



Measurement with the ATLAS detector of multi-particle azimuthal correlations in $p + \text{Pb}$ collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$ [☆]



ATLAS Collaboration ^{*}

ARTICLE INFO

Article history:

Received 8 March 2013

Received in revised form 27 June 2013

Accepted 27 June 2013

Available online 4 July 2013

Editor: W.-D. Schlatter

ABSTRACT

In order to study further the long-range correlations (“ridge”) observed recently in $p + \text{Pb}$ collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$, the second-order azimuthal anisotropy parameter of charged particles, v_2 , has been measured with the cumulant method using the ATLAS detector at the LHC. In a data sample corresponding to an integrated luminosity of approximately $1 \mu\text{b}^{-1}$, the parameter v_2 has been obtained using two- and four-particle cumulants over the pseudorapidity range $|\eta| < 2.5$. The results are presented as a function of transverse momentum and the event activity, defined in terms of the transverse energy summed over $3.1 < \eta < 4.9$ in the direction of the Pb beam. They show features characteristic of collective anisotropic flow, similar to that observed in Pb + Pb collisions. A comparison is made to results obtained using two-particle correlation methods, and to predictions from hydrodynamic models of $p + \text{Pb}$ collisions. Despite the small transverse spatial extent of the $p + \text{Pb}$ collision system, the large magnitude of v_2 and its similarity to hydrodynamic predictions provide additional evidence for the importance of final-state effects in $p + \text{Pb}$ reactions.

© 2013 CERN. Published by Elsevier B.V. All rights reserved.

1. Introduction

Recent observations of ridge-like structures in the two-particle correlation functions measured in proton-lead ($p + \text{Pb}$) collisions at 5.02 TeV [1–3] have led to differing theoretical explanations. These structures have been attributed either to mechanisms that emphasise initial-state effects, such as the saturation of parton distributions in the Pb-nucleus [4–7], or to final-state effects, such as jet-medium interactions [8], interactions induced by multiple partons [9–12], and collective anisotropic flow [13–18].

The collective flow of particles produced in nuclear collisions, which manifests itself as a significant anisotropy in the plane perpendicular to the beam direction, has been extensively studied in heavy-ion experiments at the LHC [19–24] and RHIC (for a review see Refs. [25,26]). In $p + \text{Pb}$ collisions the small size of the produced system compared to the mean free path of the interacting constituents might have been expected to generate weaker collective flow, if any, compared to heavy-ion collisions.

However, two-particle correlation studies performed recently on data from $p + \text{Pb}$ collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$ revealed the presence of a “ridge”, a structure extended in the relative pseudorapidity, $\Delta\eta$, while narrow in the relative azimuthal angle, $\Delta\phi$, on both the near-side ($\Delta\phi \sim 0$) [1] and away-side ($\Delta\phi \sim \pi$) [2,3].

Furthermore, it was shown in Refs. [2,3] that, after subtracting the component due to momentum conservation, the $\Delta\phi$ distribution in high-multiplicity interactions exhibits a predominantly $\cos(2\Delta\phi)$ shape, resembling the elliptic flow modulation of the $\Delta\phi$ distributions in Pb + Pb collisions.

The final-state anisotropy is usually characterised by the coefficients, v_n , of a Fourier decomposition of the event-by-event azimuthal-angle distribution of produced particles [25,27]:

$$v_n = \langle \cos n(\phi - \Psi_n) \rangle, \quad (1)$$

where ϕ is the azimuthal angle of the particle, Ψ_n is the event-plane angle for the n -th harmonic, and the outer brackets denote an average over charged particles in an event. In non-central heavy-ion collisions, the large and dominating v_2 coefficient is associated mainly with the elliptic shape of the nuclear overlap, and Ψ_2 defines the direction which nominally points in the direction of the classical impact parameter. In practice, initial-state fluctuations can blur the relationship between Ψ_2 and the impact parameter direction in nucleus-nucleus collisions. In contrast, Ψ_2 in proton-nucleus collisions would be unrelated to the impact parameter and determined by the initial-state fluctuations. In nucleus-nucleus collisions, the v_2 coefficient in central collisions and the other v_n coefficients in all collisions are related to various geometric configurations arising from fluctuations of the nucleon positions in the overlap region [28].

In this Letter, a direct measurement of the second-order anisotropy parameter, v_2 , is presented for $p + \text{Pb}$ collisions at

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

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

$\sqrt{s_{NN}} = 5.02$ TeV. The cumulant method [29–32] is applied to derive v_2 using two- and four-particle cumulants. The cumulant method has been developed to characterise true multi-particle correlations related to the collective expansion of the system, while suppressing correlations from resonance decays, Bose–Einstein correlations and jet production. Emphasis is placed on the estimate of v_2 , $v_2\{4\}$, obtained from the four-particle cumulants which are expected to be free from the effects of short-range two-particle correlations, e.g. from resonance decays, unlike the two-particle cumulants, used to estimate $v_2\{2\}$.

The measurements of multi-particle cumulants presented in this Letter should provide further constraints on the origin of long-range correlations observed in $p + \text{Pb}$ collisions.

2. Event and track selections

The $p + \text{Pb}$ data sample was collected during a short run in September 2012, when the LHC delivered $p + \text{Pb}$ collisions at the nucleon–nucleon centre-of-mass energy $\sqrt{s_{NN}} = 5.02$ TeV with the centre-of-mass frame shifted by -0.47 in rapidity relative to the nominal ATLAS coordinate frame.¹

The measurements were performed using the ATLAS detector [33]. The inner detector (ID) was used for measuring trajectories and momenta of charged particles for $|\eta| < 2.5$ with the silicon pixel detector and silicon microstrip detectors (SCT), and a transition radiation tracker, all placed in a 2 T axial magnetic field. For event triggering, two sets of Minimum Bias Trigger Scintillators (MBTS), located symmetrically in front of the endcap calorimeters, at $z = \pm 3.6$ m and covering the pseudorapidity range $2.1 < |\eta| < 3.9$, were used. The trigger used to select minimum-bias $p + \text{Pb}$ collisions requires a signal in at least two MBTS counters. This trigger is fully efficient for events with more than four reconstructed tracks with $p_T > 0.1$ GeV. The forward calorimeters (FCal), consisting of two symmetric systems with tungsten and copper absorbers and liquid argon as the active material, cover $3.1 < |\eta| < 4.9$ and are used to characterise the overall event activity.

The event selection follows the same requirements as used in the recent two-particle correlation analysis [3]. Events are required to have a reconstructed vertex with its z position within ± 150 mm of the nominal interaction point. Beam–gas and photonuclear interactions are suppressed by requiring at least one hit in a MBTS counter on each side of the interaction point and at most a 10 ns difference between times measured on the two sides to eliminate through-going particles. To eliminate multiple $p + \text{Pb}$ collisions (about 2% of collision events have more than one reconstructed vertex), the events with two reconstructed vertices that are separated in z by more than 15 mm are rejected. In addition, for the cumulant analysis presented here, it is required that the number of reconstructed tracks per event, passing the track selections as described below, is greater than three. With all the above selections, the analysed sample consists of about 1.9×10^6 events.

Charged particle tracks are reconstructed in the ID using the standard algorithm optimised for $p + p$ minimum-bias measurements [34]. Tracks are required to have at least six hits in the SCT detector and at least one hit in the pixel detector. A hit in the

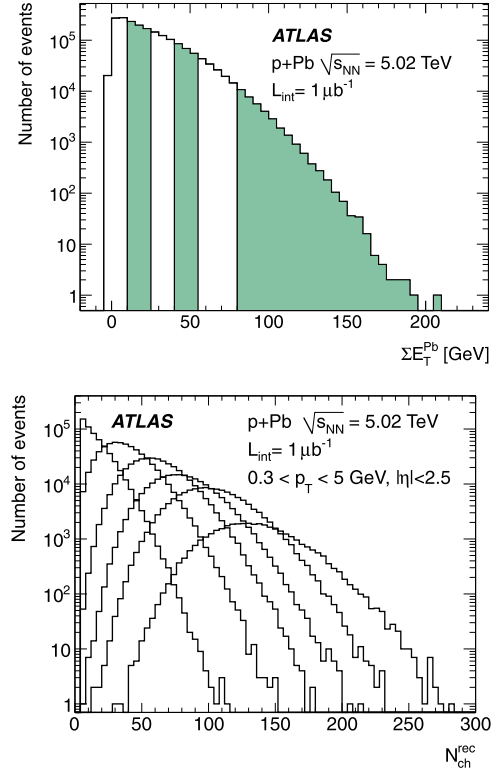


Fig. 1. Upper plot: the ΣE_T^{Pb} distribution with the six activity intervals indicated. Lower plot: the distribution of $N_{\text{ch}}^{\text{rec}}$ for each activity interval. The leftmost distribution corresponds to the interval with the lowest ΣE_T^{Pb} , etc.

first pixel layer is also required when the track crosses an active pixel module in that layer. Additional requirements are imposed on the transverse (d_0) and longitudinal ($z_0 \sin \theta$) impact parameters measured with respect to the primary vertex. These are: $|d_0|$ and $|z_0 \sin \theta|$ must be smaller than 1.5 mm and must satisfy $|d_0/\sigma_{d_0}| < 3$ and $|z_0 \sin \theta/\sigma_z| < 3$, where σ_{d_0} and σ_z are uncertainties on the transverse and longitudinal impact parameters, respectively, as obtained from the covariance matrix of the track fit. The analysis is restricted to charged particles with $0.3 < p_T < 5.0$ GeV and $|\eta| < 2.5$.

The tracking efficiency is evaluated using HIJING-generated [35] $p + \text{Pb}$ events that are fully simulated in the detector using GEANT4 [36,37], and processed through the same reconstruction software as the data. The efficiency for charged hadrons is found to depend only weakly on the event multiplicity and on p_T for transverse momenta above 0.5 GeV. An efficiency of about 82% is observed at mid-rapidity, $|\eta| < 1$, decreasing to about 68% at $|\eta| > 2$. For low- p_T tracks, between 0.3 GeV and 0.5 GeV, the efficiency ranges from 74% at $\eta = 0$ to about 50% for $|\eta| > 2$. The number of reconstructed charged particle tracks, not corrected for tracking efficiency, is denoted by $N_{\text{ch}}^{\text{rec}}$.

The analysis is performed in different intervals of ΣE_T^{Pb} , the sum of transverse energy measured in the FCal with $3.1 < |\eta| < 4.9$ in the direction of the Pb beam with no correction for the difference in response to electrons and hadrons. The distribution of ΣE_T^{Pb} for events passing all selection criteria is shown in Fig. 1. These events are divided into six ΣE_T^{Pb} intervals to study the variation of v_2 with overall event activity, as indicated in Fig. 1 and shown in Table 1. Event “activity” is characterised by ΣE_T^{Pb} : the most active events are those with the largest ΣE_T^{Pb} . The distribution of $N_{\text{ch}}^{\text{rec}}$ for each activity interval is shown in the lower plot of Fig. 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. For the $p + \text{Pb}$ collisions, the incident Pb beam travelled in the $+z$ direction. The pseudorapidity is defined in laboratory coordinates in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$. Transverse momentum and energy are defined as $p_T = p \sin \theta$ and $E_T = E \sin \theta$, respectively.

Table 1

Characterisation of activity intervals as selected by ΣE_T^{pb} . In the last column, the mean and RMS of the number of reconstructed charged particles with $|\eta| < 2.5$ and $0.3 < p_T < 5$ GeV, $N_{\text{ch}}^{\text{rec}}$, are given for each activity interval.

ΣE_T^{pb} range [GeV]	$\langle \Sigma E_T^{\text{pb}} \rangle$ [GeV]	Range in fraction of events [%]	$\langle N_{\text{ch}}^{\text{rec}} \rangle$ (RMS)
> 80	93.7	0–1.9	134 (31)
55–80	64.8	1.9–9.1	102 (26)
40–55	46.7	9.1–20.0	80 (23)
25–40	31.9	20.0–39.3	60 (20)
10–25	16.9	39.3–70.4	37 (17)
< 10	4.9	70.4–100	16 (11)

3. Data analysis

The cumulant method involves the calculation of $2k$ -particle azimuthal correlations, $\text{corr}_n\{2k\}$, and cumulants, $c_n\{2k\}$, where $k = 1, 2$ for the analysis presented in this Letter. The two- and four-particle correlations are defined as $\text{corr}_n\{2\} = \langle e^{in(\phi_1 - \phi_2)} \rangle$ and $\text{corr}_n\{4\} = \langle e^{in(\phi_1 + \phi_2 - \phi_3 - \phi_4)} \rangle$, respectively, where the angle brackets denote the average in a single event over all pairs and all combinations of four particles. After averaging over events, the two-particle cumulant is obtained as $c_n\{2\} = \langle \text{corr}_n\{2\} \rangle$, and the four-particle cumulant $c_n\{4\} = \langle \text{corr}_n\{4\} \rangle - 2 \cdot \langle \text{corr}_n\{2\} \rangle^2$. Thus the effect of two-particle correlations is explicitly removed in the expression for $c_n\{4\}$. Further details are given in Refs. [29,30,32].

Direct calculation of multi-particle correlations requires multiple passes over the particles in an event, and requires extensive computing time in high-multiplicity events. To mitigate this, it has been proposed in Ref. [32] to express multi-particle correlations in terms of the moments of the flow vector Q_n , defined as $Q_n = \sum_i e^{in\phi_i}$, where the index n denotes the flow harmonic and the sum runs over all particles in an event. This analysis is restricted to the second harmonic coefficient, $n = 2$. The method based on the flow-vector moments enables the calculation of multi-particle cumulants in a single pass over the full set of particles in each event.

The cumulant method involves two main steps [29,30]. In the first step, the so-called “reference” flow harmonic coefficients are calculated using multi-particle cumulants for particles selected inclusively from a broad range in p_T and η as:

$$v_2^{\text{ref}}\{2\} = \sqrt{c_2\{2\}}, \quad (2)$$

$$v_2^{\text{ref}}\{4\} = \sqrt[4]{-c_2\{4\}}, \quad (3)$$

where $v_2^{\text{ref}}\{2\}$ ($v_2^{\text{ref}}\{4\}$) denotes the reference estimate of the second-order anisotropy parameter obtained using two-particle, $c_2\{2\}$ (four-particle, $c_2\{4\}$) cumulants.

The flow-vector method is easiest to apply when the detector acceptance is azimuthally uniform [32]. A correction for any azimuthal non-uniformity in the reconstruction of charged particle tracks is obtained from the data [25], based on an η - ϕ map of all reconstructed tracks. For each small ($\delta\eta = 0.1$, $\delta\phi = 2\pi/64$) bin (labelled i), a weight is calculated as $w_i(\eta, \phi) = \langle N(\delta\eta) \rangle / N_i(\delta\eta, \delta\phi)$, where $\langle N(\delta\eta) \rangle$ is the event-averaged number of tracks in the $\delta\eta$ slice to which this bin belongs, while $N_i(\delta\eta, \delta\phi)$ is the number of tracks in an event within this bin. Using this weight forces the azimuthal-angle distribution of reference particles to be uniform in ϕ , but it does not change the η distribution of reconstructed tracks. A weighted Q -vector is evaluated as $Q_n = \sum_i w_i e^{in\phi_i}$ [32,38]. From Eqs. (2) and (3) it is clear that the cumulant method can be used to estimate v_2 only when $c_2\{4\}$ is negative and $c_2\{2\}$ positive.

In the second step, the harmonic coefficients are determined as functions of p_T and η , in bins in each variable (10 bins of equal width are used in η and 22 bins of varied width in p_T).

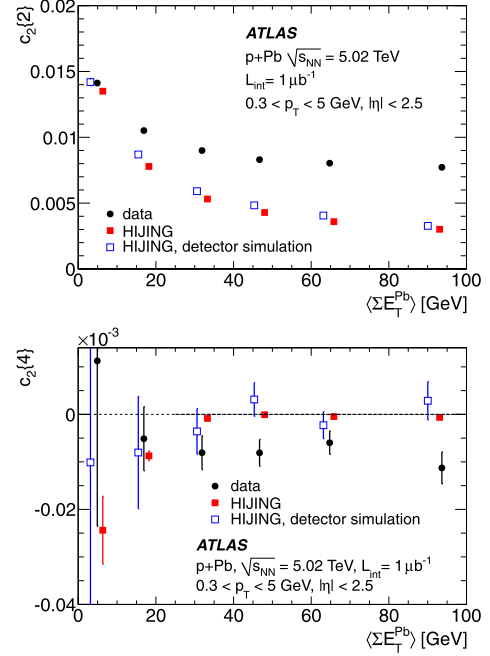


Fig. 2. The two-particle (upper plot) and four-particle (lower plot) cumulants calculated using the reference flow particles as a function of ΣE_T^{pb} for data (circles), the fully simulated HIJING events (open squares) and the large generator-level HIJING sample (filled squares). For clarity, the points for the fully simulated (generated) HIJING events are slightly shifted to the left (right).

These differential flow harmonics are calculated for “particles of interest” which fall into these small bins. First, the differential cumulants, $d_2\{2\}$ and $d_2\{4\}$, are obtained by correlating every particle of interest with one and three reference particles respectively. The differential second harmonic, $v_2\{2k\}(p_T, \eta)$, where $k = 1, 2$, is then calculated with respect to the reference flow as derived in Refs. [29,30]:

$$v_2\{2\}(p_T, \eta) = \frac{d_2\{2\}}{\sqrt{c_2\{2\}}}, \quad (4)$$

$$v_2\{4\}(p_T, \eta) = \frac{-d_2\{4\}}{\sqrt[3/4]{-c_2\{4\}}}. \quad (5)$$

The differential v_2 harmonic is then integrated over wider phase-space bins, with each small bin weighted by the appropriate charged particle multiplicity. This is obtained from the reconstructed multiplicity by applying η - and p_T -dependent efficiency factors, determined from Monte Carlo (MC) simulation as discussed in the previous section. Due to the small number of events in the data sample, the final results are integrated over the full acceptance in η .

Fig. 2 shows the two- and four-particle cumulants, averaged over events in each event-activity class defined in Table 1, as a function of ΣE_T^{pb} . It is observed that four-particle cumulants are negative only in a certain range of event activity. This restricts subsequent analysis to events with $\Sigma E_T^{\text{pb}} > 25$ GeV, for which the four-particle cumulant in data is found to be less than zero by at least two standard deviations (statistical errors only). It was also checked, by explicit removal of low-multiplicity events, that the sign of $c_2\{4\}$ is not driven by these low-multiplicity events. For example, defining N_{20} as the value of $N_{\text{ch}}^{\text{rec}}$ such that 20% of events have $N_{\text{ch}}^{\text{rec}} < N_{20}$ (i.e. N_{20} is the 20th percentile), it is found that selecting $N_{\text{ch}}^{\text{rec}} > N_{20}$ leaves $c_2\{4\}$ unchanged in sign and magnitude, within errors. And for $\Sigma E_T^{\text{pb}} > 25$ GeV this holds for any percentile selection [39].

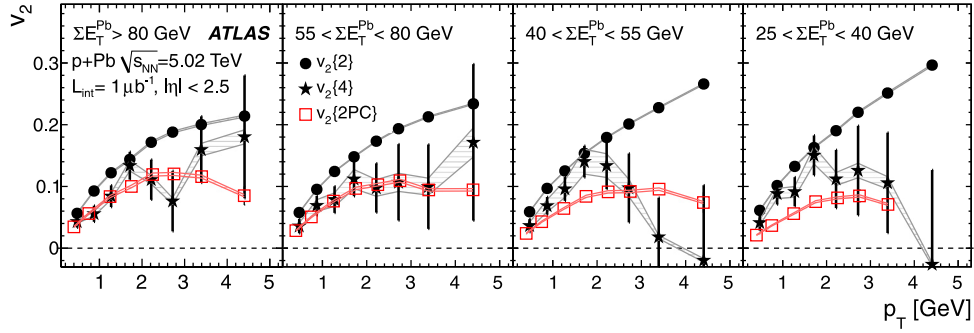


Fig. 3. The second-order harmonic calculated with the two-particle (circles) and four-particle (stars) cumulants as a function of transverse momentum in four different activity intervals. Bars denote statistical errors; systematic uncertainties are shown as shaded bands. The v_2 derived from the Fourier decomposition of two-particle correlations [3] is shown by squares.

Fig. 2 also shows the cumulants calculated for 50 million HIJING-generated events, using the true particle information only, as well as for one million fully simulated and reconstructed HIJING events, using the same methods as used for the data. The ΣE_T^{Pb} obtained from the HIJING sample is rescaled to match that measured in the data. It should be noted that the HIJING Monte Carlo model does not contain any collective flow, and the only correlations are those due to resonance decays, jet production and momentum conservation. The values of $c_2\{2\}$ for HIJING events are smaller than the values obtained from the data, and there is no significant difference between the HIJING results obtained at the generator (“truth”) level and at the reconstruction level. For $c_2\{4\}$, the HIJING events at $\Sigma E_T^{\text{Pb}} \sim 20$ GeV show a negative value comparable to the values seen in the data, indicating that correlations from jets or momentum conservation contribute significantly to $v_2\{4\}$ in events of low multiplicity. For $\Sigma E_T^{\text{Pb}} > 25$ GeV the generator-level HIJING sample’s values for $c_2\{4\}$ are also negative, but the magnitude is much smaller than in the data or in HIJING events with smaller ΣE_T^{Pb} . The size of the fully simulated HIJING event sample is too small to draw a definite conclusion about the sign or magnitude of $c_2\{4\}$.

The systematic uncertainties on $v_2\{2\}$ and $v_2\{4\}$ as a function of p_T and ΣE_T^{Pb} have been evaluated by varying several aspects of the analysis procedure. Azimuthal-angle sine terms in the Fourier expansion should be zero, but a non-zero contribution can arise due to detector biases. It was found that the magnitude of the sine terms relative to the cosine terms is negligible (below 1%) for $v_2\{2\}$ measured as a function of p_T , as well as for the p_T -integrated $v_2\{2\}$ and $v_2\{4\}$. In the case of the measurement of the p_T -dependent $v_2\{4\}$, the systematic uncertainty attributed to the residual sine terms varies between 6% and 14% in the different ΣE_T^{Pb} intervals. Uncertainties related to the tracking are obtained from the differences between the main results and those using tracking requirements modified to be either more or less restrictive. They are found to be negligible (below 0.2%) for $v_2\{2\}$. For the p_T -dependent $v_2\{4\}$ they give a contribution of less than 6% to the systematic uncertainty, and less than 1% for the p_T -integrated $v_2\{4\}$. In addition to varying the track quality requirements, an uncertainty on the p_T dependence of the efficiency corrections is also taken into account, and found to be below 1% for the $v_2\{2\}$ and $v_2\{4\}$ measurements. The correction of the azimuthal-angle uniformity is checked by comparing the results to those obtained with all weights, w_i , set equal to one. This change leads to small relative differences, below 1%, for the $v_2\{2\}$ measured as a function of p_T , as well as for the p_T -integrated $v_2\{2\}$ and $v_2\{4\}$. Up to 4% differences are observed in the p_T -dependent $v_2\{4\}$. All individual contributions to the systematic uncertainty are added in quadrature and quoted as the total systematic uncertainty. The total systematic uncertainties are

below 1% for the $v_2\{2\}$ measurement. The $v_2\{4\}$ measurement precision is limited by large statistical errors, whereas the systematic uncertainties stay below 15% for $v_2\{4\}(p_T)$ and below 2% for the p_T -integrated $v_2\{4\}$.

4. Results

Fig. 3 shows the transverse momentum dependence of $v_2\{2\}$ and $v_2\{4\}$ in four different classes of the event activity, selected according to ΣE_T^{Pb} . A significant second-order harmonic is observed. $v_2\{4\}$ is systematically smaller than $v_2\{2\}$, consistent with the suppression of non-flow effects in $v_2\{4\}$. This difference is most pronounced at high p_T and in collisions with low ΣE_T^{Pb} where jet-like correlations not diluted by the underlying event can contribute significantly. Thus, $v_2\{4\}$ appears to provide a more reliable estimate of the second-order anisotropy parameter of collective flow. As a function of transverse momentum the second-order harmonic, $v_2\{4\}$, increases with p_T up to $p_T \approx 2$ GeV. Large statistical errors preclude a definite conclusion about the p_T dependence of $v_2\{4\}$ at higher transverse momenta.

The shape and magnitude of the p_T dependence of $v_2\{4\}$ is found to be similar to that observed in $p + \text{Pb}$ collisions using two-particle correlations [2,3]. The second-order harmonic, v_2 , can be extracted from two-particle azimuthal correlations using charged particle pairs with a large pseudorapidity gap to suppress the short-range correlations on the near-side ($\Delta\phi \sim 0$) [3,22]. However, the two-particle correlation measured this way may still be affected by the dijet correlations on the away-side ($\Delta\phi \sim \pi$), which can span a large range in $\Delta\eta$. In Ref. [3], the away-side non-flow correlation is estimated using the yield measured in the lowest ΣE_T^{Pb} collisions and is then subtracted from the higher ΣE_T^{Pb} collisions. The result of that study, $v_2\{2PC\}$, is shown in Fig. 3 for the four activity intervals with largest ΣE_T^{Pb} , and compared to $v_2\{4\}$. Good agreement is observed between $v_2\{4\}$ and $v_2\{2PC\}$ for collisions with $\Sigma E_T^{\text{Pb}} > 55$ GeV. For $\Sigma E_T^{\text{Pb}} < 55$ GeV, the disagreement could be due either to the subtraction procedure used to obtain $v_2\{2PC\}$ or to non-flow effects in $v_2\{4\}$, or to a combination.

The dependence on the collision activity of the second-order harmonic, integrated over $0.3 < p_T < 5$ GeV, is shown in Fig. 4. The large magnitude of $v_2\{2\}$ compared to $v_2\{4\}$ suggests a substantial contamination from non-flow correlations. The value of $v_2\{4\}$ is approximately 0.06, with little dependence on the overall event activity for $\Sigma E_T^{\text{Pb}} > 25$ GeV. The extracted values of $v_2\{4\}$ are also compared to the $v_2\{2PC\}$ values obtained from two-particle correlations. Good agreement is observed at large ΣE_T^{Pb} , while at lower ΣE_T^{Pb} the $v_2\{2PC\}$ is smaller than $v_2\{4\}$, which may be due to different sensitivity of the two methods to non-flow contributions

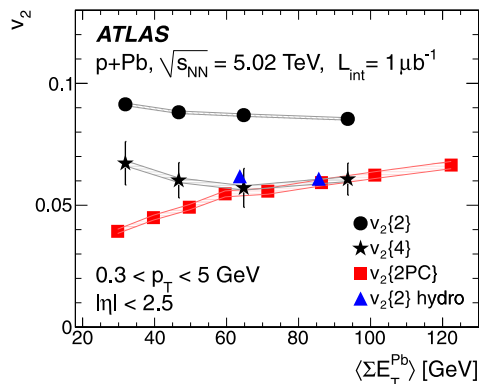


Fig. 4. The second-order harmonic, v_2 , integrated over p_T and η , calculated with two- and four-particle cumulants (circles and stars, respectively), as a function of ΣE_T^{Pb} . Systematic uncertainties are shown as shaded bands. Also shown are $v_2\{2\text{PC}\}$ (squares) and predictions from the hydrodynamic model [18] (triangles) for the same selection of charged particles as in the data.

that become more important in low ΣE_T^{Pb} collisions. Although $v_2\{4\}$ is constructed to suppress local two-particle correlations, it may still include true multi-particle correlations from jets, which should account for a larger fraction of the correlated particle production in the events with the lowest ΣE_T^{Pb} . If the HIJING results, shown in Fig. 2, were used to correct the measured cumulants for this non-flow contribution, the extracted $v_2\{4\}$ would be decreased by at most 10% for $v_2\{4\}$ shown in Fig. 4. However, this correction is not applied to the final results.

It is notable that the trend of the p_T dependence of both $v_2\{4\}$ and $v_2\{2\text{PC}\}$ in $p + \text{Pb}$ collisions resembles that observed for v_2 measured with the event-plane method in $\text{Pb} + \text{Pb}$ collisions at $\sqrt{s_{\text{NN}}} = 2.76 \text{ TeV}$ [21,22], although with a magnitude between that observed in the most central and peripheral $\text{Pb} + \text{Pb}$ collisions. While the trend is found to be nearly independent of the $\text{Pb} + \text{Pb}$ collision geometry, the magnitude in $\text{Pb} + \text{Pb}$ events depends on the initial shape of the colliding system, and has been modelled for $p_T < 2 \text{ GeV}$ using viscous hydrodynamics [40–42].

Harmonic flow coefficients in $p + \text{Pb}$ collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$ have also been predicted using viscous hydrodynamics, with similar initial conditions as the $\text{Pb} + \text{Pb}$ calculations [18]. The predicted magnitude of the second-order harmonic² is compared to the measured $v_2\{4\}$ and $v_2\{2\text{PC}\}$ in Fig. 4. It can be seen that the hydrodynamic predictions agree with our measurements over the ΣE_T^{Pb} range where the model predictions are available.

5. Conclusions

ATLAS has measured the second harmonic coefficient in $p + \text{Pb}$ collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$ using two- and four-particle cumulants. A significant magnitude of v_2 is observed using both two- and four-particle cumulants, although $v_2\{2\}$ is consistently larger than $v_2\{4\}$, indicating a sizeable contribution of non-flow correlations to $v_2\{2\}$. The transverse momentum dependence of $v_2\{4\}$ shows a behaviour similar to that measured in $\text{Pb} + \text{Pb}$ collisions at $\sqrt{s_{\text{NN}}} = 2.76 \text{ TeV}$. The magnitude of $v_2\{4\}$ increases with p_T up to about 2–3 GeV. As a function of the collision activity, $v_2\{4\}$ remains constant, at the level of about 0.06, for the collisions with

$\Sigma E_T^{\text{Pb}} > 25 \text{ GeV}$, which corresponds to about 40% of the data. The measured $v_2\{4\}$ is found to be consistent with the second harmonic coefficient extracted by the Fourier decomposition of the long-range two-particle correlation function for collisions with $\Sigma E_T^{\text{Pb}} > 55 \text{ GeV}$. Good agreement is also found with the predictions of a hydrodynamic calculation for $p + \text{Pb}$ collisions.

Extending previous results based only on two-particle correlations, the multi-particle cumulant results presented here provide additional evidence for the importance of final-state effects in the highest multiplicity $p + \text{Pb}$ reactions. Final-state effects may lead to collective flow similar to that observed in the hot, dense system created in high-energy heavy-ion collisions.

Acknowledgements

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

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWF and FWF, 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; EPLANET, ERC and NSRF, European Union; IN2P3-CNRS, CEA-DSM/IRFU, France; GNSF, Georgia; BMBF, DFG, HGF, MPG and AvH Foundation, Germany; GSRT and NSRF, Greece; ISF, MINERVA, GIF, DIP and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; BRF and 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.

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](https://www.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] CMS Collaboration, Phys. Lett. B 718 (2013) 795, arXiv:1210.5482.
- [2] ALICE Collaboration, Phys. Lett. B 719 (2013) 29, arXiv:1212.2001.
- [3] ATLAS Collaboration, Phys. Rev. Lett. 110 (2013) 182302, arXiv:1212.5198.
- [4] K. Dusling, R. Venugopalan, arXiv:1210.3890.
- [5] K. Dusling, R. Venugopalan, arXiv:1211.3701, arXiv:1302.7018.
- [6] B.A. Arbuзов, E.E. Boos, V.I. Savrin, Eur. Phys. J. C 71 (2011) 1730, arXiv:1104.1283.
- [7] Y.V. Kovchegov, D.E. Wertepny, arXiv:1212.1195.
- [8] Ch.Y. Wong, Phys. Rev. C 84 (2011) 024901, arXiv:1105.5871.
- [9] M. Strikman, Acta Phys. Pol. B 42 (2011) 2607.
- [10] S. Alderweireldt, P. Van Mechelen, arXiv:1203.2048.
- [11] M.G. Ryskin, A.D. Martin, V.A. Khoze, J. Phys. G 38 (2011) 085006, arXiv:1105.4987.

² We are grateful to the authors of Ref. [18] for providing us with the model predictions for charged particles with η and p_T ranges matching those used in the analysis. The model predictions are for two activity intervals corresponding to fractions of events of 0–3.4% and 3.4–7.8% which are then translated into the ΣE_T^{Pb} intervals using Fig. 1.

- [12] M. Diehl, A. Schafer, Phys. Lett. B 698 (2011) 389, arXiv:1102.3081.
 [13] E. Avsar, Ch. Flensburg, Y. Hatta, J.-Y. Ollitrault, T. Ueda, Phys. Lett. B 702 (2011) 394, arXiv:1009.5643.
 [14] K. Werner, Iu. Karpenko, T. Pierog, Phys. Rev. Lett. 106 (2011) 122004, arXiv:1011.0375.
 [15] T.-W. Deng, Z. Xu, C. Greiner, Phys. Lett. B 711 (2012) 301, arXiv:1112.0470.
 [16] E. Avsar, Ch. Flensburg, Y. Hatta, J.-Y. Ollitrault, T. Ueda, J. Phys. G 38 (2011) 124053, arXiv:1106.4356.
 [17] P. Božek, Phys. Rev. C 85 (2012) 014911, arXiv:1112.0915.
 [18] P. Božek, W. Broniowski, Phys. Lett. B 718 (2013) 1557, arXiv:1211.0845.
 [19] ALICE Collaboration, Phys. Rev. Lett. 105 (2010) 252302, arXiv:1011.3914.
 [20] ALICE Collaboration, Phys. Rev. Lett. 107 (2011) 032301, arXiv:1105.3865.
 [21] ATLAS Collaboration, Phys. Lett. B 707 (2012) 330, arXiv:1108.6018.
 [22] ATLAS Collaboration, Phys. Rev. C 86 (2012) 014907, arXiv:1203.3087.
 [23] CMS Collaboration, Phys. Rev. C 87 (2012) 014902, arXiv:1204.1409.
 [24] CMS Collaboration, Phys. Rev. Lett. 109 (2012) 022301, arXiv:1204.1850.
 [25] S.A. Voloshin, A.M. Poskanzer, R. Snellings, arXiv:0809.2949.
 [26] P. Sorensen, arXiv:0905.0174.
 [27] A.M. Poskanzer, S.A. Voloshin, Phys. Rev. C 58 (1998) 1671, arXiv:nucl-ex/9805001.
 [28] B. Alver, G. Roland, Phys. Rev. C 81 (2010) 054905, arXiv:1003.0194.
 [29] N. Borghini, P.M. Dinh, J.-Y. Ollitrault, Phys. Rev. C 63 (2001) 054906, arXiv:nucl-th/0007063.
 [30] N. Borghini, P.M. Dinh, J.-Y. Ollitrault, Phys. Rev. C 64 (2001) 054901, arXiv:nucl-th/0105040.
 [31] R. Kubo, J. Phys. Soc. Japan 17 (7) (1962).
 [32] A. Bilandzic, R. Snellings, S. Voloshin, Phys. Rev. C 83 (2011) 044913, arXiv:1010.0233.
 [33] ATLAS Collaboration, JINST 3 (2008) S08003.
 [34] ATLAS Collaboration, New J. Phys. 13 (2010) 053033.
 [35] X.-N. Wang, M. Gyulassy, Phys. Rev. D 44 (1991) 3501.
 [36] S. Agostinelli, et al., Nucl. Instrum. Meth. A 506 (2003) 250, arXiv:1012.5104.
 [37] ATLAS Collaboration, Eur. Phys. J. C 70 (2010) 823, arXiv:1005.4568.
 [38] ATLAS Collaboration, ATLAS-CONF-2012-118, <https://cds.cern.ch/record/1472940>.
 [39] ATLAS Collaboration, <https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HION-2013-01/>, additional auxiliary plots (Fig. 10).
 [40] M. Luzum, Phys. Rev. C 83 (2011) 044911, arXiv:1011.5173.
 [41] C. Gale, S. Jeon, B. Schenke, P. Tribedy, R. Venugopalan, Phys. Rev. Lett. 110 (2013) 012302, arXiv:1209.6330.
 [42] C. Shen, U.W. Heinz, P. Huovinen, H. Song, Phys. Rev. C 84 (2011) 044903, arXiv:1105.3226.

ATLAS Collaboration

G. Aad⁴⁸, T. Abajyan²¹, B. Abbott¹¹¹, J. Abdallah¹², S. Abdel Khalek¹¹⁵, A.A. Abdelalim⁴⁹, O. Abdinov¹¹, R. Aben¹⁰⁵, B. Abi¹¹², M. Abolins⁸⁸, O.S. AbouZeid¹⁵⁸, H. Abramowicz¹⁵³, H. Abreu¹³⁶, Y. Abulaiti^{146a,146b}, B.S. Acharya^{164a,164b,a}, L. Adamczyk^{38a}, D.L. Adams²⁵, T.N. Addy⁵⁶, J. Adelman¹⁷⁶, S. Adomeit⁹⁸, T. Adye¹²⁹, S. Aefsky²³, J.A. Aguilar-Saavedra^{124b,b}, M. Agustoni¹⁷, S.P. Ahlen²², F. Ahles⁴⁸, A. Ahmad¹⁴⁸, M. Ahsan⁴¹, G. Aielli^{133a,133b}, T.P.A. Åkesson⁷⁹, G. Akimoto¹⁵⁵, A.V. Akimov⁹⁴, M.A. Alam⁷⁶, J. Albert¹⁶⁹, S. Albrand⁵⁵, M. Aleksa³⁰, I.N. Aleksandrov⁶⁴, F. Alessandria^{89a}, C. Alexa^{26a}, G. Alexander¹⁵³, G. Alexandre⁴⁹, T. Alexopoulos¹⁰, M. Alhroob^{164a,164c}, M. Aliev¹⁶, G. Alimonti^{89a}, J. Alison³¹, B.M.M. Allbrooke¹⁸, L.J. Allison⁷¹, P.P. Allport⁷³, S.E. Allwood-Spiers⁵³, J. Almond⁸², A. Aloisio^{102a,102b}, R. Alon¹⁷², A. Alonso³⁶, F. Alonso⁷⁰, A. Althamer³⁵, B. Alvarez Gonzalez⁸⁸, M.G. Alviggi^{102a,102b}, K. Amako⁶⁵, Y. Amaral Coutinho^{24a}, C. Amelung²³, V.V. Ammosov^{128,*}, S.P. Amor Dos Santos^{124a}, A. Amorim^{124a,c}, S. Amoroso⁴⁸, N. Amram¹⁵³, C. Anastopoulos³⁰, L.S. Ancu¹⁷, N. Andari³⁰, T. Andeen³⁵, C.F. Anders^{58b}, G. Anders^{58a}, K.J. Anderson³¹, A. Andreazza^{89a,89b}, V. Andrei^{58a}, X.S. Anduaga⁷⁰, S. Angelidakis⁹, P. Anger⁴⁴, A. Angerami³⁵, F. Anghinolfi³⁰, A. Anisenkov¹⁰⁷, N. Anjos^{124a}, A. Annovi⁴⁷, A. Antonaki⁹, M. Antonelli⁴⁷, A. Antonov⁹⁶, J. Antos^{144b}, F. Anulli^{132a}, M. Aoki¹⁰¹, L. Aperio Bella¹⁸, R. Apolle^{118,d}, G. Arabidze⁸⁸, I. Aracena¹⁴³, Y. Arai⁶⁵, A.T.H. Arce⁴⁵, S. Arfaoui¹⁴⁸, J.-F. Arguin⁹³, S. Argyropoulos⁴², E. Arik^{19a,*}, M. Arik^{19a}, A.J. Armbruster⁸⁷, O. Arnaez⁸¹, V. Arnal⁸⁰, A. Artamonov⁹⁵, G. Artoni^{132a,132b}, D. Arutinov²¹, S. Asai¹⁵⁵, N. Asbah⁹³, S. Ask²⁸, B. Åsman^{146a,146b}, L. Asquith⁶, K. Assamagan²⁵, R. Astalos^{144a}, A. Astbury¹⁶⁹, M. Atkinson¹⁶⁵, B. Auerbach⁶, E. Auge¹¹⁵, K. Augsten¹²⁶, M. Aurousseau^{145a}, G. Avolio³⁰, D. Axen¹⁶⁸, G. Azuelos^{93,e}, Y. Azuma¹⁵⁵, M.A. Baak³⁰, G. Baccaglioni^{89a}, C. Bacci^{134a,134b}, A.M. Bach¹⁵, H. Bachacou¹³⁶, K. Bachas¹⁵⁴, M. Backes⁴⁹, M. Backhaus²¹, J. Backus Mayes¹⁴³, E. Badescu^{26a}, P. Bagiacchi^{132a,132b}, P. Bagnaia^{132a,132b}, Y. Bai^{33a}, D.C. Bailey¹⁵⁸, T. Bain³⁵, J.T. Baines¹²⁹, O.K. Baker¹⁷⁶, S. Baker⁷⁷, P. Balek¹²⁷, F. Balli¹³⁶, E. Banas³⁹, P. Banerjee⁹³, Sw. Banerjee¹⁷³, D. Banfi³⁰, A. Bangert¹⁵⁰, V. Bansal¹⁶⁹, H.S. Bansil¹⁸, L. Barak¹⁷², S.P. Baranov⁹⁴, T. Barber⁴⁸, E.L. Barberio⁸⁶, D. Barberis^{50a,50b}, M. Barbero⁸³, D.Y. Bardin⁶⁴, T. Barillari⁹⁹, M. Barisonzi¹⁷⁵, T. Barklow¹⁴³, N. Barlow²⁸, B.M. Barnett¹²⁹, R.M. Barnett¹⁵, A. Baroncelli^{134a}, G. Barone⁴⁹, A.J. Barr¹¹⁸, F. Barreiro⁸⁰, J. Barreiro Guimarães da Costa⁵⁷, R. Bartoldus¹⁴³, A.E. Barton⁷¹, V. Bartsch¹⁴⁹, A. Basye¹⁶⁵, R.L. Bates⁵³, L. Batkova^{144a}, J.R. Batley²⁸, A. Battaglia¹⁷, M. Battistin³⁰, F. Bauer¹³⁶, H.S. Bawa^{143,f}, S. Beale⁹⁸, T. Beau⁷⁸, P.H. Beauchemin¹⁶¹, R. Beccherle^{50a}, P. Bechtel²¹, H.P. Beck¹⁷, K. Becker¹⁷⁵, S. Becker⁹⁸, M. Beckingham¹³⁸, K.H. Becks¹⁷⁵, A.J. Beddall^{19c}, A. Beddall^{19c}, S. Bedikian¹⁷⁶, V.A. Bednyakov⁶⁴, C.P. Bee⁸³, L.J. Beemster¹⁰⁵, T.A. Beermann¹⁷⁵, M. Begel²⁵, C. Belanger-Champagne⁸⁵, P.J. Bell⁴⁹,

W.H. Bell⁴⁹, G. Bella¹⁵³, L. Bellagamba^{20a}, A. Bellerive²⁹, M. Bellomo³⁰, A. Belloni⁵⁷,
 O. Beloborodova^{107,g}, K. Belotskiy⁹⁶, O. Beltramo³⁰, O. Benary¹⁵³, D. Benchekroun^{135a},
 K. Bendtz^{146a,146b}, N. Benekos¹⁶⁵, Y. Benhammou¹⁵³, E. Benhar Noccioli⁴⁹,
 J.A. Benitez Garcia^{159b}, D.P. Benjamin⁴⁵, J.R. Bensinger²³, K. Benslama¹³⁰,
 S. Bentvelsen¹⁰⁵, D. Berge³⁰, E. Bergeaas Kuutmann¹⁶, N. Berger⁵, F. Berghaus¹⁶⁹,
 E. Berglund¹⁰⁵, J. Beringer¹⁵, P. Bernat⁷⁷, R. Bernhard⁴⁸, C. Bernius²⁵,
 F.U. Bernlochner¹⁶⁹, T. Berry⁷⁶, C. Bertella⁸³, F. Bertolucci^{122a,122b}, M.I. Besana^{89a,89b},
 G.J. Besjes¹⁰⁴, N. Besson¹³⁶, S. Bethke⁹⁹, W. Bhimji⁴⁶, R.M. Bianchi³⁰, L. Bianchini²³,
 M. Bianco^{72a,72b}, O. Biebel⁹⁸, S.P. Bieniek⁷⁷, K. Bierwagen⁵⁴, J. Biesiada¹⁵,
 M. Biglietti^{134a}, H. Bilokon⁴⁷, M. Bindi^{20a,20b}, S. Binet¹¹⁵, A. Bingul^{19c}, C. Bini^{132a,132b},
 C. Biscarat¹⁷⁸, B. Bittner⁹⁹, C.W. Black¹⁵⁰, J.E. Black¹⁴³, K.M. Black²², R.E. Blair⁶,
 J.-B. Blanchard¹³⁶, T. Blazek^{144a}, I. Bloch⁴², C. Blocker²³, J. Blocki³⁹, W. Blum⁸¹,
 U. Blumenschein⁵⁴, G.J. Bobbink¹⁰⁵, V.S. Bobrovnikov¹⁰⁷, S.S. Bocchetta⁷⁹, A. Bocci⁴⁵,
 C.R. Boddy¹¹⁸, M. Boehler⁴⁸, J. Boek¹⁷⁵, T.T. Boek¹⁷⁵, N. Boelaert³⁶, J.A. Bogaerts³⁰,
 A. Bogdanchikov¹⁰⁷, A. Bogouch^{90,*}, C. Bohm^{146a}, J. Bohm¹²⁵, V. Boisvert⁷⁶, T. Bold^{38a},
 V. Boldea^{26a}, N.M. Bolnet¹³⁶, M. Bomben⁷⁸, M. Bona⁷⁵, M. Boonekamp¹³⁶, S. Bordoni⁷⁸,
 C. Borer¹⁷, A. Borisov¹²⁸, G. Borissov⁷¹, I. Borjanovic^{13a}, M. Borri⁸², S. Borroni⁴²,
 J. Bortfeldt⁹⁸, V. Bortolotto^{134a,134b}, K. Bos¹⁰⁵, D. Boscherini^{20a}, M. Bosman¹²,
 H. Boterenbrood¹⁰⁵, J. Bouchami⁹³, J. Boudreau¹²³, E.V. Bouhova-Thacker⁷¹,
 D. Boumediene³⁴, C. Bourdarios¹¹⁵, N. Bousson⁸³, S. Boutouil^{135d}, A. Boveia³¹, J. Boyd³⁰,
 I.R. Boyko⁶⁴, I. Bozovic-Jelisavcic^{13b}, J. Bracinik¹⁸, P. Branchini^{134a}, A. Brandt⁸,
 G. Brandt¹¹⁸, O. Brandt⁵⁴, U. Bratzler¹⁵⁶, B. Brau⁸⁴, J.E. Brau¹¹⁴, H.M. Braun^{175,*},
 S.F. Brazzale^{164a,164c}, B. Brelief¹⁵⁸, J. Bremer³⁰, K. Brendlinger¹²⁰, R. Brenner¹⁶⁶,
 S. Bressler¹⁷², T.M. Bristow^{145b}, D. Britton⁵³, F.M. Brochu²⁸, I. Brock²¹, R. Brock⁸⁸,
 F. Broggi^{89a}, C. Bromberg⁸⁸, J. Bronner⁹⁹, G. Brooijmans³⁵, T. Brooks⁷⁶, W.K. Brooks^{32b},
 G. Brown⁸², P.A. Bruckman de Renstrom³⁹, D. Bruncko^{144b}, R. Bruneliere⁴⁸, S. Brunet⁶⁰,
 A. Bruni^{20a}, G. Bruni^{20a}, M. Bruschi^{20a}, L. Bryngemark⁷⁹, T. Buanes¹⁴, Q. Buat⁵⁵,
 F. Bucci⁴⁹, J. Buchanan¹¹⁸, P. Buchholz¹⁴¹, R.M. Buckingham¹¹⁸, A.G. Buckley⁴⁶,
 S.I. Buda^{26a}, I.A. Budagov⁶⁴, B. Budick¹⁰⁸, L. Bugge¹¹⁷, O. Bulekov⁹⁶, A.C. Bundock⁷³,
 M. Bunse⁴³, T. Buran^{117,*}, H. Burckhart³⁰, S. Burdin⁷³, T. Burgess¹⁴, S. Burke¹²⁹,
 E. Busato³⁴, V. Büscher⁸¹, P. Bussey⁵³, C.P. Buszello¹⁶⁶, B. Butler⁵⁷, J.M. Butler²²,
 C.M. Buttar⁵³, J.M. Butterworth⁷⁷, W. Buttinger²⁸, M. Byszewski¹⁰, S. Cabrera Urbán¹⁶⁷,
 D. Caforio^{20a,20b}, O. Cakir^{4a}, P. Calafiura¹⁵, G. Calderini⁷⁸, P. Calfayan⁹⁸, R. Calkins¹⁰⁶,
 L.P. Caloba^{24a}, R. Caloi^{132a,132b}, D. Calvet³⁴, S. Calvet³⁴, R. Camacho Toro⁴⁹,
 P. Camarri^{133a,133b}, D. Cameron¹¹⁷, L.M. Caminada¹⁵, R. Caminal Armadans¹²,
 S. Campana³⁰, M. Campanelli⁷⁷, V. Canale^{102a,102b}, F. Canelli³¹, A. Canepa^{159a},
 J. Cantero⁸⁰, R. Cantrill⁷⁶, T. Cao⁴⁰, M.D.M. Capeans Garrido³⁰, I. Caprini^{26a},
 M. Caprini^{26a}, D. Capriotti⁹⁹, M. Capua^{37a,37b}, R. Caputo⁸¹, R. Cardarelli^{133a}, T. Carli³⁰,
 G. Carlino^{102a}, L. Carminati^{89a,89b}, S. Caron¹⁰⁴, E. Carquin^{32b}, G.D. Carrillo-Montoya^{145b},
 A.A. Carter⁷⁵, J.R. Carter²⁸, J. Carvalho^{124a,h}, D. Casadei¹⁰⁸, M.P. Casado¹²,
 M. Cascella^{122a,122b}, C. Caso^{50a,50b,*}, E. Castaneda-Miranda¹⁷³, A. Castelli¹⁰⁵,
 V. Castillo Gimenez¹⁶⁷, N.F. Castro^{124a}, G. Cataldi^{72a}, P. Catastini⁵⁷, A. Catinaccio³⁰,
 J.R. Catmore³⁰, A. Cattai³⁰, G. Cattani^{133a,133b}, S. Caughron⁸⁸, V. Cavaliere¹⁶⁵,
 P. Cavalleri⁷⁸, D. Cavalli^{89a}, M. Cavalli-Sforza¹², V. Cavasinni^{122a,122b}, F. Ceradini^{134a,134b},
 B. Cerio⁴⁵, A.S. Cerqueira^{24b}, A. Cerri¹⁵, L. Cerrito⁷⁵, F. Cerutti¹⁵, A. Cervelli¹⁷,
 S.A. Cetin^{19b}, A. Chafaq^{135a}, D. Chakraborty¹⁰⁶, I. Chalupkova¹²⁷, K. Chan³, P. Chang¹⁶⁵,
 B. Chapleau⁸⁵, J.D. Chapman²⁸, J.W. Chapman⁸⁷, D.G. Charlton¹⁸, V. Chavda⁸²,
 C.A. Chavez Barajas³⁰, S. Cheatham⁸⁵, S. Chekanov⁶, S.V. Chekulaev^{159a}, G.A. Chelkov⁶⁴,
 M.A. Chelstowska¹⁰⁴, C. Chen⁶³, H. Chen²⁵, S. Chen^{33c}, X. Chen¹⁷³, Y. Chen³⁵,
 Y. Cheng³¹, A. Cheplakov⁶⁴, R. Cherkaoui El Moursli^{135e}, V. Chernyatin²⁵, E. Cheu⁷,
 S.L. Cheung¹⁵⁸, L. Chevalier¹³⁶, V. Chiarella⁴⁷, G. Chiefari^{102a,102b}, J.T. Childers³⁰,
 A. Chilingarov⁷¹, G. Chiodini^{72a}, A.S. Chisholm¹⁸, R.T. Chislett⁷⁷, A. Chitan^{26a},

M.V. Chizhov⁶⁴, G. Choudalakis³¹, S. Chouridou⁹, B.K.B. Chow⁹⁸, I.A. Christidi⁷⁷,
 A. Christov⁴⁸, D. Chromek-Burckhart³⁰, M.L. Chu¹⁵¹, J. Chudoba¹²⁵, G. Ciapetti^{132a,132b},
 A.K. Ciftci^{4a}, R. Ciftci^{4a}, D. Cinca⁶², V. Cindro⁷⁴, A. Ciochio¹⁵, M. Cirilli⁸⁷, P. Cirkovic^{13b},
 Z.H. Citron¹⁷², M. Citterio^{89a}, M. Ciubancan^{26a}, A. Clark⁴⁹, P.J. Clark⁴⁶, R.N. Clarke¹⁵,
 J.C. Clemens⁸³, B. Clement⁵⁵, C. Clement^{146a,146b}, Y. Coadou⁸³, M. Cobal^{164a,164c},
 A. Coccaro¹³⁸, J. Cochran⁶³, L. Coffey²³, J.G. Cogan¹⁴³, J. Coggeshall¹⁶⁵, J. Colas⁵,
 S. Cole¹⁰⁶, A.P. Colijn¹⁰⁵, N.J. Collins¹⁸, C. Collins-Tooth⁵³, J. Collot⁵⁵, T. Colombo^{119a,119b},
 G. Colon⁸⁴, G. Compostella⁹⁹, P. Conde Muiño^{124a}, E. Coniavitis¹⁶⁶, M.C. Conidi¹²,
 S.M. Consonni^{89a,89b}, V. Consorti⁴⁸, S. Constantinescu^{26a}, C. Conta^{119a,119b}, G. Conti⁵⁷,
 F. Conventi^{102a,i}, M. Cooke¹⁵, B.D. Cooper⁷⁷, A.M. Cooper-Sarkar¹¹⁸, N.J. Cooper-Smith⁷⁶,
 K. Copic¹⁵, T. Cornelissen¹⁷⁵, M. Corradi^{20a}, F. Corriveau^{85,j}, A. Corso-Radu¹⁶³,
 A. Cortes-Gonzalez¹⁶⁵, G. Cortiana⁹⁹, G. Costa^{89a}, M.J. Costa¹⁶⁷, D. Costanzo¹³⁹,
 D. Côté³⁰, G. Cottin^{32a}, L. Courneyea¹⁶⁹, G. Cowan⁷⁶, B.E. Cox⁸², K. Cranmer¹⁰⁸,
 S. Crépe-Renaudin⁵⁵, F. Crescioli⁷⁸, M. Cristinziani²¹, G. Crosetti^{37a,37b}, C.-M. Cuciuc^{26a},
 C. Cuenca Almenar¹⁷⁶, T. Cuhadar Donszelmann¹³⁹, J. Cummings¹⁷⁶, M. Curatolo⁴⁷,
 C.J. Curtis¹⁸, C. Cuthbert¹⁵⁰, H. Czirr¹⁴¹, P. Czodrowski⁴⁴, Z. Czynzula¹⁷⁶, S. D'Auria⁵³,
 M. D'Onofrio⁷³, A. D'Orazio^{132a,132b}, M.J. Da Cunha Sargedas De Sousa^{124a}, C. Da Via⁸²,
 W. Dabrowski^{38a}, A. Dafinca¹¹⁸, T. Dai⁸⁷, F. Dallaire⁹³, C. Dallapiccola⁸⁴, M. Dam³⁶,
 D.S. Damiani¹³⁷, A.C. Daniells¹⁸, H.O. Danielsson³⁰, V. Dao¹⁰⁴, G. Darbo^{50a},
 G.L. Darlea^{26b}, S. Darmora⁸, J.A. Dassoulas⁴², W. Davey²¹, T. Davidek¹²⁷, N. Davidson⁸⁶,
 E. Davies^{118,d}, M. Davies⁹³, O. Davignon⁷⁸, A.R. Davison⁷⁷, Y. Davygora^{58a}, E. Dawe¹⁴²,
 I. Dawson¹³⁹, R.K. Daya-Ishmukhametova²³, K. De⁸, R. de Asmundis^{102a},
 S. De Castro^{20a,20b}, S. De Cecco⁷⁸, J. de Graat⁹⁸, N. De Groot¹⁰⁴, P. de Jong¹⁰⁵,
 C. De La Taille¹¹⁵, H. De la Torre⁸⁰, F. De Lorenzi⁶³, L. De Nooij¹⁰⁵, D. De Pedis^{132a},
 A. De Salvo^{132a}, U. De Sanctis^{164a,164c}, A. De Santo¹⁴⁹, J.B. De Vivie De Regie¹¹⁵,
 G. De Zorzi^{132a,132b}, W.J. Dearnaley⁷¹, R. Debbes²⁵, C. Debenedetti⁴⁶, B. Dechenaux⁵⁵,
 D.V. Dedovich⁶⁴, J. Degenhardt¹²⁰, J. Del Peso⁸⁰, T. Del Prete^{122a,122b}, T. Delemontex⁵⁵,
 M. Deliyergiyev⁷⁴, A. Dell'Acqua³⁰, L. Dell'Asta²², M. Della Pietra^{102a,i},
 D. della Volpe^{102a,102b}, M. Delmastro⁵, P.A. Delsart⁵⁵, C. Deluca¹⁰⁵, S. Demers¹⁷⁶,
 M. Demichev⁶⁴, A. Demilly⁷⁸, B. Demirkoz^{12,k}, S.P. Denisov¹²⁸, D. Derendarz³⁹,
 J.E. Derkaoui^{135d}, F. Derue⁷⁸, P. Dervan⁷³, K. Desch²¹, P.O. Deviveiros¹⁰⁵, A. Dewhurst¹²⁹,
 B. DeWilde¹⁴⁸, S. Dhaliwal¹⁰⁵, R. Dhullipudi^{25,l}, A. Di Ciaccio^{133a,133b}, L. Di Ciaccio⁵,
 C. Di Donato^{102a,102b}, A. Di Girolamo³⁰, B. Di Girolamo³⁰, S. Di Luise^{134a,134b},
 A. Di Mattia¹⁵², B. Di Micco^{134a,134b}, R. Di Nardo⁴⁷, A. Di Simone^{133a,133b},
 R. Di Sipio^{20a,20b}, M.A. Diaz^{32a}, E.B. Diehl⁸⁷, J. Dietrich⁴², T.A. Dietzsch^{58a}, S. Diglio⁸⁶,
 K. Dindar Yagci⁴⁰, J. Dingfelder²¹, F. Dinut^{26a}, C. Dionisi^{132a,132b}, P. Dita^{26a}, S. Dita^{26a},
 F. Dittus³⁰, F. Djama⁸³, T. Djobava^{51b}, M.A.B. do Vale^{24c}, A. Do Valle Wemans^{124a,m},
 T.K.O. Doan⁵, D. Dobos³⁰, E. Dobson⁷⁷, J. Dodd³⁵, C. Doglioni⁴⁹, T. Doherty⁵³,
 T. Dohmae¹⁵⁵, Y. Doi^{65,*}, J. Dolejsi¹²⁷, Z. Dolezal¹²⁷, B.A. Dolgoshein^{96,*},
 M. Donadelli^{24d}, J. Donini³⁴, J. Dopke³⁰, A. Doria^{102a}, A. Dos Anjos¹⁷³, A. Dotti^{122a,122b},
 M.T. Dova⁷⁰, A.T. Doyle⁵³, M. Dris¹⁰, J. Dubbert⁸⁷, S. Dube¹⁵, E. Dubreuil³⁴,
 E. Duchovni¹⁷², G. Duckeck⁹⁸, D. Duda¹⁷⁵, A. Dudarev³⁰, F. Dudziak⁶³, L. Duflot¹¹⁵,
 M.-A. Dufour⁸⁵, L. Duguid⁷⁶, M. Dührssen³⁰, M. Dunford^{58a}, H. Duran Yildiz^{4a},
 M. Düren⁵², R. Duxfield¹³⁹, M. Dwuznik^{38a}, W.L. Ebenstein⁴⁵, J. Ebke⁹⁸, S. Eckweiler⁸¹,
 W. Edson², C.A. Edwards⁷⁶, N.C. Edwards⁵³, W. Ehrenfeld²¹, T. Eifert¹⁴³, G. Eigen¹⁴,
 K. Einsweiler¹⁵, E. Eisenhandler⁷⁵, T. Ekelof¹⁶⁶, M. El Kacimi^{135c}, M. Ellert¹⁶⁶, S. Elles⁵,
 F. Ellinghaus⁸¹, K. Ellis⁷⁵, N. Ellis³⁰, J. Elmsheuser⁹⁸, M. Elsing³⁰, D. Emeliyanov¹²⁹,
 Y. Enari¹⁵⁵, O.C. Endner⁸¹, R. Engelmann¹⁴⁸, A. Engl⁹⁸, B. Epp⁶¹, J. Erdmann¹⁷⁶,
 A. Ereditato¹⁷, D. Eriksson^{146a}, J. Ernst², M. Ernst²⁵, J. Ernwein¹³⁶, D. Errede¹⁶⁵,
 S. Errede¹⁶⁵, E. Ertel⁸¹, M. Escalier¹¹⁵, H. Esch⁴³, C. Escobar¹²³, X. Espinal Curull¹²,
 B. Esposito⁴⁷, F. Etienne⁸³, A.I. Etienvre¹³⁶, E. Etzion¹⁵³, D. Evangelakou⁵⁴, H. Evans⁶⁰,
 L. Fabbri^{20a,20b}, C. Fabre³⁰, G. Facini³⁰, R.M. Fakhrutdinov¹²⁸, S. Falciano^{132a}, Y. Fang^{33a},

M. Fanti^{89a,89b}, A. Farbin⁸, A. Farilla^{134a}, T. Farooque¹⁵⁸, S. Farrell¹⁶³, S.M. Farrington¹⁷⁰,
 P. Farthouat³⁰, F. Fassi¹⁶⁷, P. Fassnacht³⁰, D. Fassouliotis⁹, B. Fatholahzadeh¹⁵⁸,
 A. Favareto^{89a,89b}, L. Fayard¹¹⁵, P. Federic^{144a}, O.L. Fedin¹²¹, W. Fedorko¹⁶⁸,
 M. Fehling-Kaschek⁴⁸, L. Feligioni⁸³, C. Feng^{33d}, E.J. Feng⁶, H. Feng⁸⁷, A.B. Fenyuk¹²⁸,
 J. Ferencei^{144b}, W. Fernando⁶, S. Ferrag⁵³, J. Ferrando⁵³, V. Ferrara⁴², A. Ferrari¹⁶⁶,
 P. Ferrari¹⁰⁵, R. Ferrari^{119a}, D.E. Ferreira de Lima⁵³, A. Ferrer¹⁶⁷, D. Ferrere⁴⁹,
 C. Ferretti⁸⁷, A. Ferretto Parodi^{50a,50b}, M. Fiascaris³¹, F. Fiedler⁸¹, A. Filipčić⁷⁴,
 F. Filthaut¹⁰⁴, M. Fincke-Keeler¹⁶⁹, K.D. Finelli⁴⁵, M.C.N. Fiolhais^{124a,h}, L. Fiorini¹⁶⁷,
 A. Firan⁴⁰, J. Fischer¹⁷⁵, M.J. Fisher¹⁰⁹, E.A. Fitzgerald²³, M. Flechl⁴⁸, I. Fleck¹⁴¹,
 P. Fleischmann¹⁷⁴, S. Fleischmann¹⁷⁵, G.T. Fletcher¹³⁹, G. Fletcher⁷⁵, T. Flick¹⁷⁵,
 A. Floderus⁷⁹, L.R. Flores Castillo¹⁷³, A.C. Florez Bustos^{159b}, M.J. Flowerdew⁹⁹,
 T. Fonseca Martin¹⁷, A. Formica¹³⁶, A. Forti⁸², D. Fortin^{159a}, D. Fournier¹¹⁵, A.J. Fowler⁴⁵,
 H. Fox⁷¹, P. Francavilla¹², M. Franchini^{20a,20b}, S. Franchino³⁰, D. Francis³⁰, M. Franklin⁵⁷,
 S. Franz³⁰, M. Fraternali^{119a,119b}, S. Fratina¹²⁰, S.T. French²⁸, C. Friedrich⁴²,
 F. Friedrich⁴⁴, D. Froidevaux³⁰, J.A. Frost²⁸, C. Fukunaga¹⁵⁶, E. Fullana Torregrosa¹²⁷,
 B.G. Fulsom¹⁴³, J. Fuster¹⁶⁷, C. Gabaldon³⁰, O. Gabizon¹⁷², A. Gabrielli^{132a,132b},
 S. Gadatsch¹⁰⁵, T. Gadfort²⁵, S. Gadomski⁴⁹, G. Gagliardi^{50a,50b}, P. Gagnon⁶⁰, C. Galea⁹⁸,
 B. Galhardo^{124a}, E.J. Gallas¹¹⁸, V. Gallo¹⁷, B.J. Gallop¹²⁹, P. Gallus¹²⁶, K.K. Gan¹⁰⁹,
 R.P. Gandrajula⁶², Y.S. Gao^{143f}, A. Gaponenko¹⁵, F.M. Garay Walls⁴⁶, F. Garberson¹⁷⁶,
 C. García¹⁶⁷, J.E. García Navarro¹⁶⁷, M. Garcia-Sciveres¹⁵, R.W. Gardner³¹, N. Garelli¹⁴³,
 V. Garonne³⁰, C. Gatti⁴⁷, G. Gaudio^{119a}, B. Gaur¹⁴¹, L. Gauthier⁹³, P. Gauzzi^{132a,132b},
 I.L. Gavrilenko⁹⁴, C. Gay¹⁶⁸, G. Gaycken²¹, E.N. Gazis¹⁰, P. Ge^{33d,n}, Z. Gecse¹⁶⁸,
 C.N.P. Gee¹²⁹, D.A.A. Geerts¹⁰⁵, Ch. Geich-Gimbel²¹, K. Gellerstedt^{146a,146b}, C. Gemme^{50a},
 A. Gemmell⁵³, M.H. Genest⁵⁵, S. Gentile^{132a,132b}, M. George⁵⁴, S. George⁷⁶,
 D. Gerbaudo¹⁶³, P. Gerlach¹⁷⁵, A. Gershon¹⁵³, C. Geweniger^{58a}, H. Ghazlane^{135b},
 N. Ghodbane³⁴, B. Giacobbe^{20a}, S. Giagu^{132a,132b}, V. Giangiobbe¹², F. Gianotti³⁰,
 B. Gibbard²⁵, A. Gibson¹⁵⁸, S.M. Gibson³⁰, M. Gilchriese¹⁵, T.P.S. Gillam²⁸, D. Gillberg³⁰,
 A.R. Gillman¹²⁹, D.M. Gingrich^{3,e}, N. Giokaris⁹, M.P. Giordani^{164c}, R. Giordano^{102a,102b},
 F.M. Giorgi¹⁶, P. Giovannini⁹⁹, P.F. Giraud¹³⁶, D. Giugni^{89a}, C. Giuliani⁴⁸, M. Giunta⁹³,
 B.K. Gjelsten¹¹⁷, I. Gkialas^{154,o}, L.K. Gladilin⁹⁷, C. Glasman⁸⁰, J. Glatzer²¹, A. Glazov⁴²,
 G.L. Glonti⁶⁴, J.R. Goddard⁷⁵, J. Godfrey¹⁴², J. Godlewski³⁰, M. Goebel⁴², C. Goeringer⁸¹,
 S. Goldfarb⁸⁷, T. Golling¹⁷⁶, D. Golubkov¹²⁸, A. Gomes^{124a,c}, L.S. Gomez Fajardo⁴²,
 R. Gonçalo⁷⁶, J. Goncalves Pinto Firmino Da Costa⁴², L. Gonella²¹,
 S. González de la Hoz¹⁶⁷, G. Gonzalez Parra¹², M.L. Gonzalez Silva²⁷,
 S. Gonzalez-Sevilla⁴⁹, J.J. Goodson¹⁴⁸, L. Goossens³⁰, P.A. Gorbounov⁹⁵, H.A. Gordon²⁵,
 I. Gorelov¹⁰³, G. Gorfine¹⁷⁵, B. Gorini³⁰, E. Gorini^{72a,72b}, A. Gorišek⁷⁴, E. Gornicki³⁹,
 A.T. Goshaw⁶, C. Gössling⁴³, M.I. Gostkin⁶⁴, I. Gough Eschrich¹⁶³, M. Gouighri^{135a},
 D. Goujdami^{135c}, M.P. Goulette⁴⁹, A.G. Goussiou¹³⁸, C. Goy⁵, S. Gozpinar²³, L. Graber⁵⁴,
 I. Grabowska-Bold^{38a}, P. Grafström^{20a,20b}, K-J. Grahn⁴², E. Gramstad¹¹⁷,
 F. Grancagnolo^{72a}, S. Grancagnolo¹⁶, V. Grassi¹⁴⁸, V. Gratchev¹²¹, H.M. Gray³⁰,
 J.A. Gray¹⁴⁸, E. Graziani^{134a}, O.G. Grebenyuk¹²¹, T. Greenshaw⁷³, Z.D. Greenwood^{25,l},
 K. Gregersen³⁶, I.M. Gregor⁴², P. Grenier¹⁴³, J. Griffiths⁸, N. Grigalashvili⁶⁴,
 A.A. Grillo¹³⁷, K. Grimm⁷¹, S. Grinstein¹², Ph. Gris³⁴, Y.V. Grishkevich⁹⁷, J.-F. Grivaz¹¹⁵,
 J.P. Grohs⁴⁴, A. Grohsjean⁴², E. Gross¹⁷², J. Grosse-Knetter⁵⁴, J. Groth-Jensen¹⁷²,
 K. Grybel¹⁴¹, D. Guest¹⁷⁶, O. Gueta¹⁵³, C. Guicheney³⁴, E. Guido^{50a,50b}, T. Guillemin¹¹⁵,
 S. Guindon², U. Gul⁵³, J. Gunther¹²⁶, B. Guo¹⁵⁸, J. Guo³⁵, P. Gutierrez¹¹¹, N. Guttman¹⁵³,
 O. Gutzwiller¹⁷³, C. Guyot¹³⁶, C. Gwenlan¹¹⁸, C.B. Gwilliam⁷³, A. Haas¹⁰⁸, S. Haas³⁰,
 C. Haber¹⁵, H.K. Hadavand⁸, P. Haefner²¹, Z. Hajduk³⁹, H. Hakobyan¹⁷⁷, D. Hall¹¹⁸,
 G. Halladjian⁶², K. Hamacher¹⁷⁵, P. Hamal¹¹³, K. Hamano⁸⁶, M. Hamer⁵⁴,
 A. Hamilton^{145b,p}, S. Hamilton¹⁶¹, L. Han^{33b}, K. Hanagaki¹¹⁶, K. Hanawa¹⁶⁰, M. Hance¹⁵,
 C. Handel⁸¹, P. Hanke^{58a}, J.R. Hansen³⁶, J.B. Hansen³⁶, J.D. Hansen³⁶, P.H. Hansen³⁶,
 P. Hansson¹⁴³, K. Hara¹⁶⁰, A.S. Hard¹⁷³, T. Harenberg¹⁷⁵, S. Harkusha⁹⁰, D. Harper⁸⁷,

R.D. Harrington⁴⁶, O.M. Harris¹³⁸, J. Hartert⁴⁸, F. Hartjes¹⁰⁵, T. Haruyama⁶⁵, A. Harvey⁵⁶, S. Hasegawa¹⁰¹, Y. Hasegawa¹⁴⁰, S. Hassani¹³⁶, S. Haug¹⁷, M. Hauschild³⁰, R. Hauser⁸⁸, M. Havranek²¹, C.M. Hawkes¹⁸, R.J. Hawkins³⁰, A.D. Hawkins⁷⁹, T. Hayakawa⁶⁶, T. Hayashi¹⁶⁰, D. Hayden⁷⁶, C.P. Hays¹¹⁸, H.S. Hayward⁷³, S.J. Haywood¹²⁹, S.J. Head¹⁸, T. Heck⁸¹, V. Hedberg⁷⁹, L. Heelan⁸, S. Heim¹²⁰, B. Heinemann¹⁵, S. Heisterkamp³⁶, L. Helary²², C. Heller⁹⁸, M. Heller³⁰, S. Hellman^{146a,146b}, D. Hellmich²¹, C. Hensens¹², J. Henderson¹¹⁸, R.C.W. Henderson⁷¹, M. Henke^{58a}, A. Henrichs¹⁷⁶, A.M. Henriques Correia³⁰, S. Henrot-Versille¹¹⁵, C. Hensel⁵⁴, G.H. Herbert¹⁶, C.M. Hernandez⁸, Y. Hernández Jiménez¹⁶⁷, R. Herrberg¹⁶, G. Herten⁴⁸, R. Hertenberger⁹⁸, L. Hervas³⁰, G.G. Hesketh⁷⁷, N.P. Hessey¹⁰⁵, R. Hickling⁷⁵, E. Higón-Rodríguez¹⁶⁷, J.C. Hill²⁸, K.H. Hiller⁴², S. Hillert²¹, S.J. Hillier¹⁸, I. Hinchliffe¹⁵, E. Hines¹²⁰, M. Hirose¹¹⁶, D. Hirschbuehl¹⁷⁵, J. Hobbs¹⁴⁸, N. Hod¹⁰⁵, M.C. Hodgkinson¹³⁹, P. Hodgson¹³⁹, A. Hoecker³⁰, M.R. Hoferkamp¹⁰³, J. Hoffman⁴⁰, D. Hoffmann⁸³, J.I. Hofmann^{58a}, M. Hohlfeld⁸¹, S.O. Holmgren^{146a}, J.L. Holzbauer⁸⁸, T.M. Hong¹²⁰, L. Hooft van Huysduynen¹⁰⁸, J.-Y. Hostachy⁵⁵, S. Hou¹⁵¹, A. Hoummada^{135a}, J. Howard¹¹⁸, J. Howarth⁸², M. Hrabovsky¹¹³, I. Hristova¹⁶, J. Hrivnac¹¹⁵, T. Hryn'ova⁵, P.J. Hsu⁸¹, S.-C. Hsu¹³⁸, D. Hu³⁵, Z. Hubacek³⁰, F. Hubaut⁸³, F. Huegging²¹, A. Huettmann⁴², T.B. Huffman¹¹⁸, E.W. Hughes³⁵, G. Hughes⁷¹, M. Huhtinen³⁰, T.A. Hülsing⁸¹, M. Hurwitz¹⁵, N. Huseynov^{64,q}, J. Huston⁸⁸, J. Huth⁵⁷, G. Iacobucci⁴⁹, G. Iakovidis¹⁰, I. Ibragimov¹⁴¹, L. Iconomidou-Fayard¹¹⁵, J. Idarraga¹¹⁵, P. Iengo^{102a}, O. Igonkina¹⁰⁵, Y. Ikegami⁶⁵, K. Ikematsu¹⁴¹, M. Ikeno⁶⁵, D. Iliadis¹⁵⁴, N. Ilic¹⁵⁸, T. Ince⁹⁹, P. Ioannou⁹, M. Iodice^{134a}, K. Iordanidou⁹, V. Ippolito^{132a,132b}, A. Irlés Quiles¹⁶⁷, C. Isaksson¹⁶⁶, M. Ishino⁶⁷, M. Ishitsuka¹⁵⁷, R. Ishmukhametov¹⁰⁹, C. Issever¹¹⁸, S. Istin^{19a}, A.V. Ivashin¹²⁸, W. Iwanski³⁹, H. Iwasaki⁶⁵, J.M. Izen⁴¹, V. Izzo^{102a}, B. Jackson¹²⁰, J.N. Jackson⁷³, P. Jackson¹, M.R. Jaekel³⁰, V. Jain², K. Jakobs⁴⁸, S. Jakobsen³⁶, T. Jakoubek¹²⁵, J. Jakubek¹²⁶, D.O. Jamin¹⁵¹, D.K. Jana¹¹¹, E. Jansen⁷⁷, H. Jansen³⁰, J. Janssen²¹, A. Jantsch⁹⁹, M. Janus⁴⁸, R.C. Jared¹⁷³, G. Jarlskog⁷⁹, L. Jeanty⁵⁷, G.-Y. Jeng¹⁵⁰, I. Jen-La Plante³¹, D. Jennens⁸⁶, P. Jenni³⁰, C. Jeske¹⁷⁰, P. Jež³⁶, S. Jézéquel⁵, M.K. Jha^{20a}, H. Ji¹⁷³, W. Ji⁸¹, J. Jia¹⁴⁸, Y. Jiang^{33b}, M. Jimenez Belenguer⁴², S. Jin^{33a}, O. Jinnouchi¹⁵⁷, M.D. Joergensen³⁶, D. Joffe⁴⁰, M. Johansen^{146a,146b}, K.E. Johansson^{146a}, P. Johansson¹³⁹, S. Johnert⁴², K.A. Johns⁷, K. Jon-And^{146a,146b}, G. Jones¹⁷⁰, R.W.L. Jones⁷¹, T.J. Jones⁷³, C. Joram³⁰, P.M. Jorge^{124a}, K.D. Joshi⁸², J. Jovicevic¹⁴⁷, T. Jovin^{13b}, X. Ju¹⁷³, C.A. Jung⁴³, R.M. Jungst³⁰, P. Jussel⁶¹, A. Juste Rozas¹², S. Kabana¹⁷, M. Kaci¹⁶⁷, A. Kaczmarska³⁹, P. Kadlecik³⁶, M. Kado¹¹⁵, H. Kagan¹⁰⁹, M. Kagan⁵⁷, E. Kajomovitz¹⁵², S. Kalinin¹⁷⁵, S. Kama⁴⁰, N. Kanaya¹⁵⁵, M. Kaneda³⁰, S. Kaneti²⁸, T. Kanno¹⁵⁷, V.A. Kantserov⁹⁶, J. Kanzaki⁶⁵, B. Kaplan¹⁰⁸, A. Kapliy³¹, D. Kar⁵³, K. Karakostas¹⁰, M. Karnevskiy⁸¹, V. Kartvelishvili⁷¹, A.N. Karyukhin¹²⁸, L. Kashif¹⁷³, G. Kasieczka^{58b}, R.D. Kass¹⁰⁹, A. Kastanas¹⁴, Y. Kataoka¹⁵⁵, J. Katzy⁴², V. Kaushik⁷, K. Kawagoe⁶⁹, T. Kawamoto¹⁵⁵, G. Kawamura⁵⁴, S. Kazama¹⁵⁵, V.F. Kazanin¹⁰⁷, M.Y. Kazarinov⁶⁴, R. Keeler¹⁶⁹, P.T. Keener¹²⁰, R. Kehoe⁴⁰, M. Keil⁵⁴, J.S. Keller¹³⁸, H. Keoshkerian⁵, O. Kepka¹²⁵, B.P. Kerševan⁷⁴, S. Kersten¹⁷⁵, K. Kessoku¹⁵⁵, J. Keung¹⁵⁸, F. Khalil-zada¹¹, H. Khandanyan^{146a,146b}, A. Khanov¹¹², D. Kharchenko⁶⁴, A. Khodinov⁹⁶, A. Khomich^{58a}, T.J. Khoo²⁸, G. Khoriauli²¹, A. Khoroshilov¹⁷⁵, V. Khovanskiy⁹⁵, E. Khramov⁶⁴, J. Khubua^{51b}, H. Kim^{146a,146b}, S.H. Kim¹⁶⁰, N. Kimura¹⁷¹, O. Kind¹⁶, B.T. King⁷³, M. King⁶⁶, R.S.B. King¹¹⁸, S.B. King¹⁶⁸, J. Kirk¹²⁹, A.E. Kiryunin⁹⁹, T. Kishimoto⁶⁶, D. Kisiielewska^{38a}, T. Kitamura⁶⁶, T. Kittelmann¹²³, K. Kiuchi¹⁶⁰, E. Kladiva^{144b}, M. Klein⁷³, U. Klein⁷³, K. Kleinknecht⁸¹, M. Klemetti⁸⁵, A. Klier¹⁷², P. Klimek^{146a,146b}, A. Klimentov²⁵, R. Klingenberg⁴³, J.A. Klinger⁸², E.B. Klinkby³⁶, T. Klioutchnikova³⁰, P.F. Klok¹⁰⁴, E.-E. Kluge^{58a}, P. Kluit¹⁰⁵, S. Kluth⁹⁹, E. Kneringer⁶¹, E.B.F.G. Knoops⁸³, A. Knue⁵⁴, B.R. Ko⁴⁵, T. Kobayashi¹⁵⁵, M. Kobel⁴⁴, M. Kocian¹⁴³, P. Kodys¹²⁷, S. Koenig⁸¹, F. Koetsveld¹⁰⁴, P. Koesesarki²¹, T. Koffas²⁹, E. Koffeman¹⁰⁵, L.A. Kogan¹¹⁸, S. Kohlmann¹⁷⁵, F. Kohn⁵⁴, Z. Kohout¹²⁶,

T. Kohriki⁶⁵, T. Koi¹⁴³, H. Kolanoski¹⁶, I. Koletsou^{89a}, J. Koll⁸⁸, A.A. Komar⁹⁴,
 Y. Komori¹⁵⁵, T. Kondo⁶⁵, K. Köneke³⁰, A.C. König¹⁰⁴, T. Kono^{42,r}, A.I. Kononov⁴⁸,
 R. Konoplich^{108,s}, N. Konstantinidis⁷⁷, R. Kopeliansky¹⁵², S. Koperny^{38a}, L. Köpke⁸¹,
 A.K. Kopp⁴⁸, K. Korcyl³⁹, K. Kordas¹⁵⁴, A. Korn⁴⁶, A. Korol¹⁰⁷, I. Korolkov¹²,
 E.V. Korolkova¹³⁹, V.A. Korotkov¹²⁸, O. Kortner⁹⁹, S. Kortner⁹⁹, V.V. Kostyukhin²¹,
 S. Kotov⁹⁹, V.M. Kotov⁶⁴, A. Kotwal⁴⁵, C. Kourkoumelis⁹, V. Kouskoura¹⁵⁴,
 A. Koutsman^{159a}, R. Kowalewski¹⁶⁹, T.Z. Kowalski^{38a}, W. Kozanecki¹³⁶, A.S. Kozhin¹²⁸,
 V. Kral¹²⁶, V.A. Kramarenko⁹⁷, G. Kramberger⁷⁴, M.W. Krasny⁷⁸, A. Krasznahorkay¹⁰⁸,
 J.K. Kraus²¹, A. Kravchenko²⁵, S. Kreiss¹⁰⁸, J. Kretzschmar⁷³, K. Kreutzfeldt⁵²,
 N. Krieger⁵⁴, P. Krieger¹⁵⁸, K. Kroeninger⁵⁴, H. Kroha⁹⁹, J. Kroll¹²⁰, J. Kroseberg²¹,
 J. Krstic^{13a}, U. Kruchonak⁶⁴, H. Krüger²¹, T. Kruker¹⁷, N. Krumnack⁶³, Z.V. Krumshteyn⁶⁴,
 A. Kruse¹⁷³, M.K. Kruse⁴⁵, T. Kubota⁸⁶, S. Kuday^{4a}, S. Kuehn⁴⁸, A. Kugel^{58c}, T. Kuhl⁴²,
 V. Kukhtin⁶⁴, Y. Kulchitsky⁹⁰, S. Kuleshov^{32b}, M. Kuna⁷⁸, J. Kunkle¹²⁰, A. Kupco¹²⁵,
 H. Kurashige⁶⁶, M. Kurata¹⁶⁰, Y.A. Kurochkin⁹⁰, V. Kus¹²⁵, E.S. Kuwertz¹⁴⁷, M. Kuze¹⁵⁷,
 J. Kvita¹⁴², R. Kwee¹⁶, A. La Rosa⁴⁹, L. La Rotonda^{37a,37b}, L. Labarga⁸⁰, S. Lablak^{135a},
 C. Lacasta¹⁶⁷, F. Lacava^{132a,132b}, J. Lacey²⁹, H. Lacker¹⁶, D. Lacour⁷⁸, V.R. Lacuesta¹⁶⁷,
 E. Ladygin⁶⁴, R. Lafaye⁵, B. Laforge⁷⁸, T. Lagouri¹⁷⁶, S. Lai⁴⁸, H. Laier^{58a}, E. Laisne⁵⁵,
 L. Lambourne⁷⁷, C.L. Lampen⁷, W. Lampl⁷, E. Lançon¹³⁶, U. Landgraf⁴⁸, M.P.J. Landon⁷⁵,
 V.S. Lang^{58a}, C. Lange⁴², A.J. Lankford¹⁶³, F. Lanni²⁵, K. Lantzsch³⁰, A. Lanza^{119a},
 S. Laplace⁷⁸, C. Lapoire²¹, J.F. Laporte¹³⁶, T. Lari^{89a}, A. Larner¹¹⁸, M. Lassnig³⁰,
 P. Laurelli⁴⁷, V. Lavorini^{37a,37b}, W. Lavrijsen¹⁵, P. Laycock⁷³, O. Le Dortz⁷⁸,
 E. Le Guirriec⁸³, E. Le Menedeu¹², T. LeCompte⁶, F. Ledroit-Guillon⁵⁵, H. Lee¹⁰⁵,
 J.S.H. Lee¹¹⁶, S.C. Lee¹⁵¹, L. Lee¹⁷⁶, M. Lefebvre¹⁶⁹, M. Legendre¹³⁶, F. Legger⁹⁸,
 C. Leggett¹⁵, M. Lehmann²¹, G. Lehmann Miotto³⁰, A.G. Leister¹⁷⁶, M.A.L. Leite^{24d},
 R. Leitner¹²⁷, D. Lellouch¹⁷², B. Lemmer⁵⁴, V. Lendermann^{58a}, K.J.C. Leney^{145b},
 T. Lenz¹⁰⁵, G. Lenzen¹⁷⁵, B. Lenzi³⁰, K. Leonhardt⁴⁴, S. Leontsinis¹⁰, F. Lepold^{58a},
 C. Leroy⁹³, J.-R. Lessard¹⁶⁹, C.G. Lester²⁸, C.M. Lester¹²⁰, J. Levêque⁵, D. Levin⁸⁷,
 L.J. Levinson¹⁷², A. Lewis¹¹⁸, G.H. Lewis¹⁰⁸, A.M. Leyko²¹, M. Leyton¹⁶, B. Li^{33b}, B. Li⁸³,
 H. Li¹⁴⁸, H.L. Li³¹, S. Li^{33b,t}, X. Li⁸⁷, Z. Liang^{118,u}, H. Liao³⁴, B. Liberti^{133a}, P. Lichard³⁰,
 K. Lie¹⁶⁵, J. Liebal²¹, W. Liebig¹⁴, C. Limbach²¹, A. Limosani⁸⁶, M. Limper⁶², S.C. Lin^{151,v},
 F. Linde¹⁰⁵, B.E. Lindquist¹⁴⁸, J.T. Linnemann⁸⁸, E. Lipeles¹²⁰, A. Lipniacka¹⁴,
 M. Lisovyi⁴², T.M. Liss¹⁶⁵, D. Lissauer²⁵, A. Lister¹⁶⁸, A.M. Litke¹³⁷, D. Liu¹⁵¹, J.B. Liu^{33b},
 K. Liu^{33b,w}, L. Liu⁸⁷, M. Liu^{33b}, Y. Liu^{33b}, M. Livan^{119a,119b}, S.S.A. Livermore¹¹⁸,
 A. Lleres⁵⁵, J. Llorente Merino⁸⁰, S.L. Lloyd⁷⁵, F. Lo Sterzo^{132a,132b}, E. Lobodzinska⁴²,
 P. Loch⁷, W.S. Lockman¹³⁷, T. Lodenkoetter²¹, F.K. Loebinger⁸², A.E. Loevschall-Jensen³⁶,
 A. Loginov¹⁷⁶, C.W. Loh¹⁶⁸, T. Lohse¹⁶, K. Lohwasser⁴⁸, M. Lokajicek¹²⁵, V.P. Lombardo⁵,
 R.E. Long⁷¹, L. Lopes^{124a}, D. Lopez Mateos⁵⁷, J. Lorenz⁹⁸, N. Lorenzo Martinez¹¹⁵,
 M. Losada¹⁶², P. Loscutoff¹⁵, M.J. Losty^{159a,*}, X. Lou⁴¹, A. Lounis¹¹⁵, K.F. Loureiro¹⁶²,
 J. Love⁶, P.A. Love⁷¹, A.J. Lowe^{143,f}, F. Lu^{33a}, H.J. Lubatti¹³⁸, C. Luci^{132a,132b}, A. Lucotte⁵⁵,
 D. Ludwig⁴², I. Ludwig⁴⁸, J. Ludwig⁴⁸, F. Luehring⁶⁰, W. Lukas⁶¹, L. Luminari^{132a},
 E. Lund¹¹⁷, B. Lundberg⁷⁹, J. Lundberg^{146a,146b}, O. Lundberg^{146a,146b}, B. Lund-Jensen¹⁴⁷,
 J. Lundquist³⁶, M. Lungwitz⁸¹, D. Lynn²⁵, R. Lysak¹²⁵, E. Lytken⁷⁹, H. Ma²⁵, L.L. Ma¹⁷³,
 G. Maccarrone⁴⁷, A. Macchiolo⁹⁹, B. Maček⁷⁴, J. Machado Miguens^{124a}, D. Macina³⁰,
 R. Mackeprang³⁶, R. Madar⁴⁸, R.J. Madaras¹⁵, H.J. Maddocks⁷¹, W.F. Mader⁴⁴,
 A. Madsen¹⁶⁶, M. Maeno⁵, T. Maeno²⁵, L. Magnoni¹⁶³, E. Magradze⁵⁴, K. Mahboubi⁴⁸,
 J. Mahlstedt¹⁰⁵, S. Mahmoud⁷³, G. Mahout¹⁸, C. Maiani¹³⁶, C. Maidantchik^{24a},
 A. Maio^{124a,c}, S. Majewski²⁵, Y. Makida⁶⁵, N. Makovec¹¹⁵, P. Mal^{136,x}, B. Malaescu⁷⁸,
 Pa. Malecki³⁹, P. Malecki³⁹, V.P. Maleev¹²¹, F. Malek⁵⁵, U. Mallik⁶², D. Malon⁶,
 C. Malone¹⁴³, S. Maltezos¹⁰, V. Malyshev¹⁰⁷, S. Malyukov³⁰, J. Mamuzic^{13b},
 L. Mandelli^{89a}, I. Mandić⁷⁴, R. Mandrysch⁶², J. Maneira^{124a}, A. Manfredini⁹⁹,
 L. Manhaes de Andrade Filho^{24b}, J.A. Manjarres Ramos¹³⁶, A. Mann⁹⁸, P.M. Manning¹³⁷,
 A. Manousakis-Katsikakis⁹, B. Mansoulie¹³⁶, R. Mantifel⁸⁵, L. Mapelli³⁰, L. March¹⁶⁷,

J.F. Marchand²⁹, F. Marchese^{133a,133b}, G. Marchiori⁷⁸, M. Marcisovsky¹²⁵, C.P. Marino¹⁶⁹,
 F. Marroquim^{24a}, Z. Marshall¹²⁰, L.F. Marti¹⁷, S. Marti-Garcia¹⁶⁷, B. Martin³⁰,
 B. Martin⁸⁸, J.P. Martin⁹³, T.A. Martin¹⁷⁰, V.J. Martin⁴⁶, B. Martin dit Latour⁴⁹,
 H. Martinez¹³⁶, M. Martinez¹², S. Martin-Haugh¹⁴⁹, A.C. Martyniuk¹⁶⁹, M. Marx⁸²,
 F. Marzano^{132a}, A. Marzin¹¹¹, L. Masetti⁸¹, T. Mashimo¹⁵⁵, R. Mashinistov⁹⁴, J. Masik⁸²,
 A.L. Maslennikov¹⁰⁷, I. Massa^{20a,20b}, N. Massol⁵, P. Mastrandrea¹⁴⁸,
 A. Mastroberardino^{37a,37b}, T. Masubuchi¹⁵⁵, H. Matsunaga¹⁵⁵, T. Matsushita⁶⁶,
 P. Mättig¹⁷⁵, S. Mättig⁴², C. Mattravers^{118,d}, J. Maurer⁸³, S.J. Maxfield⁷³,
 D.A. Maximov^{107,g}, R. Mazini¹⁵¹, M. Mazur²¹, L. Mazzaferro^{133a,133b}, M. Mazzanti^{89a},
 S.P. Mc Kee⁸⁷, A. McCarn¹⁶⁵, R.L. McCarthy¹⁴⁸, T.G. McCarthy²⁹, N.A. McCubbin¹²⁹,
 K.W. McFarlane^{56,*}, J.A. Mcfayden¹³⁹, G. Mchedlize^{51b}, T. Mclaughlan¹⁸,
 S.J. McMahan¹²⁹, R.A. McPherson^{169,j}, A. Meade⁸⁴, J. Mechnich¹⁰⁵, M. Mechtel¹⁷⁵,
 M. Medinnis⁴², S. Meehan³¹, R. Meera-Lebbai¹¹¹, T. Meguro¹¹⁶, S. Mehlhase³⁶,
 A. Mehta⁷³, K. Meier^{58a}, C. Meineck⁹⁸, B. Meirose⁷⁹, C. Melachrinou³¹,
 B.R. Mellado Garcia¹⁷³, F. Meloni^{89a,89b}, L. Mendoza Navas¹⁶², A. Mengarelli^{20a,20b},
 S. Menke⁹⁹, E. Meoni¹⁶¹, K.M. Mercurio⁵⁷, N. Meric¹³⁶, P. Mermod⁴⁹, L. Merola^{102a,102b},
 C. Meroni^{89a}, F.S. Merritt³¹, H. Merritt¹⁰⁹, A. Messina^{30,y}, J. Metcalfe²⁵, A.S. Mete¹⁶³,
 C. Meyer⁸¹, C. Meyer³¹, J.-P. Meyer¹³⁶, J. Meyer³⁰, J. Meyer⁵⁴, S. Michal³⁰,
 R.P. Middleton¹²⁹, S. Migas⁷³, L. Mijović¹³⁶, G. Mikenberg¹⁷², M. Mikestikova¹²⁵,
 M. Mikuž⁷⁴, D.W. Miller³¹, W.J. Mills¹⁶⁸, C. Mills⁵⁷, A. Milov¹⁷², D.A. Milstead^{146a,146b},
 D. Milstein¹⁷², A.A. Minaenko¹²⁸, M. Miñano Moya¹⁶⁷, I.A. Minashvili⁶⁴, A.I. Mincer¹⁰⁸,
 B. Mindur^{38a}, M. Mineev⁶⁴, Y. Ming¹⁷³, L.M. Mir¹², G. Mirabelli^{132a}, J. Mitrevski¹³⁷,
 V.A. Mitsou¹⁶⁷, S. Mitsui⁶⁵, P.S. Miyagawa¹³⁹, J.U. Mjörnmark⁷⁹, T. Moa^{146a,146b},
 V. Moeller²⁸, S. Mohapatra¹⁴⁸, W. Mohr⁴⁸, R. Moles-Valls¹⁶⁷, A. Molfetas³⁰, K. Mönig⁴²,
 C. Monini⁵⁵, J. Monk³⁶, E. Monnier⁸³, J. Montejo Berlingen¹², F. Monticelli⁷⁰,
 S. Monzani^{20a,20b}, R.W. Moore³, C. Mora Herrera⁴⁹, A. Moraes⁵³, N. Morange⁶²,
 J. Morel⁵⁴, D. Moreno⁸¹, M. Moreno Llácer¹⁶⁷, P. Morettini^{50a}, M. Morgenstern⁴⁴,
 M. Morii⁵⁷, S. Moritz⁸¹, A.K. Morley³⁰, G. Mornacchi³⁰, J.D. Morris⁷⁵, L. Morvaj¹⁰¹,
 N. Möser²¹, H.G. Moser⁹⁹, M. Mosidze^{51b}, J. Moss¹⁰⁹, R. Mount¹⁴³, E. Mountricha^{10,z},
 S.V. Mouraviev^{94,*}, E.J.W. Moyse⁸⁴, R.D. Mudd¹⁸, F. Mueller^{58a}, J. Mueller¹²³,
 K. Mueller²¹, T. Mueller²⁸, T. Mueller⁸¹, D. Muenstermann³⁰, Y. Munwes¹⁵³,
 J.A. Murillo Quijada¹⁸, W.J. Murray¹²⁹, I. Mussche¹⁰⁵, E. Musto¹⁵², A.G. Myagkov¹²⁸,
 M. Myska¹²⁵, O. Nackenhorst⁵⁴, J. Nadal¹², K. Nagai¹⁶⁰, R. Nagai¹⁵⁷, Y. Nagai⁸³,
 K. Nagano⁶⁵, A. Nagarkar¹⁰⁹, Y. Nagasaka⁵⁹, M. Nagel⁹⁹, A.M. Nairz³⁰, Y. Nakahama³⁰,
 K. Nakamura⁶⁵, T. Nakamura¹⁵⁵, I. Nakano¹¹⁰, H. Namasivayam⁴¹, G. Nanava²¹,
 A. Napier¹⁶¹, R. Narayan^{58b}, M. Nash^{77,d}, T. Nattermann²¹, T. Naumann⁴², G. Navarro¹⁶²,
 H.A. Neal⁸⁷, P.Yu. Nechaeva⁹⁴, T.J. Neep⁸², A. Negri^{119a,119b}, G. Negri³⁰, M. Negrini^{20a},
 S. Nektarijevic⁴⁹, A. Nelson¹⁶³, T.K. Nelson¹⁴³, S. Nemecek¹²⁵, P. Nemethy¹⁰⁸,
 A.A. Nepomuceno^{24a}, M. Nessi^{30,aa}, M.S. Neubauer¹⁶⁵, M. Neumann¹⁷⁵, A. Neusiedl⁸¹,
 R.M. Neves¹⁰⁸, P. Nevski²⁵, F.M. Newcomer¹²⁰, P.R. Newman¹⁸, D.H. Nguyen⁶,
 V. Nguyen Thi Hong¹³⁶, R.B. Nickerson¹¹⁸, R. Nicolaidou¹³⁶, B. Nicquevert³⁰,
 F. Niedercorn¹¹⁵, J. Nielsen¹³⁷, N. Nikiforou³⁵, A. Nikiforov¹⁶, V. Nikolaenko¹²⁸,
 I. Nikolic-Audit⁷⁸, K. Nikolics⁴⁹, K. Nikolopoulos¹⁸, P. Nilsson⁸, Y. Ninomiya¹⁵⁵,
 A. Nisati^{132a}, R. Nisius⁹⁹, T. Nobe¹⁵⁷, L. Nodulman⁶, M. Nomachi¹¹⁶, I. Nomidis¹⁵⁴,
 S. Norberg¹¹¹, M. Nordberg³⁰, J. Novakova¹²⁷, M. Nozaki⁶⁵, L. Nozka¹¹³,
 A.-E. Nuncio-Quiroz²¹, G. Nunes Hanninger⁸⁶, T. Nunnemann⁹⁸, E. Nurse⁷⁷,
 B.J. O'Brien⁴⁶, D.C. O'Neil¹⁴², V. O'Shea⁵³, L.B. Oakes⁹⁸, F.G. Oakham^{29,e}, H. Oberlack⁹⁹,
 J. Ocariz⁷⁸, A. Ochi⁶⁶, M.I. Ochoa⁷⁷, S. Oda⁶⁹, S. Odaka⁶⁵, J. Odier⁸³, H. Ogren⁶⁰,
 A. Oh⁸², S.H. Oh⁴⁵, C.C. Ohm³⁰, T. Ohshima¹⁰¹, W. Okamura¹¹⁶, H. Okawa²⁵,
 Y. Okumura³¹, T. Okuyama¹⁵⁵, A. Olariu^{26a}, A.G. Olchevski⁶⁴, S.A. Olivares Pino⁴⁶,
 M. Oliveira^{124a,h}, D. Oliveira Damazio²⁵, E. Oliver Garcia¹⁶⁷, D. Olivito¹²⁰, A. Olszewski³⁹,
 J. Olszowska³⁹, A. Onofre^{124a,ab}, P.U.E. Onyisi^{31,ac}, C.J. Oram^{159a}, M.J. Oreglia³¹,

Y. Oren ¹⁵³, D. Orestano ^{134a,134b}, N. Orlando ^{72a,72b}, C. Oropeza Barrera ⁵³, R.S. Orr ¹⁵⁸,
 B. Osculati ^{50a,50b}, R. Ospanov ¹²⁰, C. Osuna ¹², G. Otero y Garzon ²⁷, J.P. Ottersbach ¹⁰⁵,
 M. Ouchrif ^{135d}, E.A. Ouellette ¹⁶⁹, F. Ould-Saada ¹¹⁷, A. Ouraou ¹³⁶, Q. Ouyang ^{33a},
 A. Ovcharova ¹⁵, M. Owen ⁸², S. Owen ¹³⁹, V.E. Ozcan ^{19a}, N. Ozturk ⁸, A. Pacheco Pages ¹²,
 C. Padilla Aranda ¹², S. Pagan Griso ¹⁵, E. Paganis ¹³⁹, C. Pahl ⁹⁹, F. Paige ²⁵, P. Pais ⁸⁴,
 K. Pajchel ¹¹⁷, G. Palacino ^{159b}, C.P. Paleari ⁷, S. Palestini ³⁰, D. Pallin ³⁴, A. Palma ^{124a},
 J.D. Palmer ¹⁸, Y.B. Pan ¹⁷³, E. Panagiotopoulou ¹⁰, J.G. Panduro Vazquez ⁷⁶, P. Pani ¹⁰⁵,
 N. Panikashvili ⁸⁷, S. Panitkin ²⁵, D. Pantea ^{26a}, A. Papadelis ^{146a}, Th.D. Papadopoulou ¹⁰,
 K. Papageorgiou ^{154,o}, A. Paramonov ⁶, D. Paredes Hernandez ³⁴, W. Park ^{25,ad},
 M.A. Parker ²⁸, F. Parodi ^{50a,50b}, J.A. Parsons ³⁵, U. Parzefall ⁴⁸, S. Pashapour ⁵⁴,
 E. Pasqualucci ^{132a}, S. Passaggio ^{50a}, A. Passeri ^{134a}, F. Pastore ^{134a,134b,*}, Fr. Pastore ⁷⁶,
 G. Pásztor ^{49,ae}, S. Pataraiia ¹⁷⁵, N.D. Patel ¹⁵⁰, J.R. Pater ⁸², S. Patricelli ^{102a,102b}, T. Pauly ³⁰,
 J. Pearce ¹⁶⁹, M. Pedersen ¹¹⁷, S. Pedraza Lopez ¹⁶⁷, M.I. Pedraza Morales ¹⁷³,
 S.V. Peleganchuk ¹⁰⁷, D. Pelikan ¹⁶⁶, H. Peng ^{33b}, B. Penning ³¹, A. Penson ³⁵, J. Penwell ⁶⁰,
 T. Perez Cavalcanti ⁴², E. Perez Codina ^{159a}, M.T. Pérez García-Estañ ¹⁶⁷, V. Perez Reale ³⁵,
 L. Perini ^{89a,89b}, H. Pernegger ³⁰, R. Perrino ^{72a}, P. Perrodo ⁵, V.D. Peshekhonov ⁶⁴,
 K. Peters ³⁰, R.F.Y. Peters ^{54,af}, B.A. Petersen ³⁰, J. Petersen ³⁰, T.C. Petersen ³⁶, E. Petit ⁵,
 A. Petridis ^{146a,146b}, C. Petridou ¹⁵⁴, E. Petrolo ^{132a}, F. Petrucci ^{134a,134b}, D. Petschull ⁴²,
 M. Petteni ¹⁴², R. Pezoa ^{32b}, A. Phan ⁸⁶, P.W. Phillips ¹²⁹, G. Piacquadio ¹⁴³, E. Pianori ¹⁷⁰,
 A. Picazio ⁴⁹, E. Piccaro ⁷⁵, M. Piccinini ^{20a,20b}, S.M. Piec ⁴², R. Piegaiia ²⁷, D.T. Pignotti ¹⁰⁹,
 J.E. Pilcher ³¹, A.D. Pilkington ⁸², J. Pina ^{124a,c}, M. Pinamonti ^{164a,164c,ag}, A. Pinder ¹¹⁸,
 J.L. Pinfold ³, A. Pingel ³⁶, B. Pinto ^{124a}, C. Pizio ^{89a,89b}, M.-A. Pleier ²⁵, V. Pleskot ¹²⁷,
 E. Plotnikova ⁶⁴, P. Plucinski ^{146a,146b}, A. Poblaguev ²⁵, S. Poddar ^{58a}, F. Podlyski ³⁴,
 R. Poettgen ⁸¹, L. Poggioli ¹¹⁵, D. Pohl ²¹, M. Pohl ⁴⁹, G. Polesello ^{119a}, A. Policicchio ^{37a,37b},
 R. Polifka ¹⁵⁸, A. Polini ^{20a}, V. Polychronakos ²⁵, D. Pomeroy ²³, K. Pommès ³⁰,
 L. Pontecorvo ^{132a}, B.G. Pope ⁸⁸, G.A. Popeneciu ^{26a}, D.S. Popovic ^{13a}, A. Poppleton ³⁰,
 X. Portell Bueso ¹², G.E. Pospelov ⁹⁹, S. Pospisil ¹²⁶, I.N. Potrap ⁶⁴, C.J. Potter ¹⁴⁹,
 C.T. Potter ¹¹⁴, G. Poulard ³⁰, J. Poveda ⁶⁰, V. Pozdnyakov ⁶⁴, R. Prabhu ⁷⁷, P. Pralavorio ⁸³,
 A. Pranko ¹⁵, S. Prasad ³⁰, R. Pravahan ²⁵, S. Prell ⁶³, K. Pretzl ¹⁷, D. Price ⁶⁰, J. Price ⁷³,
 L.E. Price ⁶, D. Prieur ¹²³, M. Primavera ^{72a}, M. Proissl ⁴⁶, K. Prokofiev ¹⁰⁸, F. Prokoshin ^{32b},
 E. Protopapadaki ¹³⁶, S. Protopopescu ²⁵, J. Proudfoot ⁶, X. Prudent ⁴⁴, M. Przybycien ^{38a},
 H. Przysiezniak ⁵, S. Psoroulas ²¹, E. Ptacek ¹¹⁴, E. Pueschel ⁸⁴, D. Puldon ¹⁴⁸,
 M. Purohit ^{25,ad}, P. Puzo ¹¹⁵, Y. Pylypchenko ⁶², J. Qian ⁸⁷, A. Quadt ⁵⁴, D.R. Quarrie ¹⁵,
 W.B. Quayle ¹⁷³, D. Quilty ⁵³, M. Raas ¹⁰⁴, V. Radeka ²⁵, V. Radescu ⁴², P. Radloff ¹¹⁴,
 F. Ragusa ^{89a,89b}, G. Rahal ¹⁷⁸, S. Rajagopalan ²⁵, M. Rammensee ⁴⁸, M. Rammes ¹⁴¹,
 A.S. Randle-Conde ⁴⁰, K. Randrianarivony ²⁹, C. Rangel-Smith ⁷⁸, K. Rao ¹⁶³, F. Rauscher ⁹⁸,
 T.C. Rave ⁴⁸, T. Ravenscroft ⁵³, M. Raymond ³⁰, A.L. Read ¹¹⁷, D.M. Rebuffi ^{119a,119b},
 A. Redelbach ¹⁷⁴, G. Redlinger ²⁵, R. Reece ¹²⁰, K. Reeves ⁴¹, A. Reinsch ¹¹⁴, I. Reisinger ⁴³,
 M. Relich ¹⁶³, C. Rembser ³⁰, Z.L. Ren ¹⁵¹, A. Renaud ¹¹⁵, M. Rescigno ^{132a}, S. Resconi ^{89a},
 B. Resende ¹³⁶, P. Reznicek ⁹⁸, R. Rezvani ⁹³, R. Richter ⁹⁹, E. Richter-Was ^{38b}, M. Ridel ⁷⁸,
 P. Rieck ¹⁶, M. Rijssenbeek ¹⁴⁸, A. Rimoldi ^{119a,119b}, L. Rinaldi ^{20a}, R.R. Rios ⁴⁰, E. Ritsch ⁶¹,
 I. Riu ¹², G. Rivoltella ^{89a,89b}, F. Rizatdinova ¹¹², E. Rizvi ⁷⁵, S.H. Robertson ^{85,j},
 A. Robichaud-Veronneau ¹¹⁸, D. Robinson ²⁸, J.E.M. Robinson ⁸², A. Robson ⁵³,
 J.G. Rocha de Lima ¹⁰⁶, C. Roda ^{122a,122b}, D. Roda Dos Santos ³⁰, A. Roe ⁵⁴, S. Roe ³⁰,
 O. Røhne ¹¹⁷, S. Rolli ¹⁶¹, A. Romaniouk ⁹⁶, M. Romano ^{20a,20b}, G. Romeo ²⁷,
 E. Romero Adam ¹⁶⁷, N. Rompotis ¹³⁸, L. Roos ⁷⁸, E. Ros ¹⁶⁷, S. Rosati ^{132a}, K. Rosbach ⁴⁹,
 A. Rose ¹⁴⁹, M. Rose ⁷⁶, G.A. Rosenbaum ¹⁵⁸, P.L. Rosendahl ¹⁴, O. Rosenthal ¹⁴¹,
 L. Rosselet ⁴⁹, V. Rossetti ¹², E. Rossi ^{132a,132b}, L.P. Rossi ^{50a}, M. Rotaru ^{26a}, I. Roth ¹⁷²,
 J. Rothberg ¹³⁸, D. Rousseau ¹¹⁵, C.R. Royon ¹³⁶, A. Rozanov ⁸³, Y. Rozen ¹⁵², X. Ruan ^{33a,ah},
 F. Rubbo ¹², I. Rubinskiy ⁴², N. Ruckstuhl ¹⁰⁵, V.I. Rud ⁹⁷, C. Rudolph ⁴⁴, M.S. Rudolph ¹⁵⁸,
 F. Rühr ⁷, A. Ruiz-Martinez ⁶³, L. Rummyantsev ⁶⁴, Z. Rurikova ⁴⁸, N.A. Rusakovich ⁶⁴,
 A. Ruschke ⁹⁸, J.P. Rutherford ⁷, N. Ruthmann ⁴⁸, P. Ruzicka ¹²⁵, Y.F. Ryabov ¹²¹,

M. Rybar¹²⁷, G. Rybkin¹¹⁵, N.C. Ryder¹¹⁸, A.F. Saavedra¹⁵⁰, A. Saddique³, I. Sadeh¹⁵³,
 H.F-W. Sadrozinski¹³⁷, R. Sadykov⁶⁴, F. Safai Tehrani^{132a}, H. Sakamoto¹⁵⁵,
 G. Salamanna⁷⁵, A. Salamon^{133a}, M. Saleem¹¹¹, D. Salek³⁰, D. Salihagic⁹⁹, A. Salnikov¹⁴³,
 J. Salt¹⁶⁷, B.M. Salvachua Ferrando⁶, D. Salvatore^{37a,37b}, F. Salvatore¹⁴⁹, A. Salvucci¹⁰⁴,
 A. Salzburger³⁰, D. Sampsonidis¹⁵⁴, A. Sanchez^{102a,102b}, J. Sánchez¹⁶⁷,
 V. Sanchez Martinez¹⁶⁷, H. Sandaker¹⁴, H.G. Sander⁸¹, M.P. Sanders⁹⁸, M. Sandhoff¹⁷⁵,
 T. Sandoval²⁸, C. Sandoval¹⁶², R. Sandstroem⁹⁹, D.P.C. Sankey¹²⁹, A. Sansoni⁴⁷,
 C. Santoni³⁴, R. Santonico^{133a,133b}, H. Santos^{124a}, I. Santoyo Castillo¹⁴⁹, K. Sapp¹²³,
 J.G. Saraiva^{124a}, T. Sarangi¹⁷³, E. Sarkisyan-Grinbaum⁸, B. Sarrazin²¹, F. Sarri^{122a,122b},
 G. Sartisohn¹⁷⁵, O. Sasaki⁶⁵, Y. Sasaki¹⁵⁵, N. Sasao⁶⁷, I. Satsounkevitch⁹⁰, G. Sauvage^{5,*},
 E. Sauvan⁵, J.B. Sauvan¹¹⁵, P. Savard^{158,e}, V. Savinov¹²³, D.O. Savu³⁰, C. Sawyer¹¹⁸,
 L. Sawyer^{25,l}, D.H. Saxon⁵³, J. Saxon¹²⁰, C. Sbarra^{20a}, A. Sbrizzi³, D.A. Scannicchio¹⁶³,
 M. Scarcella¹⁵⁰, J. Schaarschmidt¹¹⁵, P. Schacht⁹⁹, D. Schaefer¹²⁰, A. Schaelicke⁴⁶,
 S. Schaepe²¹, S. Schaezel^{58b}, U. Schäfer⁸¹, A.C. Schaffer¹¹⁵, D. Schaile⁹⁸,
 R.D. Schamberger¹⁴⁸, V. Scharf^{58a}, V.A. Schegelsky¹²¹, D. Scheirich⁸⁷, M. Schernau¹⁶³,
 M.I. Scherzer³⁵, C. Schiavi^{50a,50b}, J. Schieck⁹⁸, C. Schillo⁴⁸, M. Schioppa^{37a,37b},
 S. Schlenker³⁰, E. Schmidt⁴⁸, K. Schmieden²¹, C. Schmitt⁸¹, C. Schmitt⁹⁸, S. Schmitt^{58b},
 B. Schneider¹⁷, Y.J. Schnellbach⁷³, U. Schnoor⁴⁴, L. Schoeffel¹³⁶, A. Schoening^{58b},
 A.L.S. Schorlemmer⁵⁴, M. Schott⁸¹, D. Schouten^{159a}, J. Schovancova¹²⁵, M. Schram⁸⁵,
 C. Schroeder⁸¹, N. Schroer^{58c}, M.J. Schultens²¹, J. Schultes¹⁷⁵, H.-C. Schultz-Coulon^{58a},
 H. Schulz¹⁶, M. Schumacher⁴⁸, B.A. Schumm¹³⁷, Ph. Schune¹³⁶, A. Schwartzman¹⁴³,
 Ph. Schwegler⁹⁹, Ph. Schwemling¹³⁶, R. Schvienhorst⁸⁸, J. Schwindling¹³⁶,
 T. Schwindt²¹, M. Schwoerer⁵, F.G. Sciacca¹⁷, E. Scifo¹¹⁵, G. Sciolla²³, W.G. Scott¹²⁹,
 F. Scutti²¹, J. Searcy⁸⁷, G. Sedov⁴², E. Sedykh¹²¹, S.C. Seidel¹⁰³, A. Seiden¹³⁷, F. Seifert⁴⁴,
 J.M. Seixas^{24a}, G. Sekhniaidze^{102a}, S.J. Sekula⁴⁰, K.E. Selbach⁴⁶, D.M. Seliverstov¹²¹,
 G. Sellers⁷³, M. Seman^{144b}, N. Semprini-Cesari^{20a,20b}, C. Serfon³⁰, L. Serin¹¹⁵,
 L. Serkin⁵⁴, T. Serre⁸³, R. Seuster^{159a}, H. Severini¹¹¹, A. Sfyrla³⁰, E. Shabalina⁵⁴,
 M. Shamim¹¹⁴, L.Y. Shan^{33a}, J.T. Shank²², Q.T. Shao⁸⁶, M. Shapiro¹⁵, P.B. Shatalov⁹⁵,
 K. Shaw^{164a,164c}, P. Sherwood⁷⁷, S. Shimizu¹⁰¹, M. Shimojima¹⁰⁰, T. Shin⁵⁶,
 M. Shiyakova⁶⁴, A. Shmeleva⁹⁴, M.J. Shochet³¹, D. Short¹¹⁸, S. Shrestha⁶³, E. Shulga⁹⁶,
 M.A. Shupe⁷, P. Sicho¹²⁵, A. Sidoti^{132a}, F. Siegert⁴⁸, Dj. Sijacki^{13a}, O. Silbert¹⁷²,
 J. Silva^{124a}, Y. Silver¹⁵³, D. Silverstein¹⁴³, S.B. Silverstein^{146a}, V. Simak¹²⁶, O. Simard⁵,
 Lj. Simic^{13a}, S. Simion¹¹⁵, E. Simioni⁸¹, B. Simmons⁷⁷, R. Simoniello^{89a,89b},
 M. Simonyan³⁶, P. Sinervo¹⁵⁸, N.B. Sinev¹¹⁴, V. Sipica¹⁴¹, G. Siragusa¹⁷⁴, A. Sircar²⁵,
 A.N. Sisakyan^{64,*}, S.Yu. Sivoklov⁹⁷, J. Sjölín^{146a,146b}, T.B. Sjurson¹⁴, L.A. Skinnari¹⁵,
 H.P. Skottowe⁵⁷, K. Skovpen¹⁰⁷, P. Skubic¹¹¹, M. Slater¹⁸, T. Slavicek¹²⁶, K. Sliwa¹⁶¹,
 V. Smakhtin¹⁷², B.H. Smart⁴⁶, L. Smestad¹¹⁷, S.Yu. Smirnov⁹⁶, Y. Smirnov⁹⁶,
 L.N. Smirnova^{97,ai}, O. Smirnova⁷⁹, K.M. Smith⁵³, M. Smizanska⁷¹, K. Smolek¹²⁶,
 A.A. Snesarev⁹⁴, G. Snidero⁷⁵, J. Snow¹¹¹, S. Snyder²⁵, R. Sobie^{169,j}, J. Sodomka¹²⁶,
 A. Soffer¹⁵³, D.A. Soh^{151,u}, C.A. Solans³⁰, M. Solar¹²⁶, J. Solc¹²⁶, E.Yu. Soldatov⁹⁶,
 U. Soldevila¹⁶⁷, E. Solfaroli Camillocci^{132a,132b}, A.A. Solodkov¹²⁸, O.V. Solovyanov¹²⁸,
 V. Solovyev¹²¹, N. Soni¹, A. Sood¹⁵, V. Sopko¹²⁶, B. Sopko¹²⁶, M. Sosebee⁸,
 R. Soualah^{164a,164c}, P. Soueid⁹³, A. Soukharev¹⁰⁷, D. South⁴², S. Spagnolo^{72a,72b},
 F. Spanò⁷⁶, R. Spighi^{20a}, G. Spigo³⁰, R. Spiwoks³⁰, M. Spousta^{127,aj}, T. Spreitzer¹⁵⁸,
 B. Spurlock⁸, R.D. St. Denis⁵³, J. Stahlman¹²⁰, R. Stamen^{58a}, E. Stanecka³⁹, R.W. Stanek⁶,
 C. Stanescu^{134a}, M. Stanescu-Bellu⁴², M.M. Stanitzki⁴², S. Stapnes¹¹⁷, E.A. Starchenko¹²⁸,
 J. Stark⁵⁵, P. Staroba¹²⁵, P. Starovoitov⁴², R. Staszewski³⁹, A. Staude⁹⁸, P. Stavina^{144a,*},
 G. Steele⁵³, P. Steinbach⁴⁴, P. Steinberg²⁵, I. Stekl¹²⁶, B. Stelzer¹⁴², H.J. Stelzer⁸⁸,
 O. Stelzer-Chilton^{159a}, H. Stenzel⁵², S. Stern⁹⁹, G.A. Stewart³⁰, J.A. Stillings²¹,
 M.C. Stockton⁸⁵, M. Stoebe⁸⁵, K. Stoerig⁴⁸, G. Stoicea^{26a}, S. Stonjek⁹⁹, A.R. Stradling⁸,
 A. Straessner⁴⁴, J. Strandberg¹⁴⁷, S. Strandberg^{146a,146b}, A. Strandlie¹¹⁷, M. Strang¹⁰⁹,
 E. Strauss¹⁴³, M. Strauss¹¹¹, P. Strizenec^{144b}, R. Ströhmer¹⁷⁴, D.M. Strom¹¹⁴,

J.A. Strong^{76,*}, R. Stroynowski⁴⁰, B. Stugu¹⁴, I. Stumer^{25,*}, J. Stupak¹⁴⁸, P. Sturm¹⁷⁵,
N.A. Styles⁴², D. Su¹⁴³, HS. Subramania³, R. Subramaniam²⁵, A. Succurro¹², Y. Sugaya¹¹⁶,
C. Suhr¹⁰⁶, M. Suk¹²⁶, V.V. Sulim⁹⁴, S. Sultansoy^{4c}, T. Sumida⁶⁷, X. Sun⁵⁵,
J.E. Sundermann⁴⁸, K. Suruliz¹³⁹, G. Susinno^{37a,37b}, M.R. Sutton¹⁴⁹, Y. Suzuki⁶⁵,
Y. Suzuki⁶⁶, M. Svatos¹²⁵, S. Swedish¹⁶⁸, M. Swiatlowski¹⁴³, I. Sykora^{144a}, T. Sykora¹²⁷,
D. Ta¹⁰⁵, K. Tackmann⁴², A. Taffard¹⁶³, R. Tafirout^{159a}, N. Taiblum¹⁵³, Y. Takahashi¹⁰¹,
H. Takai²⁵, R. Takashima⁶⁸, H. Takeda⁶⁶, T. Takeshita¹⁴⁰, Y. Takubo⁶⁵, M. Talby⁸³,
A. Talyshev^{107.g}, J.Y.C. Tam¹⁷⁴, M.C. Tamsett²⁵, K.G. Tan⁸⁶, J. Tanaka¹⁵⁵, R. Tanaka¹¹⁵,
S. Tanaka¹³¹, S. Tanaka⁶⁵, A.J. Tanasijczuk¹⁴², K. Tani⁶⁶, N. Tannoury⁸³, S. Tapprogge⁸¹,
S. Tarem¹⁵², F. Tarrade²⁹, G.F. Tartarelli^{89a}, P. Tas¹²⁷, M. Tasevsky¹²⁵, T. Tashiro⁶⁷,
E. Tassi^{37a,37b}, Y. Tayalati^{135d}, C. Taylor⁷⁷, F.E. Taylor⁹², G.N. Taylor⁸⁶, W. Taylor^{159b},
M. Teinturier¹¹⁵, F.A. Teischinger³⁰, M. Teixeira Dias Castanheira⁷⁵, P. Teixeira-Dias⁷⁶,
K.K. Temming⁴⁸, H. Ten Kate³⁰, P.K. Teng¹⁵¹, S. Terada⁶⁵, K. Terashi¹⁵⁵, J. Terron⁸⁰,
M. Testa⁴⁷, R.J. Teuscher^{158.j}, J. Therhaag²¹, T. Theveneaux-Pelzer³⁴, S. Thoma⁴⁸,
J.P. Thomas¹⁸, E.N. Thompson³⁵, P.D. Thompson¹⁸, P.D. Thompson¹⁵⁸, A.S. Thompson⁵³,
L.A. Thomsen³⁶, E. Thomson¹²⁰, M. Thomson²⁸, W.M. Thong⁸⁶, R.P. Thun^{87,*}, F. Tian³⁵,
M.J. Tibbetts¹⁵, T. Tic¹²⁵, V.O. Tikhomirov⁹⁴, Y.A. Tikhonov^{107.g}, S. Timoshenko⁹⁶,
E. Tiouchichine⁸³, P. Tipton¹⁷⁶, S. Tisserant⁸³, T. Todorov⁵, S. Todorova-Nova¹⁶¹,
B. Toggerson¹⁶³, J. Tojo⁶⁹, S. Tokár^{144a}, K. Tokushuku⁶⁵, K. Tollefson⁸⁸, L. Tomlinson⁸²,
M. Tomoto¹⁰¹, L. Tompkins³¹, K. Toms¹⁰³, A. Tonoyan¹⁴, C. Topfel¹⁷, N.D. Topilin⁶⁴,
E. Torrence¹¹⁴, H. Torres⁷⁸, E. Torró Pastor¹⁶⁷, J. Toth^{83.ae}, F. Touchard⁸³, D.R. Tovey¹³⁹,
H.L. Tran¹¹⁵, T. Trefzger¹⁷⁴, L. Tremblet³⁰, A. Tricoli³⁰, I.M. Trigger^{159a},
S. Trincaz-Duvoid⁷⁸, M.F. Tripiana⁷⁰, N. Triplett²⁵, W. Trischuk¹⁵⁸, B. Trocmé⁵⁵,
C. Troncon^{89a}, M. Trottier-McDonald¹⁴², M. Trovatelli^{134a,134b}, P. True⁸⁸, M. Trzebinski³⁹,
A. Trzupek³⁹, C. Tsarouchas³⁰, J.C.-L. Tseng¹¹⁸, M. Tsiakiris¹⁰⁵, P.V. Tsiarehka⁹⁰,
D. Tsiou¹³⁶, G. Tsipolitis¹⁰, S. Tsiskaridze¹², V. Tsiskaridze⁴⁸, E.G. Tskhadadze^{51a},
I.I. Tsukerman⁹⁵, V. Tsulaia¹⁵, J.-W. Tsung²¹, S. Tsuno⁶⁵, D. Tsybychev¹⁴⁸, A. Tua¹³⁹,
A. Tudorache^{26a}, V. Tudorache^{26a}, J.M. Tuggle³¹, A.N. Tuna¹²⁰, M. Turala³⁹,
D. Turecek¹²⁶, I. Turk Cakir^{4d}, R. Turra^{89a,89b}, P.M. Tuts³⁵, A. Tykhonov⁷⁴,
M. Tylmad^{146a,146b}, M. Tyndel¹²⁹, G. Tzanakos⁹, K. Uchida²¹, I. Ueda¹⁵⁵, R. Ueno²⁹,
M. Ughetto⁸³, M. Uglund¹⁴, M. Uhlenbrock²¹, F. Ukegawa¹⁶⁰, G. Unal³⁰, A. Undrus²⁵,
G. Unel¹⁶³, F.C. Ungaro⁴⁸, Y. Unno⁶⁵, D. Urbaniec³⁵, P. Urquijo²¹, G. Usai⁸, L. Vacavant⁸³,
V. Vacek¹²⁶, B. Vachon⁸⁵, S. Vahsen¹⁵, N. Valencic¹⁰⁵, S. Valentinetti^{20a,20b}, A. Valero¹⁶⁷,
L. Valery³⁴, S. Valkar¹²⁷, E. Valladolid Gallego¹⁶⁷, S. Vallecorsa¹⁵², J.A. Valls Ferrer¹⁶⁷,
R. Van Berg¹²⁰, P.C. Van Der Deijl¹⁰⁵, R. van der Geer¹⁰⁵, H. van der Graaf¹⁰⁵,
R. Van Der Leeuw¹⁰⁵, D. van der Ster³⁰, N. van Eldik³⁰, P. van Gemmeren⁶,
J. Van Nieuwkoop¹⁴², I. van Vulpen¹⁰⁵, M. Vanadia⁹⁹, W. Vandelli³⁰, A. Vaniachine⁶,
P. Vankov⁴², F. Vannucci⁷⁸, R. Vari^{132a}, E.W. Varnes⁷, T. Varol⁸⁴, D. Varouchas¹⁵,
A. Vartapetian⁸, K.E. Varvell¹⁵⁰, V.I. Vassilakopoulos⁵⁶, F. Vazeille³⁴,
T. Vazquez Schroeder⁵⁴, F. Veloso^{124a}, S. Veneziano^{132a}, A. Ventura^{72a,72b}, D. Ventura⁸⁴,
M. Venturi⁴⁸, N. Venturi¹⁵⁸, V. Vercesi^{119a}, M. Verducci¹³⁸, W. Verkerke¹⁰⁵,
J.C. Vermeulen¹⁰⁵, A. Vest⁴⁴, M.C. Vetterli^{142.e}, I. Vichou¹⁶⁵, T. Vickey^{145b.ak},
O.E. Vickey Boeriu^{145b}, G.H.A. Viehhauser¹¹⁸, S. Viel¹⁶⁸, M. Villa^{20a,20b},
M. Villaplana Perez¹⁶⁷, E. Vilucchi⁴⁷, M.G. Vincker²⁹, V.B. Vinogradov⁶⁴, J. Virzi¹⁵,
O. Vitells¹⁷², M. Viti⁴², I. Vivarelli⁴⁸, F. Vives Vaque³, S. Vlachos¹⁰, D. Vladoiu⁹⁸,
M. Vlasak¹²⁶, A. Vogel²¹, P. Vokac¹²⁶, G. Volpi⁴⁷, M. Volpi⁸⁶, G. Volpini^{89a},
H. von der Schmitt⁹⁹, H. von Radziewski⁴⁸, E. von Toerne²¹, V. Vorobel¹²⁷, M. Vos¹⁶⁷,
R. Voss³⁰, J.H. Vossebeld⁷³, N. Vranjes¹³⁶, M. Vranjes Milosavljevic¹⁰⁵, V. Vrba¹²⁵,
M. Vreeswijk¹⁰⁵, T. Vu Anh⁴⁸, R. Vuillemet³⁰, I. Vukotic³¹, Z. Vykydal¹²⁶, W. Wagner¹⁷⁵,
P. Wagner²¹, H. Wahlen¹⁷⁵, S. Wahrmund⁴⁴, J. Wakabayashi¹⁰¹, S. Walch⁸⁷, J. Walder⁷¹,
R. Walker⁹⁸, W. Walkowiak¹⁴¹, R. Wall¹⁷⁶, P. Waller⁷³, B. Walsh¹⁷⁶, C. Wang⁴⁵,
H. Wang¹⁷³, H. Wang⁴⁰, J. Wang¹⁵¹, J. Wang^{33a}, K. Wang⁸⁵, R. Wang¹⁰³, S.M. Wang¹⁵¹,

T. Wang²¹, X. Wang¹⁷⁶, A. Warburton⁸⁵, C.P. Ward²⁸, D.R. Wardrope⁷⁷, M. Warsinsky⁴⁸,
 A. Washbrook⁴⁶, C. Wasicki⁴², I. Watanabe⁶⁶, P.M. Watkins¹⁸, A.T. Watson¹⁸,
 I.J. Watson¹⁵⁰, M.F. Watson¹⁸, G. Watts¹³⁸, S. Watts⁸², A.T. Waugh¹⁵⁰, B.M. Waugh⁷⁷,
 M.S. Weber¹⁷, J.S. Webster³¹, A.R. Weidberg¹¹⁸, P. Weigell⁹⁹, J. Weingarten⁵⁴,
 C. Weiser⁴⁸, P.S. Wells³⁰, T. Wenaus²⁵, D. Wendland¹⁶, Z. Weng^{151,u}, T. Wengler³⁰,
 S. Wenig³⁰, N. Wermes²¹, M. Werner⁴⁸, P. Werner³⁰, M. Werth¹⁶³, M. Wessels^{58a},
 J. Wetter¹⁶¹, K. Whalen²⁹, A. White⁸, M.J. White⁸⁶, R. White^{32b}, S. White^{122a,122b},
 S.R. Whitehead¹¹⁸, D. Whiteson¹⁶³, D. Whittington⁶⁰, D. Wicke¹⁷⁵, F.J. Wickens¹²⁹,
 W. Wiedenmann¹⁷³, M. Wielers⁷⁹, P. Wienemann²¹, C. Wiglesworth³⁶,
 L.A.M. Wiik-Fuchs²¹, P.A. Wijeratne⁷⁷, A. Wildauer⁹⁹, M.A. Wildt^{42,r}, I. Wilhelm¹²⁷,
 H.G. Wilkens³⁰, J.Z. Will⁹⁸, E. Williams³⁵, H.H. Williams¹²⁰, S. Williams²⁸, W. Willis^{35,*},
 S. Willocq⁸⁴, J.A. Wilson¹⁸, A. Wilson⁸⁷, I. Wingerter-Seez⁵, S. Winkelmann⁴⁸,
 F. Winklmeier³⁰, M. Wittgen¹⁴³, T. Wittig⁴³, J. Wittkowski⁹⁸, S.J. Wollstadt⁸¹,
 M.W. Wolter³⁹, H. Wolters^{124a,h}, W.C. Wong⁴¹, G. Wooden⁸⁷, B.K. Wosiek³⁹,
 J. Wotschack³⁰, M.J. Woudstra⁸², K.W. Wozniak³⁹, K. Wraight⁵³, M. Wright⁵³,
 B. Wrona⁷³, S.L. Wu¹⁷³, X. Wu⁴⁹, Y. Wu⁸⁷, E. Wulf³⁵, B.M. Wynne⁴⁶, S. Xella³⁶,
 M. Xiao¹³⁶, S. Xie⁴⁸, C. Xu^{33b,z}, D. Xu^{33a}, L. Xu^{33b}, B. Yabsley¹⁵⁰, S. Yacoob^{145a,al},
 M. Yamada⁶⁵, H. Yamaguchi¹⁵⁵, Y. Yamaguchi¹⁵⁵, A. Yamamoto⁶⁵, K. Yamamoto⁶³,
 S. Yamamoto¹⁵⁵, T. Yamamura¹⁵⁵, T. Yamanaka¹⁵⁵, K. Yamauchi¹⁰¹, T. Yamazaki¹⁵⁵,
 Y. Yamazaki⁶⁶, Z. Yan²², H. Yang^{33e}, H. Yang¹⁷³, U.K. Yang⁸², Y. Yang¹⁰⁹, Z. Yang^{146a,146b},
 S. Yanush⁹¹, L. Yao^{33a}, Y. Yasu⁶⁵, E. Yatsenko⁴², K.H. Yau Wong²¹, J. Ye⁴⁰, S. Ye²⁵,
 A.L. Yen⁵⁷, E. Yildirim⁴², M. Yilmaz^{4b}, R. Yoosofmiya¹²³, K. Yorita¹⁷¹, R. Yoshida⁶,
 K. Yoshihara¹⁵⁵, C. Young¹⁴³, C.J.S. Young¹¹⁸, S. Youssef²², D. Yu²⁵, D.R. Yu¹⁵, J. Yu⁸,
 J. Yu¹¹², L. Yuan⁶⁶, A. Yurkewicz¹⁰⁶, B. Zabinski³⁹, R. Zaidan⁶², A.M. Zaitsev¹²⁸,
 S. Zambito²³, L. Zanello^{132a,132b}, D. Zanzi⁹⁹, A. Zaytsev²⁵, C. Zeitnitz¹⁷⁵, M. Zeman¹²⁶,
 A. Zemla³⁹, O. Zenin¹²⁸, T. Ženiš^{144a}, D. Zerwas¹¹⁵, G. Zevi della Porta⁵⁷, D. Zhang⁸⁷,
 H. Zhang⁸⁸, J. Zhang⁶, L. Zhang¹⁵¹, X. Zhang^{33d}, Z. Zhang¹¹⁵, Z. Zhao^{33b},
 A. Zhemchugov⁶⁴, J. Zhong¹¹⁸, B. Zhou⁸⁷, N. Zhou¹⁶³, Y. Zhou¹⁵¹, C.G. Zhu^{33d}, H. Zhu⁴²,
 J. Zhu⁸⁷, Y. Zhu^{33b}, X. Zhuang^{33a}, V. Zhuravlov⁹⁹, A. Zibell⁹⁸, D. Zieminska⁶⁰,
 N.I. Zimin⁶⁴, C. Zimmermann⁸¹, R. Zimmermann²¹, S. Zimmermann²¹,
 S. Zimmermann⁴⁸, Z. Zinonos^{122a,122b}, M. Ziolkowski¹⁴¹, R. Zitoun⁵, L. Živković³⁵,
 V.V. Zmouchko^{128,*}, G. Zobernig¹⁷³, A. Zoccoli^{20a,20b}, M. zur Nedden¹⁶, V. Zutshi¹⁰⁶,
 L. Zwalinski³⁰

¹ School of Chemistry and Physics, University of Adelaide, Adelaide, Australia

² Physics Department, SUNY Albany, Albany, NY, United States

³ Department of Physics, University of Alberta, Edmonton, AB, Canada

⁴ (a) Department of Physics, Ankara University, Ankara; (b) Department of Physics, Gazi University, Ankara; (c) Division of Physics, TOBB University of Economics and Technology, Ankara; (d) Turkish Atomic Energy Authority, Ankara, Turkey

⁵ LAPP, CNRS/IN2P3 and Université de Savoie, Annecy-le-Vieux, France

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

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

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

⁹ Physics Department, University of Athens, Athens, Greece

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

¹¹ Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan

¹² Institut de Física d'Altes Energies and Departament de Física de la Universitat Autònoma de Barcelona and ICREA, Barcelona, Spain

¹³ (a) Institute of Physics, University of Belgrade, Belgrade; (b) Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia

¹⁴ Department for Physics and Technology, University of Bergen, Bergen, Norway

¹⁵ Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, CA, United States

¹⁶ Department of Physics, Humboldt University, Berlin, Germany

¹⁷ Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland

¹⁸ School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom

¹⁹ (a) Department of Physics, Bogazici University, Istanbul; (b) Division of Physics, Dogus University, Istanbul; (c) Department of Physics Engineering, Gaziantep University, Gaziantep, Turkey

²⁰ (a) INFN Sezione di Bologna; (b) Dipartimento di Fisica, Università di Bologna, Bologna, Italy

²¹ Physikalisches Institut, University of Bonn, Bonn, Germany

²² Department of Physics, Boston University, Boston, MA, United States

²³ Department of Physics, Brandeis University, Waltham, MA, United States

²⁴ (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

²⁵ Physics Department, Brookhaven National Laboratory, Upton, NY, United States

- 26 ^(a) National Institute of Physics and Nuclear Engineering, Bucharest; ^(b) University Politehnica Bucharest, Bucharest; ^(c) West University in Timisoara, Timisoara, Romania
- 27 Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina
- 28 Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
- 29 Department of Physics, Carleton University, Ottawa, ON, Canada
- 30 CERN, Geneva, Switzerland
- 31 Enrico Fermi Institute, University of Chicago, Chicago, IL, United States
- 32 ^(a) Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; ^(b) Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
- 33 ^(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) School of Physics, Shandong University, Shandong; ^(e) Physics Department, Shanghai Jiao Tong University, Shanghai, China
- 34 Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Clermont-Ferrand, France
- 35 Nevis Laboratory, Columbia University, Irvington, NY, United States
- 36 Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
- 37 ^(a) INFN Gruppo Collegato di Cosenza; ^(b) Dipartimento di Fisica, Università della Calabria, Rende, Italy
- 38 ^(a) AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow; ^(b) Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland
- 39 The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
- 40 Physics Department, Southern Methodist University, Dallas, TX, United States
- 41 Physics Department, University of Texas at Dallas, Richardson, TX, United States
- 42 DESY, Hamburg and Zeuthen, Germany
- 43 Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
- 44 Institut für Kern- und Teilchenphysik, Technical University Dresden, Dresden, Germany
- 45 Department of Physics, Duke University, Durham, NC, United States
- 46 SUPA – School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
- 47 INFN Laboratori Nazionali di Frascati, Frascati, Italy
- 48 Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg, 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 ^(a) E. Andronikashvili Institute of Physics, Iv. Javakishvili Tbilisi State University, Tbilisi; ^(b) High Energy Physics Institute, 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 Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan
- 60 Department of Physics, Indiana University, Bloomington, IN, United States
- 61 Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
- 62 University of Iowa, Iowa City, IA, United States
- 63 Department of Physics and Astronomy, Iowa State University, Ames, IA, United States
- 64 Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia
- 65 KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
- 66 Graduate School of Science, Kobe University, Kobe, Japan
- 67 Faculty of Science, Kyoto University, Kyoto, Japan
- 68 Kyoto University of Education, Kyoto, Japan
- 69 Department of Physics, Kyushu University, Fukuoka, 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 Matematica e 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 School of Physics and Astronomy, 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 Autónoma 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 D.V. Skobeltsyn Institute of Nuclear Physics, M.V. 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 and Kobayashi-Maskawa Institute, 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, SB RAS, 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, Université 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, 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 Czech Technical University in Prague, Praha, Czech Republic
- 127 Faculty of Mathematics and Physics, Charles 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 Matematica e Fisica, Università Roma Tre, Roma, Italy
- 135 (a) Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies and Université Hassan II, Casablanca; (b) Centre National de l'Energie des Sciences Techniques Nucleaires, Rabat; (c) Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA, Marrakech; (d) Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; (e) Faculté des sciences, Université Mohammed V-Agdal, Rabat, Morocco
- 136 DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique et aux Energies Alternatives), 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 Departments of Physics & Astronomy and Chemistry, 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 Institute 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 Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan
- 161 Department of Physics and Astronomy, 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 Chimica, Fisica e Ambiente, 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 Department of Physics, University of Warwick, Coventry, United Kingdom
¹⁷¹ Waseda University, Tokyo, Japan
¹⁷² Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
¹⁷³ Department of Physics, University of Wisconsin, Madison, WI, United States
¹⁷⁴ Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany
¹⁷⁵ Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany
¹⁷⁶ Department of Physics, Yale University, New Haven, CT, United States
¹⁷⁷ Yerevan Physics Institute, Yerevan, Armenia
¹⁷⁸ Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France

- ^a Also at Department of Physics, King's College London, London, United Kingdom.
^b Also at Laboratório de Instrumentação e Física Experimental de Partículas – LIP, Lisboa, Portugal.
^c Also at Faculdade de Ciências and CFNUL, Universidade de Lisboa, Lisboa, Portugal.
^d Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom.
^e Also at TRIUMF, Vancouver, BC, Canada.
^f Also at Department of Physics, California State University, Fresno, CA, United States.
^g Also at Novosibirsk State University, Novosibirsk, Russia.
^h Also at Department of Physics, University of Coimbra, Coimbra, Portugal.
ⁱ Also at Università di Napoli Parthenope, Napoli, Italy.
^j Also at Institute of Particle Physics (IPP), Canada.
^k Also at Department of Physics, Middle East Technical University, Ankara, Turkey.
^l Also at Louisiana Tech University, Ruston, LA, United States.
^m Also at Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal.
ⁿ Also at Department of Physics and Astronomy, Michigan State University, East Lansing, MI, United States.
^o Also at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece.
^p Also at Department of Physics, University of Cape Town, Cape Town, South Africa.
^q Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.
^r Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.
^s Also at Manhattan College, New York, NY, United States.
^t Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France.
^u Also at School of Physics and Engineering, Sun Yat-sen University, Guanzhou, China.
^v Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan.
^w Also at Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France.
^x Also at School of Physical Sciences, National Institute of Science Education and Research, Bhubaneswar, India.
^y Also at Dipartimento di Fisica, Università La Sapienza, Roma, Italy.
^z Also at DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique et aux Energies Alternatives), Gif-sur-Yvette, France.
^{aa} Also at Section de Physique, Université de Genève, Geneva, Switzerland.
^{ab} Also at Departamento de Física, Universidade de Minho, Braga, Portugal.
^{ac} Also at Department of Physics, The University of Texas at Austin, Austin, TX, United States.
^{ad} Also at Department of Physics and Astronomy, University of South Carolina, Columbia, SC, United States.
^{ae} Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary.
^{af} Also at DESY, Hamburg and Zeuthen, Germany.
^{ag} Also at International School for Advanced Studies (SISSA), Trieste, Italy.
^{ah} Also at LAL, Université Paris-Sud and CNRS/IN2P3, Orsay, France.
^{ai} Also at Faculty of Physics, M.V. Lomonosov Moscow State University, Moscow, Russia.
^{aj} Also at Nevis Laboratory, Columbia University, Irvington, NY, United States.
^{ak} Also at Department of Physics, Oxford University, Oxford, United Kingdom.
^{al} Also at Discipline of Physics, University of KwaZulu-Natal, Durban, South Africa.
^{*} Deceased.