Physics Letters B 720 (2013) 309–329

Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Search for excited leptons in pp collisions at $\sqrt{s} = 7$ TeV

CMS Collaboration *

CERN, Switzerland

A R T I C L E   I N F O

Article history:
Received 6 October 2012
Received in revised form 12 February 2013
Accepted 13 February 2013
Available online 19 February 2013
Editor: M. Doser

Keywords:
CMS
Physics

A B S T R A C T

Results are presented of a search for compositeness in electrons and muons using a data sample of pp collisions at a center-of-mass energy $\sqrt{s} = 7$ TeV collected with the CMS detector at the LHC and corresponding to an integrated luminosity of 5.0 fb^{-1}. Excited leptons (ℓ^*) are assumed to be produced via contact interactions in conjunction with a standard model lepton and to decay via $\ell^* \to \ell\gamma$, yielding a final state with two energetic leptons and a photon. The number of events observed in data is consistent with that expected from the standard model. The 95% confidence upper limits for the cross section for the production and decay of excited electrons (muons), with masses ranging from 0.6 to 2 TeV, are 1.48 to 1.24 fb (1.31 to 1.11 fb). Excited leptons with masses below 1.9 TeV are excluded for the case where the contact interaction scale equals the excited lepton mass. The limits on the cross sections are the most stringent ones published to date.

1. Introduction

The standard model (SM) of particle physics, albeit very successful, provides no explanation for the three generation structure of the fermion families. Attempts to explain the observed hierarchy have led to a family of models postulating that quarks and leptons might be composite objects of fundamental constituents [1–9]. The fundamental constituents are bound by an asymptotically free gauge interaction that becomes strong at a characteristic scale Λ. Compositeness models predict the existence of excited states of quarks (q^*) and leptons (ℓ^*) at this characteristic scale of the new binding interaction. Since these excited fermions couple to the ordinary SM fermions, they can be produced via contact interactions in collider experiments and subsequently decay radiatively to ordinary fermions through the emission of a W/Z/γ boson or via contact interactions to other fermions. The excited leptons can also be produced via gauge-mediated interactions, but the cross sections for these are negligible for the range of parameters that are probed in this search and therefore this production mechanism is not considered. The effective Lagrangian describing the interaction of excited fermions [7] is parametrized by the scale Λ. Additionally, for decay via gauge mediated interaction, two factors f and f' represent the relative strength of the coupling between the excited fermions and isovector and isoscalar gauge fields, respectively. In this Letter the convention $f = f' = 1$ is adopted. The results for arbitrary $f = f' > 0$ can be simply obtained by a rescaling of the scale Λ to Λ / f.

Searches at LEP [10–13], HERA [14], and the Tevatron [15–18] found no evidence for excited leptons. At the Large Hadron Collider (LHC) [19] at CERN, previous searches performed by the CMS [20] and the ATLAS Collaborations [21] have also shown no evidence for excited leptons. At a center-of-mass energy of $\sqrt{s} = 7$ TeV, with 36 pb^{-1} of data [20], CMS has excluded cross sections for the production and decay of the $\ell^* \to \ell\gamma$ channels higher than 0.16 to 0.21 pb (0.14 to 0.19 pb) in the e* (μ^*) channel for excited lepton masses ranging from 0.2 TeV to 2 TeV. In the same channels and with more integrated luminosity, ATLAS excluded cross sections higher than 2.3 (4.5) fb for excited electrons (muons) masses above 0.9 TeV, and excluded e* (μ^*) with masses M_{ℓ^*} below 1.87 (1.75) TeV for the scale of contact interaction $\Lambda = M_{\ell^*}$ [21].

This Letter presents a search for excited leptons, e* and μ^*, using a data sample of pp collisions at a center-of-mass energy $\sqrt{s} = 7$ TeV collected with the CMS detector at the LHC in 2011 and corresponding to an integrated luminosity of 5.0 ± 0.1 fb^{-1}. The production of an excited lepton in association with an oppositely charged lepton of the same flavor, via four-fermion contact interactions, is considered. Thus when the excited lepton decays via $\ell^* \to \ell\gamma$, there are two oppositely charged leptons and a photon in the final state.

2. The CMS detector

The central feature of the Compact Muon Solenoid (CMS) detector is a superconducting solenoid, of 6 m internal diameter and

---

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

0370-2693/ © 2013 CERN. Published by Elsevier B.V. Open access under CC BY-NC-ND license.
http://dx.doi.org/10.1016/j.physletb.2013.02.031

12.5 m in length, which provides an axial field of 3.8 T. Starting from the collision point, the first three detector components inside the solenoid are the silicon pixel and strip trackers; the lead–tungstate crystal electromagnetic calorimeter (ECAL), comprising a central (barrel) section and two forward (endcap) sections; and the brass/scintillator hadron calorimeter (HCAL). Extensive forward calorimetry complements the coverage provided by the barrel and endcap detectors. The tracker consists of 10 layers of silicon strip detectors in addition to the pixel detectors. Four stations of muon detectors are embedded in the steel yoke of the superconducting solenoid, including forward sections in order to extend the covered pseudorapidity region up to $|\eta| < 2.4$. The pseudorapidity (η) is defined as $\eta = -\ln[\tan(\theta/2)]$. The CMS detector 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 polar angle θ is measured from the positive z axis and the azimuthal angle ϕ is measured in the x–y plane. The projection of the momentum on to the x–y plane is used to define the transverse momentum p_T and the transverse energy E_T. The details of the CMS detector are described elsewhere [22].

3. Signal and background

The dominant, irreducible SM background in this search is Drell–Yan production of $\ell^+\ell^-\gamma$ where the final state photon is either radiated by an initial-state parton (initial-state radiation, ISR), or originates from one of the final-state leptons (final-state radiation, FSR). The second-most important background is due to Drell–Yan production associated with jets (Z + jets), where a jet is misidentified as a photon (see Section 5). Another important background in the e* channel is due to W + jets events with an FSR or ISR photon where a jet is misidentified as an electron. In the μ^* channel, backgrounds from these W + jets processes that lead to one true, one misidentified muon, and a true photon in the final state have been estimated to be negligible. Other less significant backgrounds originate from diboson events (WW, WZ, ZZ, $W+\gamma$), $t\bar{t}$ production, and, for the electron channel, $\gamma\gamma$ production. These backgrounds are mainly suppressed by requiring high transverse momentum thresholds on the leptons and photon. Backgrounds arising from misidentified photons or misidentified electrons are estimated using a data-driven technique which is described in Section 5. The other backgrounds are estimated from the simulation.

Signal samples in both electron and muon channels are produced using PYTHIA (PYTHIA 6.424 [23] and PYTHIA 8.145 [24] respectively) based on the leading order (LO) compositeness model described in Ref. [7]. The signal cross sections are calculated with PYTHIA 6.424, corrected to include the branching ratio for the 3-body decays via contact interaction as per Ref. [7] which is not implemented in PYTHIA, with the Q^2 scale set to the square of the mass of the excited lepton ($M^2_{\ell*}$).

Samples are obtained for different values of the excited lepton mass and $\Lambda = 4$ TeV, with the CTEQ6L1 [25] parametrization for the parton distribution functions. This particular choice of the value of Λ has no impact on the simulated kinematics and all results are presented independently of the value of Λ, except for the signal yield in Fig. 1 and Fig. 2. The SM background samples: $Z+\gamma$, $W+\gamma$, $t\bar{t}$, Z + jets, W + jets, and WW are generated with MadGraph 4.5.1 [26]. PYTHIA has been used to perform the fragmentation and hadronization of samples generated with MadGraph. The diboson samples (WZ, ZZ) are generated using PYTHIA 6.424. The main background $Z+\gamma$ has been generated to correspond to an integrated luminosity of around 7 fb^{-1}. For all these SM background processes, the cross sections are scaled to the next-to-leading order (NLO) cross sections obtained from the parton level integrator MCFM [27]. For the main background $Z+\gamma$, the theoretical scale uncertainty has been evaluated using MCFM to be +2.4%, −1.6%. All Monte Carlo events used in this analysis have been passed through the detailed simulation of the CMS detector based on Geant4 [28].

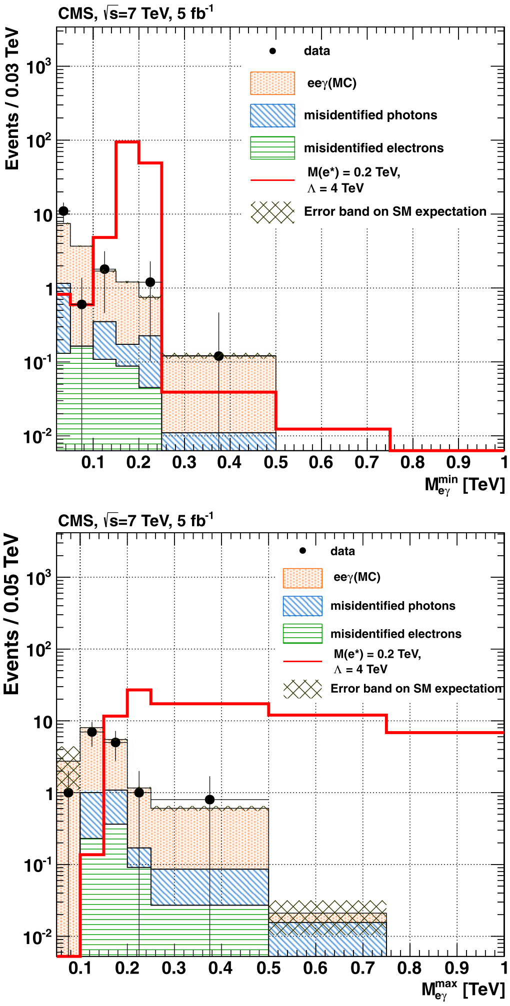

Fig. 1. The distribution of events as a function of $M^{\min}_{\ell\gamma}$ (top) and $M^{\max}_{\ell\gamma}$ (bottom), expected in the presence of an excited electron with a mass of 0.2 TeV. The red dotted histogram corresponds to the contribution from the standard model backgrounds containing two real electrons and a real photon. The blue slanting hatched (green horizontal hatched) histograms correspond to the contribution from misidentified photon (electrons). The black solid circles correspond to the observed data. The red solid line histogram corresponds to the signal distribution for a mass of 0.2 TeV. The dark grey double hatched region shows the uncertainty in the SM expectation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this Letter.)

4. Event reconstruction and selection

Candidate events for the electron (muon) channel are selected using triggers with the lowest possible thresholds on lepton transverse momentum. This corresponds to a transverse momentum threshold of 33 (24) GeV for the initial periods and 33 (40) GeV for the later periods of data collection in the electron (muon) channel. The trigger thresholds were raised in response to the increased mean instantaneous luminosity. For the leptons selected in the analysis, the trigger efficiencies are 100% (97%) in the electron (muon) channel. The two leptons and the photon in signal events are expected to be isolated from other particles in the event. This

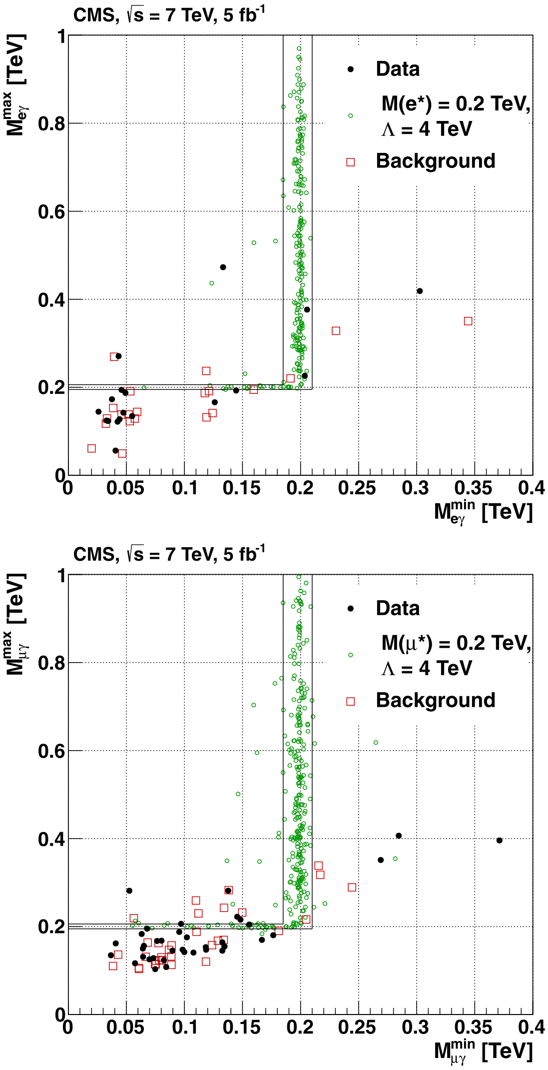

Fig. 2. Distribution of $M^{\min}_{\ell\gamma}$ and $M^{\max}_{\ell\gamma}$ for the excited electron analysis (top) and excited muon analysis (bottom). The black solid circles, the red squares and the green open circles correspond to the observed data, the background distribution and the signal distribution, respectively. The optimized selection boundaries are shown for an excited lepton mass of 0.2 TeV. The sample is normalized to 5 fb^{-1} of integrated luminosity. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this Letter.)

can be quantified by isolation variables, obtained by summing the energy deposits present inside a geometrical cone around the particle, in the tracker or in the calorimeters. Events with at least one well-reconstructed primary vertex, one isolated high-p_T photon, and two isolated high-p_T leptons are used in this analysis.

Electron identification is performed using clusters of localized energy deposits in the ECAL. An energy deposit in the ECAL due to an electron is identified by imposing requirements on shower shapes of the ECAL clusters and isolation variables as well as the ratio of the energies deposited in the hadron and electromagnetic calorimeters (H/E). A reconstructed track correctly associated with an ECAL cluster is also required. For the electron channel, the electrons are required to have a transverse energy $E_T > 35$ (40) GeV in the ECAL barrel (endcap) and $|\eta| < 2.5$, excluding the transition region $1.4442 < |\eta| < 1.560$ between the ECAL barrel and endcap regions. The electron is required to be isolated both in the tracker and calorimeter within a cone of radius $\Delta R \equiv \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.3$ around its direction. In the tracker, the scalar sum of the p_T of the tracks, that are at least 0.7 GeV in p_T and lie outside a cone of radius $\Delta R = 0.04$ relative to the electron, is required to be less than 5 GeV. For the isolation using the calorimeters, a variable E_T^{iso} is introduced, defined as the total sum of transverse energy deposits excluding deposits associated with the electron. In the barrel, E_T^{iso} is required to be less than $0.03E_T + 2.0$ GeV, and in the endcap: for $E_T < 50$ GeV, the total E_T^{iso} is required to be below 2.5 GeV; for $E_T > 50$ GeV, it is required to be below $0.03E_T + 1.0$ GeV.

For photons, identification criteria on the shower shapes, isolation variables and H/E are applied to energy clusters in the ECAL [29]. Photon candidates are required to have clusters with $E_T > 35$ GeV and to be in the central region (barrel) of the ECAL with $|\eta| < 1.4442$. The photon is also required to be isolated within a cone of radius $\Delta R < 0.4$ around its direction, both in the tracker and calorimeter. The cone axis is taken to be the direction of the line joining the barycenter of the energy cluster to the primary vertex. In the tracker, the scalar sum of the transverse momenta of the tracks, excluding tracks within an inner cone of 0.04, is required to be less than $0.001p_T + 2$ GeV. In the ECAL, the total E_T^{iso} in the barrel, excluding deposits associated with the photon, is required to be below $0.006E_T + 4.2$ GeV, whereas for the HCAL isolation, it is required to be below $0.0025E_T + 2.2$ GeV.

Muons are reconstructed by combining tracks from the inner tracker and the outer muon system, requiring at least one hit in the pixel tracker, hits in more than 8 tracker layers and track segments reconstructed in at least two muon stations. Since the segments have multiple hits that typically occur in different muon detectors and are therefore separated by thick layers of iron, the latter requirement significantly reduces the probability of a hadron being misidentified as a muon. For the muon channel, two muons are required with each having $|\eta| < 2.1$; and the higher (lower) momentum muon must have $p_T > 45$ (40) GeV. In order to reduce the cosmic-rays muon background, the transverse impact parameters of both muon tracks with respect to the primary vertex of the event are required to be less than 0.2 cm and muon pairs that are back-to-back in the transverse plane are rejected, with the angle between two muon tracks below $\pi - 0.02$. Furthermore, the muon is required to be isolated such that the scalar sum of the transverse momenta of all tracks originating at the interaction vertex, excluding the muon itself, within a $\Delta R < 0.3$ cone around its direction is less than 10% of its p_T.

In order to reject Drell–Yan events with final state radiation, the distance in (η, ϕ) coordinates between the photon and the leading lepton, $\Delta R(\ell, \gamma)$ is required to be $\Delta R(\ell, \gamma) > 0.5$ for $\ell = \text{e}$ and $\Delta R(\ell, \gamma) > 0.7$ for $\ell = \mu$. Two lepton–photon invariant masses can also be computed, because the final state is composed of two leptons and one photon. For the electron channel, the dielectron invariant mass is required to be above 60 GeV and each of the dielectron and electron–photon invariant masses are required to be outside a ±25 GeV window centered at the nominal Z mass (91.19 GeV). For the muon channel, the dilepton invariant mass is required to be 25 GeV above the nominal Z mass. Fig. 1 shows the distribution of $M^{\min}_{\ell\gamma}$ and $M^{\max}_{\ell\gamma}$, the lower and higher invariant mass respectively. In the case of a signal, the correct assignment peaks at the excited lepton mass. In the $M^{\min}_{\ell\gamma}$–$M^{\max}_{\ell\gamma}$ plane, the signal is distributed along two mutually perpendicular narrow bands. This shape determines the final selection cuts as outlined below and is illustrated in Fig. 2 for $M_{\ell^*} = 0.2$ TeV. Identical boundaries are used for the electron and muon channel. The only difference in the selection between the two channels is the Z veto, which, in the electron channel, is also applied on electron–photon invariant mass.

The background is located in the low invariant mass region, while the signal populates the higher invariant mass region. Using simulations, the boundaries of the signal region for a given

Table 1
Measured signal and expected background event numbers for the electron and muon channels as a function of the mass of the excited lepton. The signal efficiency with its corresponding uncertainty is given as ϵ_{signal}. The expected numbers of background events are reported as N_{bkgd} with Clopper–Pearson errors [30] along with the observed data N_{data}. The boundary values for $M_{\ell\gamma}^{\text{min}}$ and $M_{\ell\gamma}^{\text{max}}$, which correspond to the signal region, are also given. The signal efficiencies shown with † symbol are obtained from a polynomial curve fitted to the signal efficiencies for the mass points that have been simulated.

M_{ℓ^*} (TeV)	$M_{\ell\gamma}^{\text{min}}$ (TeV)	$M_{\ell\gamma}^{\text{max}}$ (TeV)	Electron channel			Muon channel		
			ϵ_{signal} (%)	N_{bkgd}	N_{data}	ϵ_{signal} (%)	N_{bkgd}	N_{data}
0.2	0.19–0.21	0.20–0.21	24.8 ± 1.8	$1.0^{+1.1}_{-0.5}$	2	28.2 ± 1.3	$1.2^{+1.7}_{-0.6}$	2
0.3	0.23–0.37	0.29–0.31	$30.0 \pm 2.2^{\dagger}$	$1.2^{+2.1}_{-0.8}$	1	$34.4 \pm 1.6^{\dagger}$	$5.4^{+2.6}_{-1.8}$	2
0.4	0.28–0.52	0.38–0.41	32.7 ± 2.4	$0.1^{+1.4}_{-0.1}$	1	39.1 ± 1.8	$1.6^{+2.0}_{-0.9}$	3
0.5	0.35–0.65	0.47–0.53	$34.8 \pm 2.6^{\dagger}$	$0.0^{+1.4}_{-0.0}$	1	$42.1 \pm 1.9^{\dagger}$	$0.0^{+1.4}_{-0.0}$	1
0.6	0.42–0.78	0.55–0.64	36.6 ± 2.6	$0.0^{+1.4}_{-0.0}$	0	45.4 ± 2.0	$0.0^{+1.4}_{-0.0}$	0
0.7	0.49–0.91	0.65–0.76	$37.8 \pm 2.7^{\dagger}$	$0.1^{+1.4}_{-0.0}$	0	$45.9 \pm 2.1^{\dagger}$	$1.0^{+1.7}_{-0.6}$	0
0.8	0.56–1.04	0.75–0.88	37.8 ± 2.7	$0.0^{+1.4}_{-0.0}$	0	45.3 ± 2.0	$0.0^{+1.4}_{-0.0}$	0
1.0	0.70–1.30	0.75–1.08	40.4 ± 2.8	$0.0^{+1.4}_{-0.0}$	0	48.5 ± 2.1	$0.0^{+1.4}_{-0.0}$	0
1.2	0.84–1.56	0.75–1.34	41.1 ± 2.9	$0.0^{+1.4}_{-0.0}$	0	50.0 ± 2.2	$0.0^{+1.4}_{-0.0}$	0
1.5	1.05–1.95	0.75–1.67	41.7 ± 2.9	$0.0^{+1.4}_{-0.0}$	0	50.8 ± 2.2	$0.0^{+1.4}_{-0.0}$	0
2.0	1.40–2.60	0.75–2.23	43.5 ± 3.1	$0.0^{+1.4}_{-0.0}$	0	50.4 ± 2.2	$0.0^{+1.4}_{-0.0}$	0

mass have been chosen to optimize the expected limit. The final values for different excited lepton masses are shown in Table 1. For $M_{\ell^*} = 0.2$ TeV, the horizontal band is small, in order to reduce the background contamination. For $M_{\ell^*} = 0.4$ TeV, a larger horizontal band can be used, the increase of the background contamination being compensated by the gain in signal efficiency. For higher excited lepton masses, the horizontal band is large to improve the signal efficiency in regions where almost no background is present.

5. Background due to particle misidentification

Hadronic jets in which a π^0 carries a significant fraction of the energy may be misidentified as isolated photons. Thus Z + jets events are a potential background for this search. The photon misidentification rate is measured directly from a data sample dominated by jets, with a photon-like candidate cluster embedded inside, which can potentially be misidentified as a photon. The misidentification rate is defined as the ratio of the number of photon candidates passing all the photon selection criteria (numerator) to the number of photon candidates that pass a loose set of shower shape requirements but fail one of the photon isolation criteria (denominator). The misidentification rate is estimated in bins of photon E_{T}. The numerator sample can have a contribution from isolated true photons. This misidentification rate is therefore corrected by using the probability distribution of energy-weighted shower width ($\sigma_{\eta\eta}$) of isolated true photons computed in units of crystal size, which is different from that of non-isolated photons. The true photon fraction in the numerator is estimated by fitting these two different shower shapes to the shower shape distribution of the numerator sample, and subtracted from the numerator. In order to estimate the contribution of misidentified photons in the analysis, the misidentification rate is applied to a subsample of data events containing one photon candidate and satisfying all other selection criteria. This rate is calculated in photon E_{T} bins of (0.03–0.05, 0.05–0.075, 0.075–0.09, 0.09–0.2) TeV. Fig. 3 shows the E_{T} dependence of the photon misidentification rate. The calculated misidentified photon rate is found to be 0.28, 0.07, 0.06 and 0.09 for the above mentioned E_{T} bins.

From a fit, the measured rate is parametrized by a function, $f_{\gamma}^{\text{misid}}(E_{\text{T}})$, as given in Eq. (1) with a, b and c being the fit parameters:

$$f_{\gamma}^{\text{misid}}(E_{\text{T}}) = a + \frac{b}{(E_{\text{T}})^c}. \tag{1}$$

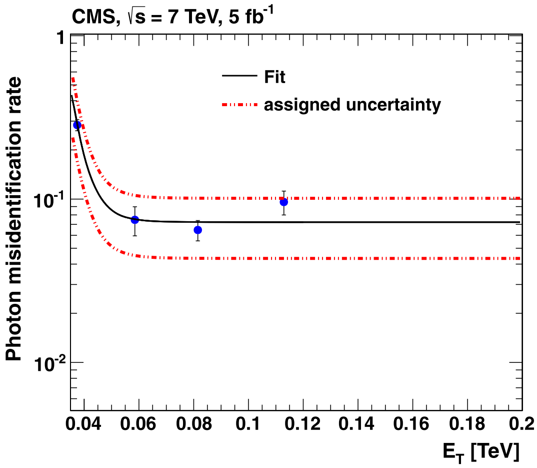

Fig. 3. The jet-to-photon misidentification rate as a function of E_{T}. The dashed line is the 40% uncertainty band.

An uncertainty of 40% is assigned to this function which envelopes the spread of data points relative to the fit. The jet to photon misidentification is estimated by applying this misidentification rate to a sample passing all our selection requirements, including triggers, except a requirement that the photon candidate fails one of the photon identification criteria and passes instead the loose identification requirements. Applied to the lowest mass point of 0.2 TeV, the contribution of photon misidentification background in the full selection is found to be $0.07^{+0.16}_{-0.07}$ events for both the electron and the muon channels. It is negligible for higher mass points.

Backgrounds with zero or one real electron can contribute to the e* search. The largest contributions come from processes such as $\text{W}(\rightarrow e\nu)$ + jet + γ where the jet in the event is misidentified as an electron. Misidentification can occur when photons coming from π^0s inside a jet convert to an e^+e^- pair and are misidentified as electrons. Other possible sources include when a charged particle within a jet provides both the track in the tracker and an electromagnetic cluster that together fake an electron signature, or when a track from a charged particle matches with a nearby energy deposition in the calorimeter from another particle. The misidentification rate is calculated as the ratio between the number of candidates passing the electron selection criteria with respect to those satisfying looser selection criteria.

Table 2

Details of the expected background compositions for several masses, showing contributions from $\mathrm{Z}+\gamma$ MC sample, misidentified γ and misidentified electron estimated from data. The uncertainties are reported as the quadratic sum of statistical and systematic errors.

M_{ℓ^*} (TeV)	Electron channel			Muon channel	
	$\mathrm{Z}+\gamma$ MC	Misid γ	Misid electron	$\mathrm{Z}+\gamma$ MC	Misid γ
0.2	$0.8^{+1.1}_{-0.5}$	$0.07^{+0.16}_{-0.07}$	$0.08^{+0.17}_{-0.07}$	$1.0\ ^{+1.7}_{-0.6}$	$0.07\ ^{+0.16}_{-0.07}$
0.4	$0.0^{+1.4}_{-0.0}$	$0.07^{+0.16}_{-0.07}$	$0.01^{+0.02}_{-0.01}$	$1.6\ ^{+1.9}_{-0.9}$	$0.00\ ^{+0.45}_{-0.00}$
$\geqslant$0.6	$0.0^{+1.4}_{-0.0}$	$0.00^{+0.45}_{-0.00}$	$0.00^{+0.08}_{-0.00}$	$0.0\ ^{+1.4}_{-0.0}$	$0.00\ ^{+0.45}_{-0.00}$

The looser selection criteria require only that the first tracker layer contributes a hit to the electron track and that offline emulations of the online trigger requirements (“loose identification requirements”) on shower shape $\sigma_{\eta\eta}$ and the ratio H/E are satisfied. This ratio is estimated as a function of E_{T} in bins of η ($f^{\text{misid}}_{\text{electron}}(E_{\mathrm{T}}, \eta)$) using a data sample selected with single-photon triggers [31]. The jet to electron misidentified background in e* is estimated by applying this misidentification rate to a sample passing all our selection requirements, including triggers, except requiring one of the electron candidates to fail the electron identification criteria and pass instead the loose identification requirements. The systematic uncertainty on $f^{\text{misid}}_{\text{electron}}(E_{\mathrm{T}}, \eta)$ is determined using a sample of events containing two reconstructed electrons as in [31]. The contribution from jet events to the dielectron mass spectrum can be determined either by applying the misidentification rate twice on events with two loose electrons or by applying the misidentification rate once on events with one fully identified electron and one loose electron. The first estimate lacks contributions from W + jets and γ + jets events while the second estimate is contaminated by Drell–Yan events. These effects are corrected using simulated samples. If the misidentification rate method is correct, the two corrected estimations should agree. Both estimates are found to agree well and the residual difference of 40% between the two estimates is taken as the systematic uncertainty on the jet to electron misidentification rate. The contribution from events which have zero or one real electron is $0.08^{+0.17}_{-0.07}$ for the lowest mass point of 0.2 TeV and is negligible for higher mass points.

6. Results

After all selection steps the expected background for $M_{\ell^*} >$ 0.7 TeV is found to be $0^{+1.4}_{-0.0}$ event in the simulated sample. The signal efficiency increases with the mass of the excited lepton, from 25% to 44% in the electron channel and 28% to 50% in the muon channel. All numbers are summarized in Table 1. The expected numbers of signal events and irreducible background events are evaluated from simulation while the contribution of misidentified particles is derived from data. The background composition for several mass points, 0.2 TeV, 0.4 TeV and $\geqslant$0.6 TeV for both channels is shown in Table 2. The uncertainties in the description of the detector performance, such as lepton energy or momentum resolution, lepton and photon energy scales, have been included in the systematic uncertainties. The impact on the signal yield corresponds to an uncertainty of ±2% and ±3.5%, for the electron and muon channels respectively. Effects caused by the increase in the typical number of additional pp interactions (‘pileup’) per LHC bunch crossing are modeled by adding to the generated events multiple collisions with a multiplicity distribution matched to the luminosity profile of the collision data. To evaluate the systematic uncertainty associated with the pileup simulation, the mean of the distribution of the pileup interactions is varied by 5%, leading to a variation of 3.0% (0.6%) in the simulated backgrounds and 1.0% (1.5%) in signal yields in the electron (muon) channel. An additional systematic uncertainty of 10% is assigned to the background to account for uncertainties associated with the choice of parton distribution functions. The uncertainty in the luminosity normalization is 2.2% [32].

As seen in Table 1, for masses above 0.5 TeV, no data events pass the criteria designed to select excited lepton signatures. Using a single bin counting method, upper limits are provided on the production cross section times branching fraction of excited electrons and excited muons at the 95% confidence level. The method is implemented in the statistical package developed by the Higgs study group [33]. The computation has been performed using both a Bayesian [34,35] and a $\mathrm{CL_s}$ [36,37] approach; the results are found to be consistent with each other. The results presented here are from the frequentist $\mathrm{CL_s}$ approach, without the use of the asymptotic approximation [33]. The background and signal uncertainties are dominated by completely uncorrelated uncertainties. The integrated luminosity normalization uncertainty is considered separately, with 100% correlation between signal and background. The nuisance parameters related to the uncertainties on the background are treated according to gamma probability distribution functions. The uncertainties on the signal yield and the integrated luminosity normalization are taken into account via a lognormal treatment of nuisance parameters. The observed limits for the electron and the muon channels are shown in Fig. 4. Production cross sections higher than 1.48 to 1.24 fb (1.31 to 1.11 fb) are excluded at the 95% confidence limit (CL) for e* (μ^*) masses ranging from 0.6 to 2 TeV. The structure observed in the expected and observed limits results from the limited sizes of the simulated background samples. The optimization of the invariant masses selecting the $M^{\text{min}}_{\ell\gamma}$–$M^{\text{max}}_{\ell\gamma}$ signal region has been determined from simulation of signal reference mass points, ranging from $M_{\ell^*} = 0.2$ TeV to 2.0 TeV in steps of 0.2 TeV. For lower masses, the selected signal regions do not overlap. For continuous coverage, additional mass points for $M_{\ell^*} < 0.6$ TeV have been added by interpolating the cut thresholds and the signal efficiencies. Limits for masses between 0.2 and 0.4 TeV are less stringent because of the presence of background in this region.

In the excited muon channel, as visible in Table 1, the bump at $M_{\mu^*} \sim 0.5$ TeV corresponds to a region where the background is found to be $0.0^{+1.4}_{-0.0}$ in the simulated sample while one data event is observed. Also in this channel, the shape of the uncertainty bands at $M_{\mu^*} = 0.7$ TeV corresponds to a region where the background is found to be $1.0^{+1.7}_{-0.6}$ in the simulated sample while zero data events are observed. For high excited lepton masses, the muon channel cross section limit is slightly lower than the electron channel limit because of the difference in the acceptance. For lower excited lepton masses, the sensitivity of the electron channel is also reduced because of misidentification of photons and electrons.

The set of Λ–M_{ℓ^*} values for which the theoretical cross section times branching fraction is higher than the 95% upper limit on cross section, is considered as excluded region of the parameter space. The exclusion region in the Λ–M_{ℓ^*} plane is shown in Fig. 5. The displayed uncertainty band corresponds to the uncertainty on the cross section limits, and does not take into account uncertainties on the theoretical signal cross section. The region is theoretically excluded, where $M_{\ell^*} > \Lambda$. The signal cross sections are estimated with the Q^2 scale set to the square of the mass of excited lepton ($M^2_{\ell^*}$). If the Q^2 scale is varied to $M^2_{\ell^*}/2$, the limit for $\Lambda = M_{\ell^*}$ increases by 1.5% and if it is varied to $2M^2_{\ell^*}$, the limit for $\Lambda = M_{\ell^*}$ decreases by 2.4%. The impact of the parton distribution functions (PDF) uncertainties on the signal is smaller than 1%.

Assuming the same masses for e* and μ^*, the two counting experiments have been combined using the $\mathrm{CL_s}$ approach, improving the excluded cross section limit to 0.73 to 0.60 fb for masses from

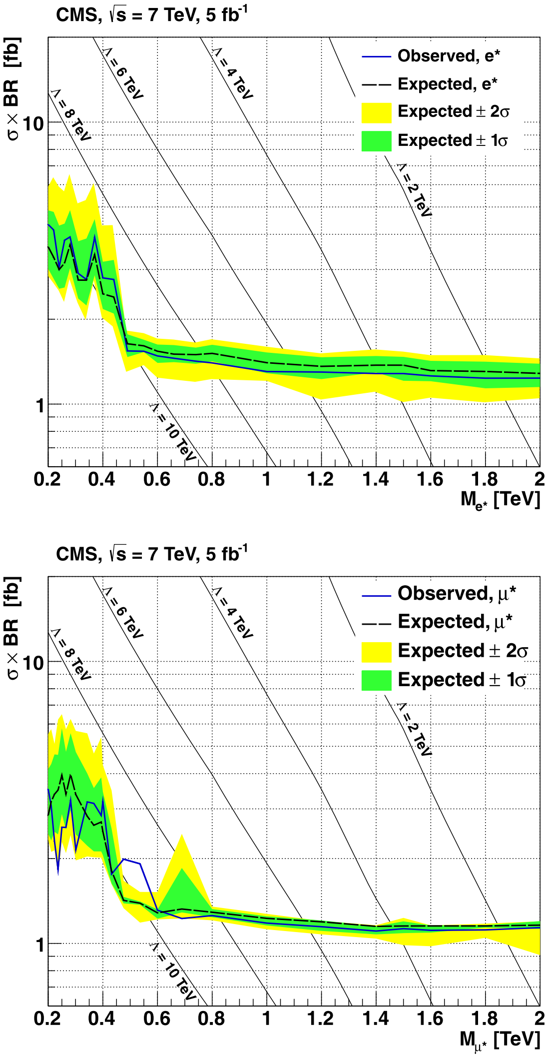

Fig. 4. Expected and observed 95% CL upper limits on the cross section of the studied channel for the different excited electron (top) and muon (bottom) mass points, using the CL$_\mathrm{s}$ method. The excluded region is above the curve. The black solid lines correspond to the excited lepton LO cross sections times branching ratio for different Λ scales. The one (two) standard deviation uncertainty bands are shown in green (yellow). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this Letter.)

0.6 to 2 TeV. Allowing e^* and μ^* to have different masses, the excluded cross sections would also be within this range. The following uncertainties have been considered as completely correlated between the two channels: the photon scale factor uncertainties in signal and background, the photon misidentification rate systematic uncertainty not related to statistics, the luminosity uncertainty, the pileup simulation uncertainty, the $\mathrm{Z}+\gamma$ normalization uncertainty, and the $\mathrm{Z}+\gamma$ PDF uncertainty. The other uncertainties are considered as 100% uncorrelated.

7. Summary

A search has been performed with the CMS detector for excited leptons in the electron ($\mathrm{pp} \to \mathrm{ee}^* \to \mathrm{ee}\gamma$) and muon ($\mathrm{pp} \to \mu\mu^* \to \mu\mu\gamma$) channels. For each excited lepton mass, the excluded cross section can be associated with a value for the new interaction scale Λ. Excited leptons (electrons or muons) with masses below 1.9 TeV are excluded for the scale of contact interaction $\Lambda = M_{\ell^*}$. Production cross sections higher than 1.48 to 1.24 fb (1.31 to 1.11 fb) are excluded at the 95% CL for e^* (μ^*) masses ranging from 0.6 to 2 TeV. The slightly better sensitivity in the muon channel is due to its better acceptance and efficiency, and also, for lower ℓ^* masses, to the fact that there is a higher background in the electron channel arising from particle misidentification. These limits are the most stringent published to date.

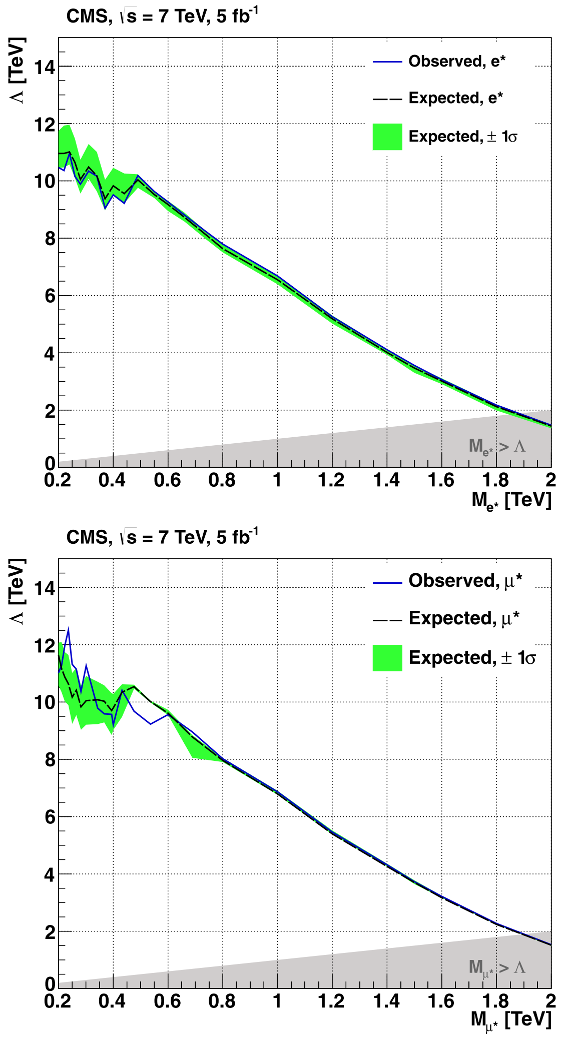

Fig. 5. Expected and observed 95% CL lower limits on the Λ scale for the different excited electron (top) and muon (bottom) mass points, using the CL$_\mathrm{s}$ method. The excluded region is below the curve. These limits are computed with the LO signal cross section obtained from PYTHIA 6.424. The one standard deviation uncertainty band is shown in green. The bands do not include the uncertainty on signal cross section. The grey area corresponds to the theoretically excluded region where $M_{\ell^*} > \Lambda$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this Letter.)

Acknowledgements

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC machine. We thank the technical and administrative staff at CERN and other CMS institutes, and acknowledge support from: FMSR (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); 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);

I± (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); MICINN and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); TUBITAK and TAEK (Turkey); STFC (United Kingdom); DOE and NSF (USA). Individuals have received support from the Marie-Curie programme and the European Research Council (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 Council of Scientific and Industrial Research, India; and the HOMING PLUS programme of Foundation for Polish Science, cofinanced from European Union, Regional Development Fund.

Open access

References

[1] J.C. Pati, A. Salam, J.A. Strathdee, Phys. Lett. B 59 (1975) 265, http://dx.doi.org/10.1016/0370-2693(75)90042-8.

[2] H. Terazawa, M. Yasuè, K. Akama, M. Hayshi, Phys. Lett. B 112 (1982) 387, http://dx.doi.org/10.1016/0370-2693(82)91075-9.

[3] M. Abolins, B. Blumenfeld, E. Eichten, H. Kagan, K. Lane, J. Leveille, D. Pellett, M. Peskin, J. Wiss, in: Elementary Particles and Future Facilities, Snowmass, 1982, 1982, p. 274, http://inspirehep.net/record/185862/files/C8206282-pg274.PDF, eConf C8206282.

[4] E. Eichten, K.D. Lane, M.E. Peskin, Phys. Rev. Lett. 50 (1983) 811, http://dx.doi.org/10.1103/PhysRevLett.50.811.

[5] H. Harari, Phys. Rept. 104 (1984) 159, http://dx.doi.org/10.1016/0370-1573(84)90207-2.

[6] K.D. Lane, F.E. Paige, T. Skwarnicki, W.J. Womersley, Phys. Rept. 278 (1997) 291, http://dx.doi.org/10.1016/S0370-1573(96)00018-X, arXiv:hep-ph/9412280.

[7] U. Baur, M. Spira, P.M. Zerwas, Phys. Rev. D 42 (1990) 815, http://dx.doi.org/10.1103/PhysRevD.42.815.

[8] O.W. Greenberg, C.A. Nelson, Phys. Rev. D 10 (1974) 2567, http://dx.doi.org/10.1103/PhysRevD.10.2567.

[9] O.W. Greenberg, J. Sucher, Phys. Lett. B 99 (1981) 339, http://dx.doi.org/10.1016/0370-2693(81)90113-1.

[10] D. Buskulic, et al., ALEPH Collaboration, Phys. Lett. B 385 (1996) 445, http://dx.doi.org/10.1016/0370-2693(96)00961-6.

[11] P. Abreu, et al., DELPHI Collaboration, Eur. Phys. J. C 8 (1999) 41, http://dx.doi.org/10.1007/s100529901074, arXiv:hep-ex/9811005.

[12] G. Abbiendi, et al., OPAL Collaboration, Eur. Phys. J. C 14 (2000) 73, http://dx.doi.org/10.1007/s100520050734, arXiv:hep-ex/0001056.

[13] P. Achard, et al., L3 Collaboration, Phys. Lett. B 568 (2003) 23, http://dx.doi.org/10.1016/j.physletb. 2003.05.004, arXiv:hep-ex/0306016.

[14] F.D. Aaron, et al., H1 Collaboration, Phys. Lett. B 666 (2008) 131, http://dx.doi.org/10.1016/j.physletb.2008.07.014, arXiv:0805.4530.

[15] D. Acosta, et al., CDF Collaboration, Phys. Rev. Lett. 94 (2005) 101802, http://dx.doi.org/10.1103/PhysRevLett.94.101802, arXiv:hep-ex/0410013.

[16] A. Abulencia, et al., CDF Collaboration, Phys. Rev. Lett. 97 (2006) 191802, http://dx.doi.org/10.1103/PhysRevLett. 97.191802, arXiv:hep-ex/0606043.

[17] V.M. Abazov, et al., D0 Collaboration, Phys. Rev. D 73 (2006) 111102, http://dx.doi.org/10.1103/PhysRevD.73.111102, arXiv:hep-ex/0604040.

[18] V.M. Abazov, et al., D0 Collaboration, Phys. Rev. D 77 (2008) 091102, http://dx.doi.org/10.1103/PhysRevD.77.091102, arXiv:0801.0877.

[19] L. Evans, P. Bryant, JINST 3 (2008) S08001, http://dx.doi.org/10.1088/1748-0221/3/08/S08001.

[20] CMS Collaboration, Phys. Lett. B 704 (2011) 143, http://dx.doi.org/10.1016/j.physletb.2011.09.021, arXiv:1107.1773.

[21] ATLAS Collaboration, Phys. Rev. D 85 (2012) 072003, http://dx.doi.org/10.1103/PhysRevD.85.072003, arXiv:1201.3293.

[22] CMS Collaboration, JINST 03 (2008) S08004, http://dx.doi.org/10.1088/1748-0221/3/08/S08004.

[23] T. Sjöstrand, S. Mrenna, P.Z. Skands, JHEP 0605 (2006) 026, http://dx.doi.org/10.1088/1126-6708/2006/05/026, arXiv:hep-ph/0603175.

[24] T. Sjöstrand, S. Mrenna, P.Z. Skands, Comput. Phys. Commun. 178 (2008) 852, http://dx.doi.org/10.1016/j.cpc.2008.01.036, arXiv:0710.3820 [hep-ph].

[25] J. Pumplin, D.R. Stump, J. Huston, H.-L. Lai, P. Nadolsky, W.-K. Tung, JHEP 0207 (2002) 012, http://dx.doi.org/10.1088/1126-6708/2002/07/012, arXiv:hep-ph/0201195.

[26] J. Alwall, et al., JHEP 0709 (2007) 028, http://dx.doi.org/10.1088/1126-6708/2007/09/028, arXiv:0706.2334.

[27] J.M. Campbell, R.K. Ellis, in: Loops and Legs in Quantum Field Theory – Proceedings of the 10th DESY Workshop on Elementary Particle Theory, Nucl. Phys. B Proc. Suppl. 205–206 (2010) 10, http://dx.doi.org/10.1016/j.nuclphysbps.2010.08.011, arXiv:1007.3492.

[28] S. Agostinelli, et al., GEANT4 Collaboration, Nucl. Instrum. Meth. A 506 (2003) 250, http://dx.doi.org/10.1016/S0168-9002(03)01368-8.

[29] CMS Collaboration, Photon reconstruction and identification at $\sqrt{s} = 7$ TeV, CMS Physics Analysis Summary EGM-10-005, 2010.

[30] C.J. Clopper, E.S. Pearson, Biometrika 26 (1934) 404, http://dx.doi.org/10.1093/biomet/26.4.404.

[31] CMS Collaboration, Search for contact interactions in $\mu^+\mu^-$ events in pp collisions at $\sqrt{s} = 7$ TeV, CMS Physics Analysis Summary CMS-PAS-EXO-11-009, 2011, http://cdsweb.cern.ch/record/1446209.

[32] CMS Collaboration, Absolute calibration of the luminosity measurement at CMS: Winter 2012 update, CMS Physics Analysis Summary CMS-PAS-SMP-12-008, 2012, http://cdsweb.cern.ch/record/1434360.

[33] ATLAS and CMS Collaborations, Procedure for the LHC Higgs boson search combination in Summer 2011, Technical Report CMS-NOTE-2011-005, ATL-PHYS-PUB-2011-011, CERN, Geneva, 2011, http://cdsweb.cern.ch/record/1379837.

[34] J. Heinrich, C. Blocker, J. Conway, L. Demortier, L. Lyons, G. Punzi, P.K. Sinervo, Interval estimation in the presence of nuisance parameters. 1. Bayesian approach, arXiv:physics/0409129, 2004.

[35] K. Nakamura, et al., J. Phys. G 37 (2010) 075021, http://dx.doi.org/10.1088/0954-3899/37/7A/075021 (Sec. 33.3.1).

[36] A.L. Read, J. Phys. G 28 (2002) 2693, http://dx.doi.org/10.1088/0954-3899/28/10/313.

[37] T. Junk, Nucl. Instrum. Meth. A 434 (1999) 435, http://dx.doi.org/10.1016/S0168-9002(99)00498-2, arXiv:hep-ex/9902006.

CMS Collaboration

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

Yerevan Physics Institute, Yerevan, Armenia

W. Adam, E. Aguilo, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan[1], M. Friedl, R. Frühwirth[1], V.M. Ghete, J. Hammer, N. Hörmann, J. Hrubec, M. Jeitler[1], W. Kiesenhofer, V. Knünz, M. Krammer[1], I. Krätschmer, D. Liko, I. Mikulec, M. Pernicka[†], B. Rahbaran, C. Rohringer, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, W. Waltenberger, G. Walzel, E. Widl, 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

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

Universiteit Antwerpen, Antwerpen, Belgium

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

Vrije Universiteit Brussel, Brussel, 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, G. Vander Marcken, C. Vander Velde, P. Vanlaer, J. Wang

Université Libre de Bruxelles, Bruxelles, Belgium

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

Ghent University, Ghent, Belgium

S. Basegmez, G. Bruno, R. Castello, L. Ceard, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco[2], J. Hollar, V. Lemaitre, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrzkowski, N. Schul, 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

G.A. Alves, M. Correa Martins Junior, D. De Jesus Damiao, T. Martins, M.E. Pol, M.H.G. Souza

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

W.L. Aldá Júnior, W. Carvalho, A. Custódio, E.M. Da Costa, C. De Oliveira Martins, S. Fonseca De Souza, D. Matos Figueiredo, L. Mundim, H. Nogima, V. Oguri, W.L. Prado Da Silva, A. Santoro, L. Soares Jorge, A. Sznajder

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

T.S. Anjos[3], C.A. Bernardes[3], F.A. Dias[4], T.R. Fernandez Perez Tomei, E.M. Gregores[3], C. Lagana, F. Marinho, P.G. Mercadante[3], S.F. Novaes, Sandra S. Padula

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

V. Genchev[5], P. Iaydjiev[5], S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, V. Tcholakov, R. Trayanov, M. Vutova

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

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

University of Sofia, Sofia, Bulgaria

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

Institute of High Energy Physics, Beijing, China

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

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

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

Universidad de Los Andes, Bogota, Colombia

N. Godinovic, D. Lelas, R. Plestina[6], D. Polic, I. Puljak[5]

Technical University of Split, Split, Croatia

Z. Antunovic, M. Kovac

University of Split, Split, Croatia

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

Institute Rudjer Boskovic, Zagreb, Croatia

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

University of Cyprus, Nicosia, Cyprus

M. Finger, M. Finger Jr.

Charles University, Prague, Czech Republic

Y. Assran[7], S. Elgammal[8], A. Ellithi Kamel[9], S. Khalil[8], M.A. Mahmoud[10], A. Radi[11,12]

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

M. Kadastik, M. Müntel, M. Raidal, L. Rebane, 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, 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

Helsinki Institute of Physics, Helsinki, Finland

K. Banzuzi, A. Karjalainen, A. Korpela, T. Tuuva

Lappeenranta University of Technology, Lappeenranta, Finland

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

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

S. Baffioni, F. Beaudette, L. Benhabib, L. Bianchini, M. Bluj[13], C. Broutin, P. Busson, C. Charlot, N. Daci, T. Dahms, L. Dobrzynski, R. Granier de Cassagnac, M. Haguenauer, P. Miné, C. Mironov, I.N. Naranjo, M. Nguyen, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Veelken, A. Zabi

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

J.-L. Agram[14], J. Andrea, D. Bloch, D. Bodin, J.-M. Brom, M. Cardaci, E.C. Chabert, C. Collard, E. Conte[14], F. Drouhin[14], C. Ferro, J.-C. Fontaine[14], D. Gelé, U. Goerlach, P. Juillot, A.-C. Le Bihan, P. Van Hove

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

F. Fassi, D. Mercier

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

S. Beauceron, N. Beaupere, O. Bondu, G. Boudoul, J. Chasserat, R. Chierici [5], 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

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

Z. Tsamalaidze [15]

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

G. Anagnostou, C. Autermann, S. Beranek, M. Edelhoff, L. Feld, N. Heracleous, O. Hindrichs, R. Jussen, K. Klein, J. Merz, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, B. Wittmer, V. Zhukov [16]

RWTH Aachen University, I. Physikalisches Institut, 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, P. Kreuzer, M. Merschmeyer, A. Meyer, M. Olschewski, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teyssier, M. Weber

RWTH Aachen University, III. Physikalisches Institut A, 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. Lingemann [5], A. Nowack, L. Perchalla, O. Pooth, P. Sauerland, A. Stahl

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

M. Aldaya Martin, J. Behr, W. Behrenhoff, U. Behrens, M. Bergholz [17], A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, E. Castro, F. Costanza, D. Dammann, C. Diez Pardos, 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, W. Lohmann [17], B. Lutz, R. Mankel, I. Marfin, M. Marienfeld, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, S. Naumann-Emme, O. Novgorodova, J. Olzem, H. Perrey, A. Petrukhin, D. Pitzl, A. Raspereza, P.M. Ribeiro Cipriano, C. Riedl, E. Ron, M. Rosin, J. Salfeld-Nebgen, R. Schmidt [17], T. Schoerner-Sadenius, N. Sen, A. Spiridonov, M. Stein, R. Walsh, C. Wissing

Deutsches Elektronen-Synchrotron, Hamburg, Germany

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

University of Hamburg, Hamburg, Germany

C. Barth, J. Berger, C. Böser, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, M. Guthoff [5], C. Hackstein, F. Hartmann, T. Hauth [5], M. Heinrich, H. Held, K.H. Hoffmann, U. Husemann, I. Katkov [16], 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

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

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

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

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

University of Athens, Athens, Greece

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

University of Ioánnina, Ioánnina, Greece

G. Bencze, C. Hajdu, P. Hidas, D. Horvath [18], F. Sikler, V. Veszpremi, G. Vesztergombi [19]

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

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

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

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

University of Debrecen, Debrecen, Hungary

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

Panjab University, Chandigarh, India

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

University of Delhi, Delhi, India

S. Banerjee, S. Bhattacharya, S. Dutta, B. Gomber, Sa. Jain, Sh. Jain, R. Khurana, S. Sarkar, M. Sharan

Saha Institute of Nuclear Physics, Kolkata, India

A. Abdulsalam, R.K. Choudhury, D. Dutta, S. Kailas, V. Kumar, P. Mehta, A.K. Mohanty [5], L.M. Pant, P. Shukla

Bhabha Atomic Research Centre, Mumbai, India

T. Aziz, S. Ganguly, M. Guchait [20], M. Maity [21], G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage

Tata Institute of Fundamental Research – EHEP, Mumbai, India

S. Banerjee, S. Dugad

Tata Institute of Fundamental Research – HECR, Mumbai, India

H. Arfaei [22], H. Bakhshiansohi, S.M. Etesami [23], A. Fahim [22], M. Hashemi, H. Hesari, A. Jafari, M. Khakzad, M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh [24], M. Zeinali

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

M. Abbrescia [a,b], L. Barbone [a,b], C. Calabria [a,b,5], S.S. Chhibra [a,b], A. Colaleo [a], D. Creanza [a,c], N. De Filippis [a,c,5], M. De Palma [a,b], L. Fiore [a], G. Iaselli [a,c], L. Lusito [a,b], G. Maggi [a,c], M. Maggi [a], B. Marangelli [a,b], S. My [a,c], S. Nuzzo [a,b], N. Pacifico [a,b], A. Pompili [a,b], G. Pugliese [a,c], G. Selvaggi [a,b], L. Silvestris [a], G. Singh [a,b], R. Venditti [a,b], G. Zito [a]

[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], 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,5], P. Giacomelli [a], C. Grandi [a], L. Guiducci [a,b], S. Marcellini [a], G. Masetti [a],

M. Meneghelli [a,b,5], A. Montanari [a], F.L. Navarria [a,b], F. Odorici [a], A. Perrotta [a], F. Primavera [a,b], A.M. Rossi [a,b], T. Rovelli [a,b], G.P. Siroli [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,b], M. Chiorboli [a,b], S. Costa [a,b], R. Potenza [a,b], A. Tricomi [a,b], C. Tuve [a,b]

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

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

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

L. Benussi, S. Bianco, S. Colafranceschi [25], F. Fabbri, D. Piccolo

INFN Laboratori Nazionali di Frascati, Frascati, Italy

P. Fabbricatore [a], R. Musenich [a], S. Tosi [a,b]

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

A. Benaglia [a,b], F. De Guio [a,b], L. Di Matteo [a,b,5], S. Fiorendi [a,b], S. Gennai [a,5], A. Ghezzi [a,b], S. Malvezzi [a], R.A. Manzoni [a,b], A. Martelli [a,b], A. Massironi [a,b,5], D. Menasce [a], L. Moroni [a], M. Paganoni [a,b], D. Pedrini [a], S. Ragazzi [a,b], N. Redaelli [a], S. Sala [a], T. Tabarelli de Fatis [a,b]

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

S. Buontempo [a], C.A. Carrillo Montoya [a], N. Cavallo [a,26], A. De Cosa [a,b,5], O. Dogangun [a,b], F. Fabozzi [a,26], A.O.M. Iorio [a], L. Lista [a], S. Meola [a,27], M. Merola [a,b], P. Paolucci [a,5]

[a] *INFN Sezione di Napoli, Napoli, Italy*
[b] *Università di Napoli "Federico II", Napoli, Italy*

P. Azzi [a], N. Bacchetta [a,5], D. Bisello [a,b], A. Branca [a,b,5], R. Carlin [a,b], P. Checchia [a], T. Dorigo [a], U. Dosselli [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,5], S. Vanini [a,b], P. Zotto [a,b], G. Zumerle [a,b]

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

M. Gabusi [a,b], S.P. Ratti [a,b], C. Riccardi [a,b], P. Torre [a,b], 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], 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]

[a] *INFN Sezione di Perugia, Perugia, Italy*
[b] *Università di Perugia, Perugia, 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,5], R. Dell'Orso [a], F. Fiori [a,b,5], L. Foà [a,c], A. Giassi [a], A. Kraan [a], F. Ligabue [a,c], T. Lomtadze [a], L. Martini [a,28], A. Messineo [a,b], F. Palla [a], A. Rizzi [a,b], A.T. Serban [a,29], P. Spagnolo [a], P. Squillacioti [a,5], R. Tenchini [a], G. Tonelli [a,b], A. Venturi [a], P.G. Verdini [a]

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

L. Barone [a,b], F. Cavallari [a], D. Del Re [a,b], M. Diemoz [a], C. Fanelli [a,b], M. Grassi [a,b,5], E. Longo [a,b], P. Meridiani [a,5], F. Micheli [a,b], S. Nourbakhsh [a,b], G. Organtini [a,b], R. Paramatti [a], S. Rahatlou [a,b], M. Sigamani [a], L. Soffi [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], C. Biino [a], N. Cartiglia [a], M. Costa [a,b], N. Demaria [a], C. Mariotti [a,5], S. Maselli [a], E. Migliore [a,b], V. Monaco [a,b], M. Musich [a,5], M.M. Obertino [a,c], N. Pastrone [a], M. Pelliccioni [a], A. Potenza [a,b], A. Romero [a,b], R. Sacchi [a,b], A. Solano [a,b], A. Staiano [a], A. Vilela Pereira [a], L. Visca [a,b]

[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], M. Marone [a,b,5], D. Montanino [a,b,5], A. Penzo [a], A. Schizzi [a,b]

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

S.G. Heo, T.Y. Kim, S.K. Nam

Kangwon National University, Chunchon, Republic of Korea

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

Kyungpook National University, Daegu, Republic of Korea

J.Y. Kim, Zero J. 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, T.J. Kim, K.S. Lee, D.H. Moon, S.K. Park

Korea University, Seoul, Republic of Korea

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

University of Seoul, Seoul, Republic of Korea

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

Sungkyunkwan University, Suwon, Republic of Korea

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

Vilnius University, Vilnius, Lithuania

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

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

S. Carrillo Moreno, F. Vazquez Valencia

Universidad Iberoamericana, Mexico City, Mexico

H.A. Salazar Ibarguen

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

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

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

D. Krofcheck

University of Auckland, Auckland, New Zealand

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

University of Canterbury, Christchurch, New Zealand

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

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

H. Bialkowska, B. Boimska, T. Frueboes, R. Gokieli, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, G. Wrochna, 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

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

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

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

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

Joint Institute for Nuclear Research, Dubna, 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

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

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

Institute for Nuclear Research, Moscow, Russia

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

Institute for Theoretical and Experimental Physics, Moscow, Russia

A. Belyaev, E. Boos, M. Dubinin[4], 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

Moscow State University, 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

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Grishin[5], V. Kachanov, 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[30], M. Djordjevic, M. Ekmedzic, D. Krpic[30], J. Milosevic

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

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

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

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

Universidad Autónoma de Madrid, Madrid, Spain

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

Universidad de Oviedo, Oviedo, Spain

J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, S.H. Chuang, J. Duarte Campderros, M. Felcini[31], 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

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, J.F. Benitez, C. Bernet[6], 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, 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.U. Mozer, M. Mulders, P. Musella, E. Nesvold, T. Orimoto, 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. Rolandi[32], C. Rovelli[33], M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas[34], D. Spiga, A. Tsirou, G.I. Veres[19], J.R. Vlimant, H.K. Wöhri, S.D. Worm[35], W.D. Zeuner

CERN, European Organization for Nuclear Research, Geneva, Switzerland

W. Bertl, K. Deiters, W. Erdmann, K. Gabathuler, R. Horisberger, Q. Ingram, H.C. Kaestli, S. König, D. Kotlinski, U. Langenegger, F. Meier, D. Renker, T. Rohe, J. Sibille[36]

Paul Scherrer Institut, Villigen, Switzerland

L. Bäni, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, A. Deisher, G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, 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. Nägeli[37], P. Nef, F. Nessi-Tedaldi, F. Pandolfi, L. Pape, F. Pauss, M. Peruzzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, A. Starodumov[38], B. Stieger, M. Takahashi, L. Tauscher[†], A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, H.A. Weber, L. Wehrli

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

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

Universität Zürich, Zurich, Switzerland

S. Bahinipati, Y.H. Chang, K.H. Chen, C.M. Kuo, S.W. Li, W. Lin, Z.K. Liu, Y.J. Lu, D. Mekterovic, A.P. Singh, R. Volpe, S.S. Yu

National Central University, Chung-Li, 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

National Taiwan University (NTU), Taipei, Taiwan

B. Asavapibhop, N. Srimanobhas

Chulalongkorn University, 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, T. Karaman, G. Karapinar[41], A. Kayis Topaksu, G. Onengut, K. Ozdemir, S. Ozturk[42], A. Polatoz, K. Sogut[43], D. Sunar Cerci[40], B. Tali[40], H. Topakli[39], L.N. Vergili, M. Vergili

Cukurova University, Adana, 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

Middle East Technical University, Physics Department, Ankara, Turkey

E. Gülmez, B. Isildak[44], M. Kaya[45], O. Kaya[45], S. Ozkorucuklu[46], N. Sonmez[47]

Bogazici University, Istanbul, Turkey

K. Cankocak

Istanbul Technical University, Istanbul, Turkey

L. Levchuk

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

F. Bostock, J.J. Brooke, E. Clement, D. Cussans, H. Flacher, R. Frazier, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, L. Kreczko, S. Metson, D.M. Newbold[35], K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, T. Williams

University of Bristol, Bristol, United Kingdom

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

Rutherford Appleton Laboratory, Didcot, United Kingdom

R. Bainbridge, G. Ball, R. Beuselinck, O. Buchmuller, D. Colling, N. Cripps, M. Cutajar, P. Dauncey, G. Davies, M. Della Negra, W. Ferguson, J. Fulcher, D. Futyan, A. Gilbert, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, M. Jarvis, G. Karapostoli, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko[38], A. Papageorgiou, J. Pela, M. Pesaresi, K. Petridis, M. Pioppi[49], D.M. Raymond, S. Rogerson, A. Rose, M.J. Ryan, C. Seez, P. Sharp[†], A. Sparrow, M. Stoye, A. Tapper, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle, T. Whyntie

Imperial College, London, 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

Brunel University, Uxbridge, United Kingdom

K. Hatakeyama, H. Liu, T. Scarborough

Baylor University, Waco, USA

O. Charaf, C. Henderson, P. Rumerio

The University of Alabama, Tuscaloosa, USA

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

Boston University, Boston, USA

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

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, J. Dolen, R. Erbacher, M. Gardner, R. Houtz, W. Ko, A. Kopecky, R. Lander, O. Mall, T. Miceli, D. Pellett, F. Ricci-tam, B. Rutherford, M. Searle, J. Smith, M. Squires, M. Tripathi, R. Vasquez Sierra

University of California, Davis, Davis, USA

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

University of California, Los Angeles, Los Angeles, USA

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

University of California, Riverside, Riverside, USA

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

University of California, San Diego, La Jolla, USA

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

University of California, Santa Barbara, Santa Barbara, USA

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

California Institute of Technology, Pasadena, USA

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

Carnegie Mellon University, Pittsburgh, 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

University of Colorado at Boulder, Boulder, USA

J. Alexander, A. Chatterjee, N. Eggert, L.K. Gibbons, B. Heltsley, 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, J. Vaughan, Y. Weng, L. Winstrom, P. Wittich

Cornell University, Ithaca, USA

D. Winn

Fairfield University, Fairfield, USA

S. Abdullin, M. Albrow, J. Anderson, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, I. Bloch, K. Burkett, J.N. Butler, V. Chetluru, H.W.K. Cheung, F. Chlebana, V.D. Elvira, I. Fisk, J. Freeman, Y. Gao, D. Green, O. Gutsche, J. Hanlon, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, B. Kilminster, B. Klima, S. Kunori, S. Kwan, C. Leonidopoulos, J. Linacre, D. Lincoln, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, S. Maruyama, D. Mason, P. McBride, K. Mishra, S. Mrenna, Y. Musienko[52], C. Newman-Holmes, V. O'Dell, O. Prokofyev, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, J. Whitmore, W. Wu, F. Yang, F. Yumiceva, J.C. Yun

Fermi National Accelerator Laboratory, Batavia, 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. Milenovic[53], G. Mitselmakher, L. Muniz, M. Park, R. Remington, A. Rinkevicius, P. Sellers, N. Skhirtladze, M. Snowball, J. Yelton, M. Zakaria

University of Florida, Gainesville, USA

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

Florida International University, Miami, 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 State University, Tallahassee, USA

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

Florida Institute of Technology, Melbourne, USA

M.R. Adams, I.M. Anghel, 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, M. Malek, C. O'Brien, C. Silkworth, D. Strom, P. Turner, N. Varelas

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

U. Akgun, E.A. Albayrak, B. Bilki[54], W. Clarida, F. Duru, S. Griffiths, J.-P. Merlo, H. Mermerkaya[55], A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, Y. Onel, F. Ozok[56], S. Sen, P. Tan, E. Tiras, J. Wetzel, T. Yetkin, K. Yi

The University of Iowa, Iowa City, USA

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

Johns Hopkins University, Baltimore, USA

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

The University of Kansas, Lawrence, USA

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

Kansas State University, Manhattan, USA

J. Gronberg, D. Lange, D. Wright

Lawrence Livermore National Laboratory, Livermore, USA

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

University of Maryland, College Park, USA

A. Apyan, G. Bauer, J. Bendavid, W. Busza, E. Butz, I.A. Cali, M. Chan, V. Dutta, G. Gomez Ceballos, M. Goncharov, K.A. Hahn, Y. Kim, M. Klute, K. Krajczar[57], 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

Massachusetts Institute of Technology, Cambridge, USA

S.I. Cooper, 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 Minnesota, Minneapolis, USA

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

University of Mississippi, Oxford, USA

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

University of Nebraska-Lincoln, Lincoln, USA

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

State University of New York at Buffalo, Buffalo, USA

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

Northeastern University, Boston, USA

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

Northwestern University, Evanston, USA

L. Antonelli, 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

University of Notre Dame, Notre Dame, USA

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

The Ohio State University, Columbus, USA

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

Princeton University, Princeton, USA

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

University of Puerto Rico, Mayaguez, 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, West Lafayette, USA

S. Guragain, N. Parashar

Purdue University Calumet, Hammond, USA

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

Rice University, Houston, 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

University of Rochester, Rochester, USA

A. Bhatti, R. Ciesielski, L. Demortier, K. Goulianos, G. Lungu, S. Malik, 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, 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

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

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

University of Tennessee, Knoxville, USA

R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon[58], 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 A&M University, College Station, USA

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

Texas Tech University, Lubbock, USA

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

Vanderbilt University, Nashville, USA

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

University of Virginia, Charlottesville, USA

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

Wayne State University, Detroit, USA

M. Anderson, D. 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, J. Leonard, R. Loveless, A. Mohapatra, I. Ojalvo, F. Palmonari, G.A. Pierro, I. Ross, A. Savin, W.H. Smith, J. Swanson

University of Wisconsin, Madison, USA

[*] Corresponding author.

[†] Deceased.

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

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

[3] Also at Universidade Federal do ABC, Santo Andre, Brazil.

[4] Also at California Institute of Technology, Pasadena, USA.

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

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

[7] Also at Suez Canal University, Suez, Egypt.

[8] Also at Zewail City of Science and Technology, Zewail, Egypt.

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

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

[11] Also at British University, Cairo, Egypt.

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

[13] Also at National Centre for Nuclear Research, Swierk, Poland.

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

[15] Now at Joint Institute for Nuclear Research, Dubna, Russia.

[16] Also at Moscow State University, Moscow, Russia.

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

[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] Also at University of Visva-Bharati, Santiniketan, India.

[22] Also at Sharif University of Technology, Tehran, Iran.

[23] Also at Isfahan University of Technology, Isfahan, Iran.

[24] Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran.

[25] Also at Facoltà Ingegneria Università di Roma, Roma, Italy.

[26] Also at Università della Basilicata, Potenza, Italy.

[27] Also at Università degli Studi Guglielmo Marconi, Roma, Italy.

[28] Also at Università degli Studi di Siena, Siena, Italy.

[29] Also at University of Bucharest, Faculty of Physics, Bucuresti-Magurele, Romania.

[30] Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia.

[31] Also at University of California, Los Angeles, Los Angeles, USA.

[32] Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy.

[33] Also at INFN Sezione di Roma; Università di Roma, Roma, Italy.

[34] Also at University of Athens, Athens, Greece.

[35] Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.

[36] Also at The University of Kansas, Lawrence, USA.

[37] Also at Paul Scherrer Institut, Villigen, Switzerland.

[38] Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.

[39] Also at Gaziosmanpasa University, Tokat, Turkey.

[40] Also at Adiyaman University, Adiyaman, Turkey.

[41] Also at Izmir Institute of Technology, Izmir, Turkey.

[42] Also at The University of Iowa, Iowa City, USA.

[43] Also at Mersin University, Mersin, Turkey.

[44] Also at Ozyegin University, Istanbul, Turkey.

[45] Also at Kafkas University, Kars, Turkey.

[46] Also at Suleyman Demirel University, Isparta, Turkey.

[47] Also at Ege University, Izmir, Turkey.

[48] Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.

[49] Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy.

[50] Also at University of Sydney, Sydney, Australia.

[51] Also at Utah Valley University, Orem, USA.

[52] Also at Institute for Nuclear Research, Moscow, Russia.

[53] Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.

[54] Also at Argonne National Laboratory, Argonne, USA.

[55] Also at Erzincan University, Erzincan, Turkey.

[56] Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.

[57] Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary.

[58] Also at Kyungpook National University, Daegu, Republic of Korea.