

# Measurement of the inclusive jet cross section in pp collisions at $\sqrt{s} = 2.76$ TeV

CMS Collaboration\*

CERN, 1211 Geneva 23, Switzerland

Received: 19 December 2015 / Accepted: 11 April 2016 / Published online: 12 May 2016

© CERN for the benefit of the CMS collaboration 2016. This article is published with open access at Springerlink.com

**Abstract** The double-differential inclusive jet cross section is measured as a function of jet transverse momentum  $p_T$  and absolute rapidity  $|y|$ , using proton-proton collision data collected with the CMS experiment at the LHC, at a center-of-mass energy of  $\sqrt{s} = 2.76$  TeV and corresponding to an integrated luminosity of  $5.43 \text{ pb}^{-1}$ . Jets are reconstructed within the  $p_T$  range of 74 to 592 GeV and the rapidity range  $|y| < 3.0$ . The reconstructed jet spectrum is corrected for detector resolution. The measurements are compared to the theoretical prediction at next-to-leading-order QCD using different sets of parton distribution functions. This inclusive cross section measurement explores a new kinematic region and is consistent with QCD predictions.

## 1 Introduction

Jets are copiously produced in proton-proton (pp) collisions at the LHC. In the standard model, the hard-scattering interaction between partons inside the protons is described by perturbative quantum chromodynamics (QCD). Particle-level predictions, however, require a nonperturbative (NP) modeling of hadronization and multiple parton interactions in addition to the QCD calculation. The predicted rate and kinematics of jet production are sensitive to the composition of the proton described by the parton distribution functions (PDF) and to the strong coupling constant ( $\alpha_S$ ). The evolution of PDFs and  $\alpha_S$  with the increase in the magnitude of the four-momentum transfer is determined by the renormalization group equations of perturbative QCD [1–3]. Precision measurements of inclusive jet production cross sections at different center-of-mass energies can be used to determine PDFs and  $\alpha_S$  as well as to search for deviations in their behavior from QCD predictions [4]. Inclusive jet cross section measurements have been performed at the LHC [5–8] and at other high energy colliders [9–16]. The measurements (up to 592 GeV) presented here extend the jet transverse momentum reach of the previous studies.

In this study, the inclusive jet production cross section,  $\sigma(\text{pp} \rightarrow \text{jet} + \text{X})$ , is measured as a function of the jet transverse momentum  $p_T$  and absolute rapidity  $|y|$ . The analysis is performed with data from pp collisions at  $\sqrt{s} = 2.76$  TeV with the CMS experiment corresponding to an integrated luminosity of  $5.43 \text{ pb}^{-1}$ . Originally designed as a reference for heavy ion studies, this data set also provides an opportunity to close the wide gap in jet measurements between the Tevatron at 1.96 TeV and the LHC at 7 and 8 TeV. When combined with the cross section measurements at other center of mass energies the present measurement can be used to improve PDF constraints. The data presented in this paper are collected at low instantaneous luminosity conditions with, on average, 1.2 primary interactions per triggered event. The measured cross section is compared to the prediction from a next-to-leading-order (NLO) QCD calculation, performed using the NLOJET++ (v.4.1.3) generator [17, 18] implemented in the FASTNLO (v.2.1.0) framework [19]. NP contributions to the cross section are taken into account in the theoretical prediction; electroweak contributions are negligible [20].

## 2 The CMS detector

The central feature of the CMS apparatus is a superconducting solenoid which provides a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter (HCAL), each composed of a barrel and two endcap sections. Forward calorimetry complements the coverage provided by the barrel and endcap detectors. Muons are measured in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in Ref. [21].

\* e-mail: cms-publication-committee-chair@cern.ch

### 3 Jet reconstruction and event selection

The particle-flow (PF) algorithm [22,23] is used to reconstruct and identify individual particles in an event with optimally combined information from the various subsystems of the CMS detector. The particles are identified as: charged hadrons, neutral hadrons, muons, electrons, and photons. The PF candidates are combined into jets using the anti- $k_T$  algorithm [24] as implemented in the FASTJET software package [25]. A wide reconstruction cone with a radius of 0.7 is used to reduce the sensitivity to final-state radiation. Particles identified as charged hadrons are assigned the pion mass, while neutral hadrons are considered massless and the four-vector sum of all reconstructed particles in the jet is calculated. The measurements of jet energy and momentum in the CMS detector are affected by a number of experimental factors, such as the limited coverage of the tracking system and the nonlinear calorimeter response. The tracking system provides superior jet reconstruction (i.e., systematic uncertainties due to energy calibration and resolution) in the central region of the detector ( $|\eta| < 2.4$ ). To correct for the detector response, the measurements are calibrated using reference processes with well-understood kinematics [26]. Jet energy corrections are derived using simulated events, generated with PYTHIA6 (v.6.4, tune Z2\*) [27] and processed with GEANT4 [28]. The most recent PYTHIA6 Z2\* tune is derived from the Z1 tune [29], which uses the CTEQ5L parton distribution set, whereas Z2\* adopts CTEQ6L [30]. The corrections are verified in data using  $\gamma$ +jet and Z+jet processes, and additional corrections are applied to compensate for any mismatch between simulation and data. The correction factors depend on jet  $p_T$  and  $\eta$ , and typically range between 1.02 and 1.10, while the jet energy resolution amounts to 15 % at a jet  $p_T$  of 10 GeV, 8 % at 100 GeV, and 4 % at 1 TeV.

The events are selected by a set of single-jet triggers with jet  $p_T$  thresholds of 40, 60, and 80 GeV with the first two triggers being prescaled. In Table 1, the effective integrated luminosity collected with each trigger and the corresponding jet  $p_T$  range is presented. The triggers are selected to ensure 99 % efficiency for the events in the corresponding  $p_T$  range of the analysis.

Events with  $E_T^{\text{miss}}/\Sigma E_T < 0.3$  are selected, consistent with the properties of QCD multijet events, thereby removing

any spurious jet-like features originating from isolated noise patterns in certain HCAL and ECAL regions. The quantities  $E_T^{\text{miss}}$  and  $\Sigma E_T$  are calculated as the negative vector sum of transverse energy and the scalar sum of transverse energy, respectively, of all PF candidates in the event. The selected events are required to have at least one well-reconstructed primary vertex. Each jet should contain more than one PF candidate. The fraction of jet energy carried by charged leptons ( $e, \mu$ ) should be less than 90 %. In addition, jets reconstructed within the acceptance range of the tracking system ( $|\eta| < 2.4$ ) must contain at least one charged particle. The electromagnetic energy fraction of such jets is required to be less than 99 %, while the neutral-hadron and the photon energy fractions are required to be less than 90 %. The jet selection efficiency is estimated to be 99 % or higher for all  $p_T$  and rapidity ranges used in this study.

### 4 Cross section measurement

The double-differential jet cross section is calculated as

$$\frac{d^2\sigma}{dp_T dy} = \frac{1}{\epsilon \mathcal{L}_{\text{int,eff}}} \frac{N}{\Delta p_T (2 \Delta |y|)}, \quad (1)$$

where  $\mathcal{L}_{\text{int,eff}}$  is the effective integrated luminosity corrected for trigger prescales,  $\epsilon$  is the overall reconstruction efficiency including the trigger and jet selection efficiencies,  $\Delta p_T$  and  $\Delta |y|$  are the sizes of a particular jet  $p_T$  and rapidity bin, and  $N$  is the number of jets in that bin. Six uniform bins in  $|y|$  are used between 0.0 and 3.0. The jet  $p_T$  values range from 74 to 592 GeV, with bin sizes increasing in proportion to the  $p_T$  resolution.

In order to facilitate the comparison of measurements with theoretical predictions, the jet  $p_T$  spectrum is corrected for detector effects. Since the  $p_T$  spectrum is steeply falling, the number of jets migrating out of a bin into the higher adjacent bin significantly exceeds the number of jets migrating to the lower adjacent bin. The unfolding procedure compensates for this effect and recovers the particle-level spectrum from the observed spectrum. The detector response function is determined using multijet events simulated with the PYTHIA6 (v.6.4, tune Z2) [27,31] event generator. A detailed detector simulation is carried out using the GEANT4 software to model the particle interactions in the detector material.

The detector is characterized by a response function that represents the probability density to reconstruct a jet with transverse momentum  $p_T^{\text{det}}$  when the particle-level jet transverse momentum is  $p_T^{\text{part}}$ . The response function is initially derived by calculating jet resolution in Monte Carlo (MC) simulation for every  $p_T$  and  $|y|$  bin. Jet resolution in data is found to be worse than in simulations [26]. The response

**Table 1** Effective integrated luminosities and jet  $p_T$  ranges for triggers used in this study

Nominal trigger threshold (GeV)	$\mathcal{L}_{\text{int,eff}}$ ( $\text{pb}^{-1}$ )	$p_T$ range (GeV)
40	0.59	74–97
60	3.48	97–133
80	5.43	133–592

**Table 2** The factors used to scale jet resolution determined in simulations to match the resolution observed in data.

$ y $	$c^{\text{data/MC}}$
0.0–0.5	$1.079 \pm 0.026$
0.5–1.0	$1.099 \pm 0.028$
1.0–1.5	$1.121 \pm 0.029$
1.5–2.0	$1.208 \pm 0.046$
2.0–2.5	$1.254 \pm 0.062$
2.5–3.0	$1.395 \pm 0.063$

function is corrected for this defect by degrading the resolution by factors  $c^{\text{data/MC}}$  that vary with  $|y|$  as listed in Table 2.

The response matrix is constructed by convolving the response function with the  $p_T^{\text{part}}$  spectrum predicted by NLO QCD calculations and the CT10 PDF set [32]. (Results with other PDF sets are discussed in Sect. 6.) The response function is represented by a kernel density estimation (KDE) technique that accurately models the tails of the distribution. The theoretical  $p_T^{\text{part}}$  spectrum is fitted with an exponential of a continuously differentiable function (Akima spline) [33]. This spline function is sampled many times and convolved with the KDE response function to obtain the response matrix. The D'Agostini iterative unfolding method [34] is used, as implemented in the ROOUNFOLD software package [35]. The unfolding procedure is regularized by early termination of iterations; four iterations are performed in each rapidity bin.

## 5 Theoretical predictions

The theoretical predictions are derived at NLO using QCD calculations with NLOJET++ [17, 18], and corrected for the NP contributions from hadronization and multiple parton interactions. Electroweak corrections are negligible at 2.76 TeV according to the studies performed in Ref. [20]. The factorization and renormalization scales are set to the jet  $p_T$  ( $\mu_F = \mu_R = p_T$ ). The theoretical predictions of the inclusive jet cross section are derived using five recent PDF sets at NLO, as listed in Table 3, with the central values of  $\alpha_S(M_Z)$  for each PDF set. Most are determined in a variable-flavor number scheme, except for the ABM11 PDF set, which employs a fixed-flavor number scheme with the number of active flavors ( $N_f$ ) set to 5 or 6. The details related to determination of the PDFs are described in the corresponding references.

The NP effects include hadronization of parton cascades leading to the formation of color neutral jets and multiple interactions of spectator partons within the colliding protons that can result in the appearance of additional jets. The corrections are derived using two event

generators with different models for parton cascades and hadronization: PYTHIA6 (v.6.4, tune Z2) [27, 31] and HERWIG++ (v.2.5.0, tune UE\_EE\_3C) [40, 41]. In PYTHIA6, the hadronization is simulated with the Lund string fragmentation model [42] while HERWIG++ employs the cluster fragmentation model [43]. The  $p_T$ - and  $|y|$ -dependent correction factors for the NP effects,  $C_{\text{NP}}$ , are derived from simulation as a ratio of differential jet cross sections with hadronization and multiple parton interactions turned on and off. The final correction factors are obtained by averaging and HERWIG++ predictions. The theoretical cross section is then calculated as  $\sigma_{\text{theory}} = \sigma_{\text{NLO}} C_{\text{NP}}$ . The  $C_{\text{NP}}$  factors vary between 1.02 and 1.10 in the  $p_T$  and rapidity range of this analysis.

## 6 Systematic uncertainties

The major experimental uncertainties in this analysis come from imperfect measurement of jet energy, limited precision in simulating jet energy resolution, and imprecise knowledge of integrated luminosity. The first source affects the jet spectrum observed in data, while the second modifies the detector response matrix used in the unfolding procedure. The third source, measured integrated luminosity, contributes an overall cross section uncertainty of 3.7 % [44]. The uncertainty associated with the jet energy determination consists of several independent contributions identified in the process of deriving the jet energy corrections. These contributions are described in detail in Ref. [26]. The corresponding cross section uncertainty is 5–22 % for the low-rapidity bins ( $|y| < 2.5$ ), increasing to 78 % in the highest rapidity bin ( $2.5 \leq |y| < 3.0$ ). The jet energy resolution uncertainty is estimated using the uncertainties in the  $c^{\text{data/MC}}$  scaling factors presented in Table 2. For the rapidity region  $|y| < 2.5$ , the corresponding cross section uncertainty is 2–3 %, increasing to 22 % for the most forward rapidity bin. The higher uncertainty at forward rapidities is caused by the significant increase in the jet energy and resolution uncertainties, and the more steeply falling  $p_T$  spectrum in comparison with the central rapidity region.

The energy offset due to additional interactions in the same bunch crossing (pileup) is small. For the lowest  $p_T$  jets considered (74 GeV) the pileup contributes an average of only 0.3 % of the energy. This fraction decreases with increasing  $p_T$ . Consequently, pileup corrections are not required and the associated uncertainties are negligible. An uncertainty arising from the potential mismodeling of trigger and jet selection requirements is found to be 1 %. The unfolding uncertainty due to the initial theoretical model is calculated by testing various models and finding the effect is negligible. The sum in quadrature of all experimental systematic uncertainties in the cross section is, on average, 6 % at low rapidity

**Table 3** The PDF sets used for deriving cross section predictions are given with the number of active flavors ( $N_f$ ), the values and ranges of  $\alpha_S(M_Z)$  used for the fits, and corresponding references

Base set	$N_f$	$\alpha_S(M_Z)$	$\alpha_S(M_Z)$ range	References
CT10	$\leq 5$	0.118	0.112–0.127	[32]
MMHT14	$\leq 5$	0.120	0.108–0.128	[36]
NNPDF3.0	$\leq 6$	0.118	0.115–0.121	[37]
HERAPDF1.5	$\leq 5$	0.1176	0.114–0.122	[38]
ABM11	5	0.118	0.110–0.130	[39]

ties ( $|y| < 2.0$ ) and varies from 10 to 80 % at higher rapidities ( $2.0 \leq |y| < 3.0$ ), across the corresponding  $p_T$  ranges.

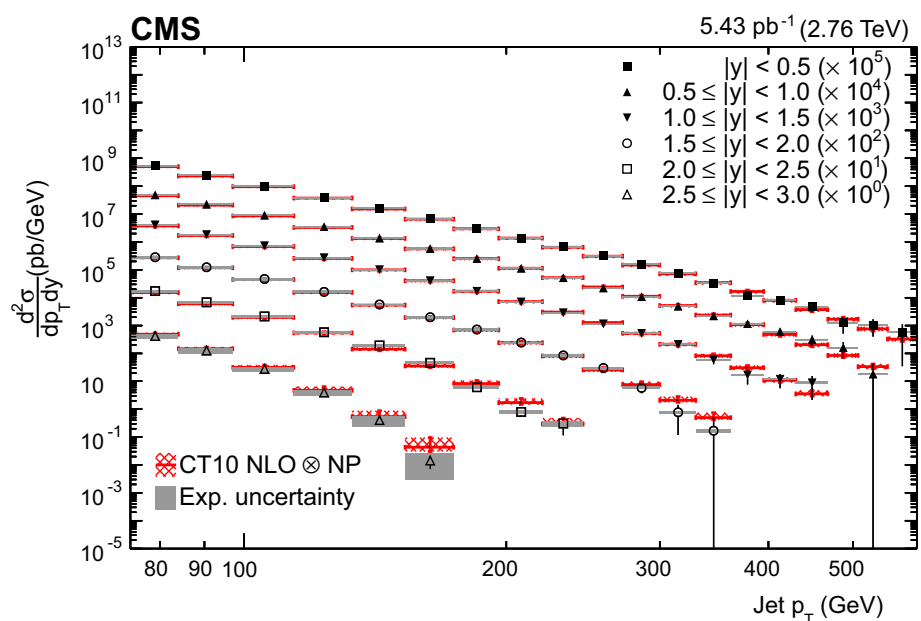
The uncertainty in the theoretical cross section prediction is estimated from the PDF uncertainties, the choice for the factorization and renormalization scales ( $\mu_F$  and  $\mu_R$ ), and the variation in the modeling of NP corrections. The PDF uncertainty, for all PDF sets except NNPDF3.0, is calculated as the change in the cross section caused by varying decorrelated PDF parameters. The relevant PDF eigenvectors are provided in the PDF sets along with the central values. The uncertainty due to each parameter is determined at 68 % confidence level (CL), and the resulting asymmetric uncertainties are combined in quadrature. In the case of NNPDF3.0, the PDF set contains an ensemble of replicas corresponding to one standard deviation in the PDF. The PDF uncertainty is calculated by evaluating the standard deviation in the cross section derived by using different replicas. The uncertainty due to the variation of the value of  $\alpha_S(M_Z)$  in the PDF sets is found to be much smaller than other uncertainties ( $< 1$  %) and is not included. The scale uncertainty is determined by varying the factorization and renormalization scales with respect

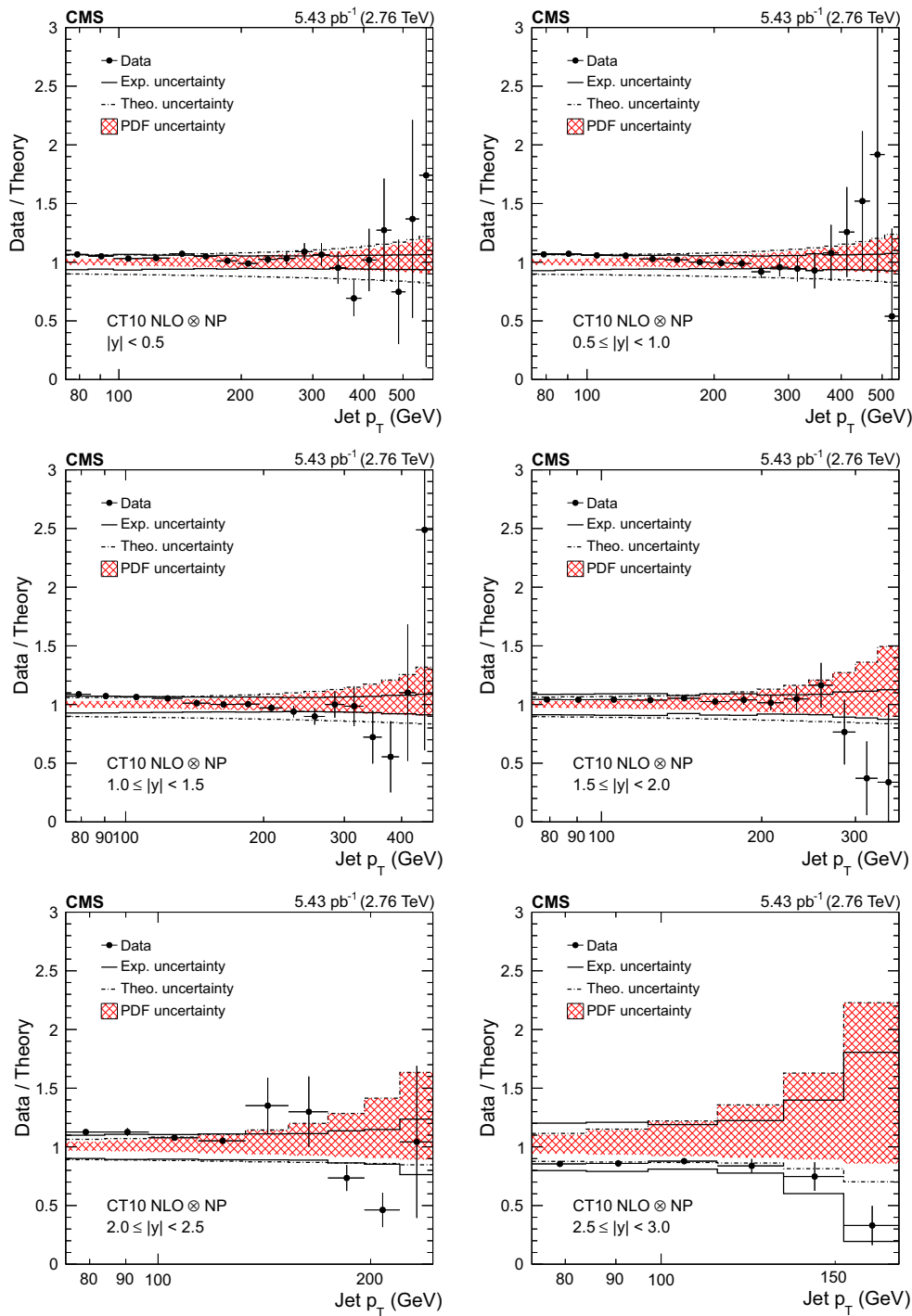
to the nominal value ( $\mu = \text{jet } p_T$ ) using the following combinations of ( $\mu_F/\mu$ ,  $\mu_R/\mu$ ) ratios: (0.5, 0.5), (1, 0.5), (0.5, 1), (1, 2), (2, 1), and (2, 2). The largest deviation from the nominal cross section, found separately in each  $p_T$  and  $|y|$  bin, is taken to represent the scale uncertainty. The scale uncertainty is asymmetric and its distribution is skewed towards lower cross sections. The largest deviation from the average value of the  $C_{NP}$  correction factors, which are obtained with the PYTHIA6 and HERWIG++ generators as discussed in Sect. 5, is used as the measure of the NP modeling uncertainty. It contributes a 2–5.6 % uncertainty in the cross section prediction. The uncertainties in the theoretical predictions differ for each PDF set considered, and typically vary in the 10–20 % range over most of the kinematic region.

## 7 Results

The measured inclusive jet cross section and the theoretical predictions are compared in Figs. 1, 2 and 3. In Fig. 1, the double-differential cross section is plotted as a function of

**Fig. 1** The inclusive jet production cross section, measured at  $\sqrt{s} = 2.76$  TeV, shown as a function of jet  $p_T$  in six  $|y|$  bins, as indicated by different symbols. The statistical (systematic) experimental uncertainties are indicated by vertical error bars (filled bands). The measurements are compared to the NLO QCD prediction using CT10 PDF set. The theoretical uncertainties are represented by hatched bands



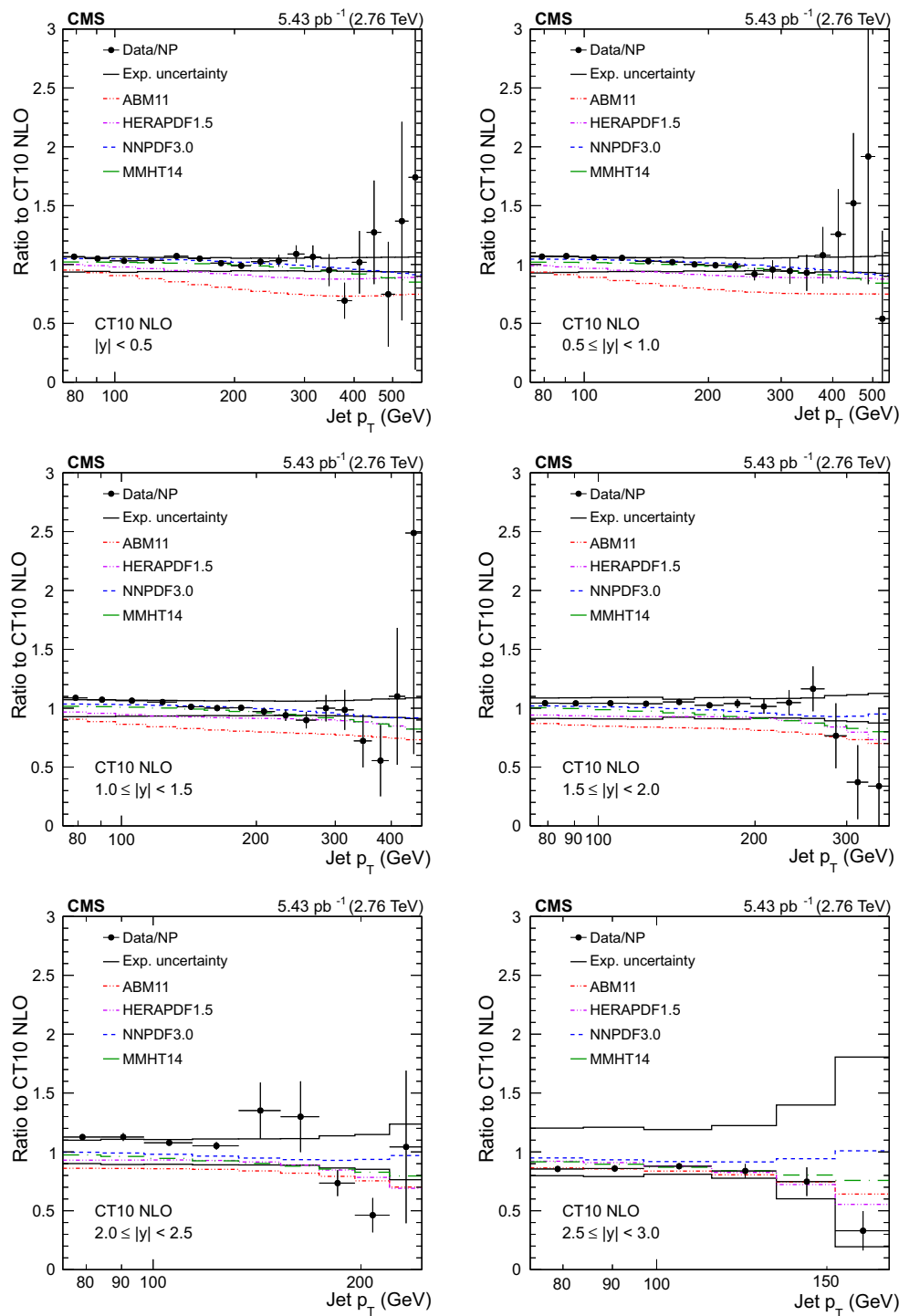


**Fig. 2** The ratio of the measured inclusive jet production cross section (closed symbols) at  $\sqrt{s} = 2.76$  TeV to the theoretical prediction using the CT10 PDF set is shown as a function of jet  $p_T$  in each measured  $|y|$  range with the statistical (vertical error bars) and systematic (solid

lines) experimental uncertainties. The total theoretical uncertainties are shown by the dash-dotted lines with the contribution from PDF uncertainties (hatched band)

jet  $p_T$  and  $|y|$ . The theoretical prediction obtained with the CT10 PDF set is shown as well. A more detailed comparison for all  $|y|$  bins is presented in Fig. 2, where the ratios of data to theory using the CT10 PDF set are shown. Within the

uncertainties, the data are well described by NLO QCD in the full kinematic range explored. In Fig. 3, the data, with NP corrections, are compared in a similar manner to the predictions from other PDF sets, normalized to the CT10 predic-



**Fig. 3** The same data shown in Fig. 2 are presented showing comparisons to the NLO QCD predictions using a variety of PDFs, which are denoted by *different line styles*. The uncertainties corresponding to

the QCD predictions are not shown. For simplicity, the NP corrections needed for the various QCD predictions have been applied to the data in this figure

tion. In general, all predictions describe the data well. Within experimental and theoretical (not shown) uncertainties, only the comparison to the prediction from the ABM11 PDF set

exhibits slight differences between the data and theory, an effect that has been observed also in other measurements, e.g. Ref. [4].

## 8 Summary

A measurement of the double-differential inclusive jet cross section was presented. The data were collected by the CMS detector in pp collisions at  $\sqrt{s} = 2.76$  TeV, with an integrated luminosity of  $5.43 \text{ pb}^{-1}$ . The measurement covers the jet kinematic ranges of  $74 \leq p_T < 592$  GeV and  $|y| < 3.0$ .

A detailed study of the experimental and theoretical uncertainties has been performed. Contributions to the experimental systematic uncertainty were evaluated from the jet energy corrections, jet energy resolution, and integrated luminosity. Jet energy corrections dominate the experimental uncertainty, followed by smaller contributions from jet energy resolution and luminosity. The theoretical uncertainty is dominated by the missing higher-order corrections that were estimated by varying the renormalization and factorization scales, and the PDF uncertainty; the contribution of nonperturbative correction uncertainty is small.

The data are corrected for detector resolution and efficiencies. The measured cross sections are compared to NLO QCD predictions obtained using different PDF sets. These cross section measurements test and confirm the predictions of QCD at  $\sqrt{s} = 2.76$  TeV and extend the kinematic range compared to previous studies.

**Acknowledgments** 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, Research and Economy and the Austrian Science Fund; 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 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, and the Croatian Science Foundation; the Research Promotion Foundation, Cyprus; the Ministry of Education and Research, Estonian Research Council via IUT23-4 and IUT23-6 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 Innovation Office, 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 Ministry of Science, ICT and Future Planning, and National Research Foundation (NRF), Republic of Korea; the Lithuanian Academy of Sciences; the Ministry of Educa-

tion, and University of Malaya (Malaysia); the Mexican Funding Agencies (CINVESTAV, CONACYT, SEP, and UASLP-FAI); the Ministry of Business, Innovation and Employment, 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, Dubna; 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 Education, Science and Technological Development of Serbia; the Secretaría de Estado de Investigación, Desarrollo e Innovación and Programa Consolider-Ingenio 2010, Spain; the Swiss Funding Agencies (ETH Board, ETH Zurich, PSI, SNF, UniZH, Canton Zurich, and SER); the Ministry of Science and Technology, Taipei; the Thailand Center of Excellence in Physics, the Institute for the Promotion of Teaching Science and Technology of Thailand, Special Task Force for Activating Research and the National Science and Technology Development Agency of Thailand; the Scientific and Technical Research Council of Turkey, and Turkish Atomic Energy Authority; the National Academy of Sciences of Ukraine, and State Fund for Fundamental Researches, Ukraine; 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 program and the European Research Council and EPLANET (European Union); the Leventis Foundation; the A. P. Sloan 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 the Czech Republic; the Council of Science and Industrial Research, India; the HOMING PLUS program of the Foundation for Polish Science, cofinanced from European Union, Regional Development Fund; the OPUS program of the National Science Center (Poland); the Compagnia di San Paolo (Torino); MIUR project 20108T4XTM (Italy); the Thalís and Aristeia programs cofinanced by EU-ESF and the Greek NSRF; the National Priorities Research Program by Qatar National Research Fund; the Rachadapisek Sompot Fund for Postdoctoral Fellowship, Chulalongkorn University (Thailand); the Chulalongkorn Academic into Its 2nd Century Project Advancement Project (Thailand); and the Welch Foundation, contract C-1845.

**Open Access** This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. Funded by SCOAP<sup>3</sup>.

## References

1. G. Altarelli, G. Parisi, Asymptotic freedom in parton language. *Nucl. Phys. B* **126**, 298 (1977). doi:[10.1016/0550-3213\(77\)90384-4](https://doi.org/10.1016/0550-3213(77)90384-4)
2. V. Gribov, L. Lipatov, Deep inelastic ep scattering in perturbation theory. *Sov. J. Nucl. Phys.* **15**, 438 (1972)
3. Y.L. Dokshitzer, Calculation of the structure functions for deep inelastic scattering and  $e^+e^-$  annihilation by perturbation theory in quantum chromodynamics. *Sov. Phys. JETP* **46**, 641 (1977)
4. CMS Collaboration, Constraints on parton distribution functions and extraction of the strong coupling constant from the inclusive jet cross section in pp collisions at  $\sqrt{s} = 7$  TeV. *Eur. Phys. J. C* **75**, 288 (2015). doi:[10.1140/epjc/s10052-015-3499-1](https://doi.org/10.1140/epjc/s10052-015-3499-1)

5. CMS Collaboration, Measurements of differential jet cross sections in proton–proton collisions at  $\sqrt{s} = 7$  TeV with the CMS detector. *Phys. Rev. D* **87**, 112002 (2013). doi:[10.1103/PhysRevD.87.112002](https://doi.org/10.1103/PhysRevD.87.112002)
6. ATLAS Collaboration, Measurement of inclusive jet and dijet production in pp collisions at  $\sqrt{s} = 7$  TeV using the ATLAS detector. *Phys. Rev. D* **86**, 014022 (2012). doi:[10.1103/PhysRevD.86.014022](https://doi.org/10.1103/PhysRevD.86.014022). arXiv:[1112.6297](https://arxiv.org/abs/1112.6297)
7. ATLAS Collaboration, Measurement of the inclusive jet cross section in pp collisions at  $\sqrt{s} = 2.76$  TeV using the ATLAS detector. *Eur. Phys. J. C* **73**, 2509 (2013). doi:[10.1140/epjc/s10052-013-2509-4](https://doi.org/10.1140/epjc/s10052-013-2509-4). arXiv:[1304.4739](https://arxiv.org/abs/1304.4739)
8. ALICE Collaboration, Measurement of the inclusive differential jet cross section in pp collisions at  $\sqrt{s} = 2.76$  TeV. *Phys. Lett. B* **722**, 262 (2013). doi:[10.1016/j.physletb.2013.04.026](https://doi.org/10.1016/j.physletb.2013.04.026). arXiv:[1301.3475](https://arxiv.org/abs/1301.3475)
9. UA1 Collaboration, Hadronic jet production at the CERN proton–antiproton collider. *Phys. Lett. B* **132**, 214 (1983). doi:[10.1016/0370-2693\(83\)90254-X](https://doi.org/10.1016/0370-2693(83)90254-X)
10. UA1 Collaboration, Measurement of the inclusive jet cross-section at the CERN  $p\bar{p}$  collider. *Phys. Lett. B* **172**, 461 (1986). doi:[10.1016/0370-2693\(86\)90290-X](https://doi.org/10.1016/0370-2693(86)90290-X)
11. UA2 Collaboration, Observation of very large transverse momentum jets at the CERN  $p\bar{p}$  collider. *Phys. Lett. B* **118**, 203 (1982). doi:[10.1016/0370-2693\(82\)90629-3](https://doi.org/10.1016/0370-2693(82)90629-3)
12. UA2 Collaboration, Measurement of the  $\sqrt{s}$  dependence of jet production at the CERN  $p\bar{p}$  collider. *Phys. Lett. B* **160**, 349 (1985). doi:[10.1016/0370-2693\(85\)91341-3](https://doi.org/10.1016/0370-2693(85)91341-3)
13. CDF Collaboration, Measurement of the inclusive jet cross section using the  $k_t$  algorithm in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96$  TeV with the CDF II detector. *Phys. Rev. D* **75**, 092006 (2007). doi:[10.1103/PhysRevD.75.092006](https://doi.org/10.1103/PhysRevD.75.092006). arXiv:[hep-ex/0701051](https://arxiv.org/abs/hep-ex/0701051). [Erratum: doi:[10.1103/PhysRevD.75.119901](https://doi.org/10.1103/PhysRevD.75.119901)]
14. CDF Collaboration, Comparison of jet production in  $p\bar{p}$  collisions at  $\sqrt{s} = 546$  GeV and 1800 GeV. *Phys. Rev. Lett.* **70**, 1376 (1993). doi:[10.1103/PhysRevLett.70.1376](https://doi.org/10.1103/PhysRevLett.70.1376)
15. D0 Collaboration, Measurement of the inclusive jet cross section in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96$  TeV. *Phys. Rev. D* **85**, 052006 (2012). doi:[10.1103/PhysRevD.85.052006](https://doi.org/10.1103/PhysRevD.85.052006). arXiv:[1110.3771](https://arxiv.org/abs/1110.3771)
16. D0 Collaboration, High- $p_T$  jets in  $p\bar{p}$  collisions at  $\sqrt{s} = 630$  GeV and 1800 GeV. *Phys. Rev. D* **64**, 032003 (2001). doi:[10.1103/PhysRevD.64.032003](https://doi.org/10.1103/PhysRevD.64.032003). arXiv:[hep-ex/0012046](https://arxiv.org/abs/hep-ex/0012046)
17. Z. Nagy, Three-jet cross sections in hadron-hadron collisions at next-to-leading order. *Phys. Rev. Lett.* **88**, 122003 (2002). doi:[10.1103/PhysRevLett.88.122003](https://doi.org/10.1103/PhysRevLett.88.122003). arXiv:[hep-ph/0110315](https://arxiv.org/abs/hep-ph/0110315)
18. Z. Nagy, Next-to-leading order calculation of three-jet observables in hadron-hadron collisions. *Phys. Rev. D* **68**, 094002 (2003). doi:[10.1103/PhysRevD.68.094002](https://doi.org/10.1103/PhysRevD.68.094002). arXiv:[hep-ph/0307268](https://arxiv.org/abs/hep-ph/0307268)
19. D. Britzger, K. Rabbertz, F. Stober, M. Wobisch, New features in version 2 of the fastNLO project, in XX Int'l Workshop on Deep-Inelastic Scattering and Related Subjects, p. 217. (2012). arXiv:[1208.3641](https://arxiv.org/abs/1208.3641). doi:[10.3204/DESY-PROC-2012-02/165](https://doi.org/10.3204/DESY-PROC-2012-02/165)
20. S. Dittmaier, A. Huss, C. Speckner, Weak radiative corrections to dijet production at hadron colliders. *JHEP* **11**, 095 (2012). doi:[10.1007/JHEP11\(2012\)095](https://doi.org/10.1007/JHEP11(2012)095). arXiv:[1210.0438](https://arxiv.org/abs/1210.0438)
21. CMS Collaboration, The CMS experiment at the CERN LHC. *JINST* **3**, S08004 (2008). doi:[10.1088/1748-0221/3/08/S08004](https://doi.org/10.1088/1748-0221/3/08/S08004)
22. 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
23. CMS Collaboration, Commissioning of the Particle-flow Event Reconstruction with the first LHC collisions recorded in the CMS detector. CMS Physics Analysis Summary CMS-PAS-PFT-10-001, 2010
24. C. Matteo, S. Gavin, G. Soyez, The anti- $k_t$  jet clustering algorithm. *JHEP* **04**, 063 (2008). doi:[10.1088/1126-6708/2008/04/063](https://doi.org/10.1088/1126-6708/2008/04/063). arXiv:[0802.1189](https://arxiv.org/abs/0802.1189)
25. M. Cacciari, G. Salam, G. Soyez, FastJet user manual. *Eur. Phys. J. C* **72**, 1896 (2012). doi:[10.1140/epjc/s10052-012-1896-2](https://doi.org/10.1140/epjc/s10052-012-1896-2). arXiv:[1111.6097](https://arxiv.org/abs/1111.6097)
26. CMS Collaboration, Determination of jet energy calibration and transverse momentum resolution in CMS. *J. Instrum.* **6**, P11002 (2011). doi:[10.1088/1748-0221/6/11/P11002](https://doi.org/10.1088/1748-0221/6/11/P11002)
27. T. Sjöstrand, S. Mrenna, P. Skands, PYTHIA 6.4 physics and manual, *JHEP* **05**, 26 (2006). doi:[10.1088/1126-6708/2006/05/026](https://doi.org/10.1088/1126-6708/2006/05/026). arXiv:[hep-ph/0603175](https://arxiv.org/abs/hep-ph/0603175)
28. GEANT4 Collaboration, GEANT4-a simulation toolkit. *Nucl. Instrum. Meth. A* **506**, 250 (2003). doi:[10.1016/S0168-9002\(03\)01368-8](https://doi.org/10.1016/S0168-9002(03)01368-8)
29. R. Field, Early LHC Underlying Event Data—Findings and Surprises. (2010). arXiv:[1010.3558](https://arxiv.org/abs/1010.3558)
30. J. Pumplin et al., New generation of parton distributions with uncertainties from global QCD analysis. *JHEP* **07**, 012 (2002). doi:[10.1088/1126-6708/2002/07/012](https://doi.org/10.1088/1126-6708/2002/07/012). arXiv:[hep-ph/0201195](https://arxiv.org/abs/hep-ph/0201195)
31. R. Field, Min-Bias and the Underlying Event at the LHC. (2011). arXiv:[1110.5530](https://arxiv.org/abs/1110.5530)
32. H. Lai et al., New parton distributions for collider physics. *Phys. Rev. D* **82**, 074024 (2010). doi:[10.1103/PhysRevD.82.074024](https://doi.org/10.1103/PhysRevD.82.074024). arXiv:[1007.2241](https://arxiv.org/abs/1007.2241)
33. H. Akima, A new method of interpolation and smooth curve fitting based on local procedures. *J. ACM* **17**, 589 (1970). doi:[10.1145/321607.321609](https://doi.org/10.1145/321607.321609)
34. G. D'Agostini, A multidimensional unfolding method based on Bayes' theorem. *Nucl. Instrum. Methods A* **362**, 487 (1995). doi:[10.1016/0168-9002\(95\)00274-X](https://doi.org/10.1016/0168-9002(95)00274-X)
35. T. Adye, Unfolding algorithms and tests using RooUnfold. (2011). arXiv:[1105.1160](https://arxiv.org/abs/1105.1160)
36. L.A. Harland-Lang, A.D. Martin, P. Motylinski, R.S. Thorne, Parton distributions in the LHC era: MMHT 2014 PDFs. *Eur. Phys. J. C* **75**, 204 (2015). doi:[10.1140/epjc/s10052-015-3397-6](https://doi.org/10.1140/epjc/s10052-015-3397-6). arXiv:[1412.3989](https://arxiv.org/abs/1412.3989)
37. R.D. Ball et al., Parton distributions for the LHC run II. *JHEP* **04**, 40 (2015). doi:[10.1007/JHEP04\(2015\)040](https://doi.org/10.1007/JHEP04(2015)040). arXiv:[1410.8849](https://arxiv.org/abs/1410.8849)
38. H1 and ZEUS Collaborations, Combined measurement and QCD analysis of the inclusive  $e^+p$  scattering cross sections at HERA. *JHEP* **01**, 10 (2010)
39. S. Alekhin, J. Blümlein, S. Moch, Parton distribution functions and benchmark cross sections at next-to-next-to-leading order. *Phys. Rev. D* **86**, 054009 (2012). doi:[10.1103/PhysRevD.86.054009](https://doi.org/10.1103/PhysRevD.86.054009). arXiv:[1202.2281](https://arxiv.org/abs/1202.2281)
40. M. Bähr et al., Herwig++ physics and manual. *Eur. Phys. J. C* **58**, 639 (2008). doi:[10.1140/epjc/s10052-008-0798-9](https://doi.org/10.1140/epjc/s10052-008-0798-9). arXiv:[0803.0883](https://arxiv.org/abs/0803.0883)
41. S. Gieseke, C. Röhr, A. Siódmok, Colour reconnections in Herwig++. *Eur. Phys. J. C* **72**, 2225 (2012). doi:[10.1140/epjc/s10052-012-2225-5](https://doi.org/10.1140/epjc/s10052-012-2225-5). arXiv:[1206.0041](https://arxiv.org/abs/1206.0041)
42. B. Andersson, The Lund model. *Nucl. Phys. A* **461**, 513 (1987). doi:[10.1016/0375-9474\(87\)90510-0](https://doi.org/10.1016/0375-9474(87)90510-0)
43. B.R. Webber, A QCD model for jet fragmentation including soft gluon interference. *Nucl. Phys. B* **238**, 492 (1984). doi:[10.1016/0550-3213\(84\)90333-X](https://doi.org/10.1016/0550-3213(84)90333-X)
44. CMS Collaboration, Luminosity calibration for the 2013 proton–lead and proton–proton data taking. CMS Physics Analysis Summary CMS-PAS-LUM-13-002, 2013



**CMS Collaboration****Yerevan Physics Institute, Yerevan, Armenia**

V. Khachatryan, A. M. Sirunyan, A. Tumasyan

**Institut für Hochenergiephysik der OeAW, Wien, Austria**

W. Adam, E. Asilar, T. Bergauer, J. Brandstetter, E. Brondolin, M. Dragicevic, J. Erö, M. Flechl, M. Friedl, R. Frühwirth<sup>1</sup>, V. M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler<sup>1</sup>, V. Knünz, A. König, M. Krammer<sup>1</sup>, I. Krätschmer, D. Liko, T. Matsushita, I. Mikulec, D. Rabady<sup>2</sup>, B. Rahbaran, H. Rohringer, J. Schieck<sup>1</sup>, R. Schöfbeck, J. Strauss, W. Treberer-Treberspurg, W. Waltenberger, C.-E. Wulz<sup>1</sup>

**National Centre for Particle and High Energy Physics, Minsk, Belarus**

V. Mossolov, N. Shumeiko, J. Suarez Gonzalez

**Universiteit Antwerpen, Antwerpen, Belgium**

S. Alderweireldt, T. Cornelis, E. A. De Wolf, X. Janssen, A. Knutsson, J. Lauwers, S. Luyckx, M. Van De Klundert, H. Van Havermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

**Vrije Universiteit Brussel, Brussel, Belgium**

S. Abu Zeid, F. Blekman, J. D'Hondt, N. Daci, I. De Bruyn, K. Deroover, N. Heracleous, J. Keaveney, S. Lowette, L. Moreels, A. Olbrechts, Q. Python, D. Strom, S. Tavernier, W. Van Doninck, P. Van Mulders, G. P. Van Onsem, I. Van Parijs

**Université Libre de Bruxelles, Bruxelles, Belgium**

P. Barria, H. Brun, C. Caillol, B. Clerbaux, G. De Lentdecker, G. Fasanella, L. Favart, R. Goldouzian, A. Grebenyuk, G. Karapostoli, T. Lenzi, A. Léonard, T. Maerschalk, A. Marinov, L. Perniè, A. Randle-conde, T. Seva, C. Vander Velde, P. Vanlaer, R. Yonamine, F. Zenoni, F. Zhang<sup>3</sup>

**Ghent University, Ghent, Belgium**

K. Beernaert, L. Benucci, A. Cimmino, S. Crucy, D. Dobur, A. Fagot, G. Garcia, M. Gul, J. Mccartin, A. A. Ocampo Rios, D. Poyraz, D. Ryckbosch, S. Salva, M. Sigamani, M. Tytgat, W. Van Driessche, E. Yazgan, N. Zaganidis

**Université Catholique de Louvain, Louvain-la-Neuve, Belgium**

S. Basegmez, C. Beluffi<sup>4</sup>, O. Bondu, S. Brochet, G. Bruno, A. Caudron, L. Ceard, C. Delaere, D. Favart, L. Forthomme, A. Giammanco<sup>5</sup>, A. Jafari, P. Jez, M. Komm, V. Lemaître, A. Mertens, M. Musich, C. Nuttens, L. Perrini, K. Piotrkowski, A. Popov<sup>6</sup>, L. Quertenmont, M. Selvaggi, M. Vidal Marono

**Université de Mons, Mons, Belgium**

N. Beliy, G. H. Hammad

**Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil**

W. L. Aldá Júnior, F. L. Alves, G. A. Alves, L. Brito, M. Correa Martins Junior, M. Hamer, C. Hensel, A. Moraes, M. E. Pol, P. Rebello Teles

**Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil**

E. Belchior Batista Das Chagas, W. Carvalho, J. Chinellato<sup>7</sup>, A. Custódio, E. M. Da Costa, D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, L.M. Huertas Guativa, H. Malbouisson, D. Matos Figueiredo, C. Mora Herrera, L. Mundim, H. Nogima, W. L. Prado Da Silva, A. Santoro, A. Sznajder, E. J. Tonelli Manganote<sup>7</sup>, A. Vilela Pereira

**Universidade Estadual Paulista<sup>a</sup>, Universidade Federal do ABC<sup>b</sup>, São Paulo, Brazil**

S. Ahuja<sup>a</sup>, C. A. Bernardes<sup>b</sup>, A. De Souza Santos<sup>b</sup>, S. Dogra<sup>a</sup>, T. R. Fernandez Perez Tomei<sup>a</sup>, E. M. Gregores<sup>b</sup>, P. G. Mercadante<sup>b</sup>, C.S. Moon<sup>a,8</sup>, S. F. Novaes<sup>a</sup>, Sandra S. Padula<sup>a</sup>, D. Romero Abad, J.C. Ruiz Vargas

**Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria**

A. Aleksandrov, R. Hadjiiska, P. Iaydjiev, M. Rodozov, S. Stoykova, G. Sultanov, M. Vutova

**University of Sofia, Sofia, Bulgaria**

A. Dimitrov, I. Glushkov, L. Litov, B. Pavlov, P. Petkov

**Institute of High Energy Physics, Beijing, China**

M. Ahmad, J. G. Bian, G. M. Chen, H. S. Chen, M. Chen, T. Cheng, R. Du, C. H. Jiang, R. Plestina<sup>9</sup>, F. Romeo, S. M. Shaheen, A. Spiezia, J. Tao, C. Wang, Z. Wang, H. Zhang

**State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China**

C. Asawatangtrakuldee, Y. Ban, Q. Li, S. Liu, Y. Mao, S. J. Qian, D. Wang, Z. Xu

**Universidad de Los Andes, Bogotá, Colombia**

C. Avila, A. Cabrera, L. F. Chaparro Sierra, C. Florez, J. P. Gomez, B. Gomez Moreno, J. C. Sanabria

**Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split, Split, Croatia**

N. Godinovic, D. Lelas, I. Puljak, P. M. Ribeiro Cipriano

**Faculty of Science, University of Split, Split, Croatia**

Z. Antunovic, M. Kovac

**Institute Rudjer Boskovic, Zagreb, Croatia**

V. Brigljevic, K. Kadija, J. Luetic, S. Micanovic, L. Sudic

**University of Cyprus, Nicosia, Cyprus**

A. Attikis, G. Mavromanolakis, J. Mousa, C. Nicolaou, F. Ptochos, P. A. Razis, H. Rykaczewski

**Charles University, Prague, Czech Republic**

M. Bodlak, M. Finger<sup>10</sup>, M. Finger Jr.<sup>10</sup>

**Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt**

E. El-khateeb<sup>11</sup>, T. Elkafrawy<sup>11</sup>, A. Mohamed<sup>12</sup>, E. Salama<sup>11,13</sup>

**National Institute of Chemical Physics and Biophysics, Tallinn, Estonia**

B. Calpas, M. Kadastik, M. Murumaa, M. Raidal, A. Tiko, C. Veelken

**Department of Physics, University of Helsinki, Helsinki, Finland**

P. Eerola, J. Pekkanen, M. Voutilainen

**Helsinki Institute of Physics, Helsinki, Finland**

J. Härkönen, V. Karimäki, R. Kinnunen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, P. Luukka, T. Peltola, E. Tuominen, J. Tuominiemi, E. Tuovinen, L. Wendland

**Lappeenranta University of Technology, Lappeenranta, Finland**

J. Talvitie, T. Tuuva

**DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France**

M. Besancon, F. Couderc, M. Dejaradin, D. Denegri, B. Fabbro, J. L. Faure, C. Favaro, F. Ferri, S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, M. Machet, J. Malcles, J. Rander, A. Rosowsky, M. Titov, A. Zghiche

**Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France**

I. Antropov, S. Baffioni, F. Beaudette, P. Busson, L. Cadamuro, E. Chapon, C. Charlot, O. Davignon, N. Filipovic, R. Granier de Cassagnac, M. Jo, S. Lisniak, L. Mastrolorenzo, P. Miné, I. N. Naranjo, M. Nguyen, C. Ochando, G. Ortona, P. Paganini, P. Pigard, S. Regnard, R. Salerno, J. B. Sauvan, Y. Sirois, T. Strebler, Y. Yilmaz, A. Zabi

**Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France**

J.-L. Agram<sup>14</sup>, J. Andrea, A. Aubin, D. Bloch, J.-M. Brom, M. Buttignol, E. C. Chabert, N. Chanon, C. Collard, E. Conte<sup>14</sup>, X. Coubez, J.-C. Fontaine<sup>14</sup>, D. Gelé, U. Goerlach, C. Goetzmann, A.-C. Le Bihan, J. A. Merlin<sup>2</sup>, K. Skovpen, P. Van Hove

**Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France**

S. Gadrat

**Institut de Physique Nucléaire de Lyon, Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Villeurbanne, France**

S. Beauceron, C. Bernet, G. Boudoul, E. Bouvier, C. A. Carrillo Montoya, R. Chierici, D. Contardo, B. Courbon, P. Depasse, H. El Mamouni, J. Fan, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, F. Lagarde, I. B. Laktineh, M. Lethuillier, L. Mirabito, A. L. Pequegnot, S. Perries, J. D. Ruiz Alvarez, D. Sabes, L. Sgandurra, V. Sordini, M. Vander Donckt, P. Verdier, S. Viret

**Georgian Technical University, Tbilisi, Georgia**

T. Toriashvili<sup>15</sup>

**Tbilisi State University, Tbilisi, Georgia**

Z. Tsamalaidze<sup>10</sup>

**I. Physikalisches Institut, RWTH Aachen University, Aachen, Germany**

C. Autermann, S. Beranek, L. Feld, A. Heister, M. K. Kiesel, K. Klein, M. Lipinski, A. Ostapchuk, M. Preuten, F. Raupach, S. Schael, J. F. Schulte, T. Verlage, H. Weber, V. Zhukov<sup>6</sup>

**III. Physikalisches Institut A, RWTH Aachen University, Aachen, Germany**

M. Ata, M. Brodski, E. Dietz-Laursonn, D. Duchardt, M. Endres, M. Erdmann, S. Erdweg, T. Esch, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, S. Knutzen, P. Kreuzer, M. Merschmeyer, A. Meyer, P. Millet, S. Mukherjee, M. Olschewski, K. Padeken, P. Papacz, T. Pook, M. Radziej, H. Reithler, M. Rieger, F. Scheuch, L. Sonnenschein, D. Teysier, S. Thüer

**III. Physikalisches Institut B, RWTH Aachen University, Aachen, Germany**

V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, F. Hoehle, B. Kargoll, T. Kress, A. Künsken, J. Lingemann, A. Nehr Korn, A. Nowack, I. M. Nugent, C. Pistone, O. Pooth, A. Stahl

**Deutsches Elektronen-Synchrotron, Hamburg, Germany**

M. Aldaya Martin, I. Asin, N. Bartosik, O. Behnke, U. Behrens, K. Borras<sup>16</sup>, A. Burgmeier, A. Campbell, C. Contreras-Campana, F. Costanza, C. Diez Pardos, G. Dolinska, S. Dooling, T. Dorland, G. Eckerlin, D. Eckstein, T. Eichhorn, G. Flucke, E. Gallo<sup>17</sup>, J. Garay Garcia, A. Geiser, A. Gzhzko, P. Gunnellini, J. Hauk, M. Hempel<sup>18</sup>, H. Jung, A. Kalogeropoulos, O. Karacheban<sup>18</sup>, M. Kasemann, P. Katsas, J. Kieseler, C. Kleinwort, I. Korol, W. Lange, J. Leonard, K. Lipka, A. Lobanov, W. Lohmann<sup>18</sup>, R. Mankel, I.-A. Melzer-Pellmann, A. B. Meyer, G. Mittag, J. Mnich, A. Mussgiller, S. Naumann-Emme, A. Nayak, E. Ntomari, H. Perrey, D. Pitzl, R. Placakyte, A. Raspereza, B. Roland, M. Ö. Sahin, P. Saxena, T. Schoerner-Sadenius, C. Seitz, S. Spannagel, K. D. Trippkewitz, R. Walsh, C. Wissing

**University of Hamburg, Hamburg, Germany**

V. Blobel, M. Centis Vignali, A. R. Draeger, J. Erfle, E. Garutti, K. Goebel, D. Gonzalez, M. Görner, J. Haller, M. Hoffmann, R. S. Höing, A. Junkes, R. Klanner, R. Kogler, N. Kovalchuk, T. Lapsien, T. Lenz, I. Marchesini, D. Marconi, M. Meyer, D. Nowatschin, J. Ott, F. Pantaleo<sup>2</sup>, T. Peiffer, A. Perieanu, N. Pietsch, J. Poehlsen, D. Rathjens, C. Sander, C. Scharf, P. Schleper, E. Schlieckau, A. Schmidt, S. Schumann, J. Schwandt, V. Sola, H. Stadie, G. Steinbrück, F. M. Stober, H. Tholen, D. Troendle, E. Usai, L. Vanelderen, A. Vanhoefer, B. Vormwald

**Institut für Experimentelle Kernphysik, Karlsruhe, Germany**

C. Barth, C. Baus, J. Berger, C. Böser, E. Butz, T. Chwalek, F. Colombo, W. De Boer, A. Descroix, A. Dierlamm, S. Fink, F. Frensch, R. Friese, M. Giffels, A. Gilbert, D. Haitz, F. Hartmann<sup>2</sup>, S. M. Heindl, U. Husemann, I. Katkov<sup>6</sup>, A. Kornmayer<sup>2</sup>, P. Lobelle Pardo, B. Maier, H. Mildner, M. U. Mozer, T. Müller, Th. Müller, M. Plagge, G. Quast, K. Rabbertz, S. Röcker, F. Roscher, M. Schröder, G. Sieber, H. J. Simonis, R. Ulrich, J. Wagner-Kuhr, S. Wayand, M. Weber, T. Weiler, S. Williamson, C. Wöhrmann, R. Wolf

**Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece**

G. Anagnostou, G. Daskalakis, T. Gerasis, V. A. Giakoumopoulou, A. Kyriakis, D. Loukas, A. Psallidas, I. Topsis-Giotis

**National and Kapodistrian, University of Athens, Athens, Greece**

A. Agapitos, S. Kesisoglou, A. Panagiotou, N. Saoulidou, E. Tziaferi

**University of Ioánnina, Ioánnina, Greece**

I. Evangelou, G. Flouris, C. Foudas, P. Kokkas, N. Loukas, N. Manthos, I. Papadopoulos, E. Paradis, J. Strogas

**Wigner Research Centre for Physics, Budapest, Hungary**

G. Bencze, C. Hajdu, A. Hazi, P. Hidas, D. Horvath<sup>19</sup>, F. Sikler, V. Veszpremi, G. Vesztergombi<sup>20</sup>, A. J. Zsigmond

**Institute of Nuclear Research ATOMKI, Debrecen, Hungary**

N. Beni, S. Czellar, J. Karancsi<sup>21</sup>, J. Molnar, Z. Szillasi<sup>2</sup>

**University of Debrecen, Debrecen, Hungary**

M. Bartók<sup>22</sup>, A. Makovec, P. Raics, Z. L. Trocsanyi, B. Ujvari

**National Institute of Science Education and Research, Bhubaneswar, India**

S. Choudhury<sup>23</sup>, P. Mal, K. Mandal, D. K. Sahoo, N. Sahoo, S. K. Swain

**Panjab University, Chandigarh, India**

S. Bansal, S. B. Beri, V. Bhatnagar, R. Chawla, R. Gupta, U. Bhawandeep, A. K. Kalsi, A. Kaur, M. Kaur, R. Kumar, A. Mehta, M. Mittal, J. B. Singh, G. Walia

**University of Delhi, Delhi, India**

Ashok Kumar, A. Bhardwaj, B. C. Choudhary, R. B. Garg, S. Malhotra, M. Naimuddin, N. Nishu, K. Ranjan, R. Sharma, V. Sharma

**Saha Institute of Nuclear Physics, Kolkata, India**

S. Bhattacharya, K. Chatterjee, S. Dey, S. Dutta, N. Majumdar, A. Modak, K. Mondal, S. Mukhopadhyay, A. Roy, D. Roy, S. Roy Chowdhury, S. Sarkar, M. Sharan

**Bhabha Atomic Research Centre, Mumbai, India**

A. Abdulsalam, R. Chudasama, D. Dutta, V. Jha, V. Kumar, A. K. Mohanty<sup>2</sup>, L. M. Pant, P. Shukla, A. Topkar

**Tata Institute of Fundamental Research, Mumbai, India**

T. Aziz, S. Banerjee, S. Bhowmik<sup>24</sup>, R. M. Chatterjee, R. K. Dewanjee, S. Dugad, S. Ganguly, S. Ghosh, M. Guchait, A. Gurtu<sup>25</sup>, Sa. Jain, G. Kole, S. Kumar, B. Mahakud, M. Maity<sup>24</sup>, G. Majumder, K. Mazumdar, S. Mitra, G. B. Mohanty, B. Parida, T. Sarkar<sup>24</sup>, N. Sur, B. Sutar, N. Wickramage<sup>26</sup>

**Indian Institute of Science Education and Research (IISER), Pune, India**

S. Chauhan, S. Dube, A. Kapoor, K. Kotheekar, S. Sharma

**Institute for Research in Fundamental Sciences (IPM), Tehran, Iran**

H. Bakhshiansohi, H. Behnamian, S. M. Etesami<sup>27</sup>, A. Fahim<sup>28</sup>, M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi, F. Rezaei Hosseinabadi, B. Safarzadeh<sup>29</sup>, M. Zeinali

**University College Dublin, Dublin, Ireland**

M. Felcini, M. Grunewald

**INFN Sezione di Bari<sup>a</sup>, Università di Bari<sup>b</sup>, Politecnico di Bari<sup>c</sup>, Bari, Italy**

M. Abbrescia<sup>a,b</sup>, C. Calabria<sup>a,b</sup>, C. Caputo<sup>a,b</sup>, A. Colaleo<sup>a</sup>, D. Creanza<sup>a,c</sup>, L. Cristella<sup>a,b</sup>, N. De Filippis<sup>a,c</sup>, M. De Palma<sup>a,b</sup>, L. Fiore<sup>a</sup>, G. Iaselli<sup>a,c</sup>, G. Maggi<sup>a,c</sup>, M. Maggi<sup>a</sup>, G. Miniello<sup>a,b</sup>, S. My<sup>a,c</sup>, S. Nuzzo<sup>a,b</sup>, A. Pompili<sup>a,b</sup>, G. Pugliese<sup>a,c</sup>, R. Radogna<sup>a,b</sup>, A. Ranieri<sup>a</sup>, G. Selvaggi<sup>a,b</sup>, L. Silvestris<sup>a,2</sup>, R. Venditti<sup>a,b</sup>

**INFN Sezione di Bologna<sup>a</sup>, Università di Bologna<sup>b</sup>, Bologna, Italy**

G. Abbiendi<sup>a</sup>, C. Battilana<sup>2</sup>, A. C. Benvenuti<sup>a</sup>, D. Bonacorsi<sup>a,b</sup>, S. Braibant-Giacomelli<sup>a,b</sup>, L. Brigliadori<sup>a,b</sup>, R. Campanini<sup>a,b</sup>, P. Capiluppi<sup>a,b</sup>, A. Castro<sup>a,b</sup>, F. R. Cavallo<sup>a</sup>, S. S. Chhibra<sup>a,b</sup>, G. Codispoti<sup>a,b</sup>, M. Cuffiani<sup>a,b</sup>, G. M. Dallavalle<sup>a</sup>, F. Fabbri<sup>a</sup>, A. Fanfani<sup>a,b</sup>, D. Fasanella<sup>a,b</sup>, P. Giacomelli<sup>a</sup>, C. Grandi<sup>a</sup>, L. Guiducci<sup>a,b</sup>, S. Marcellini<sup>a</sup>, G. Masetti<sup>a</sup>, A. Montanari<sup>a</sup>, F. L. Navarria<sup>a,b</sup>, A. Perrotta<sup>a</sup>, A. M. Rossi<sup>a,b</sup>, T. Rovelli<sup>a,b</sup>, G. P. Siroli<sup>a,b</sup>, N. Tosi<sup>a,b,2</sup>, R. Travaglini<sup>a,b</sup>

**INFN Sezione di Catania<sup>a</sup>, Università di Catania<sup>b</sup>, Catania, Italy**

G. Cappello<sup>a</sup>, M. Chiorboli<sup>a,b</sup>, S. Costa<sup>a,b</sup>, A. Di Mattia<sup>a</sup>, F. Giordano<sup>a,b</sup>, R. Potenza<sup>a,b</sup>, A. Tricomi<sup>a,b</sup>, C. Tuve<sup>a,b</sup>

**INFN Sezione di Firenze<sup>a</sup>, Università di Firenze<sup>b</sup>, Florence, Italy**

G. Barbagli<sup>a</sup>, V. Ciulli<sup>a,b</sup>, C. Civinini<sup>a</sup>, R. D'Alessandro<sup>a,b</sup>, E. Focardi<sup>a,b</sup>, V. Gori<sup>a,b</sup>, P. Lenzi<sup>a,b</sup>, M. Meschini<sup>a</sup>, S. Paoletti<sup>a</sup>, G. Sguazzoni<sup>a</sup>, L. Viliani<sup>a,b,2</sup>

**INFN Laboratori Nazionali di Frascati, Frascati, Italy**L. Benussi, S. Bianco, F. Fabbri, D. Piccolo, F. Primavera<sup>2</sup>**INFN Sezione di Genova<sup>a</sup>, Università di Genova<sup>b</sup>, Genoa, Italy**V. Calvelli<sup>a,b</sup>, F. Ferro<sup>a</sup>, M. Lo Vetere<sup>a,b</sup>, M. R. Monge<sup>a,b</sup>, E. Robutti<sup>a</sup>, S. Tosi<sup>a,b</sup>**INFN Sezione di Milano-Bicocca<sup>a</sup>, Università di Milano-Bicocca<sup>b</sup>, Milan, Italy**L. Brianza, M. E. Dinardo<sup>a,b</sup>, S. Fiorendi<sup>a,b</sup>, S. Gennai<sup>a</sup>, R. Gerosa<sup>a,b</sup>, A. Ghezzi<sup>a,b</sup>, P. Govoni<sup>a,b</sup>, S. Malvezzi<sup>a</sup>, R. A. Manzoni<sup>a,b,2</sup>, B. Marzocchi<sup>a,b</sup>, D. Menasce<sup>a</sup>, L. Moroni<sup>a</sup>, M. Paganoni<sup>a,b</sup>, D. Pedrini<sup>a</sup>, S. Ragazzi<sup>a,b</sup>, N. Redaelli<sup>a</sup>, T. Tabarelli de Fatis<sup>a,b</sup>**INFN Sezione di Napoli<sup>a</sup>, Università di Napoli ‘Federico II’<sup>b</sup>, Napoli, Italy, Università della Basilicata<sup>c</sup>, Potenza, Italy, Università G. Marconi<sup>d</sup>, Roma, Italy**S. Buontempo<sup>a</sup>, N. Cavallo<sup>a,c</sup>, S. Di Guida<sup>a,d,2</sup>, M. Esposito<sup>a,b</sup>, F. Fabozzi<sup>a,c</sup>, A. O. M. Iorio<sup>a,b</sup>, G. Lanza<sup>a</sup>, L. Lista<sup>a</sup>, S. Meola<sup>a,d,2</sup>, M. Merola<sup>a</sup>, P. Paolucci<sup>a,2</sup>, C. Sciacca<sup>a,b</sup>, F. Thyssen**INFN Sezione di Padova<sup>a</sup>, Università di Padova<sup>b</sup>, Padova, Italy, Università di Trento<sup>c</sup>, Trento, Italy**P. Azzi<sup>a,2</sup>, N. Bacchetta<sup>a</sup>, L. Benato<sup>a,b</sup>, D. Bisello<sup>a,b</sup>, A. Boletti<sup>a,b</sup>, R. Branca<sup>a,b</sup>, R. Carlin<sup>a,b</sup>, P. Checchia<sup>a</sup>, M. Dall’Osso<sup>a,b,2</sup>, T. Dorigo<sup>a</sup>, F. Fanzago<sup>a</sup>, F. Gasparini<sup>a,b</sup>, U. Gasparini<sup>a,b</sup>, F. Gonella<sup>a</sup>, A. Gozzelino<sup>a</sup>, K. Kanishchev<sup>a,c</sup>, S. Lacaprara<sup>a</sup>, M. Margoni<sup>a,b</sup>, A. T. Meneguzzo<sup>a,b</sup>, J. Pazzini<sup>a,b,2</sup>, N. Pozzobon<sup>a,b</sup>, P. Ronchese<sup>a,b</sup>, F. Simonetto<sup>a,b</sup>, E. Torassa<sup>a</sup>, M. Tosi<sup>a,b</sup>, S. Ventura<sup>a</sup>, M. Zanetti, P. Zotto<sup>a,b</sup>, A. Zucchetta<sup>a,b,2</sup>**INFN Sezione di Pavia<sup>a</sup>, Università di Pavia<sup>b</sup>, Pavia, Italy**A. Braghieri<sup>a,b</sup>, A. Magnani<sup>a</sup>, P. Montagna<sup>a,b</sup>, S. P. Ratti<sup>a,b</sup>, V. Re<sup>a</sup>, C. Riccardi<sup>a,b</sup>, P. Salvini<sup>a</sup>, I. Vai<sup>a,b</sup>, P. Vitulo<sup>a,b</sup>**INFN Sezione di Perugia<sup>a</sup>, Università di Perugia<sup>b</sup>, Perugia, Italy**L. Alunni Solestizi<sup>a,b</sup>, G. M. Bilei<sup>a</sup>, D. Ciangottini<sup>a,b,2</sup>, L. Fanò<sup>a,b</sup>, P. Lariccia<sup>a,b</sup>, G. Mantovani<sup>a,b</sup>, M. Menichelli<sup>a</sup>, A. Saha<sup>a</sup>, A. Santocchia<sup>a,b</sup>**INFN Sezione di Pisa<sup>a</sup>, Università di Pisa<sup>b</sup>, Scuola Normale Superiore di Pisa<sup>c</sup>, Pisa, Italy**K. Androsov<sup>a,30</sup>, P. Azzurri<sup>a,2</sup>, G. Bagliesi<sup>a</sup>, J. Bernardini<sup>a</sup>, T. Boccali<sup>a</sup>, R. Castaldi<sup>a</sup>, M. A. Ciocci<sup>a,30</sup>, R. Dell’Orso<sup>a</sup>, S. Donato<sup>a,c,2</sup>, G. Fedi, L. Foà<sup>a,c,†</sup>, A. Giassi<sup>a</sup>, M. T. Grippo<sup>a,30</sup>, F. Ligabue<sup>a,c</sup>, T. Lomtadze<sup>a</sup>, L. Martini<sup>a,b</sup>, A. Messineo<sup>a,b</sup>, F. Palla<sup>a</sup>, A. Rizzi<sup>a,b</sup>, A. Savoy-Navarro<sup>a,31</sup>, A. T. Serban<sup>a</sup>, P. Spagnolo<sup>a</sup>, R. Tenchini<sup>a</sup>, G. Tonelli<sup>a,b</sup>, A. Venturi<sup>a</sup>, P. G. Verdini<sup>a</sup>**INFN Sezione di Roma<sup>a</sup>, Università di Roma<sup>b</sup>, Roma, Italy**L. Barone<sup>a,b</sup>, F. Cavallari<sup>a</sup>, G. D’imperio<sup>a,b,2</sup>, D. Del Re<sup>a,b,2</sup>, M. Diemoz<sup>a</sup>, S. Gelli<sup>a,b</sup>, C. Jorda<sup>a</sup>, E. Longo<sup>a,b</sup>, F. Margaroli<sup>a,b</sup>, P. Meridiani<sup>a</sup>, G. Organtini<sup>a,b</sup>, R. Paramatti<sup>a</sup>, F. Preiato<sup>a,b</sup>, S. Rahatlou<sup>a,b</sup>, C. Rovelli<sup>a</sup>, F. Santanastasio<sup>a,b</sup>, P. Traczyk<sup>a,b,2</sup>**INFN Sezione di Torino<sup>a</sup>, Università di Torino<sup>b</sup>, Torino, Italy, Università del Piemonte Orientale<sup>c</sup>, Novara, Italy**N. Amapane<sup>a,b</sup>, R. Arcidiacono<sup>a,c,2</sup>, S. Argiro<sup>a,b</sup>, M. Arneodo<sup>a,c</sup>, R. Bellan<sup>a,b</sup>, C. Biino<sup>a</sup>, N. Cartiglia<sup>a</sup>, M. Costa<sup>a,b</sup>, R. Covarelli<sup>a,b</sup>, A. Degano<sup>a,b</sup>, N. Demaria<sup>a</sup>, L. Finco<sup>a,b,2</sup>, B. Kiani<sup>a,b</sup>, C. Mariotti<sup>a</sup>, S. Maselli<sup>a</sup>, E. Migliore<sup>a,b</sup>, V. Monaco<sup>a,b</sup>, E. Monteil<sup>a,b</sup>, M. M. Obertino<sup>a,b</sup>, L. Pacher<sup>a,b</sup>, N. Pastrone<sup>a</sup>, M. Pelliccioni<sup>a</sup>, G. L. Pinna Angioni<sup>a,b</sup>, F. Ravera<sup>a,b</sup>, A. Romero<sup>a,b</sup>, M. Ruspa<sup>a,c</sup>, R. Sacchi<sup>a,b</sup>, A. Solano<sup>a,b</sup>, A. Staiano<sup>a</sup>**INFN Sezione di Trieste<sup>a</sup>, Università di Trieste<sup>b</sup>, Trieste, Italy**S. Belforte<sup>a</sup>, V. Candelise<sup>a,b</sup>, M. Casarsa<sup>a</sup>, F. Cossutti<sup>a</sup>, G. Della Ricca<sup>a,b</sup>, B. Gobbo<sup>a</sup>, C. La Licata<sup>a,b</sup>, M. Marone<sup>a,b</sup>, A. Schizzi<sup>a,b</sup>, A. Zanicchi<sup>a</sup>**Kangwon National University, Chunchon, Korea**

A. Kropivnitskaya, S. K. Nam

**Kyungpook National University, Daegu, Korea**

D. H. Kim, G. N. Kim, M. S. Kim, D. J. Kong, S. Lee, Y. D. Oh, A. Sakharov, D. C. Son

**Chonbuk National University, Jeonju, Korea**

J. A. Brochero Cifuentes, H. Kim, T. J. Kim

**Institute for Universe and Elementary Particles, Chonnam National University, Kwangju, Korea**

S. Song

**Korea University, Seoul, Korea**

S. Choi, Y. Go, D. Gyun, B. Hong, H. Kim, Y. Kim, B. Lee, K. Lee, K. S. Lee, S. Lee, S. K. Park, Y. Roh

**Seoul National University, Seoul, Korea**

H. D. Yoo

**University of Seoul, Seoul, Korea**

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

**Sungkyunkwan University, Suwon, Korea**

Y. Choi, J. Goh, D. Kim, E. Kwon, J. Lee, I. Yu

**Vilnius University, Vilnius, Lithuania**

V. Dudenas, A. Juodagalvis, J. Vaitkus

**National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia**I. Ahmed, Z. A. Ibrahim, J. R. Komaragiri, M. A. B. Md Ali<sup>32</sup>, F. Mohamad Idris<sup>33</sup>, W. A. T. Wan Abdullah, M. N. Yusli**Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico**E. Casimiro Linares, H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-De La Cruz<sup>34</sup>, A. Hernandez-Almada, R. Lopez-Fernandez, A. Sanchez-Hernandez**Universidad Iberoamericana, Mexico City, Mexico**

S. Carrillo Moreno, F. Vazquez Valencia

**Benemerita Universidad Autonoma de Puebla, Puebla, Mexico**

I. Pedraza, H. A. Salazar Ibarquen

**Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico**

A. Morelos Pineda

**University of Auckland, Auckland, New Zealand**

D. Krofcheck

**University of Canterbury, Christchurch, New Zealand**

P. H. Butler

**National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan**

A. Ahmad, M. Ahmad, Q. Hassan, H. R. Hoorani, W. A. Khan, T. Khurshid, M. Shoaib

**National Centre for Nuclear Research, Swierk, Poland**

H. Bialkowska, M. Bluj, B. Boimska, T. Frueboes, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, P. Zalewski

**Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland**G. Brona, K. Bunkowski, A. Byszuk<sup>35</sup>, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, M. Olszewski, M. Walczak**Laboratório de Instrumentação e Física Experimental de Partículas, Lisbon, Portugal**

P. Bargassa, C. Beirão Da Cruz E Silva, A. Di Francesco, P. Faccioli, P. G. Ferreira Parracho, M. Gallinaro, J. Hollar, N. Leonardo, L. Lloret Iglesias, F. Nguyen, J. Rodrigues Antunes, J. Seixas, O. Toldaiev, D. Vadrucchio, J. Varela, P. Vischia

**Joint Institute for Nuclear Research, Dubna, Russia**S. Afanasiev, P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, A. Lanev, A. Malakhov, V. Matveev<sup>36,37</sup>, P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov, S. Shulha, N. Skatchkov, V. Smirnov, A. Zarubin

**Petersburg Nuclear Physics Institute, Gatchina, (St. Petersburg), Russia**

V. Golovtsov, Y. Ivanov, V. Kim<sup>38</sup>, E. Kuznetsova, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev

**Institute for Nuclear Research, Moscow, Russia**

Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, A. Karneyeu, M. Kirsanov, N. Krasnikov, A. Pashenkov, D. Tlisov, A. Toropin

**Institute for Theoretical and Experimental Physics, Moscow, Russia**

V. Epshteyn, V. Gavrilov, N. Lychkovskaya, V. Popov, I. Pozdnyakov, G. Safronov, A. Spiridonov, E. Vlasov, A. Zhokin

**National Research Nuclear University ‘Moscow Engineering Physics Institute’ (MEPhI), Moscow, Russia**

A. Bylinkin

**P. N. Lebedev Physical Institute, Moscow, Russia**

V. Andreev, M. Azarkin<sup>37</sup>, I. Dremin<sup>37</sup>, M. Kirakosyan, A. Leonidov<sup>37</sup>, G. Mesyats, S. V. Rusakov

**Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia**

A. Baskakov, A. Belyaev, E. Boos, M. Dubinin<sup>39</sup>, L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, I. Myagkov, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev

**State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia**

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Kachanov, A. Kalinin, D. Konstantinov, V. Krychkin, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

**Faculty of Physics and Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia**

P. Adzic<sup>40</sup>, P. Cirkovic, J. Milosevic, V. Rekoic

**Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain**

J. Alcaraz Maestre, E. Calvo, M. Cerrada, M. Chamizo Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, A. Escalante Del Valle, C. Fernandez Bedoya, J. P. Fernández Ramos, J. Flix, M. C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J. M. Hernandez, M. I. Josa, E. Navarro De Martino, A. Pérez-Calero Yzquierdo, J. Puerta Pelayo, A. Quintario Olmeda, I. Redondo, L. Romero, J. Santaolalla, M. S. Soares

**Universidad Autónoma de Madrid, Madrid, Spain**

C. Albajar, J. F. de Trocóniz, M. Missiroli, D. Moran

**Universidad de Oviedo, Oviedo, Spain**

J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, E. Palencia Cortezon, J. M. Vizan Garcia

**Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain**

I. J. Cabrillo, A. Calderon, J. R. Castiñeiras De Saa, P. De Castro Manzano, M. Fernandez, J. Garcia-Ferrero, G. Gomez, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, J. Piedra Gomez, T. Rodrigo, A. Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, N. Trevisani, 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, A. Benaglia, J. Bendavid, L. Benhabib, G. M. Berruti, P. Bloch, A. Bocci, A. Bonato, C. Botta, H. Breuker, T. Camporesi, R. Castello, G. Cerminara, M. D’Alfonso, D. d’Enterria, A. Dabrowski, V. Daponte, A. David, M. De Gruttola, F. De Guio, A. De Roeck, S. De Visscher, E. Di Marco<sup>41</sup>, M. Dobson, M. Dordevic, B. Dorney, T. du Pree, D. Duggan, M. Dünser, N. Dupont, A. Elliott-Peisert, G. Franzoni, J. Fulcher, W. Funk, D. Gigi, K. Gill, D. Giordano, M. Girone, F. Glege, R. Guida, S. Gundacker, M. Guthoff, J. Hammer, P. Harris, J. Hegeman, V. Innocente, P. Janot, H. Kirschenmann, M. J. Kortelainen, K. Kousouris, K. Krajczar, P. Lecoq, C. Lourenço, M. T. Lucchini, N. Magini, L. Malgeri, M. Mannelli, A. Martelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, F. Moortgat, S. Morovic, M. Mulders, M. V. Nemallapudi, H. Neugebauer, S. Orfanelli<sup>42</sup>, L. Orsini, L. Pape, E. Perez, M. Peruzzi, A. Petrilli, G. Petrucciani, A. Pfeiffer, M. Pierini, D. Piparo, A. Racz, T. Reis, G. Rolandi<sup>43</sup>, M. Rovere, M. Ruan, H. Sakulin, C. Schäfer, C. Schwick, M. Seidel, A. Sharma, P. Silva, M. Simon, P. Sphicas<sup>44</sup>, J. Stegmann, B. Stieger, M. Stoye, Y. Takahashi, D. Treille, A. Triossi, A. Tsiros, G. I. Veres<sup>20</sup>, N. Wardle, H. K. Wöhri, A. Zagozdinska<sup>35</sup>, W. D. Zeuner

**Paul Scherrer Institut, Villigen, Switzerland**

W. Bertl, K. Deiters, W. Erdmann, R. Horisberger, Q. Ingram, H. C. Kaestli, D. Kotlinski, U. Langenegger, D. Renker, T. Rohe

**Institute for Particle Physics, ETH Zurich, Zurich, Switzerland**

F. Bachmair, L. Bäni, L. Bianchini, B. Casal, G. Dissertori, M. Dittmar, M. Donegà, P. Eller, C. Grab, C. Heidegger, D. Hits, J. Hoss, G. Kasieczka, P. Lecomte, W. Lustermann, B. Mangano, M. Marionneau, P. Martinez Ruiz del Arbol, M. Masciovecchio, D. Meister, F. Micheli, P. Musella, F. Nessi-Tedaldi, F. Pandolfi, J. Pata, F. Pauss, L. Perrozzi, M. Quittnat, M. Rossini, M. Schönenberger, A. Starodumov<sup>45</sup>, M. Takahashi, V. R. Tavolaro, K. Theofilatos, R. Wallny

**Universität Zürich, Zurich, Switzerland**

T. K. Aarrestad, C. Amsler<sup>46</sup>, L. Caminada, M. F. Canelli, V. Chiochia, A. De Cosa, C. Galloni, A. Hinzmann, T. Hreus, B. Kilminster, C. Lange, J. Ngadiuba, D. Pinna, G. Rauco, P. Robmann, F. J. Ronga, D. Salerno, Y. Yang

**National Central University, Chung-Li, Taiwan**

M. Cardaci, K. H. Chen, T. H. Doan, Sh. Jain, R. Khurana, M. Konyushikhin, C. M. Kuo, W. Lin, Y. J. Lu, A. Pozdnyakov, S. S. Yu

**National Taiwan University (NTU), Taipei, Taiwan**

Arun Kumar, P. Chang, Y. H. Chang, Y. W. Chang, Y. Chao, K. F. Chen, P. H. Chen, C. Dietz, F. Fiori, U. Grundler, W.-S. Hou, Y. Hsiung, Y. F. Liu, R.-S. Lu, M. Miñano Moya, E. Petrakou, J. f. Tsai, Y. M. Tzeng

**Department of Physics, Faculty of Science, Chulalongkorn University, Bangkok, Thailand**

B. Asavapibhop, K. Kovitangoon, G. Singh, N. Srimanobhas, N. Suwonjandee

**Cukurova University, Adana, Turkey**

A. Adiguzel, S. Cerci<sup>47</sup>, Z. S. Demiroglu, C. Dozen, I. Dumanoglu, E. Eskut, F. H. Gecit, S. Girgis, G. Gokbulut, Y. Guler, E. Gurpinar, I. Hos, E. E. Kangal<sup>48</sup>, A. Kayis Topaksu, G. Onengut<sup>49</sup>, M. Ozcan, K. Ozdemir<sup>50</sup>, S. Ozturk<sup>51</sup>, A. Polatoz, C. Zorbilmez

**Physics Department, Middle East Technical University, Ankara, Turkey**

B. Bilin, S. Bilmis, B. Isildak<sup>52</sup>, G. Karapinar<sup>53</sup>, M. Yalvac, M. Zeyrek

**Bogazici University, Istanbul, Turkey**

E. Gülmez, M. Kaya<sup>54</sup>, O. Kaya<sup>55</sup>, E. A. Yetkin<sup>56</sup>, T. Yetkin<sup>57</sup>

**Istanbul Technical University, Istanbul, Turkey**

A. Cakir, K. Cankocak, S. Sen<sup>58</sup>, F. I. Vardarli

**Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine**

B. Grynyov

**National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine**

L. Levchuk, P. Sorokin

**University of Bristol, Bristol, UK**

R. Aggleton, F. Ball, L. Beck, J. J. Brooke, E. Clement, D. Cussans, H. Flacher, J. Goldstein, M. Grimes, G. P. Heath, H. F. Heath, J. Jacob, L. Kreczko, C. Lucas, Z. Meng, D. M. Newbold<sup>59</sup>, S. Paramesvaran, A. Poll, T. Sakuma, S. Seif El Nasr-storey, S. Senkin, D. Smith, V. J. Smith

**Rutherford Appleton Laboratory, Didcot, UK**

K. W. Bell, A. Belyaev<sup>60</sup>, C. Brew, R. M. Brown, L. Calligaris, D. Cieri, D. J. A. Cockerill, J. A. Coughlan, K. Harder, S. Harper, E. Olaiya, D. Petyt, C. H. Shepherd-Themistocleous, A. Thea, I. R. Tomalin, T. Williams, S. D. Worm

**Imperial College, London, UK**

M. Baber, R. Bainbridge, O. Buchmuller, A. Bundock, D. Burton, S. Casasso, M. Citron, D. Colling, L. Corpe, P. Dauncey, G. Davies, A. De Wit, M. Della Negra, P. Dunne, A. Elwood, D. Futyan, G. Hall, G. Iles, R. Lane, R. Lucas<sup>59</sup>, L. Lyons, A.-M. Magnan, S. Malik, J. Nash, A. Nikitenko<sup>45</sup>, J. Pela, M. Pesaresi, K. Petridis, D. M. Raymond, A. Richards, A. Rose, C. Seez, A. Tapper, K. Uchida, M. Vazquez Acosta<sup>61</sup>, T. Virdee, S. C. Zenz



**Brunel University, Uxbridge, UK**

J. E. Cole, P. R. Hobson, A. Khan, P. Kyberd, D. Leggat, D. Leslie, I. D. Reid, P. Symonds, L. Teodorescu, M. Turner

**Baylor University, Waco, USA**

A. Borzou, K. Call, J. Dittmann, K. Hatakeyama, H. Liu, N. Pastika

**The University of Alabama, Tuscaloosa, USA**

O. Charaf, S. I. Cooper, C. Henderson, P. Rumerio

**Boston University, Boston, USA**

D. Arcaro, A. Avetisyan, T. Bose, D. Gastler, D. Rankin, C. Richardson, J. Rohlf, L. Sulak, D. Zou

**Brown University, Providence, USA**

J. Alimena, E. Berry, D. Cutts, A. Ferapontov, A. Garabedian, J. Hakala, U. Heintz, E. Laird, G. Landsberg, Z. Mao, M. Narain, S. Piperov, S. Sagir, R. Syarif

**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, R. Erbacher, G. Funk, M. Gardner, W. Ko, R. Lander, C. Mclean, M. Mulhearn, D. Pellett, J. Pilot, F. Ricci-Tam, S. Shalhout, J. Smith, M. Squires, D. Stolp, M. Tripathi, S. Wilbur, R. Yohay

**University of California, Los Angeles, USA**

R. Cousins, P. Everaerts, A. Florent, J. Hauser, M. Ignatenko, D. Saltzberg, E. Takasugi, V. Valuev, M. Weber

**University of California, Riverside, Riverside, USA**

K. Burt, R. Clare, J. Ellison, J. W. Gary, G. Hanson, J. Heilman, M. Ivova PANEVA, P. Jandir, E. Kennedy, F. Lacroix, O. R. Long, M. Malberti, M. Olmedo Negrete, A. Shrinivas, H. Wei, S. Wimpenny, B. R. Yates

**University of California, San Diego, La Jolla, USA**

J. G. Branson, G. B. Cerati, S. Cittolin, R. T. D'Agno, M. Derdzinski, A. Holzner, R. Kelley, D. Klein, J. Letts, I. Macneill, D. Olivito, S. Padhi, M. Pieri, M. Sani, V. Sharma, S. Simon, M. Tadel, A. Vartak, S. Wasserbaech<sup>62</sup>, C. Welke, F. Würthwein, A. Yagil, G. Zevi Della Porta

**University of California, Santa Barbara, Santa Barbara, USA**

J. Bradmiller-Feld, C. Campagnari, A. Dishaw, V. Dutta, K. Flowers, M. Franco Sevilla, P. Geffert, C. George, F. Golf, L. Gouskos, J. Gran, J. Incandela, N. Mccoll, S. D. Mullin, J. Richman, D. Stuart, I. Suarez, C. West, J. Yoo

**California Institute of Technology, Pasadena, USA**

D. Anderson, A. Apresyan, A. Bornheim, J. Bunn, Y. Chen, J. Duarte, A. Mott, H. B. Newman, C. Pena, M. Spiropulu, J. R. Vlimant, S. Xie, R. Y. Zhu

**Carnegie Mellon University, Pittsburgh, USA**

M. B. Andrews, V. Azzolini, A. Calamba, B. Carlson, T. Ferguson, M. Paulini, J. Russ, M. Sun, H. Vogel, I. Vorobiev

**University of Colorado Boulder, Boulder, USA**

J. P. Cumalat, W. T. Ford, A. Gaz, F. Jensen, A. Johnson, M. Krohn, T. Mulholland, U. Nauenberg, K. Stenson, S. R. Wagner

**Cornell University, Ithaca, USA**

J. Alexander, A. Chatterjee, J. Chaves, J. Chu, S. Dittmer, N. Eggert, N. Mirman, G. Nicolas Kaufman, J. R. Patterson, A. Rinkevicius, A. Ryd, L. Skinnari, L. Soffi, W. Sun, S. M. Tan, W. D. Teo, J. Thom, J. Thompson, J. Tucker, Y. Weng, P. Wittich

**Fermi National Accelerator Laboratory, Batavia, USA**

S. Abdullin, M. Albrow, G. Apollinari, S. Banerjee, L. A. T. Bauerick, A. Beretvas, J. Berryhill, P. C. Bhat, G. Bolla, K. Burkett, J. N. Butler, H. W. K. Cheung, F. Chlebana, S. Cihangir, V. D. Elvira, I. Fisk, J. Freeman, E. Gottschalk, L. Gray, D. Green, S. Grünendahl, O. Gutsche, J. Hanlon, D. Hare, R. M. Harris, S. Hasegawa, J. Hirschauer, Z. Hu, B. Jayatilaka, S. Jindariani, M. Johnson, U. Joshi, B. Klima, B. Kreis, S. Lammel, J. Linacre, D. Lincoln, R. Lipton, T. Liu, R. Lopes De Sá, J. Lykken, K. Maeshima, J. M. Marraffino, S. Maruyama, D. Mason, P. McBride, P. Merkel, S. Mrenna, S. Nahn, C. Newman-Holmes<sup>†</sup>, V. O'Dell, K. Pedro, O. Prokofyev, G. Rakness, E. Sexton-Kennedy, A. Soha,

W. J. Spalding, L. Spiegel, S. Stoynev, N. Strobbe, L. Taylor, S. Tkaczyk, N. V. Tran, L. Uplegger, E. W. Vaandering, C. Vernieri, M. Verzocchi, R. Vidal, M. Wang, H. A. Weber, A. Whitbeck

**University of Florida, Gainesville, USA**

D. Acosta, P. Avery, P. Bortignon, D. Bourilkov, A. Carnes, M. Carver, D. Curry, S. Das, R. D. Field, I. K. Furic, S. V. Gleyzer, J. Konigsberg, A. Korytov, K. Kotov, P. Ma, K. Matchev, H. Mei, P. Milenovic<sup>63</sup>, G. Mitselmakher, D. Rank, R. Rossin, L. Shchutska, M. Snowball, D. Sperka, N. Terentyev, L. Thomas, J. Wang, S. Wang, J. Yelton

**Florida International University, Miami, USA**

S. Hewamanage, S. Linn, P. Markowitz, G. Martinez, J. L. Rodriguez

**Florida State University, Tallahassee, USA**

A. Ackert, J. R. Adams, T. Adams, A. Askew, S. Bein, J. Bochenek, B. Diamond, J. Haas, S. Hagopian, V. Hagopian, K. F. Johnson, A. Khatiwada, H. Prosper, M. Weinberg

**Florida Institute of Technology, Melbourne, USA**

M. M. Baarmand, V. Bhopatkar, S. Colafranceschi<sup>64</sup>, M. Hohlmann, H. Kalakhety, D. Noonan, T. Roy, F. Yumiceva

**University of Illinois at Chicago (UIC), Chicago, USA**

M. R. Adams, L. Apanasevich, D. Berry, R. R. Betts, I. Bucinskaite, R. Cavanaugh, O. Evdokimov, L. Gauthier, C. E. Gerber, D. J. Hofman, P. Kurt, C. O'Brien, I. D. Sandoval Gonzalez, P. Turner, N. Varelas, Z. Wu, M. Zakaria

**The University of Iowa, Iowa City, USA**

B. Bilki<sup>65</sup>, W. Clarida, K. Dilsiz, S. Durgut, R. P. Gandrajula, M. Haytmyradov, V. Khristenko, J.-P. Merlo, H. Mermerkaya<sup>66</sup>, A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok<sup>67</sup>, A. Penzo, C. Snyder, E. Tiras, J. Wetzel, K. Yi

**Johns Hopkins University, Baltimore, USA**

I. Anderson, B. A. Barnett, B. Blumenfeld, N. Eminizer, D. Fehling, L. Feng, A. V. Gritsan, P. Maksimovic, C. Martin, M. Osherson, J. Roskes, A. Sady, U. Sarica, M. Swartz, M. Xiao, Y. Xin, C. You

**The University of Kansas, Lawrence, USA**

P. Baringer, A. Bean, G. Benelli, C. Bruner, R. P. KennyIII, D. Majumder, M. Malek, M. Murray, S. Sanders, R. Stringer, Q. Wang

**Kansas State University, Manhattan, USA**

A. Ivanov, K. Kaadze, S. Khalil, M. Makouski, Y. Maravin, A. Mohammadi, L. K. Saini, N. Skhirtladze, S. Toda

**Lawrence Livermore National Laboratory, Livermore, USA**

D. Lange, F. Rebassoo, D. Wright

**University of Maryland, College Park, USA**

C. Anelli, A. Baden, O. Baron, A. Belloni, B. Calvert, S. C. Eno, C. Ferraioli, J. A. Gomez, N. J. Hadley, S. Jabeen, R. G. Kellogg, T. Kolberg, J. Kunkle, Y. Lu, A. C. Mignerey, Y. H. Shin, A. Skuja, M. B. Tonjes, S. C. Tonwar

**Massachusetts Institute of Technology, Cambridge, USA**

A. Apyan, R. Barbieri, A. Baty, K. Bierwagen, S. Brandt, W. Busza, I. A. Cali, Z. Demiragli, L. Di Matteo, G. Gomez Ceballos, M. Goncharov, D. Gulhan, Y. Iiyama, G. M. Innocenti, M. Klute, D. Kovalskyi, Y. S. Lai, Y.-J. Lee, A. Levin, P. D. Luckey, A. C. Marini, C. McGinn, C. Mironov, S. Narayanan, X. Niu, C. Paus, C. Roland, G. Roland, J. Salfeld-Nebgen, G. S. F. Stephens, K. Sumorok, M. Varma, D. Velicanu, J. Veverka, J. Wang, T. W. Wang, B. Wyslouch, M. Yang, V. Zhukova

**University of Minnesota, Minneapolis, USA**

B. Dahmes, A. Evans, A. Finkel, A. Gude, P. Hansen, S. Kalafut, S. C. Kao, K. Klapoetke, Y. Kubota, Z. Lesko, J. Mans, S. Nourbakhsh, N. Ruckstuhl, R. Rusack, N. Tambe, J. Turkewitz

**University of Mississippi, Oxford, USA**

J. G. Acosta, S. Oliveros

**University of Nebraska-Lincoln, Lincoln, USA**

E. Avdeeva, R. Bartek, K. Bloom, S. Bose, D. R. Claes, A. Dominguez, C. Fangmeier, R. Gonzalez Suarez, R. Kamalieddin, D. Knowlton, I. Kravchenko, F. Meier, J. Monroy, F. Ratnikov, J. E. Siado, G. R. Snow

**State University of New York at Buffalo, Buffalo, USA**

M. Alyari, J. Dolen, J. George, A. Godshalk, C. Harrington, I. Iashvili, J. Kaisen, A. Kharchilava, A. Kumar, S. Rappoccio, B. Roozbahani

**Northeastern University, Boston, USA**

G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, A. Hortiangtham, A. Massironi, D. M. Morse, D. Nash, T. Orimoto, R. Teixeira De Lima, D. Trocino, R.-J. Wang, D. Wood, J. Zhang

**Northwestern University, Evanston, USA**

S. Bhattacharya, K. A. Hahn, A. Kubik, J. F. Low, N. Mucia, N. Odell, B. Pollack, M. Schmitt, K. Sung, M. Trovato, M. Velasco

**University of Notre Dame, Notre Dame, USA**

A. Brinkerhoff, N. Dev, M. Hildreth, C. Jessop, D. J. Karmgard, N. Kellams, K. Lannon, N. Marinelli, F. Meng, C. Mueller, Y. Musienko<sup>36</sup>, M. Planer, A. Reinsvold, R. Ruchti, G. Smith, S. Taroni, N. Valls, M. Wayne, M. Wolf, A. Woodard

**The Ohio State University, Columbus, USA**

L. Antonelli, J. Brinson, B. Bylsma, L. S. Durkin, S. Flowers, A. Hart, C. Hill, R. Hughes, W. Ji, T. Y. Ling, B. Liu, W. Luo, D. Puigh, M. Rodenburg, B. L. Winer, H. W. Wulsin

**Princeton University, Princeton, USA**

O. Driga, P. Elmer, J. Hardenbrook, P. Hebda, S. A. Koay, P. Lujan, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, C. Palmer, P. Piroué, H. Saka, D. Stickland, C. Tully, A. Zuranski

**University of Puerto Rico, Mayaguez, USA**

S. Malik

**Purdue University, West Lafayette, USA**

A. Barker, V. E. Barnes, D. Benedetti, D. Bortoletto, L. Gutay, M. K. Jha, M. Jones, A. W. Jung, K. Jung, A. Kumar, D. H. Miller, N. Neumeister, B. C. Radburn-Smith, X. Shi, I. Shipsey, D. Silvers, J. Sun, A. Svyatkovskiy, F. Wang, W. Xie, L. Xu

**Purdue University Calumet, Hammond, USA**

N. Parashar, J. Stupak

**Rice University, Houston, USA**

A. Adair, B. Akgun, Z. Chen, K. M. Ecklund, F. J. M. Geurts, M. Guilbaud, W. Li, B. Michlin, M. Northup, B. P. Padley, R. Redjimi, J. Roberts, J. Rorie, Z. Tu, J. Zabel

**University of Rochester, Rochester, USA**

B. Betchart, A. Bodek, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, M. Galanti, A. Garcia-Bellido, J. Han, A. Harel, O. Hindrichs, A. Khukhunaishvili, G. Petrillo, P. Tan, M. Verzetti

**Rutgers, The State University of New Jersey, Piscataway, USA**

J. P. Chou, E. Contreras-Campana, D. Ferencek, Y. Gershtein, E. Halkiadakis, D. Hidas, E. Hughes, S. Kaplan, R. Kunnawalkam Elayavalli, A. Lath, K. Nash, S. Salur, S. Schnetzer, D. Sheffield, S. Somalwar, R. Stone, S. Thomas, P. Thomassen, M. Walker

**University of Tennessee, Knoxville, USA**

M. Foerster, G. Riley, K. Rose, S. Spanier

**Texas A&M University, College Station, USA**

O. Bouhali<sup>68</sup>, A. Castaneda Hernandez<sup>68</sup>, A. Celik, M. Dalchenko, M. De Mattia, A. Delgado, S. Dildick, R. Eusebi, J. Gilmore, T. Huang, T. Kamon<sup>69</sup>, V. Krutelyov, R. Mueller, I. Osipenkov, Y. Pakhotin, R. Patel, A. Perloff, A. Rose, A. Safonov, A. Tatarinov, K. A. Ulmer<sup>2</sup>

**Texas Tech University, Lubbock, USA**

N. Akchurin, C. Cowden, J. Damgov, C. Dragoiu, P. R. Duderu, J. Faulkner, S. Kunori, K. Lamichhane, S. W. Lee, T. Libeiro, S. Undleeb, I. Volobouev

**Vanderbilt University, Nashville, USA**

E. Appelt, A. G. Delannoy, S. Greene, A. Gurrola, R. Janjam, W. Johns, C. Maguire, Y. Mao, A. Melo, H. Ni, P. Sheldon, S. Tuo, J. Velkovska, Q. Xu

**University of Virginia, Charlottesville, USA**

M. W. Arenton, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, H. Li, C. Lin, C. Neu, T. Sinthuprasith, X. Sun, Y. Wang, E. Wolfe, J. Wood, F. Xia

**Wayne State University, Detroit, USA**

C. Clarke, R. Harr, P. E. Karchin, C. Kottachchi Kankanamge Don, P. Lamichhane, J. Sturdy

**University of Wisconsin-Madison, Madison, WI, USA**

D. A. Belknap, D. Carlsmith, M. Cepeda, S. Dasu, L. Dodd, S. Duric, B. Gomber, M. Grothe, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, A. Lanaro, A. Levine, K. Long, R. Loveless, A. Mohapatra, I. Ojalvo, T. Perry, G. A. Pierro, G. Polese, T. Ruggles, T. Sarangi, A. Savin, A. Sharma, N. Smith, W. H. Smith, D. Taylor, P. Verwilligen, N. Woods

**† Deceased**

- 1: Also at Vienna University of Technology, Vienna, Austria
- 2: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
- 3: Also at State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China
- 4: Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France
- 5: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
- 6: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
- 7: Also at Universidade Estadual de Campinas, Campinas, Brazil
- 8: Also at Centre National de la Recherche Scientifique (CNRS)-IN2P3, Paris, France
- 9: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
- 10: Also at Joint Institute for Nuclear Research, Dubna, Russia
- 11: Also at Ain Shams University, Cairo, Egypt
- 12: Also at Zewail city of Science and Technology, Zewail, Egypt
- 13: Also at British University in Egypt, Cairo, Egypt
- 14: Also at Université de Haute Alsace, Mulhouse, France
- 15: Also at Tbilisi State University, Tbilisi, Georgia
- 16: Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
- 17: Also at University of Hamburg, Hamburg, Germany
- 18: Also at Brandenburg University of Technology, Cottbus, Germany
- 19: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
- 20: Also at Eötvös Loránd University, Budapest, Hungary
- 21: Also at University of Debrecen, Debrecen, Hungary
- 22: Also at Wigner Research Centre for Physics, Budapest, Hungary
- 23: Also at Indian Institute of Science Education and Research, Bhopal, India
- 24: Also at University of Visva-Bharati, Santiniketan, India
- 25: Now at King Abdulaziz University, Jeddah, Saudi Arabia
- 26: Also at University of Ruhuna, Matara, Sri Lanka
- 27: Also at Isfahan University of Technology, Isfahan, Iran
- 28: Also at University of Tehran, Department of Engineering Science, Tehran, Iran
- 29: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
- 30: Also at Università degli Studi di Siena, Siena, Italy
- 31: Also at Purdue University, West Lafayette, USA
- 32: Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia
- 33: Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia

- 34: Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico
- 35: Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland
- 36: Also at Institute for Nuclear Research, Moscow, Russia
- 37: Now at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
- 38: Also at St. Petersburg State Polytechnical University, (St. Petersburg), Russia
- 39: Also at California Institute of Technology, Pasadena, USA
- 40: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
- 41: Also at INFN Sezione di Roma, Università di Roma, Roma, Italy
- 42: Also at National Technical University of Athens, Athens, Greece
- 43: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
- 44: Also at National and Kapodistrian University of Athens, Athens, Greece
- 45: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
- 46: Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland
- 47: Also at Adiyaman University, Adiyaman, Turkey
- 48: Also at Mersin University, Mersin, Turkey
- 49: Also at Cag University, Mersin, Turkey
- 50: Also at Piri Reis University, Istanbul, Turkey
- 51: Also at Gaziosmanpasa University, Tokat, Turkey
- 52: Also at Ozyegin University, Istanbul, Turkey
- 53: Also at Izmir Institute of Technology, Izmir, Turkey
- 54: Also at Marmara University, Istanbul, Turkey
- 55: Also at Kafkas University, Kars, Turkey
- 56: Also at Istanbul Bilgi University, Istanbul, Turkey
- 57: Also at Yildiz Technical University, Istanbul, Turkey
- 58: Also at Hacettepe University, Ankara, Turkey
- 59: Also at Rutherford Appleton Laboratory, Didcot, UK
- 60: Also at School of Physics and Astronomy, University of Southampton, Southampton, UK
- 61: Also at Instituto de Astrofísica de Canarias, La Laguna, Spain
- 62: Also at Utah Valley University, Orem, USA
- 63: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
- 64: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
- 65: Also at Argonne National Laboratory, Argonne, USA
- 66: Also at Erzincan University, Erzincan, Turkey
- 67: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
- 68: Also at Texas A&M University at Qatar, Doha, Qatar
- 69: Also at Kyungpook National University, Daegu, Korea