EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CMS-EXO-11-096

arXiv:1204.0821v2 [hep-ex] 23 Jan 2013

Search for Dark Matter and Large Extra Dimensions in pp Collisions Yielding a Photon and Missing Transverse Energy

The CMS Collaboration[*]

Abstract

Results are presented from a search for new physics in the final state containing a photon (γ) and missing transverse energy ($\not{E}_T$). The data correspond to an integrated luminosity of $5.0\,\mathrm{fb}^{-1}$ collected in pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$ by the CMS experiment. The observed event yield agrees with standard-model expectations for the $\gamma + \not{E}_T$ events. Using models for production of dark-matter particles (χ), we set 90% confidence level (CL) upper limits of 13.6–15.4 fb on χ production in the $\gamma + \not{E}_T$ state. These provide the most sensitive upper limits for spin-dependent χ-nucleon scattering for χ masses (M_χ) between 1 and 100 GeV. For spin-independent contributions, the present limits are extended to $M_\chi < 3.5\,\mathrm{GeV}$. For models with 3–6 large extra dimensions, our data exclude extra-dimensional Planck scales between 1.65 and 1.71 TeV at 95% CL.

Submitted to Physical Review Letters

[*]See Appendix A for the list of collaboration members

Final states in pp collisions at the Large Hadron Collider (LHC), containing a photon (γ) of large transverse momentum (p_T) and missing transverse energy ($\not{E}_T$), are used to investigate two proposals of physics beyond the standard model (SM). One involves a model for dark matter (DM), which is now accepted as the dominant non-baryonic contribution to the matter density of the universe [1]. Direct searches for a DM candidate (χ) rely on detection through elastic χ-nucleon scattering. Indirect searches consist of observation of photons or neutrinos produced in $\chi\overline{\chi}$ annihilations in astrophysical sources. At the LHC, DM can be produced in the reaction $q\overline{q} \to \gamma\chi\overline{\chi}$, where the photon is radiated by one of the incoming quarks. The final state is a high-p_T photon and $\not{E}_T$. Recent theoretical work [2, 3] casts this process in terms of a massive mediator in the s channel that couples to a $\chi\overline{\chi}$ pair of Dirac particles. This process is contracted into an effective theory with a contact interaction scale Λ, given by $\Lambda^{-2} = g_\chi g_q M_M^{-2}$, where M_M is the mediator mass and g_χ and g_q are its couplings to χ and quarks, respectively. The model provides a way to connect the t-channel χ-nucleon elastic scattering to the s-channel pair-production mechanism. The effective s-channel operator can be chosen to represent either a vector or axial-vector, spin-independent or spin-dependent interaction, respectively.

The $\gamma+\not{E}_T$ final state also has sensitivity to models of extra spatial dimensions. The Arkani-Hamed, Dimopoulos, and Dvali model (ADD) [4], in particular, provides a possible solution to the hierarchy problem, viz., the disparity between two fundamental scales of nature: the electroweak unification scale ($M_{EW} \approx 100\,\text{GeV}$) and the Planck scale ($M_{Pl} \approx 10^{19}\,\text{GeV}$). In this framework, space-time is postulated to have n extra compact spatial dimensions with a characteristic scale R, leading to a modified Planck scale, M_D, given by $M_{Pl}^2 \approx M_D^{n+2}R^n$. Assuming M_D is of the same order as M_{EW}, the observed large value of M_{Pl} can be interpreted as being a consequence of the "large" size of R (relative to the Planck length $\approx M_{Pl}^{-1}$) and the number of extra dimensions in the theory. The ADD model predicts the production of gravitons that appear as Kaluza-Klein (KK) modes, where momenta in the extra dimensions appear as observable massive states, except for the zero-mode of the KK excitation, which corresponds to the massless graviton in 4+n dimensions. The process $q\overline{q} \to \gamma G$, where the graviton G escapes detection, motivates the search for events with single high-p_T isolated photons. While the individual qG couplings are small, the number of expected KK graviton states is large enough to produce a measurable cross section, making it possible to discover large extra dimensions, or to set lower limits on M_D as a function of n and upper limits on the ADD cross section. The same physical phenomena can be accessed through the single-jet (monojet) production channel [5, 6].

This search uses data collected with the Compact Muon Solenoid (CMS) detector [7]. The momenta of charged particles are measured using a silicon pixel and strip tracker that is immersed in a 3.8 T superconducting solenoid, and covers the pseudorapidity range $|\eta| < 2.5$. The pseudorapidity is $\eta = -\ln[\tan(\theta/2)]$, where θ is the polar angle measured relative to the counterclockwise-beam direction. The tracker is surrounded by a crystal electromagnetic calorimeter (ECAL) and a brass-scintillator hadron calorimeter (HCAL). Both measure particle energy depositions and consist of a barrel assembly and two endcaps that provide coverage in the range of $|\eta| < 3.0$. A steel/quartz-fiber Cherenkov forward detector (HF) extends the calorimetric coverage to $|\eta| < 5$. Muons are measured in gas detectors embedded in the steel return yoke outside of the solenoid.

The primary background for the $\gamma+\not{E}_T$ signal is the irreducible SM background from $Z\gamma \to \nu\overline{\nu}\gamma$ production. This and other SM backgrounds, including $W\gamma$, $W \to e\nu$, γ+jet, multijet (referred to as QCD), and diphoton events, as well as backgrounds from beam halo and cosmic-ray muons are taken into account in the analysis.

Events are selected from a data sample corresponding to an integrated luminosity of $5.0\,\text{fb}^{-1}$

collected using a two-level trigger system, with Level-1 (L1) seeding High Level Triggers (HLT). The single-photon triggers comprising this search are not prescaled, and are fully efficient within the selected signal region of $|\eta^\gamma| < 1.44$ [8] and $p_T^\gamma > 145\,\text{GeV}$. To optimize the analysis for single high-p_T photons accompanied by large $\not{E}_T$, photon candidates are restricted to be in the central barrel region, where purity is highest. To distinguish photon candidates from jets, we apply additional calorimetric selections. The ratio of energy deposited in the HCAL to that in the ECAL within a cone of $\Delta R = 0.15$ is required to be less than 0.05, where $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$ is defined relative to the photon candidate and the azimuthal angle ϕ is measured in the plane perpendicular to the beam axis. Photon candidates must also have a shower distribution in the ECAL consistent with that expected for a photon [8].

Isolation requirements on photon candidates impose upper limits on the energy deposited in the detector around the axis defined by the EM cluster position and the primary vertex [8]. In particular, the scalar sum of p_T depositions in the ECAL within a hollow cone of $0.06 < \Delta R < 0.40$, excluding depositions within $|\Delta\eta| = 0.04$ of the cluster center, must be $<4.2\,\text{GeV} + 0.006\times p_T^\gamma$, the sum of scalar p_T depositions in the HCAL within a hollow cone of $0.15 < \Delta R < 0.40$ must be $<2.2\,\text{GeV} + 0.0025\times p_T^\gamma$, and the scalar sum of track p_T values in a hollow cone of $0.04 < \Delta R < 0.40$, excluding depositions that are closer to the cluster center than $|\Delta\eta| = 0.015$, must be $<2.0\,\text{GeV} + 0.001\times p_T^\gamma$ (with p_T in GeV units). The vetoes defined by the $|\Delta\eta|$ cutoffs are needed to maintain high efficiency for photons that initiate EM showers within the tracker. The tracker isolation requirement is based on tracks that originate from the primary vertex.

Since the high luminosity of the LHC yields multiple pp interactions per bunch crossing, there are several reconstructed vertices per event. The primary vertex is defined as the vertex that corresponds to the largest sum of the squares of the associated track-p_T values. However, to ensure that photon candidates are isolated from charged particle tracks in events with multiple vertices, the tracker isolation requirement must be passed by all reconstructed vertices, or the event is rejected.

The $\not{E}_T$ is defined by the magnitude of the vector sum of the transverse energies of all of the reconstructed objects in the event, and is computed using a particle-flow algorithm [9]. The candidate events are required to have $\not{E}_T > 130\,\text{GeV}$.

All events are required to have the energy deposited in the crystal containing the largest signal within the photon to be within $\pm 3\,\text{ns}$ of the time expected for particles from a collision. This requirement reduces instrumental background arising from showers induced by bremsstrahlung from muons in the beam halo or in cosmic rays. Spurious signals embedded within EM showers that otherwise pass selection criteria are eliminated by requiring consistency among the energy deposition times for all crystals within an electromagnetic shower. Photon candidates are removed if they are likely to be electrons, as inferred from characteristic patterns of hits in the pixel detector, called "pixel seeds," that are matched to the EM clusters [10]. In addition, a veto applied to events that contain muon candidates, including those that do not emanate from the collision point, prevents bremsstrahlung from muons in cosmic rays and the beam halo from being reconstructed as prompt photons balanced by $\not{E}_T$. Finally, events are vetoed if they contain significant hadronic activity, defined by: (i) a track with $p_T > 20\,\text{GeV}$ that is $\Delta R > 0.04$ away from the photon candidate, or (ii) a jet that is reconstructed with $p_T > 40\,\text{GeV}$ using the anti-k_T [11] particle-flow algorithm [9], within $|\eta| < 3.0$ and $\Delta R < 0.5$ of the axis of the photon.

After applying all of the selection criteria, 75 candidate events are found.

Backgrounds that are out of time with the collisions are estimated from data by examining the

transverse distribution of energy in the EM cluster and the time-of-arrival of the signal in the crystal with the largest energy deposition. Templates for anomalous signals [12], cosmic-ray muons, and beam halo events are fitted to a candidate sample that has no timing requirement, which reveals that the only significant residual contribution to the in-time sample arises from halo muons, with an estimated 11.1 ± 5.6 events.

Electrons misidentified as photons arise mainly from $W \rightarrow e\nu$ events. The matching of electron showers to pixel seeds has an efficiency of $\epsilon = 0.9940 \pm 0.0025$, as estimated with Monte-Carlo simulated events (MC) and verified with $Z \rightarrow ee$ events in data. Scaling a control sample of electron candidates by $(1 - \epsilon)/\epsilon$ yields an estimated contribution of 3.5 ± 1.5 $W \rightarrow e\nu$ events in the candidate sample.

The contamination from jets misidentified as photons is estimated by using a control sample of EM-enriched QCD events to calculate the ratio of events that pass the signal photon criteria relative to those that pass looser photon criteria but fail an isolation requirement. Since the EM-enriched sample also includes production of direct single photons, this additional contribution to the ratio is estimated by fitting templates of energy-weighted shower widths from MC-simulated γ+jets events to an independent QCD data sample, and used to subtract the γ+jets contribution. This corrected ratio is applied to a subset of the EM-enriched jet events that passes loose photon identification and additional single-photon event selection criteria, providing a background contribution of 11.2 ± 2.8 jet events.

Backgrounds from $(Z\nu\bar{\nu})\gamma$, $(W\ell\nu)\gamma$, γ+jet, and diphoton events are estimated from MC samples processed through the full GEANT4-based simulation of the CMS detector [13, 14], trigger emulation and event reconstruction used for data. The $W\gamma \rightarrow \ell\nu\gamma$ samples are generated with MADGRAPH5 [15], and the cross section is corrected to include next-to-leading order (NLO) effects through a K-factor calculated with MCFM [16]. The $Z\gamma \rightarrow \nu\bar{\nu}\gamma$, γ+jet, and diphoton samples are obtained using the PYTHIA 6.424 generator [17] at leading order (LO) and CTEQ6L1 [18] parton distribution functions (PDF). The $Z\gamma \rightarrow \nu\bar{\nu}\gamma$ sample is also scaled up to reflect NLO contributions given in Ref. [19]. Good agreement between data and the rescaled MC for the $Z\gamma \rightarrow \ell\ell\gamma$ channel has been obtained in previous CMS studies [20]. The uncertainty on $Z\gamma \rightarrow \nu\bar{\nu}\gamma$ and the other backgrounds takes into account several sources: theoretical uncertainties on the LO cross section and K-factors; the uncertainty on the scale factor that models the data–MC difference in the efficiency; and systematic uncertainties on the photon-vertex assignment, modeling of pile-up, and the accuracy of the energy calibration and resolution for photons, jets, and $\not{E}_T$. The expected contribution from the $Z\gamma \rightarrow \nu\bar{\nu}\gamma$ process to the background is 45.3 ± 6.8 events. The combined expected background from $(W\ell\nu)\gamma$, γ+jet, and diphoton events is 4.1 ± 1.0.

The 73 observed events in data agree with the total expected background of 75.1 ± 9.4 events. Distributions in photon p_T for the selected candidate events and for those estimated from background are shown in Fig. 1. The spectra expected from ADD for $M_D = 1\,\text{TeV}$ and $n = 3$ are superimposed for comparison. Based on these results, exclusion limits are set for the DM and ADD models.

The limits on the cross sections are calculated by dividing the difference between the number of events in data and the predicted number of background events by the product $A \times \epsilon \times \mathcal{L}$, where A is the geometric and kinematic acceptance of the selection criteria, ϵ is the selection efficiency for signal, and $\mathcal{L}$ is the integrated luminosity. $A \times \epsilon$ is calculated by estimating $A \times \epsilon_{MC}$ from the MC and multiplying it by a scale factor to account for the difference in efficiency between MC and data.
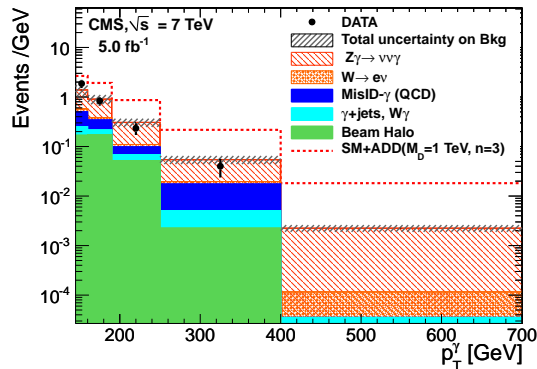
Figure 1: The photon p_T distribution for the candidate sample, compared with estimated contributions from SM backgrounds and a prediction from ADD for $M_D = 1\,\text{TeV}$ and $n = 3$.

The efficiency associated with the product $A \times \epsilon_{MC}$ for the signal cross section for both models is determined from MC samples. For the model of DM, the MC samples are produced using a software package from Ref. [3], requiring $p_T^\gamma > 125\,\text{GeV}$ and $|\eta^\gamma| < 1.5$. The estimated value of $A \times \epsilon_{MC}$ for M_χ in the range 1–100 GeV is between 30.5–31.0% for vector and 29.2–31.4% for axial-vector couplings, respectively. The spectra for ADD MC events are generated using PYTHIA 8.145 [21], requiring $p_T^\gamma > 130\,\text{GeV}$, and scaled to NLO using a K-factor from Ref. [22]. The factor $A \times \epsilon_{MC}$ for ADD is in the range of 26.5–28.5% in the parameter space spanned by $n = 3$–6 and $M_D = 1$–3 TeV.

Systematic uncertainties that contribute to the $A \times \epsilon_{MC}$ calculation are from the choice of PDF [18, 23, 24]; the selection of the primary vertex for the photon, modeling of pile-up, and the energy calibration and resolution for photons [8]; jets [25]; and $\not{E}_T$ [26]. The total systematic uncertainty on $A \times \epsilon_{MC}$ is +4.8% and −4.9%.

As mentioned above, $A \times \epsilon_{MC}$ is multiplied by a scale factor (SF) to account for the difference in efficiency between data and MC. The calculated SF of 0.90 ± 0.11 combines contributions from the trigger, photon reconstruction, consistency of cluster timing, and vetoes. The photon HLT is determined to be essentially 100% efficient for our selection criteria in data and in MC, but is assigned a 2% uncertainty due to small L1 trigger inefficiencies. Since the photon identification requirements have similar efficiencies for photons and electrons, the electron efficiency of 0.96 ± 0.02, as measured in Z $\rightarrow$ ee decays is used as the SF. Corrections for photon reconstruction are described in Ref. [20]. The photon clusters in MC always have consistent timing among individual crystals, and the SF in data is found to be 0.983 ± 0.009 based on a sample of electron events. The track and jet-veto efficiency is studied in samples of W $\rightarrow$ eν data and MC, and confirmed with Z$\gamma \rightarrow$ eeγ data. Since the efficiencies measured in these samples agree within their uncertainties, the SF is set to unity and assigned a systematic uncertainty of ± 0.10. The SF for the cosmic-ray muon veto is determined to be 0.95 ± 0.01 by comparing its efficiency in MC and data in a sample of Z $\rightarrow$ ee events.

Upper limits are placed on the DM production cross sections, as a function of M_χ, assuming vector and axial-vector operators, summarized in Table 2a. These are converted into the corresponding lower limits on the cutoff scale Λ, also listed in Table 2a. The Λ values are then translated into upper limits on the χ-nucleon cross sections, calculated within the effective theory framework. These are displayed in Fig. 2 as a function of M_χ [2]. The 90% CL limits are presented in Table 2a. Superposed are the results from selected other experiments. Previously inaccessible χ masses below $\approx 3.5\,\text{GeV}$ are excluded for a χ-nucleon cross section greater than
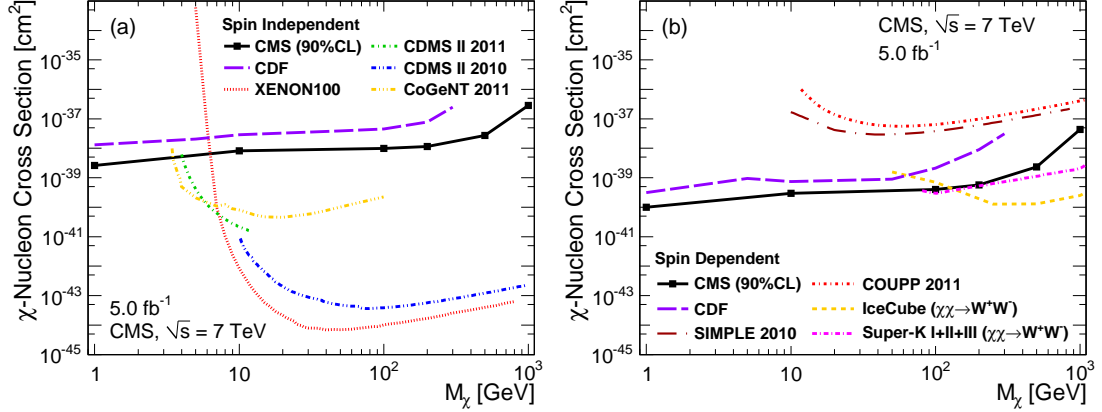
Figure 2: The 90% CL upper limits on the χ-nucleon cross section as a function of M_χ for (a) spin-independent and (b) spin-dependent scattering. Also shown are the limits from selected experiments with published [27–34] and preliminary [35] results.

Table 1: (a) Observed (expected) 90% CL upper limits on the DM production cross section σ, and 90% CL lower limits on the cutoff scale Λ for vector and axial-vector operators as a function of the DM mass M_χ. (b) Expected and observed lower limits on M_D at 95% CL, as a function of extra dimensions n, with K-factors (and without, i.e., $K = 1$).

M_χ [GeV]	Vector		Axial-Vector	
	σ [fb]	Λ [GeV]	σ [fb]	Λ [GeV]
1	14.3 (14.7)	572 (568)	14.9 (15.4)	565 (561)
10	14.3 (14.7)	571 (567)	14.1 (14.5)	573 (569)
100	15.4 (15.3)	558 (558)	13.9 (14.3)	554 (550)
200	14.3 (14.7)	549 (545)	14.0 (14.5)	508 (504)
500	13.6 (14.0)	442 (439)	13.7 (14.1)	358 (356)
1000	14.1 (14.5)	246 (244)	13.9 (14.3)	172 (171)

(a) 90% CL Limits on DM model parameters.

n	K-factors	Expected M_D [TeV]	Observed M_D [TeV]
3	1.5	1.70 (1.53)	1.73 (1.55)
4	1.4	1.65 (1.53)	1.67 (1.55)
5	1.3	1.63 (1.54)	1.64 (1.56)
6	1.2	1.62 (1.55)	1.64 (1.57)

(b) 95% CL Limits on ADD parameters.

≈ 3 fb at 90% CL. For spin-dependent scattering, the upper limits surpass all previous constraints for the mass range of 1–100 GeV. The results presented are valid for mediator masses larger than the limits on Λ, assuming unity for the couplings g_χ and g_q. The specific case of light mediators is discussed in Ref. [3, 36]. The assumptions on χ interactions made in calculating the limits vary with experiment. Further, in the case of direct and indirect searches, an astrophysical model must be assumed for the density and velocity distribution of DM.

A set of 95% confidence level (CL) upper limits are also placed on the ADD cross sections and translated into exclusions on the parameter space of the model. The upper limits are calculated
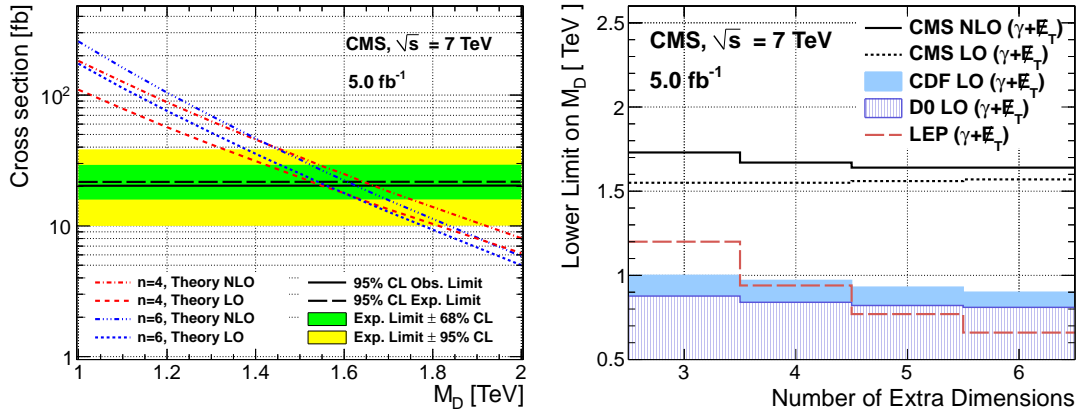
Figure 3: (a) The 95% CL upper limits on the LO and NLO ADD cross sections as a function of M_D for $n = 4$ and 6. (b) Limits on M_D as a function of n, compared to LO results from similar searches at the Tevatron [37, 38] and LEP [39].

using a CL_s method [40], with uncertainties parameterized by log-normal distributions in the fit to data. The limits on M_D, with and without K-factors, are summarized in Table 2b. Masses $M_D < 1.65$ TeV are excluded at 95% CL for $n = 3$, assuming NLO cross sections. These limits, along with existing LO ADD limits from the Tevatron [37, 38] and LEP [39], are shown in Fig. 3 as a function of M_D, for $n = 4$ and $n = 6$ extra dimensions. These results extend significantly the limits on the ADD model in the single-photon channel beyond previous measurements at the Tevatron and LEP experiments, and set limits of $M_D > 1.59$–1.66 TeV for $n = 3$–6 at 95% CL.

In summary, the agreement between single-photon production in pp collisions at 7 TeV and standard-model expectations was used to derive significant upper limits on the vector and axial-vector contributions to the χ-nucleon scattering cross section. This search was complementary to searches for elastic χ-nucleon scattering or $\chi\overline{\chi}$ annihilation. In addition, through greater sensitivity to the ADD model, the analysis attained the most stringent limits on an effective extra-dimensional Planck scale obtained in the $\gamma + \not{E}_T$ production channel.

Acknowledgements

References

[1] R. Gaitskell, "Direct Detection of Dark Matter", *Annual Review of Nuclear and Particle Science* **54** (2004) `doi:10.1146/annurev.nucl.54.070103.181244`.

[2] Y. Bai, P. J. Fox, and R. Harnik, "The Tevatron at the Frontier of Dark Matter Direct Detection", *JHEP* **12** (2010) 048, `doi:10.1007/JHEP12(2010)048`, `arXiv:1005.3797v2`.

[3] P. J. Fox et al., "Missing Energy Signatures of Dark Matter at the LHC", `arXiv:1109.4398`.

[4] N. Arkani-Hamed, S. Dimopoulos, and G. Dvali, "The Hierarchy problem and new dimensions at a millimeter", *Phys. Lett. B* **429** (1998) 263, `doi:10.1016/S0370-2693(98)00466-3`, `arXiv:hep-ph/9803315`.

[5] CMS Collaboration, "Search for New Physics with a Monojet and Missing Transverse Energy in pp Collisions at $\sqrt{s} = 7$ TeV", *Phys. Rev. Lett.* **107** (2011) 201804, `doi:10.1103/PhysRevLett.107.201804`, `arXiv:1106.4775`.

[6] ATLAS Collaboration, "Search for new phenomena with the monojet and missing transverse momentum signature using the ATLAS detector in $\sqrt{s} = 7$ TeV proton-proton collisions", *Phys. Lett. B* **705** (2011) 294, `doi:10.1016/j.physletb.2011.10.006`, `arXiv:1106.5327`.

[7] CMS Collaboration, "CMS technical design report, volume II: Physics Performance", *J. Phys. G: Nucl. Part. Phys.* **34** (2007) 995, `doi:10.1088/0954-3899/34/6/S01`.

[8] CMS Collaboration, "Isolated Photon Reconstruction and Identification at $\sqrt{s} = 7$ TeV", CMS Physics Analysis Summary CMS-PAS-EGM-10-006, (2011).

[9] CMS Collaboration, "Commissioning of the Particle-Flow Reconstruction in Minimum-Bias and Jet Events from pp Collisions at 7 TeV", CMS Physics Analysis Summary CMS-PAS-PFT-10-002, (2010).

[10] CMS Collaboration, "Electron Reconstruction and Identification at $\sqrt{s} = 7$ TeV", CMS Physics Analysis Summary CMS-PAS-EGM-10-004, (2010).

[11] M. Cacciari, G. P. Salam, and G. Soyez, "The anti-k$_\mathrm{t}$ jet clustering algorithm", *JHEP* **04** (2008) 063, `doi:10.1088/1126-6708/2008/04/063`, `arXiv:0802.1189`.

[12] CMS Collaboration, "Electromagnetic calorimeter commissioning and first results with 7 TeV data", CMS Physics Analysis Summary CMS-NOTE-2010-012, (2010).

[13] GEANT4 Collaboration, "GEANT4–a simulation toolkit", *Nucl. Instrum. Meth A* **506** (2003) 250, `doi:10.1016/S0168-9002(03)01368-8`.

[14] J. Allison et al., "Geant4 Developments and Applications", *IEEE Trans. Nucl. Sci* **53** (2006) 270, `doi:10.1109/TNS.2006.869826`.

[15] J. Alwall et al., "MadGraph 5: Going Beyond", *JHEP* **6** (2011) 128, `doi:10.1007/JHEP06(2011)128`, `arXiv:arXiv`.

[16] J. Campbell, R. Ellis, and C. Williams, "MCFM v6.1: A Monte Carlo for FeMtobarn processes at Hadron Colliders", 2011, `http://mcfm.fnal.gov/mcfm.pdf`.

[17] T. Sjöstrand, S. Mrenna, and P. Z. Skands, "PYTHIA 6.4 Physics and Manual", *JHEP* **5** (2006) 26, `doi:10.1088/1126-6708/2006/05/026`, `arXiv:hep-ph/0603175`.

[18] J. Pumplin et al., "New generation of parton distributions with uncertainties from global QCD analysis", *JHEP* **07** (2002) 012, `doi:10.1088/1126-6708/2002/07/012`, `arXiv:hep-ph/0201195`.

[19] U. Baur and E. Berger, "Probing the Weak-Boson Sector in $Z\gamma$ Production at Hadron Colliders", *Phys. Rev. D* **47** (1993) 4889, `doi:10.1103/PhysRevD.47.4889`.

[20] CMS Collaboration, "Measurement of W-gamma and Z-gamma production in pp collisions at $\sqrt{s} =$7 TeV", *Phys. Lett. B* **701** (2011) 535, `doi:10.1016/j.physletb.2011.06.034`, `arXiv:1105.2758`.

[21] T. Sjöstrand, S. Mrenna, and P. Skands, "A Brief Introduction fo PYTHIA 8.1", *Comput. Phys. Commun.* **178** (2008) 852, `doi:10.1016/j.cpc.2008.01.036`, `arXiv:0710.3820`.

[22] X. Gao et al., "Next-to-leading order QCD predictions for graviton and photon associated production in the Large Extra Dimensions model at the LHC", *Phys. Rev. D* **81** (2010) 036008, `doi:10.1103/PhysRevD.81.036008`, `arXiv:0912.0199`.

[23] M. Botje et al., "The PDF4LHC Working Group Interim Recommendations", (2011). `arXiv:1101.0538`.

[24] A. Martin et al., "Parton distributions for the LHC", *Eur. Phys. J. C* **63** (2009) 189, `doi:10.1140/epjc/s10052-009-1072-5`, `arXiv:0901.0002`.

[25] CMS Collaboration, "Determination of Jet Energy Calibration and Transverse Momentum Resolution in CMS", *JINST* **06** (2011) 11002, `doi:10.1088/1748-0221/6/11/P11002`, `arXiv:1107.4277`.

[26] CMS Collaboration, "Missing transverse energy performance of the CMS detector", *JINST* **06** (2011) 9001, `doi:10.1088/1748-0221/6/09/P09001`, `arXiv:1106.5048`.

[27] XENON100 Collaboration, "Dark Matter Results from 100 Live Days of XENON100 Data", *Phys. Rev. Lett.* **107** (2011) 131302, `doi:10.1103/PhysRevLett.107.131302`, `arXiv:1104.2549v3`.

[28] CDMS Collaboration, "Results from a Low-Energy Analysis of the CDMS II Germanium Data", *Phys. Rev. Lett.* **106** (2011) 131302, `doi:10.1103/PhysRevLett.106.131302`, `arXiv:1011.2482v3`.

[29] CDMS II Collaboration, "Dark Matter Search Results from the CDMS II Experiment", *Science* **327** (2010) 1619, `doi:10.1126/science.1186112`.

[30] CoGeNT Collaboration, "Results from a Search for Light-Mass Dark Matter with a p-Type Point Contact Germanium Detector", *Phys. Rev. Lett.* **106** (2011) 131301, `doi:10.1103/PhysRevLett.106.131301`, `arXiv:1002.4703v1`.

[31] SIMPLE Collaboration, "First Results of the Phase II SIMPLE Dark Matter Search", *Phys. Rev. Lett.* **105** (2010) 211301, `doi:10.1103/PhysRevLett.105.211301`. A more recent update can be found in arXiv:1106.3014.

[32] E. Behnke et al., "Improved Limits on Spin-dependent WIMP-Proton Interactions from a Two Liter CF$_3$ Bubble Chamber", *Phys. Rev. Lett.* **106** (2011) 021303, `doi:10.1103/PhysRevLett.106.021303, arXiv:1008.3518v2`.

[33] IceCube Collaboration, "Multiyear search for dark matter annihilations in the Sun with the AMANDA II and IceCube detectors", *Phys. Rev. D* **85** (2012) 042002, `doi:10.1103/PhysRevD.85.042002, arXiv:1112.1840`.

[34] T. Tanaka et al., "An Indirect Search for Weakly Interacting Massive Particles in the Sun Using 3109.6 Days of Upward-going Muons in Super-Kamiokande", *Astrophys. J.* **742** (2011) 78, `doi:10.1088/0004-637X/742/2/78, arXiv:1108.3384`.

[35] CDF Collaboration, "A search for dark matter in events with one jet and missing transverse energy in pp-bar collisions at sqrt(s) = 1.96 TeV", `arXiv:1203.0742`. Submitted to *Phys. Rev. Lett.*

[36] I. Shoemaker and L. Vecchi, "Unitarity and Monojet Bounds on Models for DAMA, CoGeNT, and CRESST-II", (2011). `arXiv:1112.5457`.

[37] CDF Collaboration, "Search for large extra dimensions in final states containing one photon or jet and large missing transverse energy produced in p$\bar{\text{p}}$ collisions at $\sqrt{s} = 1.96$ TeV", *Phys. Rev. Lett.* **101** (2008) 181602, `doi:10.1103/PhysRevLett.101.181602, arXiv:0807.3132`.

[38] D0 Collaboration, "Search for Large Extra Dimensions via Single Photon plus Missing Energy Final States at sqrt(s) = 1.96 TeV", *Phys. Rev. Lett.* **101** (2008) 011601, `doi:10.1103/PhysRevLett.101.011601, arXiv:0803.2137`.

[39] DELPHI Collaboration, "Photon events with missing energy in e+ e- collisions at $\sqrt{s} = 130$ GeV to 209 GeV", *Eur. Phys. J. C* **38** (2005) 395, `doi:10.1140/epjc/s2004-02051-8, arXiv:hep-ex/0406019`.

[40] Particle Data Group Collaboration, "Chapter 33: Statistics", *J. Phys. G* **37** (2010) 075021, `doi:doi:10.1088/0954-3899/37/7A/075021`.

A   The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia
S. Chatrchyan, 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. Hammer[1], N. Hörmann, J. Hrubec, M. Jeitler, W. Kiesenhofer, M. Krammer, D. Liko, I. Mikulec, M. Pernicka[†], B. Rahbaran, C. Rohringer, 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
S. Bansal, K. Cerny, T. Cornelis, E.A. De Wolf, X. Janssen, S. Luyckx, T. Maes, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, M. Selvaggi, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

Vrije Universiteit Brussel, Brussel, Belgium
F. Blekman, S. Blyweert, J. D'Hondt, R. Gonzalez Suarez, A. Kalogeropoulos, M. Maes, A. Olbrechts, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Villella

Université Libre de Bruxelles, Bruxelles, Belgium
O. Charaf, B. Clerbaux, G. De Lentdecker, V. Dero, A.P.R. Gay, T. Hreus, A. Léonard, P.E. Marage, T. Reis, L. Thomas, C. Vander Velde, P. Vanlaer

Ghent University, Ghent, Belgium
V. Adler, K. Beernaert, A. Cimmino, S. Costantini, G. Garcia, M. Grunewald, B. Klein, J. Lellouch, A. Marinov, J. Mccartin, A.A. Ocampo Rios, D. Ryckbosch, N. Strobbe, F. Thyssen, M. Tytgat, L. Vanelderen, P. Verwilligen, S. Walsh, E. Yazgan, N. Zaganidis

Université Catholique de Louvain, Louvain-la-Neuve, Belgium
S. Basegmez, G. Bruno, L. Ceard, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco[2], J. Hollar, V. Lemaitre, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrzkowski, N. Schul

Université de Mons, Mons, Belgium
N. Beliy, T. Caebergs, E. Daubie, G.H. Hammad

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil
G.A. Alves, M. Correa Martins Junior, D. De Jesus Damiao, T. Martins, M.E. Pol, M.H.G. Souza

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
W.L. Aldá Júnior, W. Carvalho, A. Custódio, E.M. Da Costa, C. De Oliveira Martins, S. Fonseca De Souza, D. Matos Figueiredo, L. Mundim, H. Nogima, V. Oguri, W.L. Prado Da Silva, A. Santoro, S.M. Silva Do Amaral, L. Soares Jorge, A. Sznajder

Instituto de Fisica Teorica, Universidade Estadual Paulista, Sao Paulo, Brazil
T.S. Anjos[3], C.A. Bernardes[3], F.A. Dias[4], T.R. Fernandez Perez Tomei, E. M. Gregores[3], C. Lagana, F. Marinho, P.G. Mercadante[3], S.F. Novaes, Sandra S. Padula

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria
V. Genchev[1], P. Iaydjiev[1], S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, V. Tcholakov, R. Trayanov, M. Vutova

University of Sofia, Sofia, Bulgaria
A. Dimitrov, R. Hadjiiska, V. Kozhuharov, L. Litov, B. Pavlov, P. Petkov

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

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

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

Technical University of Split, Split, Croatia
N. Godinovic, D. Lelas, R. Plestina[5], D. Polic, I. Puljak[1]

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

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

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

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

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt
Y. Assran[6], S. Elgammal[7], A. Ellithi Kamel[8], S. Khalil[9], M.A. Mahmoud[10], A. Radi[9,11]

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

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

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

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

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

Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
S. Baffioni, F. Beaudette, L. Benhabib, L. Bianchini, M. Bluj[12], C. Broutin, P. Busson, C. Charlot, N. Daci, T. Dahms, L. Dobrzynski, R. Granier de Cassagnac, M. Haguenauer, P. Miné, C. Mironov, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Veelken, A. Zabi

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

J.-L. Agram[13], J. Andrea, D. Bloch, D. Bodin, J.-M. Brom, M. Cardaci, E.C. Chabert, C. Collard, E. Conte[13], F. Drouhin[13], C. Ferro, J.-C. Fontaine[13], D. Gelé, U. Goerlach, P. Juillot, M. Karim[13], A.-C. Le Bihan, 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

S. Beauceron, N. Beaupere, O. Bondu, G. Boudoul, H. Brun, J. Chasserat, R. Chierici[1], D. Contardo, P. Depasse, H. El Mamouni, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, M. Lethuillier, L. Mirabito, S. Perries, V. Sordini, S. Tosi, Y. Tschudi, P. Verdier, S. Viret

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

Z. Tsamalaidze[14]

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

G. Anagnostou, S. Beranek, M. Edelhoff, L. Feld, N. Heracleous, O. Hindrichs, R. Jussen, K. Klein, J. Merz, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, B. Wittmer, V. Zhukov[15]

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

M. Ata, J. Caudron, E. Dietz-Laursonn, D. Duchardt, M. Erdmann, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, T. Klimkovich, D. Klingebiel, P. Kreuzer, D. Lanske[†], J. Lingemann, C. Magass, M. Merschmeyer, A. Meyer, M. Olschewski, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teyssier, M. Weber

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

M. Bontenackels, V. Cherepanov, M. Davids, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, A. Linn, A. Nowack, L. Perchalla, O. Pooth, J. Rennefeld, P. Sauerland, A. Stahl

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, J. Behr, W. Behrenhoff, U. Behrens, M. Bergholz[16], A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, E. Castro, F. Costanza, D. Dammann, G. Eckerlin, D. Eckstein, D. Fischer, G. Flucke, A. Geiser, I. Glushkov, S. Habib, J. Hauk, H. Jung[1], M. Kasemann, P. Katsas, C. Kleinwort, H. Kluge, A. Knutsson, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, W. Lohmann[16], B. Lutz, R. Mankel, I. Marfin, M. Marienfeld, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, S. Naumann-Emme, J. Olzem, H. Perrey, A. Petrukhin, D. Pitzl, A. Raspereza, P.M. Ribeiro Cipriano, C. Riedl, M. Rosin, J. Salfeld-Nebgen, R. Schmidt[16], T. Schoerner-Sadenius, N. Sen, A. Spiridonov, M. Stein, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany

C. Autermann, V. Blobel, S. Bobrovskyi, J. Draeger, H. Enderle, J. Erfle, U. Gebbert, M. Görner, T. Hermanns, R.S. Höing, K. Kaschube, G. Kaussen, H. Kirschenmann, R. Klanner, J. Lange, B. Mura, F. Nowak, N. Pietsch, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, M. Schröder, T. Schum, M. Seidel, H. Stadie, G. Steinbrück, J. Thomsen

Institut für Experimentelle Kernphysik, Karlsruhe, Germany
C. Barth, J. Berger, T. Chwalek, W. De Boer, A. Dierlamm, M. Feindt, M. Guthoff[1], C. Hackstein,
F. Hartmann, M. Heinrich, H. Held, K.H. Hoffmann, S. Honc, U. Husemann, I. Katkov[15],
J.R. Komaragiri, D. Martschei, S. Mueller, Th. Müller, M. Niegel, A. Nürnberg, O. Oberst,
A. Oehler, J. Ott, T. Peiffer, G. Quast, K. Rabbertz, F. Ratnikov, N. Ratnikova, S. Röcker, C. Saout,
A. Scheurer, F.-P. Schilling, M. Schmanau, G. Schott, H.J. Simonis, F.M. Stober, D. Troendle,
R. Ulrich, J. Wagner-Kuhr, T. Weiler, M. Zeise, E.B. Ziebarth

Institute of Nuclear Physics "Demokritos", Aghia Paraskevi, Greece
G. Daskalakis, T. Geralis, S. Kesisoglou, A. Kyriakis, D. Loukas, I. Manolakos, A. Markou,
C. Markou, C. Mavrommatis, E. Ntomari

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

University of Ioánnina, Ioánnina, Greece
I. Evangelou, C. Foudas[1], P. Kokkas, N. Manthos, I. Papadopoulos, V. Patras

KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
G. Bencze, C. Hajdu[1], P. Hidas, D. Horvath[17], K. Krajczar[18], B. Radics, F. Sikler[1], V. Veszpremi,
G. Vesztergombi[18]

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

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

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

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

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

Bhabha Atomic Research Centre, Mumbai, India
A. Abdulsalam, R.K. Choudhury, D. Dutta, S. Kailas, V. Kumar, A.K. Mohanty[1], L.M. Pant,
P. Shukla

Tata Institute of Fundamental Research - EHEP, Mumbai, India
T. Aziz, S. Ganguly, M. Guchait[19], A. Gurtu[20], M. Maity[21], G. Majumder, K. Mazumdar,
G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage

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

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
H. Arfaei, H. Bakhshiansohi[22], S.M. Etesami[23], A. Fahim[22], M. Hashemi, H. Hesari, A. Jafari[22],
M. Khakzad, A. Mohammadi[24], M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi,
B. Safarzadeh[25], M. Zeinali[23]

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,1], S.S. Chhibra[a,b], A. Colaleo[a], D. Creanza[a,c],
N. De Filippis[a,c,1], M. De Palma[a,b], L. Fiore[a], G. Iaselli[a,c], L. Lusito[a,b], G. Maggi[a,c],
M. Maggi[a], B. Marangelli[a,b], S. My[a,c], S. Nuzzo[a,b], N. Pacifico[a,b], A. Pompili[a,b], G. Pugliese[a,c],
G. Selvaggi[a,b], L. Silvestris[a], G. Singh[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,b], S. Braibant-Giacomelli[a,b], L. Brigliadori[a,b],
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,b,1], P. Giacomelli[a], C. Grandi[a], L. Guiducci, S. Marcellini[a],
G. Masetti[a], M. Meneghelli[a,b,1], A. Montanari[a], F.L. Navarria[a,b], F. Odorici[a], A. Perrotta[a],
F. Primavera[a,b], 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], S. Costa[a,b], R. Potenza[a,b], A. Tricomi[a,b], C. Tuve[a,b]

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], 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. Colafranceschi[26], 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,1], F. De Guio[a,b], L. Di Matteo[a,b,1], S. Fiorendi[a,b], S. Gennai[a,1], A. Ghezzi[a,b],
S. Malvezzi[a], R.A. Manzoni[a,b], A. Martelli[a,b], A. Massironi[a,b,1], 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]

INFN Sezione di Napoli [a]**, Università di Napoli "Federico II"** [b]**, Napoli, Italy**
S. Buontempo[a], C.A. Carrillo Montoya[a,1], N. Cavallo[a,27], A. De Cosa[a,b], O. Dogangun[a,b],
F. Fabozzi[a,27], A.O.M. Iorio[a,1], L. Lista[a], S. Meola[a,28], M. Merola[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,1], D. Bisello[a,b], A. Branca[a,1], R. Carlin[a,b], P. Checchia[a], T. Dorigo[a],
U. Dosselli[a], F. Gasparini[a,b], A. Gozzelino[a], K. Kanishchev[a,c], S. Lacaprara[a], I. Lazzizzera[a,c],
M. Margoni[a,b], A.T. Meneguzzo[a,b], M. Nespolo[a,1], L. Perrozzi[a], N. Pozzobon[a,b], P. Ronchese[a,b],
F. Simonetto[a,b], E. Torassa[a], M. Tosi[a,b,1], S. Vanini[a,b], P. Zotto[a,b], G. Zumerle[a,b]

INFN Sezione di Pavia [a]**, Università di Pavia** [b]**, Pavia, Italy**
M. Gabusi[a,b], S.P. Ratti[a,b], C. Riccardi[a,b], P. Torre[a,b], P. Vitulo[a,b]

INFN Sezione di Perugia [a]**, Università di Perugia** [b]**, Perugia, Italy**
G.M. Bilei[a], L. Fanò[a,b], P. Lariccia[a,b], A. Lucaroni[a,b,1], G. Mantovani[a,b], M. Menichelli[a],
A. Nappi[a,b], F. Romeo[a,b], A. Saha, A. Santocchia[a,b], S. Taroni[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], T. Boccali[a], G. Broccolo[a,c], R. Castaldi[a], R.T. D'Agnolo[a,c],
R. Dell'Orso[a], F. Fiori[a,b,1], L. Foà[a,c], A. Giassi[a], A. Kraan[a], F. Ligabue[a,c], T. Lomtadze[a],
L. Martini[a,29], A. Messineo[a,b], F. Palla[a], F. Palmonari[a], A. Rizzi[a,b], A.T. Serban[a,30], P. Spagnolo[a],
P. Squillacioti[1], 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,1], M. Diemoz[a], C. Fanelli[a,b], M. Grassi[a,1], E. Longo[a,b], P. Meridiani[a,1], F. Micheli[a,b], S. Nourbakhsh[a], G. Organtini[a,b], F. Pandolfi[a,b], R. Paramatti[a], S. Rahatlou[a,b], M. Sigamani[a], L. Soffi[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], N. Cartiglia[a], R. Castello[a,b], M. Costa[a,b], N. Demaria[a], A. Graziano[a,b], C. Mariotti[a,1], S. Maselli[a], E. Migliore[a,b], V. Monaco[a,b], M. Musich[a,1], M.M. Obertino[a,c], N. Pastrone[a], M. Pelliccioni[a], A. Potenza[a,b], A. Romero[a,b], M. Ruspa[a,c], R. Sacchi[a,b], A. Solano[a,b], A. Staiano[a], A. Vilela Pereira[a], L. Visca[a,b]

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], M. Marone[a,b,1], D. Montanino[a,b,1], A. Penzo[a], A. Schizzi[a,b]

Kangwon National University, Chunchon, Korea
S.G. Heo, T.Y. Kim, S.K. Nam

Kyungpook National University, Daegu, Korea
S. Chang, J. Chung, D.H. Kim, G.N. Kim, D.J. Kong, H. Park, S.R. Ro, D.C. Son, T. Son

Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea
J.Y. Kim, Zero J. Kim, S. Song

Konkuk University, Seoul, Korea
H.Y. Jo

Korea University, Seoul, Korea
S. Choi, D. Gyun, B. Hong, M. Jo, H. Kim, T.J. Kim, K.S. Lee, D.H. Moon, S.K. Park, E. Seo

University of Seoul, Seoul, Korea
M. Choi, S. Kang, H. Kim, J.H. Kim, C. Park, I.C. Park, S. Park, G. Ryu

Sungkyunkwan University, Suwon, Korea
Y. Cho, Y. Choi, Y.K. Choi, J. Goh, M.S. Kim, E. Kwon, B. Lee, J. Lee, S. Lee, H. Seo, I. Yu

Vilnius University, Vilnius, Lithuania
M.J. Bilinskas, I. Grigelionis, M. Janulis, A. Juodagalvis

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz, R. Lopez-Fernandez, R. Magaña Villalba, J. Martínez-Ortega, 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
D. Krofcheck

University of Canterbury, Christchurch, New Zealand
A.J. Bell, P.H. Butler, R. Doesburg, S. Reucroft, H. Silverwood

National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
M. Ahmad, M.I. Asghar, H.R. Hoorani, S. Khalid, W.A. Khan, T. Khurshid, S. Qazi, M.A. Shah, M. Shoaib

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

Soltan Institute for Nuclear Studies, Warsaw, Poland
H. Bialkowska, B. Boimska, 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, P. Bargassa, A. David, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, P. Musella, J. Seixas, J. Varela, P. Vischia

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

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

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

Institute for Theoretical and Experimental Physics, Moscow, Russia
V. Epshteyn, M. Erofeeva, V. Gavrilov, M. Kossov[1], N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, V. Stolin, E. Vlasov, A. Zhokin

Moscow State University, Moscow, Russia
A. Belyaev, E. Boos, V. Bunichev, M. Dubinin[4], L. Dudko, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, A. Markina, S. Obraztsov, M. Perfilov, S. Petrushanko, L. Sarycheva[†], V. Savrin, A. Snigirev

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

State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia
I. Azhgirey, I. Bayshev, S. Bitioukov, V. Grishin[1], V. Kachanov, D. Konstantinov, A. Korablev, V. Krychkine, V. Petrov, R. Ryutin, 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. Adzic[31], M. Djordjevic, M. Ekmedzic, D. Krpic[31], 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. Cerrada, M. Chamizo Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, 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, M.S. Soares, 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. Piedra Gomez[32], 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, S.H. Chuang, J. Duarte Campderros, M. Felcini[33], 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, T. Rodrigo, A.Y. Rodríguez-Marrero, 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, C. Bernet[5], G. Bianchi, P. Bloch, A. Bocci, A. Bonato, H. Breuker, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, D. D'Enterria, A. De Roeck, S. Di Guida, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, B. Frisch, W. Funk, G. Georgiou, M. Giffels, D. Gigi, K. Gill, D. Giordano, M. Giunta, F. Glege, R. Gomez-Reino Garrido, P. Govoni, S. Gowdy, R. Guida, M. Hansen, P. Harris, C. Hartl, J. Harvey, B. Hegner, A. Hinzmann, V. Innocente, P. Janot, K. Kaadze, E. Karavakis, K. Kousouris, P. Lecoq, P. Lenzi, C. Lourenço, T. Mäki, M. Malberti, L. Malgeri, M. Mannelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, R. Moser, M.U. Mozer, M. Mulders, E. Nesvold, M. Nguyen, T. Orimoto, L. Orsini, E. Palencia Cortezon, E. Perez, A. Petrilli, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, G. Polese, L. Quertenmont, A. Racz, W. Reece, J. Rodrigues Antunes, G. Rolandi[34], T. Rommerskirchen, C. Rovelli[35], M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas[36], D. Spiga, M. Spiropulu[4], M. Stoye, A. Tsirou, G.I. Veres[18], J.R. Vlimant, H.K. Wöhri, S.D. Worm[37], 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. Sibille[38]

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland
L. Bäni, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, Z. Chen, A. Deisher, G. Dissertori, M. Dittmar, M. Dünser, J. Eugster, K. Freudenreich, C. Grab, P. Lecomte, W. Lustermann, A.C. Marini, P. Martinez Ruiz del Arbol, N. Mohr, F. Moortgat, C. Nägeli[39], P. Nef, F. Nessi-Tedaldi, L. Pape, F. Pauss, M. Peruzzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, A. Starodumov[40], B. Stieger, M. Takahashi, L. Tauscher[†], A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, H.A. Weber, L. Wehrli

Universität Zürich, Zurich, Switzerland
E. Aguilo, C. Amsler, V. Chiochia, S. De Visscher, C. Favaro, M. Ivova Rikova, B. Millan Mejias, P. Otiougova, P. Robmann, H. Snoek, S. Tupputi, M. Verzetti

National Central University, Chung-Li, Taiwan
Y.H. Chang, K.H. Chen, A. Go, C.M. Kuo, S.W. Li, W. Lin, Z.K. Liu, Y.J. Lu, D. Mekterovic, A.P. Singh, R. Volpe, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan
P. Bartalini, P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, C. Dietz, U. Grundler, W.-S. Hou, Y. Hsiung, K.Y. Kao, Y.J. Lei, R.-S. Lu, D. Majumder, E. Petrakou, X. Shi, J.G. Shiu, Y.M. Tzeng, M. Wang

Cukurova University, Adana, Turkey
A. Adiguzel, M.N. Bakirci[41], S. Cerci[42], C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, I. Hos, E.E. Kangal, G. Karapinar, A. Kayis Topaksu, G. Onengut, K. Ozdemir, S. Ozturk[43], A. Polatoz, K. Sogut[44], D. Sunar Cerci[42], B. Tali[42], H. Topakli[41], L.N. Vergili, M. Vergili

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

Bogazici University, Istanbul, Turkey
M. Deliomeroglu, E. Gülmez, B. Isildak, M. Kaya[45], O. Kaya[45], S. Ozkorucuklu[46], N. Sonmez[47]

Istanbul Technical University, Istanbul, Turkey
K. Cankocak

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

University of Bristol, Bristol, United Kingdom
F. Bostock, J.J. Brooke, E. Clement, D. Cussans, H. Flacher, R. Frazier, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, L. Kreczko, S. Metson, D.M. Newbold[37], K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, T. Williams

Rutherford Appleton Laboratory, Didcot, United Kingdom
L. Basso[48], K.W. Bell, A. Belyaev[48], C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, J. Jackson, B.W. Kennedy, E. Olaiya, D. Petyt, B.C. Radburn-Smith, C.H. Shepherd-Themistocleous, I.R. Tomalin, W.J. Womersley

Imperial College, London, United Kingdom
R. Bainbridge, G. Ball, R. Beuselinck, O. Buchmuller, D. Colling, N. Cripps, M. Cutajar, P. Dauncey, G. Davies, M. Della Negra, W. Ferguson, J. Fulcher, D. Futyan, A. Gilbert, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, M. Jarvis, G. Karapostoli, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko[40], A. Papageorgiou, J. Pela[1], M. Pesaresi, K. Petridis, M. Pioppi[49], D.M. Raymond, S. Rogerson, N. Rompotis, A. Rose, M.J. Ryan, C. Seez, P. Sharp[†], A. Sparrow, A. Tapper, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle, T. Whyntie

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

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

The University of Alabama, Tuscaloosa, USA
C. Henderson, P. Rumerio

Boston University, Boston, USA
A. Avetisyan, T. Bose, C. Fantasia, A. Heister, J. St. John, P. Lawson, D. Lazic, J. Rohlf, D. Sperka, L. Sulak

Brown University, Providence, USA
J. Alimena, S. Bhattacharya, D. Cutts, A. Ferapontov, U. Heintz, S. Jabeen, G. Kukartsev, G. Landsberg, M. Luk, M. Narain, D. Nguyen, M. Segala, T. Sinthuprasith, T. Speer, K.V. Tsang

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

University of California, Los Angeles, Los Angeles, USA
V. Andreev, D. Cline, R. Cousins, J. Duris, S. Erhan, P. Everaerts, C. Farrell, J. Hauser, M. Ignatenko, C. Plager, G. Rakness, P. Schlein[†], J. Tucker, V. Valuev, M. Weber

University of California, Riverside, Riverside, USA
J. Babb, R. Clare, M.E. Dinardo, J. Ellison, J.W. Gary, F. Giordano, G. Hanson, G.Y. Jeng[50], H. Liu, O.R. Long, A. Luthra, H. Nguyen, S. Paramesvaran, J. Sturdy, S. Sumowidagdo, R. Wilken, S. Wimpenny

University of California, San Diego, La Jolla, USA
W. Andrews, J.G. Branson, G.B. Cerati, S. Cittolin, D. Evans, F. Golf, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, I. Macneill, B. Mangano, J. Muelmenstaedt, S. Padhi, C. Palmer, G. Petrucciani, M. Pieri, R. Ranieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech[51], F. Würthwein, A. Yagil, J. Yoo

University of California, Santa Barbara, Santa Barbara, USA
D. Barge, R. Bellan, C. Campagnari, M. D'Alfonso, T. Danielson, K. Flowers, P. Geffert, J. Incandela, C. Justus, P. Kalavase, S.A. Koay, D. Kovalskyi[1], V. Krutelyov, S. Lowette, N. Mccoll, V. Pavlunin, F. Rebassoo, J. Ribnik, J. Richman, R. Rossin, D. Stuart, W. To, C. West

California Institute of Technology, Pasadena, USA
A. Apresyan, A. Bornheim, Y. Chen, E. Di Marco, J. Duarte, M. Gataullin, Y. Ma, A. Mott, H.B. Newman, C. Rogan, 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, Y.F. Liu, M. Paulini, H. Vogel, I. Vorobiev

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

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

Fairfield University, Fairfield, USA
D. Winn

Fermi National Accelerator Laboratory, Batavia, USA
S. Abdullin, M. Albrow, J. Anderson, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, I. Bloch, K. Burkett, J.N. Butler, V. Chetluru, H.W.K. Cheung, F. Chlebana, V.D. Elvira, I. Fisk, J. Freeman, Y. Gao, D. Green, O. Gutsche, A. Hahn, J. Hanlon, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, B. Kilminster, B. Klima, S. Kunori, S. Kwan, D. Lincoln, R. Lipton, L. Lueking, J. Lykken, K. Maeshima, J.M. Marraffino, S. Maruyama, D. Mason, P. McBride, K. Mishra, S. Mrenna, Y. Musienko[52], C. Newman-Holmes, V. O'Dell, O. Prokofyev, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, P. Tan, L. Taylor, S. Tkaczyk, N.V. Tran, 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, S. Das, M. De Gruttola, G.P. Di Giovanni, D. Dobur, A. Drozdetskiy, R.D. Field, M. Fisher, Y. Fu, I.K. Furic, J. Gartner, J. Hugon, B. Kim, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypreos, J.F. Low, K. Matchev, P. Milenovic[53], G. Mitselmakher, L. Muniz, R. Remington, A. Rinkevicius, P. Sellers, N. Skhirtladze, M. Snowball, J. Yelton, M. Zakaria

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

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

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

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, O. Evdokimov, E.J. Garcia-Solis, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, F. Lacroix, M. Malek, C. O'Brien, C. Silkworth, D. Strom, N. Varelas

The University of Iowa, Iowa City, USA
U. Akgun, E.A. Albayrak, B. Bilki[54], K. Chung, W. Clarida, F. Duru, S. Griffiths, C.K. Lae, J.-P. Merlo, H. Mermerkaya[55], A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, J. Olson, Y. Onel, F. Ozok, S. Sen, E. Tiras, J. Wetzel, T. Yetkin, K. Yi

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

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

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

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

University of Maryland, College Park, USA
A. Baden, M. Boutemeur, B. Calvert, S.C. Eno, J.A. Gomez, N.J. Hadley, R.G. Kellogg, M. Kirn, T. Kolberg, Y. Lu, M. Marionneau, A.C. Mignerey, A. Peterman, K. Rossato, A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar, E. Twedt

Massachusetts Institute of Technology, Cambridge, USA
G. Bauer, J. Bendavid, W. Busza, E. Butz, I.A. Cali, M. Chan, V. Dutta, G. Gomez Ceballos, M. Goncharov, K.A. Hahn, Y. Kim, M. Klute, Y.-J. Lee, W. Li, P.D. Luckey, T. Ma, S. Nahn, C. Paus, D. Ralph, C. Roland, G. Roland, M. Rudolph, G.S.F. Stephans, F. Stöckli, K. Sumorok, K. Sung, D. Velicanu, E.A. Wenger, R. Wolf, B. Wyslouch, S. Xie, M. Yang, Y. Yilmaz, A.S. Yoon, M. Zanetti

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

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

University of Nebraska-Lincoln, Lincoln, USA
E. Avdeeva, K. Bloom, S. Bose, J. Butt, D.R. Claes, A. Dominguez, M. Eads, P. Jindal, J. Keller, I. Kravchenko, J. Lazo-Flores, 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, M. Chasco, J. Haley, D. Trocino, D. Wood, J. Zhang

Northwestern University, Evanston, USA
A. Anastassov, A. Kubik, N. Mucia, 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, A. Brinkerhoff, M. Hildreth, C. Jessop, D.J. Karmgard, J. Kolb, K. Lannon, W. Luo, S. Lynch, N. Marinelli, D.M. Morse, T. Pearson, R. Ruchti, J. Slaunwhite, N. Valls, J. Warchol, M. Wayne, M. Wolf, J. Ziegler

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

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

University of Puerto Rico, Mayaguez, USA
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, D. Benedetti, G. Bolla, D. Bortoletto, M. De Mattia, A. Everett, Z. Hu, M. Jones, O. Koybasi, M. Kress, A.T. Laasanen, N. Leonardo, V. Maroussov, P. Merkel,

D.H. Miller, N. Neumeister, I. Shipsey, D. Silvers, A. Svyatkovskiy, M. Vidal Marono, H.D. Yoo, J. Zablocki, Y. Zheng

Purdue University Calumet, Hammond, USA
S. Guragain, N. Parashar

Rice University, Houston, USA
A. Adair, C. Boulahouache, V. Cuplov, K.M. Ecklund, F.J.M. Geurts, 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, A. Garcia-Bellido, P. Goldenzweig, Y. Gotra, J. Han, A. Harel, S. Korjenevski, D.C. Miner, D. Vishnevskiy, M. Zielinski

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

Rutgers, the State University of New Jersey, Piscataway, USA
S. Arora, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Duggan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, D. Hits, A. Lath, S. Panwalkar, M. Park, R. Patel, V. Rekovic, A. Richards, J. Robles, K. Rose, S. Salur, S. Schnetzer, C. Seitz, 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
R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon[56], V. Khotilovich, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Safonov, T. Sakuma, S. Sengupta, I. Suarez, A. Tatarinov, D. Toback

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

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

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

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

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

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

2: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
3: Also at Universidade Federal do ABC, Santo Andre, Brazil
4: Also at California Institute of Technology, Pasadena, USA
5: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
6: Also at Suez Canal University, Suez, Egypt
7: Also at Zewail City of Science and Technology, Zewail, Egypt
8: Also at Cairo University, Cairo, Egypt
9: Also at British University, Cairo, Egypt
10: Also at Fayoum University, El-Fayoum, Egypt
11: Now at Ain Shams University, Cairo, Egypt
12: Also at Soltan Institute for Nuclear Studies, Warsaw, Poland
13: Also at Université de Haute-Alsace, Mulhouse, France
14: Now at Joint Institute for Nuclear Research, Dubna, Russia
15: Also at Moscow State University, Moscow, Russia
16: Also at Brandenburg University of Technology, Cottbus, Germany
17: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
18: Also at Eötvös Loránd University, Budapest, Hungary
19: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
20: Now at King Abdulaziz University, Jeddah, Saudi Arabia
21: Also at University of Visva-Bharati, Santiniketan, India
22: Also at Sharif University of Technology, Tehran, Iran
23: Also at Isfahan University of Technology, Isfahan, Iran
24: Also at Shiraz University, Shiraz, Iran
25: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Teheran, Iran
26: Also at Facoltà Ingegneria Università di Roma, Roma, Italy
27: Also at Università della Basilicata, Potenza, Italy
28: Also at Università degli Studi Guglielmo Marconi, Roma, Italy
29: Also at Università degli studi di Siena, Siena, Italy
30: Also at University of Bucharest, Bucuresti-Magurele, Romania
31: Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia
32: Also at University of Florida, Gainesville, USA
33: Also at University of California, Los Angeles, Los Angeles, USA
34: Also at Scuola Normale e Sezione dell' INFN, Pisa, Italy
35: Also at INFN Sezione di Roma; Università di Roma "La Sapienza", Roma, Italy
36: Also at University of Athens, Athens, Greece
37: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
38: Also at The University of Kansas, Lawrence, USA
39: Also at Paul Scherrer Institut, Villigen, Switzerland
40: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
41: Also at Gaziosmanpasa University, Tokat, Turkey
42: Also at Adiyaman University, Adiyaman, Turkey
43: Also at The University of Iowa, Iowa City, USA
44: Also at Mersin University, Mersin, Turkey
45: Also at Kafkas University, Kars, Turkey
46: Also at Suleyman Demirel University, Isparta, Turkey
47: Also at Ege University, Izmir, Turkey
48: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom

49: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
50: Also at University of Sydney, Sydney, Australia
51: Also at Utah Valley University, Orem, USA
52: Also at Institute for Nuclear Research, Moscow, Russia
53: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
54: Also at Argonne National Laboratory, Argonne, USA
55: Also at Erzincan University, Erzincan, Turkey
56: Also at Kyungpook National University, Daegu, Korea