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# Hypertriton Production in $p$-Pb Collisions at $\sqrt{s_{NN}} = 5.02$ TeV

S. Acharya *et al.*[*]
(A Large Ion Collider Experiment Collaboration)

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The study of nuclei and antinuclei production has proven to be a powerful tool to investigate the formation mechanism of loosely bound states in high-energy hadronic collisions. The first measurement of the production of ${}^{3}_{\Lambda}\mathrm{H}$ in $p$-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV is presented in this Letter. Its production yield measured in the rapidity interval $-1 < y < 0$ for the 40% highest-multiplicity $p$-Pb collisions is $\mathrm{d}N/\mathrm{d}y = [6.3 \pm 1.8(\mathrm{stat}) \pm 1.2(\mathrm{syst})] \times 10^{-7}$. The measurement is compared with the expectations of statistical hadronization and coalescence models, which describe the nucleosynthesis in hadronic collisions. These two models predict very different yields of the hypertriton in charged particle multiplicity environments relevant to small collision systems such as $p$-Pb, and therefore the measurement of $\mathrm{d}N/\mathrm{d}y$ is crucial to distinguish between them. The precision of this measurement leads to the exclusion with a significance larger than $6.9\sigma$ of some configurations of the statistical hadronization model, thus constraining the theory behind the production of loosely bound states at hadron colliders.

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In the last few decades, the production of deuterons, ${}^{3}\mathrm{H}$, ${}^{3}\mathrm{He}$, ${}^{4}\mathrm{He}$, and their charge conjugates was measured in many different colliding systems and energies. The results of the measurements in hadronic and heavy-ion collisions at the LHC [1–7], in $e^{+}e^{-}$ collisions at LEP [8], at lower-energy colliders [9–16], and in fixed target experiments [17–20] significantly constrained the parameter space for production models like coalescence [21–23] and statistical hadronization [24,25], yet they were unable to decisively discriminate between these two models. The interest in the phenomenon of nucleosynthesis in the final state of hadronic collisions has risen again in recent years owing to its relevance in dark matter searches in space [26,27]. A precise modeling of the production of nuclei and antinuclei is required for the interpretation of the expected fluxes of antinuclei originating from dark matter annihilation, and for the relevant Standard Model background channels.

For large colliding systems, such as Pb-Pb collisions at the LHC, the predictions of statistical hadronization and coalescence models are very similar, and they are both able to describe the measured production of nuclei [28]. The statistical hadronization model (SHM) describes the system as a hadron-resonance gas (HRG) in thermal equilibrium at hadron emission, hence it predicts particle yields starting from the volume and the temperature of the system at chemical freeze-out ($T_{\mathrm{chem}}$). The grand canonical formulation of the SHM describes the measured production yields of light hadrons and nuclei in Pb-Pb collisions at 2.76 TeV with $T_{\mathrm{chem}} = 155$ MeV [5]. This temperature, which successfully describes the yield of light hadrons in central Pb-Pb collisions, is 1–2 orders of magnitude larger than the typical binding energies of light nuclei (a few MeV), and nuclei are likely to interact with the other hadrons in the dense HRG after chemical freeze-out due to the large cross sections [29], thus further modifying the yield. How these loosely bound objects can be formed and survive in such a hostile environment is still an unsolved question [30]. The coalescence model uses a different approach to explain the production of nuclei: the size of the nucleon-emitting source, accessible through the analysis of femtoscopic correlations [31], and the nuclear wave function are the two inputs that determine the formation probability of bound states [23,26]. While the SHM can compute directly the absolute yields of particles, in the hadron coalescence model the yield of bound states can be computed only relative to the yields of other particles.

The measurement of the production of large bound states in small collision systems, such as $pp$ and $p$-Pb, is considered to allow for conclusive tests [28,32] of nucleosynthesis in hadronic collisions. An extreme example is the hypertriton ${}^{3}_{\Lambda}\mathrm{H}$, the bound state of a proton, a neutron, and a $\Lambda$ baryon. This state is characterized by a very small $\Lambda$ separation energy, of the order of a few hundreds of keV [33,34], and consequently it has a wide wave function that can extend up to a radius of $\approx 10$ fm [35,36]. The size of the ${}^{3}_{\Lambda}\mathrm{H}$ wave function is therefore much larger than the hadron emission radius estimated with a femtoscopic technique in

[*]Full author list given at the end of the article.

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$p$-Pb collisions (1–2 fm [37,38]). For this reason, the ${}^{3}_{\Lambda}\mathrm{H}$ yield in $p$-Pb collisions predicted by the coalescence model, where the ratio of nucleus size to source size directly influences its yield, is suppressed with respect to the statistical hadronization model expectations, where the nuclear size does not enter explicitly [23,25,28].

The results presented in this Letter are based on data collected during the 2013 and 2016 $p$-Pb LHC runs at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. With this beam configuration, the nucleon-nucleon center-of-mass system moves in rapidity by $\Delta y_{\mathrm{cms}} = 0.465$ in the direction of the proton beam. The ALICE detector and its performance are described in detail in Refs. [39,40]. Collision events are selected by using the information from the V0A and V0C scintillator arrays [41], located on both sides of the interaction point, covering the pseudorapidity intervals $-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$. A coincident signal in both arrays is used as a minimum-bias (MB) trigger. In addition, only events with the primary vertex position within 10 cm along the beam axis to the nominal center of the experiment are selected to benefit from the full acceptance of the detector. Furthermore, to ensure the best possible performance of the detector and the proper normalization of the results, events with more than one reconstructed primary interaction vertex (pileup events) are rejected. In total, about $7.5 \times 10^{8}$ MB events are selected for analysis, corresponding to an integrated luminosity of $\mathcal{L}_{\mathrm{int}}^{\mathrm{MB}} = 359\ \mu\mathrm{b}^{-1}$, with a relative uncertainty determined by the van der Meer scan to be 3.7% [42]. For this analysis, the 40% of events with the highest multiplicity measured by the V0A detector are used.

The ${}^{3}_{\Lambda}\mathrm{H}$ candidates are reconstructed via the charged two-body decay channel ${}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-}$ (and the related charge conjugated particles for ${}^{3}_{\bar{\Lambda}}\bar{\mathrm{H}}$). In this Letter, ${}^{3}_{\Lambda}\mathrm{H}$ and ${}^{3}_{\bar{\Lambda}}\bar{\mathrm{H}}$ are combined to reduce the statistical uncertainty.

In the following, we use the notation ${}^{3}_{\Lambda}\mathrm{H}$ and ${}^{3}\mathrm{He}$ for both the particle and the antiparticle, as well as for their average. The charged-particle tracks are reconstructed in the ALICE central barrel with the inner tracking system (ITS) [43] and the time projection chamber (TPC) [44], which are located within a solenoid that provides a homogeneous magnetic field of 0.5 T in the direction of the beam axis. These two subsystems provide full azimuthal coverage for charged-particle trajectories in the pseudorapidity interval $|\eta| < 0.8$. The TPC is also used for the particle identification (PID) of the ${}^{3}\mathrm{He}$ and the $\pi^{-}$ via their specific energy loss $\mathrm{d}E/\mathrm{d}x$ in the gas volume, with a $\mathrm{d}E/\mathrm{d}x$ resolution of about 5% [44]. The $n(\sigma_i^{\mathrm{TPC}})$ variable represents the PID response in the TPC expressed in terms of the deviation between the measured and the expected $\mathrm{d}E/\mathrm{d}x$ for a particle species $i$, normalized by the detector resolution $\sigma$. The expected $\mathrm{d}E/\mathrm{d}x$ is computed with a parametrized Bethe-Bloch function [40]. Pion and ${}^{3}\mathrm{He}$ tracks within $5\sigma^{\mathrm{TPC}}$ are selected. The identified ${}^{3}\mathrm{He}$ and $\pi$ tracks are then used to reconstruct the ${}^{3}_{\Lambda}\mathrm{H}$ weak decay topology with an algorithm similar to that used in previous analyses [45,46]. By combining the information on the decay kinematics and decay vertex, several selection variables are defined. Those used in the analysis are the radial distance of the decay vertex from the beam line, the distance of each daughter track from both the primary and the decay vertices, the proper decay length of the candidate ($ct$), and $\cos(\theta_{\mathrm{P}})$, where $\theta_{\mathrm{P}}$ is the angle between the total momentum vector of the decay daughters and the straight line connecting the primary and secondary vertices. The final candidate selection based on these variables is performed with a gradient boosted decision tree classifier (BDT) implemented by the XGBoost library [47–49] and trained on a dedicated Monte Carlo (MC) simulated event sample. The MC sample is created using the HIJING event generator [50] for simulating the underlying $p$-Pb collisions, while ${}^{3}_{\Lambda}\mathrm{H}$ are injected with a $p_{\mathrm{T}}$ distribution represented by a $m_{\mathrm{T}}$ exponential function that describes the $p_{\mathrm{T}}$ distribution of ${}^{3}\mathrm{He}$ as measured in $p$-Pb collisions [5]. The particles are transported through the detector geometry using GEANT4 [51], which simulates the interaction with the material and the weak decay of the ${}^{3}_{\Lambda}\mathrm{H}$. The BDT is a supervised learning algorithm that determines how to discriminate between two or more classes, signal and background in this case, by examining sets of examples called the training sets. In this analysis, the training sets are composed of ${}^{3}_{\Lambda}\mathrm{H}$ signal candidates extracted from the MC sample and background candidates from paired like-sign ${}^{3}\mathrm{He}$ and $\pi$ tracks from the data. For each ${}^{3}_{\Lambda}\mathrm{H}$ candidate, the BDT combines topological and single track variables to return a score, which is proportional to the candidate probability of being signal or background. The selection is based on the BDT score, defining a threshold that maximizes the expected signal significance, assuming thermal production. In this analysis, the default BDT score selection corresponds to a 72% signal efficiency and a $3 \times 10^{-5}$ background rejection factor. The candidates that pass the BDT selection are used to populate the invariant mass distribution in the transverse momentum interval $0 < p_{\mathrm{T}} < 9$ GeV/$c$. An excess of entries is observed at a mass near 2.99 GeV/$c^2$, as shown in Fig. 1. The unbinned distribution is fitted with a kernel density estimator (KDE) [52,53] function tuned on the MC sample to describe the signal and a linear function to describe the background component. The KDE is chosen for smoothing the template extracted from the MC. The invariant mass distribution with the superimposed fit is shown in Fig. 1.

The significance associated with the signal is evaluated following the procedure described in Ref. [54]: the probability for a background fluctuation to be at least as large as the observed maximum excess (local $p$-value) is computed by employing the asymptotic formulas for likelihood-based tests. The local $p$-value is expressed as a corresponding number of standard deviations using the one-sided

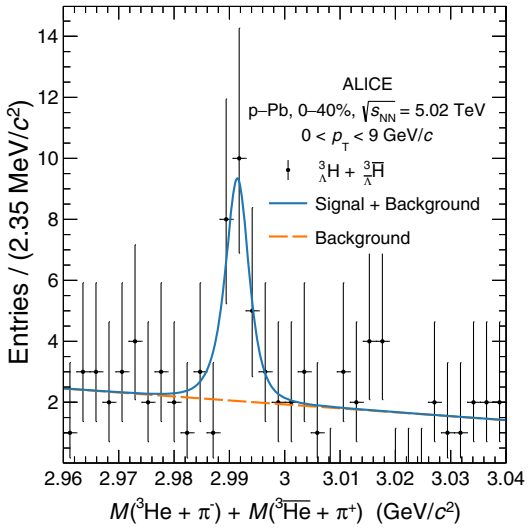



FIG. 1. Invariant mass distribution of the $^3\text{He} + \pi^-$ and charge conjugate pairs passing the analysis selections. Vertical lines represent the statistical Poissonian uncertainties. The invariant mass spectrum is fitted with a two-component model: the blue line represents the total fit, while the orange dashed line shows the background component only.

Gaussian tail convention. The excess of entries observed above the expected background has a local significance of 4.6 standard deviations at the nominal $^3_\Lambda$H mass. The production yield is obtained starting from the signal extracted from the fit to the invariant mass spectrum. Then the fitted signal is corrected for the reconstruction and the selection efficiency, including reconstruction efficiencies for the daughter particles and the topology, the acceptance of the ALICE detector, the number of analyzed events, the branching ratio (BR) of the $^3_\Lambda$H in the two-body decay channel, and the fraction of $^3_\Lambda$H that are absorbed in the ALICE detector ($f_{\text{abs}}$). The simulation of inelastic interactions of the daughter particles is done with GEANT4 and is taken into account in the reconstruction efficiency computation. The BR value is assumed to be 0.25 according to the calculation published in Ref. [55].

The systematic uncertainties originate from (1) the $^3_\Lambda$H selection and the signal extraction, (2) the choice of the $^3_\Lambda$H input $p_{\text{T}}$ distribution in the Monte Carlo sample, and (3) the $^3_\Lambda$H absorption in the detector. In addition, (4) a 9% systematic uncertainty is added due to the uncertainty of the BR, as explained later in the text. The total uncertainty is obtained as the quadratic sum of the individual contributions. The first contribution, which is the dominant one, is computed by varying simultaneously the BDT threshold (±5%) and the background fit function (constant, linear, exponential). The standard deviation (rms) of the different yields represents our systematic error associated with the BDT selection and the signal extraction, and it amounts to 14%. The second contribution is evaluated by using different input $p_{\text{T}}$ distributions for the Monte Carlo sample and evaluating the effects on the efficiency. Four different $p_{\text{T}}$ models (mT exponential, $p_{\text{T}}$ exponential, Boltzmann, and blast wave [56]) are fitted to the $^3$He $p_{\text{T}}$ distribution [5]. For each of them, the efficiency and the yield are computed assuming that the $^3$He and the $^3_\Lambda$H have the same $p_{\text{T}}$ distributions as already seen for light flavor hadrons with similar masses in all collision systems [1,45,57]. The rms among the trials is calculated, yielding a systematic uncertainty of 7%. Finally, the uncertainty of $f_{\text{abs}}$ is considered. According to Ref. [58], the expected absorption cross section of $^3_\Lambda$H due to the inelastic interactions in the ALICE detector material is ≈1.5 times that of $^3\overline{\text{He}}$ ($\sigma^{^3\overline{\text{He}}}_{\text{inel}}$). The value of $f_{\text{abs}}$ is computed by simulating the passage of hypertritons through the ALICE detector using this cross section and gives a result of ≈3%. The systematic uncertainty of $f_{\text{abs}}$ is evaluated by employing different cross sections for the $^3_\Lambda$H from zero (no interactions) to $2\sigma^{^3\text{He}}_{\text{inel}}$. For each variation, $f_{\text{abs}}$ is recalculated. This results in a systematic uncertainty on the yield of about 4%. Larger variations of the inelastic cross section are not considered here, as they spoil the exponential trend of the proper decay length spectrum measured in Pb-Pb collisions.

The resulting corrected $^3_\Lambda$H yield in the rapidity interval $-1 < y < 0$, together with its statistical and systematic uncertainties, is

$$\frac{\text{d}N}{\text{d}y} = [6.3 \pm 1.8(\text{stat}) \pm 1.2(\text{syst})] \times 10^{-7}.$$

The result is compared with the expectations from the canonical SHM [25], which assumes exact conservation of baryon number, strangeness, and electric charge across a correlation volume $V_c$. The SHM predictions are computed using a fixed chemical freeze-out temperature of $T_{\text{chem}} =$ 155 MeV, two correlation volumes extending across one unit ($V_c = \text{d}V/\text{d}y$), and three units ($V_c = 3\text{d}V/\text{d}y$) of rapidity [25]. The size of the correlation volume governs the influence of exact quantum number conservation, with smaller values leading to a stronger suppression of conserved charges and $V_c \to \infty$ leading to the grand canonical ensemble. The $^3_\Lambda$H $p_{\text{T}}$ integrated yield is $1.1 \times 10^{-6}$ and $2.0 \times 10^{-6}$ with $V_c = \text{d}V/\text{d}y$ and $V_c = 3\text{d}V/\text{d}y$, respectively. The $\text{d}N/\text{d}y$ predictions by the model were obtained using the code released together with the publication [59].

As explained above, in the case of the coalescence model, it is not possible to compare directly the measured absolute yield to the model prediction. Hence, this comparison is attained by computing the $^3_\Lambda\text{H}/\Lambda$ ratio and the strangeness population factor $S_3 = (^3_\Lambda\text{H}/^3\text{He})/(\Lambda/p)$ [60] using previous ALICE measurements of $p$, $\Lambda$, and $^3$He yields [5,57], as shown in Fig. 2. The yield of the $\Lambda$ baryon, measured in $-0.5 < y < 0$, has been extrapolated to the $^3_\Lambda$H rapidity region using MC generators [61–63] that are known to reproduce the pseudorapidity density distribution

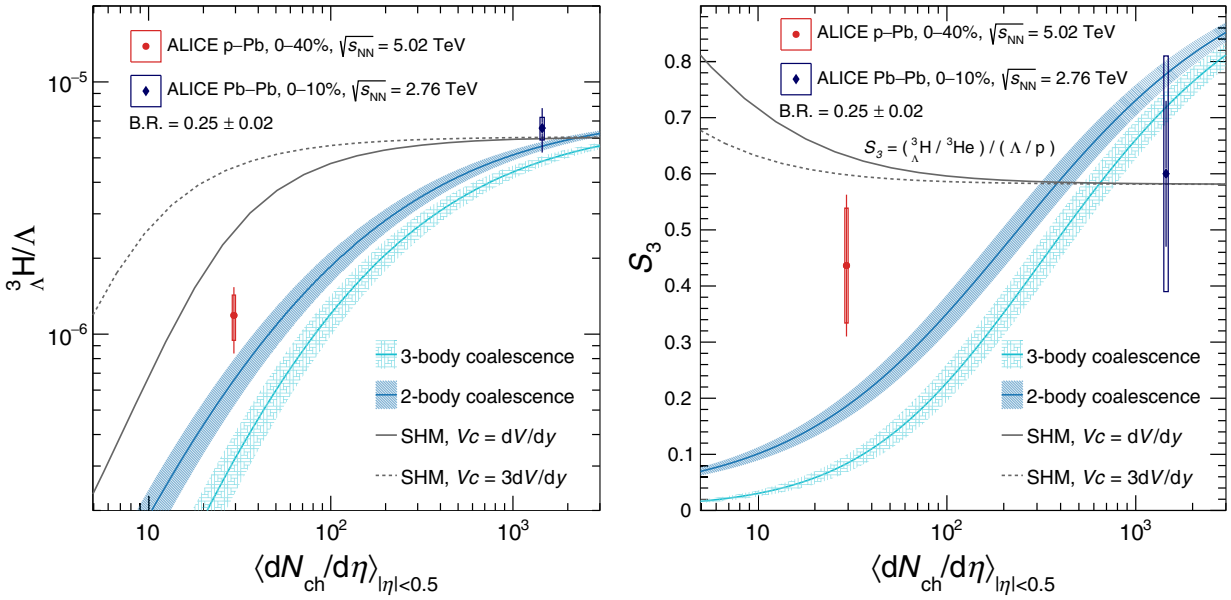



FIG. 2. $^3_\Lambda$H/Λ (on the left) and $S_3$ (on the right) measurements in $p$-Pb (in red) and Pb-Pb collisions [45] (in blue) as a function of mean charged-particle multiplicity. The vertical lines and boxes are the statistical and systematic uncertainties (including the uncertainty on the BR), respectively. The expectations for the canonical statistical hadronization [25] and coalescence models are shown [23].

of charged hadrons [64]. The corresponding correction is approximately 2%. In central Pb-Pb collisions, the data are consistent with both coalescence and SHM predictions, which are similar, as shown in Fig. 2. The situation is different for $p$-Pb collisions, where the two models are well separated. Taking into account the uncertainties of the measurement as well as the model uncertainty, the measured $S_3$ ratio is compatible with the two-body (deuteron-Λ) and three-body (proton-neutron-Λ) coalescence within $1.2\sigma$ and $2\sigma$, respectively. With its large uncertainties, also due to the large uncertainty on the $^3$He yield, the $S_3$ is compatible within $2\sigma$ with the SHM calculations too. Hence, the $^3_\Lambda$H/Λ ratio is used as a test for coalescence and SHM predictions in the following. In this case, the measurement is deviating by $3.2\sigma$ and $7.9\sigma$ from the SHM with $V_c = 1dV/dy$ and $V_c = 3dV/dy$, respectively. On the other hand, both the coalescence calculations are within $2\sigma$ of the measured $^3_\Lambda$H/Λ. It has to be noted that recent measurements of the $^3_\Lambda$H mass [34] suggest a larger binding energy, and hence a smaller wave function, of the $^3_\Lambda$H. This would further shift upward the coalescence predictions.

The value of BR = 0.25 for the $^3_\Lambda H \to {}^3H + \pi$ decay used in this analysis was computed theoretically in Ref. [55]. To investigate the uncertainty resulting from this assumption, Fig. 3 shows the measured $^3_\Lambda$H/Λ × BR. for different theoretical model calculations [23,25] assuming a possible variation of the BR value. The variation range is chosen by evaluating the relative deviation between the theoretical $R_3$ and the world average of all the $R_3$ measurements, including the most recent measurement in heavy-ion collisions [65], where $R_3$ is defined as

$$R_3 = \frac{\Gamma(^3_\Lambda H \to {}^3He + \pi^-)}{\Gamma(^3_\Lambda H \to \text{all } \pi^- \text{ decay channels})}.$$

This uncertainty on $R_3$ is propagated to the BR($^3_\Lambda H \to {}^3He + \pi^-$) and corresponds to a variation range of ±9% around the nominal value. While the two-body coalescence

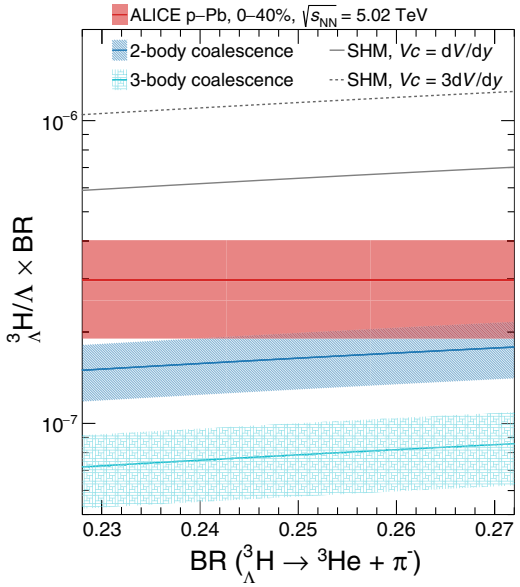



FIG. 3. $^3_\Lambda$H/Λ times branching ratio as a function of branching ratio. The horizontal line is the measured value, and the band represents statistical and systematic uncertainties added in quadrature. The expectations for the canonical statistical hadronization [25] and coalescence models are shown [23].

calculation is compatible with the data for the nominal or larger BR, a discrepancy of $2\sigma$ is observed between data and the three-body coalescence prediction. Furthermore, in the whole BR variation interval, the SHM is more than $2.7\sigma$ and $6.9\sigma$ away from the measured ${}^{3}_{\Lambda}\mathrm{H}/\Lambda \times \mathrm{BR}$ for the $V_c = 1\mathrm{d}V/\mathrm{d}y$ and $V_c = 3\mathrm{d}V/\mathrm{d}y$ configurations, respectively.

In summary, the first measurement of the production yield of hypertritons in $p$-Pb collisions at the LHC is reported. The measurements of yields of ${}^{3}_{\Lambda}\mathrm{H}$ in $p$-Pb collisions provide an opportunity to potentially discriminate between nucleosynthesis models. The measured $p_{\mathrm{T}}$ integrated yield excludes, with high significance, canonical versions of the SHM with $V_c \geq 3\mathrm{d}V/\mathrm{d}y$ to explain the (hyper)nuclei production in $p$-Pb collisions. It remains to be seen if advanced versions of the SHM using the S-matrix approach to account for the interactions among hadrons [66] will be able to solve this discrepancy. The ${}^{3}_{\Lambda}\mathrm{H}/\Lambda$ ratio is well described by the two-body coalescence prediction, while the three-body formulation is slightly disfavored by our measurement. While the general conclusions of the comparison with the models are unaltered even when considering large variations of the $\mathrm{BR}({}^{3}_{\Lambda}\mathrm{H} \to {}^{3}\mathrm{He} + \pi^{-})$ around the value available in literature, the significance of the comparison between data and models is influenced by this uncertainty. Upcoming studies using the LHC Run 2 Pb-Pb data will help to reduce this uncertainty by measuring the ${}^{3}_{\Lambda}\mathrm{H} \to d + p + \pi^{-}$ decay channel relative branching ratio. Furthermore, with the upgraded ALICE apparatus and the upcoming LHC Run 3, it will be possible to reduce both the statistical and the systematic uncertainties of the ${}^{3}_{\Lambda}\mathrm{H}$ yield measurements in $pp$ [67] and $p$-Pb collisions and to study the ${}^{3}_{\Lambda}\mathrm{H}$ production as a function of the size of the nucleon-emitting source measured with femtoscopic correlations. These studies may make it possible to decisively distinguish between the two production models.

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[1] J. Adam *et al.* (ALICE Collaboration), Production of light nuclei and anti-nuclei in $pp$ and Pb-Pb collisions at energies available at the CERN Large Hadron Collider, Phys. Rev. C **93**, 024917 (2016).

[2] S. Acharya *et al.* (ALICE Collaboration), Measurement of deuteron spectra and elliptic flow in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV at the LHC, Eur. Phys. J. C **77**, 658 (2017).

[3] S. Acharya *et al.* (ALICE Collaboration), Multiplicity dependence of (anti-)deuteron production in $pp$ collisions at $\sqrt{s} = 7$ TeV, Phys. Lett. B **794**, 50 (2019).

[4] S. Acharya *et al.* (ALICE Collaboration), Multiplicity dependence of light (anti-)nuclei production in $p$-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, Phys. Lett. B **800**, 135043 (2020).

[5] S. Acharya *et al.* (ALICE Collaboration), Production of (anti-)$^3$He and (anti-)$^3$H in $p$-Pb collisions at $\sqrt{s_{\mathrm{NN}}} =$ 5.02 TeV, Phys. Rev. C **101**, 044906 (2020).

[6] S. Acharya *et al.* (ALICE Collaboration), (Anti-)deuteron production in $pp$ collisions at $\sqrt{s} = 13$ TeV, Eur. Phys. J. C **80**, 889 (2020).

[7] S. Acharya *et al.* (ALICE Collaboration), Production of $^4$He and $^4\overline{\mathrm{He}}$ in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV at the LHC, Nucl. Phys. **A971**, 1 (2018).

[8] S. Schael *et al.* (ALEPH Collaboration), Deuteron and anti-deuteron production in $e^+e^-$ collisions at the Z resonance, Phys. Lett. B **639**, 192 (2006).

[9] B. Alper *et al.* (British-Scandinavian Collaboration), Large angle production of stable particles heavier than the proton and a search for quarks at the CERN intersecting storage rings, Phys. Lett. **46B**, 265 (1973).

[10] S. Henning *et al.* (British-Scandinavian-MIT Collaboration), Production of deuterons and anti-deuterons in proton-proton collisions at the CERN ISR, Lett. Nuovo Cimento **21**, 189 (1978).

[11] T. Alexopoulos *et al.* (E735 Collaboration), Cross-sections for deuterium, tritium, and helium production in $pp$ collisions at $s = 1.8$ TeV, Phys. Rev. D **62**, 072004 (2000).

[12] C. Adler *et al.* (STAR Collaboration), Anti-Deuteron and Anti-$^3$He Production in $\sqrt{s_{\mathrm{NN}}} = 130$ GeV Au + Au Collisions, Phys. Rev. Lett. **87**, 262301 (2001); Phys. Rev. Lett. **87**, 279902(E) (2001).

[13] S. S. Adler *et al.* (PHENIX Collaboration), Deuteron and Antideuteron Production in Au + Au Collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV, Phys. Rev. Lett. **94**, 122302 (2005).

[14] A. Aktas *et al.* (H1 Collaboration), Measurement of anti-deuteron photoproduction and a search for heavy stable charged particles at HERA, Eur. Phys. J. C **36**, 413 (2004).

[15] D. M. Asner *et al.* (CLEO Collaboration), Anti-deuteron production in Upsilon(nS) decays and the nearby continuum, Phys. Rev. D **75**, 012009 (2007).

[16] H. Agakishiev *et al.* (STAR Collaboration), Observation of the antimatter helium-4 nucleus, Nature (London) **473**, 353 (2011); Nature (London) **475**, 412(E) (2011).

[17] J. Simon-Gillo *et al.* (NA44 Collaboration), Deuteron and anti-deuteron production in CERN experiment NA44, Nucl. Phys. **A590**, 483C (1995).

[18] T. A. Armstrong *et al.* (E864 Collaboration), Anti-Deuteron Yield at the AGS and Coalescence Implications, Phys. Rev. Lett. **85**, 2685 (2000).

[19] S. V. Afanasev *et al.* (NA49 Collaboration), Deuteron production in central Pb + Pb collisions at 158A GeV, Phys. Lett. B **486**, 22 (2000).

[20] T. Anticic *et al.* (NA49 Collaboration), Energy and centrality dependence of deuteron and proton production in Pb + Pb collisions at relativistic energies, Phys. Rev. C **69**, 024902 (2004).

[21] S. Mrowczynski, Deuteron formation mechanism, J. Phys. G **13**, 1089 (1987).

[22] R. Scheibl and U. W. Heinz, Coalescence and flow in ultrarelativistic heavy ion collisions, Phys. Rev. C **59**, 1585 (1999).

[23] K.-J. Sun, C. M. Ko, and B. Dönigus, Suppression of light nuclei production in collisions of small systems at the Large Hadron Collider, Phys. Lett. B **792**, 132 (2019).

[24] A. Andronic, P. Braun-Munzinger, J. Stachel, and H. Stocker, Production of light nuclei, hypernuclei and their antiparticles in relativistic nuclear collisions, Phys. Lett. B **697**, 203 (2011).

[25] V. Vovchenko, B. Dönigus, and H. Stoecker, Multiplicity dependence of light nuclei production at LHC energies in the canonical statistical model, Phys. Lett. B **785**, 171 (2018).

[26] K. Blum, Kenny Chun Yu Ng, R. Sato, and M. Takimoto, Cosmic rays, antihelium, and an old navy spotlight, Phys. Rev. D **96**, 103021 (2017).

[27] M. Korsmeier, F. Donato, and N. Fornengo, Prospects to verify a possible dark matter hint in cosmic antiprotons with antideuterons and antihelium, Phys. Rev. D **97**, 103011 (2018).

[28] F. Bellini and A. P. Kalweit, Testing coalescence and statistical-thermal production scenarios for (anti-)(hyper-) nuclei and exotic QCD objects at LHC energies, Phys. Rev. C **99**, 054905 (2019).

[29] D. Oliinychenko, L.-G. Pang, H. Elfner, and V. Koch, Microscopic study of deuteron production in Pb-Pb collisions at $\sqrt{s} = 2.76$ TeV via hydrodynamics and a hadronic afterburner, Phys. Rev. C **99**, 044907 (2019).

[30] A. Andronic, P. Braun-Munzinger, K. Redlich, and J. Stachel, Decoding the phase structure of QCD via particle production at high energy, Nature (London) **561**, 321 (2018).

[31] S. Acharya *et al.* (ALICE Collaboration), Search for a common baryon source in high-multiplicity $pp$ collisions at the LHC, Phys. Lett. B **811**, 135849 (2020).

[32] F. Bellini, K. Blum, A. P. Kalweit, and M. Puccio, Examination of coalescence as the origin of nuclei in hadronic collisions, Phys. Rev. C **103**, 014907 (2021).

[33] D. H. Davis, 50 years of hypernuclear physics. I. The early experiments, Nucl. Phys. **A754**, 3 (2005).

[34] J. Adam *et al.* (STAR Collaboration), Measurement of the mass difference and the binding energy of the hypertriton and antihypertriton, Nat. Phys. **16**, 409 (2020).

[35] H. Nemura, Y. Suzuki, Y. Fujiwara, and C. Nakamoto, Study of light Lambda and Lambda-Lambda hypernuclei with the stochastic variational method and effective Lambda $N$ potentials, Prog. Theor. Phys. **103**, 929 (2000).

[36] F. Hildenbrand and H. W. Hammer, Three-body hypernuclei in pionless effective field theory, Phys. Rev. C **100**, 034002 (2019); Phys. Rev. C **102**, 039901(E) (2020).

[37] B. Abelev *et al.* (ALICE Collaboration), Freeze-out radii extracted from three-pion cumulants in $pp$, $p$-Pb and Pb-Pb collisions at the LHC, Phys. Lett. B **739**, 139 (2014).

[38] J. Adam *et al.* (ALICE Collaboration), Two-pion femtoscopy in $p$-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, Phys. Rev. C **91**, 034906 (2015).

[39] K. Aamodt *et al.* (ALICE Collaboration), The ALICE experiment at the CERN LHC, J. Instrum. **3**, S08002 (2008).

[40] B. Abelev *et al.* (ALICE Collaboration), Performance of the ALICE Experiment at the CERN LHC, Int. J. Mod. Phys. A **29**, 1430044 (2014).

[41] E. Abbas *et al.* (ALICE Collaboration), Performance of the ALICE VZERO system, J. Instrum. **8**, P10016 (2013).

[42] B. B. Abelev *et al.* (ALICE Collaboration), Measurement of visible cross sections in proton-lead collisions at $\sqrt{s_{\mathrm{NN}}} =$ 5.02 TeV in van der Meer scans with the ALICE detector, J. Instrum. **9**, P11003 (2014).

[43] K. Aamodt *et al.* (ALICE Collaboration), Alignment of the ALICE inner tracking system with cosmic-ray tracks, J. Instrum. **5**, P03003 (2010).

[44] J. Alme *et al.*, The ALICE TPC, a large 3-dimensional tracking device with fast readout for ultra-high multiplicity events, Nucl. Instrum. Methods Phys. Res., Sect. A **622**, 316 (2010).

[45] J. Adam *et al.* (ALICE Collaboration), ${}^{3}_{\Lambda}\mathrm{H}$ and ${}^{3}_{\Lambda}\bar{\mathrm{H}}$ production in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV, Phys. Lett. B **754**, 360 (2016).

[46] S. Acharya *et al.* (ALICE Collaboration), ${}^{3}_{\Lambda}\mathrm{H}$ and ${}^{3}_{\Lambda}\bar{\mathrm{H}}$ lifetime measurement in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} =$ 5.02 TeV via two-body decay, Phys. Lett. B **797**, 134905 (2019).

[47] T. Chen and C. Guestrin, Xgboost: A scalable tree boosting system, in *Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, KDD '16 (Association for Computing Machinery, New York, NY, USA, 2016), pp. 785–794.

[48] M. Aaboud *et al.* (ATLAS Collaboration), Observation of Higgs boson production in association with a top quark pair at the LHC with the ATLAS detector, Phys. Lett. B **784**, 173 (2018).

[49] L. Barioglio, F. Catalano, M. Concas, P. Fecchio, F. Grosa, F. Mazzaschi, and M. Puccio, hipe4ml/hipe4ml, 10.5281/zenodo.5734093 (2021).

[50] X.-N. Wang and M. Gyulassy, HIJING: A Monte Carlo model for multiple jet production in $pp$, $pA$ and $AA$ collisions, Phys. Rev. D **44**, 3501 (1991).

[51] S. Agostinelli *et al.* (GEANT4 Collaboration), GEANT4: a simulation toolkit, Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).

[52] K. S. Cranmer, Kernel estimation in high-energy physics, Comput. Phys. Commun. **136**, 198 (2001).

[53] W. Verkerke and D. P. Kirkby, The RooFit toolkit for data modeling, eConf **C0303241**, MOLT007 (2003) [arXiv:physics/0306116].

[54] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, Asymptotic formulae for likelihood-based tests of new physics, Eur. Phys. J. C **71**, 1554 (2011); Eur. Phys. J. C **73**, 2501(E) (2013).

[55] H. Kamada, J. Golak, K. Miyagawa, H. Witała, and W. Glöeckle, Pi mesonic decay of the hypertriton, Phys. Rev. C **57**, 1595 (1998).

[56] E. Schnedermann, J. Sollfrank, and U. W. Heinz, Thermal phenomenology of hadrons from 200 A/GeV S + S collisions, Phys. Rev. C **48**, 2462 (1993).

[57] B. Abelev *et al.* (ALICE Collaboration), Multiplicity dependence of pion, kaon, proton and lambda production in $p$-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, Phys. Lett. B **728**, 25 (2014).

[58] M. V. Evlanov, A. M. Sokolov, V. K. Tartakovsky, S. A. Khorozov, and Y. Lukstinsh, Interaction of hypertritons with nuclei at high-energies, Nucl. Phys. **A632**, 624 (1998).

[59] V. Vovchenko and H. Stoecker, Thermal-FIST: A package for heavy-ion collisions and hadronic equation of state, Comput. Phys. Commun. **244**, 295 (2019).

[60] S. Zhang, J. H. Chen, H. Crawford, D. Keane, Y. G. Ma, and Z. B. Xu, Searching for onset of deconfinement via hypernuclei and baryon-strangeness correlations, Phys. Lett. B **684**, 224 (2010).

[61] M. Gyulassy and X.-N. Wang, HIJING 1.0: A Monte Carlo program for parton and particle production in high-energy hadronic and nuclear collisions, Comput. Phys. Commun. **83**, 307 (1994).

[62] T. Pierog, I. Karpenko, J. M. Katzy, E. Yatsenko, and K. Werner, EPOS LHC: Test of collective hadronization with data measured at the CERN Large Hadron Collider, Phys. Rev. C **92**, 034906 (2015).

[63] S. Roesler, R. Engel, and J. Ranft, The Monte Carlo event generator DPMJET-III, in *International Conference on Advanced Monte Carlo for Radiation Physics, Particle Transport Simulation and Applications (MC 2000)* (Springer, Berlin, 2000), pp. 1033–1038.

[64] B. Abelev *et al.* (ALICE Collaboration), Pseudorapidity Density of Charged Particles in $p$ + Pb Collisions

at $\sqrt{s_{NN}} = 5.02$ TeV, Phys. Rev. Lett. **110**, 032301 (2013).

[65] L. Adamczyk *et al.* (STAR Collaboration), Measurement of the $^{3}_{\Lambda}$H lifetime in Au + Au collisions at the BNL relativistic heavy ion collider, Phys. Rev. C **97**, 054909 (2018).

[66] J. Cleymans, P. M. Lo, K. Redlich, and N. Sharma, Multiplicity dependence of (multi)strange baryons in the canonical ensemble with phase shift corrections, Phys. Rev. C **103**, 014904 (2021).

[67] ALICE Collaboration, Future high-energy $pp$ programme with ALICE (2020), http://cds.cern.ch/record/2724925.

S. Acharya,[143] D. Adamová,[98] A. Adler,[76] G. Aglieri Rinella,[35] M. Agnello,[31] N. Agrawal,[55] Z. Ahammed,[143] S. Ahmad,[16] S. U. Ahn,[78] I. Ahuja,[39] Z. Akbar,[52] A. Akindinov,[95] M. Al-Turany,[110] S. N. Alam,[16,41] D. Aleksandrov,[91] B. Alessandro,[61] H. M. Alfanda,[7] R. Alfaro Molina,[73] B. Ali,[16] Y. Ali,[14] A. Alici,[26a,26b] N. Alizadehvandchali,[127] A. Alkin,[35] J. Alme,[21] T. Alt,[70] L. Altenkamper,[21] I. Altsybeev,[115] M. N. Anaam,[7] C. Andrei,[49] D. Andreou,[93] A. Andronic,[146] M. Angeletti,[35] V. Anguelov,[107] F. Antinori,[58] P. Antonioli,[55] C. Anuj,[16] N. Apadula,[82] L. Aphecetche,[117] H. Appelshäuser,[70] S. Arcelli,[26a,26b] R. Arnaldi,[61] I. C. Arsene,[20] M. Arslandok,[107,148] A. Augustinus,[35] R. Averbeck,[110] S. Aziz,[80] M. D. Azmi,[16] A. Badalà,[57] Y. W. Baek,[42] X. Bai,[110,131] R. Bailhache,[70] Y. Bailung,[51] R. Bala,[104] A. Balbino,[31] A. Baldisseri,[140] B. Balis,[2] M. Ball,[44] D. Banerjee,[4a,4b] R. Barbera,[27a,27b] L. Barioglio,[108] M. Barlou,[87] G. G. Barnaföldi,[147] L. S. Barnby,[97] V. Barret,[137] C. Bartels,[130] K. Barth,[35] E. Bartsch,[70] F. Baruffaldi,[28a,28b] N. Bastid,[137] S. Basu,[83] G. Batigne,[117] B. Batyunya,[77] D. Bauri,[50] J. L. Bazo Alba,[114] I. G. Bearden,[92] C. Beattie,[148] I. Belikov,[139] A. D. C. Bell Hechavarria,[146] F. Bellini,[26a,26b] R. Bellwied,[127] S. Belokurova,[115] V. Belyaev,[96] G. Bencedi,[71] S. Beole,[25a,25b] A. Bercuci,[49] Y. Berdnikov,[101] A. Berdnikova,[107] L. Bergmann,[107] M. G. Besoiu,[69] L. Betev,[35] P. P. Bhaduri,[143] A. Bhasin,[104] I. R. Bhat,[104] M. A. Bhat,[4a,4b] B. Bhattacharjee,[43] P. Bhattacharya,[23a,23b] L. Bianchi,[25a,25b] N. Bianchi,[53] J. Bielčík,[38] J. Bielčíková,[98] J. Biernat,[120] A. Bilandzic,[108] G. Biro,[147] S. Biswas,[4a,4b] J. T. Blair,[121] D. Blau,[91] M. B. Blidaru,[110] C. Blume,[70] G. Boca,[29,59] F. Bock,[99] A. Bogdanov,[96] S. Boi,[23a,23b] J. Bok,[63] L. Boldizsár,[147] A. Bolozdynya,[96] M. Bombara,[39] P. M. Bond,[35] G. Bonomi,[59,142] H. Borel,[140] A. Borissov,[84] H. Bossi,[148] E. Botta,[25a,25b] L. Bratrud,[70] P. Braun-Munzinger,[110] M. Bregant,[123] M. Broz,[38] G. E. Bruno,[34a,34b,109] M. D. Buckland,[130] D. Budnikov,[111] H. Buesching,[70] S. Bufalino,[31] O. Bugnon,[117] P. Buhler,[116] Z. Buthelezi,[74,134] J. B. Butt,[14] S. A. Bysiak,[120] M. Cai,[7,28a,28b] H. Caines,[148] A. Caliva,[110] E. Calvo Villar,[114] J. M. M. Camacho,[122] R. S. Camacho,[46] P. Camerini,[24a,24b] F. D. M. Canedo,[123] F. Carnesecchi,[26a,26b,35] R. Caron,[140] J. Castillo Castellanos,[140] E. A. R. Casula,[23a,23b] F. Catalano,[31] C. Ceballos Sanchez,[77] P. Chakraborty,[50] S. Chandra,[143] S. Chapeland,[35] M. Chartier,[130] S. Chattopadhyay,[143] S. Chattopadhyay,[112] A. Chauvin,[23a,23b] T. G. Chavez,[46] T. Cheng,[7] C. Cheshkov,[138] B. Cheynis,[138] V. Chibante Barroso,[35] D. D. Chinellato,[124] S. Cho,[63] P. Chochula,[35] P. Christakoglou,[93] C. H. Christensen,[92] P. Christiansen,[83] T. Chujo,[136] C. Cicalo,[56] L. Cifarelli,[26a,26b] F. Cindolo,[55] M. R. Ciupek,[110] G. Clai,[55,b] J. Cleymans,[126,a] F. Colamaria,[54] J. S. Colburn,[113] D. Colella,[34a,34b,54,109,147] A. Collu,[82] M. Colocci,[35] M. Concas,[61,c] G. Conesa Balbastre,[81] Z. Conesa del Valle,[80] G. Contin,[24a,24b] J. G. Contreras,[38] M. L. Coquet,[140] T. M. Cormier,[99] P. Cortese,[32] M. R. Cosentino,[125] F. Costa,[35] S. Costanza,[29,59] P. Crochet,[137] R. Cruz-Torres,[82] E. Cuautle,[71] P. Cui,[7] L. Cunqueiro,[99] A. Dainese,[58] M. C. Danisch,[107] A. Danu,[69] I. Das,[112] P. Das,[89] P. Das,[4a,4b] S. Das,[4a,4b] S. Dash,[50] S. De,[89] A. De Caro,[30a,30b] G. de Cataldo,[54] L. De Cilladi,[25a,25b] J. de Cuveland,[40] A. De Falco,[23a,23b] D. De Gruttola,[30a,30b] N. De Marco,[61] C. De Martin,[24a,24b] S. De Pasquale,[30a,30b] S. Deb,[51] H. F. Degenhardt,[123] K. R. Deja,[144] L. Dello Stritto,[30a,30b] S. Delsanto,[25a,25b] W. Deng,[7] P. Dhankher,[19] D. Di Bari,[34a,34b] A. Di Mauro,[35] R. A. Diaz,[8] T. Dietel,[126] Y. Ding,[7,138] R. Divià,[35] D. U. Dixit,[19] Ø. Djuvsland,[21] U. Dmitrieva,[65] J. Do,[63] A. Dobrin,[69] B. Dönigus,[70] O. Dordic,[20] A. K. Dubey,[143] A. Dubla,[93,110] S. Dudi,[103] M. Dukhishyam,[89] P. Dupieux,[137] N. Dzalaiova,[13] T. M. Eder,[146] R. J. Ehlers,[99] V. N. Eikeland,[21] F. Eisenhut,[70] D. Elia,[54] B. Erazmus,[117] F. Ercolessi,[26a,26b] F. Erhardt,[102] A. Erokhin,[115] M. R. Ersdal,[21] B. Espagnon,[80] G. Eulisse,[35] D. Evans,[113] S. Evdokimov,[94] L. Fabbietti,[108] M. Faggin,[28a,28b] J. Faivre,[81] F. Fan,[7] A. Fantoni,[53] M. Fasel,[99] P. Fecchio,[31] A. Feliciello,[61] G. Feofilov,[115] A. Fernández Téllez,[46] A. Ferrero,[140] A. Ferretti,[25a,25b] V. J. G. Feuillard,[107] J. Figiel,[120] S. Filchagin,[111] D. Finogeev,[65] F. M. Fionda,[21,56] G. Fiorenza,[35,109] F. Flor,[127] A. N. Flores,[121] S. Foertsch,[74] P. Foka,[110] S. Fokin,[91] E. Fragiacomo,[62] E. Frajna,[147] U. Fuchs,[35] N. Funicello,[30a,30b] C. Furget,[81] A. Furs,[65] J. J. Gaardhøje,[92] M. Gagliardi,[25a,25b] A. M. Gago,[114] A. Gal,[139] C. D. Galvan,[122] P. Ganoti,[87] C. Garabatos,[110] J. R. A. Garcia,[46] E. Garcia-Solis,[10] K. Garg,[117] C. Gargiulo,[35] A. Garibli,[90] K. Garner,[146] P. Gasik,[110] E. F. Gauger,[121] A. Gautam,[129] M. B. Gay Ducati,[72] M. Germain,[117] P. Ghosh,[143] S. K. Ghosh,[4a,4b] M. Giacalone,[26a,26b] P. Gianotti,[53] P. Giubellino,[61,110] P. Giubilato,[28a,28b] A. M. C. Glaenzer,[140] P. Glässel,[107] D. J. Q. Goh,[85] V. Gonzalez,[145]

L. H. González-Trueba,[73] S. Gorbunov,[40] M. Gorgon,[2] L. Görlich,[120] S. Gotovac,[36] V. Grabski,[73] L. K. Graczykowski,[144] L. Greiner,[82] A. Grelli,[64] C. Grigoras,[35] V. Grigoriev,[96] A. Grigoryan,[1,a] S. Grigoryan,[1,77] O. S. Groettvik,[21] F. Grosa,[35,61] J. F. Grosse-Oetringhaus,[35] R. Grosso,[110] G. G. Guardiano,[124] R. Guernane,[81] M. Guilbaud,[117] K. Gulbrandsen,[92] T. Gunji,[135] W. Guo,[7] A. Gupta,[104] R. Gupta,[104] S. P. Guzman,[46] L. Gyulai,[147] M. K. Habib,[110] C. Hadjidakis,[80] G. Halimoglu,[70] H. Hamagaki,[85] G. Hamar,[147] M. Hamid,[7] R. Hannigan,[121] M. R. Haque,[89,144] A. Harlenderova,[110] J. W. Harris,[148] A. Harton,[10] J. A. Hasenbichler,[35] H. Hassan,[99] D. Hatzifotiadou,[55] P. Hauer,[44] L. B. Havener,[148] S. Hayashi,[135] S. T. Heckel,[108] E. Hellbär,[110] H. Helstrup,[37] T. Herman,[38] E. G. Hernandez,[46] G. Herrera Corral,[9] F. Herrmann,[146] K. F. Hetland,[37] H. Hillemanns,[35] C. Hills,[130] B. Hippolyte,[139] B. Hofman,[64] B. Hohlweger,[93] J. Honermann,[146] G. H. Hong,[149] D. Horak,[38] S. Hornung,[110] A. Horzyk,[2] R. Hosokawa,[15] Y. Hou,[7] P. Hristov,[35] C. Hughes,[133] P. Huhn,[70] T. J. Humanic,[100] H. Hushnud,[112] L. A. Husova,[146] A. Hutson,[127] D. Hutter,[40] J. P. Iddon,[35,130] R. Ilkaev,[111] H. Ilyas,[14] M. Inaba,[136] G. M. Innocenti,[35] M. Ippolitov,[91] A. Isakov,[38,98] M. S. Islam,[112] M. Ivanov,[110] V. Ivanov,[101] V. Izucheev,[94] M. Jablonski,[2] B. Jacak,[82] N. Jacazio,[35] P. M. Jacobs,[82] S. Jadlovska,[119] J. Jadlovsky,[119] S. Jaelani,[64] C. Jahnke,[123,124] M. J. Jakubowska,[144] A. Jalotra,[104] M. A. Janik,[144] T. Janson,[76] M. Jercic,[102] O. Jevons,[113] A. A. P. Jimenez,[71] F. Jonas,[99,146] P. G. Jones,[113] J. M. Jowett,[35,110] J. Jung,[70] M. Jung,[70] A. Junique,[35] A. Jusko,[113] J. Kaewjai,[118] P. Kalinak,[66] A. Kalweit,[35] V. Kaplin,[96] S. Kar,[7] A. Karasu Uysal,[79] D. Karatovic,[102] O. Karavichev,[65] T. Karavicheva,[65] P. Karczmarczyk,[144] E. Karpechev,[65] A. Kazantsev,[91] U. Kebschull,[76] R. Keidel,[48] D. L. D. Keijdener,[64] M. Keil,[35] B. Ketzer,[44] Z. Khabanova,[93] A. M. Khan,[7] S. Khan,[16] A. Khanzadeev,[101] Y. Kharlov,[94] A. Khatun,[16] A. Khuntia,[120] B. Kileng,[37] B. Kim,[17,63] C. Kim,[17] D. J. Kim,[128] E. J. Kim,[75] J. Kim,[149] J. S. Kim,[42] J. Kim,[107] J. Kim,[149] J. Kim,[75] M. Kim,[107] S. Kim,[18] T. Kim,[149] S. Kirsch,[70] I. Kisel,[40] S. Kiselev,[95] A. Kisiel,[144] J. P. Kitowski,[2] J. L. Klay,[6] J. Klein,[35] S. Klein,[82] C. Klein-Bösing,[146] M. Kleiner,[70] T. Klemenz,[108] A. Kluge,[35] A. G. Knospe,[127] C. Kobdaj,[118] M. K. Köhler,[107] T. Kollegger,[110] A. Kondratyev,[77] N. Kondratyeva,[96] E. Kondratyuk,[94] J. Konig,[70] S. A. Konigstorfer,[108] P. J. Konopka,[2,35] G. Kornakov,[144] S. D. Koryciak,[2] L. Koska,[119] A. Kotliarov,[98] O. Kovalenko,[88] V. Kovalenko,[115] M. Kowalski,[120] I. Králik,[66] A. Kravčáková,[39] L. Kreis,[110] M. Krivda,[66,113] F. Krizek,[98] K. Krizkova Gajdosova,[38] M. Kroesen,[107] M. Krüger,[70] E. Kryshen,[101] M. Krzewicki,[40] V. Kučera,[35] C. Kuhn,[139] P. G. Kuijer,[93] T. Kumaoka,[136] D. Kumar,[143] L. Kumar,[103] N. Kumar,[103] S. Kundu,[35,89] P. Kurashvili,[88] A. Kurepin,[65] A. B. Kurepin,[65] A. Kuryakin,[111] S. Kushpil,[98] J. Kvapil,[113] M. J. Kweon,[63] J. Y. Kwon,[63] Y. Kwon,[149] S. L. La Pointe,[40] P. La Rocca,[27a,27b] Y. S. Lai,[82] A. Lakrathok,[118] M. Lamanna,[35] R. Langoy,[132] K. Lapidus,[35] P. Larionov,[35,53] E. Laudi,[35] L. Lautner,[35,108] R. Lavicka,[38] T. Lazareva,[115] R. Lea,[24a,24b,59,142] J. Lehrbach,[40] R. C. Lemmon,[97] I. León Monzón,[122] E. D. Lesser,[19] M. Lettrich,[35,108] P. Lévai,[147] X. Li,[11] X. L. Li,[7] J. Lien,[132] R. Lietava,[113] B. Lim,[17] S. H. Lim,[17] V. Lindenstruth,[40] A. Lindner,[49] C. Lippmann,[110] A. Liu,[19] D. H. Liu,[7] J. Liu,[130] I. M. Lofnes,[21] V. Loginov,[96] C. Loizides,[99] P. Loncar,[36] J. A. Lopez,[107] X. Lopez,[137] E. López Torres,[8] J. R. Luhder,[146] M. Lunardon,[28a,28b] G. Luparello,[62] Y. G. Ma,[41] A. Maevskaya,[65] M. Mager,[35] T. Mahmoud,[44] A. Maire,[139] M. Malaev,[101] N. M. Malik,[104] Q. W. Malik,[20] L. Malinina,[77,d] D. Mal'Kevich,[95] N. Mallick,[51] P. Malzacher,[110] G. Mandaglio,[33,57] V. Manko,[91] F. Manso,[137] V. Manzari,[54] Y. Mao,[7] J. Mareš,[68] G. V. Margagliotti,[24a,24b] A. Margotti,[55] A. Marín,[110] C. Markert,[121] M. Marquard,[70] N. A. Martin,[107] P. Martinengo,[35] J. L. Martinez,[127] M. I. Martínez,[46] G. Martínez García,[117] S. Masciocchi,[110] M. Masera,[25a,25b] A. Masoni,[56] L. Massacrier,[80] A. Mastroserio,[54,141] A. M. Mathis,[108] O. Matonoha,[83] P. F. T. Matuoka,[123] A. Matyja,[120] C. Mayer,[120] A. L. Mazuecos,[35] F. Mazzaschi,[25a,25b] M. Mazzilli,[35] M. A. Mazzoni,[60,a] J. E. Mdhluli,[134] A. F. Mechler,[70] F. Meddi,[22a,22b] Y. Melikyan,[65] A. Menchaca-Rocha,[73] E. Meninno,[30a,30b,116] A. S. Menon,[127] M. Meres,[13] S. Mhlanga,[74,126] Y. Miake,[136] L. Micheletti,[25a,25b,61] L. C. Migliorin,[138] D. L. Mihaylov,[108] K. Mikhaylov,[77,95] A. N. Mishra,[147] D. Miśkowiec,[110] A. Modak,[4a,4b] A. P. Mohanty,[64] B. Mohanty,[89] M. Mohisin Khan,[16,e] M. A. Molander,[45] Z. Moravcova,[92] C. Mordasini,[108] D. A. Moreira De Godoy,[146] L. A. P. Moreno,[46] I. Morozov,[65] A. Morsch,[35] T. Mrnjavac,[35] V. Muccifora,[53] E. Mudnic,[36] D. Mühlheim,[146] S. Muhuri,[143] J. D. Mulligan,[82] A. Mulliri,[23a,23b] M. G. Munhoz,[123] R. H. Munzer,[70] H. Murakami,[135] S. Murray,[126] L. Musa,[35] J. Musinsky,[66] J. W. Myrcha,[144] B. Naik,[50,134] R. Nair,[88] B. K. Nandi,[50] R. Nania,[55] E. Nappi,[54] A. F. Nassirpour,[83] A. Nath,[107] C. Nattrass,[133] A. Neagu,[20] L. Nellen,[71] S. V. Nesbo,[37] G. Neskovic,[40] D. Nesterov,[115] B. S. Nielsen,[92] S. Nikolaev,[91] S. Nikulin,[91] V. Nikulin,[101] F. Noferini,[55] S. Noh,[12] P. Nomokonov,[77] J. Norman,[130] N. Novitzky,[136] P. Nowakowski,[144] A. Nyanin,[91] J. Nystrand,[21] M. Ogino,[85] A. Ohlson,[83] V. A. Okorokov,[96] J. Oleniacz,[144] A. C. Oliveira Da Silva,[133] M. H. Oliver,[148] A. Onnerstad,[128] C. Oppedisano,[61] A. Ortiz Velasquez,[71] T. Osako,[47] A. Oskarsson,[83] J. Otwinowski,[120] M. Oya,[47] K. Oyama,[85] Y. Pachmayer,[107] S. Padhan,[50] D. Pagano,[59,142] G. Paić,[71] A. Palasciano,[54] J. Pan,[145] S. Panebianco,[140] P. Pareek,[143] J. Park,[63] J. E. Parkkila,[128] S. P. Pathak,[127] R. N. Patra,[35,104]

B. Paul,[23a,23b] H. Pei,[7] T. Peitzmann,[64] X. Peng,[7] L. G. Pereira,[72] H. Pereira Da Costa,[140] D. Peresunko,[91] G. M. Perez,[8] S. Perrin,[140] Y. Pestov,[5] V. Petráček,[38] M. Petrovici,[49] R. P. Pezzi,[72,117] S. Piano,[62] M. Pikna,[13] P. Pillot,[117] O. Pinazza,[35,55] L. Pinsky,[127] C. Pinto,[27a,27b] S. Pisano,[53] M. Płoskoń,[82] M. Planinic,[102] F. Pliquett,[70] M. G. Poghosyan,[99] B. Polichtchouk,[94] S. Politano,[31] N. Poljak,[102] A. Pop,[49] S. Porteboeuf-Houssais,[137] J. Porter,[82] V. Pozdniakov,[77] S. K. Prasad,[4a,4b] R. Preghenella,[55] F. Prino,[61] C. A. Pruneau,[145] I. Pshenichnov,[65] M. Puccio,[35] S. Qiu,[93] L. Quaglia,[25a,25b] R. E. Quishpe,[127] S. Ragoni,[113] A. Rakotozafindrabe,[140] L. Ramello,[32] F. Rami,[139] S. A. R. Ramirez,[46] A. G. T. Ramos,[34a,34b] T. A. Rancien,[81] R. Raniwala,[105] S. Raniwala,[105] S. S. Räsänen,[45] R. Rath,[51] I. Ravasenga,[93] K. F. Read,[99,133] A. R. Redelbach,[40] K. Redlich,[88,f] A. Rehman,[21] P. Reichelt,[70] F. Reidt,[35] H. A. Reme-ness,[37] R. Renfordt,[70] Z. Rescakova,[39] K. Reygers,[107] A. Riabov,[101] V. Riabov,[101] T. Richert,[83] M. Richter,[20] W. Riegler,[35] F. Riggi,[27a,27b] C. Ristea,[69] M. Rodríguez Cahuantzi,[46] K. Røed,[20] R. Rogalev,[94] E. Rogochaya,[77] T. S. Rogoschinski,[70] D. Rohr,[35] D. Röhrich,[21] P. F. Rojas,[46] P. S. Rokita,[144] F. Ronchetti,[53] A. Rosano,[33,57] E. D. Rosas,[71] A. Rossi,[58] A. Rotondi,[29,59] A. Roy,[51] P. Roy,[112] S. Roy,[50] N. Rubini,[26a,26b] O. V. Rueda,[83] R. Rui,[24a,24b] B. Rumyantsev,[77] P. G. Russek,[2] A. Rustamov,[90] E. Ryabinkin,[91] Y. Ryabov,[101] A. Rybicki,[120] H. Rytkonen,[128] W. Rzesa,[144] O. A. M. Saarimaki,[45] R. Sadek,[117] S. Sadovsky,[94] J. Saetre,[21] K. Šafařík,[38] S. K. Saha,[143] S. Saha,[89] B. Sahoo,[50] P. Sahoo,[50] R. Sahoo,[51] S. Sahoo,[67] D. Sahu,[51] P. K. Sahu,[67] J. Saini,[143] S. Sakai,[136] S. Sambyal,[104] V. Samsonov,[96,101,a] D. Sarkar,[145] N. Sarkar,[143] P. Sarma,[43] V. M. Sarti,[108] M. H. P. Sas,[148] J. Schambach,[99,121] H. S. Scheid,[70] C. Schiaua,[49] R. Schicker,[107] A. Schmah,[107] C. Schmidt,[110] H. R. Schmidt,[106] M. O. Schmidt,[35] M. Schmidt,[106] N. V. Schmidt,[70,99] A. R. Schmier,[133] R. Schotter,[139] J. Schukraft,[35] Y. Schutz,[139] K. Schwarz,[110] K. Schweda,[110] G. Scioli,[26a,26b] E. Scomparin,[61] J. E. Seger,[15] Y. Sekiguchi,[135] D. Sekihata,[135] I. Selyuzhenkov,[96,110] S. Senyukov,[139] J. J. Seo,[63] D. Serebryakov,[65] L. Šerkšnytė,[108] A. Sevcenco,[69] T. J. Shaba,[74] A. Shabanov,[65] A. Shabetai,[117] R. Shahoyan,[35] W. Shaikh,[112] A. Shangaraev,[94] A. Sharma,[103] H. Sharma,[120] M. Sharma,[104] N. Sharma,[103] S. Sharma,[104] U. Sharma,[104] O. Sheibani,[127] K. Shigaki,[47] M. Shimomura,[86] S. Shirinkin,[95] Q. Shou,[41] Y. Sibiriak,[91] S. Siddhanta,[56] T. Siemiarczuk,[88] T. F. Silva,[123] D. Silvermyr,[83] T. Simantathammakul,[118] G. Simonetti,[35] B. Singh,[108] R. Singh,[89] R. Singh,[104] R. Singh,[51] V. K. Singh,[143] V. Singhal,[143] T. Sinha,[112] B. Sitar,[13] M. Sitta,[32] T. B. Skaali,[20] G. Skorodumovs,[107] M. Slupecki,[45] N. Smirnov,[148] R. J. M. Snellings,[64] C. Soncco,[114] J. Song,[127] A. Songmoolnak,[118] F. Soramel,[28a,28b] S. Sorensen,[133] I. Sputowska,[120] J. Stachel,[107] I. Stan,[69] P. J. Steffanic,[133] S. F. Stiefelmaier,[107] D. Stocco,[117] I. Storehaug,[20] M. M. Storetvedt,[37] C. P. Stylianidis,[93] A. A. P. Suaide,[123] T. Sugitate,[47] C. Suire,[80] M. Sukhanov,[65] M. Suljic,[35] R. Sultanov,[95] M. Šumbera,[98] V. Sumberia,[104] S. Sumowidagdo,[52] S. Swain,[67] A. Szabo,[13] I. Szarka,[13] U. Tabassam,[14] S. F. Taghavi,[108] G. Taillepied,[137] J. Takahashi,[124] G. J. Tambave,[21] S. Tang,[7,137] Z. Tang,[131] M. Tarhini,[117] M. G. Tarzila,[49] A. Tauro,[35] G. Tejeda Muñoz,[46] A. Telesca,[35] L. Terlizzi,[25a,25b] C. Terrevoli,[127] G. Tersimonov,[3] S. Thakur,[143] D. Thomas,[121] R. Tieulent,[138] A. Tikhonov,[65] A. R. Timmins,[127] M. Tkacik,[119] A. Toia,[70] N. Topilskaya,[65] M. Toppi,[53] F. Torales-Acosta,[19] T. Tork,[80] S. R. Torres,[38] A. Trifiró,[33,57] S. Tripathy,[55,71] T. Tripathy,[50] S. Trogolo,[28a,28b,35] G. Trombetta,[34a,34b] V. Trubnikov,[3] W. H. Trzaska,[128] T. P. Trzcinski,[144] B. A. Trzeciak,[38] A. Tumkin,[111] R. Turrisi,[58] T. S. Tveter,[20] K. Ullaland,[21] A. Uras,[138] M. Urioni,[59,142] G. L. Usai,[23a,23b] M. Vala,[39] N. Valle,[29,59] S. Vallero,[61] N. van der Kolk,[64] L. V. R. van Doremalen,[64] M. van Leeuwen,[93] P. Vande Vyvre,[35] D. Varga,[147] Z. Varga,[147] M. Varga-Kofarago,[147] A. Vargas,[46] M. Vasileiou,[87] A. Vasiliev,[91] O. Vázquez Doce,[53,108] V. Vechernin,[115] E. Vercellin,[25a,25b] S. Vergara Limón,[46] L. Vermunt,[64] R. Vértesi,[147] M. Verweij,[64] L. Vickovic,[36] Z. Vilakazi,[134] O. Villalobos Baillie,[113] G. Vino,[54] A. Vinogradov,[91] T. Virgili,[30a,30b] V. Vislavicius,[92] A. Vodopyanov,[77] B. Volkel,[35] M. A. Völkl,[107] K. Voloshin,[95] S. A. Voloshin,[145] G. Volpe,[34a,34b] B. von Haller,[35] I. Vorobyev,[108] D. Voscek,[119] N. Vozniuk,[65] J. Vrláková,[39] B. Wagner,[21] C. Wang,[41] D. Wang,[41] M. Weber,[116] R. J. G. V. Weelden,[93] A. Wegrzynek,[35] S. C. Wenzel,[35] J. P. Wessels,[146] J. Wiechula,[70] J. Wikne,[20] G. Wilk,[88] J. Wilkinson,[110] G. A. Willems,[146] B. Windelband,[107] M. Winn,[140] W. E. Witt,[133] J. R. Wright,[121] W. Wu,[41] Y. Wu,[131] R. Xu,[7] A. K. Yadav,[143] S. Yalcin,[79] Y. Yamaguchi,[47] K. Yamakawa,[47] S. Yang,[21] S. Yano,[47] Z. Yin,[7] H. Yokoyama,[64] I.-K. Yoo,[17] J. H. Yoon,[63] S. Yuan,[21] A. Yuncu,[107] V. Zaccolo,[24a,24b] C. Zampolli,[35] H. J. C. Zanoli,[64] N. Zardoshti,[35] A. Zarochentsev,[115] P. Závada,[68] N. Zaviyalov,[111] M. Zhalov,[101] B. Zhang,[7] S. Zhang,[41] X. Zhang,[7] Y. Zhang,[131] V. Zherebchevskii,[115] Y. Zhi,[11] N. Zhigareva,[95] D. Zhou,[7] Y. Zhou,[92] J. Zhu,[7,110] Y. Zhu,[7] A. Zichichi,[26a,26b] G. Zinovjev,[3] and N. Zurlo[59,142]

(A Large Ion Collider Experiment Collaboration)

[1]*A.I. Alikhanyan National Science Laboratory (Yerevan Physics Institute) Foundation, Yerevan*
[2]*AGH University of Science and Technolog, Krakow, Poland*

[3]Bogolyubov Institute for Theoretical Physics, National Academy of Sciences of Ukraine, Kiev, Ukraine
[4a]Bose Institute, Department of Physics, Kolkata, India
[4b]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, California, USA
[7]Central China Normal University, Wuhan, China
[8]Centro de Aplicaciones Tecnológicas y Desarrollo Nuclear (CEADEN), Havana, Cuba
[9]Centro de Investigación y de Estudios Avanzados (CINVESTAV), Mexico City and Mérida, Mexico
[10]Chicago State University, Chicago, Illinois, USA
[11]China Institute of Atomic Energy, Beijing, China
[12]Chungbuk National University, Cheongju, Republic of Korea
[13]Comenius University Bratislava, Faculty of Mathematics, Physics and Informatics, Bratislava, Slovakia
[14]COMSATS University Islamabad, Islamabad, Pakistan
[15]Creighton University, Omaha, Nebraska, USA
[16]Department of Physics, Aligarh Muslim University, Aligarh, India
[17]Department of Physics, Pusan National University, Pusan, Republic of Korea
[18]Department of Physics, Sejong University, Seoul, Republic of Korea
[19]Department of Physics, University of California, Berkeley, California, USA
[20]Department of Physics, University of Oslo, Oslo, Norway
[21]Department of Physics and Technology, University of Bergen, Bergen, Norway
[22a]Dipartimento di Fisica dell'Università 'La Sapienza', Rome, Italy
[22b]Sezione INFN, Rome, Italy
[23a]Dipartimento di Fisica dell'Università, Cagliari, Italy
[23b]Sezione INFN, Cagliari, Italy
[24a]Dipartimento di Fisica dell'Università, Trieste, Italy
[24b]Sezione INFN, Trieste, Italy
[25a]Dipartimento di Fisica dell'Università, Turin, Italy
[25b]Sezione INFN, Turin, Italy
[26a]Dipartimento di Fisica e Astronomia dell'Università, Bologna, Italy
[26b]Sezione INFN, Bologna, Italy
[27a]Dipartimento di Fisica e Astronomia dell'Università, Catania, Italy
[27b]Sezione INFN, Catania, Italy
[28a]Dipartimento di Fisica e Astronomia dell'Università, Padova, Italy
[28b]Sezione INFN, Padova, Italy
[29]Dipartimento di Fisica e Nucleare e Teorica, Università di Pavia, Pavia, Italy
[30a]Dipartimento di Fisica 'E.R. Caianiello' dell'Università, Salerno, Italy
[30b]Gruppo Collegato INFN, Salerno, Italy
[31]Dipartimento DISAT del Politecnico and Sezione INFN, Turin, Italy
[32]Dipartimento di Scienze e Innovazione Tecnologica dell'Università del Piemonte Orientale and INFN Sezione di Torino, Alessandria, Italy
[33]Dipartimento di Scienze MIFT, Università di Messina, Messina, Italy
[34a]Dipartimento Interateneo di Fisica 'M. Merlin', Bari, Italy
[34b]Sezione INFN, Bari, Italy
[35]European Organization for Nuclear Research (CERN), Geneva, Switzerland
[36]Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split, Split, Croatia
[37]Faculty of Engineering and Science, Western Norway University of Applied Sciences, Bergen, Norway
[38]Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Prague, Czech Republic
[39]Faculty of Science, P.J. Šafárik University, Košice, Slovakia
[40]Frankfurt Institute for Advanced Studies, Johann Wolfgang Goethe-Universität Frankfurt, Frankfurt, Germany
[41]Fudan University, Shanghai, China
[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]High Energy Physics Group, Universidad Autónoma de Puebla, Puebla, Mexico
[47]Hiroshima University, Hiroshima, Japan
[48]Hochschule Worms, Zentrum für Technologietransfer und Telekommunikation (ZTT), Worms, Germany
[49]Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania
[50]Indian Institute of Technology Bombay (IIT), Mumbai, India
[51]Indian Institute of Technology Indore, Indore, India

[52]Indonesian Institute of Sciences, Jakarta, Indonesia
[53]INFN, Laboratori Nazionali di Frascati, Frascati, Italy
[54]INFN, Sezione di Bari, Bari, Italy
[55]INFN, Sezione di Bologna, Bologna, Italy
[56]INFN, Sezione di Cagliari, Cagliari, Italy
[57]INFN, Sezione di Catania, Catania, Italy
[58]INFN, Sezione di Padova, Padova, Italy
[59]INFN, Sezione di Pavia, Pavia, Italy
[60]INFN, Sezione di Roma, Rome, Italy
[61]INFN, Sezione di Torino, Turin, Italy
[62]INFN, Sezione di Trieste, Trieste, Italy
[63]Inha University, Incheon, Republic of Korea
[64]Institute for Gravitational and Subatomic Physics (GRASP), Utrecht University/Nikhef, t, Netherlands
[65]Institute for Nuclear Research, Academy of Sciences, Moscow, Russia
[66]Institute of Experimental Physics, Slovak Academy of Sciences, Košice, Slovakia
[67]Institute of Physics, Homi Bhabha National Institute, 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]Jeonbuk National University, Jeonju, Republic of Korea
[76]Johann-Wolfgang-Goethe Universität Frankfurt Institut für Informatik, Fachbereich Informatik und Mathematik, Frankfurt, Germany
[77]Joint Institute for Nuclear Research (JINR), Dubna, Russia
[78]Korea Institute of Science and Technology Information, Daejeon, Republic of Korea
[79]KTO Karatay University, Konya, Turkey
[80]Laboratoire de Physique des 2 Infinis, Irène Joliot-Curie, Orsay, France
[81]Laboratoire de Physique Subatomique et de Cosmologie, Université Grenoble-Alpes, CNRS-IN2P3, Grenoble, France
[82]Lawrence Berkeley National Laboratory, California, USA
[83]Lund University Department of Physics, Division of Particle Physics, Lund, Sweden
[84]Moscow Institute for Physics and Technology, Moscow, Russia
[85]Nagasaki Institute of Applied Science, Nagasaki, Japan
[86]Nara Women's University (NWU), Nara, Japan
[87]National and Kapodistrian University of Athens, School of Science, Department of Physics, Athens, Greece
[88]National Centre for Nuclear Research, Warsaw, Poland
[89]National Institute of Science Education and Research, Homi Bhabha National Institute, Jatni, India
[90]National Nuclear Research Center, Baku, Azerbaijan
[91]National Research Centre Kurchatov Institute, Moscow, Russia
[92]Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
[93]Nikhef, National institute for subatomic physics, Amsterdam, Netherlands
[94]NRC Kurchatov Institute IHEP, Protvino, Russia
[95]NRC «Kurchatov» Institute—ITEP, Moscow, Russia
[96]NRNU Moscow Engineering Physics Institute, Moscow, Russia
[97]Nuclear Physics Group, STFC Daresbury Laboratory, Daresbury, United Kingdom
[98]Nuclear Physics Institute of the Czech Academy of Sciences, Řežu Prahy, Czech Republic
[99]Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA
[100]Ohio State University, Columbus, Ohio, USA
[101]Petersburg Nuclear Physics Institute, Zagreb, Croatia
[102]Physics department, Faculty of science, University of Zagreb, Zagreb, Croatia
[103]Physics Department, Panjab University, Chandigarh, India
[104]Physics Department, University of Jammu, Jammu, India
[105]Physics Department, University of Rajasthan, Jammu, India
[106]Physikalisches Institut, Eberhard-Karls-Universität Tübingen, Tübingen, Germany
[107]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
[108]Physik Department, Technische Universität München, Munich, Germany
[109]Politecnico di Bari, Bari, Italy
[110]Research Division and ExtreMe Matter Institute EMMI,
GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

[111]Russian Federal Nuclear Center (VNIIEF), Darmstadt, Germany
[112]Saha Institute of Nuclear Physics, Homi Bhabha National Institute, Kolkata, India
[113]School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom
[114]Sección Física, Departamento de Ciencias, Pontificia Universidad Católica del Perú, Lima, Peru
[115]St. Petersburg State University, Lima, Peru
[116]Stefan Meyer Institut für Subatomare Physik (SMI), Vienna, Austria
[117]SUBATECH, IMT Atlantique, Université de Nantes, CNRS-IN2P3, Nantes, France
[118]Suranaree University of Technology, Nakhon Ratchasima, Thailand
[119]Technical University of Košice, Košice, Slovakia
[120]The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
[121]The University of Texas at Austin, Austin, Texas, USA
[122]Universidad Autónoma de Sinaloa, Culiacán, Mexico
[123]Universidade de São Paulo (USP), São Paulo, Brazil
[124]Universidade Estadual de Campinas (UNICAMP), Campinas, Brazil
[125]Universidade Federal do ABC, Santo Andre, Brazil
[126]University of Cape Town, Cape Town, South Africa
[127]University of Houston, Houston, Texas, USA
[128]University of Jyväskylä, Jyväskylä, Finland
[129]University of Kansas, Lawrence, Kansas, USA
[130]University of Liverpool, Liverpool, United Kingdom
[131]University of Science and Technology of China, Hefei, China
[132]University of South-Eastern Norway, Tonsberg, Norway
[133]University of Tennessee, Tennessee, USA
[134]University of the Witwatersrand, Johannesburg, South Africa
[135]University of Tokyo, Tokyo, Japan
[136]University of Tsukuba, Tsukuba, Japan
[137]Université Clermont Auvergne, CNRS/IN2P3, LPC, Clermont-Ferrand, France
[138]Université de Lyon, CNRS/IN2P3, Institut de Physique des 2 Infinis de Lyon, Lyon, France
[139]Université de Strasbourg, CNRS, IPHC UMR 7178, F-67000 Strasbourg, France, Strasbourg, France
[140]Université Paris-Saclay Centre d'Etudes de Saclay (CEA), IRFU, Départment de Physique Nucléaire (DPhN), Saclay, France
[141]Università degli Studi di Foggia, Foggia, Italy
[142]Università di Brescia, Brescia, Italy
[143]Variable Energy Cyclotron Centre, Homi Bhabha National Institute, Kolkata, India
[144]Warsaw University of Technology, Warsaw, Poland
[145]Wayne State University, Michigan, USA
[146]Westfälische Wilhelms-Universität Münster, Institut für Kernphysik, Münster, Germany
[147]Wigner Research Centre for Physics, Budapest, Hungary
[148]Yale University, Connecticut, USA
[149]Yonsei University, Seoul, Republic of Korea

[a]Deceased.
[b]Also at Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Bologna, Italy.
[c]Also at Dipartimento DET del Politecnico di Torino, Turin, Italy.
[d]Also at M.V. Lomonosov Moscow State University, D.V. Skobeltsyn Institute of Nuclear, Physics, Moscow, Russia.
[e]Also at Department of Applied Physics, Aligarh Muslim University, Aligarh, India.
[f]Also at Institute of Theoretical Physics, University of Wroclaw, Poland.