EPJ manuscript No.
(will be inserted by the editor)

SLAC-PUB-17030

CERN-PH-EP-2011-148

Submitted to Eur. Phys. J. C

arXiv:1109.5816v2 [hep-ex] 11 Dec 2011

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

The ATLAS Collaboration

October 30, 2011

Abstract. The jet fragmentation function and transverse profile for jets with 25 GeV $< p_{\mathrm{T\,jet}} <$ 500 GeV and $|\eta_{jet}| < 1.2$ produced in proton-proton collisions with a center-of-mass energy of 7 TeV are presented. The measurement is performed using data with an integrated luminosity of 36 pb^{-1}. Jets are reconstructed and their momentum measured using calorimetric information. The momenta of the charged particle constituents are measured using the tracking system. The distributions corrected for detector effects are compared with various Monte Carlo event generators and generator tunes. Several of these choices show good agreement with the measured fragmentation function. None of these choices reproduce both the transverse profile and fragmentation function over the full kinematic range of the measurement.

PACS. 13.87 -a

1 Introduction and Overview

This paper presents measurements of jet properties in proton-proton (pp) collisions at a center of mass energy of 7 TeV at the CERN LHC using the ATLAS detector. Jets are identified and their momenta measured using the calorimeters. Charged particles measured by the tracking system are then associated with these jets using a geometric definition. The structure of the jets is studied using these associated particles.

Jets produced at large transverse momentum in proton-proton collisions arise from the scattering of proton constituents leading to outgoing partons (quarks and gluons) with large transverse momenta. These manifest themselves as jets of hadrons via a "fragmentation process". While the scattering of the proton constituents is well described by perturbative QCD and leads, at lowest order, to final states of gg, gq, and qq, the fragmentation process is more complex. First, fragmentation must connect the outgoing partons with the rest of the event as the jet consists of colourless hadrons while the initiating parton carries colour. Second, the process involves the production of hadrons and takes place at an energy scale where the QCD coupling constant is large and perturbation theory cannot be used. Fragmentation is therefore described using a QCD-motivated model with parameters that must be determined from experiment. The fragmentation function $D_i^h(z,Q)$ is defined as the probability that a hadron of type h carries longitudinal momentum fraction z of the momentum $\boldsymbol{p}_i$ of a parton of type i

$$z \equiv \frac{\boldsymbol{p}_i \cdot \boldsymbol{p}_h}{|\boldsymbol{p}_i|^2}. \tag{1}$$

$D(z,Q)$ depends on z and on the scale Q of the hard scattering process which produced the parton. While the value of $D_i^h(z,Q)$ cannot be calculated in perturbative QCD, the variation with Q can be predicted provided Q is sufficiently large [1–6].

In this paper a quantity related to $D_i^h(z,Q)$ is measured. After jets have been reconstructed, the data are binned for fixed ranges of jet transverse momenta ($p_{\mathrm{T\,jet}}$), each bin containing N_{jet} jets; z is then determined for each charged particle associated with the jet

$$z = \frac{\boldsymbol{p}_{\mathrm{jet}} \cdot \boldsymbol{p}_{ch}}{|\boldsymbol{p}_{\mathrm{jet}}|^2}, \tag{2}$$

where $\boldsymbol{p}_{\mathrm{jet}}$ is the momentum of the reconstructed jet and $\boldsymbol{p}_{ch}$ the momentum of the charged particle. The following quantity is measured

$$F(z, p_{\mathrm{T\,jet}}) \equiv \frac{1}{N_{\mathrm{jet}}} \frac{dN_{ch}}{dz}, \tag{3}$$

where N_{ch} is the number of charged particles in the jet. $F(z, p_{\mathrm{T\,jet}})$ is a sum over $D_i^h(z,Q)$ weighted by the rate at which each parton species (i) is produced from the hard scattering process. As particle identification is not used, h is summed over all charged hadrons. The hard scattering

This material is based upon work supported by the U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-76SF00515.

scale Q is of the same order of magnitude as $p_{\mathrm{T\,jet}}$. At small $p_{\mathrm{T\,jet}}$, gluon jets dominate due to the larger gluon parton densities in the proton and larger scattering rates for $gg \to gg$. In the pseudorapidity range used for jets in this analysis ($|\eta_{\mathrm{jet}}| < 1.2$)[1] the fraction of jets originating from a hard scattering that produces a gluon falls from 80% for $p_{\mathrm{T\,jet}} \sim 25$ GeV to 50% for $p_{\mathrm{T\,jet}} \sim 300$ GeV according to the PYTHIA [7] event generator.

The jets measured experimentally also contain particles produced from the hadronization of the beam remnants (the "underlying event"). It should be emphasized that because colour fields connect all the strongly interacting partons in the pp event, no unambiguous assignment of particles to the hard scattering parton or underlying event is possible. The integral of $F(z, p_{\mathrm{T\,jet}})$ with respect to z corresponds to the multiplicity of charged particles within the jet. A clear summary of fragmentation phenomenology is provided in [8] (Section 17) whose notation is followed here.

The derivation of $D_i^h(z, Q)$ from $F(z, p_{\mathrm{T\,jet}})$ is beyond the scope of this paper, but comparisons of $F(z, p_{\mathrm{T\,jet}})$ with the predictions of several Monte Carlo (MC) generators will be made. Different features of the Monte Carlo models are probed by these studies. At low values of $p_{\mathrm{T\,jet}}$, the comparisons are most sensitive to the non-perturbative models of fragmentation, the connection of the partons to the remainder of the event and to the accretion of particles from the underlying event into the jet. As $p_{\mathrm{T\,jet}}$ rises, the impact of these effects is diluted and, if all the Monte Carlo models implemented perturbative QCD in the same way, $F(z, p_{\mathrm{T\,jet}})$ would become similar. In particular the increase of the total particle multiplicity with the hard scattering energy, here $p_{\mathrm{T\,jet}}$, is predicted by perturbative QCD [9].

Two other related quantities that describe the transverse shape of the jets are also studied here. The variable p_{T}^{rel} is the momentum of charged particles in a jet transverse to that jet's axis:

$$p_{\mathrm{T}}^{rel} = \frac{|\boldsymbol{p}_{ch} \times \boldsymbol{p}_{\mathrm{jet}}|}{|\boldsymbol{p}_{\mathrm{jet}}|}. \tag{4}$$

The following distribution is measured

$$f(p_{\mathrm{T}}^{rel}, p_{\mathrm{T\,jet}}) \equiv \frac{1}{N_{\mathrm{jet}}} \frac{dN_{ch}}{dp_{\mathrm{T}}^{rel}}. \tag{5}$$

Finally, the density of charged particles in y-ϕ space, $\rho_{ch}(r, p_{\mathrm{T\,jet}})$, is measured as a function of the angular distance r of charged particles from the axis of the jet that contains them, where r is given by:

$$r = \Delta R(ch, jet) = \sqrt{(\phi_{ch} - \phi_{\mathrm{jet}})^2 + (y_{ch} - y_{\mathrm{jet}})^2} \tag{6}$$

Thus $\rho_{ch}(r, p_{\mathrm{T\,jet}})$ is given by:

$$\rho_{ch}(r, p_{\mathrm{T\,jet}}) \equiv \frac{1}{N_{\mathrm{jet}}} \frac{dN_{ch}}{2\pi r dr}. \tag{7}$$

As in the case of the longitudinal variables, a comparison of these transverse quantities with Monte Carlo generators is sensitive to many of their features. The non-perturbative hadronization processes produce particles that have limited transverse momentum with respect to the parton direction. The mean value of this transverse momentum is of order a few hundred MeV, the scale where the QCD coupling constant becomes non-perturbative. At low $p_{\mathrm{T\,jet}}$ this effect dominates. If there were no other contributions, p_{T}^{rel} would remain constant with increasing $p_{\mathrm{T\,jet}}$. Therefore more of the energy would be concentrated in the core of the jet as $p_{\mathrm{T\,jet}}$ increases and the jets would become narrower. However, as $p_{\mathrm{T\,jet}}$ increases contributions from processes controlled by perturbative QCD radiation become more important, contributing to jet broadening and causing the mean value of p_{T}^{rel} to rise slowly (approximately logarithmically).

The phenomena described above are incorporated in all the Monte Carlo generators used to describe jet production in pp collisions, although there are significant differences in how these effects are implemented. For example, PYTHIA describes non-perturbative hadronization using a string model while HERWIG [10] uses a cluster model. In PYTHIA, coherent colour effects are described partly by string fragmentation. These effects are also produced in HERWIG and PYTHIA from gluon radiation. Treatments of the proton remnants are also described using different phenomenological approaches. For both generators, the implementations require that a number of input parameters be tuned to the data. The results presented in this paper will test whether these Monte Carlo models and their current input parameters adequately describe jets produced at the LHC. As the results are presented in bins of $p_{\mathrm{T\,jet}}$, the explicit dependence on $p_{\mathrm{T\,jet}}$in the variables defined in Equations 3, 5 and 7 is often suppressed in the following.

The measurement is performed using data with an integrated luminosity of 36 pb^{-1} recorded in 2010 with the ATLAS detector at the LHC at a center-of-mass energy of 7 TeV. The measurement covers a kinematic range of 25 GeV $< p_{\mathrm{T\,jet}} <$ 500 GeV and $|\eta_{\mathrm{jet}}| < 1.2$. Events are triggered using a minimum bias trigger and a combination of calorimeter jet triggers. A complementary ATLAS analysis [11] studying the jet fragmentation function and transverse profile of jets reconstructed from charged particle tracks using a total integrated luminosity of 800 μb^{-1} has been completed. It explores the properties of jets at lower transverse momentum than those typically studied in this paper.

[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 coinciding with the axis of 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 rapidity y for a track or jet is defined by $y = 0.5\ln[(E+p_Z)/(E-p_Z)]$ where E denotes the energy and p_Z is the momentum along the beam direction. For tracks, the energy is calculated assuming the particle is a pion.

Previous measurement of jet fragmentation functions have been made in e^+e^- collisions [12–15], in $p\overline{p}$ collisions [16, 17] and in ep collisions [18, 19].

This paper is organized as follows. The ATLAS detector is described briefly in Section 2. The Monte Carlo generator samples are discussed in Section 3. The event and object selections are described in Section 4. Section 5 contains a description of the analysis. In Section 6 the treatment of systematic uncertainties is presented. Results and conclusions are shown in Sections 7 and 8.

2 The ATLAS Detector

The ATLAS detector is described in detail in Ref. [20]. The subsystems relevant for this analysis are the inner detector (ID), the calorimeter and the trigger. The ID is used to measure the momentum of charged particles. It consists of three subsystems: a pixel detector, a silicon strip tracker (SCT) and a transition radiation straw tube tracker (TRT). These detectors are located inside a solenoid that provides a 2 T axial field. The ID has full coverage in the azimuthal angle ϕ and over the pseudorapidity range $0 < |\eta^{track}| < 2.5$.

The electromagnetic calorimeters use liquid argon as the active detector medium. They consist of accordion-shaped electrodes and lead absorbers and cover the pseudorapidity range $|\eta| < 3.2$. The technology used for the hadronic calorimeters varies with η. In the barrel region ($|\eta| < 1.7$) the detector is made of scintillating tiles with steel radiator. In the endcap region ($1.5 < |\eta| < 3.2$) the detector uses liquid argon and copper. A forward calorimeter consisting of liquid argon and tungsten/copper absorbers serves as both electromagnetic and hadronic calorimeter at large pseudorapidity and extends the coverage to $|\eta| < 4.9$.

The calorimeters are calibrated at the electromagnetic scale which correctly reconstructs the energy deposited by electrons and photons. The calorimeters are not compensating and the response of hadrons is lower than that of electrons ($e/h > 1$). Some fraction of the hadronic energy can also be deposited in the material in front of and in-between calorimeters. The response for hadronic jets [21] is $\sim 50\%$ of the true energy for $p_{\mathrm{T\,jet}} = 20\,\mathrm{GeV}$ and $|\eta_{\mathrm{jet}}| < 0.8$ and rises both with $p_{\mathrm{T\,jet}}$ and η_{jet}. For $|\eta_{jet}| < 0.8$, the response at $p_{\mathrm{T\,jet}} = 1\,\mathrm{TeV}$ is $\sim 80\%$.

The ATLAS trigger consists of three levels of event selection: Level-1 (L1), Level-2 (L2), and Event Filter. The L2 and event filter together form the High-Level Trigger (HLT). The L1 trigger is implemented using custom-made electronics, while the HLT is based on fast data reconstruction online algorithms running on commercially available computers and networking systems. The triggers relevant for this analysis are the L1 minimum bias triggers (MBTS) and the L1 and HLT calorimeter triggers. The minimum bias trigger is based on signals from 32 scintillation counters located at pseudorapidities $2.09 < |\eta| < 3.84$. Because non-diffractive events fire the MBTS with high efficiency and negligible bias, this trigger can be used to study jets with low $p_{\mathrm{T\,jet}}$. However, MBTS triggers were highly prescaled at large instantaneous luminosities, making them unsuitable for studies of high p_{T} jets that are produced at low rate. A series of single jet inclusive triggers with different jet E_T thresholds and prescales were deployed to ensure that significant data samples were taken over the full range of $p_{\mathrm{T\,jet}}$ [22].

3 Monte Carlo Samples

Several Monte Carlo samples are used in this analysis. Some samples were processed with the ATLAS full detector simulation [23] which is based on the GEANT4 toolkit [24]. The simulated events are then passed through the same reconstruction software as the data. These are used to model the response of the detector and to correct the data for experimental effects. The baseline Monte Carlo sample used to determine these corrections is produced using Pythia [7] 6.421 with the ATLAS tune AMBT1 which uses the MRST2007LO* PDFs [25] and was derived using the measured properties of minimum bias events [26]. Several other fully simulated samples are used to assess systematic uncertainties: Pythia using the Perugia2010 tune [27] (CTEQ5L PDFs [28]); Herwig 6.5 [10] using Jimmy 3.41 [29] and Herwig++ 2.4.2 [30] (MRST2007LO* PDFs).

Additional Monte Carlo generator samples are used to compare with the final corrected data: Pythia6.421 with the ATLAS MC09 tune [31] (MRST2007LO* PDFs), Herwig++ 2.5.1 [32] (MRST2007LO* PDFs) , Sherpa [33] (CTEQ6L [34] PDFs) and Pythia8 (8.105) [35] (MRST2007LO* PDFs).

4 Reconstruction and Event Selection

Events are required to have at least one primary vertex reconstructed using ID tracks. If the event has multiple primary vertices, the vertex with the largest $\sum(p_{\mathrm{T\,track}})^2$ is tagged as the hard-scattering vertex.

Jets are reconstructed using the infrared- and collinear-safe anti-k_t algorithm [36] with radius parameter $R_c = 0.6$ using the FastJet package [37]. The detector input is based on topological clusters [38]. A topological cluster is defined to have an energy equal to the energy sum of all the included calorimeter cells, zero mass and a reconstructed direction calculated from the weighted averages of the pseudo-rapidities and azimuthal angles of the constituent cells. The weight used is the absolute cell energy and the positions of the cells are relative to the nominal ATLAS coordinate system. The energy of these clusters is measured at the electromagnetic scale, which provides the appropriate calibration for electrons and photons. A $p_{\mathrm{T\,jet}}$ and η_{jet} dependent calibration is then applied to each jet [21]. These calibrations are based on comparing the response from simulated calorimeter jets to that of jets reconstructed using generator particles and matched to the reconstructed jets in η-ϕ space. The η-ϕ position of the jet (and hence its momentum) is corrected to account

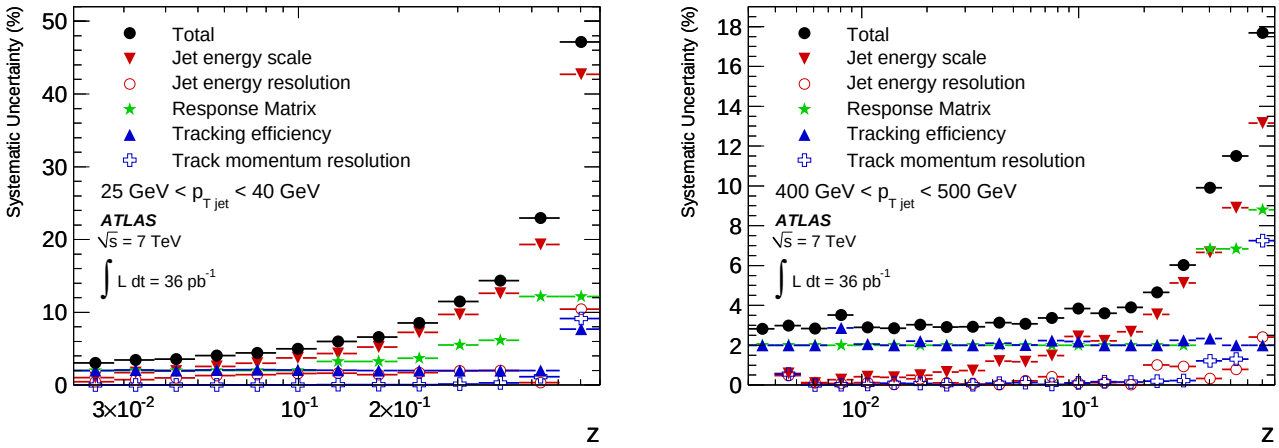

Fig. 1. Systematic uncertainty in $F(z, p_{\mathrm{T\,jet}})$ from uncertainties in the jet energy scale and resolution, the track reconstruction efficiency and momentum resolution and the response matrix for 25 GeV $< p_{\mathrm{T\,jet}} <$ 40 GeV (*left*) and 400 GeV $< p_{\mathrm{T\,jet}} <$ 500 GeV (*right*). The total uncertainty from the combination is also shown.

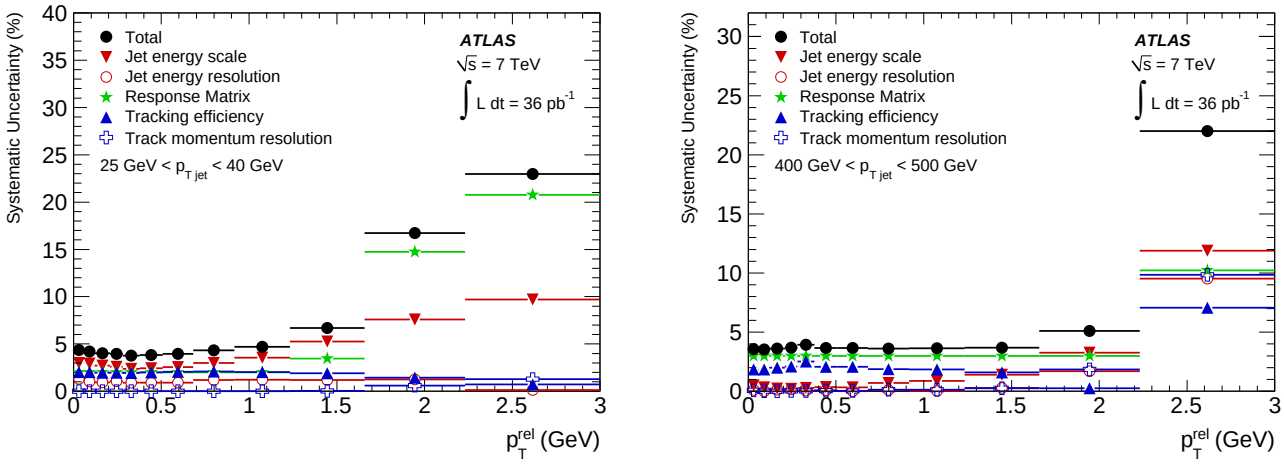

Fig. 2. Systematic uncertainty in $f(p_{\mathrm{T}}^{rel}, p_{\mathrm{T\,jet}})$ from uncertainties in the jet energy scale and resolution, the track reconstruction efficiency and momentum resolution and the response matrix for 25 GeV $< p_{\mathrm{T\,jet}} <$ 40 GeV (*left*) and 400 GeV $< p_{\mathrm{T\,jet}} <$ 500 GeV (*right*). The total uncertainty from the combination is also shown.

for the fact that the primary vertex of the interaction is not at the geometric centre of the detector. Quality criteria are applied to ensure that jets are not produced by noisy calorimeter cells, and to avoid problematic detector regions. The jet energy is corrected for the presence of additional pp interactions in the same bunch crossing using correction constants measured *in-situ* that depend on the number of reconstructed primary vertices.

Jets are required to have $|\eta_{jet}| < 1.2$. For events selected with the MBTS trigger, jets are required to pass a minimum cut of $p_{\mathrm{T\,jet}} > 20$ GeV. For events selected using jet triggers, a trigger-dependent minimum $p_{\mathrm{T\,jet}}$ threshold is imposed on jets used in the final measurements to ensure a jet trigger efficiency larger than 99%.

Tracks are selected using the following cuts:

$$p_{\mathrm{T\,track}} > 0.5\,\mathrm{GeV},\ N_{\mathrm{pixel}} \geq 1,\ N_{\mathrm{SCT}} \geq 6,$$

$$|d_0| < 1.5\,\mathrm{mm},\ |z_0 \sin\theta| < 1.5\,\mathrm{mm},$$

where N_{pixel} and N_{SCT} are the number of hits from the pixel and SCT detectors, respectively, that are associated with the track and d_0 and z_0 are the transverse and longitudinal impact parameters measured with respect to the hard-scattering vertex.

Tracks are associated with jets using a simple geometric algorithm. If the distance in η-ϕ between the track and the jet is less than the radius parameter used in the jet reconstruction ($R_c = 0.6$), the tracks are considered to belong to the jet. Track parameters are evaluated at the perigee to the primary vertex and are *not* extrapolated to the calorimeter. This simple association algorithm facilitates comparison with particles from the event generator whose parameters correspond to those measured at the primary vertex..

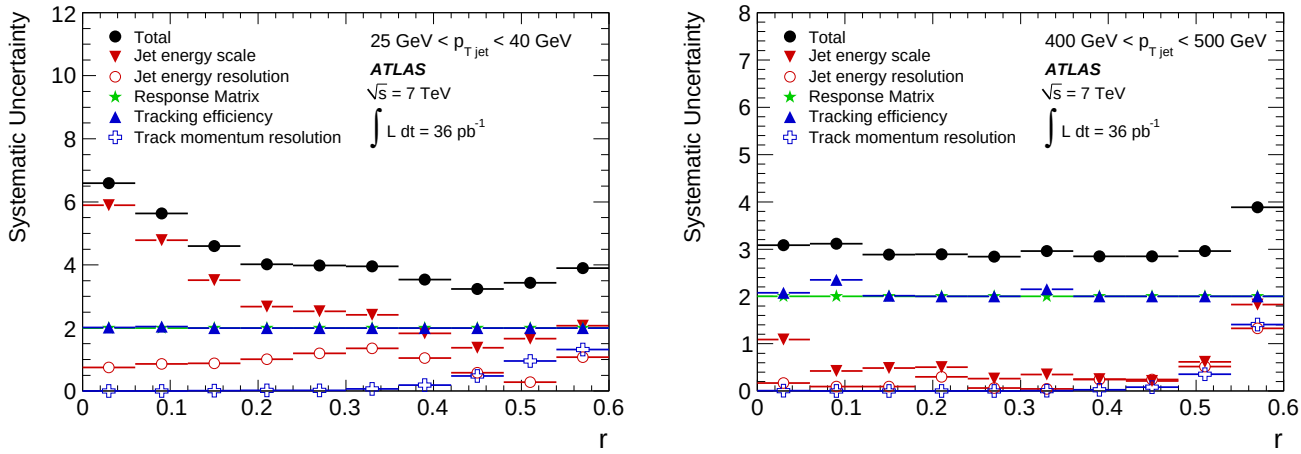

Fig. 3. Systematic uncertainty in $\rho_{ch}(r, p_{\mathrm{T\,jet}})$ from uncertainties in the jet energy scale and resolution, the track reconstruction efficiency and momentum resolution and the response matrix for 25 GeV $< p_{\mathrm{T\,jet}} <$ 40 GeV (*left*) and 400 GeV $< p_{\mathrm{T\,jet}} <$ 500 GeV (*right*). The total uncertainty from the combination is also shown.

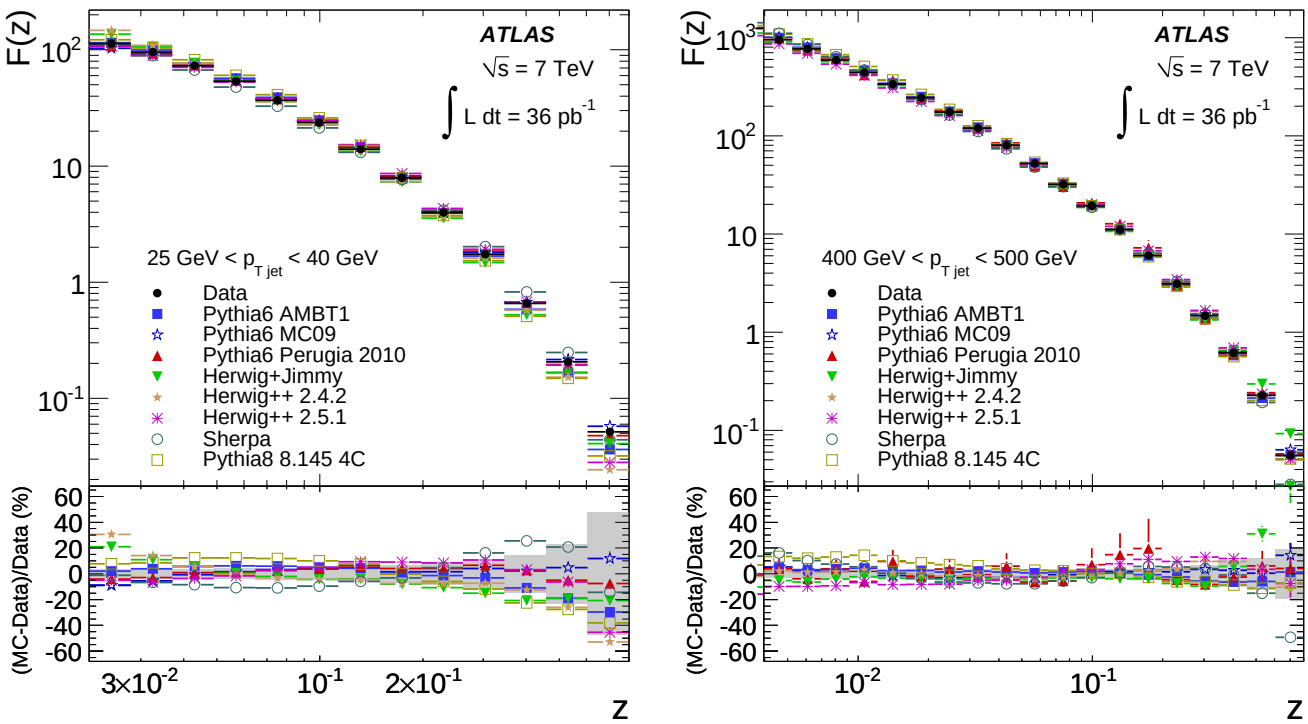

Fig. 4. Distributions of $F(z)$ for 25 GeV $< p_{\mathrm{T\,jet}} <$ 40 GeV (*left*) and 400 GeV $< p_{\mathrm{T\,jet}} <$ 500 GeV (*right*). The gray band indicates the total uncertainty.

5 Analysis

The results presented here are obtained using four measured distributions: the jet transverse momentum spectrum, $dN_{\mathrm{jet}}(p_{\mathrm{T\,jet}})/dp_{\mathrm{T\,jet}}$, and three differential distributions of the number of charged tracks, $dN_{tracks}(z, p_{\mathrm{T\,jet}})/dz$, $dN_{tracks}(p_{\mathrm{T}}^{rel}, p_{\mathrm{T\,jet}})/dp_{\mathrm{T}}^{rel}$ and $dN_{tracks}(r, p_{\mathrm{T\,jet}})/dr$. To facilitate comparison with the predictions of Monte Carlo event generators, these distributions are corrected for detector acceptance, reconstruction efficiency and migration due to track and jet momentum resolution effects. This correction procedure is called unfolding. The distributions $F(z, p_{\mathrm{T\,jet}})$, $f(p_{\mathrm{T}}^{rel}, p_{\mathrm{T\,jet}})$ and $\rho_{ch}(r, p_{\mathrm{T\,jet}})$ are obtained from the charged particle differential distributions by normalizing the distribution for each $p_{\mathrm{T\,jet}}$ range to the value of $N_{\mathrm{jet}}(p_{\mathrm{T\,jet}})$ obtained from the unfolding of the jet transverse momentum spectrum. This paper presents results for

$p_{\mathrm{T\,jet}} > 25$ GeV; however, to decrease the systematic uncertainty associated with the modeling of the $p_{\mathrm{T\,jet}}$ spectrum, jets with 20 GeV $< p_{\mathrm{T\,jet}} <$ 25 GeV are also used in the unfolding.

A Bayesian iterative unfolding method [39] implemented in the RooUnfold [40] software package is used. This procedure takes as its input the measured distributions and a response matrix obtained from simulated data that provides a mapping between reconstructed objects and those obtained directly from the event generator. This response matrix is not unitary because in mapping from generator to reconstruction some events and objects are lost due to inefficiencies and some are gained due to misreconstruction or migration of truth objects from outside the fiducial acceptance into the reconstructed observables. It is therefore not possible to obtain the unfolded distributions by inverting the response matrix and applying it to the measured data. Instead, an assumed truth distribution (the "prior") is selected, the response matrix is applied and the resulting trial reconstruction set is compared to the observed reconstruction set. A new prior is then constructed from the old prior and the difference between the trial and the observed distributions. The procedure can iterated until this difference becomes small. Monte Carlo based studies of the performance of the procedure demonstrate that in this analysis no iteration is necessary. The initial truth prior is taken to be the prediction of the baseline Monte Carlo generator. Systematic uncertainties associated with this choice and with the modeling of the response matrix are discussed in Section 6.

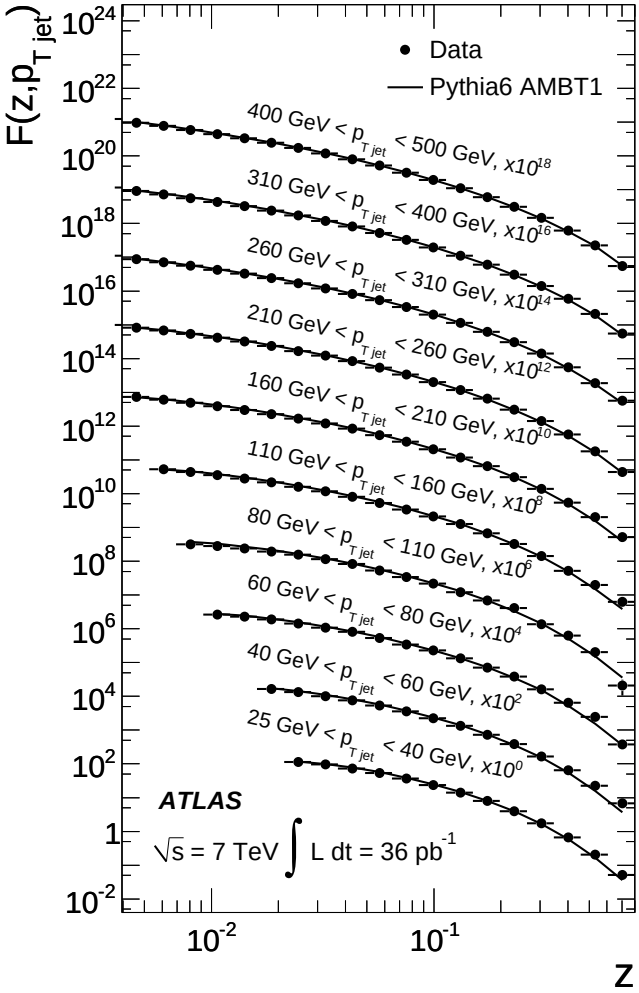

Fig. 5. Distributions of $F(z)$ in bins of $p_{\mathrm{T\,jet}}$. The circles show unfolded data and the lines are the predictions from AMBT1 Pythia.

6 Systematic Uncertainties

The following sources of systematic uncertainties are considered:

1. The jet energy scale (JES) and resolution (JER) uncertainties which affect the measurement of the number of jets in a given $p_{\mathrm{T\,jet}}$ bin and consequently the measured value of z.
2. The track reconstruction efficiency and momentum reconstruction uncertainties which affect the number of tracks in each z, p_{T}^{rel} and $N_{ch}(r)$ bin.
3. The uncertainty in the response matrix which is derived using a particular Monte Carlo sample and depends on the details of the event generator.
4. Potential bias due to the failure of the unfolding procedure to converge to the correct value.

These systematic uncertainties are addressed using Monte Carlo methods.

The first two systematic uncertainties, potential bias due to incorrect Monte Carlo modeling of the JES and/or JER and potential bias due to mismodeling by the simulation of the track reconstruction efficiency and/or resolution, are studied by modifying the detector response in simulated data. These modified Monte Carlo events are then unfolded and compared to the baseline. The systematic uncertainty on the JES is studied by varying the jet energy response by its uncertainty. The JES uncertainty varies from 4.6% at $p_{\mathrm{T\,jet}} = 20$ GeV to 2.5% at $p_{\mathrm{T\,jet}} = 500$ GeV [21]. Systematic uncertainties on the JER are studied by broadening the jet energy resolution with an additional η_{jet} and $p_{\mathrm{T\,jet}}$ dependent Gaussian term. The uncertainty on the JER is below 14% for the full $p_{\mathrm{T\,jet}}$ and η_{jet} range used in this analysis [41]. The uncertainty on the tracking efficiency is studied by randomly removing a fraction of the tracks in the simulated data. Uncertainties on the tracking efficiency are η-dependent and vary between 2% and 3% for the relevant range of η^{track} [42], dominated by the accuracy of the description of the detector material in the simulation. In addition, there can be a loss of tracking efficiency in the core of jets at high $p_{\mathrm{T\,jet}}$ due to a single pixel hit receiving contributions from more than track. Studies of such hit sharing show that the simulation and data agree well and that the resulting systematic uncertainty is negligible for $p_{\mathrm{T\,jet}} <$ 500 GeV. Uncertainties on the track momentum resolution are parametrized as an additional η-dependent

broadening of the resolution in curvature with values that vary from 0.0004 GeV^{-1} to 0.0009 GeV^{-1} [43].

While the studies described above account for systematic uncertainties associated with the accuracy of the detector simulation, they do not account for the fact that the response matrix itself depends on the fragmentation properties of the jets and hence on the physics description in the event generator. Because the response of the calorimeter to hadrons depends on the hadron momentum [44], the JES depends at the few per cent level on the momentum spectrum of particles within the jet. Because the probability that a track will share hits in the ID with another track is dependent upon the local density of particles within the jet, the tracking resolution depends weakly on the transverse profile of particles within the jet. These effects have been studied by unfolding fully simulated Monte Carlo samples created from Perugia2010, Herwig 6.5 (with Jimmy 3.41) and Herwig++ using the baseline response matrix obtained with Pythia AMBT1. Differences between the unfolded results for each tune and the true distributions obtained from that same tune are studied as a function of z, p_{T}^{rel} and $N_{ch}(r)$ for each bin in true $p_{\mathrm{T\,jet}}$ and used to assess the systematic uncertainty.

Potential bias in the unfolding procedure itself is studied by creating 1000 pseudo-experiments where the "data" are drawn from the baseline fully simulated Monte Carlo samples via a bootstrap method [45] and unfolding these "data" using the standard procedure. The mean results obtained from these samples show negligible bias and have a spread that is consistent with the reported statistical uncertainties. The systematic uncertainty due to the unfolding procedure is thus deemed to be negligible in comparison to the other uncertainties.

The resulting systematic uncertainties on $F(z, p_{\mathrm{T\,jet}})$, $f(p_{\mathrm{T}}^{rel}, p_{\mathrm{T\,jet}})$ and $\rho_{ch}(r, p_{\mathrm{T\,jet}})$ for the 25 GeV $< p_{\mathrm{T\,jet}} <$ 40 GeV (*left*) and 400 GeV $< p_{\mathrm{T\,jet}} <$ 500 GeV (*right*) are shown in Figures 1 through 3. For $F(z, p_{\mathrm{T\,jet}})$, uncertainties on the tracking efficiency and response matrix dominate at low z while the jet energy scale dominates at high z. For $f(p_{\mathrm{T}}^{rel}, p_{\mathrm{T\,jet}})$ the jet energy scale, response matrix and tracking efficiency uncertainties are all significant and the overall uncertainty rises with p_{T}^{rel}. For $\rho_{ch}(r, p_{\mathrm{T\,jet}})$, the response matrix and tracking efficiency uncertainties are significant for all $p_{\mathrm{T\,jet}}$ and r while the jet energy scale contribution is most important for small $p_{\mathrm{T\,jet}}$.

7 Results

This section presents comparisons of acceptance-corrected, unfolded data to the predictions of several Monte Carlo generators. The gray band on all the figures indicates the total uncertainty which is dominated by the systematic uncertainty. Figure 4 shows distributions of $F(z)$ in two bins of $p_{\mathrm{T\,jet}}$. Figure 5 shows distributions of $F(z)$ in all bins of $p_{\mathrm{T\,jet}}$ compared to AMBT1 Monte Carlo. Comparisons of the data and the Monte Carlo samples are shown in Figure 6. All the Pythia 6 tunings show good agreement with the data. Herwig+Jimmy disagrees with the data at large z for $p_{\mathrm{T\,jet}} > 200$ GeV. Herwig++ 2.5.1 is below the data at low z for $p_{\mathrm{T\,jet}} > 100$ GeV while Herwig++ 2.4.2 has too many particles at low z for $p_{\mathrm{T\,jet}} <$ 100 GeV. Pythia8 and Sherpa provide a poor description of the data.

Figure 7 (*left*) shows the distribution of $\langle z \rangle$ for the data and for a selection of Monte Carlo samples as a function of $p_{\mathrm{T\,jet}}$. A comparison with the Monte Carlo generators shows that the AMBT1 and MC09 Pythia and Perugia2010 datasets show good agreement with the data over the entire $p_{\mathrm{T\,jet}}$ range. The agreement with Herwig+Jimmy is satisfactory. Herwig++ 2.5.1 is inconsistent with the data for $p_{\mathrm{T\,jet}} > 40$ GeV and 2.4.2 is inconsistent for $p_{\mathrm{T\,jet}} < 100$ GeV. Pythia8 is $\sim 8\%$ below the data at all $p_{\mathrm{T\,jet}}$. Sherpa agrees well.

The charged particle multiplicity as a function of $p_{\mathrm{T\,jet}}$ is shown in Figure 7 (*right*). The Pythia 6 tunes show reasonable agreement, with AMBT1 being higher than the others. Herwig+Jimmy has slightly too few particles for $p_{\mathrm{T\,jet}} > 200$ GeV. Herwig++ 2.4.2 (2.5.1) has too many (few) particles for $p_{\mathrm{T\,jet}} < 200$ (> 300) GeV. Sherpa describes the data well while Pythia8 has $\sim 8\%$ too many particles at all $p_{\mathrm{T\,jet}}$.

The transverse profile of the jets is described by the $\rho_{ch}(r)$ and $f(p_{\mathrm{T}}^{rel})$ distributions. Figure 8 shows the distribution of $\rho_{ch}(r)$ in two bins of $p_{\mathrm{T\,jet}}$. The sharp decrease in population in the last bin is a feature of the jet algorithm, which tends to incorporate particles close to the radius parameter into the jet. The effect is also seen in [11] (Figure 6) where distributions for two radius parameters are shown. Figure 9 shows the distribution of $f(p_{\mathrm{T}}^{rel})$ in the same two $p_{\mathrm{T\,jet}}$ bins. Figures 10 and 11 show distributions of $\rho_{ch}(r)$ and $f(p_{\mathrm{T}}^{rel})$, respectively, in all $p_{\mathrm{T\,jet}}$ bins together with the predictions of the AMBT1 Monte Carlo. Comparisons of $\rho_{ch}(r)$ for all data and Monte Carlo are shown in Figure 12. Sherpa, Herwig++ 2.4.2 and Pythia8 disagree significantly with the data over the full range of the measurement. Pythia8 is consistent with the data only over a very restricted range of $p_{\mathrm{T\,jet}}$ around 80 GeV. Herwig++ 2.5.1 shows good agreement except at small r and for $p_{\mathrm{T\,jet}} > 200$ GeV. Herwig+Jimmy is consistent with the data only for $p_{\mathrm{T\,jet}} > 160$ GeV. All the Pythia 6 tunings except AMBT1 agree; AMBT1 shows disagreement for $p_{\mathrm{T\,jet}} > 200$ GeV. Comparison of $f(p_{\mathrm{T}}^{rel})$ for all data and Monte Carlos are shown in Figure 13. None of the generators agree with the data within the systematic uncertainties.

The mean value of p_{T}^{rel} as a function of $p_{\mathrm{T\,jet}}$ is shown in Figure 14. Herwig++ 2.5.1 has much too large a value of $\langle p_{\mathrm{T}}^{rel} \rangle$ for $p_{\mathrm{T\,jet}} > 100$ GeV and 2.4.2 has too small a value for $p_{\mathrm{T\,jet}} < 80$ GeV. AMBT1 has too small a value at all $p_{\mathrm{T\,jet}}$. Herwig+Jimmy has too large a value for $p_{\mathrm{T\,jet}} > 200$ GeV. Agreement of the remaining Monte Carlos is quite good.

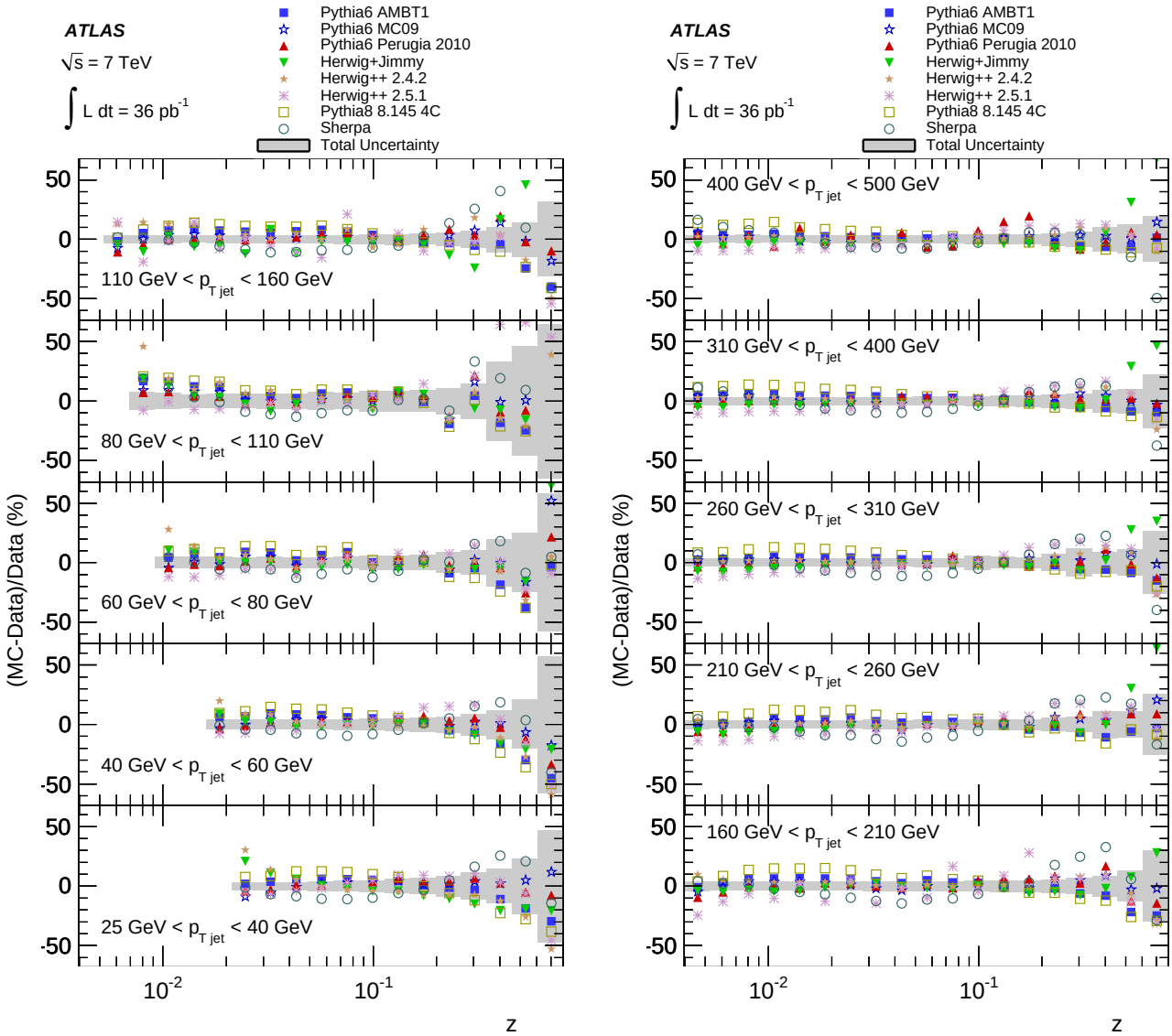

Fig. 6. The ratio of $F(z)$ predicted by various Monte Carlo generators to that measured. The gray band indicates the combined statistical and systematic uncertainties.

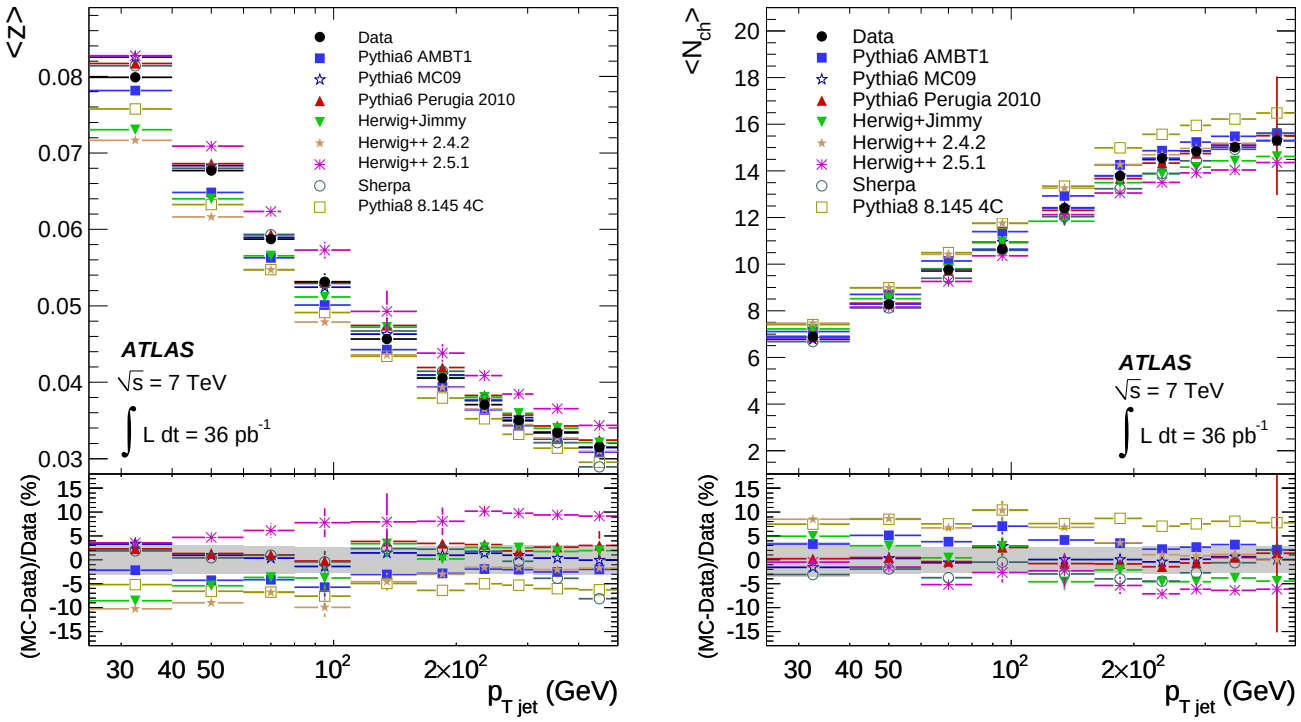

Fig. 7. Distributions of $< z >$ (left) and of the mean number of charged particles selected with the requirement $p_{\mathrm{T\,track}}$ ¿ 500 MeV (right) as a function of $p_{\mathrm{T\,jet}}$ for data and various Monte Carlos. The gray band indicated the total uncertainty.

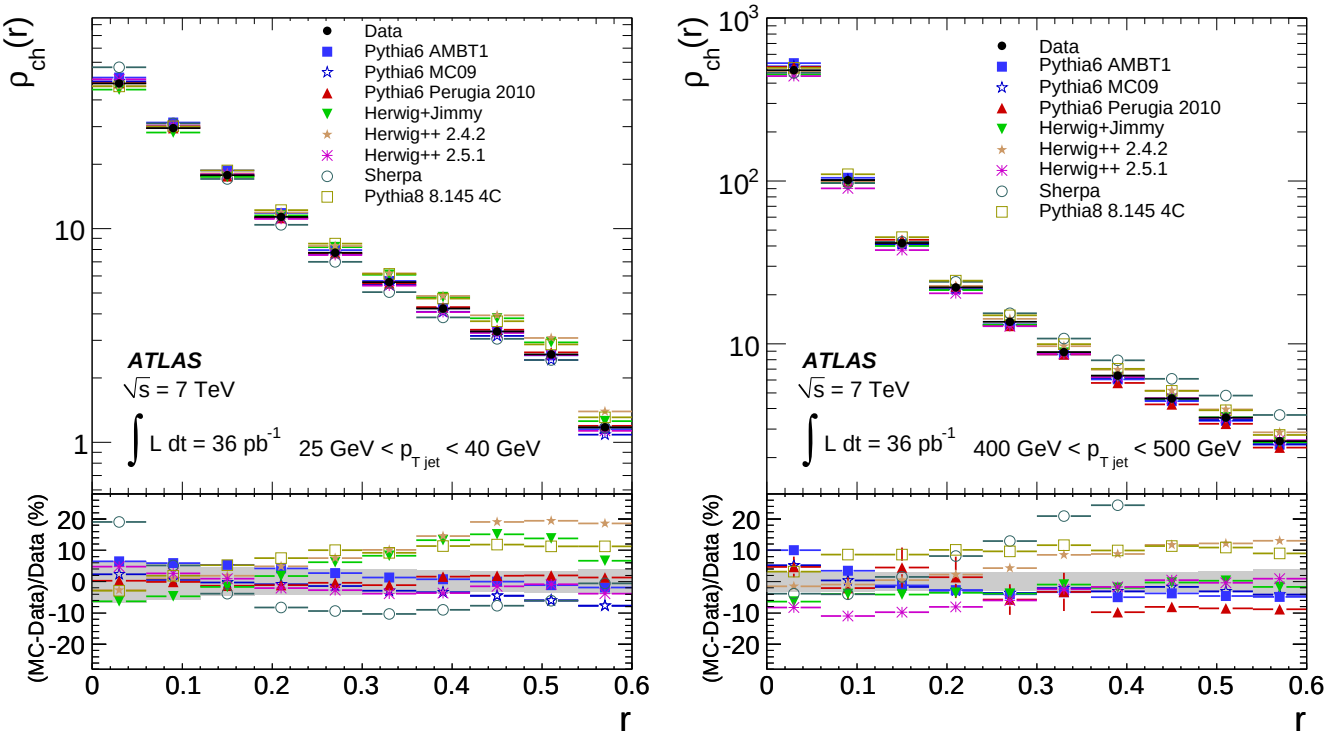

Fig. 8. Distributions of $\rho_{ch}(r)$ for 25 GeV $< p_{\mathrm{T\,jet}} <$ 40 GeV (*left*) and 400 GeV $< p_{\mathrm{T\,jet}} <$ 500 GeV (*right*). The gray band indicates the total uncertainty.

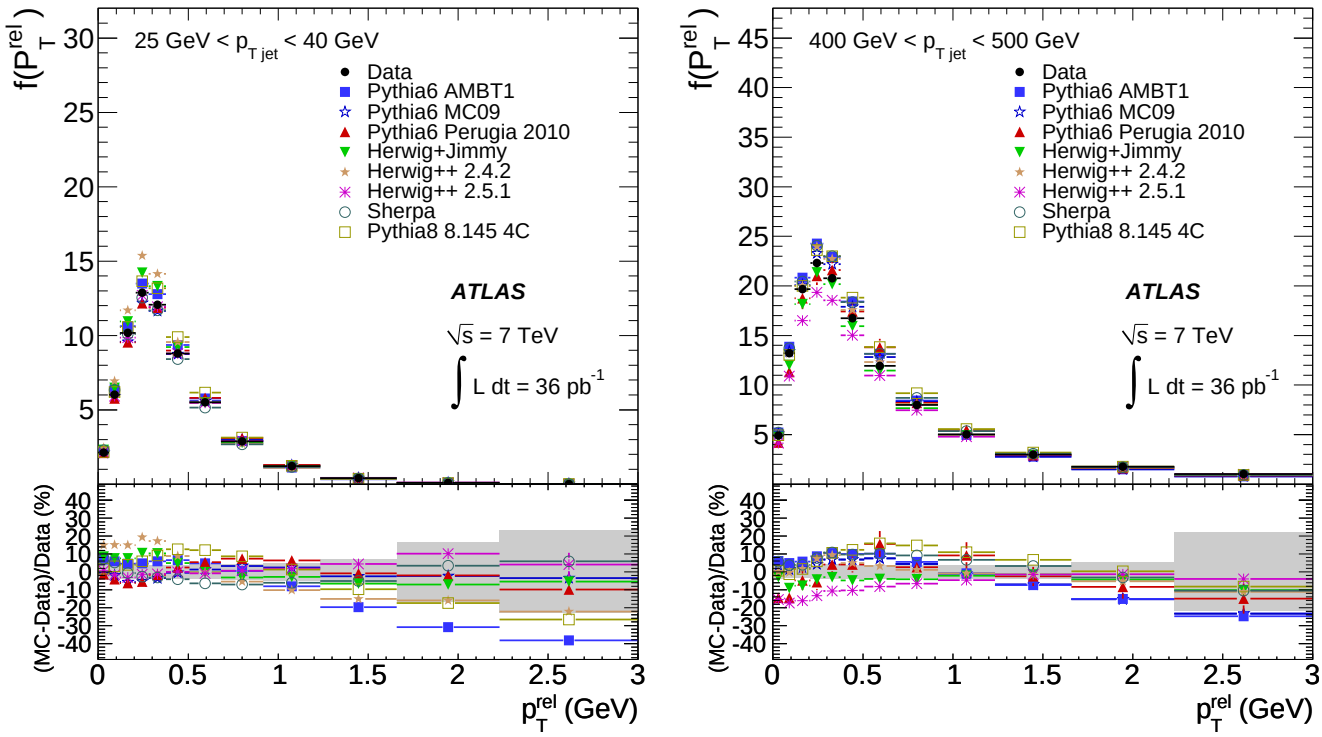

Fig. 9. Distributions of $f(p_{\mathrm{T}}^{rel})$ for 25 GeV $< p_{\mathrm{T\,jet}} <$ 40 GeV (*left*) and 400 GeV $< p_{\mathrm{T\,jet}} <$ 500 GeV (*right*). The gray band indicates the total uncertainty.

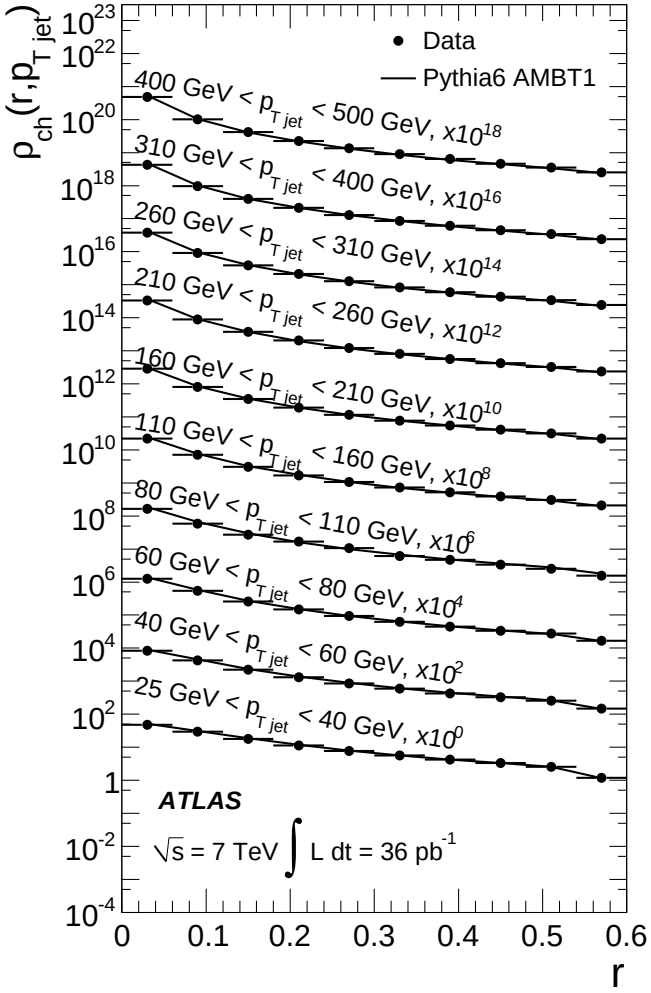

Fig. 10. Distributions of $\rho_{ch}(r)$. The circles show unfolded data. The lines are the predictions from AMBT1 PYTHIA.

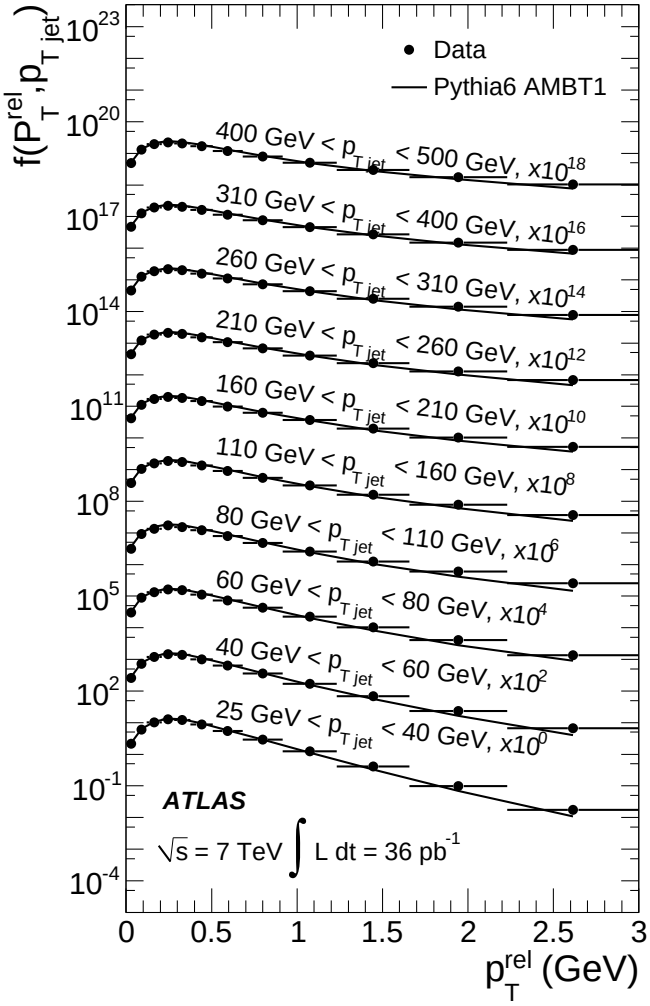

Fig. 11. Distributions of $f(p_{\mathrm{T}}^{rel})$. The circles show unfolded data. The lines are the predictions from AMBT1 PYTHIA.

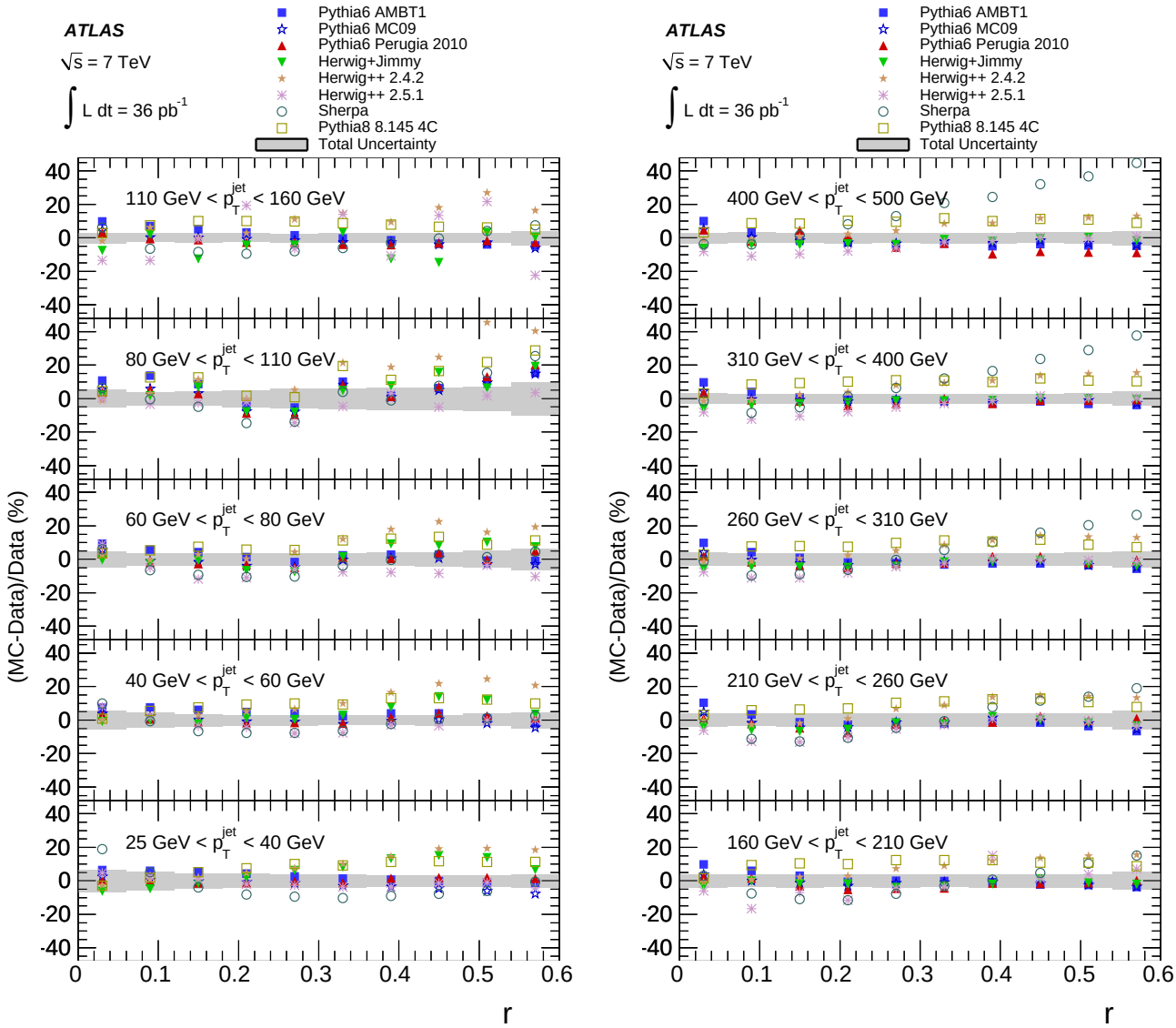

Fig. 12. The ratio of $\rho_{ch}(r)$ predicted by various Monte Carlo generators to that measured. The gray band indicates the combined statistical and systematic uncertainties.

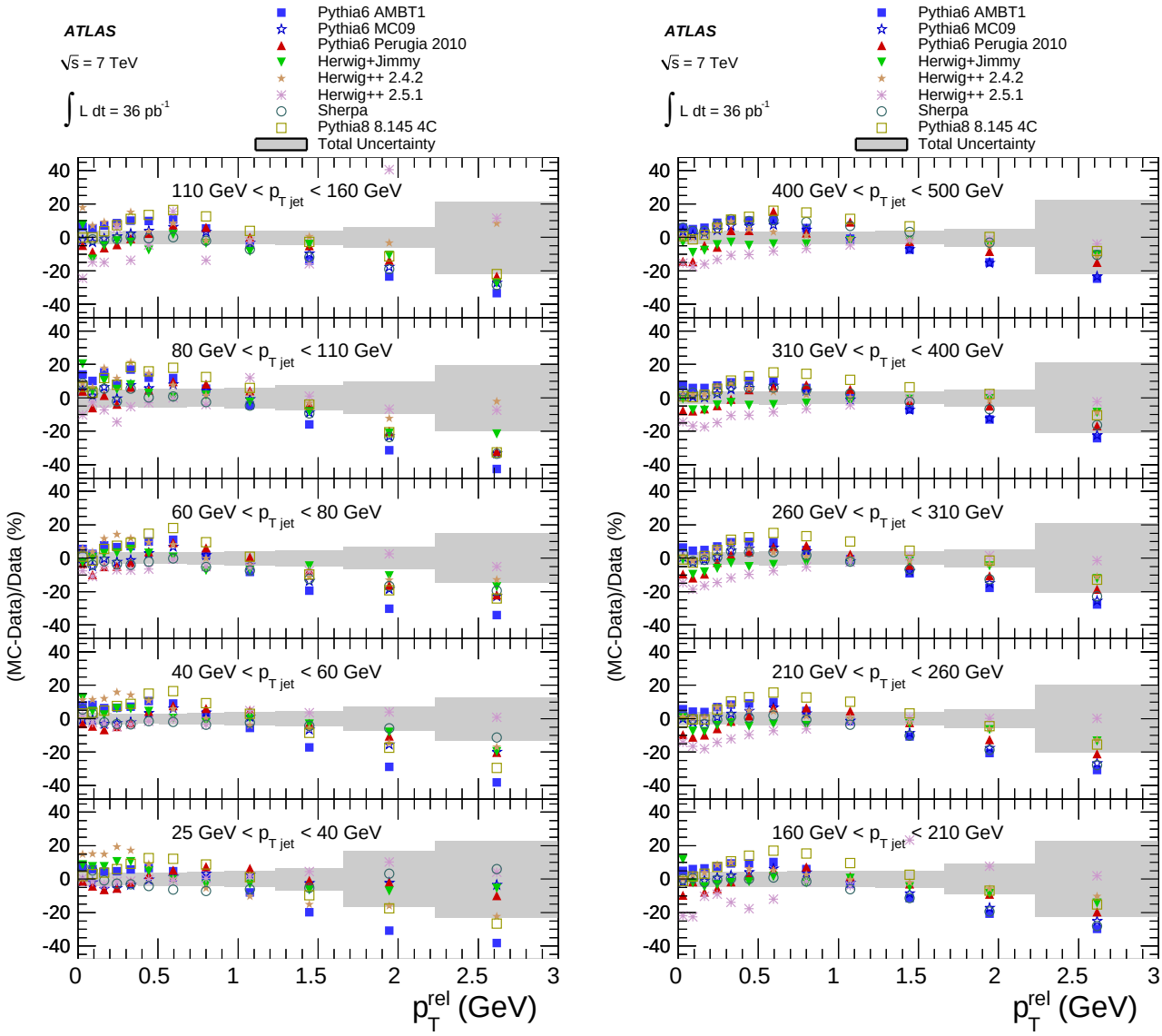

Fig. 13. The ratio of $f(p_{\mathrm{T}}^{rel})$ predicted by various Monte Carlo generators to that measured. The gray band indicates the combined statistical and systematic uncertainties.

8 Conclusion

A measurement of the jet fragmentation properties for charged particles in proton-proton collisions at a center-of-mass energy of 7 TeV is presented. The dataset recorded with the ATLAS detector at the LHC in 2010 with an integrated luminosity of 36 pb^{-1} is used. Systematic uncertainties for the fragmentation function which describes how the jet momentum is distributed amongst its constituents vary between approximately 4% and 40% depending on z and $p_{\mathrm{T\,jet}}$. The uncertainties increase strongly with z and are largest at small $p_{\mathrm{T\,jet}}$. The measurements of the distributions $\rho_{ch}(r, p_{\mathrm{T\,jet}})$ and $f(p_{\mathrm{T}}^{rel}, p_{\mathrm{T\,jet}})$ which describe the shape of jets transverse to the jet direction have uncertainties that fall as $p_{\mathrm{T\,jet}}$ increases, increase at large values of p_{T}^{rel} and are almost independent of r. They are less than 5% except in the lowest $p_{\mathrm{T\,jet}}$ range and for $p_{\mathrm{T}}^{rel} > 1$ GeV.

The measurements are sensitive to several properties of QCD as implemented in and modeled by Monte Carlo event generators. The additional QCD radiation present as $p_{\mathrm{T\,jet}}$ increases is modeled by perturbative QCD and results in a growth of the particle multiplicity. This growth is very well modeled by all the Monte Carlo generators used here. Two other effects that cannot be described by perturbative QCD impact the measured distributions. The hadronization of partons produced in a QCD radiative shower into the observed hadrons must be modeled in the Monte Carlo generators and is described by a large number of parameters which are tuned to agree with data. Particles produced from remnants of the initial protons (underlying event) can be incorporated into jets whose constituents mainly come from the hard scattering, so the measured jet properties can be sensitive to this modeling.

The measured fragmentation functions agree well with the AMBT1 Pythia and Perugia2010 Monte Carlo predictions within statistical and systematic uncertainties. Other tunes and generators show less good agreement indicating that the non-perturbative physics is not adequately modeled in these cases. Measurements of the transverse distributions $f(p_{\mathrm{T}}^{rel}, p_{\mathrm{T\,jet}})$ and $\rho_{ch}(r, p_{\mathrm{T\,jet}})$ are also presented. For the p_{T}^{rel} distribution, none of the generators agree with data within systematic uncertainties over the full kinematic range. For the $\rho_{ch}(r, p_{\mathrm{T\,jet}})$ distribution, Herwig+Jimmy, Pythia MC09 and Perugia2010 are in reasonable agreement with the data.

In summary, none of the Monte Carlo generators studied provide a good description of all the data. The measurements presented here provide valuable inputs to constrain future improvements in Monte Carlo modeling of fragmentation. The full results are available in the HEPDATA database [46], and a Rivet [47] module for the analysis is also available.

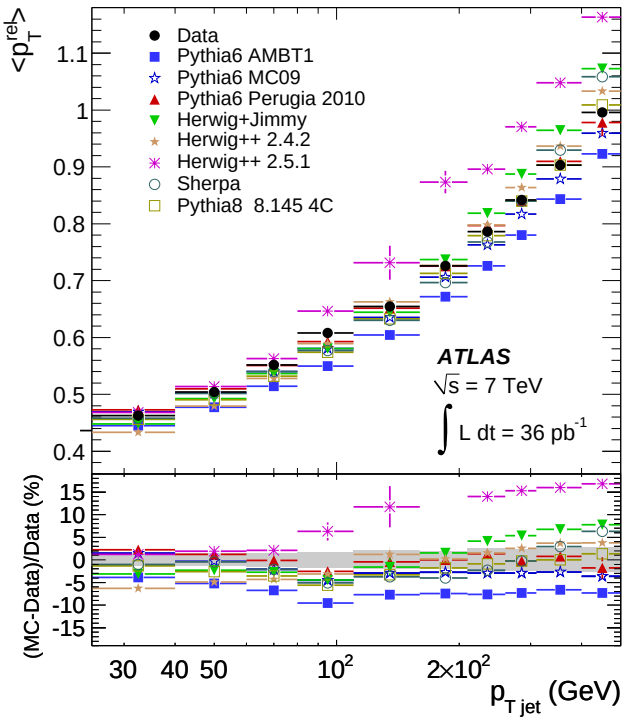

Fig. 14. Comparison of the measured value of the average value of p_{T}^{rel} as a function of $p_{\mathrm{T\,jet}}$ with various Monte Carlo expectations.

9 Acknowledgments

We honour the memory of our young colleague Christoph Ruwiedel, who was closely involved in the work described here and died shortly before its completion. 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; BMWF, 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; ARTEMIS, European Union; IN2P3-CNRS, CEA-DSM/IRFU, France; GNAS, Georgia; BMBF, DFG, HGF, MPG and AvH Foundation, Germany; GSRT, Greece; ISF, MINERVA, GIF, DIP and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; RCN, Norway; MNiSW, Poland; GRICES and FCT, Portugal; MERYS (MECTS), Romania; MES of Russia and ROSATOM, Russian Federation; JINR; MSTD, Serbia; MSSR, Slovakia; ARRS and MVZT, Slovenia; DST/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SER, SNSF and Cantons of Bern and Geneva, Switzerland; NSC, Taiwan; TAEK, Turkey; STFC, the Royal Society and Leverhulme Trust, United Kingdom; DOE and NSF, United States of America.

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. V.N. Gribov and L.N. Lipatov, Sov. J. Nucl. Phys. **15** (1972) 675–684
2. G. Altarelli and G.Parisi, Nucl. Phys. **B126** (1977) 298
3. Y.L Dokshitzer, Sov. Phys. JETP **46** (1977) 641–653
4. H. Georgi and H.D. Politzer, Nucl. Phys. **B136** (1978) 445
5. J.F. Owens, Phys. Lett. **B76** (1978) 85
6. T. Uematsu, Phys. Lett. **B79** (1978) 97
7. T. Sjöstrand, S. Mrenna and P.Z. Skands, JHEP **05** (2006) 026
8. K. Nakamura et al.(Particle Data Group), J. Phys. **G37** (2010) 075021
9. A.H. Mueller, Phys. Lett. **B104** (1981) 161–164
10. G. Corcella et al., JHEP **01** (2001) 010
11. The ATLAS Collaboration, Properties of jets from tracks in proton-proton collisions at center-of-mass energy $\sqrt{s} =$ 7 TeV with the ATLAS detector, CERN-PH-EP-2011-110, accepted by Phys. Rev. D, 2011
12. The OPAL Collaboration, Z. Phys. **C68** (1995) 203–214
13. The DELPHI Collaboration, Z. Phys. **C73** (1996) 11–60
14. The ALEPH Collaboration, Phys. Lett. **B357** (1995) 487–499
15. P. Mättig, Phys. Rept. **177** (1989) 141
16. G. Arnison et al., Phys. Lett. **B132** (1983) 223
17. The CDF Collaboration, Phys. Rev. Lett. **65** (1990) 968–971
18. ZEUS Collaboration, Phys. Lett. **B414** (1997) 428–443
19. H1 Collaboration, Phys. Lett. **B654** (2007) 148–159
20. The ATLAS Collaboration, JINST **3** (2008) S08003
21. The ATLAS Collaboration, Jet energy scale and its systematic uncertainty in proton-proton collisions at $\sqrt{s} =$ 7 TeV with ATLAS 2010 data , ATLAS-CONF-2011-032 `https://cdsweb.cern.ch/record/1337782`
22. The ATLAS Collaboration, Eur. Phys. J. C **71** (2011) 1512
23. The ATLAS Collaboration, Eur. Phys. J C **70** (2010) 823–874
24. GEANT4 Collaboration, S. Agostinelli et al., Nucl. Instr. Meth. **A506** (2003) 250–303
25. A. Sherstnev and R.S. Thorne, Eur. Phys. J. **C55** (2008) 553–575
26. The ATLAS Collaboration, New J. Phys. **13** (2011) 053033
27. P.Z. Skands, Phys. Rev. **D82** (2010) 074018
28. J. Pumplin et al., JHEP **07** (2002) 012
29. J.M. Butterworth, J.R. Forshaw and M.H. Seymour, Z. Phys. **C72** (1996) 637–646
30. M. Bahr et al., Eur. Phys. J. **C58** (2008) 639–707
31. The ATLAS Collaboration, ATLAS Monte Carlo tunes for MC09, ATL-PHYS-PUB-2010-002 `http://cdsweb.cern.ch/record/1247375/files/ATL-PHYS-PUB-2010-002.pdf`
32. S. Gieseke et al., Herwig++ 2.5 Release Note, 2011
33. T. Gleisberg et al., JHEP **02** (2009) 007
34. J. Pumplin, A. Belyaev, J. Huston, D. Stump and W.K. and Tung, JHEP **02** (2006) 032
35. T. Sjöstrand, S. Mrenna and P.Z. Skands, Comput. Phys. Commun. **178** (2008) 852–867
36. M. Cacciari, G.P. Salam and G. Soyez, JHEP **04** (2008) 063
37. M. Cacciari and G.P. Salam, Phys. Lett. B **641** (2006) 057
38. W. Lampl, et. al, Calorimeter clustering algorithms: Description and performance, ATL-LARG-PUB-2008-002 `https://cdsweb.cern.ch/record/1099735`
39. G. D'Agostini, Nucl. Instrum. Meth. **A362** (1995) 487–498
40. T. Adye, RooUnfold: unfolding framework and algorithms, presentations to the Oxford and RAL ATLAS Groups May 2008 `http://hepunx.rl.ac.uk/~adye/talks/080520-unfold.pdf`
41. The ATLAS Collaboration, Jet energy resolution and reconstruction efficiencies from in-situ techniques with the ATLAS Detector Using Proton-Proton Collisions at a Center of Mass Energy $\sqrt{s} = 7$ TeV, ATLAS-CONF-2010-054
42. The ATLAS Collaboration, New J. Phys. **13** (2011) 053033
43. The ATLAS Collaboration, Muon Momentum Resolution in First Pass Reconstruction of pp Collision Data Recorded by ATLAS in 2010, ATLAS-CONF-2011-003 `http://cdsweb.cern.ch/record/1322424`
44. The ATLAS Collaboration, ATLAS Calorimeter Response to Single Isolated Hadrons and Estimation of the Calorimeter Jet Scale Uncertainty, ATLAS-CONF-2011-028 `http://cdsweb.cern.ch/record/1337075`
45. B. Efron, Annals of Statistics **7** (1979) 1
46. A. Buckley and M. Whalley, PoS **ACAT2010** (2010) 067
47. A. Buckley et al., arXiv: **1003.0694** (2010).

The ATLAS Collaboration

G. Aad[48], B. Abbott[111], J. Abdallah[11], A.A. Abdelalim[49], A. Abdesselam[118], O. Abdinov[10], B. Abi[112], M. Abolins[88], H. Abramowicz[153], H. Abreu[115], E. Acerbi[89a,89b], B.S. Acharya[164a,164b], D.L. Adams[24], T.N. Addy[56], J. Adelman[175], M. Aderholz[99], S. Adomeit[98], P. Adragna[75], T. Adye[129], S. Aefsky[22], J.A. Aguilar-Saavedra[124b,a], M. Aharrouche[81], S.P. Ahlen[21], F. Ahles[48], A. Ahmad[148], M. Ahsan[40], G. Aielli[133a,133b], T. Akdogan[18a], T.P.A. Åkesson[79], G. Akimoto[155], A.V. Akimov [94], A. Akiyama[67], M.S. Alam[1], M.A. Alam[76], J. Albert[169], S. Albrand[55], M. Aleksa[29], I.N. Aleksandrov[65], F. Alessandria[89a], C. Alexa[25a], G. Alexander[153], G. Alexandre[49], T. Alexopoulos[9], M. Alhroob[20], M. Aliev[15], G. Alimonti[89a], J. Alison[120], M. Aliyev[10], P.P. Allport[73], S.E. Allwood-Spiers[53], J. Almond[82], A. Aloisio[102a,102b], R. Alon[171], A. Alonso[79], M.G. Alviggi[102a,102b], K. Amako[66], P. Amaral[29], C. Amelung[22], V.V. Ammosov[128], A. Amorim[124a,b], G. Amorós[167], N. Amram[153], C. Anastopoulos[29], L.S. Ancu[16], N. Andari[115], T. Andeen[34], C.F. Anders[20], G. Anders[58a], K.J. Anderson[30], A. Andreazza[89a,89b], V. Andrei[58a], M-L. Andrieux[55], X.S. Anduaga[70], A. Angerami[34], F. Anghinolfi[29], N. Anjos[124a], A. Annovi[47], A. Antonaki[8], M. Antonelli[47], A. Antonov[96], J. Antos[144b], F. Anulli[132a], S. Aoun[83], L. Aperio Bella[4], R. Apolle[118,c], G. Arabidze[88], I. Aracena[143], Y. Arai[66], A.T.H. Arce[44], J.P. Archambault[28], S. Arfaoui[29,d], J-F. Arguin[14], E. Arik[18a,*], M. Arik[18a], A.J. Armbruster[87], O. Arnaez[81], C. Arnault[115], A. Artamonov[95], G. Artoni[132a,132b], D. Arutinov[20], S. Asai[155], R. Asfandiyarov[172], S. Ask[27], B. Åsman[146a,146b], L. Asquith[5], K. Assamagan[24], A. Astbury[169], A. Astvatsatourov[52], G. Atoian[175], B. Aubert[4], E. Auge[115], K. Augsten[127], M. Aurousseau[145a], N. Austin[73], G. Avolio[163], R. Avramidou[9], D. Axen[168], C. Ay[54], G. Azuelos[93,e], Y. Azuma[155], M.A. Baak[29], G. Baccaglioni[89a], C. Bacci[134a,134b], A.M. Bach[14], H. Bachacou[136], K. Bachas[29], G. Bachy[29], M. Backes[49], M. Backhaus[20], E. Badescu[25a], P. Bagnaia[132a,132b], S. Bahinipati[2], Y. Bai[32a], D.C. Bailey[158], T. Bain[158], J.T. Baines[129], O.K. Baker[175], M.D. Baker[24], S. Baker[77], E. Banas[38], P. Banerjee[93], Sw. Banerjee[172], D. Banfi[29], A. Bangert[137], V. Bansal[169], H.S. Bansil[17], L. Barak[171], S.P. Baranov[94], A. Barashkou[65], A. Barbaro Galtieri[14], T. Barber[27], E.L. Barberio[86], D. Barberis[50a,50b], M. Barbero[20], D.Y. Bardin[65], T. Barillari[99], M. Barisonzi[174], T. Barklow[143], N. Barlow[27], B.M. Barnett[129], R.M. Barnett[14], A. Baroncelli[134a], G. Barone[49], A.J. Barr[118], F. Barreiro[80], J. Barreiro Guimarães da Costa[57], P. Barrillon[115], R. Bartoldus[143], A.E. Barton[71], D. Bartsch[20], V. Bartsch[149], R.L. Bates[53], L. Batkova[144a], J.R. Batley[27], A. Battaglia[16], M. Battistin[29], G. Battistoni[89a], F. Bauer[136], H.S. Bawa[143,f], B. Beare[158], T. Beau[78], P.H. Beauchemin[118], R. Beccherle[50a], P. Bechtle[41], H.P. Beck[16], M. Beckingham[48], K.H. Becks[174], A.J. Beddall[18c], A. Beddall[18c], S. Bedikian[175], V.A. Bednyakov[65], C.P. Bee[83], M. Begel[24], S. Behar Harpaz[152], P.K. Behera[63], M. Beimforde[99], C. Belanger-Champagne[85], P.J. Bell[49], W.H. Bell[49], G. Bella[153], L. Bellagamba[19a], F. Bellina[29], M. Bellomo[29], A. Belloni[57], O. Beloborodova[107], K. Belotskiy[96], O. Beltramello[29], S. Ben Ami[152], O. Benary[153], D. Benchekroun[135a], C. Benchouk[83], M. Bendel[81], N. Benekos[165], Y. Benhammou[153], D.P. Benjamin[44], M. Benoit[115], J.R. Bensinger[22], K. Benslama[130], S. Bentvelsen[105], D. Berge[29], E. Bergeaas Kuutmann[41], N. Berger[4], F. Berghaus[169], E. Berglund[49], J. Beringer[14], K. Bernardet[83], P. Bernat[77], R. Bernhard[48], C. Bernius[24], T. Berry[76], A. Bertin[19a,19b], F. Bertinelli[29], F. Bertolucci[122a,122b], M.I. Besana[89a,89b], N. Besson[136], S. Bethke[99], W. Bhimji[45], R.M. Bianchi[29], M. Bianco[72a,72b], O. Biebel[98], S.P. Bieniek[77], K. Bierwagen[54], J. Biesiada[14], M. Biglietti[134a,134b], H. Bilokon[47], M. Bindi[19a,19b], S. Binet[115], A. Bingul[18c], C. Bini[132a,132b], C. Biscarat[177], U. Bitenc[48], K.M. Black[21], R.E. Blair[5], J.-B. Blanchard[115], G. Blanchot[29], T. Blazek[144a], C. Blocker[22], J. Blocki[38], A. Blondel[49], W. Blum[81], U. Blumenschein[54], G.J. Bobbink[105], V.B. Bobrovnikov[107], S.S. Bocchetta[79], A. Bocci[44], C.R. Boddy[118], M. Boehler[41], J. Boek[174], N. Boelaert[35], S. Böser[77], J.A. Bogaerts[29], A. Bogdanchikov[107], A. Bogouch[90,*], C. Bohm[146a], V. Boisvert[76], T. Bold[163,g], V. Boldea[25a], N.M. Bolnet[136], M. Bona[75], V.G. Bondarenko[96], M. Bondioli[163], M. Boonekamp[136], G. Boorman[76], C.N. Booth[139], S. Bordoni[78], C. Borer[16], A. Borisov[128], G. Borissov[71], I. Borjanovic[12a], S. Borroni[87], K. Bos[105], D. Boscherini[19a], M. Bosman[11], H. Boterenbrood[105], D. Botterill[129], J. Bouchami[93], J. Boudreau[123], E.V. Bouhova-Thacker[71], C. Bourdarios[115], N. Bousson[83], A. Boveia[30], J. Boyd[29], I.R. Boyko[65], N.I. Bozhko[128], I. Bozovic-Jelisavcic[12b], J. Bracinik[17], A. Braem[29], P. Branchini[134a], G.W. Brandenburg[57], A. Brandt[7], G. Brandt[15], O. Brandt[54], U. Bratzler[156], B. Brau[84], J.E. Brau[114], H.M. Braun[174], B. Brelier[158], J. Bremer[29], R. Brenner[166], S. Bressler[152], D. Breton[115], D. Britton[53], F.M. Brochu[27], I. Brock[20], R. Brock[88], T.J. Brodbeck[71], E. Brodet[153], F. Broggi[89a], C. Bromberg[88], G. Brooijmans[34], W.K. Brooks[31b], G. Brown[82], H. Brown[7], P.A. Bruckman de Renstrom[38], D. Bruncko[144b], R. Bruneliere[48], S. Brunet[61], A. Bruni[19a], G. Bruni[19a], M. Bruschi[19a], T. Buanes[13], F. Bucci[49], J. Buchanan[118], N.J. Buchanan[2], P. Buchholz[141], R.M. Buckingham[118], A.G. Buckley[45], S.I. Buda[25a], I.A. Budagov[65], B. Budick[108], V. Büscher[81], L. Bugge[117], D. Buira-Clark[118], O. Bulekov[96], M. Bunse[42], T. Buran[117], H. Burckhart[29], S. Burdin[73], T. Burgess[13], S. Burke[129], E. Busato[33], P. Bussey[53], C.P. Buszello[166], F. Butin[29], B. Butler[143], J.M. Butler[21], C.M. Buttar[53], J.M. Butterworth[77], W. Buttinger[27], S. Cabrera Urbán[167], D. Caforio[19a,19b], O. Cakir[3a], P. Calafiura[14], G. Calderini[78], P. Calfayan[98], R. Calkins[106], L.P. Caloba[23a], R. Caloi[132a,132b], D. Calvet[33], S. Calvet[33], R. Camacho Toro[33], P. Camarri[133a,133b], M. Cambiaghi[119a,119b], D. Cameron[117], S. Campana[29], M. Campanelli[77], V. Canale[102a,102b], F. Canelli[30,h], A. Canepa[159a], J. Cantero[80], L. Capasso[102a,102b], M.D.M. Capeans Garrido[29], I. Caprini[25a], M. Caprini[25a], D. Capriotti[99], M. Capua[36a,36b], R. Caputo[148], R. Cardarelli[133a], T. Carli[29], G. Carlino[102a], L. Carminati[89a,89b], B. Caron[159a], S. Caron[48], G.D. Carrillo Montoya[172], A.A. Carter[75], J.R. Carter[27], J. Carvalho[124a,i], D. Casadei[108],

M.P. Casado[11], M. Cascella[122a,122b], C. Caso[50a,50b,*], A.M. Castaneda Hernandez[172], E. Castaneda-Miranda[172], V. Castillo Gimenez[167], N.F. Castro[124a], G. Cataldi[72a], F. Cataneo[29], A. Catinaccio[29], J.R. Catmore[71], A. Cattai[29], G. Cattani[133a,133b], S. Caughron[88], D. Cauz[164a,164c], P. Cavalleri[78], D. Cavalli[89a], M. Cavalli-Sforza[11], V. Cavasinni[122a,122b], F. Ceradini[134a,134b], A.S. Cerqueira[23a], A. Cerri[29], L. Cerrito[75], F. Cerutti[47], S.A. Cetin[18b], F. Cevenini[102a,102b], A. Chafaq[135a], D. Chakraborty[106], K. Chan[2], B. Chapleau[85], J.D. Chapman[27], J.W. Chapman[87], E. Chareyre[78], D.G. Charlton[17], V. Chavda[82], C.A. Chavez Barajas[29], S. Cheatham[85], S. Chekanov[5], S.V. Chekulaev[159a], G.A. Chelkov[65], M.A. Chelstowska[104], C. Chen[64], H. Chen[24], S. Chen[32c], T. Chen[32c], X. Chen[172], S. Cheng[32a], A. Cheplakov[65], V.F. Chepurnov[65], R. Cherkaoui El Moursli[135e], V. Chernyatin[24], E. Cheu[6], S.L. Cheung[158], L. Chevalier[136], G. Chiefari[102a,102b], L. Chikovani[51a], J.T. Childers[58a], A. Chilingarov[71], G. Chiodini[72a], M.V. Chizhov[65], G. Choudalakis[30], S. Chouridou[137], I.A. Christidi[77], A. Christov[48], D. Chromek-Burckhart[29], M.L. Chu[151], J. Chudoba[125], G. Ciapetti[132a,132b], K. Ciba[37], A.K. Ciftci[3a], R. Ciftci[3a], D. Cinca[33], V. Cindro[74], M.D. Ciobotaru[163], C. Ciocca[19a,19b], A. Ciocio[14], M. Cirilli[87], M. Ciubancan[25a], A. Clark[49], P.J. Clark[45], W. Cleland[123], J.C. Clemens[83], B. Clement[55], C. Clement[146a,146b], R.W. Clifft[129], Y. Coadou[83], M. Cobal[164a,164c], A. Coccaro[50a,50b], J. Cochran[64], P. Coe[118], J.G. Cogan[143], J. Coggeshall[165], E. Cogneras[177], C.D. Cojocaru[28], J. Colas[4], A.P. Colijn[105], C. Collard[115], N.J. Collins[17], C. Collins-Tooth[53], J. Collot[55], G. Colon[84], P. Conde Muiño[124a], E. Coniavitis[118], M.C. Conidi[11], M. Consonni[104], V. Consorti[48], S. Constantinescu[25a], C. Conta[119a,119b], F. Conventi[102a,j], J. Cook[29], M. Cooke[14], B.D. Cooper[77], A.M. Cooper-Sarkar[118], N.J. Cooper-Smith[76], K. Copic[34], T. Cornelissen[50a,50b], M. Corradi[19a], F. Corriveau[85,k], A. Cortes-Gonzalez[165], G. Cortiana[99], G. Costa[89a], M.J. Costa[167], D. Costanzo[139], T. Costin[30], D. Côté[29], L. Courneyea[169], G. Cowan[76], C. Cowden[27], B.E. Cox[82], K. Cranmer[108], F. Crescioli[122a,122b], M. Cristinziani[20], G. Crosetti[36a,36b], R. Crupi[72a,72b], S. Crépé-Renaudin[55], C.-M. Cuciuc[25a], C. Cuenca Almenar[175], T. Cuhadar Donszelmann[139], M. Curatolo[47], C.J. Curtis[17], P. Cwetanski[61], H. Czirr[141], Z. Czyczula[175], S. D'Auria[53], M. D'Onofrio[73], A. D'Orazio[132a,132b], P.V.M. Da Silva[23a], C. Da Via[82], W. Dabrowski[37], T. Dai[87], C. Dallapiccola[84], M. Dam[35], M. Dameri[50a,50b], D.S. Damiani[137], H.O. Danielsson[29], D. Dannheim[99], V. Dao[49], G. Darbo[50a], G.L. Darlea[25b], C. Daum[105], J.P. Dauvergne [29], W. Davey[86], T. Davidek[126], N. Davidson[86], R. Davidson[71], E. Davies[118,c], M. Davies[93], A.R. Davison[77], Y. Davygora[58a], E. Dawe[142], I. Dawson[139], J.W. Dawson[5,*], R.K. Daya[39], K. De[7], R. de Asmundis[102a], S. De Castro[19a,19b], P.E. De Castro Faria Salgado[24], S. De Cecco[78], J. de Graat[98], N. De Groot[104], P. de Jong[105], C. De La Taille[115], H. De la Torre[80], B. De Lotto[164a,164c], L. De Mora[71], L. De Nooij[105], D. De Pedis[132a], A. De Salvo[132a], U. De Sanctis[164a,164c], A. De Santo[149], J.B. De Vivie De Regie[115], S. Dean[77], R. Debbe[24], D.V. Dedovich[65], J. Degenhardt[120], M. Dehchar[118], C. Del Papa[164a,164c], J. Del Peso[80], T. Del Prete[122a,122b], M. Deliyergiyev[74], A. Dell'Acqua[29], L. Dell'Asta[89a,89b], M. Della Pietra[102a,j], D. della Volpe[102a,102b], M. Delmastro[29], P. Delpierre[83], N. Delruelle[29], P.A. Delsart[55], C. Deluca[148], S. Demers[175], M. Demichev[65], B. Demirkoz[11,l], J. Deng[163], S.P. Denisov[128], D. Derendarz[38], J.E. Derkaoui[135d], F. Derue[78], P. Dervan[73], K. Desch[20], E. Devetak[148], P.O. Deviveiros[158], A. Dewhurst[129], B. DeWilde[148], S. Dhaliwal[158], R. Dhullipudi[24,m], A. Di Ciaccio[133a,133b], L. Di Ciaccio[4], A. Di Girolamo[29], B. Di Girolamo[29], S. Di Luise[134a,134b], A. Di Mattia[88], B. Di Micco[29], R. Di Nardo[133a,133b], A. Di Simone[133a,133b], R. Di Sipio[19a,19b], M.A. Diaz[31a], F. Diblen[18c], E.B. Diehl[87], J. Dietrich[41], T.A. Dietzsch[58a], S. Diglio[115], K. Dindar Yagci[39], J. Dingfelder[20], C. Dionisi[132a,132b], P. Dita[25a], S. Dita[25a], F. Dittus[29], F. Djama[83], T. Djobava[51b], M.A.B. do Vale[23a], A. Do Valle Wemans[124a], T.K.O. Doan[4], M. Dobbs[85], R. Dobinson [29,*], D. Dobos[29], E. Dobson[29], M. Dobson[163], J. Dodd[34], C. Doglioni[118], T. Doherty[53], Y. Doi[66,*], J. Dolejsi[126], I. Dolenc[74], Z. Dolezal[126], B.A. Dolgoshein[96,*], T. Dohmae[155], M. Donadelli[23d], M. Donega[120], J. Donini[55], J. Dopke[29], A. Doria[102a], A. Dos Anjos[172], M. Dosil[11], A. Dotti[122a,122b], M.T. Dova[70], J.D. Dowell[17], A.D. Doxiadis[105], A.T. Doyle[53], Z. Drasal[126], J. Drees[174], N. Dressnandt[120], H. Drevermann[29], C. Driouichi[35], M. Dris[9], J. Dubbert[99], T. Dubbs[137], S. Dube[14], E. Duchovni[171], G. Duckeck[98], A. Dudarev[29], F. Dudziak[64], M. Dührssen [29], I.P. Duerdoth[82], L. Duflot[115], M-A. Dufour[85], M. Dunford[29], H. Duran Yildiz[3b], R. Duxfield[139], M. Dwuznik[37], F. Dydak [29], M. Düren[52], W.L. Ebenstein[44], J. Ebke[98], S. Eckert[48], S. Eckweiler[81], K. Edmonds[81], C.A. Edwards[76], N.C. Edwards[53], W. Ehrenfeld[41], T. Ehrich[99], T. Eifert[29], G. Eigen[13], K. Einsweiler[14], E. Eisenhandler[75], T. Ekelof[166], M. El Kacimi[135c], M. Ellert[166], S. Elles[4], F. Ellinghaus[81], K. Ellis[75], N. Ellis[29], J. Elmsheuser[98], M. Elsing[29], D. Emeliyanov[129], R. Engelmann[148], A. Engl[98], B. Epp[62], A. Eppig[87], J. Erdmann[54], A. Ereditato[16], D. Eriksson[146a], J. Ernst[1], M. Ernst[24], J. Ernwein[136], D. Errede[165], S. Errede[165], E. Ertel[81], M. Escalier[115], C. Escobar[123], X. Espinal Curull[11], B. Esposito[47], F. Etienne[83], A.I. Etienvre[136], E. Etzion[153], D. Evangelakou[54], H. Evans[61], L. Fabbri[19a,19b], C. Fabre[29], R.M. Fakhrutdinov[128], S. Falciano[132a], Y. Fang[172], M. Fanti[89a,89b], A. Farbin[7], A. Farilla[134a], J. Farley[148], T. Farooque[158], S.M. Farrington[118], P. Farthouat[29], P. Fassnacht[29], D. Fassouliotis[8], B. Fatholahzadeh[158], A. Favareto[89a,89b], L. Fayard[115], S. Fazio[36a,36b], R. Febbraro[33], P. Federic[144a], O.L. Fedin[121], W. Fedorko[88], M. Fehling-Kaschek[48], L. Feligioni[83], D. Fellmann[5], C.U. Felzmann[86], C. Feng[32d], E.J. Feng[30], A.B. Fenyuk[128], J. Ferencei[144b], J. Ferland[93], W. Fernando[109], S. Ferrag[53], J. Ferrando[53], V. Ferrara[41], A. Ferrari[166], P. Ferrari[105], R. Ferrari[119a], A. Ferrer[167], M.L. Ferrer[47], D. Ferrere[49], C. Ferretti[87], A. Ferretto Parodi[50a,50b], M. Fiascaris[30], F. Fiedler[81], A. Filipčič[74], A. Filippas[9], F. Filthaut[104], M. Fincke-Keeler[169], M.C.N. Fiolhais[124a,i], L. Fiorini[167], A. Firan[39], G. Fischer[41], P. Fischer [20],

M.J. Fisher[109], S.M. Fisher[129], M. Flechl[48], I. Fleck[141], J. Fleckner[81], P. Fleischmann[173], S. Fleischmann[174], T. Flick[174], L.R. Flores Castillo[172], M.J. Flowerdew[99], M. Fokitis[9], T. Fonseca Martin[16], D.A. Forbush[138], A. Formica[136], A. Forti[82], D. Fortin[159a], J.M. Foster[82], D. Fournier[115], A. Foussat[29], A.J. Fowler[44], K. Fowler[137], H. Fox[71], P. Francavilla[122a,122b], S. Franchino[119a,119b], D. Francis[29], T. Frank[171], M. Franklin[57], S. Franz[29], M. Fraternali[119a,119b], S. Fratina[120], S.T. French[27], F. Friedrich [43], R. Froeschl[29], D. Froidevaux[29], J.A. Frost[27], C. Fukunaga[156], E. Fullana Torregrosa[29], J. Fuster[167], C. Gabaldon[29], O. Gabizon[171], T. Gadfort[24], S. Gadomski[49], G. Gagliardi[50a,50b], P. Gagnon[61], C. Galea[98], E.J. Gallas[118], V. Gallo[16], B.J. Gallop[129], P. Gallus[125], E. Galyaev[40], K.K. Gan[109], Y.S. Gao[143,f], V.A. Gapienko[128], A. Gaponenko[14], F. Garberson[175], M. Garcia-Sciveres[14], C. García[167], J.E. García Navarro[49], R.W. Gardner[30], N. Garelli[29], H. Garitaonandia[105], V. Garonne[29], J. Garvey[17], C. Gatti[47], G. Gaudio[119a], O. Gaumer[49], B. Gaur[141], L. Gauthier[136], I.L. Gavrilenko[94], C. Gay[168], G. Gaycken[20], J-C. Gayde[29], E.N. Gazis[9], P. Ge[32d], C.N.P. Gee[129], D.A.A. Geerts[105], Ch. Geich-Gimbel[20], K. Gellerstedt[146a,146b], C. Gemme[50a], A. Gemmell[53], M.H. Genest[98], S. Gentile[132a,132b], M. George[54], S. George[76], P. Gerlach[174], A. Gershon[153], C. Geweniger[58a], H. Ghazlane[135b], P. Ghez[4], N. Ghodbane[33], B. Giacobbe[19a], S. Giagu[132a,132b], V. Giakoumopoulou[8], V. Giangiobbe[122a,122b], F. Gianotti[29], B. Gibbard[24], A. Gibson[158], S.M. Gibson[29], L.M. Gilbert[118], M. Gilchriese[14], V. Gilewsky[91], D. Gillberg[28], A.R. Gillman[129], D.M. Gingrich[2,e], J. Ginzburg[153], N. Giokaris[8], M.P. Giordani[164c], R. Giordano[102a,102b], F.M. Giorgi[15], P. Giovannini[99], P.F. Giraud[136], D. Giugni[89a], M. Giunta[93], P. Giusti[19a], B.K. Gjelsten[117], L.K. Gladilin[97], C. Glasman[80], J. Glatzer[48], A. Glazov[41], K.W. Glitza[174], G.L. Glonti[65], J. Godfrey[142], J. Godlewski[29], M. Goebel[41], T. Göpfert[43], C. Goeringer[81], C. Gössling[42], T. Göttfert[99], S. Goldfarb[87], T. Golling[175], S.N. Golovnia[128], A. Gomes[124a,b], L.S. Gomez Fajardo[41], R. Gonçalo[76], J. Goncalves Pinto Firmino Da Costa[41], L. Gonella[20], A. Gonidec[29], S. Gonzalez[172], S. González de la Hoz[167], M.L. Gonzalez Silva[26], S. Gonzalez-Sevilla[49], J.J. Goodson[148], L. Goossens[29], P.A. Gorbounov[95], H.A. Gordon[24], I. Gorelov[103], G. Gorfine[174], B. Gorini[29], E. Gorini[72a,72b], A. Gorišek[74], E. Gornicki[38], S.A. Gorokhov[128], V.N. Goryachev[128], B. Gosdzik[41], M. Gosselink[105], M.I. Gostkin[65], I. Gough Eschrich[163], M. Gouighri[135a], D. Goujdami[135c], M.P. Goulette[49], A.G. Goussiou[138], C. Goy[4], I. Grabowska-Bold[163,g], P. Grafström[29], C. Grah[174], K-J. Grahn[41], F. Grancagnolo[72a], S. Grancagnolo[15], V. Grassi[148], V. Gratchev[121], N. Grau[34], H.M. Gray[29], J.A. Gray[148], E. Graziani[134a], O.G. Grebenyuk[121], D. Greenfield[129], T. Greenshaw[73], Z.D. Greenwood[24,m], K. Gregersen[35], I.M. Gregor[41], P. Grenier[143], J. Griffiths[138], N. Grigalashvili[65], A.A. Grillo[137], S. Grinstein[11], Y.V. Grishkevich[97], J.-F. Grivaz[115], M. Groh[99], E. Gross[171], J. Grosse-Knetter[54], J. Groth-Jensen[171], K. Grybel[141], V.J. Guarino[5], D. Guest[175], C. Guicheney[33], A. Guida[72a,72b], T. Guillemin[4], S. Guindon[54], H. Guler[85,n], J. Gunther[125], B. Guo[158], J. Guo[34], A. Gupta[30], Y. Gusakov[65], V.N. Gushchin[128], A. Gutierrez[93], P. Gutierrez[111], N. Guttman[153], O. Gutzwiller[172], C. Guyot[136], C. Gwenlan[118], C.B. Gwilliam[73], A. Haas[143], S. Haas[29], C. Haber[14], R. Hackenburg[24], H.K. Hadavand[39], D.R. Hadley[17], P. Haefner[99], F. Hahn[29], S. Haider[29], Z. Hajduk[38], H. Hakobyan[176], J. Haller[54], K. Hamacher[174], P. Hamal[113], A. Hamilton[49], S. Hamilton[161], H. Han[32a], L. Han[32b], K. Hanagaki[116], M. Hance[120], C. Handel[81], P. Hanke[58a], J.R. Hansen[35], J.B. Hansen[35], J.D. Hansen[35], P.H. Hansen[35], P. Hansson[143], K. Hara[160], G.A. Hare[137], T. Harenberg[174], S. Harkusha[90], D. Harper[87], R.D. Harrington[45], O.M. Harris[138], K. Harrison[17], J. Hartert[48], F. Hartjes[105], T. Haruyama[66], A. Harvey[56], S. Hasegawa[101], Y. Hasegawa[140], S. Hassani[136], M. Hatch[29], D. Hauff[99], S. Haug[16], M. Hauschild[29], R. Hauser[88], M. Havranek[20], B.M. Hawes[118], C.M. Hawkes[17], R.J. Hawkings[29], D. Hawkins[163], T. Hayakawa[67], T. Hayashi[160], D Hayden[76], H.S. Hayward[73], S.J. Haywood[129], E. Hazen[21], M. He[32d], S.J. Head[17], V. Hedberg[79], L. Heelan[7], S. Heim[88], B. Heinemann[14], S. Heisterkamp[35], L. Helary[4], M. Heller[115], S. Hellman[146a,146b], D. Hellmich[20], C. Helsens[11], R.C.W. Henderson[71], M. Henke[58a], A. Henrichs[54], A.M. Henriques Correia[29], S. Henrot-Versille[115], F. Henry-Couannier[83], C. Hensel[54], T. Henß[174], C.M. Hernandez[7], Y. Hernández Jiménez[167], R. Herrberg[15], A.D. Hershenhorn[152], G. Herten[48], R. Hertenberger[98], L. Hervas[29], N.P. Hessey[105], A. Hidvegi[146a], E. Higón-Rodriguez[167], D. Hill[5,*], J.C. Hill[27], N. Hill[5], K.H. Hiller[41], S. Hillert[20], S.J. Hillier[17], I. Hinchliffe[14], E. Hines[120], M. Hirose[116], F. Hirsch[42], D. Hirschbuehl[174], J. Hobbs[148], N. Hod[153], M.C. Hodgkinson[139], P. Hodgson[139], A. Hoecker[29], M.R. Hoeferkamp[103], J. Hoffman[39], D. Hoffmann[83], M. Hohlfeld[81], M. Holder[141], S.O. Holmgren[146a], T. Holy[127], J.L. Holzbauer[88], Y. Homma[67], T.M. Hong[120], L. Hooft van Huysduynen[108], T. Horazdovsky[127], C. Horn[143], S. Horner[48], K. Horton[118], J-Y. Hostachy[55], S. Hou[151], M.A. Houlden[73], A. Hoummada[135a], J. Howarth[82], D.F. Howell[118], I. Hristova [15], J. Hrivnac[115], I. Hruska[125], T. Hryn'ova[4], P.J. Hsu[175], S.-C. Hsu[14], G.S. Huang[111], Z. Hubacek[127], F. Hubaut[83], F. Huegging[20], T.B. Huffman[118], E.W. Hughes[34], G. Hughes[71], R.E. Hughes-Jones[82], M. Huhtinen[29], P. Hurst[57], M. Hurwitz[14], U. Husemann[41], N. Huseynov[65,o], J. Huston[88], J. Huth[57], G. Iacobucci[49], G. Iakovidis[9], M. Ibbotson[82], I. Ibragimov[141], R. Ichimiya[67], L. Iconomidou-Fayard[115], J. Idarraga[115], P. Iengo[102a,102b], O. Igonkina[105], Y. Ikegami[66], M. Ikeno[66], Y. Ilchenko[39], D. Iliadis[154], D. Imbault[78], M. Imori[155], T. Ince[20], J. Inigo-Golfin[29], P. Ioannou[8], M. Iodice[134a], A. Irles Quiles[167], A. Ishikawa[67], M. Ishino[68], R. Ishmukhametov[39], C. Issever[118], S. Istin[18a], A.V. Ivashin[128], W. Iwanski[38], H. Iwasaki[66], J.M. Izen[40], V. Izzo[102a], B. Jackson[120], J.N. Jackson[73], P. Jackson[143], M.R. Jaekel[29], V. Jain[61], K. Jakobs[48], S. Jakobsen[35], J. Jakubek[127], D.K. Jana[111], E. Jankowski[158], E. Jansen[77], A. Jantsch[99], M. Janus[20], G. Jarlskog[79], L. Jeanty[57], K. Jelen[37], I. Jen-La Plante[30], P. Jenni[29], A. Jeremie[4], P. Jež[35], S. Jézéquel[4], M.K. Jha[19a], H. Ji[172], W. Ji[81], J. Jia[148], Y. Jiang[32b], M. Jimenez Belenguer[41], G. Jin[32b], S. Jin[32a], O. Jinnouchi[157],

M.D. Joergensen[35], D. Joffe[39], L.G. Johansen[13], M. Johansen[146a,146b], K.E. Johansson[146a], P. Johansson[139], S. Johnert[41], K.A. Johns[6], K. Jon-And[146a,146b], G. Jones[82], R.W.L. Jones[71], T.W. Jones[77], T.J. Jones[73], O. Jonsson[29], C. Joram[29], P.M. Jorge[124a,b], J. Joseph[14], T. Jovin[12b], X. Ju[130], C.A. Jung[42], V. Juranek[125], P. Jussel[62], A. Juste Rozas[11], V.V. Kabachenko[128], S. Kabana[16], M. Kaci[167], A. Kaczmarska[38], P. Kadlecik[35], M. Kado[115], H. Kagan[109], M. Kagan[57], S. Kaiser[99], E. Kajomovitz[152], S. Kalinin[174], L.V. Kalinovskaya[65], S. Kama[39], N. Kanaya[155], M. Kaneda[29], T. Kanno[157], V.A. Kantserov[96], J. Kanzaki[66], B. Kaplan[175], A. Kapliy[30], J. Kaplon[29], D. Kar[43], M. Karagoz[118], M. Karnevskiy[41], K. Karr[5], V. Kartvelishvili[71], A.N. Karyukhin[128], L. Kashif[172], A. Kasmi[39], R.D. Kass[109], A. Kastanas[13], M. Kataoka[4], Y. Kataoka[155], E. Katsoufis[9], J. Katzy[41], V. Kaushik[6], K. Kawagoe[67], T. Kawamoto[155], G. Kawamura[81], M.S. Kayl[105], V.A. Kazanin[107], M.Y. Kazarinov[65], J.R. Keates[82], R. Keeler[169], R. Kehoe[39], M. Keil[54], G.D. Kekelidze[65], M. Kelly[82], J. Kennedy[98], C.J. Kenney[143], M. Kenyon[53], O. Kepka[125], N. Kerschen[29], B.P. Kerševan[74], S. Kersten[174], K. Kessoku[155], C. Ketterer[48], J. Keung[158], M. Khakzad[28], F. Khalil-zada[10], H. Khandanyan[165], A. Khanov[112], D. Kharchenko[65], A. Khodinov[96], A.G. Kholodenko[128], A. Khomich[58a], T.J. Khoo[27], G. Khoriauli[20], A. Khoroshilov[174], N. Khovanskiy[65], V. Khovanskiy[95], E. Khramov[65], J. Khubua[51b], H. Kim[7], M.S. Kim[2], P.C. Kim[143], S.H. Kim[160], N. Kimura[170], O. Kind[15], B.T. King[73], M. King[67], R.S.B. King[118], J. Kirk[129], L.E. Kirsch[22], A.E. Kiryunin[99], T. Kishimoto[67], D. Kisielewska[37], T. Kittelmann[123], A.M. Kiver[128], E. Kladiva[144b], J. Klaiber-Lodewigs[42], M. Klein[73], U. Klein[73], K. Kleinknecht[81], M. Klemetti[85], A. Klier[171], A. Klimentov[24], R. Klingenberg[42], E.B. Klinkby[35], T. Klioutchnikova[29], P.F. Klok[104], S. Klous[105], E.-E. Kluge[58a], T. Kluge[73], P. Kluit[105], S. Kluth[99], N.S. Knecht[158], E. Kneringer[62], J. Knobloch[29], E.B.F.G. Knoops[83], A. Knue[54], B.R. Ko[44], T. Kobayashi[155], M. Kobel[43], M. Kocian[143], A. Kocnar[113], P. Kodys[126], K. Köneke[29], A.C. König[104], S. Koenig[81], L. Köpke[81], F. Koetsveld[104], P. Koevesarki[20], T. Koffas[28], E. Koffeman[105], F. Kohn[54], Z. Kohout[127], T. Kohriki[66], T. Koi[143], T. Kokott[20], G.M. Kolachev[107], H. Kolanoski[15], V. Kolesnikov[65], I. Koletsou[89a], J. Koll[88], D. Kollar[29], M. Kollefrath[48], S.D. Kolya[82], A.A. Komar[94], Y. Komori[155], T. Kondo[66], T. Kono[41,p], A.I. Kononov[48], R. Konoplich[108,q], N. Konstantinidis[77], A. Kootz[174], S. Koperny[37], S.V. Kopikov[128], K. Korcyl[38], K. Kordas[154], V. Koreshev[128], A. Korn[118], A. Korol[107], I. Korolkov[11], E.V. Korolkova[139], V.A. Korotkov[128], O. Kortner[99], S. Kortner[99], V.V. Kostyukhin[20], M.J. Kotamäki[29], S. Kotov[99], V.M. Kotov[65], A. Kotwal[44], C. Kourkoumelis[8], V. Kouskoura[154], A. Koutsman[105], R. Kowalewski[169], T.Z. Kowalski[37], W. Kozanecki[136], A.S. Kozhin[128], V. Kral[127], V.A. Kramarenko[97], G. Kramberger[74], M.W. Krasny[78], A. Krasznahorkay[108], J. Kraus[88], J.K. Kraus[20], A. Kreisel[153], F. Krejci[127], J. Kretzschmar[73], N. Krieger[54], P. Krieger[158], K. Kroeninger[54], H. Kroha[99], J. Kroll[120], J. Kroseberg[20], J. Krstic[12a], U. Kruchonak[65], H. Krüger[20], T. Kruker[16], Z.V. Krumshteyn[65], A. Kruth[20], T. Kubota[86], S. Kuehn[48], A. Kugel[58c], T. Kuhl[41], D. Kuhn[62], V. Kukhtin[65], Y. Kulchitsky[90], S. Kuleshov[31b], C. Kummer[98], M. Kuna[78], N. Kundu[118], J. Kunkle[120], A. Kupco[125], H. Kurashige[67], M. Kurata[160], Y.A. Kurochkin[90], V. Kus[125], M. Kuze[157], P. Kuzhir[91], J. Kvita[29], R. Kwee[15], A. La Rosa[172], L. La Rotonda[36a,36b], L. Labarga[80], J. Labbe[4], S. Lablak[135a], C. Lacasta[167], F. Lacava[132a,132b], H. Lacker[15], D. Lacour[78], V.R. Lacuesta[167], E. Ladygin[65], R. Lafaye[4], B. Laforge[78], T. Lagouri[80], S. Lai[48], E. Laisne[55], M. Lamanna[29], C.L. Lampen[6], W. Lampl[6], E. Lancon[136], U. Landgraf[48], M.P.J. Landon[75], H. Landsman[152], J.L. Lane[82], C. Lange[41], A.J. Lankford[163], F. Lanni[24], K. Lantzsch[29], S. Laplace[78], C. Lapoire[20], J.F. Laporte[136], T. Lari[89a], A.V. Larionov [128], A. Larner[118], C. Lasseur[29], M. Lassnig[29], P. Laurelli[47], W. Lavrijsen[14], P. Laycock[73], A.B. Lazarev[65], O. Le Dortz[78], E. Le Guirriec[83], C. Le Maner[158], E. Le Menedeu[136], C. Lebel[93], T. LeCompte[5], F. Ledroit-Guillon[55], H. Lee[105], J.S.H. Lee[150], S.C. Lee[151], L. Lee[175], M. Lefebvre[169], M. Legendre[136], A. Leger[49], B.C. LeGeyt[120], F. Legger[98], C. Leggett[14], M. Lehmacher[20], G. Lehmann Miotto[29], X. Lei[6], M.A.L. Leite[23d], R. Leitner[126], D. Lellouch[171], M. Leltchouk[34], B. Lemmer[54], V. Lendermann[58a], K.J.C. Leney[145b], T. Lenz[105], G. Lenzen[174], B. Lenzi[29], K. Leonhardt[43], S. Leontsinis[9], C. Leroy[93], J-R. Lessard[169], J. Lesser[146a], C.G. Lester[27], A. Leung Fook Cheong[172], J. Levêque[4], D. Levin[87], L.J. Levinson[171], M.S. Levitski[128], M. Lewandowska[21], A. Lewis[118], G.H. Lewis[108], A.M. Leyko[20], M. Leyton[15], B. Li[83], H. Li[172], S. Li[32b,d], X. Li[87], Z. Liang[39], Z. Liang[118,r], H. Liao[33], B. Liberti[133a], P. Lichard[29], M. Lichtnecker[98], K. Lie[165], W. Liebig[13], R. Lifshitz[152], J.N. Lilley[17], C. Limbach[20], A. Limosani[86], M. Limper[63], S.C. Lin[151,s], F. Linde[105], J.T. Linnemann[88], E. Lipeles[120], L. Lipinsky[125], A. Lipniacka[13], T.M. Liss[165], D. Lissauer[24], A. Lister[49], A.M. Litke[137], C. Liu[28], D. Liu[151,t], H. Liu[87], J.B. Liu[87], M. Liu[32b], S. Liu[2], Y. Liu[32b], M. Livan[119a,119b], S.S.A. Livermore[118], A. Lleres[55], J. Llorente Merino[80], S.L. Lloyd[75], E. Lobodzinska[41], P. Loch[6], W.S. Lockman[137], T. Loddenkoetter[20], F.K. Loebinger[82], A. Loginov[175], C.W. Loh[168], T. Lohse[15], K. Lohwasser[48], M. Lokajicek[125], J. Loken [118], V.P. Lombardo[4], R.E. Long[71], L. Lopes[124a,b], D. Lopez Mateos[57], M. Losada[162], P. Loscutoff[14], F. Lo Sterzo[132a,132b], M.J. Losty[159a], X. Lou[40], A. Lounis[115], K.F. Loureiro[162], J. Love[21], P.A. Love[71], A.J. Lowe[143,f], F. Lu[32a], H.J. Lubatti[138], C. Luci[132a,132b], A. Lucotte[55], A. Ludwig[43], D. Ludwig[41], I. Ludwig[48], J. Ludwig[48], F. Luehring[61], G. Luijckx[105], D. Lumb[48], L. Luminari[132a], E. Lund[117], B. Lund-Jensen[147], B. Lundberg[79], J. Lundberg[146a,146b], J. Lundquist[35], M. Lungwitz[81], A. Lupi[122a,122b], G. Lutz[99], D. Lynn[24], J. Lys[14], E. Lytken[79], H. Ma[24], L.L. Ma[172], J.A. Macana Goia[93], G. Maccarrone[47], A. Macchiolo[99], B. Maček[74], J. Machado Miguens[124a], R. Mackeprang[35], R.J. Madaras[14], W.F. Mader[43], R. Maenner[58c], T. Maeno[24], P. Mättig[174], S. Mättig[41], L. Magnoni[29], E. Magradze[54], Y. Mahalalel[153], K. Mahboubi[48], G. Mahout[17], C. Maiani[132a,132b], C. Maidantchik[23a], A. Maio[124a,b],

S. Majewski[24], Y. Makida[66], N. Makovec[115], P. Mal[6], Pa. Malecki[38], P. Malecki[38], V.P. Maleev[121], F. Malek[55], U. Mallik[63], D. Malon[5], C. Malone[143], S. Maltezos[9], V. Malyshev[107], S. Malyukov[29], R. Mameghani[98], J. Mamuzic[12b], A. Manabe[66], L. Mandelli[89a], I. Mandić[74], R. Mandrysch[15], J. Maneira[124a], P.S. Mangeard[88], I.D. Manjavidze[65], A. Mann[54], P.M. Manning[137], A. Manousakis-Katsikakis[8], B. Mansoulie[136], A. Manz[99], A. Mapelli[29], L. Mapelli[29], L. March [80], J.F. Marchand[29], F. Marchese[133a,133b], G. Marchiori[78], M. Marcisovsky[125], A. Marin[21,*], C.P. Marino[61], F. Marroquim[23a], R. Marshall[82], Z. Marshall[29], F.K. Martens[158], S. Marti-Garcia[167], A.J. Martin[175], B. Martin[29], B. Martin[88], F.F. Martin[120], J.P. Martin[93], Ph. Martin[55], T.A. Martin[17], V.J. Martin[45], B. Martin dit Latour[49], S. Martin–Haugh[149], M. Martinez[11], V. Martinez Outschoorn[57], A.C. Martyniuk[82], M. Marx[82], F. Marzano[132a], A. Marzin[111], L. Masetti[81], T. Mashimo[155], R. Mashinistov[94], J. Masik[82], A.L. Maslennikov[107], I. Massa[19a,19b], G. Massaro[105], N. Massol[4], P. Mastrandrea[132a,132b], A. Mastroberardino[36a,36b], T. Masubuchi[155], M. Mathes[20], P. Matricon[115], H. Matsumoto[155], H. Matsunaga[155], T. Matsushita[67], C. Mattravers[118,c], J.M. Maugain[29], S.J. Maxfield[73], D.A. Maximov[107], E.N. May[5], A. Mayne[139], R. Mazini[151], M. Mazur[20], M. Mazzanti[89a], E. Mazzoni[122a,122b], S.P. Mc Kee[87], A. McCarn[165], R.L. McCarthy[148], T.G. McCarthy[28], N.A. McCubbin[129], K.W. McFarlane[56], J.A. Mcfayden[139], H. McGlone[53], G. Mchedlidze[51b], R.A. McLaren[29], T. Mclaughlan[17], S.J. McMahon[129], R.A. McPherson[169,k], A. Meade[84], J. Mechnich[105], M. Mechtel[174], M. Medinnis[41], R. Meera-Lebbai[111], T. Meguro[116], R. Mehdiyev[93], S. Mehlhase[35], A. Mehta[73], K. Meier[58a], J. Meinhardt[48], B. Meirose[79], C. Melachrinos[30], B.R. Mellado Garcia[172], L. Mendoza Navas[162], Z. Meng[151,t], A. Mengarelli[19a,19b], S. Menke[99], C. Menot[29], E. Meoni[11], K.M. Mercurio[57], P. Mermod[118], L. Merola[102a,102b], C. Meroni[89a], F.S. Merritt[30], A. Messina[29], J. Metcalfe[103], A.S. Mete[64], C. Meyer[81], J-P. Meyer[136], J. Meyer[173], J. Meyer[54], T.C. Meyer[29], W.T. Meyer[64], J. Miao[32d], S. Michal[29], L. Micu[25a], R.P. Middleton[129], P. Miele[29], S. Migas[73], L. Mijović[41], G. Mikenberg[171], M. Mikestikova[125], M. Mikuž[74], D.W. Miller[30], R.J. Miller[88], W.J. Mills[168], C. Mills[57], A. Milov[171], D.A. Milstead[146a,146b], D. Milstein[171], A.A. Minaenko[128], M. Miñano[167], I.A. Minashvili[65], A.I. Mincer[108], B. Mindur[37], M. Mineev[65], Y. Ming[130], L.M. Mir[11], G. Mirabelli[132a], L. Miralles Verge[11], A. Misiejuk[76], J. Mitrevski[137], G.Y. Mitrofanov[128], V.A. Mitsou[167], S. Mitsui[66], P.S. Miyagawa[139], K. Miyazaki[67], J.U. Mjörnmark[79], T. Moa[146a,146b], P. Mockett[138], S. Moed[57], V. Moeller[27], K. Mönig[41], N. Möser[20], S. Mohapatra[148], W. Mohr[48], S. Mohrdieck-Möck[99], A.M. Moisseev[128,*], R. Moles-Valls[167], J. Molina-Perez[29], J. Monk[77], E. Monnier[83], S. Montesano[89a,89b], F. Monticelli[70], S. Monzani[19a,19b], R.W. Moore[2], G.F. Moorhead[86], C. Mora Herrera[49], A. Moraes[53], N. Morange[136], J. Morel[54], G. Morello[36a,36b], D. Moreno[81], M. Moreno Llácer[167], P. Morettini[50a], M. Morii[57], J. Morin[75], A.K. Morley[29], G. Mornacchi[29], S.V. Morozov[96], J.D. Morris[75], L. Morvaj[101], H.G. Moser[99], M. Mosidze[51b], J. Moss[109], R. Mount[143], E. Mountricha[136], S.V. Mouraviev[94], E.J.W. Moyse[84], M. Mudrinic[12b], F. Mueller[58a], J. Mueller[123], K. Mueller[20], T.A. Müller[98], D. Muenstermann[29], A. Muir[168], Y. Munwes[153], W.J. Murray[129], I. Mussche[105], E. Musto[102a,102b], A.G. Myagkov[128], M. Myska[125], J. Nadal[11], K. Nagai[160], K. Nagano[66], Y. Nagasaka[60], A.M. Nairz[29], Y. Nakahama[29], K. Nakamura[155], T. Nakamura[155], I. Nakano[110], G. Nanava[20], A. Napier[161], M. Nash[77,c], N.R. Nation[21], T. Nattermann[20], T. Naumann[41], G. Navarro[162], H.A. Neal[87], E. Nebot[80], P.Yu. Nechaeva[94], A. Negri[119a,119b], G. Negri[29], S. Nektarijevic[49], A. Nelson[64], S. Nelson[143], T.K. Nelson[143], S. Nemecek[125], P. Nemethy[108], A.A. Nepomuceno[23a], M. Nessi[29,u], S.Y. Nesterov[121], M.S. Neubauer[165], A. Neusiedl[81], R.M. Neves[108], P. Nevski[24], P.R. Newman[17], V. Nguyen Thi Hong[136], R.B. Nickerson[118], R. Nicolaidou[136], L. Nicolas[139], B. Nicquevert[29], F. Niedercorn[115], J. Nielsen[137], T. Niinikoski[29], N. Nikiforou[34], A. Nikiforov[15], V. Nikolaenko[128], K. Nikolaev[65], I. Nikolic-Audit[78], K. Nikolics[49], K. Nikolopoulos[24], H. Nilsen[48], P. Nilsson[7], Y. Ninomiya [155], A. Nisati[132a], T. Nishiyama[67], R. Nisius[99], L. Nodulman[5], M. Nomachi[116], I. Nomidis[154], M. Nordberg[29], B. Nordkvist[146a,146b], P.R. Norton[129], J. Novakova[126], M. Nozaki[66], L. Nozka[113], I.M. Nugent[159a], A.-E. Nuncio-Quiroz[20], G. Nunes Hanninger[86], T. Nunnemann[98], E. Nurse[77], T. Nyman[29], B.J. O'Brien[45], S.W. O'Neale[17,*], D.C. O'Neil[142], V. O'Shea[53], F.G. Oakham[28,e], H. Oberlack[99], J. Ocariz[78], A. Ochi[67], S. Oda[155], S. Odaka[66], J. Odier[83], H. Ogren[61], A. Oh[82], S.H. Oh[44], C.C. Ohm[146a,146b], T. Ohshima[101], H. Ohshita[140], T. Ohsugi[59], S. Okada[67], H. Okawa[163], Y. Okumura[101], T. Okuyama[155], M. Olcese[50a], A.G. Olchevski[65], M. Oliveira[124a,i], D. Oliveira Damazio[24], E. Oliver Garcia[167], D. Olivito[120], A. Olszewski[38], J. Olszowska[38], C. Omachi[67], A. Onofre[124a,v], P.U.E. Onyisi[30], C.J. Oram[159a], M.J. Oreglia[30], Y. Oren[153], D. Orestano[134a,134b], I. Orlov[107], C. Oropeza Barrera[53], R.S. Orr[158], B. Osculati[50a,50b], R. Ospanov[120], C. Osuna[11], G. Otero y Garzon[26], J.P Ottersbach[105], M. Ouchrif[135d], F. Ould-Saada[117], A. Ouraou[136], Q. Ouyang[32a], M. Owen[82], S. Owen[139], V.E. Ozcan[18a], N. Ozturk[7], A. Pacheco Pages[11], C. Padilla Aranda[11], S. Pagan Griso[14], E. Paganis[139], F. Paige[24], K. Pajchel[117], G. Palacino[159b], C.P. Paleari[6], S. Palestini[29], D. Pallin[33], A. Palma[124a,b], J.D. Palmer[17], Y.B. Pan[172], E. Panagiotopoulou[9], B. Panes[31a], N. Panikashvili[87], S. Panitkin[24], D. Pantea[25a], M. Panuskova[125], V. Paolone[123], A. Papadelis[146a], Th.D. Papadopoulou[9], A. Paramonov[5], W. Park[24,w], M.A. Parker[27], F. Parodi[50a,50b], J.A. Parsons[34], U. Parzefall[48], E. Pasqualucci[132a], A. Passeri[134a], F. Pastore[134a,134b], Fr. Pastore[76], G. Pásztor [49,x], S. Pataraia[174], N. Patel[150], J.R. Pater[82], S. Patricelli[102a,102b], T. Pauly[29], M. Pecsy[144a], M.I. Pedraza Morales[172], S.V. Peleganchuk[107], H. Peng[32b], R. Pengo[29], A. Penson[34], J. Penwell[61], M. Perantoni[23a], K. Perez[34,y], T. Perez Cavalcanti[41], E. Perez Codina[11], M.T. Pérez García-Estañ[167], V. Perez Reale[34], L. Perini[89a,89b], H. Pernegger[29], R. Perrino[72a], P. Perrodo[4], S. Persembe[3a], V.D. Peshekhonov[65],

B.A. Petersen[29], J. Petersen[29], T.C. Petersen[35], E. Petit[83], A. Petridis[154], C. Petridou[154], E. Petrolo[132a], F. Petrucci[134a,134b], D. Petschull[41], M. Petteni[142], R. Pezoa[31b], A. Phan[86], A.W. Phillips[27], P.W. Phillips[129], G. Piacquadio[29], E. Piccaro[75], M. Piccinini[19a,19b], A. Pickford[53], S.M. Piec[41], R. Piegaia[26], J.E. Pilcher[30], A.D. Pilkington[82], J. Pina[124a,b], M. Pinamonti[164a,164c], A. Pinder[118], J.L. Pinfold[2], J. Ping[32c], B. Pinto[124a,b], O. Pirotte[29], C. Pizio[89a,89b], R. Placakyte[41], M. Plamondon[169], M.-A. Pleier[24], A.V. Pleskach[128], A. Poblaguev[24], S. Poddar[58a], F. Podlyski[33], L. Poggioli[115], T. Poghosyan[20], M. Pohl[49], F. Polci[55], G. Polesello[119a], A. Policicchio[138], A. Polini[19a], J. Poll[75], V. Polychronakos[24], D.M. Pomarede[136], D. Pomeroy[22], K. Pommès[29], L. Pontecorvo[132a], B.G. Pope[88], G.A. Popeneciu[25a], D.S. Popovic[12a], A. Poppleton[29], X. Portell Bueso[29], R. Porter[163], C. Posch[21], G.E. Pospelov[99], S. Pospisil[127], I.N. Potrap[99], C.J. Potter[149], C.T. Potter[114], G. Poulard[29], J. Poveda[172], R. Prabhu[77], P. Pralavorio[83], S. Prasad[57], R. Pravahan[7], S. Prell[64], K. Pretzl[16], L. Pribyl[29], D. Price[61], L.E. Price[5], M.J. Price[29], P.M. Prichard[73], D. Prieur[123], M. Primavera[72a], K. Prokofiev[108], F. Prokoshin[31b], S. Protopopescu[24], J. Proudfoot[5], X. Prudent[43], H. Przysiezniak[4], S. Psoroulas[20], E. Ptacek[114], E. Pueschel[84], J. Purdham[87], M. Purohit[24,w], P. Puzo[115], Y. Pylypchenko[117], J. Qian[87], Z. Qian[83], Z. Qin[41], A. Quadt[54], D.R. Quarrie[14], W.B. Quayle[172], F. Quinonez[31a], M. Raas[104], V. Radescu[58b], B. Radics[20], T. Rador[18a], F. Ragusa[89a,89b], G. Rahal[177], A.M. Rahimi[109], D. Rahm[24], S. Rajagopalan[24], M. Rammensee[48], M. Rammes[141], M. Ramstedt[146a,146b], A.S. Randle-Conde[39], K. Randrianarivony[28], P.N. Ratoff[71], F. Rauscher[98], E. Rauter[99], M. Raymond[29], A.L. Read[117], D.M. Rebuzzi[119a,119b], A. Redelbach[173], G. Redlinger[24], R. Reece[120], K. Reeves[40], A. Reichold[105], E. Reinherz-Aronis[153], A. Reinsch[114], I. Reisinger[42], D. Reljic[12a], C. Rembser[29], Z.L. Ren[151], A. Renaud[115], P. Renkel[39], M. Rescigno[132a], S. Resconi[89a], B. Resende[136], P. Reznicek[98], R. Rezvani[158], A. Richards[77], R. Richter[99], E. Richter-Was[4,z], M. Ridel[78], S. Rieke[81], M. Rijpstra[105], M. Rijssenbeek[148], A. Rimoldi[119a,119b], L. Rinaldi[19a], R.R. Rios[39], I. Riu[11], G. Rivoltella[89a,89b], F. Rizatdinova[112], E. Rizvi[75], S.H. Robertson[85,k], A. Robichaud-Veronneau[118], D. Robinson[27], J.E.M. Robinson[77], M. Robinson[114], A. Robson[53], J.G. Rocha de Lima[106], C. Roda[122a,122b], D. Roda Dos Santos[29], S. Rodier[80], D. Rodriguez[162], A. Roe[54], S. Roe[29], O. Røhne[117], V. Rojo[1], S. Rolli[161], A. Romaniouk[96], M. Romano[19a,19b], V.M. Romanov[65], G. Romeo[26], L. Roos[78], E. Ros[167], S. Rosati[132a,132b], K. Rosbach[49], A. Rose[149], M. Rose[76], G.A. Rosenbaum[158], E.I. Rosenberg[64], P.L. Rosendahl[13], O. Rosenthal[141], L. Rosselet[49], V. Rossetti[11], E. Rossi[132a,132b], L.P. Rossi[50a], L. Rossi[89a,89b], M. Rotaru[25a], I. Roth[171], J. Rothberg[138], D. Rousseau[115], C.R. Royon[136], A. Rozanov[83], Y. Rozen[152], X. Ruan[115], I. Rubinskiy[41], B. Ruckert[98], N. Ruckstuhl[105], V.I. Rud[97], C. Rudolph[43], G. Rudolph[62], F. Rühr[6], F. Ruggieri[134a,134b], A. Ruiz-Martinez[64], E. Rulikowska-Zarebska[37], V. Rumiantsev[91,*], L. Rumyantsev[65], K. Runge[48], O. Runolfsson[20], Z. Rurikova[48], N.A. Rusakovich[65], D.R. Rust[61], J.P. Rutherfoord[6], C. Ruwiedel[14], P. Ruzicka[125], Y.F. Ryabov[121], V. Ryadovikov[128], P. Ryan[88], M. Rybar[126], G. Rybkin[115], N.C. Ryder[118], S. Rzaeva[10], A.F. Saavedra[150], I. Sadeh[153], H.F-W. Sadrozinski[137], R. Sadykov[65], F. Safai Tehrani[132a,132b], H. Sakamoto[155], G. Salamanna[75], A. Salamon[133a], M. Saleem[111], D. Salihagic[99], A. Salnikov[143], J. Salt[167], B.M. Salvachua Ferrando[5], D. Salvatore[36a,36b], F. Salvatore[149], A. Salvucci[104], A. Salzburger[29], D. Sampsonidis[154], B.H. Samset[117], A. Sanchez[102a,102b], H. Sandaker[13], H.G. Sander[81], M.P. Sanders[98], M. Sandhoff[174], T. Sandoval[27], C. Sandoval [162], R. Sandstroem[99], S. Sandvoss[174], D.P.C. Sankey[129], A. Sansoni[47], C. Santamarina Rios[85], C. Santoni[33], R. Santonico[133a,133b], H. Santos[124a], J.G. Saraiva[124a,b], T. Sarangi[172], E. Sarkisyan-Grinbaum[7], F. Sarri[122a,122b], G. Sartisohn[174], O. Sasaki[66], T. Sasaki[66], N. Sasao[68], I. Satsounkevitch[90], G. Sauvage[4], E. Sauvan[4], J.B. Sauvan[115], P. Savard[158,e], V. Savinov[123], D.O. Savu[29], P. Savva [9], L. Sawyer[24,m], D.H. Saxon[53], L.P. Says[33], C. Sbarra[19a,19b], A. Sbrizzi[19a,19b], O. Scallon[93], D.A. Scannicchio[163], J. Schaarschmidt[115], P. Schacht[99], U. Schäfer[81], S. Schaepe[20], S. Schaetzel[58b], A.C. Schaffer[115], D. Schaile[98], R.D. Schamberger[148], A.G. Schamov[107], V. Scharf[58a], V.A. Schegelsky[121], D. Scheirich[87], M. Schernau[163], M.I. Scherzer[14], C. Schiavi[50a,50b], J. Schieck[98], M. Schioppa[36a,36b], S. Schlenker[29], J.L. Schlereth[5], E. Schmidt[48], K. Schmieden[20], C. Schmitt[81], S. Schmitt[58b], M. Schmitz[20], A. Schöning[58b], M. Schott[29], D. Schouten[159a], J. Schovancova[125], M. Schram[85], C. Schroeder[81], N. Schroer[58c], S. Schuh[29], G. Schuler[29], J. Schultes[174], H.-C. Schultz-Coulon[58a], H. Schulz[15], J.W. Schumacher[20], M. Schumacher[48], B.A. Schumm[137], Ph. Schune[136], C. Schwanenberger[82], A. Schwartzman[143], Ph. Schwemling[78], R. Schwienhorst[88], R. Schwierz[43], J. Schwindling[136], T. Schwindt[20], W.G. Scott[129], J. Searcy[114], G. Sedov[41], E. Sedykh[121], E. Segura[11], S.C. Seidel[103], A. Seiden[137], F. Seifert[43], J.M. Seixas[23a], G. Sekhniaidze[102a], D.M. Seliverstov[121], B. Sellden[146a], G. Sellers[73], M. Seman[144b], N. Semprini-Cesari[19a,19b], C. Serfon[98], L. Serin[115], R. Seuster[99], H. Severini[111], M.E. Sevior[86], A. Sfyrla[29], E. Shabalina[54], M. Shamim[114], L.Y. Shan[32a], J.T. Shank[21], Q.T. Shao[86], M. Shapiro[14], P.B. Shatalov[95], L. Shaver[6], K. Shaw[164a,164c], D. Sherman[175], P. Sherwood[77], A. Shibata[108], H. Shichi[101], S. Shimizu[29], M. Shimojima[100], T. Shin[56], A. Shmeleva[94], M.J. Shochet[30], D. Short[118], M.A. Shupe[6], P. Sicho[125], A. Sidoti[132a,132b], A. Siebel[174], F. Siegert[48], J. Siegrist[14], Dj. Sijacki[12a], O. Silbert[171], J. Silva[124a,b], Y. Silver[153], D. Silverstein[143], S.B. Silverstein[146a], V. Simak[127], O. Simard[136], Lj. Simic[12a], S. Simion[115], B. Simmons[77], M. Simonyan[35], P. Sinervo[158], N.B. Sinev[114], V. Sipica[141], G. Siragusa[173], A. Sircar[24], A.N. Sisakyan[65], S.Yu. Sivoklokov[97], J. Sjölin[146a,146b], T.B. Sjursen[13], L.A. Skinnari[14], H.P. Skottowe[57], K. Skovpen[107], P. Skubic[111], N. Skvorodnev[22], M. Slater[17], T. Slavicek[127], K. Sliwa[161], J. Sloper[29], V. Smakhtin[171], S.Yu. Smirnov[96], L.N. Smirnova[97], O. Smirnova[79], B.C. Smith[57], D. Smith[143], K.M. Smith[53], M. Smizanska[71], K. Smolek[127], A.A. Snesarev[94], S.W. Snow[82], J. Snow[111], J. Snuverink[105], S. Snyder[24], M. Soares[124a], R. Sobie[169,k],

J. Sodomka[127], A. Soffer[153], C.A. Solans[167], M. Solar[127], J. Solc[127], E. Soldatov[96], U. Soldevila[167], E. Solfaroli Camillocci[132a,132b], A.A. Solodkov[128], O.V. Solovyanov[128], J. Sondericker[24], N. Soni[2], V. Sopko[127], B. Sopko[127], M. Sorbi[89a,89b], M. Sosebee[7], R. Soualah[164a,164c], A. Soukharev[107], S. Spagnolo[72a,72b], F. Spanò[76], R. Spighi[19a], G. Spigo[29], F. Spila[132a,132b], E. Spiriti[134a], R. Spiwoks[29], M. Spousta[126], T. Spreitzer[158], B. Spurlock[7], R.D. St. Denis[53], T. Stahl[141], J. Stahlman[120], R. Stamen[58a], E. Stanecka[29], R.W. Stanek[5], C. Stanescu[134a], S. Stapnes[117], E.A. Starchenko[128], J. Stark[55], P. Staroba[125], P. Starovoitov[91], A. Staude[98], P. Stavina[144a], G. Stavropoulos[14], G. Steele[53], P. Steinbach[43], P. Steinberg[24], I. Stekl[127], B. Stelzer[142], H.J. Stelzer[88], O. Stelzer-Chilton[159a], H. Stenzel[52], K. Stevenson[75], G.A. Stewart[29], J.A. Stillings[20], T. Stockmanns[20], M.C. Stockton[29], K. Stoerig[48], G. Stoicea[25a], S. Stonjek[99], P. Strachota[126], A.R. Stradling[7], A. Straessner[43], J. Strandberg[147], S. Strandberg[146a,146b], A. Strandlie[117], M. Strang[109], E. Strauss[143], M. Strauss[111], P. Strizenec[144b], R. Ströhmer[173], D.M. Strom[114], J.A. Strong[76,*], R. Stroynowski[39], J. Strube[129], B. Stugu[13], I. Stumer[24,*], J. Stupak[148], P. Sturm[174], D.A. Soh[151,r], D. Su[143], HS. Subramania[2], A. Succurro[11], Y. Sugaya[116], T. Sugimoto[101], C. Suhr[106], K. Suita[67], M. Suk[126], V.V. Sulin[94], S. Sultansoy[3d], T. Sumida[29], X. Sun[55], J.E. Sundermann[48], K. Suruliz[139], S. Sushkov[11], G. Susinno[36a,36b], M.R. Sutton[149], Y. Suzuki[66], Y. Suzuki[67], M. Svatos[125], Yu.M. Sviridov[128], S. Swedish[168], I. Sykora[144a], T. Sykora[126], B. Szeless[29], J. Sánchez[167], D. Ta[105], K. Tackmann[41], A. Taffard[163], R. Tafirout[159a], N. Taiblum[153], Y. Takahashi[101], H. Takai[24], R. Takashima[69], H. Takeda[67], T. Takeshita[140], M. Talby[83], A. Talyshev[107], M.C. Tamsett[24], J. Tanaka[155], R. Tanaka[115], S. Tanaka[131], S. Tanaka[66], Y. Tanaka[100], K. Tani[67], N. Tannoury[83], G.P. Tappern[29], S. Tapprogge[81], D. Tardif[158], S. Tarem[152], F. Tarrade[28], G.F. Tartarelli[89a], P. Tas[126], M. Tasevsky[125], E. Tassi[36a,36b], M. Tatarkhanov[14], Y. Tayalati[135d], C. Taylor[77], F.E. Taylor[92], G.N. Taylor[86], W. Taylor[159b], M. Teinturier[115], M. Teixeira Dias Castanheira[75], P. Teixeira-Dias[76], K.K. Temming[48], H. Ten Kate[29], P.K. Teng[151], S. Terada[66], K. Terashi[155], J. Terron[80], M. Terwort[41,p], M. Testa[47], R.J. Teuscher[158,k], J. Thadome[174], J. Therhaag[20], T. Theveneaux-Pelzer[78], M. Thioye[175], S. Thoma[48], J.P. Thomas[17], E.N. Thompson[84], P.D. Thompson[17], P.D. Thompson[158], A.S. Thompson[53], E. Thomson[120], M. Thomson[27], R.P. Thun[87], F. Tian[34], T. Tic[125], V.O. Tikhomirov[94], Y.A. Tikhonov[107], C.J.W.P. Timmermans[104], P. Tipton[175], F.J. Tique Aires Viegas[29], S. Tisserant[83], J. Tobias[48], B. Toczek[37], T. Todorov[4], S. Todorova-Nova[161], B. Toggerson[163], J. Tojo[66], S. Tokár[144a], K. Tokunaga[67], K. Tokushuku[66], K. Tollefson[88], M. Tomoto[101], L. Tompkins[14], K. Toms[103], G. Tong[32a], A. Tonoyan[13], C. Topfel[16], N.D. Topilin[65], I. Torchiani[29], E. Torrence[114], H. Torres[78], E. Torró Pastor[167], J. Toth[83,x], F. Touchard[83], D.R. Tovey[139], D. Traynor[75], T. Trefzger[173], L. Tremblet[29], A. Tricoli[29], I.M. Trigger[159a], S. Trincaz-Duvoid[78], T.N. Trinh[78], M.F. Tripiana[70], W. Trischuk[158], A. Trivedi[24,w], B. Trocmé[55], C. Troncon[89a], M. Trottier-McDonald[142], A. Trzupek[38], C. Tsarouchas[29], J.C-L. Tseng[118], M. Tsiakiris[105], P.V. Tsiareshka[90], D. Tsionou[4], G. Tsipolitis[9], V. Tsiskaridze[48], E.G. Tskhadadze[51a], I.I. Tsukerman[95], V. Tsulaia[14], J.-W. Tsung[20], S. Tsuno[66], D. Tsybychev[148], A. Tua[139], A. Tudorache[25a], V. Tudorache[25a], J.M. Tuggle[30], M. Turala[38], D. Turecek[127], I. Turk Cakir[3e], E. Turlay[105], R. Turra[89a,89b], P.M. Tuts[34], A. Tykhonov[74], M. Tylmad[146a,146b], M. Tyndel[129], H. Tyrvainen[29], G. Tzanakos[8], K. Uchida[20], I. Ueda[155], R. Ueno[28], M. Ugland[13], M. Uhlenbrock[20], M. Uhrmacher[54], F. Ukegawa[160], G. Unal[29], D.G. Underwood[5], A. Undrus[24], G. Unel[163], Y. Unno[66], D. Urbaniec[34], E. Urkovsky[153], P. Urrejola[31a], G. Usai[7], M. Uslenghi[119a,119b], L. Vacavant[83], V. Vacek[127], B. Vachon[85], S. Vahsen[14], J. Valenta[125], P. Valente[132a], S. Valentinetti[19a,19b], S. Valkar[126], E. Valladolid Gallego[167], S. Vallecorsa[152], J.A. Valls Ferrer[167], H. van der Graaf[105], E. van der Kraaij[105], R. Van Der Leeuw[105], E. van der Poel[105], D. van der Ster[29], N. van Eldik[84], P. van Gemmeren[5], Z. van Kesteren[105], I. van Vulpen[105], W. Vandelli[29], G. Vandoni[29], A. Vaniachine[5], P. Vankov[41], F. Vannucci[78], F. Varela Rodriguez[29], R. Vari[132a], D. Varouchas[14], A. Vartapetian[7], K.E. Varvell[150], V.I. Vassilakopoulos[56], F. Vazeille[33], G. Vegni[89a,89b], J.J. Veillet[115], C. Vellidis[8], F. Veloso[124a], R. Veness[29], S. Veneziano[132a], A. Ventura[72a,72b], D. Ventura[138], M. Venturi[48], N. Venturi[16], V. Vercesi[119a], M. Verducci[138], W. Verkerke[105], J.C. Vermeulen[105], A. Vest[43], M.C. Vetterli[142,e], I. Vichou[165], T. Vickey[145b,aa], O.E. Vickey Boeriu[145b], G.H.A. Viehhauser[118], S. Viel[168], M. Villa[19a,19b], M. Villaplana Perez[167], E. Vilucchi[47], M.G. Vincter[28], E. Vinek[29], V.B. Vinogradov[65], M. Virchaux[136,*], J. Virzi[14], O. Vitells[171], M. Viti[41], I. Vivarelli[48], F. Vives Vaque[2], S. Vlachos[9], D. Vladoiu[98], M. Vlasak[127], N. Vlasov[20], A. Vogel[20], P. Vokac[127], G. Volpi[47], M. Volpi[86], G. Volpini[89a], H. von der Schmitt[99], J. von Loeben[99], H. von Radziewski[48], E. von Toerne[20], V. Vorobel[126], A.P. Vorobiev[128], V. Vorwerk[11], M. Vos[167], R. Voss[29], T.T. Voss[174], J.H. Vossebeld[73], N. Vranjes[12a], M. Vranjes Milosavljevic[105], V. Vrba[125], M. Vreeswijk[105], T. Vu Anh[81], R. Vuillermet[29], I. Vukotic[115], W. Wagner[174], P. Wagner[120], H. Wahlen[174], J. Wakabayashi[101], J. Walbersloh[42], S. Walch[87], J. Walder[71], R. Walker[98], W. Walkowiak[141], R. Wall[175], P. Waller[73], C. Wang[44], H. Wang[172], H. Wang[32b,ab], J. Wang[151], J. Wang[32d], J.C. Wang[138], R. Wang[103], S.M. Wang[151], A. Warburton[85], C.P. Ward[27], M. Warsinsky[48], P.M. Watkins[17], A.T. Watson[17], M.F. Watson[17], G. Watts[138], S. Watts[82], A.T. Waugh[150], B.M. Waugh[77], J. Weber[42], M. Weber[129], M.S. Weber[16], P. Weber[54], A.R. Weidberg[118], P. Weigell[99], J. Weingarten[54], C. Weiser[48], H. Wellenstein[22], P.S. Wells[29], M. Wen[47], T. Wenaus[24], S. Wendler[123], Z. Weng[151,r], T. Wengler[29], S. Wenig[29], N. Wermes[20], M. Werner[48], P. Werner[29], M. Werth[163], M. Wessels[58a], C. Weydert[55], K. Whalen[28], S.J. Wheeler-Ellis[163], S.P. Whitaker[21], A. White[7], M.J. White[86], S.R. Whitehead[118], D. Whiteson[163], D. Whittington[61], F. Wicek[115], D. Wicke[174], F.J. Wickens[129], W. Wiedenmann[172], M. Wielers[129],

P. Wienemann[20], C. Wiglesworth[75], L.A.M. Wiik[48], P.A. Wijeratne[77], A. Wildauer[167], M.A. Wildt[41,p], I. Wilhelm[126], H.G. Wilkens[29], J.Z. Will[98], E. Williams[34], H.H. Williams[120], W. Willis[34], S. Willocq[84], J.A. Wilson[17], M.G. Wilson[143], A. Wilson[87], I. Wingerter-Seez[4], S. Winkelmann[48], F. Winklmeier[29], M. Wittgen[143], M.W. Wolter[38], H. Wolters[124a,i], W.C. Wong[40], G. Wooden[87], B.K. Wosiek[38], J. Wotschack[29], M.J. Woudstra[84], K. Wraight[53], C. Wright[53], M. Wright[53], B. Wrona[73], S.L. Wu[172], X. Wu[49], Y. Wu[32b,ac], E. Wulf[34], R. Wunstorf[42], B.M. Wynne[45], L. Xaplanteris[9], S. Xella[35], S. Xie[48], Y. Xie[32a], C. Xu[32b,ad], D. Xu[139], G. Xu[32a], B. Yabsley[150], S. Yacoob[145b], M. Yamada[66], H. Yamaguchi[155], A. Yamamoto[66], K. Yamamoto[64], S. Yamamoto[155], T. Yamamura[155], T. Yamanaka[155], J. Yamaoka[44], T. Yamazaki[155], Y. Yamazaki[67], Z. Yan[21], H. Yang[87], U.K. Yang[82], Y. Yang[61], Y. Yang[32a], Z. Yang[146a,146b], S. Yanush[91], Y. Yao[14], Y. Yasu[66], G.V. Ybeles Smit[130], J. Ye[39], S. Ye[24], M. Yilmaz[3c], R. Yoosoofmiya[123], K. Yorita[170], R. Yoshida[5], C. Young[143], S. Youssef[21], D. Yu[24], J. Yu[7], J. Yu[32c,ad], L. Yuan[32a,ae], A. Yurkewicz[148], V.G. Zaets [128], R. Zaidan[63], A.M. Zaitsev[128], Z. Zajacova[29], Yo.K. Zalite [121], L. Zanello[132a,132b], P. Zarzhitsky[39], A. Zaytsev[107], C. Zeitnitz[174], M. Zeller[175], M. Zeman[125], A. Zemla[38], C. Zendler[20], O. Zenin[128], T. Ženiš[144a], Z. Zenonos[122a,122b], S. Zenz[14], D. Zerwas[115], G. Zevi della Porta[57], Z. Zhan[32d], D. Zhang[32b,ab], H. Zhang[88], J. Zhang[5], X. Zhang[32d], Z. Zhang[115], L. Zhao[108], T. Zhao[138], Z. Zhao[32b], A. Zhemchugov[65], S. Zheng[32a], J. Zhong[151,af], B. Zhou[87], N. Zhou[163], Y. Zhou[151], C.G. Zhu[32d], H. Zhu[41], J. Zhu[87], Y. Zhu[32b], X. Zhuang[98], V. Zhuravlov[99], D. Zieminska[61], R. Zimmermann[20], S. Zimmermann[20], S. Zimmermann[48], M. Ziolkowski[141], R. Zitoun[4], L. Živković[34], V.V. Zmouchko[128,*], G. Zobernig[172], A. Zoccoli[19a,19b], Y. Zolnierowski[4], A. Zsenei[29], M. zur Nedden[15], V. Zutshi[106], L. Zwalinski[29].

[1] University at Albany, Albany NY, United States of America
[2] Department of Physics, University of Alberta, Edmonton AB, Canada
[3] [(a)]Department of Physics, Ankara University, Ankara; [(b)]Department of Physics, Dumlupinar University, Kutahya; [(c)]Department of Physics, Gazi University, Ankara; [(d)]Division of Physics, TOBB University of Economics and Technology, Ankara; [(e)]Turkish Atomic Energy Authority, Ankara, Turkey
[4] LAPP, CNRS/IN2P3 and Université de Savoie, Annecy-le-Vieux, France
[5] High Energy Physics Division, Argonne National Laboratory, Argonne IL, United States of America
[6] Department of Physics, University of Arizona, Tucson AZ, United States of America
[7] Department of Physics, The University of Texas at Arlington, Arlington TX, United States of America
[8] Physics Department, University of Athens, Athens, Greece
[9] Physics Department, National Technical University of Athens, Zografou, Greece
[10] Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
[11] Institut de Física d'Altes Energies and Departament de Física de la Universitat Autònoma de Barcelona and ICREA, Barcelona, Spain
[12] [(a)]Institute of Physics, University of Belgrade, Belgrade; [(b)]Vinca Institute of Nuclear Sciences, Belgrade, Serbia
[13] Department for Physics and Technology, University of Bergen, Bergen, Norway
[14] Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley CA, United States of America
[15] Department of Physics, Humboldt University, Berlin, Germany
[16] Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland
[17] School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom
[18] [(a)]Department of Physics, Bogazici University, Istanbul; [(b)]Division of Physics, Dogus University, Istanbul; [(c)]Department of Physics Engineering, Gaziantep University, Gaziantep; [(d)]Department of Physics, Istanbul Technical University, Istanbul, Turkey
[19] [(a)]INFN Sezione di Bologna; [(b)]Dipartimento di Fisica, Università di Bologna, Bologna, Italy
[20] Physikalisches Institut, University of Bonn, Bonn, Germany
[21] Department of Physics, Boston University, Boston MA, United States of America
[22] Department of Physics, Brandeis University, Waltham MA, United States of America
[23] [(a)]Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; [(b)]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
[24] Physics Department, Brookhaven National Laboratory, Upton NY, United States of America
[25] [(a)]National Institute of Physics and Nuclear Engineering, Bucharest; [(b)]University Politehnica Bucharest, Bucharest; [(c)]West University in Timisoara, Timisoara, Romania
[26] Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina
[27] Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
[28] Department of Physics, Carleton University, Ottawa ON, Canada
[29] CERN, Geneva, Switzerland
[30] Enrico Fermi Institute, University of Chicago, Chicago IL, United States of America

[31] [(a)]Departamento de Fisica, Pontificia Universidad Católica de Chile, Santiago; [(b)]Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
[32] [(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)]High Energy Physics Group, Shandong University, Shandong, China
[33] Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Aubiere Cedex, France
[34] Nevis Laboratory, Columbia University, Irvington NY, United States of America
[35] Niels Bohr Institute, University of Copenhagen, Kobenhavn, Denmark
[36] [(a)]INFN Gruppo Collegato di Cosenza; [(b)]Dipartimento di Fisica, Università della Calabria, Arcavata di Rende, Italy
[37] Faculty of Physics and Applied Computer Science, AGH-University of Science and Technology, Krakow, Poland
[38] The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
[39] Physics Department, Southern Methodist University, Dallas TX, United States of America
[40] Physics Department, University of Texas at Dallas, Richardson TX, United States of America
[41] DESY, Hamburg and Zeuthen, Germany
[42] Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
[43] Institut für Kern- und Teilchenphysik, Technical University Dresden, Dresden, Germany
[44] Department of Physics, Duke University, Durham NC, United States of America
[45] SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
[46] Fachhochschule Wiener Neustadt, Johannes Gutenbergstrasse 3, 2700 Wiener Neustadt, Austria
[47] INFN Laboratori Nazionali di Frascati, Frascati, Italy
[48] Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg i.Br., Germany
[49] Section de Physique, Université de Genève, Geneva, Switzerland
[50] [(a)]INFN Sezione di Genova; [(b)]Dipartimento di Fisica, Università di Genova, Genova, Italy
[51] [(a)]E.Andronikashvili Institute of Physics, Georgian Academy of Sciences, Tbilisi; [(b)]High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
[52] II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
[53] SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
[54] II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany
[55] Laboratoire de Physique Subatomique et de Cosmologie, Université Joseph Fourier and CNRS/IN2P3 and Institut National Polytechnique de Grenoble, Grenoble, France
[56] Department of Physics, Hampton University, Hampton VA, United States of America
[57] Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA, United States of America
[58] [(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
[59] Faculty of Science, Hiroshima University, Hiroshima, Japan
[60] Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan
[61] Department of Physics, Indiana University, Bloomington IN, United States of America
[62] Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
[63] University of Iowa, Iowa City IA, United States of America
[64] Department of Physics and Astronomy, Iowa State University, Ames IA, United States of America
[65] Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia
[66] KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
[67] Graduate School of Science, Kobe University, Kobe, Japan
[68] Faculty of Science, Kyoto University, Kyoto, Japan
[69] Kyoto University of Education, Kyoto, Japan
[70] Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
[71] Physics Department, Lancaster University, Lancaster, United Kingdom
[72] [(a)]INFN Sezione di Lecce; [(b)]Dipartimento di Fisica, Università del Salento, Lecce, Italy
[73] Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
[74] Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
[75] Department of Physics, Queen Mary University of London, London, United Kingdom
[76] Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
[77] Department of Physics and Astronomy, University College London, London, United Kingdom
[78] Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
[79] Fysiska institutionen, Lunds universitet, Lund, Sweden

[80] Departamento de Fisica Teorica C-15, Universidad Autonoma de Madrid, Madrid, Spain
[81] Institut für Physik, Universität Mainz, Mainz, Germany
[82] School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
[83] CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
[84] Department of Physics, University of Massachusetts, Amherst MA, United States of America
[85] Department of Physics, McGill University, Montreal QC, Canada
[86] School of Physics, University of Melbourne, Victoria, Australia
[87] Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
[88] Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States of America
[89] [(a)]INFN Sezione di Milano; [(b)]Dipartimento di Fisica, Università di Milano, Milano, Italy
[90] B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Republic of Belarus
[91] National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Republic of Belarus
[92] Department of Physics, Massachusetts Institute of Technology, Cambridge MA, United States of America
[93] Group of Particle Physics, University of Montreal, Montreal QC, Canada
[94] P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia
[95] Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
[96] Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia
[97] Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
[98] Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
[99] Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
[100] Nagasaki Institute of Applied Science, Nagasaki, Japan
[101] Graduate School of Science, Nagoya University, Nagoya, Japan
[102] [(a)]INFN Sezione di Napoli; [(b)]Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy
[103] Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, United States of America
[104] Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
[105] Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
[106] Department of Physics, Northern Illinois University, DeKalb IL, United States of America
[107] Budker Institute of Nuclear Physics (BINP), Novosibirsk, Russia
[108] Department of Physics, New York University, New York NY, United States of America
[109] Ohio State University, Columbus OH, United States of America
[110] Faculty of Science, Okayama University, Okayama, Japan
[111] Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States of America
[112] Department of Physics, Oklahoma State University, Stillwater OK, United States of America
[113] Palacký University, RCPTM, Olomouc, Czech Republic
[114] Center for High Energy Physics, University of Oregon, Eugene OR, United States of America
[115] LAL, Univ. Paris-Sud and CNRS/IN2P3, Orsay, France
[116] Graduate School of Science, Osaka University, Osaka, Japan
[117] Department of Physics, University of Oslo, Oslo, Norway
[118] Department of Physics, Oxford University, Oxford, United Kingdom
[119] [(a)]INFN Sezione di Pavia; [(b)]Dipartimento di Fisica Nucleare e Teorica, Università di Pavia, Pavia, Italy
[120] Department of Physics, University of Pennsylvania, Philadelphia PA, United States of America
[121] Petersburg Nuclear Physics Institute, Gatchina, Russia
[122] [(a)]INFN Sezione di Pisa; [(b)]Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
[123] Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States of America
[124] [(a)]Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisboa, Portugal; [(b)]Departamento de Fisica Teorica y del Cosmos and CAFPE, Universidad de Granada, Granada, Spain
[125] Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
[126] Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic
[127] Czech Technical University in Prague, Praha, Czech Republic
[128] State Research Center Institute for High Energy Physics, Protvino, Russia
[129] Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
[130] Physics Department, University of Regina, Regina SK, Canada
[131] Ritsumeikan University, Kusatsu, Shiga, Japan
[132] [(a)]INFN Sezione di Roma I; [(b)]Dipartimento di Fisica, Università La Sapienza, Roma, Italy
[133] [(a)]INFN Sezione di Roma Tor Vergata; [(b)]Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
[134] [(a)]INFN Sezione di Roma Tre; [(b)]Dipartimento di Fisica, Università Roma Tre, Roma, Italy

[135] [(a)]Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca; [(b)]Centre National de l'Energie des Sciences Techniques Nucleaires, Rabat; [(c)]Université Cadi Ayyad, Faculté des sciences Semlalia Département de Physique, B.P. 2390 Marrakech 40000; [(d)]Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; [(e)]Faculté des Sciences, Université Mohammed V, Rabat, Morocco
[136] DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat a l'Energie Atomique), Gif-sur-Yvette, France
[137] Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States of America
[138] Department of Physics, University of Washington, Seattle WA, United States of America
[139] Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
[140] Department of Physics, Shinshu University, Nagano, Japan
[141] Fachbereich Physik, Universität Siegen, Siegen, Germany
[142] Department of Physics, Simon Fraser University, Burnaby BC, Canada
[143] SLAC National Accelerator Laboratory, Stanford CA, United States of America
[144] [(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
[145] [(a)]Department of Physics, University of Johannesburg, Johannesburg; [(b)]School of Physics, University of the Witwatersrand, Johannesburg, South Africa
[146] [(a)]Department of Physics, Stockholm University; [(b)]The Oskar Klein Centre, Stockholm, Sweden
[147] Physics Department, Royal Institute of Technology, Stockholm, Sweden
[148] Department of Physics and Astronomy, Stony Brook University, Stony Brook NY, United States of America
[149] Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
[150] School of Physics, University of Sydney, Sydney, Australia
[151] Institute of Physics, Academia Sinica, Taipei, Taiwan
[152] Department of Physics, Technion: Israel Inst. of Technology, Haifa, Israel
[153] Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
[154] Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
[155] International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan
[156] Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
[157] Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
[158] Department of Physics, University of Toronto, Toronto ON, Canada
[159] [(a)]TRIUMF, Vancouver BC; [(b)]Department of Physics and Astronomy, York University, Toronto ON, Canada
[160] Institute of Pure and Applied Sciences, University of Tsukuba, Ibaraki, Japan
[161] Science and Technology Center, Tufts University, Medford MA, United States of America
[162] Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia
[163] Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States of America
[164] [(a)]INFN Gruppo Collegato di Udine; [(b)]ICTP, Trieste; [(c)]Dipartimento di Fisica, Università di Udine, Udine, Italy
[165] Department of Physics, University of Illinois, Urbana IL, United States of America
[166] Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
[167] Instituto de Física Corpuscular (IFIC) and Departamento de Física Atómica, Molecular y Nuclear and Departamento de Ingenierá Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain
[168] Department of Physics, University of British Columbia, Vancouver BC, Canada
[169] Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada
[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] Fachbereich C 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] Domaine scientifique de la Doua, Centre de Calcul CNRS/IN2P3, Villeurbanne Cedex, France
[a] Also at Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisboa, Portugal
[b] Also at Faculdade de Ciencias and CFNUL, Universidade de Lisboa, Lisboa, Portugal
[c] Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
[d] Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
[e] Also at TRIUMF, Vancouver BC, Canada

[f] Also at Department of Physics, California State University, Fresno CA, United States of America
[g] Also at Faculty of Physics and Applied Computer Science, AGH-University of Science and Technology, Krakow, Poland
[h] Also at Fermilab, Batavia IL, United States of America
[i] Also at Department of Physics, University of Coimbra, Coimbra, Portugal
[j] Also at Università di Napoli Parthenope, Napoli, Italy
[k] Also at Institute of Particle Physics (IPP), Canada
[l] Also at Department of Physics, Middle East Technical University, Ankara, Turkey
[m] Also at Louisiana Tech University, Ruston LA, United States of America
[n] Also at Group of Particle Physics, University of Montreal, Montreal QC, Canada
[o] Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
[p] Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany
[q] Also at Manhattan College, New York NY, United States of America
[r] Also at School of Physics and Engineering, Sun Yat-sen University, Guanzhou, China
[s] Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan
[t] Also at High Energy Physics Group, Shandong University, Shandong, China
[u] Also at Section de Physique, Université de Genève, Geneva, Switzerland
[v] Also at Departamento de Fisica, Universidade de Minho, Braga, Portugal
[w] Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States of America
[x] Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
[y] Also at California Institute of Technology, Pasadena CA, United States of America
[z] Also at Institute of Physics, Jagiellonian University, Krakow, Poland
[aa] Also at Department of Physics, Oxford University, Oxford, United Kingdom
[ab] Also at Institute of Physics, Academia Sinica, Taipei, Taiwan
[ac] Also at Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
[ad] Also at DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat a l'Energie Atomique), Gif-sur-Yvette, France
[ae] Also at Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
[af] Also at Department of Physics, Nanjing University, Jiangsu, China
* Deceased