

CERN-EP-2024-058  
2024/06/10

CMS-BPH-22-006

# Observation of the $J/\psi \rightarrow \mu^+ \mu^- \mu^+ \mu^-$ decay in proton-proton collisions at $\sqrt{s} = 13$ TeV

The CMS Collaboration\*

## Abstract

The  $J/\psi \rightarrow \mu^+ \mu^- \mu^+ \mu^-$  decay has been observed with a statistical significance in excess of five standard deviations. The analysis is based on an event sample of proton-proton collisions at a center-of-mass energy of 13 TeV, collected by the CMS experiment in 2018 and corresponding to an integrated luminosity of  $33.6 \text{ fb}^{-1}$ . Normalizing to the  $J/\psi \rightarrow \mu^+ \mu^-$  decay mode leads to a branching fraction of  $[10.1_{-2.7}^{+3.3} (\text{stat}) \pm 0.4 (\text{syst})] \times 10^{-7}$ , a value that is consistent with the standard model prediction.

*Published in Physical Review D as doi:10.1103/PhysRevD.109.L111101.*

arXiv:2403.11352v2 [hep-ex] 7 Jun 2024



Decays of particles to leptons, especially muons, provide some of the cleanest signatures at hadron collider experiments. The large data sample collected by the CMS experiment [1, 2] at the CERN LHC offers an excellent opportunity to explore rare decays to multilepton final states. The first such observation was the decay of the Z boson into four leptons [3]. Subsequently, the decays  $Z \rightarrow J/\psi \ell^+ \ell^-$  (with the  $J/\psi$  decaying to two muons) and  $\eta \rightarrow \mu^+ \mu^- \mu^+ \mu^-$  were also observed [4, 5].

The BES III Collaboration recently reported the observation of the  $J/\psi$  decays  $J/\psi \rightarrow e^+ e^- e^+ e^-$  and  $J/\psi \rightarrow e^+ e^- \mu^+ \mu^-$ , while for the  $J/\psi \rightarrow \mu^+ \mu^- \mu^+ \mu^-$  branching fraction an upper limit was established,  $1.6 \times 10^{-6}$  at 90% confidence level [6]. In the standard model (SM), these processes occur via  $\ell \rightarrow \ell \gamma^*/Z^*$  transitions, where the virtual photon or Z boson decays into a pair of leptons, as depicted in Fig. 1. These transitions provide opportunities to probe various beyond-SM scenarios, where new particles replace the  $\gamma^*$  or the  $Z^*$  boson [7–9]. Furthermore, such rare multilepton decays serve as a novel testing ground for quantum electrodynamics predictions [10, 11].

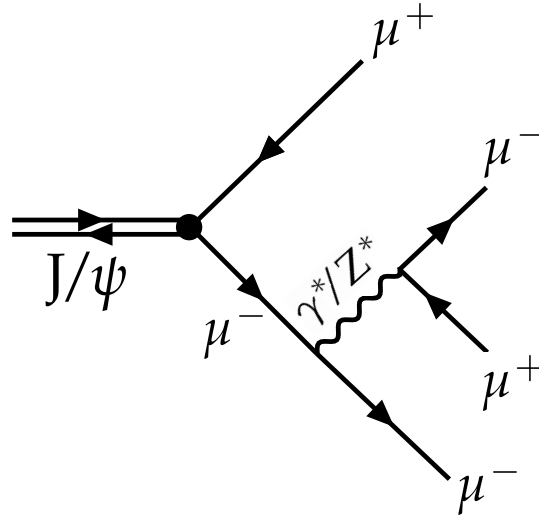


Figure 1: Leading-order Feynman diagram representing the  $J/\psi \rightarrow \mu^+ \mu^- \mu^+ \mu^-$  decay channel.

This Letter presents the first observation of the  $J/\psi \rightarrow \mu^+ \mu^- \mu^+ \mu^-$  decay and the measurement of its branching fraction, relative to the  $J/\psi \rightarrow \mu^+ \mu^-$  decay mode. The analysis is based on a sample of proton-proton collisions at a center-of-mass energy of 13 TeV, collected by the CMS experiment and corresponding to an integrated luminosity of  $33.6 \text{ fb}^{-1}$  [12].

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter, each composed of a barrel and two endcap sections. Forward calorimeters extend the pseudorapidity ( $\eta$ ) coverage provided by the barrel and endcap detectors. Muons are measured in the  $|\eta| < 2.4$  range, with detection planes made using three technologies: drift tubes, cathode strip chambers, and resistive plate chambers. A more detailed description of the CMS detector can be found in Ref. [1].

Events of interest are selected using a two-tiered trigger system. The first level, composed of custom hardware processors, uses information from the calorimeters and muon detectors to select events at a rate of around 100 kHz within a fixed latency of  $4 \mu\text{s}$  [13]. The second level consists of a farm of processors running a version of the full event reconstruction software optimized for fast processing and reduces the event rate before data storage [14].

The single-muon trigger efficiency exceeds 90% over the full  $\eta$  range, and the efficiency to reconstruct and identify muons is larger than 96%. By matching muons to tracks measured in the silicon tracker, the transverse momentum,  $p_T$ , is measured with a relative resolution of 1% in the barrel and 3% in the endcaps, for muons with  $p_T$  up to 100 GeV [15].

This study exploits the ‘‘B Parking’’ data sample collected by the CMS experiment in 2018 [16]. A specialized trigger and data storage strategy was implemented to assemble a data set enriched in b hadron decays [17]. The trigger selects events with at least one muon with  $p_T > 9$  GeV and transverse impact parameter significance (distance of closest approach of the track to the beam line [18] divided by its uncertainty) larger than 6.

Two simulated event samples, used to evaluate the efficiency to reconstruct and select the  $J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-$  and  $J/\psi \rightarrow \mu^+\mu^-$  decays, are generated with the PYTHIA 8.230 Monte Carlo event generator [19], which includes modeling of the parton shower, fragmentation, and hadronization processes. The PYTHIA output is interfaced with EVTGEN 1.3.0 [20], which simulates various b hadron decays. The samples are generated such that each event contains at least one b hadron decaying to a  $J/\psi$  meson plus other decay products, with the  $J/\psi$  meson decaying to either two or four muons using a phase space model. The underlying event is also modeled with PYTHIA 8, adopting the CP5 tune [21]. The NNPDF 3.1 [22] parton distribution functions are used. To account for additional proton-proton collisions in the same or adjacent bunch crossing (pileup), simulated minimum bias events are superimposed onto the hard scattering process, matching the multiplicity of reconstructed vertices observed in collision data. Final-state photon radiation is simulated using PHOTOS 3.61 [23]. The response of the CMS detector is emulated using GEANT4 [24]. The simulated event samples are reconstructed using the same software packages as employed for collision data.

The events selected by the trigger need to comply with additional selection criteria, including the presence of four reconstructed muons with a net charge of zero and an invariant mass in the  $2.6 < m_{\mu^+\mu^-\mu^+\mu^-} < 3.4$  GeV range. All the four selected muons are required to have  $|\eta| < 1.5$  and  $p_T > 3.5$  GeV. One of them must match the muon that triggered the event, which is ensured by requiring that it has  $p_T > 9$  GeV and a small angular distance with respect to the trigger muon,  $\sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.1$ , where  $\Delta\eta$  and  $\Delta\phi$  are the differences in pseudorapidity and azimuthal angle, respectively.

The four muons forming a  $J/\psi$  candidate are fitted to a common vertex, determined by a Kalman filter vertex fit [25]. Only candidates with a vertex-fit  $\chi^2$  probability exceeding 1% are kept. The  $p_T$  of the  $J/\psi$  meson candidate must exceed 25 GeV and its absolute rapidity is restricted to be less than 2.2. No oppositely-charged muon pair combination can have an invariant mass in the 0.75–0.80 or 0.98–1.05 GeV ranges, which are populated by dimuon decays of the  $\rho$ ,  $\omega$ , and  $\phi$  mesons.

The branching fraction of the  $J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-$  decay mode is measured relative to that of the  $J/\psi \rightarrow \mu^+\mu^-$  decay. The selection criteria used in the  $J/\psi \rightarrow \mu^+\mu^-$  events are the same as those applied to the two highest  $p_T$  muons of the  $J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-$  decay.

Unbinned maximum likelihood fits are performed on the four-muon and dimuon invariant mass distributions to determine the two signal yields. The  $\mu^+\mu^-\mu^+\mu^-$  invariant mass distribution is fitted by the superposition of two functions, one representing the  $J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-$  signal and the other the underlying continuum background. The signal is modeled by a Crystal Ball function [26], with the mean fixed to the world-average  $J/\psi$  meson mass [27] and the width and tail parameters fixed to values determined from studies of simulated events. The background is modeled by a linear function. The  $\mu^+\mu^-$  invariant mass distribution is fitted

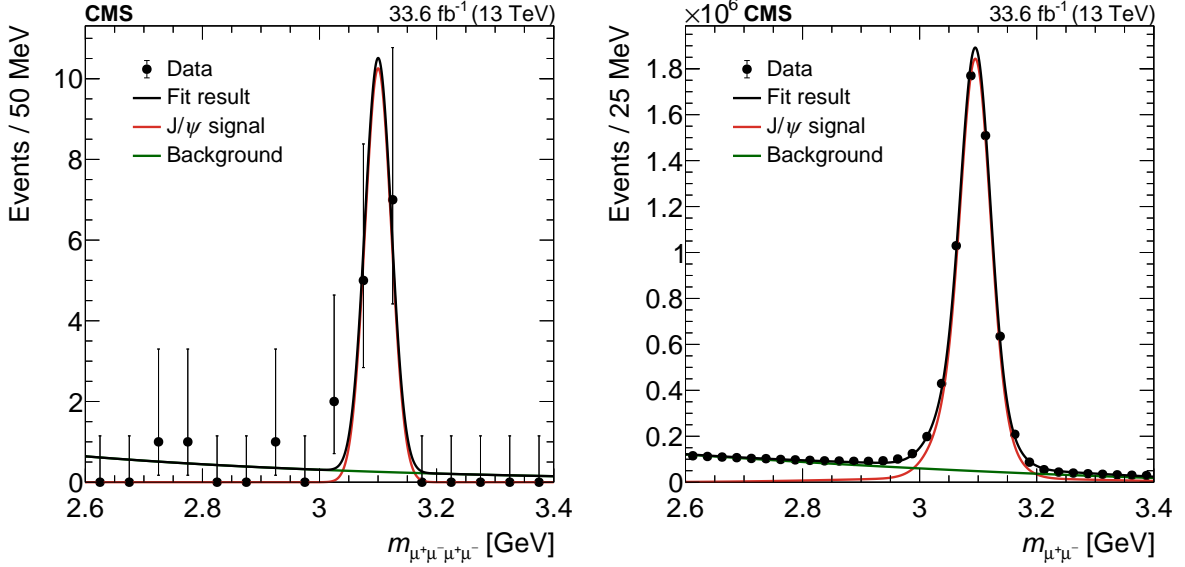


Figure 2: Measured four-muon (left) and dimuon (right) mass distributions. The vertical bars represent the statistical uncertainties. The solid black line represents the result of the unbinned fit described in the text, while the red and green lines represent the signal and background terms, respectively.

with essentially the same fit model, except that the signal is represented by the sum of a Crystal Ball function and a Gaussian function, without constraining any of the parameters. The fit models do not include peaking background terms from hadronic  $J/\psi$  decay modes because the probability that a pion reaches the muon stations and is misidentified as a muon is below the per mil level [15], so that such contributions are negligible. The measured  $m_{\mu^+\mu^-\mu^+\mu^-}$  and  $m_{\mu^+\mu^-}$  distributions are shown in Fig. 2, together with the results of the fits.

The yields returned by the fits are  $N(J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-) = 11.6_{-3.1}^{+3.8}$  and  $N(J/\psi \rightarrow \mu^+\mu^-) = (5770 \pm 3) \times 10^3$ . The significance of the  $J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-$  signal is above 7 standard deviations, evaluated from the likelihood ratio of the default signal-plus-background fit and the background-only fit, imposing  $N(J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-) = 0$ , using the standard asymptotic formula [28].

The  $J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-$  branching fraction relative to that of the  $J/\psi \rightarrow \mu^+\mu^-$  is computed as

$$\frac{\mathcal{B}(J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-)}{\mathcal{B}(J/\psi \rightarrow \mu^+\mu^-)} = \frac{N(J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-)}{N(J/\psi \rightarrow \mu^+\mu^-)} \bigg/ \frac{\epsilon_{J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-}}{\epsilon_{J/\psi \rightarrow \mu^+\mu^-}}, \quad (1)$$

where  $\mathcal{B}(J/\psi \rightarrow \mu^+\mu^-)$  is the branching fraction of the reference channel. The reconstruction efficiencies of each process are calculated as the fractions of generated events that are reconstructed, their ratio being  $\epsilon_{J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-} / \epsilon_{J/\psi \rightarrow \mu^+\mu^-} = (11.92 \pm 0.02)\%$ , where the uncertainty reflects the size of the simulated samples.

Because the signal- and reference-channel events are recorded using the same trigger and share similar event topologies, many systematic uncertainties have been seen to cancel in Eq. (1). In the following, we only describe those that do not cancel.

We evaluate the sensitivity of  $N(J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-)$  to the fit model by replacing the Crystal Ball function by a Gaussian function and the linear function by an exponential function. The corresponding systematic uncertainties are smaller than 0.1% when we replace the signal fit

model and 0.4% when we replace the background model. For the alternative modeling of the reference channel we use a sum of two Crystal Ball functions for the signal and an exponential function for the background. The fitted value of  $N(J/\psi \rightarrow \mu^+\mu^-)$  changes by 0.5% for each of the two variations. An additional 0.1% uncertainty reflects the size of the Monte Carlo samples used for calculating the reconstruction and selection efficiencies of the signal and reference channels. Differences between the reconstructed and simulated samples are accounted for through two scale factors, one reflecting the trigger efficiency and the other the reconstruction and event selection efficiencies. Varying these scale factors by their standard deviation uncertainties, we obtain the corresponding uncertainties on the branching fraction measurement: 1.9% and 1.4%, respectively. Recomputing the detection efficiencies with conservative variations of the simulated  $J/\psi$  kinematical distributions leads to a systematic uncertainty of 2.8%. The total relative systematic uncertainty is 3.7%, computed as the quadratic sum of the individual terms, so that the final result is

$$\frac{\mathcal{B}(J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-)}{\mathcal{B}(J/\psi \rightarrow \mu^+\mu^-)} = [16.9_{-4.6}^{+5.5} (\text{stat}) \pm 0.6 (\text{syst})] \times 10^{-6}.$$

Using the world's average  $\mathcal{B}(J/\psi \rightarrow \mu^+\mu^-) = (5.961 \pm 0.033)\%$  [27], and propagating its uncertainty, we obtain

$$\mathcal{B}(J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-) = [10.1_{-2.7}^{+3.3} (\text{stat}) \pm 0.4 (\text{syst})] \times 10^{-7},$$

a value consistent with the SM prediction,  $(9.74 \pm 0.05) \times 10^{-7}$  [10].

The results reported in this paper are tabulated in the HEPData record for this analysis [29].

In summary, using a data sample of proton-proton collisions at  $\sqrt{s} = 13$  TeV, collected in 2018 by the CMS Collaboration and corresponding to an integrated luminosity of  $33.6 \text{ fb}^{-1}$ , the  $J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-$  decay was observed for the first time, with a statistical significance exceeding five standard deviations. Taking the  $J/\psi \rightarrow \mu^+\mu^-$  decay mode as normalization, its branching fraction was measured to be  $\mathcal{B}(J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-) = [10.1_{-2.7}^{+3.3} (\text{stat}) \pm 0.4 (\text{syst})] \times 10^{-7}$ , a value consistent with the standard model prediction.

## Acknowledgments

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid and other centers for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC, the CMS detector, and the supporting computing infrastructure provided by the following funding agencies: SC (Armenia), BMBWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, FAPERGS, and FAPESP (Brazil); MES and BNSF (Bulgaria); CERN; CAS, MoST, and NSFC (China); MINCIENCIAS (Colombia); MSES and CSF (Croatia); RIF (Cyprus); SENESCYT (Ecuador); ERC PRG, RVTT3 and MoER TK202 (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); SRNSF (Georgia); BMBF, DFG, and HGF (Germany); GSRI (Greece); NKFIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); MES (Latvia); LMTLT (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and

UASLP-FAI (Mexico); MOS (Montenegro); MBIE (New Zealand); PAEC (Pakistan); MES and NSC (Poland); FCT (Portugal); MESTD (Serbia); MCIN/AEI and PCTI (Spain); MOSTR (Sri Lanka); Swiss Funding Agencies (Switzerland); MST (Taipei); MHESI and NSTDA (Thailand); TUBITAK and TENMAK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

## References

- [1] CMS Collaboration, “The CMS experiment at the CERN LHC”, *JINST* **3** (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.
- [2] CMS Collaboration, “Development of the CMS detector for the CERN LHC Run 3”, 2023. arXiv:2309.05466. Accepted by *JINST*.
- [3] CMS Collaboration, “Observation of Z decays to four leptons with the CMS detector at the LHC”, *JHEP* **12** (2012) 034, doi:10.1007/JHEP12(2012)034, arXiv:1210.3844.
- [4] CMS Collaboration, “Observation of the  $Z \rightarrow \psi \ell^+ \ell^-$  decay in pp collisions at  $\sqrt{s} = 13$  TeV”, *Phys. Rev. Lett.* **121** (2018) 141801, doi:10.1103/PhysRevLett.121.141801, arXiv:1806.04213.
- [5] CMS Collaboration, “Observation of the rare decay of the  $\eta$  meson to four muons”, *Phys. Rev. Lett.* **131** (2023) 091903, doi:10.1103/PhysRevLett.131.091903, arXiv:2305.04904.
- [6] BES III Collaboration, “Observation of  $J/\psi$  decays to  $e^+e^-e^+e^-$  and  $e^+e^-\mu^+\mu^-$ ”, *Phys. Rev. D* **109** (2024) 052006, doi:10.1103/PhysRevD.109.052006, arXiv:2111.13881.
- [7] M. Drees, M. Shi, and Z. Zhang, “Constraints on  $U(1)_{L_\mu-L_\tau}$  from LHC Data”, *Phys. Lett. B* **791** (2019) 130, doi:10.1016/j.physletb.2019.02.029, arXiv:1811.12446.
- [8] K. Harigaya et al., “Muon g-2 and LHC phenomenology in the  $L_\mu - L_\tau$  gauge symmetric model”, *JHEP* **03** (2014) 105, doi:10.1007/JHEP03(2014)105, arXiv:1311.0870.
- [9] N. F. Bell, Y. Cai, R. K. Leane, and A. D. Medina, “Leptophilic dark matter with  $Z'$  interactions”, *Phys. Rev. D* **90** (2014) 035027, doi:10.1103/PhysRevD.90.035027, arXiv:1407.3001.
- [10] W. Chen et al., “Four-lepton decays of neutral vector mesons”, *Phys. Rev. D* **104** (2021) 094023, doi:10.1103/PhysRevD.104.094023, arXiv:2009.12363.
- [11] C. Gütschow and M. Schönherr, “Four lepton production and the accuracy of QED FSR”, *Eur. Phys. J. C* **81** (2021) 48, doi:10.1140/epjc/s10052-020-08816-9, arXiv:2007.15360.
- [12] CMS Collaboration, “CMS luminosity measurement for the 2018 data-taking period at  $\sqrt{s} = 13$  TeV”, CMS Physics Analysis Summary CMS-PAS-LUM-18-002, 2019.
- [13] CMS Collaboration, “Performance of the CMS Level-1 trigger in proton-proton collisions at  $\sqrt{s} = 13$  TeV”, *JINST* **15** (2020) P10017, doi:10.1088/1748-0221/15/10/P10017, arXiv:2006.10165.

- 
- [14] CMS Collaboration, “The CMS trigger system”, *JINST* **12** (2017) P01020, doi:10.1088/1748-0221/12/01/P01020, arXiv:1609.02366.
- [15] CMS Collaboration, “Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at  $\sqrt{s} = 13$  TeV”, *JINST* **13** (2018) P06015, doi:10.1088/1748-0221/13/06/P06015, arXiv:1804.04528.
- [16] CMS Collaboration, “Enriching the physics program of the CMS experiment via data scouting and data parking”, arXiv:2403.16134. Submitted to *Physics Reports*.
- [17] CMS Collaboration, “Test of lepton flavor universality in  $B^{\pm} \rightarrow K^{\pm} \mu^{+} \mu^{-}$  and  $B^{\pm} \rightarrow K^{\pm} e^{+} e^{-}$  decays in proton-proton collisions at  $\sqrt{s} = 13$  TeV”, 2024. arXiv:2401.07090. Submitted to *Reports on Progress in Physics*.
- [18] CMS Collaboration, “Description and performance of track and primary-vertex reconstruction with the CMS tracker”, *JINST* **9** (2014) P10009, doi:10.1088/1748-0221/9/10/P10009, arXiv:1405.6569.
- [19] T. Sjöstrand et al., “An introduction to PYTHIA 8.2”, *Comput. Phys. Commun.* **191** (2015) 159, doi:10.1016/j.cpc.2015.01.024, arXiv:1410.3012.
- [20] D. J. Lange, “The EvtGen particle decay simulation package”, *Nucl. Instrum. Meth. A* **462** (2001) 152, doi:10.1016/S0168-9002(01)00089-4.
- [21] CMS Collaboration, “Extraction and validation of a new set of CMS PYTHIA8 tunes from underlying-event measurements”, *Eur. Phys. J. C* **80** (2020) 4, doi:10.1140/epjc/s10052-019-7499-4, arXiv:1903.12179.
- [22] NNPDF Collaboration, “Parton distributions from high-precision collider data”, *Eur. Phys. J. C* **77** (2017) 663, doi:10.1140/epjc/s10052-017-5199-5, arXiv:1706.00428.
- [23] E. Barberio and Z. Was, “PHOTOS: A universal Monte Carlo for QED radiative corrections. Version 2.0”, *Comput. Phys. Commun.* **79** (1994) 291, doi:10.1016/0010-4655(94)90074-4.
- [24] GEANT4 Collaboration, “GEANT4—a simulation toolkit”, *Nucl. Instrum. Meth. A* **506** (2003) 250, doi:10.1016/S0168-9002(03)01368-8.
- [25] R. Frühwirth, “Application of Kalman filtering to track and vertex fitting”, *Nucl. Instrum. Meth. A* **262** (1987) 444, doi:10.1016/0168-9002(87)90887-4.
- [26] M. J. Oreglia, “A study of the reactions  $\psi' \rightarrow \gamma\gamma\psi$ ”. PhD thesis, Stanford University, 1980. SLAC Report SLAC-R-236.
- [27] Particle Data Group Collaboration, “Review of Particle Physics”, *PTEP* **2022** (2022) 083C01, doi:10.1093/ptep/ptac097.
- [28] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, “Asymptotic formulae for likelihood-based tests of new physics”, *Eur. Phys. J. C* **71** (2011) 1554, doi:10.1140/epjc/s10052-011-1554-0, arXiv:1007.1727. [Erratum: doi:10.1140/epjc/s10052-013-2501-z].
- [29] HEPDATA record for this analysis, 2024. doi:10.17182/hepdata.147273.





















## 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. Mahdavihorrani , 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 Físicas, 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. Jakovic, 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**

A. Lotfy , M.A. Mahmoud 
















**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 




































































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

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

C. Dziwok , G. Flügge , T. Kress , A. Nowack , O. Pooth , A. Stahl , T. Ziemons , A. Zotz 






















### Deutsches Elektronen-Synchrotron, Hamburg, Germany

H. Aarup Petersen , M. Aldaya Martin , J. Alimena , S. Amoroso, Y. An , J. Bach , S. Baxter , M. Bayatmakou , H. Becerril Gonzalez , O. Behnke , A. Belvedere , S. Bhattacharya , F. Blekman<sup>24</sup> , K. Borras<sup>25</sup> , A. Campbell , A. Cardini , C. Cheng, F. Colombina , S. Consuegra Rodríguez , M. De Silva , G. Eckerlin, D. Eckstein , L.I. Estevez Banos , O. Filatov , E. Gallo<sup>24</sup> , A. Geiser , V. Guglielmi , M. Guthoff , A. Hinzmann , L. Jeppe , B. Kaech , M. Kasemann , C. Kleinwort , R. Kogler , M. Komm , D. Krücker , W. Lange, D. Leyva Pernia , K. Lipka<sup>26</sup> , W. Lohmann<sup>27</sup> , F. Lorkowski , R. Mankel , I.-A. Melzer-Pellmann , M. Mendizabal Morentin , A.B. Meyer , G. Milella , K. Moral Figueroa , A. Mussgiller , L.P. Nair , J. Niedziela , A. Nürnberg , Y. Otariid, J. Park , E. Ranken , A. Raspereza , D. Rastorguev , J. Rübenach, L. Rygaard, A. Saggio , M. Scham<sup>28,25</sup> , S. Schnake<sup>25</sup> , P. Schütze , C. Schwanenberger<sup>24</sup> , D. Selivanova , K. Sharko , M. Shchedrolosiev , D. Stafford, F. Vazzoler , A. Ventura Barroso , R. Walsh , D. Wang , Q. Wang , Y. Wen , K. Wichmann, L. Wiens<sup>25</sup> , C. Wissing , Y. Yang , A. Zimmermann Castro Santos 

### 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. Savoio , 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 
















**University of Delhi, Delhi, India**

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






**Indian Institute of Technology Madras, Madras, India**

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












**Tata Institute of Fundamental Research-A, Mumbai, India**

S. Dugad, M. Kumar , G.B. Mohanty , B. Parida , M. Shelake, P. Suryadevara











**Tata Institute of Fundamental Research-B, Mumbai, India**

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**

S. Bashiri, S. Chenarani<sup>44</sup> , S.M. Etesami , Y. Hosseini , M. Khakzad , E. Khazaie<sup>45</sup> , M. Mohammadi Najafabadi , S. Tizchang 



























**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> , 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. Borgonovi<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,46</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,47</sup> , A. Di Mattia<sup>a</sup> , A. Lapertosa<sup>a</sup> , R. Potenza<sup>a,b</sup>, A. Tricomi<sup>a,b,47</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>48</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,49</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,50</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. Migliorini<sup>a,b</sup> , F. Montecassiano<sup>a</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> , P. Zotto<sup>a,b</sup> , A. Zucchetta<sup>a,b</sup> , G. Zumerle<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,51</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</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. Ambrozas , A. Juodagalvis , A. Rinkevicius , G. Tamulaitis 

















**National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia**I. Yusuff<sup>52</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>53</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. Szeper , 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. Lasasa 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>54</sup> , D.D.C. Wickramarathna 













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

W.G.D. Dharmaratna<sup>55</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. Rabady , 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>56</sup> , A.G. Stahl Leitner , A. Steen , S. Summers , D. Treille , P. Tropea , D. Walter , J. Wanczyk<sup>57</sup> , J. Wang, S. Wuchterl , P. Zehetner , P. Zejdl , W.D. Zeuner

**Paul Scherrer Institut, Villigen, Switzerland**




















T. Bevilacqua<sup>58</sup> , L. Caminada<sup>58</sup> , A. Ebrahimi , W. Erdmann , R. Horisberger , Q. Ingram , H.C. Kaestli , D. Kotlinski , C. Lange , M. Missiroli<sup>58</sup> , L. Noehte<sup>58</sup> , T. Rohe 

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




T.K. Aarrestad , K. Androsov<sup>57</sup> , M. Backhaus , G. Bonomelli, A. Calandri , C. Cazaniga , K. Datta , P. De Bryas Dexmiers D'archiac<sup>57</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>57</sup> , F. Nessi-Tedaldi , F. Pauss , V. Perovic , S. Pigazzini , C. Reissel , T. Reitenspiess , B. Ristic , F. Riti , R. Seidita , J. Steggemann<sup>57</sup> , A. Tarabini , D. Valsecchi , R. Wallny 












#### Universität Zürich, Zurich, Switzerland

C. Amsler<sup>59</sup> , P. Bärtshi , 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>60</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. Asawatangtrakuldee , N. Srimanobhas , V. Wachirapusanand 

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

D. Agyel , F. Boran , F. Dolek , I. Dumanoglu<sup>61</sup> , E. Eskut , Y. Guler<sup>62</sup> , E. Gurpinar Guler<sup>62</sup> , C. Isik , O. Kara, A. Kayis Topaksu , U. Kiminsu , G. Onengut , K. Ozdemir<sup>63</sup> , A. Polatoz , B. Tali<sup>64</sup> , U.G. Tok , S. Turkcapar , E. Uslan , I.S. Zorbakir 






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

G. Sokmen, M. Yalvac<sup>65</sup> 

#### Bogazici University, Istanbul, Turkey

B. Akgun , I.O. Atakisi , E. Gülmez , M. Kaya<sup>66</sup> , O. Kaya<sup>67</sup> , S. Tekten<sup>68</sup> 





#### Istanbul Technical University, Istanbul, Turkey

A. Cakir , K. Cankocak<sup>61,69</sup> , G.G. Dincer<sup>61</sup> , Y. Komurcu , S. Sen<sup>70</sup> 

#### Istanbul University, Istanbul, Turkey

O. Aydilek<sup>71</sup> , B. Haciasahinoglu , I. Hos<sup>72</sup> , B. Kaynak , S. Ozkorucuklu , O. Potok , H. Sert , C. Simsek , C. Zorbilmez 


#### Yildiz Technical University, Istanbul, Turkey

S. Cerci<sup>64</sup> , B. Isildak<sup>73</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>74</sup> , K. Walkingshaw Pass




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

A.H. Ball, K.W. Bell , A. Belyaev<sup>75</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>76</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>77</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>78</sup> , E. Usai , R. Yi 










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

A. Akpınar , 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>79</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>80</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. Vámi , 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. Klijsma , 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>81</sup> , F. Ravera , A. Reinsvold Hall<sup>82</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>83</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. Alhousseini , D. Blend, K. Dilsiz<sup>84</sup> , L. Emediato , G. Karaman , O.K. Köseyan , J.-P. Merlo, A. Mestvirishvili<sup>85</sup> , O. Neogi, H. Ogul<sup>86</sup> , Y. Onel , A. Penzo , C. Snyder, E. Tiras<sup>87</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 
















#### **The University of Kansas, Lawrence, Kansas, USA**

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>88</sup> , C. Rogan , C. Royon , R. Salvatico , S. Sanders , C. Smith , G. Wilson 























#### **Kansas State University, Manhattan, Kansas, USA**

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

#### **University of Maryland, College Park, Maryland, USA**

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 













#### **Massachusetts Institute of Technology, Cambridge, Massachusetts, USA**

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 , 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 

















#### **University of Nebraska-Lincoln, Lincoln, Nebraska, USA**

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 



























#### **Northeastern University, Boston, Massachusetts, USA**

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 









#### **Northwestern University, Evanston, Illinois, USA**

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


















#### **University of Notre Dame, Notre Dame, Indiana, USA**

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 






















#### **Rice University, Houston, Texas, USA**

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>89</sup> , E. Popova<sup>89</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. Karachebar<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>90</sup> , R. Eusebi , J. Gilmore , T. Huang , T. Kamon<sup>91</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>92</sup>, E. Boos , V. Borshch , D. Budkouski , V. Bunichev , V. Chekhovsky, R. Chistov<sup>92</sup> , M. Danilov<sup>92</sup> , A. Dermenev , T. Dimova<sup>92</sup> , D. Druzhkin<sup>93</sup> , M. Dubinin<sup>81</sup> , L. Dudko , A. Ershov , G. Gavrilov , V. Gavrilov , S. Gninenko , V. Golovtsov , N. Golubev , I. Golutvin<sup>†</sup> , I. Gorbunov , Y. Ivanov , V. Kachanov , V. Karjavine , A. Karneyeu , V. Kim<sup>92</sup> , M. Kirakosyan, D. Kirpichnikov , M. Kirsanov , V. Klyukhin , O. Kodolova<sup>94</sup> , D. Konstantinov , V. Korenkov , A. Kozyrev<sup>92</sup> , N. Krasnikov , A. Lanev , P. Levchenko<sup>95</sup> , N. Lychkovskaya , V. Makarenko , A. Malakhov , V. Matveev<sup>92</sup> , V. Murzin , A. Nikitenko<sup>96,94</sup> , S. Obraztsov , V. Oreshkin , V. Palichik , V. Perelygin , M. Perfilov, S. Petrushanko , S. Polikarpov<sup>92</sup> , V. Popov , O. Radchenko<sup>92</sup> , M. Savina , V. Savrin , V. Shalaev , S. Shmatov , S. Shulha , Y. Skovpen<sup>92</sup> , S. Slabospitskii , V. Smirnov , D. Sosnov , V. Sulimov , E. Tcherniaev , A. Terkulov , O. Teryaev , I. Tlisova , A. Toropin , L. Uvarov , A. Uzunian , A. Vorobyev<sup>†</sup>, G. Vorotnikov , N. Voytishin , B.S. Yuldashev<sup>97</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 Babeş-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 Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Bologna, Italy
- <sup>47</sup>Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy
- <sup>48</sup>Also at Università degli Studi Guglielmo Marconi, Roma, Italy
- <sup>49</sup>Also at Scuola Superiore Meridionale, Università di Napoli 'Federico II', Napoli, Italy

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

with CERN

<sup>93</sup>Also at Universiteit Antwerpen, Antwerpen, Belgium

<sup>94</sup>Also at Yerevan Physics Institute, Yerevan, Armenia

<sup>95</sup>Also at Northeastern University, Boston, Massachusetts, USA

<sup>96</sup>Also at Imperial College, London, United Kingdom

<sup>97</sup>Also at Institute of Nuclear Physics of the Uzbekistan Academy of Sciences, Tashkent, Uzbekistan