Measurements of hadronic interactions between light and charm hadrons with femtoscopy

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GDR-QCD, GDR-InF and Gluodynamics workshop
Spectroscopy in decays & in femtoscopic correlations
Orsay, Paris | 16–17 December 2024

Outline

- Physics motivations for **D-meson – hadron femtoscopy**
  - ➡ Study **residual strong interaction**
  - ➡ Assess role of **hadronic phase in heavy-ion collisions**

- **Measurements of D-meson – hadron interactions** from ALICE
  - ➡ Study residual strong interaction

- Future perspectives
  - ➡ Interaction between charm baryons and nucleons to investigate the possible existence of **charmed nuclei**
  - ➡ Interaction between two charm hadrons to study nature of **recently discovered exotic states**

Study hadron interactions: why femtoscopy?

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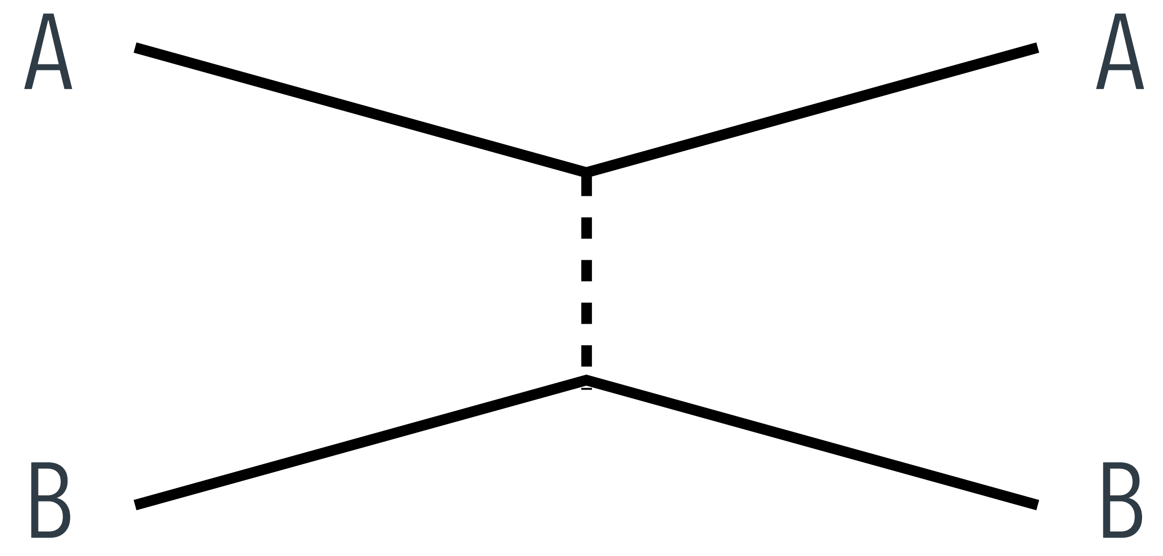
- Traditional method to study hadron-hadron interaction: **scattering experiments**



S. Navas et al. (PDG), PRD 110 (2024) 030001

Hadron	$c\tau$ (μm)
D^0	121
D^+	312
D_s^+	150
Λ_c^+	63

- Experimental challenge in case of **charm hadrons** due to their short lifetime
  - ➡ **Femtoscopy** is a very powerful tool to study hadron interaction at colliders

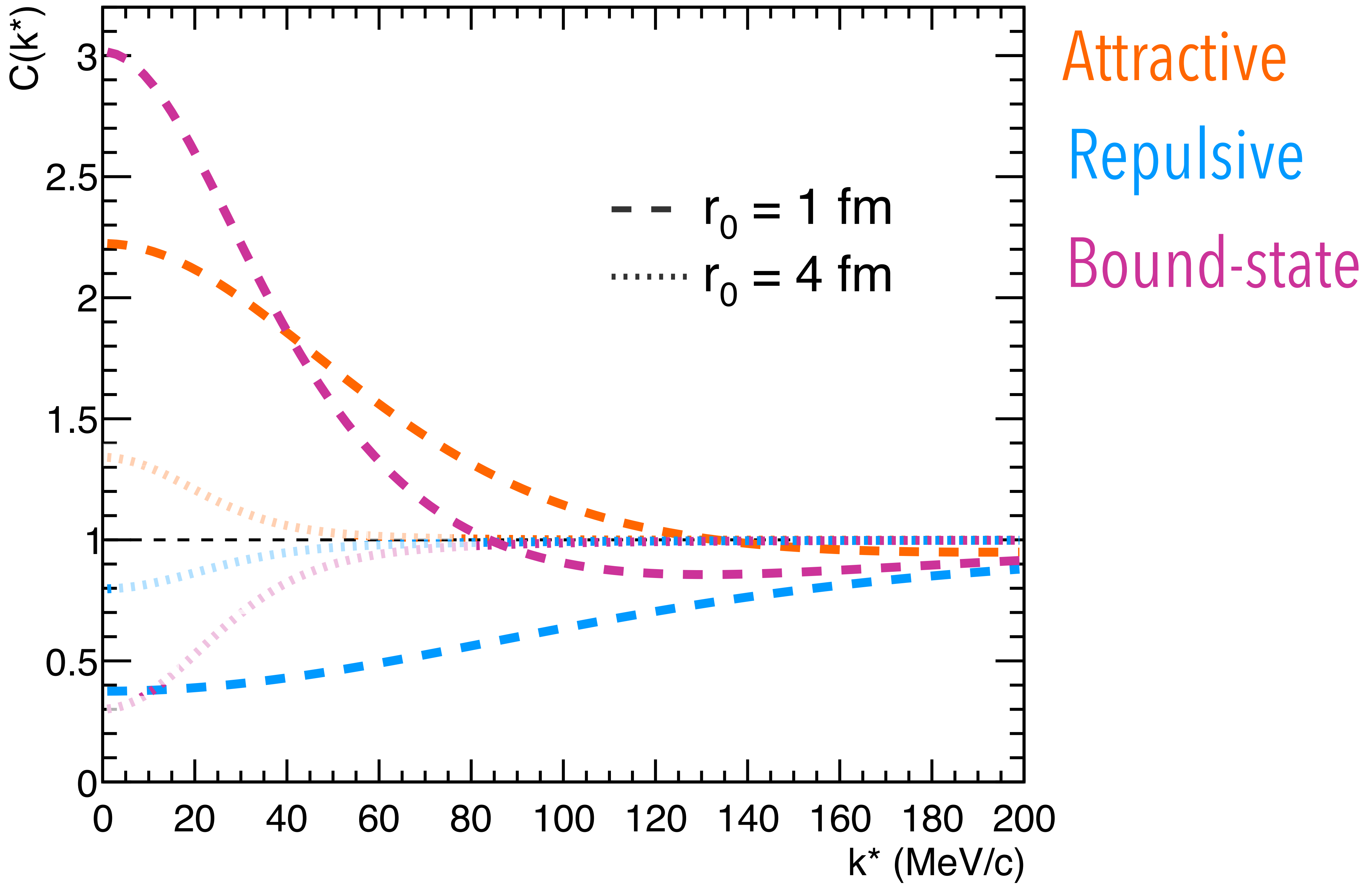
Experiment — Theory

$$C(\vec{k}^*) = \mathcal{N}\frac{N^{\text{pairs}}_{\text{same}}(k^*)}{N^{\text{pairs}}_{\text{mixed}}(k^*)} = \int S(\vec{r}^*)\,|\psi(\vec{k}^*,\vec{r}^*)|^2\,\mathrm{d}^3r^*$$

Koonin-Pratt equation

M.Lisa, S. Pratt et al, Ann.Rev.Nucl.Part.Sci. 55 (2005) 357–402

where $\vec{k}^* = \dfrac{\vec{p}^*_{\mathrm{a}} - \vec{p}^*_{\mathrm{b}}}{2}$ is in the rest frame of the particle pair



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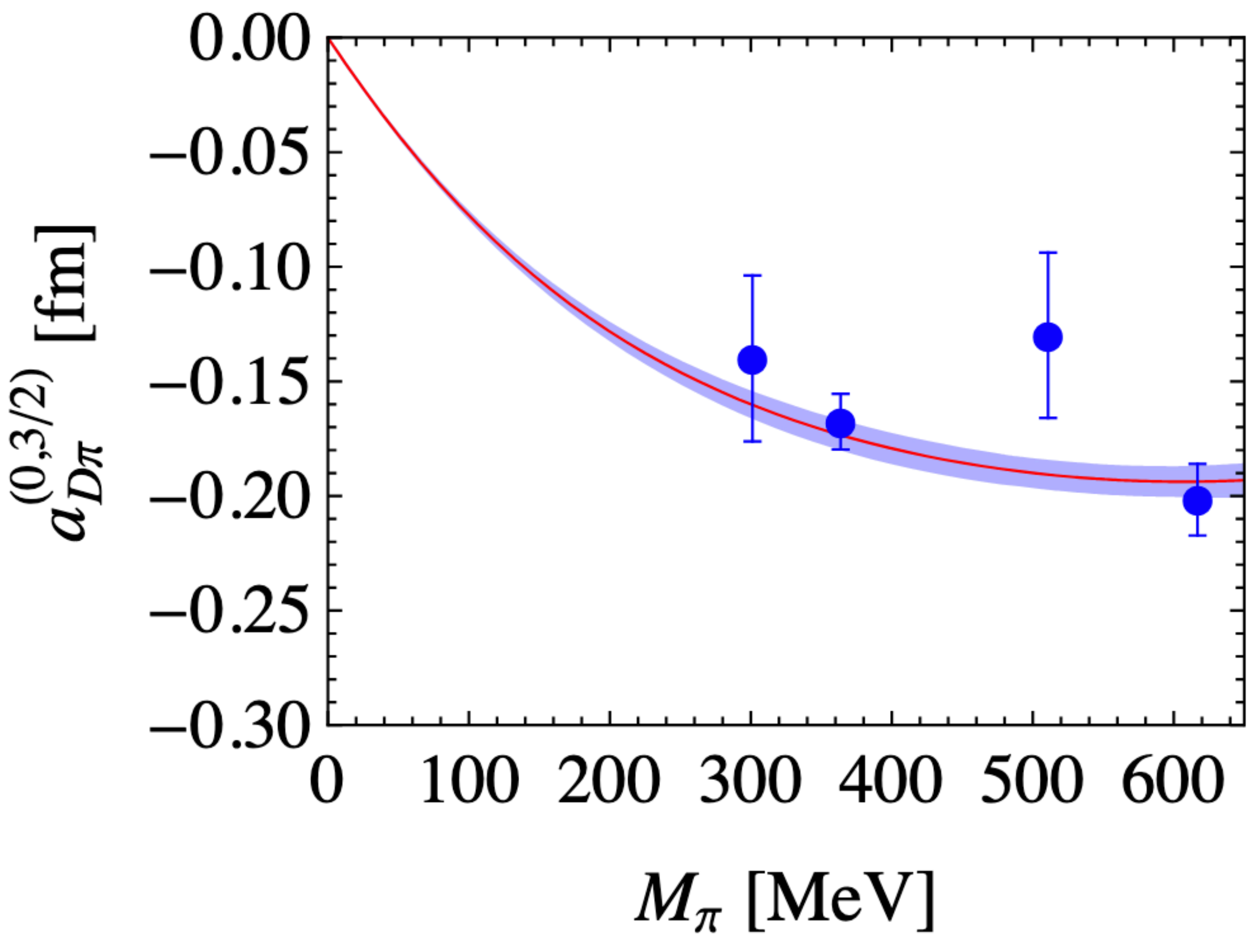
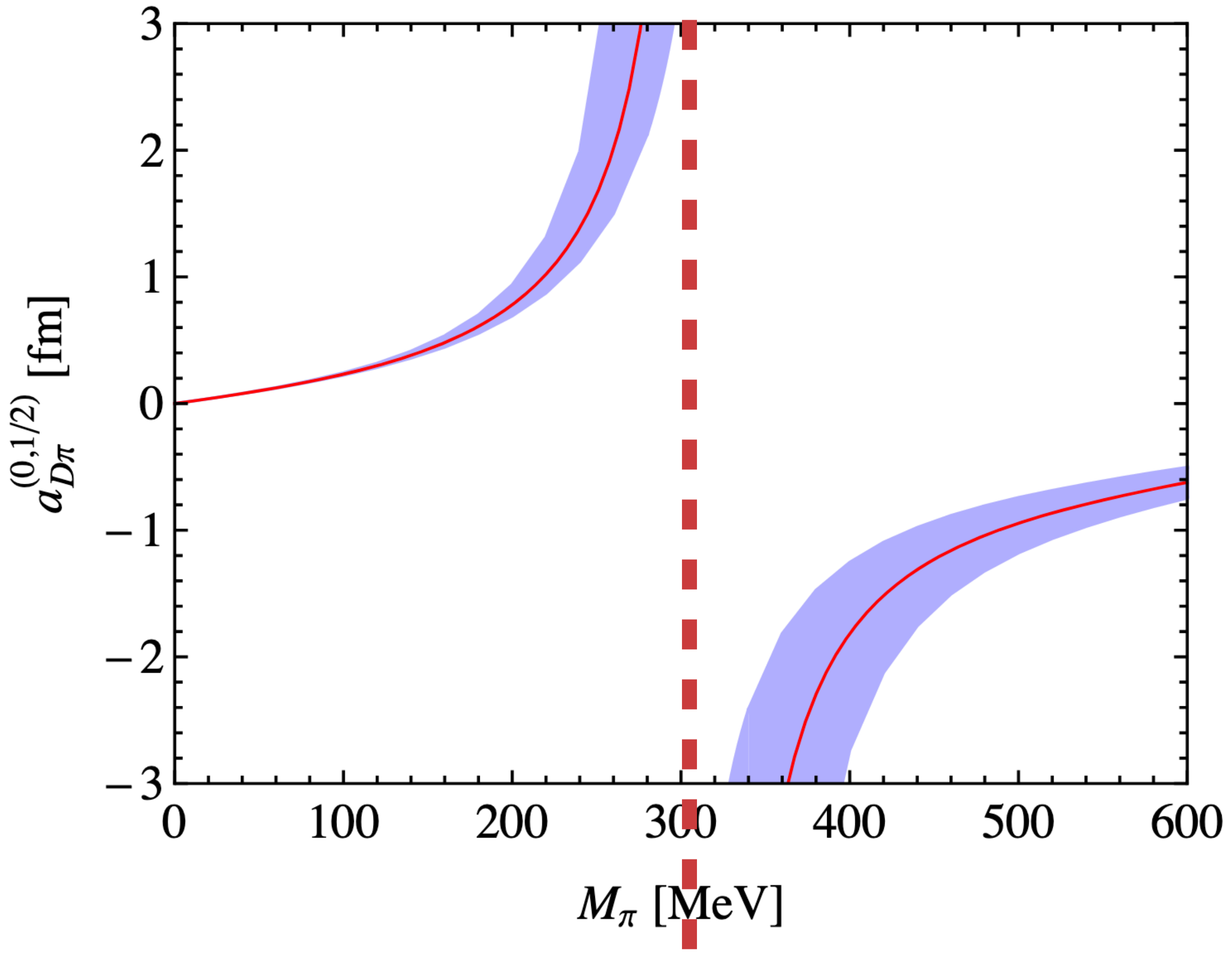
- Theory predictions based on **lattice QCD calculations** for the determination of low energy constants (i.e. **scattering length** *a*) + **unitarized chiral perturbation theory** for the extrapolation to the physical pion mass





Low-energy pole of $D_0^*(2300)$

- Example: Dπ interaction via two isospin channels
  - ➡ *I* = 3/2 purely elastic
  - ➡ *I* = 1/2 inelastic, with several **coupled channels**

Strangeness → $(0, \frac{1}{2})$ ← Isospin

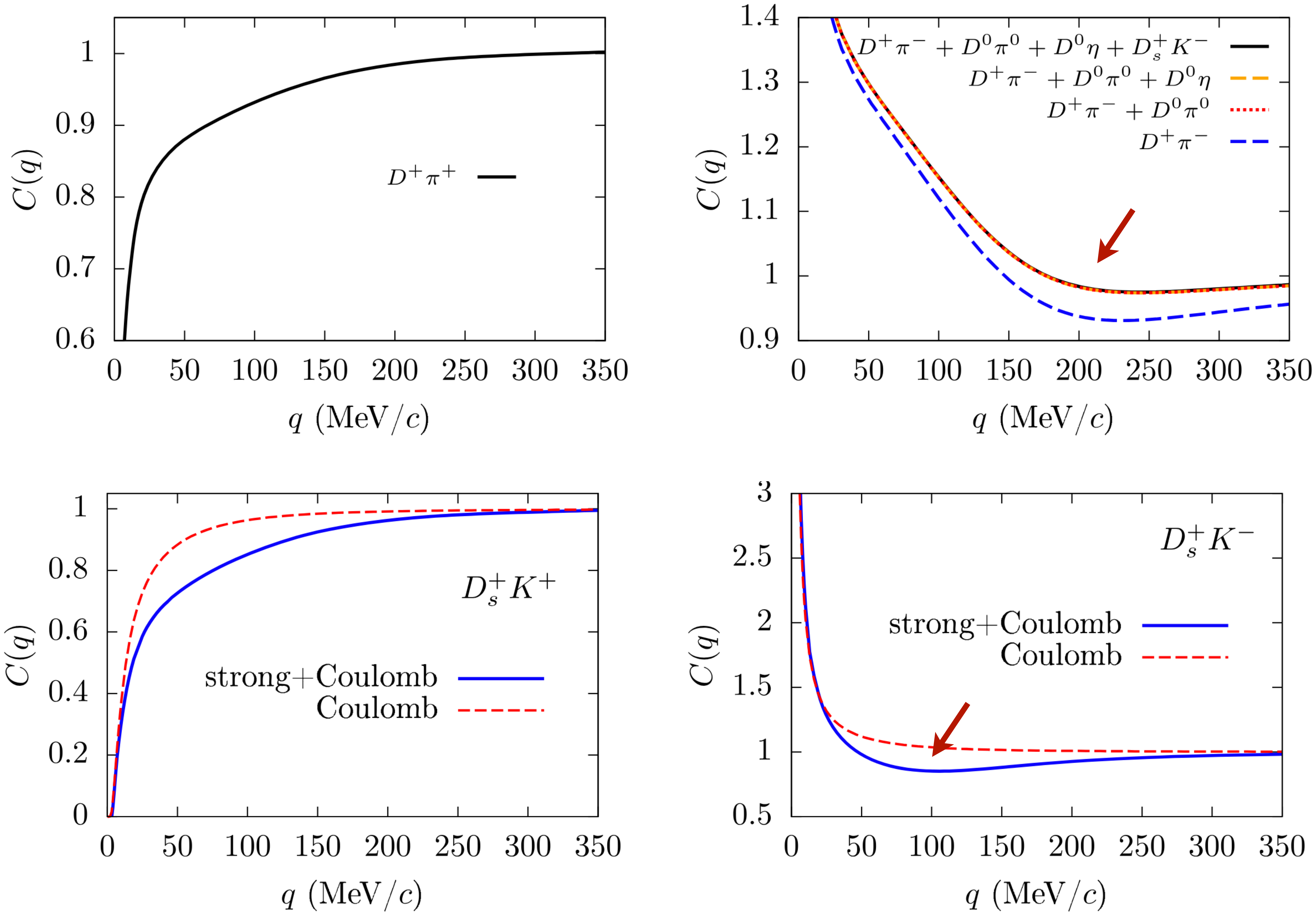
$$D\pi \to D\pi$$
$$D\eta \to D\eta$$
$$D_s\bar{K} \to D_s\bar{K}$$
$$D\eta \to D\pi$$
$$D_s\bar{K} \to D\pi$$
$$D_s\bar{K} \to D\eta$$

- Inelastic interactions might also lead to the formation of dynamical / molecular states
  - ➡ I.e. $D_0^*(2300)$ in unitarized chiral perturbation theory, is a two-pole structure dynamically formed by Dπ and $D_s\bar{K}$ interactions
  - ➡ **Impact the correlation function** measured with femtoscopy

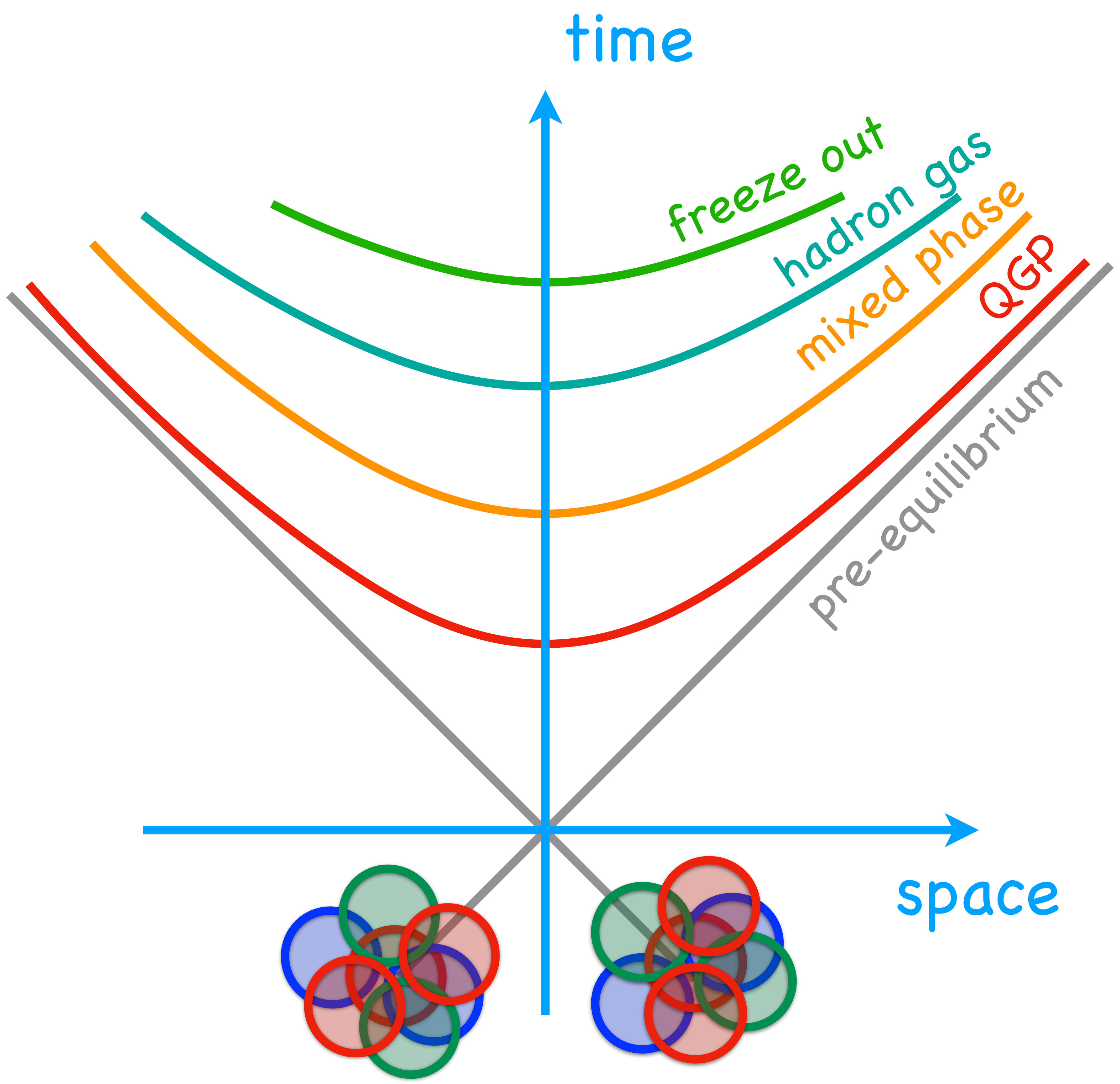
L. Liu et al, PRD 87 (2013) 014508

Study hadron interactions – theory

J.M. Torres-Rincon et al, PRD 108 (2023) 096008



- In the Dπ correlation function expected sizeable effect due to couple channels
  - ➡ Depletion around 200 MeV due to quasi-bound state (first pole of D_0*(2300)) compensated by couple channels
- Similar depletion expected in $D_s\bar{K}$ correlation function due to the second pole



- QCD calculations on lattice predict a phase transition from the ordinary nuclear matter to a **colour-deconfined medium**, called **quark–gluon plasma** (QGP)
  - ➡ created in **ultra-relativistic heavy-ion collisions**
  - ➡ ***very high energy density ε > 15 GeV/fm^3***
  - ➡ after a pre-equilibrium phase **expands hydrodynamically**

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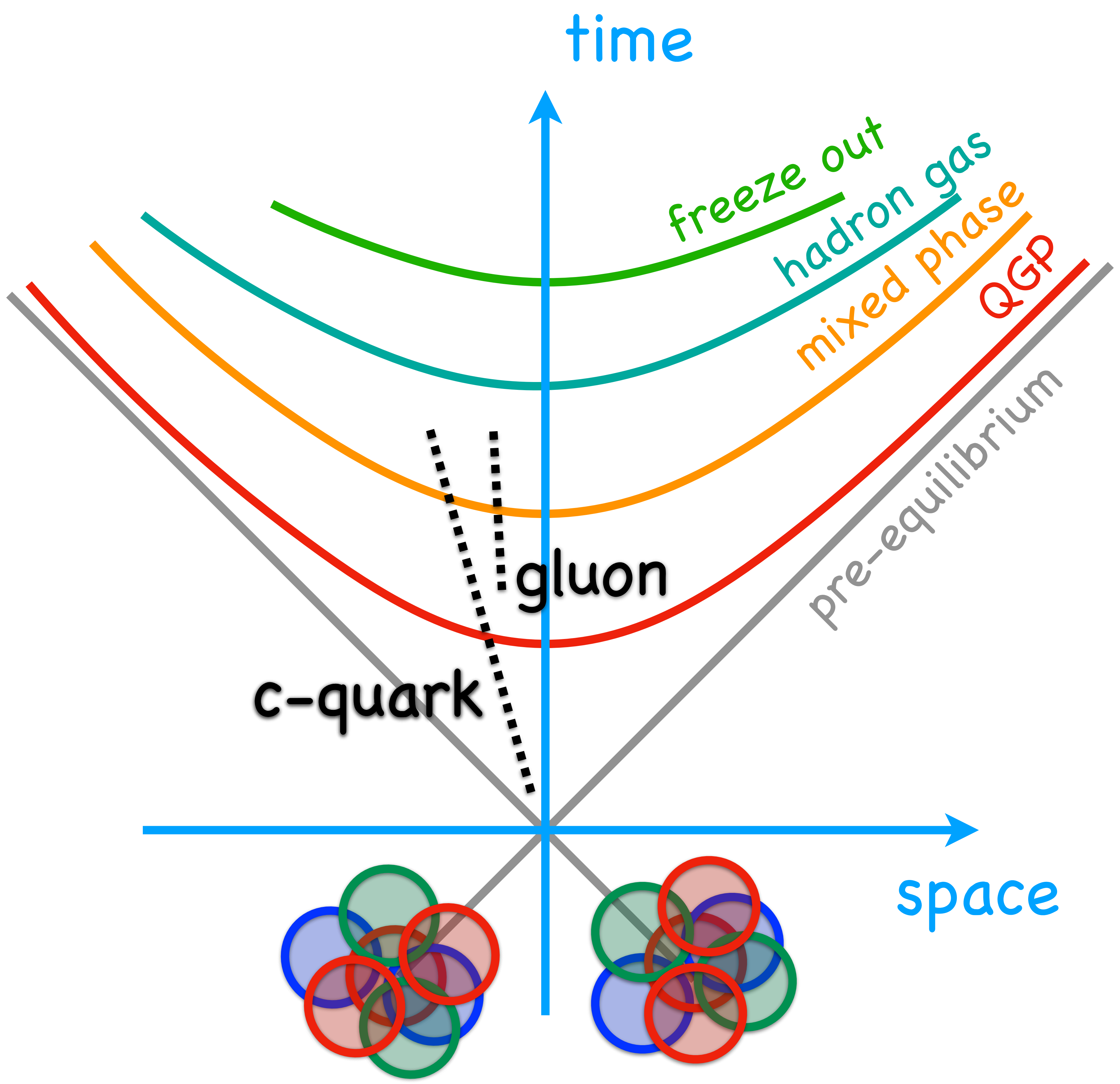
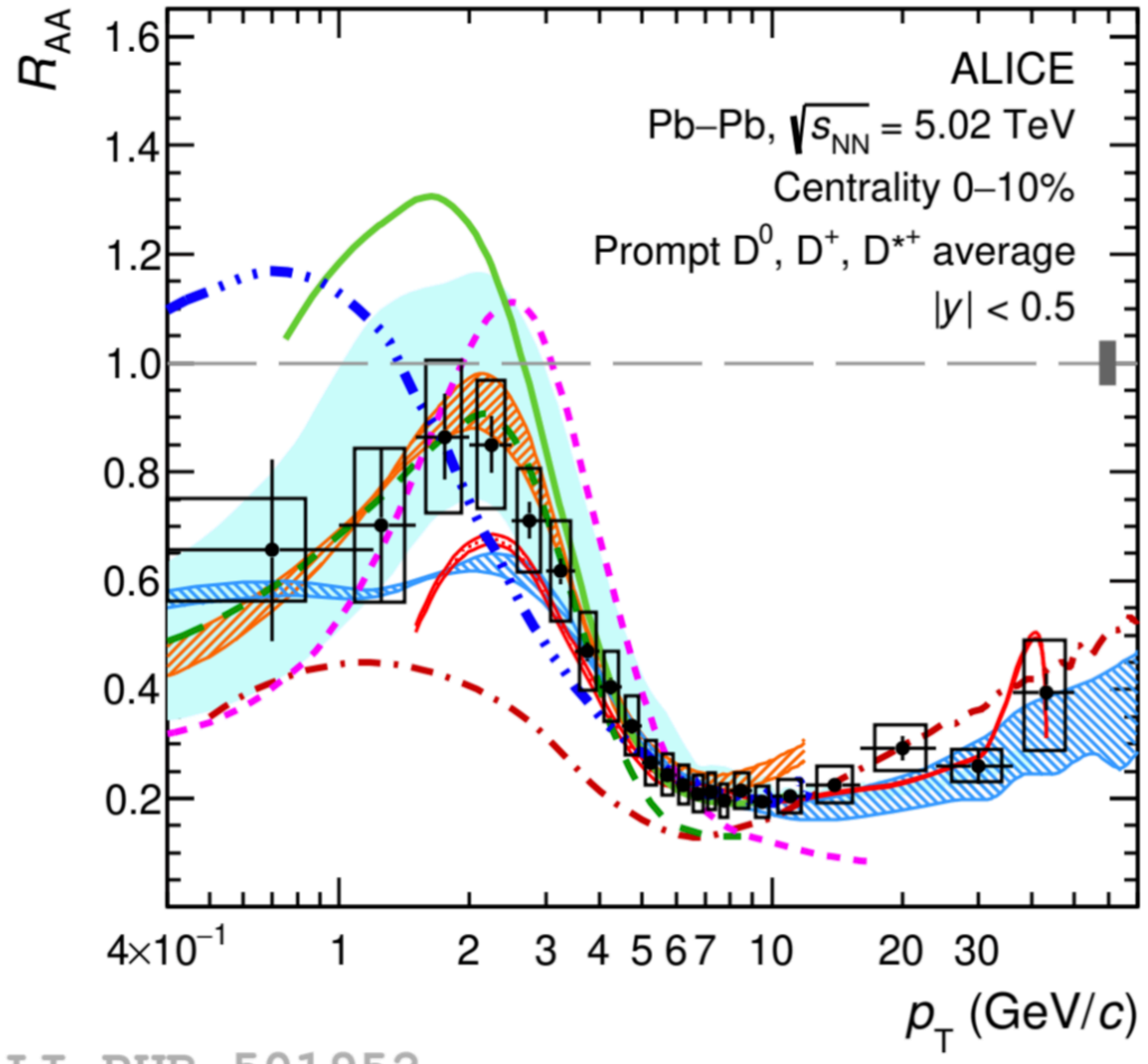


- QCD calculations on lattice predict a phase transition from the ordinary nuclear matter to a **colour-deconfined medium**, called **quark-gluon plasma** (QGP)
- Charm quarks: produced in hard scatterings before the formation of the QGP, subsequently interact with the medium constituents
  ➡ **Ideal probes of the QGP**

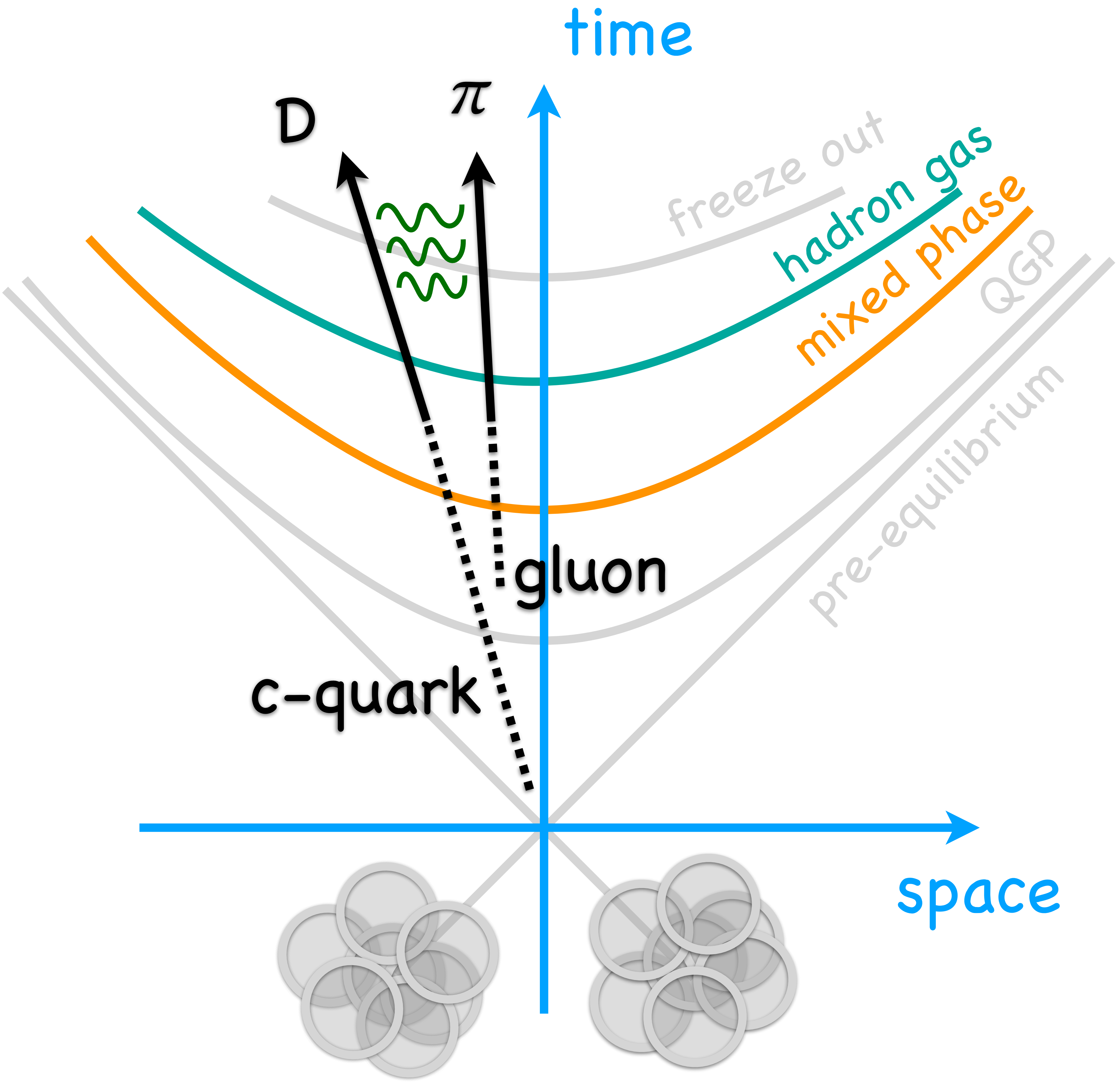


ALICE, JHEP 01 (2022) 174

Nuclear modification factor

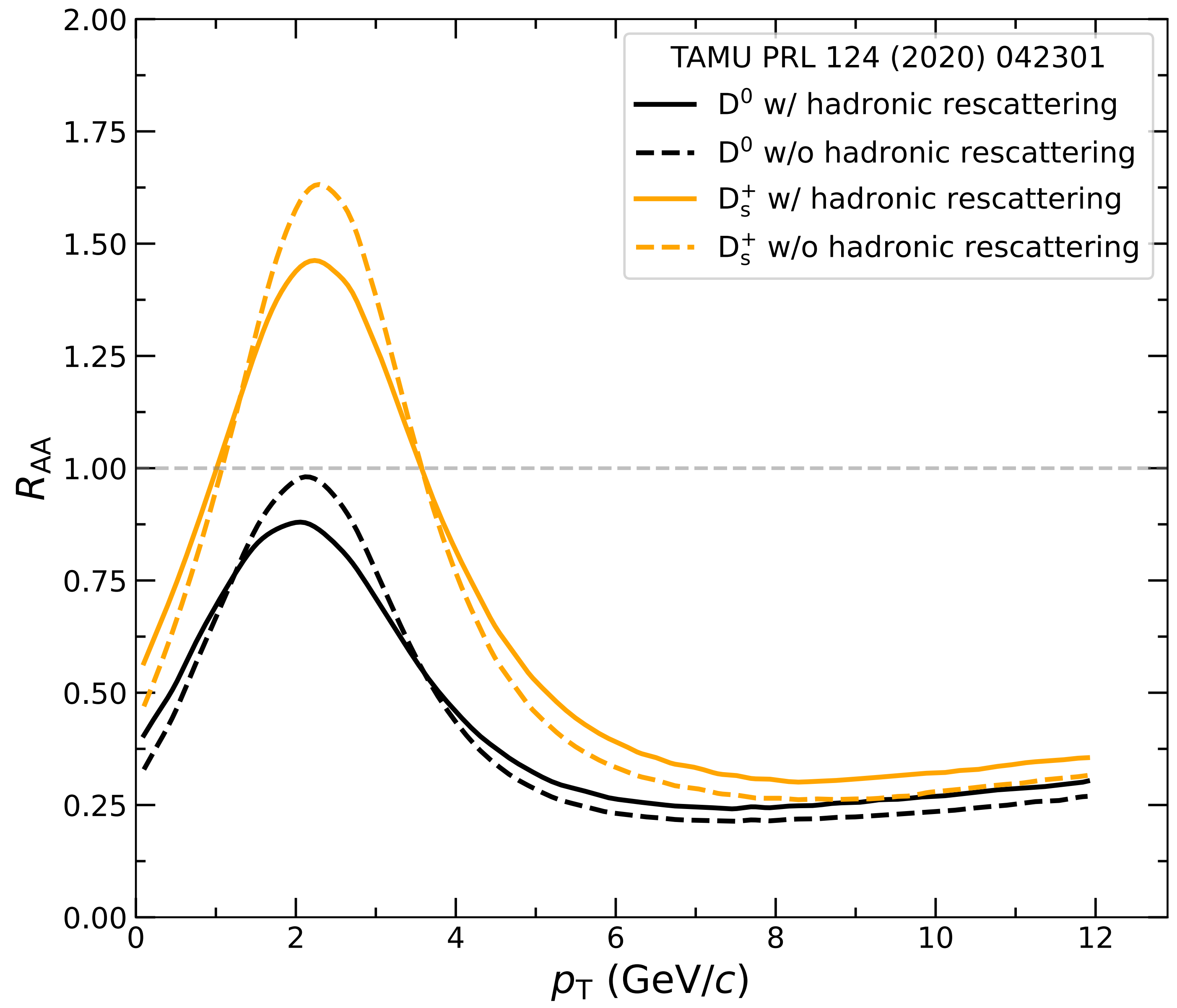
$$R_{AA}(p_T) = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$

Comparison with models based on **charm-quark transport** in the QGP to infer properties of the interaction between charm quarks and the medium



Ralf Rapp et al, PLB 701 (2011) 445–450

- QCD calculations on lattice predict a phase transition from the ordinary nuclear matter to a **colour-deconfined medium**, called **quark–gluon plasma** (QGP)
- Charm quarks: produced in hard scatterings before the formation of the QGP, subsequently interact with the medium constituents
- After the hadronisation, charm hadrons might still interact with the light hadrons produced
  - ➡ How much **hadronic rescatterings** influence our observables?



- In the TAMU model the scattering lengths used for πD and $\bar{K}$D are:
  - ➡ $a_{\pi D}(I=3/2) = -0.10$ fm
  - ➡ $a_{\bar{K}D}(I=1) = -0.22$ fm
  - ➡ **No experimental constraints**

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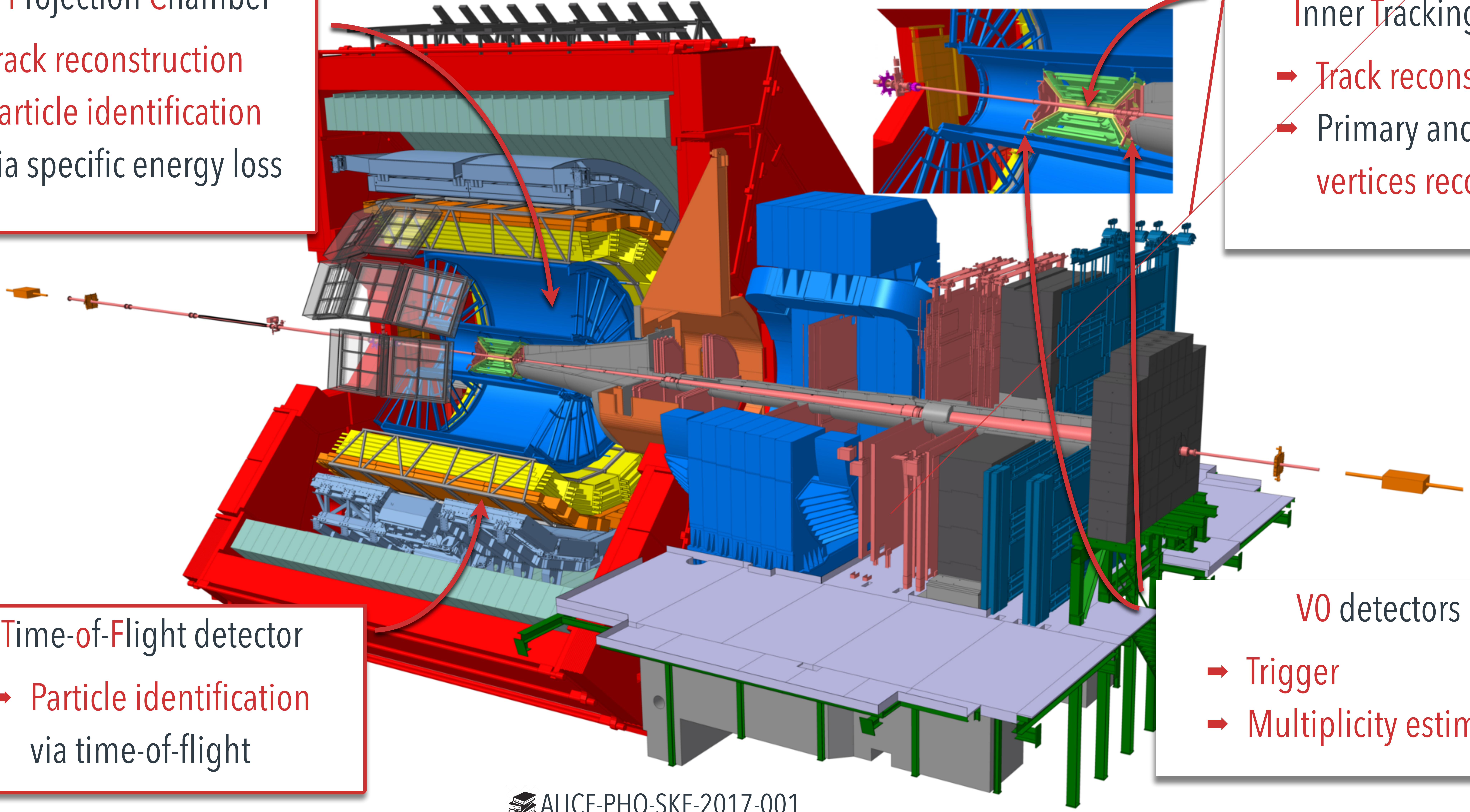
Time Projection Chamber

- ➡ Track reconstruction
- ➡ Particle identification via specific energy loss

Inner Tracking System

- ➡ Track reconstruction
- ➡ Primary and decay vertices reconstruction



Time-of-Flight detector

- ➡ Particle identification via time-of-flight

V0 detectors

- ➡ Trigger
- ➡ Multiplicity estimation

ALICE-PHO-SKE-2017-001

$D^{(*)\pm}$ - meson reconstruction with ALICE

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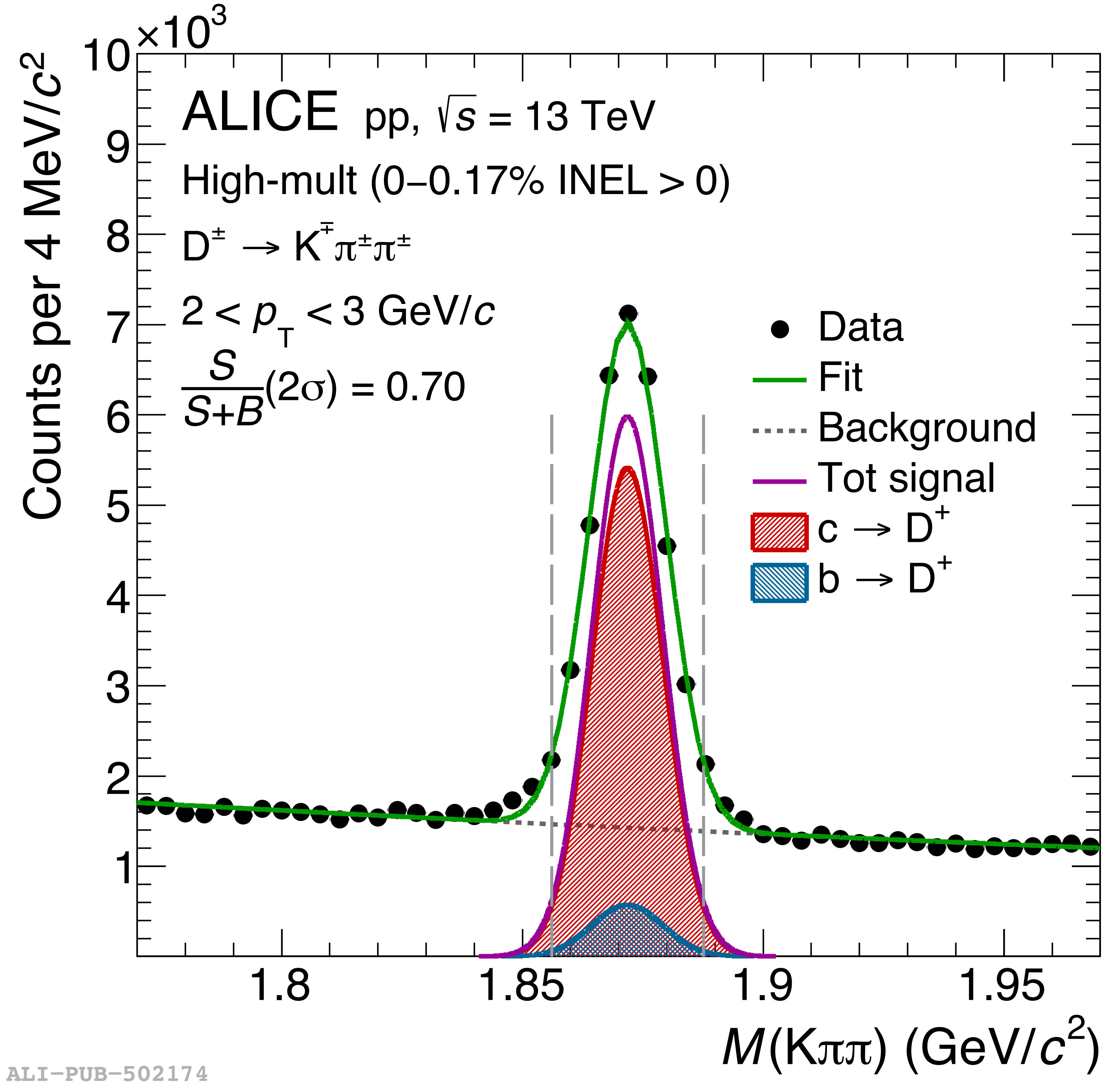
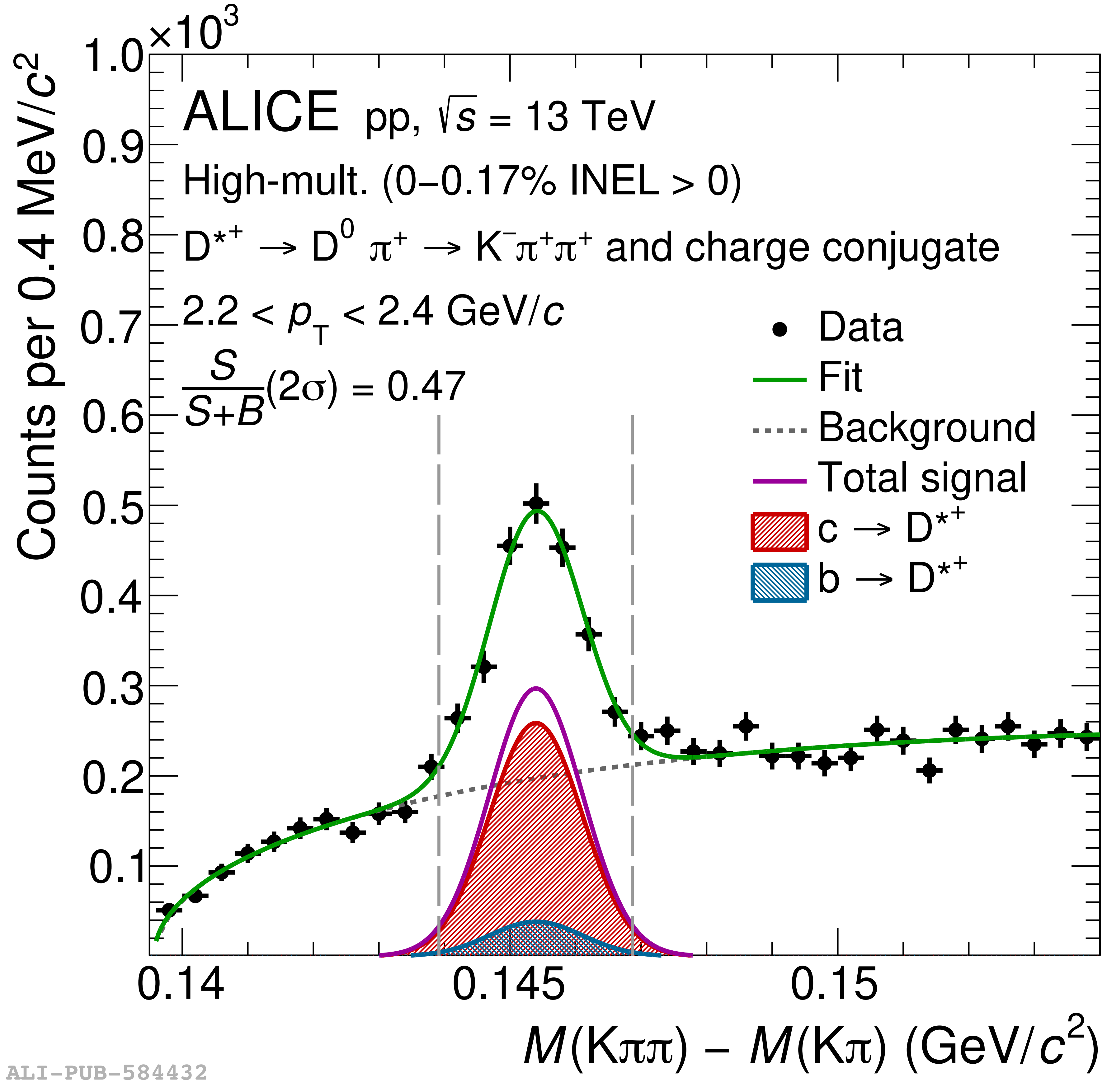
Hadron	Decay	Branching Ratio (%)
D^{*+}	$D^0(\rightarrow K^-\pi^+)\pi^+$	2.67±0.02
D^+	$K^-\pi^+\pi^+$	9.38±0.16

S. Navas et al. (PDG), PRD 110 (2024) 030001

- High-multiplicity data collected during LHC Run 2 ($L_{int} \approx 6$ pb^{-1})
- Fully reconstructed displaced decay topologies
- **Topological** and **particle-identification** (PID) selections applied to reduce combinatorial background

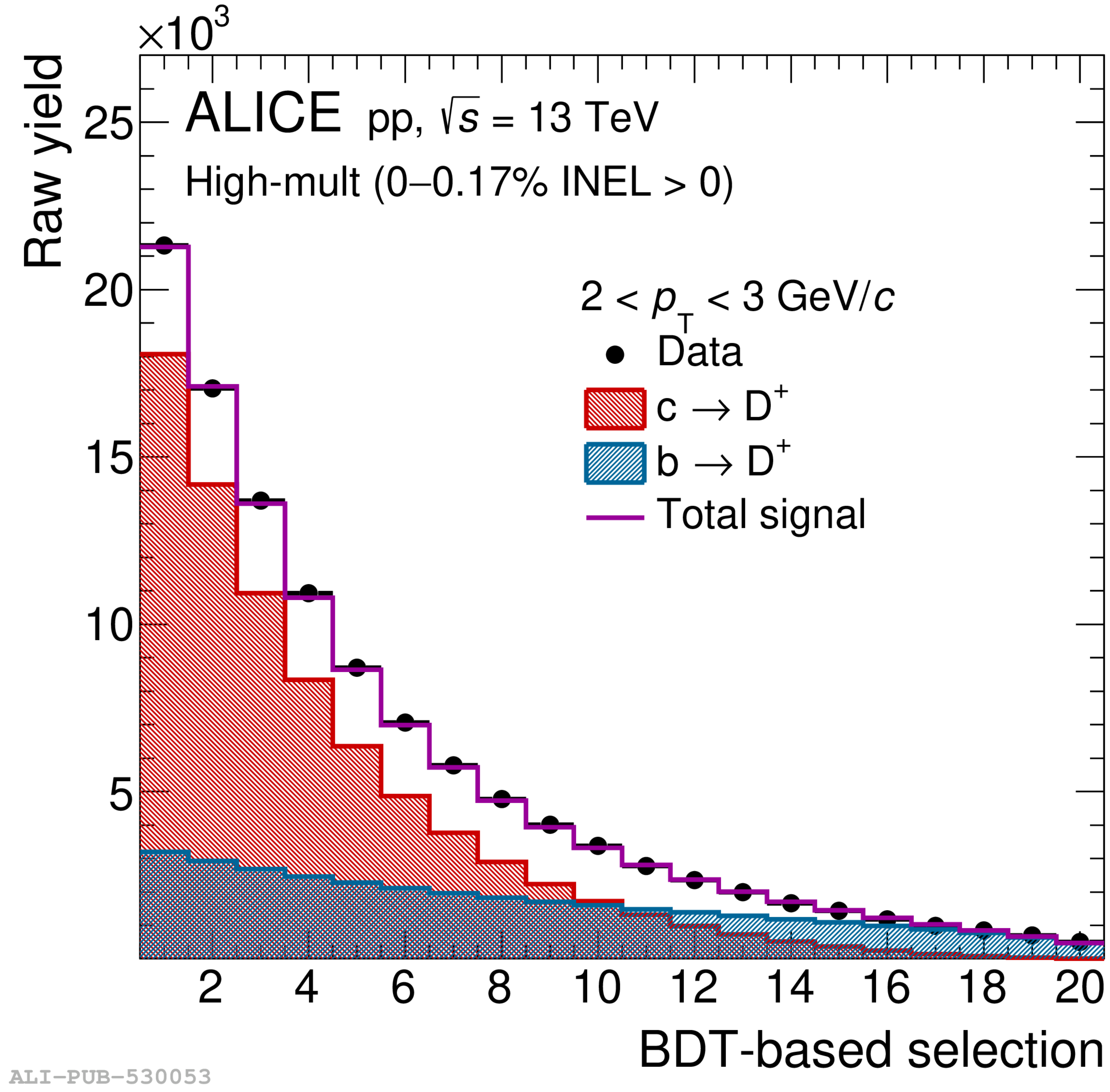


ALICE, PRD 106 (2022) 052010



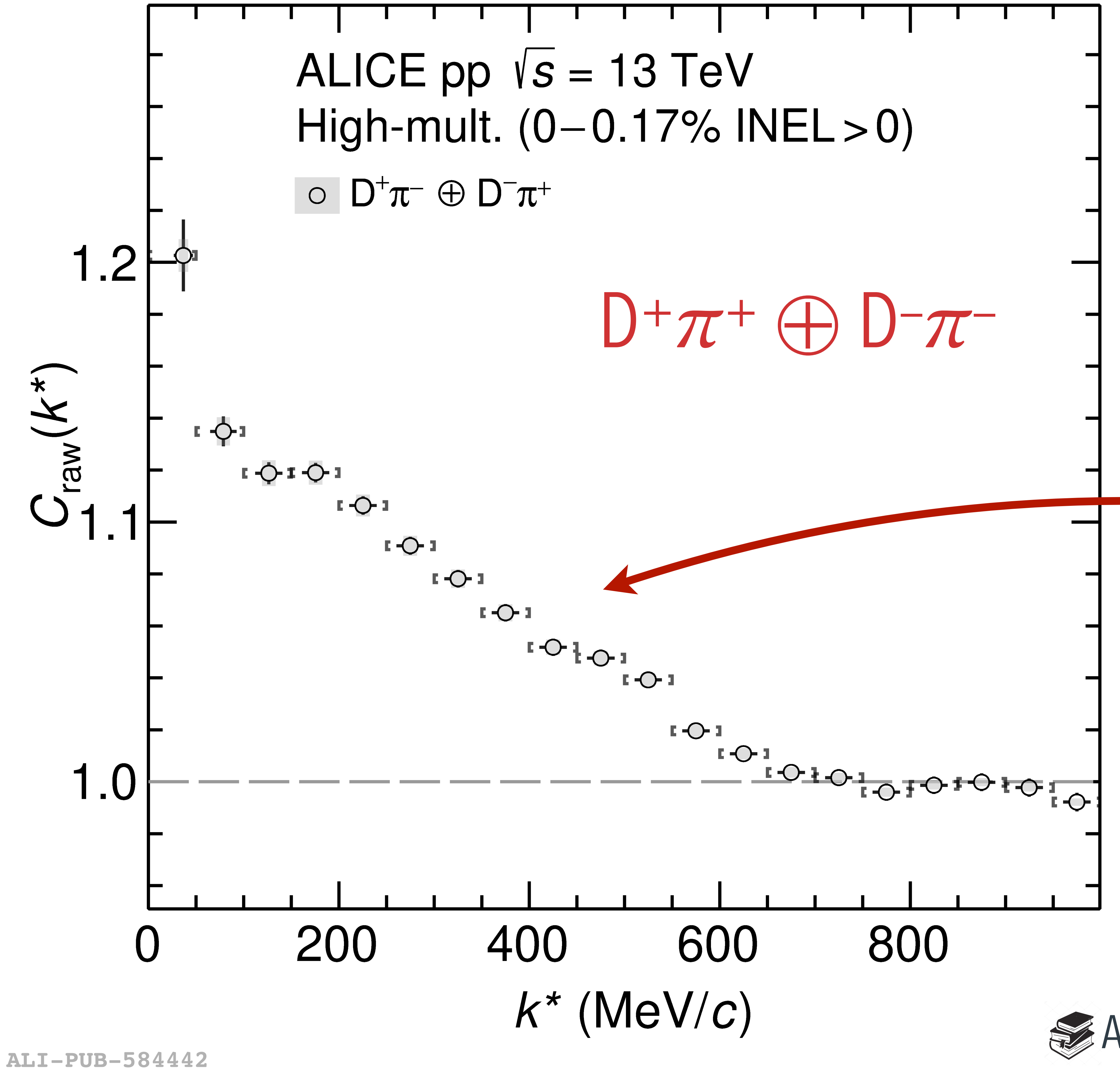
ALICE, PRD 110 (2024) 032004

Estimation of fraction from beauty-hadron decays



- Multi-class BDT classifier adopted to select D mesons and classify them as:
  - ➡ Background
  - ➡ **Prompt D mesons** (charm origin)
  - ➡ **Non-prompt D mesons** (beauty decays)
- Template fit of the raw-yield distribution obtained by sampling the BDT score rated to the probability to be non-prompt D meson
  - ➡ Provide fraction of D mesons for any given selection applied

$$C(\vec{k}^*) = \mathcal{N}\frac{N^{\mathrm{D}\pi}_{\mathrm{same}}(k^*)}{N^{\mathrm{D}\pi}_{\mathrm{mixed}}(k^*)} =$$



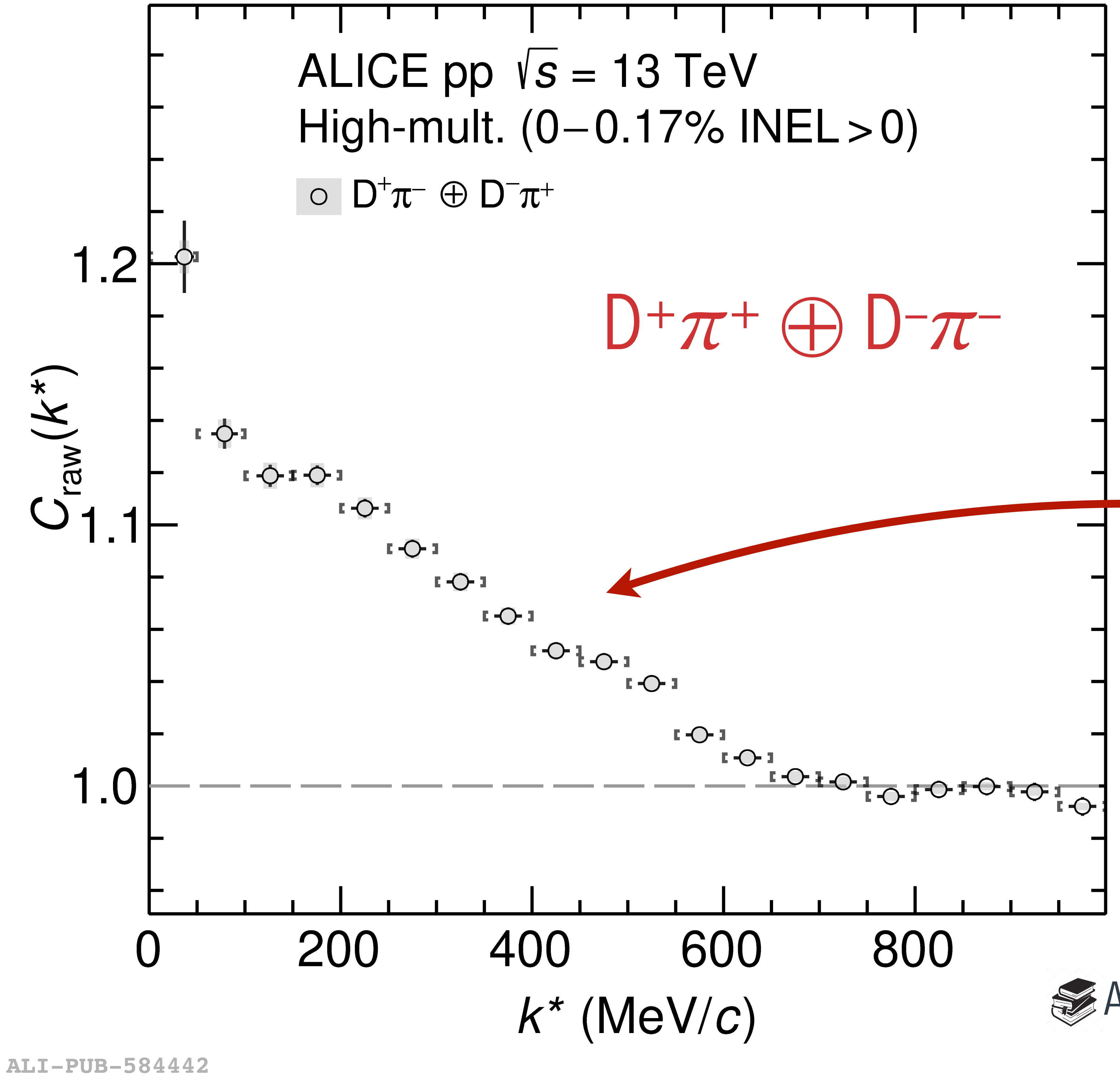
- Example: $D^{\pm}\pi^{\mp}$ candidate pairs
  - ➡ $D^{\pm}$ candidates selected in invariant-mass region of the signal (residual combinatorial background to be subtracted)
  - ➡ Pion sample selected with PID in TPC and TOF (>99% purity)

Slow rise towards low k^* due to jet-induced momentum correlations (Parton shower)

Flat at unity for large k^* (no interaction)

ALICE, PRD 110 (2024) 032004

$$C(\vec{k}^*) = \mathcal{N}\frac{N^{\mathrm{D}\pi}_{\mathrm{same}}(k^*)}{N^{\mathrm{D}\pi}_{\mathrm{mixed}}(k^*)} = \lambda_{\mathrm{SB}}C_{\mathrm{SB}}(k^*) + C_{\text{non-femto}}(k^*)\cdot[\lambda_{\mathrm{genuine}}C_{\mathrm{genuine}}(k^*) + \lambda_{\mathrm{D^+\leftarrow D^*}}C_{\mathrm{D^+\leftarrow D^*}} + \lambda_{\mathrm{flat}}]$$



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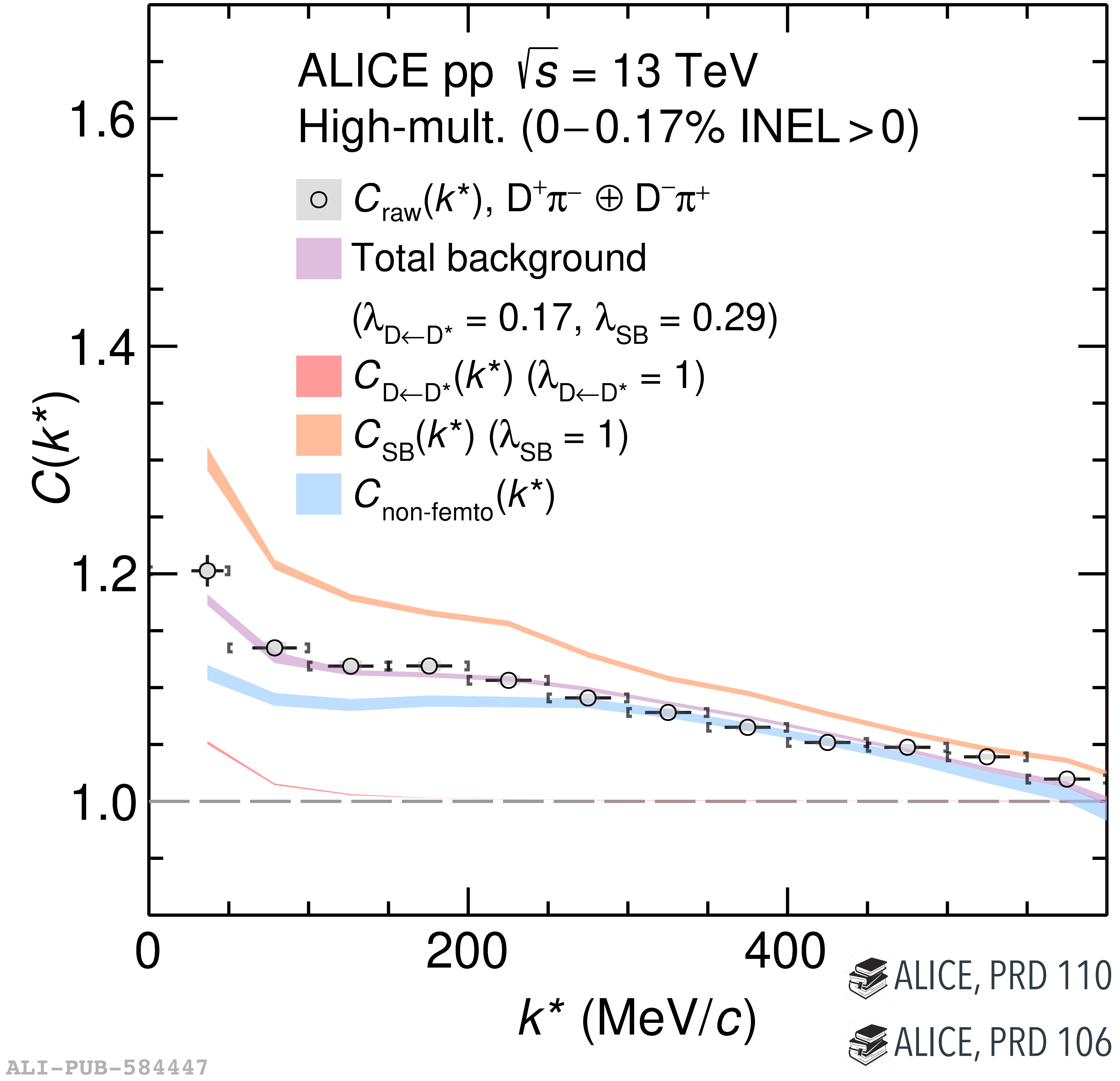
Slow rise towards low k^* due to jet-induced momentum correlations (Parton shower)

Flat at unity for large k^* (no interaction)

ALICE, PRD 110 (2024) 032004

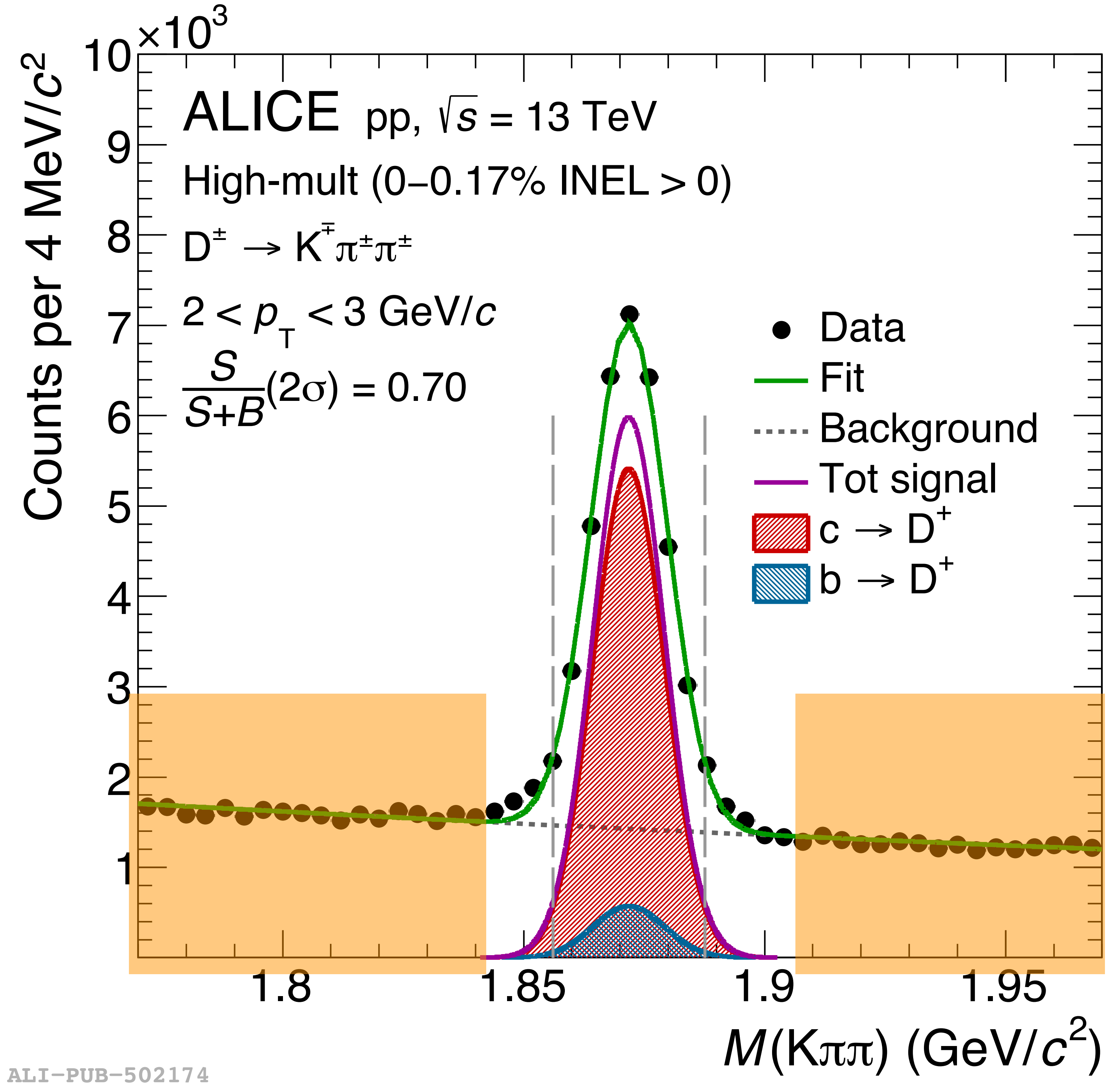
$$C_{\rm raw}(\vec{k}^*) = \lambda_{\rm SB} C_{\rm SB}(k^*) + C_{\text{non-femto}}(k^*) \cdot [\lambda_{\rm genuine} C_{\rm genuine}(k^*) + \lambda_{\rm D^+ \leftarrow D^*} C_{\rm D^+ \leftarrow D^*} + \lambda_{\rm flat}]$$



ALICE, PRD 110 (2024) 032004

ALICE, PRD 106 (2022) 052010

- Raw correlation function includes different sources of backgrounds
  i. Combinatorial background estimated from D-meson sidebands



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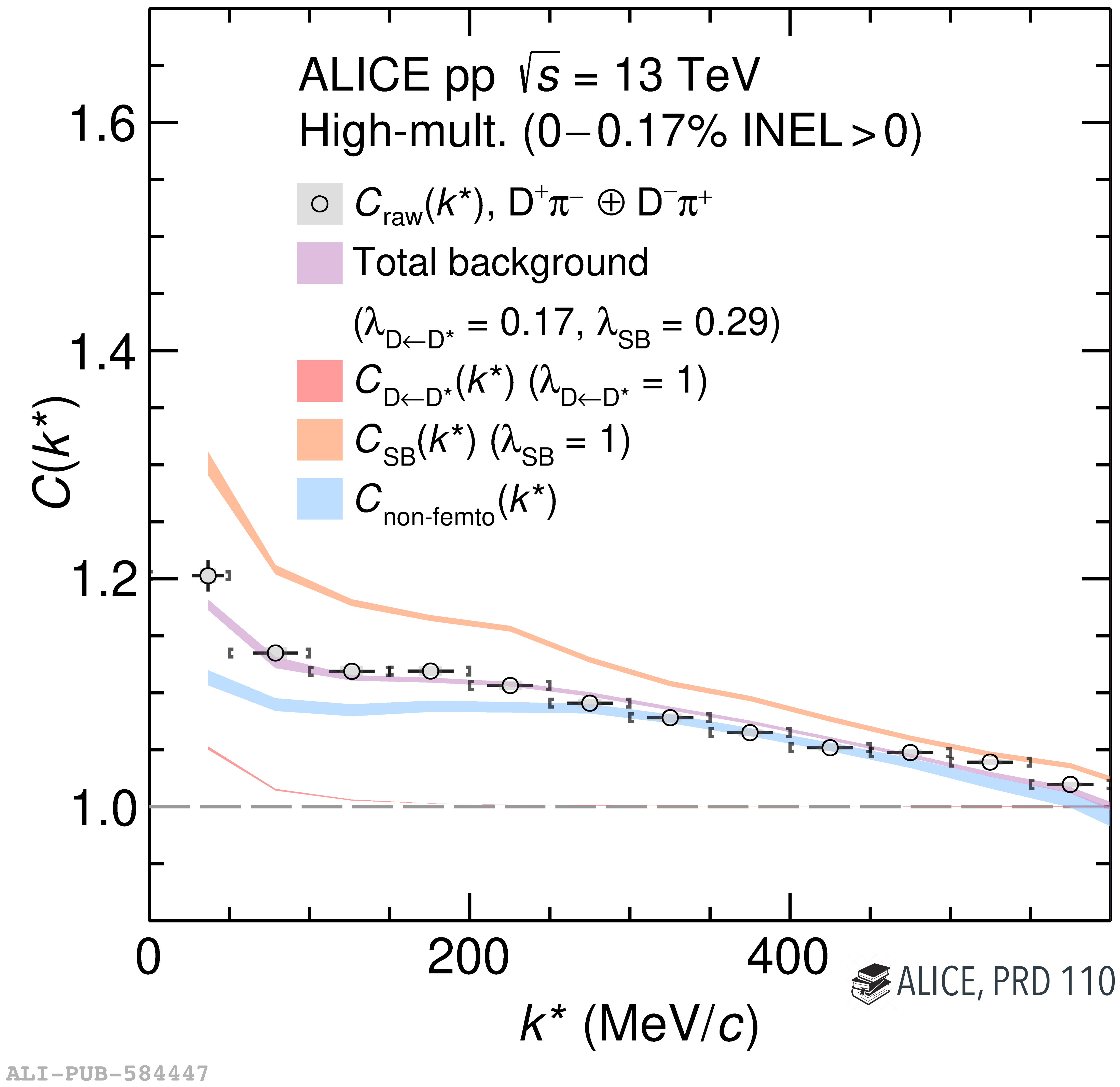
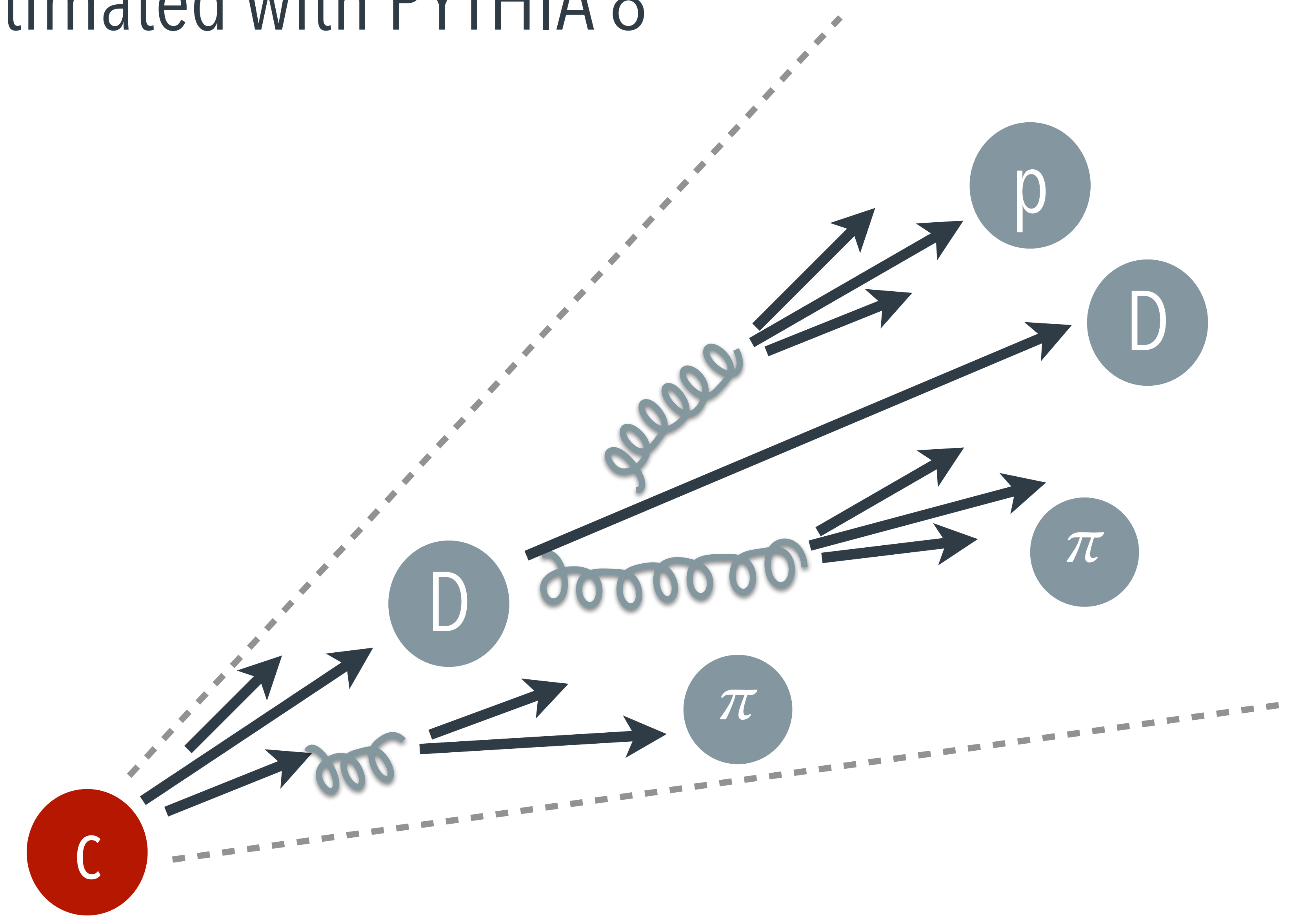
$$C_{\mathrm{raw}}(\vec{k}^{*}) = \lambda_{\mathrm{SB}} C_{\mathrm{SB}}(k^{*}) + C_{\text{non-femto}}(k^{*}) \cdot [\lambda_{\mathrm{genuine}} C_{\mathrm{genuine}}(k^{*}) + \lambda_{\mathrm{D^{+} \leftarrow D^{*}}} C_{\mathrm{D^{+} \leftarrow D^{*}}} + \lambda_{\mathrm{flat}}]$$



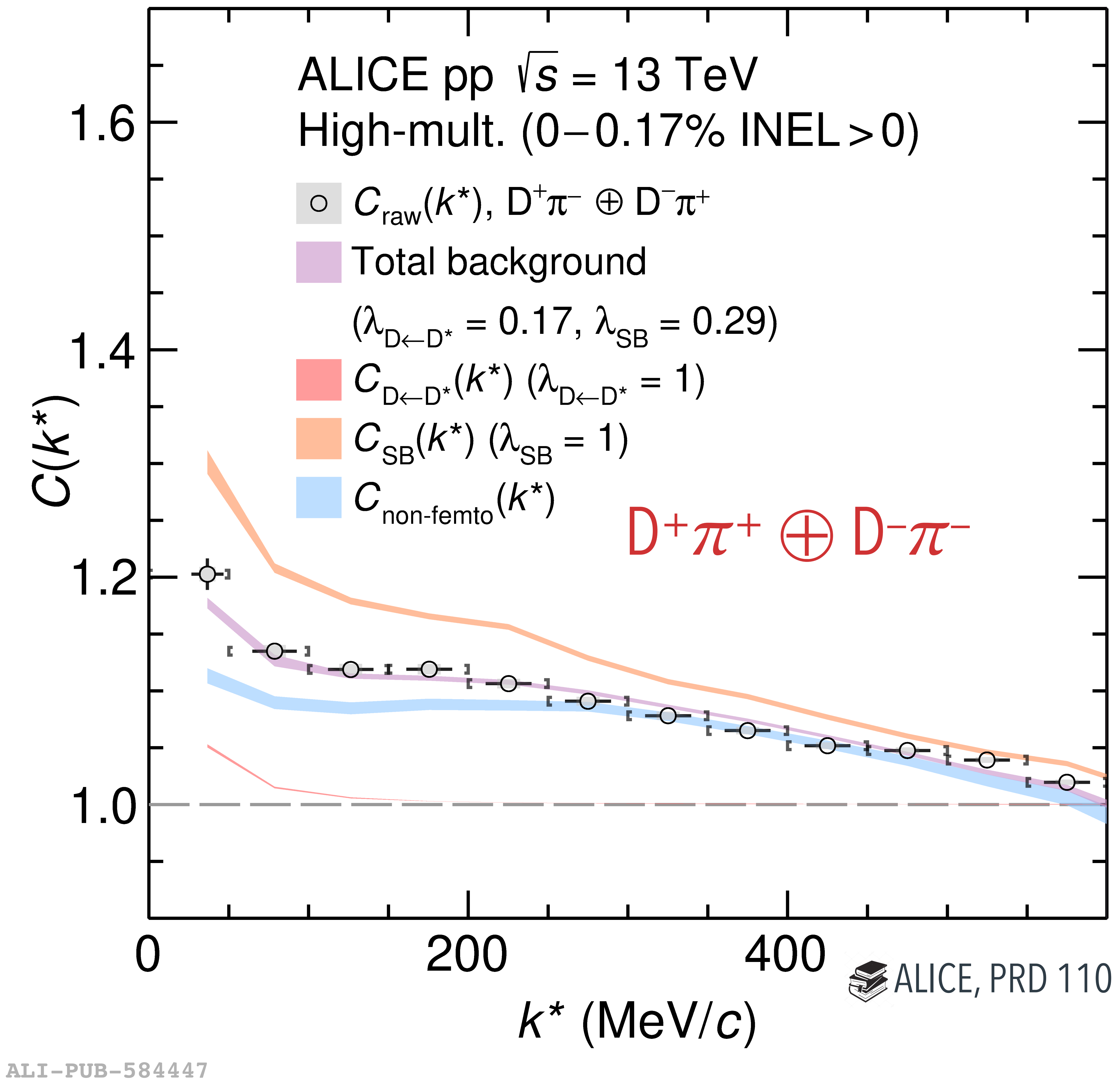
ALICE, PRD 110 (2024) 032004

- Raw correlation function includes different sources of backgrounds
  - i. Combinatorial background estimated from D-meson sidebands
  - ii. Jet-induced correlations (non-femto) estimated with PYTHIA 8



Correction of raw correlation function

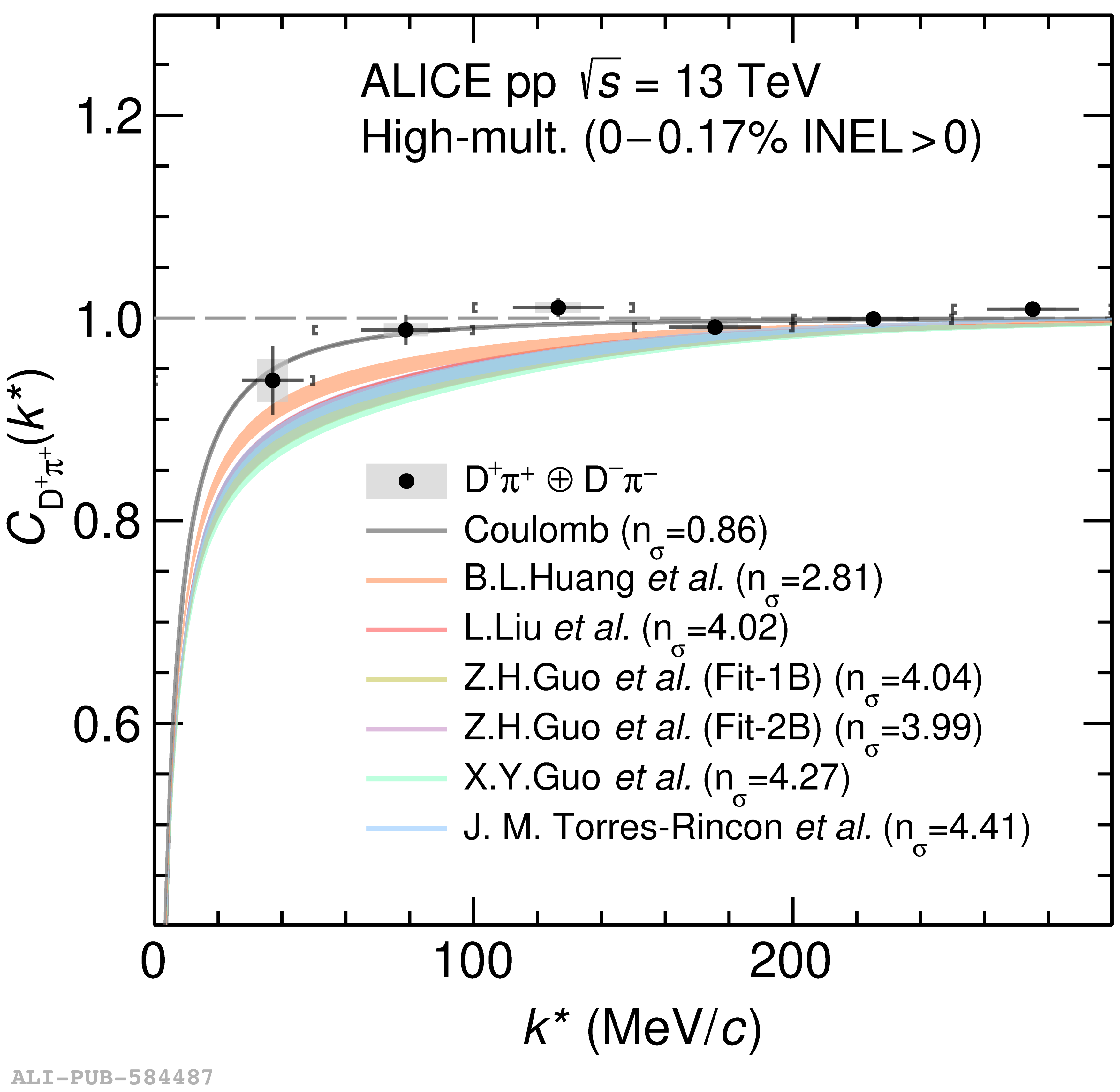
$$C_{\rm raw}(\vec{k}^*) = \lambda_{\rm SB} C_{\rm SB}(k^*) + C_{\text{non-femto}}(k^*) \cdot [\lambda_{\rm genuine} C_{\rm genuine}(k^*) + \lambda_{D^+ \leftarrow D^*} C_{D^+ \leftarrow D^*} + \lambda_{\rm flat}]$$



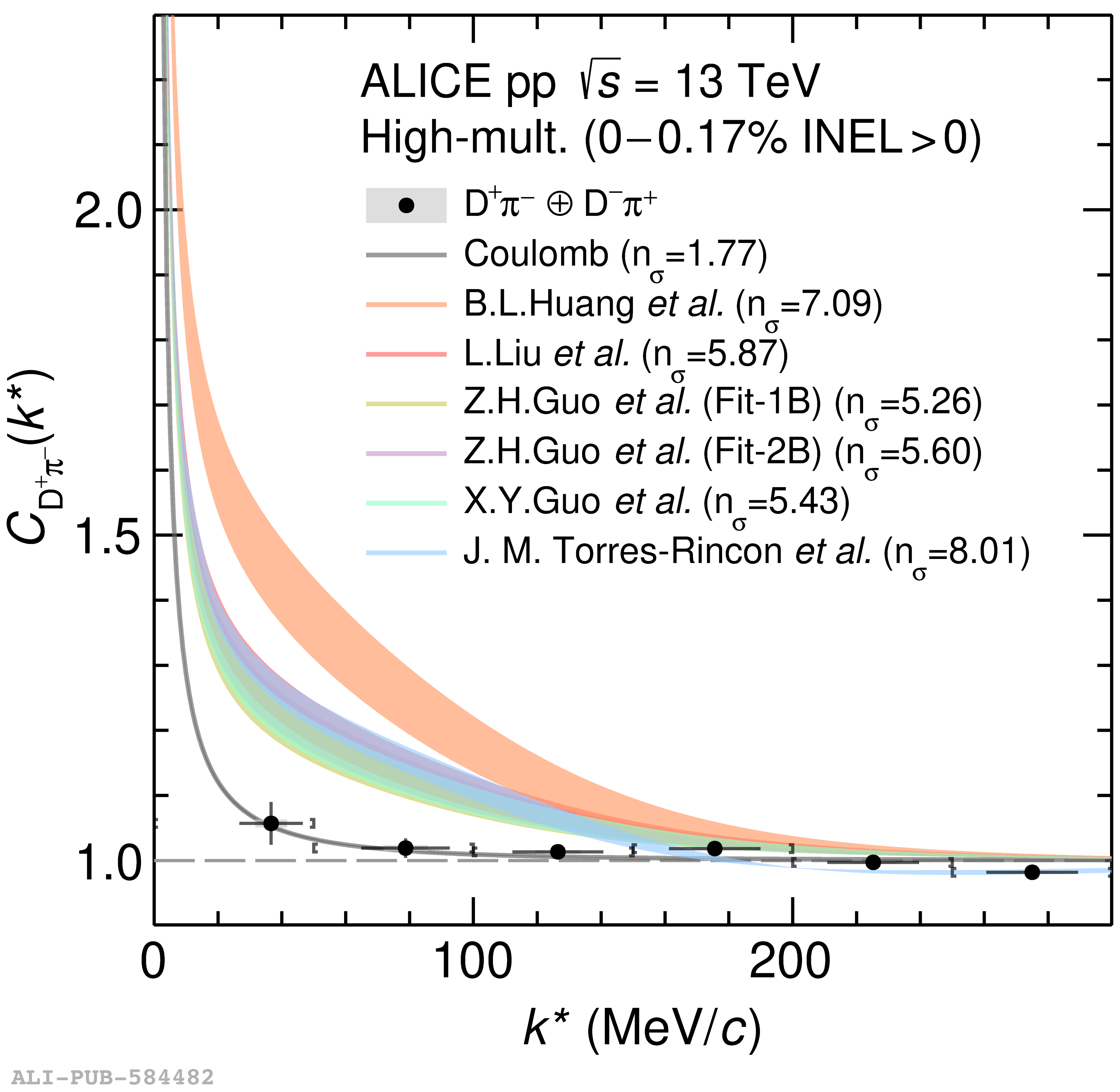
ALICE, PRD 110 (2024) 032004

- Raw correlation function includes different sources of backgrounds
  - i. Combinatorial background estimated from D-meson sidebands
  - ii. Jet-induced correlations (non-femto) estimated with PYTHIA 8
  - iii. $D^{*\pm} \rightarrow D^{\pm} + X$ obtained from $D^{*\pm}\pi^{\mp}$ measurement, converted to $D^{\pm}\pi^{\mp}$ momentum space with decay kinematics
- Total background well describes CF for large k^*

$D^+\pi^+ \oplus D^-\pi^-$



$D^+\pi^- \oplus D^-\pi^+$



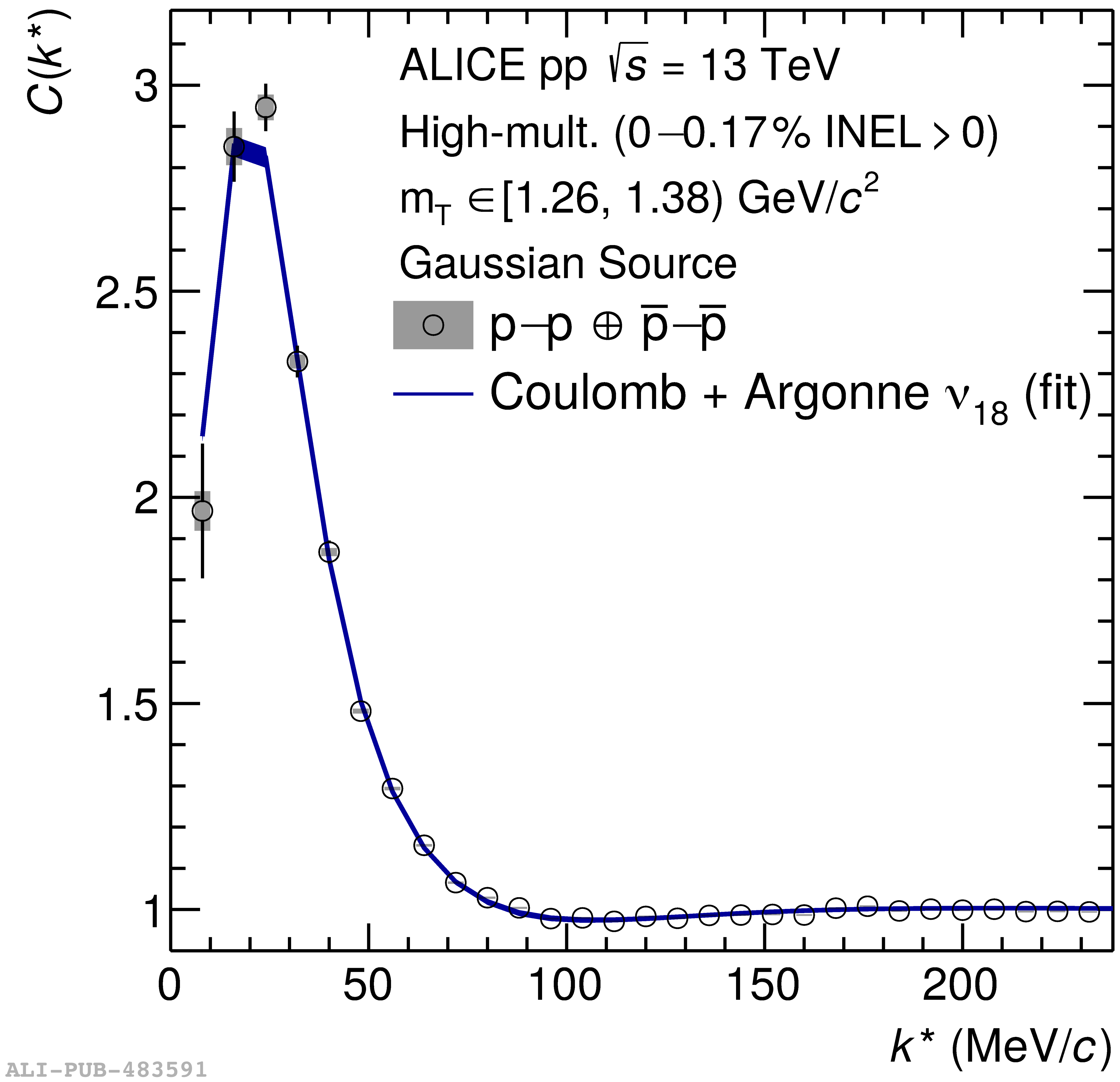
- $D^\pm\pi^\pm$
  - ➡ $I = 3/2$ channel only
- $D^\pm\pi^\mp$
  - ➡ $I = 3/2$ (33%), $I = 1/2$ (66%)

L. Liu et al, PRD 87 (2013) 014508
X.-Y. Guo et al, PRD 98 (2018) 014510
B.-L. Huang et al, PRD 105 (2022) 036016
Z.-H. Guo et al EPJC 79 (2019) 13
J.M. Torres-Rincon et al, PRD 108 (2023) 096008

- Both same-sign and opposite sign correlation functions **compatible with Coulomb-only hypothesis**
  - ➡ Strong interaction "weaker" than the one predicted by theoretical predictions

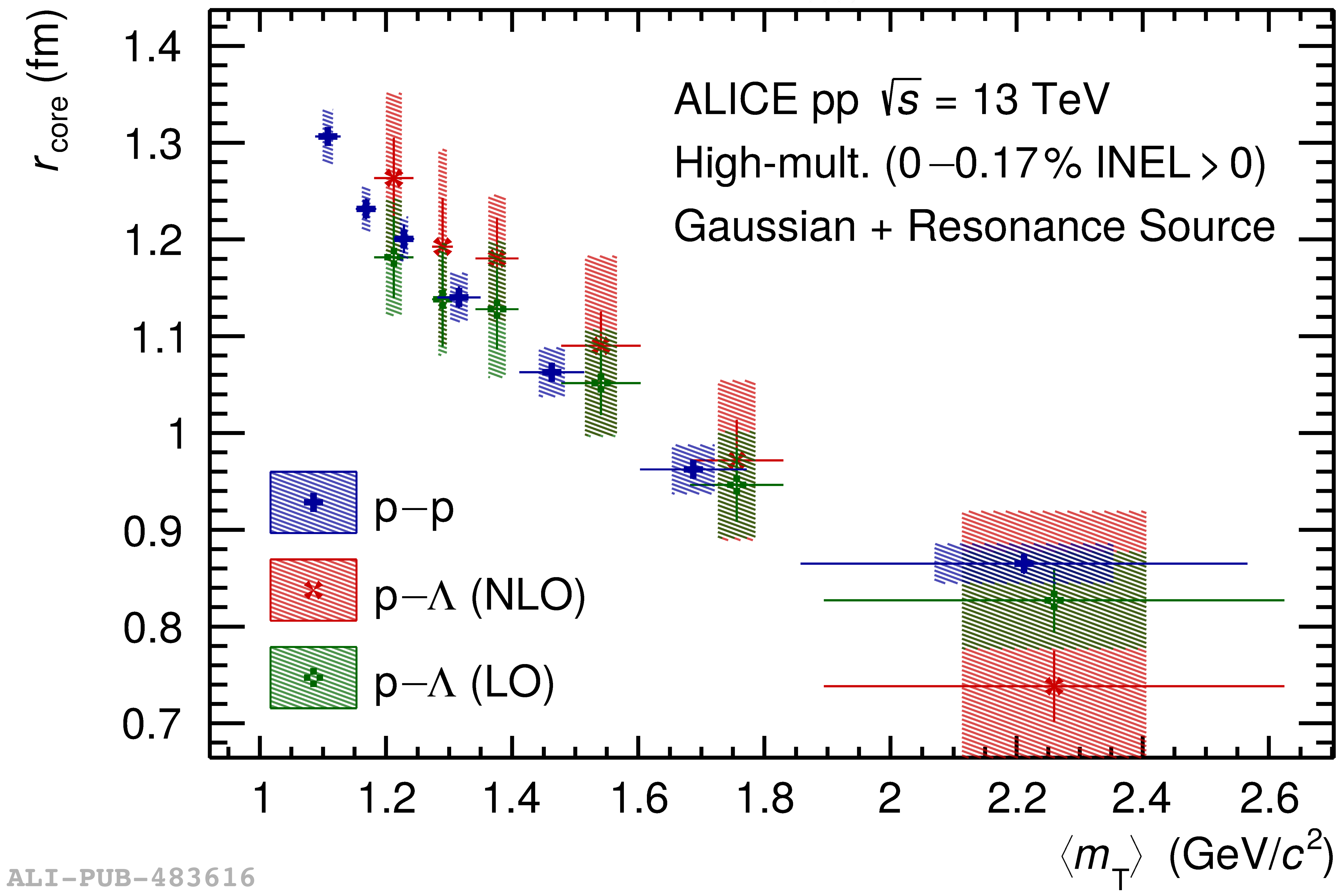
ALICE, PRD 110 (2024) 032004

Phys. Lett. B 811 (2020) 135849



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

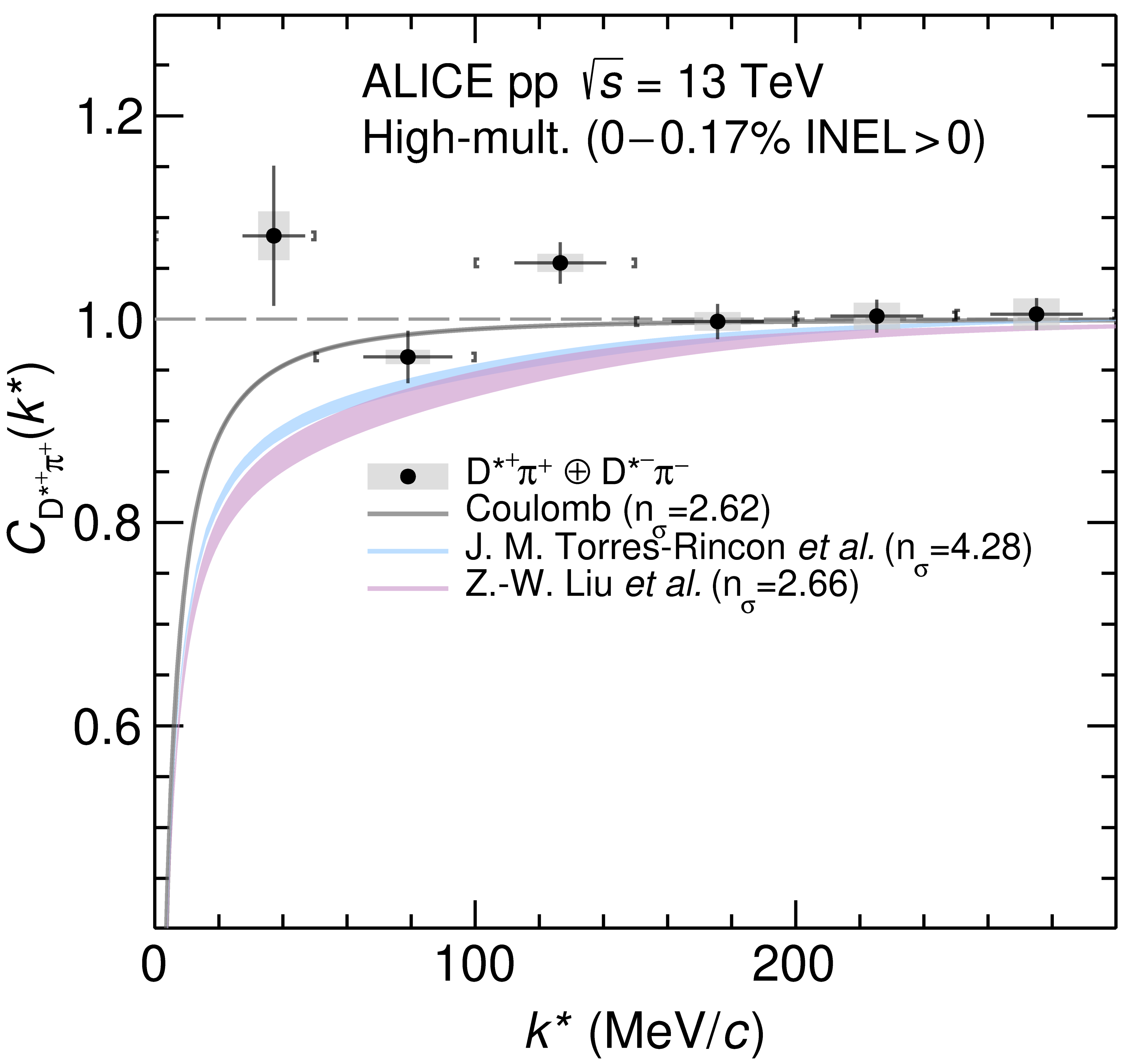
Phys. Lett. B 811 (2020) 135849



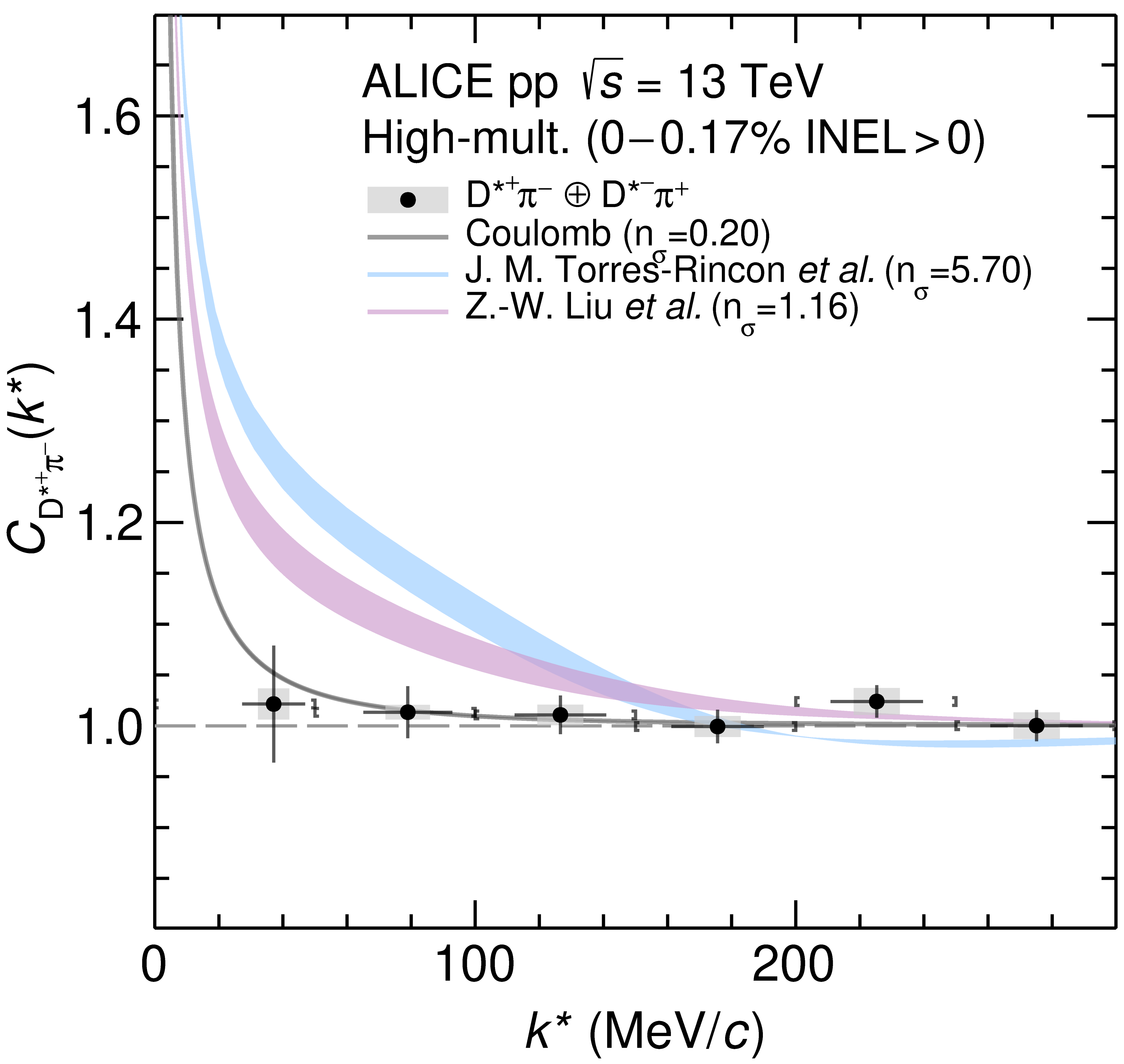
- Model the source considering the core radius corresponding to the average m_T and adding resonances

D*π interaction

$D^{*+}\pi^{+} \oplus D^{*-}\pi^{-}$



$D^{*+}\pi^{-} \oplus D^{*-}\pi^{+}$



- $D^{*\pm}\pi^{\mp}$
  - ➡ $I = 3/2$ channel only
- $D^{*\pm}\pi^{\pm}$
  - ➡ $I = 3/2$ (33%), $I = 1/2$ (66%)

L. Liu et al, Phys. Rev. D87 (2013) 014508
J.M. Torres-Rincon et al, PRD 108 (2023) 096008

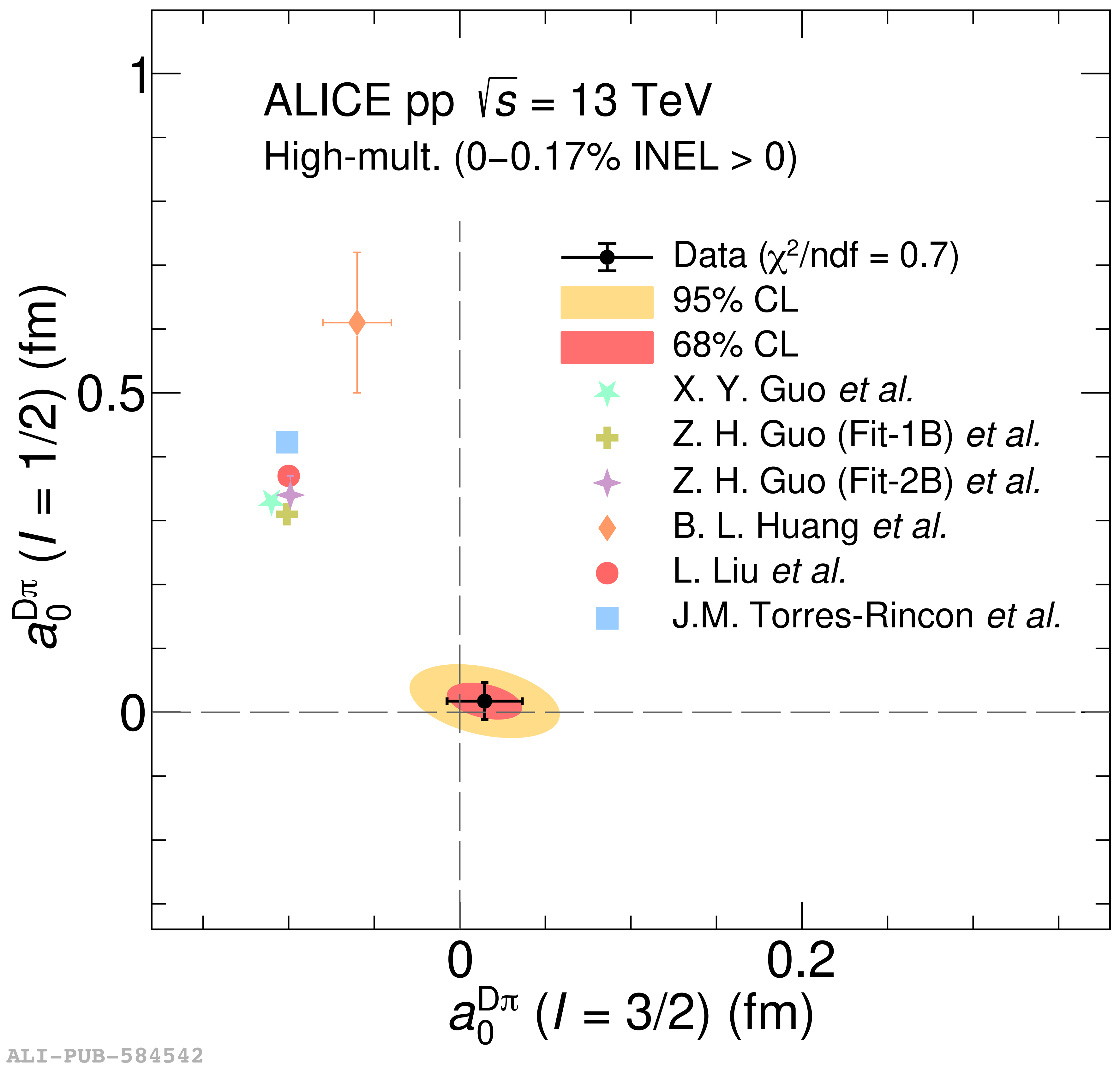
- Similar results for the $D^{*\pm}\pi^{\mp}$
  - ➡ Expected due to heavy-quark spin symmetry

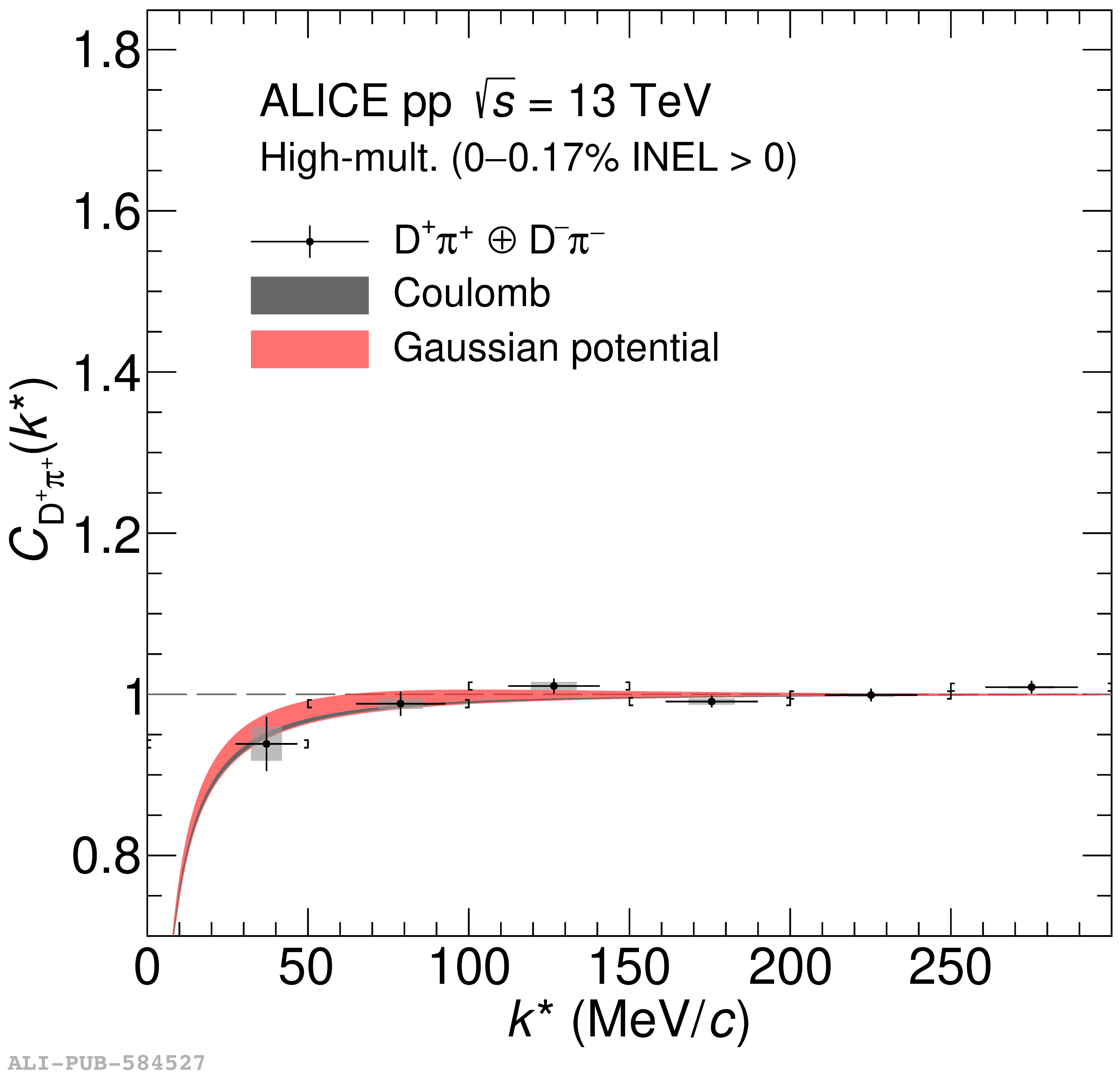
ALICE, PRD 110 (2024) 032004

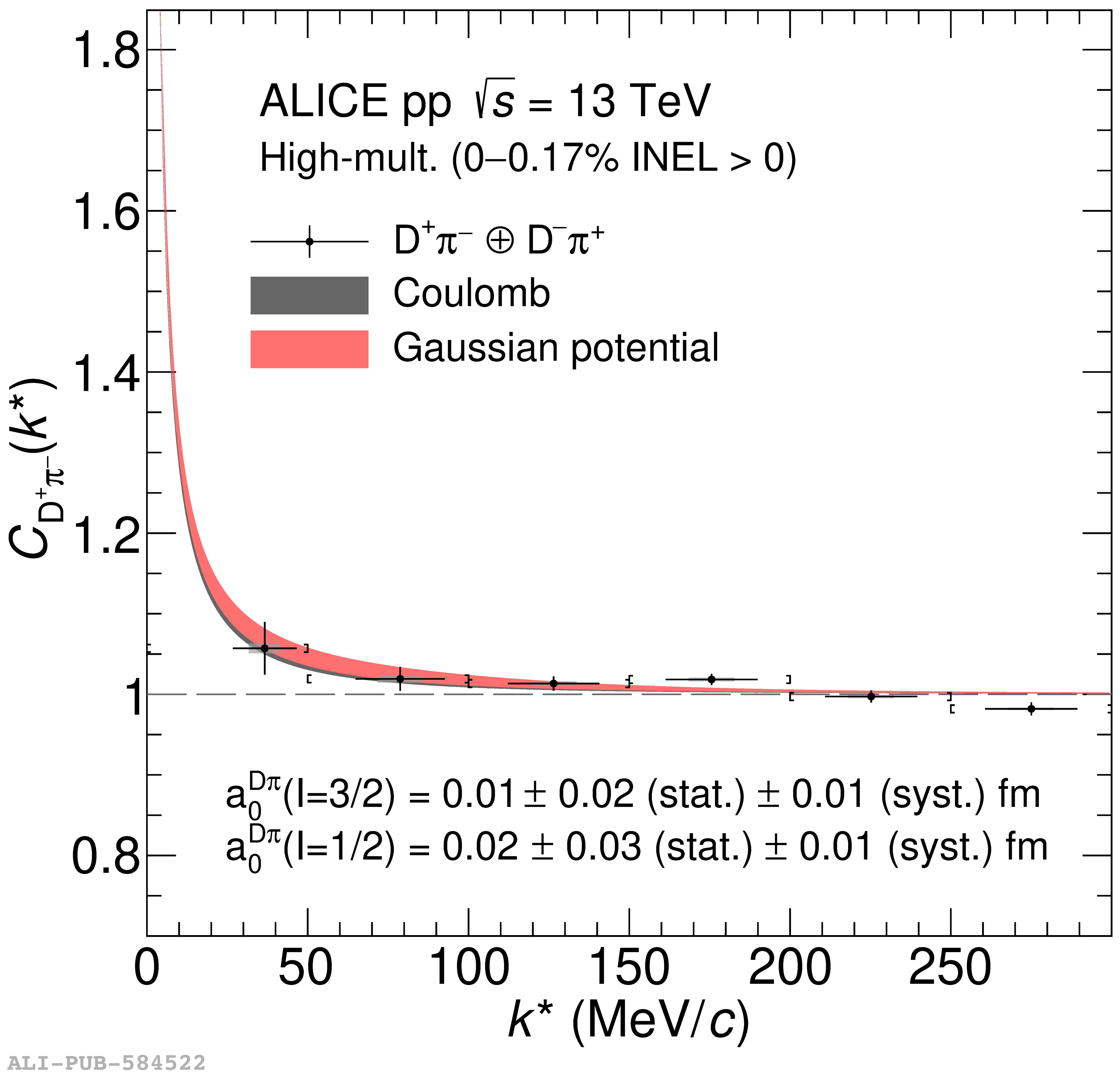
- **Scattering lengths extracted from data** via a χ^2 minimisation procedure
  - ➡ Model prediction computed varying the scattering lengths using **Gaussian-potential** approximation (meson exchange)

$$V(r) = V_0 \exp(-m_\rho^2 r^2)$$

Y. Kamyia et al, EPJA 58 (2022) 131







- Experimental scattering lengths for both isospin channels compatible with zero
  - ➡ **>5σ disagreement with models in I=1/2**

ALICE, PRD 110 (2024) 032004

D(*)K interaction

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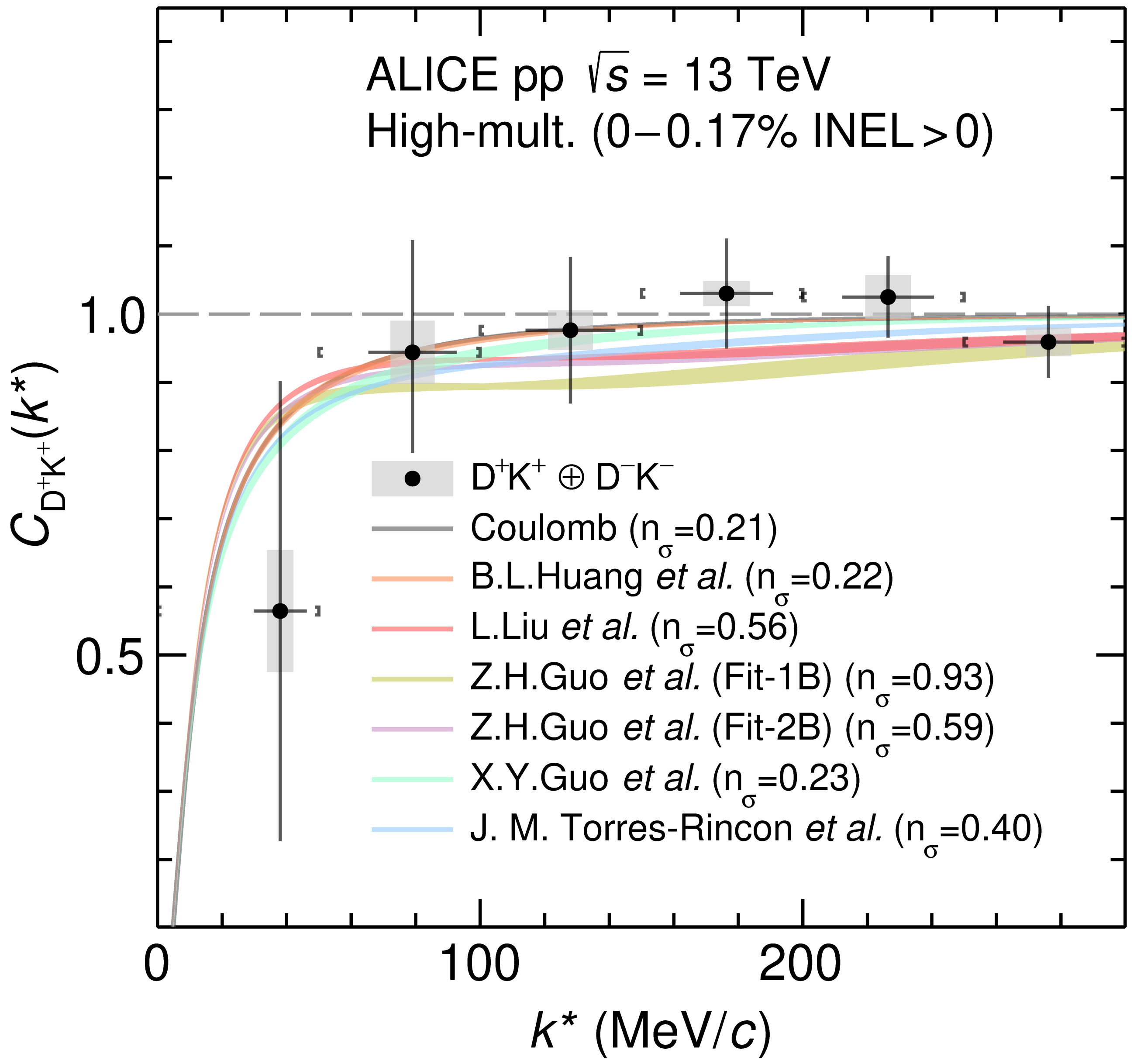
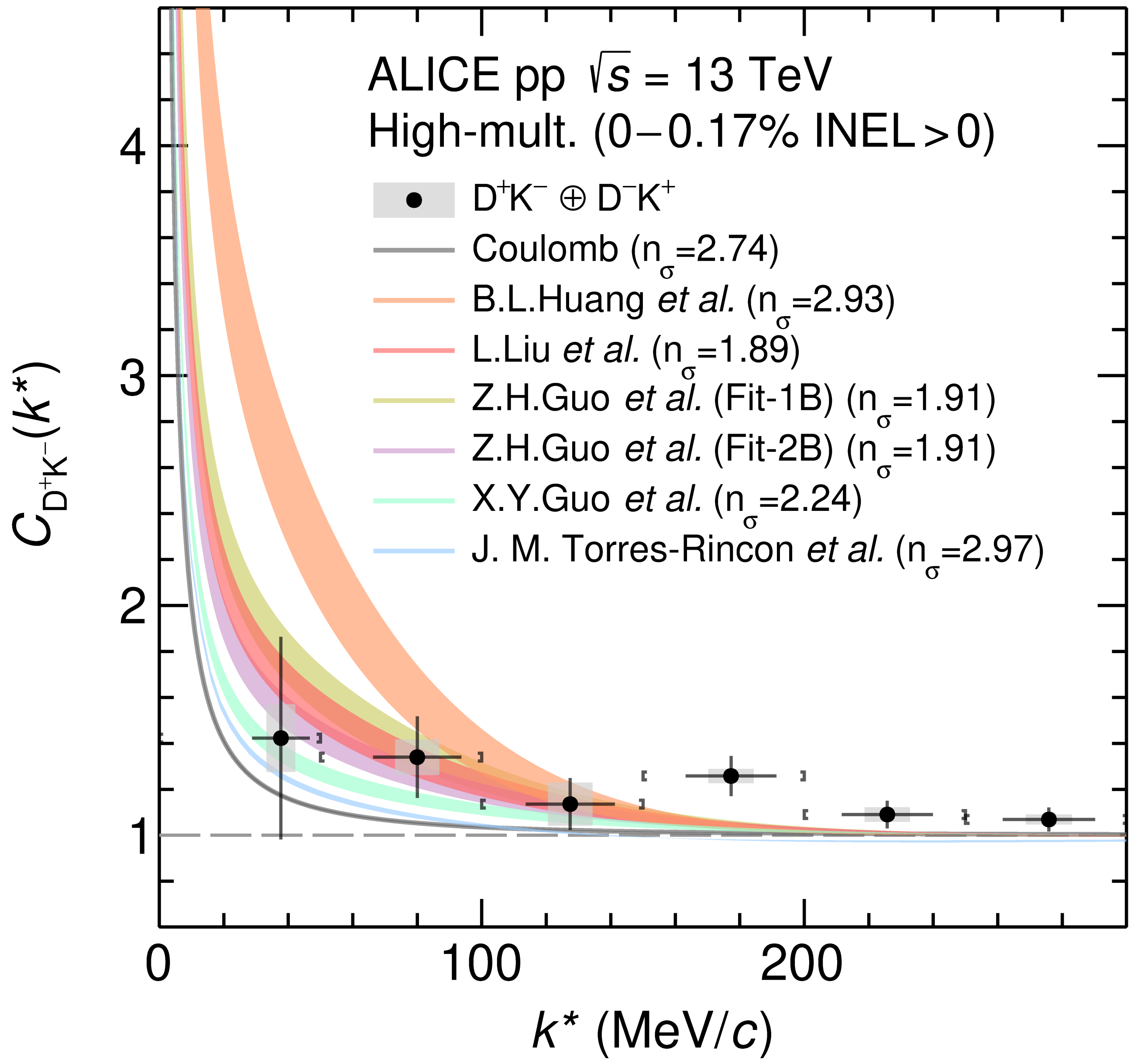
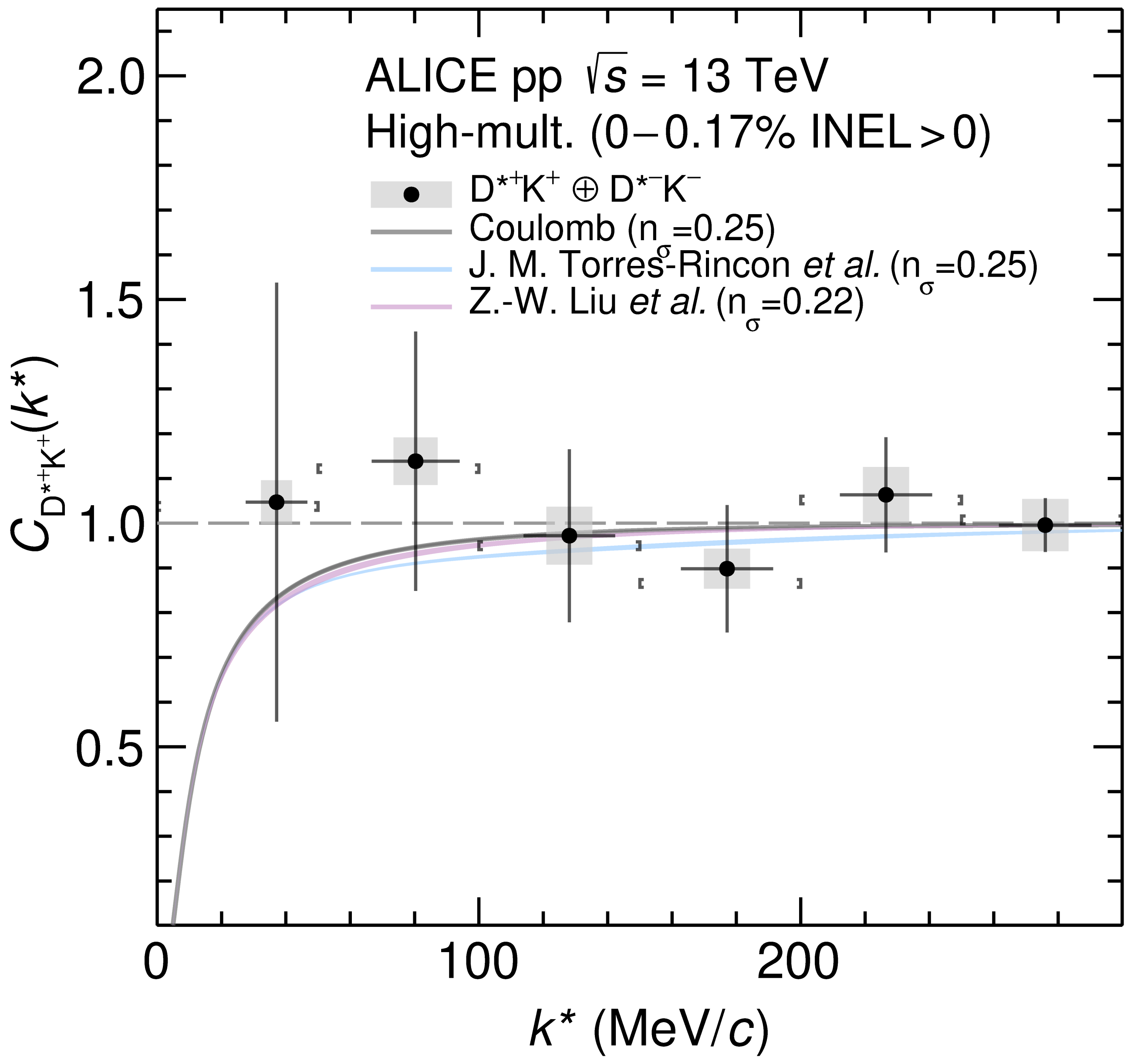


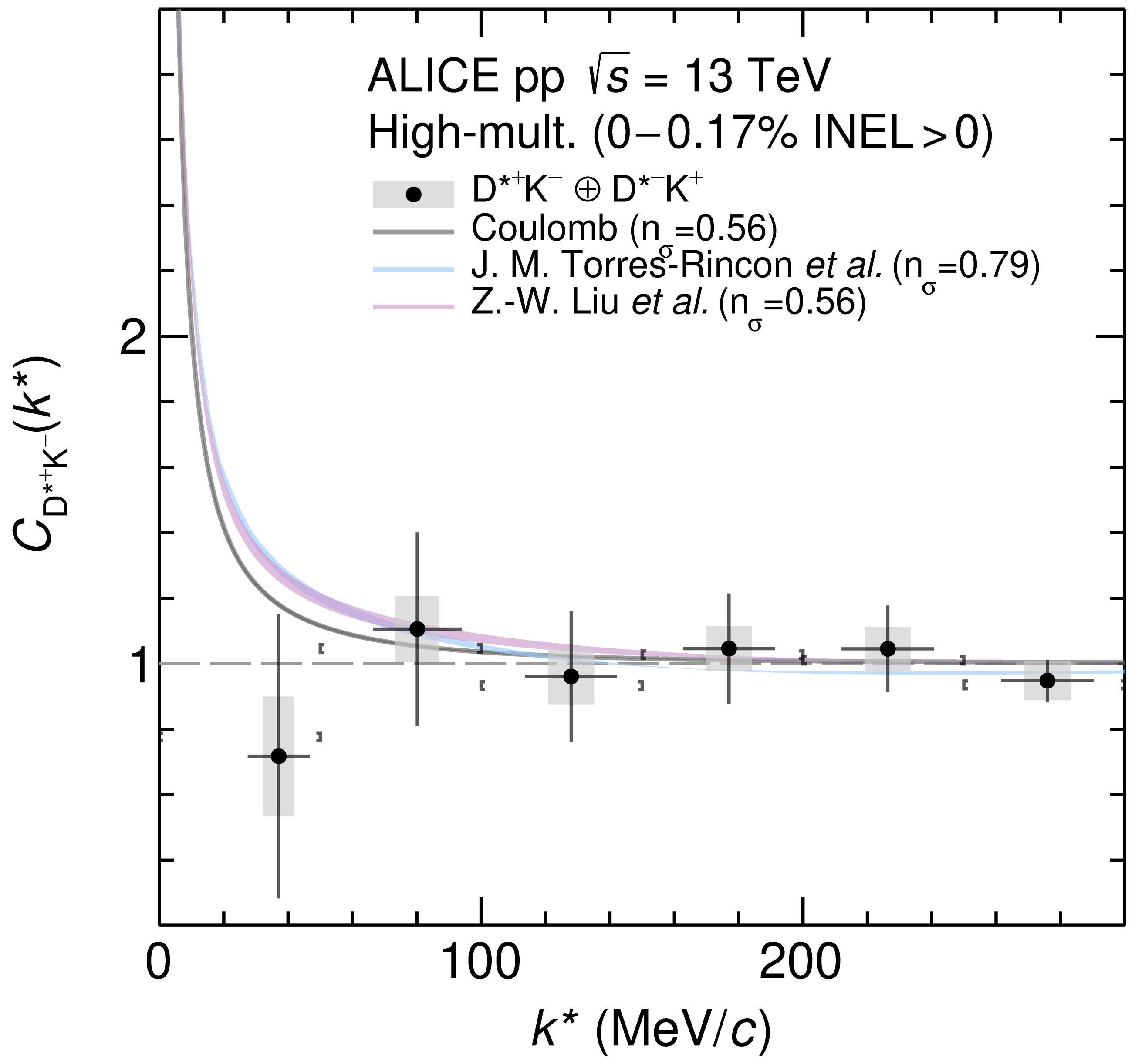
ALI-PUB-584497



ALI-PUB-584492



ALI-PUB-584517



ALI-PUB-584512

ALICE, PRD 110 (2024) 032004

- $D^{(*)\pm}K^{\pm}$
  - ➡ $I = 1$ channel only
- $D^{(*)\pm}K^{\mp}$
  - ➡ $I = 0$ (50%), $I = 1$ (50%)

- Experimental data compatible with both Coulomb interaction and Coulomb + strong interaction
  - ➡ **Higher precision needed to draw conclusions**

L. Liu et al, PRD 87 (2013) 014508
X.-Y. Guo et al, PRD 98 (2018) 014510
B.-L. Huang et al, PRD 105 (2022) 036016
Z.-H. Guo et al EPJC 79 (2019) 13
J.M. Torres-Rincon et al, PRD 108 (2023) 096008

$N\bar{D}$ interaction

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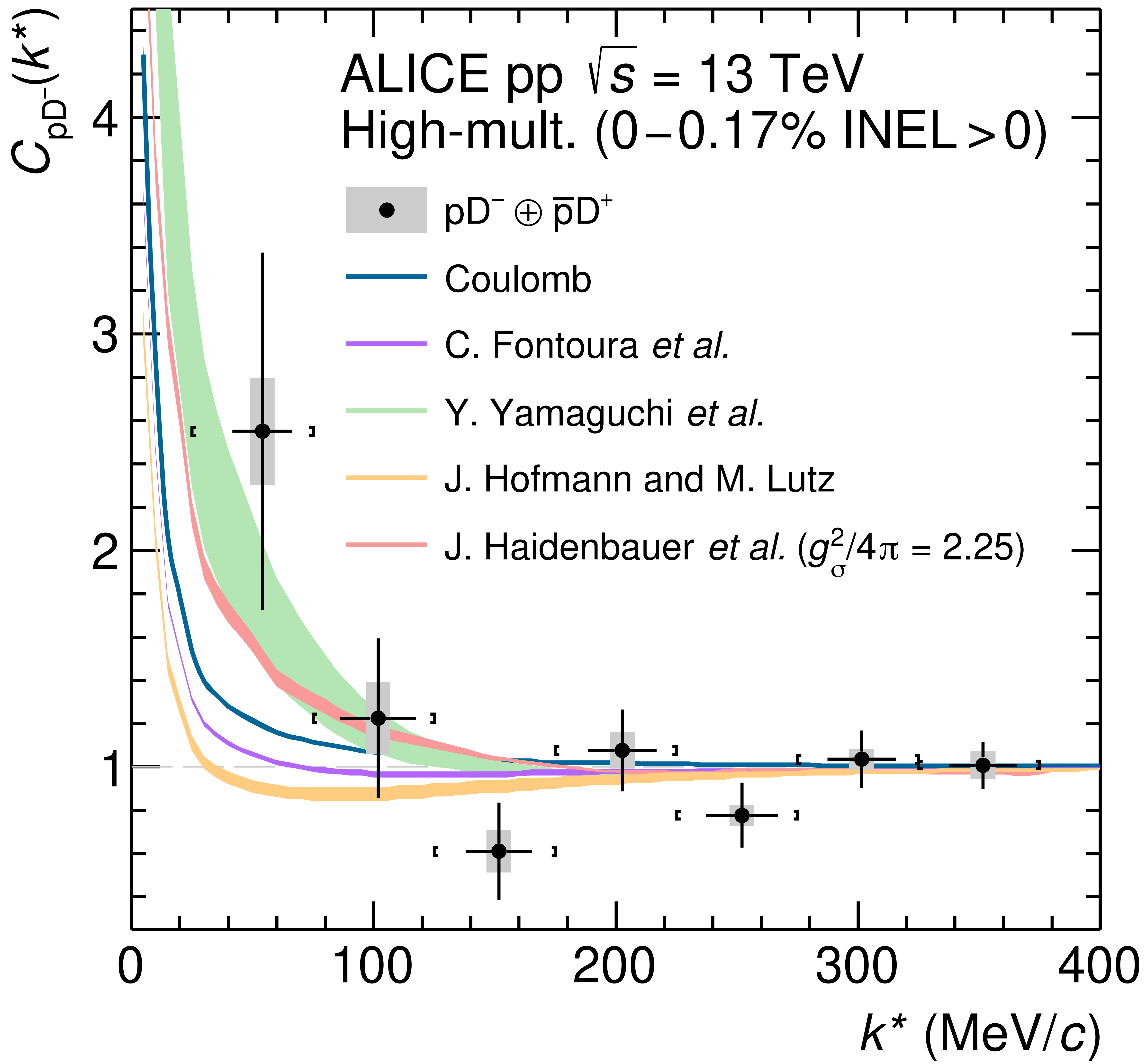
- pD^-
  - ➡ Most of the models predict repulsive interaction
  - ➡ Possible bound state formation (Yamaguchi et al)
- Data compatible with Coulomb only interaction, but comparison slightly improved when also attractive strong interaction is considered
  - ➡ **Higher precision needed to draw conclusions**

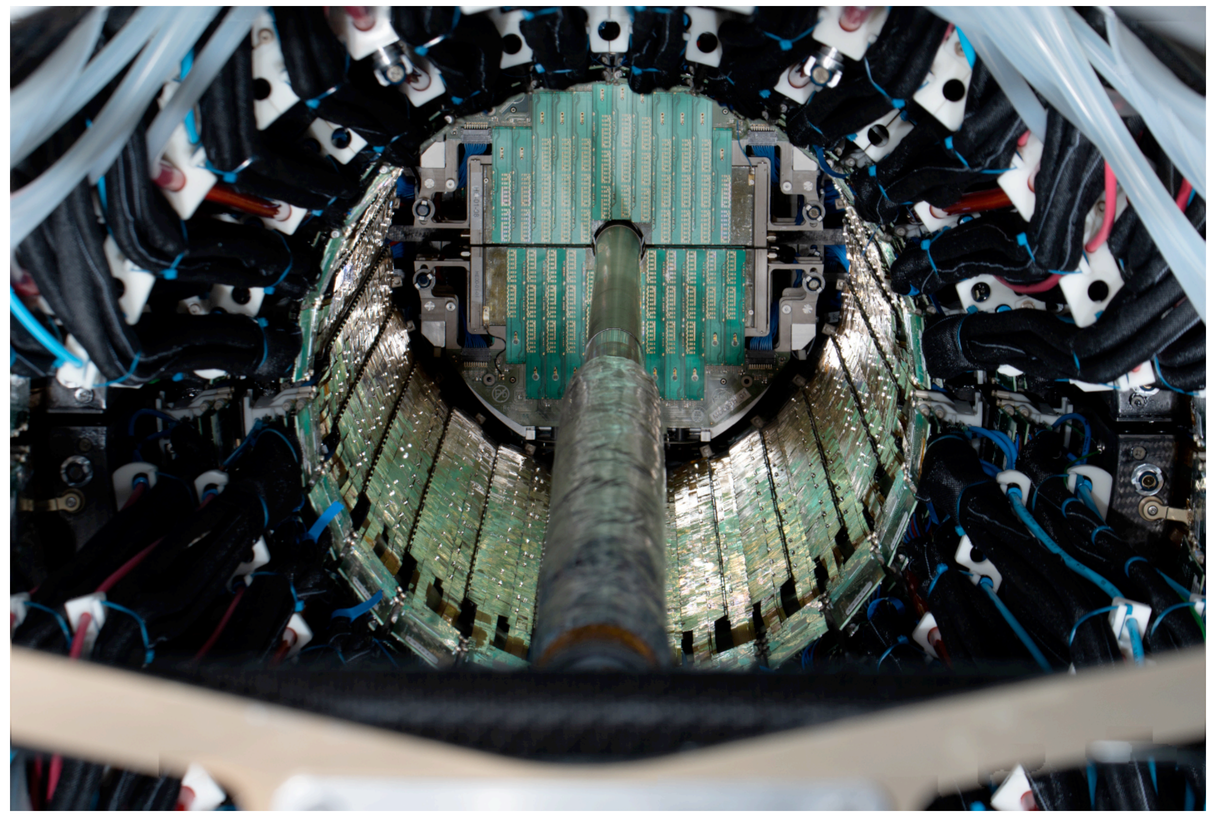


ALI−PUB−502166

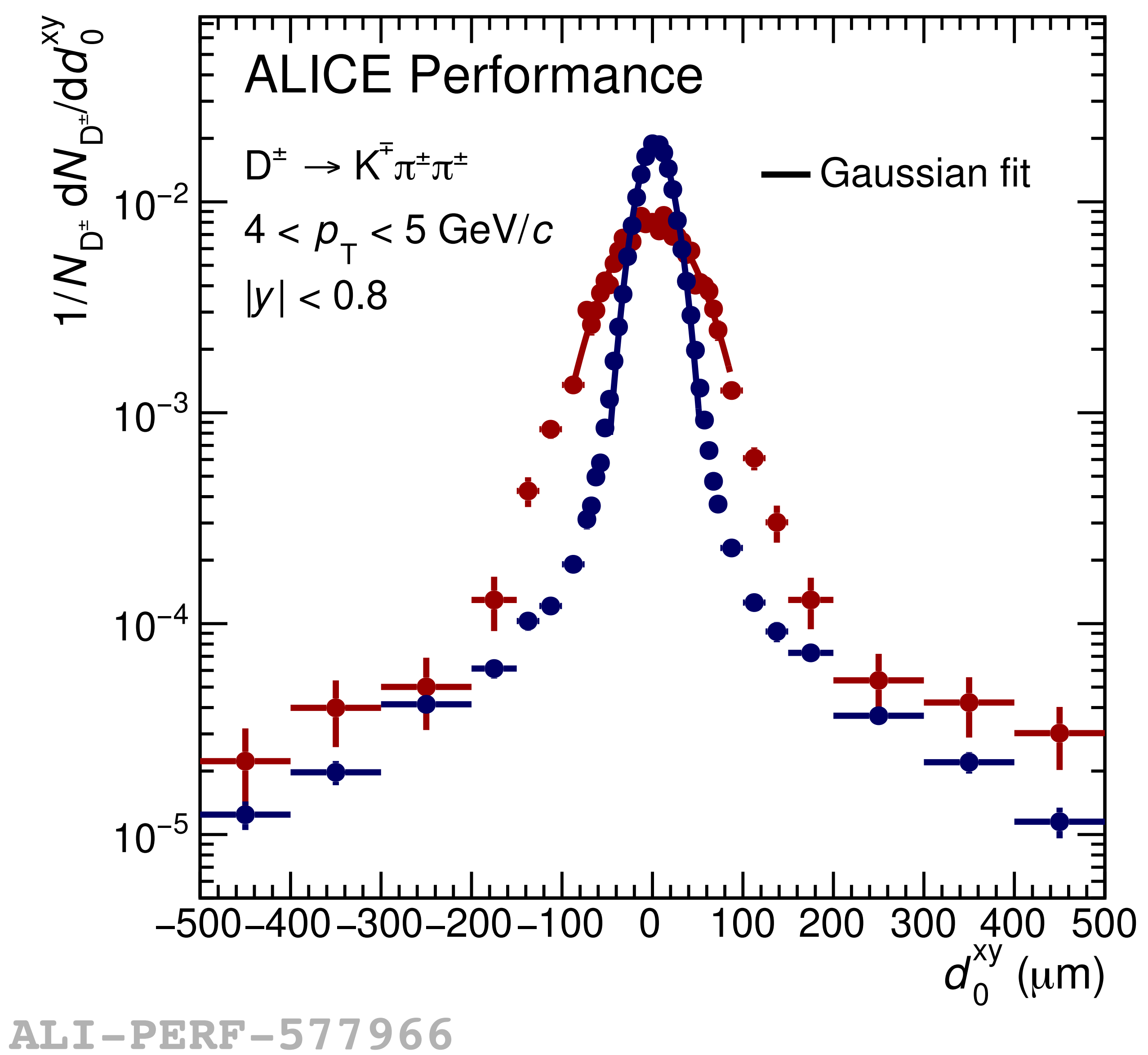
ALICE, PRD 106 (2022) 052010

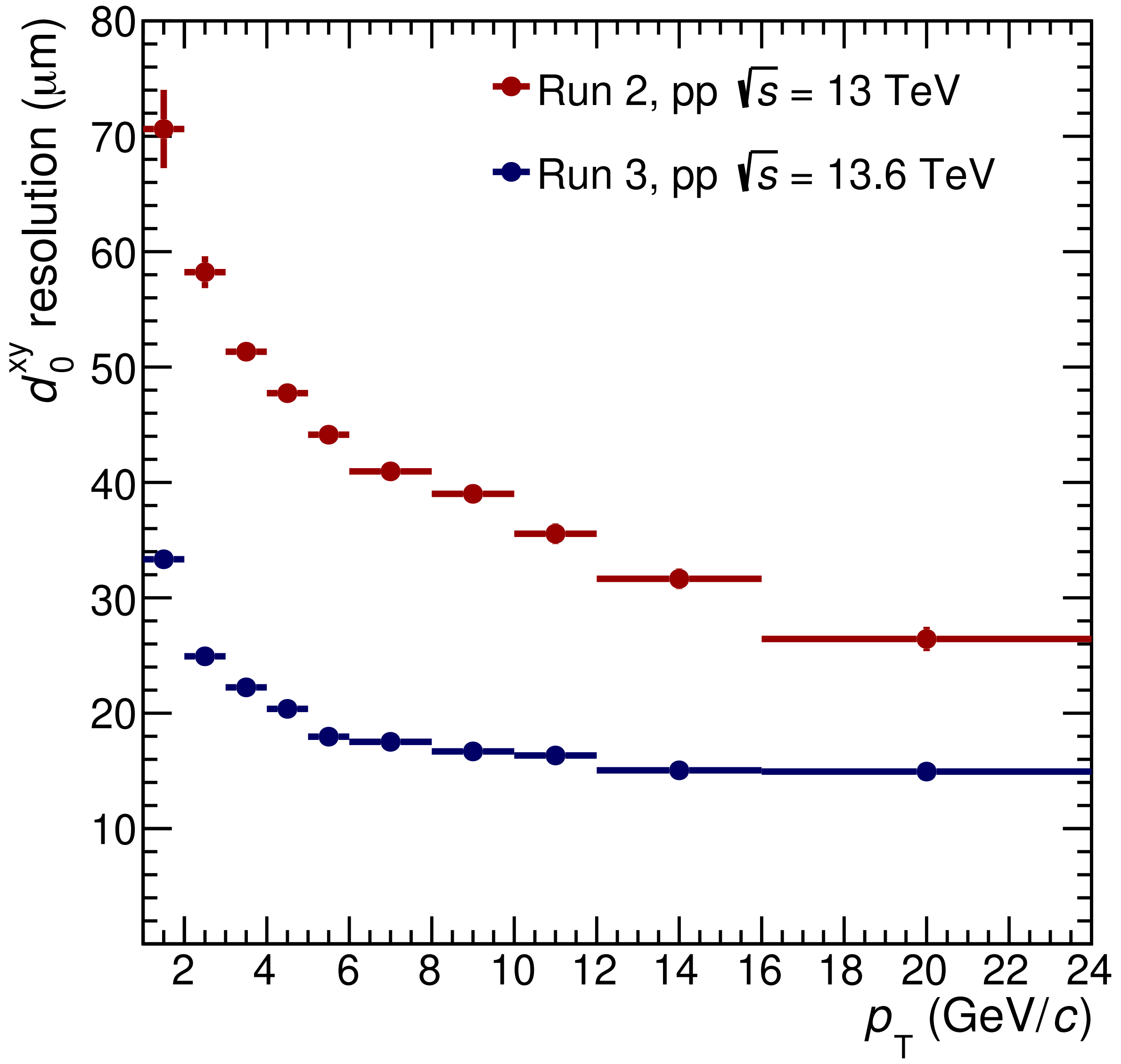
J. Haidenbauer et al, Eur. Phys. J. A33 (2007) 107–117
J. Hofmann and M. Lutz, Nucl. Phys. A 763 (2005) 90–139
Fontura et al, Phys. Rev. C 87 (2013) 025206
Yamaguchi et al, Phys. Rev. D84 (2011) 014032

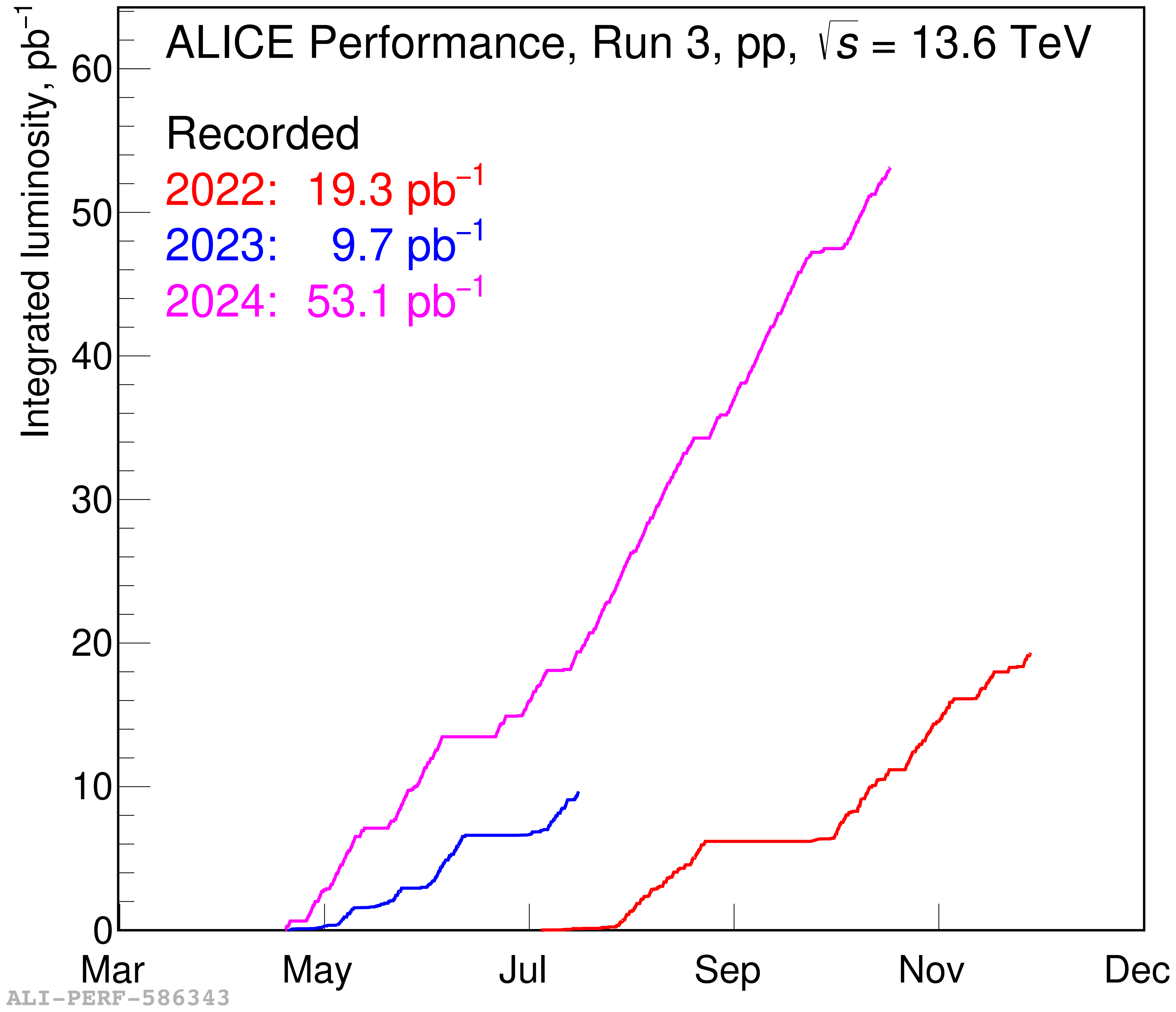
- The ALICE detector was substantially upgraded during the Long Shutdown 2
  - ➡ **New silicon inner tracker** (7 layers of monolithic active pixel sensors)



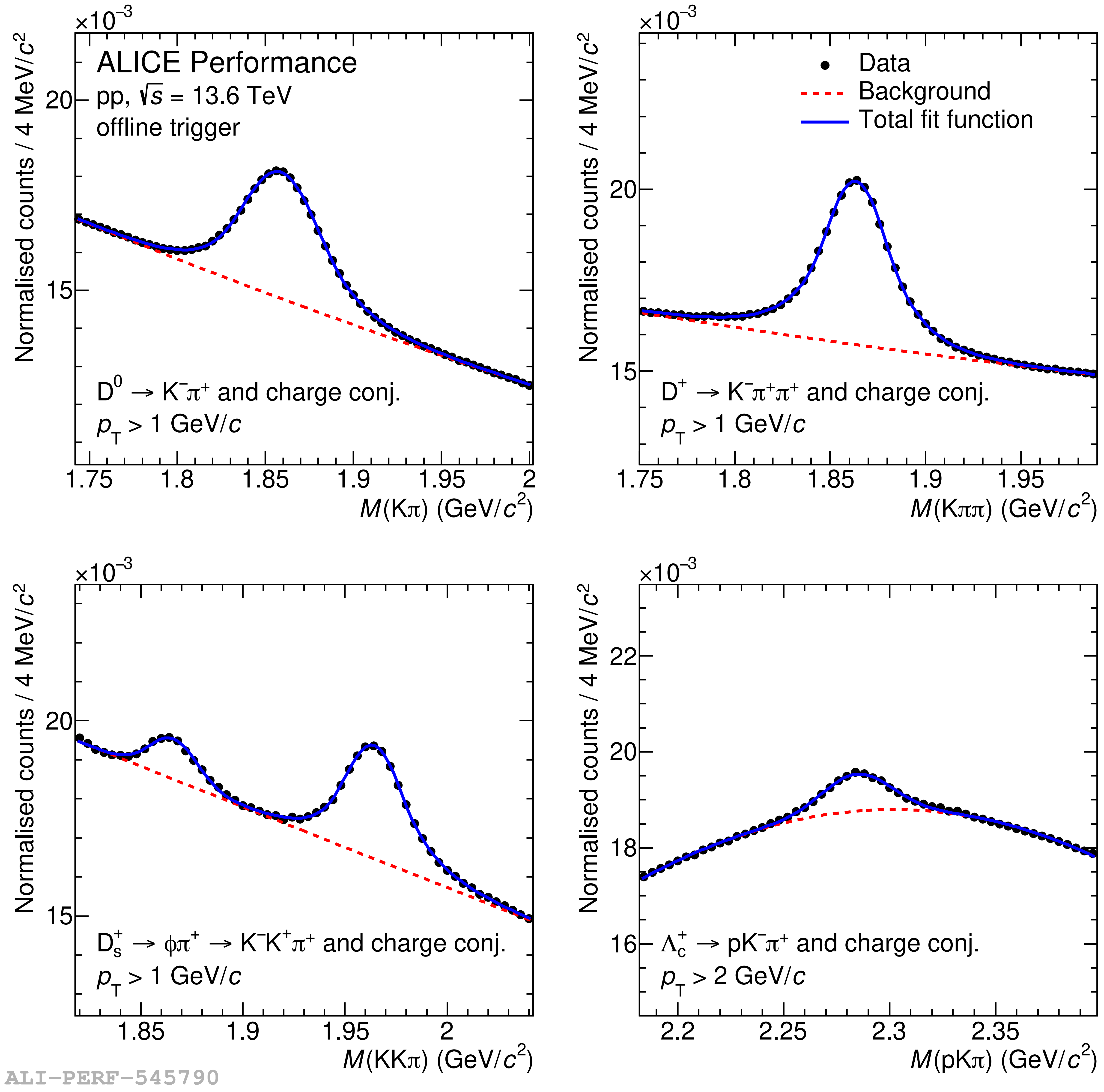
- ➡ Factor 2x-5x better impact-parameter resolution than Run 2 detector







- **Continuous readout**:
  - ➡ Readout rate increased by a factor x500 (x50) in proton–proton (Pb–Pb) collisions



- Dedicated **software triggers** for specific measurements
  - ➡ Including a trigger on events with a Λ_c^+-baryon candidate and a proton candidate having small k^*

- Performance plots from the quality control of the software triggers for a partial dataset of 2022 data

Exotic nuclei

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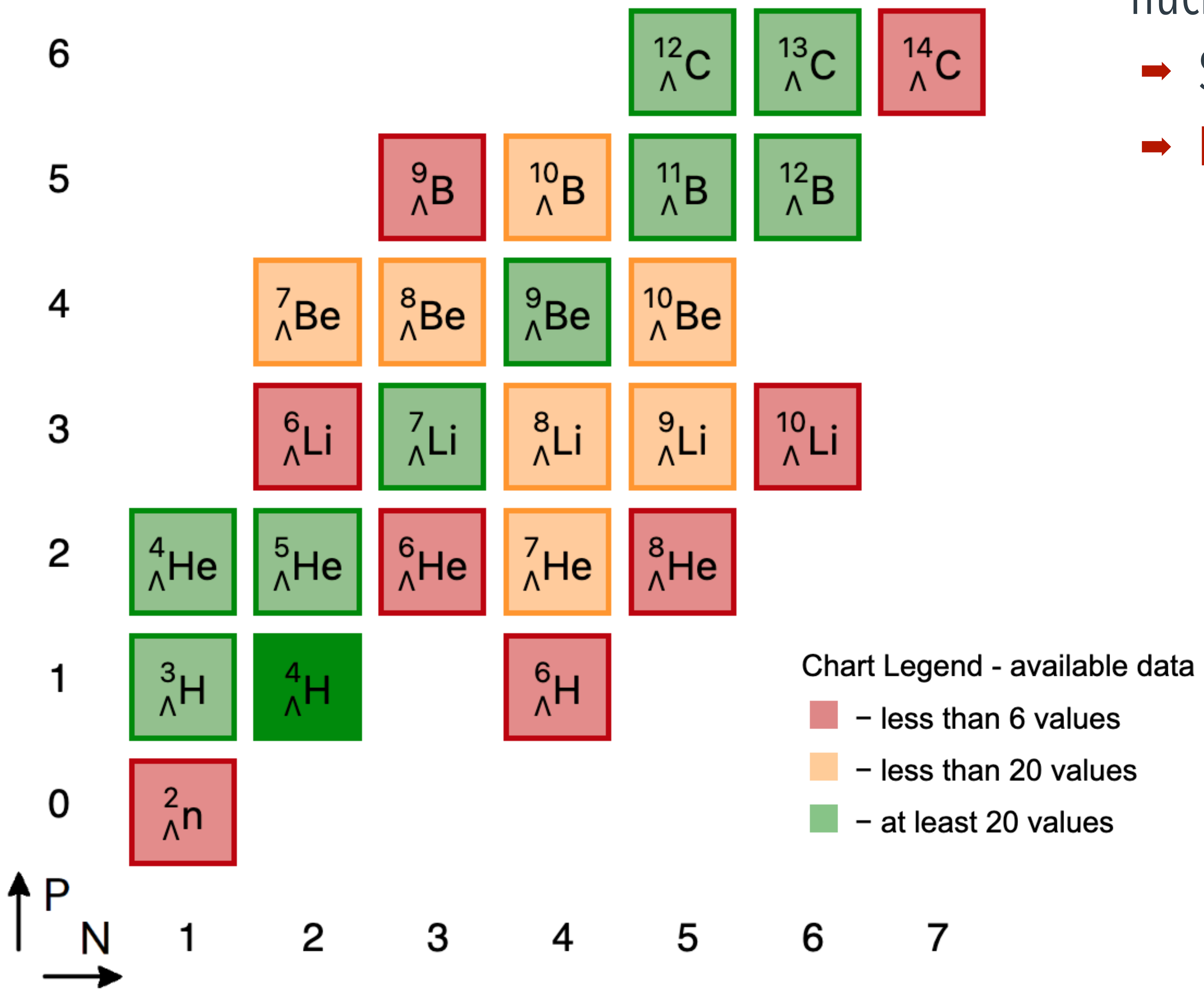
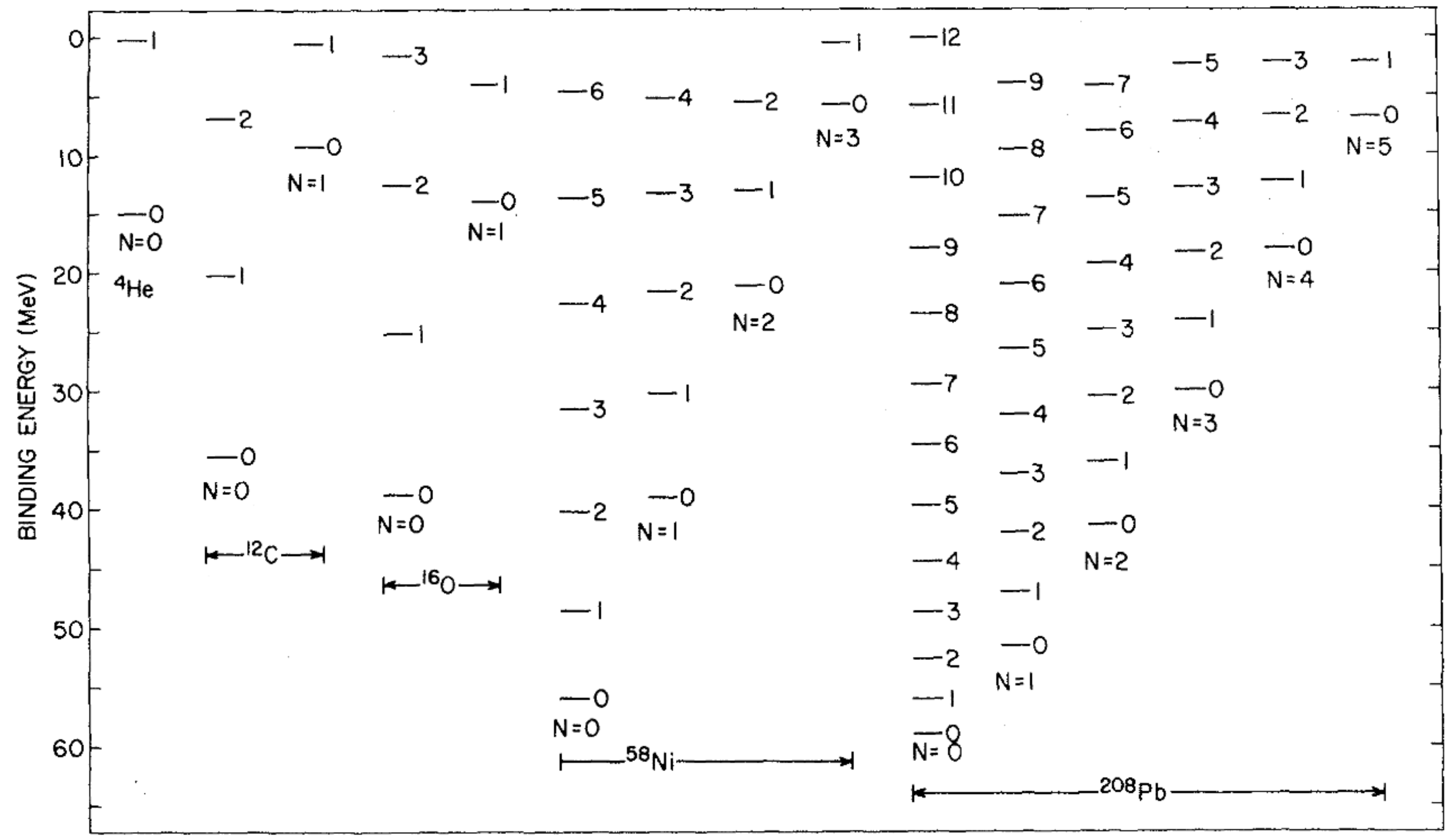
Hypernuclei database



- **Hypernuclei**: bound states of strange baryons (hyperons) and ordinary nucleons
  - ➡ Several observations starting from 1950s
  - ➡ **Extend the nuclear chart** to a third dimension, the strangeness one
    - ▸ What about **charm**?

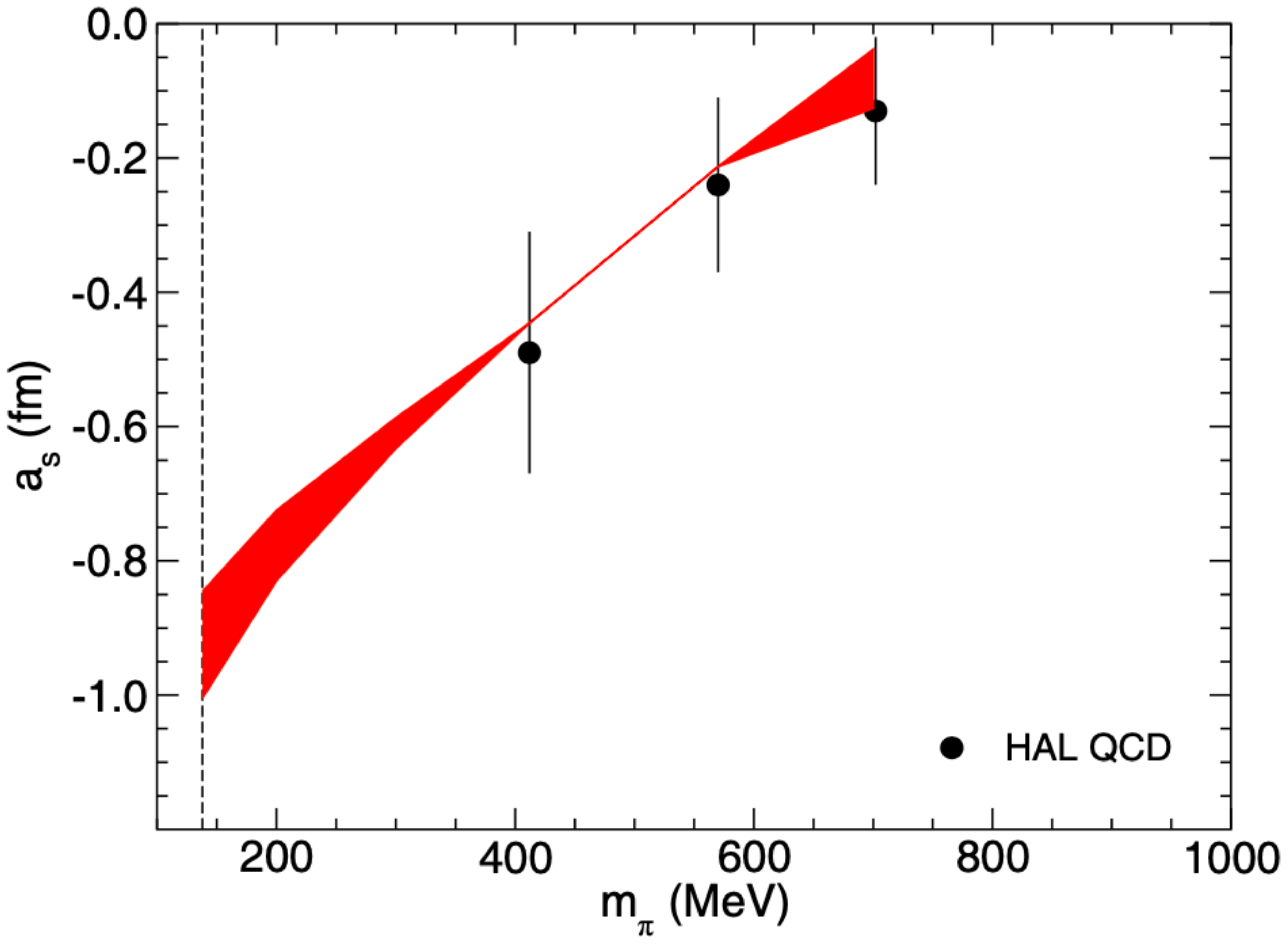


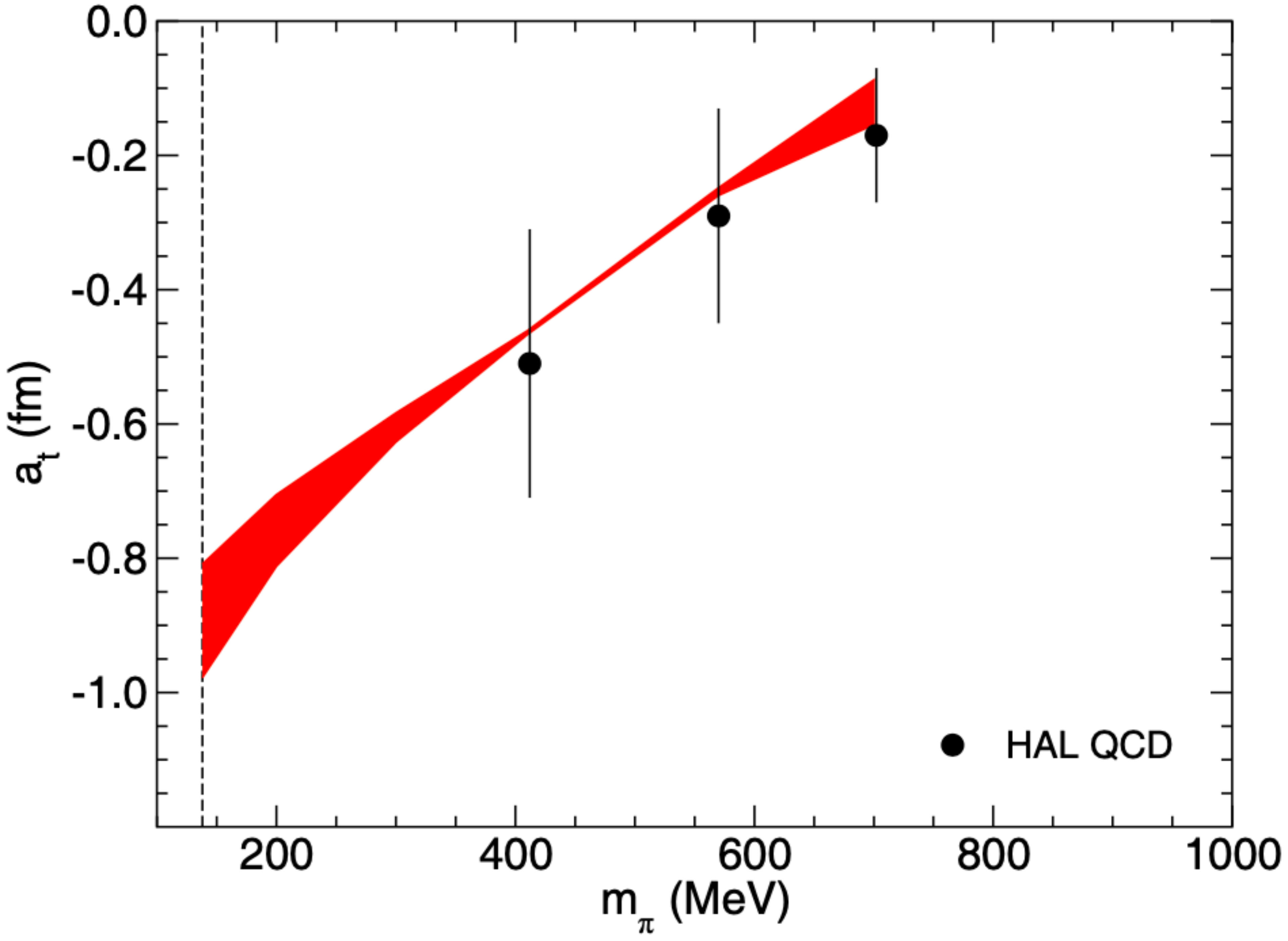
Charm hypernuclear spectrum already computed in 1977

C. B. Dover et al, PRL 39 (1997) 1506

Charm-baryon – nucleon interaction

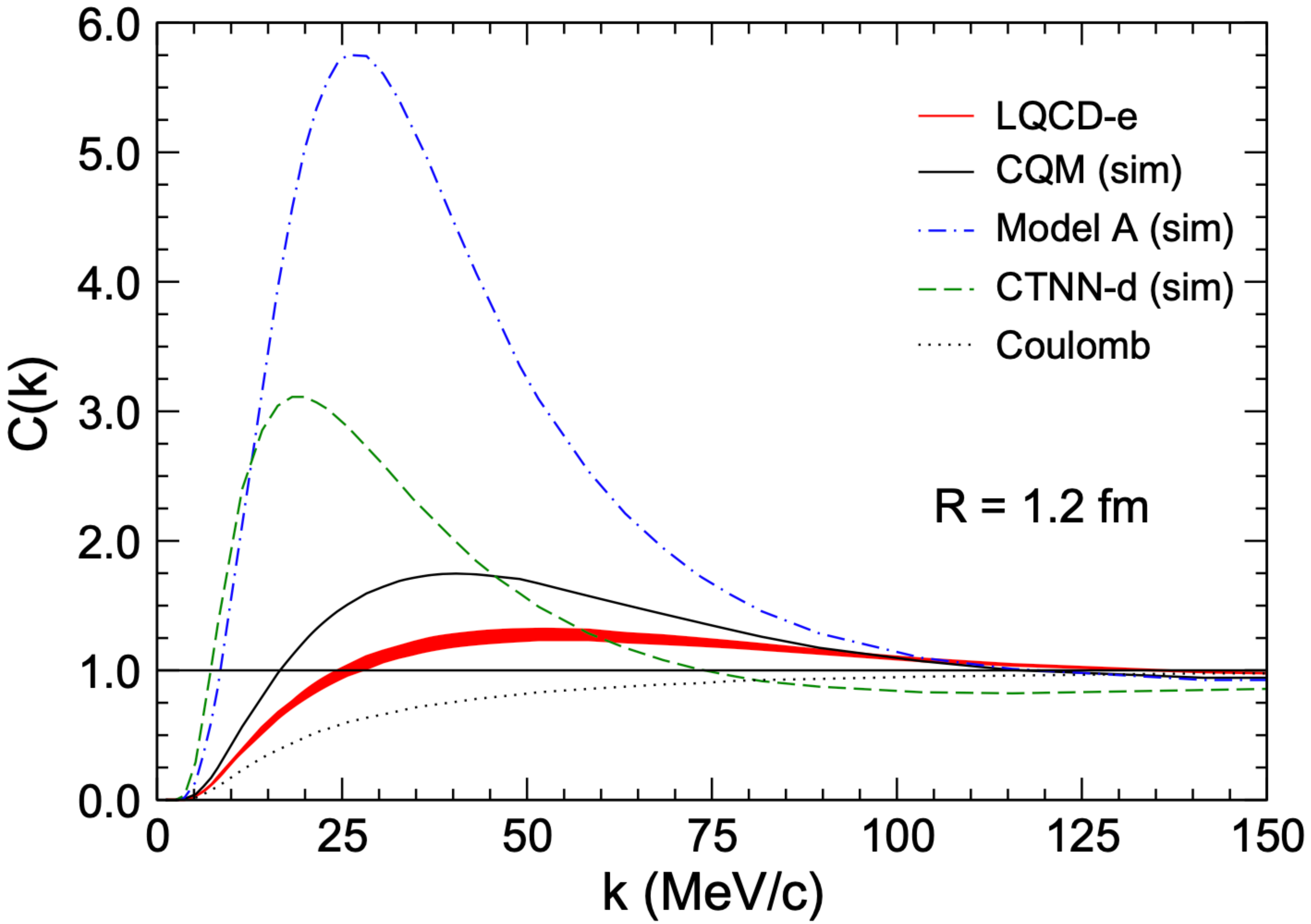
- The lightest possible charmed hypernucleus (c-deuteron) can exist only if the strong **interaction between a charm-baryon and a nucleus is attractive**
- Lattice QCD calculations (HAL QCD) available at unphysical quark masses
  - ➡ Extrapolated to physical quark masses with unitarized chiral perturbation theory





J. Haidenbauer et al, EPJA (2018) 54: 199

- Expected **attractive interaction** both in $^1S_0$ and $^3S_1$ partial waves



J. Haidenbauer et al, EPJA (2020) 56:184

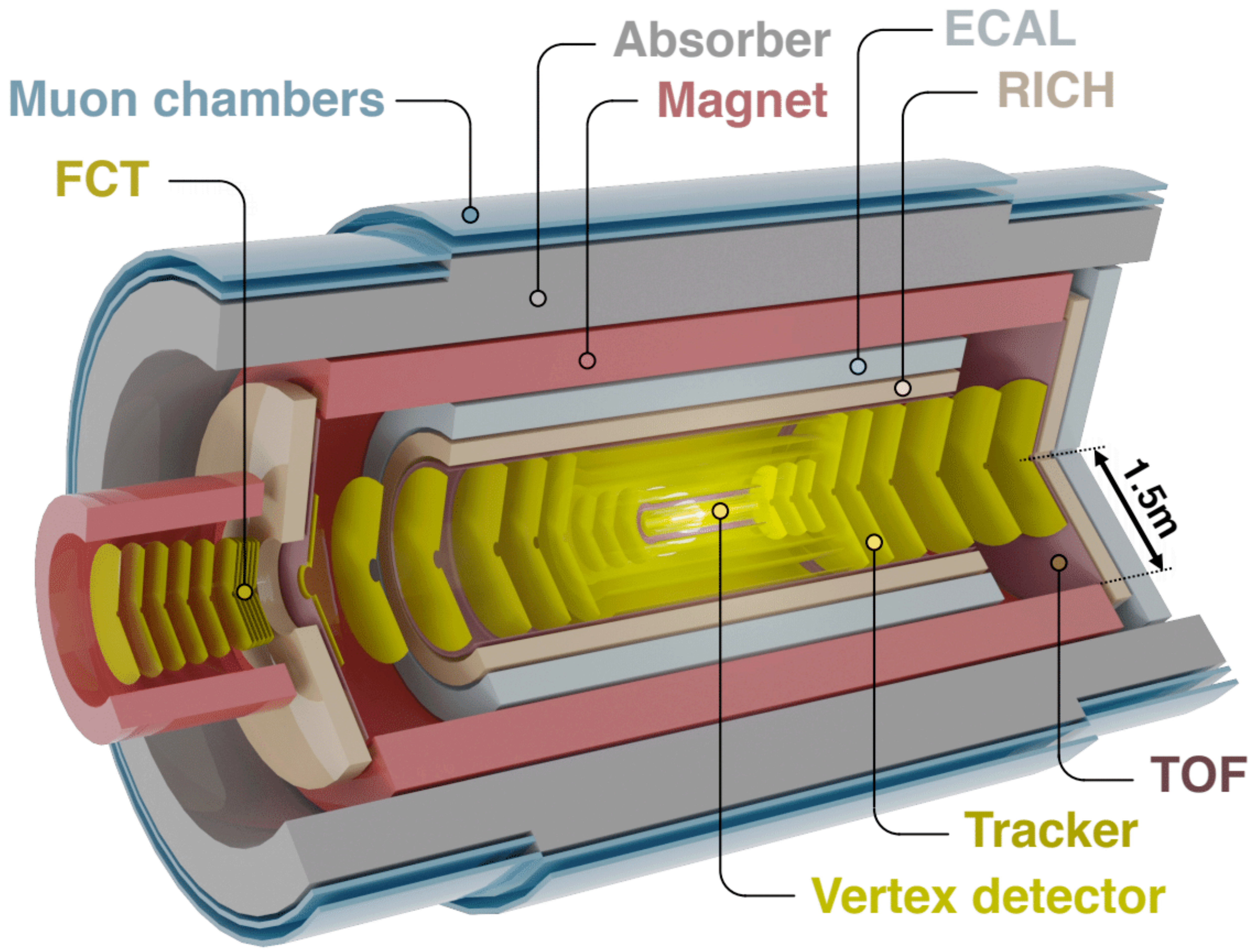
- Quantitatively different predictions from different models
  - ➡ LQCD-e (same as slide 25)

    J. Haidenbauer et al, EPJA (2018) 54: 199
  - ➡ CQM: interaction derived within the constituent-quark model

    H. Garcilazo et al, EPJC 79 (2019) 598
  - ➡ CTNN-d and Model A: extension of the meson-exchange hyperon-nucleon potential
    - ▸ Formation of bound states with binding energies of the order of that of the deuteron (CTNN-d) in both S-waves

    I. Vidana et al, PRC 99 (2019) 045208
    S. Maeda et al, PTEP 2016 (2016) 023D02

- Proposed upgrade for LHC Run 5 and 6



ALICE 3 LOI, CERN-LHCC-2022-009

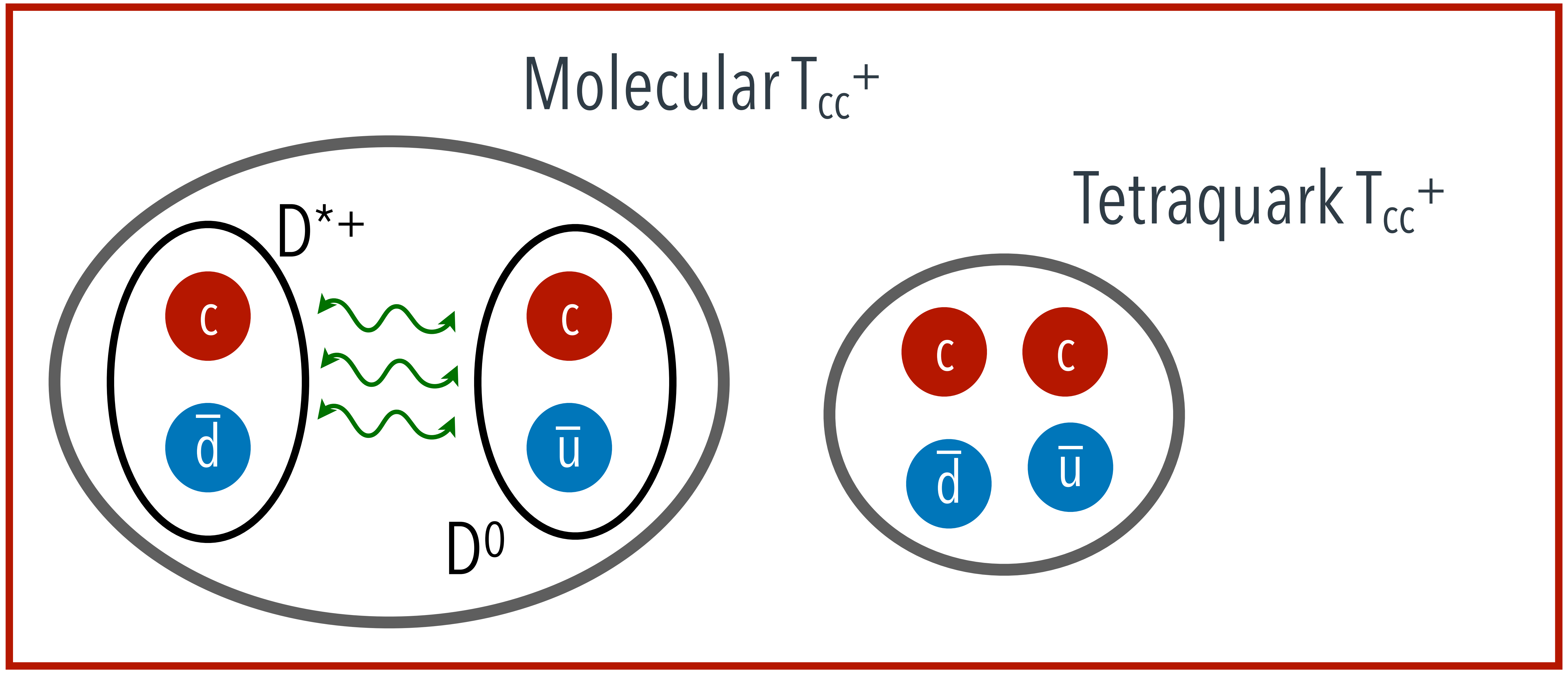
- Original proposal
  - ➡ Large acceptance ($|\eta| < 4$)
  - ➡ All silicon tracker with $\sigma_p/p \approx 1\,\%$
  - ➡ First tracking layer at 5 mm from primary vertex
  - ➡ ~10% X_0 overall material budget (0.1% X_0 for the first layer)
  - ➡ Impact parameter resolution 10 μm for tracks with p = 200 MeV/c
  - ➡ Excellent hadron and lepton PID
    - Silicon-based TOF and RICH
    - Muon chambers with absorber
  - ➡ x5 more AA luminosity than Run 3&4

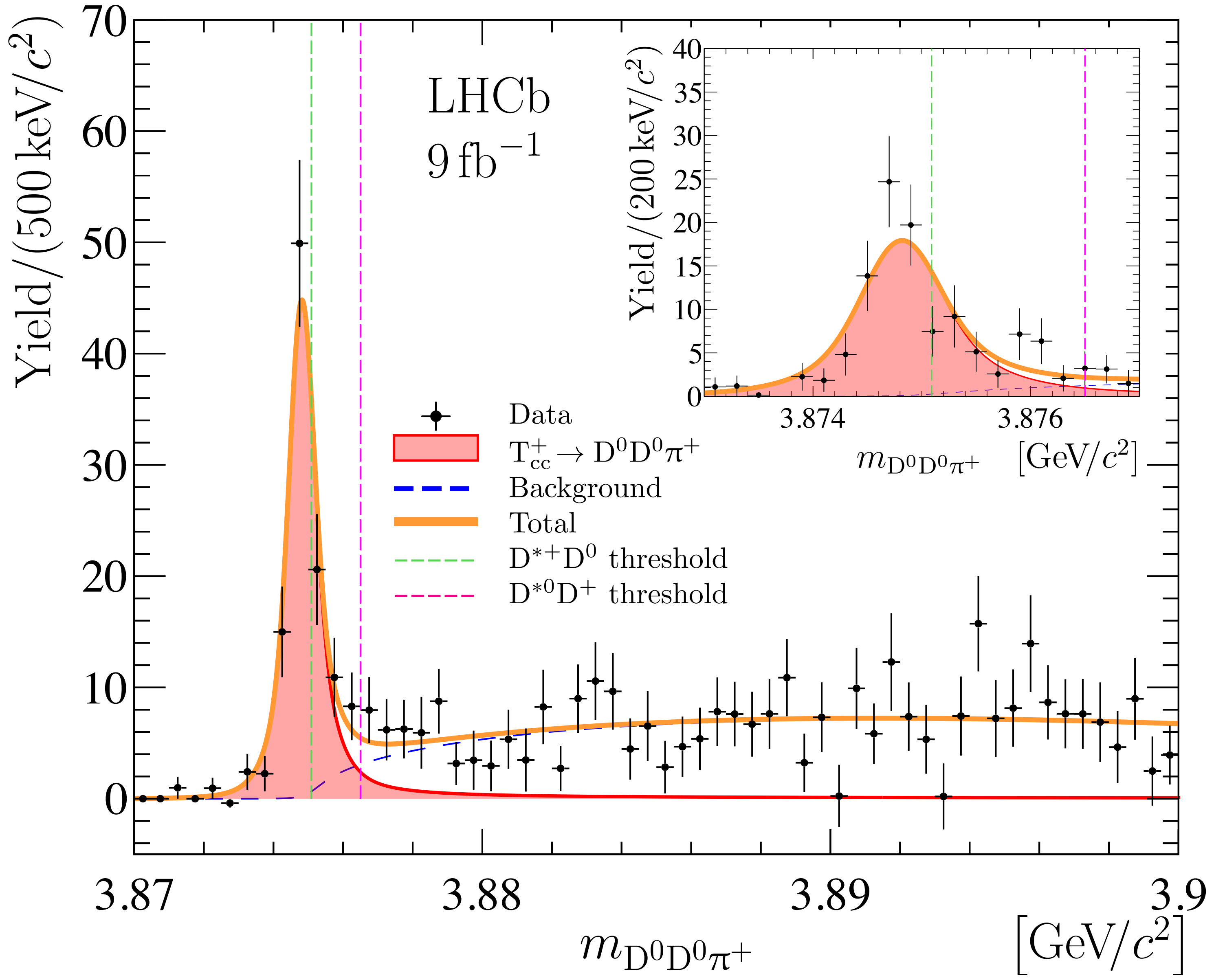
- Possible descoping under discussion

- Charm molecules?

System	I ($J^{P(C)}$)	Candidate
np	0 (1^+)	deuteron
ND	0 ($1/2^-$)	$\Lambda_c(2765)$
ND*	0 ($3/2^-$)	$\Lambda_c(2940)$
ND	0 ($1/2^-$)	$\Sigma_c(2800)$
$D^*\bar{D}$	0 (1^{++})	X(3872)
D*D	0 (1^+)	T_{cc}
$D_1\bar{D}$	0 (1^{--})	Y(4260)
$D_1\bar{D}^*$	0 (1^{--})	Y(4360)
$\Sigma\bar{D}$	1/2 ($1/2^-$)	$P_c(4312)$
$\Sigma\bar{D}^*$	1/2 ($1/2^-$)	$P_c(4457)$
$\Sigma\bar{D}^*$	1/2 ($3/2^-$)	$P_c(4440)$

Fang-Zheng Peng et al, Phys. Rev. D 105, 034028 (2022)

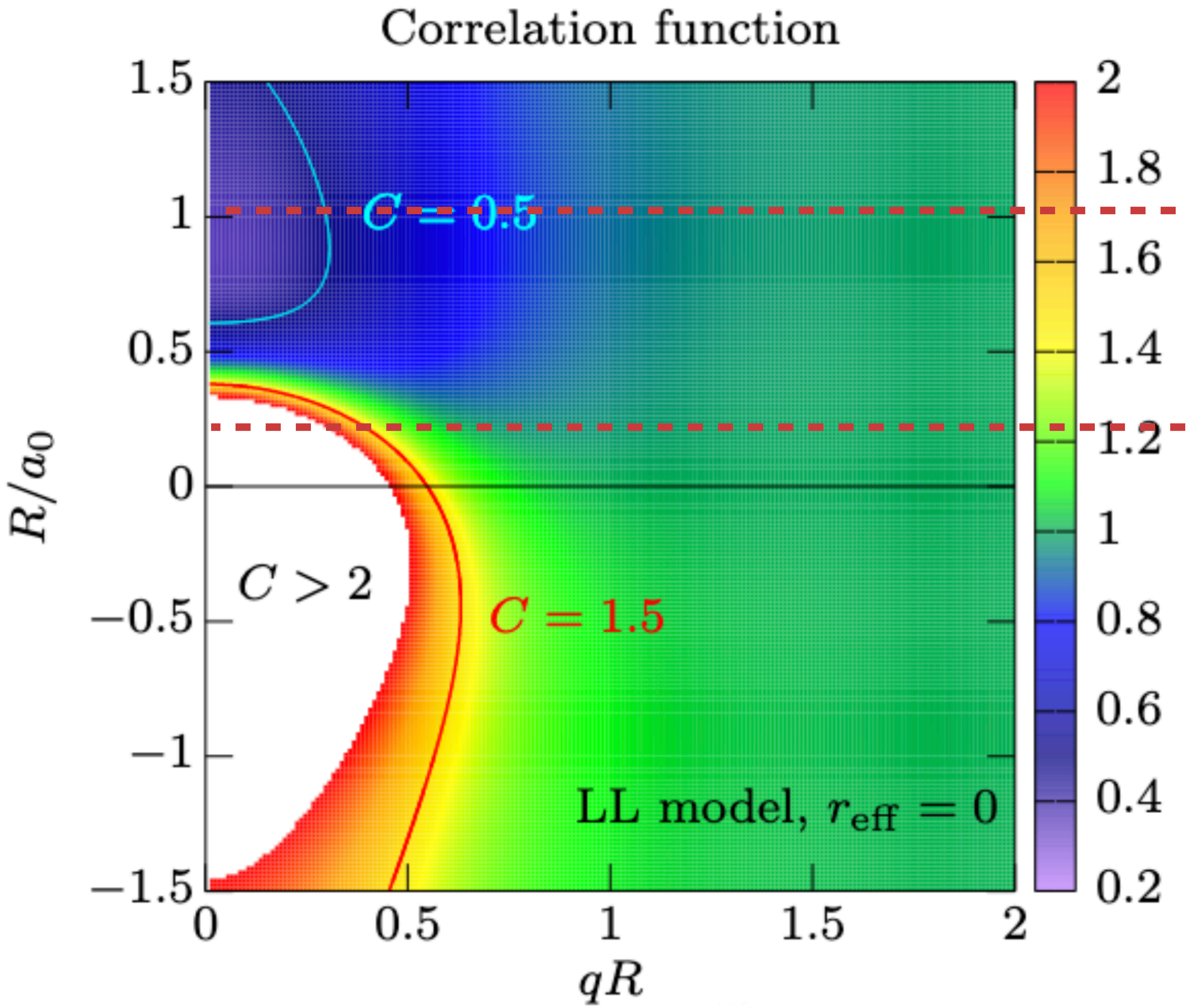


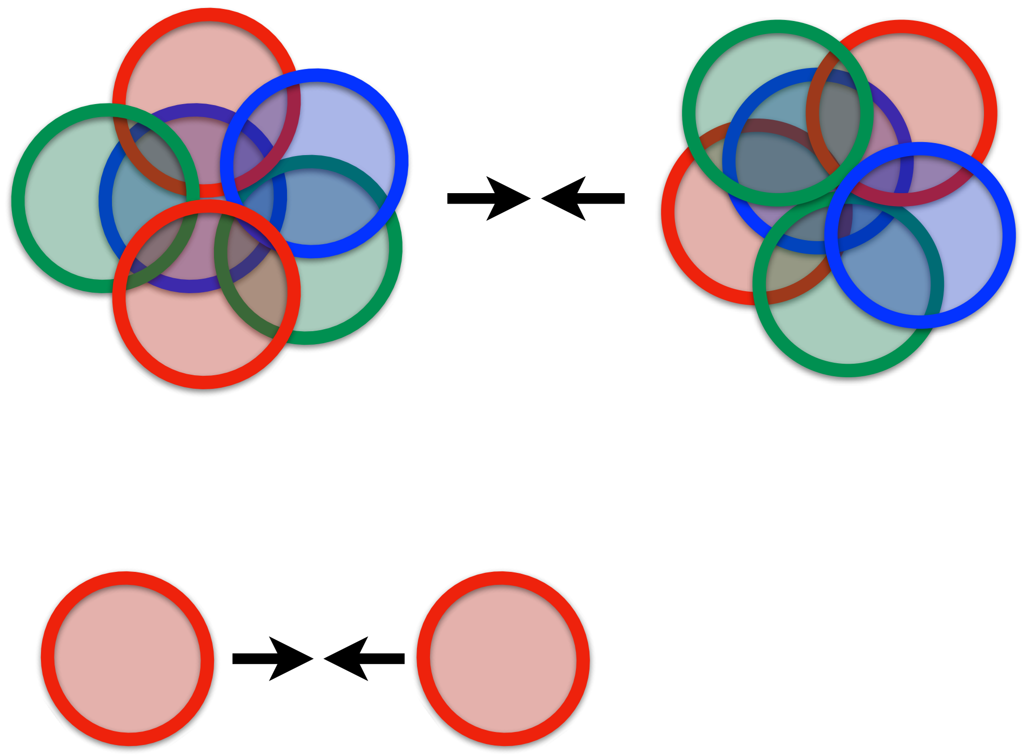


- Just below DD* threshold
  - ➡ ideal candidate to be a molecular state

LHCb, Nature Physics 18 (2022) 751–754

System-size dependence of CF in case of bound-state formation

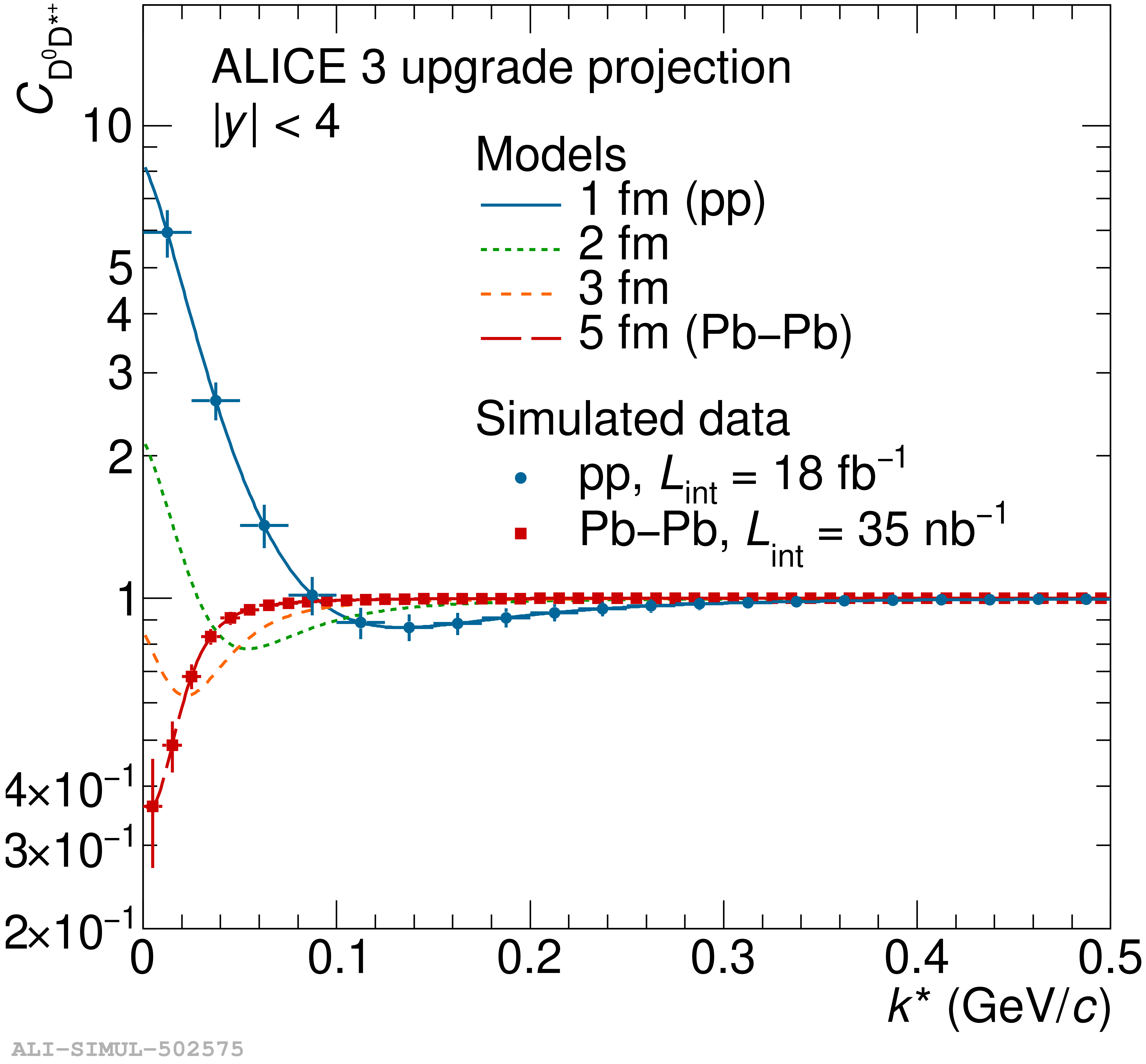




Yuki Kamyia et al, arXiv:2108.0964

- Interplay between system size and scattering length
  - ➡ size-dependent modification of the correlation function in presence of a bound state

ALICE3 LOI: CERN-LHCC-2022-009



- ALICE 3: large acceptance, high luminosity, excellent spatial resolution
  - ➡ Run 5: ideal laboratory for the measurement of charm-hadron momentum correlations in different colliding systems
- Interplay between system size and scattering length
  - ➡ size-dependent modification of the correlation function in presence of a bound state

  Yuki Kamyia et al, arXiv:2203.13814

Summary and outlook

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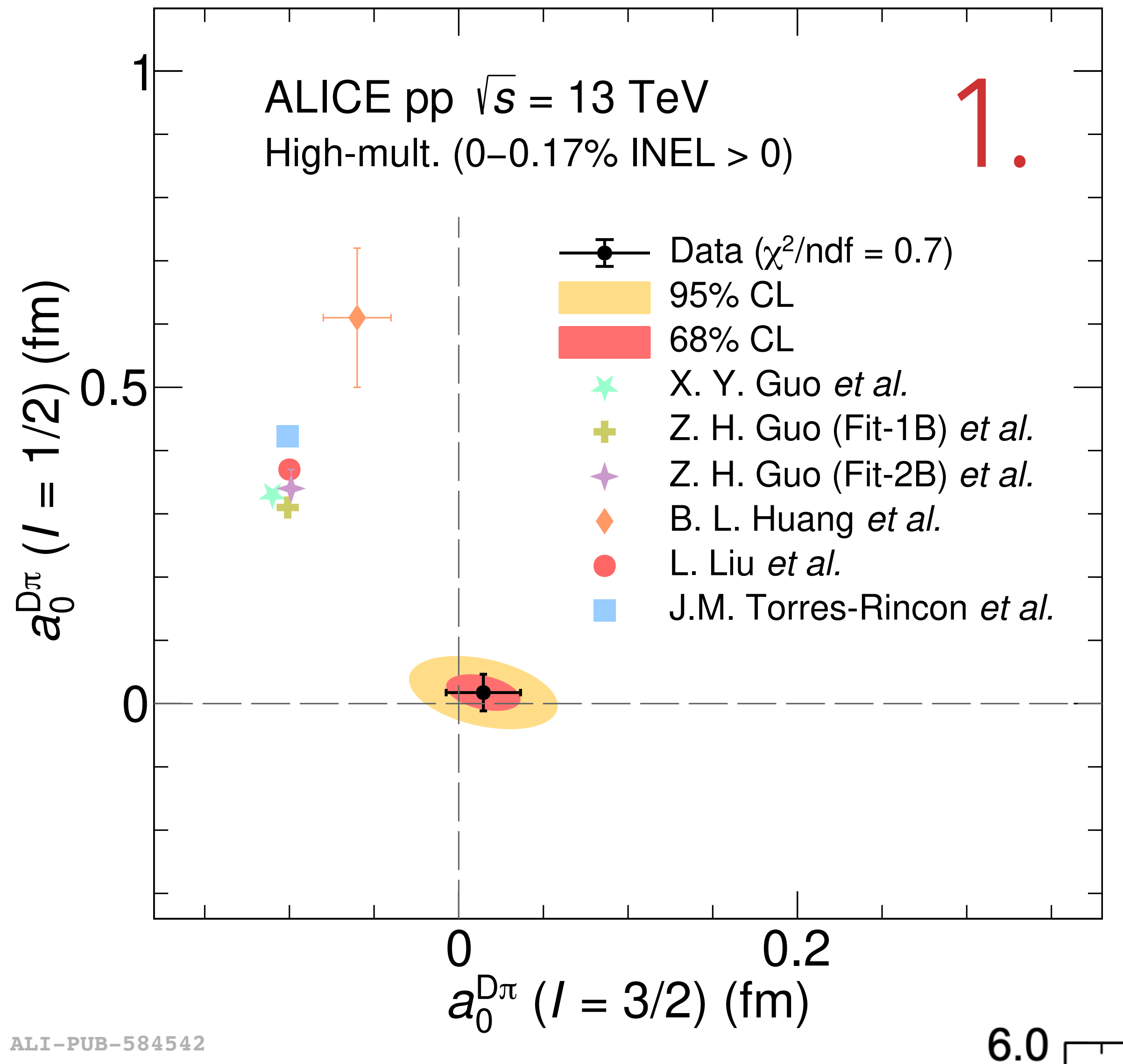
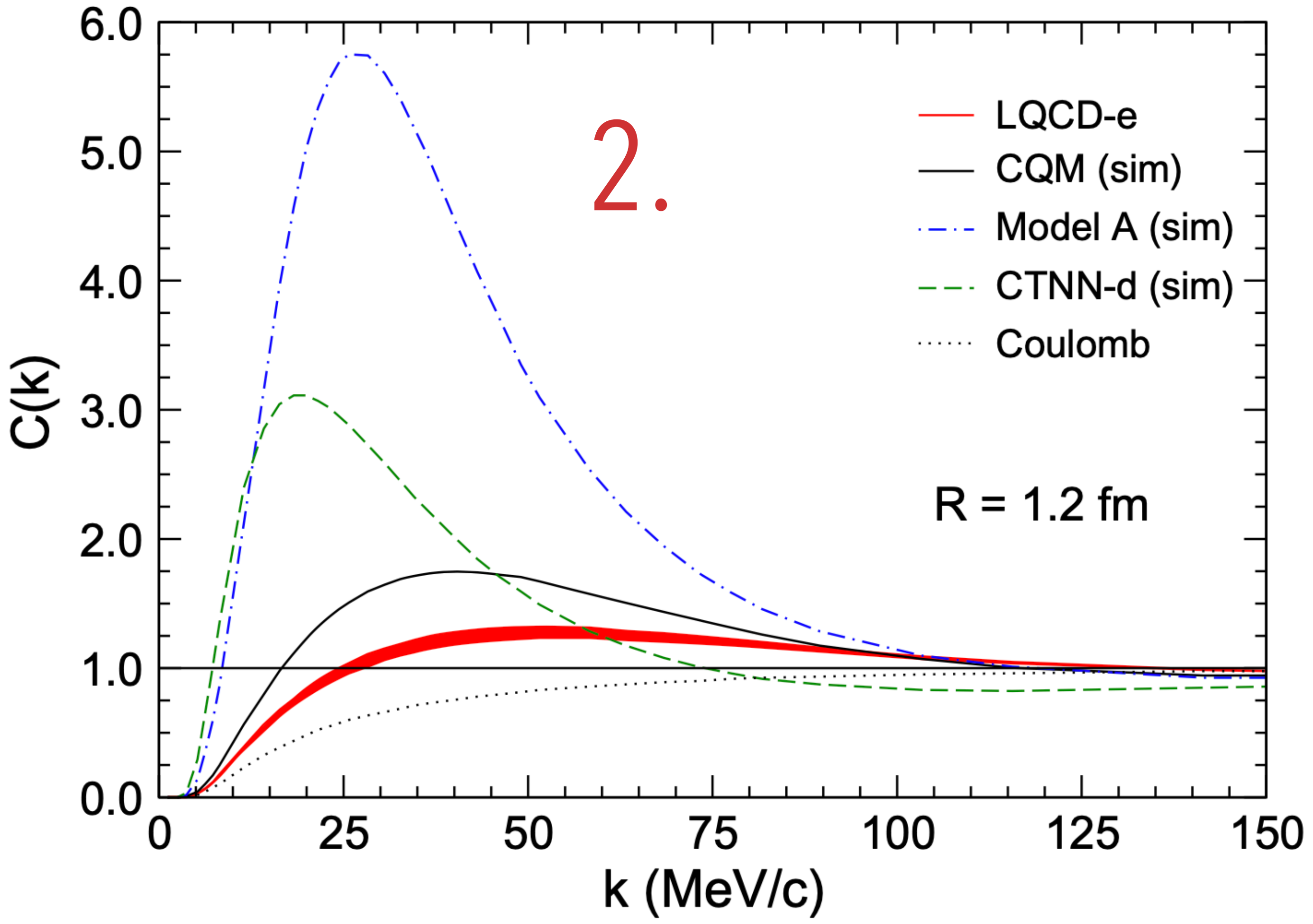
32

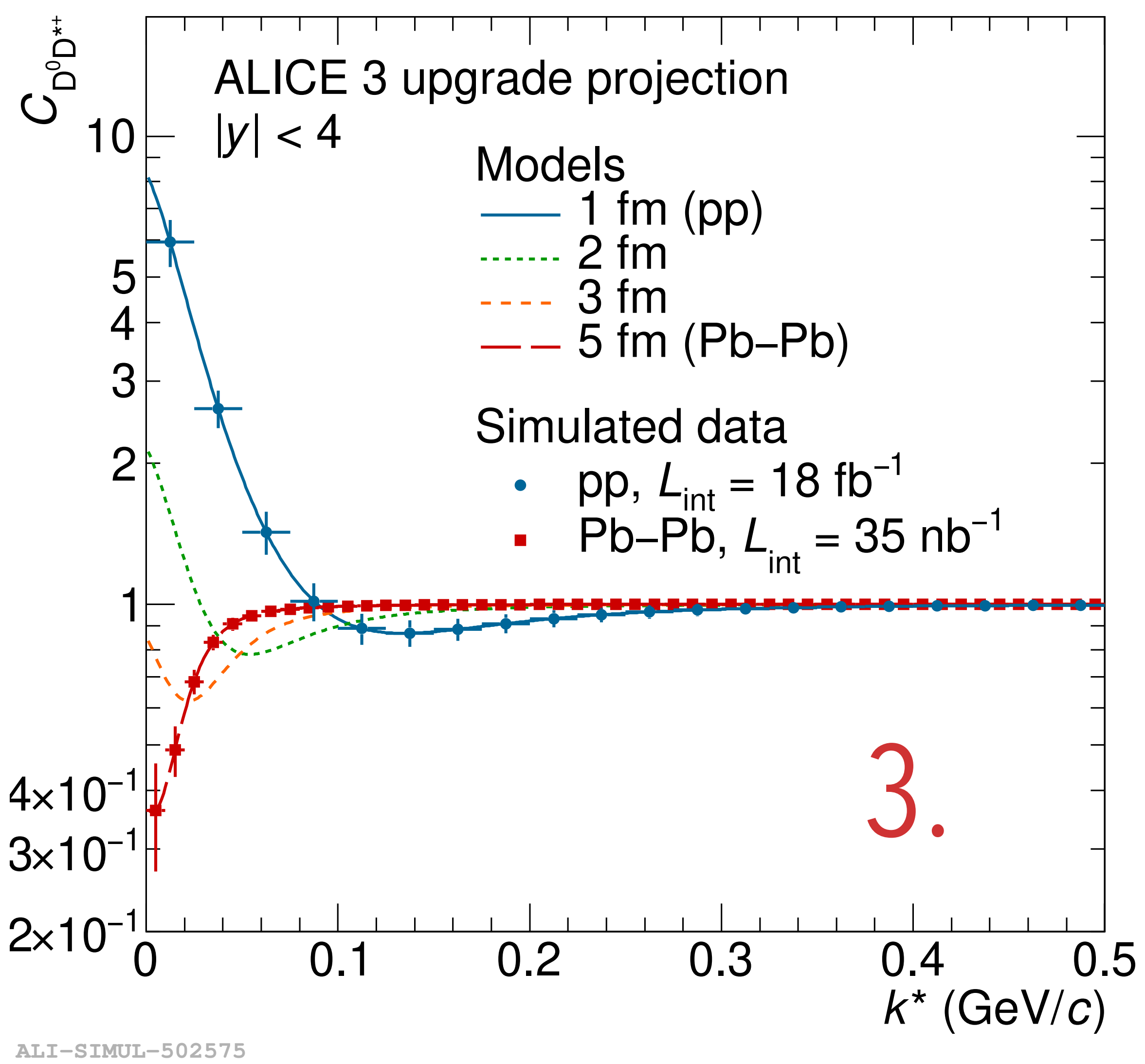
1. **First measurements of femtoscopy with charm** mesons performed with ALICE using data collected in Run 2
   ➡ Typically "weaker" strong interaction measured compared to theoretical predictions



2. **Expected significant improvements** thanks to the ALICE upgrades installed for **Run 3** (improved pointing resolution and readout capabilities)
   ➡ Measure interactions between charm baryons and nucleons



3. **Proposed** wide acceptance, ultralight silicon-based experiment for **Run 5 (ALICE 3)**
   ➡ Measure interactions between pairs of charm hadrons to investigate nature of exotic states



ADDITIONAL SLIDES

The emitting source

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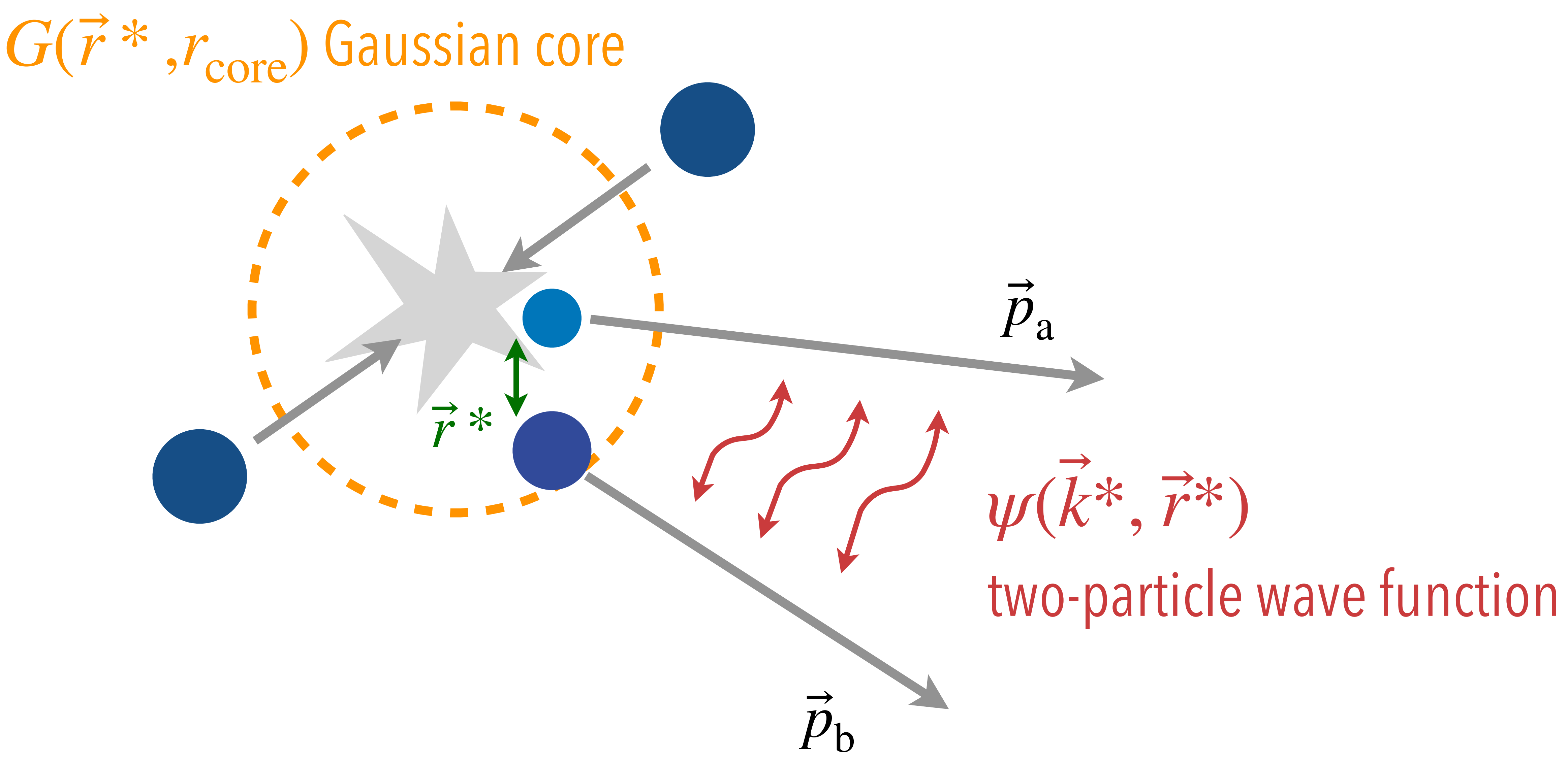
$$C(\vec{k}^*) = \int S(\vec{r}^*)\,|\psi(\vec{k}^*,\vec{r}^*)|^2\,\mathrm{d}^3r^*$$

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

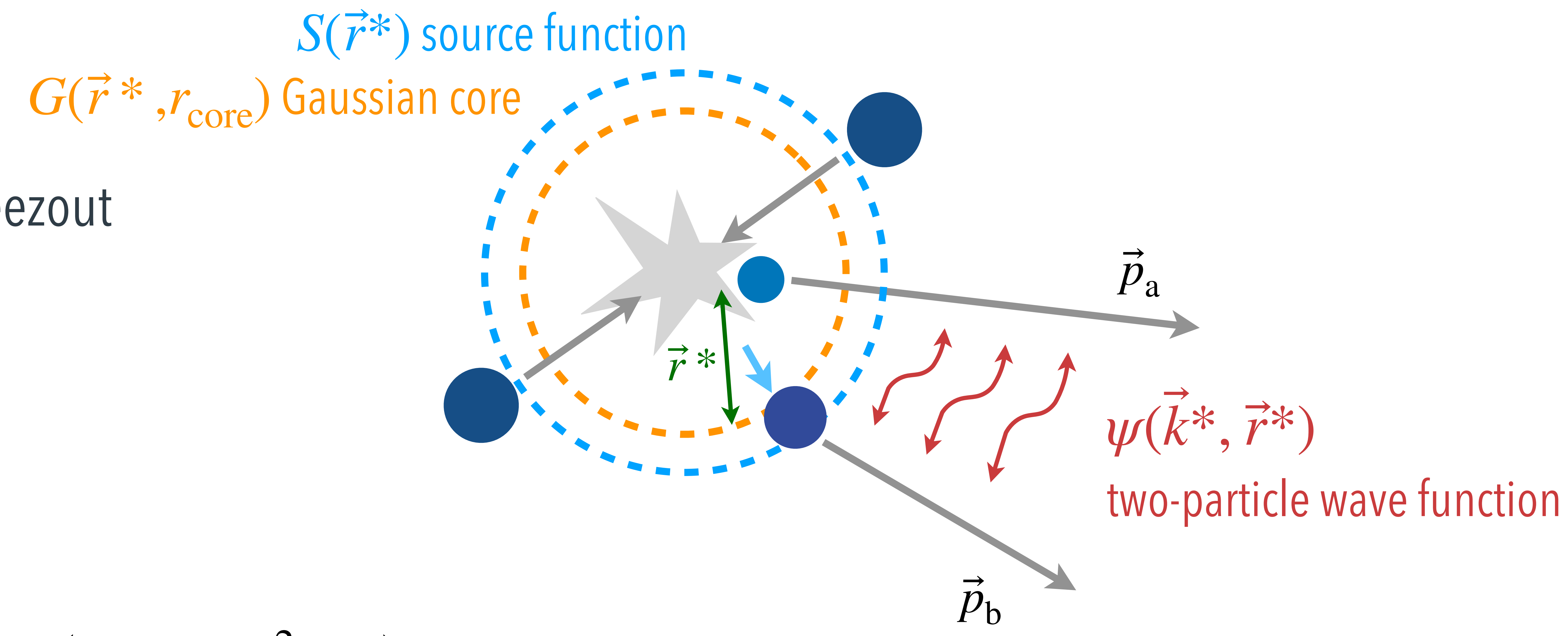


- Described with a Gaussian core

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

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

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



- Described with a Gaussian core

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

- Short-lived strongly decaying resonances effectively enlarge it

$$E(r^*, M_{\mathrm{res}}, \tau_{\mathrm{res}}, p_{\mathrm{res}}) = \frac{1}{s}\exp\left(-\frac{r^*}{s}\right) \quad \text{with} \quad s = \beta\gamma\tau_{\mathrm{res}} = \frac{p_{\mathrm{res}}}{M_{\mathrm{res}}}\tau_{\mathrm{res}}$$

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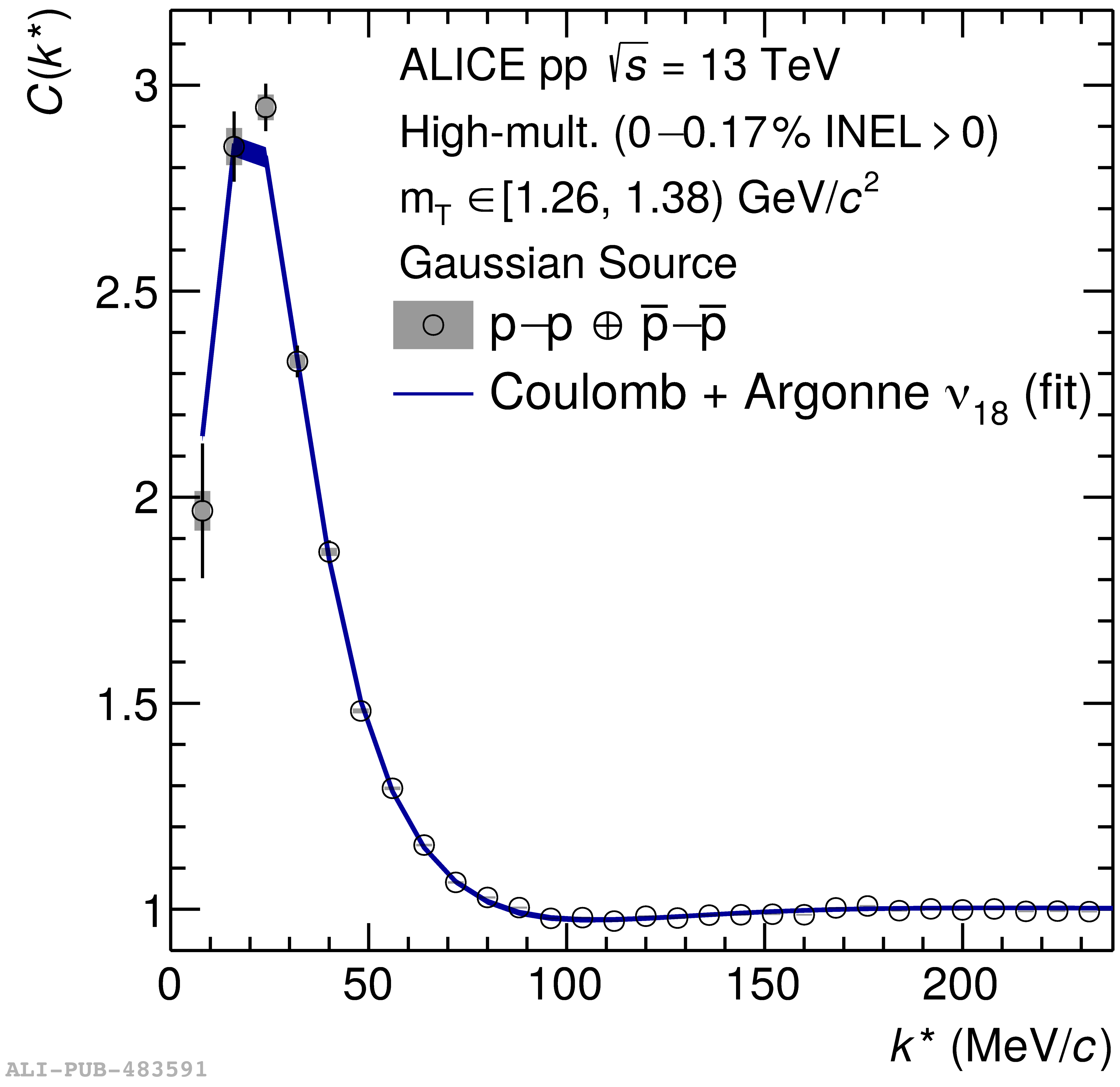
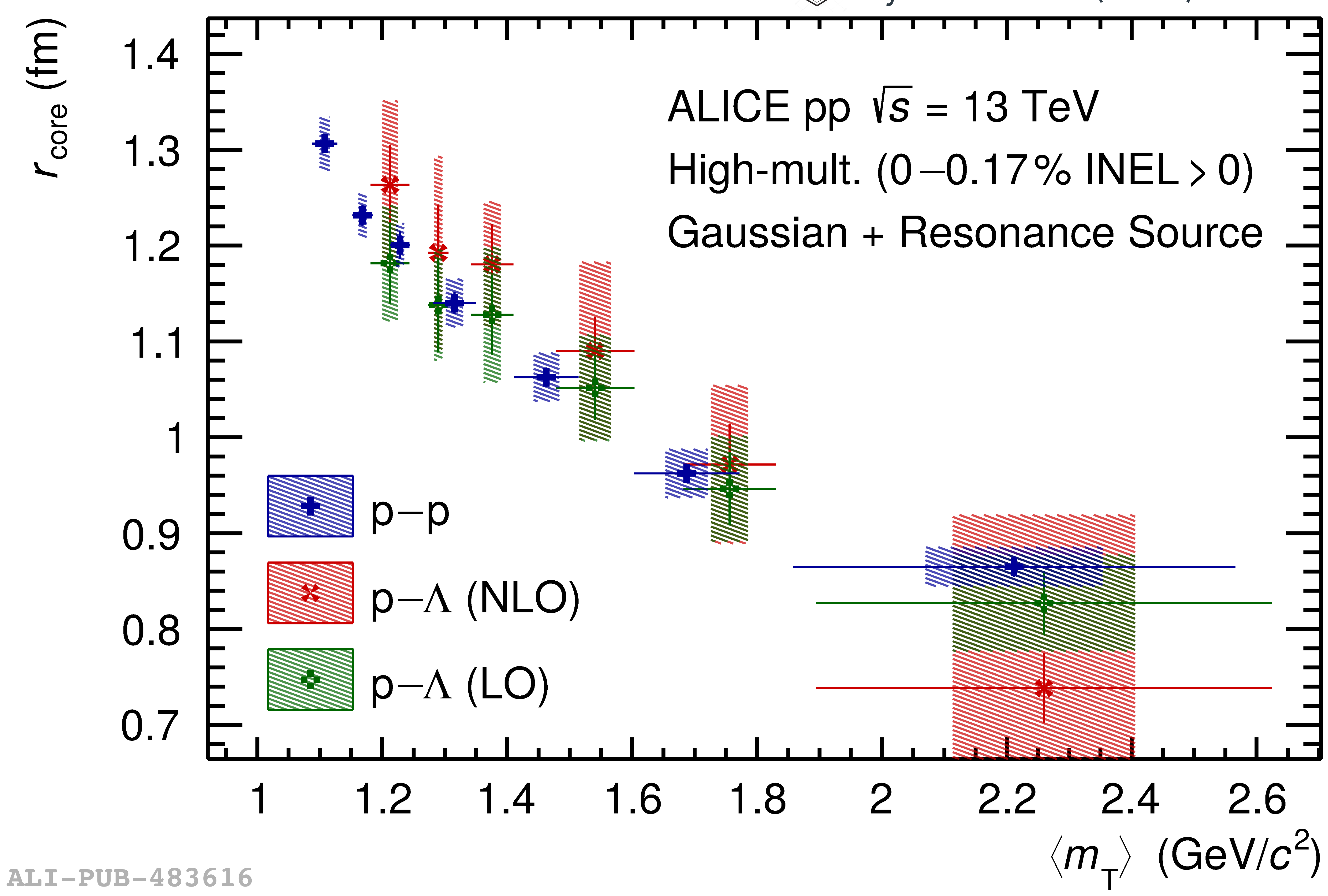
Phys. Lett. B 811 (2020) 135849



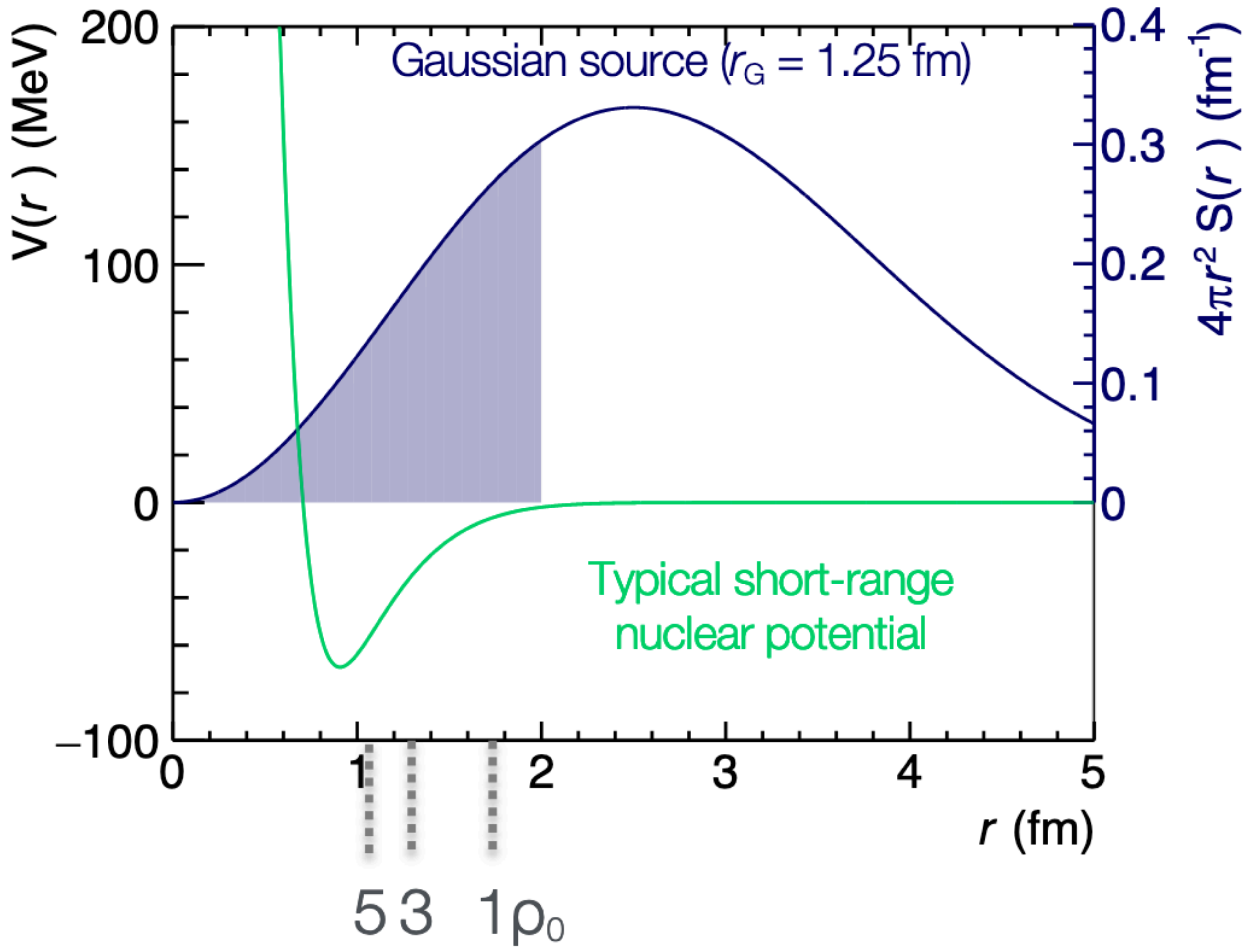
- Fit correlation functions of p–p and p–Λ pairs
  - ➡ Interaction precisely described
  - ➡ Gaussian source with radius as free parameter

Phys. Lett. B 811 (2020) 135849



- Source size ~1 fm makes the high-multiplicity pp system suitable for the study of hadron–hadron interactions

Femtoscopy with small emitting sources



- Typical range of nuclear potential around 1-2 fm
  - ➡ study of strong interaction among hadrons not possible with larger sources
  - ➡ proton–proton and proton–nucleus collisions are the ideal laboratory to study the strong interaction

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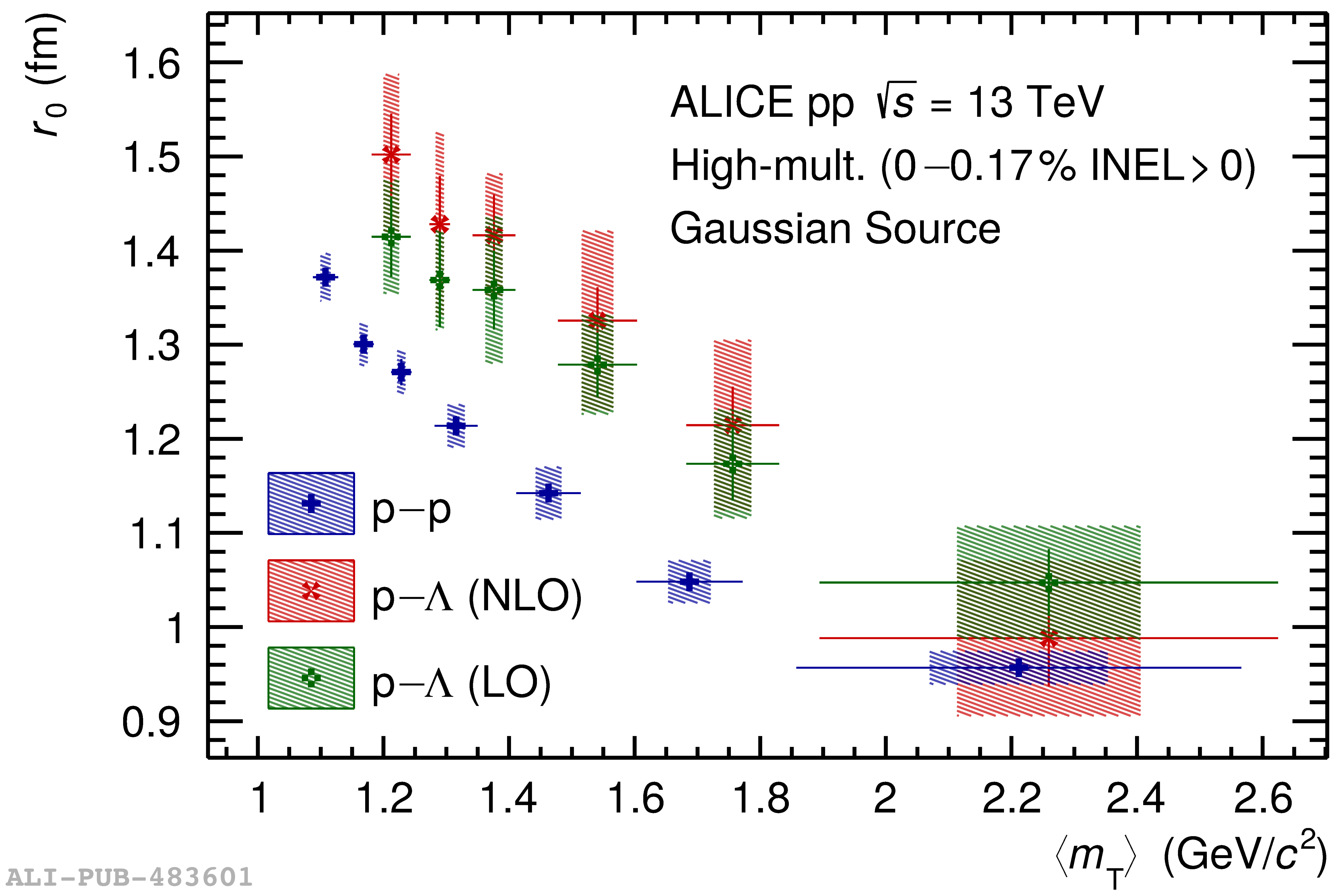
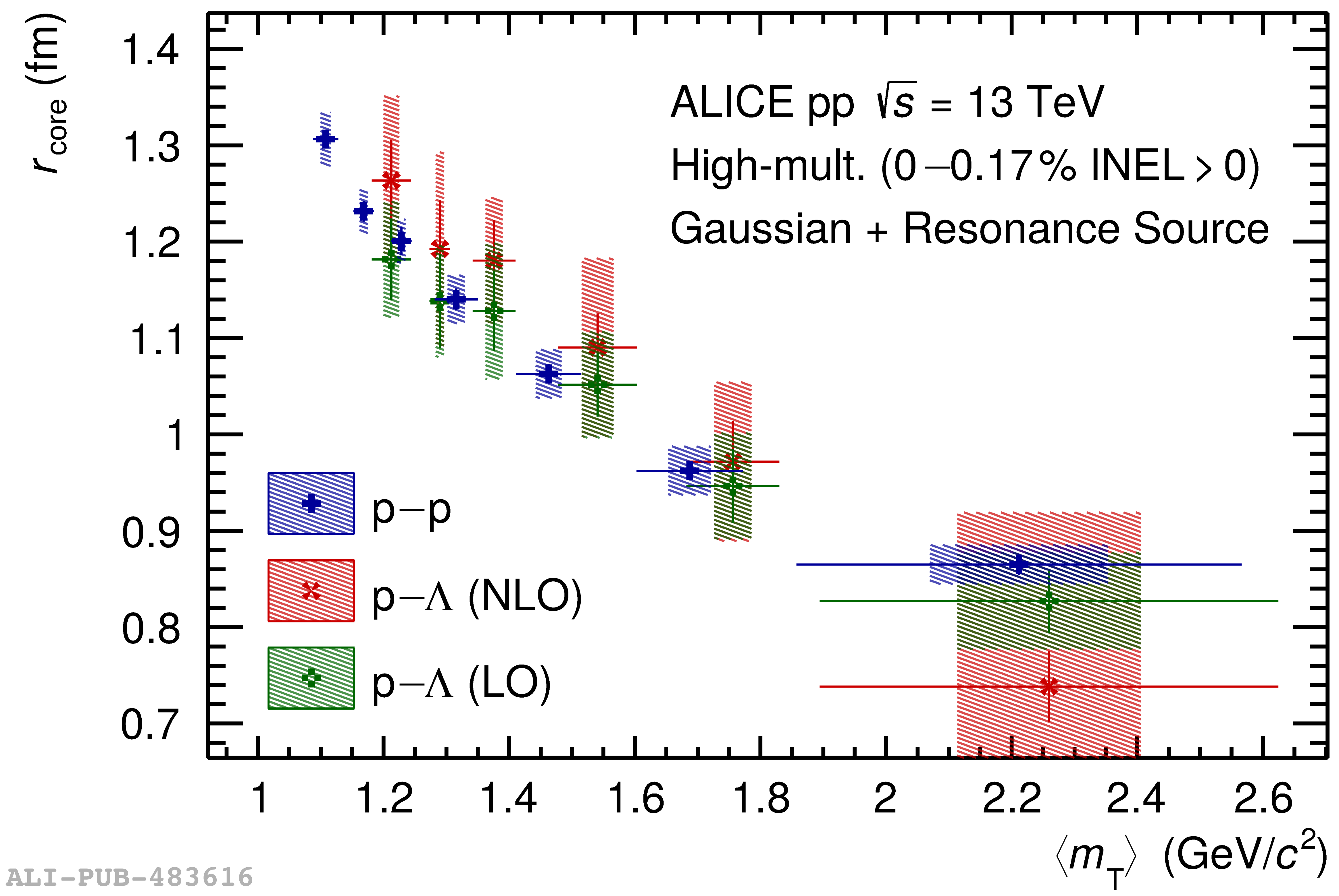
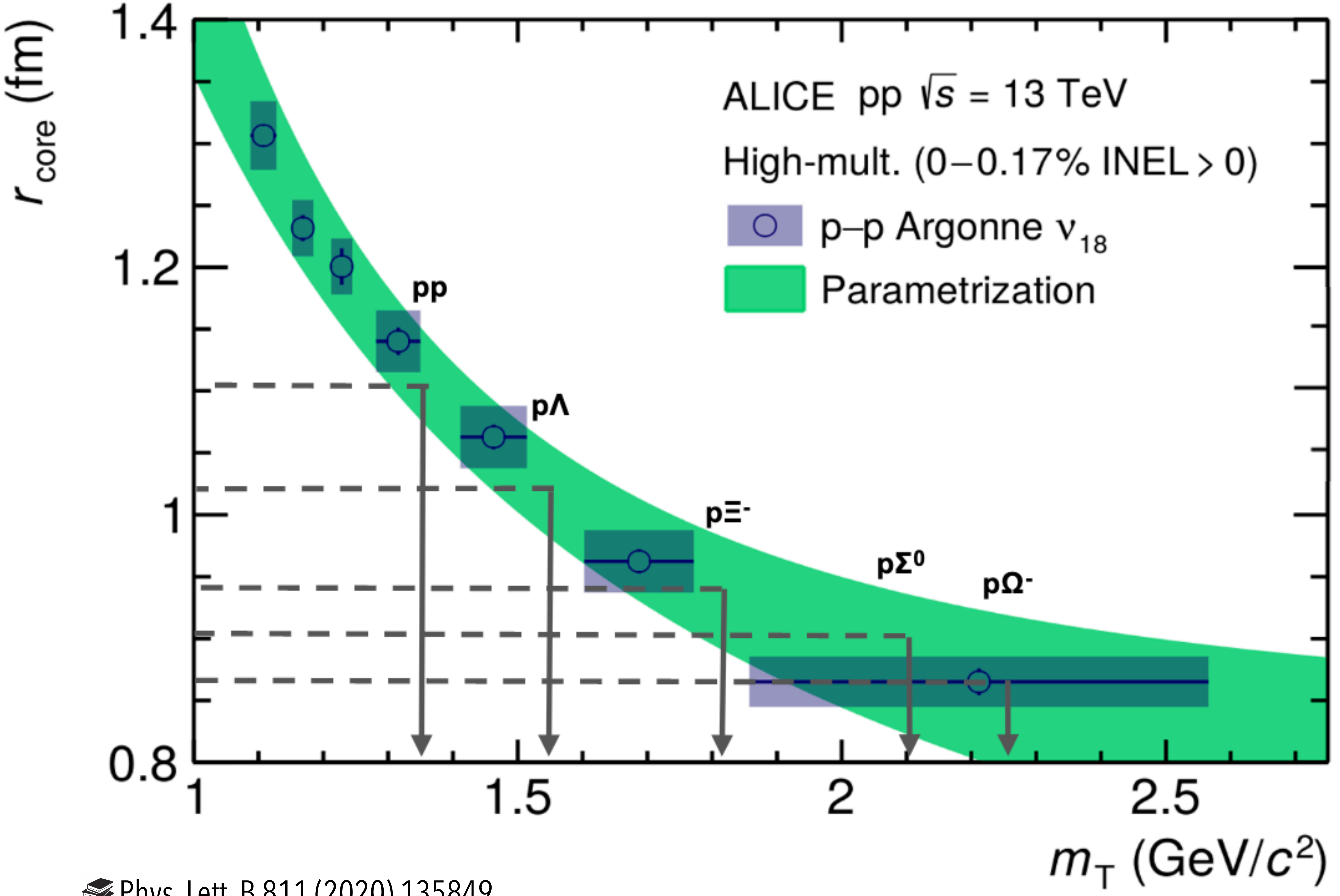
- Without considering resonances



- Considering resonances



Calibration of the emitting source



Phys. Lett. B 811 (2020) 135849

- Measurement of source radius obtained from p–p correlation used to obtain the values for other baryon species

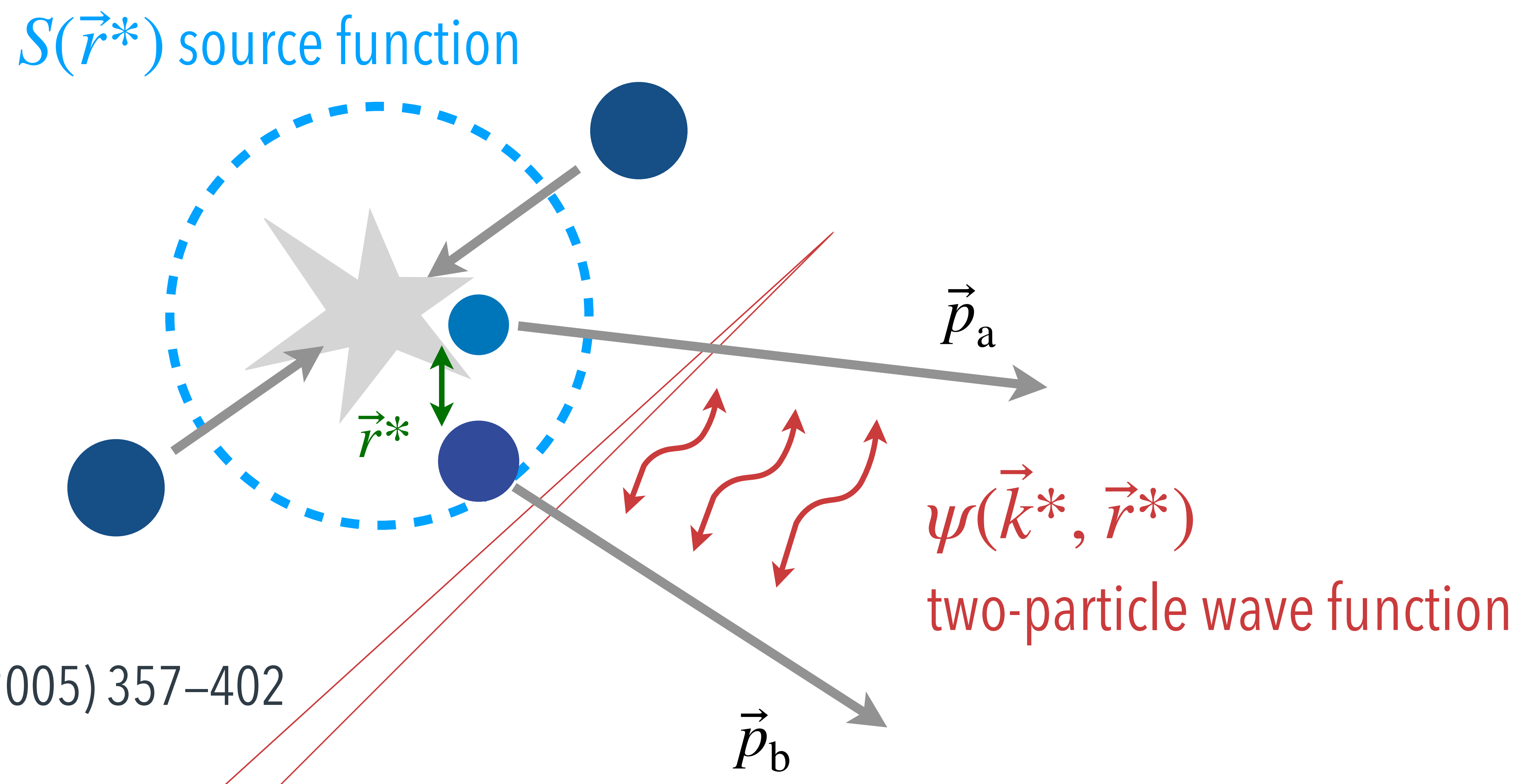
- Femtoscopy technique: based on the *correlation function (CF)*

Experiment — Theory

$$C(\vec{k}^*) = \mathcal{N}\frac{N^{\mathrm{pairs}}_{\mathrm{same}}(k^*)}{N^{\mathrm{pairs}}_{\mathrm{mixed}}(k^*)} = \int S(\vec{r}^*)\,|\psi(\vec{k}^*,\vec{r}^*)|^2\,\mathrm{d}^3r^*$$

Koonin-Pratt equation

M.Lisa, S. Pratt et al, Ann.Rev.Nucl.Part.Sci. 55 (2005) 357–402



where $\vec{k}^* = \frac{\vec{p}^*_a - \vec{p}^*_b}{2}$ is in the rest frame of the particle pair

➡ Relative wave function sensitive to interaction potential

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

CF computed in ALICE using *CATS* (Correlation Analysis Tool using the Schrödinger equation)

➡ Developed at Technische Universität München

➡ Provides exact solution of Schrödinger equation for wave function

D. L. Mihaylov et al, Eur. Phys. Journal C 78 (2018) 394

➡ CF sensitive to strong interaction when the source size ~1 fm

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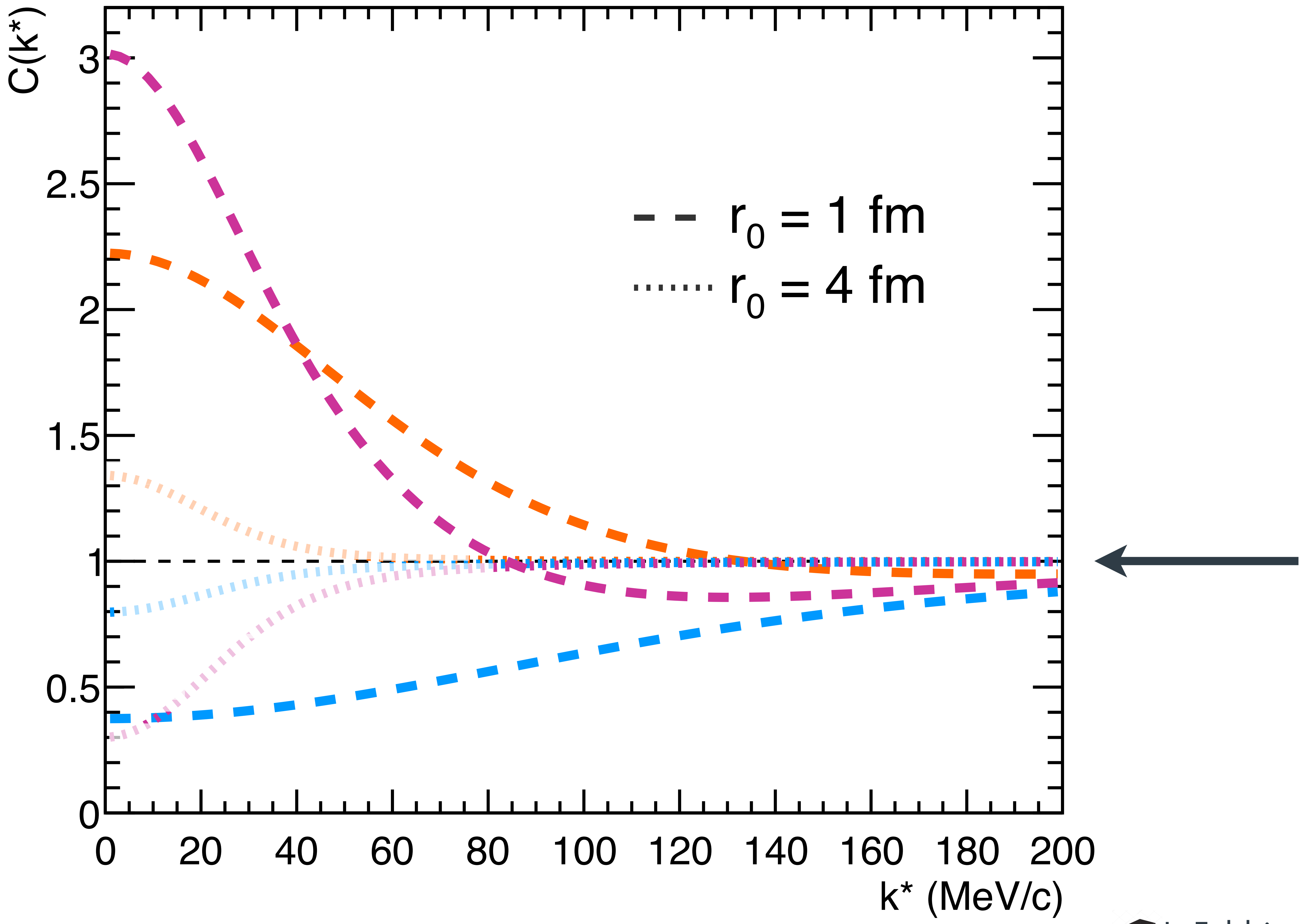
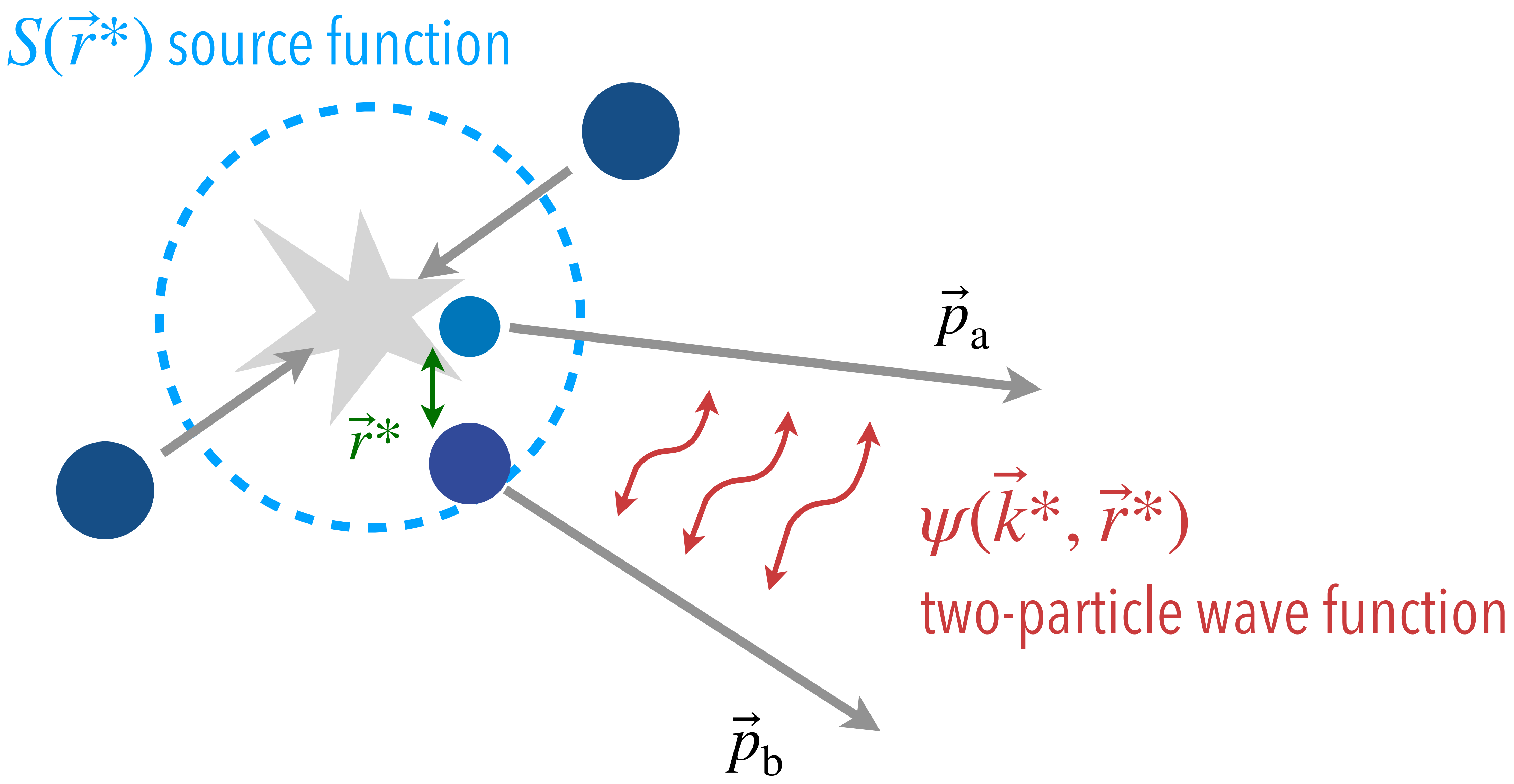
$$C(\vec{k}^*) = \int S(\vec{r}^*)\,|\psi(\vec{k}^*, \vec{r}^*)|^2\,\mathrm{d}^3 r^*$$

➡ Relative wave function sensitive to interaction potential





➡ Absence of interaction $C(k^*) = 1$

L. Fabbietti, V. Mantovani Sarti, O. Vázquez Doce, Annu. Rev. Nucl. Part. Sci. (2021) 71:377–402

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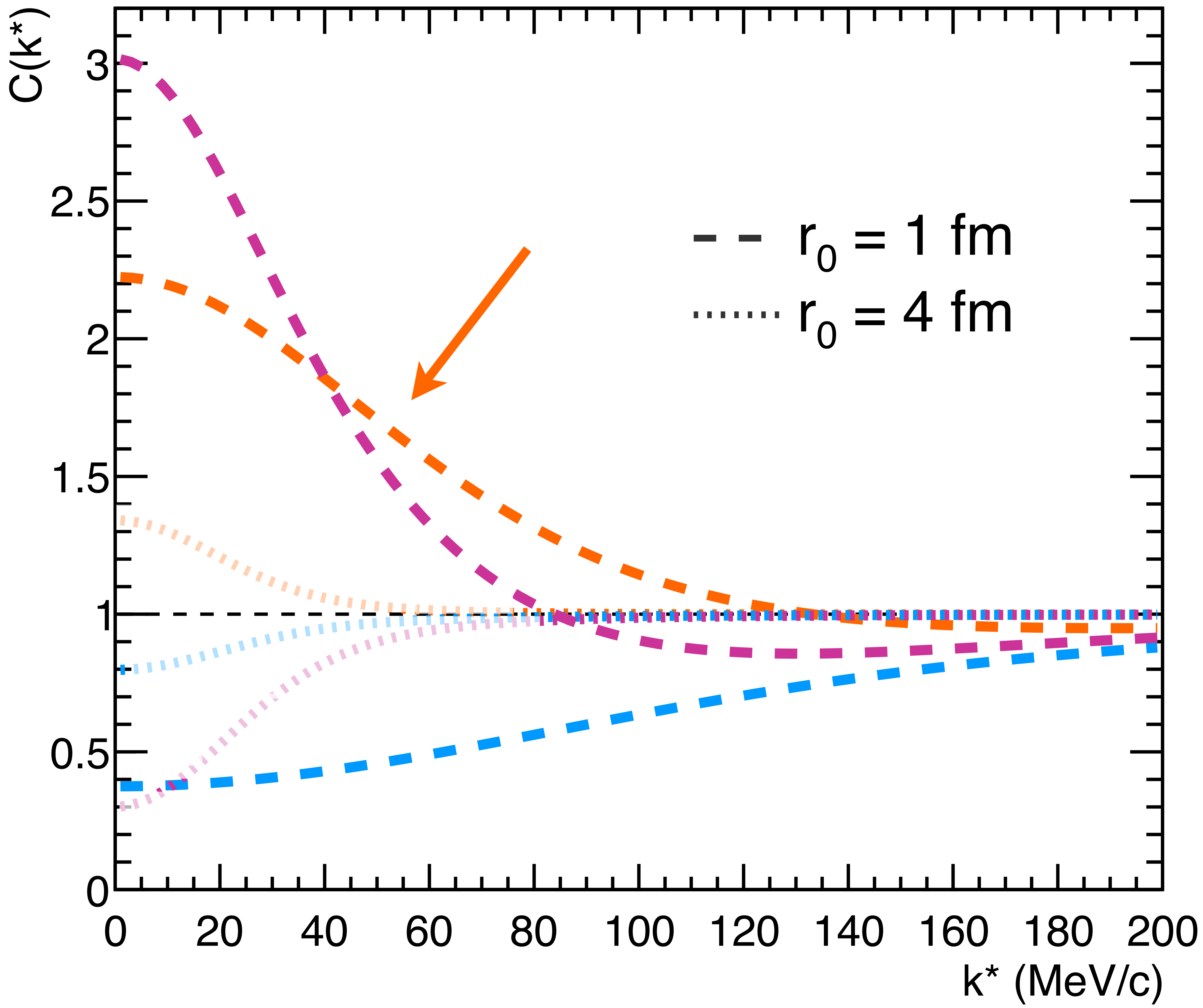
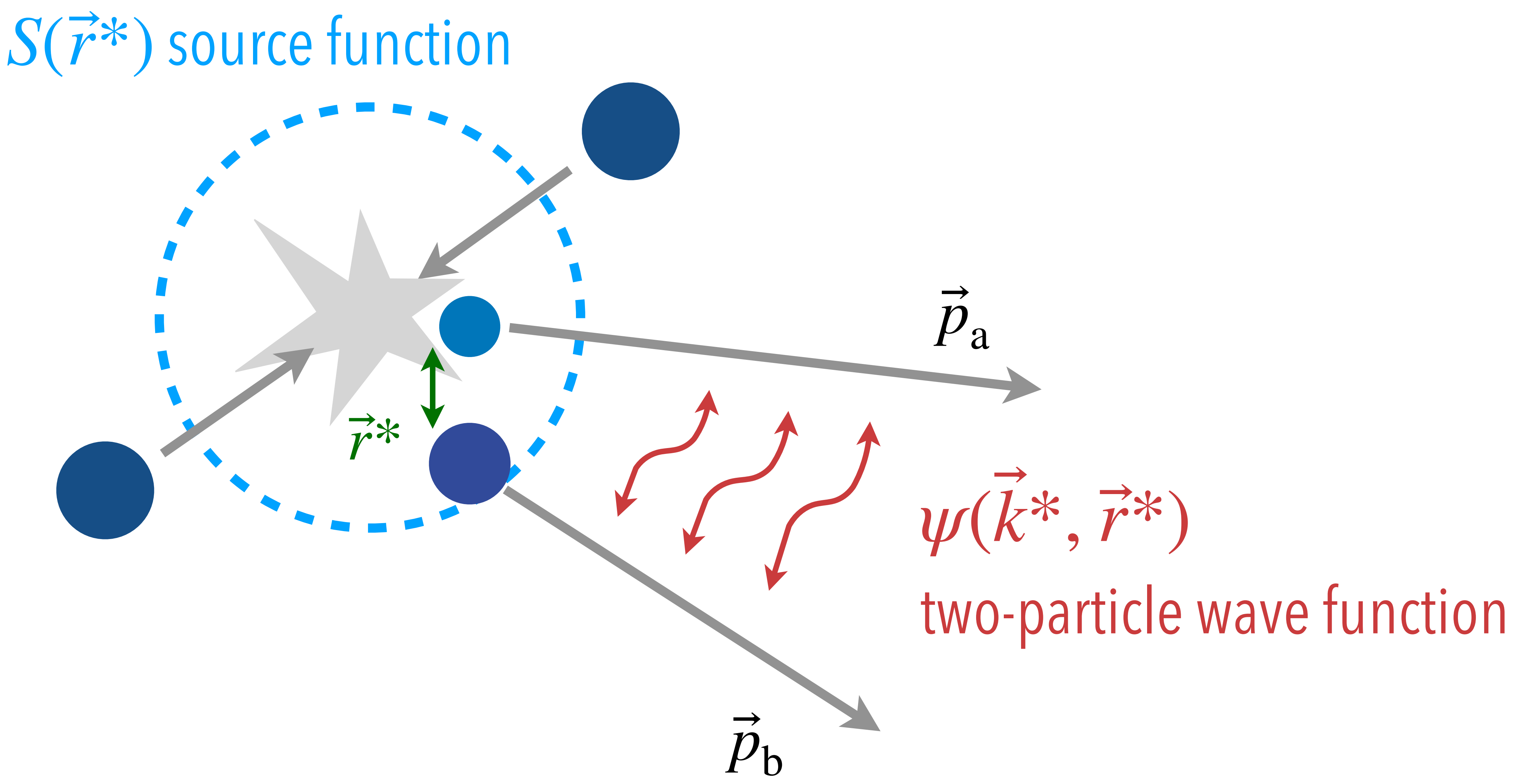
$$C(\vec{k}^*) = \int S(\vec{r}^*)\,|\psi(\vec{k}^*, \vec{r}^*)|^2 \,\mathrm{d}^3 r^*$$

- Relative wave function sensitive to interaction potential





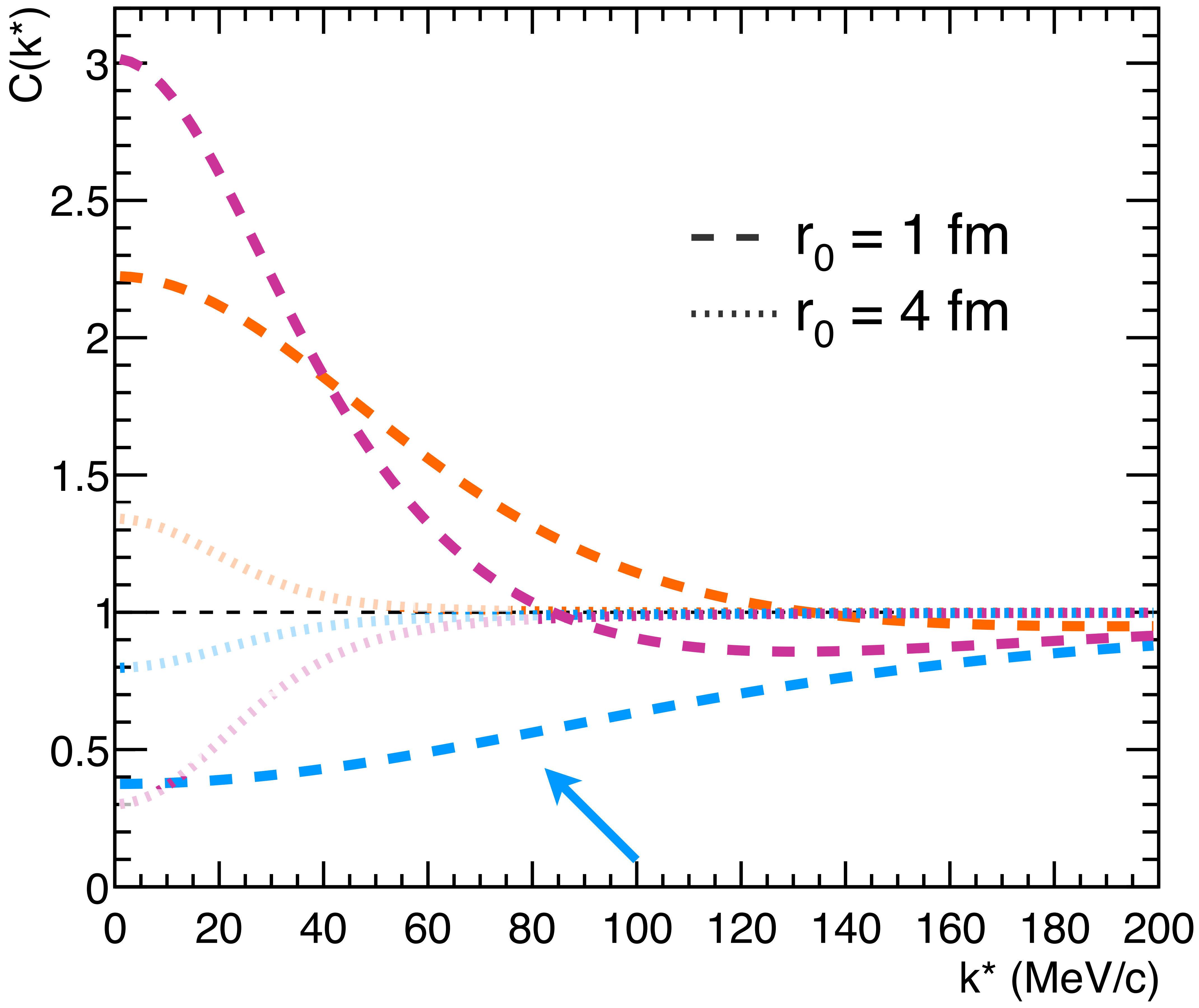
- Absence of interaction $C(k^*) = 1$
- Attractive potential $C(k^*) > 1$

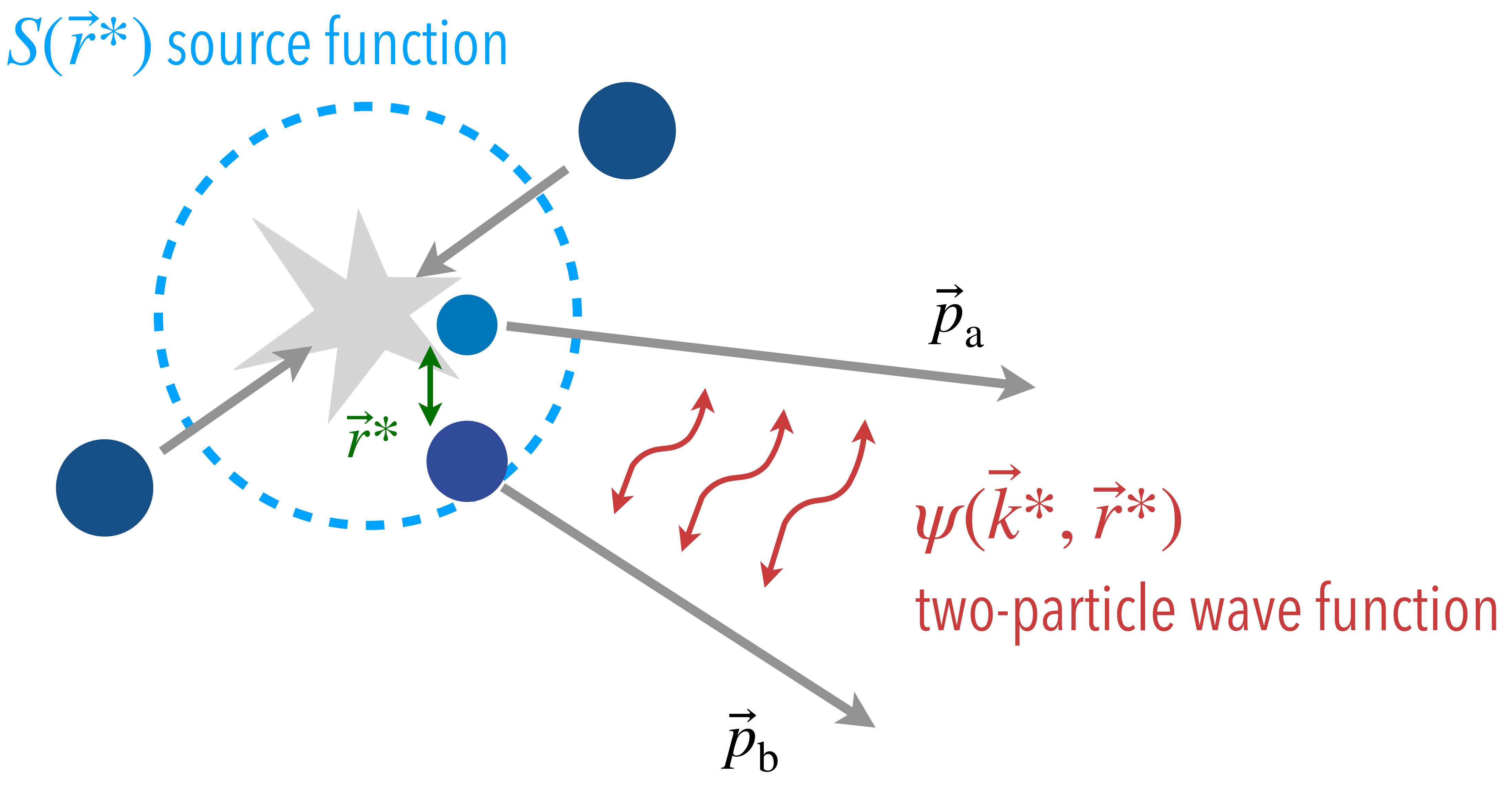
L. Fabbietti, V. Mantovani Sarti, O. Vázquez Doce, Annu. Rev. Nucl. Part. Sci. (2021) 71:377–402

Effect of the interactions on the correlation function

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

➡ Relative wave function sensitive to interaction potential





➡ Absence of interaction $C(k^*) = 1$

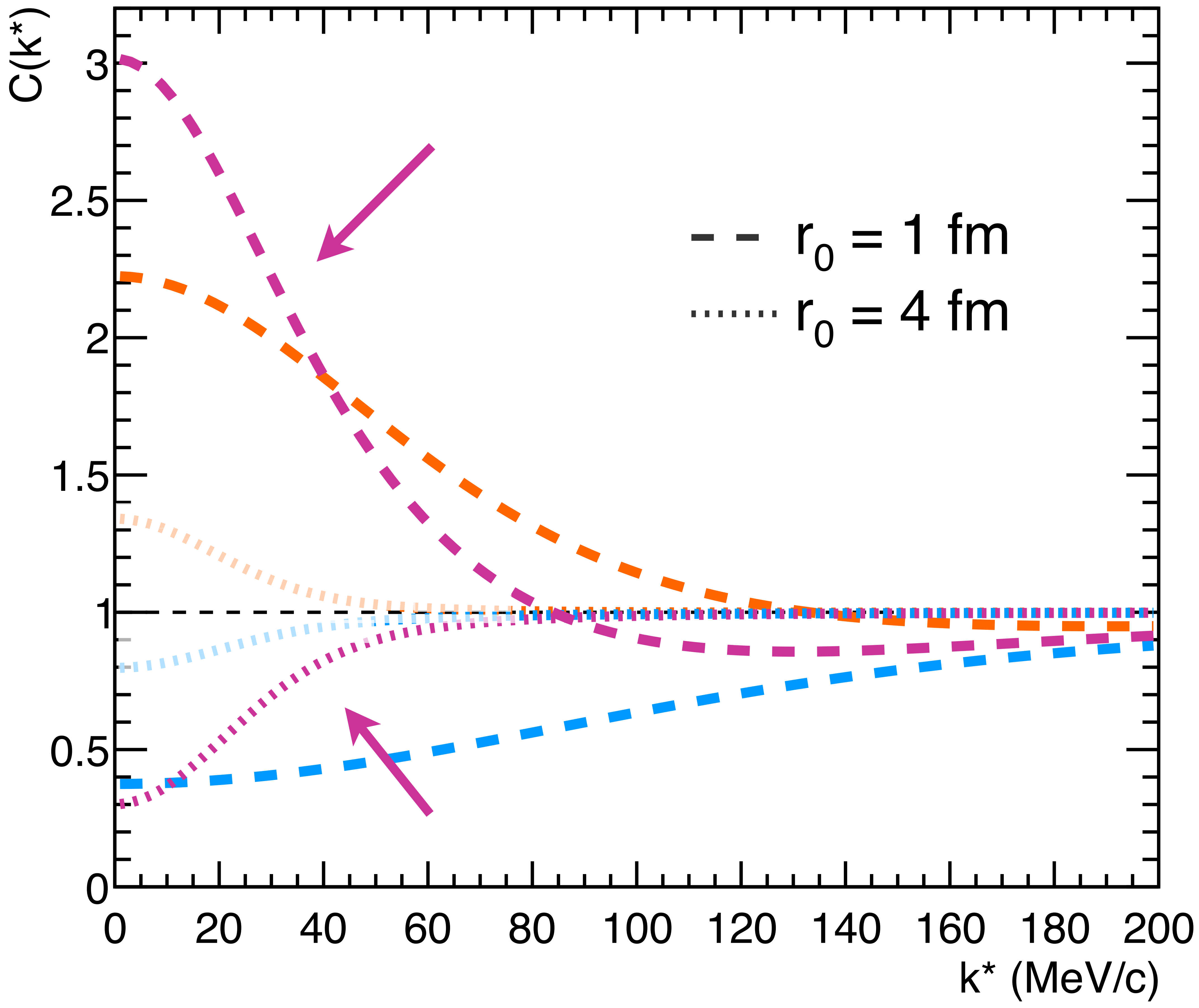
➡ Attractive potential $C(k^*) > 1$

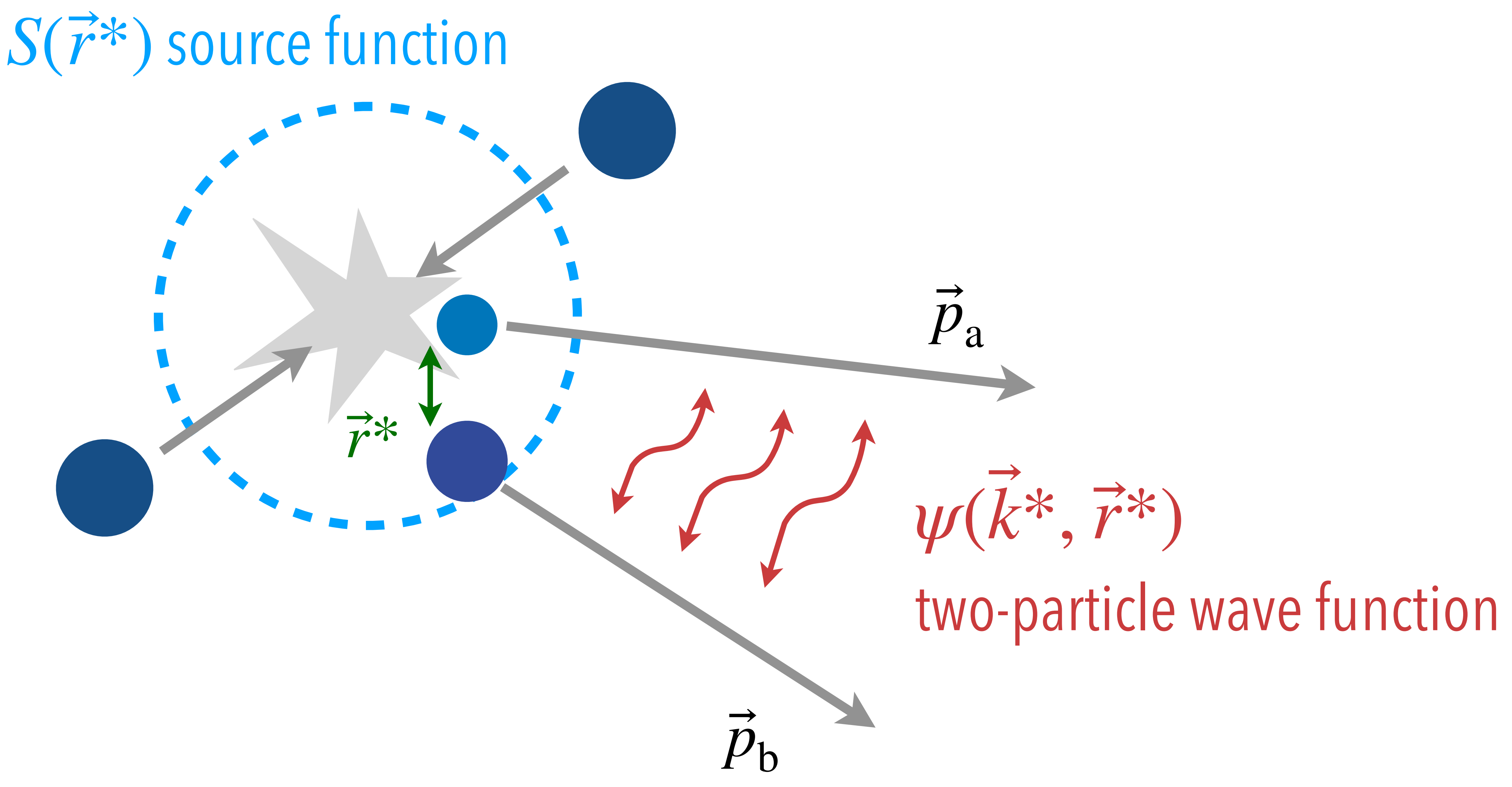
➡ Repulsive potential $C(k^*) < 1$

L. Fabbietti, V. Mantovani Sarti, O. Vázquez Doce, Annu. Rev. Nucl. Part. Sci. (2021) 71:377–402

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

➡ Relative wave function sensitive to interaction potential





➡ Absence of interaction $C(k^*) = 1$

➡ Attractive potential $C(k^*) > 1$

➡ Repulsive potential $C(k^*) < 1$

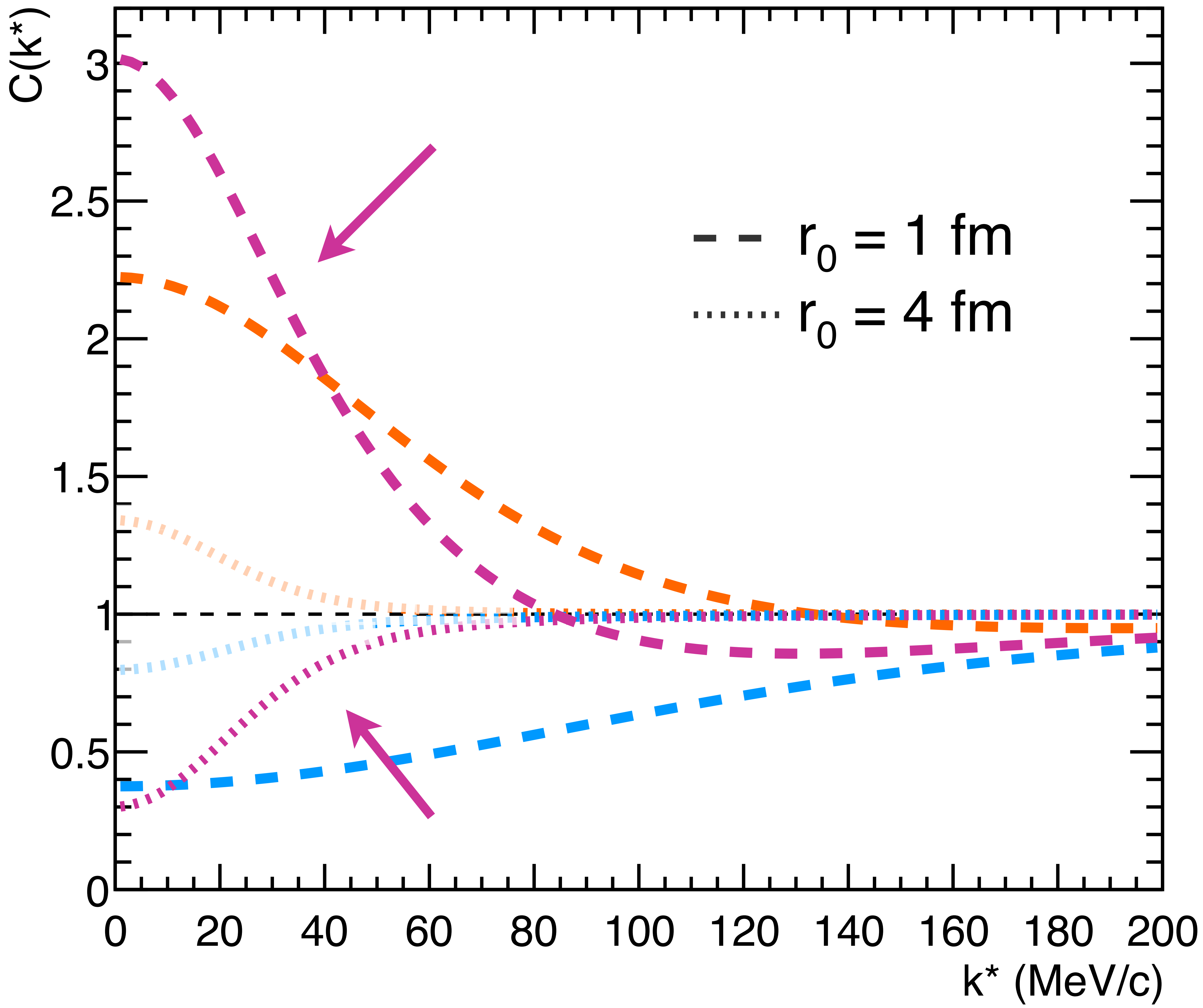
➡ Bound-state formation $C(k^*)$ <> 1

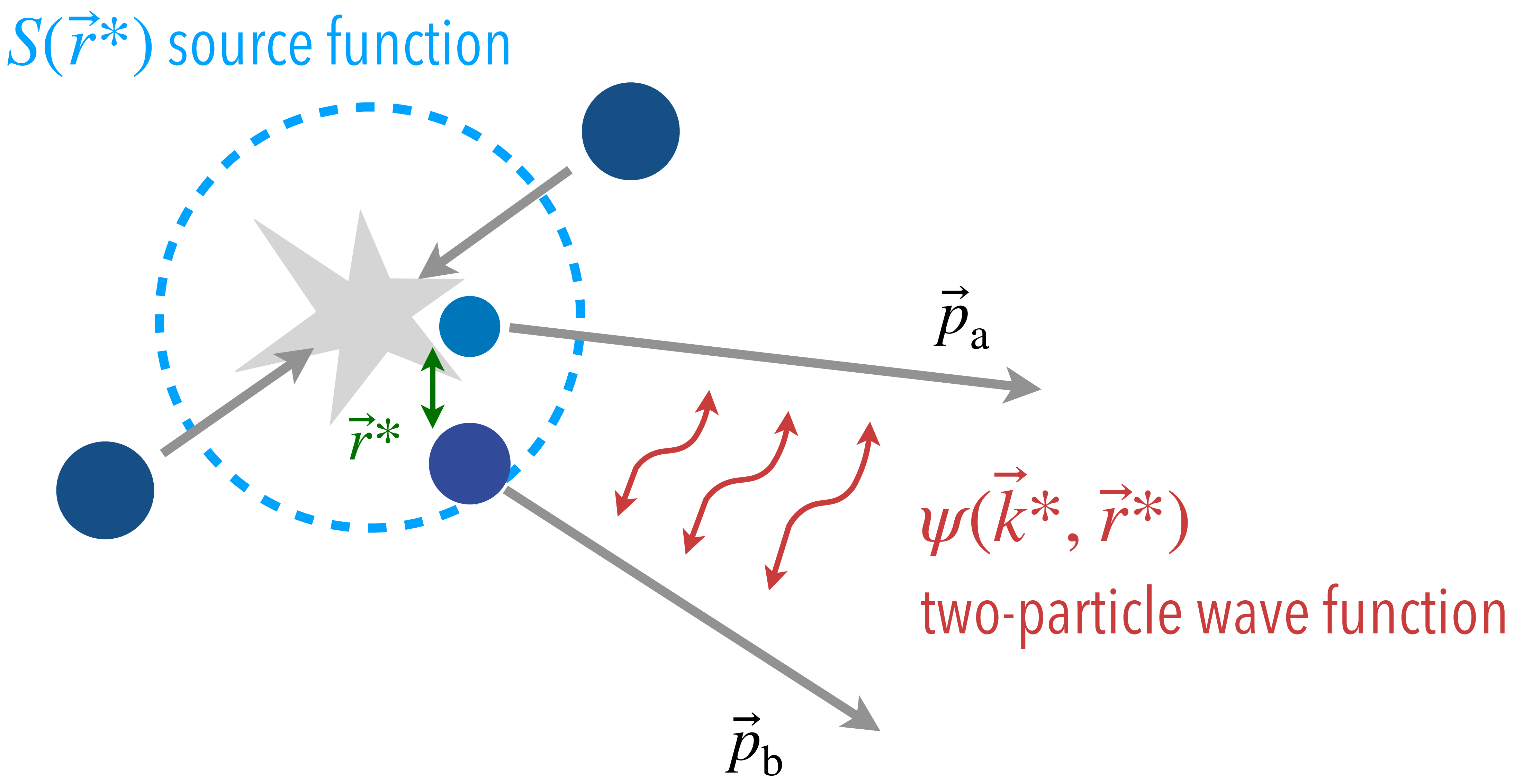
L. Fabbietti, V. Mantovani Sarti, O. Vázquez Doce, Annu. Rev. Nucl. Part. Sci. (2021) 71:377–402

Effect of the interactions on the correlation function

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

➡ Relative wave function sensitive to interaction potential





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