

UC Santa Cruz

UC Santa Cruz Previously Published Works

Title

A measurement of the ratio of the W and Z cross sections with exactly one associated jet in pp collisions at $\sqrt{s}=7$ TeV with ATLAS

Permalink

<https://escholarship.org/uc/item/36f7f61m>

Journal

Physics Letters B, 708(3-5)

ISSN

0370-2693

Authors

Collaboration, ATLAS
Aad, G
Abbott, B
[et al.](#)

Publication Date

2012-02-01

DOI

10.1016/j.physletb.2012.01.042

Copyright Information

This work is made available under the terms of a Creative Commons Attribution License, available at <https://creativecommons.org/licenses/by/4.0/>

Peer reviewed



A measurement of the ratio of the W and Z cross sections with exactly one associated jet in pp collisions at $\sqrt{s} = 7$ TeV with ATLAS [☆]

ATLAS Collaboration ^{*}

ARTICLE INFO

Article history:

Received 24 August 2011
 Received in revised form 10 January 2012
 Accepted 13 January 2012
 Available online 18 January 2012
 Editor: H. Weerts

Keywords:

W boson
 Z boson
 Standard Model
 Perturbative QCD

ABSTRACT

The ratio of production cross sections of the W and Z bosons with exactly one associated jet is presented as a function of jet transverse momentum threshold. The measurement has been designed to maximise cancellation of experimental and theoretical uncertainties, and is reported both within a particle-level kinematic range corresponding to the detector acceptance and as a total cross-section ratio. Results are obtained with the ATLAS detector at the LHC in pp collisions at a centre-of-mass energy of 7 TeV using an integrated luminosity of 33 pb^{-1} . The results are compared with perturbative leading-order, leading-log, and next-to-leading-order QCD predictions, and are found to agree within experimental and theoretical uncertainties. The ratio is measured for events with a single jet with $p_T > 30$ GeV to be $8.73 \pm 0.30(\text{stat}) \pm 0.40(\text{syst})$ in the electron channel, and $8.49 \pm 0.23(\text{stat}) \pm 0.33(\text{syst})$ in the muon channel.

© 2012 CERN. Published by Elsevier B.V. Open access under [CC BY-NC-ND license](#).

1. Introduction

Measurements of vector bosons V where $V = W$ or Z produced in association with one or more jets ($V + \text{jet}$) [1–4] provide an important test of the Standard Model (SM) description of the strong interaction in perturbative quantum chromodynamics (QCD). This is particularly important in the kinematic region accessible at the LHC in order to understand the physics at or above the electroweak symmetry-breaking scale. Production of vector bosons is also a significant source of background for studies of other SM processes, including studies of top quark properties, searches for the Higgs boson, as well as in many searches for physics beyond the Standard Model. Measurements of the kinematic properties and dynamics of $V + \text{jet}$ processes and comparisons to theoretical predictions are therefore of significant interest. Individual measurements of kinematic observables in $W + \text{jet}$ [4] and $Z + \text{jet}$ events are limited by systematic uncertainties common to both. Measurement of the ratio was first proposed in Ref. [5] to exploit the cancellation of theoretical and experimental uncertainties, therefore building the foundations for a high precision test of the Standard Model. In the present measurement, this ratio is measured, for states involving exactly one jet, as a function of the minimum jet transverse momentum. In addition to testing the predictions of perturbative QCD at various energy scales, the measurement provides model-independent sensitivity to new physics coupling to leptons and jets.

This Letter describes a measurement of the ratio of the production cross sections in the electron and muon decay channels of the W and Z gauge bosons in association with exactly one jet with transverse momentum $p_T > 30$ GeV. The measurement was performed in the active fiducial volume of the detector and in a kinematic range where events are well-measured, hence minimising any model-dependence. The results were corrected to facilitate direct comparison to theoretical predictions at the particle level. Following the detector acceptance, the fiducial regions were defined by $p_T^{\text{lepton}} > 20$ GeV, $p_T^{\nu} > 25$ GeV, $p_T^{\text{jet}} > 30$ GeV, $|\eta^{\text{jet}}| < 2.8$,¹ and for electrons by $1.52 < |\eta| < 2.47$ or $|\eta| < 1.37$ and for muons by $|\eta| < 2.4$. Events with a second jet with $p_T > 30$ GeV within this fiducial region were rejected.² The selected jet was required to be isolated from electrons by requiring $\Delta R^{e,\text{jet}} > 0.6$ (where $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$). Requirements are made on the boson masses specific to their reconstruction. For the W , the transverse mass defined by the lepton ℓ and neutrino ν transverse momenta and angles as $m_T = \sqrt{2p_T^{\ell}p_T^{\nu}(1 - \cos(\phi^{\ell} - \phi^{\nu}))}$ was required to satisfy $m_T > 40$ GeV. The dilepton invariant mass of the Z was required to be within the range $71 < m_{\ell\ell} < 111$ GeV.

¹ The nominal pp interaction point at the centre of the detector is defined as the origin of a right-handed coordinate system. The positive x -axis is directed from the interaction point to the centre of the LHC ring. The positive y -axis points upwards, while the beam direction defines the z -axis. The azimuthal angle ϕ is measured around the beam axis and the polar angle θ from the z -axis. The pseudorapidity is defined as $\eta = -\ln \tan(\theta/2)$.

² This veto is not expected to significantly affect fixed-order predictions for $V + \text{jet}$ cross sections within the presented range of jet p_T measurements.

[☆] © CERN for the benefit of the ATLAS Collaboration.

^{*} E-mail address: atlas.publications@cern.ch.

Particle-level jets were defined as jets reconstructed in simulated events by applying the anti- k_t jet reconstruction algorithm [6] with a radius parameter $R = 0.4$ to all final state particles with a lifetime longer than 10 ps (including muons and non-interacting particles). Particle-level electrons were defined by including the energy of all radiated photons within a cone of $\Delta R = 0.1$ around each electron. The results are compared to perturbative leading-order [7] (LO), leading-log [8] (LL), and next-to-leading-order [9] (NLO) QCD calculations.

2. The ATLAS detector

The ATLAS detector [10,11] consists of an inner detector tracking system (ID) surrounded by a superconducting solenoid providing a 2 T magnetic field, electromagnetic and hadronic calorimeters, and a muon spectrometer (MS). The ID consists of pixel and silicon microstrip detectors inside a transition radiation tracker (TRT). The electromagnetic calorimeter is a lead liquid-argon (LAr) detector in the barrel ($|\eta| < 1.475$) and the end-cap ($1.375 < |\eta| < 3.2$) regions. Hadron calorimetry is based on two different detector technologies. The barrel ($|\eta| < 0.8$) and extended barrel ($0.8 < |\eta| < 1.7$) calorimeters are composed of scintillator/steel, while the hadronic end-cap calorimeters ($1.5 < |\eta| < 3.2$) are LAr/Cu. The forward calorimeters ($3.1 < |\eta| < 4.9$) are instrumented with LAr/Cu and LAr/W, providing electromagnetic and hadronic energy measurements, respectively. The MS is based on three large superconducting toroids and a system of three stations of trigger chambers and precision tracking chambers.

3. Simulated event samples

Simulated event samples were used to correct signal yields for detector effects, for some of the background estimates, and for comparison of the results to theoretical expectations. Samples of $W \rightarrow \ell\nu + N_{\text{parton}}$ and $Z \rightarrow \ell\ell + N_{\text{parton}}$ (where $\ell = e, \mu, \tau$) were generated using ALPGEN v2.13 [8] with the MLM matching scheme [12], interfaced to HERWIG v6.510 [13] for parton shower and fragmentation processes, and to JIMMY v4.31 [14] for the underlying event simulation. The CTEQ6L1 [15] parton density functions (PDFs) were used for samples generated with ALPGEN. Additional inclusive samples were generated using PYTHIA 6.4.21 [7] using the MRST 2007 LO* [16] PDF for the same processes. The underlying event was generated with the ATLAS MC09 tune [17] for the ALPGEN and PYTHIA samples. A POWHEG v1.01p4 [18] NLO matrix element calculation with the CTEQ6.6M [19] PDF set and CTEQ6L1 PYTHIA parton showering and underlying event was used to generate $t\bar{t}$ samples. The radiation of photons from charged leptons was treated in HERWIG and PYTHIA using PHOTOS v2.15.4 [20], and TAUOLA v1.0.2 [21] was used for tau decays. The POWHEG sample used the ATLAS MC09 tune with one parameter adjusted.³ Inclusive samples of charm and bottom quark production were generated with PYTHIA 6.4.21. To reproduce the detector conditions, samples were also generated with multiple inelastic non-diffractive interactions overlaid on top of the hard-scattering event; the number of additional interactions followed a Poisson distribution with a mean of approximately two [22]. These MC samples were then re-weighted such that the distribution of the number of primary vertices matched that of the data. All samples were passed through the ATLAS detector simulation [23] performed using GEANT4 [24] and were subjected to the same reconstruction and analysis chain as the data.

³ The cutoff for multiple parton interactions, PARP (82), was adjusted from 2.3 to 2.1 GeV, suitable for the CTEQ6L1 PDF.

Predictions for the $W + \text{one jet}$ and $Z + \text{one jet}$ cross sections at NLO were obtained with MCFM [9] with the same jet algorithm and kinematic selection requirements as applied to the data. A correction to particle level was applied to the MCFM predictions using PYTHIA to account for initial and final state radiation, underlying event, and hadronization. Renormalisation and factorisation scales were set to $H_T/2$, where H_T is the scalar sum of the p_T of the unclustered partons, the lepton and the neutrino. The CTEQ6.6M [19] PDF was used for the NLO calculations.

4. Data and event selection

The data used in this analysis were collected in the period March to October 2010. Basic requirements on beam, detector, stable trigger conditions and data quality resulted in a data set corresponding to an integrated luminosity $\mathcal{L} = 33 \text{ pb}^{-1}$. The criteria for event selection and lepton identification followed those employed for the W and Z inclusive cross-section measurement [25] with a few differences to account for the jet selection and to optimise cancellation of systematic uncertainties in the ratio.

In the electron channel, events were selected using a trigger logic that required the presence of at least one electromagnetic cluster in the calorimeter with transverse energy $E_T = E \sin(\theta)$ above 15 GeV in the region $|\eta| < 2.5$. Electron candidates were required to be matched to a track with silicon pixel and strip measurements in the ID, to have $E_T > 20 \text{ GeV}$, and be within the fiducial region, avoiding the calorimeter barrel and end-cap transition regions. Candidates were required to satisfy standard “tight” or “medium” criteria [25]. Candidates satisfying lateral shower containment, shape and width criteria with minimal leakage into the hadronic calorimeter were classified as “medium”. Candidates satisfying additional pixel and impact parameter criteria which also satisfied further requirements on the ratio of cluster energy to track momentum and on the ratio of high-threshold hits to the total number of TRT hits were classified as “tight”.

In the muon channel, events were selected with a trigger system which identified muon candidates by the presence of hit patterns in the MS, consistent with a muon track with $p_T > 10 \text{ GeV}$ or $p_T > 13 \text{ GeV}$ (depending on the data period). The measured transverse momentum in the MS was required to satisfy $p_T > 10 \text{ GeV}$ to reject backgrounds from decays in flight. Muon candidates were required to have independent momentum measurements in both the ID and MS, which were then combined. Candidates which satisfied $p_T > 20 \text{ GeV}$ and were found to be within the fiducial region were classified as “medium”.

Muons were additionally classified as “tight” if they satisfied all of the following additional criteria: the impact parameter with respect to the nominal beam axis was consistent with prompt muon production, the ID track satisfied additional hit quality criteria, the independent ID and MS track p_T measurements were consistent, and the muon was isolated by requiring the $\sum p_T$ of all tracks within $\Delta R < 0.2$ of the muon to be less than 1.8 GeV.

Events were required to have at least one reconstructed primary vertex with three or more associated tracks consistent with the nominal luminous region. The vertex with the largest $\sum p_T^2$ of associated tracks was assumed to be the primary vertex and was required to be within 150 mm of the centre of the detector along the beam direction.

The missing transverse energy (E_T^{miss}) was calculated from the energy deposits of calorimeter cells grouped into three-dimensional clusters [26] following the prescription in Ref. [25]. These clusters were corrected to account for the different response to hadrons compared to electrons or photons, as well as dead material and energy losses [27]. The E_T^{miss} was also corrected for measured muon momenta and their energy depositions in the

calorimeter. To calculate m_T , the (x, y) components of the neutrino momentum were inferred from the corresponding E_T^{miss} components.

Events containing W boson candidates were selected by requiring one electron or muon satisfying “tight” selection criteria with no other “medium” leptons in the event, $E_T^{\text{miss}} > 25$ GeV and $m_T > 40$ GeV. Events containing Z candidates were selected by requiring at least one lepton satisfying “tight” requirements and an additional same flavour, opposite charge lepton satisfying at least “medium” criteria, for which the pair was required to satisfy $71 < m_{\ell\ell} < 111$ GeV. The less stringent requirements on the second lepton reduced the systematic uncertainty on the lepton identification within the ratio measurement. These W and Z selections were defined to ensure mutual exclusivity.

The jet reconstruction efficiency in simulated data control samples [28] was found to be close to 100% for jets with $p_T > 30$ GeV. Events containing jets arising from detector noise or cosmic rays were rejected [29]. A p_T - and η -dependent correction factor, derived from simulated events, was applied to the p_T of each jet to provide an average energy scale correction [30]. Jets were required to be reconstructed within $|\eta| < 2.8$ and with $p_T > 30$ GeV. To avoid double-counting of electrons as jets, the closest jet within $\Delta R < 0.2$ of an electron candidate was not considered. Selected jets were required to be isolated from selected “medium” electrons by requiring $\Delta R(e, \text{jet}) > 0.6$, to prevent a distortion of the jet energy response and of the jet reconstruction efficiency due to the proximity of the electron’s electromagnetic shower. Jets from multiple interactions in a bunch crossing were suppressed by requiring jets with associated tracks have a good jet-vertex fraction ($JVF > 0.75$) [4]. This algorithm used track-jet association within a cone of $\Delta R(\text{track}, \text{jet}) < 0.4$. The JVF was computed for each jet as the scalar sum p_T of all associated tracks which also originated from the primary vertex divided by the scalar sum p_T of all the associated tracks. Events were required to have exactly one jet satisfying the above criteria with transverse momentum above the jet p_T threshold. Events containing a second jet with a good JVF and $p_T > 30$ GeV were rejected.

Applying these W (Z) selection criteria, 12112 (948) events and 12995 (1376) events were retained in the electron and muon channels respectively.

5. Background estimation

Two categories of background events were considered, originating from either QCD multijet or electroweak processes. The electroweak background contributions in both channels were estimated from the simulated event samples as a fraction f_{ewk} of the total multijet-subtracted event yield, which has the advantage that there is no reliance on the measured absolute luminosity, and reduces the systematic uncertainty from detector effects on the acceptance. The multijet contributions were estimated using template methods based on simulated electroweak and multijet-enriched data samples, and were also expressed as a fraction f_{multijet} of the total event yield. The background contributions were derived in the electron and muon channels for W and Z selections separately for each jet p_T threshold value. They were subtracted from the total event yield N_{tot} from Table 1 using,

$$N_{\text{sig}} = N_{\text{tot}} \cdot (1 - f_{\text{multijet}})(1 - f_{\text{ewk}}) \quad (1)$$

to obtain the signal event yield N_{sig} . The yields and breakdown of background predictions are shown in Table 1.

The background contribution from multijet processes in the electron channel originates from events with jets misidentified as electrons and the mismeasurement of calorimetric energy result-

Table 1

Predicted and observed event yields in data in the electron and muon channels for the W and Z selections for $\mathcal{L} = 33 \text{ pb}^{-1}$. Background estimates are quoted for a jet p_T threshold of 30 GeV. “Other” includes contributions from diboson and single top events. The total statistical uncertainties on predictions are quoted.

Process	$W \rightarrow e\nu$	$Z \rightarrow ee$
$W \rightarrow e\nu$	9340 ± 40	3 ± 1
$Z \rightarrow ee$	106 ± 3	880 ± 10
$W \rightarrow \tau\nu$	191 ± 6	0.2 ± 0.2
$t\bar{t}$	33 ± 1	1.9 ± 0.2
$Z \rightarrow \tau\tau$	19 ± 1	0.3 ± 0.1
Multijet	1800 ± 60	2.9 ± 0.6
Other	58 ± 2	1.1 ± 0.1
Total	11550 ± 70	880 ± 10
Data N_{tot}	12112	948

Process	$W \rightarrow \mu\nu$	$Z \rightarrow \mu\mu$
$W \rightarrow \mu\nu$	11860 ± 40	4 ± 2
$Z \rightarrow \mu\mu$	360 ± 6	1370 ± 40
$W \rightarrow \tau\nu$	234 ± 6	0.3 ± 0.6
$Z \rightarrow \tau\tau$	22 ± 1	0.3 ± 0.6
$t\bar{t}$	35 ± 1	3 ± 2
Multijet	380 ± 70	4 ± 4
Other	117 ± 1	8 ± 3
Total	13010 ± 80	1380 ± 40
Data N_{tot}	12995	1376

ing in large E_T^{miss} . This background contribution was estimated by using a partially data-driven method [25].

The multijet background within the $W \rightarrow e\nu$ sample selection was estimated by fitting templates to the low E_T^{miss} control region $15 < E_T^{\text{miss}} < 55$ GeV. The E_T^{miss} templates for signal and electroweak processes were derived from Monte Carlo simulations, while the template for the multijet contribution was extracted from data by inverting the “tight” electron identification criteria which are not correlated with the E_T^{miss} . The result of this fit was the relative contribution of the multijet background [25] to the data. This estimate was performed for each jet p_T threshold considered.

The multijet background in the $Z \rightarrow ee$ channel was estimated with a similar fit using the di-electron invariant mass distribution. Templates for signal and electroweak processes were derived from Monte Carlo simulated events, while the template describing the multijet contribution was obtained by inverting two of the “medium” selection criteria of the Z selection.

For the W selection in the electron channel, the electroweak contributions mainly originate from $W \rightarrow \tau\nu$ events where the τ decays to an electron, and $t\bar{t}$ where one or more W decay to an electron. For the Z selection, they similarly come from $t\bar{t}$ events, and from $Z \rightarrow \tau\tau$ where both τ leptons decay to electrons. Finally, W and Z production also constitute significant background to each other, due to events in which one electron from the Z was not reconstructed, or when a W event contains an additional electron candidate. The total electroweak background fraction in the electron channel was approximately 3.4% for the selected W candidates, and less than 1% for the Z candidates.

The multijet background to $W \rightarrow \mu\nu + \text{jet}$ events is estimated from the number of events passing all signal selections except isolation, and efficiencies derived from control samples in data for signal and multijet events required to pass the isolation requirement.

To estimate the multijet backgrounds for the Z in the muon channel, non-isolated muon pairs were selected in the simulated multijet sample. By comparing the dimuon invariant mass distribution for this sample and a non-isolated sample in data, a scale

factor was derived that was used to normalise a simulated background sample with the isolation requirement applied.

For the W selection in the muon channel, the electroweak backgrounds mainly originate from decays $W \rightarrow \tau\nu$ with the τ decaying to a muon and $Z \rightarrow \mu\mu$ where one muon fails to be reconstructed. The $Z \rightarrow \tau\tau$ and $t\bar{t}$ processes where one or both W boson(s) decay to a muon, contribute a smaller background fraction. For the Z selection in the muon channel, the dominant electroweak backgrounds arise from $Z \rightarrow \tau\tau$ and $t\bar{t}$ events with two real muons in the final state. The total electroweak background fraction in the muon channel was approximately 5% for the selected W candidates, and less than 1% for the Z candidates.

6. Correction to particle-level yield

The number of events after selection and background subtraction ($N_{\text{sig}}^{\ell,V}$) for each lepton ℓ and boson V was corrected for the detector effects and selection efficiencies back to the particle level ($N_{\text{part}}^{\ell,V}$). This corrected yield can be directly compared to theoretical predictions at the particle level. The corresponding correction factors from detector to particle level were computed for each jet p_T threshold in the electron and muon channels for the W and Z selections separately.

Yields were corrected with multiplicative factors which include trigger efficiency ($\epsilon_{\text{trig}}^{\ell}$), lepton identification efficiency (ϵ^{ℓ}), and boson reconstruction and resolution (C_V^{ℓ}). The number of signal events for each boson at particle level was then obtained using

$$N_{\text{part}}^{\ell,V} = \frac{N_{\text{sig}}^{\ell,V}}{\epsilon_{\text{trig}}^{\ell} \times \epsilon^{\ell} \times C_V^{\ell}}, \quad (2)$$

where the boson corrections C_V^{ℓ} correct the observed phase space to the fiducial phase space defined above, accounting for the resolution of leptons and E_T^{miss} .

Trigger and identification efficiencies were binned to account for variations in detector response. These efficiencies were binned in E_T and η for electrons and η and ϕ for muons. Efficiencies were found to be independent of the jet multiplicity and jet p_T . Therefore, a single efficiency map was used for all jet p_T thresholds.

The methods used to derive these efficiencies and corrections were similar for the electron and muon channels. The trigger efficiency and identification efficiency were measured using a sample of unbiased leptons obtained by selecting a well-identified tag lepton in $Z \rightarrow \ell\ell$ candidate events. The boson reconstruction correction C_V^{ℓ} was computed using the ALPGEN event generator. The PYTHIA Monte Carlo, used for comparison, was found to produce a consistent correction factor.

By measuring the ratio, almost complete cancellation of jet resolution effects was achieved. A small correction C_{jet}^{ℓ} was applied to the ratio to account for remaining non-cancelling effects due to lepton selection, jet selection criteria, and isolation criteria. The ratio measured was then the ratio of yields corrected to particle level and finally corrected for these remaining effects:

$$R_{\text{jet}} = \frac{N_{\text{part}}^{\ell,W}}{N_{\text{part}}^{\ell,Z}} \times C_{\text{jet}}^{\ell}. \quad (3)$$

The jet correction for the muon channel C_{jet}^{μ} is shown in Fig. 1. Systematic uncertainties from this correction were evaluated on the ratio itself. The jet correction C_{jet}^{μ} accounts for the difference of the ratio when calculated in terms of jets defined at particle level and reconstructed jets. The correction factor is different from unity if an offset exists between $W + \text{jet}$ and $Z + \text{jet}$ events in the jet p_T migration from particle level to detector level. This offset

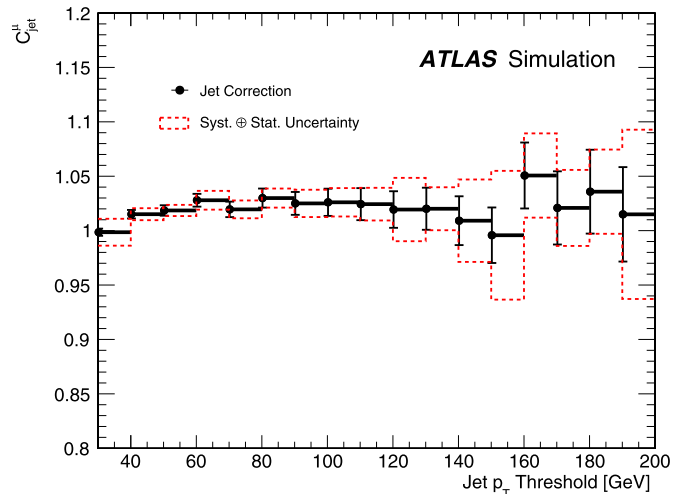


Fig. 1. Detector jet spectrum correction (C_{jet}^{μ}) on R_{jet} in the muon channel derived from ALPGEN. The uncertainty is shown as a dashed line, it accounts for the difference between PYTHIA and ALPGEN generators.

is due to the different requirements applied in the $W + \text{jet}$ and $Z + \text{jet}$ selections prior to the jet selections, placing the jets into slightly different phase space regions for the numerator and the denominator of the measurement. Performing the measurement as a function of p_T threshold instead of differentially removes the effects of migration across the upper bin edge.

7. Systematic uncertainties

To evaluate cancellations of systematic uncertainties which occur in the ratio, the correlations between W and Z systematic effects must be considered. Correlations between the measurements at each jet p_T threshold must also be accounted for. The effects of systematic uncertainties were therefore evaluated by measuring the relative change in the ratio R_{jet} from each source.

The total systematic uncertainty ranges from 4% at low jet p_T to 15% for the largest p_T threshold studied. For jet p_T thresholds of greater than 50 GeV the statistical uncertainty dominates the total measurement uncertainty.

The sources of systematic uncertainties on R_{jet} were grouped into uncertainties on the boson reconstruction (including lepton trigger, reconstruction and identification efficiencies, as well as lepton and E_T^{miss} scales and resolutions), on jet-related corrections, multijet and electroweak background predictions, and generator-related uncertainties.

In the muon channel, where the background was small, the uncertainty on R_{jet} from the background estimation was approximately 1% for the whole jet p_T range. In the electron channel, the uncertainty increases as a function of jet p_T threshold. This is due to the larger background in the electron channel and the limited statistics used to compute backgrounds for high jet p_T thresholds.

Systematic uncertainties on the multijet background fractions were estimated by varying the criteria used to derive the background fractions. Each systematic uncertainty includes a component from the statistical uncertainty on the estimate of the background fraction.

The estimate of the electroweak background is affected by systematic effects from the event selection criteria. Samples with and without multiple pp interactions included in the simulation were also compared.

The lepton trigger efficiency and identification uncertainties were estimated following the procedure documented in Ref. [25]. The uncertainty on the ratio from lepton identification efficiencies

was directly obtained by scaling the single lepton identification efficiencies by their uncertainties, taking cancellations into account. A contribution to the uncertainty on the identification efficiency was assigned from the difference between its value derived in data and Monte Carlo. The total identification uncertainty was 1.1% (1.7%) for electrons (muons) independent of jet p_T thresholds.

The uncertainties on the scale and resolution of lepton energies and E_T^{miss} were propagated to evaluate their effects on boson reconstruction by smearing the simulated signal samples using a Gaussian with a width corresponding to the nominal uncertainties. The resulting variations in R_{jet} were applied as systematic uncertainties.

Uncertainties on the jet energy scale (JES) and jet energy resolution (JER) were determined by comparing data and simulations [30]. The JES uncertainty includes components from calibration and jet sample composition differences. The JES calibration uncertainty varies with $|\eta|$ and p_T , and ranges from 4% to 8%. The JES and JER were measured with di-jet events, which have different proportions of quark and gluon initiated jets than events containing vector bosons. Therefore, an uncertainty was assigned to account for the difference in calorimeter response between jets in $V + \text{jet}$ events and the di-jet events used for calibration, ranging from 2 to 5%, and was added in quadrature to the JES calibration uncertainty. The total JES uncertainty ranges from approximately 10% at 20 GeV to 5% at 100 GeV.

To compute the effect of the JER uncertainty on the ratio R_{jet} , jets were smeared according to a Gaussian with a width corresponding to the JER. The effect of the JES uncertainty on the ratio was obtained in a similar manner, but in this case, shifting the jet energy by its uncertainty. The ratio was recomputed applying these variations simultaneously to the numerator and denominator. The change was applied as a systematic uncertainty. The uncertainties on R_{jet} due to the JER and JES were approximately 0.5% and 2% respectively. The contribution to the uncertainty on the ratio from the small component of heavy flavour jets is covered by the total JES uncertainty.

To account for systematics associated with the modelling of the signal at particle level, correction factors were re-computed with samples generated with PYTHIA instead of ALPGEN, and the observed variation was applied as a systematic uncertainty. Systematic uncertainties were assigned from this variation to the following corrections: (C_{jet}^ℓ), the boson reconstruction correction C_V^ℓ , and the electroweak background estimation f_{ewk} . At large jet p_T threshold, where the statistical uncertainty on the measurement dominates the total uncertainty, this systematic uncertainty is limited by the statistics of the samples used and is the dominant systematic uncertainty.

The uncertainties due to multiple pp interactions are dominated by uncertainties on the efficiency of the JVF algorithm. It was confirmed that the results obtained with simulated signal samples which include this effect were consistent with those obtained from samples which contained no additional interactions in the simulation. The residual difference on R_{jet} between samples with and without multiple interactions included was used as the systematic error from this JVF requirement.

Corrections to the simulation for hadronisation and the underlying event on the NLO parton-level calculation were computed with PYTHIA as a function of jet p_T threshold. The impact of this correction on R_{jet} was 1 to 6% for the electrons and 1 to 4% for the muons. The slightly larger variation for the electrons was due to the jet-electron isolation and the jet isolation veto included in the corrections.

The uncertainty on the correction of the MCFM cross-section ratio predictions for fragmentation, hadronisation and underlying event effects was estimated by comparing the PYTHIA AMBT1 [31]

Table 2

Summary of the systematic uncertainties on R_{jet} for the electron and muon channels. The value of each of the systematics for jet p_T thresholds of 30 and 100 GeV is shown. For the muon channel, the identification efficiency is included in the Boson reconstruction category.

Systematic uncertainties on R_{jet} (%)		
Electron channel	$p_T > 30$ GeV	$p_T > 100$ GeV
Trigger	0.5	0.5
Boson reconstruction	3.7	2.4
Identification efficiency	1.1	1.1
JVF	0.0	0.6
JES/JER	1.5	1.7
Multijet background	1.0	3.6
Electroweak background	1.3	1.2
Total non-generator	4.5	5.0
Generator	1.2	3.4
Total	4.6	6.1
Muon channel	$p_T > 30$ GeV	$p_T > 100$ GeV
Trigger	1.0	1.0
Boson reconstruction	2.5	2.4
JVF	1.7	0.2
JES/JER	2.0	1.9
Multijet background	0.4	0.1
Electroweak background	0.1	0.1
Total non-generator	3.8	3.2
Generator	1.4	2.7
Total	4.0	4.2

tune with the AMBT1 tune with increased underlying event activity, and without any underlying event. The uncertainty due to initial and final state radiation (ISR/FSR) was evaluated by varying the PYTHIA parameters controlling ISR and FSR [7]. For the ISR the variation ranges used were similar to the ranges used in the Perugia Soft and Perugia Hard tunes. For the FSR the variation ranges were similar to the ranges used in the Perugia 2011 radHi and Perugia 2011 radLo tunes [32].

Renormalisation and factorisation scale uncertainties were estimated by varying the scales in all combinations, up and down, by a factor of two. Although these variations are arbitrary, they are motivated by the dependence of the behaviour of the NLO $W + \text{jet}$ and $Z + \text{jet}$ cross-section on the scale. This choice has a minimal impact on the uncertainty of the R_{jet} prediction. Systematic uncertainties from imperfect knowledge of PDFs were computed by summing in quadrature the dependence on each of the 22 eigenvectors characterising the CTEQ6.6 PDF set; the uncertainty in α_s was also taken into account. An alternative PDF set, MSTW2008 [33], with its set of 68% C.L. eigenvectors was also examined, and the envelope of the uncertainties from CTEQ6.6 and MSTW2008 was used as the PDF uncertainty.

All systematic uncertainties were added in quadrature to obtain the total systematic uncertainty. A summary of sources of systematic uncertainties and their relative contributions to R_{jet} is shown in Fig. 2 and in Table 2.

8. Results

The ratio R_{jet} was measured in the fiducial region of the ATLAS detector defined by the jet p_T threshold and selection criteria. The present measurements were corrected back to the particle level and within the defined kinematic range. The electron and muon measurements were performed in slightly different phase space, due to the different η range and electron-jet isolation requirements, as well as for the different QED treatment between electron and muon definitions. The observed signal yields were corrected to recover the yield at particle level as described in Section 6.

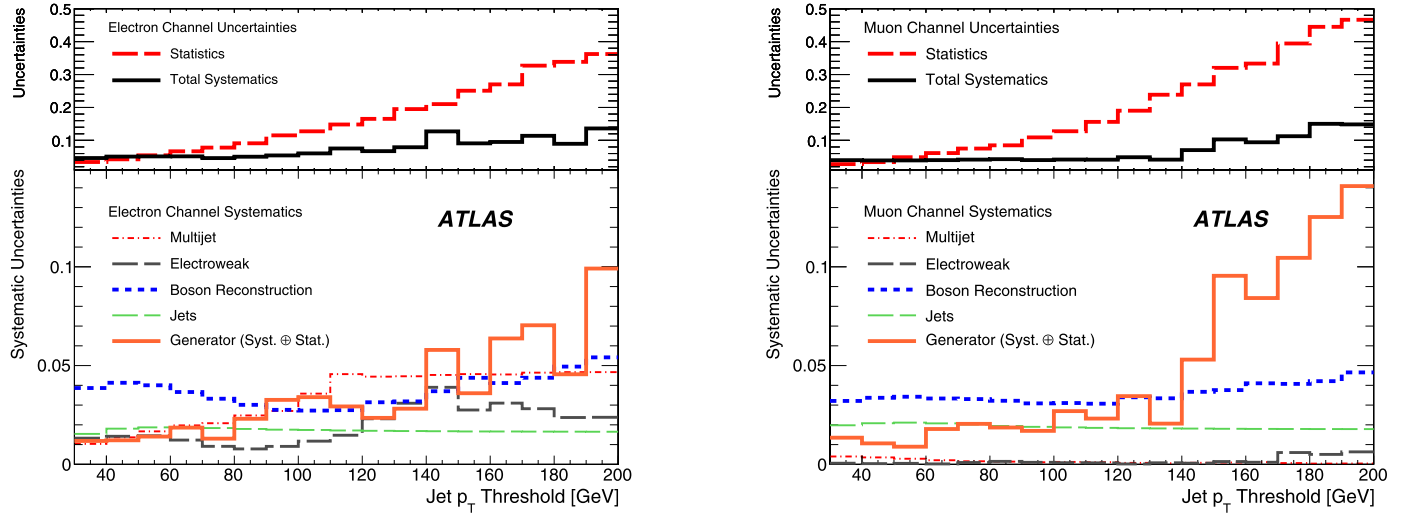


Fig. 2. Relative systematic uncertainties on R_{jet} in the electron channel (left) and in the muon channel (right). The top plot displays the total systematic and statistics uncertainty (shown as dashed line) versus jet p_T threshold. The lower plot shows the breakdown of the systematic uncertainties. Boson reconstruction contains the uncertainties related with the leptons and E_T^{miss} (including trigger and lepton identification). Jets contains systematics of the jet correction as well as the jet energy scale and resolution. Uncertainties from each group were added in quadrature.

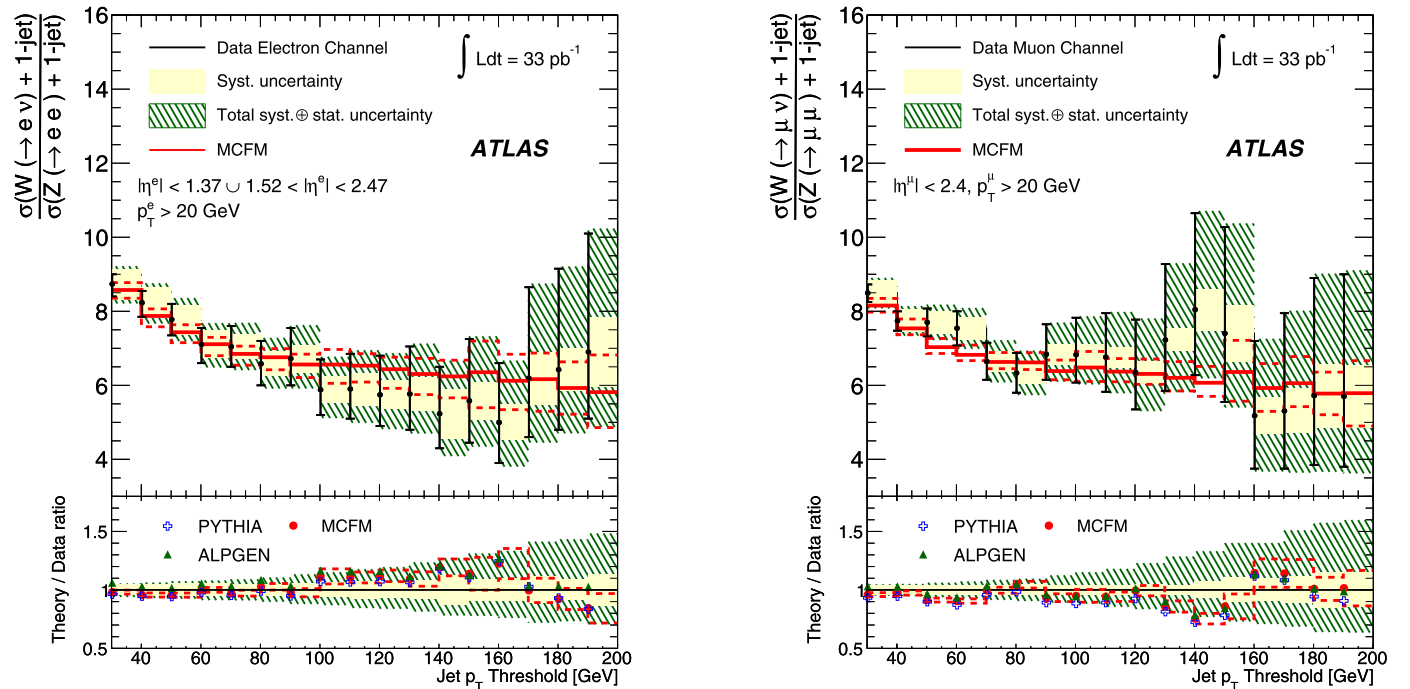


Fig. 3. Results for R_{jet} in the electron channel (left) and in the muon channel (right) for their respective fiducial regions. The results are compared to NLO predictions from MCFM (corrected to particle level using PYTHIA). Data are shown as black points at the lower bin edge corresponding to the jet p_T threshold with black error bars indicating the statistical uncertainties. The central band shows all systematic uncertainties added in quadrature and the larger hatched band shows statistical and systematic uncertainties added in quadrature. The theory uncertainty (dashed line) shown on the MCFM prediction includes uncertainties from PDF and renormalisation and factorisation scales. Note that these threshold data and their associated uncertainties are correlated between bins.

The corrected ratio R_{jet} of the production cross sections in the leptonic (electron or muon) decays of the gauge bosons W and Z in association with exactly one jet is shown in Fig. 3 as a function of the jet p_T threshold for the electron (left) and muon (right) channels. As the jet p_T threshold increases, the ratio R_{jet} is expected to decrease as the effective scale of the interaction becomes large compared to the difference in boson masses. This dependence is observed in the data. The values for the lowest jet p_T threshold of 30 GeV are:

$$R_{\text{jet}}(e) = 8.73 \pm 0.30(\text{stat}) \pm 0.40(\text{syst}),$$

$$R_{\text{jet}}(\mu) = 8.49 \pm 0.23(\text{stat}) \pm 0.33(\text{syst}).$$

The statistical uncertainties were evaluated by repeating the measurement with Monte Carlo pseudo-experiments assuming Poisson distributed data with a mean at the observed yield. Both electron and muon channel results are individually compatible with the theoretical predictions.

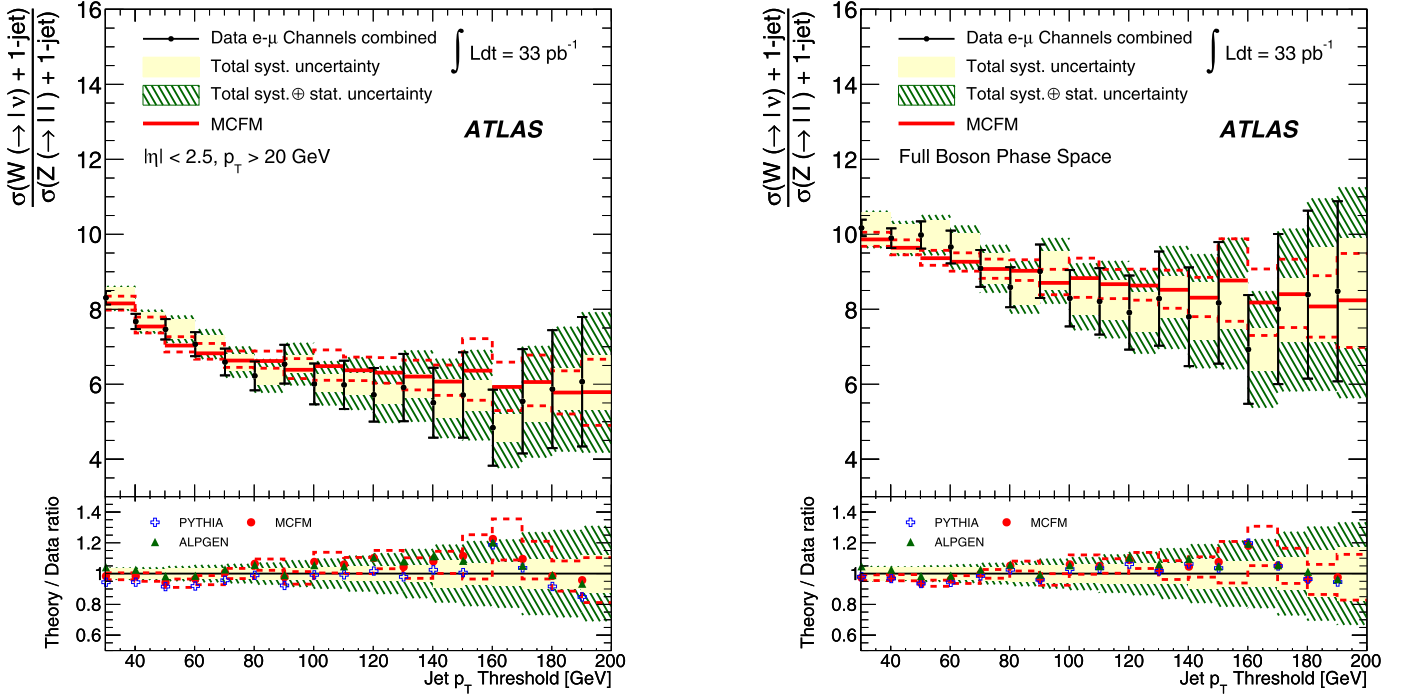


Fig. 4. Left: Combined electron and muon results for R_{jet} in a common fiducial region. The results are compared to predictions from MCFM (corrected to particle level). Data are shown with black error bars indicating the statistical uncertainties. The central band shows all systematic uncertainties added in quadrature and the larger hatched band shows statistical and systematic uncertainties added in quadrature. The theory uncertainty (dashed line) includes contributions from PDF and renormalisation and factorisation scales. Right: Combined electron and muon results for R_{jet} extrapolated to the total phase space. Note that these threshold data and their associated uncertainties are correlated between bins.

Table 3

Measured R_{jet} in the electron, muon and combined channels. The extrapolation to a common fiducial region for the combination decreases the value of the ratio for both channels. Values are reported with statistical and systematic uncertainties, respectively.

Jet p_T threshold (GeV)	Electron fiducial $ \eta^e < 2.47$ (excl. $1.37 < \eta < 1.52$)	Muon fiducial $ \eta^\mu < 2.4$	Combined $ \eta^l < 2.5$	Boson full phase space
30	$8.73 \pm 0.3 \pm 0.40$	$8.49 \pm 0.23 \pm 0.33$	$8.29 \pm 0.18 \pm 0.28$	$10.13 \pm 0.22 \pm 0.45$
40	$8.23 \pm 0.35 \pm 0.41$	$7.74 \pm 0.26 \pm 0.30$	$7.67 \pm 0.20 \pm 0.24$	$9.89 \pm 0.26 \pm 0.38$
50	$7.77 \pm 0.42 \pm 0.39$	$7.7 \pm 0.37 \pm 0.30$	$7.46 \pm 0.27 \pm 0.25$	$9.97 \pm 0.36 \pm 0.39$
60	$7.10 \pm 0.47 \pm 0.36$	$7.54 \pm 0.46 \pm 0.30$	$7.07 \pm 0.32 \pm 0.24$	$9.64 \pm 0.43 \pm 0.39$
70	$7.04 \pm 0.55 \pm 0.32$	$6.64 \pm 0.49 \pm 0.27$	$6.59 \pm 0.35 \pm 0.22$	$9.07 \pm 0.49 \pm 0.41$
80	$6.58 \pm 0.6 \pm 0.33$	$6.33 \pm 0.53 \pm 0.27$	$6.22 \pm 0.38 \pm 0.23$	$8.58 \pm 0.53 \pm 0.46$
90	$6.72 \pm 0.77 \pm 0.36$	$6.83 \pm 0.74 \pm 0.27$	$6.53 \pm 0.51 \pm 0.23$	$9.02 \pm 0.71 \pm 0.51$
100	$5.88 \pm 0.75 \pm 0.35$	$6.82 \pm 0.87 \pm 0.28$	$6.02 \pm 0.54 \pm 0.23$	$8.33 \pm 0.75 \pm 0.48$
110	$5.90 \pm 0.87 \pm 0.44$	$6.76 \pm 1.05 \pm 0.28$	$6.01 \pm 0.64 \pm 0.28$	$8.25 \pm 0.88 \pm 0.53$
120	$5.74 \pm 0.95 \pm 0.38$	$6.34 \pm 1.20 \pm 0.31$	$5.72 \pm 0.71 \pm 0.26$	$7.93 \pm 0.98 \pm 0.52$
130	$5.76 \pm 1.12 \pm 0.45$	$7.22 \pm 1.72 \pm 0.30$	$5.95 \pm 0.89 \pm 0.31$	$8.31 \pm 1.25 \pm 0.55$
140	$5.23 \pm 1.1 \pm 0.66$	$8.04 \pm 2.17 \pm 0.56$	$5.62 \pm 0.93 \pm 0.50$	$7.94 \pm 1.31 \pm 0.76$
150	$5.58 \pm 1.4 \pm 0.50$	$7.40 \pm 2.37 \pm 0.76$	$5.70 \pm 1.13 \pm 0.40$	$8.15 \pm 1.62 \pm 0.67$
160	$4.99 \pm 1.35 \pm 0.47$	$5.17 \pm 1.72 \pm 0.48$	$4.83 \pm 1.01 \pm 0.36$	$6.92 \pm 1.44 \pm 0.56$
170	$6.19 \pm 2.02 \pm 0.70$	$5.30 \pm 2.09 \pm 0.59$	$5.53 \pm 1.39 \pm 0.53$	$7.97 \pm 2.00 \pm 0.84$
180	$6.42 \pm 2.17 \pm 0.57$	$5.72 \pm 2.54 \pm 0.86$	$5.86 \pm 1.57 \pm 0.55$	$8.38 \pm 2.24 \pm 1.25$
190	$6.9 \pm 2.5 \pm 0.94$	$5.70 \pm 2.65 \pm 0.84$	$6.04 \pm 1.72 \pm 0.72$	$8.43 \pm 2.40 \pm 1.46$

Electron and muon channel results were compatible and were therefore combined to reduce the statistical and uncorrelated systematic uncertainties on the result. Each channel was extrapolated to a common phase space, defined as $|\eta_l| < 2.5$ before any QED radiation (Born level) with PYTHIA. The electron channel was further corrected for the effect on the acceptance of the electron-jet isolation requirements. This extrapolation to a common fiducial region decreases the value of the ratio for both channels primarily due to the more central distribution of leptons from the Z. The results were combined using a Bayesian approach [34] in the combination of systematic uncertainties accounting for correlations between them. The systematic uncertainties from E_T^{miss} , jet

energy scale and resolution and electroweak background sources were considered fully correlated between the electron and muon channels. The combined result is shown in Fig. 4 (left). The value of R_{jet} for the lowest jet p_T threshold of 30 GeV is found to be $8.29 \pm 0.18(\text{stat}) \pm 0.28(\text{syst})$.

The combined results were also extrapolated to the full phase space, correcting for regions of geometric and kinematic acceptance not measured (only the requirement on the invariant mass of the Z and veto on additional jets were retained), and presented as a function of jet p_T threshold. For this extrapolation, the W and Z acceptance factors were calculated at particle level using ALPGEN, and their ratio was applied as a correction to R_{jet} . This

extrapolation to the full phase space increases the value of the ratio for both channels primarily due to additional kinematic acceptance for the W . Fig. 4 (right) shows the result in the full boson acceptance phase space for the combined electron and muon channels. Due to the additional uncertainty on the correction to the generator-level acceptance, this result has larger total uncertainty than the results obtained in the fiducial regions. No significant discrepancy between data and theory is observed in any of these results.

9. Conclusions

This Letter presents a first measurement of the ratio of the production cross sections of the gauge bosons W and Z in association with exactly one jet. Results are presented as a function of jet p_T threshold, in both the electron and muon decay modes of the W and Z vector bosons. The measurement was corrected for all detector effects back to the particle level and presented within a fiducial phase space for electrons and muons. The ratio was measured to be $8.73 \pm 0.30(\text{stat}) \pm 0.40(\text{syst})$ in the electron channel, and $8.49 \pm 0.23(\text{stat}) \pm 0.33(\text{syst})$ in the muon channel at a jet p_T threshold of 30 GeV (Table 3). Results have also been extrapolated to $|\eta| < 2.5$ and combined, yielding $8.29 \pm 0.18(\text{stat}) \pm 0.28(\text{syst})$, and extrapolated to the full phase of the boson and combined giving $10.13 \pm 0.22(\text{stat}) \pm 0.45(\text{syst})$. The design of the measurement allows a cancellation of many theoretical and systematic uncertainties. These results are provided as a function of jet p_T threshold from 30 to 200 GeV, exploring the transition region of electroweak scale breaking in the perturbative jet production. This measurement builds the foundations of a high precision test of the Standard Model, and provides model-independent sensitivity to new physics coupling to leptons and jets. Comparisons with LO and NLO perturbative QCD predictions were made and found to be in agreement with data over the jet p_T threshold range covered by this measurement.

Acknowledgements

We wish to thank CERN for the efficient commissioning and operation of the LHC during this initial high-energy data-taking period as well as the support staff from our institutions without whom ATLAS could not be operated efficiently.

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF, DNSRC and Lundbeck Foundation, Denmark; ARTEMIS, European Union; IN2P3-CNRS, CEA-DSM/IRFU, France; GNAS, Georgia; BMBF, DFG, HGF, MPG and AvH Foundation, Germany; GSRT, Greece; ISF, MINERVA, GIF, DIP and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; RCN, Norway; MNiSW, Poland; GRICES and FCT, Portugal; MERYS (MECTS), Romania; MES of Russia and ROSATOM, Russian Federation; JINR; MSTB, Serbia; MSSR, Slovakia; ARRS and MVZT, Slovenia; DST/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SER, SNSF and Cantons of Bern and Geneva, Switzerland; NSC, Taiwan; TAEK, Turkey; STFC, the Royal Soci-

ety and Leverhulme Trust, United Kingdom; DOE and NSF, United States of America.

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

Open access

This article is published Open Access at sciencedirect.com. It is distributed under the terms of the Creative Commons Attribution License 3.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original authors and source are credited.

References

- [1] CDF Collaboration, Phys. Rev. D 77 (2008) 011108.
- [2] CDF Collaboration, Phys. Rev. Lett. 100 (2008) 102001.
- [3] D0 Collaboration, Phys. Lett. B 678 (2009) 45.
- [4] ATLAS Collaboration, Phys. Lett. B 698 (2011) 325.
- [5] E. Abouzaid, H. Frisch, Phys. Rev. D 68 (2003) 033014.
- [6] M. Cacciari, G.P. Salam, G. Soyez, J. High Energy Phys. 0804 (2008) 063.
- [7] T. Sjöstrand, S. Mrenna, P. Skands, J. High Energy Phys. 0605 (2006) 026.
- [8] M.L. Mangano, et al., J. High Energy Phys. 0307 (2003) 001.
- [9] J.M. Campbell, R.K. Ellis, D.L. Rainwater, Phys. Rev. D 68 (2003) 094021.
- [10] ATLAS Collaboration, J. Instrum. 3 (2008) S08003.
- [11] ATLAS Collaboration, Expected performance of the ATLAS experiment – detector, trigger and physics, CERN-OPEN-2008-020, 2009.
- [12] J. Alwall, et al., Eur. Phys. J. C 53 (2008) 473.
- [13] G. Corcella, et al., J. High Energy Phys. 0101 (2001) 010.
- [14] J.M. Butterworth, J.R. Forshaw, M.H. Seymour, Z. Phys. C 72 (1996) 637.
- [15] J. Pumplin, et al., J. High Energy Phys. 0207 (2002) 012.
- [16] A. Sherstnev, R.S. Thorne, Eur. Phys. J. C 55 (2008) 553.
- [17] ATLAS Collaboration, ATLAS Monte Carlo tunes for MC09, ATLAS-PHYS-PUB-2010-002, 2010.
- [18] S. Frixione, P. Nason, C. Oleari, J. High Energy Phys. 0711 (2007) 070.
- [19] P.M. Nadolsky, et al., Phys. Rev. D 78 (2008) 013004.
- [20] P. Golonka, Z. Was, Eur. Phys. J. C 45 (2006) 97.
- [21] N. Davidson, et al., Universal interface of TAUOLA, technical and physics documentation, IFJAN-IV-2009-10, 2010.
- [22] ATLAS Collaboration, Performance of primary vertex reconstruction in proton–proton collisions at $\sqrt{s} = 7$ TeV in the ATLAS experiment, ATLAS-CONF-2010-069, 2010.
- [23] ATLAS Collaboration, Eur. Phys. J. C 70 (2010) 823.
- [24] S. Agostinelli, et al., Nucl. Instrum. Methods Phys. Res., Sect. A 506 (2003) 250.
- [25] ATLAS Collaboration, J. High Energy Phys. 1012 (2010) 060.
- [26] W. Lampl, et al., Calorimeter clustering algorithms: description and performance, ATL-LARG-PUB-2008-002, 2008.
- [27] T. Barillari, et al., Local hadron calibration, ATL-LARG-PUB-2009-001, 2009.
- [28] ATLAS Collaboration, Jet energy resolution and selection efficiency relative to track jets from in-situ techniques with the ATLAS detector using proton–proton collisions at a center of mass energy of $\sqrt{s} = 7$ TeV, ATLAS-CONF-2010-054, 2010.
- [29] ATLAS Collaboration, Data-quality requirements and event cleaning for jets and missing transverse energy reconstruction with the ATLAS detector in proton–proton collisions at a center-of-mass energy of $\sqrt{s} = 7$ TeV, ATLAS-CONF-2010-038, 2010.
- [30] ATLAS Collaboration, Eur. Phys. J. C 71 (2011) 1512.
- [31] ATLAS Collaboration, Charged particle multiplicities in pp interactions at $\sqrt{s} = 0.9$ and 7 TeV in a diffractive limited phase space measured with the ATLAS detector at the LHC and a new PYTHIA6 tune, ATLAS-CONF-2010-031, 2010.
- [32] P.Z. Skands, Phys. Rev. D 82 (2010) 074018.
- [33] A.D. Martin, W.J. Stirling, R.S. Thorne, G. Watt, Eur. Phys. J. C 63 (2009) 189.
- [34] A.C. Caldwell, D. Kollar, K. Kroninger, J. Phys. Conf. Ser. 219 (2010) 032013.

ATLAS Collaboration

G. Aad⁴⁸, B. Abbott¹¹¹, J. Abdallah¹¹, A.A. Abdelalim⁴⁹, A. Abdesselam¹¹⁸, O. Abidinov¹⁰, B. Abi¹¹², M. Abolins⁸⁸, H. Abramowicz¹⁵³, H. Abreu¹¹⁵, E. Acerbi^{89a,89b}, B.S. Acharya^{164a,164b}, D.L. Adams²⁴, T.N. Addy⁵⁶, J. Adelman¹⁷⁵, M. Aderholz⁹⁹, S. Adomeit⁹⁸, P. Adragna⁷⁵, T. Adye¹²⁹, S. Aefsky²²,

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

L. Bugge¹¹⁷, D. Buirra-Clark¹¹⁸, O. Bulekov⁹⁶, M. Bunse⁴², T. Buran¹¹⁷, H. Burckhart²⁹, S. Burdin⁷³,
 T. Burgess¹³, S. Burke¹²⁹, E. Busato³³, P. Bussey⁵³, C.P. Buszello¹⁶⁶, F. Butin²⁹, B. Butler¹⁴³,
 J.M. Butler²¹, C.M. Buttar⁵³, J.M. Butterworth⁷⁷, W. Buttinger²⁷, T. Byatt⁷⁷, S. Cabrera Urbán¹⁶⁷,
 D. Caforio^{19a,19b}, O. Cakir^{3a}, P. Calafiura¹⁴, G. Calderini⁷⁸, P. Calfayan⁹⁸, R. Calkins¹⁰⁶, L.P. Caloba^{23a},
 R. Caloi^{132a,132b}, D. Calvet³³, S. Calvet³³, R. Camacho Toro³³, P. Camarri^{133a,133b}, M. Cambiaghi^{119a,119b},
 D. Cameron¹¹⁷, S. Campana²⁹, M. Campanelli⁷⁷, V. Canale^{102a,102b}, F. Canelli^{30,h}, A. Canepa^{159a},
 J. Cantero⁸⁰, L. Capasso^{102a,102b}, M.D.M. Capeans Garrido²⁹, I. Caprini^{25a}, M. Caprini^{25a}, D. Capriotti⁹⁹,
 M. Capua^{36a,36b}, R. Caputo¹⁴⁸, R. Cardarelli^{133a}, T. Carli²⁹, G. Carlino^{102a}, L. Carminati^{89a,89b},
 B. Caron^{159a}, S. Caron⁴⁸, G.D. Carrillo Montoya¹⁷², A.A. Carter⁷⁵, J.R. Carter²⁷, J. Carvalho^{124a,i},
 D. Casadei¹⁰⁸, M.P. Casado¹¹, M. Cascella^{122a,122b}, C. Caso^{50a,50b,*}, A.M. Castaneda Hernandez¹⁷²,
 E. Castaneda-Miranda¹⁷², V. Castillo Gimenez¹⁶⁷, N.F. Castro^{124a}, G. Cataldi^{72a}, F. Cataneo²⁹,
 A. Catinaccio²⁹, J.R. Catmore⁷¹, A. Cattai²⁹, G. Cattani^{133a,133b}, S. Caughron⁸⁸, D. Cauz^{164a,164c},
 P. Cavalleri⁷⁸, D. Cavalli^{89a}, M. Cavalli-Sforza¹¹, V. Cavasinni^{122a,122b}, F. Ceradini^{134a,134b},
 A.S. Cerqueira^{23a}, A. Cerri²⁹, L. Cerrito⁷⁵, F. Cerutti⁴⁷, S.A. Cetin^{18b}, F. Cevenini^{102a,102b}, A. Chafaq^{135a},
 D. Chakraborty¹⁰⁶, K. Chan², B. Chapleau⁸⁵, J.D. Chapman²⁷, J.W. Chapman⁸⁷, E. Chareyre⁷⁸,
 D.G. Charlton¹⁷, V. Chavda⁸², C.A. Chavez Barajas²⁹, S. Cheatham⁸⁵, S. Chekanov⁵, S.V. Chekulaev^{159a},
 G.A. Chelkov⁶⁵, M.A. Chelstowska¹⁰⁴, C. Chen⁶⁴, H. Chen²⁴, S. Chen^{32c}, T. Chen^{32c}, X. Chen¹⁷²,
 S. Cheng^{32a}, A. Cheplakov⁶⁵, V.F. Chepurinov⁶⁵, R. Cherkaoui El Moursli^{135e}, V. Chernyatin²⁴,
 E. Cheu⁶, S.L. Cheung¹⁵⁸, L. Chevalier¹³⁶, G. Chiefari^{102a,102b}, L. Chikovani⁵¹, J.T. Childers^{58a},
 A. Chilingarov⁷¹, G. Chiodini^{72a}, M.V. Chizhov⁶⁵, G. Choudalakis³⁰, S. Chouridou¹³⁷, I.A. Christidi⁷⁷,
 A. Christov⁴⁸, D. Chromek-Burckhart²⁹, M.L. Chu¹⁵¹, J. Chudoba¹²⁵, G. Ciapetti^{132a,132b}, K. Ciba³⁷,
 A.K. Ciftci^{3a}, R. Ciftci^{3a}, D. Cinca³³, V. Cindro⁷⁴, M.D. Ciobotaru¹⁶³, C. Ciocca^{19a,19b}, A. Ciocio¹⁴,
 M. Cirilli⁸⁷, M. Ciubancan^{25a}, A. Clark⁴⁹, P.J. Clark⁴⁵, W. Cleland¹²³, J.C. Clemens⁸³, B. Clement⁵⁵,
 C. Clement^{146a,146b}, R.W. Clift¹²⁹, Y. Coadou⁸³, M. Cobal^{164a,164c}, A. Coccaro^{50a,50b}, J. Cochran⁶⁴,
 P. Coe¹¹⁸, J.G. Cogan¹⁴³, J. Coggeshall¹⁶⁵, E. Cogneras¹⁷⁷, C.D. Cojocaru²⁸, J. Colas⁴, A.P. Colijn¹⁰⁵,
 C. Collard¹¹⁵, N.J. Collins¹⁷, C. Collins-Tooth⁵³, J. Collot⁵⁵, G. Colon⁸⁴, P. Conde Muiño^{124a},
 E. Coniavitis¹¹⁸, M.C. Conidi¹¹, M. Consonni¹⁰⁴, V. Consorti⁴⁸, S. Constantinescu^{25a}, C. Conta^{119a,119b},
 F. Conventi^{102a,j}, J. Cook²⁹, M. Cooke¹⁴, B.D. Cooper⁷⁷, A.M. Cooper-Sarkar¹¹⁸, N.J. Cooper-Smith⁷⁶,
 K. Copic³⁴, T. Cornelissen^{50a,50b}, M. Corradi^{19a}, F. Corriveau^{85,k}, A. Cortes-Gonzalez¹⁶⁵, G. Cortiana⁹⁹,
 G. Costa^{89a}, M.J. Costa¹⁶⁷, D. Costanzo¹³⁹, T. Costin³⁰, D. Côté²⁹, L. Courneyea¹⁶⁹, G. Cowan⁷⁶,
 C. Cowden²⁷, B.E. Cox⁸², K. Cranmer¹⁰⁸, F. Crescioli^{122a,122b}, M. Cristinziani²⁰, G. Crosetti^{36a,36b},
 R. Crupi^{72a,72b}, S. Crépé-Renaudin⁵⁵, C.-M. Cuciuc^{25a}, C. Cuenca Almenar¹⁷⁵,
 T. Cuhadar Donszelmann¹³⁹, M. Curatolo⁴⁷, C.J. Curtis¹⁷, P. Cwetanski⁶¹, H. Czirr¹⁴¹, Z. Czyczula¹¹⁷,
 S. D'Auria⁵³, M. D'Onofrio⁷³, A. D'Orazio^{132a,132b}, P.V.M. Da Silva^{23a}, C. Da Via⁸², W. Dabrowski³⁷,
 T. Dai⁸⁷, C. Dallapiccola⁸⁴, M. Dam³⁵, M. Dameri^{50a,50b}, D.S. Damiani¹³⁷, H.O. Danielsson²⁹,
 D. Dannheim⁹⁹, V. Dao⁴⁹, G. Darbo^{50a}, G.L. Darlea^{25b}, C. Daum¹⁰⁵, J.P. Dauvergne²⁹, W. Davey⁸⁶,
 T. Davidek¹²⁶, N. Davidson⁸⁶, R. Davidson⁷¹, E. Davies^{118,c}, M. Davies⁹³, A.R. Davison⁷⁷,
 Y. Davygora^{58a}, E. Dawe¹⁴², I. Dawson¹³⁹, J.W. Dawson^{5,*}, R.K. Daya³⁹, K. De⁷, R. de Asmundis^{102a},
 S. De Castro^{19a,19b}, P.E. De Castro Faria Salgado²⁴, S. De Cecco⁷⁸, J. de Graat⁹⁸, N. De Groot¹⁰⁴,
 P. de Jong¹⁰⁵, C. De La Taille¹¹⁵, H. De la Torre⁸⁰, B. De Lotto^{164a,164c}, L. De Mora⁷¹, L. De Nooij¹⁰⁵,
 D. De Pedis^{132a}, A. De Salvo^{132a}, U. De Sanctis^{164a,164c}, A. De Santo¹⁴⁹, J.B. De Vivie De Regie¹¹⁵,
 S. Dean⁷⁷, R. Debbe²⁴, D.V. Dedovich⁶⁵, J. Degenhardt¹²⁰, M. Dehchar¹¹⁸, C. Del Papa^{164a,164c},
 J. Del Peso⁸⁰, T. Del Prete^{122a,122b}, M. Deliyergiyev⁷⁴, A. Dell'Acqua²⁹, L. Dell'Asta^{89a,89b},
 M. Della Pietra^{102a,j}, D. della Volpe^{102a,102b}, M. Delmastro²⁹, P. Delpierre⁸³, N. Delruelle²⁹,
 P.A. Delsart⁵⁵, C. Deluca¹⁴⁸, S. Demers¹⁷⁵, M. Demichev⁶⁵, B. Demirkoz^{11,l}, J. Deng¹⁶³, S.P. Denisov¹²⁸,
 D. Derendarz³⁸, J.E. Derkaoui^{135d}, F. Derue⁷⁸, P. Dervan⁷³, K. Desch²⁰, E. Devetak¹⁴⁸, P.O. Deviveiros¹⁵⁸,
 A. Dewhurst¹²⁹, B. DeWilde¹⁴⁸, S. Dhaliwal¹⁵⁸, R. Dhullipudi^{24,m}, A. Di Ciaccio^{133a,133b}, L. Di Ciaccio⁴,
 A. Di Girolamo²⁹, B. Di Girolamo²⁹, S. Di Luise^{134a,134b}, A. Di Mattia⁸⁸, B. Di Micco²⁹,
 R. Di Nardo^{133a,133b}, A. Di Simone^{133a,133b}, R. Di Sipio^{19a,19b}, M.A. Diaz^{31a}, F. Diblen^{18c}, E.B. Diehl⁸⁷,
 J. Dietrich⁴¹, T.A. Dietzsch^{58a}, S. Diglio¹¹⁵, K. Dindar Yagci³⁹, J. Dingfelder²⁰, C. Dionisi^{132a,132b},
 P. Dita^{25a}, S. Dita^{25a}, F. Dittus²⁹, F. Djama⁸³, T. Djobava⁵¹, M.A.B. do Vale^{23a}, A. Do Valle Wemans^{124a},
 T.K.O. Doan⁴, M. Dobbs⁸⁵, R. Dobinson^{29,*}, D. Dobos⁴², E. Dobson²⁹, M. Dobson¹⁶³, J. Dodd³⁴,

C. Doglioni¹¹⁸, T. Doherty⁵³, Y. Doi^{66,*}, J. Dolejsi¹²⁶, I. Dolenc⁷⁴, Z. Dolezal¹²⁶, B.A. Dolgoshein^{96,*}, T. Dohmae¹⁵⁵, M. Donadelli^{23d}, M. Donega¹²⁰, J. Donini⁵⁵, J. Dopke²⁹, A. Doria^{102a}, A. Dos Anjos¹⁷², M. Dosil¹¹, A. Dotti^{122a,122b}, M.T. Dova⁷⁰, J.D. Dowell¹⁷, A.D. Doxiadis¹⁰⁵, A.T. Doyle⁵³, Z. Drasal¹²⁶, J. Drees¹⁷⁴, N. Dressnandt¹²⁰, H. Drevermann²⁹, C. Driouchi³⁵, M. Dris⁹, J. Dubbert⁹⁹, T. Dubbs¹³⁷, S. Dube¹⁴, E. Duchovni¹⁷¹, G. Duckeck⁹⁸, A. Dudarev²⁹, F. Dudziak⁶⁴, M. Dührssen²⁹, I.P. Duerdoth⁸², L. Duflost¹¹⁵, M.-A. Dufour⁸⁵, M. Dunford²⁹, H. Duran Yildiz^{3b}, R. Duxfield¹³⁹, M. Dwuznik³⁷, F. Dydak²⁹, M. Düren⁵², W.L. Ebenstein⁴⁴, J. Ebke⁹⁸, S. Eckert⁴⁸, S. Eckweiler⁸¹, K. Edmonds⁸¹, C.A. Edwards⁷⁶, N.C. Edwards⁵³, W. Ehrenfeld⁴¹, T. Ehrich⁹⁹, T. Eifert²⁹, G. Eigen¹³, K. Einsweiler¹⁴, E. Eisenhandler⁷⁵, T. Ekelof¹⁶⁶, M. El Kacimi^{135c}, M. Ellert¹⁶⁶, S. Elles⁴, F. Ellinghaus⁸¹, K. Ellis⁷⁵, N. Ellis²⁹, J. Elmsheuser⁹⁸, M. Elsing²⁹, D. Emeliyanov¹²⁹, R. Engelmann¹⁴⁸, A. Engl⁹⁸, B. Epp⁶², A. Eppig⁸⁷, J. Erdmann⁵⁴, A. Ereditato¹⁶, D. Eriksson^{146a}, J. Ernst¹, M. Ernst²⁴, J. Ernwein¹³⁶, D. Errede¹⁶⁵, S. Errede¹⁶⁵, E. Ertel⁸¹, M. Escalier¹¹⁵, C. Escobar¹²³, X. Espinal Curull¹¹, B. Esposito⁴⁷, F. Etienne⁸³, A.I. Etienvre¹³⁶, E. Etzion¹⁵³, D. Evangelakou⁵⁴, H. Evans⁶¹, L. Fabbri^{19a,19b}, C. Fabre²⁹, R.M. Fakhruddinov¹²⁸, S. Falciano^{132a}, Y. Fang¹⁷², M. Fanti^{89a,89b}, A. Farbin⁷, A. Farilla^{134a}, J. Farley¹⁴⁸, T. Farooque¹⁵⁸, S.M. Farrington¹¹⁸, P. Farthouat²⁹, P. Fassnacht²⁹, D. Fassouliotis⁸, B. Fatholahzadeh¹⁵⁸, A. Favareto^{89a,89b}, L. Fayard¹¹⁵, S. Fazio^{36a,36b}, R. Febbraro³³, P. Federic^{144a}, O.L. Fedin¹²¹, W. Fedorko⁸⁸, M. Fehling-Kaschek⁴⁸, L. Feligioni⁸³, D. Fellmann⁵, C.U. Felzmann⁸⁶, C. Feng^{32d}, E.J. Feng³⁰, A.B. Fenyuk¹²⁸, J. Ferencei^{144b}, J. Ferland⁹³, W. Fernando¹⁰⁹, S. Ferrag⁵³, J. Ferrando⁵³, V. Ferrara⁴¹, A. Ferrari¹⁶⁶, P. Ferrari¹⁰⁵, R. Ferrari^{119a}, A. Ferrer¹⁶⁷, M.L. Ferrer⁴⁷, D. Ferrere⁴⁹, C. Ferretti⁸⁷, A. Ferretto Parodi^{50a,50b}, M. Fiascaris³⁰, F. Fiedler⁸¹, A. Filipčič⁷⁴, A. Filippas⁹, F. Filthaut¹⁰⁴, M. Fincke-Keeler¹⁶⁹, M.C.N. Fiolhais^{124a,i}, L. Fiorini¹⁶⁷, A. Firan³⁹, G. Fischer⁴¹, P. Fischer²⁰, M.J. Fisher¹⁰⁹, S.M. Fisher¹²⁹, M. Flechl⁴⁸, I. Fleck¹⁴¹, J. Fleckner⁸¹, P. Fleischmann¹⁷³, S. Fleischmann¹⁷⁴, T. Flick¹⁷⁴, L.R. Flores Castillo¹⁷², M.J. Flowerdew⁹⁹, M. Fokitis⁹, T. Fonseca Martin¹⁶, D.A. Forbush¹³⁸, A. Formica¹³⁶, A. Forti⁸², D. Fortin^{159a}, J.M. Foster⁸², D. Fournier¹¹⁵, A. Foussat²⁹, A.J. Fowler⁴⁴, K. Fowler¹³⁷, H. Fox⁷¹, P. Francavilla^{122a,122b}, S. Franchino^{119a,119b}, D. Francis²⁹, T. Frank¹⁷¹, M. Franklin⁵⁷, S. Franz²⁹, M. Fraternali^{119a,119b}, S. Fratina¹²⁰, S.T. French²⁷, F. Friedrich⁴³, R. Froeschl²⁹, D. Froidevaux²⁹, J.A. Frost²⁷, C. Fukunaga¹⁵⁶, E. Fullana Torregrosa²⁹, J. Fuster¹⁶⁷, C. Gabaldon²⁹, O. Gabizon¹⁷¹, T. Gadfort²⁴, S. Gadomski⁴⁹, G. Gagliardi^{50a,50b}, P. Gagnon⁶¹, C. Galea⁹⁸, E.J. Gallas¹¹⁸, M.V. Gallas²⁹, V. Gallo¹⁶, B.J. Gallop¹²⁹, P. Gallus¹²⁵, E. Galyaev⁴⁰, K.K. Gan¹⁰⁹, Y.S. Gao^{143.f}, V.A. Gapienko¹²⁸, A. Gaponenko¹⁴, F. Garbersen¹⁷⁵, M. Garcia-Sciveres¹⁴, C. García¹⁶⁷, J.E. García Navarro⁴⁹, R.W. Gardner³⁰, N. Garelli²⁹, H. Garitaonandia¹⁰⁵, V. Garonne²⁹, J. Garvey¹⁷, C. Gatti⁴⁷, G. Gaudio^{119a}, O. Gaumer⁴⁹, B. Gaur¹⁴¹, L. Gauthier¹³⁶, I.L. Gavrilenko⁹⁴, C. Gay¹⁶⁸, G. Gaycken²⁰, J.-C. Gayde²⁹, E.N. Gazis⁹, P. Ge^{32d}, C.N.P. Gee¹²⁹, D.A.A. Geerts¹⁰⁵, Ch. Geich-Gimbel²⁰, K. Gellerstedt^{146a,146b}, C. Gemme^{50a}, A. Gemmell⁵³, M.H. Genest⁹⁸, S. Gentile^{132a,132b}, M. George⁵⁴, S. George⁷⁶, P. Gerlach¹⁷⁴, A. Gershon¹⁵³, C. Geweniger^{58a}, H. Ghazlane^{135b}, P. Ghez⁴, N. Ghodbane³³, B. Giacobbe^{19a}, S. Giagu^{132a,132b}, V. Giakoumopoulou⁸, V. Giangiobbe^{122a,122b}, F. Gianotti²⁹, B. Gibbard²⁴, A. Gibson¹⁵⁸, S.M. Gibson²⁹, L.M. Gilbert¹¹⁸, M. Gilchriese¹⁴, V. Gilevsky⁹¹, D. Gillberg²⁸, A.R. Gillman¹²⁹, D.M. Gingrich^{2,e}, J. Ginzburg¹⁵³, N. Giokaris⁸, M.P. Giordani^{164c}, R. Giordano^{102a,102b}, F.M. Giorgi¹⁵, P. Giovannini⁹⁹, P.F. Giraud¹³⁶, D. Giugni^{89a}, M. Giunta⁹³, P. Giusti^{19a}, B.K. Gjelsten¹¹⁷, L.K. Gladilin⁹⁷, C. Glasman⁸⁰, J. Glatzer⁴⁸, A. Glazov⁴¹, K.W. Glitza¹⁷⁴, G.L. Glonti⁶⁵, J. Godfrey¹⁴², J. Godlewski²⁹, M. Goebel⁴¹, T. Göpfert⁴³, C. Goeringer⁸¹, C. Gössling⁴², T. Göttfert⁹⁹, S. Goldfarb⁸⁷, T. Golling¹⁷⁵, S.N. Golovnia¹²⁸, A. Gomes^{124a,b}, L.S. Gomez Fajardo⁴¹, R. Gonçalves⁷⁶, J. Goncalves Pinto Firmino Da Costa⁴¹, L. Gonella²⁰, A. Gonidec²⁹, S. Gonzalez¹⁷², S. González de la Hoz¹⁶⁷, M.L. Gonzalez Silva²⁶, S. Gonzalez-Sevilla⁴⁹, J.J. Goodson¹⁴⁸, L. Goossens²⁹, P.A. Gorbounov⁹⁵, H.A. Gordon²⁴, I. Gorelov¹⁰³, G. Gorfine¹⁷⁴, B. Gorini²⁹, E. Gorini^{72a,72b}, A. Gorišek⁷⁴, E. Gornicki³⁸, S.A. Gorokhov¹²⁸, V.N. Goryachev¹²⁸, B. Gosdzik⁴¹, M. Gosselink¹⁰⁵, M.I. Gostkin⁶⁵, I. Gough Eschrich¹⁶³, M. Gouighri^{135a}, D. Goujdami^{135c}, M.P. Goulette⁴⁹, A.G. Goussiou¹³⁸, C. Goy⁴, I. Grabowska-Bold^{163,g}, V. Grabski¹⁷⁶, P. Grafström²⁹, C. Grah¹⁷⁴, K.-J. Grah⁴¹, F. Grancagnolo^{72a}, S. Grancagnolo¹⁵, V. Grassi¹⁴⁸, V. Gratchev¹²¹, N. Grau³⁴, H.M. Gray²⁹, J.A. Gray¹⁴⁸, E. Graziani^{134a}, O.G. Grebenyuk¹²¹, D. Greenfield¹²⁹, T. Greenshaw⁷³, Z.D. Greenwood^{24,m}, K. Gregersen³⁵, I.M. Gregor⁴¹, P. Grenier¹⁴³, J. Griffiths¹³⁸, N. Grigalashvili⁶⁵, A.A. Grillo¹³⁷, S. Grinstein¹¹, Y.V. Grishkevich⁹⁷, J.-F. Grivaz¹¹⁵, J. Grognuz²⁹, M. Groh⁹⁹, E. Gross¹⁷¹,

J. Grosse-Knetter⁵⁴, J. Groth-Jensen¹⁷¹, K. Grybel¹⁴¹, V.J. Guarino⁵, D. Guest¹⁷⁵, C. Guicheney³³,
 A. Guida^{72a,72b}, T. Guillemain⁴, S. Guindon⁵⁴, H. Guler^{85,n}, J. Gunther¹²⁵, B. Guo¹⁵⁸, J. Guo³⁴,
 A. Gupta³⁰, Y. Gusakov⁶⁵, V.N. Gushchin¹²⁸, A. Gutierrez⁹³, P. Gutierrez¹¹¹, N. Guttman¹⁵³,
 O. Gutzwiller¹⁷², C. Guyot¹³⁶, C. Gwenlan¹¹⁸, C.B. Gwilliam⁷³, A. Haas¹⁴³, S. Haas²⁹, C. Haber¹⁴,
 R. Hackenburg²⁴, H.K. Hadavand³⁹, D.R. Hadley¹⁷, P. Haefner⁹⁹, F. Hahn²⁹, S. Haider²⁹, Z. Hajduk³⁸,
 H. Hakobyan¹⁷⁶, J. Haller⁵⁴, K. Hamacher¹⁷⁴, P. Hamal¹¹³, A. Hamilton⁴⁹, S. Hamilton¹⁶¹, H. Han^{32a},
 L. Han^{32b}, K. Hanagaki¹¹⁶, M. Hance¹²⁰, C. Handel⁸¹, P. Hanke^{58a}, J.R. Hansen³⁵, J.B. Hansen³⁵,
 J.D. Hansen³⁵, P.H. Hansen³⁵, P. Hansson¹⁴³, K. Hara¹⁶⁰, G.A. Hare¹³⁷, T. Harenberg¹⁷⁴, S. Harkusha⁹⁰,
 D. Harper⁸⁷, R.D. Harrington²¹, O.M. Harris¹³⁸, K. Harrison¹⁷, J. Hartert⁴⁸, F. Hartjes¹⁰⁵, T. Haruyama⁶⁶,
 A. Harvey⁵⁶, S. Hasegawa¹⁰¹, Y. Hasegawa¹⁴⁰, S. Hassani¹³⁶, M. Hatch²⁹, D. Hauff⁹⁹, S. Haug¹⁶,
 M. Hauschild²⁹, R. Hauser⁸⁸, M. Havranek²⁰, B.M. Hawes¹¹⁸, C.M. Hawkes¹⁷, R.J. Hawkings²⁹,
 D. Hawkins¹⁶³, T. Hayakawa⁶⁷, D. Hayden⁷⁶, H.S. Hayward⁷³, S.J. Haywood¹²⁹, E. Hazen²¹, M. He^{32d},
 S.J. Head¹⁷, V. Hedberg⁷⁹, L. Heelan⁷, S. Heim⁸⁸, B. Heinemann¹⁴, S. Heisterkamp³⁵, L. Helary⁴,
 M. Heller¹¹⁵, S. Hellman^{146a,146b}, D. Hellmich²⁰, C. Helsens¹¹, R.C.W. Henderson⁷¹, M. Henke^{58a},
 A. Henrichs⁵⁴, A.M. Henriques Correia²⁹, S. Henrot-Versille¹¹⁵, F. Henry-Couannier⁸³, C. Hensel⁵⁴,
 T. Henß¹⁷⁴, C.M. Hernandez⁷, Y. Hernández Jiménez¹⁶⁷, R. Herrberg¹⁵, A.D. Hershenhorn¹⁵²,
 G. Herten⁴⁸, R. Hertenberger⁹⁸, L. Hervas²⁹, N.P. Hessey¹⁰⁵, A. Hidvegi^{146a}, E. Higón-Rodríguez¹⁶⁷,
 D. Hill^{5,*}, J.C. Hill²⁷, N. Hill⁵, K.H. Hiller⁴¹, S. Hillert²⁰, S.J. Hillier¹⁷, I. Hinchliffe¹⁴, E. Hines¹²⁰,
 M. Hirose¹¹⁶, F. Hirsch⁴², D. Hirschbuehl¹⁷⁴, J. Hobbs¹⁴⁸, N. Hod¹⁵³, M.C. Hodgkinson¹³⁹,
 P. Hodgson¹³⁹, A. Hoecker²⁹, M.R. Hoferkamp¹⁰³, J. Hoffman³⁹, D. Hoffmann⁸³, M. Hohlfeld⁸¹,
 M. Holder¹⁴¹, S.O. Holmgren^{146a}, T. Holy¹²⁷, J.L. Holzbauer⁸⁸, Y. Homma⁶⁷, T.M. Hong¹²⁰,
 L. Hooft van Huysduynen¹⁰⁸, T. Horazdovsky¹²⁷, C. Horn¹⁴³, S. Horner⁴⁸, K. Horton¹¹⁸, J.-Y. Hostachy⁵⁵,
 S. Hou¹⁵¹, M.A. Houlden⁷³, A. Hoummada^{135a}, J. Howarth⁸², D.F. Howell¹¹⁸, I. Hristova¹⁵, J. Hrivnac¹¹⁵,
 I. Hruska¹²⁵, T. Hryn'ova⁴, P.J. Hsu¹⁷⁵, S.-C. Hsu¹⁴, G.S. Huang¹¹¹, Z. Hubacek¹²⁷, F. Hubaut⁸³,
 F. Huegging²⁰, T.B. Huffman¹¹⁸, E.W. Hughes³⁴, G. Hughes⁷¹, R.E. Hughes-Jones⁸², M. Huhtinen²⁹,
 P. Hurst⁵⁷, M. Hurwitz¹⁴, U. Husemann⁴¹, N. Huseynov^{65,o}, J. Huston⁸⁸, J. Huth⁵⁷, G. Iacobucci⁴⁹,
 G. Iakovidis⁹, M. Ibbotson⁸², I. Ibragimov¹⁴¹, R. Ichimiya⁶⁷, L. Iconomidou-Fayard¹¹⁵, J. Idarraga¹¹⁵,
 M. Idzik³⁷, P. Iengo^{102a,102b}, O. Igonkina¹⁰⁵, Y. Ikegami⁶⁶, M. Ikeno⁶⁶, Y. Ilchenko³⁹, D. Iliadis¹⁵⁴,
 D. Imbault⁷⁸, M. Imhaeuser¹⁷⁴, M. Imori¹⁵⁵, T. Ince²⁰, J. Inigo-Golfin²⁹, P. Ioannou⁸, M. Iodice^{134a},
 G. Ionescu⁴, A. Irlas Quiles¹⁶⁷, K. Ishii⁶⁶, A. Ishikawa⁶⁷, M. Ishino⁶⁸, R. Ishmukhametov³⁹, C. Issever¹¹⁸,
 S. Istin^{18a}, A.V. Ivashin¹²⁸, W. Iwanski³⁸, H. Iwasaki⁶⁶, J.M. Izen⁴⁰, V. Izzo^{102a}, B. Jackson¹²⁰,
 J.N. Jackson⁷³, P. Jackson¹⁴³, M.R. Jaekel²⁹, V. Jain⁶¹, K. Jakobs⁴⁸, S. Jakobsen³⁵, J. Jakubek¹²⁷,
 D.K. Jana¹¹¹, E. Jankowski¹⁵⁸, E. Jansen⁷⁷, A. Jantsch⁹⁹, M. Janus²⁰, G. Jarlskog⁷⁹, L. Jeanty⁵⁷,
 K. Jelen³⁷, I. Jen-La Plante³⁰, P. Jenni²⁹, A. Jeremie⁴, P. Jež³⁵, S. Jézéquel⁴, M.K. Jha^{19a}, H. Ji¹⁷², W. Ji⁸¹,
 J. Jia¹⁴⁸, Y. Jiang^{32b}, M. Jimenez Belenguer⁴¹, G. Jin^{32b}, S. Jin^{32a}, O. Jinnouchi¹⁵⁷, M.D. Joergensen³⁵,
 D. Joffe³⁹, L.G. Johansen¹³, M. Johansen^{146a,146b}, K.E. Johansson^{146a}, P. Johansson¹³⁹, S. Johnert⁴¹,
 K.A. Johns⁶, K. Jon-And^{146a,146b}, G. Jones⁸², R.W.L. Jones⁷¹, T.W. Jones⁷⁷, T.J. Jones⁷³, O. Jonsson²⁹,
 C. Joram²⁹, P.M. Jorge^{124a,b}, J. Joseph¹⁴, T. Jovin^{12b}, X. Ju¹³⁰, V. Juranek¹²⁵, P. Jussel⁶², A. Juste Rozas¹¹,
 V.V. Kabachenko¹²⁸, S. Kabana¹⁶, M. Kaci¹⁶⁷, A. Kaczmarska³⁸, P. Kadlecik³⁵, M. Kado¹¹⁵, H. Kagan¹⁰⁹,
 M. Kagan⁵⁷, S. Kaiser⁹⁹, E. Kajomovitz¹⁵², S. Kalinin¹⁷⁴, L.V. Kalinovskaya⁶⁵, S. Kama³⁹, N. Kanaya¹⁵⁵,
 M. Kaneda²⁹, T. Kanno¹⁵⁷, V.A. Kantserov⁹⁶, J. Kanzaki⁶⁶, B. Kaplan¹⁷⁵, A. Kapliy³⁰, J. Kaplon²⁹,
 D. Kar⁴³, M. Karagoz¹¹⁸, M. Karnevskiy⁴¹, K. Karr⁵, V. Kartvelishvili⁷¹, A.N. Karyukhin¹²⁸, L. Kashif¹⁷²,
 A. Kasmi³⁹, R.D. Kass¹⁰⁹, A. Kastanas¹³, M. Kataoka⁴, Y. Kataoka¹⁵⁵, E. Katsoufis⁹, J. Katzy⁴¹,
 V. Kaushik⁶, K. Kawagoe⁶⁷, T. Kawamoto¹⁵⁵, G. Kawamura⁸¹, M.S. Kayl¹⁰⁵, V.A. Kazanin¹⁰⁷,
 M.Y. Kazarinov⁶⁵, J.R. Keates⁸², R. Keeler¹⁶⁹, R. Kehoe³⁹, M. Keil⁵⁴, G.D. Kekelidze⁶⁵, M. Kelly⁸²,
 J. Kennedy⁹⁸, C.J. Kenney¹⁴³, M. Kenyon⁵³, O. Kepka¹²⁵, N. Kerschen²⁹, B.P. Kerševan⁷⁴, S. Kersten¹⁷⁴,
 K. Kessoku¹⁵⁵, C. Ketterer⁴⁸, J. Keung¹⁵⁸, M. Khakzad²⁸, F. Khalil-zada¹⁰, H. Khandanyan¹⁶⁵,
 A. Khanov¹¹², D. Kharchenko⁶⁵, A. Khodinov⁹⁶, A.G. Kholodenko¹²⁸, A. Khomich^{58a}, T.J. Khoo²⁷,
 G. Khoraiuli²⁰, A. Khoroshilov¹⁷⁴, N. Khovanskiy⁶⁵, V. Khovanskiy⁹⁵, E. Khramov⁶⁵, J. Khubua⁵¹,
 H. Kim⁷, M.S. Kim², P.C. Kim¹⁴³, S.H. Kim¹⁶⁰, N. Kimura¹⁷⁰, O. Kind¹⁵, B.T. King⁷³, M. King⁶⁷,
 R.S.B. King¹¹⁸, J. Kirk¹²⁹, L.E. Kirsch²², A.E. Kiryunin⁹⁹, T. Kishimoto⁶⁷, D. Kisielewska³⁷,
 T. Kittelmann¹²³, A.M. Kiver¹²⁸, E. Kladiva^{144b}, J. Klamber-Lodewigs⁴², M. Klein⁷³, U. Klein⁷³,

K. Kleinknecht⁸¹, M. Klemetti⁸⁵, A. Klier¹⁷¹, A. Klimentov²⁴, R. Klingenberg⁴², E.B. Klinkby³⁵,
 T. Klioutchnikova²⁹, P.F. Klok¹⁰⁴, S. Klous¹⁰⁵, E.-E. Kluge^{58a}, T. Kluge⁷³, P. Kluit¹⁰⁵, S. Kluth⁹⁹,
 N.S. Knecht¹⁵⁸, E. Kneringer⁶², J. Knobloch²⁹, E.B.F.G. Knoops⁸³, A. Knue⁵⁴, B.R. Ko⁴⁴, T. Kobayashi¹⁵⁵,
 M. Kobel⁴³, M. Kocian¹⁴³, A. Kocnar¹¹³, P. Kodys¹²⁶, K. Köneke²⁹, A.C. König¹⁰⁴, S. Koenig⁸¹,
 L. Köpke⁸¹, F. Koetsveld¹⁰⁴, P. Koevesarki²⁰, T. Koffas²⁸, E. Koffeman¹⁰⁵, F. Kohn⁵⁴, Z. Kohout¹²⁷,
 T. Kohriki⁶⁶, T. Koi¹⁴³, T. Kokott²⁰, G.M. Kolachev¹⁰⁷, H. Kolanoski¹⁵, V. Kolesnikov⁶⁵, I. Koletsou^{89a},
 J. Koll⁸⁸, D. Kollar²⁹, M. Kollfrath⁴⁸, S.D. Kolya⁸², A.A. Komar⁹⁴, Y. Komori¹⁵⁵, T. Kondo⁶⁶, T. Kono^{41,p},
 A.I. Kononov⁴⁸, R. Konoplich^{108,q}, N. Konstantinidis⁷⁷, A. Kootz¹⁷⁴, S. Koperny³⁷, S.V. Kopikov¹²⁸,
 K. Korcyl³⁸, K. Kordas¹⁵⁴, V. Koreshev¹²⁸, A. Korn¹¹⁸, A. Korol¹⁰⁷, I. Korolkov¹¹, E.V. Korolkova¹³⁹,
 V.A. Korotkov¹²⁸, O. Kortner⁹⁹, S. Kortner⁹⁹, V.V. Kostyukhin²⁰, M.J. Kotamäki²⁹, S. Kotov⁹⁹,
 V.M. Kotov⁶⁵, A. Kotwal⁴⁴, C. Kourkoumelis⁸, V. Kouskoura¹⁵⁴, A. Koutsman¹⁰⁵, R. Kowalewski¹⁶⁹,
 T.Z. Kowalski³⁷, W. Kozanecki¹³⁶, A.S. Kozhin¹²⁸, V. Kral¹²⁷, V.A. Kramarenko⁹⁷, G. Kramberger⁷⁴,
 M.W. Krasny⁷⁸, A. Krasznahorkay¹⁰⁸, J. Kraus⁸⁸, A. Kreisel¹⁵³, F. Krejci¹²⁷, J. Kretzschmar⁷³,
 N. Krieger⁵⁴, P. Krieger¹⁵⁸, K. Kroeninger⁵⁴, H. Kroha⁹⁹, J. Kroll¹²⁰, J. Kroseberg²⁰, J. Krstic^{12a},
 U. Kruchonak⁶⁵, H. Krüger²⁰, T. Kruker¹⁶, Z.V. Krumshteyn⁶⁵, A. Kruth²⁰, T. Kubota⁸⁶, S. Kuehn⁴⁸,
 A. Kugel^{58c}, T. Kuhl⁴¹, D. Kuhn⁶², V. Kukhtin⁶⁵, Y. Kulchitsky⁹⁰, S. Kuleshov^{31b}, C. Kummer⁹⁸,
 M. Kuna⁷⁸, N. Kundu¹¹⁸, J. Kunkle¹²⁰, A. Kupco¹²⁵, H. Kurashige⁶⁷, M. Kurata¹⁶⁰, Y.A. Kurochkin⁹⁰,
 V. Kus¹²⁵, W. Kuykendall¹³⁸, M. Kuze¹⁵⁷, P. Kuzhir⁹¹, J. Kvita²⁹, R. Kwee¹⁵, A. La Rosa¹⁷²,
 L. La Rotonda^{36a,36b}, L. Labarga⁸⁰, J. Labbe⁴, S. Lablak^{135a}, C. Lacasta¹⁶⁷, F. Lacava^{132a,132b}, H. Lacker¹⁵,
 D. Lacour⁷⁸, V.R. Lacuesta¹⁶⁷, E. Ladygin⁶⁵, R. Lafaye⁴, B. Laforge⁷⁸, T. Lagouri⁸⁰, S. Lai⁴⁸, E. Laisne⁵⁵,
 M. Lamanna²⁹, C.L. Lampen⁶, W. Lampl⁶, E. Lancon¹³⁶, U. Landgraf⁴⁸, M.P.J. Landon⁷⁵, H. Landsman¹⁵²,
 J.L. Lane⁸², C. Lange⁴¹, A.J. Lankford¹⁶³, F. Lanni²⁴, K. Lantzsche²⁹, S. Laplace⁷⁸, C. Lapoire²⁰,
 J.F. Laporte¹³⁶, T. Lari^{89a}, A.V. Larionov¹²⁸, A. Larnier¹¹⁸, C. Lasseur²⁹, M. Lassnig²⁹, P. Laurelli⁴⁷,
 A. Lavorato¹¹⁸, W. Lavrijsen¹⁴, P. Laycock⁷³, A.B. Lazarev⁶⁵, O. Le Dortz⁷⁸, E. Le Guirriec⁸³,
 C. Le Maner¹⁵⁸, E. Le Menedeu¹³⁶, C. Lebel⁹³, T. LeCompte⁵, F. Ledroit-Guillon⁵⁵, H. Lee¹⁰⁵,
 J.S.H. Lee¹⁵⁰, S.C. Lee¹⁵¹, L. Lee¹⁷⁵, M. Lefebvre¹⁶⁹, M. Legendre¹³⁶, A. Leger⁴⁹, B.C. LeGeyt¹²⁰,
 F. Legger⁹⁸, C. Leggett¹⁴, M. Lehmann²⁰, G. Lehmann Miotto²⁹, X. Lei⁶, M.A.L. Leite^{23d}, R. Leitner¹²⁶,
 D. Lellouch¹⁷¹, M. Leltchouk³⁴, B. Lemmer⁵⁴, V. Lendermann^{58a}, K.J.C. Leney^{145b}, T. Lenz¹⁰⁵,
 G. Lenzen¹⁷⁴, B. Lenzi²⁹, K. Leonhardt⁴³, S. Leontsinis⁹, C. Leroy⁹³, J.-R. Lessard¹⁶⁹, J. Lesser^{146a},
 C.G. Lester²⁷, A. Leung Fook Cheong¹⁷², J. Levêque⁴, D. Levin⁸⁷, L.J. Levinson¹⁷¹, M.S. Levitski¹²⁸,
 M. Lewandowska²¹, A. Lewis¹¹⁸, G.H. Lewis¹⁰⁸, A.M. Leyko²⁰, M. Leyton¹⁵, B. Li⁸³, H. Li¹⁷², S. Li^{32b,d},
 X. Li⁸⁷, Z. Liang³⁹, Z. Liang^{118,r}, H. Liao³³, B. Liberti^{133a}, P. Lichard²⁹, M. Lichtnecker⁹⁸, K. Lie¹⁶⁵,
 W. Liebig¹³, R. Lifshitz¹⁵², J.N. Lilley¹⁷, C. Limbach²⁰, A. Limosani⁸⁶, M. Limper⁶³, S.C. Lin^{151,s},
 F. Linde¹⁰⁵, J.T. Linnemann⁸⁸, E. Lipeles¹²⁰, L. Lipinsky¹²⁵, A. Lipniacka¹³, T.M. Liss¹⁶⁵, D. Lissauer²⁴,
 A. Lister⁴⁹, A.M. Litke¹³⁷, C. Liu²⁸, D. Liu^{151,t}, H. Liu⁸⁷, J.B. Liu⁸⁷, M. Liu^{32b}, S. Liu², Y. Liu^{32b},
 M. Livan^{119a,119b}, S.S.A. Livermore¹¹⁸, A. Lleres⁵⁵, J. Llorente Merino⁸⁰, S.L. Lloyd⁷⁵, E. Lobodzinska⁴¹,
 P. Loch⁶, W.S. Lockman¹³⁷, T. Lodenkoetter²⁰, F.K. Loebinger⁸², A. Loginov¹⁷⁵, C.W. Loh¹⁶⁸, T. Lohse¹⁵,
 K. Lohwasser⁴⁸, M. Lokajicek¹²⁵, J. Loken¹¹⁸, V.P. Lombardo⁴, R.E. Long⁷¹, L. Lopes^{124a,b},
 D. Lopez Mateos⁵⁷, M. Losada¹⁶², P. Loscutoff¹⁴, F. Lo Sterzo^{132a,132b}, M.J. Losty^{159a}, X. Lou⁴⁰,
 A. Lounis¹¹⁵, K.F. Loureiro¹⁶², J. Love²¹, P.A. Love⁷¹, A.J. Lowe^{143,f}, F. Lu^{32a}, H.J. Lubatti¹³⁸,
 C. Luci^{132a,132b}, A. Lucotte⁵⁵, A. Ludwig⁴³, D. Ludwig⁴¹, I. Ludwig⁴⁸, J. Ludwig⁴⁸, F. Luehring⁶¹,
 G. Luijckx¹⁰⁵, D. Lumb⁴⁸, L. Luminari^{132a}, E. Lund¹¹⁷, B. Lund-Jensen¹⁴⁷, B. Lundberg⁷⁹,
 J. Lundberg^{146a,146b}, J. Lundquist³⁵, M. Lungwitz⁸¹, A. Lupi^{122a,122b}, G. Lutz⁹⁹, D. Lynn²⁴, J. Lys¹⁴,
 E. Lytken⁷⁹, H. Ma²⁴, L.L. Ma¹⁷², J.A. Macana Goia⁹³, G. Maccarrone⁴⁷, A. Macchiolo⁹⁹, B. Maček⁷⁴,
 J. Machado Miguens^{124a}, R. Mackeprang³⁵, R.J. Madaras¹⁴, W.F. Mader⁴³, R. Maenner^{58c}, T. Maeno²⁴,
 P. Mättig¹⁷⁴, S. Mättig⁴¹, L. Magnoni²⁹, E. Magradze⁵⁴, Y. Mahalalel¹⁵³, K. Mahboubi⁴⁸, G. Mahout¹⁷,
 C. Maiani^{132a,132b}, C. Maidantchik^{23a}, A. Maio^{124a,b}, S. Majewski²⁴, Y. Makida⁶⁶, N. Makovec¹¹⁵,
 P. Mal⁶, Pa. Malecki³⁸, P. Malecki³⁸, V.P. Maleev¹²¹, F. Malek⁵⁵, U. Mallik⁶³, D. Malon⁵, C. Malone¹⁴³,
 S. Maltezos⁹, V. Malyshev¹⁰⁷, S. Malyukov²⁹, R. Mameghani⁹⁸, J. Mamuzic^{12b}, A. Manabe⁶⁶,
 L. Mandelli^{89a}, I. Mandić⁷⁴, R. Mandrysch¹⁵, J. Maneira^{124a}, P.S. Mangeard⁸⁸, I.D. Manjavidze⁶⁵,
 A. Mann⁵⁴, P.M. Manning¹³⁷, A. Manousakis-Katsikakis⁸, B. Mansoulie¹³⁶, A. Manz⁹⁹, A. Mapelli²⁹,
 L. Mapelli²⁹, L. March⁸⁰, J.F. Marchand²⁹, F. Marchese^{133a,133b}, G. Marchiori⁷⁸, M. Marcisovsky¹²⁵,

A. Marin^{21,*}, C.P. Marino⁶¹, F. Marroquim^{23a}, R. Marshall⁸², Z. Marshall²⁹, F.K. Martens¹⁵⁸,
 S. Marti-Garcia¹⁶⁷, A.J. Martin¹⁷⁵, B. Martin²⁹, B. Martin⁸⁸, F.F. Martin¹²⁰, J.P. Martin⁹³, Ph. Martin⁵⁵,
 T.A. Martin¹⁷, V.J. Martin⁴⁵, B. Martin dit Latour⁴⁹, S. Martin-Haugh¹⁴⁹, M. Martinez¹¹,
 V. Martinez Outschoorn⁵⁷, A.C. Martyniuk⁸², M. Marx⁸², F. Marzano^{132a}, A. Marzin¹¹¹, L. Masetti⁸¹,
 T. Mashimo¹⁵⁵, R. Mashinistov⁹⁴, J. Masik⁸², A.L. Maslennikov¹⁰⁷, I. Massa^{19a,19b}, G. Massaro¹⁰⁵,
 N. Massol⁴, P. Mastrandrea^{132a,132b}, A. Mastroberardino^{36a,36b}, T. Masubuchi¹⁵⁵, M. Mathes²⁰,
 P. Matricon¹¹⁵, H. Matsumoto¹⁵⁵, H. Matsunaga¹⁵⁵, T. Matsushita⁶⁷, C. Mattravers^{118,c}, J.M. Maugain²⁹,
 S.J. Maxfield⁷³, D.A. Maximov¹⁰⁷, E.N. May⁵, A. Mayne¹³⁹, R. Mazini¹⁵¹, M. Mazur²⁰, M. Mazzanti^{89a},
 E. Mazzoni^{122a,122b}, S.P. Mc Kee⁸⁷, A. McCarn¹⁶⁵, R.L. McCarthy¹⁴⁸, T.G. McCarthy²⁸, N.A. McCubbin¹²⁹,
 K.W. McFarlane⁵⁶, J.A. McFayden¹³⁹, H. McGlone⁵³, G. Mchedlidze⁵¹, R.A. McLaren²⁹, T. McLaughlan¹⁷,
 S.J. McMahon¹²⁹, R.A. McPherson^{169,k}, A. Meade⁸⁴, J. Mechnich¹⁰⁵, M. Mechtel¹⁷⁴, M. Medinnis⁴¹,
 R. Meera-Lebbai¹¹¹, T. Meguro¹¹⁶, R. Mehdiyev⁹³, S. Mehlhase³⁵, A. Mehta⁷³, K. Meier^{58a},
 J. Meinhardt⁴⁸, B. Meirose⁷⁹, C. Melachrinou³⁰, B.R. Mellado Garcia¹⁷², L. Mendoza Navas¹⁶²,
 Z. Meng^{151,t}, A. Mengarelli^{19a,19b}, S. Menke⁹⁹, C. Menot²⁹, E. Meoni¹¹, K.M. Mercurio⁵⁷, P. Mermod¹¹⁸,
 L. Merola^{102a,102b}, C. Meroni^{89a}, F.S. Merritt³⁰, A. Messina²⁹, J. Metcalfe¹⁰³, A.S. Mete⁶⁴, S. Meuser²⁰,
 C. Meyer⁸¹, J.-P. Meyer¹³⁶, J. Meyer¹⁷³, J. Meyer⁵⁴, T.C. Meyer²⁹, W.T. Meyer⁶⁴, J. Miao^{32d}, S. Michal²⁹,
 L. Micu^{25a}, R.P. Middleton¹²⁹, P. Miele²⁹, S. Migas⁷³, L. Mijović⁴¹, G. Mikenberg¹⁷¹, M. Mikestikova¹²⁵,
 M. Mikuž⁷⁴, D.W. Miller¹⁴³, R.J. Miller⁸⁸, W.J. Mills¹⁶⁸, C. Mills⁵⁷, A. Milov¹⁷¹, D.A. Milstead^{146a,146b},
 D. Milstein¹⁷¹, A.A. Minaenko¹²⁸, M. Miñano¹⁶⁷, I.A. Minashvili⁶⁵, A.I. Mincer¹⁰⁸, B. Mindur³⁷,
 M. Mineev⁶⁵, Y. Ming¹³⁰, L.M. Mir¹¹, G. Mirabelli^{132a}, L. Miralles Verge¹¹, A. Misiejuk⁷⁶, J. Mitrevski¹³⁷,
 G.Y. Mitrofanov¹²⁸, V.A. Mitsou¹⁶⁷, S. Mitsui⁶⁶, P.S. Miyagawa¹³⁹, K. Miyazaki⁶⁷, J.U. Mjörnmark⁷⁹,
 T. Moa^{146a,146b}, P. Mockett¹³⁸, S. Moed⁵⁷, V. Moeller²⁷, K. Mönig⁴¹, N. Möser²⁰, S. Mohapatra¹⁴⁸,
 W. Mohr⁴⁸, S. Mohrdieck-Möck⁹⁹, A.M. Moisseev^{128,*}, R. Moles-Valls¹⁶⁷, J. Molina-Perez²⁹, J. Monk⁷⁷,
 E. Monnier⁸³, S. Montesano^{89a,89b}, F. Monticelli⁷⁰, S. Monzani^{19a,19b}, R.W. Moore², G.F. Moorhead⁸⁶,
 C. Mora Herrera⁴⁹, A. Moraes⁵³, N. Morange¹³⁶, J. Morel⁵⁴, G. Morello^{36a,36b}, D. Moreno⁸¹,
 M. Moreno Llácer¹⁶⁷, P. Morettini^{50a}, M. Morii⁵⁷, J. Morin⁷⁵, Y. Morita⁶⁶, A.K. Morley²⁹,
 G. Mornacchi²⁹, S.V. Morozov⁹⁶, J.D. Morris⁷⁵, L. Morvaj¹⁰¹, H.G. Moser⁹⁹, M. Mosidze⁵¹, J. Moss¹⁰⁹,
 R. Mount¹⁴³, E. Mountricha¹³⁶, S.V. Mouraviev⁹⁴, E.J.W. Moyse⁸⁴, M. Mudrinic^{12b}, F. Mueller^{58a},
 J. Mueller¹²³, K. Mueller²⁰, T.A. Müller⁹⁸, D. Muenstermann²⁹, A. Muir¹⁶⁸, Y. Munwes¹⁵³,
 W.J. Murray¹²⁹, I. Mussche¹⁰⁵, E. Musto^{102a,102b}, A.G. Myagkov¹²⁸, M. Myska¹²⁵, J. Nadal¹¹,
 K. Nagai¹⁶⁰, K. Nagano⁶⁶, Y. Nagasaka⁶⁰, A.M. Nairz²⁹, Y. Nakahama²⁹, K. Nakamura¹⁵⁵, I. Nakano¹¹⁰,
 G. Nanava²⁰, A. Napier¹⁶¹, M. Nash^{77,c}, N.R. Nation²¹, T. Nattermann²⁰, T. Naumann⁴¹, G. Navarro¹⁶²,
 H.A. Neal⁸⁷, E. Nebot⁸⁰, P.Yu. Nechaeva⁹⁴, A. Negri^{119a,119b}, G. Negri²⁹, S. Nektarijevic⁴⁹, A. Nelson⁶⁴,
 S. Nelson¹⁴³, T.K. Nelson¹⁴³, S. Nemecek¹²⁵, P. Nemethy¹⁰⁸, A.A. Nepomuceno^{23a}, M. Nessi^{29,u},
 S.Y. Nesterov¹²¹, M.S. Neubauer¹⁶⁵, A. Neusiedl⁸¹, R.M. Neves¹⁰⁸, P. Nevski²⁴, P.R. Newman¹⁷,
 V. Nguyen Thi Hong¹³⁶, R.B. Nickerson¹¹⁸, R. Nicolaidou¹³⁶, L. Nicolas¹³⁹, B. Nicquevert²⁹,
 F. Niedercorn¹¹⁵, J. Nielsen¹³⁷, T. Niinikoski²⁹, N. Nikiforou³⁴, A. Nikiforov¹⁵, V. Nikolaenko¹²⁸,
 K. Nikolaev⁶⁵, I. Nikolic-Audit⁷⁸, K. Nikolics⁴⁹, K. Nikolopoulos²⁴, H. Nilsen⁴⁸, P. Nilsson⁷,
 Y. Ninomiya¹⁵⁵, A. Nisati^{132a}, T. Nishiyama⁶⁷, R. Nisius⁹⁹, L. Nodulman⁵, M. Nomachi¹¹⁶, I. Nomidis¹⁵⁴,
 M. Nordberg²⁹, B. Nordkvist^{146a,146b}, P.R. Norton¹²⁹, J. Novakova¹²⁶, M. Nozaki⁶⁶, M. Nožička⁴¹,
 L. Nozka¹¹³, I.M. Nugent^{159a}, A.-E. Nuncio-Quiroz²⁰, G. Nunes Hanninger⁸⁶, T. Nunnemann⁹⁸,
 E. Nurse⁷⁷, T. Nyman²⁹, B.J. O'Brien⁴⁵, S.W. O'Neale^{17,*}, D.C. O'Neil¹⁴², V. O'Shea⁵³, F.G. Oakham^{28,e},
 H. Oberlack⁹⁹, J. Ocariz⁷⁸, A. Ochi⁶⁷, S. Oda¹⁵⁵, S. Odaka⁶⁶, J. Odier⁸³, H. Ogren⁶¹, A. Oh⁸², S.H. Oh⁴⁴,
 C.C. Ohm^{146a,146b}, T. Ohshima¹⁰¹, H. Ohshita¹⁴⁰, T.K. Ohska⁶⁶, T. Ohsugi⁵⁹, S. Okada⁶⁷, H. Okawa¹⁶³,
 Y. Okumura¹⁰¹, T. Okuyama¹⁵⁵, M. Olcese^{50a}, A.G. Olchevski⁶⁵, M. Oliveira^{124a,i}, D. Oliveira Damazio²⁴,
 E. Oliver Garcia¹⁶⁷, D. Olivito¹²⁰, A. Olszewski³⁸, J. Olszowska³⁸, C. Omachi⁶⁷, A. Onofre^{124a,v},
 P.U.E. Onyisi³⁰, C.J. Oram^{159a}, M.J. Oreglia³⁰, Y. Oren¹⁵³, D. Orestano^{134a,134b}, I. Orlov¹⁰⁷,
 C. Oropeza Barrera⁵³, R.S. Orr¹⁵⁸, B. Osculati^{50a,50b}, R. Ospanov¹²⁰, C. Osuna¹¹, G. Otero y Garzon²⁶,
 J.P. Ottersbach¹⁰⁵, M. Ouchrif^{135d}, F. Ould-Saada¹¹⁷, A. Ouraou¹³⁶, Q. Ouyang^{32a}, M. Owen⁸²,
 S. Owen¹³⁹, V.E. Ozcan^{18a}, N. Ozturk⁷, A. Pacheco Pages¹¹, C. Padilla Aranda¹¹, S. Pagan Griso¹⁴,
 E. Paganis¹³⁹, F. Paige²⁴, K. Pajchel¹¹⁷, G. Palacino^{159b}, C.P. Paelari⁶, S. Palestini²⁹, D. Pallin³³,
 A. Palma^{124a,b}, J.D. Palmer¹⁷, Y.B. Pan¹⁷², E. Panagiotopoulou⁹, B. Panes^{31a}, N. Panikashvili⁸⁷,

S. Panitkin ²⁴, D. Pantea ^{25a}, M. Panuskova ¹²⁵, V. Paolone ¹²³, A. Papadelis ^{146a}, Th.D. Papadopoulou ⁹, A. Paramonov ⁵, W. Park ^{24,w}, M.A. Parker ²⁷, F. Parodi ^{50a,50b}, J.A. Parsons ³⁴, U. Parzefall ⁴⁸, E. Pasqualucci ^{132a}, A. Passeri ^{134a}, F. Pastore ^{134a,134b}, Fr. Pastore ⁷⁶, G. Pásztor ^{49,x}, S. Pataria ¹⁷², N. Patel ¹⁵⁰, J.R. Pater ⁸², S. Patricelli ^{102a,102b}, T. Pauly ²⁹, M. Pecsý ^{144a}, M.I. Pedraza Morales ¹⁷², S.V. Peleganchuk ¹⁰⁷, H. Peng ^{32b}, R. Pengo ²⁹, A. Pensón ³⁴, J. Penwell ⁶¹, M. Perantoni ^{23a}, K. Perez ^{34,y}, T. Perez Cavalcanti ⁴¹, E. Perez Codina ¹¹, M.T. Pérez García-Estañ ¹⁶⁷, V. Perez Reale ³⁴, L. Perini ^{89a,89b}, H. Pernegger ²⁹, R. Perrino ^{72a}, P. Perrodo ⁴, S. Persema ^{3a}, V.D. Peshekhonov ⁶⁵, B.A. Petersen ²⁹, J. Petersen ²⁹, T.C. Petersen ³⁵, E. Petit ⁸³, A. Petridis ¹⁵⁴, C. Petridou ¹⁵⁴, E. Petrolo ^{132a}, F. Petrucci ^{134a,134b}, D. Petschull ⁴¹, M. Petteni ¹⁴², R. Pezoa ^{31b}, A. Phan ⁸⁶, A.W. Phillips ²⁷, P.W. Phillips ¹²⁹, G. Piacquadio ²⁹, E. Piccaro ⁷⁵, M. Piccinini ^{19a,19b}, A. Pickford ⁵³, S.M. Piec ⁴¹, R. Piegai ²⁶, J.E. Pilcher ³⁰, A.D. Pilkington ⁸², J. Pina ^{124a,b}, M. Pinamonti ^{164a,164c}, A. Pinder ¹¹⁸, J.L. Pinfold ², J. Ping ^{32c}, B. Pinto ^{124a,b}, O. Pirotte ²⁹, C. Pizio ^{89a,89b}, R. Placakyte ⁴¹, M. Plamondon ¹⁶⁹, W.G. Plano ⁸², M.-A. Pleier ²⁴, A.V. Pleskach ¹²⁸, A. Poblaguev ²⁴, S. Poddar ^{58a}, F. Podlyski ³³, L. Poggioli ¹¹⁵, T. Poghosyan ²⁰, M. Pohl ⁴⁹, F. Polci ⁵⁵, G. Polesello ^{119a}, A. Policicchio ¹³⁸, A. Polini ^{19a}, J. Poll ⁷⁵, V. Polychronakos ²⁴, D.M. Pomarede ¹³⁶, D. Pomeroy ²², K. Pommès ²⁹, L. Pontecorvo ^{132a}, B.G. Pope ⁸⁸, G.A. Popeneciu ^{25a}, D.S. Popovic ^{12a}, A. Poppleton ²⁹, X. Portell Bueso ²⁹, R. Porter ¹⁶³, C. Posch ²¹, G.E. Pospelov ⁹⁹, S. Pospisil ¹²⁷, I.N. Potrap ⁹⁹, C.J. Potter ¹⁴⁹, C.T. Potter ¹¹⁴, G. Poulard ²⁹, J. Poveda ¹⁷², R. Prabhu ⁷⁷, P. Pralavorio ⁸³, S. Prasad ⁵⁷, R. Pravahan ⁷, S. Prell ⁶⁴, K. Pretzl ¹⁶, L. Pribyl ²⁹, D. Price ⁶¹, L.E. Price ⁵, M.J. Price ²⁹, P.M. Prichard ⁷³, D. Prieur ¹²³, M. Primavera ^{72a}, K. Prokofiev ¹⁰⁸, F. Prokoshin ^{31b}, S. Protopopescu ²⁴, J. Proudfoot ⁵, X. Prudent ⁴³, H. Przysiezniak ⁴, S. Psoroulas ²⁰, E. Ptacek ¹¹⁴, E. Pueschel ⁸⁴, J. Purdham ⁸⁷, M. Purohit ^{24,w}, P. Puzo ¹¹⁵, Y. Pylypchenko ¹¹⁷, J. Qian ⁸⁷, Z. Qian ⁸³, Z. Qin ⁴¹, A. Quadt ⁵⁴, D.R. Quarrie ¹⁴, W.B. Quayle ¹⁷², F. Quinonez ^{31a}, M. Raas ¹⁰⁴, V. Radescu ^{58b}, B. Radics ²⁰, T. Rador ^{18a}, F. Ragusa ^{89a,89b}, G. Rahal ¹⁷⁷, A.M. Rahimi ¹⁰⁹, D. Rahm ²⁴, S. Rajagopalan ²⁴, M. Rammensee ⁴⁸, M. Rammes ¹⁴¹, M. Ramstedt ^{146a,146b}, A.S. Randle-Conde ³⁹, K. Randrianarivony ²⁸, P.N. Ratoff ⁷¹, F. Rauscher ⁹⁸, E. Rauter ⁹⁹, M. Raymond ²⁹, A.L. Read ¹¹⁷, D.M. Rebuzzi ^{119a,119b}, A. Redelbach ¹⁷³, G. Redlinger ²⁴, R. Reece ¹²⁰, K. Reeves ⁴⁰, A. Reichold ¹⁰⁵, E. Reinherz-Aronis ¹⁵³, A. Reinsch ¹¹⁴, I. Reisinger ⁴², D. Reljic ^{12a}, C. Rembser ²⁹, Z.L. Ren ¹⁵¹, A. Renaud ¹¹⁵, P. Renkel ³⁹, M. Rescigno ^{132a}, S. Resconi ^{89a}, B. Resende ¹³⁶, P. Reznicek ⁹⁸, R. Rezvani ¹⁵⁸, A. Richards ⁷⁷, R. Richter ⁹⁹, E. Richter-Was ^{4,z}, M. Ridel ⁷⁸, S. Rieke ⁸¹, M. Rijpstra ¹⁰⁵, M. Rijssenbeek ¹⁴⁸, A. Rimoldi ^{119a,119b}, L. Rinaldi ^{19a}, R.R. Rios ³⁹, I. Riu ¹¹, G. Rivoltella ^{89a,89b}, F. Rizatdinova ¹¹², E. Rizvi ⁷⁵, S.H. Robertson ^{85,k}, A. Robichaud-Veronneau ⁴⁹, D. Robinson ²⁷, J.E.M. Robinson ⁷⁷, M. Robinson ¹¹⁴, A. Robson ⁵³, J.G. Rocha de Lima ¹⁰⁶, C. Roda ^{122a,122b}, D. Roda Dos Santos ²⁹, S. Rodier ⁸⁰, D. Rodriguez ¹⁶², A. Roe ⁵⁴, S. Roe ²⁹, O. Røhne ¹¹⁷, V. Rojo ¹, S. Rolli ¹⁶¹, A. Romaniouk ⁹⁶, V.M. Romanov ⁶⁵, G. Romeo ²⁶, L. Roos ⁷⁸, E. Ros ¹⁶⁷, S. Rosati ^{132a,132b}, K. Rosbach ⁴⁹, A. Rose ¹⁴⁹, M. Rose ⁷⁶, G.A. Rosenbaum ¹⁵⁸, E.I. Rosenberg ⁶⁴, P.L. Rosendahl ¹³, O. Rosenthal ¹⁴¹, L. Rossetlet ⁴⁹, V. Rossetti ¹¹, E. Rossi ^{132a,132b}, L.P. Rossi ^{50a}, L. Rossi ^{89a,89b}, M. Rotaru ^{25a}, I. Roth ¹⁷¹, J. Rothberg ¹³⁸, D. Rousseau ¹¹⁵, C.R. Royon ¹³⁶, A. Rozanov ⁸³, Y. Rozen ¹⁵², X. Ruan ¹¹⁵, I. Rubinskiy ⁴¹, B. Ruckert ⁹⁸, N. Ruckstuhl ¹⁰⁵, V.I. Rud ⁹⁷, C. Rudolph ⁴³, G. Rudolph ⁶², F. Rühr ⁶, F. Ruggieri ^{134a,134b}, A. Ruiz-Martinez ⁶⁴, E. Rulikowska-Zarebska ³⁷, V. Rumyantsev ^{91,*}, L. Rumyantsev ⁶⁵, K. Runge ⁴⁸, O. Runolfsson ²⁰, Z. Rurikova ⁴⁸, N.A. Rusakovich ⁶⁵, D.R. Rust ⁶¹, J.P. Rutherford ⁶, C. Ruwiedel ¹⁴, P. Ruzicka ¹²⁵, Y.F. Ryabov ¹²¹, V. Ryadovikov ¹²⁸, P. Ryan ⁸⁸, M. Rybar ¹²⁶, G. Rybkin ¹¹⁵, N.C. Ryder ¹¹⁸, S. Rzaeva ¹⁰, A.F. Saavedra ¹⁵⁰, I. Sadeh ¹⁵³, H.F.-W. Sadrozinski ¹³⁷, R. Sadykov ⁶⁵, F. Safai Tehrani ^{132a,132b}, H. Sakamoto ¹⁵⁵, G. Salamanna ⁷⁵, A. Salamon ^{133a}, M. Saleem ¹¹¹, D. Salihagic ⁹⁹, A. Salnikov ¹⁴³, J. Salt ¹⁶⁷, B.M. Salvachua Ferrando ⁵, D. Salvatore ^{36a,36b}, F. Salvatore ¹⁴⁹, A. Salvucci ¹⁰⁴, A. Salzburger ²⁹, D. Sampsonidis ¹⁵⁴, B.H. Samset ¹¹⁷, A. Sanchez ^{102a,102b}, H. Sandaker ¹³, H.G. Sander ⁸¹, M.P. Sanders ⁹⁸, M. Sandhoff ¹⁷⁴, T. Sandoval ²⁷, C. Sandoval ¹⁶², R. Sandstroem ⁹⁹, S. Sandvoss ¹⁷⁴, D.P.C. Sankey ¹²⁹, A. Sansoni ⁴⁷, C. Santamarina Rios ⁸⁵, C. Santoni ³³, R. Santonico ^{133a,133b}, H. Santos ^{124a}, J.G. Saraiva ^{124a,b}, T. Sarangi ¹⁷², E. Sarkisyan-Grinbaum ⁷, F. Sarri ^{122a,122b}, G. Sartisohn ¹⁷⁴, O. Sasaki ⁶⁶, T. Sasaki ⁶⁶, N. Sasao ⁶⁸, I. Satsounkevitch ⁹⁰, G. Sauvage ⁴, E. Sauvan ⁴, J.B. Sauvan ¹¹⁵, P. Savard ^{158,e}, V. Savinov ¹²³, D.O. Savu ²⁹, P. Savva ⁹, L. Sawyer ^{24,m}, D.H. Saxon ⁵³, L.P. SAYS ³³, C. Sbarra ^{19a,19b}, A. Sbrizzi ^{19a,19b}, O. Scallón ⁹³, D.A. Scannicchio ¹⁶³, J. Schaarschmidt ¹¹⁵, P. Schacht ⁹⁹, U. Schäfer ⁸¹, S. Schaepe ²⁰, S. Schaezel ^{58b}, A.C. Schaffer ¹¹⁵, D. Schaile ⁹⁸, R.D. Schamberger ¹⁴⁸, A.G. Schamov ¹⁰⁷, V. Scharf ^{58a}, V.A. Schegelsky ¹²¹, D. Scheirich ⁸⁷, M. Schernau ¹⁶³, M.I. Scherzer ¹⁴, C. Schiavi ^{50a,50b},

J. Schieck⁹⁸, M. Schioppa^{36a,36b}, S. Schlenker²⁹, J.L. Schlereth⁵, E. Schmidt⁴⁸, K. Schmieden²⁰,
 C. Schmitt⁸¹, S. Schmitt^{58b}, M. Schmitz²⁰, A. Schöning^{58b}, M. Schott²⁹, D. Schouten¹⁴²,
 J. Schovancova¹²⁵, M. Schram⁸⁵, C. Schroeder⁸¹, N. Schroer^{58c}, S. Schuh²⁹, G. Schuler²⁹, J. Schultes¹⁷⁴,
 H.-C. Schultz-Coulon^{58a}, H. Schulz¹⁵, J.W. Schumacher²⁰, M. Schumacher⁴⁸, B.A. Schumm¹³⁷,
 Ph. Schune¹³⁶, C. Schwanenberger⁸², A. Schwartzman¹⁴³, Ph. Schwemling⁷⁸, R. Schwienhorst⁸⁸,
 R. Schwierz⁴³, J. Schwindling¹³⁶, T. Schwindt²⁰, W.G. Scott¹²⁹, J. Searcy¹¹⁴, E. Sedykh¹²¹, E. Segura¹¹,
 S.C. Seidel¹⁰³, A. Seiden¹³⁷, F. Seifert⁴³, J.M. Seixas^{23a}, G. Sekhniaidze^{102a}, D.M. Seliverstov¹²¹,
 B. Sellden^{146a}, G. Sellers⁷³, M. Seman^{144b}, N. Sempri-Cesari^{19a,19b}, C. Serfon⁹⁸, L. Serin¹¹⁵,
 R. Seuster⁹⁹, H. Severini¹¹¹, M.E. Sevir⁸⁶, A. Sfyrta²⁹, E. Shabalina⁵⁴, M. Shamim¹¹⁴, L.Y. Shan^{32a},
 J.T. Shank²¹, Q.T. Shao⁸⁶, M. Shapiro¹⁴, P.B. Shatalov⁹⁵, L. Shaver⁶, K. Shaw^{164a,164c}, D. Sherman¹⁷⁵,
 P. Sherwood⁷⁷, A. Shibata¹⁰⁸, H. Shichi¹⁰¹, S. Shimizu²⁹, M. Shimojima¹⁰⁰, T. Shin⁵⁶, A. Shmeleva⁹⁴,
 M.J. Shochet³⁰, D. Short¹¹⁸, M.A. Shupe⁶, P. Sicho¹²⁵, A. Sidoti^{132a,132b}, A. Siebel¹⁷⁴, F. Siegert⁴⁸,
 J. Siegrist¹⁴, Dj. Sijacki^{12a}, O. Silbert¹⁷¹, J. Silva^{124a,b}, Y. Silver¹⁵³, D. Silverstein¹⁴³, S.B. Silverstein^{146a},
 V. Simak¹²⁷, O. Simard¹³⁶, Lj. Simic^{12a}, S. Simion¹¹⁵, B. Simmons⁷⁷, M. Simonyan³⁵, P. Sinervo¹⁵⁸,
 N.B. Sinev¹¹⁴, V. Sipica¹⁴¹, G. Siragusa¹⁷³, A. Sircar²⁴, A.N. Sisakyan⁶⁵, S.Yu. Sivoklokov⁹⁷,
 J. Sjölin^{146a,146b}, T.B. Sjursen¹³, L.A. Skinnari¹⁴, K. Skovpen¹⁰⁷, P. Skubic¹¹¹, N. Skvorodnev²²,
 M. Slater¹⁷, T. Slavicek¹²⁷, K. Sliwa¹⁶¹, T.J. Sloan⁷¹, J. Sloper²⁹, V. Smakhtin¹⁷¹, S.Yu. Smirnov⁹⁶,
 L.N. Smirnova⁹⁷, O. Smirnova⁷⁹, B.C. Smith⁵⁷, D. Smith¹⁴³, K.M. Smith⁵³, M. Smizanska⁷¹,
 K. Smolek¹²⁷, A.A. Snesarev⁹⁴, S.W. Snow⁸², J. Snow¹¹¹, J. Snuverink¹⁰⁵, S. Snyder²⁴, M. Soares^{124a},
 R. Sobie^{169,k}, J. Sodomka¹²⁷, A. Soffer¹⁵³, C.A. Solans¹⁶⁷, M. Solar¹²⁷, J. Solc¹²⁷, E. Soldatov⁹⁶,
 U. Soldevila¹⁶⁷, E. Solfaroli Camillocci^{132a,132b}, A.A. Solodkov¹²⁸, O.V. Solovyanov¹²⁸, J. Sondericker²⁴,
 N. Soni², V. Sopko¹²⁷, B. Sopko¹²⁷, M. Sorbi^{89a,89b}, M. Sosebee⁷, A. Soukharev¹⁰⁷, S. Spagnolo^{72a,72b},
 F. Spanò⁷⁶, R. Spighi^{19a}, G. Spigo²⁹, F. Spila^{132a,132b}, E. Spiriti^{134a}, R. Spiwoks²⁹, M. Spousta¹²⁶,
 T. Spreitzer¹⁵⁸, B. Spurlock⁷, R.D. St. Denis⁵³, T. Stahl¹⁴¹, J. Stahlman¹²⁰, R. Stamen^{58a}, E. Stanecka²⁹,
 R.W. Stanek⁵, C. Stanescu^{134a}, S. Stapnes¹¹⁷, E.A. Starchenko¹²⁸, J. Stark⁵⁵, P. Staroba¹²⁵,
 P. Starovoitov⁹¹, A. Staude⁹⁸, P. Stavina^{144a}, G. Stavropoulos¹⁴, G. Steele⁵³, P. Steinbach⁴³,
 P. Steinberg²⁴, I. Stekl¹²⁷, B. Stelzer¹⁴², H.J. Stelzer⁸⁸, O. Stelzer-Chilton^{159a}, H. Stenzel⁵²,
 K. Stevenson⁷⁵, G.A. Stewart²⁹, J.A. Stillings²⁰, T. Stockmanns²⁰, M.C. Stockton²⁹, K. Stoerig⁴⁸,
 G. Stoicea^{25a}, S. Stonjek⁹⁹, P. Strachota¹²⁶, A.R. Stradling⁷, A. Straessner⁴³, J. Strandberg¹⁴⁷,
 S. Strandberg^{146a,146b}, A. Strandlie¹¹⁷, M. Strang¹⁰⁹, E. Strauss¹⁴³, M. Strauss¹¹¹, P. Strizenec^{144b},
 R. Ströhmer¹⁷³, D.M. Strom¹¹⁴, J.A. Strong^{76,*}, R. Stroynowski³⁹, J. Strube¹²⁹, B. Stugu¹³, I. Stumer^{24,*},
 J. Stupak¹⁴⁸, P. Sturm¹⁷⁴, D.A. Soh^{151,r}, D. Su¹⁴³, H.S. Subramania², A. Succurro¹¹, Y. Sugaya¹¹⁶,
 T. Sugimoto¹⁰¹, C. Suhr¹⁰⁶, K. Suita⁶⁷, M. Suk¹²⁶, V.V. Sulin⁹⁴, S. Sultansoy^{3d}, T. Sumida²⁹, X. Sun⁵⁵,
 J.E. Sundermann⁴⁸, K. Suruliz¹³⁹, S. Sushkov¹¹, G. Susinno^{36a,36b}, M.R. Sutton¹⁴⁹, Y. Suzuki⁶⁶,
 Y. Suzuki⁶⁷, M. Svatos¹²⁵, Yu.M. Sviridov¹²⁸, S. Swedish¹⁶⁸, I. Sykora^{144a}, T. Sykora¹²⁶, B. Szeless²⁹,
 J. Sánchez¹⁶⁷, D. Ta¹⁰⁵, K. Tackmann⁴¹, A. Taffard¹⁶³, R. Tafirout^{159a}, N. Taiblum¹⁵³, Y. Takahashi¹⁰¹,
 H. Takai²⁴, R. Takashima⁶⁹, H. Takeda⁶⁷, T. Takeshita¹⁴⁰, M. Talby⁸³, A. Talyshev¹⁰⁷, M.C. Tamssett²⁴,
 J. Tanaka¹⁵⁵, R. Tanaka¹¹⁵, S. Tanaka¹³¹, S. Tanaka⁶⁶, Y. Tanaka¹⁰⁰, K. Tani⁶⁷, N. Tannoury⁸³,
 G.P. Tappern²⁹, S. Tapprogge⁸¹, D. Tardif¹⁵⁸, S. Tarem¹⁵², F. Tarrade²⁸, G.F. Tartarelli^{89a}, P. Tas¹²⁶,
 M. Tasevsky¹²⁵, E. Tassi^{36a,36b}, M. Tatarkhanov¹⁴, Y. Tayalati^{135d}, C. Taylor⁷⁷, F.E. Taylor⁹²,
 G.N. Taylor⁸⁶, W. Taylor^{159b}, M. Teinturier¹¹⁵, M. Teixeira Dias Castanheira⁷⁵, P. Teixeira-Dias⁷⁶,
 K.K. Temming⁴⁸, H. Ten Kate²⁹, P.K. Teng¹⁵¹, S. Terada⁶⁶, K. Terashi¹⁵⁵, J. Terron⁸⁰, M. Terwort^{41,p},
 M. Testa⁴⁷, R.J. Teuscher^{158,k}, J. Thadome¹⁷⁴, J. Therhaag²⁰, T. Theveneaux-Pelzer⁷⁸, M. Thioye¹⁷⁵,
 S. Thoma⁴⁸, J.P. Thomas¹⁷, E.N. Thompson⁸⁴, P.D. Thompson¹⁷, P.D. Thompson¹⁵⁸, A.S. Thompson⁵³,
 E. Thomson¹²⁰, M. Thomson²⁷, R.P. Thun⁸⁷, F. Tian³⁴, T. Tic¹²⁵, V.O. Tikhomirov⁹⁴, Y.A. Tikhonov¹⁰⁷,
 C.J.W.P. Timmermans¹⁰⁴, P. Tipton¹⁷⁵, F.J. Tique Aires Viegas²⁹, S. Tisserant⁸³, J. Tobias⁴⁸, B. Toczek³⁷,
 T. Todorov⁴, S. Todorova-Nova¹⁶¹, B. Toggerson¹⁶³, J. Tojo⁶⁶, S. Tokár^{144a}, K. Tokunaga⁶⁷,
 K. Tokushuku⁶⁶, K. Tollefson⁸⁸, M. Tomoto¹⁰¹, L. Tompkins¹⁴, K. Toms¹⁰³, G. Tong^{32a}, A. Tonoyan¹³,
 C. Topfel¹⁶, N.D. Topilin⁶⁵, I. Torchiani²⁹, E. Torrence¹¹⁴, H. Torres⁷⁸, E. Torró Pastor¹⁶⁷, J. Toth^{83,x},
 F. Touchard⁸³, D.R. Tovey¹³⁹, D. Traynor⁷⁵, T. Trefzger¹⁷³, L. Tremblet²⁹, A. Tricoli²⁹, I.M. Trigger^{159a},
 S. Trincaz-Duvoid⁷⁸, T.N. Trinh⁷⁸, M.F. Tripiana⁷⁰, W. Trischuk¹⁵⁸, A. Trivedi^{24,w}, B. Trocme⁵⁵,
 C. Troncon^{89a}, M. Trottier-McDonald¹⁴², A. Trzupek³⁸, C. Tsarouchas²⁹, J.C.-L. Tseng¹¹⁸, M. Tsiakiris¹⁰⁵,

P.V. Tsiareshka⁹⁰, D. Tsionou⁴, G. Tsipolitis⁹, V. Tsiskaridze⁴⁸, E.G. Tskhadadze⁵¹, I.I. Tsukerman⁹⁵, V. Tsulaia¹⁴, J.-W. Tsung²⁰, S. Tsuno⁶⁶, D. Tsybychev¹⁴⁸, A. Tua¹³⁹, J.M. Tuggle³⁰, M. Turala³⁸, D. Turecek¹²⁷, I. Turk Cakir^{3e}, E. Turlay¹⁰⁵, R. Turra^{89a,89b}, P.M. Tuts³⁴, A. Tykhonov⁷⁴, M. Tylmad^{146a,146b}, M. Tyndel¹²⁹, H. Tyrvainen²⁹, G. Tzanakos⁸, K. Uchida²⁰, I. Ueda¹⁵⁵, R. Ueno²⁸, M. Ugland¹³, M. Uhlenbrock²⁰, M. Uhrmacher⁵⁴, F. Ukegawa¹⁶⁰, G. Unal²⁹, D.G. Underwood⁵, A. Undrus²⁴, G. Unel¹⁶³, Y. Unno⁶⁶, D. Urbaniec³⁴, E. Urkovsky¹⁵³, P. Urrejola^{31a}, G. Usai⁷, M. Uslenghi^{119a,119b}, L. Vacavant⁸³, V. Vacek¹²⁷, B. Vachon⁸⁵, S. Vahsen¹⁴, J. Valenta¹²⁵, P. Valente^{132a}, S. Valentini^{19a,19b}, S. Valkar¹²⁶, E. Valladolid Gallego¹⁶⁷, S. Vallecorsa¹⁵², J.A. Valls Ferrer¹⁶⁷, H. van der Graaf¹⁰⁵, E. van der Kraaij¹⁰⁵, R. Van Der Leeuw¹⁰⁵, E. van der Poel¹⁰⁵, D. van der Ster²⁹, B. Van Eijk¹⁰⁵, N. van Eldik⁸⁴, P. van Gemmeren⁵, Z. van Kesteren¹⁰⁵, I. van Vulpen¹⁰⁵, W. Vandelli²⁹, G. Vandoni²⁹, A. Vaniachine⁵, P. Vankov⁴¹, F. Vannucci⁷⁸, F. Varela Rodriguez²⁹, R. Vari^{132a}, D. Varouchas¹⁴, A. Vartapetian⁷, K.E. Varvell¹⁵⁰, V.I. Vassilakopoulos⁵⁶, F. Vazeille³³, G. Vegni^{89a,89b}, J.J. Veillet¹¹⁵, C. Vellidis⁸, F. Veloso^{124a}, R. Veness²⁹, S. Veneziano^{132a}, A. Ventura^{72a,72b}, D. Ventura¹³⁸, M. Venturi⁴⁸, N. Venturi¹⁶, V. Vercesi^{119a}, M. Verducci¹³⁸, W. Verkerke¹⁰⁵, J.C. Vermeulen¹⁰⁵, A. Vest⁴³, M.C. Vetterli^{142,e}, I. Vichou¹⁶⁵, T. Vickey^{145b,aa}, O.E. Vickey Boeriu^{145b}, G.H.A. Viehhauser¹¹⁸, S. Viel¹⁶⁸, M. Villa^{19a,19b}, M. Villaplana Perez¹⁶⁷, E. Vilucchi⁴⁷, M.G. Vincker²⁸, E. Vinek²⁹, V.B. Vinogradov⁶⁵, M. Virchaux^{136,*}, J. Virzi¹⁴, O. Vitells¹⁷¹, M. Viti⁴¹, I. Vivarelli⁴⁸, F. Vives Vaque², S. Vlachos⁹, M. Vlasak¹²⁷, N. Vlasov²⁰, A. Vogel²⁰, P. Vokac¹²⁷, G. Volpi⁴⁷, M. Volpi⁸⁶, G. Volpini^{89a}, H. von der Schmitt⁹⁹, J. von Loeben⁹⁹, H. von Radziewski⁴⁸, E. von Toerne²⁰, V. Vorobel¹²⁶, A.P. Vorobiev¹²⁸, V. Vorwerk¹¹, M. Vos¹⁶⁷, R. Voss²⁹, T.T. Voss¹⁷⁴, J.H. Vosseveld⁷³, N. Vranjes^{12a}, M. Vranjes Milosavljevic¹⁰⁵, V. Vrba¹²⁵, M. Vreeswijk¹⁰⁵, T. Vu Anh⁸¹, R. Vuillermet²⁹, I. Vukotic¹¹⁵, W. Wagner¹⁷⁴, P. Wagner¹²⁰, H. Wahlen¹⁷⁴, J. Wakabayashi¹⁰¹, J. Walbersloh⁴², S. Walch⁸⁷, J. Walder⁷¹, R. Walker⁹⁸, W. Walkowiak¹⁴¹, R. Wall¹⁷⁵, P. Waller⁷³, C. Wang⁴⁴, H. Wang¹⁷², H. Wang^{32b,ab}, J. Wang¹⁵¹, J. Wang^{32d}, J.C. Wang¹³⁸, R. Wang¹⁰³, S.M. Wang¹⁵¹, A. Warburton⁸⁵, C.P. Ward²⁷, M. Warsinsky⁴⁸, P.M. Watkins¹⁷, A.T. Watson¹⁷, M.F. Watson¹⁷, G. Watts¹³⁸, S. Watts⁸², A.T. Waugh¹⁵⁰, B.M. Waugh⁷⁷, J. Weber⁴², M. Weber¹²⁹, M.S. Weber¹⁶, P. Weber⁵⁴, A.R. Weidberg¹¹⁸, P. Weigell⁹⁹, J. Weingarten⁵⁴, C. Weiser⁴⁸, H. Wellenstein²², P.S. Wells²⁹, M. Wen⁴⁷, T. Wenaus²⁴, S. Wendler¹²³, Z. Weng^{151,r}, T. Wengler²⁹, S. Wenig²⁹, N. Wermes²⁰, M. Werner⁴⁸, P. Werner²⁹, M. Werth¹⁶³, M. Wessels^{58a}, C. Weydert⁵⁵, K. Whalen²⁸, S.J. Wheeler-Ellis¹⁶³, S.P. Whitaker²¹, A. White⁷, M.J. White⁸⁶, S.R. Whitehead¹¹⁸, D. Whiteson¹⁶³, D. Whittington⁶¹, F. Wicek¹¹⁵, D. Wicke¹⁷⁴, F.J. Wickens¹²⁹, W. Wiedenmann¹⁷², M. Wielers¹²⁹, P. Wienemann²⁰, C. Wiglesworth⁷⁵, L.A.M. Wiik⁴⁸, P.A. Wijeratne⁷⁷, A. Wildauer¹⁶⁷, M.A. Wildt^{41,p}, I. Wilhelm¹²⁶, H.G. Wilkens²⁹, J.Z. Will⁹⁸, E. Williams³⁴, H.H. Williams¹²⁰, W. Willis³⁴, S. Willocq⁸⁴, J.A. Wilson¹⁷, M.G. Wilson¹⁴³, A. Wilson⁸⁷, I. Wingerter-Seez⁴, S. Winkelmann⁴⁸, F. Winklmeier²⁹, M. Wittgen¹⁴³, M.W. Wolter³⁸, H. Wolters^{124a,i}, W.C. Wong⁴⁰, G. Wooden¹¹⁸, B.K. Wosiek³⁸, J. Wotschack²⁹, M.J. Woudstra⁸⁴, K. Wraight⁵³, C. Wright⁵³, B. Wrona⁷³, S.L. Wu¹⁷², X. Wu⁴⁹, Y. Wu^{32b,ac}, E. Wulf³⁴, R. Wunstorf⁴², B.M. Wynne⁴⁵, L. Xaplanteris⁹, S. Xella³⁵, S. Xie⁴⁸, Y. Xie^{32a}, C. Xu^{32b,ad}, D. Xu¹³⁹, G. Xu^{32a}, B. Yabsley¹⁵⁰, S. Yacoob^{145b}, M. Yamada⁶⁶, H. Yamaguchi¹⁵⁵, A. Yamamoto⁶⁶, K. Yamamoto⁶⁴, S. Yamamoto¹⁵⁵, T. Yamamura¹⁵⁵, T. Yamanaka¹⁵⁵, J. Yamaoka⁴⁴, T. Yamazaki¹⁵⁵, Y. Yamazaki⁶⁷, Z. Yan²¹, H. Yang⁸⁷, U.K. Yang⁸², Y. Yang⁶¹, Y. Yang^{32a}, Z. Yang^{146a,146b}, S. Yanush⁹¹, Y. Yao¹⁴, Y. Yasu⁶⁶, G.V. Ybeles Smit¹³⁰, J. Ye³⁹, S. Ye²⁴, M. Yilmaz^{3c}, R. Yoosofmiya¹²³, K. Yorita¹⁷⁰, R. Yoshida⁵, C. Young¹⁴³, S. Youssef²¹, D. Yu²⁴, J. Yu⁷, J. Yu^{32c,ad}, L. Yuan^{32a,ae}, A. Yurkewicz¹⁴⁸, V.G. Zaets¹²⁸, R. Zaidan⁶³, A.M. Zaitsev¹²⁸, Z. Zajacova²⁹, Yo.K. Zalite¹²¹, L. Zanello^{132a,132b}, P. Zarzhitsky³⁹, A. Zaytsev¹⁰⁷, C. Zeitnitz¹⁷⁴, M. Zeller¹⁷⁵, M. Zeman¹²⁵, A. Zemla³⁸, C. Zender²⁰, O. Zenin¹²⁸, T. Ženiš^{144a}, Z. Zenonos^{122a,122b}, S. Zenz¹⁴, D. Zerwas¹¹⁵, G. Zevi della Porta⁵⁷, Z. Zhan^{32d}, D. Zhang^{32b,ab}, H. Zhang⁸⁸, J. Zhang⁵, X. Zhang^{32d}, Z. Zhang¹¹⁵, L. Zhao¹⁰⁸, T. Zhao¹³⁸, Z. Zhao^{32b}, A. Zhemchugov⁶⁵, S. Zheng^{32a}, J. Zhong^{151,af}, B. Zhou⁸⁷, N. Zhou¹⁶³, Y. Zhou¹⁵¹, C.G. Zhu^{32d}, H. Zhu⁴¹, J. Zhu⁸⁷, Y. Zhu¹⁷², X. Zhuang⁹⁸, V. Zhuravlov⁹⁹, D. Ziemska⁶¹, R. Zimmermann²⁰, S. Zimmermann²⁰, S. Zimmermann⁴⁸, M. Ziolkowski¹⁴¹, R. Zitoun⁴, L. Živković³⁴, V.V. Zmouchko^{128,*}, G. Zobernig¹⁷², A. Zoccoli^{19a,19b}, Y. Zolnierowski⁴, A. Zsenei²⁹, M. zur Nedden¹⁵, V. Zutshi¹⁰⁶, L. Zwalinski²⁹

¹ University at Albany, Albany, NY, United States² Department of Physics, University of Alberta, Edmonton, AB, Canada

- ³ ^(a) Department of Physics, Ankara University, Ankara, Turkey; ^(b) Department of Physics, Dumlupinar University, Kutahya, Turkey; ^(c) Department of Physics, Gazi University, Ankara, Turkey; ^(d) Division of Physics, TOBB University of Economics and Technology, Ankara, Turkey; ^(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
- ⁶ Department of Physics, University of Arizona, Tucson, AZ, United States
- ⁷ Department of Physics, The University of Texas at Arlington, Arlington, TX, United States
- 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, Serbia; ^(b) Vinca Institute of Nuclear Sciences, Belgrade, Serbia
- ¹³ Department for Physics and Technology, University of Bergen, Bergen, Norway
- ¹⁴ Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, CA, United States
- 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, Turkey; ^(b) Division of Physics, Dogus University, Istanbul, Turkey; ^(c) Department of Physics Engineering, Gaziantep University, Gaziantep, Turkey; ^(d) Department of Physics, Istanbul Technical University, Istanbul, Turkey
- ¹⁹ ^(a) INFN Sezione di Bologna, Italy; ^(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
- ²² Department of Physics, Brandeis University, Waltham, MA, United States
- ²³ ^(a) Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil; ^(b) Federal University of Juiz de Fora (UFJF), Juiz de Fora, Brazil; ^(c) Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei, Brazil; ^(d) Instituto de Física, Universidade de Sao Paulo, Sao Paulo, Brazil
- ²⁴ Physics Department, Brookhaven National Laboratory, Upton, NY, United States
- ²⁵ ^(a) National Institute of Physics and Nuclear Engineering, Bucharest, Romania; ^(b) University Politehnica Bucharest, Bucharest, Romania; ^(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
- ³¹ ^(a) Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile; ^(b) Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
- ³² ^(a) Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China; ^(b) Department of Modern Physics, University of Science and Technology of China, Anhui, China; ^(c) Department of Physics, Nanjing University, Jiangsu, China; ^(d) High Energy Physics Group, Shandong University, Shandong, China
- ³³ Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Aubiere Cedex, France
- ³⁴ Nevis Laboratory, Columbia University, Irvington, NY, United States
- ³⁵ Niels Bohr Institute, University of Copenhagen, Kobenhavn, Denmark
- ³⁶ ^(a) INFN Gruppo Collegato di Cosenza, Italy; ^(b) Dipartimento di Fisica, Università della Calabria, Arcavata di Rende, Italy
- ³⁷ Faculty of Physics and Applied Computer Science, AGH-University of Science and Technology, Krakow, Poland
- ³⁸ The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
- ³⁹ Physics Department, Southern Methodist University, Dallas, TX, United States
- ⁴⁰ Physics Department, University of Texas at Dallas, Richardson, TX, United States
- 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
- 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, Italy; ^(b) Dipartimento di Fisica, Università di Genova, Genova, Italy
- ⁵¹ Institute of Physics and HEP Institute, Georgian Academy of Sciences and 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
- ⁵⁷ Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, MA, United States
- ⁵⁸ ^(a) Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany; ^(b) Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany; ^(c) ZITI Institut für technische Informatik, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany
- ⁵⁹ Faculty of Science, Hiroshima University, Hiroshima, Japan
- ⁶⁰ Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan
- ⁶¹ Department of Physics, Indiana University, Bloomington, IN, United States
- ⁶² Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
- ⁶³ University of Iowa, Iowa City, IA, United States
- ⁶⁴ Department of Physics and Astronomy, Iowa State University, Ames, IA, United States
- ⁶⁵ Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia
- ⁶⁶ KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
- ⁶⁷ Graduate School of Science, Kobe University, Kobe, Japan
- ⁶⁸ Faculty of Science, Kyoto University, Kyoto, Japan
- ⁶⁹ Kyoto University of Education, Kyoto, Japan
- ⁷⁰ Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
- ⁷¹ Physics Department, Lancaster University, Lancaster, United Kingdom
- ⁷² ^(a) INFN Sezione di Lecce, Italy; ^(b) Dipartimento di Fisica, Università del Salento, Lecce, Italy
- ⁷³ Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
- ⁷⁴ Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
- ⁷⁵ Department of Physics, Queen Mary University of London, London, United Kingdom

- 76 Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
- 77 Department of Physics and Astronomy, University College London, London, United Kingdom
- 78 Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
- 79 Fysiska institutionen, Lunds universitet, Lund, Sweden
- 80 Departamento de Física Teórica 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
- 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
- 88 Department of Physics and Astronomy, Michigan State University, East Lansing, MI, United States
- 89 ^(a) INFN Sezione di Milano, Italy; ^(b) Dipartimento di Fisica, Università di Milano, Milano, Italy
- 90 B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus
- 91 National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Belarus
- 92 Department of Physics, Massachusetts Institute of Technology, Cambridge, MA, United States
- 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, Italy; ^(b) Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy
- 103 Department of Physics and Astronomy, University of New Mexico, Albuquerque, NM, United States
- 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
- 107 Budker Institute of Nuclear Physics (BINP), Novosibirsk, Russia
- 108 Department of Physics, New York University, New York, NY, United States
- 109 Ohio State University, Columbus, OH, United States
- 110 Faculty of Science, Okayama University, Okayama, Japan
- 111 Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK, United States
- 112 Department of Physics, Oklahoma State University, Stillwater, OK, United States
- 113 Palacký University, RCPTM, Olomouc, Czech Republic
- 114 Center for High Energy Physics, University of Oregon, Eugene, OR, United States
- 115 LAL, Univ. Paris-Sud and CNRS/IN2P3, Orsay, France
- 116 Graduate School of Science, Osaka University, Osaka, Japan
- 117 Department of Physics, University of Oslo, Oslo, Norway
- 118 Department of Physics, Oxford University, Oxford, United Kingdom
- 119 ^(a) INFN Sezione di Pavia, Italy; ^(b) Dipartimento di Fisica Nucleare e Teorica, Università di Pavia, Pavia, Italy
- 120 Department of Physics, University of Pennsylvania, Philadelphia, PA, United States
- 121 Petersburg Nuclear Physics Institute, Gatchina, Russia
- 122 ^(a) INFN Sezione di Pisa, Italy; ^(b) Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
- 123 Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA, United States
- 124 ^(a) Laboratório de Instrumentação e Física Experimental de Partículas – LIP, Lisboa, Portugal; ^(b) Departamento de Física Teórica 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, Italy; ^(b) Dipartimento di Fisica, Università La Sapienza, Roma, Italy
- 133 ^(a) INFN Sezione di Roma Tor Vergata, Italy; ^(b) Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
- 134 ^(a) INFN Sezione di Roma Tre, Italy; ^(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, Morocco; ^(b) Centre National de l’Energie des Sciences Nucléaires, Rabat, Morocco; ^(c) Université Cadi Ayyad, Faculté des sciences Semlalia Département de Physique, B.P. 2390 Marrakech 40000, Morocco; ^(d) Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda, Morocco; ^(e) Faculté des Sciences, Université Mohammed V, Rabat, Morocco
- 136 DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l’Univers), CEA Saclay (Commissariat à l’Energie Atomique), Gif-sur-Yvette, France
- 137 Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, CA, United States
- 138 Department of Physics, University of Washington, Seattle, WA, United States
- 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
- 144 ^(a) Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava, Slovak Republic; ^(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, South Africa; ^(b) School of Physics, University of the Witwatersrand, Johannesburg, South Africa
- 146 ^(a) Department of Physics, Stockholm University, Sweden; ^(b) The Oskar Klein Centre, Stockholm, Sweden
- 147 Physics Department, Royal Institute of Technology, Stockholm, Sweden
- 148 Department of Physics and Astronomy, Stony Brook University, Stony Brook, NY, United States
- 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, Canada; ^(b) Department of Physics and Astronomy, York University, Toronto, ON, Canada
¹⁶⁰ Institute of Pure and Applied Sciences, University of Tsukuba, Ibaraki, Japan
¹⁶¹ Science and Technology Center, Tufts University, Medford, MA, United States
¹⁶² Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia
¹⁶³ Department of Physics and Astronomy, University of California Irvine, Irvine, CA, United States
¹⁶⁴ ^(a) INFN Gruppo Collegato di Udine, Italy; ^(b) ICTP, Trieste, Italy; ^(c) Dipartimento di Fisica, Università di Udine, Udine, Italy
¹⁶⁵ Department of Physics, University of Illinois, Urbana, IL, United States
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 Waseda University, Tokyo, Japan
¹⁷¹ Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
¹⁷² Department of Physics, University of Wisconsin, Madison, WI, United States
¹⁷³ Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany
¹⁷⁴ Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany
¹⁷⁵ Department of Physics, Yale University, New Haven, CT, United States
¹⁷⁶ Yerevan Physics Institute, Yerevan, Armenia
¹⁷⁷ Domaine scientifique de la Doua, Centre de Calcul CNRS/IN2P3, Villeurbanne Cedex, France

^a Also at Laboratório de Instrumentação e Física Experimental de Partículas – LIP, Lisboa, Portugal.

^b Also at Faculdade de Ciências and CFNUL, Universidade de Lisboa, Lisboa, Portugal.

^c Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom.

^d Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France.

^e Also at TRIUMF, Vancouver, BC, Canada.

^f Also at Department of Physics, California State University, Fresno, CA, United States.

^g Also at Faculty of Physics and Applied Computer Science, AGH-University of Science and Technology, Krakow, Poland.

^h Also at Fermilab, Batavia, IL, United States.

ⁱ Also at Department of Physics, University of Coimbra, Coimbra, Portugal.

^j Also at Università di Napoli Parthenope, Napoli, Italy.

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

^l Also at Department of Physics, Middle East Technical University, Ankara, Turkey.

^m Also at Louisiana Tech University, Ruston, LA, United States.

ⁿ Also at Group of Particle Physics, University of Montreal, Montreal, QC, Canada.

^o Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.

^p Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.

^q Also at Manhattan College, New York, NY, United States.

^r Also at School of Physics and Engineering, Sun Yat-sen University, Guanzhou, China.

^s Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan.

^t Also at High Energy Physics Group, Shandong University, Shandong, China.

^u Also at Section de Physique, Université de Genève, Geneva, Switzerland.

^v Also at Departamento de Física, Universidade de Minho, Braga, Portugal.

^w Also at Department of Physics and Astronomy, University of South Carolina, Columbia, SC, United States.

^x Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary.

^y Also at California Institute of Technology, Pasadena, CA, United States.

^z Also at Institute of Physics, Jagiellonian University, Krakow, Poland.

^{aa} Also at Department of Physics, Oxford University, Oxford, United Kingdom.

^{ab} Also at Institute of Physics, Academia Sinica, Taipei, Taiwan.

^{ac} Also at Department of Physics, The University of Michigan, Ann Arbor, MI, United States.

^{ad} Also at DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique), Gif-sur-Yvette, France.

^{ae} Also at Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France.

^{af} Also at Department of Physics, Nanjing University, Jiangsu, China.

* Deceased.