

PUBLISHED VERSION

G. Aad ... P. Jackson ... L. Lee ... A. Petridis ... N. Soni ... M. J. White ... et al. (ATLAS Collaboration)
Measurement of the centrality dependence of the charged particle pseudorapidity distribution in
lead-lead collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS detector
Physics Letters B, 2012; 710(3):363-382


© 2012 CERN. Published by Elsevier B.V. Open access under CC BY-NC-ND license.
[<https://creativecommons.org/licenses/by-nc-nd/4.0/>]

Originally published at:

<http://doi.org/10.1016/j.physletb.2012.02.045>

PERMISSIONS

<http://creativecommons.org/licenses/by-nc-nd/4.0/>




This is a human-readable summary of (and not a substitute for) the [license](#). [Disclaimer](#).


You are free to:


Share — copy and redistribute the material in any medium or format

The licensor cannot revoke these freedoms as long as you follow the license terms.

Under the following terms:

 **Attribution** — You must give [appropriate credit](#), provide a link to the license, and [indicate if changes were made](#). You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.

 **NonCommercial** — You may not use the material for [commercial purposes](#).

 **NoDerivatives** — If you [remix](#), [transform](#), or [build upon](#) the material, you may not distribute the modified material.

No additional restrictions — You may not apply legal terms or [technological measures](#) that legally restrict others from doing anything the license permits.

<http://hdl.handle.net/2440/101771>



Measurement of the centrality dependence of the charged particle pseudorapidity distribution in lead–lead collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS detector[☆]

ATLAS Collaboration^{*}

ARTICLE INFO

Article history:

Received 30 August 2011
 Received in revised form 6 February 2012
 Accepted 16 February 2012
 Available online 21 February 2012
 Editor: H. Weerts

ABSTRACT

The ATLAS experiment at the LHC has measured the centrality dependence of charged particle pseudorapidity distributions over $|\eta| < 2$ in lead–lead collisions at a nucleon–nucleon centre-of-mass energy of $\sqrt{s_{NN}} = 2.76$ TeV. In order to include particles with transverse momentum as low as 30 MeV, the data were recorded with the central solenoid magnet off. Charged particles were reconstructed with two algorithms (2-point “tracklets” and full tracks) using information from the pixel detector only. The lead–lead collision centrality was characterized by the total transverse energy in the forward calorimeter in the range $3.2 < |\eta| < 4.9$. Measurements are presented of the per-event charged particle pseudorapidity distribution, $dN_{ch}/d\eta$, and the average charged particle multiplicity in the pseudorapidity interval $|\eta| < 0.5$ in several intervals of collision centrality. The results are compared to previous mid-rapidity measurements at the LHC and RHIC. The variation of the mid-rapidity charged particle yield per colliding nucleon pair with the number of participants is consistent with lower $\sqrt{s_{NN}}$ results. The shape of the $dN_{ch}/d\eta$ distribution is found to be independent of centrality within the systematic uncertainties of the measurement.

© 2012 CERN. Published by Elsevier B.V. Open access under [CC BY-NC-ND license](http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

Collisions of lead (Pb) ions at the Large Hadron Collider provide an opportunity to study strongly interacting matter at the highest temperatures ever created in the laboratory [1]. Measurements of the centrality dependence of charged particle multiplicities and of charged particle pseudorapidity densities in such ultra-relativistic nucleus–nucleus (A+A) collisions provide essential information on the initial particle or entropy production and subsequent evolution in the created hot, dense matter. Results from the Relativistic Heavy Ion Collider (RHIC) over the centre-of-mass energy range from 19.6 to 200 GeV indicate that the multiplicity of charged particles per colliding nucleon pair has a mild dependence on the collision centrality and that the pseudorapidity dependence of the charged particle yield near mid-rapidity is essentially centrality independent [2]. The weak variation of the multiplicity per colliding nucleon pair with centrality at RHIC was initially found to be inconsistent with models such as HIJING [3] which includes a mixture of soft and hard scattering processes with a p_T cutoff on the hard scattering contribution at 2 GeV, or with a beam-energy-dependent cutoff in a more recent version [4]. In contrast, calculations based on parton saturation invoking k_T factorization were able to reproduce both the shape and centrality dependence of the RHIC charged particle pseudorapidity distributions [5,6]. How-

ever, more recent theoretical studies indicate that k_T factorization may not be applicable to nucleus–nucleus collisions, and improved soft + hard models may be able to describe RHIC multiplicity measurements. At the same time, older hydrodynamical models (e.g. Ref. [7]) have had some success describing the energy dependence of the total multiplicity as well as rapidity distributions of identified hadrons, although their domain of applicability is still not fully established.

Detailed measurements of the centrality dependence of charged particle multiplicities and pseudorapidity distributions at the LHC together with the earlier RHIC measurements could provide essential insight on the physics responsible for bulk particle production in ultra-relativistic nuclear collisions. Because hard scattering rates increase rapidly with centrality and $\sqrt{s_{NN}}$, the combined RHIC and LHC measurements should provide a strong constraint on the contribution of hard scattering processes to inclusive hadron production subject to uncertainties regarding the shadowing of nuclear parton distributions at low x . Measurements at the LHC can also provide a valuable test of recent parton saturation calculations that still claim to be able to describe inclusive particle production in ultra-relativistic nuclear collisions [5,6]. Previous measurements at the LHC [8,9] have already started addressing some of the physics raised above. In particular, those earlier measurements found a rapid rise in the particle multiplicity at the LHC compared to naive extrapolations of RHIC measurements and a variation of mid-rapidity charged particle multiplicity with centrality similar to that observed at RHIC.

[☆] © CERN for the benefit of the ATLAS Collaboration.

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

This Letter presents the results of ATLAS [10] measurements of the per-event charged particle pseudorapidity distribution, $dN_{\text{ch}}/d\eta$, in $\sqrt{s_{\text{NN}}} = 2.76$ TeV Pb + Pb collisions over $|\eta| < 2$ and as a function of collision centrality with the goal of testing and extending the results of the previous LHC measurements. In this Letter, N_{ch} denotes the per-event number of charged primary particles measured in an interval of η , which is the particle pseudorapidity.¹ The measurement was performed with the solenoid off, thereby allowing detection of charged particles down to very low transverse momenta ($p_{\text{T}} \sim 30$ MeV).

2. Experimental setup and event selection

The measurements presented here were obtained using the ATLAS inner detector [11] which contains both silicon pixel and silicon strip detectors and the ATLAS forward calorimeters. The charged particle multiplicity is measured using the pixel detector [12] which consists of three layers of pixel staves in the barrel region, inclined at an angle of 20° , at radii of 50.5, 88.5, and 122.5 mm from the nominal beam axis. The typical pixel size is $50 \mu\text{m} \times 400 \mu\text{m}$ in ϕ - z , and an average occupancy of about 0.5% is observed for the innermost pixel layer in central Pb + Pb collisions. To limit low- p_{T} multiple scattering losses in detector material, the measurement has been restricted to the barrel portion of the pixel detector, corresponding to pseudorapidity values in the range $|\eta| < 2$. Collision vertex positions were obtained by full reconstruction of nominally straight charged particle trajectories in the pixel and silicon strip detectors followed by reconstruction of a single collision vertex from the full set of particle trajectories. To maintain uniform acceptance of the pixel detector for the multiplicity measurement the vertex was required to lie within 50 mm of the nominal centre of the ATLAS detector in the longitudinal direction.

The data for the measurements presented here were collected with a minimum-bias trigger. This required a coincidence in either the two minimum-bias trigger scintillator (MBTS) detectors, located at ± 3.56 m from the interaction centre and covering $2.1 < |\eta| < 3.9$, or two zero-degree calorimeters (ZDCs), located at ± 140 m from the interaction centre and covering $|\eta| > 8.3$. The threshold on the analog energy sum in each ZDC was set below the single neutron peak. The offline analysis required the time difference between the two MBTS detectors to be $|\Delta t| < 3$ ns to eliminate upstream beam-gas interactions, a ZDC coincidence to efficiently reject photo-nuclear events [13], and a reconstructed vertex satisfying the selection described above. The measurements presented in this Letter were obtained from a 10 hour data-taking run corresponding to an integrated luminosity of approximately 480 mb^{-1} . A total of 1631 525 events passed the trigger, vertex, and offline selections.

3. Centrality

In heavy ion collisions, “centrality” reflects the overlap volume of the two colliding nuclei, controlled by the classical impact parameter. That overlap volume is closely related to the number of “participants”, the nucleons which scatter inelastically in each nuclear collision. While the number of participants, N_{part} , cannot be measured for a single collision, previous studies at RHIC and the SPS have demonstrated that the multiplicity and transverse en-

ergy of the produced particles are strongly correlated with N_{part} . Because of this, the average number of participants can be accurately estimated from a selected fraction of the multiplicity or transverse energy distribution [14]. In ATLAS, the Pb + Pb collision centrality is measured using the summed transverse energy ($\sum E_{\text{T}}$) in the forward calorimeter (FCal) over the pseudorapidity range $3.2 < |\eta| < 4.9$, calibrated at the electromagnetic energy scale. An analysis of the FCal $\sum E_{\text{T}}$ distribution after application of all trigger and selection requirements gives an estimate of the fraction of the sampled non-Coulomb inelastic cross section of $f = 98 \pm 2\%$. This estimate was derived from comparisons of the measured FCal $\sum E_{\text{T}}$ distribution with a simulated $\sum E_{\text{T}}$ distribution. The simulated distribution was obtained from a convolution of $\sqrt{s} = 2.76$ TeV proton-proton data with a Monte Carlo (MC) Glauber calculation [14,15] of the number of effective nucleon-nucleon collisions. This quantity was calculated as a linear combination of the number of participants and the number of binary collisions, similar to what was done in a previous analysis [16]. The value of f and its uncertainty was estimated by systematically varying the effect of trigger and event selection inefficiencies as well as backgrounds in the most peripheral $\sum E_{\text{T}}$ interval. This was done by artificially injecting and removing counts in that interval in order to achieve the best agreement between the measured and simulated distributions. The estimate of f was made after removal of a 1% background contamination in the most peripheral events that was evaluated using comparisons of solenoid magnet-on and solenoid magnet-off data and which was attributed to photo-nuclear events.

For the results presented in this Letter, the minimum-bias FCal $\sum E_{\text{T}}$ distribution was divided into centrality intervals according to the following percentiles: 10% intervals over 0–80%, 5% intervals over 20–80% and 2% intervals over 0–20%. By convention, the 0–10% centrality interval refers to the 10% most central events – the events with the highest $\sum E_{\text{T}}$ values – and increasing percentiles refer to events with successively lower $\sum E_{\text{T}}$. The average number of participants, $\langle N_{\text{part}} \rangle$, was evaluated for each of the experimental centrality intervals by dividing the Glauber model $\sum E_{\text{T}}$ distribution into the same percentile centrality intervals used for the data and evaluating the average number of participants of the Glauber MC events contributing to a given interval. This procedure incorporates more realistic fluctuations into the estimation of $\langle N_{\text{part}} \rangle$ than would be achieved by binning in either N_{part} itself or in the classical impact parameter. The systematic errors on $\langle N_{\text{part}} \rangle$ were evaluated from the quoted uncertainty on f and the known uncertainties in the nuclear density parameters as well as the assumed total inelastic nucleon-nucleon cross section of $\sigma_{\text{NN}} = 64 \pm 5$ mb [17].

4. Reconstruction of charged particle multiplicity

In the offline analysis, adjacent hits in the pixel modules were grouped into clusters using standard techniques. Two methods were, then, used to reconstruct charged particles from the pixel clusters. In one method, a Kalman Filter-based tracking algorithm, similar to that deployed in proton-proton collisions [18], was applied only to the pixel layers (“pixel tracks”). The other method, the “two-point tracklet” algorithm, used the reconstructed primary vertex and clusters on the first pixel layer to define a search region for clusters in the second layer consistent with a nominally straight track. Candidate tracklets were required to have deviations between projected and measured cluster positions in the second pixel layer in pseudorapidity and azimuth, $\Delta\eta$ and $\Delta\phi$, respectively, satisfying

$$\Delta\mathcal{R} \equiv \frac{1}{\sqrt{2}} \sqrt{\left(\frac{\Delta\eta}{\sigma_{\eta}(\eta)}\right)^2 + \left(\frac{\Delta\phi}{\sigma_{\phi}(\eta)}\right)^2} < 3. \quad (1)$$

¹ ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z -axis along the beam pipe. The x -axis points from the IP to the centre of the LHC ring, and the y axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$.

The widths of the $\Delta\eta$ and $\Delta\phi$ distributions characterized by the pseudorapidity-dependent resolutions $\sigma_\eta(\eta)$ and $\sigma_\phi(\eta)$ were obtained from the MC simulations described below. The η and ϕ values of the reconstructed tracklets were determined using the cluster position on the first layer and the primary vertex position. The two-point tracklet analysis excluded clusters with low energy deposits inconsistent with minimum-ionizing particles originating at the primary vertex. It also excluded duplicate clusters resulting from the overlap of the pixel modules in ϕ and from a small set of pixels at the centres of the pixel modules that share readout channels [12].

The high charged particle multiplicity in Pb + Pb collisions can generate misidentified tracks and/or two-point tracklets when only two or three measurements are made on each trajectory. The misidentified contributions have been evaluated using the MC studies described below, but to check the MC results, an independent, data-driven estimate of misidentified two-point tracklets was obtained using a variant of the two-point tracklet algorithm. In the default two-point tracklet analysis, referred to as “Method 1”, at most one tracklet was reconstructed for a given cluster on the first pixel layer. If multiple clusters on the second pixel layer fell within the search region defined in Eq. (1), the closest cluster to the projected position was chosen. This method limits, but does not eliminate, the generation of misidentified tracklets. A second implementation of the two-point tracklet algorithm, referred to as “Method 2”, produced tracklets for all combinations of clusters on the two layers consistent with the search region. Using Method 2, the rate of false tracklets resulting from random combinations of clusters was estimated by performing the same analysis but with the clusters on the second layer having their z positions inverted around the primary vertex and their azimuthal angles inverted, $\phi \rightarrow \pi - \phi$. The tracklet yield from this “flipped” analysis was then subtracted from the proper tracklet yield event-by-event to obtain the estimated yield of true tracklets,

$$N_{2p}(\eta) = N_{2p}^{\text{ev}}(\eta) - N_{2p}^{\text{fl}}(\eta), \quad (2)$$

where N_{2p}^{ev} represents the yield of two-point tracklets using Method 2 and N_{2p}^{fl} represents the yield obtained by flipping the clusters in the second pixel layer. For the 0–10% centrality interval, the flipped yield is about 50% of the unflipped yield in the $|\eta| < 0.5$ region.

The response of the detector to the charged particles produced in Pb + Pb collisions and the performance of the track and tracklet methods was evaluated by MC simulations of Pb + Pb collisions using the HIJING [3] event generator followed by GEANT4 [19] simulations of the detector response [20]. The resulting events were then reconstructed and analyzed using the full offline analysis chain that was applied to the experimental data. HIJING events were generated without jet quenching and with an unbiased impact parameter distribution. Impact parameter and p_T -dependent elliptic flow was imposed on the HIJING events after generation and prior to simulation. The GEANT4 detector geometry included a distribution of disabled pixel modules matching that in the experiment. The MC events were used to derive correction factors from reconstructed pixel tracks and two-point tracklets to the primary HIJING particles. Primary particles were defined to be either particles originating directly from the Pb + Pb collision or particles resulting from secondary decays of HIJING produced particles with lifetimes $c\tau < 1$ cm.

From the MC simulated events, correction factors accounting for particle detection efficiency, misidentified tracks or tracklets from unrelated clusters, and extra tracks or tracklets from secondary decays or from interactions in the detector were calculated. The correction factors were evaluated in 20 intervals of detector

occupancy (\mathcal{O}) parameterized using the number of reconstructed clusters in the first pixel layer in the region $|\eta| < 1$. Different corrections were applied to the pixel track and both two-point tracklet measurements. For the pixel tracks, the efficiency, ε_{pt} , for reconstructing tracks associated with charged primary particles was obtained from

$$\varepsilon_{\text{pt}}(\mathcal{O}, \eta) \equiv \frac{N_{\text{pr}}^{\text{match}}(\mathcal{O}, \eta)}{N_{\text{pr}}(\mathcal{O}, \eta)}, \quad (3)$$

where N_{pr} represents the number of charged primary particles produced by HIJING within a given η interval, and $N_{\text{pr}}^{\text{match}}$ represents the portion of those primary particles matched to reconstructed pixel tracks. The contributions to the number of reconstructed pixel tracks (N_{pt}) from “background” sources were separately evaluated to produce a “background” fraction

$$b_{\text{pt}}(\mathcal{O}, \eta) \equiv \frac{N_{\text{pt}}^{\text{backg}}(\mathcal{O}, \eta)}{N_{\text{pt}}(\mathcal{O}, \eta)}, \quad (4)$$

where $N_{\text{pt}}^{\text{backg}}$ represents the number of tracklets from secondary interactions and decays, from particles initially produced outside the kinematic acceptance of the measurement but scattering into it, and from combinations of clusters not associated with any primary or secondary particle in the GEANT4 simulation. This factor was combined with $\varepsilon_{\text{pt}}(\mathcal{O}, \eta)$ to produce a correction factor

$$C_{\text{pt}}(\mathcal{O}, \eta) \equiv \frac{1}{\varepsilon_{\text{pt}}(\mathcal{O}, \eta)} (1 - b_{\text{pt}}(\mathcal{O}, \eta)). \quad (5)$$

For the 0–10% centrality interval, ε_{pt} is about 0.55 and b_{pt} is about 0.02 in the mid-rapidity region, giving a C_{pt} of about 1.8.

For the two-point tracklet methods, a single multiplicative correction factor was obtained from the MC simulations,

$$C_{2p}(\mathcal{O}, \eta) \equiv \frac{N_{\text{pr}}(\mathcal{O}, \eta)}{N_{2p}(\mathcal{O}, \eta)}, \quad (6)$$

where $N_{2p}(\mathcal{O}, \eta)$ represents reconstructed tracklets. For the two-point tracklet Method 2, $N_{2p}(\mathcal{O}, \eta)$ was obtained from the MC events via Eq. (2) using the same flipping procedure as that applied in the data. For the 0–10% centrality interval, the correction factor is about 1.05 for Method 1 and 1.25 for Method 2 in the mid-rapidity region.

The Pb + Pb charged particle p_T spectrum measured at $\sqrt{s_{\text{NN}}} = 2.76$ TeV [21] differs from the spectrum generated by HIJING at low and high p_T , with the generator exceeding the data by 20% at $p_T = 500$ MeV, and underpredicting the charged particle yield by a factor of about two at $p_T = 1.5$ GeV. Because the MC corrections are applied to the data in matching \mathcal{O} intervals, the mismatch in the spectrum does not influence the corrections for misidentified tracks or occupancy-induced inefficiencies. However, if left uncorrected the mismatch could distort the p_T -weighted single track or tracklet efficiencies in the calculated correction factors. To avoid this distortion a p_T -dependent weight was applied to the generated particles and to tracklets or tracks that match generated particles in Eqs. (3)–(6). The p_T -dependent weights were obtained using an iterative procedure that, in each analyzed centrality interval, optimally matched the p_T spectrum of pixel tracks in Pb + Pb data with the solenoid magnet turned-on to the reweighted spectrum produced from a separate sample of HIJING + GEANT4 simulations also performed with the solenoid turned-on. Distributions of $\Delta\eta$ and $\Delta\phi$ for candidate tracklets are shown in Fig. 1 for two different pseudorapidity intervals, $|\eta| < 1$ and $1 < |\eta| < 2$. The corresponding distributions for the reweighted HIJING + GEANT4 events are also shown in the figure and compare well with the data. The max-

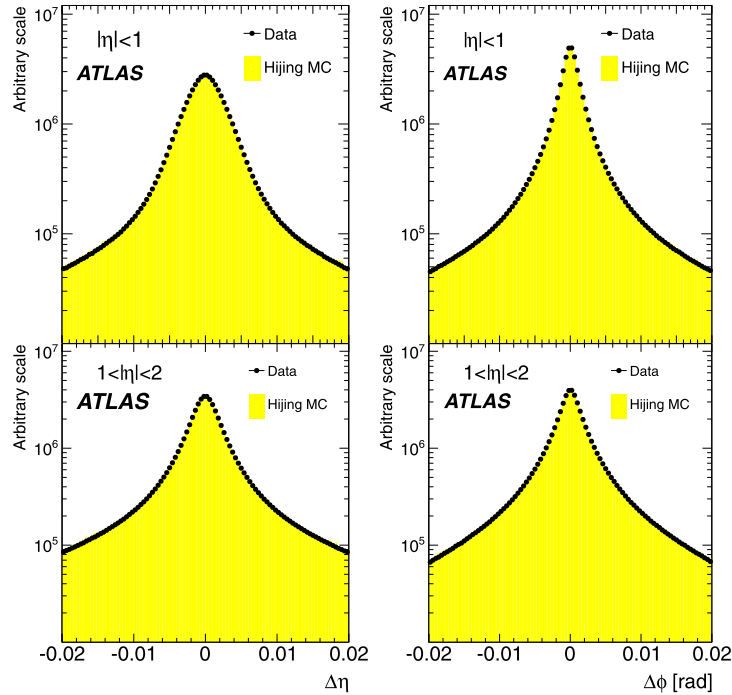


Fig. 1. Tracklet candidate $\Delta\eta$ (left) and $\Delta\phi$ (right) distributions from data (histogram) and reweighted MC (shaded region) for Pb + Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The top panels correspond to $|\eta| < 1$ and the bottom panels correspond to $1 < |\eta| < 2$. Data and MC distributions are normalized to the same area.

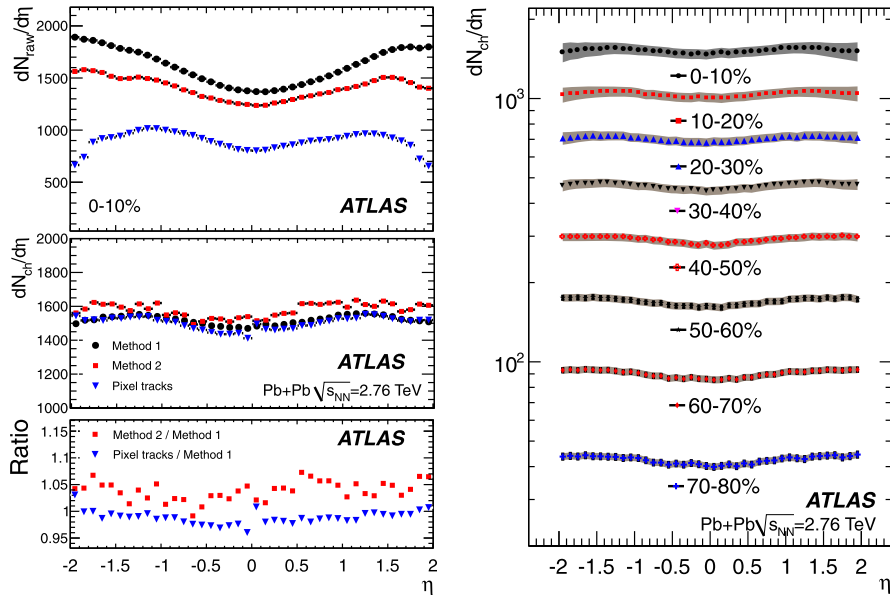


Fig. 2. Left: Top: uncorrected track/tracklet $dN_{raw}/d\eta$ distribution from tracklet Method 1 (points), tracklet Method 2 (squares) and pixel tracking (blue triangles) for 0–10% centrality events. Middle: corrected tracklet and track $dN_{ch}/d\eta$ distributions. Bottom: ratio of $dN_{ch}/d\eta$ from the tracklet Method 2 (squares) and pixel tracking (triangles) to tracklet Method 1. Right: $dN_{ch}/d\eta$ distributions from tracklet Method 1 for eight 10% centrality intervals. The statistical errors are shown as bars and the systematic errors are shown as shaded bands. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this Letter.)

imum difference between data and MC is less than 5%. It should be noted that the $\sigma_\eta(\eta)$ and $\sigma_\phi(\eta)$ mentioned above are evaluated using the unreweighted MC, but they are applied consistently to data and reweighted MC when calculating all η -dependent corrections.

Uncorrected pixel track and two-point tracklet pseudorapidity distributions for 0–10% centrality collisions are shown in the top left panel of Fig. 2. The corrections described above are applied to obtain corrected, per-event primary charged particle pseudorapidity distributions, averaged over the events in each centrality bin

(c), according to

$$\left. \frac{dN_{ch}}{d\eta} \right|_c = \frac{1}{N_{evt}} \sum_{events,c} \frac{\Delta N_{raw}}{\Delta\eta} C(\mathcal{O}, \eta), \quad (7)$$

where ΔN_{raw} indicates either the number of reconstructed pixel tracklets or two-point tracklets and $C(\mathcal{O}, \eta)$ indicates the η -dependent correction factors corresponding to the occupancy bin for each event. The corrected $dN_{ch}/d\eta$ distributions for the 0–10% centrality interval are shown in the middle left panel of Fig. 2. The

bottom left panel of Fig. 2 shows the ratio of the pixel tracking and two-point tracklet Method 2 results to the two-point tracklet Method 1 results. In spite of the factor of ~ 2 differences between the raw yields for the three reconstruction methods, the corrected pseudorapidity distributions for central collisions agree within 5%. The measurements presented in the remainder of this Letter were obtained from tracklet Method 1, which has the highest reconstruction efficiency, only a moderate contribution of misidentified tracklets, and the smallest correction factors. The resulting corrected $dN_{\text{ch}}/d\eta$ distributions are shown for 8 centrality intervals in the right-hand panel of Fig. 2.

5. Systematic uncertainties

Various studies were performed to quantify the experimental uncertainties on the $dN_{\text{ch}}/d\eta$ measurement. To address inaccuracies in the MC description of bad channels, disabled sensors, or other small instrumental problems, a comparison was made of unit-normalized η and ϕ distributions of clusters in each of the first two pixel layers between data and MC. The agreement between the η and ϕ distributions was found to be better than 0.05% and 0.4% in the first and second layers, respectively. Therefore, a combined systematic uncertainty of 0.4% is assigned to account for potential MC inaccuracies. To evaluate the impact of inaccuracies in the description of the detector material in the GEANT4 simulation, a separate set of HIJING+GEANT4 simulations was performed with an artificial 10% increase in detector material and a 15–20% increase in material in various non-instrumented regions. The results obtained using correction factors from this “extra material” sample agree with those obtained using the default corrections to better than 2%. Furthermore, the analysis was repeated using a different $\Delta\mathcal{R}$ selection (see Eq. (1)), $\Delta\mathcal{R} < 1.5$, which should have a different sensitivity to multiple scattering, secondaries, and occupancy effects. The corrections for the $\Delta\mathcal{R} < 1.5$ selection differ from those of the default analysis in central (0–10%) collisions by 10% at $\eta = 0$ and 20% at $\eta = 2$. However, the corrected pseudorapidity distributions agree to 1% in all centrality intervals. To address differences between the HIJING description of particle production in Pb + Pb collisions and reality, the analysis was performed without the p_T spectrum re-weighting; the results agree with those obtained using the re-weighting within 0.5%. To address potential errors resulting from discrepancies in particle composition between data and MC, the changes in correction factors that would result from enhanced charged kaon and proton production as observed at RHIC [22] have been evaluated. From the impact of the modified corrections on the final result, a 1% systematic uncertainty due to incomplete knowledge of the hadron composition is assigned. To further test the sensitivity of the results to the use of the HIJING generator, a set of MC simulations using the HYDJET event generator [23] was produced, and a separate set of correction factors was obtained from this MC sample. HYDJET has a more complete description of soft particle production than HIJING, including a description of elliptic flow, and the version used here was tuned to have much lower multiplicities than found in HIJING. In central collisions, the results obtained using the HYDJET-based corrections agree with the HIJING-based results to better than 0.5% at mid-rapidity, but differ by as much as 7.5% at $\eta = \pm 2$. A centrality-dependent and η -dependent systematic error is assigned to account for this difference. To address the inaccuracies from the analysis procedure, a systematic uncertainty is assigned based on the differences between the results obtained from the three reconstruction methods described in this Letter. That uncertainty is centrality-dependent and maximal for the 0–10% centrality interval for which a 3.5% uncertainty on the overall scale of the pseudorapidity distribution is assigned based on the comparison of

Table 1

Summary of the various sources of systematic uncertainties and their estimated impact on the $dN_{\text{ch}}/d\eta$ measurement in central (0–10%) and peripheral (70–80%) Pb + Pb collisions. Only the uncertainty due to the choice of the event generator is η -dependent.

Source	Uncertainty (0–10%)	(70–80%)
MC detector description	0.4%	0.4%
Extra material	2%	2%
$\Delta\mathcal{R}$ cut	1%	1%
p_T re-weighting	0.5%	0.5%
Hadron composition	1%	1%
Enhanced K_s, Λ	1%	1%
HYDJET	0.5–7.5% vs. η	0%
Analysis method	3.5%	1%
Combined ($\eta = 0$)	4%	3%
Combined ($\eta = 2$)	8.5%	3%

the three results in the left, bottom panel of Fig. 2. The systematic uncertainties described above are summarized in Table 1 for the most central (0–10%) and the most peripheral (70–80%) intervals. The total systematic uncertainties are shown as shaded bands in the right panel of Fig. 2.

6. Results

The measured charged particle $dN_{\text{ch}}/d\eta$ shown in Fig. 2, increases rapidly with collision centrality for all η . It is conventional to characterize particle production in nucleus–nucleus collisions by the mid-rapidity $dN_{\text{ch}}/d\eta$, $dN_{\text{ch}}/d\eta|_{\eta=0}$, which here is defined to be $dN_{\text{ch}}/d\eta$ averaged over $|\eta| < 0.5$. The analysis presented in this Letter yields $dN_{\text{ch}}/d\eta|_{\eta=0}$ values in central collisions of $1479 \pm 10(\text{stat.}) \pm 63(\text{syst.})$, $1598 \pm 11(\text{stat.}) \pm 68(\text{syst.})$, and $1738 \pm 12(\text{stat.}) \pm 75(\text{syst.})$ for the 0–10%, 0–6%, and 0–2% centrality intervals, respectively. Table 2 provides results of the $dN_{\text{ch}}/d\eta|_{\eta=0}$ measurements for all centrality bins.

The top panel of Fig. 3 compares the ATLAS measurement to the previously reported ALICE [8] and CMS [9] results for $|\eta| < 0.5$ for the 0–5% centrality interval in terms of $dN_{\text{ch}}/d\eta|_{\eta=0}$ per colliding nucleon pair, $dN_{\text{ch}}/d\eta|_{\eta=0}/(\langle N_{\text{part}} \rangle/2)$, and to other A + A measurements at different $\sqrt{s_{\text{NN}}}$ (see [2], which includes data from Refs. [24–29]). The ALICE and CMS 0–5% centrality measurements agree with the result reported here for the 0–6% centrality interval, $8.5 \pm 0.1(\text{stat.}) \pm 0.4(\text{syst.})$, within the quoted errors. The LHC results show that the multiplicity in central A + A collisions rises rapidly with $\sqrt{s_{\text{NN}}}$ above the RHIC top energy of $\sqrt{s_{\text{NN}}} = 200$ GeV. The three curves shown in Fig. 3 indicate possible variations of $dN_{\text{ch}}/d\eta|_{\eta=0}/(\langle N_{\text{part}} \rangle/2)$ with $\sqrt{s_{\text{NN}}}$. The dotted curve describes a $\sqrt{s_{\text{NN}}}$ dependence expected from Landau hydrodynamics [7]. It is clearly inconsistent with the data. The dot-dashed curve represents a logarithmic extrapolation of RHIC and SPS data [30] that is also excluded by the measurement presented in this Letter and by the ALICE and CMS measurements. The dashed curve shows an $s^{0.15}$ dependence suggested by ALICE [8] that is consistent with the ATLAS measurement. Also shown in the top panel in Fig. 3 are results from p + p and $\bar{p} + p$ measurements at different \sqrt{s} ([2] and references therein, as well as [31–35]). The excess of $dN_{\text{ch}}/d\eta|_{\eta=0}/(\langle N_{\text{part}} \rangle/2)$ in A + A collisions over p + p collisions observed at RHIC persists and is proportionately larger at the higher $\sqrt{s_{\text{NN}}}$ values of the LHC.

The bottom panel of Fig. 3 shows $dN_{\text{ch}}/d\eta|_{\eta=0}/(\langle N_{\text{part}} \rangle/2)$ as a function of $\langle N_{\text{part}} \rangle$ for 2% centrality intervals over 0–20%, and 5% centrality intervals over 20–80%. The values are also reported in Table 2. A moderate variation of $dN_{\text{ch}}/d\eta|_{\eta=0}/(\langle N_{\text{part}} \rangle/2)$ with $\langle N_{\text{part}} \rangle$ is observed, from a value of $4.6 \pm 0.1(\text{stat.}) \pm 0.6(\text{syst.})$ at $\langle N_{\text{part}} \rangle = 12.3$ (centrality 75–80%) to $8.8 \pm 0.1(\text{stat.}) \pm$

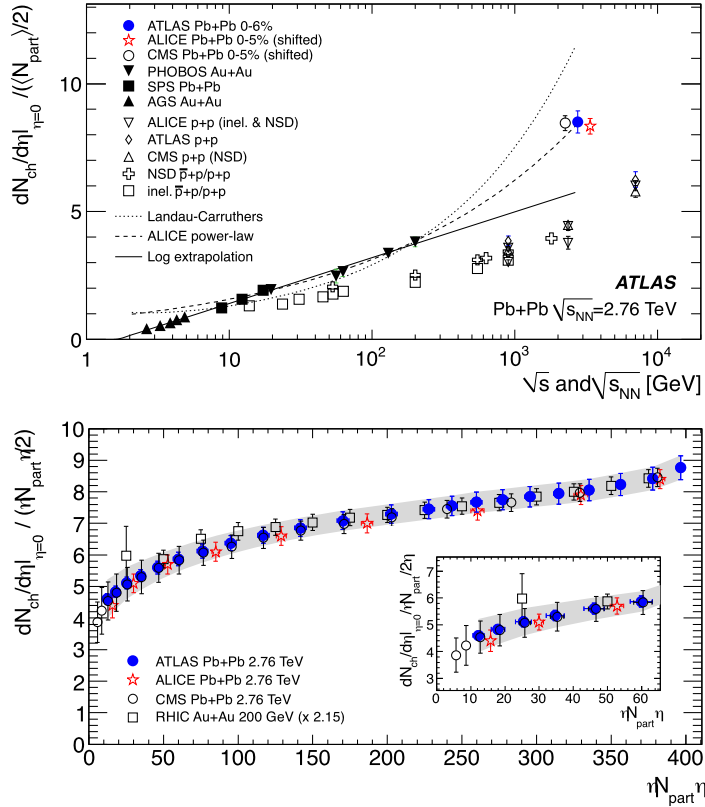


Fig. 3. Top: $\sqrt{s_{NN}}$ dependence of the charged particle $dN_{ch}/d\eta$ per colliding nucleon pair $dN_{ch}/d\eta|_{\eta=0}/(\langle N_{part} \rangle/2)$ from a variety of measurements in p + p and \bar{p} + p (inelastic and non-single diffractive results from [2] and references therein, as well as [31–35]) and central A + A collisions, including the ATLAS 0–6% centrality measurement reported here for $|\eta| < 0.5$ and the previous 0–5% centrality ALICE [8] and CMS [9] measurements (points shifted horizontally for clarity). The curves show different expectations for the $\sqrt{s_{NN}}$ dependence in A + A collisions: results of a Landau hydrodynamics calculation [7] (dotted line), an $s^{0.15}$ extrapolation of RHIC and SPS data proposed by ALICE [8] (dashed line), a logarithmic extrapolation of RHIC and SPS data from [30] (solid line). Bottom: $dN_{ch}/d\eta|_{\eta=0}/(\langle N_{part} \rangle/2)$ vs $\langle N_{part} \rangle$ for 2% centrality intervals over 0–20% and 5% centrality intervals over 20–80%. Error bars represent combined statistical and systematic uncertainties on the $dN_{ch}/d\eta|_{\eta=0}$ measurements, whereas the shaded band indicates the total systematic uncertainty including $\langle N_{part} \rangle$ uncertainties. The RHIC measurements (see text) have been multiplied by 2.15 to allow comparison with the $\sqrt{s_{NN}} = 2.76$ TeV results. The inset shows the $\langle N_{part} \rangle < 60$ region in more detail.

Table 2

Tabulation of measurements of $dN_{ch}/d\eta|_{\eta=0}$ evaluated over $|\eta| < 0.5$ and $dN_{ch}/d\eta|_{\eta=0}/(\langle N_{part} \rangle/2)$ for the full set of centrality bins considered in the analysis and shown in Fig. 3. The uncertainties on $dN_{ch}/d\eta|_{\eta=0}$ include statistical and systematic errors on the multiplicity measurement. The errors reported for $dN_{ch}/d\eta|_{\eta=0}/(\langle N_{part} \rangle/2)$ also include systematic uncertainties on the centrality selection and $\langle N_{part} \rangle$ determination.

Centrality	$\langle N_{part} \rangle$	$dN_{ch}/d\eta _{\eta=0}$	$dN_{ch}/d\eta _{\eta=0}/(\langle N_{part} \rangle/2)$
0–2%	396 ± 2	1738 ± 76	8.8 ± 0.4
2–4%	378 ± 2	1591 ± 67	8.4 ± 0.4
4–6%	356 ± 3	1467 ± 63	8.2 ± 0.4
6–8%	335 ± 3	1350 ± 57	8.1 ± 0.4
8–10%	315 ± 3	1250 ± 53	8.0 ± 0.3
10–12%	296 ± 3	1159 ± 48	7.8 ± 0.3
12–14%	277 ± 4	1074 ± 44	7.8 ± 0.3
14–16%	260 ± 4	996 ± 41	7.7 ± 0.3
16–18%	243 ± 4	918 ± 37	7.6 ± 0.3
18–20%	228 ± 4	849 ± 34	7.5 ± 0.3
20–25%	203 ± 4	739 ± 29	7.3 ± 0.3
25–30%	170 ± 4	603 ± 24	7.1 ± 0.3
30–35%	142 ± 4	486 ± 19	6.9 ± 0.3
35–40%	117 ± 4	387 ± 15	6.6 ± 0.3
40–45%	95.0 ± 3.7	303 ± 11	6.4 ± 0.3
45–50%	76.1 ± 3.5	233 ± 9	6.1 ± 0.4
50–55%	59.9 ± 3.3	176 ± 6	5.9 ± 0.4
55–60%	46.1 ± 3.0	129 ± 5	5.7 ± 0.4
60–65%	34.7 ± 2.7	93 ± 3	5.3 ± 0.5
65–70%	25.4 ± 2.3	65 ± 2	5.1 ± 0.5
70–75%	18.0 ± 2.0	43 ± 2	4.8 ± 0.6
75–80%	12.3 ± 1.6	28 ± 1	4.6 ± 0.6

0.4(syst.) at $\langle N_{part} \rangle = 396$ (centrality 0–2%). The increase of $dN_{ch}/d\eta|_{\eta=0}/(\langle N_{part} \rangle/2)$ with $\langle N_{part} \rangle$ is monotonic up to the most central interval (0–2%). This demonstrates that, even for the most central collisions, variations in centrality – as characterized by transverse energy depositions well outside the acceptance used for the multiplicity measurement – yield significant changes in the measured final state multiplicity.

The bottom panel of Fig. 3 also shows ALICE and CMS measurements of $dN_{ch}/d\eta|_{\eta=0}$ as a function of $\langle N_{part} \rangle$ that agree with the results presented here for all centrality intervals. Also shown are results from Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV obtained from an average of measurements from the four RHIC Collaborations [36–40]. Similar to the approach used in Ref. [8], the 200 GeV Au + Au results have been scaled by a factor of 2.15 to allow comparison with the $\sqrt{s_{NN}} = 2.76$ TeV data. This factor was obtained by matching the most central 200 GeV Au + Au $dN_{ch}/d\eta$ measurement at $\eta = 0$ to the $dN_{ch}/d\eta$ measurement from this Letter at $\eta = 0$ in the 2–4% centrality interval, the interval that has the closest value of $\langle N_{part} \rangle$ to the most central 200 GeV measurement. After re-scaling, the trend of the 200 GeV data is in good agreement with the 2.76 TeV measurements for all reported centrality intervals. Similar observations have been made previously in comparisons of top energy RHIC data to much lower energies [2]. Therefore, this scaling behavior appears to be a robust feature of particle production in heavy ion collisions.

To evaluate the shapes of the measured charged particle $dN_{ch}/d\eta$ distributions Fig. 4 (top) shows the $dN_{ch}/d\eta$ distribution

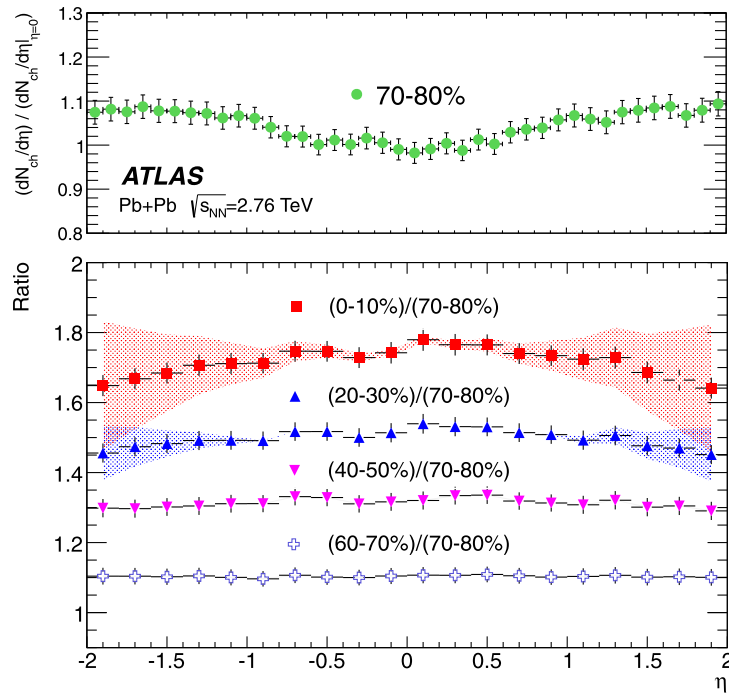


Fig. 4. Top: $dN_{\text{ch}}/d\eta$ distributions from tracklet Method 1, scaled by $dN_{\text{ch}}/d\eta|_{\eta=0}$, as a function of the pseudorapidity for the 70–80% centrality interval. The statistical errors are shown as error bars. Bottom: Ratio of $dN_{\text{ch}}/d\eta / (\langle N_{\text{part}} \rangle / 2)$ measured in different centrality intervals: 0–10% (squares), 20–30% (triangles), 40–50% (inverted triangles) and 60–70% (crosses) to that measured in peripheral collisions (70–80%). Statistical uncertainties are shown as bars while η -dependent systematic uncertainties are shown as shaded bands.

divided by $dN_{\text{ch}}/d\eta|_{\eta=0}$ for the 70–80% centrality interval. For this centrality interval, the $dN_{\text{ch}}/d\eta$ increases by $7\% \pm 1\%$ from $\eta = 0$ to $|\eta| > 1$. The bottom panel shows ratios of $dN_{\text{ch}}/d\eta / (\langle N_{\text{part}} \rangle / 2)$ for several other 10% centrality intervals to the same quantity in the 70–80% interval. No significant variation of the shape of $dN_{\text{ch}}/d\eta$ with centrality is observed within the systematic uncertainties.

7. Conclusions

This Letter presents results on the measurement of charged particle pseudorapidity distributions over $|\eta| < 2$ as a function of collision centrality in a sample of $\sqrt{s_{\text{NN}}} = 2.76$ TeV lead–lead collisions recorded with the ATLAS detector at the LHC. Three different analysis methods are used, based on the pixel detector and using events with the solenoid magnet turned off in order to measure particles with transverse momenta as low as 30 MeV. The charged particle mid-rapidity $dN_{\text{ch}}/d\eta$, normalized by $\langle N_{\text{part}} \rangle / 2$, is found to increase significantly with beam energy by about a factor of two relative to earlier RHIC data, and is substantially larger than $p + p$ data at the same energy. The relative centrality dependence of $dN_{\text{ch}}/d\eta|_{\eta=0} / (\langle N_{\text{part}} \rangle / 2)$ agrees well with that observed at RHIC. These results agree well with previous mid-rapidity measurements from ALICE and CMS. Furthermore, the peripheral (70–80%) $dN_{\text{ch}}/d\eta$ distribution shows a significant rise with increasing $|\eta|$ away from $\eta = 0$. No variation of the shape of the $dN_{\text{ch}}/d\eta$ distribution with centrality outside the reported systematic uncertainties is observed.

Acknowledgements

We thank CERN for the efficient commissioning and operation of the LHC during this initial heavy ion data taking period 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; BMWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF, DNSRC and Lundbeck Foundation, Denmark; ARTEMIS, European Union; IN2P3–CNRS, CEA–DSM/IRFU, France; GNAS, Georgia; BMBF, DFG, HGF, MPG and AvH Foundation, Germany; GSRT, Greece; ISF, MINERVA, GIF, DIP and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; RCN, Norway; MNiSW, Poland; GRICES and FCT, Portugal; MERYS (MECTS), Romania; MES of Russia and ROSATOM, Russian Federation; JINR; MSTB, Serbia; MSSR, Slovakia; ARRS and MVZT, Slovenia; DST/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SER, SNSF and Cantons of Bern and Geneva, Switzerland; NSC, Taiwan; TAEK, Turkey; STFC, the Royal Society and Leverhulme Trust, United Kingdom; DOE and NSF, United States of America.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN and 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) and in the Tier-2 facilities worldwide.

Open access

This article is published Open Access at sciencedirect.com. It is distributed under the terms of the Creative Commons Attribution License 3.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original authors and source are credited.

References

- [1] P. Giubellino, arXiv:0809.1062 [nucl-ex].

- [2] PHOBOS Collaboration, Phys. Rev. C 83 (2011) 024913.
 [3] X.-N. Wang, M. Gyulassy, Phys. Rev. D 44 (1991) 3501, HIJING version 1.38b with no additional tuning, and with jet quenching switched-off.
 [4] W.-T. Deng, X.-N. Wang, R. Xu, Phys. Rev. C 83 (2011) 014915.
 [5] J.L. Albacete, A. Dumitru, arXiv:1011.5161 [hep-ph].
 [6] E. Levin, A.H. Rezaeian, Phys. Rev. D 82 (2010) 014022.
 [7] P. Carruthers, M. Doung-van, Phys. Rev. D 8 (1973) 859.
 [8] ALICE Collaboration, Phys. Rev. Lett. 106 (2011) 032301.
 [9] CMS Collaboration, JHEP 1108 (2011) 141.
 [10] ATLAS Collaboration, JINST 3 (2008) S08003.
 [11] ATLAS Collaboration, JINST 3 (2008) S08003.
 [12] ATLAS Collaboration, JINST 3 (2008) P07007.
 [13] O. Djuvsland, J. Nystrand, Phys. Rev. C 83 (2011) 041901.
 [14] M.L. Miller, et al., Ann. Rev. Nucl. Part. Sci. 57 (2007) 205.
 [15] B. Alver, et al., arXiv:0805.4411 [nucl-ex].
 [16] ATLAS Collaboration, Phys. Lett. B 697 (2011) 294.
 [17] K. Nakamura, et al., Particle Data Group Collaboration, J. Phys. G 37 (2010) 075021.
 [18] T. Cornelissen, et al., J. Phys. Conf. Ser. 119 (2008) 032014.
 [19] GEANT4 Collaboration, S. Agostinelli, et al., Nucl. Instrum. Meth. A 506 (2003) 250.
 [20] ATLAS Collaboration, Eur. Phys. J. C 70 (2010) 823.
 [21] ALICE Collaboration, Phys. Lett. B 696 (2011) 30.
 [22] PHENIX Collaboration, Phys. Rev. C 64 (2004) 034909.
 [23] I.P. Lokhtin, A.M. Snigirev, Eur. Phys. J. C 46 (2006) 211.
 [24] E802 Collaboration, Phys. Rev. C 57 (1998) 466.
 [25] E866 Collaboration, E917 Collaboration, Phys. Lett. B 490 (2000) 53.
 [26] NA49 Collaboration, Phys. Rev. C 66 (2002) 054902.
 [27] PHOBOS Collaboration, Phys. Rev. C 66 (2002) 054901.
 [28] E895 Collaboration, Phys. Rev. C 68 (2003) 054905.
 [29] NA49 Collaboration, Phys. Rev. C 69 (2004) 024902.
 [30] W. Busza, J. Phys. G 35 (2008) 044040;
 PHOBOS Collaboration, Phys. Rev. C 74 (2006) 021901.
 [31] ATLAS Collaboration, New J. Phys. 13 (2011) 053033.
 [32] CMS Collaboration, JHEP 1002 (2010) 041.
 [33] CMS Collaboration, Phys. Rev. Lett. 105 (2010) 022002.
 [34] ALICE Collaboration, Eur. Phys. J. C 68 (2010) 345.
 [35] ALICE Collaboration, Eur. Phys. J. C 68 (2010) 89.
 [36] PHENIX Collaboration, Phys. Rev. C 71 (2005) 034908;
 PHENIX Collaboration, Phys. Rev. C 71 (2005) 049901, Erratum.
 [37] BRAHMS Collaboration, Phys. Lett. B 523 (2001) 227.
 [38] BRAHMS Collaboration, Phys. Rev. Lett. 88 (2002) 202301.
 [39] PHOBOS Collaboration, Phys. Rev. C 65 (2002) 061901.
 [40] STAR Collaboration, Phys. Rev. C 70 (2004) 054907.

ATLAS Collaboration

G. Aad⁴⁸, B. Abbott¹¹¹, J. Abdallah¹¹, A.A. Abdelalim⁴⁹, A. Abdesselam¹¹⁸, O. Abidinov¹⁰, B. Abi¹¹², M. Abolins⁸⁸, H. Abramowicz¹⁵³, H. Abreu¹¹⁵, E. Acerbi^{89a,89b}, B.S. Acharya^{164a,164b}, D.L. Adams²⁴, T.N. Addy⁵⁶, J. Adelman¹⁷⁵, M. Aderholz⁹⁹, S. Adomeit⁹⁸, P. Adragna⁷⁵, T. Adye¹²⁹, S. Aefsky²², J.A. Aguilar-Saavedra^{124b,a}, M. Aharrouché⁸¹, S.P. Ahlen²¹, F. Ahles⁴⁸, A. Ahmad¹⁴⁸, M. Ahsan⁴⁰, G. Aielli^{133a,133b}, T. Akdogan^{18a}, T.P.A. Åkesson⁷⁹, G. Akimoto¹⁵⁵, A.V. Akimov⁹⁴, A. Akiyama⁶⁷, M.S. Alam¹, M.A. Alam⁷⁶, J. Albert¹⁶⁹, S. Albrand⁵⁵, M. Aleksa²⁹, I.N. Aleksandrov⁶⁵, F. Alessandria^{89a}, C. Alexa^{25a}, G. Alexander¹⁵³, G. Alexandre⁴⁹, T. Alexopoulos⁹, M. Alhroob²⁰, M. Aliev¹⁵, G. Alimonti^{89a}, J. Alison¹²⁰, M. Aliyev¹⁰, P.P. Allport⁷³, S.E. Allwood-Spiers⁵³, J. Almond⁸², A. Aloisio^{102a,102b}, R. Alon¹⁷¹, A. Alonso⁷⁹, M.G. Alviggi^{102a,102b}, K. Amako⁶⁶, P. Amaral²⁹, C. Amelung²², V.V. Ammosov¹²⁸, A. Amorim^{124a,b}, G. Amorós¹⁶⁷, N. Amram¹⁵³, C. Anastopoulos²⁹, N. Andari¹¹⁵, T. Andeen³⁴, C.F. Anders²⁰, K.J. Anderson³⁰, A. Andreazza^{89a,89b}, V. Andrei^{58a}, M.-L. Andrieux⁵⁵, X.S. Anduaga⁷⁰, A. Angerami³⁴, F. Anghinolfi²⁹, N. Anjos^{124a}, A. Annovi⁴⁷, A. Antonaki⁸, M. Antonelli⁴⁷, A. Antonov⁹⁶, J. Antos^{144b}, F. Anulli^{132a}, S. Aoun⁸³, L. Aperio Bella⁴, R. Apolle^{118,c}, G. Arabidze⁸⁸, I. Aracena¹⁴³, Y. Arai⁶⁶, A.T.H. Arce⁴⁴, J.P. Archambault²⁸, S. Arfaoui^{29,d}, J.-F. Arguin¹⁴, E. Arik^{18a,*}, M. Arik^{18a}, A.J. Armbruster⁸⁷, O. Arnaez⁸¹, C. Arnault¹¹⁵, A. Artamonov⁹⁵, G. Artoni^{132a,132b}, D. Arutinov²⁰, S. Asai¹⁵⁵, R. Asfandiyarov¹⁷², S. Ask²⁷, B. Åsman^{146a,146b}, L. Asquith⁵, K. Assamagan²⁴, A. Astbury¹⁶⁹, A. Astvatsatourov⁵², G. Atoian¹⁷⁵, B. Aubert⁴, B. Auerbach¹⁷⁵, E. Auge¹¹⁵, K. Augsten¹²⁷, M. Aurousseau^{145a}, N. Austin⁷³, G. Avolio¹⁶³, R. Avramidou⁹, D. Axen¹⁶⁸, C. Ay⁵⁴, G. Azuelos^{93,e}, Y. Azuma¹⁵⁵, M.A. Baak²⁹, G. Baccaglioni^{89a}, C. Bacci^{134a,134b}, A.M. Bach¹⁴, H. Bachacou¹³⁶, K. Bachas²⁹, G. Bachy²⁹, M. Backes⁴⁹, M. Backhaus²⁰, E. Badescu^{25a}, P. Bagnaia^{132a,132b}, S. Bahinipati², Y. Bai^{32a}, D.C. Bailey¹⁵⁸, T. Bain¹⁵⁸, J.T. Baines¹²⁹, O.K. Baker¹⁷⁵, M.D. Baker²⁴, S. Baker⁷⁷, F. Baltasar Dos Santos Pedrosa²⁹, E. Banas³⁸, P. Banerjee⁹³, Sw. Banerjee¹⁷², D. Banfi²⁹, A. Bangert¹³⁷, V. Bansal¹⁶⁹, H.S. Bansil¹⁷, L. Barak¹⁷¹, S.P. Baranov⁹⁴, A. Barashkou⁶⁵, A. Barbaro Galtieri¹⁴, T. Barber²⁷, E.L. Barberio⁸⁶, D. Barberis^{50a,50b}, M. Barbero²⁰, D.Y. Bardin⁶⁵, T. Barillari⁹⁹, M. Barisonzi¹⁷⁴, T. Barklow¹⁴³, N. Barlow²⁷, B.M. Barnett¹²⁹, R.M. Barnett¹⁴, A. Baroncelli^{134a}, G. Barone⁴⁹, A.J. Barr¹¹⁸, F. Barreiro⁸⁰, J. Barreiro Guimarães da Costa⁵⁷, P. Barrillon¹¹⁵, R. Bartoldus¹⁴³, A.E. Barton⁷¹, D. Bartsch²⁰, V. Bartsch¹⁴⁹, R.L. Bates⁵³, L. Batkova^{144a}, J.R. Batley²⁷, A. Battaglia¹⁶, M. Battistin²⁹, G. Battistoni^{89a}, F. Bauer¹³⁶, H.S. Bawa^{143,f}, B. Beare¹⁵⁸, T. Beau⁷⁸, P.H. Beauchemin¹¹⁸, R. Beccherle^{50a}, P. Bechtel⁴¹, H.P. Beck¹⁶, M. Beckingham⁴⁸, K.H. Becks¹⁷⁴, A.J. Beddall^{18c}, A. Beddall^{18c}, S. Bedikian¹⁷⁵, V.A. Bednyakov⁶⁵, C.P. Bee⁸³, M. Begel²⁴, S. Behar Harpaz¹⁵², P.K. Behera⁶³, M. Beimforde⁹⁹, C. Belanger-Champagne⁸⁵, P.J. Bell⁴⁹, W.H. Bell⁴⁹, G. Bella¹⁵³, L. Bellagamba^{19a}, F. Bellina²⁹, M. Bellomo^{119a}, A. Belloni⁵⁷, O. Beloborodova¹⁰⁷, K. Belotskiy⁹⁶, O. Beltramello²⁹, S. Ben Ami¹⁵², O. Benary¹⁵³, D. Bencheekroun^{135a}, C. Benchouk⁸³, M. Bendel⁸¹, B.H. Benedict¹⁶³, N. Benekos¹⁶⁵, Y. Benhammou¹⁵³, D.P. Benjamin⁴⁴, M. Benoit¹¹⁵, J.R. Bensinger²², K. Benslama¹³⁰, S. Bentvelsen¹⁰⁵, D. Berge²⁹, E. Bergeaas Kuutmann⁴¹, N. Berger⁴, F. Berghaus¹⁶⁹,

E. Berglund⁴⁹, J. Beringer¹⁴, K. Bernardet⁸³, P. Bernat⁷⁷, R. Bernhard⁴⁸, C. Bernius²⁴, T. Berry⁷⁶,
 A. Bertin^{19a,19b}, F. Bertinelli²⁹, F. Bertolucci^{122a,122b}, M.I. Besana^{89a,89b}, N. Besson¹³⁶, S. Bethke⁹⁹,
 W. Bhimji⁴⁵, R.M. Bianchi²⁹, M. Bianco^{72a,72b}, O. Biebel⁹⁸, S.P. Bieniek⁷⁷, J. Biesiada¹⁴,
 M. Biglietti^{134a,134b}, H. Bilokon⁴⁷, M. Bindi^{19a,19b}, S. Binet¹¹⁵, A. Bingul^{18c}, C. Bini^{132a,132b},
 C. Biscarat¹⁷⁷, U. Bitenc⁴⁸, K.M. Black²¹, R.E. Blair⁵, J.-B. Blanchard¹¹⁵, G. Blanchot²⁹, T. Blazek^{144a},
 C. Blocker²², J. Blocki³⁸, A. Blondel⁴⁹, W. Blum⁸¹, U. Blumenschein⁵⁴, G.J. Bobbink¹⁰⁵,
 V.B. Bobrovnikov¹⁰⁷, S.S. Bocchetta⁷⁹, A. Bocci⁴⁴, C.R. Boddy¹¹⁸, M. Boehler⁴¹, J. Boek¹⁷⁴, N. Boelaert³⁵,
 S. Böser⁷⁷, J.A. Bogaerts²⁹, A. Bogdanchikov¹⁰⁷, A. Bogouch^{90,*}, C. Boehm^{146a}, V. Boisvert⁷⁶, T. Bold^{163,g},
 V. Boldea^{25a}, N.M. Bolnet¹³⁶, M. Bona⁷⁵, V.G. Bondarenko⁹⁶, M. Boonekamp¹³⁶, G. Boorman⁷⁶,
 C.N. Booth¹³⁹, S. Bordini⁷⁸, C. Borer¹⁶, A. Borisov¹²⁸, G. Borissov⁷¹, I. Borjanovic^{12a}, S. Borroni^{132a,132b},
 K. Bos¹⁰⁵, D. Boscherini^{19a}, M. Bosman¹¹, H. Boterenbrood¹⁰⁵, D. Botterill¹²⁹, J. Bouchami⁹³,
 J. Boudreau¹²³, E.V. Bouhova-Thacker⁷¹, C. Boulahouache¹²³, C. Bourdarios¹¹⁵, N. Bousson⁸³,
 A. Boveia³⁰, J. Boyd²⁹, I.R. Boyko⁶⁵, N.I. Bozhko¹²⁸, I. Bozovic-Jelisavcic^{12b}, J. Bracinik¹⁷,
 A. Braem²⁹, P. Branchini^{134a}, G.W. Brandenburg⁵⁷, A. Brandt⁷, G. Brandt¹⁵, O. Brandt⁵⁴, U. Bratzler¹⁵⁶,
 B. Brau⁸⁴, J.E. Brau¹¹⁴, H.M. Braun¹⁷⁴, B. Breliev¹⁵⁸, J. Bremer²⁹, R. Brenner¹⁶⁶, S. Bressler¹⁵²,
 D. Breton¹¹⁵, D. Britton⁵³, F.M. Brochu²⁷, I. Brock²⁰, R. Brock⁸⁸, T.J. Brodbeck⁷¹, E. Brodet¹⁵³,
 F. Broggi^{89a}, C. Bromberg⁸⁸, G. Brooijmans³⁴, W.K. Brooks^{31b}, G. Brown⁸², H. Brown⁷,
 P.A. Bruckman de Renstrom³⁸, D. Bruncko^{144b}, R. Bruneliere⁴⁸, S. Brunet⁶¹, A. Bruni^{19a}, G. Bruni^{19a},
 M. Bruschi^{19a}, T. Buanes¹³, F. Bucci⁴⁹, J. Buchanan¹¹⁸, N.J. Buchanan², P. Buchholz¹⁴¹,
 R.M. Buckingham¹¹⁸, A.G. Buckley⁴⁵, S.I. Buda^{25a}, I.A. Budagov⁶⁵, B. Budick¹⁰⁸, V. Büscher⁸¹,
 L. Bugge¹¹⁷, D. Buirar-Clark¹¹⁸, O. Bulekov⁹⁶, M. Bunse⁴², T. Buran¹¹⁷, H. Burckhart²⁹, S. Burdin⁷³,
 T. Burgess¹³, S. Burke¹²⁹, E. Busato³³, P. Bussey⁵³, C.P. Buszello¹⁶⁶, F. Butin²⁹, B. Butler¹⁴³,
 J.M. Butler²¹, C.M. Buttar⁵³, J.M. Butterworth⁷⁷, W. Buttinger²⁷, T. Byatt⁷⁷, S. Cabrera Urbán¹⁶⁷,
 D. Caforio^{19a,19b}, O. Cakir^{3a}, P. Calafiura¹⁴, G. Calderini⁷⁸, P. Calfayan⁹⁸, R. Calkins¹⁰⁶, L.P. Caloba^{23a},
 R. Caloi^{132a,132b}, D. Calvet³³, S. Calvet³³, R. Camacho Toro³³, P. Camarri^{133a,133b}, M. Cambiaghi^{119a,119b},
 D. Cameron¹¹⁷, S. Campana²⁹, M. Campanelli⁷⁷, V. Canale^{102a,102b}, F. Canelli^{30,h}, A. Canepa^{159a},
 J. Cantero⁸⁰, L. Capasso^{102a,102b}, M.D.M. Capeans Garrido²⁹, I. Caprini^{25a}, M. Caprini^{25a}, D. Capriotti⁹⁹,
 M. Capua^{36a,36b}, R. Caputo¹⁴⁸, R. Cardarelli^{133a}, T. Carli²⁹, G. Carlino^{102a}, L. Carminati^{89a,89b},
 B. Caron^{159a}, S. Caron⁴⁸, G.D. Carrillo Montoya¹⁷², A.A. Carter⁷⁵, J.R. Carter²⁷, J. Carvalho^{124a,i},
 D. Casadei¹⁰⁸, M.P. Casado¹¹, M. Cascella^{122a,122b}, C. Caso^{50a,50b,*}, A.M. Castaneda Hernandez¹⁷²,
 E. Castaneda-Miranda¹⁷², V. Castillo Gimenez¹⁶⁷, N.F. Castro^{124a}, G. Cataldi^{72a}, F. Cataneo²⁹,
 A. Catinaccio²⁹, J.R. Catmore⁷¹, A. Cattai²⁹, G. Cattani^{133a,133b}, S. Caughron⁸⁸, D. Cauz^{164a,164c},
 P. Cavalleri⁷⁸, D. Cavalli^{89a}, M. Cavalli-Sforza¹¹, V. Cavasinni^{122a,122b}, F. Ceradini^{134a,134b},
 A.S. Cerqueira^{23a}, A. Cerri²⁹, L. Cerrito⁷⁵, F. Cerutti⁴⁷, S.A. Cetin^{18b}, F. Cevenini^{102a,102b}, A. Chafaq^{135a},
 D. Chakraborty¹⁰⁶, K. Chan², B. Chapleau⁸⁵, J.D. Chapman²⁷, J.W. Chapman⁸⁷, E. Chareyre⁷⁸,
 D.G. Charlton¹⁷, V. Chavda⁸², C.A. Chavez Barajas²⁹, S. Cheatham⁸⁵, S. Chekanov⁵, S.V. Chekulaev^{159a},
 G.A. Chelkov⁶⁵, M.A. Chelstowska¹⁰⁴, C. Chen⁶⁴, H. Chen²⁴, S. Chen^{32c}, T. Chen^{32c}, X. Chen¹⁷²,
 Y. Chen³⁴, S. Cheng^{32a}, A. Cheplakov⁶⁵, V.F. Chepurinov⁶⁵, R. Cherkaoui El Moursli^{135e}, V. Chernyatin²⁴,
 E. Cheu⁶, S.L. Cheung¹⁵⁸, L. Chevalier¹³⁶, G. Chiefari^{102a,102b}, L. Chikovani⁵¹, J.T. Childers^{58a},
 A. Chilingarov⁷¹, G. Chiodini^{72a}, M.V. Chizhov⁶⁵, G. Choudalakis³⁰, S. Chouridou¹³⁷, I.A. Christidi⁷⁷,
 A. Christov⁴⁸, D. Chromek-Burckhart²⁹, M.L. Chu¹⁵¹, J. Chudoba¹²⁵, G. Ciapetti^{132a,132b}, K. Ciba³⁷,
 A.K. Ciftci^{3a}, R. Ciftci^{3a}, D. Cinca³³, V. Cindro⁷⁴, M.D. Ciobotaru¹⁶³, C. Ciocca^{19a,19b}, A. Ciocio¹⁴,
 M. Cirilli⁸⁷, M. Ciubancan^{25a}, A. Clark⁴⁹, P.J. Clark⁴⁵, W. Cleland¹²³, J.C. Clemens⁸³, B. Clement⁵⁵,
 C. Clement^{146a,146b}, R.W. Clift¹²⁹, Y. Coadou⁸³, M. Cobal^{164a,164c}, A. Coccaro^{50a,50b}, J. Cochran⁶⁴,
 P. Coe¹¹⁸, J.G. Cogan¹⁴³, J. Coggeshall¹⁶⁵, E. Cogneras¹⁷⁷, C.D. Cojocar²⁸, J. Colas⁴, A.P. Colijn¹⁰⁵,
 C. Collard¹¹⁵, N.J. Collins¹⁷, C. Collins-Tooth⁵³, J. Collot⁵⁵, G. Colon⁸⁴, P. Conde Muiño^{124a},
 E. Coniavitis¹¹⁸, M.C. Conidi¹¹, M. Consonni¹⁰⁴, V. Consorti⁴⁸, S. Constantinescu^{25a}, C. Conta^{119a,119b},
 F. Conventi^{102a,j}, J. Cook²⁹, M. Cooke¹⁴, B.D. Cooper⁷⁷, A.M. Cooper-Sarkar¹¹⁸, N.J. Cooper-Smith⁷⁶,
 K. Copic³⁴, T. Cornelissen^{50a,50b}, M. Corradi^{19a}, F. Corriveau^{85,k}, A. Cortes-Gonzalez¹⁶⁵, G. Cortiana⁹⁹,
 G. Costa^{89a}, M.J. Costa¹⁶⁷, D. Costanzo¹³⁹, T. Costin³⁰, D. Côté²⁹, R. Coura Torres^{23a}, L. Courneyea¹⁶⁹,
 G. Cowan⁷⁶, C. Cowden²⁷, B.E. Cox⁸², K. Cranmer¹⁰⁸, F. Crescioli^{122a,122b}, M. Cristinziani²⁰,
 G. Crosetti^{36a,36b}, R. Crupi^{72a,72b}, S. Crépe- Renaudin⁵⁵, C.-M. Cuciuc^{25a}, C. Cuenca Almenar¹⁷⁵,

T. Cuhadar Donszelmann ¹³⁹, S. Cuneo ^{50a,50b}, M. Curatolo ⁴⁷, C.J. Curtis ¹⁷, P. Cwetanski ⁶¹, H. Czirr ¹⁴¹,
 Z. Czyzula ¹¹⁷, S. D'Auria ⁵³, M. D'Onofrio ⁷³, A. D'Orazio ^{132a,132b}, P.V.M. Da Silva ^{23a}, C. Da Via ⁸²,
 W. Dabrowski ³⁷, T. Dai ⁸⁷, C. Dallapiccola ⁸⁴, M. Dam ³⁵, M. Dameri ^{50a,50b}, D.S. Damiani ¹³⁷,
 H.O. Danielsson ²⁹, D. Dannheim ⁹⁹, V. Dao ⁴⁹, G. Darbo ^{50a}, G.L. Darlea ^{25b}, C. Daum ¹⁰⁵, J.P. Dauvergne ²⁹,
 W. Davey ⁸⁶, T. Davidek ¹²⁶, N. Davidson ⁸⁶, R. Davidson ⁷¹, E. Davies ^{118,c}, M. Davies ⁹³, A.R. Davison ⁷⁷,
 Y. Davygora ^{58a}, E. Dawe ¹⁴², I. Dawson ¹³⁹, J.W. Dawson ^{5,*}, R.K. Daya ³⁹, K. De ⁷, R. de Asmundis ^{102a},
 S. De Castro ^{19a,19b}, P.E. De Castro Faria Salgado ²⁴, S. De Cecco ⁷⁸, J. de Graat ⁹⁸, N. De Groot ¹⁰⁴,
 P. de Jong ¹⁰⁵, C. De La Taille ¹¹⁵, H. De la Torre ⁸⁰, B. De Lotto ^{164a,164c}, L. De Mora ⁷¹, L. De Nooij ¹⁰⁵,
 M. De Oliveira Branco ²⁹, D. De Pedis ^{132a}, P. de Saintignon ⁵⁵, A. De Salvo ^{132a}, U. De Sanctis ^{164a,164c},
 A. De Santo ¹⁴⁹, J.B. De Vivie De Regie ¹¹⁵, S. Dean ⁷⁷, R. Debbe ²⁴, D.V. Dedovich ⁶⁵, J. Degenhardt ¹²⁰,
 M. Dehchar ¹¹⁸, M. Deile ⁹⁸, C. Del Papa ^{164a,164c}, J. Del Peso ⁸⁰, T. Del Prete ^{122a,122b}, M. Deliyergiyev ⁷⁴,
 A. Dell'Acqua ²⁹, L. Dell'Asta ^{89a,89b}, M. Della Pietra ^{102a,j}, D. della Volpe ^{102a,102b}, M. Delmastro ²⁹,
 P. Delpierre ⁸³, N. Delruelle ²⁹, P.A. Delsart ⁵⁵, C. Deluca ¹⁴⁸, S. Demers ¹⁷⁵, M. Demichev ⁶⁵,
 B. Demirkoz ^{11,l}, J. Deng ¹⁶³, S.P. Denisov ¹²⁸, D. Derendarz ³⁸, J.E. Derkaoui ^{135d}, F. Derue ⁷⁸, P. Dervan ⁷³,
 K. Desch ²⁰, E. Devetak ¹⁴⁸, P.O. Deviveiros ¹⁵⁸, A. Dewhurst ¹²⁹, B. DeWilde ¹⁴⁸, S. Dhaliwal ¹⁵⁸,
 R. Dhullipudi ^{24,m}, A. Di Ciaccio ^{133a,133b}, L. Di Ciaccio ⁴, A. Di Girolamo ²⁹, B. Di Girolamo ²⁹,
 S. Di Luise ^{134a,134b}, A. Di Mattia ⁸⁸, B. Di Micco ²⁹, R. Di Nardo ^{133a,133b}, A. Di Simone ^{133a,133b},
 R. Di Sipio ^{19a,19b}, M.A. Diaz ^{31a}, F. Diblen ^{18c}, E.B. Diehl ⁸⁷, J. Dietrich ⁴¹, T.A. Dietzsch ^{58a}, S. Diglio ¹¹⁵,
 K. Dindar Yagci ³⁹, J. Dingfelder ²⁰, C. Dionisi ^{132a,132b}, P. Dita ^{25a}, S. Dita ^{25a}, F. Dittus ²⁹, F. Djama ⁸³,
 T. Djobava ⁵¹, M.A.B. do Vale ^{23a}, A. Do Valle Wemans ^{124a}, T.K.O. Doan ⁴, M. Dobbs ⁸⁵, R. Dobinson ^{29,*},
 D. Dobos ⁴², E. Dobson ²⁹, M. Dobson ¹⁶³, J. Dodd ³⁴, C. Doglioni ¹¹⁸, T. Doherty ⁵³, Y. Doi ^{66,*}, J. Dolejsi ¹²⁶,
 I. Dolenc ⁷⁴, Z. Dolezal ¹²⁶, B.A. Dolgoshein ^{96,*}, T. Dohmae ¹⁵⁵, M. Donadelli ^{23d}, M. Donega ¹²⁰,
 J. Donini ⁵⁵, J. Dopke ²⁹, A. Doria ^{102a}, A. Dos Anjos ¹⁷², M. Dosil ¹¹, A. Dotti ^{122a,122b}, M.T. Dova ⁷⁰,
 J.D. Dowell ¹⁷, A.D. Doxiadis ¹⁰⁵, A.T. Doyle ⁵³, Z. Drasal ¹²⁶, J. Drees ¹⁷⁴, N. Dressnandt ¹²⁰,
 H. Drevermann ²⁹, C. Driouichi ³⁵, M. Dris ⁹, J. Dubbert ⁹⁹, T. Dubbs ¹³⁷, S. Dube ¹⁴, E. Duchovni ¹⁷¹,
 G. Duckeck ⁹⁸, A. Dudarev ²⁹, F. Dudziak ⁶⁴, M. Dührssen ²⁹, I.P. Duerdoth ⁸², L. Duflot ¹¹⁵, M.-A. Dufour ⁸⁵,
 M. Dunford ²⁹, H. Duran Yildiz ^{3b}, R. Duxfield ¹³⁹, M. Dwuznik ³⁷, F. Dydak ²⁹, D. Dzahini ⁵⁵, M. Düren ⁵²,
 W.L. Ebenstein ⁴⁴, J. Ebke ⁹⁸, S. Eckert ⁴⁸, S. Eckweiler ⁸¹, K. Edmonds ⁸¹, C.A. Edwards ⁷⁶, N.C. Edwards ⁵³,
 W. Ehrenfeld ⁴¹, T. Ehrich ⁹⁹, T. Eifert ²⁹, G. Eigen ¹³, K. Einsweiler ¹⁴, E. Eisenhandler ⁷⁵, T. Ekelof ¹⁶⁶,
 M. El Kacimi ^{135c}, M. Ellert ¹⁶⁶, S. Elles ⁴, F. Ellinghaus ⁸¹, K. Ellis ⁷⁵, N. Ellis ²⁹, J. Elmsheuser ⁹⁸,
 M. Elsing ²⁹, R. Ely ¹⁴, D. Emeliyanov ¹²⁹, R. Engelmann ¹⁴⁸, A. Engl ⁹⁸, B. Epp ⁶², A. Eppig ⁸⁷,
 J. Erdmann ⁵⁴, A. Ereditato ¹⁶, D. Eriksson ^{146a}, J. Ernst ¹, M. Ernst ²⁴, J. Ernwein ¹³⁶, D. Errede ¹⁶⁵,
 S. Errede ¹⁶⁵, E. Ertel ⁸¹, M. Escalier ¹¹⁵, C. Escobar ¹⁶⁷, X. Espinal Curull ¹¹, B. Esposito ⁴⁷, F. Etienne ⁸³,
 A.I. Etievre ¹³⁶, E. Etzion ¹⁵³, D. Evangelakou ⁵⁴, H. Evans ⁶¹, L. Fabbri ^{19a,19b}, C. Fabre ²⁹,
 R.M. Fakhruddinov ¹²⁸, S. Falciano ^{132a}, Y. Fang ¹⁷², M. Fanti ^{89a,89b}, A. Farbin ⁷, A. Farilla ^{134a}, J. Farley ¹⁴⁸,
 T. Farooque ¹⁵⁸, S.M. Farrington ¹¹⁸, P. Farthouat ²⁹, P. Fassnacht ²⁹, D. Fassouliotis ⁸, B. Fatholahzadeh ¹⁵⁸,
 A. Favareto ^{89a,89b}, L. Fayard ¹¹⁵, S. Fazio ^{36a,36b}, R. Febbraro ³³, P. Federic ^{144a}, O.L. Fedin ¹²¹,
 W. Fedorko ⁸⁸, M. Fehling-Kaschek ⁴⁸, L. Feligioni ⁸³, D. Fellmann ⁵, C.U. Felzmann ⁸⁶, C. Feng ^{32d},
 E.J. Feng ³⁰, A.B. Fenyuk ¹²⁸, J. Ferencei ^{144b}, J. Ferland ⁹³, W. Fernando ¹⁰⁹, S. Ferrag ⁵³, J. Ferrando ⁵³,
 V. Ferrara ⁴¹, A. Ferrari ¹⁶⁶, P. Ferrari ¹⁰⁵, R. Ferrari ^{119a}, A. Ferrer ¹⁶⁷, M.L. Ferrer ⁴⁷, D. Ferrere ⁴⁹,
 C. Ferretti ⁸⁷, A. Ferretto Parodi ^{50a,50b}, M. Fiascaris ³⁰, F. Fiedler ⁸¹, A. Filipčič ⁷⁴, A. Filippas ⁹,
 F. Filthaut ¹⁰⁴, M. Fincke-Keeler ¹⁶⁹, M.C.N. Fiolhais ^{124a,i}, L. Fiorini ¹⁶⁷, A. Firan ³⁹, G. Fischer ⁴¹,
 P. Fischer ²⁰, M.J. Fisher ¹⁰⁹, S.M. Fisher ¹²⁹, M. Flechl ⁴⁸, I. Fleck ¹⁴¹, J. Fleckner ⁸¹, P. Fleischmann ¹⁷³,
 S. Fleischmann ¹⁷⁴, T. Flick ¹⁷⁴, L.R. Flores Castillo ¹⁷², M.J. Flowerdew ⁹⁹, F. Föhlich ^{58a}, M. Fokitis ⁹,
 T. Fonseca Martin ¹⁶, D.A. Forbush ¹³⁸, A. Formica ¹³⁶, A. Forti ⁸², D. Fortin ^{159a}, J.M. Foster ⁸²,
 D. Fournier ¹¹⁵, A. Foussat ²⁹, A.J. Fowler ⁴⁴, K. Fowler ¹³⁷, H. Fox ⁷¹, P. Francavilla ^{122a,122b},
 S. Franchino ^{119a,119b}, D. Francis ²⁹, T. Frank ¹⁷¹, M. Franklin ⁵⁷, S. Franz ²⁹, M. Fraternali ^{119a,119b},
 S. Fratina ¹²⁰, S.T. French ²⁷, R. Froeschl ²⁹, D. Froidevaux ²⁹, J.A. Frost ²⁷, C. Fukunaga ¹⁵⁶,
 E. Fullana Torregrosa ²⁹, J. Fuster ¹⁶⁷, C. Gabaldon ²⁹, O. Gabizon ¹⁷¹, T. Gadfort ²⁴, S. Gadomski ⁴⁹,
 G. Gagliardi ^{50a,50b}, P. Gagnon ⁶¹, C. Galea ⁹⁸, E.J. Gallas ¹¹⁸, M.V. Gallas ²⁹, V. Gallo ¹⁶, B.J. Gallop ¹²⁹,
 P. Gallus ¹²⁵, E. Galyaev ⁴⁰, K.K. Gan ¹⁰⁹, Y.S. Gao ^{143,f}, V.A. Gapienko ¹²⁸, A. Gaponenko ¹⁴,
 F. Garberon ¹⁷⁵, M. Garcia-Sciveres ¹⁴, C. García ¹⁶⁷, J.E. García Navarro ⁴⁹, R.W. Gardner ³⁰, N. Garelli ²⁹,

H. Garitaonandia¹⁰⁵, V. Garonne²⁹, J. Garvey¹⁷, C. Gatti⁴⁷, G. Gaudio^{119a}, O. Gaumer⁴⁹, B. Gaur¹⁴¹, L. Gauthier¹³⁶, I.L. Gavrilenko⁹⁴, C. Gay¹⁶⁸, G. Gaycken²⁰, J.-C. Gayde²⁹, E.N. Gazis⁹, P. Ge^{32d}, C.N.P. Gee¹²⁹, D.A.A. Geerts¹⁰⁵, Ch. Geich-Gimbel²⁰, K. Gellerstedt^{146a,146b}, C. Gemme^{50a}, A. Gemmell⁵³, M.H. Genest⁹⁸, S. Gentile^{132a,132b}, M. George⁵⁴, S. George⁷⁶, P. Gerlach¹⁷⁴, A. Gershon¹⁵³, C. Geweniger^{58a}, H. Ghazlane^{135b}, P. Ghez⁴, N. Ghodbane³³, B. Giacobbe^{19a}, S. Giagu^{132a,132b}, V. Giakoumopoulou⁸, V. Giangiobbe^{122a,122b}, F. Gianotti²⁹, B. Gibbard²⁴, A. Gibson¹⁵⁸, S.M. Gibson²⁹, L.M. Gilbert¹¹⁸, M. Gilchriese¹⁴, V. Gilewsky⁹¹, D. Gillberg²⁸, A.R. Gillman¹²⁹, D.M. Gingrich^{2,e}, J. Ginzburg¹⁵³, N. Giokaris⁸, M.P. Giordani^{164c}, R. Giordano^{102a,102b}, F.M. Giorgi¹⁵, P. Giovannini⁹⁹, P.F. Giraud¹³⁶, D. Giugni^{89a}, M. Giunta^{132a,132b}, P. Giusti^{19a}, B.K. Gjelsten¹¹⁷, L.K. Gladilin⁹⁷, C. Glasman⁸⁰, J. Glatzer⁴⁸, A. Glazov⁴¹, K.W. Glitza¹⁷⁴, G.L. Glonti⁶⁵, J. Godfrey¹⁴², J. Godlewski²⁹, M. Goebel⁴¹, T. Göpfert⁴³, C. Goeringer⁸¹, C. Gössling⁴², T. Göttfert⁹⁹, S. Goldfarb⁸⁷, D. Goldin³⁹, T. Golling¹⁷⁵, S.N. Golovnia¹²⁸, A. Gomes^{124a,b}, L.S. Gomez Fajardo⁴¹, R. Gonçalves⁷⁶, J. Goncalves Pinto Firmino Da Costa⁴¹, L. Gonella²⁰, A. Gonidec²⁹, S. Gonzalez¹⁷², S. González de la Hoz¹⁶⁷, M.L. Gonzalez Silva²⁶, S. Gonzalez-Sevilla⁴⁹, J.J. Goodson¹⁴⁸, L. Goossens²⁹, P.A. Gorbounov⁹⁵, H.A. Gordon²⁴, I. Gorelov¹⁰³, G. Gorfine¹⁷⁴, B. Gorini²⁹, E. Gorini^{72a,72b}, A. Gorišek⁷⁴, E. Gornicki³⁸, S.A. Gorokhov¹²⁸, V.N. Goryachev¹²⁸, B. Gosdzik⁴¹, M. Gosselink¹⁰⁵, M.I. Gostkin⁶⁵, M. Gouanère⁴, I. Gough Eschrich¹⁶³, M. Goughri^{135a}, D. Goujdami^{135c}, M.P. Goulette⁴⁹, A.G. Goussiou¹³⁸, C. Goy⁴, I. Grabowska-Bold^{163,g}, V. Grabski¹⁷⁶, P. Grafström²⁹, C. Grah¹⁷⁴, K.-J. Grah⁴¹, F. Grancagnolo^{72a}, S. Grancagnolo¹⁵, V. Grassi¹⁴⁸, V. Gratchev¹²¹, N. Grau³⁴, H.M. Gray²⁹, J.A. Gray¹⁴⁸, E. Graziani^{134a}, O.G. Grebenyuk¹²¹, D. Greenfield¹²⁹, T. Greenshaw⁷³, Z.D. Greenwood^{24,m}, I.M. Gregor⁴¹, P. Grenier¹⁴³, J. Griffiths¹³⁸, N. Grigalashvili⁶⁵, A.A. Grillo¹³⁷, S. Grinstein¹¹, Y.V. Grishkevich⁹⁷, J.-F. Grivaz¹¹⁵, J. Grognuz²⁹, M. Groh⁹⁹, E. Gross¹⁷¹, J. Grosse-Knetter⁵⁴, J. Groth-Jensen¹⁷¹, K. Grybel¹⁴¹, V.J. Guarino⁵, D. Guest¹⁷⁵, C. Guicheney³³, A. Guida^{72a,72b}, T. Guillemin⁴, S. Guindon⁵⁴, H. Guler^{85,n}, J. Gunther¹²⁵, B. Guo¹⁵⁸, J. Guo³⁴, A. Gupta³⁰, Y. Gusakov⁶⁵, V.N. Gushchin¹²⁸, A. Gutierrez⁹³, P. Gutierrez¹¹¹, N. Guttman¹⁵³, O. Gutzwiller¹⁷², C. Guyot¹³⁶, C. Gwenlan¹¹⁸, C.B. Gwilliam⁷³, A. Haas¹⁴³, S. Haas²⁹, C. Haber¹⁴, R. Hackenburg²⁴, H.K. Hadavand³⁹, D.R. Hadley¹⁷, P. Haefner⁹⁹, F. Hahn²⁹, S. Haider²⁹, Z. Hajduk³⁸, H. Hakobyan¹⁷⁶, J. Haller⁵⁴, K. Hamacher¹⁷⁴, P. Hamal¹¹³, A. Hamilton⁴⁹, S. Hamilton¹⁶¹, H. Han^{32a}, L. Han^{32b}, K. Hanagaki¹¹⁶, M. Hance¹²⁰, C. Handel⁸¹, P. Hanke^{58a}, J.R. Hansen³⁵, J.B. Hansen³⁵, J.D. Hansen³⁵, P.H. Hansen³⁵, P. Hansson¹⁴³, K. Hara¹⁶⁰, G.A. Hare¹³⁷, T. Harenberg¹⁷⁴, S. Harkusha⁹⁰, D. Harper⁸⁷, R.D. Harrington²¹, O.M. Harris¹³⁸, K. Harrison¹⁷, J. Hartert⁴⁸, F. Hartjes¹⁰⁵, T. Haruyama⁶⁶, A. Harvey⁵⁶, S. Hasegawa¹⁰¹, Y. Hasegawa¹⁴⁰, S. Hassani¹³⁶, M. Hatch²⁹, D. Hauff⁹⁹, S. Haug¹⁶, M. Hauschild²⁹, R. Hauser⁸⁸, M. Havranek²⁰, B.M. Hawes¹¹⁸, C.M. Hawkes¹⁷, R.J. Hawking²⁹, D. Hawkins¹⁶³, T. Hayakawa⁶⁷, D. Hayden⁷⁶, H.S. Hayward⁷³, S.J. Haywood¹²⁹, E. Hazen²¹, M. He^{32d}, S.J. Head¹⁷, V. Hedberg⁷⁹, L. Heelan⁷, S. Heim⁸⁸, B. Heinemann¹⁴, S. Heisterkamp³⁵, L. Helary⁴, M. Heller¹¹⁵, S. Hellman^{146a,146b}, D. Hellmich²⁰, C. Helsens¹¹, R.C.W. Henderson⁷¹, M. Henke^{58a}, A. Henrichs⁵⁴, A.M. Henriques Correia²⁹, S. Henrot-Versille¹¹⁵, F. Henry-Couannier⁸³, C. Hensel⁵⁴, T. Henß¹⁷⁴, C.M. Hernandez⁷, Y. Hernández Jiménez¹⁶⁷, R. Herrberg¹⁵, A.D. Hershenhorn¹⁵², G. Herten⁴⁸, R. Hertenberger⁹⁸, L. Hervas²⁹, N.P. Hessey¹⁰⁵, A. Hidvegi^{146a}, E. Higón-Rodríguez¹⁶⁷, D. Hill^{5,*}, J.C. Hill²⁷, N. Hill⁵, K.H. Hiller⁴¹, S. Hillert²⁰, S.J. Hillier¹⁷, I. Hinchliffe¹⁴, E. Hines¹²⁰, M. Hirose¹¹⁶, F. Hirsch⁴², D. Hirschbuehl¹⁷⁴, J. Hobbs¹⁴⁸, N. Hod¹⁵³, M.C. Hodgkinson¹³⁹, P. Hodgson¹³⁹, A. Hoecker²⁹, M.R. Hoferkamp¹⁰³, J. Hoffman³⁹, D. Hoffmann⁸³, M. Hohlfeld⁸¹, M. Holder¹⁴¹, A. Holmes¹¹⁸, S.O. Holmgren^{146a}, T. Holy¹²⁷, J.L. Holzbauer⁸⁸, Y. Homma⁶⁷, T.M. Hong¹²⁰, L. Hooft van Huysduynen¹⁰⁸, T. Horazdovsky¹²⁷, C. Horn¹⁴³, S. Horner⁴⁸, K. Horton¹¹⁸, J.-Y. Hostachy⁵⁵, S. Hou¹⁵¹, M.A. Houlden⁷³, A. Hoummada^{135a}, J. Howarth⁸², D.F. Howell¹¹⁸, I. Hristova¹⁵, J. Hrivnac¹¹⁵, I. Hruska¹²⁵, T. Hryn'ova⁴, P.J. Hsu¹⁷⁵, S.-C. Hsu¹⁴, G.S. Huang¹¹¹, Z. Hubacek¹²⁷, F. Hubaut⁸³, F. Huegging²⁰, T.B. Huffman¹¹⁸, E.W. Hughes³⁴, G. Hughes⁷¹, R.E. Hughes-Jones⁸², M. Huhtinen²⁹, P. Hurst⁵⁷, M. Hurwitz¹⁴, U. Husemann⁴¹, N. Huseynov^{65,o}, J. Huston⁸⁸, J. Huth⁵⁷, G. Iacobucci⁴⁹, G. Iakovidis⁹, M. Ibbotson⁸², I. Ibragimov¹⁴¹, R. Ichimiya⁶⁷, L. Iconomidou-Fayard¹¹⁵, J. Idarraga¹¹⁵, M. Idzik³⁷, P. Iengo^{102a,102b}, O. Igonkina¹⁰⁵, Y. Ikegami⁶⁶, M. Ikeno⁶⁶, Y. Ilchenko³⁹, D. Iliadis¹⁵⁴, D. Imbault⁷⁸, M. Imhaeuser¹⁷⁴, M. Imori¹⁵⁵, T. Ince²⁰, J. Inigo-Golfín²⁹, P. Ioannou⁸, M. Iodice^{134a}, G. Ionescu⁴, A. Irlles Quiles¹⁶⁷, K. Ishii⁶⁶, A. Ishikawa⁶⁷, M. Ishino⁶⁶, R. Ishmukhametov³⁹, C. Issever¹¹⁸,

S. Istin^{18a}, Y. Itoh¹⁰¹, A.V. Ivashin¹²⁸, W. Iwanski³⁸, H. Iwasaki⁶⁶, J.M. Izen⁴⁰, V. Izzo^{102a}, B. Jackson¹²⁰, J.N. Jackson⁷³, P. Jackson¹⁴³, M.R. Jaekel²⁹, V. Jain⁶¹, K. Jakobs⁴⁸, S. Jakobsen³⁵, J. Jakubek¹²⁷, D.K. Jana¹¹¹, E. Jankowski¹⁵⁸, E. Jansen⁷⁷, A. Jantsch⁹⁹, M. Janus²⁰, G. Jarlskog⁷⁹, L. Jeanty⁵⁷, K. Jelen³⁷, I. Jen-La Plante³⁰, P. Jenni²⁹, A. Jeremie⁴, P. Jež³⁵, S. Jézéquel⁴, M.K. Jha^{19a}, H. Ji¹⁷², W. Ji⁸¹, J. Jia¹⁴⁸, Y. Jiang^{32b}, M. Jimenez Belenguer⁴¹, G. Jin^{32b}, S. Jin^{32a}, O. Jinnouchi¹⁵⁷, M.D. Joergensen³⁵, D. Joffe³⁹, L.G. Johansen¹³, M. Johansen^{146a,146b}, K.E. Johansson^{146a}, P. Johansson¹³⁹, S. Johnert⁴¹, K.A. Johns⁶, K. Jon-And^{146a,146b}, G. Jones⁸², R.W.L. Jones⁷¹, T.W. Jones⁷⁷, T.J. Jones⁷³, O. Jonsson²⁹, C. Joram²⁹, P.M. Jorge^{124a,b}, J. Joseph¹⁴, T. Jovin^{12b}, X. Ju¹³⁰, V. Juranek¹²⁵, P. Jussel⁶², V.V. Kabachenko¹²⁸, S. Kabana¹⁶, M. Kaci¹⁶⁷, A. Kaczmarska³⁸, P. Kadlecik³⁵, M. Kado¹¹⁵, H. Kagan¹⁰⁹, M. Kagan⁵⁷, S. Kaiser⁹⁹, E. Kajomovitz¹⁵², S. Kalinin¹⁷⁴, L.V. Kalinovskaya⁶⁵, S. Kama³⁹, N. Kanaya¹⁵⁵, M. Kaneda²⁹, T. Kanno¹⁵⁷, V.A. Kantserov⁹⁶, J. Kanzaki⁶⁶, B. Kaplan¹⁷⁵, A. Kapliy³⁰, J. Kaplon²⁹, D. Kar⁴³, M. Karagoz¹¹⁸, M. Karnevskiy⁴¹, K. Karr⁵, V. Kartvelishvili⁷¹, A.N. Karyukhin¹²⁸, L. Kashif¹⁷², A. Kasmi³⁹, R.D. Kass¹⁰⁹, A. Kastanas¹³, M. Kataoka⁴, Y. Kataoka¹⁵⁵, E. Katsoufis⁹, J. Katzy⁴¹, V. Kaushik⁶, K. Kawagoe⁶⁷, T. Kawamoto¹⁵⁵, G. Kawamura⁸¹, M.S. Kayl¹⁰⁵, V.A. Kazanin¹⁰⁷, M.Y. Kazarinov⁶⁵, J.R. Keates⁸², R. Keeler¹⁶⁹, R. Kehoe³⁹, M. Keil⁵⁴, G.D. Kekelidze⁶⁵, M. Kelly⁸², J. Kennedy⁹⁸, C.J. Kenney¹⁴³, M. Kenyon⁵³, O. Kepka¹²⁵, N. Kerschen²⁹, B.P. Kerševan⁷⁴, S. Kersten¹⁷⁴, K. Kessoku¹⁵⁵, C. Ketterer⁴⁸, J. Keung¹⁵⁸, M. Khakzad²⁸, F. Khalil-zada¹⁰, H. Khandanyan¹⁶⁵, A. Khanov¹¹², D. Kharchenko⁶⁵, A. Khodinov⁹⁶, A.G. Kholodenko¹²⁸, A. Khomich^{58a}, T.J. Khoo²⁷, G. Khoraiuli²⁰, A. Khoroshilov¹⁷⁴, N. Khovanskiy⁶⁵, V. Khovanskiy⁹⁵, E. Khramov⁶⁵, J. Khubua⁵¹, H. Kim⁷, M.S. Kim², P.C. Kim¹⁴³, S.H. Kim¹⁶⁰, N. Kimura¹⁷⁰, O. Kind¹⁵, B.T. King⁷³, M. King⁶⁷, R.S.B. King¹¹⁸, J. Kirk¹²⁹, G.P. Kirsch¹¹⁸, L.E. Kirsch²², A.E. Kiryunin⁹⁹, D. Kisielewska³⁷, T. Kittelmann¹²³, A.M. Kiver¹²⁸, H. Kiyamura⁶⁷, E. Kladiva^{144b}, J. Klaiber-Lodewigs⁴², M. Klein⁷³, U. Klein⁷³, K. Kleinknecht⁸¹, M. Klemetti⁸⁵, A. Klier¹⁷¹, A. Klimentov²⁴, R. Klingenberg⁴², E.B. Klinkby³⁵, T. Klioutchnikova²⁹, P.F. Klok¹⁰⁴, S. Klous¹⁰⁵, E.-E. Kluge^{58a}, T. Kluge⁷³, P. Kluit¹⁰⁵, S. Kluth⁹⁹, E. Kneringer⁶², J. Knobloch²⁹, E.B.F.G. Knoops⁸³, A. Knue⁵⁴, B.R. Ko⁴⁴, T. Kobayashi¹⁵⁵, M. Kobel⁴³, M. Kocian¹⁴³, A. Kocnar¹¹³, P. Kodys¹²⁶, K. Köneke²⁹, A.C. König¹⁰⁴, S. Koenig⁸¹, L. Köpke⁸¹, F. Koetsveld¹⁰⁴, P. Koevesarki²⁰, T. Koffas²⁹, E. Koffeman¹⁰⁵, F. Kohn⁵⁴, Z. Kohout¹²⁷, T. Kohriki⁶⁶, T. Koi¹⁴³, T. Kokott²⁰, G.M. Kolachev¹⁰⁷, H. Kolanoski¹⁵, V. Kolesnikov⁶⁵, I. Koletsou^{89a}, J. Koll⁸⁸, D. Kollar²⁹, M. Kollefrath⁴⁸, S.D. Kolya⁸², A.A. Komar⁹⁴, J.R. Komaragiri¹⁴², Y. Komori¹⁵⁵, T. Kondo⁶⁶, T. Kono^{41,p}, A.I. Kononov⁴⁸, R. Konoplich^{108,q}, N. Konstantinidis⁷⁷, A. Kootz¹⁷⁴, S. Koperny³⁷, S.V. Kopikov¹²⁸, K. Korcyl³⁸, K. Kordas¹⁵⁴, V. Koreshev¹²⁸, A. Korn¹⁴, A. Korol¹⁰⁷, I. Korolkov¹¹, E.V. Korolkova¹³⁹, V.A. Korotkov¹²⁸, O. Kortner⁹⁹, S. Kortner⁹⁹, V.V. Kostyukhin²⁰, M.J. Kotamäki²⁹, S. Kotov⁹⁹, V.M. Kotov⁶⁵, A. Kotwal⁴⁴, C. Kourkoumelis⁸, V. Kouskoura¹⁵⁴, A. Koutsman¹⁰⁵, R. Kowalewski¹⁶⁹, T.Z. Kowalski³⁷, W. Kozanecki¹³⁶, A.S. Kozhin¹²⁸, V. Kral¹²⁷, V.A. Kramarenko⁹⁷, G. Kramberger⁷⁴, O. Krasel⁴², M.W. Krasny⁷⁸, A. Krasznahorkay¹⁰⁸, J. Kraus⁸⁸, A. Kreisel¹⁵³, F. Krejci¹²⁷, J. Kretzschmar⁷³, N. Krieger⁵⁴, P. Krieger¹⁵⁸, K. Kroeninger⁵⁴, H. Kroha⁹⁹, J. Kroll¹²⁰, J. Kroseberg²⁰, J. Krstic^{12a}, U. Kruchonak⁶⁵, H. Krüger²⁰, T. Kruker¹⁶, Z.V. Krumshteyn⁶⁵, A. Kruth²⁰, T. Kubota⁸⁶, S. Kuehn⁴⁸, A. Kugel^{58c}, T. Kuhl⁴¹, D. Kuhn⁶², V. Kukhtin⁶⁵, Y. Kulchitsky⁹⁰, S. Kuleshov^{31b}, C. Kummer⁹⁸, M. Kuna⁷⁸, N. Kundu¹¹⁸, J. Kunkle¹²⁰, A. Kupco¹²⁵, H. Kurashige⁶⁷, M. Kurata¹⁶⁰, Y.A. Kurochkin⁹⁰, V. Kus¹²⁵, W. Kuykendall¹³⁸, M. Kuze¹⁵⁷, P. Kuzhir⁹¹, O. Kvasnicka¹²⁵, J. Kvita²⁹, R. Kwee¹⁵, A. La Rosa¹⁷², L. La Rotonda^{36a,36b}, L. Labarga⁸⁰, J. Labbe⁴, S. Lablak^{135a}, C. Lacasta¹⁶⁷, F. Lacava^{132a,132b}, H. Lacker¹⁵, D. Lacour⁷⁸, V.R. Lacuesta¹⁶⁷, E. Ladygin⁶⁵, R. Lafaye⁴, B. Laforge⁷⁸, T. Lagouri⁸⁰, S. Lai⁴⁸, E. Laisne⁵⁵, M. Lamanna²⁹, C.L. Lampen⁶, W. Lampl⁶, E. Lancon¹³⁶, U. Landgraf⁴⁸, M.P.J. Landon⁷⁵, H. Landsman¹⁵², J.L. Lane⁸², C. Lange⁴¹, A.J. Lankford¹⁶³, F. Lanni²⁴, K. Lantzsch²⁹, S. Laplace⁷⁸, C. Lapoire²⁰, J.F. Laporte¹³⁶, T. Lari^{89a}, A.V. Larionov¹²⁸, A. Larner¹¹⁸, C. Lasseur²⁹, M. Lassnig²⁹, W. Lau¹¹⁸, P. Laurelli⁴⁷, A. Lavorato¹¹⁸, W. Lavrijsen¹⁴, P. Laycock⁷³, A.B. Lazarev⁶⁵, A. Lazzaro^{89a,89b}, O. Le Dortz⁷⁸, E. Le Guirriec⁸³, C. Le Maner¹⁵⁸, E. Le Menedeu¹³⁶, C. Lebel⁹³, T. LeCompte⁵, F. Ledroit-Guillon⁵⁵, H. Lee¹⁰⁵, J.S.H. Lee¹⁵⁰, S.C. Lee¹⁵¹, L. Lee¹⁷⁵, M. Lefebvre¹⁶⁹, M. Legendre¹³⁶, A. Leger⁴⁹, B.C. LeGeyt¹²⁰, F. Legger⁹⁸, C. Leggett¹⁴, M. Lehmann²⁰, G. Lehmann Miotto²⁹, X. Lei⁶, M.A.L. Leite^{23d}, R. Leitner¹²⁶, D. Lellouch¹⁷¹, M. Leltchouk³⁴, V. Lendermann^{58a}, K.J.C. Leney^{145b}, T. Lenz¹⁰⁵, G. Lenzen¹⁷⁴, B. Lenzi²⁹, K. Leonhardt⁴³, S. Leontsinis⁹, C. Leroy⁹³, J.-R. Lessard¹⁶⁹, J. Lesser^{146a}, C.G. Lester²⁷, A. Leung Fook Cheong¹⁷², J. Levêque⁴,

D. Levin⁸⁷, L.J. Levinson¹⁷¹, M.S. Levitski¹²⁸, M. Lewandowska²¹, A. Lewis¹¹⁸, G.H. Lewis¹⁰⁸,
 A.M. Leyko²⁰, M. Leyton¹⁵, B. Li⁸³, H. Li¹⁷², S. Li^{32b,d}, X. Li⁸⁷, Z. Liang³⁹, Z. Liang^{118,r}, B. Liberti^{133a},
 P. Lichard²⁹, M. Lichtnecker⁹⁸, K. Lie¹⁶⁵, W. Liebig¹³, R. Lifshitz¹⁵², J.N. Lilley¹⁷, C. Limbach²⁰,
 A. Limosani⁸⁶, M. Limper⁶³, S.C. Lin^{151,s}, F. Linde¹⁰⁵, J.T. Linnemann⁸⁸, E. Lipeles¹²⁰, L. Lipinsky¹²⁵,
 A. Lipniacka¹³, T.M. Liss¹⁶⁵, D. Lissauer²⁴, A. Lister⁴⁹, A.M. Litke¹³⁷, C. Liu²⁸, D. Liu^{151,t}, H. Liu⁸⁷,
 J.B. Liu⁸⁷, M. Liu^{32b}, S. Liu², Y. Liu^{32b}, M. Livan^{119a,119b}, S.S.A. Livermore¹¹⁸, A. Lleres⁵⁵,
 J. Llorente Merino⁸⁰, S.L. Lloyd⁷⁵, E. Lobodzinska⁴¹, P. Loch⁶, W.S. Lockman¹³⁷, S. Lockwitz¹⁷⁵,
 T. Loddenkoetter²⁰, F.K. Loebinger⁸², A. Loginov¹⁷⁵, C.W. Loh¹⁶⁸, T. Lohse¹⁵, K. Lohwasser⁴⁸,
 M. Lokajicek¹²⁵, J. Loken¹¹⁸, V.P. Lombardo⁴, R.E. Long⁷¹, L. Lopes^{124a,b}, D. Lopez Mateos^{34,u},
 M. Losada¹⁶², P. Loscutoff¹⁴, F. Lo Sterzo^{132a,132b}, M.J. Losty^{159a}, X. Lou⁴⁰, A. Lounis¹¹⁵,
 K.F. Loureiro¹⁶², J. Love²¹, P.A. Love⁷¹, A.J. Lowe^{143,f}, F. Lu^{32a}, H.J. Lubatti¹³⁸, C. Luci^{132a,132b},
 A. Lucotte⁵⁵, A. Ludwig⁴³, D. Ludwig⁴¹, I. Ludwig⁴⁸, J. Ludwig⁴⁸, F. Luehring⁶¹, G. Luijckx¹⁰⁵,
 D. Lumb⁴⁸, L. Luminari^{132a}, E. Lund¹¹⁷, B. Lund-Jensen¹⁴⁷, B. Lundberg⁷⁹, J. Lundberg^{146a,146b},
 J. Lundquist³⁵, M. Lungwitz⁸¹, A. Lupi^{122a,122b}, G. Lutz⁹⁹, D. Lynn²⁴, J. Lys¹⁴, E. Lytken⁷⁹, H. Ma²⁴,
 L.L. Ma¹⁷², J.A. Macana Goia⁹³, G. Maccarrone⁴⁷, A. Macchiolo⁹⁹, B. Maček⁷⁴, J. Machado Miguens^{124a},
 R. Mackeprang³⁵, R.J. Madaras¹⁴, W.F. Mader⁴³, R. Maenner^{58c}, T. Maeno²⁴, P. Mättig¹⁷⁴, S. Mättig⁴¹,
 P.J. Magalhaes Martins^{124a,i}, L. Magnoni²⁹, E. Magradze⁵⁴, Y. Mahalalel¹⁵³, K. Mahboubi⁴⁸,
 G. Mahout¹⁷, C. Maiani^{132a,132b}, C. Maidantchik^{23a}, A. Maio^{124a,b}, S. Majewski²⁴, Y. Makida⁶⁶,
 N. Makovec¹¹⁵, P. Mal⁶, Pa. Malecki³⁸, P. Malecki³⁸, V.P. Maleev¹²¹, F. Malek⁵⁵, U. Mallik⁶³, D. Malon⁵,
 S. Maltezos⁹, V. Malyshev¹⁰⁷, S. Malyukov²⁹, R. Mameghani⁹⁸, J. Mamuzic^{12b}, A. Manabe⁶⁶,
 L. Mandelli^{89a}, I. Mandić⁷⁴, R. Mandrysch¹⁵, J. Maneira^{124a}, P.S. Mangear⁸⁸, I.D. Manjavidze⁶⁵,
 A. Mann⁵⁴, P.M. Manning¹³⁷, A. Manousakis-Katsikakis⁸, B. Mansoulie¹³⁶, A. Manz⁹⁹, A. Mapelli²⁹,
 L. Mapelli²⁹, L. March⁸⁰, J.F. Marchand²⁹, F. Marchese^{133a,133b}, G. Marchiori⁷⁸, M. Marcisovsky¹²⁵,
 A. Marin^{21,*}, C.P. Marino⁶¹, F. Marroquim^{23a}, R. Marshall⁸², Z. Marshall²⁹, F.K. Martens¹⁵⁸,
 S. Marti-Garcia¹⁶⁷, A.J. Martin¹⁷⁵, B. Martin²⁹, B. Martin⁸⁸, F.F. Martin¹²⁰, J.P. Martin⁹³, Ph. Martin⁵⁵,
 T.A. Martin¹⁷, V.J. Martin⁴⁵, B. Martin dit Latour⁴⁹, M. Martinez¹¹, V. Martinez Outschoorn⁵⁷,
 A.C. Martyniuk⁸², M. Marx⁸², F. Marzano^{132a}, A. Marzin¹¹¹, L. Masetti⁸¹, T. Mashimo¹⁵⁵,
 R. Mashinistov⁹⁴, J. Masik⁸², A.L. Maslennikov¹⁰⁷, M. Maß⁴², I. Massa^{19a,19b}, G. Massaro¹⁰⁵,
 N. Massol⁴, P. Mastrandrea^{132a,132b}, A. Mastroberardino^{36a,36b}, T. Masubuchi¹⁵⁵, M. Mathes²⁰,
 P. Matricon¹¹⁵, H. Matsumoto¹⁵⁵, H. Matsunaga¹⁵⁵, T. Matsushita⁶⁷, C. Mattravers^{118,c}, J.M. Maugain²⁹,
 S.J. Maxfield⁷³, D.A. Maximov¹⁰⁷, E.N. May⁵, A. Mayne¹³⁹, R. Mazini¹⁵¹, M. Mazur²⁰, M. Mazzanti^{89a},
 E. Mazzoni^{122a,122b}, S.P. Mc Kee⁸⁷, A. McCarn¹⁶⁵, R.L. McCarthy¹⁴⁸, T.G. McCarthy²⁸, N.A. McCubbin¹²⁹,
 K.W. McFarlane⁵⁶, J.A. McFayden¹³⁹, H. McGlone⁵³, G. Mchedlidze⁵¹, R.A. McLaren²⁹, T. McLaughlan¹⁷,
 S.J. McMahan¹²⁹, R.A. McPherson^{169,k}, A. Meade⁸⁴, J. Mechnich¹⁰⁵, M. Mechtel¹⁷⁴, M. Medinnis⁴¹,
 R. Meera-Lebbai¹¹¹, T. Meguro¹¹⁶, R. Mehdiyev⁹³, S. Mehlhase³⁵, A. Mehta⁷³, K. Meier^{58a},
 J. Meinhardt⁴⁸, B. Meirose⁷⁹, C. Melachrinou³⁰, B.R. Mellado Garcia¹⁷², L. Mendoza Navas¹⁶²,
 Z. Meng^{151,t}, A. Mengarelli^{19a,19b}, S. Menke⁹⁹, C. Menot²⁹, E. Meoni¹¹, K.M. Mercurio⁵⁷, P. Mermod¹¹⁸,
 L. Merola^{102a,102b}, C. Meroni^{89a}, F.S. Merritt³⁰, A. Messina²⁹, J. Metcalfe¹⁰³, A.S. Mete⁶⁴, S. Meuser²⁰,
 C. Meyer⁸¹, J.-P. Meyer¹³⁶, J. Meyer¹⁷³, J. Meyer⁵⁴, T.C. Meyer²⁹, W.T. Meyer⁶⁴, J. Miao^{32d}, S. Michal²⁹,
 L. Micu^{25a}, R.P. Middleton¹²⁹, P. Miele²⁹, S. Migas⁷³, L. Mijović⁴¹, G. Mikenberg¹⁷¹, M. Mikestikova¹²⁵,
 M. Mikuš⁷⁴, D.W. Miller¹⁴³, R.J. Miller⁸⁸, W.J. Mills¹⁶⁸, C. Mills⁵⁷, A. Milov¹⁷¹, D.A. Milstead^{146a,146b},
 D. Milstein¹⁷¹, A.A. Minaenko¹²⁸, M. Miñano¹⁶⁷, I.A. Minashvili⁶⁵, A.I. Mincer¹⁰⁸, B. Mindur³⁷,
 M. Mineev⁶⁵, Y. Ming¹³⁰, L.M. Mir¹¹, G. Mirabelli^{132a}, L. Miralles Verge¹¹, A. Misiejuk⁷⁶,
 J. Mitrevski¹³⁷, G.Y. Mitrofanov¹²⁸, V.A. Mitsou¹⁶⁷, S. Mitsui⁶⁶, P.S. Miyagawa⁸², K. Miyazaki⁶⁷,
 J.U. Mjörnmark⁷⁹, T. Moa^{146a,146b}, P. Mockett¹³⁸, S. Moed⁵⁷, V. Moeller²⁷, K. Mönig⁴¹, N. Möser²⁰,
 S. Mohapatra¹⁴⁸, B. Mohn¹³, W. Mohr⁴⁸, S. Mohrdieck-Möck⁹⁹, A.M. Moiseev^{128,*}, R. Moles-Valls¹⁶⁷,
 J. Molina-Perez²⁹, J. Monk⁷⁷, E. Monnier⁸³, S. Montesano^{89a,89b}, F. Monticelli⁷⁰, S. Monzani^{19a,19b},
 R.W. Moore², G.F. Moorhead⁸⁶, C. Mora Herrera⁴⁹, A. Moraes⁵³, A. Morais^{124a,b}, N. Morange¹³⁶,
 J. Morel⁵⁴, G. Morello^{36a,36b}, D. Moreno⁸¹, M. Moreno Llácer¹⁶⁷, P. Morettini^{50a}, M. Morii⁵⁷, J. Morin⁷⁵,
 Y. Morita⁶⁶, A.K. Morley²⁹, G. Mornacchi²⁹, M.-C. Morone⁴⁹, S.V. Morozov⁹⁶, J.D. Morris⁷⁵,
 L. Morvaj¹⁰¹, H.G. Moser⁹⁹, M. Mosidze⁵¹, J. Moss¹⁰⁹, R. Mount¹⁴³, E. Mountricha¹³⁶, S.V. Mouraviev⁹⁴,
 E.J.W. Moyse⁸⁴, M. Mudrinic^{12b}, F. Mueller^{58a}, J. Mueller¹²³, K. Mueller²⁰, T.A. Müller⁹⁸,

D. Muenstermann²⁹, A. Muijs¹⁰⁵, A. Muir¹⁶⁸, Y. Munwes¹⁵³, K. Murakami⁶⁶, W.J. Murray¹²⁹,
 I. Mussche¹⁰⁵, E. Musto^{102a,102b}, A.G. Myagkov¹²⁸, M. Myska¹²⁵, J. Nadal¹¹, K. Nagai¹⁶⁰, K. Nagano⁶⁶,
 Y. Nagasaka⁶⁰, A.M. Nairz²⁹, Y. Nakahama²⁹, K. Nakamura¹⁵⁵, I. Nakano¹¹⁰, G. Nanava²⁰, A. Napier¹⁶¹,
 M. Nash^{77,c}, N.R. Nation²¹, T. Nattermann²⁰, T. Naumann⁴¹, G. Navarro¹⁶², H.A. Neal⁸⁷, E. Nebot⁸⁰,
 P.Yu. Nechaeva⁹⁴, A. Negri^{119a,119b}, G. Negri²⁹, S. Nektarijevic⁴⁹, A. Nelson⁶⁴, S. Nelson¹⁴³,
 T.K. Nelson¹⁴³, S. Nemecek¹²⁵, P. Nemethy¹⁰⁸, A.A. Nepomuceno^{23a}, M. Nessi^{29,v}, S.Y. Nesterov¹²¹,
 M.S. Neubauer¹⁶⁵, A. Neusiedl⁸¹, R.M. Neves¹⁰⁸, P. Nevski²⁴, P.R. Newman¹⁷, V. Nguyen Thi Hong¹³⁶,
 R.B. Nickerson¹¹⁸, R. Nicolaidou¹³⁶, L. Nicolas¹³⁹, B. Nicquevert²⁹, F. Niedercorn¹¹⁵, J. Nielsen¹³⁷,
 T. Niinikoski²⁹, A. Nikiforov¹⁵, V. Nikolaenko¹²⁸, K. Nikolaev⁶⁵, I. Nikolic-Audit⁷⁸, K. Nikolics⁴⁹,
 K. Nikolopoulos²⁴, H. Nilsen⁴⁸, P. Nilsson⁷, Y. Ninomiya¹⁵⁵, A. Nisati^{132a}, T. Nishiyama⁶⁷, R. Nisius⁹⁹,
 L. Nodulman⁵, M. Nomachi¹¹⁶, I. Nomidis¹⁵⁴, M. Nordberg²⁹, B. Nordkvist^{146a,146b}, P.R. Norton¹²⁹,
 J. Novakova¹²⁶, M. Nozaki⁶⁶, M. Nožička⁴¹, L. Nozka¹¹³, I.M. Nugent^{159a}, A.-E. Nuncio-Quiroz²⁰,
 G. Nunes Hanninger⁸⁶, T. Nunnemann⁹⁸, E. Nurse⁷⁷, T. Nyman²⁹, B.J. O'Brien⁴⁵, S.W. O'Neale^{17,*},
 D.C. O'Neil¹⁴², V. O'Shea⁵³, F.G. Oakham^{28,e}, H. Oberlack⁹⁹, J. Ocariz⁷⁸, A. Ochi⁶⁷, S. Oda¹⁵⁵,
 S. Odaka⁶⁶, J. Odier⁸³, H. Ogren⁶¹, A. Oh⁸², S.H. Oh⁴⁴, C.C. Ohm^{146a,146b}, T. Ohshima¹⁰¹, H. Ohshita¹⁴⁰,
 T.K. Ohsaka⁶⁶, T. Ohsugi⁵⁹, S. Okada⁶⁷, H. Okawa¹⁶³, Y. Okumura¹⁰¹, T. Okuyama¹⁵⁵, M. Olcese^{50a},
 A.G. Olchevski⁶⁵, M. Oliveira^{124a,i}, D. Oliveira Damazio²⁴, E. Oliver Garcia¹⁶⁷, D. Olivito¹²⁰,
 A. Olszewski³⁸, J. Olszowska³⁸, C. Omachi⁶⁷, A. Onofre^{124a,w}, P.U.E. Onyisi³⁰, C.J. Oram^{159a},
 M.J. Oreglia³⁰, Y. Oren¹⁵³, D. Orestano^{134a,134b}, I. Orlov¹⁰⁷, C. Oropeza Barrera⁵³, R.S. Orr¹⁵⁸,
 B. Osculati^{50a,50b}, R. Ospanov¹²⁰, C. Osuna¹¹, G. Otero y Garzon²⁶, J.P. Ottersbach¹⁰⁵, M. Ouchrif^{135d},
 F. Ould-Saada¹¹⁷, A. Ouraou¹³⁶, Q. Ouyang^{32a}, M. Owen⁸², S. Owen¹³⁹, O.K. Øye¹³, V.E. Ozcan^{18a},
 N. Ozturk⁷, A. Pacheco Pages¹¹, C. Padilla Aranda¹¹, S. Pagan Griso¹⁴, E. Paganis¹³⁹, F. Paige²⁴,
 K. Pajchel¹¹⁷, S. Palestini²⁹, D. Pallin³³, A. Palma^{124a,b}, J.D. Palmer¹⁷, Y.B. Pan¹⁷², E. Panagiotopoulou⁹,
 B. Panes^{31a}, N. Panikashvili⁸⁷, S. Panitkin²⁴, D. Pantea^{25a}, M. Panuskova¹²⁵, V. Paolone¹²³,
 A. Papadelis^{146a}, Th.D. Papadopoulou⁹, A. Paramonov⁵, W. Park^{24,x}, M.A. Parker²⁷, F. Parodi^{50a,50b},
 J.A. Parsons³⁴, U. Parzefall⁴⁸, E. Pasqualucci^{132a}, A. Passeri^{134a}, F. Pastore^{134a,134b}, Fr. Pastore²⁹,
 G. Pásztor^{49,y}, S. Patarraia¹⁷², N. Patel¹⁵⁰, J.R. Pater⁸², S. Patricelli^{102a,102b}, T. Pauly²⁹, M. Pecsý^{144a},
 M.I. Pedraza Morales¹⁷², S.V. Peleganchuk¹⁰⁷, H. Peng^{32b}, R. Pengo²⁹, A. Penson³⁴, J. Penwell⁶¹,
 M. Perantoni^{23a}, K. Perez^{34,u}, T. Perez Cavalcanti⁴¹, E. Perez Codina¹¹, M.T. Pérez García-Estañ¹⁶⁷,
 V. Perez Reale³⁴, L. Perini^{89a,89b}, H. Pernegger²⁹, R. Perrino^{72a}, P. Perrodo⁴, S. Persebe^{3a},
 V.D. Peshekhonov⁶⁵, O. Peters¹⁰⁵, B.A. Petersen²⁹, J. Petersen²⁹, T.C. Petersen³⁵, E. Petit⁸³,
 A. Petridis¹⁵⁴, C. Petridou¹⁵⁴, E. Petrolo^{132a}, F. Petrucci^{134a,134b}, D. Petschull⁴¹, M. Petteni¹⁴²,
 R. Pezoa^{31b}, A. Phan⁸⁶, A.W. Phillips²⁷, P.W. Phillips¹²⁹, G. Piacquadio²⁹, E. Piccaro⁷⁵,
 M. Piccinini^{19a,19b}, A. Pickford⁵³, S.M. Piec⁴¹, R. Piegai²⁶, J.E. Pilcher³⁰, A.D. Pilkington⁸², J. Pina^{124a,b},
 M. Pinamonti^{164a,164c}, A. Pinder¹¹⁸, J.L. Pinfold², J. Ping^{32c}, B. Pinto^{124a,b}, O. Pirotte²⁹, C. Pizio^{89a,89b},
 R. Placakyte⁴¹, M. Plamondon¹⁶⁹, W.G. Plano⁸², M.-A. Pleier²⁴, A.V. Pleskach¹²⁸, A. Poblaguev²⁴,
 S. Poddar^{58a}, F. Podlyski³³, L. Poggioli¹¹⁵, T. Poghosyan²⁰, M. Pohl⁴⁹, F. Polci⁵⁵, G. Polesello^{119a},
 A. Policicchio¹³⁸, A. Polini^{19a}, J. Poll⁷⁵, V. Polychronakos²⁴, D.M. Pomarede¹³⁶, D. Pomeroy²²,
 K. Pommès²⁹, L. Pontecorvo^{132a}, B.G. Pope⁸⁸, G.A. Popeneciu^{25a}, D.S. Popovic^{12a}, A. Poppleton²⁹,
 X. Portell Bueso²⁹, R. Porter¹⁶³, C. Posch²¹, G.E. Pospelov⁹⁹, S. Pospisil¹²⁷, I.N. Potrap⁹⁹, C.J. Potter¹⁴⁹,
 C.T. Potter¹¹⁴, G. Poulard²⁹, J. Poveda¹⁷², R. Prabhu⁷⁷, P. Pralavorio⁸³, S. Prasad⁵⁷, R. Pravahan⁷,
 S. Prell⁶⁴, K. Pretzl¹⁶, L. Pribyl²⁹, D. Price⁶¹, L.E. Price⁵, M.J. Price²⁹, P.M. Prichard⁷³, D. Prieur¹²³,
 M. Primavera^{72a}, K. Prokofiev¹⁰⁸, F. Prokoshin^{31b}, S. Protopopescu²⁴, J. Proudfoot⁵, X. Prudent⁴³,
 H. Przysiezniak⁴, S. Psoroulas²⁰, E. Ptacek¹¹⁴, J. Purdham⁸⁷, M. Purohit^{24,x}, P. Puzo¹¹⁵,
 Y. Pylypchenko¹¹⁷, J. Qian⁸⁷, Z. Qian⁸³, Z. Qin⁴¹, A. Quadt⁵⁴, D.R. Quarrie¹⁴, W.B. Quayle¹⁷²,
 F. Quinonez^{31a}, M. Raas¹⁰⁴, V. Radescu^{58b}, B. Radics²⁰, T. Rador^{18a}, F. Ragusa^{89a,89b}, G. Rahal¹⁷⁷,
 A.M. Rahimi¹⁰⁹, D. Rahm²⁴, S. Rajagopalan²⁴, M. Rammensee⁴⁸, M. Rammes¹⁴¹, M. Ramstedt^{146a,146b},
 K. Randrianarivony²⁸, P.N. Ratoff⁷¹, F. Rauscher⁹⁸, E. Rauter⁹⁹, M. Raymond²⁹, A.L. Read¹¹⁷,
 D.M. Rebuzzi^{119a,119b}, A. Redelbach¹⁷³, G. Redlinger²⁴, R. Reece¹²⁰, K. Reeves⁴⁰, A. Reichold¹⁰⁵,
 E. Reinherz-Aronis¹⁵³, A. Reinsch¹¹⁴, I. Reisinger⁴², D. Reljic^{12a}, C. Rembser²⁹, Z.L. Ren¹⁵¹,
 A. Renaud¹¹⁵, P. Renkel³⁹, M. Rescigno^{132a}, S. Resconi^{89a}, B. Resende¹³⁶, P. Reznicek⁹⁸, R. Rezvani¹⁵⁸,
 A. Richards⁷⁷, R. Richter⁹⁹, E. Richter-Was^{38,z}, M. Ridel⁷⁸, S. Rieke⁸¹, M. Rijpstra¹⁰⁵, M. Rijssenbeek¹⁴⁸,

A. Rimoldi ^{119a,119b}, L. Rinaldi ^{19a}, R.R. Rios ³⁹, I. Riu ¹¹, G. Rivoltella ^{89a,89b}, F. Rizatdinova ¹¹², E. Rizvi ⁷⁵,
 S.H. Robertson ^{85,k}, A. Robichaud-Veronneau ⁴⁹, D. Robinson ²⁷, J.E.M. Robinson ⁷⁷, M. Robinson ¹¹⁴,
 A. Robson ⁵³, J.G. Rocha de Lima ¹⁰⁶, C. Roda ^{122a,122b}, D. Roda Dos Santos ²⁹, S. Rodier ⁸⁰,
 D. Rodriguez ¹⁶², A. Roe ⁵⁴, S. Roe ²⁹, O. Røhne ¹¹⁷, V. Rojo ¹, S. Rolli ¹⁶¹, A. Romaniouk ⁹⁶,
 V.M. Romanov ⁶⁵, G. Romeo ²⁶, D. Romero Maltrana ^{31a}, L. Roos ⁷⁸, E. Ros ¹⁶⁷, S. Rosati ^{132a,132b},
 K. Rosbach ⁴⁹, M. Rose ⁷⁶, G.A. Rosenbaum ¹⁵⁸, E.I. Rosenberg ⁶⁴, P.L. Rosendahl ¹³, L. Rosselet ⁴⁹,
 V. Rossetti ¹¹, E. Rossi ^{102a,102b}, L.P. Rossi ^{50a}, L. Rossi ^{89a,89b}, M. Rotaru ^{25a}, I. Roth ¹⁷¹, J. Rothberg ¹³⁸,
 D. Rousseau ¹¹⁵, C.R. Royon ¹³⁶, A. Rozanov ⁸³, Y. Rozen ¹⁵², X. Ruan ¹¹⁵, I. Rubinskiy ⁴¹, B. Ruckert ⁹⁸,
 N. Ruckstuhl ¹⁰⁵, V.I. Rud ⁹⁷, C. Rudolph ⁴³, G. Rudolph ⁶², F. Rühr ⁶, F. Ruggieri ^{134a,134b},
 A. Ruiz-Martinez ⁶⁴, E. Rulikowska-Zarebska ³⁷, V. Rumiantsev ^{91,*}, L. Rummyantsev ⁶⁵, K. Runge ⁴⁸,
 O. Runolfsson ²⁰, Z. Rurikova ⁴⁸, N.A. Rusakovich ⁶⁵, D.R. Rust ⁶¹, J.P. Rutherford ⁶, C. Ruwiedel ¹⁴,
 P. Ruzicka ¹²⁵, Y.F. Ryabov ¹²¹, V. Ryadovikov ¹²⁸, P. Ryan ⁸⁸, M. Rybar ¹²⁶, G. Rybkin ¹¹⁵, N.C. Ryder ¹¹⁸,
 S. Rzaeva ¹⁰, A.F. Saavedra ¹⁵⁰, I. Sadeh ¹⁵³, H.F.-W. Sadrozinski ¹³⁷, R. Sadykov ⁶⁵, F. Safai Tehrani ^{132a,132b},
 H. Sakamoto ¹⁵⁵, G. Salamanna ⁷⁵, A. Salamon ^{133a}, M. Saleem ¹¹¹, D. Salihagic ⁹⁹, A. Salnikov ¹⁴³,
 J. Salt ¹⁶⁷, B.M. Salvachua Ferrando ⁵, D. Salvatore ^{36a,36b}, F. Salvatore ¹⁴⁹, A. Salvucci ¹⁰⁴, A. Salzburger ²⁹,
 D. Sampsonidis ¹⁵⁴, B.H. Samset ¹¹⁷, A. Sanchez ^{102a,102b}, H. Sandaker ¹³, H.G. Sander ⁸¹, M.P. Sanders ⁹⁸,
 M. Sandhoff ¹⁷⁴, T. Sandoval ²⁷, R. Sandstroem ⁹⁹, S. Sandvoss ¹⁷⁴, D.P.C. Sankey ¹²⁹, A. Sansoni ⁴⁷,
 C. Santamarina Rios ⁸⁵, C. Santoni ³³, R. Santonico ^{133a,133b}, H. Santos ^{124a}, J.G. Saraiva ^{124a,b}, T. Sarangi ¹⁷²,
 E. Sarkisyan-Grinbaum ⁷, F. Sarri ^{122a,122b}, G. Sartisohn ¹⁷⁴, O. Sasaki ⁶⁶, T. Sasaki ⁶⁶, N. Sasao ⁶⁸,
 I. Satsounkevitch ⁹⁰, G. Sauvage ⁴, E. Sauvan ⁴, J.B. Sauvan ¹¹⁵, P. Savard ^{158,e}, V. Savinov ¹²³, D.O. Savu ²⁹,
 P. Savva ⁹, L. Sawyer ^{24,m}, D.H. Saxon ⁵³, L.P. SAYS ³³, C. Sbarra ^{19a,19b}, A. Sbrizzi ^{19a,19b}, O. Scallon ⁹³,
 D.A. Scannicchio ¹⁶³, J. Schaarschmidt ¹¹⁵, P. Schacht ⁹⁹, U. Schäfer ⁸¹, S. Schaepe ²⁰, S. Schaezel ^{58b},
 A.C. Schaffer ¹¹⁵, D. Schaile ⁹⁸, R.D. Schamberger ¹⁴⁸, A.G. Schamov ¹⁰⁷, V. Scharf ^{58a}, V.A. Schegelsky ¹²¹,
 D. Scheirich ⁸⁷, M. Schernau ¹⁶³, M.I. Scherzer ¹⁴, C. Schiavi ^{50a,50b}, J. Schieck ⁹⁸, M. Schioppa ^{36a,36b},
 S. Schlenker ²⁹, J.L. Schlereth ⁵, E. Schmidt ⁴⁸, K. Schmieden ²⁰, C. Schmitt ⁸¹, S. Schmitt ^{58b}, M. Schmitz ²⁰,
 A. Schöning ^{58b}, M. Schott ²⁹, D. Schouten ¹⁴², J. Schovancova ¹²⁵, M. Schram ⁸⁵, C. Schroeder ⁸¹,
 N. Schroer ^{58c}, S. Schuh ²⁹, G. Schuler ²⁹, J. Schultes ¹⁷⁴, H.-C. Schultz-Coulon ^{58a}, H. Schulz ¹⁵,
 J.W. Schumacher ²⁰, M. Schumacher ⁴⁸, B.A. Schumm ¹³⁷, Ph. Schune ¹³⁶, C. Schwanenberger ⁸²,
 A. Schwartzman ¹⁴³, Ph. Schwemling ⁷⁸, R. Schwienhorst ⁸⁸, R. Schwierz ⁴³, J. Schwindling ¹³⁶,
 W.G. Scott ¹²⁹, J. Searcy ¹¹⁴, E. Sedykh ¹²¹, E. Segura ¹¹, S.C. Seidel ¹⁰³, A. Seiden ¹³⁷, F. Seifert ⁴³,
 J.M. Seixas ^{23a}, G. Sekhniaidze ^{102a}, D.M. Seliverstov ¹²¹, B. Sellden ^{146a}, G. Sellers ⁷³, M. Seman ^{144b},
 N. Semprini-Cesari ^{19a,19b}, C. Serfon ⁹⁸, L. Serin ¹¹⁵, R. Seuster ⁹⁹, H. Severini ¹¹¹, M.E. Sevier ⁸⁶,
 A. Sfyrla ²⁹, E. Shabalina ⁵⁴, M. Shamim ¹¹⁴, L.Y. Shan ^{32a}, J.T. Shank ²¹, Q.T. Shao ⁸⁶, M. Shapiro ¹⁴,
 P.B. Shatalov ⁹⁵, L. Shaver ⁶, C. Shaw ⁵³, K. Shaw ^{164a,164c}, D. Sherman ¹⁷⁵, P. Sherwood ⁷⁷, A. Shibata ¹⁰⁸,
 H. Shichi ¹⁰¹, S. Shimizu ²⁹, M. Shimojima ¹⁰⁰, T. Shin ⁵⁶, A. Shmeleva ⁹⁴, M.J. Shochet ³⁰, D. Short ¹¹⁸,
 M.A. Shupe ⁶, P. Sicho ¹²⁵, A. Sidoti ^{132a,132b}, A. Siebel ¹⁷⁴, F. Siegert ⁴⁸, J. Siegrist ¹⁴, Dj. Sijacki ^{12a},
 O. Silbert ¹⁷¹, J. Silva ^{124a,b}, Y. Silver ¹⁵³, D. Silverstein ¹⁴³, S.B. Silverstein ^{146a}, V. Simak ¹²⁷, O. Simard ¹³⁶,
 Lj. Simic ^{12a}, S. Simion ¹¹⁵, B. Simmons ⁷⁷, M. Simonyan ³⁵, P. Sinervo ¹⁵⁸, N.B. Sinev ¹¹⁴, V. Sipica ¹⁴¹,
 G. Siragusa ¹⁷³, A.N. Sisakyan ⁶⁵, S.Yu. Sivoklokov ⁹⁷, J. Sjölin ^{146a,146b}, T.B. Sjursten ¹³, L.A. Skinnari ¹⁴,
 K. Skovpen ¹⁰⁷, P. Skubic ¹¹¹, N. Skvorodnev ²², M. Slater ¹⁷, T. Slavicek ¹²⁷, K. Sliwa ¹⁶¹, T.J. Sloan ⁷¹,
 J. Sloper ²⁹, V. Smakhtin ¹⁷¹, S.Yu. Smirnov ⁹⁶, L.N. Smirnova ⁹⁷, O. Smirnova ⁷⁹, B.C. Smith ⁵⁷, D. Smith ¹⁴³,
 K.M. Smith ⁵³, M. Smizanska ⁷¹, K. Smolek ¹²⁷, A.A. Snesarev ⁹⁴, S.W. Snow ⁸², J. Snow ¹¹¹, J. Snuverink ¹⁰⁵,
 S. Snyder ²⁴, M. Soares ^{124a}, R. Sobie ^{169,k}, J. Sodomka ¹²⁷, A. Soffer ¹⁵³, C.A. Solans ¹⁶⁷, M. Solar ¹²⁷,
 J. Solc ¹²⁷, E. Soldatov ⁹⁶, U. Soldevila ¹⁶⁷, E. Solfaroli Camillocci ^{132a,132b}, A.A. Solodkov ¹²⁸,
 O.V. Solovyanov ¹²⁸, J. Sondericker ²⁴, N. Soni ², V. Sopko ¹²⁷, B. Sopko ¹²⁷, M. Sorbi ^{89a,89b}, M. Sosebee ⁷,
 A. Soukharev ¹⁰⁷, S. Spagnolo ^{72a,72b}, F. Spanò ³⁴, R. Spighi ^{19a}, G. Spigo ²⁹, F. Spila ^{132a,132b}, E. Spiriti ^{134a},
 R. Spiwoks ²⁹, M. Spousta ¹²⁶, T. Spreitzer ¹⁵⁸, B. Spurlock ⁷, R.D. St. Denis ⁵³, T. Stahl ¹⁴¹, J. Stahlman ¹²⁰,
 R. Stamen ^{58a}, E. Stanecka ²⁹, R.W. Stanek ⁵, C. Stanescu ^{134a}, S. Stapnes ¹¹⁷, E.A. Starchenko ¹²⁸, J. Stark ⁵⁵,
 P. Staroba ¹²⁵, P. Starovoitov ⁹¹, A. Staude ⁹⁸, P. Stavina ^{144a}, G. Stavropoulos ¹⁴, G. Steele ⁵³, P. Steinbach ⁴³,
 P. Steinberg ²⁴, I. Stekl ¹²⁷, B. Stelzer ¹⁴², H.J. Stelzer ⁸⁸, O. Stelzer-Chilton ^{159a}, H. Stenzel ⁵²,
 K. Stevenson ⁷⁵, G.A. Stewart ²⁹, J.A. Stillings ²⁰, T. Stockmanns ²⁰, M.C. Stockton ²⁹, K. Stoerig ⁴⁸,
 G. Stoica ^{25a}, S. Stonjek ⁹⁹, P. Strachota ¹²⁶, A.R. Stradling ⁷, A. Straessner ⁴³, J. Strandberg ¹⁴⁷,

S. Strandberg^{146a,146b}, A. Strandlie¹¹⁷, M. Strang¹⁰⁹, E. Strauss¹⁴³, M. Strauss¹¹¹, P. Strizenec^{144b}, R. Ströhmer¹⁷³, D.M. Strom¹¹⁴, J.A. Strong^{76,*}, R. Stroynowski³⁹, J. Strube¹²⁹, B. Stugu¹³, I. Stumer^{24,*}, J. Stupak¹⁴⁸, P. Sturm¹⁷⁴, D.A. Soh^{151,r}, D. Su¹⁴³, H.S. Subramania², A. Succurro¹¹, Y. Sugaya¹¹⁶, T. Sugimoto¹⁰¹, C. Suhr¹⁰⁶, K. Suita⁶⁷, M. Suk¹²⁶, V.V. Sulin⁹⁴, S. Sultansoy^{3d}, T. Sumida²⁹, X. Sun⁵⁵, J.E. Sundermann⁴⁸, K. Suruliz¹³⁹, S. Sushkov¹¹, G. Susinno^{36a,36b}, M.R. Sutton¹⁴⁹, Y. Suzuki⁶⁶, M. Svatos¹²⁵, Yu.M. Sviridov¹²⁸, S. Swedish¹⁶⁸, I. Sykora^{144a}, T. Sykora¹²⁶, B. Szeless²⁹, J. Sánchez¹⁶⁷, D. Ta¹⁰⁵, K. Tackmann⁴¹, A. Taffard¹⁶³, R. Tafirout^{159a}, A. Taga¹¹⁷, N. Taiblum¹⁵³, Y. Takahashi¹⁰¹, H. Takai²⁴, R. Takashima⁶⁹, H. Takeda⁶⁷, T. Takeshita¹⁴⁰, M. Talby⁸³, A. Talyshev¹⁰⁷, M.C. Tamsett²⁴, J. Tanaka¹⁵⁵, R. Tanaka¹¹⁵, S. Tanaka¹³¹, S. Tanaka⁶⁶, Y. Tanaka¹⁰⁰, K. Tani⁶⁷, N. Tannoury⁸³, G.P. Tappern²⁹, S. Tapprogge⁸¹, D. Tardif¹⁵⁸, S. Tarem¹⁵², F. Tarrade²⁴, G.F. Tartarelli^{89a}, P. Tas¹²⁶, M. Tasevsky¹²⁵, E. Tassi^{36a,36b}, M. Tatarkhanov¹⁴, Y. Tayalati^{135d}, C. Taylor⁷⁷, F.E. Taylor⁹², G.N. Taylor⁸⁶, W. Taylor^{159b}, M. Teixeira Dias Castanheira⁷⁵, P. Teixeira-Dias⁷⁶, K.K. Temming⁴⁸, H. Ten Kate²⁹, P.K. Teng¹⁵¹, S. Terada⁶⁶, K. Terashi¹⁵⁵, J. Terron⁸⁰, M. Terwort^{41,p}, M. Testa⁴⁷, R.J. Teuscher^{158,k}, J. Thadome¹⁷⁴, J. Therhaag²⁰, T. Theveneaux-Pelzer⁷⁸, M. Thioye¹⁷⁵, S. Thoma⁴⁸, J.P. Thomas¹⁷, E.N. Thompson⁸⁴, P.D. Thompson¹⁷, P.D. Thompson¹⁵⁸, A.S. Thompson⁵³, E. Thomson¹²⁰, M. Thomson²⁷, R.P. Thun⁸⁷, T. Tic¹²⁵, V.O. Tikhomirov⁹⁴, Y.A. Tikhonov¹⁰⁷, C.J.W.P. Timmermans¹⁰⁴, P. Tipton¹⁷⁵, F.J. Tique Aires Viegas²⁹, S. Tisserant⁸³, J. Tobias⁴⁸, B. Toczec³⁷, T. Todorov⁴, S. Todorova-Nova¹⁶¹, B. Toggerson¹⁶³, J. Tojo⁶⁶, S. Tokár^{144a}, K. Tokunaga⁶⁷, K. Tokushuku⁶⁶, K. Tollefson⁸⁸, M. Tomoto¹⁰¹, L. Tompkins¹⁴, K. Toms¹⁰³, G. Tong^{32a}, A. Tonoyan¹³, C. Topfel¹⁶, N.D. Topilin⁶⁵, I. Torchiani²⁹, E. Torrence¹¹⁴, H. Torres⁷⁸, E. Torró Pastor¹⁶⁷, J. Toth^{83,y}, F. Touchard⁸³, D.R. Tovey¹³⁹, D. Traynor⁷⁵, T. Trefzger¹⁷³, L. Tremblet²⁹, A. Tricoli²⁹, I.M. Trigger^{159a}, S. Trincaz-Duvoid⁷⁸, T.N. Trinh⁷⁸, M.F. Tripiana⁷⁰, W. Trischuk¹⁵⁸, A. Trivedi^{24,x}, B. Trocmé⁵⁵, C. Troncon^{89a}, M. Trottier-McDonald¹⁴², A. Trzupek³⁸, C. Tsarouchas²⁹, J.C.-L. Tseng¹¹⁸, M. Tsiakiris¹⁰⁵, P.V. Tsiarehka⁹⁰, D. Tsiou⁴, G. Tsipolitis⁹, V. Tsiskaridze⁴⁸, E.G. Tskhadadze⁵¹, I.I. Tsukerman⁹⁵, V. Tsulaia¹⁴, J.-W. Tsung²⁰, S. Tsuno⁶⁶, D. Tsybychev¹⁴⁸, A. Tua¹³⁹, J.M. Tuggle³⁰, M. Turala³⁸, D. Turecek¹²⁷, I. Turk Cakir^{3e}, E. Turlay¹⁰⁵, R. Turra^{89a,89b}, P.M. Tuts³⁴, A. Tykhonov⁷⁴, M. Tylmad^{146a,146b}, M. Tyndel¹²⁹, H. Tyrvalinen²⁹, G. Tzanakos⁸, K. Uchida²⁰, I. Ueda¹⁵⁵, R. Ueno²⁸, M. Uglund¹³, M. Uhlenbrock²⁰, M. Uhrmacher⁵⁴, F. Ukegawa¹⁶⁰, G. Unal²⁹, D.G. Underwood⁵, A. Undrus²⁴, G. Unel¹⁶³, Y. Unno⁶⁶, D. Urbaniec³⁴, E. Urkovsky¹⁵³, P. Urrejola^{31a}, G. Usai⁷, M. Uslenghi^{119a,119b}, L. Vacavant⁸³, V. Vacek¹²⁷, B. Vachon⁸⁵, S. Vahsen¹⁴, J. Valenta¹²⁵, P. Valente^{132a}, S. Valentini^{19a,19b}, S. Valkar¹²⁶, E. Valladolid Gallego¹⁶⁷, S. Vallecorsa¹⁵², J.A. Valls Ferrer¹⁶⁷, H. van der Graaf¹⁰⁵, E. van der Kraaij¹⁰⁵, R. Van Der Leeuw¹⁰⁵, E. van der Poel¹⁰⁵, D. van der Ster²⁹, B. Van Eijk¹⁰⁵, N. van Eldik⁸⁴, P. van Gemmeren⁵, Z. van Kesteren¹⁰⁵, I. van Vulpen¹⁰⁵, W. Vandelli²⁹, G. Vandoni²⁹, A. Vaniachine⁵, P. Vankov⁴¹, F. Vannucci⁷⁸, F. Varela Rodriguez²⁹, R. Vari^{132a}, E.W. Varnes⁶, D. Varouchas¹⁴, A. Vartapetian⁷, K.E. Varvell¹⁵⁰, V.I. Vassilakopoulos⁵⁶, F. Vazeille³³, G. Vegni^{89a,89b}, J.J. Veillet¹¹⁵, C. Vellidis⁸, F. Veloso^{124a}, R. Veness²⁹, S. Veneziano^{132a}, A. Ventura^{72a,72b}, D. Ventura¹³⁸, M. Venturi⁴⁸, N. Venturi¹⁶, V. Vercesi^{119a}, M. Verducci¹³⁸, W. Verkerke¹⁰⁵, J.C. Vermeulen¹⁰⁵, A. Vest⁴³, M.C. Vetterli^{142,e}, I. Vichou¹⁶⁵, T. Vickey^{145b,aa}, G.H.A. Viehhauser¹¹⁸, S. Viel¹⁶⁸, M. Villa^{19a,19b}, M. Villaplana Perez¹⁶⁷, E. Vilucchi⁴⁷, M.G. Vincker²⁸, E. Vinek²⁹, V.B. Vinogradov⁶⁵, M. Virchaux^{136,*}, J. Virzi¹⁴, O. Vitells¹⁷¹, M. Viti⁴¹, I. Vivarelli⁴⁸, F. Vives Vaque¹¹, S. Vlachos⁹, M. Vlasak¹²⁷, N. Vlasov²⁰, A. Vogel²⁰, P. Vokac¹²⁷, G. Volpi⁴⁷, M. Volpi⁸⁶, G. Volpini^{89a}, H. von der Schmitt⁹⁹, J. von Loeben⁹⁹, H. von Radziewski⁴⁸, E. von Toerne²⁰, V. Vorobel¹²⁶, A.P. Vorobiev¹²⁸, V. Vorwerk¹¹, M. Vos¹⁶⁷, R. Voss²⁹, T.T. Voss¹⁷⁴, J.H. Vossebeld⁷³, N. Vranjes^{12a}, M. Vranjes Milosavljevic^{12a}, V. Vrba¹²⁵, M. Vreeswijk¹⁰⁵, T. Vu Anh⁸¹, R. Vuillermet²⁹, I. Vukotic¹¹⁵, W. Wagner¹⁷⁴, P. Wagner¹²⁰, H. Wahlen¹⁷⁴, J. Wakabayashi¹⁰¹, J. Walbersloh⁴², S. Walch⁸⁷, J. Walder⁷¹, R. Walker⁹⁸, W. Walkowiak¹⁴¹, R. Wall¹⁷⁵, P. Waller⁷³, C. Wang⁴⁴, H. Wang¹⁷², H. Wang^{32b,ab}, J. Wang¹⁵¹, J. Wang^{32d}, J.C. Wang¹³⁸, R. Wang¹⁰³, S.M. Wang¹⁵¹, A. Warburton⁸⁵, C.P. Ward²⁷, M. Warsinsky⁴⁸, P.M. Watkins¹⁷, A.T. Watson¹⁷, M.F. Watson¹⁷, G. Watts¹³⁸, S. Watts⁸², A.T. Waugh¹⁵⁰, B.M. Waugh⁷⁷, J. Weber⁴², M. Weber¹²⁹, M.S. Weber¹⁶, P. Weber⁵⁴, A.R. Weidberg¹¹⁸, P. Weigell⁹⁹, J. Weingarten⁵⁴, C. Weiser⁴⁸, H. Wellenstein²², P.S. Wells²⁹, M. Wen⁴⁷, T. Wenaus²⁴, S. Wendler¹²³, Z. Weng^{151,r}, T. Wengler²⁹, S. Wenig²⁹, N. Wermes²⁰, M. Werner⁴⁸, P. Werner²⁹, M. Werth¹⁶³, M. Wessels^{58a}, C. Weydert⁵⁵, K. Whalen²⁸,

S.J. Wheeler-Ellis¹⁶³, S.P. Whitaker²¹, A. White⁷, M.J. White⁸⁶, S. White²⁴, S.R. Whitehead¹¹⁸, D. Whiteson¹⁶³, D. Whittington⁶¹, F. Wicek¹¹⁵, D. Wicke¹⁷⁴, F.J. Wickens¹²⁹, W. Wiedenmann¹⁷², M. Wielers¹²⁹, P. Wienemann²⁰, C. Wiglesworth⁷⁵, L.A.M. Wiik⁴⁸, P.A. Wijeratne⁷⁷, A. Wildauer¹⁶⁷, M.A. Wildt^{41,p}, I. Wilhelm¹²⁶, H.G. Wilkens²⁹, J.Z. Will⁹⁸, E. Williams³⁴, H.H. Williams¹²⁰, W. Willis³⁴, S. Willocq⁸⁴, J.A. Wilson¹⁷, M.G. Wilson¹⁴³, A. Wilson⁸⁷, I. Wingerter-Seez⁴, S. Winkelmann⁴⁸, F. Winklmeier²⁹, M. Wittgen¹⁴³, M.W. Wolter³⁸, H. Wolters^{124a,i}, G. Wooden¹¹⁸, B.K. Wosiek³⁸, J. Wotschack²⁹, M.J. Woudstra⁸⁴, K. Wraight⁵³, C. Wright⁵³, B. Wrona⁷³, S.L. Wu¹⁷², X. Wu⁴⁹, Y. Wu^{32b,ac}, E. Wulf³⁴, R. Wunstorf⁴², B.M. Wynne⁴⁵, L. Xaplanteris⁹, S. Xella³⁵, S. Xie⁴⁸, Y. Xie^{32a}, C. Xu^{32b,ad}, D. Xu¹³⁹, G. Xu^{32a}, B. Yabsley¹⁵⁰, M. Yamada⁶⁶, A. Yamamoto⁶⁶, K. Yamamoto⁶⁴, S. Yamamoto¹⁵⁵, T. Yamamura¹⁵⁵, J. Yamaoka⁴⁴, T. Yamazaki¹⁵⁵, Y. Yamazaki⁶⁷, Z. Yan²¹, H. Yang⁸⁷, U.K. Yang⁸², Y. Yang⁶¹, Y. Yang^{32a}, Z. Yang^{146a,146b}, S. Yanush⁹¹, W.-M. Yao¹⁴, Y. Yao¹⁴, Y. Yasu⁶⁶, G.V. Ybeles Smit¹³⁰, J. Ye³⁹, S. Ye²⁴, M. Yilmaz^{3c}, R. Yoosofmiya¹²³, K. Yorita¹⁷⁰, R. Yoshida⁵, C. Young¹⁴³, S. Youssef²¹, D. Yu²⁴, J. Yu⁷, J. Yu^{32c,ad}, L. Yuan^{32a,ae}, A. Yurkewicz¹⁴⁸, V.G. Zaets¹²⁸, R. Zaidan⁶³, A.M. Zaitsev¹²⁸, Z. Zajacova²⁹, Yo.K. Zalite¹²¹, L. Zanello^{132a,132b}, P. Zarzhitsky³⁹, A. Zaytsev¹⁰⁷, C. Zeitnitz¹⁷⁴, M. Zeller¹⁷⁵, A. Zemla³⁸, C. Zender²⁰, A.V. Zenin¹²⁸, O. Zenin¹²⁸, T. Ženiš^{144a}, Z. Zenonos^{122a,122b}, S. Zenz¹⁴, D. Zerwas¹¹⁵, G. Zevi della Porta⁵⁷, Z. Zhan^{32d}, D. Zhang^{32b,ab}, H. Zhang⁸⁸, J. Zhang⁵, X. Zhang^{32d}, Z. Zhang¹¹⁵, L. Zhao¹⁰⁸, T. Zhao¹³⁸, Z. Zhao^{32b}, A. Zhemchugov⁶⁵, S. Zheng^{32a}, J. Zhong^{151,af}, B. Zhou⁸⁷, N. Zhou¹⁶³, Y. Zhou¹⁵¹, C.G. Zhu^{32d}, H. Zhu⁴¹, J. Zhu⁸⁷, Y. Zhu¹⁷², X. Zhuang⁹⁸, V. Zhuravlov⁹⁹, D. Zieminska⁶¹, R. Zimmermann²⁰, S. Zimmermann²⁰, S. Zimmermann⁴⁸, M. Ziolkowski¹⁴¹, R. Zitoun⁴, L. Živković³⁴, V.V. Zmouchko^{128,*}, G. Zobernig¹⁷², A. Zoccoli^{19a,19b}, Y. Zolnierowski⁴, A. Zsenei²⁹, M. zur Nedden¹⁵, V. Zutshi¹⁰⁶, L. Zwalinski²⁹

¹ University at Albany, Albany, NY, United States

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

³ (a) Department of Physics, Ankara University, Ankara; (b) Department of Physics, Dumlupinar University, Kutahya; (c) Department of Physics, Gazi University, Ankara; (d) Division of Physics, TOBB University of Economics and Technology, Ankara; (e) Turkish Atomic Energy Authority, Ankara, Turkey

⁴ LAPP, CNRS/IN2P3 and Université de Savoie, Annecy-le-Vieux, France

⁵ High Energy Physics Division, Argonne National Laboratory, Argonne, IL, United States

⁶ Department of Physics, University of Arizona, Tucson, AZ, United States

⁷ Department of Physics, The University of Texas at Arlington, Arlington, TX, United States

⁸ Physics Department, University of Athens, Athens, Greece

⁹ Physics Department, National Technical University of Athens, Zografou, Greece

¹⁰ Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan

¹¹ Institut de Física d'Altes Energies and Departament de Física de la Universitat Autònoma de Barcelona and ICREA, Barcelona, Spain

¹² (a) Institute of Physics, University of Belgrade, Belgrade; (b) Vinca Institute of Nuclear Sciences, Belgrade, Serbia

¹³ Department for Physics and Technology, University of Bergen, Bergen, Norway

¹⁴ Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, CA, United States

¹⁵ Department of Physics, Humboldt University, Berlin, Germany

¹⁶ Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland

¹⁷ School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom

¹⁸ (a) Department of Physics, Bogazici University, Istanbul; (b) Division of Physics, Dogus University, Istanbul; (c) Department of Physics Engineering, Gaziantep University, Gaziantep;

(d) Department of Physics, Istanbul Technical University, Istanbul, Turkey

¹⁹ (a) INFN Sezione di Bologna; (b) Dipartimento di Fisica, Università di Bologna, Bologna, Italy

²⁰ Physikalisches Institut, University of Bonn, Bonn, Germany

²¹ Department of Physics, Boston University, Boston, MA, United States

²² Department of Physics, Brandeis University, Waltham, MA, United States

²³ (a) Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; (b) Federal University of Juiz de Fora (UFJF), Juiz de Fora; (c) Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei; (d) Instituto de Física, Universidade de Sao Paulo, Sao Paulo, Brazil

²⁴ Physics Department, Brookhaven National Laboratory, Upton, NY, United States

²⁵ (a) National Institute of Physics and Nuclear Engineering, Bucharest; (b) University Politehnica Bucharest, Bucharest; (c) West University in Timisoara, Timisoara, Romania

²⁶ Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina

²⁷ Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom

²⁸ Department of Physics, Carleton University, Ottawa, ON, Canada

²⁹ CERN, Geneva, Switzerland

³⁰ Enrico Fermi Institute, University of Chicago, Chicago, IL, United States

³¹ (a) Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; (b) Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile

³² (a) Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; (b) Department of Modern Physics, University of Science and Technology of China, Anhui; (c) Department of Physics, Nanjing University, Jiangsu; (d) High Energy Physics Group, Shandong University, Shandong, China

³³ Laboratoire de Physique Corpusculaire, Clermont Université and CNRS/IN2P3, Aubiere Cedex, France

³⁴ Nevis Laboratory, Columbia University, Irvington, NY, United States

³⁵ Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark

³⁶ (a) INFN Gruppo Collegato di Cosenza; (b) Dipartimento di Fisica, Università della Calabria, Arcavacata di Rende, Italy

³⁷ Faculty of Physics and Applied Computer Science, AGH-University of Science and Technology, Krakow, Poland

³⁸ The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland

³⁹ Physics Department, Southern Methodist University, Dallas, TX, United States

⁴⁰ Physics Department, University of Texas at Dallas, Richardson, TX, United States

⁴¹ DESY, Hamburg and Zeuthen, Germany

⁴² Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany

- ⁴³ Institut für Kern- und Teilchenphysik, Technical University Dresden, Dresden, Germany
- ⁴⁴ Department of Physics, Duke University, Durham, NC, United States
- ⁴⁵ SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
- ⁴⁶ Fachhochschule Wiener Neustadt, Johannes Gutenbergstrasse 3, 2700 Wiener Neustadt, Austria
- ⁴⁷ INFN Laboratori Nazionali di Frascati, Frascati, Italy
- ⁴⁸ Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg i.Br., Germany
- ⁴⁹ Section de Physique, Université de Genève, Geneva, Switzerland
- ⁵⁰ ^(a) INFN Sezione di Genova; ^(b) Dipartimento di Fisica, Università di Genova, Genova, Italy
- ⁵¹ Institute of Physics and HEP Institute, Georgian Academy of Sciences and Tbilisi State University, Tbilisi, Georgia
- ⁵² II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
- ⁵³ SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
- ⁵⁴ II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany
- ⁵⁵ Laboratoire de Physique Subatomique et de Cosmologie, Université Joseph Fourier and CNRS/IN2P3 and Institut National Polytechnique de Grenoble, Grenoble, France
- ⁵⁶ Department of Physics, Hampton University, Hampton, VA, United States
- ⁵⁷ Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, MA, United States
- ⁵⁸ ^(a) Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; ^(b) Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; ^(c) ZITI Institut für technische Informatik, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany
- ⁵⁹ Faculty of Science, Hiroshima University, Hiroshima, Japan
- ⁶⁰ Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan
- ⁶¹ Department of Physics, Indiana University, Bloomington, IN, United States
- ⁶² Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
- ⁶³ University of Iowa, Iowa City, IA, United States
- ⁶⁴ Department of Physics and Astronomy, Iowa State University, Ames, IA, United States
- ⁶⁵ Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia
- ⁶⁶ KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
- ⁶⁷ Graduate School of Science, Kobe University, Kobe, Japan
- ⁶⁸ Faculty of Science, Kyoto University, Kyoto, Japan
- ⁶⁹ Kyoto University of Education, Kyoto, Japan
- ⁷⁰ Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
- ⁷¹ Physics Department, Lancaster University, Lancaster, United Kingdom
- ⁷² ^(a) INFN Sezione di Lecce; ^(b) Dipartimento di Fisica, Università del Salento, Lecce, Italy
- ⁷³ Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
- ⁷⁴ Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
- ⁷⁵ Department of Physics, Queen Mary University of London, London, United Kingdom
- ⁷⁶ Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
- ⁷⁷ Department of Physics and Astronomy, University College London, London, United Kingdom
- ⁷⁸ Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
- ⁷⁹ Fysiska institutionen, Lunds universitet, Lund, Sweden
- ⁸⁰ Departamento de Física Teórica C-15, Universidad Autonoma de Madrid, Madrid, Spain
- ⁸¹ Institut für Physik, Universität Mainz, Mainz, Germany
- ⁸² School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
- ⁸³ CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
- ⁸⁴ Department of Physics, University of Massachusetts, Amherst, MA, United States
- ⁸⁵ Department of Physics, McGill University, Montreal, QC, Canada
- ⁸⁶ School of Physics, University of Melbourne, Victoria, Australia
- ⁸⁷ Department of Physics, The University of Michigan, Ann Arbor, MI, United States
- ⁸⁸ Department of Physics and Astronomy, Michigan State University, East Lansing, MI, United States
- ⁸⁹ ^(a) INFN Sezione di Milano; ^(b) Dipartimento di Fisica, Università di Milano, Milano, Italy
- ⁹⁰ B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus
- ⁹¹ National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Belarus
- ⁹² Department of Physics, Massachusetts Institute of Technology, Cambridge, MA, United States
- ⁹³ Group of Particle Physics, University of Montreal, Montreal, QC, Canada
- ⁹⁴ P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia
- ⁹⁵ Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
- ⁹⁶ Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia
- ⁹⁷ Skobel'syn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
- ⁹⁸ Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
- ⁹⁹ Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
- ¹⁰⁰ Nagasaki Institute of Applied Science, Nagasaki, Japan
- ¹⁰¹ Graduate School of Science, Nagoya University, Nagoya, Japan
- ¹⁰² ^(a) INFN Sezione di Napoli; ^(b) Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy
- ¹⁰³ Department of Physics and Astronomy, University of New Mexico, Albuquerque, NM, United States
- ¹⁰⁴ Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
- ¹⁰⁵ Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
- ¹⁰⁶ Department of Physics, Northern Illinois University, DeKalb, IL, United States
- ¹⁰⁷ Budker Institute of Nuclear Physics (BINP), Novosibirsk, Russia
- ¹⁰⁸ Department of Physics, New York University, New York, NY, United States
- ¹⁰⁹ Ohio State University, Columbus, OH, United States
- ¹¹⁰ Faculty of Science, Okayama University, Okayama, Japan
- ¹¹¹ Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK, United States
- ¹¹² Department of Physics, Oklahoma State University, Stillwater, OK, United States
- ¹¹³ Palacký University, RCPTM, Olomouc, Czech Republic
- ¹¹⁴ Center for High Energy Physics, University of Oregon, Eugene, OR, United States
- ¹¹⁵ LAL, Univ. Paris-Sud and CNRS/IN2P3, Orsay, France
- ¹¹⁶ Graduate School of Science, Osaka University, Osaka, Japan
- ¹¹⁷ Department of Physics, University of Oslo, Oslo, Norway
- ¹¹⁸ Department of Physics, Oxford University, Oxford, United Kingdom
- ¹¹⁹ ^(a) INFN Sezione di Pavia; ^(b) Dipartimento di Fisica Nucleare e Teorica, Università di Pavia, Pavia, Italy
- ¹²⁰ Department of Physics, University of Pennsylvania, Philadelphia, PA, United States

- ¹²¹ Petersburg Nuclear Physics Institute, Gatchina, Russia
¹²² ^(a) INFN Sezione di Pisa; ^(b) Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
¹²³ Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA, United States
¹²⁴ ^(a) Laboratório de Instrumentação e Física Experimental de Partículas – LIP, Lisboa, Portugal; ^(b) Departamento de Física Teórica y del Cosmos and CAFPE, Universidad de Granada, Granada, Spain
¹²⁵ Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
¹²⁶ Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic
¹²⁷ Czech Technical University in Prague, Praha, Czech Republic
¹²⁸ State Research Center Institute for High Energy Physics, Protvino, Russia
¹²⁹ Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
¹³⁰ Physics Department, University of Regina, Regina, SK, Canada
¹³¹ Ritsumeikan University, Kusatsu, Shiga, Japan
¹³² ^(a) INFN Sezione di Roma I; ^(b) Dipartimento di Fisica, Università La Sapienza, Roma, Italy
¹³³ ^(a) INFN Sezione di Roma Tor Vergata; ^(b) Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
¹³⁴ ^(a) INFN Sezione di Roma Tre; ^(b) Dipartimento di Fisica, Università Roma Tre, Roma, Italy
¹³⁵ ^(a) Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies, Université Hassan II, Casablanca; ^(b) Centre National de l’Energie des Sciences Techniques Nucleaires, Rabat; ^(c) Université Cadi Ayyad, Faculté des sciences Semlalia Département de Physique, B.P. 2390 Marrakech 40000; ^(d) Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; ^(e) Faculté des Sciences, Université Mohammed V, Rabat, Morocco
¹³⁶ DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l’Univers), CEA Saclay (Commissariat a l’Energie Atomique), Gif-sur-Yvette, France
¹³⁷ Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, CA, United States
¹³⁸ Department of Physics, University of Washington, Seattle, WA, United States
¹³⁹ Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
¹⁴⁰ Department of Physics, Shinshu University, Nagano, Japan
¹⁴¹ Fachbereich Physik, Universität Siegen, Siegen, Germany
¹⁴² Department of Physics, Simon Fraser University, Burnaby, BC, Canada
¹⁴³ SLAC National Accelerator Laboratory, Stanford, CA, United States
¹⁴⁴ ^(a) Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava; ^(b) Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic
¹⁴⁵ ^(a) Department of Physics, University of Johannesburg, Johannesburg; ^(b) School of Physics, University of the Witwatersrand, Johannesburg, South Africa
¹⁴⁶ ^(a) Department of Physics, Stockholm University; ^(b) The Oskar Klein Centre, Stockholm, Sweden
¹⁴⁷ Physics Department, Royal Institute of Technology, Stockholm, Sweden
¹⁴⁸ Department of Physics and Astronomy, Stony Brook University, Stony Brook, NY, United States
¹⁴⁹ Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
¹⁵⁰ School of Physics, University of Sydney, Sydney, Australia
¹⁵¹ Institute of Physics, Academia Sinica, Taipei, Taiwan
¹⁵² Department of Physics, Technion: Israel Inst. of Technology, Haifa, Israel
¹⁵³ Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
¹⁵⁴ Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
¹⁵⁵ International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan
¹⁵⁶ Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
¹⁵⁷ Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
¹⁵⁸ Department of Physics, University of Toronto, Toronto, ON, Canada
¹⁵⁹ ^(a) TRIUMF, Vancouver, BC; ^(b) Department of Physics and Astronomy, York University, Toronto, ON, Canada
¹⁶⁰ Institute of Pure and Applied Sciences, University of Tsukuba, Ibaraki, Japan
¹⁶¹ Science and Technology Center, Tufts University, Medford, MA, United States
¹⁶² Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia
¹⁶³ Department of Physics and Astronomy, University of California Irvine, Irvine, CA, United States
¹⁶⁴ ^(a) INFN Gruppo Collegato di Udine; ^(b) ICTP, Trieste; ^(c) Dipartimento di Fisica, Università di Udine, Udine, Italy
¹⁶⁵ Department of Physics, University of Illinois, Urbana, IL, United States
¹⁶⁶ Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
¹⁶⁷ Instituto de Física Corpuscular (IFIC) and Departamento de Física Atómica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain
¹⁶⁸ Department of Physics, University of British Columbia, Vancouver, BC, Canada
¹⁶⁹ Department of Physics and Astronomy, University of Victoria, Victoria, BC, Canada
¹⁷⁰ Waseda University, Tokyo, Japan
¹⁷¹ Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
¹⁷² Department of Physics, University of Wisconsin, Madison, WI, United States
¹⁷³ Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany
¹⁷⁴ Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany
¹⁷⁵ Department of Physics, Yale University, New Haven, CT, United States
¹⁷⁶ Yerevan Physics Institute, Yerevan, Armenia
¹⁷⁷ Domaine scientifique de la Doua, Centre de Calcul CNRS/IN2P3, Villeurbanne Cedex, France

^a Also at Laboratório de Instrumentação e Física Experimental de Partículas – LIP, Lisboa, Portugal.

^b Also at Faculdade de Ciências and CFNUL, Universidade de Lisboa, Lisboa, Portugal.

^c Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom.

^d Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France.

^e Also at TRIUMF, Vancouver, BC, Canada.

^f Also at Department of Physics, California State University, Fresno, CA, United States.

^g Also at Faculty of Physics and Applied Computer Science, AGH-University of Science and Technology, Krakow, Poland.

^h Also at Fermilab, Batavia, IL, United States.

ⁱ Also at Department of Physics, University of Coimbra, Coimbra, Portugal.

^j Also at Università di Napoli Parthenope, Napoli, Italy.

^k Also at Institute of Particle Physics (IPP), Canada.

^l Also at Department of Physics, Middle East Technical University, Ankara, Turkey.

^m Also at Louisiana Tech University, Ruston, LA, United States.

ⁿ Also at Group of Particle Physics, University of Montreal, Montreal, QC, Canada.

^o Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.

^p Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.

^q Also at Manhattan College, New York, NY, United States.

^r Also at School of Physics and Engineering, Sun Yat-sen University, Guanzhou, China.

^s Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan.

^t Also at High Energy Physics Group, Shandong University, Shandong, China.

^u Also at California Institute of Technology, Pasadena, CA, United States.

^v Also at Section de Physique, Université de Genève, Geneva, Switzerland.

^w Also at Departamento de Física, Universidade de Minho, Braga, Portugal.

^x Also at Department of Physics and Astronomy, University of South Carolina, Columbia, SC, United States.

^y Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary.

^z Also at Institute of Physics, Jagiellonian University, Krakow, Poland.

^{aa} Also at Department of Physics, Oxford University, Oxford, United Kingdom.

^{ab} Also at Institute of Physics, Academia Sinica, Taipei, Taiwan.

^{ac} Also at Department of Physics, The University of Michigan, Ann Arbor, MI, United States.

^{ad} Also at DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique), Gif-sur-Yvette, France.

^{ae} Also at Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France.

^{af} Also at Department of Physics, Nanjing University, Jiangsu, China.

* Deceased.