Abstract

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 $^3\Lambda$H in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ 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 $dN/dy = [6.3 \pm 1.8\,(\text{stat.}) \pm 1.2\,(\text{syst.})] \times 10^{-7}$. The measurement is compared with the expectations of statistical hadronisation 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 $dN/dy$ 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.
In the last few decades, the production of deuterons, $^3$H, $^3$He, $^4$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 collider [9–16] and fixed target experiments [17–20] significantly constrained the parameter space for production models like coalescence [21–23] and statistical hadronisation [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 modelling 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 hadronisation and coalescence models are very similar and they are both able to describe the measured production of nuclei [28]. The statistical hadronisation 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 ($T_{\text{chem}}$). 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 $T_{\text{chem}} = 155$ MeV [5]. This temperature, which successfully describes the yield of light hadrons in central Pb–Pb collisions, is one to two orders of magnitude larger than the typical binding energies of light nuclei (a few MeVs), 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 $^3\Lambda\text{H}$, the bound state of a proton, a neutron, and a $\Lambda$ baryon. This state is characterised 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 $^3\Lambda\text{H}$ wave function is therefore much larger than the hadron emission radius estimated with a femtoscopic technique in p–Pb collisions (1–2 fm, [37, 38]). For this reason, the $^3\Lambda\text{H}$ 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 hadronisation 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 $\sqrt{s_{\text{NN}}} = 5.02$ TeV. With this beam configuration, the nucleon–nucleon centre-of-mass system moves in rapidity by $\Delta y_{\text{cms}} = 0.465$ in the direction of the proton beam. The ALICE detector and its performance are described in detail in [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 centre 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 normalisation of the results, events with more than one reconstructed primary interaction vertex (pile-up events) are rejected. In total, about 750 million MB events are selected for analysis,
corresponding to an integrated luminosity of $\mathcal{L}^{\text{MB}} = 359 \mu\text{b}^{-1}$, 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 $^3_\Lambda$H candidates are reconstructed via the charged two-body decay channel $^3_\Lambda$H → $^3$He + $\pi^-$ (and the related charge conjugated particles for $^\Lambda_\bar{\Lambda}$). In this work, $^3_\Lambda$H and $^\Lambda_\bar{\Lambda}$ are combined to reduce the statistical uncertainty.

In the following, we use the notation $^3_\Lambda$H and $^3$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 $^3$He and the $\pi^-$ via their specific energy loss $dE/dx$ in the gas volume, with a $dE/dx$ resolution of about 5% [44]. The $n(\sigma_T^{\text{TPC}})$ variable represents the PID response in the TPC expressed in terms of the deviation between the measured and the expected $dE/dx$ for a particle species $i$, normalized by the detector resolution $\sigma$.

The expected $dE/dx$ is computed with a parameterised Bethe-Bloch function [40]. Pion and $^3$He tracks within $5\sigma_T^{\text{TPC}}$ are selected. The identified $^3$He and $\pi$ tracks are then used to reconstruct the $^3_\Lambda$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 vertex, the proper decay length of the candidate ($ct$) and $\cos(\theta_p)$, where $\theta_p$ 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 $^3_\Lambda$H were injected with a $p_T$ distribution represented by a $m_T$ exponential function that describes the $p_T$ distribution of $^3$He as measured in p–Pb collisions [8]. The particles are transported through the detector geometry using GEANT4 [51], which simulates the interaction with the material and the weak decay of the $^3_\Lambda$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 $^3_\Lambda$H signal candidates extracted from the MC sample and background candidates from paired like-sign $^3$He and $\pi$ tracks from the data. For each $^3_\Lambda$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 maximises the expected signal significance assuming thermal production. In this analysis the default BDT score selection corresponds to a 72% signal efficiency and a 3x10^-5 background rejection factor. The candidates that pass the BDT selection are used to populate the invariant mass distribution in the transverse momentum interval $0 < p_T < 9$ 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 [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 formulae for likelihood-based tests. The local p-value is expressed as a corresponding number of standard deviations using the one-sided Gaussian tail convention. The excess of entries observed above the expected background has a local significance of
Hypertriton production in p–Pb collisions at the $\sqrt{s_{NN}}$ = 5.02 TeV

ALICE Collaboration

2.96 2.97 2.98 2.99 3 3.01 3.02 3.03 3.04 )
2c)  (GeV/+π + He3(M) + -πHe + 3(M2
4
6
8
10
12
14
)2 c Entries / (2.35 MeV/ ALICE
 = 5.02 TeV
NNs40%, −Pb, 0−p c
 < 9 GeV/T
p0 < H
3Λ
H +  3Λ
 Signal + Background

Figure 1: Invariant mass distribution of the $^3$He + π− 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.

4.6 standard deviations at the nominal $^3$ΛH 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 analysed events, the branching ratio (B.R.) of the $^3$ΛH in the two-body decay channel and the fraction of $^3$ΛH that are absorbed in the ALICE detector ($f_{abs}$). The simulation of inelastic interactions of the daughter particles is done with GEANT4 and is taken into account in the reconstruction efficiency computation. The B.R. value is assumed to be 0.25 according to the calculation published in [55].

The systematic uncertainties originate from (1) the $^3$ΛH selection and the signal extraction, (2) the choice of the $^3$ΛH input $p_T$ distribution in the Monte Carlo sample, and (3) the $^3$ΛH absorption in the detector. In addition (4), a 9% systematic uncertainty is added due to the uncertainty of the B.R. 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 $p_T$ distributions for the Monte Carlo sample and evaluating the effects on the efficiency. Four different $p_T$ models (mT exponential, $p_T$ exponential, Boltzmann and Blast Wave [56]) are fitted to the $^3$He $p_T$ distribution [5]. For each of them the efficiency and the yield are computed assuming that the $^3$He and the $^3$ΛH have the same $p_T$ distributions as already seen for light flavour 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 $f_{abs}$ is considered. According to [58], the expected absorption cross section of $^3$ΛH due to the inelastic interactions in the ALICE detector material is ≈ 1.5 times that of $^3$He ($\sigma_{He}^{inel}$). The value of $f_{abs}$ 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 $f_{abs}$ is evaluated by employing different cross sections for the $^3$ΛH from zero (no interactions) to $2\sigma_{He}^{inel}$. For each variation $f_{abs}$ is recalculated. This results in a systematic uncertainty on the yield of about 4%. Larger variations of the inelastic cross section are here not considered as they spoil the exponential trend of the proper
Hypertriton production in p–Pb collisions at the $\sqrt{s_{NN}} = 5.02$ TeV

ALICE Collaboration

Figure 2: $^3\Lambda$/H (on the left) and $S_1$ (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 B.R.), respectively. The expectations for the canonical statistical hadronization [25] and coalescence models are shown [23].

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 and two correlation volumes extending across one unit ($V_c = dV/dy$), and three units ($V_c = 3dV/dy$) 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 $p_T$ integrated yield is $1.1 \times 10^{-6}$ and $2.0 \times 10^{-6}$ with $V_c = dV/dy$ and $V_c = 3dV/dy$, respectively. The $dN/dy$ 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 $^3\Lambda$/H/$\Lambda$ ratio and the strangeness population factor $S_1 = (H/3He)/(\Lambda/p)$ [60] using previous ALICE measurements of p, $\Lambda$, and $^3$He yields [51,57], as shown in Fig. 2. The yield of the $\Lambda$ baryon, measured in $-0.5 < y < 0$, has been extrapolated to the $^3\Lambda$ rapidity region using MC generators [61,63] that are known to reproduce the pseudorapidity density distribution 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 $S_1$ ratio is compatible with the two-body (deuteron-3H) and three-body (proton-neutron-3H) coalescence within 1.2σ and 2σ, respectively. With its large uncertainties, also due to the large uncertainty on the $^3$He yield, the $S_1$ is compatible within 2σ with the SHM calculations too. Hence, the $^3\Lambda$/H/$\Lambda$ ratio is used as a test for coalescence and SHM predictions.

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

$$\frac{dN}{dy} = [6.3 \pm 1.8(\text{stat.}) \pm 1.2(\text{syst.})] \times 10^{-7}.$$
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 $\Lambda_3^H/\Lambda$. It has to be noted that recent measurements of the $\Lambda_3^H$ mass [34] suggest a larger binding energy, and hence a smaller wave function, of the $\Lambda_3^H$. This would further shift upward the coalescence predictions.

![Figure 3: $\Lambda_3^H/\Lambda$ 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].](image-url)

The value of B.R. = 0.25 for the $\Lambda_3^H \rightarrow 3\text{He} + \pi^-$ decay used in this analysis was computed theoretically in Ref. [55]. To investigate the uncertainty resulting from this assumption, Fig. 3 shows the measured $\Lambda_3^H/\Lambda \times \text{B.R.}$ for different theoretical model calculations [23, 25] assuming a possible variation of the B.R. 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:

$$R_3 = \frac{\Gamma(\Lambda_3^H \rightarrow 3\text{He} + \pi^-)}{\Gamma(\Lambda_3^H \rightarrow \text{all } \pi^- \text{ decay channels})}.$$ 

This uncertainty on $R_3$ is propagated to the B.R. ($\Lambda_3^H \rightarrow 3\text{He} + \pi^-$) and corresponds to a variation range of ±9% around the nominal value. While the two-body coalescence calculation is compatible with the data for the nominal or larger B.R., a discrepancy of $2\sigma$ is observed between data and the three-body coalescence prediction. Furthermore, in the whole B.R. variation interval, the SHM is more than $2.7\sigma$ and $6.9\sigma$ away from the measured $\Lambda_3^H/\Lambda \times \text{B.R.}$ for the $V_c = 1dV/dy$ and $V_c = 3dV/dy$ configurations, respectively.

In summary, the first measurement of the production yield of hypertriton in p–Pb collisions at the LHC is reported. The measurements of yields of $\Lambda_3^H$ in p–Pb collisions provide an opportunity to potentially discriminate between nucleosynthesis models. The measured $p_T$ integrated yield excludes, with high significance, canonical versions of the SHM with $V_c \geq 3dV/dy$ 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 $\Lambda_3^H/\Lambda$ ratio
is well described by the two-body coalescence prediction, while the three-body formulation is slightly disfavoured by our measurement. While the general conclusions of the comparison with the models are unaltered even when considering large variations of the B.R.($^3\Lambda_H \rightarrow ^3\text{He}^+\pi^-$) 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 $^3\Lambda_H \rightarrow d + p + \pi^-$ 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 $^3\Lambda_H$ yield measurements in pp [67] and p–Pb collisions and to study the $^3\Lambda_H$ 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.

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 (ANSL), State Committee of Science and World Federation of Scientists (WFS), Armenia; Austrian Academy of Sciences, Austrian Science Fund (FWF): [M 2467-N36] 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), Financiadora de Estudos e Projetos (Finep), Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and Universidade Federal do Rio Grande do Sul (UFRGS), Brazil; Ministry of Education of China (MOEC), Ministry of Science & Technology of China (MSTC) and National Natural Science Foundation of China (NSFC), China; Ministry of Science and Education and Croatian Science Foundation, Croatia; Centro de Aplicaciones Tecnológicas y Desarrollo Nuclear (CEADEN), Cubaenergía, Cuba; Ministry of Education, Youth and Sports of the Czech Republic, Czech Republic; The Danish Council for Independent Research | Natural Sciences, the VILLUM FONDEN 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 und Forschung (BMBF) and GSI Helmholtzzentrum für Schwerionenforschung GmbH, Germany; General Secretariat for Research and Technology, Ministry of Education, Research and Religion, 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; Istituto Nazionale di Fisica Nucleare (INFN), Italy; Institute for Innovative Science and Technology, Nagasaki Institute of Applied Science (IIST), Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) and Japan Society for the Promotion of Science (JSPS) KAKENHI, 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 Education and Science, National Science Centre and WUT ID-UB, Poland; Korea Institute of Science and Technology Information and National Research Foundation of Korea (NRF), Republic of Korea; Ministry of
Hypertriton production in p–Pb collisions at the $\sqrt{s_{\text{NN}}} = 5.02$ TeV

ALICE Collaboration

Education and Scientific Research, Institute of Atomic Physics and Ministry of Research and Innovation and Institute of Atomic Physics, Romania; Joint Institute for Nuclear Research (JINR), Ministry of Education and Science of the Russian Federation, National Research Centre Kurchatov Institute, Russian Science Foundation and Russian Foundation for Basic Research, Russia; Ministry of Education, Science, Research and Sport of the Slovak Republic, Slovakia; National Research Foundation of South Africa, South Africa; Swedish Research Council (VR) and Knut & Alice Wallenberg Foundation (KAWS) Sweden; European Organization for Nuclear Research, Switzerland; Suranaree University of Technology (SUT), National Science and Technology Development Agency (NSDTA) and Office of the Higher Education Commission under NRU project of Thailand, Thailand; Turkish Energy, Nuclear and Mineral Research Agency (TENMAK), 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] ALICE Collaboration, J. Adam et al., “Production of light nuclei and anti-nuclei in pp and Pb–Pb collisions at energies available at the CERN Large Hadron Collider”, Phys. Rev. C93 (2016) 024917, arXiv:1506.08951 [nucl-ex].

[2] ALICE Collaboration, S. Acharya et al., “Measurement of deuteron spectra and elliptic flow in Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 2.76$ TeV at the LHC”, Eur. Phys. J. C77 (2017) 658 arXiv:1707.07304 [nucl-ex].

[3] ALICE Collaboration, S. Acharya et al., “Multiplicity dependence of (anti-)deuteron production in pp collisions at $\sqrt{s} = 7$ TeV”, Phys. Lett. B794 (2019) 50–63 arXiv:1902.09290 [nucl-ex].

[4] ALICE Collaboration, S. Acharya et al., “Multiplicity dependence of light (anti-)nuclei production in p-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV”, Phys. Lett. B800 (2020) 135043 arXiv:1906.03136 [nucl-ex].

[5] ALICE Collaboration, S. Acharya et al., “Production of (anti-)3He and (anti-)3H in p-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV”, Phys. Rev. C101 (2020) 044906 arXiv:1910.14401 [nucl-ex].

[6] ALICE Collaboration, S. Acharya et al., “(Anti-)deuteron production in pp collisions at $\sqrt{s} = 13$ TeV”, Eur. Phys. J. C80 (2020) 889 arXiv:2003.03184 [nucl-ex].

[7] ALICE Collaboration, S. Acharya et al., “Production of 4He and 4He in Pb-Pb collisions at $\sqrt{s_{\text{NN}}} = 2.76$ TeV at the LHC”, Nucl. Phys. A971 (2018) 1–20 arXiv:1710.07531 [nucl-ex].

[8] ALEPH Collaboration, S. Schael et al., “Deuteron and anti-deuteron production in e+ e-collisions at the Z resonance”, Phys. Lett. B 639 (2006) 192–201 arXiv:hep-ex/0604023.

[9] British-Scandinavian Collaboration, B. Alper et al., “Large angle production of stable particles heavier than the proton and a search for quarks at the cern intersecting storage rings”, Phys. Lett. 46B (1973) 265–268.

[10] British-Scandinavian-MIT Collaboration, S. Henning et al., “Production of Deuterons and anti-Deuterons in Proton Proton Collisions at the CERN ISR”, Lett. Nuovo Cim. 21 (1978) 189.

[11] E735 Collaboration, T. Alexopoulos et al., “Cross-sections for deuterium, tritium, and helium production in p p collisions at s = 1.8-Tev”, Phys. Rev. D 62 (2000) 072004.
Hypertriton production in p–Pb collisions at the $\sqrt{s_{NN}} = 5.02$ TeV

ALICE Collaboration

[12] STAR Collaboration, C. Adler et al., “Anti-deuteron and anti-$^3$He production in $\sqrt{s_{NN}} = 130$ GeV Au+Au collisions”, *Phys. Rev. Lett.* 87 (2001) 262301, arXiv:nucl-ex/0108022 [nucl-ex] [Erratum: Phys. Rev. Lett.87,279902(2001)].

[13] PHENIX Collaboration, S. S. Adler et al., “Deuteron and antideuteron production in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV”, *Phys. Rev. Lett.* 94 (2005) 122302, arXiv:nucl-ex/0406004 [nucl-ex]

[14] H1 Collaboration, A. Aktas et al., “Measurement of anti-deuteron photoproduction and a search for heavy stable charged particles at HERA”, *Eur. Phys. J. C* 36 (2004) 413–423, arXiv:hep-ex/0403056

[15] CLEO Collaboration, D. M. Asner et al., “Anti-deuteron production in Upsilon(nS) decays and the nearby continuum”, *Phys. Rev. D* 75 (2007) 012009, arXiv:hep-ex/0612019

[16] STAR Collaboration, H. Agakishiev et al., “Observation of the antimatter helium-4 nucleus”, *Nature* 473 (2011) 353, arXiv:1103.3312 [nucl-ex] [Erratum: Nature 475, 412 (2011)].

[17] NA44 Collaboration, J. Simon-Gillo et al., “Deuteron and anti-deuteron production in CERN experiment NA44”, *Nucl. Phys.* A590 (1995) 483C–486C.

[18] E864 Collaboration, T. A. Armstrong et al., “Anti-deuteron yield at the AGS and coalescence implications”, *Phys. Rev. Lett.* 85 (2000) 2685–2688, arXiv:nucl-ex/0005001 [nucl-ex]

[19] NA49 Collaboration, S. V. Afanasev et al., “Deuteron production in central Pb + Pb collisions at 158-A-GeV”, *Phys. Lett.* B486 (2000) 22–28

[20] NA49 Collaboration, T. Anticic et al., “Energy and centrality dependence of deuteron and proton production in Pb + Pb collisions at relativistic energies”, *Phys. Rev.* C69 (2004) 024902

[21] S. Mrowczynski, “Deuteron formation mechanism”, *J. Phys. G* 13 (1987) 1089–1097.

[22] R. Scheibl and U. W. Heinz, “Coalescence and flow in ultrarelativistic heavy ion collisions”, *Phys. Rev. C* 59 (1999) 1585–1602, arXiv:nucl-th/9809092 [nucl-th]

[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 (2019) 132–137, arXiv:1812.05175 [nucl-th]

[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 (2011) 203–207, arXiv:1010.2995 [nucl-th]

[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 (2018) 171–174, arXiv:1808.05245 [hep-ph]

[26] K. Blum, K. C. Y. Ng, R. Sato, and M. Takimoto, “Cosmic rays, antihelium, and an old navy spotlight”, *Phys. Rev. D* 96 (2017) 103021, arXiv:1704.05431 [astro-ph.HE]

[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 (2018) 103011, arXiv:1711.08465 [astro-ph.HE]

[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 (2019) 054905, arXiv:1807.05894 [hep-ph]
D. Oliinychenko, L.-G. Pang, H. Elfner, and V. Koch, “Microscopic study of deuteron production in PbPb collisions at $\sqrt{s} = 2.76\text{TeV}$ via hydrodynamics and a hadronic afterburner”, *Phys. Rev. C* **99** (2019) 044907, [arXiv:1809.03071 [hep-ph]]

A. Andronic, P. Braun-Munzinger, K. Redlich, and J. Stachel, “Decoding the phase structure of QCD via particle production at high energy”, *Nature* **561** (2018) 321–330, [arXiv:1710.01750 [nucl-th]]

ALICE Collaboration, S. Acharya et al., “Search for a common baryon source in high-multiplicity pp collisions at the LHC”, *Phys. Lett. B* **811** (2020) 135849, [arXiv:2004.08018 [nucl-ex]]

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** (2021) 014907, [arXiv:2007.01750 [nucl-th]]

D. H. Davis, “50 years of hypernuclear physics. I. The early experiments”, *Nucl. Phys. A* **754** (2005) 3–13.

STAR Collaboration, J. Adam et al., “Measurement of the mass difference and the binding energy of the hypertriton and antihypertriton”, *Nature Phys.* **16** (2020) 409–412, [arXiv:1904.10520 [hep-ex]]

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** (2000) 929–958, [arXiv:nucl-th/9912065]

F. Hildenbrand and H. W. Hammer, “Three-Body Hypernuclei in Pionless Effective Field Theory”, *Phys. Rev. C* **100** (2019) 034002, [arXiv:1904.05818 [nucl-th]] [Erratum: Phys.Rev.C 102, 039901 (2020)].

ALICE Collaboration, B. Abelev et al., “Freeze-out radii extracted from three-pion cumulants in pp, p–Pb and Pb–Pb collisions at the LHC”, *Phys. Lett. B* **739** (2014) 139–151, [arXiv:1404.1194 [nucl-ex]]

ALICE Collaboration, J. Adam et al., “Two-pion femtoscopy in p-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV”, *Phys. Rev. C* **91** (2015) 034906, [arXiv:1502.00559 [nucl-ex]]

ALICE Collaboration, K. Aamodt et al., “The ALICE experiment at the CERN LHC”, *JINST* **3** (2008) S08002.

ALICE Collaboration, B. Abelev et al., “Performance of the ALICE Experiment at the CERN LHC”, *Int. J. Mod. Phys.* **A29** (2014) I430044, [arXiv:1402.4476 [nucl-ex]]

ALICE Collaboration, E. Abbas et al., “Performance of the ALICE VZERO system”, *JINST* **8** (2013) P10016, [arXiv:1306.3130 [nucl-ex]]

ALICE Collaboration, B. B. Abelev et al., “Measurement of visible cross sections in proton-lead collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV in van der Meer scans with the ALICE detector”, *JINST* **9** (2014) P11003, [arXiv:1405.1849 [nucl-ex]]

ALICE Collaboration, K. Aamodt et al., “Alignment of the ALICE Inner Tracking System with cosmic-ray tracks”, *JINST* **5** (2010) P03003, [arXiv:1001.0502 [physics.ins-det]]

J. Alme et al., “The ALICE TPC, a large 3-dimensional tracking device with fast readout for ultra-high multiplicity events”, *Nucl. Instrum. Meth.* **A622** (2010) 316–367, [arXiv:1001.1950 [physics.ins-det]]
[45] ALICE Collaboration, J. Adam et al., “$^3\Lambda H$ and $^3\bar{\Lambda} H$ production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV”, Phys. Lett. B 754 (2016) 360–372, arXiv:1506.08453 [nucl-ex].

[46] ALICE Collaboration, S. Acharya et al., “$^3\Lambda H$ and $^3\bar{\Lambda} H$ lifetime measurement in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV via two-body decay”, Phys. Lett. B 797 (2019) 134905, arXiv:1907.06906 [nucl-ex].

[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, p. 785–794. Association for Computing Machinery, New York, NY, USA, 2016. https://doi.org/10.1145/2939672.2939785.

[48] ATLAS Collaboration, M. Aaboud et al., “Observation of Higgs boson production in association with a top quark pair at the LHC with the ATLAS detector”, Phys. Lett. B 784 (2018) 173–191, arXiv:1806.00425 [hep-ex].

[49] L. Barioglio, F. Catalano, M. Concas, P. Fecchio, F. Grosa, F. Mazzaschi, and M. Puccio, “hipe4ml/hipe4ml”, Nov., 2021. https://doi.org/10.5281/zenodo.5734093.

[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 (1991) 3501–3516.

[51] GEANT4 Collaboration, S. Agostinelli et al., “GEANT4—a simulation toolkit”, Nucl. Instrum. Meth. A 506 (2003) 250–303.

[52] K. S. Cranmer, “Kernel estimation in high-energy physics”, Comput. Phys. Commun. 136 (2001) 198–207, arXiv:hep-ex/0011057.

[53] W. Verkerke and D. P. Kirkby, “The RooFit toolkit for data modeling”, eConf C0303241 (2003) MOLT007, 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 (2011) 1554, arXiv:1007.1727 [physics.data-an]. [Erratum: Eur.Phys.J.C 73, 2501 (2013)].

[55] H. Kamada, J. Golak, K. Miyagawa, H. Witala, and W. Gloeckle, “Pi mesonic decay of the hypertriton”, Phys. Rev. C 57 (1998) 1595–1603, arXiv:nucl-th/9709035.

[56] E. Schnedermann, J. Sollfrank, and U. W. Heinz, “Thermal phenomenology of hadrons from 200-A/GeV S+S collisions”, Phys. Rev. C 48 (1993) 2462–2475, arXiv:nucl-th/9307020.

[57] ALICE Collaboration, B. Abelev et al., “Multiplicity Dependence of Pion, Kaon, Proton and Lambda Production in p-Pb Collisions at $\sqrt{s_{NN}} = 5.02$ TeV”, Phys. Lett. B 728 (2014) 25–38, arXiv:1307.6796 [nucl-ex].

[58] M. V. Evlanov, A. M. Sokolov, V. K. Tartakovskiy, S. A. Khorozov, and Y. Lukstinsh, “Interaction of hypertritons with nuclei at high-energies”, Nucl. Phys. A 632 (1998) 624–632.

[59] V. Vovchenko and H. Stoecker, “Thermal-FIST: A package for heavy-ion collisions and hadronic equation of state”, Comput. Phys. Commun. 244 (2019) 295–310, arXiv:1901.05249 [nucl-th].

[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 (2010) 224–227, arXiv:0908.3357 [nucl-ex].
Hypertiron production in p–Pb collisions at the $\sqrt{s_{NN}} = 5.02$ TeV

ALICE Collaboration

[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** (1994) 307, [arXiv:nucl-th/9502021](http://arxiv.org/abs/nucl-th/9502021).

[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** (2015) 034906, [arXiv:1306.0121 [hep-ph]](http://arxiv.org/abs/1306.0121).

[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)*, pp. 1033–1038. Springer, Berlin, Dec, 2000. [arXiv:hep-ph/0012252](http://arxiv.org/abs/hep-ph/0012252).

[64] ALICE Collaboration, B. Abelev et al., “Pseudorapidity density of charged particles in $p +$ Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV”, *Phys. Rev. Lett.* **110** (2013) 032301, [arXiv:1210.3615 [nucl-ex]](http://arxiv.org/abs/1210.3615).

[65] STAR Collaboration, L. Adamczyk et al., “Measurement of the $\Lambda$H lifetime in Au+Au collisions at the BNL Relativistic Heavy Ion Collider”, *Phys. Rev. C* **97** (2018) 054909, [arXiv:1710.00436 [nucl-ex]](http://arxiv.org/abs/1710.00436).

[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** (2021) 014904, [arXiv:2009.04844 [hep-ph]](http://arxiv.org/abs/2009.04844).

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

S. Acharya143, D. Adamová98, A. Adler76, G. Aglieri Rinella135, M. Agnello31, N. Agrawal55, Z. Ahammed143, S. Ahmad16, S.U. Ahn78, I. Ahuja39, Z. Akbar52, A. Akindinov95, M. Al-Turany110, S.N. Alan16,41, D. Aleksandrov31, B. Alessandro61, H.M. Alfanda7, R. Alfaro Molina73, B. Ali36, Y. Ali38, A. Alić26, N. Alizadeh-Vandchali127, A. Alkin35, J. Alme21, T. Alt70, L. Altenkamper21, I. Altsybeeve115, M.N. Aamañ7, C. Andrei49, D. Andreyev93, A. Andronic146, M. Angeletti35, V. Anguelov107, F. Antinori58, P. Antonioli35, C. Anu16, N. Apadula82, L. Aphricete117, H. Appelshäuser70, S. Arcelli26, R. Arnaldi61, I.C. Arsene20, M. Arslanbek148, A. Augustinus35, R. Avebecker110, S. Aziz38, M.D. Azmi11, A. Badalà57, Y.W. Baek62, X. Bai131,110, R. Bailhache70, Y. Bailung51, R. Bala104, A. Baldin211, A. Baldisseri140, B. Balis2, M. Ball44, D. Banerjee4, R. Barberi27, L. Barigioli108, M. Barlou67, G.G. Barnaföldi147, L.S. Barnby97, V. Barrett137, C. Bartels130, K. Barth53, E. Bartosch70, F. Baruffaldi28, N. Bastid137, S. Basì83, G. Batigne117, B. Batyunna77, D. Baur50, J.L. Bazo Alba114, I.G. Bearden92, C. Beattie148, I. Belikov139, A.D.C. Bell Hechavarria146, F. Bellini26, R. Bellwied27, S. Belokurov115, V. Belyaev60, G. Bencedi71, S. Beole25, A. Bercuci49, Y. Berdnikov101, A. Berdnikova107, L. Bergmann107, M.G. Besoù99, L. Betev35, P.P. Bhaduri143, A. Bhasin104, I.R. Bhat104, M.A. Bhat4, B. Bhattacharjee43, P. Bhattacharya23, L. Bianchi25, N. Bianchi33, J. Bielčíková78, J. Biernat20, A. Bilandzic108, G. Biro147, S. Biswas4, J.T. Blair121, D. Blau91, M.B. Blidaru110, C. Blume70, G. Bocca79,59, F. Bock99, A. Bogdanov96, S. Boi23, J. Bok63, L. Boldizsár147, A. Bolozdynya96, M. Bombara99, P.M. Bond35, G. Bonomi34,59, H. Borel140, A. Borissov84, H. Bossi148, E. Botta25, L. Bratrud70, P. Braun-Munzinger110, M. Bregant123, M. Broz86, G.E. Bruno109,34, M.D. Buckland130, D. Budnikov111, H. Buesching70, S. Bufalino31, O. Bugnon117, P. Bulher116, Z. Buthelezi74,134, J.B. Butt14, S.A. Byssiak120, M. Cai28,7, H. Caines148, A. Caliva110, E. Calvo Villar114, J.M.M. Camacho122, R.S. Camacho46, P. Camerin24, F.D.M. Canedo123, F. Carnesecchi35,26, R. Caron40, J. Castillo Castellanos140,16, E.A.R. Casula23, F. Catalano31, C. Ceballos Sanchez77, P. Charkraborty50, S. Chandri143, S. Chapeland35, M. Chartier130, S. Chattopadhyay143, S. Chattopadhyay112, A. Chauvin23, T.G. Chavez46, T. Cheng7, C. Cheshkov138, B. Cheynis138, V. Chibante Barroso35, D. Cho63, P. Chocolla35, P. Christakoglou93, C.H. Christensen92, P. Christiansen83, T. Chujo136, C. Cicalo56, L. Cifarelli26, F. Cindolo55, M.R. Ciupek110, G. Chai40,55, J. Clymays126, F. Colamarina54, J.S. Colburn113, D. Colella109,54,34,147, A. Collu48, M. Colocci35, M. Concas81, G. Conesa del Valle80, G. Contin24, J.G. Contreras88, M.L. Coquet140, T.M. Cormier99, P. Cortese52, M.R. Cosentino125, F. Costa25, S. Costanza79,59, P. Crochet137, R. Cruz-Torres82, E. Cuaudelle71, P. Cui7, L. Cunquero99, A. Dainese58, M.C. Danisch107, A. Danu69, I. Das112, P. Das9, P. Das4, S. Das4, S. Dash50, S. De9, A. De Caro30, G. de Cataldo58, L. De Cilli85, J. de Cuveland89, A. De Falco23, D. De Gruttola30, N. De Marco64, C. De Martin24, S. De Pasquale30, S. Deh51, H.F. Degenhardt123, K.R. Deja144, L. Dello Stritto30, S. Delsanto25, W. Deng7, P. Dhankher19, D. Di Bari34, A. Di Mauro35, R.A. Diaz8, T. Dietel126, Y. Ding138,7, R. Divij35, D.U. Dixit19, Ø. Djupsund21, U. Dmitrieva65, J. Do63, A. Dobrin69, B. Dönigus70, O. Dordic20, A.K. Dubey143, A. Dubla110,93, S. Dudi103, M. Dukhishyam89, P. Dupieux137, N. Dzalaiova13, T.M. Edet146, R.J. Ehlers99, V.N. Ekelund21, F. Eisenhut50, D. Elia54, B. Erazmus117, F. Ercoli26, F. Erhardt102, A. Erokhin115, M.R. Erdal21, B. Espagnon80, G. Eulisse35, D. Evans113, S. Evdokimov84, L. Fabbietti108, M. Faggin28, J. Faiivre81, F. Fan7, A. Fantoni33, M. Fasel99, P. Fecchio17, A. Felicioli61, G. Feofilov115, A. Fernández Téllez46, A. Ferrero140, A. Ferretti25, V.J.G. Feuillard107, J. Figiel120, S. Filchagin111, D. Finogeev65, F.M. Fionda56,21, G. Fiorenza35,109, F. Flor27, A.N. Flores21, S. Foertsch74, P. Foka110, S. Fokin91, E. Fragaiocono62, E. Frajmai47, U. Fuchs35, N. Fumicello35, C. Furgert84, A. Furs69, J.J. Gaardhøje92, M. Gagliardi23, A.M. Gago114, A. Gal39, C.D. Galvan122, P. Ganoti87, C. Garabatos140, J.R.A. Garcia46, E. Garcia-Solis10, K. Garg117, C. Gargiulo35, A. Garibelli90, K. Garner146, P. Gasik110, E.F. Gauger121, A. Gautam129, M.B. Gay Ducati72, M. Germain117, P. Ghosh143, S.K. Ghosh4, M. Giacalone26,
Hypertriton production in p–Pb collisions at the √sNN = 5.02 TeV

P. Gianotti, P. Giubellino, P. Giubilato, A.M.C. Glaenzer, P. Glässel, D.J.Q. Goh, V. Gonzalez, L.H. González-Trueba, S. Gorbunov, M. Gorgon, L. Görlich, S. Gotovac, V. Grabski, L.K. Graczykowski, L. Greiner, A. Grelli, C. Grigoras, V. Grigoriev, A. Grigoryan, S. Grigoryan, O.S. Groetto, F. Grosa, J.F. Grose-Oettinghaus, R. Gross, G.G. Guardiano, R. Guernane, M. Guibaud, K. Gulbransen, T. Gunji, W. Guo, A. Gupta, R. Gupta, S.P. Guzman, L. Gyulai, M.K. Habib, C. Hadijidakis, G. Halimoglu, H. Hamagaki, G. Hamar, H. Hamid, R. Hannigan, M.R. Haque, A. Harlenderova, J.W. Harris, A.G. Barton, J.A. Hasenbichler, H. Hassan, D. Hatzifotiouda, P. Hauer, L.B. Havener, S. Hayashi, S.T. Heckel, E. Helbärr, H. Helstrup, T. Herman, E.G. Hernandez, G. Herrera Corral, F. Herrmann, K.F. Hetland, H. Hillemanns, C. Hills, A. Hippolyte, B. Hofman, B. Hohlwege, J. Honermann, G.H. Hong, D. Horak, S. Horning, A. Horzyk, R. Hosokawa, Y. Hou, P. Hristov, C. Hughes, P. Huhn, T.J. Humanic, L.P. Hummitzsch, L.A. Husova, A. Hutson, D. Hutter, J.P. Iddon, R. Ilkaev, H. Ilyas, M. Inaba, G.M. Innocent, M. Ippolito, A. Isakov, M. Islam, M. Ivanov, V. Ivanov, V. Izuchev, M. Jablonski, B. Jacak, N. Jacazio, P.M. Jacobs, S. Jadlovecka, J. Jadlovsky, S. Jaehn, C. Jahneke, M.J. Jakubowska, A. Jalotra, M.A. Janik, T. Janson, M. Jercic, O. Jevons, A.A.P. Jimenez, F. Jonas, P.G. Jones, J.M. Jowett, J. Jung, K. Jung, O. Junike, A. Jusko, J. Kaewjai, P. Kalina, A. Kalweit, V. Kaplin, S. Kar, A. Karasus Uysal, D. Karatovic, O. Karavichev, T. Karavicheva, P. Karczmarczyk, E. Karpechev, A. Kazantsev, U. Kebschull, R. Keidel, D.L.D. Keijjender, B. Keitel, Z. Khabanova, A.M. Khan, S. Khan, A. Khanzadeev, Y. Khilarov, A. Khatun, A. Khuntia, B. Kileng, B. Kim, C. Kim, D.J. Kim, E.J. Kim, J. Kim, J. Kim, J. Kim, J. Kim, J. Kim, T. Kim, S. Kirsch, I. Kisel, R. Kiselev, A. Kisiel, I.P. Kitowski, J.L. Klay, J. Klein, S. Klein, S. Klein-Bösing, M. Kleiner, T. Klement, A. Kluge, A.G. Knope, C. Kobdaj, M.K. Köhler, T. Kollegger, A. Kondratyev, N. Kondratyeva, E. Kondratyuk, J. König, S.A. Konigstorfer, P.J. Konopka, G. Kornak, A. Koryciak, L. Koska, A. Kotliar, O. Kovalenko, V. Kovalenko, M. Kowalski, J. Kralik, A. Kravčáková, L. Kreis, M. Krivda, F. Krizek, K. Krickova Gajdosova, M. Kroesen, M. Krüger, E. Kryshen, M. Krzewicki, V. Kucera, C. Kuhn, P.G. Kuijer, T. Kumaoka, D. Kurems, L. Kumar, N. Kumar, S. Kundi, P. Kurashvili, A. Kurepin, A.B. Kurepin, A. Kuryakin, S. Kushpil, J. Kvapil, M.J. Kweon, J.Y. Kwon, S.L. La Pointe, P. La Rocca, Y.S. Lai, A. Lakrathok, M. Lamanna, R. Langoy, K. Lapidus, P. Larionov, E. Laudi, L. Lautner, R. Lavicka, T. Lazareva, R. Lea, J. Lehrbach, R.C. Lemmon, I. León Monzón, E.D. Lesser, M. Lettrich, P. Lővay, X. Li, X.L. Li, J. Lien, R. Lietava, B. Lim, S.H. Lim, V. Lindenstruth, A. Lindner, C. Lippmann, A. Liu, D.H. Liu, J. Liou, J.M. Lofnés, V. Logino, C. Loizides, P. Long, J.A. Lopez, X. Lopez, E. López Torres, J.R. Luhder, M. Lunardoni, G. Luparello, Y.G. Mǎ, A. Maevskaya, M. Mager, T. Mahmoud, A. Maire, M. Malaeve, N.M. Malik, Q.W. Malik, L. Malinina, D. Mal’kevich, N. Mallick, P. Malzacher, G. Mandaglio, V. Manko, F. Manso, V. Manzari, Y. Mao, J. Mareš, G.V. Margagliotti, A. Margotti, A. Marin, C. Markert, B. Marquard, N.A. Martin, J.L. Martinengo, M.I. Martínez, G. Martínez García, S. Masciocchi, M. Masera, A. Masoni, L. Massacrier, A. Mastrosersio, A.M. Mathis, O. Matonoha, P.F.T. Matuoka, A. Matyja, C. Mayer, A.L. Mazuecos, F. Mazzaschi, M. Mazzilli, M.A. Mazzeo, I. Mdlulis, A.F. Mechler, F. Meddi, Y. Melikyan, A. Mencach-Rocha, E. Meninno, A. Menconi, S. Mnihova, S. Mlhanga, S. Miček, L. Michelelli, L.C. Migliorini, D.L. Mihaylov, K. Mikhaylov, A.N. Mishra, D. Miękowicz, A. Modak, A.P. Mohanty, B. Mohanty, M. Mohisins Khan, M.A. Molander, Z. Moravecova, C. Mordasini, D.A. Moreira De Godoy, L.A.P. Moreno, I. Morozov, A. Morsch, T. Mnjavac, V. Muccioni, E. Mudnic.
Hypertriton production in p–Pb collisions at the √s_{NN} = 5.02 TeV

ALICE Collaboration

D. Mühlheim, S. Muhuri, J.D. Mulligan, A. Mulliri, M.G. Munhoz, R.H. Munzer, H. Murakami, S. Murray, L. Musa, J. Musinsky, J.W. Myrcha, B. Naik, R. Nair, B.K. Nandi, R. Nania, E. Nappi, A.F. Nassirpour, A. Nath, C. Natrass, A. Neagu, L. Nellen, S.V. Nesbo, G. Neskovik, D. Nesterov, B.S. Nielsen, S. Nikolaj, S. Níkulin, V. Níkulin, F. Noferini, S. Noah, 2, P. Nomokonov, J. Norman, S. Novitzky, P. Nowakowski, A. Nyann, J. Nystrand, M. Ogino, A. Ohlson, V.A. Okorokov, J. Oleniacz, A.C. Oliveira Da Silva, M.H. Oliver, A. Onnerstad, C. Oppedison, A. Ortiz Velasquez, T. Osako, A. Oskarsson, J. Otwinowski, M. Oya, K. Oyama, Y. Pachmayer, S. Padhan, D. Pagano, G.S. Pai, T. Palacios, M. Pan, J. Pan, S. Panebianco, P. Pareek, J. Park, J.E. Parkkila, S.P. Pathak, R.N. Patri, B. Pauj, H. Pei, T. Peitzmann, X. Peng, L.G. Pereira, H. Pereira Da Costa, G. Perniciaro, G. Peter, G. Petri, M. Petrecz, M. Petrovic, R.P. Pezzi, S. Piano, M. Pikna, P. Pilot, O. Pinazza, L. Pinsky, C. Pinto, S. Pisano, M. Ploskon, M. Planinic, F. Pliquett, M.G. Poghosyan, B. Polchbouck, S. Polito, N. Poljak, A. Pop, S. Porteboef-Houssais, J. Porter, V. Pozdniakov, S.K. Prasad, R. Preghenella, F. Prino, C.A. Pruneau, I. Pshenichny, M. Puccio, S. Qiu, L. Quagliola, R.E. Quishpe, S. Ragoni, I. Rakotozafindrabe, L. Ramello, F. Rani, S.A.R. Ramirez, A.G.T. Ramos, T.A. Rancien, R. Raniwala, S. Raniwala, S.S. Räisänen, R. Rath, I. Ravasengar, K.F. Read, A.R. Redelbach, K. Redlich, A. Rehman, P. Reichelt, F. Reidt, H.A. Remee, R. Renfordt, Z. Rescakova, K. Reygers, A. Riabov, V. Riabov, T. Richert, M. Richter, W. Riegler, F. Riggi, C. Ristea, H. Rodeck, R. Rogalev, E. Rogochaya, T.S. Rogoschinski, D. Rohr, D. Röhrich, P.F. Rojas, P.S. Rokita, F. Ronchetti, A. Rosano, E.D. Rosas, T. Rossi, R. Rotoni, R. Roy, P. Roy, S. Roy, N. Rubini, O.V. Rueda, R. Rui, B. Rumyanetz, P.G. Russek, A. Rustamov, E. Ryabinkin, Y. Ryabov, A. Rybick, H. Rytkonen, W. Rzesza, O.A.M. Saarimaki, R. Sadek, S. Sadovsky, J. Saetre, K. Šafářík, S.K. Saha, B. Sahoo, P. Sahoo, R. Sahoo, S. Sahoo, D. Sahu, P.K. Sahu, J. Sain, S. Sakai, S. Sambyal, V. Samsonov, D. Sarkar, N. Sarkar, P. Sarma, V.M. Sarti, M.H.P. Sas, J. Schambach, H.S. Scheid, C. Schiaua, R. Schicker, A. Schmah, C. Schmidt, H.R. Schmidt, M.O. Schmidt, M. Schmidt, N.V. Schmid, A.R. Schmier, R. Schotter, J. Schukraft, Y. Schutz, K. Schwarz, K. Schweda, G. Scioli, E. Scomparin, J.E. Seger, Y. Sekiguchi, D. Sekihata, I. Selyuzhenkov, S. Senyukov, J.J. See, D. Serebyakov, L. Šerkšnytė, A. Sevcenco, T.J. Shaba, A. Shabanov, A. Shabetai, R. Shahoyan, W. Shaikh, A. Shangaraev, A. Sharma, H. Sharma, M. Sharma, N. Sharma, S. Sharma, U. Sharma, O. Sheibani, K. Shigaki, M. Shimomura, S. Shirinkin, Q. Shou, Y. Sibiriak, S. Siddhanta, T. Siemiarczuk, H.S. Siffa, T.F. Silla, D.M. Silvermy, T. Simantathammakul, G. Simonetti, S. Singh, R. Singh, V.K. Singh, V. Singhal, T. Sinha, B. Sitar, M. Sitta, T.B. Skaali, G. Skordoumos, M. Slupecki, N. Smirnov, R.J.M. Snellings, C. Sonce, J. Song, A. Songmoolnak, F. Soramale, S. Sorensen, I. Spetoska, J. Stachel, I. Stan, P.J. Steffanic, S.F. Stiefelmaier, D. Stocco, I. Storehaug, M.M. Storetvedt, C.P. Stylianidis, A.A.P. Suáide, T. Sugita, C. Suirie, M. Sukhanov, M. Suljic, R. Sultanov, M. Šumbera, V. Sumberia, S. Sumowidagdo, S. Swain, A. Szabo, I. Szarka, U. Tabassam, S.F. Taghavi, G. Tailliepied, J. Takahashi, G.J. Tambave, S. Tangle, Z. Tang, M. Tarhini, M.G. Tarzila, A. Tauro, G. Tejeda Muñoz, A. Telesca, L. Terlizzi, C. Terrevoli, G. Tersimonov, S. Thakur, D. Thomas, R. Tieulent, A. Tikhonov, A.R. Timmins, M. Tkacik, A. Toia, N. Topilskaya, M. Toppi, F. Torales-Acosta, T. Tork, S.R. Torres, A. Trifirò, M. Tripat, I. Tripathy, T. Tripathy, S. Trogolo, G. Trombetta, V. Trubnikov, W.H. Trzaska, T.P. Trzciński, B.A. Trzciak, A. Tumkin, R. Turrisi, T.S. Tveter, K. Ullaland, A. Uras, M. Urioni, G.L. Usai, M. Vala, N. Valle, S. Vallero, N. van der Kolk, L.V.R. van Doremalen, M. van Leeuwen, R.J.G. van Weelden,
Hypertriton production in p–Pb collisions at the $\sqrt{s_{NN}}=5.02$ TeV

ALICE Collaboration

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. Vecherin$^{115}$, E. Vercellin$^{25}$, S. Vergara Limón$^{46}$, L. Vermunt$^{113}$, R. Vértesi$^{147}$, M. Verweij$^{36}$, L. Vickovic$^{26}$, Z. Vilakazi$^{134}$, O. Villalobos Baillie$^{113}$, G. Vine$^{54}$, A. Vinogradov$^{91}$, T. Virgili$^{30}$, V. Vlasiu$^{92}$, A. Vodopyanov$^{77}$, B. Volkel$^{55}$, M.A. Völkl$^{107}$, K. Voloshin$^{75}$, S.A. Voloshin$^{145}$, G. Volpe$^{34}$, B. von Haller$^{35}$, I. Vorobyev$^{108}$, D. Voscek$^{119}$, N. Vozniuk$^{65}$, J. Vrálková$^{39}$, B. Wagner$^{21}$, C. Wang$^{41}$, D. Wang$^{41}$, M. Weber$^{116}$, A. Wegzryn$^{155}$, S.C. Wenzel$^{15}$, 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$^{1}$, A.K. Yadav$^{143}$, S. Yalçin$^{79}$, 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$^{24}$, C. Zampolli$^{35}$, H.J.C. Zanolfi$^{64}$, 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$^{52}$, J. Zhu$^{7,110}$, Y. Zhu$^{1}$, A. Zichichi$^{26}$, G. Zinovjev$^{3}$, N. Zurlo$^{42,59}$

1 Deceased

Also at: Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Bologna, Italy

Also at: Dipartimento DET del Politecnico di Torino, Turin, Italy

Also at: M.V. Lomonosov Moscow State University, D.V. Skobeltsyn Institute of Nuclear, Physics, Moscow, Russia

Also at: Department of Applied Physics, Aligarh Muslim University, Aligarh, India

Also at: Institute of Theoretical Physics, Wroclaw University, Poland

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

2 AGH University of Science and Technology, Cracow, Poland

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, California, United States

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, United States

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, United States

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, United States

20 Department of Physics, University of Oslo, Oslo, Norway

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

22 Dipartimento di Fisica dell’Università ‘La Sapienza’ and Sezione INFN, Rome, Italy

23 Dipartimento di Fisica dell’Università di Cagliari, Cagliari, Italy
Hypertriton production in p–Pb collisions at the $\sqrt{s_{NN}} = 5.02$ TeV

ALICE Collaboration

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, Berkeley, California, United States
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, Rež u Prahy, Czech Republic
99 Oak Ridge National Laboratory, Oak Ridge, Tennessee, United States
100 Ohio State University, Columbus, Ohio, United States
101 Petersburg Nuclear Physics Institute, Gatchina, Russia
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, Jaipur, 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 and Sezione INFN, Bari, Italy
110 Research Division and ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany
111 Russian Federal Nuclear Center (VNIIEF), Sarov, Russia
Hyperttriton production in p–Pb collisions at the $\sqrt{s_{\text{NN}}}$ = 5.02 TeV

ALICE Collaboration

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, St. Petersburg, Russia
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, Cracow, Poland
121 The University of Texas at Austin, Austin, Texas, United States
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 André, Brazil
126 University of Cape Town, Cape Town, South Africa
127 University of Houston, Houston, Texas, United States
128 University of Jyväskylä, Jyväskylä, Finland
129 University of Kansas, Lawrence, Kansas, United States
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, Knoxville, Tennessee, United States
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
140 Université Paris-Saclay Centre d’Études de Saclay (CEA), IRFU, Département 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, Detroit, Michigan, United States
146 Westfälische Wilhelms-Universität Münster, Institut für Kernphysik, Münster, Germany
147 Wigner Research Centre for Physics, Budapest, Hungary
148 Yale University, New Haven, Connecticut, United States
149 Yonsei University, Seoul, Republic of Korea

19