Femtoscopic measurement of proton source in pp collisions at $\sqrt{s}$ = 900 GeV with ALICE

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The coalescence model for deuteron

The formation mechanism for deuterons in high-energy collisions is still not well understood, but it can be constrained by using the LHC data.

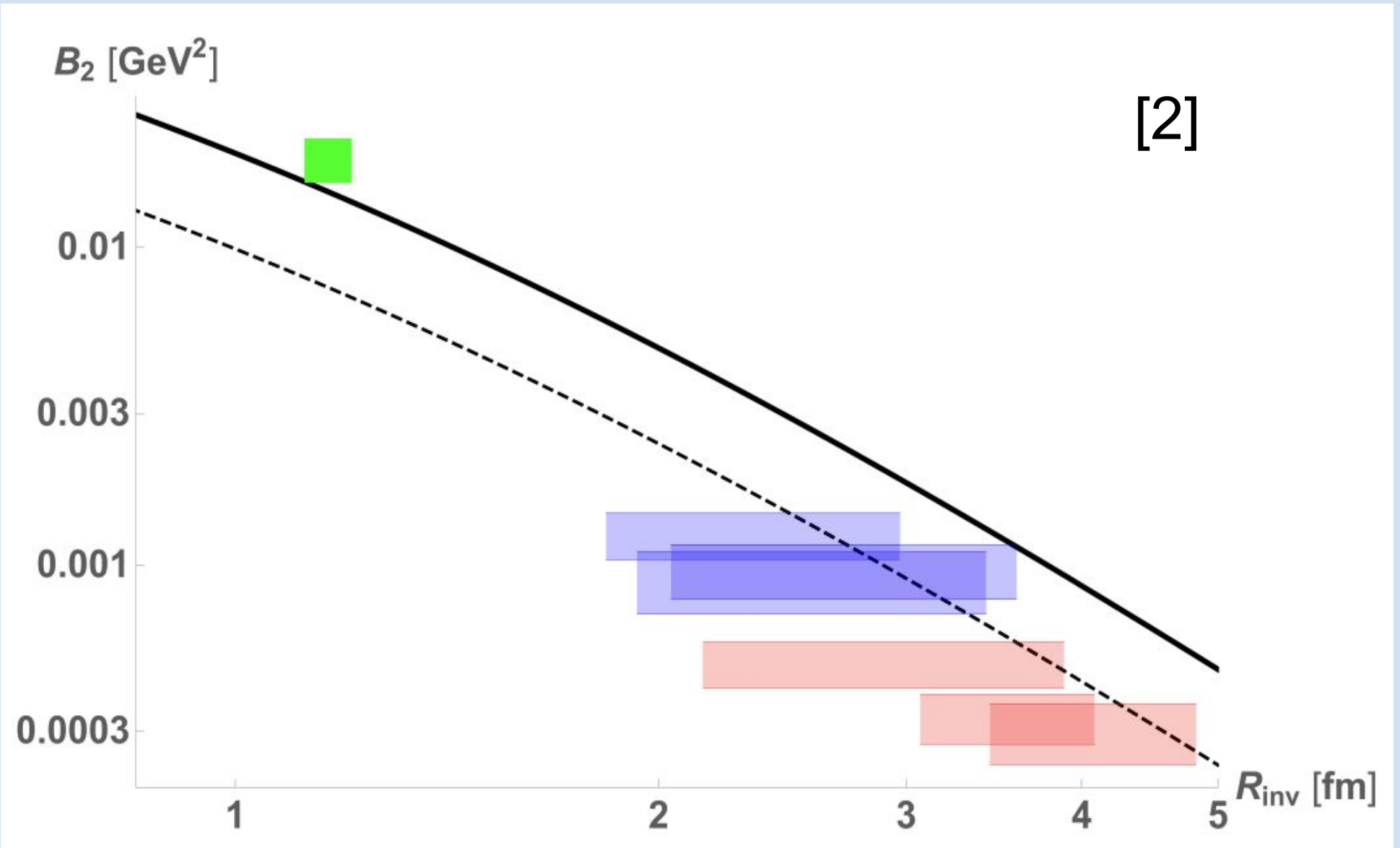
In the coalescence model, nucleons close in phase space at the freeze-out can bind to form a nucleus with probability **$B_A(p)$.**

For deuteron[1] :

$$B_2(p) \approx \frac{2(2s_d+1)}{m(2s_N+1)^2}(2\pi)^3 \int d^3\boldsymbol{r}\,|\,\psi_d(\boldsymbol{r})|^2 S_2(\boldsymbol{r})$$

- **S_2(r)**: distribution of relative distances of nucleons in the particle emitting source.
- **ψ_d(r)**: nucleus internal wave function.
- **s_d** and **s_N**: deuteron and nucleon spins.

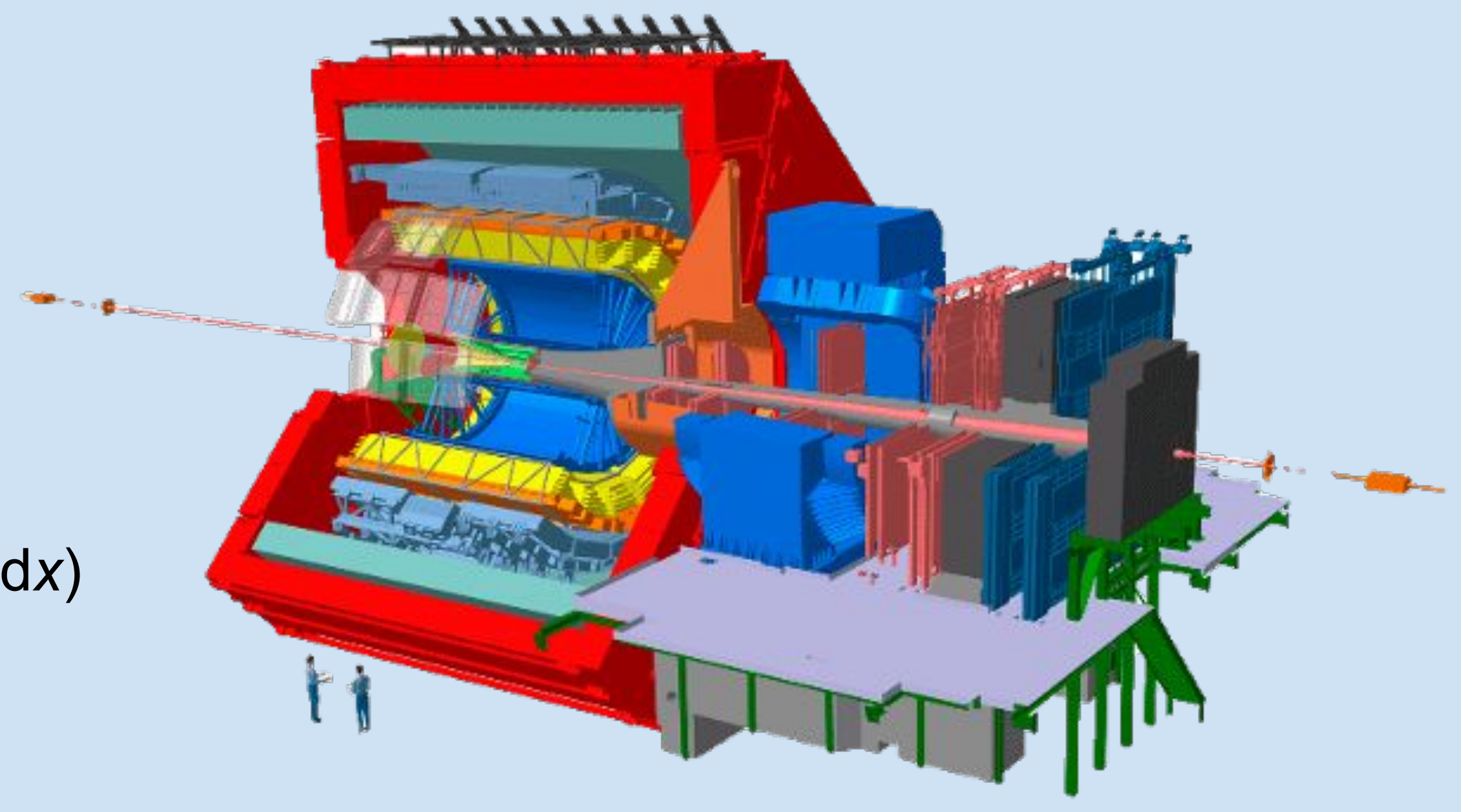
→ proton source size can be used as an **input parameter for the coalescence modelling.**



The ALICE detector for LHC Run 3

ALICE[4] has optimal characteristics for femtoscopic analysis:

- Optimal Particle Identification (PID) capabilities down to low momenta (≈ 150 MeV/*c*);
- Optimal track and vertex reconstruction;
- Mid-rapidity coverage ($|\eta|$ < 0.8).



Inner Tracking System (ITS)

- Tracking
- Vertex reconstruction

Time Projection Chamber (TPC)

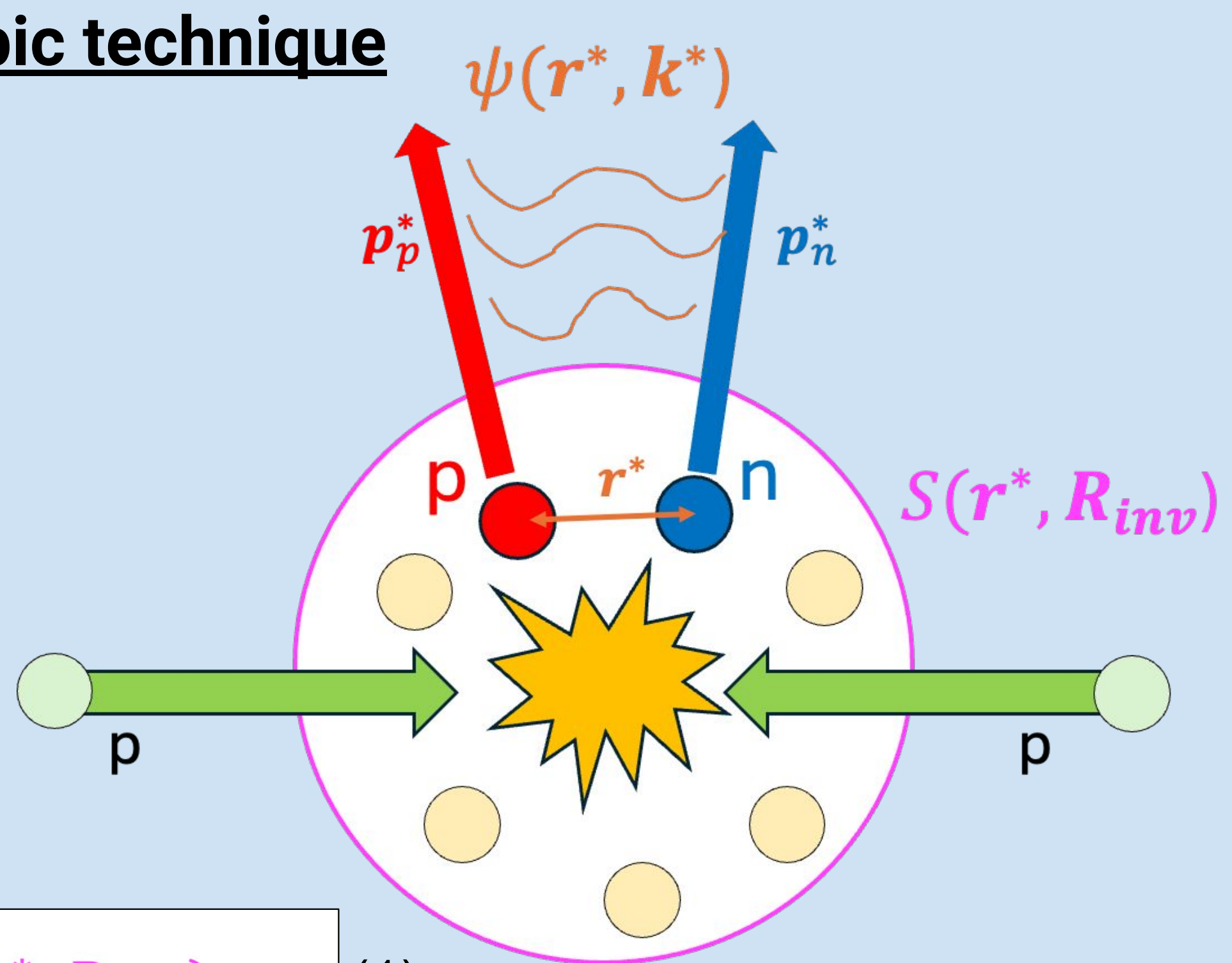
- Tracking
- PID by particle energy loss (d*E*/d*x*)

Time of Flight (TOF)

- PID by the time of flight ($\boldsymbol{\beta}$)

Run 3 integrated luminosity[5] at 900 GeV ≈ 2.7 nb^{-1} at few kHz of interaction rate.

The femtoscopic technique



Femtoscopic technique[3] is used to describe the particle-emitting source by measuring **correlations in momentum** among nucleon pairs.

Relative distance $\boldsymbol{r^* = r^*_p - r^*_n}$
Relative momentum $\boldsymbol{k^* = \frac{1}{2}\,|\,p^*_p - p^*_n\,|}$
in the pair rest frame.

$$C^{th}(\boldsymbol{k}^*) = \int d^3\boldsymbol{r}^*\,|\,\psi(\boldsymbol{r}^*,\boldsymbol{k}^*)|^2 S\,(\boldsymbol{r}^*, R_{inv}) \quad (1)$$

$$C^{exp}(\boldsymbol{k}^*) = N(\boldsymbol{k}^*)\frac{SE(\boldsymbol{k}^*)}{ME(\boldsymbol{k}^*)} = 1 - \lambda(C^{th}(\boldsymbol{k}^*) - 1) \quad (2)$$

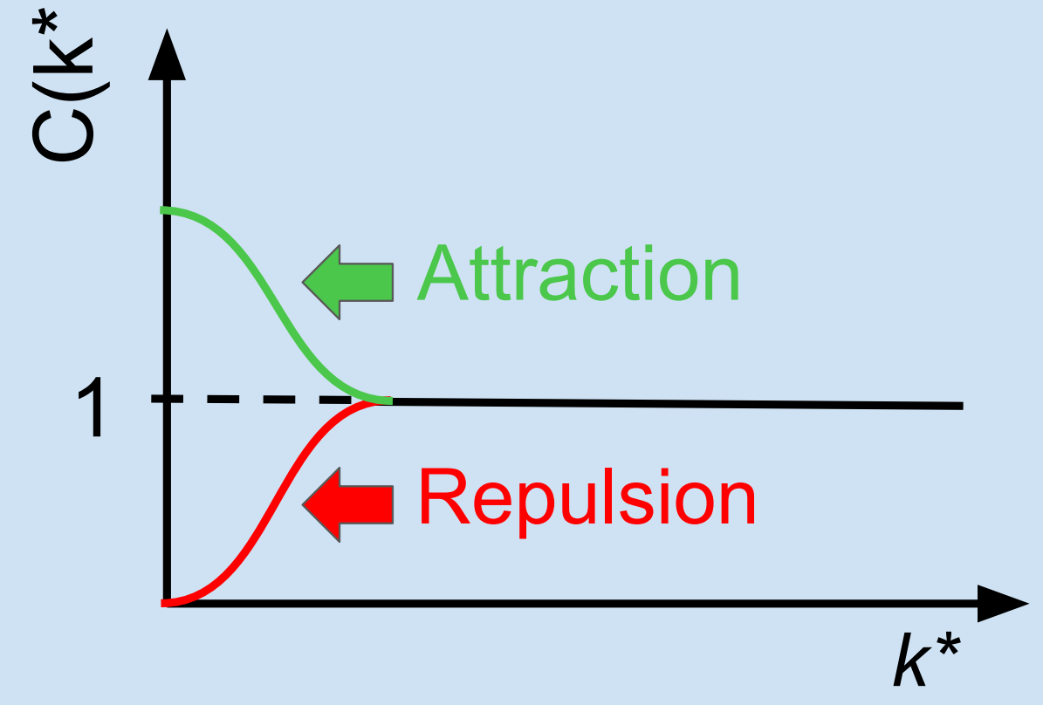
Pair wave function, $\psi(r^*, k^*)$:
→ Solution of the Schrödinger equation for a given **interaction potential** for a particle pair.

Source function, $S(r^*, R_{inv})$:
→ Considering a Gaussian source profile, the p.d.f. of finding two nucleons at a relative distance ***r**** distributed with standard deviation R_{inv}.

Experimental correlation function (CF) (eq. 2):

- ➔ ***SE***: same event correlations.
- ➔ ***ME***: mixed event correlations (background).
- ➔ ***N***: normalisation factor calculated outside of the femtoscopic signal region (>0.24 GeV/*c*).
- ➔ $\boldsymbol{\lambda}$: related to correlations from misidentified or non-primary proton pairs (non-genuine correlations).

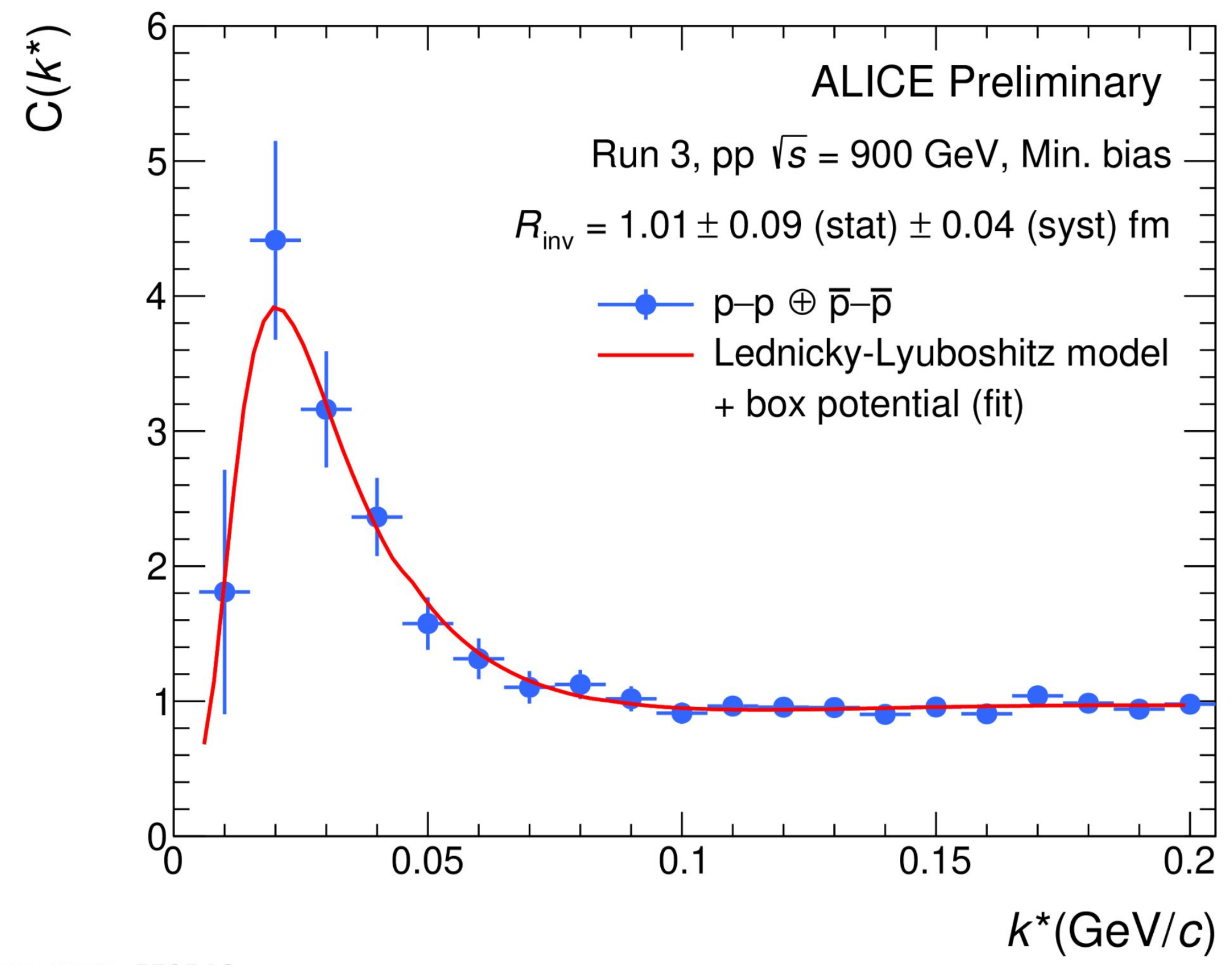
$$\begin{cases} < 1 & \text{if the interaction is repulsive} \\ = 1 & \text{if there is no correlation (for } \boldsymbol{k^*} \to +\infty) \\ > 1 & \text{if the interaction is attractive} \end{cases}$$



Proton source measurement in pp at $\sqrt{s}$ = 900 GeV

1. **First ever measurement at pp collisions at $\sqrt{s}$ = 900 GeV of the p–p correlation function.**
2. The total CF is the sum of p–p and (anti)p–(anti)p CFs.
3. The total CF is fitted with the **Lednický-Lyuboshitz model** [6, 7] **with a box potential approach.**
4. The **source size R_{inv}** and the **λ parameter** are **free fit parameters.**
5. The obtained λ parameter represents the fraction of genuine CF. It is consistent with the value estimated by multiplying the pair particle purity and primary fraction from the Monte Carlo simulations within the statistical uncertainties.

$$R_{inv} = 1.01 \pm 0.09 \pm 0.04 \text{ fm}$$
$$\lambda = 0.78 \pm 0.11 \pm 0.05$$



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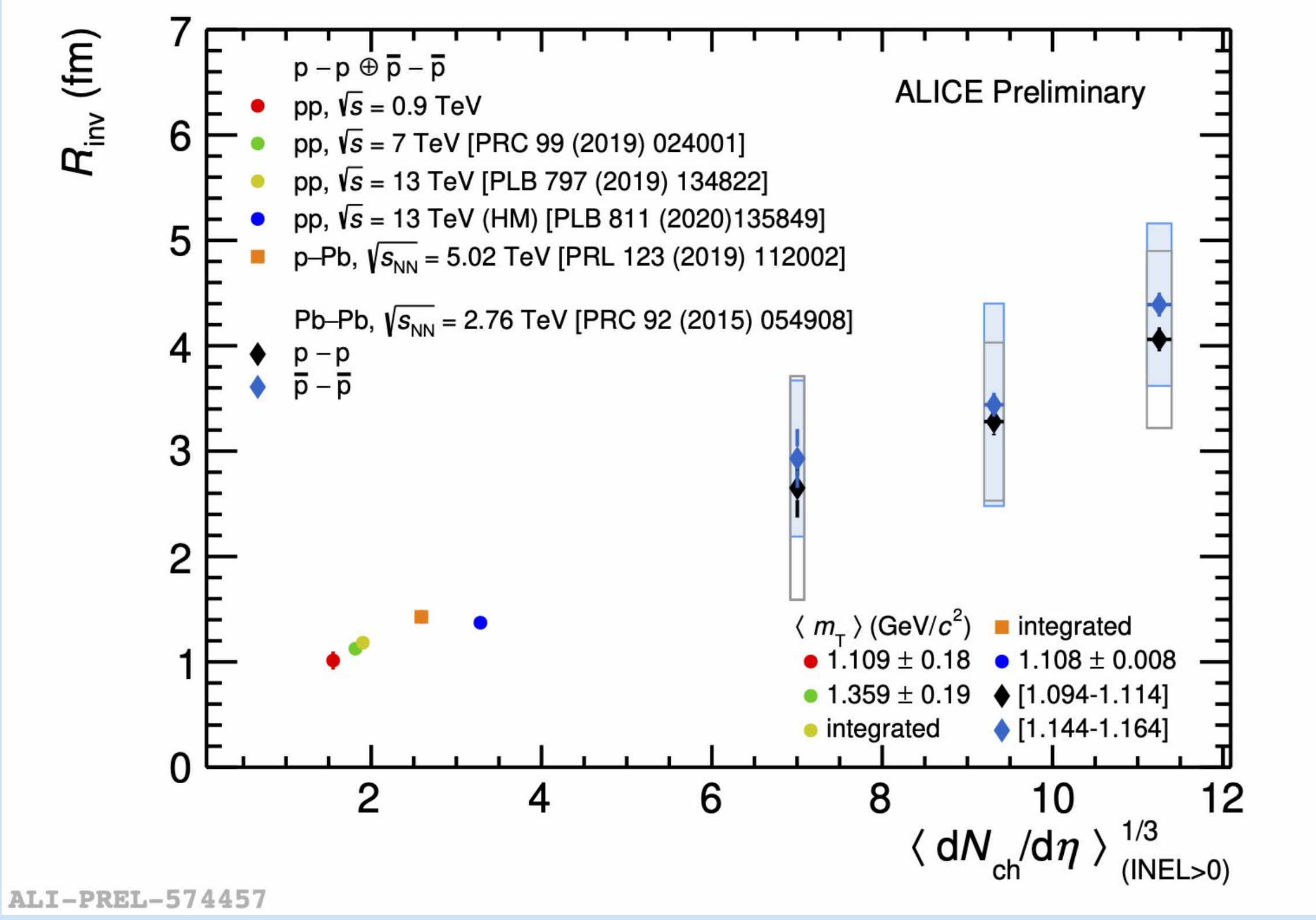
Comparison to published results in pp, p–Pb and Pb–Pb collisions with similar pair transverse mass $\langle m_T \rangle$:
→ **Smallest source** in pp collisions at $\sqrt{s}$ = 900 GeV.
→ **A clear charged-particle multiplicity scaling is observed.**



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Future perspectives

- Use the **measured proton source size** for the coalescence modelling to **estimate deuteron coalescence probability**.
- Study the $\langle m_T \rangle$ dependence of the proton source size.

References

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[7] Lednický, R., Phys.Part.Nucl. 40 (2009) 307-352

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