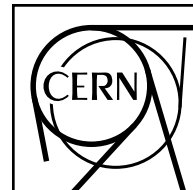


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Measurement with the ATLAS detector of multi-particle azimuthal correlations in $p+\text{Pb}$ collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV

The ATLAS Collaboration

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1. Introduction

Recent observations of ridge-like structures in the two-particle correlation functions measured in proton-lead (p +Pb) collisions at 5.02 TeV [1–3] have led to differing theoretical explanations. These structures have been attributed either to mechanisms that emphasize 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 +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 +Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ 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 characterized 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 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 +Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ 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 characterize 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 +Pb collisions.

2. Event and track selections

The p +Pb data sample was collected during a short run in September 2012, when the LHC delivered p +Pb collisions at the nucleon–nucleon centre-of-mass energy $\sqrt{s_{\text{NN}}} = 5.02$ TeV with the centre-of-mass frame shifted by -0.47 in rapidity relative to the nominal ATLAS coordinate frame¹.

The measurements were performed using the ATLAS detector [33]. The inner detector (ID) was used for measuring trajectories and momenta

¹ATLAS 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 +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 $p_{\text{T}} = p \sin \theta$ and $E_{\text{T}} = E \sin \theta$, respectively.

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 +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 $p_{\text{T}} > 0.1$ 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 characterize 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 +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 optimized 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 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

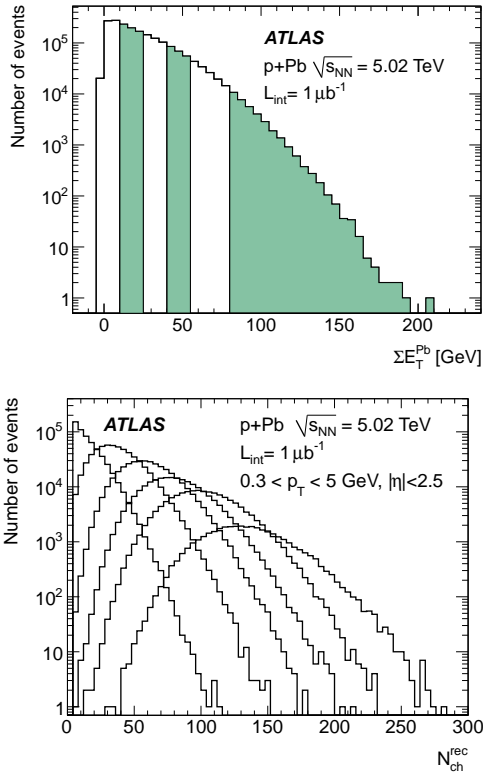


Fig. 1: Upper plot: the ΣE_T^{Pb} distribution with the six activity intervals indicated. Lower plot: the distribution of N_{ch}^{rec} for each activity interval. The leftmost distribution corresponds to the interval with the lowest ΣE_T^{Pb} , etc.

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] $p+Pb$ 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_{ch}^{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

ΣE_T^{Pb} range [GeV]	$\langle \Sigma E_T^{Pb} \rangle$ [GeV]	range in fraction of events [%]	$\langle N_{ch}^{rec} \rangle$ (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)

Table 1: Characterization 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_{ch}^{rec} , is given for each activity interval.

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 characterized by ΣE_T^{Pb} : the most active events are those with the largest ΣE_T^{Pb} . The distribution of N_{ch}^{rec} for each activity interval is shown in the lower plot of Fig. 1.

3. Data analysis

The cumulant method involves the calculation of $2k$ -particle azimuthal correlations, $corr_n\{2k\}$, and cumulants, $c_n\{2k\}$, where $k = 1, 2$ for the analysis presented in this paper. The two- and four-particle correlations are defined as $corr_n\{2\} = \langle e^{in(\phi_1 - \phi_2)} \rangle$ and $corr_n\{4\} = \langle e^{in(\phi_1 + \phi_2 - \phi_3 - \phi_4)} \rangle$, 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 $c_n\{2\} = \langle corr_n\{2\} \rangle$, and the four-particle cumulant $c_n\{4\} = \langle corr_n\{4\} \rangle - 2 \cdot \langle corr_n\{2\} \rangle^2$. 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

195 over all particles in an event. This analysis is re-
 196 stricted to the second harmonic coefficient, $n = 2$.
 197 The method based on the flow-vector moments en-
 198 ables the calculation of multi-particle cumulants in
 199 a single pass over the full set of particles in each
 200 event.

201 The cumulant method involves two main steps
 202 [29, 30]. In the first step, the so-called “refer-
 203 ence” flow harmonic coefficients are calculated us-
 204 ing multi-particle cumulants for particles selected
 205 inclusively from a broad range in p_T and η as:

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

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

206 where $v_2^{\text{ref}}\{2\}$ ($v_2^{\text{ref}}\{4\}$) denotes the reference es-
 207 timate of the second-order anisotropy parameter
 208 obtained using two-particle, $c_2\{2\}$ (four-particle,
 209 $c_2\{4\}$) cumulants.

210 The flow-vector method is easiest to apply when
 211 the detector acceptance is azimuthally uniform [32].
 212 A correction for any azimuthal non-uniformity in
 213 the reconstruction of charged particle tracks is ob-
 214 tained from the data [25], based on an η - ϕ map
 215 of all reconstructed tracks. For each small ($\delta\eta =$
 216 $0.1, \delta\phi = 2\pi/64$) bin (labelled i), a weight is cal-
 217 culated as $w_i(\eta, \phi) = \langle N(\delta\eta) \rangle / N_i(\delta\eta, \delta\phi)$, where
 218 $\langle N(\delta\eta) \rangle$ is the event-averaged number of tracks
 219 in the $\delta\eta$ slice to which this bin belongs, while
 220 $N_i(\delta\eta, \delta\phi)$ is the number of tracks in an event
 221 within this bin. Using this weight forces the az-
 222 imuthal angle distribution of reference particles to
 223 be uniform in ϕ , but it does not change the η
 224 distribution of reconstructed tracks. A weighted
 225 Q -vector is evaluated as $Q_n = \sum_i w_i e^{in\phi_i}$ [32].
 226 From Eqs. (2) and (3) it is clear that the cumu-
 227 lant method can be used to estimate v_2 only when
 228 $c_2\{4\}$ is negative and $c_2\{2\}$ positive.

229 In the second step, the harmonic coefficients are
 230 determined as functions of p_T and η , in bins in each
 231 variable (10 bins of equal width are used in η and 22
 232 bins of varied width in p_T). These differential flow
 233 harmonics are calculated for “particles of interest”
 234 which fall into these small bins. First, the differ-
 235 ential cumulants, $d_2\{2\}$ and $d_2\{4\}$, are obtained by
 236 correlating every particle of interest with one and
 237 three reference particles respectively. The differ-
 238 ential second harmonic, $v_2\{2k\}(p_T, \eta)$, where $k = 1, 2$,
 239 is then calculated with respect to the reference flow
 240 as derived in Refs. [29, 30]:

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

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

241 The differential v_2 harmonic is then integrated
 242 over wider phase-space bins, with each small bin
 243 weighted by the appropriate charged particle mul-
 244 tiplicity. This is obtained from the reconstructed
 245 multiplicity by applying η - and p_T -dependent effi-
 246 ciency factors, determined from Monte Carlo (MC)
 247 simulation as discussed in the previous section. Due
 248 to the small number of events in the data sample,
 249 the final results are integrated over the full accep-
 tance in η .

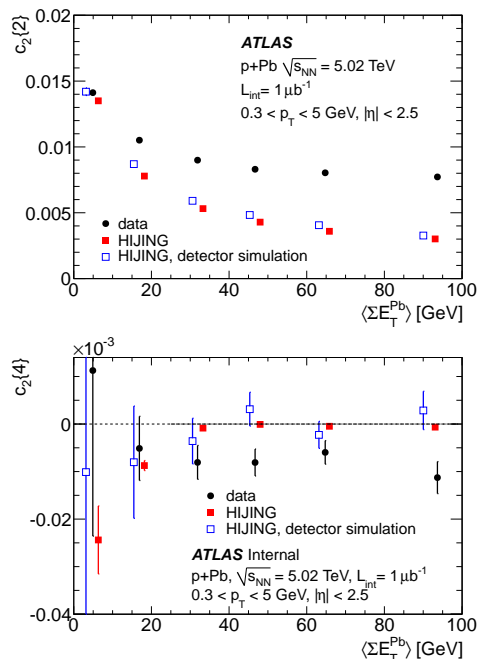


Fig. 2: The two-particle (upper plot) and four-particle (lower plot) cumulants calculated using the reference flow particles as a function of ΣE_T^{Pb} for data (circles), the fully simulated HIJING events (open squares) and the large generator-level HIJING sample (filled squares). For clarity, the points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

250 Fig. 2 shows the two- and four-particle cumu-
 251 lants, averaged over events in each event-activity
 252 class defined in Table 1, as a function of ΣE_T^{Pb} . It
 253 is observed that four-particle cumulants are nega-
 254 tive only in a certain range of event activity.
 255 This restricts subsequent analysis to events with
 256 $\Sigma E_T^{\text{Pb}} > 25$ GeV, for which the four-particle cumu-
 257 lant in data is found to be less than zero by at least
 258 two standard deviations (statistical errors only). It
 259

was also checked that for these events $c_2\{4\}$ is unchanged within errors for any high-multiplicity selection. 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), then selecting $N_{\text{ch}}^{\text{rec}} > N_{20}$ leaves $c_2\{4\}$ unchanged within errors. And for $\Sigma E_{\text{T}}^{\text{Pb}} > 25$ GeV this holds for any percentile selection.

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 $\Sigma E_{\text{T}}^{\text{Pb}}$ 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 $\Sigma E_{\text{T}}^{\text{Pb}} \sim 20$ 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 $\Sigma E_{\text{T}}^{\text{Pb}} > 25$ 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 $\Sigma E_{\text{T}}^{\text{Pb}}$. 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 $\Sigma E_{\text{T}}^{\text{Pb}}$ 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 $\Sigma E_{\text{T}}^{\text{Pb}}$ 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 $v_2\{4\}(p_{\text{T}})$ 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 $\Sigma E_{\text{T}}^{\text{Pb}}$. 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 $\Sigma E_{\text{T}}^{\text{Pb}}$ 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 $p_{\text{T}} \approx 2$ 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 +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

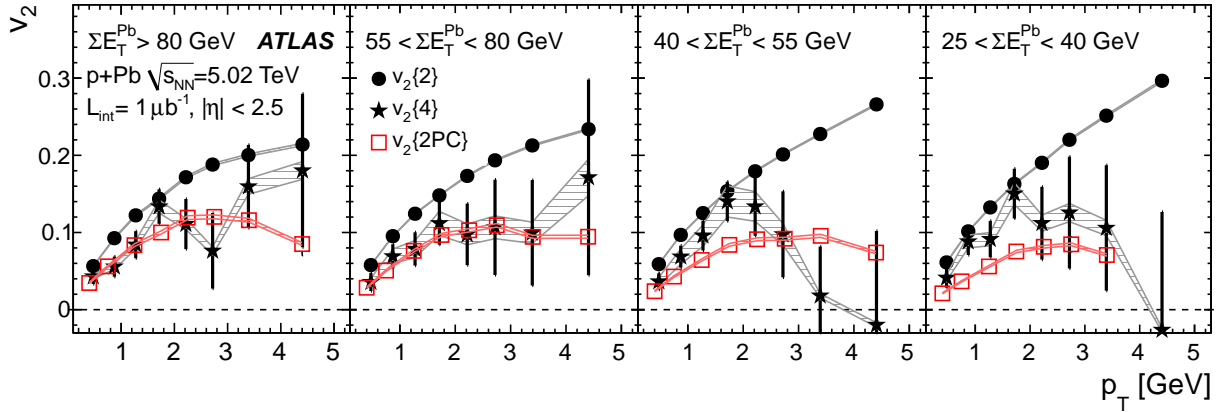


Fig. 3: The second-order harmonic calculated with the two-particle (circles) and four-particle (stars) cumulants as a function of transverse momentum in four different activity intervals. Bars denote statistical errors; systematic uncertainties are shown as shaded bands. The v_2 derived from the Fourier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

362 affected by the dijet correlations on the away-side
 363 ($\Delta\phi \sim \pi$), which can span a large range in $\Delta\eta$.
 364 In Ref. [3], the away-side non-flow correlation is
 365 estimated using the yield measured in the lowest
 366 ΣE_T^{Pb} collisions and is then subtracted from the
 367 higher ΣE_T^{Pb} collisions. The result of that study,
 368 $v_2\{2PC\}$, is shown in Fig. 3 for the four activ-
 369 ity intervals with largest ΣE_T^{Pb} , and compared to
 370 $v_2\{4\}$. Good agreement is observed between $v_2\{4\}$
 371 and $v_2\{2PC\}$ for collisions with $\Sigma E_T^{\text{Pb}} > 55$ GeV.
 372 For $\Sigma E_T^{\text{Pb}} < 55$ GeV, the disagreement could be
 373 due either to the subtraction procedure used to ob-
 374 tain $v_2\{2PC\}$ or to non-flow effects in $v_2\{4\}$, or to
 375 a combination.

376 The dependence on the collision activity of the
 377 second-order harmonic, integrated over $0.3 < p_T <$
 378 5 GeV, is shown in Fig. 4. The large magni-
 379 tude of $v_2\{2\}$ compared to $v_2\{4\}$ suggests a sub-
 380 stantial contamination from non-flow correlations.
 381 The value of $v_2\{4\}$ is approximately 0.06, with lit-
 382 tle dependence on the overall event activity for
 383 $\Sigma E_T^{\text{Pb}} > 25$ GeV. The extracted values of $v_2\{4\}$
 384 are also compared to the $v_2\{2PC\}$ values obtained
 385 from two-particle correlations. Good agreement is
 386 observed at large ΣE_T^{Pb} , while at lower ΣE_T^{Pb} the
 387 $v_2\{2PC\}$ is smaller than $v_2\{4\}$, which may be due
 388 to different sensitivity of the two methods to non-
 389 flow contributions that become more important in
 390 low ΣE_T^{Pb} collisions. Although $v_2\{4\}$ is constructed
 391 to suppress local two-particle correlations, it may
 392 still include true multi-particle correlations from
 393 jets, which should account for a larger fraction of
 394 the correlated particle production in the events with

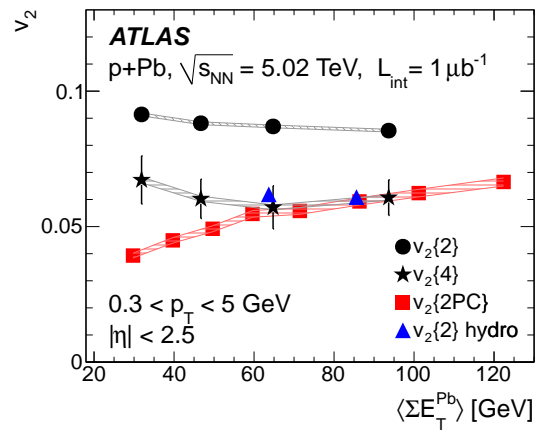


Fig. 4: The second-order harmonic, v_2 , integrated over p_T and η , calculated with two- and four-particle cumulants (circles and stars, respectively), as a function of ΣE_T^{Pb} . Systematic uncertainties are shown as shaded bands. Also shown is $v_2\{2PC\}$ (squares) and predictions from the hydrodynamic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

395 the lowest ΣE_T^{Pb} . If the HIJING results, shown in
 396 Fig. 2, were used to correct the measured cumulants
 397 for this non-flow contribution, the extracted $v_2\{4\}$
 398 would be decreased by at most 10% for $v_2\{4\}$ shown
 399 in Fig. 4. However, this correction is not applied to
 400 the final results.

401 It is notable that the trend of the p_T depen-
 402 dence of both $v_2\{4\}$ and $v_2\{2PC\}$ in p +Pb col-
 403 lisions resembles that observed for v_2 measured
 404 with the event-plane method in Pb+Pb collisions

at $\sqrt{s_{NN}} = 2.76$ TeV [21, 22], although with a magnitude between that observed in the most central and peripheral Pb+Pb collisions. While the trend is found to be nearly independent of the Pb+Pb collision geometry, the magnitude in Pb+Pb events depends on the initial shape of the colliding system, and has been modelled for $p_T < 2$ GeV using viscous hydrodynamics [39–41].

Harmonic flow coefficients in p +Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV have also been predicted using viscous hydrodynamics, with similar initial conditions as the Pb+Pb calculations [18]. The predicted magnitude of the second-order harmonic² is compared to the measured $v_2\{4\}$ and $v_2\{2PC\}$ 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 +Pb collisions at $\sqrt{s_{NN}} = 5.02$ 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 Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ 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 $\Sigma E_T^{Pb} > 25$ 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 $\Sigma E_T^{Pb} > 55$ GeV. Good agreement is also found with the predictions of a hydrodynamic calculation for p +Pb collisions.

Extending previous results based only on two-particle correlations, the multi-particle cumulant results presented here provide additional evidence

²We 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.

for the importance of final-state effects in the highest multiplicity p +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.

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 657 M.J. Costa¹⁶⁷, D. Costanzo¹³⁹, D. Côté³⁰, G. Cottin^{32a}, L. Courneyea¹⁶⁹, G. Cowan⁷⁶, B.E. Cox⁸²,
 658 K. Cranmer¹⁰⁸, S. Crépe-Renaudin⁵⁵, F. Crescioli⁷⁸, M. Cristinziani²¹, G. Crosetti^{37a,37b}, C.-M. Cuciuc^{26a},
 659 C. Cuenca Almenar¹⁷⁶, T. Cuhadar Donszelmann¹³⁹, J. Cummings¹⁷⁶, M. Curatolo⁴⁷, C.J. Curtis¹⁸,
 660 C. Cuthbert¹⁵⁰, H. Czirr¹⁴¹, P. Czodrowski⁴⁴, Z. Czynzula¹⁷⁶, S. D'Auria⁵³, M. D'Onofrio⁷³,
 661 A. D'Orazio^{132a,132b}, M.J. Da Cunha Sargedas De Sousa^{124a}, C. Da Via⁸², W. Dabrowski^{38a},
 662 A. Dafinca¹¹⁸, T. Dai⁸⁷, F. Dallaire⁹³, C. Dallapiccola⁸⁴, M. Dam³⁶, D.S. Damiani¹³⁷, A.C. Daniells¹⁸,
 663 H.O. Danielsson³⁰, V. Dao¹⁰⁴, G. Darbo^{50a}, G.L. Darlea^{26b}, S. Darmora⁸, J.A. Dassoulas⁴², W. Davey²¹,
 664 T. Davidek¹²⁷, N. Davidson⁸⁶, E. Davies^{118,d}, M. Davies⁹³, O. Davignon⁷⁸, A.R. Davison⁷⁷,
 665 Y. Davygora^{58a}, E. Dawe¹⁴², I. Dawson¹³⁹, R.K. Daya-Ishmukhametova²³, K. De⁸, R. de Asmundis^{102a},
 666 S. De Castro^{20a,20b}, S. De Cecco⁷⁸, J. de Graat⁹⁸, N. De Groot¹⁰⁴, P. de Jong¹⁰⁵, C. De La Taille¹¹⁵,
 667 H. De la Torre⁸⁰, F. De Lorenzi⁶³, L. De Noij¹⁰⁵, D. De Pedis^{132a}, A. De Salvo^{132a}, U. De Sanctis^{164a,164c},
 668 A. De Santo¹⁴⁹, J.B. De Vivie De Regie¹¹⁵, G. De Zorzi^{132a,132b}, W.J. Dearnaley⁷¹, R. Debbe²⁵,
 669 C. Debenedetti⁴⁶, B. Dechenaux⁵⁵, D.V. Dedovich⁶⁴, J. Degenhardt¹²⁰, J. Del Peso⁸⁰,
 670 T. Del Prete^{122a,122b}, T. Delemontex⁵⁵, M. Deliyergiyev⁷⁴, A. Dell'Acqua³⁰, L. Dell'Asta²²,
 671 M. Della Pietra^{102a,i}, D. della Volpe^{102a,102b}, M. Delmastro⁵, P.A. Delsart⁵⁵, C. Deluca¹⁰⁵, S. Demers¹⁷⁶,

672 M. Demichev⁶⁴, A. Demilly⁷⁸, B. Demirkoz^{12,k}, S.P. Denisov¹²⁸, D. Derendarz³⁹, J.E. Derkaoui^{135d},
 673 F. Derue⁷⁸, P. Dervan⁷³, K. Desch²¹, P.O. Deviveiros¹⁰⁵, A. Dewhurst¹²⁹, B. DeWilde¹⁴⁸, S. Dhaliwal¹⁰⁵,
 674 R. Dhullipudi^{25,l}, A. Di Ciaccio^{133a,133b}, L. Di Ciaccio⁵, C. Di Donato^{102a,102b}, A. Di Girolamo³⁰,
 675 B. Di Girolamo³⁰, S. Di Luise^{134a,134b}, A. Di Mattia¹⁵², B. Di Micco^{134a,134b}, R. Di Nardo⁴⁷,
 676 A. Di Simone^{133a,133b}, R. Di Sipio^{20a,20b}, M.A. Diaz^{32a}, E.B. Diehl⁸⁷, J. Dietrich⁴², T.A. Dietzsch^{58a},
 677 S. Diglio⁸⁶, K. Dindar Yagci⁴⁰, J. Dingfelder²¹, F. Dinut^{26a}, C. Dionisi^{132a,132b}, P. Dita^{26a}, S. Dita^{26a},
 678 F. Dittus³⁰, F. Djama⁸³, T. Djobava^{51b}, M.A.B. do Vale^{24c}, A. Do Valle Wemans^{124a,m}, T.K.O. Doan⁵,
 679 D. Dobos³⁰, E. Dobson⁷⁷, J. Dodd³⁵, C. Doglioni⁴⁹, T. Doherty⁵³, T. Dohmae¹⁵⁵, Y. Doi^{65,*}, J. Dolejsi¹²⁷,
 680 Z. Dolezal¹²⁷, B.A. Dolgoshein^{96,*}, M. Donadelli^{24d}, J. Donini³⁴, J. Dopke³⁰, A. Doria^{102a},
 681 A. Dos Anjos¹⁷³, A. Dotti^{122a,122b}, M.T. Dova⁷⁰, A.T. Doyle⁵³, M. Dris¹⁰, J. Dubbert⁸⁷, S. Dube¹⁵,
 682 E. Dubreuil³⁴, E. Duchovni¹⁷², G. Duckeck⁹⁸, D. Duda¹⁷⁵, A. Dudarev³⁰, F. Dudziak⁶³, L. Dufлот¹¹⁵,
 683 M-A. Dufour⁸⁵, L. Duguid⁷⁶, M. Dührssen³⁰, M. Dunford^{58a}, H. Duran Yildiz^{4a}, M. Düren⁵²,
 684 R. Duxfield¹³⁹, M. Dwuznik^{38a}, W.L. Ebenstein⁴⁵, J. Ebke⁹⁸, S. Eckweiler⁸¹, W. Edson², C.A. Edwards⁷⁶,
 685 N.C. Edwards⁵³, W. Ehrenfeld²¹, T. Eifert¹⁴³, G. Eigen¹⁴, K. Einsweiler¹⁵, E. Eisenhandler⁷⁵, T. Ekelof¹⁶⁶,
 686 M. El Kacimi^{135c}, M. Ellert¹⁶⁶, S. Elles⁵, F. Ellinghaus⁸¹, K. Ellis⁷⁵, N. Ellis³⁰, J. Elmsheuser⁹⁸,
 687 M. Elsing³⁰, D. Emeliyanov¹²⁹, Y. Enari¹⁵⁵, O.C. Endner⁸¹, R. Engelmann¹⁴⁸, A. Engi⁹⁸, B. Epp⁶¹,
 688 J. Erdmann¹⁷⁶, A. Ereditato¹⁷, D. Eriksson^{146a}, J. Ernst², M. Ernst²⁵, J. Ernwein¹³⁶, D. Errede¹⁶⁵,
 689 S. Errede¹⁶⁵, E. Ertel⁸¹, M. Escalier¹¹⁵, H. Esch⁴³, C. Escobar¹²³, X. Espinal Curull¹², B. Esposito⁴⁷,
 690 F. Etienne⁸³, A.I. Etievre¹³⁶, E. Etzion¹⁵³, D. Evangelakou⁵⁴, H. Evans⁶⁰, L. Fabbri^{20a,20b}, C. Fabre³⁰,
 691 G. Facini³⁰, R.M. Fakhruddinov¹²⁸, S. Falciano^{132a}, Y. Fang^{33a}, M. Fanti^{89a,89b}, A. Farbin⁸, A. Farilla^{134a},
 692 T. Farooque¹⁵⁸, S. Farrell¹⁶³, S.M. Farrington¹⁷⁰, P. Farthouat³⁰, F. Fassi¹⁶⁷, P. Fassnacht³⁰,
 693 D. Fassouliotis⁹, B. Fatholahzadeh¹⁵⁸, A. Favareto^{89a,89b}, L. Fayard¹¹⁵, P. Federic^{144a}, O.L. Fedin¹²¹,
 694 W. Fedorko¹⁶⁸, M. Fehling-Kaschek⁴⁸, L. Felgioni⁸³, C. Feng^{33d}, E.J. Feng⁶, H. Feng⁸⁷, A.B. Fenyuk¹²⁸,
 695 J. Ferencei^{144b}, W. Fernando⁶, S. Ferrag⁵³, J. Ferrando⁵³, V. Ferrara⁴², A. Ferrari¹⁶⁶, P. Ferrari¹⁰⁵,
 696 R. Ferrari^{119a}, D.E. Ferreira de Lima⁵³, A. Ferrer¹⁶⁷, D. Ferrere⁴⁹, C. Ferretti⁸⁷, A. Ferretto Parodi^{50a,50b},
 697 M. Fiascaris³¹, F. Fiedler⁸¹, A. Filipčić⁷⁴, F. Filthaut¹⁰⁴, M. Fincke-Keeler¹⁶⁹, K.D. Finelli⁴⁵,
 698 M.C.N. Fiolhais^{124a,h}, L. Fiorini¹⁶⁷, A. Firan⁴⁰, J. Fischer¹⁷⁵, M.J. Fisher¹⁰⁹, E.A. Fitzgerald²³,
 699 M. Flechl⁴⁸, I. Fleck¹⁴¹, P. Fleischmann¹⁷⁴, S. Fleischmann¹⁷⁵, G.T. Fletcher¹³⁹, G. Fletcher⁷⁵,
 700 T. Flick¹⁷⁵, A. Floderus⁷⁹, L.R. Flores Castillo¹⁷³, A.C. Florez Bustos^{159b}, M.J. Flowerdew⁹⁹,
 701 T. Fonseca Martin¹⁷, A. Formica¹³⁶, A. Forti⁸², D. Fortin^{159a}, D. Fournier¹¹⁵, A.J. Fowler⁴⁵, H. Fox⁷¹,
 702 P. Francavilla¹², M. Franchini^{20a,20b}, S. Franchino³⁰, D. Francis³⁰, M. Franklin⁵⁷, S. Franz³⁰,
 703 M. Fraternali^{119a,119b}, S. Fratina¹²⁰, S.T. French²⁸, C. Friedrich⁴², F. Friedrich⁴⁴, D. Froidevaux³⁰,
 704 J.A. Frost²⁸, C. Fukunaga¹⁵⁶, E. Fullana Torregrosa¹²⁷, B.G. Fulsom¹⁴³, J. Fuster¹⁶⁷, C. Gabaldon³⁰,
 705 O. Gabizon¹⁷², A. Gabrielli^{132a,132b}, S. Gadatsch¹⁰⁵, T. Gadfort²⁵, S. Gadomski⁴⁹, G. Gagliardi^{50a,50b},
 706 P. Gagnon⁶⁰, C. Galea⁹⁸, B. Galhardo^{124a}, E.J. Gallas¹¹⁸, V. Gallo¹⁷, B.J. Gallop¹²⁹, P. Gallus¹²⁶,
 707 K.K. Gan¹⁰⁹, R.P. Gandrajula⁶², Y.S. Gao^{143,f}, A. Gaponenko¹⁵, F.M. Garay Walls⁴⁶, F. Garbersson¹⁷⁶,
 708 C. García¹⁶⁷, J.E. García Navarro¹⁶⁷, M. Garcia-Sciveres¹⁵, R.W. Gardner³¹, N. Garelli¹⁴³, V. Garonne³⁰,
 709 C. Gatti⁴⁷, G. Gaudio^{119a}, B. Gaur¹⁴¹, L. Gauthier⁹³, P. Gauzzi^{132a,132b}, I.L. Gavrilenko⁹⁴, C. Gay¹⁶⁸,
 710 G. Gaycken²¹, E.N. Gazis¹⁰, P. Ge^{33d,n}, Z. Gece¹⁶⁸, C.N.P. Gee¹²⁹, D.A.A. Geerts¹⁰⁵,
 711 Ch. Geich-Gimbel²¹, K. Gellerstedt^{146a,146b}, C. Gemme^{50a}, A. Gemmell⁵³, M.H. Genest⁵⁵,
 712 S. Gentile^{132a,132b}, M. George⁵⁴, S. George⁷⁶, D. Gerbaudo¹⁶³, P. Gerlach¹⁷⁵, A. Gershon¹⁵³,
 713 C. Geweniger^{58a}, H. Ghazlane^{135b}, N. Ghodbane³⁴, B. Giacobbe^{20a}, S. Giagu^{132a,132b}, V. Giangiobbe¹²,
 714 F. Gianotti³⁰, B. Gibbard²⁵, A. Gibson¹⁵⁸, S.M. Gibson³⁰, M. Gilchriese¹⁵, T.P.S. Gillam²⁸, D. Gillberg³⁰,
 715 A.R. Gillman¹²⁹, D.M. Gingrich^{3,e}, N. Giokaris⁹, M.P. Giordani^{164c}, R. Giordano^{102a,102b}, F.M. Giorgi¹⁶,
 716 P. Giovannini⁹⁹, P.F. Giraud¹³⁶, D. Giugni^{89a}, C. Giuliani⁴⁸, M. Giunta⁹³, B.K. Gjelsten¹¹⁷,
 717 I. Gkialas^{154,o}, L.K. Gladilin⁹⁷, C. Glasman⁸⁰, J. Glatzer²¹, A. Glazov⁴², G.L. Glonti⁶⁴, J.R. Goddard⁷⁵,
 718 J. Godfrey¹⁴², J. Godlewski³⁰, M. Goebel⁴², C. Goeringer⁸¹, S. Goldfarb⁸⁷, T. Golling¹⁷⁶, D. Golubkov¹²⁸,
 719 A. Gomes^{124a,c}, L.S. Gomez Fajardo⁴², R. Gonçalo⁷⁶, J. Goncalves Pinto Firmino Da Costa⁴²,
 720 L. Gonella²¹, S. González de la Hoz¹⁶⁷, G. Gonzalez Parra¹², M.L. Gonzalez Silva²⁷, S. Gonzalez-Sevilla⁴⁹,
 721 J.J. Goodson¹⁴⁸, L. Goossens³⁰, P.A. Gorbounov⁹⁵, H.A. Gordon²⁵, I. Gorelov¹⁰³, G. Gorfine¹⁷⁵,
 722 B. Gorini³⁰, E. Gorini^{72a,72b}, A. Gorišek⁷⁴, E. Gornicki³⁹, A.T. Goshaw⁶, C. Gössling⁴³, M.I. Gostkin⁶⁴,
 723 I. Gough Eschrich¹⁶³, M. Goughri^{135a}, D. Goujdami^{135c}, M.P. Goulette⁴⁹, A.G. Goussiou¹³⁸, C. Goy⁵,

724 S. Gozpinar²³, L. Graber⁵⁴, I. Grabowska-Bold^{38a}, P. Grafström^{20a,20b}, K.-J. Grahn⁴², E. Gramstad¹¹⁷,
 725 F. Grancagnolo^{72a}, S. Grancagnolo¹⁶, V. Grassi¹⁴⁸, V. Gratchev¹²¹, H.M. Gray³⁰, J.A. Gray¹⁴⁸,
 726 E. Graziani^{134a}, O.G. Grebenyuk¹²¹, T. Greenshaw⁷³, Z.D. Greenwood^{25,l}, K. Gregersen³⁶, I.M. Gregor⁴²,
 727 P. Grenier¹⁴³, J. Griffiths⁸, N. Grigalashvili⁶⁴, A.A. Grillo¹³⁷, K. Grimm⁷¹, S. Grinstein¹², Ph. Gris³⁴,
 728 Y.V. Grishkevich⁹⁷, J.-F. Grivaz¹¹⁵, J.P. Grohs⁴⁴, A. Grohsjean⁴², E. Gross¹⁷², J. Grosse-Knetter⁵⁴,
 729 J. Groth-Jensen¹⁷², K. Grybel¹⁴¹, D. Guest¹⁷⁶, O. Gueta¹⁵³, C. Guicheney³⁴, E. Guido^{50a,50b},
 730 T. Guillemin¹¹⁵, S. Guindon², U. Gul⁵³, J. Gunther¹²⁶, B. Guo¹⁵⁸, J. Guo³⁵, P. Gutierrez¹¹¹,
 731 N. Guttman¹⁵³, O. Gutzwiller¹⁷³, C. Guyot¹³⁶, C. Gwenlan¹¹⁸, C.B. Gwilliam⁷³, A. Haas¹⁰⁸, S. Haas³⁰,
 732 C. Haber¹⁵, H.K. Hadavand⁸, P. Haefner²¹, Z. Hajduk³⁹, H. Hakobyan¹⁷⁷, D. Hall¹¹⁸, G. Halladjian⁶²,
 733 K. Hamacher¹⁷⁵, P. Hamal¹¹³, K. Hamano⁸⁶, M. Hamer⁵⁴, A. Hamilton^{145b,p}, S. Hamilton¹⁶¹, L. Han^{33b},
 734 K. Hanagaki¹¹⁶, K. Hanawa¹⁶⁰, M. Hance¹⁵, C. Handel⁸¹, P. Hanke^{58a}, J.R. Hansen³⁶, J.B. Hansen³⁶,
 735 J.D. Hansen³⁶, P.H. Hansen³⁶, P. Hansson¹⁴³, K. Hara¹⁶⁰, A.S. Hard¹⁷³, T. Harenberg¹⁷⁵, S. Harkusha⁹⁰,
 736 D. Harper⁸⁷, R.D. Harrington⁴⁶, O.M. Harris¹³⁸, J. Hartert⁴⁸, F. Hartjes¹⁰⁵, T. Haruyama⁶⁵, A. Harvey⁵⁶,
 737 S. Hasegawa¹⁰¹, Y. Hasegawa¹⁴⁰, S. Hassani¹³⁶, S. Haug¹⁷, M. Hauschild³⁰, R. Hauser⁸⁸, M. Havranek²¹,
 738 C.M. Hawkes¹⁸, R.J. Hawkings³⁰, A.D. Hawkins⁷⁹, T. Hayakawa⁶⁶, T. Hayashi¹⁶⁰, D. Hayden⁷⁶,
 739 C.P. Hays¹¹⁸, H.S. Hayward⁷³, S.J. Haywood¹²⁹, S.J. Head¹⁸, T. Heck⁸¹, V. Hedberg⁷⁹, L. Heelan⁸,
 740 S. Heim¹²⁰, B. Heinemann¹⁵, S. Heisterkamp³⁶, L. Helary²², C. Heller⁹⁸, M. Heller³⁰, S. Hellman^{146a,146b},
 741 D. Hellmich²¹, C. Helsen¹², J. Henderson¹¹⁸, R.C.W. Henderson⁷¹, M. Henke^{58a}, A. Henrichs¹⁷⁶,
 742 A.M. Henriques Correia³⁰, S. Henrot-Versille¹¹⁵, C. Hensel⁵⁴, G.H. Herbert¹⁶, C.M. Hernandez⁸,
 743 Y. Hernández Jiménez¹⁶⁷, R. Herrberg¹⁶, G. Herten⁴⁸, R. Hertenberger⁹⁸, L. Hervas³⁰, G.G. Hesketh⁷⁷,
 744 N.P. Hesse¹⁰⁵, R. Hickling⁷⁵, E. Higón-Rodríguez¹⁶⁷, J.C. Hill²⁸, K.H. Hiller⁴², S. Hillert²¹, S.J. Hillier¹⁸,
 745 I. Hinchliffe¹⁵, E. Hines¹²⁰, M. Hirose¹¹⁶, D. Hirschbuehl¹⁷⁵, J. Hobbs¹⁴⁸, N. Hod¹⁰⁵, M.C. Hodgkinson¹³⁹,
 746 P. Hodgson¹³⁹, A. Hoecker³⁰, M.R. Hoefkamp¹⁰³, J. Hoffman⁴⁰, D. Hoffmann⁸³, J.I. Hofmann^{58a},
 747 M. Hohlfeld⁸¹, S.O. Holmgren^{146a}, J.L. Holzbauer⁸⁸, T.M. Hong¹²⁰, L. Hooft van Huysduynden¹⁰⁸,
 748 J.-Y. Hostachy⁵⁵, S. Hou¹⁵¹, A. Houmada^{135a}, J. Howard¹¹⁸, J. Howarth⁸², M. Hrabovsky¹¹³,
 749 I. Hristova¹⁶, J. Hrivnac¹¹⁵, T. Hryn'ova⁵, P.J. Hsu⁸¹, S.-C. Hsu¹³⁸, D. Hu³⁵, Z. Hubacek³⁰, F. Hubaut⁸³,
 750 F. Huegging²¹, A. Huettmann⁴², T.B. Huffman¹¹⁸, E.W. Hughes³⁵, G. Hughes⁷¹, M. Huhtinen³⁰,
 751 T.A. Hülsing⁸¹, M. Hurwitz¹⁵, N. Huseynov^{64,q}, J. Huston⁸⁸, J. Huth⁵⁷, G. Iacobucci⁴⁹, G. Iakovidis¹⁰,
 752 I. Ibragimov¹⁴¹, L. Iconomidou-Fayard¹¹⁵, J. Idarraga¹¹⁵, P. Iengo^{102a}, O. Igonkina¹⁰⁵, Y. Ikegami⁶⁵,
 753 K. Ikematsu¹⁴¹, M. Ikeno⁶⁵, D. Iliadis¹⁵⁴, N. Ilic¹⁵⁸, T. Ince⁹⁹, P. Ioannou⁹, M. Iodice^{134a}, K. Iordanidou⁹,
 754 V. Ippolito^{132a,132b}, A. Irles Quiles¹⁶⁷, C. Isaksson¹⁶⁶, M. Ishino⁶⁷, M. Ishitsuka¹⁵⁷, R. Ishmukhametov¹⁰⁹,
 755 C. Issever¹¹⁸, S. Istin^{19a}, A.V. Ivashin¹²⁸, W. Iwanski³⁹, H. Iwasaki⁶⁵, J.M. Izen⁴¹, V. Izzo^{102a},
 756 B. Jackson¹²⁰, J.N. Jackson⁷³, P. Jackson¹, M.R. Jaekel³⁰, V. Jain², K. Jakobs⁴⁸, S. Jakobsen³⁶,
 757 T. Jakoubek¹²⁵, J. Jakubek¹²⁶, D.O. Jamin¹⁵¹, D.K. Jana¹¹¹, E. Jansen⁷⁷, H. Jansen³⁰, J. Janssen²¹,
 758 A. Jantsch⁹⁹, M. Janus⁴⁸, R.C. Jared¹⁷³, G. Jarlskog⁷⁹, L. Jeanty⁵⁷, G.-Y. Jeng¹⁵⁰, I. Jen-La Plante³¹,
 759 D. Jennens⁸⁶, P. Jenni³⁰, C. Jeske¹⁷⁰, P. Jež³⁶, S. Jézéquel⁵, M.K. Jha^{20a}, H. Ji¹⁷³, W. Ji⁸¹, J. Jia¹⁴⁸,
 760 Y. Jiang^{33b}, M. Jimenez Belenguer⁴², S. Jin^{33a}, O. Jinnouchi¹⁵⁷, M.D. Joergensen³⁶, D. Joffe⁴⁰,
 761 M. Johansen^{146a,146b}, K.E. Johansson^{146a}, P. Johansson¹³⁹, S. Johnert⁴², K.A. Johns⁷,
 762 K. Jon-And^{146a,146b}, G. Jones¹⁷⁰, R.W.L. Jones⁷¹, T.J. Jones⁷³, C. Joram³⁰, P.M. Jorge^{124a}, K.D. Joshi⁸²,
 763 J. Jovicevic¹⁴⁷, T. Jovin^{13b}, X. Ju¹⁷³, C.A. Jung⁴³, R.M. Jungst³⁰, P. Jussel⁶¹, A. Juste Rozas¹²,
 764 S. Kabana¹⁷, M. Kaci¹⁶⁷, A. Kaczmarzka³⁹, P. Kadlecik³⁶, M. Kado¹¹⁵, H. Kagan¹⁰⁹, M. Kagan⁵⁷,
 765 E. Kajomovitz¹⁵², S. Kalinin¹⁷⁵, S. Kama⁴⁰, N. Kanaya¹⁵⁵, M. Kaneda³⁰, S. Kaneti²⁸, T. Kanno¹⁵⁷,
 766 V.A. Kantserov⁹⁶, J. Kanzaki⁶⁵, B. Kaplan¹⁰⁸, A. Kapliy³¹, D. Kar⁵³, K. Karakostas¹⁰, M. Karnevskiy⁸¹,
 767 V. Kartvelishvili⁷¹, A.N. Karyukhin¹²⁸, L. Kashif¹⁷³, G. Kasieczka^{58b}, R.D. Kass¹⁰⁹, A. Kastanas¹⁴,
 768 Y. Kataoka¹⁵⁵, J. Katzy⁴², V. Kaushik⁷, K. Kawagoe⁶⁹, T. Kawamoto¹⁵⁵, G. Kawamura⁵⁴, S. Kazama¹⁵⁵,
 769 V.F. Kazanin¹⁰⁷, M.Y. Kazarinov⁶⁴, R. Keeler¹⁶⁹, P.T. Keener¹²⁰, R. Kehoe⁴⁰, M. Keil⁵⁴, J.S. Keller¹³⁸,
 770 H. Keoshkerian⁵, O. Kepka¹²⁵, B.P. Kerševan⁷⁴, S. Kersten¹⁷⁵, K. Kessoku¹⁵⁵, J. Keung¹⁵⁸,
 771 F. Khalil-zada¹¹, H. Khandanyan^{146a,146b}, A. Khanov¹¹², D. Kharchenko⁶⁴, A. Khodinov⁹⁶,
 772 A. Khomich^{58a}, T.J. Khoo²⁸, G. Khoriauli²¹, A. Khoroshilov¹⁷⁵, V. Khovanskiy⁹⁵, E. Khramov⁶⁴,
 773 J. Khubua^{51b}, H. Kim^{146a,146b}, S.H. Kim¹⁶⁰, N. Kimura¹⁷¹, O. Kind¹⁶, B.T. King⁷³, M. King⁶⁶,
 774 R.S.B. King¹¹⁸, S.B. King¹⁶⁸, J. Kirk¹²⁹, A.E. Kiryunin⁹⁹, T. Kishimoto⁶⁶, D. Kisielewska^{38a},
 775 T. Kitamura⁶⁶, T. Kittelmann¹²³, K. Kiuchi¹⁶⁰, E. Kladiva^{144b}, M. Klein⁷³, U. Klein⁷³, K. Kleinknecht⁸¹,

776 M. Klemetti⁸⁵, A. Klier¹⁷², P. Klimek^{146a,146b}, A. Klimentov²⁵, R. Klingenberg⁴³, J.A. Klinger⁸²,
777 E.B. Klinkby³⁶, T. Klioutchnikova³⁰, P.F. Klok¹⁰⁴, E.-E. Kluge^{58a}, P. Kluit¹⁰⁵, S. Kluth⁹⁹, E. Kneringer⁶¹,
778 E.B.F.G. Knoop⁸³, A. Knue⁵⁴, B.R. Ko⁴⁵, T. Kobayashi¹⁵⁵, M. Kobel⁴⁴, M. Kocian¹⁴³, P. Kodys¹²⁷,
779 S. Koenig⁸¹, F. Koetsveld¹⁰⁴, P. Koevesarki²¹, T. Koffas²⁹, E. Koffeman¹⁰⁵, L.A. Kogan¹¹⁸,
780 S. Kohlmann¹⁷⁵, F. Kohn⁵⁴, Z. Kohout¹²⁶, T. Kohriki⁶⁵, T. Koi¹⁴³, H. Kolanoski¹⁶, I. Koletsou^{89a},
781 J. Koll⁸⁸, A.A. Komar⁹⁴, Y. Komori¹⁵⁵, T. Kondo⁶⁵, K. Kōneke³⁰, A.C. König¹⁰⁴, T. Kono^{42,r},
782 A.I. Kononov⁴⁸, R. Konoplich^{108,s}, N. Konstantinidis⁷⁷, R. Kopeliānsky¹⁵², S. Koperny^{38a}, L. Köpke⁸¹,
783 A.K. Kopp⁴⁸, K. Korcyl³⁹, K. Kordas¹⁵⁴, A. Korn⁴⁶, A. Korol¹⁰⁷, I. Korolkov¹², E.V. Korolkova¹³⁹,
784 V.A. Korotkov¹²⁸, O. Kortner⁹⁹, S. Kortner⁹⁹, V.V. Kostyukhin²¹, S. Kotov⁹⁹, V.M. Kotov⁶⁴,
785 A. Kotwal⁴⁵, C. Kourkoumelis⁹, V. Kouskoura¹⁵⁴, A. Koutsman^{159a}, R. Kowalewski¹⁶⁹, T.Z. Kowalski^{38a},
786 W. Kozanecki¹³⁶, A.S. Kozhin¹²⁸, V. Kral¹²⁶, V.A. Kramarenko⁹⁷, G. Kramberger⁷⁴, M.W. Krasny⁷⁸,
787 A. Krasznahorkay¹⁰⁸, J.K. Kraus²¹, A. Kravchenko²⁵, S. Kreiss¹⁰⁸, J. Kretschmar⁷³, K. Kreutzfeldt⁵²,
788 N. Krieger⁵⁴, P. Krieger¹⁵⁸, K. Kroeninger⁵⁴, H. Kroha⁹⁹, J. Kroll¹²⁰, J. Kroseberg²¹, J. Krstić^{13a},
789 U. Kruchonak⁶⁴, H. Krüger²¹, T. Kruker¹⁷, N. Krumnack⁶³, Z.V. Krumshteyn⁶⁴, A. Kruse¹⁷³,
790 M.K. Kruse⁴⁵, T. Kubota⁸⁶, S. Kудay^{4a}, S. Kuehn⁴⁸, A. Kugel^{58c}, T. Kuhl⁴², V. Kukhtin⁶⁴,
791 Y. Kulchitsky⁹⁰, S. Kuleshov^{32b}, M. Kuna⁷⁸, J. Kunkle¹²⁰, A. Kupco¹²⁵, H. Kurashige⁶⁶, M. Kurata¹⁶⁰,
792 Y.A. Kurochkin⁹⁰, V. Kus¹²⁵, E.S. Kuwertz¹⁴⁷, M. Kuze¹⁵⁷, J. Kvita¹⁴², R. Kwee¹⁶, A. La Rosa⁴⁹,
793 L. La Rotonda^{37a,37b}, L. Labarga⁸⁰, S. Lablak^{135a}, C. Lacasta¹⁶⁷, F. Lacava^{132a,132b}, J. Lacey²⁹,
794 H. Lacker¹⁶, D. Lacour⁷⁸, V.R. Lacuesta¹⁶⁷, E. Ladygin⁶⁴, R. Lafaye⁵, B. Laforge⁷⁸, T. Lagouri¹⁷⁶,
795 S. Lai⁴⁸, H. Laier^{58a}, E. Laisne⁵⁵, L. Lambourne⁷⁷, C.L. Lampen⁷, W. Lampl⁷, E. Lançon¹³⁶,
796 U. Landgraf⁴⁸, M.P.J. Landon⁷⁵, V.S. Lang^{58a}, C. Lange⁴², A.J. Lankford¹⁶³, F. Lanni²⁵, K. Lantzscht³⁰,
797 A. Lanza^{119a}, S. Laplace⁷⁸, C. Lapoire²¹, J.F. Laporte¹³⁶, T. Lari^{89a}, A. Larner¹¹⁸, M. Lassnig³⁰,
798 P. Laurelli⁴⁷, V. Lavorini^{37a,37b}, W. Lavrijsen¹⁵, P. Laycock⁷³, O. Le Dortz⁷⁸, E. Le Guirriec⁸³,
799 E. Le Menedeu¹², T. LeCompte⁶, F. Ledroit-Guillon⁵⁵, H. Lee¹⁰⁵, J.S.H. Lee¹¹⁶, S.C. Lee¹⁵¹, L. Lee¹⁷⁶,
800 M. Lefebvre¹⁶⁹, M. Legendre¹³⁶, F. Legger⁹⁸, C. Leggett¹⁵, M. Lehmacher²¹, G. Lehmann Miotto³⁰,
801 A.G. Leister¹⁷⁶, M.A.L. Leite^{24d}, R. Leitner¹²⁷, D. Lellouch¹⁷², B. Lemmer⁵⁴, V. Lendermann^{58a},
802 K.J.C. Leney^{145b}, T. Lenz¹⁰⁵, G. Lenzen¹⁷⁵, B. Lenzi³⁰, K. Leonhardt⁴⁴, S. Leontsinis¹⁰, F. Lepold^{58a},
803 C. Leroy⁹³, J.-R. Lessard¹⁶⁹, C.G. Lester²⁸, C.M. Lester¹²⁰, J. Levêque⁵, D. Levin⁸⁷, L.J. Levinson¹⁷²,
804 A. Lewis¹¹⁸, G.H. Lewis¹⁰⁸, A.M. Leyko²¹, M. Leyton¹⁶, B. Li^{33b}, B. Li⁸³, H. Li¹⁴⁸, H.L. Li³¹, S. Li^{33b,t},
805 X. Li⁸⁷, Z. Liang^{118,u}, H. Liao³⁴, B. Liberti^{133a}, P. Lichard³⁰, K. Lie¹⁶⁵, J. Liebal²¹, W. Liebig¹⁴,
806 C. Limbach²¹, A. Limosani⁸⁶, M. Limper⁶², S.C. Lin^{151,v}, F. Linde¹⁰⁵, B.E. Lindquist¹⁴⁸,
807 J.T. Linnemann⁸⁸, E. Lipeles¹²⁰, A. Lipniacka¹⁴, M. Lisovsky⁴², T.M. Liss¹⁶⁵, D. Lissauer²⁵, A. Lister¹⁶⁸,
808 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},
809 S.S.A. Livermore¹¹⁸, A. Lleres⁵⁵, J. Llorente Merino⁸⁰, S.L. Lloyd⁷⁵, F. Lo Sterzo^{132a,132b},
810 E. Lobodzinska⁴², P. Loch⁷, W.S. Lockman¹³⁷, T. Loddenkoetter²¹, F.K. Loebinger⁸²,
811 A.E. Loevschall-Jensen³⁶, A. Loginov¹⁷⁶, C.W. Loh¹⁶⁸, T. Lohse¹⁶, K. Lohwasser⁴⁸, M. Lokajicek¹²⁵,
812 V.P. Lombardo⁵, R.E. Long⁷¹, L. Lopes^{124a}, D. Lopez Mateos⁵⁷, J. Lorenz⁹⁸, N. Lorenzo Martinez¹¹⁵,
813 M. Losada¹⁶², P. Loscutoff¹⁵, M.J. Losty^{159a,*}, X. Lou⁴¹, A. Lounis¹¹⁵, K.F. Loureiro¹⁶², J. Love⁶,
814 P.A. Love⁷¹, A.J. Lowe^{143,f}, F. Lu^{33a}, H.J. Lubatti¹³⁸, C. Luci^{132a,132b}, A. Lucotte⁵⁵, D. Ludwig⁴²,
815 I. Ludwig⁴⁸, J. Ludwig⁴⁸, F. Luehring⁶⁰, W. Lukas⁶¹, L. Luminari^{132a}, E. Lund¹¹⁷, B. Lundberg⁷⁹,
816 J. Lundberg^{146a,146b}, O. Lundberg^{146a,146b}, B. Lund-Jensen¹⁴⁷, J. Lundquist³⁶, M. Lungwitz⁸¹, D. Lynn²⁵,
817 R. Lysak¹²⁵, E. Lytken⁷⁹, H. Ma²⁵, L.L. Ma¹⁷³, G. Maccarrone⁴⁷, A. Macchiolo⁹⁹, B. Maček⁷⁴,
818 J. Machado Miguens^{124a}, D. Macina³⁰, R. Mackeprang³⁶, R. Madar⁴⁸, R.J. Madaras¹⁵, H.J. Maddocks⁷¹,
819 W.F. Mader⁴⁴, A. Madsen¹⁶⁶, M. Maeno⁵, T. Maeno²⁵, L. Magnoni¹⁶³, E. Magradze⁵⁴, K. Mahboubi⁴⁸,
820 J. Mahlstedt¹⁰⁵, S. Mahmoud⁷³, G. Mahout¹⁸, C. Maiani¹³⁶, C. Maidantchik^{24a}, A. Maio^{124a,c},
821 S. Majewski²⁵, Y. Makida⁶⁵, N. Makovec¹¹⁵, P. Mal^{136,x}, B. Malaescu⁷⁸, Pa. Malecki³⁹, P. Malecki³⁹,
822 V.P. Maleev¹²¹, F. Malek⁵⁵, U. Mallik⁶², D. Malon⁶, C. Malone¹⁴³, S. Maltezos¹⁰, V. Malyshev¹⁰⁷,
823 S. Malyukov³⁰, J. Mamuzic^{13b}, L. Mandelli^{89a}, I. Mandić⁷⁴, R. Mandrysch⁶², J. Maneira^{124a},
824 A. Manfredini⁹⁹, L. Manhaes de Andrade Filho^{24b}, J.A. Manjarres Ramos¹³⁶, A. Mann⁹⁸,
825 P.M. Manning¹³⁷, A. Manousakis-Katsikakis⁹, B. Mansoulie¹³⁶, R. Mantifel⁸⁵, L. Mapelli³⁰, L. March¹⁶⁷,
826 J.F. Marchand²⁹, F. Marchese^{133a,133b}, G. Marchiori⁷⁸, M. Marcisovsky¹²⁵, C.P. Marino¹⁶⁹,
827 F. Marroquim^{24a}, Z. Marshall¹²⁰, L.F. Marti¹⁷, S. Marti-Garcia¹⁶⁷, B. Martin³⁰, B. Martin⁸⁸,

828 J.P. Martin⁹³, T.A. Martin¹⁷⁰, V.J. Martin⁴⁶, B. Martin dit Latour⁴⁹, H. Martinez¹³⁶, M. Martinez¹²,
 829 S. Martin-Haugh¹⁴⁹, A.C. Martyniuk¹⁶⁹, M. Marx⁸², F. Marzano^{132a}, A. Marzin¹¹¹, L. Masetti⁸¹,
 830 T. Mashimo¹⁵⁵, R. Mashinistov⁹⁴, J. Masik⁸², A.L. Maslennikov¹⁰⁷, I. Massa^{20a,20b}, N. Massol⁵,
 831 P. Mastrandrea¹⁴⁸, A. Mastroberardino^{37a,37b}, T. Masubuchi¹⁵⁵, H. Matsunaga¹⁵⁵, T. Matsushita⁶⁶,
 832 P. Mättig¹⁷⁵, S. Mättig⁴², C. Mattravers^{118,d}, J. Maurer⁸³, S.J. Maxfield⁷³, D.A. Maximov^{107,g},
 833 R. Mazini¹⁵¹, M. Mazur²¹, L. Mazzaferro^{133a,133b}, M. Mazzanti^{89a}, S.P. Mc Kee⁸⁷, A. McCarn¹⁶⁵,
 834 R.L. McCarthy¹⁴⁸, T.G. McCarthy²⁹, N.A. McCubbin¹²⁹, K.W. McFarlane^{56,*}, J.A. Mcfayden¹³⁹,
 835 G. Mchedlidze^{51b}, T. Mclaughlan¹⁸, S.J. McMahon¹²⁹, R.A. McPherson^{169,j}, A. Meade⁸⁴, J. Mechnich¹⁰⁵,
 836 M. Mechtel¹⁷⁵, M. Medinnis⁴², S. Meehan³¹, R. Meera-Lebbai¹¹¹, T. Meguro¹¹⁶, S. Mehlhase³⁶,
 837 A. Mehta⁷³, K. Meier^{58a}, C. Meineck⁹⁸, B. Meirose⁷⁹, C. Melachrinou³¹, B.R. Mellado Garcia¹⁷³,
 838 F. Meloni^{89a,89b}, L. Mendoza Navas¹⁶², A. Mengarelli^{20a,20b}, S. Menke⁹⁹, E. Meoni¹⁶¹, K.M. Mercurio⁵⁷,
 839 N. Meric¹³⁶, P. Mermod⁴⁹, L. Merola^{102a,102b}, C. Meroni^{89a}, F.S. Merritt³¹, H. Merritt¹⁰⁹, A. Messina^{30,y},
 840 J. Metcalfe²⁵, A.S. Mete¹⁶³, C. Meyer⁸¹, C. Meyer³¹, J-P. Meyer¹³⁶, J. Meyer³⁰, J. Meyer⁵⁴, S. Michal³⁰,
 841 R.P. Middleton¹²⁹, S. Migas⁷³, L. Mijović¹³⁶, G. Mikenberg¹⁷², M. Mikestikova¹²⁵, M. Mikuz⁷⁴,
 842 D.W. Miller³¹, W.J. Mills¹⁶⁸, C. Mills⁵⁷, A. Milov¹⁷², D.A. Milstead^{146a,146b}, D. Milstein¹⁷²,
 843 A.A. Minaenko¹²⁸, M. Miñano Moya¹⁶⁷, I.A. Minashvili⁶⁴, A.I. Mincer¹⁰⁸, B. Mindur^{38a}, M. Mineev⁶⁴,
 844 Y. Ming¹⁷³, L.M. Mir¹², G. Mirabelli^{132a}, J. Mitrevski¹³⁷, V.A. Mitsou¹⁶⁷, S. Mitsui⁶⁵, P.S. Miyagawa¹³⁹,
 845 J.U. Mjörnmark⁷⁹, T. Moa^{146a,146b}, V. Moeller²⁸, S. Mohapatra¹⁴⁸, W. Mohr⁴⁸, R. Moles-Valls¹⁶⁷,
 846 A. Molfetas³⁰, K. Mönig⁴², C. Monini⁵⁵, J. Monk³⁶, E. Monnier⁸³, J. Montejo Berlingen¹², F. Monticelli⁷⁰,
 847 S. Monzani^{20a,20b}, R.W. Moore³, C. Mora Herrera⁴⁹, A. Moraes⁵³, N. Morange⁶², J. Morel⁵⁴, D. Moreno⁸¹,
 848 M. Moreno Llácer¹⁶⁷, P. Morettini^{50a}, M. Morgenstern⁴⁴, M. Morii⁵⁷, S. Moritz⁸¹, A.K. Morley³⁰,
 849 G. Mornacchi³⁰, J.D. Morris⁷⁵, L. Morvaj¹⁰¹, N. Möser²¹, H.G. Moser⁹⁹, M. Mosidze^{51b}, J. Moss¹⁰⁹,
 850 R. Mount¹⁴³, E. Mountricha^{10,z}, S.V. Mouraviev^{94,*}, E.J.W. Moyse⁸⁴, R.D. Mudd¹⁸, F. Mueller^{58a},
 851 J. Mueller¹²³, K. Mueller²¹, T. Mueller²⁸, T. Mueller⁸¹, D. Muenstermann³⁰, Y. Munwes¹⁵³,
 852 J.A. Murillo Quijada¹⁸, W.J. Murray¹²⁹, I. Mussche¹⁰⁵, E. Musto¹⁵², A.G. Myagkov¹²⁸, M. Myska¹²⁵,
 853 O. Nackenhorst⁵⁴, J. Nadal¹², K. Nagai¹⁶⁰, R. Nagai¹⁵⁷, Y. Nagai⁸³, K. Nagano⁶⁵, A. Nagarkar¹⁰⁹,
 854 Y. Nagasaka⁵⁹, M. Nagel⁹⁹, A.M. Nairz³⁰, Y. Nakahama³⁰, K. Nakamura⁶⁵, T. Nakamura¹⁵⁵, I. Nakano¹¹⁰,
 855 H. Namasiyayam⁴¹, G. Nanava²¹, A. Napier¹⁶¹, R. Narayan^{58b}, M. Nash^{77,d}, T. Nattermann²¹,
 856 T. Naumann⁴², G. Navarro¹⁶², H.A. Neal⁸⁷, P.Yu. Nechaeva⁹⁴, T.J. Neep⁸², A. Negri^{119a,119b}, G. Negri³⁰,
 857 M. Negrini^{20a}, S. Nektarijevic⁴⁹, A. Nelson¹⁶³, T.K. Nelson¹⁴³, S. Nemecek¹²⁵, P. Nemethy¹⁰⁸,
 858 A.A. Nepomuceno^{24a}, M. Nessi^{30,aa}, M.S. Neubauer¹⁶⁵, M. Neumann¹⁷⁵, A. Neusiedl⁸¹, R.M. Neves¹⁰⁸,
 859 P. Nevski²⁵, F.M. Newcomer¹²⁰, P.R. Newman¹⁸, D.H. Nguyen⁶, V. Nguyen Thi Hong¹³⁶,
 860 R.B. Nickerson¹¹⁸, R. Nicolaidou¹³⁶, B. Nicquevert³⁰, F. Niedercorn¹¹⁵, J. Nielsen¹³⁷, N. Nikiforou³⁵,
 861 A. Nikiforov¹⁶, V. Nikolaenko¹²⁸, I. Nikolic-Audit⁷⁸, K. Nikolics⁴⁹, K. Nikolopoulos¹⁸, P. Nilsson⁸,
 862 Y. Ninomiya¹⁵⁵, A. Nisati^{132a}, R. Nisius⁹⁹, T. Nobe¹⁵⁷, L. Nodulman⁶, M. Nomachi¹¹⁶, I. Nomidis¹⁵⁴,
 863 S. Norberg¹¹¹, M. Nordberg³⁰, J. Novakova¹²⁷, M. Nozaki⁶⁵, L. Nozka¹¹³, A.-E. Nuncio-Quiroz²¹,
 864 G. Nunes Hanninger⁸⁶, T. Nunnemann⁹⁸, E. Nurse⁷⁷, B.J. O'Brien⁴⁶, D.C. O'Neil¹⁴², V. O'Shea⁵³,
 865 L.B. Oakes⁹⁸, F.G. Oakham^{29,e}, H. Oberlack⁹⁹, J. Ocariz⁷⁸, A. Ochi⁶⁶, M.I. Ochoa⁷⁷, S. Oda⁶⁹,
 866 S. Odaka⁶⁵, J. Odier⁸³, H. Ogren⁶⁰, A. Oh⁸², S.H. Oh⁴⁵, C.C. Ohm³⁰, T. Ohshima¹⁰¹, W. Okamura¹¹⁶,
 867 H. Okawa²⁵, Y. Okumura³¹, T. Okuyama¹⁵⁵, A. Olariu^{26a}, A.G. Olchevski⁶⁴, S.A. Olivares Pino⁴⁶,
 868 M. Oliveira^{124a,h}, D. Oliveira Damazio²⁵, E. Oliver Garcia¹⁶⁷, D. Olivito¹²⁰, A. Olszewski³⁹,
 869 J. Olszowska³⁹, A. Onofre^{124a,ab}, P.U.E. Onyisi^{31,ac}, C.J. Oram^{159a}, M.J. Oreglia³¹, Y. Oren¹⁵³,
 870 D. Orestano^{134a,134b}, N. Orlando^{72a,72b}, C. Oropeza Barrera⁵³, R.S. Orr¹⁵⁸, B. Osculati^{50a,50b},
 871 R. Ospanov¹²⁰, C. Osuna¹², G. Otero y Garzon²⁷, J.P. Ottersbach¹⁰⁵, M. Ouchrif^{135d}, E.A. Ouellette¹⁶⁹,
 872 F. Ould-Saada¹¹⁷, A. Ouraou¹³⁶, Q. Ouyang^{33a}, A. Ovcharova¹⁵, M. Owen⁸², S. Owen¹³⁹, V.E. Ozcan^{19a},
 873 N. Ozturk⁸, A. Pacheco Pages¹², C. Padilla Aranda¹², S. Pagan Griso¹⁵, E. Paganis¹³⁹, C. Pahl⁹⁹,
 874 F. Paige²⁵, P. Pais⁸⁴, K. Pajchel¹¹⁷, G. Palacino^{159b}, C.P. Paleari⁷, S. Palestini³⁰, D. Pallin³⁴,
 875 A. Palma^{124a}, J.D. Palmer¹⁸, Y.B. Pan¹⁷³, E. Panagiotopoulou¹⁰, J.G. Panduro Vazquez⁷⁶, P. Pani¹⁰⁵,
 876 N. Panikashvili⁸⁷, S. Panitkin²⁵, D. Pantea^{26a}, A. Papadelis^{146a}, Th.D. Papadopoulou¹⁰,
 877 K. Papageorgiou^{154,o}, A. Paramonov⁶, D. Paredes Hernandez³⁴, W. Park^{25,ad}, M.A. Parker²⁸,
 878 F. Parodi^{50a,50b}, J.A. Parsons³⁵, U. Parzefall⁴⁸, S. Pashapour⁵⁴, E. Pasqualucci^{132a}, S. Passaggio^{50a},
 879 A. Passeri^{134a}, F. Pastore^{134a,134b,*}, Fr. Pastore⁷⁶, G. Pásztor^{49,ae}, S. Patariaia¹⁷⁵, N.D. Patel¹⁵⁰,

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 882 J. Penwell⁶⁰, T. Perez Cavalcanti⁴², E. Perez Codina^{159a}, M.T. Pérez García-Estañ¹⁶⁷, V. Perez Reale³⁵,
 883 L. Perini^{89a,89b}, H. Pernegger³⁰, R. Perrino^{72a}, P. Perrodo⁵, V.D. Peshekhonov⁶⁴, K. Peters³⁰,
 884 R.F.Y. Peters^{54,af}, B.A. Petersen³⁰, J. Petersen³⁰, T.C. Petersen³⁶, E. Petit⁵, A. Petridis^{146a,146b},
 885 C. Petridou¹⁵⁴, E. Petrolo^{132a}, F. Petrucci^{134a,134b}, D. Petschull⁴², M. Petteni¹⁴², R. Pezoa^{32b}, A. Phan⁸⁶,
 886 P.W. Phillips¹²⁹, G. Piacquadio¹⁴³, E. Pianori¹⁷⁰, A. Picazio⁴⁹, E. Piccaro⁷⁵, M. Piccinini^{20a,20b},
 887 S.M. Piec⁴², R. Piegaia²⁷, D.T. Pignotti¹⁰⁹, J.E. Pilcher³¹, A.D. Pilkington⁸², J. Pina^{124a,c},
 888 M. Pinamonti^{164a,164c,ag}, A. Pinder¹¹⁸, J.L. Pinfold³, A. Pingel³⁶, B. Pinto^{124a}, C. Pizio^{89a,89b},
 889 M.-A. Pleier²⁵, V. Pleskot¹²⁷, E. Plotnikova⁶⁴, P. Plucinski^{146a,146b}, A. Poblaguev²⁵, S. Poddar^{58a},
 890 F. Podlyski³⁴, R. Poettgen⁸¹, L. Poggioli¹¹⁵, D. Pohl²¹, M. Pohl⁴⁹, G. Polesello^{119a}, A. Policicchio^{37a,37b},
 891 R. Polifka¹⁵⁸, A. Polini^{20a}, V. Polychronakos²⁵, D. Pomeroy²³, K. Pommès³⁰, L. Pontecorvo^{132a},
 892 B.G. Pope⁸⁸, G.A. Popeneciu^{26a}, D.S. Popovic^{13a}, A. Poppleton³⁰, X. Portell Bueso¹², G.E. Pospelov⁹⁹,
 893 S. Pospisil¹²⁶, I.N. Potrap⁶⁴, C.J. Potter¹⁴⁹, C.T. Potter¹¹⁴, G. Poulard³⁰, J. Poveda⁶⁰, V. Pozdnyakov⁶⁴,
 894 R. Prabhu⁷⁷, P. Pralavorio⁸³, A. Pranko¹⁵, S. Prasad³⁰, R. Pravahan²⁵, S. Prell⁶³, K. Pretzl¹⁷, D. Price⁶⁰,
 895 J. Price⁷³, L.E. Price⁶, D. Prieur¹²³, M. Primavera^{72a}, M. Proissl⁴⁶, K. Prokofiev¹⁰⁸, F. Prokoshin^{32b},
 896 E. Protopapadaki¹³⁶, S. Protopopescu²⁵, J. Proudfoot⁶, X. Prudent⁴⁴, M. Przybycien^{38a}, H. Przysieznik⁵,
 897 S. Psoroulas²¹, E. Ptacek¹¹⁴, E. Pueschel⁸⁴, D. Puldon¹⁴⁸, M. Purohit^{25,ad}, P. Puzo¹¹⁵, Y. Pylypchenko⁶²,
 898 J. Qian⁸⁷, A. Quadt⁵⁴, D.R. Quarrie¹⁵, W.B. Quayle¹⁷³, D. Quilty⁵³, M. Raas¹⁰⁴, V. Radeka²⁵,
 899 V. Radescu⁴², P. Radloff¹¹⁴, F. Ragusa^{89a,89b}, G. Rahal¹⁷⁸, S. Rajagopalan²⁵, M. Rammensee⁴⁸,
 900 M. Rammes¹⁴¹, A.S. Randle-Conde⁴⁰, K. Randrianarivony²⁹, C. Rangel-Smith⁷⁸, K. Rao¹⁶³,
 901 F. Rauscher⁹⁸, T.C. Rave⁴⁸, T. Ravenscroft⁵³, M. Raymond³⁰, A.L. Read¹¹⁷, D.M. Rebuzzi^{119a,119b},
 902 A. Redelbach¹⁷⁴, G. Redlinger²⁵, R. Reece¹²⁰, K. Reeves⁴¹, A. Reinsch¹¹⁴, I. Reisinger⁴³, M. Relich¹⁶³,
 903 C. Rembser³⁰, Z.L. Ren¹⁵¹, A. Renaud¹¹⁵, M. Rescigno^{132a}, S. Resconi^{89a}, B. Resende¹³⁶, P. Reznicek⁹⁸,
 904 R. Rezvani⁹³, R. Richter⁹⁹, E. Richter-Was^{38b}, M. Ridel⁷⁸, P. Rieck¹⁶, M. Rijssenbeek¹⁴⁸,
 905 A. Rimoldi^{119a,119b}, L. Rinaldi^{20a}, R.R. Rios⁴⁰, E. Ritsch⁶¹, I. Riu¹², G. Rivoltella^{89a,89b},
 906 F. Rizatdinova¹¹², E. Rizvi⁷⁵, S.H. Robertson^{85,j}, A. Robichaud-Veronneau¹¹⁸, D. Robinson²⁸,
 907 J.E.M. Robinson⁸², A. Robson⁵³, J.G. Rocha de Lima¹⁰⁶, C. Roda^{122a,122b}, D. Roda Dos Santos³⁰,
 908 A. Roe⁵⁴, S. Roe³⁰, O. Røhne¹¹⁷, S. Rolli¹⁶¹, A. Romaniouk⁹⁶, M. Romano^{20a,20b}, G. Romeo²⁷,
 909 E. Romero Adam¹⁶⁷, N. Rompotis¹³⁸, L. Roos⁷⁸, E. Ros¹⁶⁷, S. Rosati^{132a}, K. Rosbach⁴⁹, A. Rose¹⁴⁹,
 910 M. Rose⁷⁶, G.A. Rosenbaum¹⁵⁸, P.L. Rosendahl¹⁴, O. Rosenthal¹⁴¹, L. Rosselet⁴⁹, V. Rossetti¹²,
 911 E. Rossi^{132a,132b}, L.P. Rossi^{50a}, M. Rotaru^{26a}, I. Roth¹⁷², J. Rothberg¹³⁸, D. Rousseau¹¹⁵, C.R. Royon¹³⁶,
 912 A. Rozanov⁸³, Y. Rozen¹⁵², X. Ruan^{33a,ah}, F. Rubbo¹², I. Rubinskiy⁴², N. Ruckstuhl¹⁰⁵, V.I. Rud⁹⁷,
 913 C. Rudolph⁴⁴, M.S. Rudolph¹⁵⁸, F. Rühr⁷, A. Ruiz-Martinez⁶³, L. Rumyantsev⁶⁴, Z. Rurikova⁴⁸,
 914 N.A. Rusakovich⁶⁴, A. Ruschke⁹⁸, J.P. Rutherford⁷, N. Ruthmann⁴⁸, P. Ruzicka¹²⁵, Y.F. Ryabov¹²¹,
 915 M. Rybar¹²⁷, G. Rybkin¹¹⁵, N.C. Ryder¹¹⁸, A.F. Saavedra¹⁵⁰, A. Saddique³, I. Sadeh¹⁵³,
 916 H.F.-W. Sadrozinski¹³⁷, R. Sadykov⁶⁴, F. Safai Tehrani^{132a}, H. Sakamoto¹⁵⁵, G. Salamanna⁷⁵,
 917 A. Salamon^{133a}, M. Saleem¹¹¹, D. Salek³⁰, D. Salihagic⁹⁹, A. Salnikov¹⁴³, J. Salt¹⁶⁷,
 918 B.M. Salvachua Ferrando⁶, D. Salvatore^{37a,37b}, F. Salvatore¹⁴⁹, A. Salvucci¹⁰⁴, A. Salzburger³⁰,
 919 D. Sampsonidis¹⁵⁴, A. Sanchez^{102a,102b}, J. Sánchez¹⁶⁷, V. Sanchez Martinez¹⁶⁷, H. Sandaker¹⁴,
 920 H.G. Sander⁸¹, M.P. Sanders⁹⁸, M. Sandhoff¹⁷⁵, T. Sandoval²⁸, C. Sandoval¹⁶², R. Sandstroem⁹⁹,
 921 D.P.C. Sankey¹²⁹, A. Sansoni⁴⁷, C. Santoni³⁴, R. Santonico^{133a,133b}, H. Santos^{124a}, I. Santoyo Castillo¹⁴⁹,
 922 K. Sapp¹²³, J.G. Saraiva^{124a}, T. Sarangi¹⁷³, E. Sarkisyan-Grinbaum⁸, B. Sarrazin²¹, F. Sarri^{122a,122b},
 923 G. Sartisohn¹⁷⁵, O. Sasaki⁶⁵, Y. Sasaki¹⁵⁵, N. Sasao⁶⁷, I. Satsounkevitch⁹⁰, G. Sauvage^{5,*}, E. Sauvan⁵,
 924 J.B. Sauvan¹¹⁵, P. Savard^{158,e}, V. Savinov¹²³, D.O. Savu³⁰, C. Sawyer¹¹⁸, L. Sawyer^{25,l}, D.H. Saxon⁵³,
 925 J. Saxon¹²⁰, C. Sbarra^{20a}, A. Sbrizzi³, D.A. Scannicchio¹⁶³, M. Scarcella¹⁵⁰, J. Schaarschmidt¹¹⁵,
 926 P. Schacht⁹⁹, D. Schaefer¹²⁰, A. Schaelicke⁴⁶, S. Schaepe²¹, S. Schatzel^{58b}, U. Schäfer⁸¹, A.C. Schaffer¹¹⁵,
 927 D. Schaile⁹⁸, R.D. Schamberger¹⁴⁸, V. Scharf^{58a}, V.A. Schegelsky¹²¹, D. Scheirich⁸⁷, M. Schernau¹⁶³,
 928 M.I. Scherzer³⁵, C. Schiavi^{50a,50b}, J. Schieck⁹⁸, C. Schillo⁴⁸, M. Schioppa^{37a,37b}, S. Schlenker³⁰,
 929 E. Schmidt⁴⁸, K. Schmieden²¹, C. Schmitt⁸¹, C. Schmitt⁹⁸, S. Schmitt^{58b}, B. Schneider¹⁷,
 930 Y.J. Schnellbach⁷³, U. Schnoor⁴⁴, L. Schoeffel¹³⁶, A. Schoening^{58b}, A.L.S. Schorlemmer⁵⁴, M. Schott⁸¹,
 931 D. Schouten^{159a}, J. Schovancova¹²⁵, M. Schram⁸⁵, C. Schroeder⁸¹, N. Schroer^{58c}, M.J. Schultens²¹,

932 J. Schultes¹⁷⁵, H.-C. Schultz-Coulon^{58a}, H. Schulz¹⁶, M. Schumacher⁴⁸, B.A. Schumm¹³⁷, Ph. Schune¹³⁶,
 933 A. Schwartzman¹⁴³, Ph. Schwegler⁹⁹, Ph. Schwemling¹³⁶, R. Schwienhorst⁸⁸, J. Schwindling¹³⁶,
 934 T. Schwindt²¹, M. Schwoerer⁵, F.G. Sciacca¹⁷, E. Scifo¹¹⁵, G. Sciolla²³, W.G. Scott¹²⁹, F. Scutti²¹,
 935 J. Searcy⁸⁷, G. Sedov⁴², E. Sedykh¹²¹, S.C. Seidel¹⁰³, A. Seiden¹³⁷, F. Seifert⁴⁴, J.M. Seixas^{24a},
 936 G. Sekhniaidze^{102a}, S.J. Sekula⁴⁰, K.E. Selbach⁴⁶, D.M. Seliverstov¹²¹, G. Sellers⁷³, M. Seman^{144b},
 937 N. Semprini-Cesari^{20a,20b}, C. Serfon³⁰, L. Serin¹¹⁵, L. Serkin⁵⁴, T. Serre⁸³, R. Seuster^{159a}, H. Severini¹¹¹,
 938 A. Sfyrila³⁰, E. Shabalina⁵⁴, M. Shamim¹¹⁴, L.Y. Shan^{33a}, J.T. Shank²², Q.T. Shao⁸⁶, M. Shapiro¹⁵,
 939 P.B. Shatalov⁹⁵, K. Shaw^{164a,164c}, P. Sherwood⁷⁷, S. Shimizu¹⁰¹, M. Shimojima¹⁰⁰, T. Shin⁵⁶,
 940 M. Shiyakova⁶⁴, A. Shmeleva⁹⁴, M.J. Shochet³¹, D. Short¹¹⁸, S. Shrestha⁶³, E. Shulga⁹⁶, M.A. Shupe⁷,
 941 P. Sicho¹²⁵, A. Sidoti^{132a}, F. Siegert⁴⁸, Dj. Sijacki^{13a}, O. Silbert¹⁷², J. Silva^{124a}, Y. Silver¹⁵³,
 942 D. Silverstein¹⁴³, S.B. Silverstein^{146a}, V. Simak¹²⁶, O. Simard⁵, Lj. Simic^{13a}, S. Simion¹¹⁵, E. Simioni⁸¹,
 943 B. Simmons⁷⁷, R. Simoniello^{89a,89b}, M. Simonyan³⁶, P. Sinervo¹⁵⁸, N.B. Sinev¹¹⁴, V. Sipica¹⁴¹,
 944 G. Siragusa¹⁷⁴, A. Sircar²⁵, A.N. Sisakyan^{64,*}, S.Yu. Sivoklokov⁹⁷, J. Sjölin^{146a,146b}, T.B. Sjursen¹⁴,
 945 L.A. Skinnari¹⁵, H.P. Skottowe⁵⁷, K. Skovpen¹⁰⁷, P. Skubic¹¹¹, M. Slater¹⁸, T. Slavicek¹²⁶, K. Sliwa¹⁶¹,
 946 V. Smakhtin¹⁷², B.H. Smart⁴⁶, L. Smestad¹¹⁷, S.Yu. Smirnov⁹⁶, Y. Smirnov⁹⁶, L.N. Smirnova^{97,ai},
 947 O. Smirnova⁷⁹, K.M. Smith⁵³, M. Smizanska⁷¹, K. Smolek¹²⁶, A.A. Snesarev⁹⁴, G. Snidero⁷⁵, J. Snow¹¹¹,
 948 S. Snyder²⁵, R. Sobie^{169,j}, J. Sodomka¹²⁶, A. Soffer¹⁵³, D.A. Soh^{151,u}, C.A. Solans³⁰, M. Solar¹²⁶,
 949 J. Solc¹²⁶, E.Yu. Soldatov⁹⁶, U. Soldevila¹⁶⁷, E. Solfaroli Camillocci^{132a,132b}, A.A. Solodkov¹²⁸,
 950 O.V. Solovyanov¹²⁸, V. Solovyev¹²¹, N. Soni¹, A. Sood¹⁵, V. Sopko¹²⁶, B. Sopko¹²⁶, M. Sosebee⁸,
 951 R. Soualah^{164a,164c}, P. Soueid⁹³, A. Soukharev¹⁰⁷, D. South⁴², S. Spagnolo^{72a,72b}, F. Spanò⁷⁶, R. Spighi^{20a},
 952 G. Spigo³⁰, R. Spiwoks³⁰, M. Spousta^{127,aj}, T. Spreitzer¹⁵⁸, B. Spurlock⁸, R.D. St. Denis⁵³,
 953 J. Stahlman¹²⁰, R. Stamen^{58a}, E. Stanecka³⁹, R.W. Stanek⁶, C. Stanescu^{134a}, M. Stanescu-Bellu⁴²,
 954 M.M. Stanitzki⁴², S. Stapnes¹¹⁷, E.A. Starchenko¹²⁸, J. Stark⁵⁵, P. Staroba¹²⁵, P. Starovoitov⁴²,
 955 R. Staszewski³⁹, A. Staude⁹⁸, P. Stavina^{144a,*}, G. Steele⁵³, P. Steinbach⁴⁴, P. Steinberg²⁵, I. Stekl¹²⁶,
 956 B. Stelzer¹⁴², H.J. Stelzer⁸⁸, O. Stelzer-Chilton^{159a}, H. Stenzel⁵², S. Stern⁹⁹, G.A. Stewart³⁰,
 957 J.A. Stillings²¹, M.C. Stockton⁸⁵, M. Stoebe⁸⁵, K. Stoerig⁴⁸, G. Stoicea^{26a}, S. Stonjek⁹⁹, A.R. Stradling⁸,
 958 A. Straessner⁴⁴, J. Strandberg¹⁴⁷, S. Strandberg^{146a,146b}, A. Strandlie¹¹⁷, M. Strang¹⁰⁹, E. Strauss¹⁴³,
 959 M. Strauss¹¹¹, P. Strizenc^{144b}, R. Ströhmer¹⁷⁴, D.M. Strom¹¹⁴, J.A. Strong^{76,*}, R. Stroynowski⁴⁰,
 960 B. Stugu¹⁴, I. Stumer^{25,*}, J. Stupak¹⁴⁸, P. Sturm¹⁷⁵, N.A. Styles⁴², D. Su¹⁴³, HS. Subramania³,
 961 R. Subramaniam²⁵, A. Succurro¹², Y. Sugaya¹¹⁶, C. Suhr¹⁰⁶, M. Suk¹²⁶, V.V. Sulin⁹⁴, S. Sultansoy^{4c},
 962 T. Sumida⁶⁷, X. Sun⁵⁵, J.E. Sundermann⁴⁸, K. Suruliz¹³⁹, G. Susinno^{37a,37b}, M.R. Sutton¹⁴⁹, Y. Suzuki⁶⁵,
 963 Y. Suzuki⁶⁶, M. Svatos¹²⁵, S. Swedish¹⁶⁸, M. Swiatlowski¹⁴³, I. Sykora^{144a}, T. Sykora¹²⁷, D. Ta¹⁰⁵,
 964 K. Tackmann⁴², A. Taffard¹⁶³, R. Tafirout^{159a}, N. Taiblum¹⁵³, Y. Takahashi¹⁰¹, H. Takai²⁵,
 965 R. Takashima⁶⁸, H. Takeda⁶⁶, T. Takeshita¹⁴⁰, Y. Takubo⁶⁵, M. Talby⁸³, A. Talyshev^{107,g}, J.Y.C. Tam¹⁷⁴,
 966 M.C. Tamssett²⁵, K.G. Tan⁸⁶, J. Tanaka¹⁵⁵, R. Tanaka¹¹⁵, S. Tanaka¹³¹, S. Tanaka⁶⁵, A.J. Tanasijczuk¹⁴²,
 967 K. Tani⁶⁶, N. Tannoury⁸³, S. Tapprogge⁸¹, S. Tarem¹⁵², F. Tarrade²⁹, G.F. Tartarelli^{89a}, P. Tas¹²⁷,
 968 M. Tasevsky¹²⁵, T. Tashiro⁶⁷, E. Tassi^{37a,37b}, Y. Tayalati^{135d}, C. Taylor⁷⁷, F.E. Taylor⁹², G.N. Taylor⁸⁶,
 969 W. Taylor^{159b}, M. Teinturier¹¹⁵, F.A. Teischinger³⁰, M. Teixeira Dias Castanheira⁷⁵, P. Teixeira-Dias⁷⁶,
 970 K.K. Temming⁴⁸, H. Ten Kate³⁰, P.K. Teng¹⁵¹, S. Terada⁶⁵, K. Terashi¹⁵⁵, J. Terron⁸⁰, M. Testa⁴⁷,
 971 R.J. Teuscher^{158,j}, J. Therhaag²¹, T. Theveneaux-Pelzer³⁴, S. Thoma⁴⁸, J.P. Thomas¹⁸,
 972 E.N. Thompson³⁵, P.D. Thompson¹⁸, P.D. Thompson¹⁵⁸, A.S. Thompson⁵³, L.A. Thomsen³⁶,
 973 E. Thomson¹²⁰, M. Thomson²⁸, W.M. Thong⁸⁶, R.P. Thun^{87,*}, F. Tian³⁵, M.J. Tibbetts¹⁵, T. Tic¹²⁵,
 974 V.O. Tikhomirov⁹⁴, Y.A. Tikhonov^{107,g}, S. Timoshenko⁹⁶, E. Tiouchichine⁸³, P. Tipton¹⁷⁶, S. Tisserant⁸³,
 975 T. Todorov⁵, S. Todorova-Nova¹⁶¹, B. Toggerson¹⁶³, J. Tojo⁶⁹, S. Tokár^{144a}, K. Tokushuku⁶⁵,
 976 K. Tollefson⁸⁸, L. Tomlinson⁸², M. Tomoto¹⁰¹, L. Tompkins³¹, K. Toms¹⁰³, A. Tonoyan¹⁴, C. Topfel¹⁷,
 977 N.D. Topilin⁶⁴, E. Torrence¹¹⁴, H. Torres⁷⁸, E. Torró Pastor¹⁶⁷, J. Toth^{83,ae}, F. Touchard⁸³,
 978 D.R. Tovey¹³⁹, H.L. Tran¹¹⁵, T. Trefzger¹⁷⁴, L. Tremblet³⁰, A. Tricoli³⁰, I.M. Trigger^{159a},
 979 S. Trincaz-Duvoid⁷⁸, M.F. Tripiana⁷⁰, N. Triplett²⁵, W. Trischuk¹⁵⁸, B. Trocme⁵⁵, C. Troncon^{89a},
 980 M. Trottier-McDonald¹⁴², M. Trovatelli^{134a,134b}, P. True⁸⁸, M. Trzebinski³⁹, A. Trzupek³⁹,
 981 C. Tsarouchas³⁰, J.C.-L. Tseng¹¹⁸, M. Tsiakiris¹⁰⁵, P.V. Tsiarehshka⁹⁰, D. Tsionou¹³⁶, G. Tsipolitis¹⁰,
 982 S. Tsiskaridze¹², V. Tsiskaridze⁴⁸, E.G. Tskhadadze^{51a}, I.I. Tsukerman⁹⁵, V. Tsulaia¹⁵, J.-W. Tsung²¹,
 983 S. Tsuno⁶⁵, D. Tsybychev¹⁴⁸, A. Tua¹³⁹, A. Tudorache^{26a}, V. Tudorache^{26a}, J.M. Tuggle³¹, A.N. Tuna¹²⁰,

984 M. Turala³⁹, D. Turecek¹²⁶, I. Turk Cakir^{4d}, R. Turra^{89a,89b}, P.M. Tuts³⁵, A. Tykhonov⁷⁴,
 985 M. Tylmad^{146a,146b}, M. Tyndel¹²⁹, G. Tzanakos⁹, K. Uchida²¹, I. Ueda¹⁵⁵, R. Ueno²⁹, M. Ughetto⁸³,
 986 M. Ugland¹⁴, M. Uhlenbrock²¹, F. Ukegawa¹⁶⁰, G. Unal³⁰, A. Undrus²⁵, G. Unel¹⁶³, F.C. Ungaro⁴⁸,
 987 Y. Unno⁶⁵, D. Urbaniec³⁵, P. Urquijo²¹, G. Usai⁸, L. Vacavant⁸³, V. Vacek¹²⁶, B. Vachon⁸⁵, S. Vahsen¹⁵,
 988 N. Valencic¹⁰⁵, S. Valentinetti^{20a,20b}, A. Valero¹⁶⁷, L. Valery³⁴, S. Valkar¹²⁷, E. Valladolid Gallego¹⁶⁷,
 989 S. Vallecorsa¹⁵², J.A. Valls Ferrer¹⁶⁷, R. Van Berg¹²⁰, P.C. Van Der Deijl¹⁰⁵, R. van der Geer¹⁰⁵,
 990 H. van der Graaf¹⁰⁵, R. Van Der Leeuw¹⁰⁵, D. van der Ster³⁰, N. van Eldik³⁰, P. van Gemmeren⁶,
 991 J. Van Nieuwkoop¹⁴², I. van Vulpen¹⁰⁵, M. Vanadia⁹⁹, W. Vandelli³⁰, A. Vaniachine⁶, P. Vankov⁴²,
 992 F. Vannucci⁷⁸, R. Vari^{132a}, E.W. Varnes⁷, T. Varol⁸⁴, D. Varouchas¹⁵, A. Vartapetian⁸, K.E. Varvell¹⁵⁰,
 993 V.I. Vassilakopoulos⁵⁶, F. Vazeille³⁴, T. Vazquez Schroeder⁵⁴, F. Veloso^{124a}, S. Veneziano^{132a},
 994 A. Ventura^{72a,72b}, D. Ventura⁸⁴, M. Venturi⁴⁸, N. Venturi¹⁵⁸, V. Vercesi^{119a}, M. Verducci¹³⁸,
 995 W. Verkerke¹⁰⁵, J.C. Vermeulen¹⁰⁵, A. Vest⁴⁴, M.C. Vetterli^{142,e}, I. Vichou¹⁶⁵, T. Vickey^{145b,ak},
 996 O.E. Vickey Boeriu^{145b}, G.H.A. Viehhauser¹¹⁸, S. Viel¹⁶⁸, M. Villa^{20a,20b}, M. Villaplana Perez¹⁶⁷,
 997 E. Vilucchi⁴⁷, M.G. Vincter²⁹, V.B. Vinogradov⁶⁴, J. Virzi¹⁵, O. Vitells¹⁷², M. Viti⁴², I. Vivarelli⁴⁸,
 998 F. Vives Vaque³, S. Vlachos¹⁰, D. Vladoiu⁹⁸, M. Vlasak¹²⁶, A. Vogel²¹, P. Vokac¹²⁶, G. Volpi⁴⁷,
 999 M. Volpi⁸⁶, G. Volpini^{89a}, H. von der Schmitt⁹⁹, H. von Radziewski⁴⁸, E. von Toerne²¹, V. Vorobel¹²⁷,
 1000 M. Vos¹⁶⁷, R. Voss³⁰, J.H. Vossebeld⁷³, N. Vranjes¹³⁶, M. Vranjes Milosavljevic¹⁰⁵, V. Vrba¹²⁵,
 1001 M. Vreeswijk¹⁰⁵, T. Vu Anh⁴⁸, R. Vuillermet³⁰, I. Vukotic³¹, Z. Vykydal¹²⁶, W. Wagner¹⁷⁵, P. Wagner²¹,
 1002 H. Wahlen¹⁷⁵, S. Wahrmund⁴⁴, J. Wakabayashi¹⁰¹, S. Walch⁸⁷, J. Walder⁷¹, R. Walker⁹⁸,
 1003 W. Walkowiak¹⁴¹, R. Wall¹⁷⁶, P. Waller⁷³, B. Walsh¹⁷⁶, C. Wang⁴⁵, H. Wang¹⁷³, H. Wang⁴⁰, J. Wang¹⁵¹,
 1004 J. Wang^{33a}, K. Wang⁸⁵, R. Wang¹⁰³, S.M. Wang¹⁵¹, T. Wang²¹, X. Wang¹⁷⁶, A. Warburton⁸⁵,
 1005 C.P. Ward²⁸, D.R. Wardrope⁷⁷, M. Warsinsky⁴⁸, A. Washbrook⁴⁶, C. Wasicki⁴², I. Watanabe⁶⁶,
 1006 P.M. Watkins¹⁸, A.T. Watson¹⁸, I.J. Watson¹⁵⁰, M.F. Watson¹⁸, G. Watts¹³⁸, S. Watts⁸², A.T. Waugh¹⁵⁰,
 1007 B.M. Waugh⁷⁷, M.S. Weber¹⁷, J.S. Webster³¹, A.R. Weidberg¹¹⁸, P. Weigell⁹⁹, J. Weingarten⁵⁴,
 1008 C. Weiser⁴⁸, P.S. Wells³⁰, T. Wenaus²⁵, D. Wendland¹⁶, Z. Weng^{151,u}, T. Wengler³⁰, S. Wenig³⁰,
 1009 N. Wermes²¹, M. Werner⁴⁸, P. Werner³⁰, M. Werth¹⁶³, M. Wessels^{58a}, J. Wetter¹⁶¹, K. Whalen²⁹,
 1010 A. White⁸, M.J. White⁸⁶, R. White^{32b}, S. White^{122a,122b}, S.R. Whitehead¹¹⁸, D. Whiteson¹⁶³,
 1011 D. Whittington⁶⁰, D. Wicke¹⁷⁵, F.J. Wickens¹²⁹, W. Wiedenmann¹⁷³, M. Wielers⁷⁹, P. Wienemann²¹,
 1012 C. Wiglesworth³⁶, L.A.M. Wiik-Fuchs²¹, P.A. Wijeratne⁷⁷, A. Wildauer⁹⁹, M.A. Wildt^{42,r}, I. Wilhelm¹²⁷,
 1013 H.G. Wilkens³⁰, J.Z. Will⁹⁸, E. Williams³⁵, H.H. Williams¹²⁰, S. Williams²⁸, W. Willis^{35,*}, S. Willocq⁸⁴,
 1014 J.A. Wilson¹⁸, A. Wilson⁸⁷, I. Wingerter-Seez⁵, S. Winkelmann⁴⁸, F. Winklmeier³⁰, M. Wittgen¹⁴³,
 1015 T. Wittig⁴³, J. Wittkowski⁹⁸, S.J. Wollstadt⁸¹, M.W. Wolter³⁹, H. Wolters^{124a,h}, W.C. Wong⁴¹,
 1016 G. Wooden⁸⁷, B.K. Wosiek³⁹, J. Wotschack³⁰, M.J. Woudstra⁸², K.W. Wozniak³⁹, K. Wraight⁵³,
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