ANTINUCLEI FROM THE LABORATORY TO THE COSMOS: GETTING READY FOR THE LHC RUN 3

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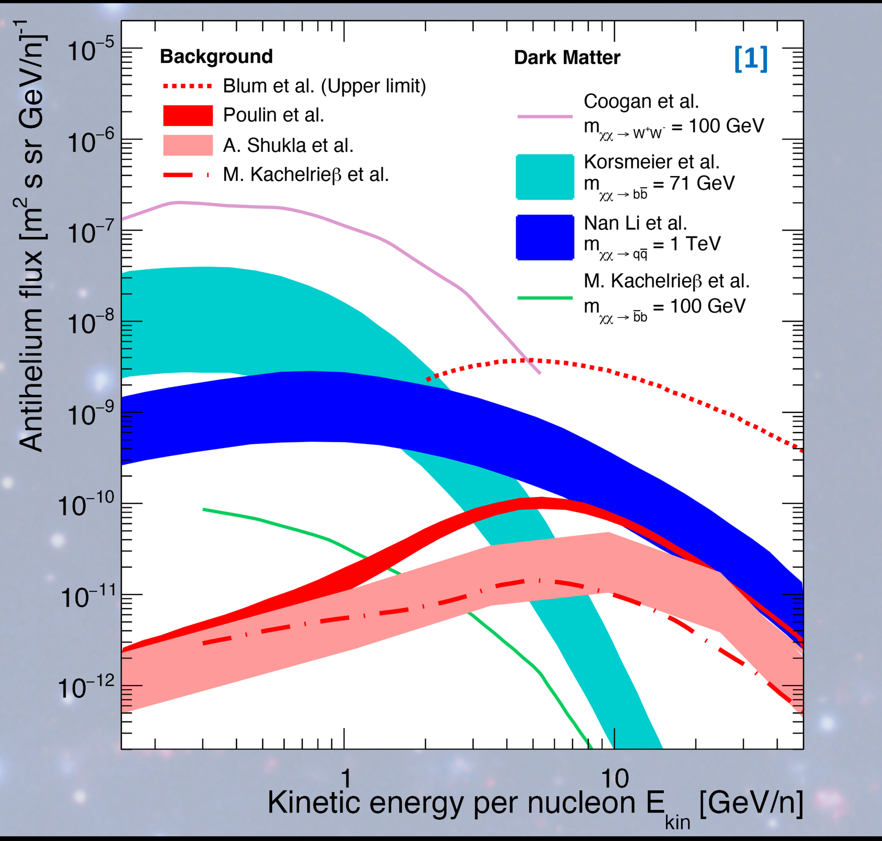
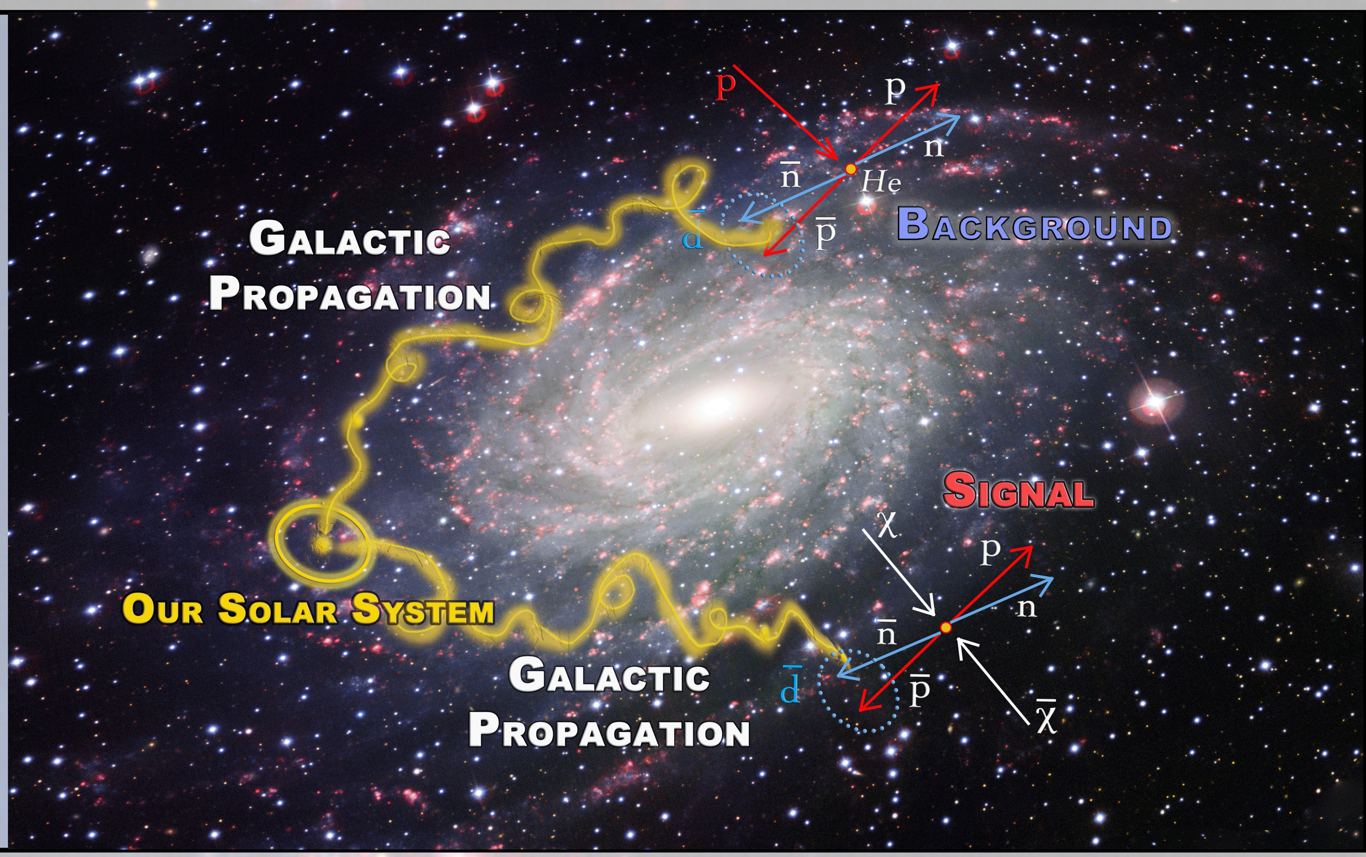
Antinuclei as smoking guns for dark matter

A significant number of **cosmological and astrophysical evidences** suggestes the existence of **dark matter** (DM), its existence and nature **have not been proven yet**.

One possible strategy: search for products of DM **annihilation** in cosmic rays with space-based experiments (AMS[1], GAPS[1]).

Light **antinuclei** ($\bar{d}$, $^3\overline{He}$) are considered promising detection channels for dark matter due to the expected low background from ordinary cosmic ray interactions with interstellar medium[2].



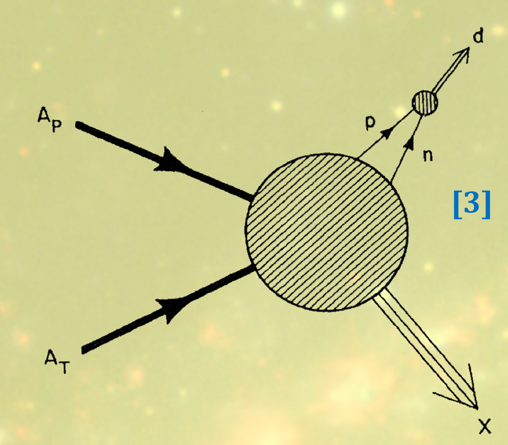


(Anti)nuclei formation by coalescence

Nuclei formation can be described by

COALESCENCE

Formation probability is given by the **overlap** of the **nucleus wave function** with the **phase-space distributions of the nucleons**



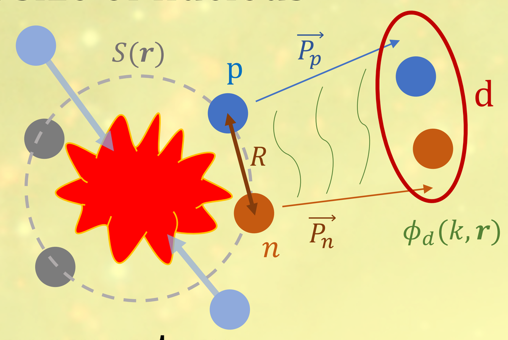
Probability is related to the **coalescence parameter B_A**:

$$E_A \frac{d^3N_A}{dp_A^3} = B_A \left(E_p \frac{d^3N_p}{dp_p^3}\right)^Z \bigg|_{\vec{p}_p=\frac{\vec{p}_A}{A}} \left(E_n \frac{d^3N_n}{dp_n^3}\right)^N \bigg|_{\vec{p}_n=\frac{\vec{p}_A}{A}}$$

NUCLEUS — NUCLEONS — PROTONS — NEUTRONS

In state of the art models, B_A depends on **A**, **p_T**, size of nucleus and **particle source**[4]:

$$B_A = \frac{2J_A+1}{2^A}\frac{1}{\sqrt{A}}\frac{1}{m_T^{A-1}}\left(\frac{2\pi}{R^2+\left(\frac{r_A}{2}\right)^2}\right)^{3/2(A-1)}$$



New approach via **femtoscopic correlations**: momentum correlations provide information about particle interaction of the final-state.

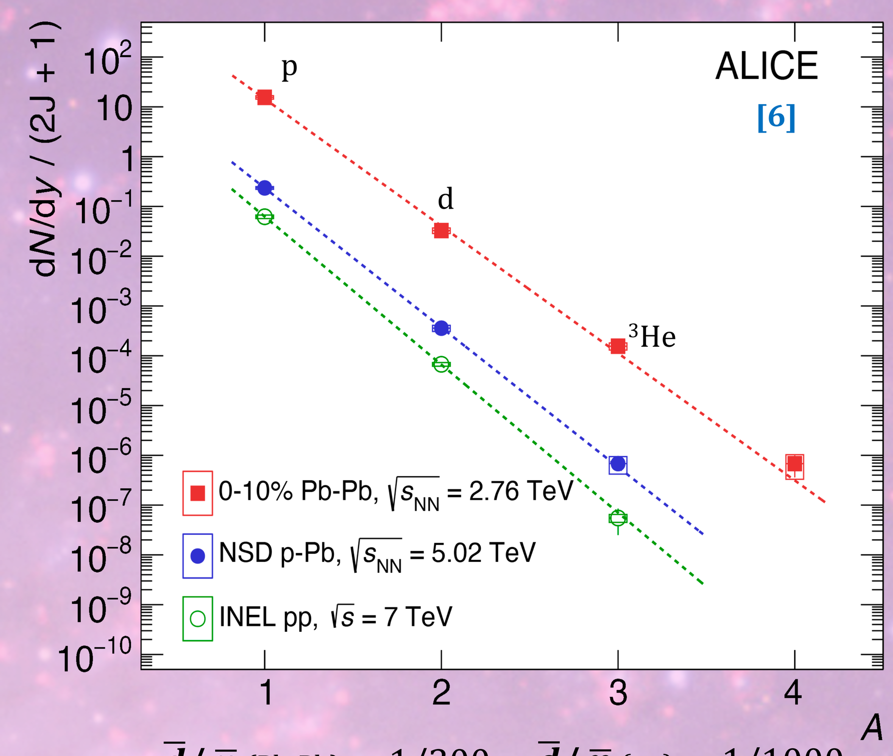
i.e. deuteron[5]:

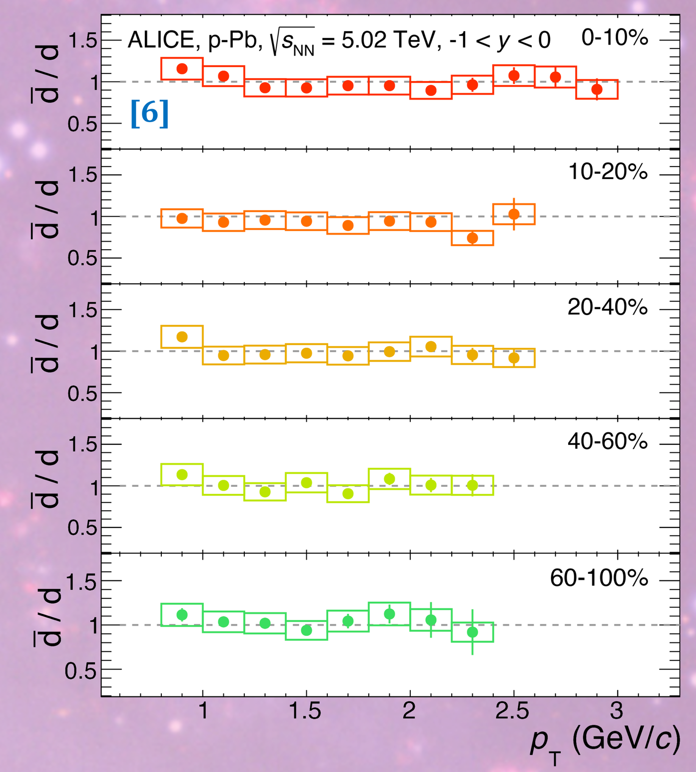
$$B_2(p) \approx \frac{2(2s_d+1)}{m(2s_N+1)^2}(2\pi)^3 \int d^3\mathbf{r}\, |\phi_d(\mathbf{r})|^2 S_2(\mathbf{r}) \qquad B_2(p) \approx \frac{2(2s_d+1)}{m(2s_N+1)^2}\int d^3\mathbf{k}\, \mathcal{F}_d(\mathbf{k})\, \mathcal{C}_2(p,\mathbf{k})$$

NUCLEUS WAVE FUNCTION ⇔ FORM FACTOR

SOURCE ⇔ MOMENTUM CORRELATION FUNCTION

LHC is an antinucleus factory



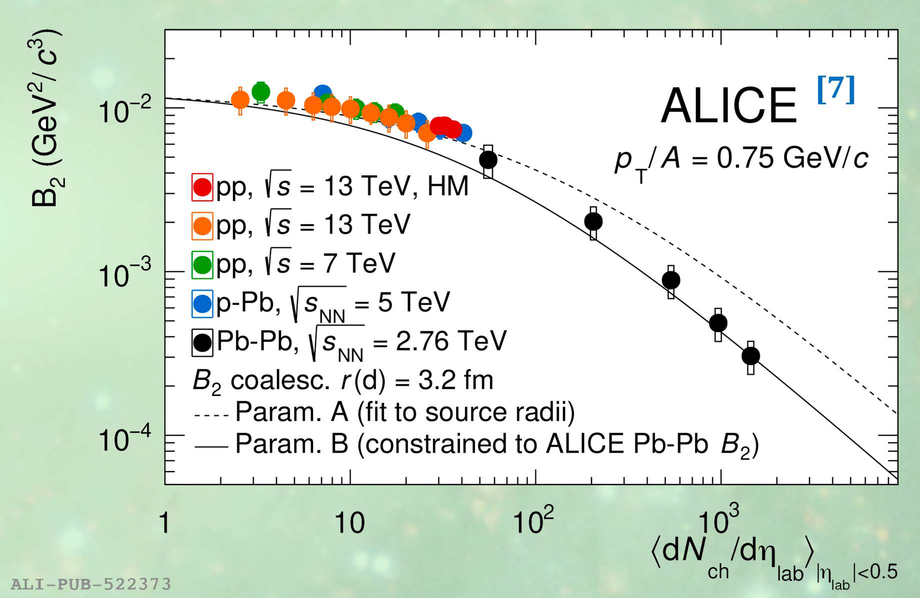


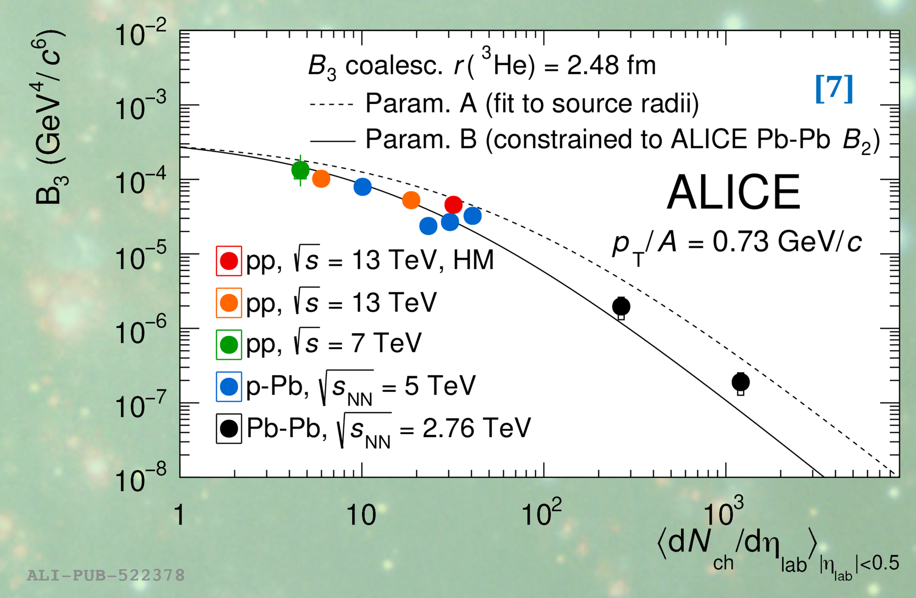
$\bar{d}/\bar{p}$ (Pb-Pb) ~ 1/300 $\quad$ $\bar{d}/\bar{p}$ (pp) ~ 1/1000

$^3\overline{He}/\bar{p}$ (Pb-Pb) ~ $1/10^5$ $\quad$ $^3\overline{He}/\bar{p}$ (pp) ~ $1/10^6$

$\frac{\text{antimatter}}{\text{matter}} \sim 1$

Measurementes of B_A with ALICE: state of the art

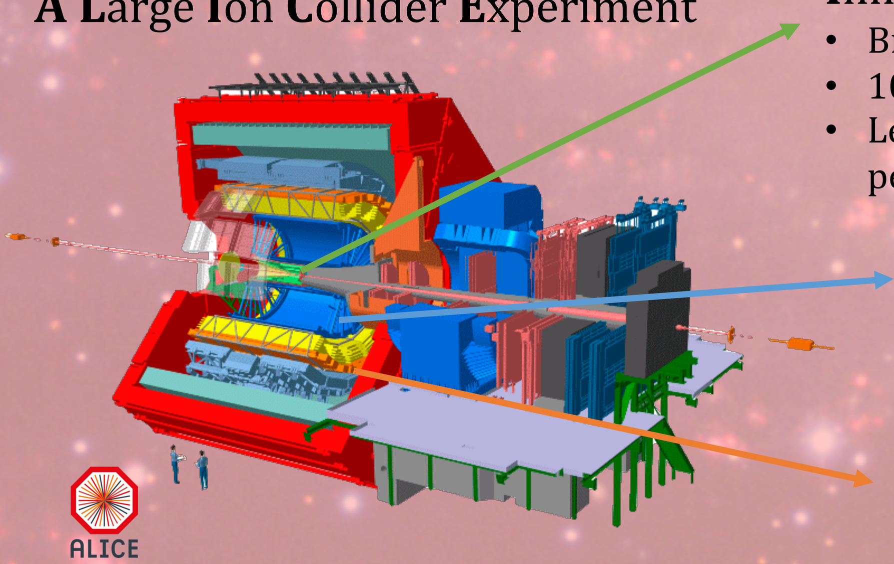




B_A decreases from low multiplicity to high multiplicity events with continuity across collision systems. This reflects the dependence of coalescence on the size and characteristics of the nucleon emitting source.

ALICE upgraded for Run 3

A Large **I**on **C**ollider **E**xperiment



Inner **T**racking **S**ystem (**ITS**)
- Brand new 7 layer pixel detector
- 10 m² (12.5 GP) silicon tracker based on MAPS
- Less material budget, improved tracking performance **at low p_T**

Time **P**rojection **C**hamber (**TPC**)
- New GEM-based readout pads
- Allows continous readout
- PID via dE/dx in the TPC gas

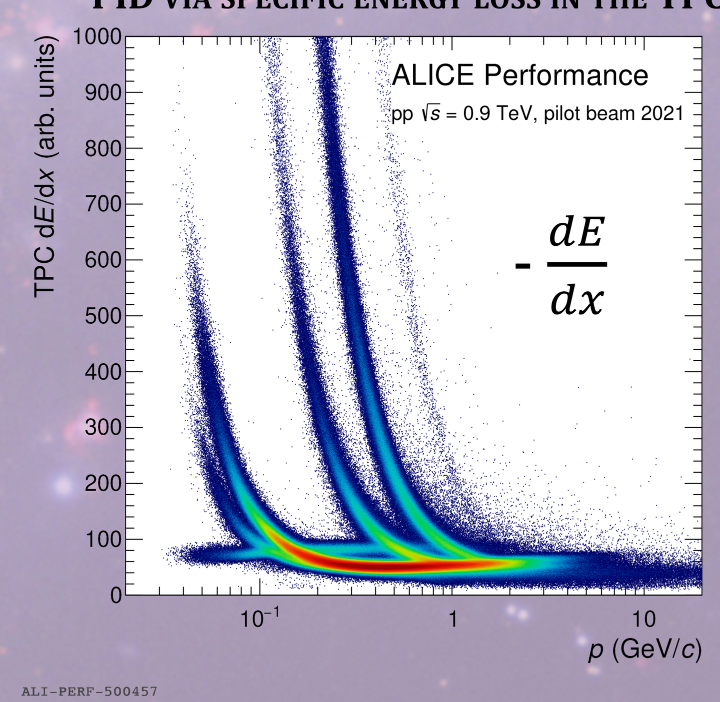
Time **O**f **F**light detector (**TOF**)
- PID via time-of-flight measurements

Also new **Integrated Online-Offline system** (O^2) to perform Run 3 (and 4) events reconstruction

LHC Run 3 target integrated luminosity = **13 nb⁻¹** (Pb-Pb) with interaction rates ~ **50 kHz**
200 nb⁻¹ (pp) with interaction rates ~ **1 MHz**

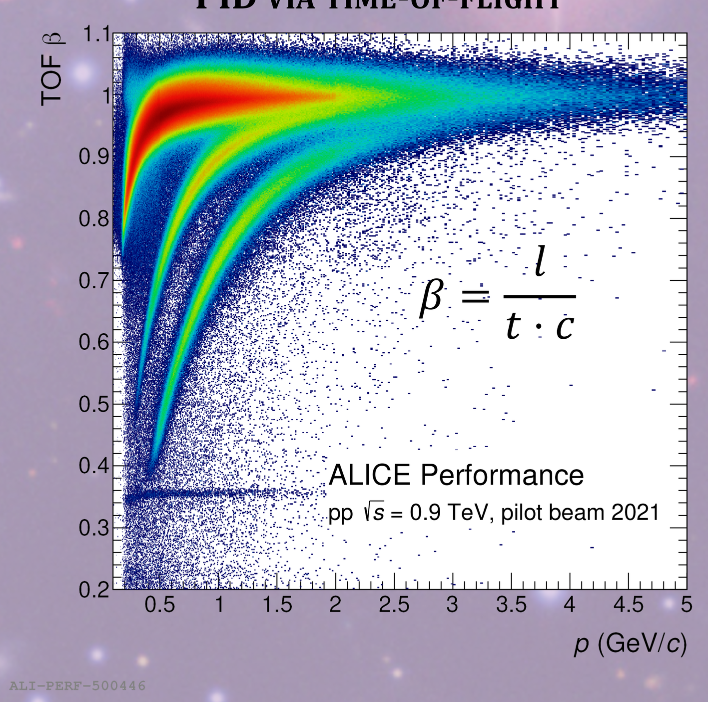
Performance with first Run 3 pp collisions at $\sqrt{s}$ = 900 GeV

PID via specific energy loss in the TPC



Excellent **separation** of different particle species at **low p_T**

PID via time-of-flight



Excellent **separation** of different particle species at **intermediate p_T**

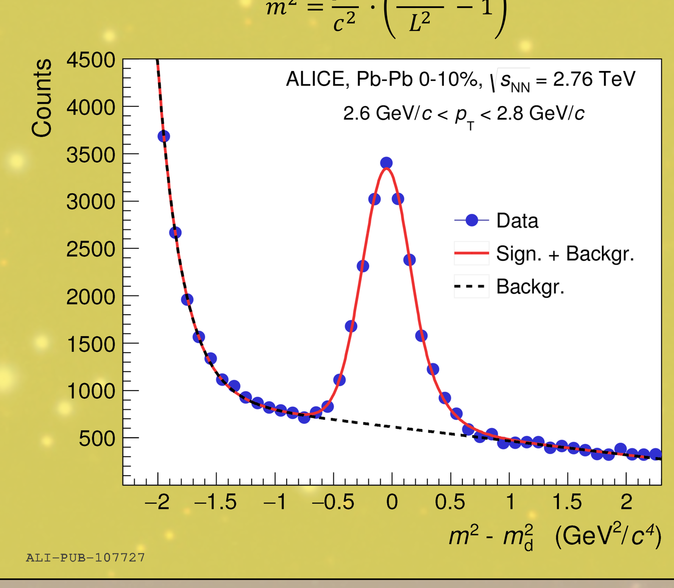
How to meausure (anti)nuclei in ALICE

1. Tracking and identification

Pre-selection via TPC energy loss ($5\sigma_{TPC}$)

Particle identification with TPC and TOF

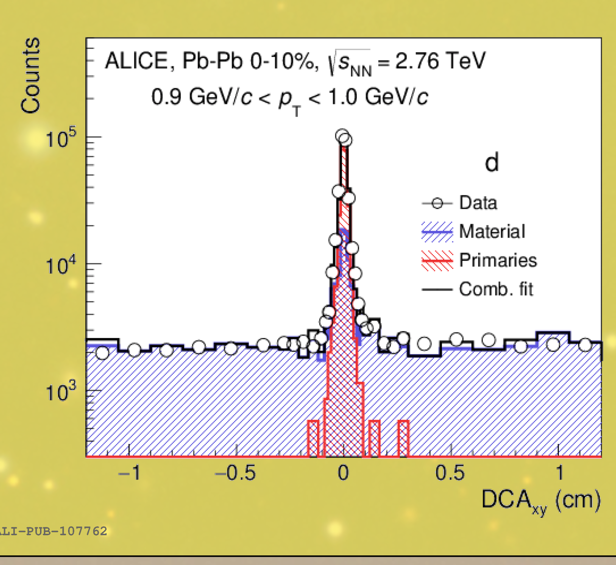
$$m^2 = \frac{p^2}{c^2}\left(\frac{c^2t^2}{L^2}-1\right)$$



2. Corrections

Correction for **secondary nuclei** from material based on fits to the distance of closest approach to the primary vertex

Correction for **efficiency x acceptance**

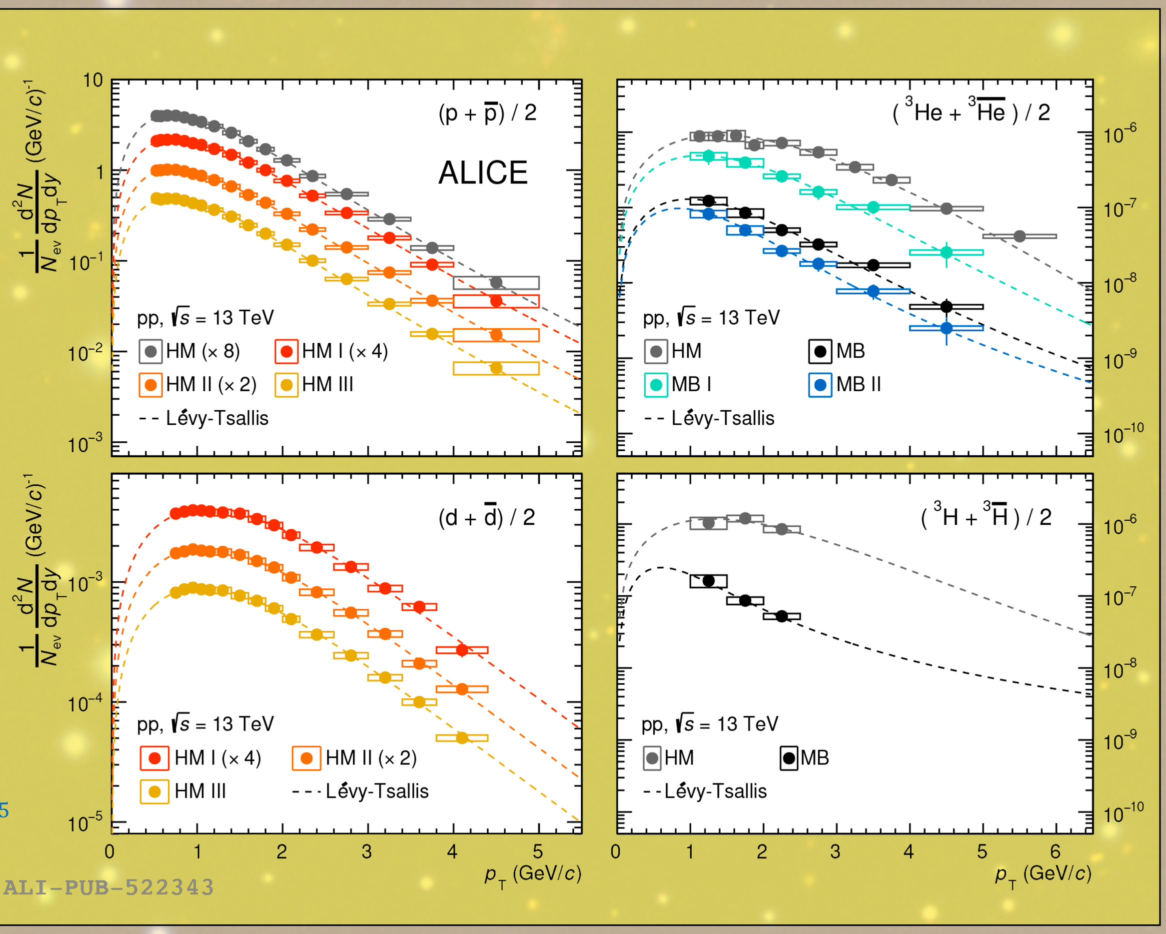


3. Determination of yield and B_A

Fit to the p_T spectrum to extract per-event p_T integrated **yield dN/dy** in the unmeasured region

Repeat the analysis to measure proton spectrum and **extract B_A**

B_3 measurements with Run 3: more differential in multiplicity and p_T, improved statistical precision



References:

[1]: P. von Doetinchem *et al.*, JCAP **08**, 035 (2020)
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[3]: J.I. Kapusta, Phys. Rev. C **21**, 1301 (1980)
[4]: F. Bellini *and* A. P. Kalweit, Phys. Rev. C **99** no. 5, (2019) 054905
[5]: F. Bellini *et al.*, Phys. Rev. C **103**, (2021) 014907
[6]: S. Acharya *et al.* [ALICE], Phys. Lett. B **800**, 135043 (2020)
[7]: S. Acharya *et al.* [ALICE], JHEP **01**, 106 (2022)