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

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The coalescence model for deuteron

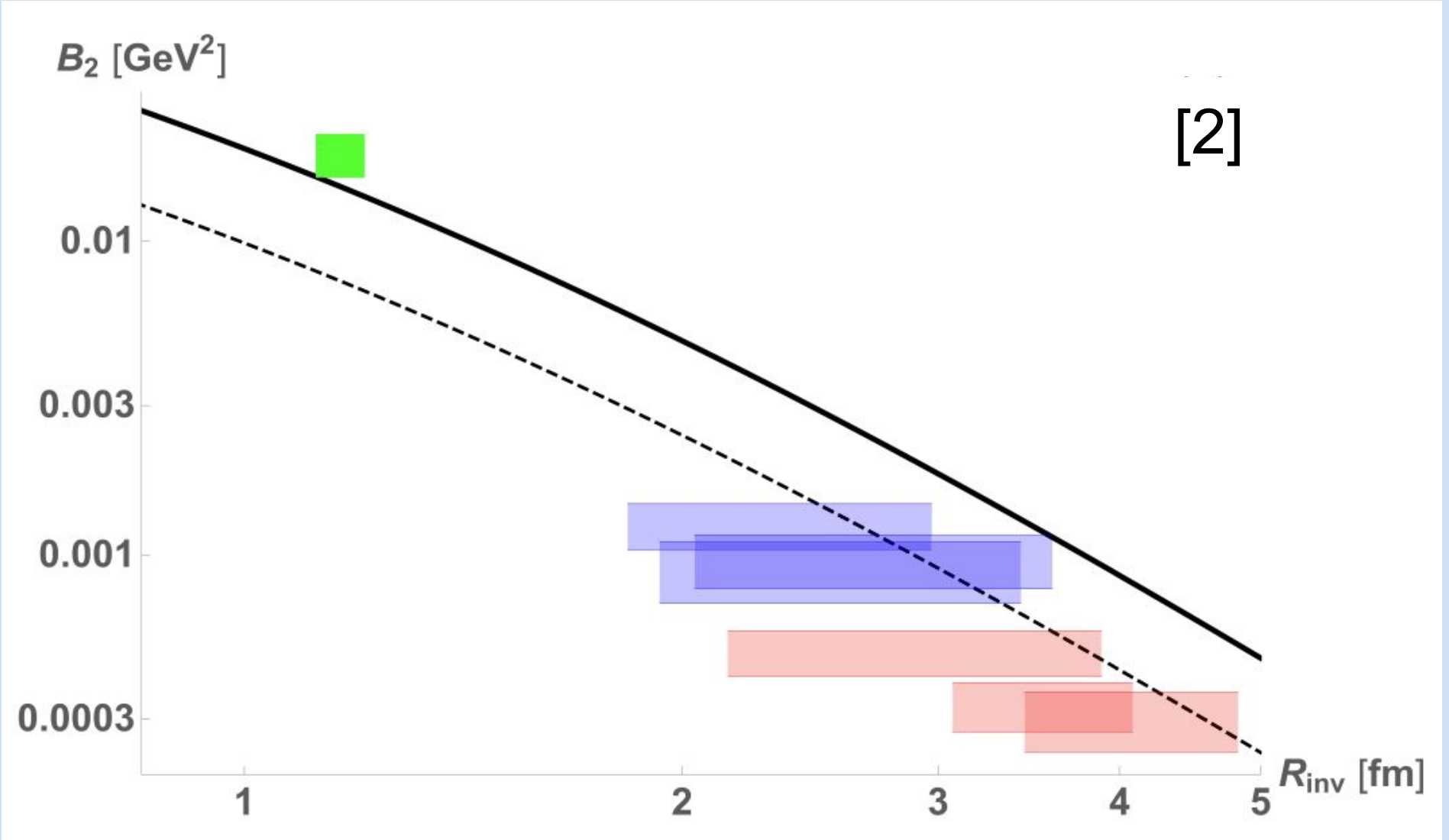
The formation mechanism for deuterons in high-energy collisions is still not well understood, but it can be constrained by using the LHC data.

In the coalescence model, nucleons closed in phase space at the freeze-out can bind to form a nucleus. **The coalescence probability of forming a deuteron**[1] is:

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

The coalescence probability is related to:
→ the distribution of relative distances of nucleons in the **particle emitting source S_2(r)**.
→ the **nucleus internal wave function** ψ_d(r*)
→ **deuteron and nucleon spins** (s_d and s_N)

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



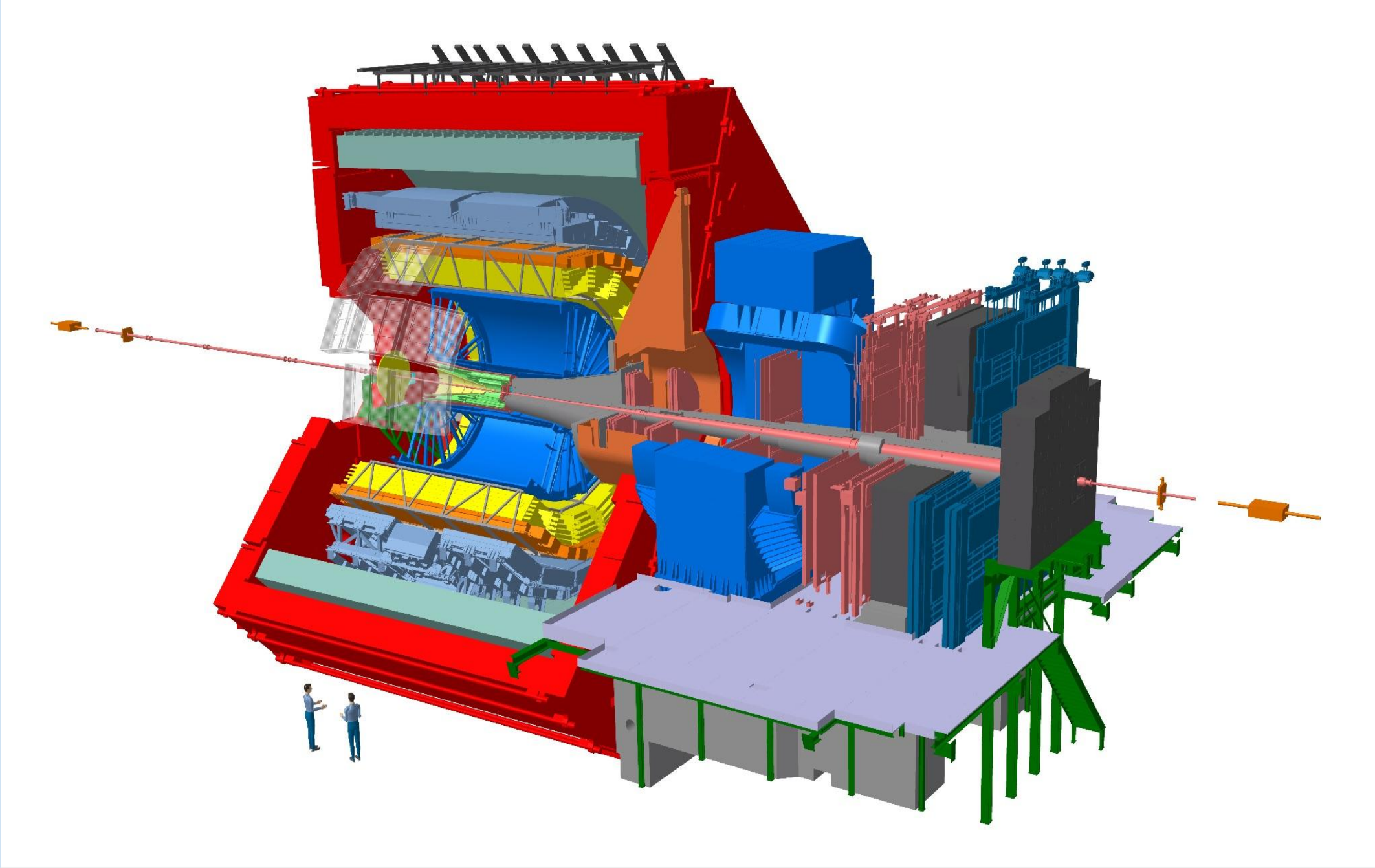
The ALICE detector for LHC Run 3

A Large **I**on **C**ollider **E**xperiment[4] has the excellent characteristics for femtoscopic correlation 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*/dx)

Time of Flight (TOF)
- PID by the time of flight (β)



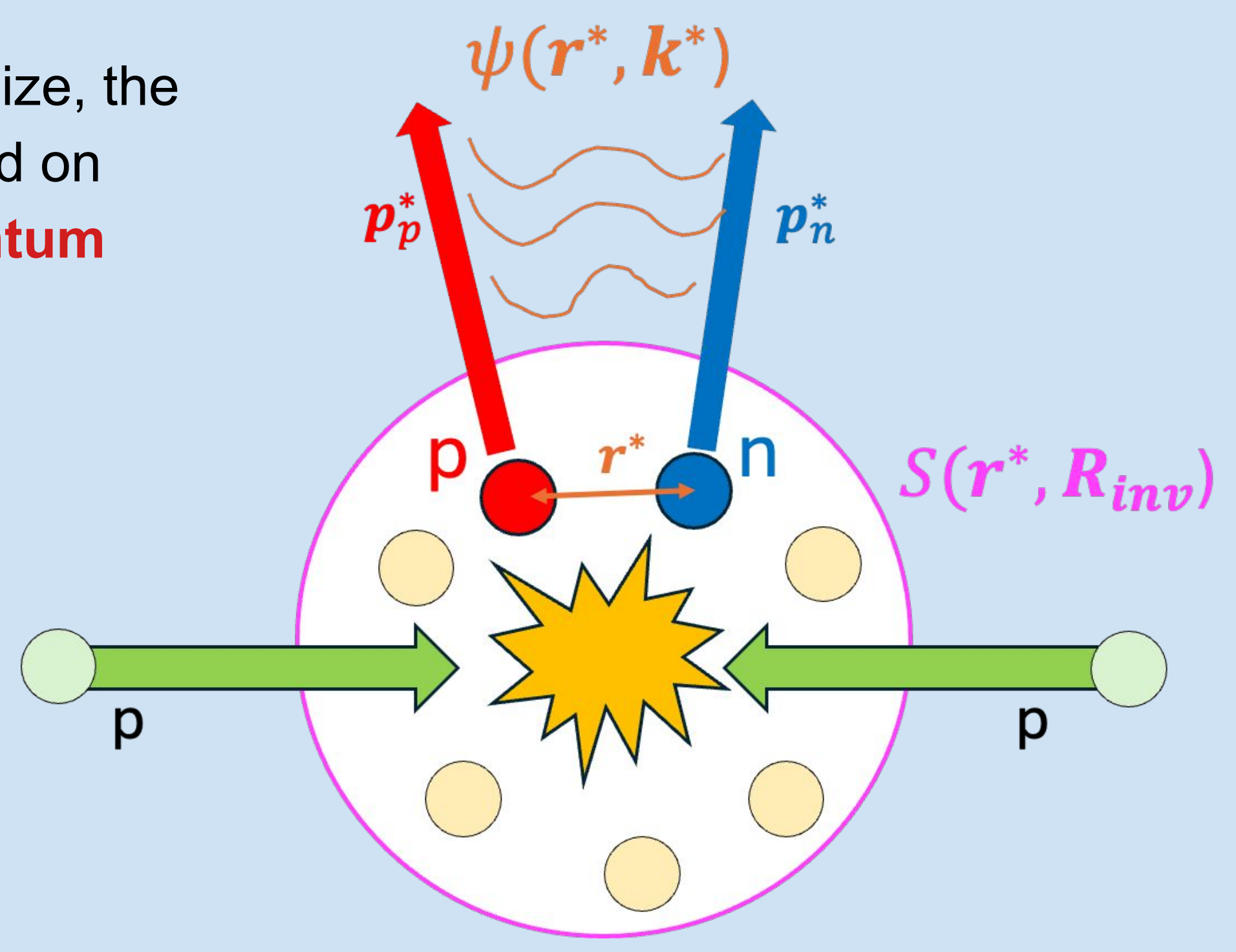
LHC Run 3 integrated luminosity[5] at 900 GeV ≈ 2.7 nb^{-1} (p-p) at few kHz of interaction rate.

The femtoscopic technique

To access the information about the source size, the **femtoscopic technique**[3] is used. It is based on the measurement of **correlations in momentum** among nucleons (eq. 1).

The experimental correlation function (CF) is according to equation (eq. 2) by pairing protons from the same event (***SE***).

→ The mixed Event (***ME***) distribution is used to estimate the uncorrelated background.



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

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

\ Relative distance $\boldsymbol{r^*} = \boldsymbol{r^*_p} - \boldsymbol{r^*_n}$ and momentum $\boldsymbol{k^*} = ½ \mid \boldsymbol{p^*_p} - \boldsymbol{p^*_n} \mid$ are measured in the pair rest frame.

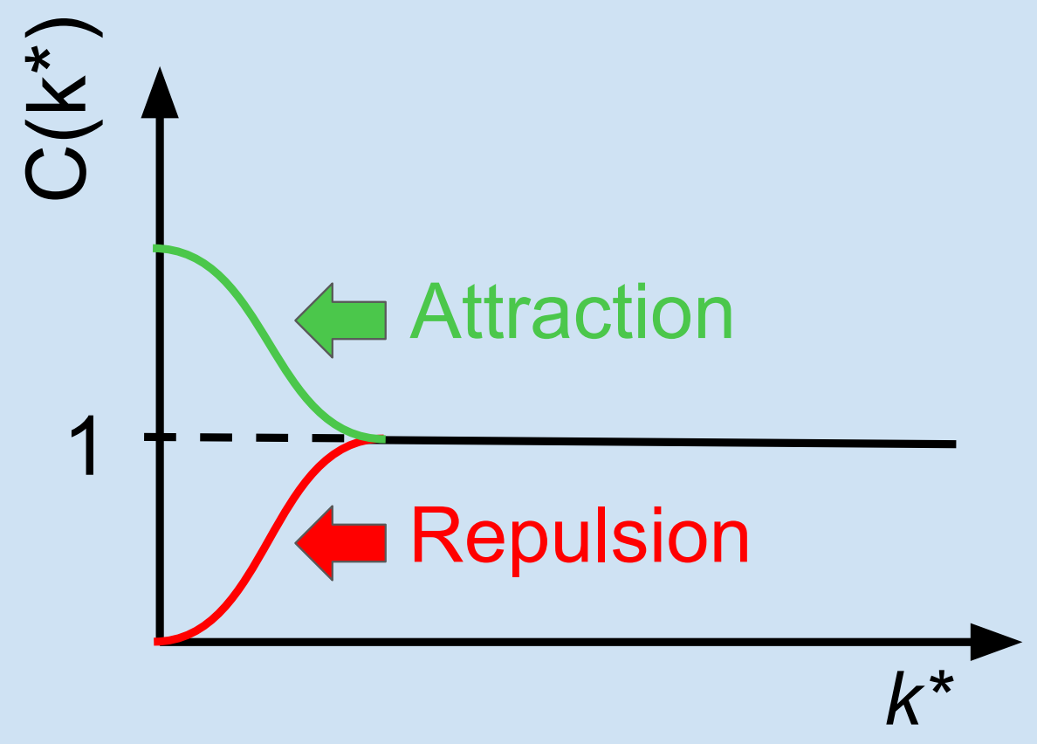
Pair wave function, $\psi(r^*, k^*)$:
→ Solution of the Schrödinger equation for a given **interaction potential** for a particle pair.

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 $\boldsymbol{R_{inv}}$.

The experimental CF also includes non-genuine correlation from misidentified or non primary proton pairs, estimated via the **λ parameter.**

→ ***N(k*)*** is a normalising factor, calculated outside of the femtoscopic signal region (> 240 MeV/*c*).

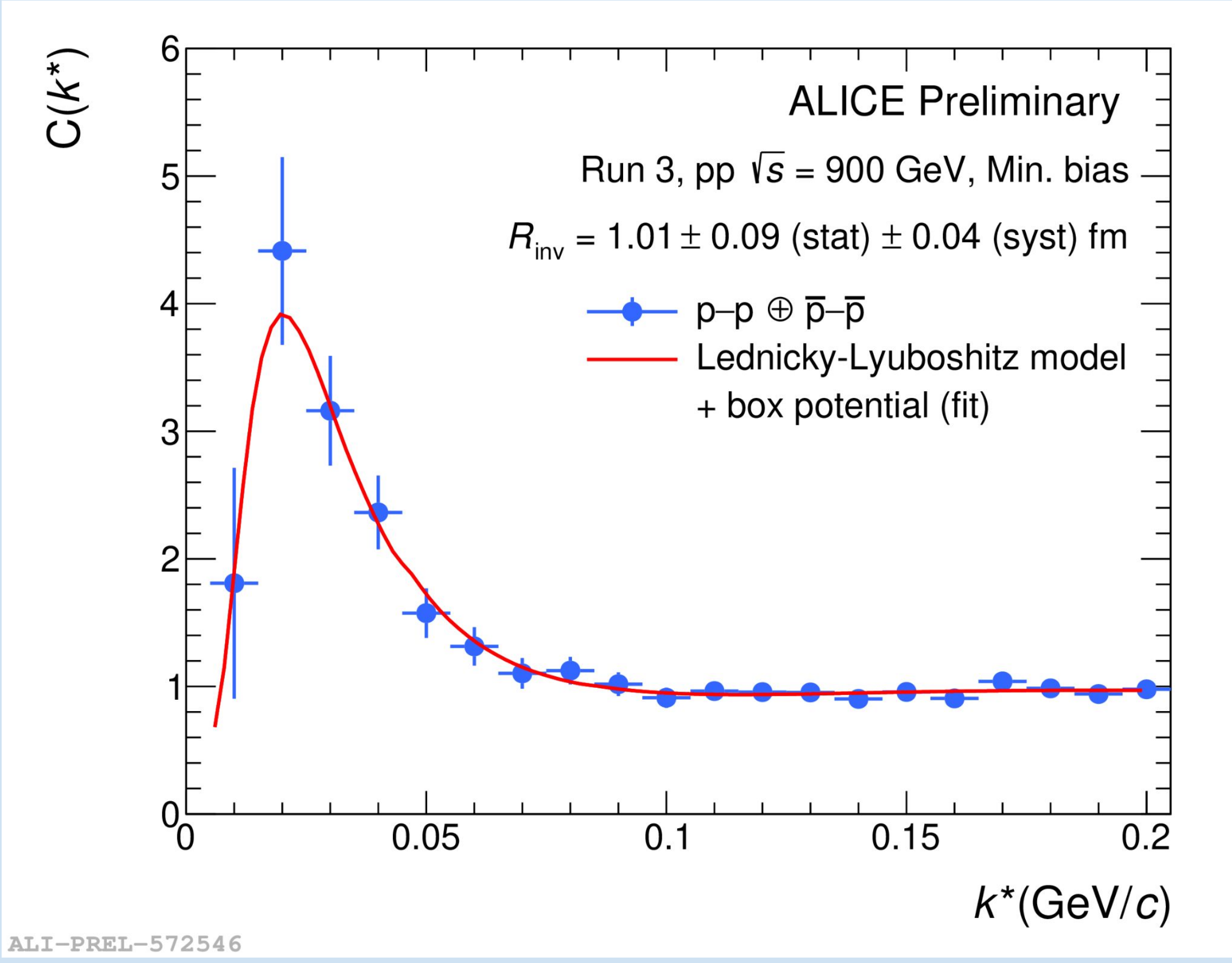
$$\begin{cases} < 1 \text{ if the interaction is repulsive} \\ = 1 \text{ if there is no correlation (for } \boldsymbol{k^*} \to +\infty) \\ > 1 \text{ if the interaction is attractive} \end{cases}$$



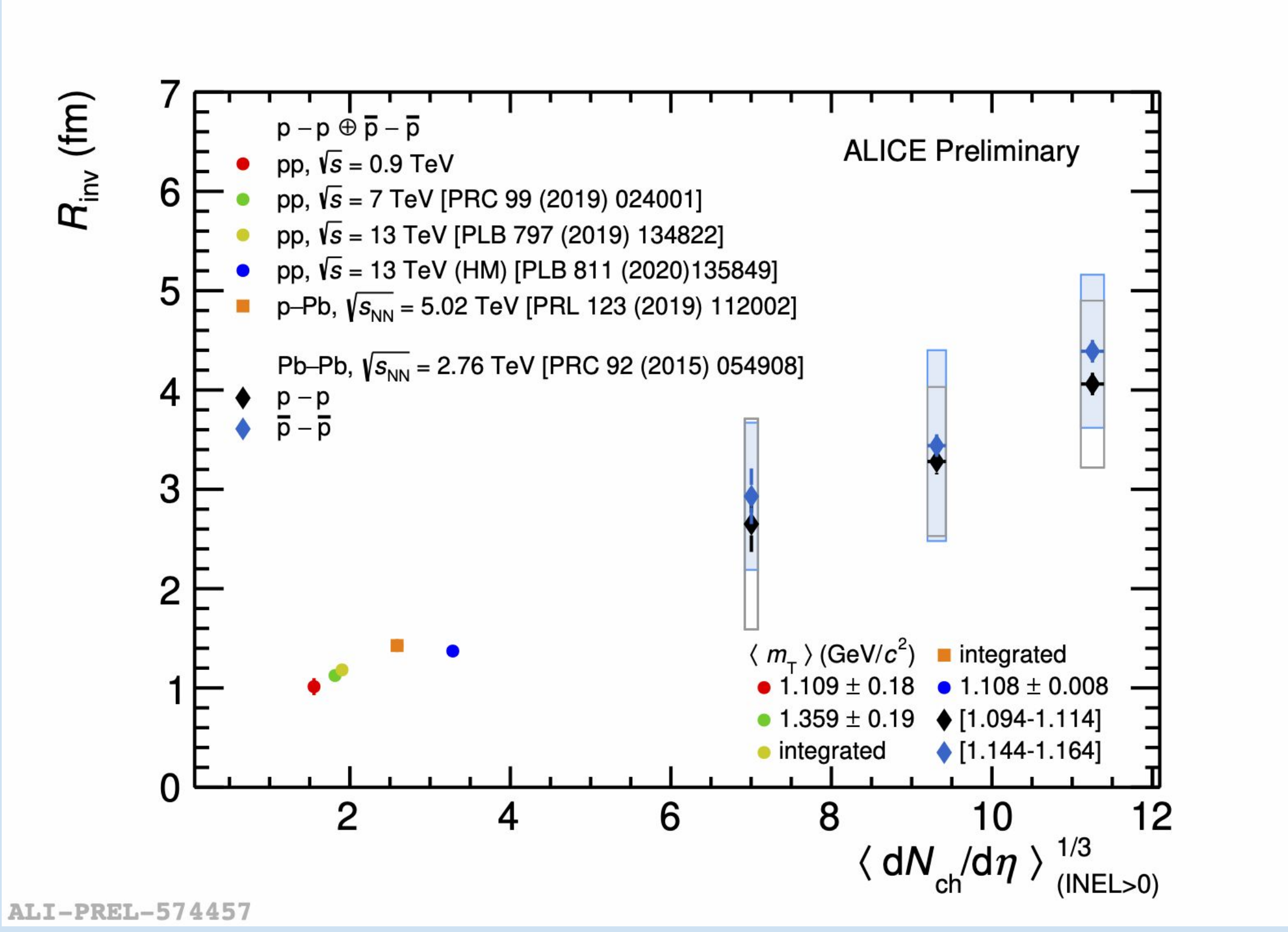
Proton source measurement in pp at $\sqrt{s}$ = 900 GeV

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 CF is normalized by the *N(k*)* factor determined in 0.24 < ***k**** < 0.34 GeV/*c*.
4. The total CF is fitted with the **Lednicky-Lyuboshitz model** [6, 7] **with a box potential approach.**
5. The **source size R_{inv}** and the **λ parameter** are **free fit parameters.**
6. 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.

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



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.**



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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