



**University of
Zurich**^{UZH}

**Zurich Open Repository and
Archive**

University of Zurich
Main Library
Strickhofstrasse 39
CH-8057 Zurich
www.zora.uzh.ch

Year: 2011

Measurement of Dijet angular distributions and search for quark compositeness in pp collisions at $\sqrt{s} = 7$ TeV

CMS Collaboration; Khachatryan, V; Amsler, C; Chiochia, V

Abstract: Dijet angular distributions are measured over a wide range of dijet invariant masses in pp collisions at $\sqrt{s}=7$ TeV, at the CERN LHC. The event sample, recorded with the CMS detector, corresponds to an integrated luminosity of 36 pb⁻¹. The data are found to be in good agreement with the predictions of perturbative QCD, and yield no evidence of quark compositeness. With a modified frequentist approach, a lower limit on the contact interaction scale for left-handed quarks of $\Lambda_+ = 5.6$ TeV ($\Lambda_- = 6.7$ TeV) for destructive (constructive) interference is obtained at the 95% confidence level. Published by the American Physical Society under the terms of the Creative Commons Attribution 3.0 License. Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI. © 2011 CERN, for the CMS Collaboration

DOI: <https://doi.org/10.1103/PhysRevLett.106.201804>

Posted at the Zurich Open Repository and Archive, University of Zurich

ZORA URL: <https://doi.org/10.5167/uzh-58563>

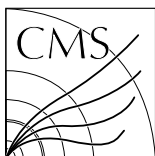
Journal Article

Accepted Version

Originally published at:

CMS Collaboration; Khachatryan, V; Amsler, C; Chiochia, V (2011). Measurement of Dijet angular distributions and search for quark compositeness in pp collisions at $\sqrt{s} = 7$ TeV. *Physical Review Letters*, 106(20):201804.

DOI: <https://doi.org/10.1103/PhysRevLett.106.201804>

CERN-PH-EP/2010-092
2011/02/11

CMS-QCD-10-016

Measurement of Dijet Angular Distributions and Search for Quark Compositeness in pp Collisions at $\sqrt{s} = 7$ TeV

The CMS Collaboration*

Abstract

Dijet angular distributions are measured over a wide range of dijet invariant masses in pp collisions at $\sqrt{s} = 7$ TeV, at the CERN LHC. The event sample, recorded with the CMS detector, corresponds to an integrated luminosity of 36 pb^{-1} . The data are found to be in good agreement with the predictions of perturbative QCD, and yield no evidence of quark compositeness. With a modified frequentist approach, a lower limit on the contact interaction scale for left-handed quarks of $\Lambda = 5.6$ TeV is obtained at the 95% confidence level.

Submitted to Physical Review Letters

arXiv:1102.2020v1 [hep-ex] 10 Feb 2011

*See Appendix A for the list of collaboration members

In the standard model, point like parton-parton scatterings in high energy proton-proton collisions can give rise to final states with energetic jets. At large momentum transfers, events with at least two energetic jets (dijets) may be used to confront the predictions of perturbative Quantum Chromodynamics (pQCD) and to search for signatures of new physics. In parton-parton scattering, the angular distribution of the outgoing partons, $d\hat{\sigma}/d\cos\theta^*$, is directly sensitive to the spin of the exchanged particle, where $\hat{\sigma}$ is the parton-level cross section and θ^* is the polar scattering angle in the parton-parton center-of-mass (CM) frame. While QCD predicts a noticeable deviation of the dijet angular distribution from Rutherford scattering, at small CM scattering angles the angular distribution is proportional to the Rutherford cross section, $d\hat{\sigma}/d\cos\theta^* \sim 1/(1 - \cos\theta^*)^2$, characteristic of spin-1 particle exchange. The dijet angular distributions do not strongly depend on the details of the parton distribution functions (PDFs), since the angular distributions for the underlying processes, $qg \rightarrow qg$, $qq' \rightarrow qq'$, and $gg \rightarrow gg$, are similar.

For the scattering of massless partons, which are assumed to be collinear with the beam protons, the longitudinal boost of the parton-parton CM frame with respect to the proton-proton CM frame, y_{boost} , and θ^* are obtained from the rapidities y_1 and y_2 of the jets from the two scattered partons by $y_{\text{boost}} = \frac{1}{2}(y_1 + y_2)$ and $|\cos\theta^*| = \tanh y^*$, where $y^* = \frac{1}{2}|y_1 - y_2|$ and where $\pm y^*$ are the rapidities of the two jets in the parton-parton CM frame. The rapidity is related to the jet energy E and the projection of the jet momentum on the beam axis p_z by $y = \frac{1}{2} \ln[(E + p_z)/(E - p_z)]$. The variable $\chi_{\text{dijet}} = \exp(2y^*)$ is used to measure the dijet angular distribution, which for collinear massless-parton scattering takes the form $\chi_{\text{dijet}} = (1 + |\cos\theta^*|)/(1 - |\cos\theta^*|)$. This choice of χ_{dijet} , rather than θ^* , is motivated by the fact that $d\sigma_{\text{dijet}}/d\chi_{\text{dijet}}$ is flat for Rutherford scattering. It also allows signatures of new physics that might have a more isotropic angular distribution than QCD (e.g. quark compositeness) to be more easily examined as they would produce an excess at low values of χ_{dijet} . The quantity studied in this analysis is $(1/\sigma_{\text{dijet}})(d\sigma_{\text{dijet}}/d\chi_{\text{dijet}})$, for several ranges of the dijet invariant mass M_{jj} . Previous searches for quark compositeness using the dijet angular distribution or related observables in pp and p \bar{p} collisions have been reported at the Sp \bar{p} S by the UA1 [1] collaboration, at the Tevatron by the D0 [2, 3] and CDF [4] collaborations, and at the Large Hadron Collider (LHC) by the ATLAS [5] collaboration. The CMS collaboration has also published a search on quark compositeness with a smaller data sample using the dijet centrality ratio [6]. In this Letter, we present the first measurement of dijet angular distributions from CMS in pp collisions at $\sqrt{s} = 7$ TeV.

The central feature of the CMS apparatus is a superconducting solenoid, of 6 m internal diameter, providing an axial field of 3.8 T. Within the field volume are the silicon pixel and silicon strip tracker, the electromagnetic calorimeter (ECAL) and the hadron calorimeter (HCAL). The ECAL is made up of lead-tungstate crystals, while the HCAL is made of layers of plates of brass and plastic scintillator. These calorimeters provide coverage in pseudorapidity up to $|\eta| \leq 3$, where $\eta = -\ln \tan(\theta/2)$ and θ is the polar angle relative to the counterclockwise proton beam direction. An iron/quartz-fiber Čerenkov hadron calorimeter (HF) covers pseudorapidities $3 < |\eta| < 5$. In addition, a preshower detector made of silicon sensor planes and lead absorbers is located in front of the ECAL at $1.653 < |\eta| < 2.6$. The calorimeter cells are grouped in projective towers of granularity in pseudorapidity and azimuthal angle of 0.087×0.087 at central pseudorapidities, with coarser granularity at forward pseudorapidities. Muons are measured in gas-ionization detectors embedded in the steel magnetic field return yoke. A detailed description of the CMS detector can be found elsewhere [7].

Events were collected online with a two-tiered trigger system: Level-1 (L1) and the High Level Trigger (HLT). For this study, events were selected with five inclusive single-jet triggers, with

the following jet transverse momentum p_T thresholds at L1 (HLT): 20 GeV (30 GeV), 30 GeV (50 GeV), 40 GeV (70 GeV), 60 GeV (100 GeV), and 60 GeV (140 GeV). The jets at L1 and HLT were reconstructed using energies measured by the ECAL, HCAL, and HF, and were not corrected for the jet energy response of the calorimeters. All except the highest-threshold jet trigger were prescaled as the LHC instantaneous luminosity increased during the course of data taking. In each case, the trigger efficiency was measured as a function of dijet invariant mass M_{jj} using events selected by a lower-threshold trigger. For the analysis, M_{jj} - and χ_{dijet} -regions were chosen such that the trigger efficiencies exceeded 99%.

Jets were reconstructed offline from energies measured in the calorimeter towers using the anti- k_T clustering-algorithm [8] with a distance parameter $R = 0.5$. Spurious jets from noise and non-collision backgrounds were eliminated by loose quality criteria on the jet properties [9]. The jet four-momenta were corrected for the non-linear response of the calorimeters [10]. The performance of the CMS detector with respect to jet reconstruction is described in detail elsewhere [11].

Events were required to have a primary vertex reconstructed within 24 cm of the detector center along the beam line [12]. Events having at least two jets were selected and the two highest- p_T jets were used to measure the dijet angular distributions for different ranges in M_{jj} . We required $\chi_{\text{dijet}} < 16$ and $|y_{\text{boost}}| < 1.11$, thus restricting the rapidities y_1 and y_2 of the two highest- p_T jets to be less than 2.5. Nine analysis ranges were defined with the boundaries $0.25 < M_{jj} < 0.35$ TeV, $0.35 < M_{jj} < 0.5$ TeV, $0.5 < M_{jj} < 0.65$ TeV, $0.65 < M_{jj} < 0.85$ TeV, $0.85 < M_{jj} < 1.1$ TeV, $1.1 < M_{jj} < 1.4$ TeV, $1.4 < M_{jj} < 1.8$ TeV, $1.8 < M_{jj} < 2.2$ TeV, and $M_{jj} > 2.2$ TeV. The data correspond to integrated luminosities of 0.4, 3.5, 9.2, and 19.8 pb^{-1} for the lowest four M_{jj} ranges and 36 pb^{-1} for the remaining ones. The uncertainty on the integrated luminosity has been estimated to be 11% [13].

The dijet angular distributions are corrected for migration effects in χ_{dijet} and M_{jj} due to the finite jet energy and position resolutions of the detector. The correction factors were determined using two independent Monte Carlo (MC) samples: PYTHIA 6.422 [14] with tune D6T [15] and HERWIG++ 2.4.2 [16]. The four-momentum, rapidity, and azimuthal angle of each generated jet were smeared to reproduce the measured resolutions. The ratio of the two dijet angular distributions (the generated distribution and the smeared one) determined the unfolding correction factors for a given MC sample and for each M_{jj} range. The average of the correction factors for each M_{jj} range from the two MC samples formed the final unfolding correction applied to the data. The correction factors change the normalized dijet angular distributions for all M_{jj} ranges by less than 3%. For each M_{jj} range, the systematic uncertainty associated with each correction factor was conservatively set at 50% of its value. This approach covers the variations of the unfolding correction factors determined from HERWIG++ and different PYTHIA tunes (D6T and Z2 [17]) that vary on their modelling of the jet kinematic distributions. The use of a parameterized model to simulate the finite jet p_T and position resolutions of the detector, to determine the unfolding correction factors, resulted in a systematic uncertainty. This was estimated to be less than 1% for all M_{jj} ranges and was added in quadrature to the unfolding uncertainties.

The normalized dijet angular distributions are relatively insensitive to many systematic effects, in particular they show little dependence on the overall jet energy scale. However, since χ_{dijet} depends on y^* , they are sensitive to the rapidity dependence of the jet energy calibration. Typical values for the jet energy scale uncertainties for the considered phase space in the variables of jet p_T and η covered in this analysis are between 3% and 4% [10]. The uncertainty on the χ_{dijet} distributions due to the jet energy calibration uncertainties was found to be less than 2.5%. The uncertainty on the dijet angular distributions from the jet p_T resolution uncertainty, estimated

to be 10% [11], was found to be less than 1%. The total systematic uncertainty on the χ_{dijet} distributions, calculated as the quadratic sum of the contributions due to the uncertainties in the jet energy calibration, the jet p_T resolution, and the unfolding correction, is less than 3% for all M_{jj} ranges.

The corrected differential dijet angular distributions for different M_{jj} ranges, normalized to their respective integrals, are shown in Fig. 1. The data are compared to pQCD predictions at next-to-leading order (NLO) calculated with NLOJET++ [18] in the FASTNLO [19] framework. The calculations were performed with the CTEQ6.6 PDFs [20]. The factorization (μ_f) and renormalization (μ_r) scales were set to $\langle p_T \rangle$, the average dijet p_T . Non-perturbative corrections due to hadronization and multiple parton interactions, determined using the average correction from PYTHIA (D6T tune) and HERWIG++, were applied to the prediction. The uncertainties on the pQCD predictions, indicated by the shaded band in Fig. 1, are less than 6% (9%) at low (high) M_{jj} . These uncertainties include contributions due to scale variations and PDF uncertainties, as well as the uncertainties from the non-perturbative corrections. The uncertainty due to the choice of μ_f and μ_r scales was evaluated by varying the default choice of scales in the following six combinations: $(\mu_f, \mu_r) = (\langle p_T \rangle/2, \langle p_T \rangle/2), (\langle p_T \rangle/2, \langle p_T \rangle), (\langle p_T \rangle, \langle p_T \rangle/2), (2\langle p_T \rangle, 2\langle p_T \rangle), (2\langle p_T \rangle, \langle p_T \rangle)$ and $(\langle p_T \rangle, 2\langle p_T \rangle)$. These scale variations modify the predictions of the normalized χ_{dijet} distributions by less than 5% (9%) at low (high) M_{jj} . The uncertainty due to the choice of PDFs was determined from the 22 CTEQ6.6 uncertainty eigenvectors using the procedure described in Ref. [20], and was found to be less than 0.5% for all M_{jj} ranges. Half the difference between the non-perturbative corrections from PYTHIA and HERWIG++ was taken as the systematic uncertainty, and was found to be less than 4% (0.1%) at low (high) M_{jj} . Overall there is good agreement between the measured dijet angular distributions and the theoretical predictions for all M_{jj} ranges.

The measured dijet angular distributions can be used to set limits on quark compositeness represented by a four-fermion contact interaction term in addition to the QCD Lagrangian. The value of the mass scale Λ characterizes the strengths of the quark substructure binding interactions and the physical size of the composite states. A contact interaction (CI) of left-handed quarks with destructive interference between the QCD and the new physics terms gives rise to an effective Lagrangian term: $\mathcal{L}_{qq} = +\frac{2\pi}{\Lambda^2}(\bar{q}_L \gamma^\mu q_L)(\bar{q}_L \gamma_\mu q_L)$ [21]. We investigate a model in which all quarks are considered composite as implemented in the PYTHIA event generator.

The contributions of the CI term in PYTHIA are calculated to leading order (LO), whereas the QCD predictions for the dijet angular distributions are known up to NLO. In order to account for this difference in the QCD plus CI prediction, the cross-section difference $\sigma_{\text{NLO}}^{\text{QCD}} - \sigma_{\text{LO}}^{\text{QCD}}$ was added to the LO QCD+CI prediction in each M_{jj} and χ_{dijet} bin. With this procedure, we obtain a QCD+CI prediction where the QCD terms are corrected to NLO while the CI terms are calculated at LO. Non-perturbative corrections due to hadronization and multiple parton interactions were also applied to the prediction. The prediction for QCD+CI at the scale of $\Lambda = 5$ TeV is shown in Fig. 1, for the four highest M_{jj} ranges.

We perform a statistical test discriminating between the QCD-only hypothesis and the QCD+CI hypothesis as a function of the scale Λ based on the log-likelihood-ratio $Q = -2 \ln\left(\frac{L_{\text{QCD+CI}}}{L_{\text{QCD}}}\right)$. The likelihood functions $L_{\text{QCD+CI}}$ and L_{QCD} are modelled as a product of Poisson likelihood functions for each bin in χ_{dijet} and M_{jj} in the four highest M_{jj} ranges. The prediction for each M_{jj} range is normalized to the number of data events in that range. The p-values, $P_{\text{QCD+CI}}(Q \geq Q_{\text{obs}})$ and $P_{\text{QCD}}(Q \leq Q_{\text{obs}})$, are obtained from ensembles of pseudo-experiments. A modified frequentist approach [22–24] based on the quantity

$$\text{CL}_s = \frac{P_{\text{QCD+CI}}(Q \geq Q_{\text{obs}})}{1 - P_{\text{QCD}}(Q \leq Q_{\text{obs}})}$$

is used to set limits on Λ . This approach is more conservative than a pure frequentist approach (Neyman construction) and prevents an exclusion claim when the data may have little sensitivity to new physics [25]. Systematic uncertainties were introduced via Bayesian integration [26] by varying them as nuisance parameters in the ensembles of pseudo-experiments according to a Gaussian distribution convoluted with the shape variation induced to the χ_{dijet} distributions. We consider the QCD+CI model to be excluded at the 95% confidence level if $\text{CL}_s < 0.05$. Figure 2 shows the observed and expected CL_s as a function of the CI scale Λ . From this we determine the lower limit on Λ to be 5.6 TeV. The observed limit agrees within 1.4 standard deviations with the expected limit of 5.0 TeV, which was evaluated at the median of the test statistics distribution of the QCD model. The observed limit is slightly higher than the expected one because, for the range $M_{jj} > 2.2$ TeV, the measured dijet angular distribution at low χ_{dijet} is lower than, although statistically compatible with, the QCD prediction. The limit for the CI scale was also extracted using an alternate procedure in which the data were not corrected for detector effects and instead the MC predictions were resolution-smearred. The limit obtained was found to agree with the quoted one within 0.4%.

Shortly before the completion of this Letter, an exact NLO calculation of QCD effects to quark compositeness became available [27]. This calculation indicates that the limit on Λ obtained in the present analysis, which only takes into account the LO prediction for the contribution of the contact interaction, might be overestimated by up to 10% compared to the value obtained if the NLO calculation were used.

In summary, CMS has measured the dijet angular distributions over a wide range of dijet invariant masses. The χ_{dijet} distributions are found to be in good agreement with NLO pQCD predictions, and are used to exclude a range of a contact interaction scale Λ for a left-handed quark compositeness model. With a modified frequentist approach, a lower limit on the contact interaction scale of $\Lambda = 5.6$ TeV at the 95% confidence level is obtained, which may be compared with a limit of 5.0 TeV, expected for the number of events recorded. This is the most stringent limit on the contact interaction scale of left-handed quarks to date.

We wish to congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC machine. We thank the technical and administrative staff at CERN and other CMS institutes, and acknowledge support from: FMSR (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); Academy of Sciences and NICPB (Estonia); Academy of Finland, ME, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NKTH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); NRF and WCU (Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); PAEC (Pakistan); SCSR (Poland); FCT (Portugal); JINR (Armenia, Belarus, Georgia, Ukraine, Uzbekistan); MST and MAE (Russia); MSTB (Serbia); MICINN and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); TUBITAK and TAEK (Turkey); STFC (United Kingdom); DOE and NSF (USA).

References

- [1] UA1 Collaboration, “Angular distributions for High Mass Jet Pairs and a Limit on the

-
- Energy Scale of Compositeness for Quarks from the CERN $p\bar{p}$ Collider”, *Phys. Lett.* **B177** (1986) 244. doi:doi:10.1016/0370-2693(86)91065-8.
- [2] D0 Collaboration, “Measurement of Dijet Angular Distributions at $\sqrt{s} = 1.96$ TeV and Searches for Quark Compositeness and Extra Spatial Dimensions”, *Phys. Rev. Lett.* **103** (2009) 191803. doi:10.1103/PhysRevLett.103.191803.
- [3] D0 Collaboration, “High- p_T jets in $p\bar{p}$ collisions at $\sqrt{s} = 630$ and 1800 GeV”, *Phys. Rev.* **D64** (2001) 032003. doi:10.1103/PhysRevD.64.032003.
- [4] CDF Collaboration, “Measurement of Dijet Angular Distributions at CDF”, [*Erratum-ibid.* **78**, 4307 (1997)] *Phys. Rev. Lett.* **77** (1996) 5336. doi:10.1103/PhysRevLett.77.5336.
- [5] ATLAS Collaboration, “Search for quark contact interactions in dijet angular distributions in pp collisions at $\sqrt{s} = 7$ TeV measured with the ATLAS detector”, *Phys. Lett.* **B694** (2010) 327. doi:10.1016/j.physletb.2010.10.021.
- [6] CMS Collaboration, “Search for Quark Compositeness with the Dijet Centrality Ratio in pp Collisions at $\sqrt{s}=7$ TeV”, *Phys. Rev. Lett.* **105** (2010) 262001. doi:10.1103/PhysRevLett.105.262001.
- [7] CMS Collaboration, “The CMS experiment at the CERN LHC”, *JINST* **3** (2008) S08004. doi:10.1088/1748-0221/3/08/S08004.
- [8] M. Cacciari, G. P. Salam, and G. Soyez, “The anti-kt Jet Clustering Algorithm”, *JHEP* **04** (2008) 63. doi:10.1088/1126-6708/2008/04/063.
- [9] CMS Collaboration, “Calorimeter Jet Quality Criteria for the First CMS Collision Data”, *CMS Physics Analysis Summary* **CMS-PAS-JME-09-008** (2009).
- [10] CMS Collaboration, “Determination of the Jet Energy Scale in CMS with pp Collisions at $\sqrt{s}=7$ TeV”, *CMS Physics Analysis Summary* **CMS-PAS-JME-10-010** (2010).
- [11] CMS Collaboration, “CMS Jet Performance in pp Collisions at $\sqrt{s} = 7$ TeV”, *CMS Physics Analysis Summary* **CMS-PAS-JME-10-003** (2010).
- [12] CMS Collaboration, “Tracking and Primary Vertex Results in First 7 TeV Collisions”, *CMS Physics Analysis Summary* **CMS-PAS-TRK-10-005** (2010).
- [13] CMS Collaboration, “Measurement of CMS Luminosity”, *CMS Physics Analysis Summary* **CMS-PAS-EWK-10-004** (2010).
- [14] 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.
- [15] R. Field, “Early LHC Underlying Event Data-Findings and Surprises”. arXiv:1010.3558.
- [16] M. Bahr et al., “Herwig++ Physics and Manual”, *Eur. Phys. J.* **C58** (2008) 639. doi:10.1140/epjc/s10052-008-0798-9.
- [17] The PYTHIA6 Z2 tune is identical to the Z1 tune described in [15] except that Z2 uses the CTEQ6L PDF while Z1 uses CTEQ5L.

- [18] Z. Nagy, “Three-Jet Cross Sections in Hadron-Hadron Collisions at Next-To-Leading Order”, *Phys. Rev. Lett.* **88** (2002) 122003. doi:10.1103/PhysRevLett.88.122003.
- [19] T. Kluge, K. Rabbertz, and M. Wobisch, “Fast pQCD calculations for PDF fits”, arXiv:hep-ph/0609285.
- [20] P. M. Nadolsky et al., “Implications of CTEQ global analysis for collider observables”, *Phys. Rev.* **D78** (2008) 013004. doi:10.1103/PhysRevD.78.013004.
- [21] E. Eichten, K. Lane, and M. Peskin, “New tests for quark and lepton substructure”, *Phys. Rev. Lett.* **50** (1983) 811. doi:10.1103/PhysRevLett.50.811.
- [22] T. Junk, “Confidence Level Computation for Combining Searches with Small Statistics”, *Nucl. Instrum. Meth.* **A434** (1999) 435. doi:10.1016/S0168-9002(99)00498-2.
- [23] A. L. Read, “Modified frequentist analysis of search results”, in *First Workshop on Confidence Limits*, p. p81, CERN. Geneva, Switzerland, 2000.
- [24] A. L. Read, “Presentation of search results: the CL_s technique”, *J. Phys. G: Nucl. Part. Phys.* **28** (2002) 2693. doi:10.1088/0954-3899/28/10/313.
- [25] K. Nakamura et al. (Particle Data Group), “Review of Particle Physics”, *J. Phys. G: Nucl. Part. Phys.* **37** (2010) 075021. doi:10.1088/0954-3899/37/7A/075021.
- [26] R. D. Cousins and V. L. Highland, “Incorporating systematic uncertainties into an upper limit”, *Nucl. Instrum. Meth.* **A320** (1992) 331. doi:10.1016/0168-9002(92)90794-5.
- [27] J. Gao et al., “Next-to-leading QCD effect to the quark compositeness search at the LHC”. arXiv:1101.4611.

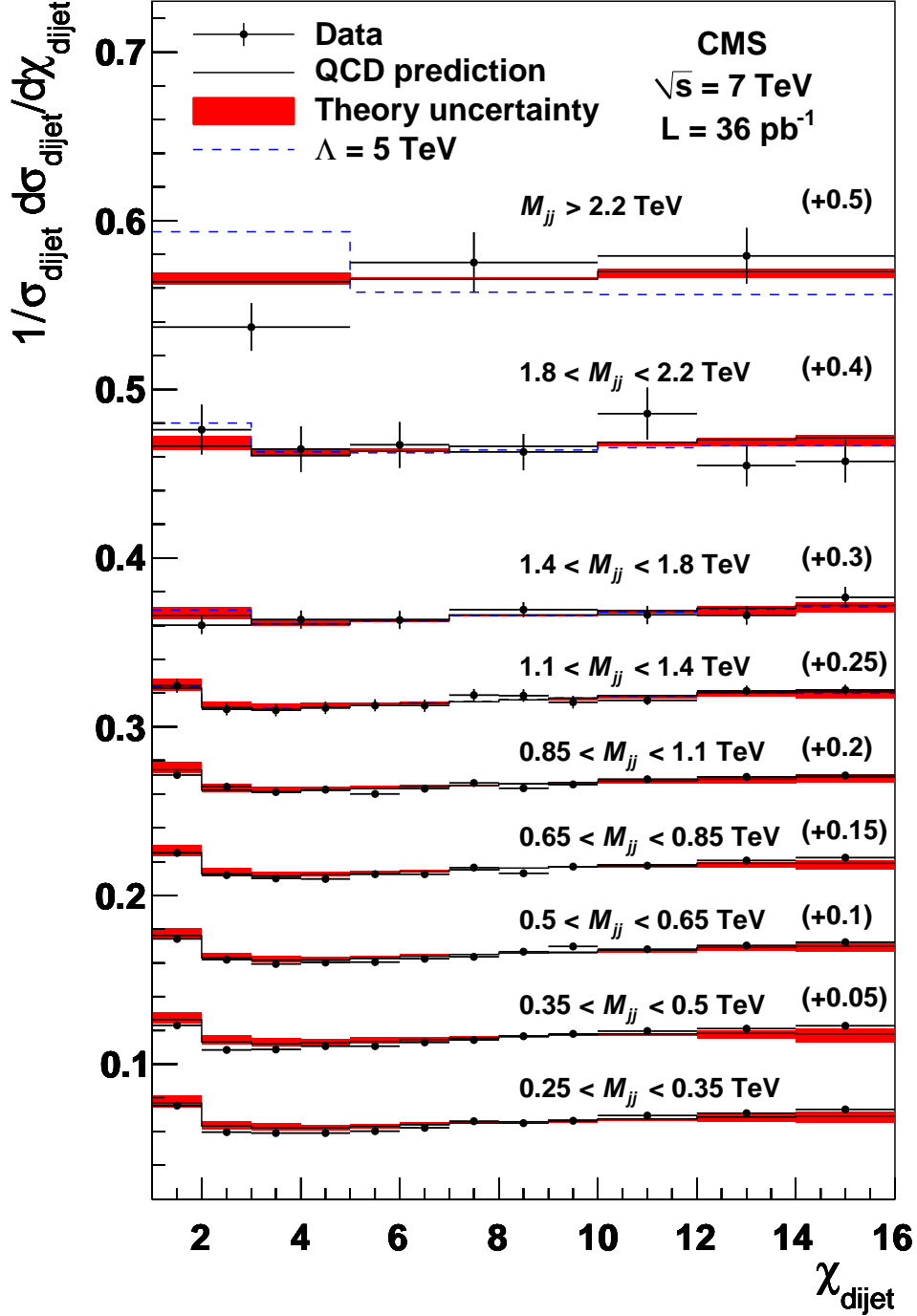


Figure 1: Normalized dijet angular distributions in several M_{jj} ranges, shifted vertically by the additive amounts given in parentheses in the figure for clarity. The data points include statistical and systematic uncertainties. The results are compared with the predictions of pQCD at NLO (solid histogram) and with the predictions including a contact interaction term of compositeness scale $\Lambda = 5$ TeV (dashed histogram). The shaded band shows the effect on the NLO pQCD predictions due to μ_r and μ_f scale variations and PDF uncertainties, as well as the uncertainties from the non-perturbative corrections added in quadrature.

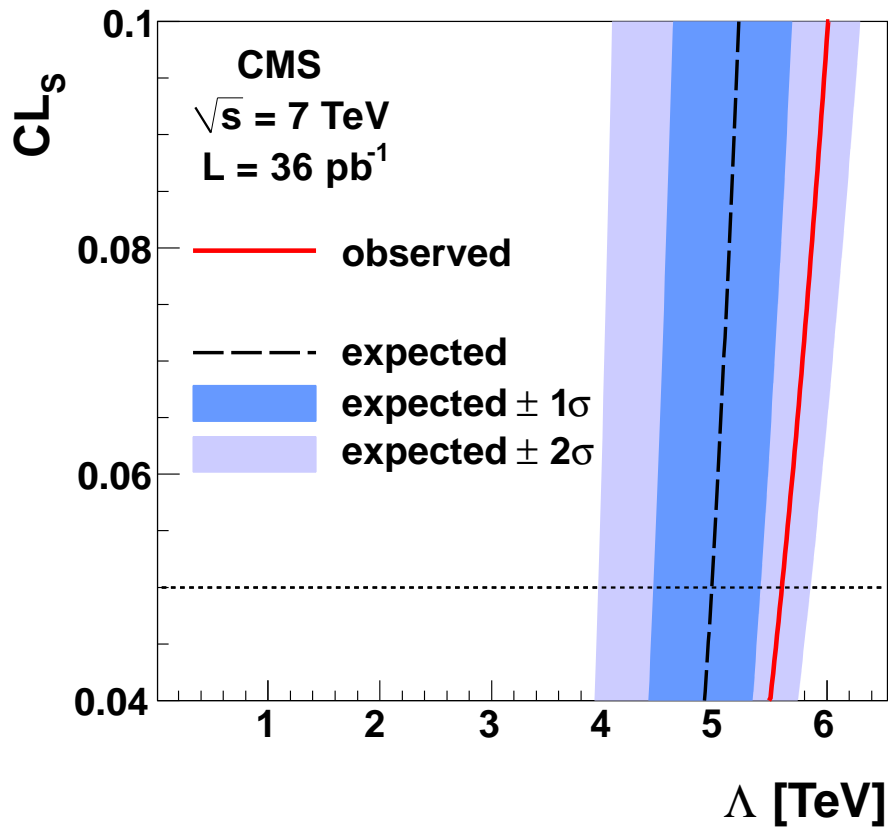


Figure 2: Observed CL_s (solid line) and expected CL_s (dashed line) with one (two) standard deviation indicated by the dark (light) band as a function of the contact interaction scale Λ . The 95% confidence level limits on Λ are extracted from the intersections of the observed and expected CL_s lines with the horizontal line at $CL_s=0.05$.

A The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia

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

Institut für Hochenergiephysik der OeAW, Wien, Austria

W. Adam, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan, M. Friedl, R. Frühwirth, V.M. Ghete, J. Hammer¹, S. Häsnel, C. Hartl, M. Hoch, N. Hörmann, J. Hrubec, M. Jeitler, G. Kasieczka, W. Kiesenhofer, M. Krammer, D. Liko, I. Mikulec, M. Pernicka, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, F. Teischinger, P. Wagner, W. Waltenberger, G. Walzel, E. Widl, C.-E. Wulz

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

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

Universiteit Antwerpen, Antwerpen, Belgium

L. Benucci, K. Cerny, E.A. De Wolf, X. Janssen, T. Maes, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, M. Selvaggi, H. Van Haeve, P. Van Mechelen, N. Van Remortel

Vrije Universiteit Brussel, Brussel, Belgium

S. Beauceron, F. Blekman, S. Blyweert, J. D'Hondt, O. Devroede, R. Gonzalez Suarez, A. Kalogeropoulos, J. Maes, M. Maes, S. Tavernier, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Vilella

Université Libre de Bruxelles, Bruxelles, Belgium

O. Charaf, B. Clerbaux, G. De Lentdecker, V. Dero, A.P.R. Gay, G.H. Hammad, T. Hreus, P.E. Marage, L. Thomas, C. Vander Velde, P. Vanlaer, J. Wickens

Ghent University, Ghent, Belgium

V. Adler, S. Costantini, M. Grunewald, B. Klein, A. Marinov, J. Mccartin, D. Ryckbosch, F. Thyssen, M. Tytgat, L. Vanelderen, P. Verwilligen, S. Walsh, N. Zaganidis

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

S. Basegmez, G. Bruno, J. Caudron, L. Ceard, J. De Favereau De Jeneret, C. Delaere, P. Demin, D. Favart, A. Giammanco, G. Grégoire, J. Hollar, V. Lemaitre, J. Liao, O. Militaru, S. Oryn, D. Pagano, A. Pin, K. Piotrkowski, N. Schul

Université de Mons, Mons, Belgium

N. Bely, T. Caebergs, E. Daubie

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

G.A. Alves, D. De Jesus Damiao, M.E. Pol, M.H.G. Souza

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

W. Carvalho, E.M. Da Costa, C. De Oliveira Martins, S. Fonseca De Souza, L. Mundim, H. Nogima, V. Oguri, W.L. Prado Da Silva, A. Santoro, S.M. Silva Do Amaral, A. Sznajder, F. Torres Da Silva De Araujo

Instituto de Fisica Teorica, Universidade Estadual Paulista, Sao Paulo, Brazil

F.A. Dias, M.A.F. Dias, T.R. Fernandez Perez Tomei, E. M. Gregores², F. Marinho, S.F. Novaes, Sandra S. Padula

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

N. Darnenov¹, L. Dimitrov, V. Genchev¹, P. Iaydjiev¹, S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, V. Tcholakov, R. Trayanov, I. Vankov

University of Sofia, Sofia, Bulgaria

M. Dyulendarova, R. Hadjiiska, V. Kozuharov, L. Litov, E. Marinova, M. Mateev, 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, J. Wang, J. Wang, X. Wang, Z. Wang, M. Xu, M. Yang, J. Zang, Z. Zhang

State Key Lab. of Nucl. Phys. and Tech., Peking University, Beijing, China

Y. Ban, S. Guo, Y. Guo, W. Li, Y. Mao, S.J. Qian, H. Teng, L. Zhang, B. Zhu, W. Zou

Universidad de Los Andes, Bogota, Colombia

A. Cabrera, B. Gomez Moreno, A.A. Ocampo Rios, A.F. Osorio Oliveros, J.C. Sanabria

Technical University of Split, Split, Croatia

N. Godinovic, D. Lelas, K. Lelas, R. Plestina³, D. Polic, I. Puljak

University of Split, Split, Croatia

Z. Antunovic, M. Dzelalija

Institute Rudjer Boskovic, Zagreb, Croatia

V. Brigljevic, S. Duric, K. Kadija, S. Morovic

University of Cyprus, Nicosia, Cyprus

A. Attikis, M. Galanti, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis, H. Rykaczewski

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. Assran⁴, M.A. Mahmoud⁵

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

A. Hektor, M. Kadastik, K. Kannike, M. Müntel, M. Raidal, L. Rebane

Department of Physics, University of Helsinki, Helsinki, Finland

V. Azzolini, P. Eerola

Helsinki Institute of Physics, Helsinki, Finland

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

Lappeenranta University of Technology, Lappeenranta, Finland

K. Banzuzi, A. Korpela, T. Tuuva

Laboratoire d'Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France

D. Sillou

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, F.X. Gentit, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, J. Malcles, M. Marionneau, L. Millischer, J. Rander, A. Rosowsky, I. Shreyber, M. Titov, P. Verrecchia

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

S. Baffioni, F. Beaudette, L. Bianchini, M. Bluj⁶, C. Broutin, P. Busson, C. Charlot, T. Dahms, L. Dobrzynski, R. Granier de Cassagnac, M. Haguenaer, P. Miné, C. Mironov, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Thiebaut, B. Wyslouch⁷, A. Zabi

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

J.-L. Agram⁸, J. Andrea, A. Besson, D. Bloch, D. Bodin, J.-M. Brom, M. Cardaci, E.C. Chabert, C. Collard, E. Conte⁸, F. Drouhin⁸, C. Ferro, J.-C. Fontaine⁸, D. Gelé, U. Goerlach, S. Greder, P. Juillot, M. Karim⁸, A.-C. Le Bihan, Y. Mikami, P. Van Hove

Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules (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

C. Baty, N. Beaupere, M. Bedjidian, O. Bondu, G. Boudoul, D. Boumediene, H. Brun, N. Chanon, R. Chierici, D. Contardo, P. Depasse, H. El Mamouni, A. Falkiewicz, J. Fay, S. Gascon, B. Ille, T. Kurca, T. Le Grand, M. Lethuillier, L. Mirabito, S. Perries, V. Sordini, S. Tosi, Y. Tschudi, P. Verdier, H. Xiao

E. Andronikashvili Institute of Physics, Academy of Science, Tbilisi, Georgia

L. Megreldze, V. Roinishvili

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

D. Lomidze

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

G. Anagnostou, M. Edelhoff, L. Feld, N. Heracleous, O. Hindrichs, R. Jussen, K. Klein, J. Merz, N. Mohr, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, M. Weber, B. Wittmer

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

M. Ata, W. Bender, M. Erdmann, J. Frangenheim, T. Hebbeker, A. Hinzmann, K. Hoepfner, C. Hof, T. Klimkovich, D. Klingebiel, P. Kreuzer, D. Lanske[†], C. Magass, G. Masetti, M. Merschmeyer, A. Meyer, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teysier

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

M. Bontenackels, M. Davids, M. Duda, G. Flügge, H. Geenen, M. Giffels, W. Haj Ahmad, D. Heydhausen, T. Kress, Y. Kuessel, A. Linn, A. Nowack, L. Perchalla, O. Pooth, J. Rennefeld, P. Sauerland, A. Stahl, M. Thomas, D. Tornier, M.H. Zoeller

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, W. Behrenhoff, U. Behrens, M. Bergholz⁹, K. Borras, A. Cakir, A. Campbell, E. Castro, D. Dammann, G. Eckerlin, D. Eckstein, A. Flossdorf, G. Flucke, A. Geiser, I. Glushkov, J. Hauk, H. Jung, M. Kasemann, I. Katkov, P. Katsas, C. Kleinwort, H. Kluge, A. Knutsson, D. Krücker, E. Kuznetsova, W. Lange, W. Lohmann⁹, R. Mankel, M. Marienfeld, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, J. Olzem, A. Parenti, A. Raspereza, A. Raval, R. Schmidt⁹, T. Schoerner-Sadenius, N. Sen, M. Stein, J. Tomaszewska, D. Volyanskyy, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany

C. Autermann, S. Bobrovskiy, J. Draeger, H. Enderle, U. Gebbert, K. Kaschube, G. Kaussen, R. Klanner, J. Lange, B. Mura, S. Naumann-Emme, F. Nowak, N. Pietsch, C. Sander, H. Schettler, P. Schleper, M. Schröder, T. Schum, J. Schwandt, A.K. Srivastava, H. Stadie, G. Steinbrück, J. Thomsen, R. Wolf

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

C. Barth, J. Bauer, V. Buege, T. Chwalek, W. De Boer, A. Dierlamm, G. Dirkes, M. Feindt, J. Gruschke, C. Hackstein, F. Hartmann, S.M. Heindl, M. Heinrich, H. Held, K.H. Hoffmann, S. Honc, T. Kuhr, D. Martschei, S. Mueller, Th. Müller, M. Niegel, O. Oberst, A. Oehler, J. Ott, T. Peiffer, D. Piparo, G. Quast, K. Rabbertz, F. Ratnikov, M. Renz, C. Saout, A. Scheurer, P. Schieferdecker, F-P. Schilling, G. Schott, H.J. Simonis, F.M. Stober, D. Troendle, J. Wagner-Kuhr, M. Zeise, V. Zhukov¹⁰, E.B. Ziebarth

Institute of Nuclear Physics "Demokritos", Aghia Paraskevi, Greece

G. Daskalakis, T. Gerasis, S. Kesisoglou, A. Kyriakis, D. Loukas, I. Manolakos, A. Markou, C. Markou, C. Mavrommatis, E. Ntomari, E. Petrakou

University of Athens, Athens, Greece

L. Gouskos, T.J. Mertzimekis, A. Panagiotou

University of Ioánnina, Ioánnina, Greece

I. Evangelou, C. Foudas, P. Kokkas, N. Manthos, I. Papadopoulos, V. Patras, F.A. Triantis

KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary

A. Aranyi, G. Bencze, L. Boldizsar, G. Debreczeni, C. Hajdu¹, D. Horvath¹¹, A. Kapusi, K. Krajczar¹², A. Laszlo, F. Sikler, G. Vesztergombi¹²

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

N. Beni, J. Molnar, J. Palinkas, Z. Szillasi, V. Veszpremi

University of Debrecen, Debrecen, Hungary

P. Raics, Z.L. Trocsanyi, B. Ujvari

Panjab University, Chandigarh, India

S. Bansal, S.B. Beri, V. Bhatnagar, N. Dhingra, R. Gupta, M. Jindal, M. Kaur, J.M. Kohli, M.Z. Mehta, N. Nishu, L.K. Saini, A. Sharma, A.P. Singh, J.B. Singh, S.P. Singh

University of Delhi, Delhi, India

S. Ahuja, S. Bhattacharya, B.C. Choudhary, P. Gupta, S. Jain, S. Jain, A. Kumar, R.K. Shivpuri

Bhabha Atomic Research Centre, Mumbai, India

R.K. Choudhury, D. Dutta, S. Kailas, S.K. Kataria, A.K. Mohanty¹, L.M. Pant, P. Shukla

Tata Institute of Fundamental Research - EHEP, Mumbai, India

T. Aziz, M. Guchait¹³, A. Gurtu, M. Maity¹⁴, D. Majumder, G. Majumder, K. Mazumdar, G.B. Mohanty, A. Saha, K. Sudhakar, N. Wickramage

Tata Institute of Fundamental Research - HECR, Mumbai, India

S. Banerjee, S. Dugad, N.K. Mondal

Institute for Research and Fundamental Sciences (IPM), Tehran, Iran

H. Arfaei, H. Bakhshiansohi, S.M. Etesami, A. Fahim, M. Hashemi, A. Jafari, M. Khakzad, A. Mohammadi, M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh, M. Zeinali

INFN Sezione di Bari ^a, Università di Bari ^b, Politecnico di Bari ^c, Bari, Italy

M. Abbrescia^{a,b}, L. Barbone^{a,b}, C. Calabria^{a,b}, A. Colaleo^a, D. Creanza^{a,c}, N. De Filippis^{a,c}, M. De Palma^{a,b}, A. Dimitrov^a, L. Fiore^a, G. Iaselli^{a,c}, L. Lusito^{a,b,1}, G. Maggi^{a,c}, M. Maggi^a, N. Manna^{a,b}, B. Marangelli^{a,b}, S. My^{a,c}, S. Nuzzo^{a,b}, N. Pacifico^{a,b}, G.A. Pierro^a, A. Pompili^{a,b}, G. Pugliese^{a,c}, F. Romano^{a,c}, G. Roselli^{a,b}, G. Selvaggi^{a,b}, L. Silvestris^a, R. Trentadue^a, S. Tupputi^{a,b}, G. Zito^a

INFN Sezione di Bologna ^a, Università di Bologna ^b, Bologna, Italy

G. Abbiendi^a, A.C. Benvenuti^a, D. Bonacorsi^a, S. Braibant-Giacomelli^{a,b}, L. Brigliadori^a, P. Capiluppi^{a,b}, A. Castro^{a,b}, F.R. Cavallo^a, M. Cuffiani^{a,b}, G.M. Dallavalle^a, F. Fabbri^a, A. Fanfani^{a,b}, D. Fasanella^a, P. Giacomelli^a, M. Giunta^a, C. Grandi^a, S. Marcellini^a, M. Meneghelli^{a,b}, A. Montanari^a, F.L. Navarra^{a,b}, F. Odorici^a, A. Perrotta^a, F. Primavera^a, A.M. Rossi^{a,b}, T. Rovelli^{a,b}, G. Siroli^{a,b}, R. Travaglini^{a,b}

INFN Sezione di Catania ^a, Università di Catania ^b, Catania, Italy

S. Albergo^{a,b}, G. Cappello^{a,b}, M. Chiorboli^{a,b,1}, S. Costa^{a,b}, A. Tricomi^{a,b}, C. Tuve^a

INFN Sezione di Firenze ^a, Università di Firenze ^b, Firenze, Italy

G. Barbagli^a, V. Ciulli^{a,b}, C. Civinini^a, R. D'Alessandro^{a,b}, E. Focardi^{a,b}, S. Frosali^{a,b}, E. Gallo^a, S. Gonzi^{a,b}, P. Lenzi^{a,b}, M. Meschini^a, S. Paoletti^a, G. Sguazzoni^a, A. Tropiano^{a,1}

INFN Laboratori Nazionali di Frascati, Frascati, Italy

L. Benussi, S. Bianco, S. Colafranceschi¹⁵, F. Fabbri, D. Piccolo

INFN Sezione di Genova, Genova, Italy

P. Fabbricatore, R. Musenich

INFN Sezione di Milano-Bicocca ^a, Università di Milano-Bicocca ^b, Milano, Italy

A. Benaglia^{a,b}, F. De Guio^{a,b,1}, L. Di Matteo^{a,b}, A. Ghezzi^{a,b,1}, M. Malberti^{a,b}, S. Malvezzi^a, A. Martelli^{a,b}, A. Massironi^{a,b}, D. Menasce^a, L. Moroni^a, M. Paganoni^{a,b}, D. Pedrini^a, S. Ragazzi^{a,b}, N. Redaelli^a, S. Sala^a, T. Tabarelli de Fatis^{a,b}, V. Tancini^{a,b}

INFN Sezione di Napoli ^a, Università di Napoli "Federico II" ^b, Napoli, Italy

S. Buontempo^a, C.A. Carrillo Montoya^a, A. Cimmino^{a,b}, A. De Cosa^{a,b}, M. De Gruttola^{a,b}, F. Fabozzi^{a,16}, A.O.M. Iorio^a, L. Lista^a, M. Merola^{a,b}, P. Noli^{a,b}, P. Paolucci^a

INFN Sezione di Padova ^a, Università di Padova ^b, Università di Trento (Trento) ^c, Padova, Italy

P. Azzi^a, N. Bacchetta^a, P. Bellan^{a,b}, D. Bisello^{a,b}, A. Branca^a, R. Carlin^{a,b}, P. Checchia^a, E. Conti^a, M. De Mattia^{a,b}, T. Dorigo^a, U. Dosselli^a, F. Fanzago^a, F. Gasparini^{a,b}, P. Giubilato^{a,b}, A. Gresele^{a,c}, S. Lacaprara^{a,17}, I. Lazzizzera^{a,c}, M. Margoni^{a,b}, M. Mazzucato^a, A.T. Meneguzzo^{a,b}, M. Nespolo^{a,1}, L. Perrozzi^{a,1}, N. Pozzobon^{a,b}, P. Ronchese^{a,b}, F. Simonetto^{a,b}, E. Torassa^a, M. Tosi^{a,b}, S. Vanini^{a,b}, P. Zotto^{a,b}, G. Zumerle^{a,b}

INFN Sezione di Pavia ^a, Università di Pavia ^b, Pavia, Italy

U. Berzano^a, C. Riccardi^{a,b}, P. Torre^{a,b}, P. Vitulo^{a,b}

INFN Sezione di Perugia ^a, Università di Perugia ^b, Perugia, Italy

M. Biasini^{a,b}, G.M. Bilei^a, B. Caponeri^{a,b}, L. Fanò^{a,b}, P. Lariccia^{a,b}, A. Lucaroni^{a,b,1}, G. Mantovani^{a,b}, M. Menichelli^a, A. Nappi^{a,b}, A. Santocchia^{a,b}, L. Servoli^a, S. Taroni^{a,b}, M. Valdata^{a,b}, R. Volpe^{a,b,1}

INFN Sezione di Pisa ^a, Università di Pisa ^b, Scuola Normale Superiore di Pisa ^c, Pisa, Italy

P. Azzurri^{a,c}, G. Bagliesi^a, J. Bernardini^{a,b}, T. Boccali^{a,1}, G. Broccolo^{a,c}, R. Castaldi^a, R.T. D'Agnolo^{a,c}, R. Dell'Orso^a, F. Fiori^{a,b}, L. Foà^{a,c}, A. Giassi^a, A. Kraan^a, F. Ligabue^{a,c},

T. Lomtadze^a, L. Martini^{a,18}, A. Messineo^{a,b}, F. Palla^a, F. Palmonari^a, S. Sarkar^{a,c}, G. Segneri^a, A.T. Serban^a, P. Spagnolo^a, R. Tenchini^a, G. Tonelli^{a,b,1}, A. Venturi^{a,1}, P.G. Verdini^a

INFN Sezione di Roma ^a, Università di Roma "La Sapienza" ^b, Roma, Italy

L. Barone^{a,b}, F. Cavallari^a, D. Del Re^{a,b}, E. Di Marco^{a,b}, M. Diemoz^a, D. Franci^{a,b}, M. Grassi^a, E. Longo^{a,b}, S. Nourbakhsh^a, G. Organtini^{a,b}, A. Palma^{a,b}, F. Pandolfi^{a,b,1}, R. Paramatti^a, S. Rahatlou^{a,b}

INFN Sezione di Torino ^a, Università di Torino ^b, Università del Piemonte Orientale (Novara) ^c, Torino, Italy

N. Amapane^{a,b}, R. Arcidiacono^{a,c}, S. Argiro^{a,b}, M. Arneodo^{a,c}, C. Biino^a, C. Botta^{a,b,1}, N. Cartiglia^a, R. Castello^{a,b}, M. Costa^{a,b}, N. Demaria^a, A. Graziano^{a,b,1}, C. Mariotti^a, M. Marone^{a,b}, S. Maselli^a, E. Migliore^{a,b}, G. Mila^{a,b}, V. Monaco^{a,b}, M. Musich^{a,b}, M.M. Obertino^{a,c}, N. Pastrone^a, M. Pelliccioni^{a,b,1}, A. Romero^{a,b}, M. Ruspa^{a,c}, R. Sacchi^{a,b}, V. Sola^{a,b}, A. Solano^{a,b}, A. Staiano^a, D. Trocino^{a,b}, A. Vilela Pereira^{a,b,1}

INFN Sezione di Trieste ^a, Università di Trieste ^b, Trieste, Italy

S. Belforte^a, F. Cossutti^a, G. Della Ricca^{a,b}, B. Gobbo^a, D. Montanino^{a,b}, A. Penzo^a

Kangwon National University, Chunchon, Korea

S.G. Heo

Kyungpook National University, Daegu, Korea

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

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

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

Korea University, Seoul, Korea

S. Choi, B. Hong, M. Jo, H. Kim, J.H. Kim, T.J. Kim, K.S. Lee, D.H. Moon, S.K. Park, H.B. Rhee, E. Seo, S. Shin, K.S. Sim

University of Seoul, Seoul, Korea

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

Sungkyunkwan University, Suwon, Korea

Y. Choi, Y.K. Choi, J. Goh, J. Lee, S. Lee, H. Seo, I. Yu

Vilnius University, Vilnius, Lithuania

M.J. Bilinskas, I. Grigelionis, M. Janulis, D. Martisiute, P. Petrov, T. Sabonis

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico

H. Castilla-Valdez, E. De La Cruz-Burelo, R. Lopez-Fernandez, A. Sánchez-Hernández, L.M. Villasenor-Cendejas

Universidad Iberoamericana, Mexico City, Mexico

S. Carrillo Moreno, F. Vazquez Valencia

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

H.A. Salazar Ibarguen

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

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

University of Auckland, Auckland, New Zealand

P. Allfrey, D. Krofcheck

University of Canterbury, Christchurch, New Zealand

P.H. Butler, R. Doesburg, H. Silverwood

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

M. Ahmad, I. Ahmed, M.I. Asghar, H.R. Hoorani, W.A. Khan, T. Khurshid, S. Qazi

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland

M. Cwiok, W. Dominik, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski

Soltan Institute for Nuclear Studies, Warsaw, Poland

T. Frueboes, R. Gokieli, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, G. Wrochna, P. Zalewski

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal

N. Almeida, A. David, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, P. Martins, P. Musella, A. Nayak, P.Q. Ribeiro, J. Seixas, P. Silva, J. Varela, H.K. Wöhri

Joint Institute for Nuclear Research, Dubna, Russia

I. Belotelov, P. Bunin, I. Golutvin, A. Kamenev, V. Karjavin, G. Kozlov, A. Lanev, P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov, V. Smirnov, A. Volodko, A. Zarubin

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

N. Bondar, V. Golovtsov, Y. Ivanov, V. Kim, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev

Institute for Nuclear Research, Moscow, Russia

Yu. Andreev, S. Gninenko, N. Golubev, M. Kirsanov, N. Krasnikov, V. Matveev, A. Pashenkov, A. Toropin, S. Troitsky

Institute for Theoretical and Experimental Physics, Moscow, Russia

V. Epshteyn, V. Gavrilov, V. Kaftanov[†], M. Kossov¹, A. Krokhotin, N. Lychkovskaya, G. Safronov, S. Semenov, V. Stolin, E. Vlasov, A. Zhokin

Moscow State University, Moscow, Russia

E. Boos, M. Dubinin¹⁹, L. Dudko, A. Ershov, A. Gribushin, O. Kodolova, I. Lokhtin, S. Obraztsov, S. Petrushanko, L. Sarycheva, V. Savrin, A. Snigirev

P.N. Lebedev Physical Institute, Moscow, Russia

V. Andreev, M. Azarkin, I. Dremin, M. Kirakosyan, S.V. Rusakov, A. Vinogradov

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

I. Azhgirey, S. Bitioukov, V. Grishin¹, V. Kachanov, D. Konstantinov, A. Korablev, V. Krychkine, V. Petrov, R. Ryutin, S. Slabospitsky, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

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

P. Adzic²⁰, M. Djordjevic, D. Krpic²⁰, J. Milosevic

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

M. Aguilar-Benitez, J. Alcaraz Maestre, P. Arce, C. Battilana, E. Calvo, M. Cepeda, M. Cerrada, N. Colino, B. De La Cruz, C. Diez Pardos, D. Domínguez Vázquez, C. Fernandez Bedoya, J.P. Fernández Ramos, A. Ferrando, J. Flix, M.C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez,

S. Goy Lopez, J.M. Hernandez, M.I. Josa, G. Merino, J. Puerta Pelayo, I. Redondo, L. Romero, J. Santaolalla, C. Willmott

Universidad Autónoma de Madrid, Madrid, Spain

C. Albajar, G. Codispoti, J.F. de Trocóniz

Universidad de Oviedo, Oviedo, Spain

J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias, J.M. Vizan Garcia

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

J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, M. Chamizo Llatas, S.H. Chuang, J. Duarte Campderros, M. Felcini²¹, M. Fernandez, G. Gomez, J. Gonzalez Sanchez, C. Jorda, P. Lobelle Pardo, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, J. Piedra Gomez²², T. Rodrigo, A. Ruiz-Jimeno, L. Scodellaro, M. Sobron Sanudo, I. Vila, R. Vilar Cortabitarte

CERN, European Organization for Nuclear Research, Geneva, Switzerland

D. Abbaneo, E. Auffray, G. Auzinger, P. Baillon, A.H. Ball, D. Barney, A.J. Bell²³, D. Benedetti, C. Bernet³, W. Bialas, P. Bloch, A. Bocci, S. Bolognesi, H. Breuker, G. Brona, K. Bunkowski, T. Camporesi, E. Cano, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, B. Curé, D. D'Enterria, A. De Roeck, S. Di Guida, F. Duarte Ramos, A. Elliott-Peisert, B. Frisch, W. Funk, A. Gaddi, S. Gennai, G. Georgiou, H. Gerwig, D. Gigi, K. Gill, D. Giordano, F. Glege, R. Gomez-Reino Garrido, M. Gouzevitch, P. Govoni, S. Gowdy, L. Guiducci, M. Hansen, J. Harvey, J. Hegeman, B. Hegner, C. Henderson, G. Hesketh, H.F. Hoffmann, A. Honma, V. Innocente, P. Janot, K. Kaadze, E. Karavakis, P. Lecoq, C. Lourenço, A. Macpherson, T. Mäki, L. Malgeri, M. Mannelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, R. Moser, M.U. Mozer, M. Mulders, E. Nesvold¹, M. Nguyen, T. Orimoto, L. Orsini, E. Perez, A. Petrilli, A. Pfeiffer, M. Pierini, M. Pimiä, G. Polese, A. Racz, J. Rodrigues Antunes, G. Rolandi²⁴, T. Rommerskirchen, C. Rovelli²⁵, M. Rovere, H. Sakulin, C. Schäfer, C. Schwick, I. Segoni, A. Sharma, P. Siegrist, M. Simon, P. Sphicas²⁶, D. Spiga, M. Spiropulu¹⁹, F. Stöckli, M. Stoye, P. Tropea, A. Tsirou, A. Tsyganov, G.I. Veres¹², P. Vichoudis, M. Voutilainen, 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. Kotlinski, U. Langenegger, F. Meier, D. Renker, T. Rohe, J. Sibille²⁷, A. Starodumov²⁸

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

P. Bortignon, L. Caminada²⁹, Z. Chen, S. Cittolin, G. Dissertori, M. Dittmar, J. Eugster, K. Freudenreich, C. Grab, A. Hervé, W. Hintz, P. Lecomte, W. Lustermann, C. Marchica²⁹, P. Martinez Ruiz del Arbol, P. Meridiani, P. Milenov³⁰, F. Moortgat, P. Nef, F. Nessi-Tedaldi, L. Pape, F. Pauss, T. Punz, A. Rizzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, M.-C. Sawley, B. Stieger, L. Tauscher[†], A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, M. Weber, L. Wehrli, J. Weng

Universität Zürich, Zurich, Switzerland

E. Aguiló, C. Amsler, V. Chiochia, S. De Visscher, C. Favaro, M. Ivova Rikova, B. Millan Mejias, C. Regenfus, P. Robmann, A. Schmidt, H. Snoek

National Central University, Chung-Li, Taiwan

Y.H. Chang, K.H. Chen, W.T. Chen, S. Dutta, A. Go, C.M. Kuo, S.W. Li, W. Lin, M.H. Liu, Z.K. Liu, Y.J. Lu, D. Mekterovic, J.H. Wu, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan

P. Bartalini, P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, W.-S. Hou, Y. Hsiung, K.Y. Kao, Y.J. Lei, R.-S. Lu, J.G. Shiu, Y.M. Tzeng, M. Wang

Cukurova University, Adana, Turkey

A. Adiguzel, M.N. Bakirci³¹, S. Cerci³², Z. Demir, C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, Y. Guler, E. Gurpinar, I. Hos, E.E. Kangal, T. Karaman, A. Kayis Topaksu, A. Nart, G. Onengut, K. Ozdemir, S. Ozturk, A. Polatoz, K. Sogut³³, B. Tali, H. Topakli³¹, D. Uzun, L.N. Vergili, M. Vergili, C. Zorbilmez

Middle East Technical University, Physics Department, Ankara, Turkey

I.V. Akin, T. Aliev, S. Bilmis, M. Deniz, H. Gamsizkan, A.M. Guler, K. Ocalan, A. Ozpineci, M. Serin, R. Sever, U.E. Surat, E. Yildirim, M. Zeyrek

Bogazici University, Istanbul, Turkey

M. Deliomeroğlu, D. Demir³⁴, E. Gülmez, A. Halu, B. Isildak, M. Kaya³⁵, O. Kaya³⁵, S. Ozkorucuklu³⁶, N. Sonmez³⁷

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

L. Levchuk

University of Bristol, Bristol, United Kingdom

P. Bell, F. Bostock, J.J. Brooke, T.L. Cheng, E. Clement, D. Cussans, R. Frazier, J. Goldstein, M. Grimes, M. Hansen, D. Hartley, G.P. Heath, H.F. Heath, B. Huckvale, J. Jackson, L. Kreczko, S. Metson, D.M. Newbold³⁸, K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, S. Ward

Rutherford Appleton Laboratory, Didcot, United Kingdom

L. Basso, K.W. Bell, A. Belyaev, C. Brew, R.M. Brown, B. Camanzi, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, B.W. Kennedy, E. Olaiya, D. Petyt, B.C. Radburn-Smith, C.H. Shepherd-Themistocleous, I.R. Tomalin, W.J. Womersley, S.D. Worm

Imperial College, London, United Kingdom

R. Bainbridge, G. Ball, J. Ballin, R. Beuselinck, O. Buchmuller, D. Colling, N. Cripps, M. Cutajar, G. Davies, M. Della Negra, J. Fulcher, D. Futyan, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, G. Karapostoli, L. Lyons, A.-M. Magnan, J. Marrouche, R. Nandi, J. Nash, A. Nikitenko²⁸, A. Papageorgiou, M. Pesaresi, K. Petridis, M. Pioppi³⁹, D.M. Raymond, N. Rompotis, A. Rose, M.J. Ryan, C. Seez, P. Sharp, A. Sparrow, A. Tapper, S. Tourneur, M. Vazquez Acosta, T. Virdee, S. Wakefield, D. Wardrope, T. Whyntie

Brunel University, Uxbridge, United Kingdom

M. Barrett, M. Chadwick, J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, D. Leslie, W. Martin, I.D. Reid, L. Teodorescu

Baylor University, Waco, USA

K. Hatakeyama

Boston University, Boston, USA

T. Bose, E. Carrera Jarrin, C. Fantasia, A. Heister, J. St. John, P. Lawson, D. Lazic, J. Rohlf, D. Sperka, L. Sulak

Brown University, Providence, USA

A. Avetisyan, S. Bhattacharya, J.P. Chou, D. Cutts, A. Ferapontov, U. Heintz, S. Jabeen, G. Kukartsev, G. Landsberg, M. Narain, D. Nguyen, M. Segala, T. Speer, K.V. Tsang

University of California, Davis, Davis, USA

M.A. Borgia, R. Breedon, M. Calderon De La Barca Sanchez, D. Cebra, S. Chauhan, M. Chertok, J. Conway, P.T. Cox, J. Dolen, R. Erbacher, E. Friis, W. Ko, A. Kopecky, R. Lander, H. Liu, S. Maruyama, T. Miceli, M. Nikolic, D. Pellett, J. Robles, S. Salur, T. Schwarz, M. Searle, J. Smith, M. Squires, M. Tripathi, R. Vasquez Sierra, C. Veelken

University of California, Los Angeles, Los Angeles, USA

V. Andreev, K. Arisaka, D. Cline, R. Cousins, A. Deisher, J. Duris, S. Erhan, C. Farrell, J. Hauser, M. Ignatenko, C. Jarvis, C. Plager, G. Rakness, P. Schlein[†], J. Tucker, V. Valuev

University of California, Riverside, Riverside, USA

J. Babb, R. Clare, J. Ellison, J.W. Gary, F. Giordano, G. Hanson, G.Y. Jeng, S.C. Kao, F. Liu, H. Liu, A. Luthra, H. Nguyen, B.C. Shen[†], R. Stringer, J. Sturdy, S. Sumowidagdo, R. Wilken, S. Wimpenny

University of California, San Diego, La Jolla, USA

W. Andrews, J.G. Branson, G.B. Cerati, E. Dusinger, D. Evans, F. Golf, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, B. Mangano, J. Muelmenstaedt, S. Padhi, C. Palmer, G. Petrucciani, H. Pi, M. Pieri, R. Ranieri, M. Sani, V. Sharma¹, S. Simon, Y. Tu, A. Vartak, F. Würthwein, A. Yagil

University of California, Santa Barbara, Santa Barbara, USA

D. Barge, R. Bellan, C. Campagnari, M. D'Alfonso, T. Danielson, K. Flowers, P. Geffert, J. Incandela, C. Justus, P. Kalavase, S.A. Koay, D. Kovalskyi, V. Krutelyov, S. Lowette, N. Mccoll, V. Pavlunin, F. Rebassoo, J. Ribnik, J. Richman, R. Rossin, D. Stuart, W. To, J.R. Vlimant

California Institute of Technology, Pasadena, USA

A. Bornheim, J. Bunn, Y. Chen, M. Gataullin, D. Kcira, V. Litvine, Y. Ma, A. Mott, H.B. Newman, C. Rogan, V. Timciuc, P. Traczyk, J. Veverka, R. Wilkinson, Y. Yang, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA

B. Akgun, R. Carroll, T. Ferguson, Y. Iiyama, D.W. Jang, S.Y. Jun, Y.F. Liu, M. Paulini, J. Russ, N. Terentyev, H. Vogel, I. Vorobiev

University of Colorado at Boulder, Boulder, USA

J.P. Cumalat, M.E. Dinardo, B.R. Drell, C.J. Edelmaier, W.T. Ford, A. Gaz, B. Heyburn, E. Luiggi Lopez, U. Nauenberg, J.G. Smith, K. Stenson, K.A. Ulmer, S.R. Wagner, S.L. Zang

Cornell University, Ithaca, USA

L. Agostino, J. Alexander, A. Chatterjee, S. Das, N. Eggert, L.J. Fields, L.K. Gibbons, B. Heltsley, W. Hopkins, A. Khukhunaishvili, B. Kreis, V. Kuznetsov, G. Nicolas Kaufman, J.R. Patterson, D. Puigh, D. Riley, A. Ryd, X. Shi, W. Sun, W.D. Teo, J. Thom, J. Thompson, J. Vaughan, Y. Weng, L. Winstrom, P. Wittich

Fairfield University, Fairfield, USA

A. Biselli, G. Cirino, D. Winn

Fermi National Accelerator Laboratory, Batavia, USA

S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, M. Atac, J.A. Bakken, S. Banerjee, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, I. Bloch, F. Borchering, K. Burkett, J.N. Butler, V. Chetluru, H.W.K. Cheung, F. Chlebana, S. Cihangir, M. Demarteau, D.P. Eartly, V.D. Elvira, S. Esen, I. Fisk, J. Freeman, Y. Gao, E. Gottschalk, D. Green, K. Gunthoti, O. Gutsche, A. Hahn, J. Hanlon, R.M. Harris, J. Hirschauer, B. Hooberman, E. James, H. Jensen, M. Johnson, U. Joshi, R. Khatiwada, B. Kilminster, B. Klima, K. Kousouris, S. Kunori, S. Kwan,

C. Leonidopoulos, P. Limon, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, D. Mason, P. McBride, T. McCauley, T. Miao, K. Mishra, S. Mrenna, Y. Musienko⁴⁰, C. Newman-Holmes, V. O'Dell, S. Popescu⁴¹, R. Pordes, O. Prokofyev, N. Saoulidou, E. Sexton-Kennedy, S. Sharma, A. Soha, W.J. Spalding, L. Spiegel, P. Tan, L. Taylor, S. Tkaczyk, L. Uplegger, E.W. Vaandering, R. Vidal, J. Whitmore, W. Wu, F. Yang, F. Yumiceva, J.C. Yun

University of Florida, Gainesville, USA

D. Acosta, P. Avery, D. Bourilkov, M. Chen, G.P. Di Giovanni, D. Dobur, A. Drozdetskiy, R.D. Field, M. Fisher, Y. Fu, I.K. Furic, J. Gartner, S. Goldberg, B. Kim, S. Klimentko, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypreos, K. Matchev, G. Mitselmakher, L. Muniz, Y. Pakhotin, C. Prescott, R. Remington, M. Schmitt, B. Scurlock, P. Sellers, N. Skhirtladze, D. Wang, J. Yelton, M. Zakaria

Florida International University, Miami, USA

C. Ceron, V. Gaultney, L. Kramer, L.M. Lebolo, S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

Florida State University, Tallahassee, USA

T. Adams, A. Askew, D. Bandurin, J. Bochenek, J. Chen, B. Diamond, S.V. Gleyzer, J. Haas, S. Hagopian, V. Hagopian, M. Jenkins, K.F. Johnson, H. Prosper, L. Quertenmont, S. Sekmen, V. Veeraraghavan

Florida Institute of Technology, Melbourne, USA

M.M. Baarmand, B. Dorney, S. Guragain, M. Hohlmann, H. Kalakhety, R. Ralich, I. Vodopyanov

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

M.R. Adams, I.M. Anghel, L. Apanasevich, Y. Bai, V.E. Bazterra, R.R. Betts, J. Callner, R. Cavanaugh, C. Dragoiu, E.J. Garcia-Solis, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, F. Lacroix, M. Malek, C. O'Brien, C. Silvestre, A. Smoron, D. Strom, N. Varelas

The University of Iowa, Iowa City, USA

U. Akgun, E.A. Albayrak, B. Bilki, K. Cankocak⁴², W. Clarida, F. Duru, C.K. Lae, E. McCliment, J.-P. Merlo, H. Mermerkaya, A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, J. Olson, Y. Onel, F. Ozok, S. Sen, J. Wetzel, T. Yetkin, K. Yi

Johns Hopkins University, Baltimore, USA

B.A. Barnett, B. Blumenfeld, A. Bonato, C. Eskew, D. Fehling, G. Giurgiu, A.V. Gritsan, Z.J. Guo, G. Hu, P. Maksimovic, S. Rappoccio, M. Swartz, N.V. Tran, A. Whitbeck

The University of Kansas, Lawrence, USA

P. Baringer, A. Bean, G. Benelli, O. Grachov, M. Murray, D. Noonan, V. Radicci, S. Sanders, J.S. Wood, V. Zhukova

Kansas State University, Manhattan, USA

T. Bolton, I. Chakaberia, A. Ivanov, M. Makouski, Y. Maravin, S. Shrestha, I. Svintradze, Z. Wan

Lawrence Livermore National Laboratory, Livermore, USA

J. Gronberg, D. Lange, D. Wright

University of Maryland, College Park, USA

A. Baden, M. Boutemour, S.C. Eno, D. Ferencek, J.A. Gomez, N.J. Hadley, R.G. Kellogg, M. Kirn, Y. Lu, A.C. Mignerey, K. Rossato, P. Rumerio, F. Santanastasio, A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar, E. Twedt

Massachusetts Institute of Technology, Cambridge, USA

B. Alver, G. Bauer, J. Bendavid, W. Busza, E. Butz, I.A. Cali, M. Chan, V. Dutta, P. Everaerts, G. Gomez Ceballos, M. Goncharov, K.A. Hahn, P. Harris, Y. Kim, M. Klute, Y.-J. Lee, W. Li, C. Loizides, P.D. Luckey, T. Ma, S. Nahn, C. Paus, D. Ralph, C. Roland, G. Roland, M. Rudolph, G.S.F. Stephans, K. Sumorok, K. Sung, E.A. Wenger, S. Xie, M. Yang, Y. Yilmaz, A.S. Yoon, M. Zanetti

University of Minnesota, Minneapolis, USA

P. Cole, S.I. Cooper, P. Cushman, B. Dahmes, A. De Benedetti, P.R. Duderod, G. Franzoni, J. Haupt, K. Klapoetke, Y. Kubota, J. Mans, V. Rekovic, R. Rusack, M. Sasseville, A. Singovsky

University of Mississippi, University, USA

L.M. Cremaldi, R. Godang, R. Kroeger, L. Perera, R. Rahmat, D.A. Sanders, D. Summers

University of Nebraska-Lincoln, Lincoln, USA

K. Bloom, S. Bose, J. Butt, D.R. Claes, A. Dominguez, M. Eads, J. Keller, T. Kelly, I. Kravchenko, J. Lazo-Flores, C. Lundstedt, H. Malbouisson, S. Malik, G.R. Snow

State University of New York at Buffalo, Buffalo, USA

U. Baur, A. Godshalk, I. Iashvili, S. Jain, A. Kharchilava, A. Kumar, S.P. Shipkowski, K. Smith

Northeastern University, Boston, USA

G. Alverson, E. Barberis, D. Baumgartel, O. Boeriu, M. Chasco, S. Reucroft, J. Swain, D. Wood, J. Zhang

Northwestern University, Evanston, USA

A. Anastassov, A. Kubik, N. Odell, R.A. Ofierzynski, B. Pollack, A. Pozdnyakov, M. Schmitt, S. Stoynev, M. Velasco, S. Won

University of Notre Dame, Notre Dame, USA

L. Antonelli, D. Berry, M. Hildreth, C. Jessop, D.J. Karmgard, J. Kolb, T. Kolberg, K. Lannon, W. Luo, S. Lynch, N. Marinelli, D.M. Morse, T. Pearson, R. Ruchti, J. Slaunwhite, N. Valls, J. Warchol, M. Wayne, J. Ziegler

The Ohio State University, Columbus, USA

B. Bylsma, L.S. Durkin, J. Gu, C. Hill, P. Killewald, K. Kotov, T.Y. Ling, M. Rodenburg, G. Williams

Princeton University, Princeton, USA

N. Adam, E. Berry, P. Elmer, D. Gerbaudo, V. Halyo, P. Hebda, A. Hunt, J. Jones, E. Laird, D. Lopes Pegna, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, P. Piroué, X. Quan, H. Saka, D. Stickland, C. Tully, J.S. Werner, A. Zuranski

University of Puerto Rico, Mayaguez, USA

J.G. Acosta, X.T. Huang, A. Lopez, H. Mendez, S. Oliveros, J.E. Ramirez Vargas, A. Zatserklyaniy

Purdue University, West Lafayette, USA

E. Alagoz, V.E. Barnes, G. Bolla, L. Borrello, D. Bortoletto, A. Everett, A.F. Garfinkel, Z. Gecse, L. Gutay, Z. Hu, M. Jones, O. Koybasi, M. Kress, A.T. Laasanen, N. Leonardo, C. Liu, V. Maroussov, P. Merkel, D.H. Miller, N. Neumeister, I. Shipsey, D. Silvers, A. Svyatkovskiy, H.D. Yoo, J. Zablocki, Y. Zheng

Purdue University Calumet, Hammond, USA

P. Jindal, N. Parashar

Rice University, Houston, USA

C. Boulahouache, V. Cuplov, K.M. Ecklund, F.J.M. Geurts, J.H. Liu, 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, H. Flacher, A. Garcia-Bellido, P. Goldenzweig, Y. Gotra, J. Han, A. Harel, D.C. Miner, D. Orbaker, G. Petrillo, D. Vishnevskiy, M. Zielinski

The Rockefeller University, New York, USA

A. Bhatti, R. Ciesielski, L. Demortier, K. Goulianos, G. Lungu, C. Mesropian, M. Yan

Rutgers, the State University of New Jersey, Piscataway, USA

O. Atramentov, A. Barker, D. Duggan, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, D. Hits, A. Lath, S. Panwalkar, R. Patel, A. Richards, K. Rose, S. Schnetzer, S. Somalwar, R. Stone, S. Thomas

University of Tennessee, Knoxville, USA

G. Cerizza, M. Hollingsworth, S. Spanier, Z.C. Yang, A. York

Texas A&M University, College Station, USA

J. Asaadi, R. Eusebi, J. Gilmore, A. Gurrola, T. Kamon, V. Khotilovich, R. Montalvo, C.N. Nguyen, I. Osipenkov, J. Pivarski, A. Safonov, S. Sengupta, A. Tatarinov, D. Toback, M. Weinberger

Texas Tech University, Lubbock, USA

N. Akchurin, J. Damgov, C. Jeong, K. Kovitanggoon, S.W. Lee, Y. Roh, A. Sill, I. Volobouev, R. Wigmans, E. Yazgan

Vanderbilt University, Nashville, USA

E. Appelt, E. Brownson, D. Engh, C. Florez, W. Gabella, W. Johns, P. Kurt, C. Maguire, A. Melo, P. Sheldon, S. Tuo, J. Velkovska

University of Virginia, Charlottesville, USA

M.W. Arenton, M. Balazs, S. Boutle, M. Buehler, S. Conetti, B. Cox, B. Francis, R. Hirosky, A. Ledovskoy, C. Lin, C. Neu, R. Yohay

Wayne State University, Detroit, USA

S. Gollapinni, R. Harr, P.E. Karchin, P. Lamichhane, M. Mattson, C. Milstène, A. Sakharov

University of Wisconsin, Madison, USA

M. Anderson, M. Bachtis, J.N. Bellinger, D. Carlsmith, S. Dasu, J. Efron, L. Gray, K.S. Grogg, M. Grothe, R. Hall-Wilton¹, M. Herndon, P. Klabbers, J. Klukas, A. Lanaro, C. Lazaridis, J. Leonard, R. Loveless, A. Mohapatra, D. Reeder, I. Ross, A. Savin, W.H. Smith, J. Swanson, M. Weinberg

†: Deceased

1: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland

2: Also at Universidade Federal do ABC, Santo Andre, Brazil

3: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France

4: Also at Suez Canal University, Suez, Egypt

5: Also at Fayoum University, El-Fayoum, Egypt

6: Also at Soltan Institute for Nuclear Studies, Warsaw, Poland

7: Also at Massachusetts Institute of Technology, Cambridge, USA

8: Also at Université de Haute-Alsace, Mulhouse, France

- 9: Also at Brandenburg University of Technology, Cottbus, Germany
- 10: Also at Moscow State University, Moscow, Russia
- 11: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
- 12: Also at Eötvös Loránd University, Budapest, Hungary
- 13: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
- 14: Also at University of Visva-Bharati, Santiniketan, India
- 15: Also at Facoltà Ingegneria Università di Roma "La Sapienza", Roma, Italy
- 16: Also at Università della Basilicata, Potenza, Italy
- 17: Also at Laboratori Nazionali di Legnaro dell' INFN, Legnaro, Italy
- 18: Also at Università degli studi di Siena, Siena, Italy
- 19: Also at California Institute of Technology, Pasadena, USA
- 20: Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia
- 21: Also at University of California, Los Angeles, Los Angeles, USA
- 22: Also at University of Florida, Gainesville, USA
- 23: Also at Université de Genève, Geneva, Switzerland
- 24: Also at Scuola Normale e Sezione dell' INFN, Pisa, Italy
- 25: Also at INFN Sezione di Roma; Università di Roma "La Sapienza", Roma, Italy
- 26: Also at University of Athens, Athens, Greece
- 27: Also at The University of Kansas, Lawrence, USA
- 28: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
- 29: Also at Paul Scherrer Institut, Villigen, Switzerland
- 30: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
- 31: Also at Gaziosmanpasa University, Tokat, Turkey
- 32: Also at Adiyaman University, Adiyaman, Turkey
- 33: Also at Mersin University, Mersin, Turkey
- 34: Also at Izmir Institute of Technology, Izmir, Turkey
- 35: Also at Kafkas University, Kars, Turkey
- 36: Also at Suleyman Demirel University, Isparta, Turkey
- 37: Also at Ege University, Izmir, Turkey
- 38: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
- 39: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
- 40: Also at Institute for Nuclear Research, Moscow, Russia
- 41: Also at Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania
- 42: Also at Istanbul Technical University, Istanbul, Turkey