# Medium-Induced Modification of Z-Tagged Charged Particle Yields in Pb+Pb Collisions at 5.02 TeV with the ATLAS Detector

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# Medium-Induced Modification of $Z$-Tagged Charged Particle Yields in Pb + Pb Collisions at 5.02 TeV with the ATLAS Detector

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The yield of charged particles opposite to a $Z$ boson with large transverse momentum ($p_T$) is measured in 260 $\mathrm{pb}^{-1}$ of $pp$ and 1.7 $\mathrm{nb}^{-1}$ of Pb + Pb collision data at 5.02 TeV per nucleon pair recorded with the ATLAS detector at the Large Hadron Collider. The $Z$ boson tag is used to select hard-scattered partons with specific kinematics, and to observe how their showers are modified as they propagate through the quark-gluon plasma created in Pb + Pb collisions. Compared with $pp$ collisions, charged-particle yields in Pb + Pb collisions show significant modifications as a function of charged-particle $p_T$ in a way that depends on event centrality and $Z$ boson $p_T$. The data are compared with a variety of theoretical calculations and provide new information about the medium-induced energy loss of partons in a $p_T$ regime difficult to measure through other channels.

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Collisions of heavy nuclei at ultrarelativistic energies at the Large Hadron Collider (LHC) and the Relativistic Heavy Ion Collider (RHIC) are understood to produce an extended region of hot and dense matter where partons exist in a deconfined state known as the quark-gluon plasma (QGP). The high density of unscreened color charges in the QGP causes the showers of hard-scattered partons with large transverse momentum ($p_T$) to be modified as they traverse the medium [1]. These modifications are observed in measurements of dijet and photon-jet momentum imbalance [2–5], and in jet fragmentation functions [6,7].

The large integrated luminosity of Pb + Pb collisions delivered during LHC Run 2 has enabled measurements of jets produced in association with a high-$p_T$ $Z$ boson. At leading order, the $Z$ boson and the jet are produced back to back in the azimuthal plane, with equal $p_T$. Since $Z$ bosons and their decay leptons, or similarly, photons, do not participate in the strong interaction and are not modified by the QGP [8,9], they provide an estimate of the $p_T$ and azimuthal direction of the partner hard-scattered parton before the developing shower is modified through interactions with the QGP [10,11]. Measurements of photon-tagged fragmentation functions at the LHC [12,13] and photon-hadron correlations at RHIC [14,15] used this feature to perform detailed studies of jet quenching. At fixed $p_T$, jets balancing $Z$ bosons and photons arise from processes with different $Q^2$, and can test the sensitivity of the energy loss process to parton virtuality. Additionally, the use of isolated photons at low photon $p_T$ ($\lesssim$60 GeV) is difficult due to the large hadron-decay background, motivating the use of $Z$ bosons. A measurement of $Z$ + jet production with $p_T^Z > 60$ GeV by CMS demonstrates that the total $p_T$ carried inside the jet cone is decreased in Pb + Pb events compared with that in $pp$ events [16]. However, the modification of the jet's constituent particle $p_T$ distributions, or any lower $p_\mathrm{T}^Z$ selections, have not yet been studied.

This Letter presents a measurement of the yield of charged particles produced opposite in azimuth to a $Z$ boson with $p_T^Z > 15$ GeV in Pb + Pb and $pp$ collisions at a nucleon-nucleon center-of-mass energy $\sqrt{s_\mathrm{NN}} = 5.02$ TeV with the ATLAS detector at the LHC. The Pb + Pb and $pp$ data were recorded in 2018 and 2017, respectively, and correspond to integrated luminosities of up to 1.7 $\mathrm{nb}^{-1}$ and 260 $\mathrm{pb}^{-1}$. The charged particles are required to have $p_T^\mathrm{ch} > 1$ GeV and be approximately back to back with the $Z$ boson in the transverse plane, with azimuthal separation $\Delta\phi$ larger than $3\pi/4$ [17]. In simulations of $pp$ collisions, particles meeting these criteria reside primarily in the leading jet azimuthally opposite to the $Z$ boson. The per-$Z$ yields of charged particles, $N_\mathrm{ch}$, are reported as a function of $p_T^\mathrm{ch}$, $(1/N_Z)(d^2N_\mathrm{ch}/dp_T^\mathrm{ch}d\Delta\phi)$, in $pp$ and Pb + Pb collisions. To quantify the modification resulting from the partons' propagation through the QGP, the ratio of particle yields between Pb + Pb and $pp$ collisions, $I_{AA}$, is reported and compared with the expectations from theoretical calculations. This measurement explores phenomena similar to those in measurements of the photon-tagged jet fragmentation function [12]. However, requiring a

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reconstructed jet may result in a bias towards events with less energy loss than average [18–20]. Since there is no such requirement in this measurement, it provides additional insight into energy loss in an unbiased way, at low $p_T^{Z/\gamma}$ values which have not yet been measured at the LHC and where theoretical models have not been tested.

The ATLAS experiment [21] is a multipurpose particle detector with a forward-backward symmetric cylindrical geometry and a near $4\pi$ coverage in solid angle. It consists of an inner tracking detector surrounded by a superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadron calorimeters, and a muon spectrometer. The inner tracking detector covers the pseudorapidity range $|\eta| < 2.5$. It consists of silicon pixel, silicon microstrip, and transition radiation tracking detectors [22,23]. Lead/liquid-argon (LAr) sampling calorimeters provide electromagnetic (EM) energy measurements with high granularity. A steel/scintillator-tile hadron calorimeter covers the central pseudorapidity range ($|\eta| < 1.7$). Liquid-argon calorimeters with separate EM and hadronic compartments instrument the end cap (up to $|\eta| = 3.2$) and forward (FCal, up to $|\eta| = 4.9$) regions. The muon spectrometer surrounds the calorimeters and includes three air-core toroidal superconducting magnets with field integrals ranging between 2.0 and 6.0 T m, a system of precision tracking chambers, and fast detectors for triggering. During Pb + Pb data taking, the muon system was operational for only 1.4 nb$^{-1}$ of the total integrated luminosity. Thus the dimuon channel is analyzed only in this subset of data.

Events with a high-$p_T$ electron or muon are initially selected for analysis by the single-lepton triggers described in Refs. [24,25]. The centrality of Pb + Pb events is defined using the total transverse energy measured in the FCal [4,26], $\Sigma E_T^{\mathrm{Pb}}$. Pb + Pb events are divided into three categories which correspond to the 0%–10%, 10%–30%, and 30%–80% centrality intervals in minimum-bias (MB) events, the smaller values indicating larger nuclear overlap regions and thus larger, hotter QGP regions. The orientation of the underlying event (UE) elliptic flow is determined from the azimuthal distribution of the FCal energy [27,28]. In $pp$ events, the average number of interactions per bunch crossing ranged from 2 to 4, and thus all charged-particle tracks are required to originate from the primary reconstructed vertex [29].

Monte Carlo simulations of $\sqrt{s} = 5.02$ TeV $pp$ collisions with $Z$ bosons decaying in the dielectron and dimuon channels, as well as data-driven studies, are used to correct the data for bin migration and reconstruction inefficiencies. Generated events were passed through a GEANT4 simulation [30,31] of the ATLAS detector under the same conditions present during data taking and were digitized and reconstructed in the same way as the data. The $Z$ boson events were generated at next-to-leading order (NLO) with the POWHEG-BOX v2 program [32–35] interfaced to the PYTHIA 8.186 parton shower model [36]. The NLO CT10 parton distribution function (PDF) set [37] was used in the matrix element, while the CTEQ6L1 PDF set [38] and the AZNLO tuned set of parameters [39] were used to model the parton shower.

Four million events were generated to serve as the simulation sample for $pp$ collisions. To model Pb + Pb events, fifteen million simulated $pp$ events were overlaid at the detector-hit level with MB Pb + Pb events in data. This data-overlay sample was reweighted on an event-by-event basis to match the $\Sigma E_T^{\mathrm{Pb}}$ distribution for Pb + Pb events containing $Z$ bosons.

The $Z$ bosons in $pp$ and Pb + Pb events are reconstructed in opposite-sign dielectron and dimuon decay channels using procedures similar to those described in Refs. [9,40]. Reconstructed electrons are required to have a transverse momentum $p_T^e > 20$ GeV, to lie within the fiducial acceptance of the EM barrel ($|\eta^e| < 1.37$) or end cap ($1.52 < |\eta^e| < 2.47$) detectors, and to satisfy "loose" likelihood-based identification criteria, which have been optimized separately for $pp$ and Pb + Pb events [41]. Reconstructed muons are required to have a transverse momentum $p_T^\mu > 20$ GeV, to lie within the fiducial acceptance of the muon spectrometer ($|\eta^\mu| < 2.5$), and to pass the "medium" selection requirements described in Ref. [42]. The $Z \to \ell\ell$ candidates are required to be within the mass range $76 < m_{\ell\ell} < 106$ GeV and have $p_T^Z > 15$ GeV. This selection ensures that the contribution from multijet and other backgrounds is smaller than 1.5% (0.1%) for the dielectron (dimuon) channel, and is considered negligible. In total, these criteria select approximately 21 000 (28 000) $Z \to ee$ ($Z \to \mu\mu$) events in $pp$ data, and 3400 (4100) events in Pb + Pb data.

Each $Z$ data event is assigned a series of weights, derived from simulation and data, to account for the trigger, reconstruction and selection efficiencies of its decay leptons. Individual lepton trigger efficiencies are determined directly in $pp$ and Pb + Pb data using tag-and-probe techniques [24,25], and are 0.70–0.80 for each muon and 0.75–0.95 for each electron. Reconstruction and selection efficiencies are determined using simulation and are 0.65–0.80 for muons and 0.65–0.95 for electrons. Although the efficiencies may vary substantially with the individual lepton $p_T$, $\eta$, and $\phi$, the resulting dependence on $p_T^Z$ is weak due to the large $Z$ mass and weak correlation between bosons and their decay leptons.

Charged-particle tracks are reconstructed from hits in the inner detector using an algorithm [43] which, in Pb + Pb collisions, is optimized for the high-occupancy conditions [44]. They are required to meet several criteria intended to select primary charged particles [6]. All reconstructed tracks with $p_T > 1$ GeV, $|\eta| < 2.5$ and $\Delta\phi > 3\pi/4$ are considered. The charged-particle yield is corrected for reconstruction and selection inefficiency on a per-track basis using a simulation-derived efficiency which varies from 0.6 to 0.8 depending on both detector occupancy and track kinematics. A small correction, typically 1%–2%, accounts for the contribution of reconstructed tracks not associated with primary particles. The $p_T^{\rm ch}$ resolution is found to have a negligible effect ($\lesssim$0.3%) on the results and is not corrected for.

The contribution to the yield from UE particles in Pb + Pb collisions is estimated using MB events and is statistically subtracted from the measured yields. For each $Z$ event in data, 40–160 unique MB events are used for this estimation. These MB events are centrality matched to within 1% in peripheral events, decreasing to within 0.1% in central events. Furthermore, to match the azimuthal modulation of the UE, the elliptic flow angles [28] in the $Z$ data event and in the matching MB event must match within $\pi/16$. The signal-to-background ratio varies strongly with $p_T^{\rm ch}$, $p_T^Z$, and Pb + Pb centrality, with a minimum of $5 \times 10^{-3}$ at the lowest $p_T^{\rm ch}$ and $p_T^Z$ values in the most central events. In $pp$ events, the UE is known to have larger activity in a $Z$ event than in an ordinary MB $pp$ collision [45,46], necessitating a different procedure. Here, the UE is determined in events with $1 < p_T^Z < 12$ GeV in the azimuthal region perpendicular to the $Z$ boson to avoid the contribution from jet particles.

The data are further corrected for bin migration resulting from the finite resolution in the $p_T^Z$ measurement. This is evaluated by comparing the per-$Z$ charged-particle yields, where the $Z$ selection is made at the generator level, with those after reconstruction, and is typically a 2%–3% correction.

The primary sources of systematic uncertainty in the yield measurement are those affecting the $Z$ boson reconstruction, those affecting the charged-particle selection, and those affecting the UE background estimation and subtraction. The uncertainties associated with the electron and muon energy scales are evaluated using a common set of uncertainties [42,47], and are typically negligible ($\lesssim$1%) except at high $p_T^{\rm ch}$. Those associated with lepton trigger and selection efficiency determination are smaller than the ones related to the energy scale. Several sources of tracking-related uncertainty are considered, which are described in previous measurements of charged-particle fragmentation functions, and of which the largest is the sensitivity to the track selection criteria, which is 2%–3% [6,48].

The uncertainty in the determination of the UE background yield is evaluated by propagating the statistical uncertainty of the UE estimation in MB events. The sensitivity of the UE estimation to the matching criteria for the elliptic flow [27] angles between signal and MB events, or the additional requirement to match the triangular flow angles, are investigated. However, since these variations give statistically compatible results, they are not included. As a check of the background subtraction procedure, the full analysis is performed on simulated $Z$ events overlaid with HIJING [49] Pb + Pb background, and compared with the generator-level distributions. An absolute uncertainty in the background estimation of 0.3% is derived using this study.

Finally, an internal consistency check is performed by comparing the per-$Z$ yields between the electron and muon decay channels. A difference was observed in the $15 < p_T^Z < 30$ GeV selections and was included as an uncertainty of at most 4% in $pp$ and 14% in central Pb + Pb events.

For the yields at low $p_T^{\rm ch}$ and in central events, the uncertainty from the UE determination is dominant and can be as large as 30%. For yields at high $p_T^{\rm ch}$ and in lower-multiplicity events, the uncertainties associated with the track selection and the lepton energy scale are typically dominant, and as large as 5%. Uncertainty sources common to Pb + Pb and $pp$ are canceled in the $I_{\rm AA}$ ratio when possible, such that the resulting measurement is dominated by uncertainties specific to Pb + Pb events. In all cases, the statistical uncertainty in the $I_{\rm AA}$ is larger than the total systematic uncertainty.

Figure 1 presents the charged-particle yield per $Z$ boson, in Pb + Pb and $pp$ events, as a function of $p_T^{\rm ch}$, for the selection $\Delta\phi > 3\pi/4$. The yields in Pb + Pb collisions are observed to be modified relative to those in $pp$ collisions.

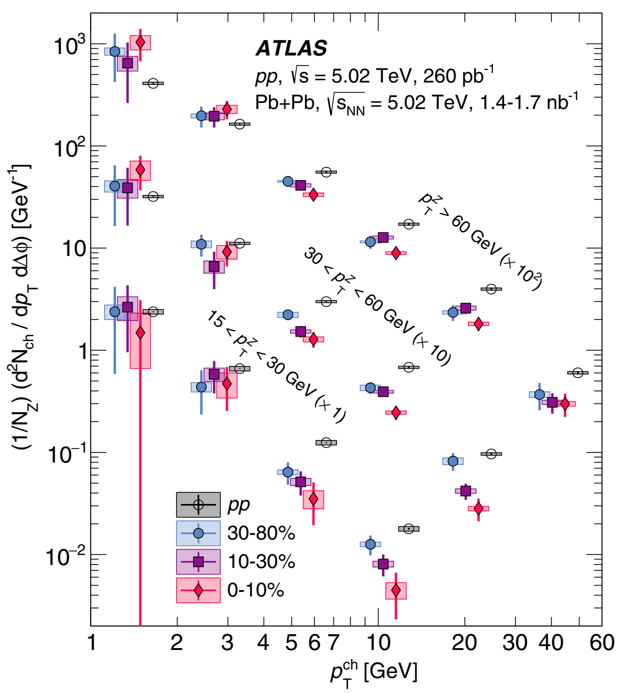


FIG. 1. Charged-particle yield per $Z$ boson as a function of $p_T^{\rm ch}$, for the selection $\Delta\phi > 3\pi/4$, reported for $15 < p_T^Z < 30$ GeV, $30 < p_T^Z < 60$ GeV, and $p_T^Z > 60$ GeV. Results are shown for $pp$ events and the three centralities of Pb + Pb events. These are offset horizontally around the bin centers, which are located between the 0%–10% and 10%–30% points, for visibility. The vertical bars and boxes correspond to the statistical and systematic uncertainties of the data.

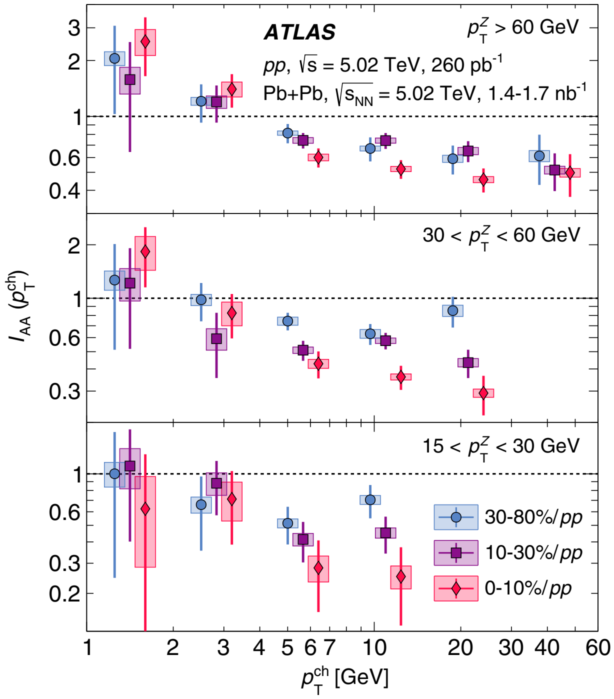


FIG. 2. Ratio of the charged-particle yield in Pb + Pb collisions to that in $pp$ collisions, $I_{AA}$, as a function of charged-particle $p_T^{ch}$, for the selection $\Delta\phi > 3\pi/4$. The vertical bars and boxes correspond to the statistical and systematic uncertainties of the data. The 0%–10% and 30%–80% data are offset horizontally for visibility.

To better reveal the modification, Fig. 2 presents $I_{AA}$ values, the ratios of yields in Pb + Pb events to those in $pp$ events. The $I_{AA}$ values are suppressed below unity at large $p_T^{ch}$, with a systematically larger suppression in more central events and for lower $p_T^Z$ selections. For $p_T^Z > 60$ GeV, the $I_{AA}$ values at low $p_T^{ch}$, less than 2–3 GeV, are significantly different than those at high $p_T^{ch}$, and typically greater than unity. Lower $p_T^Z$ selections are compatible with a similar increase at low $p_T^{ch}$, although the uncertainties limit the significance of this enhancement. The suppression over a wide range of $p_T^{ch}$ values, and the general enhancement of the $I_{AA}$ above unity at lower $p_T^{ch}$, are qualitatively similar to those observed in the ratios of jet fragmentation functions in photon-tagged events [12].

Figure 3 compares the $I_{AA}$ in 0%–10% Pb + Pb events with the following theoretical calculations, where available, which use the same kinematic selections as the data: (1) a perturbative calculation within the framework of soft-collinear effective field theory with Glauber gluons (SCET$_G$) in the soft-gluon-emission (energy-loss) limit, with jet-medium coupling $g = 2.0 \pm 0.2$ [50,51]; (2) the Hybrid Strong/Weak Coupling model [52], which combines initial production using PYTHIA 8 with a parameterization of energy loss derived from holographic methods, including backreaction effects; (3) JEWEL, an MC event generator which simulates QCD jet evolution in heavy-ion collisions, including radiative and elastic energy loss processes, and configured to include medium recoils [53]; and (4) a coupled linearized Boltzmann transport (COLBT) and hydrodynamics model [54,55], which includes jet-induced medium excitations. All models qualitatively reproduce the degree of suppression at large $p_T^{ch}$, greater than 10 GeV. The Hybrid model, JEWEL and COLBT qualitatively capture the increase at low $p_T^{ch}$. For these three models, removing the backreaction, medium recoils, and jet-induced medium excitations, respectively, results in a significant underprediction of the data in this region. Several of these models also capture the relative difference in the $I_{AA}$ between the three $p_T^Z$ selections. A full evaluation of theoretical uncertainties is needed to further discriminate between the mechanisms of energy loss and medium response in the data.

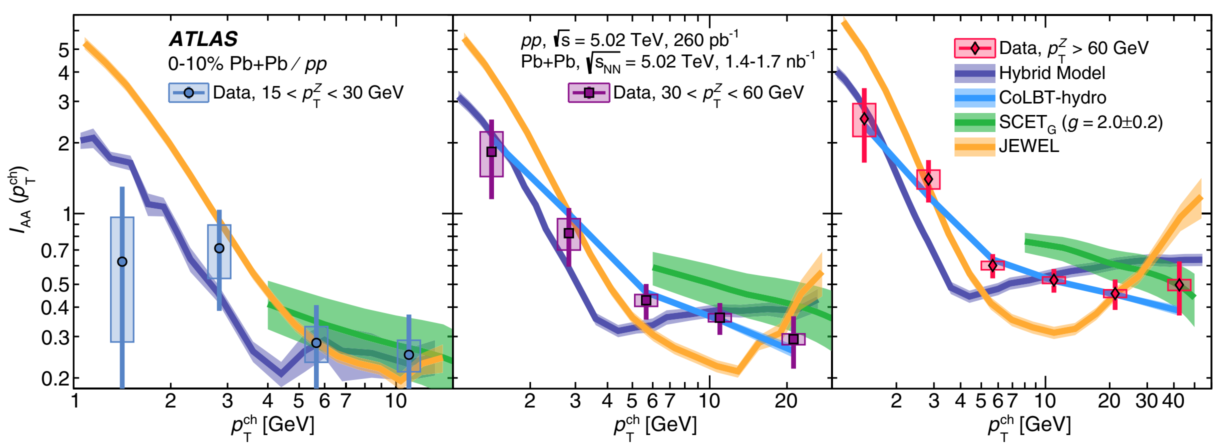


FIG. 3. The $I_{AA}$ ratio as a function of $p_T^{ch}$ in data compared with theoretical calculations (see text), for the selection $\Delta\phi > 3\pi/4$. The vertical bars and boxes correspond to the statistical and systematic uncertainties, while the shaded bands represent the theoretical uncertainty (statistical for JEWEL, Hybrid, and COLBT-hydro, parametric for SCET$_G$). The $I_{AA}$ is shown for 0%–10% Pb + Pb events for $p_T^Z = 15$–30 GeV (left), 30–60 GeV (center), and > 60 GeV (right).

In conclusion, this Letter presents a measurement of charged-particle yields produced in the azimuthal direction opposite to a $Z$ boson with $p_T > 15$ GeV. The measurement is performed using 260 pb$^{-1}$ of $pp$ and up to 1.7 nb$^{-1}$ of Pb + Pb collision data at 5.02 TeV with the ATLAS detector at the Large Hadron Collider. The per-$Z$ yields are systematically modified in Pb + Pb collisions compared with $pp$ collisions due to the interactions between the parton shower and the hot and dense QGP medium. The charged-particle $p_T$ distribution in Pb + Pb collisions is softer than that in $pp$ collisions, with a suppression at high $p_T^{\mathrm{ch}}$ and an enhancement at low $p_T^{\mathrm{ch}}$. The degree of modification varies with Pb + Pb event centrality, consistent with a larger and hotter QGP being created in more central events. At high $p_T^Z$, the modification pattern is qualitatively similar to that observed in measurements of photon-tagged jet fragmentation functions. In addition to the particular theoretical comparisons presented here, the data will allow systematic tests of models across centrality and $p_T^Z$ selections. The data can also test energy loss models for low-$p_T$ partons that are otherwise difficult to access experimentally at the LHC, but which are valuable for direct comparison to future measurements at RHIC.

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[1] W. Busza, K. Rajagopal, and W. van der Schee, Heavy ion collisions: The big picture and the big questions, Annu. Rev. Nucl. Part. Sci. **68**, 339 (2018).

[2] ATLAS Collaboration, Measurement of jet $p_T$ correlations in Pb + Pb and $pp$ collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV with the ATLAS detector, Phys. Lett. B **774**, 379 (2017).

[3] CMS Collaboration, Jet momentum dependence of jet quenching in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B **712**, 176 (2012).

[4] ATLAS Collaboration, Measurement of photon-jet transverse momentum correlations in 5.02 TeV Pb + Pb and $pp$ collisions with ATLAS, Phys. Lett. B **789**, 167 (2019).

[5] CMS Collaboration, Study of jet quenching with isolated-photon+jet correlations in PbPb and pp collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, Phys. Lett. B **785**, 14 (2018).

[6] ATLAS Collaboration, Measurement of jet fragmentation in Pb + Pb and $pp$ collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with the ATLAS detector, Phys. Rev. C **98**, 024908 (2018).

[7] CMS Collaboration, Measurement of jet fragmentation in PbPb and $pp$ collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV, Phys. Rev. C **90**, 024908 (2014).

[8] ATLAS Collaboration, Measurement of $Z$ Boson Production in Pb-Pb Collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV with the ATLAS Detector, Phys. Rev. Lett. **110**, 022301 (2013).

[9] ATLAS Collaboration, $Z$ boson production in Pb + Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV measured by the ATLAS experiment, Phys. Lett. B **802**, 135262 (2020).

[10] V. Kartvelishvili, R. Kvatadze, and R. Shanidze, On Z and Z + jet production in heavy ion collisions, Phys. Lett. B **356**, 589 (1995).

[11] R. B. Neufeld and I. Vitev, $Z^0$-Tagged Jet Event Asymmetry in Heavy-Ion Collisions at the CERN Large Hadron Collider, Phys. Rev. Lett. **108**, 242001 (2012).

[12] ATLAS Collaboration, Comparison of Fragmentation Functions for Jets Dominated by Light Quarks and Gluons from $pp$ and Pb + Pb Collisions in ATLAS, Phys. Rev. Lett. **123**, 042001 (2019).

[13] CMS Collaboration, Observation of Medium-Induced Modifications of Jet Fragmentation in Pb-Pb Collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV Using Isolated Photon-Tagged Jets, Phys. Rev. Lett. **121**, 242301 (2018).

[14] PHENIX Collaboration, Medium Modification of Jet Fragmentation in Au + Au Collisions at $\sqrt{s_{NN}} = 200$ GeV Measured in Direct Photon-Hadron Correlations, Phys. Rev. Lett. **111**, 032301 (2013).
[15] STAR Collaboration, Jet-like correlations with direct-photon and neutral-pion triggers at $\sqrt{s_{NN}} = 200$ GeV, Phys. Lett. B **760**, 689 (2016).
[16] CMS Collaboration, Study of Jet Quenching with $Z+\mathrm{jet}$ Correlations in Pb-Pb and $pp$ Collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, Phys. Rev. Lett. **119**, 082301 (2017).
[17] 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. Cylindrical coordinates $(r, \phi)$ are used in the transverse plane, $\phi$ being the azimuthal angle around the $z$ axis. The pseudorapidity is defined in terms of the polar angle $\theta$ as $\eta = -\ln\tan(\theta/2)$.
[18] STAR Collaboration, Experimental studies of di-jet survival and surface emission bias in Au + Au collisions via angular correlations with respect to back-to-back leading hadrons, Phys. Rev. C **83** (2011) 061901.
[19] T. Renk, Biased showers: A common conceptual framework for the interpretation of high-$P_T$ observables in heavy-ion collisions, Phys. Rev. C **88**, 054902 (2013).
[20] J. G. Milhano and K. C. Zapp, Origins of the di-jet asymmetry in heavy-ion collisions, Eur. Phys. J. C **76**, 288 (2016).
[21] ATLAS Collaboration, The ATLAS experiment at the CERN large hadron collider, J. Instrum. **3**, S08003 (2008).
[22] ATLAS Collaboration, ATLAS insertable B-layer technical design report, CERN Report No. ATLAS-TDR-19, 2010, https://cds.cern.ch/record/1291633.
[23] B. Abbott *et al.*, Production and integration of the ATLAS insertable B-layer, J. Instrum. **13**, T05008 (2018).
[24] ATLAS Collaboration, Performance of the ATLAS trigger system in 2015, Eur. Phys. J. C **77**, 317 (2017).
[25] ATLAS Collaboration, Performance of electron and photon triggers in ATLAS during LHC Run 2, Eur. Phys. J. C **80**, 47 (2020).
[26] ATLAS Collaboration, Prompt and non-prompt $J/\psi$ and $\psi(2S)$ suppression at high transverse momentum in 5.02 TeV Pb + Pb collisions with the ATLAS experiment, Eur. Phys. J. C **78**, 762 (2018).
[27] ATLAS Collaboration, Measurement of the azimuthal anisotropy of charged particles produced in $\sqrt{s_{\mathrm{NN}}} =$ 5.02 TeV Pb + Pb collisions with the ATLAS detector, Eur. Phys. J. C **78**, 997 (2018).
[28] ATLAS Collaboration, Measurement of azimuthal anisotropy of muons from charm and bottom hadrons in Pb + Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the ATLAS detector, Phys. Lett. B **807** (2020) 135595.
[29] ATLAS Collaboration, Track reconstruction performance of the ATLAS inner detector at $\sqrt{s} = 13$ TeV, CERN Report No. ATL-PHYS-PUB-2015-018, 2015, https://cds.cern.ch/record/2037683.
[30] S. Agostinelli *et al.*, GEANT4—A simulation toolkit, Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).
[31] ATLAS Collaboration, The ATLAS simulation infrastructure, Eur. Phys. J. C **70**, 823 (2010).
[32] P. Nason, A new method for combining NLO QCD with shower Monte Carlo algorithms, J. High Energy Phys. 11 (2004) 040.
[33] S. Frixione, P. Nason, and C. Oleari, Matching NLO QCD computations with parton shower simulations: The POWHEG method, J. High Energy Phys. 11 (2007) 070.
[34] S. Alioli, P. Nason, C. Oleari, and E. Re, NLO vector-boson production matched with shower in POWHEG, J. High Energy Phys. 07 (2008) 060.
[35] S. Alioli, P. Nason, C. Oleari, and E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: The POWHEG BOX, J. High Energy Phys. 06 (2010) 043.
[36] T. Sjöstrand, S. Mrenna, and P. Z. Skands, A brief introduction to PYTHIA 8.1, Comput. Phys. Commun. **178**, 852 (2008).
[37] H.-L. Lai, M. Guzzi, J. Huston, Z. Li, P. M. Nadolsky, J. Pumplin, and C. P. Yuan, New parton distributions for collider physics, Phys. Rev. D **82**, 074024 (2010).
[38] J. Pumplin, D. R. Stump, J. Huston, H.-L. Lai, P. Nadolsky, and W.-K. Tung, New generation of parton distributions with uncertainties from global QCD analysis, J. High Energy Phys. 07 (2002) 012.
[39] ATLAS Collaboration, Measurement of the $Z/\gamma^*$ boson transverse momentum distribution in $pp$ collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector, J. High Energy Phys. 09 (2014) 145.
[40] ATLAS Collaboration, Measurements of $W$ and $Z$ boson production in $pp$ collisions at $\sqrt{s} = 5.02$ TeV with the ATLAS detector, Eur. Phys. J. C **79**, 128 (2019); , Erratum, Eur. Phys. J. C **79**, 374 (2019).
[41] ATLAS Collaboration, Electron reconstruction and identification in the ATLAS experiment using the 2015 and 2016 LHC proton-proton collision data at $\sqrt{s} = 13$ TeV, Eur. Phys. J. C **79**, 639 (2019).
[42] ATLAS Collaboration, Muon reconstruction performance of the ATLAS detector in proton-proton collision data at $\sqrt{s} = 13$ TeV, Eur. Phys. J. C **76**, 292 (2016).
[43] ATLAS Collaboration, Performance of the ATLAS track reconstruction algorithms in dense environments in LHC Run 2, Eur. Phys. J. C **77**, 673 (2017).
[44] ATLAS Collaboration, Measurement of charged-particle spectra in Pb + Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV with the ATLAS detector at the LHC, J. High Energy Phys. 09 (2015) 050.
[45] CMS Collaboration, Measurement of the underlying event activity in inclusive $Z$ boson production in proton-proton collisions at $\sqrt{s} = 13$ TeV, J. High Energy Phys. 07 (2018) 032.
[46] ATLAS Collaboration, Measurement of distributions sensitive to the underlying event in inclusive $Z$ boson production in $pp$ collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Eur. Phys. J. C **79**, 666 (2019).
[47] ATLAS Collaboration, Electron and photon performance measurements with the ATLAS detector using the 2015–2017 LHC proton-proton collision data, J. Instrum. **14**, P12006 (2019).
[48] ATLAS Collaboration, Study of the material of the ATLAS inner detector for Run 2 of the LHC, J. Instrum. **12**, P12009 (2017).

[49] M. Gyulassy and X.-N. Wang, HIJING 1.0: A Monte Carlo program for parton and particle production in high-energy hadronic and nuclear collisions, Comput. Phys. Commun. **83**, 307 (1994).
[50] Y.-T. Chien, A. Emerman, Z.-B. Kang, G. Ovanesyan, and I. Vitev, Jet quenching from QCD evolution, Phys. Rev. D **93**, 074030 (2016).
[51] H. T. Li and I. Vitev, Jet charge modification in finite QCD matter, Phys. Rev. D **101**, 076020 (2020).
[52] J. Casalderrey-Solana, D. C. Gulhan, J. G. Milhano, D. Pablos, and K. Rajagopal, Predictions for boson-jet observables and fragmentation function ratios from a hybrid strong/weak coupling model for jet quenching, J. High Energy Phys. 03 (2016) 053.
[53] R. Kunnawalkam Elayavalli and K. C. Zapp, Simulating V + jet processes in heavy ion collisions with JEWEL, Eur. Phys. J. C **76**, 695 (2016).
[54] W. Chen, S. Cao, T. Luo, L.-G. Pang, and X.-N. Wang, Effects of jet-induced medium excitation in $\gamma$-hadron correlation in A + A collisions, Phys. Lett. B **777**, 86 (2018).
[55] W. Chen, S. Cao, T. Luo, L.-G. Pang, and X.-N. Wang, Medium modification of $\gamma$-jet fragmentation functions in Pb + Pb collisions at LHC, Phys. Lett. B **810**, 135783 (2020).
[56] ATLAS Collaboration, ATLAS computing acknowledgements, CERN Report No. ATL-SOFT-PUB-2020-001, 2020, https://cds.cern.ch/record/2717821.

G. Aad,[102] B. Abbott,[128] D. C. Abbott,[103] A. Abed Abud,[36] K. Abeling,[53] D. K. Abhayasinghe,[94] S. H. Abidi,[167] O. S. AbouZeid,[40] N. L. Abraham,[156] H. Abramowicz,[161] H. Abreu,[160] Y. Abulaiti,[6] B. S. Acharya,[67a,67b,b] B. Achkar,[53] L. Adam,[100] C. Adam Bourdarios,[5] L. Adamczyk,[84a] L. Adamek,[167] J. Adelman,[121] M. Adersberger,[114] A. Adiguzel,[12c] S. Adorni,[54] T. Adye,[143] A. A. Affolder,[145] Y. Afik,[160] C. Agapopoulou,[65] M. N. Agaras,[38] A. Aggarwal,[119] C. Agheorghiesei,[28c] J. A. Aguilar-Saavedra,[139f,139a,c] A. Ahmad,[36] F. Ahmadov,[80] W. S. Ahmed,[104] X. Ai,[18] G. Aielli,[74a,74b] S. Akatsuka,[86] M. Akbiyik,[100] T. P. A. Åkesson,[97] E. Akilli,[54] A. V. Akimov,[111] K. Al Khoury,[65] G. L. Alberghi,[23b,23a] J. Albert,[176] M. J. Alconada Verzini,[161] S. Alderweireldt,[36] M. Aleksa,[36] I. N. Aleksandrov,[80] C. Alexa,[28b] T. Alexopoulos,[10] A. Alfonsi,[120] F. Alfonsi,[23b,23a] M. Alhroob,[128] B. Ali,[141] S. Ali,[158] M. Aliev,[166] G. Alimonti,[69a] C. Allaire,[36] B. M. M. Allbrooke,[156] B. W. Allen,[131] P. P. Allport,[21] A. Aloisio,[70a,70b] F. Alonso,[89] C. Alpigiani,[148] E. Alunno Camelia,[74a,74b] M. Alvarez Estevez,[99] M. G. Alviggi,[70a,70b] Y. Amaral Coutinho,[81b] A. Ambler,[104] L. Ambroz,[134] C. Amelung,[36] D. Amidei,[106] S. P. Amor Dos Santos,[139a] S. Amoroso,[46] C. S. Amrouche,[54] F. An,[79] C. Anastopoulos,[149] N. Andari,[144] T. Andeen,[11] J. K. Anders,[20] S. Y. Andrean,[45a,45b] A. Andreazza,[69a,69b] V. Andrei,[61a] C. R. Anelli,[176] S. Angelidakis,[9] A. Angerami,[39] A. V. Anisenkov,[122b,122a] A. Annovi,[72a] C. Antel,[54] M. T. Anthony,[149] E. Antipov,[129] M. Antonelli,[51] D. J. A. Antrim,[18] F. Anulli,[73a] M. Aoki,[82] J. A. Aparisi Pozo,[174] M. A. Aparo,[156] L. Aperio Bella,[46] N. Aranzabal,[36] V. Araujo Ferraz,[81a] R. Araujo Pereira,[81b] C. Arcangeletti,[51] A. T. H. Arce,[49] F. A. Arduh,[89] J-F. Arguin,[110] S. Argyropoulos,[52] J.-H. Arling,[46] A. J. Armbruster,[36] A. Armstrong,[171] O. Arnaez,[167] H. Arnold,[120] Z. P. Arrubarrena Tame,[114] G. Artoni,[134] H. Asada,[117] K. Asai,[126] S. Asai,[163] T. Asawatavonvanich,[165] N. Asbah,[59] E. M. Asimakopoulou,[172] L. Asquith,[156] J. Assahsah,[35d] K. Assamagan,[26b] R. Astalos,[29a] R. J. Atkin,[33a] M. Atkinson,[173] N. B. Atlay,[19] H. Atmani,[65] P. A. Atmasiddha,[106] K. Augsten,[141] V. A. Austrup,[182] G. Avolio,[36] M. K. Ayoub,[15a] G. Azuelos,[110,d] D. Babal,[29a] H. Bachacou,[144] K. Bachas,[162] F. Backman,[45a,45b] P. Bagnaia,[73a,73b] M. Bahmani,[85] H. Bahrasemani,[152] A. J. Bailey,[174] V. R. Bailey,[173] J. T. Baines,[143] C. Bakalis,[10] O. K. Baker,[183] P. J. Bakker,[120] E. Bakos,[16] D. Bakshi Gupta,[8] S. Balaji,[157] R. Balasubramanian,[120] E. M. Baldin,[122b,122a] P. Balek,[180] F. Balli,[144] W. K. Balunas,[134] J. Balz,[100] E. Banas,[85] M. Bandieramonte,[138] A. Bandyopadhyay,[24] Sw. Banerjee,[181,e] L. Barak,[161] W. M. Barbe,[38] E. L. Barberio,[105] D. Barberis,[55b,55a] M. Barbero,[102] G. Barbour,[95] T. Barillari,[115] M-S. Barisits,[36] J. Barkeloo,[131] T. Barklow,[153] R. Barnea,[160] B. M. Barnett,[143] R. M. Barnett,[18] Z. Barnovska-Blenessy,[60a] A. Baroncelli,[60a] G. Barone,[26b] A. J. Barr,[134] L. Barranco Navarro,[45a,45b] F. Barreiro,[99] J. Barreiro Guimarães da Costa,[15a] U. Barron,[161] S. Barsov,[137] F. Bartels,[61a] R. Bartoldus,[153] G. Bartolini,[102] A. E. Barton,[90] P. Bartos,[29a] A. Basalaev,[46] A. Basan,[100] A. Bassalat,[65,f] M. J. Basso,[167] R. L. Bates,[57] S. Batlamous,[35e] J. R. Batley,[32] B. Batool,[151] M. Battaglia,[145] M. Bauce,[73a,73b] F. Bauer,[144] P. Bauer,[24] H. S. Bawa,[31] A. Bayirli,[12c] J. B. Beacham,[49] T. Beau,[135] P. H. Beauchemin,[170] F. Becherer,[52] P. Bechtle,[24] H. C. Beck,[53] H. P. Beck,[20,g] K. Becker,[178] C. Becot,[46] A. Beddall,[12d] A. J. Beddall,[12a] V. A. Bednyakov,[80] M. Bedognetti,[120] C. P. Bee,[155] T. A. Beermann,[182] M. Begalli,[81b] M. Begel,[26b] A. Behera,[155] J. K. Behr,[46] F. Beisiegel,[24] M. Belfkir,[5] A. S. Bell,[95] G. Bella,[161] L. Bellagamba,[23b] A. Bellerive,[34] P. Bellos,[9] K. Beloborodov,[122b,122a] K. Belotskiy,[112] N. L. Belyaev,[112] D. Benchekroun,[35a] N. Benekos,[10] Y. Benhammou,[161] D. P. Benjamin,[6] M. Benoit,[26b] J. R. Bensinger,[27] S. Bentvelsen,[120] L. Beresford,[134] M. Beretta,[51] D. Berge,[19] E. Bergeaas Kuutmann,[172] N. Berger,[5] B. Bergmann,[141]

L. J. Bergsten,[27] J. Beringer,[18] S. Berlendis,[7] G. Bernardi,[135] C. Bernius,[153] F. U. Bernlochner,[24] T. Berry,[94] P. Berta,[100] A. Berthold,[48] I. A. Bertram,[90] O. Bessidskaia Bylund,[182] N. Besson,[144] A. Bethani,[101] S. Bethke,[115] A. Betti,[42] A. J. Bevan,[93] J. Beyer,[115] S. Bhatta,[155] D. S. Bhattacharya,[177] P. Bhattarai,[27] V. S. Bhopatkar,[6] R. Bi,[138] R. M. Bianchi,[138] O. Biebel,[114] D. Biedermann,[19] R. Bielski,[36] K. Bierwagen,[100] N. V. Biesuz,[72a,72b] M. Biglietti,[75a] T. R. V. Billoud,[141] M. Bindi,[53] A. Bingul,[12d] C. Bini,[73a,73b] S. Biondi,[23b,23a] C. J. Birch-sykes,[101] M. Birman,[180] T. Bisanz,[36] J. P. Biswal,[3] D. Biswas,[181,e] A. Bitadze,[101] C. Bittrich,[48] K. Bjørke,[133] T. Blazek,[29a] I. Bloch,[46] C. Blocker,[27] A. Blue,[57] U. Blumenschein,[93] G. J. Bobbink,[120] V. S. Bobrovnikov,[122b,122a] S. S. Bocchetta,[97] D. Bogavac,[14] A. G. Bogdanchikov,[122b,122a] C. Bohm,[45a] V. Boisvert,[94] P. Bokan,[172,53] T. Bold,[84a] A. E. Bolz,[61b] M. Bomben,[135] M. Bona,[93] J. S. Bonilla,[131] M. Boonekamp,[144] C. D. Booth,[94] A. G. Borbély,[57] H. M. Borecka-Bielska,[91] L. S. Borgna,[95] A. Borisov,[123] G. Borissov,[90] D. Bortoletto,[134] D. Boscherini,[23b] M. Bosman,[14] J. D. Bossio Sola,[104] K. Bouaouda,[35a] J. Boudreau,[138] E. V. Bouhova-Thacker,[90] D. Boumediene,[38] A. Boveia,[127] J. Boyd,[36] D. Boye,[33c] I. R. Boyko,[80] A. J. Bozson,[94] J. Bracinik,[21] N. Brahimi,[60d] G. Brandt,[182] O. Brandt,[32] F. Braren,[46] B. Brau,[103] J. E. Brau,[131] W. D. Breaden Madden,[57] K. Brendlinger,[46] R. Brener,[160] L. Brenner,[36] R. Brenner,[172] S. Bressler,[180] B. Brickwedde,[100] D. L. Briglin,[21] D. Britton,[57] D. Britzger,[115] I. Brock,[24] R. Brock,[107] G. Brooijmans,[39] W. K. Brooks,[146d] E. Brost,[26b] P. A. Bruckman de Renstrom,[85] B. Brüers,[46] D. Bruncko,[29b] A. Bruni,[23b] G. Bruni,[23b] M. Bruschi,[23b] N. Bruscino,[73a,73b] L. Bryngemark,[153] T. Buanes,[17] Q. Buat,[155] P. Buchholz,[151] A. G. Buckley,[57] I. A. Budagov,[80] M. K. Bugge,[133] F. Bührer,[52] O. Bulekov,[112] B. A. Bullard,[59] T. J. Burch,[121] S. Burdin,[91] C. D. Burgard,[120] A. M. Burger,[129] B. Burghgrave,[8] J. T. P. Burr,[46] C. D. Burton,[11] J. C. Burzynski,[103] V. Büscher,[100] E. Buschmann,[53] P. J. Bussey,[57] J. M. Butler,[25] C. M. Buttar,[57] J. M. Butterworth,[95] P. Butti,[36] W. Buttinger,[143] C. J. Buxo Vazquez,[107] A. Buzatu,[158] A. R. Buzykaev,[122b,122a] G. Cabras,[23b,23a] S. Cabrera Urbán,[174] D. Caforio,[56] H. Cai,[138] V. M. M. Cairo,[153] O. Cakir,[4a] N. Calace,[36] P. Calafiura,[18] G. Calderini,[135] P. Calfayan,[66] G. Callea,[57] L. P. Caloba,[81b] A. Caltabiano,[74a,74b] S. Calvente Lopez,[99] D. Calvet,[38] S. Calvet,[38] T. P. Calvet,[102] M. Calvetti,[72a,72b] R. Camacho Toro,[135] S. Camarda,[36] D. Camarero Munoz,[99] P. Camarri,[74a,74b] M. T. Camerlingo,[75a,75b] D. Cameron,[133] C. Camincher,[36] S. Campana,[36] M. Campanelli,[95] A. Camplani,[40] V. Canale,[70a,70b] A. Canesse,[104] M. Cano Bret,[78] J. Cantero,[129] T. Cao,[161] Y. Cao,[173] M. D. M. Capeans Garrido,[36] M. Capua,[41b,41a] R. Cardarelli,[74a] F. Cardillo,[174] G. Carducci,[41b,41a] I. Carli,[142] T. Carli,[36] G. Carlino,[70a] B. T. Carlson,[138] E. M. Carlson,[176,168a] L. Carminati,[69a,69b] R. M. D. Carney,[153] S. Caron,[119] E. Carquin,[146d] S. Carrá,[46] G. Carratta,[23b,23a] J. W. S. Carter,[167] T. M. Carter,[50] M. P. Casado,[14,h] A. F. Casha,[167] E. G. Castiglia,[183] F. L. Castillo,[174] L. Castillo Garcia,[14] V. Castillo Gimenez,[174] N. F. Castro,[139a,139e] A. Catinaccio,[36] J. R. Catmore,[133] A. Cattai,[36] V. Cavaliere,[26b] V. Cavasinni,[72a,72b] E. Celebi,[12b] F. Celli,[134] K. Cerny,[130] A. S. Cerqueira,[81a] A. Cerri,[156] L. Cerrito,[74a,74b] F. Cerutti,[18] A. Cervelli,[23b,23a] S. A. Cetin,[12b] Z. Chadi,[35a] D. Chakraborty,[121] J. Chan,[181] W. S. Chan,[120] W. Y. Chan,[91] J. D. Chapman,[32] B. Chargeishvili,[159b] D. G. Charlton,[21] T. P. Charman,[93] M. Chatterjee,[20] C. C. Chau,[34] S. Che,[127] S. Chekanov,[6] S. V. Chekulaev,[168a] G. A. Chelkov,[80,i] B. Chen,[79] C. Chen,[60a] C. H. Chen,[79] H. Chen,[15c] H. Chen,[26b] J. Chen,[60a] J. Chen,[39] J. Chen,[27] S. Chen,[136] S. J. Chen,[15c] X. Chen,[15b] Y. Chen,[60a] Y-H. Chen,[46] H. C. Cheng,[63a] H. J. Cheng,[15a] A. Cheplakov,[80] E. Cheremushkina,[123] R. Cherkaoui El Moursli,[35e] E. Cheu,[7] K. Cheung,[64] T. J. A. Chevalérias,[144] L. Chevalier,[144] V. Chiarella,[51] G. Chiarelli,[72a] G. Chiodini,[68a] A. S. Chisholm,[21] A. Chitan,[28b] I. Chiu,[163] Y. H. Chiu,[176] M. V. Chizhov,[80] K. Choi,[11] A. R. Chomont,[73a,73b] Y. Chou,[103] Y. S. Chow,[120] L. D. Christopher,[33e] M. C. Chu,[63a] X. Chu,[15a,15d] J. Chudoba,[140] J. J. Chwastowski,[85] L. Chytka,[130] D. Cieri,[115] K. M. Ciesla,[85] V. Cindro,[92] I. A. Cioară,[28b] A. Ciocio,[18] F. Cirotto,[70a,70b] Z. H. Citron,[180,j] M. Citterio,[69a] D. A. Ciubotaru,[28b] B. M. Ciungu,[167] A. Clark,[54] P. J. Clark,[50] S. E. Clawson,[101] C. Clement,[45a,45b] Y. Coadou,[102] M. Cobal,[67a,67c] A. Coccaro,[55b] J. Cochran,[79] R. Coelho Lopes De Sa,[103] H. Cohen,[161] A. E. C. Coimbra,[36] B. Cole,[39] A. P. Colijn,[120] J. Collot,[58] P. Conde Muiño,[139a,139h] S. H. Connell,[33c] I. A. Connelly,[57] S. Constantinescu,[28b] F. Conventi,[70a,k] A. M. Cooper-Sarkar,[134] F. Cormier,[175] K. J. R. Cormier,[167] L. D. Corpe,[95] M. Corradi,[73a,73b] E. E. Corrigan,[97] F. Corriveau,[104,l] M. J. Costa,[174] F. Costanza,[5] D. Costanzo,[149] G. Cowan,[94] J. W. Cowley,[32] J. Crane,[101] K. Cranmer,[125] R. A. Creager,[136] S. Crépé-Renaudin,[58] F. Crescioli,[135] M. Cristinziani,[24] V. Croft,[170] G. Crosetti,[41b,41a] A. Cueto,[5] T. Cuhadar Donszelmann,[171] H. Cui,[15a,15d] A. R. Cukierman,[153] W. R. Cunningham,[57] S. Czekierda,[85] P. Czodrowski,[36] M. M. Czurylo,[61b] M. J. Da Cunha Sargedas De Sousa,[60b] J. V. Da Fonseca Pinto,[81b] C. Da Via,[101] W. Dabrowski,[84a] F. Dachs,[36] T. Dado,[47] S. Dahbi,[33e] T. Dai,[106] C. Dallapiccola,[103] M. Dam,[40] G. D'amen,[26b] V. D'Amico,[75a,75b] J. Damp,[100] J. R. Dandoy,[136] M. F. Daneri,[30] M. Danninger,[152] V. Dao,[36] G. Darbo,[55b] O. Dartsi,[5] A. Dattagupta,[131] T. Daubney,[46] S. D'Auria,[69a,69b] C. David,[168b] T. Davidek,[142] D. R. Davis,[49] I. Dawson,[149] K. De,[8] R. De Asmundis,[70a] M. De Beurs,[120] S. De Castro,[23b,23a] N. De Groot,[119] P. de Jong,[120]

H. De la Torre,[107] A. De Maria,[15c] D. De Pedis,[73a] A. De Salvo,[73a] U. De Sanctis,[74a,74b] M. De Santis,[74a,74b] A. De Santo,[156] J. B. De Vivie De Regie,[65] D. V. Dedovich,[80] A. M. Deiana,[42] J. Del Peso,[99] Y. Delabat Diaz,[46] D. Delgove,[65] F. Deliot,[144] C. M. Delitzsch,[7] M. Della Pietra,[70a,70b] D. Della Volpe,[54] A. Dell'Acqua,[36] L. Dell'Asta,[74a,74b] M. Delmastro,[5] C. Delporte,[65] P. A. Delsart,[58] S. Demers,[183] M. Demichev,[80] G. Demontigny,[110] S. P. Denisov,[123] L. D'Eramo,[121] D. Derendarz,[85] J. E. Derkaoui,[35d] F. Derue,[135] P. Dervan,[91] K. Desch,[24] K. Dette,[167] C. Deutsch,[24] M. R. Devesa,[30] P. O. Deviveiros,[36] F. A. Di Bello,[73a,73b] A. Di Ciaccio,[74a,74b] L. Di Ciaccio,[5] W. K. Di Clemente,[136] C. Di Donato,[70a,70b] A. Di Girolamo,[36] G. Di Gregorio,[72a,72b] A. Di Luca,[76a,76b] B. Di Micco,[75a,75b] R. Di Nardo,[75a,75b] K. F. Di Petrillo,[59] R. Di Sipio,[167] C. Diaconu,[102] F. A. Dias,[120] T. Dias Do Vale,[139a] M. A. Diaz,[146a] F. G. Diaz Capriles,[24] J. Dickinson,[18] M. Didenko,[166] E. B. Diehl,[106] J. Dietrich,[19] S. Díez Cornell,[46] C. Diez Pardos,[151] A. Dimitrievska,[18] W. Ding,[15b] J. Dingfelder,[24] S. J. Dittmeier,[61b] F. Dittus,[36] F. Djama,[102] T. Djobava,[159b] J. I. Djuvsland,[17] M. A. B. Do Vale,[147] M. Dobre,[28b] D. Dodsworth,[27] C. Doglioni,[97] J. Dolejsi,[142] Z. Dolezal,[142] M. Donadelli,[81c] B. Dong,[60c] J. Donini,[38] A. D'onofrio,[15c] M. D'Onofrio,[91] J. Dopke,[143] A. Doria,[70a] M. T. Dova,[89] A. T. Doyle,[57] E. Drechsler,[152] E. Dreyer,[152] T. Dreyer,[53] A. S. Drobac,[170] D. Du,[60b] T. A. du Pree,[120] Y. Duan,[60d] F. Dubinin,[111] M. Dubovsky,[29a] A. Dubreuil,[54] E. Duchovni,[180] G. Duckeck,[114] O. A. Ducu,[36] D. Duda,[115] A. Dudarev,[36] A. C. Dudder,[100] E. M. Duffield,[18] M. D'uffizi,[101] L. Duflot,[65] M. Dührssen,[36] C. Dülsen,[182] M. Dumancic,[180] A. E. Dumitriu,[28b] M. Dunford,[61a] S. Dungs,[47] A. Duperrin,[102] H. Duran Yildiz,[4a] M. Düren,[56] A. Durglishvili,[159b] D. Duschinger,[48] B. Dutta,[46] D. Duvnjak,[1] G. I. Dyckes,[136] M. Dyndal,[36] S. Dysch,[101] B. S. Dziedzic,[85] M. G. Eggleston,[49] T. Eifert,[8] G. Eigen,[17] K. Einsweiler,[18] T. Ekelof,[172] H. El Jarrari,[35e] V. Ellajosyula,[172] M. Ellert,[172] F. Ellinghaus,[182] A. A. Elliot,[93] N. Ellis,[36] J. Elmsheuser,[26b] M. Elsing,[36] D. Emeliyanov,[143] A. Emerman,[39] Y. Enari,[163] M. B. Epland,[49] J. Erdmann,[47] A. Ereditato,[20] P. A. Erland,[85] M. Errenst,[182] M. Escalier,[65] C. Escobar,[174] O. Estrada Pastor,[174] E. Etzion,[161] G. E. Evans,[139a] H. Evans,[66] M. O. Evans,[156] A. Ezhilov,[137] F. Fabbri,[57] L. Fabbri,[23b,23a] V. Fabiani,[119] G. Facini,[178] R. M. Fakhrutdinov,[123] S. Falciano,[73a] P. J. Falke,[24] S. Falke,[36] J. Faltova,[142] Y. Fang,[15a] Y. Fang,[15a] G. Fanourakis,[44] M. Fanti,[69a,69b] M. Faraj,[67a,67c] A. Farbin,[8] A. Farilla,[75a] E. M. Farina,[71a,71b] T. Farooque,[107] S. M. Farrington,[50] P. Farthouat,[36] F. Fassi,[35e] P. Fassnacht,[36] D. Fassouliotis,[9] M. Faucci Giannelli,[50] W. J. Fawcett,[32] L. Fayard,[65] O. L. Fedin,[137,m] W. Fedorko,[175] A. Fehr,[20] M. Feickert,[173] L. Feligioni,[102] A. Fell,[149] C. Feng,[60b] M. Feng,[49] M. J. Fenton,[171] A. B. Fenyuk,[123] S. W. Ferguson,[43] J. Ferrando,[46] A. Ferrari,[172] P. Ferrari,[120] R. Ferrari,[71a] D. E. Ferreira de Lima,[61b] A. Ferrer,[174] D. Ferrere,[54] C. Ferretti,[106] F. Fiedler,[100] A. Filipčič,[92] F. Filthaut,[119] K. D. Finelli,[25] M. C. N. Fiolhais,[139a,139c,n] L. Fiorini,[174] F. Fischer,[114] J. Fischer,[100] W. C. Fisher,[107] T. Fitschen,[21] I. Fleck,[151] P. Fleischmann,[106] T. Flick,[182] B. M. Flierl,[114] L. Flores,[136] L. R. Flores Castillo,[63a] F. M. Follega,[76a,76b] N. Fomin,[17] J. H. Foo,[167] G. T. Forcolin,[76a,76b] B. C. Forland,[66] A. Formica,[144] F. A. Förster,[14] A. C. Forti,[101] E. Fortin,[102] M. G. Foti,[134] D. Fournier,[65] H. Fox,[90] P. Francavilla,[72a,72b] S. Francescato,[73a,73b] M. Franchini,[23b,23a] S. Franchino,[61a] D. Francis,[36] L. Franco,[5] L. Franconi,[20] M. Franklin,[59] G. Frattari,[73a,73b] A. N. Fray,[93] P. M. Freeman,[21] B. Freund,[110] W. S. Freund,[81b] E. M. Freundlich,[47] D. C. Frizzell,[128] D. Froidevaux,[36] J. A. Frost,[134] M. Fujimoto,[126] C. Fukunaga,[164] E. Fullana Torregrosa,[174] T. Fusayasu,[116] J. Fuster,[174] A. Gabrielli,[23b,23a] A. Gabrielli,[36] S. Gadatsch,[54] P. Gadow,[115] G. Gagliardi,[55b,55a] L. G. Gagnon,[110] G. E. Gallardo,[134] E. J. Gallas,[134] B. J. Gallop,[143] R. Gamboa Goni,[93] K. K. Gan,[127] S. Ganguly,[180] J. Gao,[60a] Y. Gao,[50] Y. S. Gao,[31,o] F. M. Garay Walls,[146a] C. García,[174] J. E. García Navarro,[174] J. A. García Pascual,[15a] C. Garcia-Argos,[52] M. Garcia-Sciveres,[18] R. W. Gardner,[37] N. Garelli,[153] S. Gargiulo,[52] C. A. Garner,[167] V. Garonne,[133] S. J. Gasiorowski,[148] P. Gaspar,[81b] A. Gaudiello,[55b,55a] G. Gaudio,[71a] P. Gauzzi,[73a,73b] I. L. Gavrilenko,[111] A. Gavrilyuk,[124] C. Gay,[175] G. Gaycken,[46] E. N. Gazis,[10] A. A. Geanta,[28b] C. M. Gee,[145] C. N. P. Gee,[143] J. Geisen,[97] M. Geisen,[100] C. Gemme,[55b] M. H. Genest,[58] C. Geng,[106] S. Gentile,[73a,73b] S. George,[94] T. Geralis,[44] L. O. Gerlach,[53] P. Gessinger-Befurt,[100] G. Gessner,[47] S. Ghasemi,[151] M. Ghasemi Bostanabad,[176] M. Ghneimat,[151] A. Ghosh,[65] A. Ghosh,[78] B. Giacobbe,[23b] S. Giagu,[73a,73b] N. Giangiacomi,[23b,23a] P. Giannetti,[72a] A. Giannini,[70a,70b] G. Giannini,[14] S. M. Gibson,[94] M. Gignac,[145] D. T. Gil,[84b] B. J. Gilbert,[39] D. Gillberg,[34] G. Gilles,[182] N. E. K. Gillwald,[46] D. M. Gingrich,[3,d] M. P. Giordani,[67a,67c] P. F. Giraud,[144] G. Giugliarelli,[67a,67c] D. Giugni,[69a] F. Giuli,[74a,74b] S. Gkaitatzis,[162] I. Gkialas,[9,p] E. L. Gkougkousis,[14] P. Gkountoumis,[10] L. K. Gladilin,[113] C. Glasman,[99] J. Glatzer,[14] P. C. F. Glaysher,[46] A. Glazov,[46] G. R. Gledhill,[131] I. Gnesi,[41b,q] M. Goblirsch-Kolb,[27] D. Godin,[110] S. Goldfarb,[105] T. Golling,[54] D. Golubkov,[123] A. Gomes,[139a,139b] R. Goncalves Gama,[53] R. Gonçalo,[139a,139c] G. Gonella,[131] L. Gonella,[21] A. Gongadze,[80] F. Gonnella,[21] J. L. Gonski,[39] S. González de la Hoz,[174] S. Gonzalez Fernandez,[14] R. Gonzalez Lopez,[91] C. Gonzalez Renteria,[18] R. Gonzalez Suarez,[172] S. Gonzalez-Sevilla,[54] G. R. Gonzalvo Rodriguez,[174] L. Goossens,[36] N. A. Gorasia,[21] P. A. Gorbounov,[124] H. A. Gordon,[26b] B. Gorini,[36] E. Gorini,[68a,68b] A. Gorišek,[92] A. T. Goshaw,[49]

M. I. Gostkin,[80] C. A. Gottardo,[119] M. Gouighri,[35b] A. G. Goussiou,[148] N. Govender,[33c] C. Goy,[5] I. Grabowska-Bold,[84a] E. C. Graham,[91] J. Gramling,[171] E. Gramstad,[133] S. Grancagnolo,[19] M. Grandi,[156] V. Gratchev,[137] P. M. Gravila,[28f] F. G. Gravili,[68a,68b] C. Gray,[57] H. M. Gray,[18] C. Grefe,[24] K. Gregersen,[97] I. M. Gregor,[46] P. Grenier,[153] K. Grevtsov,[46] C. Grieco,[14] N. A. Grieser,[128] A. A. Grillo,[145] K. Grimm,[31,r] S. Grinstein,[14,s] J.-F. Grivaz,[65] S. Groh,[100] E. Gross,[180] J. Grosse-Knetter,[53] Z. J. Grout,[95] C. Grud,[106] A. Grummer,[118] J. C. Grundy,[134] L. Guan,[106] W. Guan,[181] C. Gubbels,[175] J. Guenther,[77] A. Guerguichon,[65] J. G. R. Guerrero Rojas,[174] F. Guescini,[115] D. Guest,[77] R. Gugel,[100] A. Guida,[46] T. Guillemin,[5] S. Guindon,[36] J. Guo,[60c] W. Guo,[106] Y. Guo,[60a] Z. Guo,[102] R. Gupta,[46] S. Gurbuz,[12c] G. Gustavino,[128] M. Guth,[52] P. Gutierrez,[128] C. Gutschow,[95] C. Guyot,[144] C. Gwenlan,[134] C. B. Gwilliam,[91] E. S. Haaland,[133] A. Haas,[125] C. Haber,[18] H. K. Hadavand,[8] A. Hadef,[60a] M. Haleem,[177] J. Haley,[129] J. J. Hall,[149] G. Halladjian,[107] G. D. Hallewell,[102] K. Hamano,[176] H. Hamdaoui,[35e] M. Hamer,[24] G. N. Hamity,[50] K. Han,[60a] L. Han,[15c] L. Han,[60a] S. Han,[18] Y. F. Han,[167] K. Hanagaki,[82,t] M. Hance,[145] D. M. Handl,[114] M. D. Hank,[37] R. Hankache,[135] E. Hansen,[97] J. B. Hansen,[40] J. D. Hansen,[40] M. C. Hansen,[24] P. H. Hansen,[40] E. C. Hanson,[101] K. Hara,[169] T. Harenberg,[182] S. Harkusha,[108] P. F. Harrison,[178] N. M. Hartman,[153] N. M. Hartmann,[114] Y. Hasegawa,[150] A. Hasib,[50] S. Hassani,[144] S. Haug,[20] R. Hauser,[107] M. Havranek,[141] C. M. Hawkes,[21] R. J. Hawkings,[36] S. Hayashida,[117] D. Hayden,[107] C. Hayes,[106] R. L. Hayes,[175] C. P. Hays,[134] J. M. Hays,[93] H. S. Hayward,[91] S. J. Haywood,[143] F. He,[60a] Y. He,[165] M. P. Heath,[50] V. Hedberg,[97] A. L. Heggelund,[133] C. Heidegger,[52] K. K. Heidegger,[52] W. D. Heidorn,[79] J. Heilman,[34] S. Heim,[46] T. Heim,[18] B. Heinemann,[46,u] J. G. Heinlein,[136] J. J. Heinrich,[131] L. Heinrich,[36] J. Hejbal,[140] L. Helary,[46] A. Held,[125] S. Hellesund,[133] C. M. Helling,[145] S. Hellman,[45a,45b] C. Helsens,[36] R. C. W. Henderson,[90] L. Henkelmann,[32] A. M. Henriques Correia,[36] H. Herde,[27] Y. Hernández Jiménez,[33e] H. Herr,[100] M. G. Herrmann,[114] T. Herrmann,[48] G. Herten,[52] R. Hertenberger,[114] L. Hervas,[36] T. C. Herwig,[136] G. G. Hesketh,[95] N. P. Hessey,[168a] H. Hibi,[83] S. Higashino,[82] E. Higón-Rodriguez,[174] K. Hildebrand,[37] J. C. Hill,[32] K. K. Hill,[26b] K. H. Hiller,[46] S. J. Hillier,[21] M. Hils,[48] I. Hinchliffe,[18] F. Hinterkeuser,[24] M. Hirose,[132] S. Hirose,[169] D. Hirschbuehl,[182] B. Hiti,[92] O. Hladik,[140] J. Hobbs,[155] R. Hobincu,[28e] N. Hod,[180] M. C. Hodgkinson,[149] A. Hoecker,[36] D. Hohn,[52] D. Hohov,[65] T. Holm,[24] T. R. Holmes,[37] M. Holzbock,[115] L. B. A. H. Hommels,[32] T. M. Hong,[138] J. C. Honig,[52] A. Hönle,[115] B. H. Hooberman,[173] W. H. Hopkins,[6] Y. Horii,[117] P. Horn,[48] L. A. Horyn,[37] S. Hou,[158] A. Hoummada,[35a] J. Howarth,[57] J. Hoya,[89] M. Hrabovsky,[130] J. Hrivnac,[65] A. Hrynevich,[109] T. Hryn'ova,[5] P. J. Hsu,[64] S.-C. Hsu,[148] Q. Hu,[39] S. Hu,[60c] Y. F. Hu,[15a,15d,v] D. P. Huang,[95] X. Huang,[15c] Y. Huang,[60a] Y. Huang,[15a] Z. Hubacek,[141] F. Hubaut,[102] M. Huebner,[24] F. Huegging,[24] T. B. Huffman,[134] M. Huhtinen,[36] R. Hulsken,[58] R. F. H. Hunter,[34] N. Huseynov,[80,w] J. Huston,[107] J. Huth,[59] R. Hyneman,[153] S. Hyrych,[29a] G. Iacobucci,[54] G. Iakovidis,[26b] I. Ibragimov,[151] L. Iconomidou-Fayard,[65] P. Iengo,[36] R. Ignazzi,[40] R. Iguchi,[163] T. Iizawa,[54] Y. Ikegami,[82] M. Ikeno,[82] N. Ilic,[119,167,l] F. Iltzsche,[48] H. Imam,[35a] G. Introzzi,[71a,71b] M. Iodice,[75a] K. Iordanidou,[168a] V. Ippolito,[73a,73b] M. F. Isacson,[172] M. Ishino,[163] W. Islam,[129] C. Issever,[19,46] S. Istin,[160] J. M. Iturbe Ponce,[63a] R. Iuppa,[76a,76b] A. Ivina,[180] J. M. Izen,[43] V. Izzo,[70a] P. Jacka,[140] P. Jackson,[1] R. M. Jacobs,[46] B. P. Jaeger,[152] V. Jain,[2] G. Jäkel,[182] K. B. Jakobi,[100] K. Jakobs,[52] T. Jakoubek,[180] J. Jamieson,[57] K. W. Janas,[84a] R. Jansky,[54] M. Janus,[53] P. A. Janus,[84a] G. Jarlskog,[97] A. E. Jaspan,[91] N. Javadov,[80,w] T. Javůrek,[36] M. Javurkova,[103] F. Jeanneau,[144] L. Jeanty,[131] J. Jejelava,[159a] P. Jenni,[52,x] N. Jeong,[46] S. Jézéquel,[5] J. Jia,[155] Z. Jia,[15c] H. Jiang,[79] Y. Jiang,[60a] Z. Jiang,[153] S. Jiggins,[52] F. A. Jimenez Morales,[38] J. Jimenez Pena,[115] S. Jin,[15c] A. Jinaru,[28b] O. Jinnouchi,[165] H. Jivan,[33e] P. Johansson,[149] K. A. Johns,[7] C. A. Johnson,[66] E. Jones,[178] R. W. L. Jones,[90] S. D. Jones,[156] T. J. Jones,[91] J. Jongmanns,[61a] J. Jovicevic,[36] X. Ju,[18] J. J. Junggeburth,[115] A. Juste Rozas,[14,s] A. Kaczmarska,[85] M. Kado,[73a,73b] H. Kagan,[127] M. Kagan,[153] A. Kahn,[39] C. Kahra,[100] T. Kaji,[179] E. Kajomovitz,[160] C. W. Kalderon,[26b] A. Kaluza,[100] A. Kamenshchikov,[123] M. Kaneda,[163] N. J. Kang,[145] S. Kang,[79] Y. Kano,[117] J. Kanzaki,[82] L. S. Kaplan,[181] D. Kar,[33e] K. Karava,[134] M. J. Kareem,[168b] I. Karkanias,[162] S. N. Karpov,[80] Z. M. Karpova,[80] V. Kartvelishvili,[90] A. N. Karyukhin,[123] E. Kasimi,[162] A. Kastanas,[45a,45b] C. Kato,[60d] J. Katzy,[46] K. Kawade,[150] K. Kawagoe,[88] T. Kawaguchi,[117] T. Kawamoto,[144] G. Kawamura,[53] E. F. Kay,[176] F. I. Kaya,[170] S. Kazakos,[14] V. F. Kazanin,[122b,122a] J. M. Keaveney,[33a] R. Keeler,[176] J. S. Keller,[34] E. Kellermann,[97] D. Kelsey,[156] J. J. Kempster,[21] J. Kendrick,[21] K. E. Kennedy,[39] O. Kepka,[140] S. Kersten,[182] B. P. Kerševan,[92] S. Ketabchi Haghighat,[167] F. Khalil-Zada,[13] M. Khandoga,[144] A. Khanov,[129] A. G. Kharlamov,[122b,122a] T. Kharlamova,[122b,122a] E. E. Khoda,[175] T. J. Khoo,[77] G. Khoriauli,[177] E. Khramov,[80] J. Khubua,[159b] S. Kido,[83] M. Kiehn,[36] E. Kim,[165] Y. K. Kim,[37] N. Kimura,[95] A. Kirchhoff,[53] D. Kirchmeier,[48] J. Kirk,[143] A. E. Kiryunin,[115] T. Kishimoto,[163] D. P. Kisliuk,[167] V. Kitali,[46] C. Kitsaki,[10] O. Kivernyk,[24] T. Klapdor-Kleingrothaus,[52] M. Klassen,[61a] C. Klein,[34] M. H. Klein,[106] M. Klein,[91] U. Klein,[91] K. Kleinknecht,[100] P. Klimek,[36] A. Klimentov,[26b] T. Klingl,[24] T. Klioutchnikova,[36] F. F. Klitzner,[114] P. Kluit,[120] S. Kluth,[115] E. Kneringer,[77] E. B. F. G. Knoops,[102] A. Knue,[52] D. Kobayashi,[88] M. Kobel,[48]

M. Kocian,[153] T. Kodama,[163] P. Kodys,[142] D. M. Koeck,[156] P. T. Koenig,[24] T. Koffas,[34] N. M. Köhler,[36] M. Kolb,[144] I. Koletsou,[5] T. Komarek,[130] T. Kondo,[82] K. Köneke,[52] A. X. Y. Kong,[1] A. C. König,[119] T. Kono,[126] V. Konstantinides,[95] N. Konstantinidis,[95] B. Konya,[97] R. Kopeliansky,[66] S. Koperny,[84a] K. Korcyl,[85] K. Kordas,[162] G. Koren,[161] A. Korn,[95] I. Korolkov,[14] E. V. Korolkova,[149] N. Korotkova,[113] O. Kortner,[115] S. Kortner,[115] V. V. Kostyukhin,[149,166] A. Kotsokechagia,[65] A. Kotwal,[49] A. Koulouris,[10] A. Kourkoumeli-Charalampidi,[71a,71b] C. Kourkoumelis,[9] E. Kourlitis,[6] V. Kouskoura,[26b] R. Kowalewski,[176] W. Kozanecki,[101] A. S. Kozhin,[123] V. A. Kramarenko,[113] G. Kramberger,[92] D. Krasnopevtsev,[60a] M. W. Krasny,[135] A. Krasznahorkay,[36] D. Krauss,[115] J. A. Kremer,[100] J. Kretzschmar,[91] P. Krieger,[167] F. Krieter,[114] S. Krishnamurthy,[103] A. Krishnan,[61b] M. Krivos,[142] K. Krizka,[18] K. Kroeninger,[47] H. Kroha,[115] J. Kroll,[140] J. Kroll,[136] K. S. Krowpman,[107] U. Kruchonak,[80] H. Krüger,[24] N. Krumnack,[79] M. C. Kruse,[49] J. A. Krzysiak,[85] A. Kubota,[165] O. Kuchinskaia,[166] S. Kuday,[4b] D. Kuechler,[46] J. T. Kuechler,[46] S. Kuehn,[36] T. Kuhl,[46] V. Kukhtin,[80] Y. Kulchitsky,[108,y] S. Kuleshov,[146b] Y. P. Kulinich,[173] M. Kuna,[58] A. Kupco,[140] T. Kupfer,[47] O. Kuprash,[52] H. Kurashige,[83] L. L. Kurchaninov,[168a] Y. A. Kurochkin,[108] A. Kurova,[112] M. G. Kurth,[15a,15d] E. S. Kuwertz,[36] M. Kuze,[165] A. K. Kvam,[148] J. Kvita,[130] T. Kwan,[104] F. La Ruffa,[41b,41a] C. Lacasta,[174] F. Lacava,[73a,73b] D. P. J. Lack,[101] H. Lacker,[19] D. Lacour,[135] E. Ladygin,[80] R. Lafaye,[5] B. Laforge,[135] T. Lagouri,[146c] S. Lai,[53] I. K. Lakomiec,[84a] J. E. Lambert,[128] S. Lammers,[66] W. Lampl,[7] C. Lampoudis,[162] E. Lançon,[26b] U. Landgraf,[52] M. P. J. Landon,[93] V. S. Lang,[52] J. C. Lange,[53] R. J. Langenberg,[103] A. J. Lankford,[171] F. Lanni,[26b] K. Lantzsch,[24] A. Lanza,[71a] A. Lapertosa,[55b,55a] J. F. Laporte,[144] T. Lari,[69a] F. Lasagni Manghi,[23b,23a] M. Lassnig,[36] V. Latonova,[140] T. S. Lau,[63a] A. Laudrain,[100] A. Laurier,[34] M. Lavorgna,[70a,70b] S. D. Lawlor,[94] M. Lazzaroni,[69a,69b] B. Le,[101] E. Le Guirriec,[102] A. Lebedev,[79] M. LeBlanc,[7] T. LeCompte,[6] F. Ledroit-Guillon,[58] A. C. A. Lee,[95] C. A. Lee,[26b] G. R. Lee,[17] L. Lee,[59] S. C. Lee,[158] S. Lee,[79] B. Lefebvre,[168a] H. P. Lefebvre,[94] M. Lefebvre,[176] C. Leggett,[18] K. Lehmann,[152] N. Lehmann,[20] G. Lehmann Miotto,[36] W. A. Leight,[46] A. Leisos,[162,z] M. A. L. Leite,[81c] C. E. Leitgeb,[114] R. Leitner,[142] K. J. C. Leney,[42] T. Lenz,[24] S. Leone,[72a] C. Leonidopoulos,[50] A. Leopold,[135] C. Leroy,[110] R. Les,[107] C. G. Lester,[32] M. Levchenko,[137] J. Levêque,[5] D. Levin,[106] L. J. Levinson,[180] D. J. Lewis,[21] B. Li,[15b] B. Li,[106] C-Q. Li,[60c,60d] F. Li,[60c] H. Li,[60a] H. Li,[60b] J. Li,[60c] K. Li,[148] L. Li,[60c] M. Li,[15a,15d] Q. Y. Li,[60a] S. Li,[60d,60c] X. Li,[46] Y. Li,[46] Z. Li,[60b] Z. Li,[134] Z. Li,[104] Z. Li,[91] Z. Liang,[15a] M. Liberatore,[46] B. Liberti,[74a] K. Lie,[63c] S. Lim,[26b] C. Y. Lin,[32] K. Lin,[107] R. A. Linck,[66] R. E. Lindley,[7] J. H. Lindon,[21] A. Linss,[46] A. L. Lionti,[54] E. Lipeles,[136] A. Lipniacka,[17] T. M. Liss,[173,aa] A. Lister,[175] J. D. Little,[8] B. Liu,[79] B. X. Liu,[152] H. B. Liu,[26b] J. B. Liu,[60a] J. K. K. Liu,[37] K. Liu,[60d] M. Liu,[60a] M. Y. Liu,[60a] P. Liu,[15a] X. Liu,[60a] Y. Liu,[46] Y. Liu,[15a,15d] Y. L. Liu,[106] Y. W. Liu,[60a] M. Livan,[71a,71b] A. Lleres,[58] J. Llorente Merino,[152] S. L. Lloyd,[93] C. Y. Lo,[63b] E. M. Lobodzinska,[46] P. Loch,[7] S. Loffredo,[74a,74b] T. Lohse,[19] K. Lohwasser,[149] M. Lokajicek,[140] J. D. Long,[173] R. E. Long,[90] I. Longarini,[73a,73b] L. Longo,[36] K. A. Looper,[127] I. Lopez Paz,[101] A. Lopez Solis,[149] J. Lorenz,[114] N. Lorenzo Martinez,[5] A. M. Lory,[114] P. J. Lösel,[114] A. Lösle,[52] X. Lou,[45a,45b] X. Lou,[15a] A. Lounis,[65] J. Love,[6] P. A. Love,[90] J. J. Lozano Bahilo,[174] M. Lu,[60a] Y. J. Lu,[64] H. J. Lubatti,[148] C. Luci,[73a,73b] F. L. Lucio Alves,[15c] A. Lucotte,[58] F. Luehring,[66] I. Luise,[155] L. Luminari,[73a] B. Lund-Jensen,[154] N. A. Luongo,[131] M. S. Lutz,[161] D. Lynn,[26b] H. Lyons,[91] R. Lysak,[140] E. Lytken,[97] F. Lyu,[15a] V. Lyubushkin,[80] T. Lyubushkina,[80] H. Ma,[26b] L. L. Ma,[60b] Y. Ma,[95] D. M. Mac Donell,[176] G. Maccarrone,[51] C. M. Macdonald,[149] J. C. MacDonald,[149] J. Machado Miguens,[136] D. Madaffari,[174] R. Madar,[38] W. F. Mader,[48] M. Madugoda Ralalage Don,[129] N. Madysa,[48] J. Maeda,[83] T. Maeno,[26b] M. Maerker,[48] V. Magerl,[52] N. Magini,[79] J. Magro,[67a,67c,bb] D. J. Mahon,[39] C. Maidantchik,[81b] T. Maier,[114] A. Maio,[139a,139b,139d] K. Maj,[84a] O. Majersky,[29a] S. Majewski,[131] Y. Makida,[82] N. Makovec,[65] B. Malaescu,[135] Pa. Malecki,[85] V. P. Maleev,[137] F. Malek,[58] D. Malito,[41b,41a] U. Mallik,[78] C. Malone,[32] S. Maltezos,[10] S. Malyukov,[80] J. Mamuzic,[174] G. Mancini,[51] J. P. Mandalia,[93] I. Mandić,[92] L. Manhaes de Andrade Filho,[81a] I. M. Maniatis,[162] J. Manjarres Ramos,[48] K. H. Mankinen,[97] A. Mann,[114] A. Manousos,[77] B. Mansoulie,[144] I. Manthos,[162] S. Manzoni,[120] A. Marantis,[162] G. Marceca,[30] L. Marchese,[134] G. Marchiori,[135] M. Marcisovsky,[140] L. Marcoccia,[74a,74b] C. Marcon,[97] M. Marjanovic,[128] Z. Marshall,[18] M. U. F. Martensson,[172] S. Marti-Garcia,[174] C. B. Martin,[127] T. A. Martin,[178] V. J. Martin,[50] B. Martin dit Latour,[17] L. Martinelli,[75a,75b] M. Martinez,[14,s] P. Martinez Agullo,[174] V. I. Martinez Outschoorn,[103] S. Martin-Haugh,[143] V. S. Martoiu,[28b] A. C. Martyniuk,[95] A. Marzin,[36] S. R. Maschek,[115] L. Masetti,[100] T. Mashimo,[163] R. Mashinistov,[111] J. Masik,[101] A. L. Maslennikov,[122b,122a] L. Massa,[23b,23a] P. Massarotti,[70a,70b] P. Mastrandrea,[72a,72b] A. Mastroberardino,[41b,41a] T. Masubuchi,[163] D. Matakias,[26b] A. Matic,[114] N. Matsuzawa,[163] P. Mättig,[24] J. Maurer,[28b] B. Maček,[92] D. A. Maximov,[122b,122a] R. Mazini,[158] I. Maznas,[162] S. M. Mazza,[145] C. Mc Ginn,[26a] J. P. Mc Gowan,[104] S. P. Mc Kee,[106] T. G. McCarthy,[115] W. P. McCormack,[18] E. F. McDonald,[105] A. E. McDougall,[120] J. A. Mcfayden,[18] G. Mchedlidze,[159b]

M. A. McKay,[42] K. D. McLean,[176] S. J. McMahon,[143] P. C. McNamara,[105] C. J. McNicol,[178] R. A. McPherson,[176,l] J. E. Mdhluli,[33e] Z. A. Meadows,[103] S. Meehan,[36] T. Megy,[38] S. Mehlhase,[114] A. Mehta,[91] B. Meirose,[43] D. Melini,[160] B. R. Mellado Garcia,[33e] J. D. Mellenthin,[53] M. Melo,[29a] F. Meloni,[46] A. Melzer,[24] E. D. Mendes Gouveia,[139a,139e] A. M. Mendes Jacques Da Costa,[21] H. Y. Meng,[167] L. Meng,[36] X. T. Meng,[106] S. Menke,[115] E. Meoni,[41b,41a] S. Mergelmeyer,[19] S. A. M. Merkt,[138] C. Merlassino,[134] P. Mermod,[54] L. Merola,[70a,70b] C. Meroni,[69a] G. Merz,[106] O. Meshkov,[113,111] J. K. R. Meshreki,[151] J. Metcalfe,[6] A. S. Mete,[6] C. Meyer,[66] J-P. Meyer,[144] M. Michetti,[19] R. P. Middleton,[143] L. Mijović,[50] G. Mikenberg,[180] M. Mikestikova,[140] M. Mikuž,[92] H. Mildner,[149] A. Milic,[167] C. D. Milke,[42] D. W. Miller,[37] L. S. Miller,[34] A. Milov,[180] D. A. Milstead,[45a,45b] A. A. Minaenko,[123] I. A. Minashvili,[159b] L. Mince,[57] A. I. Mincer,[125] B. Mindur,[84a] M. Mineev,[80] Y. Minegishi,[163] Y. Mino,[86] L. M. Mir,[14] M. Mironova,[134] K. P. Mistry,[136] T. Mitani,[179] J. Mitrevski,[114] V. A. Mitsou,[174] M. Mittal,[60c] O. Miu,[167] A. Miucci,[20] P. S. Miyagawa,[93] A. Mizukami,[82] J. U. Mjörnmark,[97] T. Mkrtchyan,[61a] M. Mlynarikova,[121] T. Moa,[45a,45b] S. Mobius,[53] K. Mochizuki,[110] P. Moder,[46] P. Mogg,[114] S. Mohapatra,[39] R. Moles-Valls,[24] K. Mönig,[46] E. Monnier,[102] A. Montalbano,[152] J. Montejo Berlingen,[36] M. Montella,[95] F. Monticelli,[89] S. Monzani,[69a] N. Morange,[65] A. L. Moreira De Carvalho,[139a] D. Moreno,[22a] M. Moreno Llácer,[174] C. Moreno Martinez,[14] P. Morettini,[55b] M. Morgenstern,[160] S. Morgenstern,[48] D. Mori,[152] M. Morii,[59] M. Morinaga,[179] V. Morisbak,[133] A. K. Morley,[36] G. Mornacchi,[36] A. P. Morris,[95] L. Morvaj,[36] P. Moschovakos,[36] B. Moser,[120] M. Mosidze,[159b] T. Moskalets,[144] P. Moskvitina,[119] J. Moss,[31,cc] E. J. W. Moyse,[103] S. Muanza,[102] J. Mueller,[138] R. S. P. Mueller,[114] D. Muenstermann,[90] G. A. Mullier,[97] D. P. Mungo,[69a,69b] J. L. Munoz Martinez,[14] F. J. Munoz Sanchez,[101] P. Murin,[29b] W. J. Murray,[178,143] A. Murrone,[69a,69b] J. M. Muse,[128] M. Muškinja,[18] C. Mwewa,[33a] A. G. Myagkov,[123,i] A. A. Myers,[138] G. Myers,[66] J. Myers,[131] M. Myska,[141] B. P. Nachman,[18] O. Nackenhorst,[47] A. Nag Nag,[48] K. Nagai,[134] K. Nagano,[82] Y. Nagasaka,[62] J. L. Nagle,[26b] E. Nagy,[102] A. M. Nairz,[36] Y. Nakahama,[117] K. Nakamura,[82] T. Nakamura,[163] H. Nanjo,[132] F. Napolitano,[61a] R. F. Naranjo Garcia,[46] R. Narayan,[42] I. Naryshkin,[137] M. Naseri,[34] T. Naumann,[46] G. Navarro,[22a] P. Y. Nechaeva,[111] F. Nechansky,[46] T. J. Neep,[21] A. Negri,[71a,71b] M. Negrini,[23b] C. Nellist,[119] C. Nelson,[104] M. E. Nelson,[45a,45b] S. Nemecek,[140] M. Nessi,[36,dd] M. S. Neubauer,[173] F. Neuhaus,[100] M. Neumann,[182] R. Newhouse,[175] P. R. Newman,[21] C. W. Ng,[138] Y. S. Ng,[19] Y. W. Y. Ng,[171] B. Ngair,[35e] H. D. N. Nguyen,[102] T. Nguyen Manh,[110] E. Nibigira,[38] R. B. Nickerson,[134] R. Nicolaidou,[144] D. S. Nielsen,[40] J. Nielsen,[145] M. Niemeyer,[53] N. Nikiforou,[11] V. Nikolaenko,[123,i] I. Nikolic-Audit,[135] K. Nikolopoulos,[21] P. Nilsson,[26b] H. R. Nindhito,[54] A. Nisati,[73a] N. Nishu,[60c] R. Nisius,[115] I. Nitsche,[47] T. Nitta,[179] T. Nobe,[163] D. L. Noel,[32] Y. Noguchi,[86] I. Nomidis,[135] M. A. Nomura,[26b] M. Nordberg,[36] J. Novak,[92] T. Novak,[92] O. Novgorodova,[48] R. Novotny,[118] L. Nozka,[130] K. Ntekas,[171] E. Nurse,[95] F. G. Oakham,[34,d] J. Ocariz,[135] A. Ochi,[83] I. Ochoa,[39] J. P. Ochoa-Ricoux,[146a] K. O'Connor,[27] S. Oda,[88] S. Odaka,[82] S. Oerdek,[53] A. Ogrodnik,[84a] A. Oh,[101] C. C. Ohm,[154] H. Oide,[165] M. L. Ojeda,[167] H. Okawa,[169] Y. Okazaki,[86] M. W. O'Keefe,[91] Y. Okumura,[163] A. Olariu,[28b] L. F. Oleiro Seabra,[139a] S. A. Olivares Pino,[146a] D. Oliveira Damazio,[26b] J. L. Oliver,[1] M. J. R. Olsson,[171] A. Olszewski,[85] J. Olszowska,[85] Ö. O. Öncel,[24] D. C. O'Neil,[152] A. P. O'neill,[134] A. Onofre,[139a,139e] P. U. E. Onyisi,[11] H. Oppen,[133] R. G. Oreamuno Madriz,[121] M. J. Oreglia,[37] G. E. Orellana,[89] D. Orestano,[75a,75b] N. Orlando,[14] R. S. Orr,[167] V. O'Shea,[57] R. Ospanov,[60a] G. Otero y Garzon,[30] H. Otono,[88] P. S. Ott,[61a] G. J. Ottino,[18] M. Ouchrif,[35d] J. Ouellette,[26b] F. Ould-Saada,[133] A. Ouraou,[144,a] Q. Ouyang,[15a] M. Owen,[57] R. E. Owen,[143] V. E. Ozcan,[12c] N. Ozturk,[8] J. Pacalt,[130] H. A. Pacey,[32] K. Pachal,[49] A. Pacheco Pages,[14] C. Padilla Aranda,[14] S. Pagan Griso,[18] G. Palacino,[66] S. Palazzo,[50] S. Palestini,[36] M. Palka,[84b] P. Palni,[84a] C. E. Pandini,[54] J. G. Panduro Vazquez,[94] P. Pani,[46] G. Panizzo,[67a,67c] L. Paolozzi,[54] C. Papadatos,[110] K. Papageorgiou,[9,p] S. Parajuli,[42] A. Paramonov,[6] C. Paraskevopoulos,[10] D. Paredes Hernandez,[63b] S. R. Paredes Saenz,[134] B. Parida,[180] T. H. Park,[167] A. J. Parker,[31] M. A. Parker,[32] F. Parodi,[55b,55a] E. W. Parrish,[121] J. A. Parsons,[39] U. Parzefall,[52] L. Pascual Dominguez,[135] V. R. Pascuzzi,[18] J. M. P. Pasner,[145] F. Pasquali,[120] E. Pasqualucci,[73a] S. Passaggio,[55b] F. Pastore,[94] P. Pasuwan,[45a,45b] S. Pataraia,[100] J. R. Pater,[101] A. Pathak,[181,e] J. Patton,[91] T. Pauly,[36] J. Pearkes,[153] M. Pedersen,[133] L. Pedraza Diaz,[119] R. Pedro,[139a] T. Peiffer,[53] S. V. Peleganchuk,[122b,122a] O. Penc,[140] C. Peng,[63b] H. Peng,[60a] B. S. Peralva,[81a] M. M. Perego,[65] A. P. Pereira Peixoto,[139a] L. Pereira Sanchez,[45a,45b] D. V. Perepelitsa,[26b] E. Perez Codina,[168a] F. Peri,[19] L. Perini,[69a,69b] H. Pernegger,[36] S. Perrella,[36] A. Perrevoort,[120] K. Peters,[46] R. F. Y. Peters,[101] B. A. Petersen,[36] T. C. Petersen,[40] E. Petit,[102] V. Petousis,[141] C. Petridou,[162] F. Petrucci,[75a,75b] M. Pettee,[183] N. E. Pettersson,[103] K. Petukhova,[142] A. Peyaud,[144] R. Pezoa,[146d] L. Pezzotti,[71a,71b] T. Pham,[105] P. W. Phillips,[143] M. W. Phipps,[173] G. Piacquadio,[155] E. Pianori,[18] A. Picazio,[103] R. H. Pickles,[101] R. Piegaia,[30] D. Pietreanu,[28b] J. E. Pilcher,[37] A. D. Pilkington,[101] M. Pinamonti,[67a,67c] J. L. Pinfold,[3] C. Pitman Donaldson,[95] M. Pitt,[161] L. Pizzimento,[74a,74b] A. Pizzini,[120] M.-A. Pleier,[26b] V. Plesanovs,[52] V. Pleskot,[142]

E. Plotnikova,[80] P. Podberezko,[122b,122a] R. Poettgen,[97] R. Poggi,[54] L. Poggioli,[135] I. Pogrebnyak,[107] D. Pohl,[24] I. Pokharel,[53] G. Polesello,[71a] A. Poley,[152,168a] A. Policicchio,[73a,73b] R. Polifka,[142] A. Polini,[23b] C. S. Pollard,[46] V. Polychronakos,[26b] D. Ponomarenko,[112] L. Pontecorvo,[36] S. Popa,[28a] G. A. Popeneciu,[28d] L. Portales,[5] D. M. Portillo Quintero,[58] S. Pospisil,[141] K. Potamianos,[46] I. N. Potrap,[80] C. J. Potter,[32] H. Potti,[11] T. Poulsen,[97] J. Poveda,[174] T. D. Powell,[149] G. Pownall,[46] M. E. Pozo Astigarraga,[36] A. Prades Ibanez,[174] P. Pralavorio,[102] M. M. Prapa,[44] S. Prell,[79] D. Price,[101] M. Primavera,[68a] M. L. Proffitt,[148] N. Proklova,[112] K. Prokofiev,[63c] F. Prokoshin,[80] S. Protopopescu,[26b] J. Proudfoot,[6] M. Przybycien,[84a] D. Pudzha,[137] A. Puri,[173] P. Puzo,[65] D. Pyatiizbyantseva,[112] J. Qian,[106] Y. Qin,[101] A. Quadt,[53] M. Queitsch-Maitland,[36] M. Racko,[29a] F. Ragusa,[69a,69b] G. Rahal,[98] J. A. Raine,[54] S. Rajagopalan,[26b] A. Ramirez Morales,[93] K. Ran,[15a,15d] D. M. Rauch,[46] F. Rauscher,[114] S. Rave,[100] B. Ravina,[57] I. Ravinovich,[180] J. H. Rawling,[101] M. Raymond,[36] A. L. Read,[133] N. P. Readioff,[149] M. Reale,[68a,68b] D. M. Rebuzzi,[71a,71b] G. Redlinger,[26b] K. Reeves,[43] D. Reikher,[161] A. Reiss,[100] A. Rej,[151] C. Rembser,[36] A. Renardi,[46] M. Renda,[28b] M. B. Rendel,[115] A. G. Rennie,[57] S. Resconi,[69a] E. D. Resseguie,[18] S. Rettie,[95] B. Reynolds,[127] E. Reynolds,[21] O. L. Rezanova,[122b,122a] P. Reznicek,[142] E. Ricci,[76a,76b] R. Richter,[115] S. Richter,[46] E. Richter-Was,[84b] M. Ridel,[135] P. Rieck,[115] O. Rifki,[46] M. Rijssenbeek,[155] A. Rimoldi,[71a,71b] M. Rimoldi,[46] L. Rinaldi,[23b] T. T. Rinn,[173] G. Ripellino,[154] I. Riu,[14] P. Rivadeneira,[46] J. C. Rivera Vergara,[176] F. Rizatdinova,[129] E. Rizvi,[93] C. Rizzi,[36] S. H. Robertson,[104,l] M. Robin,[46] D. Robinson,[32] C. M. Robles Gajardo,[146d] M. Robles Manzano,[100] A. Robson,[57] A. Rocchi,[74a,74b] C. Roda,[72a,72b] S. Rodriguez Bosca,[174] A. Rodriguez Rodriguez,[52] A. M. Rodríguez Vera,[168b] S. Roe,[36] J. Roggel,[182] O. Røhne,[133] R. Röhrig,[115] R. A. Rojas,[146d] B. Roland,[52] C. P. A. Roland,[66] J. Roloff,[26b] A. Romaniouk,[112] M. Romano,[23b,23a] N. Rompotis,[91] M. Ronzani,[125] L. Roos,[135] S. Rosati,[73a] G. Rosin,[103] B. J. Rosser,[136] E. Rossi,[46] E. Rossi,[75a,75b] E. Rossi,[70a,70b] L. P. Rossi,[55b] L. Rossini,[46] R. Rosten,[14] M. Rotaru,[28b] B. Rottler,[52] D. Rousseau,[65] G. Rovelli,[71a,71b] A. Roy,[11] D. Roy,[33e] A. Rozanov,[102] Y. Rozen,[160] X. Ruan,[33e] T. A. Ruggeri,[1] F. Rühr,[52] A. Ruiz-Martinez,[174] A. Rummler,[36] Z. Rurikova,[52] N. A. Rusakovich,[80] H. L. Russell,[104] L. Rustige,[38,47] J. P. Rutherfoord,[7] E. M. Rüttinger,[149] M. Rybar,[142] G. Rybkin,[65] E. B. Rye,[133] A. Ryzhov,[123] J. A. Sabater Iglesias,[46] P. Sabatini,[174] L. Sabetta,[73a,73b] S. Sacerdoti,[65] H. F-W. Sadrozinski,[145] R. Sadykov,[80] F. Safai Tehrani,[73a] B. Safarzadeh Samani,[156] M. Safdari,[153] P. Saha,[121] S. Saha,[104] M. Sahinsoy,[115] A. Sahu,[182] M. Saimpert,[36] M. Saito,[163] T. Saito,[163] H. Sakamoto,[163] D. Salamani,[54] G. Salamanna,[75a,75b] A. Salnikov,[153] J. Salt,[174] A. Salvador Salas,[14] D. Salvatore,[41b,41a] F. Salvatore,[156] A. Salvucci,[63a] A. Salzburger,[36] J. Samarati,[36] D. Sammel,[52] D. Sampsonidis,[162] D. Sampsonidou,[60d,60c] J. Sánchez,[174] A. Sanchez Pineda,[67a,36,67c] H. Sandaker,[133] C. O. Sander,[46] I. G. Sanderswood,[90] M. Sandhoff,[182] C. Sandoval,[22b] D. P. C. Sankey,[143] M. Sannino,[55b,55a] Y. Sano,[117] A. Sansoni,[51] C. Santoni,[38] H. Santos,[139a,139b] S. N. Santpur,[18] A. Santra,[174] K. A. Saoucha,[149] A. Sapronov,[80] J. G. Saraiva,[139a,139d] O. Sasaki,[82] K. Sato,[169] F. Sauerburger,[52] E. Sauvan,[5] P. Savard,[167,d] R. Sawada,[163] C. Sawyer,[143] L. Sawyer,[96] I. Sayago Galvan,[174] C. Sbarra,[23b] A. Sbrizzi,[67a,67c] T. Scanlon,[95] J. Schaarschmidt,[148] P. Schacht,[115] D. Schaefer,[37] L. Schaefer,[136] U. Schäfer,[100] A. C. Schaffer,[65] D. Schaile,[114] R. D. Schamberger,[155] E. Schanet,[114] C. Scharf,[19] N. Scharmberg,[101] V. A. Schegelsky,[137] D. Scheirich,[142] F. Schenck,[19] M. Schernau,[171] C. Schiavi,[55b,55a] L. K. Schildgen,[24] Z. M. Schillaci,[27] E. J. Schioppa,[68a,68b] M. Schioppa,[41b,41a] K. E. Schleicher,[52] S. Schlenker,[36] K. R. Schmidt-Sommerfeld,[115] K. Schmieden,[100] C. Schmitt,[100] S. Schmitt,[46] L. Schoeffel,[144] A. Schoening,[61b] P. G. Scholer,[52] E. Schopf,[134] M. Schott,[100] J. F. P. Schouwenberg,[119] J. Schovancova,[36] S. Schramm,[54] F. Schroeder,[182] A. Schulte,[100] H-C. Schultz-Coulon,[61a] M. Schumacher,[52] B. A. Schumm,[145] Ph. Schune,[144] A. Schwartzman,[153] T. A. Schwarz,[106] Ph. Schwemling,[144] R. Schwienhorst,[107] A. Sciandra,[145] G. Sciolla,[27] M. Scornajenghi,[41b,41a] F. Scuri,[72a] F. Scutti,[105] L. M. Scyboz,[115] C. D. Sebastiani,[91] K. Sedlaczek,[47] P. Seema,[19] S. C. Seidel,[118] A. Seiden,[145] B. D. Seidlitz,[26b] T. Seiss,[37] C. Seitz,[46] J. M. Seixas,[81b] G. Sekhniaidze,[70a] S. J. Sekula,[42] N. Semprini-Cesari,[23b,23a] S. Sen,[49] C. Serfon,[26b] L. Serin,[65] L. Serkin,[67a,67b] M. Sessa,[60a] H. Severini,[128] S. Sevova,[153] F. Sforza,[55b,55a] A. Sfyrla,[54] E. Shabalina,[53] J. D. Shahinian,[136] N. W. Shaikh,[45a,45b] D. Shaked Renous,[180] L. Y. Shan,[15a] M. Shapiro,[18] A. Sharma,[36] A. S. Sharma,[1] P. B. Shatalov,[124] K. Shaw,[156] S. M. Shaw,[101] M. Shehade,[180] Y. Shen,[128] A. D. Sherman,[25] P. Sherwood,[95] L. Shi,[95] C. O. Shimmin,[183] Y. Shimogama,[179] M. Shimojima,[116] J. D. Shinner,[94] I. P. J. Shipsey,[134] S. Shirabe,[165] M. Shiyakova,[80,ee] J. Shlomi,[180] A. Shmeleva,[111] M. J. Shochet,[37] J. Shojaii,[105] D. R. Shope,[154] S. Shrestha,[127] E. M. Shrif,[33e] M. J. Shroff,[176] E. Shulga,[180] P. Sicho,[140] A. M. Sickles,[173] E. Sideras Haddad,[33e] O. Sidiropoulou,[36] A. Sidoti,[23b,23a] F. Siegert,[48] Dj. Sijacki,[16] M. Silva Jr.,[181] M. V. Silva Oliveira,[36] S. B. Silverstein,[45a] S. Simion,[65] R. Simoniello,[100] C. J. Simpson-allsop,[21] S. Simsek,[12b] P. Sinervo,[167] V. Sinetckii,[113] S. Singh,[152] M. Sioli,[23b,23a] I. Siral,[131] S. Yu. Sivoklokov,[113] J. Sjölin,[45a,45b] A. Skaf,[53] E. Skorda,[97] P. Skubic,[128] M. Slawinska,[85] K. Sliwa,[170] V. Smakhtin,[180] B. H. Smart,[143] J. Smiesko,[29b] N. Smirnov,[112] S. Yu. Smirnov,[112]

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Varol,[158] D. Varouchas,[65] K. E. Varvell,[157] M. E. Vasile,[28b] G. A. Vasquez,[176] F. Vazeille,[38] D. Vazquez Furelos,[14] T. Vazquez Schroeder,[36] J. Veatch,[53] V. Vecchio,[101] M. J. Veen,[120] L. M. Veloce,[167] F. Veloso,[139a,139c] S. Veneziano,[73a] A. Ventura,[68a,68b] A. Verbytskyi,[115] V. Vercesi,[71a] M. Verducci,[72a,72b] C. M. Vergel Infante,[79] C. Vergis,[24] W. Verkerke,[120] A. T. Vermeulen,[120] J. C. Vermeulen,[120] C. Vernieri,[153] P. J. Verschuuren,[94] M. C. Vetterli,[152,d] N. Viaux Maira,[146d] T. Vickey,[149] O. E. Vickey Boeriu,[149] G. H. A. Viehhauser,[134] L. Vigani,[61b] M. Villa,[23b,23a] M. Villaplana Perez,[3] E. M. Villhauer,[50] E. Vilucchi,[51] M. G. Vincter,[34] G. S. Virdee,[21] A. Vishwakarma,[50] C. Vittori,[23b,23a] I. Vivarelli,[156] M. Vogel,[182] P. Vokac,[141] J. Von Ahnen,[46] S. E. von Buddenbrock,[33e] E. Von Toerne,[24] V. Vorobel,[142] K. Vorobev,[112] M. Vos,[174] J. H. Vossebeld,[91] M. Vozak,[101] N. Vranjes,[16] M. Vranjes Milosavljevic,[16] V. Vrba,[141] M. Vreeswijk,[120] N. K. Vu,[102] R. Vuillermet,[36] I. Vukotic,[37] S. Wada,[169] P. Wagner,[24] W. Wagner,[182] J. Wagner-Kuhr,[114] S. Wahdan,[182] H. Wahlberg,[89] R. Wakasa,[169] V. M. Walbrecht,[115] J. Walder,[143] R. Walker,[114] S. D. Walker,[94] W. Walkowiak,[151] V. Wallangen,[45a,45b] A. M. Wang,[59] A. Z. Wang,[181] C. Wang,[60a] C. Wang,[60c] H. Wang,[18] H. Wang,[3] J. Wang,[63a] P. Wang,[42] Q. Wang,[128] R.-J. Wang,[100] R. Wang,[60a] R. Wang,[6] S. M. Wang,[158] W. T. Wang,[60a] W. Wang,[15c] W. X. Wang,[60a] Y. Wang,[60a]

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