] J. Roloff,[29] A. Romaniouk,[37] E. Romano,[73a,73b] M. Romano,[23b] A. C. Romero Hernandez,[162] N. Rompotis,[92] L. Roos,[127] S. Rosati,[75a] B. J. Rosser,[39] E. Rossi,[126] E. Rossi,[72a,72b] L. P. Rossi,[57b] L. Rossini,[54] R. Rosten,[119] M. Rotaru,[27b] B. Rottler,[54] C. Rougier,[102,ee] D. Rousseau,[66] D. Rousso,[32] A. Roy,[162] S. Roy-Garand,[155] A. Rozanov,[102] Y. Rozen,[150] X. Ruan,[33g] A. Rubio Jimenez,[163] A. J. Ruby,[92] V. H. Ruelas Rivera,[18] T. A. Ruggeri,[1] A. Ruggiero,[126] A. Ruiz-Martinez,[163] A. Rummler,[36] Z. Rurikova,[54] N. A. Rusakovich,[38] H. L. Russell,[165] G. Russo,[75a,75b] J. P. Rutherfoord,[7] S. Rutherford Colmenares,[32] K. Rybacki,[91] M. Rybar,[133] E. B. Rye,[125] A. Ryzhov,[44] J. A. Sabater Iglesias,[56] P. Sabatini,[163] L. Sabetta,[75a,75b] H. F-W. Sadrozinski,[136] F. Safai Tehrani,[75a] B. Safarzadeh Samani,[146] M. Safdari,[143] S. Saha,[165] M. Sahinsoy,[110] M. Saimpert,[135] M. Saito,[153] T. Saito,[153] D. Salamani,[36] A. Salnikov,[143] J. Salt,[163] A. Salvador Salas,[13] D. Salvatore,[43b,43a] F. Salvatore,[146] A. Salzburger,[36] D. Sammel,[54] D. Sampsonidis,[152,bb] D. Sampsonidou,[123] J. Sánchez,[163] A. Sanchez Pineda,[4] V. Sanchez Sebastian,[163] H. Sandaker,[125] C. O. Sander,[48] J. A. Sandesara,[103] M. Sandhoff,[171] C. Sandoval,[22b] D. P. C. Sankey,[134] T. Sano,[88] A. Sansoni,[53] L. Santi,[75a,75b] C. Santoni,[40] H. Santos,[130a,130b] S. N. Santpur,[17a] A. Santra,[169] K. A. Saoucha,[116b] J. G. Saraiva,[130a,130d] J. Sardain,[7] O. Sasaki,[84] K. Sato,[157] C. Sauer,[63b] F. Sauerburger,[54] E. Sauvan,[4] P. Savard,[155,e] R. Sawada,[153] C. Sawyer,[134] L. Sawyer,[97] I. Sayago Galvan,[163] C. Sbarra,[23b] A. Sbrizzi,[23b,23a] T. Scanlon,[96] J. Schaarschmidt,[138] P. Schacht,[110] D. Schaefer,[39] U. Schäfer,[100] A. C. Schaffer,[66,44] D. Schaile,[109] R. D. Schamberger,[145] C. Scharf,[18] M. M. Schefer,[19] V. A. Schegelsky,[37] D. Scheirich,[133] F. Schenck,[18] M. Schernau,[160] C. Scheulen,[55] C. Schiavi,[57b,57a] E. J. Schioppa,[70a,70b] M. Schioppa,[43b,43a] B. Schlag,[143,u] K. E. Schleicher,[54] S. Schlenker,[36] J. Schmeing,[171] M. A. Schmidt,[171] K. Schmieden,[100] C. Schmitt,[100] S. Schmitt,[48] L. Schoeffel,[135] A. Schoening,[63b] P. G. Scholer,[54] E. Schopf,[126] M. Schott,[100] J. Schovancova,[36] S. Schramm,[56] F. Schroeder,[171] T. Schroer,[56] H-C. Schultz-Coulon,[63a] M. Schumacher,[54] B. A. Schumm,[136] Ph. Schune,[135] A. J. Schuy,[138] H. R. Schwartz,[136] A. Schwartzman,[143] T. A. Schwarz,[106] Ph. Schwemling,[135] R. Schwienhorst,[107] A. Sciandra,[136] G. Sciolla,[26] F. Scuri,[74a] C. D. Sebastiani,[92] K. Sedlaczek,[115] P. Seema,[18] S. C. Seidel,[112]

A. Seiden,[136] B. D. Seidlitz,[41] C. Seitz,[48] J. M. Seixas,[83b] G. Sekhniaidze,[72a] S. J. Sekula,[44] L. Selem,[60]
N. Semprini-Cesari,[23b,23a] D. Sengupta,[56] V. Senthilkumar,[163] L. Serin,[66] L. Serkin,[69a,69b] M. Sessa,[76a,76b]
H. Severini,[120] F. Sforza,[57b,57a] A. Sfyrla,[56] E. Shabalina,[55] R. Shaheen,[144] J. D. Shahinian,[128]
D. Shaked Renous,[169] L. Y. Shan,[14a] M. Shapiro,[17a] A. Sharma,[36] A. S. Sharma,[164] P. Sharma,[80] S. Sharma,[48]
P. B. Shatalov,[37] K. Shaw,[146] S. M. Shaw,[101] A. Shcherbakova,[37] Q. Shen,[62c,5] P. Sherwood,[96] L. Shi,[96]
X. Shi,[14a] C. O. Shimmin,[172] J. D. Shinner,[95] I. P. J. Shipsey,[126] S. Shirabe,[56,gg] M. Shiyakova,[38,hh] J. Shlomi,[169]
M. J. Shochet,[39] J. Shojaii,[105] D. R. Shope,[125] B. Shrestha,[120] S. Shrestha,[119,ii] E. M. Shrif,[33g] M. J. Shroff,[165]
P. Sicho,[131] A. M. Sickles,[162] E. Sideras Haddad,[33g] A. Sidoti,[23b] F. Siegert,[50] Dj. Sijacki,[15] R. Sikora,[86a]
F. Sili,[90] J. M. Silva,[20] M. V. Silva Oliveira,[29] S. B. Silverstein,[47a] S. Simion,[66] R. Simoniello,[36] E. L. Simpson,[59]
H. Simpson,[146] L. R. Simpson,[106] N. D. Simpson,[98] S. Simsek,[82] S. Sindhu,[55] P. Sinervo,[155] S. Singh,[155]
S. Sinha,[48] S. Sinha,[101] M. Sioli,[23b,23a] I. Siral,[36] E. Sitnikova,[48] S. Yu. Sivoklokov,[37,a] J. Sjölin,[47a,47b]
A. Skaf,[55] E. Skorda,[20] P. Skubic,[120] M. Slawinska,[87] V. Smakhtin,[169] B. H. Smart,[134] J. Smiesko,[36]
S. Yu. Smirnov,[37] Y. Smirnov,[37] L. N. Smirnova,[37,l] O. Smirnova,[98] A. C. Smith,[41] E. A. Smith,[39]
H. A. Smith,[126] J. L. Smith,[92] R. Smith,[143] M. Smizanska,[91] K. Smolek,[132] A. A. Snesarev,[37] S. R. Snider,[155]
H. L. Snoek,[114] S. Snyder,[29] R. Sobie,[165,p] A. Soffer,[151] C. A. Solans Sanchez,[36] E. Yu. Soldatov,[37]
U. Soldevila,[163] A. A. Solodkov,[37] S. Solomon,[26] A. Soloshenko,[38] K. Solovieva,[54] O. V. Solovyanov,[40]
V. Solovyev,[37] P. Sommer,[36] A. Sonay,[13] W. Y. Song,[156b] J. M. Sonneveld,[114] A. Sopczak,[132] A. L. Sopio,[96]
F. Sopkova,[28b] V. Sothilingam,[63a] S. Sottocornola,[68] R. Soualah,[116b] Z. Soumaimi,[35e] D. South,[48]
N. Soybelman,[169] S. Spagnolo,[70a,70b] M. Spalla,[110] D. Sperlich,[54] G. Spigo,[36] S. Spinali,[91] D. P. Spiteri,[59]
M. Spousta,[133] E. J. Staats,[34] A. Stabile,[71a,71b] R. Stamen,[63a] A. Stampekis,[20] M. Standke,[24] E. Stanecka,[87]
M. V. Stange,[50] B. Stanislaus,[17a] M. M. Stanitzki,[48] B. Stapf,[48] E. A. Starchenko,[37] G. H. Stark,[136] J. Stark,[102,ee]
D. M. Starko,[156b] P. Staroba,[131] P. Starovoitov,[63a] S. Stärz,[104] R. Staszewski,[87] G. Stavropoulos,[46] J. Steentoft,[161]
P. Steinberg,[29] B. Stelzer,[142,156a] H. J. Stelzer,[129] O. Stelzer-Chilton,[156a] H. Stenzel,[58] T. J. Stevenson,[146]
G. A. Stewart,[36] J. R. Stewart,[121] M. C. Stockton,[36] G. Stoicea,[27b] M. Stolarski,[130a] S. Stonjek,[110]
A. Straessner,[50] J. Strandberg,[144] S. Strandberg,[47a,47b] M. Stratmann,[171] M. Strauss,[120] T. Strebler,[102]
P. Strizenec,[28b] R. Ströhmer,[166] D. M. Strom,[123] L. R. Strom,[48] R. Stroynowski,[44] A. Strubig,[47a,47b]
S. A. Stucci,[29] B. Stugu,[16] J. Stupak,[120] N. A. Styles,[48] D. Su,[143] S. Su,[62a] W. Su,[62d] X. Su,[62a,66]
K. Sugizaki,[153] V. V. Sulin,[37] M. J. Sullivan,[92] D. M. S. Sultan,[78a,78b] L. Sultanaliyeva,[37] S. Sultansoy,[3b]
T. Sumida,[88] S. Sun,[106] S. Sun,[170] O. Sunneborn Gudnadottir,[161] N. Sur,[102] M. R. Sutton,[146] H. Suzuki,[157]
M. Svatos,[131] M. Swiatlowski,[156a] T. Swirski,[166] I. Sykora,[28a] M. Sykora,[133] T. Sykora,[133] D. Ta,[100]
K. Tackmann,[48,jj] A. Taffard,[160] R. Tafirout,[156a] J. S. Tafoya Vargas,[66] E. P. Takeva,[52] Y. Takubo,[84] M. Talby,[102]
A. A. Talyshev,[37] K. C. Tam,[64b] N. M. Tamir,[151] A. Tanaka,[153] J. Tanaka,[153] R. Tanaka,[66] M. Tanasini,[57b,57a]
Z. Tao,[164] S. Tapia Araya,[137f] S. Tapprogge,[100] A. Tarek Abouelfadl Mohamed,[107] S. Tarem,[150] K. Tariq,[14a]
G. Tarna,[102,27b] G. F. Tartarelli,[71a] P. Tas,[133] M. Tasevsky,[131] E. Tassi,[43b,43a] A. C. Tate,[162] G. Tateno,[153]
Y. Tayalati,[35e,kk] G. N. Taylor,[105] W. Taylor,[156b] H. Teagle,[92] A. S. Tee,[170] R. Teixeira De Lima,[143]
P. Teixeira-Dias,[95] J. J. Teoh,[155] K. Terashi,[153] J. Terron,[99] S. Terzo,[13] M. Testa,[53] R. J. Teuscher,[155,p]
A. Thaler,[79] O. Theiner,[56] N. Themistokleous,[52] T. Theveneaux-Pelzer,[102] O. Thielmann,[171] D. W. Thomas,[95]
J. P. Thomas,[20] E. A. Thompson,[17a] P. D. Thompson,[20] E. Thomson,[128] Y. Tian,[55] V. Tikhomirov,[37,l]
Yu. A. Tikhonov,[37] S. Timoshenko,[37] D. Timoshyn,[133] E. X. L. Ting,[1] P. Tipton,[172] S. H. Tlou,[33g] A. Tnourji,[40]
K. Todome,[154] S. Todorova-Nova,[133] S. Todt,[50] M. Togawa,[84] J. Tojo,[89] S. Tokár,[28a] K. Tokushuku,[84]
O. Toldaiev,[68] R. Tombs,[32] M. Tomoto,[84,111] L. Tompkins,[143,u] K. W. Topolnicki,[86b] E. Torrence,[123]
H. Torres,[102,ee] E. Torró Pastor,[163] M. Toscani,[30] C. Tosciri,[39] M. Tost,[11] D. R. Tovey,[139] A. Traeet,[16]
I. S. Trandafir,[27b] T. Trefzger,[166] A. Tricoli,[29] I. M. Trigger,[156a] S. Trincaz-Duvoid,[127] D. A. Trischuk,[26]
B. Trocmé,[60] C. Troncon,[71a] L. Truong,[33c] M. Trzebinski,[87] A. Trzupek,[87] F. Tsai,[145] M. Tsai,[106]
A. Tsiamis,[152,bb] P. V. Tsiareshka,[37] S. Tsigaridas,[156a] A. Tsirigotis,[152,cc] V. Tsiskaridze,[155] E. G. Tskhadadze,[149a]
M. Tsopoulou,[152,bb] Y. Tsujikawa,[88] I. I. Tsukerman,[37] V. Tsulaia,[17a] S. Tsuno,[84] O. Tsur,[150] K. Tsuri,[118]
D. Tsybychev,[145] Y. Tu,[64b] A. Tudorache,[27b] V. Tudorache,[27b] A. N. Tuna,[36] S. Turchikhin,[57b,57a]
I. Turk Cakir,[3a] R. Turra,[71a] T. Turtuvshin,[38,ll] P. M. Tuts,[41] S. Tzamarias,[152,bb] P. Tzanis,[10] E. Tzovara,[100]
F. Ukegawa,[157] P. A. Ulloa Poblete,[137c,137b] E. N. Umaka,[29] G. Unal,[36] M. Unal,[11] A. Undrus,[29] G. Unel,[160]

J. Urban,[28b] P. Urquijo,[105] G. Usai,[8] R. Ushioda,[154] M. Usman,[108] Z. Uysal,[21b] L. Vacavant,[102] V. Vacek,[132] B. Vachon,[104] K. O. H. Vadla,[125] T. Vafeiadis,[36] A. Vaitkus,[96] C. Valderanis,[109] E. Valdes Santurio,[47a,47b] M. Valente,[156a] S. Valentinetti,[23b,23a] A. Valero,[163] E. Valiente Moreno,[163] A. Vallier,[102,ee] J. A. Valls Ferrer,[163] D. R. Van Arneman,[114] T. R. Van Daalen,[138] A. Van Der Graaf,[49] P. Van Gemmeren,[6] M. Van Rijnbach,[125,36] S. Van Stroud,[96] I. Van Vulpen,[114] M. Vanadia,[76a,76b] W. Vandelli,[36] M. Vandenbroucke,[135] E. R. Vandewall,[121] D. Vannicola,[151] L. Vannoli,[57b,57a] R. Vari,[75a] E. W. Varnes,[7] C. Varni,[17b] T. Varol,[148] D. Varouchas,[66] L. Varriale,[163] K. E. Varvell,[147] M. E. Vasile,[27b] L. Vaslin,[40] G. A. Vasquez,[165] A. Vasyukov,[38] F. Vazeille,[40] T. Vazquez Schroeder,[36] J. Veatch,[31] V. Vecchio,[101] M. J. Veen,[103] I. Veliscek,[126] L. M. Veloce,[155] F. Veloso,[130a,130c] S. Veneziano,[75a] A. Ventura,[70a,70b] S. Ventura Gonzalez,[135] A. Verbytskyi,[110] M. Verducci,[74a,74b] C. Vergis,[24] M. Verissimo De Araujo,[83b] W. Verkerke,[114] J. C. Vermeulen,[114] C. Vernieri,[143] M. Vessella,[103] M. C. Vetterli,[142,e] A. Vgenopoulos,[152,bb] N. Viaux Maira,[137f] T. Vickey,[139] O. E. Vickey Boeriu,[139] G. H. A. Viehhauser,[126] L. Vigani,[63b] M. Villa,[23b,23a] M. Villaplana Perez,[163] E. M. Villhauer,[52] E. Vilucchi,[53] M. G. Vincter,[34] G. S. Virdee,[20] A. Vishwakarma,[52] A. Visibile,[114] C. Vittori,[36] I. Vivarelli,[146] V. Vladimirov,[167] E. Voevodina,[110] F. Vogel,[109] P. Vokac,[132] Yu. Volkotrub,[86a] J. Von Ahnen,[48] E. Von Toerne,[24] B. Vormwald,[36] V. Vorobel,[133] K. Vorobev,[37] M. Vos,[163] K. Voss,[141] J. H. Vossebeld,[92] M. Vozak,[114] L. Vozdecky,[94] N. Vranjes,[15] M. Vranjes Milosavljevic,[15] M. Vreeswijk,[114] R. Vuillermet,[36] O. Vujinovic,[100] I. Vukotic,[39] S. Wada,[157] C. Wagner,[103] J. M. Wagner,[17a] W. Wagner,[171] S. Wahdan,[171] H. Wahlberg,[90] M. Wakida,[111] J. Walder,[134] R. Walker,[109] W. Walkowiak,[141] A. Wall,[128] T. Wamorkar,[6] A. Z. Wang,[170] C. Wang,[100] C. Wang,[62c] H. Wang,[17a] J. Wang,[64a] R.-J. Wang,[100] R. Wang,[61] R. Wang,[6] S. M. Wang,[148] S. Wang,[62b] T. Wang,[62a] W. T. Wang,[80] W. Wang,[14a] X. Wang,[14c] X. Wang,[162] X. Wang,[62c] Y. Wang,[62d] Y. Wang,[14c] Z. Wang,[106] Z. Wang,[62d,51,62c] Z. Wang,[106] A. Warburton,[104] R. J. Ward,[20] N. Warrack,[59] A. T. Watson,[20] H. Watson,[59] M. F. Watson,[20] E. Watton,[59,134] G. Watts,[138] B. M. Waugh,[96] C. Weber,[29] H. A. Weber,[18] M. S. Weber,[19] S. M. Weber,[63a] C. Wei,[62a] Y. Wei,[126] A. R. Weidberg,[126] E. J. Weik,[117] J. Weingarten,[49] M. Weirich,[100] C. Weiser,[54] C. J. Wells,[48] T. Wenaus,[29] B. Wendland,[49] T. Wengler,[36] N. S. Wenke,[110] N. Wermes,[24] M. Wessels,[63a] A. M. Wharton,[91] A. S. White,[61] A. White,[8] M. J. White,[1] D. Whiteson,[160] L. Wickremasinghe,[124] W. Wiedenmann,[170] C. Wiel,[50] M. Wielers,[134] C. Wiglesworth,[42] D. J. Wilbern,[120] H. G. Wilkens,[36] D. M. Williams,[41] H. H. Williams,[128] S. Williams,[32] S. Willocq,[103] B. J. Wilson,[101] P. J. Windischhofer,[39] F. I. Winkel,[30] F. Winklmeier,[123] B. T. Winter,[54] J. K. Winter,[101] M. Wittgen,[143] M. Wobisch,[97] Z. Wolffs,[114] J. Wollrath,[160] M. W. Wolter,[87] H. Wolters,[130a,130c] A. F. Wongel,[48] S. D. Worm,[48] B. K. Wosiek,[87] K. W. Woźniak,[87] S. Wozniewski,[55] K. Wraight,[59] C. Wu,[20] J. Wu,[14a,14e] M. Wu,[64a] M. Wu,[113] S. L. Wu,[170] X. Wu,[56] Y. Wu,[62a] Z. Wu,[135] J. Wuerzinger,[110,x] T. R. Wyatt,[101] B. M. Wynne,[52] S. Xella,[42] L. Xia,[14c] M. Xia,[14b] J. Xiang,[64c] M. Xie,[62a] X. Xie,[62a] S. Xin,[14a,14e] J. Xiong,[17a] D. Xu,[14a] H. Xu,[62a] L. Xu,[62a] R. Xu,[128] T. Xu,[106] Y. Xu,[14b] Z. Xu,[52] Z. Xu,[14a] B. Yabsley,[147] S. Yacoob,[33a] Y. Yamaguchi,[154] E. Yamashita,[153] H. Yamauchi,[157] T. Yamazaki,[17a] Y. Yamazaki,[85] J. Yan,[62c] S. Yan,[126] Z. Yan,[25] H. J. Yang,[62c,62d] H. T. Yang,[62a] S. Yang,[62a] T. Yang,[64c] X. Yang,[62a] X. Yang,[14a] Y. Yang,[44] Y. Yang,[62a] Z. Yang,[62a] W-M. Yao,[17a] Y. C. Yap,[48] H. Ye,[14c] H. Ye,[55] J. Ye,[14a] S. Ye,[29] X. Ye,[62a] Y. Yeh,[96] I. Yeletskikh,[38] B. K. Yeo,[17b] M. R. Yexley,[96] P. Yin,[41] K. Yorita,[168] S. Younas,[27b] C. J. S. Young,[36] C. Young,[143] Y. Yu,[62a] M. Yuan,[106] R. Yuan,[62b,mm] L. Yue,[96] M. Zaazoua,[62a] B. Zabinski,[87] E. Zaid,[52] T. Zakareishvili,[149b] N. Zakharchuk,[34] S. Zambito,[56] J. A. Zamora Saa,[137d,137b] J. Zang,[153] D. Zanzi,[54] O. Zaplatilek,[132] C. Zeitnitz,[171] H. Zeng,[14a] J. C. Zeng,[162] D. T. Zenger Jr.,[26] O. Zenin,[37] T. Ženiš,[28a] S. Zenz,[94] S. Zerradi,[35a] D. Zerwas,[66] M. Zhai,[14a,14e] B. Zhang,[14c] D. F. Zhang,[139] J. Zhang,[62b] J. Zhang,[6] K. Zhang,[14a,14e] L. Zhang,[14c] P. Zhang,[14a,14e] R. Zhang,[170] S. Zhang,[106] T. Zhang,[153] X. Zhang,[62c] X. Zhang,[62b] Y. Zhang,[62c,5] Y. Zhang,[96] Z. Zhang,[17a] Z. Zhang,[66] H. Zhao,[138] P. Zhao,[51] T. Zhao,[62b] Y. Zhao,[136] Z. Zhao,[62a] A. Zhemchugov,[38] J. Zheng,[14c] K. Zheng,[162] X. Zheng,[62a] Z. Zheng,[143] D. Zhong,[162] B. Zhou,[106] H. Zhou,[7] N. Zhou,[62c] Y. Zhou,[7] C. G. Zhu,[62b] J. Zhu,[106] Y. Zhu,[62c] Y. Zhu,[62a] X. Zhuang,[14a] K. Zhukov,[37] V. Zhulanov,[37] N. I. Zimine,[38] J. Zinsser,[63b] M. Ziolkowski,[141] L. Živković,[15] A. Zoccoli,[23b,23a] K. Zoch,[56] T. G. Zorbas,[139] O. Zormpa,[46] W. Zou,[41] and L. Zwalinski[36]

(ATLAS Collaboration)

[1]*Department of Physics, University of Adelaide, Adelaide, Australia*
[2]*Department of Physics, University of Alberta, Edmonton, Alberta, Canada*
[3a]*Department of Physics, Ankara University, Ankara, Türkiye*
[3b]*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, Illinois, USA*
[7]*Department of Physics, University of Arizona, Tucson, Arizona, USA*
[8]*Department of Physics, University of Texas at Arlington, Arlington, Texas, USA*
[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, Texas, USA*
[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*
[14a]*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China*
[14b]*Physics Department, Tsinghua University, Beijing, China*
[14c]*Department of Physics, Nanjing University, Nanjing, China*
[14d]*School of Science, Shenzhen Campus of Sun Yat-sen University, China*
[14e]*University of Chinese Academy of Science (UCAS), Beijing, China*
[15]*Institute of Physics, University of Belgrade, Belgrade, Serbia*
[16]*Department for Physics and Technology, University of Bergen, Bergen, Norway*
[17a]*Physics Division, Lawrence Berkeley National Laboratory, Berkeley, California, USA*
[17b]*University of California, Berkeley, California, USA*
[18]*Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany*
[19]*Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland*
[20]*School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom*
[21a]*Department of Physics, Bogazici University, Istanbul, Türkiye*
[21b]*Department of Physics Engineering, Gaziantep University, Gaziantep, Türkiye*
[21c]*Department of Physics, Istanbul University, Istanbul, Türkiye*
[22a]*Facultad de Ciencias y Centro de Investigaciónes, Universidad Antonio Nariño, Bogotá, Colombia*
[22b]*Departamento de Física, Universidad Nacional de Colombia, Bogotá, Colombia*
[23a]*Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna, Italy*
[23b]*INFN Sezione di Bologna, Italy*
[24]*Physikalisches Institut, Universität Bonn, Bonn, Germany*
[25]*Department of Physics, Boston University, Boston, Massachusetts, USA*
[26]*Department of Physics, Brandeis University, Waltham, Massachusetts, USA*
[27a]*Transilvania University of Brasov, Brasov, Romania*
[27b]*Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania*
[27c]*Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi, Romania*
[27d]*National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca, Romania*
[27e]*University Politehnica Bucharest, Bucharest, Romania*
[27f]*West University in Timisoara, Timisoara, Romania*
[27g]*Faculty of Physics, University of Bucharest, Bucharest, Romania*
[28a]*Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovak Republic*
[28b]*Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic*
[29]*Physics Department, Brookhaven National Laboratory, Upton, New York, USA*
[30]*Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Física, y CONICET, Instituto de Física de Buenos Aires (IFIBA), Buenos Aires, Argentina*
[31]*California State University, California, USA*
[32]*Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*
[33a]*Department of Physics, University of Cape Town, Cape Town, South Africa*
[33b]*iThemba Labs, Western Cape, South Africa*
[33c]*Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, South Africa*
[33d]*National Institute of Physics, University of the Philippines Diliman (Philippines), Philippines*
[33e]*University of South Africa, Department of Physics, Pretoria, South Africa*
[33f]*University of Zululand, KwaDlangezwa, South Africa*
[33g]*School of Physics, University of the Witwatersrand, Johannesburg, South Africa*
[34]*Department of Physics, Carleton University, Ottawa, Ontario, Canada*

[35a]Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca, Morocco
[35b]Faculté des Sciences, Université Ibn-Tofail, Kénitra, Morocco
[35c]Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Morocco
[35d]LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda, Morocco
[35e]Faculté des sciences, Université Mohammed V, Rabat, Morocco
[35f]Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir, Morocco
[36]CERN, Geneva, Switzerland
[37]Affiliated with an institute covered by a cooperation agreement with CERN
[38]Affiliated with an international laboratory covered by a cooperation agreement with CERN
[39]Enrico Fermi Institute, University of Chicago, Chicago, Illinois, USA
[40]LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand, France
[41]Nevis Laboratory, Columbia University, Irvington, New York, USA
[42]Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
[43a]Dipartimento di Fisica, Università della Calabria, Rende, Italy
[43b]INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Italy
[44]Physics Department, Southern Methodist University, Dallas, Texas, USA
[45]Physics Department, University of Texas at Dallas, Richardson, Texas, USA
[46]National Centre for Scientific Research "Demokritos", Agia Paraskevi, Greece
[47a]Department of Physics, Stockholm University, Sweden
[47b]Oskar Klein Centre, Stockholm, Sweden
[48]Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen, Germany
[49]Fakultät Physik, Technische Universität Dortmund, Dortmund, Germany
[50]Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany
[51]Department of Physics, Duke University, Durham, North Carolina, USA
[52]SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
[53]INFN e Laboratori Nazionali di Frascati, Frascati, Italy
[54]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany
[55]II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany
[56]Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland
[57a]Dipartimento di Fisica, Università di Genova, Genova, Italy
[57b]INFN Sezione di Genova, Italy
[58]II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
[59]SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
[60]LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble, France
[61]Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, Massachusetts, USA
[62a]Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, China
[62b]Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao, China
[62c]School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai, China
[62d]Tsung-Dao Lee Institute, Shanghai, China
[63a]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
[63b]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
[64a]Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China
[64b]Department of Physics, University of Hong Kong, Hong Kong, China
[64c]Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China
[65]Department of Physics, National Tsing Hua University, Hsinchu, Taiwan
[66]IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay, France
[67]Centro Nacional de Microelectrónica (IMB-CNM-CSIC), Barcelona, Spain
[68]Department of Physics, Indiana University, Bloomington, Indiana, USA
[69a]INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, Italy
[69b]ICTP, Trieste, Italy
[69c]Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine, Italy
[70a]INFN Sezione di Lecce, Italy
[70b]Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
[71a]INFN Sezione di Milano, Italy
[71b]Dipartimento di Fisica, Università di Milano, Milano, Italy

[72a]*INFN Sezione di Napoli, Italy*
[72b]*Dipartimento di Fisica, Università di Napoli, Napoli, Italy*
[73a]*INFN Sezione di Pavia, Italy*
[73b]*Dipartimento di Fisica, Università di Pavia, Pavia, Italy*
[74a]*INFN Sezione di Pisa, Italy*
[74b]*Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy*
[75a]*INFN Sezione di Roma, Italy*
[75b]*Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy*
[76a]*INFN Sezione di Roma Tor Vergata, Italy*
[76b]*Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy*
[77a]*INFN Sezione di Roma Tre, Italy*
[77b]*Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy*
[78a]*INFN-TIFPA, Italy*
[78b]*Università degli Studi di Trento, Trento, Italy*
[79]*Universität Innsbruck, Department of Astro and Particle Physics, Innsbruck, Austria*
[80]*University of Iowa, Iowa City, Iowa, USA*
[81]*Department of Physics and Astronomy, Iowa State University, Ames, Iowa, USA*
[82]*Istinye University, Sariyer, Istanbul, Türkiye*
[83a]*Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora, Brazil*
[83b]*Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil*
[83c]*Instituto de Física, Universidade de São Paulo, São Paulo, Brazil*
[83d]*Rio de Janeiro State University, Rio de Janeiro, Brazil*
[84]*KEK, High Energy Accelerator Research Organization, Tsukuba, Japan*
[85]*Graduate School of Science, Kobe University, Kobe, Japan*
[86a]*AGH University of Krakow, Faculty of Physics and Applied Computer Science, Krakow, Poland*
[86b]*Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland*
[87]*Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland*
[88]*Faculty of Science, Kyoto University, Kyoto, Japan*
[89]*Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka, Japan*
[90]*Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina*
[91]*Physics Department, Lancaster University, Lancaster, United Kingdom*
[92]*Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom*
[93]*Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia*
[94]*School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom*
[95]*Department of Physics, Royal Holloway University of London, Egham, United Kingdom*
[96]*Department of Physics and Astronomy, University College London, London, United Kingdom*
[97]*Louisiana Tech University, Ruston, Louisiana, USA*
[98]*Fysiska institutionen, Lunds universitet, Lund, Sweden*
[99]*Departamento de Física Teorica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid, Spain*
[100]*Institut für Physik, Universität Mainz, Mainz, Germany*
[101]*School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom*
[102]*CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France*
[103]*Department of Physics, University of Massachusetts, Amherst, Massachusetts, USA*
[104]*Department of Physics, McGill University, Montreal, Québec, Canada*
[105]*School of Physics, University of Melbourne, Victoria, Australia*
[106]*Department of Physics, University of Michigan, Ann Arbor, Michigan, USA*
[107]*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA*
[108]*Group of Particle Physics, University of Montreal, Montreal, Québec, Canada*
[109]*Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany*
[110]*Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany*
[111]*Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan*
[112]*Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico, USA*
[113]*Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen, Netherlands*
[114]*Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands*
[115]*Department of Physics, Northern Illinois University, DeKalb, Illinois, USA*
[116a]*New York University Abu Dhabi, Abu Dhabi, United Arab Emirates*
[116b]*University of Sharjah, Sharjah, United Arab Emirates*
[117]*Department of Physics, New York University, New York, New York, USA*
[118]*Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo, Japan*

[119]*Ohio State University, Columbus, Ohio, USA*
[120]*Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma, USA*
[121]*Department of Physics, Oklahoma State University, Stillwater, Oklahoma, USA*
[122]*Palacký University, Joint Laboratory of Optics, Olomouc, Czech Republic*
[123]*Institute for Fundamental Science, University of Oregon, Eugene, Oregon, USA*
[124]*Graduate School of Science, Osaka University, Osaka, Japan*
[125]*Department of Physics, University of Oslo, Oslo, Norway*
[126]*Department of Physics, Oxford University, Oxford, United Kingdom*
[127]*LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris, France*
[128]*Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania, USA*
[129]*Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania, USA*
[130a]*Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa, Portugal*
[130b]*Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal*
[130c]*Departamento de Física, Universidade de Coimbra, Coimbra, Portugal*
[130d]*Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal*
[130e]*Departamento de Física, Universidade do Minho, Braga, Portugal*
[130f]*Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain), Spain*
[130g]*Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal*
[131]*Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic*
[132]*Czech Technical University in Prague, Prague, Czech Republic*
[133]*Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic*
[134]*Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom*
[135]*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
[136]*Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, California, USA*
[137a]*Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile*
[137b]*Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago, Chile*
[137c]*Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, y Departamento de Física, Universidad de La Serena, Chile*
[137d]*Universidad Andres Bello, Department of Physics, Santiago, Chile*
[137e]*Instituto de Alta Investigación, Universidad de Tarapacá, Arica, Chile*
[137f]*Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile*
[138]*Department of Physics, University of Washington, Seattle, Washington State, USA*
[139]*Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom*
[140]*Department of Physics, Shinshu University, Nagano, Japan*
[141]*Department Physik, Universität Siegen, Siegen, Germany*
[142]*Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada*
[143]*SLAC National Accelerator Laboratory, Stanford, California, USA*
[144]*Department of Physics, Royal Institute of Technology, Stockholm, Sweden*
[145]*Departments of Physics and Astronomy, Stony Brook University, Stony Brook, New York, USA*
[146]*Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom*
[147]*School of Physics, University of Sydney, Sydney, Australia*
[148]*Institute of Physics, Academia Sinica, Taipei, Taiwan*
[149a]*E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia*
[149b]*High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia*
[149c]*University of Georgia, Tbilisi, Georgia*
[150]*Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel*
[151]*Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel*
[152]*Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*
[153]*International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan*
[154]*Department of Physics, Tokyo Institute of Technology, Tokyo, Japan*
[155]*Department of Physics, University of Toronto, Toronto, Ontario, Canada*
[156a]*TRIUMF, Vancouver, British Columbia, Canada*
[156b]*Department of Physics and Astronomy, York University, Toronto, Ontario, Canada*
[157]*Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan*
[158]*Department of Physics and Astronomy, Tufts University, Medford, Massachusetts, USA*
[159]*United Arab Emirates University, Al Ain, United Arab Emirates*
[160]*Department of Physics and Astronomy, University of California Irvine, Irvine, California, USA*
[161]*Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*
[162]*Department of Physics, University of Illinois, Urbana, Illinois, USA*
[163]*Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Valencia, Spain*

[164]*Department of Physics, University of British Columbia, Vancouver, British Columbia, Canada*
[165]*Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia, Canada*
[166]*Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany*
[167]*Department of Physics, University of Warwick, Coventry, United Kingdom*
[168]*Waseda University, Tokyo, Japan*
[169]*Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot, Israel*
[170]*Department of Physics, University of Wisconsin, Madison, Wisconsin, USA*
[171]*Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany*
[172]*Department of Physics, Yale University, New Haven, Connecticut, USA*

[a] Deceased.
[b] Also at Department of Physics, King's College London, London, United Kingdom.
[c] Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.
[d] Also at Lawrence Livermore National Laboratory, Livermore, USA.
[e] Also at TRIUMF, Vancouver, British Columbia, Canada.
[f] Also at Department of Physics, University of Thessaly, Greece.
[g] Also at An-Najah National University, Nablus, Palestine.
[h] Also at Department of Physics, University of Fribourg, Fribourg, Switzerland.
[i] Also at University of Colorado Boulder, Department of Physics, Colorado, USA.
[j] Also at Department of Physics, Westmont College, Santa Barbara, USA.
[k] Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona, Spain.
[l] Also at Affiliated with an institute covered by a cooperation agreement with CERN.
[m] Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing, China.
[n] Also at Department of Physics, Ben Gurion University of the Negev, Beer Sheva, Israel.
[o] Also at Università di Napoli Parthenope, Napoli, Italy.
[p] Also at Institute of Particle Physics (IPP), Canada.
[q] Also at Borough of Manhattan Community College, City University of New York, New York, New York, USA.
[r] Also at National Institute of Physics, University of the Philippines Diliman (Philippines), Philippines.
[s] Also at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece.
[t] Also at Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo, Japan.
[u] Also at Department of Physics, Stanford University, Stanford, California, USA.
[v] Also at Centro Studi e Ricerche Enrico Fermi, Italy.
[w] Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.
[x] Also at Technical University of Munich, Munich, Germany.
[y] Also at Yeditepe University, Physics Department, Istanbul, Türkiye.
[z] Also at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia.
[aa] Also at CERN, Geneva, Switzerland.
[bb] Also at Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki, Greece.
[cc] Also at Hellenic Open University, Patras, Greece.
[dd] Also at Center for High Energy Physics, Peking University, China.
[ee] Also at L2IT, Université de Toulouse, CNRS/IN2P3, UPS, Toulouse, France.
[ff] Also at Department of Physics, California State University, Sacramento, USA.
[gg] Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland.
[hh] Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria.
[ii] Also at Washington College, Chestertown, Maryland, USA.
[jj] Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.
[kk] Also at Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir, Morocco.
[ll] Also at Institute of Physics and Technology, Ulaanbaatar, Mongolia.
[mm] Also at Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA.
[nn] Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.