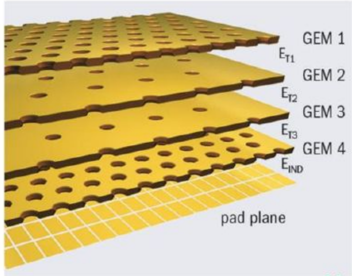
First Measurement of the Proton-Deuteron Correlation Function with Data Taken by ALICE in Run 3

Anton Riedel
for the ALICE collaboration
Technical University of Munich

61st International Winter Meeting on Nuclear Physics, Bormio, Italy
30.01.2025

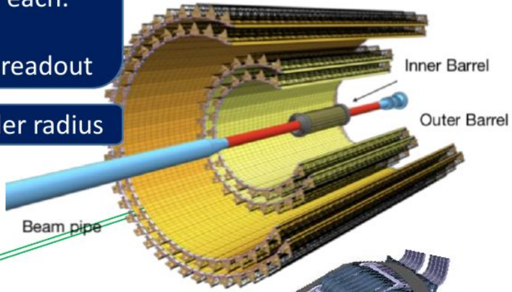
Upgraded ALICE detector in Run 3

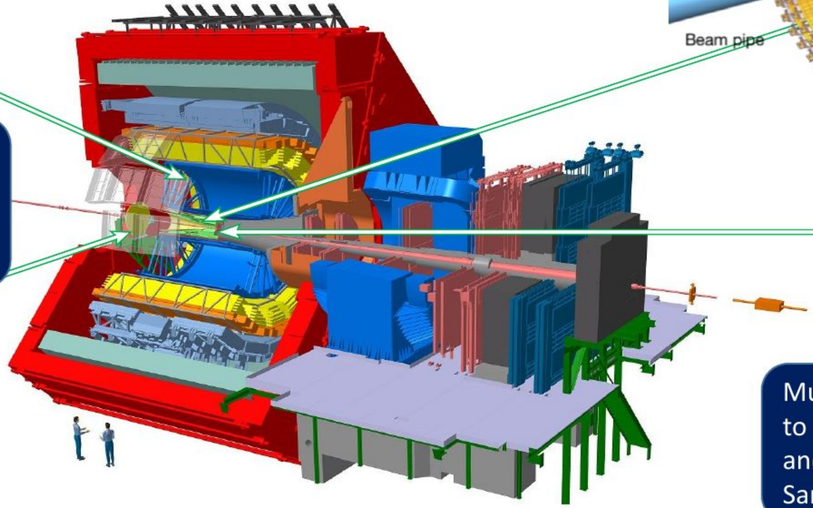


TPC MWPC readout → 4 layer GEM
(Intrinsic ion backflow ~99% blocking)
5MHz continuous sampling

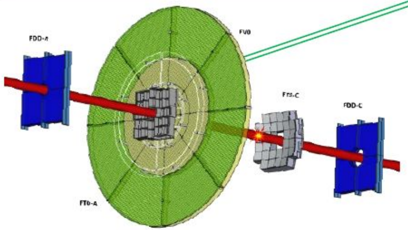
New Si Inner Tracker: 10 m^2 of MAPS with 29x27μm^2 pixel size
3 inner layers ~0.3% X0 each.
Closer to the beam
50-500 kHz continuous readout

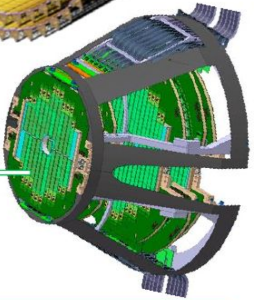
New beam pipe of smaller radius





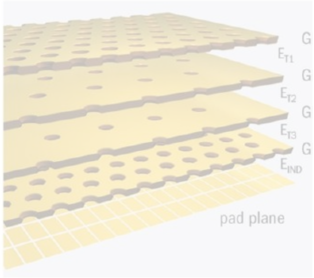
Fast Interaction Trigger (FIT) detector
Scintillator (FV0, FDD) + Cerenkov (FT0) detectors to provide Min.Bias trigger for detectors with triggered R/O





Muon Forward Tracker
to match muons before and after the absorber.
Same Si chips as new ITS

Upgraded ALICE detector in Run 3



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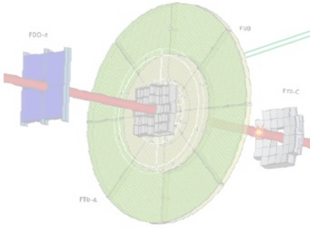

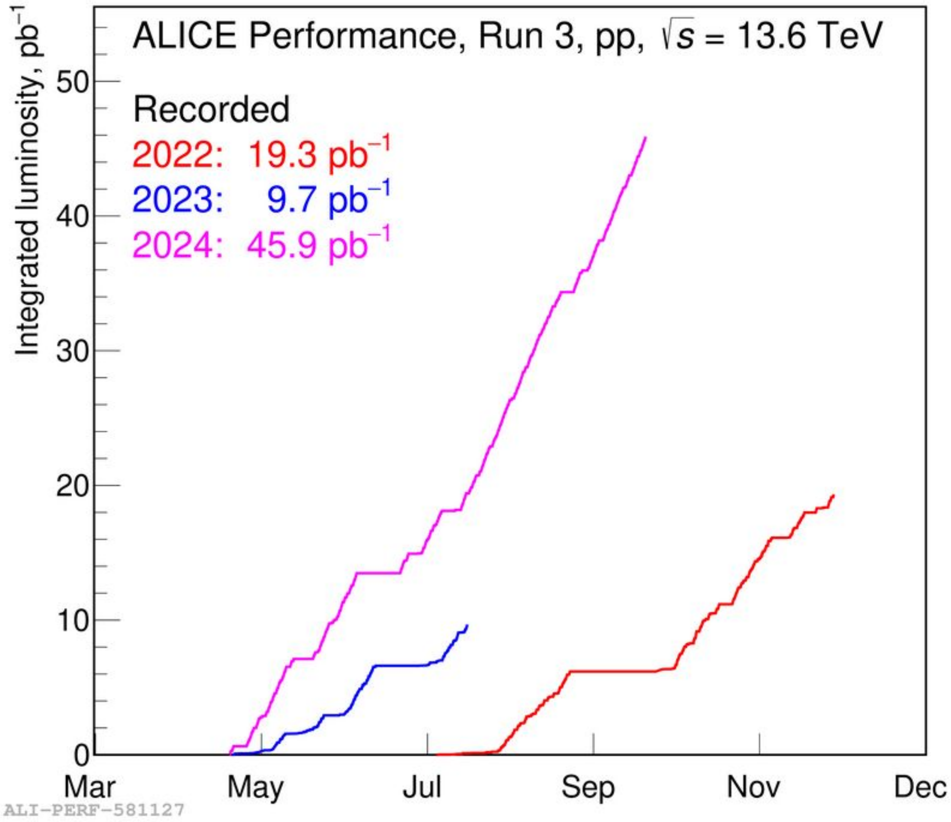

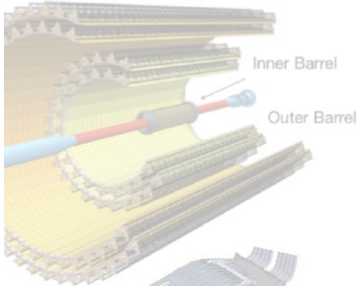

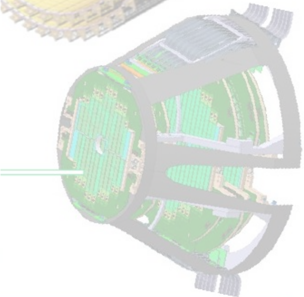

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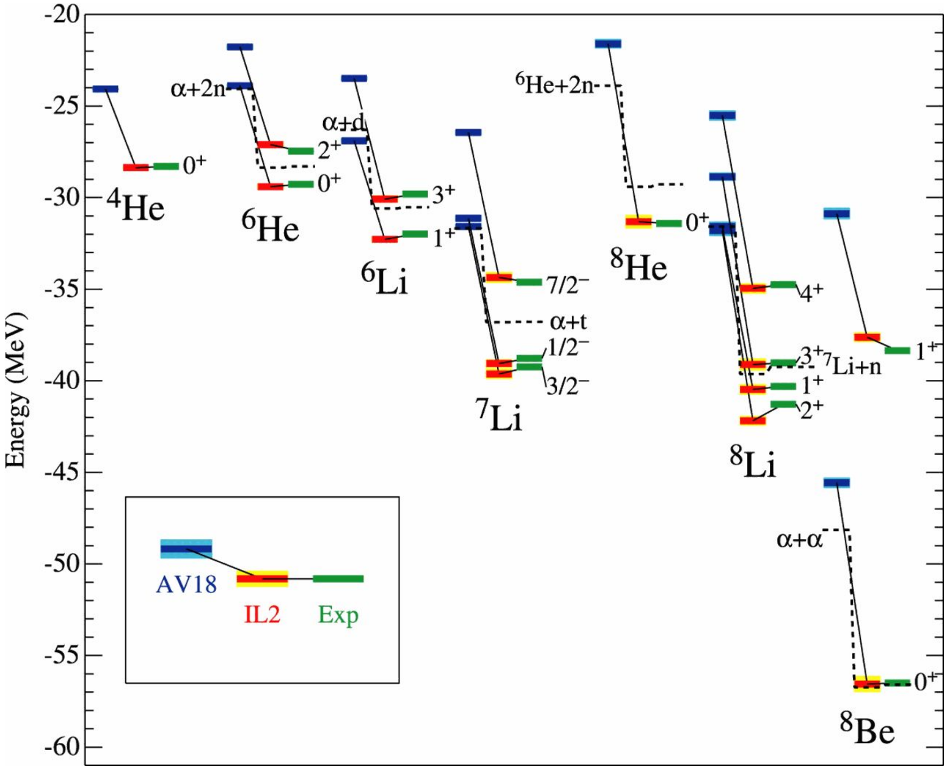
Motivation

- State-of-the-art interaction models for NN and NNN are need to predict nuclei binding energies correctly
- Experimental constraints on three-body interaction can be provided by femtoscopy

Pieper and Wiringa, Ann.Rev.Nucl.Part.Sci.51:53-90 (2001)



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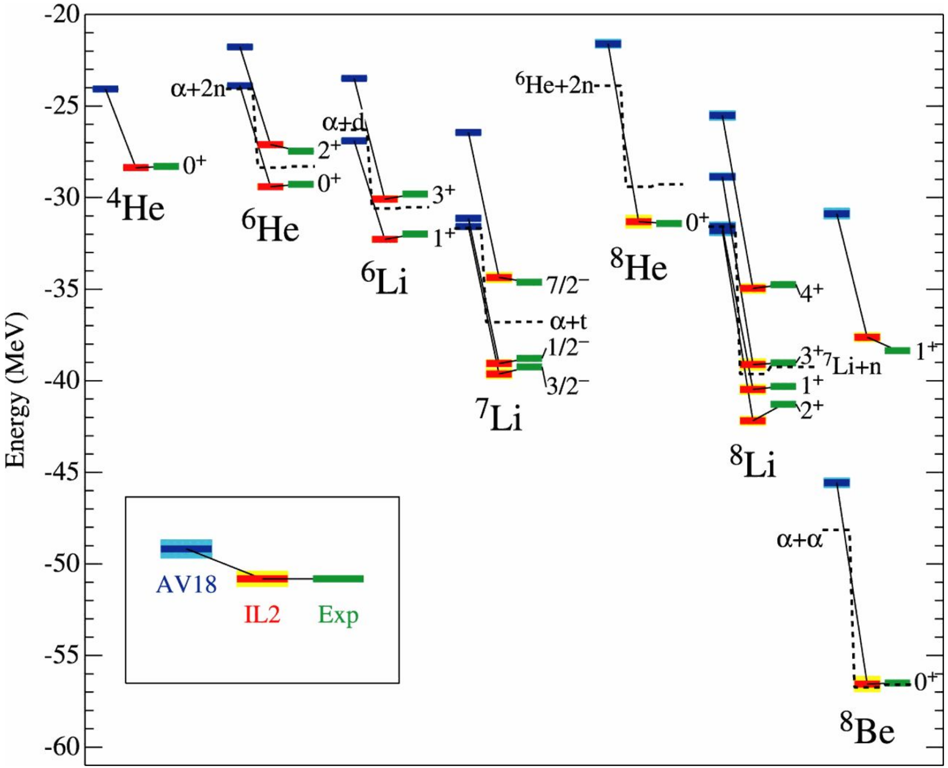
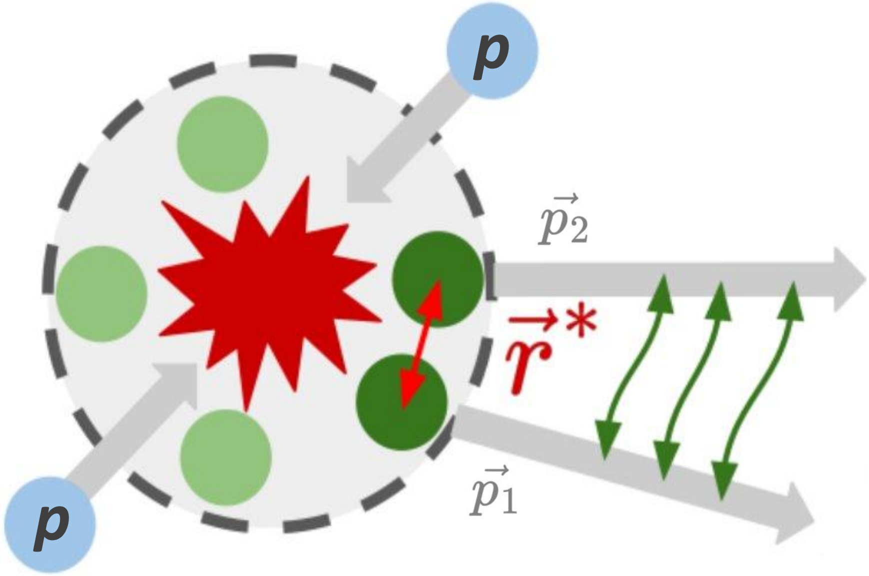
- State-of-the-art interaction models for NN and NNN are need to predict nuclei binding energies correctly
- Experimental constraints on three-body interaction can be provided by femtoscopy
- **p–d is ideal system to access genuine three-body nucleon (NNN) interaction**



Femtoscopy



M. A. Lisa et al., Ann.Rev.Nucl.Part.Sci.55:357-402 (2005)

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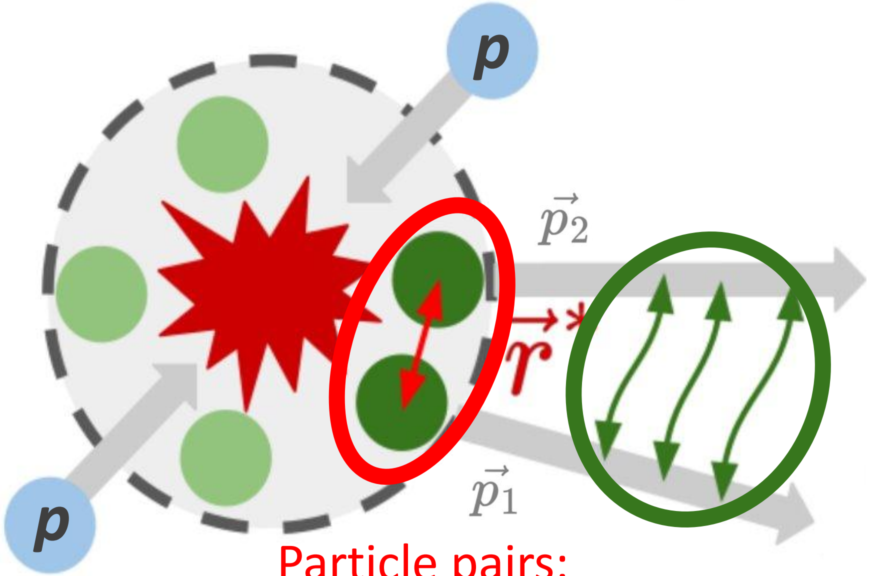

Interactions:
- Quantum stats
- Coulomb
- Strong
- …

Particle pairs:
p–p, p–Λ, …

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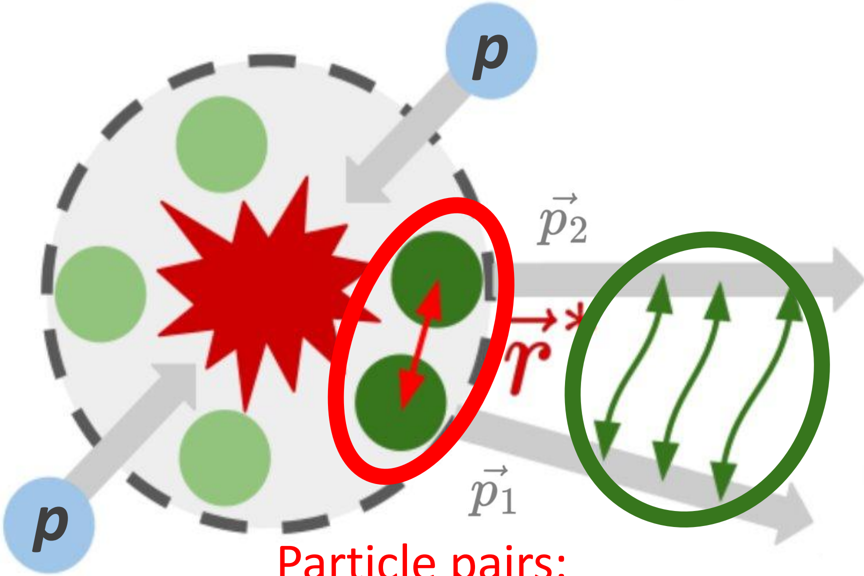
Femtoscopy

$$k^* = \frac{1}{2}\left|\vec{p}_1^{\,*} - \vec{p}_2^{\,*}\right|$$



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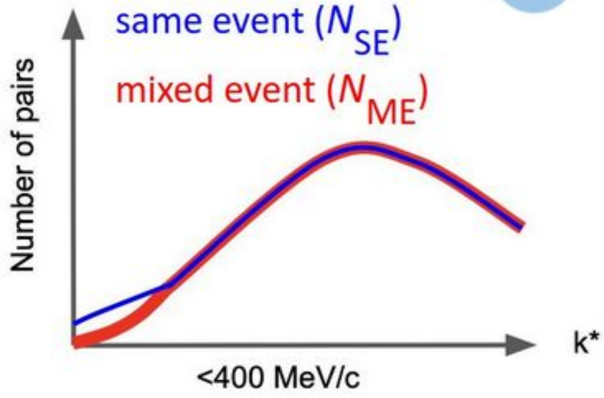
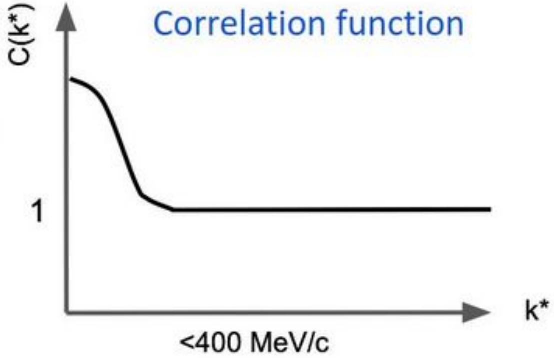


$\xrightarrow{N_{SE}/N_{ME}}$



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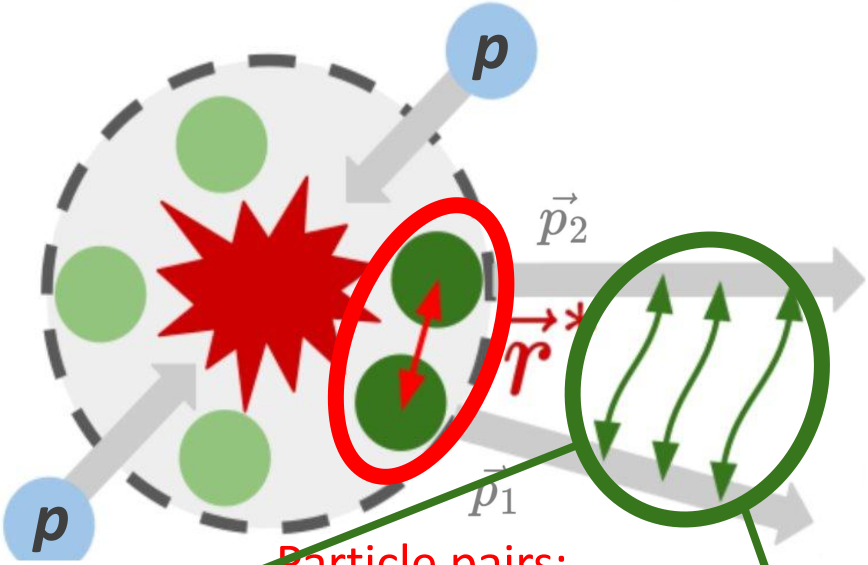

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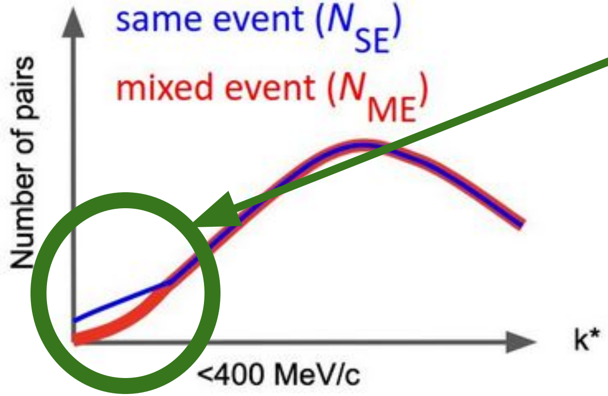

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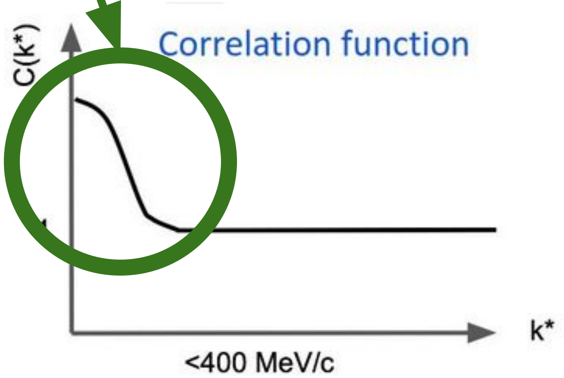

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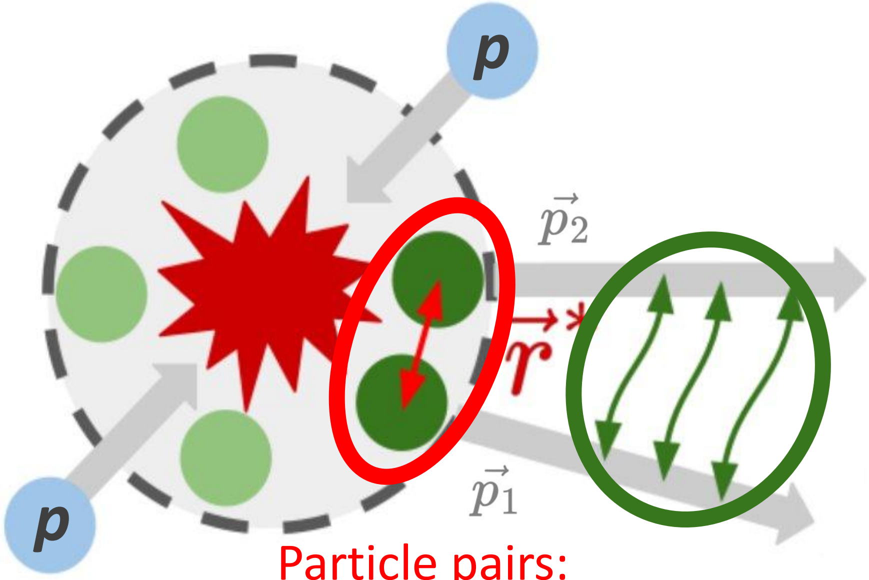

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$$C(k^*) = \mathcal{N}\frac{N_{\mathrm{SE}}(k^*)}{N_{\mathrm{ME}}(k^*)} = \int S(r^*)\left|\Psi(r^*,k^*)\right|^2 \mathrm{d}^3r^* \xrightarrow{k^*\to\infty} 1$$

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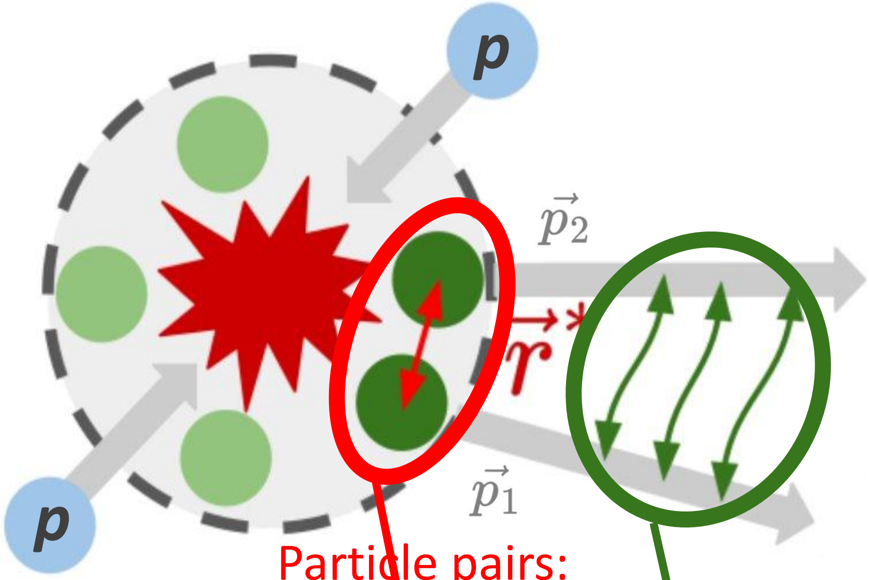

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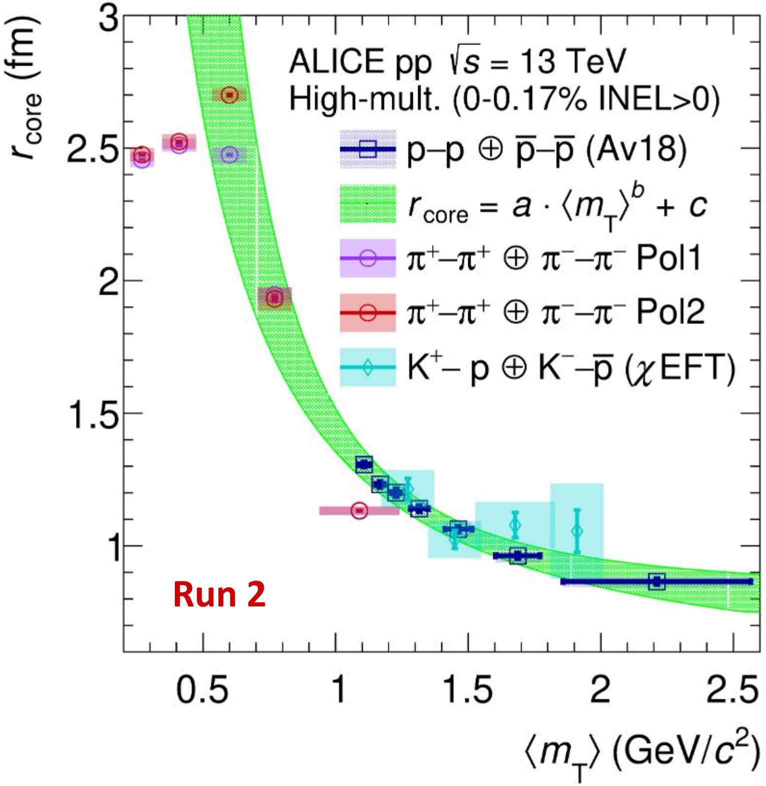
The source

- Common source for primary produced hadrons in pp collisions

$$S(r^*) = \frac{1}{(2\pi r_{\text{core}})^{\frac{3}{2}}} \exp\left(\frac{r^*}{2r_{\text{core}}}\right)^2$$

- Source size is modified by short-lived resonances
- Source size is universal for baryon-baryon and baryon-meson pairs

ALICE, arXiv:2311.14527, accepted by EPJC



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=> Do deuterons follow the same m_T scaling?

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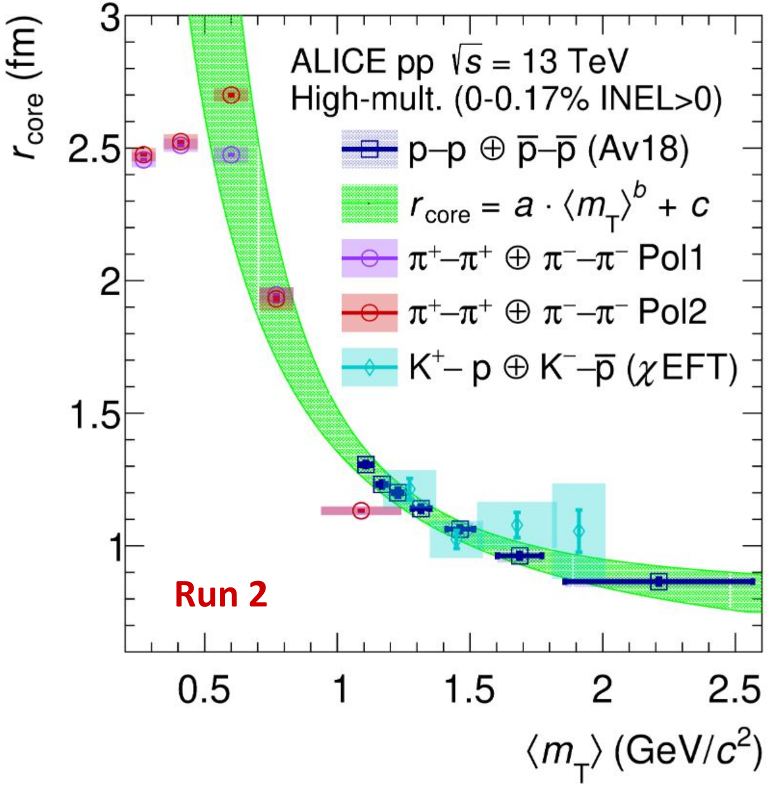


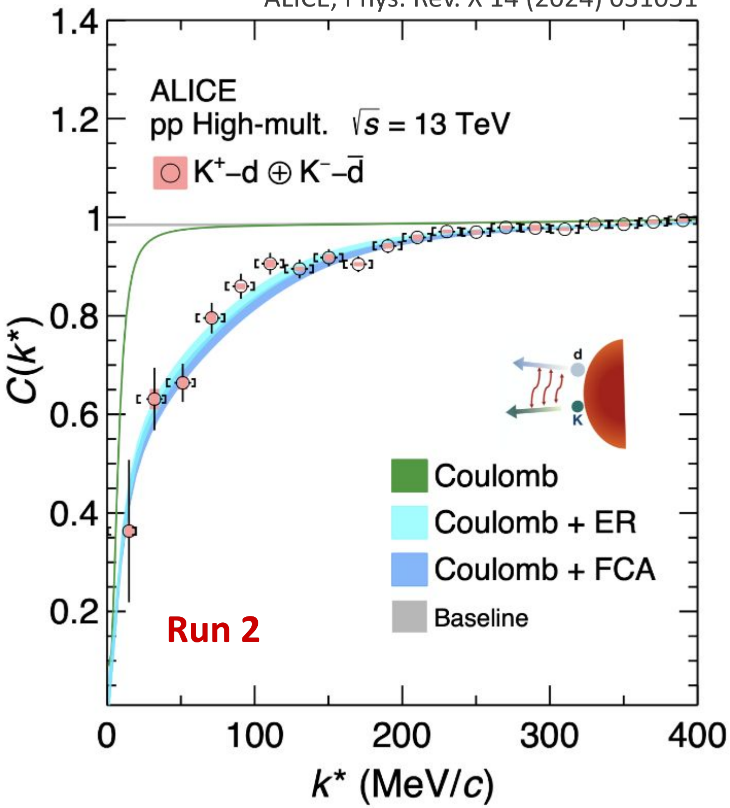
Benchmark: Kaon-deuteron correlation

- Effective source size computed from common source:

$$r_{\text{eff}}^{\text{K}^+\text{d}} = 1.35^{+0.04}_{-0.05}\ \text{fm}$$

- System model as two-body system with Lednický-Lyuboshits
(R. Lednický, Phys. Part. Nuclei 40, 307–352 (2009))
- Scattering parameters based on available scattering data
- **Good agreement with the data**

ALICE, Phys. Rev. X 14 (2024) 031051



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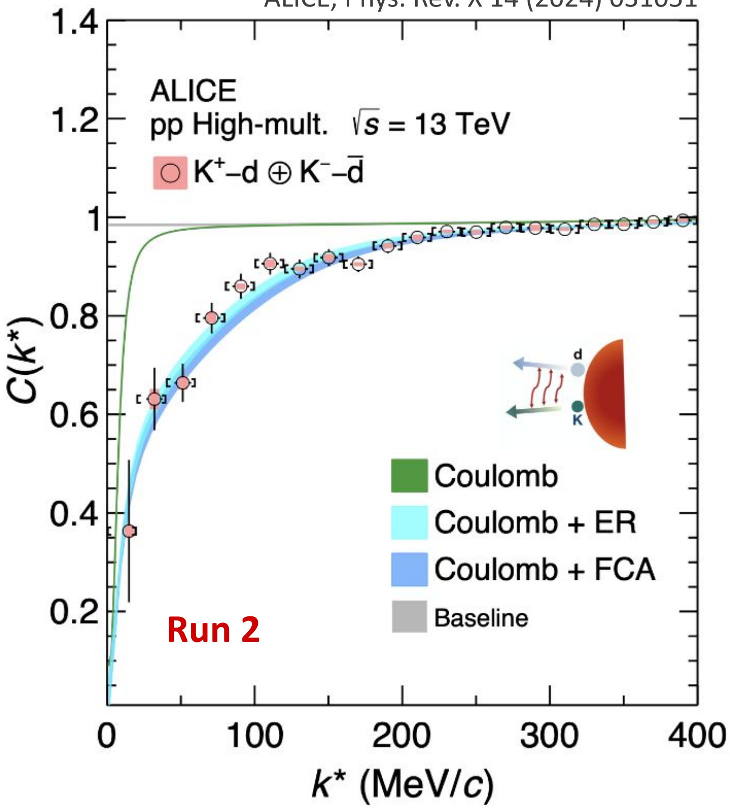
=> pairs with deuterons follow the same m_T scaling!



Proton-deuteron correlation

- Effective source size computed from common source:

$$r_{\mathrm{eff}}^{\mathrm{pd}} = 1.08^{+0.06}_{-0.06}\ \mathrm{fm}$$

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- **Large deviations between model and data**

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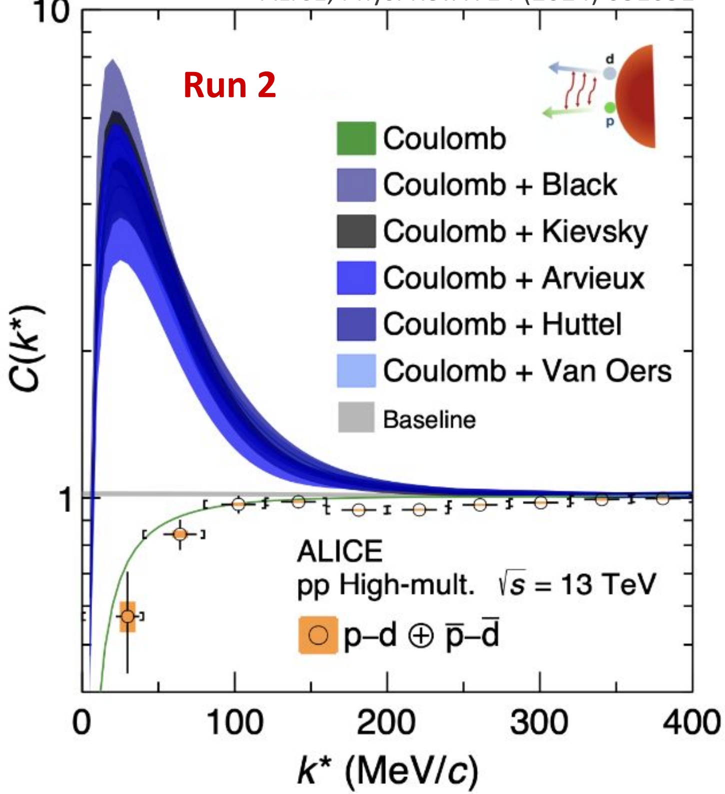

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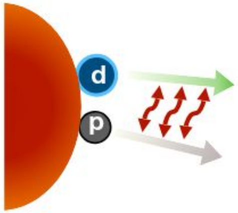

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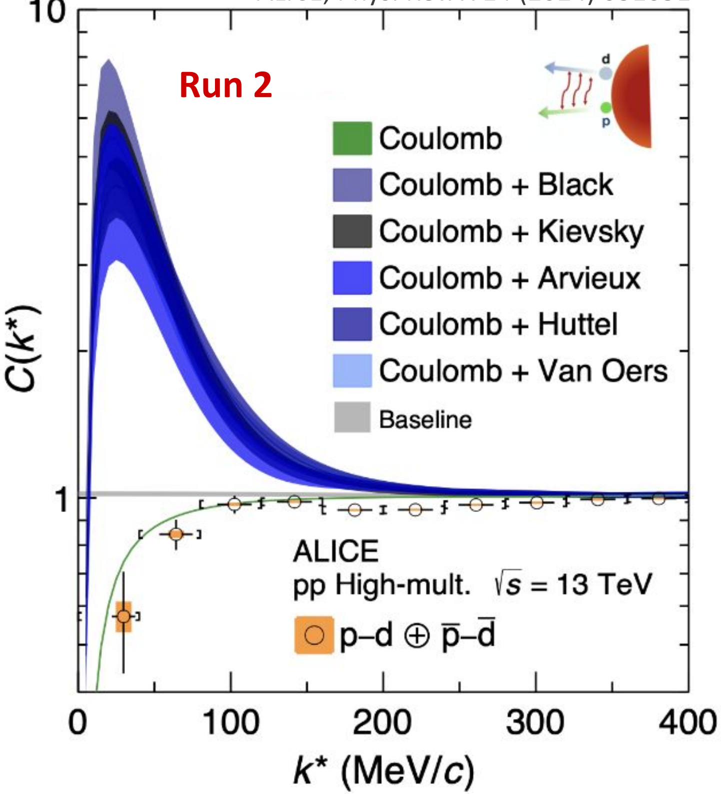

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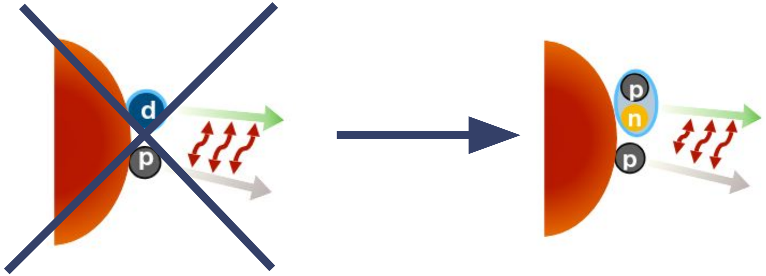

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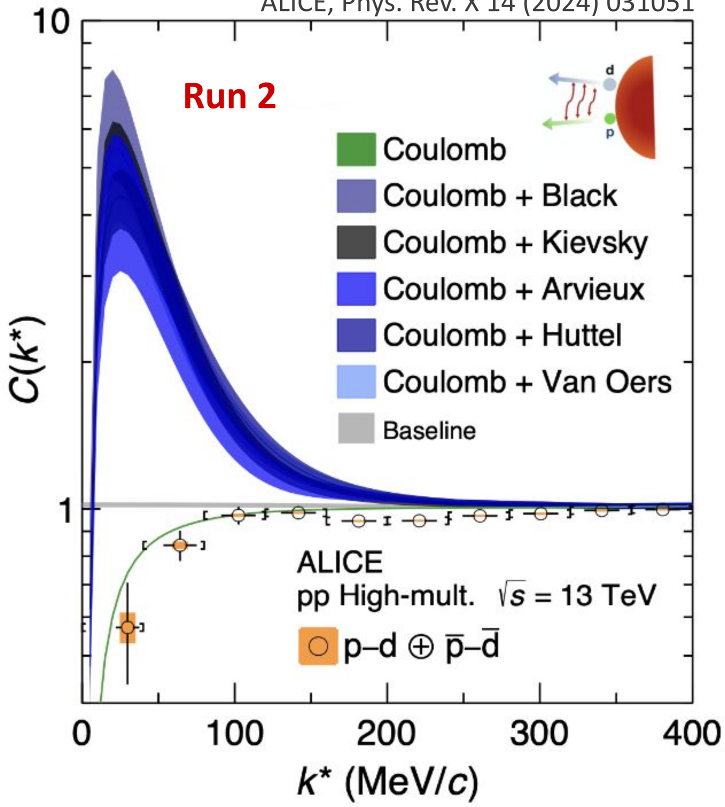


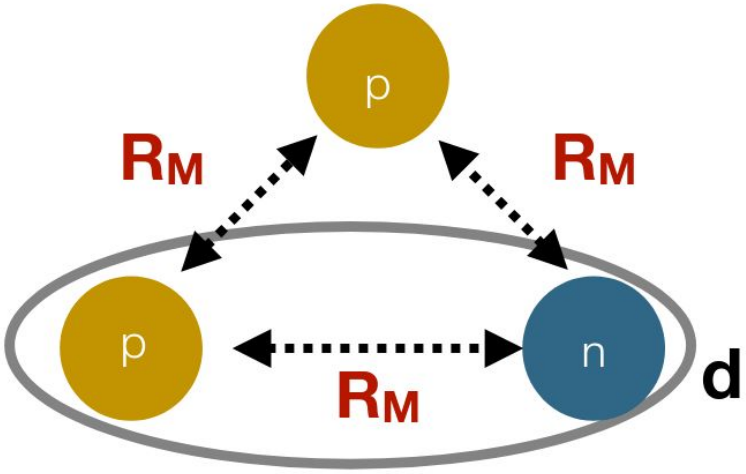
Proton-deuteron correlation

- Full three-body calculation necessary

Three-nucleon wave function

$$C_{\mathrm{pd}}(k^*) = \frac{1}{16A_{\mathrm{d}}}\int S(\rho, R_{\mathrm{M}})|\Psi(k^*,\rho)|^2\rho^5\mathrm{d}\rho\mathrm{d}\Omega$$

Effective nucleon-nucleon source size in the p-d system



M. Viviani et. al., Phys. Rev. C **108**, 064002 (2023)

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Effective nucleon-nucleon source size in the p-d system

- Calculation performed with hyperspherical harmonics approach with Argonne V18 (AV18) + Urbana IX (UIX) potentials
- **Good agreement with the data**

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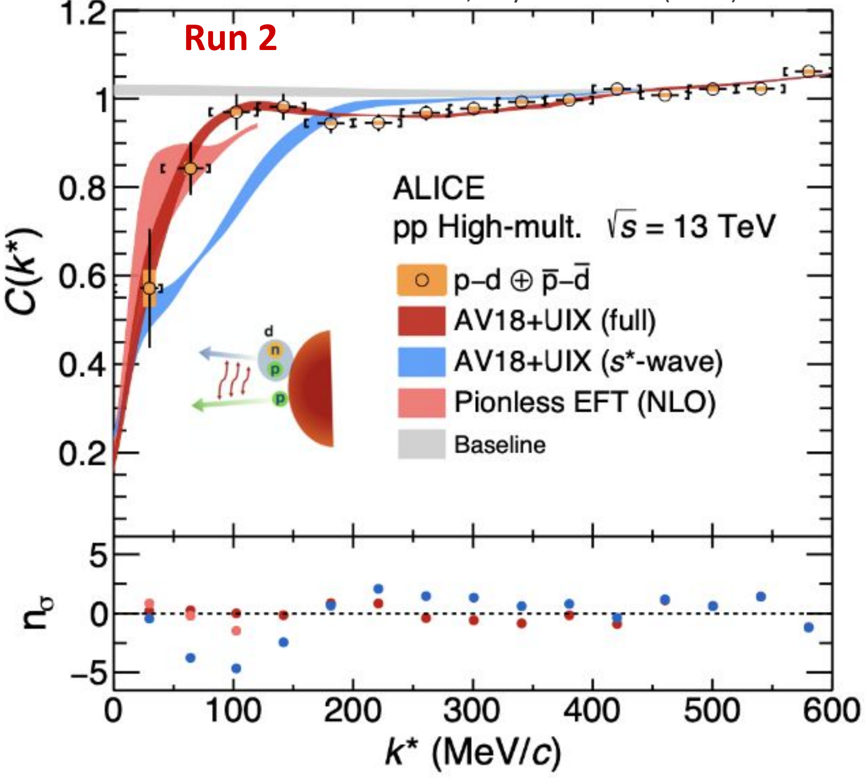

Proton-deuteron correlation

- Ratio of correlation function with and without three-body force
  - Up to 5% effect from three-body interaction
  - No sensitivity in Run 2 due to limited statistics
  - Only probe one radius with one m_T bin

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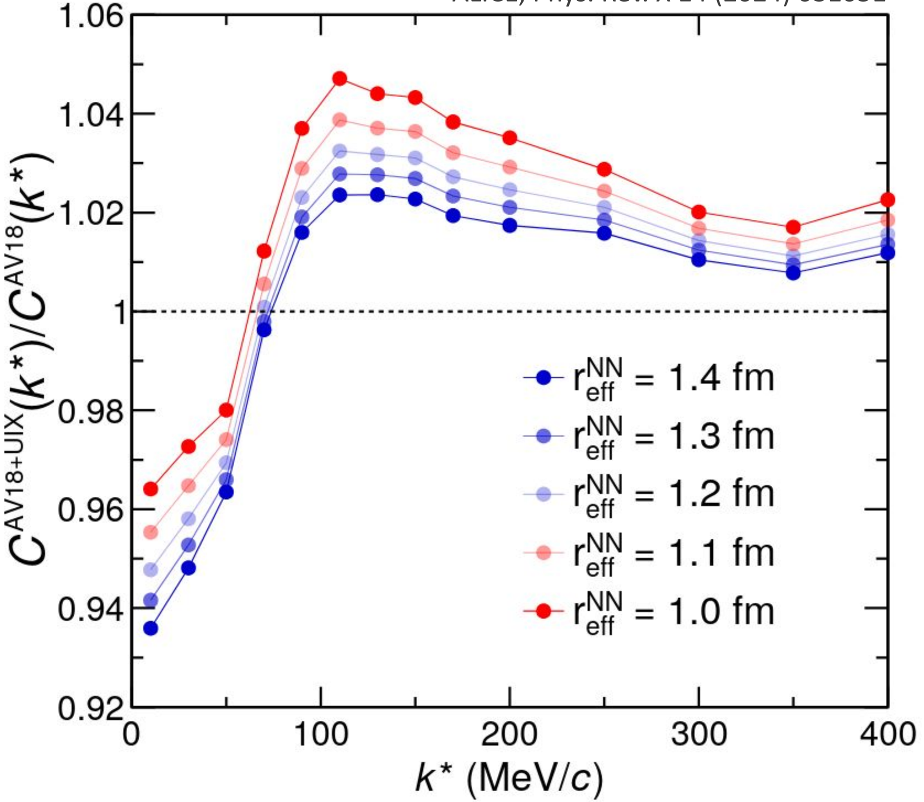

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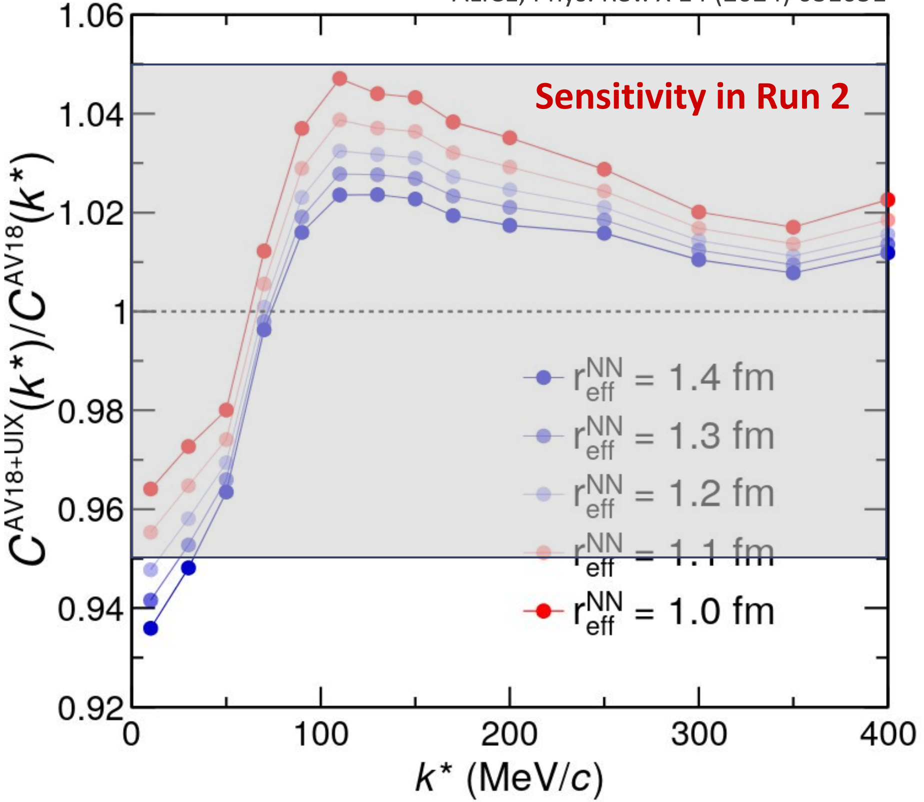

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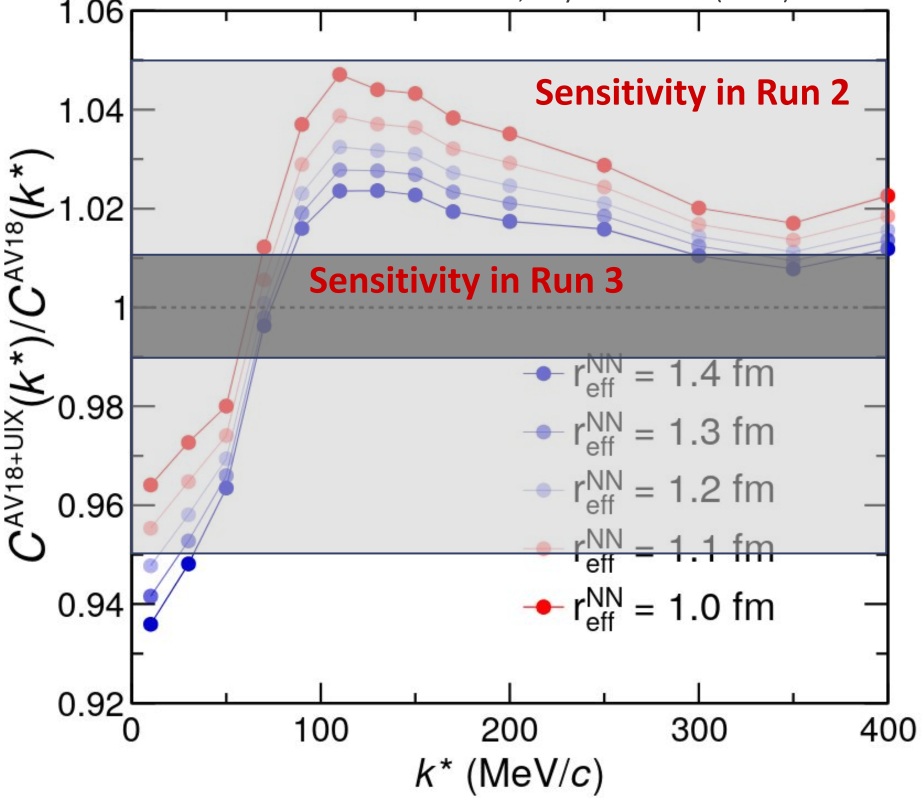

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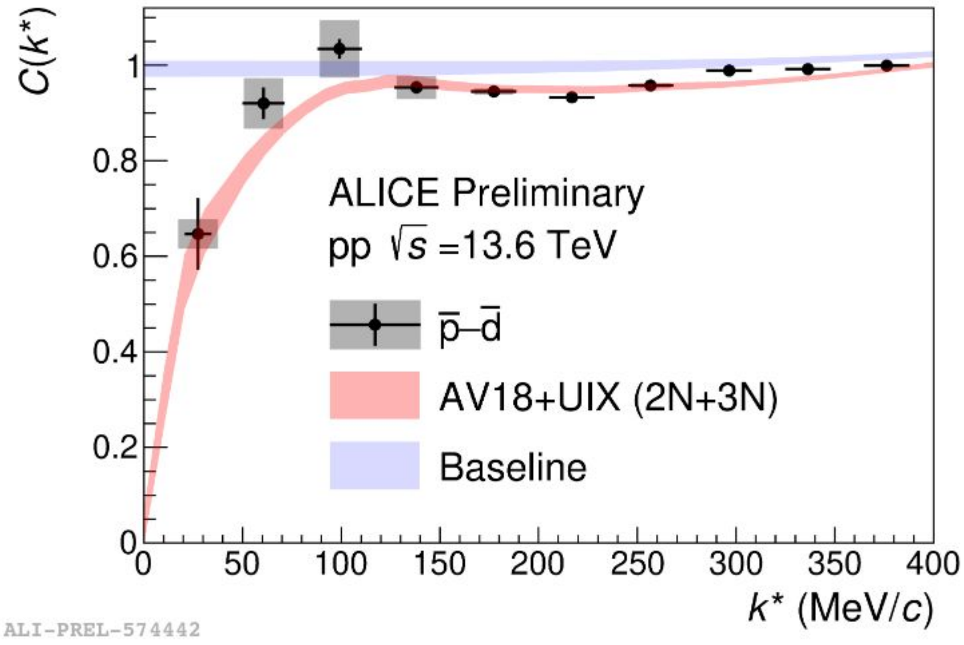
  - Only probe one radius with one m_T bin
- **LHC Run 3!**
  - Preliminary result only using data from 2022 and antiparticle pairs already increased statistics ~5
  - Possibility to perform m_T differential analysis

New result with Run 3 data!



Summary and outlook

- K^+–d: pairs containing deuterons follow same m_T scaling observed for hadrons
- p–d:
  - System is sensitive to three-body dynamics
  - Resolve three-body effect with Run 3 statistics (increase statistics by ~30 compared to Run 2 by 2025)
  - Run 3 statistics will allow for m_T differential study

New result with Run 3 data!