


Longitudinal Flow Decorrelations in Xe + Xe Collisions at $\sqrt{s_{NN}} = 5.44$ TeV with the ATLAS Detector

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

 (Received 14 January 2020; revised 16 June 2020; accepted 12 February 2021; published 24 March 2021)

The first measurement of longitudinal decorrelations of harmonic flow amplitudes v_n for $n = 2-4$ in Xe + Xe collisions at $\sqrt{s_{NN}} = 5.44$ TeV is obtained using $3 \mu\text{b}^{-1}$ of data with the ATLAS detector at the LHC. The decorrelation signal for v_3 and v_4 is found to be nearly independent of collision centrality and transverse momentum (p_T) requirements on final-state particles, but for v_2 a strong centrality and p_T dependence is seen. When compared with the results from Pb + Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, the longitudinal decorrelation signal in midcentral Xe + Xe collisions is found to be larger for v_2 , but smaller for v_3 . Current hydrodynamic models reproduce the ratios of the v_n measured in Xe + Xe collisions to those in Pb + Pb collisions but fail to describe the magnitudes and trends of the ratios of longitudinal flow decorrelations between Xe + Xe and Pb + Pb. The results on the system-size dependence provide new insights and an important lever arm to separate effects of the longitudinal structure of the initial state from other early and late time effects in heavy-ion collisions.

DOI: [10.1103/PhysRevLett.126.122301](https://doi.org/10.1103/PhysRevLett.126.122301)

High-energy heavy-ion collisions create a new state of matter known as a quark-gluon plasma (QGP), whose space-time dynamics is well described by relativistic viscous hydrodynamic models [1–3]. During its expansion, the large pressure gradients of the QGP convert the spatial anisotropies in the initial-state geometry into momentum anisotropies of the final-state particles. Such momentum anisotropies are often characterized by a Fourier expansion of particle density in the azimuthal angle ϕ , $dN/d\phi \propto 1 + 2 \sum_{n=1}^{\infty} v_n \cos n(\phi - \Phi_n)$, where v_n and Φ_n are the magnitude and phase of the n th-order flow vector $V_n = v_n e^{-in\Phi_n}$. The V_n reflects the hydrodynamic response of the QGP to the shape of the overlap region in the transverse plane, described by eccentricity vector $\mathcal{E}_n = \varepsilon_n e^{-in\Psi_n}$ [4]. Extensive studies of V_n and their event-by-event fluctuations in a broad range of beam energy and collision systems [5–15] have provided strong constraints on the \mathcal{E}_n and the properties of the QGP [4,16–20].

Most previous efforts assume that the shape of the initial overlap and dynamic evolution of the QGP are boost invariant. Recently, LHC experiments made the first observation of “flow decorrelations” in Pb + Pb collisions [21,22], which show that, even in a single event, v_n and Φ_n can fluctuate along the longitudinal direction. This can be

attributed to the fact that the distribution of particle production sources, and the associated eccentricity vectors, fluctuates along pseudorapidity (η). For example, the number of forward- and backward-going nucleon participants, and the corresponding eccentricity vectors \mathcal{E}_n^F and \mathcal{E}_n^B , are not the same in a given event. While the harmonic flow V_n are driven by the average of the two eccentricity vectors $V_n \propto \mathcal{E}_n \approx (\mathcal{E}_n^F + \mathcal{E}_n^B)/2$, the flow decorrelation is related to the difference between them, $\mathcal{E}_{n-} = (\mathcal{E}_n^F - \mathcal{E}_n^B)/2$ [23]. Indeed, hydrodynamic model and transport model calculations [24–29] show that the flow decorrelations are driven mostly by longitudinal fluctuation of \mathcal{E}_n in the initial-state geometry. They are also influenced by other early time effects, such as initial-state momentum anisotropy [30] and hydrodynamic fluctuations [31], but are insensitive to late time dynamics, including shear viscosity [27]. These different early time contributions compete with each other, and current measurements [21,22] from a single system (Pb + Pb) in a limited energy range ($\sqrt{s_{NN}} = 2.76-5.02$ TeV) do not disentangle these effects. To improve our understanding of the longitudinal structure of the QGP, it is crucial to extend the measurements to a broad range in the beam energy and size of the collision systems [27,32].

This Letter investigates the system-size dependence of longitudinal decorrelations of v_2 , v_3 , and v_4 by performing measurements in $^{129}\text{Xe} + ^{129}\text{Xe}$ collisions and comparing them with $^{208}\text{Pb} + ^{208}\text{Pb}$ collisions. Recent measurements show that the inclusive v_n exhibit modest differences (< 10%–20%) between these two systems as a function of centrality, except in the central collisions where the difference for v_2 is significantly larger [33–35]. These are

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

Published by the American Physical Society under the terms of the [Creative Commons Attribution 4.0 International license](https://creativecommons.org/licenses/by/4.0/). Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI.

sensitive to the differences in the initial eccentricities and viscous effects in the two systems [36,37]. Similarly, comparison of v_n decorrelation between Xe + Xe and Pb + Pb, together with the comparison of inclusive v_n , could improve our understanding of the longitudinal structures of the QGP and, in particular, answer the question whether the decorrelation is controlled by the overall system size or the shape of the overlap region.

The measurement is performed using the ATLAS inner detector (ID) and forward calorimeters (FCals) along with the trigger and data acquisition system [38,39]. The ID measures charged particles over a pseudorapidity range $|\eta| < 2.5$ using a combination of silicon pixel detectors, silicon microstrip detectors, and a straw-tube transition radiation tracker, all immersed in a 2 T axial magnetic field [40–42]. [ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector and the z axis along the beam pipe. The x axis points from the IP to the center of the LHC ring, and the y axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$.] The FCal measures the sum of the transverse energy $\sum E_T$ over $3.2 < |\eta| < 4.9$ to determine the event centrality and uses copper and tungsten absorbers with liquid argon as the active medium. The ATLAS trigger system [39] consists of a level-one (L1) trigger based on electronics and a software-based high-level trigger.

This analysis uses $3 \mu\text{b}^{-1}$ of $\sqrt{s_{NN}} = 5.44$ TeV Xe + Xe data collected in 2017. The events are selected by requiring the total transverse energy deposited in the calorimeters over $|\eta| < 4.9$ at L1 to be larger than 4 GeV. In the off-line analysis, the z position of the primary vertex [43] of each event is required to be within 100 mm of the IP. Events containing more than one inelastic interaction are suppressed by exploiting the correlation between the $\sum E_T$ measured in the FCal and the number of tracks associated with a primary vertex. The event centrality classification is based on the $\sum E_T$ in the FCal [44]. A Glauber model [45,46] is used to determine the mapping between $\sum E_T$ in the FCal and the centrality percentiles, as well as to estimate the average number of participating nucleons N_{part} for each centrality interval.

Charged-particle tracks are reconstructed from ionization hits in the ID using a reconstruction procedure optimized for heavy-ion collisions [47]. Tracks used in this analysis are required to have $|\eta| < 2.4$ and transverse momentum in the range $0.5 < p_T < 3$ GeV. In addition, the point of closest approach of the track to the primary vertex is required to be within 1 mm in both the transverse and longitudinal directions. More details of the track selection can be found in Ref. [35].

The efficiency $\epsilon(p_T, \eta)$ of the track reconstruction and track selection requirements is evaluated using minimum-bias Xe + Xe Monte Carlo (MC) events produced with the

HIJING [48] event generator with the effect of flow added via Ref. [49]. The response of the detector was simulated [50] using GEANT4 [51], and the resulting events are reconstructed with the same algorithms as applied to the data. The efficiency varies from 40% to 73% depending on η and p_T , with an uncertainty of 1%–4% arising mainly from the uncertainty in the detector material budget. The rate of falsely reconstructed (fake) tracks $f(p_T, \eta)$ is significant only for $p_T < 0.8$ GeV in central collisions, where it ranges from 2% for η near zero to 6% for $|\eta| > 2$.

The method and analysis procedure closely follow those established in Ref. [22] and are described briefly below. The n th-order azimuthal anisotropy in an event is estimated using the observed flow vectors

$$\mathbf{q}_n \equiv \sum_j w_j e^{in\phi_j} / (\sum_j w_j), \quad (1)$$

where the sum runs over charged particles (for the ID) or calorimeter towers (for the FCal) in a specified η interval, and ϕ_j and w_j are the azimuthal angle and the weight assigned to each track or tower, respectively. The weight for the FCal is the E_T of each tower, and the weight for the ID is calculated as $d(\eta, \phi)(1 - f(p_T, \eta))/\epsilon(p_T, \eta)$ to correct for tracking performance [52]. The additional factor $d(\eta, \phi)$, derived from the data, corrects for azimuthal nonuniformity of the detector performance in each η interval.

The flow decorrelations are studied using product of flow vectors $\mathbf{q}_n(\eta)$ in the ID and $\mathbf{q}_n(\eta_{\text{ref}})$ in the FCal [21] averaged over events in a given centrality interval,

$$\begin{aligned} r_{n|n}(\eta) &= \frac{\langle \mathbf{q}_n(-\eta) \mathbf{q}_n^*(\eta_{\text{ref}}) \rangle}{\langle \mathbf{q}_n(\eta) \mathbf{q}_n^*(\eta_{\text{ref}}) \rangle} \\ &= \frac{\langle v_n(-\eta) v_n(\eta_{\text{ref}}) \cos n[\Phi_n(-\eta) - \Phi_n(\eta_{\text{ref}})] \rangle}{\langle v_n(\eta) v_n(\eta_{\text{ref}}) \cos n[\Phi_n(\eta) - \Phi_n(\eta_{\text{ref}})] \rangle}, \quad (2) \end{aligned}$$

where η_{ref} is a reference pseudorapidity range in the FCal, common to both the numerator and the denominator. The $r_{n|n}$ correlator defined this way quantifies the decorrelation between η and $-\eta$ [21,23]. Three reference η ranges, $3.2 < |\eta_{\text{ref}}| < 4.0$, $4.0 < |\eta_{\text{ref}}| < 4.9$, and $3.2 < |\eta_{\text{ref}}| < 4.9$ are used. Since $\langle \mathbf{q}_n(-\eta) \mathbf{q}_n^*(\eta_{\text{ref}}) \rangle = \langle \mathbf{q}_n(\eta) \mathbf{q}_n^*(-\eta_{\text{ref}}) \rangle$ for a symmetric system, the correlator is further symmetrized to enhance the statistics and reduce detector effects: $r_{n|n}(\eta) = [\langle \mathbf{q}_n(-\eta) \mathbf{q}_n^*(\eta_{\text{ref}}) \rangle + \langle \mathbf{q}_n(\eta) \mathbf{q}_n^*(-\eta_{\text{ref}}) \rangle] / [\langle \mathbf{q}_n(\eta) \mathbf{q}_n^*(\eta_{\text{ref}}) \rangle + \langle \mathbf{q}_n(-\eta) \mathbf{q}_n^*(-\eta_{\text{ref}}) \rangle]$.

If flow harmonics for two-particle correlation from two different η factorize into single-particle harmonics, then it is expected that $r_{n|n}(\eta) = 1$. Therefore, a value of $r_{n|n}(\eta)$ incompatible with unity implies a factorization-breaking effect due to longitudinal flow decorrelations. The deviation of $r_{n|n}$ from unity can be parametrized with a linear function $r_{n|n}(\eta) = 1 - 2F_n \eta$. The slope parameter F_n is obtained via a simple linear regression of the $r_{n|n}(\eta)$ data [22]. Using a Glauber model with a parametrized

longitudinal structure, it was shown that $F_n \propto A_{\varepsilon_n} = \langle \varepsilon_{n-}^2 \rangle / \langle \varepsilon_n^2 \rangle$ with $\varepsilon_{n-} = |\mathcal{E}_{n-}|$ [32]; i.e., F_n is sensitive to the difference between the eccentricity for forward- and backward-going participants. Since effects of viscosity partially cancels in the ratio, F_n is less sensitive to late time effects.

Systematic uncertainties in $r_{n|n}$ and the slope parameter F_n arise from the uncertainties in the reconstruction and track selection efficiency, acceptance reweighting procedure, and centrality definition. The systematic uncertainties are estimated by varying different aspects of the analysis, recalculating $r_{n|n}$ and F_n , and comparing them with the nominal values. The systematic uncertainty associated with fake tracks is estimated by loosening the requirements on the transverse and longitudinal impact parameters [35]; the resulting changes are 1%–2% for F_2 , 1%–4% for F_3 , and 1%–9% for F_4 . The uncertainty associated with $\epsilon(p_T, \eta)$ is evaluated to be less than 1% for F_n . The effect of reweighting is studied by setting $d(\eta, \phi) = 1$ and repeating the analysis. The change is found to be 0.6%–2% for F_2 and F_3 , and 2%–7% for F_4 . The uncertainty due to the centrality definition is estimated by varying the mapping between $\sum E_T$ and centrality percentiles; the influence is 0.5%–4% for F_2 and F_3 , and 0.5%–8% for F_4 .

Figure 1 shows the measured $r_{n|n}(\eta)$ for $n = 2$ –4 in two centrality intervals, quantifying the flow decorrelation between η and $-\eta$ according to Eq. (2). The $r_{n|n}$ values show an approximately linear decrease with η , implying stronger flow decorrelation at large η . The magnitudes of decorrelation for $r_{3|3}$ and $r_{4|4}$ are significantly larger than that for $r_{2|2}$. The range $4.0 < |\eta_{\text{ref}}| < 4.9$ chosen for $r_{2|2}$ is different from the range $3.2 < |\eta_{\text{ref}}| < 4.9$ used for $r_{3|3}$ and $r_{4|4}$ in order to reduce sensitivity to nonflow correlations; this is further discussed below.

The slope parameters F_n for $r_{n|n}$ are summarized in Fig. 2 as a function of centrality percentile with smaller percentile corresponding to more-central collisions. The left panels show the F_n for three $|\eta_{\text{ref}}|$ ranges and right

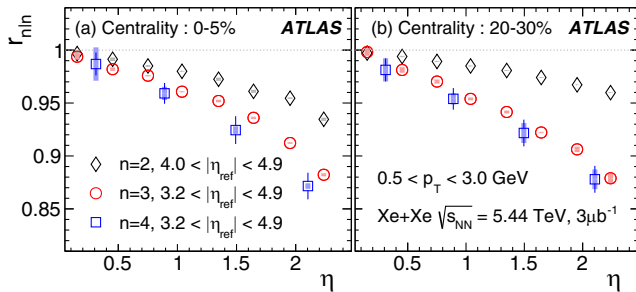


FIG. 1. The η dependence of $r_{2|2}$, $r_{3|3}$, and $r_{4|4}$ in Xe + Xe collisions for two centrality intervals: (a) 0%–5%, (b) 20%–30%. The $|\eta_{\text{ref}}|$ is chosen to be $4.0 < |\eta_{\text{ref}}| < 4.9$ for $r_{2|2}$ and $3.2 < |\eta_{\text{ref}}| < 4.9$ for $r_{3|3}$ and $r_{4|4}$. The error bars and shaded boxes represent statistical and systematic uncertainties, respectively.

panels show the F_n for three p_T ranges. Within uncertainties, F_3 and F_4 show very weak dependence on centrality. The F_2 values, on the other hand, show a strong centrality dependence: they are smallest in the 20%–30% centrality interval and larger toward more-central or more-peripheral collisions. This strong centrality dependence is related to the fact that v_2 is dominated by the average elliptic geometry in midcentral collisions and therefore is less affected by decorrelations, while it is dominated by fluctuation-driven collision geometries in central and peripheral collisions [26,27].

Figure 2 also shows that F_2 has sizable variation between choices of $|\eta_{\text{ref}}|$ or p_T in central and midcentral collisions. The contribution from nonflow correlations associated with back-to-back dijets are expected to contribute to the denominator more than the numerator due to a small gap between η and η_{ref} , and therefore tend to increase the F_n values [22,53]. Such nonflow contributions are expected to be larger for smaller $|\eta_{\text{ref}}|$ or larger p_T . However, although the data show a larger F_2 for smaller $|\eta_{\text{ref}}|$ compatible with nonflow, they show a smaller F_2 for larger p_T , opposite to the expectation from nonflow contributions. Such p_T and η_{ref} dependences are most significant in ultracentral collisions, suggesting a nonlinear behavior of v_2 decorrelation due to disappearance of average elliptic geometry in these collisions. Within uncertainties, the F_3 and F_4 , as well as the original $r_{3|3}$

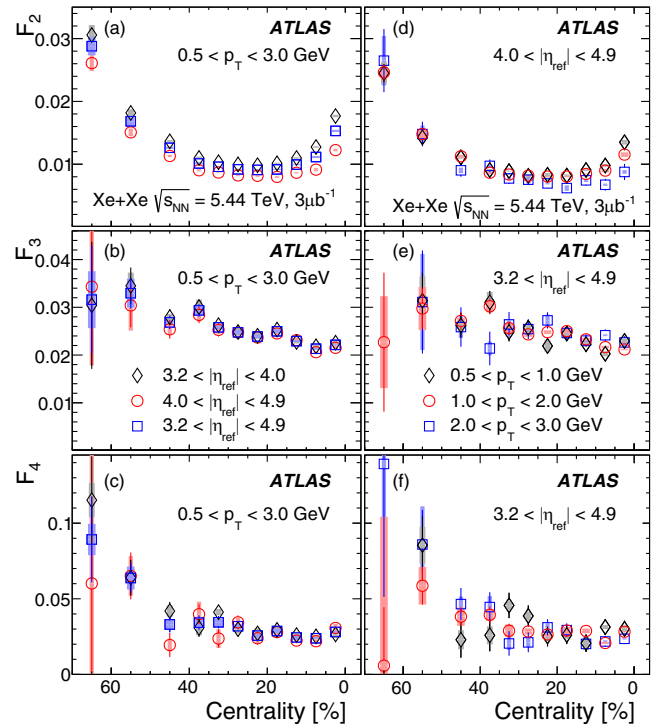


FIG. 2. The centrality dependence of F_n calculated for three $|\eta_{\text{ref}}|$ ranges (left) and three p_T ranges (right) for (a),(d) $n = 2$, (b),(e) $n = 3$, and (c),(f) $n = 4$. The error bars and shaded boxes represent statistical and systematic uncertainties, respectively.

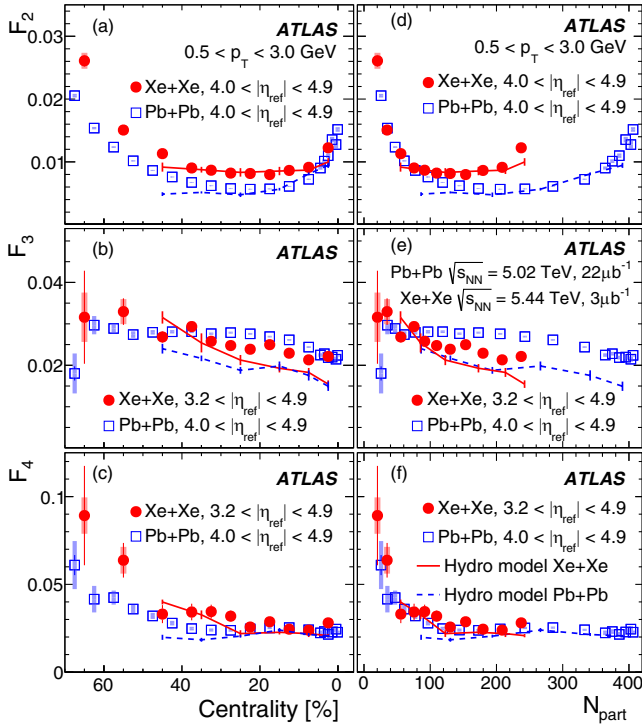


FIG. 3. The F_n compared between Xe + Xe and Pb + Pb [22] collisions as a function of centrality percentiles (left) and N_{part} (right) for (a),(d) $n = 2$, (b),(e) $n = 3$, and (c),(f) $n = 4$. The error bars and shaded boxes on the data represent statistical and systematic uncertainties, respectively. The results from a hydrodynamic model [30,54] are shown as solid lines (Xe + Xe) and dashed lines (Pb + Pb) with the vertical error bars denoting statistical uncertainty of the model predictions.

and $r_{4|4}$, show no differences between various p_T or $|\eta_{\text{ref}}|$ ranges, suggesting that they are not affected by nonflow. Based on results in Fig. 2, $4.0 < |\eta_{\text{ref}}| < 4.9$ is chosen for F_2 to reduce nonflow, but a wider range $3.2 < |\eta_{\text{ref}}| < 4.9$ is chosen for F_3 and F_4 to improve the precision of the measurement.

To gain insights into the system-size dependence of the longitudinal fluctuations, Fig. 3 compares the F_n from the Xe + Xe system with those obtained from the Pb + Pb system at $\sqrt{s_{NN}} = 5.02$ TeV from Ref. [22] as a function of centrality percentile (left column) or N_{part} (right column). For both systems, F_2 shows a strong dependence on centrality percentile and N_{part} , while the F_3 and F_4 each show rather weak dependence. The F_4 values depend weakly on both centrality percentile and N_{part} , and they agree between the two systems. In the noncentral collisions (centrality percentiles $\gtrsim 30\%$ or $N_{\text{part}} \lesssim 80$), the F_2 for the two systems agree only as a function of N_{part} , while the F_3 agree as a function of either centrality percentiles or N_{part} . In the midcentral collisions, F_2 is much larger in Xe + Xe collisions than in Pb + Pb collisions, while an opposite trend is observed for F_3 . This reverse system-size ordering between F_2 and F_3 is also observed for A_{ε_2} and A_{ε_3} from

Ref. [32], which strongly suggests that the flow decorrelations are driven by longitudinal fluctuations of the eccentricity vector in the initial state. The data are also compared with results from a hydrodynamic model with longitudinal fluctuations included [30,54]. The model quantitatively describes the behavior of F_2 and F_4 in midcentral collisions, but fails to describe the magnitude of F_3 and the splitting between the two systems, pointing to an inadequate description of the initial state and its system-size dependence implemented in this model.

To help further understand the relationship between the transverse harmonic flow and its longitudinal fluctuations, Fig. 4 compares the ratios of flow decorrelation $F_n^{\text{XeXe}}/F_n^{\text{PbPb}}$ (F_n ratios) with ratios of flow harmonics $v_n^{\text{XeXe}}/v_n^{\text{PbPb}}$ (v_n ratios) from Ref. [35] as a function of centrality percentile. While the v_n ratios all decrease with centrality percentile, the F_n ratios increase with centrality percentile; this opposite trend implies that, when the ratio of average flow is larger, the ratio of its relative fluctuations in the longitudinal direction is smaller and vice versa. Beyond this overall opposite trend, there are other contrasting features between the two types of ratios. The F_2 ratio is always above 1, while the v_2 ratio decreases to below 1 around 10%–20% centrality; the F_2 ratio is larger than the v_2 ratio except in the 0%–5% centrality interval, where the v_2 ratio is enhanced due to the deformation of the Xe nucleus [36]. The differences between the F_3 ratio and the v_3 ratio are smaller, but with different centrality dependencies: while the v_3 ratio decreases nearly linearly with centrality percentile, the F_3 ratio first decreases and then increases as a function of centrality percentile. The F_4 ratio has larger uncertainties, but shows much stronger centrality dependence compared with the v_4 ratio.

Figure 4 compares these ratios with hydrodynamic model calculations [30,36,54]. The advantage of comparison in terms of ratios is that the model uncertainties in the initial-state geometry as well as final-state dynamics are expected to partially cancel out. While the calculations from Ref. [36] quantitatively describe the trend of the v_n ratios, they agree less well with the F_n ratios and, in particular, the model [30,54] overestimates the F_2 and F_3 ratios for centrality percentiles beyond 20%–30%. Therefore, these hydrodynamic models fail to describe the longitudinal flow fluctuations and their system-size dependence trends, even though they have been tuned to describe the overall transverse collective dynamics. This failure is likely due to an inadequate description of the longitudinal structure of the initial state in these models. In fact, a recent calculation [32] based on a simple Glauber model with the parametrized longitudinal structure was able to describe simultaneously the system-size dependence of the v_n decorrelation and inclusive v_n , supporting this conjecture. One future direction is to develop a framework based on the three-dimensional initial condition dynamically generated from gluon saturation physics,

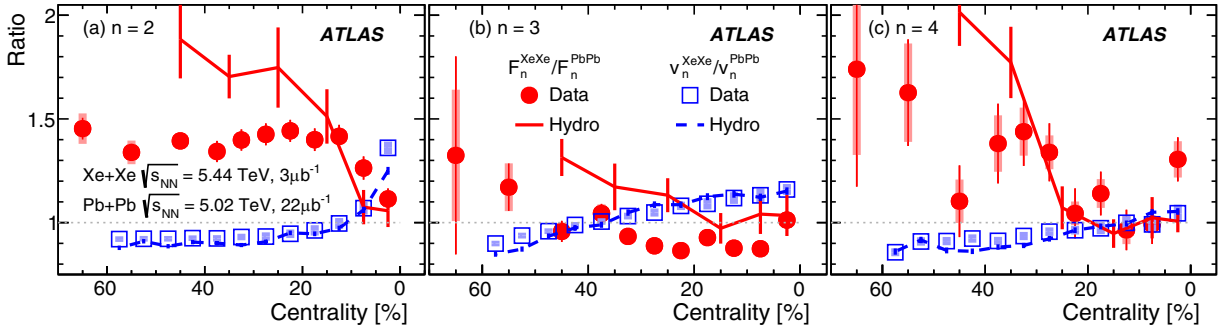


FIG. 4. The ratios $F_n^{\text{XeXe}}/F_n^{\text{PbPb}}$ from data [22] (solid symbols) and model [30,54] (solid lines) and $v_n^{\text{XeXe}}/v_n^{\text{PbPb}}$ from data [35] (open symbols) and model [36] (dashed lines) as a function of centrality for (a) $n = 2$, (b) $n = 3$, and (c) $n = 4$, respectively. The error bars and shaded boxes on the data represent statistical and systematic uncertainties, respectively. The vertical error bars on the theory calculations represent the statistical uncertainties.

coupled with a hydrodynamic model [55,56]. The part of \mathcal{E}_{n-} arising from gluon saturation is related to the saturation scale (Q_s) controlled by the overall system size, while that arising from the forward-backward asymmetry is related to the shape of the overlap controlled by the centrality. Therefore, one could fix the Q_s evolution in the Pb + Pb and make predictions in the Xe + Xe system, which will help to separate different initial-state effects. The system-size dependence of the v_n and v_n decorrelation data provides important input to stimulate further theoretical efforts along this direction.

In summary, ATLAS presents the first measurement of longitudinal decorrelations for harmonic flow v_n in Xe + Xe collisions at $\sqrt{s_{NN}} = 5.44$ TeV, based on $3 \mu\text{b}^{-1}$ of data collected at the LHC. The v_n decorrelations are nearly independent of centrality percentile and p_T for $n = 3$ and 4. For $n = 2$, the v_n decorrelations are smallest in midcentral collisions and increases for more-central or more-peripheral collisions, and also depends on p_T . A comparison with Pb + Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV shows that the v_2 decorrelation is larger in Xe + Xe collisions than in Pb + Pb collisions in most of the centrality range, while the opposite trend is observed for v_3 decorrelation. This reverse ordering is consistent with the expected behavior of eccentricity decorrelations in the two systems and is not observed for the ratios of v_2 and v_3 between the two systems. Hydrodynamic models are found to describe the ratios of v_n between Xe + Xe and Pb + Pb, but fail to describe most of the magnitudes and trends of the ratios of the v_n decorrelations between Xe + Xe and Pb + Pb. This suggests that current models tuned to describe the transverse dynamics do not describe the longitudinal structure of the initial-state geometry.

Understanding the initial conditions and early time effects is vital for adequate modeling of heavy-ion collisions [57]. System-size dependence of flow decorrelations, together with measurements of the inclusive flow harmonics, provide new insights and an important lever arm to separate effects of the longitudinal structure of the initial

state from other early time and late time effects. This measurement gives important input for complete modeling of the three-dimensional initial conditions and space-time dynamics of heavy-ion collisions used in hydrodynamic models.

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently. We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC, and CFI, Canada; CERN; ANID, Chile; CAS, MOST, and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR, and VSC CR, Czech Republic; DNRF and DNSRC, Denmark; IN2P3-CNRS and CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF, and MPG, Germany; GSRT, Greece; RGC and Hong Kong SAR, China; ISF and Benozio Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MNiSW and NCN, Poland; FCT, Portugal; MNE/IFA, Romania; JINR; MES of Russia and NRC KI, Russian Federation; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DST/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF, and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TAEK, Turkey; STFC, United Kingdom; DOE and NSF, U.S. In addition, individual groups and members have received support from BCKDF, CANARIE, Compute Canada, CRC, and IVADO, Canada; Beijing Municipal Science and Technology Commission, China; COST, ERC, ERDF, Horizon 2020, and Marie Skłodowska-Curie Actions, European Union; Investissements d’Avenir Labex, Investissements d’Avenir Idex, and ANR, France; DFG and AvH Foundation, Germany; Herakleitos, Thales, and Aristeia programmes cofinanced by EU-ESF and the Greek NSRF, Greece; BSF-NSF and GIF, Israel; La Caixa Banking Foundation,

CERCA Programme Generalitat de Catalunya, and PROMETEO and GenT Programmes Generalitat Valenciana, Spain; Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom. The crucial computing support from all WLCG partners is acknowledged gratefully, in particular, from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK), and BNL (U.S.), the Tier-2 facilities worldwide, and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [58].

-
- [1] C. Gale, S. Jeon, and B. Schenke, Hydrodynamic modeling of heavy-ion collisions, *Int. J. Mod. Phys. A* **28**, 1340011 (2013).
- [2] U. Heinz and R. Snellings, Collective flow and viscosity in relativistic heavy-ion collisions, *Annu. Rev. Nucl. Part. Sci.* **63**, 123 (2013).
- [3] J. Jia, Event-shape fluctuations and flow correlations in ultra-relativistic heavy-ion collisions, *J. Phys. G* **41**, 124003 (2014).
- [4] H. Niemi, G. S. Denicol, H. Holopainen, and P. Huovinen, Event-by-event distributions of azimuthal asymmetries in ultrarelativistic heavy-ion collisions, *Phys. Rev. C* **87**, 054901 (2013).
- [5] PHENIX Collaboration, Measurements of Higher-Order Flow Harmonics in Au+Au Collisions at $\sqrt{s_{NN}}=200$ GeV, *Phys. Rev. Lett.* **107**, 252301 (2011).
- [6] ALICE Collaboration, Higher Harmonic Anisotropic Flow Measurements of Charged Particles in Pb-Pb Collisions at $\sqrt{s_{NN}} = 2.76$ TeV, *Phys. Rev. Lett.* **107**, 032301 (2011).
- [7] ATLAS Collaboration, Measurement of the azimuthal anisotropy for charged particle production in $\sqrt{s_{NN}} = 2.76$ TeV lead-lead collisions with the ATLAS detector, *Phys. Rev. C* **86**, 014907 (2012).
- [8] CMS Collaboration, Measurement of higher-order harmonic azimuthal anisotropy in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, *Phys. Rev. C* **89**, 044906 (2014).
- [9] ATLAS Collaboration, Measurement of the distributions of event-by-event flow harmonics in lead-lead collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS detector at the LHC, *J. High Energy Phys.* **11** (2013) 183.
- [10] ATLAS Collaboration, Measurement of event-plane correlations in $\sqrt{s_{NN}} = 2.76$ TeV lead-lead collisions with the ATLAS detector, *Phys. Rev. C* **90**, 024905 (2014).
- [11] ATLAS Collaboration, Measurement of the correlation between flow harmonics of different order in lead-lead collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS detector, *Phys. Rev. C* **92**, 034903 (2015).
- [12] ALICE Collaboration, Correlated Event-by-Event Fluctuations of Flow Harmonics in Pb-Pb Collisions at $\sqrt{s_{NN}} = 2.76$ TeV, *Phys. Rev. Lett.* **117**, 182301 (2016).
- [13] CMS Collaboration, Non-Gaussian elliptic-flow fluctuations in PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, *Phys. Lett. B* **789**, 643 (2019).
- [14] ALICE Collaboration, Energy dependence and fluctuations of anisotropic flow in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ and 2.76 TeV, *J. High Energy Phys.* **07** (2018) 103.
- [15] STAR Collaboration, Azimuthal Harmonics in Small and Large Collision Systems at RHIC Top Energies, *Phys. Rev. Lett.* **122**, 172301 (2019).
- [16] M. Luzum and J.-Y. Ollitrault, Extracting the shear viscosity of the quark-gluon plasma from flow in ultra-central heavy-ion collisions, *Nucl. Phys. A* **904–905**, 377 (2013).
- [17] D. Teaney and L. Yan, Triangularity and dipole asymmetry in relativistic heavy ion collisions, *Phys. Rev. C* **83**, 064904 (2011).
- [18] C. Gale, S. Jeon, B. Schenke, P. Tribedy, and R. Venugopalan, Event-By-Event Anisotropic Flow in Heavy-ion Collisions from Combined Yang-Mills and Viscous Fluid Dynamics, *Phys. Rev. Lett.* **110**, 012302 (2013).
- [19] Z. Qiu and U. Heinz, Hydrodynamic event-plane correlations in Pb + Pb collisions at $\sqrt{s} = 2.76$ A TeV, *Phys. Lett. B* **717**, 261 (2012).
- [20] D. Teaney and L. Yan, Event-plane correlations and hydrodynamic simulations of heavy ion collisions, *Phys. Rev. C* **90**, 024902 (2014).
- [21] CMS Collaboration, Evidence for transverse momentum and pseudorapidity dependent event plane fluctuations in PbPb and pPb collisions, *Phys. Rev. C* **92**, 034911 (2015).
- [22] ATLAS Collaboration, Measurement of longitudinal flow decorrelations in Pb + Pb collisions at $\sqrt{s_{NN}} = 2.76$ and 5.02 TeV with the ATLAS detector, *Eur. Phys. J. C* **78**, 142 (2018).
- [23] J. Jia, P. Huo, G. Ma, and M. Nie, Observables for longitudinal flow correlations in heavy-ion collisions, *J. Phys. G* **44**, 075106 (2017).
- [24] P. Bozek, W. Broniowski, and J. Moreira, Torqued fireballs in relativistic heavy-ion collisions, *Phys. Rev. C* **83**, 034911 (2011).
- [25] J. Jia and P. Huo, Forward-backward eccentricity and participant-plane angle fluctuations and their influences on longitudinal dynamics of collective flow, *Phys. Rev. C* **90**, 034915 (2014).
- [26] P. Bozek and W. Broniowski, The torque effect and fluctuations of entropy deposition in rapidity in ultra-relativistic nuclear collisions, *Phys. Lett. B* **752**, 206 (2016).
- [27] L.-G. Pang, H. Petersen, G.-Y. Qin, V. Roy, and X.-N. Wang, Decorrelation of anisotropic flow along the longitudinal direction, *Eur. Phys. J. A* **52**, 97 (2016).
- [28] C. Shen and B. Schenke, Dynamical initial state model for relativistic heavy-ion collisions, *Phys. Rev. C* **97**, 024907 (2018).
- [29] P. Bozek and W. Broniowski, Longitudinal decorrelation measures of flow magnitude and event-plane angles in ultrarelativistic nuclear collisions, *Phys. Rev. C* **97**, 034913 (2018).
- [30] L.-G. Pang, H. Petersen, and X.-N. Wang, Pseudorapidity distribution and decorrelation of anisotropic flow within the open-computing-language implementation CLVisc hydrodynamics, *Phys. Rev. C* **97**, 064918 (2018).

- [31] A. Sakai, K. Murase, and T. Hirano, Rapidity decorrelation of anisotropic flow caused by hydrodynamic fluctuations, *Phys. Rev. C* **102**, 064903 (2020).
- [32] A. Behera, M. Nie, and J. Jia, Longitudinal eccentricity decorrelations in heavy ion collisions, *Phys. Rev. Research* **2**, 023362 (2020).
- [33] ALICE Collaboration, Anisotropic flow in Xe-Xe collisions at $\sqrt{s_{NN}} = 5.44$ TeV, *Phys. Lett. B* **784**, 82 (2018).
- [34] CMS Collaboration, Charged-particle angular correlations in XeXe collisions at $\sqrt{s_{NN}} = 5.44$ TeV, *Phys. Rev. C* **100**, 044902 (2019).
- [35] ATLAS Collaboration, Measurement of the azimuthal anisotropy of charged-particle production in Xe + Xe collisions at $\sqrt{s_{NN}} = 5.44$ TeV with the ATLAS detector, *Phys. Rev. C* **101**, 024906 (2020).
- [36] G. Giacalone, J. Noronha-Hostler, M. Luzum, and J.-Y. Ollitrault, Hydrodynamic predictions for 5.44 TeV Xe + Xe collisions, *Phys. Rev. C* **97**, 034904 (2018).
- [37] K. J. Eskola, H. Niemi, R. Paatelainen, and K. Tuominen, Predictions for multiplicities and flow harmonics in 5.44 TeV Xe + Xe collisions at the CERN large hadron collider, *Phys. Rev. C* **97**, 034911 (2018).
- [38] ATLAS Collaboration, The ATLAS experiment at the CERN large hadron collider, *J. Instrum.* **3**, S08003 (2008).
- [39] ATLAS Collaboration, Performance of the ATLAS trigger system in 2015, *Eur. Phys. J. C* **77**, 317 (2017).
- [40] ATLAS Collaboration, The ATLAS inner detector commissioning and calibration, *Eur. Phys. J. C* **70**, 787 (2010).
- [41] ATLAS Collaboration, ATLAS insertable B-layer technical design report, CERN Report No. ATLAS-TDR-19, 2010, <https://cds.cern.ch/record/1291633>; Addendum, CERN Report No. ATLAS-TDR-19-ADD-1, 2012, <https://cds.cern.ch/record/1451888>.
- [42] B. Abbott *et al.*, Production and integration of the ATLAS insertable B-layer, *J. Instrum.* **13**, T05008 (2018).
- [43] ATLAS Collaboration, Vertex reconstruction performance of the ATLAS detector at $\sqrt{s} = 13$ TeV, CERN Report No. ATL-PHYS-PUB-2015-026, 2015, <https://cds.cern.ch/record/2037717>.
- [44] ATLAS Collaboration, Measurement of the azimuthal anisotropy of charged particles produced in $\sqrt{s_{NN}} = 5.02$ TeV Pb + Pb collisions with the ATLAS detector, *Eur. Phys. J. C* **78**, 997 (2018).
- [45] M. L. Miller, K. Reygers, S. J. Sanders, and P. Steinberg, Glauber modeling in high-energy nuclear collisions, *Annu. Rev. Nucl. Part. Sci.* **57**, 205 (2007).
- [46] ATLAS Collaboration, Measurement of the centrality dependence of the charged particle pseudorapidity distribution in lead-lead collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS detector, *Phys. Lett. B* **710**, 363 (2012).
- [47] ATLAS Collaboration, The optimization of ATLAS track reconstruction in dense environments, CERN Report No. ATL-PHYS-PUB-2015-006, 2015, <https://cds.cern.ch/record/2002609>.
- [48] M. Gyulassy and X.-N. Wang, HIJING 1.0: A Monte Carlo program for parton and particle production in high-energy hadronic and nuclear collisions, *Comput. Phys. Commun.* **83**, 307 (1994).
- [49] M. Maseara, G. Ortona, M. G. Poghosyan, and F. Prino, Anisotropic transverse flow introduction in Monte Carlo generators for heavy ion collisions, *Phys. Rev. C* **79**, 064909 (2009).
- [50] ATLAS Collaboration, The ATLAS simulation infrastructure, *Eur. Phys. J. C* **70**, 823 (2010).
- [51] S. Agostinelli *et al.*, GEANT4—A simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [52] ATLAS Collaboration, Measurement of flow harmonics with multi-particle cumulants in Pb + Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS detector, *Eur. Phys. J. C* **74**, 3157 (2014).
- [53] J. Jia, M. Zhou, and A. Trzupek, Revealing long-range multiparticle collectivity in small collision systems via subevent cumulants, *Phys. Rev. C* **96**, 034906 (2017).
- [54] X.-Y. Wu, L.-G. Pang, G.-Y. Qin, and X.-N. Wang, Longitudinal fluctuations and decorrelations of anisotropic flows at energies available at the CERN large hadron collider and at the BNL relativistic heavy ion collider, *Phys. Rev. C* **98**, 024913 (2018).
- [55] B. Schenke and S. Schlichting, 3D glasma initial state for relativistic heavy ion collisions, *Phys. Rev. C* **94**, 044907 (2016).
- [56] S. McDonald, S. Jeon, and C. Gale, Exploring longitudinal observables with 3 + 1D IP-Glasma, *Nucl. Phys. A* **1005**, 121771 (2021).
- [57] W. Busza, K. Rajagopal, and W. van der Schee, Heavy ion collisions: The big picture, and the big questions, *Annu. Rev. Nucl. Part. Sci.* **68**, 339 (2018).
- [58] ATLAS Collaboration, ATLAS computing acknowledgements, Report No. ATL-GEN-PUB-2016-002, 2016, <https://cds.cern.ch/record/2202407>.

G. Aad,¹⁰² B. Abbott,¹²⁸ D. C. Abbott,¹⁰³ A. Abed Abud,³⁶ K. Abeling,⁵³ D. K. Abhayasinghe,⁹⁴ S. H. Abidi,¹⁶⁷ O. S. AbouZeid,⁴⁰ N. L. Abraham,¹⁵⁶ H. Abramowicz,¹⁶¹ H. Abreu,¹⁶⁰ Y. Abulaiti,⁶ B. S. Acharya,^{67a,67b} B. Achkar,⁵³ S. Adachi,¹⁶³ L. Adam,¹⁰⁰ C. Adam Bourdarios,⁵ L. Adamczyk,^{84a} L. Adamek,¹⁶⁷ J. Adelman,¹²¹ M. Adersberger,¹¹⁴ A. Adiguzel,^{12c,c} S. Adorni,⁵⁴ T. Adye,¹⁴³ A. A. Affolder,¹⁴⁵ Y. Afik,¹⁶⁰ C. Agapopoulou,⁶⁵ M. N. Agaras,³⁸ A. Aggarwal,¹¹⁹ C. Agheorghiesei,^{27c} J. A. Aguilar-Saavedra,^{139f,139a,d} F. Ahmadov,⁸⁰ W. S. Ahmed,¹⁰⁴ X. Ai,¹⁸ G. Aielli,^{74a,74b} S. Akatsuka,⁸⁶ T. P. A. Åkesson,⁹⁷ E. Akilli,⁵⁴ A. V. Akimov,¹¹¹ K. Al Khoury,⁶⁵ G. L. Alberghi,^{23b,23a} J. Albert,¹⁷⁶ M. J. Alconada Verzini,¹⁶¹ S. Alderweireldt,³⁶ M. Aleksa,³⁶ I. N. Aleksandrov,⁸⁰ C. Alexa,^{27b} T. Alexopoulos,¹⁰ A. Alfonsi,¹²⁰ F. Alfonsi,^{23b,23a} M. Alhroob,¹²⁸ B. Ali,¹⁴¹ M. Aliev,¹⁶⁶ G. Alimonti,^{69a} C. Allaire,⁶⁵ B. M. M. Allbrooke,¹⁵⁶

B. W. Allen,¹³¹ P. P. Allport,²¹ A. Aloisio,^{70a,70b} F. Alonso,⁸⁹ C. Alpigliani,¹⁴⁸ A. A. Alshehri,⁵⁷ E. Alunno Camelia,^{74a,74b}
 M. Alvarez Estevez,⁹⁹ M. G. Alviggi,^{70a,70b} Y. Amaral Coutinho,^{81b} A. Ambler,¹⁰⁴ L. Ambroz,¹³⁴ C. Amelung,²⁶
 D. Amidei,¹⁰⁶ S. P. Amor Dos Santos,^{139a} S. Amoroso,⁴⁶ C. S. Amrouche,⁵⁴ F. An,⁷⁹ C. Anastopoulos,¹⁴⁹ N. Andari,¹⁴⁴
 T. Andeen,¹¹ C. F. Anders,^{61b} J. K. Anders,²⁰ S. Y. Andrean,^{45a,45b} A. Andreazza,^{69a,69b} V. Andrei,^{61a} C. R. Anelli,¹⁷⁶
 S. Angelidakis,³⁸ A. Angerami,³⁹ A. V. Anisenkov,^{122b,122a} A. Annovi,^{72a} C. Antel,⁵⁴ M. T. Anthony,¹⁴⁹ E. Antipov,¹²⁹
 M. Antonelli,⁵¹ D. J. A. Antrim,¹⁷¹ F. Anulli,^{73a} M. Aoki,⁸² J. A. Aparisi Pozo,¹⁷⁴ M. A. Aparo,¹⁵⁶ L. Aperio Bella,^{15a}
 J. P. Araque,^{139a} V. Araujo Ferraz,^{81b} R. Araujo Pereira,^{81b} C. Arcangeletti,⁵¹ A. T. H. Arce,⁴⁹ F. A. Arduh,⁸⁹ J-F. Arguin,¹¹⁰
 S. Argyropoulos,⁵² J.-H. Arling,⁴⁶ A. J. Armbruster,³⁶ A. Armstrong,¹⁷¹ O. Arnaez,¹⁶⁷ H. Arnold,¹²⁰
 Z. P. Arrubarrena Tame,¹¹⁴ G. Artoni,¹³⁴ S. Artz,¹⁰⁰ S. Asai,¹⁶³ T. Asawatavonvanich,¹⁶⁵ N. Asbah,⁵⁹
 E. M. Asimakopoulou,¹⁷² L. Asquith,¹⁵⁶ J. Assahsah,^{35d} K. Assamagan,²⁹ R. Astalos,^{28a} R. J. Atkin,^{33a} M. Atkinson,¹⁷³
 N. B. Atlay,¹⁹ H. Atmani,⁶⁵ K. Augsten,¹⁴¹ G. Avolio,³⁶ M. K. Ayoub,^{15a} G. Azuelos,^{110,e} H. Bachacou,¹⁴⁴ K. Bachas,¹⁶²
 M. Backes,¹³⁴ F. Backman,^{45a,45b} P. Bagnaia,^{73a,73b} M. Bahmani,⁸⁵ H. Bahrasemani,¹⁵² A. J. Bailey,¹⁷⁴ V. R. Bailey,¹⁷³
 J. T. Baines,¹⁴³ C. Bakalis,¹⁰ O. K. Baker,¹⁸³ P. J. Bakker,¹²⁰ D. Bakshi Gupta,⁸ S. Balaji,¹⁵⁷ E. M. Baldin,^{122b,122a} P. Balek,¹⁸⁰
 F. Balli,¹⁴⁴ W. K. Balunas,¹³⁴ J. Balz,¹⁰⁰ E. Banas,⁸⁵ M. Bandieramonte,¹³⁸ A. Bandyopadhyay,²⁴ Sw. Banerjee,^{181,f}
 L. Barak,¹⁶¹ W. M. Barbe,³⁸ E. L. Barberio,¹⁰⁵ D. Barberis,^{55b,55a} M. Barbero,¹⁰² G. Barbour,⁹⁵ T. Barillari,¹¹⁵
 M-S. Barisits,³⁶ J. Barkeloo,¹³¹ T. Barklow,¹⁵³ R. Barnea,¹⁶⁰ B. M. Barnett,¹⁴³ R. M. Barnett,¹⁸ Z. Barnovska-Blenessy,^{60a}
 A. Baroncelli,^{60a} G. Barone,²⁹ A. J. Barr,¹³⁴ L. Barranco Navarro,^{45a,45b} F. Barreiro,⁹⁹ J. Barreiro Guimarães da Costa,^{15a}
 S. Barsov,¹³⁷ F. Bartels,^{61a} R. Bartoldus,¹⁵³ G. Bartolini,¹⁰² A. E. Barton,⁹⁰ P. Bartos,^{28a} A. Basalaeu,⁴⁶ A. Basan,¹⁰⁰
 A. Bassalat,^{65,g} M. J. Basso,¹⁶⁷ R. L. Bates,⁵⁷ S. Batlamous,^{35e} J. R. Batley,³² B. Batool,¹⁵¹ M. Battaglia,¹⁴⁵ M. Bause,^{73a,73b}
 F. Bauer,¹⁴⁴ K. T. Bauer,¹⁷¹ H. S. Bawa,³¹ J. B. Beacham,⁴⁹ T. Beau,¹³⁵ P. H. Beauchemin,¹⁷⁰ F. Becherer,⁵² P. Bechtle,²⁴
 H. C. Beck,⁵³ H. P. Beck,^{20,h} K. Becker,¹⁷⁸ C. Becot,⁴⁶ A. Beddall,^{12d} A. J. Beddall,^{12a} V. A. Bednyakov,⁸⁰ M. Bedognetti,¹²⁰
 C. P. Bee,¹⁵⁵ T. A. Beermann,¹⁸² M. Begalli,^{81b} M. Begel,²⁹ A. Behera,¹⁵⁵ J. K. Behr,⁴⁶ F. Beisiegel,²⁴ A. S. Bell,⁹⁵
 G. Bella,¹⁶¹ L. Bellagamba,^{23b} A. Bellerive,³⁴ P. Bellos,⁹ K. Beloborodov,^{122b,122a} K. Belotskiy,¹¹² N. L. Belyaev,¹¹²
 D. Benckroun,^{35a} N. Benekos,¹⁰ Y. Benhammou,¹⁶¹ D. P. Benjamin,⁶ M. Benoit,⁵⁴ J. R. Bensinger,²⁶ S. Bentvelsen,¹²⁰
 L. Beresford,¹³⁴ M. Beretta,⁵¹ D. Berge,¹⁹ E. Bergeaas Kuutmann,¹⁷² N. Berger,⁵ B. Bergmann,¹⁴¹ L. J. Bergsten,²⁶
 J. Beringer,¹⁸ S. Berlendis,⁷ G. Bernardi,¹³⁵ C. Bernius,¹⁵³ F. U. Bernlochner,²⁴ T. Berry,⁹⁴ P. Berta,¹⁰⁰ C. Bertella,^{15a}
 I. A. Bertram,⁹⁰ O. Bessidskaia Bylund,¹⁸² N. Besson,¹⁴⁴ A. Bethani,¹⁰¹ S. Bethke,¹¹⁵ A. Betti,⁴² A. J. Bevan,⁹³ J. Beyer,¹¹⁵
 D. S. Bhattacharya,¹⁷⁷ P. Bhattarai,²⁶ R. Bi,¹³⁸ R. M. Bianchi,¹³⁸ O. Biebel,¹¹⁴ D. Biedermann,¹⁹ R. Bielski,³⁶
 K. Bierwagen,¹⁰⁰ N. V. Biesuz,^{72a,72b} M. Biglietti,^{75a} T. R. V. Billoud,¹¹⁰ M. Bindi,⁵³ A. Bingul,^{12d} C. Bini,^{73a,73b}
 S. Biondi,^{23b,23a} M. Birman,¹⁸⁰ T. Bisanz,³⁶ J. P. Biswal,³ D. Biswas,^{181,f} A. Bitadze,¹⁰¹ C. Bittrich,⁴⁸ K. Bjørke,¹³³
 T. Blazek,^{28a} I. Bloch,⁴⁶ C. Blocker,²⁶ A. Blue,⁵⁷ U. Blumenschein,⁹³ G. J. Bobbink,¹²⁰ V. S. Bobrovnikov,^{122b,122a}
 S. S. Bocchetta,⁹⁷ A. Bocci,⁴⁹ D. Bogavac,¹⁴ A. G. Bogdanchikov,^{122b,122a} C. Bohm,^{45a} V. Boisvert,⁹⁴ P. Bokan,⁵³ T. Bold,^{84a}
 A. E. Bolz,^{61b} M. Bomben,¹³⁵ M. Bona,⁹³ J. S. Bonilla,¹³¹ M. Boonekamp,¹⁴⁴ C. D. Booth,⁹⁴ H. M. Borecka-Bielska,⁹¹
 L. S. Borgna,⁹⁵ A. Borisov,¹²³ G. Borissov,⁹⁰ J. Bortfeldt,³⁶ D. Bortoletto,¹³⁴ D. Boscherini,^{23b} M. Bosman,¹⁴
 J. D. Bossio Sola,¹⁰⁴ K. Bouaouda,^{35a} J. Boudreau,¹³⁸ E. V. Bouhova-Thacker,⁹⁰ D. Boumediene,³⁸ S. K. Boutle,⁵⁷
 A. Boveia,¹²⁷ J. Boyd,³⁶ D. Boye,^{33c,i} I. R. Boyko,⁸⁰ A. J. Bozson,⁹⁴ J. Bracik,²¹ N. Brahimi,¹⁰² G. Brandt,¹⁸² O. Brandt,³²
 F. Braren,⁴⁶ B. Brau,¹⁰³ J. E. Brau,¹³¹ W. D. Breaden Madden,⁵⁷ K. Brendlinger,⁴⁶ L. Brenner,⁴⁶ R. Brenner,¹⁷² S. Bressler,¹⁸⁰
 B. Brickwedde,¹⁰⁰ D. L. Briglin,²¹ D. Britton,⁵⁷ D. Britzger,¹¹⁵ I. Brock,²⁴ R. Brock,¹⁰⁷ G. Brooijmans,³⁹ W. K. Brooks,^{146d}
 E. Brost,²⁹ J. H. Broughton,²¹ P. A. Bruckman de Renstrom,⁸⁵ D. Bruncko,^{28b} A. Bruni,^{23b} G. Bruni,^{23b} L. S. Bruni,¹²⁰
 S. Bruno,^{74a,74b} M. Bruschi,^{23b} N. Bruscino,^{73a,73b} L. Bryngemark,⁹⁷ T. Buanes,¹⁷ Q. Buat,³⁶ P. Buchholz,¹⁵¹ A. G. Buckley,⁵⁷
 I. A. Budagov,⁸⁰ M. K. Bugge,¹³³ F. Bühner,⁵² O. Bulekov,¹¹² T. J. Burch,¹²¹ S. Burdin,⁹¹ C. D. Burgard,¹²⁰ A. M. Burger,¹²⁹
 B. Burghgrave,⁸ J. T. P. Burr,⁴⁶ C. D. Burton,¹¹ J. C. Burzynski,¹⁰³ V. Büscher,¹⁰⁰ E. Buschmann,⁵³ P. J. Bussey,⁵⁷
 J. M. Butler,²⁵ C. M. Buttar,⁵⁷ J. M. Butterworth,⁹⁵ P. Butti,³⁶ W. Buttinger,³⁶ C. J. Buxo Vazquez,¹⁰⁷ A. Buzatu,¹⁵⁸
 A. R. Buzykaev,^{122b,122a} G. Cabras,^{23b,23a} S. Cabrera Urbán,¹⁷⁴ D. Caforio,⁵⁶ H. Cai,¹⁷³ V. M. M. Cairo,¹⁵³ O. Cakir,^{4a}
 N. Calace,³⁶ P. Calafiura,¹⁸ G. Calderini,¹³⁵ P. Calfayan,⁶⁶ G. Callea,⁵⁷ L. P. Caloba,^{81b} A. Caltabiano,^{74a,74b}
 S. Calvente Lopez,⁹⁹ D. Calvet,³⁸ S. Calvet,³⁸ T. P. Calvet,¹⁵⁵ M. Calvetti,^{72a,72b} R. Camacho Toro,¹³⁵ S. Camarda,³⁶
 D. Camarero Munoz,⁹⁹ P. Camarri,^{74a,74b} D. Cameron,¹³³ C. Camincher,³⁶ S. Campana,³⁶ M. Campanelli,⁹⁵ A. Camplani,⁴⁰
 A. Campoverde,¹⁵¹ V. Canale,^{70a,70b} A. Canesse,¹⁰⁴ M. Cano Bret,^{60c} J. Cantero,¹²⁹ T. Cao,¹⁶¹ Y. Cao,¹⁷³
 M. D. M. Capeans Garrido,³⁶ M. Capua,^{41b,41a} R. Cardarelli,^{74a} F. Cardillo,¹⁴⁹ G. Carducci,^{41b,41a} I. Carli,¹⁴² T. Carli,³⁶

G. Carlino,^{70a} B. T. Carlson,¹³⁸ E. M. Carlson,^{176,168a} L. Carminati,^{69a,69b} R. M. D. Carney,¹⁵³ S. Caron,¹¹⁹ E. Carquin,^{146d} S. Carrá,⁴⁶ J. W. S. Carter,¹⁶⁷ M. P. Casado,^{14j} A. F. Casha,¹⁶⁷ F. L. Castillo,¹⁷⁴ L. Castillo Garcia,¹⁴ V. Castillo Gimenez,¹⁷⁴ N. F. Castro,^{139a,139e} A. Catinaccio,³⁶ J. R. Catmore,¹³³ A. Cattai,³⁶ V. Cavaliere,²⁹ E. Cavallaro,¹⁴ M. Cavalli-Sforza,¹⁴ V. Cavasinni,^{72a,72b} E. Celebi,^{12b} L. Cerda Alberich,¹⁷⁴ K. Cerny,¹³⁰ A. S. Cerqueira,^{81a} A. Cerri,¹⁵⁶ L. Cerrito,^{74a,74b} F. Cerutti,¹⁸ A. Cervelli,^{23b,23a} S. A. Cetin,^{12b} Z. Chadi,^{35a} D. Chakraborty,¹²¹ J. Chan,¹⁸¹ W. S. Chan,¹²⁰ W. Y. Chan,⁹¹ J. D. Chapman,³² B. Chargeishvili,^{159b} D. G. Charlton,²¹ T. P. Charman,⁹³ C. C. Chau,³⁴ S. Che,¹²⁷ S. Chekanov,⁶ S. V. Chekulaev,^{168a} G. A. Chelkov,^{80,k} B. Chen,⁷⁹ C. Chen,^{60a} C. H. Chen,⁷⁹ H. Chen,²⁹ J. Chen,^{60a} J. Chen,³⁹ J. Chen,²⁶ S. Chen,¹³⁶ S. J. Chen,^{15c} X. Chen,^{15b} Y-H. Chen,⁴⁶ H. C. Cheng,^{63a} H. J. Cheng,^{15a} A. Cheplakov,⁸⁰ E. Cheremushkina,¹²³ R. Cherkaoui El Moursli,^{35e} E. Cheu,⁷ K. Cheung,⁶⁴ T. J. A. Chevaléras,¹⁴⁴ L. Chevalier,¹⁴⁴ V. Chiarella,⁵¹ G. Chiarelli,^{72a} G. Chiodini,^{68a} A. S. Chisholm,²¹ A. Chitan,^{27b} I. Chiu,¹⁶³ Y. H. Chiu,¹⁷⁶ M. V. Chizhov,⁸⁰ K. Choi,¹¹ A. R. Chomont,^{73a,73b} S. Chouridou,¹⁶² Y. S. Chow,¹²⁰ M. C. Chu,^{63a} X. Chu,^{15a,15d} J. Chudoba,¹⁴⁰ J. J. Chwastowski,⁸⁵ L. Chytka,¹³⁰ D. Cieri,¹¹⁵ K. M. Ciesla,⁸⁵ D. Cinca,⁴⁷ V. Cindro,⁹² I. A. Cioară,^{27b} A. Ciocio,¹⁸ F. Ciroto,^{70a,70b} Z. H. Citron,^{180,l} M. Citterio,^{69a} D. A. Ciubotaru,^{27b} B. M. Ciungu,¹⁶⁷ A. Clark,⁵⁴ M. R. Clark,³⁹ P. J. Clark,⁵⁰ C. Clement,^{45a,45b} Y. Coadou,¹⁰² M. Cobal,^{67a,67c} A. Coccaro,^{55b} J. Cochran,⁷⁹ R. Coelho Lopes De Sa,¹⁰³ H. Cohen,¹⁶¹ A. E. C. Coimbra,³⁶ B. Cole,³⁹ A. P. Colijn,¹²⁰ J. Collot,⁵⁸ P. Conde Muño,^{139a,139h} S. H. Connell,^{33c} I. A. Connelly,⁵⁷ S. Constantinescu,^{27b} F. Conventi,^{70a,m} A. M. Cooper-Sarkar,¹³⁴ F. Cormier,¹⁷⁵ K. J. R. Cormier,¹⁶⁷ L. D. Corpe,⁹⁵ M. Corradi,^{73a,73b} E. E. Corrigan,⁹⁷ F. Corriveau,^{104,n} M. J. Costa,¹⁷⁴ F. Costanza,⁵ D. Costanzo,¹⁴⁹ G. Cowan,⁹⁴ J. W. Cowley,³² J. Crane,¹⁰¹ K. Cranmer,¹²⁵ S. J. Crawley,⁵⁷ R. A. Creager,¹³⁶ S. Crépe-Renaudin,⁵⁸ F. Crescioli,¹³⁵ M. Cristinziani,²⁴ V. Croft,¹⁷⁰ G. Crosetti,^{41b,41a} A. Cueto,⁵ T. Cuhadar Donszelmann,¹⁷¹ A. R. Cukierman,¹⁵³ W. R. Cunningham,⁵⁷ S. Czekerda,⁸⁵ P. Czodrowski,³⁶ M. M. Czurylo,^{61b} M. J. Da Cunha Sargedas De Sousa,^{60b} J. V. Da Fonseca Pinto,^{81b} C. Da Via,¹⁰¹ W. Dabrowski,^{84a} F. Dachs,³⁶ T. Dado,^{28a} S. Dahbi,^{33e} T. Dai,¹⁰⁶ C. Dallapiccola,¹⁰³ M. Dam,⁴⁰ G. D'amen,²⁹ V. D'Amico,^{75a,75b} J. Damp,¹⁰⁰ J. R. Dandoy,¹³⁶ M. F. Daneri,³⁰ N. S. Dann,¹⁰¹ M. Danninger,¹⁵² V. Dao,³⁶ G. Darbo,^{55b} O. Darsi,⁵ A. Dattagupta,¹³¹ T. Daubney,⁴⁶ S. D'Auria,^{69a,69b} C. David,^{168b} T. Davidek,¹⁴² D. R. Davis,⁴⁹ I. Dawson,¹⁴⁹ K. De,⁸ R. De Asmundis,^{70a} M. De Beurs,¹²⁰ S. De Castro,^{23b,23a} S. De Cecco,^{73a,73b} N. De Groot,¹¹⁹ P. de Jong,¹²⁰ H. De la Torre,¹⁰⁷ A. De Maria,^{15c} D. De Pedis,^{73a} A. De Salvo,^{73a} U. De Sanctis,^{74a,74b} M. De Santis,^{74a,74b} A. De Santo,¹⁵⁶ K. De Vasconcelos Corga,¹⁰² J. B. De Vivie De Regie,⁶⁵ C. Debenedetti,¹⁴⁵ D. V. Dedovich,⁸⁰ A. M. Deiana,⁴² J. Del Peso,⁹⁹ Y. Delabat Diaz,⁴⁶ D. Delgove,⁶⁵ F. Deliot,^{144,o} C. M. Delitzsch,⁷ M. Della Pietra,^{70a,70b} D. Della Volpe,⁵⁴ A. Dell'Acqua,³⁶ L. Dell'Asta,^{74a,74b} M. Delmastro,⁵ C. Delporte,⁶⁵ P. A. Delsart,⁵⁸ D. A. DeMarco,¹⁶⁷ S. Demers,¹⁸³ M. Demichev,⁸⁰ G. Demontigny,¹¹⁰ S. P. Denisov,¹²³ L. D'Eramo,¹³⁵ D. Derendarz,⁸⁵ J. E. Derkaoui,^{35d} F. Derue,¹³⁵ P. Dervan,⁹¹ K. Desch,²⁴ C. Deterre,⁴⁶ K. Dette,¹⁶⁷ C. Deutsch,²⁴ M. R. Devesa,³⁰ P. O. Deviveiros,³⁶ F. A. Di Bello,^{73a,73b} A. Di Ciaccio,^{74a,74b} L. Di Ciaccio,⁵ W. K. Di Clemente,¹³⁶ C. Di Donato,^{70a,70b} A. Di Girolamo,³⁶ G. Di Gregorio,^{72a,72b} B. Di Micco,^{75a,75b} R. Di Nardo,^{75a,75b} K. F. Di Petrillo,⁵⁹ R. Di Sipio,¹⁶⁷ C. Diaconu,¹⁰² F. A. Dias,⁴⁰ T. Dias Do Vale,^{139a} M. A. Diaz,^{146a} J. Dickinson,¹⁸ E. B. Diehl,¹⁰⁶ J. Dietrich,¹⁹ S. Díez Cornell,⁴⁶ A. Dimitrievska,¹⁸ W. Ding,^{15b} J. Dingfelder,²⁴ F. Dittus,³⁶ F. Djama,¹⁰² T. Djobava,^{159b} J. I. Djuvsland,¹⁷ M. A. B. Do Vale,¹⁴⁷ M. Dobre,^{27b} D. Dodsworth,²⁶ C. Doglioni,⁹⁷ J. Dolejsi,¹⁴² Z. Dolezal,¹⁴² M. Donadelli,^{81c} B. Dong,^{60c} J. Donini,³⁸ A. D'onofrio,^{15c} M. D'Onofrio,⁹¹ J. Dopke,¹⁴³ A. Doria,^{70a} M. T. Dova,⁸⁹ A. T. Doyle,⁵⁷ E. Drechsler,¹⁵² E. Dreyer,¹⁵² T. Dreyer,⁵³ A. S. Drobac,¹⁷⁰ D. Du,^{60b} Y. Duan,^{60b} F. Dubinin,¹¹¹ M. Dubovsky,^{28a} A. Dubreuil,⁵⁴ E. Duchovni,¹⁸⁰ G. Duckeck,¹¹⁴ A. Ducourthial,¹³⁵ O. A. Ducu,¹¹⁰ D. Duda,¹¹⁵ A. Dudarev,³⁶ A. C. Dudder,¹⁰⁰ E. M. Duffield,¹⁸ L. Dufлот,⁶⁵ M. Dührssen,³⁶ C. Dülsen,¹⁸² M. Dumancic,¹⁸⁰ A. E. Dumitriu,^{27b} A. K. Duncan,⁵⁷ M. Dunford,^{61a} A. Duperrin,¹⁰² H. Duran Yildiz,^{4a} M. Düren,⁵⁶ A. Durglishvili,^{159b} D. Duschinger,⁴⁸ B. Dutta,⁴⁶ D. Duvnjak,¹ G. I. Dyckes,¹³⁶ M. Dyndal,³⁶ S. Dysch,¹⁰¹ B. S. Dziejic,⁸⁵ K. M. Ecker,¹¹⁵ M. G. Eggleston,⁴⁹ T. Eifert,⁸ G. Eigen,¹⁷ K. Einsweiler,¹⁸ T. Ekelof,¹⁷² H. El Jarrari,^{35e} R. El Kosseifi,¹⁰² V. Ellajosyula,¹⁷² M. Ellert,¹⁷² F. Ellinghaus,¹⁸² A. A. Elliot,⁹³ N. Ellis,³⁶ J. Elmsheuser,²⁹ M. Elsing,³⁶ D. Emelianov,¹⁴³ A. Emerman,³⁹ Y. Enari,¹⁶³ M. B. Epland,⁴⁹ J. Erdmann,⁴⁷ A. Ereditato,²⁰ P. A. Erland,⁸⁵ M. Errenst,³⁶ M. Escalier,⁶⁵ C. Escobar,¹⁷⁴ O. Estrada Pastor,¹⁷⁴ E. Etzion,¹⁶¹ H. Evans,⁶⁶ M. O. Evans,¹⁵⁶ A. Ezhilov,¹³⁷ F. Fabbri,⁵⁷ L. Fabbri,^{23b,23a} V. Fabiani,¹¹⁹ G. Facini,¹⁷⁸ R. M. Faisca Rodrigues Pereira,^{139a} R. M. Fakhruddinov,¹²³ S. Falciano,^{73a} P. J. Falke,⁵ S. Falke,⁵ J. Faltova,¹⁴² Y. Fang,^{15a} Y. Fang,^{15a} G. Fanourakis,⁴⁴ M. Fanti,^{69a,69b} M. Faraj,^{67a,67c,p} A. Farbin,⁸ A. Farilla,^{75a} E. M. Farina,^{71a,71b} T. Farooque,¹⁰⁷ S. M. Farrington,⁵⁰ P. Farthouat,³⁶ F. Fassi,^{35e} P. Fassnacht,³⁶ D. Fassouliotis,⁹ M. Fauci Giannelli,⁵⁰ W. J. Fawcett,³² L. Fayard,⁶⁵ O. L. Fedin,^{137,q} W. Fedorko,¹⁷⁵ A. Fehr,²⁰ M. Feickert,¹⁷³ L. Feligioni,¹⁰² A. Fell,¹⁴⁹ C. Feng,^{60b} M. Feng,⁴⁹ M. J. Fenton,¹⁷¹ A. B. Fenyuk,¹²³ S. W. Ferguson,⁴³ J. Ferrando,⁴⁶ A. Ferrante,¹⁷³ A. Ferrari,¹⁷²

P. Ferrari,¹²⁰ R. Ferrari,^{71a} D. E. Ferreira de Lima,^{61b} A. Ferrer,¹⁷⁴ D. Ferrere,⁵⁴ C. Ferretti,¹⁰⁶ F. Fiedler,¹⁰⁰ A. Filipčić,⁹²
 F. Filthaut,¹¹⁹ K. D. Finelli,²⁵ M. C. N. Fiolhais,^{139a,139c,r} L. Fiorini,¹⁷⁴ F. Fischer,¹¹⁴ W. C. Fisher,¹⁰⁷ I. Fleck,¹⁵¹
 P. Fleischmann,¹⁰⁶ T. Flick,¹⁸² B. M. Flierl,¹¹⁴ L. Flores,¹³⁶ L. R. Flores Castillo,^{63a} F. M. Follega,^{76a,76b} N. Fomin,¹⁷
 J. H. Foo,¹⁶⁷ G. T. Forcolin,^{76a,76b} A. Formica,¹⁴⁴ F. A. Förster,¹⁴ A. C. Forti,¹⁰¹ A. G. Foster,²¹ M. G. Foti,¹³⁴ D. Fournier,⁶⁵
 H. Fox,⁹⁰ P. Francavilla,^{72a,72b} S. Francescato,^{73a,73b} M. Franchini,^{23b,23a} S. Franchino,^{61a} D. Francis,³⁶ L. Franconi,²⁰
 M. Franklin,⁵⁹ A. N. Fray,⁹³ P. M. Freeman,²¹ B. Freund,¹¹⁰ W. S. Freund,^{81b} E. M. Freundlich,⁴⁷ D. C. Frizzell,¹²⁸
 D. Froidevaux,³⁶ J. A. Frost,¹³⁴ C. Fukunaga,¹⁶⁴ E. Fullana Torregrosa,¹⁷⁴ T. Fusayasu,¹¹⁶ J. Fuster,¹⁷⁴ A. Gabrielli,^{23b,23a}
 A. Gabrielli,¹⁸ S. Gadatsch,⁵⁴ P. Gadow,¹¹⁵ G. Gagliardi,^{55b,55a} L. G. Gagnon,¹¹⁰ B. Galhardo,^{139a} G. E. Gallardo,¹³⁴
 E. J. Gallas,¹³⁴ B. J. Gallop,¹⁴³ G. Galster,⁴⁰ R. Gamboa Goni,⁹³ K. K. Gan,¹²⁷ S. Ganguly,¹⁸⁰ J. Gao,^{60a} Y. Gao,⁵⁰
 Y. S. Gao,^{31,s} C. García,¹⁷⁴ J. E. García Navarro,¹⁷⁴ J. A. García Pascual,^{15a} C. Garcia-Argos,⁵² M. Garcia-Sciveres,¹⁸
 R. W. Gardner,³⁷ N. Garelli,¹⁵³ S. Gargiulo,⁵² C. A. Garner,¹⁶⁷ V. Garonne,¹³³ S. J. Gasiorowski,¹⁴⁸ P. Gaspar,^{81b}
 A. Gaudiello,^{55b,55a} G. Gaudio,^{71a} I. L. Gavrilenko,¹¹¹ A. Gavrilyuk,¹²⁴ C. Gay,¹⁷⁵ G. Gaycken,⁴⁶ E. N. Gazis,¹⁰
 A. A. Geanta,^{27b} C. M. Gee,¹⁴⁵ C. N. P. Gee,¹⁴³ J. Geisen,⁹⁷ M. Geisen,¹⁰⁰ C. Gemme,^{55b} M. H. Genest,⁵⁸ C. Geng,¹⁰⁶
 S. Gentile,^{73a,73b} S. George,⁹⁴ T. Geralis,⁴⁴ L. O. Gerlach,⁵³ P. Gessinger-Befurt,¹⁰⁰ G. Gessner,⁴⁷ S. Ghasemi,¹⁵¹
 M. Ghasemi Bostanabad,¹⁷⁶ M. Ghneimat,¹⁵¹ A. Ghosh,⁶⁵ A. Ghosh,⁷⁸ B. Giacobbe,^{23b} S. Giagu,^{73a,73b}
 N. Giangiacomi,^{23b,23a} P. Giannetti,^{72a} A. Giannini,^{70a,70b} G. Giannini,¹⁴ S. M. Gibson,⁹⁴ M. Gignac,¹⁴⁵ D. Gillberg,³⁴
 G. Gilles,¹⁸² D. M. Gingrich,^{3,e} M. P. Giordani,^{67a,67c} P. F. Giraud,¹⁴⁴ G. Giugliarelli,^{67a,67c} D. Giugni,^{69a} F. Giuli,^{74a,74b}
 S. Gkaitatzis,¹⁶² I. Gkialas,^{9,t} E. L. Gkougkousis,¹⁴ P. Gkoutoumis,¹⁰ L. K. Gladilin,¹¹³ C. Glasman,⁹⁹ J. Glatzer,¹⁴
 P. C. F. Glaysheer,⁴⁶ A. Glazov,⁴⁶ G. R. Gledhill,¹³¹ I. Gnesi,^{41b} M. Goblirsch-Kolb,²⁶ D. Godin,¹¹⁰ S. Goldfarb,¹⁰⁵
 T. Golling,⁵⁴ D. Golubkov,¹²³ A. Gomes,^{139a,139b} R. Goncalves Gama,⁵³ R. Gonçalves,^{139a} G. Gonella,¹³¹ L. Gonella,²¹
 A. Gongadze,⁸⁰ F. Gonnella,²¹ J. L. Gonski,³⁹ S. González de la Hoz,¹⁷⁴ S. Gonzalez Fernandez,¹⁴ C. Gonzalez Renteria,¹⁸
 S. Gonzalez-Sevilla,⁵⁴ G. R. Gonzalvo Rodriguez,¹⁷⁴ L. Goossens,³⁶ N. A. Gorasia,²¹ P. A. Gorbounov,¹²⁴ H. A. Gordon,²⁹
 B. Gorini,³⁶ E. Gorini,^{68a,68b} A. Gorišek,⁹² A. T. Goshaw,⁴⁹ M. I. Gostkin,⁸⁰ C. A. Gottardo,¹¹⁹ M. Goughri,^{35b}
 A. G. Goussiou,¹⁴⁸ N. Govender,^{33c} C. Goy,⁵ E. Gozani,¹⁶⁰ I. Grabowska-Bold,^{84a} E. C. Graham,⁹¹ J. Gramling,¹⁷¹
 E. Gramstad,¹³³ S. Grancagnolo,¹⁹ M. Grandi,¹⁵⁶ V. Gratchev,¹³⁷ P. M. Gravila,^{27f} F. G. Gravili,^{68a,68b} C. Gray,⁵⁷
 H. M. Gray,¹⁸ C. Grefe,²⁴ K. Gregersen,⁹⁷ I. M. Gregor,⁴⁶ P. Grenier,¹⁵³ K. Grevtsov,⁴⁶ C. Grieco,¹⁴ N. A. Grieser,¹²⁸
 A. A. Grillo,¹⁴⁵ K. Grimm,^{31,u} S. Grinstein,^{14,v} J.-F. Grivaz,⁶⁵ S. Groh,¹⁰⁰ E. Gross,¹⁸⁰ J. Grosse-Knetter,⁵³ Z. J. Grout,⁹⁵
 C. Grud,¹⁰⁶ A. Grummer,¹¹⁸ L. Guan,¹⁰⁶ W. Guan,¹⁸¹ C. Gubbels,¹⁷⁵ J. Guenther,³⁶ A. Guerguichon,⁶⁵
 J. G. R. Guerrero Rojas,¹⁷⁴ F. Guescini,¹¹⁵ D. Guest,¹⁷¹ R. Gugel,⁵² T. Guillemin,⁵ S. Guindon,³⁶ U. Gul,⁵⁷ J. Guo,^{60c}
 W. Guo,¹⁰⁶ Y. Guo,^{60a} Z. Guo,¹⁰² R. Gupta,⁴⁶ S. Gurbuz,^{12c} G. Gustavino,¹²⁸ M. Guth,⁵² P. Gutierrez,¹²⁸ C. Gutschow,⁹⁵
 C. Guyot,¹⁴⁴ C. Gwenlan,¹³⁴ C. B. Gwilliam,⁹¹ A. Haas,¹²⁵ C. Haber,¹⁸ H. K. Hadavand,⁸ A. Hadeif,^{60a} M. Haleem,¹⁷⁷
 J. Haley,¹²⁹ G. Halladjian,¹⁰⁷ G. D. Hallewell,¹⁰² K. Hamacher,¹⁸² P. Hamal,¹³⁰ K. Hamano,¹⁷⁶ H. Hamdaoui,^{35e} M. Hamer,²⁴
 G. N. Hamity,⁵⁰ K. Han,^{60a,w} L. Han,^{60a} S. Han,^{15a} Y. F. Han,¹⁶⁷ K. Hanagaki,^{82,x} M. Hance,¹⁴⁵ D. M. Handl,¹¹⁴ B. Haney,¹³⁶
 R. Hankache,¹³⁵ E. Hansen,⁹⁷ J. B. Hansen,⁴⁰ J. D. Hansen,⁴⁰ M. C. Hansen,²⁴ P. H. Hansen,⁴⁰ E. C. Hanson,¹⁰¹ K. Hara,¹⁶⁹
 T. Harenberg,¹⁸² S. Harkusha,¹⁰⁸ P. F. Harrison,¹⁷⁸ N. M. Hartman,¹⁵³ N. M. Hartmann,¹¹⁴ Y. Hasegawa,¹⁵⁰ A. Hasib,⁵⁰
 S. Hassani,¹⁴⁴ S. Haug,²⁰ R. Hauser,¹⁰⁷ L. B. Havener,³⁹ M. Havranek,¹⁴¹ C. M. Hawkes,²¹ R. J. Hawkings,³⁶ D. Hayden,¹⁰⁷
 C. Hayes,¹⁰⁶ R. L. Hayes,¹⁷⁵ C. P. Hays,¹³⁴ J. M. Hays,⁹³ H. S. Hayward,⁹¹ S. J. Haywood,¹⁴³ F. He,^{60a} M. P. Heath,⁵⁰
 V. Hedberg,⁹⁷ S. Heer,²⁴ K. K. Heidegger,⁵² W. D. Heidorn,⁷⁹ J. Heilman,³⁴ S. Heim,⁴⁶ T. Heim,¹⁸ B. Heinemann,^{46,y}
 J. J. Heinrich,¹³¹ L. Heinrich,³⁶ J. Hejbal,¹⁴⁰ L. Helary,^{61b} A. Held,¹²⁵ S. Hellesund,¹³³ C. M. Helling,¹⁴⁵ S. Hellman,^{45a,45b}
 C. Hensens,³⁶ R. C. W. Henderson,⁹⁰ Y. Heng,¹⁸¹ L. Henkelmann,³² A. M. Henriques Correia,³⁶ H. Herde,²⁶
 Y. Hernández Jiménez,^{33e} H. Herr,¹⁰⁰ M. G. Herrmann,¹¹⁴ T. Herrmann,⁴⁸ G. Herten,⁵² R. Hertenberger,¹¹⁴ L. Hervas,³⁶
 T. C. Herwig,¹³⁶ G. G. Hesketh,⁹⁵ N. P. Hessey,^{168a} H. Hibi,⁸³ A. Higashida,¹⁶³ S. Higashino,⁸² E. Higón-Rodríguez,¹⁷⁴
 K. Hildebrand,³⁷ J. C. Hill,³² K. K. Hill,²⁹ K. H. Hiller,⁴⁶ S. J. Hillier,²¹ M. Hils,⁴⁸ I. Hinchliffe,¹⁸ F. Hinterkeuser,²⁴
 M. Hirose,¹³² S. Hirose,⁵² D. Hirschbuehl,¹⁸² B. Hiti,⁹² O. Hladik,¹⁴⁰ D. R. Hlaluku,^{33e} J. Hobbs,¹⁵⁵ N. Hod,¹⁸⁰
 M. C. Hodgkinson,¹⁴⁹ A. Hoecker,³⁶ D. Hohn,⁵² D. Hohov,⁶⁵ T. Holm,²⁴ T. R. Holmes,³⁷ M. Holzbock,¹¹⁴
 L. B. A. H. Hommels,³² S. Honda,¹⁶⁹ T. M. Hong,¹³⁸ J. C. Honig,⁵² A. Hönle,¹¹⁵ B. H. Hooberman,¹⁷³ W. H. Hopkins,⁶
 Y. Hori,¹¹⁷ P. Horn,⁴⁸ L. A. Horyn,³⁷ S. Hou,¹⁵⁸ A. Hoummada,^{35a} J. Howarth,⁵⁷ J. Hoya,⁸⁹ M. Hrabovsky,¹³⁰ J. Hrdinka,⁷⁷
 I. Hristova,¹⁹ J. Hrivnac,⁶⁵ A. Hrynevich,¹⁰⁹ T. Hryn'ova,⁵ P. J. Hsu,⁶⁴ S.-C. Hsu,¹⁴⁸ Q. Hu,²⁹ S. Hu,^{60c} Y. F. Hu,^{15a,15d}
 D. P. Huang,⁹⁵ Y. Huang,^{60a} Y. Huang,^{15a} Z. Hubacek,¹⁴¹ F. Hubaut,¹⁰² M. Huebner,²⁴ F. Huegging,²⁴ T. B. Huffman,¹³⁴

M. Huhtinen,³⁶ R. F. H. Hunter,³⁴ P. Huo,¹⁵⁵ N. Huseynov,^{80,z} J. Huston,¹⁰⁷ J. Huth,⁵⁹ R. Hyneman,¹⁰⁶ S. Hyrych,^{28a}
 G. Iacobucci,⁵⁴ G. Iakovidis,²⁹ I. Ibragimov,¹⁵¹ L. Iconomidou-Fayard,⁶⁵ P. Iengo,³⁶ R. Ignazzi,⁴⁰ O. Igonkina,^{120,a,aa}
 R. Iguchi,¹⁶³ T. Iizawa,⁵⁴ Y. Ikegami,⁸² M. Ikeno,⁸² D. Iliadis,¹⁶² N. Ilic,^{119,167,n} F. Iltzsche,⁴⁸ G. Introzzi,^{71a,71b} M. Iodice,^{75a}
 K. Iordanidou,^{168a} V. Ippolito,^{73a,73b} M. F. Isacson,¹⁷² M. Ishino,¹⁶³ W. Islam,¹²⁹ C. Issever,^{19,46} S. Istin,¹⁶⁰ F. Ito,¹⁶⁹
 J. M. Iturbe Ponce,^{63a} R. Iuppa,^{76a,76b} A. Ivina,¹⁸⁰ H. Iwasaki,⁸² J. M. Izen,⁴³ V. Izzo,^{70a} P. Jacka,¹⁴⁰ P. Jackson,¹
 R. M. Jacobs,²⁴ B. P. Jaeger,¹⁵² V. Jain,² G. Jäkel,¹⁸² K. B. Jakobi,¹⁰⁰ K. Jakobs,⁵² T. Jakoubek,¹⁴⁰ J. Jamieson,⁵⁷
 K. W. Janas,^{84a} R. Jansky,⁵⁴ M. Janus,⁵³ P. A. Janus,^{84a} G. Jarlskog,⁹⁷ A. E. Jaspan,⁹¹ N. Javadov,^{80,z} T. Javůrek,³⁶
 M. Javurkova,¹⁰³ F. Jeanneau,¹⁴⁴ L. Jeanty,¹³¹ J. Jejelava,^{159a} A. Jelinskas,¹⁷⁸ P. Jenni,^{52,bb} N. Jeong,⁴⁶ S. Jézéquel,⁵ H. Ji,¹⁸¹
 J. Jia,¹⁵⁵ H. Jiang,⁷⁹ Y. Jiang,^{60a} Z. Jiang,¹⁵³ S. Jiggins,⁵² F. A. Jimenez Morales,³⁸ J. Jimenez Pena,¹¹⁵ S. Jin,^{15c} A. Jinaru,^{27b}
 O. Jinnouchi,¹⁶⁵ H. Jivan,^{33e} P. Johansson,¹⁴⁹ K. A. Johns,⁷ C. A. Johnson,⁶⁶ R. W. L. Jones,⁹⁰ S. D. Jones,¹⁵⁶ S. Jones,⁷
 T. J. Jones,⁹¹ J. Jongmanns,^{61a} P. M. Jorge,^{139a} J. Jovicevic,³⁶ X. Ju,¹⁸ J. J. Junggeburth,¹¹⁵ A. Juste Rozas,^{14,v}
 A. Kaczmarzka,⁸⁵ M. Kado,^{73a,73b} H. Kagan,¹²⁷ M. Kagan,¹⁵³ A. Kahn,³⁹ C. Kahra,¹⁰⁰ T. Kaji,¹⁷⁹ E. Kajomovitz,¹⁶⁰
 C. W. Kalderon,²⁹ A. Kaluza,¹⁰⁰ A. Kamenshchikov,¹²³ M. Kaneda,¹⁶³ N. J. Kang,¹⁴⁵ S. Kang,⁷⁹ Y. Kano,¹¹⁷ J. Kanzaki,⁸²
 L. S. Kaplan,¹⁸¹ D. Kar,^{33e} K. Karava,¹³⁴ M. J. Kareem,^{168b} I. Karkanias,¹⁶² S. N. Karpov,⁸⁰ Z. M. Karpova,⁸⁰
 V. Kartvelishvili,⁹⁰ A. N. Karyukhin,¹²³ A. Kastanas,^{45a,45b} C. Kato,^{60d,60c} J. Katzy,⁴⁶ K. Kawade,¹⁵⁰ K. Kawagoe,⁸⁸
 T. Kawaguchi,¹¹⁷ T. Kawamoto,¹⁴⁴ G. Kawamura,⁵³ E. F. Kay,¹⁷⁶ V. F. Kazanin,^{122b,122a} R. Keeler,¹⁷⁶ R. Kehoe,⁴²
 J. S. Keller,³⁴ E. Kellermann,⁹⁷ D. Kelsey,¹⁵⁶ J. J. Kempster,²¹ J. Kendrick,²¹ K. E. Kennedy,³⁹ O. Kepka,¹⁴⁰ S. Kersten,¹⁸²
 B. P. Kerševan,⁹² S. Ketabchi Haghighat,¹⁶⁷ M. Khader,¹⁷³ F. Khalil-Zada,¹⁴⁴ M. Khandoga,¹⁴⁴ A. Khanov,¹²⁹
 A. G. Kharlamov,^{122b,122a} T. Kharlamova,^{122b,122a} E. E. Khoda,¹⁷⁵ A. Khodinov,¹⁶⁶ T. J. Khoo,⁵⁴ E. Khranov,⁸⁰
 J. Khubua,^{159b} S. Kido,⁸³ M. Kiehn,⁵⁴ C. R. Kilby,⁹⁴ E. Kim,¹⁶⁵ Y. K. Kim,³⁷ N. Kimura,⁹⁵ O. M. Kind,¹⁹ B. T. King,^{91,a}
 D. Kirchmeier,⁴⁸ J. Kirk,¹⁴³ A. E. Kiryunin,¹¹⁵ T. Kishimoto,¹⁶³ D. P. Kisiuk,¹⁶⁷ V. Kitali,⁴⁶ O. Kivernyk,²⁴
 T. Klapdor-Kleingrothaus,⁵² M. Klassen,^{61a} C. Klein,³⁴ M. H. Klein,¹⁰⁶ M. Klein,⁹¹ U. Klein,⁹¹ K. Kleinknecht,¹⁰⁰
 P. Klimek,¹²¹ A. Klimentov,²⁹ T. Klingl,²⁴ T. Klioutchnikova,³⁶ F. F. Klitzner,¹¹⁴ P. Kluit,¹²⁰ S. Kluth,¹¹⁵ E. Kneringer,⁷⁷
 E. B. F. G. Knoops,¹⁰² A. Knue,⁵² D. Kobayashi,⁸⁸ T. Kobayashi,¹⁶³ M. Kobel,⁴⁸ M. Kocian,¹⁵³ T. Kodama,¹⁶³ P. Kodys,¹⁴²
 D. M. Koeck,¹⁵⁶ P. T. Koenig,²⁴ T. Koffas,³⁴ N. M. Köhler,³⁶ M. Kolb,¹⁴⁴ I. Koletsou,⁵ T. Komarek,¹³⁰ T. Kondo,⁸²
 K. Köneke,⁵² A. X. Y. Kong,¹ A. C. König,¹¹⁹ T. Kono,¹²⁶ V. Konstantinides,⁹⁵ N. Konstantinidis,⁹⁵ B. Konya,⁹⁷
 R. Kopeliansky,⁶⁶ S. Koperny,^{84a} K. Korcyl,⁸⁵ K. Kordas,¹⁶² G. Koren,¹⁶¹ A. Korn,⁹⁵ I. Korolkov,¹⁴ E. V. Korolkova,¹⁴⁹
 N. Korotkova,¹¹³ O. Kortner,¹¹⁵ S. Kortner,¹¹⁵ V. V. Kostyukhin,^{149,166} A. Kotskechagia,⁶⁵ A. Kotwal,⁴⁹ A. Koulouris,¹⁰
 A. Kourkoumeli-Charalampidi,^{71a,71b} C. Kourkoumelis,⁹ E. Kourlitis,¹⁴⁹ V. Kouskoura,²⁹ A. B. Kowalewska,⁸⁵
 R. Kowalewski,¹⁷⁶ W. Kozanecki,¹⁰¹ A. S. Kozhin,¹²³ V. A. Kramarenko,¹¹³ G. Kramberger,⁹² D. Krasnopevtsev,^{60a}
 M. W. Krasny,¹³⁵ A. Krasznahorkay,³⁶ D. Krauss,¹¹⁵ J. A. Kremer,^{84a} J. Kretzschmar,⁹¹ P. Krieger,¹⁶⁷ F. Krieter,¹¹⁴
 A. Krishnan,^{61b} K. Krizka,¹⁸ K. Kroeninger,⁴⁷ H. Kroha,¹¹⁵ J. Kroll,¹⁴⁰ J. Kroll,¹³⁶ K. S. Krowpman,¹⁰⁷ U. Kruchonak,⁸⁰
 H. Krüger,²⁴ N. Krumnack,⁷⁹ M. C. Kruse,⁴⁹ J. A. Krzysiak,⁸⁵ T. Kubota,¹⁰⁵ O. Kuchinskaia,¹⁶⁶ S. Kuday,^{4b} D. Kuechler,⁴⁶
 J. T. Kuechler,⁴⁶ S. Kuehn,³⁶ A. Kugel,^{61a} T. Kuhl,⁴⁶ V. Kukhtin,⁸⁰ R. Kukla,¹⁰² Y. Kulchitsky,^{108,cc} S. Kuleshov,^{146b}
 Y. P. Kulinich,¹⁷³ M. Kuna,⁵⁸ T. Kunigo,⁸⁶ A. Kupco,¹⁴⁰ T. Kupfer,⁴⁷ O. Kuprash,⁵² H. Kurashige,⁸³ L. L. Kurchaninov,^{168a}
 Y. A. Kurochkin,¹⁰⁸ A. Kurova,¹¹² M. G. Kurth,^{15a,15d} E. S. Kuwertz,³⁶ M. Kuze,¹⁶⁵ A. K. Kvam,¹⁴⁸ J. Kvita,¹³⁰ T. Kwan,¹⁰⁴
 L. La Rotonda,^{41b,41a} F. La Ruffa,^{41b,41a} C. Lacasta,¹⁷⁴ F. Lacava,^{73a,73b} D. P. J. Lack,¹⁰¹ H. Lacker,¹⁹ D. Lacour,¹³⁵
 E. Ladygin,⁸⁰ R. Lafaye,⁵ B. Laforge,¹³⁵ T. Lagouri,^{146b} S. Lai,⁵³ I. K. Lakomic,^{84a} S. Lammers,⁶⁶ W. Lampl,⁷
 C. Lampoudis,¹⁶² E. Lançon,²⁹ U. Landgraf,⁵² M. P. J. Landon,⁹³ M. C. Lanfermann,⁵⁴ V. S. Lang,⁴⁶ J. C. Lange,⁵³
 R. J. Langenberg,¹⁰³ A. J. Lankford,¹⁷¹ F. Lanni,²⁹ K. Lantzsck,²⁴ A. Lanza,^{71a} A. Lapertosa,^{55b,55a} S. Laplace,¹³⁵
 J. F. Laporte,¹⁴⁴ T. Lari,^{69a} F. Lasagni Manghi,^{23b,23a} M. Lassnig,³⁶ T. S. Lau,^{63a} A. Laudrain,⁶⁵ A. Laurier,³⁴
 M. Lavorgna,^{70a,70b} S. D. Lawlor,⁹⁴ M. Lazzaroni,^{69a,69b} B. Le,¹⁰¹ E. Le Guirriec,¹⁰² A. Lebedev,⁷⁹ M. LeBlanc,⁷
 T. LeCompte,⁶ F. Ledroit-Guillon,⁵⁸ A. C. A. Lee,⁹⁵ C. A. Lee,²⁹ G. R. Lee,¹⁷ L. Lee,⁵⁹ S. C. Lee,¹⁵⁸ S. Lee,⁷⁹
 B. Lefebvre,^{168a} H. P. Lefebvre,⁹⁴ M. Lefebvre,¹⁷⁶ C. Leggett,¹⁸ K. Lehmann,¹⁵² N. Lehmann,²⁰ G. Lehmann Miotto,³⁶
 W. A. Leight,⁴⁶ A. Leisos,^{162,dd} M. A. L. Leite,^{81c} C. E. Leitgeb,¹¹⁴ R. Leitner,¹⁴² D. Lellouch,^{180,a} K. J. C. Leney,⁴²
 T. Lenz,²⁴ R. Leone,⁷ S. Leone,^{72a} C. Leonidopoulos,⁵⁰ A. Leopold,¹³⁵ C. Leroy,¹¹⁰ R. Les,¹⁶⁷ C. G. Lester,³²
 M. Levchenko,¹³⁷ J. Levêque,⁵ D. Levin,¹⁰⁶ L. J. Levinson,¹⁸⁰ D. J. Lewis,²¹ B. Li,^{15b} B. Li,¹⁰⁶ C-Q. Li,^{60a} F. Li,^{60c} H. Li,^{60a}
 H. Li,^{60b} J. Li,^{60c} K. Li,¹⁴⁸ L. Li,^{60c} M. Li,^{15a,15d} Q. Li,^{15a,15d} Q. Y. Li,^{60a} S. Li,^{60d,60c} X. Li,⁴⁶ Y. Li,⁴⁶ Z. Li,^{60b} Z. Li,¹⁰⁴
 Z. Liang,^{15a} B. Liberti,^{74a} A. Liblong,¹⁶⁷ K. Lie,^{63c} S. Lim,²⁹ C. Y. Lin,³² K. Lin,¹⁰⁷ T. H. Lin,¹⁰⁰ R. A. Linck,⁶⁶

R. E. Lindley,⁷ J. H. Lindon,²¹ A. L. Lioni,⁵⁴ E. Lipeles,¹³⁶ A. Lipniacka,¹⁷ T. M. Liss,^{173,ee} A. Lister,¹⁷⁵ J. D. Little,⁸ B. Liu,⁷⁹ B. X. Liu,⁶ H. B. Liu,²⁹ H. Liu,¹⁰⁶ J. B. Liu,^{60a} J. K. K. Liu,³⁷ K. Liu,^{60d} M. Liu,^{60a} P. Liu,^{15a} Y. Liu,⁴⁶ Y. Liu,^{15a,15d} Y. L. Liu,¹⁰⁶ Y. W. Liu,^{60a} M. Livan,^{71a,71b} A. Lleres,⁵⁸ J. Llorente Merino,¹⁵² S. L. Lloyd,⁹³ C. Y. Lo,^{63b} E. M. Lobodzinska,⁴⁶ P. Loch,^{74a,74b} S. Loffredo,¹⁹ T. Lohse,¹⁹ K. Lohwasser,¹⁴⁹ M. Lokajicek,¹⁴⁰ J. D. Long,¹⁷³ R. E. Long,⁹⁰ L. Longo,³⁶ K. A.Looper,¹²⁷ I. Lopez Paz,¹⁰¹ A. Lopez Solis,¹⁴⁹ J. Lorenz,¹¹⁴ N. Lorenzo Martinez,⁵ A. M. Lory,¹¹⁴ P. J. Lösel,¹¹⁴ A. Lösle,⁵² X. Lou,⁴⁶ X. Lou,^{15a} A. Lounis,⁶⁵ J. Love,⁶ P. A. Love,⁹⁰ J. J. Lozano Bahilo,¹⁷⁴ M. Lu,^{60a} Y. J. Lu,⁶⁴ H. J. Lubatti,¹⁴⁸ C. Luci,^{73a,73b} A. Lucotte,⁵⁸ C. Luedtke,⁵² F. Luehring,⁶⁶ I. Luise,¹³⁵ L. Luminari,^{73a} B. Lund-Jensen,¹⁵⁴ M. S. Lutz,¹⁰³ D. Lynn,²⁹ H. Lyons,⁹¹ R. Lysak,¹⁴⁰ E. Lytken,⁹⁷ F. Lyu,^{15a} V. Lyubushkin,⁸⁰ T. Lyubushkina,⁸⁰ H. Ma,²⁹ L. L. Ma,^{60b} Y. Ma,⁹⁵ G. Maccarrone,⁵¹ A. Macchiolo,¹¹⁵ C. M. Macdonald,¹⁴⁹ J. Machado Miguens,¹³⁶ D. Madaffari,¹⁷⁴ R. Madar,³⁸ W. F. Mader,⁴⁸ M. Madugoda Ralalage Don,¹²⁹ N. Madysa,⁴⁸ J. Maeda,⁸³ T. Maeno,²⁹ M. Maerker,⁴⁸ V. Magerl,⁵² N. Magini,⁷⁹ J. Magro,^{67a,67c,p} D. J. Mahon,³⁹ C. Maidantchik,^{81b} T. Maier,¹¹⁴ A. Maio,^{139a,139b,139d} K. Maj,^{84a} O. Majersky,^{28a} S. Majewski,¹³¹ Y. Makida,⁸² N. Makovec,⁶⁵ B. Malaescu,¹³⁵ Pa. Malecki,⁸⁵ V. P. Maleev,¹³⁷ F. Malek,⁵⁸ U. Mallik,⁷⁸ D. Malon,⁶ C. Malone,³² S. Maltezos,¹⁰ S. Malyukov,⁸⁰ J. Mamuzic,¹⁷⁴ G. Mancini,⁵¹ I. Mandić,⁹² L. Manhaes de Andrade Filho,^{81a} I. M. Maniatis,¹⁶² J. Manjarres Ramos,⁴⁸ K. H. Mankinen,⁹⁷ A. Mann,¹¹⁴ A. Manousos,⁷⁷ B. Mansoulie,¹⁴⁴ I. Manthos,¹⁶² S. Manzoni,¹²⁰ A. Marantis,¹⁶² G. Marceca,³⁰ L. Marchese,¹³⁴ G. Marchiori,¹³⁵ M. Marcisovsky,¹⁴⁰ L. Marcocchia,^{74a,74b} C. Marcon,⁹⁷ C. A. Marin Tobon,³⁶ M. Marjanovic,¹²⁸ Z. Marshall,¹⁸ M. U. F. Martensson,¹⁷² S. Marti-Garcia,¹⁷⁴ C. B. Martin,¹²⁷ T. A. Martin,¹⁷⁸ V. J. Martin,⁵⁰ B. Martin dit Latour,¹⁷ L. Martinelli,^{75a,75b} M. Martinez,^{14,v} V. I. Martinez Outschoorn,¹⁰³ S. Martin-Haugh,¹⁴³ V. S. Martoiu,^{27b} A. C. Martyniuk,⁹⁵ A. Marzin,³⁶ S. R. Maschek,¹¹⁵ L. Masetti,¹⁰⁰ T. Mashimo,¹⁶³ R. Mashinistov,¹¹¹ J. Masik,¹⁰¹ A. L. Maslennikov,^{122b,122a} L. Massa,^{23b,23a} P. Massarotti,^{70a,70b} P. Mastrandrea,^{72a,72b} A. Mastroberardino,^{41b,41a} T. Masubuchi,¹⁶³ D. Matakias,²⁹ A. Matic,¹¹⁴ N. Matsuzawa,¹⁶³ P. Mättig,²⁴ J. Maurer,^{27b} B. Maček,⁹² D. A. Maximov,^{122b,122a} R. Mazini,¹⁵⁸ I. Maznas,¹⁶² S. M. Mazza,¹⁴⁵ S. P. Mc Kee,¹⁰⁶ T. G. McCarthy,¹¹⁵ W. P. McCormack,¹⁸ E. F. McDonald,¹⁰⁵ J. A. Mcfayden,³⁶ G. Mchedlidze,^{159b} M. A. McKay,⁴² K. D. McLean,¹⁷⁶ S. J. McMahon,¹⁴³ P. C. McNamara,¹⁰⁵ C. J. McNicol,¹⁷⁸ R. A. McPherson,^{176,n} J. E. Mdhluli,^{33e} Z. A. Meadows,¹⁰³ S. Meehan,³⁶ T. Megy,³⁸ S. Mehlhase,¹¹⁴ A. Mehta,⁹¹ T. Meideck,⁵⁸ B. Meirose,⁴³ D. Melini,¹⁶⁰ B. R. Mellado Garcia,^{33e} J. D. Mellenthin,⁵³ M. Melo,^{28a} F. Meloni,⁴⁶ A. Melzer,²⁴ S. B. Menary,¹⁰¹ E. D. Mendes Gouveia,^{139a,139e} L. Meng,³⁶ X. T. Meng,¹⁰⁶ S. Menke,¹¹⁵ E. Meoni,^{41b,41a} S. Mergelmeyer,¹⁹ S. A. M. Merkt,¹³⁸ C. Merlassino,¹³⁴ P. Mermod,⁵⁴ L. Merola,^{70a,70b} C. Meroni,^{69a} G. Merz,¹⁰⁶ O. Meshkov,^{113,111} J. K. R. Meshreki,¹⁵¹ A. Messina,^{73a,73b} J. Metcalfe,⁶ A. S. Mete,⁶ C. Meyer,⁶⁶ J-P. Meyer,¹⁴⁴ H. Meyer Zu Theenhausen,^{61a} F. Miano,¹⁵⁶ M. Michetti,¹⁹ R. P. Middleton,¹⁴³ L. Mijović,⁵⁰ G. Mikenberg,¹⁸⁰ M. Mikestikova,¹⁴⁰ M. Mikuž,⁹² H. Mildner,¹⁴⁹ M. Milesi,¹⁰⁵ A. Milic,¹⁶⁷ C. D. Milke,⁴² D. W. Miller,³⁷ A. Milov,¹⁸⁰ D. A. Milstead,^{45a,45b} R. A. Mina,¹⁵³ A. A. Minaenko,¹²³ M. Miñano Moya,¹⁷⁴ I. A. Minashvili,^{159b} A. I. Mincer,¹²⁵ B. Mindur,^{84a} M. Mineev,⁸⁰ Y. Minegishi,¹⁶³ L. M. Mir,¹⁴ A. Mirto,^{68a,68b} K. P. Mistry,¹³⁶ T. Mitani,¹⁷⁹ J. Mitrevski,¹¹⁴ V. A. Mitsou,¹⁷⁴ M. Mittal,^{60c} O. Miu,¹⁶⁷ A. Miucci,²⁰ P. S. Miyagawa,¹⁴⁹ A. Mizukami,⁸² J. U. Mjörnmark,⁹⁷ T. Mkrtchyan,^{61a} M. Mlynarikova,¹⁴² T. Moa,^{45a,45b} K. Mochizuki,¹¹⁰ P. Mogg,¹¹⁴ S. Mohapatra,³⁹ R. Moles-Valls,²⁴ M. C. Mondragon,¹⁰⁷ K. Mönig,⁴⁶ J. Monk,⁴⁰ E. Monnier,¹⁰² A. Montalbano,¹⁵² J. Montejo Berlingen,³⁶ M. Montella,⁹⁵ F. Monticelli,⁸⁹ S. Monzani,^{69a} N. Morange,⁶⁵ D. Moreno,^{22a} M. Moreno Llácer,¹⁷⁴ C. Moreno Martinez,¹⁴ P. Morettini,^{55b} M. Morgenstern,¹⁶⁰ S. Morgenstern,⁴⁸ D. Mori,¹⁵² M. Morii,⁵⁹ M. Morinaga,¹⁷⁹ V. Morisbak,¹³³ A. K. Morley,³⁶ G. Mornacchi,³⁶ A. P. Morris,⁹⁵ L. Morvaj,¹⁵⁵ P. Moschovakos,³⁶ B. Moser,¹²⁰ M. Mosidze,^{159b} T. Moskalets,¹⁴⁴ H. J. Moss,¹⁴⁹ J. Moss,^{31,ff} E. J. W. Moyse,¹⁰³ S. Muanza,¹⁰² J. Mueller,¹³⁸ R. S. P. Mueller,¹¹⁴ D. Muenstermann,⁹⁰ G. A. Mullier,⁹⁷ D. P. Mungo,^{69a,69b} J. L. Munoz Martinez,¹⁴ F. J. Munoz Sanchez,¹⁰¹ P. Murin,^{28b} W. J. Murray,^{178,143} A. Murrone,^{69a,69b} M. Muškinja,¹⁸ C. Mwewa,^{33a} A. G. Myagkov,^{123,k} A. A. Myers,¹³⁸ J. Myers,¹³¹ M. Myska,¹⁴¹ B. P. Nachman,¹⁸ O. Nackenhorst,⁴⁷ A. Nag Nag,⁴⁸ K. Nagai,¹³⁴ K. Nagano,⁸² Y. Nagasaka,⁶² J. L. Nagle,²⁹ E. Nagy,¹⁰² A. M. Nairz,³⁶ Y. Nakahama,¹¹⁷ K. Nakamura,⁸² T. Nakamura,¹⁶³ H. Nanjo,¹³² F. Napolitano,^{61a} R. F. Naranjo Garcia,⁴⁶ R. Narayan,⁴² I. Naryshkin,¹³⁷ T. Naumann,⁴⁶ G. Navarro,^{22a} P. Y. Nechaeva,¹¹¹ F. Nechansky,⁴⁶ T. J. Neep,²¹ A. Negri,^{71a,71b} M. Negrini,^{23b} C. Nellist,¹¹⁹ M. E. Nelson,^{45a,45b} S. Nemecek,¹⁴⁰ M. Nessi,^{36,gg} M. S. Neubauer,¹⁷³ F. Neuhaus,¹⁰⁰ M. Neumann,¹⁸² R. Newhouse,¹⁷⁵ P. R. Newman,²¹ C. W. Ng,¹³⁸ Y. S. Ng,¹⁹ Y. W. Y. Ng,¹⁷¹ B. Ngair,^{35e} H. D. N. Nguyen,¹⁰² T. Nguyen Manh,¹¹⁰ E. Nibigira,³⁸ R. B. Nickerson,¹³⁴ R. Nicolaidou,¹⁴⁴ D. S. Nielsen,⁴⁰ J. Nielsen,¹⁴⁵ N. Nikiforou,¹¹ V. Nikolaenko,^{123,k} I. Nikolic-Audit,¹³⁵ K. Nikolopoulos,²¹ P. Nilsson,²⁹ H. R. Nindhito,⁵⁴ Y. Ninomiya,⁸² A. Nisati,^{73a} N. Nishu,^{60c} R. Nisius,¹¹⁵

I. Nitsche,⁴⁷ T. Nitta,¹⁷⁹ T. Nobe,¹⁶³ Y. Noguchi,⁸⁶ I. Nomidis,¹³⁵ M. A. Nomura,²⁹ M. Nordberg,³⁶ T. Novak,⁹² O. Novgorodova,⁴⁸ R. Novotny,¹⁴¹ L. Nozka,¹³⁰ K. Ntekas,¹⁷¹ E. Nurse,⁹⁵ F. G. Oakham,^{34,e} H. Oberlack,¹¹⁵ J. Ocariz,¹³⁵ A. Ochi,⁸³ I. Ochoa,³⁹ J. P. Ochoa-Ricoux,^{146a} K. O'Connor,²⁶ S. Oda,⁸⁸ S. Odaka,⁸² S. Oerdek,⁵³ A. Ogrodnik,^{84a} A. Oh,¹⁰¹ S. H. Oh,⁴⁹ C. C. Ohm,¹⁵⁴ H. Oide,¹⁶⁵ M. L. Ojeda,¹⁶⁷ H. Okawa,¹⁶⁹ Y. Okazaki,⁸⁶ M. W. O'Keefe,⁹¹ Y. Okumura,¹⁶³ T. Okuyama,⁸² A. Olariu,^{27b} L. F. Oleiro Seabra,^{139a} S. A. Olivares Pino,^{146a} D. Oliveira Damazio,²⁹ J. L. Oliver,¹ M. J. R. Olsson,¹⁷¹ A. Olszewski,⁸⁵ J. Olszowska,⁸⁵ D. C. O'Neil,¹⁵² A. P. O'Neill,¹³⁴ A. Onofre,^{139a,139e} P. U. E. Onyisi,¹¹ H. Oppen,¹³³ M. J. Oreglia,³⁷ G. E. Orellana,⁸⁹ D. Orestano,^{75a,75b} N. Orlando,¹⁴ R. S. Orr,¹⁶⁷ V. O'Shea,⁵⁷ R. Ospanov,^{60a} G. Otero y Garzon,³⁰ H. Otono,⁸⁸ P. S. Ott,^{61a} G. J. Ottino,¹⁸ M. Ouchrif,^{35d} J. Ouellette,²⁹ F. Ould-Saada,¹³³ A. Ouraou,^{144,a} Q. Ouyang,^{15a} M. Owen,⁵⁷ R. E. Owen,²¹ V. E. Ozcan,^{12c} N. Ozturk,⁸ J. Pacalt,¹³⁰ H. A. Pacey,³² K. Pachal,⁴⁹ A. Pacheco Pages,¹⁴ C. Padilla Aranda,¹⁴ S. Pagan Griso,¹⁸ M. Paganini,¹⁸³ G. Palacino,⁶⁶ S. Palazzo,⁵⁰ S. Palestini,³⁶ M. Palka,^{84b} D. Pallin,³⁸ P. Palmi,^{84a} I. Panagoulas,¹⁰ C. E. Pandini,³⁶ J. G. Panduro Vazquez,⁹⁴ P. Pani,⁴⁶ G. Panizzo,^{67a,67c} L. Paolozzi,⁵⁴ C. Papadatos,¹¹⁰ K. Papageorgiou,^{9,t} S. Parajuli,⁴² A. Paramonov,⁶ D. Paredes Hernandez,^{63b} S. R. Paredes Saenz,¹³⁴ B. Parida,¹⁶⁶ T. H. Park,¹⁶⁷ A. J. Parker,³¹ M. A. Parker,³² F. Parodi,^{55b,55a} E. W. Parrish,¹²¹ J. A. Parsons,³⁹ U. Parzefall,⁵² L. Pascual Dominguez,¹³⁵ V. R. Pascuzzi,¹⁸ J. M. P. Pasner,¹⁴⁵ F. Pasquali,¹²⁰ E. Pasqualucci,^{73a} S. Passaggio,^{55b} F. Pastore,⁹⁴ P. Pasuwan,^{45a,45b} S. Patariaia,¹⁰⁰ J. R. Pater,¹⁰¹ A. Pathak,^{181,f} J. Patton,⁹¹ T. Pauly,³⁶ J. Pearkes,¹⁵³ B. Pearson,¹¹⁵ M. Pedersen,¹³³ L. Pedraza Diaz,¹¹⁹ R. Pedro,^{139a} T. Peiffer,⁵³ S. V. Peleganchuk,^{122b,122a} O. Penc,¹⁴⁰ H. Peng,^{60a} B. S. Peralva,^{81a} M. M. Perego,⁶⁵ A. P. Pereira Peixoto,^{139a} L. Pereira Sanchez,^{45a,45b} D. V. Perepelitsa,²⁹ F. Peri,¹⁹ L. Perini,^{69a,69b} H. Pernegger,³⁶ S. Perrella,^{139a} A. Perrevoort,¹²⁰ K. Peters,⁴⁶ R. F. Y. Peters,¹⁰¹ B. A. Petersen,³⁶ T. C. Petersen,⁴⁰ E. Petit,¹⁰² A. Petridis,¹ C. Petridou,¹⁶² F. Petrucci,^{75a,75b} M. Pettee,¹⁸³ N. E. Pettersson,¹⁰³ K. Petukhova,¹⁴² A. Peyaud,¹⁴⁴ R. Pezoa,^{146d} L. Pezzotti,^{71a,71b} T. Pham,¹⁰⁵ F. H. Phillips,¹⁰⁷ P. W. Phillips,¹⁴³ M. W. Phipps,¹⁷³ G. Piacquadio,¹⁵⁵ E. Pianori,¹⁸ A. Picazio,¹⁰³ R. H. Pickles,¹⁰¹ R. Piegaiia,³⁰ D. Pietreanu,^{27b} J. E. Pilcher,³⁷ A. D. Pilkington,¹⁰¹ M. Pinamonti,^{67a,67c} J. L. Pinfold,³ C. Pitman Donaldson,⁹⁵ M. Pitt,¹⁶¹ L. Pizzimento,^{74a,74b} M.-A. Pleier,²⁹ V. Pleskot,¹⁴² E. Plotnikova,⁸⁰ P. Podberezko,^{122b,122a} R. Poettgen,⁹⁷ R. Poggi,⁵⁴ L. Poggioli,¹³⁵ I. Pogrebnyak,¹⁰⁷ D. Pohl,²⁴ I. Pokharel,⁵³ G. Polesello,^{71a} A. Poley,¹⁸ A. Policicchio,^{73a,73b} R. Polifka,¹⁴² A. Polini,^{23b} C. S. Pollard,⁴⁶ V. Polychronakos,²⁹ D. Ponomarenko,¹¹² L. Pontecorvo,³⁶ S. Popa,^{27a} G. A. Popeneciu,^{27d} L. Portales,⁵ D. M. Portillo Quintero,⁵⁸ S. Pospisil,¹⁴¹ K. Potamianos,⁴⁶ I. N. Potrap,⁸⁰ C. J. Potter,³² H. Potti,¹¹ T. Poulsen,⁹⁷ J. Poveda,³⁶ T. D. Powell,¹⁴⁹ G. Pownall,⁴⁶ M. E. Pozo Astigarraga,³⁶ P. Pralavorio,¹⁰² S. Prell,⁷⁹ D. Price,¹⁰¹ M. Primavera,^{68a} S. Prince,¹⁰⁴ M. L. Proffitt,¹⁴⁸ N. Proklova,¹¹² K. Prokofiev,^{63c} F. Prokoshin,⁸⁰ S. Protopopescu,²⁹ J. Proudfoot,⁶ M. Przybycien,^{84a} D. Pudzha,¹³⁷ A. Puri,¹⁷³ P. Puzo,⁶⁵ J. Qian,¹⁰⁶ Y. Qin,¹⁰¹ A. Quadt,⁵³ M. Queitsch-Maitland,³⁶ A. Qureshi,¹ M. Racko,^{28a} F. Ragusa,^{69a,69b} G. Rahal,⁹⁸ J. A. Raine,⁵⁴ S. Rajagopalan,²⁹ A. Ramirez Morales,⁹³ K. Ran,^{15a,15d} T. Rashid,⁶⁵ S. Raspopov,⁵ D. M. Rauch,⁴⁶ F. Rauscher,¹¹⁴ S. Rave,¹⁰⁰ B. Ravina,¹⁴⁹ I. Ravinovich,¹⁸⁰ J. H. Rawling,¹⁰¹ M. Raymond,³⁶ A. L. Read,¹³³ N. P. Readioff,⁵⁸ M. Reale,^{68a,68b} D. M. Rebuffi,^{71a,71b} G. Redlinger,²⁹ K. Reeves,⁴³ L. Rehnisch,¹⁹ J. Reichert,¹³⁶ D. Reikher,¹⁶¹ A. Reiss,¹⁰⁰ A. Rej,¹⁵¹ C. Rembser,³⁶ A. Renardi,⁴⁶ M. Renda,^{27b} M. Rescigno,^{73a} S. Resconi,^{69a} E. D. Resseguie,¹⁸ S. Rettie,⁹⁵ B. Reynolds,¹²⁷ E. Reynolds,²¹ O. L. Rezanova,^{122b,122a} P. Reznicek,¹⁴² E. Ricci,^{76a,76b} R. Richter,¹¹⁵ S. Richter,⁴⁶ E. Richter-Was,^{84b} O. Ricken,²⁴ M. Ridel,¹³⁵ P. Rieck,¹¹⁵ O. Rifki,⁴⁶ M. Rijssenbeek,¹⁵⁵ A. Rimoldi,^{71a,71b} M. Rimoldi,⁴⁶ L. Rinaldi,^{23b} G. Ripellino,¹⁵⁴ I. Riu,¹⁴ J. C. Rivera Vergara,¹⁷⁶ F. Rizatdinova,¹²⁹ E. Rizvi,⁹³ C. Rizzi,³⁶ R. T. Roberts,¹⁰¹ S. H. Robertson,^{104,n} M. Robin,⁴⁶ D. Robinson,³² C. M. Robles Gajardo,^{146d} M. Robles Manzano,¹⁰⁰ A. Robson,⁵⁷ A. Rocchi,^{74a,74b} E. Rocco,¹⁰⁰ C. Roda,^{72a,72b} S. Rodriguez Bosca,¹⁷⁴ A. Rodriguez Perez,¹⁴ D. Rodriguez Rodriguez,¹⁷⁴ A. M. Rodríguez Vera,^{168b} S. Roe,³⁶ O. Røhne,¹³³ R. Røhrig,¹¹⁵ R. A. Rojas,^{146d} B. Roland,⁵² C. P. A. Roland,⁶⁶ J. Roloff,²⁹ A. Romaniouk,¹¹² M. Romano,^{23b,23a} N. Rompotis,⁹¹ M. Ronzani,¹²⁵ L. Roos,¹³⁵ S. Rosati,^{73a} G. Rosin,¹⁰³ B. J. Rosser,¹³⁶ E. Rossi,⁴⁶ E. Rossi,^{75a,75b} E. Rossi,^{70a,70b} L. P. Rossi,^{55b} L. Rossini,^{69a,69b} R. Rosten,¹⁴ M. Rotaru,^{27b} B. Rottler,⁵² D. Rousseau,⁶⁵ G. Rovelli,^{71a,71b} A. Roy,¹¹ D. Roy,^{33e} A. Rozanov,¹⁰² Y. Rozen,¹⁶⁰ X. Ruan,^{33e} F. Rühr,⁵² A. Ruiz-Martinez,¹⁷⁴ A. Rummler,³⁶ Z. Rurikova,⁵² N. A. Rusakovich,⁸⁰ H. L. Russell,¹⁰⁴ L. Rustige,^{38,47} J. P. Rutherford,⁷ E. M. Rüttinger,¹⁴⁹ M. Rybar,³⁹ G. Rybkin,⁶⁵ E. B. Rye,¹³³ A. Ryzhov,¹²³ J. A. Sabater Iglesias,⁴⁶ P. Sabatini,⁵³ S. Sacerdoti,⁶⁵ H. F-W. Sadrozinski,¹⁴⁵ R. Sadykov,⁸⁰ F. Safai Tehrani,^{73a} B. Safarzadeh Samani,¹⁵⁶ M. Safdari,¹⁵³ P. Saha,¹²¹ S. Saha,¹⁰⁴ M. Sahinsoy,^{61a} A. Sahu,¹⁸² M. Saimpert,³⁶ M. Saito,¹⁶³ T. Saito,¹⁶³ H. Sakamoto,¹⁶³ D. Salamani,⁵⁴ G. Salamanna,^{75a,75b} J. E. Salazar Loyola,^{146d} A. Salnikov,¹⁵³ J. Salt,¹⁷⁴ A. Salvador Salas,¹⁴ D. Salvatore,^{41b,41a} F. Salvatore,¹⁵⁶

A. Salvucci,^{63a,63b,63c} A. Salzburger,³⁶ J. Samarati,³⁶ D. Sammel,⁵² D. Sampsonidis,¹⁶² D. Sampsonidou,¹⁶² J. Sánchez,¹⁷⁴
A. Sanchez Pineda,^{67a,36,67c} H. Sandaker,¹³³ C. O. Sander,⁴⁶ I. G. Sanderswood,⁹⁰ M. Sandhoff,¹⁸² C. Sandoval,^{22a}
D. P. C. Sankey,¹⁴³ M. Sannino,^{55b,55a} Y. Sano,¹¹⁷ A. Sansoni,⁵¹ C. Santoni,³⁸ H. Santos,^{139a,139b} S. N. Santpur,¹⁸ A. Santra,¹⁷⁴
A. Sapronov,⁸⁰ J. G. Saraiva,^{139a,139d} O. Sasaki,⁸² K. Sato,¹⁶⁹ F. Sauerburger,⁵² E. Sauvan,⁵ P. Savard,^{167,e} R. Sawada,¹⁶³
C. Sawyer,¹⁴³ L. Sawyer,^{96,hh} C. Sbarra,^{23b} A. Sbrizzi,^{23a} T. Scanlon,⁹⁵ J. Schaarschmidt,¹⁴⁸ P. Schacht,¹¹⁵
B. M. Schachtner,¹¹⁴ D. Schaefer,³⁷ L. Schaefer,¹³⁶ J. Schaeffer,¹⁰⁰ S. Schaepe,³⁶ U. Schäfer,¹⁰⁰ A. C. Schaffer,⁶⁵
D. Schaile,¹¹⁴ R. D. Schamberger,¹⁵⁵ N. Scharmberg,¹⁰¹ V. A. Schegelsky,¹³⁷ D. Scheirich,¹⁴² F. Schenck,¹⁹ M. Schernau,¹⁷¹
C. Schiavi,^{55b,55a} L. K. Schildgen,²⁴ Z. M. Schillaci,²⁶ E. J. Schioppa,^{68a,68b} M. Schioppa,^{41b,41a} K. E. Schleicher,⁵²
S. Schlenker,³⁶ K. R. Schmidt-Sommerfeld,¹¹⁵ K. Schmieden,³⁶ C. Schmitt,¹⁰⁰ S. Schmitt,⁴⁶ S. Schmitz,¹⁰⁰
J. C. Schmoeckel,⁴⁶ L. Schoeffel,¹⁴⁴ A. Schoening,^{61b} P. G. Scholer,⁵² E. Schopf,¹³⁴ M. Schott,¹⁰⁰ J. F. P. Schouwenberg,¹¹⁹
J. Schovancova,³⁶ S. Schramm,⁵⁴ F. Schroeder,¹⁸² A. Schulte,¹⁰⁰ H-C. Schultz-Coulon,^{61a} M. Schumacher,⁵²
B. A. Schumm,¹⁴⁵ Ph. Schune,¹⁴⁴ A. Schwartzman,¹⁵³ T. A. Schwarz,¹⁰⁶ Ph. Schwemling,¹⁴⁴ R. Schwienhorst,¹⁰⁷
A. Sciandra,¹⁴⁵ G. Sciolla,²⁶ M. Scodreggio,⁴⁶ M. Scornajenghi,^{41b,41a} F. Scuri,^{72a} F. Scutti,¹⁰⁵ L. M. Scyboz,¹¹⁵
C. D. Sebastiani,^{73a,73b} P. Seema,¹⁹ S. C. Seidel,¹¹⁸ A. Seiden,¹⁴⁵ B. D. Seidlitz,²⁹ T. Seiss,³⁷ C. Seitz,⁴⁶ J. M. Seixas,^{81b}
G. Sekhniaidze,^{70a} S. J. Sekula,⁴² N. Semprini-Cesari,^{23b,23a} S. Sen,⁴⁹ C. Serfon,⁷⁷ L. Serin,⁶⁵ L. Serkin,^{67a,67b} M. Sessa,^{60a}
H. Severini,¹²⁸ S. Sevova,¹⁵³ F. Sforza,^{55b,55a} A. Sfyrla,⁵⁴ E. Shabalina,⁵³ J. D. Shahinian,¹⁴⁵ N. W. Shaikh,^{45a,45b}
D. Shaked Renous,¹⁸⁰ L. Y. Shan,^{15a} M. Shapiro,¹⁸ A. Sharma,¹³⁴ A. S. Sharma,¹ P. B. Shatalov,¹²⁴ K. Shaw,¹⁵⁶
S. M. Shaw,¹⁰¹ M. Shehade,¹⁸⁰ Y. Shen,¹²⁸ A. D. Sherman,²⁵ P. Sherwood,⁹⁵ L. Shi,¹⁵⁸ S. Shimizu,⁸² C. O. Shimmin,¹⁸³
Y. Shimogama,¹⁷⁹ M. Shimojima,¹¹⁶ I. P. J. Shipsey,¹³⁴ S. Shirabe,¹⁶⁵ M. Shiyakova,^{80,ii} J. Shlomi,¹⁸⁰ A. Shmeleva,¹¹¹
M. J. Shochet,³⁷ J. Shojaii,¹⁰⁵ D. R. Shope,¹²⁸ S. Shrestha,¹²⁷ E. M. Shrif,^{33e} E. Shulga,¹⁸⁰ P. Sicho,¹⁴⁰ A. M. Sickles,¹⁷³
P. E. Sidebo,¹⁵⁴ E. Sideras Haddad,^{33e} O. Sidiropoulou,³⁶ A. Sidoti,^{23b,23a} F. Siegert,⁴⁸ Dj. Sijacki,¹⁶ M. Silva Jr.,¹⁸¹
M. V. Silva Oliveira,^{81a} S. B. Silverstein,^{45a} S. Simion,⁶⁵ R. Simoniello,¹⁰⁰ C. J. Simpson-allsoy,²¹ S. Simsek,^{12b}
P. Sinervo,¹⁶⁷ V. Sinetckii,¹¹³ S. Singh,¹⁵² M. Sioli,^{23b,23a} I. Siral,¹³¹ S. Yu. Sivoklov,¹¹³ J. Sjölin,^{45a,45b} E. Skorda,⁹⁷
P. Skubic,¹²⁸ M. Slawinska,⁸⁵ K. Sliwa,¹⁷⁰ R. Slovak,¹⁴² V. Smakhtin,¹⁸⁰ B. H. Smart,¹⁴³ J. Smiesko,^{28b} N. Smirnov,¹¹²
S. Yu. Smirnov,¹¹² Y. Smirnov,¹¹² L. N. Smirnova,^{113,ji} O. Smirnova,⁹⁷ J. W. Smith,⁵³ M. Smizanska,⁹⁰ K. Smolek,¹⁴¹
A. Smykiewicz,⁸⁵ A. A. Snesarev,¹¹¹ H. L. Snoek,¹²⁰ I. M. Snyder,¹³¹ S. Snyder,²⁹ R. Sobie,^{176,n} A. Soffer,¹⁶¹ A. Søggaard,⁵⁰
F. Sohns,⁵³ C. A. Solans Sanchez,³⁶ E. Yu. Soldatov,¹¹² U. Soldevila,¹⁷⁴ A. A. Solodkov,¹²³ A. Soloshenko,⁸⁰
O. V. Solovyanov,¹²³ V. Solovyev,¹³⁷ P. Sommer,¹⁴⁹ H. Son,¹⁷⁰ W. Song,¹⁴³ W. Y. Song,^{168b} A. Sopczak,¹⁴¹ A. L. Sapiro,⁹⁵
F. Sopkova,^{28b} C. L. Sotiropoulou,^{72a,72b} S. Sottocornola,^{71a,71b} R. Soualah,^{67a,67c,kk} A. M. Soukharev,^{122b,122a} D. South,⁴⁶
S. Spagnolo,^{68a,68b} M. Spalla,¹¹⁵ M. Spangenberg,¹⁷⁸ F. Spanò,⁹⁴ D. Sperlich,⁵² T. M. Spieker,^{61a} G. Spigo,³⁶ M. Spina,¹⁵⁶
D. P. Spiteri,⁵⁷ M. Spousta,¹⁴² A. Stabile,^{69a,69b} B. L. Stamas,¹²¹ R. Stamen,^{61a} M. Stamenkovic,¹²⁰ E. Stanecka,⁸⁵
B. Stanislaus,¹³⁴ M. M. Stanitzki,⁴⁶ M. Stankaityte,¹³⁴ B. Stapf,¹²⁰ E. A. Starchenko,¹²³ G. H. Stark,¹⁴⁵ J. Stark,⁵⁸
P. Staroba,¹⁴⁰ P. Starovoitov,^{61a} S. Stärz,¹⁰⁴ R. Staszewski,⁸⁵ G. Stavropoulos,⁴⁴ M. Stegler,⁴⁶ P. Steinberg,²⁹
A. L. Steinhebel,¹³¹ B. Stelzer,¹⁵² H. J. Stelzer,¹³⁸ O. Stelzer-Chilton,^{168a} H. Stenzel,⁵⁶ T. J. Stevenson,¹⁵⁶ G. A. Stewart,³⁶
M. C. Stockton,³⁶ G. Stoicea,^{27b} M. Stolarski,^{139a} S. Stonjek,¹¹⁵ A. Straessner,⁴⁸ J. Strandberg,¹⁵⁴ S. Strandberg,^{45a,45b}
M. Strauss,¹²⁸ P. Strizenc,^{28b} R. Ströhmer,¹⁷⁷ D. M. Strom,¹³¹ R. Stroynowski,⁴² A. Strubig,⁵⁰ S. A. Stucci,²⁹ B. Stugu,¹⁷
J. Stupak,¹²⁸ N. A. Styles,⁴⁶ D. Su,¹⁵³ W. Su,^{60c,148} S. Suchek,^{61a} V. V. Sulin,¹¹¹ M. J. Sullivan,⁹¹ D. M. S. Sultan,⁵⁴
S. Sultansoy,^{4c} T. Sumida,⁸⁶ S. Sun,¹⁰⁶ X. Sun,¹⁰¹ K. Suruliz,¹⁵⁶ C. J. E. Suster,¹⁵⁷ M. R. Sutton,¹⁵⁶ S. Suzuki,⁸² M. Svatos,¹⁴⁰
M. Swiatlowski,^{168a} S. P. Swift,² T. Swirski,¹⁷⁷ A. Sydorenko,¹⁰⁰ I. Sykora,^{28a} M. Sykora,¹⁴² T. Sykora,¹⁴² D. Ta,¹⁰⁰
K. Tackmann,^{46,ii} J. Taenzer,¹⁶¹ A. Taffard,¹⁷¹ R. Tafirout,^{168a} R. Takashima,⁸⁷ K. Takeda,⁸³ T. Takeshita,¹⁵⁰ E. P. Takeva,⁵⁰
Y. Takubo,⁸² M. Talby,¹⁰² A. A. Talyshev,^{122b,122a} N. M. Tamir,¹⁶¹ J. Tanaka,¹⁶³ R. Tanaka,⁶⁵ S. Tapia Araya,¹⁷³
S. Tapprogge,¹⁰⁰ A. Tarek Abouelfadl Mohamed,¹⁰⁷ S. Tarem,¹⁶⁰ K. Tariq,^{60b} G. Tarna,^{27b,mmm} G. F. Tartarelli,^{69a} P. Tas,¹⁴²
M. Tasevsky,¹⁴⁰ T. Tashiro,⁸⁶ E. Tassi,^{41b,41a} A. Tavares Delgado,^{139a} Y. Tayalati,^{35e} A. J. Taylor,⁵⁰ G. N. Taylor,¹⁰⁵
W. Taylor,^{168b} H. Teagle,⁹¹ A. S. Tee,⁹⁰ R. Teixeira De Lima,¹⁵³ P. Teixeira-Dias,⁹⁴ H. Ten Kate,³⁶ J. J. Teoh,¹²⁰ S. Terada,⁸²
K. Terashi,¹⁶³ J. Terron,⁹⁹ S. Terzo,¹⁴ M. Testa,⁵¹ R. J. Teuscher,^{167,n} S. J. Thais,¹⁸³ N. Themistokleous,⁵⁰
T. Thevenaux-Pelzer,⁴⁶ F. Thiele,⁴⁰ D. W. Thomas,⁹⁴ J. O. Thomas,⁴² J. P. Thomas,²¹ P. D. Thompson,²¹ L. A. Thomsen,¹⁸³
E. Thomson,¹³⁶ E. J. Thorpe,⁹³ R. E. Ticse Torres,⁵³ V. O. Tikhomirov,^{111,nn} Yu. A. Tikhonov,^{122b,122a} S. Timoshenko,¹¹²
P. Tipton,¹⁸³ S. Tisserant,¹⁰² K. Todome,^{23b,23a} S. Todorova-Nova,¹⁴² S. Todt,⁴⁸ J. Tojo,⁸⁸ S. Tokár,^{28a} K. Tokushuku,⁸²

E. Tolley,¹²⁷ K. G. Tomiwa,^{33e} M. Tomoto,¹¹⁷ L. Tompkins,¹⁵³ P. Tornambe,¹⁰³ E. Torrence,¹³¹ H. Torres,⁴⁸
 E. Torró Pastor,¹⁴⁸ C. Tosciri,¹³⁴ J. Toth,^{102,oo} D. R. Tovey,¹⁴⁹ A. Traeet,¹⁷ C. J. Treado,¹²⁵ T. Trefzger,¹⁷⁷ F. Tresoldi,¹⁵⁶
 A. Tricoli,²⁹ I. M. Trigger,^{168a} S. Trincaz-Duvoid,¹³⁵ D. A. Trischuk,¹⁷⁵ W. Trischuk,¹⁶⁷ B. Trocmé,⁵⁸ A. Trofymov,¹⁴⁴
 C. Troncon,^{69a} F. Trovato,¹⁵⁶ L. Truong,^{33c} M. Trzebinski,⁸⁵ A. Trzuppek,⁸⁵ F. Tsai,⁴⁶ J. C-L. Tseng,¹³⁴ P. V. Tsiareshka,^{108,cc}
 A. Tsirigotis,^{162,dd} V. Tsiskaridze,¹⁵⁵ E. G. Tskhadadze,^{159a} M. Tsopoulou,¹⁶² I. I. Tsukerman,¹²⁴ V. Tsulaia,¹⁸ S. Tsuno,⁸²
 D. Tsybychev,¹⁵⁵ Y. Tu,^{63b} A. Tudorache,^{27b} V. Tudorache,^{27b} T. T. Tulbure,^{27a} A. N. Tuna,⁵⁹ S. Turchikhin,⁸⁰
 D. Turgeman,¹⁸⁰ I. Turk Cakir,^{4b,pp} R. J. Turner,²¹ R. Turra,^{69a} P. M. Tuts,³⁹ S. Tzamarias,¹⁶² E. Tzovara,¹⁰⁰ G. Ucchielli,⁴⁷
 K. Uchida,¹⁶³ F. Ukegawa,¹⁶⁹ G. Unal,³⁶ A. Undrus,²⁹ G. Unel,¹⁷¹ F. C. Ungaro,¹⁰⁵ Y. Unno,⁸² K. Uno,¹⁶³ J. Urban,^{28b}
 P. Urquijo,¹⁰⁵ G. Usai,⁸ Z. Uysal,^{12d} V. Vacek,¹⁴¹ B. Vachon,¹⁰⁴ K. O. H. Vadla,¹³³ A. Vaidya,⁹⁵ C. Valderanis,¹¹⁴
 E. Valdes Santurio,^{45a,45b} M. Valente,⁵⁴ S. Valentinetti,^{23b,23a} A. Valero,¹⁷⁴ L. Valéry,⁴⁶ R. A. Vallance,²¹ A. Vallier,³⁶
 J. A. Valls Ferrer,¹⁷⁴ T. R. Van Daalen,¹⁴ P. Van Gemmeren,⁶ I. Van Vulpen,¹²⁰ M. Vanadia,^{74a,74b} W. Vandelli,³⁶
 M. Vandenbroucke,¹⁴⁴ E. R. Vandewall,¹²⁹ A. Vaniachine,¹⁶⁶ D. Vannicola,^{73a,73b} R. Vari,^{73a} E. W. Varnes,⁷ C. Varni,^{55b,55a}
 T. Varol,¹⁵⁸ D. Varouchas,⁶⁵ K. E. Varvell,¹⁵⁷ M. E. Vasile,^{27b} G. A. Vasquez,¹⁷⁶ F. Vazeille,³⁸ D. Vazquez Furelos,¹⁴
 T. Vazquez Schroeder,³⁶ J. Veatch,⁵³ V. Vecchio,^{75a,75b} M. J. Veen,¹²⁰ L. M. Veloce,¹⁶⁷ F. Veloso,^{139a,139c} S. Veneziano,^{73a}
 A. Ventura,^{68a,68b} N. Venturi,³⁶ A. Verbytskyi,¹¹⁵ V. Vercesi,^{71a} M. Verducci,^{72a,72b} C. M. Vergel Infante,⁷⁹ C. Vergis,²⁴
 W. Verkerke,¹²⁰ A. T. Vermeulen,¹²⁰ J. C. Vermeulen,¹²⁰ C. Vernieri,¹⁵³ M. C. Vetterli,^{152,e} N. Viaux Maira,^{146d} T. Vickey,¹⁴⁹
 O. E. Vickey Boeriu,¹⁴⁹ G. H. A. Viehhauser,¹³⁴ L. Vigani,^{61b} M. Villa,^{23b,23a} M. Villaplana Perez,³ E. Vilucchi,⁵¹
 M. G. Vincter,³⁴ G. S. Virdee,²¹ A. Vishwakarma,⁴⁶ C. Vittori,^{23b,23a} I. Vivarelli,¹⁵⁶ M. Vogel,¹⁸² P. Vokac,¹⁴¹
 S. E. von Buddenbrock,^{33e} E. Von Toerne,²⁴ V. Vorobel,¹⁴² K. Vorobev,¹¹² M. Vos,¹⁷⁴ J. H. Vossebeld,⁹¹ M. Vozak,¹⁰¹
 N. Vranjes,¹⁶ M. Vranjes Milosavljevic,¹⁶ V. Vrba,¹⁴¹ M. Vreeswijk,¹²⁰ R. Vuillermet,³⁶ I. Vukotic,³⁷ S. Wada,¹⁶⁹
 P. Wagner,²⁴ W. Wagner,¹⁸² J. Wagner-Kuhr,¹¹⁴ S. Wahdan,¹⁸² H. Wahlberg,⁸⁹ R. Wakasa,¹⁶⁹ V. M. Walbrecht,¹¹⁵ J. Walder,⁹⁰
 R. Walker,¹¹⁴ S. D. Walker,⁹⁴ W. Walkowiak,¹⁵¹ V. Wallangen,^{45a,45b} A. M. Wang,⁵⁹ A. Z. Wang,¹⁸¹ C. Wang,^{60c} F. Wang,¹⁸¹
 H. Wang,¹⁸ H. Wang,³ J. Wang,^{63a} J. Wang,^{61b} P. Wang,⁴² Q. Wang,¹²⁸ R.-J. Wang,¹⁰⁰ R. Wang,^{60a} R. Wang,⁶ S. M. Wang,¹⁵⁸
 W. T. Wang,^{60a} W. Wang,^{15c} W. X. Wang,^{60a} Y. Wang,^{60a} Z. Wang,^{60c} C. Wanotayaroj,⁴⁶ A. Warburton,¹⁰⁴ C. P. Ward,³²
 D. R. Wardrope,⁹⁵ N. Warrack,⁵⁷ A. Washbrook,⁵⁰ A. T. Watson,²¹ M. F. Watson,²¹ G. Watts,¹⁴⁸ B. M. Waugh,⁹⁵
 A. F. Webb,¹¹ C. Weber,¹⁸³ M. S. Weber,²⁰ S. A. Weber,³⁴ S. M. Weber,^{61a} A. R. Weidberg,¹³⁴ J. Weingarten,⁴⁷
 M. Weirich,¹⁰⁰ C. Weiser,⁵² P. S. Wells,³⁶ T. Wenaus,²⁹ T. Wengler,³⁶ S. Wenig,³⁶ N. Wermes,²⁴ M. D. Werner,⁷⁹
 M. Wessels,^{61a} T. D. Weston,²⁰ K. Whalen,¹³¹ N. L. Whallon,¹⁴⁸ A. M. Wharton,⁹⁰ A. S. White,¹⁰⁶ A. White,⁸ M. J. White,¹
 D. Whiteson,¹⁷¹ B. W. Whitmore,⁹⁰ W. Wiedenmann,¹⁸¹ C. Wiel,⁴⁸ M. Wielers,¹⁴³ N. Wieseotte,¹⁰⁰ C. Wiglesworth,⁴⁰
 L. A. M. Wiik-Fuchs,⁵² H. G. Wilkens,³⁶ L. J. Wilkins,⁹⁴ H. H. Williams,¹³⁶ S. Williams,³² C. Willis,¹⁰⁷ S. Willocq,¹⁰³
 I. Wingerter-Seez,⁵ E. Winkels,¹⁵⁶ F. Winklmeier,¹³¹ B. T. Winter,⁵² M. Wittgen,¹⁵³ M. Wobisch,⁹⁶ A. Wolf,¹⁰⁰
 T. M. H. Wolf,¹²⁰ R. Wolff,¹⁰² R. Wölker,¹³⁴ J. Wollrath,⁵² M. W. Wolter,⁸⁵ H. Wolters,^{139a,139c} V. W. S. Wong,¹⁷⁵
 N. L. Woods,¹⁴⁵ S. D. Worm,⁴⁶ B. K. Wosiek,⁸⁵ K. W. Woźniak,⁸⁵ K. Wraight,⁵⁷ S. L. Wu,¹⁸¹ X. Wu,⁵⁴ Y. Wu,^{60a}
 T. R. Wyatt,¹⁰¹ B. M. Wynne,⁵⁰ S. Xella,⁴⁰ Z. Xi,¹⁰⁶ L. Xia,¹⁷⁸ X. Xiao,¹⁰⁶ I. Xiotidis,¹⁵⁶ D. Xu,^{15a} H. Xu,^{60a} H. Xu,^{60a}
 L. Xu,²⁹ T. Xu,¹⁴⁴ W. Xu,¹⁰⁶ Z. Xu,^{60b} Z. Xu,¹⁵³ B. Yabsley,¹⁵⁷ S. Yacooob,^{33a} K. Yajima,¹³² D. P. Yallup,⁹⁵ N. Yamaguchi,⁸⁸
 Y. Yamaguchi,¹⁶⁵ A. Yamamoto,⁸² M. Yamatani,¹⁶³ T. Yamazaki,¹⁶³ Y. Yamazaki,⁸³ J. Yan,^{60c} Z. Yan,²⁵ H. J. Yang,^{60c,60d}
 H. T. Yang,¹⁸ S. Yang,^{60a} T. Yang,^{63c} X. Yang,^{60b,58} Y. Yang,¹⁶³ Z. Yang,^{60a} W-M. Yao,¹⁸ Y. C. Yap,⁴⁶ Y. Yasu,⁸²
 E. Yatsenko,^{60c,60d} H. Ye,^{15c} J. Ye,⁴² S. Ye,²⁹ I. Yeletsikh,⁸⁰ M. R. Yexley,⁹⁰ E. Yigitbasi,²⁵ K. Yorita,¹⁷⁹ K. Yoshihara,⁷⁹
 C. J. S. Young,³⁶ C. Young,¹⁵³ J. Yu,⁷⁹ R. Yuan,^{60b,qq} X. Yue,^{61a} M. Zaazoua,^{35e} B. Zabinski,⁸⁵ G. Zacharis,¹⁰ E. Zaffaroni,⁵⁴
 J. Zahreddine,¹³⁵ A. M. Zaitsev,^{123,k} T. Zakareishvili,^{159b} N. Zakharchuk,³⁴ S. Zambito,⁵⁹ D. Zanzi,³⁶ D. R. Zaripovas,⁵⁷
 S. V. ZeiBner,⁴⁷ C. Zeitnitz,¹⁸² G. Zemaityte,¹³⁴ J. C. Zeng,¹⁷³ O. Zenin,¹²³ T. Ženiš,^{28a} D. Zerwas,⁶⁵ M. Zgubič,¹³⁴
 B. Zhang,^{15c} D. F. Zhang,^{15b} G. Zhang,^{15b} H. Zhang,^{15c} J. Zhang,⁶ K. Zhang,^{15a} L. Zhang,^{15c} L. Zhang,^{60a} M. Zhang,¹⁷³
 R. Zhang,¹⁸¹ S. Zhang,¹⁰⁶ X. Zhang,^{60c} X. Zhang,^{60b} Y. Zhang,^{15a,15d} Z. Zhang,^{63a} Z. Zhang,⁶⁵ P. Zhao,⁴⁹ Z. Zhao,^{60a}
 A. Zhemchugov,⁸⁰ Z. Zheng,¹⁰⁶ D. Zhong,¹⁷³ B. Zhou,¹⁰⁶ C. Zhou,¹⁸¹ H. Zhou,⁷ M. S. Zhou,^{15a,15d} M. Zhou,¹⁵⁵ N. Zhou,^{60c}
 Y. Zhou,⁷ C. G. Zhu,^{60b} C. Zhu,^{15a,15d} H. L. Zhu,^{60a} H. Zhu,^{15a} J. Zhu,¹⁰⁶ Y. Zhu,^{60a} X. Zhuang,^{15a} K. Zhukov,¹¹¹
 V. Zhulanov,^{122b,122a} D. Zieminska,⁶⁶ N. I. Zimine,⁸⁰ S. Zimmermann,^{52,a} Z. Zinonos,¹¹⁵ M. Ziolkowski,¹⁵¹ L. Živković,¹⁶
 G. Zobernig,¹⁸¹ A. Zoccoli,^{23b,23a} K. Zoch,⁵³ T. G. Zorbas,¹⁴⁹ R. Zou,³⁷ and L. Zwalinski³⁶

(ATLAS Collaboration)

- ¹*Department of Physics, University of Adelaide, Adelaide, Australia*
- ²*Physics Department, SUNY Albany, Albany, New York, USA*
- ³*Department of Physics, University of Alberta, Edmonton, Alberta, Canada*
- ^{4a}*Department of Physics, Ankara University, Ankara, Turkey*
- ^{4b}*Istanbul Aydin University, Application and Research Center for Advanced Studies, Istanbul, Turkey*
- ^{4c}*Division of Physics, TOBB University of Economics and Technology, Ankara, Turkey*
- ⁵*LAPP, Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy, France*
- ⁶*High Energy Physics Division, Argonne National Laboratory, Argonne, Illinois, USA*
- ⁷*Department of Physics, University of Arizona, Tucson, Arizona, USA*
- ⁸*Department of Physics, University of Texas at Arlington, Arlington, Texas, USA*
- ⁹*Physics Department, National and Kapodistrian University of Athens, Athens, Greece*
- ¹⁰*Physics Department, National Technical University of Athens, Zografou, Greece*
- ¹¹*Department of Physics, University of Texas at Austin, Austin, Texas, USA*
- ^{12a}*Bahcesehir University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey*
- ^{12b}*Istanbul Bilgi University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey*
- ^{12c}*Department of Physics, Bogazici University, Istanbul, Turkey*
- ^{12d}*Department of Physics Engineering, Gaziantep University, Gaziantep, Turkey*
- ¹³*Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan*
- ¹⁴*Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona, Spain*
- ^{15a}*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China*
- ^{15b}*Physics Department, Tsinghua University, Beijing, China*
- ^{15c}*Department of Physics, Nanjing University, Nanjing, China*
- ^{15d}*University of Chinese Academy of Science (UCAS), Beijing, China*
- ¹⁶*Institute of Physics, University of Belgrade, Belgrade, Serbia*
- ¹⁷*Department for Physics and Technology, University of Bergen, Bergen, Norway*
- ¹⁸*Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, California, USA*
- ¹⁹*Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany*
- ²⁰*Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland*
- ²¹*School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom*
- ^{22a}*Facultad de Ciencias y Centro de Investigaciones, Universidad Antonio Nariño, Bogotá, Colombia*
- ^{22b}*Departamento de Física, Universidad Nacional de Colombia, Bogotá, Colombia, Colombia*
- ^{23a}*INFN Bologna and Università di Bologna, Dipartimento di Fisica, Italy*
- ^{23b}*INFN Sezione di Bologna, Italy*
- ²⁴*Physikalisches Institut, Universität Bonn, Bonn, Germany*
- ²⁵*Department of Physics, Boston University, Boston, Massachusetts, USA*
- ²⁶*Department of Physics, Brandeis University, Waltham, Massachusetts, USA*
- ^{27a}*Transilvania University of Brasov, Brasov, Romania*
- ^{27b}*Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania*
- ^{27c}*Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi, Romania*
- ^{27d}*National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca, Romania*
- ^{27e}*University Politehnica Bucharest, Bucharest, Romania*
- ^{27f}*West University in Timisoara, Timisoara, Romania*
- ^{28a}*Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovak Republic*
- ^{28b}*Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic*
- ²⁹*Physics Department, Brookhaven National Laboratory, Upton, New York, USA*
- ³⁰*Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina*
- ³¹*California State University, California, USA*
- ³²*Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*
- ^{33a}*Department of Physics, University of Cape Town, Cape Town, South Africa*
- ^{33b}*iThemba Labs, Western Cape, South Africa*
- ^{33c}*Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, South Africa*
- ^{33d}*University of South Africa, Department of Physics, Pretoria, South Africa*
- ^{33e}*School of Physics, University of the Witwatersrand, Johannesburg, South Africa*
- ³⁴*Department of Physics, Carleton University, Ottawa ON, Canada*
- ^{35a}*Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies—Université Hassan II, Casablanca, Morocco*
- ^{35b}*Faculté des Sciences, Université Ibn-Tofail, Kénitra, Morocco*
- ^{35c}*Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Morocco*

- ^{35d}*Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda, Morocco*
- ^{35c}*Faculté des sciences, Université Mohammed V, Rabat, Morocco*
- ³⁶*CERN, Geneva, Switzerland*
- ³⁷*Enrico Fermi Institute, University of Chicago, Chicago, Illinois, USA*
- ³⁸*LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand, France*
- ³⁹*Nevis Laboratory, Columbia University, Irvington, New York, USA*
- ⁴⁰*Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark*
- ^{41a}*Dipartimento di Fisica, Università della Calabria, Rende, Italy*
- ^{41b}*INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Italy*
- ⁴²*Physics Department, Southern Methodist University, Dallas, Texas, USA*
- ⁴³*Physics Department, University of Texas at Dallas, Richardson, Texas, USA*
- ⁴⁴*National Centre for Scientific Research “Demokritos”, Agia Paraskevi, Greece*
- ^{45a}*Department of Physics, Stockholm University, Sweden*
- ^{45b}*Oskar Klein Centre, Stockholm, Sweden*
- ⁴⁶*Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen, Germany*
- ⁴⁷*Lehrstuhl für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany*
- ⁴⁸*Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany*
- ⁴⁹*Department of Physics, Duke University, Durham, North Carolina, USA*
- ⁵⁰*SUPA—School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom*
- ⁵¹*INFN e Laboratori Nazionali di Frascati, Frascati, Italy*
- ⁵²*Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany*
- ⁵³*II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany*
- ⁵⁴*Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland*
- ^{55a}*Dipartimento di Fisica, Università di Genova, Genova, Italy*
- ^{55b}*INFN Sezione di Genova, Italy*
- ⁵⁶*II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany*
- ⁵⁷*SUPA—School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom*
- ⁵⁸*LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble, France*
- ⁵⁹*Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, Massachusetts, USA*
- ^{60a}*Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, China*
- ^{60b}*Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao, China*
- ^{60c}*School of Physics and Astronomy, Shanghai Jiao Tong University, KLPPAC-MoE, SKLPPC, Shanghai, China*
- ^{60d}*Tsung-Dao Lee Institute, Shanghai, China*
- ^{61a}*Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
- ^{61b}*Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
- ⁶²*Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan*
- ^{63a}*Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China*
- ^{63b}*Department of Physics, University of Hong Kong, Hong Kong, China*
- ^{63c}*Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China*
- ⁶⁴*Department of Physics, National Tsing Hua University, Hsinchu, Taiwan*
- ⁶⁵*IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay, France*
- ⁶⁶*Department of Physics, Indiana University, Bloomington, Indiana, USA*
- ^{67a}*INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, Italy*
- ^{67b}*ICTP, Trieste, Italy*
- ^{67c}*Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine, Italy*
- ^{68a}*INFN Sezione di Lecce, Italy*
- ^{68b}*Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy*
- ^{69a}*INFN Sezione di Milano, Italy*
- ^{69b}*Dipartimento di Fisica, Università di Milano, Milano, Italy*
- ^{70a}*INFN Sezione di Napoli, Italy*
- ^{70b}*Dipartimento di Fisica, Università di Napoli, Napoli, Italy*
- ^{71a}*INFN Sezione di Pavia, Italy*
- ^{71b}*Dipartimento di Fisica, Università di Pavia, Pavia, Italy*
- ^{72a}*INFN Sezione di Pisa, Italy*
- ^{72b}*Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy*
- ^{73a}*INFN Sezione di Roma, Italy*
- ^{73b}*Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy*

- ^{74a}*INFN Sezione di Roma Tor Vergata, Italy*
^{74b}*Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy*
^{75a}*INFN Sezione di Roma Tre, Italy*
^{75b}*Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy*
^{76a}*INFN-TIFPA, Italy*
^{76b}*Università degli Studi di Trento, Trento, Italy*
⁷⁷*Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria*
⁷⁸*University of Iowa, Iowa City, Iowa, USA*
⁷⁹*Department of Physics and Astronomy, Iowa State University, Ames, Iowa, USA*
⁸⁰*Joint Institute for Nuclear Research, Dubna, Russia*
^{81a}*Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora, Brazil*
^{81b}*Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil*
^{81c}*Instituto de Física, Universidade de São Paulo, São Paulo, Brazil*
⁸²*KEK, High Energy Accelerator Research Organization, Tsukuba, Japan*
⁸³*Graduate School of Science, Kobe University, Kobe, Japan*
^{84a}*AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland*
^{84b}*Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland*
⁸⁵*Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland*
⁸⁶*Faculty of Science, Kyoto University, Kyoto, Japan*
⁸⁷*Kyoto University of Education, Kyoto, Japan*
⁸⁸*Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka, Japan*
⁸⁹*Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina*
⁹⁰*Physics Department, Lancaster University, Lancaster, United Kingdom*
⁹¹*Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom*
⁹²*Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia*
⁹³*School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom*
⁹⁴*Department of Physics, Royal Holloway University of London, Egham, United Kingdom*
⁹⁵*Department of Physics and Astronomy, University College London, London, United Kingdom*
⁹⁶*Louisiana Tech University, Ruston, Louisiana, USA*
⁹⁷*Fysiska institutionen, Lunds universitet, Lund, Sweden*
⁹⁸*Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France*
⁹⁹*Departamento de Física Teórica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid, Spain*
¹⁰⁰*Institut für Physik, Universität Mainz, Mainz, Germany*
¹⁰¹*School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom*
¹⁰²*CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France*
¹⁰³*Department of Physics, University of Massachusetts, Amherst, Massachusetts, USA*
¹⁰⁴*Department of Physics, McGill University, Montreal, Quebec, Canada*
¹⁰⁵*School of Physics, University of Melbourne, Victoria, Australia*
¹⁰⁶*Department of Physics, University of Michigan, Ann Arbor, Michigan, USA*
¹⁰⁷*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA*
¹⁰⁸*B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus*
¹⁰⁹*Research Institute for Nuclear Problems of Byelorussian State University, Minsk, Belarus*
¹¹⁰*Group of Particle Physics, University of Montreal, Montreal, Quebec, Canada*
¹¹¹*P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia*
¹¹²*National Research Nuclear University MEPhI, Moscow, Russia*
¹¹³*D.V. Skobel'syn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia*
¹¹⁴*Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany*
¹¹⁵*Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany*
¹¹⁶*Nagasaki Institute of Applied Science, Nagasaki, Japan*
¹¹⁷*Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan*
¹¹⁸*Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico, USA*
¹¹⁹*Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands*
¹²⁰*Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands*
¹²¹*Department of Physics, Northern Illinois University, DeKalb, Illinois, USA*
^{122a}*Budker Institute of Nuclear Physics and NSU, SB RAS, Novosibirsk, Russia*
^{122b}*Novosibirsk State University Novosibirsk, Russia*
¹²³*Institute for High Energy Physics of the National Research Centre Kurchatov Institute, Protvino, Russia*
¹²⁴*Institute for Theoretical and Experimental Physics named by A.I. Alkhanov of National Research Centre "Kurchatov Institute", Moscow, Russia*

- ¹²⁵*Department of Physics, New York University, New York, New York, USA*
- ¹²⁶*Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo, Japan*
- ¹²⁷*Ohio State University, Columbus, Ohio, USA*
- ¹²⁸*Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma, USA*
- ¹²⁹*Department of Physics, Oklahoma State University, Stillwater, Oklahoma, USA*
- ¹³⁰*Palacký University, RCPTM, Joint Laboratory of Optics, Olomouc, Czech Republic*
- ¹³¹*Institute for Fundamental Science, University of Oregon, Eugene, Oregon, USA*
- ¹³²*Graduate School of Science, Osaka University, Osaka, Japan*
- ¹³³*Department of Physics, University of Oslo, Oslo, Norway*
- ¹³⁴*Department of Physics, Oxford University, Oxford, United Kingdom*
- ¹³⁵*LPNHE, Sorbonne Université, Université de Paris, CNRS/IN2P3, Paris, France*
- ¹³⁶*Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania, USA*
- ¹³⁷*Konstantinov Nuclear Physics Institute of National Research Centre “Kurchatov Institute”, PNPI, St. Petersburg, Russia*
- ¹³⁸*Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania, USA*
- ^{139a}*Laboratório de Instrumentação e Física Experimental de Partículas—LIP, Lisboa, Portugal*
- ^{139b}*Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal*
- ^{139c}*Departamento de Física, Universidade de Coimbra, Coimbra, Portugal*
- ^{139d}*Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal*
- ^{139e}*Departamento de Física, Universidade do Minho, Braga, Portugal*
- ^{139f}*Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain), Spain*
- ^{139g}*Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal*
- ^{139h}*Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal*
- ¹⁴⁰*Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic*
- ¹⁴¹*Czech Technical University in Prague, Prague, Czech Republic*
- ¹⁴²*Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic*
- ¹⁴³*Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom*
- ¹⁴⁴*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
- ¹⁴⁵*Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, California, USA*
- ^{146a}*Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile*
- ^{146b}*Universidad Andres Bello, Department of Physics, Santiago, Chile*
- ^{146c}*Instituto de Alta Investigación, Universidad de Tarapacá, Chile*
- ^{146d}*Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile*
- ¹⁴⁷*Universidade Federal de São João del Rei (UFSJ), São João del Rei, Brazil*
- ¹⁴⁸*Department of Physics, University of Washington, Seattle, Washington, D.C., USA*
- ¹⁴⁹*Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom*
- ¹⁵⁰*Department of Physics, Shinshu University, Nagano, Japan*
- ¹⁵¹*Department Physik, Universität Siegen, Siegen, Germany*
- ¹⁵²*Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada*
- ¹⁵³*SLAC National Accelerator Laboratory, Stanford, California, USA*
- ¹⁵⁴*Physics Department, Royal Institute of Technology, Stockholm, Sweden*
- ¹⁵⁵*Departments of Physics and Astronomy, Stony Brook University, Stony Brook, New York, USA*
- ¹⁵⁶*Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom*
- ¹⁵⁷*School of Physics, University of Sydney, Sydney, Australia*
- ¹⁵⁸*Institute of Physics, Academia Sinica, Taipei, Taiwan*
- ^{159a}*E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia*
- ^{159b}*High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia*
- ¹⁶⁰*Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel*
- ¹⁶¹*Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel*
- ¹⁶²*Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*
- ¹⁶³*International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan*
- ¹⁶⁴*Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan*
- ¹⁶⁵*Department of Physics, Tokyo Institute of Technology, Tokyo, Japan*
- ¹⁶⁶*Tomsk State University, Tomsk, Russia*
- ¹⁶⁷*Department of Physics, University of Toronto, Toronto ON, Canada*
- ^{168a}*TRIUMF, Vancouver BC, Canada*
- ^{168b}*Department of Physics and Astronomy, York University, Toronto ON, Canada*
- ¹⁶⁹*Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan*
- ¹⁷⁰*Department of Physics and Astronomy, Tufts University, Medford, Massachusetts, USA*
- ¹⁷¹*Department of Physics and Astronomy, University of California Irvine, Irvine, California, USA*

¹⁷²*Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*

¹⁷³*Department of Physics, University of Illinois, Urbana, Illinois, USA*

¹⁷⁴*Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia—CSIC, Valencia, Spain*

¹⁷⁵*Department of Physics, University of British Columbia, Vancouver, British Columbia, Canada*

¹⁷⁶*Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia, Canada*

¹⁷⁷*Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany*

¹⁷⁸*Department of Physics, University of Warwick, Coventry, United Kingdom*

¹⁷⁹*Waseda University, Tokyo, Japan*

¹⁸⁰*Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot, Israel*

¹⁸¹*Department of Physics, University of Wisconsin, Madison, Wisconsin, USA*

¹⁸²*Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany*

¹⁸³*Department of Physics, Yale University, New Haven, Connecticut, USA*

^aDeceased.

^bAlso at Department of Physics, King's College London, London, United Kingdom.

^cAlso at Istanbul University, Dept. of Physics, Istanbul, Turkey.

^dAlso at Instituto de Física Teórica, IFT-UAM/CSIC, Madrid, Spain.

^eAlso at TRIUMF, Vancouver, British Columbia, Canada.

^fAlso at Department of Physics and Astronomy, University of Louisville, Louisville, Kentucky, USA.

^gAlso at Physics Department, An-Najah National University, Nablus, Palestine.

^hAlso at Department of Physics, University of Fribourg, Fribourg, Switzerland.

ⁱAlso at Physics Dept, University of South Africa, Pretoria, South Africa.

^jAlso at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona, Spain.

^kAlso at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.

^lAlso at Department of Physics, Ben Gurion University of the Negev, Beer Sheva, Israel.

^mAlso at Università di Napoli Parthenope, Napoli, Italy.

ⁿAlso at Institute of Particle Physics (IPP), Canada.

^oAlso at Department of Physics, University of Adelaide, Adelaide, Australia.

^pAlso at Dipartimento di Matematica, Informatica e Fisica, Università di Udine, Udine, Italy.

^qAlso at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia.

^rAlso at Borough of Manhattan Community College, City University of New York, New York, New York, USA.

^sAlso at Department of Physics, California State University, Fresno, USA.

^tAlso at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece.

^uAlso at Department of Physics, California State University, East Bay, USA.

^vAlso at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.

^wAlso at IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405 Orsay, France.

^xAlso at Graduate School of Science, Osaka University, Osaka, Japan.

^yAlso at Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany.

^zAlso at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.

^{aa}Also at Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands.

^{bb}Also at CERN, Geneva, Switzerland.

^{cc}Also at Joint Institute for Nuclear Research, Dubna, Russia.

^{dd}Also at Hellenic Open University, Patras, Greece.

^{ee}Also at The City College of New York, New York, New York, USA.

^{ff}Also at Department of Physics, California State University, Sacramento, USA.

^{gg}Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland.

^{hh}Also at Louisiana Tech University, Ruston, Louisiana, USA.

ⁱⁱAlso at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria.

^{jj}Also at Faculty of Physics, M.V. Lomonosov Moscow State University, Moscow, Russia.

^{kk}Also at Department of Applied Physics and Astronomy, University of Sharjah, Sharjah, United Arab Emirates.

^{ll}Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.

^{mmm}Also at CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France.

ⁿⁿAlso at National Research Nuclear University MEPhI, Moscow, Russia.

^{oo}Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary.

^{pp}Also at Giresun University, Faculty of Engineering, Giresun, Turkey.

^{qq}Also at Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA.