

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletbInclusive J/ψ production in Xe–Xe collisions at $\sqrt{s_{NN}} = 5.44$ TeV

ALICE Collaboration*



ARTICLE INFO

Article history:

Received 23 May 2018

Received in revised form 26 July 2018

Accepted 23 August 2018

Available online 31 August 2018

Editor: W.-D. Schlatter

ABSTRACT

Inclusive J/ψ production is studied in Xe–Xe interactions at a centre-of-mass energy per nucleon pair of $\sqrt{s_{NN}} = 5.44$ TeV, using the ALICE detector at the CERN LHC. The J/ψ meson is reconstructed via its decay into a muon pair, in the centre-of-mass rapidity interval $2.5 < y < 4$ and down to zero transverse momentum. In this Letter, the nuclear modification factors R_{AA} for inclusive J/ψ , measured in the centrality range 0–90% as well as in the centrality intervals 0–20% and 20–90% are presented. The R_{AA} values are compared to previously published results for Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and to the calculation of a transport model. A good agreement is found between Xe–Xe and Pb–Pb results as well as between data and the model.

© 2018 Organisation européenne pour la recherche nucléaire. Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>). Funded by SCOAP³.

The study of the production of quarkonium states plays an important role in the characterization of the properties of the Quark–Gluon Plasma (QGP) [1]. This state of matter, where quarks and gluons are not confined into hadrons, can be produced in heavy-ion collisions at ultrarelativistic energies. Quarkonia are bound states of heavy quark–antiquark pairs (charmonia, $c\bar{c}$ and bottomonia, $b\bar{b}$) and their production rate is significantly affected by the QGP. In particular, the color force responsible for the binding of heavy quarks is expected to be screened in the QGP, leading to a suppression of quarkonium production which can be related to the initial temperature of the system [2,3]. In addition, at very high energies, such as those available at the LHC, the abundant production of charm–anticharm pairs leads to a recombination process, which may occur both in the QGP phase or when the system cools down and hadrons are formed out of the free quarks and gluons [4,5]. The study of the interplay between suppression and recombination processes offers the possibility of a quantitative investigation of the existence of colorless bound states of heavy quarks in the QGP.

An extended set of results was obtained for the J/ψ , a charmonium state with quantum numbers $J^{PC} = 1^{--}$, at LHC energies ($\sqrt{s_{NN}} = 2.76$ and 5.02 TeV) in Pb–Pb collisions [6–12]. Comparison of these results to theoretical models [13–17] and to lower energy data [18,19] favors the picture described above. The study of the collision of nuclei lighter than Pb may give additional important information on the relative contribution of suppression and recombination mechanisms.

A step in this direction is performed in this Letter, where first results on J/ψ production at LHC energies in Xe–Xe, a collision sys-

tem ($A_{Xe} = 129$) lighter than Pb–Pb ($A_{Pb} = 208$), are presented. Data were collected by the ALICE Collaboration at the centre-of-mass energy per nucleon pair $\sqrt{s_{NN}} = 5.44$ TeV, during a short run carried out at the end of 2017. Due to the limited integrated luminosity, $L_{int} \sim 0.34 \mu\text{b}^{-1}$, the statistical uncertainties are significantly larger than those of the Pb–Pb results [10], but nevertheless allow a meaningful comparison between the two systems, in terms of the nuclear modification factor R_{AA} . This quantity is obtained as the ratio between the production yields in nucleus–nucleus collisions and the corresponding proton–proton (pp) cross section, normalized to the nuclear thickness function (T_{AA}) [20]. Values of R_{AA} smaller (larger) than unity indicate suppression (enhancement) effects for the particle under study. The results shown in this Letter correspond to the centre-of-mass rapidity range $2.5 < y < 4$, are integrated over transverse momentum (p_T) and were obtained by studying the $J/\psi \rightarrow \mu^+\mu^-$ decay channel. The nuclear modification factor is studied as a function of the centrality of the collision [21], expressed as a percentage of the hadronic Xe–Xe cross section. The results correspond to inclusive J/ψ production, which is the sum of a prompt component (directly produced J/ψ and feed-down from other charmonium states) and a non-prompt component, due to the decay of particles containing a b quark.

ALICE is the LHC experiment dedicated to the study of nuclear collisions, and is described in detail in Refs. [22,23]. The main detector used in this analysis is a muon spectrometer [24], covering the pseudorapidity range $-4 < \eta < -2.5$.¹ It includes tracking and trigger chambers, and reconstructs muons with p_T larger than a

¹ In the ALICE reference frame, the muon spectrometer covers a negative η range and consequently a negative y range. We have chosen to present our results with a positive y notation.

* E-mail address: alice-publications@cern.ch.

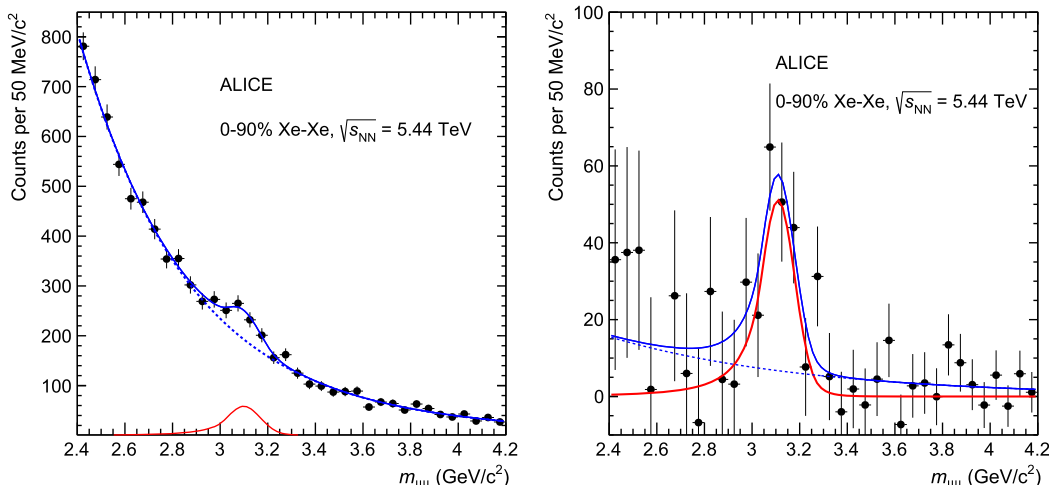


Fig. 1. Fits to invariant mass distributions of opposite-sign dimuons, for 0–90% Xe–Xe collisions. In the left panel, the result of a fit to the raw invariant mass spectrum is shown, while in the right panel the fit to the same distribution after subtraction of the mixed-event background is presented. The fit curves shown in blue represent the sum of the signal and background shapes, while the red lines correspond to the J/ψ signal and the blue dashed ones to the background (see text for details). (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

given threshold, which is set at the trigger level. In addition, the V0 [25], a set of scintillator detectors covering $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$, is used to define the minimum bias (MB) interaction trigger via a coincidence of signals at positive and negative η values. The V0 is also used for the centrality estimate via a fit of the distribution of the total signal amplitudes in the framework of the Glauber model [21]. The reconstruction of the primary collision vertex is carried out in the two layers of the Silicon Pixel Detector (SPD), the innermost part of the Inner Tracking System of the experiment [26], covering $|\eta| < 2$ and $|\eta| < 1.4$ respectively. Finally, rejection of non-hadronic Xe–Xe collisions is performed using the Zero Degree Calorimeters (ZDC) [27], which identifies electromagnetic interactions, while the V0 detects beam-gas collisions occurring outside the nominal interaction point region.

The data analyzed in this Letter are taken with a trigger formed by the coincidence of the MB trigger signal and of at least one muon triggered in the muon spectrometer, with a $p_T = 0.5$ GeV/c threshold. The definition of the trigger is less restrictive than the one usually adopted for Pb–Pb data taking (1 GeV/c threshold and two detected muons), due to the much smaller instantaneous luminosity for Xe–Xe collisions. Standard selection criteria [10] are then applied to such events and to the muon candidates. In particular, it is required (i) that two opposite-sign tracks reconstructed in the tracking chambers of the muon spectrometer are matched to track segments in the trigger system, (ii) that both muons belonging to the pair (dimuon) have $-4 < \eta_\mu < -2.5$, and (iii) that their transverse position R_{abs} at the end of the hadron absorber of the muon spectrometer satisfies the condition $17.6 < R_{\text{abs}} < 89.5$ cm. Finally, the reconstructed dimuon should lay in the fiducial rapidity region of the muon spectrometer, $2.5 < y < 4$.

The nuclear modification factor R_{AA} for the collision system under study is defined, for the centrality interval i , as

$$R_{AA}^i = \frac{N_{J/\psi}^i}{\text{BR}_{J/\psi \rightarrow \mu^+\mu^-} N_{\text{MB}}^i A \varepsilon^i \langle T_{AA}^i \rangle \sigma_{J/\psi}^{\text{pp}}}, \quad (1)$$

where $N_{J/\psi}^i$ is the number of detected J/ψ in the i -th centrality interval, $\text{BR}_{J/\psi \rightarrow \mu^+\mu^-} = (5.96 \pm 0.03)\%$ is the branching ratio of the dimuon decay channel [28], N_{MB}^i is the number of MB events corresponding to the analyzed triggered event sample, $A \varepsilon^i$ is the product of the detector acceptance times the reconstruction efficiency, $\langle T_{AA}^i \rangle$ is the average nuclear thickness function [29], and

$\sigma_{J/\psi}^{\text{pp}}$ is the inclusive J/ψ cross section for pp collisions, at the same energy and in the same kinematic range as the Xe–Xe data. Results are given for the centrality interval 0–90% and for the two sub-intervals 0–20% and 20–90%.

Except for the determination of $\sigma_{J/\psi}^{\text{pp}}$, the other quantities entering the definition of R_{AA} are evaluated following the same procedure used for the analysis of the Pb–Pb data sample and detailed in Ref. [10].

The extraction of $N_{J/\psi}$ is performed with two different approaches. In the first, the raw opposite-sign dimuon invariant mass distribution is fitted with a superposition of resonance and background shapes [30], the former being tuned to Monte Carlo (MC) simulations and the latter corresponding to empirical functions. In the second, the background is estimated via a mixed-event invariant mass distribution, obtained from the collected sample of muon-triggered events and subtracted from the raw spectrum [9]. The resulting distribution is then fitted with the sum of a resonance shape and a continuum function accounting for the small residual background component. Due to the low statistical significance of the present data sample, the width of the J/ψ meson, which is usually kept as a free parameter in the invariant mass fits, is fixed to $\sigma_{J/\psi} = 70$ MeV/c², corresponding to the value of this quantity obtained in previous analyses [10,31,32]. For each of the two approaches, several fits were performed varying the fit mass range, the signal and background shapes and the J/ψ width by ± 1 MeV/c². The obtained value for the centrality interval 0–90% is $N_{J/\psi} = 241 \pm 47(\text{stat.}) \pm 26(\text{syst.})$, where the central value and the statistical uncertainty correspond to the average of the fit results and to the average of the corresponding statistical uncertainties, respectively. The systematic uncertainty is obtained as the root mean square of the distribution of the $N_{J/\psi}$ values obtained with the various fits. The corresponding values for the 0–20% and 20–90% centrality sub-intervals are $N_{J/\psi} = 175 \pm 42(\text{stat.}) \pm 23(\text{syst.})$ and $N_{J/\psi} = 77 \pm 20(\text{stat.}) \pm 7(\text{syst.})$, respectively.

Fig. 1 shows as an example the results of two fits to the 0–90% Xe–Xe dimuon invariant mass distribution, corresponding to fitting the raw spectrum (left panel) or the mixed-event background subtracted mass distribution (right panel).

The product of the acceptance times the reconstruction efficiency $A \varepsilon$ for J/ψ is evaluated via a MC simulation, based on the GEANT3 transport model [33], which takes into account the

alignment of the muon spectrometer detectors and their efficiency. The input p_T and y distributions for the J/ψ acceptance calculation cannot be tuned directly to data, due to the low integrated luminosity of the data sample. It is therefore assumed that the shape of the y and p_T distributions is similar for different collision systems in centrality intervals corresponding to the same average number of participant nucleons, weighted by the corresponding number of nucleon–nucleon collisions, $\langle N_{\text{part}}^w \rangle$. The weighting is introduced to take into account that the J/ψ production cross section is proportional to the number of nucleon–nucleon collisions and that therefore the average N_{part} in wide centrality bins is systematically shifted towards higher values. Following this argument, the differential distributions measured in Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV [10] for the 20–40% centrality range are used as input distribution for the MC calculation, since $\langle N_{\text{part}}^w \rangle_{\text{PbPb}, 20-40\%}$ is equal, within $\sim 2\%$, to $\langle N_{\text{part}}^w \rangle_{\text{XeXe}, 0-90\%}$, estimated via a Glauber MC calculation. The systematic uncertainty on the J/ψ acceptance value due to the choice of the J/ψ rapidity and transverse momentum distributions amounts to 2% and is evaluated by choosing alternative input shapes corresponding to other Pb–Pb centrality ranges.

Concerning the reconstruction efficiency, it slightly depends on the collision centrality, due to the detector occupancy in the muon spectrometer. The effect was evaluated in the analysis of Pb–Pb events [10] by embedding the simulated J/ψ signal into real events corresponding to various centralities. For this analysis, starting from the Pb–Pb results, the decrease in $A\varepsilon_{\text{XeXe}, 0-90\%}$ with respect to a simulation containing only J/ψ is estimated to be 4.2% (values for 0–20% and 20–90% centrality ranges are 5.5% and 1.6%, respectively). The systematic uncertainty on the reconstruction efficiency is evaluated following the procedure used in Ref. [10], leading to a 3.6% effect.

The resulting value for the product of acceptance times reconstruction efficiency for J/ψ production in 0–90% Xe–Xe collisions is $A\varepsilon_{\text{XeXe}, 0-90\%} = 0.228 \pm 0.009(\text{syst.})$, with a negligible statistical uncertainty.

The normalization factor N_{MB} is evaluated by multiplying the number of opposite-sign dimuon triggers by a factor F_{norm} , corresponding to the inverse of the probability of having a triggered muon in a MB event. This quantity is computed from the event trigger input information and the level-0 trigger mask. The procedure and the evaluation of the systematic uncertainty are described in Ref. [10]. The obtained value is $F_{\text{norm}} = 2.428 \pm 0.001(\text{stat.}) \pm 0.024(\text{syst.})$.

The reference cross section for the calculation of R_{AA} is obtained starting from the measured value of the inclusive J/ψ cross section in pp collisions at $\sqrt{s} = 5.02$ TeV [10]. This quantity is then corrected to account for the different centre-of-mass energy of the Xe–Xe data, using an interpolation of available ALICE pp results at $\sqrt{s} = 2.76, 5.02, 7, 8$ and 13 TeV [32]. The obtained value is $\sigma_{J/\psi}^{\text{pp}} = 5.99 \pm 0.09(\text{stat.}) \pm 0.30(\text{syst.}) \mu\text{b}^{-1}$, where the systematic uncertainty contains a small term (0.4%) related to the interpolation procedure, calculated as the maximum spread between results obtained with various interpolating functions [34].

The nuclear thickness function $\langle T_{\text{AA}} \rangle$ is evaluated for the various centrality intervals via a Glauber model calculation, and its uncertainty is estimated by varying within uncertainties the density parameters of the Xe nucleus [29,35]. For 0–90% centrality its value amounts to $\langle T_{\text{AA}} \rangle = 3.25 \pm 0.25 \text{ mb}^{-1}$, while for 0–20% and 20–90% one obtains $\langle T_{\text{AA}} \rangle = 9.90 \pm 0.62 \text{ mb}^{-1}$ and $\langle T_{\text{AA}} \rangle = 1.35 \pm 0.14 \text{ mb}^{-1}$, respectively.

Finally, a systematic uncertainty on the definition of the centrality intervals is evaluated by varying the value of the V0 signal amplitude corresponding to 90% centrality by $\pm 0.5\%$ and recalculating correspondingly the centrality intervals.

Table 1

Summary of systematic uncertainties on the calculation of the nuclear modification factors. The tracking efficiency term includes a 1% contribution due to the choice of the χ^2 cut of the matching between the information of tracking and trigger detectors. All the uncertainties are correlated among the various centrality ranges, except those on the signal extraction, $\langle T_{\text{AA}} \rangle$ and the definition of the centrality intervals.

Source	0–90%	0–20%	20–90%
Signal extraction	11%	13%	8%
MC input	2%	2%	2%
Tracking efficiency	2%	2%	2%
Trigger efficiency	3%	3%	3%
F_{norm}	1%	1%	1%
$\langle T_{\text{AA}} \rangle$	8%	6%	10%
Centrality	0%	0%	1%
pp reference	5%	5%	5%

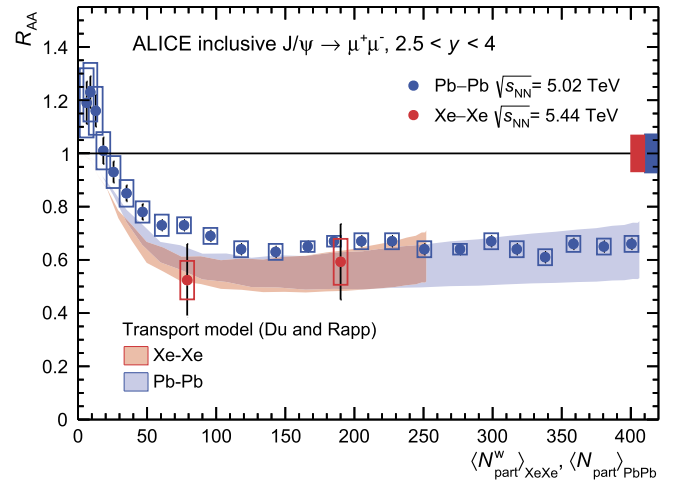


Fig. 2. The inclusive J/ψ nuclear modification factor for Xe–Xe collisions at $\sqrt{s_{\text{NN}}} = 5.44$ TeV. The results are plotted using as centrality variable $\langle N_{\text{part}}^w \rangle$, obtained by weighting, in each centrality interval, the N_{part} distribution with the corresponding distribution of the number of nucleon–nucleon collisions. The error bars represent the statistical uncertainties, the boxes around the points the uncorrelated systematic uncertainties. Correlated uncertainties are shown as a filled box around unity. The results are compared with the same quantity for Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV [10] and to the results of a transport model [13, 14]. For Pb–Pb, the weighting of N_{part} with the number of nucleon–nucleon collisions was not performed, since it leads to a negligible effect when the centrality intervals are narrow.

Table 1 shows a summary of the systematic uncertainties for the R_{AA} measurement for the three analyzed centrality ranges. The main contributions come from the estimate of $\langle T_{\text{AA}} \rangle$ and from the signal extraction. The former is dominated by the uncertainty on the surface thickness of the Xe nucleus. The latter, being estimated in a data-driven way as detailed above, may suffer from the statistical limitations of the data sample. The quoted values can therefore be considered to be a conservative estimate.

The p_T -integrated nuclear modification factor for inclusive J/ψ production in Xe–Xe collisions at $\sqrt{s_{\text{NN}}} = 5.44$ TeV, measured in $2.5 < y < 4$ and in the 0–90% centrality range, is $R_{\text{AA}} = 0.54 \pm 0.11(\text{stat.}) \pm 0.08(\text{syst.})$. This value can be compared with the corresponding one for Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV, $R_{\text{AA}}^{\text{PbPb}} = 0.65 \pm 0.01(\text{stat.}) \pm 0.04(\text{syst.})$ [10]. Their ratio amounts to $0.84 \pm 0.16(\text{stat.}) \pm 0.13(\text{syst.})$, showing that the two values agree within about 0.8σ . Following the approach of Ref. [9], it can be shown that the Xe–Xe nuclear modification factor for prompt J/ψ could be up to 10% higher (lower) than the inclusive R_{AA} if the non-prompt J/ψ component from the decays of hadrons containing a b quark is not (completely) suppressed. In Fig. 2 the R_{AA} values for 0–20% and 20–90% Xe–Xe collisions are plotted, and compared

with the centrality dependence of the nuclear modification factor for Pb–Pb collisions [10]. The latter shows, after a decrease up to $N_{\text{part}} \sim 100$, a saturation at $R_{AA} \sim 0.65\text{--}0.7$ towards more central events, and the two Xe–Xe points are found to be in agreement, within their larger uncertainties, with the Pb–Pb results. The Xe–Xe and Pb–Pb results are also compared with the calculation of a transport model by Du and Rapp [13,14]. A close similarity of the predicted suppression patterns for Pb–Pb and Xe–Xe is observed, which fairly reproduces the experimental results.

In summary, we have measured inclusive J/ψ production in Xe–Xe collisions at $\sqrt{s_{NN}} = 5.44$ TeV. Results on the nuclear modification factors were given for various centrality selections and compared to corresponding results for Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and to a theoretical model. Within the experimental uncertainties, a good agreement is found between the R_{AA} measured in the two systems and with the calculation. These results show that the relative contribution of suppression and regeneration processes is similar for collisions producing similar N_{part} values from different collision systems.

Acknowledgements

The ALICE Collaboration would like to thank all its engineers and technicians for their invaluable contributions to the construction of the experiment and the CERN accelerator teams for the outstanding performance of the LHC complex. The ALICE Collaboration gratefully acknowledges the resources and support provided by all Grid centres and the Worldwide LHC Computing Grid (WLCG) collaboration. The ALICE Collaboration acknowledges the following funding agencies for their support in building and running the ALICE detector: A.I. Alikhanyan National Science Laboratory (Yerevan Physics Institute) Foundation (ANSI), State Committee of Science and World Federation of Scientists (WFS), Armenia; Austrian Academy of Sciences and Nationalstiftung für Forschung, Technologie und Entwicklung, Austria; Ministry of Communications and High Technologies, National Nuclear Research Center, Azerbaijan; Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Universidade Federal do Rio Grande do Sul (UFRGS), Financiadora de Estudos e Projetos (Finep) and Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), Brazil; Ministry of Science & Technology of China (MSTC), National Natural Science Foundation of China (NSFC) and Ministry of Education of China (MOEC), China; Ministry of Science and Education, Croatia; Ministry of Education, Youth and Sports of the Czech Republic, Czech Republic; The Danish Council for Independent Research – Natural Sciences, the Carlsberg Foundation and Danish National Research Foundation (DNRF), Denmark; Helsinki Institute of Physics (HIP), Finland; Commissariat à l’Energie Atomique (CEA) and Institut National de Physique Nucléaire et de Physique des Particules (IN2P3) and Centre National de la Recherche Scientifique (CNRS), France; Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF) and GSI Helmholtzzentrum für Schwerionenforschung GmbH, Germany; General Secretariat for Research and Technology, Ministry of Education, Research and Religions, Greece; National Research, Development and Innovation Office, Hungary; Department of Atomic Energy, Government of India (DAE), Department of Science and Technology, Government of India (DST), University Grants Commission, Government of India (UGC) and Council of Scientific and Industrial Research (CSIR), India; Indonesian Institute of Science, Indonesia; Centro Fermi – Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi and Istituto Nazionale di Fisica Nucleare (INFN), Italy; Institute for Innovative Science and Technology, Nagasaki Institute of Applied Science (IIST), Japan Society for the Promotion of Science (JSPS) KAKENHI and Japanese Ministry of Education, Culture, Sports, Science and

Technology (MEXT), Japan; Consejo Nacional de Ciencia (CONACYT) y Tecnología, through Fondo de Cooperación Internacional en Ciencia y Tecnología (FONCICYT) and Dirección General de Asuntos del Personal Académico (DGAPA), Mexico; Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO), Netherlands; The Research Council of Norway, Norway; Commission on Science and Technology for Sustainable Development in the South (COMSATS), Pakistan; Pontificia Universidad Católica del Perú, Peru; Ministry of Science and Higher Education and National Science Centre, Poland; Korea Institute of Science and Technology Information and National Research Foundation of Korea (NRF), Republic of Korea; Ministry of Education and Scientific Research, Institute of Atomic Physics and Romanian National Agency for Science, Technology and Innovation, Romania; Joint Institute for Nuclear Research (JINR), Ministry of Education and Science of the Russian Federation and National Research Centre Kurchatov Institute, Russia; Ministry of Education, Science, Research and Sport of the Slovak Republic, Slovakia; National Research Foundation of South Africa, South Africa; Centro de Aplicaciones Tecnológicas y Desarrollo Nuclear (CEADEN), Cubaenergía, Cuba and Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Spain; Swedish Research Council (VR) and Knut & Alice Wallenberg Foundation (KAW), Sweden; European Organization for Nuclear Research, Switzerland; National Science and Technology Development Agency (NSDTA), Suranaree University of Technology (SUT) and Office of the Higher Education Commission under NRU project of Thailand, Thailand; Turkish Atomic Energy Agency (TAEK), Turkey; National Academy of Sciences of Ukraine, Ukraine; Science and Technology Facilities Council (STFC), United Kingdom; National Science Foundation of the United States of America (NSF) and United States Department of Energy, Office of Nuclear Physics (DOE NP), United States of America.

References

- [1] E.V. Shuryak, Quark-gluon plasma and hadronic production of leptons, photons and pions, *Phys. Lett. B* 78 (1978) 150, *Yad. Fiz.* 28 (1978) 796.
- [2] T. Matsui, H. Satz, J/ψ suppression by quark-gluon plasma formation, *Phys. Lett. B* 178 (1986) 416.
- [3] S. Digal, P. Petreczky, H. Satz, Quarkonium feed down and sequential suppression, *Phys. Rev. D* 64 (2001) 094015, arXiv:hep-ph/0106017 [hep-ph].
- [4] P. Braun-Munzinger, J. Stachel, (Non)thermal aspects of charmonium production and a new look at J/ψ suppression, *Phys. Lett. B* 490 (2000) 196–202.
- [5] R.L. Thews, M. Schroedter, J. Rafelski, Enhanced J/ψ production in deconfined quark matter, *Phys. Rev. C* 63 (2001) 054905, arXiv:hep-ph/0007323 [hep-ph].
- [6] ALICE Collaboration, B. Abelev, et al., J/ψ suppression at forward rapidity in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, *Phys. Rev. Lett.* 109 (2012) 072301, arXiv:1202.1383 [hep-ex].
- [7] CMS Collaboration, S. Chatrchyan, et al., Suppression of non-prompt J/ψ , prompt J/ψ , and $\Upsilon(1S)$ in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, *J. High Energy Phys.* 05 (2012) 063, arXiv:1201.5069 [nucl-ex].
- [8] ALICE Collaboration, B. Abelev, et al., Centrality, rapidity and transverse momentum dependence of J/ψ suppression in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, *Phys. Lett. B* 743 (2014) 314–327, arXiv:1311.0214 [nucl-ex].
- [9] ALICE Collaboration, J. Adam, et al., Differential studies of inclusive J/ψ and $\psi(2S)$ production at forward rapidity in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, *J. High Energy Phys.* 05 (2016) 179, arXiv:1506.08804 [nucl-ex].
- [10] ALICE Collaboration, J. Adam, et al., J/ψ suppression at forward rapidity in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, *Phys. Lett. B* 766 (2017) 212–224, arXiv:1606.08197 [nucl-ex].
- [11] CMS Collaboration, V. Khachatryan, et al., Suppression and azimuthal anisotropy of prompt and nonprompt J/ψ production in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, *Eur. Phys. J. C* 77 (4) (2017) 252, arXiv:1610.00613 [nucl-ex].
- [12] CMS Collaboration, A.M. Sirunyan, et al., Measurement of prompt and non-prompt charmonium suppression in PbPb collisions at 5.02 TeV, arXiv:1712.08959 [nucl-ex].
- [13] X. Zhao, R. Rapp, Medium modifications and production of charmonia at LHC, *Nucl. Phys. A* 859 (2011) 114–125, arXiv:1102.2194 [hep-ph].
- [14] X. Du, R. Rapp, Sequential regeneration of charmonia in heavy-ion collisions, *Nucl. Phys. A* 943 (2015) 147–158, arXiv:1504.00670 [hep-ph].
- [15] A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel, The statistical model in Pb–Pb collisions at the LHC, *Nucl. Phys. A* 904–905 (2013) 535c–538c, arXiv:1210.7724 [nucl-th].

- [16] E.G. Ferreira, Excited charmonium suppression in proton-nucleus collisions as a consequence of comovers, *Phys. Lett. B* 749 (2015) 98–103, arXiv:1411.0549 [hep-ph].
- [17] K. Zhou, N. Xu, Z. Xu, P. Zhuang, Medium effects on charmonium production at ultrarelativistic energies available at the CERN Large Hadron Collider, *Phys. Rev. C* 89 (5) (2014) 054911, arXiv:1401.5845 [nucl-th].
- [18] PHENIX Collaboration, A. Adare, et al., J/ψ suppression at forward rapidity in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, *Phys. Rev. C* 84 (2011) 054912, arXiv:1103.6269 [nucl-ex].
- [19] STAR Collaboration, B.I. Abelev, et al., J/ψ production at high transverse momentum in p+p and Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV, *Phys. Rev. C* 80 (2009) 041902, arXiv:0904.0439 [nucl-ex].
- [20] M.L. Miller, K. Reygers, S.J. Sanders, P. Steinberg, Glauber modeling in high energy nuclear collisions, *Annu. Rev. Nucl. Part. Sci.* 57 (2007) 205–243, arXiv:nucl-ex/0701025 [nucl-ex].
- [21] ALICE Collaboration, B. Abelev, et al., Centrality determination of Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with ALICE, *Phys. Rev. C* 88 (4) (2013) 044909, arXiv:1301.4361 [nucl-ex].
- [22] ALICE Collaboration, K. Aamodt, et al., The ALICE experiment at the CERN LHC, *J. Instrum.* 3 (2008) S08002.
- [23] ALICE Collaboration, B. Abelev, et al., Performance of the ALICE experiment at the CERN LHC, *Int. J. Mod. Phys. A* 29 (2014) 1430044, arXiv:1402.4476 [nucl-ex].
- [24] ALICE Collaboration, K. Aamodt, et al., Rapidity and transverse momentum dependence of inclusive J/ψ production in pp collisions at $\sqrt{s} = 7$ TeV, *Phys. Lett. B* 704 (2011) 442–455, <http://arxiv.org/abs/1105.0380>.
- [25] ALICE Collaboration, E. Abbas, et al., Performance of the ALICE VZERO system, *J. Instrum.* 8 (2013) P10016, arXiv:1306.3130 [nucl-ex].
- [26] ALICE Collaboration, K. Aamodt, et al., Alignment of the ALICE inner tracking system with cosmic-ray tracks, *J. Instrum.* 5 (2010) P03003, arXiv:1001.0502 [physics.ins-det].
- [27] ALICE Collaboration, B. Abelev, et al., Measurement of the cross section for electromagnetic dissociation with neutron emission in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, *Phys. Rev. Lett.* 109 (2012) 252302, arXiv:1203.2436 [nucl-ex].
- [28] Particle Data Group Collaboration, C. Patrignani, et al., Review of particle physics, *Chin. Phys. C* 40 (10) (2016) 100001.
- [29] ALICE Collaboration, Centrality determination using the Glauber model in Xe–Xe collisions at $\sqrt{s_{NN}} = 5.44$ TeV, <http://cds.cern.ch/record/2315401>.
- [30] ALICE Collaboration, Quarkonium signal extraction in ALICE, ALICE-PUBLIC-2015-006, 2015.
- [31] ALICE Collaboration, B. Abelev, et al., J/ψ production and nuclear effects in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, *J. High Energy Phys.* 1402 (2014) 073, arXiv:1308.6726 [nucl-ex].
- [32] ALICE Collaboration, S. Acharya, et al., Energy dependence of forward-rapidity J/ψ and $\psi(2S)$ production in pp collisions at the LHC, *Eur. Phys. J. C* 77 (6) (2017) 392, arXiv:1702.00557 [hep-ex].
- [33] R. Brun, F. Carminati, S. Giani, GEANT Detector Description and Simulation Tool, CERN Program Library Long Writeup, CERN-W5013, 1994.
- [34] ALICE Collaboration, LHCb Collaboration, Reference pp cross-sections for J/ψ studies in proton-lead collisions at $\sqrt{s_{NN}} = 5.02$ TeV and comparisons between ALICE and LHCb results, <http://cds.cern.ch/record/1639617>, CONF-2013-013.
- [35] C. Loizides, J. Kamin, D. d’Enterria, Improved Monte Carlo Glauber predictions at present and future nuclear colliders, *Phys. Rev. C* 97 (5) (2018) 054910, arXiv:1710.07098 [nucl-ex].

ALICE Collaboration

S. Acharya¹³⁹, F.T.-. Acosta²², D. Adamová⁹⁴, J. Adolfsson⁸¹, M.M. Aggarwal⁹⁸, G. Aglieri Rinella³⁶, M. Agnello³³, N. Agrawal⁴⁹, Z. Ahammed¹³⁹, S.U. Ahn⁷⁷, S. Aiola¹⁴⁴, A. Akindinov⁶⁵, M. Al-Turany¹⁰⁴, S.N. Alam¹³⁹, D.S.D. Albuquerque¹²⁰, D. Aleksandrov⁸⁸, B. Alessandro⁵⁹, R. Alfaro Molina⁷³, Y. Ali¹⁶, A. Alici^{11,54,29}, A. Alkin³, J. Alme²⁴, T. Alt⁷⁰, L. Altenkamper²⁴, I. Altsybeev¹³⁸, M.N. Anaam⁷, C. Andrei⁴⁸, D. Andreou³⁶, H.A. Andrews¹⁰⁸, A. Andronic^{142,104}, M. Angeletti³⁶, V. Anguelov¹⁰², C. Anson¹⁷, T. Antičić¹⁰⁵, F. Antinori⁵⁷, P. Antonioli⁵⁴, R. Anwar¹²⁴, N. Apadula⁸⁰, L. Aphecetche¹¹², H. Appelshäuser⁷⁰, S. Arcelli²⁹, R. Arnaldi⁵⁹, O.W. Arnold^{103,115}, I.C. Arsene²³, M. Arslandok¹⁰², B. Audurier¹¹², A. Augustinus³⁶, R. Averbeck¹⁰⁴, M.D. Azmi¹⁸, A. Badalà⁵⁶, Y.W. Baek^{61,42}, S. Bagnasco⁵⁹, R. Bailhache⁷⁰, R. Bala⁹⁹, A. Baldissari¹³⁴, M. Ball⁴⁴, R.C. Baral⁸⁶, A.M. Barbano²⁸, R. Barbera³⁰, F. Barile⁵³, L. Barioglio²⁸, G.G. Barnaföldi¹⁴³, L.S. Barnby⁹³, V. Barret¹³¹, P. Bartalini⁷, K. Barth³⁶, E. Bartsch⁷⁰, N. Bastid¹³¹, S. Basu¹⁴¹, G. Batigne¹¹², B. Batyunya⁷⁶, P.C. Batzing²³, J.L. Bazo Alba¹⁰⁹, I.G. Bearden⁸⁹, H. Beck¹⁰², C. Bedda⁶⁴, N.K. Behera⁶¹, I. Belikov¹³³, F. Bellini³⁶, H. Bello Martinez², R. Bellwied¹²⁴, L.G.E. Beltran¹¹⁸, V. Belyaev⁹², G. Bencedi¹⁴³, S. Beole²⁸, A. Bercuci⁴⁸, Y. Berdnikov⁹⁶, D. Berenyi¹⁴³, R.A. Bertens¹²⁷, D. Berzano^{36,59}, L. Betev³⁶, P.P. Bhaduri¹³⁹, A. Bhasin⁹⁹, I.R. Bhat⁹⁹, H. Bhatt⁴⁹, B. Bhattacharjee⁴³, J. Bhom¹¹⁶, A. Bianchi²⁸, L. Bianchi¹²⁴, N. Bianchi⁵², J. Bielčik³⁹, J. Bielčíková⁹⁴, A. Bilandzic^{115,103}, G. Biro¹⁴³, R. Biswas⁴, S. Biswas⁴, J.T. Blair¹¹⁷, D. Blau⁸⁸, C. Blume⁷⁰, G. Boca¹³⁶, F. Bock³⁶, A. Bogdanov⁹², L. Boldizsár¹⁴³, M. Bombara⁴⁰, G. Bonomi¹³⁷, M. Bonora³⁶, H. Borel¹³⁴, A. Borissov^{20,142}, M. Borri¹²⁶, E. Botta²⁸, C. Bourjau⁸⁹, L. Bratrud⁷⁰, P. Braun-Munzinger¹⁰⁴, M. Bregant¹¹⁹, T.A. Broker⁷⁰, M. Broz³⁹, E.J. Brucken⁴⁵, E. Bruna⁵⁹, G.E. Bruno^{36,35}, D. Budnikov¹⁰⁶, H. Buesching⁷⁰, S. Bufalino³³, P. Buhler¹¹¹, P. Buncic³⁶, O. Busch^{130,i}, Z. Buthelezi⁷⁴, J.B. Butt¹⁶, J.T. Buxton¹⁹, J. Cabala¹¹⁴, D. Caffarri⁹⁰, H. Caines¹⁴⁴, A. Caliva¹⁰⁴, E. Calvo Villar¹⁰⁹, R.S. Camacho², P. Camerini²⁷, A.A. Capon¹¹¹, F. Carena³⁶, W. Carena³⁶, F. Carnesecchi^{29,11}, J. Castillo Castellanos¹³⁴, A.J. Castro¹²⁷, E.A.R. Casula⁵⁵, C. Ceballos Sanchez⁹, S. Chandra¹³⁹, B. Chang¹²⁵, W. Chang⁷, S. Chapeland³⁶, M. Chartier¹²⁶, S. Chattopadhyay¹³⁹, S. Chattopadhyay¹⁰⁷, A. Chauvin^{103,115}, C. Cheshkov¹³², B. Cheynis¹³², V. Chibante Barroso³⁶, D.D. Chinellato¹²⁰, S. Cho⁶¹, P. Chochula³⁶, T. Chowdhury¹³¹, P. Christakoglou⁹⁰, C.H. Christensen⁸⁹, P. Christiansen⁸¹, T. Chujo¹³⁰, S.U. Chung²⁰, C. Cicalo⁵⁵, L. Cifarelli^{11,29}, F. Cindolo⁵⁴, J. Cleymans¹²³, F. Colamaria⁵³, D. Colella^{66,36,53}, A. Collu⁸⁰, M. Colocci²⁹, M. Concas^{59,ii}, G. Conesa Balbastre⁷⁹, Z. Conesa del Valle⁶², J.G. Contreras³⁹, T.M. Cormier⁹⁵, Y. Corrales Morales⁵⁹, P. Cortese³⁴, M.R. Cosentino¹²¹, F. Costa³⁶, S. Costanza¹³⁶, J. Crkovská⁶², P. Crochet¹³¹, E. Cuautle⁷¹, L. Cunqueiro^{142,95}, T. Dahms^{103,115}, A. Dainese⁵⁷, S. Dani⁶⁷, M.C. Danisch¹⁰², A. Danu⁶⁹, D. Das¹⁰⁷,

I. Das¹⁰⁷, S. Das⁴, A. Dash⁸⁶, S. Dash⁴⁹, S. De⁵⁰, A. De Caro³², G. de Cataldo⁵³, C. de Conti¹¹⁹, J. de Cuveland⁴¹, A. De Falco²⁶, D. De Gruttola^{11,32}, N. De Marco⁵⁹, S. De Pasquale³², R.D. De Souza¹²⁰, H.F. Degenhardt¹¹⁹, A. Deisting^{104,102}, A. Deloff⁸⁵, S. Delsanto²⁸, C. Deplano⁹⁰, P. Dhankher⁴⁹, D. Di Bari³⁵, A. Di Mauro³⁶, B. Di Ruzza⁵⁷, R.A. Diaz⁹, T. Dietel¹²³, P. Dillenseger⁷⁰, Y. Ding⁷, R. Divià³⁶, Ø. Djuvsland²⁴, A. Dobrin³⁶, D. Domenicis Gimenez¹¹⁹, B. Dönigus⁷⁰, O. Dordic²³, L.V.R. Doremalen⁶⁴, A.K. Dubey¹³⁹, A. Dubla¹⁰⁴, L. Ducroux¹³², S. Dudi⁹⁸, A.K. Duggal⁹⁸, M. Dukhishyam⁸⁶, P. Dupieux¹³¹, R.J. Ehlers¹⁴⁴, D. Elia⁵³, E. Endress¹⁰⁹, H. Engel⁷⁵, E. Epple¹⁴⁴, B. Erazmus¹¹², F. Erhardt⁹⁷, M.R. Ersdal²⁴, B. Espagnon⁶², G. Eulisse³⁶, J. Eum²⁰, D. Evans¹⁰⁸, S. Evdokimov⁹¹, L. Fabbietti^{103,115}, M. Faggin³¹, J. Faivre⁷⁹, A. Fantoni⁵², M. Fasel⁹⁵, L. Feldkamp¹⁴², A. Feliciello⁵⁹, G. Feofilov¹³⁸, A. Fernández Téllez², A. Ferretti²⁸, A. Festanti^{31,36}, V.J.G. Feuillard¹⁰², J. Figiel¹¹⁶, M.A.S. Figueredo¹¹⁹, S. Filchagin¹⁰⁶, D. Finogeev⁶³, F.M. Fionda²⁴, G. Fiorenza⁵³, F. Flor¹²⁴, M. Floris³⁶, S. Foertsch⁷⁴, P. Foka¹⁰⁴, S. Fokin⁸⁸, E. Fragiaco⁶⁰, A. Francescon³⁶, A. Francisco¹¹², U. Frankendorf¹⁰⁴, G.G. Fronze²⁸, U. Fuchs³⁶, C. Furget⁷⁹, A. Furs⁶³, M. Fusco Girard³², J.J. Gaardhøje⁸⁹, M. Gagliardi²⁸, A.M. Gago¹⁰⁹, K. Gajdosova⁸⁹, M. Gallio²⁸, C.D. Galvan¹¹⁸, P. Ganoti⁸⁴, C. Garabatos¹⁰⁴, E. Garcia-Solis¹², K. Garg³⁰, C. Gargiulo³⁶, P. Gasik^{115,103}, E.F. Gauger¹¹⁷, M.B. Gay Ducati⁷², M. Germain¹¹², J. Ghosh¹⁰⁷, P. Ghosh¹³⁹, S.K. Ghosh⁴, P. Gianotti⁵², P. Giubellino^{104,59}, P. Giubilato³¹, P. Glässel¹⁰², D.M. Gómez Coral⁷³, A. Gomez Ramirez⁷⁵, V. Gonzalez¹⁰⁴, P. González-Zamora², S. Gorbunov⁴¹, L. Görlich¹¹⁶, S. Gotovac³⁷, V. Grabski⁷³, L.K. Graczykowski¹⁴⁰, K.L. Graham¹⁰⁸, L. Greiner⁸⁰, A. Grelli⁶⁴, C. Grigoras³⁶, V. Grigoriev⁹², A. Grigoryan¹, S. Grigoryan⁷⁶, J.M. Gronefeld¹⁰⁴, F. Grosa³³, J.F. Grosse-Oetringhaus³⁶, R. Grosso¹⁰⁴, R. Guernane⁷⁹, B. Guerzoni²⁹, M. Guittiere¹¹², K. Gulbrandsen⁸⁹, T. Gunji¹²⁹, A. Gupta⁹⁹, R. Gupta⁹⁹, I.B. Guzman², R. Haake³⁶, M.K. Habib¹⁰⁴, C. Hadjidakis⁶², H. Hamagaki⁸², G. Hamar¹⁴³, M. Hamid⁷, J.C. Hamon¹³³, R. Hannigan¹¹⁷, M.R. Haque⁶⁴, J.W. Harris¹⁴⁴, A. Harton¹², H. Hassan⁷⁹, D. Hatzifotiadou^{54,11}, S. Hayashi¹²⁹, S.T. Heckel⁷⁰, E. Hellbär⁷⁰, H. Helstrup³⁸, A. Herghelegiu⁴⁸, E.G. Hernandez², G. Herrera Corral¹⁰, F. Herrmann¹⁴², K.F. Hetland³⁸, T.E. Hilden⁴⁵, H. Hillemanns³⁶, C. Hills¹²⁶, B. Hippolyte¹³³, B. Hohlweger¹⁰³, D. Horak³⁹, S. Hornung¹⁰⁴, R. Hosokawa^{130,79}, J. Hota⁶⁷, P. Hristov³⁶, C. Huang⁶², C. Hughes¹²⁷, P. Huhn⁷⁰, T.J. Humanic¹⁹, H. Hushnud¹⁰⁷, N. Hussain⁴³, T. Hussain¹⁸, D. Hutter⁴¹, D.S. Hwang²¹, J.P. Iddon¹²⁶, S.A. Iga Buitron⁷¹, R. Ilkaev¹⁰⁶, M. Inaba¹³⁰, M. Ippolitov⁸⁸, M.S. Islam¹⁰⁷, M. Ivanov¹⁰⁴, V. Ivanov⁹⁶, V. Izucheev⁹¹, B. Jacak⁸⁰, N. Jacazio²⁹, P.M. Jacobs⁸⁰, M.B. Jadhav⁴⁹, S. Jadlovská¹¹⁴, J. Jadlovsky¹¹⁴, S. Jaelani⁶⁴, C. Jahnke^{119,115}, M.J. Jakubowska¹⁴⁰, M.A. Janik¹⁴⁰, C. Jena⁸⁶, M. Jercic⁹⁷, O. Jevons¹⁰⁸, R.T. Jimenez Bustamante¹⁰⁴, M. Jin¹²⁴, P.G. Jones¹⁰⁸, A. Jusko¹⁰⁸, P. Kalinak⁶⁶, A. Kalweit³⁶, J.H. Kang¹⁴⁵, V. Kaplin⁹², S. Kar⁷, A. Karasu Uysal⁷⁸, O. Karavichev⁶³, T. Karavicheva⁶³, P. Karczmarczyk³⁶, E. Karpechev⁶³, U. Keschull⁷⁵, R. Keidel⁴⁷, D.L.D. Keijdener⁶⁴, M. Keil³⁶, B. Ketzer⁴⁴, Z. Khabanova⁹⁰, A.M. Khan⁷, S. Khan¹⁸, S.A. Khan¹³⁹, A. Khanzadeev⁹⁶, Y. Kharlov⁹¹, A. Khatun¹⁸, A. Khuntia⁵⁰, M.M. Kielbowicz¹¹⁶, B. Kileng³⁸, B. Kim¹³⁰, D. Kim¹⁴⁵, D.J. Kim¹²⁵, E.J. Kim¹⁴, H. Kim¹⁴⁵, J.S. Kim⁴², J. Kim¹⁰², M. Kim^{61,102}, S. Kim²¹, T. Kim¹⁴⁵, T. Kim¹⁴⁵, S. Kirsch⁴¹, I. Kisel⁴¹, S. Kiselev⁶⁵, A. Kisiel¹⁴⁰, J.L. Klay⁶, C. Klein⁷⁰, J. Klein^{36,59}, C. Klein-Bösing¹⁴², S. Klewin¹⁰², A. Kluge³⁶, M.L. Knichel³⁶, A.G. Knospe¹²⁴, C. Kobdaj¹¹³, M. Kofarago¹⁴³, M.K. Köhler¹⁰², T. Kollegger¹⁰⁴, N. Kondratyeva⁹², E. Kondratyuk⁹¹, A. Konevskikh⁶³, M. Konyushikhin¹⁴¹, O. Kovalenko⁸⁵, V. Kovalenko¹³⁸, M. Kowalski¹¹⁶, I. Králik⁶⁶, A. Kravčáková⁴⁰, L. Kreis¹⁰⁴, M. Krivda^{66,108}, F. Krizek⁹⁴, M. Krüger⁷⁰, E. Kryshen⁹⁶, M. Krzewicki⁴¹, A.M. Kubera¹⁹, V. Kučera^{94,61}, C. Kuhn¹³³, P.G. Kuijer⁹⁰, J. Kumar⁴⁹, L. Kumar⁹⁸, S. Kumar⁴⁹, S. Kundu⁸⁶, P. Kurashvili⁸⁵, A. Kurepin⁶³, A.B. Kurepin⁶³, A. Kuryakin¹⁰⁶, S. Kuschpil⁹⁴, J. Kvapil¹⁰⁸, M.J. Kweon⁶¹, Y. Kwon¹⁴⁵, S.L. La Pointe⁴¹, P. La Rocca³⁰, Y.S. Lai⁸⁰, I. Lakomov³⁶, R. Langoy¹²², K. Lapidus¹⁴⁴, C. Lara⁷⁵, A. Lardeux²³, P. Larionov⁵², E. Laudi³⁶, R. Lavicka³⁹, R. Lea²⁷, L. Leardini¹⁰², S. Lee¹⁴⁵, F. Lehas⁹⁰, S. Lehner¹¹¹, J. Lehrbach⁴¹, R.C. Lemmon⁹³, I. León Monzón¹¹⁸, P. Lévai¹⁴³, X. Li¹³, X.L. Li⁷, J. Lien¹²², R. Lietava¹⁰⁸, B. Lim²⁰, S. Lindal²³, V. Lindenstruth⁴¹, S.W. Lindsay¹²⁶, C. Lippmann¹⁰⁴, M.A. Lisa¹⁹, V. Litichevskiy⁴⁵, A. Liu⁸⁰, H.M. Ljunggren⁸¹, W.J. Llope¹⁴¹, D.F. Lodato⁶⁴, V. Loginov⁹², C. Loizides^{95,80}, P. Loncar³⁷, X. Lopez¹³¹, E. López Torres⁹, A. Lowe¹⁴³, P. Luettig⁷⁰, J.R. Luhder¹⁴², M. Lunardon³¹, G. Luparello⁶⁰, M. Lupi³⁶, A. Maevskaya⁶³, M. Mager³⁶, S.M. Mahmood²³, A. Maire¹³³, R.D. Majka¹⁴⁴, M. Malaev⁹⁶, Q.W. Malik²³, L. Malinina^{76,iii}, D. Mal'Kevich⁶⁵, P. Malzacher¹⁰⁴, A. Mamonov¹⁰⁶, V. Manko⁸⁸, F. Manso¹³¹, V. Manzari⁵³, Y. Mao⁷, M. Marchisone^{128,74,132}, J. Mareš⁶⁸, G.V. Margagliotti²⁷,

A. Margotti⁵⁴, J. Margutti⁶⁴, A. Marín¹⁰⁴, C. Markert¹¹⁷, M. Marquard⁷⁰, N.A. Martin¹⁰⁴,
 P. Martinengo³⁶, J.L. Martinez¹²⁴, M.I. Martínez², G. Martínez García¹¹², M. Martinez Pedreira³⁶,
 S. Masciocchi¹⁰⁴, M. Maserà²⁸, A. Masoni⁵⁵, L. Massacrier⁶², E. Masson¹¹², A. Mastroserio^{53,135},
 A.M. Mathis^{115,103}, P.F.T. Matuoka¹¹⁹, A. Matyjka^{116,127}, C. Mayer¹¹⁶, M. Mazzilli³⁵, M.A. Mazzoni⁵⁸,
 F. Meddi²⁵, Y. Melikyan⁹², A. Menchaca-Rocha⁷³, E. Meninno³², J. Mercado Pérez¹⁰², M. Meres¹⁵,
 C.S. Meza¹⁰⁹, S. Mhlanga¹²³, Y. Miake¹³⁰, L. Micheletti²⁸, M.M. Mieskolainen⁴⁵, D.L. Mihaylov¹⁰³,
 K. Mikhaylov^{65,76}, A. Mischke⁶⁴, A.N. Mishra⁷¹, D. Miśkowiec¹⁰⁴, J. Mitra¹³⁹, C.M. Mitu⁶⁹,
 N. Mohammadi³⁶, A.P. Mohanty⁶⁴, B. Mohanty⁸⁶, M. Mohisin Khan^{18.iv}, D.A. Moreira De Godoy¹⁴²,
 L.A.P. Moreno², S. Moretto³¹, A. Morreale¹¹², A. Morsch³⁶, V. Muccifora⁵², E. Mudnic³⁷,
 D. Mühlheim¹⁴², S. Muhuri¹³⁹, M. Mukherjee⁴, J.D. Mulligan¹⁴⁴, M.G. Munhoz¹¹⁹, K. Mürning⁴⁴,
 M.I.A. Munoz⁸⁰, R.H. Munzer⁷⁰, H. Murakami¹²⁹, S. Murray⁷⁴, L. Musa³⁶, J. Musinsky⁶⁶, C.J. Myers¹²⁴,
 J.W. Myrcha¹⁴⁰, B. Naik⁴⁹, R. Nair⁸⁵, B.K. Nandi⁴⁹, R. Nania^{54,11}, E. Nappi⁵³, A. Narayan⁴⁹, M.U. Naru¹⁶,
 A.F. Nassirpour⁸¹, H. Natal da Luz¹¹⁹, C. Nattrass¹²⁷, S.R. Navarro², K. Nayak⁸⁶, R. Nayak⁴⁹,
 T.K. Nayak¹³⁹, S. Nazarenko¹⁰⁶, R.A. Negrao De Oliveira^{70,36}, L. Nellen⁷¹, S.V. Nesbo³⁸, G. Neskovic⁴¹,
 F. Ng¹²⁴, M. Nicassio¹⁰⁴, J. Niedziela^{140,36}, B.S. Nielsen⁸⁹, S. Nikolaev⁸⁸, S. Nikulin⁸⁸, V. Nikulin⁹⁶,
 F. Noferini^{11,54}, P. Nomokonov⁷⁶, G. Nooren⁶⁴, J.C.C. Noris², J. Norman⁷⁹, A. Nyanin⁸⁸, J. Nystrand²⁴,
 H. Oh¹⁴⁵, A. Ohlson¹⁰², J. Oleniacz¹⁴⁰, A.C. Oliveira Da Silva¹¹⁹, M.H. Oliver¹⁴⁴, J. Onderwaater¹⁰⁴,
 C. Oppedisano⁵⁹, R. Orava⁴⁵, M. Oravec¹¹⁴, A. Ortiz Velasquez⁷¹, A. Oskarsson⁸¹, J. Otwinowski¹¹⁶,
 K. Oyama⁸², Y. Pachmayer¹⁰², V. Pacik⁸⁹, D. Pagano¹³⁷, G. Paic⁷¹, P. Palni⁷, J. Pan¹⁴¹, A.K. Pandey⁴⁹,
 S. Panebianco¹³⁴, V. Papikyan¹, P. Pareek⁵⁰, J. Park⁶¹, J.E. Parkkila¹²⁵, S. Parmar⁹⁸, A. Passfeld¹⁴²,
 S.P. Pathak¹²⁴, R.N. Patra¹³⁹, B. Paul⁵⁹, H. Pei⁷, T. Peitzmann⁶⁴, X. Peng⁷, L.G. Pereira⁷²,
 H. Pereira Da Costa¹³⁴, D. Peresunko⁸⁸, E. Perez Lezama⁷⁰, V. Peskov⁷⁰, Y. Pestov⁵, V. Petráček³⁹,
 M. Petrovici⁴⁸, C. Petta³⁰, R.P. Pezzi⁷², S. Piano⁶⁰, M. Pikna¹⁵, P. Pillot¹¹², L.O.D.L. Pimentel⁸⁹,
 O. Pinazza^{54,36}, L. Pinsky¹²⁴, S. Pisano⁵², D.B. Piyarathna¹²⁴, M. Płoskoń⁸⁰, M. Planinic⁹⁷, F. Pliquett⁷⁰,
 J. Pluta¹⁴⁰, S. Pochybova¹⁴³, P.L.M. Podesta-Lerma¹¹⁸, M.G. Poghosyan⁹⁵, B. Polichtchouk⁹¹, N. Poljak⁹⁷,
 W. Poonsawat¹¹³, A. Pop⁴⁸, H. Poppenborg¹⁴², S. Porteboeuf-Houssais¹³¹, V. Pozdniakov⁷⁶, S.K. Prasad⁴,
 R. Preghenella⁵⁴, F. Prino⁵⁹, C.A. Pruneau¹⁴¹, I. Pshenichnov⁶³, M. Puccio²⁸, V. Punin¹⁰⁶, J. Putschke¹⁴¹,
 S. Raha⁴, S. Rajput⁹⁹, J. Rak¹²⁵, A. Rakotozafindrabe¹³⁴, L. Ramello³⁴, F. Rami¹³³, R. Raniwala¹⁰⁰,
 S. Raniwala¹⁰⁰, S.S. Räsänen⁴⁵, B.T. Rascanu⁷⁰, V. Ratza⁴⁴, I. Ravasenga³³, K.F. Read^{127,95}, K. Redlich^{85.v},
 A. Rehman²⁴, P. Reichelt⁷⁰, F. Reidt³⁶, X. Ren⁷, R. Renfordt⁷⁰, A. Reshetin⁶³, J.-P. Revol¹¹, K. Reygers¹⁰²,
 V. Riabov⁹⁶, T. Richert^{64,81}, M. Richter²³, P. Riedler³⁶, W. Riegler³⁶, F. Riggi³⁰, C. Ristea⁶⁹, S.P. Rode⁵⁰,
 M. Rodríguez Cahuantzi², K. Røed²³, R. Rogalev⁹¹, E. Rogochaya⁷⁶, D. Rohr³⁶, D. Röhrich²⁴,
 P.S. Rokita¹⁴⁰, F. Ronchetti⁵², E.D. Rosas⁷¹, K. Roslon¹⁴⁰, P. Rosnet¹³¹, A. Rossi³¹, A. Rotondi¹³⁶,
 F. Roukoutakis⁸⁴, C. Roy¹³³, P. Roy¹⁰⁷, O.V. Rueda⁷¹, R. Rui²⁷, B. Rumyantsev⁷⁶, A. Rustamov⁸⁷,
 E. Ryabinkin⁸⁸, Y. Ryabov⁹⁶, A. Rybicki¹¹⁶, S. Saarinen⁴⁵, S. Sadhu¹³⁹, S. Sadovsky⁹¹, K. Šafařík³⁶,
 S.K. Saha¹³⁹, B. Sahoo⁴⁹, P. Sahoo⁵⁰, R. Sahoo⁵⁰, S. Sahoo⁶⁷, P.K. Sahu⁶⁷, J. Saini¹³⁹, S. Sakai¹³⁰,
 M.A. Saleh¹⁴¹, S. Sambyal⁹⁹, V. Samsonov^{96,92}, A. Sandoval⁷³, A. Sarkar⁷⁴, D. Sarkar¹³⁹, N. Sarkar¹³⁹,
 P. Sarma⁴³, M.H.P. Sas⁶⁴, E. Scapparone⁵⁴, F. Scarlassara³¹, B. Schaefer⁹⁵, H.S. Scheid⁷⁰, C. Schiaua⁴⁸,
 R. Schicker¹⁰², C. Schmidt¹⁰⁴, H.R. Schmidt¹⁰¹, M.O. Schmidt¹⁰², M. Schmidt¹⁰¹, N.V. Schmidt^{95,70},
 J. Schukraft³⁶, Y. Schutz^{36,133}, K. Schwarz¹⁰⁴, K. Schweda¹⁰⁴, G. Scioli²⁹, E. Scapparone⁵⁹, M. Šefčík⁴⁰,
 J.E. Seger¹⁷, Y. Sekiguchi¹²⁹, D. Sekihata⁴⁶, I. Selyuzhenkov^{104,92}, K. Senosi⁷⁴, S. Senyukov¹³³,
 E. Serradilla⁷³, P. Sett⁴⁹, A. Sevcenco⁶⁹, A. Shabanov⁶³, A. Shabetai¹¹², R. Shahoyan³⁶, W. Shaikh¹⁰⁷,
 A. Shangaraev⁹¹, A. Sharma⁹⁸, A. Sharma⁹⁹, M. Sharma⁹⁹, N. Sharma⁹⁸, A.I. Sheikh¹³⁹, K. Shigaki⁴⁶,
 M. Shimomura⁸³, S. Shirinkin⁶⁵, Q. Shou^{7,110}, K. Shtejer²⁸, Y. Sibiriak⁸⁸, S. Siddhanta⁵⁵,
 K.M. Sielewicz³⁶, T. Siemiarczuk⁸⁵, D. Silvermyr⁸¹, G. Simatovic⁹⁰, G. Simonetti^{36,103}, R. Singaraju¹³⁹,
 R. Singh⁸⁶, R. Singh⁹⁹, V. Singhal¹³⁹, T. Sinha¹⁰⁷, B. Sitar¹⁵, M. Sitta³⁴, T.B. Skaali²³, M. Slupecki¹²⁵,
 N. Smirnov¹⁴⁴, R.J.M. Snellings⁶⁴, T.W. Snellman¹²⁵, J. Song²⁰, F. Soramel³¹, S. Sorensen¹²⁷, F. Sozzi¹⁰⁴,
 I. Sputowska¹¹⁶, J. Stachel¹⁰², I. Stan⁶⁹, P. Stankus⁹⁵, E. Stenlund⁸¹, D. Stocco¹¹², M.M. Stortvedt³⁸,
 P. Strmen¹⁵, A.A.P. Suaide¹¹⁹, T. Sugitate⁴⁶, C. Suire⁶², M. Suleymanov¹⁶, M. Suljic^{36,27}, R. Sultanov⁶⁵,
 M. Šumbera⁹⁴, S. Sumowidagdo⁵¹, K. Suzuki¹¹¹, S. Swain⁶⁷, A. Szabo¹⁵, I. Szarka¹⁵, U. Tabassam¹⁶,
 J. Takahashi¹²⁰, G.J. Tambave²⁴, N. Tanaka¹³⁰, M. Tarhini¹¹², M. Tariq¹⁸, M.G. Tarzila⁴⁸, A. Tauro³⁶,
 G. Tejeda Muñoz², A. Telesca³⁶, C. Terrevoli³¹, B. Teyssier¹³², D. Thakur⁵⁰, S. Thakur¹³⁹, D. Thomas¹¹⁷,

F. Thoresen⁸⁹, R. Tieulent¹³², A. Tikhonov⁶³, A.R. Timmins¹²⁴, A. Toia⁷⁰, N. Topilskaya⁶³, M. Toppi⁵², S.R. Torres¹¹⁸, S. Tripathy⁵⁰, S. Trogolo²⁸, G. Trombetta³⁵, L. Tropp⁴⁰, V. Trubnikov³, W.H. Trzaska¹²⁵, T.P. Trzcinski¹⁴⁰, B.A. Trzeciak⁶⁴, T. Tsuji¹²⁹, A. Tumkin¹⁰⁶, R. Turrisi⁵⁷, T.S. Tveter²³, K. Ullaland²⁴, E.N. Umaka¹²⁴, A. Uras¹³², G.L. Usai²⁶, A. Utrobicic⁹⁷, M. Vala¹¹⁴, J.W. Van Hoorne³⁶, M. van Leeuwen⁶⁴, P. Vande Vyvre³⁶, D. Varga¹⁴³, A. Vargas², M. Vargyas¹²⁵, R. Varma⁴⁹, M. Vasileiou⁸⁴, A. Vasiliev⁸⁸, A. Vauthier⁷⁹, O. Vázquez Doce^{103,115}, V. Vechernin¹³⁸, A.M. Veen⁶⁴, E. Vercellin²⁸, S. Vergara Limón², L. Vermunt⁶⁴, R. Vernet⁸, R. Vértesi¹⁴³, L. Vickovic³⁷, J. Viinikainen¹²⁵, Z. Vilakazi¹²⁸, O. Villalobos Baillie¹⁰⁸, A. Villatoro Tello², A. Vinogradov⁸⁸, T. Virgili³², V. Vislavicius^{89,81}, A. Vodopyanov⁷⁶, M.A. Völkl¹⁰¹, K. Voloshin⁶⁵, S.A. Voloshin¹⁴¹, G. Volpe³⁵, B. von Haller³⁶, I. Vorobyev^{115,103}, D. Voscek¹¹⁴, D. Vranic^{104,36}, J. Vrláková⁴⁰, B. Wagner²⁴, H. Wang⁶⁴, M. Wang⁷, Y. Watanabe¹³⁰, M. Weber¹¹¹, S.G. Weber¹⁰⁴, A. Wegrzynek³⁶, D.F. Weiser¹⁰², S.C. Wenzel³⁶, J.P. Wessels¹⁴², U. Westerhoff¹⁴², A.M. Whitehead¹²³, J. Wiechula⁷⁰, J. Wikne²³, G. Wilk⁸⁵, J. Wilkinson⁵⁴, G.A. Willems^{142,36}, M.C.S. Williams⁵⁴, E. Willsher¹⁰⁸, B. Windelband¹⁰², W.E. Witt¹²⁷, R. Xu⁷, S. Yalcin⁷⁸, K. Yamakawa⁴⁶, S. Yano⁴⁶, Z. Yin⁷, H. Yokoyama^{79,130}, I.-K. Yoo²⁰, J.H. Yoon⁶¹, V. Yurchenko³, V. Zaccolo⁵⁹, A. Zaman¹⁶, C. Zampolli³⁶, H.J.C. Zanoli¹¹⁹, N. Zardoshti¹⁰⁸, A. Zarochentsev¹³⁸, P. Závada⁶⁸, N. Zaviyalov¹⁰⁶, H. Zbroszczyk¹⁴⁰, M. Zhalov⁹⁶, X. Zhang⁷, Y. Zhang⁷, Z. Zhang^{7,131}, C. Zhao²³, V. Zherebchevskii¹³⁸, N. Zhigareva⁶⁵, D. Zhou⁷, Y. Zhou⁸⁹, Z. Zhou²⁴, H. Zhu⁷, J. Zhu⁷, Y. Zhu⁷, A. Zichichi^{29,11}, M.B. Zimmermann³⁶, G. Zinovjev³, J. Zmeskal¹¹¹, S. Zou⁷

¹ A.I. Alikhanyan National Science Laboratory (Yerevan Physics Institute) Foundation, Yerevan, Armenia

² Benemérita Universidad Autónoma de Puebla, Puebla, Mexico

³ Bogolyubov Institute for Theoretical Physics, National Academy of Sciences of Ukraine, Kiev, Ukraine

⁴ Bose Institute, Department of Physics and Centre for Astroparticle Physics and Space Science (CAPSS), Kolkata, India

⁵ Budker Institute for Nuclear Physics, Novosibirsk, Russia

⁶ California Polytechnic State University, San Luis Obispo, CA, United States

⁷ Central China Normal University, Wuhan, China

⁸ Centre de Calcul de l'IN2P3, Villeurbanne, Lyon, France

⁹ Centro de Aplicaciones Tecnológicas y Desarrollo Nuclear (CEADEN), Havana, Cuba

¹⁰ Centro de Investigación y de Estudios Avanzados (CINVESTAV), Mexico City and Mérida, Mexico

¹¹ Centro Fermi – Museo Storico della Fisica e Centro Studi e Ricerche “Enrico Fermi”, Rome, Italy

¹² Chicago State University, Chicago, IL, United States

¹³ China Institute of Atomic Energy, Beijing, China

¹⁴ Chonbuk National University, Jeonju, Republic of Korea

¹⁵ Comenius University Bratislava, Faculty of Mathematics, Physics and Informatics, Bratislava, Slovakia

¹⁶ COMSATS Institute of Information Technology (CIIT), Islamabad, Pakistan

¹⁷ Creighton University, Omaha, NE, United States

¹⁸ Department of Physics, Aligarh Muslim University, Aligarh, India

¹⁹ Department of Physics, Ohio State University, Columbus, OH, United States

²⁰ Department of Physics, Pusan National University, Pusan, Republic of Korea

²¹ Department of Physics, Sejong University, Seoul, Republic of Korea

²² Department of Physics, University of California, Berkeley, CA, United States

²³ Department of Physics, University of Oslo, Oslo, Norway

²⁴ Department of Physics and Technology, University of Bergen, Bergen, Norway

²⁵ Dipartimento di Fisica dell'Università 'La Sapienza' and Sezione INFN, Rome, Italy

²⁶ Dipartimento di Fisica dell'Università and Sezione INFN, Cagliari, Italy

²⁷ Dipartimento di Fisica dell'Università and Sezione INFN, Trieste, Italy

²⁸ Dipartimento di Fisica dell'Università and Sezione INFN, Turin, Italy

²⁹ Dipartimento di Fisica e Astronomia dell'Università and Sezione INFN, Bologna, Italy

³⁰ Dipartimento di Fisica e Astronomia dell'Università and Sezione INFN, Catania, Italy

³¹ Dipartimento di Fisica e Astronomia dell'Università and Sezione INFN, Padova, Italy

³² Dipartimento di Fisica 'E.R. Caianiello' dell'Università and Gruppo Collegato INFN, Salerno, Italy

³³ Dipartimento DISAT del Politecnico and Sezione INFN, Turin, Italy

³⁴ Dipartimento di Scienze e Innovazione Tecnologica dell'Università del Piemonte Orientale and INFN Sezione di Torino, Alessandria, Italy

³⁵ Dipartimento Interateneo di Fisica 'M. Merlin' and Sezione INFN, Bari, Italy

³⁶ European Organization for Nuclear Research (CERN), Geneva, Switzerland

³⁷ Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split, Split, Croatia

³⁸ Faculty of Engineering and Science, Western Norway University of Applied Sciences, Bergen, Norway

³⁹ Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Prague, Czech Republic

⁴⁰ Faculty of Science, P.J. Šafárik University, Košice, Slovakia

⁴¹ Frankfurt Institute for Advanced Studies, Johann Wolfgang Goethe-Universität Frankfurt, Frankfurt, Germany

⁴² Gangneung-Wonju National University, Gangneung, Republic of Korea

⁴³ Gauhati University, Department of Physics, Guwahati, India

⁴⁴ Helmholtz-Institut für Strahlen- und Kernphysik, Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn, Germany

⁴⁵ Helsinki Institute of Physics (HIP), Helsinki, Finland

⁴⁶ Hiroshima University, Hiroshima, Japan

⁴⁷ Hochschule Worms, Zentrum für Technologietransfer und Telekommunikation (ZTT), Worms, Germany

⁴⁸ Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania

⁴⁹ Indian Institute of Technology Bombay (IIT), Mumbai, India

⁵⁰ Indian Institute of Technology Indore, Indore, India

⁵¹ Indonesian Institute of Sciences, Jakarta, Indonesia

- 52 INFN, Laboratori Nazionali di Frascati, Frascati, Italy
- 53 INFN, Sezione di Bari, Bari, Italy
- 54 INFN, Sezione di Bologna, Bologna, Italy
- 55 INFN, Sezione di Cagliari, Cagliari, Italy
- 56 INFN, Sezione di Catania, Catania, Italy
- 57 INFN, Sezione di Padova, Padova, Italy
- 58 INFN, Sezione di Roma, Rome, Italy
- 59 INFN, Sezione di Torino, Turin, Italy
- 60 INFN, Sezione di Trieste, Trieste, Italy
- 61 Inha University, Incheon, Republic of Korea
- 62 Institut de Physique Nucléaire d'Orsay (IPNO), Institut National de Physique Nucléaire et de Physique des Particules (IN2P3/CNRS), Université de Paris-Sud, Université Paris-Saclay, Orsay, France
- 63 Institute for Nuclear Research, Academy of Sciences, Moscow, Russia
- 64 Institute for Subatomic Physics, Utrecht University/Nikhef, Utrecht, Netherlands
- 65 Institute for Theoretical and Experimental Physics, Moscow, Russia
- 66 Institute of Experimental Physics, Slovak Academy of Sciences, Košice, Slovakia
- 67 Institute of Physics, Bhubaneswar, India
- 68 Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic
- 69 Institute of Space Science (ISS), Bucharest, Romania
- 70 Institut für Kernphysik, Johann Wolfgang Goethe-Universität Frankfurt, Frankfurt, Germany
- 71 Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Mexico City, Mexico
- 72 Instituto de Física, Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, Brazil
- 73 Instituto de Física, Universidad Nacional Autónoma de México, Mexico City, Mexico
- 74 iThemba LABS, National Research Foundation, Somerset West, South Africa
- 75 Johann-Wolfgang-Goethe Universität Frankfurt Institut für Informatik, Fachbereich Informatik und Mathematik, Frankfurt, Germany
- 76 Joint Institute for Nuclear Research (JINR), Dubna, Russia
- 77 Korea Institute of Science and Technology Information, Daejeon, Republic of Korea
- 78 KTO Karatay University, Konya, Turkey
- 79 Laboratoire de Physique Subatomique et de Cosmologie, Université Grenoble-Alpes, CNRS-IN2P3, Grenoble, France
- 80 Lawrence Berkeley National Laboratory, Berkeley, CA, United States
- 81 Lund University Department of Physics, Division of Particle Physics, Lund, Sweden
- 82 Nagasaki Institute of Applied Science, Nagasaki, Japan
- 83 Nara Women's University (NWU), Nara, Japan
- 84 National and Kapodistrian University of Athens, School of Science, Department of Physics, Athens, Greece
- 85 National Centre for Nuclear Research, Warsaw, Poland
- 86 National Institute of Science Education and Research, HBNI, Jatni, India
- 87 National Nuclear Research Center, Baku, Azerbaijan
- 88 National Research Centre Kurchatov Institute, Moscow, Russia
- 89 Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
- 90 Nikhef, National institute for subatomic physics, Amsterdam, Netherlands
- 91 NRC Kurchatov Institute IHEP, Protvino, Russia
- 92 NRNU Moscow Engineering Physics Institute, Moscow, Russia
- 93 Nuclear Physics Group, STFC Daresbury Laboratory, Daresbury, United Kingdom
- 94 Nuclear Physics Institute of the Czech Academy of Sciences, Řež u Prahy, Czech Republic
- 95 Oak Ridge National Laboratory, Oak Ridge, TN, United States
- 96 Petersburg Nuclear Physics Institute, Gatchina, Russia
- 97 Physics department, Faculty of science, University of Zagreb, Zagreb, Croatia
- 98 Physics Department, Panjab University, Chandigarh, India
- 99 Physics Department, University of Jammu, Jammu, India
- 100 Physics Department, University of Rajasthan, Jaipur, India
- 101 Physikalisches Institut, Eberhard-Karls-Universität Tübingen, Tübingen, Germany
- 102 Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
- 103 Physik Department, Technische Universität München, Munich, Germany
- 104 Research Division and ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany
- 105 Rudjer Bošković Institute, Zagreb, Croatia
- 106 Russian Federal Nuclear Center (VNIIEF), Sarov, Russia
- 107 Saha Institute of Nuclear Physics, Kolkata, India
- 108 School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom
- 109 Sección Física, Departamento de Ciencias, Pontificia Universidad Católica del Perú, Lima, Peru
- 110 Shanghai Institute of Applied Physics, Shanghai, China
- 111 Stefan Meyer Institut für Subatomare Physik (SMI), Vienna, Austria
- 112 SUBATECH, IMT Atlantique, Université de Nantes, CNRS-IN2P3, Nantes, France
- 113 Suranaree University of Technology, Nakhon Ratchasima, Thailand
- 114 Technical University of Košice, Košice, Slovakia
- 115 Technische Universität München, Excellence Cluster 'Universe', Munich, Germany
- 116 The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Cracow, Poland
- 117 The University of Texas at Austin, Austin, TX, United States
- 118 Universidad Autónoma de Sinaloa, Culiacán, Mexico
- 119 Universidade de São Paulo (USP), São Paulo, Brazil
- 120 Universidade Estadual de Campinas (UNICAMP), Campinas, Brazil
- 121 Universidade Federal do ABC, Santo Andre, Brazil
- 122 University College of Southeast Norway, Tonsberg, Norway
- 123 University of Cape Town, Cape Town, South Africa
- 124 University of Houston, Houston, TX, United States
- 125 University of Jyväskylä, Jyväskylä, Finland
- 126 University of Liverpool, Department of Physics Oliver Lodge Laboratory, Liverpool, United Kingdom
- 127 University of Tennessee, Knoxville, TN, United States
- 128 University of the Witwatersrand, Johannesburg, South Africa
- 129 University of Tokyo, Tokyo, Japan

- ¹³⁰ University of Tsukuba, Tsukuba, Japan
¹³¹ Université Clermont Auvergne, CNRS/IN2P3, LPC, Clermont-Ferrand, France
¹³² Université de Lyon, Université Lyon 1, CNRS/IN2P3, IPN-Lyon, Villeurbanne, Lyon, France
¹³³ Université de Strasbourg, CNRS, IPHC UMR 7178, F-67000, Strasbourg, France
¹³⁴ Université Paris-Saclay Centre d'Études de Saclay (CEA), IRFU, Department de Physique Nucléaire (DPhN), Saclay, France
¹³⁵ Università degli Studi di Foggia, Foggia, Italy
¹³⁶ Università degli Studi di Pavia, Pavia, Italy
¹³⁷ Università di Brescia, Brescia, Italy
¹³⁸ V. Fock Institute for Physics, St. Petersburg State University, St. Petersburg, Russia
¹³⁹ Variable Energy Cyclotron Centre, Kolkata, India
¹⁴⁰ Warsaw University of Technology, Warsaw, Poland
¹⁴¹ Wayne State University, Detroit, MI, United States
¹⁴² Westfälische Wilhelms-Universität Münster, Institut für Kernphysik, Münster, Germany
¹⁴³ Wigner Research Centre for Physics, Hungarian Academy of Sciences, Budapest, Hungary
¹⁴⁴ Yale University, New Haven, CT, United States
¹⁴⁵ Yonsei University, Seoul, Republic of Korea

ⁱ Deceased.

ⁱⁱ Dipartimento DET del Politecnico di Torino, Turin, Italy.

ⁱⁱⁱ M.V. Lomonosov Moscow State University, D.V. Skobeltsyn Institute of Nuclear, Physics, Moscow, Russia.

^{iv} Department of Applied Physics, Aligarh Muslim University, Aligarh, India.

^v Institute of Theoretical Physics, University of Wrocław, Poland.