Measurements of differential jet cross sections in proton-proton collisions at $\sqrt{s}=7$ TeV with the CMS detector

CMS Collaboration; Amsler, C; Chiochia, V; Kilminster, B; et al

Abstract: Measurements of inclusive jet and dijet production cross sections are presented. Data from LHC proton-proton collisions at $\sqrt{s}=7$ TeV, corresponding to 5.0 fb$^{-1}$ of integrated luminosity, have been collected with the CMS detector. Jets are reconstructed up to rapidity 2.5, transverse momentum 2 TeV, and dijet invariant mass 5 TeV, using the anti-kT clustering algorithm with distance parameter $R=0.7$. The measured cross sections are corrected for detector effects and compared to perturbative QCD predictions at next-to-leading order, using five sets of parton distribution functions.

DOI: [https://doi.org/10.1103/PhysRevD.87.112002](https://doi.org/10.1103/PhysRevD.87.112002)

ZORA URL: [https://doi.org/10.5167/uzh-75824](https://doi.org/10.5167/uzh-75824)

Originally published at:
CMS Collaboration; Amsler, C; Chiochia, V; Kilminster, B; et al (2013). Measurements of differential jet cross sections in proton-proton collisions at $\sqrt{s}=7$ TeV with the CMS detector. Physical Review D (Particles, Fields, Gravitation and Cosmology), 87(11):112002.

DOI: [https://doi.org/10.1103/PhysRevD.87.112002](https://doi.org/10.1103/PhysRevD.87.112002)
Measurements of differential jet cross sections in proton-proton collisions at $\sqrt{s} = 7$ TeV with the CMS detector

The CMS Collaboration

Abstract

Measurements of inclusive jet and dijet production cross sections are presented. Data from LHC proton-proton collisions at $\sqrt{s} = 7$ TeV, corresponding to 5.0 fb$^{-1}$ of integrated luminosity, have been collected with the CMS detector. Jets are reconstructed up to rapidity 2.5, transverse momentum 2 TeV, and dijet invariant mass 5 TeV, using the anti-$k_T$ clustering algorithm with distance parameter $R = 0.7$. The measured cross sections are corrected for detector effects and compared to perturbative QCD predictions at next-to-leading order, using five sets of parton distribution functions.

Submitted to Physical Review D

*See Appendix A for the list of collaboration members
1 Introduction

Events with high transverse momentum jets in proton-proton collisions are described by quantum chromodynamics (QCD) in terms of parton-parton scattering, where the outgoing scattered partons manifest themselves as hadronic jets. Measurements of the inclusive jet and dijet cross sections can be used to test the predictions of perturbative QCD, constrain parton distribution functions (PDFs) of the proton, differentiate among PDF sets, and look for possible deviations from the standard model.

In this paper, measurements of the double-differential inclusive jet \( p + p \rightarrow \text{jet} + X \) and dijet \( p + p \rightarrow \text{jet} + \text{jet} + X \) production cross sections are reported as functions of jet rapidity \( y \) and either jet transverse momentum \( p_T \) or dijet invariant mass \( M_{jj} \), at \( \sqrt{s} = 7 \text{ TeV} \). The data were collected with the Compact Muon Solenoid (CMS) detector at the CERN Large Hadron Collider (LHC) during the 2011 run and correspond to an integrated luminosity of 5.0 fb\(^{-1} \), two orders of magnitude larger than the published LHC results from the 2010 run \([1, 2]\). Jets are reconstructed up to rapidity 2.5, transverse momentum 2 TeV, and dijet invariant mass 5 TeV. The measured cross sections are corrected for detector effects and compared to the next-to-leading-order QCD predictions.

2 Apparatus

The CMS coordinate system has its origin at the center of the detector, with the \( z \) axis pointing along the direction of the counterclockwise beam. The azimuthal angle is denoted as \( \phi \), the polar angle as \( \theta \), and the pseudorapidity is defined as \( \eta = - \ln \left[ \tan \left( \theta/2 \right) \right] \). The central feature of the CMS detector is a superconducting solenoid, of 6 m internal diameter, that produces an axial magnetic field of 3.8 T. Within the field volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL) and a brass/plastic scintillator hadronic calorimeter. Outside the field volume and in the forward region \( (3 < |\eta| < 5) \) is an iron/quartz-fiber hadronic calorimeter. Muons are measured in gas ionization detectors embedded in the steel return yoke outside the solenoid, in the pseudorapidity range \( |\eta| < 2.4 \). A detailed description of the CMS apparatus can be found in Ref. \([4]\).

3 Jet reconstruction

The rapidity \( y \) and the transverse momentum \( p_T \) of a jet with energy \( E \) and momentum \( \vec{p} = (p_x, p_y, p_z) \) are defined as \( y = (1/2) \ln \left[ (E + p_z)/(E - p_z) \right] \) and \( p_T = \sqrt{p_x^2 + p_y^2} \). The inputs to the jet clustering algorithm are the four-momentum vectors of the reconstructed particle candidates. Each such candidate is constructed using the particle-flow technique \([5]\), which combines the information from several subdetectors and is calibrated to account for the nonlinear and nonuniform response of the CMS calorimetric system to hadrons. Jets are reconstructed using the anti-\( k_T \) clustering algorithm \([6]\) with distance parameter \( R = 0.7 \). The clustering is performed using four-momentum summation with the FASTJET package \([7]\), where the chosen distance parameter allows for the capture of most of the parton shower and improves the dijet mass resolution with respect to smaller sizes. The total transverse energy \( \Sigma E_T \) and missing transverse energy \( \vec{E}_T^{\text{miss}} \) are used in the event selection and are derived from the reconstructed particle-flow objects. They are defined as \( \Sigma E_T = \sum_i E_{Ti}, \) with \( E_{Ti} = E_i \sin \theta_i \), and \( \vec{E}_T^{\text{miss}} = - \sum_i (E_i \sin \theta_i \cos \phi_i \hat{x} + E_i \sin \theta_i \sin \phi_i \hat{y}) \), where the sum refers to all particle candidates and \( \hat{x}, \hat{y} \) are the unit vectors in the direction of the \( x \) and \( y \) axes.
The reconstructed jets require a small additional energy correction, mostly due to thresholds on reconstructed tracks and clusters in the particle-flow algorithm, and various reconstruction inefficiencies. These jet energy corrections are derived using simulated events, generated by PYTHIA6 (version 6.4.22) \[8\] and processed through the CMS detector simulation based on GEANT4 \[9\], and in situ measurements with dijet, photon+jet, and Z+jet events \[10\]. These jet energy corrections correct reconstructed jets to the hadron level, as opposed to the parton level. An offset correction is also applied to account for the extra energy from additional proton-proton interactions within the same or neighboring bunch crossings (in-time and out-of-time pileup) \[10\]. The pileup effects are important for the lowest-$p_T$ jets (10% jet energy scale correction and 1% systematic uncertainty \[11\] for jets with $p_T \sim 100$ GeV) and progressively decrease with jet $p_T$. For jets with $p_T > 200$ GeV the pileup effects are negligible. The jet energy correction depends on $\eta$ and $p_T$ of the jet, and is applied as a multiplicative factor to the jet four-momentum vector. The factor is typically between 1.0 and 1.2 and is approximately uniform in $\eta$. For a jet $p_T = 100$ GeV the factor is 1.1, decreasing towards 1.0 with increasing $p_T$. The typical jet $p_T$ resolution is 10% at $p_T = 100$ GeV. The dijet mass $M_{jj}$ is calculated from the corrected four-momentum vectors of the two jets with the highest $p_T$ (leading jets). The relative dijet-mass resolution, estimated from the simulation, ranges from 7% at $M_{jj} = 0.2$ TeV to 3% at $M_{jj} = 3$ TeV.

4 Data samples and event selection

The data samples used for this measurement were collected with single-jet high-level triggers (HLT) \[12\] that require at least one jet in the event to have $p_T > 60, 110, 190, 240, \text{ or } 370$ GeV, respectively, in corrected jet transverse momentum. The online jet reconstruction uses only calorimetric information and the resulting HLT jets typically have worse energy resolution than the offline particle-flow jets. The lower-$p_T$ triggers were prescaled and the corresponding integrated luminosity of each trigger sample, $L_{\text{eff}}$, is listed in Table 1. In the offline analysis, events are required to have at least one well reconstructed proton-proton interaction vertex \[13\]. In order to suppress nonphysical jets, i.e., jets resulting from noise in the electromagnetic and/or hadronic calorimeters, the jets are required to satisfy the following identification criteria. Each jet should contain at least two particles, one of which is a charged hadron, and the jet energy fraction carried by neutral hadrons and photons should be less than 90%. These criteria have an efficiency greater than 99% for physical jets.

| Min. jet trigger $p_T$ (GeV) | 60 | 110 | 190 | 240 | 370 |
|-----------------------------|----|-----|-----|-----|-----|
| Jet trigger name            | Jet60 | Jet110 | Jet190 | Jet240 | Jet370 |
| $L_{\text{eff}}$ (pb$^{-1}$) | 0.41 | 7.3 | 152 | 512 | 4980 |

The inclusive single-jet cross section measurements are made in five rapidity regions of size $\Delta|y| = 0.5$ over the range $0.0$–$2.5$. Jets that do not satisfy the jet identification criteria are discarded and events are required to contain at least one jet that satisfies these criteria. In order to avoid any trigger bias, the jets are additionally required to have $p_T > 110, 200, 300, 360, \text{ and } 510$ GeV for the five single-jet HLT triggers used, respectively. Figure 1(left) shows the trigger efficiency as a function of the jet $p_T$, for the central rapidity bin $|y| < 0.5$ and for the highest trigger threshold. The efficiency of each trigger path has been measured using events collected with a lower threshold single-jet trigger and confirmed with events collected with single-muon triggers.
Jets from rare events with instrumental noise, beam halo effects, and spurious signals that might survive the jet identification criteria are suppressed by requiring $E_{\text{T}}^{\text{miss}} / \Sigma E_{\text{T}} < 0.3$. Hard QCD processes do not generate true $E_{\text{T}}^{\text{miss}}$ and so the measured values of $E_{\text{T}}^{\text{miss}}$ in such events, due to jet mismeasurements and the energy resolution of the detector, are small compared to the total transverse energy. Hence, the distribution of the variable $E_{\text{T}}^{\text{miss}} / \Sigma E_{\text{T}}$ peaks close to zero for QCD events, while events contaminated with noise give larger values. Figure 2 (left) shows a typical distribution of the variable $E_{\text{T}}^{\text{miss}} / \Sigma E_{\text{T}}$ for events with at least one jet with $p_{\text{T}} > 510 \text{ GeV}$, collected with the 370 GeV single-jet trigger. The data points exceed the QCD predictions at large values of $E_{\text{T}}^{\text{miss}}$ due to instrumental backgrounds and physics processes such as Z+jet(s), where the Z boson decays to neutrinos, and W+jet(s), where the W boson decays to leptons.

For the dijet measurement, at least two jets with $p_{\text{T},1} > 60 \text{ GeV}$ and $p_{\text{T},2} > 30 \text{ GeV}$ and satisfying the tight identification criteria are required. If either of the leading jets fails the identification criteria, the event is discarded. The dijet measurement is performed in five rapidity regions, defined by the maximum absolute rapidity $|y|_{\text{max}} = \max(|y_{1}|, |y_{2}|)$ of the two leading jets in the event. The use of the variable $|y|_{\text{max}}$ divides the phase space of the dijet system into exclusive rapidity bins, which correspond to different scattering angles in the center-of-mass frame.

Low values of $|y|_{\text{max}}$ probe $s$-channel scattering at large angles, while large values of $|y|_{\text{max}}$ probe $t$-channel scattering at small angles. For each rapidity bin the trigger efficiency is expressed as a function of $M_{jj}$, and the events are required to satisfy a minimum mass threshold, which increases with $|y|_{\text{max}}$. Figure 2 (right) shows the trigger efficiency for the central rapidity bin and for the highest trigger threshold. Because of the dijet topology, no further cut is needed on the $E_{\text{T}}^{\text{miss}} / \Sigma E_{\text{T}}$ variable, as can be seen in Fig. 2 (right).

Figure 1: Trigger efficiency as a function of the jet $p_{\text{T}}$ (left) and dijet mass $M_{jj}$ (right) for the 370 GeV single-jet trigger and for the central rapidity bins.

5 Measurement of the differential jet and dijet cross sections

In this section the construction of the jet transverse momentum and dijet mass spectra from the different samples is presented. Then the unfolding procedure, which translates the reconstructed spectra into true spectra, is described. Finally, the experimental uncertainties related to the measurements are described and discussed.

5.1 Determination of transverse momentum and dijet mass spectra

The jet $p_{\text{T}}$ (dijet invariant mass) spectrum is obtained by populating each bin with the number of jets (events) collected using the highest threshold trigger which gave more than 99% trigger
The observed inclusive jet yields are transformed into double-differential cross sections as follows:

\[
\frac{d^2\sigma}{dp_T^2dy} = \frac{1}{\epsilon \cdot \mathcal{L}_{\text{eff}} \Delta p_T \Delta y} \frac{N_{\text{jets}}}{},
\]

where \( N_{\text{jets}} \) is the number of jets in the bin, \( \mathcal{L}_{\text{eff}} \) is the integrated luminosity of the data sample from which the events are taken, \( \epsilon \) is the product of the trigger and event selection efficiencies, both of which are greater than 99%, and \( \Delta p_T \) and \( \Delta y \) are the transverse momentum and rapidity bin widths, respectively. The width of the \( p_T \) bins is proportional to the \( p_T \) resolution and so increases with \( p_T \). The statistical uncertainty assigned to each \( p_T \) bin takes into account the number of independent events that contribute least one jet in the bin. The largest fraction (more than 90%) of the observed jets in each \( p_T \) bin originate from different events, however a small fraction of events contribute more than one jet. Such events are typically back-to-back dijet events, so closely balanced in \( p_T \) that both jets end up in the same \( y \) and \( p_T \) bin.
The statistical uncertainty in the number of jets in a bin is $\epsilon_{\text{stat}} = \sqrt{\frac{4 - 3f}{2 - f}} \cdot \sqrt{\frac{N_{\text{jets}}}{N_{\text{ev}}}}$, where $f = N_1 / N_{\text{ev}}$ is the fraction of events that contribute one jet in the given bin. The formula is valid under the assumption that the number of events that contribute more than two jets in each bin is negligible, which has been verified for the current measurement.

The observed dijet yields are transformed into double-differential cross sections as follows:

$$\frac{d^2\sigma}{dM_{jj}d|y|_{\text{max}}} = \frac{1}{\epsilon \cdot L_{\text{eff}} \cdot \Delta M_{jj} \Delta |y|_{\text{max}}},$$

where $\Delta M_{jj}$ and $\Delta |y|_{\text{max}}$ are the mass and rapidity bin widths, respectively. The size of the dijet mass bins is approximately equal to or larger than the mass resolution at the bin center, while the bins at the edge of the spectrum have been merged to assure a minimal number of events in each bin.

## 5.2 Unfolding

Because of the detector resolution and the steeply falling spectra, the measured differential cross sections are smeared with respect to the particle-level cross sections. Each $p_T$ and mass bin contains events that have migrated in from neighboring bins and is missing events that have migrated out. For a steeply falling spectrum more events migrate into a bin than out. In order to allow for a direct comparison of experimental measurements with corresponding results from other experiments and with QCD predictions, the spectra are unfolded in order to correct for detector effects. The response matrix is obtained from the detector simulation and corrected for the measured differences in the resolution between data and simulation [10]. Figure 4 shows the response matrices for the jet $p_T$ (left) and the dijet mass (right) in the central rapidity bins. The unfolding is done with the RooUnfold package [14] using the D’Agostini method [15].

![Figure 4: Response matrices for the inclusive jet $p_T$ spectrum (left) and the dijet mass spectrum (right) in the central rapidity bins.](image)

## 5.3 Experimental uncertainties

The dominant experimental uncertainties are related to the jet energy scale (JES), the luminosity, and the jet $p_T$ resolution. Other sources of systematic uncertainty, such as the jet angular resolution, are negligible. The agreement of the results for positive and negative rapidities has
also been confirmed. Figure 5 shows the effects of the experimental uncertainties in all rapidity bins for the cross section measurements. For rapidities up to $|y| = 1.5$ the total uncertainty of both cross sections ranges from 5% at low $p_T$ or $M_{jj}$ to 20% at high $p_T$ or $M_{jj}$, respectively. For higher rapidities the total uncertainty increases to 10–30% in both cases, with the exception of the highest dijet mass bin in the outer rapidity region of $2.0 < |y|_{\text{max}} < 2.5$, where the uncertainty is substantially larger. A discussion of the individual contributions to the uncertainty follows.

5.3.1 Jet energy scale (JES) uncertainty

The jet energy scale is the dominant source of systematic uncertainty. Because of the steep slope of the $p_T$ spectrum, a small uncertainty in the $p_T$ scale translates into a large uncertainty in the cross section for a given value of $p_T$. The jet energy scale uncertainty is dependent on $p_T$ and $\eta$ and has been estimated to be 2.0–2.5% [11]. The individual, uncorrelated contributions to the JES uncertainty have been estimated and are discussed below.

The JES uncertainty sources account for the $p_T$ and $\eta$ dependence of the JES within the total uncertainty. For the phase space of jets considered here, 16 mutually uncorrelated sources contribute to the total uncertainty, where each such source represents a signed 1σ variation from a given systematic effect for each point in $(p_T, \eta)$. Summing up separately the positive or negative variations of the sources in quadrature will reproduce the total upward and downward JES uncertainties at each point. The uncertainties from all 16 independent sources are included in the HEPDATA record for this paper.

The uncertainty sources are divided into four broad categories: pileup effects, relative calibration of jet energy scale versus $\eta$, absolute energy scale including $p_T$ dependence, and differences in quark- and gluon-initiated jets. The first category, containing pileup effects, has relatively little impact on the analyses presented in this paper.

The second category, containing $\eta$-dependent effects, parameterizes the possible relative variations in JES, which for the dijet and inclusive jet analyses lead to correlations between rapidity bins. In principle these effects could also have a $p_T$ dependence, but systematic studies on data and Monte Carlo (MC) events indicate that the $p_T$ and $\eta$ dependence of the uncertainties factorize to a good approximation.

The third category deals with the uncertainty in the absolute energy scale and its $p_T$ dependence and is the most relevant one for these analyses. The photon+jet and Z+jet events only constrain the JES directly in a limited jet $p_T$ range of about 30–600 GeV, and the response at higher (and lower) $p_T$ is estimated by MC simulation. The $p_T$-dependent uncertainty arising from modeling of the underlying event and jet fragmentation is obtained by comparing predictions from PYTHIA6 and HERWIG++. Most studies show that both generators agree with the data with differences comparable to those seen between data and MC. The uncertainty arising from the calorimeter response to single hadrons is estimated by varying the response parameterization by $\pm 3\%$ as compared to the central value. The final uncertainty arises from differences in the JES for quark- and gluon-initiated jets and is determined from MC studies.

5.3.2 Luminosity uncertainty

The luminosity uncertainty is estimated to be 2.2% [16], which can be directly translated into a 2.2% uncertainty on the cross section normalization. It is fully correlated across all $p_T$ and mass bins.
Figure 5: Effect of the relative experimental uncertainties for the inclusive jet (left column) and dijet (right column) cross section measurements, and for all five $|y|$ and $|y|_{\text{max}}$ bins, respectively. The upward and downward uncertainties are estimated separately.
5.3.3 Unfolding uncertainty

The unfolding correction is closely related to the dependence on the $p_T$ and $M_{jj}$ resolution and the spectrum slope. For the inclusive jet $p_T$ spectrum it varies between 5% and 10%, while for the dijet mass spectrum it ranges between 2% and 5%. The shape of the unfolding correction and uncertainty as displayed in Fig. 5 is understood as follows: the resolution in the observable, $p_T$ or $M_{jj}$, improves when going from low to high values. As a consequence the effect of smearing is more pronounced in the lower $p_T$ or $M_{jj}$ region. On the other hand the $p_T$ and $M_{jj}$ spectra become steeper when approaching the kinematic limit at high $p_T$ or $M_{jj}$, leading again to a larger smearing effect than observed at medium values.

The uncertainty introduced by the unfolding is caused by the modeling of the jet $p_T$ (dijet mass) resolution and the jet $p_T$ (dijet mass) spectrum in the simulation. In order to estimate the sensitivity of the correction to these inputs, the jet $p_T$ resolution is varied by $\pm 10\%$ and the jet (dijet mass) spectrum slope by $\pm 5\%$. The former is motivated by the observed difference between data and simulation in the jet energy resolution [10], and the latter is a conservative estimate based on comparisons of the theoretical and measured spectrum shapes. An additional constant 2% uncertainty is assigned to the dependence on the unfolding method. Overall, the unfolding uncertainty is of the order of 3–4%, fully correlated across the $p_T$ and mass bins.

5.3.4 Other uncertainty sources

The contributions from small trigger and jet identification inefficiencies, time dependence of the jet $p_T$ resolution, and uncertainty on the trigger prescale factor have been shown to be much smaller than 1%. To account for these residual effects a conservative uncertainty of 1% is assigned to each jet $p_T$ and dijet mass bin, uncorrelated across the bins.

6 Theoretical predictions

The theoretical predictions for the jet cross sections consist of a next-to-leading-order (NLO) QCD calculation and a nonperturbative (NP) correction to account for the multiparton interactions (MPI) and hadronization effects.

6.1 NLO calculations

The NLO calculations are performed using the NLOJet++ program (v2.0.1) [17] within the framework of the fastNLO package (v1.4) [18]. The renormalization and factorization scales ($\mu_R$ and $\mu_F$) for the inclusive and dijet measurements are identified with the jet $p_T$ and the average transverse momentum $p_T^{\text{ave}}$ of the two jets, respectively. The NLO calculation is performed using five different PDF sets: CT10 [19], MSTW2008NLO [20], NNPDF2.1 [21], HERAPDF1.5 [22], and ABKM09 [23] at the corresponding default values of the strong coupling constant $\alpha_S(M_Z) = 0.1180, 0.120, 0.119, 0.1176, \text{and } 0.1179$, respectively.

6.2 Systematic uncertainties

The PDF variation introduces uncertainties in the theoretical prediction of up to 30%, while the variation of $\alpha_S(M_Z)$ by $\pm 0.001$ introduces an additional 1–2% uncertainty. The uncertainty due to the choice of factorization and renormalization scales is estimated as the maximum deviation at the six points $(\mu_F/\mu, \mu_R/\mu) = (0.5, 0.5), (2, 2), (1, 0.5), (1, 2), (0.5, 1), (2, 1)$, where $\mu = p_T$ (inclusive) or $\mu = p_T^{\text{ave}}$ (dijet). An additional uncertainty of at most 10% is caused by the nonperturbative correction. The scale uncertainty ranges from 5% to 10% for $|y| < 1.5$ but increases to 40% for the outer $|y|$ bins and for high dijet masses and jet $p_T$. Overall, the PDF
uncertainty is dominant for the high $p_T$ and high dijet mass regions. Figure 6 shows the effect of the systematic uncertainties for the two observables in all rapidity bins and for the NNPDF2.1 PDF set.

### 6.3 Nonperturbative corrections

The nonperturbative effects are estimated from the simulation, using the event generators PYTHIA6 (tune Z2) and HERWIG++ 2.4.2 [24]. (The PYTHIA6 Z2 tune is identical to the Z1 tune described in [25] except that Z2 uses the CTEQ6L PDF while Z1 uses CTEQ5L.) These models are representative of the possible values of the nonperturbative corrections, due to their different physics descriptions. The nonperturbative correction is defined as the ratio of the cross section predicted with the nominal generator settings divided by the cross section predicted with the MPI and hadronization switched off. The central value of the nonperturbative correction is calculated from the average of the two models considered, and ranges from 1% to 20%, being larger in the dijet spectrum because of the involvement of lower $p_T$ jets.

### 7 Results

The unfolded inclusive jet and dijet spectra are shown in Fig. 7 compared to the theoretical predictions.

To compare the CMS data and the theoretical prediction, the ratio of the two is taken. Figures 8–9 show this ratio using the central value of the NNPDF2.1 PDF set, accompanied by the total experimental and theoretical uncertainties. The theoretical uncertainties vary considerably among the different PDF sets, and in particular in the high-$p_T$ and high-$M_{jj}$ region. The experimental uncertainty is comparable to the theoretical uncertainty. The additional curves represent the ratio of the central values of the other PDF sets to NNPDF2.1. Agreement is observed between data and theory in all rapidity bins, given the statistical and systematic uncertainties, with the various theoretical predictions showing differences of the order of 10%.

### 8 Summary

Measurements of the double-differential inclusive jet and dijet cross sections are presented using 5.0 fb$^{-1}$ of data collected with the CMS detector in proton-proton collisions at $\sqrt{s} = 7$ TeV. The measurements cover the jet $p_T$ range from 0.1 TeV to 2 TeV, and the dijet-mass range from 0.3 TeV to 5 TeV in five rapidity bins up to $|y| = 2.5$. The measured cross sections agree with the predictions of perturbative QCD at next-to-leading order obtained with five different PDF sets. Theoretical and experimental uncertainties are comparable, even at the limits of the experimental phase space, so these results may be used to constrain global PDF fits.

### Acknowledgements

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: the Austrian Federal Ministry of Science
Figure 6: Effect of the relative theoretical uncertainties for the inclusive jet (left column) and dijet (right column) cross section measurements for all five $|y|$ and $|y|_{\text{max}}$ bins, respectively. The upward and downward uncertainties are estimated separately.
Figure 7: Inclusive jet (left) and dijet (right) cross sections for the five different rapidity bins, for data (markers) and theory (thick lines) using the NNPDF2.1 PDF set.

and Research; the Belgian Fonds de la Recherche Scientifique, and Fonds voor Wetenschappelijk Onderzoek; the Brazilian Funding Agencies (CNPq, CAPES, FAPERJ, and FAPESP); the Bulgarian Ministry of Education, Youth and Science; CERN; the Chinese Academy of Sciences, Ministry of Science and Technology, and National Natural Science Foundation of China; the Colombian Funding Agency (COLCIENCIAS); the Croatian Ministry of Science, Education and Sport; the Research Promotion Foundation, Cyprus; the Ministry of Education and Research, Recurrent financing contract SF0690030s09 and European Regional Development Fund, Estonia; the Academy of Finland, Finnish Ministry of Education and Culture, and Helsinki Institute of Physics; the Institut National de Physique Nucléaire et de Physique des Particules / CNRS, and Commissariat à l’Énergie Atomique et aux Énergies Alternatives / CEA, France; the Bundesministerium für Bildung und Forschung, Deutsche Forschungsgemeinschaft, and Helmholtz-Gemeinschaft Deutscher Forschungszentren, Germany; the General Secretariat for Research and Technology, Greece; the National Scientific Research Foundation, and National Office for Research and Technology, Hungary; the Department of Atomic Energy and the Department of Science and Technology, India; the Institute for Studies in Theoretical Physics and Mathematics, Iran; the Science Foundation, Ireland; the Istituto Nazionale di Fisica Nucleare, Italy; the Korean Ministry of Education, Science and Technology and the World Class University program of NRF, Republic of Korea; the Lithuanian Academy of Sciences; the Mexican Funding Agencies (CINVESTAV, CONACYT, SEP, and UASLP-FAI); the Ministry of Science and Innovation, New Zealand; the Pakistan Atomic Energy Commission; the Ministry of Science and Higher Education and the National Science Centre, Poland; the Fundação para a Ciência e a Tecnologia, Portugal; JINR (Armenia, Belarus, Georgia, Ukraine, Uzbekistan); the Ministry of Education and Science of the Russian Federation, the Federal Agency of Atomic Energy of the Russian Federation, Russian Academy of Sciences, and the Russian Foundation for Basic Research; the Ministry of Science and Technological Development of Serbia; the Secretaría de Estado de Investigación, Desarrollo e Innovación y Programa Consolider-Ingenio 2010, Spain; the Swiss Funding Agencies (ETH Board, ETH Zurich, PSI, SNF, UniZH, Canton Zurich, and SER); the National Science Council, Taipei; the Thailand Center of Excellence in Physics, the Institute for the Promotion of Teaching Science and Technology of Thailand and the National Science and Technology Development Agency of Thailand; the Scientific and Technical
Figure 8: Ratio of inclusive jet (left) and dijet (right) cross sections to the theoretical prediction using the central value of the NNPDF2.1 PDF set for the first three $|y|$ and $|y|_{\text{max}}$ bins respectively. The solid histograms show the ratio of the cross sections calculated with the other PDF sets to that calculated with NNPDF2.1. The experimental and theoretical systematic uncertainties are represented by the continuous and hatched bands, respectively.
Figure 9: Ratio of inclusive jet (left) and dijet (right) cross sections to the theoretical prediction using the central value of the NNPDF2.1 PDF set for the last two $|y|$ and $|y|_{\text{max}}$ bins respectively. The solid histograms show the ratio of the cross sections calculated with the other PDF sets to that calculated with NNPDF2.1. The experimental and theoretical systematic uncertainties are represented by the continuous and hatched bands, respectively.
Research Council of Turkey, and Turkish Atomic Energy Authority; the Science and Technology Facilities Council, UK; the US Department of Energy, and the US National Science Foundation. Individuals have received support from the Marie-Curie programme and the European Research Council (European Union); the Leventis Foundation; the Alexander von Humboldt Foundation; the Belgian Federal Science Policy Office; the Fonds pour la Formation à la Recherche dans l’Industrie et dans l’Agriculture (FRIA-Belgium); the Agentschap voor Innovatie door Wetenschap en Technologie (IWT-Belgium); the Ministry of Education, Youth and Sports (MEYS) of Czech Republic; the Council of Science and Industrial Research, India; the Compagnia di San Paolo (Torino); and the HOMING PLUS programme of Foundation for Polish Science, cofinanced from European Union, Regional Development Fund.

References

[1] ATLAS Collaboration, “Measurement of inclusive jet and dijet production in pp collisions at 7 TeV using the ATLAS detector”, Phys. Rev. D 86 (2012) 014022, doi:10.1103/PhysRevD.86.014022.

[2] CMS Collaboration, “Measurement of the differential dijet mass cross section in proton-proton collisions at √s = 7 TeV”, Phys. Lett. B 700 (2011) 187, doi:10.1016/j.physletb.2011.05.027.

[3] CMS Collaboration, “Measurement of the Inclusive Jet Cross Section in pp Collisions at 7 TeV”, Phys. Rev. Lett. 107 (2011) 132001, doi:10.1103/PhysRevLett.107.132001.

[4] CMS Collaboration, “The CMS experiment at the CERN LHC”, JINST 03 (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.

[5] CMS Collaboration, “Particle–Flow Event Reconstruction in CMS and Performance for Jets, Taus, and E_{T}^{miss}”, CMS Physics Analysis Summary CMS-PAS-PFT-09-001, (2009).

[6] M. Cacciari, G. P. Salam, and G. Soyez, “The anti-kt jet clustering algorithm”, JHEP 04 (2008) 063, doi:10.1088/1126-6708/2008/04/063.

[7] M. Cacciari and G. P. Salam, “Dispelling the N^2 myth for the k_t jet-finder”, Phys. Lett. B 641 (2006) 57, doi:10.1016/j.physletb.2006.08.037.

[8] T. Sjöstrand, S. Mrenna, and P. Skands, “PYTHIA 6.4 physics and manual”, JHEP 05 (2006) 026, doi:10.1088/1126-6708/2006/05/026.

[9] S. Agostinelli et al., “GEANT4—a simulation toolkit”, Nucl. Inst. Meth. A 506 (2003) 250, doi:10.1016/S0168-9002(03)01368-8.

[10] CMS Collaboration, “Determination of Jet Energy Calibration and Transverse Momentum Resolution in CMS”, JINST 6 (2011) P11002, doi:10.1088/1748-0221/6/11/P11002.

[11] CMS Collaboration, “Jet Energy Scale performance in 2011”, CMS Detector Performance Summary CMS DP-2012/006, (2012).

[12] CMS Collaboration, “The CMS High Level Trigger”, Eur. Phys. J. C 46 (2006) 605, doi:10.1140/epjc/s2006-02495-8.

[13] CMS Collaboration, “Tracking and Primary Vertex Results in First 7 TeV Collisions”, CMS Physics Analysis Summary CMS-PAS-TRK-10-005, (2010).
[14] T. Adye, “Unfolding algorithms and tests using RooUnfold”, (2006). arXiv:1105.1160

[15] G. D’Agostini, “A multidimensional unfolding method based on Bayes’ theorem”, Nucl. Instrum. Meth. A 362 (1995) 487, doi:10.1016/0168-9002(95)00274-X

[16] CMS Collaboration, “Absolute Calibration of the Luminosity Measurement at CMS: Winter 2012 Update”, CMS Physics Analysis Summary CMS-PAS-SMP-12-008, (2012).

[17] Z. Nagy, “Next-to-leading order calculation of three jet observables in hadron-hadron collisions”, Phys. Rev. D 68 (2003) 094002, doi:10.1103/PhysRevD.68.094002

[18] T. Kluge, K. Rabbertz, and M. Wobisch, “fastNLO: Fast pQCD calculations for PDF fits”, (2006). arXiv:hep-ph/0609285v2

[19] H.-L. Lai et al., “New parton distributions for collider physics”, Phys. Rev. D 82 (2010) 074024, doi:10.1103/PhysRevD.82.074024

[20] A. D. Martin et al., “Parton distributions for the LHC”, Eur. Phys. J. C 63 (2009) 189, doi:10.1140/epjc/s10052-009-1072-5

[21] R. D. Ball et al., “A first unbiased global NLO determination of parton distributions and their uncertainties”, Nucl. Phys. B 838 (2010) 136, doi:10.1016/j.nuclphysb.2010.05.008

[22] F. D. Aaron et al., “Combined Measurement and QCD Analysis of the Inclusive ep Scattering Cross Sections at HERA”, JHEP 01 (2010) 109, doi:10.1007/JHEP01(2010)109

[23] S. Alekhin et al., “The 3-, 4-, and 5-flavor NNLO Parton from Deep-Inelastic-Scattering Data and at Hadron Colliders”, Phys. Rev. D 81 (2010) 014032, doi:10.1103/PhysRevD.81.014032

[24] M. Bähr et al., “Herwig++ Physics and Manual”, Eur. Phys. J. C 58 (2008) 639, doi:10.1140/epjc/s10052-008-0798-9

[25] R. Field, “Early LHC Underlying Event Data-Findings and Surprises”, (2010). arXiv:1010.3588v1
University of Sofia, Sofia, Bulgaria
A. Dimitrov, R. Hadjiiska, V. Kozhuharov, L. Litov, B. Pavlov, P. Petkov

Institute of High Energy Physics, Beijing, China
J.G. Bian, G.M. Chen, H.S. Chen, C.H. Jiang, D. Liang, S. Liang, X. Meng, J. Tao, J. Wang, X. Wang, Z. Wang, H. Xiao, M. Xu, J. Zang, Z. Zhang

State Key Lab. of Nucl. Phys. and Tech., Peking University, Beijing, China
C. Asawatangtrakuldee, Y. Ban, Y. Guo, W. Li, S. Liu, Y. Mao, S.J. Qian, H. Teng, D. Wang, L. Zhang, W. Zou

Universidad de Los Andes, Bogota, Colombia
C. Avila, J.P. Gomez, B. Gomez Moreno, A.F. Osorio Oliveros, J.C. Sanabria

Technical University of Split, Split, Croatia
N. Godinovic, D. Lelas, R. Plestina, D. Polic, I. Puljak

University of Split, Split, Croatia
Z. Antunovic, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia
V. Brigljevic, S. Duric, K. Kadija, J. Luetic, D. Mekterovic, S. Morovic

University of Cyprus, Nicosia, Cyprus
A. Attikis, M. Galanti, G. Mavromanolakis, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis

Charles University, Prague, Czech Republic
M. Finger, M. Finger Jr.

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt
Y. Assran, S. Elgammal, A. Ellithi Kamel, M.A. Mahmoud, A. Radi

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
M. Kadastik, M. Müntel, M. Raidal, L. Rebane, A. Tiko

Department of Physics, University of Helsinki, Helsinki, Finland
P. Eerola, G. Fedi, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland
J. Härkönen, A. Heikkinen, V. Karimäki, R. Kinnunen, M.J. Kortelainen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, P. Luukka, T. Mäenpää, T. Peltola, E. Tuominen, J. Tuominiemi, E. Tuovinen, D. Ungaro, L. Wendland

Lappeenranta University of Technology, Lappeenranta, Finland
K. Banzuzi, A. Karjalainen, A. Korpela, T. Tuuva

DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France
M. Besancon, S. Choudhury, M. Dejardin, D. Denegri, B. Fabbro, J.L. Faure, F. Ferri, S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, J. Malcles, L. Millischer, A. Nayak, J. Rander, A. Rosowsky, M. Titov

Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
S. Baffioni, F. Beaudette, L. Benhabib, L. Bianchini, M. Bluji, P. Busson, C. Charlot, N. Daci, T. Dahms, M. Dalchenko, L. Dobrzynski, A. Florent, R. Granier de Cassagnac, M. Haguenauer, P. Miné, C. Mironov, I.N. Naranjo, M. Nguyen, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Veelken, A. Zabi
Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France
J.-L. Agram, J. Andrea, D. Bloch, D. Bodin, J.-M. Brom, M. Cardaci, E.C. Chabert, C. Collard, E. Conte, F. Drouhin, J.-C. Fontaine, D. Gelé, U. Goerlach, P. Juillot, A.-C. Le Bihan, P. Van Hove

Centre de Calcul de l’Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France
F. Fassi, D. Mercier

Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France
S. Beauceron, N. Beaupere, O. Bondu, G. Boudoul, J. Chasserat, R. Chierici, D. Contardo, P. Depasse, H. El Mamouni, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, M. Lethuillier, L. Mirabito, S. Perries, L. Sgandurra, V. Sordini, Y. Tschudi, P. Verdier, S. Viret

Institute of High Energy Physics and Informatization, Tbilisi State University, Tbilisi, Georgia
Z. Tsamalaidze

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
C. Autermann, S. Beranek, B. Calpas, M. Edelhoff, L. Feld, N. Heracleous, O. Hindrichs, R. Jussen, K. Klein, J. Merz, A. O斯塔pchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, B. Wittmer, V. Zhukov

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
M. Ata, J. Caudron, E. Dietz-Laursonn, D. Duchardt, M. Erdmann, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, D. Klingebiel, P. Kreuzer, M. Merschmeyer, A. Meyer, M. Olschewski, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teyssier, S. Thüer, M. Weber

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany
M. Bontenackels, V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, J. Lingemann, A. Nowack, L. Perchalla, O. Pooth, P. Sauerland, A. Stahl

Deutsches Elektronen-Synchrotron, Hamburg, Germany
M. Aldaya Martin, J. Behr, W. Behrenhoff, U. Behrens, M. Bergholz, A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, E. Castro, F. Costanza, D. Dammann, C. Diez Pardos, G. Eckerlin, D. Eckstein, G. Flick, A. Geiser, I. Glushkov, P. Gunnellini, S. Habib, J. Hauk, G. Hellwig, H. Jung, M. Kasemann, P. Katsas, C. Kleinwort, H. Kluge, A. Knutsson, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, J. Leonard, W. Lohmann, B. Lutz, R. Mankel, I. Marfin, M. Marienfeld, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, S. Naumann-Emme, O. Novgorodova, J. Olzem, H. Perrey, A. Petrakhin, D. Pitzl, A. Raspereza, P.M. Ribeiro Cipriano, C. Riedl, E. Ron, M. Rosin, J. Salfeld-Nebgen, R. Schmidt, T. Schoerner-Sadenius, N. Sen, A. Spiridonov, M. Stein, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany
V. Blobel, H. Enderle, J. Erfle, U. Gebbert, M. Görner, M. Gosselink, J. Haller, T. Hermanns, R.S. Höing, K. Kaschube, G. Kaussen, H. Kirschenmann, R. Klaner, J. Lange, F. Nowak, T. Peiffer, N. Pietsch, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, M. Schröder, T. Schum, M. Seidel, J. Sibille, V. Sola, H. Stadie, G. Steinbrück, J. Thomsen, L. Vanelderen
Institut für Experimentelle Kernphysik, Karlsruhe, Germany
C. Barth, J. Berger, C. Böser, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, M. Guthoff, C. Hackstein, F. Hartmann, T. Hauth, M. Heinrich, H. Held, K.H. Hoffmann, U. Husemann, I. Katkov, J.R. Komaragiri, P. Lobelle Pardo, D. Martschei, S. Mueller, Th. Müller, M. Niegel, A. Nürnberg, O. Oberst, A. Oehler, J. Ott, G. Quast, K. Rabbertz, F. Ratnikov, N. Ratnikova, S. Röcker, F.-P. Schilling, G. Schott, H.J. Simonis, F.M. Stober, D. Troendle, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, M. Zeise

Institute of Nuclear Physics ’Demokritos’, Aghia Paraskevi, Greece
G. Anagnostou, G. Daskalakis, T. Geralis, S. Kesisoglou, A. Kyriakis, D. Loukas, I. Manolakos, A. Markou, C. Markou, C. Pavrommatis, E. Ntomari

University of Athens, Athens, Greece
L. Gouskos, T.J. Mertzimekis, A. Panagiotou, N. Saoulidou

University of Ioánnina, Ioánnina, Greece
I. Evangelou, C. Foudas, P. Kokkas, N. Manthos, I. Papadopoulos, V. Patras

KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
G. Bencze, C. Hajdu, P. Hidas, D. Horvath, F. Sikler, V. Veszpremi, G. Vesztergombi

Institute of Nuclear Research ATOMKI, Debrecen, Hungary
N. Beni, S. Czellar, J. Molnar, J. Palinkas, Z. Szilasi

University of Debrecen, Debrecen, Hungary
J. Karancsi, P. Raics, Z.L. Trocsanyi, B. Ujvari

Panjab University, Chandigarh, India
S.B. Beri, V. Bhatnagar, N. Dhingra, R. Gupta, M. Kaur, M.Z. Mehta, N. Nishu, L.K. Saini, A. Sharma, J.B. Singh

University of Delhi, Delhi, India
Ashok Kumar, Arun Kumar, S. Ahuja, A. Bhawdaj, B.C. Choudhary, S. Malhotra, M. Naimuddin, K. Ranjan, V. Sharma, R.K. Shivpuri

Saha Institute of Nuclear Physics, Kolkata, India
S. Banerjee, S. Bhattacharya, S. Dutta, B. Gomber, Sa. Jain, Sh. Jain, R. Khurana, S. Sarkar, M. Sharan

Bhabha Atomic Research Centre, Mumbai, India
A. Abdulsalam, D. Dutta, S. Kailas, V. Kumar, A.K. Mohanty, L.M. Pant, P. Shukla

Tata Institute of Fundamental Research - EHEP, Mumbai, India
T. Aziz, S. Ganguly, M. Guchait, A. Gurtu, M. Maity, G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage

Tata Institute of Fundamental Research - HECR, Mumbai, India
S. Banerjee, S. Dugad

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
H. Arfæi, H. Bakhshiansohi, S.M. Etesami, A. Fahim, M. Hashemi, H. Hesari, A. Jafari, M. Khakzad, M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh, M. Zeinali

INFN Sezione di Bari, b, Università di Bari, c, Politecnico di Bari, c, Bari, Italy
M. Abbrescia, L. Barbone, C. Calabria, S.S. Chhibra, A. Colaleo, D. Creanza, N. De Filippis, M. De Palma, L. Fiore, G. Iaselli, G. Maggi, M. Maggi, B. Marangelli,
S. Mya,c, S. Nuzzoa,b, N. Pacificoa, A. Pompiliab, G. Pugliesea,c, G. Selvaggia,b, L. Silvestria, G. Singhb, R. Venditti, b, P. Verwilligen, G. Zitoad

**INFN Sezione di Bologna a**, Università di Bologna b, Bologna, Italy
G. Abbiendi, A.C. Benvenuti, b, D. Bonacorsia,b, S. Braibant-Giacomelliab, b, L. Brigliadoria,b, P. Capiluppaia,b, A. Castra,b, F.R. Cavalloa, M. Cuffianniab, b, G.M. Dallavallea, F. Fabbria, A. Fanfinia,b, D. Fasanellaab, b, P. Giacomelli, c, G. Grandia, b, L. Guiduccia,b, b, S. Marcellinia, G. Masetta, b, M. Meneghelliab, ad, A. Montanari, F.L. Navarraab, b, F. Odorici, F. Perrotta, b, F. Primaveraab, b, A.M. Rossiba, b, T. Rovellia,b, b, G.P. Sirolia, b, N. Tosi, R. Travagliniab

**INFN Sezione di Catania a**, Università di Catania b, Catania, Italy
S. Albergoa,b, G. Cappelloa,b, M. Chiorboli, b, S. Costaab, b, R. Potenzaab, a, A. Tricomiab, b, C. Tuvea,b

**INFN Sezione di Firenze a**, Firenze, Italy
G. Barbaglia, V. Ciullia,b, C. Civinini, R. D’Alessandroab, b, E. Focardiab, b, S. Frosaliab, E. Galloa, S. Gonziab, b, M. Meschini, S. Paolettiab, G. Sguazzonia, A. Tropianoa

**INFN Laboratori Nazionali di Frascati, Frascati, Italy**
L. Benussi, S. Bianco, S. Colafranceschi22, F. Fabbriv, D. Piccolo

**INFN Sezione di Genova a**, Università di Genova b, Genova, Italy
P. Fabbricatorea, R. Musenicha, b, S. Tosis

**INFN Sezione di Milano-Bicocca a**, Università di Milano-Bicocca b, Milano, Italy
A. Benagliaa, F. De Guioab, L. Di Matteoa,b, ab, S. Fiorendia,b, b, S. Genniai,a,b, A. Ghezzi,a,b, S. Malvezzia,a, b, R.A. Manzoniia,b, A. Martellia,b, A. Massionia,b, b, D. Menasce, L. Moroni, M. Paganonia,b, b, D. Pedrini, S. Ragazziab, b, N. Redaelli, S. Sala, T. Tabarelli de Fattiaa,b

**INFN Sezione di Napoli a**, Università di Napoli ‘Federico II’ b, Università della Basilicata (Potenza) c, Università G. Marconi (Roma) d, Napoli, Italy
S. Buontempoa, C.A. Carrillo Montoyaab, N. Cavalloa,c, A. De Cosaab, b, O. Doganguna,b, F. Fabozzic,a, A.O.M. Iorioab, L. Lista, S. Meolaa,d,28, M. Merolaa, b, P. Paoluccia,d

**INFN Sezione di Padova a**, Università di Padova b, Università di Trento (Trento) c, Padova, Italy
P. Azziab, N. Bacchettaab, D. Biseloa,b, A. Brancaab, b, R. Carlinab, P. Chechция, T. Dorigoa, F. Gasparinab, b, U. Gasparinab, A. Gozzelinia, K. Kanishcheva,c, S. Lacapra, I. Lazzizzera,c, M. Margonia,b, A.T. Meneguzzoa,b, J. Pazzinia,b, N. Pozzobona,b, b, P. Roncheseab, M. Sgaravattoa, F. Simonettaab, E. Torassa, M. Tosiab, b, S. Vaninab, P. Zottob, G. Zumerleab

**INFN Sezione di Pavia a**, Università di Pavia b, Pavia, Italy
M. Gabusia,b, S.P. Rattia,b, C. Riccardia,b, P. Torreab, b, P. Vituloab

**INFN Sezione di Perugia a**, Università di Perugia b, Perugia, Italy
M. Biasiniab, G.M. Bileia, L. Fanab, b, P. Laricciaab, b, G. Mantovania, b, M. Menichella, A. Nappia,b, b, F. Romeoab, a, S. Saha, A. Santoccchiaab, A. Spieziaab, b, S. Taronia

**INFN Sezione di Pisa a**, Università di Pisa b, Scuola Normale Superiore di Pisa c, Pisa, Italy
P. Azzurrca, c, G. Bagliesiab, J. Bernardinib, T. Bocchila, G. Broccolica,c, R. Castaldia, R.T. D’Agnoloc,c, R. Dell’Orsaod, F. Fiorib, b, A. Giassia, A. Kraana, F. Ligabua,c, T. Lomtadzea, L. Martinia,c,29, A. Messineoa,b, F. Palla, b, A. Rizzia,b, A.T. Serbanab,30, P. Spagnoloa, P. Squillaciotia,d,4, R. Tencinia, G. Tonellia,b, A. Venturi, P.G. Verdinia

**INFN Sezione di Roma a**, Università di Roma b, Roma, Italy
L. Baroneab, F. Cavallaric, D. Del Reab, M. Diemoza, b, C. Fanellia,b, M. Grassia,b,4, E. Longoa,b
P. Meridiani\textsuperscript{a,4}, F. Michel\textsuperscript{a,b}, S. Nourbakhsh\textsuperscript{a,b}, G. Organtini\textsuperscript{a,b}, R. Paramatti\textsuperscript{a}, S. Rahatlou\textsuperscript{a,b}, M. Sigamani\textsuperscript{a}, L. Soffi\textsuperscript{a,b}

\textbf{INFN Sezione di Torino \textsuperscript{a}, Università di Torino \textsuperscript{b}, Università del Piemonte Orientale (Novara) \textsuperscript{c}, Torino, Italy}

N. Amapane\textsuperscript{a,b}, R. Arcidiacono\textsuperscript{a,c}, S. Argiro\textsuperscript{a,b}, M. Arneodo\textsuperscript{a,c}, C. Biino\textsuperscript{a}, N. Cartiglia\textsuperscript{a}, S. Casasso\textsuperscript{a,b}, M. Costa\textsuperscript{a,b}, N. Demaria\textsuperscript{a}, C. Mariotti\textsuperscript{a,4}, S. Maselli\textsuperscript{a}, E. Migliore\textsuperscript{a,b}, V. Monaco\textsuperscript{a,b}, M. Musichi\textsuperscript{a,4}, M.M. Obertino\textsuperscript{a,c}, N. Pastrone\textsuperscript{a}, M. Pelliccioni\textsuperscript{a}, A. Potenza\textsuperscript{a,b}, A. Romero\textsuperscript{a,b}, M. Ruspa\textsuperscript{a,c}, R. Sacchi\textsuperscript{a,b}, A. Solano\textsuperscript{a,b}, A. Staiano\textsuperscript{d}

\textbf{INFN Sezione di Trieste \textsuperscript{a}, Università di Trieste \textsuperscript{b}, Trieste, Italy}

S. Belforte\textsuperscript{a}, V. Candelise\textsuperscript{a,b}, M. Casarsa\textsuperscript{a}, F. Cossutti\textsuperscript{a}, G. Della Ricca\textsuperscript{a,b}, B. Gobbo\textsuperscript{a}, M. Marone\textsuperscript{a,b,4}, D. Montanino\textsuperscript{a,b,4}, A. Penzo\textsuperscript{a}, A. Schizzi\textsuperscript{a,b}

\textbf{Kangwon National University, Chunchon, Korea}

T.Y. Kim, S.K. Nam

\textbf{Kyungpook National University, Daegu, Korea}

S. Chang, D.H. Kim, G.N. Kim, D.J. Kong, H. Park, D.C. Son, T. Son

\textbf{Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea}

J.Y. Kim, Zero J. Kim, S. Song

\textbf{Korea University, Seoul, Korea}

S. Choi, D. Gyun, B. Hong, M. Jo, H. Kim, T.J. Kim, K.S. Lee, D.H. Moon, S.K. Park

\textbf{University of Seoul, Seoul, Korea}

M. Choi, J.H. Kim, C. Park, I.C. Park, S. Park, G. Ryu

\textbf{Sungkyunkwan University, Suwon, Korea}

Y. Choi, Y.K. Choi, J. Goh, M.S. Kim, E. Kwon, B. Lee, J. Lee, S. Lee, H. Seo, I. Yu

\textbf{Vilnius University, Vilnius, Lithuania}

M.J. Bilinskas, I. Grigelionis, M. Janulis, A. Juodagalvis

\textbf{Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico}

H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz, R. Lopez-Fernandez, J. Martinez-Ortega, A. Sanchez-Hernandez, L.M. Villasenor-Cendejas

\textbf{Universidad Iberoamericana, Mexico City, Mexico}

S. Carrillo Moreno, F. Vazquez Valencia

\textbf{Benemerita Universidad Autonoma de Puebla, Puebla, Mexico}

H.A. Salazar Ibarguen

\textbf{Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico}

E. Casimiro Linares, A. Morelos Pineda, M.A. Reyes-Santos

\textbf{University of Auckland, Auckland, New Zealand}

D. Krofcheck

\textbf{University of Canterbury, Christchurch, New Zealand}

A.J. Bell, P.H. Butler, R. Doesburg, S. Reucroft, H. Silverwood
National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
M. Ahmad, M.I. Asghar, J. Butt, H.R. Hoorani, S. Khalid, W.A. Khan, T. Khurshid, S. Qazi, M.A. Shah, M. Shoaib

National Centre for Nuclear Research, Swierk, Poland
H. Bialkowska, B. Boimska, T. Frueboes, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, G. Wrochna, P. Zalewski

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
G. Brona, K. Bunkowski, M. Cwiok, W. Dominik, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
N. Almeida, P. Bargassa, A. David, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, J. Seixas, J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia
P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, V. Karjavin, V. Konoplyanikov, G. Kozlov, A. Lanev, A. Malakhov, P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov, S. Shulha, V. Smirnov, A. Volodko, A. Zarubin

Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia
S. Evtushukhin, V. Golovtsov, Y. Ivanov, V. Kim, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev, An. Vorobyev

Institute for Nuclear Research, Moscow, Russia
Yu. Andreev, A. Dermenev, S. Gnilenkov, N. Golubev, M. Kirsanov, N. Krasnikov, V. Matveev, A. Pashenkov, D. Tlisov, A. Toropin

Institute for Theoretical and Experimental Physics, Moscow, Russia
V. Epshteyn, M. Erofeeva, V. Gavrilov, M. Kossov, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, I. Shreyber, V. Stolin, E. Vlasov, A. Zhokin

Moscow State University, Moscow, Russia
A. Belyaev, E. Boos, M. Dubinin, L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, A. Markina, S. Obraztsov, M. Perfilov, S. Petrushanko, A. Popov, L. Sarycheva, V. Savrin, A. Snigirev

P.N. Lebedev Physical Institute, Moscow, Russia
V. Andreev, M. Azarkin, I. Dremin, M. Kirakosyan, A. Leonidov, G. Mesyats, S.V. Rusakov, A. Vinogradov

State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia
I. Azhgirey, I. Bayshev, S. Bitioukov, V. Grishin, V. Kachanov, D. Konstantinov, V. Krychkine, V. Petrov, R. Ryutin, A. Sobol, L. Tourchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
P. Adzic, M. Djordjevic, M. Ekmedzic, D. Kricic, I. Milosevic

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
M. Aguilar-Benitez, J. Alcaraz Maestre, P. Arce, C. Battilana, E. Calvo, M. Cerrada, M. Chamizo Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, D. Domínguez Vázquez, C. Fernandez
Bedoya, J.P. Fernández Ramos, A. Ferrando, J. Flix, M.C. Fouz, P. García-Abia, O. González Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, G. Merino, J. Puerta Pelayo, A. Quintario Olmeda, I. Redondo, L. Romero, J. Santolalla, M.S. Soares, C. Willmott

**Universidad Autónoma de Madrid, Madrid, Spain**
C. Albajar, G. Codispoti, J.F. de Trocóniz

**Universidad de Oviedo, Oviedo, Spain**
H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias, J. Piedra Gomez

**Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain**
J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, S.H. Chuang, J. Duarte Campderros, M. Felcini32, M. Fernandez, G. Gomez, J. Gonzalez Sanchez, A. Graziano, C. Jorda, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivera, F. Matorras, F.J. Munoz Sanchez, T. Rodrigo, A.Y. Rodriguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, I. Vila, R. Vilar Cortabitarte

**CERN, European Organization for Nuclear Research, Geneva, Switzerland**
D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, J.F. Benitez, C. Bernet35, G. Bianchi, P. Bloch, A. Boci, A. Bonato, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, D. D’Enterria, A. Dabrowski, A. De Roeck, S. Di Guida, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, B. Frisch, W. Funk, G. Georgiou, M. Giffels, D. Gigi, K. Gill, D. Giordano, M. Girone, M. Giunta, F. Glege, R. Gomez-Reino Garrido, P. Govoni, S. Gowdy, R. Guida, S. Gundacker, M. Hansen, P. Harris, C. Hartl, J. Harvey, B. Hegner, A. Hinzmann, V. Innocente, P. Janot, K. Kaadze, E. Karavakis, K. Kousouris, P. Lecoq, Y.-J. Lee, P. Lenzi, C. Lourenço, N. Magini, T. Mäki, M. Malberti, L. Malgeri, M. Mannelli, L. Masetti, F. Meijsers, S. Mersi, E. Meschi, R. Moser, M.U. Mozer, M. Mulders, P. Musella, E. Nesvold, T. Orimoto, L. Orsini, E. Palencia Cortezon, E. Perez, L. Perrozzi, A. Petrilli, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, G. Polese, L. Quertenmont, A. Racz, W. Reece, J. Rodrigues Antunes, J. Rojo, G. Rolandi33, C. Rovelli34, M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Spichas35, D. Spiga, A. Tsirou, G.I. Veres19, J.R. Vlimant, H.K. Wöhri, S.D. Worm36, W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland
W. Bertl, K. Deiters, W. Erdmann, K. Gabathuler, R. Horisberger, Q. Ingram, H.C. Kaestli, S. König, D. Kottlinski, U. Langenegger, F. Meier, D. Renker, T. Rohe

**Institute for Particle Physics, ETH Zurich, Zurich, Switzerland**
L. Bäni, P. Bertignon, M.A. Buchmann, B. Casal, N. Chanon, A. Deisher, G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, J. Euster, K. Freudenreich, C. Grab, D. Hits, P. Lecomte, W. Lüstermann, A.C. Marini, P. Martinez Ruiz del Arbol, N. Mohr, F. Moortgat, C. Nägeli37, P. Nef, F. Nessi-Tedaldi, F. Pandolfi, L. Pape, F. Pauss, M. Peruzzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, A. Starodumov38, B. Stieger, M. Takahashi, L. Tauscher, A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, H.A. Weber, L. Wehrli

**Universität Zürich, Zurich, Switzerland**
C. Amsler39, V. Chiochia, S. De Visscher, C. Favaro, M. Ivova Rikova, B. Kilminster, B. Millan Mejias, P. Otiougova, P. Robmann, H. Snoek, S. Tuppen, M. Verzetti

National Central University, Chung-Li, Taiwan
Y.H. Chang, K.H. Chen, C. Ferro, C.M. Kuo, S.W. Li, W. Lin, Y.J. Lu, A.P. Singh, R. Volpe, S.S. Yu
National Taiwan University (NTU), Taipei, Taiwan
P. Bartalini, P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, C. Dietz, U. Grundler, W.-S. Hou, Y. Hsiung, K.Y. Kao, Y.J. Lei, R.-S. Lu, D. Majumder, E. Petrakou, X. Shi, J.G. Shiu, Y.M. Tzeng, X. Wan, M. Wang

Chulalongkorn University, Bangkok, Thailand
B. Asavapibhop, N. Srimanobhas

Cukurova University, Adana, Turkey
A. Adiguzel, M.N. Bakirci, S. Cerci, C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, E. Gurpinar, I. Hos, E.E. Kangal, T. Karaman, G. Karapinar, A. Kayis Topaksu, G. Onengut, K. Ozdemir, S. Ozturk, A. Polatoz, K. Sogut, D. Sunar Cerci, B. Tali, T. Karaman, G. Karapinar, Tali

Middle East Technical University, Physics Department, Ankara, Turkey
I.V. Akin, T. Aliev, B. Bilin, S. Bilmis, M. Deniz, H. Gamsizkan, A.M. Guler, K. Ocalan, A. Ozpineci, M. Serin, R. Sever, U.E. Surat, M. Yalvac, E. Yildirim, M. Zeyrek

Bogazici University, Istanbul, Turkey
E. Gülmez, B. Isildak, M. Kaya, O. Kaya, S. Ozkorucuklu, N. Sonmez

Istanbul Technical University, Istanbul, Turkey
K. Cankocak

National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine
L. Levchuk

University of Bristol, Bristol, United Kingdom
J.J. Brooke, E. Clement, D. Cussans, H. Flacher, R. Frazier, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, L. Kreczko, S. Metson, D.M. Newbold, K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, T. Williams

Rutherford Appleton Laboratory, Didcot, United Kingdom
L. Basso, K.W. Bell, A. Belyaev, C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, J. Jackson, B.W. Kennedy, E. Olaiya, D. Petyt, B.C. Radburn-Smith, C.H. Shepherd-Themistocleous, I.R. Tomalin, W.J. Womersley

Imperial College, London, United Kingdom
R. Bainbridge, G. Ball, R. Beuselinck, O. Buchmuller, D. Colling, N. Cripps, M. Cutajar, P. Dauncey, G. Davies, M. Della Negra, W. Ferguson, J. Fulcher, D. Futyan, A. Gilbert, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, M. Jarvis, G. Karapostoli, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko, A. Papageorgiou, J. Pela, M. Pesaresi, K. Petridis, M. Pioppi, D.M. Raymond, S. Rogerson, A. Rose, M.J. Ryan, C. Seez, P. Sharp, A. Sparrow, M. Stoye, A. Tapper, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle, T. Whyntie

Brunel University, Uxbridge, United Kingdom
M. Chadwick, J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, D. Leggat, D. Leslie, W. Martin, I.D. Reid, P. Symonds, L. Teodorescu, M. Turner

Baylor University, Waco, USA
K. Hatakeyama, H. Liu, T. Scarborough

The University of Alabama, Tuscaloosa, USA
O. Charaf, C. Henderson, P. Rumerio
Boston University, Boston, USA
A. Avetisyan, T. Bose, C. Fantasia, A. Heister, J. St. John, P. Lawson, D. Lazic, J. Rohlf, D. Sperka, L. Sulak

Brown University, Providence, USA
J. Alimena, S. Bhattacharya, G. Christopher, D. Cutts, Z. Demiragli, A. Ferapontov, A. Garabedian, U. Heintz, S. Jabeen, G. Kukartsev, E. Laird, G. Landsberg, M. Luk, M. Narain, D. Nguyen, M. Segala, T. Sinthuprasith, T. Speer

University of California, Davis, Davis, USA
R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, J. Dolen, R. Erbacher, M. Gardner, R. Houtz, W. Ko, A. Kopecky, R. Lander, O. Mall, T. Miceli, D. Pellett, F. Ricci-Tam, B. Rutherford, M. Searle, J. Smith, M. Squires, M. Tripathi, R. Vasquez Sierra, R. Yohay

University of California, Los Angeles, USA
V. Andreev, D. Cline, R. Cousins, J. Duris, S. Erhan, P. Everaerts, C. Farrell, J. Hauser, M. Ignatenko, C. Jarvis, G. Rakness, P. Schlein1, P. Traczyk, V. Valuev, M. Weber

University of California, Riverside, Riverside, USA
J. Babb, R. Clare, M.E. Dinardo, J. Ellison, J.W. Gary, F. Giordano, G. Hanson, H. Liu, O.R. Long, A. Luthra, H. Nguyen, S. Paramesvaran, J. Sturdy, S. Sumowidagdo, R. Wilken, S. Wimpenny

University of California, San Diego, La Jolla, USA
W. Andrews, J.G. Branson, G.B. Cerati, S. Cittolin, D. Evans, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, I. Macneill, B. Mangano, S. Padhi, C. Palmer, G. Petrucciani, M. Pieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech51, F. Würthwein, A. Yagil, J. Yoo

University of California, Santa Barbara, Santa Barbara, USA
D. Barge, R. Bellan, C. Campagnari, M. D’Alfonso, T. Danielson, K. Flowers, P. Geffert, F. Golf, J. Incandela, C. Justus, P. Kalavase, D. Kovalskyi, V. Krutelyov, S. Lowette, R. Magaña Villalba, N. Mccoll, V. Pavlunin, J. Ribnik, J. Richman, R. Rossin, D. Stuart, W. To, C. West

California Institute of Technology, Pasadena, USA
A. Apresyan, A. Bornheim, Y. Chen, E. Di Marco, J. Duarte, M. Gataullin, Y. Ma, A. Mott, H.B. Newman, C. Rogan, M. Spiropulu, V. Timciuc, J. Veverka, R. Wilkinson, S. Xie, Y. Yang, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA
V. Azzolini, A. Calamba, R. Carroll, T. Ferguson, Y. Iiyama, D.W. Jang, Y.F. Liu, M. Paulini, H. Vogel, I. Vorobiev

University of Colorado at Boulder, Boulder, USA
J.P. Cumalat, B.R. Drell, W.T. Ford, A. Gaz, E. Luiggi Lopez, J.G. Smith, K. Stenson, K.A. Ulmer, S.R. Wagner

Cornell University, Ithaca, USA
J. Alexander, A. Chatterjee, N. Eggert, L.K. Gibbons, B. Heltsley, A. Khukhunaishvili, B. Kreis, N. Mirman, G. Nicolas Kaufman, J.R. Patterson, A. Ryd, E. Salvati, W. Sun, W.D. Teo, J. Thom, J. Thompson, J. Tucker, J. Vaughan, Y. Weng, L. Winstrom, P. Wittich

Fairfield University, Fairfield, USA
D. Winn
Fermi National Accelerator Laboratory, Batavia, USA
S. Abdullin, M. Albrow, J. Anderson, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, K. Burkett, J.N. Butler, V. Chetluru, H.W.K. Cheung, F. Chlebana, V.D. Elvira, I. Fisk, J. Freeman, Y. Gao, D. Green, O. Gutsche, J. Hanlon, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, B. Klima, S. Kunori, S. Kwan, C. Leonidopoulos, J. Linacre, D. Lincoln, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, S. Maruyama, D. Mason, P. McBride, K. Mishra, S. Mrenna, Y. Musienko, C. Newman-Holmes, V. O’Dell, O. Prokofyev, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, J. Whitmore, W. Wu, F. Yang, J.C. Yun

University of Florida, Gainesville, USA
D. Acosta, P. Avery, D. Bourilkov, M. Chen, T. Cheng, S. Das, M. De Gruttola, G.P. Di Giovranni, D. Dobur, A. Drozdetskiy, R.D. Field, M. Fisher, Y. Fu, I.K. Furic, J. Gartner, J. Hugon, B. Kim, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypres, J.F. Low, K. Matchev, P. Milenovic, G. Mitselmakher, L. Muniz, M. Park, R. Remington, A. Rinkevicius, P. Sellers, N. Skhirtladze, M. Snowball, J. Yelton, M. Zakaria

Florida International University, Miami, USA
V. Gaultney, S. Hewamanage, L.M. Lebolo, S. Linn, P. Markowitz, G. Martine, J.L. Rodriguez

Florida State University, Tallahassee, USA
T. Adams, A. Askew, J. Bochenek, J. Chen, B. Diamond, S.V. Gleyzer, J. Haas, S. Hagopian, V. Hagopian, M. Jenkins, K.F. Johnson, H. Prosper, V. Veeraraghavan, M. Weinberg

Florida Institute of Technology, Melbourne, USA
M.M. Baarmand, B. Dorney, M. Hohlmann, H. Kalakhety, I. Vodopiyanov, F. Yumiceva

University of Illinois at Chicago (UIC), Chicago, USA
M.R. Adams, I.M. Anghel, L. Apanasevich, Y. Bai, V.E. Bazterra, R.R. Betts, I. Bucinskaite, J. Callner, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, F. Lacroix, C. O’Brien, C. Silkworth, D. Strom, P. Turner, N. Varelas

The University of Iowa, Iowa City, USA
U. Akgun, E.A. Albayrak, B. Bilki, W. Clarida, F. Duru, J.-P. Merlo, H. Mermerkaya, A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, Y. Onel, F. Ozok, S. Sen, P. Tan, E. Tiras, J. Wetzel, T. Yetkin, K. Yi

Johns Hopkins University, Baltimore, USA
B.A. Barnett, B. Blumenfeld, S. Bolognesi, D. Fehling, G. Giurgiu, A.V. Gritsan, Z.J. Guo, G. Hu, P. Maksimovic, M. Swartz, A. Whitbeck

The University of Kansas, Lawrence, USA
P. Baringer, A. Bean, G. Benelli, R.P. Kenny Iii, M. Murray, D. Noonan, S. Sanders, R. Stringer, G. Tinti, J.S. Wood

Kansas State University, Manhattan, USA
A.F. Barfuss, T. Bolton, I. Chakaberia, A. Ivanov, S. Khalil, M. Makouski, Y. Maravin, S. Shrestha, I. Svintradze

Lawrence Livermore National Laboratory, Livermore, USA
J. Gronberg, D. Lange, F. Rebassoo, D. Wright

University of Maryland, College Park, USA
A. Baden, B. Calvert, S.C. Eno, J.A. Gomez, N.J. Hadley, R.G. Kellogg, M. Kim, T. Kolberg, Y. Lu, M. Marionneau, A.C. Mignerey, K. Pedro, A. Sikuja, J. Temple, M.B. Tonjes, S.C. Tonwar
Massachusetts Institute of Technology, Cambridge, USA
A. Apyan, G. Bauer, J. Bendavid, W. Busza, E. Butz, I.A. Cali, M. Chan, V. Dutta, G. Gomez Ceballos, M. Goncharov, Y. Kim, M. Klute, K. Krajczar, A. Levin, P.D. Luckey, T. Ma, S. Nahn, C. Paus, D. Ralph, C. Roland, G. Roland, M. Rudolph, G.S.F. Stephens, F. Stöckli, K. Sumorok, K. Sung, D. Velicanu, E.A. Wenger, R. Wolf, B. Wyslouch, M. Yang, Y. Yilmaz, A.S. Yoon, M. Zanetti, V. Zhukova

University of Minnesota, Minneapolis, USA
S.I. Cooper, B. Dahmes, A. De Benedetti, G. Franzoni, A. Gude, S.C. Kao, K. Klapoetke, Y. Kubota, J. Mans, N. Pastika, R. Rusack, M. Sasseville, A. Singovsky, N. Tambe, J. Turkewitz

University of Mississippi, Oxford, USA
L.M. Cremaldi, R. Kroeger, L. Perera, R. Rahmat, D.A. Sanders

University of Nebraska-Lincoln, Lincoln, USA
E. Avdeeeva, K. Bloom, S. Bose, D.R. Claes, A. Dominguez, M. Eads, J. Keller, I. Kravchenko, J. Lazo-Flores, S. Malik, G.R. Snow

State University of New York at Buffalo, Buffalo, USA
A. Godshalk, I. Iashvili, S. Jain, A. Kharchilava, A. Kumar, S. Rappoccio

Northeastern University, Boston, USA
G. Alveson, E. Barberis, D. Baumgartel, M. Chasco, J. Haley, D. Nash, D. Trocino, D. Wood, J. Zhang

Northwestern University, Evanston, USA
A. Anastassov, K.A. Hahn, A. Kubik, L. Lusito, N. Mucia, N. Odell, R.A. Oferzynski, B. Pollack, A. Pozdniakov, M. Schmitt, S. Stoynev, M. Velasco, S. Won

University of Notre Dame, Notre Dame, USA
L. Antonelli, D. Berry, A. Brinkerhoff, K.M. Chan, M. Hildreth, C. Jessop, D.J. Karmgard, J. Kolb, K. Lannon, W. Luo, S. Lynch, N. Marinelli, D.M. Morse, T. Pearson, M. Planer, R. Ruchti, J. Slaunwhite, N. Valls, M. Wayne, M. Wolf

The Ohio State University, Columbus, USA
B. Bylsma, L.S. Durkin, C. Hill, R. Hughes, K. Kotov, T.Y. Ling, D. Puigh, M. Rodenburg, C. Vuosalo, G. Williams, B.L. Winer

Princeton University, Princeton, USA
E. Berry, P. Elmer, V. Halyo, P. Hebda, J. Hegeman, A. Hunt, P. Jindal, S.A. Koay, D. Lopes Pegna, P. Lujan, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, P. Piroué, X. Quan, A. Raval, H. Saka, D. Stickland, C. Tully, J.S. Werner, A. Zuranski

University of Puerto Rico, Mayaguez, USA
E. Brownson, A. Lopez, H. Mendez, J.E. Ramirez Vargas

Purdue University, West Lafayette, USA
E. Alagöz, V.E. Barnes, D. Benedetti, G. Bolla, D. Bortoletto, M. De Mattia, A. Everett, Z. Hu, M. Jones, O. Koybasi, M. Kress, A.T. Laasanen, N. Leonardo, V. Maroussov, P. Merkel, D.H. Miller, N. Neumeister, I. Shipsey, D. Silvers, A. Svyatkovskiy, M. Vidal Marono, H.D. Yoo, J. Zablocki, Y. Zheng

Purdue University Calumet, Hammond, USA
S. Guragain, N. Parashar
Rice University, Houston, USA
A. Adair, B. Akgun, C. Boulahouache, K.M. Ecklund, F.J.M. Geurts, W. Li, B.P. Padley, R. Redjimi, J. Roberts, J. Zabel

University of Rochester, Rochester, USA
B. Betchart, A. Bodek, Y.S. Chung, R. Covarelli, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, A. Garcia-Bellido, P. Goldenzweig, J. Han, A. Harel, D.C. Miner, D. Vishnevskiy, M. Zielinski

The Rockefeller University, New York, USA
A. Bhatti, R. Ciesielski, L. Demortier, K. Goulianos, G. Lungu, S. Malik, C. Mesropian

Rutgers, the State University of New Jersey, Piscataway, USA
S. Arora, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Duggan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, A. Lath, S. Panwalkar, M. Park, R. Patel, V. Rekovic, J. Robles, K. Rose, S. Salur, S. Schnetzer, C. Seitz, S. Somalwar, R. Stone, S. Thomas, M. Walker

University of Tennessee, Knoxville, USA
G. Cerizza, M. Hollingsworth, S. Spanier, Z.C. Yang, A. York

Texas A&M University, College Station, USA
R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon59, V. Khotilovich, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Safonov, T. Sakuma, S. Sengupta, I. Suarez, A. Tatarinov, D. Toback

Texas Tech University, Lubbock, USA
N. Akchurin, J. Damgov, C. Dragoiu, P.R. Dudero, C. Jeong, K. Kovitanggoon, S.W. Lee, T. Libeiro, Y. Roh, I. Volobouev

Vanderbilt University, Nashville, USA
E. Appelt, A.G. Delannoy, C. Florez, S. Greene, A. Gurrola, W. Johns, P. Kurt, C. Maguire, A. Melo, M. Sharma, P. Sheldon, B. Snook, S. Tuo, J. Velkovska

University of Virginia, Charlottesville, USA
M.W. Arenton, M. Balazs, S. Boutle, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, C. Lin, C. Neu, J. Wood

Wayne State University, Detroit, USA
S. Gollapinni, R. Harr, P.E. Karchin, C. Kottachchi Kankanamge Don, P. Lamicchane, A. Sakharov

University of Wisconsin, Madison, USA
M. Anderson, D.A. Belknap, L. Borrello, D. Carlsmith, M. Cepeda, S. Dasu, E. Friis, L. Gray, K.S. Grogg, M. Grothe, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, J. Klukas, A. Lanaro, C. Lazaridis, R. Loveless, A. Mohapatra, I. Ojalvo, F. Palmonari, G.A. Pierro, I. Ross, A. Savin, W.H. Smith, J. Swanson

†: Deceased
1: Also at Vienna University of Technology, Vienna, Austria
2: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
3: Also at California Institute of Technology, Pasadena, USA
4: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
5: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
6: Also at Suez Canal University, Suez, Egypt
7: Also at Zewail City of Science and Technology, Zewail, Egypt
8: Also at Cairo University, Cairo, Egypt
9: Also at Fayoum University, El-Fayoum, Egypt
10: Also at British University in Egypt, Cairo, Egypt
11: Now at Ain Shams University, Cairo, Egypt
12: Also at National Centre for Nuclear Research, Swierk, Poland
13: Also at Université de Haute-Alsace, Mulhouse, France
14: Also at Joint Institute for Nuclear Research, Dubna, Russia
15: Also at Moscow State University, Moscow, Russia
16: Also at Brandenburg University of Technology, Cottbus, Germany
17: Also at The University of Kansas, Lawrence, USA
18: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
19: Also at Eötvös Loránd University, Budapest, Hungary
20: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
21: Now at King Abdulaziz University, Jeddah, Saudi Arabia
22: Also at University of Visva-Bharati, Santiniketan, India
23: Also at Sharif University of Technology, Tehran, Iran
24: Also at Isfahan University of Technology, Isfahan, Iran
25: Also at Shiraz University, Shiraz, Iran
26: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
27: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
28: Also at Università degli Studi Guglielmo Marconi, Roma, Italy
29: Also at Università degli Studi di Siena, Siena, Italy
30: Also at University of Bucharest, Faculty of Physics, Bucuresti-Magurele, Romania
31: Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia
32: Also at University of California, Los Angeles, USA
33: Also at Scuola Normale e Sezione dell’INFN, Pisa, Italy
34: Also at INFN Sezione di Roma; Università di Roma, Roma, Italy
35: Also at University of Athens, Athens, Greece
36: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
37: Also at Paul Scherrer Institut, Villigen, Switzerland
38: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
39: Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland
40: Also at Gaziosmanpasa University, Tokat, Turkey
41: Also at Adiyaman University, Adiyaman, Turkey
42: Also at Izmir Institute of Technology, Izmir, Turkey
43: Also at The University of Iowa, Iowa City, USA
44: Also at Mersin University, Mersin, Turkey
45: Also at Ozyegin University, Istanbul, Turkey
46: Also at Kahkas University, Kars, Turkey
47: Also at Suleyman Demirel University, Isparta, Turkey
48: Also at Ege University, Izmir, Turkey
49: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
50: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
51: Also at Utah Valley University, Orem, USA
52: Now at University of Edinburgh, Scotland, Edinburgh, United Kingdom
53: Also at Institute for Nuclear Research, Moscow, Russia
54: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences,
Belgrade, Serbia
55: Also at Argonne National Laboratory, Argonne, USA
56: Also at Erzincan University, Erzincan, Turkey
57: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
58: Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
59: Also at Kyungpook National University, Daegu, Korea