Physics Letters B 769 (2017) 391–412

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Search for supersymmetry in events with photons and missing transverse energy in pp collisions at 13 TeV

The CMS Collaboration *

CERN, Switzerland

ARTICLE INFO

Article history:
Received 20 November 2016
Received in revised form 5 April 2017
Accepted 5 April 2017
Available online 7 April 2017
Editor: M. Doser

Keywords:
CMS
Physics
Supersymmetry
Photons and missing transverse energy

ABSTRACT

The results of a search for new physics in final states with photons and missing transverse energy are reported. The study is based on a sample of proton–proton collisions collected at a center-of-mass energy of 13 TeV with the CMS detector in 2015, corresponding to an integrated luminosity of 2.3 fb^{-1}. Final states with two photons and significant missing transverse energy are used to search for supersymmetric particles in models of supersymmetry (SUSY) with general gauge-mediated (GGM) supersymmetry breaking. No excess is observed with respect to the standard model expectation, and the results are used to set limits on gluino pair production and squark pair production in the GGM SUSY framework. Gluino masses below 1.65 TeV and squark masses below 1.37 TeV are excluded at a 95% confidence level.

1. Introduction

Final states in proton–proton collisions containing photons with high transverse momentum p_T and significant missing transverse energy $E_\mathrm{T}^\mathrm{miss}$ emerge naturally from a variety of new-physics scenarios, particularly in models of supersymmetry (SUSY) broken via gauge mediation that require a stable, weakly interacting lightest supersymmetric particle (LSP) [1–6]. The $E_\mathrm{T}^\mathrm{miss}$ in an event, defined as the magnitude of the vector sum of the transverse momenta of all visible particles, is a consequence of undetected particles such as neutrinos or LSPs. Models with general gauge mediation (GGM) [7–14] can have a wide range of features, but typically entail a nearly massless gravitino LSP, $\widetilde{\mathrm{G}}$, and a next-to-lightest supersymmetric particle (NLSP) often taken to be a neutralino $\widetilde{\chi}_1^0$. Photons in the final state arise when the neutralino decays to a gravitino and a photon, $\widetilde{\chi}_1^0 \to \widetilde{\mathrm{G}}\gamma$.

In this Letter we present a search for GGM SUSY in final states involving two photons and significant $E_\mathrm{T}^\mathrm{miss}$. The data sample, corresponding to an integrated luminosity of 2.3 fb^{-1} of proton–proton collisions at $\sqrt{s} = 13$ TeV, was collected with the CMS detector at the CERN LHC in 2015. The increased center-of-mass energy substantially improves the sensitivity of the analysis compared to searches performed at the LHC in Run 1 at $\sqrt{s} = 8$ TeV [15,16]. A similar analysis was performed by the ATLAS Collaboration at $\sqrt{s} = 13$ TeV [17]. For the interpretation of the results we use the T5gg and T6gg simplified models [18]. The T5gg (T6gg) simplified model assumes gluino $\widetilde{\mathrm{g}}$ (squark $\widetilde{q}$) pair production, with subsequent decays as shown in Fig. 1. The branching fraction of the NLSP neutralino to decay to a gravitino and a photon, $\widetilde{\chi}_1^0 \to \widetilde{\mathrm{G}}\gamma$, resulting in characteristic events with two photons and large $E_\mathrm{T}^\mathrm{miss}$, is assumed to be unity. In more general GGM SUSY models, a bino-like neutralino could also decay to a gravitino and a Z boson, $\widetilde{\chi}_1^0 \to \widetilde{\mathrm{G}}\mathrm{Z}$.

Events with two photons and $E_\mathrm{T}^\mathrm{miss}$ can also arise from several standard model (SM) processes, including direct diphoton production with initial-state radiation and multijet events (possibly with associated photon production). These processes lack intrinsic $E_\mathrm{T}^\mathrm{miss}$ but can emulate the signal if the hadronic activity in the event is mismeasured. In the latter case, photons may be reconstructed in the event as a result of the misidentification of electromagnetically rich jets. A smaller background comes from events with intrinsic $E_\mathrm{T}^\mathrm{miss}$, principally $\mathrm{W}\gamma$ and W+jet production, where an electron is misidentified as a photon in $\mathrm{W} \to \mathrm{e}\nu$ decays.

2. Detector, data, and simulated samples

The data were collected with the CMS detector in 2015. The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker covering the pseudorapidity region $|\eta| < 2.5$, as well as a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter (HCAL), each composed of a barrel and

---

* *E-mail address:* cms-publication-committee-chair@cern.ch.

http://dx.doi.org/10.1016/j.physletb.2017.04.005

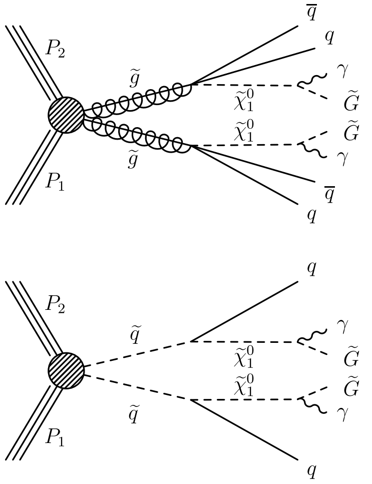

Fig. 1. Diagrams showing the production of signal events in the collision of two protons with four momenta P_1 and P_2. In gluino $\tilde{g}$ pair production in the T5gg simplified model (top), the gluino decays to an antiquark $\bar{q}$, quark q, and neutralino $\tilde{\chi}_1^0$. In squark $\tilde{q}$ pair production in the T6gg simplified model (bottom), the squark decays to a quark and a neutralino. In both cases, the neutralino subsequently decays to a photon γ and a gravitino $\tilde{G}$. In the second diagram, we do not distinguish between squarks and antisquarks.

two endcap sections and covering the range $|\eta| < 3.0$. Forward calorimeters extend the coverage up to $|\eta| < 5.0$. Muons are measured in gas-ionization detectors embedded in the iron flux-return yoke outside the solenoid and cover the range $|\eta| < 2.4$. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in Ref. [19].

The data used in this analysis were selected with a diphoton trigger requiring a leading photon with $p_T > 30$ GeV and a subleading photon with $p_T > 18$ GeV. In order to keep the trigger rate low and to exclude $Z \to ee$ events, a combined invariant mass $M_{\gamma\gamma} > 95$ GeV was also required. In addition, the photons were required to pass isolation and cluster shape requirements. A sample of $Z \to ee$ events for additional studies was collected with a trigger nearly identical to the diphoton trigger, but with an invariant mass requirement $M_{ee} > 70$ GeV and with the additional requirement that both electromagnetic (EM) objects be matched to a pixel detector seed (at least two measurements in the pixel detector consistent with a track from a charged particle).

Monte Carlo simulations of the signal and background processes are used to validate the performance of the analysis and determine signal efficiencies, as well as to determine the contributions of some of the smaller backgrounds, as described in Section 4. The leading-order event generator MadGraph 5.1.3.30 [20] is used to simulate the signal samples, which were generated with either two gluinos or two squarks and up to two additional partons in the matrix element calculation. The parton showering, hadronization, multiple-parton interactions, and the underlying event were described by the pythia8 [21] event generator. The parton distribution functions are obtained from NNPDF3.0 [22]. For the background processes, the detector response is simulated using Geant4 [23], while the CMS fast simulation [24] is used for the signal events.

The signal events were generated using the T5gg and T6gg simplified models and are characterized by the masses of the particles in the decay chain. For the gluino (squark) mass we simulate a range of values from 1.0 to 1.8 TeV (1.2 to 2.0 TeV) in steps of 50 GeV. These mass ranges were selected to overlap and expand upon the mass ranges excluded by previous searches [15–17]. For each gluino (squark) mass, the $\tilde{\chi}_1^0$ mass ranges from 100 GeV to 1.9 TeV in 100 GeV increments, with the requirement that $M_{\tilde{\chi}_1^0} < M_{\tilde{g}}$ ($M_{\tilde{\chi}_1^0} < M_{\tilde{q}}$). We assume branching fractions of unity for the decays $\tilde{g} \to qq\tilde{\chi}_1^0$, $\tilde{q} \to q\tilde{\chi}_1^0$ and $\tilde{\chi}_1^0 \to \tilde{G}\gamma$. For the T6gg model, the gluino mass is set to 10 TeV, and t-channel production is not considered.

The production cross sections for these processes are calculated as functions of $M_{\tilde{g}}$ and $M_{\tilde{q}}$ at next-to-leading-order (NLO) accuracy including the resummation of soft gluon emission at next-to-leading-logarithmic (NLL) accuracy [25,26], and the uncertainties are calculated as described in Ref. [27].

3. Event selection

Photon, electron, muon, charged hadron, and neutral hadron candidates are reconstructed with the particle-flow (PF) algorithm [28,29], which reconstructs particles produced in a collision based on information from all detector subsystems. Photons are reconstructed from energy deposits in the ECAL. We require the shape of ECAL clusters to be consistent with that of an electromagnetic object, and we require that the energy present in the corresponding region of the HCAL not exceed 5% of the ECAL energy, as electromagnetic showers are expected to be contained almost entirely within the ECAL. In order to ensure that the photons pass the trigger with high efficiency, all photons are required to satisfy $E_T > 40$ GeV. Because the SUSY signal models used in this analysis produce photons primarily in the central region of the detector and because the magnitude of the background increases considerably at high $|\eta|$, we consider only photons within the barrel fiducial region of the detector ($|\eta| < 1.44$).

To suppress photon candidates originating from quark and gluon jets, photons are required to be isolated from other reconstructed particles. Separate requirements are made on the scalar p_T sums of charged hadrons, neutral hadrons, and electromagnetic objects in a cone of radius $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.3$ (where ϕ is the azimuthal angle measured in radians) around the photon candidate. Each momentum sum is corrected for the effect of additional proton–proton collisions in the event (pileup), and in each case the momentum of the photon candidate itself is excluded. We further require that the photon candidate have no pixel track seed, to distinguish the candidate from an electron.

Due to the similarity of the ECAL response to electrons and photons, $Z \to ee$ events are used to measure the photon identification efficiency. The selection of electron candidates is identical to that of photons, with the exception that the candidate is required to be matched to a pixel seed consistent with a track, to ensure that the selection is orthogonal to that of photons. The photon efficiency is measured via the tag-and-probe method [30] in both data and simulation. The ratio of the efficiency in data and simulation was measured as a function of the p_T and η of the electron and the ΔR separation between the electron and the nearest jet. It is determined that this ratio does not depend significantly on any measured kinematic variables, and the overall ratio is computed to be $\epsilon_e^{data}/\epsilon_e^{sim} = 0.983 \pm 0.012$.

Muon candidates, which are included among the objects counted in the photon isolation requirement, are reconstructed by performing a global fit that requires consistent hit patterns in the tracker and the muon system [31]. We require muons to have $p_T > 30$ GeV and to satisfy track quality and isolation requirements. Photons and electrons that overlap within $\Delta R < 0.3$ of any muons are rejected, but otherwise no requirement is made on the number of muons in the event. In addition, photons must be separated by $\Delta R > 0.3$ from electrons.

Jets are reconstructed from PF candidates using the anti-k_T clustering algorithm [32] with a distance parameter of 0.4. The jet energy and momentum are corrected both for the nonlinear response of the detector and for the effect of pileup via the procedure described in Ref. [33]. Jets are required to have corrected $p_T > 30$ GeV and to be reconstructed within $|\eta| < 2.4$. In addition, jets are required to be separated from other objects in the event by $\Delta R > 0.4$.

For the purpose of defining the various control regions used in the analysis, we apply an additional set of selection criteria. Misidentified photons are defined as those photon candidates passing the photon selection but failing either the shape requirement for the ECAL clusters or the charged-hadron isolation requirement, but not both. In order to ensure that misidentified photons do not differ too much from our photon selection, upper limits are applied to both the charged-hadron isolation and cluster shape requirements.

Events are then sorted into one of four mutually exclusive categories depending on the selection of their highest-p_T electromagnetic objects: $\gamma\gamma$, ee, two misidentified ("fake") photons (ff), and eγ. Due to the trigger requirements described in Section 2, the invariant mass of the two electromagnetic objects is required to be greater than 105 GeV. The size of the data sample limits any improvements in the sensitivity of the analysis from categorizing events by jet multiplicity. Therefore, no requirements are made on the number of jets in the event.

The signal region is defined by the events in the $\gamma\gamma$ category with $E_T^{miss} \geq 100$ GeV and is split into four bins: $100 \leq E_T^{miss} < 110$ GeV, $110 \leq E_T^{miss} < 120$ GeV, $120 \leq E_T^{miss} < 140$ GeV, and $E_T^{miss} \geq 140$ GeV. The bins are chosen in such a way that there is a sufficient amount of data in each bin in the ee and ff control samples used for background estimation. The bin with $E_T^{miss} < 100$ GeV is used as a control region.

4. Estimation of backgrounds

The dominant background for this analysis comes from multijet production from quantum chromodynamics (QCD) processes without intrinsic E_T^{miss}, where the high-E_T^{miss} signature is mimicked by the mismeasurement of the hadronic activity in the event. A subdominant contribution comes from electroweak (EWK) processes that include intrinsic E_T^{miss} from neutrino production.

The contribution from the QCD background is modeled in a fully data-driven way from the ee and ff control samples. Both of these control samples are dominated by processes without intrinsic E_T^{miss} and can therefore be used to model the E_T^{miss} in the QCD background. These control samples differ in hadronic activity from the candidate $\gamma\gamma$ sample due to different event topologies. In particular, the ee control sample has a large contribution from $Z \to ee$ events, where the electromagnetic objects come from one parent particle. In contrast, the ff control samples are primarily multijet events where the two electromagnetic objects are produced independently. To account for this difference, the di-EM p_T variable, defined as the magnitude of the vector sum of the transverse momenta of the two electromagnetic objects, is used to model the hadronic recoil in the event. Events in the ee and ff control samples are reweighted by the di-EM p_T distribution of the $\gamma\gamma$ events to correct for any differences in hadronic recoil. The E_T^{miss} distributions of these di-EM p_T reweighted control samples are then normalized to that of the $\gamma\gamma$ sample in the region $E_T^{miss} < 50$ GeV and used to predict the contribution of QCD processes to the high-E_T^{miss} signal region. A comparison of the reweighted E_T^{miss} distributions to the distribution of $\gamma\gamma$ events is shown in Fig. 2 in the sideband of the search region ($E_T^{miss} < 100$ GeV). There is an agreement within statistical uncertainties between the $\gamma\gamma$ and each of the reweighted distributions.

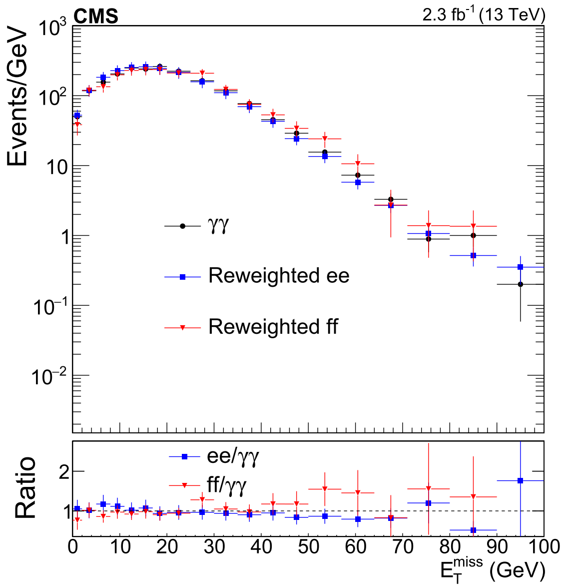

Fig. 2. The E_T^{miss} distributions of the candidate $\gamma\gamma$, reweighted ee, and reweighted ff samples in the $E_T^{miss} < 100$ GeV sideband.

Similarly, we consider differences in the E_T^{miss} distribution due to the number of jets in the event. A direct comparison of the candidate sample and the two control samples shows little dependence on the jet multiplicity N_{jets} at low E_T^{miss}, so we take the difference as a systematic uncertainty in the prediction, as described in Section 5.

In addition, there is a small contribution in the QCD control samples from comparatively rare processes with intrinsic E_T^{miss}, including $t\bar{t}$ events and $Z \to \overline{\nu} +$ jets events. Due to their small cross sections, these processes are estimated with simulation, and their contributions are subtracted from the ee and ff control samples for the final prediction.

The primary estimate of the QCD contribution comes from the reweighted ee distribution. The reweighted ff control sample serves as a cross-check, and the difference between them is taken as a symmetric systematic uncertainty on the prediction. Due to the limited number of ff events with $E_T^{miss} > 100$ GeV, a looser misidentification definition is used. In the looser definition, misidentified photons are not required to pass any photon isolation or neutral-hadron isolation cuts, and the upper limits on charged-hadron isolation and the shape requirement for the ECAL clusters are loosened further. The looser ff sample is used to obtain the shape of the ff distribution in the $E_T^{miss} > 100$ GeV signal region, while the normalization comes from the tighter, more photon-like misidentification definition.

As an additional cross-check on this background estimation method, the ratio of the candidate $\gamma\gamma$ distribution to the unweighted ff distribution as a function of E_T^{miss} is fit with different functional forms. The predicted number of QCD background events in each E_T^{miss} bin is then given by the function multiplied by the number of ff events seen in that bin. The primary prediction from the ee sample is consistent with the prediction from this cross-check within the fit uncertainties, and we conclude that the predictions from these two methods are compatible.

The electroweak background comes from Wγ events where the W decays to an electron and a neutrino, and the electron is misidentified as a photon. We estimate this misidentification rate by comparing the Z-boson mass peak in the ee invariant mass spectrum to the peak in the eγ spectrum. The data are modeled using an extended likelihood fit to the mass spec-

Table 1
Systematic uncertainties from the QCD background estimation.

E_T^{miss} bin (GeV)	Di-EM p_T reweighting	Jet multiplicity reweighting	Shape difference between ee and ff	Statistical uncertainty of ee sample
$100 \le E_T^{miss} < 110$	15%	34%	18%	31%
$110 \le E_T^{miss} < 120$	17%	15%	12%	33%
$120 \le E_T^{miss} < 140$	33%	29%	14%	42%
$E_T^{miss} \ge 140$	39%	20%	150%	71%

trum for the signal plus background hypothesis. The misidentification rate $f_{e\to\gamma}$ is then computed from the signal events as $f_{e\to\gamma} = N_{e\gamma}/(2N_{ee} + N_{e\gamma}) = (2.13 \pm 0.21)\%$. This rate is used to compute a scaling factor $f_{e\to\gamma}/(1 - f_{e\to\gamma})$, which is then applied to the sample of eγ events with $E_T^{miss} > 100$ GeV to obtain an estimate of the electroweak background in the signal region.

5. Sources of systematic uncertainty

We evaluate systematic uncertainties from each of the background predictions, the signal efficiency, and the integrated luminosity. For each source of uncertainty, we give the uncertainty value and describe the method used for its estimation.

The largest systematic uncertainties come from the QCD background estimation method. We consider three sources of systematic uncertainty from the QCD background estimate: the di-EM p_T reweighting, the jet multiplicity dependence, and the E_T^{miss} shape difference between the ee and ff control samples. The magnitudes of these uncertainties for each of the E_T^{miss} bins in the signal region are shown in Table 1.

The uncertainty from di-EM p_T reweighting is estimated from the distributions of the di-EM p_T ratio in simulated pseudo-experiments, allowing the ratio to vary bin by bin according to a Gaussian distribution with a standard deviation computed from the statistical uncertainty of unweighted events in the bin. The E_T^{miss} distribution of the ee control sample is then reweighted by each of these distributions, and the standard deviation is determined for the prediction. The magnitude of this uncertainty ranges from 15% to 39%.

The effect of the difference in the E_T^{miss} distribution as a function of the jet multiplicity is determined directly by taking the difference between the ee estimate with di-EM p_T and N_{jets} reweighting and with di-EM p_T reweighting alone. The resulting systematic uncertainty ranges from 15% to 34% in the four signal E_T^{miss} bins. The shape uncertainty of the ee control sample is determined by fitting the high-E_T^{miss} tails of the ee and ff samples to the empirical three-parameter function $\mathrm{d}N/\mathrm{d}E_T^{miss} = (E_T^{miss})^{p_0} \mathrm{e}^{p_1 (E_T^{miss})^{p_2}}$. The systematic uncertainty in the shape is symmetric and taken to be the fractional difference in each E_T^{miss} bin between these fitted functions. This yields a systematic effect between 12% and 18% in the lower three E_T^{miss} signal bins, and a systematic effect of 150% in the final bin that covers E_T^{miss} above 140 GeV.

The main source of uncertainty in the electroweak background estimate comes from the uncertainty in the extended likelihood fit used to calculate the misidentification rate. This is computed by shifting the rate up and down by its uncertainty and scaling the E_T^{miss} distribution of the eγ control sample by the altered rates. The difference between the estimates from the two shifted misidentification rates gives the systematic uncertainty in the rate of electroweak events. Because this represents an uncertainty in the overall normalization, it is constant across E_T^{miss} bins. The uncertainty is a constant 19% across the E_T^{miss} bins.

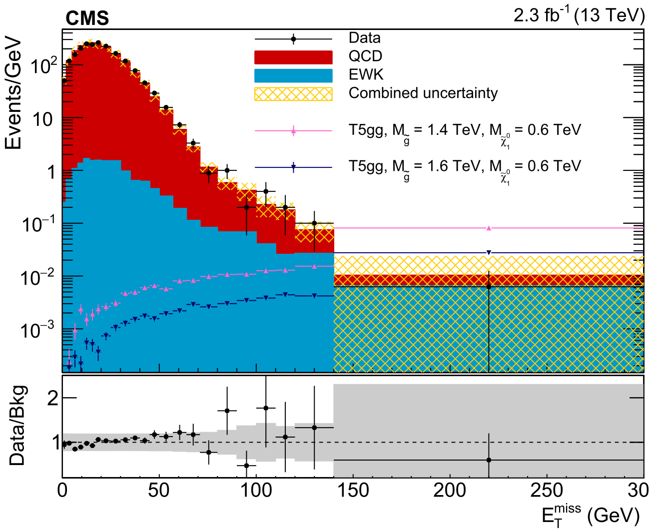

Fig. 3. Measured E_T^{miss} distribution in comparison with the background prediction. The four bins with $E_T^{miss} \ge 100$ GeV constitute the signal region, and the $E_T^{miss} < 100$ GeV bins serve mainly to normalize the background. The systematic uncertainty on the background prediction and the ratio of the data to the prediction are also shown. The last bin includes all events with $E_T^{miss} \ge 140$ GeV, but for normalization by bin width, the bin is taken to be from $140 \le E_T^{miss} < 300$ GeV. The distributions for two signal model points are overlaid for comparison.

The signal efficiency uncertainties are related to the statistical uncertainty from the finite size of the T5gg and T6gg signal samples (0–16%), knowledge of the jet energy scale (0–23% depending on the $\tilde{g}$–$\tilde{\chi}_1^0$ mass difference), parton distribution function uncertainties (13–22% depending on the signal point), and photon identification and reconstruction efficiencies (2%). The uncertainty related to the integrated luminosity of the data sample is 2.7% [34].

6. Results

The measured E_T^{miss} distribution and corresponding background predictions are shown in Fig. 3. The expected number of events from the QCD and EWK backgrounds, as well as the total number of expected and observed events, are shown in Table 2 for each bin in the signal region. We observe 9 events total in the signal region, compared to an expected background of 7.2 ± 2.5 events. The number of events in the signal region agrees with the background estimate within the uncertainties.

We determine 95% confidence level (CL) upper limits on gluino pair and squark pair production cross sections using the modified frequentist CL$_s$ method [35,36] based on a log-likelihood test statistic that compares the likelihood of the SM-only hypothesis to the likelihood of the presence of a signal in addition to the SM contributions. The likelihood function is constructed from the background and signal E_T^{miss} distributions across the four bins described in Section 3. The systematic uncertainties described in Sec-

Table 2

Numbers of expected and observed events in the signal region. The last row shows the total number of expected and observed events in the inclusive bin $E_T^{\text{miss}} \geq 100$ GeV. The expected numbers of events for two T5gg mass points are also shown. For Signal A, $M_{\tilde{g}} = 1400$ GeV and $M_{\tilde{\chi}_1^0} = 600$ GeV. For Signal B, $M_{\tilde{g}} = 1600$ GeV and $M_{\tilde{\chi}_1^0} = 600$ GeV. The uncertainties include all of the systematic uncertainties described in Section 5.

E_T^{miss} bin (GeV)	QCD	EWK	Total background	Signal A	Signal B	Observed
$100 \leq E_T^{\text{miss}} < 110$	1.9±1.0	0.4±0.1	2.3±1.0	0.12±0.01	0.04±0.01	4
$110 \leq E_T^{\text{miss}} < 120$	1.5±0.6	0.3±0.1	1.8±0.6	0.13±0.02	0.04±0.01	2
$120 \leq E_T^{\text{miss}} < 140$	1.0±0.6	0.5±0.2	1.5±0.6	0.31±0.04	0.08±0.01	2
$E_T^{\text{miss}} \geq 140$	0.6±2.2	1.0±0.3	1.6±2.2	13.0±0.7	4.4±0.2	1
$E_T^{\text{miss}} \geq 100$	5.0±2.5	2.2±0.3	7.2±2.5	13.6±0.7	4.6±0.2	9

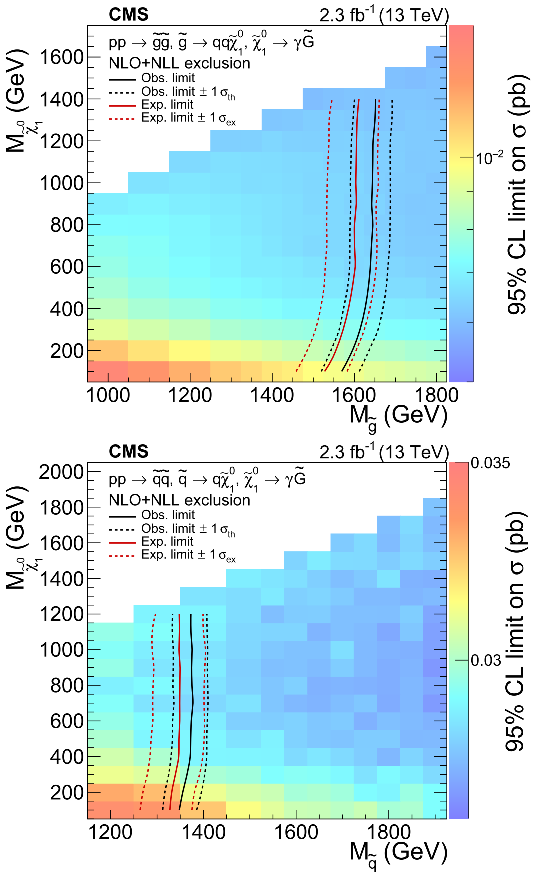

Fig. 4. The 95% CL upper limits on the gluino (top) and squark (bottom) pair production cross sections as a function of neutralino versus gluino (squark) mass. The contours show the observed and median expected exclusions assuming the NLO+NLL cross sections, with their one standard deviation uncertainties. The limit curves terminate at the centers of the bins used to sample the cross section.

tion 5 are included in the test statistic as nuisance parameters, with log-normal probability distributions.

In Fig. 4 we present 95% CL upper limits on the cross section as a function of the mass pair values for the two models considered in this analysis, $M_{\tilde{\chi}_1^0}$ versus $M_{\tilde{g}}$ and $M_{\tilde{\chi}_1^0}$ versus $M_{\tilde{q}}$ for gluino pair and squark pair production, respectively. From the NLO+NLL predicted cross sections and their uncertainties we derive contours representing lower limits in the SUSY mass plane. We also show expected limit contours based on the expected experimental cross section limits and their uncertainties. For typical values of the neutralino mass, we expect to exclude gluino masses up to 1.60 TeV and squark masses up to 1.35 TeV, and we observe exclusions of 1.65 and 1.37 TeV respectively. The excluded mass ranges for gluino pair production have been improved by approximately 300 GeV with respect to previous searches performed at $\sqrt{s} = 8$ TeV [15,16]. The observed exclusions are consistent with the results of the ATLAS analysis performed at $\sqrt{s} = 13$ TeV [17].

7. Summary

A search is performed for supersymmetry with general gauge mediation in proton–proton collisions yielding events with two photons and large missing transverse energy. The data were collected at a center-of-mass energy of 13 TeV with the CMS detector in 2015, and correspond to an integrated luminosity of 2.3 fb^{-1}.

The data are interpreted in the context of two simplified SUSY models with gauge-mediated supersymmetry breaking, one assuming gluino pair production and the second assuming squark pair production. In both models, the branching fraction of the NLSP neutralino to decay to a gravitino and a photon is assumed to be unity. Using background estimation methods based on control samples in data, limits are determined on the gluino and squark pair production cross sections, and those limits are used together with NLO+NLL cross section calculations to constrain the masses of gluinos, squarks, and neutralinos. Gluino masses below 1.65 TeV and squark masses below 1.37 TeV are excluded at a 95% confidence level. This represents an improvement of approximately 300 GeV with respect to previous analyses performed at a center-of-mass energy of 8 TeV [15,16] and is consistent with the results of the ATLAS analysis performed at a center-of-mass energy of 13 TeV [17].

Acknowledgements

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centres and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: BMWFW and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES and CSF (Croatia); RPF (Cyprus); SENESCYT (Ecuador); MoER, ERC IUT, and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); LAS (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and UASLP-FAI (Mexico); MBIE (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS, and RFBR (Russia); MESTD (Serbia); SEIDI and CPAN (Spain); Swiss Funding Agencies (Switzerland); MST (Taipei); ThEPCenter, IPST, STAR, and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU and SFFR (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

Individuals have received support from the Marie-Curie programme and the European Research Council and EPLANET (European Union); the Leventis Foundation; the A.P. Sloan Foundation; the Alexander von Humboldt Foundation; the Belgian Federal Science Policy Office; the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA-Belgium); the Agentschap voor Innovatie door Wetenschap en Technologie (IWT-Belgium); the Ministry of Education, Youth and Sports (MEYS) of the Czech Republic; the Council of Science and Industrial Research, India; the HOMING PLUS programme of the Foundation for Polish Science, cofinanced from European Union, Regional Development Fund, the Mobility Plus programme of the Ministry of Science and Higher Education, the National Science Center (Poland), contracts Harmonia 2014/14/M/ST2/00428, Opus 2013/11/B/ST2/04202, 2014/13/B/ST2/02543 and 2014/15/B/ST2/03998, Sonata-bis 2012/07/E/ST2/01406; the Thalis and Aristeia programmes cofinanced by EU-ESF and the Greek NSRF; the National Priorities Research Program by Qatar National Research Fund; the Programa Clarín-COFUND del Principado de Asturias; the Rachadapisek Sompot Fund for Postdoctoral Fellowship, Chulalongkorn University and the Chulalongkorn Academic into Its 2nd Century Project Advancement Project (Thailand); and the Welch Foundation, contract C-1845.

References

[1] C.R. Nappi, B.A. Ovrut, Supersymmetric extension of the su(3)×su(2)×u(1) model, Phys. Lett. B 113 (1982) 175, http://dx.doi.org/10.1016/0370-2693(82)90418-X.

[2] M. Dine, W. Fischler, A phenomenological model of particle physics based on supersymmetry, Phys. Lett. B 110 (1982) 227, http://dx.doi.org/10.1016/0370-2693(82)91241-2.

[3] L. Alvarez-Gaumé, M. Claudson, M.B. Wise, Low-energy supersymmetry, Nucl. Phys. B 207 (1982) 96, http://dx.doi.org/10.1016/0550-3213(82)90138-9.

[4] M. Dine, A.E. Nelson, Dynamical supersymmetry breaking at low-energies, Phys. Rev. D 48 (1993) 1277, http://dx.doi.org/10.1103/PhysRevD.48.1277, arXiv:hep-ph/9303230.

[5] M. Dine, A.E. Nelson, Y. Shirman, Low-energy dynamical supersymmetry breaking simplified, Phys. Rev. D 51 (1995) 1362, http://dx.doi.org/10.1103/PhysRevD.51.1362, arXiv:hep-ph/9408384.

[6] M. Dine, A.E. Nelson, Y. Nir, Y. Shirman, New tools for low-energy dynamical supersymmetry breaking, Phys. Rev. D 53 (1996) 2658, http://dx.doi.org/10.1103/PhysRevD.53.2658, arXiv:hep-ph/9507378.

[7] S. Dimopoulos, G.F. Giudice, A. Pomarol, Dark matter in theories of gauge-mediated supersymmetry breaking, Phys. Lett. B 389 (1996) 37, http://dx.doi.org/10.1016/S0370-2693(96)01241-5, arXiv:hep-ph/9607225.

[8] S.P. Martin, Generalized messengers of supersymmetry breaking and the sparticle mass spectrum, Phys. Rev. D 55 (1997) 3177, http://dx.doi.org/10.1103/PhysRevD.55.3177, arXiv:hep-ph/9608224.

[9] E. Poppitz, S.P. Trivedi, Some remarks on gauge-mediated supersymmetry breaking, Phys. Lett. B 401 (1997) 38, http://dx.doi.org/10.1016/S0370-2693(97)00367-5, arXiv:hep-ph/9703246.

[10] P. Meade, N. Seiberg, D. Shih, General gauge mediation, Prog. Theor. Phys. Suppl. 177 (2009) 143, http://dx.doi.org/10.1143/PTPS.177.143, arXiv:0801.3278.

[11] M. Buican, P. Meade, N. Seiberg, D. Shih, Exploring general gauge mediation, J. High Energy Phys. 03 (2009) 016, http://dx.doi.org/10.1088/1126-6708/2009/03/016, arXiv:0812.3668.

[12] S. Abel, M.J. Dolan, J. Jaeckel, V.V. Khoze, Phenomenology of pure general gauge mediation, J. High Energy Phys. 12 (2009) 001, http://dx.doi.org/10.1088/1126-6708/2009/12/001, arXiv:0910.2674.

[13] L.M. Carpenter, M. Dine, G. Festuccia, J.D. Mason, Implementing general gauge mediation, Phys. Rev. D 79 (2009) 035002, http://dx.doi.org/10.1103/PhysRevD.79.035002, arXiv:0805.2944.

[14] T.T. Dumitrescu, Z. Komargodski, N. Seiberg, D. Shih, General messenger gauge mediation, J. High Energy Phys. 05 (2010) 96, http://dx.doi.org/10.1007/JHEP05(2010)096, arXiv:1003.2661.

[15] ATLAS Collaboration, Search for photonic signatures of gauge-mediated supersymmetry in 8 TeV *pp* collisions with the ATLAS detector, Phys. Rev. D 92 (2015) 072001, http://dx.doi.org/10.1103/PhysRevD.92.072001, arXiv:1507.05493.

[16] CMS Collaboration, Search for supersymmetry with photons in *pp* collisions at $\sqrt{s} = 8$ TeV, Phys. Rev. D 92 (2015) 072006, http://dx.doi.org/10.1103/PhysRevD.92.072006, arXiv:1507.02898.

[17] ATLAS Collaboration, Search for supersymmetry in a final state containing two photons and missing transverse momentum in $\sqrt{s} = 13$ TeV *pp* collisions at the LHC using the ATLAS detector, Eur. Phys. J. C 76 (2016) 517, http://dx.doi.org/10.1140/epjc/s10052-016-4344-x, arXiv:1606.09150.

[18] CMS Collaboration, Interpretation of searches for supersymmetry with simplified models, Phys. Rev. D 88 (2013) 052017, http://dx.doi.org/10.1103/PhysRevD.88.052017.

[19] CMS Collaboration, The CMS experiment at the CERN LHC, J. Instrum. 3 (2008) S08004, http://dx.doi.org/10.1088/1748-0221/3/08/S08004.

[20] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H.S. Shao, T. Stelzer, P. Torrielli, M. Zaro, The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations, J. High Energy Phys. 07 (2014) 079, http://dx.doi.org/10.1007/JHEP07(2014)079, arXiv:1405.0301.

[21] T. Sjöstrand, S. Mrenna, P.Z. Skands, A brief introduction to PYTHIA 8.1, Comput. Phys. Commun. 178 (2008) 852, http://dx.doi.org/10.1016/j.cpc.2008.01.036, arXiv:0710.3820.

[22] R.D. Ball, et al., NNPDF, Parton distributions for the LHC Run II, J. High Energy Phys. 04 (2015) 040, http://dx.doi.org/10.1007/JHEP04(2015)040, arXiv:1410.8849.

[23] S. Agostinelli, et al., GEANT4, GEANT4—a simulation toolkit, Nucl. Instrum. Methods A 506 (2003) 250, http://dx.doi.org/10.1016/S0168-9002(03)01368-8.

[24] CMS Collaboration, The fast simulation of the CMS detector at LHC, J. Phys. Conf. Ser. 331 (2011) 032049, http://dx.doi.org/10.1088/1742-6596/331/3/032049.

[25] A. Kulesza, L. Motyka, Soft gluon resummation for the production of gluino-gluino and squark–antisquark pairs at the LHC, Phys. Rev. D 80 (2009) 095004, http://dx.doi.org/10.1103/PhysRevD.80.095004, arXiv:0905.4749.

[26] W. Beenakker, S. Brensing, M. Krämer, A. Kulesza, E. Laenen, I. Niessen, Soft-gluon resummation for squark and gluino hadroproduction, J. High Energy Phys. 12 (2009) 041, http://dx.doi.org/10.1088/1126-6708/2009/12/041, arXiv:0909.4418.

[27] C. Borschensky, M. Krämer, A. Kulesza, M. Mangano, S. Padhi, T. Plehn, X. Portell, Squark and gluino production cross sections in *pp* collisions at $\sqrt{s} =$ 13, 14, 33 and 100 TeV, Eur. Phys. J. C 74 (2014) 3174, http://dx.doi.org/10.1140/epjc/s10052-014-3174-y, arXiv:1407.5066.

[28] CMS Collaboration, Particle–flow event reconstruction in CMS and performance for jets, taus, and $E_{\mathrm{T}}^{\mathrm{miss}}$, CMS Physics Analysis Summary CMS-PAS-PFT-09-001, 2009. URL: http://cdsweb.cern.ch/record/1194487.

[29] CMS Collaboration, Commissioning of the particle-flow event reconstruction with the first LHC collisions recorded in the CMS detector, CMS Physics Analysis Summary CMS-PAS-PFT-10-001, 2010. URL: http://cdsweb.cern.ch/record/1247373.

[30] CMS Collaboration, Performance of photon reconstruction and identification with the CMS detector in proton–proton collisions at $\sqrt{s} = 8$ TeV, J. Instrum. 10 (2015) P08010, http://dx.doi.org/10.1088/1748-0221/10/08/P08010, arXiv:1502.02702.

[31] CMS Collaboration, Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7$ TeV, J. Instrum. 7 (2012) P10002, http://dx.doi.org/10.1088/1748-0221/7/10/P10002, arXiv:1206.4071.

[32] M. Cacciari, G.P. Salam, G. Soyez, The anti-k_t jet clustering algorithm, J. High Energy Phys. 04 (2008) 063, http://dx.doi.org/10.1088/1126-6708/2008/04/063, arXiv:0802.1189.

[33] CMS Collaboration, Determination of jet energy calibration and transverse momentum resolution in CMS, J. Instrum. 6 (2011) P11002, http://dx.doi.org/10.1088/1748-0221/6/11/P11002.

[34] CMS Collaboration, CMS luminosity measurement for the 2015 data taking period, CMS Physics Analysis Summary CMS-PAS-LUM-15–001, 2016. URL: https://cds.cern.ch/record/2138682.

[35] T. Junk, Confidence level computation for combining searches with small statistics, Nucl. Instrum. Methods A 434 (1999) 435, http://dx.doi.org/10.1016/S0168-9002(99)00498-2, arXiv:hep-ex/9902006.

[36] A.L. Read, Presentation of search results: the CL_s technique, J. Phys. G 28 (2002) 2693, http://dx.doi.org/10.1088/0954-3899/28/10/313, from the workshop Advanced Statistical Techniques in Particle Physics, in: Proceedings, Conference, Durham, UK, March 18–22, 2002.

The CMS Collaboration

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

Yerevan Physics Institute, Yerevan, Armenia

W. Adam, E. Asilar, T. Bergauer, J. Brandstetter, E. Brondolin, M. Dragicevic, J. Erö, M. Flechl, M. Friedl, R. Frühwirth[1], V.M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler[1], A. König, I. Krätschmer, D. Liko, T. Matsushita, I. Mikulec, D. Rabady, N. Rad, B. Rahbaran, H. Rohringer, J. Schieck[1], J. Strauss, W. Waltenberger, C.-E. Wulz[1]

Institut für Hochenergiephysik, Wien, Austria

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

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

S. Alderweireldt, E.A. De Wolf, X. Janssen, J. Lauwers, M. Van De Klundert, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

Universiteit Antwerpen, Antwerpen, Belgium

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

Vrije Universiteit Brussel, Brussel, Belgium

H. Brun, C. Caillol, B. Clerbaux, G. De Lentdecker, H. Delannoy, G. Fasanella, L. Favart, R. Goldouzian, A. Grebenyuk, G. Karapostoli, T. Lenzi, A. Léonard, J. Luetic, T. Maerschalk, A. Marinov, A. Randle-conde, T. Seva, C. Vander Velde, P. Vanlaer, R. Yonamine, F. Zenoni, F. Zhang[2]

Université Libre de Bruxelles, Bruxelles, Belgium

A. Cimmino, T. Cornelis, D. Dobur, A. Fagot, G. Garcia, M. Gul, D. Poyraz, S. Salva, R. Schöfbeck, A. Sharma, M. Tytgat, W. Van Driessche, E. Yazgan, N. Zaganidis

Ghent University, Ghent, Belgium

H. Bakhshiansohi, C. Beluffi[3], O. Bondu, S. Brochet, G. Bruno, A. Caudron, S. De Visscher, C. Delaere, M. Delcourt, B. Francois, A. Giammanco, A. Jafari, P. Jez, M. Komm, V. Lemaitre, A. Magitteri, A. Mertens, M. Musich, C. Nuttens, K. Piotrzkowski, L. Quertenmont, M. Selvaggi, M. Vidal Marono, S. Wertz

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

N. Beliy

Université de Mons, Mons, Belgium

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

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

E. Belchior Batista Das Chagas, W. Carvalho, J. Chinellato[4], A. Custódio, E.M. Da Costa, G.G. Da Silveira[5], D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, L.M. Huertas Guativa, H. Malbouisson, D. Matos Figueiredo, C. Mora Herrera, L. Mundim, H. Nogima, W.L. Prado Da Silva, A. Santoro, A. Sznajder, E.J. Tonelli Manganote[4], A. Vilela Pereira

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

S. Ahuja [a], C.A. Bernardes [b], S. Dogra [a], T.R. Fernandez Perez Tomei [a], E.M. Gregores [b], P.G. Mercadante [b], C.S. Moon [a], S.F. Novaes [a], Sandra S. Padula [a], D. Romero Abad [b], J.C. Ruiz Vargas

[a] *Universidade Estadual Paulista, São Paulo, Brazil*
[b] *Universidade Federal do ABC, São Paulo, Brazil*

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

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

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

University of Sofia, Sofia, Bulgaria

W. Fang [6]

Beihang University, Beijing, China

M. Ahmad, J.G. Bian, G.M. Chen, H.S. Chen, M. Chen, Y. Chen [7], T. Cheng, C.H. Jiang, D. Leggat, Z. Liu, F. Romeo, S.M. Shaheen, A. Spiezia, J. Tao, C. Wang, Z. Wang, H. Zhang, J. Zhao

Institute of High Energy Physics, Beijing, China

Y. Ban, G. Chen, Q. Li, S. Liu, Y. Mao, S.J. Qian, D. Wang, Z. Xu

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

C. Avila, A. Cabrera, L.F. Chaparro Sierra, C. Florez, J.P. Gomez, C.F. González Hernández, J.D. Ruiz Alvarez, J.C. Sanabria

Universidad de Los Andes, Bogota, Colombia

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

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

Z. Antunovic, M. Kovac

University of Split, Faculty of Science, Split, Croatia

V. Brigljevic, D. Ferencek, K. Kadija, S. Micanovic, L. Sudic, T. Susa

Institute Rudjer Boskovic, Zagreb, Croatia

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

University of Cyprus, Nicosia, Cyprus

M. Finger [8], M. Finger Jr. [8]

Charles University, Prague, Czech Republic

E. Carrera Jarrin

Universidad San Francisco de Quito, Quito, Ecuador

A.A. Abdelalim [9,10], Y. Mohammed [11], E. Salama [12,13]

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

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

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

P. Eerola, J. Pekkanen, M. Voutilainen

Department of Physics, University of Helsinki, Helsinki, Finland

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

Helsinki Institute of Physics, Helsinki, Finland

J. Talvitie, T. Tuuva

Lappeenranta University of Technology, Lappeenranta, Finland

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

IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France

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

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

J.-L. Agram[14], J. Andrea, A. Aubin, D. Bloch, J.-M. Brom, M. Buttignol, E.C. Chabert, N. Chanon, C. Collard, E. Conte[14], X. Coubez, J.-C. Fontaine[14], D. Gelé, U. Goerlach, A.-C. Le Bihan, K. Skovpen, P. Van Hove

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

S. Gadrat

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

S. Beauceron, C. Bernet, G. Boudoul, E. Bouvier, C.A. Carrillo Montoya, R. Chierici, D. Contardo, B. Courbon, P. Depasse, H. El Mamouni, J. Fan, J. Fay, S. Gascon, M. Gouzevitch, G. Grenier, B. Ille, F. Lagarde, I.B. Laktineh, M. Lethuillier, L. Mirabito, A.L. Pequegnot, S. Perries, A. Popov[15], D. Sabes, V. Sordini, M. Vander Donckt, P. Verdier, S. Viret

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

A. Khvedelidze[8]

Georgian Technical University, Tbilisi, Georgia

Z. Tsamalaidze[8]

Tbilisi State University, Tbilisi, Georgia

C. Autermann, S. Beranek, L. Feld, A. Heister, M.K. Kiesel, K. Klein, M. Lipinski, A. Ostapchuk, M. Preuten, F. Raupach, S. Schael, C. Schomakers, J. Schulz, T. Verlage, H. Weber, V. Zhukov[15]

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

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

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

V. Cherepanov, G. Flügge, F. Hoehle, B. Kargoll, T. Kress, A. Künsken, J. Lingemann, T. Müller, A. Nehrkorn, A. Nowack, I.M. Nugent, C. Pistone, O. Pooth, A. Stahl[16]

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

M. Aldaya Martin, T. Arndt, C. Asawatangtrakuldee, K. Beernaert, O. Behnke, U. Behrens, A.A. Bin Anuar, K. Borras [17], A. Campbell, P. Connor, C. Contreras-Campana, F. Costanza, C. Diez Pardos, G. Dolinska, G. Eckerlin, D. Eckstein, T. Eichhorn, E. Eren, E. Gallo [18], J. Garay Garcia, A. Geiser, A. Gizhko, J.M. Grados Luyando, P. Gunnellini, A. Harb, J. Hauk, M. Hempel [19], H. Jung, A. Kalogeropoulos, O. Karacheban [19], M. Kasemann, J. Keaveney, C. Kleinwort, I. Korol, D. Krücker, W. Lange, A. Lelek, J. Leonard, K. Lipka, A. Lobanov, W. Lohmann [19], R. Mankel, I.-A. Melzer-Pellmann, A.B. Meyer, G. Mittag, J. Mnich, A. Mussgiller, E. Ntomari, D. Pitzl, R. Placakyte, A. Raspereza, B. Roland, M.Ö. Sahin, P. Saxena, T. Schoerner-Sadenius, C. Seitz, S. Spannagel, N. Stefaniuk, G.P. Van Onsem, R. Walsh, C. Wissing

Deutsches Elektronen-Synchrotron, Hamburg, Germany

V. Blobel, M. Centis Vignali, A.R. Draeger, T. Dreyer, E. Garutti, D. Gonzalez, J. Haller, M. Hoffmann, A. Junkes, R. Klanner, R. Kogler, N. Kovalchuk, T. Lapsien, T. Lenz, I. Marchesini, D. Marconi, M. Meyer, M. Niedziela, D. Nowatschin, F. Pantaleo [16], T. Peiffer, A. Perieanu, J. Poehlsen, C. Sander, C. Scharf, P. Schleper, A. Schmidt, S. Schumann, J. Schwandt, H. Stadie, G. Steinbrück, F.M. Stober, M. Stöver, H. Tholen, D. Troendle, E. Usai, L. Vanelderen, A. Vanhoefer, B. Vormwald

University of Hamburg, Hamburg, Germany

C. Barth, C. Baus, J. Berger, E. Butz, T. Chwalek, F. Colombo, W. De Boer, A. Dierlamm, S. Fink, R. Friese, M. Giffels, A. Gilbert, P. Goldenzweig, D. Haitz, F. Hartmann [16], S.M. Heindl, U. Husemann, I. Katkov [15], P. Lobelle Pardo, B. Maier, H. Mildner, M.U. Mozer, Th. Müller, M. Plagge, G. Quast, K. Rabbertz, S. Röcker, F. Roscher, M. Schröder, I. Shvetsov, G. Sieber, H.J. Simonis, R. Ulrich, J. Wagner-Kuhr, S. Wayand, M. Weber, T. Weiler, S. Williamson, C. Wöhrmann, R. Wolf

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

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

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

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

National and Kapodistrian University of Athens, Athens, Greece

I. Evangelou, G. Flouris, C. Foudas, P. Kokkas, N. Loukas, N. Manthos, I. Papadopoulos, E. Paradas

University of Ioánnina, Ioánnina, Greece

N. Filipovic

MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary

G. Bencze, C. Hajdu, P. Hidas, D. Horvath [20], F. Sikler, V. Veszpremi, G. Vesztergombi [21], A.J. Zsigmond

Wigner Research Centre for Physics, Budapest, Hungary

N. Beni, S. Czellar, J. Karancsi [22], A. Makovec, J. Molnar, Z. Szillasi

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

M. Bartók [21], P. Raics, Z.L. Trocsanyi, B. Ujvari

Institute of Physics, University of Debrecen, Debrecen, Hungary

S. Bahinipati, S. Choudhury [23], P. Mal, K. Mandal, A. Nayak [24], D.K. Sahoo, N. Sahoo, S.K. Swain

National Institute of Science Education and Research, Bhubaneswar, India

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

Panjab University, Chandigarh, India

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

University of Delhi, Delhi, India

R. Bhattacharya, S. Bhattacharya, K. Chatterjee, S. Dey, S. Dutt, S. Dutta, S. Ghosh, N. Majumdar, A. Modak, K. Mondal, S. Mukhopadhyay, S. Nandan, A. Purohit, A. Roy, D. Roy, S. Roy Chowdhury, S. Sarkar, M. Sharan, S. Thakur

Saha Institute of Nuclear Physics, Kolkata, India

P.K. Behera

Indian Institute of Technology Madras, Madras, India

R. Chudasama, D. Dutta, V. Jha, V. Kumar, A.K. Mohanty [16], P.K. Netrakanti, L.M. Pant, P. Shukla, A. Topkar

Bhabha Atomic Research Centre, Mumbai, India

T. Aziz, S. Dugad, G. Kole, B. Mahakud, S. Mitra, G.B. Mohanty, B. Parida, N. Sur, B. Sutar

Tata Institute of Fundamental Research-A, Mumbai, India

S. Banerjee, S. Bhowmik [25], R.K. Dewanjee, S. Ganguly, M. Guchait, Sa. Jain, S. Kumar, M. Maity [25], G. Majumder, K. Mazumdar, T. Sarkar [25], N. Wickramage [26]

Tata Institute of Fundamental Research-B, Mumbai, India

S. Chauhan, S. Dube, V. Hegde, A. Kapoor, K. Kothekar, A. Rane, S. Sharma

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

H. Behnamian, S. Chenarani [27], E. Eskandari Tadavani, S.M. Etesami [27], A. Fahim [28], M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi [29], F. Rezaei Hosseinabadi, B. Safarzadeh [30], M. Zeinali

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

M. Felcini, M. Grunewald

University College Dublin, Dublin, Ireland

M. Abbrescia [a,b], C. Calabria [a,b], C. Caputo [a,b], A. Colaleo [a], D. Creanza [a,c], L. Cristella [a,b], N. De Filippis [a,c], M. De Palma [a,b], L. Fiore [a], G. Iaselli [a,c], G. Maggi [a,c], M. Maggi [a], G. Miniello [a,b], S. My [a,b], S. Nuzzo [a,b], A. Pompili [a,b], G. Pugliese [a,c], R. Radogna [a,b], A. Ranieri [a], G. Selvaggi [a,b], L. Silvestris [a,16], R. Venditti [a,b], P. Verwilligen [a]

[a] *INFN Sezione di Bari, Bari, Italy*
[b] *Università di Bari, Bari, Italy*
[c] *Politecnico di Bari, Bari, Italy*

G. Abbiendi [a], C. Battilana, D. Bonacorsi [a,b], S. Braibant-Giacomelli [a,b], L. Brigliadori [a,b], R. Campanini [a,b], P. Capiluppi [a,b], A. Castro [a,b], F.R. Cavallo [a], S.S. Chhibra [a,b], G. Codispoti [a,b], M. Cuffiani [a,b], G.M. Dallavalle [a], F. Fabbri [a], A. Fanfani [a,b], D. Fasanella [a,b], P. Giacomelli [a], C. Grandi [a], L. Guiducci [a,b], S. Marcellini [a], G. Masetti [a], A. Montanari [a], F.L. Navarria [a,b], A. Perrotta [a], A.M. Rossi [a,b], T. Rovelli [a,b], G.P. Siroli [a,b], N. Tosi [a,b,16]

[a] *INFN Sezione di Bologna, Bologna, Italy*
[b] *Università di Bologna, Bologna, Italy*

S. Albergo [a,b], M. Chiorboli [a,b], S. Costa [a,b], A. Di Mattia [a], F. Giordano [a,b], R. Potenza [a,b], A. Tricomi [a,b], C. Tuve [a,b]

[a] *INFN Sezione di Catania, Catania, Italy*
[b] *Università di Catania, Catania, Italy*

G. Barbagli [a], V. Ciulli [a,b], C. Civinini [a], R. D'Alessandro [a,b], E. Focardi [a,b], V. Gori [a,b], P. Lenzi [a,b], M. Meschini [a], S. Paoletti [a], G. Sguazzoni [a], L. Viliani [a,b,16]

[a] *INFN Sezione di Firenze, Firenze, Italy*
[b] *Università di Firenze, Firenze, Italy*

L. Benussi, S. Bianco, F. Fabbri, D. Piccolo, F. Primavera [16]

INFN Laboratori Nazionali di Frascati, Frascati, Italy

V. Calvelli [a,b], F. Ferro [a], M. Lo Vetere [a,b], M.R. Monge [a,b], E. Robutti [a], S. Tosi [a,b]

[a] *INFN Sezione di Genova, Genova, Italy*
[b] *Università di Genova, Genova, Italy*

L. Brianza [16], M.E. Dinardo [a,b], S. Fiorendi [a,b], S. Gennai [a], A. Ghezzi [a,b], P. Govoni [a,b], M. Malberti, S. Malvezzi [a], R.A. Manzoni [a,b,16], D. Menasce [a], L. Moroni [a], M. Paganoni [a,b], D. Pedrini [a], S. Pigazzini, S. Ragazzi [a,b], T. Tabarelli de Fatis [a,b]

[a] *INFN Sezione di Milano-Bicocca, Milano, Italy*
[b] *Università di Milano-Bicocca, Milano, Italy*

S. Buontempo [a], N. Cavallo [a,c], G. De Nardo, S. Di Guida [a,d,16], M. Esposito [a,b], F. Fabozzi [a,c], F. Fienga [a,b], A.O.M. Iorio [a,b], G. Lanza [a], L. Lista [a], S. Meola [a,d,16], P. Paolucci [a,16], C. Sciacca [a,b], F. Thyssen

[a] *INFN Sezione di Napoli, Napoli, Italy*
[b] *Università di Napoli 'Federico II', Napoli, Italy*
[c] *Università della Basilicata, Potenza, Italy*
[d] *Università G. Marconi, Roma, Italy*

P. Azzi [a,16], N. Bacchetta [a], L. Benato [a,b], D. Bisello [a,b], A. Boletti [a,b], R. Carlin [a,b], A. Carvalho Antunes De Oliveira [a,b], P. Checchia [a], M. Dall'Osso [a,b], P. De Castro Manzano [a], T. Dorigo [a], U. Dosselli [a], F. Gasparini [a,b], U. Gasparini [a,b], A. Gozzelino [a], S. Lacaprara [a], M. Margoni [a,b], A.T. Meneguzzo [a,b], J. Pazzini [a,b], N. Pozzobon [a,b], P. Ronchese [a,b], F. Simonetto [a,b], E. Torassa [a], M. Zanetti, P. Zotto [a,b], G. Zumerle [a,b]

[a] *INFN Sezione di Padova, Padova, Italy*
[b] *Università di Padova, Padova, Italy*
[c] *Università di Trento, Trento, Italy*

A. Braghieri [a], A. Magnani [a,b], P. Montagna [a,b], S.P. Ratti [a,b], V. Re [a], C. Riccardi [a,b], P. Salvini [a], I. Vai [a,b], P. Vitulo [a,b]

[a] *INFN Sezione di Pavia, Pavia, Italy*
[b] *Università di Pavia, Pavia, Italy*

L. Alunni Solestizi [a,b], G.M. Bilei [a], D. Ciangottini [a,b], L. Fanò [a,b], P. Lariccia [a,b], R. Leonardi [a,b], G. Mantovani [a,b], M. Menichelli [a], A. Saha [a], A. Santocchia [a,b]

[a] *INFN Sezione di Perugia, Perugia, Italy*
[b] *Università di Perugia, Perugia, Italy*

K. Androsov [a,31], P. Azzurri [a,16], G. Bagliesi [a], J. Bernardini [a], T. Boccali [a], R. Castaldi [a], M.A. Ciocci [a,31], R. Dell'Orso [a], S. Donato [a,c], G. Fedi, A. Giassi [a], M.T. Grippo [a,31], F. Ligabue [a,c], T. Lomtadze [a], L. Martini [a,b], A. Messineo [a,b], F. Palla [a], A. Rizzi [a,b], A. Savoy-Navarro [a,32], P. Spagnolo [a], R. Tenchini [a], G. Tonelli [a,b], A. Venturi [a], P.G. Verdini [a]

[a] *INFN Sezione di Pisa, Pisa, Italy*
[b] *Università di Pisa, Pisa, Italy*
[c] *Scuola Normale Superiore di Pisa, Pisa, Italy*

L. Barone [a,b], F. Cavallari [a], M. Cipriani [a,b], G. D'imperio [a,b,16], D. Del Re [a,b,16], M. Diemoz [a], S. Gelli [a,b], E. Longo [a,b], F. Margaroli [a,b], B. Marzocchi [a,b], P. Meridiani [a], G. Organtini [a,b], R. Paramatti [a], F. Preiato [a,b],

S. Rahatlou[a,b], C. Rovelli[a], F. Santanastasio[a,b]

[a] *INFN Sezione di Roma, Roma, Italy*
[b] *Università di Roma, Roma, Italy*

N. Amapane[a,b], R. Arcidiacono[a,c,16], S. Argiro[a,b], M. Arneodo[a,c], N. Bartosik[a], R. Bellan[a,b], C. Biino[a], N. Cartiglia[a], F. Cenna[a,b], M. Costa[a,b], R. Covarelli[a,b], A. Degano[a,b], N. Demaria[a], L. Finco[a,b], B. Kiani[a,b], C. Mariotti[a], S. Maselli[a], E. Migliore[a,b], V. Monaco[a,b], E. Monteil[a,b], M.M. Obertino[a,b], L. Pacher[a,b], N. Pastrone[a], M. Pelliccioni[a], G.L. Pinna Angioni[a,b], F. Ravera[a,b], A. Romero[a,b], M. Ruspa[a,c], R. Sacchi[a,b], K. Shchelina[a,b], V. Sola[a], A. Solano[a,b], A. Staiano[a], P. Traczyk[a,b]

[a] *INFN Sezione di Torino, Torino, Italy*
[b] *Università di Torino, Torino, Italy*
[c] *Università del Piemonte Orientale, Novara, Italy*

S. Belforte[a], M. Casarsa[a], F. Cossutti[a], G. Della Ricca[a,b], A. Zanetti[a]

[a] *INFN Sezione di Trieste, Trieste, Italy*
[b] *Università di Trieste, Trieste, Italy*

D.H. Kim, G.N. Kim, M.S. Kim, S. Lee, S.W. Lee, Y.D. Oh, S. Sekmen, D.C. Son, Y.C. Yang

Kyungpook National University, Daegu, Republic of Korea

A. Lee

Chonbuk National University, Jeonju, Republic of Korea

H. Kim

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

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

Hanyang University, Seoul, Republic of Korea

S. Cho, S. Choi, Y. Go, D. Gyun, S. Ha, B. Hong, Y. Jo, Y. Kim, B. Lee, K. Lee, K.S. Lee, S. Lee, J. Lim, S.K. Park, Y. Roh

Korea University, Seoul, Republic of Korea

J. Almond, J. Kim, H. Lee, S.B. Oh, B.C. Radburn-Smith, S.h. Seo, U.K. Yang, H.D. Yoo, G.B. Yu

Seoul National University, Seoul, Republic of Korea

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

University of Seoul, Seoul, Republic of Korea

Y. Choi, J. Goh, C. Hwang, J. Lee, I. Yu

Sungkyunkwan University, Suwon, Republic of Korea

V. Dudenas, A. Juodagalvis, J. Vaitkus

Vilnius University, Vilnius, Lithuania

I. Ahmed, Z.A. Ibrahim, J.R. Komaragiri, M.A.B. Md Ali[33], F. Mohamad Idris[34], W.A.T. Wan Abdullah, M.N. Yusli, Z. Zolkapli

National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia

H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-De La Cruz[35], A. Hernandez-Almada, R. Lopez-Fernandez, R. Magaña Villalba, J. Mejia Guisao, A. Sanchez-Hernandez

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

S. Carrillo Moreno, C. Oropeza Barrera, F. Vazquez Valencia

Universidad Iberoamericana, Mexico City, Mexico

S. Carpinteyro, I. Pedraza, H.A. Salazar Ibarguen, C. Uribe Estrada

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

A. Morelos Pineda

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

D. Krofcheck

University of Auckland, Auckland, New Zealand

P.H. Butler

University of Canterbury, Christchurch, New Zealand

A. Ahmad, M. Ahmad, Q. Hassan, H.R. Hoorani, W.A. Khan, A. Saddique, M.A. Shah, M. Shoaib, M. Waqas

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

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

National Centre for Nuclear Research, Swierk, Poland

K. Bunkowski, A. Byszuk[36], K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, M. Olszewski, M. Walczak

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

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

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

S. Afanasiev, V. Alexakhin, P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, V. Karjavin, A. Lanev, A. Malakhov, V. Matveev[37,38], V. Palichik, V. Perelygin, M. Savina, S. Shmatov, S. Shulha, N. Skatchkov, V. Smirnov, A. Zarubin

Joint Institute for Nuclear Research, Dubna, Russia

L. Chtchipounov, V. Golovtsov, Y. Ivanov, V. Kim[39], E. Kuznetsova[40], V. Murzin, V. Oreshkin, V. Sulimov, A. Vorobyev

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

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

Institute for Nuclear Research, Moscow, Russia

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

Institute for Theoretical and Experimental Physics, Moscow, Russia

A. Bylinkin[38]

Moscow Institute of Physics and Technology, Moscow, Russia

R. Chistov[41], M. Danilov[41], V. Rusinov

National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia

V. Andreev, M. Azarkin[38], I. Dremin[38], M. Kirakosyan, A. Leonidov[38], S.V. Rusakov, A. Terkulov

P.N. Lebedev Physical Institute, Moscow, Russia

A. Baskakov, A. Belyaev, E. Boos, V. Bunichev, M. Dubinin[42], L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, I. Miagkov, S. Obraztsov, S. Petrushanko, V. Savrin

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

V. Blinov[43], Y. Skovpen[43]

Novosibirsk State University (NSU), Novosibirsk, Russia

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

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

P. Adzic[44], P. Cirkovic, D. Devetak, M. Dordevic, J. Milosevic, V. Rekovic

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

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

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

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

Universidad Autónoma de Madrid, Madrid, Spain

J. Cuevas, J. Fernandez Menendez, I. Gonzalez Caballero, J.R. González Fernández, E. Palencia Cortezon, S. Sanchez Cruz, I. Suárez Andrés, J.M. Vizan Garcia

Universidad de Oviedo, Oviedo, Spain

I.J. Cabrillo, A. Calderon, J.R. Castiñeiras De Saa, E. Curras, M. Fernandez, J. Garcia-Ferrero, G. Gomez, A. Lopez Virto, J. Marco, C. Martinez Rivero, F. Matorras, J. Piedra Gomez, T. Rodrigo, A. Ruiz-Jimeno, L. Scodellaro, N. Trevisani, I. Vila, R. Vilar Cortabitarte

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

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, P. Bloch, A. Bocci, A. Bonato, C. Botta, T. Camporesi, R. Castello, M. Cepeda, G. Cerminara, M. D'Alfonso, D. d'Enterria, A. Dabrowski, V. Daponte, A. David, M. De Gruttola, A. De Roeck, E. Di Marco[45], M. Dobson, B. Dorney, T. du Pree, D. Duggan, M. Dünser, N. Dupont, A. Elliott-Peisert, S. Fartoukh, G. Franzoni, J. Fulcher, W. Funk, D. Gigi, K. Gill, M. Girone, F. Glege, D. Gulhan, S. Gundacker, M. Guthoff, J. Hammer, P. Harris, J. Hegeman, V. Innocente, P. Janot, J. Kieseler, H. Kirschenmann, V. Knünz, A. Kornmayer[16], M.J. Kortelainen, K. Kousouris, M. Krammer[1], C. Lange, P. Lecoq, C. Lourenço, M.T. Lucchini, L. Malgeri, M. Mannelli, A. Martelli, F. Meijers, J.A. Merlin, S. Mersi, E. Meschi, F. Moortgat, S. Morovic, M. Mulders, H. Neugebauer, S. Orfanelli, L. Orsini, L. Pape, E. Perez, M. Peruzzi, A. Petrilli, G. Petrucciani, A. Pfeiffer, M. Pierini, A. Racz, T. Reis, G. Rolandi[46], M. Rovere, M. Ruan, H. Sakulin, J.B. Sauvan, C. Schäfer, C. Schwick, M. Seidel, A. Sharma, P. Silva, P. Sphicas[47], J. Steggemann, M. Stoye, Y. Takahashi, M. Tosi,

D. Treille, A. Triossi, A. Tsirou, V. Veckalns[48], G.I. Veres[21], N. Wardle, H.K. Wöhri, A. Zagozdzinska[36], W.D. Zeuner

CERN, European Organization for Nuclear Research, Geneva, Switzerland

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

Paul Scherrer Institut, Villigen, Switzerland

F. Bachmair, L. Bäni, L. Bianchini, B. Casal, G. Dissertori, M. Dittmar, M. Donegà, C. Grab, C. Heidegger, D. Hits, J. Hoss, G. Kasieczka, P. Lecomte[†], W. Lustermann, B. Mangano, M. Marionneau, P. Martinez Ruiz del Arbol, M. Masciovecchio, M.T. Meinhard, D. Meister, F. Micheli, P. Musella, F. Nessi-Tedaldi, F. Pandolfi, J. Pata, F. Pauss, G. Perrin, L. Perrozzi, M. Quittnat, M. Rossini, M. Schönenberger, A. Starodumov[49], V.R. Tavolaro, K. Theofilatos, R. Wallny

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

T.K. Aarrestad, C. Amsler[50], L. Caminada, M.F. Canelli, A. De Cosa, C. Galloni, A. Hinzmann, T. Hreus, B. Kilminster, J. Ngadiuba, D. Pinna, G. Rauco, P. Robmann, D. Salerno, Y. Yang, A. Zucchetta

Universität Zürich, Zurich, Switzerland

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

National Central University, Chung-Li, Taiwan

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

National Taiwan University (NTU), Taipei, Taiwan

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

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

A. Adiguzel, M.N. Bakirci[51], S. Damarseckin, Z.S. Demiroglu, C. Dozen, E. Eskut, S. Girgis, G. Gokbulut, Y. Guler, I. Hos, E.E. Kangal[52], O. Kara, U. Kiminsu, M. Oglakci, G. Onengut[53], K. Ozdemir[54], S. Ozturk[51], A. Polatoz, D. Sunar Cerci[55], S. Turkcapar, I.S. Zorbakir, C. Zorbilmez

Cukurova University, Physics Department, Science and Art Faculty, Adana, Turkey

B. Bilin, S. Bilmis, B. Isildak[56], G. Karapinar[57], M. Yalvac, M. Zeyrek

Middle East Technical University, Physics Department, Ankara, Turkey

E. Gülmez, M. Kaya[58], O. Kaya[59], E.A. Yetkin[60], T. Yetkin[61]

Bogazici University, Istanbul, Turkey

A. Cakir, K. Cankocak, S. Sen[62]

Istanbul Technical University, Istanbul, Turkey

B. Grynyov

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

L. Levchuk, P. Sorokin

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

R. Aggleton, F. Ball, L. Beck, J.J. Brooke, D. Burns, E. Clement, D. Cussans, H. Flacher, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, J. Jacob, L. Kreczko, C. Lucas, D.M. Newbold[63], S. Paramesvaran, A. Poll, T. Sakuma, S. Seif El Nasr-storey, D. Smith, V.J. Smith

University of Bristol, Bristol, United Kingdom

K.W. Bell, A. Belyaev[64], C. Brew, R.M. Brown, L. Calligaris, D. Cieri, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, E. Olaiya, D. Petyt, C.H. Shepherd-Themistocleous, A. Thea, I.R. Tomalin, T. Williams

Rutherford Appleton Laboratory, Didcot, United Kingdom

M. Baber, R. Bainbridge, O. Buchmuller, A. Bundock, D. Burton, S. Casasso, M. Citron, D. Colling, L. Corpe, P. Dauncey, G. Davies, A. De Wit, M. Della Negra, R. Di Maria, P. Dunne, A. Elwood, D. Futyan, Y. Haddad, G. Hall, G. Iles, T. James, R. Lane, C. Laner, R. Lucas[63], L. Lyons, A.-M. Magnan, S. Malik, L. Mastrolorenzo, J. Nash, A. Nikitenko[49], J. Pela, B. Penning, M. Pesaresi, D.M. Raymond, A. Richards, A. Rose, C. Seez, S. Summers, A. Tapper, K. Uchida, M. Vazquez Acosta[65], T. Virdee[16], J. Wright, S.C. Zenz

Imperial College, London, United Kingdom

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

Brunel University, Uxbridge, United Kingdom

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

Baylor University, Waco, USA

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

The University of Alabama, Tuscaloosa, USA

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

Boston University, Boston, USA

G. Benelli, E. Berry, D. Cutts, A. Garabedian, J. Hakala, U. Heintz, J.M. Hogan, O. Jesus, K.H.M. Kwok, E. Laird, G. Landsberg, Z. Mao, M. Narain, S. Piperov, S. Sagir, E. Spencer, R. Syarif

Brown University, Providence, USA

R. Breedon, G. Breto, D. Burns, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, R. Erbacher, C. Flores, G. Funk, M. Gardner, W. Ko, R. Lander, C. Mclean, M. Mulhearn, D. Pellett, J. Pilot, S. Shalhout, J. Smith, M. Squires, D. Stolp, M. Tripathi, S. Wilbur, R. Yohay

University of California, Davis, Davis, USA

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

University of California, Los Angeles, USA

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

University of California, Riverside, Riverside, USA

J.G. Branson, G.B. Cerati, S. Cittolin, M. Derdzinski, R. Gerosa, A. Holzner, D. Klein, V. Krutelyov, J. Letts, I. Macneill, D. Olivito, S. Padhi, M. Pieri, M. Sani, V. Sharma, S. Simon, M. Tadel, A. Vartak, S. Wasserbaech[66], C. Welke, J. Wood, F. Würthwein, A. Yagil, G. Zevi Della Porta

University of California, San Diego, La Jolla, USA

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

University of California, Santa Barbara, Department of Physics, Santa Barbara, USA

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

California Institute of Technology, Pasadena, USA

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

Carnegie Mellon University, Pittsburgh, USA

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

University of Colorado Boulder, Boulder, USA

J. Alexander, J. Chaves, J. Chu, S. Dittmer, K. Mcdermott, N. Mirman, G. Nicolas Kaufman, J.R. Patterson, A. Rinkevicius, A. Ryd, L. Skinnari, L. Soffi, S.M. Tan, Z. Tao, J. Thom, J. Tucker, P. Wittich, M. Zientek

Cornell University, Ithaca, USA

D. Winn

Fairfield University, Fairfield, USA

S. Abdullin, M. Albrow, G. Apollinari, S. Banerjee, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, G. Bolla, K. Burkett, J.N. Butler, H.W.K. Cheung, F. Chlebana, S. Cihangir[†], M. Cremonesi, V.D. Elvira, I. Fisk, J. Freeman, E. Gottschalk, L. Gray, D. Green, S. Grünendahl, O. Gutsche, D. Hare, R.M. Harris, S. Hasegawa, J. Hirschauer, Z. Hu, B. Jayatilaka, S. Jindariani, M. Johnson, U. Joshi, B. Klima, B. Kreis, S. Lammel, J. Linacre, D. Lincoln, R. Lipton, M. Liu, T. Liu, R. Lopes De Sá, J. Lykken, K. Maeshima, N. Magini, J.M. Marraffino, S. Maruyama, D. Mason, P. McBride, P. Merkel, S. Mrenna, S. Nahn, C. Newman-Holmes[†], V. O'Dell, K. Pedro, O. Prokofyev, G. Rakness, L. Ristori, E. Sexton-Kennedy, A. Soha, W.J. Spalding, L. Spiegel, S. Stoynev, N. Strobbe, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, C. Vernieri, M. Verzocchi, R. Vidal, M. Wang, H.A. Weber, A. Whitbeck

Fermi National Accelerator Laboratory, Batavia, USA

D. Acosta, P. Avery, P. Bortignon, D. Bourilkov, A. Brinkerhoff, A. Carnes, M. Carver, D. Curry, S. Das, R.D. Field, I.K. Furic, J. Konigsberg, A. Korytov, P. Ma, K. Matchev, H. Mei, P. Milenovic[67], G. Mitselmakher, D. Rank, L. Shchutska, D. Sperka, L. Thomas, J. Wang, S. Wang, J. Yelton

University of Florida, Gainesville, USA

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

Florida International University, Miami, USA

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

Florida State University, Tallahassee, USA

M.M. Baarmand, V. Bhopatkar, S. Colafranceschi[68], M. Hohlmann, D. Noonan, T. Roy, F. Yumiceva

Florida Institute of Technology, Melbourne, USA

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

H. Wang, Z. Wu, M. Zakaria, J. Zhang

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

B. Bilki[69], W. Clarida, K. Dilsiz, S. Durgut, R.P. Gandrajula, M. Haytmyradov, V. Khristenko, J.-P. Merlo, H. Mermerkaya[70], A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok[71], A. Penzo, C. Snyder, E. Tiras, J. Wetzel, K. Yi

The University of Iowa, Iowa City, USA

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

Johns Hopkins University, Baltimore, USA

A. Al-bataineh, P. Baringer, A. Bean, S. Boren, J. Bowen, C. Bruner, J. Castle, L. Forthomme, R.P. Kenny III, A. Kropivnitskaya, D. Majumder, W. Mcbrayer, M. Murray, S. Sanders, R. Stringer, J.D. Tapia Takaki, Q. Wang

The University of Kansas, Lawrence, USA

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

Kansas State University, Manhattan, USA

F. Rebassoo, D. Wright

Lawrence Livermore National Laboratory, Livermore, USA

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

University of Maryland, College Park, USA

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

Massachusetts Institute of Technology, Cambridge, USA

A.C. Benvenuti, R.M. Chatterjee, A. Evans, A. Finkel, A. Gude, P. Hansen, S. Kalafut, S.C. Kao, Y. Kubota, Z. Lesko, J. Mans, S. Nourbakhsh, N. Ruckstuhl, R. Rusack, N. Tambe, J. Turkewitz

University of Minnesota, Minneapolis, USA

J.G. Acosta, S. Oliveros

University of Mississippi, Oxford, USA

E. Avdeeva, R. Bartek, K. Bloom, D.R. Claes, A. Dominguez, C. Fangmeier, R. Gonzalez Suarez, R. Kamalieddin, I. Kravchenko, A. Malta Rodrigues, F. Meier, J. Monroy, J.E. Siado, G.R. Snow, B. Stieger

University of Nebraska-Lincoln, Lincoln, USA

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

State University of New York at Buffalo, Buffalo, USA

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

Northeastern University, Boston, USA

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

Northwestern University, Evanston, USA

N. Dev, M. Hildreth, K. Hurtado Anampa, C. Jessop, D.J. Karmgard, N. Kellams, K. Lannon, N. Marinelli, F. Meng, C. Mueller, Y. Musienko[37], M. Planer, A. Reinsvold, R. Ruchti, G. Smith, S. Taroni, M. Wayne, M. Wolf, A. Woodard

University of Notre Dame, Notre Dame, USA

J. Alimena, L. Antonelli, J. Brinson, B. Bylsma, L.S. Durkin, S. Flowers, B. Francis, A. Hart, C. Hill, R. Hughes, W. Ji, B. Liu, W. Luo, D. Puigh, B.L. Winer, H.W. Wulsin

The Ohio State University, Columbus, USA

S. Cooperstein, O. Driga, P. Elmer, J. Hardenbrook, P. Hebda, D. Lange, J. Luo, D. Marlow, T. Medvedeva, K. Mei, M. Mooney, J. Olsen, C. Palmer, P. Piroué, D. Stickland, C. Tully, A. Zuranski

Princeton University, Princeton, USA

S. Malik

University of Puerto Rico, Mayaguez, USA

A. Barker, V.E. Barnes, S. Folgueras, L. Gutay, M.K. Jha, M. Jones, A.W. Jung, D.H. Miller, N. Neumeister, J.F. Schulte, X. Shi, J. Sun, A. Svyatkovskiy, F. Wang, W. Xie, L. Xu

Purdue University, West Lafayette, USA

N. Parashar, J. Stupak

Purdue University Calumet, Hammond, USA

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

Rice University, Houston, USA

B. Betchart, A. Bodek, P. de Barbaro, R. Demina, Y.t. Duh, T. Ferbel, M. Galanti, A. Garcia-Bellido, J. Han, O. Hindrichs, A. Khukhunaishvili, K.H. Lo, P. Tan, M. Verzetti

University of Rochester, Rochester, USA

A. Agapitos, J.P. Chou, E. Contreras-Campana, Y. Gershtein, T.A. Gómez Espinosa, E. Halkiadakis, M. Heindl, D. Hidas, E. Hughes, S. Kaplan, R. Kunnawalkam Elayavalli, S. Kyriacou, A. Lath, K. Nash, H. Saka, S. Salur, S. Schnetzer, D. Sheffield, S. Somalwar, R. Stone, S. Thomas, P. Thomassen, M. Walker

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

A.G. Delannoy, M. Foerster, J. Heideman, G. Riley, K. Rose, S. Spanier, K. Thapa

University of Tennessee, Knoxville, USA

O. Bouhali[72], A. Celik, M. Dalchenko, M. De Mattia, A. Delgado, S. Dildick, R. Eusebi, J. Gilmore, T. Huang, E. Juska, T. Kamon[73], R. Mueller, Y. Pakhotin, R. Patel, A. Perloff, L. Perniè, D. Rathjens, A. Rose, A. Safonov, A. Tatarinov, K.A. Ulmer

Texas A&M University, College Station, USA

N. Akchurin, C. Cowden, J. Damgov, F. De Guio, C. Dragoiu, P.R. Dudero, J. Faulkner, E. Gurpinar, S. Kunori, K. Lamichhane, S.W. Lee, T. Libeiro, T. Peltola, S. Undleeb, I. Volobouev, Z. Wang

Texas Tech University, Lubbock, USA

S. Greene, A. Gurrola, R. Janjam, W. Johns, C. Maguire, A. Melo, H. Ni, P. Sheldon, S. Tuo, J. Velkovska, Q. Xu

Vanderbilt University, Nashville, USA

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

University of Virginia, Charlottesville, USA

C. Clarke, R. Harr, P.E. Karchin, J. Sturdy

Wayne State University, Detroit, USA

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

University of Wisconsin - Madison, Madison, WI, USA

[†] Deceased.
[1] Also at Vienna University of Technology, Vienna, Austria.
[2] Also at State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China.
[3] Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France.
[4] Also at Universidade Estadual de Campinas, Campinas, Brazil.
[5] Also at Universidade Federal de Pelotas, Pelotas, Brazil.
[6] Also at Université Libre de Bruxelles, Bruxelles, Belgium.
[7] Also at Deutsches Elektronen-Synchrotron, Hamburg, Germany.
[8] Also at Joint Institute for Nuclear Research, Dubna, Russia.
[9] Also at Helwan University, Cairo, Egypt.
[10] Now at Zewail City of Science and Technology, Zewail, Egypt.
[11] Now at Fayoum University, El-Fayoum, Egypt.
[12] Also at British University in Egypt, Cairo, Egypt.
[13] Now at Ain Shams University, Cairo, Egypt.
[14] Also at Université de Haute Alsace, Mulhouse, France.
[15] Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia.
[16] Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.
[17] Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.
[18] Also at University of Hamburg, Hamburg, Germany.
[19] Also at Brandenburg University of Technology, Cottbus, Germany.
[20] Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
[21] Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary.
[22] Also at Institute of Physics, University of Debrecen, Debrecen, Hungary.
[23] Also at Indian Institute of Science Education and Research, Bhopal, India.
[24] Also at Institute of Physics, Bhubaneswar, India.
[25] Also at University of Visva-Bharati, Santiniketan, India.
[26] Also at University of Ruhuna, Matara, Sri Lanka.
[27] Also at Isfahan University of Technology, Isfahan, Iran.
[28] Also at University of Tehran, Department of Engineering Science, Tehran, Iran.
[29] Also at Yazd University, Yazd, Iran.
[30] Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran.
[31] Also at Università degli Studi di Siena, Siena, Italy.
[32] Also at Purdue University, West Lafayette, USA.
[33] Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia.
[34] Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia.
[35] Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico.
[36] Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland.
[37] Also at Institute for Nuclear Research, Moscow, Russia.
[38] Now at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia.
[39] Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia.
[40] Also at University of Florida, Gainesville, USA.
[41] Also at P.N. Lebedev Physical Institute, Moscow, Russia.

[42] Also at California Institute of Technology, Pasadena, USA.
[43] Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia.
[44] Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
[45] Also at INFN Sezione di Roma; Università di Roma, Roma, Italy.
[46] Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy.
[47] Also at National and Kapodistrian University of Athens, Athens, Greece.
[48] Also at Riga Technical University, Riga, Latvia.
[49] Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.
[50] Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland.
[51] Also at Gaziosmanpasa University, Tokat, Turkey.
[52] Also at Mersin University, Mersin, Turkey.
[53] Also at Cag University, Mersin, Turkey.
[54] Also at Piri Reis University, Istanbul, Turkey.
[55] Also at Adiyaman University, Adiyaman, Turkey.
[56] Also at Ozyegin University, Istanbul, Turkey.
[57] Also at Izmir Institute of Technology, Izmir, Turkey.
[58] Also at Marmara University, Istanbul, Turkey.
[59] Also at Kafkas University, Kars, Turkey.
[60] Also at Istanbul Bilgi University, Istanbul, Turkey.
[61] Also at Yildiz Technical University, Istanbul, Turkey.
[62] Also at Hacettepe University, Ankara, Turkey.
[63] Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
[64] Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
[65] Also at Instituto de Astrofísica de Canarias, La Laguna, Spain.
[66] Also at Utah Valley University, Orem, USA.
[67] Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.
[68] Also at Facoltà Ingegneria, Università di Roma, Roma, Italy.
[69] Also at Argonne National Laboratory, Argonne, USA.
[70] Also at Erzincan University, Erzincan, Turkey.
[71] Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
[72] Also at Texas A&M University at Qatar, Doha, Qatar.
[73] Also at Kyungpook National University, Daegu, Korea.