

To the memory of Prof. Akira Ohnishi

Three-body dynamics in nuclear physics

- Fundamental ingredient for the study of the nuclear structure
- Three-body forces necessary to describe properties of nuclei and hypernuclei
S. C. Pieper, R. B. Wiringa, Ann. Rev. Nucl. Part. Sci. 51:53 (2001)
K. Miyagawa et al., Phys. Rev. C 51, 2905 (1995)
- Relevant for dense nuclear matter and neutron stars
D. Lonardoni et al., Phys. Rev. Lett. 114, 092301 (2015)

The method: Femtoscopy in pp collisions

Measured correlation function obtained from experimental distribution of relative momentum (k^*) of particle pairs emitted in the collision

$$C(k^*) = \frac{N_{\text{same}}(k^*)}{N_{\text{mixed}}(k^*)}$$

Theoretical correlation function obtained from two-particle wave function and emission source

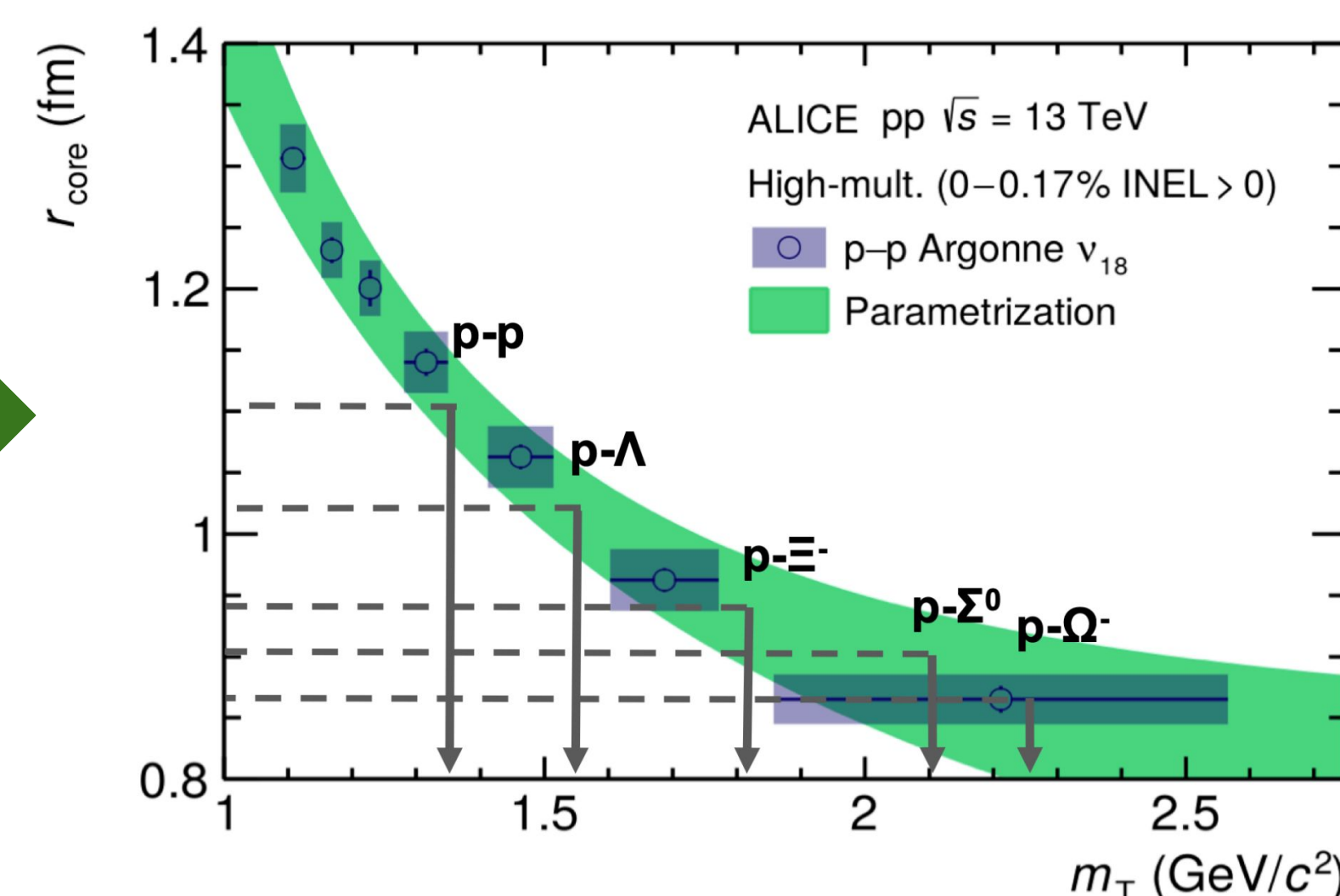
$$C(k^*) = \int d^3r^* S(r^*) |\psi(k^*, r^*)|^2$$

source wave function

Source size in pp high-multiplicity collisions for a given hadron-hadron pair determined by ALICE as a function of m_T ALICE Coll. Phys. Lett. B 811 (2020) 135849

$$k^* = \frac{|\vec{p}_a^* - \vec{p}_b^*|}{2} \quad m_T = (k_T^2 + m^2)^{1/2}$$

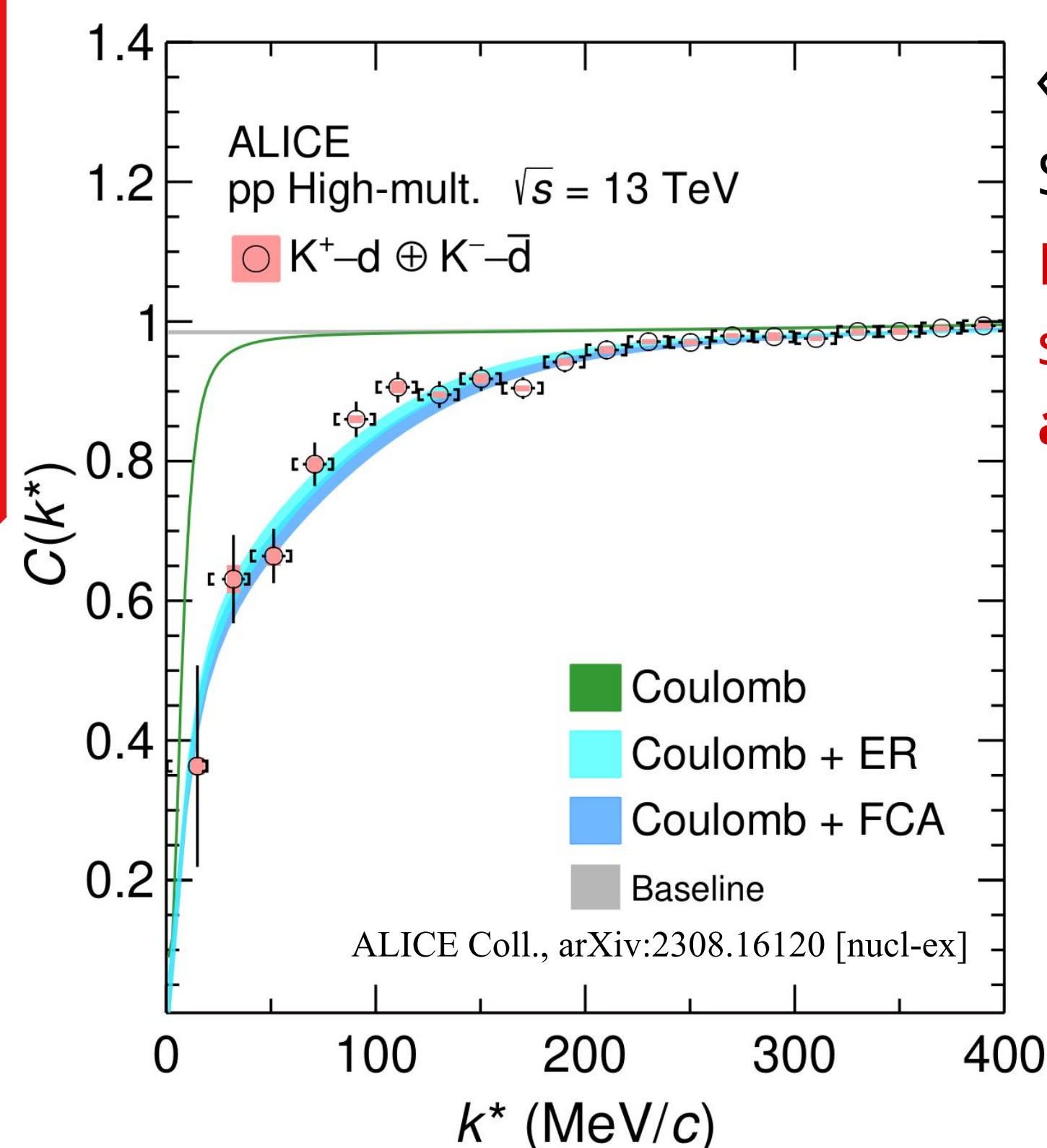
(* evaluated in pair rest frame)



Hadron-deuteron correlation function as a two-body problem

ALICE data compared with theoretical correlation function considering deuteron as a point-like particle

- Lednický model:** s-wave asymptotic wave function from scattering parameters R. Lednický, Phys. Part. Nucl. 40, 307 (2009)
- Scattering parameters available from analysis of scattering data



← Kaon-deuteron pairs

Source size $r = 1.35^{+0.04}_{-0.05}$ fm

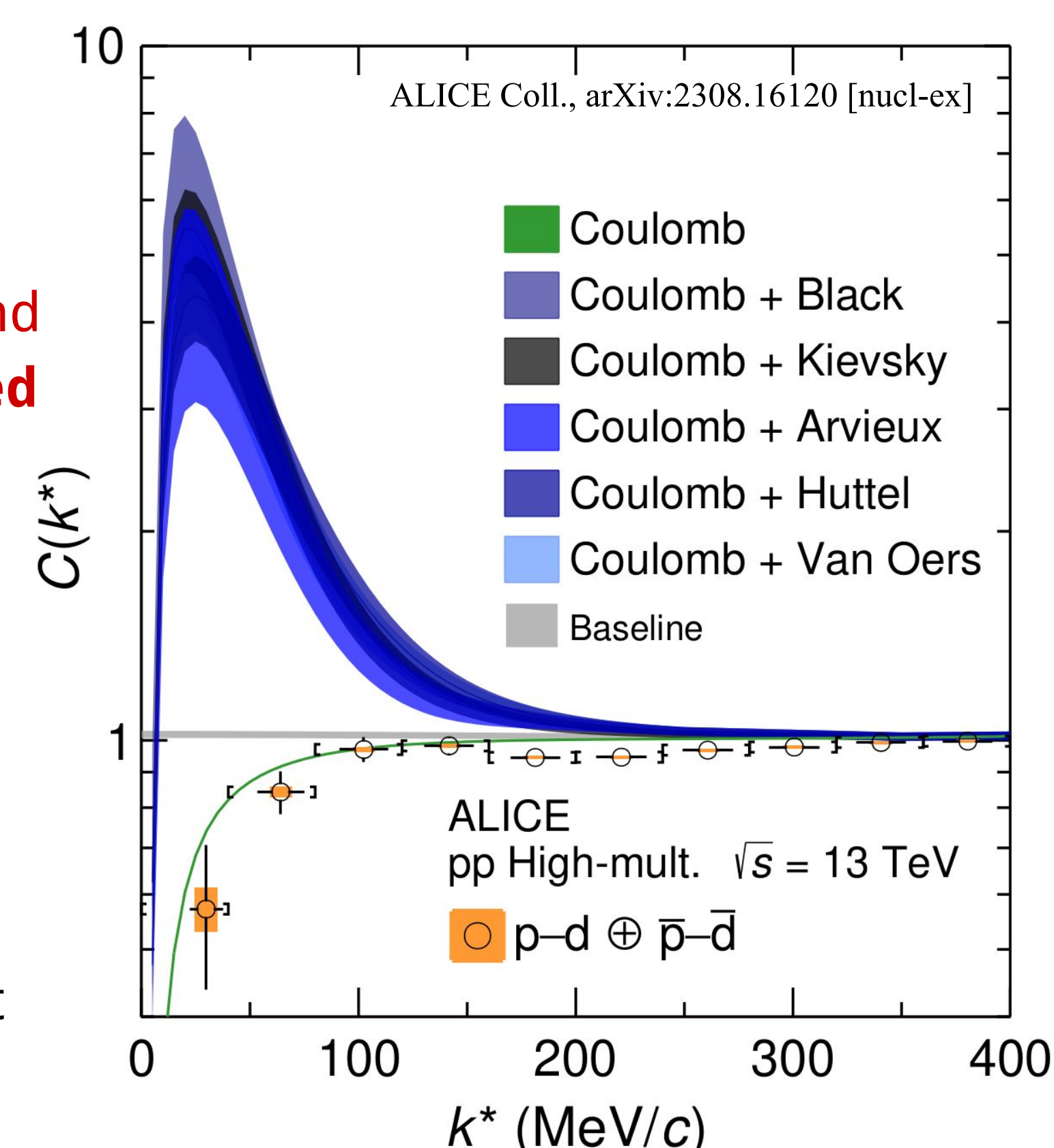
For K^+-d , calculation using Coulomb + strong interaction and small radius describes the data ⇒ **deuterons are produced at very short distances w.r.t. to other hadrons**

Proton-deuteron pairs ⇒

Source size $r = 1.08^{+0.06}_{-0.06}$ fm

For p-d, calculations with two point-like particles fail to reproduce the data.

- Pauli blocking for p-(pn) at short distances
- Asymptotic strong interaction not sufficient for small distances



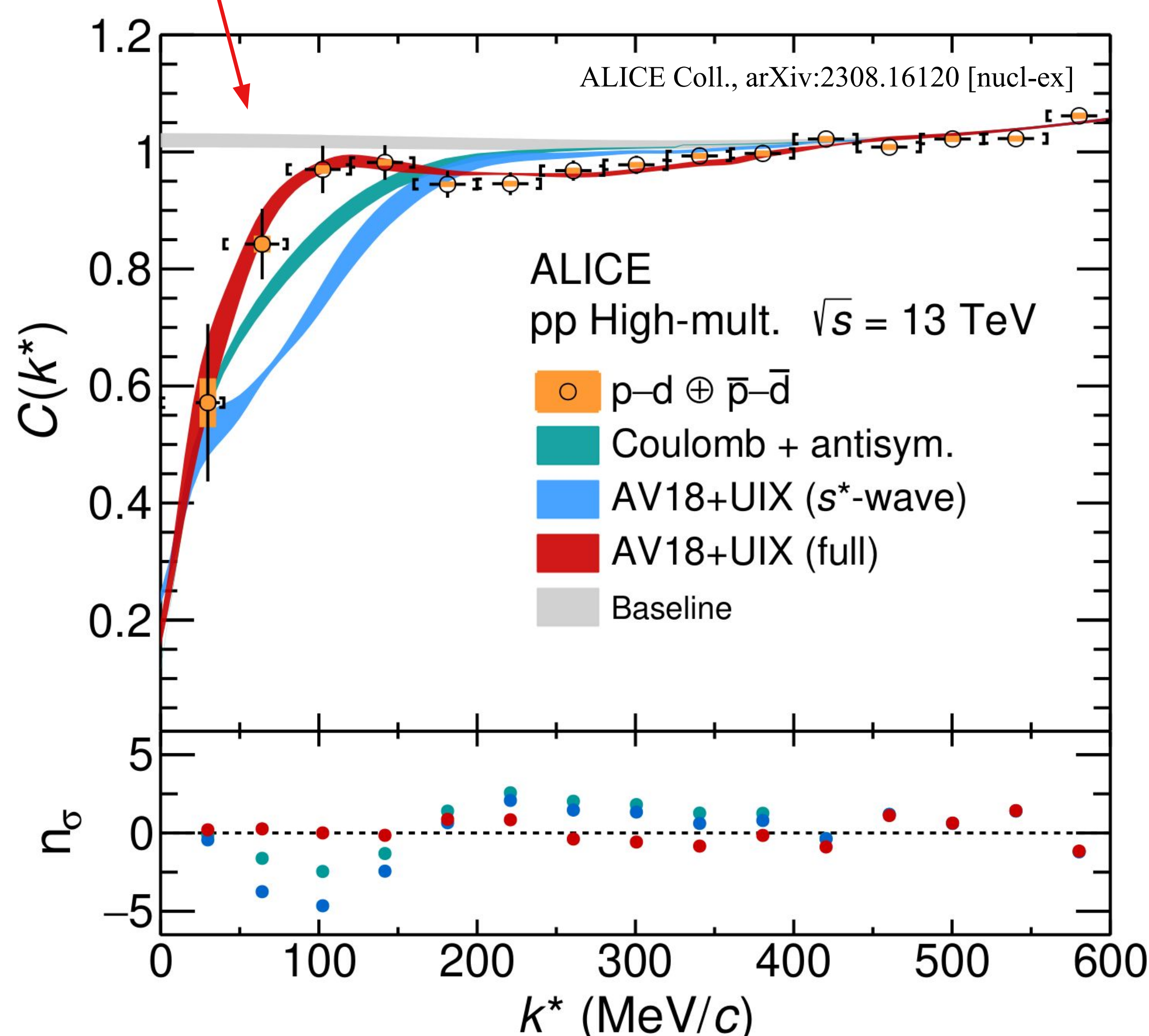
p-d correlation function including three-body dynamics

First formulation of the p-d correlation function starting from p-(pn) dynamics that form the p-d state

$$C_{pd}(k^*) = \frac{1}{16A_d} \sum_{m_2, m_1} \int \rho^5 d\rho d\Omega \left| \Psi_{m_2, m_1, k^*} \right|^2 \frac{e^{-\rho^2/4R_M^2}}{(4\pi R_M^2)^3}$$

with: Ψ_{m_2, m_1, k^*} three-nucleon wave function, p-(pn) to p-d state asymptotically
 A_d deuteron formation probability using deuteron wave function

M. Viviani, S. König, A. Kievsky, L. E. Marcucci, B. Singh, O. Vázquez Doce, arXiv:2306.02478 [nucl-th]



⇒ **ALICE measurement of the p-d correlation function sensitive to dynamics of the three-body p-(pn) system at short distances**

- nucleon-nucleon source size in the p-d system from m_T scaling: $R_M = 1.43 \pm 0.16$ fm

Full-fledged three-body calculation describes the data (red curve) by including:

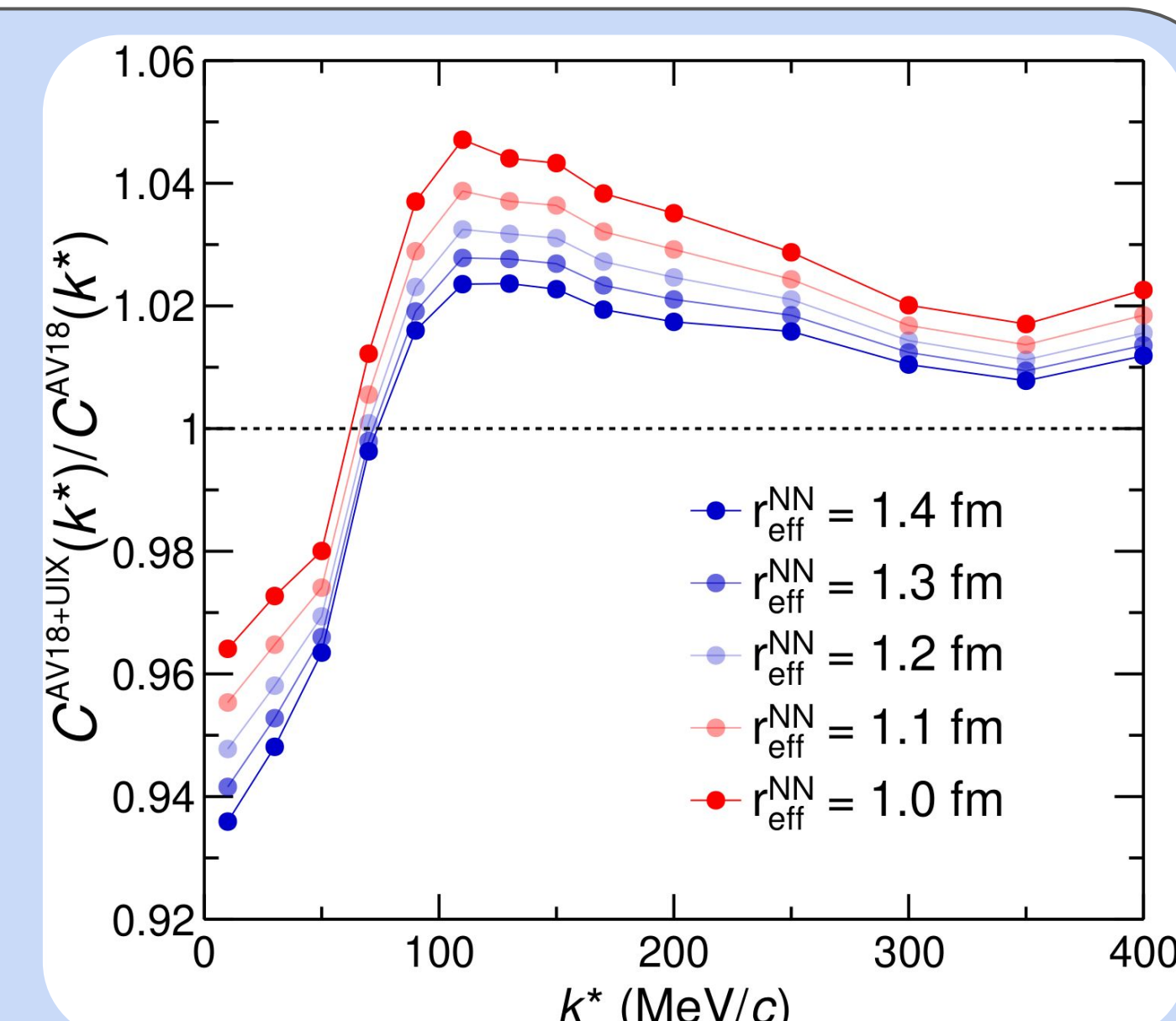
- AV18, two-nucleon potential
- Urbana IX, three-nucleon force
- Calculation up to d-wave

s-wave only (blue curve) and Coulomb only (green curve) calculations disagree with the data

Open possibilities for the future

Sizeable effects in ratio of p-d correlation with/without genuine three-body force:

- LHC Run 3 + ALICE upgraded apparatus will enable the study of the interaction at small distances
- Studies of three-baryon systems in the **strange and charm sectors** will be accessible



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ALICE Coll., arXiv:2308.16120 [nucl-ex]
See also talk by B. Singh in Light flavour session