Physics Letters B 755 (2016) 102–124

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Search for new phenomena in monophoton final states in proton–proton collisions at $\sqrt{s} = 8$ TeV

CMS Collaboration *

CERN, Switzerland

ARTICLE INFO

Article history:
Received 31 October 2014
Received in revised form 24 January 2016
Accepted 26 January 2016
Available online 1 February 2016
Editor: Dr. M. Doser

Keywords:
CMS
Physics
Monophoton
Dark matter

ABSTRACT

Results are presented from a search for new physics in final states containing a photon and missing transverse momentum. The data correspond to an integrated luminosity of 19.6 fb^{-1} collected in proton–proton collisions at $\sqrt{s} = 8$ TeV with the CMS experiment at the LHC. No deviation from the standard model predictions is observed for these final states. New, improved limits are set on dark matter production and on parameters of models with large extra dimensions. In particular, the first limits from the LHC on branon production are found and significantly extend previous limits from LEP and the Tevatron. An upper limit of 14.0 fb on the cross section is set at the 95% confidence level for events with a monophoton final state with photon transverse momentum greater than 145 GeV and missing transverse momentum greater than 140 GeV.

1. Introduction

The production of events containing photons with large transverse momentum and having large missing transverse momentum at the CERN LHC is sensitive to physics beyond the standard model (SM). In this Letter we investigate three possible extensions of the SM: a model incorporating pair production of dark matter (DM) particles, and two models with extra spatial dimensions, as described below.

At the LHC, DM particles (χ) [1] can be produced in the process $\mathrm{q\bar{q}} \rightarrow \gamma\chi\bar{\chi}$, where the photon is radiated by one of the incoming quarks. With a photon in the final state, we gain sensitivity to the production of invisible particles. The SM–DM interaction is assumed to be mediated by a virtual particle ("mediator") with a mass M much heavier than the fermionic DM particle mass (M_χ). Various processes are contracted into an effective field theory (EFT) [2–5], assuming M much larger than the momentum transfer scale Q (i.e. $M \gg Q$) and a contact interaction scale Λ given by $\Lambda^{-2} = g_\chi g_\mathrm{q} M^{-2}$, where g_χ and g_q are the mediator couplings to χ and to quarks, respectively. Using this formalism, results from searches at the LHC can be related to limits for direct searches sensitive to χ-nucleon scattering [5].

The ADD model [6,7] of large extra dimensions is postulated to have n extra compactified spatial dimensions at a characteristic scale R that reflects an effective Planck scale M_D through $M_\mathrm{Pl}^2 \approx M_\mathrm{D}^{n+2} R^n$, where M_Pl is the Planck scale. If M_D is of the same order as the electroweak scale ($M_\mathrm{EW} \sim 10^2$ GeV), the large value of M_Pl can be interpreted as being a consequence of large-volume ($\sim R^n$) suppression from extra dimensional space. This model predicts a sizable cross section for the process $\mathrm{q\bar{q}} \rightarrow \gamma\mathrm{G}$, where G is a graviton that escapes detection, and motivates the search for events with a single γ and missing transverse momentum.

In both the ADD and branon models, the SM particles are constrained to live on a $3+1$ dimensional 3-brane surface. In the branon family of models [8–11], it is assumed that the brane fluctuates in the extra dimensions, in contrast to the ADD model, where the brane is rigid. In this alternative scheme, the brane tension scale f is expected to be much smaller than other relevant scales such as M_D. The particles associated with such fluctuations are scalar particles called branons. Branons are stable and massive scalar particles of mass M_B, and are natural candidates for dark matter [12]. They can be pair-produced in association with SM particles at the LHC, giving rise to γ + missing transverse momentum final states [13]. If N extra dimensions are considered, then N branons are expected and their production cross section scales with N. In the following, only the $N = 1$ case is considered.

The primary background to the γ + missing transverse momentum signal is the irreducible SM background from $\mathrm{Z}\gamma \rightarrow \nu\bar{\nu}\gamma$ production. Other backgrounds include $\mathrm{W}\gamma \rightarrow \ell\nu\gamma$ (where ℓ is an undetected charged lepton), $\mathrm{W} \rightarrow \mathrm{e}\nu$ (where the electron is misidentified as a photon), γ + jet, QCD multijet (with a jet misidentified as a photon), $\mathrm{Z}\gamma \rightarrow \ell\ell\gamma$, and diphoton events, as well as backgrounds from beam halo.

---

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

http://dx.doi.org/10.1016/j.physletb.2016.01.057

2. The CMS detector

The CMS experiment uses a right-handed coordinate system, with the origin at the nominal interaction point, the x axis pointing to the center of the LHC, the y axis pointing up (perpendicular to the LHC plane), and the z axis along the anticlockwise-beam direction. The azimuthal angle ϕ is measured from the x-axis in the x–y plane and the polar angle θ is measured from the z-axis. Pseudorapidity is defined as $\eta = -\ln[\tan(\theta/2)]$.

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 superconducting solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter (HCAL), each composed of a barrel ($|\eta| < 1.479$) and two endcap ($1.479 < |\eta| < 3.0$) sections. Electrons are found by associating clusters of ECAL energy with adjacent tracker hits. Muons are detected in the pseudorapidity range $|\eta| < 2.4$, using gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid, and reconstructed from tracks in these detectors combined with those from the silicon tracker. Extensive forward calorimetry ($3.15 < |\eta| < 4.9$) complements the coverage provided by the barrel and endcap detectors. The energy resolution for photons with transverse momentum ≥60 GeV varies between 1.1% and 2.6% over the solid angle of the ECAL barrel, and from 2.2% to 5.0% in the endcaps [14]. The timing measurement of the ECAL has a resolution better than 200 ps for energy deposits larger than 10 GeV [14]. In the η–ϕ plane, and for $|\eta| < 1.48$, the HCAL cells map onto 5×5 arrays of ECAL crystals to form calorimeter towers projecting radially outward from the nominal interaction point. 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. [15].

3. Event selection

In the following, it is convenient to refer to the missing transverse momentum vector, $\vec{\not{E}}_T$, defined as the projection on the plane perpendicular to the beams of the negative vector sum of the momenta of all reconstructed particles in an event. Its magnitude is referred to as $\not{E}_T$.

Events are selected from a data sample corresponding to an integrated luminosity of 19.6 fb^{-1} collected in proton–proton collisions at $\sqrt{s} = 8$ TeV with the CMS experiment at the LHC. Triggers requiring at least one electromagnetic cluster or a cluster along with large $\not{E}_T$ are used. For the selected signal region of transverse energy $E_T^\gamma > 145$ GeV, pseudorapidity $|\eta^\gamma| < 1.44$, and $\not{E}_T > 140$ GeV, these triggers are ≈96% efficient for E_T^γ in the 145–160 GeV range, and fully efficient for $E_T^\gamma > 160$ GeV. Events are required to have at least one primary vertex reconstructed within a longitudinal distance of $|z| < 24$ cm of the center of the detector and at a distance <2 cm from the z-axis. The primary vertex is chosen to be the vertex with the highest sum in p_T^2 of its associated tracks, where p_T is the transverse momentum.

Candidate electromagnetic (EM) showers are restricted to the barrel region of the ECAL, where their purity is highest [16]. Photon candidates [17] are selected by requiring the ratio of the energy deposited in the closest HCAL tower to the energy of the EM showers in the ECAL to be less than 0.05 and the spatial distribution of energy in the EM shower to be consistent with that expected for a photon. In order to reject hadronic activity, photon candidates are required to be isolated, using the sum of the transverse energy of additional particles within a cone of $\Delta R < 0.3$ centered on the shower axis, where $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$, reconstructed using a particle-flow algorithm [18,19]. In this isolation cone, the sum of the transverse energy (in GeV) of additional photons is required to be less than $(0.7 + 0.005 E_T^\gamma)$, of neutral hadrons is required to be less than $(1.0 + 0.04 E_T^\gamma)$, and of charged hadrons is required to be less than 1.5. The charged hadron contribution includes that calculated from the other interaction vertices in the event (pileup), arising from the uncertainty in assigning the photon candidate to a particular vertex. The effect of pileup on the isolation variables is mitigated using the scheme presented in Ref. [20].

The ECAL crystal containing the highest energy within the cluster of the photon candidate is required to have a time of deposition within ±3 ns of particles arriving from the collision. This selection suppresses contributions from noncollision backgrounds. To reduce contamination from beam halo, the crystals (excluding those associated with the photon candidate) are examined for evidence of the passage of a minimum-ionizing particle roughly parallel to the beam axis (beam halo tag). If sufficient energy is found along such a trajectory, the event is rejected. Highly ionizing particles traversing the sensitive volume of the readout photodiodes can give rise to spurious signals within the EM shower [21]. These EM showers are eliminated by requiring consistency among the timings of energy depositions in all crystals within the shower. Photon candidates are rejected 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 candidate EM showers [22].

Jets are reconstructed with the anti-k_T algorithm [23] using a radius parameter of $R = 0.5$. Jets that are identified as arising from pileup are rejected [24]. In order to reduce QCD multijet backgrounds, events are rejected if there is more than one jet with $p_T > 30$ GeV at $\Delta R > 0.5$ relative to the photon. Events with isolated leptons (electron or muon) with $p_T > 10$ GeV, $|\eta| < 2.4$ (2.5) for muons (electrons) and $\Delta R > 0.5$ relative to the photon, are also rejected to suppress $W\gamma \to \ell\nu\gamma$ and $Z\gamma \to \ell\ell\gamma$ backgrounds. Lepton isolation is computed using the sum of transverse energies of tracks, ECAL, and HCAL depositions within a surrounding cone of $\Delta R < 0.3$. For electron isolation, each contributing component of transverse energy (tracker, ECAL, and HCAL) is required to be less than 20% of the electron p_T, while for muons only the tracker component is considered and is required to be less than 10% of the muon p_T.

The candidate events are required to have $\not{E}_T > 140$ GeV. A topological requirement of $\Delta\phi(\vec{\not{E}}_T, \gamma) > 2$ rad is applied to suppress the contribution from the $\gamma +$jet background.

A major source of background comes from events with mismeasured $\not{E}_T$ due to finite detector resolution, mainly associated with jets. In order to reduce the contribution from events with mismeasured $\not{E}_T$, for each event a χ^2 function is constructed and minimized:

$$\chi^2 = \sum_i \left(\frac{(p_T^{\text{reco}})_i - (\widetilde{p}_T)_i}{(\sigma_{p_T})_i} \right)^2 + \left(\frac{\widetilde{\not{E}}_x}{\sigma_{\widetilde{\not{E}}_x}} \right)^2 + \left(\frac{\widetilde{\not{E}}_y}{\sigma_{\widetilde{\not{E}}_y}} \right)^2 , \tag{1}$$

where the summation is over the reconstructed particles, i.e., the photon and the jets. In the above equation, $(p_T^{\text{reco}})_i$ are the transverse momenta, and the $(\sigma_{p_T})_i$, the expected momentum resolutions of the reconstructed particles. The $(\widetilde{p}_T)_i$ are the free parameters allowed to vary in order to minimize the function. The resolution parametrization associated with the $\not{E}_T$ is obtained from Ref. [25]. Lastly, $\widetilde{\not{E}}_x$ and $\widetilde{\not{E}}_y$ can be expressed as:

$$\begin{aligned} \widetilde{\not{E}}_{x,y} &= \not{E}_{x,y}^{\text{reco}} + \sum_{i=\text{objects}} (p_{x,y}^{\text{reco}})_i - (\widetilde{p}_{x,y})_i \\ &= -\sum_{i=\text{objects}} (\widetilde{p}_{x,y})_i \end{aligned} \tag{2}$$

In events with no genuine $\not\!\!E_{\mathrm{T}}$, the mismeasured quantities will be more readily re-distributed back into the particle momenta, which will result in a low χ^2 value. On the other hand, in events with genuine $\not\!\!E_{\mathrm{T}}$ from undetected particles, minimization of the χ^2 function will be more difficult and generally will result in larger χ^2 values. To reduce the contribution of events with mismeasured $\not\!\!E_{\mathrm{T}}$, the probability value obtained from the χ^2 minimization is required to be smaller than 10^{-6} and $\widetilde{\not\!\!E}_{\mathrm{T}} = \sqrt{\widetilde{\not\!\!E}_x^2 + \widetilde{\not\!\!E}_y^2}$, in which the original reconstructed particle momenta are replaced with those obtained with the χ^2 minimization, is required to be greater than 120 GeV. These requirements are optimized using the significance estimator $\mathrm{S}/\sqrt{\mathrm{S}+\mathrm{B}}$ and remove 80% (35%) of γ + jet (QCD multijet) events, while keeping 99.5% of signal events.

After applying all selection criteria, 630 candidate events remain in the sample.

4. Background determination

Backgrounds from $\mathrm{Z}\gamma \to \nu\bar{\nu}\gamma$, $\mathrm{W}\gamma \to \ell\nu\gamma$, γ + jet, $\mathrm{Z}\gamma \to \ell\ell\gamma$, and diphoton production are estimated from simulated samples processed through the full GEANT4-based simulation of the CMS detector [26,27], trigger emulation, and the same event reconstruction programs as used for data. The $\mathrm{Z}\gamma \to \nu\bar{\nu}\gamma$ and $\mathrm{W}\gamma \to \ell\nu\gamma$ samples are generated with MADGRAPH 5v1.3.30 [28], and the cross section is corrected to include next-to-leading-order (NLO) effects through an E_{T}^{γ} dependent correction factor calculated with MCFM 6.1 [29]. The central values of the NLO cross section and the prediction for the photon E_{T} spectrum are calculated following the prescriptions of the PDF4LHC Working Group [30–32]. This prescription is also used to calculate the systematic uncertainties due to the parton distribution functions (PDF), and the strong coupling α_s and its dependence on the factorization scale and renormalization scale. The systematic uncertainties in the NLO cross sections are found to be in the range 8% to 48% and 16% to 82% for $\mathrm{Z}\gamma \to \nu\bar{\nu}\gamma$ and $\mathrm{W}\gamma \to \ell\nu\gamma$, respectively, over the E_{T}^{γ} spectrum from 145 GeV to 1000 GeV. The strong correlation in the uncertainties of the two channels is propagated to the final result. The $\mathrm{Z}\gamma \to \ell\ell\gamma$ sample is obtained using the MADGRAPH 5v1.3.30 generator [28]. The γ + jet and diphoton samples are obtained using the PYTHIA 6.426 generator [33] at leading order (LO), with the CTEQ6L1 [34] PDF. The γ + jet cross section is corrected to include NLO effects.

The backgrounds estimated from simulations are scaled by a factor F to correct for observed differences in efficiency between data and simulation. This overall data/simulation correction factor receives contributions from four sources as follows: the photon reconstruction efficiency ratio, estimated to be 0.97 ± 0.02 using $\mathrm{Z} \to \mathrm{ee}$ decays; the ratio of probabilities for satisfying a crystal timing requirement, estimated to be 0.99 ± 0.03 from a sample of electron data; the lepton veto efficiency ratio, estimated to be 0.99 ± 0.02 using $\mathrm{W} \to \mathrm{e}\nu$ decays; and the jet veto efficiency ratio, estimated to be 0.99 ± 0.05 using $\mathrm{W} \to \mathrm{e}\nu$ decays, and confirmed using $\mathrm{Z}\gamma \to \mathrm{ee}\gamma$ data samples. The total correction factor obtained by combining these contributions is $F = 0.94 \pm 0.06$.

The total uncertainty in the backgrounds estimated through simulation includes contributions from the theoretical cross section, data-simulation factor F, pileup modeling, and the accuracy of energy calibration and resolution for photons [14], jets [35], and $\not\!\!E_{\mathrm{T}}$ [36]. The estimated contribution from the $\mathrm{Z}\gamma \to \nu\bar{\nu}\gamma$ and $\mathrm{W}\gamma \to \ell\nu\gamma$ processes to the background are, respectively, 345 ± 43 and 103 ± 21 events, where the dominant uncertainty is from the theoretical cross section calculations. To gain confidence in the estimates from simulation, control regions, which are dominated by these backgrounds and have negligible contributions from a signal, are defined in the data. As a crosscheck, the total contribution from $\mathrm{Z}\gamma \to \nu\bar{\nu}\gamma$ is estimated in data using a sample of $\mathrm{Z}\gamma \to \mu\mu\gamma$ candidates, where the muons from the decay of the Z boson are considered as invisible particles hence contributing to $\not\!\!E_{\mathrm{T}}$ [37]. The normalization is corrected both for the ratio of the branching fractions of $\mathrm{Z}\gamma \to \nu\bar{\nu}\gamma$ and $\mathrm{Z}\gamma \to \mu\mu\gamma$, and for differences in the acceptance and selection efficiencies. This crosscheck provides an estimate of 341 ± 50 events, where the uncertainty is dominated by the size of the sample. A control region dominated by the $\mathrm{W}\gamma$ process is also studied by using the signal selection but inverting the lepton veto i.e., the final state is required to contain a reconstructed charged lepton. After this selection, 104 events are observed and 126 ± 23 are expected.

Electrons misidentified as photons arise mainly from highly off-shell W boson ($\mathrm{W}^* \to \mathrm{e}\nu$) events. These backgrounds are inclusively estimated from data. The efficiency, ϵ_{pix}, of matching electron showers in the calorimeter to pixel seeds is estimated using a tag-and-probe technique [38] on $\mathrm{Z} \to \mathrm{ee}$ events in data, verified with simulated events. The efficiency is found to be $\epsilon_{\mathrm{pix}} = 0.984 \pm 0.002$ for electrons with $E_{\mathrm{T}} > 100$ GeV. A control sample of $\mathrm{W}^* \to \mathrm{e}\nu$ events is also obtained from data through use of all the standard candidate selections, with the exception of the pixel seed, which is inverted. The number of events in this sample is scaled by the value of $(1-\epsilon_{\mathrm{pix}})/\epsilon_{\mathrm{pix}}$ resulting in an inclusive estimate of 60 ± 6 $\mathrm{W}^* \to \mathrm{e}\nu$ events in the signal region.

The contamination from jets misidentified as photons is estimated in data using a control sample with $\not\!\!E_{\mathrm{T}} < 30$ GeV, dominated by QCD events. This sample is used to measure the ratio of the number of objects that pass photon identification criteria to the number that fail at least one of the isolation requirements. The control sample also contains objects from QCD direct photon production that must be removed from the numerator of the ratio. This contribution is estimated by fitting the shower shape distribution with template distributions. For true photons, a template for the shower width is formed using simulated γ + jets events. For jets misidentified as photons, the template is formed using a separate control sample, where the objects are required to fail charged hadron isolation. This corrected ratio is used to scale a set of data events that pass the denominator selection of the fake ratio and all other candidate requirements, providing an inclusive estimate for all backgrounds in which jets are misidentified as photons of 45 ± 14 events.

Noncollision backgrounds are estimated from data by examining the shower width of the EM cluster and the time-of-arrival of the signal in the crystal containing the largest deposition of energy. Templates for anomalous signals, cosmic ray muons, and beam halo events are obtained by inverting the shower shape and beam halo tag requirements, and are fitted to the timing distribution of the candidate sample. The only nonnegligible residual contribution to the candidate sample is found to arise from the beam halo, with an estimated 25 ± 6 events.

5. Results

Table 1 shows the estimated number of events and associated uncertainty from each background process along with the total number of events observed in the data, for the entire data set, which corresponds to 19.6 fb^{-1}. The number of events observed in data agrees with the expectation from SM background. The photon E_{T} and $\not\!\!E_{\mathrm{T}}$ distributions for the selected candidates and estimated backgrounds are shown in Fig. 1. The spectra expected from the ADD model for $M_{\mathrm{D}} = 2$ TeV and $n = 3$ are also shown for comparison. Limits are set for the DM, ADD, and branon models using the E_{T}^{γ} spectrum.

Table 1
Summary of estimated backgrounds and observed total number of candidates. Backgrounds listed as "Others" include the small contributions from $W \to \mu\nu$, $W \to \tau\nu$, $Z\gamma \to \ell\ell\gamma$, $\gamma\gamma$, and γ + jet. Uncertainties include both statistical and systematic contributions, and the total systematic uncertainty includes the effect of correlations in the individual estimates.

Process	Estimate
$Z(\to \nu\bar{\nu}) + \gamma$	345 ± 43
$W(\to \ell\nu) + \gamma$	103 ± 21
electron $\to \gamma$ MisID	60 ± 6
jet $\to \gamma$ MisID	45 ± 14
Beam halo	25 ± 6
Others	36 ± 3
Total background	614 ± 63
Data	630

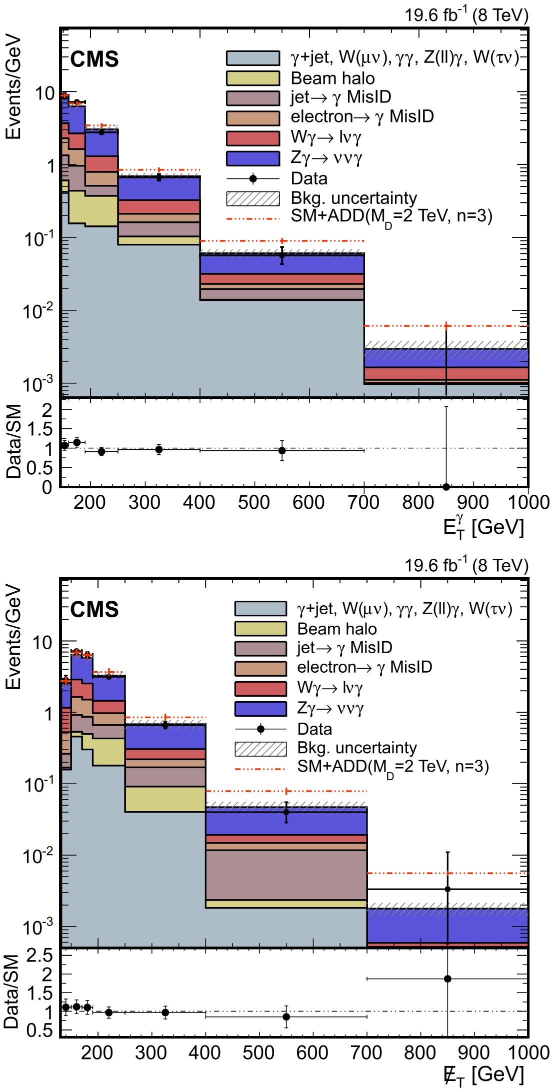

Fig. 1. The photon E_T and $\not{E}_T$ distributions for the candidate sample, compared with estimated contributions from SM backgrounds, and the predictions from the ADD model for $M_D = 2$ TeV and $n = 3$. The horizontal bar on each data point indicates the width of the bin. The background uncertainty includes statistical and systematic components. The bottom panel shows the ratio of data and SM background predictions.

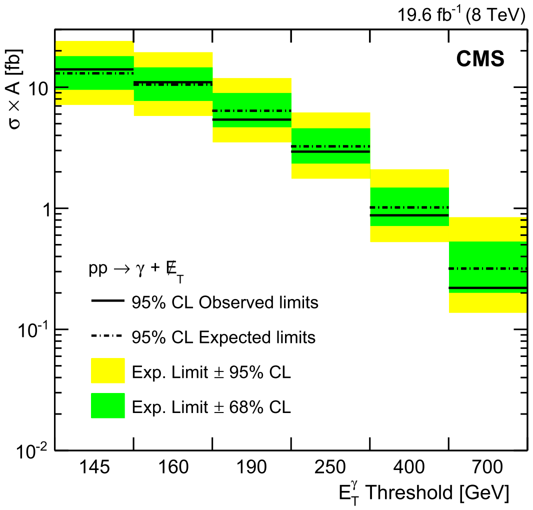

Fig. 2. Upper limits at 95% confidence level (CL) on the product of cross section and acceptance as a function of the E_T^γ threshold (>145 GeV) for the photon and $\not{E}_T$ final state.

Table 2
Observed (expected) 95% CL and 90% CL upper limits on σA as a function of the cut on the E_T^γ for the photon and $\not{E}_T$ final state. The $\not{E}_T$ threshold is fixed at 140 GeV. In addition to 95% CL upper limits, 90% limits are also shown to allow direct comparison with results from astrophysics DM searches.

E_T^γ threshold [GeV]	σA [fb] (95% CL)	σA [fb] (90% CL)
145	14 (13)	12 (11)
160	11 (10)	9.3 (8.8)
190	5.4 (6.4)	4.4 (5.4)
250	2.9 (3.2)	2.4 (2.7)
400	0.87 (1.0)	0.71 (0.83)
700	0.22 (0.32)	0.16 (0.25)

The product of the acceptance and the efficiency ($A\epsilon$) is estimated by calculating $A\epsilon_{MC}$ from the simulation, and multiplying it by the F to account for the difference in efficiency between simulation and data. The ADD, DM, and branon simulated samples are processed through the full GEANT4-based simulation of the CMS detector [26,27], trigger emulation, and the same event reconstruction programs as used for data. For DM production, the simulated samples are produced using MADGRAPH 5v1.3.12 [39], and requiring $E_T^\gamma > 130$ GeV and $|\eta^\gamma| < 1.5$. The estimated value of $A\epsilon_{MC}$ for M_χ in the range 1–1000 GeV varies over the range 41.6–44.4% for vector and 41.4–44.1% for axial-vector couplings, respectively. The E_T^γ spectra for ADD simulated events are generated using PYTHIA 8.153 [40], requiring $E_T^\gamma > 130$ GeV. The $A\epsilon_{MC}$ for the ADD model varies over the range 33.4–37.4% in the parameter space spanned by $n = 3$–6 and $M_D = 1$–3 TeV. The spectra for simulated branon events are generated using MADGRAPH 5v1.5.5 [39], requiring $E_T^\gamma > 130$ GeV. The value of $A\epsilon_{MC}$ for branon production varies over the range 41.3–48.9% in the parameter space spanned by the range of branon masses $M_B = 100$–3500 GeV and brane tensions $f = 100$–1000 GeV. The systematic uncertainty in $A\epsilon_{MC}$ from the modeling of pileup, the energy calibration, and the resolution for photons, jets, and $\not{E}_T$ is $\pm 2.1\%$. The systematic uncertainty from the scale factor is 6.4%, resulting in a total systematic uncertainty in $A\epsilon_{MC}$ of 6.7%. The systematic uncertainty in the measured integrated luminosity is $\pm 2.6\%$ [41]. Theoretical uncertainties in the acceptance of the signal processes, based on the choice of PDF and scale, are found to be of order 1%, and thus have a negligible effect on the observed limits.

Upper limits on the signal cross section are calculated using the CL_s method [42,43]. In the fit to the observed spectra, systematic uncertainties are represented by nuisance parameters with log-normal prior probability density functions. The changes in shape of the expected spectra that result from varying the photon energy

Table 3
Dark matter production cross sections as a function of the DM mass, assuming a vector interaction: theoretical DM production cross sections, where the generated photon transverse momentum is greater than 130 GeV and the contact interaction scale Λ is 10 TeV; observed (expected) 90% CL upper limits on the DM production cross section σ; 90% CL lower limits on the contact interaction scale Λ; and 90% CL upper limits on the χ-nucleon cross section.

Mass [GeV]	σ_{theo} [fb]	σ [fb]	Λ [GeV]	$\sigma_{\chi-\text{nucleon}}$ [cm^2]
1	2.5×10^{-4}	7.8 (10.6)	750 (694)	8.2×10^{-40} (1.1×10^{-39})
10	2.5×10^{-4}	8.0 (10.5)	745 (696)	2.6×10^{-39} (3.5×10^{-39})
100	2.4×10^{-4}	8.0 (11.2)	742 (684)	3.2×10^{-39} (4.4×10^{-39})
200	2.2×10^{-4}	7.6 (9.9)	729 (684)	3.4×10^{-39} (4.4×10^{-39})
300	1.8×10^{-4}	6.9 (9.4)	714 (660)	3.7×10^{-39} (5.1×10^{-39})
500	1.0×10^{-4}	5.2 (7.8)	666 (602)	4.9×10^{-39} (7.4×10^{-39})
1000	1.5×10^{-5}	4.9 (7.2)	422 (382)	3.1×10^{-38} (4.6×10^{-38})

Table 4
Dark matter production cross sections as a function of the DM mass, assuming an axial-vector interaction: theoretical DM production cross sections, where the generated photon transverse momentum is greater than 130 GeV and the contact interaction scale Λ is 10 TeV; observed (expected) 90% CL upper limits on the DM production cross section σ; 90% CL lower limits on the contact interaction scale Λ; and 90% CL upper limits on the χ-nucleon cross section.

Mass [GeV]	σ_{theo} [fb]	σ [fb]	Λ [GeV]	$\sigma_{\chi-\text{nucleon}}$ [cm^2]
1	2.4×10^{-4}	7.9 (10.5)	746 (694)	3.1×10^{-41} (4.1×10^{-41})
10	2.5×10^{-4}	7.9 (11.0)	748 (688)	9.6×10^{-41} (1.3×10^{-40})
100	2.2×10^{-4}	8.2 (10.7)	718 (671)	1.3×10^{-40} (1.7×10^{-40})
200	1.6×10^{-4}	6.7 (9.5)	702 (643)	1.5×10^{-40} (2.0×10^{-40})
300	1.1×10^{-4}	5.8 (8.5)	663 (604)	1.8×10^{-40} (2.6×10^{-40})
500	4.9×10^{-5}	5.5 (8.1)	544 (495)	4.0×10^{-40} (5.9×10^{-40})
1000	4.2×10^{-6}	5.3 (7.7)	298 (272)	4.5×10^{-39} (6.5×10^{-39})

scale and the theoretical differential cross section within their respective uncertainties are treated using a morphing technique [44]. The signal region studied in this analysis is defined with the requirement $E_{\text{T}}^{\gamma} > 145$ GeV. The observed and expected upper limits on the product of cross section and acceptance (σA), plotted as a function of the E_{T}^{γ} threshold (>145 GeV), are shown in Fig. 2 and listed in Table 2. Results shown can be generally applied to any new physics that leads to the photon and $\not\!\!E_{\text{T}}$ final state.

Tables 3 and 4 summarize the 90% CL upper limits on the production cross sections of the DM particles $\chi\bar{\chi}$, as a function of M_χ. In general, the effective operator could be a mixture of vector and axial terms; for explicitness, the limiting cases of pure vector and pure axial vector operators have been chosen, corresponding to spin-independent and spin-dependent interactions, respectively. Following the procedures of Refs. [2] and [5], the upper limits on the DM production cross sections are converted into corresponding lower limits on the contact interaction scale Λ, which are then translated into upper limits on the χ-nucleon scattering cross sections, calculated within the EFT framework. These results, as a function of M_χ, are listed in Tables 3 and 4 and also displayed in Fig. 3. Superimposed are the results published by other experiments [46–56].

The validity of the EFT framework at the energy scale probed by the LHC has been recently explored in detail [2,3,5,65–67]. These studies show that the condition $M \gg Q$ may not always be satisfied because of the high momentum transfer scale at the LHC energies. Therefore, to interpret the data in a meaningful way where the EFT does not hold, following [3] we consider a simplified model predicting DM production via an s-channel vector mediator. For this simplified model, the simulated samples are produced using MadGraph 5v1.5.12 [39], and requiring $E_{\text{T}}^{\gamma} > 130$ GeV and $|\eta^{\gamma}| < 1.5$. Limits on the SM–DM interaction mediator mass divided by coupling, for this model, are shown in Fig. 4. The mass of the mediator is varied for two fixed values of the mass of the DM particle: 50 GeV and 500 GeV, and the width of the mediator is varied from $M/8\pi$ to $M/3$ [3]. The contours for fixed values of $\sqrt{g_\chi g_{\text{q}}}$ are also shown for comparison. For $M_\chi = 500$ GeV the results for a mediator with a mass $\gtrsim$5 TeV are similar to those obtained from the EFT approach as listed in Table 3, while the limits are weaker for $M \lesssim 100$ GeV. The limits are stronger than those of the EFT approach in the range of M from ∼100 GeV to ∼4 TeV, because of the resonance production enhancement in the cross section. In other words, the limits derived within the EFT framework are conservative in this region. For illustration purposes, similar distributions for $M_\chi = 50$ GeV are also shown in Fig. 4.

Upper limits at 95% CL are also placed on the production cross section of the ADD and branon models, and translated into exclusions on the parameter space of the models. For the ADD model we follow the convention of Ref. [69] and only consider $\hat{s} < M_{\text{D}}^2$ when calculating the cross sections. The limits on M_{D} for several values of n, the number of extra dimensions, are summarized in Table 5. These limits, along with existing ADD limits from the Tevatron [58,59] and LEP [60–63], are shown in Fig. 5 as a function of M_{D}. All these results are based on LO cross sections. Our results extend significantly the experimental limits on the ADD model in the single-photon channel [64,70], and set limits of $M_{\text{D}} > 2.12$–1.97 TeV for $n = 3$–6, at 95% CL. These results are comparable with the recent ATLAS limits [57].

Limits on f for branons are summarized in Table 6. For massless branons, the brane tension f is found to be greater than 410 GeV at 95% CL. These limits along with the existing limits from LEP [68] and the Tevatron [13], are shown in Fig. 6. Branon masses $M_{\text{B}} < 3.5$ TeV are excluded at 95% CL for low brane tension (20 GeV). These bounds are the most stringent published to date. These limits complement astrophysical constraints already set on the branon parameters [12].

6. Summary

Proton–proton collision events containing a photon and missing transverse momentum have been investigated to search for new phenomena. In the $\sqrt{s} = 8$ TeV data set corresponding to 19.6 fb^{-1} of integrated luminosity, no deviations from the standard model predictions are observed. Bounds are placed on models predicting monophoton events; specifically, 95% confidence level upper limits for the cross section times acceptance for the selected final state are set and vary from 14.0 fb for $E_{\text{T}}^{\gamma} > 145$ GeV to 0.22 fb for $E_{\text{T}}^{\gamma} > 700$ GeV. Constraints are set on χ production and translated into upper limits on vector and axial-vector contributions to the χ-nucleon scattering cross section, assuming the validity of the

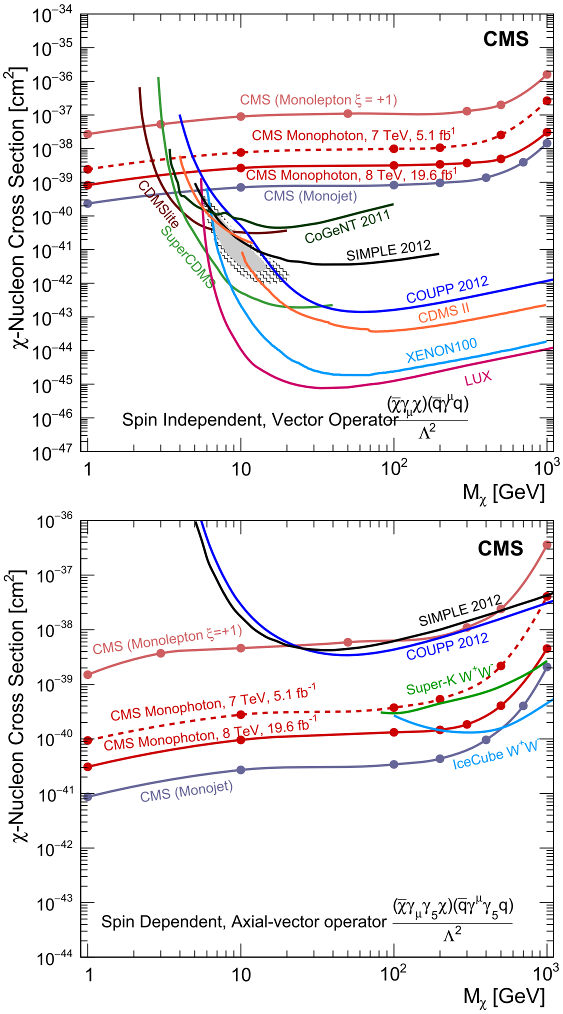

Fig. 3. The 90% CL upper limits on the χ-nucleon cross section as a function of the DM particle mass M_χ for spin-independent couplings (top) and spin-dependent couplings (bottom). Results from the current search are shown as "CMS Monophoton, 8 TeV". Shown are the limits from CMS using monojet [37] and monolepton [45] signatures (where ξ is the interference parameter addressing potentially different couplings to up- and down-type quarks and values of $\xi = \pm 1$ maximize the effects of interference). Also shown are the limits from several published direct detection experiments [46–55]. The solid and hatched contours show the 68% and 95% CL contours respectively for a possible signal from CDMS [56]. Limits similar to those from the current search are obtained by ATLAS [57].

EFT framework. For $M_\chi = 10$ GeV, the χ-nucleon cross section is constrained to be less than 2.6×10^{-39} cm^2 (9.6×10^{-41} cm^2) for a spin-independent (spin-dependent) interaction at 90% confidence level. In addition the most stringent limits to date are obtained on the effective Planck scale in the ADD model with large spatial extra dimensions and on the brane tension scale in the branon model.

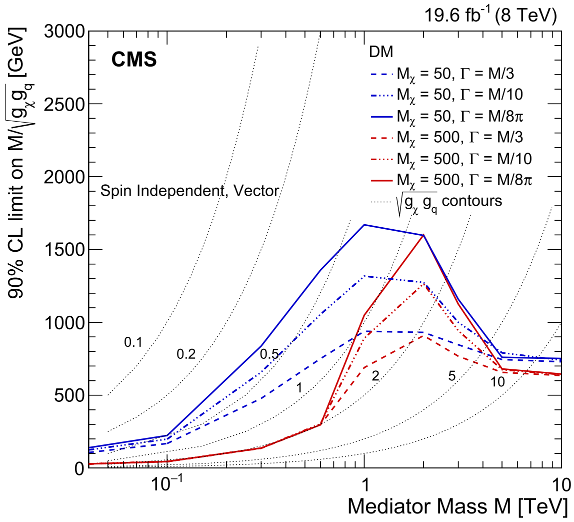

Fig. 4. Observed limits on the SM–DM interaction mediator mass divided by coupling, $M/\sqrt{g_\chi g_q}$, as a function of the mediator mass M, assuming vector interactions, for DM particle masses of 50 GeV and 500 GeV. The width, Γ, of the mediator is varied between $M/8\pi$ and $M/3$. The dotted lines show contours of constant coupling.

Table 5
Observed and expected 95% CL lower limits on ADD model parameters M_D, the effective Planck scale, as a function of n, the number of extra dimensions.

n	Obs. limit [TeV]	Exp. limit [TeV]
3	2.12	1.96
4	2.07	1.92
5	2.02	1.89
6	1.97	1.88

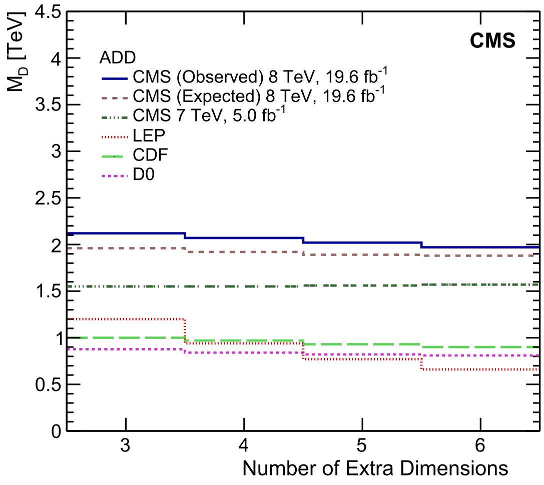

Fig. 5. The 95% CL lower limits on the effective Planck scale, M_D, as a function of the number of extra dimensions in the ADD model, together with LO results from similar searches at the Tevatron [58,59], LEP [60–63] and CMS [64].

Acknowledgements

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: BMWFW and FWF (Austria); Fonds De La Recherche Scientifique - 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); 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); NRF and WCU (Republic of Korea); LAS (Lithua-

Table 6
Observed and expected 95% CL lower limits on the brane tension f as a function of the branon mass M_B for $N = 1$.

	M_B [GeV]									
	100	500	1000	1500	2000	2500	2800	3000	3200	3500
Obs. limit [GeV]	410	380	320	240	170	97	59	48	36	20
Exp. limit [GeV]	400	370	310	240	170	97	59	48	36	20

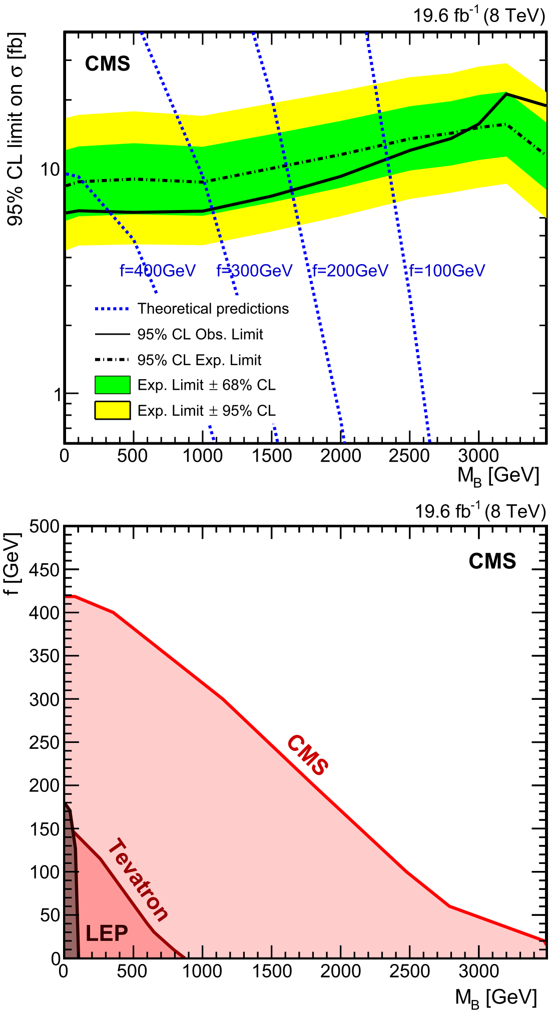

Fig. 6. The 95% CL upper limits on the branon cross sections as a function of the branon mass M_B for $N = 1$. Also shown are the theoretical cross sections in the branon model for the brane tension scale $f = 100$, 200, 300, and 400 GeV (top). Limits on f as a function of M_B, compared to results from similar searches at LEP [68] and the Tevatron [13] (bottom).

nia); MOE and UM (Malaysia); CINVESTAV, CONACYT, 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 Foundation for Polish Science, cofinanced from European Union, Regional Development Fund; the Compagnia di San Paolo (Torino); the Consorzio per la Fisica (Trieste); MIUR project 20108T4XTM (Italy); the Thalis and Aristeia programmes cofinanced by EU-ESF and the Greek NSRF; and the National Priorities Research Program by Qatar National Research Fund.

References

[1] R. Gaitskell, Direct detection of dark matter, Annu. Rev. Nucl. Part. Sci. 54 (2004) 315, http://dx.doi.org/10.1146/annurev.nucl.54.070103.181244.

[2] Y. Bai, P.J. Fox, R. Harnik, The Tevatron at the frontier of dark matter direct detection, J. High Energy Phys. 12 (2010) 048, http://dx.doi.org/10.1007/JHEP12(2010)048, arXiv:1005.3797v2.

[3] P.J. Fox, R. Harnik, J. Kopp, Y. Tsai, Missing energy signatures of dark matter at the LHC, Phys. Rev. D 85 (2012) 056011, http://dx.doi.org/10.1103/PhysRevD.85.056011, arXiv:1109.4398.

[4] J. Goodman, M. Ibe, A. Rajaraman, W. Shepherd, T.M.P. Tait, H.-B. Yu, Constraints on light Majorana dark matter from colliders, Phys. Lett. B 695 (2011) 185, http://dx.doi.org/10.1016/j.physletb.2010.11.009, arXiv:1005.1286.

[5] J. Goodman, M. Ibe, A. Rajaraman, W. Shepherd, T.M.P. Tait, H.-B. Yu, Constraints on dark matter from colliders, Phys. Rev. D 82 (2010) 116010, http://dx.doi.org/10.1103/PhysRevD.82.116010, arXiv:1008.1783.

[6] N. Arkani-Hamed, S. Dimopoulos, G.R. Dvali, The hierarchy problem and new dimensions at a millimeter, Phys. Lett. B 429 (1998) 263, http://dx.doi.org/10.1016/S0370-2693(98)00466-3, arXiv:hep-ph/9803315.

[7] N. Arkani-Hamed, S. Dimopoulos, G.R. Dvali, Phenomenology, astrophysics and cosmology of theories with submillimeter dimensions and TeV scale quantum gravity, Phys. Rev. D 59 (1999) 086004, http://dx.doi.org/10.1103/PhysRevD.59.086004, arXiv:hep-ph/9807344.

[8] R. Sundrum, Effective field theory for a three-brane universe, Phys. Rev. D 59 (1999) 085009, http://dx.doi.org/10.1103/PhysRevD.59.085009, arXiv:hep-ph/9805471.

[9] A. Dobado, A.L. Maroto, The dynamics of the goldstone bosons on the brane, Nucl. Phys. B 592 (2001) 203, http://dx.doi.org/10.1016/S0550-3213(00)00574-5, arXiv:hep-ph/0007100.

[10] J.A.R. Cembranos, A. Dobado, A.L. Maroto, Brane skyrmions and wrapped states, Phys. Rev. D 65 (2002) 026005, http://dx.doi.org/10.1103/PhysRevD.65.026005, arXiv:hep-ph/0106322.

[11] J.A.R. Cembranos, R.L. Delgado, A. Dobado, Brane worlds at the LHC: branons and KK gravitons, Phys. Rev. D 88 (2013) 075021, http://dx.doi.org/10.1103/PhysRevD.88.075021, arXiv:1306.4900.

[12] J.A.R. Cembranos, A. Dobado, A.L. Maroto, Cosmological and astrophysical limits on brane fluctuations, Phys. Rev. D 68 (2003) 103505, http://dx.doi.org/10.1103/PhysRevD.68.103505, arXiv:hep-ph/0307062.

[13] J.A.R. Cembranos, A. Dobado, A.L. Maroto, Branon search in hadronic colliders, Phys. Rev. D 70 (2004) 096001, http://dx.doi.org/10.1103/PhysRevD.70.096001, arXiv:hep-ph/0405286.

[14] CMS Collaboration, Energy calibration and resolution of the CMS electromagnetic calorimeter in pp collisions at $\sqrt{s} = 7$ TeV, J. Instrum. 8 (2013) P09009, http://dx.doi.org/10.1088/1748-0221/8/09/P09009, arXiv:1306.2016.

[15] 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.

[16] CMS Collaboration, Performance of photon reconstruction and identification with the CMS detector in proton–proton collisions at $\sqrt{s} = 8$ TeV, J. Instrum. (2015), arXiv:1502.02702, submitted for publication.

[17] CMS Collaboration, Isolated photon reconstruction and identification at $\sqrt{s} = 7$ TeV, CMS physics analysis summary CMS-PAS-EGM-10-006, 2011, URL: http://cdsweb.cern.ch/record/1324545.

[18] CMS Collaboration, Particle-flow event reconstruction in CMS and performance for jets, taus, and MET, CMS physics analysis summary CMS-PAS-PFT-09-001, 2009, URL: http://cdsweb.cern.ch/record/1194487.

[19] 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.

[20] M. Cacciari, G.P. Salam, G. Soyez, The catchment area of jets, J. High Energy Phys. 04 (2008) 005, http://dx.doi.org/10.1088/1126-6708/2008/04/005, arXiv:0802.1188.

[21] CMS Collaboration, Mitigation of anomalous APD signals in the CMS electromagnetic calorimeter, in: XVth International Conference on Calorimetry in High Energy Physics, CALOR2012, Santa Fe, USA, 2012, J. Phys. Conf. Ser. 404 (2012) 012043, http://dx.doi.org/10.1088/1742-6596/404/1/012043.

[22] CMS Collaboration, Electron reconstruction and identification at $\sqrt{s} = 7$ TeV, CMS physics analysis summary CMS-PAS-EGM-10-004, 2010, URL: http://cdsweb.cern.ch/record/1299116.

[23] 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.

[24] CMS Collaboration, Pileup jet identification, CMS physics analysis summary CMS-PAS-JME-13-005, 2013, URL: http://cdsweb.cern.ch/record/1581583.

[25] CMS Collaboration, MET performance in 8 TeV data, CMS physics analysis summary CMS-PAS-JME-12-002, 2013, URL: http://cdsweb.cern.ch/record/1543527.

[26] S. Agostinelli, et al., GEANT4 Collaboration, Geant4—a simulation toolkit, Nucl. Instrum. Methods A 506 (2003) 250, http://dx.doi.org/10.1016/S0168-9002(03)01368-8.

[27] J. Allison, et al., Geant4 developments and applications, IEEE Trans. Nucl. Sci. 53 (2006) 270, http://dx.doi.org/10.1109/TNS.2006.869826.

[28] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H.-S. Shao, T. Stelzer, P. Torielli, 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.

[29] J. Campbell, R. Ellis, C. Williams, MCFM v6.1: a Monte Carlo for FeMtobarn processes at hadron colliders, URL: http://mcfm.fnal.gov/mcfm.pdf, 2011.

[30] S. Alekhin, et al., The PDF4LHC working group interim report, arXiv:1101.0536, 2011.

[31] M. Botje, J. Butterworth, A. Cooper-Sarkar, A. de Roeck, J. Feltesse, S. Forte, A. Glazov, J. Huston, R. McNulty, T. Sjöstrand, R. Thorne, The PDF4LHC working group interim recommendations, arXiv:1101.0538, 2011.

[32] R.D. Ball, V. Bertone, F. Cerutti, L. Del Debbio, S. Forte, A. Guffanti, J.I. Latorre, J. Rojo, M. Ubiali, NNPDF Collaboration, Impact of heavy quark masses on parton distributions and LHC phenomenology, Nucl. Phys. B 849 (2011) 296, http://dx.doi.org/10.1016/j.nuclphysb.2011.03.021, arXiv:1101.1300.

[33] T. Sjöstrand, S. Mrenna, P.Z. Skands, Pythia 6.4 physics and manual, J. High Energy Phys. 05 (2006) 26, http://dx.doi.org/10.1088/1126-6708/2006/05/026, arXiv:hep-ph/0603175.

[34] J. Pumplin, D.R. Stump, J. Huston, H.-L. Lai, P. Nadolsky, W.-K. Tung, New generation of parton distributions with uncertainties from global QCD analysis, J. High Energy Phys. 07 (2002) 012, http://dx.doi.org/10.1088/1126-6708/2002/07/012, arXiv:hep-ph/0201195.

[35] 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, arXiv:1107.4277.

[36] CMS Collaboration, Missing transverse energy performance of the CMS detector, J. Instrum. 6 (2011) P09001, http://dx.doi.org/10.1088/1748-0221/6/09/P09001.

[37] CMS Collaboration, Search for dark matter, extra dimensions, and unparticles in monojet events in proton–proton collisions at $\sqrt{s} = 8$ TeV, Eur. Phys. J. C (2014), arXiv:1408.3583, submitted for publication.

[38] CMS Collaboration, Measurement of the inclusive W and Z production cross sections in pp collisions at $\sqrt{s} = 7$ TeV with the CMS experiment, J. High Energy Phys. 10 (2011) 132, http://dx.doi.org/10.1007/JHEP10(2011)132.

[39] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer, T. Stelzer, MadGraph 5: going beyond, J. High Energy Phys. 06 (2011) 128, http://dx.doi.org/10.1007/JHEP06(2011)128, arXiv:1106.0522.

[40] T. Sjöstrand, S. Mrenna, P. 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.

[41] CMS Collaboration, CMS luminosity based on pixel cluster counting – summer 2013 update, CMS physics analysis summary CMS-PAS-LUM-13-001 2013, URL: http://cdsweb.cern.ch/record/1598864.

[42] 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.

[43] 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.

[44] J.S. Conway, Nuisance parameters in likelihoods for multisource spectra, in: H.B. Propser, L. Lyons (Eds.), Proceedings of PHYSTAT 2011 Workshop on Statistical Issues Related to Discovery Claims in Search Experiments and Unfolding, CERN, Geneva, Switzerland, 2011, p. 115.

[45] CMS Collaboration, Search for physics beyond the standard model in final states with a lepton and missing transverse energy in proton–proton collisions at $\sqrt{s} = 8$ TeV, Phys. Rev. D (2014), arXiv:1408.2745, submitted for publication.

[46] E. Aprile, et al., XENON100 Collaboration, Dark matter results from 225 live days of XENON100 data, Phys. Rev. Lett. 109 (2012) 181301, http://dx.doi.org/10.1103/PhysRevLett.109.181301, arXiv:1207.5988.

[47] Z. Ahmed, et al., CDMS Collaboration, Results from a low-energy analysis of the CDMS II germanium data, Phys. Rev. Lett. 106 (2011) 131302, http://dx.doi.org/10.1103/PhysRevLett.106.131302, arXiv:1011.2482v3.

[48] Z. Ahmed, et al., CDMS II Collaboration, Dark matter search results from the CDMS II experiment, Science 327 (2010) 1619, http://dx.doi.org/10.1126/science.1186112.

[49] C.E. Aalseth, et al., 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, http://dx.doi.org/10.1103/PhysRevLett.106.131301, arXiv:1002.4703.

[50] M. Felizardo, et al., SIMPLE Collaboration, Final analysis and results of the phase II SIMPLE dark matter search, Phys. Rev. Lett. 108 (2012) 201302, http://dx.doi.org/10.1103/PhysRevLett.108.201302, arXiv:1106.3014.

[51] E. Behnke, et al., COUPP Collaboration, First dark matter search results from a 4-kg CF_3I bubble chamber operated in a deep underground site, Phys. Rev. D 86 (2012) 052001, http://dx.doi.org/10.1103/PhysRevD.86.052001, arXiv:1204.3094.

[52] M.G. Aartsen, et al., IceCube Collaboration, Search for dark matter annihilations in the sun with the 79-string IceCube detector, Phys. Rev. Lett. 110 (2013) 131302, http://dx.doi.org/10.1103/PhysRevLett.110.131302, arXiv:1212.4097.

[53] T. Tanaka, et al., Super-Kamiokande Collaboration, 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, http://dx.doi.org/10.1088/0004-637X/742/2/78, arXiv:1108.3384.

[54] D.S. Akerib, et al., LUX Collaboration, First results from the LUX dark matter experiment at the Sanford Underground Research Facility, Phys. Rev. Lett. 112 (2014) 091303, http://dx.doi.org/10.1103/PhysRevLett.112.091303, arXiv:1310.8214.

[55] R. Agnese, et al., SuperCDMS Soudan Collaboration, Search for low-mass weakly interacting massive particles using voltage-assisted calorimetric ionization detection in the SuperCDMS experiment, Phys. Rev. Lett. 112 (2014) 041302, http://dx.doi.org/10.1103/PhysRevLett.112.041302, arXiv:1309.3259.

[56] R. Agnese, et al., CDMS Collaboration, Silicon detector dark matter results from the final exposure of CDMS II, Phys. Rev. Lett. 111 (2013) 251301, http://dx.doi.org/10.1103/PhysRevLett.111.251301, arXiv:1304.4279.

[57] ATLAS Collaboration, Search for new phenomena in events with a photon and missing transverse momentum in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector, Phys. Rev. D 91 (2015) 012008, http://dx.doi.org/10.1103/PhysRevD.91.012008, arXiv:1411.1559.

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

[59] V.M. Abazov, et al., 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, http://dx.doi.org/10.1103/PhysRevLett.101.011601, arXiv:0803.2137.

[60] J. Abdallah, et al., 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, http://dx.doi.org/10.1140/epjc/s2004-02051-8, arXiv:hep-ex/0406019.

[61] P. Achard, et al., L3 Collaboration, Single- and multi-photon events with missing energy in e^+e^- collisions at LEP, Phys. Lett. B 587 (2004) 16, http://dx.doi.org/10.1016/j.physletb.2004.01.010, arXiv:hep-ex/0402002.

[62] G. Abbiendi, et al., OPAL Collaboration, Photonic events with missing energy in e^+e^- collisions at $\sqrt{s} = 189$ GeV, Eur. Phys. J. C 18 (2000) 253, http://dx.doi.org/10.1007/s100520000522, arXiv:hep-ex/0005002.

[63] A. Heister, et al., ALEPH Collaboration, Single photon and multiphoton production in e^+e^- collisions at $\sqrt{s}$ up to 209 GeV, Eur. Phys. J. C 28 (2003) 1, http://dx.doi.org/10.1140/epjc/s2002-01129-7.

[64] CMS Collaboration, Search for dark matter and large extra dimensions in pp collisions yielding a photon and missing transverse energy, Phys. Rev. Lett. 108 (2012) 261803, http://dx.doi.org/10.1103/PhysRevLett.108.261803, arXiv:1204.0821.
[65] H. An, X. Ji, L.-T. Wang, Light dark matter and Z' dark force at colliders, J. High Energy Phys. 07 (2012) 182, http://dx.doi.org/10.1007/JHEP07(2012)182, arXiv:1202.2894.
[66] A. Friedland, M.L. Graesser, I.M. Shoemaker, L. Vecchi, Probing nonstandard standard model backgrounds with LHC monojets, Phys. Lett. B 714 (2012) 267, http://dx.doi.org/10.1016/j.physletb.2012.06.078, arXiv:1111.5331.
[67] O. Buchmueller, M.J. Dolan, C. McCabe, Beyond effective field theory for dark matter searches at the LHC, J. High Energy Phys. 01 (2014) 025, http://dx.doi.org/10.1007/JHEP01(2014)025, arXiv:1308.6799.
[68] P. Achard, et al., L3 Collaboration, Search for branons at LEP, Phys. Lett. B 597 (2004) 145, http://dx.doi.org/10.1016/j.physletb.2004.07.014, arXiv:hep-ex/0407017.
[69] G.F. Giudice, R. Rattazzi, J.D. Wells, Quantum gravity and extra dimensions at high-energy colliders, Nucl. Phys. B 544 (1999) 3, http://dx.doi.org/10.1016/S0550-3213(99)00044-9, arXiv:hep-ph/9811291.
[70] ATLAS Collaboration, Search for dark matter candidates and large extra dimensions in events with a photon and missing transverse momentum in pp collision data at $\sqrt{s} = 7$ TeV with the ATLAS detector, Phys. Rev. Lett. 110 (2013) 011802, http://dx.doi.org/10.1103/PhysRevLett.110.011802, arXiv:1209.4625.

CMS Collaboration

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

Yerevan Physics Institute, Yerevan, Armenia

W. Adam, T. Bergauer, M. Dragicevic, J. Erö, M. Friedl, R. Frühwirth [1], V.M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler [1], W. Kiesenhofer, V. Knünz, M. Krammer [1], I. Krätschmer, D. Liko, I. Mikulec, D. Rabady [2], B. Rahbaran, H. Rohringer, R. Schöfbeck, J. Strauss, W. Treberer-Treberspurg, W. Waltenberger, C.-E. Wulz [1]

Institut für Hochenergiephysik der OeAW, Wien, Austria

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

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

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

Universiteit Antwerpen, Antwerpen, Belgium

F. Blekman, S. Blyweert, J. D'Hondt, N. Daci, N. Heracleous, J. Keaveney, S. Lowette, M. Maes, A. Olbrechts, Q. Python, D. Strom, S. Tavernier, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Villella

Vrije Universiteit Brussel, Brussel, Belgium

C. Caillol, B. Clerbaux, G. De Lentdecker, D. Dobur, L. Favart, A.P.R. Gay, A. Grebenyuk, A. Léonard, A. Mohammadi, L. Perniè [2], T. Reis, T. Seva, L. Thomas, C. Vander Velde, P. Vanlaer, J. Wang, F. Zenoni

Université Libre de Bruxelles, Bruxelles, Belgium

V. Adler, K. Beernaert, L. Benucci, A. Cimmino, S. Costantini, S. Crucy, S. Dildick, A. Fagot, G. Garcia, J. Mccartin, A.A. Ocampo Rios, D. Ryckbosch, S. Salva Diblen, M. Sigamani, N. Strobbe, F. Thyssen, M. Tytgat, E. Yazgan, N. Zaganidis

Ghent University, Ghent, Belgium

S. Basegmez, C. Beluffi [3], G. Bruno, R. Castello, A. Caudron, L. Ceard, G.G. Da Silveira, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco [4], J. Hollar, A. Jafari, P. Jez, M. Komm, V. Lemaitre, C. Nuttens, D. Pagano, L. Perrini, A. Pin, K. Piotrzkowski, A. Popov [5], L. Quertenmont, M. Selvaggi, M. Vidal Marono, J.M. Vizan Garcia

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

N. Beliy, T. Caebergs, E. Daubie, G.H. Hammad

Université de Mons, Mons, Belgium

W.L. Aldá Júnior, G.A. Alves, L. Brito, M. Correa Martins Junior, T. Dos Reis Martins, C. Mora Herrera, M.E. Pol

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

W. Carvalho, J. Chinellato[6], A. Custódio, E.M. Da Costa, D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, H. Malbouisson, D. Matos Figueiredo, L. Mundim, H. Nogima, W.L. Prado Da Silva, J. Santaolalla, A. Santoro, A. Sznajder, E.J. Tonelli Manganote[6], A. Vilela Pereira

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

C.A. Bernardes[b], S. Dogra[a], T.R. Fernandez Perez Tomei[a], E.M. Gregores[b], P.G. Mercadante[b], S.F. Novaes[a], Sandra S. Padula[a]

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

A. Aleksandrov, V. Genchev[2], P. Iaydjiev, A. Marinov, S. Piperov, M. Rodozov, G. Sultanov, M. Vutova

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

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

University of Sofia, Sofia, Bulgaria

J.G. Bian, G.M. Chen, H.S. Chen, M. Chen, T. Cheng, R. Du, C.H. Jiang, R. Plestina[7], F. Romeo, J. Tao, Z. Wang

Institute of High Energy Physics, Beijing, China

C. Asawatangtrakuldee, Y. Ban, Q. Li, S. Liu, Y. Mao, S.J. Qian, D. Wang, W. Zou

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

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

Universidad de Los Andes, Bogota, Colombia

N. Godinovic, D. Lelas, D. Polic, I. Puljak

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, K. Kadija, J. Luetic, D. Mekterovic, L. Sudic

Institute Rudjer Boskovic, Zagreb, Croatia

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

University of Cyprus, Nicosia, Cyprus

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

Charles University, Prague, Czech Republic

Y. Assran[9], S. Elgammal[10], M.A. Mahmoud[11], A. Radi[12,13]

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

M. Kadastik, M. Murumaa, M. Raidal, A. Tiko

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

P. Eerola, G. Fedi, M. Voutilainen

Department of Physics, University of Helsinki, Helsinki, Finland

J. Härkönen, 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, 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, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, J. Malcles, J. Neveu, J. Rander, A. Rosowsky, M. Titov

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

S. Baffioni, F. Beaudette, P. Busson, C. Charlot, T. Dahms, M. Dalchenko, L. Dobrzynski, N. Filipovic, A. Florent, R. Granier de Cassagnac, L. Mastrolorenzo, P. Miné, C. Mironov, I.N. Naranjo, M. Nguyen, C. Ochando, P. Paganini, S. Regnard, R. Salerno, J.B. Sauvan, Y. Sirois, C. Veelken, 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, E.C. Chabert, C. Collard, E. Conte[14], J.-C. Fontaine[14], D. Gelé, U. Goerlach, C. Goetzmann, A.-C. Le Bihan, 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, N. Beaupere, G. Boudoul[2], E. Bouvier, S. Brochet, C.A. Carrillo Montoya, J. Chasserat, R. Chierici, D. Contardo[2], P. Depasse, H. El Mamouni, J. Fan, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, M. Lethuillier, L. Mirabito, S. Perries, J.D. Ruiz Alvarez, D. Sabes, L. Sgandurra, V. Sordini, M. Vander Donckt, P. Verdier, S. Viret, H. Xiao

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

L. Rurua

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

C. Autermann, S. Beranek, M. Bontenackels, M. Edelhoff, L. Feld, A. Heister, O. Hindrichs, K. Klein, A. Ostapchuk, F. Raupach, J. Sammet, S. Schael, H. Weber, B. Wittmer, V. Zhukov[5]

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

M. Ata, M. Brodski, E. Dietz-Laursonn, D. Duchardt, M. Erdmann, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, D. Klingebiel, S. Knutzen, P. Kreuzer, M. Merschmeyer, A. Meyer, P. Millet, M. Olschewski, K. Padeken, P. Papacz, H. Reithler, S.A. Schmitz, L. Sonnenschein, D. Teyssier, S. Thüer, M. Weber

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

V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, A. Künsken, J. Lingemann[2], A. Nowack, I.M. Nugent, L. Perchalla, O. Pooth, A. Stahl

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

I. Asin, N. Bartosik, J. Behr, W. Behrenhoff, U. Behrens, A.J. Bell, M. Bergholz [15], A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, S. Choudhury, F. Costanza, C. Diez Pardos, G. Dolinska, S. Dooling, T. Dorland, G. Eckerlin, D. Eckstein, T. Eichhorn, G. Flucke, J. Garay Garcia, A. Geiser, P. Gunnellini, J. Hauk, M. Hempel [15], D. Horton, H. Jung, A. Kalogeropoulos, M. Kasemann, P. Katsas, J. Kieseler, C. Kleinwort, I. Korol, D. Krücker, W. Lange, J. Leonard, K. Lipka, A. Lobanov, W. Lohmann [15], B. Lutz, R. Mankel, I. Marfin [15], I.-A. Melzer-Pellmann, A.B. Meyer, G. Mittag, J. Mnich, A. Mussgiller, S. Naumann-Emme, A. Nayak, O. Novgorodova, E. Ntomari, H. Perrey, D. Pitzl, R. Placakyte, A. Raspereza, P.M. Ribeiro Cipriano, B. Roland, E. Ron, M.Ö. Sahin, J. Salfeld-Nebgen, P. Saxena, R. Schmidt [15], T. Schoerner-Sadenius, M. Schröder, C. Seitz, S. Spannagel, A.D.R. Vargas Trevino, R. Walsh, C. Wissing

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, V. Blobel, M. Centis Vignali, A.R. Draeger, J. Erfle, E. Garutti, K. Goebel, M. Görner, J. Haller, M. Hoffmann, R.S. Höing, H. Kirschenmann, R. Klanner, R. Kogler, J. Lange, T. Lapsien, T. Lenz, I. Marchesini, J. Ott, T. Peiffer, A. Perieanu, N. Pietsch, J. Poehlsen, T. Poehlsen, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, M. Seidel, V. Sola, H. Stadie, G. Steinbrück, D. Troendle, E. Usai, L. Vanelderen, A. Vanhoefer

University of Hamburg, Hamburg, Germany

C. Barth, C. Baus, J. Berger, C. Böser, E. Butz, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, F. Frensch, M. Giffels, A. Gilbert, F. Hartmann [2], T. Hauth [2], U. Husemann, I. Katkov [5], A. Kornmayer [2], E. Kuznetsova, P. Lobelle Pardo, M.U. Mozer, Th. Müller, A. Nürnberg, G. Quast, K. Rabbertz, S. Röcker, H.J. Simonis, F.M. Stober, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, R. Wolf

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

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

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

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

University of Athens, Athens, Greece

X. Aslanoglou, I. Evangelou, G. Flouris, C. Foudas, P. Kokkas, N. Manthos, I. Papadopoulos, E. Paradas, J. Strologas

University of Ioánnina, Ioánnina, Greece

G. Bencze, C. Hajdu, P. Hidas, D. Horvath [16], F. Sikler, V. Veszpremi, G. Vesztergombi [17], A.J. Zsigmond

Wigner Research Centre for Physics, Budapest, Hungary

N. Beni, S. Czellar, J. Karancsi [18], J. Molnar, J. Palinkas, Z. Szillasi

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

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

University of Debrecen, Debrecen, Hungary

S.K. Swain

National Institute of Science Education and Research, Bhubaneswar, India

S.B. Beri, V. Bhatnagar, R. Gupta, U. Bhawandeep, A.K. Kalsi, M. Kaur, R. Kumar, M. Mittal, N. Nishu, J.B. Singh

Panjab University, Chandigarh, India

Ashok Kumar, Arun Kumar, S. Ahuja, A. Bhardwaj, B.C. Choudhary, A. Kumar, S. Malhotra, M. Naimuddin, K. Ranjan, V. Sharma

University of Delhi, Delhi, India

S. Banerjee, S. Bhattacharya, K. Chatterjee, S. Dutta, B. Gomber, Sa. Jain, Sh. Jain, R. Khurana, A. Modak, S. Mukherjee, D. Roy, S. Sarkar, M. Sharan

Saha Institute of Nuclear Physics, Kolkata, India

A. Abdulsalam, D. Dutta, S. Kailas, V. Kumar, A.K. Mohanty [2], L.M. Pant, P. Shukla, A. Topkar

Bhabha Atomic Research Centre, Mumbai, India

T. Aziz, S. Banerjee, S. Bhowmik [19], R.M. Chatterjee, R.K. Dewanjee, S. Dugad, S. Ganguly, S. Ghosh, M. Guchait, A. Gurtu [20], G. Kole, S. Kumar, M. Maity [19], G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage [21]

Tata Institute of Fundamental Research, Mumbai, India

H. Bakhshiansohi, H. Behnamian, S.M. Etesami [22], A. Fahim [23], R. Goldouzian, M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi, F. Rezaei Hosseinabadi, B. Safarzadeh [24], 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], S.S. Chhibra [a,b], A. Colaleo [a], D. Creanza [a,c], N. De Filippis [a,c], M. De Palma [a,b], L. Fiore [a], G. Iaselli [a,c], G. Maggi [a,c], M. Maggi [a], S. My [a,c], S. Nuzzo [a,b], A. Pompili [a,b], G. Pugliese [a,c], R. Radogna [a,b,2], G. Selvaggi [a,b], A. Sharma, L. Silvestris [a,2], R. Venditti [a,b]

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

G. Abbiendi [a], A.C. Benvenuti [a], 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], 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], F. Primavera [a,b], A.M. Rossi [a,b], T. Rovelli [a,b], G.P. Siroli [a,b], N. Tosi [a,b], R. Travaglini [a,b]

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

S. Albergo [a,b], G. Cappello [a], M. Chiorboli [a,b], S. Costa [a,b], F. Giordano [a,c,2], 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*
[c] *CSFNSM, Catania, Italy*

G. Barbagli [a], V. Ciulli [a,b], C. Civinini [a], R. D'Alessandro [a,b], E. Focardi [a,b], E. Gallo [a], S. Gonzi [a,b], V. Gori [a,b,2], P. Lenzi [a,b], M. Meschini [a], S. Paoletti [a], G. Sguazzoni [a], A. Tropiano [a,b]

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

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

INFN Laboratori Nazionali di Frascati, Frascati, Italy

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

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

M.E. Dinardo [a,b], S. Fiorendi [a,b], S. Gennai [a,2], R. Gerosa [a,b,2], A. Ghezzi [a,b], P. Govoni [a,b], M.T. Lucchini [a,b,2], S. Malvezzi [a], R.A. Manzoni [a,b], A. Martelli [a,b], B. Marzocchi [a,b], D. Menasce [a], L. Moroni [a], M. Paganoni [a,b], D. Pedrini [a], S. Ragazzi [a,b], N. Redaelli [a], 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], S. Di Guida [a,d,2], F. Fabozzi [a,c], A.O.M. Iorio [a,b], L. Lista [a], S. Meola [a,d,2], M. Merola [a], P. Paolucci [a,2]

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

P. Azzi [a], N. Bacchetta [a], D. Bisello [a,b], A. Branca [a,b], R. Carlin [a,b], P. Checchia [a], M. Dall'Osso [a,b], T. Dorigo [a], M. Galanti [a,b], U. Gasparini [a,b], P. Giubilato [a,b], A. Gozzelino [a], K. Kanishchev [a,c], 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. Tosi [a,b], S. Vanini [a,b], S. Ventura [a], P. Zotto [a,b], A. Zucchetta [a,b], G. Zumerle [a,b]

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

M. Gabusi [a,b], S.P. Ratti [a,b], V. Re [a], C. Riccardi [a,b], P. Salvini [a], P. Vitulo [a,b]

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

M. Biasini [a,b], G.M. Bilei [a], D. Ciangottini [a,b], L. Fanò [a,b], P. Lariccia [a,b], G. Mantovani [a,b], M. Menichelli [a], A. Saha [a], A. Santocchia [a,b], A. Spiezia [a,b,2]

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

K. Androsov [a,25], P. Azzurri [a], G. Bagliesi [a], J. Bernardini [a], T. Boccali [a], G. Broccolo [a,c], R. Castaldi [a], M.A. Ciocci [a,25], R. Dell'Orso [a], S. Donato [a,c], F. Fiori [a,c], L. Foà [a,c], A. Giassi [a], M.T. Grippo [a,25], F. Ligabue [a,c], T. Lomtadze [a], L. Martini [a,b], A. Messineo [a,b], C.S. Moon [a,26], F. Palla [a,2], A. Rizzi [a,b], A. Savoy-Navarro [a,27], A.T. Serban [a], P. Spagnolo [a], P. Squillacioti [a,25], R. Tenchini [a], G. Tonelli [a,b], A. Venturi [a], P.G. Verdini [a], C. Vernieri [a,c,2]

[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], G. D'imperio [a,b], D. Del Re [a,b], M. Diemoz [a], C. Jorda [a], E. Longo [a,b], F. Margaroli [a,b], P. Meridiani [a], F. Micheli [a,b,2], S. Nourbakhsh [a,b], G. Organtini [a,b], R. Paramatti [a], S. Rahatlou [a,b], C. Rovelli [a], F. Santanastasio [a,b], L. Soffi [a,b,2], P. Traczyk [a,b]

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

N. Amapane [a,b], R. Arcidiacono [a,c], S. Argiro [a,b], M. Arneodo [a,c], R. Bellan [a,b], C. Biino [a], N. Cartiglia [a], S. Casasso [a,b,2], M. Costa [a,b], A. Degano [a,b], N. Demaria [a], L. Finco [a,b], C. Mariotti [a], S. Maselli [a], E. Migliore [a,b], V. Monaco [a,b], M. Musich [a], M.M. Obertino [a,c,2], G. Ortona [a,b], L. Pacher [a,b], N. Pastrone [a], M. Pelliccioni [a], G.L. Pinna Angioni [a,b], A. Potenza [a,b], A. Romero [a,b], M. Ruspa [a,c], R. Sacchi [a,b], A. Solano [a,b], A. Staiano [a], U. Tamponi [a]

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

S. Belforte [a], V. Candelise [a,b], M. Casarsa [a], F. Cossutti [a], G. Della Ricca [a,b], B. Gobbo [a], C. La Licata [a,b], M. Marone [a,b], A. Schizzi [a,b], T. Umer [a,b], A. Zanetti [a]

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

S. Chang, A. Kropivnitskaya, S.K. Nam

Kangwon National University, Chunchon, Republic of Korea

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

Kyungpook National University, Daegu, Republic of Korea

T.J. Kim

Chonbuk National University, Jeonju, Republic of Korea

J.Y. Kim, S. Song

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

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

Korea University, Seoul, Republic of Korea

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

University of Seoul, Seoul, Republic of Korea

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

Sungkyunkwan University, Suwon, Republic of Korea

A. Juodagalvis

Vilnius University, Vilnius, Lithuania

J.R. Komaragiri, M.A.B. Md Ali

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

E. Casimiro Linares, H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz [28], A. Hernandez-Almada, R. Lopez-Fernandez, A. Sanchez-Hernandez

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

S. Carrillo Moreno, F. Vazquez Valencia

Universidad Iberoamericana, Mexico City, Mexico

I. Pedraza, H.A. Salazar Ibarguen

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, S. Reucroft

University of Canterbury, Christchurch, New Zealand

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

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

G. Brona, K. Bunkowski, M. Cwiok, W. Dominik, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, M. Olszewski, W. Wolszczak

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

P. Bargassa, C. Beirão Da Cruz E Silva, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, L. Lloret Iglesias, F. Nguyen, J. Rodrigues Antunes, J. Seixas, J. Varela, P. Vischia

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

S. Afanasiev, P. Bunin, I. Golutvin, V. Karjavin, V. Konoplyanikov, G. Kozlov, A. Lanev, A. Malakhov, V. Matveev[29], P. Moisenz, V. Palichik, V. Perelygin, M. Savina, S. Shmatov, S. Shulha, N. Skatchkov, V. Smirnov, A. Zarubin

Joint Institute for Nuclear Research, Dubna, Russia

V. Golovtsov, Y. Ivanov, V. Kim[30], P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev, An. Vorobyev

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

Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, 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, S. Semenov, A. Spiridonov, V. Stolin, E. Vlasov, A. Zhokin

Institute for Theoretical and Experimental Physics, Moscow, Russia

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

P.N. Lebedev Physical Institute, Moscow, Russia

A. Belyaev, E. Boos, V. Bunichev, M. Dubinin[31], L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, S. Obraztsov, V. Savrin, A. Snigirev

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

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

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

P. Adzic[32], M. Ekmedzic, J. Milosevic, V. Rekovic

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

J. Alcaraz Maestre, C. Battilana, E. Calvo, M. Cerrada, M. Chamizo Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, D. Domínguez Vázquez, 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

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

Universidad Autónoma de Madrid, Madrid, Spain

H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero

Universidad de Oviedo, Oviedo, Spain

J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, J. Duarte Campderros, M. Fernandez, G. Gomez, A. Graziano, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, J. Piedra Gomez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, 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, A. Benaglia, J. Bendavid, L. Benhabib, J.F. Benitez, C. Bernet[7], P. Bloch, A. Bocci, A. Bonato, O. Bondu, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, S. Colafranceschi[33], M. D’Alfonso, D. d’Enterria, A. Dabrowski, A. David, F. De Guio, A. De Roeck, S. De Visscher, E. Di Marco, M. Dobson, M. Dordevic, N. Dupont-Sagorin, A. Elliott-Peisert, J. Eugster, G. Franzoni, W. Funk, D. Gigi, K. Gill, D. Giordano, M. Girone, F. Glege, R. Guida, S. Gundacker, M. Guthoff, J. Hammer, M. Hansen, P. Harris, J. Hegeman, V. Innocente, P. Janot, K. Kousouris, K. Krajczar, P. Lecoq, C. Lourenço, N. Magini, L. Malgeri, M. Mannelli, J. Marrouche, L. Masetti, F. Meijers, S. Mersi, E. Meschi, F. Moortgat, S. Morovic, M. Mulders, P. Musella, L. Orsini, L. Pape, E. Perez, L. Perrozzi, A. Petrilli, G. Petrucciani, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, M. Plagge, A. Racz, G. Rolandi[34], M. Rovere, H. Sakulin, C. Schäfer, C. Schwick, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas[35], D. Spiga, J. Steggemann, B. Stieger, M. Stoye, Y. Takahashi, D. Treille, A. Tsirou, G.I. Veres[17], N. Wardle, H.K. Wöhri, H. Wollny, 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, D. Renker, T. Rohe

Paul Scherrer Institut, Villigen, Switzerland

F. Bachmair, L. Bäni, L. Bianchini, M.A. Buchmann, B. Casal, N. Chanon, G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, P. Eller, C. Grab, D. Hits, J. Hoss, W. Lustermann, B. Mangano, A.C. Marini, P. Martinez Ruiz del Arbol, M. Masciovecchio, D. Meister, N. Mohr, C. Nägeli[36], F. Nessi-Tedaldi, F. Pandolfi, F. Pauss, M. Peruzzi, M. Quittnat, L. Rebane, M. Rossini, A. Starodumov[37], M. Takahashi, K. Theofilatos, R. Wallny, H.A. Weber

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

C. Amsler[38], M.F. Canelli, V. Chiochia, A. De Cosa, A. Hinzmann, T. Hreus, B. Kilminster, C. Lange, B. Millan Mejias, J. Ngadiuba, P. Robmann, F.J. Ronga, S. Taroni, M. Verzetti, Y. Yang

Universität Zürich, Zurich, Switzerland

M. Cardaci, K.H. Chen, C. Ferro, C.M. Kuo, W. Lin, Y.J. Lu, R. Volpe, S.S. Yu

National Central University, Chung-Li, Taiwan

P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, P.H. Chen, C. Dietz, U. Grundler, W.-S. Hou, K.Y. Kao, Y.F. Liu, R.-S. Lu, D. Majumder, E. Petrakou, Y.M. Tzeng, R. Wilken

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[39], S. Cerci[40], C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, E. Gurpinar, I. Hos, E.E. Kangal, A. Kayis Topaksu, G. Onengut[41], K. Ozdemir, S. Ozturk[39], A. Polatoz, D. Sunar Cerci[40], B. Tali[40], H. Topakli[39], M. Vergili

Cukurova University, Adana, Turkey

I.V. Akin, B. Bilin, S. Bilmis, H. Gamsizkan[42], B. Isildak[43], G. Karapinar[44], K. Ocalan[45], S. Sekmen, U.E. Surat, M. Yalvac, M. Zeyrek

Middle East Technical University, Physics Department, Ankara, Turkey

E.A. Albayrak[46], E. Gülmez, M. Kaya[47], O. Kaya[48], T. Yetkin[49]

Bogazici University, Istanbul, Turkey

K. Cankocak, F.I. Vardarlı

Istanbul Technical University, Istanbul, Turkey

L. Levchuk, P. Sorokin

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

J.J. Brooke, E. Clement, D. Cussans, H. Flacher, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, J. Jacob, L. Kreczko, C. Lucas, Z. Meng, D.M. Newbold[50], S. Paramesvaran, A. Poll, T. Sakuma, S. Senkin, V.J. Smith, T. Williams

University of Bristol, Bristol, United Kingdom

K.W. Bell, A. Belyaev[51], C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, E. Olaiya, D. Petyt, C.H. Shepherd-Themistocleous, A. Thea, I.R. Tomalin, W.J. Womersley, S.D. Worm

Rutherford Appleton Laboratory, Didcot, United Kingdom

M. Baber, R. Bainbridge, O. Buchmuller, D. Burton, D. Colling, N. Cripps, M. Cutajar, P. Dauncey, G. Davies, M. Della Negra, P. Dunne, W. Ferguson, J. Fulcher, D. Futyan, G. Hall, G. Iles, M. Jarvis, G. Karapostoli, M. Kenzie, R. Lane, R. Lucas[50], L. Lyons, A.-M. Magnan, S. Malik, B. Mathias, J. Nash, A. Nikitenko[37], J. Pela, M. Pesaresi, K. Petridis, D.M. Raymond, S. Rogerson, A. Rose, C. Seez, P. Sharp[†], A. Tapper, M. Vazquez Acosta, T. Virdee, S.C. Zenz

Imperial College, London, United Kingdom

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

Brunel University, Uxbridge, United Kingdom

J. Dittmann, K. Hatakeyama, A. Kasmi, H. Liu, T. Scarborough

Baylor University, Waco, USA

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

The University of Alabama, Tuscaloosa, USA

A. Avetisyan, T. Bose, C. Fantasia, P. Lawson, C. Richardson, J. Rohlf, J. St. John, L. Sulak

Boston University, Boston, USA

J. Alimena, E. Berry, S. Bhattacharya, G. Christopher, D. Cutts, Z. Demiragli, N. Dhingra, A. Ferapontov, A. Garabedian, U. Heintz, G. Kukartsev, E. Laird, G. Landsberg, M. Luk, M. Narain, M. Segala, T. Sinthuprasith, T. Speer, J. Swanson

Brown University, Providence, USA

R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, R. Erbacher, M. Gardner, W. Ko, R. Lander, T. Miceli, M. Mulhearn, D. Pellett, J. Pilot, F. Ricci-Tam, M. Searle, S. Shalhout, J. Smith, M. Squires, D. Stolp, M. Tripathi, S. Wilbur, R. Yohay

University of California, Davis, Davis, USA

R. Cousins, P. Everaerts, C. Farrell, J. Hauser, M. Ignatenko, G. Rakness, E. Takasugi, V. Valuev, M. Weber

University of California, Los Angeles, USA

K. Burt, R. Clare, J. Ellison, J.W. Gary, G. Hanson, J. Heilman, M. Ivova Rikova, P. Jandir, E. Kennedy, F. Lacroix, O.R. Long, A. Luthra, M. Malberti, M. Olmedo Negrete, A. Shrinivas, S. Sumowidagdo, S. Wimpenny

University of California, Riverside, Riverside, USA

J.G. Branson, G.B. Cerati, S. Cittolin, R.T. D'Agnolo, A. Holzner, R. Kelley, D. Klein, J. Letts, I. Macneill, D. Olivito, S. Padhi, C. Palmer, M. Pieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, C. Welke, F. Würthwein, A. Yagil

University of California, San Diego, La Jolla, USA

D. Barge, J. Bradmiller-Feld, C. Campagnari, T. Danielson, A. Dishaw, V. Dutta, K. Flowers, M. Franco Sevilla, P. Geffert, C. George, F. Golf, L. Gouskos, J. Incandela, C. Justus, N. Mccoll, J. Richman, D. Stuart, W. To, C. West, J. Yoo

University of California, Santa Barbara, Santa Barbara, USA

A. Apresyan, A. Bornheim, J. Bunn, Y. Chen, J. Duarte, A. Mott, H.B. Newman, C. Pena, C. Rogan, M. Spiropulu, V. Timciuc, J.R. Vlimant, R. Wilkinson, S. Xie, R.Y. Zhu

California Institute of Technology, Pasadena, USA

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

Carnegie Mellon University, Pittsburgh, USA

J.P. Cumalat, W.T. Ford, A. Gaz, M. Krohn, E. Luiggi Lopez, U. Nauenberg, J.G. Smith, K. Stenson, K.A. Ulmer, S.R. Wagner

University of Colorado at Boulder, Boulder, USA

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

Cornell University, Ithaca, USA

D. Winn

Fairfield University, Fairfield, USA

S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, 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, V.D. Elvira, I. Fisk, J. Freeman, Y. Gao, E. Gottschalk, L. Gray, D. Green, S. Grünendahl, O. Gutsche, J. Hanlon, D. Hare, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, K. Kaadze, B. Klima, B. Kreis, S. Kwan, J. Linacre, D. Lincoln, R. Lipton, T. Liu, J. Lykken, K. Maeshima, J.M. Marraffino, V.I. Martinez Outschoorn, S. Maruyama, D. Mason, P. McBride, P. Merkel, K. Mishra, S. Mrenna, Y. Musienko[29], S. Nahn, C. Newman-Holmes, V. O'Dell, O. Prokofyev, E. Sexton-Kennedy, S. Sharma, A. Soha, W.J. Spalding, L. Spiegel, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, A. Whitbeck, J. Whitmore, F. Yang

Fermi National Accelerator Laboratory, Batavia, USA

D. Acosta, P. Avery, P. Bortignon, D. Bourilkov, M. Carver, D. Curry, S. Das, M. De Gruttola, G.P. Di Giovanni, R.D. Field, M. Fisher, I.K. Furic, J. Hugon, J. Konigsberg, A. Korytov, T. Kypreos, J.F. Low, K. Matchev, P. Milenovic[52], G. Mitselmakher, L. Muniz, A. Rinkevicius, L. Shchutska, M. Snowball, D. Sperka, J. Yelton, M. Zakaria

University of Florida, Gainesville, USA

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

Florida International University, Miami, USA

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

Florida State University, Tallahassee, USA

M.M. Baarmand, M. Hohlmann, H. Kalakhety, F. Yumiceva

Florida Institute of Technology, Melbourne, USA

M.R. Adams, L. Apanasevich, V.E. Bazterra, D. Berry, R.R. Betts, I. Bucinskaite, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, P. Kurt, D.H. Moon, C. O'Brien, C. Silkworth, P. Turner, N. Varelas

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

B. Bilki[53], W. Clarida, K. Dilsiz, F. Duru, M. Haytmyradov, J.-P. Merlo, H. Mermerkaya[54], A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok[46], A. Penzo, R. Rahmat, S. Sen, P. Tan, E. Tiras, J. Wetzel, K. Yi

The University of Iowa, Iowa City, USA

B.A. Barnett, B. Blumenfeld, S. Bolognesi, D. Fehling, A.V. Gritsan, P. Maksimovic, C. Martin, M. Swartz

Johns Hopkins University, Baltimore, USA

P. Baringer, A. Bean, G. Benelli, C. Bruner, R.P. Kenny III, M. Malek, M. Murray, D. Noonan, S. Sanders, J. Sekaric, R. Stringer, Q. Wang, J.S. Wood

The University of Kansas, Lawrence, USA

I. Chakaberia, A. Ivanov, S. Khalil, M. Makouski, Y. Maravin, L.K. Saini, S. Shrestha, N. Skhirtladze, I. Svintradze

Kansas State University, Manhattan, USA

J. Gronberg, D. Lange, F. Rebassoo, D. Wright

Lawrence Livermore National Laboratory, Livermore, USA

A. Baden, A. Belloni, B. Calvert, S.C. Eno, J.A. Gomez, N.J. Hadley, R.G. Kellogg, T. Kolberg, Y. Lu, M. Marionneau, A.C. Mignerey, K. Pedro, A. Skuja, M.B. Tonjes, S.C. Tonwar

University of Maryland, College Park, USA

A. Apyan, R. Barbieri, G. Bauer, W. Busza, I.A. Cali, M. Chan, L. Di Matteo, G. Gomez Ceballos, M. Goncharov, D. Gulhan, M. Klute, Y.S. Lai, Y.-J. Lee, A. Levin, P.D. Luckey, T. Ma, C. Paus, D. Ralph, C. Roland, G. Roland, G.S.F. Stephans, F. Stöckli, K. Sumorok, D. Velicanu, J. Veverka, B. Wyslouch, M. Yang, M. Zanetti, V. Zhukova

Massachusetts Institute of Technology, Cambridge, USA

B. Dahmes, A. Gude, S.C. Kao, K. Klapoetke, Y. Kubota, J. Mans, N. Pastika, R. Rusack, A. Singovsky, N. Tambe, J. Turkewitz

University of Minnesota, Minneapolis, USA

J.G. Acosta, S. Oliveros

University of Mississippi, Oxford, USA

E. Avdeeva, K. Bloom, S. Bose, D.R. Claes, A. Dominguez, R. Gonzalez Suarez, J. Keller, D. Knowlton, I. Kravchenko, J. Lazo-Flores, S. Malik, F. Meier, F. Ratnikov, G.R. Snow, M. Zvada

University of Nebraska-Lincoln, Lincoln, USA

J. Dolen, A. Godshalk, I. Iashvili, A. Kharchilava, A. Kumar, S. Rappoccio

State University of New York at Buffalo, Buffalo, USA

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

Northeastern University, Boston, USA

K.A. Hahn, A. Kubik, N. Mucia, N. Odell, B. Pollack, A. Pozdnyakov, M. Schmitt, S. Stoynev, K. Sung, M. Velasco, S. Won

Northwestern University, Evanston, USA

A. Brinkerhoff, K.M. Chan, A. Drozdetskiy, M. Hildreth, C. Jessop, D.J. Karmgard, N. Kellams, K. Lannon, W. Luo, S. Lynch, N. Marinelli, T. Pearson, M. Planer, R. Ruchti, N. Valls, M. Wayne, M. Wolf, A. Woodard

University of Notre Dame, Notre Dame, USA

L. Antonelli, J. Brinson, B. Bylsma, L.S. Durkin, S. Flowers, A. Hart, C. Hill, R. Hughes, K. Kotov, T.Y. Ling, D. Puigh, M. Rodenburg, G. Smith, B.L. Winer, H. Wolfe, H.W. Wulsin

The Ohio State University, Columbus, USA

O. Driga, P. Elmer, J. Hardenbrook, P. Hebda, A. Hunt, S.A. Koay, P. Lujan, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, P. Piroué, X. Quan, H. Saka, D. Stickland[2], C. Tully, J.S. Werner, A. Zuranski

Princeton University, Princeton, USA

E. Brownson, H. Mendez, J.E. Ramirez Vargas

University of Puerto Rico, Mayaguez, USA

V.E. Barnes, D. Benedetti, D. Bortoletto, M. De Mattia, L. Gutay, Z. Hu, M.K. Jha, M. Jones, K. Jung, M. Kress, N. Leonardo, D. Lopes Pegna, V. Maroussov, D.H. Miller, N. Neumeister, B.C. Radburn-Smith, X. Shi, I. Shipsey, D. Silvers, A. Svyatkovskiy, F. Wang, W. Xie, L. Xu, H.D. Yoo, J. Zablocki, Y. Zheng

Purdue University, West Lafayette, USA

N. Parashar, J. Stupak

Purdue University Calumet, Hammond, USA

A. Adair, B. Akgun, K.M. Ecklund, F.J.M. Geurts, W. Li, B. Michlin, B.P. Padley, R. Redjimi, J. Roberts, J. Zabel

Rice University, Houston, USA

B. Betchart, A. Bodek, R. Covarelli, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, A. Garcia-Bellido, P. Goldenzweig, J. Han, A. Harel, A. Khukhunaishvili, S. Korjenevski, G. Petrillo, D. Vishnevskiy

University of Rochester, Rochester, USA

R. Ciesielski, L. Demortier, K. Goulianos, G. Lungu, C. Mesropian

The Rockefeller University, New York, 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, S. Kaplan, A. Lath, S. Panwalkar, M. Park, R. Patel, S. Salur, S. Schnetzer, S. Somalwar, R. Stone, S. Thomas, P. Thomassen, M. Walker

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

K. Rose, S. Spanier, A. York

University of Tennessee, Knoxville, USA

O. Bouhali[55], A. Castaneda Hernandez, R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon[56], V. Khotilovich, V. Krutelyov, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Rose, A. Safonov, I. Suarez, A. Tatarinov

Texas A&M University, College Station, USA

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

Texas Tech University, Lubbock, USA

E. Appelt, A.G. Delannoy, S. Greene, A. Gurrola, W. Johns, C. Maguire, Y. Mao, A. Melo, M. Sharma, P. Sheldon, B. Snook, S. Tuo, J. Velkovska

Vanderbilt University, Nashville, USA

M.W. Arenton, S. Boutle, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, H. Li, C. Lin, C. Neu, J. Wood

University of Virginia, Charlottesville, USA

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

Wayne State University, Detroit, USA

D.A. Belknap, D. Carlsmith, M. Cepeda, S. Dasu, L. Dodd, S. Duric, E. Friis, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, A. Lanaro, C. Lazaridis, A. Levine, R. Loveless, A. Mohapatra, I. Ojalvo, T. Perry, G.A. Pierro, G. Polese, I. Ross, T. Sarangi, A. Savin, W.H. Smith, D. Taylor, P. Verwilligen, C. Vuosalo, N. Woods

University of Wisconsin, Madison, USA

[†] Deceased.

[1] Also at Vienna University of Technology, Vienna, Austria.

[2] Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.

[3] Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France.

[4] Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia.

[5] Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia.

[6] Also at Universidade Estadual de Campinas, Campinas, Brazil.

[7] Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France.

[8] Also at Joint Institute for Nuclear Research, Dubna, Russia.

[9] Also at Suez University, Suez, Egypt.

[10] Also at British University in Egypt, Cairo, Egypt.

[11] Also at Fayoum University, El-Fayoum, Egypt.

[12] Also at Ain Shams University, Cairo, Egypt.

[13] Now at Sultan Qaboos University, Muscat, Oman.

[14] Also at Université de Haute Alsace, Mulhouse, France.

[15] Also at Brandenburg University of Technology, Cottbus, Germany.

[16] Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.

[17] Also at Eötvös Loránd University, Budapest, Hungary.

[18] Also at University of Debrecen, Debrecen, Hungary.

[19] Also at University of Visva-Bharati, Santiniketan, India.
[20] Now at King Abdulaziz University, Jeddah, Saudi Arabia.
[21] Also at University of Ruhuna, Matara, Sri Lanka.
[22] Also at Isfahan University of Technology, Isfahan, Iran.
[23] Also at University of Tehran, Department of Engineering Science, Tehran, Iran.
[24] Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran.
[25] Also at Università degli Studi di Siena, Siena, Italy.
[26] Also at Centre National de la Recherche Scientifique (CNRS) – IN2P3, Paris, France.
[27] Also at Purdue University, West Lafayette, USA.
[28] Also at Universidad Michoacana de San Nicolas de Hidalgo, Morelia, Mexico.
[29] Also at Institute for Nuclear Research, Moscow, Russia.
[30] Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia.
[31] Also at California Institute of Technology, Pasadena, USA.
[32] Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
[33] Also at Facoltà Ingegneria, Università di Roma, Roma, Italy.
[34] Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy.
[35] Also at University of Athens, Athens, Greece.
[36] Also at Paul Scherrer Institut, Villigen, Switzerland.
[37] Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.
[38] Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland.
[39] Also at Gaziosmanpasa University, Tokat, Turkey.
[40] Also at Adiyaman University, Adiyaman, Turkey.
[41] Also at Cag University, Mersin, Turkey.
[42] Also at Anadolu University, Eskisehir, Turkey.
[43] Also at Ozyegin University, Istanbul, Turkey.
[44] Also at Izmir Institute of Technology, Izmir, Turkey.
[45] Also at Necmettin Erbakan University, Konya, Turkey.
[46] Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
[47] Also at Marmara University, Istanbul, Turkey.
[48] Also at Kafkas University, Kars, Turkey.
[49] Also at Yildiz Technical University, Istanbul, Turkey.
[50] Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
[51] Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
[52] Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.
[53] Also at Argonne National Laboratory, Argonne, USA.
[54] Also at Erzincan University, Erzincan, Turkey.
[55] Also at Texas A&M University at Qatar, Doha, Qatar.
[56] Also at Kyungpook National University, Daegu, Republic of Korea.