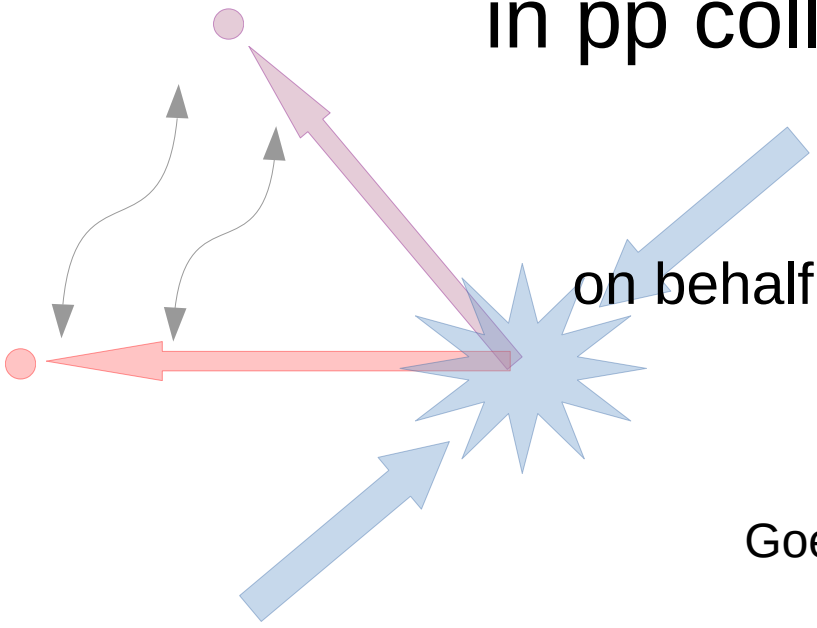
Measurement of proton-deuteron correlations in pp collisions at $\sqrt{s}$ = 13 TeV



Michael Jung
on behalf of the ALICE Collaboration

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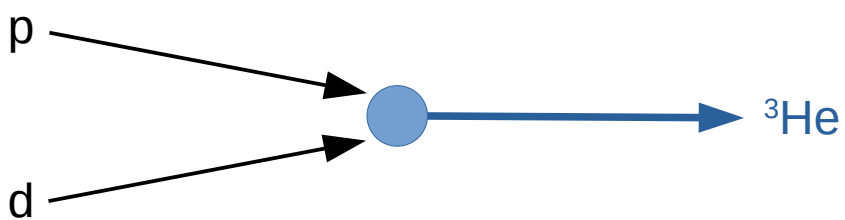
08th of September 2021

Physics motivation

- The proton-deuteron interaction is well known from scattering experiments
- Production mechanism of light nuclei is not yet clear

  → Statistical Hadronisation Model
  abundances from statistical equilibrium at the common freeze-out temperature

  → Coalesence Model
  particles close in phase space (overlapping nuclear wave-functions) can form a nucleus



- Correlations of p-d

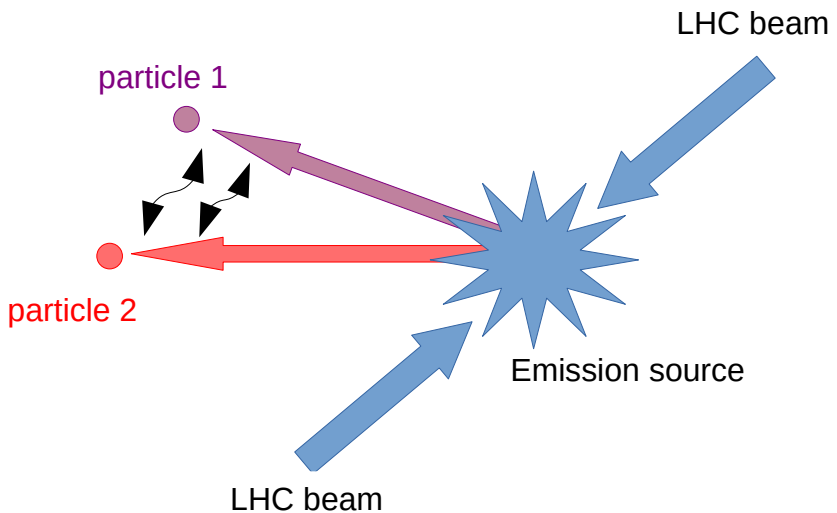
  → can be used as a probe for the formation time of the deuteron

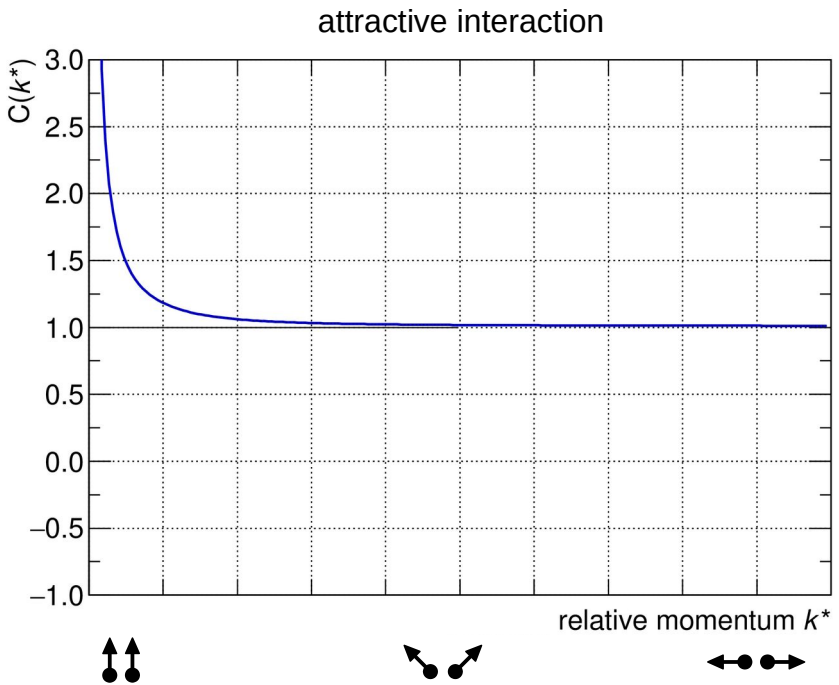
Two-particle correlations

- Correlation function as a function of the relative momentum: $k^* = \frac{1}{2} \cdot |\vec{p}_1 - \vec{p}_2|$
- Use the two-particle wave functions and the source geometry (study interaction)

$$C(k^*) = \int S(\vec{r}) \cdot |\Psi(\vec{k}^*, \vec{r})|^2 d^3\vec{r} = N \cdot \frac{SE}{ME} > 1$$

theoretical definition — experimental definition





Mihaylov et al. *European Physical Journal C*, 78:394 (2018)

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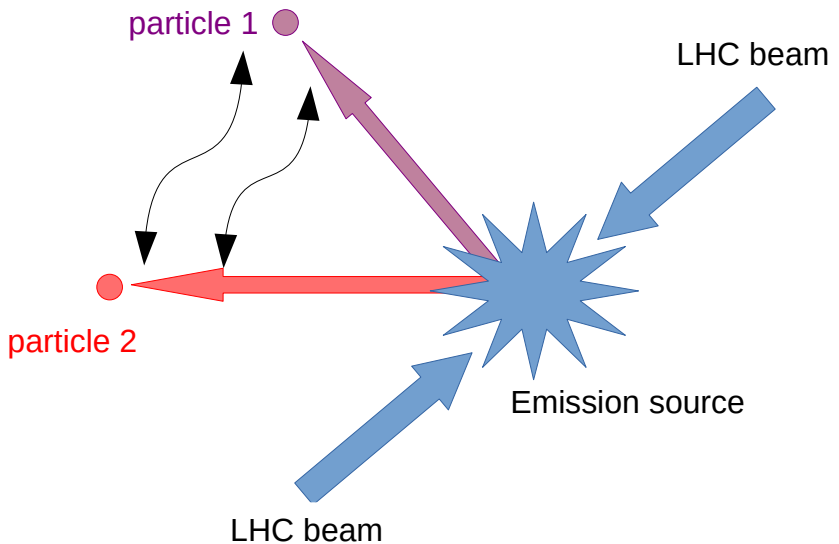

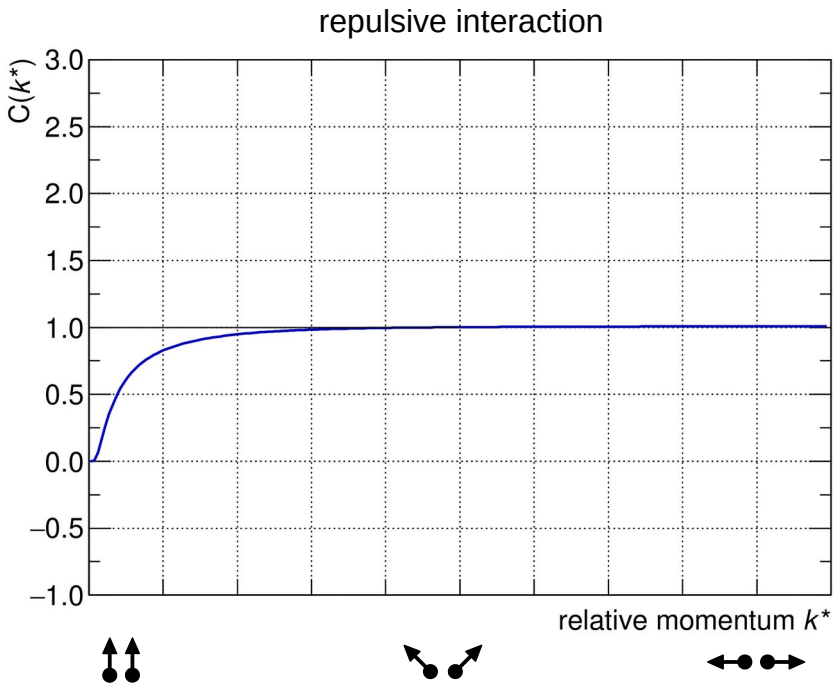

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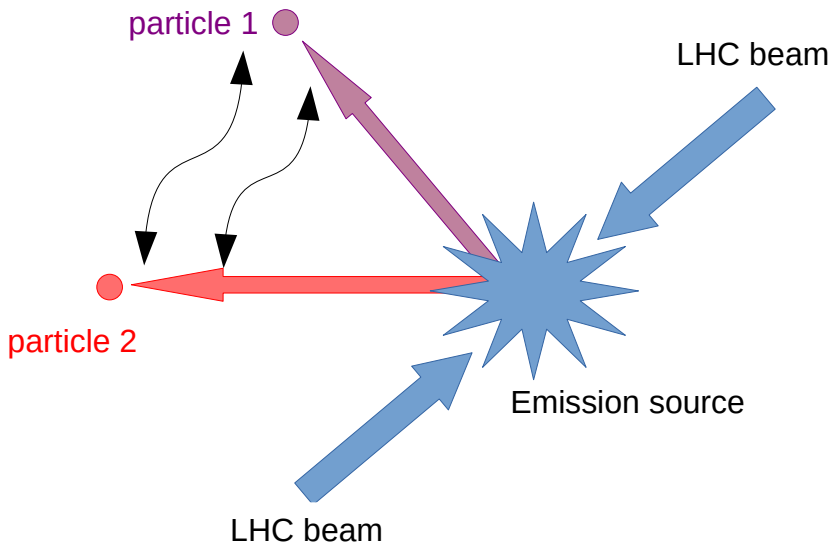
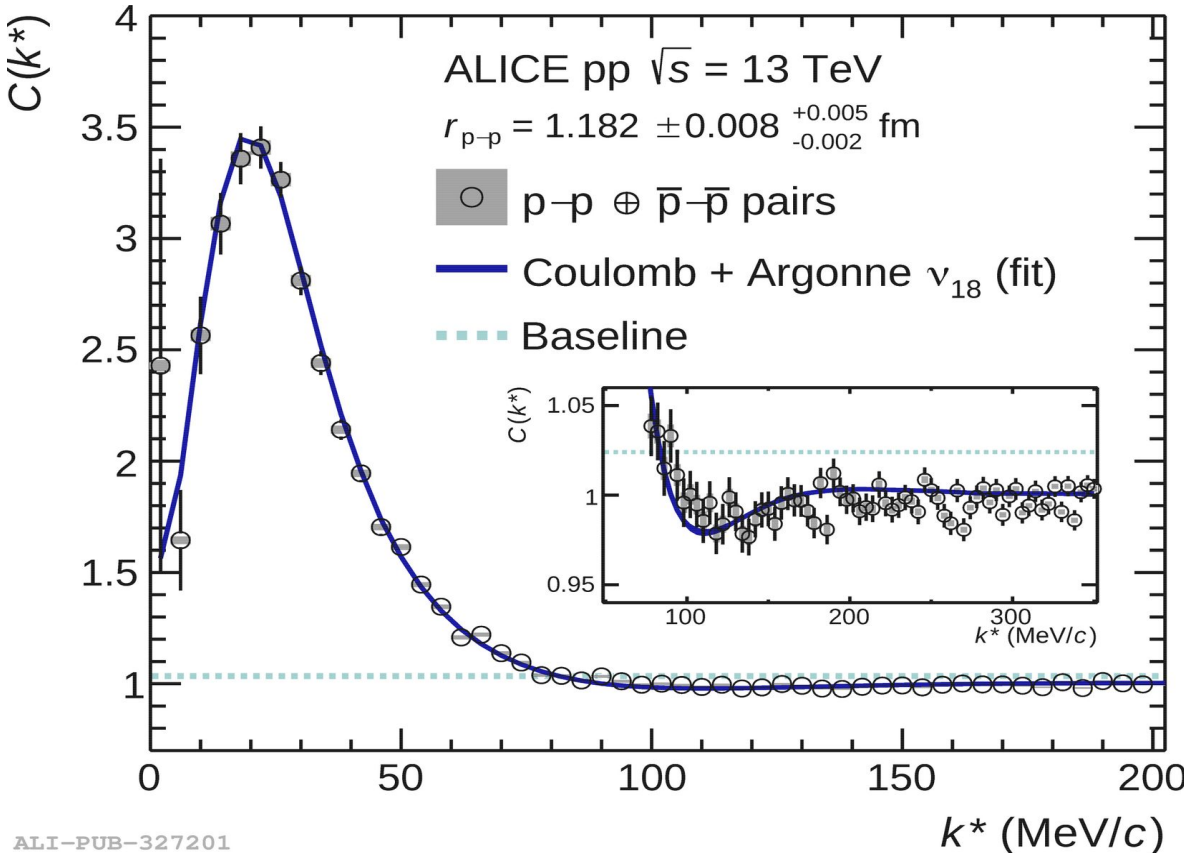


Development of femtoscopy in nuclear physics

	known	study	example
1.	FSI	source	p-p
2.	source	FSI	Λ-Λ
3.	FSI & source	production mechanism	p-d

Measurement of p-p correlation

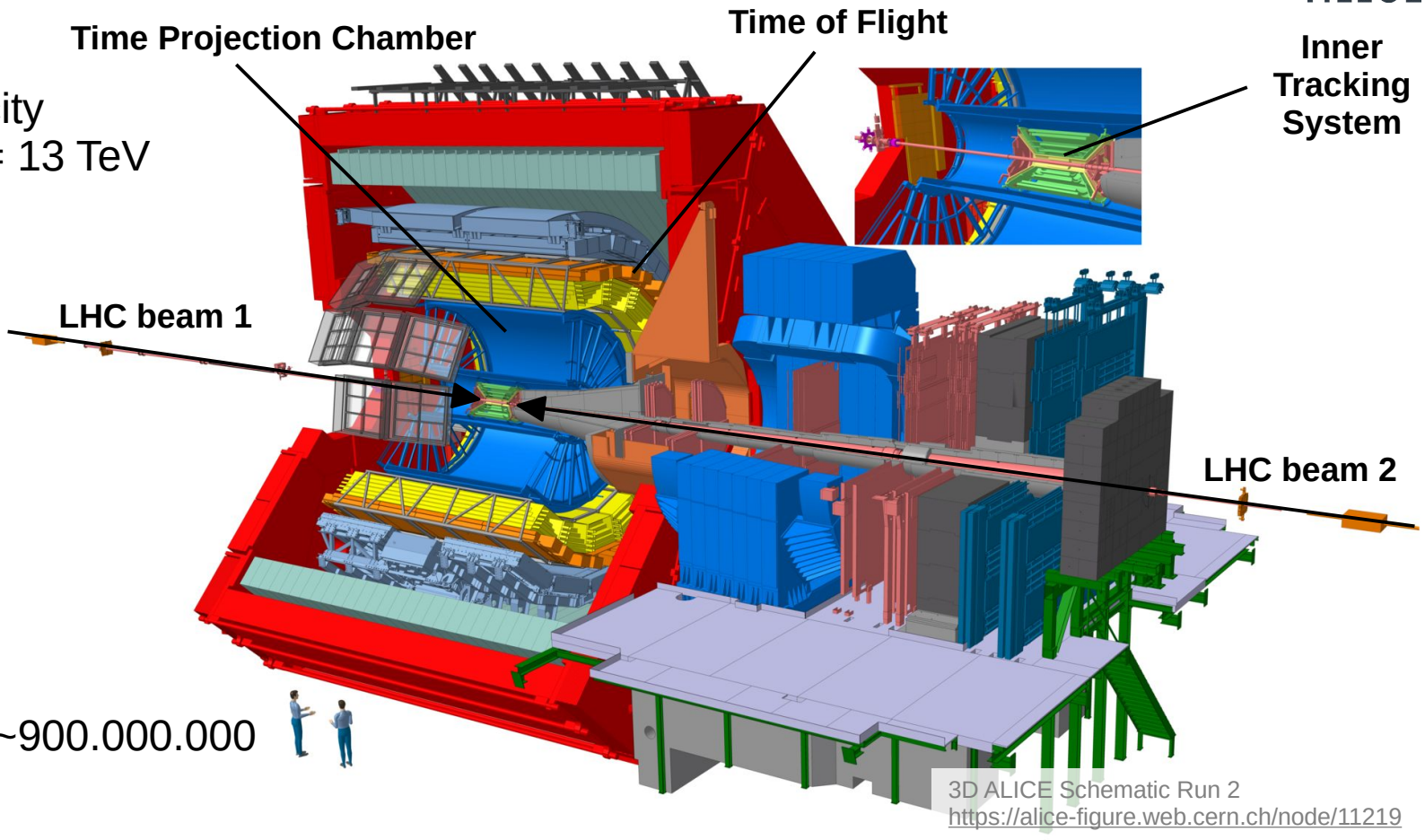
- proton-proton correlation perfectly understood
- Taken into account:
  - Coulomb interaction
  - Strong interaction
  - Anti-symmetric wave-functions
- Calculation in good agreement
- Source size can be extracted



ALICE Collaboration. Physics Letters B, 797:134822 (2019)

The experiment: ALICE

- Using high-multiplicity pp collisions at √s = 13 TeV



- Number of events: ~900.000.000

3D ALICE Schematic Run 2
https://alice-figure.web.cern.ch/node/11219

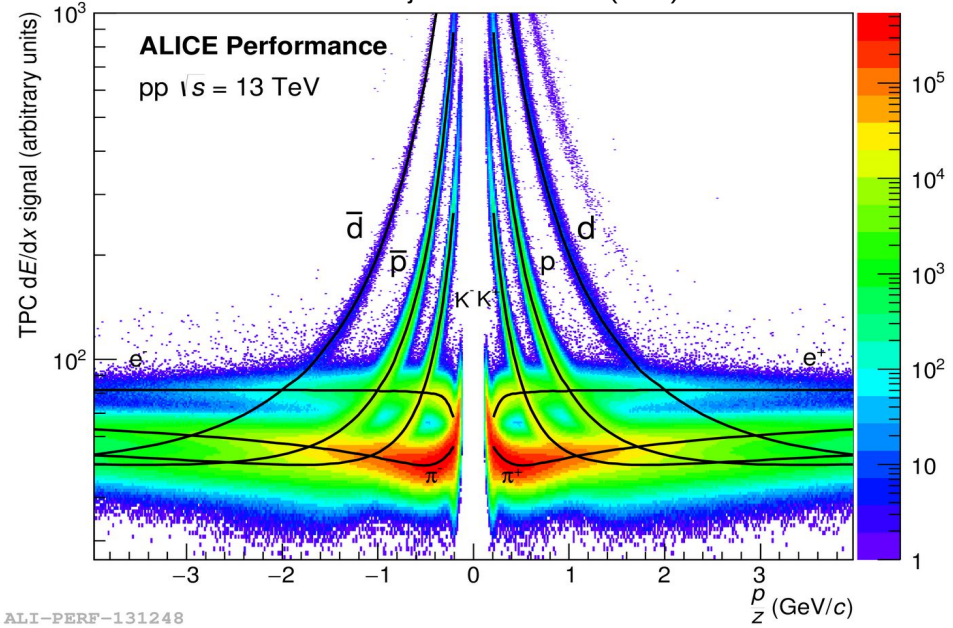
Particle Identification

- The Time Projection Chamber and the Time of Flight are used to identify protons and deuterons

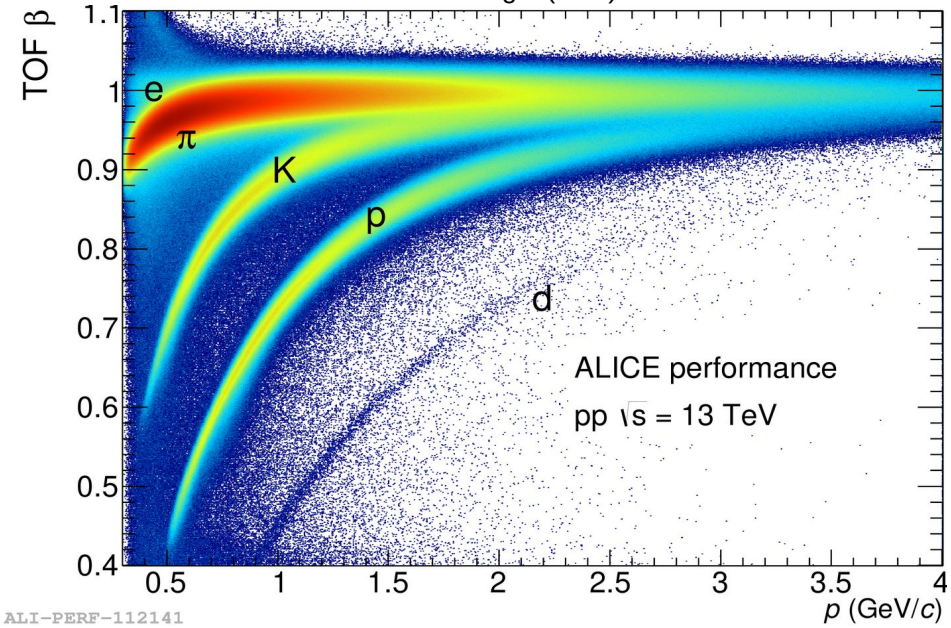
- p_T of protons: 0.5 GeV/c < p_T < 4.05 GeV/c (purity: ~98%)
- p_T of deuterons: 0.5 GeV/c < p_T < 1.40 GeV/c (purity: ~100%)

particle	abundancy
p	~500.000.000
$\bar{p}$	~450.000.000
d	~450.000
$\bar{d}$	~350.000

Time Projection Chamber (TPC)

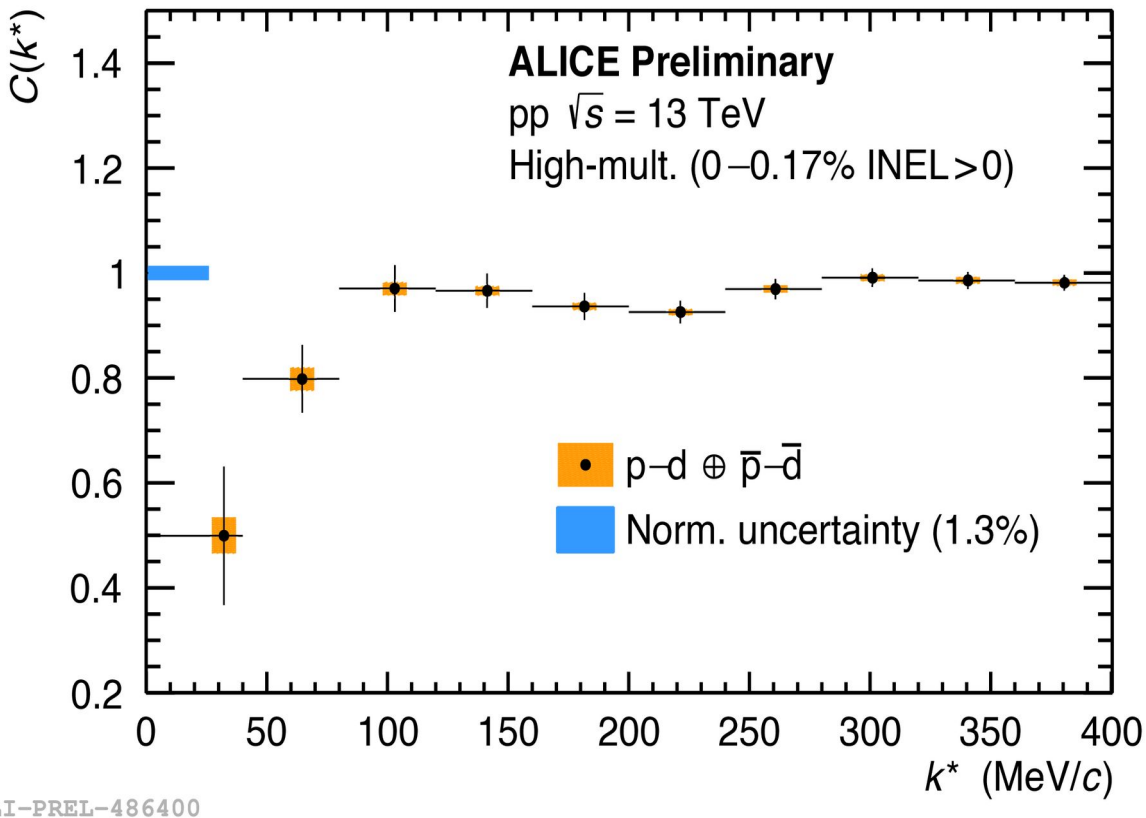


Time of Flight (TOF)



Experimental correlation function

- Combined p-d and $\bar{p}$-$\bar{d}$ correlations
- Statistics below k^* = 200 MeV/c
  - $\bar{p}$-d pairs: 1747
  - p-$\bar{d}$ pairs: 1250
- Blue box around 1: uncertainty due to normalization procedure
- The correlation shows a significant depletion at low k^*



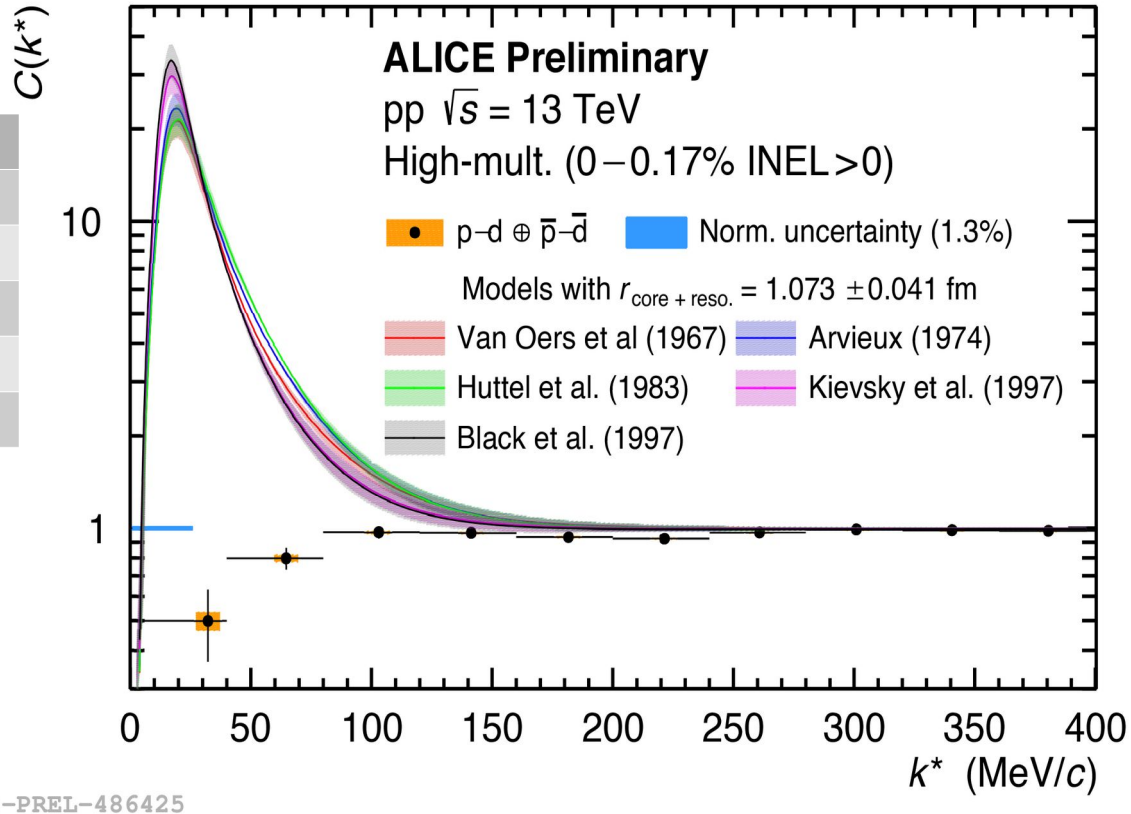
Theoretical p-d correlation

- Calculated correlation function using a Coulomb-corrected wave-function for charged particles Lednický, R. Phys. Part. Nuclei 40, 307-352 (2009)

- Use measured scattering lengths:

	doublet $^2S_{1/2}$	quartet $^4S_{3/2}$
Van Oers et al. (1967)	$1.30^{+0.2}_{-0.2}$ fm	$11.40^{+1.8}_{-1.2}$ fm
Arvieux (1974)	$2.73^{+0.1}_{-0.1}$ fm	$11.88^{+0.4}_{-0.1}$ fm
Huttel et al. (1983)	4.0 fm	11.3 fm
Kievsky et al. (1997)	0.024 fm	13.8 fm
Black et al. (1999)	$-0.13^{+0.04}_{-0.04}$ fm	$14.70^{+2.3}_{-2.3}$ fm

Van Oers, Brockman. *Nuclear Physics, A* 92:561-583 (1967)
Arvieux. *Nuclear Physics A,* 221:253-268 (1973)
Huttel et al. *Nuclear Physics A,* 406:443-455 (1983)
Kievsky et al. *Physics Letters B,* 406:292-296 (1997)
Black et al. *Physics Letters B,* 471:103-107 (1999)

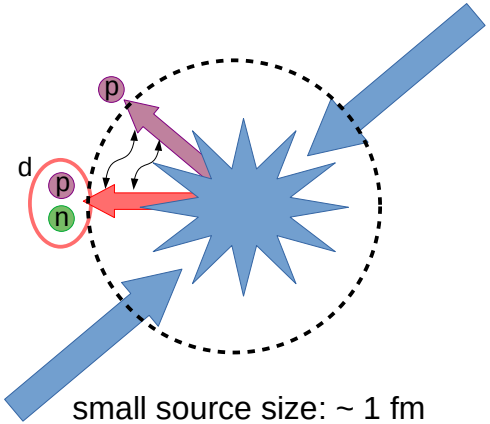


- The calculated correlation differs dramatically from the measurement

Late formation of the deuteron

Case 1: Proton and Deuteron are formed at the same time

→ The p-d correlation should reflect the strong interaction



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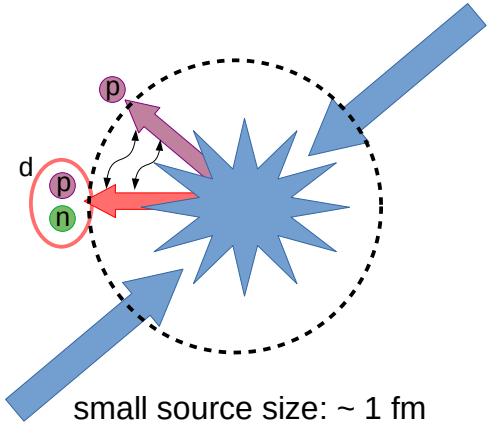
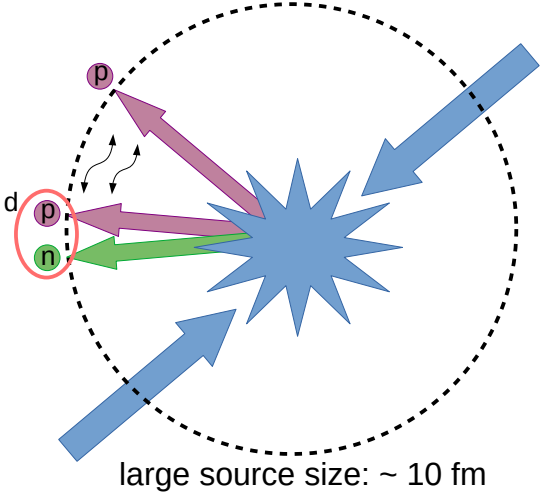


Case 2: Deuteron is formed late

→ The interaction between the particles weakens

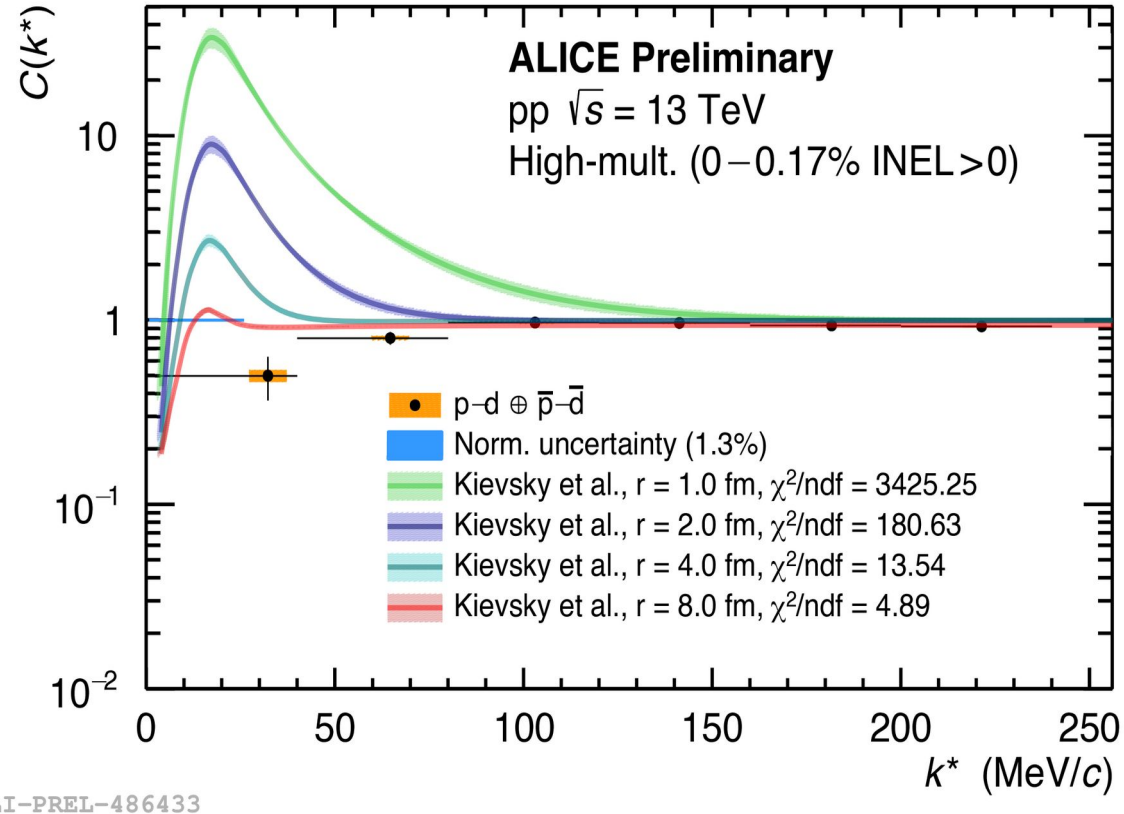


Different source radii

- Theoretical radius scan using the Kievsky parameters

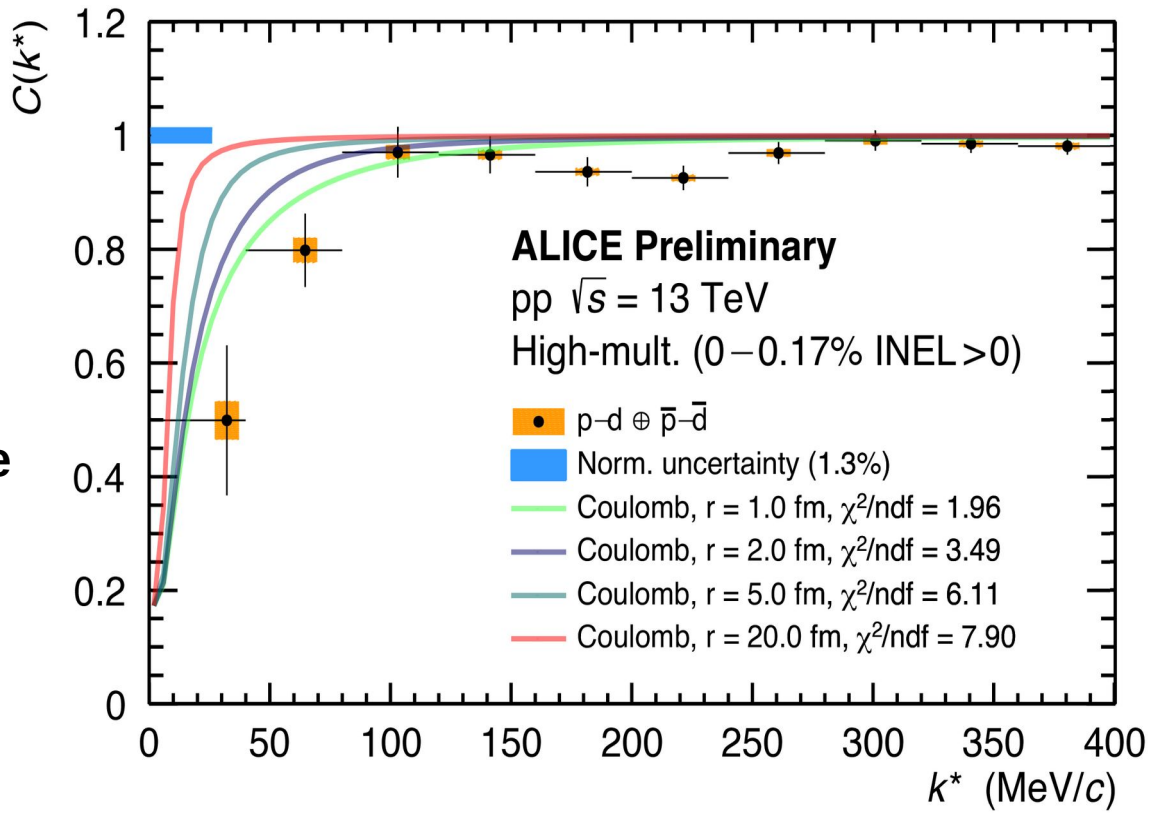
Kievsky et al. *Physics Letters B*, 406:292-296 (1997)

- Measurement and calculation get closer with increasing radius
- There is still a discrepancy between data and calculation in the first bin
- This could be a hint for coalesence of ^{3}He



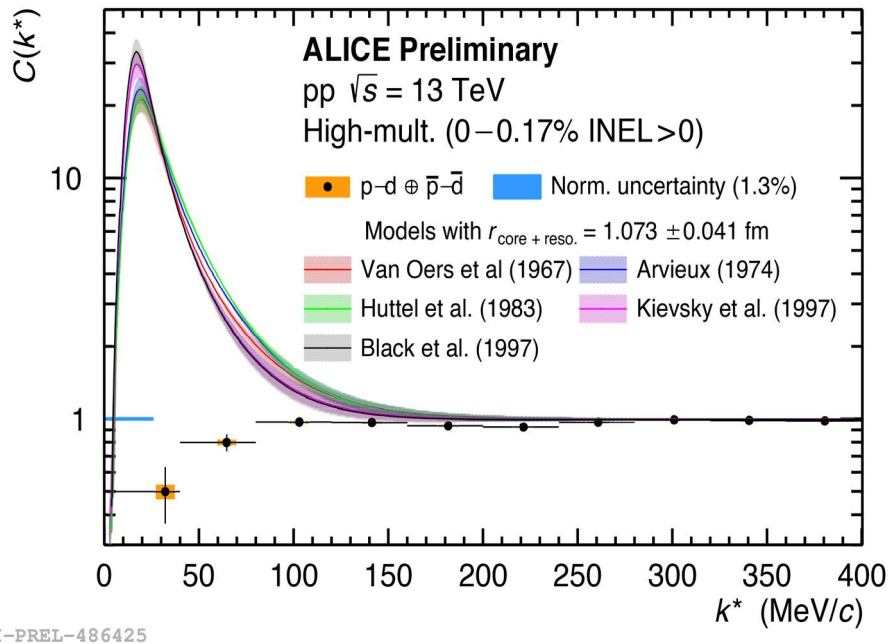
Increasing the source radius further

- Going to larger distances allows to neglect the strong interaction
- Calculations using a Coulomb-only interaction
- With increasing radius the correlation function tends towards 1
- A late formation of the deuteron **alone** cannot cause a depletion of the CF



Summary and Outlook

- Summary
  - Measurement of p-d correlation in high-multiplicity pp collisions at √s = 13 TeV
  - Measured correlation function and calculation are not in agreement
- Interpretation
  - Late formation time of the deuteron
  - Hint for coalescence of ^{3}He
- Outlook:
  - More precise data with Run 3



Thank you for your attention