

Measurement of the Centrality Dependence of the Dijet Yield in $p + \text{Pb}$ Collisions at $\sqrt{s_{\text{NN}}} = 8.16$ TeV with the ATLAS Detector

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

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ATLAS measured the centrality dependence of the dijet yield using 165 nb^{-1} of $p + \text{Pb}$ data collected at $\sqrt{s_{\text{NN}}} = 8.16$ TeV in 2016. The event centrality, which reflects the $p + \text{Pb}$ impact parameter, is characterized by the total transverse energy registered in the Pb-going side of the forward calorimeter. The central-to-peripheral ratio of the scaled dijet yields, R_{CP} , is evaluated, and the results are presented as a function of variables that reflect the kinematics of the initial hard parton scattering process. The R_{CP} shows a scaling with the Bjorken x of the parton originating from the proton, x_p , while no such trend is observed as a function of x_{Pb} . This analysis provides unique input to understanding the role of small proton spatial configurations in $p + \text{Pb}$ collisions by covering parton momentum fractions from the valence region down to $x_p \sim 10^{-3}$ and $x_{\text{Pb}} \sim 4 \times 10^{-4}$.

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Proton-nucleus ($p + A$) reactions at colliders provide unique opportunities to study the structure of both the proton and the nucleus [1]. By measuring high transverse momentum (p_T) probes generated in $p + A$ collisions over a wide rapidity range, it is possible to investigate modifications of parton distribution functions (PDFs) in the nuclear environment [2–5] from small parton fractional momenta (x) up to the valence quark dominance region. Inclusive jet production rates were measured in $p + \text{Pb}$ collisions at the LHC [6–9] and in $d + \text{Au}$ collisions at RHIC [10]. ALICE also measured the jet production cross sections and nuclear modification of charged jets at 5.02 TeV [6]. None of these results observed a substantial modification of jet rates relative to the geometrical expectation constructed from proton-proton (pp) collisions, i.e., for $p + A$, scaling with the atomic mass number A : $\sigma^{p+A} \simeq A\sigma^{p+p}$. ATLAS [9] and PHENIX [10] analyzed the centrality dependence of the jet production. In this context, centrality is an experimental classification of the collision geometry based on a measurement of the underlying event (UE) activity in a rapidity region entirely separated from the hard-scattering measurement. In $p/d + A$ collisions, centrality is sensitive to the multiple interactions between the projectile and the nucleons in the nucleus, with more central (peripheral) events characterized by a higher (lower) average number of nucleon-nucleon

(NN) collisions. Both Refs. [9,10] observed a suppression of the jet yield in central events and an enhancement in peripheral events. ATLAS found the relationship between the suppression and the enhancement to be a function of only the total jet energy. However, the initial hard parton-parton kinematics in each measurement were not fully constrained by the measurement of a single jet. To test for a trivial dependence on the kinematics of an NN collision, ATLAS also performed a measurement of the forward transverse energy in pp collisions [11] and found only a weak correlation between x of the proton beam and the transverse energy in the opposite direction, a trend that is at odds with the $p + \text{Pb}$ results. This implied that the scaling observed in $p + \text{Pb}$ collisions was not a property of the NN collision itself. CMS measured a shift in the Pb beam direction of the mean dijet pseudorapidity as a function of the total forward transverse energy [7], which is dominated by the energy deposited by the Pb debris. The inclusive measurement was observed to be consistent with predictions based on nuclear parton distribution functions (nPDFs), but the relative changes with centrality were found to be much larger than those expected from model predictions using nPDFs [12]. While this result had qualitative similarities to those reported by ATLAS [9], it covered a more limited kinematic range in only a single dijet p_T interval, making it difficult to assess more quantitatively.

These measurements inspired several theoretical works [13–15]. The models proposed in Refs. [13,14] were able to partially reproduce the ATLAS data [9] but were strongly disfavored by the results of Ref. [11]. In Ref. [15], the authors were able to reproduce inclusive jet results at both RHIC [10] and LHC [9] energies using a model based on a

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

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color fluctuation-related [16] interpretation. The interaction strength of the proton, as well as its transverse size, are treated as dynamic quantities that depend on the instantaneous partonic configuration, considered frozen during the propagation of the proton through the nucleus. Because of QCD color screening, the overall interaction strength of a color-neutral configuration is expected to vary with the transverse area subtended by its color charges [17], which is smaller in hadrons where one parton carries a considerable fraction of the momentum. Therefore, hard $p + \text{Pb}$ scatterings involving configurations of the proton with a large- x parton, typical of the valence quark dominance region, are characterized by a smaller than average size and interaction strength of the projectile. These configurations have a reduced number of soft interactions with the nucleus, resulting in lower underlying event activity and, thus, shifting the event into a more peripheral centrality interval. This can be interpreted as a manifestation of color transparency phenomena [17–20]. Triple differential measurements of the dijet production as a function of centrality would allow for connecting these effects directly to the kinematics of the parton scattering, providing crucial input to advance the understanding of small proton configurations and their relation to the suppression of the overall interaction strength in $p + A$ collisions.

This Letter presents measurements of the centrality dependence of the differential dijet yield in ATLAS $p + \text{Pb}$ data at an NN center-of-mass energy of 8.16 TeV. It uses data collected in 2016 corresponding to an integrated luminosity of 165 nb^{-1} . The LHC was configured with a 6.5 TeV proton beam and a Pb beam with an energy of 2.56 TeV per nucleon. In this measurement, positive (negative) rapidities correspond to the proton-going (Pb-going) direction. The beam configuration resulted in a rapidity shift of the center of mass by $+0.465$ units in the proton-going direction relative to the laboratory frame.

The measurement presented here was performed using the ATLAS calorimeters, inner detector, trigger, and data acquisition systems [21]. The calorimeter system consists of a sampling liquid-argon (LAr) electromagnetic (EM) calorimeter covering $|\eta| < 3.2$ [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 (ρ, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\text{Intan}(\theta/2)$. Angular distance is measured in units of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$], a steel-scintillator sampling hadronic calorimeter covering $|\eta| < 1.7$, LAr hadronic calorimeters covering $1.5 < |\eta| < 3.2$, and two LAr forward calorimeters (FCal) covering $3.2 < |\eta| < 4.9$. The EM calorimeters are segmented longitudinally in shower depth into three layers with an additional presampler layer covering

$|\eta| < 1.8$. The hadronic calorimeters have three sampling layers longitudinal in shower depth in $|\eta| < 1.7$ and four sampling layers in $1.5 < |\eta| < 3.2$, with a slight overlap in η . During the 2016 $p + \text{Pb}$ run, a sector of the hadronic end cap calorimeter (HEC), corresponding to $1.5 < \eta < 3.2$ and $-\pi < \phi < -\pi/2$, was disabled. An extensive software suite [22] is used in data simulation, in the reconstruction and analysis of real and simulated data, in detector operations, and in the trigger and data acquisition systems of the experiment.

The dijet yield was measured as a function of

$$p_{T,\text{Avg}} = \frac{p_{T,1} + p_{T,2}}{2}, \quad y_b = \frac{y_1^{\text{c.m.}} + y_2^{\text{c.m.}}}{2}, \quad \text{and} \\ y^* = \frac{|y_1^{\text{c.m.}} - y_2^{\text{c.m.}}|}{2}, \quad (1)$$

where the superscript ‘‘c.m.’’ denotes variables translated in the center-of-mass frame of the collision, while the subscripts 1 and 2 refer to the jets with the highest (leading) and second-highest (subleading) p_T in a given event, respectively. $p_{T,\text{Avg}}$ is the average transverse momentum, and y_b and y^* are the boost and the half-rapidity separation of the dijet system, respectively. Note that y^* is directly related to the $2 \rightarrow 2$ scattering angle. These variables can be approximately related to

$$x_p = \frac{p_{T,1} e^{y_1^{\text{c.m.}}} + p_{T,2} e^{y_2^{\text{c.m.}}}}{\sqrt{s_{\text{NN}}}} \simeq \frac{2p_{T,\text{Avg}}}{\sqrt{s_{\text{NN}}}} e^{y_b} \cosh(y^*) \quad (2)$$

and

$$x_{\text{Pb}} = \frac{p_{T,1} e^{-y_1^{\text{c.m.}}} + p_{T,2} e^{-y_2^{\text{c.m.}}}}{\sqrt{s_{\text{NN}}}} \simeq \frac{2p_{T,\text{Avg}}}{\sqrt{s_{\text{NN}}}} e^{-y_b} \cosh(y^*), \quad (3)$$

the longitudinal momentum fractions carried by the incident partons in a $2 \rightarrow 2$ QCD scattering in the proton and Pb nucleus, respectively.

Centrality in $p + \text{Pb}$ collisions can be directly related to the number of inelastic collisions between the proton and the nucleons bound in the Pb nucleus. In this analysis, centrality was characterized using the total transverse energy ΣE_T^{Pb} , measured in the FCal in the Pb-going direction [9,23,24], with the resulting distribution being divided into percentiles. A Glauber Monte Carlo (MC) model [25,26] was used to relate ΣE_T^{Pb} to the average value of the nuclear thickness function, T_{AB} [27], in a given centrality class. The reported results were obtained using the 0%–10% (central) and 60%–90% (peripheral) centrality intervals. The resultant $\langle T_{AB} \rangle$ values and associated uncertainties are (0.205 ± 0.013) and $(0.043 \pm 0.009) \text{ mb}^{-1}$ for central and peripheral collisions, respectively.

Nuclear modification effects are typically characterized by the ratio of the hard scattering rates in the presence and absence of a nuclear environment. In this analysis, the dijet

yield was measured in different centrality intervals to construct the central-to-peripheral ratio R_{CP} defined as

$$R_{CP}(p_{T,Avg}, y_b, y^*) = \frac{\frac{1}{\langle T_{AB}^{0\%-10\%} \rangle} \frac{1}{N_{evt}^{0\%-10\%}} \frac{d^3 N_{dijet}^{0\%-10\%}}{dp_{T,Avg} dy_b dy^*}}{\frac{1}{\langle T_{AB}^{60\%-90\%} \rangle} \frac{1}{N_{evt}^{60\%-90\%}} \frac{d^3 N_{dijet}^{60\%-90\%}}{dp_{T,Avg} dy_b dy^*}}, \quad (4)$$

where $N_{evt}^{0\%-10\%}$ ($N_{evt}^{60\%-90\%}$) and $N_{dijet}^{0\%-10\%}$ ($N_{dijet}^{60\%-90\%}$) represent the number of sampled minimum-bias and dijet events in central (peripheral) collisions, respectively. The R_{CP} quantifies the deviations in the dijet yield in more central collisions from geometric expectations relative to peripheral collisions, assuming little to no nuclear final state modification in the latter. An R_{CP} of unity implies no centrality-dependent modifications.

The $p + Pb$ data used in this analysis were required to satisfy detector and data-quality requirements and to contain at least one reconstructed primary vertex and at least two reconstructed jets. A set of central and forward single-jet triggers [28], characterized by different p_T thresholds, were chosen to provide full p_T coverage over a wide pseudorapidity range, corresponding to $-2.8 < \eta < 4.5$. The leading jet was required to have passed the trigger that sampled the largest luminosity and was 99% efficient for the given jet η and p_T . The leading (subleading) jet was further required to have $p_T > 40(30)$ GeV. Events were discarded if either of the jets fell in the acceptance of the disabled HEC region. To define a rejection criterion for the analysis, the disabled region was increased by an additional 0.4 margin in both the pseudorapidity and azimuthal angle. Pileup events were rejected using vertex and track requirements. The exclusion of events in the 90%–100% centrality interval, combined with a rapidity gap requirement [29] in the Pb-going direction, effectively rejected any contribution from ultra-peripheral collisions.

Jets used in this measurement were reconstructed using the anti- k_t algorithm [30] as implemented within the `FastJet` software package [31]. Jets with $R = 0.4$ were formed by clustering four-vectors corresponding to massless calorimeter towers with size $\Delta\eta \times \Delta\phi = 0.1 \times (\pi/32)$. The background energy arising from the UE was subtracted from each tower. An iterative procedure was used to estimate the UE average transverse energy density $\rho(\eta)$ while excluding regions of the detector populated by jets [32]. The UE evaluation was additionally corrected for η - ϕ dependent nonuniformities of the detector.

The performance of the jet reconstruction was evaluated using `GEANT4` [33,34] to simulate the detector response and a `PYTHIA8` [35] MC sample consisting of dijet events from 8.16 TeV pp collisions, including the boost in rapidity relative to the lab frame that is present in data. The MC sample was generated using `PYTHIA8` with the A14 set of tuned parameters [36] and the `NNPDF2.3LO` parton distribution functions [37]. Events from the dijet sample were

overlaid with minimum-bias $p + Pb$ collisions recorded by ATLAS during the same data-taking period as the analyzed data, ensuring a proper UE description in the MC sample.

To correct for the effects of detector response on the measurement, the dijet yield was unfolded in $p_{T,Avg}$ using a one-dimensional Bayesian procedure [38], implemented within the `RooUnfold` package [39]. For each y_b , y^* , and centrality interval, a response matrix was filled using pairs of true and reconstructed jets from the `PYTHIA8` overlay MC sample. The statistical uncertainty on the dijet yield was evaluated using a bootstrapping method [40] to generate statistically correlated response matrices.

An efficiency correction was included during the unfolding to account for reconstructed dijets that migrated between y_b and y^* bins or out of the measurement phase space at the detector level due to energy resolution effects. Dijets impacted by the disabled HEC region exclusion were also accounted for with this correction. The size of the efficiency correction on the yields is significant only in the pseudorapidity region corresponding to the disabled HEC, where it reaches approximately a factor of 3. It is on the order of a few percent in the remaining phase space due to migration between y_b and y^* bins and energy resolution effects.

To estimate the systematic uncertainty on the jet energy scale (JES), jet energy resolution (JER), and unfolding procedure, the difference between the nominal result and that obtained by repeating the analysis with modified response matrices was calculated. The JES and JER smearing factors were obtained via *in situ* studies [41], as well as by accounting for reconstruction and calibration differences [32] between this measurement and 13 TeV pp data, where components of the uncertainty were derived. An additional component accounting for MC modeling of the quark and gluon jets is included in the JES uncertainty. The total systematic uncertainty on the dijet yield is dominated by the JES uncertainty, which is approximately 10% in all kinematic intervals. The JER uncertainty is subdominant, reaching up to $\sim 10\%$ only for the highest y^* values. The uncertainty on the unfolding procedure is related to its sensitivity to the choice of prior, which was reweighted to have better data-MC agreement. To address this, an approach similar to one found in Ref. [9] was used to vary the reweighting, producing modified response matrices. The systematic uncertainty on the unfolding is at the subpercent level for all bins.

The systematic uncertainty associated with the disabled HEC exclusion was evaluated by increasing the fiducial cuts by 0.1 in all directions in azimuth and pseudorapidity and repeating the analysis procedure. The resultant uncertainty was found to be on the order of 1%–2% in the majority of the measurement's phase space.

Correlations in the JES, JER, and HEC uncertainties between central and peripheral bins were accounted for in the propagation of the uncertainties to the R_{CP} . The partial

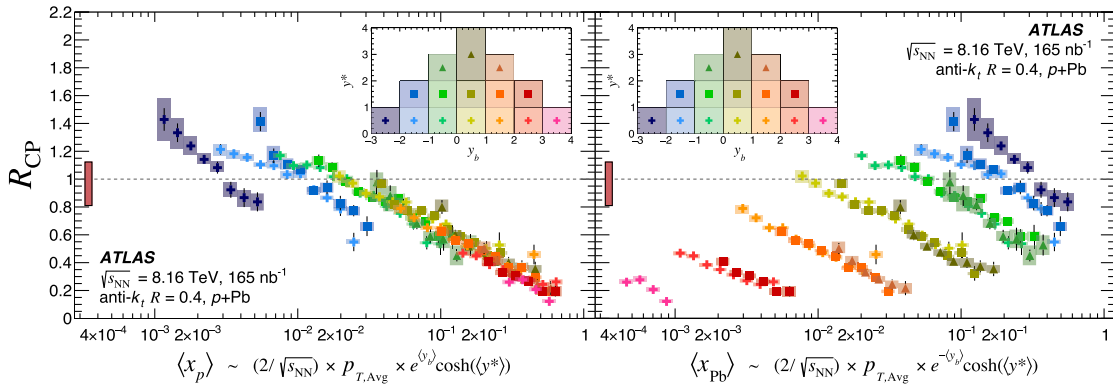


FIG. 1. R_{CP} plotted as a function of approximated x_p (left panel) and x_{Pb} (right panel), constructed using $\langle y_b \rangle$ and $\langle y^* \rangle$. An inset legend is included, showing the (y_b, y^*) bins and their corresponding markers. The proton-going direction is defined by $y_b > 0$. Shaded rectangles represent the total systematic uncertainty, while the vertical error bars represent the statistical uncertainty. The solid rectangle on the left side of each panel represents the uncertainty on the T_{AB} .

cancellation of the resulting systematic uncertainties from these sources results in considerably smaller uncertainties on the R_{CP} compared with those on the dijet yield. The normalization uncertainty on the R_{CP} corresponding to the T_{AB} is $+12\% / -19\%$ and is independent of jet p_T and η .

The measured central and peripheral dijet yields are used to construct the R_{CP} as a function of $p_{T,Avg}$. The R_{CP} values are then plotted against the approximated kinematics of the hard parton scattering, constructed using Eqs. (2) and (3) as $\langle x_p \rangle \sim (2p_{T,Avg}/\sqrt{s_{NN}})e^{(y_b)} \cosh(y^*)$ and $\langle x_{Pb} \rangle \sim (2p_{T,Avg}/\sqrt{s_{NN}}) \times e^{-(y_b)} \cosh(y^*)$, where $\langle y_b \rangle$ and $\langle y^* \rangle$ are the average values of the dijet boost and half-rapidity separation in each given kinematic bin, respectively. The level of accuracy of this approximation was evaluated via PYTHIA8 MC simulations and found to be accurate within the bin widths used for the measurement.

Figure 1 shows the results as a function of $\langle x_p \rangle$ (left) and $\langle x_{Pb} \rangle$ (right). A distinct x_p scaling of the $R_{CP}(x_p)$ is observed in the valence quark dominance region, characterized by a log-linear decreasing trend. No similar scaling is observed for smaller values of x_p or for any region when expressed as a function of x_{Pb} . Recently, the analysis of forward dijet production in $p + Pb$ collisions at LHC energies was proposed in order to search for the onset of gluon saturation [42] at low values of x_{Pb} . The saturation scale in the nuclear environment is expected to be enhanced by a factor $A^{1/3}$. The lack of monotonic scaling with decreasing x_{Pb} observed in Fig. 1 suggests that gluon saturation is not the dominant source of the observed effect. These observations can be expected from the color fluctuation-related interpretation discussed at the beginning of this Letter. The measured suppression of the R_{CP} is qualitatively consistent with an x_p -dependent decrease in the interaction strength of proton configurations containing high- x partons, resulting in a modification of the UE activity and, therefore, the centrality. Centrality estimates

for events with hard scatterings have been found to be biased by modifications in soft processes, an effect that is typically enhanced with small pseudorapidity separations $\Delta\eta$ between a hard probe and the centrality detector acceptance [23,43,44]. The effect is strongly reduced at large $\Delta\eta$ and is expected to have negligible impact on the R_{CP} x_p scaling reported in Fig. 1.

The x_p scaling observed in Fig. 1 is qualitatively similar to that observed in the 5.02 TeV run 1 inclusive jet analysis [9] as a function of the jet energy. A direct comparison between the results could clarify whether or not they are connected by the same underlying physics. The measurements can be compared by making use of the Feynman scaling variable x_F [45]. Figure 2 shows the dijet results as a function of the approximated x_F computed in each

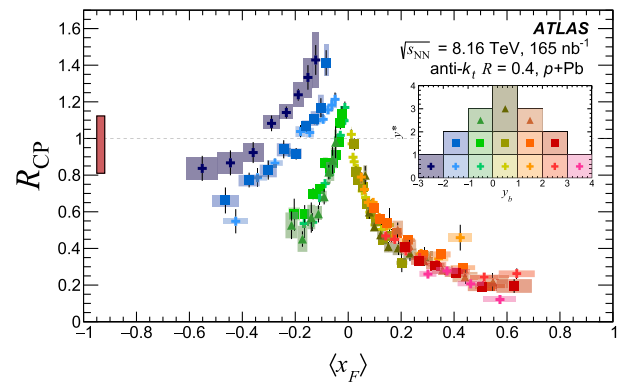


FIG. 2. R_{CP} plotted as a function of approximated x_F , here indicated with $\langle x_F \rangle$ and constructed using $\langle y_b \rangle$ and $\langle y^* \rangle$. An inset legend is included, showing the (y_b, y^*) bins and their corresponding markers. The proton-going direction is defined by $y_b > 0$. Shaded rectangles represent the total systematic uncertainty, while the vertical error bars represent the statistical uncertainty. The solid rectangle on the left side of the panel represents the uncertainty on the T_{AB} .

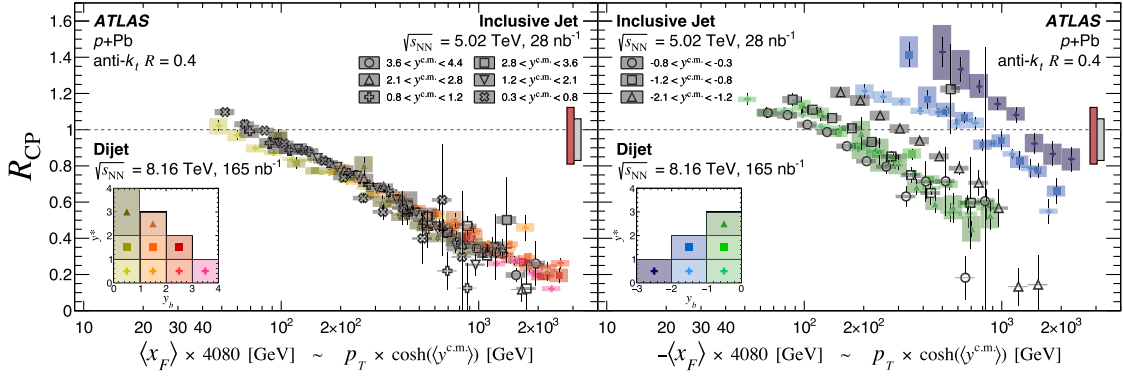


FIG. 3. Dijet R_{CP} results from this Letter compared with inclusive jet R_{CP} at 5.02 TeV measured by ATLAS [9]. The dijet results are denoted by full markers and are reported as a function of $\pm \langle x_F \rangle \times 4080$ GeV, for positive (+, left panel) and negative (–, right panel) y_b ($y^{c.m.}$) results, respectively. An inset legend is included, showing the (y_b, y^*) bins and their corresponding markers. The inclusive jet results are displayed as a function of $p_T \times \cosh(\langle y^{c.m.} \rangle)$ and use open markers. Shaded rectangles represent the total systematic uncertainty, while the vertical error bars represent the statistical uncertainty. The uncertainties on the T_{AB} on the dijet (inclusive jet) results are reported using the left (right) solid rectangle on the right side of each panel. The 5.02 TeV data for $-0.3 < y^{c.m.} < 0.3$ were omitted, since they belong to the transition region between the two panels.

kinematic bin as $\langle x_F \rangle = \langle x_p \rangle - \langle x_{pb} \rangle$. The mapping of the R_{CP} to $\langle x_F \rangle$ allows for factoring out the beam energy from the results while isolating the dependence of the dijet yield on the parton momentum fractions characterizing the hard scattering. Large positive (negative) values of $\langle x_F \rangle$ are associated to scatterings dominated by the longitudinal momentum of the parton originating from the proton (nucleus). In inclusive jet measurements, x_F can also be constructed as a property of the final state, i.e., $x_F = 2p_z / \sqrt{s_{NN}}$, where p_z is the longitudinal momentum of the measured jet. Assuming the jet mass to be small compared to its transverse momentum and considering $y^{c.m.}$ values large enough that $\sinh y^{c.m.} \simeq \pm \cosh y^{c.m.}$, with the positive (negative) sign corresponding to $y^{c.m.} > 0$ ($y^{c.m.} < 0$):

$$x_F = \frac{2m_T \times \sinh y^{c.m.}}{\sqrt{s_{NN}}} \sim \pm \frac{2p_T \times \cosh y^{c.m.}}{\sqrt{s_{NN}}}. \quad (5)$$

Therefore, because the results in Ref. [9] were reported as a function of $p_T \times \cosh y^{c.m.}$, a comparison to the results presented in this Letter can be achieved using the relation $\pm x_F \sqrt{s_{NN}} / 2 \sim p_T \times \cosh y^{c.m.}$, where the sign of the left-hand side of the equation corresponds to the sign of $y^{c.m.}$. This comparison is shown in Fig. 3. A striking agreement is observed between the results obtained at positive $y^{c.m.}$ and y_b , corresponding to the high- x_p region. This comparison shows that the physics mechanism responsible for the R_{CP} suppression in this kinematic region is the same in the two analyses, and the scaling behavior observed at 5.02 TeV as a function of the jet energy is effectively governed by the proton configuration. The agreement between the data progressively worsens when moving toward the negative rapidity region, where the majority of the momentum in the hard scattering is contributed by the parton from the Pb

nucleus. These results provide new input to further parametrize color fluctuation effects in $p + A$ collisions. Improvements in the understanding of these effects will also pave the way for future studies of color transparency at the electron-ion collider [46].

These new dijet data can also be used to provide further interpretation of the dijet pseudorapidity measurement as a function of the forward transverse energy carried out by CMS [7]. Analyzing the rapidity dependence of the results in Fig. 1, a more substantial R_{CP} suppression is associated with larger values of y_b , corresponding to higher values of x_p . This observation is directly linked to a shift in the $\langle y_b \rangle$ dependence of the dijet yield measured in central and peripheral events; refer to the Appendix for more details. Thus, these results can be used to recast the observations reported by CMS as a manifestation of the x_p -related scaling reported in this Letter.

In summary, this Letter presents the measurement of the centrality dependence of the dijet yield over a wide range of $p_{T,Avg}$, y_b , and y^* . The measured R_{CP} is reported in terms of approximated kinematics of the hard parton-parton scattering. In the valence quark dominance region of the proton, a striking x_p scaling of the R_{CP} is observed. Such scaling behavior is not present when the R_{CP} is analyzed as a function of x_{pb} . By making use of the Feynman variable x_F and a few kinematic considerations, the results are compared with those obtained by ATLAS for the centrality dependence of inclusive jet production at 5.02 TeV [9]. The comparison between the two measurements strongly suggests that the observed $p_T \times \cosh y^{c.m.}$ scaling at 5.02 TeV is driven by the kinematics of the parton originating from the proton. The outcome of this analysis provides new input to explain the systematic shift in the mean $\langle y_b \rangle$ measured by CMS at 5.02 TeV [7]. These results are qualitatively in agreement with the x_p -dependent color fluctuation effects

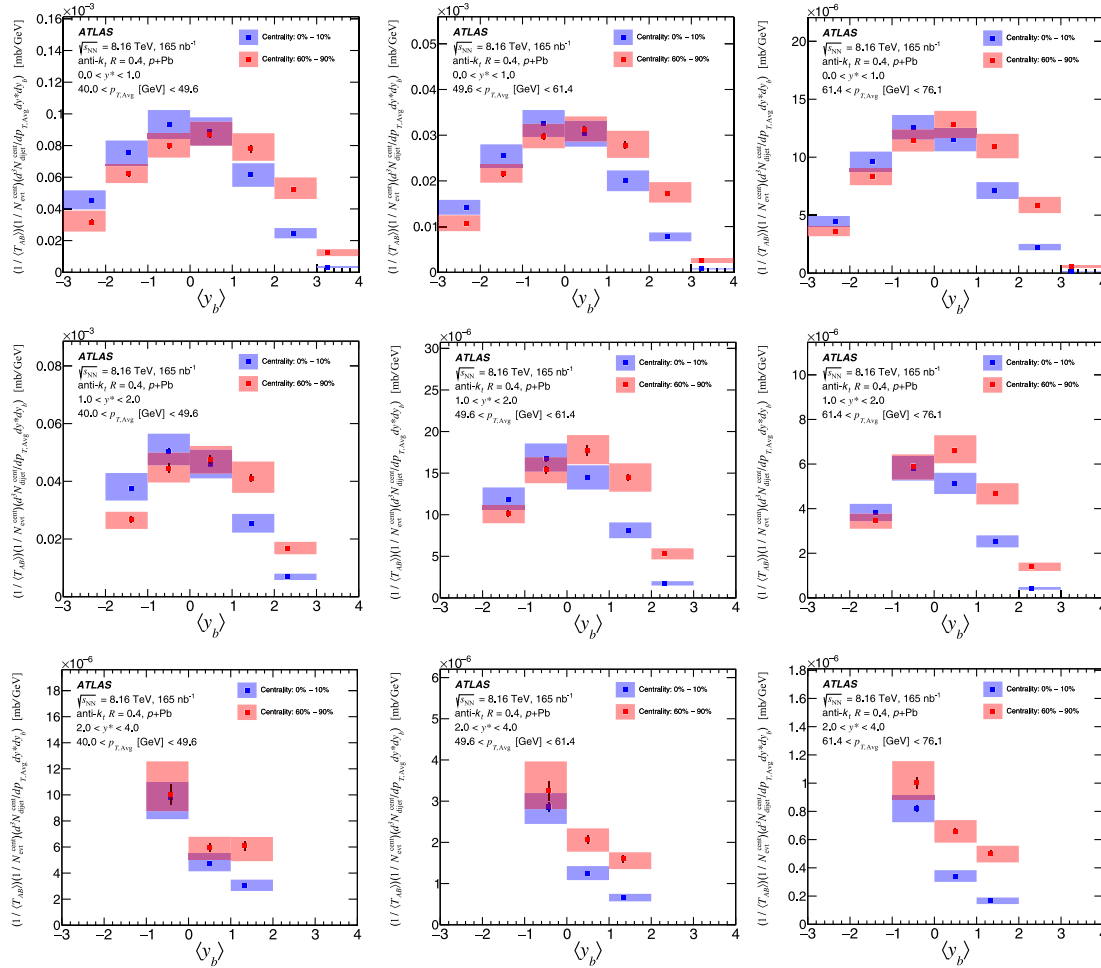


FIG. 4. $\langle T_{AB} \rangle$ normalized per-event dijet yields in 0%–10% (blue) and 60%–90% (red) collisions as a function of $\langle y_b \rangle$ in three representative $p_{T,Avg}$ bins for $0.0 < y^* < 1.0$ (top row), $1.0 < y^* < 2.0$ (middle row), and $2.0 < y^* < 4.0$ (bottom row). Shaded rectangles represent the total systematic uncertainty, while the vertical error bars represent the statistical uncertainty. The systematic uncertainties for the two distributions are highly correlated.

described in Ref. [15], directly related to small configurations of the proton characterized by a reduced interaction strength. The measurement presented in this Letter represents an essential step forward in the understanding of jet production in $p + \text{Pb}$ collisions in terms of the hard-scattering kinematics.

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Appendix.—The measured triple differential dijet yields can also be used to study the centrality dependence of the $\langle y_b \rangle$ distribution. Figure 4 shows the results as a function of $\langle y_b \rangle$ for central and peripheral intervals in a few representative $p_{T,Avg}$ and y^* selections. A shift from zero of the two distributions is observed in all the kinematic bins. This deviation is found to be monotonically decreasing as a function of $p_{T,Avg}$ for peripheral yields in all the y^* ranges. Conversely, central yields show a shift from zero decreasing in magnitude with increasing $p_{T,Avg}$ only in $0 < y^* < 1$. A moderate increase with $p_{T,Avg}$ is observed in $1 < y^* < 2$, while in $2 < y^* < 4$ the shift goes from positive (low $p_{T,Avg}$) to negative (high $p_{T,Avg}$). These kinematic dependencies are directly reflected in the x_p scaling of the R_{CP} reported in Fig. 1.

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R. J. Atkin^{33a} M. Atkinson,¹⁶² H. Atmani,^{35f} P. A. Atmasiddha¹²⁸ K. Augsten¹³² S. Auricchio^{72a,72b}
A. D. Auriol²⁰ V. A. Austrup¹⁰¹ G. Avolio³⁶ K. Axiotis⁵⁶ G. Azuelos^{108,e} D. Babal^{28b} H. Bachacou¹³⁵
K. Bachas^{152,f} A. Bachiu³⁴ F. Backman^{47a,47b} A. Badea⁶¹ T. M. Baer¹⁰⁶ P. Bagnaia^{75a,75b} M. Bahmani¹⁸
D. Bahner⁵⁴ A. J. Bailey¹⁶³ V. R. Bailey¹⁶² J. T. Baines¹³⁴ L. Baines⁹⁴ O. K. Baker¹⁷² E. Bakos¹⁵
D. Bakshi Gupta⁸ V. Balakrishnan¹²⁰ R. Balasubramanian¹¹⁴ E. M. Baldin³⁷ P. Balek^{86a} E. Ballabene^{23b,23a}
F. Balli¹³⁵ L. M. Baltés^{63a} W. K. Balunas³² J. Balz¹⁰⁰ E. Banas⁸⁷ M. Bandieramonte¹²⁹
A. Bandyopadhyay²⁴ S. Bansal²⁴ L. Barak¹⁵¹ M. Barakat⁴⁸ E. L. Barberio¹⁰⁵ D. Barberis^{57b,57a}
M. Barbero¹⁰² M. Z. Barel¹¹⁴ K. N. Barends^{33a} T. Barillari¹¹⁰ M-S. Barisits³⁶ T. Barklow¹⁴³ P. Baron¹²²
D. A. Baron Moreno¹⁰¹ A. Baroncelli^{62a} G. Barone²⁹ A. J. Barr¹²⁶ J. D. Barr⁹⁶ L. Barranco Navarro^{47a,47b}
F. Barreiro⁹⁹ J. Barreiro Guimarães da Costa^{14a} U. Barron¹⁵¹ M. G. Barros Teixeira^{130a} S. Barsov³⁷
F. Bartels^{63a} R. Bartoldus¹⁴³ A. E. Barton⁹¹ P. Bartos^{28a} A. Basan¹⁰⁰ M. Baselga⁴⁹ A. Bassalat^{66,g}
M. J. Basso^{156a} C. R. Basson¹⁰¹ R. L. Bates⁵⁹ S. Batlamous^{35e} J. R. Batley³² B. Batool¹⁴¹ M. Battaglia¹³⁶
D. Battulga¹⁸ M. Bauce^{75a,75b} M. Bauer³⁶ P. Bauer²⁴ L. T. Bazzano Hurrell³⁰ J. B. Beacham⁵¹ T. Beau¹²⁷
J. Y. Beaucamp⁹⁰ P. H. Beauchemin¹⁵⁸ F. Becherer⁵⁴ P. Bechtler²⁴ H. P. Beck^{19,h} K. Becker¹⁶⁷
A. J. Beddall⁸² V. A. Bednyakov³⁸ C. P. Bee¹⁴⁵ L. J. Beamster¹⁵ T. A. Beermann³⁶ M. Begalli^{83d} M. Begel²⁹
A. Behera¹⁴⁵ J. K. Behr⁴⁸ J. F. Beirer³⁶ F. Beisiegel²⁴ M. Belfkir¹⁵⁹ G. Bella¹⁵¹ L. Bellagamba^{23b}
A. Bellerive³⁴ P. Bellos²⁰ K. Beloborodov³⁷ D. Benckekroun^{35a} F. Bendebba^{35a} Y. Benhammou¹⁵¹
M. Benoit²⁹ J. R. Bensinger²⁶ S. Bentvelsen¹¹⁴ L. Beresford⁴⁸ M. Beretta⁵³ E. Bergeas Kuutmann¹⁶¹
N. Berger⁴ B. Bergmann¹³² J. Beringer^{17a} G. Bernardi⁵ C. Bernius¹⁴³ F. U. Bernlochner²⁴ F. Bernon^{36,102}
A. Berrocal Guardia¹³ T. Berry⁹⁵ P. Berta¹³³ A. Berthold⁵⁰ I. A. Bertram⁹¹ S. Bethke¹¹⁰ A. Betti^{75a,75b}
A. J. Bevan⁹⁴ N. K. Bhalla⁵⁴ M. Bhamjee^{33c} S. Bhatta¹⁴⁵ D. S. Bhattacharya¹⁶⁶ P. Bhattarai¹⁴³
V. S. Bhopatkar¹²¹ R. Bi^{29,i} R. M. Bianchi¹²⁹ G. Bianco^{23b,23a} O. Biebel¹⁰⁹ R. Bielski¹²³ M. Biglietti^{77a}
M. Bindi⁵⁵ A. Bingul^{21b} C. Bini^{75a,75b} A. Biondini⁹² C. J. Birch-sykes¹⁰¹ G. A. Bird^{20,134} M. Birman¹⁶⁹
M. Biros¹³³ S. Biryukov¹⁴⁶ T. Bisanz⁴⁹ E. Bisceglie^{43b,43a} J. P. Biswal¹³⁴ D. Biswas¹⁴¹ A. Bitadze¹⁰¹
K. Bjørke¹²⁵ I. Bloch⁴⁸ A. Blue⁵⁹ U. Blumenschein⁹⁴ J. Blumenthal¹⁰⁰ G. J. Bobbink¹¹⁴
V. S. Bobrovnikov³⁷ M. Boehler⁵⁴ B. Boehm¹⁶⁶ D. Bogavac³⁶ A. G. Bogdanchikov³⁷ C. Bohm^{47a}
V. Boisvert⁹⁵ P. Bokan⁴⁸ T. Bold^{86a} M. Bomben⁵ M. Bona⁹⁴ M. Boonekamp¹³⁵ C. D. Booth⁹⁵
A. G. Borbély⁵⁹ I. S. Bordulev³⁷ H. M. Borecka-Bielska¹⁰⁸ G. Borissov⁹¹ D. Bortoletto¹²⁶ D. Boscherini^{23b}
M. Bosman¹³ J. D. Bossio Sola³⁶ K. Bouaouda^{35a} N. Bouchhar¹⁶³ J. Boudreau¹²⁹ E. V. Bouhova-Thacker⁹¹
D. Boumediene⁴⁰ R. Bouquet¹⁶⁵ A. Boveia¹¹⁹ J. Boyd³⁶ D. Boye²⁹ I. R. Boyko³⁸ J. Bracinik²⁰
N. Brahimi^{62d} G. Brandt¹⁷¹ O. Brandt³² F. Braren⁴⁸ B. Brau¹⁰³ J. E. Brau¹²³ R. Brenner¹⁶⁹ L. Brenner¹¹⁴
R. Brenner¹⁶¹ S. Bressler¹⁶⁹ D. Britton⁵⁹ D. Britzger¹¹⁰ I. Brock²⁴ G. Brooijmans⁴¹ W. K. Brooks^{137f}
E. Brost²⁹ L. M. Brown¹⁶⁵ L. E. Bruce⁶¹ T. L. Bruckler¹²⁶ P. A. Bruckman de Renstrom⁸⁷ B. Brüers⁴⁸
A. Bruni^{23b} G. Bruni^{23b} M. Bruschi^{23b} N. Bruscinò^{75a,75b} T. Buanes¹⁶ Q. Buat¹³⁸ D. Buchin¹¹⁰
A. G. Buckley⁵⁹ O. Bulekov³⁷ B. A. Bullard¹⁴³ S. Burdin⁹² C. D. Burgard⁴⁹ A. M. Burger⁴⁰ B. Burghgrave⁸
O. Burlayenko⁵⁴ J. T. P. Burr³² C. D. Burton¹¹ J. C. Burzynski¹⁴² E. L. Busch⁴¹ V. Büscher¹⁰⁰ P. J. Bussey⁵⁹
J. M. Butler²⁵ C. M. Buttar⁵⁹ J. M. Butterworth⁹⁶ W. Buttinger¹³⁴ C. J. Buxo Vazquez¹⁰⁷ A. R. Buzykaev³⁷
S. Cabrera Urbán¹⁶³ L. Cadamuro⁶⁶ D. Caforio⁵⁸ H. Cai¹²⁹ Y. Cai^{14a,14e} Y. Cai^{14c} V. M. M. Cairo³⁶
O. Cakir^{3a} N. Calace³⁶ P. Calafiura^{17a} G. Calderini¹²⁷ P. Calfayan⁶⁸ G. Callea⁵⁹ L. P. Caloba^{83b} D. Calvet⁴⁰
S. Calvet⁴⁰ T. P. Calvet¹⁰² M. Calvetti^{74a,74b} R. Camacho Toro¹²⁷ S. Camarda³⁶ D. Camarero Munoz²⁶
P. Camarri^{76a,76b} M. T. Camerlingo^{72a,72b} D. Cameron³⁶ C. Camincher¹⁶⁵ M. Campanelli⁹⁶ A. Camplani⁴²
V. Canale^{72a,72b} A. Canesse¹⁰⁴ J. Cantero¹⁶³ Y. Cao¹⁶² F. Capocasa²⁶ M. Capua^{43b,43a} A. Carbone^{71a,71b}
R. Cardarelli^{76a} J. C. J. Cardenas⁸ F. Cardillo¹⁶³ G. Carducci^{43b,43a} T. Carli³⁶ G. Carlino^{72a} J. I. Carlotto¹³
B. T. Carlson^{129,j} E. M. Carlson^{165,156a} L. Carminati^{71a,71b} A. Carnelli¹³⁵ M. Carnesale^{75a,75b} S. Caron¹¹³
E. Carquin^{137f} S. Carrá^{71a,71b} G. Carratta^{23b,23a} F. Carrio Argos^{33g} J. W. S. Carter¹⁵⁵ T. M. Carter⁵²
M. P. Casado^{13,k} M. Caspar⁴⁸ F. L. Castillo⁴ L. Castillo Garcia¹³ V. Castillo Gimenez¹⁶³ N. F. Castro^{130a,130e}
A. Catinaccio³⁶ J. R. Catmore¹²⁵ V. Cavaliere²⁹ N. Cavalli^{23b,23a} V. Cavasinni^{74a,74b} Y. C. Cekmecelioglu⁴⁸
E. Celebi^{21a} F. Celli¹²⁶ M. S. Centonze^{70a,70b} V. Cepaitis⁵⁶ K. Cerny¹²² A. S. Cerqueira^{83a} A. Cerri¹⁴⁶
L. Cerrito^{76a,76b} F. Cerutti^{17a} B. Cervato¹⁴¹ A. Cervelli^{23b} G. Cesarini⁵³ S. A. Cetin⁸² D. Chakraborty¹¹⁵

J. Chan¹⁷⁰ W. Y. Chan¹⁵³ J. D. Chapman³² E. Chapon¹³⁵ B. Chargeishvili^{149b} D. G. Charlton²⁰
M. Chatterjee¹⁹ C. Chauhan¹³³ S. Chekanov⁶ S. V. Chekulaev^{156a} G. A. Chelkov^{38,1} A. Chen¹⁰⁶ B. Chen¹⁵¹
B. Chen¹⁶⁵ H. Chen^{14c} H. Chen²⁹ J. Chen^{62c} J. Chen¹⁴² M. Chen¹²⁶ S. Chen¹⁵³ S. J. Chen^{14c}
X. Chen^{62c,135} X. Chen^{14b,m} Y. Chen^{62a} C. L. Cheng¹⁷⁰ H. C. Cheng^{64a} S. Cheong¹⁴³ A. Cheplakov³⁸
E. Cheremushkina⁴⁸ E. Cherepanova¹¹⁴ R. Cherkaoui El Moursli^{35c} E. Cheu⁷ K. Cheung⁶⁵ L. Chevalier¹³⁵
V. Chiarella⁵³ G. Chiarelli^{74a} N. Chiedde¹⁰² G. Chiodini^{70a} A. S. Chisholm²⁰ A. Chitan^{27b} M. Chitishvili¹⁶³
M. V. Chizhov³⁸ K. Choi¹¹ A. R. Chomont^{75a,75b} Y. Chou¹⁰³ E. Y. S. Chow¹¹³ T. Chowdhury^{33g} K. L. Chu¹⁶⁹
M. C. Chu^{64a} X. Chu^{14a,14e} J. Chudoba¹³¹ J. J. Chwastowski⁸⁷ D. Cieri¹¹⁰ K. M. Ciesla^{86a} V. Cindro⁹³
A. Ciocio^{17a} F. Ciroto^{72a,72b} Z. H. Citron^{169,n} M. Citterio^{71a} D. A. Ciubotaru^{27b} A. Clark⁵⁶ P. J. Clark⁵²
C. Clarry¹⁵⁵ J. M. Clavijo Columbie⁴⁸ S. E. Clawson⁴⁸ C. Clement^{47a,47b} J. Clercx⁴⁸ Y. Coadou¹⁰²
M. Cobal^{69a,69c} A. Coccaro^{57b} R. F. Coelho Barrue^{130a} R. Coelho Lopes De Sa¹⁰³ S. Coelli^{71a}
A. E. C. Coimbra^{71a,71b} B. Cole⁴¹ J. Collot⁶⁰ P. Conde Muiño^{130a,130g} M. P. Connell^{33c} S. H. Connell^{33c}
I. A. Connelly⁵⁹ E. I. Conroy¹²⁶ F. Conventi^{72a,o} H. G. Cooke²⁰ A. M. Cooper-Sarkar¹²⁶
A. Cordeiro Oudot Choi¹²⁷ L. D. Corpe⁴⁰ M. Corradi^{75a,75b} F. Corriveau^{104,p} A. Cortes-Gonzalez¹⁸
M. J. Costa¹⁶³ F. Costanza⁴ D. Costanzo¹³⁹ B. M. Cote¹¹⁹ G. Cowan⁹⁵ K. Cranmer¹⁷⁰ D. Cremonini^{23b,23a}
S. Crépe-Renaudin⁶⁰ F. Crescioli¹²⁷ M. Cristinziani¹⁴¹ M. Cristoforetti^{78a,78b} V. Croft¹¹⁴ J. E. Crosby¹²¹
G. Crosetti^{43b,43a} A. Cueto⁹⁹ T. Cuhadar Donszelmann¹⁶⁰ H. Cui^{14a,14e} Z. Cui⁷ W. R. Cunningham⁵⁹
F. Curcio^{43b,43a} P. Czodrowski³⁶ M. M. Czurylo^{63b} M. J. Da Cunha Sargedas De Sousa^{57b,57a}
J. V. Da Fonseca Pinto^{83b} C. Da Via¹⁰¹ W. Dabrowski^{86a} T. Dado⁴⁹ S. Dahbi^{33g} T. Dai¹⁰⁶ D. Dal Santo¹⁹
C. Dallapiccola¹⁰³ M. Dam⁴² G. D'amen²⁹ V. D'Amico¹⁰⁹ J. Damp¹⁰⁰ J. R. Dandoy³⁴ M. F. Daneri³⁰
M. Danninger¹⁴² V. Dao³⁶ G. Darbo^{57b} S. Darmora⁶ S. J. Das^{29,i} S. D'Auria^{71a,71b} C. David^{156b}
T. Davidek¹³³ B. Davis-Purcell³⁴ I. Dawson⁹⁴ H. A. Day-hall¹³² K. De⁸ R. De Asmundis^{72a} N. De Biase⁴⁸
S. De Castro^{23b,23a} N. De Groot¹¹³ P. de Jong¹¹⁴ H. De la Torre¹¹⁵ A. De Maria^{14c} A. De Salvo^{75a}
U. De Sanctis^{76a,76b} F. De Santis^{70a,70b} A. De Santo¹⁴⁶ J. B. De Vivie De Regie⁶⁰ D. V. Dedovich³⁸ J. Degens¹¹⁴
A. M. Deiana⁴⁴ F. Del Corso^{23b,23a} J. Del Peso⁹⁹ F. Del Rio^{63a} L. Delagrance¹²⁷ F. Deliot¹³⁵
C. M. Delitzsch⁴⁹ M. Della Pietra^{72a,72b} D. Della Volpe⁵⁶ A. Dell'Acqua³⁶ L. Dell'Asta^{71a,71b} M. Delmastro⁴
P. A. Delsart⁶⁰ S. Demers¹⁷² M. Demichev³⁸ S. P. Denisov³⁷ L. D'Eramo⁴⁰ D. Derendarz⁸⁷ F. Derue¹²⁷
P. Dervan⁹² K. Desch²⁴ C. Deutsch²⁴ F. A. Di Bello^{57b,57a} A. Di Ciaccio^{76a,76b} L. Di Ciaccio⁴
A. Di Domenico^{75a,75b} C. Di Donato^{72a,72b} A. Di Girolamo³⁶ G. Di Gregorio³⁶ A. Di Luca^{78a,78b}
B. Di Micco^{77a,77b} R. Di Nardo^{77a,77b} C. Diaconu¹⁰² M. Diamantopoulou³⁴ F. A. Dias¹¹⁴ T. Dias Do Vale¹⁴²
M. A. Diaz^{137a,137b} F. G. Diaz Capriles²⁴ M. Didenko¹⁶³ E. B. Diehl¹⁰⁶ L. Diehl⁵⁴ S. Díez Cornell⁴⁸
C. Díez Pardos¹⁴¹ C. Dimitriadi^{161,24} A. Dimitrievska^{17a} J. Dingfelder²⁴ I-M. Dinu^{27b} S. J. Dittmeier^{63b}
F. Dittus³⁶ F. Djama¹⁰² T. Djobava^{149b} J. I. Djuvsland¹⁶ C. Doglioni^{101,98} A. Dohnalova^{28a} J. Dolejsi¹³³
Z. Dolezal¹³³ K. M. Dona³⁹ M. Donadelli^{83c} B. Dong¹⁰⁷ J. Donini⁴⁰ A. D'Onofrio^{72a,72b} M. D'Onofrio⁹²
J. Dopke¹³⁴ A. Doria^{72a} N. Dos Santos Fernandes^{130a} P. Dougan¹⁰¹ M. T. Dova⁹⁰ A. T. Doyle⁵⁹
M. A. Draguet¹²⁶ E. Dreyer¹⁶⁹ I. Drivas-koulouris¹⁰ M. Drnevich¹¹⁷ A. S. Drobac¹⁵⁸ M. Drozdova⁵⁶
D. Du^{62a} T. A. du Pree¹¹⁴ F. Dubinin³⁷ M. Dubovsky^{28a} E. Duchovni¹⁶⁹ G. Duckeck¹⁰⁹ O. A. Ducu^{27b}
D. Duda⁵² A. Dudarev³⁶ E. R. Duden²⁶ M. D'uffizi¹⁰¹ L. Duflot⁶⁶ M. Dührssen³⁶ C. Dülsen¹⁷¹
A. E. Dumitriu^{27b} M. Dunford^{63a} S. Dungs⁴⁹ K. Dunne^{47a,47b} A. Duperrin¹⁰² H. Duran Yildiz^{3a} M. Düren⁵⁸
A. Durglishvili^{149b} B. L. Dwyer¹¹⁵ G. I. Dyckes^{17a} M. Dyndal^{86a} B. S. Dziedzic⁸⁷ Z. O. Earnshaw¹⁴⁶
G. H. Eberwein¹²⁶ B. Eckerova^{28a} S. Eggebrecht⁵⁵ E. Egidio Purcino De Souza¹²⁷ L. F. Ehrke⁵⁶ G. Eigen¹⁶
K. Einsweiler^{17a} T. Ekelof¹⁶¹ P. A. Ekman⁹⁸ S. El Farkh^{35b} Y. El Ghazali^{35b} H. El Jarrari³⁶
A. El Moussaouy¹⁰⁸ V. Ellajosyula¹⁶¹ M. Ellert¹⁶¹ F. Ellinghaus¹⁷¹ N. Ellis³⁶ J. Elmsheuser²⁹ M. Elsing³⁶
D. Emelianov¹³⁴ Y. Enari¹⁵³ I. Ene^{17a} S. Epari¹³ J. Erdmann⁴⁹ P. A. Erland⁸⁷ M. Errenst¹⁷¹ M. Escalier⁶⁶
C. Escobar¹⁶³ E. Etzion¹⁵¹ G. Evans^{130a} H. Evans⁶⁸ L. S. Evans⁹⁵ M. O. Evans¹⁴⁶ A. Ezhilov³⁷
S. Ezzarqtouni^{35a} F. Fabbri⁵⁹ L. Fabbri^{23b,23a} G. Facini⁹⁶ V. Fadeyev¹³⁶ R. M. Fakhruddinov³⁷
D. Fakoudis¹⁰⁰ S. Falciano^{75a} L. F. Falda Ulhoa Coelho³⁶ P. J. Falke²⁴ J. Faltova¹³³ C. Fan¹⁶² Y. Fan^{14a}
Y. Fang^{14a,14e} M. Fanti^{71a,71b} M. Faraj^{69a,69b} Z. Farazpay⁹⁷ A. Farbin⁸ A. Farilla^{77a} T. Farrowque¹⁰⁷
S. M. Farrington⁵² F. Fassi^{35e} D. Fassouliotis⁹ M. Fauci Giannelli^{76a,76b} W. J. Fawcett³² L. Fayard⁶⁶

P. Federic¹³³ P. Federicova¹³¹ O. L. Fedin^{37,1} G. Fedotov³⁷ M. Feickert¹⁷⁰ L. Feligioni¹⁰² D. E. Fellers¹²³
 C. Feng^{62b} M. Feng^{14b} Z. Feng¹¹⁴ M. J. Fenton¹⁶⁰ A. B. Fenyuk³⁷ L. Ferencz⁴⁸ R. A. M. Ferguson⁹¹
 S. I. Fernandez Luengo^{137f} P. Fernandez Martinez¹³ M. J. V. Fernoux¹⁰² J. Ferrando⁴⁸ A. Ferrari¹⁶¹
 P. Ferrari^{114,113} R. Ferrari^{73a} D. Ferrere⁵⁶ C. Ferretti¹⁰⁶ F. Fiedler¹⁰⁰ P. Fiedler¹³² A. Filipčić⁹³
 E. K. Filmer¹ F. Filthaut¹¹³ M. C. N. Fiolhais^{130a,130c,q} L. Fiorini¹⁶³ W. C. Fisher¹⁰⁷ T. Fitschen¹⁰¹
 P. M. Fitzhugh¹³⁵ I. Fleck¹⁴¹ P. Fleischmann¹⁰⁶ T. Flick¹⁷¹ M. Flores^{33d,r} L. R. Flores Castillo^{64a}
 L. Flores Sanz De Acedo³⁶ F. M. Follega^{78a,78b} N. Fomin¹⁶ J. H. Foo¹⁵⁵ B. C. Forland⁶⁸ A. Formica¹³⁵
 A. C. Forti¹⁰¹ E. Fortin³⁶ A. W. Fortman⁶¹ M. G. Foti^{17a} L. Fountas^{9,s} D. Fournier⁶⁶ H. Fox⁹¹
 P. Francavilla^{74a,74b} S. Francescato⁶¹ S. Franchellucci⁵⁶ M. Franchini^{23b,23a} S. Franchino^{63a} D. Francis³⁶
 L. Franco¹¹³ V. Franco Lima³⁶ L. Franconi⁴⁸ M. Franklin⁶¹ G. Frattari²⁶ A. C. Freegard⁹⁴ W. S. Freund^{83b}
 Y. Y. Frid¹⁵¹ J. Friend⁵⁹ N. Fritzsche⁵⁰ A. Froch⁵⁴ D. Froidevaux³⁶ J. A. Frost¹²⁶ Y. Fu^{62a}
 S. Fuenzalida Garrido^{137f} M. Fujimoto¹⁰² K. Y. Fung^{64a} E. Furtado De Simas Filho^{83b} M. Furukawa¹⁵³
 J. Fuster¹⁶³ A. Gabrielli^{23b,23a} A. Gabrielli¹⁵⁵ P. Gadow³⁶ G. Gagliardi^{57b,57a} L. G. Gagnon^{17a} E. J. Gallas¹²⁶
 B. J. Gallop¹³⁴ K. K. Gan¹¹⁹ S. Ganguly¹⁵³ Y. Gao⁵² F. M. Garay Walls^{137a,137b} B. Garcia^{29,i} C. García¹⁶³
 A. Garcia Alonso¹¹⁴ A. G. Garcia Caffaro¹⁷² J. E. García Navarro¹⁶³ M. Garcia-Sciveres^{17a} G. L. Gardner¹²⁸
 R. W. Gardner³⁹ N. Garelli¹⁵⁸ D. Garg⁸⁰ R. B. Garg^{143,t} J. M. Gargan⁵² C. A. Garner¹⁵⁵ C. M. Garvey^{33a}
 P. Gaspar^{83b} V. K. Gassmann¹⁵⁸ G. Gaudio^{73a} V. Gautam¹³ P. Gauzzi^{75a,75b} I. L. Gavrilenko³⁷ A. Gavrilyuk³⁷
 C. Gay¹⁶⁴ G. Gaycken⁴⁸ E. N. Gazis¹⁰ A. A. Geanta^{27b} C. M. Gee¹³⁶ A. Gekow¹¹⁹ C. Gemme^{57b}
 M. H. Genest⁶⁰ S. Gentile^{75a,75b} A. D. Gentry¹¹² S. George⁹⁵ W. F. George²⁰ T. Geralis⁴⁶
 P. Gessinger-Befurt³⁶ M. E. Geyik¹⁷¹ M. Ghani¹⁶⁷ M. Ghneimat¹⁴¹ K. Ghorbanian⁹⁴ A. Ghosal¹⁴¹
 A. Ghosh¹⁶⁰ A. Ghosh⁷ B. Giacobbe^{23b} S. Giagu^{75a,75b} T. Giani¹¹⁴ P. Giannetti^{74a} A. Giannini^{62a}
 S. M. Gibson⁹⁵ M. Gignac¹³⁶ D. T. Gil^{86b} A. K. Gilbert^{86a} B. J. Gilbert⁴¹ D. Gillberg³⁴ G. Gilles¹¹⁴
 N. E. K. Gillwald⁴⁸ L. Ginabat¹²⁷ D. M. Gingrich^{2,e} M. P. Giordani^{69a,69c} P. F. Giraud¹³⁵ G. Giugliarelli^{69a,69c}
 D. Giugni^{71a} F. Giuli³⁶ I. Gkialas^{9,s} L. K. Gladilin³⁷ C. Glasman⁹⁹ G. R. Gledhill¹²³ G. Glemža⁴⁸
 M. Glisic¹²³ I. Gnesi^{43b,u} Y. Go^{29,i} M. Goblirsch-Kolb³⁶ B. Gocke⁴⁹ D. Godin¹⁰⁸ B. Gokturk^{21a}
 S. Goldfarb¹⁰⁵ T. Golling⁵⁶ M. G. D. Gololo^{33g} D. Golubkov³⁷ J. P. Gombas¹⁰⁷ A. Gomes^{130a,130b}
 G. Gomes Da Silva¹⁴¹ A. J. Gomez Delegido¹⁶³ R. Gonçalves^{130a,130c} G. Gonella¹²³ L. Gonella²⁰
 A. Gongadze^{149c} F. Gonnella²⁰ J. L. Gonski⁴¹ R. Y. González Andana⁵² S. González de la Hoz¹⁶³
 S. Gonzalez Fernandez¹³ R. Gonzalez Lopez⁹² C. Gonzalez Renteria^{17a} M. V. Gonzalez Rodrigues⁴⁸
 R. Gonzalez Suarez¹⁶¹ S. Gonzalez-Sevilla⁵⁶ G. R. Gonzalvo Rodriguez¹⁶³ L. Goossens³⁶ B. Gorini³⁶
 E. Gorini^{70a,70b} A. Gorišek⁹³ T. C. Gosart¹²⁸ A. T. Goshaw⁵¹ M. I. Gostkin³⁸ S. Goswami¹²¹
 C. A. Gottardo³⁶ S. A. Gotz¹⁰⁹ M. Goughri^{35b} V. Goumarre⁴⁸ A. G. Goussiou¹³⁸ N. Govender^{33c}
 I. Grabowska-Bold^{86a} K. Graham³⁴ E. Gramstad¹²⁵ S. Grancagnolo^{70a,70b} M. Grandi¹⁴⁶ C. M. Grant^{1,135}
 P. M. Gravila^{27f} F. G. Gravili^{70a,70b} H. M. Gray^{17a} M. Greco^{70a,70b} C. Grefe²⁴ I. M. Gregor⁴⁸ P. Grenier¹⁴³
 S. G. Grewe¹¹⁰ C. Grieco¹³ A. A. Grillo¹³⁶ K. Grimm³¹ S. Grinstein^{13,v} J.-F. Grivaz⁶⁶ E. Gross¹⁶⁹
 J. Grosse-Knetter⁵⁵ C. Grud¹⁰⁶ J. C. Grundy¹²⁶ L. Guan¹⁰⁶ W. Guan²⁹ C. Gubbels¹⁶⁴
 J. G. R. Guerrero Rojas¹⁶³ G. Guerrieri^{69a,69c} F. Guescini¹¹⁰ R. Gugel¹⁰⁰ J. A. M. Guhit¹⁰⁶ A. Guida¹⁸
 E. Guillon^{167,134} S. Guindon³⁶ F. Guo^{14a,14e} J. Guo^{62c} L. Guo⁴⁸ Y. Guo¹⁰⁶ R. Gupta⁴⁸ R. Gupta¹²⁹
 S. Gurbuz²⁴ S. S. Gurdasani⁵⁴ G. Gustavino³⁶ M. Guth⁵⁶ P. Gutierrez¹²⁰ L. F. Gutierrez Zagazeta¹²⁸
 M. Gutsche⁵⁰ C. Gutschow⁹⁶ C. Gwenlan¹²⁶ C. B. Gwilliam⁹² E. S. Haaland¹²⁵ A. Haas¹¹⁷ M. Habedank⁴⁸
 C. Haber^{17a} H. K. Hadavand⁸ A. Hadeef⁵⁰ S. Hadzic¹¹⁰ A. I. Hagan⁹¹ J. J. Hahn¹⁴¹ E. H. Haines⁹⁶
 M. Haleem¹⁶⁶ J. Haley¹²¹ J. J. Hall¹³⁹ G. D. Hallewell¹⁰² L. Halser¹⁹ K. Hamano¹⁶⁵ M. Hamer²⁴
 G. N. Hamity⁵² E. J. Hampshire⁹⁵ J. Han^{62b} K. Han^{62a} L. Han^{14c} L. Han^{62a} S. Han^{17a} Y. F. Han¹⁵⁵
 K. Hanagaki⁸⁴ M. Hance¹³⁶ D. A. Hangal^{41,d} H. Hanif¹⁴² M. D. Hank¹²⁸ R. Hankache¹⁰¹ J. B. Hansen⁴²
 J. D. Hansen⁴² P. H. Hansen⁴² K. Hara¹⁵⁷ D. Harada⁵⁶ T. Harenberg¹⁷¹ S. Harkusha³⁷ M. L. Harris¹⁰³
 Y. T. Harris¹²⁶ J. Harrison¹³ N. M. Harrison¹¹⁹ P. F. Harrison¹⁶⁷ N. M. Hartman¹¹⁰ N. M. Hartmann¹⁰⁹
 Y. Hasegawa¹⁴⁰ R. Hauser¹⁰⁷ C. M. Hawkes²⁰ R. J. Hawkings³⁶ Y. Hayashi¹⁵³ S. Hayashida¹¹¹
 D. Hayden¹⁰⁷ C. Hayes¹⁰⁶ R. L. Hayes¹¹⁴ C. P. Hays¹²⁶ J. M. Hays⁹⁴ H. S. Hayward⁹² F. He^{62a}
 M. He^{14a,14e} Y. He¹⁵⁴ Y. He⁴⁸ N. B. Heatley⁹⁴ V. Hedberg⁹⁸ A. L. Heggelund¹²⁵ N. D. Hehir⁹⁴

C. Heidegger⁵⁴, K. K. Heidegger⁵⁴, W. D. Heidorn⁸¹, J. Heilman³⁴, S. Heim⁴⁸, T. Heim^{17a}, J. G. Heinlein¹²⁸, J. J. Heinrich¹²³, L. Heinrich^{110,w}, J. Hejbal¹³¹, L. Helary⁴⁸, A. Held¹⁷⁰, S. Hellesund¹⁶, C. M. Helling¹⁶⁴, S. Hellman^{47a,47b}, R. C. W. Henderson⁹¹, L. Henkelmann³², A. M. Henriques Correia³⁶, H. Herde⁹⁸, Y. Hernández Jiménez¹⁴⁵, L. M. Herrmann²⁴, T. Herrmann⁵⁰, G. Herten⁵⁴, R. Hertenberger¹⁰⁹, L. Hervas³⁶, M. E. Hesping¹⁰⁰, N. P. Hessey^{156a}, H. Hibi⁸⁵, E. Hill¹⁵⁵, S. J. Hillier²⁰, J. R. Hinds¹⁰⁷, F. Hinterkeuser²⁴, M. Hirose¹²⁴, S. Hirose¹⁵⁷, D. Hirschbuehl¹⁷¹, T. G. Hitchings¹⁰¹, B. Hiti⁹³, J. Hobbs¹⁴⁵, R. Hobincu^{27e}, N. Hod¹⁶⁹, M. C. Hodgkinson¹³⁹, B. H. Hodgkinson³², A. Hoecker³⁶, D. D. Hofer¹⁰⁶, J. Hofer⁴⁸, T. Holm²⁴, M. Holzbock¹¹⁰, L. B. A. H. Hommels³², B. P. Honan¹⁰¹, J. Hong^{62c}, T. M. Hong¹²⁹, B. H. Hooberman¹⁶², W. H. Hopkins⁶, Y. Horii¹¹¹, S. Hou¹⁴⁸, A. S. Howard⁹³, J. Howarth⁵⁹, J. Hoya⁶, M. Hrabovsky¹²², A. Hrynevich⁴⁸, T. Hryn'ova⁴, P. J. Hsu⁶⁵, S.-C. Hsu¹³⁸, Q. Hu^{62a}, Y. F. Hu^{14a,14c}, S. Huang^{64b}, X. Huang^{14c}, X. Huang^{14a,14e}, Y. Huang¹³⁹, Y. Huang^{14a}, Z. Huang¹⁰¹, Z. Hubacek¹³², M. Huebner²⁴, F. Huegging²⁴, T. B. Huffman¹²⁶, C. A. Hugli⁴⁸, M. Huhtinen³⁶, S. K. Huiberts¹⁶, R. Hulsken¹⁰⁴, N. Huseynov¹², J. Huston¹⁰⁷, J. Huth⁶¹, R. Hyneman¹⁴³, G. Iacobucci⁵⁶, G. Iakovidis²⁹, I. Ibragimov¹⁴¹, L. Iconomidou-Fayard⁶⁶, P. Iengo^{72a,72b}, R. Iguchi¹⁵³, T. Iizawa¹²⁶, Y. Ikegami⁸⁴, N. Ilic¹⁵⁵, H. Imam^{35a}, M. Ince Lezki⁵⁶, T. Ingebretsen Carlson^{47a,47b}, G. Introzzi^{73a,73b}, M. Iodice^{77a}, V. Ippolito^{75a,75b}, R. K. Irwin⁹², M. Ishino¹⁵³, W. Islam¹⁷⁰, C. Issever^{18,48}, S. Istin^{21a,x}, H. Ito¹⁶⁸, J. M. Iturbe Ponce^{64a}, R. Iuppa^{78a,78b}, A. Ivina¹⁶⁹, J. M. Izen⁴⁵, V. Izzo^{72a}, P. Jacka^{131,132}, P. Jackson¹, R. M. Jacobs⁴⁸, B. P. Jaeger¹⁴², C. S. Jagfeld¹⁰⁹, G. Jain^{156a}, P. Jain⁵⁴, K. Jakobs⁵⁴, T. Jakoubek¹⁶⁹, J. Jamieson⁵⁹, K. W. Janas^{86a}, M. Javurkova¹⁰³, F. Jeanneau¹³⁵, L. Jeanty¹²³, J. Jejelava^{149a,y}, P. Jenni^{54,z}, C. E. Jessiman³⁴, S. Jézéquel⁴, C. Jia^{62b}, J. Jia¹⁴⁵, X. Jia⁶¹, X. Jia^{14a,14c}, Z. Jia^{14c}, S. Jiggins⁴⁸, J. Jimenez Pena¹³, S. Jin^{14c}, A. Jinaru^{27b}, O. Jinnouchi¹⁵⁴, P. Johansson¹³⁹, K. A. Johns⁷, J. W. Johnson¹³⁶, D. M. Jones³², E. Jones⁴⁸, P. Jones³², R. W. L. Jones⁹¹, T. J. Jones⁹², H. L. Joos^{55,36}, R. Joshi¹¹⁹, J. Jovicevic¹⁵, X. Ju^{17a}, J. J. Junggeburth¹⁰³, T. Junkermann^{63a}, A. Juste Rozas^{13,v}, M. K. Juzek⁸⁷, S. Kabana^{137e}, A. Kaczmarzka⁸⁷, M. Kado¹¹⁰, H. Kagan¹¹⁹, M. Kagan¹⁴³, A. Kahn⁴¹, A. Kahn¹²⁸, C. Kahra¹⁰⁰, T. Kaji¹⁵³, E. Kajomovitz¹⁵⁰, N. Kakati¹⁶⁹, I. Kalaitzidou⁵⁴, C. W. Kalderon²⁹, A. Kamenshchikov¹⁵⁵, N. J. Kang¹³⁶, D. Kar^{33g}, K. Karava¹²⁶, M. J. Kareem^{156b}, E. Karentzos⁵⁴, I. Karkanias¹⁵², O. Karkout¹¹⁴, S. N. Karpov³⁸, Z. M. Karpova³⁸, V. Kartvelishvili⁹¹, A. N. Karyukhin³⁷, E. Kasimi¹⁵², J. Katzy⁴⁸, S. Kaur³⁴, K. Kawade¹⁴⁰, M. P. Kawale¹²⁰, C. Kawamoto⁸⁸, T. Kawamoto^{62a}, E. F. Kay³⁶, F. I. Kaya¹⁵⁸, S. Kazakos¹⁰⁷, V. F. Kazanin³⁷, Y. Ke¹⁴⁵, J. M. Keaveney^{33a}, R. Keeler¹⁶⁵, G. V. Kehris⁶¹, J. S. Keller³⁴, A. S. Kelly⁹⁶, J. J. Kempster¹⁴⁶, K. E. Kennedy⁴¹, P. D. Kennedy¹⁰⁰, O. Kepka¹³¹, B. P. Kerridge¹⁶⁷, S. Kersten¹⁷¹, B. P. Kerševan⁹³, S. Keshri⁶⁶, L. Keszeghova^{28a}, S. Ketabchi Haghighat¹⁵⁵, R. A. Khan¹²⁹, M. Khandoga¹²⁷, A. Khanov¹²¹, A. G. Kharlamov³⁷, T. Kharlamova³⁷, E. E. Khoda¹³⁸, M. Kholodenko³⁷, T. J. Khoo¹⁸, G. Khoriauli¹⁶⁶, J. Khubua^{149b}, Y. A. R. Khwaira⁶⁶, A. Kilgallon¹²³, D. W. Kim^{47a,47b}, Y. K. Kim³⁹, N. Kimura⁹⁶, M. K. Kingston⁵⁵, A. Kirchhoff⁵⁵, C. Kirfel²⁴, F. Kirfel²⁴, J. Kirk¹³⁴, A. E. Kiryunin¹¹⁰, C. Kitsaki¹⁰, O. Kivernyk²⁴, M. Klassen^{63a}, C. Klein³⁴, L. Klein¹⁶⁶, M. H. Klein¹⁰⁶, M. Klein⁹², S. B. Klein⁵⁶, U. Klein⁹², P. Klimek³⁶, A. Klimentov²⁹, T. Klioutchnikova³⁶, P. Kluit¹¹⁴, S. Kluth¹¹⁰, E. Kneringer⁷⁹, T. M. Knight¹⁵⁵, A. Knue⁴⁹, R. Kobayashi⁸⁸, D. Kobylanskii¹⁶⁹, S. F. Koch¹²⁶, M. Kocian¹⁴³, P. Kodyš¹³³, D. M. Koeck¹²³, P. T. Koenig²⁴, T. Koffas³⁴, O. Kolay⁵⁰, I. Koletsou⁴, T. Komarek¹²², K. Köneke⁵⁴, A. X. Y. Kong¹, T. Kono¹¹⁸, N. Konstantinidis⁹⁶, P. Kontaxakis⁵⁶, B. Konya⁹⁸, R. Kopeliansky⁶⁸, S. Koperny^{86a}, K. Korcyl⁸⁷, K. Kordas^{152,aa}, G. Koren¹⁵¹, A. Korn⁹⁶, S. Korn⁵⁵, I. Korolkov¹³, N. Korotkova³⁷, B. Kortman¹¹⁴, O. Kortner¹¹⁰, S. Kortner¹¹⁰, W. H. Kostecka¹¹⁵, V. V. Kostyukhin¹⁴¹, A. Kotsokhechagia¹³⁵, A. Kotwal⁵¹, A. Koulouris³⁶, A. Kourkouveli-Charalampidi^{73a,73b}, C. Kourkouvelis⁹, E. Kourlitis^{110,w}, O. Kovanda¹⁴⁶, R. Kowalewski¹⁶⁵, W. Kozanecki¹³⁵, A. S. Kozhin³⁷, V. A. Kramarenko³⁷, G. Kramberger⁹³, P. Kramer¹⁰⁰, M. W. Krasny¹²⁷, A. Krasznahorkay³⁶, J. W. Kraus¹⁷¹, J. A. Kremer⁴⁸, T. Kresse⁵⁰, J. Kretschmar⁹², K. Kreul¹⁸, P. Krieger¹⁵⁵, S. Krishnamurthy¹⁰³, M. Krivos¹³³, K. Krizka²⁰, K. Kroeninger⁴⁹, H. Kroha¹¹⁰, J. Kroll¹³¹, J. Kroll¹²⁸, K. S. Krowpman¹⁰⁷, U. Kruchonak³⁸, H. Krüger²⁴, N. Krumnack⁸¹, M. C. Kruse⁵¹, O. Kuchinskaia³⁷, S. Kuday^{3a}, S. Kuehn³⁶, R. Kuesters⁵⁴, T. Kuhl⁴⁸, V. Kukhtin³⁸, Y. Kulchitsky^{37,1}, S. Kuleshov^{137d,137b}, M. Kumar^{33g}, N. Kumari⁴⁸, P. Kumari^{156b}, A. Kupco¹³¹, T. Kupfer⁴⁹, A. Kupich³⁷, O. Kuprash⁵⁴, H. Kurashige⁸⁵, L. L. Kurchaninov^{156a}, O. Kurdysh⁶⁶, Y. A. Kurochkin³⁷, A. Kurova³⁷, M. Kuze¹⁵⁴, A. K. Kvam¹⁰³, J. Kvita¹²², T. Kwan¹⁰⁴, N. G. Kyriacou¹⁰⁶

L. A. O. Laatu¹⁰² C. Lacasta¹⁶³ F. Lacava^{75a,75b} H. Lacker¹⁸ D. Lacour¹²⁷ N. N. Lad⁹⁶ E. Ladygin³⁸
 B. Laforge¹²⁷ T. Lagouri^{137e} F. Z. Lahbabi^{35a} S. Lai⁵⁵ I. K. Lakomic^{86a} N. Lalloue⁶⁰ J. E. Lambert¹⁶⁵
 S. Lammers⁶⁸ W. Lampl⁷ C. Lampoudis^{152,aa} A. N. Lancaster¹¹⁵ E. Lançon²⁹ U. Landgraf⁵⁴
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 K. Lantzsch²⁴ A. Lanza^{73a} A. Lapertosa^{57b,57a} J. F. Laporte¹³⁵ T. Lari^{71a} F. Lasagni Manghi^{23b} M. Lassnig³⁶
 V. Latonova¹³¹ A. Laudrain¹⁰⁰ A. Laurier¹⁵⁰ S. D. Lawlor¹³⁹ Z. Lawrence¹⁰¹ R. Lazaridou¹⁶⁷
 M. Lazzaroni^{71a,71b} B. Le¹⁰¹ E. M. Le Boulicaut⁵¹ B. Leban⁹³ A. Lebedev⁸¹ M. LeBlanc¹⁰¹
 F. Ledroit-Guillon⁶⁰ A. C. A. Lee⁹⁶ S. C. Lee¹⁴⁸ S. Lee^{47a,47b} T. F. Lee⁹² L. L. Leeuw^{33c} H. P. Lefebvre⁹⁵
 M. Lefebvre¹⁶⁵ C. Leggett^{17a} G. Lehmann Miotto³⁶ M. Leigh⁵⁶ W. A. Leight¹⁰³ W. Leinonen¹¹³
 A. Leisos^{152,bb} M. A. L. Leite^{83c} C. E. Leitgeb⁴⁸ R. Leitner¹³³ K. J. C. Leney⁴⁴ T. Lenz²⁴ S. Leone^{74a}
 C. Leonidopoulos⁵² A. Leopold¹⁴⁴ C. Leroy¹⁰⁸ R. Les¹⁰⁷ C. G. Lester³² M. Levchenko³⁷ J. Levêque⁴
 D. Levin¹⁰⁶ L. J. Levinson¹⁶⁹ M. P. Lewicki⁸⁷ D. J. Lewis⁴ A. Li⁵ B. Li^{62b} C. Li^{62a} C-Q. Li¹¹⁰ H. Li^{62a}
 H. Li^{62b} H. Li^{14c} H. Li^{14b} H. Li^{62b} J. Li^{62c} K. Li¹³⁸ L. Li^{62c} M. Li^{14a,14e} Q. Y. Li^{62a} S. Li^{14a,14e}
 S. Li^{62d,62c,cc} T. Li⁵ X. Li¹⁰⁴ Z. Li¹²⁶ Z. Li¹⁰⁴ Z. Li^{14a,14e} S. Liang^{14a,14e} Z. Liang^{14a} M. Liberatore¹³⁵
 B. Liberti^{76a} K. Lie^{64c} J. Lieber Marin^{83b} H. Lien⁶⁸ K. Lin¹⁰⁷ R. E. Lindley⁷ J. H. Lindon² E. Lipeles¹²⁸
 A. Lipniacka¹⁶ A. Lister¹⁶⁴ J. D. Little⁴ B. Liu^{14a} B. X. Liu¹⁴² D. Liu^{62d,62c} J. B. Liu^{62a} J. K. K. Liu³²
 K. Liu^{62d,62c} M. Liu^{62a} M. Y. Liu^{62a} P. Liu^{14a} Q. Liu^{62d,138,62c} X. Liu^{62a} X. Liu^{62b} Y. Liu^{14d,14e}
 Y. L. Liu^{62b} Y. W. Liu^{62a} J. Llorente Merino¹⁴² S. L. Lloyd⁹⁴ E. M. Lobodzinska⁴⁸ P. Loch⁷ T. Lohse¹⁸
 K. Lohwasser¹³⁹ E. Loiacono⁴⁸ M. Lokajicek^{131,a} J. D. Lomas²⁰ J. D. Long¹⁶² I. Longarini¹⁶⁰
 L. Longo^{70a,70b} R. Longo¹⁶² I. Lopez Paz⁶⁷ A. Lopez Solis⁴⁸ N. Lorenzo Martinez⁴ A. M. Lory¹⁰⁹
 G. Löschcke Centeno¹⁴⁶ O. Loseva³⁷ X. Lou^{47a,47b} X. Lou^{14a,14e} A. Lounis⁶⁶ J. Love⁶ P. A. Love⁹¹
 G. Lu^{14a,14e} M. Lu⁸⁰ S. Lu¹²⁸ Y. J. Lu⁶⁵ H. J. Lubatti¹³⁸ C. Luci^{75a,75b} F. L. Lucio Alves^{14c} A. Lucotte⁶⁰
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 A. B. Lux²⁵ D. Lynn²⁹ H. Lyons⁹² R. Lysak¹³¹ E. Lytken⁹⁸ V. Lyubushkin³⁸ T. Lyubushkina³⁸
 M. M. Lyukova¹⁴⁵ H. Ma²⁹ K. Ma^{62a} L. L. Ma^{62b} W. Ma^{62a} Y. Ma¹²¹ D. M. Mac Donell¹⁶⁵ G. Maccarrone⁵³
 J. C. MacDonald¹⁰⁰ P. C. Machado De Abreu Farias^{83b} R. Madar⁴⁰ W. F. Mader⁵⁰ T. Madula⁹⁶ J. Maeda⁸⁵
 T. Maeno²⁹ H. Maguire¹³⁹ V. Maiboroda¹³⁵ A. Maio^{130a,130b,130d} K. Maj^{86a} O. Majersky⁴⁸ S. Majewski¹²³
 N. Makovec⁶⁶ V. Maksimovic¹⁵ B. Malaescu¹²⁷ Pa. Malecki⁸⁷ V. P. Maleev³⁷ F. Malek⁶⁰ M. Mali⁹³
 D. Malito⁹⁵ U. Mallik⁸⁰ S. Maltezos¹⁰ S. Malyukov³⁸ J. Mamuzic¹³ G. Mancini⁵³ G. Manco^{73a,73b}
 J. P. Mandalia⁹⁴ I. Mandić⁹³ L. Manhaes de Andrade Filho^{83a} I. M. Maniatis¹⁶⁹ J. Manjarres Ramos^{102,dd}
 D. C. Mankad¹⁶⁹ A. Mann¹⁰⁹ B. Mansoulié¹³⁵ S. Manzoni³⁶ L. Mao^{62c} X. Mapekula^{33c} A. Marantis^{152,bb}
 G. Marchiori⁵ M. Marcisovsky¹³¹ C. Marcon^{71a,71b} M. Marinescu²⁰ S. Marium⁴⁸ M. Marjanovic¹²⁰
 E. J. Marshall⁹¹ Z. Marshall^{17a} S. Marti-Garcia¹⁶³ T. A. Martin¹⁶⁷ V. J. Martin⁵² B. Martin dit Latour¹⁶
 L. Martinelli^{75a,75b} M. Martinez^{13,v} P. Martinez Agullo¹⁶³ V. I. Martinez Outschoorn¹⁰³ P. Martinez Suarez¹³
 S. Martin-Haugh¹³⁴ V. S. Martoiu^{27b} A. C. Martyniuk⁹⁶ A. Marzin³⁶ D. Mascione^{78a,78b} L. Masetti¹⁰⁰
 T. Mashimo¹⁵³ J. Masik¹⁰¹ A. L. Maslennikov³⁷ L. Massa^{23b} P. Massarotti^{72a,72b} P. Mastrandrea^{74a,74b}
 A. Mastroberardino^{43b,43a} T. Masubuchi¹⁵³ T. Mathisen¹⁶¹ J. Matousek¹³³ N. Matsuzawa¹⁵³ J. Maurer^{27b}
 B. Maček⁹³ D. A. Maximov³⁷ R. Mazini¹⁴⁸ I. Maznas¹⁵² M. Mazza¹⁰⁷ S. M. Mazza¹³⁶ E. Mazzeo^{71a,71b}
 C. Mc Ginn²⁹ J. P. Mc Gowan¹⁰⁴ S. P. Mc Kee¹⁰⁶ C. C. McCracken¹⁶⁴ E. F. McDonald¹⁰⁵ A. E. McDougall¹¹⁴
 J. A. Mcfayden¹⁴⁶ R. P. McGovern¹²⁸ G. Mchedlidze^{149b} R. P. Mckenzie^{33g} T. C. Mclachlan⁴⁸
 D. J. McLaughlin⁹⁶ S. J. McMahon¹³⁴ C. M. Mcpartland⁹² R. A. McPherson^{165,p} S. Mehlhase¹⁰⁹ A. Mehta⁹²
 D. Melini¹⁵⁰ B. R. Mellado Garcia^{33g} A. H. Melo⁵⁵ F. Meloni⁴⁸ A. M. Mendes Jacques Da Costa¹⁰¹
 H. Y. Meng¹⁵⁵ L. Meng⁹¹ S. Menke¹¹⁰ M. Mentink³⁶ E. Meoni^{43b,43a} G. Mercado¹¹⁵ C. Merlassino^{69a,69c}
 L. Merola^{72a,72b} C. Meroni^{71a,71b} G. Merz¹⁰⁶ J. Metcalfe⁶ A. S. Mete⁶ C. Meyer⁶⁸ J-P. Meyer¹³⁵
 R. P. Middleton¹³⁴ L. Mijović⁵² G. Mikenberg¹⁶⁹ M. Mikesstikova¹³¹ M. Mikuž⁹³ H. Mildner¹⁰⁰ A. Milic³⁶
 C. D. Milke⁴⁴ D. W. Miller³⁹ L. S. Miller³⁴ A. Milov¹⁶⁹ D. A. Milstead^{47a,47b} T. Min^{14c} A. A. Minaenko³⁷
 I. A. Minashvili^{149b} L. Mince⁵⁹ A. I. Mincer¹¹⁷ B. Mindur^{86a} M. Mineev³⁸ Y. Mino⁸⁸ L. M. Mir¹³
 M. Miralles Lopez¹⁶³ M. Mironova^{17a} A. Mishima¹⁵³ M. C. Missio¹¹³ A. Mitra¹⁶⁷ V. A. Mitsou¹⁶³
 Y. Mitsumori¹¹¹ O. Miu¹⁵⁵ P. S. Miyagawa⁹⁴ T. Mkrtychyan^{63a} M. Mlinarevic⁹⁶ T. Mlinarevic⁹⁶

M. Mlynarikova³⁶ S. Mobius¹⁹ P. Moder⁴⁸ P. Mogg¹⁰⁹ M. H. Mohamed Farook¹¹² A. F. Mohammed^{14a,14e}
 S. Mohapatra⁴¹ G. Mokgatitwane^{33g} L. Moleri¹⁶⁹ B. Mondal¹⁴¹ S. Mondal¹³² K. Mönig⁴⁸ E. Monnier¹⁰²
 L. Monsonis Romero¹⁶³ J. Montejo Berlingen¹³ M. Montella¹¹⁹ F. Montekali^{77a,77b} F. Monticelli⁹⁰
 S. Monzani^{69a,69c} N. Morange⁶⁶ A. L. Moreira De Carvalho^{130a} M. Moreno Llácer¹⁶³ C. Moreno Martinez⁵⁶
 P. Morettini^{57b} S. Morgenstern³⁶ M. Morii⁶¹ M. Morinaga¹⁵³ A. K. Morley³⁶ F. Morodei^{75a,75b} L. Morvaj³⁶
 P. Moschovakos³⁶ B. Moser³⁶ M. Mosidze^{149b} T. Moskalets⁵⁴ P. Moskvitina¹¹³ J. Moss^{31,ee} E. J. W. Moyse¹⁰³
 O. Mtintsilana^{33g} S. Muanza¹⁰² J. Mueller¹²⁹ D. Muenstermann⁹¹ R. Müller¹⁹ G. A. Mullier¹⁶¹ A. J. Mullin,³²
 J. J. Mullin,¹²⁸ D. P. Mungo¹⁵⁵ D. Munoz Perez¹⁶³ F. J. Munoz Sanchez¹⁰¹ M. Murin¹⁰¹ W. J. Murray^{167,134}
 A. Murrone^{71a,71b} M. Muškinja^{17a} C. Mwewa²⁹ A. G. Myagkov^{37,1} A. J. Myers⁸ G. Myers⁶⁸ M. Myska¹³²
 B. P. Nachman^{17a} O. Nackenhorst⁴⁹ A. Nag⁵⁰ K. Nagai¹²⁶ K. Nagano⁸⁴ J. L. Nagle^{29,i} E. Nagy¹⁰²
 A. M. Nairz³⁶ Y. Nakahama⁸⁴ K. Nakamura⁸⁴ K. Nakkalil⁵ H. Nanjo¹²⁴ R. Narayan⁴⁴ E. A. Narayanan¹¹²
 I. Naryshkin³⁷ M. Naseri³⁴ S. Nasri¹⁵⁹ C. Nass²⁴ G. Navarro^{22a} J. Navarro-Gonzalez¹⁶³ R. Nayak¹⁵¹
 A. Nayaz¹⁸ P. Y. Nechaeva³⁷ F. Nechansky⁴⁸ L. Nedic¹²⁶ T. J. Neep²⁰ A. Negri^{73a,73b} M. Negrini^{23b}
 C. Nellist¹¹⁴ C. Nelson¹⁰⁴ K. Nelson¹⁰⁶ S. Nemecek¹³¹ M. Nessi^{36,ff} M. S. Neubauer¹⁶² F. Neuhaus¹⁰⁰
 J. Neundorff⁴⁸ R. Newhouse¹⁶⁴ P. R. Newman²⁰ C. W. Ng¹²⁹ Y. W. Y. Ng⁴⁸ B. Ngair^{35e} H. D. N. Nguyen¹⁰⁸
 R. B. Nickerson¹²⁶ R. Nicolaidou¹³⁵ J. Nielsen¹³⁶ M. Niemeyer⁵⁵ J. Niermann^{55,36} N. Nikiforou³⁶
 V. Nikolaenko^{37,1} I. Nikolic-Audit¹²⁷ K. Nikolopoulos²⁰ P. Nilsson²⁹ I. Ninca⁴⁸ H. R. Nindhito⁵⁶
 G. Ninio¹⁵¹ A. Nisati^{75a} N. Nishu² R. Nisius¹¹⁰ J.-E. Nitschke⁵⁰ E. K. Nkadimeng^{33g} T. Nobe¹⁵³
 D. L. Noel³² T. Nommensen¹⁴⁷ M. B. Norfolk¹³⁹ R. R. B. Norisam⁹⁶ B. J. Norman³⁴ M. Noury^{35a}
 J. Novak⁹³ T. Novak⁴⁸ L. Novotny¹³² R. Novotny¹¹² L. Nozka¹²² K. Ntekas¹⁶⁰
 N. M. J. Nunes De Moura Junior^{83b} E. Nurse⁹⁶ J. Ocariz¹²⁷ A. Ochi⁸⁵ I. Ochoa^{130a} S. Oerdek⁴⁸
 J. T. Offermann³⁹ A. Ogrodnik¹³³ A. Oh¹⁰¹ C. C. Ohm¹⁴⁴ H. Oide⁸⁴ R. Oishi¹⁵³ M. L. Ojeda⁴⁸
 M. W. O'Keefe⁹² Y. Okumura¹⁵³ L. F. Oleiro Seabra^{130a} S. A. Olivares Pino^{137d} D. Oliveira Damazio²⁹
 D. Oliveira Goncalves^{83a} J. L. Oliver¹⁶⁰ Ö. O. Öncel⁵⁴ A. P. O'Neill¹⁹ A. Onofre^{130a,130e} P. U. E. Onyisi¹¹
 M. J. Oreglia³⁹ G. E. Orellana⁹⁰ D. Orestano^{77a,77b} N. Orlando¹³ R. S. Orr¹⁵⁵ V. O'Shea⁵⁹ L. M. Osojnak¹²⁸
 R. Ospanov^{62a} G. Otero y Garzon³⁰ H. Otono⁸⁹ P. S. Ott^{63a} G. J. Ottino^{17a} M. Ouchrif^{35d} J. Ouellette²⁹
 F. Ould-Saada¹²⁵ M. Owen⁵⁹ R. E. Owen¹³⁴ K. Y. Oyulmaz^{21a} V. E. Ozcan^{21a} F. Ozturk⁸⁷ N. Ozturk⁸
 S. Ozturk⁸² H. A. Pacey¹²⁶ A. Pacheco Pages¹³ C. Padilla Aranda¹³ G. Padovano^{75a,75b} S. Pagan Griso^{17a}
 G. Palacino⁶⁸ A. Palazzo^{70a,70b} S. Palestini³⁶ J. Pan¹⁷² T. Pan^{64a} D. K. Panchal¹¹ C. E. Pandini¹¹⁴
 J. G. Panduro Vazquez⁹⁵ H. D. Pandya¹ H. Pang^{14b} P. Pani⁴⁸ G. Panizzo^{69a,69c} L. Paolozzi⁵⁶ C. Papadatos¹⁰⁸
 S. Parajuli⁴⁴ A. Paramonov⁶ C. Paraskevopoulos¹⁰ D. Paredes Hernandez^{64b} K. R. Park⁴¹ T. H. Park¹⁵⁵
 M. A. Parker³² F. Parodi^{57b,57a} E. W. Parrish¹¹⁵ V. A. Parrish⁵² J. A. Parsons⁴¹ U. Parzefall⁵⁴
 B. Pascual Dias¹⁰⁸ L. Pascual Dominguez¹⁵¹ E. Pasqualucci^{75a} S. Passaggio^{57b} F. Pastore⁹⁵ P. Pasuwan^{47a,47b}
 P. Patel⁸⁷ U. M. Patel⁵¹ J. R. Pater¹⁰¹ T. Pauly³⁶ J. Parkes¹⁴³ M. Pedersen¹²⁵ R. Pedro^{130a}
 S. V. Peleganchuk³⁷ O. Penc³⁶ E. A. Pender⁵² K. E. Pensi¹⁰⁹ M. Penzin³⁷ B. S. Peralva^{83d}
 A. P. Pereira Peixoto⁶⁰ L. Pereira Sanchez^{47a,47b} D. V. Perepelitsa^{29,i} E. Perez Codina^{156a} M. Perganti¹⁰
 L. Perini^{71a,71b,a} H. Pernegger³⁶ O. Perrin⁴⁰ K. Peters⁴⁸ R. F. Y. Peters¹⁰¹ B. A. Petersen³⁶ T. C. Petersen⁴²
 E. Petit¹⁰² V. Petousis¹³² C. Petridou^{152,aa} A. Petrukhin¹⁴¹ M. Pettee^{17a} N. E. Pettersson³⁶ A. Petukhov³⁷
 K. Petukhova¹³³ R. Pezoa^{137f} L. Pezzotti³⁶ G. Pezzullo¹⁷² T. M. Pham¹⁷⁰ T. Pham¹⁰⁵ P. W. Phillips¹³⁴
 G. Piacquadio¹⁴⁵ E. Pianori^{17a} F. Piazza¹²³ R. Piegaia³⁰ D. Pietreanu^{27b} A. D. Pilkington¹⁰¹
 M. Pinamonti^{69a,69c} J. L. Pinfeld² B. C. Pinheiro Pereira^{130a} A. E. Pinto Pinoargote^{100,135} L. Pintucci^{69a,69c}
 K. M. Piper¹⁴⁶ A. Pirttikoski⁵⁶ D. A. Pizzi³⁴ L. Pizzimento^{64b} A. Pizzini¹¹⁴ M.-A. Pleier²⁹ V. Plesanovs,⁵⁴
 V. Pleskot¹³³ E. Plotnikova,³⁸ G. Poddar⁴ R. Poettgen⁹⁸ L. Poggioli¹²⁷ I. Pokharel⁵⁵ S. Polacek¹³³
 G. Polesello^{73a} A. Poley^{142,156a} R. Polifka¹³² A. Polini^{23b} C. S. Pollard¹⁶⁷ Z. B. Pollock¹¹⁹
 V. Polychronakos²⁹ E. Pompa Pacchi^{75a,75b} D. Ponomarenko¹¹³ L. Pontecorvo³⁶ S. Popa^{27a}
 G. A. Popeneciu^{27d} A. Poreba³⁶ D. M. Portillo Quintero^{156a} S. Pospisil¹³² M. A. Postill¹³⁹ P. Postolache^{27c}
 K. Potamianos¹⁶⁷ P. A. Potepa^{86a} I. N. Potrap³⁸ C. J. Potter³² H. Potti¹ T. Poulsen⁴⁸ J. Poveda¹⁶³
 M. E. Pozo Astigarraga³⁶ A. Prades Ibanez¹⁶³ J. Pretel⁵⁴ D. Price¹⁰¹ M. Primavera^{70a} M. A. Principe Martin⁹⁹
 R. Privara¹²² T. Procter⁵⁹ M. L. Proffitt¹³⁸ N. Proklova¹²⁸ K. Prokofiev^{64c} G. Proto¹¹⁰ S. Protopopescu²⁹

J. Proudfoot⁶, M. Przybycien^{86a}, W. W. Przygoda^{86b}, J. E. Puddefoot¹³⁹, D. Pudzha³⁷, D. Pyatiizbyantseva³⁷,
 J. Qian¹⁰⁶, D. Qichen¹⁰¹, Y. Qin¹⁰¹, T. Qiu⁵², A. Quadt⁵⁵, M. Queitsch-Maitland¹⁰¹, G. Quetant⁵⁶,
 R. P. Quinn¹⁶⁴, G. Rabanal Bolanos⁶¹, D. Rafanoharana⁵⁴, F. Ragusa^{71a,71b}, J. L. Rainbolt³⁹, J. A. Raine⁵⁶,
 S. Rajagopalan²⁹, E. Ramakoti³⁷, I. A. Ramirez-Berend³⁴, K. Ran^{48,14e}, N. P. Rapheeha^{33g}, H. Rasheed^{27b},
 V. Raskina¹²⁷, D. F. Rassloff^{63a}, A. Rastogi^{17a}, S. Rave¹⁰⁰, B. Ravina⁵⁵, I. Ravinovich¹⁶⁹, M. Raymond³⁶,
 A. L. Read¹²⁵, N. P. Readioff¹³⁹, D. M. Rebutti^{73a,73b}, G. Redlinger²⁹, A. S. Reed¹¹⁰, K. Reeves²⁶,
 J. A. Reidelsturz¹⁷¹, D. Reikher¹⁵¹, A. Rej⁴⁹, C. Rembser³⁶, A. Renardi⁴⁸, M. Renda^{27b}, M. B. Rendel¹¹⁰,
 F. Renner⁴⁸, A. G. Rennie¹⁶⁰, A. L. Rescia⁴⁸, S. Resconi^{71a}, M. Ressegotti^{57b,57a}, S. Rettie³⁶,
 J. G. Reyes Rivera¹⁰⁷, E. Reynolds^{17a}, O. L. Rezanova³⁷, P. Reznicek¹³³, N. Ribaric⁹¹, E. Ricci^{78a,78b},
 R. Richter¹¹⁰, S. Richter^{47a,47b}, E. Richter-Was^{86b}, M. Ridel¹²⁷, S. Ridouani^{35d}, P. Rieck¹¹⁷, P. Riedler³⁶,
 E. M. Riefel^{47a,47b}, J. O. Rieger¹¹⁴, M. Rijssenbeek¹⁴⁵, A. Rimoldi^{73a,73b}, M. Rimoldi³⁶, L. Rinaldi^{23b,23a},
 T. T. Rinn²⁹, M. P. Rinnagel¹⁰⁹, G. Ripellino¹⁶¹, I. Riu¹³, P. Rivadeneira⁴⁸, J. C. Rivera Vergara¹⁶⁵,
 F. Rizatdinova¹²¹, E. Rizvi⁹⁴, B. A. Roberts¹⁶⁷, B. R. Roberts^{17a}, S. H. Robertson^{104,p}, D. Robinson³²,
 C. M. Robles Gajardo^{137f}, M. Robles Manzano¹⁰⁰, A. Robson⁵⁹, A. Rocchi^{76a,76b}, C. Roda^{74a,74b},
 S. Rodriguez Bosca^{63a}, Y. Rodriguez Garcia^{22a}, A. Rodriguez Rodriguez⁵⁴, A. M. Rodríguez Vera^{156b}, S. Roe³⁶,
 J. T. Roemer¹⁶⁰, A. R. Roepe-Gier¹³⁶, J. Roggel¹⁷¹, O. Røhne¹²⁵, R. A. Rojas¹⁰³, C. P. A. Roland¹²⁷, J. Roloff²⁹,
 A. Romaniouk³⁷, E. Romano^{73a,73b}, M. Romano^{23b}, A. C. Romero Hernandez¹⁶², N. Rompotis⁹², L. Roos¹²⁷,
 S. Rosati^{75a}, B. J. Rosser³⁹, E. Rossi¹²⁶, E. Rossi^{72a,72b}, L. P. Rossi^{57b}, L. Rossini⁵⁴, R. Rosten¹¹⁹,
 M. Rotaru^{27b}, B. Rottler⁵⁴, C. Rougier^{102,dd}, D. Rousseau⁶⁶, D. Rouso³², A. Roy¹⁶², S. Roy-Garand¹⁵⁵,
 A. Rozanov¹⁰², Z. M. A. Rozario⁵⁹, Y. Rozen¹⁵⁰, X. Ruan^{33g}, A. Rubio Jimenez¹⁶³, A. J. Ruby⁹²,
 V. H. Ruelas Rivera¹⁸, T. A. Ruggeri¹, A. Ruggiero¹²⁶, A. Ruiz-Martinez¹⁶³, A. Rummler³⁶, Z. Rurikova⁵⁴,
 N. A. Rusakovich³⁸, H. L. Russell¹⁶⁵, G. Russo^{75a,75b}, J. P. Rutherford⁷, S. Rutherford Colmenares³²,
 K. Rybacki⁹¹, M. Rybar¹³³, E. B. Rye¹²⁵, A. Ryzhov⁴⁴, J. A. Sabater Iglesias⁵⁶, P. Sabatini¹⁶³,
 H. F-W. Sadrozinski¹³⁶, F. Safai Tehrani^{75a}, B. Safarzadeh Samani¹³⁴, M. Safdari¹⁴³, S. Saha¹⁶⁵, M. Sahinsoy¹¹⁰,
 A. Saibel¹⁶³, M. Saimpert¹³⁵, M. Saito¹⁵³, T. Saito¹⁵³, D. Salamani³⁶, A. Salnikov¹⁴³, J. Salt¹⁶³,
 A. Salvador Salas¹⁵¹, D. Salvatore^{43b,43a}, F. Salvatore¹⁴⁶, A. Salzburger³⁶, D. Sammel⁵⁴, D. Sampsonidis^{152,aa},
 D. Sampsonidou¹²³, J. Sánchez¹⁶³, A. Sanchez Pineda⁴, V. Sanchez Sebastian¹⁶³, H. Sandaker¹²⁵, C. O. Sander⁴⁸,
 J. A. Sandesara¹⁰³, M. Sandhoff¹⁷¹, C. Sandoval^{22b}, D. P. C. Sankey¹³⁴, T. Sano⁸⁸, A. Sansoni⁵³, L. Santi^{75a,75b},
 C. Santoni⁴⁰, H. Santos^{130a,130b}, S. N. Santpur^{17a}, A. Santra¹⁶⁹, K. A. Saoucha^{116b}, J. G. Saraiva^{130a,130d},
 J. Sardain⁷, O. Sasaki⁸⁴, K. Sato¹⁵⁷, C. Sauer^{63b}, F. Sauerburger⁵⁴, E. Sauvan⁴, P. Savard^{155,e}, R. Sawada¹⁵³,
 C. Sawyer¹³⁴, L. Sawyer⁹⁷, I. Sayago Galvan¹⁶³, C. Sbarra^{23b}, A. Sbrizzi^{23b,23a}, T. Scanlon⁹⁶, J. Schaarschmidt¹³⁸,
 P. Schacht¹¹⁰, U. Schäfer¹⁰⁰, A. C. Schaffer^{66,44}, D. Schaile¹⁰⁹, R. D. Schamberger¹⁴⁵, C. Scharf¹⁸,
 M. M. Schefer¹⁹, V. A. Schegelsky³⁷, D. Scheirich¹³³, F. Schenck¹⁸, M. Schernau¹⁶⁰, C. Scheulen⁵⁵,
 C. Schiavi^{57b,57a}, E. J. Schioppa^{70a,70b}, M. Schioppa^{43b,43a}, B. Schlag^{143,t}, K. E. Schleicher⁵⁴, S. Schlenker³⁶,
 J. Schmeing¹⁷¹, M. A. Schmidt¹⁷¹, K. Schmieden¹⁰⁰, C. Schmitt¹⁰⁰, N. Schmitt¹⁰⁰, S. Schmitt⁴⁸, L. Schoeffel¹³⁵,
 A. Schoening^{63b}, P. G. Scholer⁵⁴, E. Schopf¹²⁶, M. Schott¹⁰⁰, J. Schovancova³⁶, S. Schramm⁵⁶, F. Schroeder¹⁷¹,
 T. Schroer⁵⁶, H-C. Schultz-Coulon^{63a}, M. Schumacher⁵⁴, B. A. Schumm¹³⁶, Ph. Schune¹³⁵, A. J. Schuy¹³⁸,
 H. R. Schwartz¹³⁶, A. Schwartzman¹⁴³, T. A. Schwarz¹⁰⁶, Ph. Schwemling¹³⁵, R. Schwienhorst¹⁰⁷,
 A. Sciandra¹³⁶, G. Sciolla²⁶, F. Scuri^{74a}, C. D. Sebastiani⁹², K. Sedlaczek¹¹⁵, P. Seema¹⁸, S. C. Seidel¹¹²,
 A. Seiden¹³⁶, B. D. Seidlitz⁴¹, C. Seitz⁴⁸, J. M. Seixas^{83b}, G. Sekhniaidze^{72a}, S. J. Sekula⁴⁴, L. Selem⁶⁰,
 N. Semprini-Cesari^{23b,23a}, D. Sengupta⁵⁶, V. Senthikumar¹⁶³, L. Serin⁶⁶, L. Serkin^{69a,69b}, M. Sessa^{76a,76b},
 H. Severini¹²⁰, F. Sforza^{57b,57a}, A. Sfyrla⁵⁶, E. Shabalina⁵⁵, R. Shaheen¹⁴⁴, J. D. Shahinian¹²⁸,
 D. Shaked Renous¹⁶⁹, L. Y. Shan^{14a}, M. Shapiro^{17a}, A. Sharma³⁶, A. S. Sharma¹⁶⁴, P. Sharma⁸⁰, S. Sharma⁴⁸,
 P. B. Shatalov³⁷, K. Shaw¹⁴⁶, S. M. Shaw¹⁰¹, A. Shcherbakova³⁷, Q. Shen^{62c,5}, D. J. Sheppard¹⁴², P. Sherwood⁹⁶,
 L. Shi⁹⁶, X. Shi^{14a}, C. O. Shimmin¹⁷², J. D. Shinner⁹⁵, I. P. J. Shipsey¹²⁶, S. Shirabe^{56,ff}, M. Shiyakova^{38,gg},
 J. Shlomi¹⁶⁹, M. J. Shochet³⁹, J. Shojaii¹⁰⁵, D. R. Shope¹²⁵, B. Shrestha¹²⁰, S. Shrestha^{119,hh}, E. M. Shrif^{33g},
 M. J. Shroff¹⁶⁵, P. Sicho¹³¹, A. M. Sickles¹⁶², E. Sideras Haddad^{33g}, A. Sidoti^{23b}, F. Siegert⁵⁰, Dj. Sijacki¹⁵,
 F. Sili⁹⁰, J. M. Silva²⁰, M. V. Silva Oliveira²⁹, S. B. Silverstein^{47a}, S. Simion⁶⁶, R. Simoniello³⁶, E. L. Simpson⁵⁹,
 H. Simpson¹⁴⁶, L. R. Simpson¹⁰⁶, N. D. Simpson⁹⁸, S. Simsek⁸², S. Sindhu⁵⁵, P. Sinervo¹⁵⁵, S. Singh¹⁵⁵

S. Sinha⁴⁸, S. Sinha¹⁰¹, M. Sioli^{23b,23a}, I. Siral³⁶, E. Sitnikova⁴⁸, S. Yu. Sivoklokov^{37,a}, J. Sjölin^{47a,47b},
A. Skaf⁵⁵, E. Skorda²⁰, P. Skubic¹²⁰, M. Slawinska⁸⁷, V. Smakhtin¹⁶⁹, B. H. Smart¹³⁴, J. Smiesko³⁶,
S. Yu. Smirnov³⁷, Y. Smirnov³⁷, L. N. Smirnova^{37,1}, O. Smirnova⁹⁸, A. C. Smith⁴¹, E. A. Smith³⁹,
H. A. Smith¹²⁶, J. L. Smith⁹², R. Smith¹⁴³, M. Smizanska⁹¹, K. Smolek¹³², A. A. Snesarev³⁷, S. R. Snider¹⁵⁵,
H. L. Snoek¹¹⁴, S. Snyder²⁹, R. Sobie^{165,p}, A. Soffer¹⁵¹, C. A. Solans Sanchez³⁶, E. Yu. Soldatov³⁷,
U. Soldevila¹⁶³, A. A. Solodkov³⁷, S. Solomon²⁶, A. Soloshenko³⁸, K. Solovieva⁵⁴, O. V. Solovyanov⁴⁰,
V. Solovyev³⁷, P. Sommer³⁶, A. Sonay¹³, W. Y. Song^{156b}, J. M. Sonneveld¹¹⁴, A. Sopczak¹³², A. L. Sopio⁹⁶,
F. Sopkova^{28b}, I. R. Sotarriva Alvarez¹⁵⁴, V. Sothilingam^{63a}, O. J. Soto Sandoval^{137c,137b}, S. Sottocornola⁶⁸,
R. Soualah^{116b}, Z. Soumami^{35e}, D. South⁴⁸, N. Soybelman¹⁶⁹, S. Spagnolo^{70a,70b}, M. Spalla¹¹⁰, D. Sperlich⁵⁴,
G. Spigo³⁶, S. Spinali⁹¹, D. P. Spiteri⁵⁹, M. Spousta¹³³, E. J. Staats³⁴, A. Stabile^{71a,71b}, R. Stamen^{63a},
A. Stampekis²⁰, M. Standke²⁴, E. Stanecka⁸⁷, M. V. Stange⁵⁰, B. Stanislaus^{17a}, M. M. Stanitzki⁴⁸, B. Stapf⁴⁸,
E. A. Starchenko³⁷, G. H. Stark¹³⁶, J. Stark^{102,dd}, D. M. Starke^{156b}, P. Staroba¹³¹, P. Starovoitov^{63a}, S. Stärz¹⁰⁴,
R. Staszewski⁸⁷, G. Stavropoulos⁴⁶, J. Steentoft¹⁶¹, P. Steinberg²⁹, B. Stelzer^{142,156a}, H. J. Stelzer¹²⁹,
O. Stelzer-Chilton^{156a}, H. Stenzel⁵⁸, T. J. Stevenson¹⁴⁶, G. A. Stewart³⁶, J. R. Stewart¹²¹, M. C. Stockton³⁶,
G. Stoicea^{27b}, M. Stolarski^{130a}, S. Stonjek¹¹⁰, A. Straessner⁵⁰, J. Strandberg¹⁴⁴, S. Strandberg^{47a,47b},
M. Stratmann¹⁷¹, M. Strauss¹²⁰, T. Streblor¹⁰², P. Strizenc^{28b}, R. Ströhmer¹⁶⁶, D. M. Strom¹²³,
R. Stroynowski⁴⁴, A. Strubig^{47a,47b}, S. A. Stucci²⁹, B. Stugu¹⁶, J. Stupak¹²⁰, N. A. Styles⁴⁸, D. Su¹⁴³, S. Su^{62a},
W. Su^{62d}, X. Su^{62a,66}, K. Sugizaki¹⁵³, V. V. Sulim³⁷, M. J. Sullivan⁹², D. M. S. Sultan^{78a,78b}, L. Sultanliyeva³⁷,
S. Sultansoy^{3b}, T. Sumida⁸⁸, S. Sun¹⁰⁶, S. Sun¹⁷⁰, O. Sunneborn Gudnadottir¹⁶¹, N. Sur¹⁰², M. R. Sutton¹⁴⁶,
H. Suzuki¹⁵⁷, M. Svatos¹³¹, M. Swiatlowski^{156a}, T. Swirski¹⁶⁶, I. Sykora^{28a}, M. Sykora¹³³, T. Sykora¹³³,
D. Ta¹⁰⁰, K. Tackmann^{48,ii}, A. Taffard¹⁶⁰, R. Tafirout^{156a}, J. S. Tafoya Vargas⁶⁶, E. P. Takeva⁵², Y. Takubo⁸⁴,
M. Talby¹⁰², A. A. Talyshev³⁷, K. C. Tam^{64b}, N. M. Tamir¹⁵¹, A. Tanaka¹⁵³, J. Tanaka¹⁵³, R. Tanaka⁶⁶,
M. Tanasini^{57b,57a}, Z. Tao¹⁶⁴, S. Tapia Araya^{137f}, S. Tapprogge¹⁰⁰, A. Tarek Abouelfadl Mohamed¹⁰⁷, S. Tarem¹⁵⁰,
K. Tariq^{14a}, G. Tarna^{102,27b}, G. F. Tartarelli^{71a}, P. Tas¹³³, M. Tasevsky¹³¹, E. Tassi^{43b,43a}, A. C. Tate¹⁶²,
G. Tateno¹⁵³, Y. Tayalati^{35e,ij}, G. N. Taylor¹⁰⁵, W. Taylor^{156b}, A. S. Tee¹⁷⁰, R. Teixeira De Lima¹⁴³,
P. Teixeira-Dias⁹⁵, J. J. Teoh¹⁵⁵, K. Terashi¹⁵³, J. Terron⁹⁹, S. Terzo¹³, M. Testa⁵³, R. J. Teuscher^{155,p},
A. Thaler⁷⁹, O. Theiner⁵⁶, N. Themistokleous⁵², T. Theveneaux-Pelzer¹⁰², O. Thielmann¹⁷¹, D. W. Thomas⁹⁵,
J. P. Thomas²⁰, E. A. Thompson^{17a}, P. D. Thompson²⁰, E. Thomson¹²⁸, Y. Tian⁵⁵, V. Tikhomirov^{37,1},
Yu. A. Tikhonov³⁷, S. Timoshenko³⁷, D. Timoshyn¹³³, E. X. L. Ting¹, P. Tipton¹⁷², S. H. Tlou^{33g}, A. Tnourji⁴⁰,
K. Todome¹⁵⁴, S. Todorova-Nova¹³³, S. Todt⁵⁰, M. Togawa⁸⁴, J. Tojo⁸⁹, S. Tokár^{28a}, K. Tokushuku⁸⁴,
O. Toldaiev⁶⁸, R. Tombs³², M. Tomoto^{84,111}, L. Tompkins^{143,t}, K. W. Topolnicki^{86b}, E. Torrence¹²³,
H. Torres^{102,dd}, E. Torró Pastor¹⁶³, M. Toscani³⁰, C. Toscirri³⁹, M. Tost¹¹, D. R. Tovey¹³⁹, A. Traeet¹⁶,
I. S. Trandafir^{27b}, T. Trefzger¹⁶⁶, A. Tricoli²⁹, I. M. Trigger^{156a}, S. Trincaz-Duvoid¹²⁷, D. A. Trischuk²⁶,
B. Trocme⁶⁰, C. Troncon^{71a}, L. Truong^{33c}, M. Trzebinski⁸⁷, A. Trzupek⁸⁷, F. Tsai¹⁴⁵, M. Tsai¹⁰⁶,
A. Tsiamis^{152,aa}, P. V. Tsiarshka³⁷, S. Tsigaridas^{156a}, A. Tsigiriotis^{152,bb}, V. Tsiskaridze¹⁵⁵, E. G. Tskhadadze^{149a},
M. Tsopoulou^{152,aa}, Y. Tsujikawa⁸⁸, I. I. Tsukerman³⁷, V. Tsulaia^{17a}, S. Tsuno⁸⁴, K. Tsurii¹¹⁸, D. Tsybychev¹⁴⁵,
Y. Tu^{64b}, A. Tudorache^{27b}, V. Tudorache^{27b}, A. N. Tuna⁶¹, S. Turchikhin^{57b,57a}, I. Turk Cakir^{3a}, R. Turra^{71a},
T. Turtuvshin^{38,kk}, P. M. Tuts⁴¹, S. Tzamarias^{152,aa}, P. Tzanis¹⁰, E. Tzovara¹⁰⁰, F. Ukegawa¹⁵⁷,
P. A. Ulloa Poblete^{137c,137b}, E. N. Umaka²⁹, G. Unal³⁶, M. Unal¹¹, A. Undrus²⁹, G. Unel¹⁶⁰, J. Urban^{28b},
P. Urquijo¹⁰⁵, P. Urrejola^{137a}, G. Usai⁸, R. Ushioda¹⁵⁴, M. Usman¹⁰⁸, Z. Uysal^{21b}, V. Vacek¹³², B. Vachon¹⁰⁴,
K. O. H. Vadla¹²⁵, T. Vafeiadis³⁶, A. Vaitkus⁹⁶, C. Valderanis¹⁰⁹, E. Valdes Santurio^{47a,47b}, M. Valente^{156a},
S. Valentinetti^{23b,23a}, A. Valero¹⁶³, E. Valiente Moreno¹⁶³, A. Vallier^{102,dd}, J. A. Valls Ferrer¹⁶³,
D. R. Van Arneeman¹¹⁴, T. R. Van Daalen¹³⁸, A. Van Der Graaf⁴⁹, P. Van Gemmeren⁶, M. Van Rijnbach^{125,36},
S. Van Stroud⁹⁶, I. Van Vulpen¹¹⁴, M. Vanadia^{76a,76b}, W. Vandelli³⁶, M. Vandenbroucke¹³⁵, E. R. Vandewall¹²¹,
D. Vannicola¹⁵¹, L. Vannoli^{57b,57a}, R. Vari^{75a}, E. W. Varnes⁷, C. Varni^{17b}, T. Varol¹⁴⁸, D. Varouchas⁶⁶,
L. Varriale¹⁶³, K. E. Varvell¹⁴⁷, M. E. Vasile^{27b}, L. Vaslin⁸⁴, G. A. Vasquez¹⁶⁵, A. Vasyukov³⁸, F. Vazeille⁴⁰,
T. Vazquez Schroeder³⁶, J. Veatch³¹, V. Vecchio¹⁰¹, M. J. Veen¹⁰³, I. Veliscek¹²⁶, L. M. Veloce¹⁵⁵,
F. Veloso^{130a,130c}, S. Veneziano^{75a}, A. Ventura^{70a,70b}, S. Ventura Gonzalez¹³⁵, A. Verbytskyi¹¹⁰, M. Verducci^{74a,74b},
C. Vergis²⁴, M. Verissimo De Araujo^{83b}, W. Verkerke¹¹⁴, J. C. Vermeulen¹¹⁴, C. Vernieri¹⁴³, M. Vessella¹⁰³

M. C. Vetterli^{142,e} A. Vgenopoulos^{152,aa} N. Viaux Maira^{137f} T. Vickey¹³⁹ O. E. Vickey Boeriu¹³⁹
 G. H. A. Viehhauser¹²⁶ L. Vigani^{63b} M. Villa^{23b,23a} M. Villaplana Perez¹⁶³ E. M. Villhauer⁵² E. Vilucchi⁵³
 M. G. Vincter³⁴ G. S. Virdee²⁰ A. Vishwakarma⁵² A. Visibile¹¹⁴ C. Vittori³⁶ I. Vivarelli¹⁴⁶ E. Voevodina¹¹⁰
 F. Vogel¹⁰⁹ J. C. Voigt⁵⁰ P. Vokac¹³² Yu. Volkotrub^{86a} J. Von Ahnen⁴⁸ E. Von Toerne²⁴ B. Vormwald³⁶
 V. Vorobel¹³³ K. Vorobev³⁷ M. Vos¹⁶³ K. Voss¹⁴¹ J. H. Vosseveld⁹² M. Vozak¹¹⁴ L. Vozdecky⁹⁴
 N. Vranjes¹⁵ M. Vranjes Milosavljevic¹⁵ M. Vreeswijk¹¹⁴ R. Vuillermet³⁶ O. Vujinovic¹⁰⁰ I. Vukotic³⁹
 S. Wada¹⁵⁷ C. Wagner¹⁰³ J. M. Wagner^{17a} W. Wagner¹⁷¹ S. Wahdan¹⁷¹ H. Wahlberg⁹⁰ M. Wakida¹¹¹
 J. Walder¹³⁴ R. Walker¹⁰⁹ W. Walkowiak¹⁴¹ A. Wall¹²⁸ T. Wamorkar⁶ A. Z. Wang¹³⁶ C. Wang¹⁰⁰
 C. Wang^{62c} H. Wang^{17a} J. Wang^{64a} R.-J. Wang¹⁰⁰ R. Wang⁶¹ R. Wang⁶ S. M. Wang¹⁴⁸ S. Wang^{62b}
 T. Wang^{62a} W. T. Wang⁸⁰ W. Wang^{14a} X. Wang^{14c} X. Wang¹⁶² X. Wang^{62c} Y. Wang^{62d} Y. Wang^{14c}
 Z. Wang¹⁰⁶ Z. Wang^{62d,51,62c} Z. Wang¹⁰⁶ A. Warburton¹⁰⁴ R. J. Ward²⁰ N. Warrack⁵⁹ A. T. Watson²⁰
 H. Watson⁵⁹ M. F. Watson²⁰ E. Watton^{59,134} G. Watts¹³⁸ B. M. Waugh⁹⁶ C. Weber²⁹ H. A. Weber¹⁸
 M. S. Weber¹⁹ S. M. Weber^{63a} C. Wei^{62a} Y. Wei¹²⁶ A. R. Weidberg¹²⁶ E. J. Weik¹¹⁷ J. Weingarten⁴⁹
 M. Weirich¹⁰⁰ C. Weiser⁵⁴ C. J. Wells⁴⁸ T. Wenaus²⁹ B. Wendland⁴⁹ T. Wengler³⁶ N. S. Wenke¹¹⁰
 N. Wermes²⁴ M. Wessels^{63a} A. M. Wharton⁹¹ A. S. White⁶¹ A. White⁸ M. J. White¹ D. Whiteson¹⁶⁰
 L. Wickremasinghe¹²⁴ W. Wiedenmann¹⁷⁰ C. Wiel⁵⁰ M. Wielers¹³⁴ C. Wiglesworth⁴² D. J. Wilbern¹²⁰
 H. G. Wilkens³⁶ D. M. Williams⁴¹ H. H. Williams¹²⁸ S. Williams³² S. Willocq¹⁰³ B. J. Wilson¹⁰¹
 P. J. Windischhofer³⁹ F. I. Winkel³⁰ F. Winklmeier¹²³ B. T. Winter⁵⁴ J. K. Winter¹⁰¹ M. Wittgen¹⁴³
 M. Wobisch⁹⁷ Z. Wolffs¹¹⁴ J. Wollrath¹⁶⁰ M. W. Wolter⁸⁷ H. Wolters^{130a,130c} A. F. Wongel⁴⁸
 E. L. Woodward⁴¹ S. D. Worm⁴⁸ B. K. Wosiek⁸⁷ K. W. Woźniak⁸⁷ S. Wozniowski⁵⁵ K. Wraight⁵⁹ C. Wu²⁰
 J. Wu^{14a,14e} M. Wu^{64a} M. Wu¹¹³ S. L. Wu¹⁷⁰ X. Wu⁵⁶ Y. Wu^{62a} Z. Wu¹³⁵ J. Wuerzinger^{110,w}
 T. R. Wyatt¹⁰¹ B. M. Wynne⁵² S. Xella⁴² L. Xia^{14c} M. Xia^{14b} J. Xiang^{64c} M. Xie^{62a} X. Xie^{62a}
 S. Xin^{14a,14e} A. Xiong¹²³ J. Xiong^{17a} D. Xu^{14a} H. Xu^{62a} L. Xu^{62a} R. Xu¹²⁸ T. Xu¹⁰⁶ Y. Xu^{14b} Z. Xu⁵²
 Z. Xu^{14c} B. Yabsley¹⁴⁷ S. Yacoob^{33a} Y. Yamaguchi¹⁵⁴ E. Yamashita¹⁵³ H. Yamauchi¹⁵⁷ T. Yamazaki^{17a}
 Y. Yamazaki⁸⁵ J. Yan^{62c} S. Yan¹²⁶ Z. Yan²⁵ H. J. Yang^{62c,62d} H. T. Yang^{62a} S. Yang^{62a} T. Yang^{64c}
 X. Yang³⁶ X. Yang^{14a} Y. Yang⁴⁴ Y. Yang^{62a} Z. Yang^{62a} W.-M. Yao^{17a} Y. C. Yap⁴⁸ H. Ye^{14c} H. Ye⁵⁵
 J. Ye^{14a} S. Ye²⁹ X. Ye^{62a} Y. Yeh⁹⁶ I. Yeletsikh³⁸ B. K. Yeo^{17b} M. R. Yexley⁹⁶ P. Yin⁴¹ K. Yorita¹⁶⁸
 S. Younas^{27b} C. J. S. Young³⁶ C. Young¹⁴³ C. Yu^{14a,14e,11} Y. Yu^{62a} M. Yuan¹⁰⁶ R. Yuan^{62b} L. Yue⁹⁶
 M. Zaazoua^{62a} B. Zabinski⁸⁷ E. Zaid⁵² Z. K. Zak⁸⁷ T. Zakareishvili^{149b} N. Zakharchuk³⁴ S. Zambito⁵⁶
 J. A. Zamora Saa^{137d,137b} J. Zang¹⁵³ D. Zanzi⁵⁴ O. Zaplatilek¹³² C. Zeitnitz¹⁷¹ H. Zeng^{14a} J. C. Zeng¹⁶²
 D. T. Zenger Jr.²⁶ O. Zenin³⁷ T. Ženiš^{28a} S. Zenz⁹⁴ S. Zerradi^{35a} D. Zerwas⁶⁶ M. Zhai^{14a,14e} B. Zhang^{14c}
 D. F. Zhang¹³⁹ J. Zhang^{62b} J. Zhang⁶ K. Zhang^{14a,14e} L. Zhang^{14c} P. Zhang^{14a,14e} R. Zhang¹⁷⁰ S. Zhang¹⁰⁶
 S. Zhang⁴⁴ T. Zhang¹⁵³ X. Zhang^{62c} X. Zhang^{62b} Y. Zhang^{62c,5} Y. Zhang⁹⁶ Y. Zhang^{14c} Z. Zhang^{17a}
 Z. Zhang⁶⁶ H. Zhao¹³⁸ T. Zhao^{62b} Y. Zhao¹³⁶ Z. Zhao^{62a} A. Zhemchugov³⁸ J. Zheng^{14c} K. Zheng¹⁶²
 X. Zheng^{62a} Z. Zheng¹⁴³ D. Zhong¹⁶² B. Zhou¹⁰⁶ H. Zhou⁷ N. Zhou^{62c} Y. Zhou⁷ C. G. Zhu^{62b} J. Zhu¹⁰⁶
 Y. Zhu^{62c} Y. Zhu^{62a} X. Zhuang^{14a} K. Zhukov³⁷ V. Zhulanov³⁷ N. I. Zimine³⁸ J. Zinsser^{63b}
 M. Ziolkowski¹⁴¹ L. Živković¹⁵ A. Zoccoli^{23b,23a} K. Zoch⁶¹ T. G. Zorbas¹³⁹ O. Zormpa⁴⁶
 W. Zou⁴¹ and L. Zwalinski³⁶

(ATLAS Collaboration)

¹Department of Physics, University of Adelaide, Adelaide, Australia
²Department of Physics, University of Alberta, Edmonton, Alberta, Canada
^{3a}Department of Physics, Ankara University, Ankara, Türkiye
^{3b}Division of Physics, TOBB University of Economics and Technology, Ankara, Türkiye
⁴LAPP, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy, France
⁵APC, Université Paris Cité, CNRS/IN2P3, Paris, France
⁶High Energy Physics Division, Argonne National Laboratory, Argonne, Illinois, USA
⁷Department of Physics, University of Arizona, Tucson, Arizona, USA
⁸Department of Physics, University of Texas at Arlington, Arlington, Texas, USA

- ⁹Physics Department, National and Kapodistrian University of Athens, Athens, Greece
- ¹⁰Physics Department, National Technical University of Athens, Zografou, Greece
- ¹¹Department of Physics, University of Texas at Austin, Austin, Texas, USA
- ¹²Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
- ¹³Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona, Spain
- ^{14a}Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China
- ^{14b}Physics Department, Tsinghua University, Beijing, China
- ^{14c}Department of Physics, Nanjing University, Nanjing, China
- ^{14d}School of Science, Shenzhen Campus of Sun Yat-sen University, China
- ^{14e}University of Chinese Academy of Science (UCAS), Beijing, China
- ¹⁵Institute of Physics, University of Belgrade, Belgrade, Serbia
- ¹⁶Department for Physics and Technology, University of Bergen, Bergen, Norway
- ^{17a}Physics Division, Lawrence Berkeley National Laboratory, Berkeley, California, USA
- ^{17b}University of California, Berkeley, California, USA
- ¹⁸Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany
- ¹⁹Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland
- ²⁰School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom
- ^{21a}Department of Physics, Bogazici University, Istanbul, Türkiye
- ^{21b}Department of Physics Engineering, Gaziantep University, Gaziantep, Türkiye
- ^{21c}Department of Physics, Istanbul University, Istanbul, Türkiye
- ^{22a}Facultad de Ciencias y Centro de Investigaciones, Universidad Antonio Nariño, Bogotá, Colombia
- ^{22b}Departamento de Física, Universidad Nacional de Colombia, Bogotá, Colombia
- ^{23a}Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna, Italy
- ^{23b}INFN Sezione di Bologna, Italy
- ²⁴Physikalisches Institut, Universität Bonn, Bonn, Germany
- ²⁵Department of Physics, Boston University, Boston, Massachusetts, USA
- ²⁶Department of Physics, Brandeis University, Waltham, Massachusetts, USA
- ^{27a}Transilvania University of Brasov, Brasov, Romania
- ^{27b}Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania
- ^{27c}Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi, Romania
- ^{27d}National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca, Romania
- ^{27e}University Politehnica Bucharest, Bucharest, Romania
- ^{27f}West University in Timisoara, Timisoara, Romania
- ^{27g}Faculty of Physics, University of Bucharest, Bucharest, Romania
- ^{28a}Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovak Republic
- ^{28b}Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic
- ²⁹Physics Department, Brookhaven National Laboratory, Upton, New York, USA
- ³⁰Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Física, y CONICET, Instituto de Física de Buenos Aires (IFIBA), Buenos Aires, Argentina
- ³¹California State University, California, USA
- ³²Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
- ^{33a}Department of Physics, University of Cape Town, Cape Town, South Africa
- ^{33b}iThemba Labs, Western Cape, South Africa
- ^{33c}Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, South Africa
- ^{33d}National Institute of Physics, University of the Philippines Diliman (Philippines), Philippines
- ^{33e}University of South Africa, Department of Physics, Pretoria, South Africa
- ^{33f}University of Zululand, KwaDlangezwa, South Africa
- ^{33g}School of Physics, University of the Witwatersrand, Johannesburg, South Africa
- ³⁴Department of Physics, Carleton University, Ottawa, Ontario, Canada
- ^{35a}Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies—Université Hassan II, Casablanca, Morocco
- ^{35b}Faculté des Sciences, Université Ibn-Tofail, Kénitra, Morocco
- ^{35c}Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Morocco
- ^{35d}LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda, Morocco
- ^{35e}Faculté des sciences, Université Mohammed V, Rabat, Morocco
- ^{35f}Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir, Morocco
- ³⁶CERN, Geneva, Switzerland
- ³⁷Affiliated with an institute covered by a cooperation agreement with CERN
- ³⁸Affiliated with an international laboratory covered by a cooperation agreement with CERN

- ³⁹*Enrico Fermi Institute, University of Chicago, Chicago, Illinois, USA*
- ⁴⁰*LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand, France*
- ⁴¹*Nevis Laboratory, Columbia University, Irvington, New York, USA*
- ⁴²*Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark*
- ^{43a}*Dipartimento di Fisica, Università della Calabria, Rende, Italy*
- ^{43b}*INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Italy*
- ⁴⁴*Physics Department, Southern Methodist University, Dallas, Texas, USA*
- ⁴⁵*Physics Department, University of Texas at Dallas, Richardson, Texas, USA*
- ⁴⁶*National Centre for Scientific Research “Demokritos”, Agia Paraskevi, Greece*
- ^{47a}*Department of Physics, Stockholm University, Sweden*
- ^{47b}*Oskar Klein Centre, Stockholm, Sweden*
- ⁴⁸*Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen, Germany*
- ⁴⁹*Fakultät Physik, Technische Universität Dortmund, Dortmund, Germany*
- ⁵⁰*Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany*
- ⁵¹*Department of Physics, Duke University, Durham, North Carolina, USA*
- ⁵²*SUPA—School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom*
- ⁵³*INFN e Laboratori Nazionali di Frascati, Frascati, Italy*
- ⁵⁴*Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany*
- ⁵⁵*II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany*
- ⁵⁶*Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland*
- ^{57a}*Dipartimento di Fisica, Università di Genova, Genova, Italy*
- ^{57b}*INFN Sezione di Genova, Italy*
- ⁵⁸*II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany*
- ⁵⁹*SUPA—School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom*
- ⁶⁰*LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble, France*
- ⁶¹*Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, Massachusetts, USA*
- ^{62a}*Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, China*
- ^{62b}*Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao, China*
- ^{62c}*School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai, China*
- ^{62d}*Tsung-Dao Lee Institute, Shanghai, China*
- ^{62e}*School of Physics and Microelectronics, Zhengzhou University, China*
- ^{63a}*Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
- ^{63b}*Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
- ^{64a}*Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China*
- ^{64b}*Department of Physics, University of Hong Kong, Hong Kong, China*
- ^{64c}*Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China*
- ⁶⁵*Department of Physics, National Tsing Hua University, Hsinchu, Taiwan*
- ⁶⁶*IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay, France*
- ⁶⁷*Centro Nacional de Microelectrónica (IMB-CNM-CSIC), Barcelona, Spain*
- ⁶⁸*Department of Physics, Indiana University, Bloomington, Indiana, USA*
- ^{69a}*INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, Italy*
- ^{69b}*ICTP, Trieste, Italy*
- ^{69c}*Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine, Italy*
- ^{70a}*INFN Sezione di Lecce, Italy*
- ^{70b}*Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy*
- ^{71a}*INFN Sezione di Milano, Italy*
- ^{71b}*Dipartimento di Fisica, Università di Milano, Milano, Italy*
- ^{72a}*INFN Sezione di Napoli, Italy*
- ^{72b}*Dipartimento di Fisica, Università di Napoli, Napoli, Italy*
- ^{73a}*INFN Sezione di Pavia, Italy*
- ^{73b}*Dipartimento di Fisica, Università di Pavia, Pavia, Italy*
- ^{74a}*INFN Sezione di Pisa, Italy*
- ^{74b}*Dipartimento di Fisica E.Fermi, Università di Pisa, Pisa, Italy*
- ^{75a}*INFN Sezione di Roma, Italy*
- ^{75b}*Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy*
- ^{76a}*INFN Sezione di Roma Tor Vergata, Italy*

- ^{76b}*Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy*
^{77a}*INFN Sezione di Roma Tre, Italy*
- ^{77b}*Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy*
^{78a}*INFN-TIFPA, Italy*
^{78b}*Università degli Studi di Trento, Trento, Italy*
- ⁷⁹*Universität Innsbruck, Department of Astro and Particle Physics, Innsbruck, Austria*
⁸⁰*University of Iowa, Iowa City, Iowa, USA*
- ⁸¹*Department of Physics and Astronomy, Iowa State University, Ames, Iowa, USA*
⁸²*Istinye University, Sariyer, Istanbul, Türkiye*
- ^{83a}*Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora, Brazil*
^{83b}*Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil*
^{83c}*Instituto de Física, Universidade de São Paulo, São Paulo, Brazil*
^{83d}*Rio de Janeiro State University, Rio de Janeiro, Brazil*
- ⁸⁴*KEK, High Energy Accelerator Research Organization, Tsukuba, Japan*
⁸⁵*Graduate School of Science, Kobe University, Kobe, Japan*
- ^{86a}*AGH University of Krakow, Faculty of Physics and Applied Computer Science, Krakow, Poland*
^{86b}*Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland*
⁸⁷*Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland*
⁸⁸*Faculty of Science, Kyoto University, Kyoto, Japan*
- ⁸⁹*Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka, Japan*
⁹⁰*Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina*
⁹¹*Physics Department, Lancaster University, Lancaster, United Kingdom*
⁹²*Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom*
- ⁹³*Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia*
- ⁹⁴*School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom*
⁹⁵*Department of Physics, Royal Holloway University of London, Egham, United Kingdom*
⁹⁶*Department of Physics and Astronomy, University College London, London, United Kingdom*
⁹⁷*Louisiana Tech University, Ruston, Louisiana, USA*
⁹⁸*Fysiska institutionen, Lunds universitet, Lund, Sweden*
- ⁹⁹*Departamento de Física 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*Group of Particle Physics, University of Montreal, Montreal, Quebec, Canada*
¹⁰⁹*Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany*
¹¹⁰*Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany*
- ¹¹¹*Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan*
¹¹²*Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico, USA*
- ¹¹³*Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen, Netherlands*
¹¹⁴*Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands*
¹¹⁵*Department of Physics, Northern Illinois University, DeKalb, Illinois, USA*
^{116a}*New York University Abu Dhabi, Abu Dhabi, United Arab Emirates*
^{116b}*University of Sharjah, Sharjah, United Arab Emirates*
- ¹¹⁷*Department of Physics, New York University, New York, New York, USA*
¹¹⁸*Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo, Japan*
¹¹⁹*The Ohio State University, Columbus, Ohio, USA*
- ¹²⁰*Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma, USA*
¹²¹*Department of Physics, Oklahoma State University, Stillwater, Oklahoma, USA*
¹²²*Palacký University, Joint Laboratory of Optics, Olomouc, Czech Republic*
¹²³*Institute for Fundamental Science, University of Oregon, Eugene, Oregon, USA*
¹²⁴*Graduate School of Science, Osaka University, Osaka, Japan*
¹²⁵*Department of Physics, University of Oslo, Oslo, Norway*
¹²⁶*Department of Physics, Oxford University, Oxford, United Kingdom*
¹²⁷*LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris, France*

- ¹²⁸*Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania, USA*
- ¹²⁹*Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania, USA*
- ^{130a}*Laboratório de Instrumentação e Física Experimental de Partículas—LIP, Lisboa, Portugal*
- ^{130b}*Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal*
- ^{130c}*Departamento de Física, Universidade de Coimbra, Coimbra, Portugal*
- ^{130d}*Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal*
- ^{130e}*Departamento de Física, Universidade do Minho, Braga, Portugal*
- ^{130f}*Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain), Spain*
- ^{130g}*Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal*
- ¹³¹*Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic*
- ¹³²*Czech Technical University in Prague, Prague, Czech Republic*
- ¹³³*Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic*
- ¹³⁴*Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom*
- ¹³⁵*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
- ¹³⁶*Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, California, USA*
- ^{137a}*Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile*
- ^{137b}*Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago, Chile*
- ^{137c}*Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, y Departamento de Física, Universidad de La Serena, Chile*
- ^{137d}*Universidad Andres Bello, Department of Physics, Santiago, Chile*
- ^{137e}*Instituto de Alta Investigación, Universidad de Tarapacá, Arica, Chile*
- ^{137f}*Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile*
- ¹³⁸*Department of Physics, University of Washington, Seattle, Washington DC, USA*
- ¹³⁹*Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom*
- ¹⁴⁰*Department of Physics, Shinshu University, Nagano, Japan*
- ¹⁴¹*Department Physik, Universität Siegen, Siegen, Germany*
- ¹⁴²*Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada*
- ¹⁴³*SLAC National Accelerator Laboratory, Stanford, California, USA*
- ¹⁴⁴*Department of Physics, Royal Institute of Technology, Stockholm, Sweden*
- ¹⁴⁵*Departments of Physics and Astronomy, Stony Brook University, Stony Brook, New York, USA*
- ¹⁴⁶*Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom*
- ¹⁴⁷*School of Physics, University of Sydney, Sydney, Australia*
- ¹⁴⁸*Institute of Physics, Academia Sinica, Taipei, Taiwan*
- ^{149a}*E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia*
- ^{149b}*High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia*
- ^{149c}*University of Georgia, Tbilisi, Georgia*
- ¹⁵⁰*Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel*
- ¹⁵¹*Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel*
- ¹⁵²*Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*
- ¹⁵³*International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan*
- ¹⁵⁴*Department of Physics, Tokyo Institute of Technology, Tokyo, Japan*
- ¹⁵⁵*Department of Physics, University of Toronto, Toronto, Ontario, Canada*
- ^{156a}*TRIUMF, Vancouver, British Columbia, Canada*
- ^{156b}*Department of Physics and Astronomy, York University, Toronto, Ontario, Canada*
- ¹⁵⁷*Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan*
- ¹⁵⁸*Department of Physics and Astronomy, Tufts University, Medford, Massachusetts, USA*
- ¹⁵⁹*United Arab Emirates University, Al Ain, United Arab Emirates*
- ¹⁶⁰*Department of Physics and Astronomy, University of California Irvine, Irvine, California, USA*
- ¹⁶¹*Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*
- ¹⁶²*Department of Physics, University of Illinois, Urbana, Illinois, USA*
- ¹⁶³*Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia—CSIC, Valencia, Spain*
- ¹⁶⁴*Department of Physics, University of British Columbia, Vancouver, British Columbia, Canada*
- ¹⁶⁵*Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia, Canada*
- ¹⁶⁶*Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany*
- ¹⁶⁷*Department of Physics, University of Warwick, Coventry, United Kingdom*
- ¹⁶⁸*Waseda University, Tokyo, Japan*
- ¹⁶⁹*Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot, Israel*
- ¹⁷⁰*Department of Physics, University of Wisconsin, Madison, Wisconsin, USA*
- ¹⁷¹*Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany*
- ¹⁷²*Department of Physics, Yale University, New Haven, Connecticut, USA*

^aDeceased.

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

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

^dAlso at Lawrence Livermore National Laboratory, Livermore, USA.

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

^fAlso at Department of Physics, University of Thessaly, Greece.

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

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

ⁱAlso at University of Colorado Boulder, Department of Physics, Colorado, USA.

^jAlso at Department of Physics, Westmont College, Santa Barbara, USA.

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

^lAlso at Affiliated with an institute covered by a cooperation agreement with CERN.

^mAlso at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing, China.

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

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

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

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

^rAlso at National Institute of Physics, University of the Philippines Diliman (Philippines), Philippines.

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

^tAlso at Department of Physics, Stanford University, Stanford, California, USA.

^uAlso at Centro Studi e Ricerche Enrico Fermi, Italy.

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

^wAlso at Technical University of Munich, Munich, Germany.

^xAlso at Yeditepe University, Physics Department, Istanbul, Türkiye.

^yAlso at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia.

^zAlso at CERN, Geneva, Switzerland.

^{aa}Also at Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki, Greece.

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

^{cc}Also at Center for High Energy Physics, Peking University, China.

^{dd}Also at L2IT, Université de Toulouse, CNRS/IN2P3, UPS, Toulouse, France.

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

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

^{gg}Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria.

^{hh}Also at Washington College, Chestertown, Maryland, USA.

ⁱⁱAlso at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.

^{jj}Also at Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir, Morocco.

^{kk}Also at Institute of Physics and Technology, Ulaanbaatar, Mongolia.

^{ll}Also at University of Chinese Academy of Sciences (UCAS), Beijing, China.