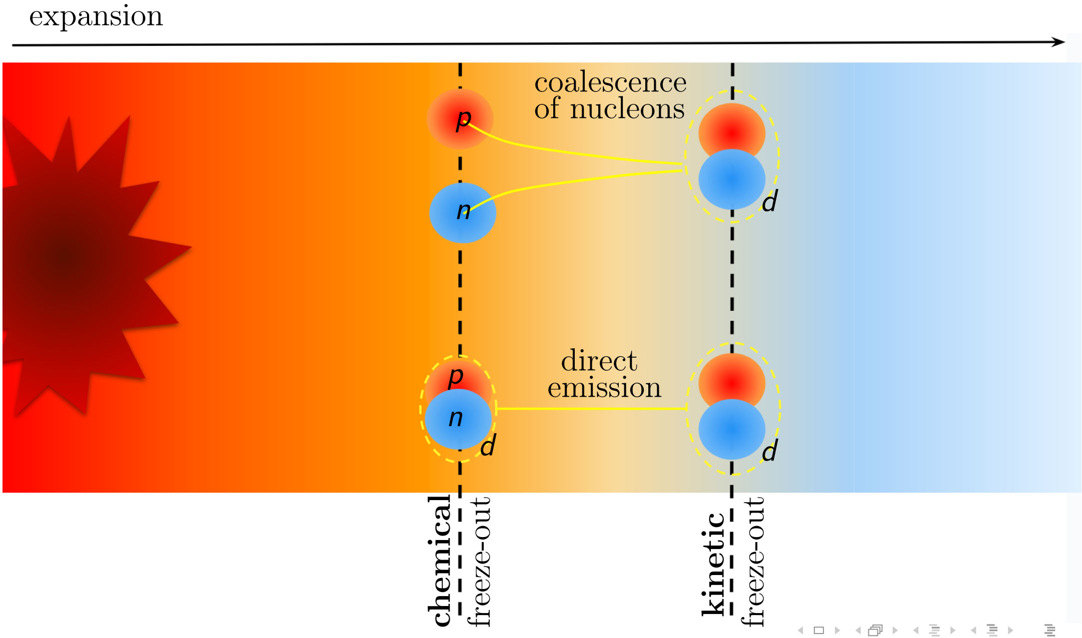
Modeling proton–deuteron interactions for the femtoscopic correlation method using exact calculations of two-body dynamic

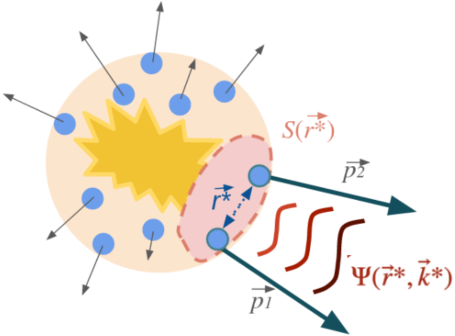
Speaker: Wioleta Rzęsa (Warsaw University of Technology)

HIN 2025 – Kyoto

Motivation – production of deuterons



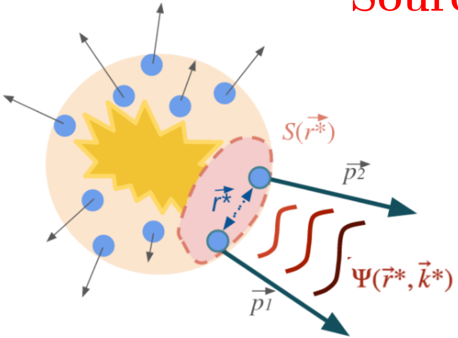
Femtoscopy



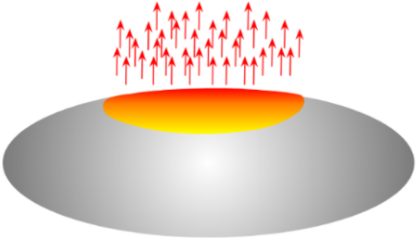
$$C(k^*) = \int S(r^*)|\Psi(k^*, r^*)|^2 d^3 r$$

Femtoscopy

Source function



$$S(r^*) \sim e^{-\frac{r^{*2}}{4R^2}}$$



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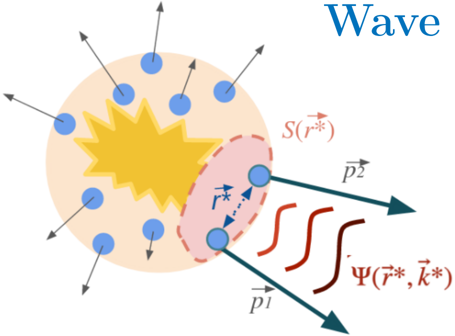
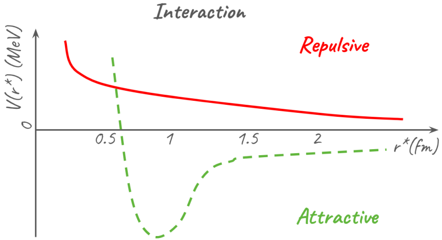
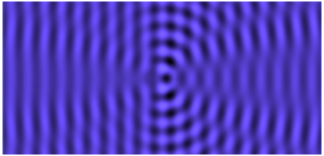
Femtoscopy



Wave function





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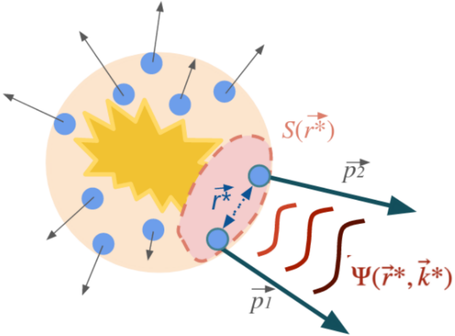

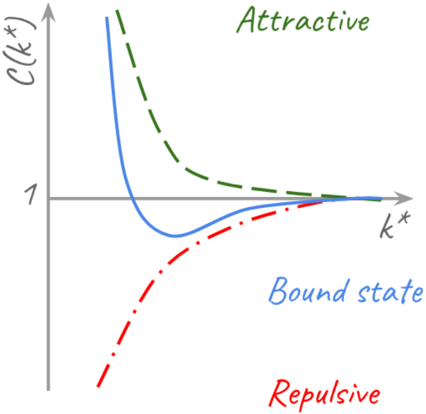

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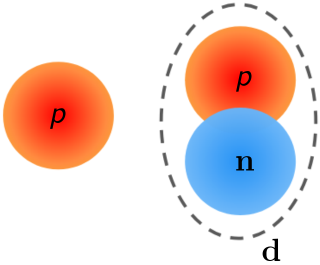
But what is the dynamics of the interaction?



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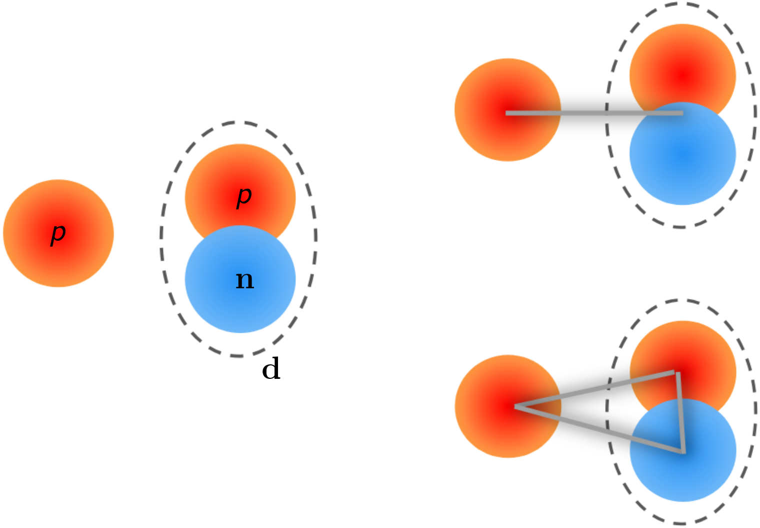
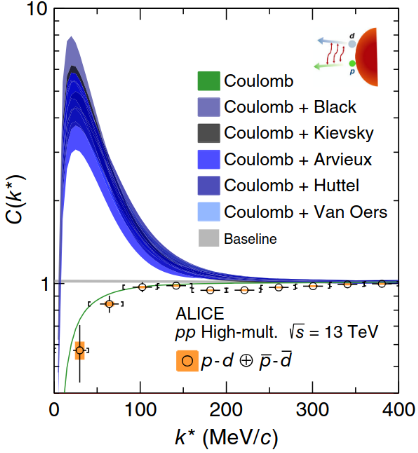


two-body system?

three-body system?

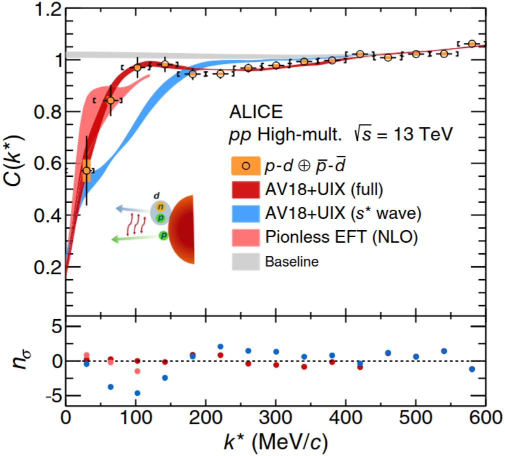
Measurements in small systems

Two-body (s-waves only)



Failed

Three-body (s,p,d-waves)



Perfect agreement

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

Lednický-Lyuboshitz model

$C(k^*) = \int S(r^*)|\Psi(k^*, r^*)|^2 d^3 r$

$S(\mathrm{r}^*) \sim exp\left(-\frac{r^{*2}}{4R^2}\right)$ ⟵ **Gaussian 1D parameterisation**

$|\psi(r^*, k^*)| = \sqrt{A_C(\eta)}\left[exp(-ik^* r^*)F(-i\eta, 1, i\xi) + f_c(k^*)\frac{G}{r^*}\right]$ ⟵ **Coulomb + strong**

$$f_c(k^*) = \left(\frac{1}{f_0} + \frac{d_0 \cdot k^{*2}}{2} - \frac{-2h(k^* a_c)}{a_c} - ik^* A_C(k^*)\right)^{-1},$$ [ref]

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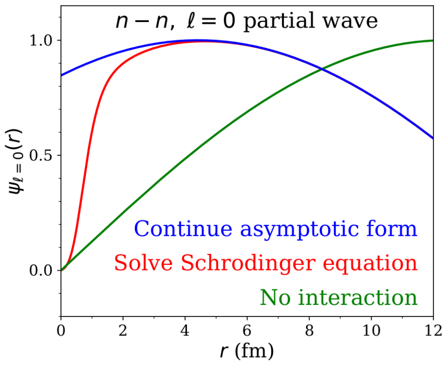
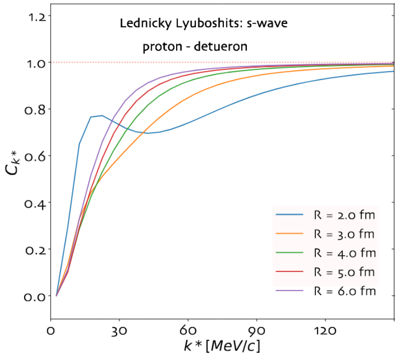
$f_c(k^*) = \left(\frac{1}{f_0} + \frac{d_0 \cdot k^{*2}}{2} - \frac{-2h(k^* a_c)}{s_c} - ik^* A_C(k^*)\right)^{-1}$, [ref]

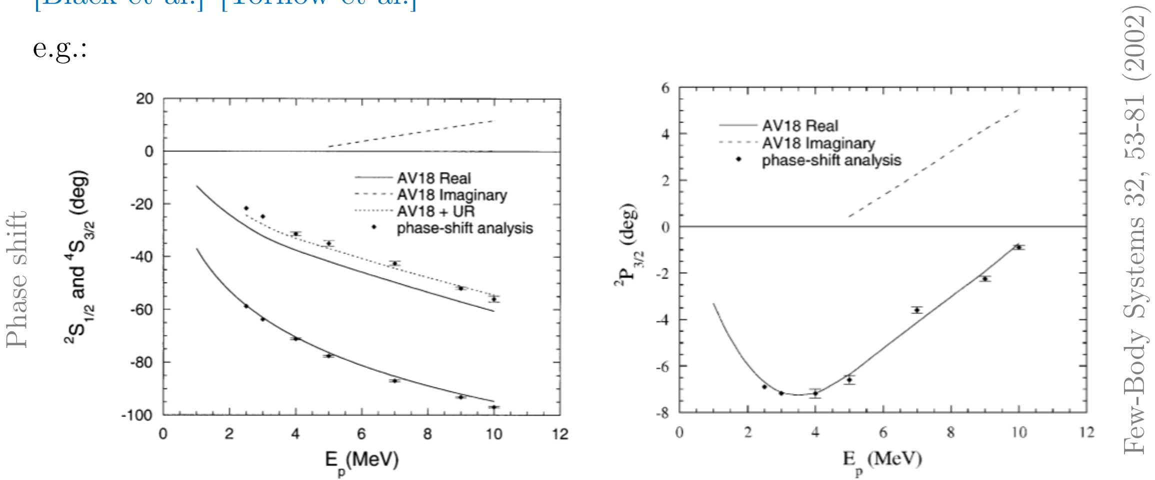




Exact solution

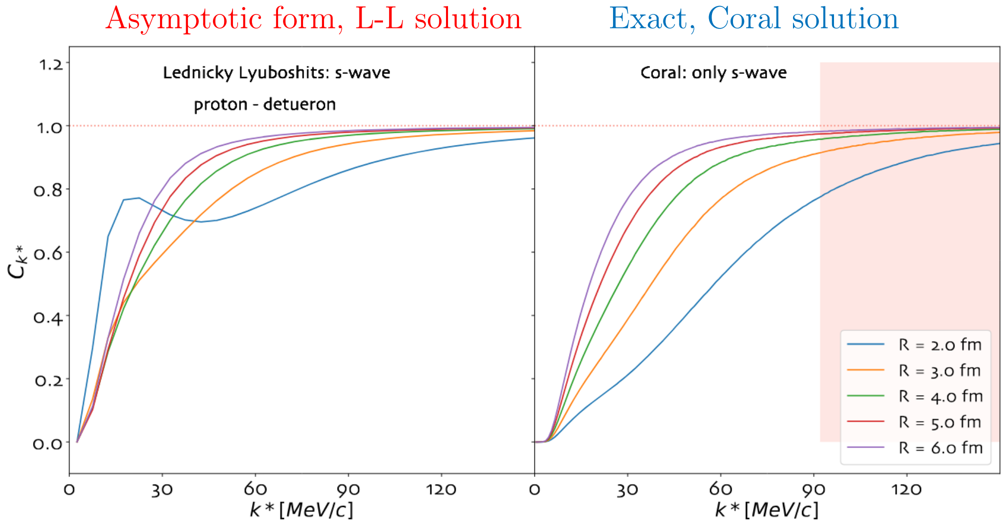
Schrödinger based solutions of the wave function calculated in the [CorAL] package with potentials derived from experimentally measured phase shifts:
[Black et al.] [Tornow et al.]

e.g.:



Exact solution – s-waves

No peak-structure ∼25 MeV/c in the solution for s-waves



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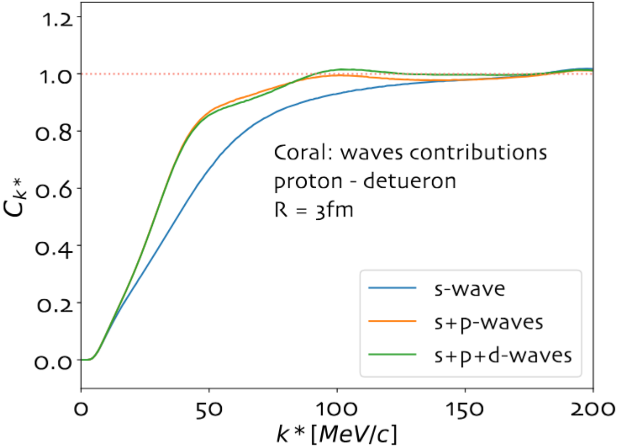
Exact solution – higher-order partial waves

Two-body (s,p,d-waves)



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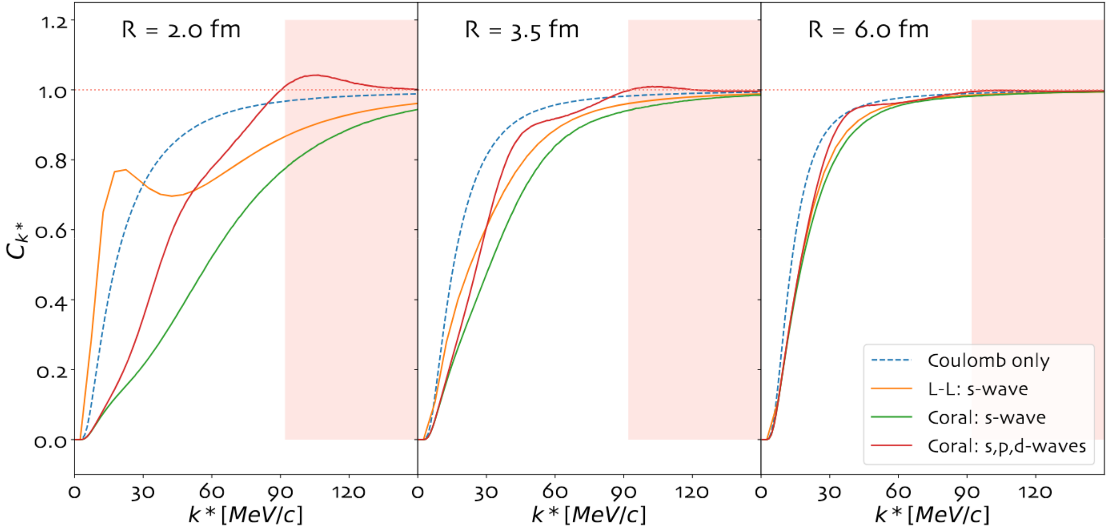
Higher-order partial waves reduce the repulsiveness of the interaction.

Exact solution – different emission source sizes

The differences between exact and approximate solutions diminish for R∼3.5 fm



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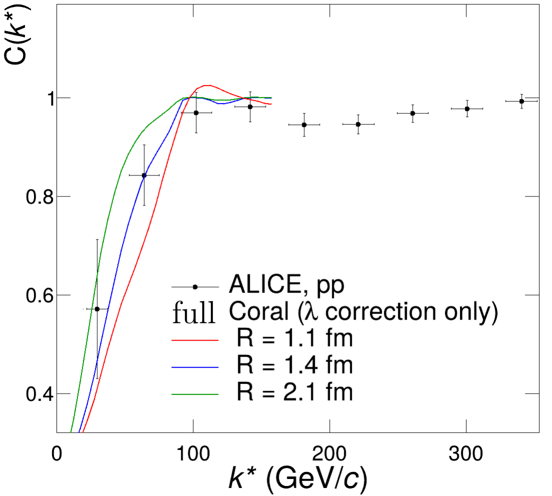
Two-body, exact solution + experimental data



Good agreement!

Conclusions

- The proton-deuteron correlation in small systems should be described using the exact solution of the wave function while employing the two-body method.
- Approximate and exact solutions converge in big femtoscopic sources.


THANK YOU!