CERN-PH-EP/2013-010
2013/05/01

CMS-EXO-12-010

Search for new physics in final states with a lepton and missing transverse energy in pp collisions at the LHC

The CMS Collaboration*

Abstract

This letter describes the search for an enhanced production rate of events with a charged lepton and a neutrino in high-energy pp collisions at the LHC. The analysis uses data collected with the CMS detector, with an integrated luminosity of 5.0 fb^{-1} at $\sqrt{s} = 7 \text{ TeV}$, and a further 3.7 fb^{-1} at $\sqrt{s} = 8 \text{ TeV}$. No evidence is found for an excess. The results are interpreted in terms of limits on a heavy charged gauge boson (W') in the sequential standard model, a split universal extra dimension model, and contact interactions in the helicity-non-conserving model. For the last, values of the binding energy below 10.5 (8.8) TeV in the electron (muon) channel are excluded at a 95% confidence level. Interpreting the $\ell\nu$ final state in terms of a heavy W' with standard model couplings, masses below 2.90 TeV are excluded.

Submitted to Physical Review D

1 Introduction

New heavy gauge bosons are predicted by various extensions of the standard model (SM). The sequential standard model (SSM) [1] postulates the existence of a W' boson, a heavy analogue of the W . In such a theory, the W' is expected to appear as a narrow resonance with decay modes and branching fractions similar to those of the W . For W' masses above 180 GeV, where the $t\bar{b}$ decay channel opens up, the predicted branching fraction is about 8.5% for each of the leptonic final states. Previous searches [2, 3] with pp collision data at $\sqrt{s} = 7$ TeV by the Compact Muon Solenoid (CMS) and ATLAS experiments at the Large Hadron Collider (LHC), based on an integrated luminosity of up to 5 fb^{-1} , have excluded SSM W' bosons with masses up to 2.6 TeV.

Other models for new physics predict the same final state, such as those with universal extra dimensions (UED) and bulk fermions, or split UED [4, 5]. Such models of extended space-time assume one additional compact dimension of radius R . The split-UED parameter space is defined by $1/R$ and μ , with μ being the bulk mass parameter of the fermion field in five dimensions. For suitable non-zero values of μ , as assumed by split-UED models, the cross sections are sufficiently large to allow observation by LHC experiments. All SM particles have corresponding Kaluza-Klein (KK) partners, for instance W_{KK}^n , where n denotes the n -th KK excitation mode. Only KK-even modes of W_{KK}^n couple to SM fermions, owing to KK-parity conservation [6]. Modes with $n \geq 4$ have a smaller cross section and are not expected to be accessible at $\sqrt{s} = 8$ TeV, hence the only mode considered is $n = 2$.

Motivated by the observation of mass hierarchies in the fermion sector, theories have been developed where leptons and quarks are composite objects [7]. At energies much lower than the binding energy of these fundamental constituents, typically called Λ , quark and lepton compositeness would manifest itself as a four-fermion contact interaction (CI). One of the possible contact interactions between two quarks, a neutrino and a charged lepton is described by the helicity-non-conserving (HNC) model [8]. The corresponding cross section is proportional to the square of the partonic centre-of-mass energy and to Λ^{-4} . While CDF has set a limit on $\Lambda > 2.81$ TeV [9] based on a final state with an electron and a neutrino, no limit in the HNC model has yet been set in the muon channel.

In this letter, a search is presented for an excess of events with an isolated charged lepton (an electron or muon) and a neutrino in the final state, using the CMS detector. The data sample corresponds to an integrated luminosity of 5.0 fb^{-1} at $\sqrt{s} = 7$ TeV collected in 2011, and 3.7 fb^{-1} at $\sqrt{s} = 8$ TeV collected in 2012. The CMS 2011 result has been published in ref. [2].

2 The CMS detector

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/scintillator hadron calorimeter (HCAL). Muons are measured in gas-ionization detectors embedded in the steel return yoke. Extensive forward calorimetry complements the coverage provided by the barrel and endcap detectors. A more detailed description of the CMS detector can be found in Ref. [10]. CMS uses a right-handed coordinate system, with the origin at the nominal interaction point, the x axis pointing to the centre of the LHC, the y axis pointing up (perpendicular to the LHC plane), and the z axis along the anticlockwise-beam direction. The polar angle θ is measured from the positive z axis and the azimuthal angle ϕ is measured in the x - y plane.

3 The search strategy

Candidate events with at least one high transverse momentum (p_T) electron or muon are selected using single-lepton triggers. Isolated high- p_T leptons are reconstructed using very stringent quality criteria while the neutrino gives rise to experimentally observed missing transverse energy (E_T^{miss}). The details on lepton identification and E_T^{miss} reconstruction, as optimized for the 2011 analysis, can be found in Ref. [2]. The discriminating variable of this analysis is the transverse mass M_T of the lepton- E_T^{miss} system, calculated as

$$M_T = \sqrt{2 \cdot p_T^\ell \cdot E_T^{\text{miss}} \cdot (1 - \cos \Delta\phi_{\ell,\nu})}, \quad (1)$$

where $\Delta\phi_{\ell,\nu}$ is the azimuthal angle between the charged lepton's transverse momentum p_T^ℓ and the E_T^{miss} direction.

In W' decays, as well as for the other models considered, the lepton and E_T^{miss} are expected to be almost back-to-back in the transverse plane, and balanced in transverse energy. Additional kinematic criteria therefore select events with a ratio of the lepton p_T^ℓ and the E_T^{miss} , $0.4 < p_T^\ell/E_T^{\text{miss}} < 1.5$, along with the requirement of the angular difference, $|\Delta\phi_{\ell,\nu} - \pi| < 0.2\pi$. For simulated SSM W' events with masses between 0.5 and 2.5 TeV passing these selection criteria, the signal efficiency (including 90% geometrical acceptance) is found to be 70–75% with 2% uncertainty in the electron channel and 67–72% with 1% uncertainty in the muon channel. For the HNC contact-interaction model the signal efficiency is independent of the interaction scale Λ and has been determined from simulation to be 80% with 1% uncertainty for the electron channel and 77% with 4% uncertainty for the muon channel. The transverse mass distributions for accepted SM events in the electron and muon channels are shown in Fig. 1, along with two example W' signals. The observed event with the highest transverse mass in the electron channel has $M_T = 2.38 \pm 0.05$ TeV based on $E_T = 1.2$ TeV with 1% uncertainty. In the muon channel the maximum transverse mass is $M_T = 1.33 \pm 0.03$ TeV with a measured p_T^ℓ of 690 ± 22 GeV. The two types of processes, W' production and compositeness, can be distinguished by examining the shape of the lepton- E_T^{miss} transverse-mass spectrum. Both processes manifest themselves through an excess of events at the high end of the spectrum. The W' signal events are expected to concentrate in a Jacobian peak around the W' mass, as shown in Fig. 1. Compositeness would rather yield an unstructured excess, with the excess relative to the standard model contribution increasing as a function of M_T , as shown in Fig. 2.

4 Signal and backgrounds

The W' (this also includes $W_{\text{KK}}^{n=2}$) and CI signals are generated at leading order (LO) with PYTHIA 6.4.26. [11] using the CTEQ6L1 [12] parton distribution functions (PDF). They are scaled to the next-to-next-to-leading order (NNLO) cross section calculated with FEWZ [13, 14] for each W' ($W_{\text{KK}}^{n=2}$) mass point. In the absence of higher-order calculations, LO cross sections are used for the CI model.

The primary source of background is the off-peak, high- M_T tail of the standard model $W \rightarrow \ell\nu$ decays. Other important backgrounds arise from $t\bar{t}$, Drell-Yan, and diboson (WW , WZ , ZZ) events. An important background also comes from QCD multijet processes, but this is largely removed by the analysis selections and therefore cannot be readily distinguished in Fig. 1. Contributions from decays with τ leptons in the final state that subsequently decay to an electron or muon and neutrinos are considered as well, but found to be negligible. The PYTHIA 6 generator is used for all background processes except for $t\bar{t}$, which is generated with MADGRAPH 4 [15]

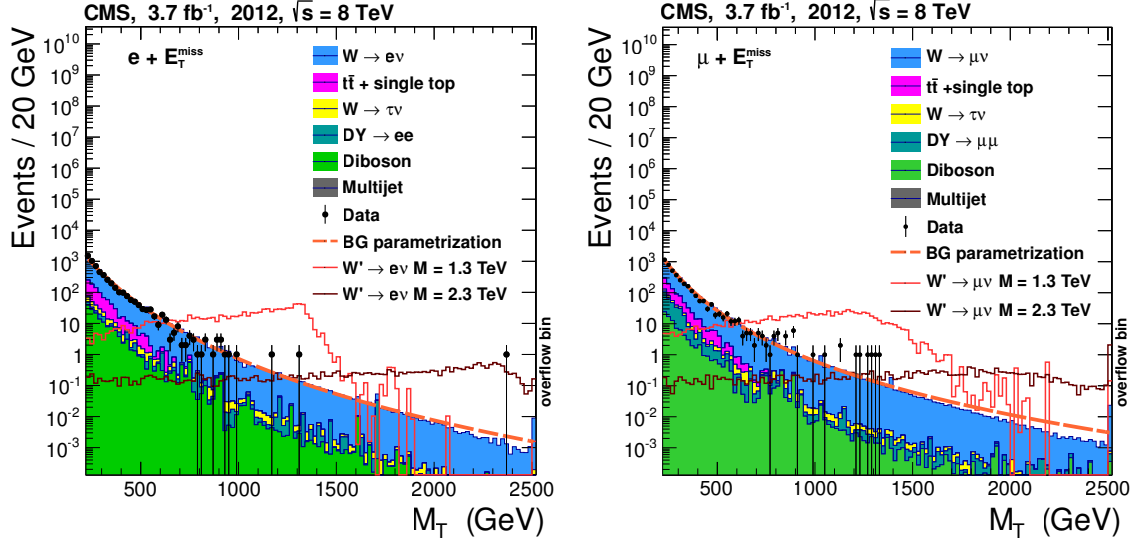


Figure 1: Observed lepton- E_T^{miss} transverse mass distributions in the electron (left) and the muon (right) channel. The dashed lines show the parametrization of the background as described in the text (labelled as BG parametrization in the legend). Simulated signal distributions for a SSM W' are also shown, including detector resolution effects. The simulated background labeled as ‘diboson’ includes WW , ZZ , and WZ contributions. The last bin contains the contributions of all bins above the displayed range.

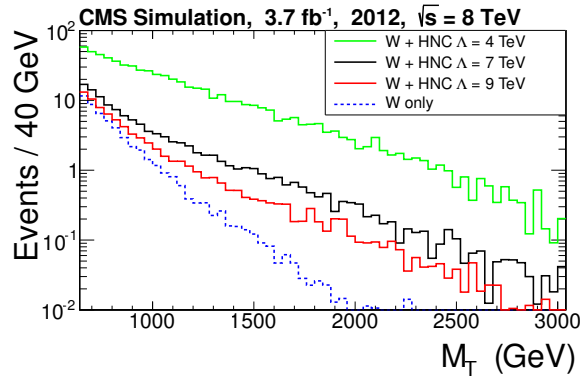


Figure 2: Simulated transverse mass distribution shown for contact interaction (HNC model), in the muon+ E_T^{miss} channel at generator level for CI signals with $\Lambda = 4, 7,$ and 9 TeV, and the SM background ($W \rightarrow \mu\nu$).

Table 1: Data, background, and signal event yields for different transverse mass thresholds.

	$M_T > 1.0 \text{ TeV}$	$M_T > 1.5 \text{ TeV}$	$M_T > 2.0 \text{ TeV}$
Electron channel			
Data	3	1	1
SM background	6.8 ± 0.4	$0.69^{+0.05}_{-0.04}$	0.13 ± 0.02
$M_{W'} = 2.5 \text{ TeV}$	9.7 ± 0.3	7.5 ± 0.2	4.7 ± 0.2
$M_{W'} = 3 \text{ TeV}$	1.98 ± 0.06	1.5 ± 0.05	$1.15^{+0.05}_{-0.04}$
CI, $\Lambda = 4 \text{ TeV}$	220 ± 5	72 ± 3	21 ± 1
CI, $\Lambda = 9 \text{ TeV}$	8.6 ± 0.2	2.8 ± 0.1	$0.81^{+0.05}_{-0.04}$
Muon channel			
Data	9	0	0
SM background	$6.5^{+1.9}_{-1.5}$	$0.92^{+0.49}_{-0.32}$	$0.20^{+0.14}_{-0.08}$
$M_{W'} = 2.5 \text{ TeV}$	9.4 ± 0.3	7.0 ± 0.5	$4.1^{+0.8}_{-0.7}$
$M_{W'} = 3 \text{ TeV}$	1.9 ± 0.1	1.4 ± 0.1	$0.94^{+0.12}_{-0.10}$
CI, $\Lambda = 4 \text{ TeV}$	240 ± 20	80^{+15}_{-13}	28^{+8}_{-6}
CI, $\Lambda = 9 \text{ TeV}$	34 ± 3	12^{+3}_{-2}	$3.5^{+1.2}_{-0.9}$

in combination with PYTHIA. The numbers of Monte Carlo events are normalized using the integrated luminosity of the recorded data and with NNLO cross sections, except diboson and multijet samples, for which the next-to-leading order and LO cross sections are used, respectively. In all event samples, additional minimum bias interactions are superimposed onto the main background processes to match the luminosity profile of the analyzed data set.

The background prediction is based on the transverse-mass distributions of these simulations, as seen in Fig. 1. The summed background distribution is parametrized with a function of form $f(M_T) = \frac{a}{(M_T+b)^c}$ to avoid event fluctuations due to the limited size of the Monte Carlo event sample, also shown in Fig. 1. In the low mass control region, e.g. for $M_T > 500 \text{ GeV}$, the background prediction in the electron channel is 169 events from a direct count and 155 ± 16 events from the parametrization. The corresponding event numbers in the muon channel are 162 and 138 ± 12 , from the direct count and the parametrization respectively. The number of observed events in each channel is 153. The expected background due to SM processes drops significantly with increasing M_T . The number of events observed and the number expected from the parametrization, above three characteristic high M_T thresholds, are shown in Table 1 for the electron and the muon channels. Also summarised are the expected numbers of W' and CI signal events, as evaluated from simulation, including systematic uncertainties due to imperfections in the description of the detector performance.

5 Results and exclusion limits

For determining the exclusion limits, systematic uncertainties on the signal and background yields are included via nuisance parameters with a log-normal prior distribution in the same way as in our previous analysis from Ref. [2]. The lepton-energy calibration and resolution distort the transverse mass spectrum. Uncertainties in the energy scale and the energy reso-

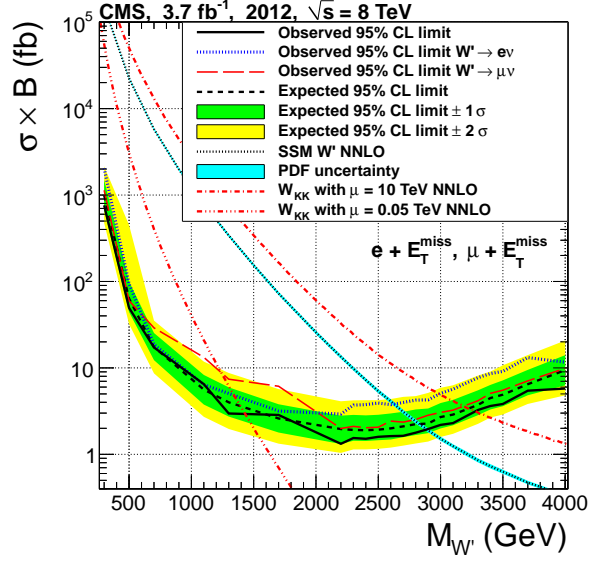


Figure 3: Limits on the cross section times the single channel branching fraction ($\sigma \times \mathcal{B}$) for heavy W' bosons based on the 2012 data for the electron and the muon channels. For the individual channels, only the observed limits are shown. For the combination, the observed limit, the expected limit, the 1σ , and the 2σ bands are displayed. The model assumes equal branching fractions for the electron and the muon channel, hence the combination corresponds to doubling the number of events. All limits are displayed for the single channel branching fraction. The W' mass limits are derived with a Bayesian method for the models of a SSM W' and $W_{KK}^{n=2}$ in split UED. The $W_{KK}^{n=2}$ is the lowest mass state that can couple to SM fermions and has the same final state as the SM-like W' . Since it has even KK parity it can be produced singly.

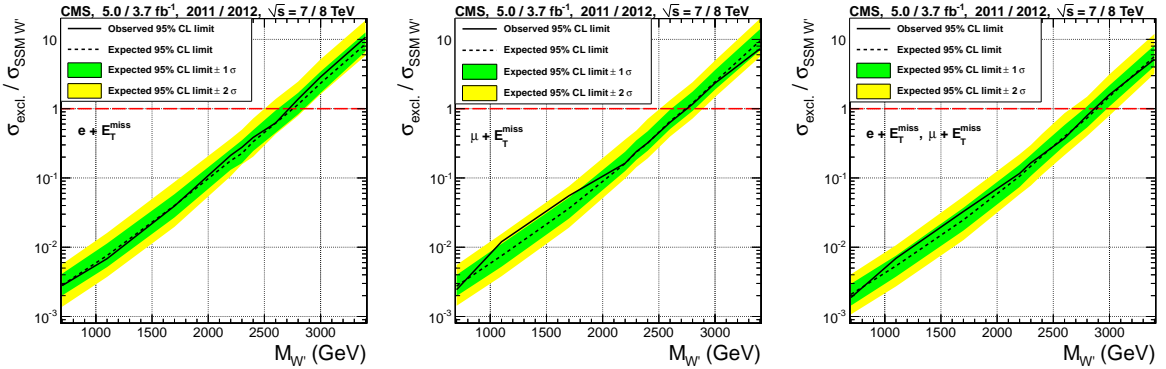


Figure 4: Combination of 2011 and 2012 data for the electron and the muon channels using 5.0 fb^{-1} of data at $\sqrt{s} = 7 \text{ TeV}$ from 2011 and 3.7 fb^{-1} of data at $\sqrt{s} = 8 \text{ TeV}$ from 2012. The upper row shows the individual combinations for the electron (left) and muon channel (right). To the right the combination of both is displayed. The limits are derived with a Bayesian method. Plotted is the signal strength modifier $\sigma_{\text{excl.}}/\sigma_{\text{SSM } W'}$ as a function of the W' mass, where $\sigma_{\text{excl.}}$ is the cross section excluded at a 95% confidence level and $\sigma_{\text{SSM } W'}$ is the cross section predicted by the SSM. All W' mass points below the ratio $\sigma_{\text{excl.}}/\sigma_{\text{SSM } W'} = 1$, shown as a red dashed line, are excluded in the sequential standard model.

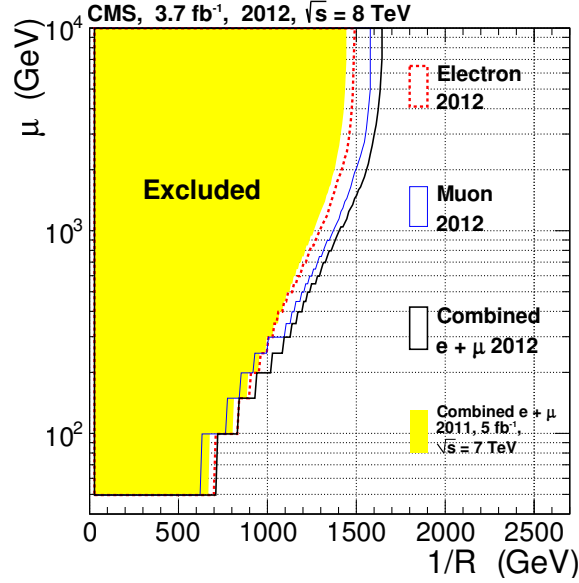


Figure 5: The 95% confidence limits on the split-UED parameters μ and $1/R$ derived from the W' mass limits taking into account the corresponding width of the $W'_{KK}{}^{n=2}$. For the 3.7 fb^{-1} of 2012 data the individual limits for the electron and muon channels are shown together with their combination, improving the excluded parameter space based on the 2011 data shown in yellow.

lution make comparable contributions to the overall uncertainty in the electron channel: the energy scale has an uncertainty of 1(3)% in the barrel(endcaps) and the resolution has an uncertainty of 1.4(3)% for the barrel (endcaps) [16]. For muons, the dominant uncertainty stems from the momentum scale, which is taken to be $5\% \times p_T / \text{TeV}$ [17] and results in larger errors on the background and signal event yields in the muon channel, as can be seen in Table 1. The muon p_T resolution has been determined with cosmic ray muons to be 10% at high p_T with an uncertainty of 0.6% [17].

Similarly, the impact of the E_T^{miss} energy scale is modelled by shifting the hadronic component event-by-event by 10%, while the resolution is taken into account by a 10% smearing. In all cases, the impact on the expected number of signal events is around 1% for each source of uncertainty. The background parametrization procedure is repeated using the distorted distributions. Additionally, an uncertainty is derived by fitting the undistorted background with two different functions. The estimates shown in Table 1 include a systematic uncertainty that covers the range of results from these fits, with the statistical uncertainty coming from the fit to the original distribution. Additionally, an uncertainty of 4.4% is considered on the integrated luminosity [18].

The number of data events above a transverse mass threshold M_T^{min} is compared to the expected number of signal and background events, with the M_T^{min} threshold being optimized for the best expected exclusion limit, using steps of 50 GeV. Very similar results are achieved when optimizing for discovery. The same optimization procedure is applied for the W' and CI searches but the optimized M_T thresholds are specific to each analysis. For a W' mass of up to 2.5 TeV the optimization tends to select a value for M_T^{min} a little below the peak of the Jacobian, retaining most of the events in the peak. To keep a significant signal contribution for higher masses, the M_T^{min} threshold is shifted to lower values owing to the increasing off-shell fraction. For CI no such effect exists and the optimized M_T^{min} threshold is roughly constant around 1 TeV.

No significant excess has been observed in the data, and upper limits are set on the production cross section times the branching fraction $\sigma \times \mathcal{B}(W' \rightarrow \ell\nu)$, with $\ell = e$ or μ , using a Bayesian method with the assumption of a flat prior for the parameter of interest. The expected and observed upper cross section limits on a SSM W' , at 95% confidence level (CL), for $\sqrt{s} = 8$ TeV data, are shown in Fig. 3 for both channels and their combination. Using the central value of the theoretical NNLO SSM W' cross section times branching fraction, which is assumed to be identical in the two channels, we exclude masses less than 2.60 TeV in the electron and 2.75 TeV in the muon channel. The expected limits are 2.70 TeV and 2.65 TeV, respectively. The observed limit for $W' \rightarrow e\nu$ is slightly lower than the expectation because of one event with a transverse mass of 2.3 TeV (Fig. 1). Combining both channels, the limit increases to 2.85 TeV (Table 2). To further enhance the sensitivity the new results can be combined with the published [2] $\sqrt{s} = 7$ TeV results, based on an integrated luminosity of 5 fb^{-1} , thus extending the limit to 2.90 TeV as shown in Fig. 4 and Table 2.

The limit can be reinterpreted in terms of $W_{\text{KK}}^{n=2}$ mass, as shown in Fig. 3, for values of the Dirac mass term $\mu = 0.05 \text{ TeV}$ and $\mu = 10 \text{ TeV}$ and directly translated to bounds on the split-UED parameter space, $(1/R, \mu)$ (Fig. 5). The four-fermion contact interaction of the HNC model is excluded for values of $\Lambda < 10.5 \text{ TeV}$ in the electron channel and $\Lambda < 8.8 \text{ TeV}$ in the muon channel (Fig. 6). While the expected sensitivity is comparable in both search channels, the exclusion limit in the electron channel is higher because of a downward fluctuation of data (see Table 1) in the search region of $M_T > 1 \text{ TeV}$. These limits are summarized in Table 3.

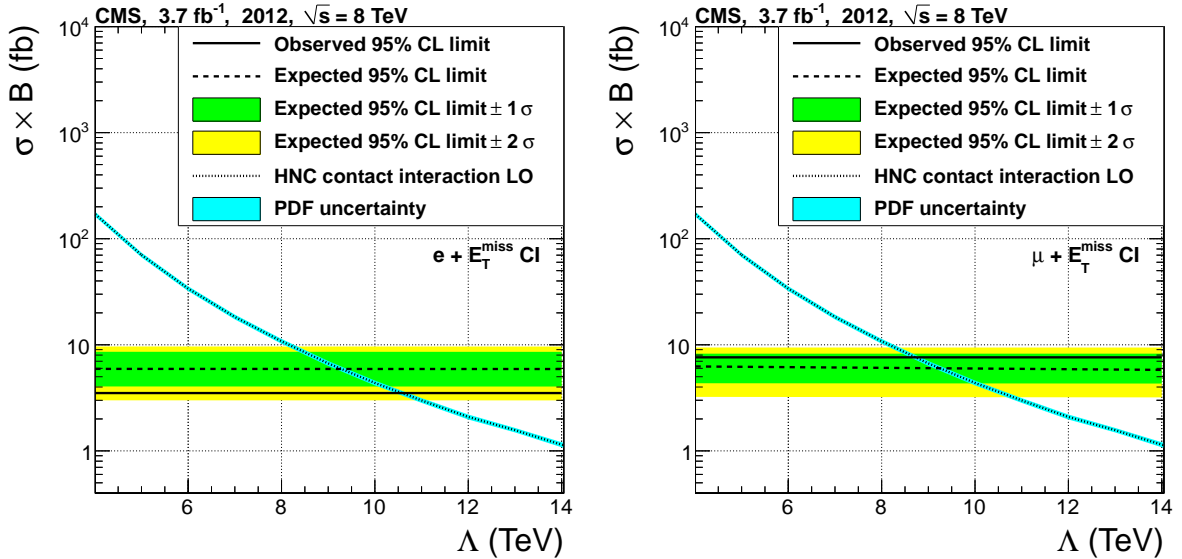


Figure 6: Bayesian limits on the cross section times the single channel branching fraction ($\sigma \times \mathcal{B}$) for contact interactions (HNC model) in the electron+ E_T^{miss} (left) and the muon+ E_T^{miss} channel (right) based on an integrated luminosity of 3.7 fb^{-1} of $\sqrt{s} = 8 \text{ TeV}$ data. The expected limit in either channel excludes values of the new interaction scale $\Lambda < 9 \text{ TeV}$. The observed limit, driven by the data, excludes $\Lambda < 10.5 \text{ TeV}$ (8.8) in the electron (muon) channel. The signal efficiency is independent of Λ .

6 Summary

A search for new physics has been carried out using pp collisions recorded with the CMS detector at centre-of-mass energies of $\sqrt{s} = 7 \text{ TeV}$ and 8 TeV . The transverse mass spectrum of either

electrons or muons and missing transverse energy has been measured. The observed spectra are consistent with the standard model expectation, and mass limits on sequential standard model W' and $W_{\text{KK}}^{n=2}$ have been set at the 95% CL. These are the most stringent limits to date. For the first time, a limit on the compositeness scale Λ has been set for contact interactions in the HNC model based on the final state with a muon and $E_{\text{T}}^{\text{miss}}$. The corresponding exclusion limit in the electron channel significantly improves the existing one.

Table 2: Exclusion limits in TeV on the SSM W' mass for the electron and muon channel as well as their combinations based on 5.0 fb^{-1} of 2011 data at $\sqrt{s} = 7 \text{ TeV}$ and 3.7 fb^{-1} of 2012 data at $\sqrt{s} = 8 \text{ TeV}$.

Channel	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
	2011	2011	2012	2012	2011+2012	2011+2012
e	2.40	2.45	2.60	2.70	2.70	2.75
μ	2.40	2.45	2.75	2.65	2.75	2.70
e + μ	2.50	2.60	2.85	2.80	2.90	2.90

Table 3: Exclusion limits for other model interpretations for the electron and muon channel or their combination based on 3.7 fb^{-1} of 2012 data at $\sqrt{s} = 8 \text{ TeV}$.

Model	Channel	Observed limit	Expected limit
$W_{\text{KK}}^{n=2}$ $\mu = 0.05 \text{ TeV}$	e+ μ	$m_{W_{\text{KK}}^{n=2}} < 1.5 \text{ TeV}$	$m_{W_{\text{KK}}^{n=2}} < 1.4 \text{ TeV}$
$W_{\text{KK}}^{n=2}$ $\mu = 10.0 \text{ TeV}$	e+ μ	$m_{W_{\text{KK}}^{n=2}} < 3.3 \text{ TeV}$	$m_{W_{\text{KK}}^{n=2}} < 3.2 \text{ TeV}$
HNC CI	e	$\Lambda < 10.5 \text{ TeV}$	$\Lambda < 9.0 \text{ TeV}$
HNC CI	μ	$\Lambda < 8.8 \text{ TeV}$	$\Lambda < 9.0 \text{ TeV}$

Acknowledgements

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centres and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: BMWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MEYS (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); MoER, SF0690030s09 and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NKTH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); NRF and WCU (Republic of Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); MSI (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Armenia, Belarus, Georgia, Ukraine, Uzbekistan); MON, RosAtom, RAS and RFBR (Russia); MSTD

(Serbia); SEIDI and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); ThEP-Center, IPST and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

References

- [1] G. Altarelli, B. Mele, and M. Ruiz-Altaba, "Searching for New Heavy Vector Bosons in $p\bar{p}$ Colliders", *Z. Phys. C* **45** (1989) 109, doi:10.1007/BF01556677.
- [2] CMS Collaboration, "Search for leptonic decays of W bosons in pp collisions at $\sqrt{s} = 7$ TeV", *JHEP* **08** (2012) 023, doi:10.1007/JHEP08(2012)023, arXiv:1204.4764.
- [3] ATLAS Collaboration, "ATLAS search for a heavy gauge boson decaying to a charged lepton and a neutrino in pp collisions at $\sqrt{s} = 7$ TeV", (2012). arXiv:1209.4446. submitted to *Eur. Phys. J. C*.
- [4] C.-R. Chen et al., "Dark matter and collider phenomenology of split-UED", *JHEP* **09** (2009) 078, doi:10.1088/1126-6708/2009/09/078, arXiv:0903.1971.
- [5] K. Kong, S. C. Park, and T. G. Rizzo, "Collider Phenomenology with Split-UED", *JHEP* **04** (2010) 081, doi:10.1007/JHEP04(2010)081, arXiv:1002.0602.
- [6] T. Appelquist, H.-C. Cheng, and B. A. Dobrescu, "Bounds on universal extra dimensions", *Phys. Rev. D* **64** (2001) 035002, doi:10.1103/PhysRevD.64.035002, arXiv:hep-ph/0012100.
- [7] H. Terazawa et al., "Observable effects of the possible sub-structure of leptons and quarks", *Phys. Lett. B* **112** (1982) 387, doi:10.1016/0370-2693(82)91075-9.
- [8] K. D. Lane et al., "Simulations of supercollider physics", *Phys. Rept.* **278** (1997) 291, doi:10.1016/S0370-1573(96)00018-X, arXiv:hep-ph/9412280.
- [9] CDF Collaboration, "Search for quark lepton compositeness and a heavy W boson using the $e\nu$ channel in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV", *Phys. Rev. Lett.* **87** (2001) 231803, doi:10.1103/PhysRevLett.87.231803, arXiv:hep-ex/0107008.
- [10] CMS Collaboration, "The CMS experiment at the CERN LHC", *JINST* **03** (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.
- [11] T. Sjöstrand, S. Mrenna, and P. Z. Skands, "PYTHIA 6.4 Physics and Manual", *JHEP* **05** (2006) 026, doi:10.1088/1126-6708/2006/05/026, arXiv:hep-ph/0603175.
- [12] J. Pumplin et al., "New generation of parton distributions with uncertainties from global QCD analysis", *JHEP* **07** (2002) 012, doi:10.1088/1126-6708/2002/07/012, arXiv:hep-ph/0201195.
- [13] R. Gavin et al., "FEWZ 2.0: A code for hadronic Z production at next-to-next-to-leading order", *Comput. Phys. Commun.* **182** (2011), no. 11, 2388, doi:10.1016/j.cpc.2011.06.008, arXiv:1011.3540.
- [14] S. Quackenbush et al., "W physics at the LHC with FEWZ 2.1", *Computer Physics Communications* **184** (2013), no. 1, 209, doi:10.1016/j.cpc.2012.09.005, arXiv:1201.5896.

-
- [15] J. Alwall et al., “MadGraph/MadEvent v4: the new web generation”, *JHEP* **09** (2007) 028, doi:10.1088/1126-6708/2007/09/028.
- [16] CMS Collaboration, “ECAL Detector Performance, 2011 Data”, CMS Detector Performance Summary DP-12-007, (2012).
- [17] CMS Collaboration, “Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7$ TeV”, (2011). arXiv:1206.4071. Submitted to *JINST*.
- [18] CMS Collaboration, “CMS Luminosity Based on Pixel Cluster Counting - Summer 2012 Update”, CMS Physics Analysis Summary CMS-PAS-LUM-12-001, (2012).

A The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia

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

Institut für Hochenergiephysik der OeAW, Wien, Austria

W. Adam, E. Aguilo, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan¹, M. Friedl, R. Frühwirth¹, V.M. Ghete, N. Hörmann, J. Hrubec, M. Jeitler¹, W. Kiesenhofer, V. Knünz, M. Krammer¹, I. Krätschmer, D. Liko, I. Mikulec, M. Pernicka[†], D. Rabady², B. Rahbaran, C. Rohringer, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, W. Waltenberger, C.-E. Wulz¹

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

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

Universiteit Antwerpen, Antwerpen, Belgium

S. Alderweireldt, M. Bansal, S. Bansal, T. Cornelis, E.A. De Wolf, X. Janssen, S. Luyckx, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, M. Selvaggi, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

Vrije Universiteit Brussel, Brussel, Belgium

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

Université Libre de Bruxelles, Bruxelles, Belgium

B. Clerbaux, G. De Lentdecker, V. Dero, A.P.R. Gay, T. Hreus, A. Léonard, P.E. Marage, A. Mohammadi, T. Reis, L. Thomas, C. Vander Velde, P. Vanlaer, J. Wang

Ghent University, Ghent, Belgium

V. Adler, K. Bernaert, A. Cimmino, S. Costantini, G. Garcia, M. Grunewald, B. Klein, J. Lellouch, A. Marinov, J. McCartin, A.A. Ocampo Rios, D. Ryckbosch, M. Sigamani, N. Strobbe, F. Thyssen, M. Tytgat, S. Walsh, E. Yazgan, N. Zaganidis

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

S. Basegmez, G. Bruno, R. Castello, L. Ceard, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco³, J. Hollar, V. Lemaitre, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrkowski, J.M. Vizan Garcia

Université de Mons, Mons, Belgium

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

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

G.A. Alves, M. Correa Martins Junior, T. Martins, M.E. Pol, M.H.G. Souza

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

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

Universidade Estadual Paulista ^a, Universidade Federal do ABC ^b, São Paulo, Brazil

T.S. Anjos^b, C.A. Bernardes^b, F.A. Dias^{a,4}, T.R. Fernandez Perez Tomei^a, E.M. Gregores^b, C. Lagana^a, F. Marinho^a, P.G. Mercadante^b, S.F. Novaes^a, Sandra S. Padula^a

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

V. Genchev², P. Iaydjiev², S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, V. Tcholakov, R. Trayanov, M. Vutova

University of Sofia, Sofia, Bulgaria

A. Dimitrov, R. Hadjiiska, V. Kozhuharov, L. Litov, B. Pavlov, P. Petkov

Institute of High Energy Physics, Beijing, China

J.G. Bian, G.M. Chen, H.S. Chen, C.H. Jiang, D. Liang, S. Liang, X. Meng, J. Tao, J. Wang, X. Wang, Z. Wang, H. Xiao, M. Xu, J. Zang, Z. Zhang

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

C. Asawatrangkuldee, Y. Ban, Y. Guo, W. Li, S. Liu, Y. Mao, S.J. Qian, H. Teng, D. Wang, L. Zhang, W. Zou

Universidad de Los Andes, Bogota, Colombia

C. Avila, C.A. Carrillo Montoya, J.P. Gomez, B. Gomez Moreno, A.F. Osorio Oliveros, J.C. Sanabria

Technical University of Split, Split, Croatia

N. Godinovic, D. Lelas, R. Plestina⁵, D. Polic, I. Puljak²

University of Split, Split, Croatia

Z. Antunovic, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia

V. Brigljevic, S. Duric, K. Kadija, J. Luetic, D. Mekterovic, S. Morovic, L. Tikvica

University of Cyprus, Nicosia, Cyprus

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

Charles University, Prague, Czech Republic

M. Finger, M. Finger Jr.

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

Y. Assran⁶, S. Elgammal⁷, A. Ellithi Kamel⁸, A.M. Kuotb Awad⁹, M.A. Mahmoud⁹, A. Radi^{10,11}

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

M. Kadastik, M. Müntel, M. Murumaa, M. Raidal, L. Rebane, A. Tiko

Department of Physics, University of Helsinki, Helsinki, Finland

P. Eerola, G. Fedi, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland

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

Lappeenranta University of Technology, Lappeenranta, Finland

A. Korpela, T. Tuuva

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

M. Besancon, S. Choudhury, F. Couderc, M. Dejardin, D. Denegri, B. Fabbro, J.L. Faure, F. Ferri, S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, J. Malcles, L. Millischer, A. Nayak, J. Rander, A. Rosowsky, M. Titov

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

S. Baffioni, F. Beaudette, L. Benhabib, L. Bianchini, M. Bluj¹², P. Busson, C. Charlot, N. Daci, T. Dahms, M. Dalchenko, L. Dobrzynski, A. Florent, R. Granier de Cassagnac, M. Haguenaer,

P. Miné, C. Mironov, I.N. Naranjo, M. Nguyen, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Veelken, A. Zabi

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

J.-L. Agram¹³, J. Andrea, D. Bloch, D. Bodin, J.-M. Brom, M. Cardaci, E.C. Chabert, C. Collard, E. Conte¹³, F. Drouhin¹³, J.-C. Fontaine¹³, D. Gelé, U. Goerlach, P. Juillot, A.-C. Le Bihan, P. Van Hove

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

S. Beauceron, N. Beaupere, O. Bondu, G. Boudoul, S. Brochet, J. Chasserat, R. Chierici², D. Contardo, P. Depasse, H. El Mamouni, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, M. Lethuillier, L. Mirabito, S. Perries, L. Sgandurra, V. Sordini, Y. Tschudi, P. Verdier, S. Viret

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

Z. Tsamalaidze¹⁴

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

C. Autermann, S. Beranek, B. Calpas, M. Edelhoff, L. Feld, N. Heracleous, O. Hindrichs, R. Jussen, K. Klein, J. Merz, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, B. Wittmer, V. Zhukov¹⁵

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

M. Ata, J. Caudron, 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. Pieta, H. Reithler, S.A. Schmitz, F. Schneider, L. Sonnenschein, J. Steggemann, D. Teyssier, S. Thüer, M. Weber

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

M. Bontenackels, V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, J. Lingemann², A. Nowack, I.M. Nugent, L. Perchalla, O. Pooth, P. Sauerland, A. Stahl

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, I. Asin, N. Bartosik, J. Behr, W. Behrenhoff, U. Behrens, M. Bergholz¹⁶, A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, E. Castro, F. Costanza, D. Dammann, C. Diez Pardos, T. Dorland, G. Eckerlin, D. Eckstein, G. Flucke, A. Geiser, I. Glushkov, P. Gunnellini, S. Habib, J. Hauk, G. Hellwig, H. Jung, M. Kasemann, P. Katsas, C. Kleinwort, H. Kluge, A. Knutsson, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, J. Leonard, W. Lohmann¹⁶, B. Lutz, R. Mankel, I. Marfin, M. Marienfeld, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, S. Naumann-Emme, O. Novgorodova, F. Nowak, J. Olzem, H. Perrey, A. Petrukhin, D. Pitzl, A. Raspereza, P.M. Ribeiro Cipriano, C. Riedl, E. Ron, M. Rosin, J. Salfeld-Nebgen, R. Schmidt¹⁶, T. Schoerner-Sadenius, N. Sen, A. Spiridonov, M. Stein, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany

V. Blobel, H. Enderle, J. Erfle, U. Gebbert, M. Görner, M. Gosselink, J. Haller, T. Hermanns, R.S. Höing, K. Kaschube, G. Kaussen, H. Kirschenmann, R. Klanner, J. Lange, T. Peiffer, N. Pietsch, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt,

M. Schröder, T. Schum, M. Seidel, J. Sibille¹⁷, V. Sola, H. Stadie, G. Steinbrück, J. Thomsen, L. Vanelderren

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

C. Barth, C. Baus, J. Berger, C. Böser, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, M. Guthoff², C. Hackstein, F. Hartmann², T. Hauth², M. Heinrich, H. Held, K.H. Hoffmann, U. Husemann, I. Katkov¹⁵, J.R. Komaragiri, P. Lobelle Pardo, D. Martschei, S. Mueller, Th. Müller, M. Niegel, A. Nürnberg, O. Oberst, A. Oehler, J. Ott, G. Quast, K. Rabbertz, F. Ratnikov, N. Ratnikova, S. Röcker, F.-P. Schilling, G. Schott, H.J. Simonis, F.M. Stober, D. Troendle, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, M. Zeise

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

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

University of Athens, Athens, Greece

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

University of Ioánnina, Ioánnina, Greece

I. Evangelou, C. Foudas, P. Kokkas, N. Manthos, I. Papadopoulos

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

G. Bencze, C. Hajdu, P. Hidas, D. Horvath¹⁸, F. Sikler, V. Veszpremi, G. Vesztergombi¹⁹, A.J. Zsigmond

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

N. Beni, S. Czellar, J. Molnar, J. Palinkas, Z. Szillasi

University of Debrecen, Debrecen, Hungary

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

Panjab University, Chandigarh, India

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

University of Delhi, Delhi, India

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

Saha Institute of Nuclear Physics, Kolkata, 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

Bhabha Atomic Research Centre, Mumbai, India

A. Abdulsalam, D. Dutta, S. Kailas, V. Kumar, A.K. Mohanty², L.M. Pant, P. Shukla

Tata Institute of Fundamental Research - EHEP, Mumbai, India

T. Aziz, R.M. Chatterjee, S. Ganguly, M. Guchait²⁰, A. Gurtu²¹, M. Maity²², G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage

Tata Institute of Fundamental Research - HECR, Mumbai, India

S. Banerjee, S. Dugad

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

H. Arfaei²³, H. Bakhshiansohi, S.M. Etesami²⁴, A. Fahim²³, M. Hashemi²⁵, H. Hesari, A. Jafari, M. Khakzad, M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh²⁶, M. Zeinali

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

M. Abbrescia^{a,b}, L. Barbone^{a,b}, C. Calabria^{a,b,2}, S.S. Chhibra^{a,b}, A. Colaleo^a, D. Creanza^{a,c}, N. De Filippis^{a,c,2}, M. De Palma^{a,b}, L. Fiore^a, G. Iaselli^{a,c}, G. Maggi^{a,c}, M. Maggi^a, B. Marangelli^{a,b}, S. My^{a,c}, S. Nuzzo^{a,b}, N. Pacifico^a, A. Pompili^{a,b}, G. Pugliese^{a,c}, G. Selvaggi^{a,b}, L. Silvestris^a, G. Singh^{a,b}, R. Venditti^{a,b}, P. Verwilligen^a, G. Zito^a

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

G. Abbiendi^a, A.C. Benvenuti^a, D. Bonacorsi^{a,b}, S. Braibant-Giacomelli^{a,b}, L. Brigliadori^{a,b}, P. Capiluppi^{a,b}, A. Castro^{a,b}, F.R. Cavallo^a, M. Cuffiani^{a,b}, G.M. Dallavalle^a, F. Fabbri^a, A. Fanfani^{a,b}, D. Fasanella^{a,b}, P. Giacomelli^a, C. Grandi^a, L. Guiducci^{a,b}, S. Marcellini^a, G. Masetti^a, M. Meneghelli^{a,b,2}, A. Montanari^a, F.L. Navarra^{a,b}, F. Odorici^a, A. Perrotta^a, F. Primavera^{a,b}, A.M. Rossi^{a,b}, T. Rovelli^{a,b}, G.P. Siroli^{a,b}, N. Tosi, R. Travaglini^{a,b}

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

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

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

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

INFN Laboratori Nazionali di Frascati, Frascati, Italy

L. Benussi, S. Bianco, S. Colafranceschi²⁷, F. Fabbri, D. Piccolo

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

P. Fabbriatore^a, R. Musenich^a, S. Tosi^{a,b}

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

A. Benaglia^a, F. De Guio^{a,b}, L. Di Matteo^{a,b,2}, S. Fiorendi^{a,b}, S. Gennai^{a,2}, A. Ghezzi^{a,b}, M.T. Lucchini², S. Malvezzi^a, R.A. Manzoni^{a,b}, A. Martelli^{a,b}, A. Massironi^{a,b}, D. Menasce^a, L. Moroni^a, M. Paganoni^{a,b}, D. Pedrini^a, S. Ragazzi^{a,b}, N. Redaelli^a, T. Tabarelli de Fatis^{a,b}

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

S. Buontempo^a, N. Cavallo^{a,c}, A. De Cosa^{a,b,2}, O. Dogangun^{a,b}, F. Fabozzi^{a,c}, A.O.M. Iorio^{a,b}, L. Lista^a, S. Meola^{a,d,28}, M. Merola^a, P. Paolucci^{a,2}

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

P. Azzi^a, N. Bacchetta^{a,2}, D. Bisello^{a,b}, A. Branca^{a,b,2}, R. Carlin^{a,b}, P. Checchia^a, T. Dorigo^a, F. Gasparini^{a,b}, U. Gasparini^{a,b}, A. Gozzelino^a, K. Kanishchev^{a,c}, S. Lacaprara^a, I. Lazzizzera^{a,c}, M. Margoni^{a,b}, A.T. Meneguzzo^{a,b}, 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}, P. Zotto^{a,b}, A. Zucchetta^{a,b}, G. Zumerle^{a,b}

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

M. Gabusi^{a,b}, S.P. Ratti^{a,b}, C. Riccardi^{a,b}, P. Torre^{a,b}, P. Vitulo^{a,b}

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

M. Biasini^{a,b}, G.M. Bilei^a, L. Fanò^{a,b}, P. Lariccia^{a,b}, G. Mantovani^{a,b}, M. Menichelli^a, A. Nappi^{a,b†}, F. Romeo^{a,b}, A. Saha^a, A. Santocchia^{a,b}, A. Spiezia^{a,b}, S. Taroni^{a,b}

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

P. Azzurri^{a,c}, G. Bagliesi^a, J. Bernardini^a, T. Boccali^a, G. Broccolo^{a,c}, R. Castaldi^a, R.T. D'Agnolo^{a,c,2}, R. Dell'Orso^a, F. Fiori^{a,b,2}, L. Foà^{a,c}, A. Giassi^a, A. Kraan^a, F. Ligabue^{a,c}, T. Lomtadze^a, L. Martini^{a,29}, A. Messineo^{a,b}, F. Palla^a, A. Rizzi^{a,b}, A.T. Serban^{a,30}, P. Spagnolo^a, P. Squillacioti^{a,2}, R. Tenchini^a, G. Tonelli^{a,b}, A. Venturi^a, P.G. Verdini^a

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

L. Barone^{a,b}, F. Cavallari^a, D. Del Re^{a,b}, M. Diemoz^a, C. Fanelli^{a,b}, M. Grassi^{a,b,2}, E. Longo^{a,b}, P. Meridiani^{a,2}, F. Micheli^{a,b}, S. Nourbakhsh^{a,b}, G. Organtini^{a,b}, R. Paramatti^a, S. Rahatlou^{a,b}, L. Soffi^{a,b}

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

N. Amapane^{a,b}, R. Arcidiacono^{a,c}, S. Argiro^{a,b}, M. Arneodo^{a,c}, C. Biino^a, N. Cartiglia^a, S. Casasso^{a,b}, M. Costa^{a,b}, N. Demaria^a, C. Mariotti^{a,2}, S. Maselli^a, E. Migliore^{a,b}, V. Monaco^{a,b}, M. Musich^{a,2}, M.M. Obertino^{a,c}, N. Pastrone^a, M. Pelliccioni^a, A. Potenza^{a,b}, A. Romero^{a,b}, M. Ruspa^{a,c}, R. Sacchi^{a,b}, A. Solano^{a,b}, A. Staiano^a

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

S. Belforte^a, V. Candelise^{a,b}, M. Casarsa^a, F. Cossutti^{a,2}, G. Della Ricca^{a,b}, B. Gobbo^a, M. Marone^{a,b,2}, D. Montanino^{a,b}, A. Penzo^a, A. Schizzi^{a,b}

Kangwon National University, Chunchon, Korea

T.Y. Kim, S.K. Nam

Kyungpook National University, Daegu, Korea

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

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

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

Korea University, Seoul, Korea

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

University of Seoul, Seoul, Korea

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

Sungkyunkwan University, Suwon, Korea

Y. Choi, Y.K. Choi, J. Goh, M.S. Kim, E. Kwon, B. Lee, J. Lee, S. Lee, H. Seo, I. Yu

Vilnius University, Vilnius, Lithuania

M.J. Bilinskas, I. Grigelionis, M. Janulis, A. Juodagalvis

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

H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz, R. Lopez-Fernandez, J. Martínez-Ortega, A. Sanchez-Hernandez, L.M. Villasenor-Cendejas

Universidad Iberoamericana, Mexico City, Mexico

S. Carrillo Moreno, F. Vazquez Valencia

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

H.A. Salazar Ibarguen

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

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

University of Auckland, Auckland, New Zealand

D. Krofcheck

University of Canterbury, Christchurch, New Zealand

A.J. Bell, P.H. Butler, R. Doesburg, S. Reucroft, H. Silverwood

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

M. Ahmad, M.I. Asghar, J. Butt, H.R. Hoorani, S. Khalid, W.A. Khan, T. Khurshid, S. Qazi, M.A. Shah, M. Shoaib

National Centre for Nuclear Research, Swierk, Poland

H. Bialkowska, B. Boimska, T. Frueboes, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szeleper, G. Wrochna, P. Zalewski

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

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

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

N. Almeida, P. Bargassa, A. David, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, J. Seixas, J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia

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

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

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

Institute for Nuclear Research, Moscow, Russia

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

Institute for Theoretical and Experimental Physics, Moscow, Russia

V. Epshteyn, M. Erofeeva, V. Gavrilo, M. Kossov, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, I. Shreyber, V. Stolin, E. Vlasov, A. Zhokin

P.N. Lebedev Physical Institute, Moscow, Russia

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

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

A. Belyaev, E. Boos, M. Dubinin⁴, L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, A. Markina, S. Obraztsov, M. Perfilov, S. Petrushanko, A. Popov, L. Sarycheva[†], V. Savrin, A. Snigirev

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

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Grishin², V. Kachanov, D. Konstantinov, V. Krychkin, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

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

P. Adzic³¹, M. Djordjevic, M. Ekmedzic, D. Krpic³¹, J. Milosevic

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

M. Aguilar-Benitez, J. Alcaraz Maestre, P. Arce, C. Battilana, E. Calvo, M. Cerrada, M. Chamizo

Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, D. Domínguez Vázquez, C. Fernandez Bedoya, J.P. Fernández Ramos, A. Ferrando, J. Flix, M.C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, G. Merino, J. Puerta Pelayo, A. Quintario Olmeda, I. Redondo, L. Romero, J. Santaolalla, M.S. Soares, C. Willmott

Universidad Autónoma de Madrid, Madrid, Spain

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

Universidad de Oviedo, Oviedo, Spain

H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias, J. Piedra Gomez

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

J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, S.H. Chuang, J. Duarte Campderros, M. Felcini³², M. Fernandez, G. Gomez, J. Gonzalez Sanchez, A. Graziano, C. Jorda, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, I. Vila, R. Vilar Cortabitarte

CERN, European Organization for Nuclear Research, Geneva, Switzerland

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, J.F. Benitez, C. Bernet⁵, G. Bianchi, P. Bloch, A. Bocci, A. Bonato, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, D. D'Enterria, A. Dabrowski, A. De Roeck, S. Di Guida, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, B. Frisch, W. Funk, G. Georgiou, M. Giffels, D. Gigi, K. Gill, D. Giordano, M. Girone, M. Giunta, F. Glege, R. Gomez-Reino Garrido, P. Govoni, S. Gowdy, R. Guida, J. Hammer, M. Hansen, P. Harris, C. Hartl, J. Harvey, B. Hegner, A. Hinzmann, V. Innocente, P. Janot, K. Kaadze, E. Karavakis, K. Kousouris, P. Lecoq, Y.-J. Lee, P. Lenzi, C. Lourenço, N. Magini, T. Mäki, M. Malberti, L. Malgeri, M. Mannelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, R. Moser, M. Mulders, P. Musella, E. Nesvold, L. Orsini, E. Palencia Cortezon, E. Perez, L. Perrozzi, A. Petrilli, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, G. Polese, L. Quertenmont, A. Racz, W. Reece, J. Rodrigues Antunes, G. Rolandi³³, C. Rovelli³⁴, M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas³⁵, D. Spiga, A. Tsiros, G.I. Veres¹⁹, J.R. Vlimant, H.K. Wöhri, S.D. Worm³⁶, W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland

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

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

F. Bachmair, L. Bäni, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, A. Deisher, G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, P. Eller, J. Eugster, K. Freudenreich, C. Grab, D. Hits, P. Lecomte, W. Lustermann, A.C. Marini, P. Martinez Ruiz del Arbol, N. Mohr, F. Moortgat, C. Nägeli³⁷, P. Nef, F. Nessi-Tedaldi, F. Pandolfi, L. Pape, F. Pauss, M. Peruzzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, A. Starodumov³⁸, B. Stieger, M. Takahashi, L. Tauscher[†], A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, H.A. Weber, L. Wehrli

Universität Zürich, Zurich, Switzerland

C. AMSLER³⁹, V. Chiochia, S. De Visscher, C. Favaro, M. Ivova Rikova, B. Kilminster, B. Millan Mejias, P. Otiougova, P. Robmann, H. Snoek, S. Tuppiti, M. Verzetti

National Central University, Chung-Li, Taiwan

Y.H. Chang, K.H. Chen, C. Ferro, C.M. Kuo, S.W. Li, W. Lin, Y.J. Lu, A.P. Singh, R. Volpe, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan

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

Chulalongkorn University, Bangkok, Thailand

B. Asavapibhop, E. Simili, N. Srimanobhas, N. Suwonjandee

Cukurova University, Adana, Turkey

A. Adiguzel, M.N. Bakirci⁴⁰, S. Cerci⁴¹, C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, E. Gurpinar, I. Hos, E.E. Kangal, T. Karaman, G. Karapinar⁴², A. Kayis Topaksu, G. Onengut, K. Ozdemir, S. Ozturk⁴³, A. Polatoz, K. Sogut⁴⁴, D. Sunar Cerci⁴¹, B. Tali⁴¹, H. Topakli⁴⁰, L.N. Vergili, M. Vergili

Middle East Technical University, Physics Department, Ankara, Turkey

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

Bogazici University, Istanbul, Turkey

E. Gülmez, B. Isildak⁴⁵, M. Kaya⁴⁶, O. Kaya⁴⁶, S. Ozkorucuklu⁴⁷, N. Sonmez⁴⁸

Istanbul Technical University, Istanbul, Turkey

H. Bahtiyar⁴⁹, E. Barlas, K. Cankocak, Y.O. Günaydin⁵⁰, F.I. Vardarli, M. Yücel

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

L. Levchuk

University of Bristol, Bristol, United Kingdom

J.J. Brooke, E. Clement, D. Cussans, H. Flacher, R. Frazier, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, L. Kreczko, S. Metson, D.M. Newbold³⁶, K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, T. Williams

Rutherford Appleton Laboratory, Didcot, United Kingdom

L. Basso⁵¹, K.W. Bell, A. Belyaev⁵¹, C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, J. Jackson, B.W. Kennedy, E. Olaiya, D. Petyt, B.C. Radburn-Smith, C.H. Shepherd-Themistocleous, I.R. Tomalin, W.J. Womersley

Imperial College, London, United Kingdom

R. Bainbridge, G. Ball, R. Beuselinck, O. Buchmuller, D. Colling, N. Cripps, M. Cutajar, P. Dauncey, G. Davies, M. Della Negra, W. Ferguson, J. Fulcher, D. Futyan, A. Gilbert, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, M. Jarvis, G. Karapostoli, M. Kenzie, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko³⁸, J. Pela, M. Pesaresi, K. Petridis, M. Pioppi⁵², D.M. Raymond, S. Rogerson, A. Rose, C. Seez, P. Sharp[†], A. Sparrow, M. Stoye, A. Tapper, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle, T. Whyntie

Brunel University, Uxbridge, United Kingdom

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

Baylor University, Waco, USA

K. Hatakeyama, H. Liu, T. Scarborough

The University of Alabama, Tuscaloosa, USA

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

Boston University, Boston, USA

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

Brown University, Providence, USA

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

University of California, Davis, Davis, USA

R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, M. Caulfield, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, J. Dolen, R. Erbacher, M. Gardner, R. Houtz, W. Ko, A. Kopecky, R. Lander, O. Mall, T. Miceli, R. Nelson, D. Pellett, F. Ricci-Tam, B. Rutherford, M. Searle, J. Smith, M. Squires, M. Tripathi, R. Vasquez Sierra, R. Yohay

University of California, Los Angeles, USA

V. Andreev, D. Cline, R. Cousins, J. Duris, S. Erhan, P. Everaerts, C. Farrell, J. Hauser, M. Ignatenko, C. Jarvis, G. Rakness, P. Schlein[†], P. Traczyk, V. Valuev, M. Weber

University of California, Riverside, Riverside, USA

J. Babb, R. Clare, M.E. Dinardo, J. Ellison, J.W. Gary, F. Giordano, G. Hanson, H. Liu, O.R. Long, A. Luthra, H. Nguyen, S. Paramesvaran, J. Sturdy, S. Sumowidagdo, R. Wilken, S. Wimpenny

University of California, San Diego, La Jolla, USA

W. Andrews, J.G. Branson, G.B. Cerati, S. Cittolin, D. Evans, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, I. Macneill, B. Mangano, S. Padhi, C. Palmer, G. Petrucciani, M. Pieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech⁵³, F. Würthwein, A. Yagil, J. Yoo

University of California, Santa Barbara, Santa Barbara, USA

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

California Institute of Technology, Pasadena, USA

A. Apresyan, A. Bornheim, J. Bunn, Y. Chen, E. Di Marco, J. Duarte, M. Gataullin, D. Kcira, Y. Ma, A. Mott, H.B. Newman, C. Rogan, M. Spiropulu, V. Timciuc, J. Veverka, R. Wilkinson, S. Xie, Y. Yang, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA

V. Azzolini, A. Calamba, R. Carroll, T. Ferguson, Y. Iiyama, D.W. Jang, Y.F. Liu, M. Paulini, H. Vogel, I. Vorobiev

University of Colorado at Boulder, Boulder, USA

J.P. Cumalat, B.R. Drell, W.T. Ford, A. Gaz, E. Luiggi Lopez, J.G. Smith, K. Stenson, K.A. Ulmer, S.R. Wagner

Cornell University, Ithaca, USA

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

Fairfield University, Fairfield, USA

D. Winn

Fermi National Accelerator Laboratory, Batavia, USA

S. Abdullin, M. Albrow, J. Anderson, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, K. Burkett, J.N. Butler, V. Chetluru, H.W.K. Cheung, F. Chlebana, S. Cihangir, V.D. Elvira, I. Fisk, J. Freeman, Y. Gao, D. Green, O. Gutsche, J. Hanlon, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, B. Klima, S. Kunori, S. Kwan, C. Leonidopoulos⁵⁴, J. Linacre, D. Lincoln, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, V.I. Martinez Outschoorn, S. Maruyama, D. Mason, P. McBride, K. Mishra, S. Mrenna, Y. Musienko⁵⁵, C. Newman-Holmes, V. O'Dell, O. Prokofyev, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, J. Whitmore, W. Wu, F. Yang, J.C. Yun

University of Florida, Gainesville, USA

D. Acosta, P. Avery, D. Bourilkov, M. Chen, T. Cheng, S. Das, M. De Gruttola, G.P. Di Giovanni, D. Dobur, A. Drozdetskiy, R.D. Field, M. Fisher, Y. Fu, I.K. Furic, J. Gartner, J. Hugon, B. Kim, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypreos, J.F. Low, K. Matchev, P. Milenovic⁵⁶, G. Mitselmakher, L. Muniz, M. Park, R. Remington, A. Rinkevicius, P. Sellers, N. Skhirtladze, M. Snowball, J. Yelton, M. Zakaria

Florida International University, Miami, USA

V. Gaultney, S. Hewamanage, L.M. Lebolo, S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

Florida State University, Tallahassee, USA

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

Florida Institute of Technology, Melbourne, USA

M.M. Baarmand, B. Dorney, M. Hohlmann, H. Kalakhety, I. Vodopiyanov, F. Yumiceva

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

M.R. Adams, L. Apanasevich, Y. Bai, V.E. Bazterra, R.R. Betts, I. Bucinskaite, J. Callner, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, F. Lacroix, C. O'Brien, C. Silkworth, D. Strom, P. Turner, N. Varelas

The University of Iowa, Iowa City, USA

U. Akgun, E.A. Albayrak, B. Bilki⁵⁷, W. Clarida, F. Duru, S. Griffiths, J.-P. Merlo, H. Mermerkaya⁵⁸, A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, Y. Onel, F. Ozok⁴⁹, S. Sen, P. Tan, E. Tiras, J. Wetzel, T. Yetkin, K. Yi

Johns Hopkins University, Baltimore, USA

B.A. Barnett, B. Blumenfeld, S. Bolognesi, D. Fehling, G. Giurgiu, A.V. Gritsan, Z.J. Guo, G. Hu, P. Maksimovic, M. Swartz, A. Whitbeck

The University of Kansas, Lawrence, USA

P. Baringer, A. Bean, G. Benelli, R.P. Kenny Iii, M. Murray, D. Noonan, S. Sanders, R. Stringer, G. Tinti, J.S. Wood

Kansas State University, Manhattan, USA

A.F. Barfuss, T. Bolton, I. Chakaberia, A. Ivanov, S. Khalil, M. Makouski, Y. Maravin, S. Shrestha, I. Svintradze

Lawrence Livermore National Laboratory, Livermore, USA

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

University of Maryland, College Park, USA

A. Baden, B. Calvert, S.C. Eno, J.A. Gomez, N.J. Hadley, R.G. Kellogg, M. Kirn, T. Kolberg,

Y. Lu, M. Marionneau, A.C. Mignerey, K. Pedro, A. Peterman, A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar

Massachusetts Institute of Technology, Cambridge, USA

A. Apyan, G. Bauer, J. Bendavid, W. Busza, E. Butz, I.A. Cali, M. Chan, V. Dutta, G. Gomez Ceballos, M. Goncharov, Y. Kim, M. Klute, K. Krajczar⁵⁹, A. Levin, P.D. Luckey, T. Ma, S. Nahn, C. Paus, D. Ralph, C. Roland, G. Roland, M. Rudolph, G.S.F. Stephans, F. Stöckli, K. Sumorok, K. Sung, D. Velicanu, E.A. Wenger, R. Wolf, B. Wyslouch, M. Yang, Y. Yilmaz, A.S. Yoon, M. Zanetti, V. Zhukova

University of Minnesota, Minneapolis, USA

B. Dahmes, A. De Benedetti, G. Franzoni, A. Gude, S.C. Kao, K. Klapoetke, Y. Kubota, J. Mans, N. Pastika, R. Rusack, M. Sasseville, A. Singovsky, N. Tambe, J. Turkewitz

University of Mississippi, Oxford, USA

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

University of Nebraska-Lincoln, Lincoln, USA

E. Avdeeva, K. Bloom, S. Bose, D.R. Claes, A. Dominguez, M. Eads, J. Keller, I. Kravchenko, J. Lazo-Flores, S. Malik, G.R. Snow

State University of New York at Buffalo, Buffalo, USA

A. Godshalk, I. Iashvili, S. Jain, A. Kharchilava, A. Kumar, S. Rappoccio, Z. Wan

Northeastern University, Boston, USA

G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, J. Haley, D. Nash, T. Orimoto, D. Trocino, D. Wood, J. Zhang

Northwestern University, Evanston, USA

A. Anastassov, K.A. Hahn, A. Kubik, L. Lusito, N. Mucia, N. Odell, R.A. Ofierzynski, B. Pollack, A. Pozdnyakov, M. Schmitt, S. Stoynev, M. Velasco, S. Won

University of Notre Dame, Notre Dame, USA

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

The Ohio State University, Columbus, USA

L. Antonelli, B. Bylsma, L.S. Durkin, C. Hill, R. Hughes, K. Kotov, T.Y. Ling, D. Puigh, M. Rodenburg, C. Vuosalo, G. Williams, B.L. Winer

Princeton University, Princeton, USA

E. Berry, P. Elmer, V. Halyo, P. Hebda, J. Hegeman, A. Hunt, P. Jindal, S.A. Koay, D. Lopes Pegna, P. Lujan, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, P. Piroué, X. Quan, A. Raval, H. Saka, D. Stickland, C. Tully, J.S. Werner, S.C. Zenz, A. Zuranski

University of Puerto Rico, Mayaguez, USA

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

Purdue University, West Lafayette, USA

E. Alagoz, V.E. Barnes, D. Benedetti, G. Bolla, D. Bortoletto, M. De Mattia, A. Everett, Z. Hu, M. Jones, O. Koybasi, M. Kress, A.T. Laasanen, N. Leonardo, V. Maroussov, P. Merkel, D.H. Miller, N. Neumeister, I. Shipsey, D. Silvers, A. Svyatkovskiy, M. Vidal Marono, H.D. Yoo, J. Zablocki, Y. Zheng

Purdue University Calumet, Hammond, USA

S. Guragain, N. Parashar

Rice University, Houston, USA

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

University of Rochester, Rochester, USA

B. Betchart, A. Bodek, Y.S. Chung, R. Covarelli, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, A. Garcia-Bellido, P. Goldenzweig, J. Han, A. Harel, D.C. Miner, D. Vishnevskiy, M. Zielinski

The Rockefeller University, New York, USA

A. Bhatti, R. Ciesielski, L. Demortier, K. Goulios, G. Lungu, S. Malik, C. Mesropian

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

S. Arora, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Duggan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, A. Lath, S. Panwalkar, M. Park, R. Patel, V. Rekovic, J. Robles, K. Rose, S. Salur, S. Schnetzer, C. Seitz, S. Somalwar, R. Stone, S. Thomas, M. Walker

University of Tennessee, Knoxville, USA

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

Texas A&M University, College Station, USA

R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon⁶⁰, V. Khotilovich, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Safonov, T. Sakuma, S. Sengupta, I. Suarez, A. Tatarinov, D. Toback

Texas Tech University, Lubbock, USA

N. Akchurin, J. Damgov, C. Dragoiu, P.R. Duderu, C. Jeong, K. Kovitanggoon, S.W. Lee, T. Libeiro, I. Volobouev

Vanderbilt University, Nashville, USA

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

University of Virginia, Charlottesville, USA

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

Wayne State University, Detroit, USA

S. Gollapinni, R. Harr, P.E. Karchin, C. Kottachchi Kankanamge Don, P. Lamichhane, A. Sakharov

University of Wisconsin, Madison, USA

M. Anderson, D.A. Belknap, L. Borrello, D. Carlsmith, M. Cepeda, S. Dasu, E. Friis, L. Gray, K.S. Grogg, M. Grothe, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, J. Klukas, A. Lanaro, C. Lazaridis, R. Loveless, A. Mohapatra, M.U. Mozer, I. Ojalvo, F. Palmonari, G.A. Pierro, I. Ross, A. Savin, W.H. Smith, J. Swanson

†: Deceased

1: Also at Vienna University of Technology, Vienna, Austria

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

3: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

4: Also at California Institute of Technology, Pasadena, USA

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

United Kingdom

52: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy

53: Also at Utah Valley University, Orem, USA

54: Now at University of Edinburgh, Scotland, Edinburgh, United Kingdom

55: Also at Institute for Nuclear Research, Moscow, Russia

56: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia

57: Also at Argonne National Laboratory, Argonne, USA

58: Also at Erzincan University, Erzincan, Turkey

59: Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary

60: Also at Kyungpook National University, Daegu, Korea