

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)



Submitted to: EPJC



CERN-PH-EP-2016-001
July 13, 2016

Measurement of the charged-particle multiplicity inside jets from $\sqrt{s} = 8$ TeV pp collisions with the ATLAS detector

The ATLAS Collaboration

Abstract

The number of charged particles inside jets is a widely used discriminant for identifying the quark or gluon nature of the initiating parton and is sensitive to both the perturbative and non-perturbative components of fragmentation. This paper presents a measurement of the average number of charged particles with $p_T > 500$ MeV inside high-momentum jets in dijet events using 20.3 fb^{-1} of data recorded with the ATLAS detector in pp collisions at $\sqrt{s} = 8$ TeV collisions at the LHC. The jets considered have transverse momenta from 50 GeV up to and beyond 1.5 TeV. The reconstructed charged-particle track multiplicity distribution is unfolded to remove distortions from detector effects and the resulting charged-particle multiplicity is compared to several models. Furthermore, quark and gluon jet fractions are used to extract the average charged-particle multiplicity for quark and gluon jets separately.

© 2016 CERN for the benefit of the ATLAS Collaboration.

Reproduction of this article or parts of it is allowed as specified in the CC-BY-4.0 license.

arXiv:1602.00988v2 [hep-ex] 12 Jul 2016

1 Introduction

Quarks and gluons produced in high-energy particle collisions hadronize before they can be observed directly. However, the properties of the resulting collimated sprays of hadrons, known as jets, depend on the type of parton which initiated them. One jet observable sensitive to the quark or gluon nature is the number of charged particles inside the jet. Due to their larger colour-charge under the strong force, gluon-initiated jets contain on average more particles than quark-initiated jets. The average (charged) particle multiplicity inside jets increases with jet energy, but increases faster for gluon-initiated jets than for quark-initiated jets [1]. These properties were used recently at the Large Hadron Collider (LHC) to differentiate between jets originating from a quark or a gluon [2–6]. These studies have found significant differences in the charged-particle multiplicity between the available simulations and data. Improved modelling based on measurements of the number of charged particles inside jets is thus crucial for future studies.

This paper presents a measurement of the average charged-particle multiplicity inside jets as a function of the jet transverse momentum in dijet events in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector. The measurement of the charged-particle multiplicity inside jets has a long history from the SPS [7–9], PETRA [10, 11], PEP [12–15], TRISTAN [16], CESR [17], LEP [18–29], and the Tevatron [30]. At the LHC, both ATLAS [31, 32] and CMS [33] have measured the charged-particle multiplicity inside jets at $\sqrt{s} = 7$ TeV. One ATLAS result [31] used jets that are reconstructed using tracks and have transverse momentum less than 40 GeV. A second ATLAS analysis [32] has measured charged particles inside jets with transverse momenta spanning the range from 50 to 500 GeV with approximately constant 3–4% uncertainties. The CMS measurement [33] spans jet transverse momenta between 50 and 800 GeV with 5–10% uncertainties in the bins of highest transverse momentum. The analysis presented here uses the full $\sqrt{s} = 8$ TeV ATLAS dataset, which allows for a significant improvement in the precision at high transverse momentum up to and beyond 1.5 TeV.

This paper is organized as follows. After a description of the ATLAS detector and object and event selection in Sect. 2, simulated samples are described in Sect. 3. In order for the measured charged-particle multiplicity to be compared with particle-level models, the data are unfolded to remove distortions from detector effects, as described in Sect. 4. Systematic uncertainties in the measured charged-particle multiplicity are discussed in Sect. 5 and the results are presented in Sect. 6.

2 Object and event selection

ATLAS is a general-purpose detector designed to measure the properties of particles produced in high-energy pp collisions with nearly a full 4π coverage in solid angle. Charged-particle momenta are measured by a series of tracking detectors covering a range¹ of $|\eta| < 2.5$ and immersed in a 2 T axial magnetic field, providing measurements of the transverse momentum, p_T , with a resolution $\sigma_{p_T}/p_T \sim 0.05\% \times p_T/\text{GeV} \oplus 1\%$. Electromagnetic and hadronic calorimeters surround the tracking detector, with

¹ ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z -axis along the beam pipe. The x -axis points from the IP to the centre of the LHC ring, and the y -axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$. The variable $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$ is a measure of how close two objects are in the (η, ϕ) plane.

forward calorimeters allowing electromagnetic and hadronic energy measurements up to $|\eta| = 4.5$. A detailed description of the ATLAS detector can be found in Ref. [34].

This measurement uses the dataset of pp collisions recorded by the ATLAS detector in 2012, corresponding to an integrated luminosity of 20.3 fb^{-1} at a center-of-mass energy of $\sqrt{s} = 8 \text{ TeV}$. The data acquisition and object/event selection are described in detail in Ref. [35] and highlighted here for completeness. Jets are clustered using the anti- k_t jet algorithm [36] with radius parameter $R = 0.4$ implemented in FastJet [37] using as inputs topological calorimeter-cell clusters [38], calibrated using the local cluster weighting (LCW) algorithm [39, 40]. An overall jet energy calibration accounts for residual detector effects as well as contributions from multiple proton–proton collisions in the same bunch crossing (pileup) [41] in order to make the reconstructed jet energy correspond to an unbiased measurement of the particle-level jet energy. Jets are required to be central ($|\eta| < 2.1$) so that their charged particles are within the $|\eta| < 2.5$ coverage of the tracking detector. Events are further required to have at least two jets with $p_T > 50 \text{ GeV}$ and only the leading two jets are considered for the charged-particle multiplicity measurement. To select dijet topologies where the jets are balanced in p_T , the two leading jets must have $p_T^{\text{lead}}/p_T^{\text{sublead}} < 1.5$, where p_T^{lead} and p_T^{sublead} are the transverse momenta of the jets with the highest and second-highest p_T , respectively. The jet with the smaller (larger) absolute pseudorapidity $|\eta|$ is classified as the more central (more forward) jet. A measurement of the more forward and more central average charged-particle multiplicities can exploit the rapidity dependence of the jet type to extract information about the multiplicity for quark- and gluon-initiated jets as is described in Sect. 6. The more forward jet tends to be correlated with the parton with higher longitudinal momentum fraction x , and is less likely to be a gluon-initiated jet.

Tracks are required to have $p_T \geq 500 \text{ MeV}$, $|\eta| < 2.5$, and a χ^2 per degree of freedom (resulting from the track fit) less than 3.0. Additional quality criteria are applied to select tracks originating from the collision vertex and reject fake tracks reconstructed from random hits in the detector. In particular, tracks are matched to the hard-scatter vertex by requiring $|z_0 \sin(\theta)| < 1.5 \text{ mm}$ and $|d_0| < 1 \text{ mm}$, where z_0 and d_0 are the track longitudinal and transverse impact parameters, respectively, calculated with respect to the primary vertex. Tracks must furthermore have at least one hit in the silicon pixel detector and at least six hits in the semiconductor microstrip detector. The matching of tracks with the calorimeter-based jets is performed via the ghost-association technique [42]: the jet clustering process is repeated with the addition of ‘ghost’ versions of measured tracks that have the same direction but infinitesimally small p_T , so that they do not change the properties of the calorimeter-based jets. A track is associated with a jet if its ghost version is contained in the jet after reclustering. The distribution of the number of tracks in three representative jet p_T ranges is shown in Fig. 1. The number of tracks increases with jet p_T and the data fall mostly between the distributions predicted by PYTHIA and HERWIG++ Monte Carlo simulations.

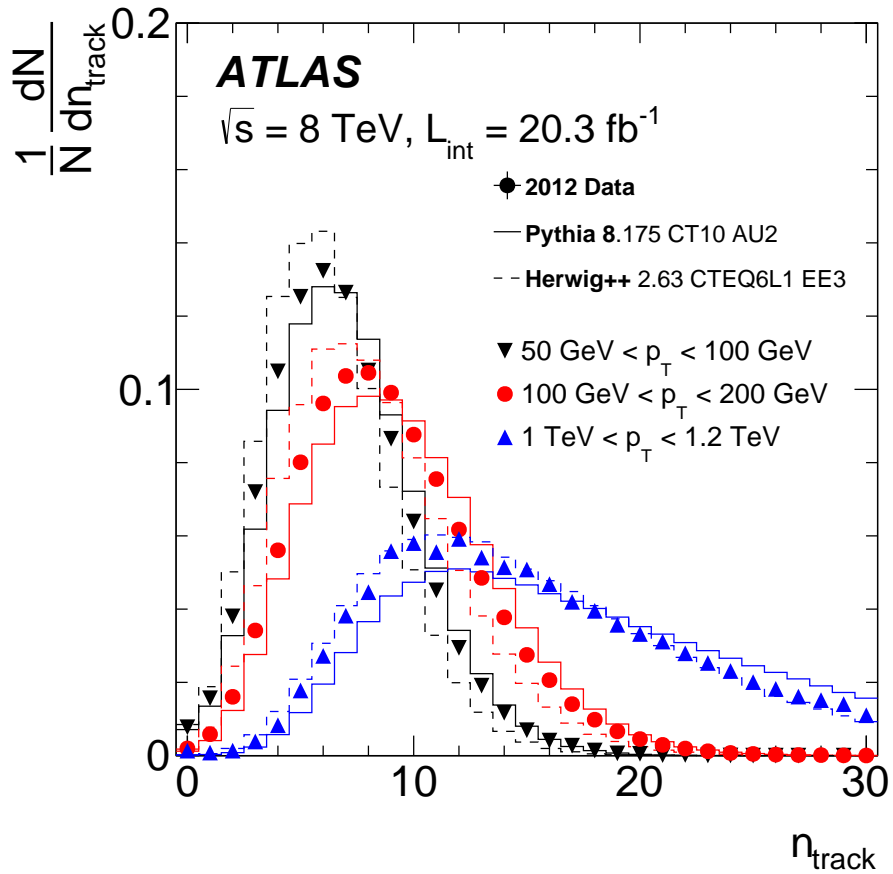


Figure 1: The distribution of the number of reconstructed tracks associated with a jet (not unfolded) in three example jet p_T ranges: $50 \text{ GeV} < p_T < 100 \text{ GeV}$, $100 \text{ GeV} < p_T < 200 \text{ GeV}$, and $1 \text{ TeV} < p_T < 1.2 \text{ TeV}$ for data and for PYTHIA 8 and HERWIG++ predictions. The simulated samples are described in Sect. 3. The data points have statistical uncertainties which in all bins are smaller than the marker size. There is one entry per jet.

3 Event simulation

Monte Carlo (MC) samples are used in order to determine how the detector response affects the charged-particle multiplicity and to make comparisons with the corrected data. The details of the samples used are shown in Table 1. The sample generated with PYTHIA 8.175 [43] using the AU2 [44] set of tuned parameters (tune) and the HERWIG++ 2.6.3 [45] sample with the UE-EE3 [46] tune are further processed with the ATLAS detector simulation [47] based on GEANT4 [48]. The effects of pileup are modelled by adding to the generated hard-scatter events (before the detector simulation) multiple minimum-bias events generated with PYTHIA 8.160, the A2 tune [44], and the MSTW2008LO [49] Parton distribution function (PDF) set. The distribution of the number of interactions is then weighted to reflect the pileup distribution in the data.

ME Generator	PDF	Tune
PYTHIA 8.175 [43]	CT10 [50]	AU2 [44]
PYTHIA 8.186	NNPDF2.3 [51]	Monash [52]
PYTHIA 8.186	NNPDF2.3	A14 [53]
HERWIG++ 2.6.3 [45, 54]	CTEQ6L1 [55]	UE-EE3 [46]
HERWIG++ 2.7.1 [56]	CTEQ6L1	UE-EE5 [57]
PYTHIA 6.428 [58]	CTEQ6L1	P2012 [59]
PYTHIA 6.428	CTEQ6L1	P2012RadLo [59]
PYTHIA 6.428	CTEQ6L1	P2012RadHi [59]

Table 1: Monte Carlo samples used in this analysis. The abbreviations ME, PDF, and UE respectively stand for matrix element, parton distribution function, and underlying event. ‘Tune’ refers to the set of tunable MC parameters used.

4 Unfolding

The measurement is carried out within a fiducial volume matching the experimental selection to avoid extrapolation into unmeasured kinematic regions that have additional model dependence and related uncertainties. Particle-level definitions of the reconstructed objects are chosen to be as close as possible to those described in Sect. 2. Particle-level jets are clustered from generated stable particles with a mean lifetime $\tau > 30$ ps, excluding muons and neutrinos. As with the detector-level jets, particle-level jets are clustered with the anti- k_t $R = 0.4$ algorithm. Any charged particle clustered in a particle-level jet is considered for the charged-particle multiplicity calculation if it has $p_T > 500$ MeV. Events are required to have at least two jets with $|\eta| < 2.1$ and $p_T > 50$ GeV and the two highest- p_T jets must satisfy the same p_T -balance requirement between the leading and subleading jet as at detector level ($p_T^{\text{lead}}/p_T^{\text{sublead}} < 1.5$). The p_T symmetry requirement enriches the sample in a back-to-back topology and suppresses non-isolated jets. In more than 70% of events, the nearest jet in ΔR with $p_T > 25$ GeV is the other selected jet and in less than 7% of events, there is a jet with $p_T > 25$ GeV within $\Delta R = 0.8$ from one of the two selected jets. Due to the high-energy and well-separated nature of the selected jets, the hard-scatter quarks and

gluons can be cleanly matched to the outgoing jets. In this analysis, the type of a jet is defined as that of the highest-energy parton in simulation within a $\Delta R = 0.4$ cone around the particle-jet's axis.² Figure 2 shows the fraction of gluon-initiated jets as a function of jet p_T for the more forward and more central jet within the event. The fraction of gluon-initiated jets decreases with p_T , but the difference between the more forward and more central jets peaks around $p_T \sim 350$ GeV. This difference is exploited in Sect. 6 to extract separately the average quark- and gluon-initiated jet charged-particle multiplicity.

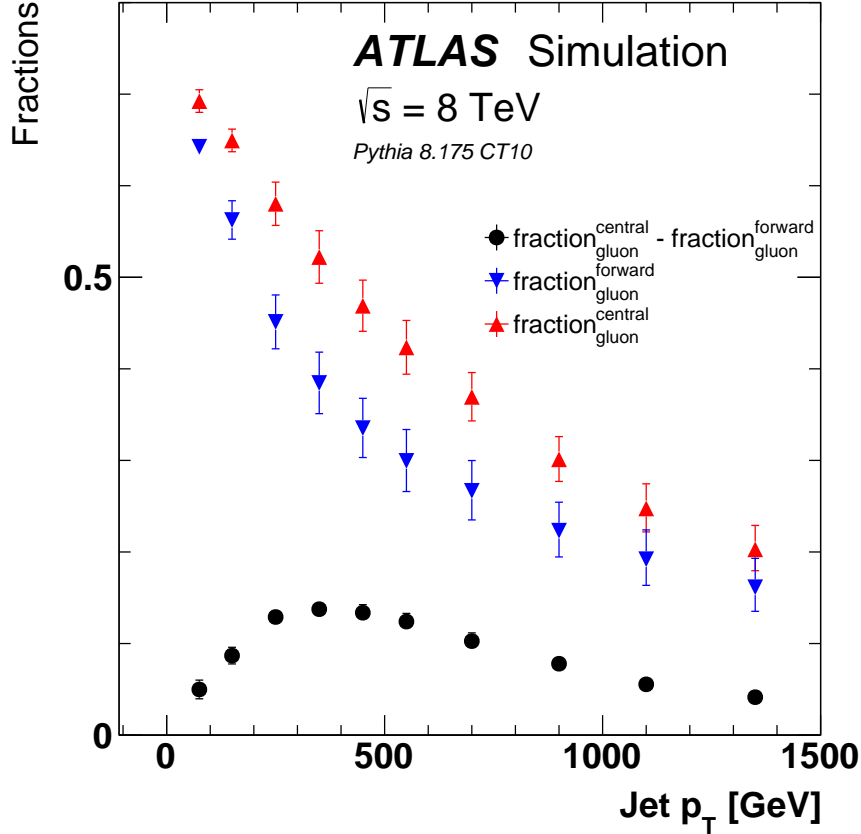


Figure 2: The simulated fraction of jets originating from gluons as a function of jet p_T for the more forward jet (down triangle), the more central jet (up triangle), and the difference between these two fractions (circle). The fractions are derived from PYTHIA 8 with the CT10 PDF set and the error bars represent the PDF and matrix element uncertainties, further discussed in Sect. 6. The uncertainties on the fraction difference are computed from propagating the uncertainties on the more forward and more central fractions, treating as fully correlated.

The average charged-particle multiplicity in particle-level jets is determined as a function of jet p_T . An iterative Bayesian (IB) technique [61] as implemented in the RooUnfold framework [62] is used to unfold the two-dimensional charged-particle multiplicity and jet p_T distribution. In the IB unfolding technique, the number of iterations and the prior distribution are the input parameters. The raw data are corrected

² While it is possible to classify jets as quark- or gluon-initiated beyond leading order in $m_{\text{jet}}/E_{\text{jet}}$ [60], the classification is jet algorithm-dependent and unnecessary for the present considerations. For the results presented in Sect. 6 that rely on jet-type labelling, alternative definitions were considered and found to have a negligible impact compared to other sources of theoretical and experimental uncertainty.

using the simulation to account for events that pass the fiducial selection at detector level, but not the corresponding selection at particle level; this correction is the *fake factor*. Then, the IB method iteratively applies Bayes' theorem using the *response matrix* to connect the prior distribution to the posterior distribution at each step, with the nominal PYTHIA 8.175 sample used for the initial prior distribution. The response matrix describes the bin migrations between the particle-level and detector-level two-dimensional distribution of charged-particle multiplicity and jet p_T . Although the response matrix is nearly diagonal, the resolution degrades at high p_T where more bin-to-bin migrations from particle level to detector level occur.

The number of iterations in the IB method trades off unfolding bias against statistical fluctuations. An optimal value of four iterations is obtained by minimizing the bias when unfolding pseudo-data derived from HERWIG++ using a prior distribution and a response matrix derived from PYTHIA as a test of the methodology. Lastly, unfolding applies another correction from simulation to the unfolded data to account for events passing the particle-level selection but not the detector-level selection; this correction is the *inefficiency factor*.

Figure 3 displays the p_T dependence of the average charged-particle multiplicity for uncorrected data and detector-level simulation and for particle-level simulation as well as the unfolded data. The prediction from PYTHIA 8 with the AU2 tune has too many tracks compared with the uncorrected data, and the size of the data/MC difference increases with decreasing track p_T threshold (Fig. 3(a)). The difference between the detector-level and particle-level simulation in Fig. 3(b) (for which the ratio is given in Fig. 3(d)) gives an indication of the corrections required to account for detector acceptance and resolution effects in the unfolding procedure. Particle-level distributions in Fig. 3(c) show similar trends to the detector-level ones in Fig. 3(a).

5 Systematic uncertainties

All stages of the charged-particle multiplicity measurement are sensitive to sources of potential bias. The three stages of the measurement are listed below, with an overview of the systematic uncertainties that impact the results at each stage:

Response Matrix: For events that pass both the detector-level and particle-level fiducial selections, the response matrix describes migrations between bins when moving between the detector level and the particle level. The response matrix is taken from simulation and various experimental uncertainties in the charged-particle multiplicity and jet p_T spectra result in uncertainties in the matrix. These uncertainties can be divided into two classes: those impacting the calorimeter-based jet p_T and those impacting track reconstruction inside jets. The dominant uncertainty at high jet p_T is due to the loss of charged-particle tracks in the jet core due to track merging. This charged energy loss uncertainty is estimated using the data/MC differences in the ratio of the track-based jet p_T to the calorimeter-based jet p_T [35]. More charged energy is lost in the data than in the MC and thus this uncertainty is one-sided. There are other tracking uncertainties in the track momentum scale and resolution, the track reconstruction efficiency, and the rate of tracks formed from random combinations of hits (fake tracks). The prescription for these sub-dominant tracking uncertainties is identical to Ref. [35]. The uncertainties related to the calorimeter-based jet are sub-dominant (except in the lowest p_T bins) and are due to the uncertainty in the jet energy scale and the jet energy resolution.

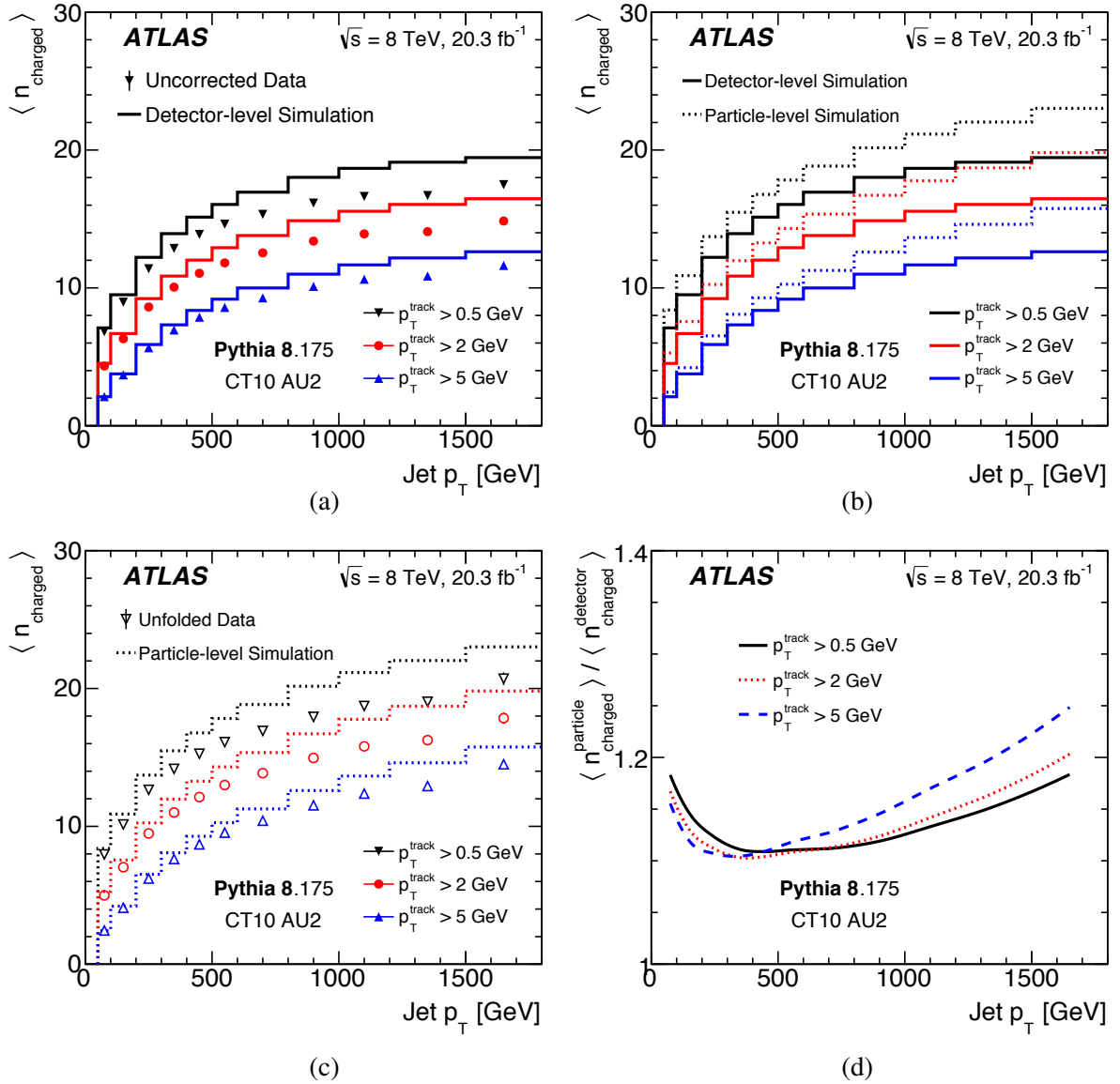


Figure 3: The jet p_T dependence of (a) the average reconstructed track multiplicity for uncorrected data and detector-level simulation, (b) the average reconstructed track multiplicity for the detector-level simulation and the average charged-particle multiplicity for the particle-level simulation, (c) the average charged-particle multiplicity for the unfolded data and the particle-level simulation, and (d) the average charged-particle multiplicity divided by the average reconstructed track multiplicity in simulation. Three charged-particle and track p_T thresholds are used in each case: 0.5 GeV, 2 GeV, and 5 GeV. PYTHIA 8 with the CT10 PDF and the AU2 tune are used for the simulation. For the data, only statistical uncertainties are included in the error bars (which are smaller than the markers for most bins).

Correction Factors: Fake and inefficiency factors are derived from simulation to account for the fraction of events that pass either the detector-level or particle-level fiducial selection ($p_T > 50$ GeV $|\eta| < 2.1$, and $p_T^{\text{lead}}/p_T^{\text{sublead}} < 1.5$), but not both. These factors are derived in bins of jet p_T and charged particle multiplicity, separately for the more forward and more central jets. They are generally between 0.9 and 1.0 except in the first jet- p_T interval ($50 < p_T < 100$ GeV), where threshold

effects cause the correction factors to take values down to 0.8. Experimental uncertainties correlated with the detector-level selection acceptance, such as the jet energy scale uncertainty, result in uncertainties in these correction factors. Another source of uncertainty in the correction factors is the explicit dependence on the particle-level multiplicity and jet p_T spectrum. A comparison of particle-level models (PYTHIA and HERWIG++) is used to estimate the impact on the correction factors.

Unfolding Procedure: A data-driven technique is used to estimate the potential bias from a given choice of a prior distribution and number of iterations in the IB method [63]. The particle-level spectrum is reweighted so that the simulated detector-level spectrum, from propagating the reweighted particle-level spectrum through the response matrix, has significantly improved agreement with the uncorrected data. The modified detector-level distribution is unfolded with the nominal response matrix and the difference between this and the reweighted particle-level spectrum is an indication of the bias due to the unfolding method (in particular, the choice of a prior distribution).

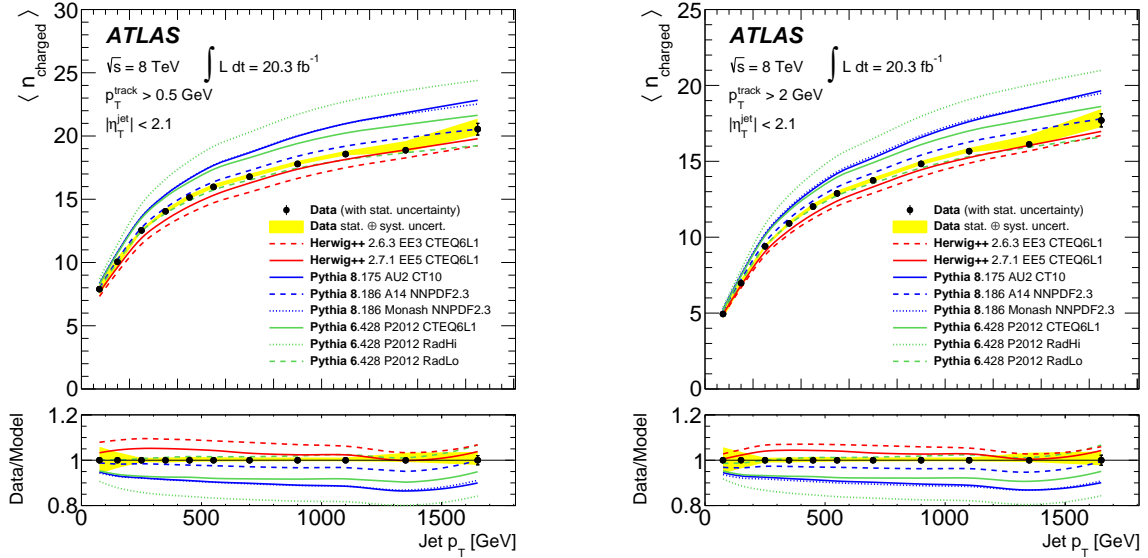
A summary of the systematic uncertainties can be found in Table 2 and more detail about the evaluation of each uncertainty can be found in Ref. [35]. The response matrix uncertainty shown in Table 2 is decomposed into four categories, as described above.

Average n_{charged} Systematic Uncertainty [%]	Jet p_T Range [100 GeV]										
	[0.5,1]	[1,2]	[2,3]	[3,4]	[4,5]	[5,6]	[6,8]	[8,10]	[10,12]	[12,15]	[15,18]
Response Matrix											
Total Jet Energy Scale	+1.9 -1.9	+0.7 -0.9	+0.6 -0.8	+0.8 -0.7	+0.7 -0.7	+0.6 -0.7	+0.6 -0.7	+0.6 -0.5	+0.4 -0.4	+0.3 -0.3	+0.8 -0.7
Jet Energy Resolution	+0.6 -0.6	+0.1 -0.1	+0.1 -0.1	+0.1 -0.1	+0.1 -0.1	+0.1 -0.1	+0.1 -0.1	+0.2 -0.2	+0.1 -0.1	+0.1 -0.1	+0.2 -0.2
Charged Energy Loss	+0.0 -0.0	+0.0 -0.0	+0.0 -0.0	+0.0 -0.0	+1.2 -0.0	+1.1 -0.0	+1.1 -0.0	+1.1 -0.0	+1.0 -0.0	+3.6 -0.0	+3.3 -0.0
Other Tracking	+1.2 -0.0	+1.0 -0.0	+0.9 -0.0	+0.8 -0.0	+0.8 -0.0	+0.7 -0.0	+0.7 -0.0	+0.7 -0.0	+0.7 -0.0	+0.7 -0.0	+0.8 -0.0
Correction Factors	+0.1 -0.1	+0.1 -0.1	+0.1 -0.1	+0.1 -0.1	+0.1 -0.1	+0.1 -0.1	+0.0 -0.0	+0.0 -0.0	+0.0 -0.0	+0.0 -0.0	+0.0 -0.0
Unfolding Procedure	+6.4 -6.4	+3.4 -3.4	+0.6 -0.6	+0.8 -0.8	+0.6 -0.6	+0.4 -0.4	+0.4 -0.4	+0.2 -0.2	+0.2 -0.2	+0.2 -0.2	+0.1 -0.1
Total Systematic	+6.8 -6.7	+3.6 -3.5	+1.2 -1.0	+1.4 -1.1	+1.7 -0.9	+1.5 -0.8	+1.5 -0.8	+1.4 -0.6	+1.3 -0.5	+3.7 -0.4	+3.5 -0.7
Data Statistics	0.5	0.2	0.1	0.1	0.0	0.1	0.1	0.3	0.6	1.2	3.9
Total Uncertainty	+6.8 -6.7	+3.6 -3.6	+1.2 -1.0	+1.4 -1.1	+1.7 -0.9	+1.5 -0.8	+1.5 -0.8	+1.4 -0.6	+1.5 -0.8	+3.9 -1.3	+5.2 -4.0
Measured Value	7.87	9.87	12.19	13.54	14.59	15.41	16.28	17.41	18.25	18.71	20.78

Table 2: A summary of all the systematic uncertainties and their impact on the n_{track} mean for $p_T^{\text{track}} > 0.5$ GeV and the more forward jet. Uncertainties are given in percent. The last row is the measured average charged particle multiplicity. A value of 0.0 is quoted if the uncertainty is below 0.05%.

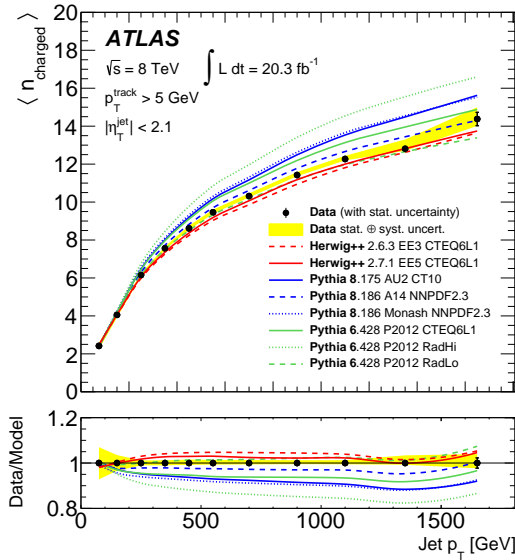
6 Results

The unfolded average charged-particle multiplicity combining both the more forward and the more central jets is shown in Fig. 4, compared with various model predictions. As was already observed for the reconstructed data in Fig. 1, the average charged-particle multiplicity in data falls between the predictions of PYTHIA 8 and HERWIG++, independently of the underlying-event tunes. The PYTHIA 8 predictions are generally higher than the data and this is more pronounced at higher jet p_T . The default ATLAS tune in Run 1 (AU2) performs similarly to the Monash tune, but the prediction with A14 (the ATLAS default for the analysis of Run 2 data) is significantly closer to the data. A previous ATLAS measurement [31] of charged-particle multiplicity inside jets was included in the tuning of A14, but the jets in that measurement have $p_T \lesssim 50$ GeV. One important difference between A14 and Monash is that the value of α_s governing the amount of final-state radiation is about 10% lower in A14 than in Monash. This parameter has a large impact on the average charged-particle multiplicity, which is shown by the PYTHIA 6 lines in Fig. 4 where the Perugia radHi and radLo tunes are significantly separated from the central P2012 tune. The α_s value that regulates final-state radiation is changed by factors of one half and two for these tunes with respect to the nominal Perugia 2012 tune. The recent (and Run 2 default) EE5 underlying-event tune for HERWIG++ improves the modelling of the average charged-particle multiplicity with respect to the EE3 tune (Run 1 default).



(a)

(b)



(c)

Figure 4: The measured average charged-particle multiplicity as a function of the jet p_T , combining the more forward and the more central jets for (a) $p_T^{\text{track}} > 0.5$ GeV, (b) $p_T^{\text{track}} > 2$ GeV, and (c) $p_T^{\text{track}} > 5$ GeV. The band around the data is the sum in quadrature of the statistical and systematic uncertainties. Error bars on the data points represent the statistical uncertainty (which are smaller than the markers for most bins).

The difference in the average charged-particle multiplicity between the more forward and the more central jet is sensitive to the difference between quark and gluon constituent multiplicities. Figure 5(a) shows that the difference is significant for $p_T \lesssim 1.1$ TeV. The shape is governed by the difference in the gluon fraction between the more forward and the more central jet, which was shown in Fig. 2 to peak around $p_T \sim 350$ GeV. The average difference, combined with the gluon fraction, can be used to extract the average charged-particle multiplicity for quark- and gluon-initiated jets separately. Given the quark and gluon fractions $f_{q,g}^{f,c}$ with $f = \text{more forward}$, $c = \text{more central}$, $q = \text{quark}$, $g = \text{gluon}$ and $f_q + f_g = 1$, the average charged-particle multiplicity for quark- and gluon-initiated jets is extracted by solving the system of equations in Eq. (1);

$$\begin{aligned}\langle n_{\text{charged}}^f \rangle &= f_q^f \langle n_{\text{charged}}^q \rangle + f_g^f \langle n_{\text{charged}}^g \rangle \\ \langle n_{\text{charged}}^c \rangle &= f_q^c \langle n_{\text{charged}}^q \rangle + f_g^c \langle n_{\text{charged}}^g \rangle.\end{aligned}\tag{1}$$

Given the jet p_T , the charged particle multiplicity inside jets does not vary significantly with η . This is confirmed by checking that the solution to Eq. 1 reproduces the quark and gluon jet charged particle multiplicities for both PYTHIA 8 and HERWIG++ to better than 1% across most of the p_T range. The extracted p_T dependence of the average charged-particle multiplicities for quark- and gluon-initiated jets is shown in Fig. 5(b). PYTHIA 8 with the CT10 PDF set is used to determine the gluon fractions. The experimental uncertainties are propagated through Eq. (1) by recomputing the quark and gluon average charged-particle multiplicities for each variation accounting for a systematic uncertainty; the more forward and more central jet uncertainties are treated as being fully correlated. In addition to the experimental uncertainties, the error bands in Fig. 5(b) include uncertainties in the gluon fractions from both the PDF and matrix element (ME) uncertainties. The PDF uncertainty is determined using the CT10 eigenvector PDF sets and validated by comparing CT10 and NNPDF. The ME uncertainty is estimated by comparing the fractions $f_{q,g}^{f,c}$ from PYTHIA 8 and HERWIG++ after reweighting the PYTHIA 8 sample with CT10 to CTEQ6L1 to match the PDF used for HERWIG++. All PDF re-weighting is performed using LHAPDF6 [64]. The PDF and ME uncertainties are comparable in size to the total experimental uncertainty. As expected, the average multiplicity increases with jet p_T for both the quark-initiated jets and gluon-initiated jets, but increases faster for gluon-initiated jets. Furthermore, the multiplicity is significantly higher for gluon-initiated jets than for quark-initiated jets. The average charged-particle multiplicity in PYTHIA 8 with the AU2 tune is higher than in the data for both the quark- and gluon-initiated jets. In addition to predictions from leading-logarithm parton shower simulations, calculations of the scale dependence for the parton multiplicity inside jets have been performed in perturbative quantum chromodynamics (pQCD). Up to a non-perturbative factor that is constant for the jet p_T range considered in this analysis,³ these calculations can be interpreted as a prediction for the scale dependence of $\langle n_{\text{charged}} \rangle$ for quark- and gluon-initiated jets. There are further caveats to the predictability of such a calculation since n_{charged} is not infrared safe or even Sudakov safe [65]. Therefore, the formal accuracy of the series expansion in $\sqrt{\alpha_s}$ is unknown. Given these caveats, the next-to-next-to-next-to-leading-order (N³LO) pQCD calculation [66, 67] is overlaid in Fig. 5 with renormalization scale $\mu = Rp_T$ in the five-flavour scheme and $R = 0.4$. The theoretical error band is calculated by varying μ by a factor of two. The prediction cannot give the absolute scale, and therefore the curve is normalized in the second p_T bin ($100 \text{ GeV} < p_T < 200 \text{ GeV}$) where the statistical uncertainty is small. The predicted scale dependence for gluon-initiated jets is consistent with the data within the uncertainty bands while the curve for quark-initiated jets is higher than the data by about one standard deviation.

³ This factor is found to be about 0.19 for gluon jets and 0.25 for quark-initiated jets.

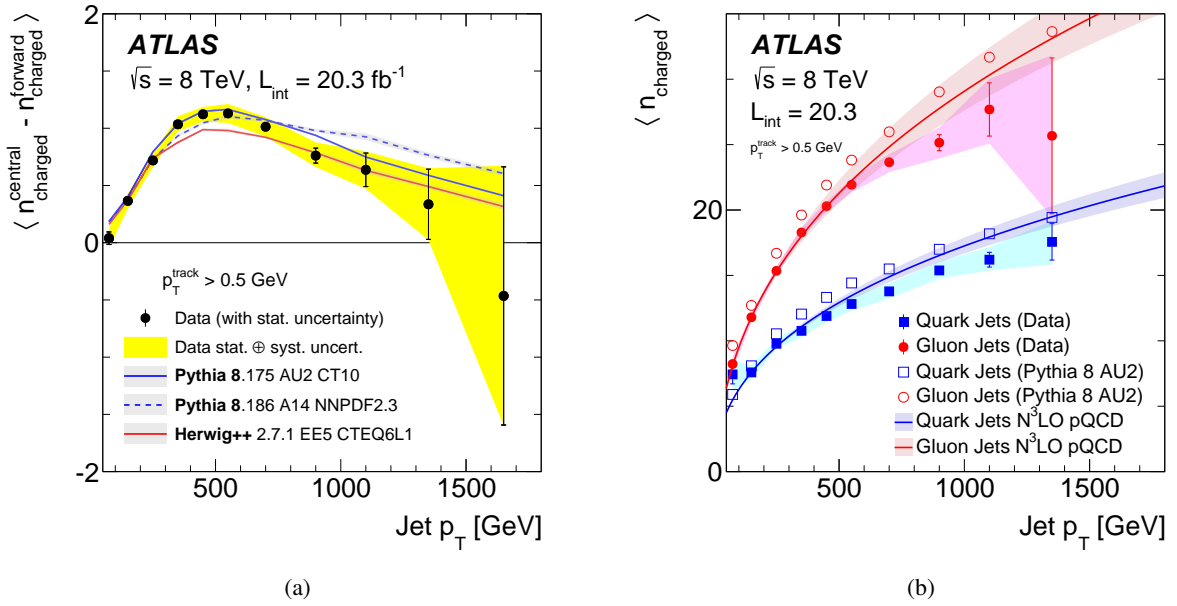


Figure 5: The jet p_T dependence of (a) the difference in the average charged-particle multiplicity ($p_T^{\text{track}} > 0.5$ GeV) between the more forward and the more central jet. The band for the data is the sum in quadrature of the systematic and statistical uncertainties and the error bars on the data points represent the statistical uncertainty. Bands on the simulation include MC statistical uncertainty. The jet p_T dependence of (b) the average charged-particle multiplicity ($p_T^{\text{track}} > 0.5$ GeV) for quark- and gluon-initiated jets, extracted with the gluon fractions from PYTHIA 8.175 with the CT10 PDF. In addition to the experimental uncertainties, the error bands include uncertainties in the gluon fractions from both the PDF and ME uncertainties. The MC statistical uncertainties on the open markers are smaller than the markers. The uncertainty band for the N³LO pQCD prediction is determined by varying the scale μ by a factor of two up and down. The markers are truncated at the penultimate p_T bin in the right because within statistical uncertainty, the more forward and more central jet constituent charged-particle multiplicities are consistent with each other in the last bin.

7 Summary

This paper presents a measurement of the p_T dependence of the average jet charged-particle multiplicity in dijet events from 20.3 fb^{-1} of $\sqrt{s} = 8 \text{ TeV}$ pp collision data recorded by the ATLAS detector at the LHC. The measured charged-particle multiplicity distribution is unfolded to correct for the detector acceptance and resolution to facilitate direct comparison to particle-level models. Comparisons are made at particle level between the measured average charged-particle multiplicity and various models of jet formation. Significant differences are observed between the simulations using Run 1 tunes and the data, but the Run 2 tunes for both PYTHIA 8 and HERWIG++ significantly improve the modelling of the average n_{charge} . Furthermore, quark- and gluon-initiated jet constituent charged-particle multiplicities are extracted and compared with simulations and calculations. As expected, the extracted gluon-initiated jet constituent charged-particle multiplicity is higher than the corresponding quantity for quark-initiated jets and a calculation of the p_T -dependence accurately models the trend observed in the data. The particle-level spectra are available [68] for further interpretation and can serve as a benchmark for future measurements of the evolution of non-perturbative jet observables to validate MC predictions and tune their model parameters.

Acknowledgements

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

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF, DNSRC and Lundbeck Foundation, Denmark; IN2P3-CNRS, CEA-DSM/IRFU, France; GNSF, Georgia; BMBF, HGF, and MPG, Germany; GSRT, Greece; RGC, Hong Kong SAR, China; ISF, I-CORE and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; RCN, Norway; MNiSW and NCN, Poland; FCT, Portugal; MNE/IFA, Romania; MES of Russia and NRC KI, Russian Federation; JINR; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DST/NRF, South Africa; MINECO, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TAEK, Turkey; STFC, United Kingdom; DOE and NSF, United States of America. In addition, individual groups and members have received support from BCKDF, the Canada Council, CANARIE, CRC, Compute Canada, FQRNT, and the Ontario Innovation Trust, Canada; EPLANET, ERC, FP7, Horizon 2020 and Marie Skłodowska-Curie Actions, European Union; Investissements d'Avenir Labex and Idex, ANR, Region Auvergne and Fondation Partager le Savoir, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF; BSF, GIF and Minerva, Israel; BRF, Norway; the Royal Society and Leverhulme Trust, United Kingdom.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN and the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA) and in the Tier-2 facilities worldwide.

References

- [1] R. Ellis, W. Stirling, and B. Webber, *QCD and Collider Physics*, Cambridge University Press, 2003, ISBN: 0521545897.
- [2] **ATLAS** Collaboration, *Light-quark and gluon jet discrimination in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector*, *Eur. Phys. J. C* **74** (2014) 3023, arXiv:1405.6583 [hep-ex].
- [3] **ATLAS** Collaboration, *Search for high-mass diboson resonances with boson-tagged jets in proton-proton collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector*, *JHEP* **12** (2015) 055, arXiv:1506.00962 [hep-ex].
- [4] **ATLAS** Collaboration, *Jet energy measurement and its systematic uncertainty in proton-proton collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector*, *Eur. Phys. J. C* **75** (2015) 17, arXiv:1406.0076 [hep-ex].
- [5] **CMS** Collaboration, *Search for the standard model Higgs boson produced through vector boson fusion and decaying to $b\bar{b}$* , *Phys. Rev. D* **92** (2015) 032008, arXiv:1506.01010 [hep-ex].
- [6] **CMS** Collaboration, *Measurement of electroweak production of two jets in association with a Z boson in proton-proton collisions at $\sqrt{s} = 8$ TeV*, *Eur. Phys. J. C* **75** (2015) 66, arXiv:1410.3153 [hep-ex].
- [7] **UA1** Collaboration, G. Arnison et al., *Analysis of the fragmentation properties of quark and gluon jets at the CERN SPS $p\bar{p}$ collider*, *Nucl. Phys. B* **276** (1986) 253.
- [8] **UA2** Collaboration, P. Bagnaia et al., *Measurement of jet fragmentation properties at the CERN $p\bar{p}$ Collider*, *Phys. Lett. B* **144** (1984) 291.
- [9] **UA2** Collaboration, P. Bagnaia et al., *Measurement of production and properties of jets at the CERN $p\bar{p}$ collider*, *Z. Phys. B* **20** (1983) 117.
- [10] **JADE** Collaboration, W. Bartel et al., *Experimental Evidence for Differences in p_T Between Quark Jets and Gluon Jets*, *Phys. Lett. B* **123** (1983) 460.
- [11] **TASSO** Collaboration, W. Braunschweig et al., *Charged multiplicity distributions and correlations in e^+e^- annihilation at PETRA energies*, *Z. Phys. C* **45** (1989) 193–208.
- [12] **HRS** Collaboration, M. Derrick et al., *Comparison of charged particle multiplicities in quark and gluon jets produced in e^+e^- annihilation at 29 GeV*, *Phys. Lett. B* **165** (1985) 449.
- [13] **MARK II** Collaboration, A. Petersen et al., *Inclusive Charged-Particle Distribution in Nearly Threefold-Symmetric Three-Jet Events at $E_{c.m.} = 29$ GeV*, *Phys. Rev. Lett.* **55** (1985) 1954.
- [14] **SLD** Collaboration, K. Abe et al., *Measurement of the charged multiplicity of $Z^0 \rightarrow b\bar{b}$ events*, *Phys. Rev. Lett.* **72** (1994) 3145, arXiv:hep-ex/9405004 [hep-ex].
- [15] **SLD** Collaboration, K. Abe et al., *Measurement of the charged multiplicities in b, c and light quark events from Z^0 decays*, *Phys. Lett. B* **386** (1996) 475, arXiv:hep-ex/9608008.

- [16] **AMY** Collaboration, Y.K. Kim et al.,
Comparison of quark and gluon jets produced in high-energy e^+e^- annihilations,
[Phys. Rev. Lett. **63** \(1989\) 1772.](#)
- [17] **CLEO** Collaboration, S. Alam et al.,
Study of gluon versus quark fragmentation in $\Upsilon \rightarrow gg\gamma$ and $e^+e^- \rightarrow q\bar{q}\gamma$ events at $\sqrt{s}=10$ GeV,
[Phys. Rev. **D56** \(1997\) 17,](#) arXiv:[hep-ex/9701006 \[hep-ex\]](#).
- [18] **OPAL** Collaboration, G. Alexander et al.,
A Direct observation of quark - gluon jet differences at LEP, [Phys. Lett. **B265** \(1991\) 462–474.](#)
- [19] **OPAL** Collaboration, G. Alexander et al.,
A Study of differences between quark and gluon jets using vertex tagging of quark jets,
[Z. Phys. **C58** \(1993\) 387.](#)
- [20] **OPAL** Collaboration, R. Akers et al.,
A model independent measurement of quark and gluon jet properties and differences,
[Z. Phys. **V68** \(1995\) 179.](#)
- [21] **ALEPH** Collaboration, D. Buskulic et al., *Study of the subjet structure of quark and gluon jets,*
[Phys. Lett. **B346** \(1995\) 389.](#)
- [22] **OPAL** Collaboration, G. Alexander et al.,
Test of QCD analytic predictions for the multiplicity ratio between gluon and quark jets,
[Phys. Lett. **B388** \(1996\) 659.](#)
- [23] **ALEPH** Collaboration, D. Buskulic et al.,
Quark and gluon jet properties in symmetric three-jet events, [Phys. Lett. **B384** \(1996\) 353.](#)
- [24] **DELPHI** Collaboration, P. Abreu et al.,
Energy dependence of the differences between the quark and gluon jet fragmentation,
[Z. Phys. **B70** \(1996\) 179.](#)
- [25] **OPAL** Collaboration, K. Ackerstaff et al.,
Multiplicity distributions of gluon and quark jets and tests of QCD analytic predictions,
[Eur. Phys. J. **C1** \(1998\) 479,](#) arXiv:[hep-ex/9708029 \[hep-ex\]](#).
- [26] **DELPHI** Collaboration, P. Abreu et al., *The scale dependence of the hadron multiplicity in quark and gluon jets and a precise determination of C_A/C_F ,* [Phys. Lett. **B449** \(1999\) 383,](#)
arXiv:[hep-ex/9903073 \[hep-ex\]](#).
- [27] **OPAL** Collaboration, G. Abbiendi et al.,
Experimental properties of gluon and quark jets from a point source,
[Eur. Phys. J. **C11** \(1999\) 217,](#) arXiv:[hep-ex/9903027 \[hep-ex\]](#).
- [28] **OPAL** Collaboration, M. Z. Akrawy et al., *A study of coherence of soft gluons in hadron jets,*
[Phys. Lett. **B247** \(1990\) 617.](#)
- [29] **OPAL** Collaboration, G. Abbiendi et al., *Scaling violations of quark and gluon jet fragmentation functions in e^+e^- annihilations at $\sqrt{s} = 91.2$ and $183 - 209$ GeV,* [Eur. Phys. J. **C37** \(2004\) 25,](#)
arXiv:[hep-ex/0404026 \[hep-ex\]](#).
- [30] **CDF** Collaboration, T. Affolder et al.,
Charged particle multiplicity in jets in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV,
[Phys. Rev. Lett. **87** \(2001\) 211804.](#)

- [31] **ATLAS** Collaboration, *Properties of jets measured from tracks in proton-proton collisions at center-of-mass energy $\sqrt{s} = 7$ TeV with the ATLAS detector*, *Phys. Rev.* **D84** (2011) 054001, arXiv:1107.3311 [hep-ex].
- [32] **ATLAS** Collaboration, *Measurement of the jet fragmentation function and transverse profile in proton-proton collisions at a center-of-mass energy of 7 TeV with the ATLAS detector*, *Eur. Phys. J.* **C71** (2011) 1795, arXiv:1109.5816 [hep-ex].
- [33] **CMS** Collaboration, *Shape, Transverse Size, and Charged Hadron Multiplicity of Jets in pp Collisions at 7 TeV*, *JHEP* **06** (2012) 160, arXiv:1204.3170 [hep-ex].
- [34] **ATLAS** Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *JINST* **3** (2008) S08003.
- [35] **ATLAS** Collaboration, *Measurement of jet charge in dijet events from $\sqrt{s} = 8$ TeV pp collisions with the ATLAS detector*, (2015), arXiv:1509.05190 [hep-ex].
- [36] M. Cacciari, G. P. Salam, and G. Soyez, *The Anti-k(t) jet clustering algorithm*, *JHEP* **04** (2008) 063, arXiv:0802.1189 [hep-ph].
- [37] M. Cacciari, G. P. Salam, and G. Soyez, *FastJet User Manual*, *Eur. Phys. J.* **C72** (2012) 1896, arXiv:1111.6097 [hep-ph].
- [38] W Lampl et al., *Calorimeter Clustering Algorithms: Description and Performance*, (2008), URL: <https://cds.cern.ch/record/1099735>.
- [39] C. Cojocaru et al., *Hadronic calibration of the ATLAS liquid argon end-cap calorimeter in the pseudorapidity region $1.6 < |\eta| < 1.8$ in beam tests*, *Nucl. Instrum. Meth.* **A531** (2004) 481, arXiv:0407009.
- [40] **ATLAS** Collaboration, *Local hadronic calibration*, (2009), URL: <https://cds.cern.ch/record/1112035>.
- [41] **ATLAS** Collaboration, *Performance of pile-up mitigation techniques for jets in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector*, (2015), arXiv:1510.03823 [hep-ex].
- [42] M. Cacciari, G. P. Salam, and G. Soyez, *The Catchment Area of Jets*, *JHEP* **04** (2008) 005.
- [43] T. Sjöstrand, S. Mrenna, and P. Z. Skands, *A Brief Introduction to PYTHIA 8.1*, *Comput. Phys. Commun.* **178** (2008) 852, arXiv:0710.3820 [hep-ph].
- [44] **ATLAS** Collaboration, *Summary of ATLAS Pythia 8 tunes*, (2012), URL: <https://cds.cern.ch/record/1474107>.
- [45] M. Bähr et al., *Herwig++ Physics and Manual*, *Eur. Phys. J.* **C58** (2008) 639–707, arXiv:0803.0883 [hep-ph].
- [46] S. Gieseke, C. Röhr, and A. Siodmok, *Colour reconnections in Herwig++*, *Eur. Phys. J.* **C72** (2012) 2225, arXiv:1206.0041 [hep-ph].
- [47] **ATLAS** Collaboration, *The ATLAS Simulation Infrastructure*, *Eur. Phys. J.* **C70** (2010) 823, arXiv:1005.4568 [physics.ins-det].
- [48] S. Agostinelli et al. (**GEANT4** Collaboration), *GEANT4: A Simulation toolkit*, *Nucl. Instrum. Meth.* **A506** (2003) 250.

- [49] A. D. Martin et al., *Parton distributions for the LHC*, *Eur. Phys. J.* **C63** (2009) 189–285, arXiv:0901.0002 [hep-ph].
- [50] J. Gao et al., *CT10 next-to-next-to-leading order global analysis of QCD*, *Phys. Rev.* **D89** (2014) 033009, arXiv:1302.6246 [hep-ph].
- [51] R. D. Ball et al., *Parton distributions with LHC data*, *Nucl. Phys.* **B867** (2013) 244, arXiv:1207.1303 [hep-ph].
- [52] P. Skands, S. Carrazza, and J. Rojo, *Tuning PYTHIA 8.1: the Monash 2013 Tune*, *Eur. Phys. J.* **C74** (2014) 3024, arXiv:1404.5630 [hep-ph].
- [53] ATLAS Collaboration, *ATLAS Run 1 Pythia 8 tunes*, (2014), URL: <https://cds.cern.ch/record/1966419>.
- [54] K. Arnold et al., *Herwig++ 2.6 Release Note*, (2012), arXiv:1205.4902 [hep-ph].
- [55] D. Stump et al., *Inclusive jet production, parton distributions, and the search for new physics*, *JHEP* **10** (2003) 046, arXiv:hep-ph/0303013 [hep-ph].
- [56] J. Bellm et al., *Herwig++ 2.7 Release Note*, (2013), arXiv:1310.6877 [hep-ph].
- [57] M. H. Seymour and A. Siodmok, *Constraining MPI models using σ_{eff} and recent Tevatron and LHC Underlying Event data*, *JHEP* **10** (2013) 113, arXiv:1307.5015 [hep-ph].
- [58] T. Sjöstrand, S. Mrenna, and P. Z. Skands, *PYTHIA 6.4 Physics and Manual*, *JHEP* **05** (2006) 026, arXiv:hep-ph/0603175 [hep-ph].
- [59] P. Z. Skands, *Tuning Monte Carlo Generators: The Perugia Tunes*, *Phys. Rev.* **D82** (2010) 074018, arXiv:1005.3457 [hep-ph].
- [60] A. Banfi, G. P. Salam, and G. Zanderighi, *Infrared safe definition of jet flavor*, *Eur. Phys. J.* **C47** (2006) 113, arXiv:hep-ph/0601139 [hep-ph].
- [61] G. D’Agostini, *A Multidimensional unfolding method based on Bayes’ theorem*, *Nucl. Instrum. Meth.* **A362** (1995) 487.
- [62] T. Adye, *Unfolding algorithms and tests using RooUnfold*, (2011), arXiv:1105.1160 [physics.data-an].
- [63] B. Malaescu, *An Iterative, dynamically stabilized method of data unfolding*, (2009), arXiv:0907.3791 [physics.data-an].
- [64] A. Buckley et al., *LHAPDF6: parton density access in the LHC precision era*, *Eur. Phys. J.* **C75** (2015) 132, arXiv:1412.7420 [hep-ph].
- [65] A. J. Larkoski, S. Marzani, and J. Thaler, *Sudakov Safety in Perturbative QCD*, *Phys. Rev.* **D91** (2015) 111501, arXiv:1502.01719 [hep-ph].
- [66] A. Capella et al., *Evolution of average multiplicities of quark and gluon jets*, *Phys. Rev.* **D61** (2000) 074009, arXiv:hep-ph/9910226 [hep-ph].
- [67] I. M. Dremin and J. W. Gary, *Energy dependence of mean multiplicities in gluon and quark jets at the next-to-next-to-next-to leading order*, *Phys. Lett.* **B459** (1999) 341, arXiv:hep-ph/9905477 [hep-ph].
- [68] <http://hepdata.cedar.ac.uk/view/ins1419070>.

The ATLAS Collaboration

G. Aad⁸⁷, B. Abbott¹¹⁴, J. Abdallah¹⁵², O. Abdinov¹¹, B. Abeloos¹¹⁸, R. Aben¹⁰⁸, M. Abolins⁹², O.S. AbouZeid¹³⁸, N.L. Abraham¹⁵⁰, H. Abramowicz¹⁵⁴, H. Abreu¹⁵³, R. Abreu¹¹⁷, Y. Abulaiti^{147a,147b}, B.S. Acharya^{163a,163b,a}, L. Adamczyk^{39a}, D.L. Adams²⁶, J. Adelman¹⁰⁹, S. Adomeit¹⁰¹, T. Adye¹³², A.A. Affolder⁷⁶, T. Agatonovic-Jovin¹³, J. Agricola⁵⁵, J.A. Aguilar-Saavedra^{127a,127f}, S.P. Ahlen²³, F. Ahmadov^{67,b}, G. Aielli^{134a,134b}, H. Akerstedt^{147a,147b}, T.P.A. Åkesson⁸³, A.V. Akimov⁹⁷, G.L. Alberghi^{21a,21b}, J. Albert¹⁶⁸, S. Albrand⁵⁶, M.J. Alconada Verzini⁷³, M. Aleksa³¹, I.N. Aleksandrov⁶⁷, C. Alexa^{27b}, G. Alexander¹⁵⁴, T. Alexopoulos¹⁰, M. Alhroob¹¹⁴, G. Alimonti^{93a}, J. Alison³², S.P. Alkire³⁶, B.M.M. Allbrooke¹⁵⁰, B.W. Allen¹¹⁷, P.P. Allport¹⁸, A. Aloisio^{105a,105b}, A. Alonso³⁷, F. Alonso⁷³, C. Alpigiani¹³⁹, B. Alvarez Gonzalez³¹, D. Álvarez Piqueras¹⁶⁶, M.G. Alvigi^{105a,105b}, B.T. Amadio¹⁵, K. Amako⁶⁸, Y. Amaral Coutinho^{25a}, C. Amelung²⁴, D. Amidei⁹¹, S.P. Amor Dos Santos^{127a,127c}, A. Amorim^{127a,127b}, S. Amoroso³¹, N. Amram¹⁵⁴, G. Amundsen²⁴, C. Anastopoulos¹⁴⁰, L.S. Ancu⁵⁰, N. Andari¹⁰⁹, T. Andeen³², C.F. Anders^{59b}, G. Anders³¹, J.K. Anders⁷⁶, K.J. Anderson³², A. Andreazza^{93a,93b}, V. Andrei^{59a}, S. Angelidakis⁹, I. Angelozzi¹⁰⁸, P. Anger⁴⁵, A. Angerami³⁶, F. Anghinolfi³¹, A.V. Anisenkov^{110,c}, N. Anjos¹², A. Annovi^{125a,125b}, M. Antonelli⁴⁸, A. Antonov⁹⁹, J. Antos^{145b}, F. Anulli^{133a}, M. Aoki⁶⁸, L. Aperio Bella¹⁸, G. Arabidze⁹², Y. Arai⁶⁸, J.P. Araque^{127a}, A.T.H. Arce⁴⁶, F.A. Arduh⁷³, J-F. Arguin⁹⁶, S. Argyropoulos⁶⁴, M. Arik^{19a}, A.J. Armbruster³¹, L.J. Armitage⁷⁸, O. Arnaez³¹, H. Arnold⁴⁹, M. Arratia²⁹, O. Arslan²², A. Artamonov⁹⁸, G. Artoni¹²¹, S. Artz⁸⁵, S. Asai¹⁵⁶, N. Asbah⁴³, A. Ashkenazi¹⁵⁴, B. Åsman^{147a,147b}, L. Asquith¹⁵⁰, K. Assamagan²⁶, R. Astalos^{145a}, M. Atkinson¹⁶⁵, N.B. Atlay¹⁴², K. Augsten¹²⁹, G. Avolio³¹, B. Axen¹⁵, M.K. Ayoub¹¹⁸, G. Azuelos^{96,d}, M.A. Baak³¹, A.E. Baas^{59a}, M.J. Baca¹⁸, H. Bachacou¹³⁷, K. Bachas^{75a,75b}, M. Backes³¹, M. Backhaus³¹, P. Bagiacchi^{133a,133b}, P. Bagnaia^{133a,133b}, Y. Bai^{34a}, J.T. Baines¹³², O.K. Baker¹⁷⁵, E.M. Baldin^{110,c}, P. Balek¹³⁰, T. Balestri¹⁴⁹, F. Balli¹³⁷, W.K. Balunas¹²³, E. Banas⁴⁰, Sw. Banerjee^{172,e}, A.A.E. Bannoura¹⁷⁴, L. Barak³¹, E.L. Barberio⁹⁰, D. Barberis^{51a,51b}, M. Barbero⁸⁷, T. Barillari¹⁰², M. Barisonzi^{163a,163b}, T. Barklow¹⁴⁴, N. Barlow²⁹, S.L. Barnes⁸⁶, B.M. Barnett¹³², R.M. Barnett¹⁵, Z. Barnovska⁵, A. Baroncelli^{135a}, G. Barone²⁴, A.J. Barr¹²¹, L. Barranco Navarro¹⁶⁶, F. Barreiro⁸⁴, J. Barreiro Guimarães da Costa^{34a}, R. Bartoldus¹⁴⁴, A.E. Barton⁷⁴, P. Bartos^{145a}, A. Basalaeu¹²⁴, A. Bassalat¹¹⁸, A. Basye¹⁶⁵, R.L. Bates⁵⁴, S.J. Batista¹⁵⁹, J.R. Batley²⁹, M. Battaglia¹³⁸, M. Baucé^{133a,133b}, F. Bauer¹³⁷, H.S. Bawa^{144,f}, J.B. Beacham¹¹², M.D. Beattie⁷⁴, T. Beau⁸², P.H. Beauchemin¹⁶², P. Bechtel²², H.P. Beck^{17,g}, K. Becker¹²¹, M. Becker⁸⁵, M. Beckingham¹⁶⁹, C. Becot¹¹¹, A.J. Beddall^{19e}, A. Beddall^{19b}, V.A. Bednyakov⁶⁷, M. Bedognetti¹⁰⁸, C.P. Bee¹⁴⁹, L.J. Beemster¹⁰⁸, T.A. Beermann³¹, M. Begel²⁶, J.K. Behr⁴³, C. Belanger-Champagne⁸⁹, A.S. Bell⁸⁰, W.H. Bell⁵⁰, G. Bella¹⁵⁴, L. Bellagamba^{21a}, A. Bellerive³⁰, M. Bellomo⁸⁸, K. Belotskiy⁹⁹, O. Beltramello³¹, N.L. Belyaev⁹⁹, O. Benary¹⁵⁴, D. Bencheikroun^{136a}, M. Bender¹⁰¹, K. Bendtz^{147a,147b}, N. Benekos¹⁰, Y. Benhammou¹⁵⁴, E. Benhar Nocchioli¹⁷⁵, J. Benitez⁶⁴, J.A. Benitez Garcia^{160b}, D.P. Benjamin⁴⁶, J.R. Bensinger²⁴, S. Bentvelsen¹⁰⁸, L. Beresford¹²¹, M. Beretta⁴⁸, D. Berge¹⁰⁸, E. Bergeas Kuutmann¹⁶⁴, N. Berger⁵, F. Berghaus¹⁶⁸, J. Beringer¹⁵, S. Berlendis⁵⁶, N.R. Bernard⁸⁸, C. Bernius¹¹¹, F.U. Bernlochner²², T. Berry⁷⁹, P. Berta¹³⁰, C. Bertella⁸⁵, G. Bertoli^{147a,147b}, F. Bertolucci^{125a,125b}, I.A. Bertram⁷⁴, C. Bertsche¹¹⁴, D. Bertsche¹¹⁴, G.J. Besjes³⁷, O. Bessidskaia Bylund^{147a,147b}, M. Bessner⁴³, N. Besson¹³⁷, C. Betancourt⁴⁹, S. Bethke¹⁰², A.J. Bevan⁷⁸, W. Bhimji¹⁵, R.M. Bianchi¹²⁶, L. Bianchini²⁴, M. Bianco³¹, O. Biebel¹⁰¹, D. Biedermann¹⁶, R. Bielski⁸⁶, N.V. Biesuz^{125a,125b}, M. Biglietti^{135a}, J. Bilbao De Mendizabal⁵⁰, H. Bilokon⁴⁸, M. Bindi⁵⁵, S. Binet¹¹⁸, A. Bingul^{19b}, C. Bini^{133a,133b}, S. Biondi^{21a,21b}, D.M. Bjergaard⁴⁶, C.W. Black¹⁵¹, J.E. Black¹⁴⁴, K.M. Black²³, D. Blackburn¹³⁹, R.E. Blair⁶, J.-B. Blanchard¹³⁷, J.E. Blanco⁷⁹, T. Blazek^{145a}, I. Bloch⁴³, C. Blocker²⁴,

W. Blum^{85,*}, U. Blumenschein⁵⁵, S. Blunier^{33a}, G.J. Bobbink¹⁰⁸, V.S. Bobrovnikov^{110,c},
 S.S. Bocchetta⁸³, A. Bocci⁴⁶, C. Bock¹⁰¹, M. Boehler⁴⁹, D. Boerner¹⁷⁴, J.A. Bogaerts³¹, D. Bogovac¹³,
 A.G. Bogdanchikov¹¹⁰, C. Bohm^{147a}, V. Boisvert⁷⁹, T. Bold^{39a}, V. Boldea^{27b}, A.S. Boldyrev^{163a,163c},
 M. Bomben⁸², M. Bona⁷⁸, M. Boonekamp¹³⁷, A. Borisov¹³¹, G. Borissov⁷⁴, J. Bortfeldt¹⁰¹,
 D. Bortoletto¹²¹, V. Bortolotto^{61a,61b,61c}, K. Bos¹⁰⁸, D. Boscherini^{21a}, M. Bosman¹², J.D. Bossio Sola²⁸,
 J. Boudreau¹²⁶, J. Bouffard², E.V. Bouhova-Thacker⁷⁴, D. Boumediene³⁵, C. Bourdarios¹¹⁸,
 S.K. Boutle⁵⁴, A. Boveia³¹, J. Boyd³¹, I.R. Boyko⁶⁷, J. Bracini¹⁸, A. Brandt⁸, G. Brandt⁵⁵,
 O. Brandt^{59a}, U. Bratzler¹⁵⁷, B. Brau⁸⁸, J.E. Brau¹¹⁷, H.M. Braun^{174,*}, W.D. Breaden Madden⁵⁴,
 K. Brendlinger¹²³, A.J. Brennan⁹⁰, L. Brenner¹⁰⁸, R. Brenner¹⁶⁴, S. Bressler¹⁷¹, T.M. Bristow⁴⁷,
 D. Britton⁵⁴, D. Britzger⁴³, F.M. Brochu²⁹, I. Brock²², R. Brock⁹², G. Brooijmans³⁶, T. Brooks⁷⁹,
 W.K. Brooks^{33b}, J. Brosamer¹⁵, E. Brost¹¹⁷, J.H. Broughton¹⁸, P.A. Bruckman de Renstrom⁴⁰,
 D. Bruncko^{145b}, R. Bruneliere⁴⁹, A. Bruni^{21a}, G. Bruni^{21a}, B.H. Brunt²⁹, M. Bruschi^{21a}, N. Bruscinò²²,
 P. Bryant³², L. Bryngemark⁸³, T. Buanes¹⁴, Q. Buat¹⁴³, P. Buchholz¹⁴², A.G. Buckley⁵⁴, I.A. Budagov⁶⁷,
 F. Buehrer⁴⁹, M.K. Bugge¹²⁰, O. Bulekov⁹⁹, D. Bullock⁸, H. Burckhart³¹, S. Burdin⁷⁶, C.D. Burgard⁴⁹,
 B. Burghgrave¹⁰⁹, K. Burka⁴⁰, S. Burke¹³², I. Burmeister⁴⁴, E. Busato³⁵, D. Büscher⁴⁹, V. Büscher⁸⁵,
 P. Bussey⁵⁴, J.M. Butler²³, A.I. Butt³, C.M. Buttar⁵⁴, J.M. Butterworth⁸⁰, P. Butti¹⁰⁸, W. Buttinger²⁶,
 A. Buzatu⁵⁴, A.R. Buzykaev^{110,c}, S. Cabrera Urbán¹⁶⁶, D. Caforio¹²⁹, V.M. Cairo^{38a,38b}, O. Cakir^{4a},
 N. Calace⁵⁰, P. Calafiura¹⁵, A. Calandri⁸⁷, G. Calderini⁸², P. Calfayan¹⁰¹, L.P. Caloba^{25a}, D. Calvet³⁵,
 S. Calvet³⁵, T.P. Calvet⁸⁷, R. Camacho Toro³², S. Camarda³¹, P. Camarri^{134a,134b}, D. Cameron¹²⁰,
 R. Caminal Armadans¹⁶⁵, C. Camincher⁵⁶, S. Campana³¹, M. Campanelli⁸⁰, A. Campoverde¹⁴⁹,
 V. Canale^{105a,105b}, A. Canepa^{160a}, M. Cano Bret^{34e}, J. Cantero⁸⁴, R. Cantrill^{127a}, T. Cao⁴¹,
 M.D.M. Capeans Garrido³¹, I. Caprini^{27b}, M. Caprini^{27b}, M. Capua^{38a,38b}, R. Caputo⁸⁵, R.M. Carbone³⁶,
 R. Cardarelli^{134a}, F. Cardillo⁴⁹, T. Carli³¹, G. Carlino^{105a}, L. Carminati^{93a,93b}, S. Caron¹⁰⁷,
 E. Carquin^{33b}, G.D. Carrillo-Montoya³¹, J.R. Carter²⁹, J. Carvalho^{127a,127c}, D. Casadei⁸⁰,
 M.P. Casado^{12,h}, M. Casolino¹², D.W. Casper⁶⁶, E. Castaneda-Miranda^{146a}, A. Castelli¹⁰⁸,
 V. Castillo Gimenez¹⁶⁶, N.F. Castro^{127a,i}, A. Catinaccio³¹, J.R. Catmore¹²⁰, A. Cattai³¹, J. Caudron⁸⁵,
 V. Cavaliere¹⁶⁵, E. Cavallaro¹², D. Cavalli^{93a}, M. Cavalli-Sforza¹², V. Cavasinni^{125a,125b},
 F. Ceradini^{135a,135b}, L. Cerda Alberich¹⁶⁶, B.C. Cerio⁴⁶, A.S. Cerqueira^{25b}, A. Cerri¹⁵⁰, L. Cerrito⁷⁸,
 F. Cerutti¹⁵, M. Cervi³¹, A. Cervelli¹⁷, S.A. Cetin^{19d}, A. Chafaq^{136a}, D. Chakraborty¹⁰⁹,
 I. Chalupkova¹³⁰, S.K. Chan⁵⁸, Y.L. Chan^{61a}, P. Chang¹⁶⁵, J.D. Chapman²⁹, D.G. Charlton¹⁸,
 A. Chatterjee⁵⁰, C.C. Chau¹⁵⁹, C.A. Chavez Barajas¹⁵⁰, S. Che¹¹², S. Cheatham⁷⁴, A. Chegwidan⁹²,
 S. Chekanov⁶, S.V. Chekulaev^{160a}, G.A. Chelkov^{67,j}, M.A. Chelstowska⁹¹, C. Chen⁶⁵, H. Chen²⁶,
 K. Chen¹⁴⁹, S. Chen^{34c}, S. Chen¹⁵⁶, X. Chen^{34f}, Y. Chen⁶⁹, H.C. Cheng⁹¹, H.J. Cheng^{34a}, Y. Cheng³²,
 A. Cheplakov⁶⁷, E. Cheremushkina¹³¹, R. Cherkaoui El Moursli^{136e}, V. Chernyatin^{26,*}, E. Cheu⁷,
 L. Chevalier¹³⁷, V. Chiarella⁴⁸, G. Chiarelli^{125a,125b}, G. Chiodini^{75a}, A.S. Chisholm¹⁸, A. Chitan^{27b},
 M.V. Chizhov⁶⁷, K. Choi⁶², A.R. Chomont³⁵, S. Chouridou⁹, B.K.B. Chow¹⁰¹, V. Christodoulou⁸⁰,
 D. Chromek-Burckhart³¹, J. Chudoba¹²⁸, A.J. Chuinard⁸⁹, J.J. Chwastowski⁴⁰, L. Chytka¹¹⁶,
 G. Ciapetti^{133a,133b}, A.K. Ciftci^{4a}, D. Cinca⁵⁴, V. Cindro⁷⁷, I.A. Cioara²², A. Ciocio¹⁵, F. Ciroto^{105a,105b},
 Z.H. Citron¹⁷¹, M. Ciubancan^{27b}, A. Clark⁵⁰, B.L. Clark⁵⁸, M.R. Clark³⁶, P.J. Clark⁴⁷, R.N. Clarke¹⁵,
 C. Clement^{147a,147b}, Y. Coadou⁸⁷, M. Cobal^{163a,163c}, A. Coccaro⁵⁰, J. Cochran⁶⁵, L. Coffey²⁴,
 L. Colasurdo¹⁰⁷, B. Cole³⁶, S. Cole¹⁰⁹, A.P. Colijn¹⁰⁸, J. Collot⁵⁶, T. Colombo³¹, G. Compostella¹⁰²,
 P. Conde Muiño^{127a,127b}, E. Coniavitis⁴⁹, S.H. Connell^{146b}, I.A. Connelly⁷⁹, V. Consorti⁴⁹,
 S. Constantinescu^{27b}, C. Conta^{122a,122b}, G. Conti³¹, F. Conventi^{105a,k}, M. Cooke¹⁵, B.D. Cooper⁸⁰,
 A.M. Cooper-Sarkar¹²¹, T. Cornelissen¹⁷⁴, M. Corradi^{133a,133b}, F. Corriveau^{89,l}, A. Corso-Radu⁶⁶,
 A. Cortes-Gonzalez¹², G. Cortiana¹⁰², G. Costa^{93a}, M.J. Costa¹⁶⁶, D. Costanzo¹⁴⁰, G. Cottin²⁹,
 G. Cowan⁷⁹, B.E. Cox⁸⁶, K. Cranmer¹¹¹, S.J. Crawley⁵⁴, G. Cree³⁰, S. Crépe-Renaudin⁵⁶, F. Crescioli⁸²,
 W.A. Cribbs^{147a,147b}, M. Crispin Ortuzar¹²¹, M. Cristinziani²², V. Croft¹⁰⁷, G. Crosetti^{38a,38b},

T. Cuhadar Donszelmann¹⁴⁰, J. Cummings¹⁷⁵, M. Curatolo⁴⁸, J. Cúth⁸⁵, C. Cuthbert¹⁵¹, H. Czirr¹⁴², P. Czodrowski³, S. D'Auria⁵⁴, M. D'Onofrio⁷⁶, M.J. Da Cunha Sargedas De Sousa^{127a,127b}, C. Da Via⁸⁶, W. Dabrowski^{39a}, T. Dai⁹¹, O. Dale¹⁴, F. Dallaire⁹⁶, C. Dallapiccola⁸⁸, M. Dam³⁷, J.R. Dandoy³², N.P. Dang⁴⁹, A.C. Daniells¹⁸, N.S. Dann⁸⁶, M. Danninger¹⁶⁷, M. Dano Hoffmann¹³⁷, V. Dao⁴⁹, G. Darbo^{51a}, S. Darmora⁸, J. Dassoulas³, A. Dattagupta⁶², W. Davey²², C. David¹⁶⁸, T. Davidek¹³⁰, M. Davies¹⁵⁴, P. Davison⁸⁰, Y. Davygora^{59a}, E. Dawe⁹⁰, I. Dawson¹⁴⁰, R.K. Daya-Ishmukhametova⁸⁸, K. De⁸, R. de Asmundis^{105a}, A. De Benedetti¹¹⁴, S. De Castro^{21a,21b}, S. De Cecco⁸², N. De Groot¹⁰⁷, P. de Jong¹⁰⁸, H. De la Torre⁸⁴, F. De Lorenzi⁶⁵, D. De Pedis^{133a}, A. De Salvo^{133a}, U. De Sanctis¹⁵⁰, A. De Santo¹⁵⁰, J.B. De Vivie De Regie¹¹⁸, W.J. Dearnaley⁷⁴, R. Debbe²⁶, C. Debenedetti¹³⁸, D.V. Dedovich⁶⁷, I. Deigaard¹⁰⁸, J. Del Peso⁸⁴, T. Del Prete^{125a,125b}, D. Delgove¹¹⁸, F. Deliot¹³⁷, C.M. Delitzsch⁵⁰, M. Deliyergiyev⁷⁷, A. Dell'Acqua³¹, L. Dell'Asta²³, M. Dell'Orso^{125a,125b}, M. Della Pietra^{105a,k}, D. della Volpe⁵⁰, M. Delmastro⁵, P.A. Delsart⁵⁶, C. Deluca¹⁰⁸, D.A. DeMarco¹⁵⁹, S. Demers¹⁷⁵, M. Demichev⁶⁷, A. Demilly⁸², S.P. Denisov¹³¹, D. Denysiuk¹³⁷, D. Derendarz⁴⁰, J.E. Derkaoui^{136d}, F. Derue⁸², P. Dervan⁷⁶, K. Desch²², C. Deterre⁴³, K. Dette⁴⁴, P.O. Deviveiros³¹, A. Dewhurst¹³², S. Dhaliwal²⁴, A. Di Ciaccio^{134a,134b}, L. Di Ciaccio⁵, W.K. Di Clemente¹²³, A. Di Domenico^{133a,133b}, C. Di Donato^{133a,133b}, A. Di Girolamo³¹, B. Di Girolamo³¹, A. Di Mattia¹⁵³, B. Di Micco^{135a,135b}, R. Di Nardo⁴⁸, A. Di Simone⁴⁹, R. Di Sipio¹⁵⁹, D. Di Valentino³⁰, C. Diaconu⁸⁷, M. Diamond¹⁵⁹, F.A. Dias⁴⁷, M.A. Diaz^{33a}, E.B. Diehl⁹¹, J. Dietrich¹⁶, S. Diglio⁸⁷, A. Dimitrievska¹³, J. Dingfelder²², P. Dita^{27b}, S. Dita^{27b}, F. Dittus³¹, F. Djama⁸⁷, T. Djobava^{52b}, J.I. Djuvsland^{59a}, M.A.B. do Vale^{25c}, D. Dobos³¹, M. Dobre^{27b}, C. Doglioni⁸³, T. Dohmae¹⁵⁶, J. Dolejsi¹³⁰, Z. Dolezal¹³⁰, B.A. Dolgoshein^{99,*}, M. Donadelli^{25d}, S. Donati^{125a,125b}, P. Dondero^{122a,122b}, J. Donini³⁵, J. Dopke¹³², A. Doria^{105a}, M.T. Dova⁷³, A.T. Doyle⁵⁴, E. Drechsler⁵⁵, M. Dris¹⁰, Y. Du^{34d}, J. Duarte-Camperderros¹⁵⁴, E. Duchovni¹⁷¹, G. Duckeck¹⁰¹, O.A. Ducu^{27b}, D. Duda¹⁰⁸, A. Dudarev³¹, L. Dufflot¹¹⁸, L. Duguid⁷⁹, M. Dührssen³¹, M. Dunford^{59a}, H. Duran Yildiz^{4a}, M. Düren⁵³, A. Durglishvili^{52b}, D. Duschinger⁴⁵, B. Dutta⁴³, M. Dyndal^{39a}, C. Eckardt⁴³, K.M. Ecker¹⁰², R.C. Edgar⁹¹, W. Edson², N.C. Edwards⁴⁷, T. Eifert³¹, G. Eigen¹⁴, K. Einsweiler¹⁵, T. Ekelof¹⁶⁴, M. El Kacimi^{136c}, V. Ellajosyula⁸⁷, M. Ellert¹⁶⁴, S. Elles⁵, F. Ellinghaus¹⁷⁴, A.A. Elliot¹⁶⁸, N. Ellis³¹, J. Elmsheuser²⁶, M. Elsing³¹, D. Emelianov¹³², Y. Enari¹⁵⁶, O.C. Endner⁸⁵, M. Endo¹¹⁹, J.S. Ennis¹⁶⁹, J. Erdmann⁴⁴, A. Ereditato¹⁷, G. Ernis¹⁷⁴, J. Ernst², M. Ernst²⁶, S. Errede¹⁶⁵, E. Ertel⁸⁵, M. Escalier¹¹⁸, H. Esch⁴⁴, C. Escobar¹²⁶, B. Esposito⁴⁸, A.I. Etienne¹³⁷, E. Etzion¹⁵⁴, H. Evans⁶², A. Ezhilov¹²⁴, F. Fabbri^{21a,21b}, L. Fabbri^{21a,21b}, G. Facini³², R.M. Fakhruddinov¹³¹, S. Falciano^{133a}, R.J. Falla⁸⁰, J. Faltova¹³⁰, Y. Fang^{34a}, M. Fanti^{93a,93b}, A. Farbin⁸, A. Farilla^{135a}, C. Farina¹²⁶, T. Farooque¹², S. Farrell¹⁵, S.M. Farrington¹⁶⁹, P. Farthouat³¹, F. Fassi^{136e}, P. Fassnacht³¹, D. Fassouliotis⁹, M. Fauci Giannelli⁷⁹, A. Favareto^{51a,51b}, W.J. Fawcett¹²¹, L. Fayard¹¹⁸, O.L. Fedin^{124,m}, W. Fedorko¹⁶⁷, S. Feigl¹²⁰, L. Felgioni⁸⁷, C. Feng^{34d}, E.J. Feng³¹, H. Feng⁹¹, A.B. Fenyuk¹³¹, L. Feremenga⁸, P. Fernandez Martinez¹⁶⁶, S. Fernandez Perez¹², J. Ferrando⁵⁴, A. Ferrari¹⁶⁴, P. Ferrari¹⁰⁸, R. Ferrari^{122a}, D.E. Ferreira de Lima⁵⁴, A. Ferrer¹⁶⁶, D. Ferrere⁵⁰, C. Ferretti⁹¹, A. Ferretto Parodi^{51a,51b}, F. Fiedler⁸⁵, A. Filipčić⁷⁷, M. Filipuzzi⁴³, F. Filthaut¹⁰⁷, M. Fincke-Keeler¹⁶⁸, K.D. Finelli¹⁵¹, M.C.N. Fiolhais^{127a,127c}, L. Fiorini¹⁶⁶, A. Firan⁴¹, A. Fischer², C. Fischer¹², J. Fischer¹⁷⁴, W.C. Fisher⁹², N. Flaschel⁴³, I. Fleck¹⁴², P. Fleischmann⁹¹, G.T. Fletcher¹⁴⁰, G. Fletcher⁷⁸, R.R.M. Fletcher¹²³, T. Flick¹⁷⁴, A. Floderus⁸³, L.R. Flores Castillo^{61a}, M.J. Flowerdew¹⁰², G.T. Forcolin⁸⁶, A. Formica¹³⁷, A. Forti⁸⁶, A.G. Foster¹⁸, D. Fournier¹¹⁸, H. Fox⁷⁴, S. Fracchia¹², P. Francavilla⁸², M. Franchini^{21a,21b}, D. Francis³¹, L. Franconi¹²⁰, M. Franklin⁵⁸, M. Frate⁶⁶, M. Fraternali^{122a,122b}, D. Freeborn⁸⁰, S.M. Fressard-Batraneanu³¹, F. Friedrich⁴⁵, D. Froidevaux³¹, J.A. Frost¹²¹, C. Fukunaga¹⁵⁷, E. Fullana Torregrosa⁸⁵, T. Fusayasu¹⁰³, J. Fuster¹⁶⁶, C. Gabaldon⁵⁶, O. Gabizon¹⁷⁴, A. Gabrielli^{21a,21b}, A. Gabrielli¹⁵, G.P. Gach^{39a}, S. Gadatsch³¹, S. Gadomski⁵⁰, G. Gagliardi^{51a,51b}, L.G. Gagnon⁹⁶, P. Gagnon⁶², C. Galea¹⁰⁷, B. Galhardo^{127a,127c}, E.J. Gallas¹²¹, B.J. Gallop¹³², P. Gallus¹²⁹, G. Galster³⁷, K.K. Gan¹¹², J. Gao^{34b,87}, Y. Gao⁴⁷,

Y.S. Gao^{144,f}, F.M. Garay Walls⁴⁷, C. García¹⁶⁶, J.E. García Navarro¹⁶⁶, M. Garcia-Sciveres¹⁵,
 R.W. Gardner³², N. Garelli¹⁴⁴, V. Garonne¹²⁰, A. Gascon Bravo⁴³, C. Gatti⁴⁸, A. Gaudiello^{51a,51b},
 G. Gaudio^{122a}, B. Gaur¹⁴², L. Gauthier⁹⁶, I.L. Gavrilenko⁹⁷, C. Gay¹⁶⁷, G. Gaycken²², E.N. Gazis¹⁰,
 Z. Gecse¹⁶⁷, C.N.P. Gee¹³², Ch. Geich-Gimbel²², M.P. Geisler^{59a}, C. Gemme^{51a}, M.H. Genest⁵⁶,
 C. Geng^{34b,n}, S. Gentile^{133a,133b}, S. George⁷⁹, D. Gerbaudo⁶⁶, A. Gershon¹⁵⁴, S. Ghasemi¹⁴²,
 H. Ghazlane^{136b}, M. Ghneimat²², B. Giacobbe^{21a}, S. Giagu^{133a,133b}, P. Giannetti^{125a,125b}, B. Gibbard²⁶,
 S.M. Gibson⁷⁹, M. Gignac¹⁶⁷, M. Gilchriese¹⁵, T.P.S. Gillam²⁹, D. Gillberg³⁰, G. Gilles¹⁷⁴,
 D.M. Gingrich^{3,d}, N. Giokaris⁹, M.P. Giordani^{163a,163c}, F.M. Giorgi^{21a}, F.M. Giorgi¹⁶, P.F. Giraud¹³⁷,
 P. Giromini⁵⁸, D. Giugni^{93a}, F. Giuli¹²¹, C. Giuliani¹⁰², M. Giulini^{59b}, B.K. Gjølsten¹²⁰, S. Gkaitatzis¹⁵⁵,
 I. Gkialas¹⁵⁵, E.L. Gkougkousis¹¹⁸, L.K. Gladilin¹⁰⁰, C. Glasman⁸⁴, J. Glatzer³¹, P.C.F. Glaysher⁴⁷,
 A. Glazov⁴³, M. Goblirsch-Kolb¹⁰², J. Godlewski⁴⁰, S. Goldfarb⁹¹, T. Golling⁵⁰, D. Golubkov¹³¹,
 A. Gomes^{127a,127b,127d}, R. Gonçalo^{127a}, J. Goncalves Pinto Firmino Da Costa¹³⁷, L. Gonella¹⁸,
 A. Gongadze⁶⁷, S. González de la Hoz¹⁶⁶, G. Gonzalez Parra¹², S. Gonzalez-Sevilla⁵⁰, L. Goossens³¹,
 P.A. Gorbounov⁹⁸, H.A. Gordon²⁶, I. Gorelov¹⁰⁶, B. Gorini³¹, E. Gorini^{75a,75b}, A. Gorišek⁷⁷,
 E. Gornicki⁴⁰, A.T. Goshaw⁴⁶, C. Gössling⁴⁴, M.I. Gostkin⁶⁷, C.R. Goudet¹¹⁸, D. Goujdami^{136c},
 A.G. Goussiou¹³⁹, N. Govender^{146b}, E. Gozani¹⁵³, L. Graber⁵⁵, I. Grabowska-Bold^{39a}, P.O.J. Gradin¹⁶⁴,
 P. Grafström^{21a,21b}, J. Gramling⁵⁰, E. Gramstad¹²⁰, S. Grancagnolo¹⁶, V. Gratchev¹²⁴, H.M. Gray³¹,
 E. Graziani^{135a}, Z.D. Greenwood^{81,o}, C. Grefe²², K. Gregersen⁸⁰, I.M. Gregor⁴³, P. Grenier¹⁴⁴,
 K. Grevtsov⁵, J. Griffiths⁸, A.A. Grillo¹³⁸, K. Grimm⁷⁴, S. Grinstein^{12,p}, Ph. Gris³⁵, J.-F. Grivaz¹¹⁸,
 S. Groh⁸⁵, J.P. Grohs⁴⁵, E. Gross¹⁷¹, J. Grosse-Knetter⁵⁵, G.C. Grossi⁸¹, Z.J. Grout¹⁵⁰, L. Guan⁹¹,
 W. Guan¹⁷², J. Guenther¹²⁹, F. Guescini⁵⁰, D. Guest⁶⁶, O. Gueta¹⁵⁴, E. Guido^{51a,51b}, T. Guillemin⁵,
 S. Guindon², U. Gul⁵⁴, C. Gumpert³¹, J. Guo^{34e}, Y. Guo^{34b,n}, S. Gupta¹²¹, G. Gustavino^{133a,133b},
 P. Gutierrez¹¹⁴, N.G. Gutierrez Ortiz⁸⁰, C. Gutsche⁴⁵, C. Guyot¹³⁷, C. Gwenlan¹²¹, C.B. Gwilliam⁷⁶,
 A. Haas¹¹¹, C. Haber¹⁵, H.K. Hadavand⁸, N. Haddad^{136e}, A. Hadeef⁸⁷, P. Haefner²², S. Hageböck²²,
 Z. Hajduk⁴⁰, H. Hakobyan^{176,*}, M. Haleem⁴³, J. Haley¹¹⁵, D. Hall¹²¹, G. Halladjian⁹², G.D. Hallewell⁸⁷,
 K. Hamacher¹⁷⁴, P. Hamal¹¹⁶, K. Hamano¹⁶⁸, A. Hamilton^{146a}, G.N. Hamity¹⁴⁰, P.G. Hamnett⁴³,
 L. Han^{34b}, K. Hanagaki^{68,q}, K. Hanawa¹⁵⁶, M. Hance¹³⁸, B. Haney¹²³, P. Hanke^{59a}, R. Hanna¹³⁷,
 J.B. Hansen³⁷, J.D. Hansen³⁷, M.C. Hansen²², P.H. Hansen³⁷, K. Hara¹⁶¹, A.S. Hard¹⁷²,
 T. Harenberg¹⁷⁴, F. Hariri¹¹⁸, S. Harkusha⁹⁴, R.D. Harrington⁴⁷, P.F. Harrison¹⁶⁹, F. Hartjes¹⁰⁸,
 M. Hasegawa⁶⁹, Y. Hasegawa¹⁴¹, A. Hasib¹¹⁴, S. Hassani¹³⁷, S. Haug¹⁷, R. Hauser⁹², L. Hauswald⁴⁵,
 M. Havranek¹²⁸, C.M. Hawkes¹⁸, R.J. Hawkins³¹, A.D. Hawkins⁸³, D. Hayden⁹², C.P. Hays¹²¹,
 J.M. Hays⁷⁸, H.S. Hayward⁷⁶, S.J. Haywood¹³², S.J. Head¹⁸, T. Heck⁸⁵, V. Hedberg⁸³, L. Heelan⁸,
 S. Heim¹²³, T. Heim¹⁵, B. Heinemann¹⁵, J.J. Heinrich¹⁰¹, L. Heinrich¹¹¹, C. Heinz⁵³, J. Hejbal¹²⁸,
 L. Helary²³, S. Hellman^{147a,147b}, C. Helsens³¹, J. Henderson¹²¹, R.C.W. Henderson⁷⁴, Y. Heng¹⁷²,
 S. Henkelmann¹⁶⁷, A.M. Henriques Correia³¹, S. Henrot-Versille¹¹⁸, G.H. Herbert¹⁶,
 Y. Hernández Jiménez¹⁶⁶, G. Herten⁴⁹, R. Hertenberger¹⁰¹, L. Hervas³¹, G.G. Hesketh⁸⁰,
 N.P. Hesse¹⁰⁸, J.W. Hetherly⁴¹, R. Hickling⁷⁸, E. Higón-Rodríguez¹⁶⁶, E. Hill¹⁶⁸, J.C. Hill²⁹,
 K.H. Hiller⁴³, S.J. Hillier¹⁸, I. Hinchliffe¹⁵, E. Hines¹²³, R.R. Hinman¹⁵, M. Hirose¹⁵⁸,
 D. Hirschbuehl¹⁷⁴, J. Hobbs¹⁴⁹, N. Hod¹⁰⁸, M.C. Hodgkinson¹⁴⁰, P. Hodgson¹⁴⁰, A. Hoecker³¹,
 M.R. Hoferkamp¹⁰⁶, F. Hoenig¹⁰¹, M. Hohlfeld⁸⁵, D. Hohn²², T.R. Holmes¹⁵, M. Homann⁴⁴,
 T.M. Hong¹²⁶, B.H. Hooberman¹⁶⁵, W.H. Hopkins¹¹⁷, Y. Horii¹⁰⁴, A.J. Horton¹⁴³, J.-Y. Hostachy⁵⁶,
 S. Hou¹⁵², A. Hoummada^{136a}, J. Howard¹²¹, J. Howarth⁴³, M. Hrabovsky¹¹⁶, I. Hristova¹⁶,
 J. Hrivnac¹¹⁸, T. Hryn'ova⁵, A. Hrynevich⁹⁵, C. Hsu^{146c}, P.J. Hsu^{152,r}, S.-C. Hsu¹³⁹, D. Hu³⁶, Q. Hu^{34b},
 Y. Huang⁴³, Z. Hubacek¹²⁹, F. Hubaut⁸⁷, F. Huegging²², T.B. Huffman¹²¹, E.W. Hughes³⁶, G. Hughes⁷⁴,
 M. Huhtinen³¹, T.A. Hülsing⁸⁵, N. Huseynov^{67,b}, J. Huston⁹², J. Huth⁵⁸, G. Iacobucci⁵⁰, G. Iakovidis²⁶,
 I. Ibragimov¹⁴², L. Iconomidou-Fayard¹¹⁸, E. Ideal¹⁷⁵, Z. Idrissi^{136e}, P. Iengo³¹, O. Igonkina¹⁰⁸,
 T. Iizawa¹⁷⁰, Y. Ikegami⁶⁸, M. Ikeno⁶⁸, Y. Ilchenko^{32,s}, D. Iliadis¹⁵⁵, N. Ilic¹⁴⁴, T. Ince¹⁰²,

G. Introzzi^{122a,122b}, P. Ioannou^{9,*}, M. Iodice^{135a}, K. Iordanidou³⁶, V. Ippolito⁵⁸, A. Irls Quiles¹⁶⁶, C. Isaksson¹⁶⁴, M. Ishino⁷⁰, M. Ishitsuka¹⁵⁸, R. Ishmukhametov¹¹², C. Issever¹²¹, S. Istin^{19a}, F. Ito¹⁶¹, J.M. Iturbe Ponce⁸⁶, R. Iuppa^{134a,134b}, J. Ivarsson⁸³, W. Iwanski⁴⁰, H. Iwasaki⁶⁸, J.M. Izen⁴², V. Izzo^{105a}, S. Jabbar³, B. Jackson¹²³, M. Jackson⁷⁶, P. Jackson¹, V. Jain², K.B. Jakobi⁸⁵, K. Jakobs⁴⁹, S. Jakobsen³¹, T. Jakoubek¹²⁸, D.O. Jamin¹¹⁵, D.K. Jana⁸¹, E. Jansen⁸⁰, R. Jansky⁶³, J. Janssen²², M. Janus⁵⁵, G. Jarlskog⁸³, N. Javadov^{67,b}, T. Javůrek⁴⁹, F. Jeanneau¹³⁷, L. Jeanty¹⁵, J. Jejelava^{52a,t}, G.-Y. Jeng¹⁵¹, D. Jennens⁹⁰, P. Jenni^{49,u}, J. Jentzsch⁴⁴, C. Jeske¹⁶⁹, S. Jézéquel⁵, H. Ji¹⁷², J. Jia¹⁴⁹, H. Jiang⁶⁵, Y. Jiang^{34b}, S. Jiggins⁸⁰, J. Jimenez Pena¹⁶⁶, S. Jin^{34a}, A. Jinaru^{27b}, O. Jinnouchi¹⁵⁸, P. Johansson¹⁴⁰, K.A. Johns⁷, W.J. Johnson¹³⁹, K. Jon-And^{147a,147b}, G. Jones¹⁶⁹, R.W.L. Jones⁷⁴, S. Jones⁷, T.J. Jones⁷⁶, J. Jongmanns^{59a}, P.M. Jorge^{127a,127b}, J. Jovicevic^{160a}, X. Ju¹⁷², A. Juste Rozas^{12,p}, M.K. Köhler¹⁷¹, A. Kaczmarek⁴⁰, M. Kado¹¹⁸, H. Kagan¹¹², M. Kagan¹⁴⁴, S.J. Kahn⁸⁷, E. Kajomovitz⁴⁶, C.W. Kalderon¹²¹, A. Kaluza⁸⁵, S. Kama⁴¹, A. Kamenshchikov¹³¹, N. Kanaya¹⁵⁶, S. Kaneti²⁹, V.A. Kantserov⁹⁹, J. Kanzaki⁶⁸, B. Kaplan¹¹¹, L.S. Kaplan¹⁷², A. Kapliy³², D. Kar^{146c}, K. Karakostas¹⁰, A. Karamaoun³, N. Karastathis^{10,108}, M.J. Kareem⁵⁵, E. Karentzos¹⁰, M. Karnevskiy⁸⁵, S.N. Karpov⁶⁷, Z.M. Karpova⁶⁷, K. Karthik¹¹¹, V. Kartvelishvili⁷⁴, A.N. Karyukhin¹³¹, K. Kasahara¹⁶¹, L. Kashif⁷², R.D. Kass¹¹², A. Kastanas¹⁴, Y. Kataoka¹⁵⁶, C. Kato¹⁵⁶, A. Katre⁵⁰, J. Katzy⁴³, K. Kawade¹⁰⁴, K. Kawagoe⁷², T. Kawamoto¹⁵⁶, G. Kawamura⁵⁵, S. Kazama¹⁵⁶, V.F. Kazanin^{110,c}, R. Keeler¹⁶⁸, R. Kehoe⁴¹, J.S. Keller⁴³, J.J. Kempster⁷⁹, H. Keoshkerian⁸⁶, O. Kepka¹²⁸, B.P. Kerševan⁷⁷, S. Kersten¹⁷⁴, R.A. Keyes⁸⁹, F. Khalil-zada¹¹, H. Khandanyan^{147a,147b}, A. Khanov¹¹⁵, A.G. Kharlamov^{110,c}, T.J. Khoo²⁹, V. Khovanskij⁹⁸, E. Khramov⁶⁷, J. Khubua^{52b,v}, S. Kido⁶⁹, H.Y. Kim⁸, S.H. Kim¹⁶¹, Y.K. Kim³², N. Kimura¹⁵⁵, O.M. Kind¹⁶, B.T. King⁷⁶, M. King¹⁶⁶, S.B. King¹⁶⁷, J. Kirk¹³², A.E. Kiryunin¹⁰², T. Kishimoto⁶⁹, D. Kisielewska^{39a}, F. Kiss⁴⁹, K. Kiuchi¹⁶¹, O. Kivernyk¹³⁷, E. Kladiva^{145b}, M.H. Klein³⁶, M. Klein⁷⁶, U. Klein⁷⁶, K. Kleinknecht⁸⁵, P. Klimek^{147a,147b}, A. Klimentov²⁶, R. Klingenberg⁴⁴, J.A. Klinger¹⁴⁰, T. Klioutchnikova³¹, E.-E. Kluge^{59a}, P. Kluit¹⁰⁸, S. Kluth¹⁰², J. Knapik⁴⁰, E. Kneringer⁶³, E.B.F.G. Knoops⁸⁷, A. Knue⁵⁴, A. Kobayashi¹⁵⁶, D. Kobayashi¹⁵⁸, T. Kobayashi¹⁵⁶, M. Kobel⁴⁵, M. Kocian¹⁴⁴, P. Kodys¹³⁰, T. Koffas³⁰, E. Koffeman¹⁰⁸, L.A. Kogan¹²¹, T. Kohriki⁶⁸, T. Koi¹⁴⁴, H. Kolanoski¹⁶, M. Kolb^{59b}, I. Koletsou⁵, A.A. Komar^{97,*}, Y. Komori¹⁵⁶, T. Kondo⁶⁸, N. Kondrashova⁴³, K. Köneke⁴⁹, A.C. König¹⁰⁷, T. Kono^{68,w}, R. Konoplich^{111,x}, N. Konstantinidis⁸⁰, R. Kopeliansky⁶², S. Koperny^{39a}, L. Köpke⁸⁵, A.K. Kopp⁴⁹, K. Korcyl⁴⁰, K. Kordas¹⁵⁵, A. Korn⁸⁰, A.A. Korol^{110,c}, I. Korolkov¹², E.V. Korolkova¹⁴⁰, O. Kortner¹⁰², S. Kortner¹⁰², T. Kosek¹³⁰, V.V. Kostyukhin²², V.M. Kotov⁶⁷, A. Kotwal⁴⁶, A. Kourkoumeli-Charalampidi¹⁵⁵, C. Kourkoumelis⁹, V. Kouskoura²⁶, A. Koutsman^{160a}, A.B. Kowalewska⁴⁰, R. Kowalewski¹⁶⁸, T.Z. Kowalski^{39a}, W. Kozanecki¹³⁷, A.S. Kozhin¹³¹, V.A. Kramarenko¹⁰⁰, G. Kramberger⁷⁷, D. Krasnopevtsev⁹⁹, M.W. Krasny⁸², A. Krasznahorkay³¹, J.K. Kraus²², A. Kravchenko²⁶, M. Kretz^{59c}, J. Kretzschmar⁷⁶, K. Kreutzfeldt⁵³, P. Krieger¹⁵⁹, K. Krizka³², K. Kroeninger⁴⁴, H. Kroha¹⁰², J. Kroll¹²³, J. Kroseberg²², J. Krstic¹³, U. Kruchonak⁶⁷, H. Krüger²², N. Krumnack⁶⁵, A. Kruse¹⁷², M.C. Kruse⁴⁶, M. Kruskal²³, T. Kubota⁹⁰, H. Kucuk⁸⁰, S. Kудay^{4b}, J.T. Kuechler¹⁷⁴, S. Kuehn⁴⁹, A. Kugel^{59c}, F. Kuger¹⁷³, A. Kuhl¹³⁸, T. Kuhl⁴³, V. Kukhtin⁶⁷, R. Kukla¹³⁷, Y. Kulchitsky⁹⁴, S. Kuleshov^{33b}, M. Kuna^{133a,133b}, T. Kunigo⁷⁰, A. Kupco¹²⁸, H. Kurashige⁶⁹, Y.A. Kurochkin⁹⁴, V. Kus¹²⁸, E.S. Kuwertz¹⁶⁸, M. Kuze¹⁵⁸, J. Kvita¹¹⁶, T. Kwan¹⁶⁸, D. Kyriazopoulos¹⁴⁰, A. La Rosa¹⁰², J.L. La Rosa Navarro^{25d}, L. La Rotonda^{38a,38b}, C. Lacasta¹⁶⁶, F. Lacava^{133a,133b}, J. Lacey³⁰, H. Lacker¹⁶, D. Lacour⁸², V.R. Lacuesta¹⁶⁶, E. Ladygin⁶⁷, R. Lafaye⁵, B. Laforge⁸², T. Lagouri¹⁷⁵, S. Lai⁵⁵, S. Lammers⁶², W. Lampl⁷, E. Lançon¹³⁷, U. Landgraf⁴⁹, M.P.J. Landon⁷⁸, V.S. Lang^{59a}, J.C. Lange¹², A.J. Lankford⁶⁶, F. Lanni²⁶, K. Lantsch²², A. Lanza^{122a}, S. Laplace⁸², C. Lapoire³¹, J.F. Laporte¹³⁷, T. Lari^{93a}, F. Lasagni Manghi^{21a,21b}, M. Lassnig³¹, P. Laurelli⁴⁸, W. Lavrijsen¹⁵, A.T. Law¹³⁸, P. Laycock⁷⁶, T. Lazovich⁵⁸, M. Lazzaroni^{93a,93b}, O. Le Dortz⁸², E. Le Guirriec⁸⁷, E. Le Menedeu¹², E.P. Le Quilleuc¹³⁷, M. LeBlanc¹⁶⁸, T. LeCompte⁶,

F. Ledroit-Guillon⁵⁶, C.A. Lee²⁶, S.C. Lee¹⁵², L. Lee¹, G. Lefebvre⁸², M. Lefebvre¹⁶⁸, F. Legger¹⁰¹,
 C. Leggett¹⁵, A. Lehan⁷⁶, G. Lehmann Miotto³¹, X. Lei⁷, W.A. Leight³⁰, A. Leisos^{155,y}, A.G. Leister¹⁷⁵,
 M.A.L. Leite^{25d}, R. Leitner¹³⁰, D. Lellouch¹⁷¹, B. Lemmer⁵⁵, K.J.C. Leney⁸⁰, T. Lenz²², B. Lenzi³¹,
 R. Leone⁷, S. Leone^{125a,125b}, C. Leonidopoulos⁴⁷, S. Leontsinis¹⁰, G. Lerner¹⁵⁰, C. Leroy⁹⁶,
 A.A.J. Lesage¹³⁷, C.G. Lester²⁹, M. Levchenko¹²⁴, J. Levêque⁵, D. Levin⁹¹, L.J. Levinson¹⁷¹,
 M. Levy¹⁸, A.M. Leyko²², M. Leyton⁴², B. Li^{34b,z}, H. Li¹⁴⁹, H.L. Li³², L. Li⁴⁶, L. Li^{34e}, Q. Li^{34a},
 S. Li⁴⁶, X. Li⁸⁶, Y. Li¹⁴², Z. Liang¹³⁸, H. Liao³⁵, B. Liberti^{134a}, A. Liblong¹⁵⁹, P. Lichard³¹, K. Lie¹⁶⁵,
 J. Liebal²², W. Liebig¹⁴, C. Limbach²², A. Limosani¹⁵¹, S.C. Lin^{152,aa}, T.H. Lin⁸⁵, B.E. Lindquist¹⁴⁹,
 E. Lipeles¹²³, A. Lipniacka¹⁴, M. Lisovyi^{59b}, T.M. Liss¹⁶⁵, D. Lissauer²⁶, A. Lister¹⁶⁷, A.M. Litke¹³⁸,
 B. Liu^{152,ab}, D. Liu¹⁵², H. Liu⁹¹, H. Liu²⁶, J. Liu⁸⁷, J.B. Liu^{34b}, K. Liu⁸⁷, L. Liu¹⁶⁵, M. Liu⁴⁶, M. Liu^{34b},
 Y.L. Liu^{34b}, Y. Liu^{34b}, M. Livan^{122a,122b}, A. Lleres⁵⁶, J. Llorente Merino⁸⁴, S.L. Lloyd⁷⁸, F. Lo Sterzo¹⁵²,
 E. Lobodzinska⁴³, P. Loch⁷, W.S. Lockman¹³⁸, F.K. Loebinger⁸⁶, A.E. Loevschall-Jensen³⁷,
 K.M. Loew²⁴, A. Loginov¹⁷⁵, T. Lohse¹⁶, K. Lohwasser⁴³, M. Lokajicek¹²⁸, B.A. Long²³, J.D. Long¹⁶⁵,
 R.E. Long⁷⁴, L. Longo^{75a,75b}, K.A. Looper¹¹², L. Lopes^{127a}, D. Lopez Mateos⁵⁸, B. Lopez Paredes¹⁴⁰,
 I. Lopez Paz¹², A. Lopez Solis⁸², J. Lorenz¹⁰¹, N. Lorenzo Martinez⁶², M. Losada²⁰, P.J. Lösel¹⁰¹,
 X. Lou^{34a}, A. Lounis¹¹⁸, J. Love⁶, P.A. Love⁷⁴, H. Lu^{61a}, N. Lu⁹¹, H.J. Lubatti¹³⁹, C. Luci^{133a,133b},
 A. Lucotte⁵⁶, C. Luedtke⁴⁹, F. Luehring⁶², W. Lukas⁶³, L. Luminari^{133a}, O. Lundberg^{147a,147b},
 B. Lund-Jensen¹⁴⁸, D. Lynn²⁶, R. Lysak¹²⁸, E. Lytken⁸³, V. Lyubushkin⁶⁷, H. Ma²⁶, L.L. Ma^{34d},
 Y. Ma^{34d}, G. Maccarrone⁴⁸, A. Macchiolo¹⁰², C.M. Macdonald¹⁴⁰, B. Maček⁷⁷,
 J. Machado Miguens^{123,127b}, D. Madaffari⁸⁷, R. Madar³⁵, H.J. Maddocks¹⁶⁴, W.F. Mader⁴⁵,
 A. Madsen⁴³, J. Maeda⁶⁹, S. Maeland¹⁴, T. Maeno²⁶, A. Maevskiy¹⁰⁰, E. Magradze⁵⁵, J. Mahlstedt¹⁰⁸,
 C. Maiani¹¹⁸, C. Maidantchik^{25a}, A.A. Maier¹⁰², T. Maier¹⁰¹, A. Maio^{127a,127b,127d}, S. Majewski¹¹⁷,
 Y. Makida⁶⁸, N. Makovec¹¹⁸, B. Malaescu⁸², Pa. Malecki⁴⁰, V.P. Maleev¹²⁴, F. Malek⁵⁶, U. Mallik⁶⁴,
 D. Malon⁶, C. Malone¹⁴⁴, S. Maltezos¹⁰, V.M. Malyshev¹¹⁰, S. Malyukov³¹, J. Mamuzic⁴³,
 G. Mancini⁴⁸, B. Mandelli³¹, L. Mandelli^{93a}, I. Mandić⁷⁷, J. Maneira^{127a,127b},
 L. Manhaes de Andrade Filho^{25b}, J. Manjarres Ramos^{160b}, A. Mann¹⁰¹, B. Mansoulié¹³⁷, R. Mantifel⁸⁹,
 M. Mantoani⁵⁵, S. Manzoni^{93a,93b}, L. Mapelli³¹, G. Marceca²⁸, L. March⁵⁰, G. Marchiori⁸²,
 M. Marcisovsky¹²⁸, M. Marjanovic¹³, D.E. Marley⁹¹, F. Marroquim^{25a}, S.P. Marsden⁸⁶, Z. Marshall¹⁵,
 L.F. Marti¹⁷, S. Marti-Garcia¹⁶⁶, B. Martin⁹², T.A. Martin¹⁶⁹, V.J. Martin⁴⁷, B. Martin dit Latour¹⁴,
 M. Martinez^{12,p}, S. Martin-Haugh¹³², V.S. Martoiu^{27b}, A.C. Martyniuk⁸⁰, M. Marx¹³⁹, F. Marzano^{133a},
 A. Marzin³¹, L. Masetti⁸⁵, T. Mashimo¹⁵⁶, R. Mashinistov⁹⁷, J. Masik⁸⁶, A.L. Maslennikov^{110,c},
 I. Massa^{21a,21b}, L. Massa^{21a,21b}, P. Mastrandrea⁵, A. Mastroberardino^{38a,38b}, T. Masubuchi¹⁵⁶,
 P. Mättig¹⁷⁴, J. Mattmann⁸⁵, J. Maurer^{27b}, S.J. Maxfield⁷⁶, D.A. Maximov^{110,c}, R. Mazini¹⁵²,
 S.M. Mazza^{93a,93b}, N.C. Mc Fadden¹⁰⁶, G. Mc Goldrick¹⁵⁹, S.P. Mc Kee⁹¹, A. McCarn⁹¹,
 R.L. McCarthy¹⁴⁹, T.G. McCarthy³⁰, L.I. McClymont⁸⁰, K.W. McFarlane^{57,*}, J.A. McFayden⁸⁰,
 G. Mchedlidze⁵⁵, S.J. McMahon¹³², R.A. McPherson^{168,l}, M. Medinnis⁴³, S. Meehan¹³⁹,
 S. Mehlhase¹⁰¹, A. Mehta⁷⁶, K. Meier^{59a}, C. Meineck¹⁰¹, B. Meirose⁴², B.R. Mellado Garcia^{146c},
 F. Meloni¹⁷, A. Mengarelli^{21a,21b}, S. Menke¹⁰², E. Meoni¹⁶², K.M. Mercurio⁵⁸, S. Mergelmeyer¹⁶,
 P. Mermod⁵⁰, L. Merola^{105a,105b}, C. Meroni^{93a}, F.S. Merritt³², A. Messina^{133a,133b}, J. Metcalfe⁶,
 A.S. Mete⁶⁶, C. Meyer⁸⁵, C. Meyer¹²³, J-P. Meyer¹³⁷, J. Meyer¹⁰⁸, H. Meyer Zu Theenhausen^{59a},
 R.P. Middleton¹³², S. Miglioranza^{163a,163c}, L. Mijović²², G. Mikenberg¹⁷¹, M. Mikesstikova¹²⁸,
 M. Mikuž⁷⁷, M. Milesi⁹⁰, A. Milic³¹, D.W. Miller³², C. Mills⁴⁷, A. Milov¹⁷¹, D.A. Milstead^{147a,147b},
 A.A. Minaenko¹³¹, Y. Minami¹⁵⁶, I.A. Minashvili⁶⁷, A.I. Mincer¹¹¹, B. Mindur^{39a}, M. Mineev⁶⁷,
 Y. Ming¹⁷², L.M. Mir¹², K.P. Mistry¹²³, T. Mitani¹⁷⁰, J. Mitrevski¹⁰¹, V.A. Mitsou¹⁶⁶, A. Miucci⁵⁰,
 P.S. Miyagawa¹⁴⁰, J.U. Mjörnmark⁸³, T. Moa^{147a,147b}, K. Mochizuki⁸⁷, S. Mohapatra³⁶, W. Mohr⁴⁹,
 S. Molander^{147a,147b}, R. Moles-Valls²², R. Monden⁷⁰, M.C. Mondragon⁹², K. Mönig⁴³, J. Monk³⁷,
 E. Monnier⁸⁷, A. Montalbano¹⁴⁹, J. Montejo Berlingen³¹, F. Monticelli⁷³, S. Monzani^{93a,93b},

R.W. Moore³, N. Morange¹¹⁸, D. Moreno²⁰, M. Moreno Llácer⁵⁵, P. Morettini^{51a}, D. Mori¹⁴³, T. Mori¹⁵⁶, M. Morii⁵⁸, M. Morinaga¹⁵⁶, V. Morisbak¹²⁰, S. Moritz⁸⁵, A.K. Morley¹⁵¹, G. Mornacchi³¹, J.D. Morris⁷⁸, S.S. Mortensen³⁷, L. Morvaj¹⁴⁹, M. Mosidze^{52b}, J. Moss¹⁴⁴, K. Motohashi¹⁵⁸, R. Mount¹⁴⁴, E. Mountricha²⁶, S.V. Mouraviev^{97,*}, E.J.W. Moyse⁸⁸, S. Muanza⁸⁷, R.D. Mudd¹⁸, F. Mueller¹⁰², J. Mueller¹²⁶, R.S.P. Mueller¹⁰¹, T. Mueller²⁹, D. Muenstermann⁷⁴, P. Mullen⁵⁴, G.A. Mullier¹⁷, F.J. Munoz Sanchez⁸⁶, J.A. Murillo Quijada¹⁸, W.J. Murray^{169,132}, H. Musheghyan⁵⁵, M. Muskinja⁷⁷, A.G. Myagkov^{131.ac}, M. Myska¹²⁹, B.P. Nachman¹⁴⁴, O. Nackenhorst⁵⁰, J. Nadal⁵⁵, K. Nagai¹²¹, R. Nagai^{68,w}, K. Nagano⁶⁸, Y. Nagasaka⁶⁰, K. Nagata¹⁶¹, M. Nagel¹⁰², E. Nagy⁸⁷, A.M. Nairz³¹, Y. Nakahama³¹, K. Nakamura⁶⁸, T. Nakamura¹⁵⁶, I. Nakano¹¹³, H. Namasivayam⁴², R.F. Naranjo Garcia⁴³, R. Narayan³², D.I. Narrias Villar^{59a}, I. Naryshkin¹²⁴, T. Naumann⁴³, G. Navarro²⁰, R. Nayyar⁷, H.A. Neal⁹¹, P.Yu. Nechaeva⁹⁷, T.J. Neep⁸⁶, P.D. Nef¹⁴⁴, A. Negri^{122a,122b}, M. Negrini^{21a}, S. Nektarijevic¹⁰⁷, C. Nellist¹¹⁸, A. Nelson⁶⁶, S. Nemecek¹²⁸, P. Nemethy¹¹¹, A.A. Nepomuceno^{25a}, M. Nessi^{31.ad}, M.S. Neubauer¹⁶⁵, M. Neumann¹⁷⁴, R.M. Neves¹¹¹, P. Nevski²⁶, P.R. Newman¹⁸, D.H. Nguyen⁶, R.B. Nickerson¹²¹, R. Nicolaidou¹³⁷, B. Nicquevert³¹, J. Nielsen¹³⁸, A. Nikiforov¹⁶, V. Nikolaenko^{131.ac}, I. Nikolic-Audit⁸², K. Nikolopoulos¹⁸, J.K. Nilsen¹²⁰, P. Nilsson²⁶, Y. Ninomiya¹⁵⁶, A. Nisati^{133a}, R. Nisius¹⁰², T. Nobe¹⁵⁶, L. Nodulman⁶, M. Nomachi¹¹⁹, I. Nomidis³⁰, T. Nooney⁷⁸, S. Norberg¹¹⁴, M. Nordberg³¹, N. Norjoharuddeen¹²¹, O. Novgorodova⁴⁵, S. Nowak¹⁰², M. Nozaki⁶⁸, L. Nozka¹¹⁶, K. Ntekas¹⁰, E. Nurse⁸⁰, F. Nuti⁹⁰, F. O'grady⁷, D.C. O'Neil¹⁴³, A.A. O'Rourke⁴³, V. O'Shea⁵⁴, F.G. Oakham^{30.d}, H. Oberlack¹⁰², T. Obermann²², J. Ocariz⁸², A. Ochi⁶⁹, I. Ochoa³⁶, J.P. Ochoa-Ricoux^{33a}, S. Oda⁷², S. Odaka⁶⁸, H. Ogren⁶², A. Oh⁸⁶, S.H. Oh⁴⁶, C.C. Ohm¹⁵, H. Ohman¹⁶⁴, H. Oide³¹, H. Okawa¹⁶¹, Y. Okumura³², T. Okuyama⁶⁸, A. Olariu^{27b}, L.F. Oleiro Seabra^{127a}, S.A. Olivares Pino⁴⁷, D. Oliveira Damazio²⁶, A. Olszewski⁴⁰, J. Olszowska⁴⁰, A. Onofre^{127a,127e}, K. Onogi¹⁰⁴, P.U.E. Onyisi^{32,s}, C.J. Oram^{160a}, M.J. Oreglia³², Y. Oren¹⁵⁴, D. Orestano^{135a,135b}, N. Orlando^{61b}, R.S. Orr¹⁵⁹, B. Osculati^{51a,51b}, R. Ospanov⁸⁶, G. Otero y Garzon²⁸, H. Otono⁷², M. Ouchrif^{136d}, F. Ould-Saada¹²⁰, A. Ouraou¹³⁷, K.P. Oussoren¹⁰⁸, Q. Ouyang^{34a}, A. Ovcharova¹⁵, M. Owen⁵⁴, R.E. Owen¹⁸, V.E. Ozcan^{19a}, N. Ozturk⁸, K. Pachal¹⁴³, A. Pacheco Pages¹², C. Padilla Aranda¹², M. Pagáčová⁴⁹, S. Pagan Griso¹⁵, F. Paige²⁶, P. Pais⁸⁸, K. Pajchel¹²⁰, G. Palacino^{160b}, S. Palestini³¹, M. Palka^{39b}, D. Pallin³⁵, A. Palma^{127a,127b}, E.St. Panagiotopoulou¹⁰, C.E. Pandini⁸², J.G. Panduro Vazquez⁷⁹, P. Pani^{147a,147b}, S. Panitkin²⁶, D. Pantea^{27b}, L. Paolozzi⁵⁰, Th.D. Papadopoulou¹⁰, K. Papageorgiou¹⁵⁵, A. Paramonov⁶, D. Paredes Hernandez¹⁷⁵, A.J. Parker⁷⁴, M.A. Parker²⁹, K.A. Parker¹⁴⁰, F. Parodi^{51a,51b}, J.A. Parsons³⁶, U. Parzefall⁴⁹, V. Pascuzzi¹⁵⁹, E. Pasqualucci^{133a}, S. Passaggio^{51a}, F. Pastore^{135a,135b,*}, Fr. Pastore⁷⁹, G. Pásztor³⁰, S. Pataraja¹⁷⁴, N.D. Patel¹⁵¹, J.R. Pater⁸⁶, T. Pauly³¹, J. Pearce¹⁶⁸, B. Pearson¹¹⁴, L.E. Pedersen³⁷, M. Pedersen¹²⁰, S. Pedraza Lopez¹⁶⁶, R. Pedro^{127a,127b}, S.V. Peleganchuk^{110,c}, D. Pelikan¹⁶⁴, O. Penc¹²⁸, C. Peng^{34a}, H. Peng^{34b}, J. Penwell⁶², B.S. Peralva^{25b}, M.M. Perego¹³⁷, D.V. Perepelitsa²⁶, E. Perez Codina^{160a}, L. Perini^{93a,93b}, H. Pernegger³¹, S. Perrella^{105a,105b}, R. Peschke⁴³, V.D. Peshekhonov⁶⁷, K. Peters³¹, R.F.Y. Peters⁸⁶, B.A. Petersen³¹, T.C. Petersen³⁷, E. Petit⁵⁶, A. Petridis¹, C. Petridou¹⁵⁵, P. Petroff¹¹⁸, E. Petrolo^{133a}, M. Petrov¹²¹, F. Petrucci^{135a,135b}, N.E. Pettersson¹⁵⁸, A. Peyaud¹³⁷, R. Pezoa^{33b}, P.W. Phillips¹³², G. Piacquadio¹⁴⁴, E. Pianori¹⁶⁹, A. Picazio⁸⁸, E. Piccaro⁷⁸, M. Piccinini^{21a,21b}, M.A. Pickering¹²¹, R. Piegaia²⁸, J.E. Pilcher³², A.D. Pilkington⁸⁶, A.W.J. Pin⁸⁶, J. Pina^{127a,127b,127d}, M. Pinamonti^{163a,163c,ae}, J.L. Pinfeld³, A. Pingel³⁷, S. Pires⁸², H. Pirumov⁴³, M. Pitt¹⁷¹, L. Plazak^{145a}, M.-A. Pleier²⁶, V. Pleskot⁸⁵, E. Plotnikova⁶⁷, P. Plucinski^{147a,147b}, D. Pluth⁶⁵, R. Poettgen^{147a,147b}, L. Poggioli¹¹⁸, D. Pohl²², G. Polesello^{122a}, A. Poley⁴³, A. Policicchio^{38a,38b}, R. Polifka¹⁵⁹, A. Polini^{21a}, C.S. Pollard⁵⁴, V. Polychronakos²⁶, K. Pommès³¹, L. Pontecorvo^{133a}, B.G. Pope⁹², G.A. Popeneciu^{27c}, D.S. Popovic¹³, A. Poppleton³¹, S. Pospisil¹²⁹, K. Potamianos¹⁵, I.N. Potrap⁶⁷, C.J. Potter²⁹, C.T. Potter¹¹⁷, G. Poulard³¹, J. Poveda³¹, V. Pozdnyakov⁶⁷, M.E. Pozo Astigarraga³¹, P. Pralavorio⁸⁷, A. Pranko¹⁵, S. Prell⁶⁵, D. Price⁸⁶,

L.E. Price⁶, M. Primavera^{75a}, S. Prince⁸⁹, M. Proissl⁴⁷, K. Prokofiev^{61c}, F. Prokoshin^{33b},
 S. Protopopescu²⁶, J. Proudfoot⁶, M. Przybycien^{39a}, D. Puddu^{135a,135b}, D. Puldon¹⁴⁹, M. Purohit^{26,af},
 P. Puzo¹¹⁸, J. Qian⁹¹, G. Qin⁵⁴, Y. Qin⁸⁶, A. Quadt⁵⁵, W.B. Quayle^{163a,163b}, M. Queitsch-Maitland⁸⁶,
 D. Quilty⁵⁴, S. Raddum¹²⁰, V. Radeka²⁶, V. Radescu^{59b}, S.K. Radhakrishnan¹⁴⁹, P. Radloff¹¹⁷,
 P. Rados⁹⁰, F. Ragusa^{93a,93b}, G. Rahal¹⁷⁷, J.A. Raine⁸⁶, S. Rajagopalan²⁶, M. Rammensee³¹,
 C. Rangel-Smith¹⁶⁴, M.G. Ratti^{93a,93b}, F. Rauscher¹⁰¹, S. Rave⁸⁵, T. Ravenscroft⁵⁴, M. Raymond³¹,
 A.L. Read¹²⁰, N.P. Readioff⁷⁶, D.M. Rebuffi^{122a,122b}, A. Redelbach¹⁷³, G. Redlinger²⁶, R. Reece¹³⁸,
 K. Reeves⁴², L. Rehnisch¹⁶, J. Reichert¹²³, H. Reisin²⁸, C. Rembser³¹, H. Ren^{34a}, M. Rescigno^{133a},
 S. Resconi^{93a}, O.L. Rezanova^{110,c}, P. Reznicek¹³⁰, R. Rezvani⁹⁶, R. Richter¹⁰², S. Richter⁸⁰,
 E. Richter-Was^{39b}, O. Ricken²², M. Ridel⁸², P. Rieck¹⁶, C.J. Riegel¹⁷⁴, J. Rieger⁵⁵, O. Rifki¹¹⁴,
 M. Rijssenbeek¹⁴⁹, A. Rimoldi^{122a,122b}, L. Rinaldi^{21a}, B. Ristić⁵⁰, E. Ritsch³¹, I. Riu¹²,
 F. Rizatdinova¹¹⁵, E. Rizvi⁷⁸, C. Rizzi¹², S.H. Robertson^{89,l}, A. Robichaud-Veronneau⁸⁹, D. Robinson²⁹,
 J.E.M. Robinson⁴³, A. Robson⁵⁴, C. Roda^{125a,125b}, Y. Rodina⁸⁷, A. Rodriguez Perez¹²,
 D. Rodriguez Rodriguez¹⁶⁶, S. Roe³¹, C.S. Rogan⁵⁸, O. Røhne¹²⁰, A. Romaniouk⁹⁹, M. Romano^{21a,21b},
 S.M. Romano Saez³⁵, E. Romero Adam¹⁶⁶, N. Rompotis¹³⁹, M. Ronzani⁴⁹, L. Roos⁸², E. Ros¹⁶⁶,
 S. Rosati^{133a}, K. Rosbach⁴⁹, P. Rose¹³⁸, O. Rosenthal¹⁴², V. Rossetti^{147a,147b}, E. Rossi^{105a,105b},
 L.P. Rossi^{51a}, J.H.N. Rosten²⁹, R. Rosten¹³⁹, M. Rotaru^{27b}, I. Roth¹⁷¹, J. Rothberg¹³⁹, D. Rousseau¹¹⁸,
 C.R. Royon¹³⁷, A. Rozanov⁸⁷, Y. Rozen¹⁵³, X. Ruan^{146c}, F. Rubbo¹⁴⁴, I. Rubinskiy⁴³, V.I. Rud¹⁰⁰,
 M.S. Rudolph¹⁵⁹, F. Rühr⁴⁹, A. Ruiz-Martinez³¹, Z. Rurikova⁴⁹, N.A. Rusakovich⁶⁷, A. Ruschke¹⁰¹,
 H.L. Russell¹³⁹, J.P. Rutherford⁷, N. Ruthmann³¹, Y.F. Ryabov¹²⁴, M. Rybar¹⁶⁵, G. Rybkin¹¹⁸, S. Ryu⁶,
 A. Ryzhov¹³¹, A.F. Saavedra¹⁵¹, G. Sabato¹⁰⁸, S. Sacerdoti²⁸, H.F.W. Sadrozinski¹³⁸, R. Sadykov⁶⁷,
 F. Safai Tehrani^{133a}, P. Saha¹⁰⁹, M. Sahinsoy^{59a}, M. Saimpert¹³⁷, T. Saito¹⁵⁶, H. Sakamoto¹⁵⁶,
 Y. Sakurai¹⁷⁰, G. Salamanna^{135a,135b}, A. Salamon^{134a,134b}, J.E. Salazar Loyola^{33b}, D. Salek¹⁰⁸,
 P.H. Sales De Bruin¹³⁹, D. Salihagic¹⁰², A. Salnikov¹⁴⁴, J. Salt¹⁶⁶, D. Salvatore^{38a,38b}, F. Salvatore¹⁵⁰,
 A. Salvucci^{61a}, A. Salzburger³¹, D. Sammel⁴⁹, D. Sampsonidis¹⁵⁵, A. Sanchez^{105a,105b}, J. Sánchez¹⁶⁶,
 V. Sanchez Martinez¹⁶⁶, H. Sandaker¹²⁰, R.L. Sandbach⁷⁸, H.G. Sander⁸⁵, M.P. Sanders¹⁰¹,
 M. Sandhoff¹⁷⁴, C. Sandoval²⁰, R. Sandstroem¹⁰², D.P.C. Sankey¹³², M. Sannino^{51a,51b}, A. Sansoni⁴⁸,
 C. Santoni³⁵, R. Santonico^{134a,134b}, H. Santos^{127a}, I. Santoyo Castillo¹⁵⁰, K. Sapp¹²⁶, A. Saponov⁶⁷,
 J.G. Saraiva^{127a,127d}, B. Sarrazin²², O. Sasaki⁶⁸, Y. Sasaki¹⁵⁶, K. Sato¹⁶¹, G. Sauvage^{5,*}, E. Sauvan⁵,
 G. Savage⁷⁹, P. Savard^{159,d}, C. Sawyer¹³², L. Sawyer^{81,o}, J. Saxon³², C. Sbarra^{21a}, A. Sbrizzi^{21a,21b},
 T. Scanlon⁸⁰, D.A. Scannicchio⁶⁶, M. Scarcella¹⁵¹, V. Scarfone^{38a,38b}, J. Schaarschmidt¹⁷¹,
 P. Schacht¹⁰², D. Schaefer³¹, R. Schaefer⁴³, J. Schaeffer⁸⁵, S. Schaepe²², S. Schaezel^{59b}, U. Schäfer⁸⁵,
 A.C. Schaffer¹¹⁸, D. Schaile¹⁰¹, R.D. Schamberger¹⁴⁹, V. Scharf^{59a}, V.A. Schegelsky¹²⁴, D. Scheirich¹³⁰,
 M. Schernau⁶⁶, C. Schiavi^{51a,51b}, C. Schillo⁴⁹, M. Schioppa^{38a,38b}, S. Schlenker³¹, K. Schmieden³¹,
 C. Schmitt⁸⁵, S. Schmitt⁴³, S. Schmitz⁸⁵, B. Schneider^{160a}, Y.J. Schnellbach⁷⁶, U. Schnoor⁴⁹,
 L. Schoeffel¹³⁷, A. Schoening^{59b}, B.D. Schoenrock⁹², E. Schopf²², A.L.S. Schorlemmer⁴⁴, M. Schott⁸⁵,
 J. Schovancova⁸, S. Schramm⁵⁰, M. Schreyer¹⁷³, N. Schuh⁸⁵, M.J. Schultens²²,
 H.-C. Schultz-Coulon^{59a}, H. Schulz¹⁶, M. Schumacher⁴⁹, B.A. Schumm¹³⁸, Ph. Schune¹³⁷,
 C. Schwanenberger⁸⁶, A. Schwartzman¹⁴⁴, T.A. Schwarz⁹¹, Ph. Schwegler¹⁰², H. Schweiger⁸⁶,
 Ph. Schwemling¹³⁷, R. Schwienhorst⁹², J. Schwindling¹³⁷, T. Schwindt²², G. Sciolla²⁴, F. Scuri^{125a,125b},
 F. Scutti⁹⁰, J. Searcy⁹¹, P. Seema²², S.C. Seidel¹⁰⁶, A. Seiden¹³⁸, F. Seifert¹²⁹, J.M. Seixas^{25a},
 G. Sekhniaidze^{105a}, K. Sekhon⁹¹, S.J. Sekula⁴¹, D.M. Seliverstov^{124,*}, N. Semprini-Cesari^{21a,21b},
 C. Serfon³¹, L. Serin¹¹⁸, L. Serkin^{163a,163b}, M. Sessa^{135a,135b}, R. Seuster^{160a}, H. Severini¹¹⁴, T. Sfiligoj⁷⁷,
 F. Sforza³¹, A. Sfyrla⁵⁰, E. Shabalina⁵⁵, N.W. Shaikh^{147a,147b}, L.Y. Shan^{34a}, R. Shang¹⁶⁵, J.T. Shank²³,
 M. Shapiro¹⁵, P.B. Shatalov⁹⁸, K. Shaw^{163a,163b}, S.M. Shaw⁸⁶, A. Shcherbakova^{147a,147b}, C.Y. Shehu¹⁵⁰,
 P. Sherwood⁸⁰, L. Shi^{152,ag}, S. Shimizu⁶⁹, C.O. Shimmin⁶⁶, M. Shimojima¹⁰³, M. Shiyakova^{67,ah},
 A. Shmeleva⁹⁷, D. Shoaleh Saadi⁹⁶, M.J. Shochet³², S. Shojai^{93a,93b}, S. Shrestha¹¹², E. Shulga⁹⁹,

M.A. Shupe⁷, P. Sicho¹²⁸, P.E. Sidebo¹⁴⁸, O. Sidiropoulou¹⁷³, D. Sidorov¹¹⁵, A. Sidoti^{21a,21b},
F. Siegert⁴⁵, Dj. Sijacki¹³, J. Silva^{127a,127d}, S.B. Silverstein^{147a}, V. Simak¹²⁹, O. Simard⁵, Lj. Simic¹³,
S. Simion¹¹⁸, E. Simioni⁸⁵, B. Simmons⁸⁰, D. Simon³⁵, M. Simon⁸⁵, P. Sinervo¹⁵⁹, N.B. Sinev¹¹⁷,
M. Sioli^{21a,21b}, G. Siragusa¹⁷³, S.Yu. Sivoklov¹⁰⁰, J. Sjölin^{147a,147b}, T.B. Sjursen¹⁴, M.B. Skinner⁷⁴,
H.P. Skottowe⁵⁸, P. Skubic¹¹⁴, M. Slater¹⁸, T. Slavicek¹²⁹, M. Slawinska¹⁰⁸, K. Sliwa¹⁶², R. Slovak¹³⁰,
V. Smakhtin¹⁷¹, B.H. Smart⁵, L. Smestad¹⁴, S.Yu. Smirnov⁹⁹, Y. Smirnov⁹⁹, L.N. Smirnova^{100,ai},
O. Smirnova⁸³, M.N.K. Smith³⁶, R.W. Smith³⁶, M. Smizanska⁷⁴, K. Smolek¹²⁹, A.A. Snesarev⁹⁷,
G. Snidero⁷⁸, S. Snyder²⁶, R. Sobie^{168,l}, F. Socher⁴⁵, A. Soffer¹⁵⁴, D.A. Soh^{152,ag}, G. Sokhrannyi⁷⁷,
C.A. Solans Sanchez³¹, M. Solar¹²⁹, E.Yu. Soldatov⁹⁹, U. Soldevila¹⁶⁶, A.A. Solodkov¹³¹,
A. Soloshenko⁶⁷, O.V. Solovyanov¹³¹, V. Solovyev¹²⁴, P. Sommer⁴⁹, H. Son¹⁶², H.Y. Song^{34b,z},
A. Sood¹⁵, A. Sopczak¹²⁹, V. Sopko¹²⁹, V. Sorin¹², D. Sosa^{59b}, C.L. Sotiropoulou^{125a,125b},
R. Soualah^{163a,163c}, A.M. Soukharev^{110,c}, D. South⁴³, B.C. Sowden⁷⁹, S. Spagnolo^{75a,75b},
M. Spalla^{125a,125b}, M. Spangenberg¹⁶⁹, F. Spanò⁷⁹, D. Sperlich¹⁶, F. Spettel¹⁰², R. Spighi^{21a}, G. Spigo³¹,
L.A. Spiller⁹⁰, M. Spousta¹³⁰, R.D. St. Denis^{54,*}, A. Stabile^{93a}, S. Staerz³¹, J. Stahlman¹²³,
R. Stamen^{59a}, S. Stamm¹⁶, E. Stanecka⁴⁰, R.W. Stanek⁶, C. Stanescu^{135a}, M. Stanescu-Bellu⁴³,
M.M. Stanitzki⁴³, S. Stapnes¹²⁰, E.A. Starchenko¹³¹, G.H. Stark³², J. Stark⁵⁶, P. Staroba¹²⁸,
P. Starovoitov^{59a}, R. Staszewski⁴⁰, P. Steinberg²⁶, B. Stelzer¹⁴³, H.J. Stelzer³¹, O. Stelzer-Chilton^{160a},
H. Stenzel⁵³, G.A. Stewart⁵⁴, J.A. Stillings²², M.C. Stockton⁸⁹, M. Stoebe⁸⁹, G. Stoica^{27b}, P. Stolte⁵⁵,
S. Stonjek¹⁰², A.R. Stradling⁸, A. Straessner⁴⁵, M.E. Stramaglia¹⁷, J. Strandberg¹⁴⁸,
S. Strandberg^{147a,147b}, A. Strandlie¹²⁰, M. Strauss¹¹⁴, P. Strizenec^{145b}, R. Ströhmer¹⁷³, D.M. Strom¹¹⁷,
R. Stroynowski⁴¹, A. Strubig¹⁰⁷, S.A. Stucci¹⁷, B. Stugu¹⁴, N.A. Styles⁴³, D. Su¹⁴⁴, J. Su¹²⁶,
R. Subramaniam⁸¹, S. Suchek^{59a}, Y. Sugaya¹¹⁹, M. Suk¹²⁹, V.V. Sulin⁹⁷, S. Sultansoy^{4c}, T. Sumida⁷⁰,
S. Sun⁵⁸, X. Sun^{34a}, J.E. Sundermann⁴⁹, K. Suruliz¹⁵⁰, G. Susinno^{38a,38b}, M.R. Sutton¹⁵⁰, S. Suzuki⁶⁸,
M. Svatos¹²⁸, M. Swiatlowski³², I. Sykora^{145a}, T. Sykora¹³⁰, D. Ta⁴⁹, C. Taccini^{135a,135b}, K. Tackmann⁴³,
J. Taenzer¹⁵⁹, A. Taffard⁶⁶, R. Tafirout^{160a}, N. Taiblum¹⁵⁴, H. Takai²⁶, R. Takashima⁷¹, H. Takeda⁶⁹,
T. Takeshita¹⁴¹, Y. Takubo⁶⁸, M. Talby⁸⁷, A.A. Talyshev^{110,c}, J.Y.C. Tam¹⁷³, K.G. Tan⁹⁰, J. Tanaka¹⁵⁶,
R. Tanaka¹¹⁸, S. Tanaka⁶⁸, B.B. Tannenwald¹¹², S. Tapia Araya^{33b}, S. Tapprogge⁸⁵, S. Tarem¹⁵³,
G.F. Tartarelli^{93a}, P. Tas¹³⁰, M. Tasevsky¹²⁸, T. Tashiro⁷⁰, E. Tassi^{38a,38b}, A. Tavares Delgado^{127a,127b},
Y. Tayalati^{136d}, A.C. Taylor¹⁰⁶, G.N. Taylor⁹⁰, P.T.E. Taylor⁹⁰, W. Taylor^{160b}, F.A. Teischinger³¹,
P. Teixeira-Dias⁷⁹, K.K. Temming⁴⁹, D. Temple¹⁴³, H. Ten Kate³¹, P.K. Teng¹⁵², J.J. Teoh¹¹⁹,
F. Tepel¹⁷⁴, S. Terada⁶⁸, K. Terashi¹⁵⁶, J. Terron⁸⁴, S. Terzo¹⁰², M. Testa⁴⁸, R.J. Teuscher^{159,l},
T. Thevenaux-Pelzer⁸⁷, J.P. Thomas¹⁸, J. Thomas-Wilsker⁷⁹, E.N. Thompson³⁶, P.D. Thompson¹⁸,
R.J. Thompson⁸⁶, A.S. Thompson⁵⁴, L.A. Thomsen¹⁷⁵, E. Thomson¹²³, M. Thomson²⁹, M.J. Tibbetts¹⁵,
R.E. Ticse Torres⁸⁷, V.O. Tikhomirov^{97,aj}, Yu.A. Tikhonov^{110,c}, S. Timoshenko⁹⁹, P. Tipton¹⁷⁵,
S. Tisserant⁸⁷, K. Todome¹⁵⁸, T. Todorov^{5,*}, S. Todorova-Nova¹³⁰, J. Tojo⁷², S. Tokár^{145a},
K. Tokushuku⁶⁸, E. Tolley⁵⁸, L. Tomlinson⁸⁶, M. Tomoto¹⁰⁴, L. Tompkins^{144,ak}, K. Toms¹⁰⁶, B. Tong⁵⁸,
E. Torrence¹¹⁷, H. Torres¹⁴³, E. Torró Pastor¹³⁹, J. Toth^{87,al}, F. Touchard⁸⁷, D.R. Tovey¹⁴⁰,
T. Trefzger¹⁷³, L. Tremblet³¹, A. Tricoli³¹, I.M. Trigger^{160a}, S. Trincaz-Duvoid⁸², M.F. Tripiana¹²,
W. Trischuk¹⁵⁹, B. Trocme⁵⁶, A. Trofymov⁴³, C. Troncon^{93a}, M. Trotter-McDonald¹⁵, M. Trovatelli¹⁶⁸,
L. Truong^{163a,163b}, M. Trzebinski⁴⁰, A. Trzupek⁴⁰, J.C-L. Tseng¹²¹, P.V. Tsiarehka⁹⁴, G. Tsipolitis¹⁰,
N. Tsirintanis⁹, S. Tsiskaridze¹², V. Tsiskaridze⁴⁹, E.G. Tskhadadze^{52a}, K.M. Tsui^{61a}, I.I. Tsukerman⁹⁸,
V. Tsulaia¹⁵, S. Tsuno⁶⁸, D. Tsybychev¹⁴⁹, A. Tudorache^{27b}, V. Tudorache^{27b}, A.N. Tuna⁵⁸,
S.A. Tupputi^{21a,21b}, S. Turchikhin^{100,ai}, D. Turecek¹²⁹, D. Turgeman¹⁷¹, R. Turra^{93a,93b}, A.J. Turvey⁴¹,
P.M. Tuts³⁶, M. Tyndel¹³², G. Ucchielli^{21a,21b}, I. Ueda¹⁵⁶, R. Ueno³⁰, M. Ughetto^{147a,147b},
F. Ukegawa¹⁶¹, G. Unal³¹, A. Undrus²⁶, G. Unel⁶⁶, F.C. Ungaro⁹⁰, Y. Unno⁶⁸, C. Unverdorben¹⁰¹,
J. Urban^{145b}, P. Urquijo⁹⁰, P. Urrejola⁸⁵, G. Usai⁸, A. Usanova⁶³, L. Vacavant⁸⁷, V. Vacek¹²⁹,
B. Vachon⁸⁹, C. Valderanis¹⁰¹, E. Valdes Santurio^{147a,147b}, N. Valencic¹⁰⁸, S. Valentineti^{21a,21b},

A. Valero¹⁶⁶, L. Valery¹², S. Valkar¹³⁰, S. Vallecorsa⁵⁰, J.A. Valls Ferrer¹⁶⁶, W. Van Den Wollenberg¹⁰⁸, P.C. Van Der Deijl¹⁰⁸, R. van der Geer¹⁰⁸, H. van der Graaf¹⁰⁸, N. van Eldik¹⁵³, P. van Gemmeren⁶, J. Van Nieuwkoop¹⁴³, I. van Vulpen¹⁰⁸, M.C. van Woerden³¹, M. Vanadia^{133a,133b}, W. Vandelli³¹, R. Vanguri¹²³, A. Vaniachine⁶, P. Vankov¹⁰⁸, G. Vardanyan¹⁷⁶, R. Vari^{133a}, E.W. Varnes⁷, T. Varol⁴¹, D. Varouchas⁸², A. Vartapetian⁸, K.E. Varvell¹⁵¹, J.G. Vasquez¹⁷⁵, F. Vazeille³⁵, T. Vazquez Schroeder⁸⁹, J. Veatch⁷, L.M. Veloce¹⁵⁹, F. Veloso^{127a,127c}, S. Veneziano^{133a}, A. Ventura^{75a,75b}, M. Venturi¹⁶⁸, N. Venturi¹⁵⁹, A. Venturini²⁴, V. Vercesi^{122a}, M. Verducci^{133a,133b}, W. Verkerke¹⁰⁸, J.C. Vermeulen¹⁰⁸, A. Vest^{45.am}, M.C. Vetterli^{143,d}, O. Viazlo⁸³, I. Vichou¹⁶⁵, T. Vickey¹⁴⁰, O.E. Vickey Boeriu¹⁴⁰, G.H.A. Viehhauser¹²¹, S. Viel¹⁵, L. Vignani¹²¹, R. Vigne⁶³, M. Villa^{21a,21b}, M. Villaplana Perez^{93a,93b}, E. Vilucchi⁴⁸, M.G. Vincter³⁰, V.B. Vinogradov⁶⁷, C. Vittori^{21a,21b}, I. Vivarelli¹⁵⁰, S. Vlachos¹⁰, M. Vlasak¹²⁹, M. Vogel¹⁷⁴, P. Vokac¹²⁹, G. Volpi^{125a,125b}, M. Volpi⁹⁰, H. von der Schmitt¹⁰², E. von Toerne²², V. Vorobel¹³⁰, K. Vorobev⁹⁹, M. Vos¹⁶⁶, R. Voss³¹, J.H. Vossebeld⁷⁶, N. Vranjes¹³, M. Vranjes Milosavljevic¹³, V. Vrba¹²⁸, M. Vreeswijk¹⁰⁸, R. Vuillermet³¹, I. Vukotic³², Z. Vykydal¹²⁹, P. Wagner²², W. Wagner¹⁷⁴, H. Wahlberg⁷³, S. Wahrmund⁴⁵, J. Wakabayashi¹⁰⁴, J. Walder⁷⁴, R. Walker¹⁰¹, W. Walkowiak¹⁴², V. Wallangen^{147a,147b}, C. Wang¹⁵², C. Wang^{34d,87}, F. Wang¹⁷², H. Wang¹⁵, H. Wang⁴¹, J. Wang⁴³, J. Wang¹⁵¹, K. Wang⁸⁹, R. Wang⁶, S.M. Wang¹⁵², T. Wang²², T. Wang³⁶, X. Wang¹⁷⁵, C. Wanotayaroj¹¹⁷, A. Warburton⁸⁹, C.P. Ward²⁹, D.R. Wardrope⁸⁰, A. Washbrook⁴⁷, P.M. Watkins¹⁸, A.T. Watson¹⁸, I.J. Watson¹⁵¹, M.F. Watson¹⁸, G. Watts¹³⁹, S. Watts⁸⁶, B.M. Waugh⁸⁰, S. Webb⁸⁵, M.S. Weber¹⁷, S.W. Weber¹⁷³, J.S. Webster⁶, A.R. Weidberg¹²¹, B. Weinert⁶², J. Weingarten⁵⁵, C. Weiser⁴⁹, H. Weits¹⁰⁸, P.S. Wells³¹, T. Wenaus²⁶, T. Wengler³¹, S. Wenig³¹, N. Wermes²², M. Werner⁴⁹, P. Werner³¹, M. Wessels^{59a}, J. Wetter¹⁶², K. Whalen¹¹⁷, N.L. Whallon¹³⁹, A.M. Wharton⁷⁴, A. White⁸, M.J. White¹, R. White^{33b}, S. White^{125a,125b}, D. Whiteson⁶⁶, F.J. Wickens¹³², W. Wiedenmann¹⁷², M. Wielers¹³², P. Wienemann²², C. Wiglesworth³⁷, L.A.M. Wiik-Fuchs²², A. Wildauer¹⁰², F. Wilk⁸⁶, H.G. Wilkens³¹, H.H. Williams¹²³, S. Williams¹⁰⁸, C. Willis⁹², S. Willocq⁸⁸, J.A. Wilson¹⁸, I. Wingerter-Seez⁵, F. Winklmeier¹¹⁷, O.J. Winston¹⁵⁰, B.T. Winter²², M. Wittgen¹⁴⁴, J. Wittkowski¹⁰¹, S.J. Wollstadt⁸⁵, M.W. Wolter⁴⁰, H. Wolters^{127a,127c}, B.K. Wosiek⁴⁰, J. Wotschack³¹, M.J. Woudstra⁸⁶, K.W. Wozniak⁴⁰, M. Wu⁵⁶, M. Wu³², S.L. Wu¹⁷², X. Wu⁵⁰, Y. Wu⁹¹, T.R. Wyatt⁸⁶, B.M. Wynne⁴⁷, S. Xella³⁷, D. Xu^{34a}, L. Xu²⁶, B. Yabsley¹⁵¹, S. Yacoub^{146a}, R. Yakabe⁶⁹, D. Yamaguchi¹⁵⁸, Y. Yamaguchi¹¹⁹, A. Yamamoto⁶⁸, S. Yamamoto¹⁵⁶, T. Yamanaka¹⁵⁶, K. Yamauchi¹⁰⁴, Y. Yamazaki⁶⁹, Z. Yan²³, H. Yang^{34e}, H. Yang¹⁷², Y. Yang¹⁵², Z. Yang¹⁴, W-M. Yao¹⁵, Y.C. Yap⁸², Y. Yasu⁶⁸, E. Yatsenko⁵, K.H. Yau Wong²², J. Ye⁴¹, S. Ye²⁶, I. Yeletskikh⁶⁷, A.L. Yen⁵⁸, E. Yildirim⁴³, K. Yorita¹⁷⁰, R. Yoshida⁶, K. Yoshihara¹²³, C. Young¹⁴⁴, C.J.S. Young³¹, S. Youssef²³, D.R. Yu¹⁵, J. Yu⁸, J.M. Yu⁹¹, J. Yu⁶⁵, L. Yuan⁶⁹, S.P.Y. Yuen²², I. Yusuff^{29.am}, B. Zabinski⁴⁰, R. Zaidan^{34d}, A.M. Zaitsev^{131.ac}, N. Zakharuk⁴³, J. Zalieckas¹⁴, A. Zaman¹⁴⁹, S. Zambito⁵⁸, L. Zanello^{133a,133b}, D. Zanzi⁹⁰, C. Zeitnitz¹⁷⁴, M. Zeman¹²⁹, A. Zemla^{39a}, J.C. Zeng¹⁶⁵, Q. Zeng¹⁴⁴, K. Zengel²⁴, O. Zenin¹³¹, T. Ženiš^{145a}, D. Zerwas¹¹⁸, D. Zhang⁹¹, F. Zhang¹⁷², G. Zhang^{34b,z}, H. Zhang^{34c}, J. Zhang⁶, L. Zhang⁴⁹, R. Zhang²², R. Zhang^{34b,ao}, X. Zhang^{34d}, Z. Zhang¹¹⁸, X. Zhao⁴¹, Y. Zhao^{34d,118}, Z. Zhao^{34b}, A. Zhemchugov⁶⁷, J. Zhong¹²¹, B. Zhou⁹¹, C. Zhou⁴⁶, L. Zhou³⁶, L. Zhou⁴¹, M. Zhou¹⁴⁹, N. Zhou^{34f}, C.G. Zhu^{34d}, H. Zhu^{34a}, J. Zhu⁹¹, Y. Zhu^{34b}, X. Zhuang^{34a}, K. Zhukov⁹⁷, A. Zibell¹⁷³, D. Ziemska⁶², N.I. Zimine⁶⁷, C. Zimmermann⁸⁵, S. Zimmermann⁴⁹, Z. Zinonos⁵⁵, M. Zinser⁸⁵, M. Ziolkowski¹⁴², L. Živković¹³, G. Zobernig¹⁷², A. Zoccoli^{21a,21b}, M. zur Nedden¹⁶, G. Zurzolo^{105a,105b}, L. Zwalinski³¹.

¹ Department of Physics, University of Adelaide, Adelaide, Australia

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

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

⁴ (a) Department of Physics, Ankara University, Ankara; (b) Istanbul Aydin University, Istanbul; (c)

Division of Physics, TOBB University of Economics and Technology, Ankara, Turkey

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

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

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

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

⁹ Physics Department, University of Athens, Athens, Greece

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

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

¹² Institut de Física d'Altes Energies (IFAE), The Barcelona Institute of Science and Technology, Barcelona, Spain, Spain

¹³ Institute of Physics, University of Belgrade, Belgrade, Serbia

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

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

¹⁶ Department of Physics, Humboldt University, Berlin, Germany

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

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

¹⁹ ^(a) Department of Physics, Bogazici University, Istanbul; ^(b) Department of Physics Engineering, Gaziantep University, Gaziantep; ^(d) Istanbul Bilgi University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey; ^(e) Bahcesehir University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey, Turkey

²⁰ Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia

²¹ ^(a) INFN Sezione di Bologna; ^(b) Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna, Italy

²² Physikalisches Institut, University of Bonn, Bonn, Germany

²³ Department of Physics, Boston University, Boston MA, United States of America

²⁴ Department of Physics, Brandeis University, Waltham MA, United States of America

²⁵ ^(a) Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; ^(b) Electrical Circuits Department, Federal University of Juiz de Fora (UFJF), Juiz de Fora; ^(c) Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei; ^(d) Instituto de Fisica, Universidade de Sao Paulo, Sao Paulo, Brazil

²⁶ Physics Department, Brookhaven National Laboratory, Upton NY, United States of America

²⁷ ^(a) Transilvania University of Brasov, Brasov, Romania; ^(b) National Institute of Physics and Nuclear Engineering, Bucharest; ^(c) National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj Napoca; ^(d) University Politehnica Bucharest, Bucharest; ^(e) West University in Timisoara, Timisoara, Romania

²⁸ Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina

²⁹ Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom

³⁰ Department of Physics, Carleton University, Ottawa ON, Canada

³¹ CERN, Geneva, Switzerland

³² Enrico Fermi Institute, University of Chicago, Chicago IL, United States of America

³³ ^(a) Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; ^(b) Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile

³⁴ ^(a) Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; ^(b) Department of Modern Physics, University of Science and Technology of China, Anhui; ^(c) Department of Physics, Nanjing University, Jiangsu; ^(d) School of Physics, Shandong University, Shandong; ^(e) Department of Physics and Astronomy, Shanghai Key Laboratory for Particle Physics and Cosmology, Shanghai Jiao

Tong University, Shanghai; (also affiliated with PKU-CHEP); ^(f) Physics Department, Tsinghua University, Beijing 100084, China

³⁵ Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Clermont-Ferrand, France

³⁶ Nevis Laboratory, Columbia University, Irvington NY, United States of America

³⁷ Niels Bohr Institute, University of Copenhagen, Kobenhavn, Denmark

³⁸ ^(a) INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati; ^(b) Dipartimento di Fisica, Università della Calabria, Rende, Italy

³⁹ ^(a) AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow; ^(b) Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland

⁴⁰ Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland

⁴¹ Physics Department, Southern Methodist University, Dallas TX, United States of America

⁴² Physics Department, University of Texas at Dallas, Richardson TX, United States of America

⁴³ DESY, Hamburg and Zeuthen, Germany

⁴⁴ Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany

⁴⁵ Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany

⁴⁶ Department of Physics, Duke University, Durham NC, United States of America

⁴⁷ SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom

⁴⁸ INFN Laboratori Nazionali di Frascati, Frascati, Italy

⁴⁹ Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg, Germany

⁵⁰ Section de Physique, Université de Genève, Geneva, Switzerland

⁵¹ ^(a) INFN Sezione di Genova; ^(b) Dipartimento di Fisica, Università di Genova, Genova, Italy

⁵² ^(a) E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi; ^(b) High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia

⁵³ II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany

⁵⁴ SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom

⁵⁵ II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany

⁵⁶ Laboratoire de Physique Subatomique et de Cosmologie, Université Grenoble-Alpes, CNRS/IN2P3, Grenoble, France

⁵⁷ Department of Physics, Hampton University, Hampton VA, United States of America

⁵⁸ Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA, United States of America

⁵⁹ ^(a) Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; ^(b) Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; ^(c) ZITI Institut für technische Informatik, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany

⁶⁰ Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan

⁶¹ ^(a) Department of Physics, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong; ^(b) Department of Physics, The University of Hong Kong, Hong Kong; ^(c) Department of Physics, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China

⁶² Department of Physics, Indiana University, Bloomington IN, United States of America

⁶³ Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria

⁶⁴ University of Iowa, Iowa City IA, United States of America

⁶⁵ Department of Physics and Astronomy, Iowa State University, Ames IA, United States of America

⁶⁶ Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States of America

⁶⁷ Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia

⁶⁸ KEK, High Energy Accelerator Research Organization, Tsukuba, Japan

- 69 Graduate School of Science, Kobe University, Kobe, Japan
- 70 Faculty of Science, Kyoto University, Kyoto, Japan
- 71 Kyoto University of Education, Kyoto, Japan
- 72 Department of Physics, Kyushu University, Fukuoka, Japan
- 73 Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
- 74 Physics Department, Lancaster University, Lancaster, United Kingdom
- 75 ^(a) INFN Sezione di Lecce; ^(b) Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
- 76 Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
- 77 Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
- 78 School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom
- 79 Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
- 80 Department of Physics and Astronomy, University College London, London, United Kingdom
- 81 Louisiana Tech University, Ruston LA, United States of America
- 82 Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
- 83 Fysiska institutionen, Lunds universitet, Lund, Sweden
- 84 Departamento de Física Teórica C-15, Universidad Autónoma de Madrid, Madrid, Spain
- 85 Institut für Physik, Universität Mainz, Mainz, Germany
- 86 School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
- 87 CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
- 88 Department of Physics, University of Massachusetts, Amherst MA, United States of America
- 89 Department of Physics, McGill University, Montreal QC, Canada
- 90 School of Physics, University of Melbourne, Victoria, Australia
- 91 Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
- 92 Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States of America
- 93 ^(a) INFN Sezione di Milano; ^(b) Dipartimento di Fisica, Università di Milano, Milano, Italy
- 94 B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Republic of Belarus
- 95 National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Republic of Belarus
- 96 Group of Particle Physics, University of Montreal, Montreal QC, Canada
- 97 P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia
- 98 Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
- 99 National Research Nuclear University MEPhI, Moscow, Russia
- 100 D.V. Skobel'syn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia
- 101 Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
- 102 Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
- 103 Nagasaki Institute of Applied Science, Nagasaki, Japan
- 104 Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan
- 105 ^(a) INFN Sezione di Napoli; ^(b) Dipartimento di Fisica, Università di Napoli, Napoli, Italy
- 106 Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, United States of America
- 107 Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands

- ¹⁰⁸ Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
- ¹⁰⁹ Department of Physics, Northern Illinois University, DeKalb IL, United States of America
- ¹¹⁰ Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia
- ¹¹¹ Department of Physics, New York University, New York NY, United States of America
- ¹¹² Ohio State University, Columbus OH, United States of America
- ¹¹³ Faculty of Science, Okayama University, Okayama, Japan
- ¹¹⁴ Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States of America
- ¹¹⁵ Department of Physics, Oklahoma State University, Stillwater OK, United States of America
- ¹¹⁶ Palacký University, RCPTM, Olomouc, Czech Republic
- ¹¹⁷ Center for High Energy Physics, University of Oregon, Eugene OR, United States of America
- ¹¹⁸ LAL, Univ. Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France
- ¹¹⁹ Graduate School of Science, Osaka University, Osaka, Japan
- ¹²⁰ Department of Physics, University of Oslo, Oslo, Norway
- ¹²¹ Department of Physics, Oxford University, Oxford, United Kingdom
- ¹²² ^(a) INFN Sezione di Pavia; ^(b) Dipartimento di Fisica, Università di Pavia, Pavia, Italy
- ¹²³ Department of Physics, University of Pennsylvania, Philadelphia PA, United States of America
- ¹²⁴ National Research Centre "Kurchatov Institute" B.P.Konstantinov Petersburg Nuclear Physics Institute, St. Petersburg, Russia
- ¹²⁵ ^(a) INFN Sezione di Pisa; ^(b) Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
- ¹²⁶ Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States of America
- ¹²⁷ ^(a) Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa; ^(b) Faculdade de Ciências, Universidade de Lisboa, Lisboa; ^(c) Department of Physics, University of Coimbra, Coimbra; ^(d) Centro de Física Nuclear da Universidade de Lisboa, Lisboa; ^(e) Departamento de Física, Universidade do Minho, Braga; ^(f) Departamento de Física Teórica y del Cosmos and CAFPE, Universidad de Granada, Granada (Spain); ^(g) Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal
- ¹²⁸ Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
- ¹²⁹ Czech Technical University in Prague, Praha, Czech Republic
- ¹³⁰ Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic
- ¹³¹ State Research Center Institute for High Energy Physics (Protvino), NRC KI, Russia
- ¹³² Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
- ¹³³ ^(a) INFN Sezione di Roma; ^(b) Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy
- ¹³⁴ ^(a) INFN Sezione di Roma Tor Vergata; ^(b) Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
- ¹³⁵ ^(a) INFN Sezione di Roma Tre; ^(b) Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy
- ¹³⁶ ^(a) Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca; ^(b) Centre National de l'Énergie des Sciences Techniques Nucleaires, Rabat; ^(c) Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech; ^(d) Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; ^(e) Faculté des sciences, Université Mohammed V, Rabat, Morocco
- ¹³⁷ DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Énergie Atomique et aux Énergies Alternatives), Gif-sur-Yvette, France
- ¹³⁸ Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States of America

States of America

- ¹³⁹ Department of Physics, University of Washington, Seattle WA, United States of America
- ¹⁴⁰ Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
- ¹⁴¹ Department of Physics, Shinshu University, Nagano, Japan
- ¹⁴² Fachbereich Physik, Universität Siegen, Siegen, Germany
- ¹⁴³ Department of Physics, Simon Fraser University, Burnaby BC, Canada
- ¹⁴⁴ SLAC National Accelerator Laboratory, Stanford CA, United States of America
- ¹⁴⁵ ^(a) Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava; ^(b) Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic
- ¹⁴⁶ ^(a) Department of Physics, University of Cape Town, Cape Town; ^(b) Department of Physics, University of Johannesburg, Johannesburg; ^(c) School of Physics, University of the Witwatersrand, Johannesburg, South Africa
- ¹⁴⁷ ^(a) Department of Physics, Stockholm University; ^(b) The Oskar Klein Centre, Stockholm, Sweden
- ¹⁴⁸ Physics Department, Royal Institute of Technology, Stockholm, Sweden
- ¹⁴⁹ Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook NY, United States of America
- ¹⁵⁰ Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
- ¹⁵¹ School of Physics, University of Sydney, Sydney, Australia
- ¹⁵² Institute of Physics, Academia Sinica, Taipei, Taiwan
- ¹⁵³ Department of Physics, Technion: Israel Institute of Technology, Haifa, Israel
- ¹⁵⁴ Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
- ¹⁵⁵ Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
- ¹⁵⁶ International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan
- ¹⁵⁷ Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
- ¹⁵⁸ Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
- ¹⁵⁹ Department of Physics, University of Toronto, Toronto ON, Canada
- ¹⁶⁰ ^(a) TRIUMF, Vancouver BC; ^(b) Department of Physics and Astronomy, York University, Toronto ON, Canada
- ¹⁶¹ Faculty of Pure and Applied Sciences, and Center for Integrated Research in Fundamental Science and Engineering, University of Tsukuba, Tsukuba, Japan
- ¹⁶² Department of Physics and Astronomy, Tufts University, Medford MA, United States of America
- ¹⁶³ ^(a) INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine; ^(b) ICTP, Trieste; ^(c) Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy
- ¹⁶⁴ Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
- ¹⁶⁵ Department of Physics, University of Illinois, Urbana IL, United States of America
- ¹⁶⁶ Instituto de Física Corpuscular (IFIC) and Departamento de Física Atómica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain
- ¹⁶⁷ Department of Physics, University of British Columbia, Vancouver BC, Canada
- ¹⁶⁸ Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada
- ¹⁶⁹ Department of Physics, University of Warwick, Coventry, United Kingdom
- ¹⁷⁰ Waseda University, Tokyo, Japan
- ¹⁷¹ Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
- ¹⁷² Department of Physics, University of Wisconsin, Madison WI, United States of America

- ¹⁷³ Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany
- ¹⁷⁴ Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany
- ¹⁷⁵ Department of Physics, Yale University, New Haven CT, United States of America
- ¹⁷⁶ Yerevan Physics Institute, Yerevan, Armenia
- ¹⁷⁷ Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France
- ^a Also at Department of Physics, King's College London, London, United Kingdom
- ^b Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
- ^c Also at Novosibirsk State University, Novosibirsk, Russia
- ^d Also at TRIUMF, Vancouver BC, Canada
- ^e Also at Department of Physics & Astronomy, University of Louisville, Louisville, KY, United States of America
- ^f Also at Department of Physics, California State University, Fresno CA, United States of America
- ^g Also at Department of Physics, University of Fribourg, Fribourg, Switzerland
- ^h Also at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona, Spain
- ⁱ Also at Departamento de Física e Astronomia, Faculdade de Ciências, Universidade do Porto, Portugal
- ^j Also at Tomsk State University, Tomsk, Russia
- ^k Also at Università di Napoli Parthenope, Napoli, Italy
- ^l Also at Institute of Particle Physics (IPP), Canada
- ^m Also at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia
- ⁿ Also at Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
- ^o Also at Louisiana Tech University, Ruston LA, United States of America
- ^p Also at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain
- ^q Also at Graduate School of Science, Osaka University, Osaka, Japan
- ^r Also at Department of Physics, National Tsing Hua University, Taiwan
- ^s Also at Department of Physics, The University of Texas at Austin, Austin TX, United States of America
- ^t Also at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia
- ^u Also at CERN, Geneva, Switzerland
- ^v Also at Georgian Technical University (GTU), Tbilisi, Georgia
- ^w Also at O Chadai Academic Production, Ochanomizu University, Tokyo, Japan
- ^x Also at Manhattan College, New York NY, United States of America
- ^y Also at Hellenic Open University, Patras, Greece
- ^z Also at Institute of Physics, Academia Sinica, Taipei, Taiwan
- ^{aa} Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan
- ^{ab} Also at School of Physics, Shandong University, Shandong, China
- ^{ac} Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia
- ^{ad} Also at Section de Physique, Université de Genève, Geneva, Switzerland
- ^{ae} Also at International School for Advanced Studies (SISSA), Trieste, Italy
- ^{af} Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States of America
- ^{ag} Also at School of Physics and Engineering, Sun Yat-sen University, Guangzhou, China
- ^{ah} Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria
- ^{ai} Also at Faculty of Physics, M.V.Lomonosov Moscow State University, Moscow, Russia
- ^{aj} Also at National Research Nuclear University MEPhI, Moscow, Russia

^{ak} Also at Department of Physics, Stanford University, Stanford CA, United States of America

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

^{am} Also at Flensburg University of Applied Sciences, Flensburg, Germany

^{an} Also at University of Malaya, Department of Physics, Kuala Lumpur, Malaysia

^{ao} Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France

* Deceased