Istituto Nazionale di Fisica Nucleare

ALICE

(Hyper)nuclei and anti-(hyper)nuclei production in Pb-Pb collisions in ALICE at LHC

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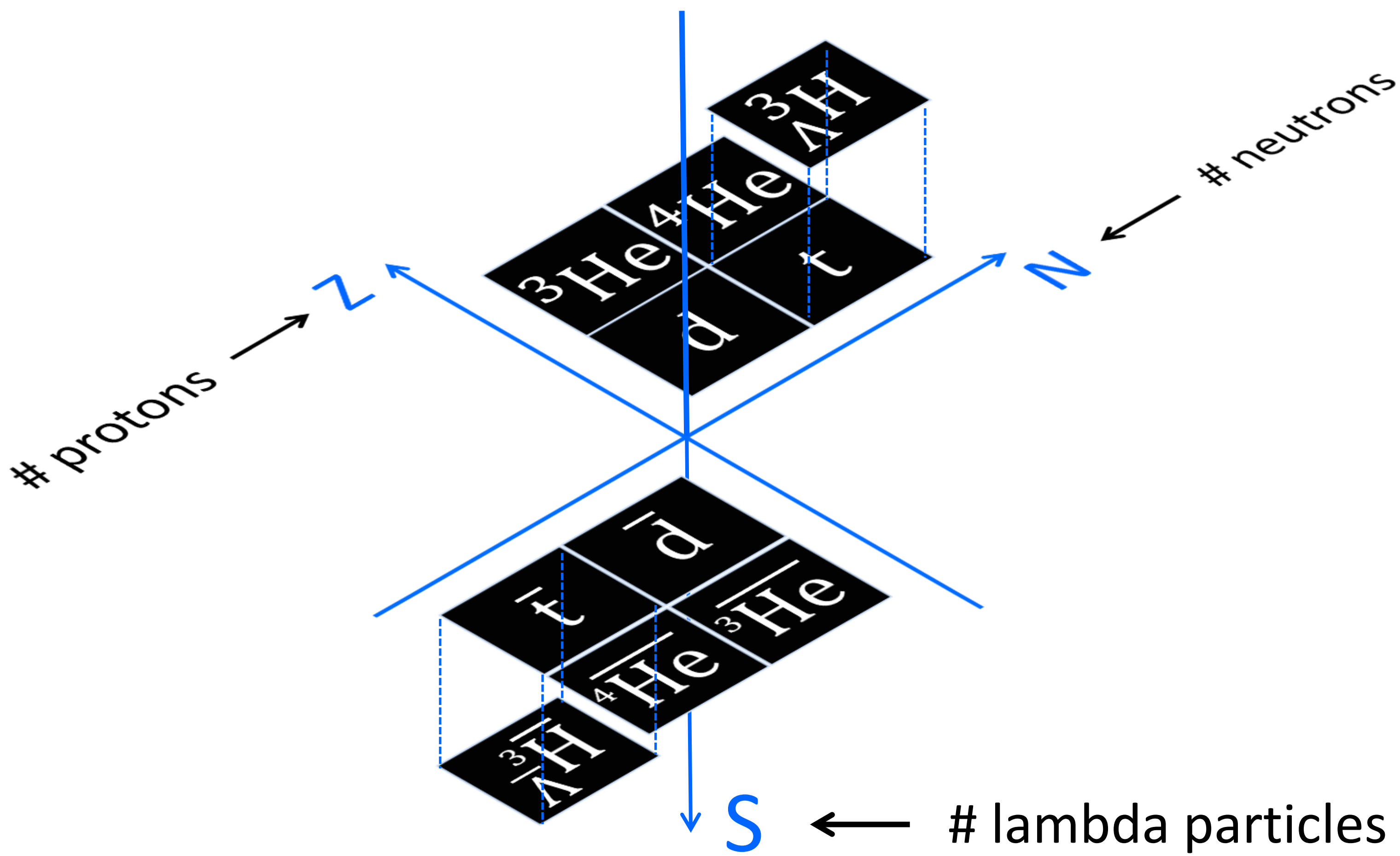
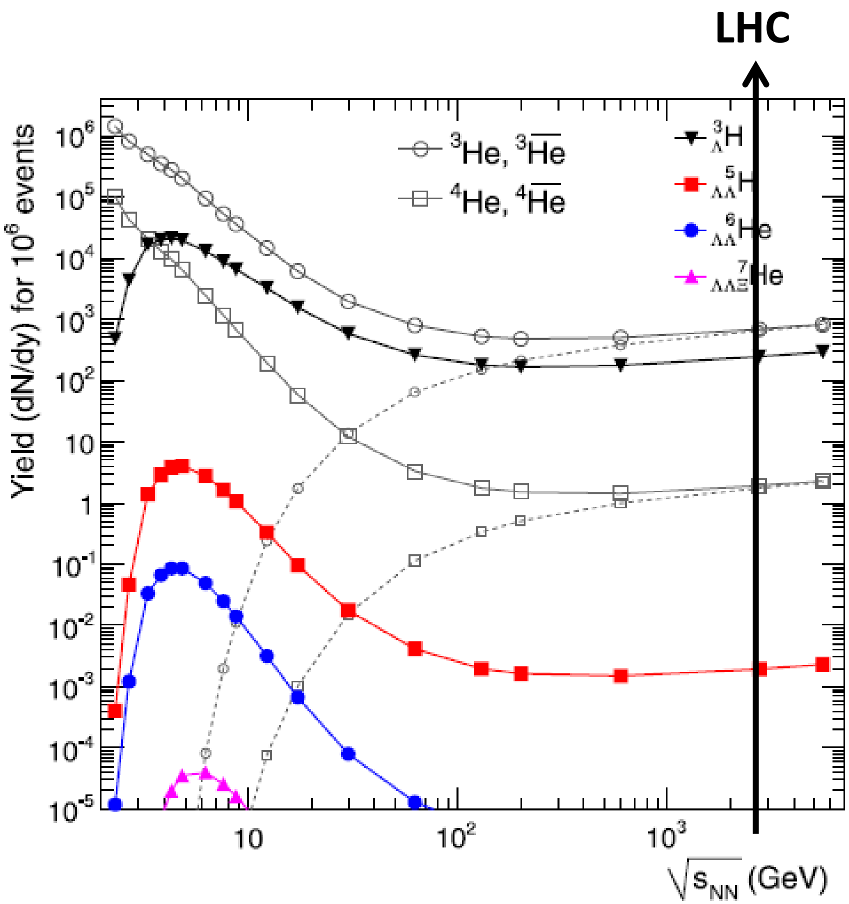
HOT QUARKS '14
Workshop for young scientists on the physics of ultrarelativistic nucleus-nucleus collisions
Sept. 21-28
Las Negras -- Cabo de Gata Natural Park, Andalucia, Spain

Which nuclei?



Predictions: thermal approach



In nucleus-nucleus collisions the yields of light nuclei and their antiparticles are predicted by thermal models [1]:

➡ in this approach the only parameters are the chemical freeze-out temperature T_{ch}, the baryo-chemical potential μ_b and the fireball volume V

Their binding energies are much less than T_{ch}:

⚠ the relative yield of particles composed by nucleons is determined by the entropy (fixed at the chemical freeze-out)

The nuclei abundance is strongly sensitive to T_{ch} due to their large mass: it is proportional to the Boltzmann factor $e^{-m/T_{ch}}$

[1] A. Andronic et al., Phys. Lett. B 697, 203 (2013)

Predictions: coalescence

In coalescence picture the (anti)nuclei are formed at the last stage of the system evolution (kinematic freeze-out)

➡ their production is proportional to the primordial nucleon density in coordinate and momentum space [1]

⚠ Once produced at the chemical freeze-out they could break and be generated again via final-state coalescence

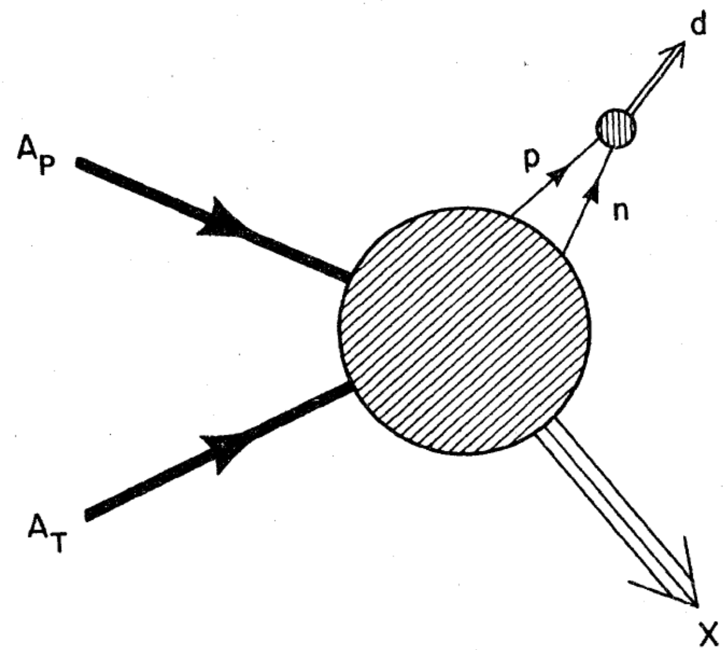
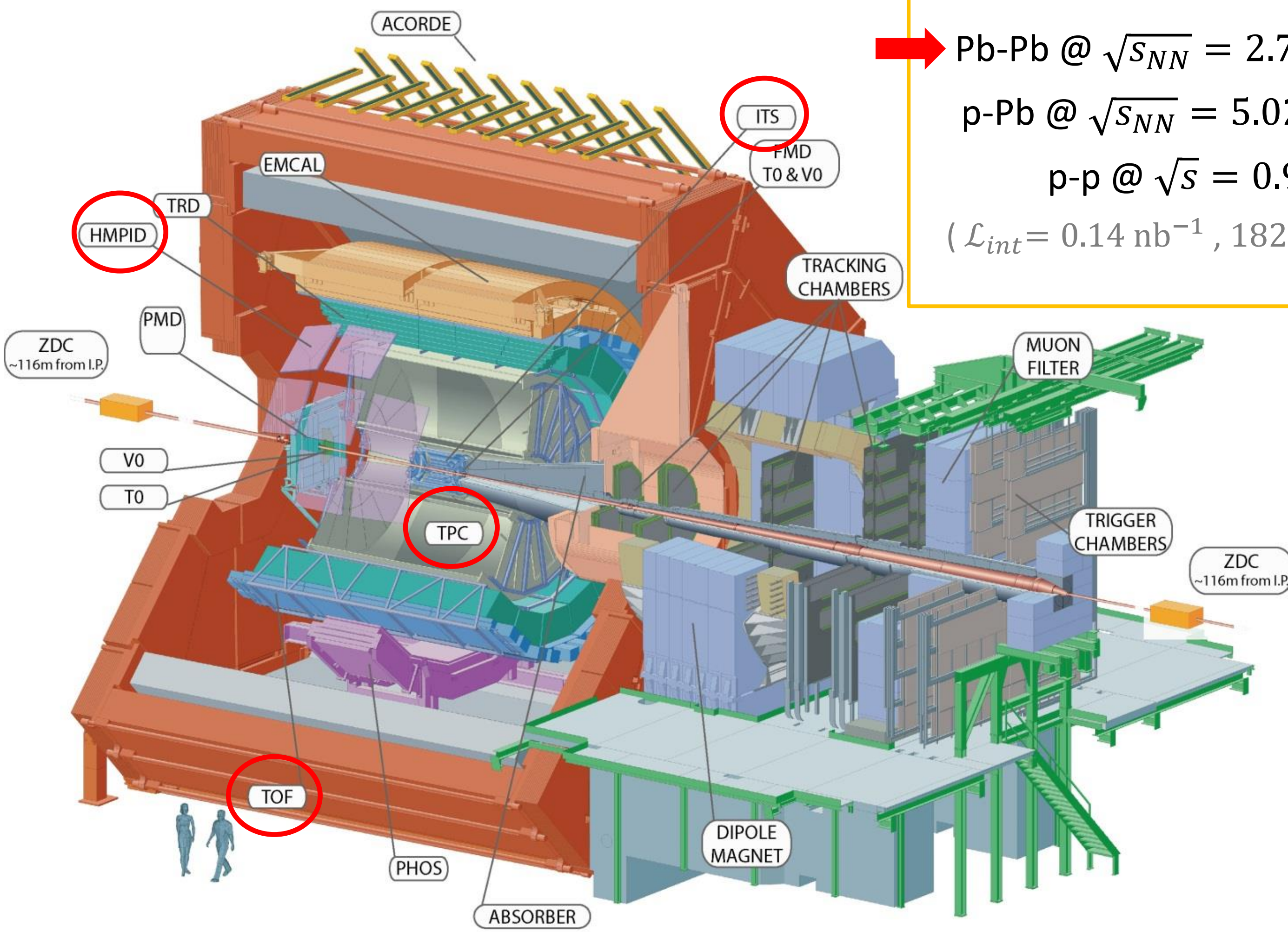


FIG. 1. Schematic for the production of a deuteron in the final state of a relativistic collision between two heavy nuclei.

[1] L. Xue et al., Phys. Rev. C 85, 064912 (2012)

The ALICE detector



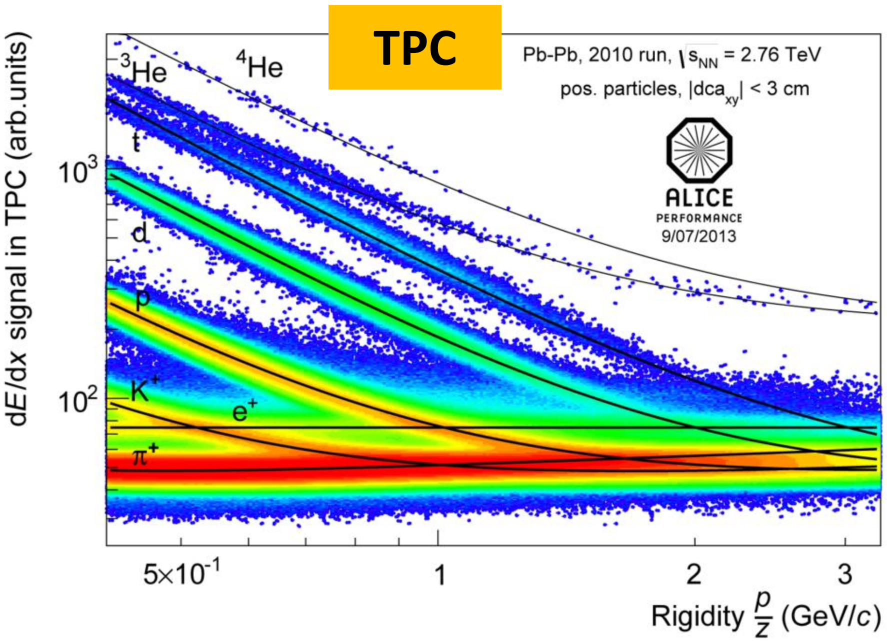
Pb-Pb @ $\sqrt{s_{NN}}$ = 2.76 TeV ($\mathcal{L}_{int}$ = 153 μb^{-1})

p-Pb @ $\sqrt{s_{NN}}$ = 5.02 TeV ($\mathcal{L}_{int}$ = 31.9 nb^{-1})

p-p @ $\sqrt{s}$ = 0.9, 2.76, 7, 8 TeV

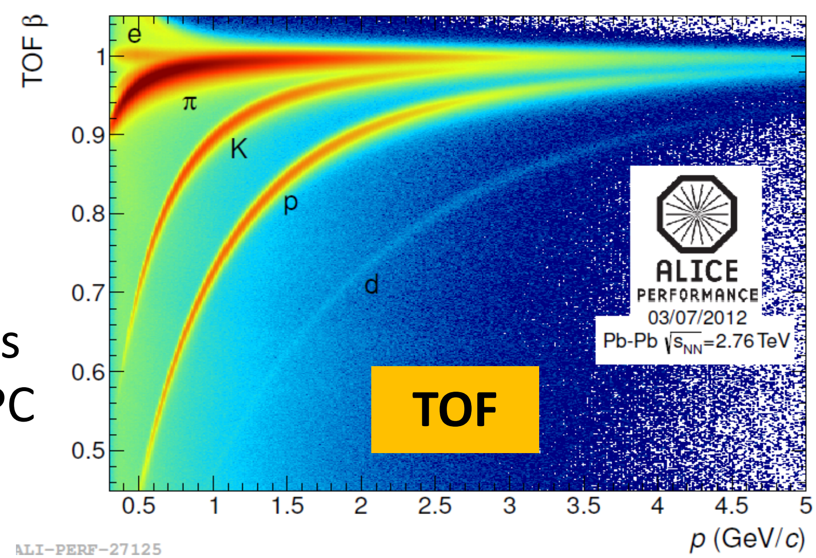
($\mathcal{L}_{int}$ = 0.14 nb^{-1} , 182 nb^{-1}, 5.4 pb^{-1}, 9.96 pb^{-1})

The (anti)nuclei identification (I)

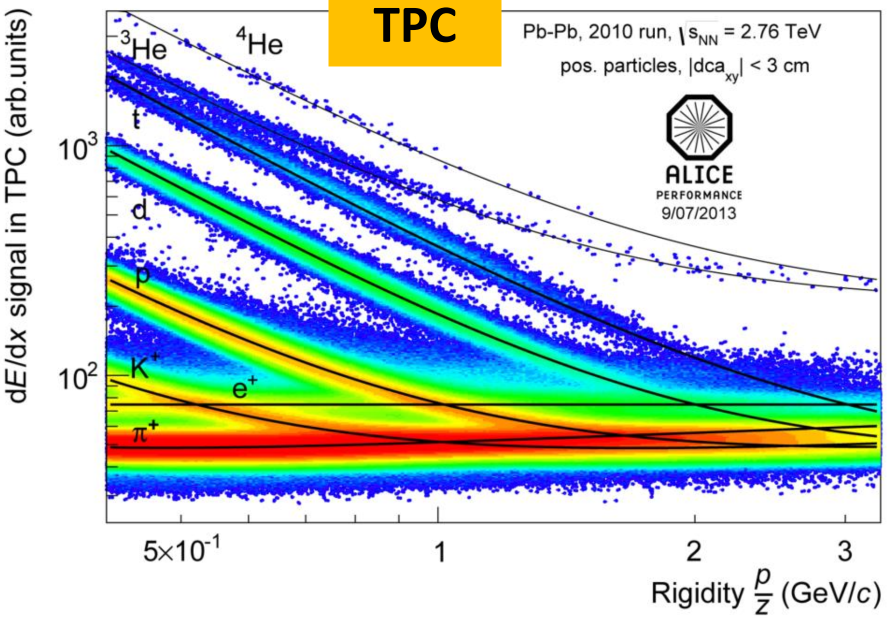


Time Projection Chamber: measurement of dE/dx with a resolution of $\sigma_{TPC} \simeq 7\%$ in central Pb-Pb collisions

Time Of Flight: resolution of of $\sigma_{TOF} \simeq 80$ ps in central Pb-Pb collisions and with a similar acceptance as the TPC

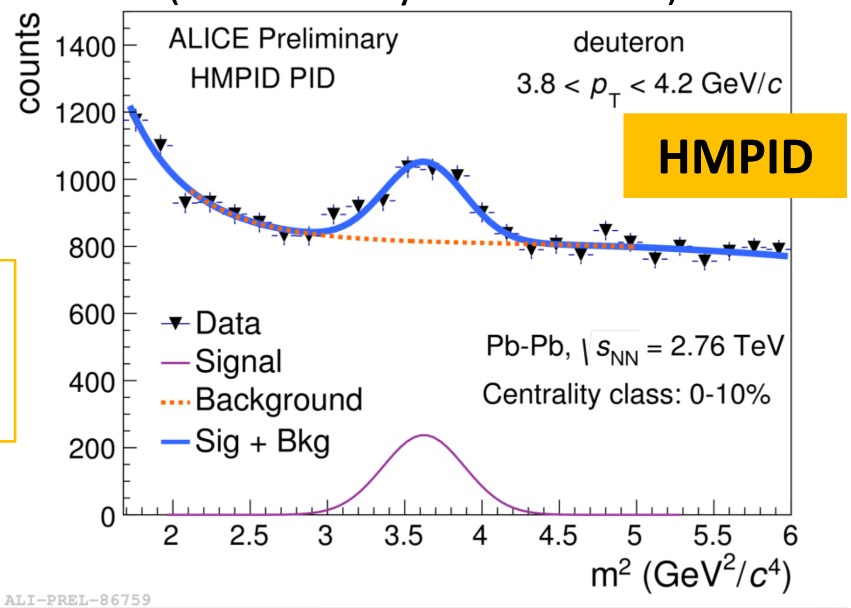


The (anti)nuclei identification (I)



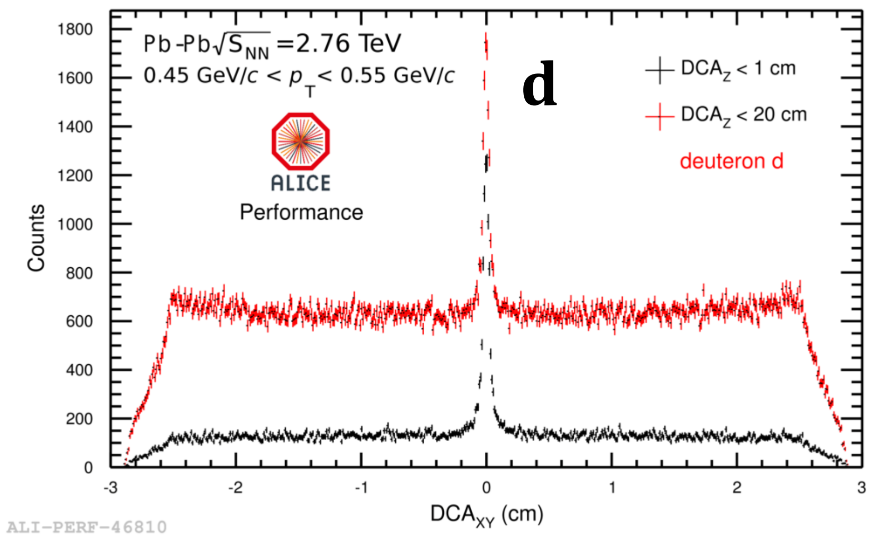
Time Projection Chamber:
measurement of dE/dx with a resolution of $\sigma_{TPC} \simeq 7\%$ in central Pb-Pb collisions

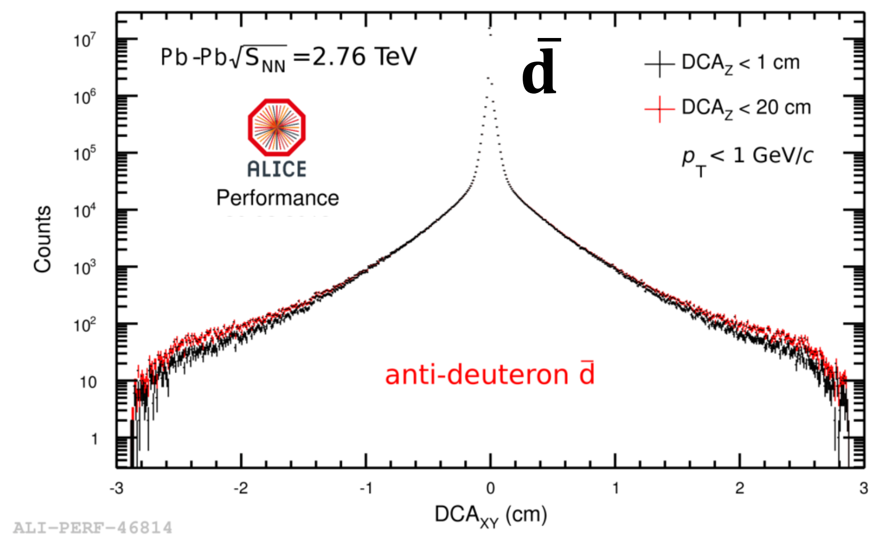
High Momentum Particle IDentification:
Cherenkov radiation for resolution at high momenta (in Centrality class: 0-10%)



Identification of ^3He in $2 < p_T < 10$ GeV/c and d over the full momentum range

The (anti)nuclei identification (II)



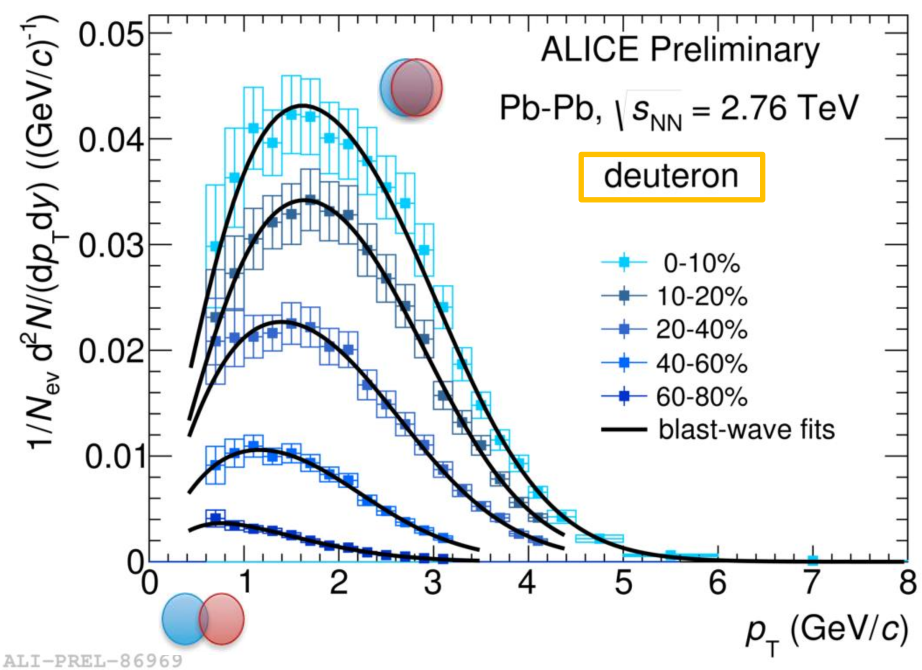


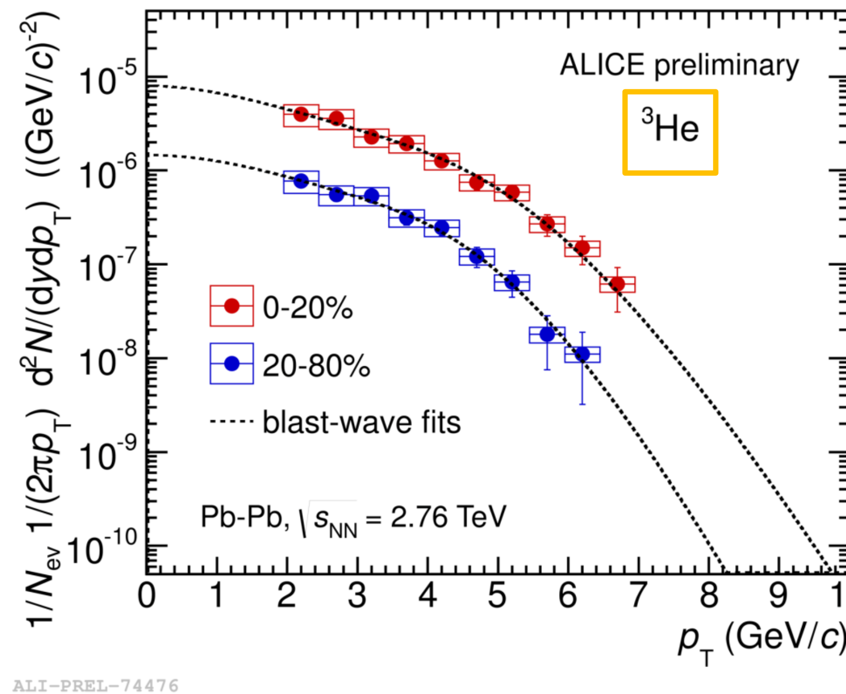
Inner Tracking System: measurement of DCA (*Distance of Closest Approach*) distribution

- a tight |DCAz| cut (1cm) reduces a large fraction of secondary nuclei produced from material "knock out"
- DCAxy component is fitted with two different MC templates to separate primary and secondary nuclei

Results

Spectra (d, ^{3}He)





Decoding of information about the collective transverse expansion:

- spectra fitted by the blast-wave model in order to extract integrated yield
- mean $\langle p_T \rangle$ rises with the centrality as expected from a radiating expanding source

Coalescence parameter B_2

$$E_\mathrm{d} \frac{dN_\mathrm{d}}{dp_\mathrm{d}} \approx B_2 \left(E_\mathrm{p} \frac{dN_\mathrm{p}}{dp_\mathrm{p}} \right)^2$$

$$B_2 \propto V_{eff}^{-1}$$

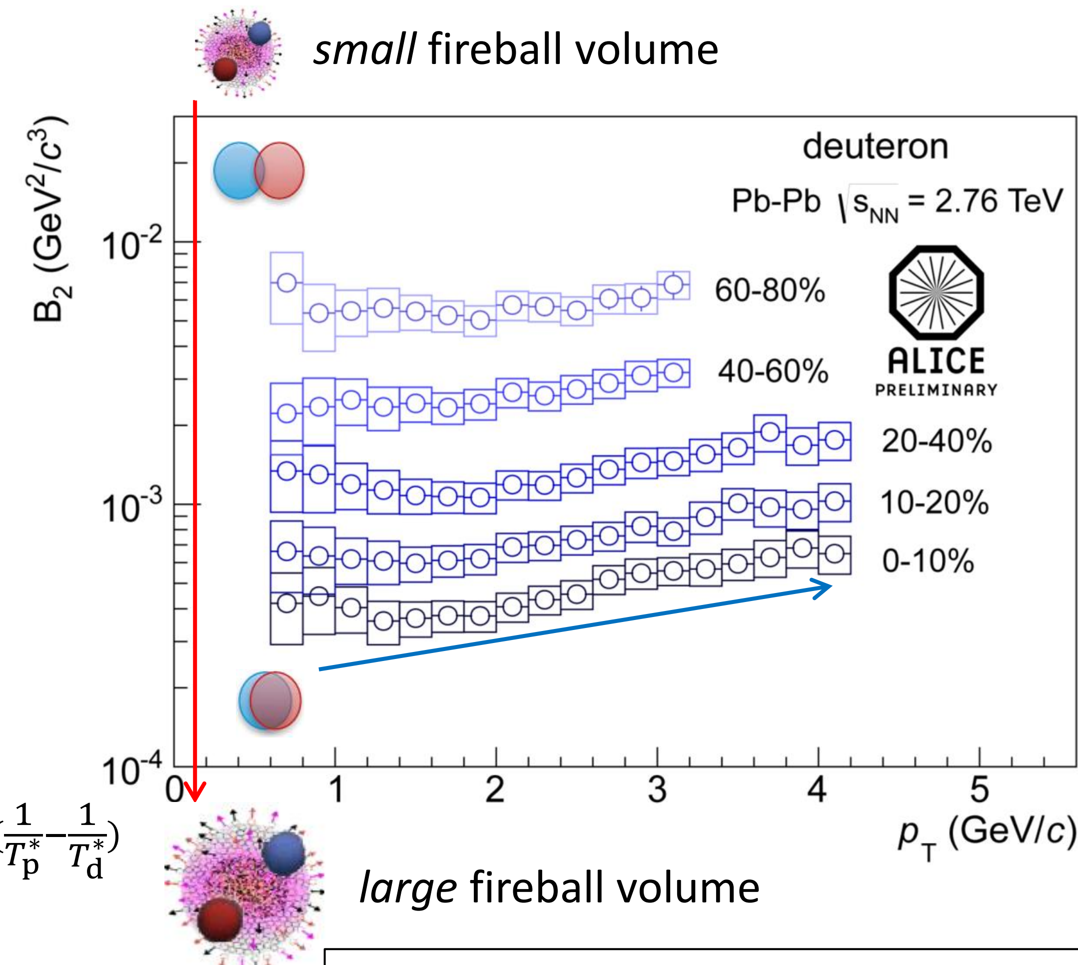
Strong centrality dependence:

➡ central collisions create a larger fireball volume than the peripheral case

p_T dependence in central collisions:

⬇

$$B_2 = \frac{3\pi^{3/2}\langle C_d \rangle}{2m_\mathrm{T} R_\perp^2(m_\mathrm{T}) R_\parallel(m_\mathrm{T})} e^{2(m_\mathrm{T}-m_0)\left(\frac{1}{T_\mathrm{p}^*}-\frac{1}{T_\mathrm{d}^*}\right)}$$



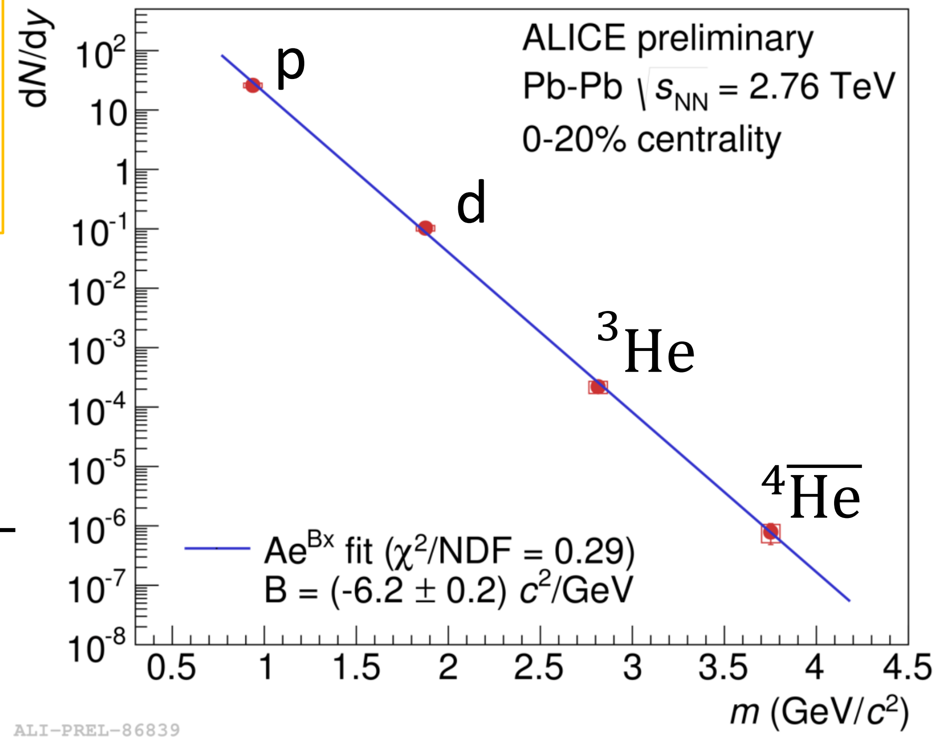
[1] R. Scheibl and U. Heinz, Phys. Rev. C 59, 1585 (1999)

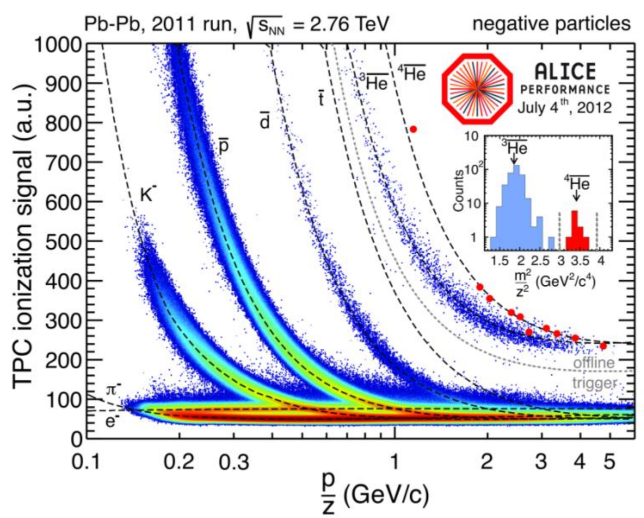
Production rate vs. mass

Decreasing exponential term with the atomic mass number as predicted by thermal models:

$$dN/dy \propto e^{-m/T_{ch}}$$

- reduction factor close to 300 for each additional nucleon
- generation of next stable antimatter ($^{6}\overline{\mathrm{Li}}$) seems impossible with current luminosity





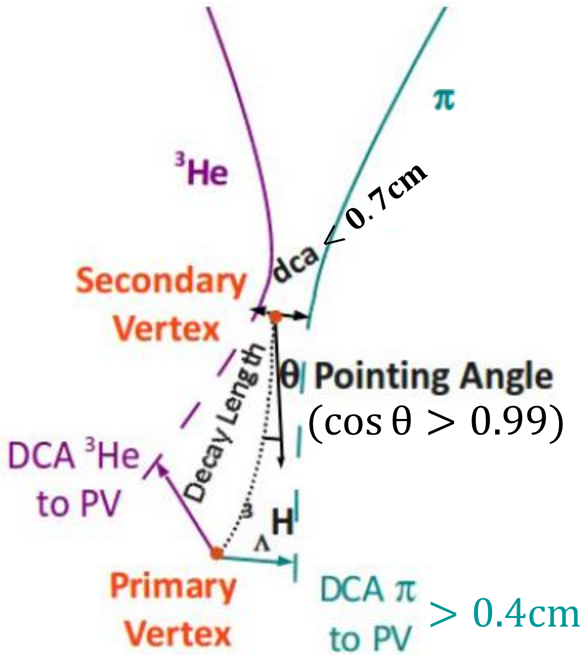
10 candidates $^{4}\overline{\mathrm{He}}$ are identified in 2011 data, extracted from $23 \cdot 10^{6}$ events

Hypermatter

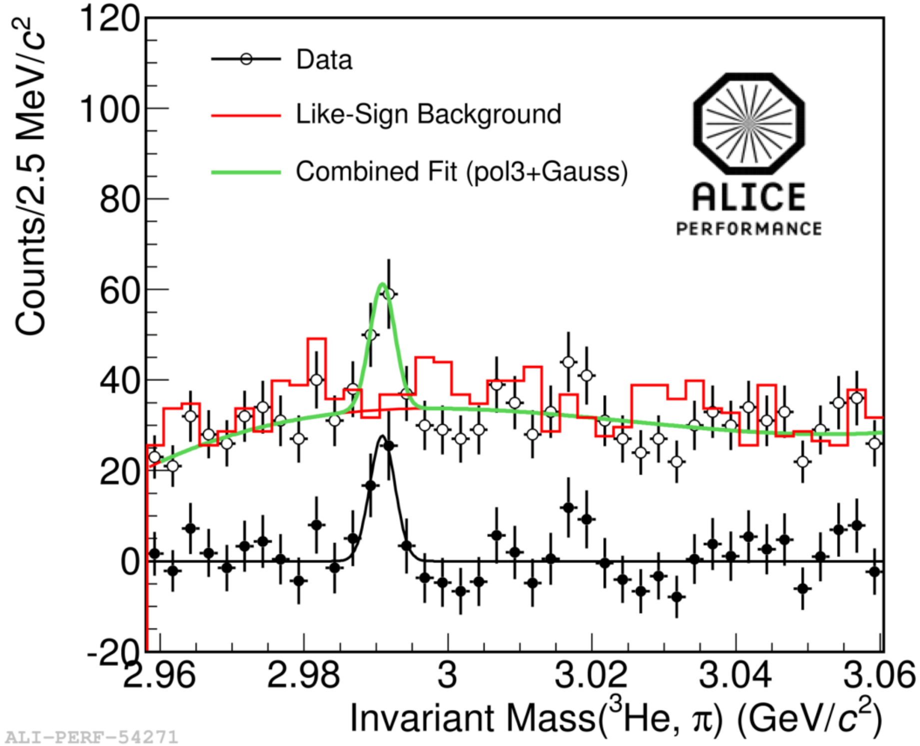
(Anti-)hypertriton: identification

$^{3}_{\Lambda}\mathrm{H}\ (\Lambda pn) \rightarrow {}^{3}\mathrm{He} + \pi^{-}$

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



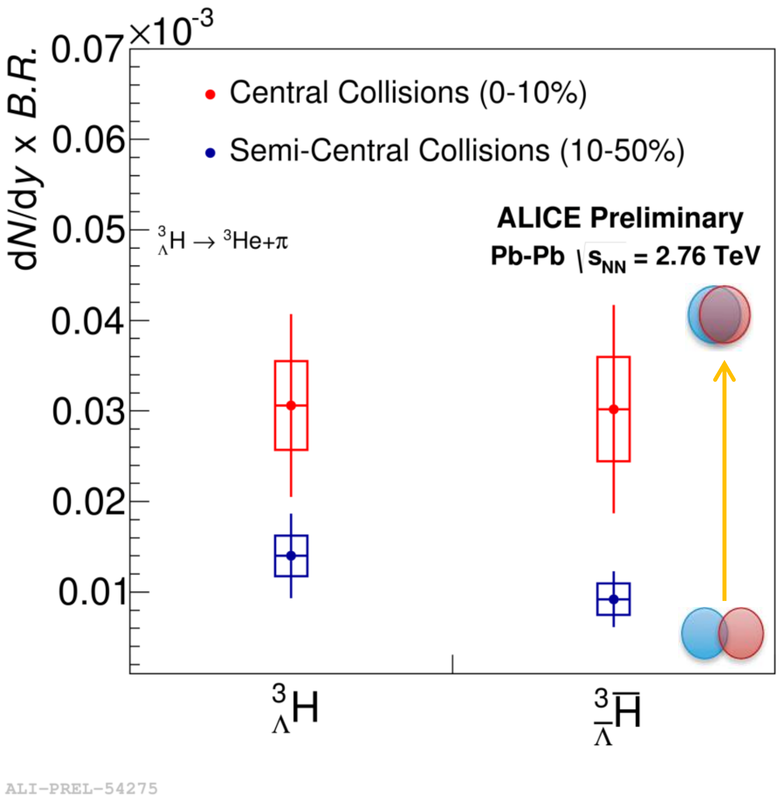
Invariant mass $(^{3}\mathrm{He} + \pi^{-}) + (^{3}\overline{\mathrm{He}} + \pi^{+})$

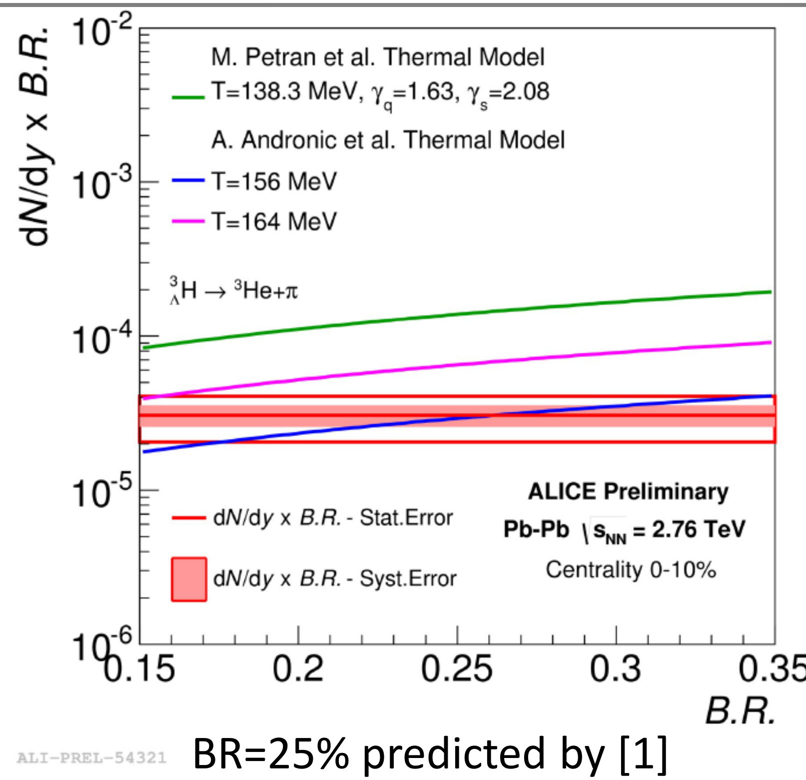


Both daughter particles identified using the TPC over a wide range of momenta

The $^{3}_{\Lambda}\mathrm{H}$ and $^{3}_{\Lambda}\overline{\mathrm{H}}$ signals are clearly identified in central and semicentral collisions in $2 < p_{\mathrm{T}} < 10\ \mathrm{GeV}/c$

(Anti-)hypertriton: yield



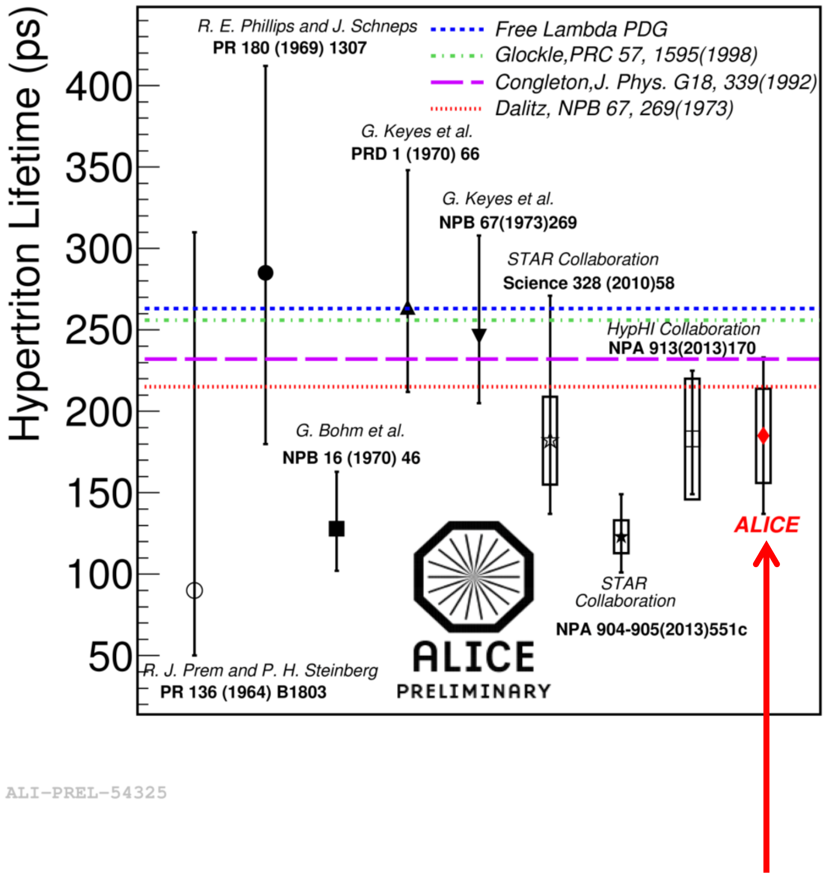


BR=25% predicted by [1]

- (Anti)$^{3}_{\Lambda}\mathrm{H}$ production increase with charged multiplicity
- Data ($^{3}_{\Lambda}\mathrm{H}$) favour equilibrium models with $\mathrm{T_{ch}} = 156\ \mathrm{MeV}$

[1] H. Kamada et al., Phys. Rev C 57 1595 (1998)

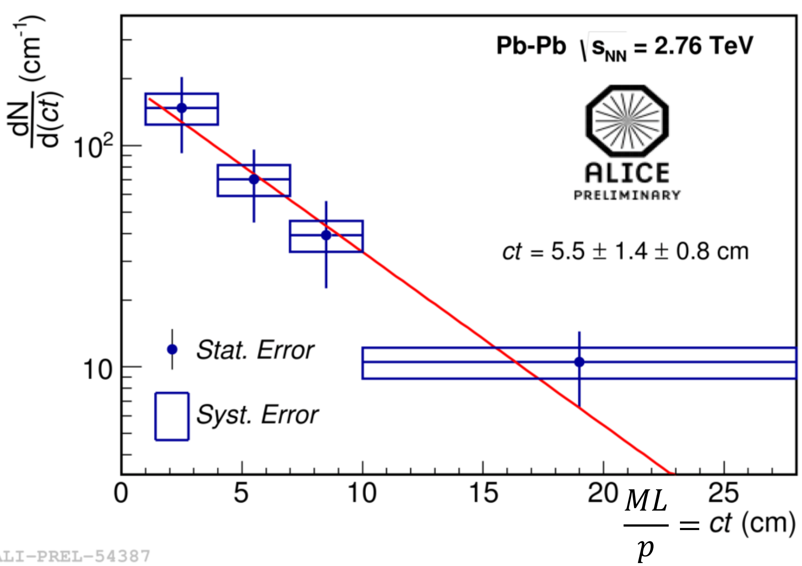
(Anti-)hypertriton: lifetime



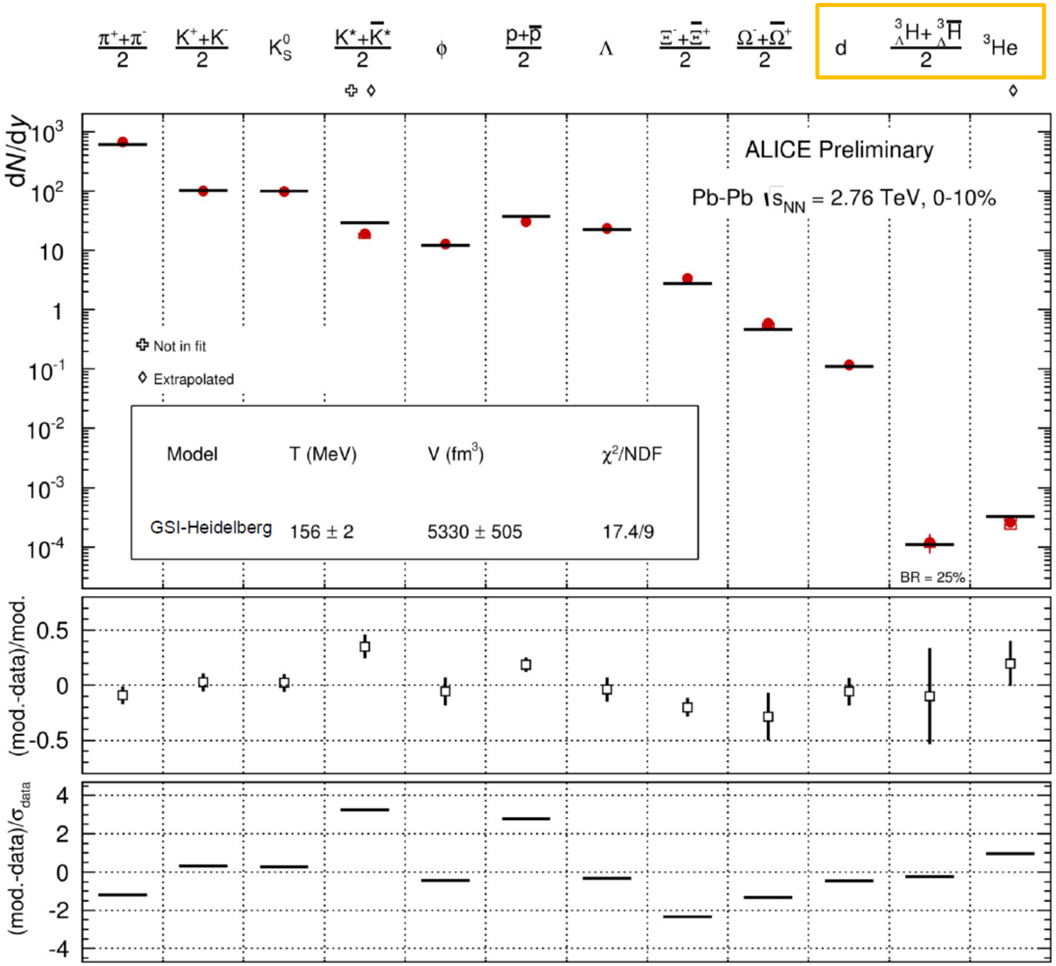
From a very good determination of primary and secondary vertex also the lifetime of hypertriton is measured:

$$\tau = 181 \pm 44(stat.) \pm 29(syst.)\ \text{ps}$$

←free Λ



Comparison with thermal model



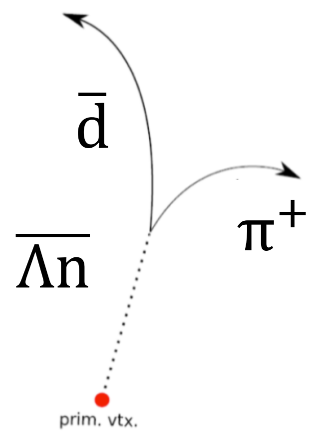
→ The production yield of light (hyper)nuclei is in good agreement with statistical thermal model indicating a chemical freeze-out temperature $T_{ch} = 156(2)$ MeV

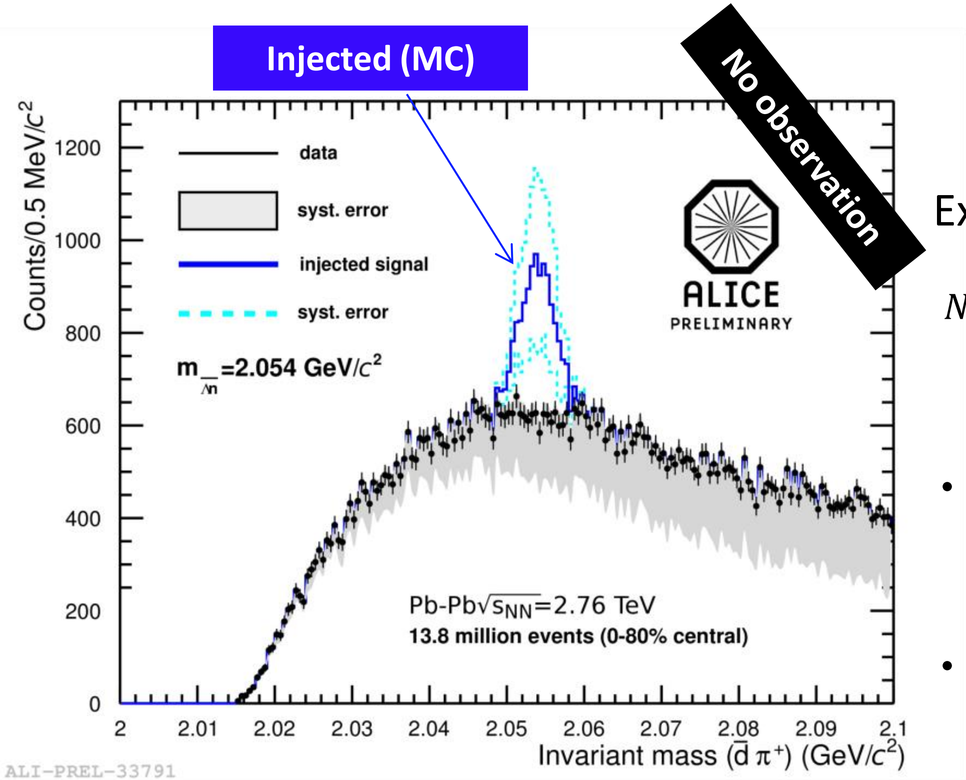
Search for exotica

Search for $\overline{\Lambda n}$

Experimental evidence of a new state Λn in the channel $d + \pi^-$ (HypHI experiment [1])

➡ Search for a possible $\overline{\Lambda n}$: lower background compared to the corresponding particle





Expected signal:

$$N_{\overline{\Lambda n}} = \underbrace{1.38 \cdot 10^6}_{events} \times \underbrace{0.0255}_{eff.} \times \underbrace{0.35}_{BR} \times \underbrace{1.6 \cdot 10^{-2}}_{dN/dy} \times \underbrace{2}_{dy} = 4003$$

- Efficiency estimated with a MC sample: p_T spectrum extrapolated from the blast-wave fits on π, K, p at the same energy
- Production yield from thermal model predictions

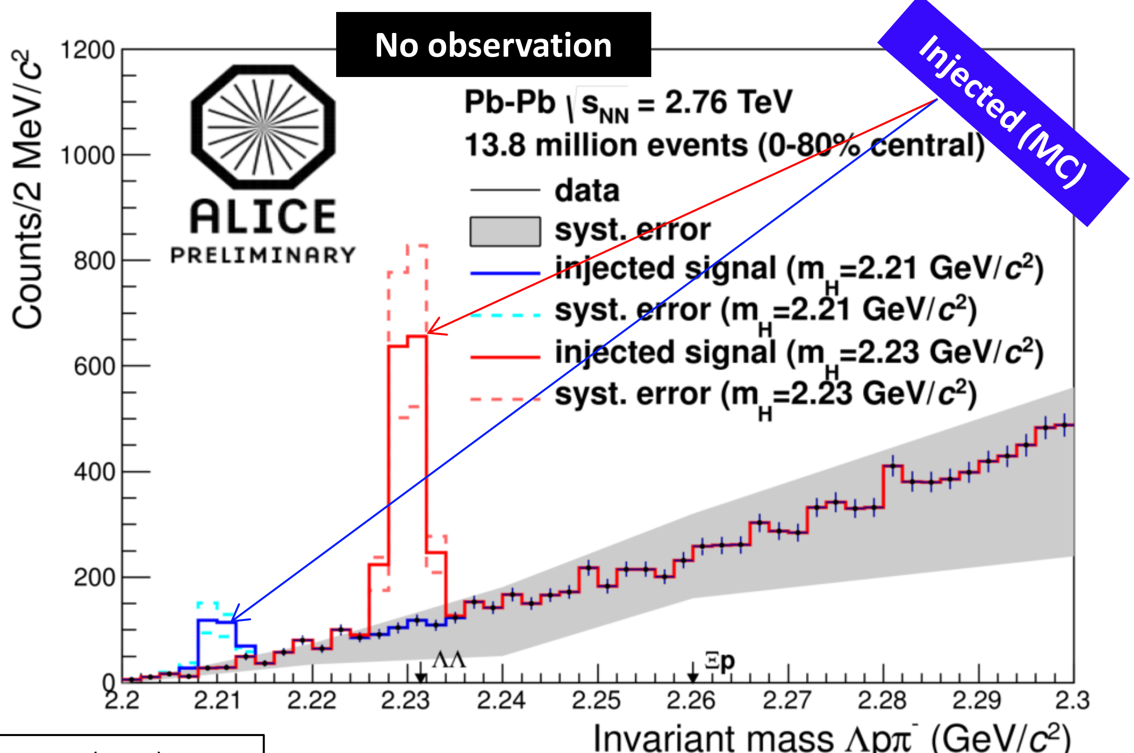
[1] C. Rappold et al., Phys. Rev. C 88, 041001(R) (1999)

Search for H-dibaryon

H-dibaryon is a possible uuddss (ΛΛ) state [1]. Its search is made in the channel:

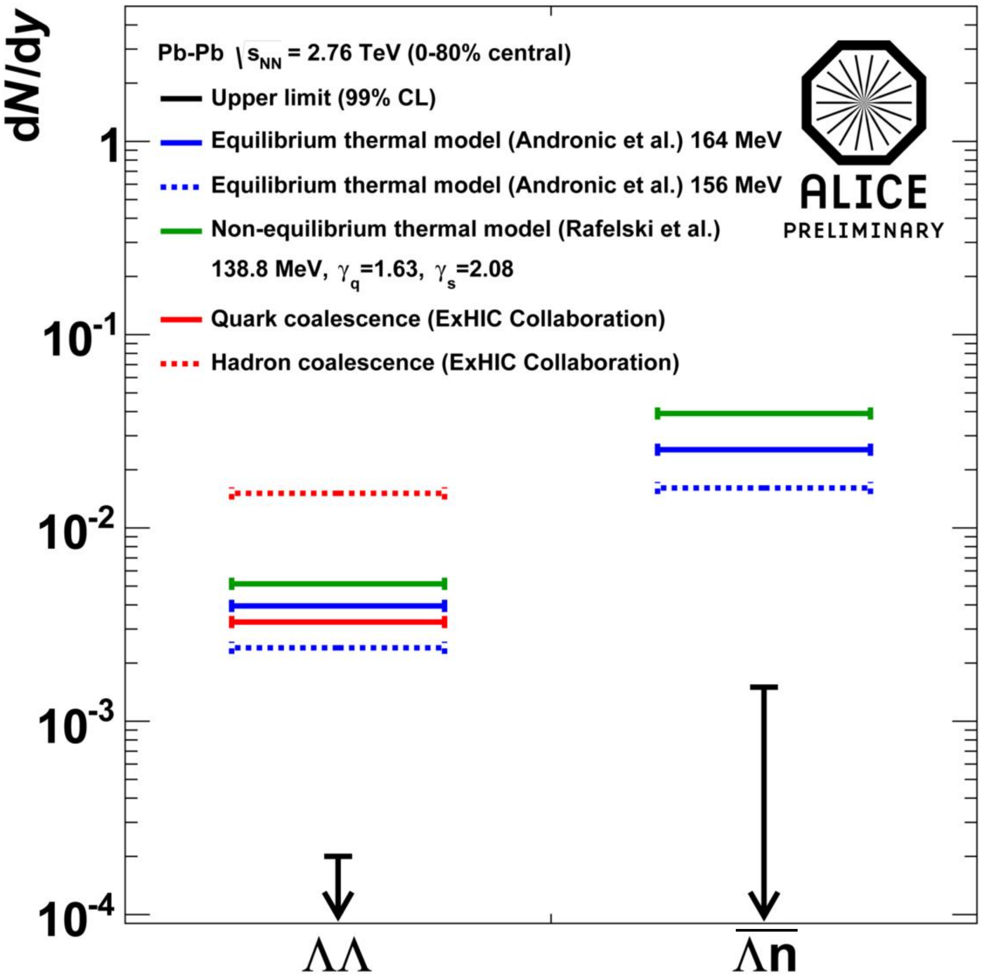
$$H(\Lambda\Lambda) \longrightarrow \Lambda + p + \pi^{-} \quad (2.21 < m_H < 2.23 \text{ GeV}/c^2)$$

- Number of the expected particles for the 2010 data set using thermal model predictions: 211 strongly bound (20 MeV) states and 1350 lightly bound (1MeV) particles



[1] R.L. Jaffe, Phys. Rev. Lett. 38, 195 (1977)

Comparison to models



The non observations set upper limits for the two searched particles at least a factor 10 below than the model expectations*

*Thermal model describes precisely the production yield of d, ^{3}He and (anti-)$^{3}_{\Lambda}$He

Conclusions

- Combining the TPC, TOF, HMPID information, the ALICE detector identifies the nuclear and hyper-nuclear (anti)matter with excellent performance.
- The qualitative behavior of B_A follows the coalescence model expectations.
- The production yield of light (hyper)nuclei is in good agreement with statistical thermal model indicating a chemical freeze-out temperature $\mathrm{T}_{ch} = 156(2)\ \mathrm{MeV}$
- An exponential behavior is observed for the yields versus nuclei mass as predicted by thermal models.
- The (anti)hypertriton ${}^{3}_{\Lambda}\mathrm{H}$ have been clearly identified in Pb-Pb collisions.
- A search for possible exotic hypermatter, suggested by recent QCD calculations, has been performed.

Backup

HBT interferometry [1]

The Hanbury Brown – Twiss (HBT) interferometry* is a method which also predicts the length of homogeneity in an emitting source. In a coalescence picture, it determine the probability of the cluster formation.

Historically, cluster formation has been characterized in terms of coalescence parameter B_A. It is related to the HBT radii ($R_\perp$ and $R_\parallel$):

Quanto-mechanical correction [...]

$$B_2 = \frac{3\,\pi^{3/2}\,\langle \mathcal{C}_\mathrm{d} \rangle}{2m_t\,\mathcal{R}_\perp^2(m_t)\,\mathcal{R}_\parallel(m_t)}\,e^{2(m_t-m)\left(\frac{1}{T_\mathrm{p}^*}-\frac{1}{T_\mathrm{d}^*}\right)}$$

Transverse mass $m_T = \sqrt{m^2 + p_\mathrm{T}^2}$

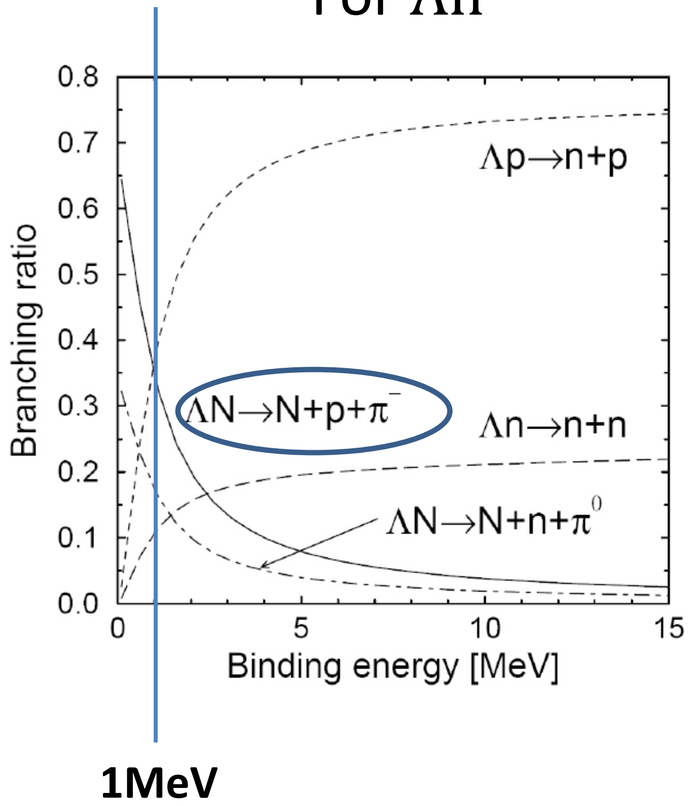
Slope of proton and deuteron spectra

[1] R. Scheibl and U. Heinz, Phys. Rev. C 59, 1585 (1999)

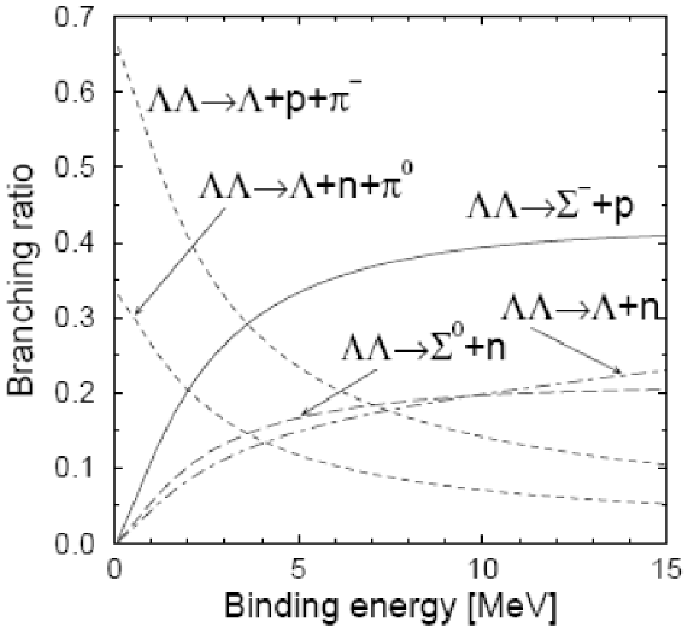
*Hanbury Brown – Twiss (HBT) interferometry is a method which exploits the effects on the phase-space density of Bose-Einstein symmetrization (or Pauli antisymmetrization) of multiparticle states of identical particles. In particle physics one measures the correlation function as a function of the momentum difference between the two baryons (fermions) and extracts from it information about the space-time extension of the emitting source.

$\overline{\Lambda n}$ and H-dibaryon B.R.

For $\overline{\Lambda n}$



For H-dibaryon



[1] J. Schaffner-Bielich et al., Phys. Rev. Lett. 84, 4305 (2000)