A Large Ion Collider Experiment

Alma Mater Studiorum Università di Bologna

(Hyper)nuclei and anti-(hyper) nuclei production in ALICE experiment at the LHC

Manuel Colocci on behalf of ALICE Collaboration

Introduction

LHC as an anti- and (hyper)nuclei factory

- At LHC energies large and almost equal amounts of matter and anti-matter are produced in the central rapidity region
- Thanks to its high tracking and particle identification capabilities the ALICE detector allows one to measure and study the production of anti- and (hyper)nuclei

Production scenarios

Thermal production [1] during the hadronization process investigated with:

- d and ^{3}He spectra
- p_{T}-integrated particle yield (dN/dy)

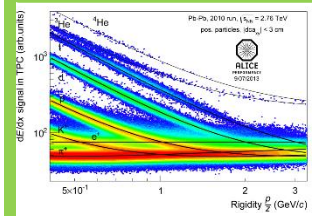
Coalescence process of two or more (anti-)baryons at the last stage of the collision [2] explored measuring:

- coalescence parameter B_A
- d/p ratio versus charged multiplicity

Hypermatter investigation

- anti-hypertriton ($^{3}_{\bar{\Lambda}}\bar{\mathrm{H}}$) observation
- (anti-)$^{3}_{\Lambda}$H lifetime determination
- search for $\overline{\Lambda n} \longrightarrow \bar{d}\pi^{+}$
- search for H-dibaryon $\longrightarrow \Lambda p \pi^{-}$

Particle identification

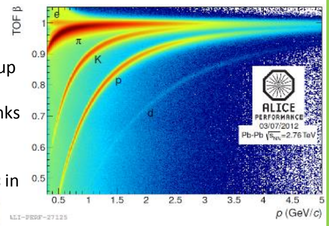


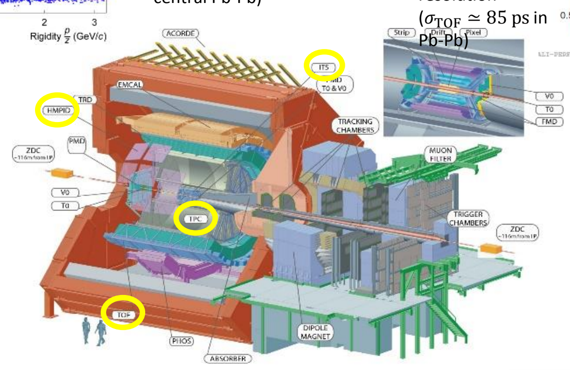
Time Projection Chamber

- clear nuclei separation thanks to specific energy loss dE/dx ($\sigma_{TPC} \simeq 7\%$ in central Pb-Pb)

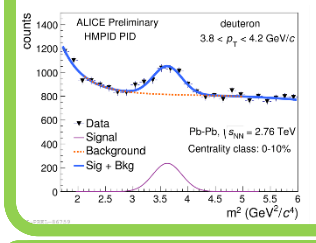
Time Of Flight

- deuteron identification up to higher momenta thanks to excellent resolution ($\sigma_{TOF} \simeq 85$ ps in Pb-Pb)





Pb-Pb, $\sqrt{s_{NN}} = 2.76$ TeV
p-Pb, $\sqrt{s_{NN}} = 5.02$ TeV
pp, $\sqrt{s} = 0.9,\ 2.76,\ 7,\ 8$ TeV

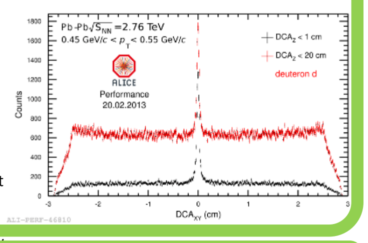


High Momentum Particle Identification

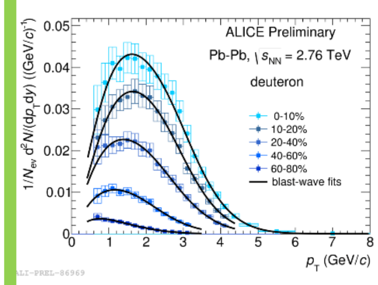
- the resolution of the Cherenkov radiation allows for the deuteron measurement at intermediate momenta (with the available statistics, up to $p_T \simeq 8$ GeV/c in Pb-Pb in 0-10% centrality class)

Inner Tracking System

- separation of primary and secondary nuclei which are produced in the material "knock out" thanks to the measurement of the Distance Of Closest Approach (DCA) to the primary vertex

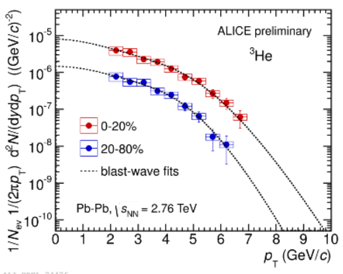


(Anti-)nuclei



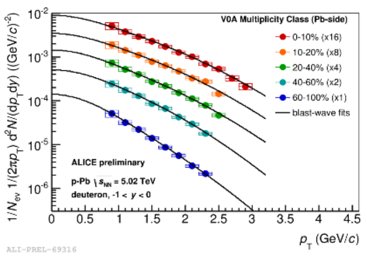
deuteron and ^{3}He spectra as a function of centrality class in Pb-Pb events

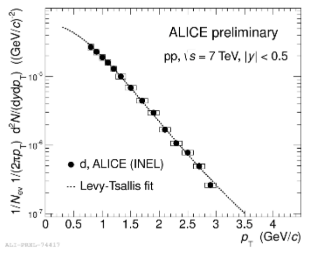
- hardening of spectra with centrality explained as a consequence of the expanding source [3]
- Blast-wave function [4] for p_T-integrated yield extrapolation

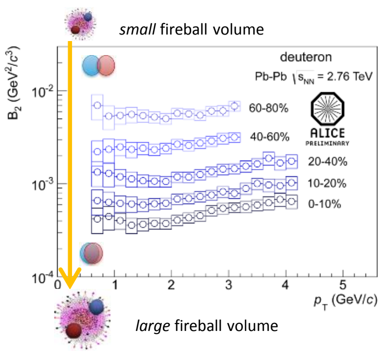


deuteron spectra measured also in p-Pb and in pp collisions

- p-Pb: hardening of spectra as observed in Pb-Pb
- pp: Levy-Tsallis fit [5] to extrapolate the unmeasured region





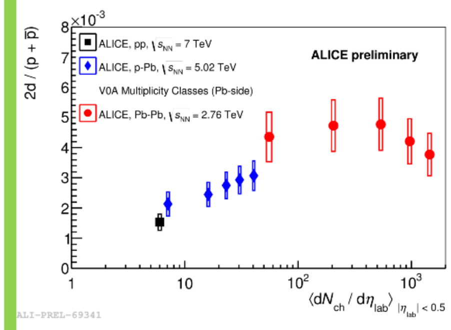


coalescence parameter B_2

$$E_d \frac{dN_d}{dp_d} \approx B_2 \left(E_p \frac{dN_p}{dp_p}\right)^2$$

- strong centrality dependence: $B_2 \propto V_{eff}^{-1}$ creation of a larger fireball volume [6]
- p_T dependence in central collisions due to significant contribution of the exponential term at LHC energies: it is related to the position-momentum correlations in an expanding source and provides information about nucleon density profile and radial flow [6]

$$B_2 = \frac{3\pi^{3/2}\langle C_d\rangle}{2 m_T R_\perp^2(m_T) R_\parallel(m_T)} e^{2(m_T - m_0)\left(\frac{1}{T_p^*} - \frac{1}{T_d^*}\right)}$$



deuteron-over-proton ratio

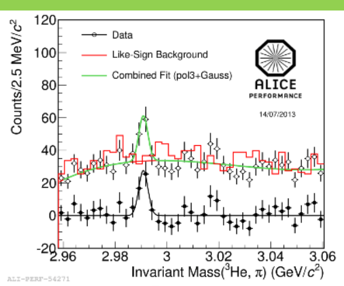
- d/p ratio in p-Pb:
  - rising with multiplicity: consistent with an increased deuteron production at higher nucleon densities as predicted by coalescence model --> models using nucleon density instead of multiplicity are clearly favoured
  - consistent with pp at lower multiplicity
  - consistent with Pb-Pb at higher multiplicity
- constant in Pb-Pb collisions
- in pp about 2.5 lower than Pb-Pb

(Anti-)hypernuclei

$^{3}_{\Lambda}$H and $^{3}_{\bar{\Lambda}}\bar{\mathrm{H}}$ observation

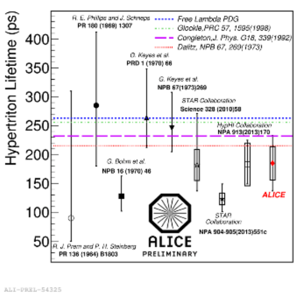
- $^{3}_{\Lambda}$H ≡ lightest strange nucleus formed by a proton, a neutron and a Λ particle
- clear identification in Pb-Pb of also the antimatter counterpart ($^{3}_{\bar{\Lambda}}\bar{\mathrm{H}}$) via their decay channel up to $p_T \simeq 8$ GeV/c

$$^{3}_{\Lambda}\mathrm{H}\ (\Lambda p n) \longrightarrow {}^{3}\mathrm{He} + \pi^{-}$$
$$^{3}_{\bar{\Lambda}}\bar{\mathrm{H}}\ (\bar{\Lambda}\bar{p}\bar{n}) \longrightarrow {}^{3}\overline{\mathrm{He}} + \pi^{+}$$



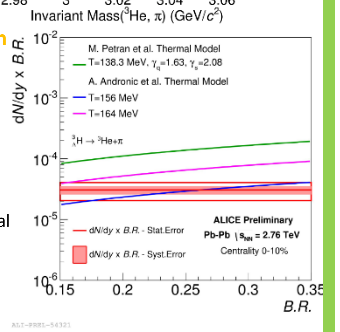
Lifetime determination

- agreement with other experimental results
- hypertriton decays after a few centimeters, its lifetime is close to that of the free Λ particle

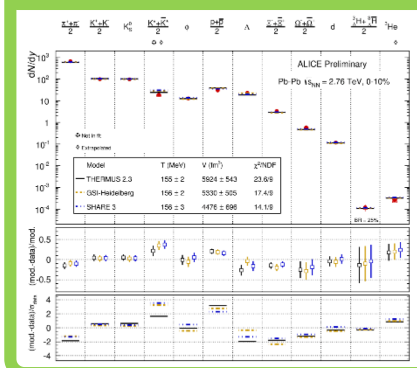


Comparison with thermal models

- production yield compared with thermal models [2] [7]
- it favours model assuming thermal equilibrium (Andronic et al. [2]) during the hadronization process



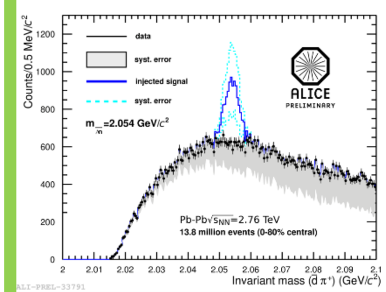
Thermal fit



- In heavy-ion collisions the particle yields can be successfully described by thermal models
  - main parameters: temperature (T_{ch}), bariochemical potential (μ_B) and the volume (V) at chemical freeze-out
  - THERMUS 2.3 [10], GSI-Heidelberg [11], SHARE 3 [12]
- nuclei are in good agreement with models assuming thermal equilibrium and a temperature $T_{ch} = 156(2)$ MeV

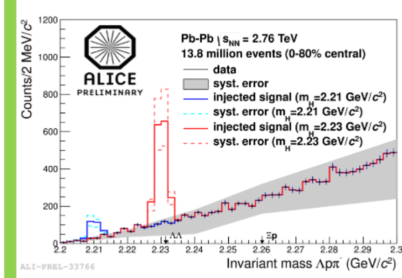
See also poster by N. Jacazio

Exotica



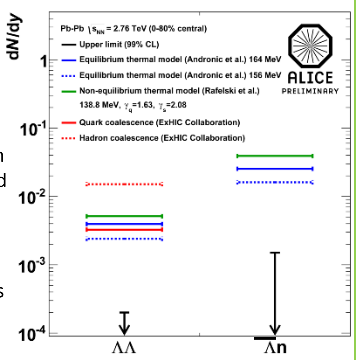
$\overline{\Lambda n}$ bound state

- experimental evidence of a new state Λn in the channel dπ⁻ reported by HypHI experiment [8]
- ALICE searches for a possible $\overline{\Lambda n}$ in Pb-Pb: lower background expected compared to the corresponding particle
- ALICE searches do not confirm its existence (4003 expected particles from thermal models)



H-dibaryon (ΛΛ)

- hypothetical *uuddss* (ΛΛ) state [9]
- search (Pb-Pb) via H(ΛΛ) $\longrightarrow \Lambda + p + \pi^{-}$
- 211 strongly bound or 1350 lightly bound dibaryons from thermal models



The NON OBSERVATION sets upper limits for the two searched particles at least a factor 10 below than the thermal model predictions*

* which are in agreement with the production yield measured for d, ^{3}He and $^{3}_{\Lambda}$H

References

[1] L. Xue, Y. G. Ma, J. H. Chen, S. Zang. Phys. Rev. C 85, 064912 (2012).
[2] A. Andronic, P. Braun-Munzicher, J. Stachel, H. Stoker. Phys. Lett B 697, 203 (2011).
[3] B. I. Abelev et al. (ALICE Collaboration). Phys. Rev. Lett. 109, 252301 (2014).
[4] E. Schnedermann, J. Sollfrank, U. W. Heinz. Phys. Rev. C 48, 2462 (1993).
[5] C. Tsallis. J. Statist. Phys 52, 479 (1988).
[6] R.Scheibl, U.Heinz. Phys. Rev. C 59, 1585 (1999).
[7] M. Petráň, J. Latessier, V. Petráček, J. Rafelski. Phys. Rev. C 88 034907 (2013).
[8] C. Rappold et al. Phys. Rev. C 88, 041001(R) (1999).
[9] R.L. Jaffe. Phys. Rev. Lett. 38, 195 (1977), et erratum ibid 38, 617 (1977).
[10] S. Wheaton et al. Comp. Phys. Commun. 180, 84 (2009).
[11] A. Andronic, P. Braun-Munzicher, J. Stachel. Phys. Lett B 673, 142 (2009).
[12] M. Petran, J. Letessier, J. Rafelski, G. Torrieri. arXiv:1310.5108v2.