Study of the multiplicity dependence of (anti-)deuteron production in pp collisions at 5 TeV with ALICE at the LHC

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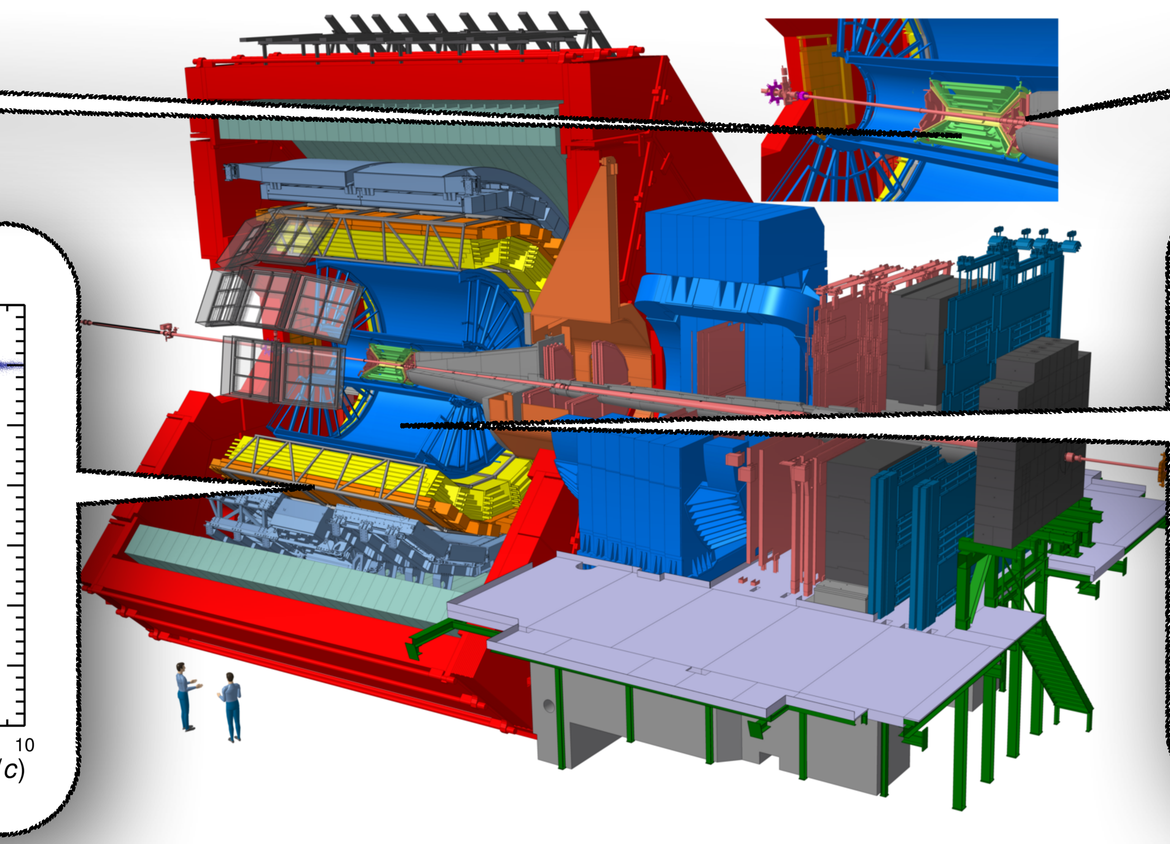
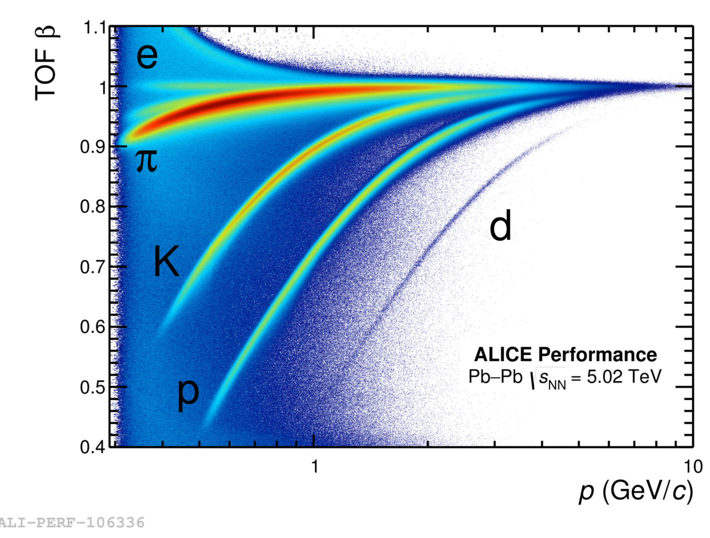
The ALICE detector

Inner Tracking System
- $\sigma_{DCA_{xy}}$ < 100 μm for p_T > 0.5 GeV/c in Pb-Pb
  - ✓ Separate primary and secondary vertices
- PID of low momentum particles

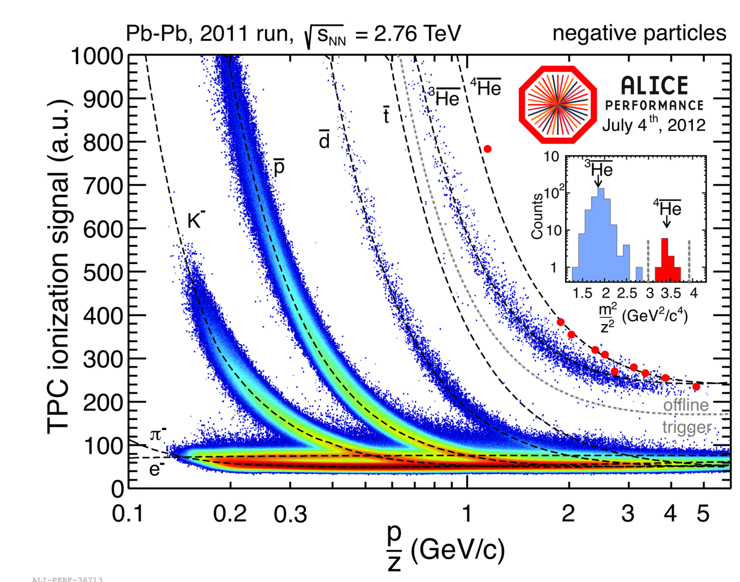
V0 detector
- multiplicity determination and trigger



Time Of Flight
- PID through the time of flight measurement
- σ_{TOF} ~ 85 ps for central Pb-Pb collisions
  - ✓ deuteron identification from p ~ 1 GeV/c up to 5 GeV/c



Time Projection Chamber
- Tracking
- PID through the specific energy loss (dE/dx) measurement
- $\sigma_{dE/dx}$ ~ 7% for central Pb-Pb collisions
  - ✓ Nuclei identification at low p/z



Nuclear matter production

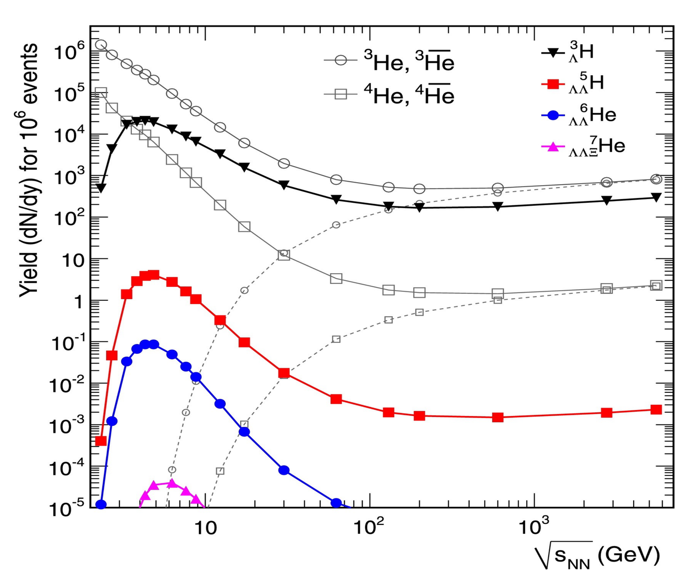
- At the high energies reached in proton-proton (pp), proton-lead (p-Pb) and lead-lead (Pb-Pb) collisions at the LHC a significant production of light (anti-)nuclei, such as (anti-)deuterons, is observed.
- Two different theoretical models are available to describe the production mechanism of light (anti-)nuclei:

Statistical-thermal model [1]

- The yield of the hadronic species ***dN/dy*** is fixed at **chemical freeze-out** and it depends on the freeze-out temperature T_{ch} and on the **mass** of the hadron:

$$\frac{dN}{dy} \propto \exp\left(-\frac{m}{T_{ch}}\right)$$

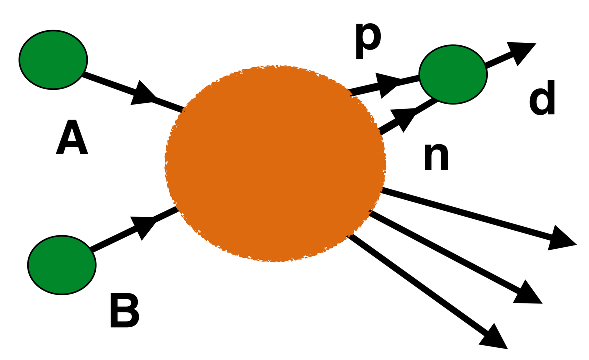
- Since the mass of the nuclei is high, small variations in T_{ch} drastically change the yield of nuclei.



Coalescence model [2]

- The baryons that are close in phase space at the kinetic freeze out can coalesce to form (anti-)nuclei.
- The probability of producing a nucleus by coalescence can be expressed through the **coalescence parameter B_A** [3]:

$$B_A = \frac{E_A \frac{d^3N_A}{d^3p_A}}{\left(E_p \frac{d^3N_p}{d^3p_p}\right)^A}$$



Schematic picture for the deuteron production via coalescence mechanism

E_p : proton energy
p_p : proton momentum
d^3N/d^3p_p : proton density
A : number of nucleons
$E_A = A \cdot E_p$: energy of the nuclei with A nucleons
$p_A = A \cdot p_p$: momentum of the nuclei with A nucleons
d^3N_A/d^3p_A : density of the nuclei with A nucleons

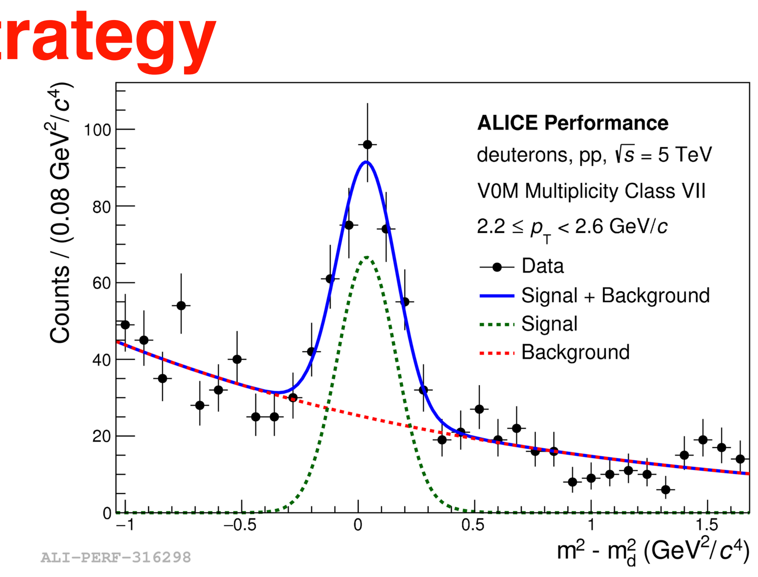
Analysis strategy

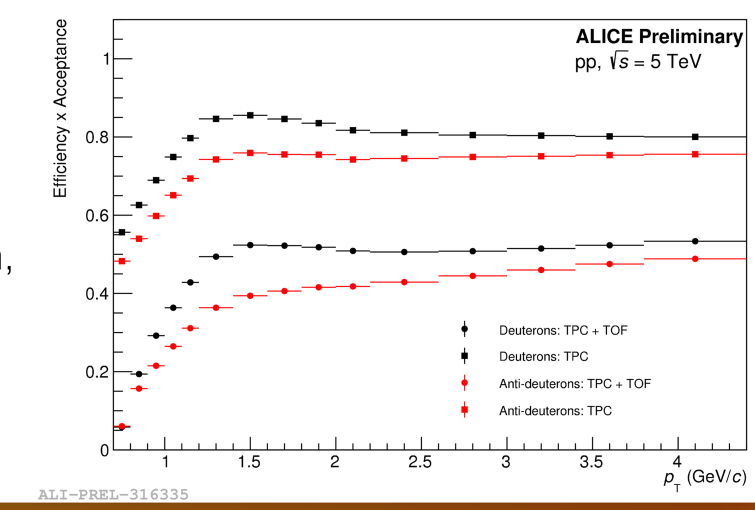
- **9 multiplicity classes** + integrated multiplicity

Particle Identification
Signal extracted from:
- **TOF** squared **mass** distribution
- **TPC** number of **sigmas** distribution

Corrections
- **efficiency x acceptance**
- rejection of **secondaries**

Systematic Uncertainties
- Many sources (track selection, signal extraction, rejection of secondaries, material budget, TPC-TOF matching efficiency)





Results

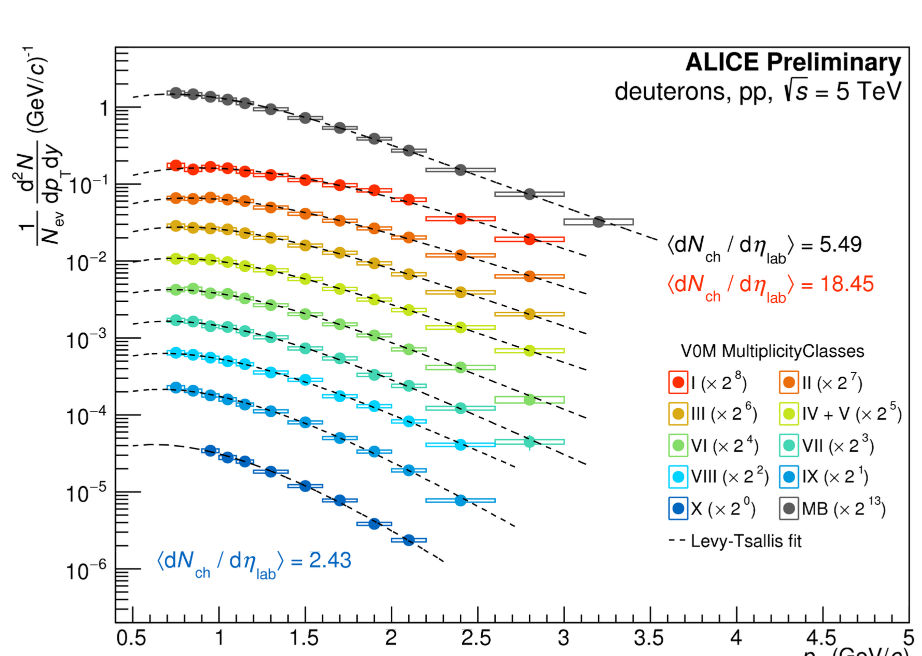
Transverse momentum spectra vs multiplicity

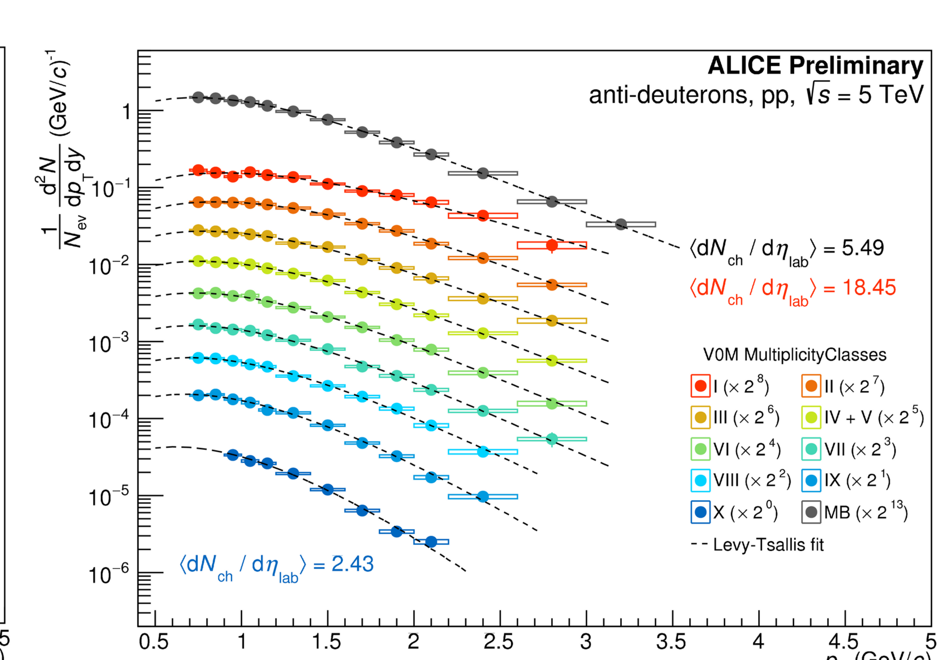
- The transverse momentum (p_T) spectra have been measured for **(anti-)deuterons**.
- The p_T spectra are fitted using a **Levy-Tsallis distribution** [4]:

$$f(p_T) = p_T \frac{dN}{dy} \frac{(n-1)(n-2)}{nC[nC + m_0(n-2)]} \left[1 + \frac{(p_T^2 + m_0^2)^{1/2} - m_0}{nC}\right]^{-n}$$

m_0 = 1.875 GeV/c^2 (deuteron mass)
n, C : free parameters
dN/dy : p_T integrated yield

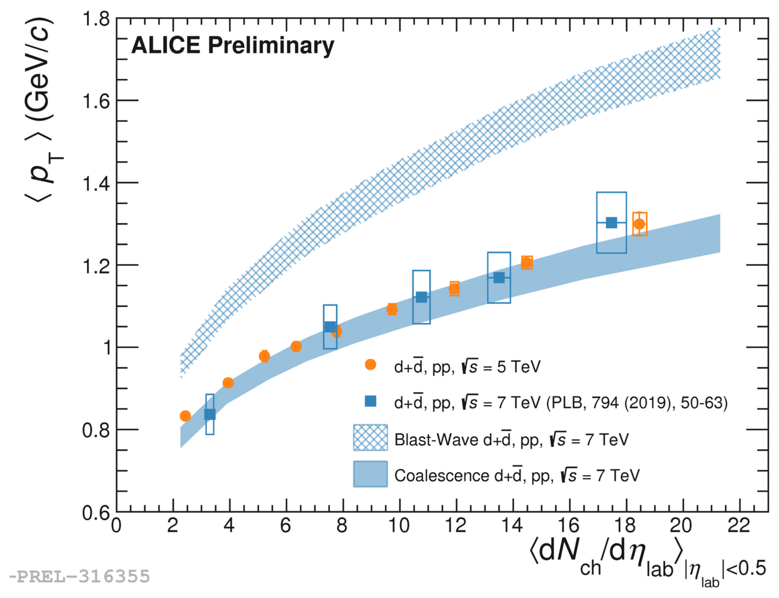
The fit to the production spectra is aimed to:
- ✓ extrapolate the spectra in the unmeasured p_T region
- ✓ evaluate the p_T integrated yield **d*N*/d*y*** and the mean transverse momentum **<*p*T>**

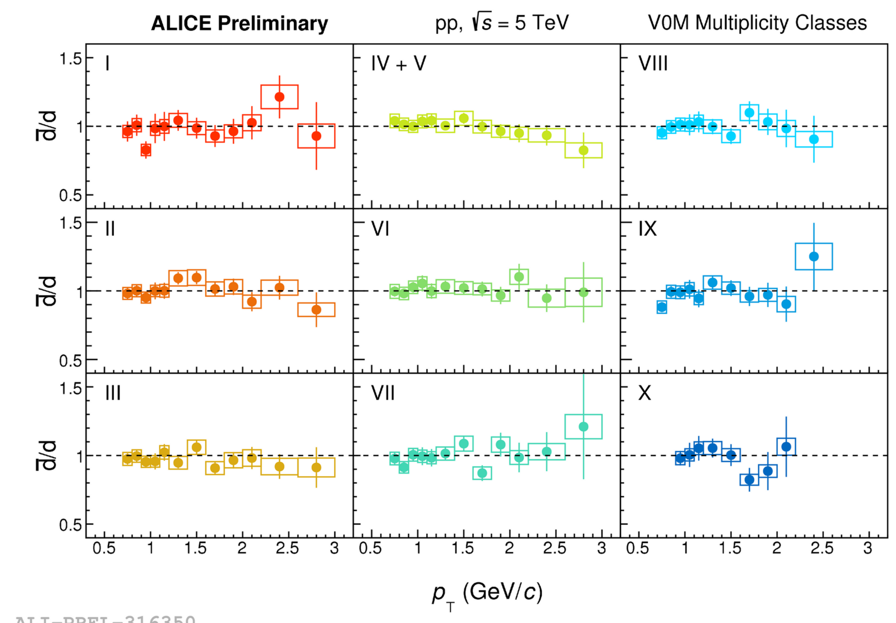




Mean transverse momentum

- The **mean transverse momentum** (<p_T>) has been evaluated from the Levy-Tsallis fits to the spectra as a function of the mean charged particle multiplicity (<dN/dη_{lab}>) produced in the collision.
- Very good agreement between the results in pp collisions at 5 TeV and 7 TeV [5]:
  - ✓ same increasing trend with the charged particle multiplicity.
- **Model predictions** for pp collisions at 5 TeV are not available yet
  - ✓ a simple coalescence model describes the results obtained in pp collisions better than the Blast Wave model.





Ratio

- The **anti-deuteron/deuteron ratio** is compatible with unity independently of p_T and multiplicity, such as expected from both statistical-thermal and coalescence models:
  - ✓ the regime of **nuclear transparency** is reached, i.e. in the central rapidity region the initial **baryo-chemical potential** is **vanishing** (μ ~ 0).

References

[1] A. Andronic, et al. *Phys. Lett. B* 697, 203 (2011)
[2] S. T. Butler, C. A. Pearson. *Phys. Rev.* 129, 836 (1963)
[3] J. I. Kapusta, *Phys. Rev. C* 21.4, 1301 (1980)
[4] C. Tsallis. J. Stat. *Phys.* 52, 479 (1988)
[5] ALICE Collaboration, Phys. Lett. B, 794 (2019), 50-63 (arXiv:1902.09290)