Extending the ALICE strong-interaction studies to nuclei: measurement of proton-deuteron correlations in pp collisions at √s =13 TeV

Bhawani Singh on behalf of the ALICE Collaboration
Technical **U**niversity of **M**unich
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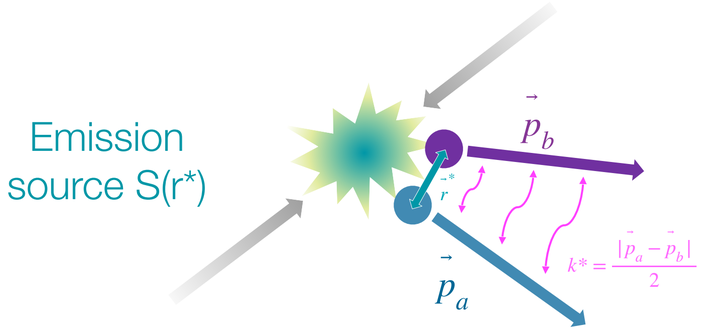
Motivation

- **Proton-deuteron (p-d) interaction:**
  - Three-nucleon system: doorway to test three-body forces.
  - p-d interaction is constrained with scattering experiments.
- **Formation mechanism of light (anti)nuclei is still under debate in the scientific community:**
  - Two models are employed to describe (anti)deuteron spectra and yields: Statistical Hadronisation Model[1,2] and Coalescence Model[3].
  - No test of the (anti)deuteron formation time so far!
- **Femtoscopy correlation:** probes the interaction and the source size for proton-deuteron pairs.

[1]J. Cleymans et al., Phys. Rev. C 74, 034903 (2006),
[2]J. Cleymans and H. Satz., Z. Phys. C 57, 135–147 (1993)
[3]K. Blum et al. Phys. Rev. C 99, 04491(2019)

bhawani.singh@cern.ch

Femtoscopy



- The main observable is the **correlation function(CF)**:

$$C(k^*) = \int S(\vec{r}^*)\,|\psi(\vec{k}^*, \vec{r}^*)|^2\,\mathrm{d}^3 r^* = \mathcal{N}\frac{N_{\mathrm{same}}(k^*)}{N_{\mathrm{mixed}}(k^*)}$$

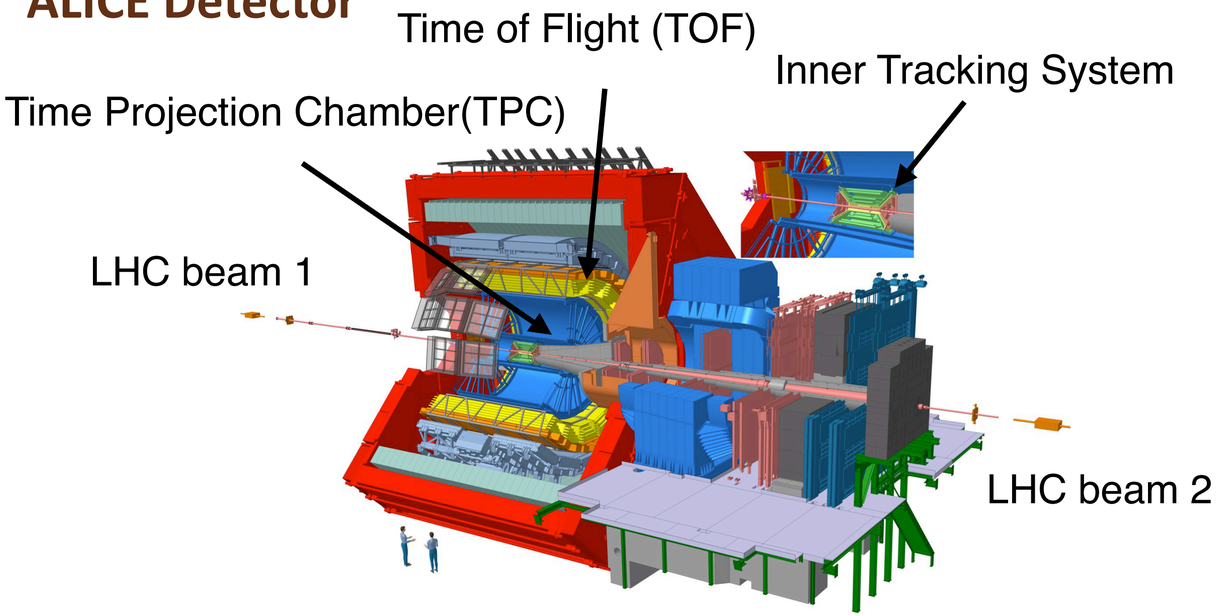
Theory Experiment

- Two ingredients:
  - **Emitting source**: hypersurface of kinematic freeze-out for final-state particles
    - in pp collision $r_{\mathrm{eff}} \sim 1$ fm (Gaussian profile)
  - **Two-particle relative wave function**: expresses the interaction between particles.

CATS: D.L. Mihaylov et al, Eur.Phys.J. C78 (2018) no.5, 394

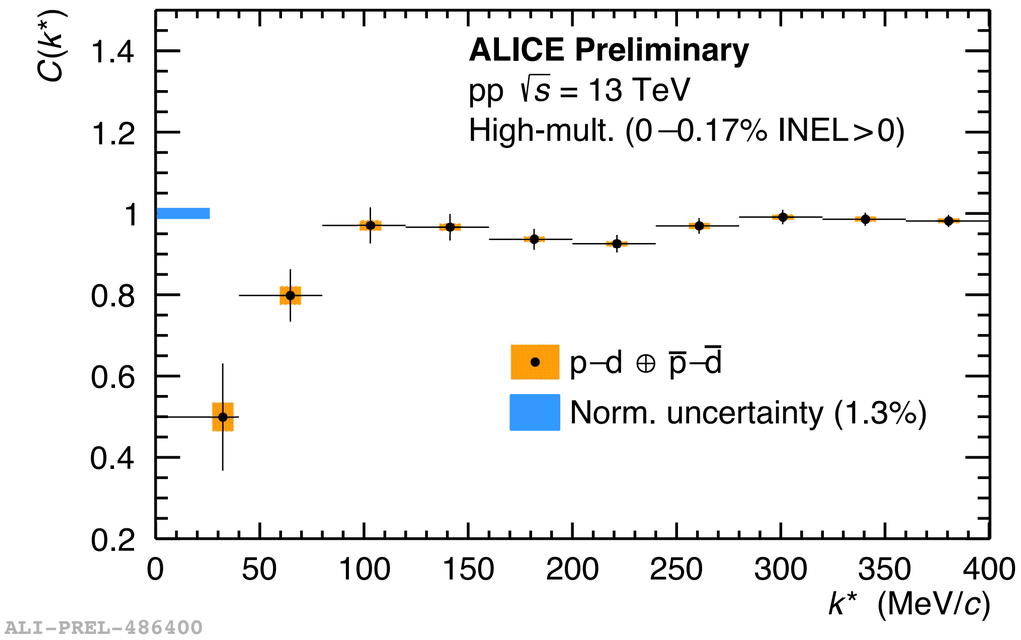
The analysis

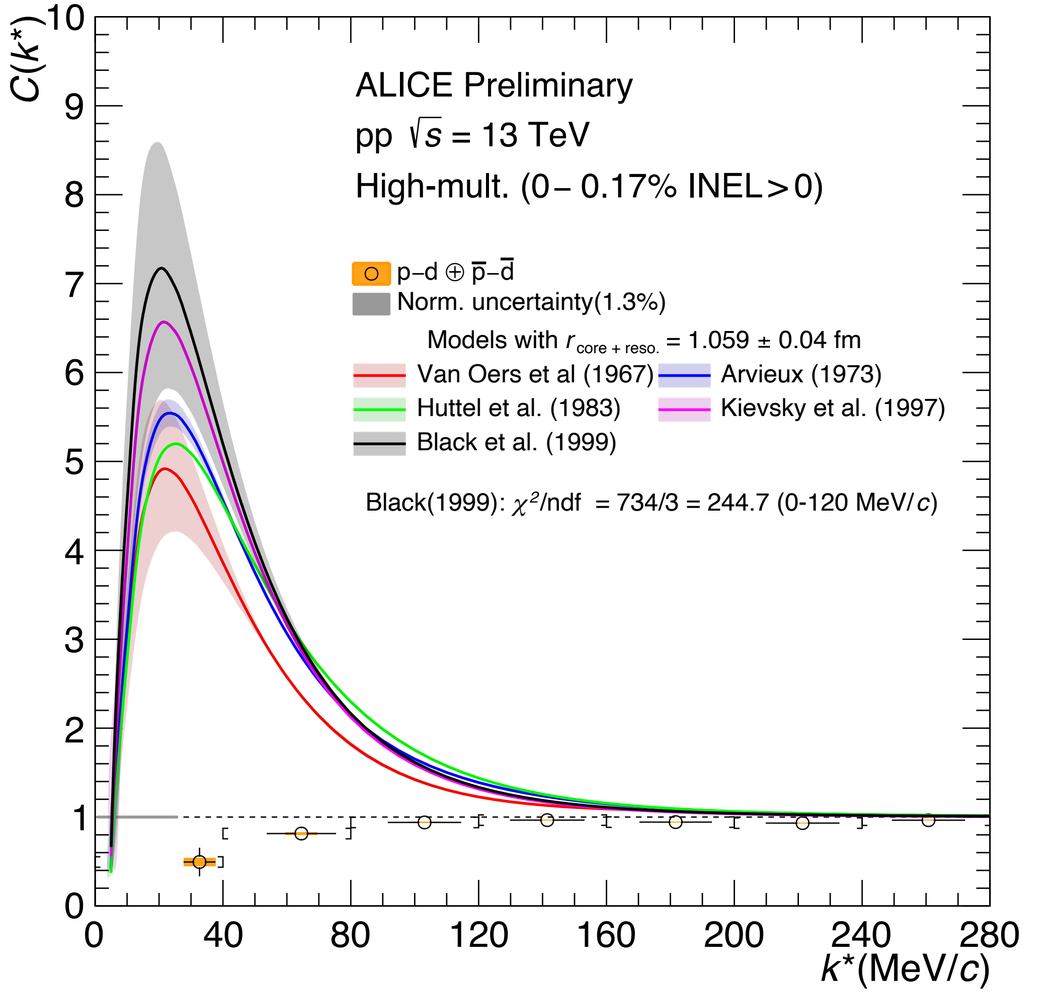
ALICE Detector



- Collision system: pp at √s =13 TeV high-multiplicity trigger
- Momentum reconstruction: TPC and TPC+TOF
- (anti)proton: $0.5 < p_{\mathrm{T}} < 4.0$ GeV/c
- (anti)deuteron: $0.5 < p_{\mathrm{T}} < 1.4$ GeV/c
- Avg. transverse mass($\langle m_{\mathrm{T}} \rangle$): 1.65 GeV/$c^2$

Measurement: p-d correlations and model



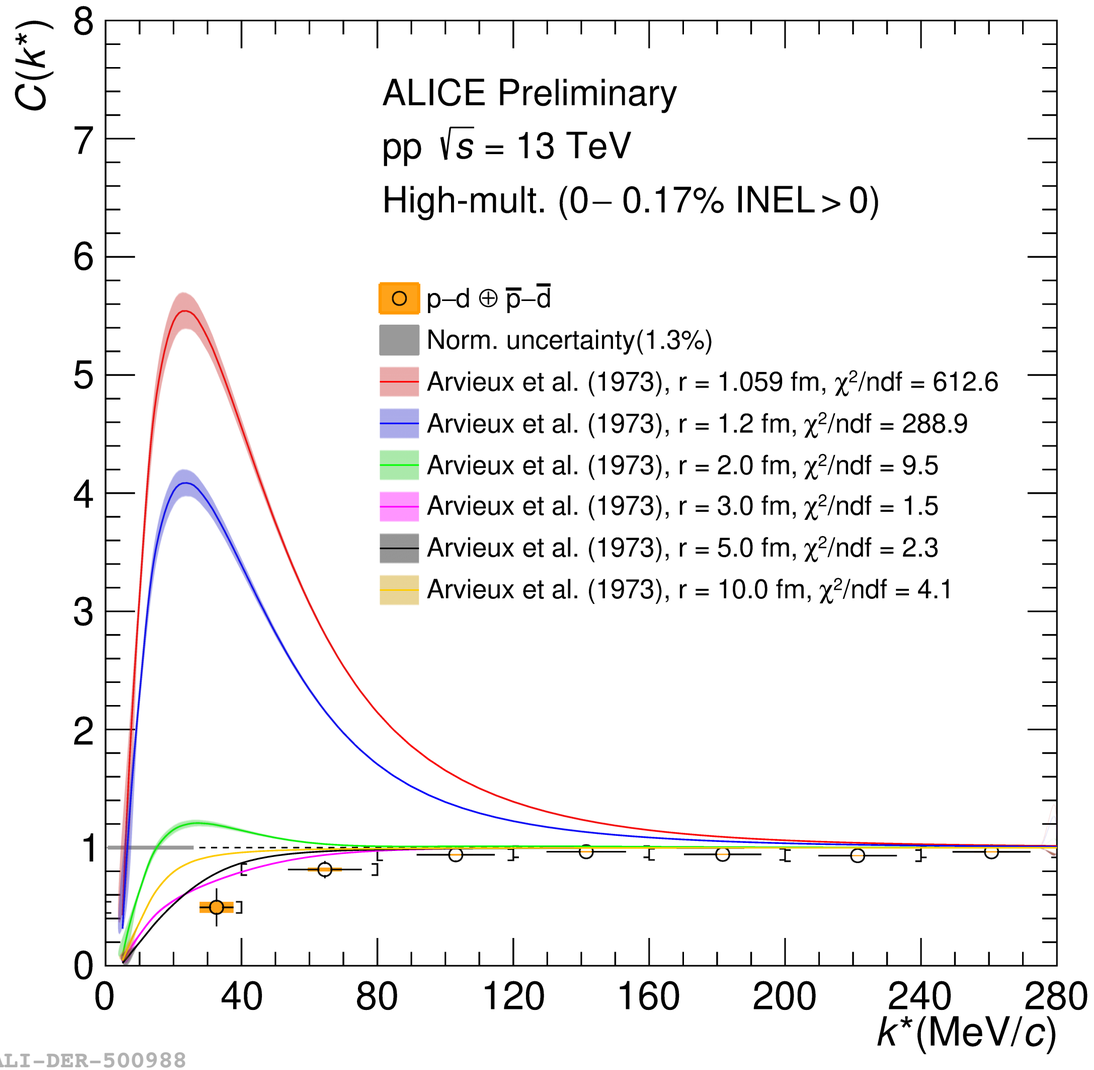


- Two-particle s-wavefunction accounting for Coulomb and strong interaction[1].
- Coulomb + strong interaction (S = 1/2 and S = 3/2) .
- Assumption: p and d are point-like particles!
- The source size $\mathbf{r_{eff} = 1.06 \pm 0.04}$ fm: extracted by using $\langle m_T \rangle$ = 1.67 GeV/c^2 and effects of resonances are added[2].

model and the data disagree!

[1]R. Lednick`y, Phys. Part. Nuclei 40, 307–352 (2009)
[2]ALICE Coll. PLB 811 135849 (2020)

Delayed deuteron formation?



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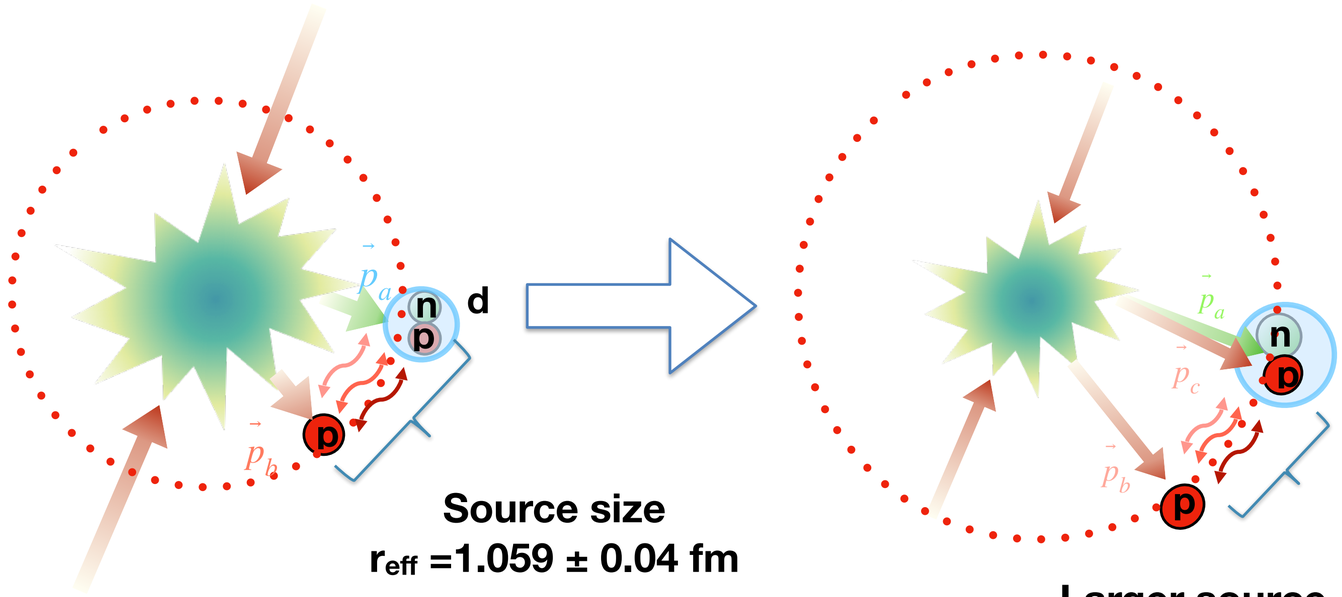
Delayed formation of d



Source size
r_{eff} =1.059 ± 0.04 fm

Larger source
r_{eff} = 4-5 fm

- At large r ~ 3.0 fm the agreement is best between model and the data.
- Effect of attractive strong interaction in the CF is washed off.
- The source size increase is consistent with a delayed formation of the deuteron.

J. Arvieux et al. Nucl. Phys. A 221 253-268 (1973)

Summary and outlook

Summary:

- First measurement of proton-deuteron correlations in high multiplicity pp collisions at $\sqrt{s}$ = 13 TeV.
- In contrast to the p-d data, the models show a huge peak at low k^*.
- Delay in formation time of (anti)deuterons in hadron-hadron collisions could be the reason behind discrepancies.

Outlook:

- Work in progress: p-d potential models based on three-body dynamics to strengthen the physics message.
- More precision studies with the large data samples in Run 3.