Regular Article - Experimental Physics

Measurement of event shapes at large momentum transfer with the ATLAS detector in pp collisions at $\sqrt{s} = 7$ TeV

The ATLAS Collaboration[⋆]

CERN, 1211 Geneva 23, Switzerland

Abstract A measurement of event shape variables is presented for large momentum transfer proton-proton collisions using the ATLAS detector at the Large Hadron Collider. Six event shape variables calculated using hadronic jets are studied in inclusive multi-jet events in 35 pb^{-1} of integrated luminosity at a center-of-mass energy of $\sqrt{s} = 7$ TeV. These measurements are compared to predictions by three Monte Carlo event generators containing leading-logarithmic parton showers matched to leading order matrix elements for $2 \to 2$ and $2 \to n$ ($n = 2, \ldots, 6$) scattering. Measurements of the third-jet resolution parameter, aplanarity, thrust, sphericity, and transverse sphericity are generally well described. The mean value of each event shape variable is evaluated as a function of the average momentum of the two leading jets $p_{T,1}$ and $p_{T,2}$, with a mean p_T approaching 1 TeV.

1 Introduction

Event shapes represent a generic class of observables that describe the patterns, correlations, and origins of the energy flow in an interaction. In terms of hadronic jet production, event shapes are an indirect probe of multi-jet topologies. These observables have had a long and fruitful history, having been used to measure the strong coupling constant α_S and to test asymptotic freedom [1–4], to constrain color factors for quark and gluon couplings [5], to assess the accuracy of leading order (LO) and next-to-leading order (NLO) Monte Carlo (MC) generators [6, 7], to determine the contribution of non-perturbative quantum chromodynamics (QCD) power corrections [8], and to search for physics beyond the Standard Model [9]. Furthermore, recent efforts to provide advanced, high-precision theoretical calculations of a range of event shapes for the Large Hadron Collider [10, 11] provide renewed impetus for making such measurements.

This analysis considers six event shapes calculated using hadronic jets. These observables are crucially tied to both the multi-jet nature of the final state produced in high energy collisions and have a strong history in the literature: the third-jet resolution parameter [4, 12–14], y_{23}; the sphericity and transverse sphericity [15, 16], S and $S_\perp$; the aplanarity, A; and the event thrust and its minor component [17], $\tau_\perp$ and $T_{m,\perp}$. Events with high transverse momentum central leading-jet pairs are used for the measurements. Each event shape variable is defined such that it vanishes in the limit of a pure $2 \to 2$ process and increases to a maximum for uniformly distributed energy within a multi-jet event. Hard gluon emission is thereby signified by large non-zero values of each observable. Furthermore, some of the event shape variables are evaluated as ratios of final state observables, which reduces their sensitivity to jet energy scale (JES) calibration uncertainties as well as other experimental and theoretical uncertainties. These measurements permit detailed tests of the phenomenological models of QCD in leading order MC programs and indirectly test the running of α_S through measurements performed as a function of the average leading jet momentum. In addition, these results may be used to provide input to tune MC generators in the future.

All event shapes measured in this analysis are defined using jets to represent the final state four-momenta, as discussed in Sect. 2. The ATLAS detector is described in Sect. 3, with a particular emphasis on the components relevant for the measurement of event shape variables. Section 4 presents the event selection and description of simulated events which are compared to the data. Jet definitions, calibrations, and selection criteria are also described in Sect. 4. Finally, the results of these measurements are presented in Sect. 5.

2 Event shape definitions

Six event shapes are measured using high transverse momentum (p_T) jets. The first observable, y_{23}, is a measure of

the third-jet p_T relative to the summed transverse momenta of the two leading jets in a multi-jet event and is defined as:

$$y_{23} = \frac{p_{T,3}^2}{H_{T,2}^2}, \tag{1}$$

where $H_{T,2} = (p_{T,1} + p_{T,2})$ is the scalar sum of jet momenta and the subscript $i = 1, 2, 3$ refers to the leading, subleading, or third leading jet in the event. The range of allowed values for y_{23} is $0 \le y_{23} < 1/4$ and it is often expressed as $\ln y_{23}$ [11, 16]. This definition is different from the original [12] definition which uses the JADE jet algorithm [18]. Equation (1) is defined with an explicit third-jet as opposed to a continuously variable threshold in the jet algorithm. The sphericity, S, transverse sphericity, $S_\perp$, and aplanarity, A, embody more global information about the full momentum tensor of the event, M_{xyz}, via its eigenvalues λ_1, λ_2 and λ_3:

$$M_{xyz} = \sum_i \begin{pmatrix} p_{xi}^2 & p_{xi} p_{yi} & p_{xi} p_{zi} \\ p_{yi} p_{xi} & p_{yi}^2 & p_{yi} p_{zi} \\ p_{zi} p_{xi} & p_{zi} p_{yi} & p_{zi}^2 \end{pmatrix}, \tag{2}$$

where the sum runs over all jets used in the measurement. The individual eigenvalues are normalized and ordered such that $\lambda_1 > \lambda_2 > \lambda_3$ and $\sum_i \lambda_i = 1$ by definition. These terms are used to define the three observables as

$$S = \frac{3}{2}(\lambda_2 + \lambda_3), \tag{3}$$

$$S_\perp = \frac{2\lambda_2}{\lambda_1 + \lambda_2}, \tag{4}$$

$$A = \frac{3}{2}\lambda_3. \tag{5}$$

Sphericity, Eq. (3), and transverse sphericity, Eq. (4), measure the total transverse momentum with respect to the sphericity axis defined by the four-momenta used for the event shape measurement (specifically, the first eigenvector). The allowed range of S values is $0 \le S < 1$, but due to the inclusion of the smallest eigenvalue, λ_3, the typical maximum achieved experimentally is $S \sim 0.8$. Conversely, the transverse sphericity is constructed using the two largest eigenvalues, and the typical range coincides with the allowed range, $0 \le S_\perp < 1$. Aplanarity (Eq. (5)) measures the amount of transverse momentum in or out of the plane formed by the two leading jets via only the smallest eigenvalue of M_{xyz}, λ_3, with allowed values $0 \le A < 1/2$. Typical measured values lie between $0 \le A < 0.3$, with values near zero indicating relatively planar events. The transverse thrust, $T_\perp$, and its minor component, $T_{m,\perp}$, define a so-called thrust axis for the event, with respect to which, the total transverse momentum of the jets used in the measurement is minimized. These quantities are defined as

$$T_\perp = \max_{\hat{n}_\perp} \frac{\sum_i |\mathbf{p}_{Ti} \cdot \hat{n}_\perp|}{\sum_i p_{Ti}}, \tag{6}$$

$$\tau_\perp = 1 - T_\perp, \tag{7}$$

$$T_{m,\perp} = \frac{\sum_i |\mathbf{p}_{Ti} \times \hat{n}_\perp|}{\sum_i p_{Ti}}, \tag{8}$$

where $T_\perp$ is translated into $\tau_\perp$ in order to maintain a common event shape definition in which a large value indicates a departure from a two-body system. The unit vector $\hat{n}_\perp$ defines the thrust axis of the event. The so-called event plane is defined by $\hat{n}_\perp$ and the beam direction and allows a measurement of $T_{m,\perp}$. The variable $T_{m,\perp}$ quantifies the sum of all transverse momenta $\mathbf{p}_{Ti}$ out of the event plane, where the sum again runs over each jet i considered in the final state. The allowed values for $\tau_\perp$ span the range $0 \le \tau_\perp < 1/3$ due to the range over which both $T_\perp$ and $T_{m,\perp}$ may fall, $0 \le T_\perp$, $T_{m,\perp} < 2/3$.

Event shapes constructed using hadronic jets in this way offer several advantages over explicit cross-section calculations for inclusive and multi-jet production. Event shapes may be defined as normalized ratios of hadronic final state observables, thus reducing the sensitivity to experimental uncertainties. Various choices of event shape quantities can also lead to enhanced or suppressed sensitivity to different components of the fundamental physical processes involved [11]. The effect of the underlying event and parton shower can be reduced by focusing only on the leading jets. The choice of renormalization and factorization scales used in calculating the LO and NLO cross-sections may be less important when considering ratios of quantities. Systematic uncertainties, such as the jet energy scale and detector effects, are partially mitigated by examining the normalized shapes as opposed to absolute cross-sections.

3 The ATLAS detector

The ATLAS detector [19, 20] provides nearly full solid angle coverage around the collision point[1] with an inner tracking system covering $|\eta| < 2.5$, electromagnetic and hadronic calorimeters covering $|\eta| < 4.9$, and a muon spectrometer covering $|\eta| < 2.7$. Of the multiple ATLAS subsystems, the most relevant to this analysis are the inner tracking detector (ID) [21], the barrel and end-cap calorimeters [22, 23] and the trigger [24].

The ID is comprised of a pixel tracker closest to the beamline, a microstrip silicon tracker, and lastly a straw-tube transition radiation tracker at the largest radii. These

---

[1] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the center of the LHC ring, and the y axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$.

systems are layered radially upon each other in the central region. A thin solenoid surrounding the tracker provides an axial 2T field enabling measurement of charged particle momenta.

The calorimeter is built of multiple sub-detectors with several different designs spanning the pseudorapidity range up to $|\eta| < 4.9$. The measurements of event shapes are predominantly performed using data from the central calorimeters, comprised of the liquid argon (LAr) barrel electromagnetic calorimeter ($|\eta| < 1.475$) and the Tile hadronic calorimeter ($|\eta| < 1.7$). Three additional calorimeter subsystems are located in the forward regions of the detector: the LAr electromagnetic end-cap calorimeters, the LAr hadronic end-cap calorimeter, and the forward calorimeter comprised of separate electromagnetic and hadronic components.

The precision and accuracy of energy measurements made by the calorimeter system is integral to this analysis and the procedures to establish such measurements are described in Ref. [25]. The baseline electromagnetic (EM) energy scale of the calorimeters derives from the calibration of the signal for the energy deposited by electromagnetic showers. The hadronic calorimeter has been calibrated with electrons and muons in beam tests and the energy scale has been validated using muons produced by cosmic rays with the detector in situ in the experimental hall [23]. The invariant mass of the Z boson in $Z \rightarrow ee$ events measured in situ in the same data-taking period is used to adjust the calibration for the EM calorimeters.

Dedicated trigger and data acquisition systems are responsible for the online event selection which is performed in three stages: Level 1, Level 2, and the Event Filter. Level 1 utilizes information from the calorimeter and muon systems using hardware-based algorithms. Level 2 and the Event Filter are collectively referred to as the High Level Trigger and utilize software algorithms running on large farms of commercial processors. The measurements presented in this paper rely primarily on the hardware-based Level 1 calorimeter trigger. At this level, coarse calorimeter information is used to reconstruct jets in the trigger system with a square sliding-window algorithm in η–ϕ space.

4 Data samples and event selection

4.1 Data sample and event selection

The data used for the analysis of event shapes represent the entire 2010 dataset collected at $\sqrt{s} = 7$ TeV and correspond to an integrated luminosity of $\int \mathcal{L}\,dt = 35.0 \pm 1.1$ pb^{-1} [26].

A sample of events containing high-p_T jets is selected via a Level 1 inclusive single jet trigger with a nominal transverse energy threshold of 95 GeV at the EM energy

scale. The offline selection requires two leading jets with a mean transverse momentum $\frac{1}{2}H_{T,2} > 250$ GeV and that the rapidity of each leading jet satisfy $|y| < 1.0$. Subleading jets yield non-zero values of each event shape variable and must have $p_T > 30$ GeV and be within $|y| < 1.5$ in order to be used in the calculations. This choice of event selection is partially driven by the trigger threshold which is at least 99.8 % efficient only at an offline jet transverse momentum of $p_T > 250$ GeV. High momentum jets are also less susceptible to the impact of multiple proton-proton interactions (pile-up) and have a smaller jet energy scale relative uncertainty. The use of $\frac{1}{2}H_{T,2}$ instead of the leading jet p_T is motivated by studies that demonstrate that $\frac{1}{2}H_{T,2}$ is significantly more stable against higher-order corrections to the jet cross section [27]. The inclusive single jet trigger efficiency is evaluated with respect to the offline $\frac{1}{2}H_{T,2}$ selection, as shown in Fig. 1, and is on average greater than 99.8 %, thereby removing the need for trigger efficiency corrections. This determination is made in situ using a trigger selection with a threshold of 30 GeV at the EM energy scale.

The presence of pile-up in these data has the potential to impact both event selection and jet reconstruction. Experimentally, reconstruction of primary vertices using tracks measured in the ID provides a measure of the multiplicity of such additional interactions on an event-by-event basis. The 2010 data contain an average number of primary vertices, N_{PV}, of approximately $\langle N_{PV} \rangle = 3$, with a tail extending to $N_{PV} \geq 10$. The vertex with the highest total squared track momentum, $\sum p_{T,track}^2$, is assumed to be the vertex at which the hard scattering that triggered the event occurred.

Two primary effects are expected from pile-up: augmentation of the jet energy scale for jets produced in the hard scattering and pile-up jets produced directly by the additional pp collisions within the same bunch crossing. The consequence of the former is typically an offset to the measured jet energy which is corrected as described below. The
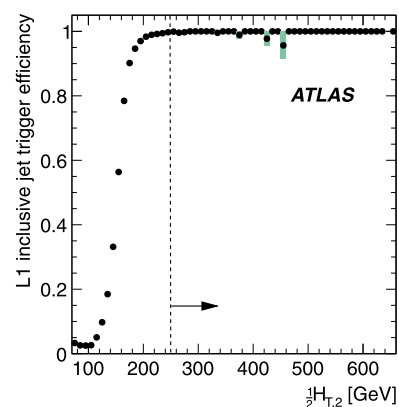

Fig. 1 Inclusive jet trigger efficiency as a function of $\frac{1}{2}H_{T,2}$ evaluated offline. The efficiency to select events with $\frac{1}{2}H_{T,2} > 250$ GeV using this trigger is greater than 99.8 %

presence and impact of pile-up jets on the event shape measurements is discussed in more detail in Sect. 5.2.

4.2 Jet reconstruction and calibration

Jets reconstructed with the anti-k_t algorithm [28, 29] are used for the event shape measurements presented here. This algorithm yields regular, approximately circular jets whose boundaries are well described by the nominal jet radius. A jet radius of $R = 0.6$ is used here, as in many Standard Model jet-physics measurements in ATLAS, compared to the smaller radius $R = 0.4$ jets used for a variety of new physics searches and top-quark measurements. This choice is made in order to minimize jet-by-jet corrections due to higher-order emissions and to maximize the reconstruction efficiency. Anti-k_t jets have been shown to be less susceptible than other jet algorithms to systematic effects such as pile-up and close-by jet activity. The inputs to the jet algorithm are topological energy clusters at the EM energy scale [30]. Following an average offset correction derived in situ to account for noise and contributions due to pile-up, an η- and p_T-dependent jet energy correction referred to as the EM+JES correction [25] is applied to all jets to compensate for energy loss in the calorimeters, detector geometry and other effects. Jet quality criteria such as the timing of calorimeter cell signals, the EM energy fraction, and pulse shape information are used to select only those jets that are unlikely to be affected by instrumental effects. These criteria are designed to remove events that are likely to have contamination due to beam-related backgrounds, cosmic rays, or detector defects. In order to further reduce non-collision backgrounds, each event must contain at least one primary vertex consisting of at least five tracks with transverse momenta $p_T^{\text{track}} > 150$ MeV. The MC simulation is reweighted in order to match the primary vertex multiplicity observed in the data.

4.3 Monte Carlo simulation

Dijet and multi-jet events are generated using two approaches. The first uses direct perturbative calculation of the tree-level matrix elements in powers of the strong coupling constant, α_S. The matrix elements are evaluated at LO in α_S for each relevant partonic subprocess. This is a so-called "multi-leg" method. The second approach implements a sampling of the phase space available for gluon emission with some suitable approximations. The latter uses LO perturbative calculations of matrix elements for $2 \rightarrow 2$ processes and relies on the parton shower implementation to produce the equivalent of multi-parton final states. This procedure is referred to as LO matrix element plus leading-logarithm resummation, where the parton shower itself is responsible for the latter.

The multi-leg technique is used by ALPGEN [31]. In the analysis presented here, ALPGEN 2.13 is used with up to six final-state partons. ALPGEN is interfaced to both HERWIG 6.510 [32] to provide the parton shower and hadronization model, and to JIMMY 4.31 [33] for the underlying event model. The CTEQ6L1 LO [34] parton distribution function (PDF) with LO α_S is used for ALPGEN.

The parton shower simulation programs PYTHIA [35] and HERWIG++ [36] both implement the second approach for QCD jet production and rely on the parton shower to generate multi-jet final states. PYTHIA 6.423 with the Perugia 2010 tune [37] and HERWIG++ 2.4.2 are used to compare to the data; these provide shower models that are p_T ordered and angular ordered, respectively. LO PDFs are taken from the MRST2007 LO* [38, 39] PDF for HERWIG++, and from the CTEQ6L1 LO [34] PDF in PYTHIA.

The MC programs used for comparison to the measurements of event shapes are chosen in part for their ability to describe other ATLAS jet-based measurements. The multi-jet cross section measurements [40], which constitute the same final states as those probed in this analysis, exhibit very good agreement with the predictions from ALPGEN. HERWIG++ not only exhibits good agreement with individual jet shape measurements [41] but is also tuned to yield good agreement with event shape measurements from the Large Electron Positron (LEP) collider experiments. Finally, the Perugia 2010 tune of PYTHIA also shows good agreement with the ATLAS jet shape measurements and has been tuned using the theoretical input from higher-order calculations of event shapes presented in Ref. [11]. These three MC programs thus provide well motivated predictions for the final state observables measured via event shapes.

Events generated by these MC programs are passed through a full simulation [42] of the ATLAS detector and trigger based on GEANT4 [43] and processed in the same way as collision data. The Quark-Gluon String Precompound (QGSP) model [44] is used for high energy inelastic scattering of hadrons by nuclei, and the Bertini cascade model [45] is used to describe the interactions of hadrons with the nuclear medium. Alternative GEANT4 physics lists that specify particle and process definitions, using a combination of the FRITIOF [46] and Bertini models and QGSP without Bertini, are used as part of the studies to understand the uncertainties on the jet energy scale.

5 Results and systematic uncertainties

The event shape measurements using jets presented here are corrected to particle-level, after accounting for detector efficiencies and instrumental effects. Particle-level jets are constructed from all final state particles from the MC simulation with lifetimes longer than 10 ps. Direct comparisons

can thus be made between the results presented here and MC generator data after parton shower and hadronization. The dependence of these observables on $\frac{1}{2}H_{T,2}$ is also evaluated. This allows the isolation of discrepancies observed in the inclusive event shape distributions that primarily appear at low or high $\frac{1}{2}H_{T,2}$.

5.1 Accounting for detector effects

In order to compare the predictions of MC event generators with the measurements, several effects must be accounted for. Efficiency loss due to detector coverage and resolution, detector biases such as angular resolutions, may affect the measured value of an event shape variable. In order to account for such effects, the MC and detector simulation are used to estimate their impact. MC events after full detector simulation are used to derive bin-by-bin corrections that are applied to the detector-level measurements of each event shape variable to obtain the unfolded, particle-level result to which the MC simulated events after parton shower may be compared. These corrections differ from one by less than 10 %. The bin sizes were chosen to be approximately commensurate with resolution, with individual bin purities required to be at least 60 %. Bin purity is defined as the fraction of events with a given value of the event shape observable measured at the detector-level for which the particle-level measurement for that same event falls within the same bin.

The primary MC generator used for evaluating the corrections is ALPGEN, since the detector-level distributions are well described and ALPGEN models the multi-jet cross-section well [40]. As a cross-check of the method, the corrections evaluated with ALPGEN are compared to those obtained from HERWIG++ and PYTHIA. For $\ln y_{23}$, A, and S, this component of the uncertainty is approximately 2 %–8 %, which is smaller than both that due to the overall JES systematic uncertainty discussed below and the finite sample size with which the correction factors are determined. However, for the thrust event shape variables, in particular for $T_{m,\perp}$, and $S_\perp$, the generator dependence of these corrections is approximately 10 % for the majority of the range of those measurements.

5.2 Systematic uncertainties

Multiple effects are present in the measurement of event shapes due to the inclusive nature of these observables. These include the uncertainty due to the jet energy scale, the effects of multiple pp interactions, the finite resolution, and the fiducial range of the detector. All of these effects are evaluated and accounted for in the measurement. The dominant uncertainties are the jet energy scale and generator dependence of the corrections in regions of high statistical precision.

The uncertainty on the JES established by the jet calibration procedure [25] influences the final event shape measurement via both the thresholds used to select events and the momenta used to calculate the event shape observables. This uncertainty is primarily established by the measurement of the single hadron response using test beam data, but is also verified in situ during 2010. For jets used in these measurements the typical JES uncertainties are 2.3 %–3.0 %. The impact of this source of systematic uncertainty is reduced by the explicit use of ratios of jet momenta for several observables, although the jet yield can still vary for a given event due to these selections. Variations of the individual jet momenta are performed within the systematic uncertainties of the JES measurement. For nearly all measured event shape variables, the overall JES uncertainty has the largest impact apart from statistical precision. Most observables have an approximate 5 % uncertainty due to the JES, with A and $\tau_\perp$ being impacted by up to 15 % in the steeply falling tails of the distributions.

Additional jets present in the event due to pile-up may also alter the observed event shape. This may be of particular importance for those measurements that are explicitly dependent upon the jet multiplicity, such as those computed from the event transverse momentum tensor. Although the impact of pile-up on the jet energy is accounted for by the energy scale corrections and uncertainty discussed above, an alternate method is necessary for mitigating the impact of additional jets due directly to pile-up.

A crucial tool in the identification of jets from pile-up is the jet-vertex fraction, or JVF [47]. This discriminant estimates the contribution of pile-up to a single jet by measuring the fraction of charged particle momentum in the jet that originates in the hard scatter. The rate of additional jets from pile-up in events with between five and eight primary vertices exhibits an increase of a factor of two compared to events with two primary vertices. Because the overall fraction of events with greater than five reconstructed primary vertices is approximately two percent, and these jets tend to have a much softer p_T spectrum, the impact due to additional jets is significantly smaller than other systematic and statistical uncertainties for all measurements. For the majority of events with a primary vertex multiplicity below three, the JVF selection rejects approximately 0.2–0.4 % of third-leading jets above $p_T > 30$ GeV, whereas for the first and second leading jets the impact is negligible. In the two percent of events with a primary vertex multiplicity greater than 5, the fraction of jets rejected by the JVF selection increases to nearly 2 %. From MC simulations, the purity of 30 GeV jets after the JVF selection is greater than 99 %.

To further establish the systematic uncertainty incurred by pile-up, comparisons are made between the observed detector-level distributions in events with and without additional reconstructed vertices. A slight variation of a few

Table 1 Summary of systematic uncertainties accounted for in the measurement of each event shape observable. Values represent the median per-bin uncertainty for each component. The median total uncertainty includes the statistical uncertainty on the bin-by-bin correction factors

Observable	JES	MC variation	Pile-up	Total
$\ln y_{23}$	3.0 %	4.0 %	2.7 %	8.2 %
A	7.2 %	4.6 %	2.0 %	13 %
$\tau_\perp$	5.8 %	9.1 %	3.7 %	17 %
$T_{m,\perp}$	4.9 %	8.6 %	4.3 %	18 %
S	2.0 %	3.3 %	2.3 %	10 %
$S_\perp$	2.5 %	6.5 %	1.3 %	10 %

percent at low $\ln y_{23}$ is observed as well as a relative 10 % increase in the fraction of events at higher $\tau_\perp$. Similar observations are made by evaluating the impact of the JES uncertainty. Furthermore, each event shape is measured as a function of the *JVF* of the third jet in the event to directly test the effect of pile-up on the final state observables. Variations of less than 3 % are observed when requiring that jets contain a high fraction of associated track momentum originating in the identified hard-scatter vertex. This effect is taken into account in the systematic uncertainty in the final result.

The median systematic uncertainty for each component and for each observable measured, is shown in Table 1. The values represent the median systematic uncertainty across all bins used in the measurement, and the statistical uncertainty on the bin-by-bin correction factors is included in the total.

5.3 Event shape distributions

The normalized distributions of the third-jet resolution parameter and aplanarity are shown in Figs. 2(a) and (b). In the case of y_{23}, where the primary sensitivity is to the description of the momentum of the third jet, PYTHIA provides the most accurate description of the data, whereas HERWIG++ exhibits slightly better agreement than ALPGEN. Although ALPGEN provides exact tree-level matrix element calculations for up to six jets, it overestimates the fractions of events in the range $\ln y_{23} < -5$. This is qualitatively expected because ALPGEN's more precise calculation of the high jet multiplicity states is primarily concerned with jets near the hard scale of the event. In this region, the leading-logarithm resummation calculations of PYTHIA and HERWIG++ are observed to give more accurate modelings. As a result, PYTHIA and HERWIG++ both describe the data more accurately than ALPGEN for this event shape variable, particularly at small values of $\ln y_{23}$.

Aplanarity measures the sum of the transverse momenta out of the event plane defined primarily by the two hardest jets. The deviation of the MC prediction from the data is

significant for HERWIG++, with some differences observed with respect to ALPGEN as well. The measurements consistently support more highly aplanar events than predicted by HERWIG++, with the majority of the distribution observed to be significantly different from the MC prediction. The agreement with PYTHIA is good across the full distribution. These results suggest that the event shape is more accurately described by the exact multi-jet prediction provided by the multi-leg matrix element generator (such as ALPGEN) and the model provided by PYTHIA.

The measurement of the transverse thrust, $\tau_\perp$, also suggests that the descriptions of the data provided by ALPGEN and PYTHIA are more accurate than that provided by HERWIG++. Figure 2(c) exhibits the same behavior as observed in the aplanarity: HERWIG++ predicts fewer than observed highly isotropic events at large $\tau_\perp$. Throughout the distribution, ALPGEN and PYTHIA both predict the measured thrust well. The minor component of the thrust, $T_{m,\perp}$, or the out-of-plane thrust magnitude, shown in Fig. 2(d), does not exhibit as large a difference as observed in the aplanarity. A slight overestimation by PYTHIA is observed for intermediate values of the thrust minor component, $0.25 < T_{m,\perp} < 0.40$.

Lastly, the sphericity and transverse sphericity distributions shown in Figs. 2(a) and (f) exhibit differences between all three generators and the data. The construction of the transverse sphericity as a ratio of eigenvalues of the momentum tensor of the event leads to a slightly improved description. In both cases, PYTHIA provides the best description of the data, and the data are better described by ALPGEN than HERWIG++. In particular, HERWIG++ underestimates the number of highly spherical events in the range $0.40 < S < 0.72$.

5.4 Dependence on $\frac{1}{2}H_{T,2}$

The measurement of the distribution of event shape observables allows for a detailed comparison with MC predictions for a large range of kinematic phase space defined by $\frac{1}{2}H_{T,2}$ in multi-jet events. It is informative to evaluate the explicit dependence of these shapes on the kinematic properties of the event in order to determine potential differences in the modeling of the data for different jet momentum ranges. The evolution of each event shape variable with $\frac{1}{2}H_{T,2}$ exhibits a similar trend as that expected by the running of α_S which leads to a reduction in extra gluon radiation and thus a reduction in the value of each event shape.

Figure 3 depicts the dependence of the mean of each event shape variable on $\frac{1}{2}H_{T,2}$ as it approaches 1 TeV. In all cases, a general trend is observed in which the mean decreases as $\frac{1}{2}H_{T,2}$ increases. This can be understood in terms of how the dynamics of the $2 \rightarrow 2$ process evolves with energy. As the energy in the leading jets increases, the di-jet
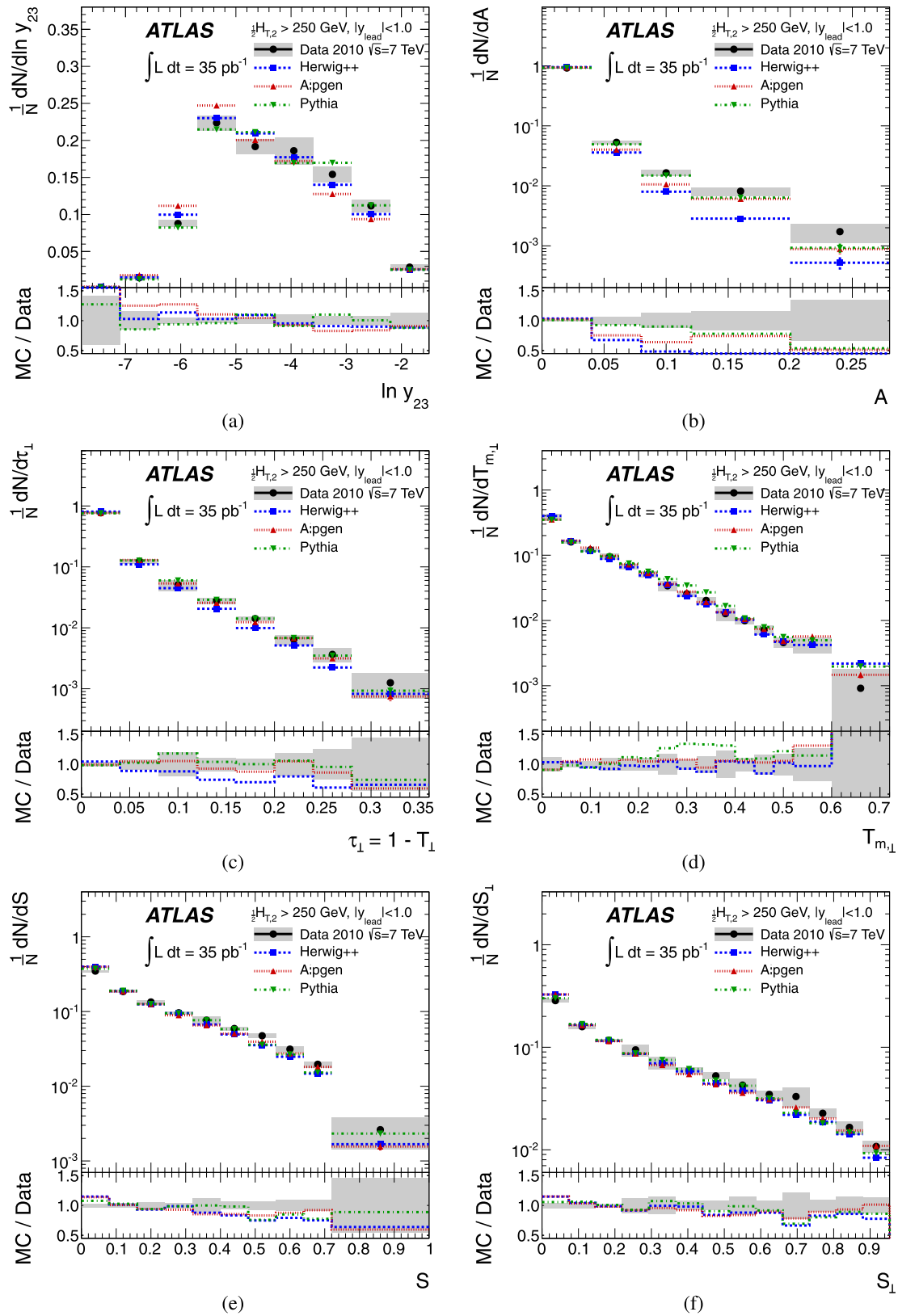
Fig. 2 Unfolded hadron-level distributions of the (**a**) third-jet resolution parameter, $\ln y_{23}$, (**b**) aplanarity, A, (**c**) transverse thrust, $\tau_\perp$, (**d**) minor component of the transverse thrust, $T_{m,\perp}$, (**e**) sphericity, S, and (**f**) transverse sphericity, $S_\perp$. The uncertainty shown for the data includes statistical and systematic uncertainties

Fig. 3 Mean value of each event shape variable as a function of $\frac{1}{2}H_{T,2}$. Comparisons are made between the MC generators HERWIG++, ALPGEN and PYTHIA

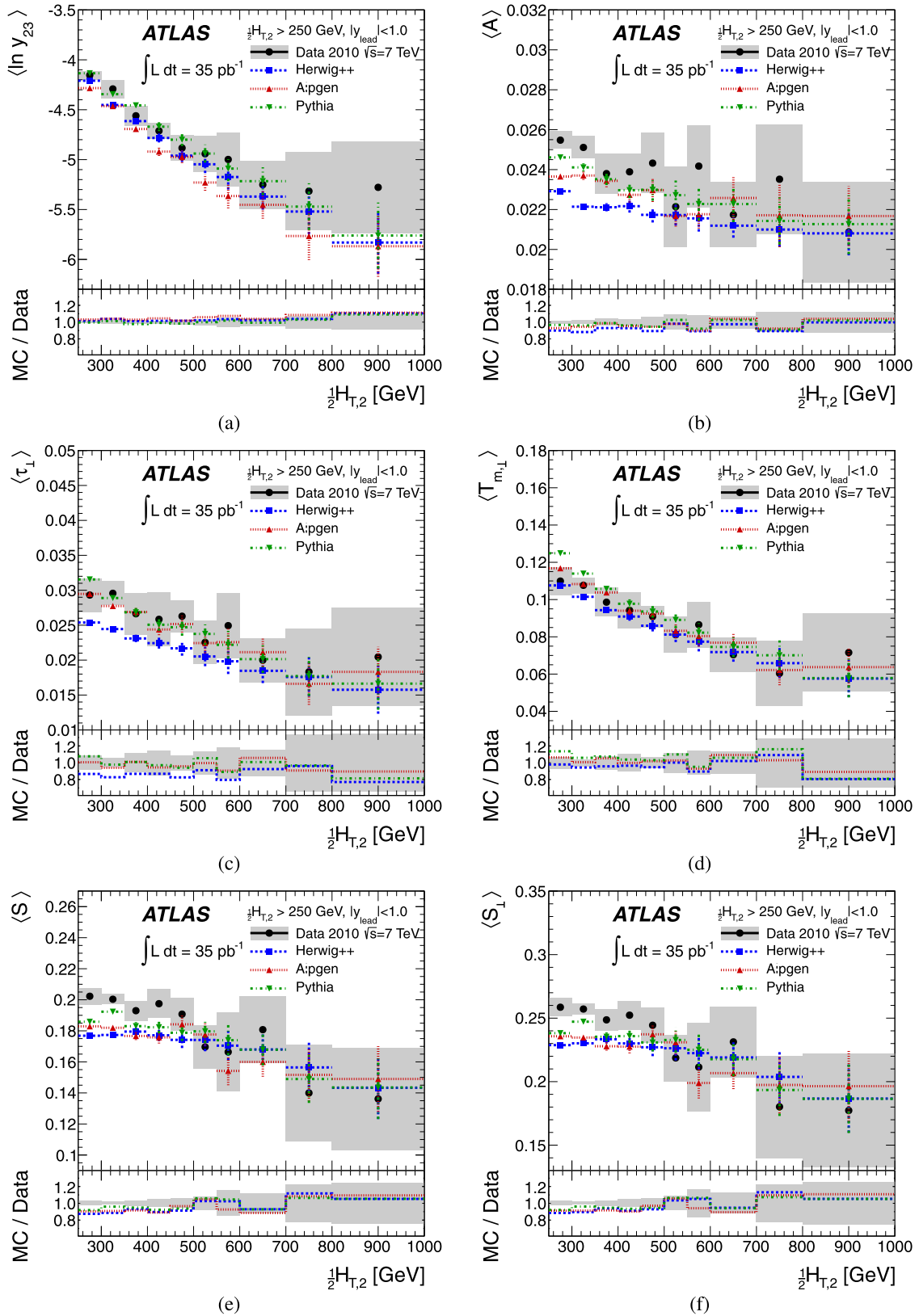structure dominates because of kinematics and because α_S decreases as $\frac{1}{2}H_{T,2}$ increases, causing the dominant NLO corrections which generate higher relative momentum gluon emission to decrease as well.

The variation as a function of $\frac{1}{2}H_{T,2}$ is the largest for $\langle \ln y_{23} \rangle$, which indicates a change of y_{23} of nearly a factor of five between $\frac{1}{2}H_{T,2} = 300$ GeV and 800 GeV. Nonetheless, the agreement between the MC prediction and the observed event shape variable dependence is good for all generators. The observation made above that too few highly aplanar events are present in the predictions from HERWIG++ is again observed in the evolution of $\langle A \rangle$ with the momentum scale of the event. The agreement among the mean values measured and the MC predictions improves for $\frac{1}{2}H_{T,2} > 500$ GeV, although the systematic uncertainties are larger and the statistical power of the measurement is reduced. Similarly, the evolution of $\langle \tau_\perp \rangle$ with $\frac{1}{2}H_{T,2}$ in Fig. 3(c) is underestimated by HERWIG++. ALPGEN and PYTHIA consistently predict the mean value of $\tau_\perp$ and its evolution with $\frac{1}{2}H_{T,2}$ more accurately, whereas all of the generators describe $\langle T_{m,\perp} \rangle$ vs. $\frac{1}{2}H_{T,2}$ well. Finally, the sphericity and the transverse sphericity (Figs. 3(e) and (f)) are both measured to be approximately 10 % larger than predicted by the three MC programs at low $\frac{1}{2}H_{T,2}$, whereas the agreement again improves for higher values. This difference is driven by the underestimate of highly spherical events observed in Figs. 2(e) and (f) which decreases as the average sphericity decreases as a function of $\frac{1}{2}H_{T,2}$.

6 Summary

Six event shape observables are measured with jets in proton-proton collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector with a data sample of 35 pb^{-1}.

Measurements are performed up to an event $H_{T,2}$ of 2 TeV and are compared with different Monte Carlo event generators. Overall shape comparisons are made with these MC programs, as well as the kinematic evolution of the mean value of each event shape variable with $\frac{1}{2}H_{T,2}$. Reasonable agreement is observed in most kinematic and topological regions. The measurements suggest that the modeling of the data by PYTHIA (Perugia 2010) and ALPGEN are more accurate than that by HERWIG++, in particular for the aplanarity, A, and transverse thrust, $\tau_\perp$. The good description provided by ALPGEN (+HERWIG/JIMMY) of the multi-jet cross-section [40] is reflected as well in these measurements, although the description provided by PYTHIA tends to model the data more accurately. PYTHIA predicts a slightly higher mean $T_{m,\perp}$ at low $\frac{1}{2}H_{T,2}$ than observed in the data whereas HERWIG++ predicts a slightly lower mean thrust. The systematic uncertainties in the measurement of S and $S_\perp$ are found to be relatively small. The observation

that the measured mean value of each event shape variable decreases with $\frac{1}{2}H_{T,2}$ is consistent with the trend expected from the running of α_S and is generally well modeled by the MC simulations.

Comparisons of these results to previously published LHC measurements of hadronic event shapes [7] indicate that the slight overestimate by PYTHIA of events with thrust minor component, $T_{m,\perp}$, in the range $0.25 < T_{m,\perp} < 0.40$ is observed in each case. However, the good agreement observed in this study between data and both PYTHIA and ALPGEN for the thrust, $\tau_\perp$ is not seen in Ref. [7]. The different tunes of HERWIG++ and PYTHIA, as well as the different underlying event and hadronization models interfaced to ALPGEN in the two measurements, may account for these differences. Furthermore, the systematic uncertainties associated with these measurements are in many cases similar to the differences between the generators.

ATLAS measurements of the jet shape [41], jet fragmentation function [48], and multi-jet cross-section also provide additional insight into the results shown here. PYTHIA and HERWIG++ 2.4.2 both provide a reasonable description of the fragmentation function of high momentum jets in the data, whereas only the former models the jet shape accurately. ALPGEN, on the other hand, yields a fairly accurate description of the three-jet to two-jet cross-section ratio [40], although it produces internal jet shapes that are significantly narrower than those measured. The latter is primarily affected by softer, collinear radiation inside of the jet cone, whereas the cross-section ratio is dominated by the presence of hard emissions and additional partons that form distinct additional jets in the event.

These results, supported by other ATLAS measurements of the hadronic final state, reinforce the importance of the leading-order matrix element calculation plus leading-logarithm resummation in parton shower MC event generators. They also demonstrate the ability of leading order MC to provide a reasonable description of multi-jet event shapes.

References

1. OPAL Collaboration, Measurement of event shape distributions and moments in $e^+e^- \to$ hadrons at 91–209 GeV and a determination of α_s. Eur. Phys. J. C **40**, 287 (2005)
2. H1 Collaboration, Event shapes in deep inelastic scattering at HERA. Eur. Phys. J. C **46**, 343 (2006)
3. ZEUS Collaboration, Event shapes in deep inelastic scattering at HERA. Nucl. Phys. B **767**, 1 (2007)
4. JADE Collaboration, Determination of the strong coupling α_s from hadronic event shapes and NNLO QCD predictions using JADE data. Eur. Phys. J. C **64**, 351 (2009)
5. S. Kluth et al., A measurement of the QCD colour factors using event shape distributions at $\sqrt{s} = 14$ to 189 GeV. Eur. Phys. J. C **21**, 199 (2001)
6. I.W. Stewart, F.J. Tackmann, W.J. Waalewijn, N-Jettiness: an inclusive event shape to veto jets (2010). arXiv:1004.2489 [hep-ph]
7. CMS Collaboration, First measurement of hadronic event shapes in pp collisions at $\sqrt{s} = 7$ TeV. Phys. Lett. B **699**, 48 (2011)
8. B.R. Webber, QCD power corrections from a simple model for the running coupling. J. High Energy Phys. **10**, 012 (1998)
9. L.A. Anchordoqui et al., Searching for the layered structure of space at the LHC. Phys. Rev. D **83**, 114046 (2011)
10. A. Banfi, G.P. Salam, G. Zanderighi, Resummed event shapes at hadron–hadron colliders. J. High Energy Phys. **08**, 062 (2004)
11. A. Banfi, G.P. Salam, G. Zanderighi, Phenomenology of event shapes at hadron colliders. J. High Energy Phys. **06**, 038 (2010)
12. OPAL Collaboration, A study of jet production rates and a test of QCD on the Z0 resonance. Phys. Lett. B **235**, 389 (1990)
13. JADE Collaboration, Observation of four-jet structure in e^+e^- annihilation at $\sqrt{s} = 33$ GeV. Phys. Lett. B **115**, 338 (1982)
14. S. Kluth, $\alpha_s(M_Z)$ from JADE event shapes (2009). arXiv:0905.4891 [hep-ex]
15. J. Bjorken, S. Brodsky, Statistical model for electron–positron annihilation into hadrons. Phys. Rev. D **1**, 1416 (1970)
16. ALEPH Collaboration, Studies of quantum chromodynamics with the ALEPH detector. Phys. Rep. **294**, 1 (1998)
17. S. Brandt, C. Peyrou, R. Sosnowski, A. Wroblewski, The principal axis of jets—an attempt to analyse high-energy collisions as two-body processes. Phys. Lett. **12**, 57 (1964)
18. JADE Collaboration, Experimental studies on multijet production in e^+e^- annihilation at PETRA energies. Z. Phys. C **33**, 23 (1986)
19. ATLAS Collaboration, The ATLAS experiment at the CERN large hadron collider. J. Instrum. **3**, S08003 (2008)
20. ATLAS Collaboration, Performance of the ATLAS detector using first collision data. J. High Energy Phys. **09**, 056 (2010)
21. ATLAS Collaboration, The ATLAS inner detector commissioning and calibration. Eur. Phys. J. C **70**, 787 (2010)
22. ATLAS Collaboration, Readiness of the ATLAS liquid argon calorimeter for LHC collisions. Eur. Phys. J. C **70**, 723 (2010)
23. ATLAS Collaboration, Readiness of the ATLAS Tile calorimeter for LHC collisions. Eur. Phys. J. C **70**, 1193 (2010)
24. ATLAS Collaboration, Performance of the ATLAS trigger system in 2010. Eur. Phys. J. C **72**, 1849 (2012)
25. ATLAS Collaboration, Jet energy measurement with the ATLAS detector in proton–proton collisions at $\sqrt{s} = 7$ TeV (2011). arXiv:1112.6426 [hep-ex]. Eur. Phys. J. C, to be published
26. ATLAS Collaboration, Luminosity determination in pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector at the LHC. Eur. Phys. J. C **71**, 1630 (2011)
27. M. Rubin, G.P. Salam, S. Sapeta, Giant QCD K-factors beyond NLO (2010). arXiv:1006.2144 [hep-ph]
28. M. Cacciari, G.P. Salam, G. Soyez, The anti-k_t jet clustering algorithm. J. High Energy Phys. **04**, 063 (2008)
29. M. Cacciari, G.P. Salam, Dispelling the N^3 myth for the k_t jet-finder. Phys. Lett. B **641**, 57 (2006)
30. W. Lampl, S. Laplace, D. Lelas, P. Loch, H. Ma, S. Menke, S. Rajagopalan, D. Rousseau, S. Snyder, G. Unal, Calorimeter clustering algorithms: description and performance, ATL-LARG-PUB-2008-002 (2008)
31. M.L. Mangano et al., ALPGEN, a generator for hard multiparton processes in hadronic collisions. J. High Energy Phys. **07**, 001 (2003)
32. G. Corcella et al., HERWIG 6: an event generator for hadron emission reactions with interfering gluons (including supersymmetric processes). J. High Energy Phys. **01**, 010 (2001)
33. J.M. Butterworth, J.R. Forshaw, M.H. Seymour, Multiparton interactions in photoproduction at HERA. Z. Phys. C **72**, 637 (1996)
34. J. Pumplin et al., New generation of parton distributions with uncertainties from global QCD analysis. J. High Energy Phys. **07**, 012 (2002)
35. T. Sjöstrand, High-energy-physics event generation with PYTHIA 6.1. Comput. Phys. Commun. **135**, 238 (2001)
36. M. Bahr et al., Herwig++ physics and manual, Eur. Phys. J. C **58**, 639 (2008)
37. P.Z. Skands, Tuning Monte Carlo generators: the Perugia tunes. Phys. Rev. D **82**, 074018 (2010)
38. A.D. Martin, W.J. Stirling, R.S. Thorne, G. Watt, Parton distributions for the LHC. Eur. Phys. J. C **63**, 189 (2009)
39. A. Sherstnev, R.S. Thorne, Parton distributions for LO generators. Eur. Phys. J. C **55**, 553 (2008)
40. ATLAS Collaboration, Measurement of multi-jet cross sections in proton–proton collisions at a 7 TeV center-of-mass energy. Eur. Phys. J. C **71**, 1763 (2011)
41. ATLAS Collaboration, Study of jet shapes in inclusive jet production in pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector. Phys. Rev. D **83**, 052003 (2011)
42. ATLAS Collaboration, The ATLAS simulation infrastructure. Eur. Phys. J. C **70**, 823 (2010)
43. S. Agostinelli et al. (GEANT4 Collaboration), GEANT4: a simulation toolkit. Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003)
44. G. Folger, J.P. Wellisch, String parton models in Geant4 (2003). arXiv:nucl-th/0306007
45. H.W. Bertini, Intranuclear-cascade calculation of the secondary nucleon spectra from nucleon–nucleus interactions in the energy range 340 to 2900 MeV and comparisons with experiment. Phys. Rev. A **188**, 1711 (1969)
46. B. Andersson, G. Gustafson, B. Nilsson-Almqvist, A model for low-p_T hadronic reactions with generalizations to hadron–nucleus and nucleus–nucleus collisions. Nucl. Phys. B **281**, 289 (1987)
47. ATLAS Collaboration, Study of jets produced in association with a W boson in pp collisions at $\sqrt{s} = 7$ TeV. Phys. Rev. D **85**, 092002 (2012)
48. ATLAS Collaboration, Measurement of the jet fragmentation function and transverse profile in proton–proton collisions at a center-of-mass energy of 7 TeV with the ATLAS detector. Eur. Phys. J. C **71**, 1795 (2011)

The ATLAS Collaboration

G. Aad[48], B. Abbott[111], J. Abdallah[11], S. Abdel Khalek[115], A.A. Abdelalim[49], O. Abdinov[10], B. Abi[112], M. Abolins[88], O.S. AbouZeid[158], H. Abramowicz[153], H. Abreu[136], E. Acerbi[89a,89b], B.S. Acharya[164a,164b], L. Adamczyk[37], D.L. Adams[24], T.N. Addy[56], J. Adelman[176], S. Adomeit[98], P. Adragna[75], T. Adye[129], S. Aefsky[22], J.A. Aguilar-Saavedra[124b,a], M. Agustoni[16], 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], M.S. Alam[1], M.A. Alam[76], J. Albert[169], S. Albrand[55], M. Aleksa[29], I.N. Aleksandrov[64], F. Alessandria[89a], C. Alexa[25a], G. Alexander[153], G. Alexandre[49], T. Alexopoulos[9], M. Alhroob[164a,164c], M. Aliev[15], G. Alimonti[89a], J. Alison[120], B.M.M. Allbrooke[17], P.P. Allport[73], S.E. Allwood-Spiers[53], J. Almond[82], A. Aloisio[102a,102b], R. Alon[172], A. Alonso[79], B. Alvarez Gonzalez[88], M.G. Alviggi[102a,102b], K. Amako[65], C. Amelung[22], V.V. Ammosov[128], A. Amorim[124a,b], N. Amram[153], C. Anastopoulos[29], L.S. Ancu[16], N. Andari[115], T. Andeen[34], C.F. Anders[58b], G. Anders[58a], K.J. Anderson[30], A. Andreazza[89a,89b], V. Andrei[58a], X.S. Anduaga[70], P. Anger[43], A. Angerami[34], F. Anghinolfi[29], A. Anisenkov[107], 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[65], A.T.H. Arce[44], S. Arfaoui[148], J-F. Arguin[14], E. Arik[18a,*], M. Arik[18a], A.J. Armbruster[87], O. Arnaez[81], V. Arnal[80], C. Arnault[115], A. Artamonov[95], G. Artoni[132a,132b], D. Arutinov[20], S. Asai[155], R. Asfandiyarov[173], S. Ask[27], B. Åsman[146a,146b], L. Asquith[5], K. Assamagan[24], A. Astbury[169], B. Aubert[4], E. Auge[115], K. Augsten[127], M. Aurousseau[145a], G. Avolio[163], R. Avramidou[9], D. Axen[168], G. Azuelos[93,d], Y. Azuma[155], M.A. Baak[29], G. Baccaglioni[89a], C. Bacci[134a,134b], A.M. Bach[14], H. Bachacou[136], K. Bachas[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[176], M.D. Baker[24], S. Baker[77], E. Banas[38], P. Banerjee[93], Sw. Banerjee[173], D. Banfi[29], A. Bangert[150], V. Bansal[169], H.S. Bansil[17], L. Barak[172], S.P. Baranov[94], A. Barbaro Galtieri[14], T. Barber[48], E.L. Barberio[86], D. Barberis[50a,50b], M. Barbero[20], D.Y. Bardin[64], T. Barillari[99], M. Barisonzi[175], 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], V. Bartsch[149], R.L. Bates[53], L. Batkova[144a], J.R. Batley[27], A. Battaglia[16], M. Battistin[29], F. Bauer[136], H.S. Bawa[143,e], S. Beale[98], T. Beau[78], P.H. Beauchemin[161], R. Beccherle[50a], P. Bechtle[20], H.P. Beck[16], A.K. Becker[175], S. Becker[98], M. Beckingham[138], K.H. Becks[175], A.J. Beddall[18c], A. Beddall[18c], S. Bedikian[176], V.A. Bednyakov[64], C.P. Bee[83], M. Begel[24], S. Behar Harpaz[152], 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,f], K. Belotskiy[96], O. Beltramello[29], O. Benary[153], D. Benchekroun[135a], K. Bendtz[146a,146b], N. Benekos[165], Y. Benhammou[153], E. Benhar Noccioli[49], J.A. Benitez Garcia[159b], 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[105], J. Beringer[14], P. Bernat[77], R. Bernhard[48], C. Bernius[24], T. Berry[76], C. Bertella[83], A. Bertin[19a,19b], F. Bertolucci[122a,122b], M.I. Besana[89a,89b], G.J. Besjes[104], 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], H. Bilokon[47], M. Bindi[19a,19b], S. Binet[115], A. Bingul[18c], C. Bini[132a,132b], C. Biscarat[178], U. Bitenc[48], K.M. Black[21], R.E. Blair[5], J.-B. Blanchard[136], 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[175], N. Boelaert[35], J.A. Bogaerts[29], A. Bogdanchikov[107], A. Bogouch[90,*], C. Bohm[146a], J. Bohm[125], V. Boisvert[76], T. Bold[37], V. Boldea[25a], N.M. Bolnet[136], M. Bomben[78], M. Bona[75], M. Boonekamp[136], C.N. Booth[139], S. Bordoni[78], C. Borer[16], A. Borisov[128], G. Borissov[71], I. Borjanovic[12a], M. Borri[82], S. Borroni[87], V. Bortolotto[134a,134b], 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], D. Boumediene[33], C. Bourdarios[115], N. Bousson[83], A. Boveia[30], J. Boyd[29], I.R. Boyko[64], I. Bozovic-Jelisavcic[12b], J. Bracinik[17], P. Branchini[134a], A. Brandt[7], G. Brandt[118], O. Brandt[54], U. Bratzler[156], B. Brau[84], J.E. Brau[114], H.M. Braun[175], S.F. Brazzale[164a,164c], B. Brelier[158], J. Bremer[29], K. Brendlinger[120], R. Brenner[166], S. Bressler[172], D. Britton[53], F.M. Brochu[27], I. Brock[20], R. Brock[88], E. Brodet[153], F. Broggi[89a], C. Bromberg[88], J. Bronner[99], G. Brooijmans[34], T. Brooks[76], W.K. Brooks[31b], G. Brown[82], H. Brown[7], P.A. Bruckman de Renstrom[38], D. Bruncko[144b], R. Bruneliere[48], S. Brunet[60], A. Bruni[19a], G. Bruni[19a], M. Bruschi[19a], T. Buanes[13], Q. Buat[55], F. Bucci[49], J. Buchanan[118], P. Buchholz[141], R.M. Buckingham[118], A.G. Buckley[45], S.I. Buda[25a], I.A. Budagov[64], B. Budick[108], V. Büscher[81], L. Bugge[117], O. Bulekov[96], A.C. Bundock[73], 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], 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], D. Cameron[117], L.M. Caminada[14], S. Campana[29], M. Campanelli[77], V. Canale[102a,102b], F. Canelli[30,g], A. Canepa[159a], J. Cantero[80], R. Cantrill[76], 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[81], R. Cardarelli[133a], T. Carli[29], G. Carlino[102a], L. Carminati[89a,89b], B. Caron[85], S. Caron[104], E. Carquin[31b], G.D. Carrillo Montoya[173], A.A. Carter[75], J.R. Carter[27], J. Carvalho[124a,h], D. Casadei[108], M.P. Casado[11], M. Cascella[122a,122b], C. Caso[50a,50b,*], A.M. Castaneda Hernandez[173,i], E. Castaneda-Miranda[173], V. Castillo Gimenez[167], N.F. Castro[124a], G. Cataldi[72a], P. Catastini[57], A. Catinaccio[29], J.R. Catmore[29], A. Cattai[29], G. Cattani[133a,133b], S. Caughron[88], P. Cavalleri[78], D. Cavalli[89a], M. Cavalli-Sforza[11], V. Cavasinni[122a,122b], F. Ceradini[134a,134b], A.S. Cerqueira[23b], A. Cerri[29], L. Cerrito[75], F. Cerutti[47], S.A. Cetin[18b], A. Chafaq[135a], D. Chakraborty[106], I. Chalupkova[126], 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[64], M.A. Chelstowska[104], C. Chen[63], H. Chen[24], S. Chen[32c], X. Chen[173], Y. Chen[34], A. Cheplakov[64], 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[29], A. Chilingarov[71], G. Chiodini[72a], A.S. Chisholm[17], R.T. Chislett[77], A. Chitan[25a], M.V. Chizhov[64], 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], A.K. Ciftci[3a], R. Ciftci[3a], D. Cinca[33], V. Cindro[74], C. Ciocca[19a,19b], A. Ciocio[14], M. Cirilli[87], P. Cirkovic[12b], M. Citterio[89a], M. Ciubancan[25a], A. Clark[49], P.J. Clark[45], R.N. Clarke[14], W. Cleland[123], J.C. Clemens[83], B. Clement[55], C. Clement[146a,146b], Y. Coadou[83], M. Cobal[164a,164c], A. Coccaro[138], J. Cochran[63], J.G. Cogan[143], J. Coggeshall[165], E. Cogneras[178], J. Colas[4], A.P. Colijn[105], N.J. Collins[17], C. Collins-Tooth[53], J. Collot[55], T. Colombo[119a,119b], G. Colon[84], P. Conde Muiño[124a], E. Coniavitis[118], M.C. Conidi[11], S.M. Consonni[89a,89b], V. Consorti[48], S. Constantinescu[25a], C. Conta[119a,119b], G. Conti[57], F. Conventi[102a,j], M. Cooke[14], B.D. Cooper[77], A.M. Cooper-Sarkar[118], K. Copic[14], T. Cornelissen[175], 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[176], T. Cuhadar Donszelmann[139], M. Curatolo[47], C.J. Curtis[17], C. Cuthbert[150], P. Cwetanski[60], H. Czirr[141], P. Czodrowski[43], Z. Czyczula[176], S. D'Auria[53], M. D'Onofrio[73], A. D'Orazio[132a,132b], M.J. Da Cunha Sargedas De Sousa[124a], C. Da Via[82], W. Dabrowski[37], A. Dafinca[118], T. Dai[87], C. Dallapiccola[84], M. Dam[35], M. Dameri[50a,50b], D.S. Damiani[137], H.O. Danielsson[29], V. Dao[49], G. Darbo[50a], G.L. Darlea[25b], W. Davey[20], 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], R.K. Daya-Ishmukhametova[22], K. De[7], R. de Asmundis[102a], S. De Castro[19a,19b], 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], F. De Lorenzi[63], 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], G. De Zorzi[132a,132b], W.J. Dearnaley[71], R. Debbe[24], C. Debenedetti[45], B. Dechenaux[55], D.V. Dedovich[64], J. Degenhardt[120], C. Del Papa[164a,164c], J. Del Peso[80], T. Del Prete[122a,122b], T. Delemontex[55], M. Deliyergiyev[74], A. Dell'Acqua[29], L. Dell'Asta[21], M. Della Pietra[102a,j], D. della Volpe[102a,102b], M. Delmastro[4], P.A. Delsart[55], C. Deluca[105], S. Demers[176], M. Demichev[64], 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[105], 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[173], B. Di Micco[29], R. Di Nardo[47], A. Di Simone[133a,133b], R. Di Sipio[19a,19b], M.A. Diaz[31a], E.B. Diehl[87], J. Dietrich[41], T.A. Dietzsch[58a], S. Diglio[86], K. Dindar Yagci[39], J. Dingfelder[20], F. Dinut[25a], C. Dionisi[132a,132b], P. Dita[25a], S. Dita[25a], F. Dittus[29], F. Djama[83], T. Djobava[51b], M.A.B. do Vale[23c], A. Do Valle Wemans[124a,n], T.K.O. Doan[4], M. Dobbs[85], R. Dobinson[29,*], D. Dobos[29], E. Dobson[29,o], J. Dodd[34], C. Doglioni[49], T. Doherty[53], Y. Doi[65,*], J. Dolejsi[126], I. Dolenc[74], Z. Dolezal[126], B.A. Dolgoshein[96,*], T. Dohmae[155], M. Donadelli[23d], J. Donini[33], J. Dopke[29], A. Doria[102a], A. Dos Anjos[173], A. Dotti[122a,122b], M.T. Dova[70], A.D. Doxiadis[105], A.T. Doyle[53], M. Dris[9], J. Dubbert[99], S. Dube[14], E. Duchovni[172], G. Duckeck[98], A. Dudarev[29], F. Dudziak[63], M. Dührssen[29], I.P. Duerdoth[82], L. Duflot[115], M-A. Dufour[85], M. Dunford[29], H. Duran Yildiz[3a], R. Duxfield[139], M. Dwuznik[37], F. Dydak[29], M. Düren[52], J. Ebke[98], S. Eckweiler[81], K. Edmonds[81], C.A. Edwards[76], N.C. Edwards[53], W. Ehrenfeld[41], T. Eifert[143], 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[61], 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], H. Esch[42], 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[60], L. Fabbri[19a,19b], C. Fabre[29], R.M. Fakhrutdinov[128], S. Falciano[132a], Y. Fang[173], M. Fanti[89a,89b], A. Farbin[7], A. Farilla[134a], J. Farley[148], T. Farooque[158], S. Farrell[163], 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. Feng[32d], E.J. Feng[5], A.B. Fenyuk[128], J. Ferencei[144b], W. Fernando[5], S. Ferrag[53], J. Ferrando[53], V. Ferrara[41], A. Ferrari[166], P. Ferrari[105], R. Ferrari[119a], D.E. Ferreira de Lima[53], A. Ferrer[167], D. Ferrere[49], C. Ferretti[87], A. Ferretto Parodi[50a,50b], M. Fiascaris[30], F. Fiedler[81], A. Filipčič[74], F. Filthaut[104], M. Fincke-

Keeler[169], M.C.N. Fiolhais[124a,h], L. Fiorini[167], A. Firan[39], G. Fischer[41], M.J. Fisher[109], M. Flechl[48], I. Fleck[141], J. Fleckner[81], P. Fleischmann[174], S. Fleischmann[175], T. Flick[175], A. Floderus[79], L.R. Flores Castillo[173], M.J. Flowerdew[99], T. Fonseca Martin[16], A. Formica[136], A. Forti[82], D. Fortin[159a], D. Fournier[115], H. Fox[71], P. Francavilla[11], S. Franchino[119a,119b], D. Francis[29], T. Frank[172], S. Franz[29], M. Fraternali[119a,119b], S. Fratina[120], S.T. French[27], C. Friedrich[41], F. Friedrich[43], R. Froeschl[29], D. Froidevaux[29], J.A. Frost[27], C. Fukunaga[156], E. Fullana Torregrosa[29], B.G. Fulsom[143], J. Fuster[167], C. Gabaldon[29], O. Gabizon[172], T. Gadfort[24], S. Gadomski[49], G. Gagliardi[50a,50b], P. Gagnon[60], C. Galea[98], E.J. Gallas[118], V. Gallo[16], B.J. Gallop[129], P. Gallus[125], K.K. Gan[109], Y.S. Gao[143,e], A. Gaponenko[14], F. Garberson[176], M. Garcia-Sciveres[14], C. García[167], J.E. García Navarro[167], R.W. Gardner[30], N. Garelli[29], H. Garitaonandia[105], V. Garonne[29], J. Garvey[17], C. Gatti[47], G. Gaudio[119a], B. Gaur[141], L. Gauthier[136], P. Gauzzi[132a,132b], I.L. Gavrilenko[94], C. Gay[168], G. Gaycken[20], E.N. Gazis[9], P. Ge[32d], Z. Gecse[168], 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[55], S. Gentile[132a,132b], M. George[54], S. George[76], P. Gerlach[175], A. Gershon[153], C. Geweniger[58a], H. Ghazlane[135b], N. Ghodbane[33], B. Giacobbe[19a], S. Giagu[132a,132b], V. Giakoumopoulou[8], V. Giangiobbe[11], F. Gianotti[29], B. Gibbard[24], A. Gibson[158], S.M. Gibson[29], D. Gillberg[28], A.R. Gillman[129], D.M. Gingrich[2,d], 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[175], G.L. Glonti[64], J.R. Goddard[75], J. Godfrey[142], J. Godlewski[29], M. Goebel[41], T. Göpfert[43], C. Goeringer[81], C. Gössling[42], S. Goldfarb[87], T. Golling[176], A. Gomes[124a,b], L.S. Gomez Fajardo[41], R. Gonçalo[76], J. Goncalves Pinto Firmino Da Costa[41], L. Gonella[20], S. Gonzalez[173], S. González de la Hoz[167], G. Gonzalez Parra[11], 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[175], B. Gorini[29], E. Gorini[72a,72b], A. Gorišek[74], E. Gornicki[38], B. Gosdzik[41], A.T. Goshaw[5], M. Gosselink[105], M.I. Gostkin[64], I. Gough Eschrich[163], M. Gouighri[135a], D. Goujdami[135c], M.P. Goulette[49], A.G. Goussiou[138], C. Goy[4], S. Gozpinar[22], I. Grabowska-Bold[37], P. Grafström[19a,19b], 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], T. Greenshaw[73], Z.D. Greenwood[24,m], K. Gregersen[35], I.M. Gregor[41], P. Grenier[143], J. Griffiths[138], N. Grigalashvili[64], A.A. Grillo[137], S. Grinstein[11], Y.V. Grishkevich[97], J.-F. Grivaz[115], E. Gross[172], J. Grosse-Knetter[54], J. Groth-Jensen[172], K. Grybel[141], D. Guest[176], C. Guicheney[33], A. Guida[72a,72b], S. Guindon[54], U. Gul[53], H. Guler[85,p], J. Gunther[125], B. Guo[158], J. Guo[34], P. Gutierrez[111], N. Guttman[153], O. Gutzwiller[173], C. Guyot[136], C. Gwenlan[118], C.B. Gwilliam[73], A. Haas[143], S. Haas[29], C. Haber[14], H.K. Hadavand[39], D.R. Hadley[17], P. Haefner[20], F. Hahn[29], S. Haider[29], Z. Hajduk[38], H. Hakobyan[177], D. Hall[118], J. Haller[54], K. Hamacher[175], P. Hamal[113], M. Hamer[54], A. Hamilton[145b,q], S. Hamilton[161], L. Han[32b], K. Hanagaki[116], K. Hanawa[160], M. Hance[14], 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[175], S. Harkusha[90], D. Harper[87], R.D. Harrington[45], O.M. Harris[138], J. Hartert[48], F. Hartjes[105], T. Haruyama[65], A. Harvey[56], S. Hasegawa[101], Y. Hasegawa[140], S. Hassani[136], S. Haug[16], M. Hauschild[29], R. Hauser[88], M. Havranek[20], C.M. Hawkes[17], R.J. Hawkings[29], A.D. Hawkins[79], D. Hawkins[163], T. Hayakawa[66], T. Hayashi[160], D. Hayden[76], C.P. Hays[118], H.S. Hayward[73], S.J. Haywood[129], M. He[32d], S.J. Head[17], V. Hedberg[79], L. Heelan[7], S. Heim[88], B. Heinemann[14], S. Heisterkamp[35], L. Helary[21], C. Heller[98], M. Heller[29], 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], C. Hensel[54], T. Henß[175], C.M. Hernandez[7], Y. Hernández Jiménez[167], R. Herrberg[15], G. Herten[48], R. Hertenberger[98], L. Hervas[29], G.G. Hesketh[77], N.P. Hessey[105], E. Higón-Rodriguez[167], J.C. Hill[27], 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[175], 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], T.M. Hong[120], L. Hooft van Huysduynen[108], C. Horn[143], S. Horner[48], J-Y. Hostachy[55], S. Hou[151], A. Hoummada[135a], J. Howard[118], J. Howarth[82], I. Hristova[15], J. Hrivnac[115], T. Hryn'ova[4], P.J. Hsu[81], S.-C. Hsu[14], Z. Hubacek[127], F. Hubaut[83], F. Huegging[20], A. Huettmann[41], T.B. Huffman[118], E.W. Hughes[34], G. Hughes[71], M. Huhtinen[29], M. Hurwitz[14], U. Husemann[41], N. Huseynov[64,r], J. Huston[88], J. Huth[57], G. Iacobucci[49], G. Iakovidis[9], M. Ibbotson[82], I. Ibragimov[141], L. Iconomidou-Fayard[115], J. Idarraga[115], P. Iengo[102a], O. Igonkina[105], Y. Ikegami[65], M. Ikeno[65], D. Iliadis[154], N. Ilic[158], T. Ince[20], J. Inigo-Golfin[29], P. Ioannou[8], M. Iodice[134a], K. Iordanidou[8], V. Ippolito[132a,132b], A. Irles Quiles[167], C. Isaksson[166], M. Ishino[67], M. Ishitsuka[157], R. Ishmukhametov[39], C. Issever[118], S. Istin[18a], A.V. Ivashin[128], W. Iwanski[38], H. Iwasaki[65], J.M. Izen[40], V. Izzo[102a], B. Jackson[120], J.N. Jackson[73], P. Jackson[143], M.R. Jaekel[29], V. Jain[60], K. Jakobs[48], S. Jakobsen[35], T. Jakoubek[125], J. Jakubek[127], D.K. Jana[111], E. Jansen[77], H. Jansen[29], A. Jantsch[99], M. Janus[48], G. Jarlskog[79], L. Jeanty[57], I. Jen-La Plante[30], P. Jenni[29], A. Jeremie[4], P. Jež[35], S. Jézéquel[4], M.K. Jha[19a], H. Ji[173], W. Ji[81], J. Jia[148], Y. Jiang[32b], M. Jimenez Belenguer[41], S. Jin[32a], O. Jinnouchi[157], M.D. Joergensen[35], D. Joffe[39], 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[170], R.W.L. Jones[71], T.J. Jones[73], C. Joram[29], P.M. Jorge[124a],

K.D. Joshi[82], J. Jovicevic[147], T. Jovin[12b], X. Ju[173], C.A. Jung[42], R.M. Jungst[29], V. Juranek[125], P. Jussel[61], A. Juste Rozas[11], S. Kabana[16], M. Kaci[167], A. Kaczmarska[38], P. Kadlecik[35], M. Kado[115], H. Kagan[109], M. Kagan[57], E. Kajomovitz[152], S. Kalinin[175], L.V. Kalinovskaya[64], S. Kama[39], N. Kanaya[155], M. Kaneda[29], S. Kaneti[27], T. Kanno[157], V.A. Kantserov[96], J. Kanzaki[65], B. Kaplan[176], A. Kapliy[30], J. Kaplon[29], D. Kar[53], M. Karagounis[20], K. Karakostas[9], M. Karnevskiy[41], V. Kartvelishvili[71], A.N. Karyukhin[128], L. Kashif[173], G. Kasieczka[58b], R.D. Kass[109], A. Kastanas[13], M. Kataoka[4], Y. Kataoka[155], E. Katsoufis[9], J. Katzy[41], V. Kaushik[6], K. Kawagoe[69], T. Kawamoto[155], G. Kawamura[81], M.S. Kayl[105], V.A. Kazanin[107], M.Y. Kazarinov[64], R. Keeler[169], R. Kehoe[39], M. Keil[54], G.D. Kekelidze[64], J.S. Keller[138], M. Kenyon[53], O. Kepka[125], N. Kerschen[29], B.P. Kerševan[74], S. Kersten[175], K. Kessoku[155], J. Keung[158], F. Khalilzada[10], H. Khandanyan[165], A. Khanov[112], D. Kharchenko[64], A. Khodinov[96], A. Khomich[58a], T.J. Khoo[27], G. Khoriauli[20], A. Khoroshilov[175], V. Khovanskiy[95], E. Khramov[64], J. Khubua[51b], H. Kim[146a,146b], S.H. Kim[160], N. Kimura[171], O. Kind[15], B.T. King[73], M. King[66], R.S.B. King[118], J. Kirk[129], A.E. Kiryunin[99], T. Kishimoto[66], D. Kisielewska[37], T. Kittelmann[123], E. Kladiva[144b], M. Klein[73], U. Klein[73], K. Kleinknecht[81], M. Klemetti[85], A. Klier[172], P. Klimek[146a,146b], A. Klimentov[24], R. Klingenberg[42], J.A. Klinger[82], 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[61], E.B.F.G. Knoops[83], A. Knue[54], B.R. Ko[44], T. Kobayashi[155], M. Kobel[43], M. Kocian[143], 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], L.A. Kogan[118], S. Kohlmann[175], F. Kohn[54], Z. Kohout[127], T. Kohriki[65], T. Koi[143], G.M. Kolachev[107], H. Kolanoski[15], V. Kolesnikov[64], I. Koletsou[89a], J. Koll[88], M. Kollefrath[48], A.A. Komar[94], Y. Komori[155], T. Kondo[65], T. Kono[41,s], A.I. Kononov[48], R. Konoplich[108,t], N. Konstantinidis[77], S. Koperny[37], K. Korcyl[38], K. Kordas[154], 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], S. Kotov[99], V.M. Kotov[64], A. Kotwal[44], C. Kourkoumelis[8], V. Kouskoura[154], A. Koutsman[159a], 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], S. Kreiss[108], 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[64], H. Krüger[20], T. Kruker[16], N. Krumnack[63], Z.V. Krumshteyn[64], A. Kruth[20], T. Kubota[86], S. Kuday[3a], S. Kuehn[48], A. Kugel[58c], T. Kuhl[41], D. Kuhn[61], V. Kukhtin[64], Y. Kulchitsky[90], S. Kuleshov[31b], C. Kummer[98], M. Kuna[78], J. Kunkle[120], A. Kupco[125], H. Kurashige[66], M. Kurata[160], Y.A. Kurochkin[90], V. Kus[125], E.S. Kuwertz[147], M. Kuze[157], J. Kvita[142], R. Kwee[15], A. La Rosa[49], 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[64], R. Lafaye[4], B. Laforge[78], T. Lagouri[80], S. Lai[48], E. Laisne[55], M. Lamanna[29], L. Lambourne[77], C.L. Lampen[6], W. Lampl[6], E. Lancon[136], U. Landgraf[48], M.P.J. Landon[75], J.L. Lane[82], V.S. Lang[58a], C. Lange[41], A.J. Lankford[163], F. Lanni[24], K. Lantzsch[175], S. Laplace[78], C. Lapoire[20], J.F. Laporte[136], T. Lari[89a], A. Larner[118], M. Lassnig[29], P. Laurelli[47], V. Lavorini[36a,36b], W. Lavrijsen[14], P. Laycock[73], O. Le Dortz[78], E. Le Guirriec[83], C. Le Maner[158], E. Le Menedeu[11], T. LeCompte[5], F. Ledroit-Guillon[55], H. Lee[105], J.S.H. Lee[116], S.C. Lee[151], L. Lee[176], M. Lefebvre[169], M. Legendre[136], 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[172], B. Lemmer[54], V. Lendermann[58a], K.J.C. Leney[145b], T. Lenz[105], G. Lenzen[175], B. Lenzi[29], K. Leonhardt[43], S. Leontsinis[9], F. Lepold[58a], C. Leroy[93], J-R. Lessard[169], C.G. Lester[27], C.M. Lester[120], J. Levêque[4], D. Levin[87], L.J. Levinson[172], A. Lewis[118], G.H. Lewis[108], A.M. Leyko[20], M. Leyton[15], B. Li[83], H. Li[173,u], S. Li[32b,v], X. Li[87], Z. Liang[118,w], H. Liao[33], B. Liberti[133a], P. Lichard[29], M. Lichtnecker[98], K. Lie[165], W. Liebig[13], C. Limbach[20], A. Limosani[86], M. Limper[62], S.C. Lin[151,x], F. Linde[105], J.T. Linnemann[88], E. Lipeles[120], A. Lipniacka[13], T.M. Liss[165], D. Lissauer[24], A. Lister[49], A.M. Litke[137], C. Liu[28], D. Liu[151], H. Liu[87], J.B. Liu[87], L. Liu[87], M. Liu[32b], 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[176], C.W. Loh[168], T. Lohse[15], K. Lohwasser[48], M. Lokajicek[125], V.P. Lombardo[4], R.E. Long[71], L. Lopes[124a], D. Lopez Mateos[57], J. Lorenz[98], N. Lorenzo Martinez[115], 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,e], 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[60], G. Luijckx[105], W. Lukas[61], D. Lumb[48], L. Luminari[132a], E. Lund[117], B. Lund-Jensen[147], B. Lundberg[79], J. Lundberg[146a,146b], O. Lundberg[146a,146b], J. Lundquist[35], M. Lungwitz[81], D. Lynn[24], E. Lytken[79], H. Ma[24], L.L. Ma[173], 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[175], S. Mättig[41], L. Magnoni[29], E. Magradze[54], K. Mahboubi[48], S. Mahmoud[73], G. Mahout[17], C. Maiani[136], C. Maidantchik[23a], A. Maio[124a,b], S. Majewski[24], Y. Makida[65], N. Makovec[115], P. Mal[136], B. Malaescu[29], Pa. Malecki[38], P. Malecki[38], V.P. Maleev[121], F. Malek[55], U. Mallik[62], D. Malon[5], C. Malone[143], S. Maltezos[9], V. Malyshev[107], S. Malyukov[29], R. Mameghani[98], J. Mamuzic[12b], A. Manabe[65], L. Mandelli[89a], I. Mandić[74], R. Mandrysch[15], J. Maneira[124a], P.S. Mangeard[88], L. Manhaes de Andrade Filho[23a], A. Mann[54], P.M. Manning[137], A. Manousakis-Katsikakis[8], B. Mansoulie[136], A. Mapelli[29], L. Mapelli[29], L. March[80], J.F. Marchand[28], F. Marchese[133a,133b],

G. Marchiori[78], M. Marcisovsky[125], C.P. Marino[169], F. Marroquim[23a], Z. Marshall[29], F.K. Martens[158], L.F. Marti[16], S. Marti-Garcia[167], B. Martin[29], B. Martin[88], J.P. Martin[93], 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[169], 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], A. Mastroberardino[36a,36b], T. Masubuchi[155], P. Matricon[115], H. Matsunaga[155], T. Matsushita[66], C. Mattravers[118,c], J. Maurer[83], S.J. Maxfield[73], A. Mayne[139], R. Mazini[151], M. Mazur[20], L. Mazzaferro[133a,133b], M. Mazzanti[89a], 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], T. Mclaughlan[17], S.J. McMahon[129], R.A. McPherson[169,k], A. Meade[84], J. Mechnich[105], M. Mechtel[175], M. Medinnis[41], R. Meera-Lebbai[111], T. Meguro[116], R. Mehdiyev[93], S. Mehlhase[35], A. Mehta[73], K. Meier[58a], B. Meirose[79], C. Melachrinos[30], B.R. Mellado Garcia[173], F. Meloni[89a,89b], L. Mendoza Navas[162], Z. Meng[151,u], A. Mengarelli[19a,19b], S. Menke[99], E. Meoni[161], K.M. Mercurio[57], P. Mermod[49], L. Merola[102a,102b], C. Meroni[89a], F.S. Merritt[30], H. Merritt[109], A. Messina[29,y], J. Metcalfe[103], A.S. Mete[163], C. Meyer[81], C. Meyer[30], J-P. Meyer[136], J. Meyer[174], J. Meyer[54], T.C. Meyer[29], W.T. Meyer[63], J. Miao[32d], S. Michal[29], L. Micu[25a], R.P. Middleton[129], S. Migas[73], L. Mijović[41], G. Mikenberg[172], M. Mikestikova[125], M. Mikuž[74], D.W. Miller[30], R.J. Miller[88], W.J. Mills[168], C. Mills[57], A. Milov[172], D.A. Milstead[146a,146b], D. Milstein[172], A.A. Minaenko[128], M. Miñano Moya[167], I.A. Minashvili[64], A.I. Mincer[108], B. Mindur[37], M. Mineev[64], Y. Ming[173], L.M. Mir[11], G. Mirabelli[132a], J. Mitrevski[137], V.A. Mitsou[167], S. Mitsui[65], P.S. Miyagawa[139], J.U. Mjörnmark[79], T. Moa[146a,146b], V. Moeller[27], K. Mönig[41], N. Möser[20], S. Mohapatra[148], W. Mohr[48], R. Moles-Valls[167], J. Monk[77], E. Monnier[83], J. Montejo Berlingen[11], 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. Morgenstern[43], M. Morii[57], A.K. Morley[29], G. Mornacchi[29], J.D. Morris[75], L. Morvaj[101], H.G. Moser[99], M. Mosidze[51b], J. Moss[109], R. Mount[143], E. Mountricha[9,z], S.V. Mouraviev[94], E.J.W. Moyse[84], F. Mueller[58a], J. Mueller[123], K. Mueller[20], T.A. Müller[98], T. Mueller[81], D. Muenstermann[29], 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[65], A. Nagarkar[109], Y. Nagasaka[59], M. Nagel[99], A.M. Nairz[29], Y. Nakahama[29], K. Nakamura[155], T. Nakamura[155], I. Nakano[110], G. Nanava[20], A. Napier[161], R. Narayan[58b], M. Nash[77,c], T. Nattermann[20], T. Naumann[41], G. Navarro[162], H.A. Neal[87], P.Yu. Nechaeva[94], T.J. Neep[82], A. Negri[119a,119b], G. Negri[29], S. Nektarijevic[49], A. Nelson[163], T.K. Nelson[143], S. Nemecek[125], P. Nemethy[108], A.A. Nepomuceno[23a], M. Nessi[29,aa], 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], B. Nicquevert[29], F. Niedercorn[115], J. Nielsen[137], N. Nikiforou[34], A. Nikiforov[15], V. Nikolaenko[128], I. Nikolic-Audit[78], K. Nikolics[49], K. Nikolopoulos[24], H. Nilsen[48], P. Nilsson[7], Y. Ninomiya[155], A. Nisati[132a], R. Nisius[99], T. Nobe[157], L. Nodulman[5], M. Nomachi[116], I. Nomidis[154], M. Nordberg[29], P.R. Norton[129], J. Novakova[126], M. Nozaki[65], L. Nozka[113], I.M. Nugent[159a], A.-E. Nuncio-Quiroz[20], G. Nunes Hanninger[86], T. Nunnemann[98], E. Nurse[77], B.J. O'Brien[45], S.W. O'Neale[17,*], D.C. O'Neil[142], V. O'Shea[53], L.B. Oakes[98], F.G. Oakham[28,d], H. Oberlack[99], J. Ocariz[78], A. Ochi[66], S. Oda[69], S. Odaka[65], J. Odier[83], H. Ogren[60], A. Oh[82], S.H. Oh[44], C.C. Ohm[146a,146b], T. Ohshima[101], H. Okawa[163], Y. Okumura[30], T. Okuyama[155], A. Olariu[25a], A.G. Olchevski[64], S.A. Olivares Pino[31a], M. Oliveira[124a,h], D. Oliveira Damazio[24], E. Oliver Garcia[167], D. Olivito[120], A. Olszewski[38], J. Olszowska[38], A. Onofre[124a,ab], P.U.E. Onyisi[30], C.J. Oram[159a], M.J. Oreglia[30], Y. Oren[153], D. Orestano[134a,134b], N. Orlando[72a,72b], 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], E.A. Ouellette[169], F. Ould-Saada[117], A. Ouraou[136], Q. Ouyang[32a], A. Ovcharova[14], 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], P. Pais[84], K. Pajchel[117], G. Palacino[159b], C.P. Paleari[6], S. Palestini[29], D. Pallin[33], A. Palma[124a], J.D. Palmer[17], Y.B. Pan[173], E. Panagiotopoulou[9], P. Pani[105], N. Panikashvili[87], S. Panitkin[24], D. Pantea[25a], A. Papadelis[146a], Th.D. Papadopoulou[9], A. Paramonov[5], D. Paredes Hernandez[33], W. Park[24,ac], M.A. Parker[27], F. Parodi[50a,50b], J.A. Parsons[34], U. Parzefall[48], S. Pashapour[54], E. Pasqualucci[132a], S. Passaggio[50a], A. Passeri[134a], F. Pastore[134a,134b], Fr. Pastore[76], G. Pásztor[49,ad], S. Pataraia[175], N. Patel[150], J.R. Pater[82], S. Patricelli[102a,102b], T. Pauly[29], M. Pecsy[144a], M.I. Pedraza Morales[173], S.V. Peleganchuk[107], D. Pelikan[166], H. Peng[32b], B. Penning[30], A. Penson[34], J. Penwell[60], M. Perantoni[23a], K. Perez[34,ae], T. Perez Cavalcanti[41], E. Perez Codina[159a], M.T. Pérez García-Estañ[167], V. Perez Reale[34], L. Perini[89a,89b], H. Pernegger[29], R. Perrino[72a], P. Perrodo[4], V.D. Peshekhonov[64], K. Peters[29], B.A. Petersen[29], J. Petersen[29], T.C. Petersen[35], E. Petit[4], 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], P.W. Phillips[129], G. Piacquadio[29], A. Picazio[49], E. Piccaro[75], M. Piccinini[19a,19b], S.M. Piec[41], R. Piegaia[26], D.T. Pignotti[109], J.E. Pilcher[30], A.D. Pilkington[82], J. Pina[124a,b], M. Pinamonti[164a,164c], A. Pinder[118], J.L. Pinfold[2], B. Pinto[124a], C. Pizio[89a,89b], M. Plamondon[169], M.-A. Pleier[24], E. Plotnikova[64], A. Poblaguev[24], S. Poddar[58a], F. Podlyski[33], L. Poggioli[115], T. Poghosyan[20], M. Pohl[49], G. Polesello[119a], A. Policicchio[36a,36b], A. Polini[19a], J. Poll[75], V. Polychronakos[24], 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], G.E. Pospelov[99],

S. Pospisil[127], I.N. Potrap[99], C.J. Potter[149], C.T. Potter[114], G. Poulard[29], J. Poveda[60], V. Pozdnyakov[64], R. Prabhu[77], P. Pralavorio[83], A. Pranko[14], S. Prasad[29], R. Pravahan[24], S. Prell[63], K. Pretzl[16], D. Price[60], J. Price[73], L.E. Price[5], D. Prieur[123], M. Primavera[72a], K. Prokofiev[108], F. Prokoshin[31b], S. Protopopescu[24], J. Proudfoot[5], X. Prudent[43], M. Przybycien[37], H. Przysiezniak[4], S. Psoroulas[20], E. Ptacek[114], E. Pueschel[84], J. Purdham[87], M. Purohit[24,ac], P. Puzo[115], Y. Pylypchenko[62], J. Qian[87], A. Quadt[54], D.R. Quarrie[14], W.B. Quayle[173], F. Quinonez[31a], M. Raas[104], V. Radescu[41], P. Radloff[114], T. Rador[18a], F. Ragusa[89a,89b], G. Rahal[178], A.M. Rahimi[109], D. Rahm[24], S. Rajagopalan[24], M. Rammensee[48], M. Rammes[141], A.S. Randle-Conde[39], K. Randrianarivony[28], F. Rauscher[98], T.C. Rave[48], M. Raymond[29], A.L. Read[117], D.M. Rebuzzi[119a,119b], A. Redelbach[174], G. Redlinger[24], R. Reece[120], K. Reeves[40], E. Reinherz-Aronis[153], A. Reinsch[114], I. Reisinger[42], C. Rembser[29], Z.L. Ren[151], A. Renaud[115], M. Rescigno[132a], S. Resconi[89a], B. Resende[136], P. Reznicek[98], R. Rezvani[158], R. Richter[99], E. Richter-Was[4,af], M. Ridel[78], 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], A. Robson[53], J.G. Rocha de Lima[106], C. Roda[122a,122b], D. Roda Dos Santos[29], A. Roe[54], S. Roe[29], O. Røhne[117], S. Rolli[161], A. Romaniouk[96], M. Romano[19a,19b], G. Romeo[26], E. Romero Adam[167], L. Roos[78], E. Ros[167], S. Rosati[132a], K. Rosbach[49], A. Rose[149], M. Rose[76], G.A. Rosenbaum[158], E.I. Rosenberg[63], P.L. Rosendahl[13], O. Rosenthal[141], L. Rosselet[49], V. Rossetti[11], E. Rossi[132a,132b], L.P. Rossi[50a], M. Rotaru[25a], I. Roth[172], J. Rothberg[138], D. Rousseau[115], C.R. Royon[136], A. Rozanov[83], Y. Rozen[152], X. Ruan[32a,ag], F. Rubbo[11], I. Rubinskiy[41], B. Ruckert[98], N. Ruckstuhl[105], V.I. Rud[97], C. Rudolph[43], G. Rudolph[61], F. Rühr[6], A. Ruiz-Martinez[63], L. Rumyantsev[64], Z. Rurikova[48], N.A. Rusakovich[64], J.P. Rutherfoord[6], C. Ruwiedel[14], P. Ruzicka[125], Y.F. Ryabov[121], P. Ryan[88], M. Rybar[126], G. Rybkin[115], N.C. Ryder[118], A.F. Saavedra[150], I. Sadeh[153], H.F-W. Sadrozinski[137], R. Sadykov[64], F. Safai Tehrani[132a], H. Sakamoto[155], G. Salamanna[75], A. Salamon[133a], M. Saleem[111], D. Salek[29], 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], V. Sanchez Martinez[167], H. Sandaker[13], H.G. Sander[81], M.P. Sanders[98], M. Sandhoff[175], T. Sandoval[27], C. Sandoval[162], R. Sandstroem[99], 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], T. Sarangi[173], E. Sarkisyan-Grinbaum[7], F. Sarri[122a,122b], G. Sartisohn[175], O. Sasaki[65], N. Sasao[67], I. Satsounkevitch[90], G. Sauvage[4], E. Sauvan[4], J.B. Sauvan[115], P. Savard[158,d], V. Savinov[123], D.O. Savu[29], L. Sawyer[24,m], D.H. Saxon[53], J. Saxon[120], C. Sbarra[19a], A. Sbrizzi[19a,19b], O. Scallon[93], D.A. Scannicchio[163], M. Scarcella[150], J. Schaarschmidt[115], P. Schacht[99], D. Schaefer[120], 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[34], C. Schiavi[50a,50b], J. Schieck[98], M. Schioppa[36a,36b], S. Schlenker[29], E. Schmidt[48], K. Schmieden[20], C. Schmitt[81], S. Schmitt[58b], M. Schmitz[20], B. Schneider[16], U. Schnoor[43], A. Schöning[58b], A.L.S. Schorlemmer[54], M. Schott[29], D. Schouten[159a], J. Schovancova[125], M. Schram[85], C. Schroeder[81], N. Schroer[58c], M.J. Schultens[20], J. Schultes[175], H.-C. Schultz-Coulon[58a], H. Schulz[15], 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], M. Schwoerer[4], G. Sciolla[22], W.G. Scott[129], J. Searcy[114], G. Sedov[41], E. Sedykh[121], S.C. Seidel[103], A. Seiden[137], F. Seifert[43], J.M. Seixas[23a], G. Sekhniaidze[102a], S.J. Sekula[39], K.E. Selbach[45], D.M. Seliverstov[121], B. Sellden[146a], G. Sellers[73], M. Seman[144b], N. Semprini-Cesari[19a,19b], C. Serfon[98], L. Serin[115], L. Serkin[54], R. Seuster[99], H. Severini[111], 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], K. Shaw[164a,164c], D. Sherman[176], P. Sherwood[77], A. Shibata[108], S. Shimizu[29], M. Shimojima[100], T. Shin[56], M. Shiyakova[64], A. Shmeleva[94], M.J. Shochet[30], D. Short[118], S. Shrestha[63], E. Shulga[96], M.A. Shupe[6], P. Sicho[125], A. Sidoti[132a], F. Siegert[48], Dj. Sijacki[12a], O. Silbert[172], J. Silva[124a], Y. Silver[153], D. Silverstein[143], S.B. Silverstein[146a], V. Simak[127], O. Simard[136], Lj. Simic[12a], S. Simion[115], E. Simioni[81], B. Simmons[77], R. Simoniello[89a,89b], M. Simonyan[35], P. Sinervo[158], N.B. Sinev[114], V. Sipica[141], G. Siragusa[174], A. Sircar[24], A.N. Sisakyan[64], 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], M. Slater[17], T. Slavicek[127], K. Sliwa[161], V. Smakhtin[172], B.H. Smart[45], S.Yu. Smirnov[96], Y. 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], S. Snyder[24], R. Sobie[169,k], J. Sodomka[127], A. Soffer[153], C.A. Solans[167], M. Solar[127], J. Solc[127], E.Yu. Soldatov[96], U. Soldevila[167], E. Solfaroli Camillocci[132a,132b], A.A. Solodkov[128], O.V. Solovyanov[128], N. Soni[2], V. Sopko[127], B. Sopko[127], 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], R. Spiwoks[29], M. Spousta[126], T. Spreitzer[158], B. Spurlock[7], R.D. St. Denis[53], J. Stahlman[120], R. Stamen[58a], E. Stanecka[38], R.W. Stanek[5], C. Stanescu[134a], M. Stanescu-Bellu[41], S. Stapnes[117], E.A. Starchenko[128], J. Stark[55], P. Staroba[125], P. Starovoitov[41], R. Staszewski[38], A. Staude[98], P. Stavina[144a], 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], S. Stern[99], G.A. Stewart[29], J.A. Stillings[20], M.C. Stockton[85], 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[174], 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[175], N.A. Styles[41], D.A. Soh[151,w], D. Su[143], HS. Subramania[2], A. Succurro[11], Y. Sugaya[116], C. Suhr[106], M. Suk[126], V.V. Sulin[94], S. Sultansoy[3d], T. Sumida[67], X. Sun[55], J.E. Sundermann[48], K. Suruliz[139], G. Susinno[36a,36b], M.R. Sutton[149], Y. Suzuki[65], Y. Suzuki[66], M. Svatos[125], S. Swedish[168], I. Sykora[144a], T. Sykora[126], 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[68], H. Takeda[66], T. Takeshita[140], Y. Takubo[65], M. Talby[83], A. Talyshev[107,f], M.C. Tamsett[24], J. Tanaka[155], R. Tanaka[115], S. Tanaka[131], S. Tanaka[65], A.J. Tanasijczuk[142], K. Tani[66], N. Tannoury[83], 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[65], K. Terashi[155], J. Terron[80], M. Testa[47], R.J. Teuscher[158,k], J. Therhaag[20], T. Theveneaux-Pelzer[78], S. Thoma[48], J.P. Thomas[17], E.N. Thompson[34], P.D. Thompson[17], P.D. Thompson[158], A.S. Thompson[53], L.A. Thomsen[35], E. Thomson[120], M. Thomson[27], R.P. Thun[87], F. Tian[34], M.J. Tibbetts[14], T. Tic[125], V.O. Tikhomirov[94], Y.A. Tikhonov[107,f], S. Timoshenko[96], P. Tipton[176], F.J. Tique Aires Viegas[29], S. Tisserant[83], T. Todorov[4], S. Todorova-Nova[161], B. Toggerson[163], J. Tojo[69], S. Tokár[144a], K. Tokushuku[65], K. Tollefson[88], M. Tomoto[101], L. Tompkins[30], K. Toms[103], A. Tonoyan[13], C. Topfel[16], N.D. Topilin[64], I. Torchiani[29], E. Torrence[114], H. Torres[78], E. Torró Pastor[167], J. Toth[83,ad], F. Touchard[83], D.R. Tovey[139], T. Trefzger[174], L. Tremblet[29], A. Tricoli[29], I.M. Trigger[159a], S. Trincaz-Duvoid[78], M.F. Tripiana[70], W. Trischuk[158], B. Trocmé[55], C. Troncon[89a], M. Trottier-McDonald[142], M. Trzebinski[38], A. Trzupek[38], C. Tsarouchas[29], J.C-L. Tseng[118], M. Tsiakiris[105], P.V. Tsiareshka[90], D. Tsionou[4,ah], G. Tsipolitis[9], V. Tsiskaridze[48], E.G. Tskhadadze[51a], I.I. Tsukerman[95], V. Tsulaia[14], J.-W. Tsung[20], S. Tsuno[65], 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], 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], A. Undrus[24], G. Unel[163], Y. Unno[65], D. Urbaniec[34], 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], A. Valero[167], 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[29], P. van Gemmeren[5], I. van Vulpen[105], M. Vanadia[99], W. Vandelli[29], A. Vaniachine[5], P. Vankov[41], F. Vannucci[78], R. Vari[132a], T. Varol[84], D. Varouchas[14], A. Vartapetian[7], K.E. Varvell[150], V.I. Vassilakopoulos[56], F. Vazeille[33], T. Vazquez Schroeder[54], G. Vegni[89a,89b], J.J. Veillet[115], F. Veloso[124a], R. Veness[29], S. Veneziano[132a], A. Ventura[72a,72b], D. Ventura[84], M. Venturi[48], N. Venturi[158], V. Vercesi[119a], M. Verducci[138], W. Verkerke[105], J.C. Vermeulen[105], A. Vest[43], M.C. Vetterli[142,d], I. Vichou[165], T. Vickey[145b,ai], 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[64], M. Virchaux[136,*], J. Virzi[14], O. Vitells[172], M. Viti[41], I. Vivarelli[48], F. Vives Vaque[2], S. Vlachos[9], D. Vladoiu[98], M. Vlasak[127], 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], V. Vorwerk[11], M. Vos[167], R. Voss[29], T.T. Voss[175], J.H. Vossebeld[73], N. Vranjes[136], M. Vranjes Milosavljevic[105], V. Vrba[125], M. Vreeswijk[105], T. Vu Anh[48], R. Vuillermet[29], I. Vukotic[115], W. Wagner[175], P. Wagner[120], H. Wahlen[175], S. Wahrmund[43], J. Wakabayashi[101], S. Walch[87], J. Walder[71], R. Walker[98], W. Walkowiak[141], R. Wall[176], P. Waller[73], C. Wang[44], H. Wang[173], H. Wang[32b,aj], J. Wang[151], J. Wang[55], R. Wang[103], S.M. Wang[151], T. Wang[20], A. Warburton[85], C.P. Ward[27], M. Warsinsky[48], A. Washbrook[45], C. Wasicki[41], P.M. Watkins[17], A.T. Watson[17], I.J. Watson[150], M.F. Watson[17], G. Watts[138], S. Watts[82], A.T. Waugh[150], B.M. Waugh[77], 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], T. Wenaus[24], D. Wendland[15], Z. Weng[151,w], T. Wengler[29], S. Wenig[29], N. Wermes[20], M. Werner[48], P. Werner[29], M. Werth[163], M. Wessels[58a], J. Wetter[161], C. Weydert[55], K. Whalen[28], S.J. Wheeler-Ellis[163], A. White[7], M.J. White[86], S. White[122a,122b], S.R. Whitehead[118], D. Whiteson[163], D. Whittington[60], F. Wicek[115], D. Wicke[175], F.J. Wickens[129], W. Wiedenmann[173], M. Wielers[129], P. Wienemann[20], C. Wiglesworth[75], L.A.M. Wiik-Fuchs[48], P.A. Wijeratne[77], A. Wildauer[167], M.A. Wildt[41,s], 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], S.J. Wollstadt[81], M.W. Wolter[38], H. Wolters[124a,h], W.C. Wong[40], G. Wooden[87], B.K. Wosiek[38], J. Wotschack[29], M.J. Woudstra[82], K.W. Wozniak[38], K. Wraight[53], C. Wright[53], M. Wright[53], B. Wrona[73], S.L. Wu[173], X. Wu[49], Y. Wu[32b,ak], E. Wulf[34], B.M. Wynne[45], S. Xella[35], M. Xiao[136], S. Xie[48], C. Xu[32b,z], D. Xu[139], B. Yabsley[150], S. Yacoob[145b], M. Yamada[65], H. Yamaguchi[155], A. Yamamoto[65], K. Yamamoto[63], S. Yamamoto[155], T. Yamamura[155], T. Yamanaka[155], J. Yamaoka[44], T. Yamazaki[155], Y. Yamazaki[66], Z. Yan[21], H. Yang[87], U.K. Yang[82], Y. Yang[60], Z. Yang[146a,146b], S. Yanush[91], L. Yao[32a], Y. Yao[14], Y. Yasu[65], G.V. Ybeles Smit[130], J. Ye[39], S. Ye[24], M. Yilmaz[3c], R. Yoosoofmiya[123], K. Yorita[171], R. Yoshida[5], C. Young[143], C.J. Young[118], S. Youssef[21], D. Yu[24], J. Yu[7], J. Yu[112], L. Yuan[66], A. Yurkewicz[106], B. Zabinski[38], R. Zaidan[62], A.M. Zaitsev[128], Z. Zajacova[29], L. Zanello[132a,132b], A. Zaytsev[107], C. Zeitnitz[175], M. Zeman[125], A. Zemla[38], C. Zendler[20], O. Zenin[128], T. Ženiš[144a], Z. Zinonos[122a,122b], S. Zenz[14], D. Zerwas[115],

G. Zevi della Porta[57], Z. Zhan[32d], D. Zhang[32b,aj], H. Zhang[88], J. Zhang[5], X. Zhang[32d], Z. Zhang[115], L. Zhao[108], T. Zhao[138], Z. Zhao[32b], A. Zhemchugov[64], J. Zhong[118], 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[60], N.I. Zimin[64], R. Zimmermann[20], S. Zimmermann[20], S. Zimmermann[48], M. Ziolkowski[141], R. Zitoun[4], L. Živković[34], V.V. Zmouchko[128,*], G. Zobernig[173], A. Zoccoli[19a,19b], 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, University of Belgrade, 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 Física, 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)School of Physics, 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] AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, 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, Tbilisi State University, 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 Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan

[60] Department of Physics, Indiana University, Bloomington IN, United States of America

[61] Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria

[62] University of Iowa, Iowa City IA, United States of America

[63] Department of Physics and Astronomy, Iowa State University, Ames IA, United States of America

[64] Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia

[65] KEK, High Energy Accelerator Research Organization, Tsukuba, Japan

[66] Graduate School of Science, Kobe University, Kobe, Japan

[67] Faculty of Science, Kyoto University, Kyoto, Japan

[68] Kyoto University of Education, Kyoto, Japan

[69] Department of Physics, Kyushu University, Fukuoka, 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 Matematica e 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] School of Physics and Astronomy, 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, SB RAS, 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, Université 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, 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)Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech; (d)Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; (e)Faculté des sciences, Université Mohammed V-Agdal, 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] Departments of Physics & Astronomy and Chemistry, 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 Institute 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, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8571, 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, Udine; (b)ICTP, Trieste; (c)Dipartimento di Chimica, Fisica e Ambiente, 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 Ingeniería 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] Department of Physics, University of Warwick, Coventry, United Kingdom

[171] Waseda University, Tokyo, Japan

[172] Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel

[173] Department of Physics, University of Wisconsin, Madison WI, United States of America

[174] Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany

[175]Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany

[176]Department of Physics, Yale University, New Haven CT, United States of America

[177]Yerevan Physics Institute, Yerevan, Armenia

[178]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 TRIUMF, Vancouver BC, Canada

[e]Also at Department of Physics, California State University, Fresno CA, United States of America

[f]Also at Novosibirsk State University, Novosibirsk, Russia

[g]Also at Fermilab, Batavia IL, United States of America

[h]Also at Department of Physics, University of Coimbra, Coimbra, Portugal

[i]Also at Department of Physics, UASLP, San Luis Potosi, Mexico

[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 Dep Fisica and CEFITEC of Faculdade de Ciencias e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal

[o]Also at Department of Physics and Astronomy, University College London, London, United Kingdom

[p]Also at Group of Particle Physics, University of Montreal, Montreal QC, Canada

[q]Also at Department of Physics, University of Cape Town, Cape Town, South Africa

[r]Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan

[s]Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany

[t]Also at Manhattan College, New York NY, United States of America

[u]Also at School of Physics, Shandong University, Shandong, China

[v]Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France

[w]Also at School of Physics and Engineering, Sun Yat-sen University, Guanzhou, China

[x]Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan

[y]Also at Dipartimento di Fisica, Università La Sapienza, Roma, Italy

[z]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

[aa]Also at Section de Physique, Université de Genève, Geneva, Switzerland

[ab]Also at Departamento de Fisica, Universidade de Minho, Braga, Portugal

[ac]Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States of America

[ad]Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary

[ae]Also at California Institute of Technology, Pasadena CA, United States of America

[af]Also at Institute of Physics, Jagiellonian University, Krakow, Poland

[ag]Also at LAL, Université Paris-Sud and CNRS/IN2P3, Orsay, France

[ah]Also at Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom

[ai]Also at Department of Physics, Oxford University, Oxford, United Kingdom

[aj]Also at Institute of Physics, Academia Sinica, Taipei, Taiwan

[ak]Also at Department of Physics, The University of Michigan, Ann Arbor MI, United States of America

[*]Deceased