Selected results on hyperon and related studies with ALICE

With personal bias

张晓明

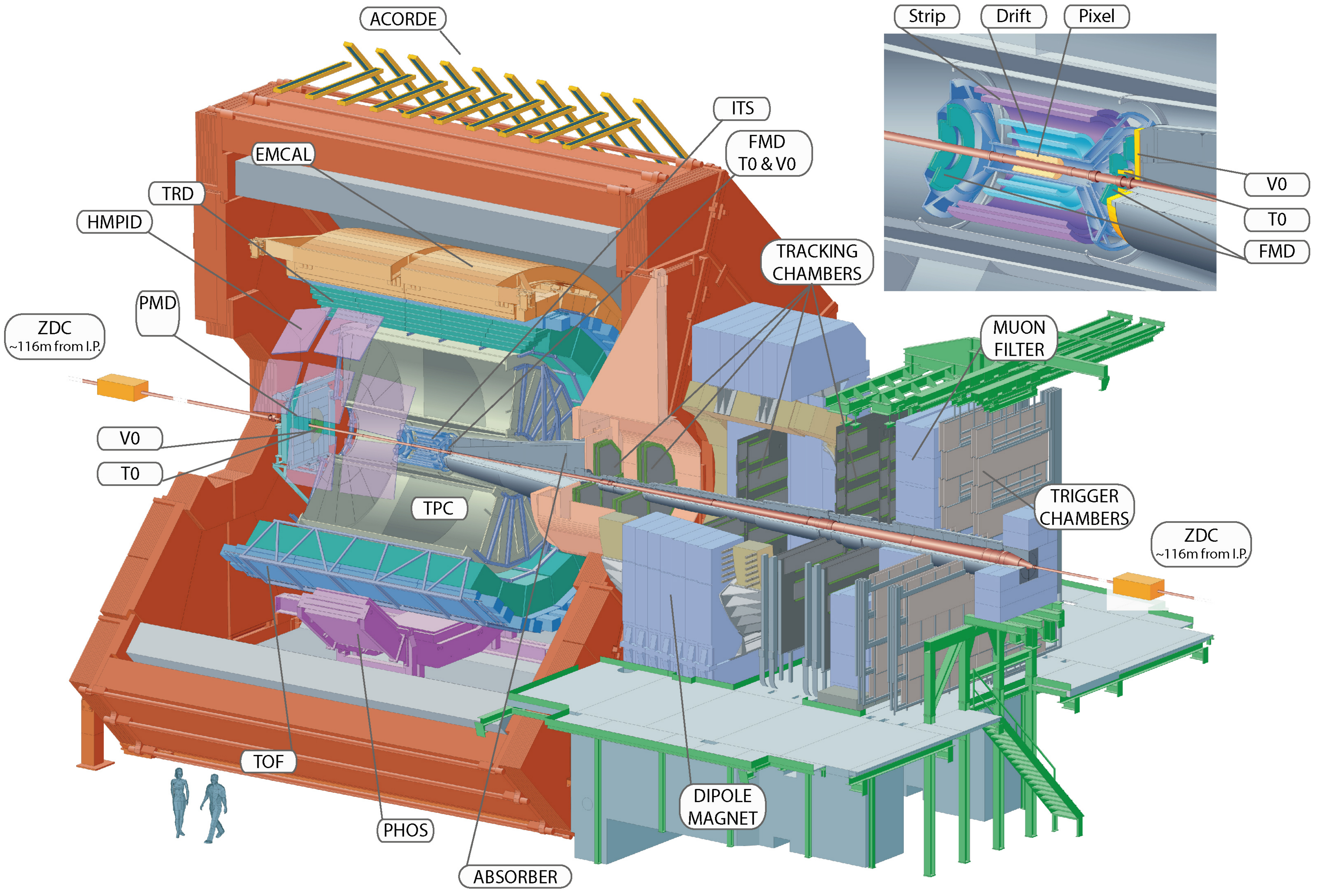
华中师范大学

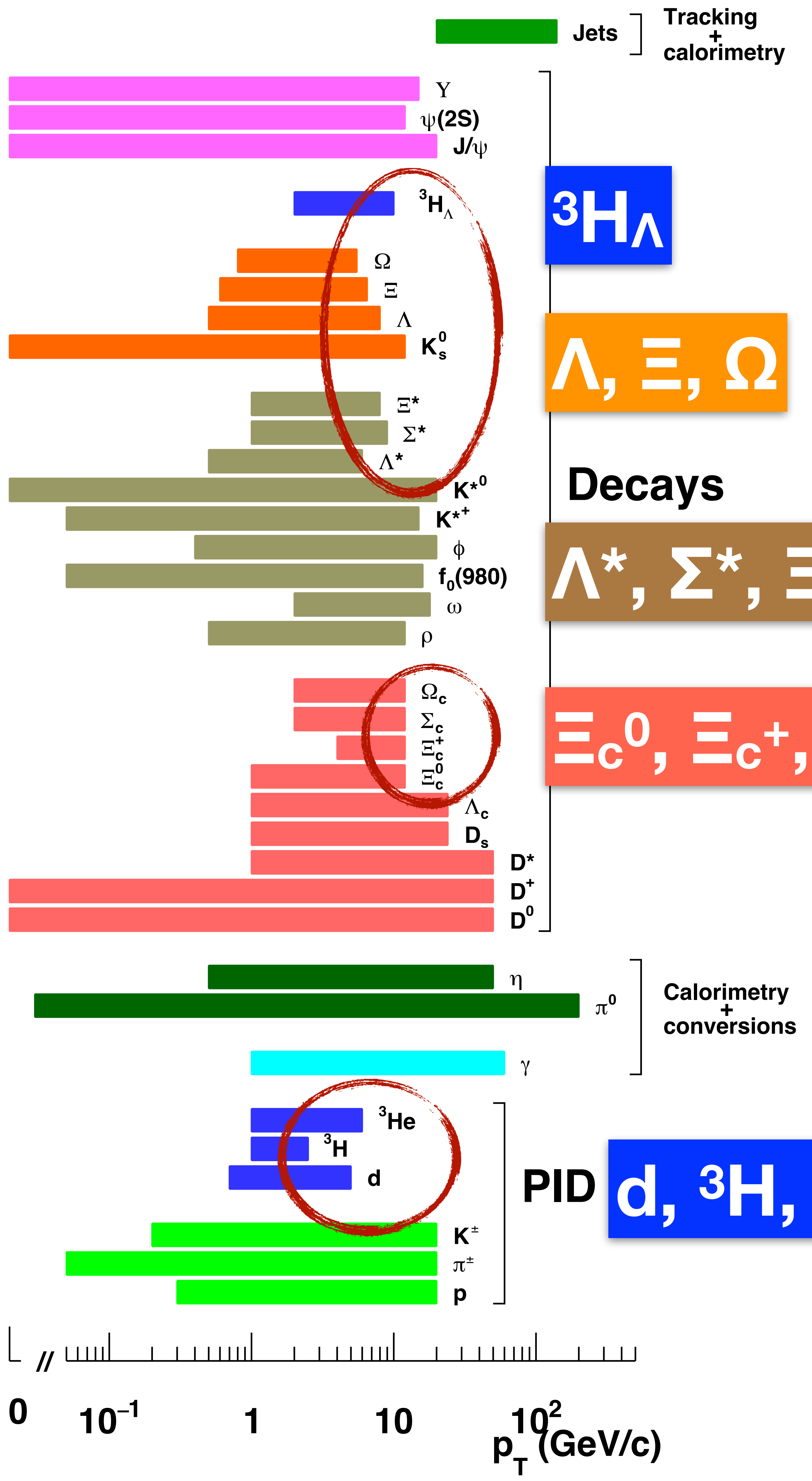
CENTRAL CHINA NORMAL UNIVERSITY

The 1st Workshop on Hyperon Physics
12 – 15 April 2024, Huizhou, China

ALICE

ALICE apparatus





$^3H_\Lambda$

Λ, Ξ, Ω

Decays

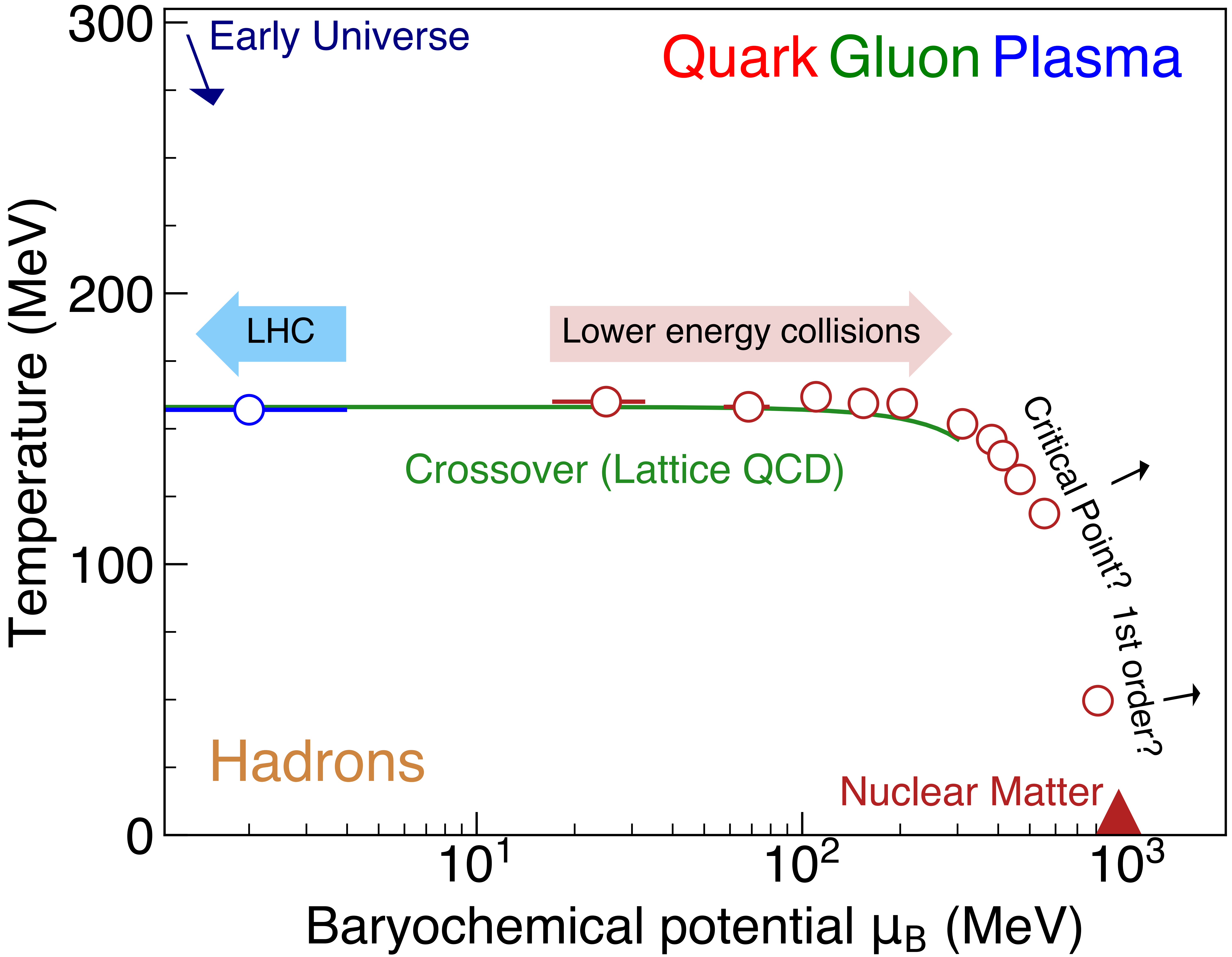
Λ^*, Σ^*, Ξ^*

Ξ_c^0, Ξ_c^+, Ω_c

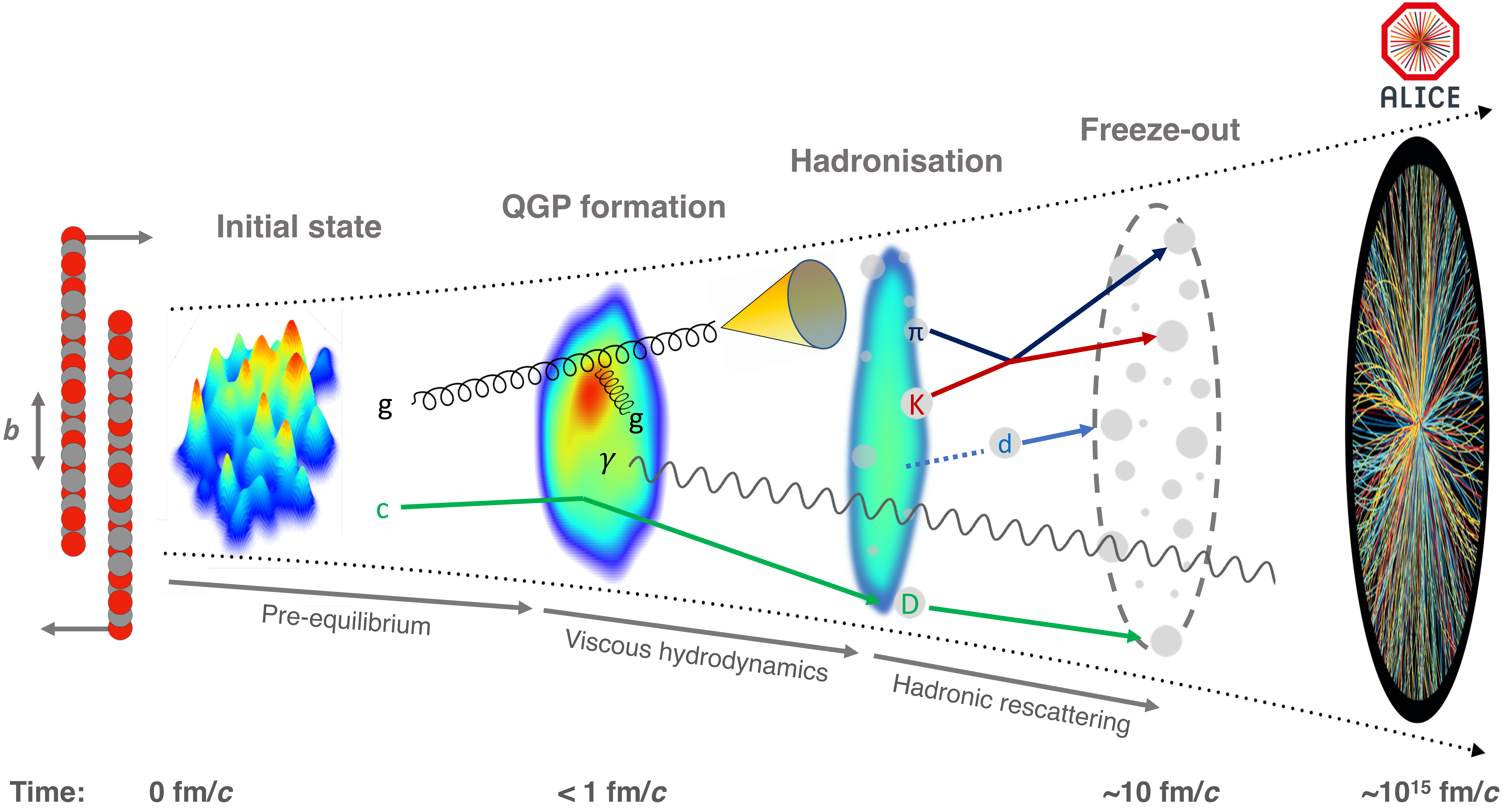
PID

d, ^3H, ^3He

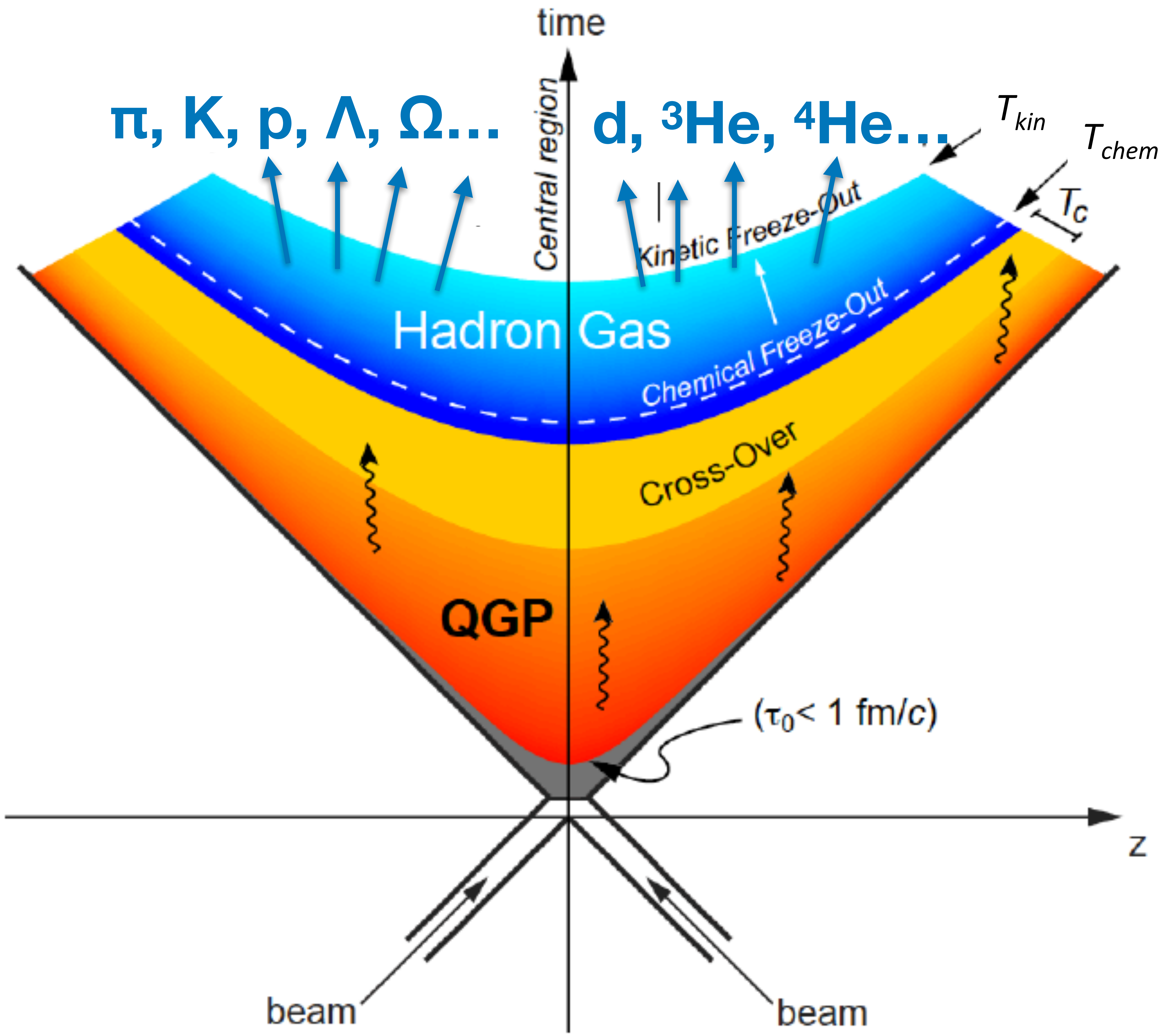
QCD phase diagram



Heavy-ion collisions

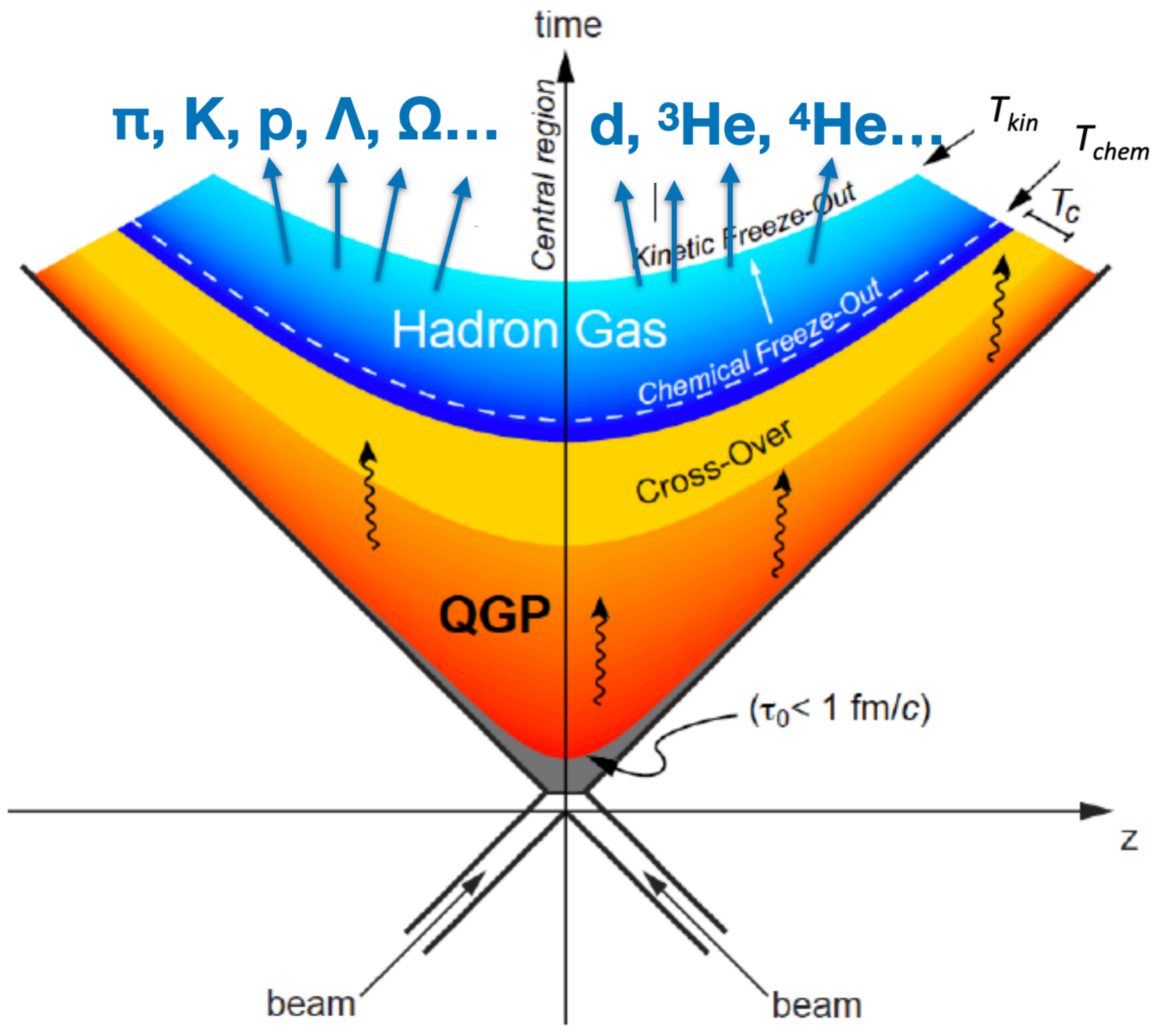


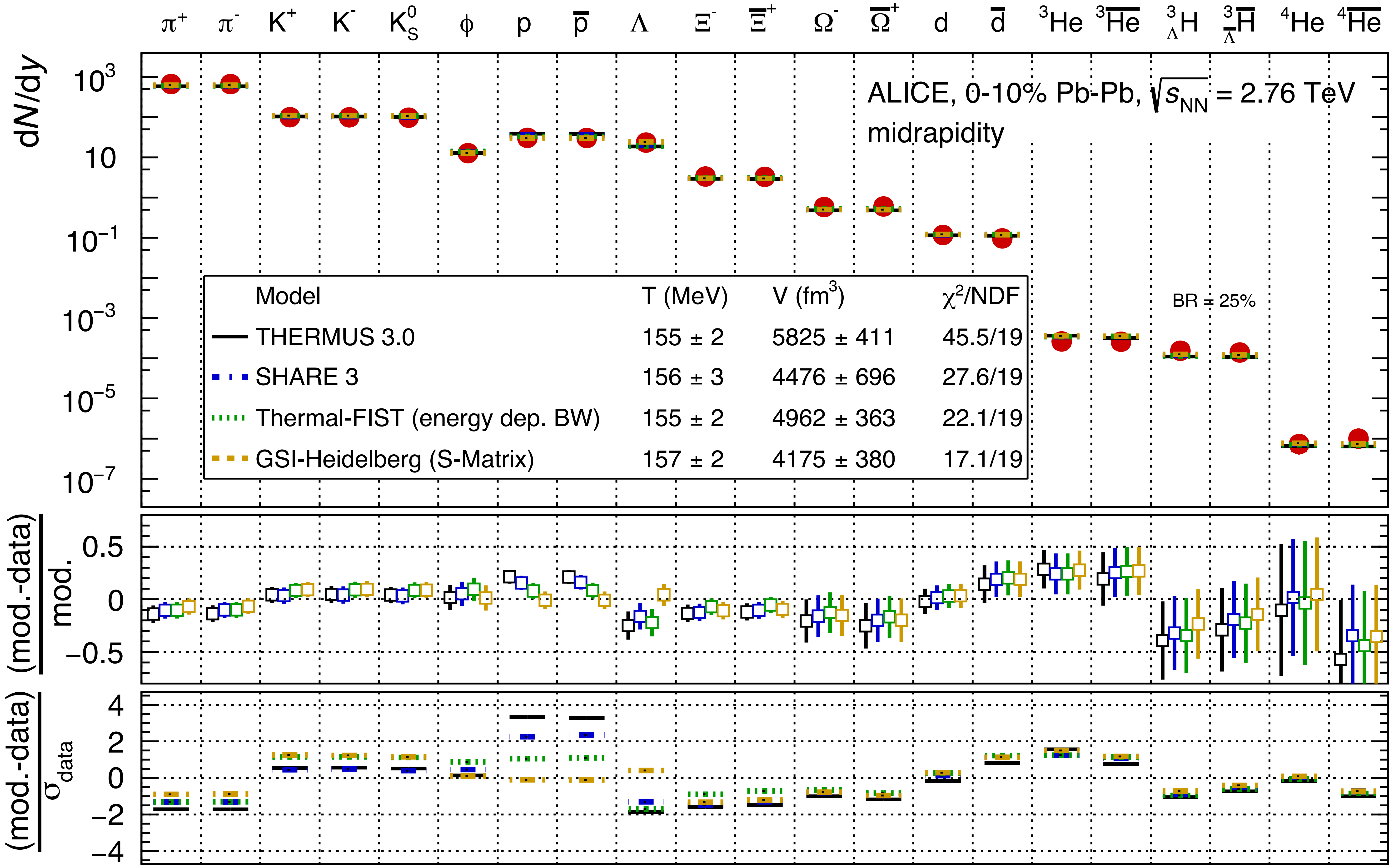
Particle formation



- Pre-equilibrium phase $\tau < 0.5$ fm/*c*
- Quark-gluon plasma $\tau \sim 10$ fm/*c*
- Mixed phase
- Chemical freeze-out – T_{ch}
  ➡ Particle composition is fixed
- Kinetic freeze-out – T_{kin}
  ➡ Particle spectra are fixed

Particle and nucleus abundances

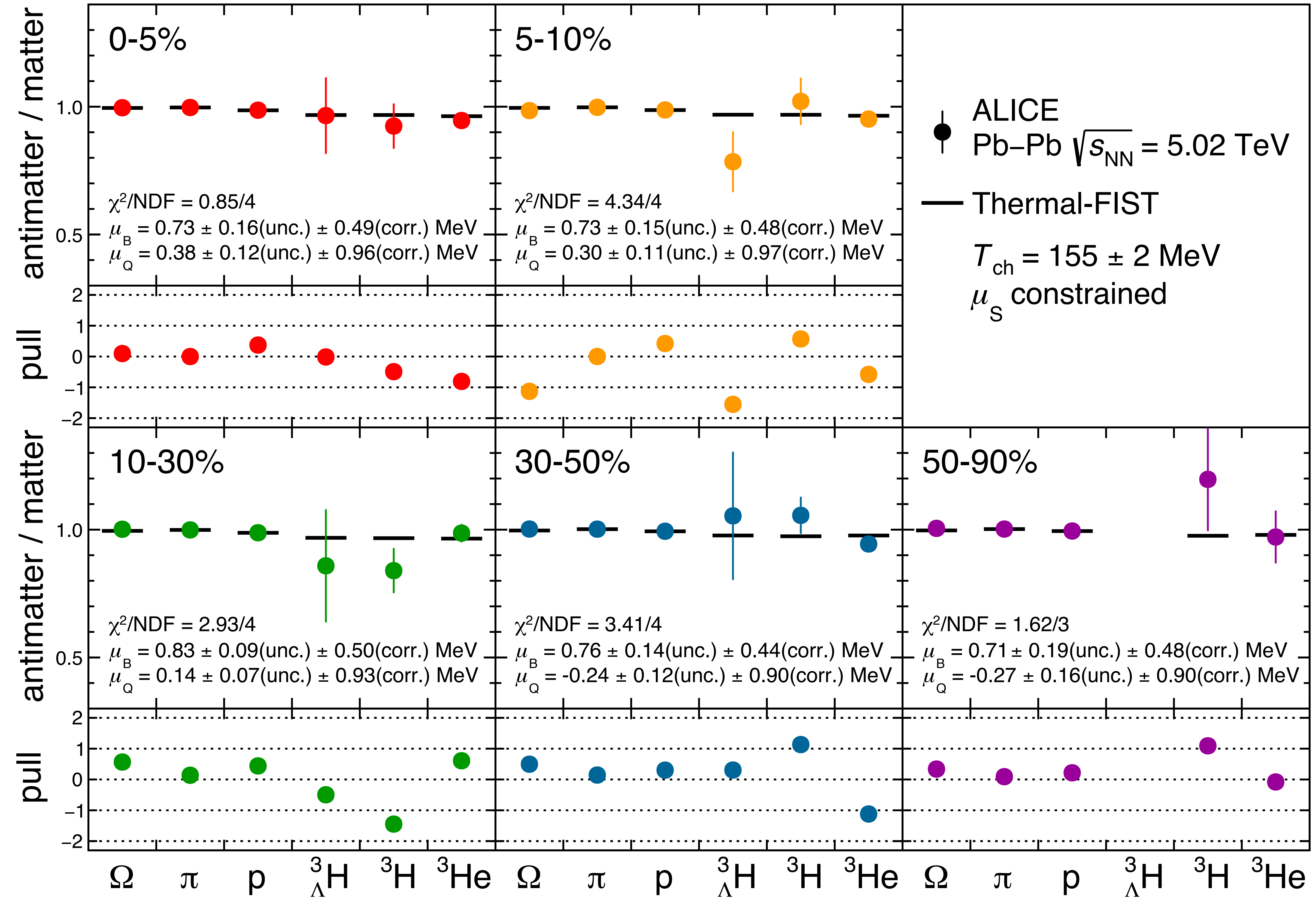




ALICE arXiv:2211.04384

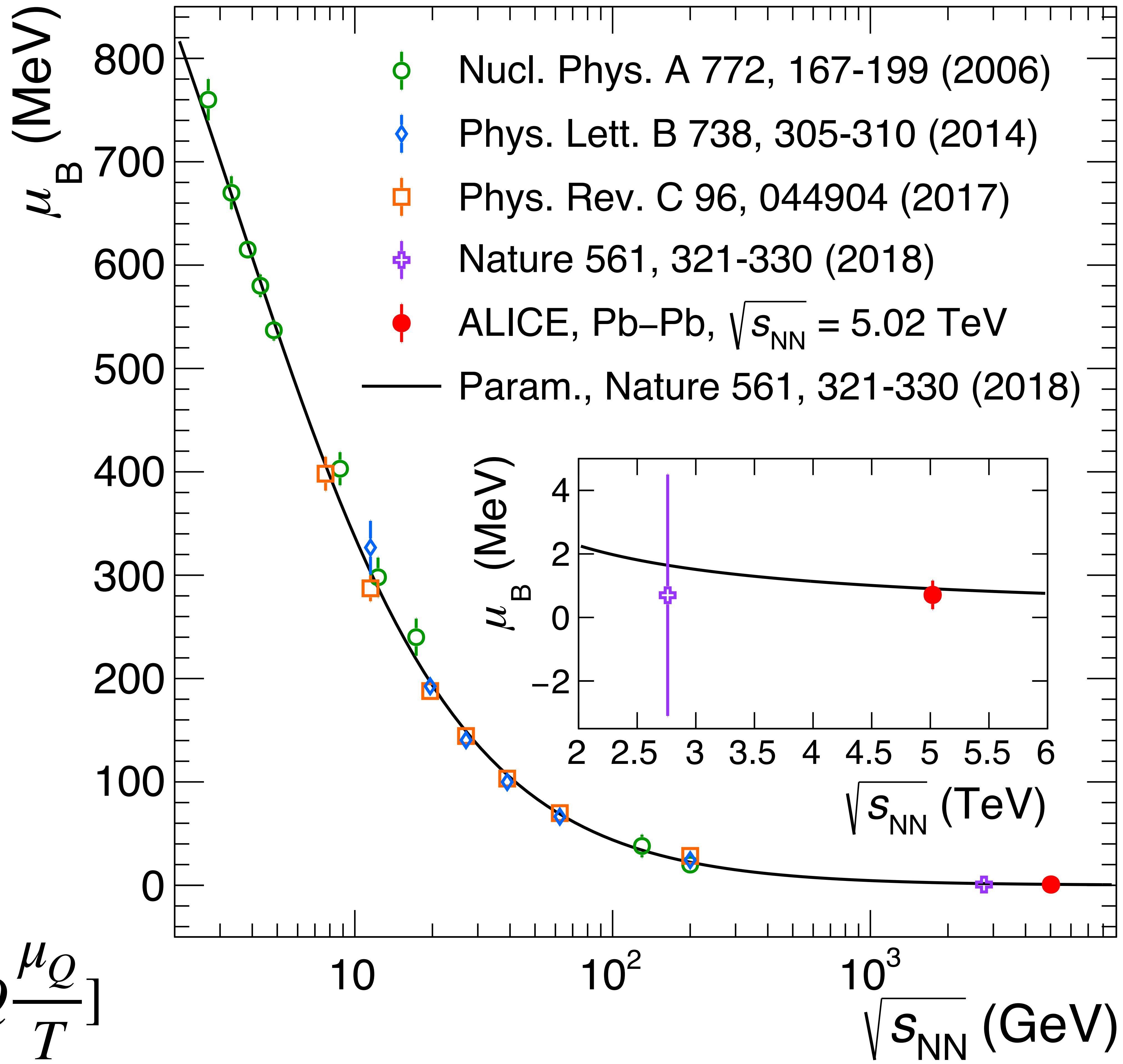
- Measurements are well described by statistical hadronization models fit over 9 orders of magnitude
- Chemical freeze-out temperature T_{ch} ~ 156 MeV at μ_B ~ 0

Antimatter/matter imbalance



ALICE arXiv:2311.13332

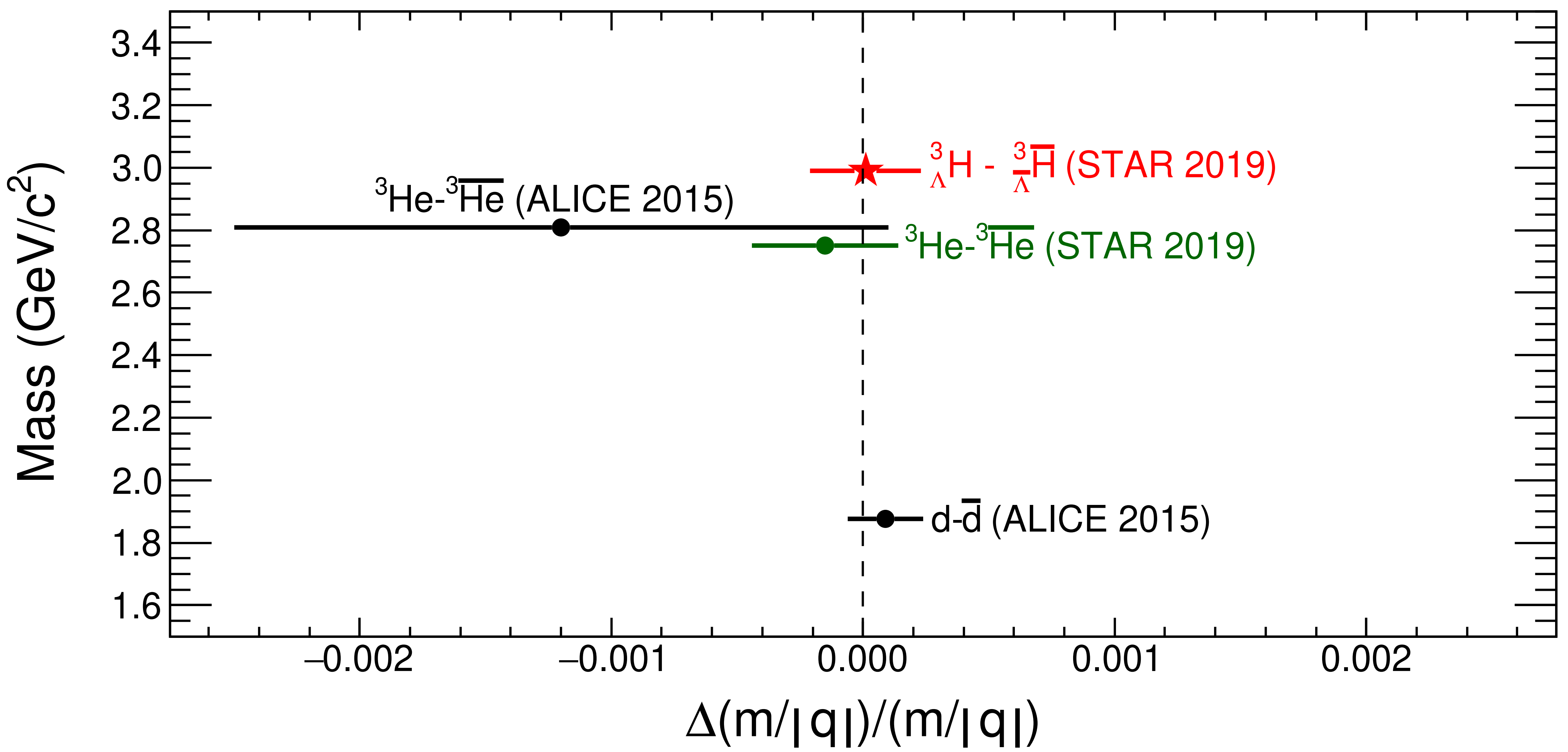
$$\bar{h}/h \propto \exp[-2(B + \frac{S}{3})\frac{\mu_B}{T} - 2Q\frac{\mu_Q}{T}]$$



- Improved precision by cancelation of correlated uncertainties in the ratio
- μ_B = 0.71 ± 0.45 MeV – compatible with zero within 1.6σ

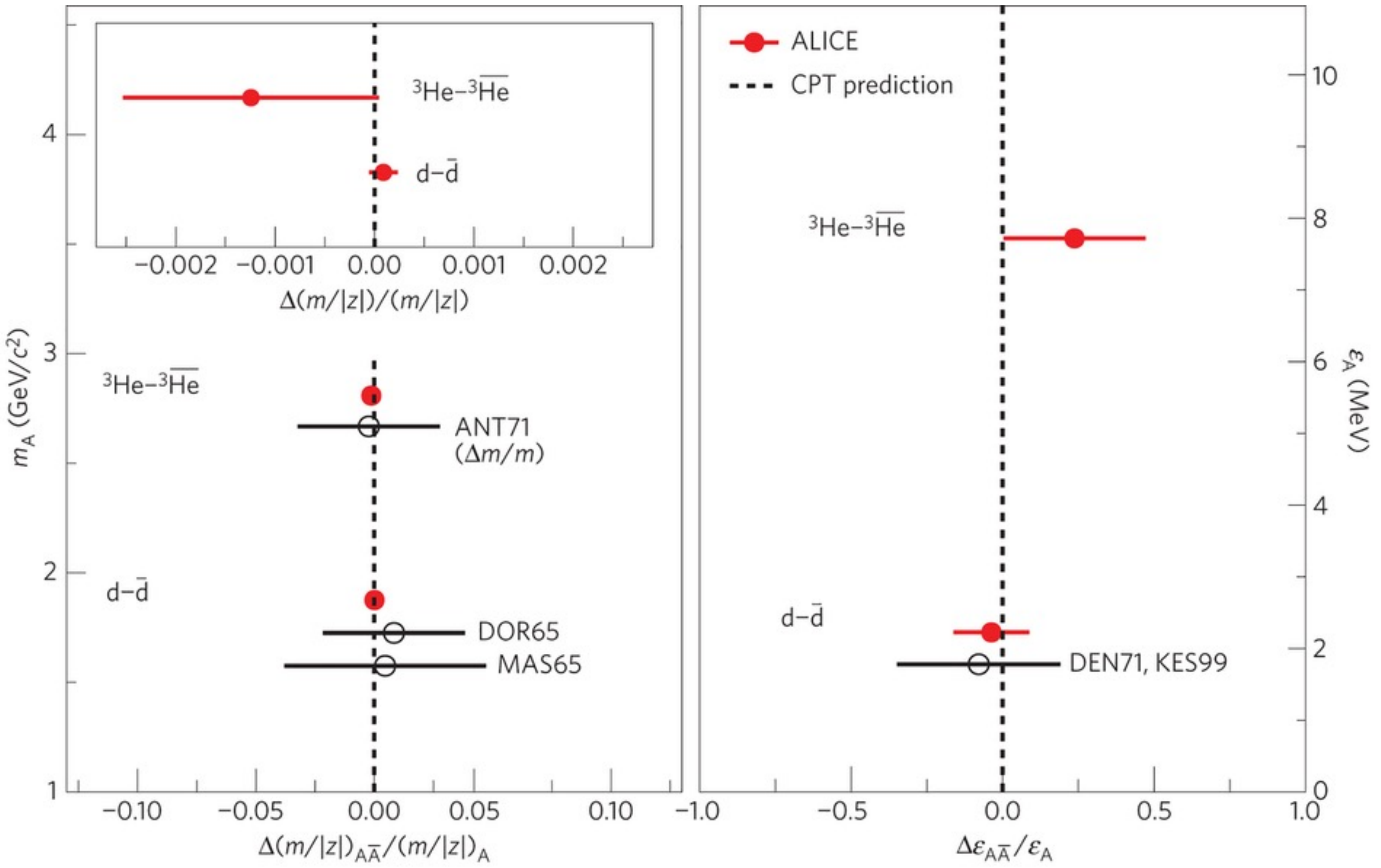
Mass difference of (anti)-nuclei

- Test of CPT invariance of residual nuclear force by measuring mass difference in the nuclei sector – Confirms CPT invariance for (light) nuclei



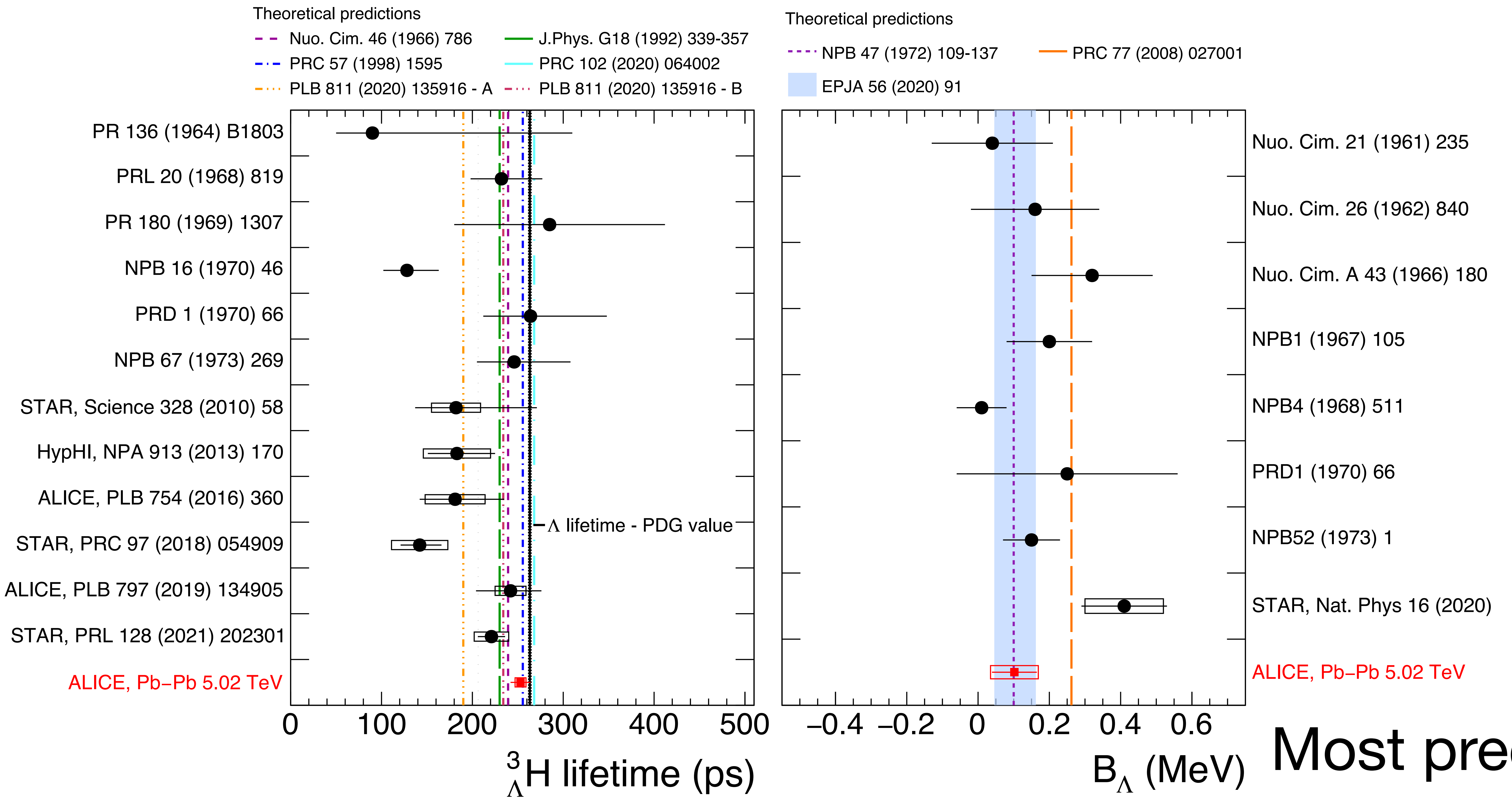
STAR *Nature Physics* 16 (2020) 4

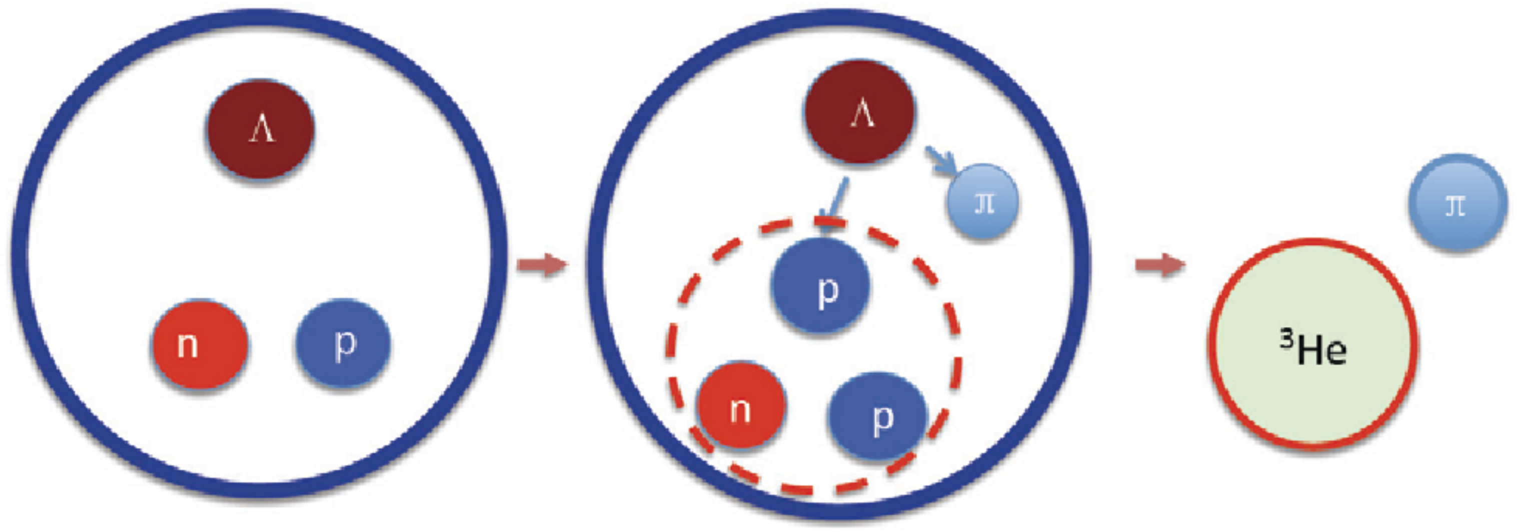
ALICE *Nature Physics* 11 (2017) 811

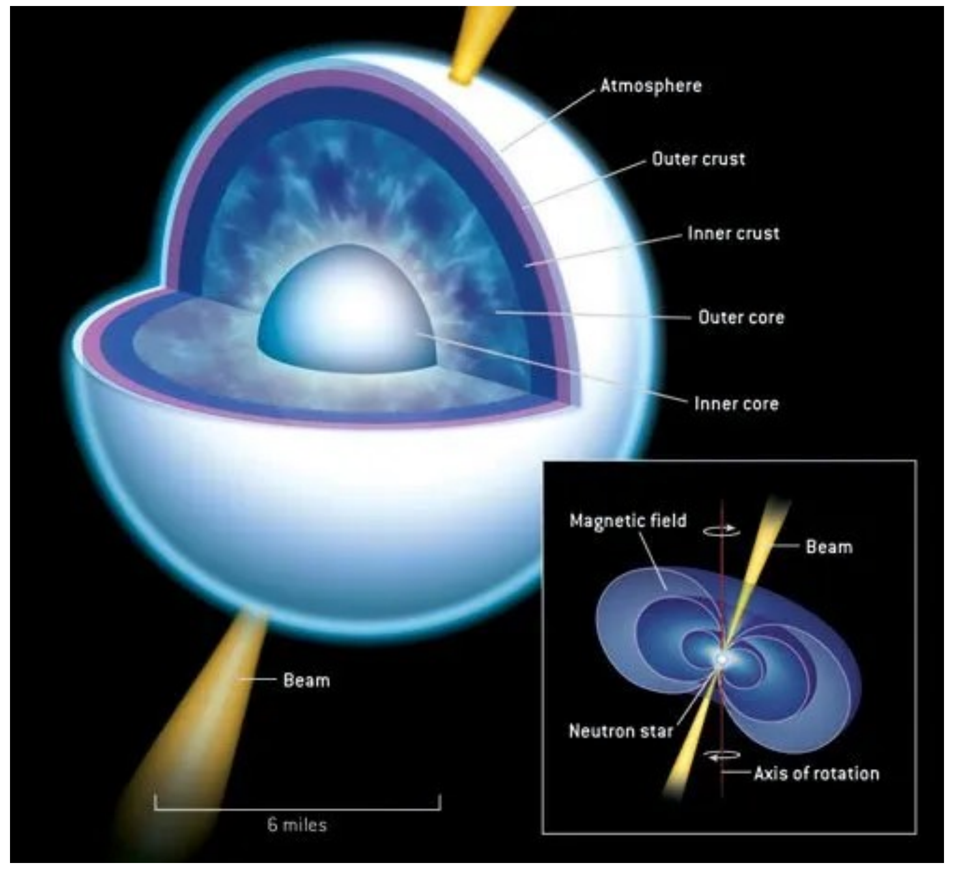


- **STAR** Measure hypertriton binding energy (best ever) and systematically larger than previous measured

Hypertriton lifetime







ALICE ***Phys. Rev. Lett.*** **131 (2023) 10**

Most precise measurement

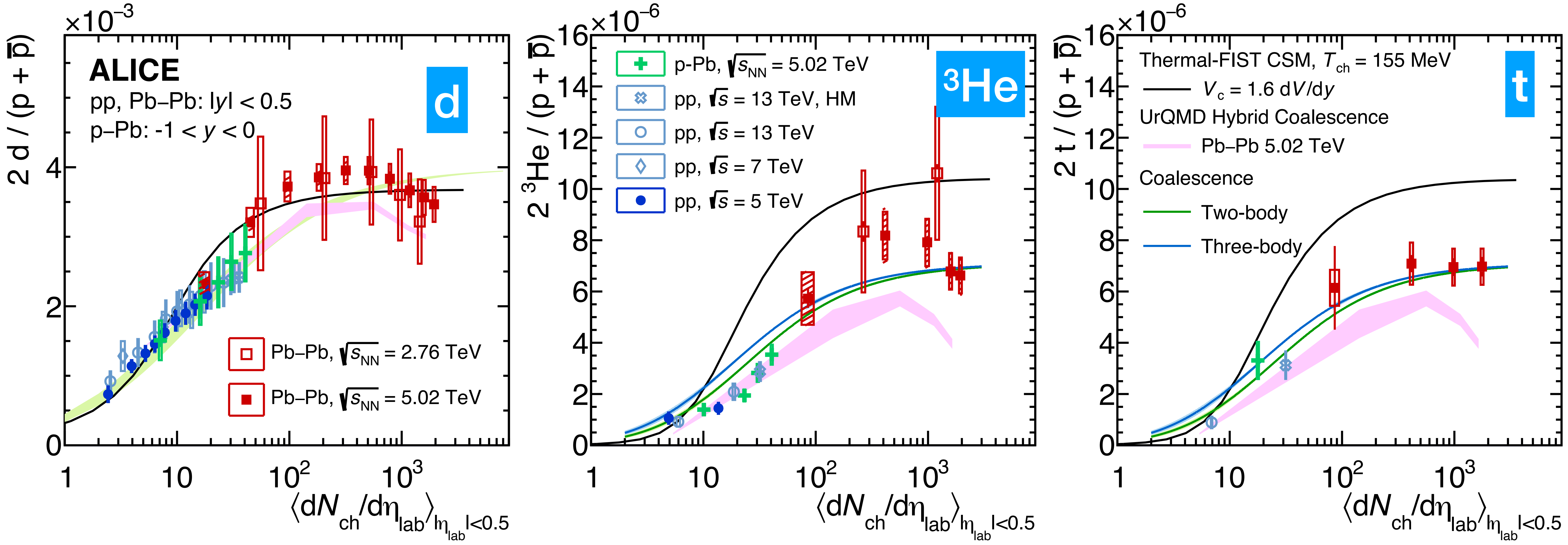
➡ τ = 253 ± 11 (stat.) ± 6 (syst.) ps

➡ B_Λ = 102 ± 63 (stat.) ± 67 (syst.) keV

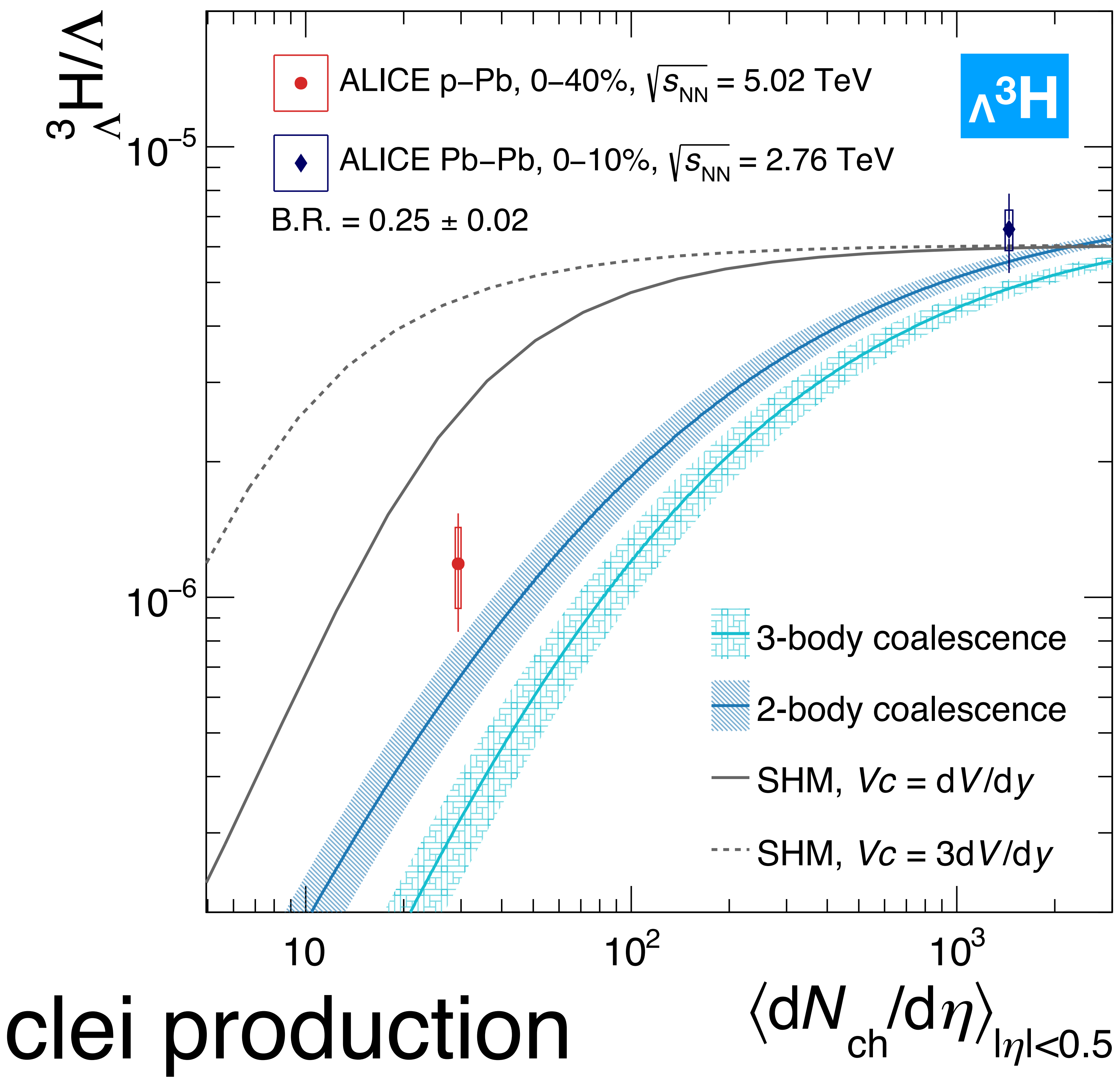
Hypernuclei – probes of Y-N interaction

➡ EoS of neutron stars – hyperon "puzzle" ($M_{NS} > 2M_\odot$)

Light/hyper nuclei production

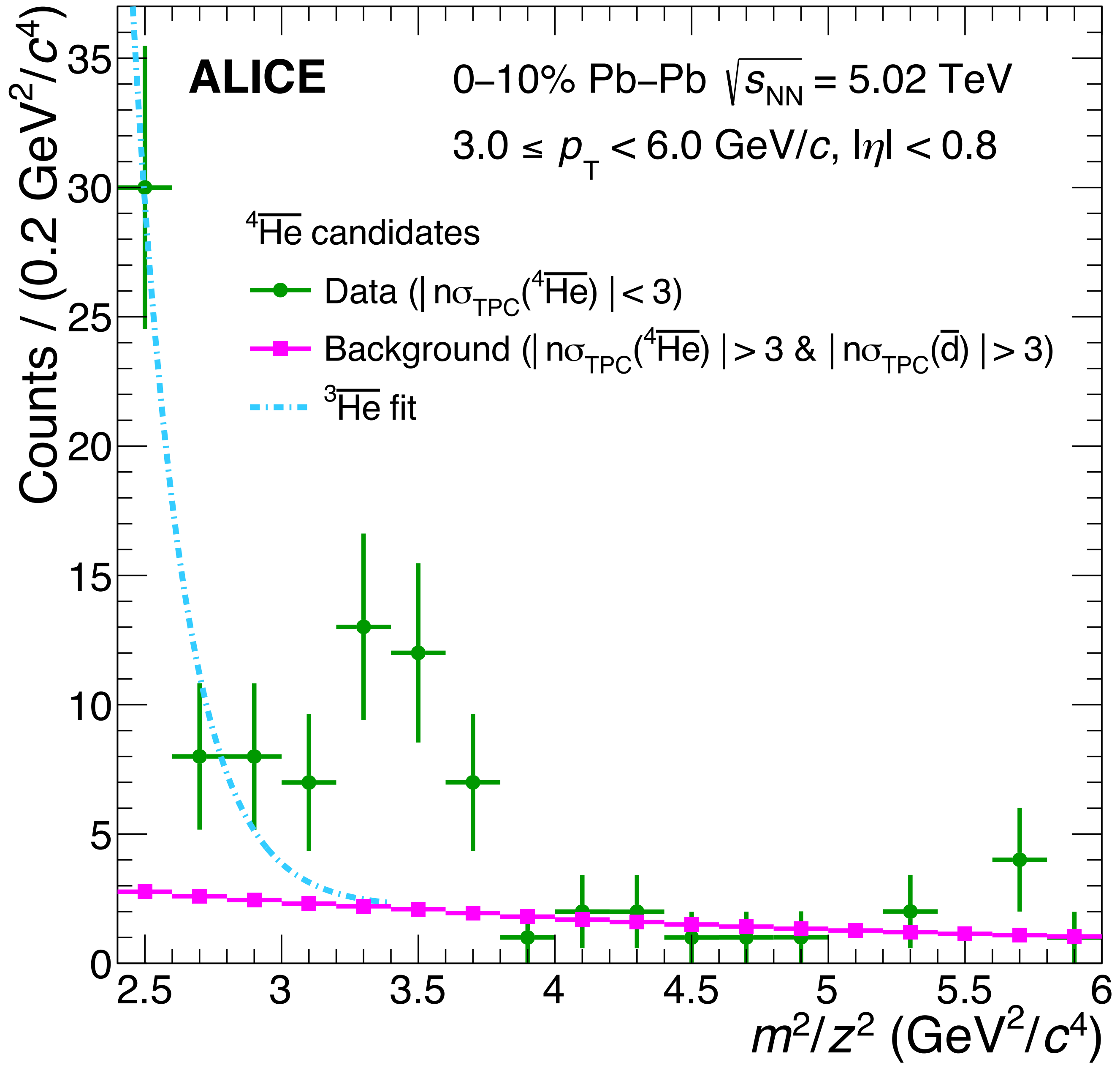


ALICE *Phys. Rev.* C107 (2023) 064904
ALICE *Phys. Rev. Lett.* 128 (2022) 252003

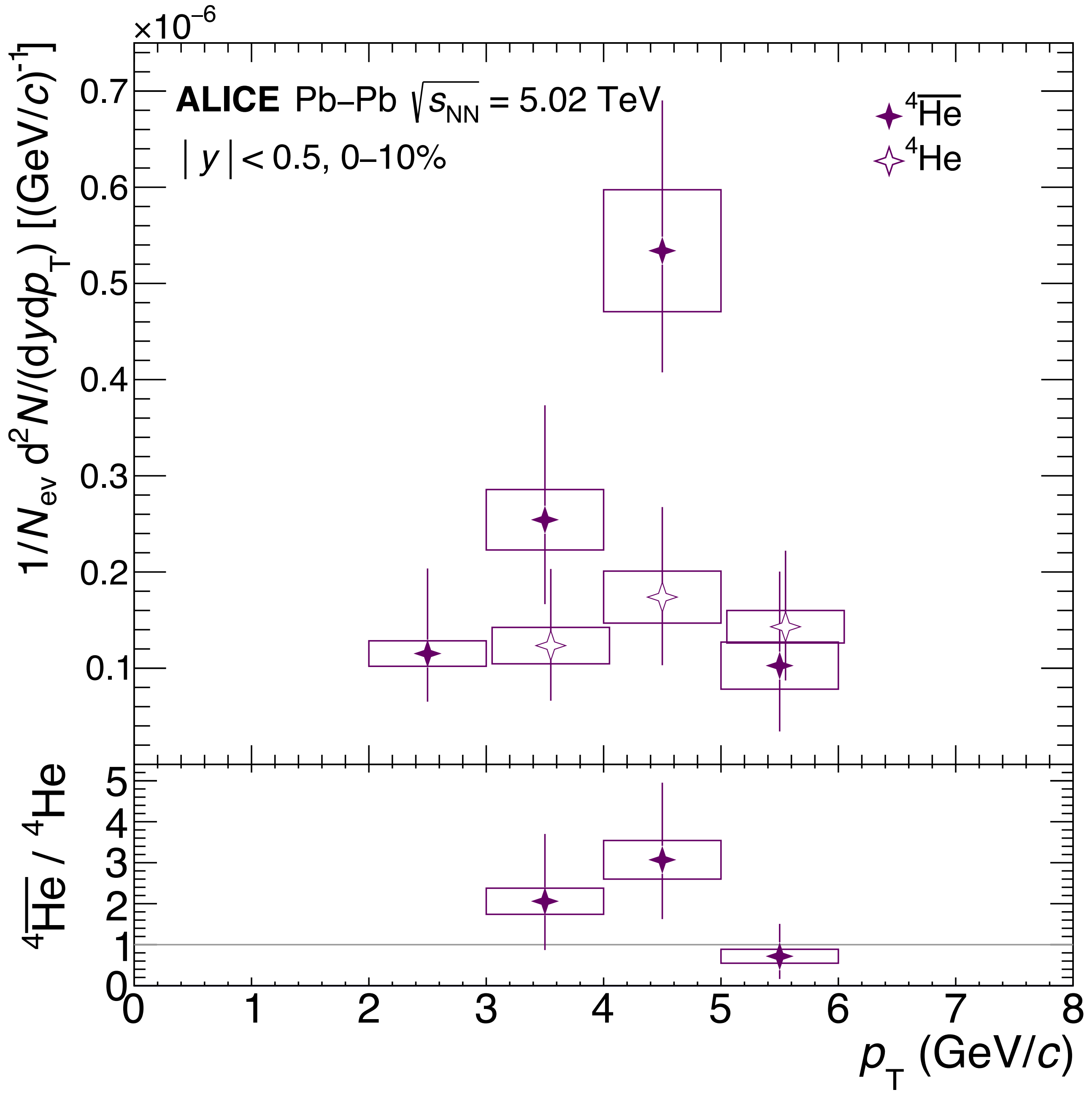


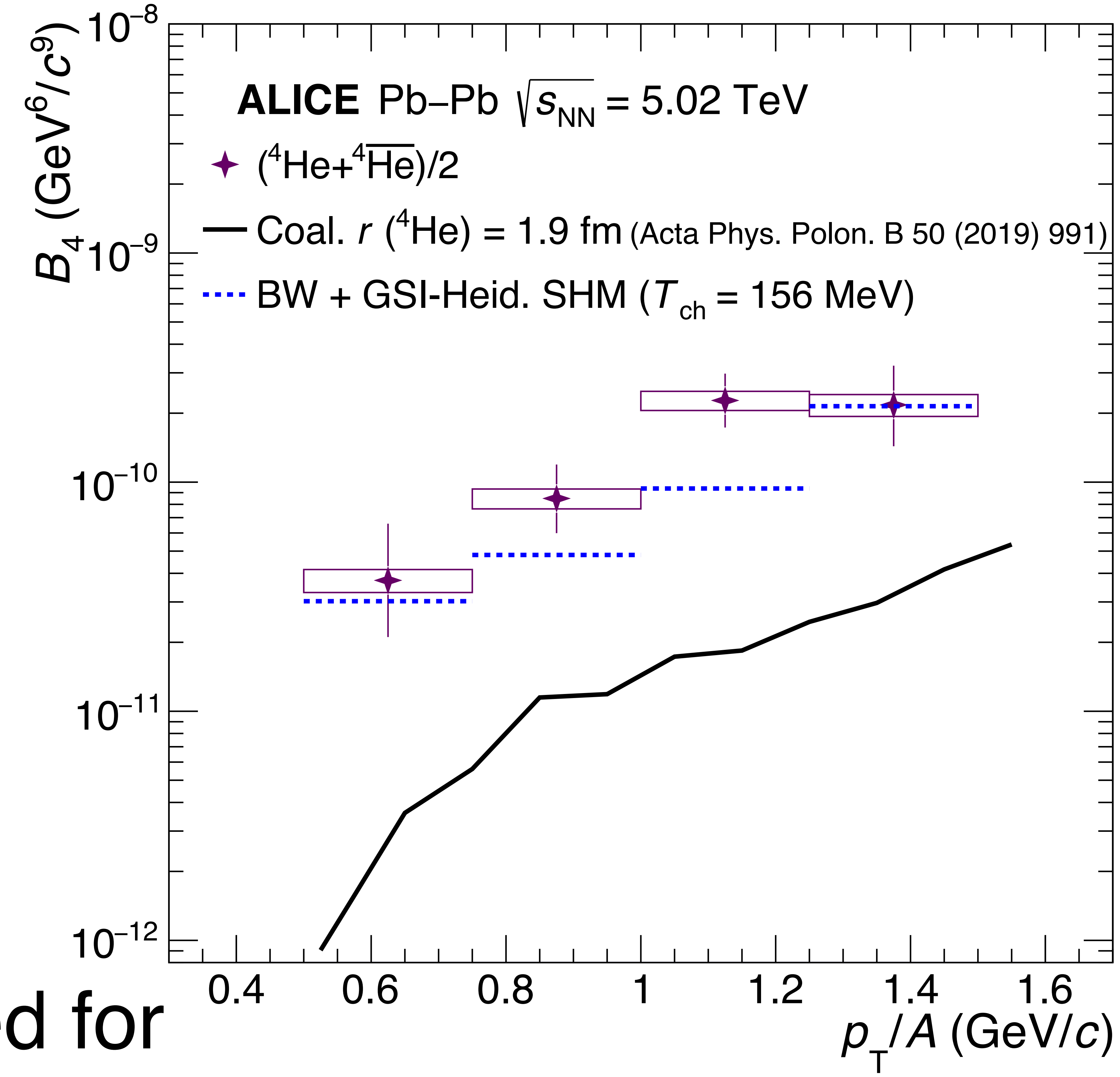
- Two approaches that describe light/hyper nuclei production
  - ➡ Statistical hadronization models (SHM): abundance is fixed at T_{ch}
  - ➡ Coalescence of nucleons: associated with T_{kin}
- Data of deuterium, tritium, ^{3}He and hypertriton prefers coalescence

Alpha production at the LHC



ALICE arXiv:2311.11758

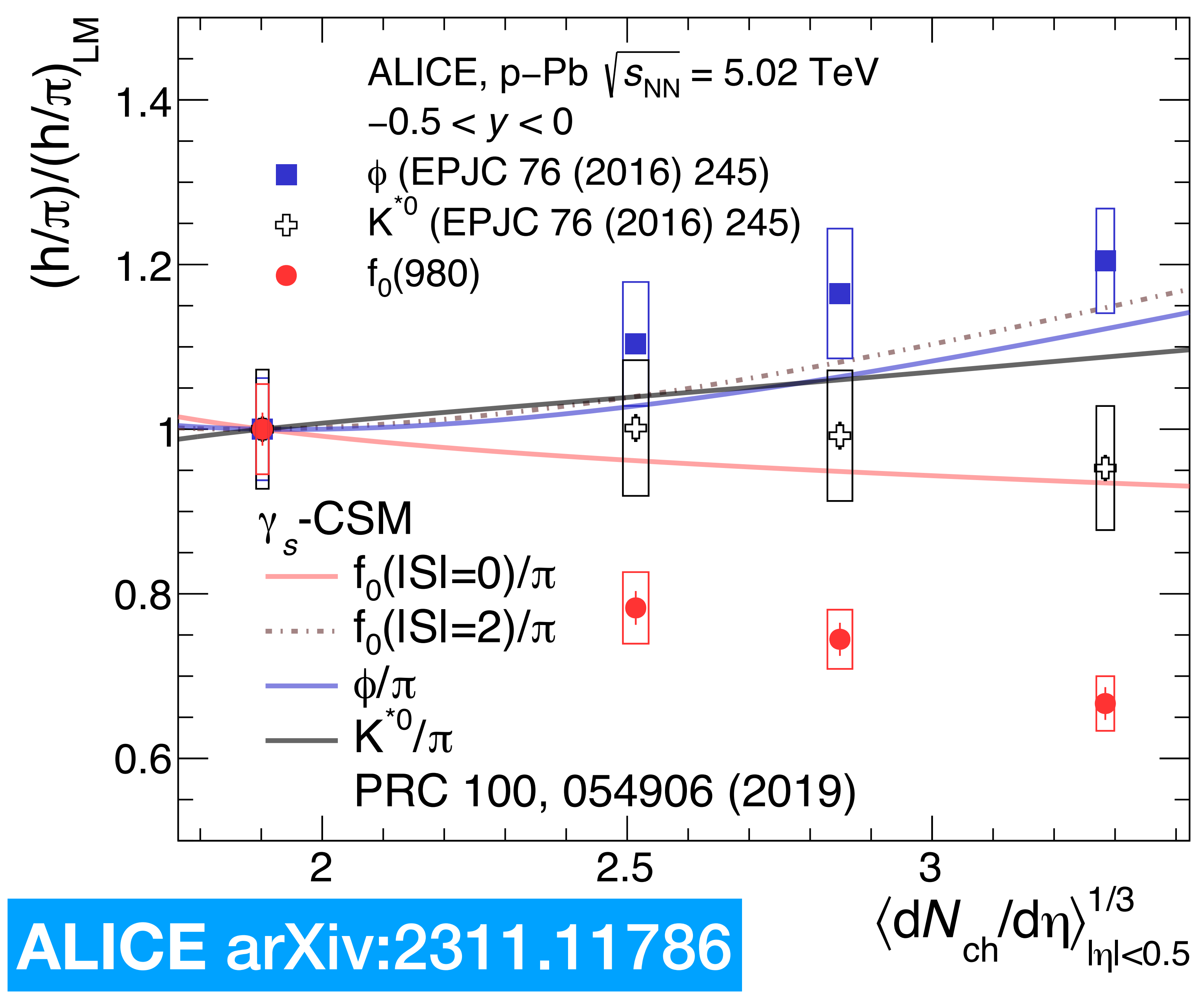


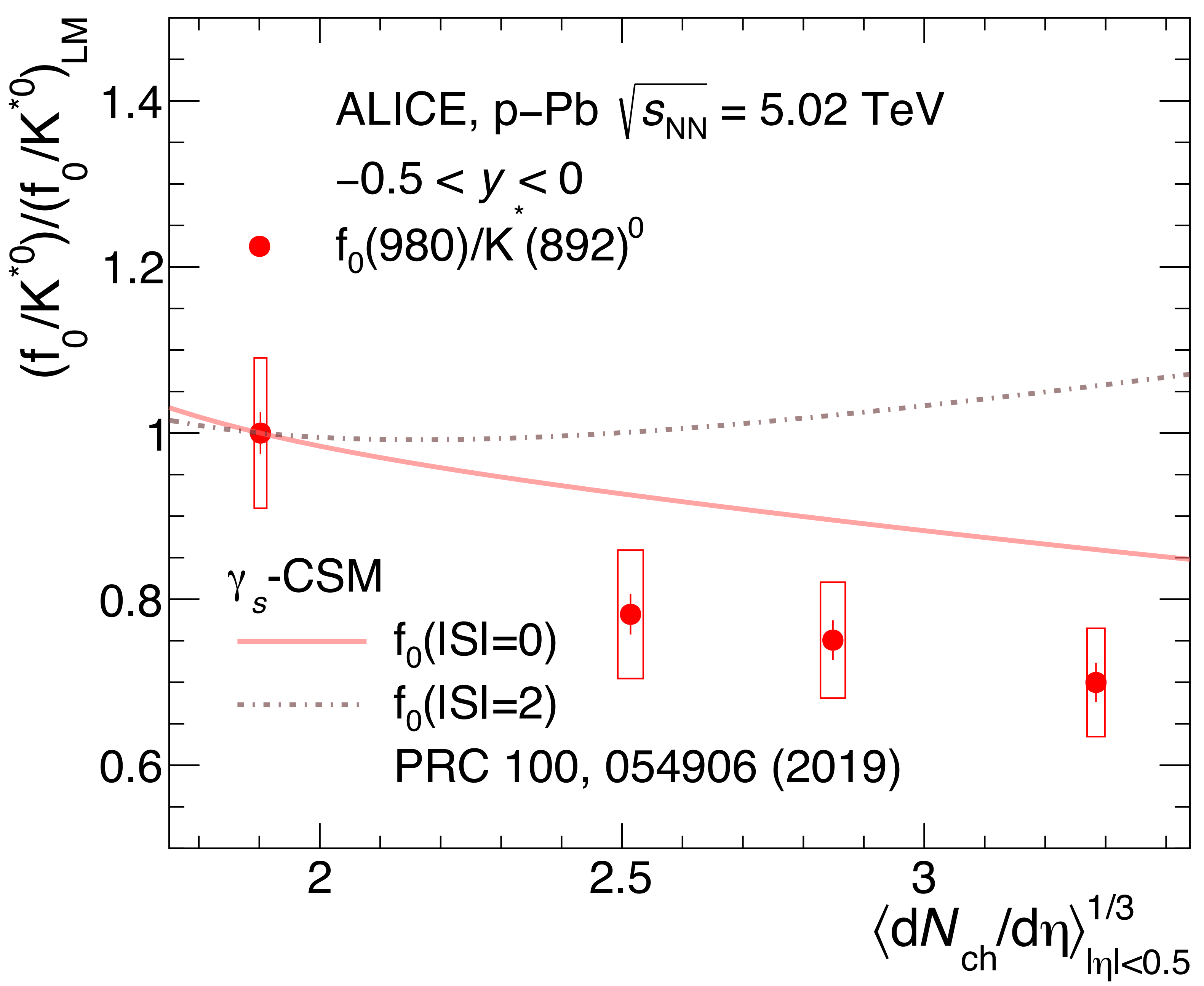


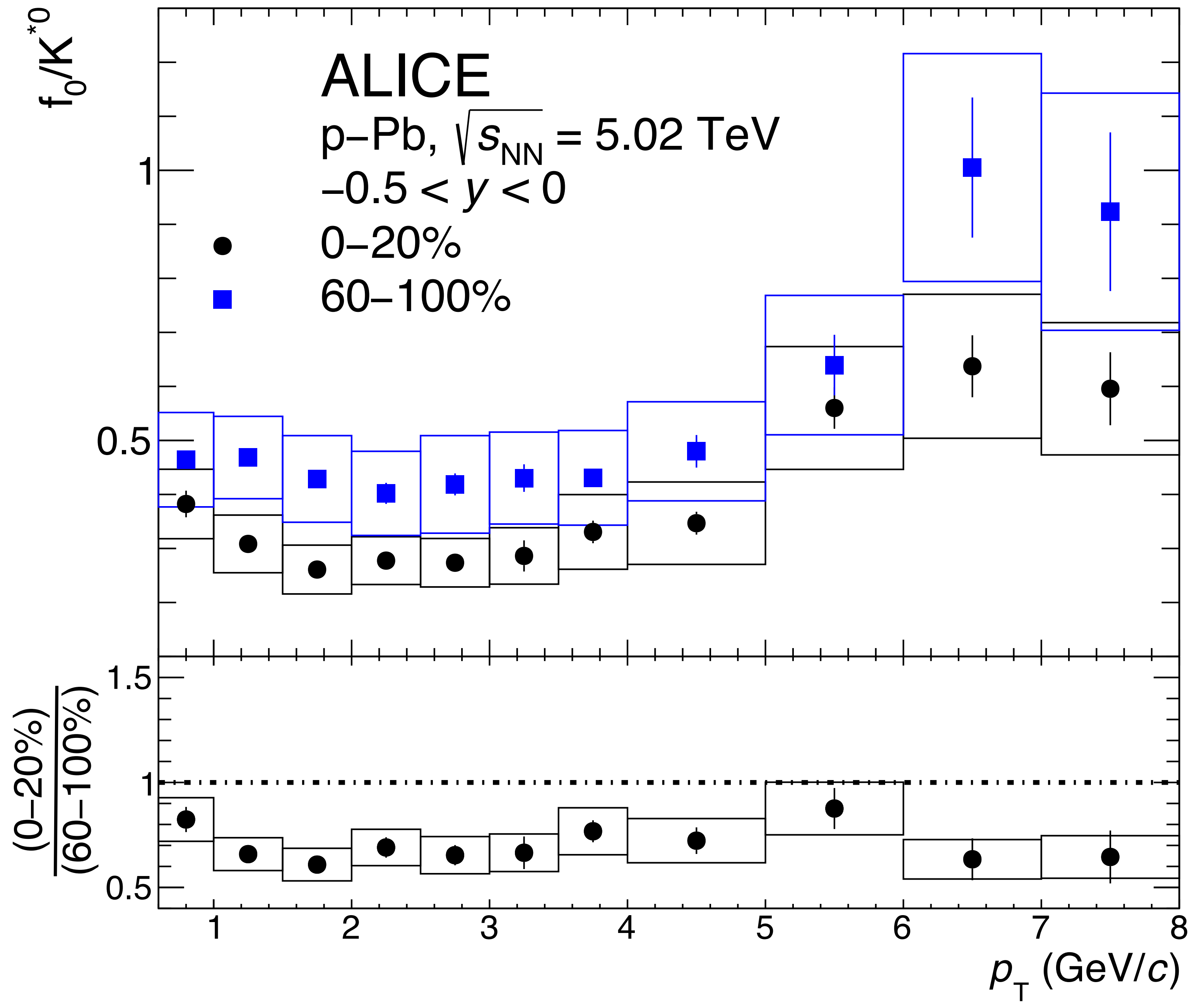
- Anti-alpha p_T-differential distribution is measured for the first time at the LHC
- (Anti-)alpha production is underestimated by the coalescence mode – different picture from light nuclei

$$B_A = E_A \frac{d^3E_A}{dp_A^3}\left(E_p \frac{d^3E_p}{dp_p^3}\right)^{-1}$$

Abnormal $f_0(980)$ suppression







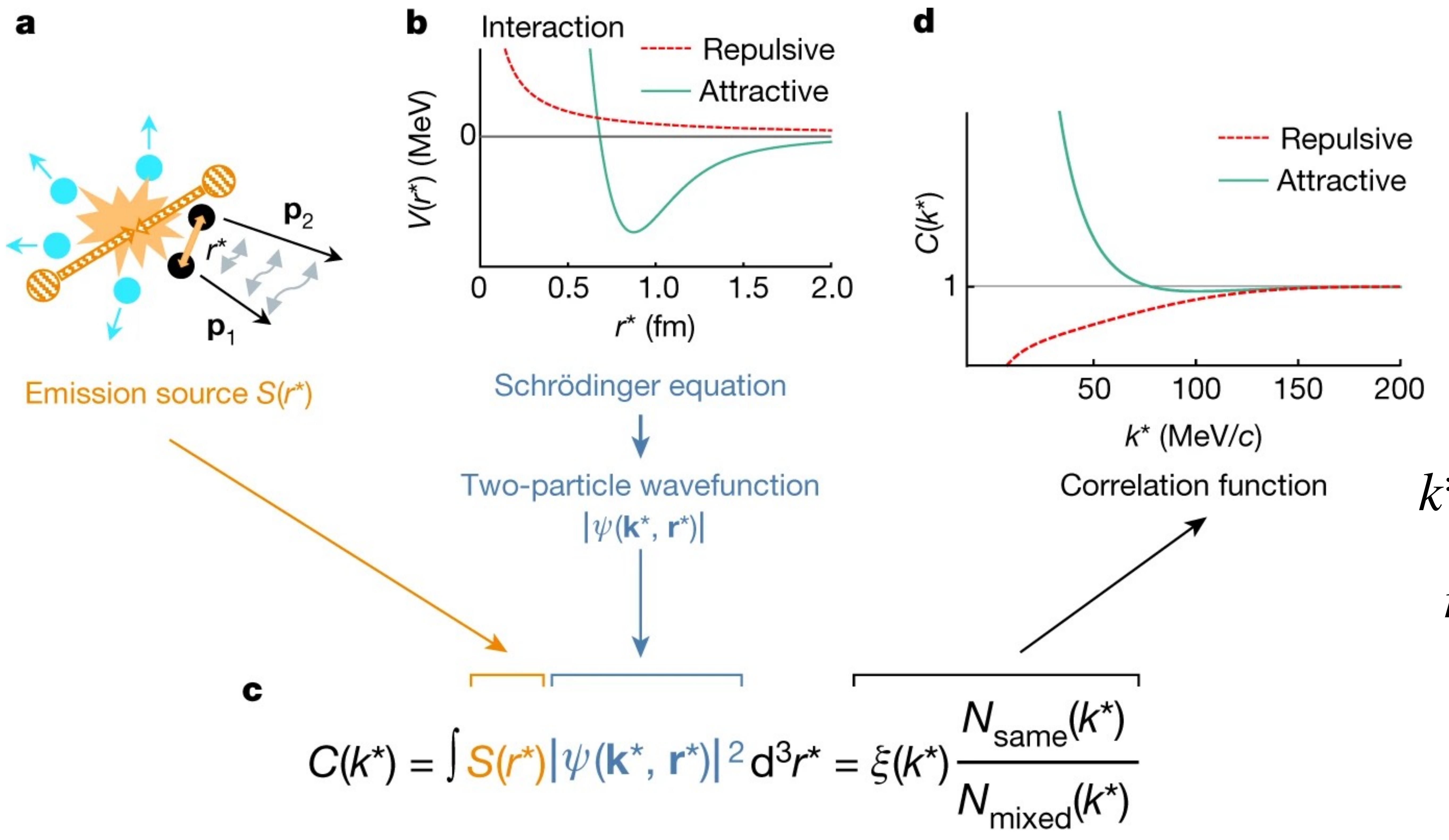
ALICE arXiv:2311.11786

$f_0(980)$ – meson, tetraquark or K-Kbar molecule?

- ϕ/π: increases with multiplicity (system size): strange enhancement
- K^{*0}/π: insensitive to multiplicity: strange enhancement vs. rescattering
- $f_0(980)/K^{*0}$: less sensitive to hadronic interactions

➡ Suggest hidden |S| = 0 and a conventional meson scenario

Unveiling strong interactions

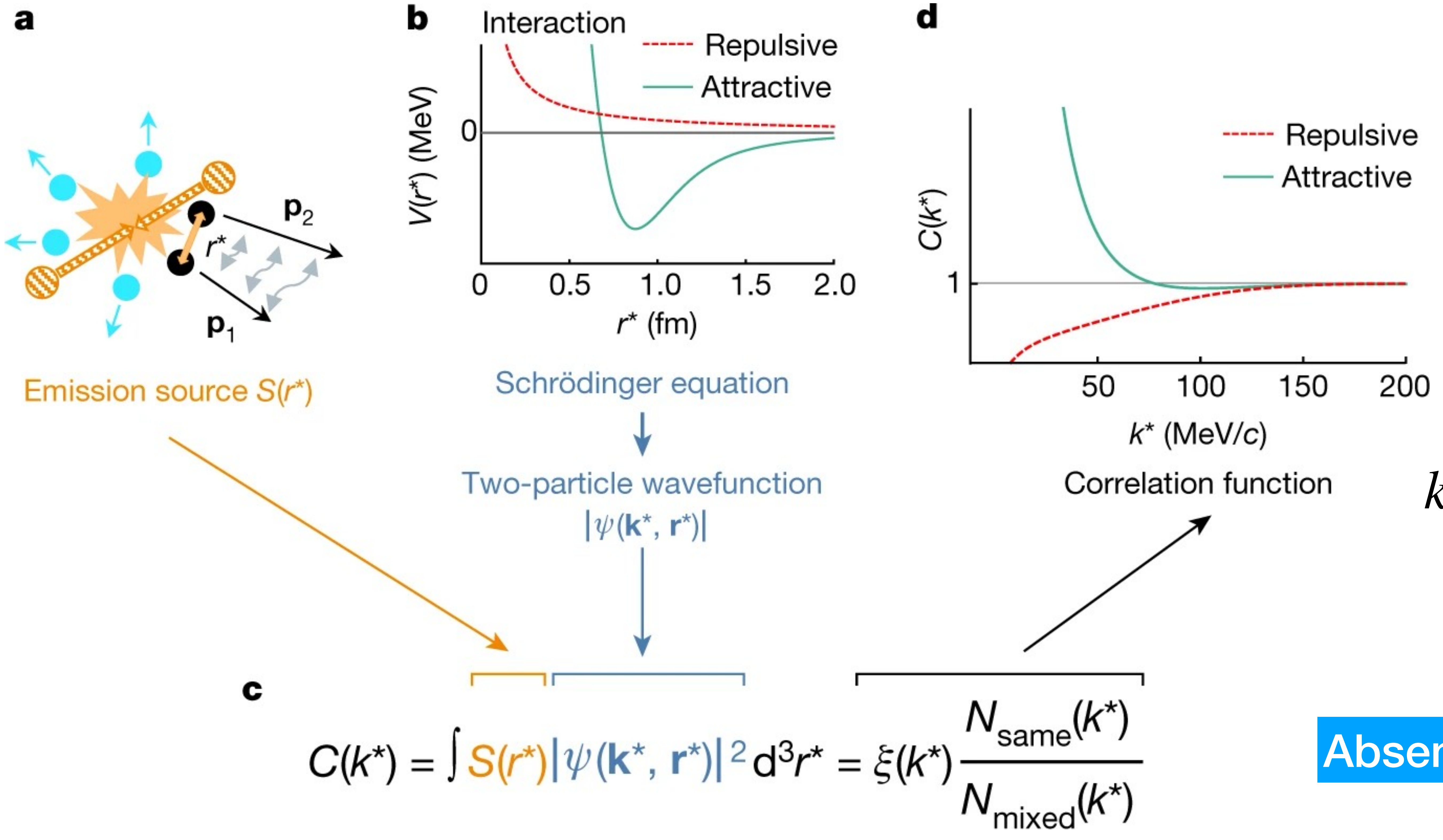


$$k^* = |\vec{p}_1^* - \vec{p}_2^*|/2$$

$$r^* = |\vec{r}_1^* - r_2^*|$$

- Further constraints on the residual strong interaction between NN, YN and YY
- Important input of EoS of neutron stars

Unveiling strong interactions



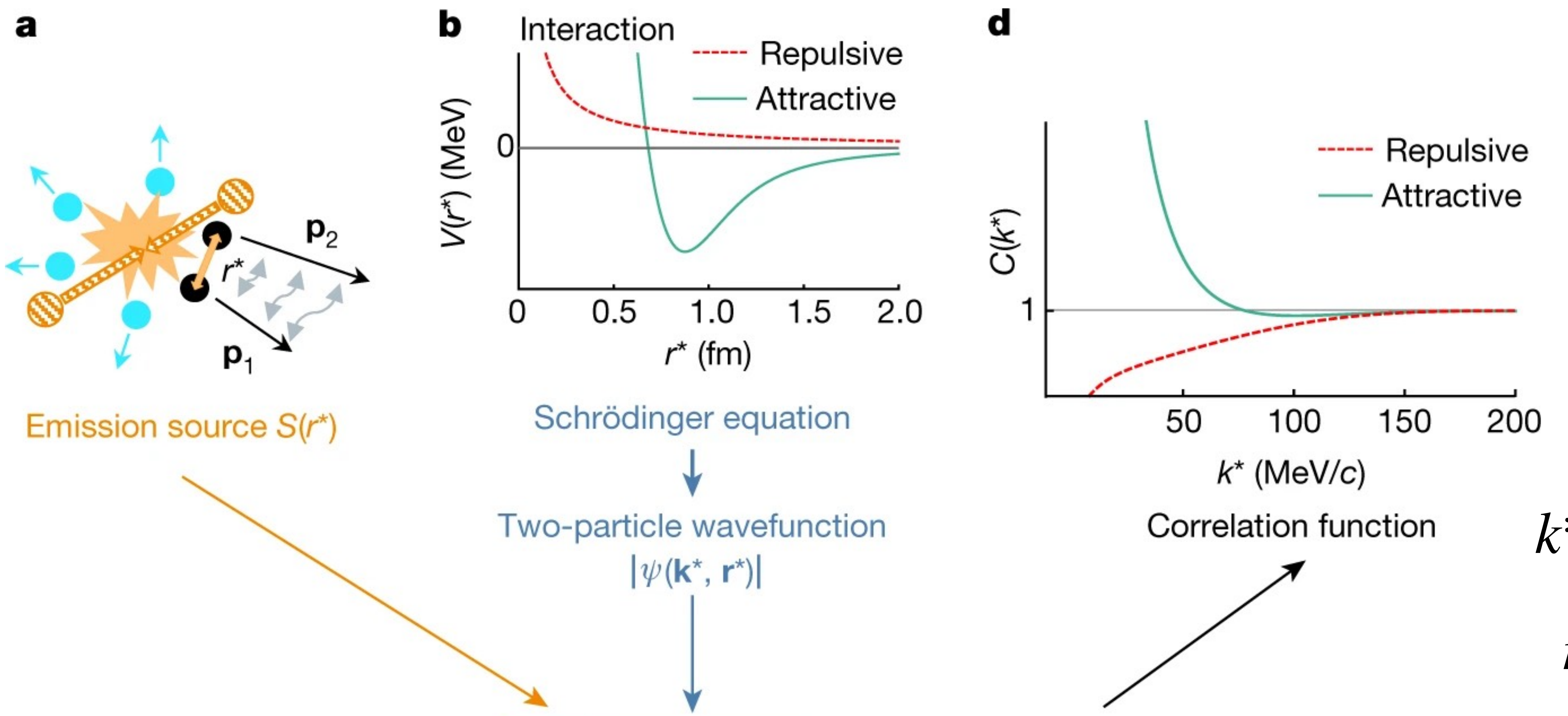
$$k^* = |\vec{p}_1^* - \vec{p}_2^*|/2$$

$$r^* = |\vec{r}_1^* - r_2^*|$$

Absence interaction $C(k^*) = 1$

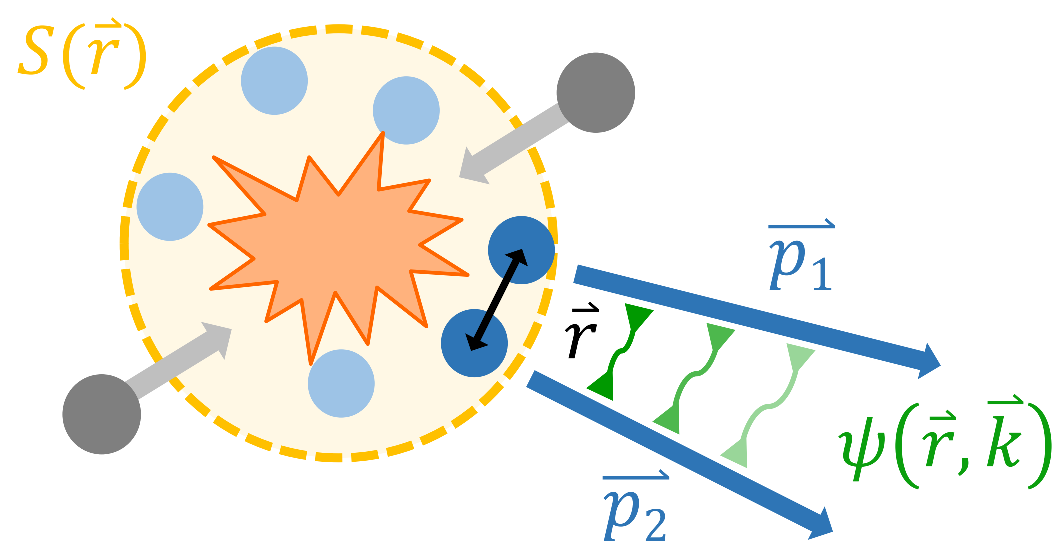
- Further constraints on the residual strong interaction between NN, YN and YY
- Important input of EoS of neutron stars

Unveiling strong interactions



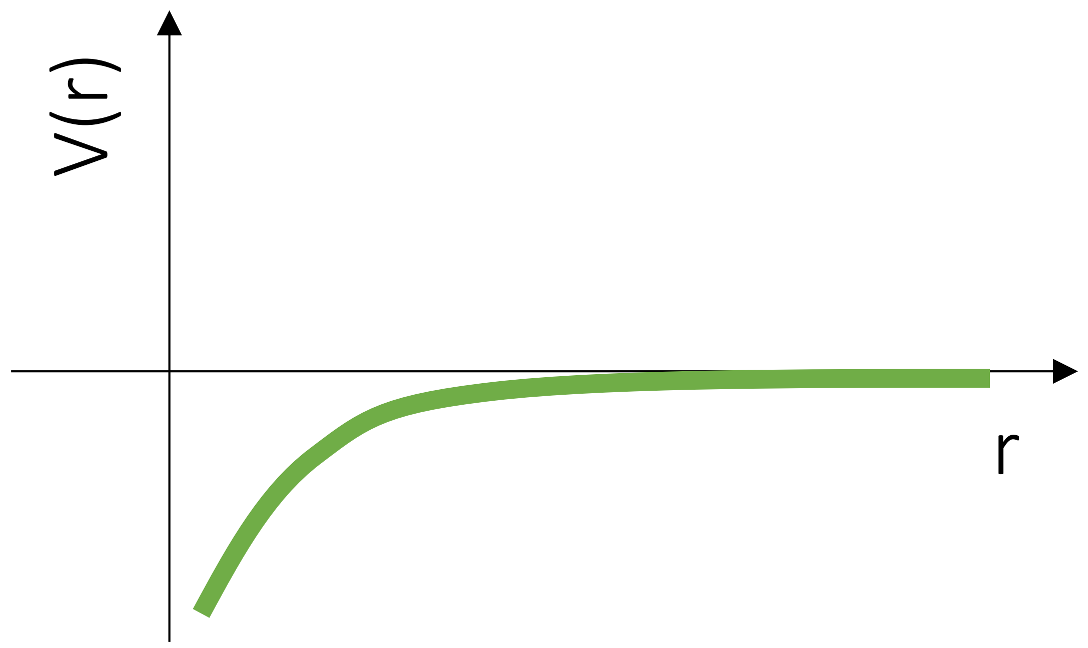
c

$$C(k^*) = \int S(r^*) |\psi(\mathbf{k}^*, \mathbf{r}^*)|^2 d^3 r^* = \xi(k^*) \frac{N_{same}(k^*)}{N_{mixed}(k^*)}$$



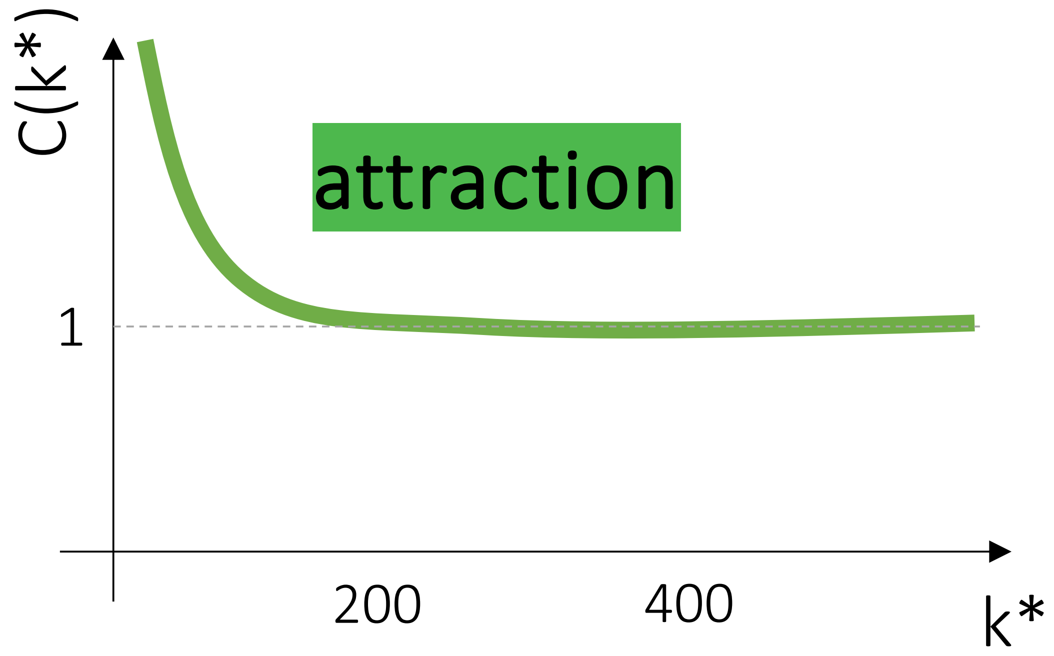
$$k^* = |\vec{p}_1^* - \vec{p}_2^*|/2$$

$$r^* = |\vec{r}_1^* - r_2^*|$$



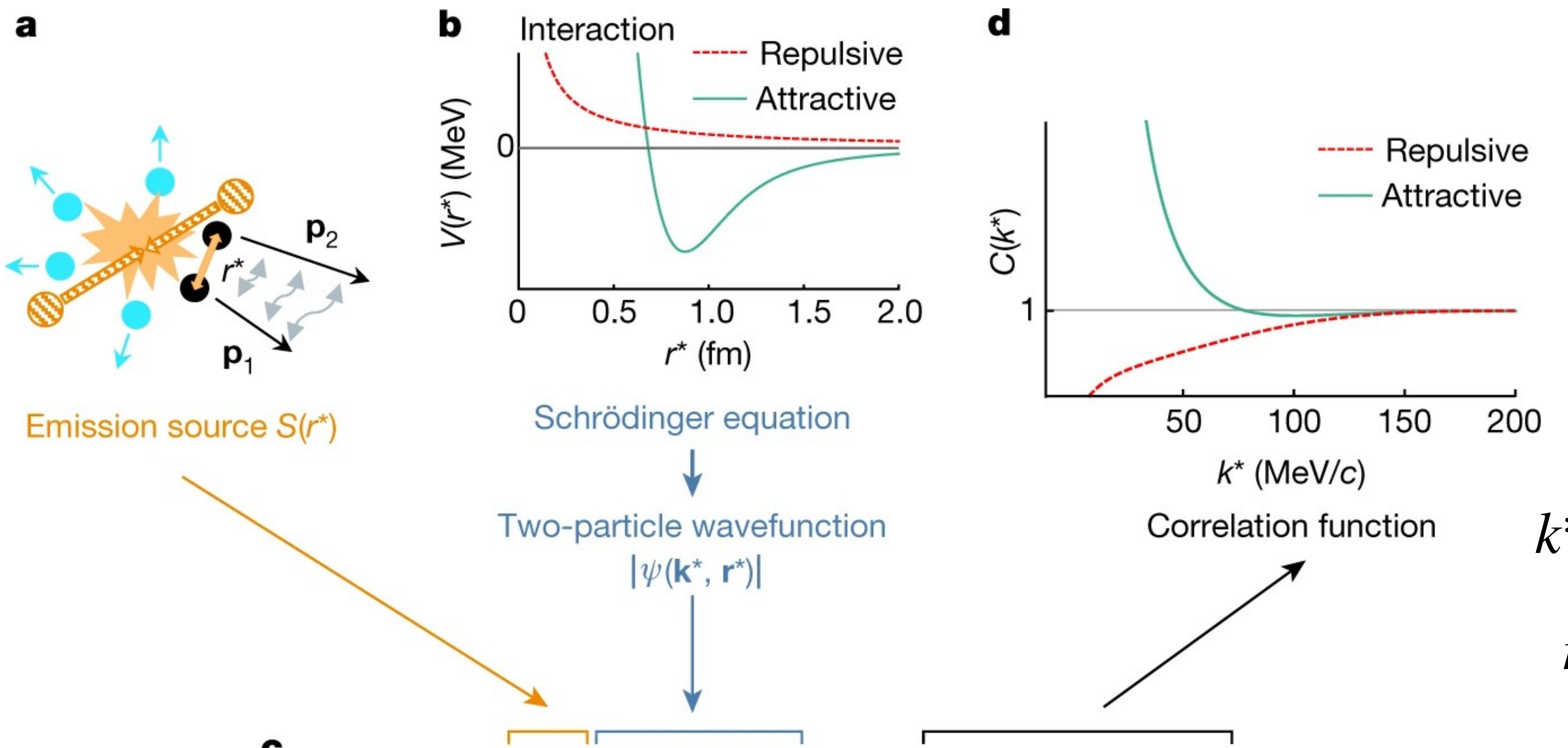
Absence interaction C(k^*) = 1

Attractive potential C(k^*) > 1



- Further constraints on the residual strong interaction between NN, YN and YY
- Important input of EoS of neutron stars

Unveiling strong interactions

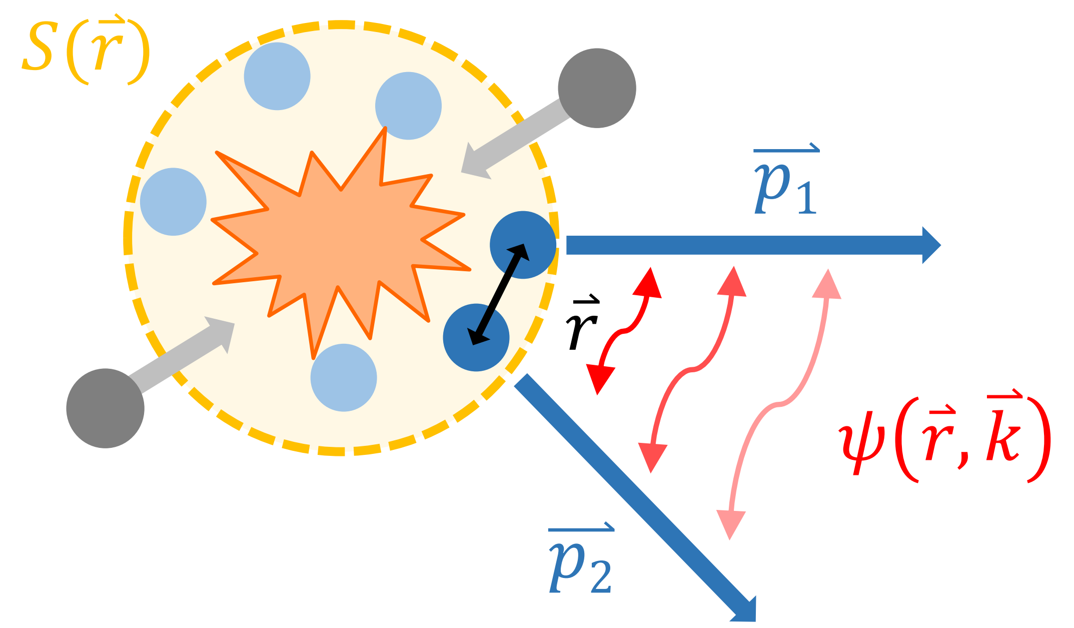


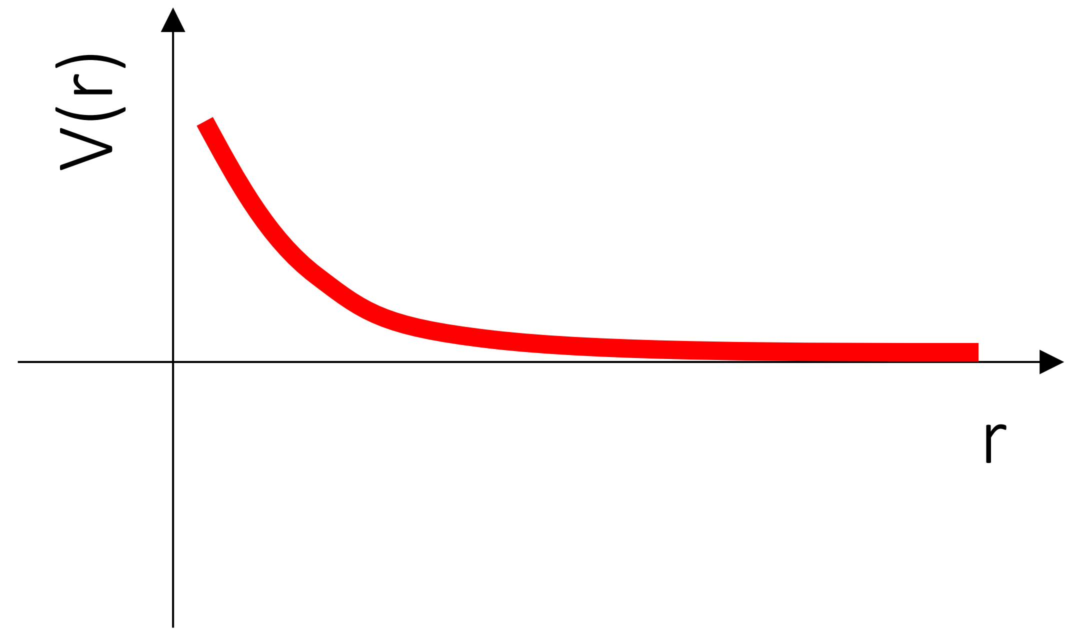
c

$$C(k^*) = \int S(r^*) |\psi(\mathbf{k}^*, \mathbf{r}^*)|^2 d^3 r^* = \xi(k^*) \frac{N_{same}(k^*)}{N_{mixed}(k^*)}$$

$$k^* = |\vec{p}_1^* - \vec{p}_2^*|/2$$

$$r^* = |\vec{r}_1^* - \vec{r}_2^*|$$

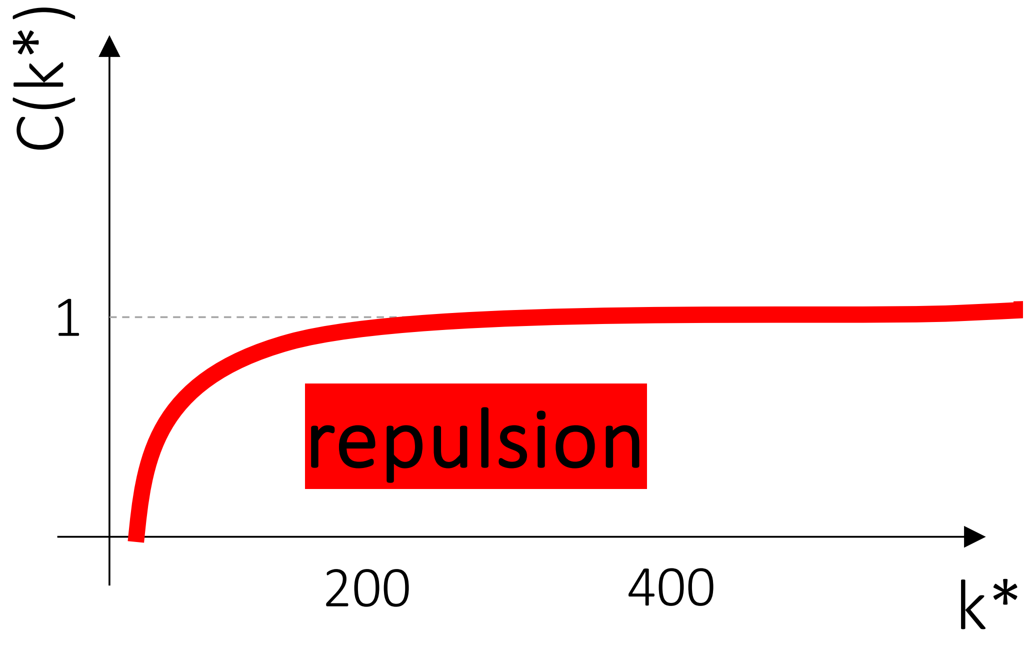




Absence interaction $C(k^*) = 1$

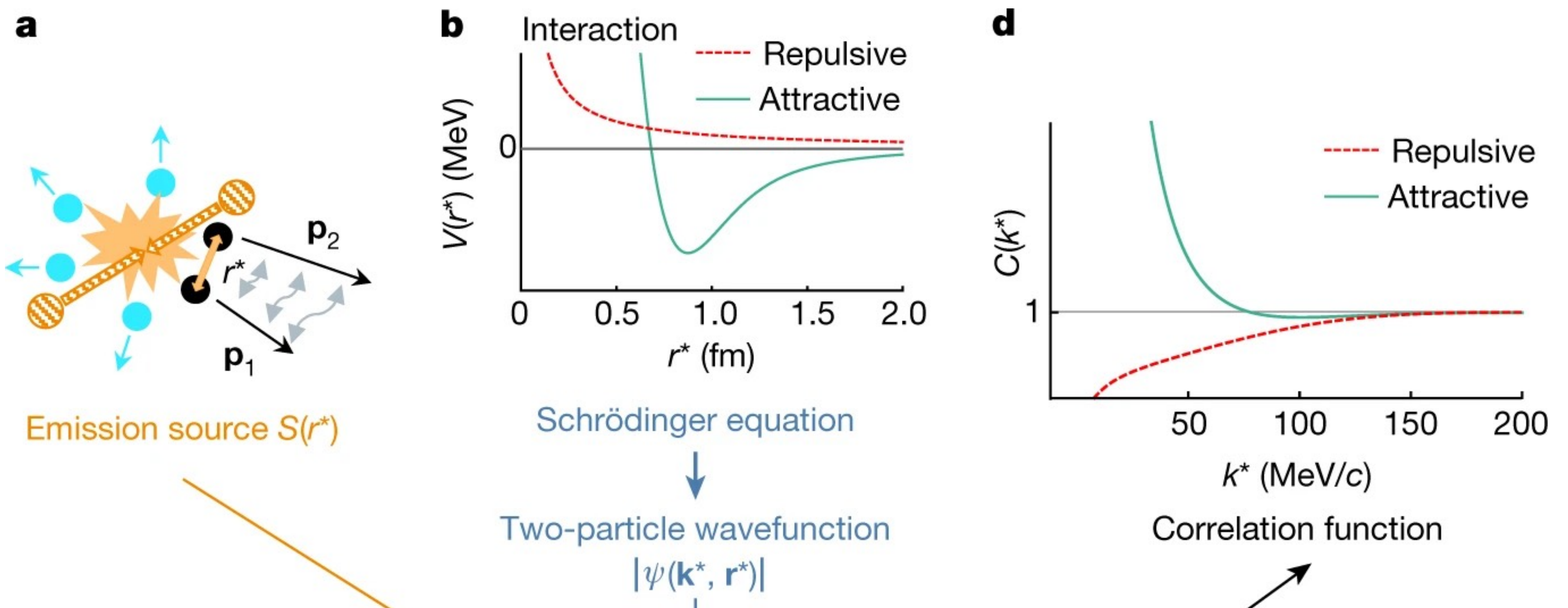
Attractive potential $C(k^*) > 1$

Repulsive potential $C(k^*) < 1$



- Further constraints on the residual strong interaction between NN, YN and YY
- Important input of EoS of neutron stars

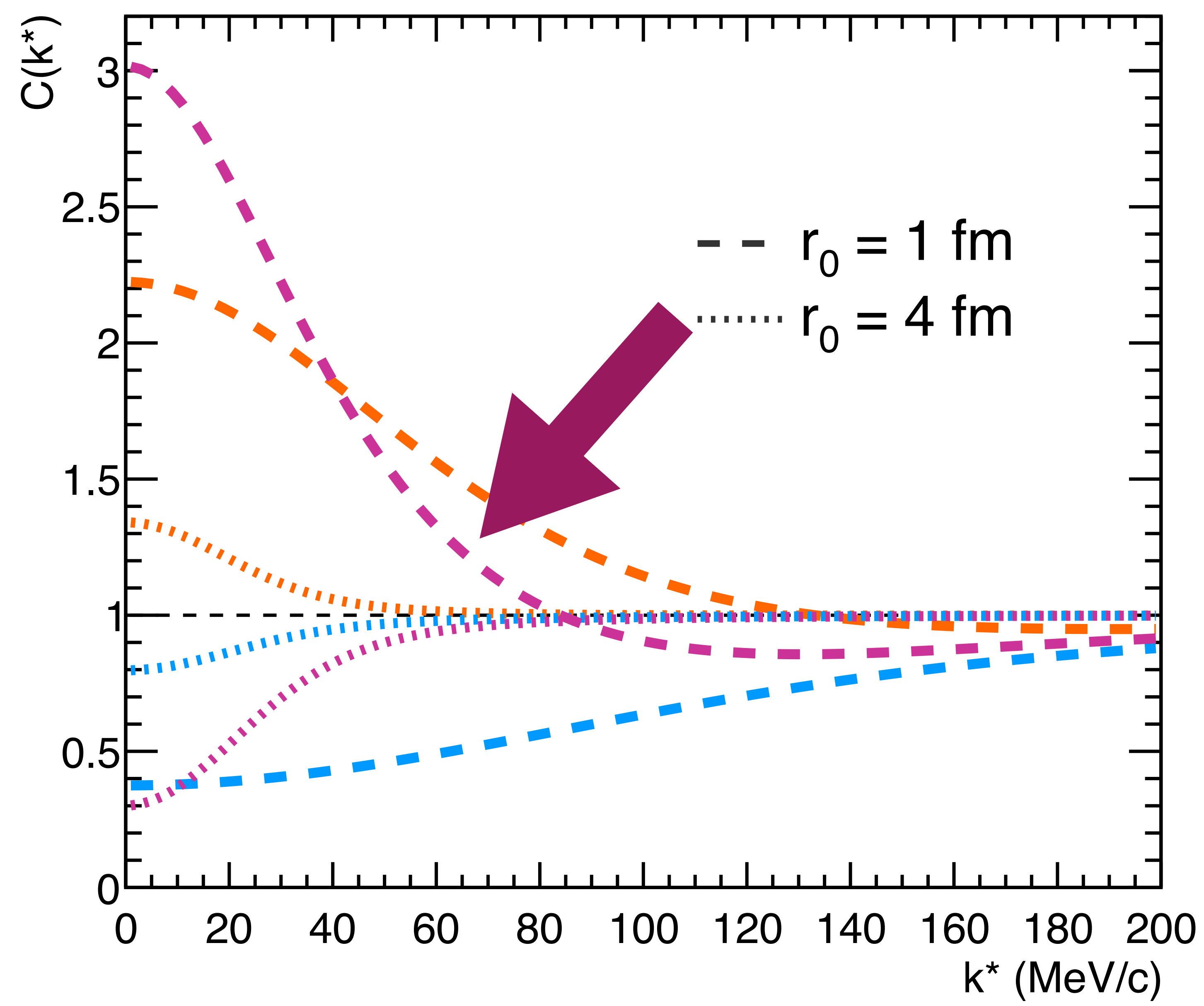
Unveiling strong interactions



c

$$C(k^*) = \int S(r^*)|\psi(\mathbf{k}^*, \mathbf{r}^*)|^2 d^3r^* = \xi(k^*)\frac{N_{same}(k^*)}{N_{mixed}(k^*)}$$

Ann. Rev. Nucl. Part. Sci. 71 (2021) 377

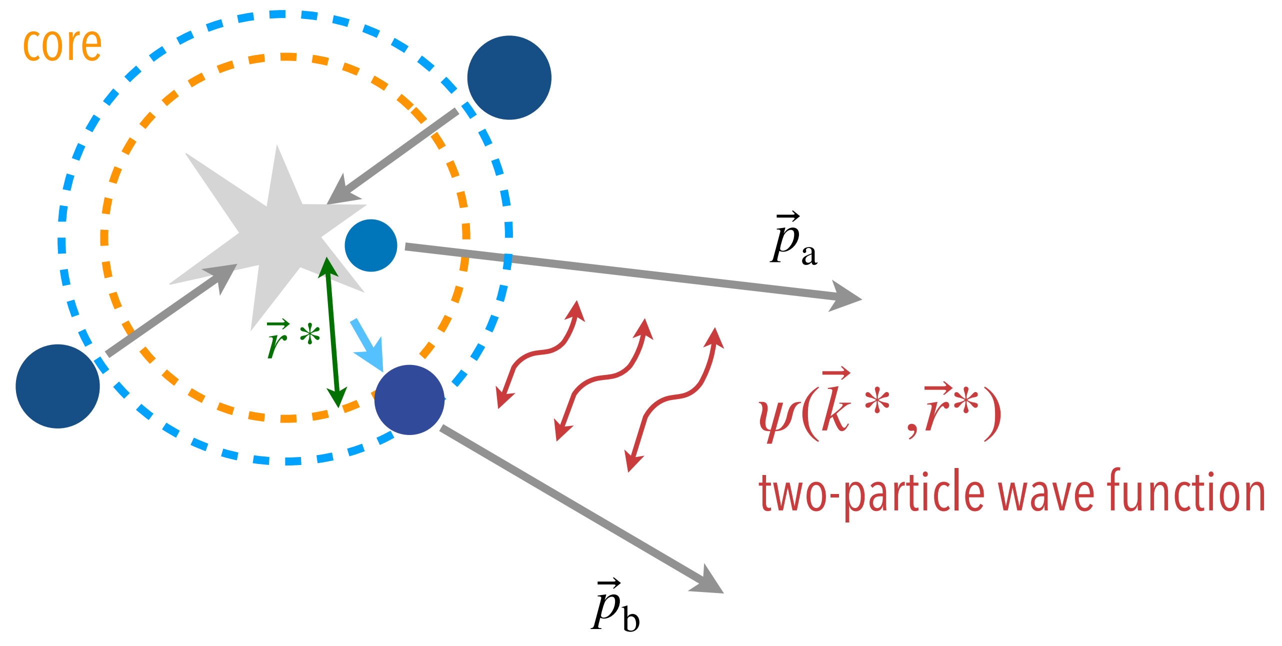


Absence interaction C(k*) = 1

Attractive potential C(k*) > 1

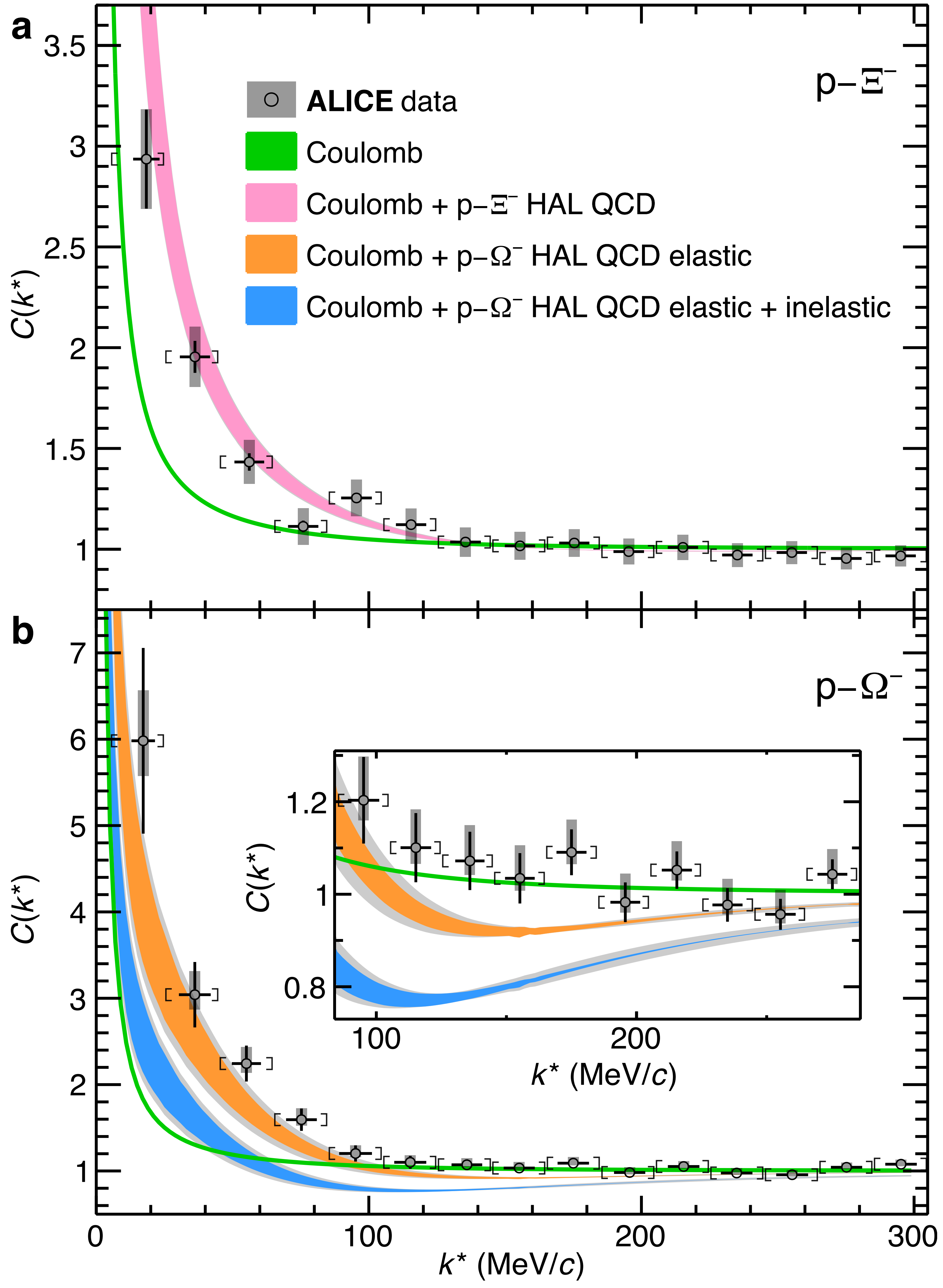
Repulsive potential C(k*) < 1

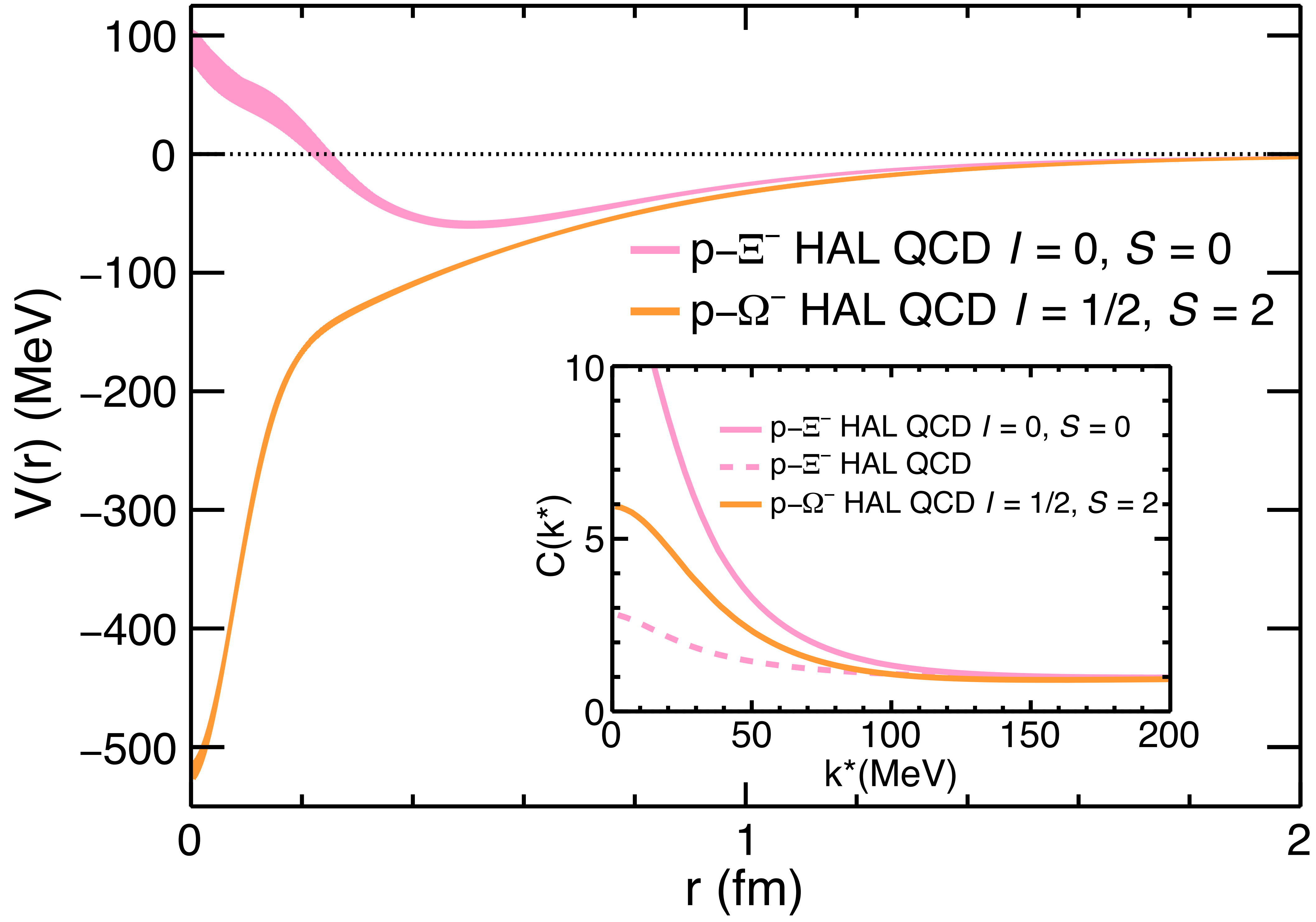
Bound-state formation C(k*) ≷ 1



- Further constraints on the residual strong interaction between NN, YN and YY
- Important input of EoS of neutron stars

Proton–hyperon interaction



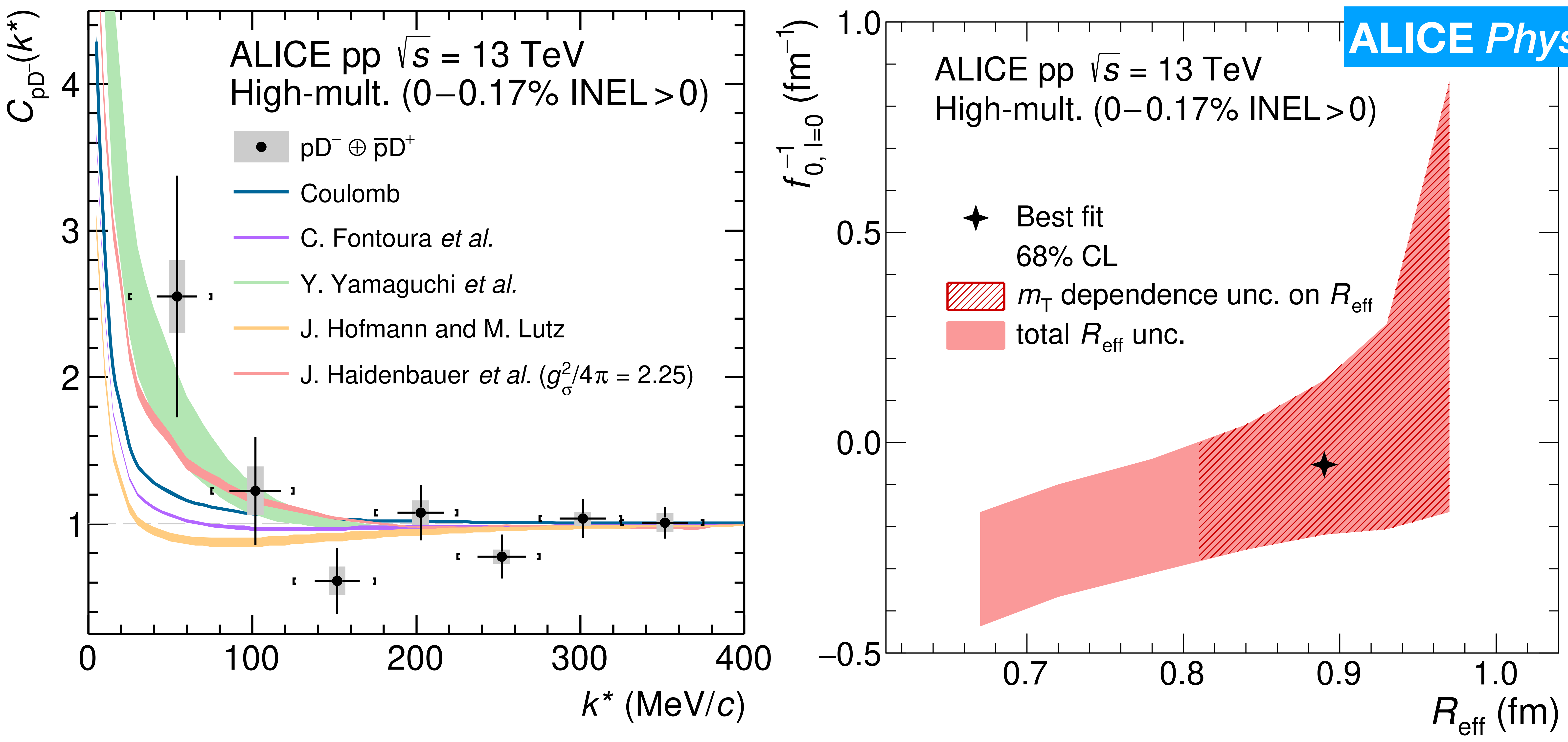


ALICE *Nature Physics* 588 (2020) 232

- p–Ω^- correlation signal is around two time larger than p–Ξ^-, large difference in strong interaction
- p–Ω bound-state is not yet observed in data

p–D- interactions

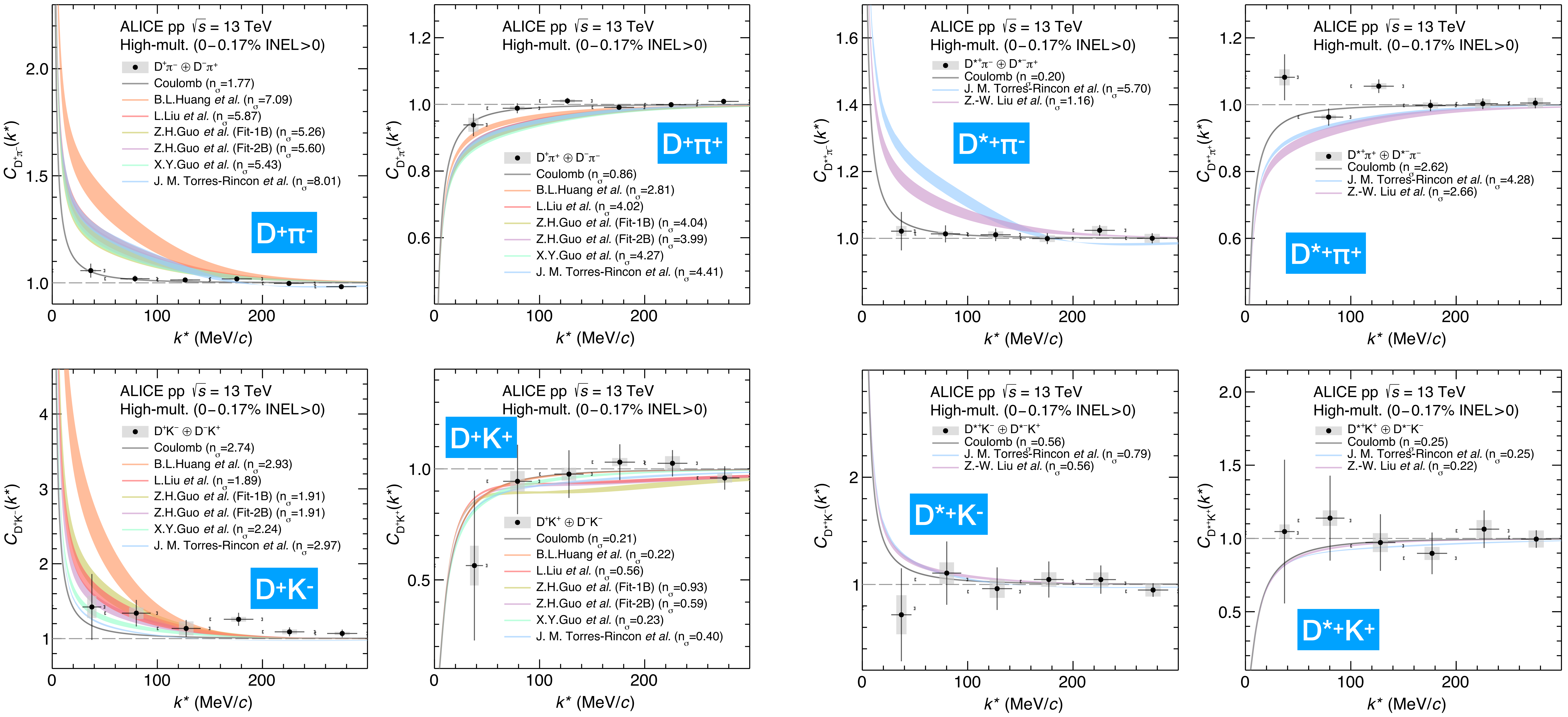
ALICE *Phys. Rev.* D106 (2022) 052010



- Data is compatible with the Coulomb-only interaction within 1.1–1.5σ
- Scattering length $f^{-1} \in [-0.4, 0.9]$ fm^{-1} for $I = 0$ at 68% CL

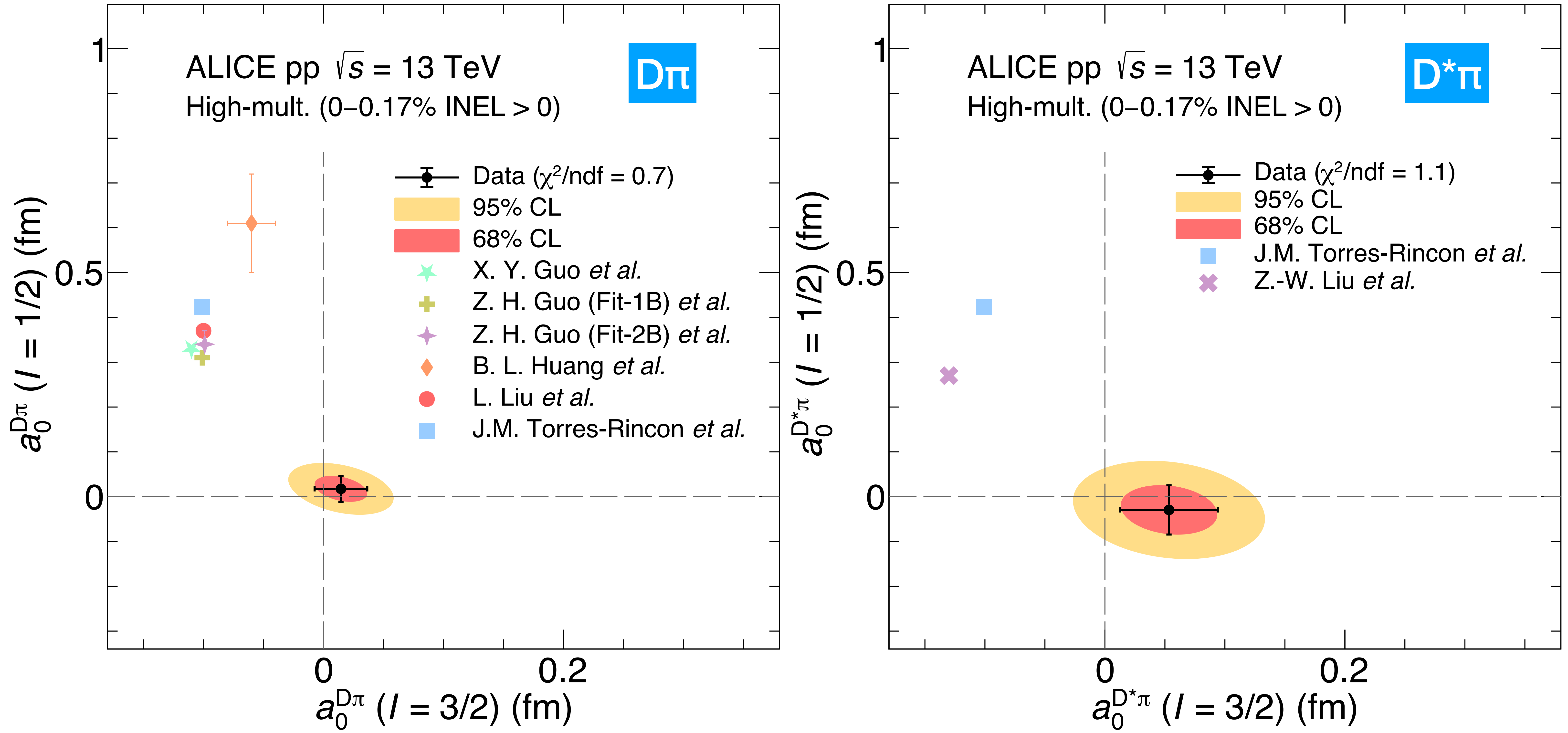
  ➡ Indicate either attractive interaction w/ or w/o bound-state formation
- Important for modeling charm quark transport in the quark-gluon plasma

D–π and D–K interactions



Correlation functions are compatible with the Coulomb-only hypothesis

D–π scattering length



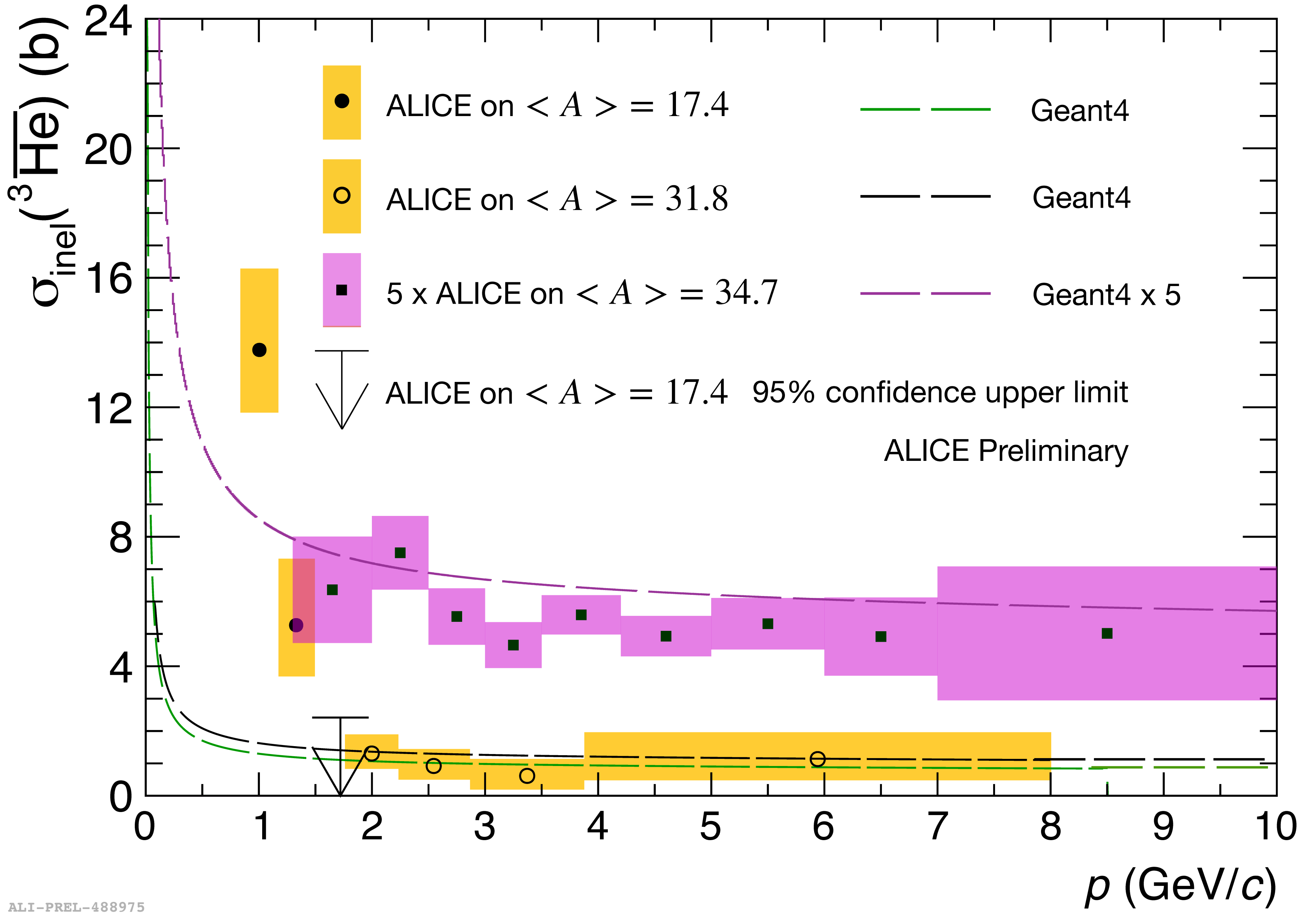
ALICE arXiv:2401.13541

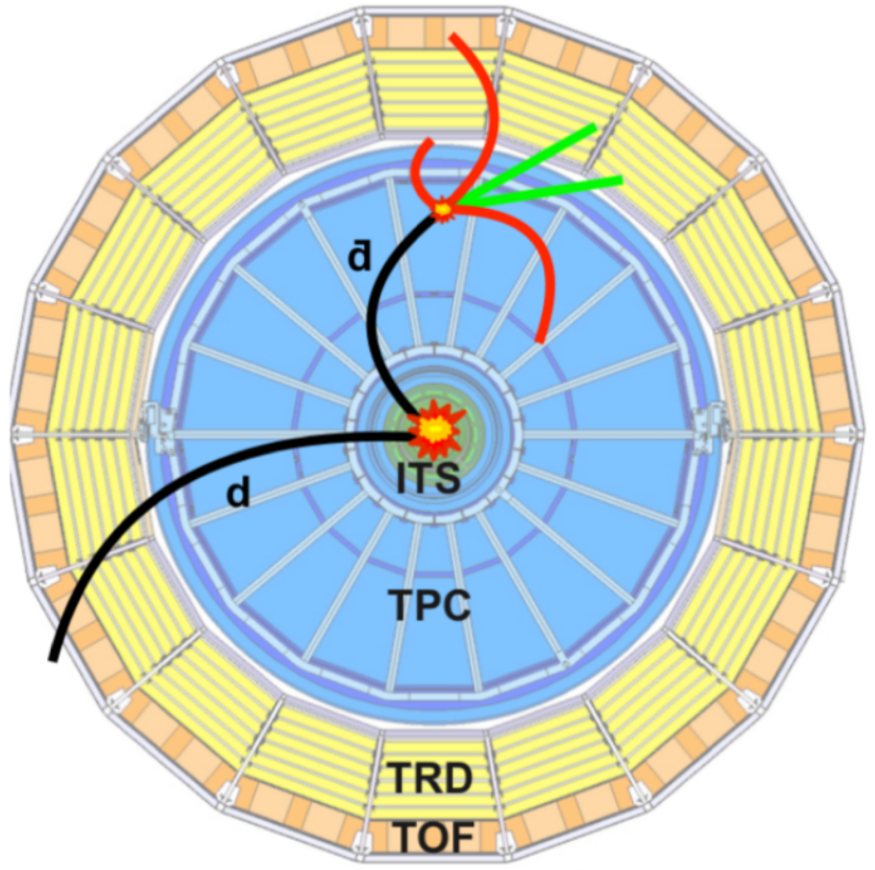
- Deviation between data and models including the strong interaction

➡ Challenging the current understanding on the residual strong interaction between D mesons and pions

- Indicate small or almost vanished scattering of D mesons with hadrons

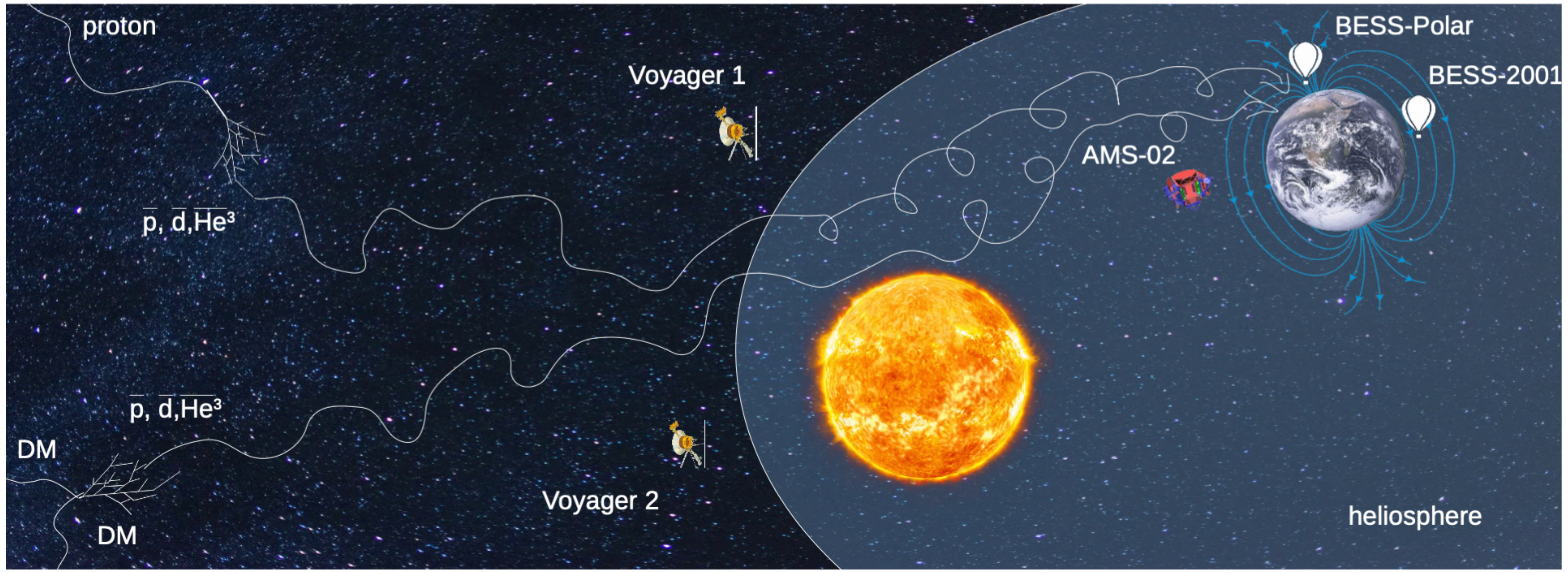
(Anti-)nuclei factory





- Production not yet fully understood
- Nucleon coalescence, statistical hadronizaton…
- New tool to study QGP hadronizaton

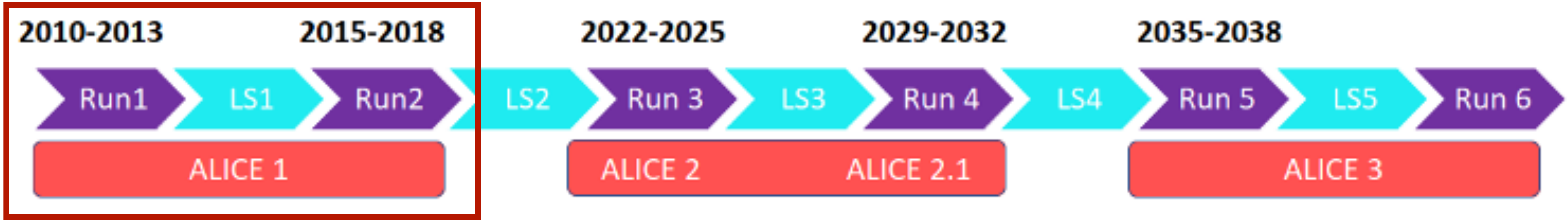
ALICE *Phys. Rev. Lett.* **127** (2021) 172301
Nature Phys. **19** (2023) 61

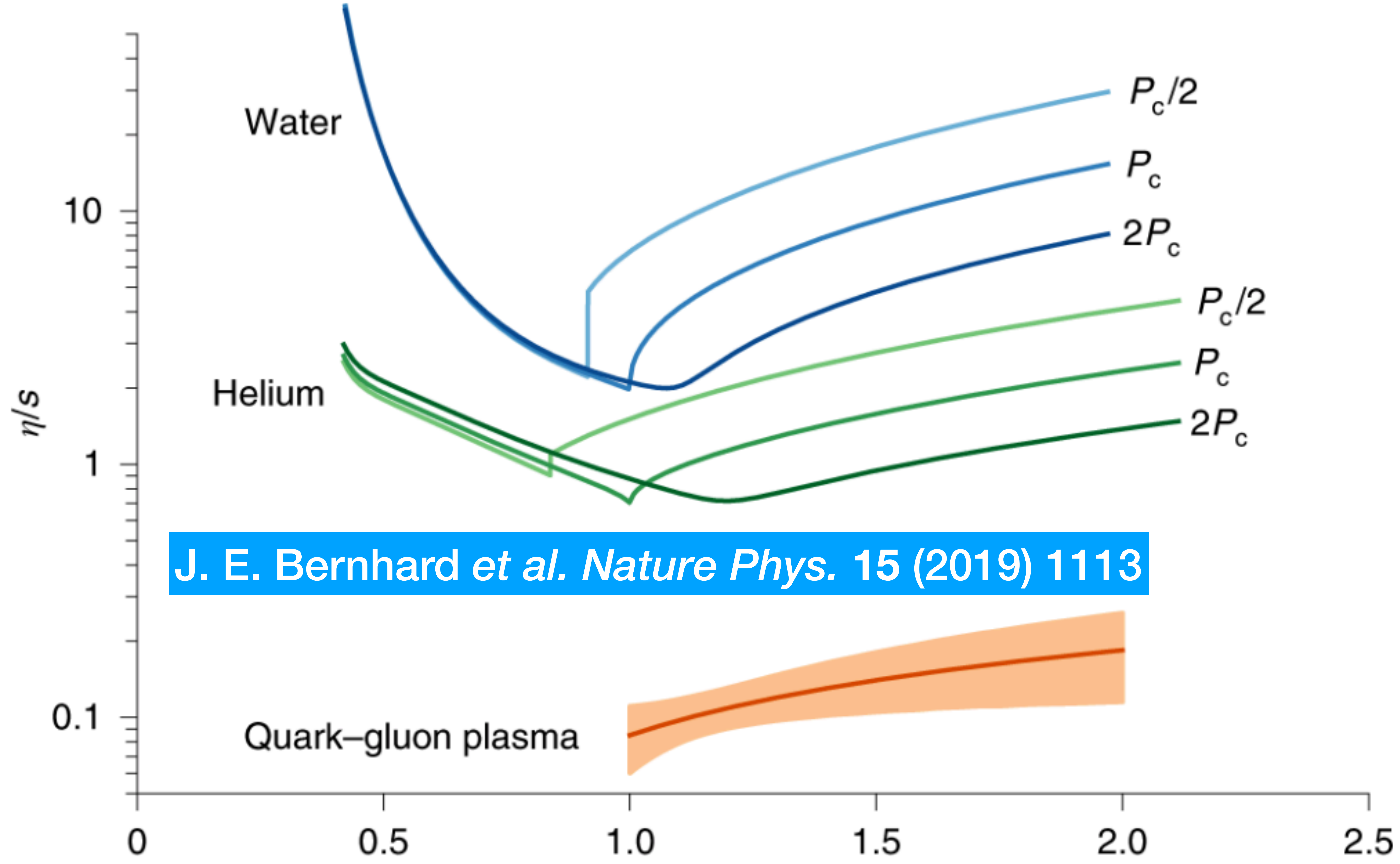


- Strong impact on Dark Matter searches, e.g.

➡ $\chi_0\chi_0 \rightarrow \bar{\text{d}}, \overline{^3\text{He}} + X$

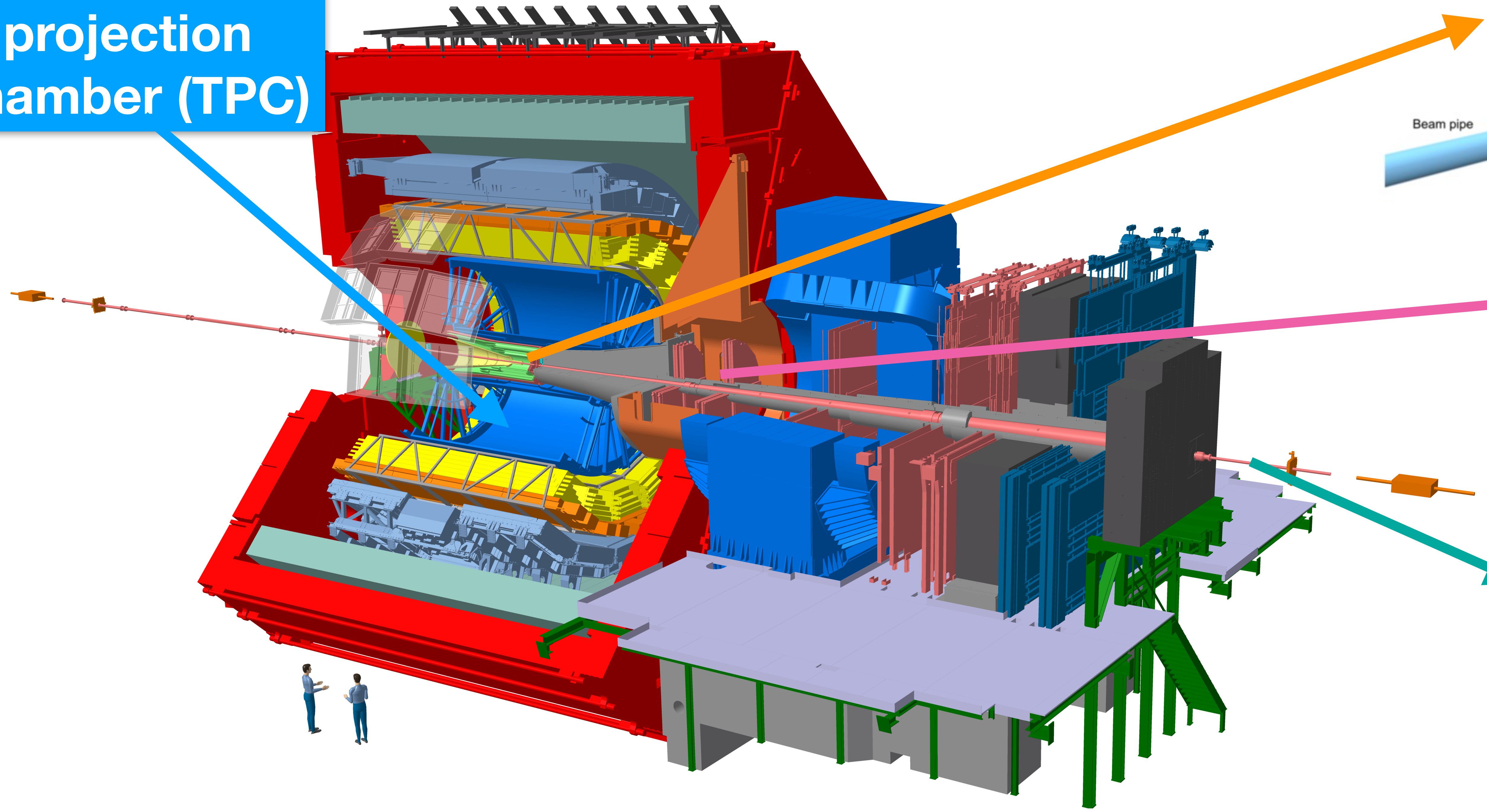
A journey through QCD

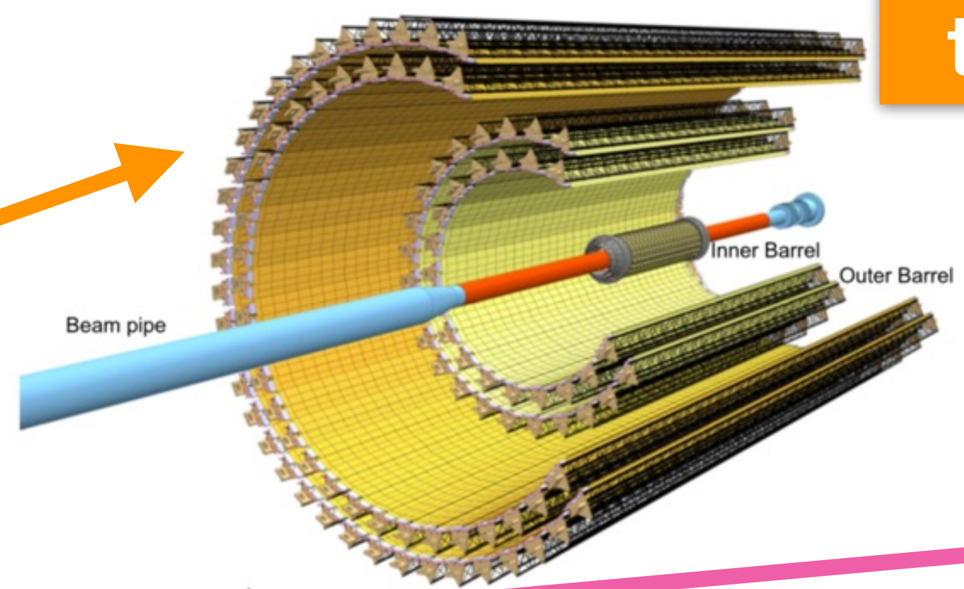




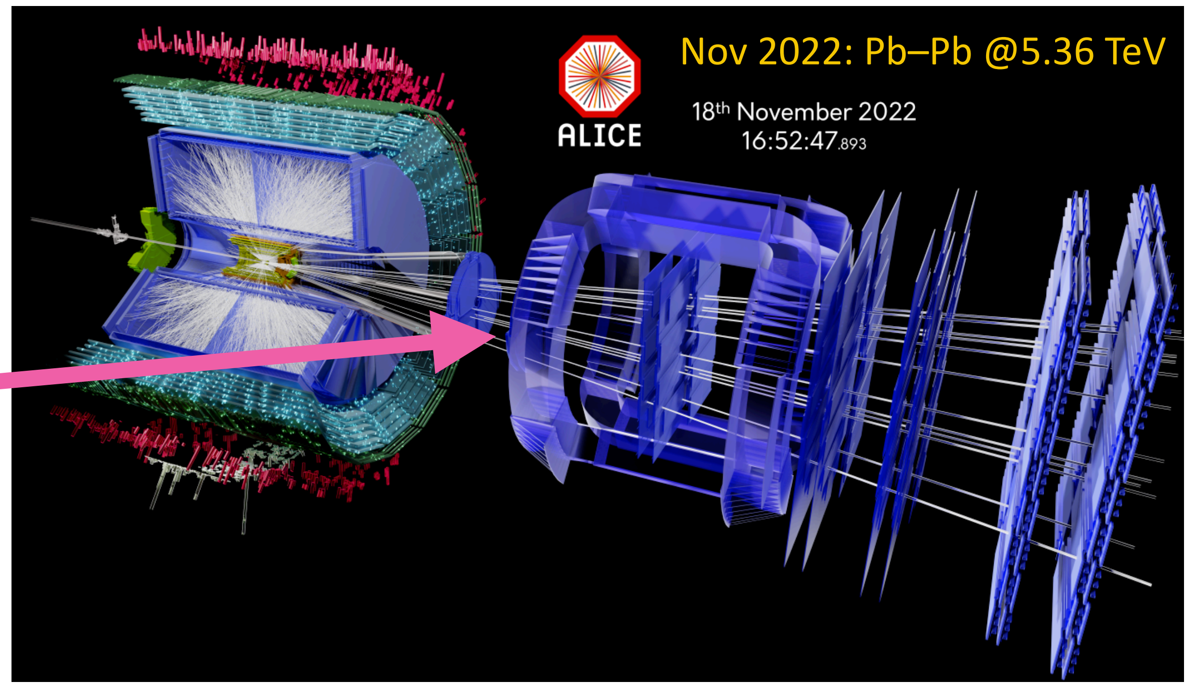
Microscopic of the QCD

Upgraded readout of time projection chamber (TPC)

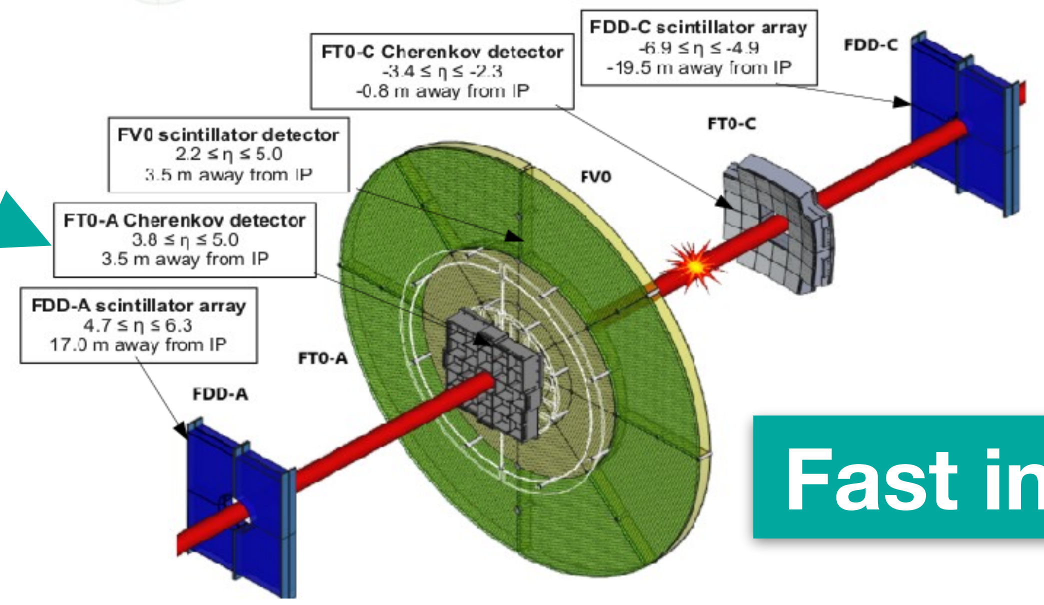




The 2nd generation inner tracking system (ITS2)



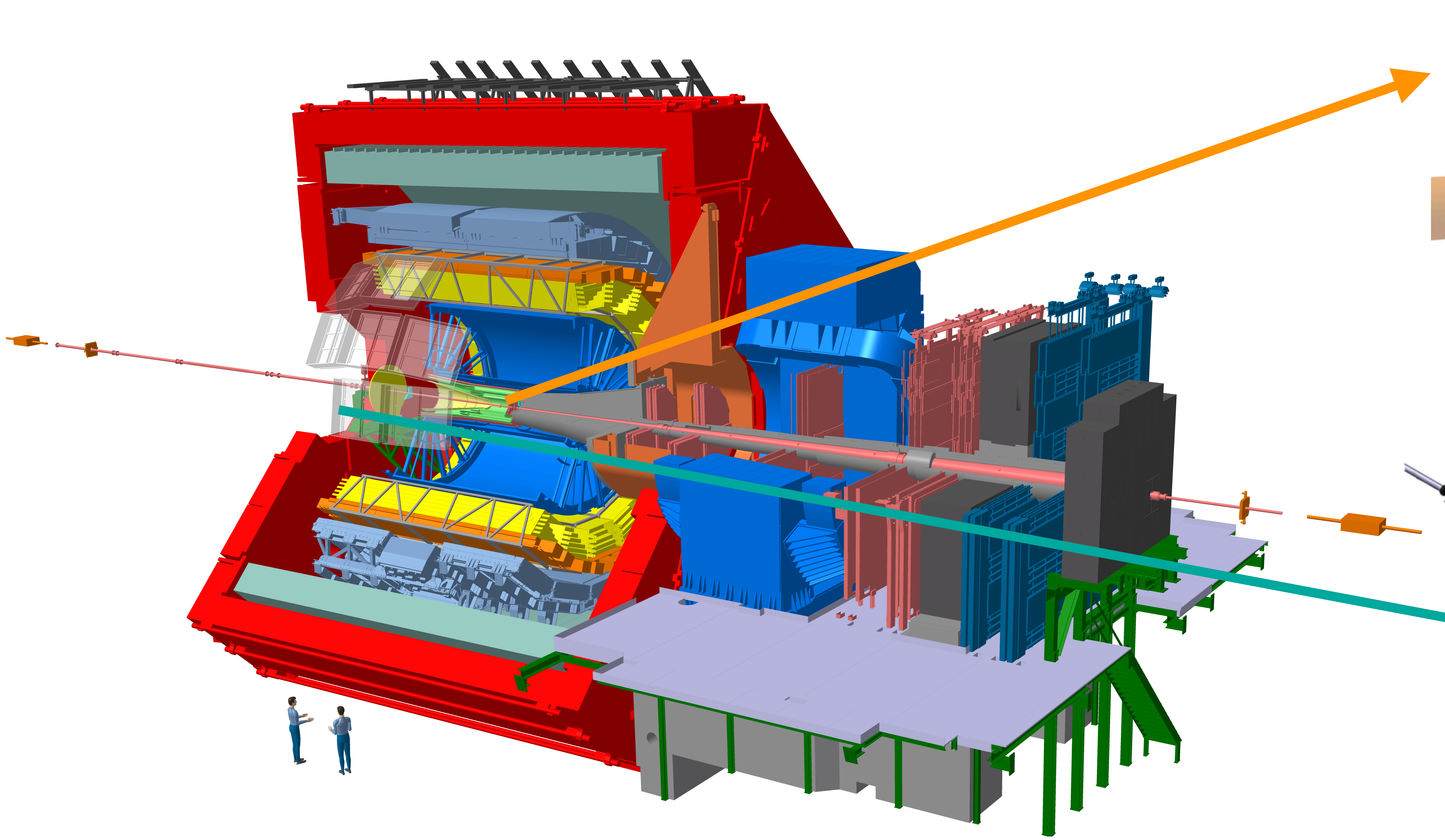
Muon forward tracker (MFT)



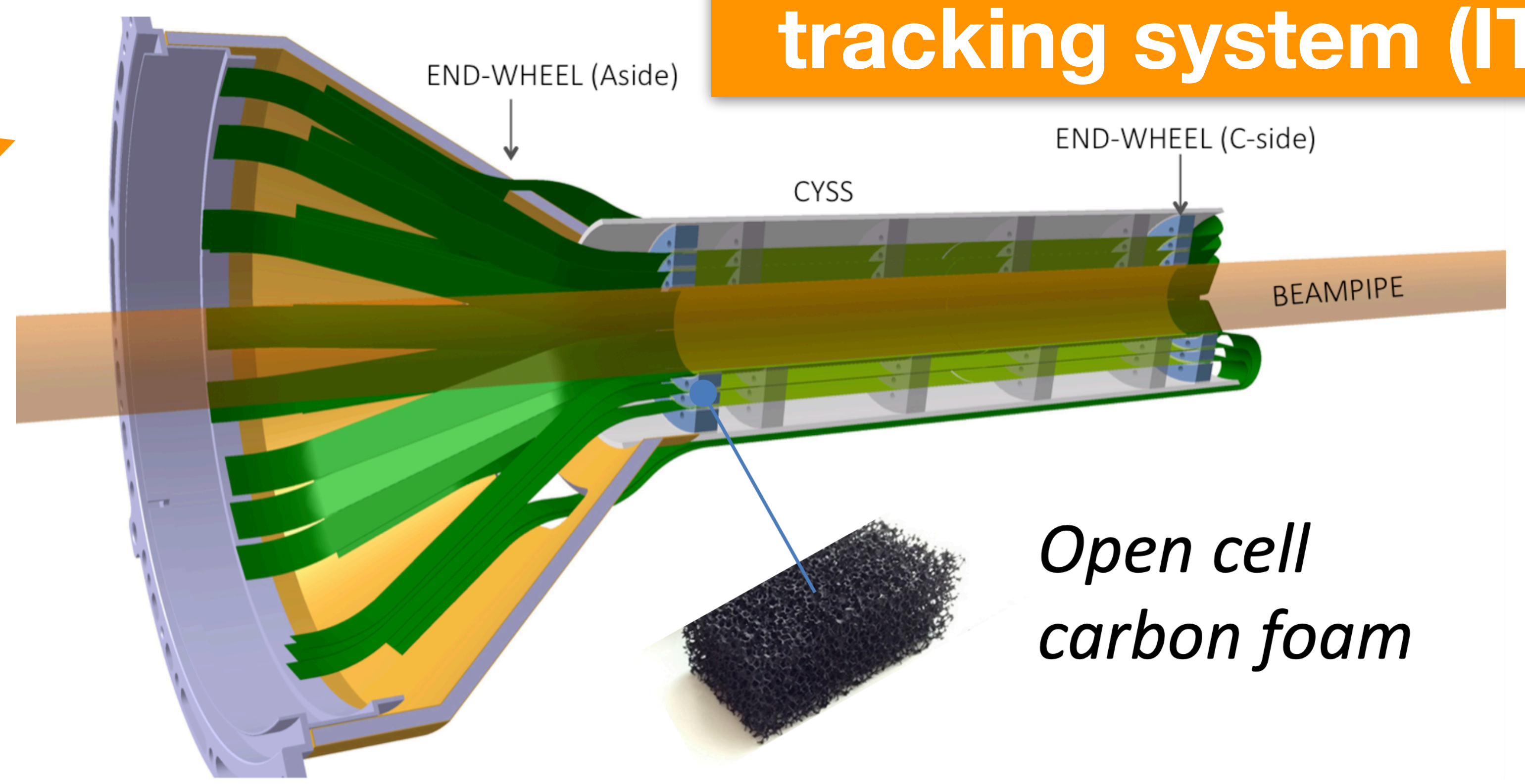
Fast integrated trigger (FIT)

Femtoscopic of the QCD

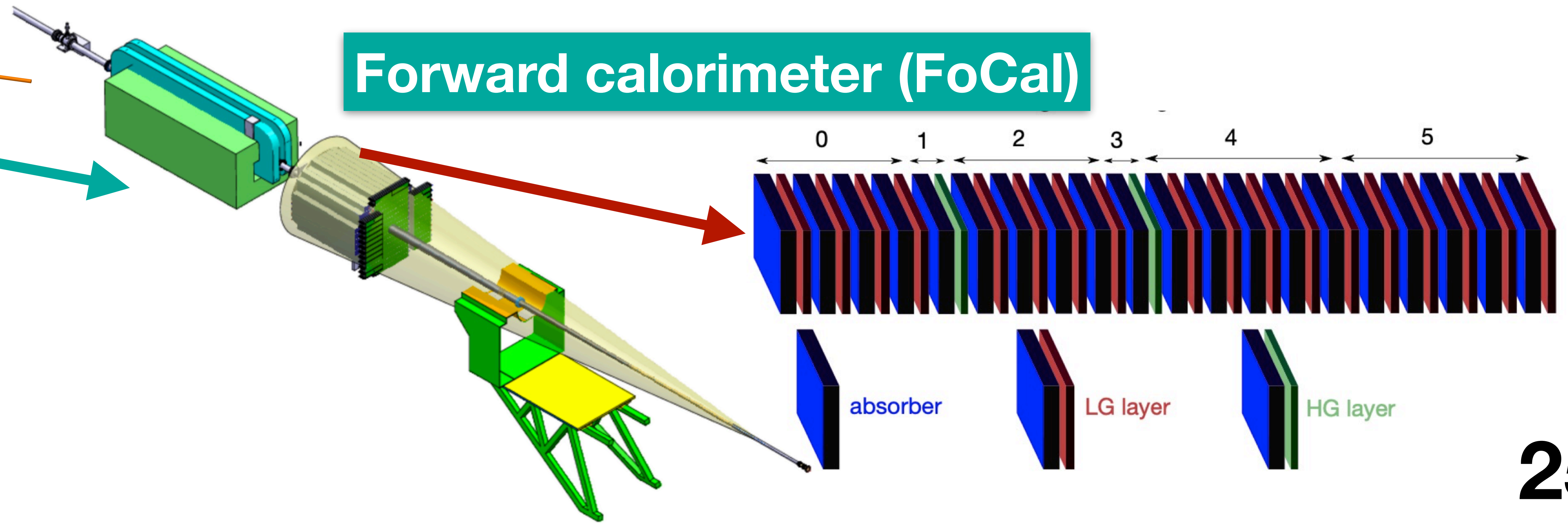
2010-2013		2015-2018		2022-2025		2029-2032		2035-2038		
Run1	LS1	Run2	LS2	Run 3	LS3	Run 4	LS4	Run 5	LS5	Run 6
ALICE 1				ALICE 2		ALICE 2.1		ALICE 3		



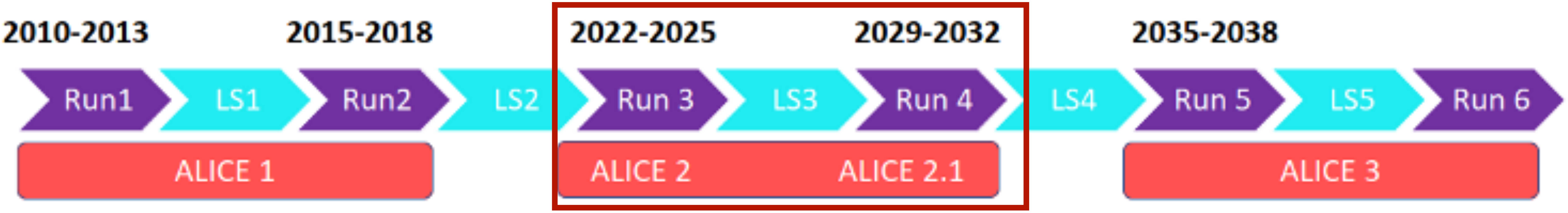
The 3rd generation inner tracking system (ITS3)

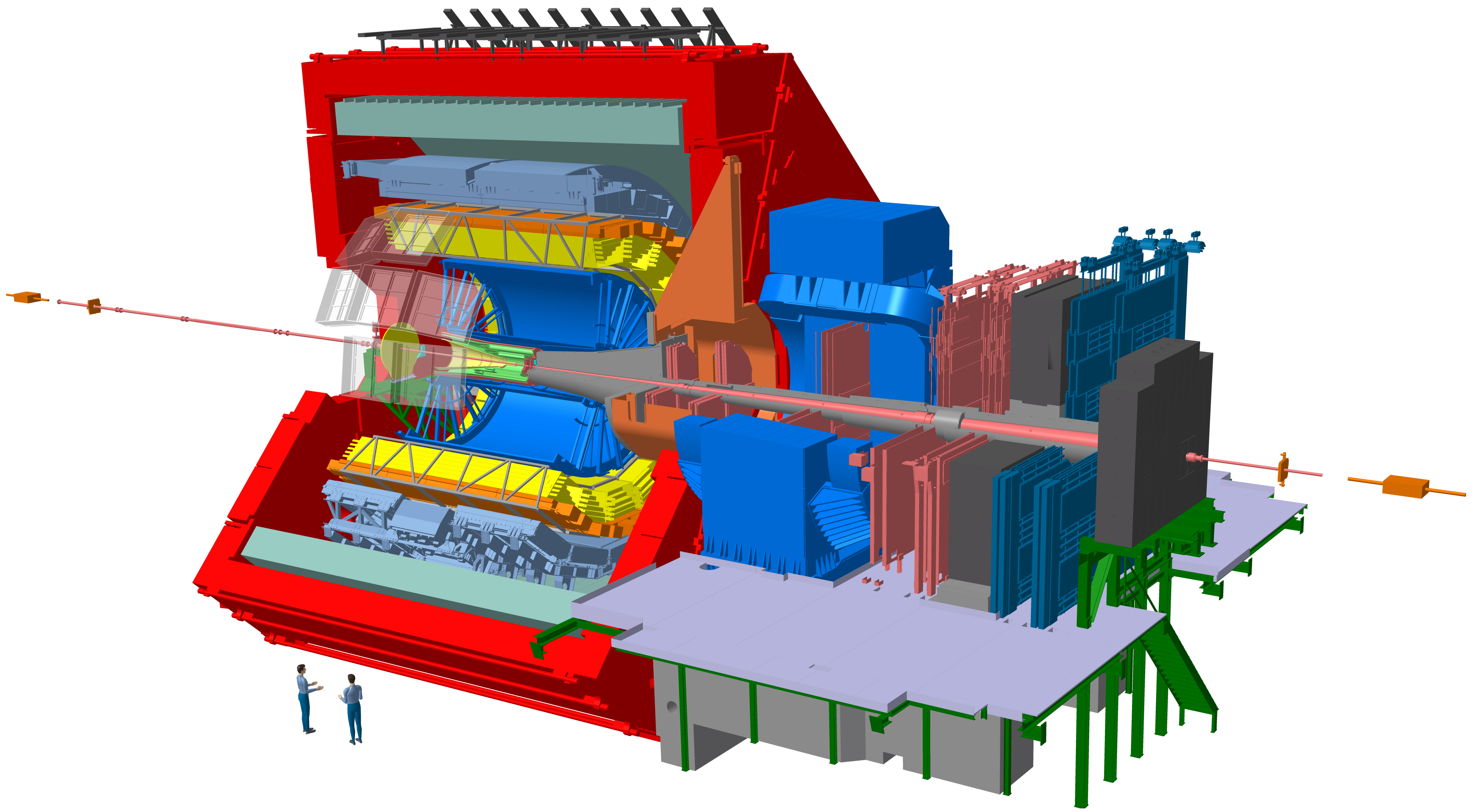


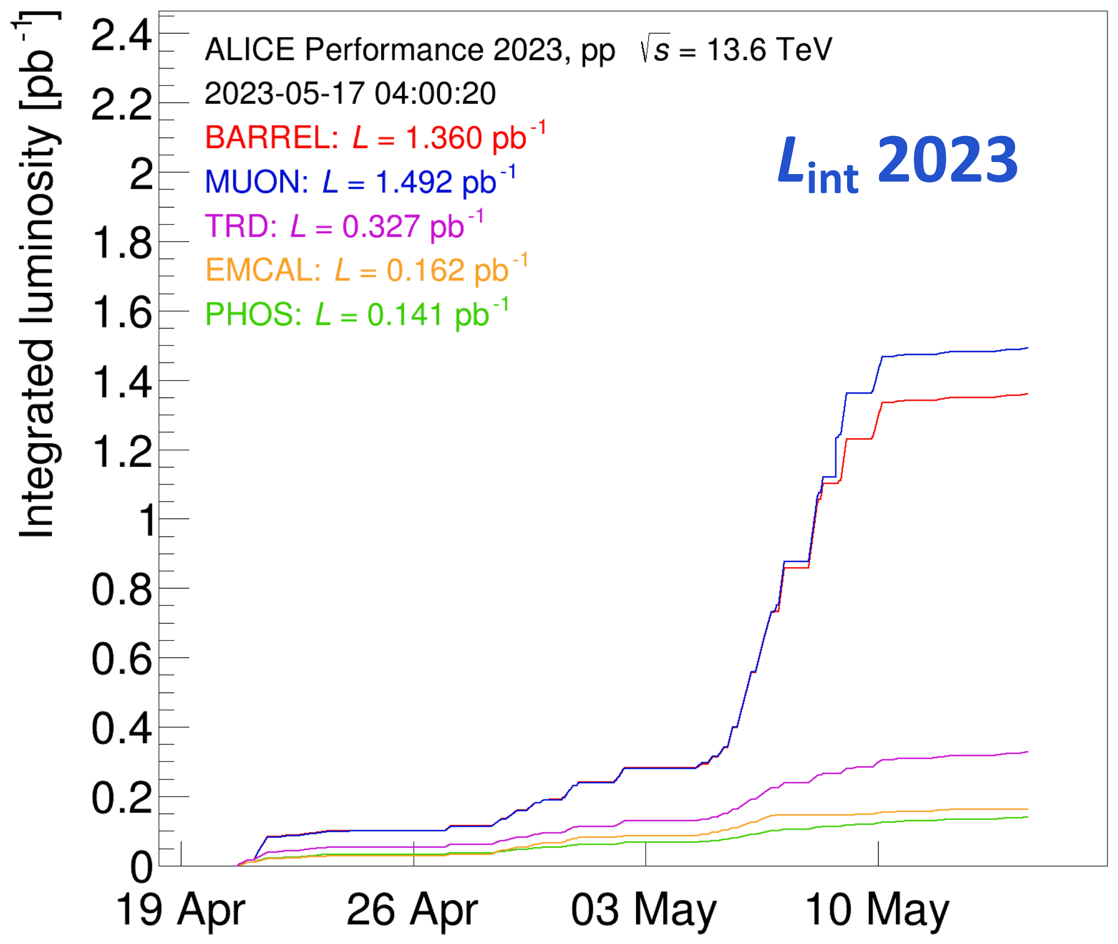
Forward calorimeter (FoCal)

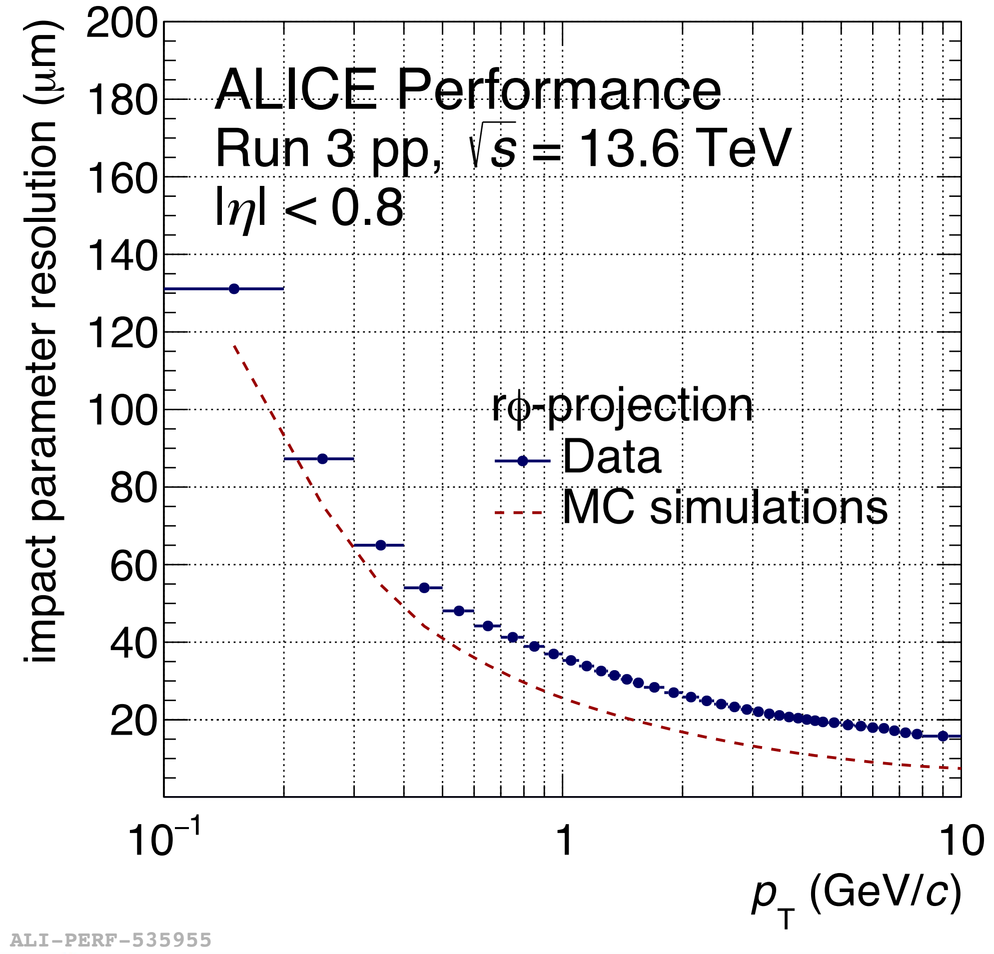


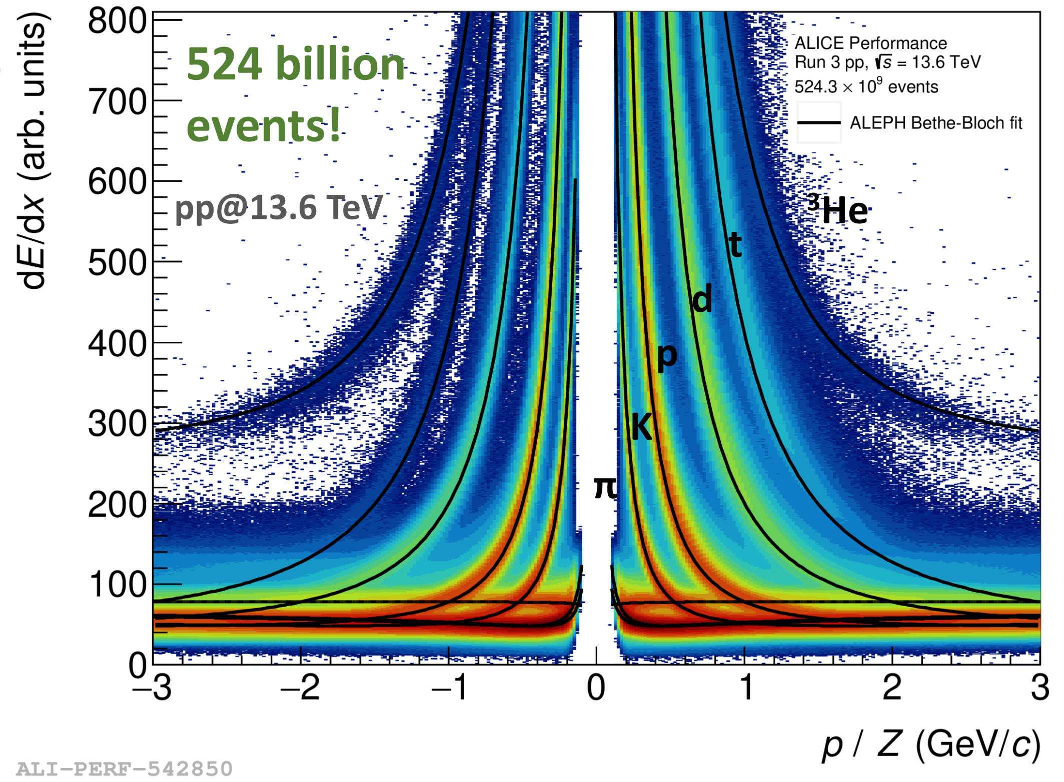
Femtoscopic of the QCD

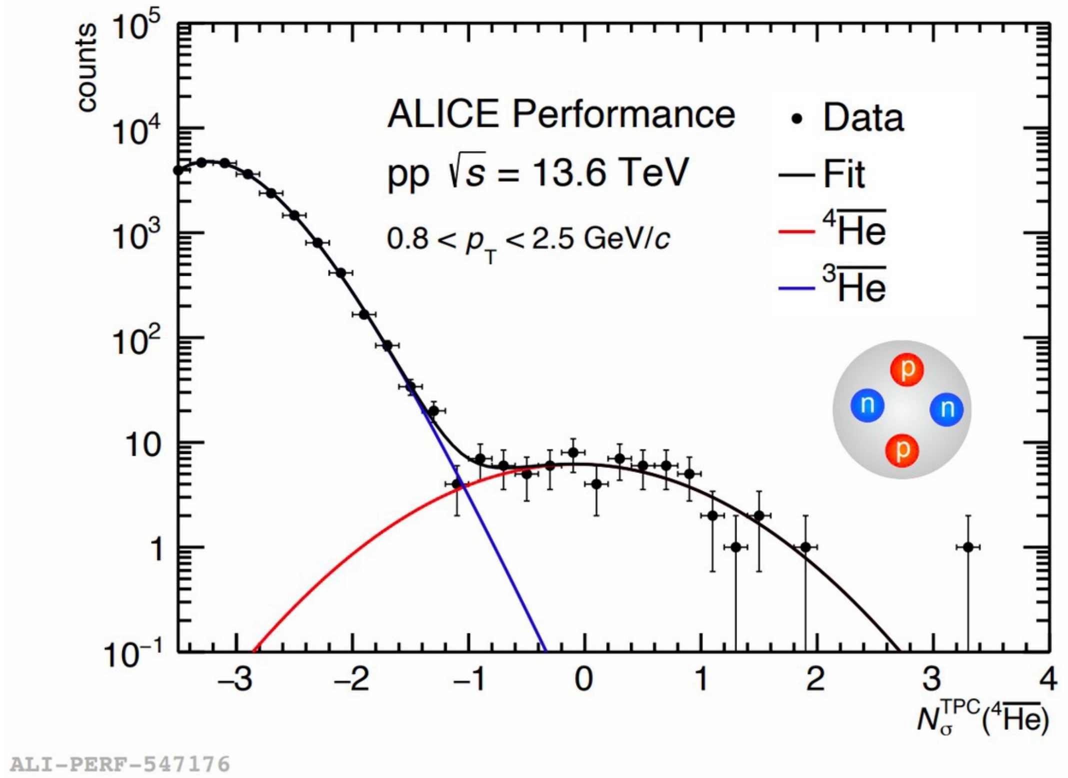




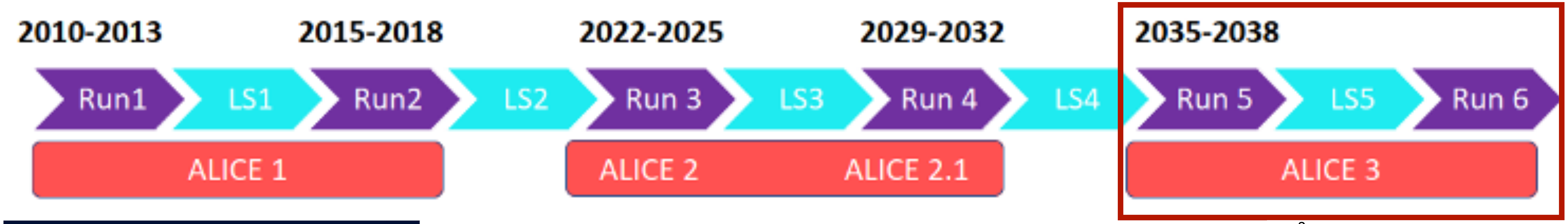


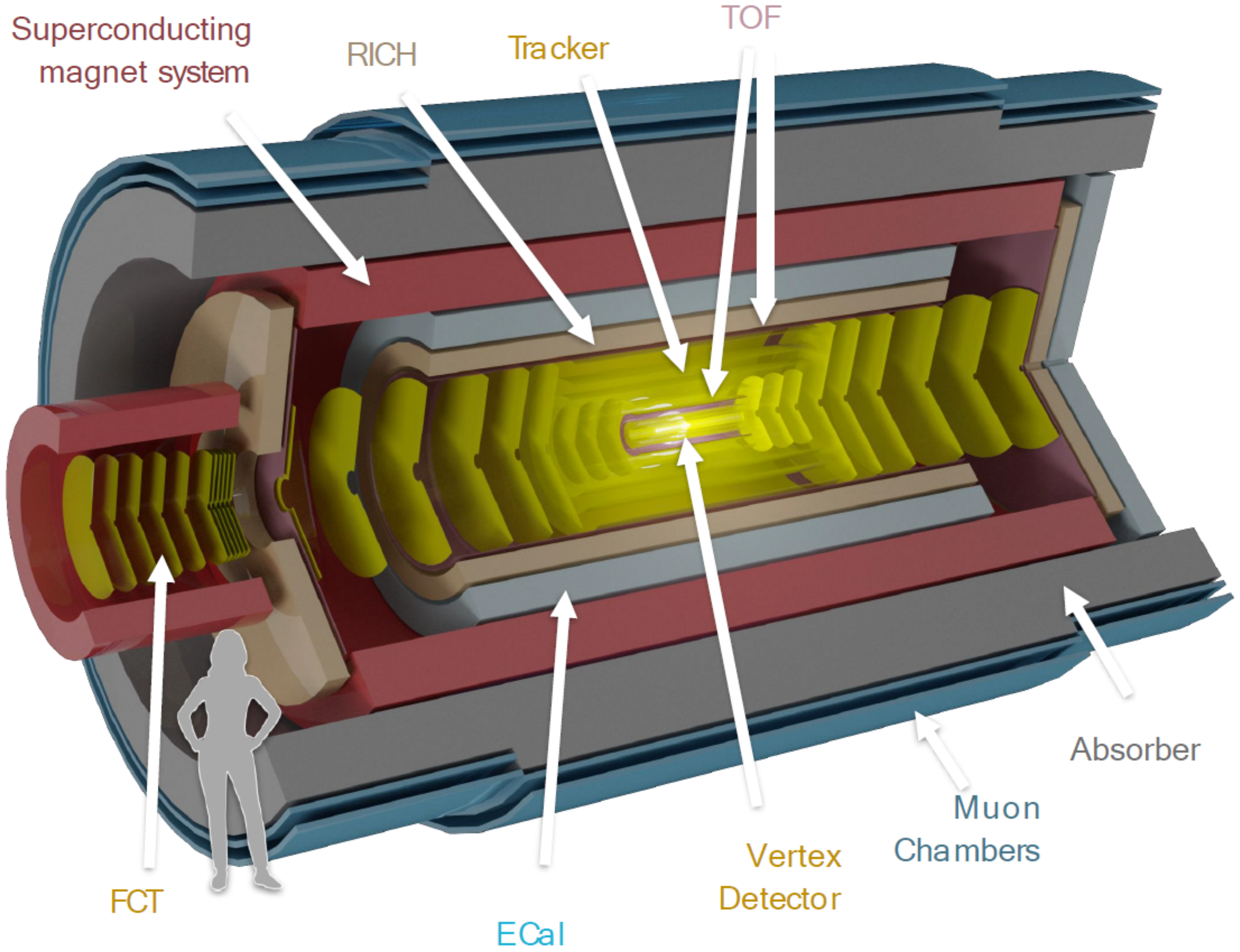


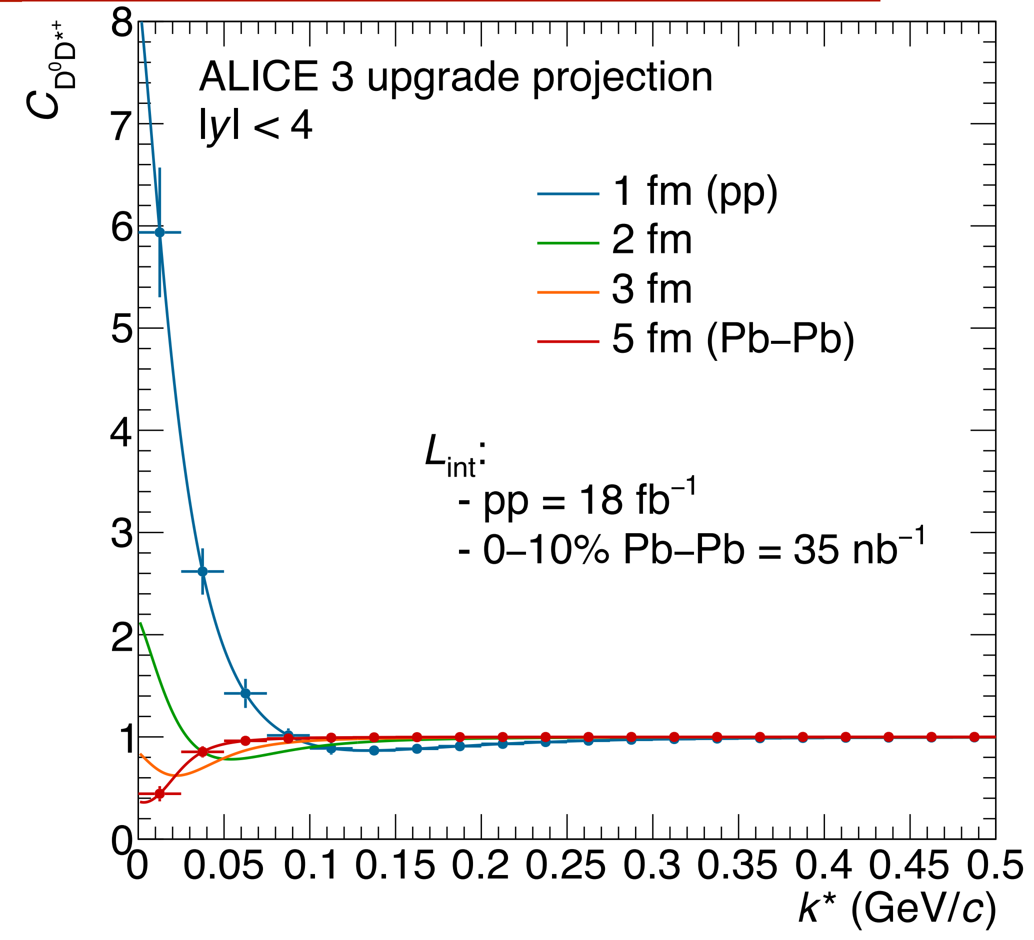


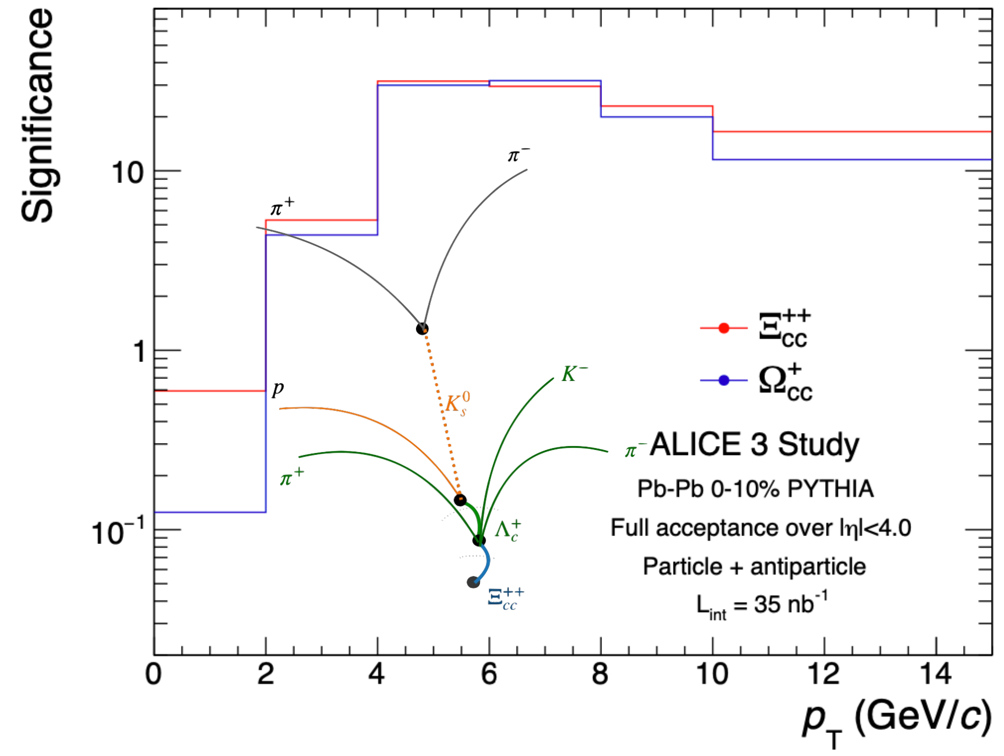


Next-generation experiment



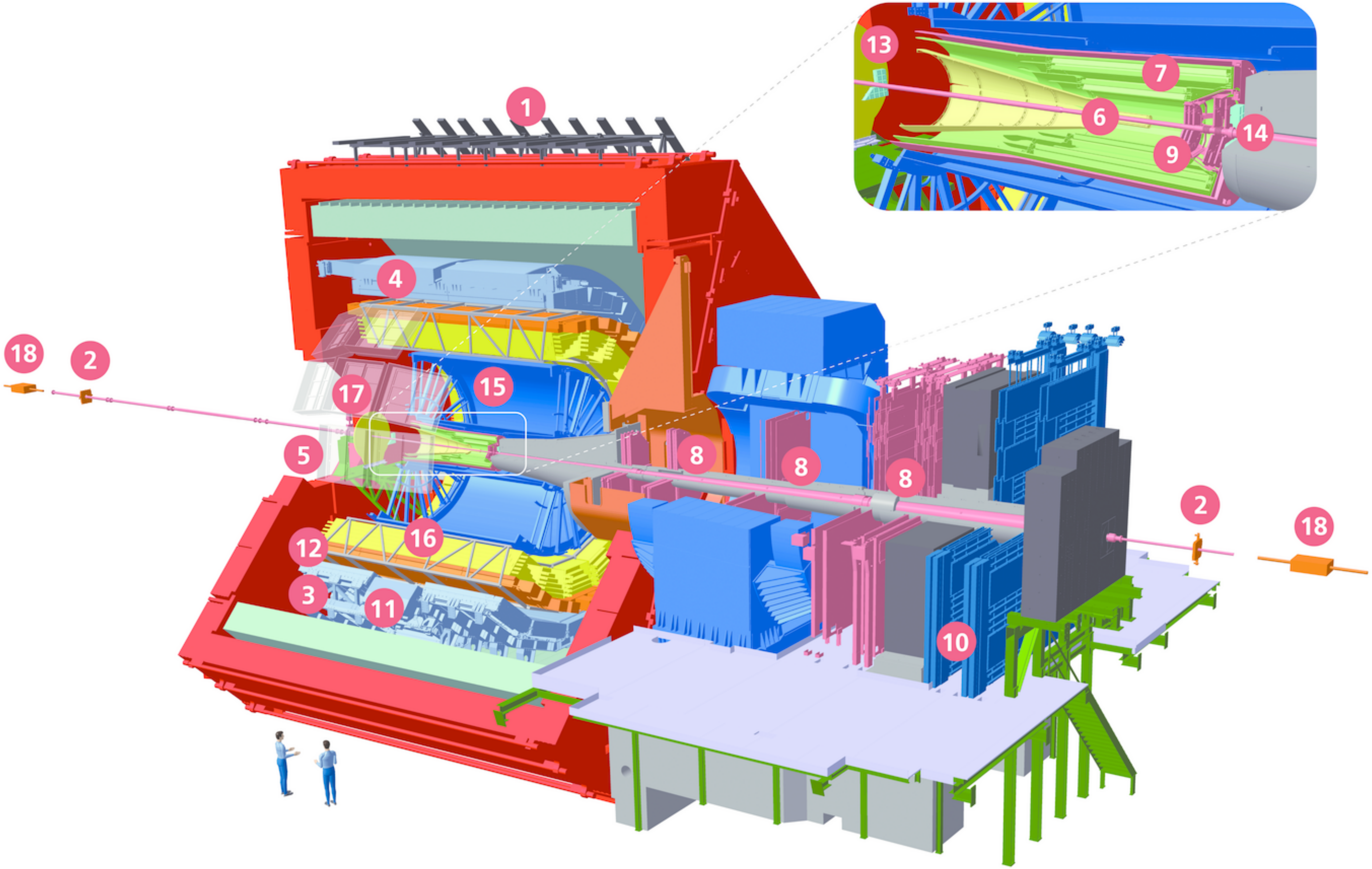






Backup

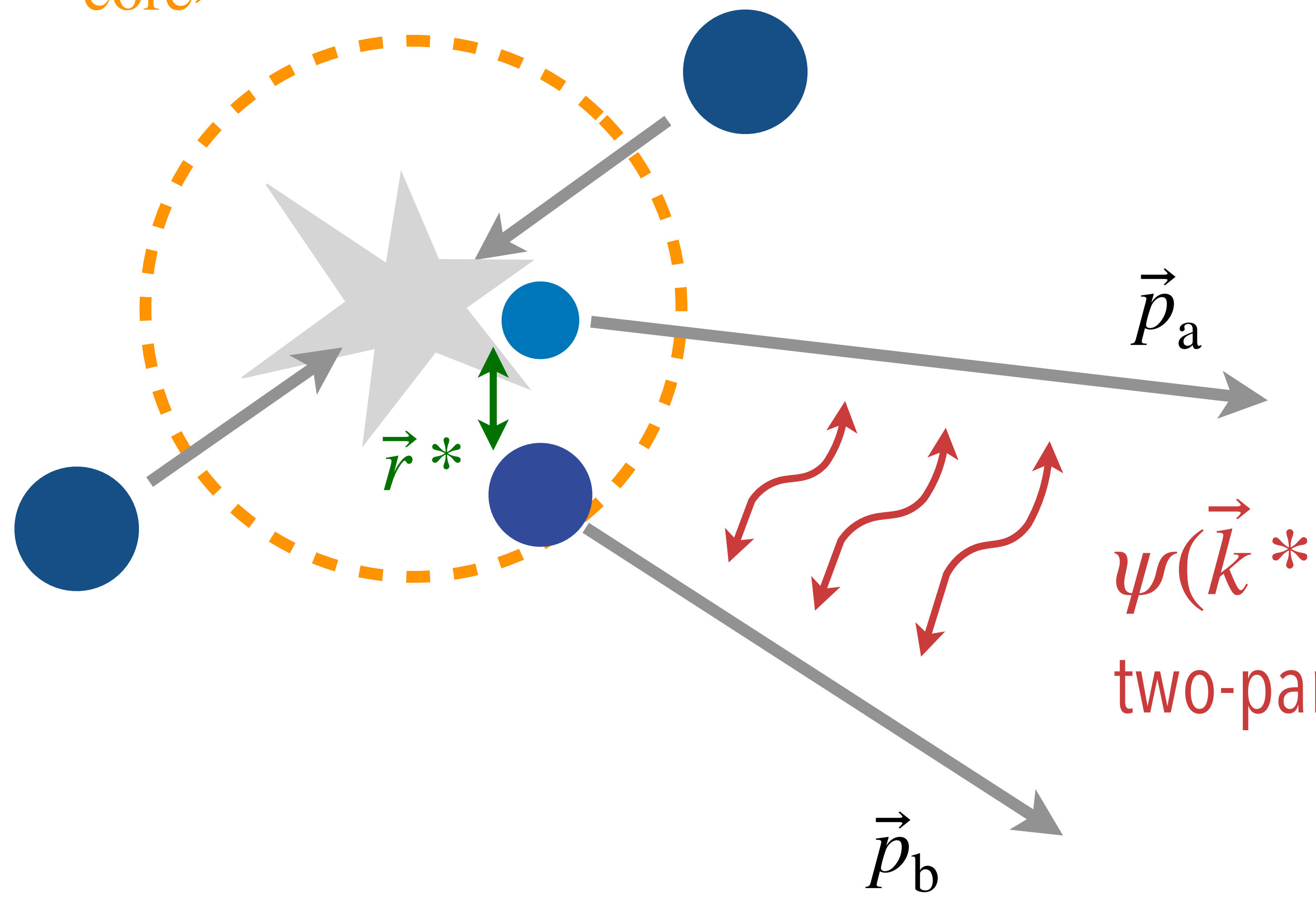
ALICE experiment at the LHC



1. **ACORDE** | ALICE Cosmic Rays Detector
2. **AD** | ALICE Diffractive Detector
3. **DCal** | Di-jet Calorimeter
4. **EMCal** | Electromagnetic Calorimeter
5. **HMPID** | High Momentum Particle Identification Detector
6. **ITS-IB** | Inner Tracking System - Inner Barrel
7. **ITS-OB** | Inner Tracking System - Outer Barrel
8. **MCH** | Muon Tracking Chambers
9. **MFT** | Muon Forward Tracker
10. **MID** | Muon Identifier
11. **PHOS / CPV** | Photon Spectrometer
12. **TOF** | Time Of Flight
13. **T0+A** | Tzero + A
14. **T0+C** | Tzero + C
15. **TPC** | Time Projection Chamber
16. **TRD** | Transition Radiation Detector
17. **V0+** | Vzero + Detector
18. **ZDC** | Zero Degree Calorimeter

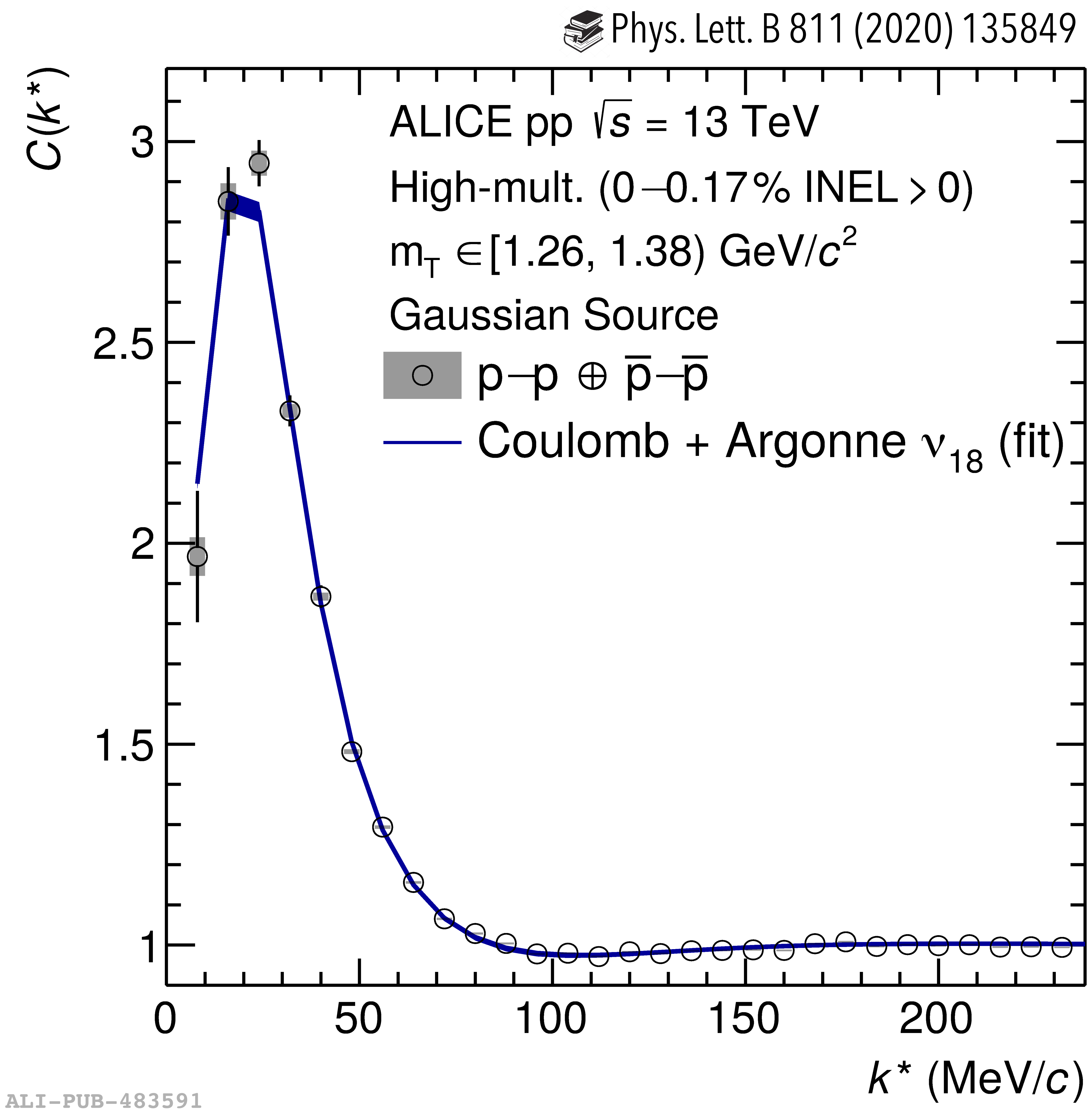
$$C(\vec{k}^*) = \int S(\vec{r}^*) \, |\psi(\vec{k}^*, \vec{r}^*)|^2 \, d^3 r^*$$

➡ Emitting source: hypersurface at kinematic freezout of final-state particles

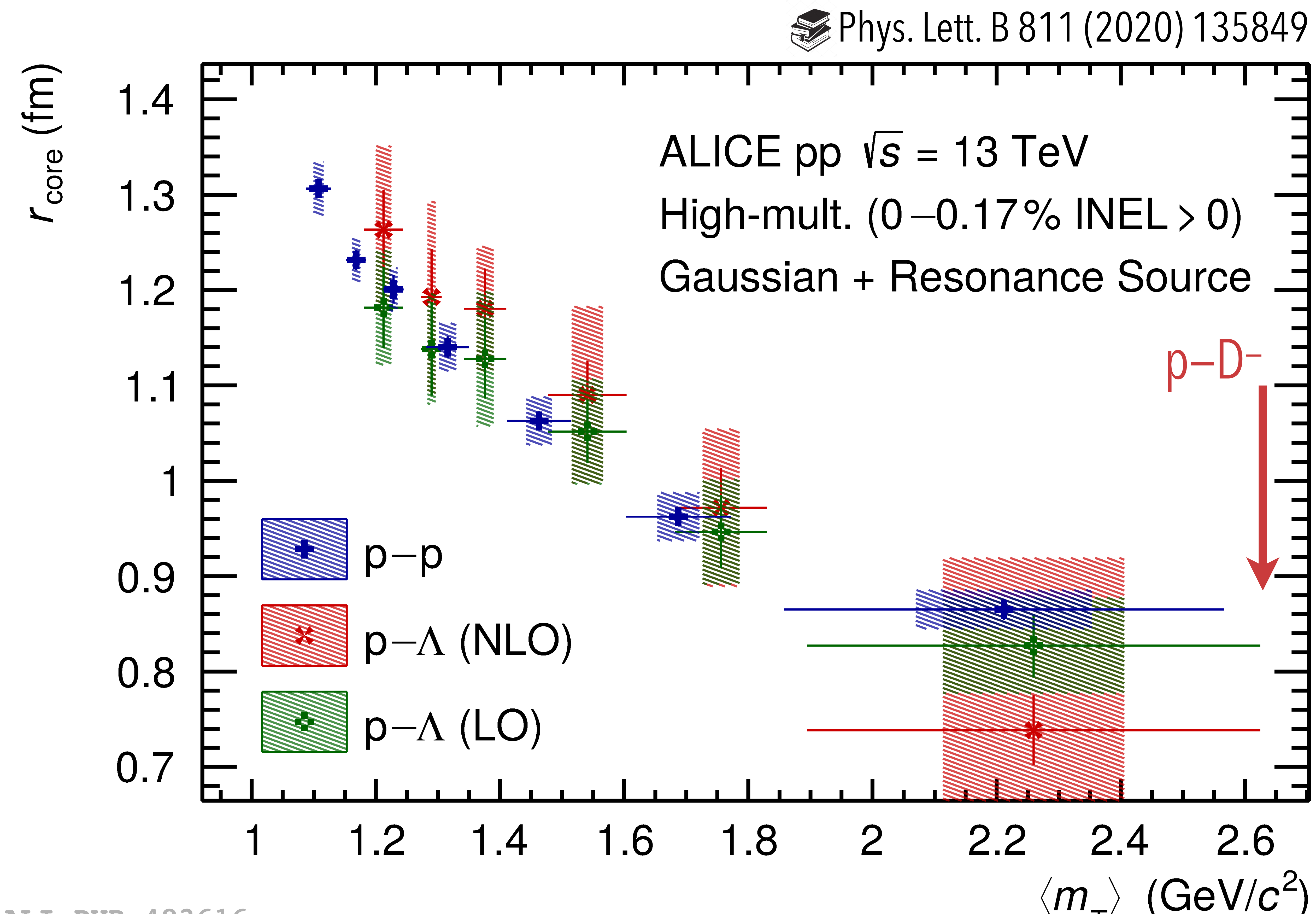


- Described with a Gaussian core

$$G(r^*, r_{\mathrm{core}}(m_{\mathrm{T}})) = \frac{1}{(4\pi r_{\mathrm{core}}^2(m_{\mathrm{T}}))^{3/2}} \cdot \exp\left(-\frac{r^{*2}}{4 r_{\mathrm{core}}^2(m_{\mathrm{T}})}\right)$$



- Fit correlation functions of p–p and p–Λ pairs
  - ➡ Interaction precisely described
  - ➡ Gaussian source with radius as free parameter



- Source size ~1fm makes the high-multiplicity pp system