Recent results on light (anti-)nuclei from ALICE at the LHC

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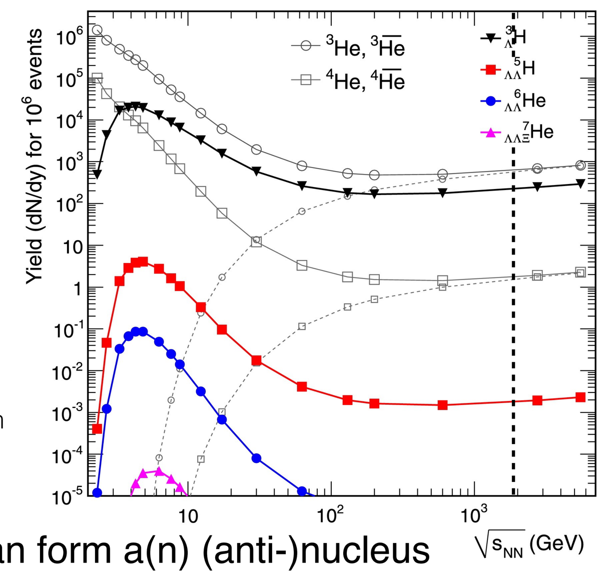
PRODUCTION OF LIGHT (ANTI-)NUCLEI

- High energies at LHC enhance the production probabilities for nuclei and anti-nuclei
- At these energies large and equal amounts of particles and anti-particles are produced in the mid-rapidity region
- Production mechanisms:

THERMAL production [1]

- Hadrons emitted from the interaction region at the *chemical freeze-out* temperature (T_{chem})
- Abundance of species $\propto \exp(-m/T_{chem})$
- (Anti-)nuclei: large mass (m) ⟶ strong dependence on T_{chem}



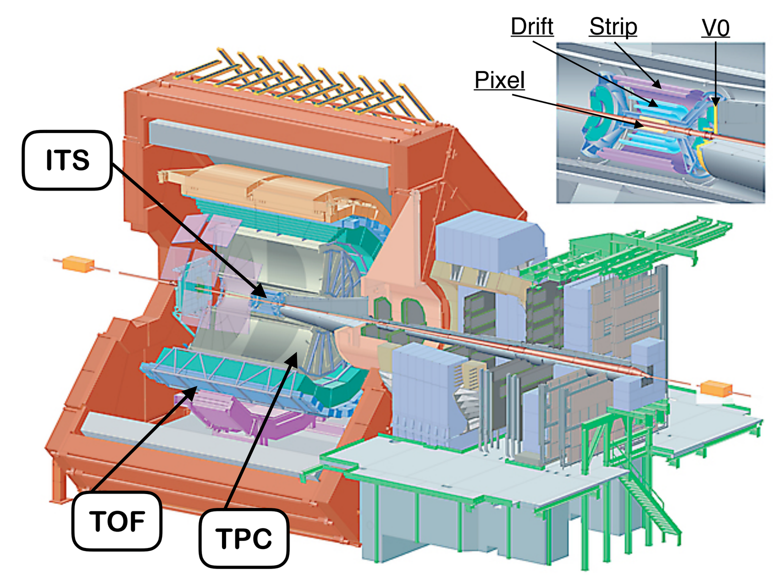
COALESCENCE production [2]

- (Anti-)baryons close in phase space at the *kinetic freeze-out* can form a(n) (anti-)nucleus
- In this scenario, the formation probability can be written in the simplest way using the *coalescence parameter* B_A
- In a simple approach B_A is expected to be independent of p_T and centrality $B_A = \dfrac{E_A \frac{d^3N_A}{dp_A^3}}{\left(E_p \frac{d^3N_p}{dp_p^3}\right)^A}$ [3]

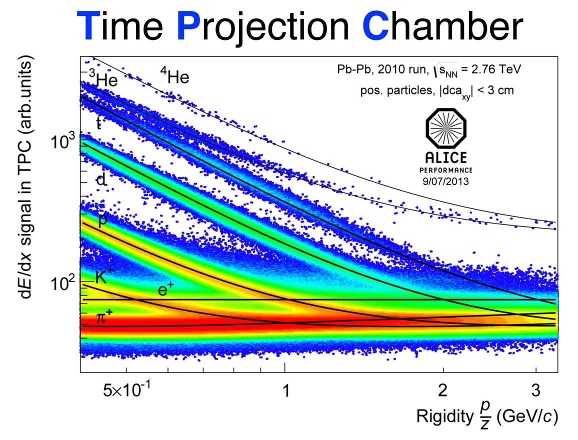
*A = $N_{proton} + N_{neutron}$; $E_A = A \cdot E_p$; $p_A = A \cdot p_p$

A Large Ion Collider Experiment [4]

- Excellent **particle identification** and **high performance tracking** and **vertexing** allows for the efficient measurement of the production of (anti-)nuclei

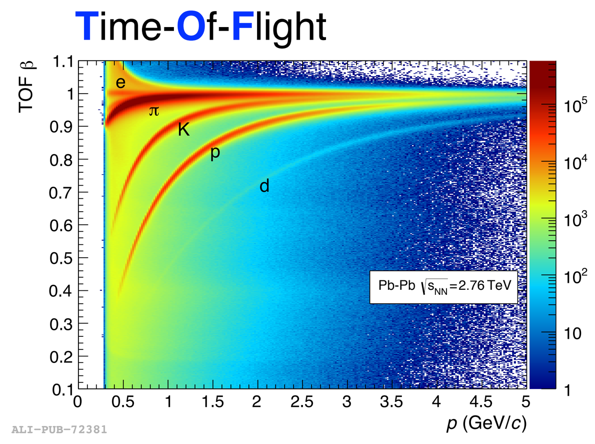


Time Projection Chamber



- Specific energy loss dE/dx ($\sigma_{TPC} \approx 6.5\%$ in central Pb-Pb)
- Clear nuclei separation at low p/z

Time-Of-Flight

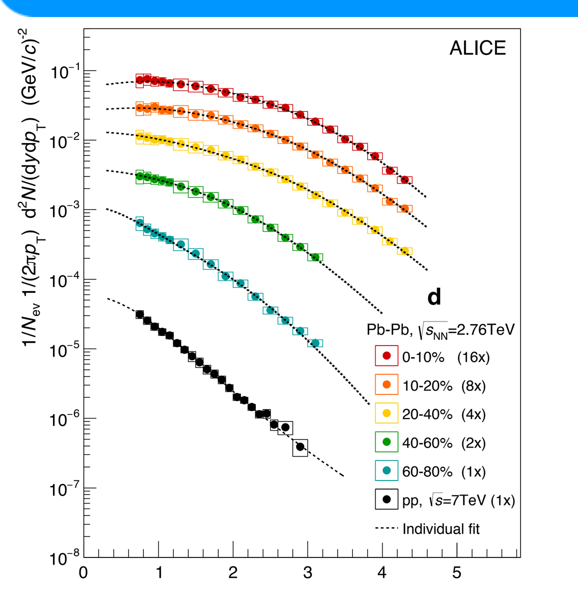


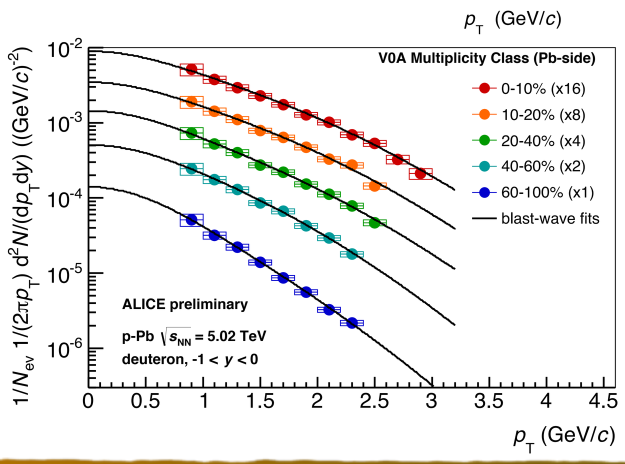
- $\sigma_{TOF} \approx 85$ ps in central Pb-Pb
- deuteron identification up to 5 GeV/c in Pb-Pb collisions

Inner Tracking System

- $\sigma_{DCA_{xy}} < 100$ µm for $p_T > 0.5$ GeV/c in Pb-Pb
- separation of primary and secondary nuclei produced in material knock-out via DCA_{xy} measurement

NUCLEI SPECTRA





Pb-Pb [5]

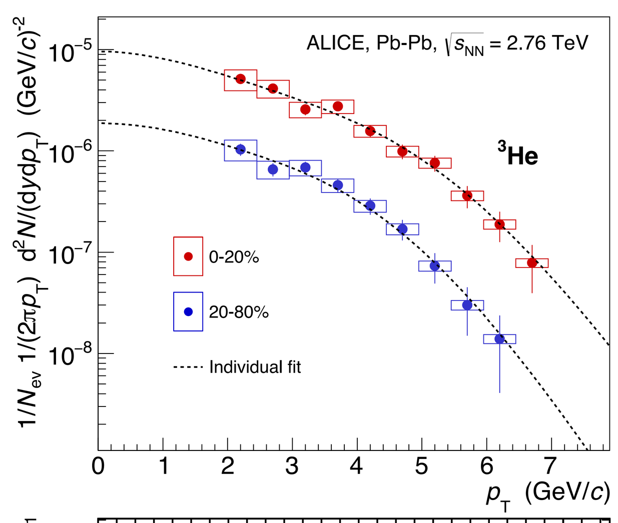
- d and ^{3}He p_T spectra become **harder** as the **collision centrality increases**
- similar behaviour observed also for protons → explained by **radial flow**
- **Blast-Wave** [6] fit used to extrapolate towards *unmeasured regions* and to extract p_T *integrated yields*

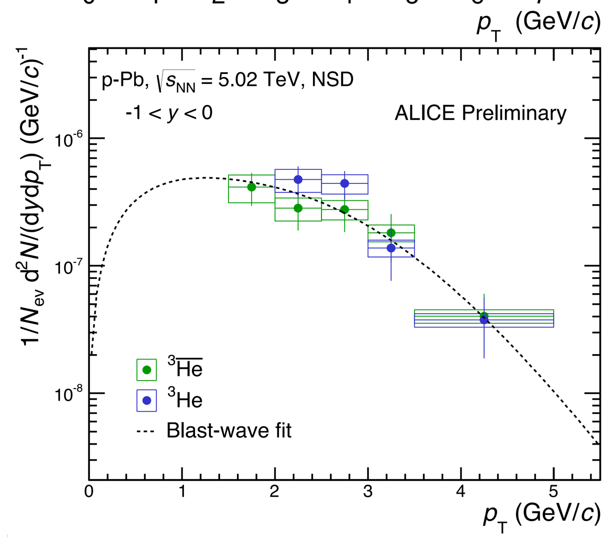
p-Pb

- d p_T spectra become **harder** as the **multiplicity increases**
- individual **Blast-Wave** fits to the single spectra describe the data well
- ^{3}He and $^3\overline{\text{He}}$ p_T spectra measured for full multiplicity range

pp [5]

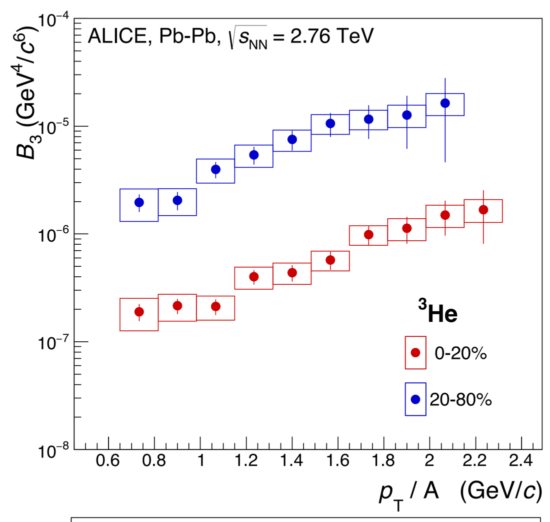
- **Levy-Tsallis** [7] fit to d spectrum to obtain the p_T integrated yield dN/dy

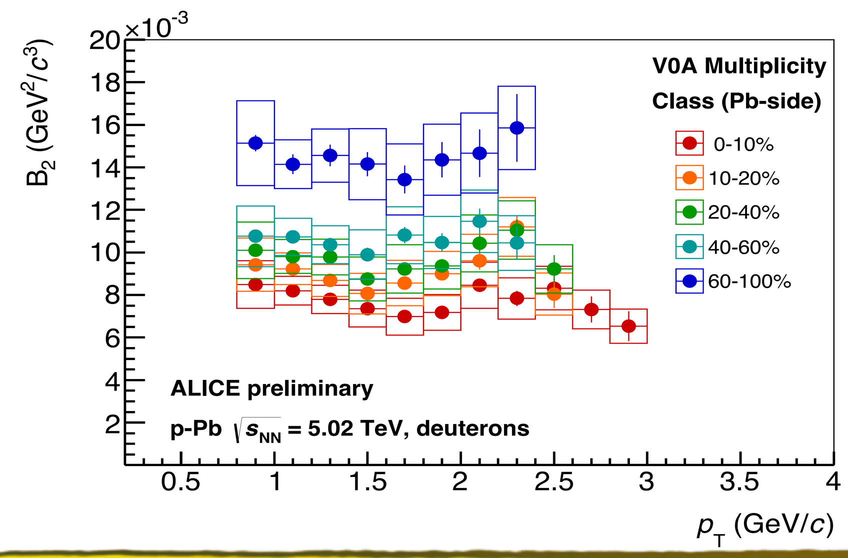


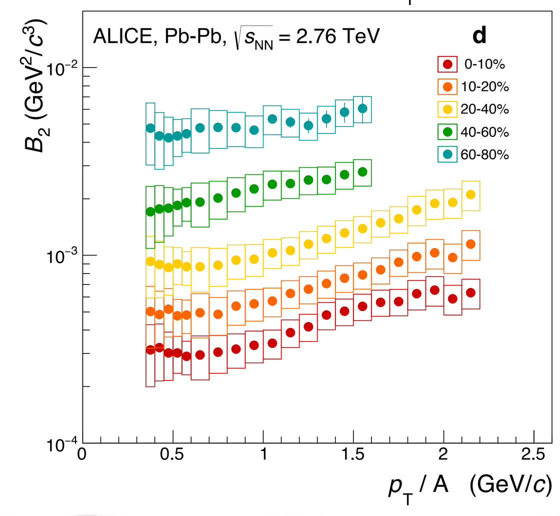


Coalescence parameter B_2 and B_3

- **decrease with increasing centrality**: $B_{2,3} \propto V_{eff}^{-1}$ where $V_{eff} \propto R_\perp^2 R_\parallel$ is source volume (obtained from femtoscopy)
- p_T **dependence** for central collisions not well reproduced by a simple coalescence model [3]
- explained by space-momentum correlations caused by radial flow [8]







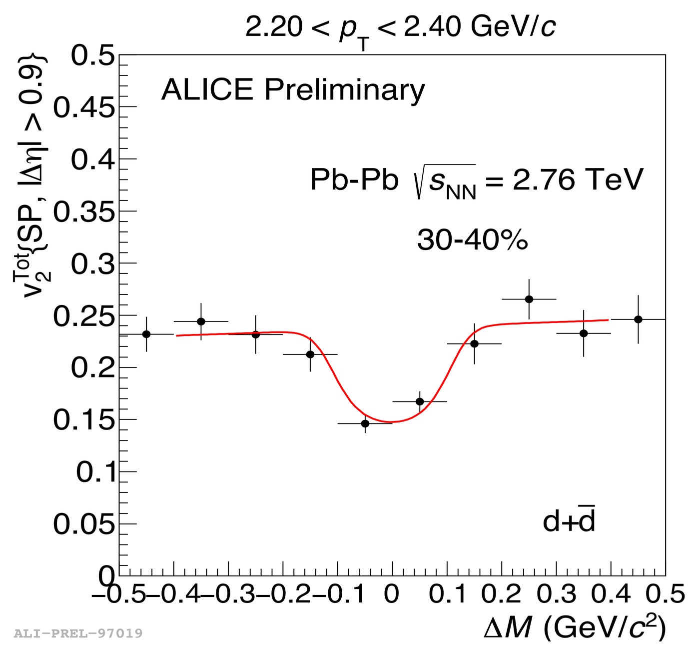
DEUTERON FLOW

Elliptic flow

- (anti-)deuterons are identified for p_T up to 5 GeV/c via energy loss in the **TPC** and **TOF** measurement
- **Event Plane** determination with the **V0** detectors located at forward ($2.8 < \eta < 5.1$) and backward ($-3.7 < \eta < -1.7$) pseudorapidity
- v_2 analysis method: **Scalar Product** (SP)

$$v_n\{SP\} = \frac{\left\langle\left\langle u_{n,i}(p_T,\eta)\cdot\frac{Q_n^*}{M}\right\rangle_p\right\rangle_e}{\sqrt{\left\langle\frac{Q_{n,A}}{M_A}\cdot\frac{Q_{n,B}^*}{M_B}\right\rangle_e}}$$

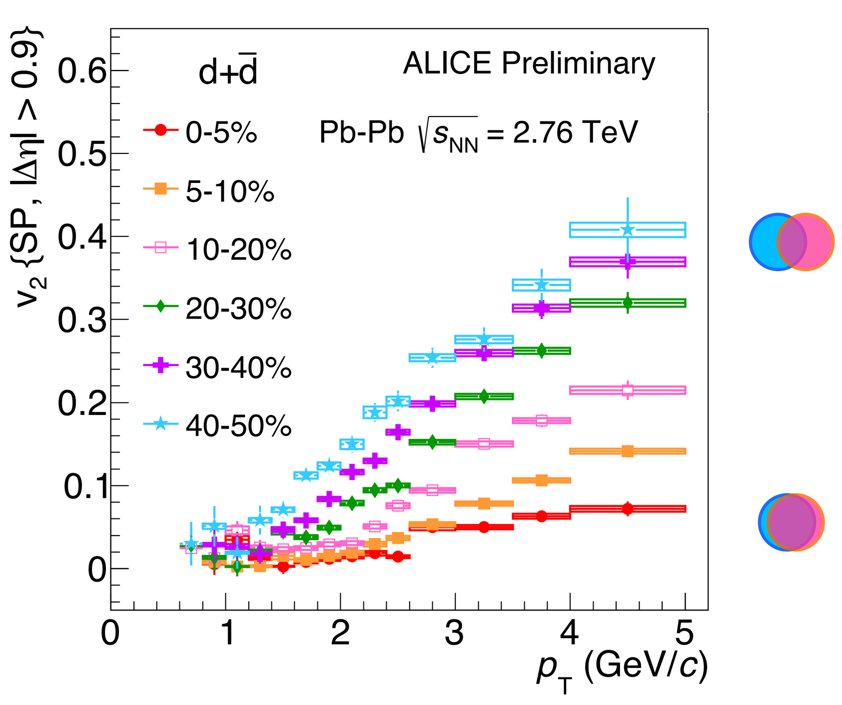
$u_{n,i}$: unit momentum vector
Q^*_n: flow vector complex conjugate
M: event multiplicity
A, B: sub-events
p: particle
e: events

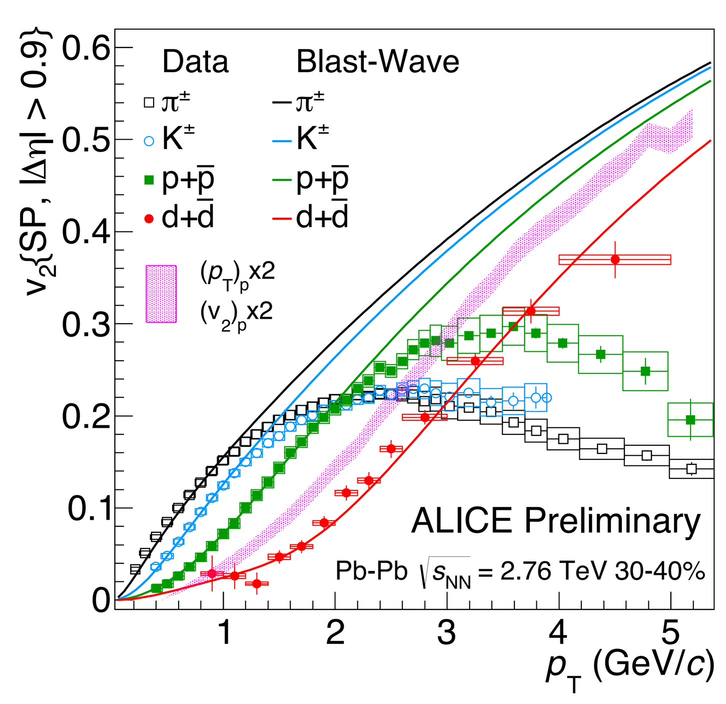


$$v_2^{Tot}(\Delta M) = v_2^{Sig}(\Delta M)\frac{N^{Sig}}{N^{Tot}}(\Delta M) + v_2^{Bkg}(\Delta M)\frac{N^{Bkg}}{N^{Tot}}(\Delta M)$$

N^{Sig}, N^{Bkg}: from fits to the m_{TOF} distribution

- contribution of **misidentified deuterons** (v_2^{Bkg}) removed by studying the azimuthal correlation versus $\Delta M = m_{TOF} - m_d$





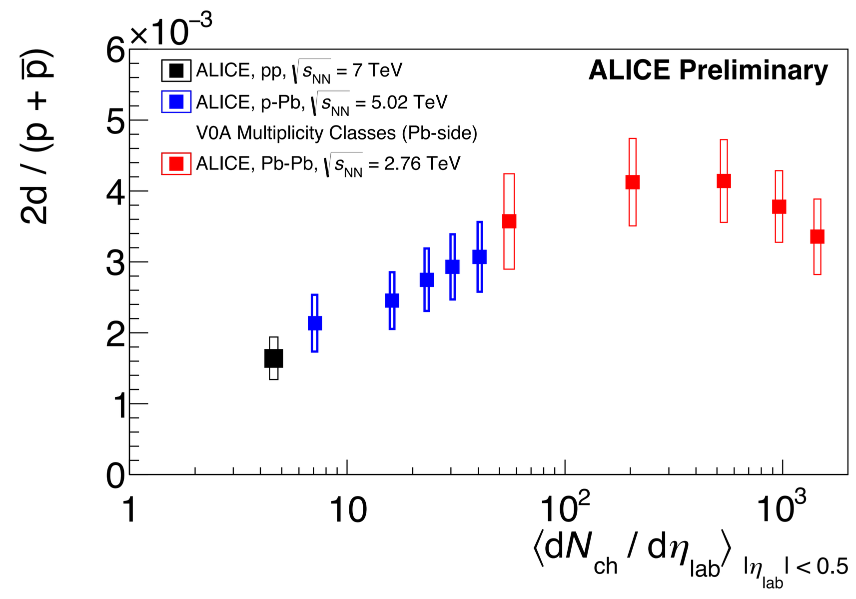
v_2 vs. p_T

- value of v_2 **increases** from central to semi-central collisions
- Cross-check: results obtained using *Event-Plane* method **are in agreement** with results from *SP* method

Blast-Wave vs. Coalescence

- deuteron v_2 follows the **mass ordering**
- a **Blast-Wave** (red curve) parameterisation obtained from lower mass species can describe the deuteron v_2 reasonably well
- a **simple coalescence model** (magenta band) is not able to reproduce the v_2

NUCLEI PRODUCTION: Where are we?

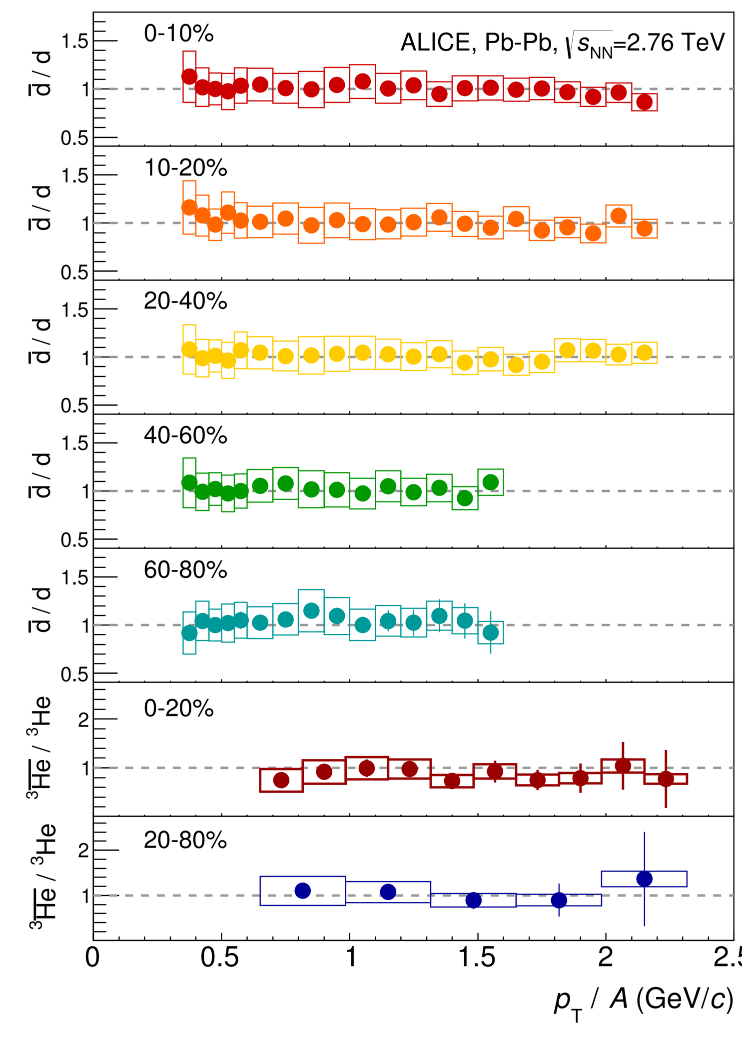


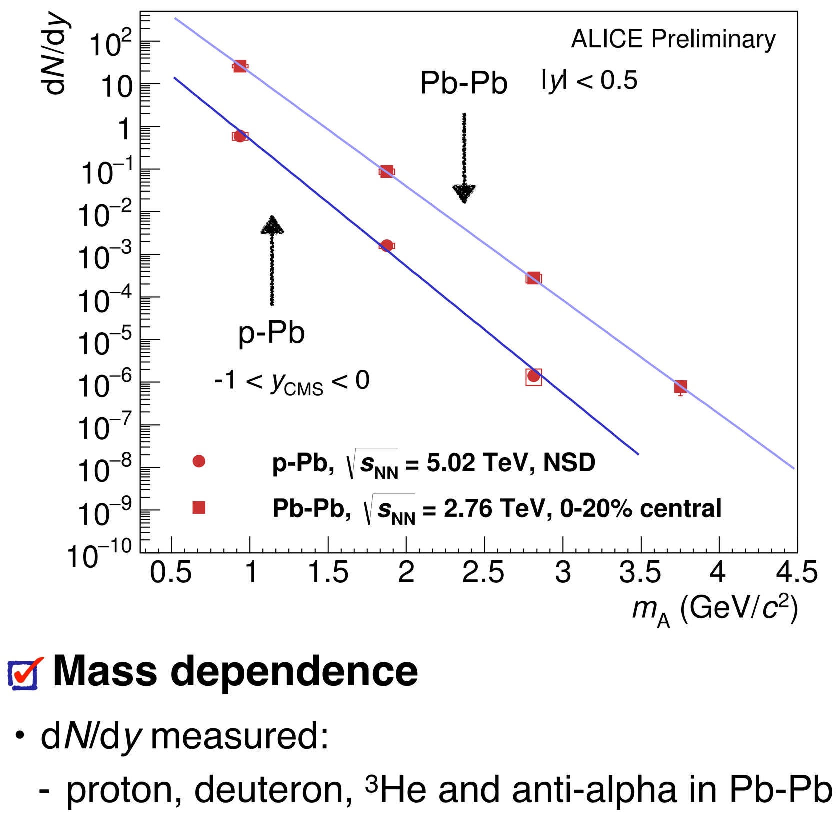
***d/p* vs. multiplicity**

- **low multiplicity**: *p-Pb* is compatible with *pp* value
- **high multiplicity**: *p-Pb* is consistent with *Pb-Pb* value → thermal model (T_{chem} = 156 MeV) $d/p = 3\times10^{-3}$ [1]
- increase of the d/p with charged particle multiplicity from pp to Pb-Pb is consistent with **coalescence picture**

Matter vs. antimatter

- at LHC energies → transparency regime (initial $\mu_B \approx 0$)
- anti-nuclei/nuclei ratios in agreement with **unity** and with **thermal** and **coalescence** model predictions
- ratios are **independent** of transverse momentum and centrality





Mass dependence

- dN/dy measured:
  - proton, deuteron, ^{3}He and anti-alpha in Pb-Pb
  - proton, deuteron and ^{3}He in p-Pb NSD
- nuclei production yields follow an exponential decrease with mass (m_A) as predicted by thermal model
- **penalty factor** in dN/dy for adding one baryon (A → A+1):
  - ~ 300 in Pb-Pb
  - ~ 600 in p-Pb

References

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