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# Search for soft unclustered energy patterns in proton-proton collisions at 13 TeV

The CMS Collaboration\*

## Abstract

The first search for soft unclustered energy patterns (SUEPs) is performed using an integrated luminosity of  $138 \text{ fb}^{-1}$  of proton-proton collision data at  $\sqrt{s} = 13 \text{ TeV}$ , collected in 2016–2018 by the CMS detector at the LHC. Such SUEPs are predicted by Hidden Valley models with a new, confining force with a large 't Hooft coupling. In events with boosted topologies, selected by high-threshold hadronic triggers, the multiplicity and sphericity of clustered tracks are used to reject the background from standard model quantum chromodynamics. With no observed excess of events over the standard model expectation, limits are set on the cross section for production via gluon fusion of a scalar mediator with SUEP-like decays.

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Recent experimental searches have not found evidence for beyond the standard model (BSM) physics. Therefore, new models with unconventional experimental signatures that may have evaded previous constraints are being examined more closely. In particular, Hidden Valley (HV) models [1–6] predict a wide array of possible signals that have the potential to address unanswered questions in the standard model (SM). The HV models considered here include a dark sector that extends the SM with a non-Abelian gauge group, similar to quantum chromodynamics (QCD), with new matter and gauge fields analogous to the SM quark and gluon fields. The SM particles are neutral under the new, dark interaction—“dark QCD”—and communicate with this sector only through a mediator particle that couples to both sectors. The model that motivates this search [7, 8] includes a quasi-conformal dark sector where the dark QCD force has a large ‘t Hooft coupling  $\lambda \gg 1$  above its confinement scale. When dark partons are produced, they shower and form dark mesons, whose mass scale is much smaller than the mediator mass scale. The showering process includes efficient branching over a larger energy range than SM QCD, and all information about the momenta of the initial partons is lost. The result is a high multiplicity of light HV bound states emitted with a spherical, rather than conical, distribution in the center-of-mass frame of the shower. This characteristic final state consisting of many low-momentum, isotropically distributed particles is described as a soft unclustered energy pattern (SUEP). Similar signatures can arise in other models, such as many-step decays in a hidden sector [9], theories with extra spatial dimensions [10–12], and instantons [13]. In this Letter, the first dedicated search for SUEP signatures is presented, using data corresponding to a total integrated luminosity of  $138 \text{ fb}^{-1}$  from proton-proton collisions at a center-of-mass energy of 13 TeV, collected with the CMS detector at the CERN LHC in 2016–2018. The numerical results from this Letter can be found in its HEPData record [14].

This search focuses on a benchmark model in which a dark QCD sector is accessed by a heavy scalar mediator  $S$ , which is produced via gluon fusion and couples directly to a dark quark-antiquark pair. If the dark quark masses  $m_{q_D}$  are below the confinement scale  $\Lambda_D$ , and  $\Lambda_D \ll \sqrt{s}$ , the dark quarks undergo a quasi-conformal showering and form an isotropic spray of dark pseudoscalar mesons  $\phi$ . In this strongly coupled model, the  $\phi$   $p_T$  spectrum can be described by a Boltzmann distribution determined by the mass of the dark meson,  $m_\phi$ , and a temperature  $T_D$  at the scale of the cutoff,  $\Lambda_D$ . Each  $\phi$  subsequently decays to a pair of dark photons  $A'$ . The dark photon kinetically mixes with the SM hypercharge gauge field and decays promptly to SM particles. A prompt decay is chosen rather than a displaced decay, which would result in an emerging jet signature [15, 16], or extremely long lifetimes, which would result in missing transverse momentum or semivisible jets [17, 18]. To enforce promptness, defined as a decay length less than 1 mm, and to avoid dark photon mass ( $m_{A'}$ ) ranges that would already be excluded by collider searches [8], we choose  $m_{A'}$  values at the GeV scale. The decay branching fraction ( $\mathcal{B}$ ) is dictated by the  $m_{A'}$  value [19]. We consider three cases with different branching fractions:  $m_{A'} = 0.5 \text{ GeV}$  ( $A' \rightarrow e^+e^-, \mu^+\mu^-, \pi^+\pi^-$  with  $\mathcal{B} = 40, 40, 20\%$ ),  $m_{A'} = 0.7 \text{ GeV}$  ( $A' \rightarrow e^+e^-, \mu^+\mu^-, \pi^+\pi^-$  with  $\mathcal{B} = 15, 15, 70\%$ ), and  $m_{A'} = 1.0 \text{ GeV}$  ( $A' \rightarrow \pi^+\pi^-$  with  $\mathcal{B} = 100\%$ ). A schematic diagram for this signal model is shown in Fig. 1.

Signal samples are generated using a PYTHIA plugin based on Refs. [8, 20]. Multijet QCD samples used for closure tests are produced with MADGRAPH5\_aMC@NLO 2.6.5 [21]. The PYTHIA 8.240 [22] package is used for parton showering, hadronization, and the underlying event simulation, with the event tune CP5 [23]. The NNPDF 3.1 [24] set of parton distribution functions is used. The GEANT4 package [25] is employed to perform a detailed simulation of the CMS detector response. Signal samples are generated with various model parameter values:  $m_\phi$ ,  $T_D$ ,  $m_{A'}$ , and the mediator mass  $m_S$ , limited by what is feasibly produced at the LHC;  $m_{A'}$  is var-

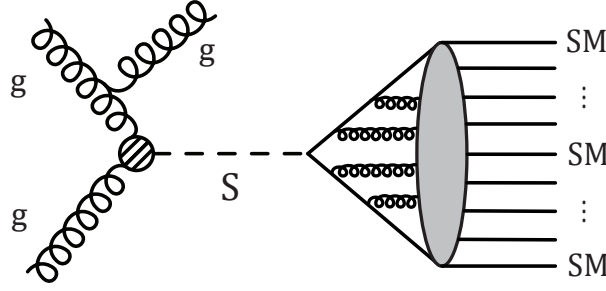


Figure 1: A schematic Feynman diagram of the benchmark signal model resulting in a SUEP signature.

ied as described above. Low values of  $T_D/m_\phi$  ( $\leq 0.25$ ) are not expected to be realized by any pseudo-conformal hidden sector, while high values constitute the “dark pion regime”, where an approximate symmetry generates pseudo-Goldstone bosons [26].

The CMS apparatus [27] is a multipurpose, nearly hermetic detector, designed to trigger on [28, 29] and identify electrons, muons, photons, and hadrons [30–32]. A global “particle-flow” algorithm [33] aims to reconstruct all individual particles in an event, combining information provided by the all-silicon inner tracker and by the crystal electromagnetic and brass-scintillator hadron calorimeters, operating inside a 3.8 T superconducting solenoid, with data from the gas-ionization muon detectors embedded in the flux-return yoke outside the solenoid. The primary vertex (PV) is taken to be the vertex corresponding to the hardest scattering in the event, evaluated using tracking information alone, as described in Section 9.4.1 of Ref. [34]. The reconstructed particles (particle-flow candidates) are clustered into jets using the anti- $k_T$  algorithm [35, 36] with a distance parameter of  $R = 0.4$ , after rejecting charged hadrons that do not originate from the PV but rather from extraneous proton-proton interactions (pileup); subsequently, neutral pileup contributions are subtracted [37].

This search uses events that pass a hadronic trigger with a threshold of  $H_T > 900$  (1050) GeV for 2016 (2017 and 2018), where  $H_T$  is defined as the scalar  $p_T$  sum of jets with  $p_T > 30$  GeV and  $|\eta| < 2.5$ . In addition, an offline selection of  $H_T > 1200$  GeV is applied to all data to ensure the trigger is efficient. This implies that all potential SUEP events will have large amounts of hadronic activity. As a consequence, the SUEP system will recoil against an initial state radiation (ISR) jet with large  $p_T$  and therefore will be highly boosted. In addition to this selection, events are rejected if they contain an electron or muon satisfying  $p_T > 25$  GeV,  $|\eta| < 2.4$ , and isolation requirements [30, 31], in order to avoid any overlap with associated production channels where a W or Z boson is produced and decays leptonically.

For events passing the trigger, all reconstructed charged-particle tracks fitting to the PV with  $p_T > 0.7$  GeV and  $|\eta| < 2.5$  are clustered into wide jets using the anti- $k_T$  algorithm with a distance parameter of  $R = 1.5$ . These wide jets are required to have  $p_T > 150$  GeV. The two wide jets with the highest  $p_T$  are defined as the SUEP-ISR system, where the jet with the larger number of tracks is defined as the SUEP candidate, while the other is defined as the ISR candidate. The number of constituent tracks in the SUEP candidate jet is defined as  $n_{\text{constituent}}^{\text{SUEP}}$ . These tracks are then boosted into the rest frame of the SUEP candidate, where the scalar mediator decay pattern is expected to be spherically symmetric. The sphericity of the boosted SUEP candidate is defined using the second and third largest eigenvalues ( $\lambda_2, \lambda_3$ ) of the infrared and collinearly safe generalized sphericity tensor:  $S_{\text{boosted}}^{\text{SUEP}} \equiv \frac{3}{2} (\lambda_2 + \lambda_3)$  [38]. The  $S_{\text{boosted}}^{\text{SUEP}}$  can range from 0, maximally non-spherical, to 1, perfectly spherical. Events where the SUEP candidates have  $n_{\text{constituent}}^{\text{SUEP}} < 30$  or  $S_{\text{boosted}}^{\text{SUEP}} < 0.3$  are rejected, while the signal region (SR) is defined to

include events with  $n_{\text{constituent}}^{\text{SUEP}} > 70$  and  $S_{\text{boosted}}^{\text{SUEP}} > 0.5$ .

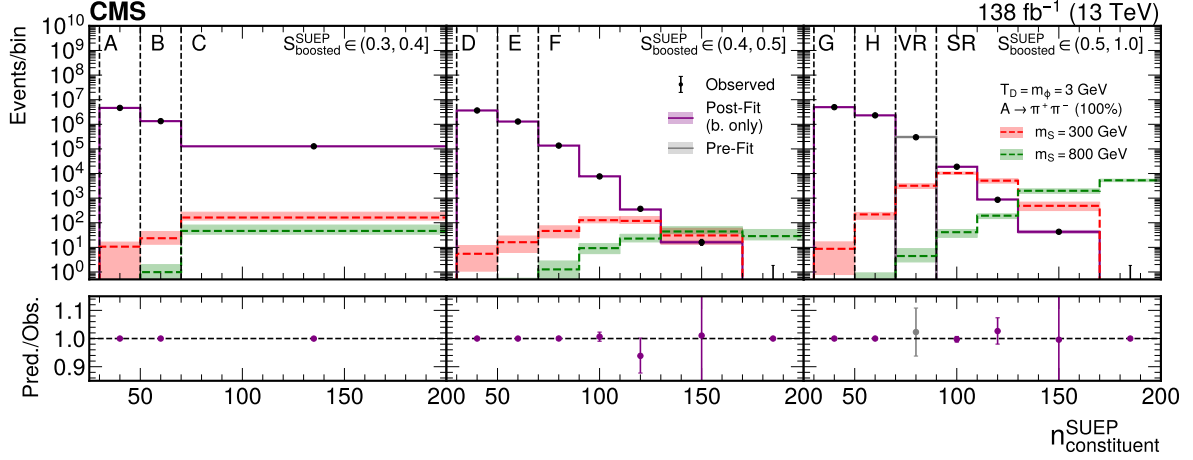


Figure 2: The number of observed events as a function of the number of tracks in the SUEP candidate, for all CRs A–H and the SR, as well as two signal samples. The three figures correspond to contiguous  $S_{\text{boosted}}^{\text{SUEP}}$  ranges. The pre-fit predicted background distribution is shown in the VR, the first bin of the SR. For all other regions and bins, the post-fit values for a background-only fit are shown.

The primary background consists of events from the QCD multijet process with a large number of tracks. The background in this search is estimated from data, using the extended “ABCD” method proposed in Ref. [39]. The ABCD method makes use of two variables, chosen here to be  $S_{\text{boosted}}^{\text{SUEP}}$  and  $n_{\text{constituent}}^{\text{SUEP}}$ . The classical ABCD method defines one signal region (SR) that includes events passing selection requirements on the two variables and three control regions (CRs) that include events failing one or both selection requirements (“pass-fail”, “fail-pass”, and “fail-fail”). In contrast, to correct for linear correlations between the discriminating variables, the extended ABCD method splits each of the pass-fail and fail-pass CRs into two regions and the fail-fail CR into four regions, resulting in a total of eight CRs, as shown in Fig. 2. In this analysis, the SR is further split into bins of  $n_{\text{constituent}}^{\text{SUEP}}$  with edges: 70, 90, 100, 130, 170,  $\infty$ . This binning is optimized for sensitivity across the full range of  $m_S$  values. The prediction for each bin  $i$  in the SR is computed from the yield  $N$  in each of the CRs,

$$N_{\text{SR}}^i = N_{\text{F}} \frac{N_{\text{F}} N_{\text{H}}^2 N_{\text{D}}^2 N_{\text{B}}^2}{N_{\text{G}} N_{\text{C}} N_{\text{A}} N_{\text{E}}^4}. \quad (1)$$

Because of the large number of QCD background events, the statistical uncertainty is small,  $< 0.3\%$  in all CRs. The contamination of SUEP signal events in the CRs is negligible for the same reason. The accuracy of the background estimation method is verified with simulated QCD multijet samples by testing the agreement between the prediction from simulated CRs and the simulated yield in the SR. Further, we define the first bin of the SR, which has negligible contribution from signal, as a validation region (VR) in which we perform a closure test.

Systematic uncertainties in the SUEP signal simulation originate from possible mismodeling in the event generation or detector response, and from correction factors that are included when determining the SR selection efficiency. These include uncertainties in the integrated luminosity measurement for each year of data-taking [40–42] and the reweighting to match the observed pileup distribution. There is an uncertainty in the trigger efficiency as a function of  $H_{\text{T}}$ ; additionally, the uncertainties in the jet energy corrections and jet energy resolution affect the total  $H_{\text{T}}$  used to select events. Uncertainties in the parton showering simulation and the

track reconstruction algorithms are applied. The effect of the track reconstruction efficiency is estimated by comparing yields after artificially removing tracks based on measured reconstruction inefficiencies [43]. For the model in which the mediator has the same mass as the Higgs boson, additional  $p_T$  reweighting corrections are included [44]. Finally, corrections for a radiation-induced timing shift in the electromagnetic calorimeter readout, resulting in “prefiring” of the trigger system, are applied to 2016 and 2017 simulations [28]. The uncertainties in the parton shower modeling and the  $p_T$  reweighting corrections for the  $m_S = 125$  GeV case are the largest, corresponding to  $\sim 10\%$  of the signal yield. The other aforementioned systematic uncertainties correspond to 0–4% of the signal yield.

Further systematic uncertainties in the prediction of the extended ABCD method are estimated from data. A first systematic uncertainty covers higher-order correlations between the sphericity and number of constituent tracks in the SUEP candidate that are not taken into account by the extended ABCD method. This is estimated using the ISR candidate, which is a separate set of tracks from the SUEP candidate in each event. The same ABCD method and selections are applied to the ISR candidate, and the discrepancy between the total predicted yield and the measured yield in the SR of 8% is taken as a systematic uncertainty in the normalization value of the predicted background yield. As shown in Eq. (1), the computed prediction in each SR bin  $i$  is proportional to  $N_F^i N_F / N_C$ ; region F is subdivided, but region C is not, to reduce the statistical uncertainty. The difference in the  $n_{\text{constituent}}^{\text{SUEP}}$  distribution between CRs F and C is used as a proxy for the difference between CR F and the SR, which impacts the final prediction. The uncertainty is assessed as the ratio  $(N_F^i / N_F) / (N_C^i / N_C)$ , measured by binning the C region and using the first two bins, which are the most populated. The ratio is linearly extrapolated to the less-populated bins as a function of the  $n_{\text{constituent}}^{\text{SUEP}}$  centroid for each SR bin and validated in simulation. This ratio approximates  $N_{\text{SR}}^i / N_F^i$ ; it is treated as correlated among all bins because of the extrapolation procedure and set to 100% for the last bin, which has no centroid.

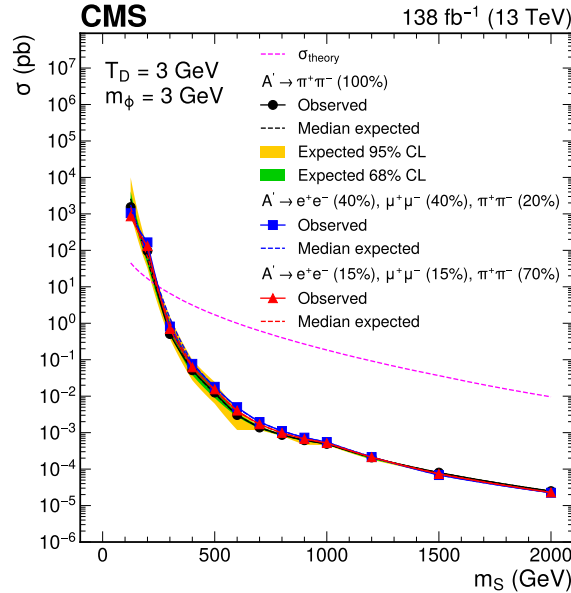


Figure 3: The 95% CL exclusion limits on the production cross section  $\sigma$  are shown as a function of  $m_S$  for  $m_\phi = T_D = 3$  GeV, for all decay modes.

We perform a binned maximum likelihood fit to the  $n_{\text{constituent}}^{\text{SUEP}}$  distribution in the SR, excluding the VR. For each individual SR bin, a Poisson likelihood term is used to describe the statistical fluctuations of the data around the expected central value. The expected values are calculated by the prediction from the extended ABCD method where the yields in all CRs are allowed

to float. The signal-to-background ratios are different among the three data-taking periods, so they are kept separate in the fit. The observed and post-fit yields are shown as a function of  $n_{\text{constituent}}^{\text{SUEP}}$  in Fig. 2.

We observe no significant excess of events over the SM prediction. The post-fit predictions for the F and SR bins with the highest  $n_{\text{constituent}}^{\text{SUEP}}$  range are  $3.5 \times 10^{-6} \pm 8.4 \times 10^{-4}$  and  $1.2 \times 10^{-5} \pm 2.9 \times 10^{-3}$ , respectively. The modified frequentist construction  $\text{CL}_s$  [45, 46] is used to compute 95% confidence level (CL) upper limits on the signal cross section. By comparing these limits to the theoretical cross section for the production of a BSM Higgs boson via gluon fusion through a point-like effective interaction [47], ranges of the  $m_S - m_\phi - m_{A'} - T_D$  parameter space can be excluded. Figure 3 shows the 95% CL exclusion limits as a functions of  $m_S$  for several  $T_D$  and  $m_\phi$  values and for all  $A'$  decay cases; the sensitivity to each case is similar, so the subsequent results only consider  $A' \rightarrow \pi^+ \pi^-$ . Figure 4 shows the exclusion limits for various scalar masses in the plane of  $m_\phi$  versus  $T_D$ . We are able to set stringent limits on the production cross section for the most SUEP-like cases with  $m_S/T_D \sim m_S/m_\phi \sim 100$ , where the final state has sufficient track multiplicity to populate the last bins of the SR, where the background is small.

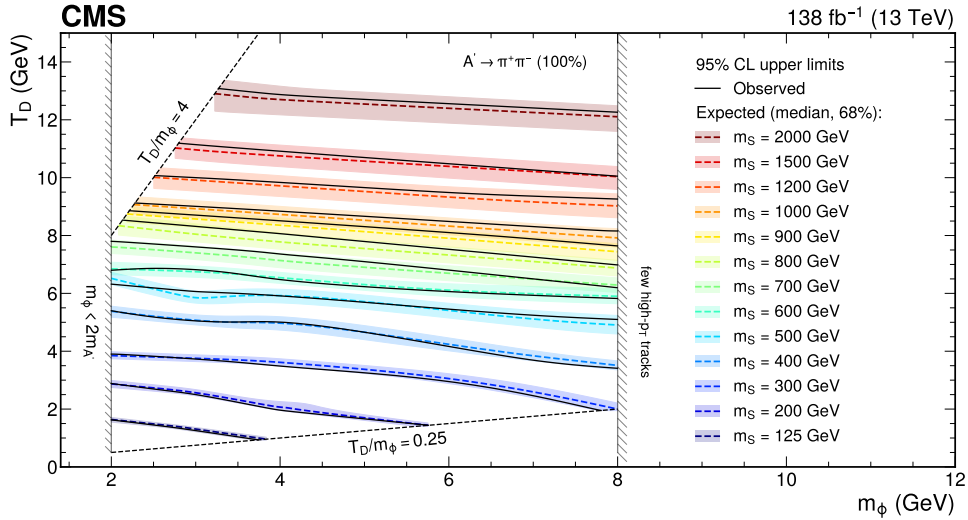


Figure 4: The observed and expected exclusions for the nominal S cross section in the plane of  $m_\phi$  and  $T_D$ , for various  $m_S$  values, for the case  $m_{A'} = 1.0 \text{ GeV}$  ( $A' \rightarrow \pi^+ \pi^-$  with  $\mathcal{B} = 100\%$ ). The regions below the observed limits are excluded.

In summary, this Letter presents the first search for soft unclustered energy patterns (SUEPs). Data corresponding to an integrated luminosity of  $138 \text{ fb}^{-1}$  are used, collected with a trigger requiring a high scalar sum of jet transverse momenta and reconstructed with the full offline processing. This strategy preferentially selects events with initial-state radiation; the characteristic isotropic event shape of the SUEPs is recovered by boosting into the scalar mediator rest frame and removing the initial-state radiation particles. The number of tracks and the associated sphericity in the SUEP candidate are used to discriminate between the signal and the background from standard model quantum chromodynamics, which is estimated from data in suitable control regions. Stringent limits are placed on the most SUEP-like Hidden Valley scenarios with highly isotropic dark showers producing a large multiplicity of tracks.

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




## A The CMS Collaboration




### Yerevan Physics Institute, Yerevan, Armenia

A. Hayrapetyan, A. Tumasyan<sup>1</sup> 













### Institut für Hochenergiephysik, Vienna, Austria

W. Adam , J.W. Andrejkovic, T. Bergauer , S. Chatterjee , K. Damanakis , M. Dragicevic , P.S. Hussain , M. Jeitler<sup>2</sup> , N. Krammer , A. Li , D. Liko , I. Mikulec , J. Schieck<sup>2</sup> , R. Schöfbeck , D. Schwarz , M. Sonawane , S. Templ , W. Waltenberger , C.-E. Wulz<sup>2</sup> 

















### Universiteit Antwerpen, Antwerpen, Belgium

M.R. Darwish<sup>3</sup> , T. Janssen , P. Van Mechelen 













### Vrije Universiteit Brussel, Brussel, Belgium

N. Breugelmans, J. D'Hondt , S. Dansana , A. De Moor , M. Delcourt , F. Heyen, S. Lowette , I. Makarenko , D. Müller , S. Tavernier , M. Tytgat<sup>4</sup> , G.P. Van Onsem , S. Van Putte , D. Vannerom 















### Université Libre de Bruxelles, Bruxelles, Belgium

B. Clerbaux , A.K. Das, G. De Lentdecker , H. Evard , L. Favart , P. Gianneios , D. Hohov , J. Jaramillo , A. Khalilzadeh, F.A. Khan , K. Lee , M. Mahdavihorrami , A. Malara , S. Paredes , M.A. Shahzad, L. Thomas , M. Vanden Bemden , C. Vander Velde , P. Vanlaer 










### Ghent University, Ghent, Belgium

M. De Coen , D. Dobur , G. Gokbulut , Y. Hong , J. Knolle , L. Lambrecht , D. Marckx , G. Mestdach, K. Mota Amarilo , A. Samalan, K. Skovpen , N. Van Den Bossche , J. van der Linden , L. Wezenbeek 


















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

A. Benecke , A. Bethani , G. Bruno , C. Caputo , J. De Favereau De Jeneret , C. Delaere , I.S. Donertas , A. Giammanco , A.O. Guzel , Sa. Jain , V. Lemaitre, J. Lidrych , P. Mastrapasqua , T.T. Tran , S. Wertz 










### Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

G.A. Alves , M. Alves Gallo Pereira , E. Coelho , G. Correia Silva , C. Hensel , T. Menezes De Oliveira , A. Moraes , P. Rebello Teles , M. Soeiro, A. Vilela Pereira<sup>5</sup> 

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

W.L. Aldá Júnior , M. Barroso Ferreira Filho , H. Brandao Malbouisson , W. Carvalho , J. Chinellato<sup>6</sup>, E.M. Da Costa , G.G. Da Silveira<sup>7</sup> , D. De Jesus Damiao , S. Fonseca De Souza , R. Gomes De Souza, M. Macedo , J. Martins<sup>8</sup> , C. Mora Herrera , L. Mundim , H. Nogima , J.P. Pinheiro , A. Santoro , A. Sznajder , M. Thiel 

### Universidade Estadual Paulista, Universidade Federal do ABC, São Paulo, Brazil

C.A. Bernardes<sup>7</sup> , L. Calligaris , T.R. Fernandez Perez Tomei , E.M. Gregores , I. Maietto Silverio , P.G. Mercadante , S.F. Novaes , B. Orzari , Sandra S. Padula 

### Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria

A. Aleksandrov , G. Antchev , R. Hadjiiska , P. Iaydjiev , M. Misheva , M. Shopova , G. Sultanov 



### University of Sofia, Sofia, Bulgaria

A. Dimitrov , L. Litov , B. Pavlov , P. Petkov , A. Petrov , E. Shumka 



**Instituto De Alta Investigación, Universidad de Tarapacá, Casilla 7 D, Arica, Chile**

S. Keshri , S. Thakur 













**Beihang University, Beijing, China**

T. Cheng , T. Javaid , L. Yuan 













**Department of Physics, Tsinghua University, Beijing, China**

Z. Hu , Z. Liang, J. Liu, K. Yi<sup>9,10</sup> 

**Institute of High Energy Physics, Beijing, China**

G.M. Chen<sup>11</sup> , H.S. Chen<sup>11</sup> , M. Chen<sup>11</sup> , F. Iemmi , C.H. Jiang, A. Kapoor<sup>12</sup> ,  
H. Liao , Z.-A. Liu<sup>13</sup> , R. Sharma<sup>14</sup> , J.N. Song<sup>13</sup>, J. Tao , C. Wang<sup>11</sup>, J. Wang , Z. Wang<sup>11</sup>,  
H. Zhang , J. Zhao 


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

A. Agapitos , Y. Ban , S. Deng , B. Guo, C. Jiang , A. Levin , C. Li , Q. Li , Y. Mao,  
S. Qian, S.J. Qian , X. Qin, X. Sun , D. Wang , H. Yang, L. Zhang , Y. Zhao, C. Zhou 

**Guangdong Provincial Key Laboratory of Nuclear Science and Guangdong-Hong Kong Joint Laboratory of Quantum Matter, South China Normal University, Guangzhou, China**

S. Yang 

**Sun Yat-Sen University, Guangzhou, China**

Z. You 

**University of Science and Technology of China, Hefei, China**

K. Jaffel , N. Lu 

**Nanjing Normal University, Nanjing, China**

G. Bauer<sup>15</sup>, B. Li, J. Zhang 

**Institute of Modern Physics and Key Laboratory of Nuclear Physics and Ion-beam Application (MOE) - Fudan University, Shanghai, China**

X. Gao<sup>16</sup> 

**Zhejiang University, Hangzhou, Zhejiang, China**

Z. Lin , C. Lu , M. Xiao 





**Universidad de Los Andes, Bogota, Colombia**

C. Avila , D.A. Barbosa Trujillo, A. Cabrera , C. Florez , J. Fraga , J.A. Reyes Vega

**Universidad de Antioquia, Medellin, Colombia**

F. Ramirez , C. Rendón, M. Rodriguez , A.A. Ruales Barbosa, J.D. Ruiz Alvarez 

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

D. Giljanovic , N. Godinovic , D. Lelas , A. Sculac 

**University of Split, Faculty of Science, Split, Croatia**

M. Kovac , A. Petkovic, T. Sculac 




**Institute Rudjer Boskovic, Zagreb, Croatia**

P. Bargassa , V. Brigljevic , B.K. Chitroda , D. Ferencek , K. Jakovcic, S. Mishra ,  
A. Starodumov<sup>17</sup> , T. Susa 

**University of Cyprus, Nicosia, Cyprus**

A. Attikis , K. Christoforou , A. Hadjiagapiou, C. Leonidou, J. Mousa , C. Nicolaou, L. Paizanos, F. Ptochos , P.A. Razis , H. Rykaczewski, H. Saka , A. Stepennov 

**Charles University, Prague, Czech Republic**

M. Finger , M. Finger Jr. , A. Kveton 

**Universidad San Francisco de Quito, Quito, Ecuador**

E. Carrera Jarrin 




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

Y. Assran<sup>18,19</sup>, B. El-mahdy, S. Elgammal<sup>19</sup>

**Center for High Energy Physics (CHEP-FU), Fayoum University, El-Fayoum, Egypt**

M.A. Mahmoud , Y. Mohammed 
















**National Institute of Chemical Physics and Biophysics, Tallinn, Estonia**

K. Ehataht , M. Kadastik, T. Lange , S. Nandan , C. Nielsen , J. Pata , M. Raidal , L. Tani , C. Veelken 

**Department of Physics, University of Helsinki, Helsinki, Finland**

H. Kirschenmann , K. Osterberg , M. Voutilainen 


















**Helsinki Institute of Physics, Helsinki, Finland**

S. Bharthuar , N. Bin Norjoharuddeen , E. Brücken , F. Garcia , P. Inkaew , K.T.S. Kallonen , T. Lampén , K. Lassila-Perini , S. Lehti , T. Lindén , L. Martikainen , M. Myllymäki , M.m. Rantanen , H. Siikonen , J. Tuominiemi 



























**Lappeenranta-Lahti University of Technology, Lappeenranta, Finland**

P. Luukka , H. Petrow 


















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

M. Besancon , F. Couderc , M. Dejardin , D. Denegri, J.L. Faure, F. Ferri , S. Ganjour , P. Gras , G. Hamel de Monchenault , V. Lohezic , J. Malcles , F. Orlandi , L. Portales , A. Rosowsky , M.Ö. Sahin , A. Savoy-Navarro<sup>20</sup> , P. Simkina , M. Titov , M. Tornago 

**Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France**

F. Beaudette , P. Busson , A. Cappati , C. Charlot , M. Chiusi , F. Damas , O. Davignon , A. De Wit , I.T. Ehle , B.A. Fontana Santos Alves , S. Ghosh , A. Gilbert , R. Granier de Cassagnac , A. Hakimi , B. Harikrishnan , L. Kalipoliti , G. Liu , M. Nguyen , C. Ochando , R. Salerno , J.B. Sauvan , Y. Sirois , L. Urda Gómez , E. Vernazza , A. Zabi , A. Zghiche 











**Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France**

J.-L. Agram<sup>21</sup> , J. Andrea , D. Apparú , D. Bloch , J.-M. Brom , E.C. Chabert , C. Collard , S. Falke , U. Goerlach , R. Haeberle , A.-C. Le Bihan , M. Meena , O. Poncet , G. Saha , M.A. Sessini , P. Van Hove , P. Vaucelle 

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

A. Di Florio 

**Institut de Physique des 2 Infinis de Lyon (IP2I ), Villeurbanne, France**

D. Amram, S. Beauceron , B. Blancon , G. Boudoul , N. Chanon , D. Contardo , P. Depasse , C. Dozen<sup>22</sup> , H. El Mamouni, J. Fay , S. Gascon , M. Gouzevitch 

C. Greenberg, G. Grenier , B. Ille , E. Jourd'huy, I.B. Laktineh, M. Lethuillier , L. Mirabito, S. Perries, A. Purohit , M. Vander Donckt , P. Verdier , J. Xiao 






























### Georgian Technical University, Tbilisi, Georgia

G. Adamov, I. Lomidze , Z. Tsamalaidze<sup>17</sup> 









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

V. Botta , L. Feld , K. Klein , M. Lipinski , D. Meuser , A. Pauls , D. Pérez Adán , N. Röwert , M. Teroerde 






































































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S. Diekmann , A. Dodonova , N. Eich , D. Eliseev , F. Engelke , J. Erdmann , M. Erdmann , P. Fackeldey , B. Fischer , T. Hebbeker , K. Hoepfner , F. Ivone , A. Jung , M.y. Lee , F. Mausolf , M. Merschmeyer , A. Meyer , S. Mukherjee , D. Noll , F. Nowotny, A. Pozdnyakov , Y. Rath, W. Redjeb , F. Rehm, H. Reithler , V. Sarkisovi , A. Schmidt , A. Sharma , J.L. Spah , A. Stein , F. Torres Da Silva De Araujo<sup>23</sup> , S. Wiedenbeck , S. Zaleski







































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

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



















### Deutsches Elektronen-Synchrotron, Hamburg, Germany

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### University of Hamburg, Hamburg, Germany

A. Albrecht , S. Albrecht , M. Antonello , S. Bein , L. Benato , S. Bollweg, M. Bonanomi , P. Connor , K. El Morabit , Y. Fischer , E. Garutti , A. Grohsjean , J. Haller , H.R. Jabusch , G. Kasieczka , P. Keicher, R. Klanner , W. Korcari , T. Kramer , C.c. Kuo, V. Kutzner , F. Labe , J. Lange , A. Lobanov , C. Matthies , L. Moureaux , M. Mrowietz, A. Nigamova , Y. Nissan, A. Paasch , K.J. Pena Rodriguez , T. Quadfasel , B. Raciti , M. Rieger , D. Savoie , J. Schindler , P. Schleper , M. Schröder , J. Schwandt , M. Sommerhalder , H. Stadie , G. Steinbrück , A. Tews, M. Wolf 

### Karlsruher Institut fuer Technologie, Karlsruhe, Germany

S. Brommer , M. Burkart, E. Butz , T. Chwalek , A. Dierlamm , A. Droll, N. Faltermann , M. Giffels , A. Gottmann , F. Hartmann<sup>29</sup> , R. Hofsaess , M. Horzela , U. Husemann , J. Kieseler , M. Klute , R. Koppenhöfer , J.M. Lawhorn , M. Link, A. Lintuluoto , B. Maier , S. Maier , S. Mitra , M. Mormile , Th. Müller , M. Neukum,



M. Oh , E. Pfeffer , M. Presilla , G. Quast , K. Rabbertz , B. Regnery , N. Shadskiy , I. Shvetsov , H.J. Simonis , L. Sowa, L. Stockmeier, K. Tauqeer, M. Toms , N. Trevisani , R.F. Von Cube , M. Wassmer , S. Wieland , F. Wittig, R. Wolf , X. Zuo 





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

G. Anagnostou, G. Daskalakis , A. Kyriakis, A. Papadopoulos<sup>29</sup>, A. Stakia 

**National and Kapodistrian University of Athens, Athens, Greece**

P. Kontaxakis , G. Melachroinos, Z. Painesis , I. Papavergou , I. Paraskevas , N. Saoulidou , K. Theofilatos , E. Tziaferi , K. Vellidis , I. Zisopoulos 






**National Technical University of Athens, Athens, Greece**

G. Bakas , T. Chatzistavrou, G. Karapostoli , K. Kousouris , I. Papakrivopoulos , E. Siamarkou, G. Tsipolitis, A. Zacharopoulou

**University of Ioánnina, Ioánnina, Greece**

K. Adamidis, I. Bestintzanos, I. Evangelou , C. Foudas, C. Kamtsikis, P. Katsoulis, P. Kokkas , P.G. Kosmoglou Kioseoglou , N. Manthos , I. Papadopoulos , J. Strologas 

**HUN-REN Wigner Research Centre for Physics, Budapest, Hungary**

C. Hajdu , D. Horvath<sup>30,31</sup> , K. Márton, A.J. Rádl<sup>32</sup> , F. Sikler , V. Veszpremi 

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

M. Csanád , K. Farkas , A. Fehérkuti<sup>33</sup> , M.M.A. Gadallah<sup>34</sup> , Á. Kadlecik , P. Major , G. Pásztor , G.I. Veres 

**Faculty of Informatics, University of Debrecen, Debrecen, Hungary**

B. Ujvari , G. Zilizi 















**Institute of Nuclear Research ATOMKI, Debrecen, Hungary**

G. Bencze, S. Czellar, J. Molnar, Z. Szillasi

**Karoly Robert Campus, MATE Institute of Technology, Gyongyos, Hungary**

T. Csorgo<sup>33</sup> , T. Novak 

**Panjab University, Chandigarh, India**

J. Babbar , S. Bansal , S.B. Beri, V. Bhatnagar , G. Chaudhary , S. Chauhan , N. Dhingra<sup>35</sup> , A. Kaur , A. Kaur , H. Kaur , M. Kaur , S. Kumar , K. Sandeep , T. Sheokand, J.B. Singh , A. Singla 
















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A. Ahmed , A. Bhardwaj , A. Chhetri , B.C. Choudhary , A. Kumar , A. Kumar , M. Naimuddin , K. Ranjan , M.K. Saini, S. Saumya 

**Saha Institute of Nuclear Physics, HBNI, Kolkata, India**

S. Baradia , S. Barman<sup>36</sup> , S. Bhattacharya , S. Das Gupta, S. Dutta , S. Dutta, S. Sarkar







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M.M. Ameen , P.K. Behera , S.C. Behera , S. Chatterjee , G. Dash , P. Jana , P. Kalbhor , S. Kamble , J.R. Komaragiri<sup>37</sup> , D. Kumar<sup>37</sup> , P.R. Pujahari , N.R. Saha , A. Sharma , A.K. Sikdar , R.K. Singh, P. Verma, S. Verma , A. Vijay








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






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A. Bala , S. Banerjee , R.M. Chatterjee , M. Guchait , Sh. Jain , A. Jaiswal , S. Kumar , G. Majumder , K. Mazumdar , S. Parolia , A. Thachayath 




**National Institute of Science Education and Research, An OCC of Homi Bhabha National Institute, Bhubaneswar, Odisha, India**

S. Bahinipati<sup>38</sup> , C. Kar , D. Maity<sup>39</sup> , P. Mal , T. Mishra , V.K. Muraleedharan Nair Bindhu<sup>39</sup> , K. Naskar<sup>39</sup> , A. Nayak<sup>39</sup> , S. Nayak , K. Pal , P. Sadangi , S.K. Swain , S. Varghese<sup>39</sup> , D. Vats<sup>39</sup> 









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

S. Acharya<sup>40</sup> , A. Alpana , S. Dube , B. Gomber<sup>40</sup> , P. Hazarika , B. Kansal , A. Laha , B. Sahu<sup>40</sup> , S. Sharma , K.Y. Vaish 

**Isfahan University of Technology, Isfahan, Iran**

H. Bakhshiansohi<sup>41</sup> , A. Jafari<sup>42</sup> , M. Zeinali<sup>43</sup> 





















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

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









**University College Dublin, Dublin, Ireland**

M. Felcini , M. Grunewald 







**INFN Sezione di Bari<sup>a</sup>, Università di Bari<sup>b</sup>, Politecnico di Bari<sup>c</sup>, Bari, Italy**

M. Abbrescia<sup>a,b</sup> , A. Colaleo<sup>a,b</sup> , D. Creanza<sup>a,c</sup> , B. D'Anzi<sup>a,b</sup> , N. De Filippis<sup>a,c</sup> , M. De Palma<sup>a,b</sup> , W. Elmetenawee<sup>a,b,46</sup> , L. Fiore<sup>a</sup> , G. Iaselli<sup>a,c</sup> , L. Longo<sup>a</sup> , M. Louka<sup>a,b</sup> , G. Maggi<sup>a,c</sup> , M. Maggi<sup>a</sup> , I. Margjeka<sup>a</sup> , V. Mastrapasqua<sup>a,b</sup> , S. My<sup>a,b</sup> , S. Nuzzo<sup>a,b</sup> , A. Pellecchia<sup>a,b</sup> , A. Pompili<sup>a,b</sup> , G. Pugliese<sup>a,c</sup> , R. Radogna<sup>a,b</sup> , D. Ramos<sup>a</sup> , A. Ranieri<sup>a</sup> , L. Silvestris<sup>a</sup> , F.M. Simone<sup>a,c</sup> , Ü. Sözbilir<sup>a</sup> , A. Stamerra<sup>a,b</sup> , D. Troiano<sup>a,b</sup> , R. Venditti<sup>a,b</sup> , P. Verwilligen<sup>a</sup> , A. Zaza<sup>a,b</sup> 













**INFN Sezione di Bologna<sup>a</sup>, Università di Bologna<sup>b</sup>, Bologna, Italy**

G. Abbiendi<sup>a</sup> , C. Battilana<sup>a,b</sup> , D. Bonacorsi<sup>a,b</sup> , L. Borghonovi<sup>a</sup> , P. Capiluppi<sup>a,b</sup> , A. Castro<sup>†a,b</sup> , F.R. Cavallo<sup>a</sup> , M. Cuffiani<sup>a,b</sup> , G.M. Dallavalle<sup>a</sup> , T. Diotallevi<sup>a,b</sup> , F. Fabbri<sup>a</sup> , A. Fanfani<sup>a,b</sup> , D. Fasanella<sup>a</sup> , P. Giacomelli<sup>a</sup> , L. Giommi<sup>a,b</sup> , C. Grandi<sup>a</sup> , L. Guiducci<sup>a,b</sup> , S. Lo Meo<sup>a,47</sup> , M. Lorusso<sup>a,b</sup> , L. Lunerti<sup>a</sup> , S. Marcellini<sup>a</sup> , G. Masetti<sup>a</sup> , F.L. Navarra<sup>a,b</sup> , G. Paggi<sup>a,b</sup> , A. Perrotta<sup>a</sup> , F. Primavera<sup>a,b</sup> , A.M. Rossi<sup>a,b</sup> , S. Rossi Tisbeni<sup>a,b</sup> , T. Rovelli<sup>a,b</sup> , G.P. Siroli<sup>a,b</sup> 

**INFN Sezione di Catania<sup>a</sup>, Università di Catania<sup>b</sup>, Catania, Italy**

S. Costa<sup>a,b,48</sup> , A. Di Mattia<sup>a</sup> , A. Lapertosa<sup>a</sup> , R. Potenza<sup>a,b</sup> , A. Tricomi<sup>a,b,48</sup> , C. Tuve<sup>a,b</sup> 

**INFN Sezione di Firenze<sup>a</sup>, Università di Firenze<sup>b</sup>, Firenze, Italy**

P. Assiouras<sup>a</sup> , G. Barbagli<sup>a</sup> , G. Bardelli<sup>a,b</sup> , B. Camaiani<sup>a,b</sup> , A. Cassese<sup>a</sup> , R. Ceccarelli<sup>a</sup> , V. Ciulli<sup>a,b</sup> , C. Civinini<sup>a</sup> , R. D'Alessandro<sup>a,b</sup> , E. Focardi<sup>a,b</sup> , T. Kello<sup>a</sup> , G. Latino<sup>a,b</sup> , P. Lenzi<sup>a,b</sup> , M. Lizzo<sup>a</sup> , M. Meschini<sup>a</sup> , S. Paoletti<sup>a</sup> , A. Papanastassiou<sup>a,b</sup> , G. Sguazzoni<sup>a</sup> , L. Viliani<sup>a</sup> 

























**INFN Laboratori Nazionali di Frascati, Frascati, Italy**

L. Benussi , S. Bianco , S. Meola<sup>49</sup> , D. Piccolo 

**INFN Sezione di Genova<sup>a</sup>, Università di Genova<sup>b</sup>, Genova, Italy**

P. Chatagnon<sup>a</sup> , F. Ferro<sup>a</sup> , E. Robutti<sup>a</sup> , S. Tosi<sup>a,b</sup> 





























**INFN Sezione di Milano-Bicocca<sup>a</sup>, Università di Milano-Bicocca<sup>b</sup>, Milano, Italy**

A. Benaglia<sup>a</sup> , G. Boldrini<sup>a,b</sup> , F. Brivio<sup>a</sup> , F. Cetorelli<sup>a,b</sup> , F. De Guio<sup>a,b</sup> , M.E. Dinardo<sup>a,b</sup> , P. Dini<sup>a</sup> , S. Gennai<sup>a</sup> , R. Gerosa<sup>a,b</sup> , A. Ghezzi<sup>a,b</sup> , P. Govoni<sup>a,b</sup> , L. Guzzi<sup>a</sup> , M.T. Lucchini<sup>a,b</sup> , M. Malberti<sup>a</sup> , S. Malvezzi<sup>a</sup> , A. Massironi<sup>a</sup> , D. Menasce<sup>a</sup> , L. Moroni<sup>a</sup> , M. Paganoni<sup>a,b</sup> , S. Palluotto<sup>a,b</sup> , D. Pedrini<sup>a</sup> , A. Perego<sup>a,b</sup> , B.S. Pinolini<sup>a</sup>, G. Pizzati<sup>a,b</sup>, S. Ragazzi<sup>a,b</sup> , T. Tabarelli de Fatis<sup>a,b</sup> 










**INFN Sezione di Napoli<sup>a</sup>, Università di Napoli 'Federico II'<sup>b</sup>, Napoli, Italy; Università della Basilicata<sup>c</sup>, Potenza, Italy; Scuola Superiore Meridionale (SSM)<sup>d</sup>, Napoli, Italy**

S. Buontempo<sup>a</sup> , A. Cagnotta<sup>a,b</sup> , F. Carnevali<sup>a,b</sup>, N. Cavallo<sup>a,c</sup> , F. Fabozzi<sup>a,c</sup> , A.O.M. Iorio<sup>a,b</sup> , L. Lista<sup>a,b,50</sup> , P. Paolucci<sup>a,29</sup> , B. Rossi<sup>a</sup> 













**INFN Sezione di Padova<sup>a</sup>, Università di Padova<sup>b</sup>, Padova, Italy; Università di Trento<sup>c</sup>, Trento, Italy**

R. Ardino<sup>a</sup> , P. Azzi<sup>a</sup> , N. Bacchetta<sup>a,51</sup> , D. Bisello<sup>a,b</sup> , P. Bortignon<sup>a</sup> , G. Bortolato<sup>a,b</sup>, A. Bragagnolo<sup>a,b</sup> , A.C.M. Bulla<sup>a</sup> , R. Carlin<sup>a,b</sup> , P. Checchia<sup>a</sup> , T. Dorigo<sup>a</sup> , F. Gasparini<sup>a,b</sup> , U. Gasparini<sup>a,b</sup> , E. Lusiani<sup>a</sup> , M. Margoni<sup>a,b</sup> , A.T. Meneguzzo<sup>a,b</sup> , M. Michelotto<sup>a</sup> , M. Migliorini<sup>a,b</sup> , J. Pazzini<sup>a,b</sup> , P. Ronchese<sup>a,b</sup> , R. Rossin<sup>a,b</sup> , F. Simonetto<sup>a,b</sup> , G. Strong<sup>a</sup> , M. Tosi<sup>a,b</sup> , A. Triossi<sup>a,b</sup> , S. Ventura<sup>a</sup> , M. Zanetti<sup>a,b</sup> , P. Zotto<sup>a,b</sup> , A. Zucchetta<sup>a,b</sup> 


































**INFN Sezione di Pavia<sup>a</sup>, Università di Pavia<sup>b</sup>, Pavia, Italy**

C. Aimè<sup>a</sup> , A. Braghieri<sup>a</sup> , S. Calzaferri<sup>a</sup> , D. Fiorina<sup>a</sup> , P. Montagna<sup>a,b</sup> , V. Re<sup>a</sup> , C. Riccardi<sup>a,b</sup> , P. Salvini<sup>a</sup> , I. Vai<sup>a,b</sup> , P. Vitulo<sup>a,b</sup> 





















**INFN Sezione di Perugia<sup>a</sup>, Università di Perugia<sup>b</sup>, Perugia, Italy**

S. Ajmal<sup>a,b</sup> , M.E. Ascioti<sup>a,b</sup>, G.M. Bilei<sup>a</sup> , C. Carrivale<sup>a,b</sup>, D. Ciangottini<sup>a,b</sup> , L. Fanò<sup>a,b</sup> , M. Magherini<sup>a,b</sup> , V. Mariani<sup>a,b</sup> , M. Menichelli<sup>a</sup> , F. Moscatelli<sup>a,52</sup> , A. Rossi<sup>a,b</sup> , A. Santocchia<sup>a,b</sup> , D. Spiga<sup>a</sup> , T. Tedeschi<sup>a,b</sup> 




























**INFN Sezione di Pisa<sup>a</sup>, Università di Pisa<sup>b</sup>, Scuola Normale Superiore di Pisa<sup>c</sup>, Pisa, Italy; Università di Siena<sup>d</sup>, Siena, Italy**














C.A. Alexe<sup>a,c</sup> , P. Asenov<sup>a,b</sup> , P. Azzurri<sup>a</sup> , G. Bagliesi<sup>a</sup> , R. Bhattacharya<sup>a</sup> , L. Bianchini<sup>a,b</sup> , T. Boccali<sup>a</sup> , E. Bossini<sup>a</sup> , D. Bruschini<sup>a,c</sup> , R. Castaldi<sup>a</sup> , M.A. Ciocci<sup>a,b</sup> , M. Cipriani<sup>a,b</sup> , V. D'Amante<sup>a,d</sup> , R. Dell'Orso<sup>a</sup> , S. Donato<sup>a</sup> , A. Giassi<sup>a</sup> , F. Ligabue<sup>a,c</sup> , D. Matos Figueiredo<sup>a</sup> , A. Messineo<sup>a,b</sup> , M. Musich<sup>a,b</sup> , F. Palla<sup>a</sup> , A. Rizzi<sup>a,b</sup> , G. Rolandi<sup>a,c</sup> , S. Roy Chowdhury<sup>a</sup> , T. Sarkar<sup>a</sup> , A. Scribano<sup>a</sup> , P. Spagnolo<sup>a</sup> , R. Tenchini<sup>a</sup> , G. Tonelli<sup>a,b</sup> , N. Turini<sup>a,d</sup> , F. Vaselli<sup>a,c</sup> , A. Venturi<sup>a</sup> , P.G. Verdini<sup>a</sup> 

**INFN Sezione di Roma<sup>a</sup>, Sapienza Università di Roma<sup>b</sup>, Roma, Italy**







C. Baldenegro Barrera<sup>a,b</sup> , P. Barria<sup>a</sup> , C. Basile<sup>a,b</sup> , M. Campana<sup>a,b</sup> , F. Cavallari<sup>a</sup> , L. Cunqueiro Mendez<sup>a,b</sup> , D. Del Re<sup>a,b</sup> , E. Di Marco<sup>a,b</sup> , M. Diemoz<sup>a</sup> , F. Errico<sup>a,b</sup> , E. Longo<sup>a,b</sup> , J. Mijuskovic<sup>a,b</sup> , G. Organtini<sup>a,b</sup> , F. Pandolfi<sup>a</sup> , R. Paramatti<sup>a,b</sup> , C. Quaranta<sup>a,b</sup> , S. Rahatlou<sup>a,b</sup> , C. Rovelli<sup>a</sup> , F. Santanastasio<sup>a,b</sup> , L. Soffi<sup>a</sup> 

**INFN Sezione di Torino<sup>a</sup>, Università di Torino<sup>b</sup>, Torino, Italy; Università del Piemonte Orientale<sup>c</sup>, Novara, Italy**

N. Amapane<sup>a,b</sup> , R. Arcidiacono<sup>a,c</sup> , S. Argiro<sup>a,b</sup> , M. Arneodo<sup>a,c</sup> , N. Bartosik<sup>a</sup> , R. Bellan<sup>a,b</sup> , A. Bellora<sup>a,b</sup> , C. Biino<sup>a</sup> , C. Borca<sup>a,b</sup> , N. Cartiglia<sup>a</sup> , M. Costa<sup>a,b</sup> , R. Covarelli<sup>a,b</sup> , N. Demaria<sup>a</sup> , L. Finco<sup>a</sup> , M. Grippo<sup>a,b</sup> , B. Kiani<sup>a,b</sup> , F. Legger<sup>a</sup> , F. Luongo<sup>a,b</sup> , C. Mariotti<sup>a</sup> , L. Markovic<sup>a,b</sup> , S. Maselli<sup>a</sup> , A. Mecca<sup>a,b</sup> , L. Menzio<sup>a,b</sup>, P. Meridiani<sup>a</sup> , E. Migliore<sup>a,b</sup> , M. Monteno<sup>a</sup> , R. Mulargia<sup>a</sup> , M.M. Obertino<sup>a,b</sup> 

G. Ortona<sup>a</sup> , L. Pacher<sup>a,b</sup> , N. Pastrone<sup>a</sup> , M. Pelliccioni<sup>a</sup> , M. Ruspa<sup>a,c</sup> ,  
F. Siviero<sup>a,b</sup> , V. Sola<sup>a,b</sup> , A. Solano<sup>a,b</sup> , A. Staiano<sup>a</sup> , C. Tarricone<sup>a,b</sup> , D. Trocino<sup>a</sup> ,  
G. Umoret<sup>a,b</sup> , R. White<sup>a,b</sup> 


**INFN Sezione di Trieste<sup>a</sup>, Università di Trieste<sup>b</sup>, Trieste, Italy**

S. Belforte<sup>a</sup> , V. Candelise<sup>a,b</sup> , M. Casarsa<sup>a</sup> , F. Cossutti<sup>a</sup> , K. De Leo<sup>a</sup> ,  
G. Della Ricca<sup>a,b</sup> 


**Kyungpook National University, Daegu, Korea**

S. Dogra , J. Hong , C. Huh , B. Kim , J. Kim, D. Lee, H. Lee, S.W. Lee , C.S. Moon ,  
Y.D. Oh , M.S. Ryu , S. Sekmen , B. Tae, Y.C. Yang 

**Department of Mathematics and Physics - GWNU, Gangneung, Korea**

M.S. Kim 

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

G. Bak , P. Gwak , H. Kim , D.H. Moon 

**Hanyang University, Seoul, Korea**

E. Asilar , J. Choi , D. Kim , T.J. Kim , J.A. Merlin, Y. Ryou

**Korea University, Seoul, Korea**

S. Choi , S. Han, B. Hong , K. Lee, K.S. Lee , S. Lee , J. Yoo 

**Kyung Hee University, Department of Physics, Seoul, Korea**

J. Goh , S. Yang 








**Sejong University, Seoul, Korea**

H. S. Kim , Y. Kim, S. Lee



**Seoul National University, Seoul, Korea**

J. Almond, J.H. Bhyun, J. Choi , J. Choi, W. Jun , J. Kim , S. Ko , H. Kwon , H. Lee ,  
J. Lee , J. Lee , B.H. Oh , S.B. Oh , H. Seo , U.K. Yang, I. Yoon 

**University of Seoul, Seoul, Korea**

W. Jang , D.Y. Kang, Y. Kang , S. Kim , B. Ko, J.S.H. Lee , Y. Lee , I.C. Park , Y. Roh,  
I.J. Watson 

**Yonsei University, Department of Physics, Seoul, Korea**

S. Ha , H.D. Yoo 

**Sungkyunkwan University, Suwon, Korea**

M. Choi , M.R. Kim , H. Lee, Y. Lee , I. Yu 


**College of Engineering and Technology, American University of the Middle East (AUM),  
Dasman, Kuwait**

T. Beyrouthy

**Riga Technical University, Riga, Latvia**
















































K. Dreimanis , A. Gaile , G. Pikurs, A. Potrebko , M. Seidel , D. Sidiropoulos Kontos

**University of Latvia (LU), Riga, Latvia**














N.R. Strautnieks 

**Vilnius University, Vilnius, Lithuania**

M. Ambrozys , A. Juodagalvis , A. Rinkevicius , G. Tamulaitis 

**National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia**I. Yusuff<sup>53</sup> , Z. Zolkapli**Universidad de Sonora (UNISON), Hermosillo, Mexico**J.F. Benitez , A. Castaneda Hernandez , H.A. Encinas Acosta, L.G. Gallegos Maríñez, M. León Coello , J.A. Murillo Quijada , A. Sehrawat , L. Valencia Palomo **Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico**G. Ayala , H. Castilla-Valdez , H. Crotte Ledesma, E. De La Cruz-Burelo , I. Heredia-De La Cruz<sup>54</sup> , R. Lopez-Fernandez , J. Mejia Guisao , C.A. Mondragon Herrera, A. Sánchez Hernández **Universidad Iberoamericana, Mexico City, Mexico**C. Oropeza Barrera , D.L. Ramirez Guadarrama, M. Ramírez García **Benemerita Universidad Autonoma de Puebla, Puebla, Mexico**I. Bautista , I. Pedraza , H.A. Salazar Ibarguen , C. Uribe Estrada **University of Montenegro, Podgorica, Montenegro**I. Bubanja, N. Raicevic **University of Canterbury, Christchurch, New Zealand**P.H. Butler **National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan**A. Ahmad , M.I. Asghar, A. Awais , M.I.M. Awan, H.R. Hoorani , W.A. Khan **AGH University of Krakow, Faculty of Computer Science, Electronics and Telecommunications, Krakow, Poland**V. Avati, L. Grzanka , M. Malawski **National Centre for Nuclear Research, Swierk, Poland**H. Bialkowska , M. Bluj , M. Górski , M. Kazana , M. Szleper , P. Zalewski **Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland**K. Bunkowski , K. Doroba , A. Kalinowski , M. Konecki , J. Krolikowski , A. Muhammad **Warsaw University of Technology, Warsaw, Poland**K. Pozniak , W. Zabolotny **Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal**M. Araujo , D. Bastos , C. Beirão Da Cruz E Silva , A. Boletti , M. Bozzo , T. Camporesi , G. Da Molin , P. Faccioli , M. Gallinaro , J. Hollar , N. Leonardo , G.B. Marozzo, T. Niknejad , A. Petrilli , M. Pisano , J. Seixas , J. Varela , J.W. Wulff**Faculty of Physics, University of Belgrade, Belgrade, Serbia**P. Adzic , P. Milenovic **VINCA Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia**M. Dordevic , J. Milosevic , L. Nadderd , V. Rekovic**Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain**J. Alcaraz Maestre , Cristina F. Bedoya , Oliver M. Carretero , M. Cepeda , M. Cerrada , N. Colino , B. De La Cruz , A. Delgado Peris , A. Escalante Del Valle , D. Fernández Del Val , J.P. Fernández Ramos , J. Flix , M.C. Fouz , O. Gonzalez Lopez 

















S. Goy Lopez , J.M. Hernandez , M.I. Josa , E. Martin Viscasillas , D. Moran , C.M. Morcillo Perez , Á. Navarro Tobar , C. Perez Dengra , A. Pérez-Calero Yzquierdo , J. Puerta Pelayo , I. Redondo , S. Sánchez Navas , J. Sastre , J. Vazquez Escobar 




















**Universidad Autónoma de Madrid, Madrid, Spain**

J.F. de Trocóniz 

**Universidad de Oviedo, Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA), Oviedo, Spain**

B. Alvarez Gonzalez , J. Cuevas , J. Fernandez Menendez , S. Folgueras , I. Gonzalez Caballero , J.R. González Fernández , P. Leguina , E. Palencia Cortezon , C. Ramón Álvarez , V. Rodríguez Bouza , A. Soto Rodríguez , A. Trapote , C. Vico Villalba , P. Vischia 

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

S. Bhowmik , S. Blanco Fernández , J.A. Brochero Cifuentes , I.J. Cabrillo , A. Calderon , J. Duarte Campderros , M. Fernandez , G. Gomez , C. Lasaosa García , R. Lopez Ruiz , C. Martinez Rivero , P. Martinez Ruiz del Arbol , F. Matorras , P. Matorras Cuevas , E. Navarrete Ramos , J. Piedra Gomez , L. Scodellaro , I. Vila , J.M. Vizan Garcia 



















































































**University of Colombo, Colombo, Sri Lanka**

B. Kailasapathy<sup>55</sup> , D.D.C. Wickramarathna 









**University of Ruhuna, Department of Physics, Matara, Sri Lanka**

W.G.D. Dharmaratna<sup>56</sup> , K. Liyanage , N. Perera 
























**CERN, European Organization for Nuclear Research, Geneva, Switzerland**


















D. Abbaneo , C. Amendola , E. Auffray , G. Auzinger , J. Baechler , D. Barney , A. Bermúdez Martínez , M. Bianco , B. Bilin , A.A. Bin Anuar , A. Bocci , C. Botta , E. Brondolin , C. Caillol , G. Cerminara , N. Chernyavskaya , D. d'Enterria , A. Dabrowski , A. David , A. De Roeck , M.M. Defranchis , M. Deile , M. Dobson , G. Franzoni , W. Funk , S. Giani , D. Gigi , K. Gill , F. Glege , J. Hegeman , J.K. Heikkilä , B. Huber , V. Innocente , T. James , P. Janot , O. Kaluzinska , S. Laurila , P. Lecoq , E. Leutgeb , C. Lourenço , L. Malgeri , M. Mannelli , A.C. Marini , M. Matthewman , A. Mehta , F. Meijers , S. Mersi , E. Meschi , V. Milosevic , F. Monti , F. Moortgat , M. Mulders , I. Neutelings , S. Orfanelli , F. Pantaleo , G. Petrucciani , A. Pfeiffer , M. Pierini , H. Qu , D. Rabaday , B. Ribeiro Lopes , M. Rovere , H. Sakulin , S. Sanchez Cruz , S. Scarfi , C. Schwick , M. Selvaggi , A. Sharma , K. Shchelina , P. Silva , P. Sphicas<sup>57</sup> , A.G. Stahl Leiton , A. Steen , S. Summers , D. Treille , P. Tropea , D. Walter , J. Wanczyk<sup>58</sup> , J. Wang , S. Wuchterl , P. Zehetner , P. Zejdl , W.D. Zeuner

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

T. Bevilacqua<sup>59</sup> , L. Caminada<sup>59</sup> , A. Ebrahimi , W. Erdmann , R. Horisberger , Q. Ingram , H.C. Kaestli , D. Kotlinski , C. Lange , M. Missiroli<sup>59</sup> , L. Noehte<sup>59</sup> , T. Rohe 

**ETH Zurich - Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland**








T.K. Aarrestad , K. Androsov<sup>58</sup> , M. Backhaus , G. Bonomelli , A. Calandri , C. Cazzaniga , K. Datta , P. De Bryas Dexmiers D'archiac<sup>58</sup> , A. De Cosa , G. Dissertori , M. Dittmar , M. Donegà , F. Eble , M. Galli , K. Gedia , F. Glessgen , C. Grab , N. Härringer , T.G. Harte , D. Hits , W. Lustermann , A.-M. Lyon , R.A. Manzoni 

M. Marchegiani , L. Marchese , C. Martin Perez , A. Mascellani<sup>58</sup> , F. Nessi-Tedaldi , F. Pauss , V. Perovic , S. Pigazzini , C. Reissel , T. Reitenspiess , B. Ristic , F. Riti , R. Seidita , J. Steggemann<sup>58</sup> , A. Tarabini , D. Valsecchi , R. Wallny 



















#### **Universität Zürich, Zurich, Switzerland**

C. Amsler<sup>60</sup> , P. Bärtschi , M.F. Canelli , K. Cormier , M. Huwiler , W. Jin , A. Jofrehei , B. Kilminster , S. Leontsinis , S.P. Liechti , A. Macchiolo , P. Meiring , F. Meng , U. Molinatti , J. Motta , A. Reimers , P. Robmann , M. Senger , E. Shokr , F. Stäger , R. Tramontano 




#### **National Central University, Chung-Li, Taiwan**

C. Adloff<sup>61</sup> , D. Bhowmik , C.M. Kuo , W. Lin , P.K. Rout , P.C. Tiwari<sup>37</sup> , S.S. Yu 




















#### **National Taiwan University (NTU), Taipei, Taiwan**

L. Ceard , K.F. Chen , P.s. Chen , Z.g. Chen , A. De Iorio , W.-S. Hou , T.h. Hsu , Y.w. Kao , S. Karmakar , G. Kole , Y.y. Li , R.-S. Lu , E. Paganis , X.f. Su , J. Thomas-Wilsker , L.s. Tsai , H.y. Wu , E. Yazgan 



#### **High Energy Physics Research Unit, Department of Physics, Faculty of Science, Chulalongkorn University, Bangkok, Thailand**

C. Asawatrangkuldee , N. Srimanobhas , V. Wachirapusanand 

#### **Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey**

D. Agyel , F. Boran , F. Dolek , I. Dumanoglu<sup>62</sup> , E. Eskut , Y. Guler<sup>63</sup> , E. Gulpinar Guler<sup>63</sup> , C. Isik , O. Kara , A. Kayis Topaksu , U. Kiminsu , G. Onengut , K. Ozdemir<sup>64</sup> , A. Polatoz , B. Tali<sup>65</sup> , U.G. Tok , S. Turkcapar , E. Uslan , I.S. Zorbakir 






#### **Middle East Technical University, Physics Department, Ankara, Turkey**

G. Sokmen , M. Yalvac<sup>66</sup> 


#### **Bogazici University, Istanbul, Turkey**

B. Akgun , I.O. Atakisi , E. Gülmez , M. Kaya<sup>67</sup> , O. Kaya<sup>68</sup> , S. Tekten<sup>69</sup> 





#### **Istanbul Technical University, Istanbul, Turkey**

A. Cakir , K. Cankocak<sup>62,70</sup> , G.G. Dincer<sup>62</sup> , Y. Komurcu , S. Sen<sup>71</sup> 

#### **Istanbul University, Istanbul, Turkey**

O. Aydilek<sup>72</sup> , B. Haciasahinoglu , I. Hos<sup>73</sup> , B. Kaynak , S. Ozkorucuklu , O. Potok , H. Sert , C. Simsek , C. Zorbilmez 


#### **Yildiz Technical University, Istanbul, Turkey**

S. Cerci<sup>65</sup> , B. Isildak<sup>74</sup> , D. Sunar Cerci , T. Yetkin 



















#### **Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkiv, Ukraine**

A. Boyaryntsev , B. Grynyov 




















#### **National Science Centre, Kharkiv Institute of Physics and Technology, Kharkiv, Ukraine**

L. Levchuk 




































#### **University of Bristol, Bristol, United Kingdom**

D. Anthony , J.J. Brooke , A. Bundock , F. Bury , E. Clement , D. Cussans , H. Flacher , M. Glowacki , J. Goldstein , H.F. Heath , M.-L. Holmberg , L. Kreczko , S. Paramesvaran , L. Robertshaw , S. Seif El Nasr-Storey , V.J. Smith , N. Stylianou<sup>75</sup> , K. Walkingshaw Pass 




**Rutherford Appleton Laboratory, Didcot, United Kingdom**

A.H. Ball, K.W. Bell , A. Belyaev<sup>76</sup> , C. Brew , R.M. Brown , D.J.A. Cockerill , C. Cooke , A. Elliot , K.V. Ellis, K. Harder , S. Harper , J. Linacre , K. Manolopoulos, D.M. Newbold , E. Olaiya, D. Petyt , T. Reis , A.R. Sahasransu , G. Salvi , T. Schuh, C.H. Shepherd-Themistocleous , I.R. Tomalin , K.C. Whalen , T. Williams 

**Imperial College, London, United Kingdom**

I. Andreou , R. Bainbridge , P. Bloch , C.E. Brown , O. Buchmuller, V. Cacchio, C.A. Carrillo Montoya , G.S. Chahal<sup>77</sup> , D. Colling , J.S. Dancu, I. Das , P. Dauncey , G. Davies , J. Davies, M. Della Negra , S. Fayer, G. Fedi , G. Hall , M.H. Hassanshahi , A. Howard, G. Iles , M. Knight , J. Langford , J. León Holgado , L. Lyons , A.-M. Magnan , S. Mallios, M. Mieskolainen , J. Nash<sup>78</sup> , M. Pesaresi , P.B. Pradeep, B.C. Radburn-Smith , A. Richards, A. Rose , K. Savva , C. Seez , R. Shukla , A. Tapper , K. Uchida , G.P. Uttley , L.H. Vage, T. Virdee<sup>29</sup> , M. Vojinovic , N. Wardle , D. Winterbottom 






**Brunel University, Uxbridge, United Kingdom**

K. Coldham, J.E. Cole , A. Khan, P. Kyberd , I.D. Reid 

**Baylor University, Waco, Texas, USA**

S. Abdullin , A. Brinkerhoff , B. Caraway , E. Collins , J. Dittmann , K. Hatakeyama , J. Hiltbrand , B. McMaster , J. Samudio , S. Sawant , C. Sutantawibul , J. Wilson 



















**Catholic University of America, Washington, DC, USA**

R. Bartek , A. Dominguez , C. Huerta Escamilla, A.E. Simsek , R. Uniyal , A.M. Vargas Hernandez 



















**The University of Alabama, Tuscaloosa, Alabama, USA**

B. Bam , A. Buchot Perraguin , R. Chudasama , S.I. Cooper , C. Crovella , S.V. Gleyzer , E. Pearson, C.U. Perez , P. Rumerio<sup>79</sup> , E. Usai , R. Yi 




















**Boston University, Boston, Massachusetts, USA**

A. Akpinar , C. Cosby , G. De Castro, Z. Demiragli , C. Erice , C. Fangmeier , C. Fernandez Madrazo , E. Fontanesi , D. Gastler , F. Golf , S. Jeon , J. O'cain, I. Reed , J. Rohlf , K. Salyer , D. Sperka , D. Spitzbart , I. Suarez , A. Tsatsos , A.G. Zecchinelli 



**Brown University, Providence, Rhode Island, USA**

G. Benelli , X. Coubez<sup>25</sup>, D. Cutts , L. Gouskos , M. Hadley , U. Heintz , J.M. Hogan<sup>80</sup> , T. Kwon , G. Landsberg , K.T. Lau , D. Li , J. Luo , S. Mondal , M. Narain<sup>†</sup> , N. Pervan , T. Russell, S. Sagir<sup>81</sup> , F. Simpson , M. Stamenkovic , N. Venkatasubramanian, X. Yan , W. Zhang

**University of California, Davis, Davis, California, USA**

S. Abbott , C. Brainerd , R. Breedon , H. Cai , M. Calderon De La Barca Sanchez , M. Chertok , M. Citron , J. Conway , P.T. Cox , R. Erbacher , F. Jensen , O. Kukral , G. Mocellin , M. Mulhearn , S. Ostrom , W. Wei , Y. Yao , S. Yoo , F. Zhang 

**University of California, Los Angeles, California, USA**


























M. Bachtis , R. Cousins , A. Datta , G. Flores Avila, J. Hauser , M. Ignatenko , M.A. Iqbal , T. Lam , E. Manca , A. Nunez Del Prado, D. Saltzberg , V. Valuev 

**University of California, Riverside, Riverside, California, USA**










R. Clare , J.W. Gary , M. Gordon, G. Hanson , W. Si , S. Wimpenny<sup>†</sup> 



### University of California, San Diego, La Jolla, California, USA

A. Aportela , A. Arora , J.G. Branson , S. Cittolin , S. Cooperstein , D. Diaz , J. Duarte , L. Giannini , Y. Gu, J. Guiang , R. Kansal , V. Krutelyov , R. Lee , J. Letts , M. Masciovecchio , F. Mokhtar , S. Mukherjee , M. Pieri , M. Quinnan , B.V. Sathia Narayanan , V. Sharma , M. Tadel , E. Vourliotis , F. Würthwein , Y. Xiang , A. Yagil 

















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

A. Barzdukas , L. Brennan , C. Campagnari , K. Downham , C. Grieco , J. Incandela , J. Kim , A.J. Li , P. Masterson , H. Mei , J. Richman , S.N. Santpur , U. Sarica , R. Schmitz , F. Setti , J. Sheplock , D. Stuart , T.Á. Vami , S. Wang , D. Zhang















### California Institute of Technology, Pasadena, California, USA

A. Bornheim , O. Cerri, A. Latorre, J. Mao , H.B. Newman , G. Reales Gutiérrez, M. Spiropulu , J.R. Vlimant , C. Wang , S. Xie , R.Y. Zhu 
















### Carnegie Mellon University, Pittsburgh, Pennsylvania, USA

J. Alison , S. An , M.B. Andrews , P. Bryant , M. Cremonesi, V. Dutta , T. Ferguson , T.A. Gómez Espinosa , A. Harilal , A. Kallil Tharayil, C. Liu , T. Mudholkar , S. Murthy , P. Palit , K. Park, M. Paulini , A. Roberts , A. Sanchez , W. Terrill 
























































### University of Colorado Boulder, Boulder, Colorado, USA

J.P. Cumalat , W.T. Ford , A. Hart , A. Hassani , G. Karathanasis , N. Manganeli , A. Perloff , C. Savard , N. Schonbeck , K. Stenson , K.A. Ulmer , S.R. Wagner , N. Zipper , D. Zuolo 



















### Cornell University, Ithaca, New York, USA

J. Alexander , S. Bright-Thonney , X. Chen , D.J. Cranshaw , J. Fan , X. Fan , S. Hogan , P. Kotamnives, J. Monroy , M. Oshiro , J.R. Patterson , M. Reid , A. Ryd , J. Thom , P. Wittich , R. Zou 













### Fermi National Accelerator Laboratory, Batavia, Illinois, USA

M. Albrow , M. Alyari , O. Amram , G. Apollinari , A. Apresyan , L.A.T. Bauerdick , D. Berry , J. Berryhill , P.C. Bhat , K. Burkett , J.N. Butler , A. Canepa , G.B. Cerati , H.W.K. Cheung , F. Chlebana , G. Cummings , J. Dickinson , I. Dutta , V.D. Elvira , Y. Feng , J. Freeman , A. Gandrakota , Z. Gecse , L. Gray , D. Green, A. Grummer , S. Grünendahl , D. Guerrero , O. Gutsche , R.M. Harris , R. Heller , T.C. Herwig , J. Hirschauer , B. Jayatilaka , S. Jindariani , M. Johnson , U. Joshi , T. Klijnsma , B. Klima , K.H.M. Kwok , S. Lammel , D. Lincoln , R. Lipton , T. Liu , C. Madrid , K. Maeshima , C. Mantilla , D. Mason , P. McBride , P. Merkel , S. Mrenna , S. Nahn , J. Ngadiuba , D. Noonan , S. Norberg, V. Papadimitriou , N. Pastika , K. Pedro , C. Pena<sup>82</sup> , F. Ravera , A. Reinsvold Hall<sup>83</sup> , L. Ristori , M. Safdari , E. Sexton-Kennedy , N. Smith , A. Soha , L. Spiegel , S. Stoynev , J. Strait , L. Taylor , S. Tkaczyk , N.V. Tran , L. Uplegger , E.W. Vaandering , I. Zoi 






### University of Florida, Gainesville, Florida, USA

C. Aruta , P. Avery , D. Bourilkov , P. Chang , V. Cherepanov , R.D. Field, E. Koenig , M. Kolosova , J. Konigsberg , A. Korytov , K. Matchev , N. Menendez , G. Mitselmakher , K. Mohrman , A. Muthirakalayil Madhu , N. Rawal , S. Rosenzweig , Y. Takahashi , J. Wang 
























### Florida State University, Tallahassee, Florida, USA

T. Adams , A. Al Kadhim , A. Askew , S. Bower , R. Habibullah , V. Hagopian , R. Hashmi , R.S. Kim , S. Kim , T. Kolberg , G. Martinez, H. Prosper , P.R. Prova, M. Wulansatiti , R. Yohay , J. Zhang











#### **Florida Institute of Technology, Melbourne, Florida, USA**

B. Alsufyani, M.M. Baarmand , S. Butalla , S. Das , T. Elkafrawy<sup>84</sup> , M. Hohlmann , M. Rahmani, E. Yanes












#### **University of Illinois Chicago, Chicago, USA, Chicago, USA**

M.R. Adams , A. Baty , C. Bennett, R. Cavanaugh , R. Escobar Franco , O. Evdokimov , C.E. Gerber , M. Hawksworth, A. Hingrajiya, D.J. Hofman , J.h. Lee , D. S. Lemos , A.H. Merrit , C. Mills , S. Nanda , G. Oh , B. Ozek , D. Pilipovic , R. Pradhan , E. Prifti, T. Roy , S. Rudrabhatla , M.B. Tonjes , N. Varelas , M.A. Wadud , Z. Ye , J. Yoo 

























#### **The University of Iowa, Iowa City, Iowa, USA**

M. Alhusseini , D. Blend, K. Dilsiz<sup>85</sup> , L. Emediato , G. Karaman , O.K. Köseyan , J.-P. Merlo, A. Mestvirishvili<sup>86</sup> , O. Neogi, H. Ogul<sup>87</sup> , Y. Onel , A. Penzo , C. Snyder, E. Tiras<sup>88</sup> 









#### **Johns Hopkins University, Baltimore, Maryland, USA**

B. Blumenfeld , L. Corcodilos , J. Davis , A.V. Gritsan , L. Kang , S. Kyriacou , P. Maksimovic , M. Roguljic , J. Roskes , S. Sekhar , M. Swartz 
















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A. Abreu , L.F. Alcerro Alcerro , J. Anguiano , S. Arteaga Escatel , P. Baringer , A. Bean , Z. Flowers , D. Grove , J. King , G. Krintiras , M. Lazarovits , C. Le Mahieu , J. Marquez , N. Minafra , M. Murray , M. Nickel , M. Pitt , S. Popescu<sup>89</sup> , C. Rogan , C. Royon , R. Salvatico , S. Sanders , C. Smith , G. Wilson 























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B. Allmond , R. Gujju Gurunadha , A. Ivanov , K. Kaadze , Y. Maravin , J. Natoli , D. Roy , G. Sorrentino 

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A. Baden , A. Belloni , J. Bistany-riebman, Y.M. Chen , S.C. Eno , N.J. Hadley , S. Jabeen , R.G. Kellogg , T. Koeth , B. Kronheim, Y. Lai , S. Lascio , A.C. Mignerey , S. Nabili , C. Palmer , C. Papageorgakis , M.M. Paranjpe, L. Wang 













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J. Bendavid , I.A. Cali , P.c. Chou , M. D'Alfonso , J. Eysermans , C. Freer , G. Gomez-Ceballos , M. Goncharov, G. Grosso, P. Harris, D. Hoang, D. Kovalskyi , J. Krupa , L. Lavezzo , Y.-J. Lee , K. Long , C. McGinn, A. Novak , C. Paus , D. Rankin , C. Roland , G. Roland , S. Rothman , G.S.F. Stephans , P. Van Steenweghen, Z. Wang , B. Wyslouch , T. J. Yang 











#### **University of Minnesota, Minneapolis, Minnesota, USA**

B. Crossman , B.M. Joshi , C. Kapsiak , M. Krohn , D. Mahon , J. Mans , B. Marzocchi , M. Revering , R. Rusack , R. Saradhy , N. Strobbe 

















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K. Bloom , D.R. Claes , G. Haza , J. Hossain , C. Joo , I. Kravchenko , J.E. Siado , W. Tabb , A. Vagnerini , A. Wightman , F. Yan , D. Yu 

#### **State University of New York at Buffalo, Buffalo, New York, USA**

H. Bandyopadhyay , L. Hay , H.w. Hsia, I. Iashvili , A. Kalogeropoulos , A. Kharchilava , M. Morris , D. Nguyen , S. Rappoccio , H. Rejeb Sfar, A. Williams , P. Young 



























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G. Alverson , E. Barberis , J. Bonilla , J. Dervan, Y. Haddad , Y. Han , A. Krishna , J. Li , M. Lu , G. Madigan , R. Mccarthy , D.M. Morse , V. Nguyen , T. Orimoto , A. Parker , L. Skinnari , D. Wood 









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J. Bueghly, S. Dittmer , K.A. Hahn , Y. Liu , Y. Miao , D.G. Monk , M.H. Schmitt , A. Taliercio , M. Velasco


















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G. Agarwal , R. Band , R. Bucci, S. Castells , A. Das , R. Goldouzian , M. Hildreth , K.W. Ho , K. Hurtado Anampa , T. Ivanov , C. Jessop , K. Lannon , J. Lawrence , N. Loukas , L. Lutton , J. Mariano, N. Marinelli, I. Mcalister, T. McCauley , C. Mcgrady , C. Moore , Y. Musienko<sup>17</sup> , H. Nelson , M. Osherson , A. Piccinelli , R. Ruchti , A. Townsend , Y. Wan, M. Wayne , H. Yockey, M. Zarucki , L. Zygala 

#### **The Ohio State University, Columbus, Ohio, USA**

A. Basnet , B. Bylsma, M. Carrigan , L.S. Durkin , C. Hill , M. Joyce , M. Nunez Ornelas , K. Wei, B.L. Winer , B. R. Yates 


















#### **Princeton University, Princeton, New Jersey, USA**

H. Bouchamaoui , P. Das , G. Dezoort , P. Elmer , A. Frankenthal , B. Greenberg , N. Haubrich , K. Kennedy, G. Kopp , S. Kwan , D. Lange , A. Loeliger , D. Marlow , I. Ojalvo , J. Olsen , A. Shevelev , D. Stickland , C. Tully 




#### **University of Puerto Rico, Mayaguez, Puerto Rico, USA**

S. Malik 

#### **Purdue University, West Lafayette, Indiana, USA**

A.S. Bakshi , S. Chandra , R. Chawla , A. Gu , L. Gutay, M. Jones , A.W. Jung , A.M. Koshy, M. Liu , G. Negro , N. Neumeister , G. Paspalaki , S. Piperov , V. Scheurer, J.F. Schulte , M. Stojanovic , J. Thieman , A. K. Viridi , F. Wang , W. Xie 

#### **Purdue University Northwest, Hammond, Indiana, USA**

J. Dolen , N. Parashar , A. Pathak 






















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D. Acosta , T. Carnahan , K.M. Ecklund , P.J. Fernández Manteca , S. Freed, P. Gardner, F.J.M. Geurts , W. Li , J. Lin , O. Miguel Colin , B.P. Padley , R. Redjimi, J. Rotter , E. Yigitbasi , Y. Zhang 











#### **University of Rochester, Rochester, New York, USA**

A. Bodek , P. de Barbaro , R. Demina , J.L. Dulemba , A. Garcia-Bellido , O. Hindrichs , A. Khukhunaishvili , N. Parmar, P. Parygin<sup>90</sup> , E. Popova<sup>90</sup> , R. Taus 















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

B. Chiarito, J.P. Chou , S.V. Clark , D. Gadkari , Y. Gershtein , E. Halkiadakis , M. Heindl , C. Houghton , D. Jaroslawski , O. Karacheban<sup>27</sup> , S. Konstantinou , I. Laflotte , A. Lath , R. Montalvo, K. Nash, J. Reichert , H. Routray , P. Saha , S. Salur , S. Schnetzer, S. Somalwar , R. Stone , S.A. Thayil , S. Thomas, J. Vora , H. Wang 

**University of Tennessee, Knoxville, Tennessee, USA**

H. Acharya, D. Ally , A.G. Delannoy , S. Fiorendi , S. Higginbotham , T. Holmes , A.R. Kanuganti , N. Karunarathna , L. Lee , E. Nibigira , S. Spanier 












**Texas A&M University, College Station, Texas, USA**

D. Aebi , M. Ahmad , T. Akhter , O. Bouhali<sup>91</sup> , R. Eusebi , J. Gilmore , T. Huang , T. Kamon<sup>92</sup> , H. Kim , S. Luo , R. Mueller , D. Overton , D. Rathjens , A. Safonov 







**Texas Tech University, Lubbock, Texas, USA**

N. Akchurin , J. Damgov , N. Gogate , V. Hegde , A. Hussain , Y. Kazhykarim, K. Lamichhane , S.W. Lee , A. Mankel , T. Peltola , I. Volobouev 

**Vanderbilt University, Nashville, Tennessee, USA**

E. Appelt , Y. Chen , S. Greene, A. Gurrola , W. Johns , R. Kunnawalkam Elayavalli , A. Melo , F. Romeo , P. Sheldon , S. Tuo , J. Velkovska , J. Viinikainen 























**University of Virginia, Charlottesville, Virginia, USA**

B. Cardwell , B. Cox , J. Hakala , R. Hirosky , A. Ledovsky , C. Neu 

**Wayne State University, Detroit, Michigan, USA**

S. Bhattacharya , P.E. Karchin 

**University of Wisconsin - Madison, Madison, Wisconsin, USA**

A. Aravind, S. Banerjee , K. Black , T. Bose , S. Dasu , I. De Bruyn , P. Everaerts , C. Galloni, H. He , M. Herndon , A. Herve , C.K. Koraka , A. Lanaro, R. Loveless , J. Madhusudanan Sreekala , A. Mallampalli , A. Mohammadi , S. Mondal, G. Parida , L. Pétré , D. Pinna, A. Savin, V. Shang , V. Sharma , W.H. Smith , D. Teague, H.F. Tsoi , W. Vetens , A. Warden 

**Authors affiliated with an institute or an international laboratory covered by a cooperation agreement with CERN**

S. Afanasiev , V. Alexakhin , V. Andreev , Yu. Andreev , T. Aushev , M. Azarkin , A. Babaev , V. Blinov<sup>93</sup>, E. Boos , V. Borshch , D. Budkouski , V. Bunichev , V. Chekhovsky, R. Chistov<sup>93</sup> , M. Danilov<sup>93</sup> , A. Dermenev , T. Dimova<sup>93</sup> , D. Druzhkin<sup>94</sup> , M. Dubinin<sup>82</sup> , L. Dudko , A. Ershov , G. Gavrilov , V. Gavrilov , S. Gninenko , V. Golovtcov , N. Golubev , I. Golutvin<sup>†</sup> , I. Gorbunov , A. Gribushin , Y. Ivanov , V. Kachanov , V. Karjavine , A. Karneyeu , V. Kim<sup>93</sup> , M. Kirakosyan, D. Kirpichnikov , M. Kirsanov , V. Klyukhin , O. Kodolova<sup>95</sup> , D. Konstantinov , V. Korenkov , A. Kozyrev<sup>93</sup> , N. Krasnikov , A. Lanev , P. Levchenko<sup>96</sup> , N. Lychkovskaya , V. Makarenko , A. Malakhov , V. Matveev<sup>93</sup> , V. Murzin , A. Nikitenko<sup>97,95</sup> , S. Obraztsov , V. Oreshkin , V. Palichik , V. Perelygin , S. Petrushanko , S. Polikarpov<sup>93</sup> , V. Popov , O. Radchenko<sup>93</sup> , M. Savina , V. Savrin , V. Shalaev , S. Shmatov , S. Shulha , Y. Skovpen<sup>93</sup> , S. Slabospitskii , V. Smirnov , A. Snigirev , D. Sosnov , V. Sulimov , E. Tcherniaev , A. Terkulov , O. Teryaev , I. Tlisova , A. Toropin , L. Uvarov , A. Uzunian , A. Vorobyev<sup>†</sup>, N. Voytishin , B.S. Yuldashev<sup>98</sup>, A. Zarubin , I. Zhizhin , A. Zhokin 

†: Deceased

<sup>1</sup>Also at Yerevan State University, Yerevan, Armenia

<sup>2</sup>Also at TU Wien, Vienna, Austria

<sup>3</sup>Also at Institute of Basic and Applied Sciences, Faculty of Engineering, Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt

<sup>4</sup>Also at Ghent University, Ghent, Belgium

- 
- <sup>5</sup>Also at Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
- <sup>6</sup>Also at Universidade Estadual de Campinas, Campinas, Brazil
- <sup>7</sup>Also at Federal University of Rio Grande do Sul, Porto Alegre, Brazil
- <sup>8</sup>Also at UFMS, Nova Andradina, Brazil
- <sup>9</sup>Also at Nanjing Normal University, Nanjing, China
- <sup>10</sup>Now at The University of Iowa, Iowa City, Iowa, USA
- <sup>11</sup>Also at University of Chinese Academy of Sciences, Beijing, China
- <sup>12</sup>Also at China Center of Advanced Science and Technology, Beijing, China
- <sup>13</sup>Also at University of Chinese Academy of Sciences, Beijing, China
- <sup>14</sup>Also at China Spallation Neutron Source, Guangdong, China
- <sup>15</sup>Now at Henan Normal University, Xinxiang, China
- <sup>16</sup>Also at Université Libre de Bruxelles, Bruxelles, Belgium
- <sup>17</sup>Also at an institute or an international laboratory covered by a cooperation agreement with CERN
- <sup>18</sup>Also at Suez University, Suez, Egypt
- <sup>19</sup>Now at British University in Egypt, Cairo, Egypt
- <sup>20</sup>Also at Purdue University, West Lafayette, Indiana, USA
- <sup>21</sup>Also at Université de Haute Alsace, Mulhouse, France
- <sup>22</sup>Also at Department of Physics, Tsinghua University, Beijing, China
- <sup>23</sup>Also at The University of the State of Amazonas, Manaus, Brazil
- <sup>24</sup>Also at University of Hamburg, Hamburg, Germany
- <sup>25</sup>Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
- <sup>26</sup>Also at Bergische University Wuppertal (BUW), Wuppertal, Germany
- <sup>27</sup>Also at Brandenburg University of Technology, Cottbus, Germany
- <sup>28</sup>Also at Forschungszentrum Jülich, Juelich, Germany
- <sup>29</sup>Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
- <sup>30</sup>Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
- <sup>31</sup>Now at Universitatea Babes-Bolyai - Facultatea de Fizica, Cluj-Napoca, Romania
- <sup>32</sup>Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary
- <sup>33</sup>Also at HUN-REN Wigner Research Centre for Physics, Budapest, Hungary
- <sup>34</sup>Also at Physics Department, Faculty of Science, Assiut University, Assiut, Egypt
- <sup>35</sup>Also at Punjab Agricultural University, Ludhiana, India
- <sup>36</sup>Also at University of Visva-Bharati, Santiniketan, India
- <sup>37</sup>Also at Indian Institute of Science (IISc), Bangalore, India
- <sup>38</sup>Also at IIT Bhubaneswar, Bhubaneswar, India
- <sup>39</sup>Also at Institute of Physics, Bhubaneswar, India
- <sup>40</sup>Also at University of Hyderabad, Hyderabad, India
- <sup>41</sup>Also at Deutsches Elektronen-Synchrotron, Hamburg, Germany
- <sup>42</sup>Also at Isfahan University of Technology, Isfahan, Iran
- <sup>43</sup>Also at Sharif University of Technology, Tehran, Iran
- <sup>44</sup>Also at Department of Physics, University of Science and Technology of Mazandaran, Behshahr, Iran
- <sup>45</sup>Also at Department of Physics, Isfahan University of Technology, Isfahan, Iran
- <sup>46</sup>Also at Helwan University, Cairo, Egypt
- <sup>47</sup>Also at Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Bologna, Italy
- <sup>48</sup>Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy
- <sup>49</sup>Also at Università degli Studi Guglielmo Marconi, Roma, Italy

- <sup>50</sup>Also at Scuola Superiore Meridionale, Università di Napoli 'Federico II', Napoli, Italy
- <sup>51</sup>Also at Fermi National Accelerator Laboratory, Batavia, Illinois, USA
- <sup>52</sup>Also at Consiglio Nazionale delle Ricerche - Istituto Officina dei Materiali, Perugia, Italy
- <sup>53</sup>Also at Department of Applied Physics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Malaysia
- <sup>54</sup>Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico
- <sup>55</sup>Also at Trincomalee Campus, Eastern University, Sri Lanka, Nilaveli, Sri Lanka
- <sup>56</sup>Also at Saegis Campus, Nugegoda, Sri Lanka
- <sup>57</sup>Also at National and Kapodistrian University of Athens, Athens, Greece
- <sup>58</sup>Also at Ecole Polytechnique Fédérale Lausanne, Lausanne, Switzerland
- <sup>59</sup>Also at Universität Zürich, Zurich, Switzerland
- <sup>60</sup>Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria
- <sup>61</sup>Also at Laboratoire d'Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France
- <sup>62</sup>Also at Near East University, Research Center of Experimental Health Science, Mersin, Turkey
- <sup>63</sup>Also at Konya Technical University, Konya, Turkey
- <sup>64</sup>Also at Izmir Bakircay University, Izmir, Turkey
- <sup>65</sup>Also at Adiyaman University, Adiyaman, Turkey
- <sup>66</sup>Also at Bozok Universitetesi Rektörlüğü, Yozgat, Turkey
- <sup>67</sup>Also at Marmara University, Istanbul, Turkey
- <sup>68</sup>Also at Milli Savunma University, Istanbul, Turkey
- <sup>69</sup>Also at Kafkas University, Kars, Turkey
- <sup>70</sup>Now at Istanbul Okan University, Istanbul, Turkey
- <sup>71</sup>Also at Hacettepe University, Ankara, Turkey
- <sup>72</sup>Also at Erzincan Binali Yildirim University, Erzincan, Turkey
- <sup>73</sup>Also at Istanbul University - Cerrahpasa, Faculty of Engineering, Istanbul, Turkey
- <sup>74</sup>Also at Yildiz Technical University, Istanbul, Turkey
- <sup>75</sup>Also at Vrije Universiteit Brussel, Brussel, Belgium
- <sup>76</sup>Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
- <sup>77</sup>Also at IPPP Durham University, Durham, United Kingdom
- <sup>78</sup>Also at Monash University, Faculty of Science, Clayton, Australia
- <sup>79</sup>Also at Università di Torino, Torino, Italy
- <sup>80</sup>Also at Bethel University, St. Paul, Minnesota, USA
- <sup>81</sup>Also at Karamanoğlu Mehmetbey University, Karaman, Turkey
- <sup>82</sup>Also at California Institute of Technology, Pasadena, California, USA
- <sup>83</sup>Also at United States Naval Academy, Annapolis, Maryland, USA
- <sup>84</sup>Also at Ain Shams University, Cairo, Egypt
- <sup>85</sup>Also at Bingöl University, Bingöl, Turkey
- <sup>86</sup>Also at Georgian Technical University, Tbilisi, Georgia
- <sup>87</sup>Also at Sinop University, Sinop, Turkey
- <sup>88</sup>Also at Erciyes University, Kayseri, Turkey
- <sup>89</sup>Also at Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania
- <sup>90</sup>Now at an institute or an international laboratory covered by a cooperation agreement with CERN
- <sup>91</sup>Also at Texas A&M University at Qatar, Doha, Qatar
- <sup>92</sup>Also at Kyungpook National University, Daegu, Korea

<sup>93</sup>Also at another institute or international laboratory covered by a cooperation agreement with CERN

<sup>94</sup>Also at Universiteit Antwerpen, Antwerpen, Belgium

<sup>95</sup>Also at Yerevan Physics Institute, Yerevan, Armenia

<sup>96</sup>Also at Northeastern University, Boston, Massachusetts, USA

<sup>97</sup>Also at Imperial College, London, United Kingdom

<sup>98</sup>Also at Institute of Nuclear Physics of the Uzbekistan Academy of Sciences, Tashkent, Uzbekistan