From particle emission at accelerator facilities to axion properties in neutron stars: results and implications of the latest femtoscopic studies involving pions by ALICE

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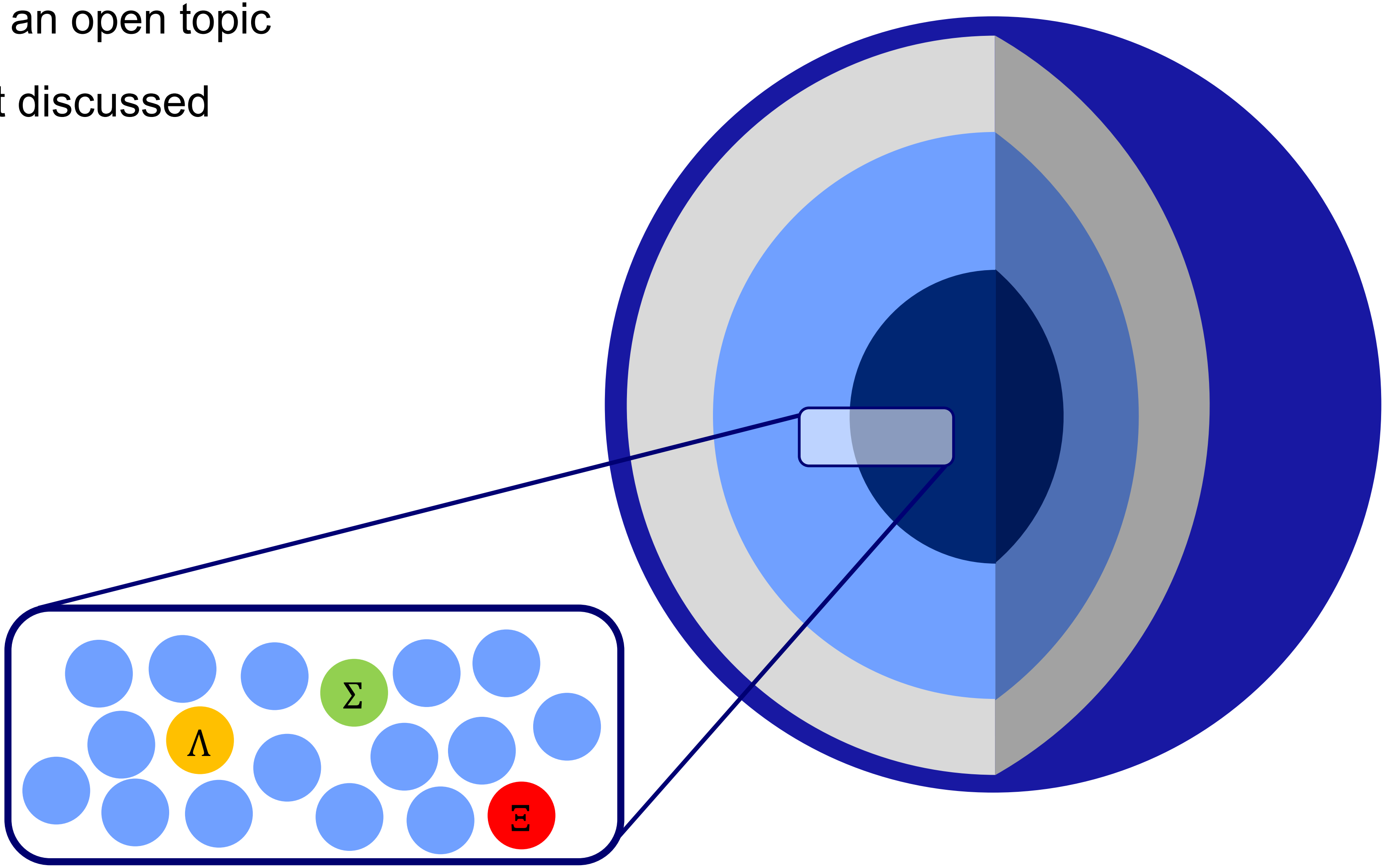
on behalf of the ALICE Collaboration

Technical University of Munich

19th of June 2024
ICHEP 2024, Prague

Neutron stars

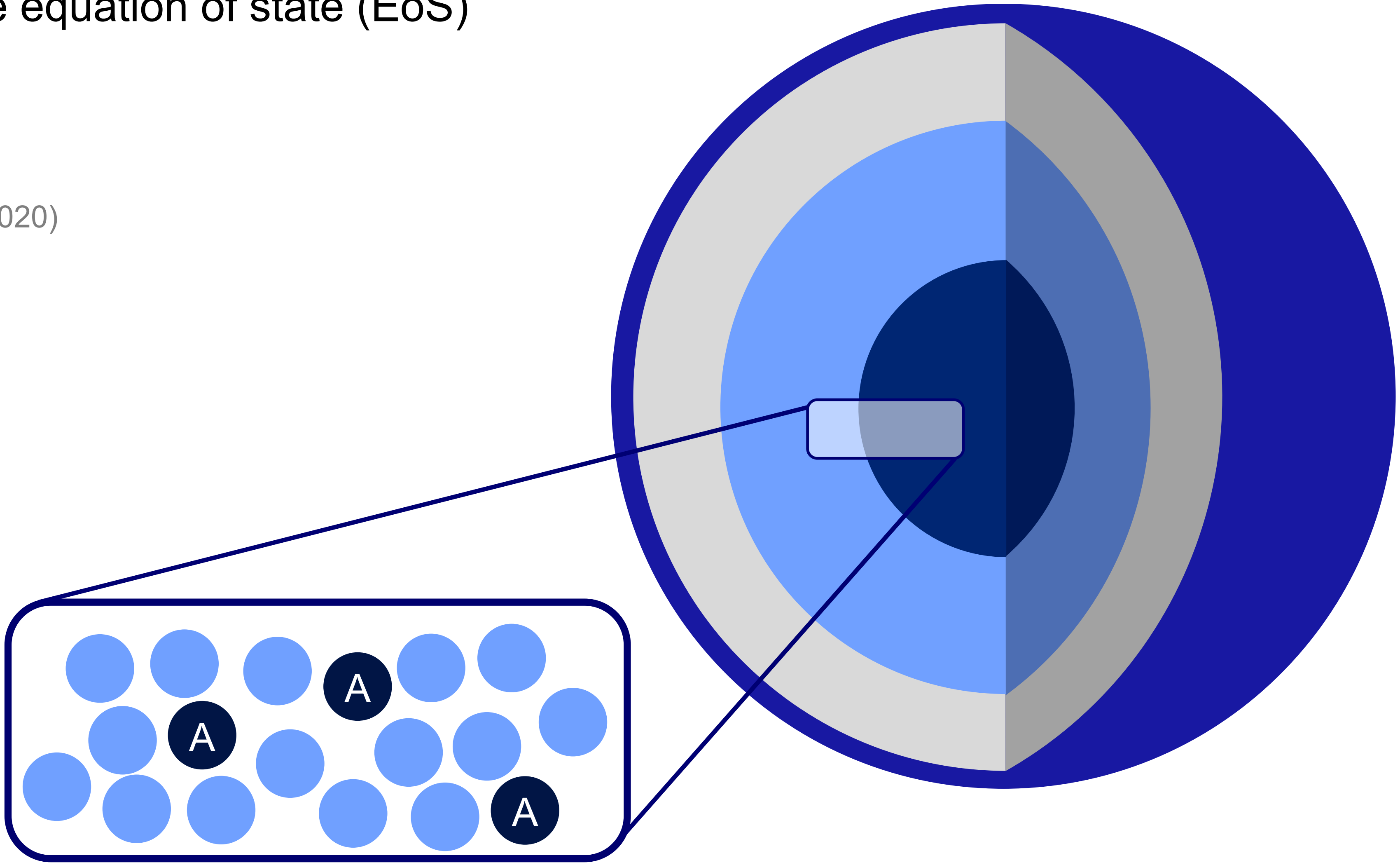
- Inside of neutron stars is still an open topic
- Hyperons as one of the most discussed scenarios (YN & YNN)



Neutron stars and QCD axions

- Impact of QCD axions on the equation of state (EoS)
  → Can lead to stiffer EoS

Reuven Balkin et al., JHEP 2020, 221 (2020)
Reuven Balkin et al., arXiv 2307.14418



Neutron stars and QCD axions

- Impact of QCD axions on the equation of state (EoS)
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- Axion properties linked to in-medium properties of pion

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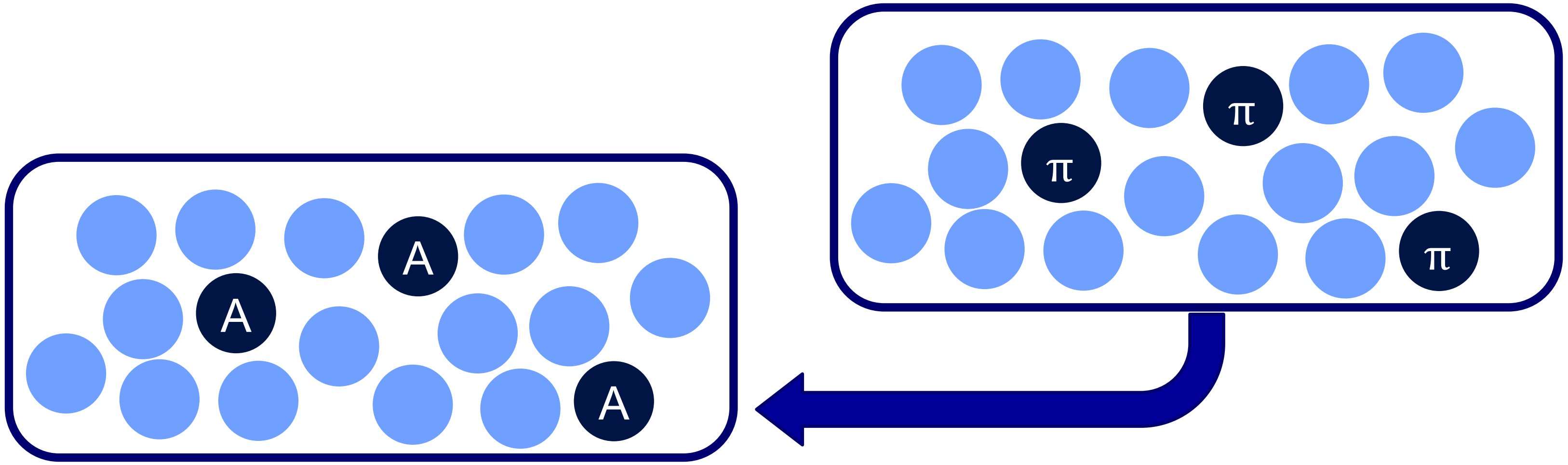

Neutron stars and QCD axions

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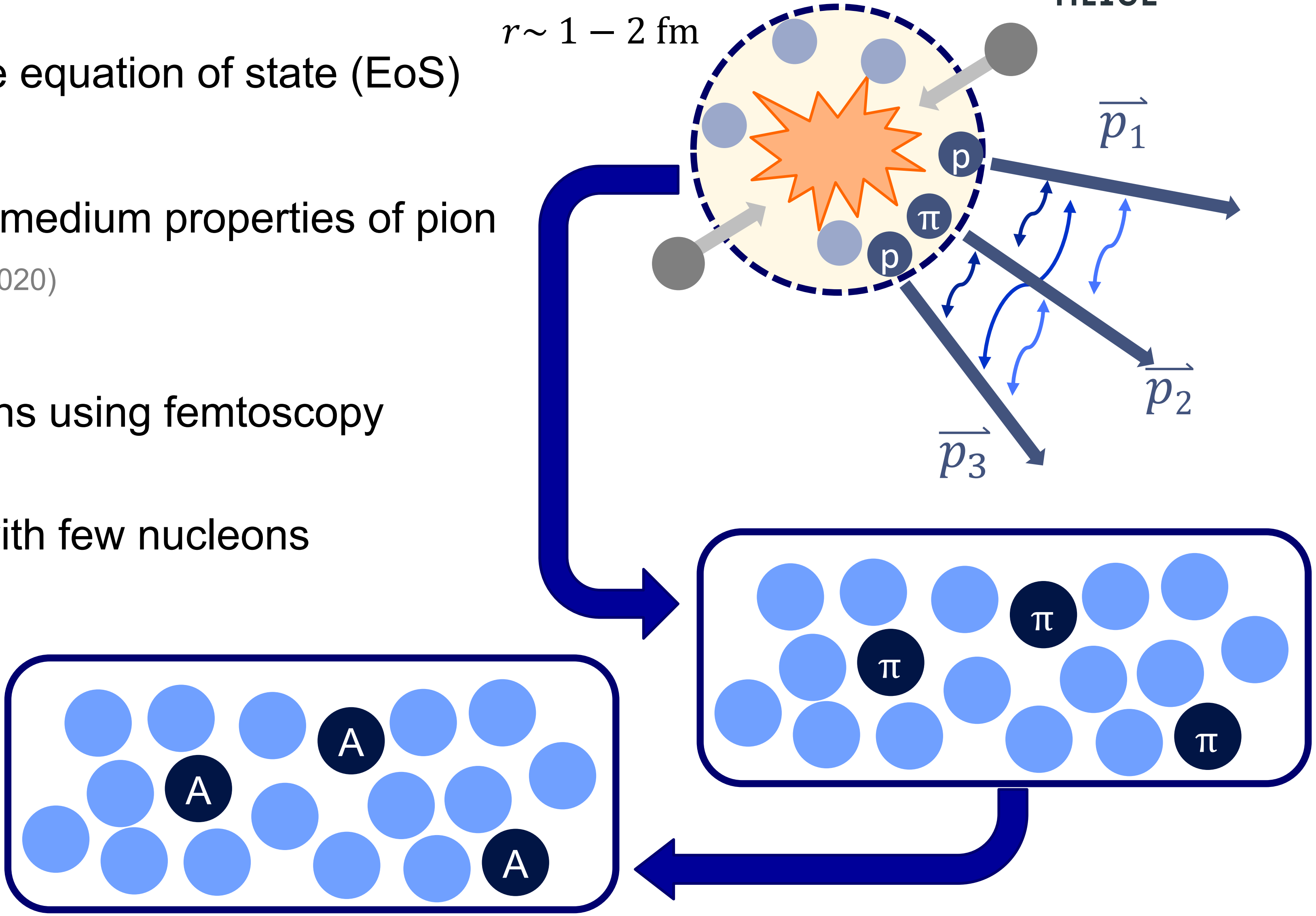
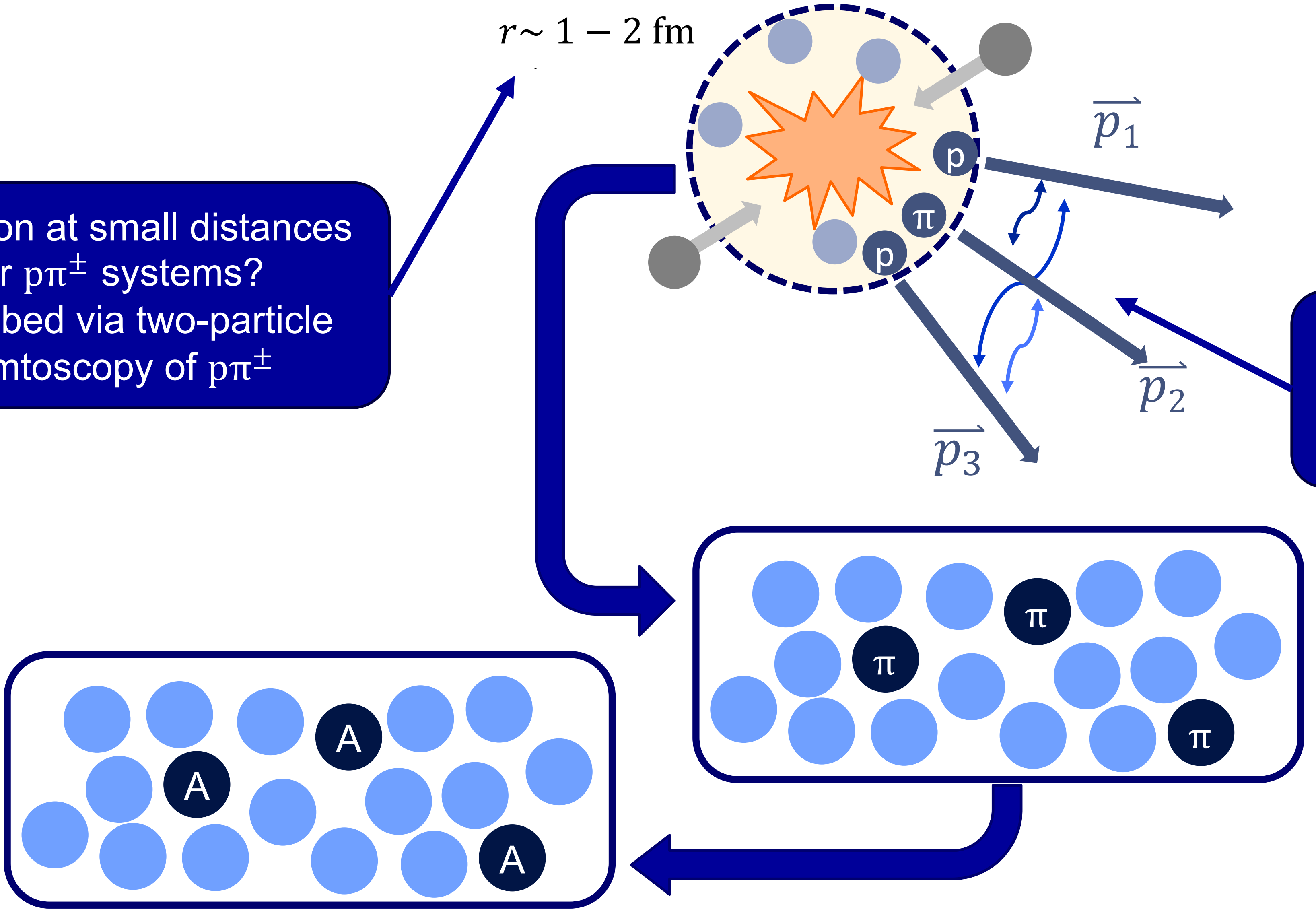
Goal: Study of $pp\pi^{\pm}$ interactions using femtoscopy in small colliding systems
→ Access dynamics of pions with few nucleons



On today's menu

Emission at small distances for $p\pi^{\pm}$ systems?
→ Probed via two-particle femtoscopy of $p\pi^{\pm}$



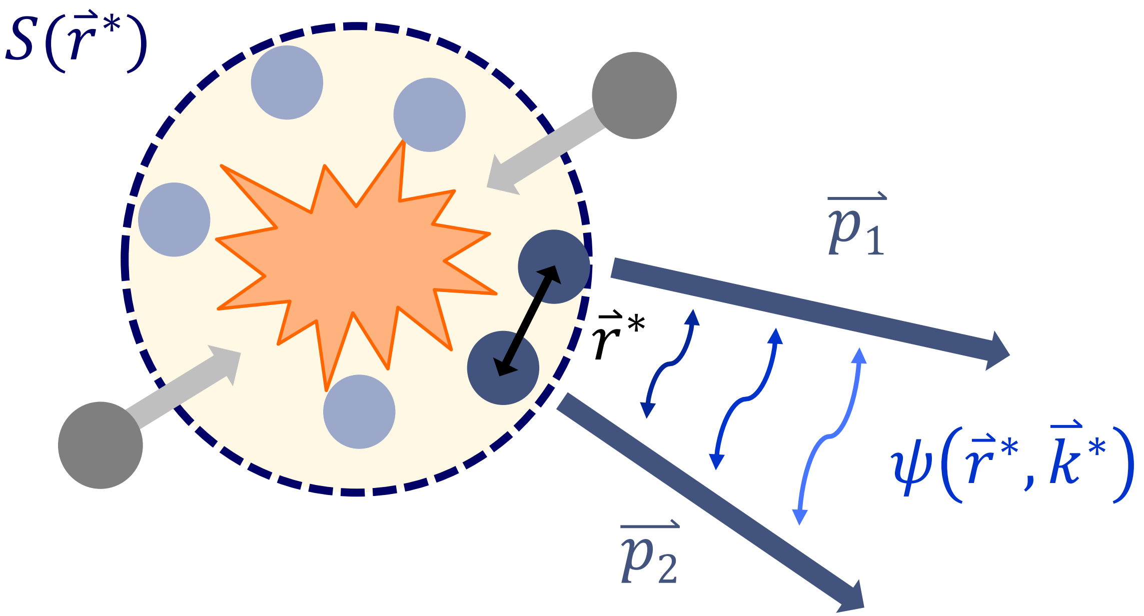
Do we see effects beyond pairwise interactions in $pp\pi^{\pm}$?

Two-particle femtoscopy

- Observed femtoscopic correlation functions depend on
  - final-state interaction $|\psi(\vec{k}^*, \vec{r}^*)|^2$
  - particle emitting source $S(\vec{r}^*)$

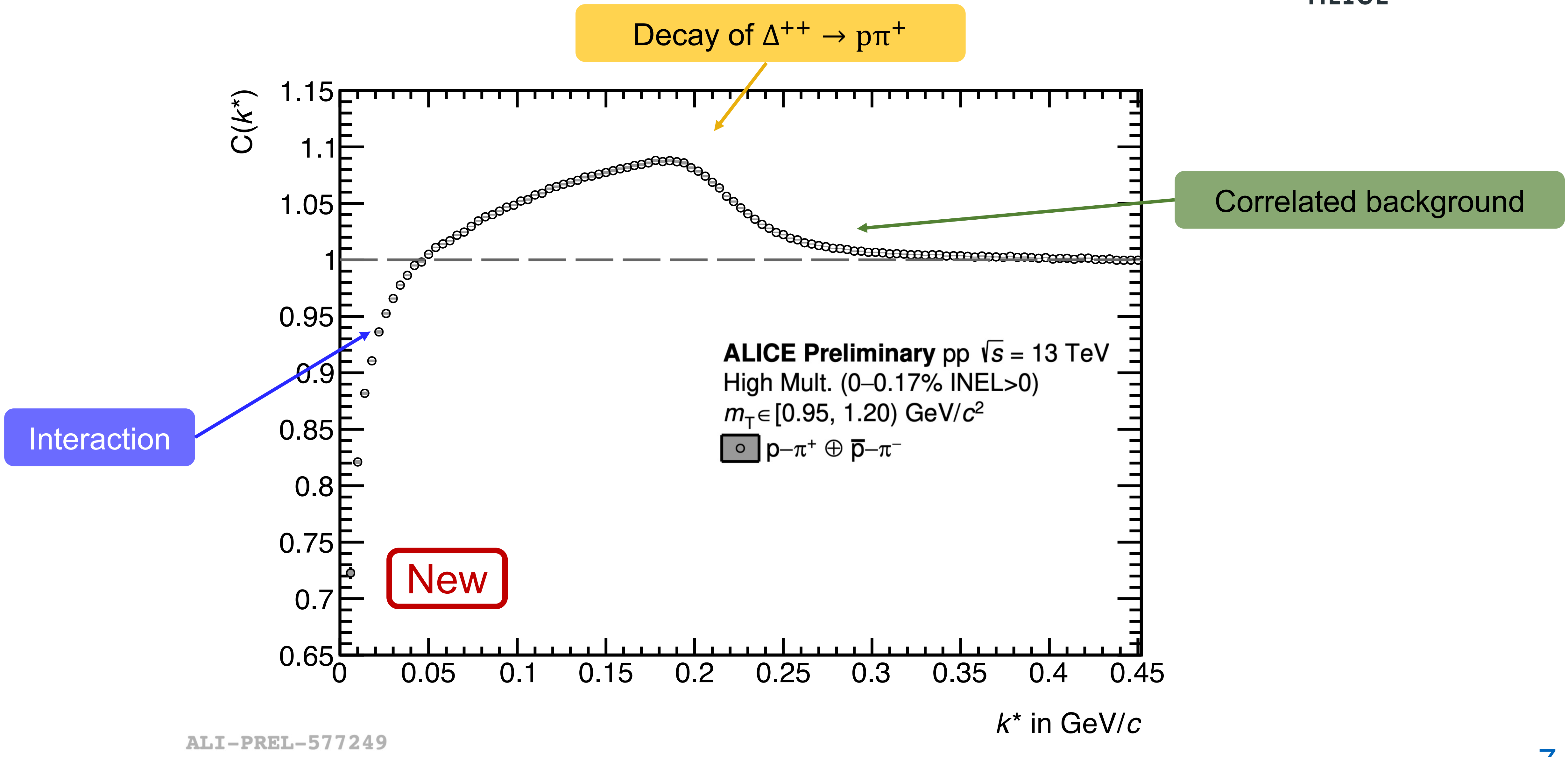
  → Talk by M. Korwieser (19th of July 17:00)
- The study of the interactions needs a well constrained source!
- Two-body $p\pi^{\pm}$ interaction known from scattering experiments

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



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

Two-particle correlation function of $p\pi^+$



Fitting of data of $p\pi^+$

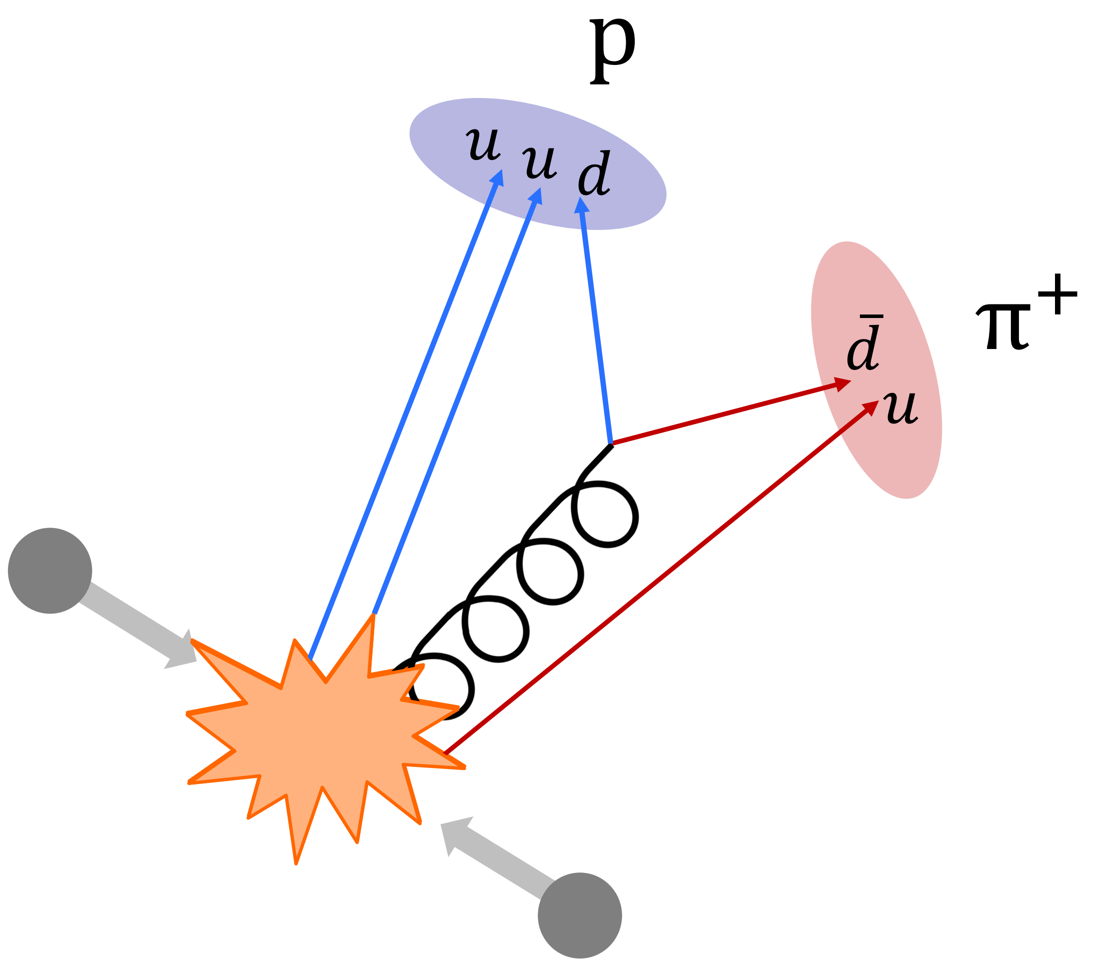
$C_{\mathrm{total}} = \mathcal{N} \times$ [redacted] $\times$ [redacted] $+$ [redacted]

Fitting of data of $p\pi^+$

$$C_{\mathrm{total}} = \mathcal{N} \times C_{\mathrm{bckg}} \times \text{[redacted]} + \text{[redacted]}$$

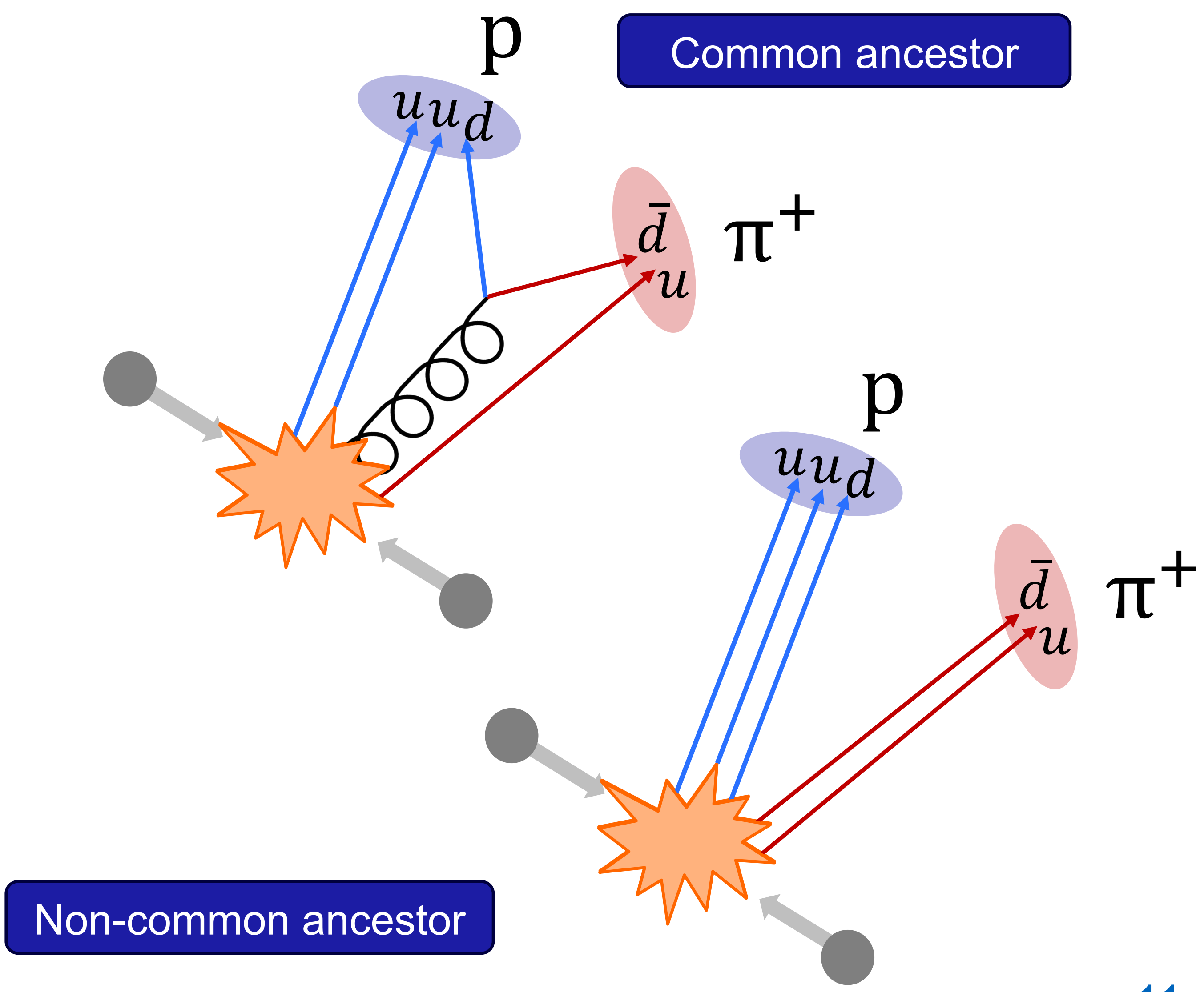
Background contribution

- Correlated background due to “mini-jet” contribution from hadronization process



Background contribution

- Correlated background due to "mini-jet" contribution from hadronization process
- Background modelled with MC simulations using Pythia:
  - Obtain MC correlation function for pairs with common and non-common partonic origin (ancestors) separately
  - Use common C_{c} and non-common C_{nc} as templates to build the background
  - $C_{\mathrm{bckg}} = \mathcal{N} \times [w_{\mathrm{c}} C_{\mathrm{c}} + (1 - w_{\mathrm{c}}) C_{\mathrm{nc}}]$



Fitting of data of $p\pi^{+}$

$C_{\mathrm{total}} = \mathcal{N} \times C_{\mathrm{bckg}} \times$ [redacted] $+$ [redacted]

- Background C_{bckg} via MC templates, controlled by w_{c}

Fitting of data of $p\pi^+$

ALICE TUM

$$C_{\text{total}} = \mathcal{N} \times C_{\text{bckg}} \times [\lambda_{\text{Gen}} C_0 + (1 - \lambda_{\text{Gen}})] + \text{[redacted]}$$

- Background C_{bckg} via MC templates, controlled by w_{c}
- Interaction $C_0(r_{\text{core}})$ Coulomb + strong interaction (fixed from scattering lengths)

  M. Hoferichter et al., Phys.Rept. 625 (2016) 1–88
  M. Hennebach et al., EPJA 50 (2014) 12, 190

M. Hoferichter et al., Phys.Rept. 625 (2016) 1-88.

	$p\pi^+$	$p\pi^-$
Scattering Length	-0.125 fm	0.121 fm

Fitting of Data pπ^+

$$C_{\text{total}} = \mathcal{N} \times C_{\text{bckg}} \times [\lambda_{\text{Gen}} C_0 + (1-\lambda_{\text{Gen}})] + N_\Delta PS(p_{\text{T}}, T) \times Sill(M_\Delta, \Gamma_\Delta)$$

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- Resonance description: Sill distribution $Sill(M_\Delta, \Gamma_\Delta)$, M_Δ fixed to 1215 MeV

  F. Giacosa et al., EPJA 57 (2021) 12

- $PS(p_{\text{T}}, T)$ phase-space factor

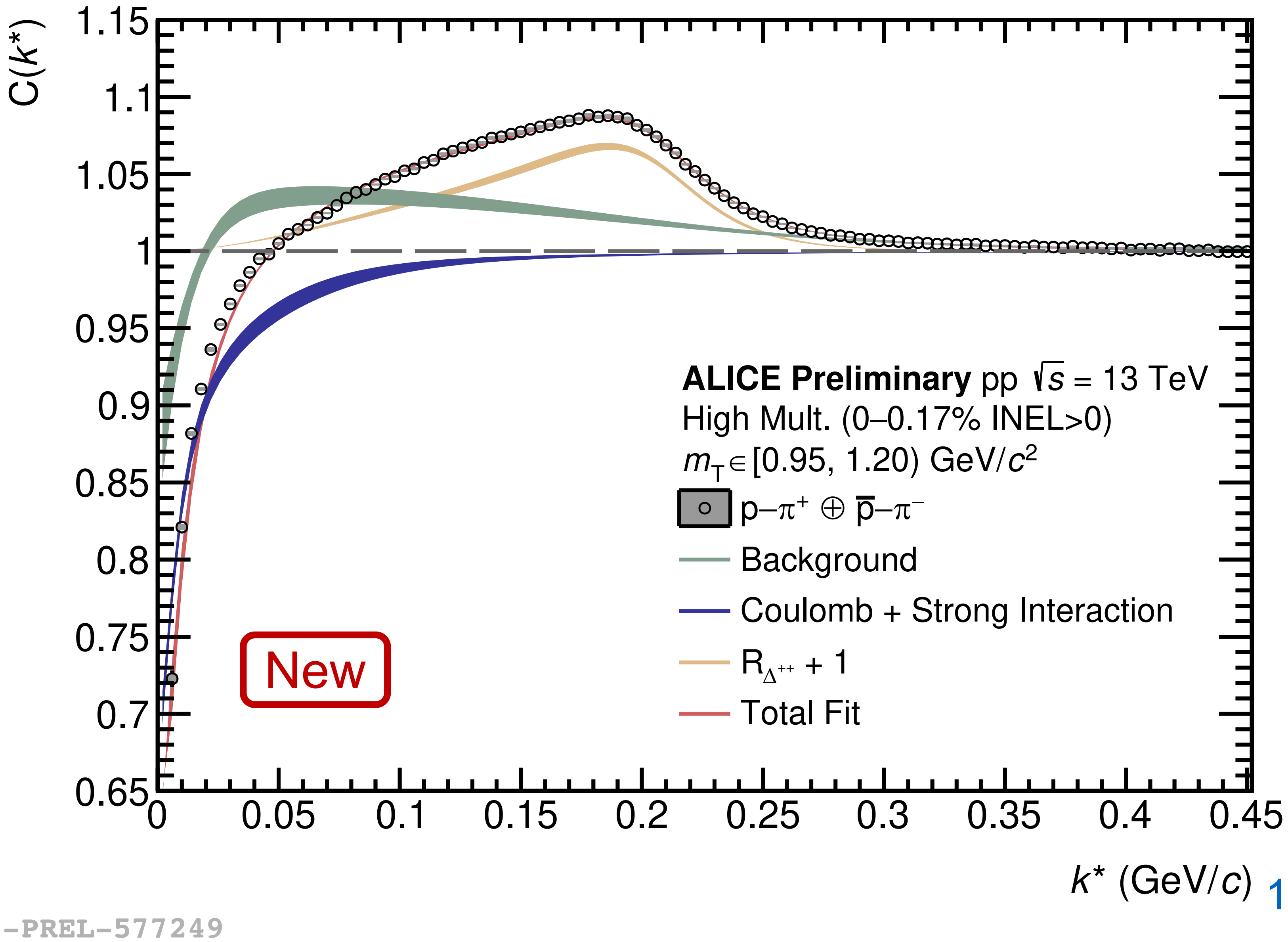
$$PS(p_{\text{T}}, T) \propto \frac{m}{\sqrt{m^2+p_{\text{T}}^2}} \times \exp\left(-\frac{\sqrt{m^2+p_{\text{T}}^2}}{T}\right)$$

- Fit between between 0 and 450 MeV in *k**

Fitting of the $p\pi^+$ correlation function

- Fit procedure repeated for different pair transverse mass ranges

- $m_T = \sqrt{\bar{m}^2 + k_T^2}$ and $\vec{k}_T = \frac{1}{2}[\vec{p}_{T,1} + \vec{p}_{T,2}]$



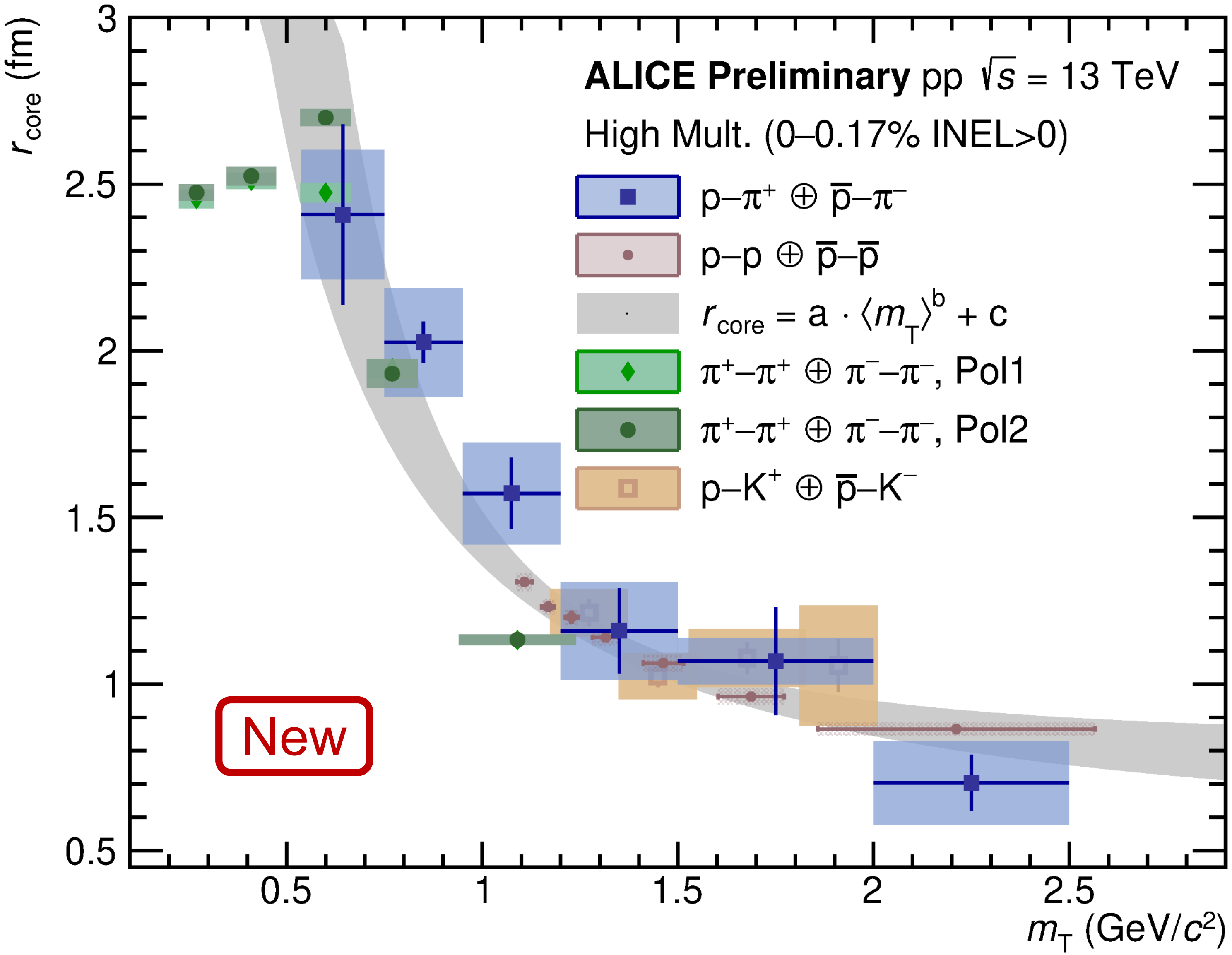
Core radius scaling $p\pi^+$

- r_{core}: size of emission source of **primordial** particles
- r_{core} of $p\pi^+$ follows common scaling of $pp, pK^+, \pi^\pm\pi^\pm$ in pp collisions

ALICE, PLB, 811:135849, 2020

ALICE, arXiv:2311.14527, EPJC in press

→ Common emission source for all hadrons



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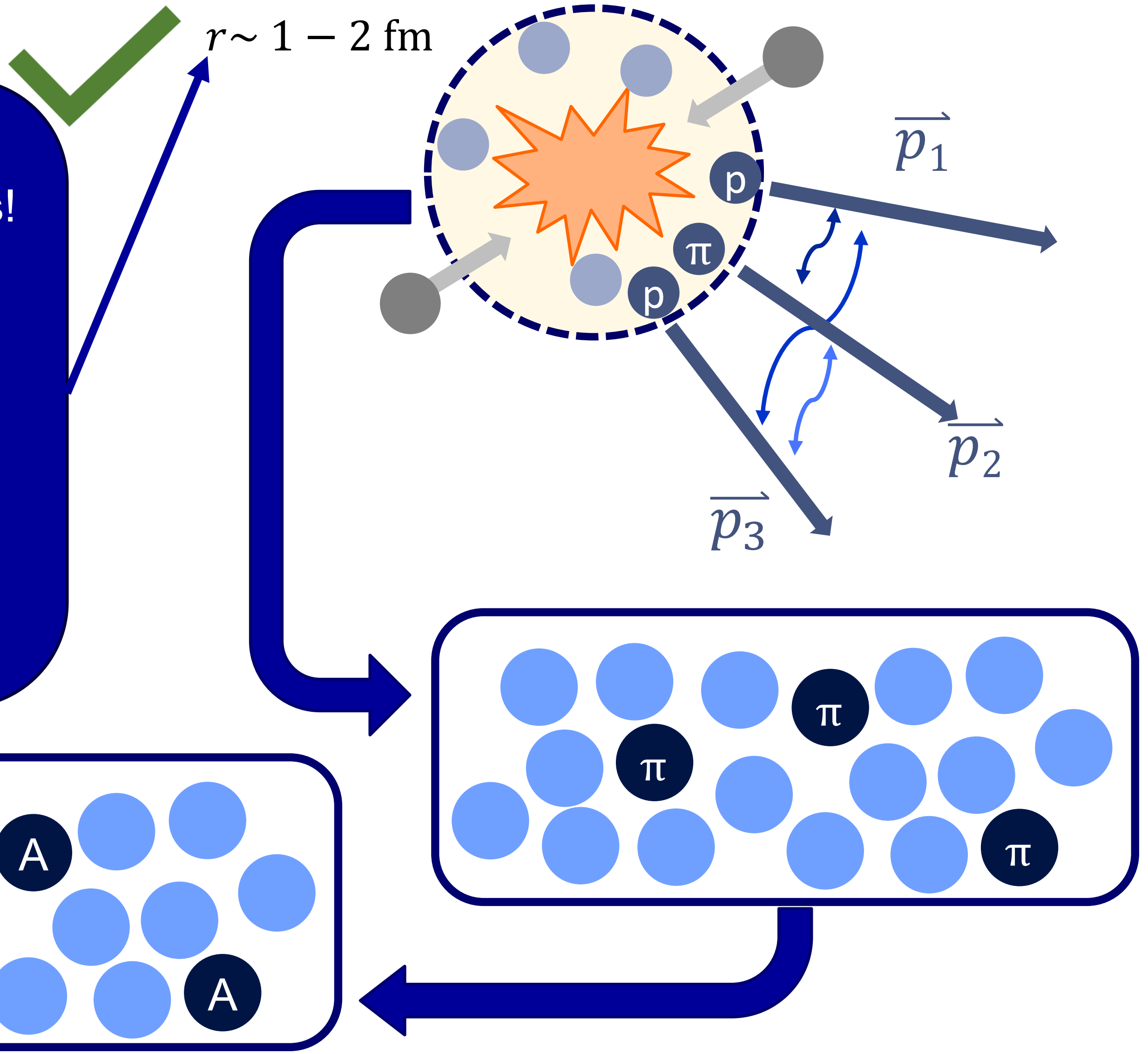
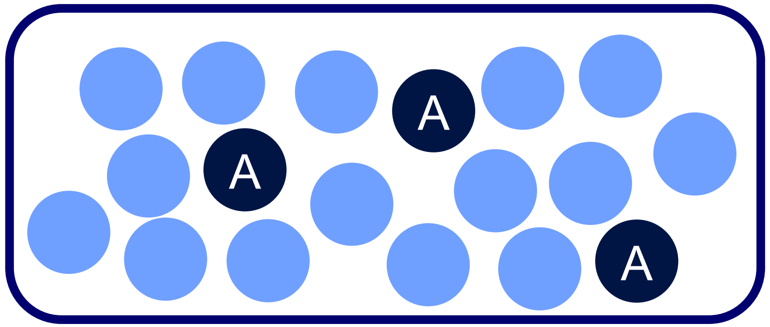
On today's menu

Emission at small distances for $p\pi^{\pm}$ systems!

Common source scaling observed in meson-meson, meson-baryon, and baryon-baryon systems
→ Common emission source for all hadrons





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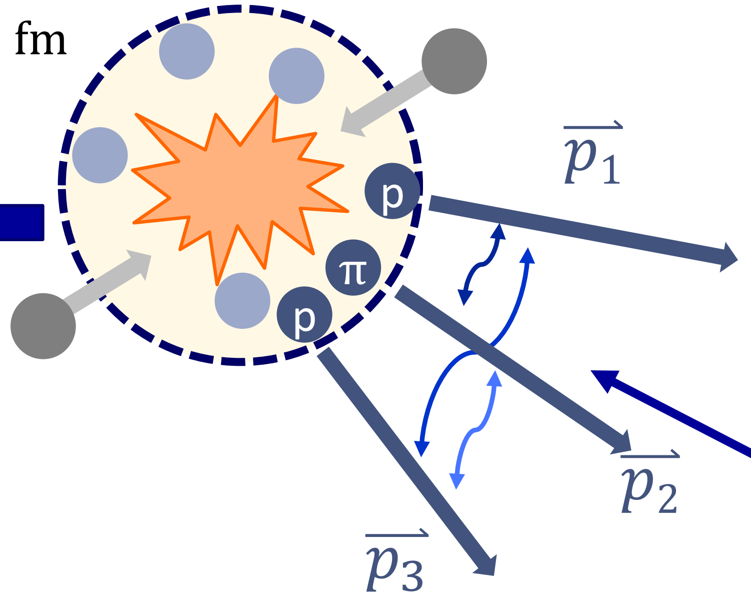
$r \sim 1-2$ fm



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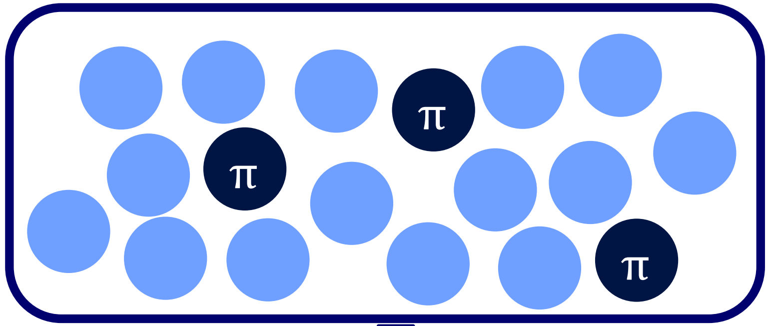
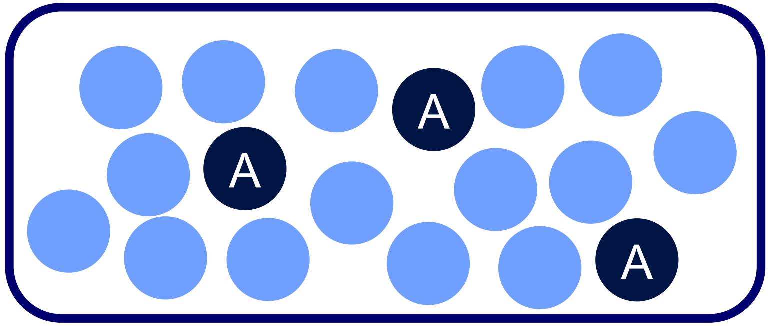


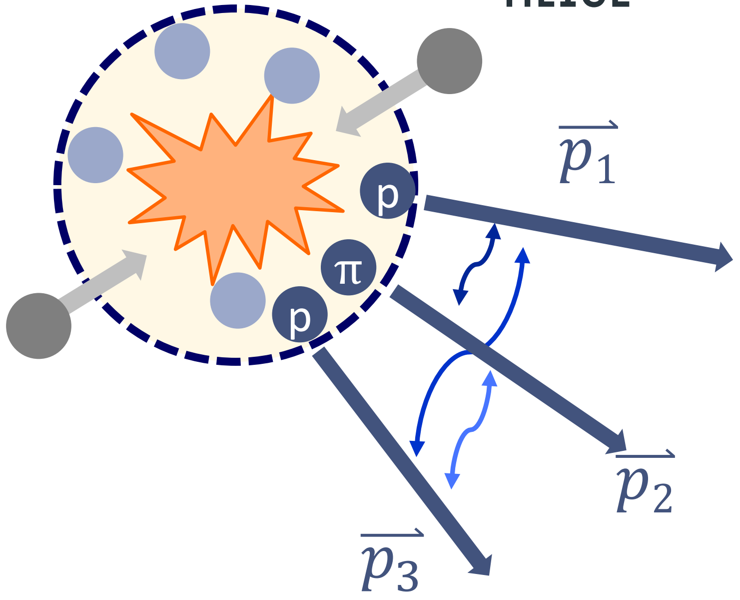


Three-particle femtoscopy

- Pair relative momentum not applicable in three-body system
  → Use Lorentz-invariant hyper-momentum Q_3

$$Q_3 = \sqrt{-q_{12}^2 - q_{23}^2 - q_{13}^2}$$

ALICE, PRC 89 (2014) 2, 024911



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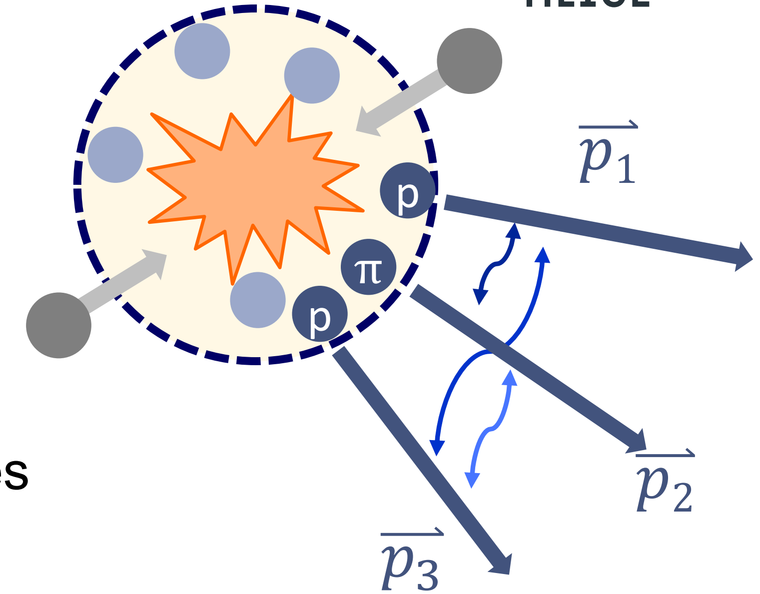
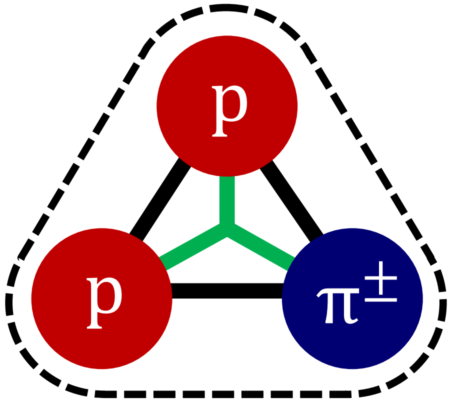


- Three-particle correlation functions: 3 → 3 scattering processes



$$C(Q_3) = \mathcal{N}\frac{N_{same}(Q_3)}{N_{mixed}(Q_3)}$$

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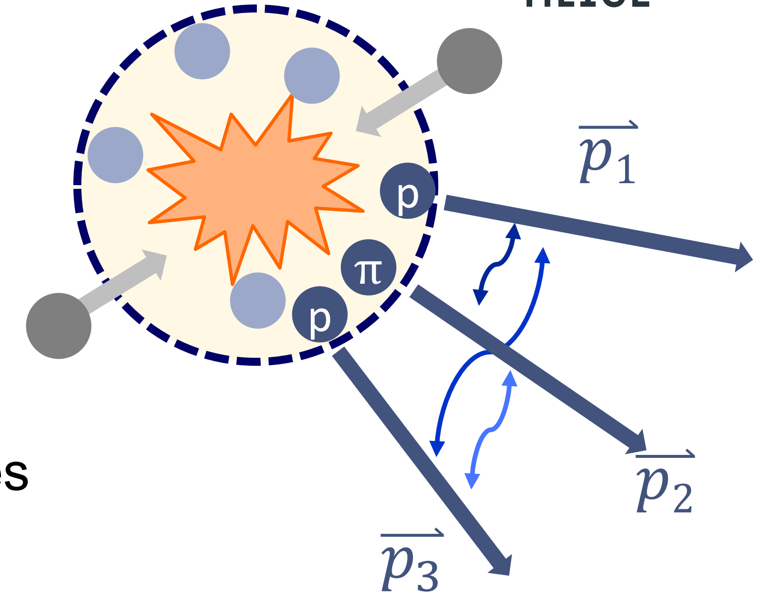

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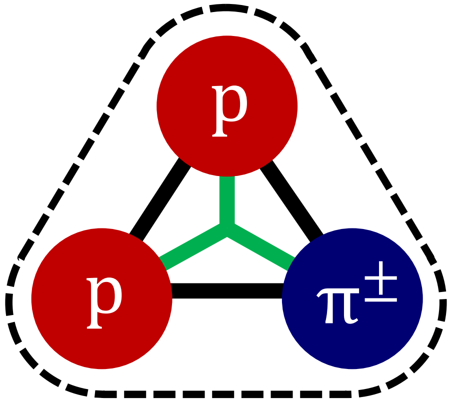


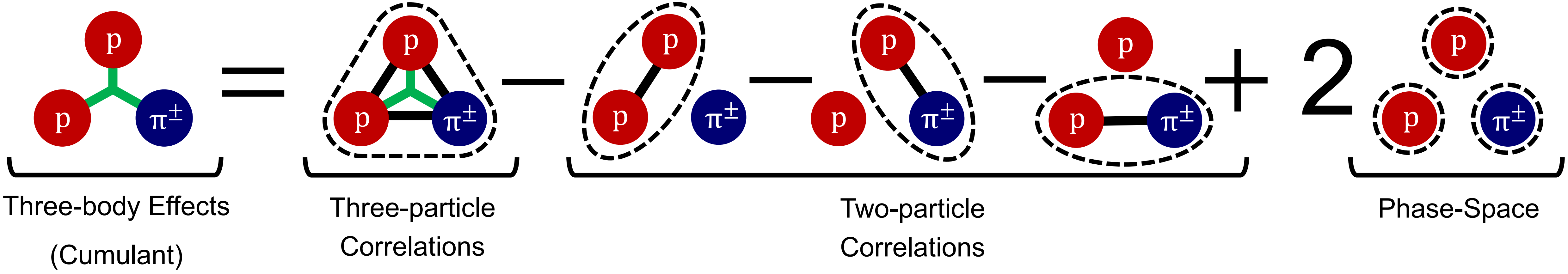
$$C(Q_3) = \mathcal{N} \frac{N_{\text{same}}(Q_3)}{N_{\text{mixed}}(Q_3)}$$

- Challenge of isolating three-body effects
  → Effects of two-body and potential three-body interactions in the system

Smoking guns of three-body interactions

- Cumulant decomposition:

R. Kubo, Journal of the Physical Society of Japan 17 no. 7, (1962) 1100–1120



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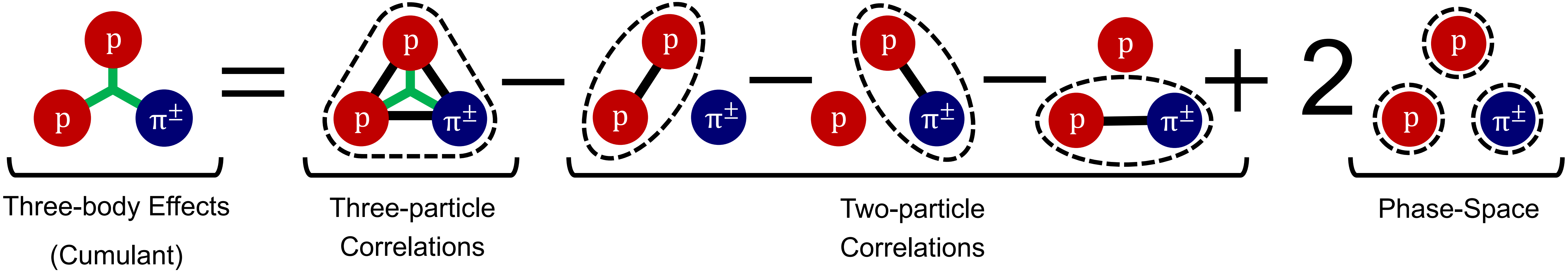
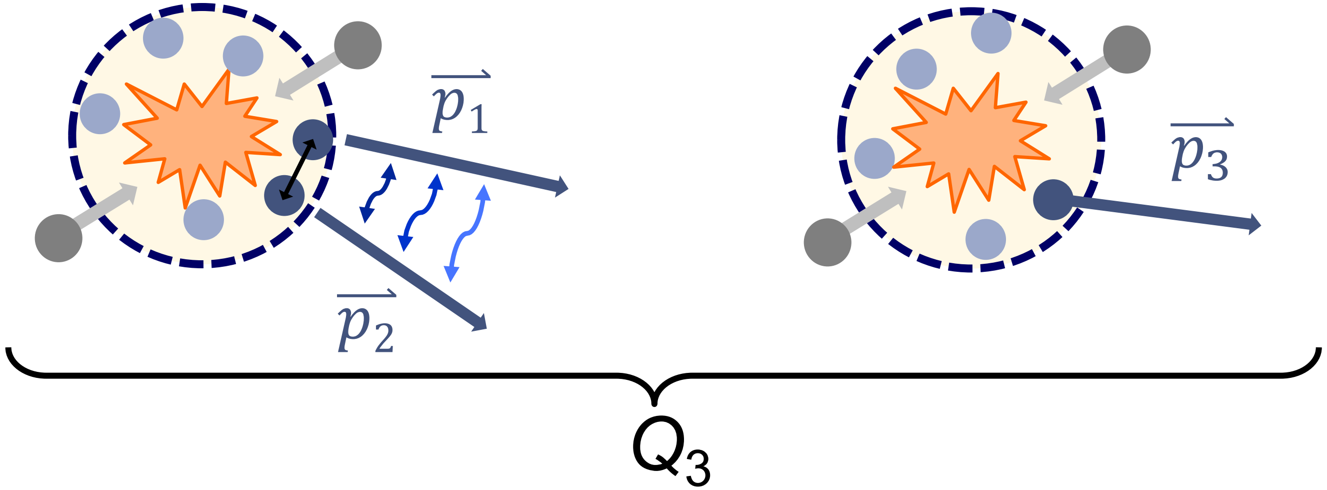
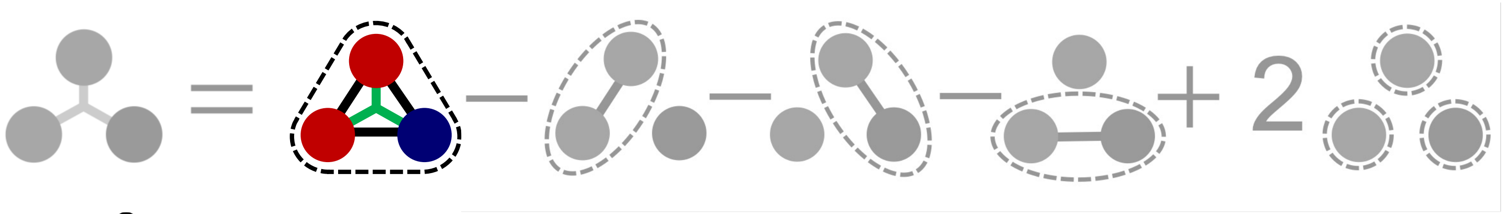


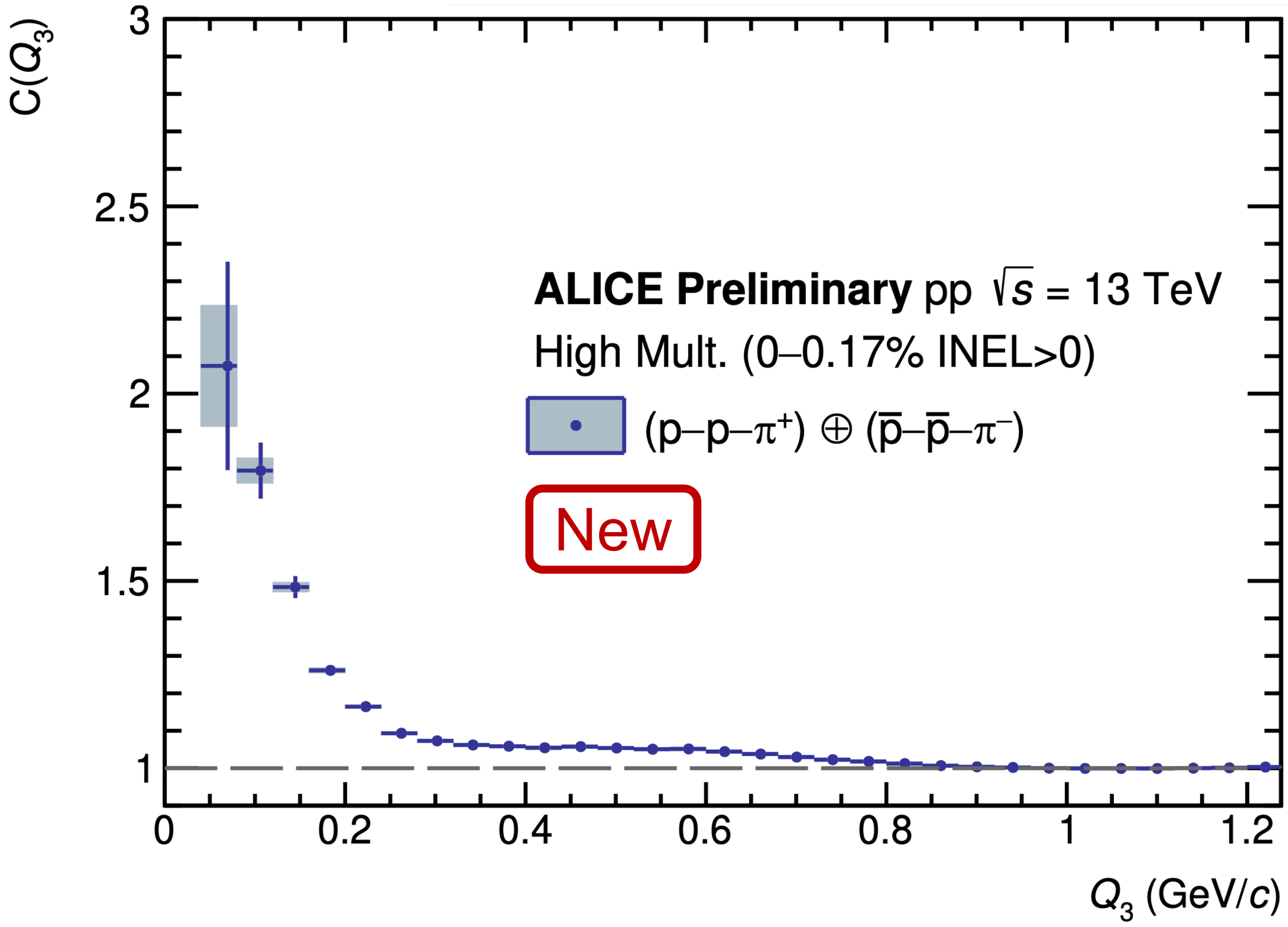
- Lower-order contributions estimated in a data-driven way using the same- and mixed-events distributions



Three-particle correlation function of $pp\pi^+$

- Overall attractive effects in triplet correlation function
- Signal consisting of two-body and potential three-body effects





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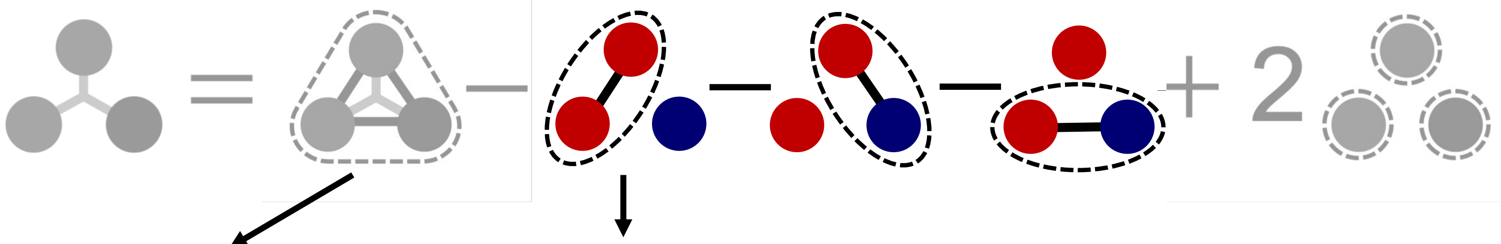
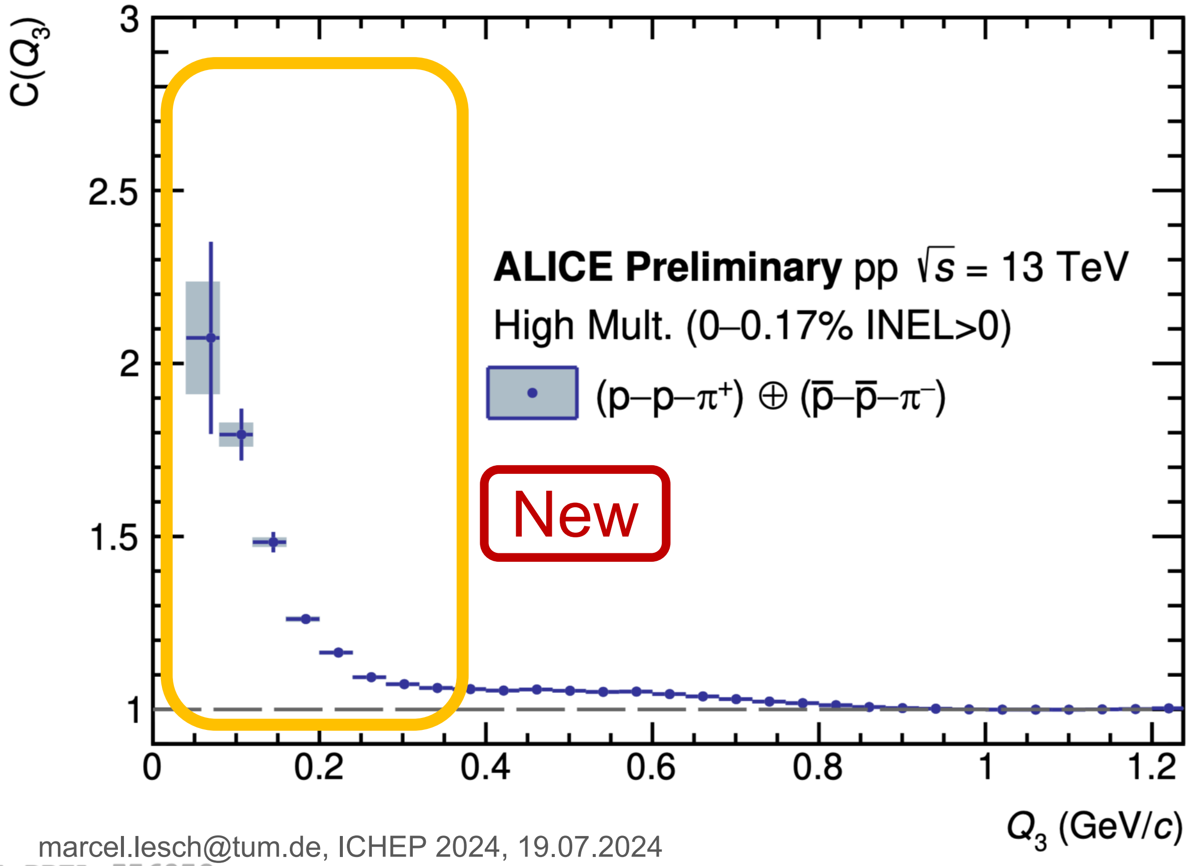
Two-particle contributions of $pp\pi^+$

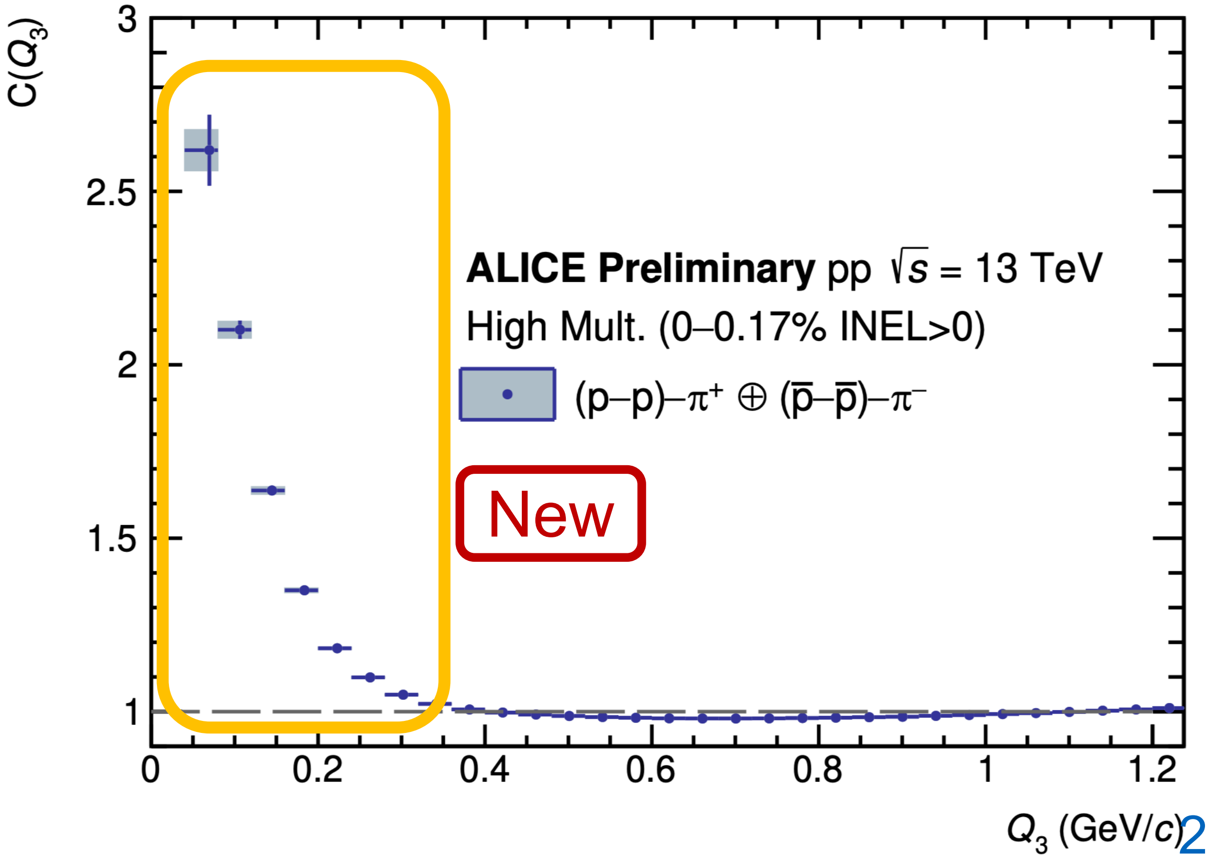
- Contribution from attractive strong interaction of pp



Three-Particle

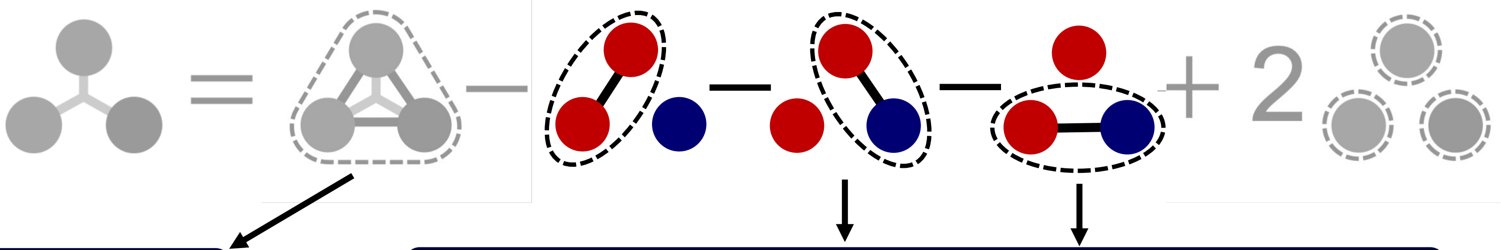


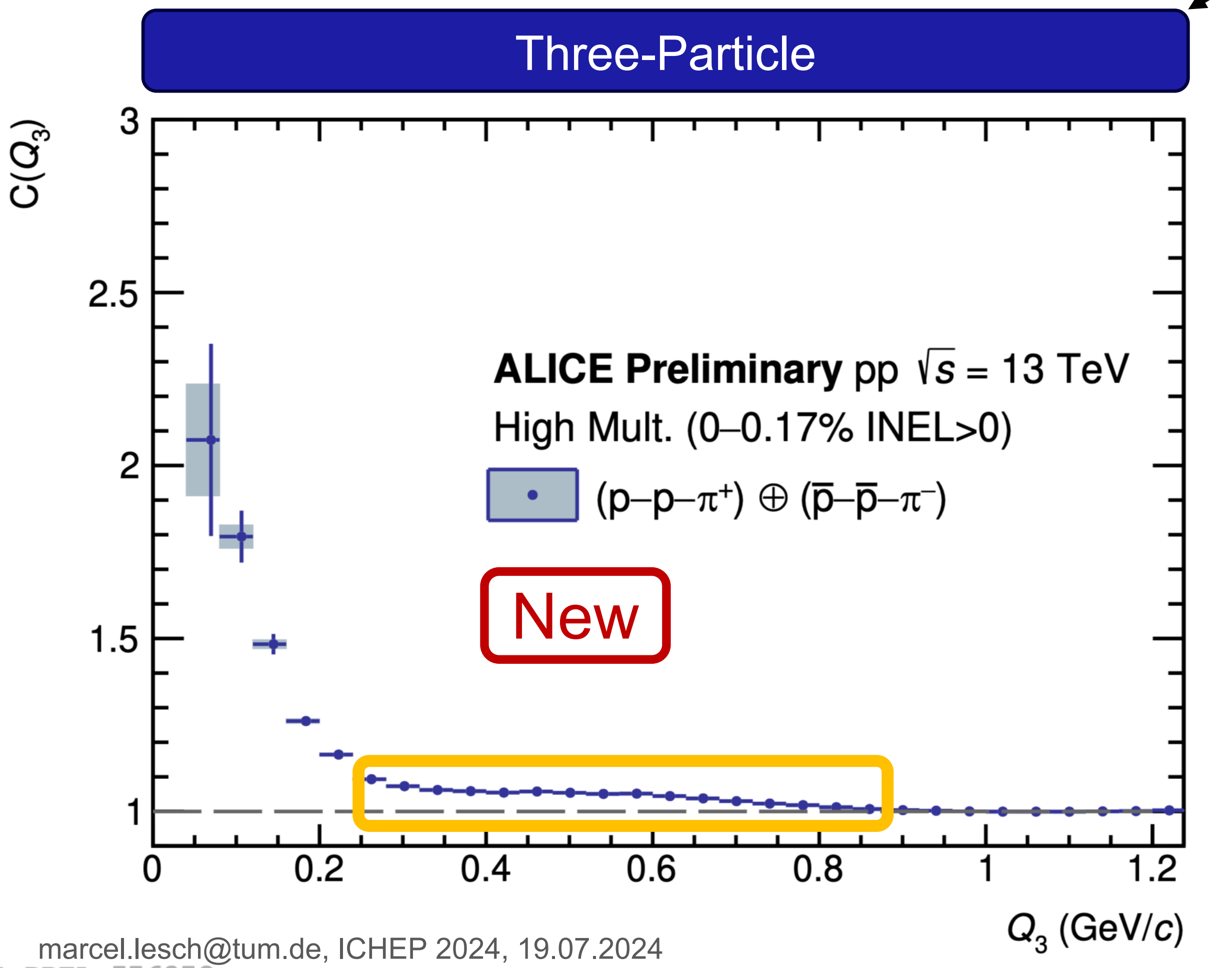
Lower-Order

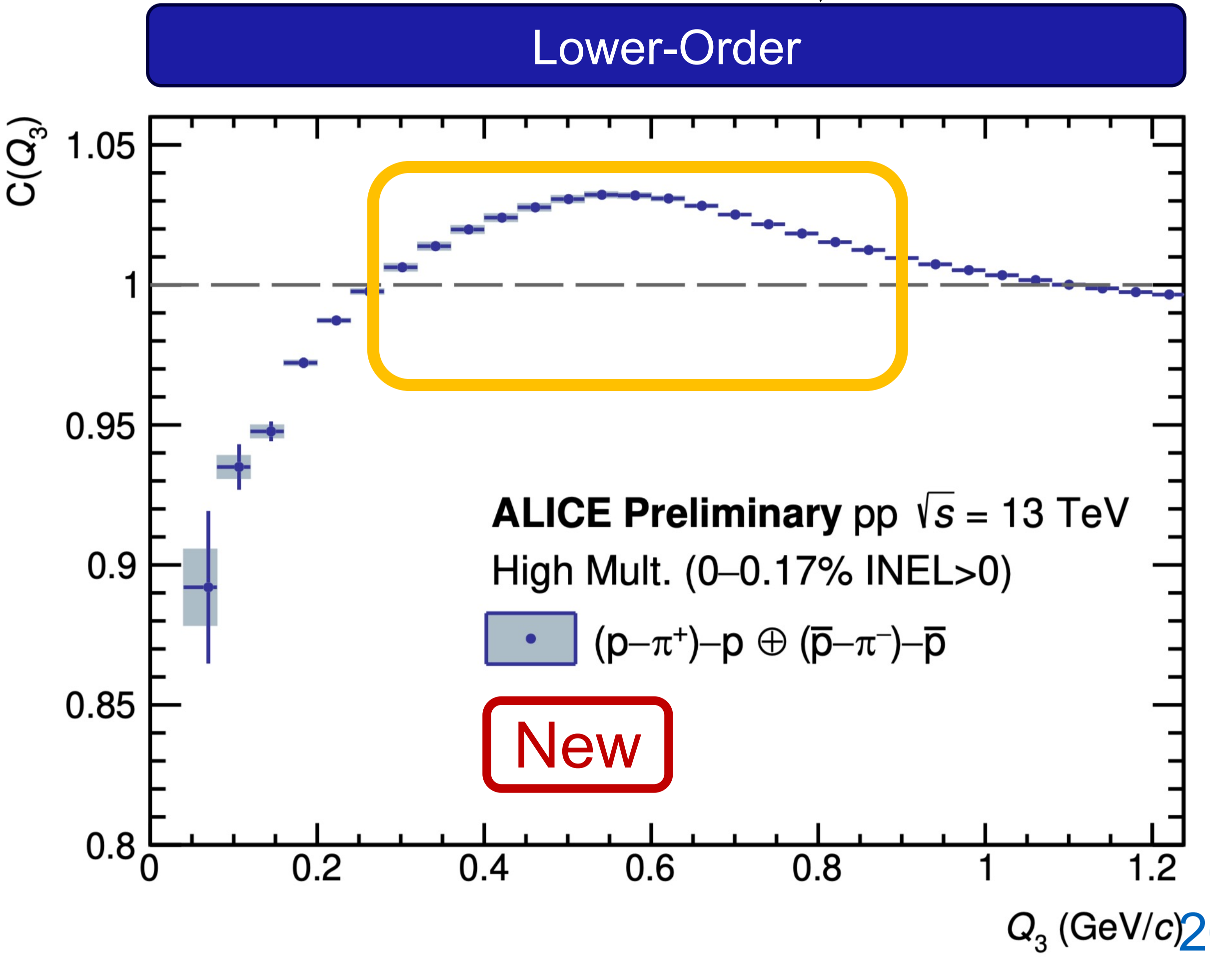


Two-body contributions of $pp\pi^+$

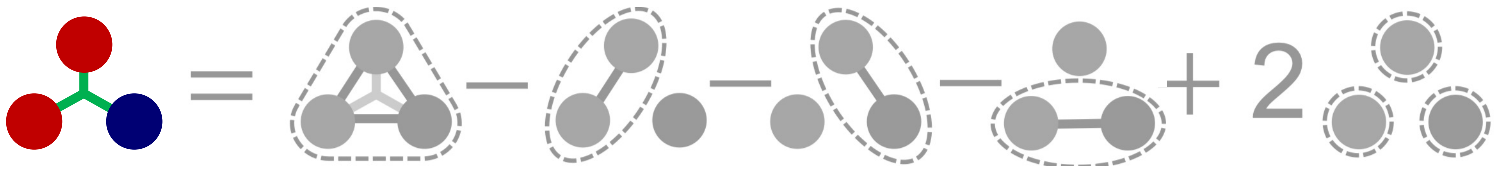
- Visible contribution from $\Delta^{++}(1232) \rightarrow p\pi^+$

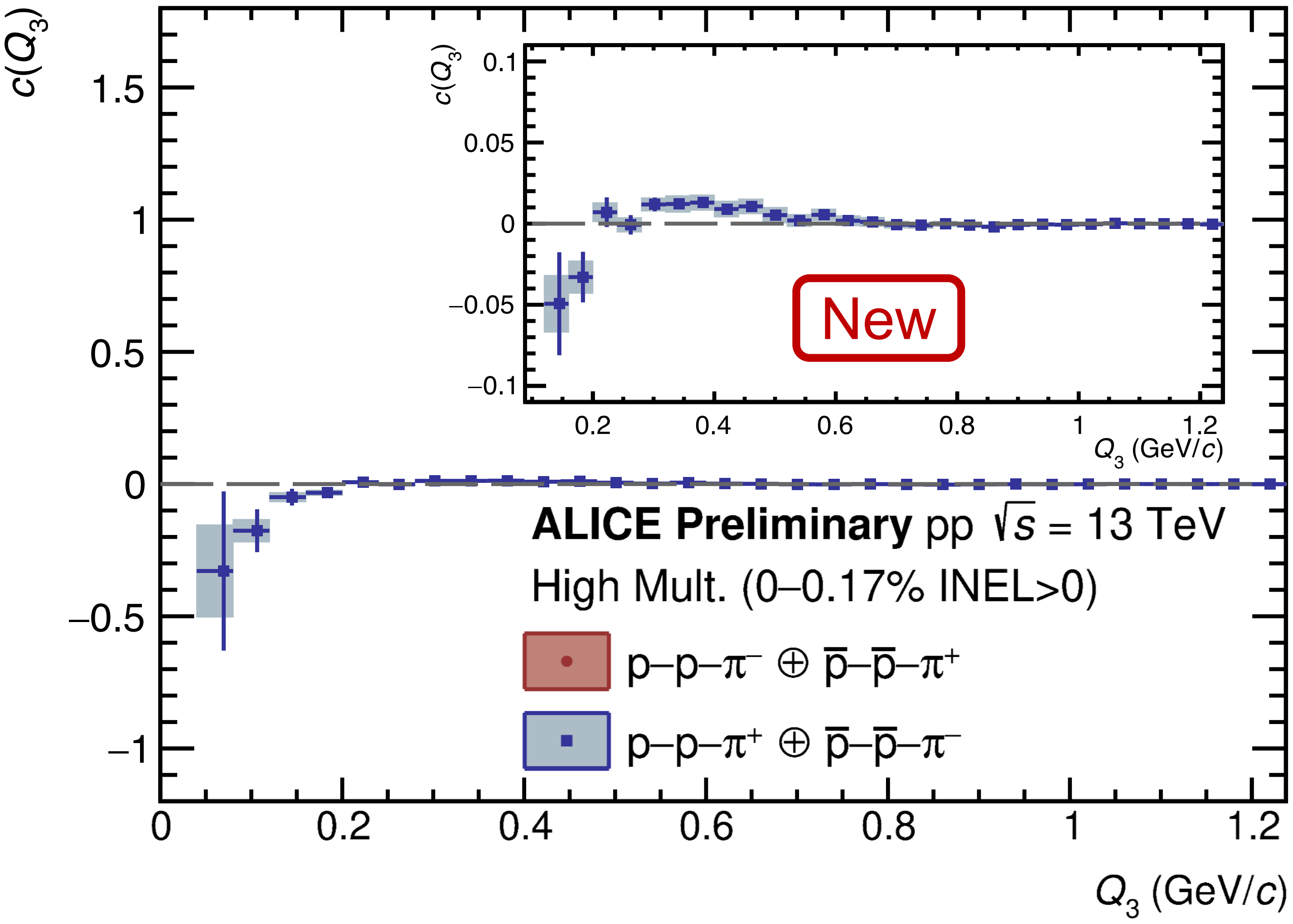






Three-body effects in ppπ$^{\pm}$





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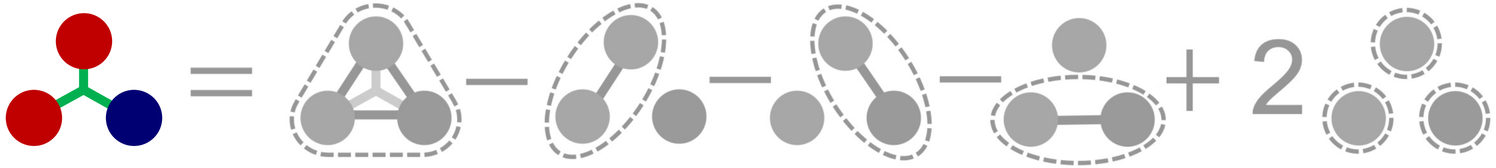
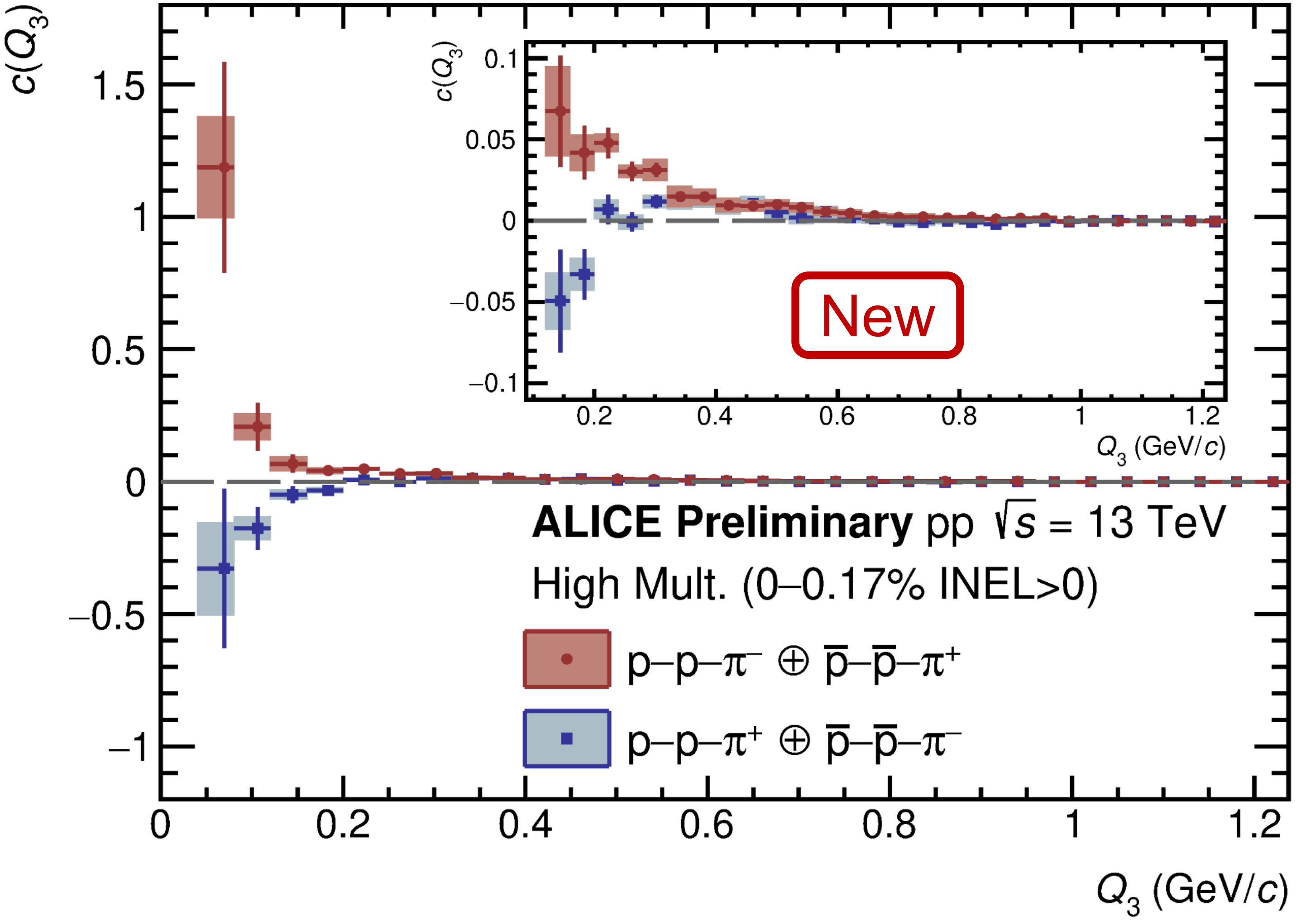
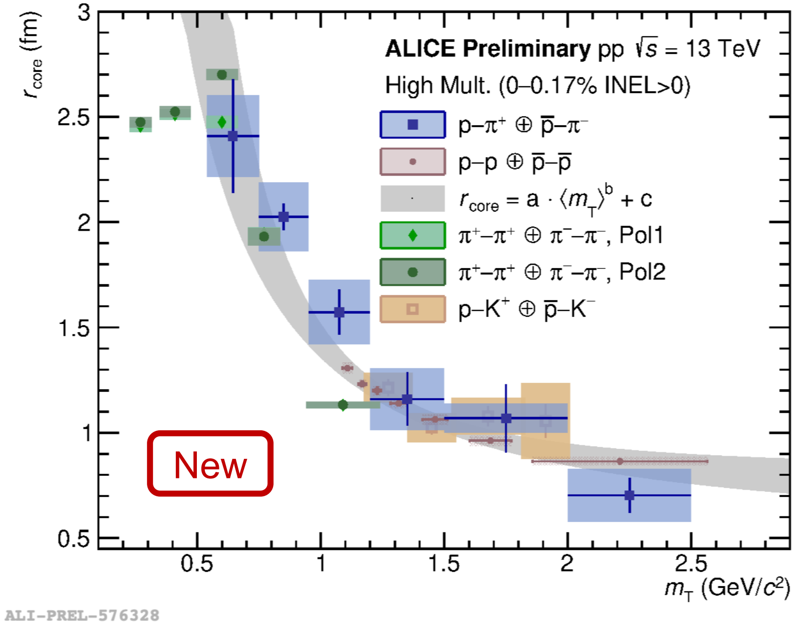
Three-body effects in $pp\pi^{\pm}$

- In both cases cumulant compatible with zero for large Q_3
  → No three-body effects
- Three-body effects for small Q_3< 200 MeV/*c*
  - Repulsion for $pp\pi^{+}$
  - Attraction for $pp\pi^{-}$



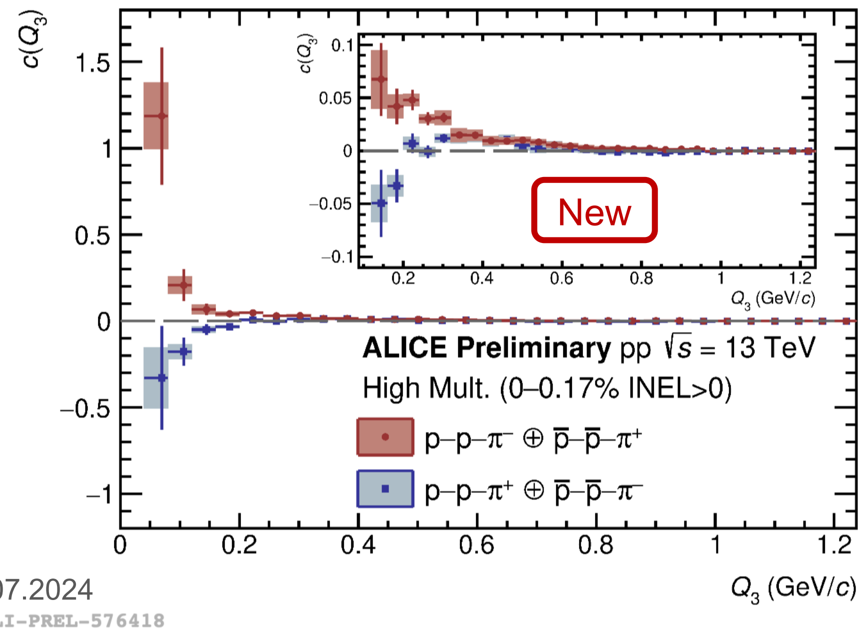


What to take home



Common hadron emission source in pp collisions at the LHC

ALICE can access $3 \rightarrow 3$ scattering processes of $pp\pi^{\pm}$



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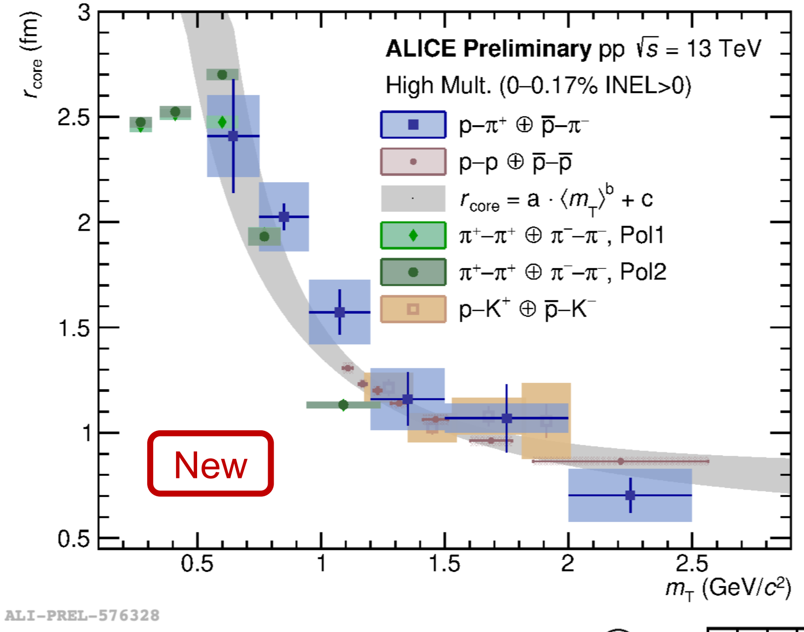

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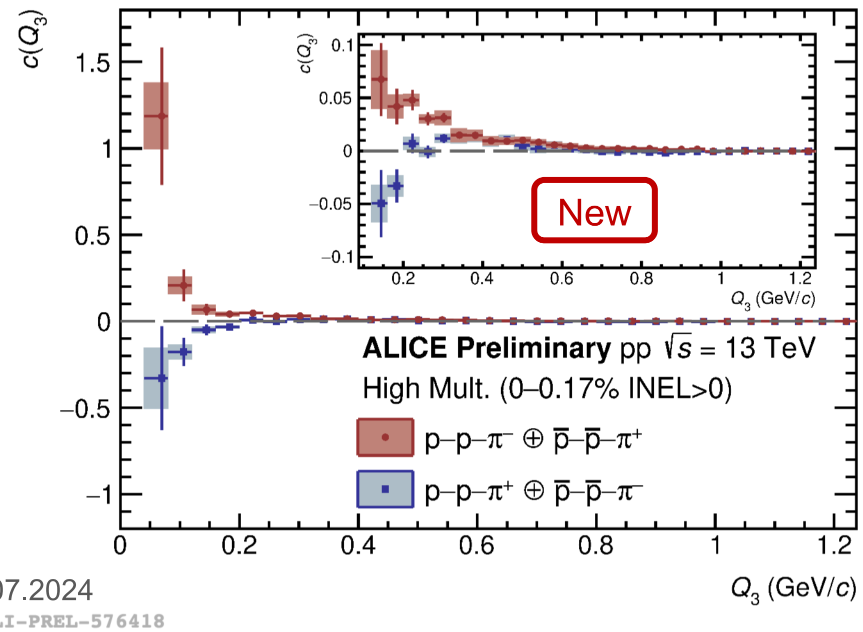
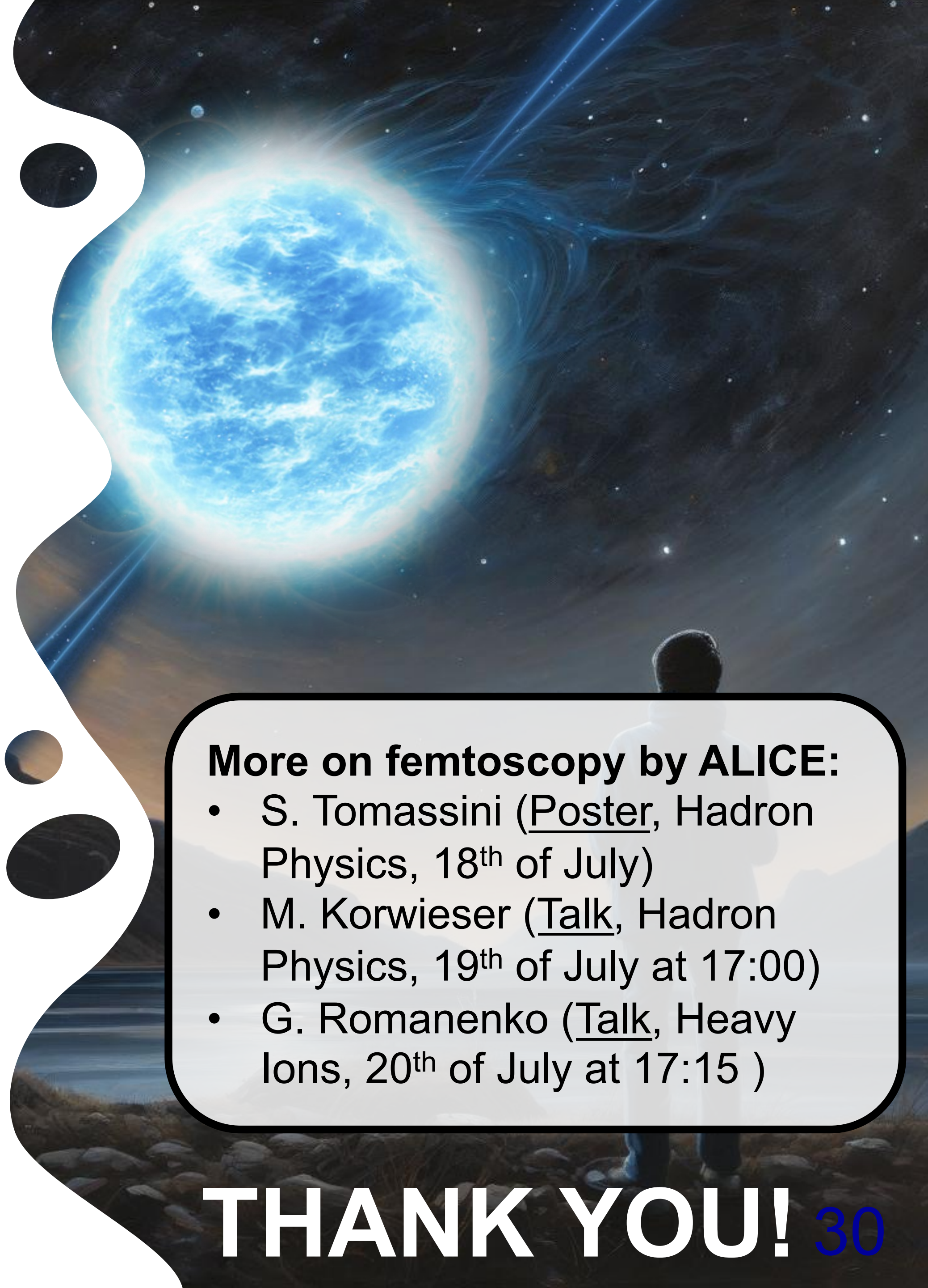




More on femtoscopy by ALICE:

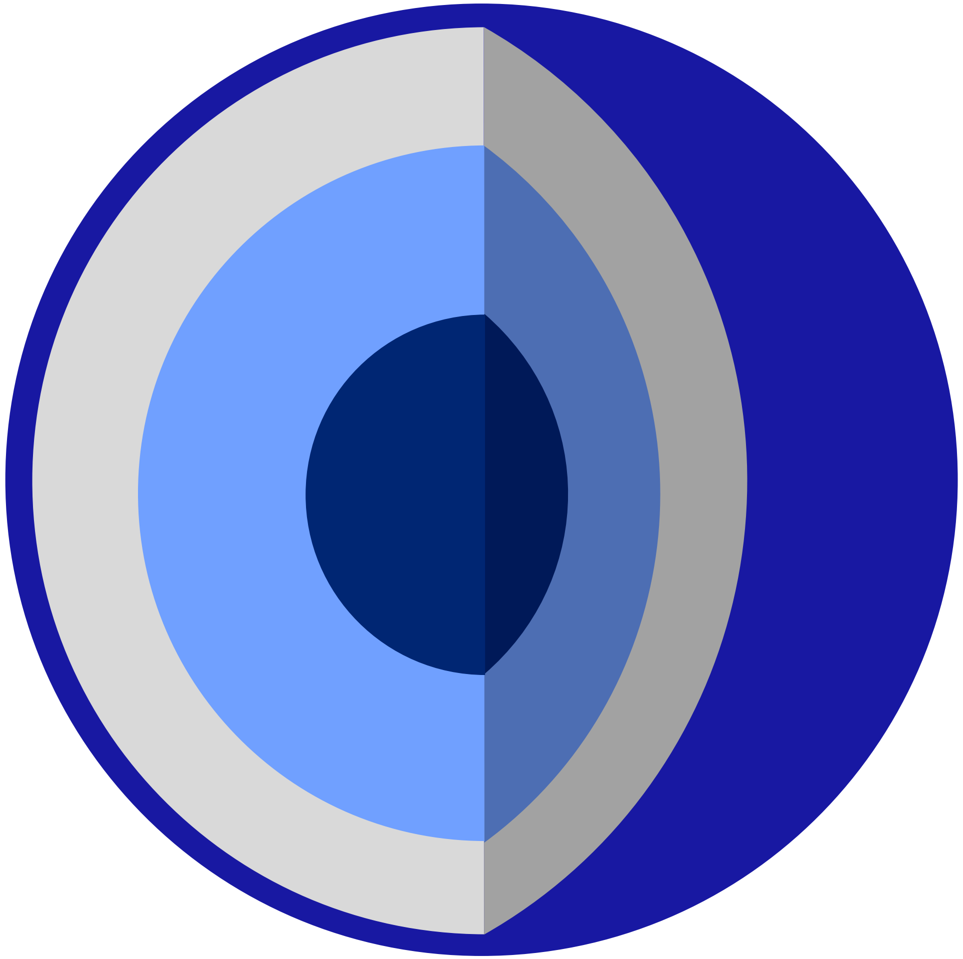
- S. Tomassini (Poster, Hadron Physics, 18th of July)
- M. Korwieser (Talk, Hadron Physics, 19th of July at 17:00)
- G. Romanenko (Talk, Heavy Ions, 20th of July at 17:15)

THANK YOU!

Backup

Neutron Stars

- Final product of supernova explosions
- Very compact objects:
  - $M \approx 1\text{-}2\ M_{\odot}$
  - R ≈ 10-15 km (~ size of Munich area!)



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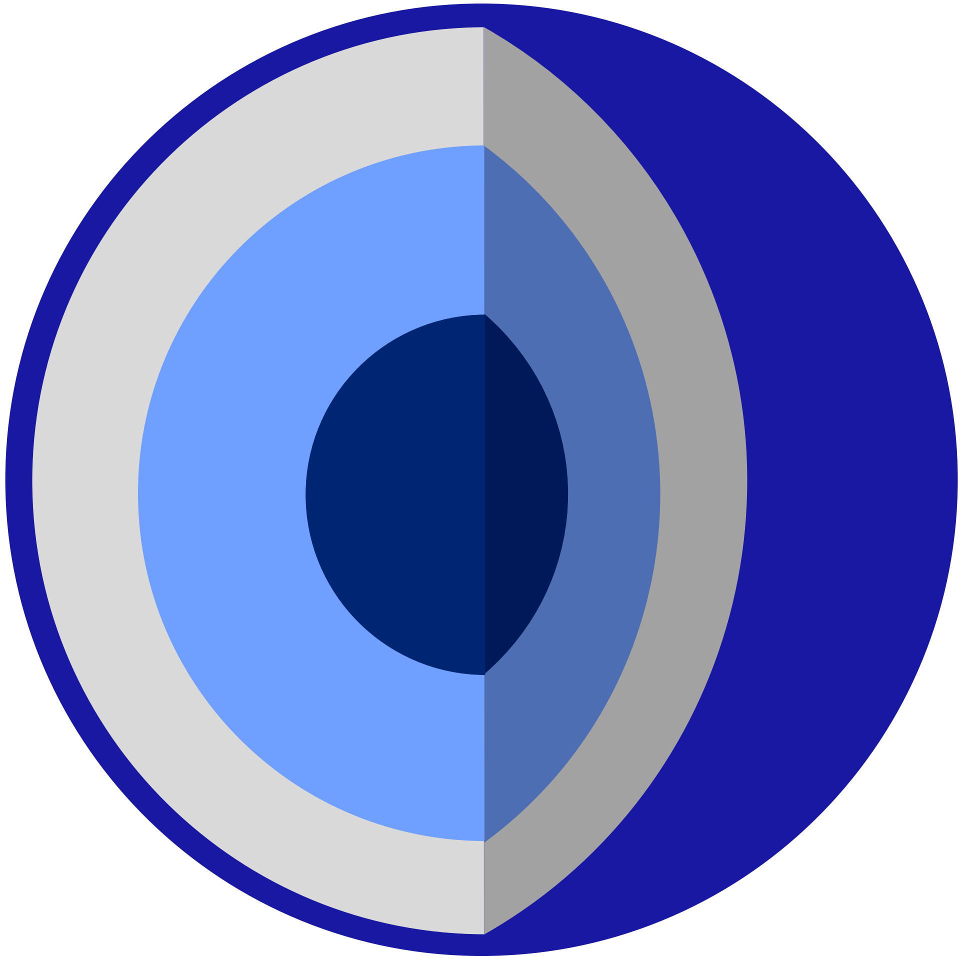
- Very dense and rather cold objects:
  - extreme densities of several ρ_0
  - T_{max} ~ few MeV



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- Very dense and rather cold objects:
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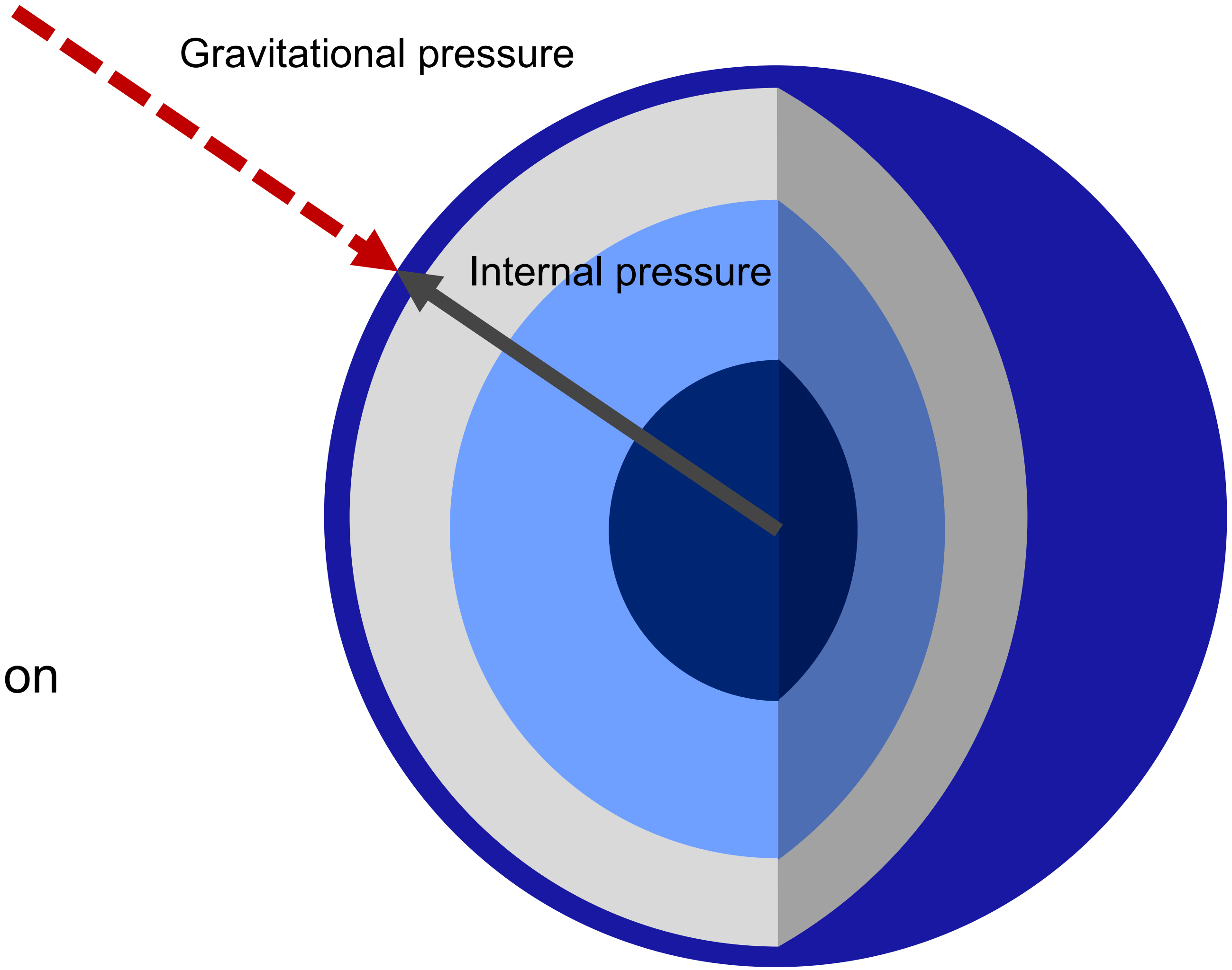
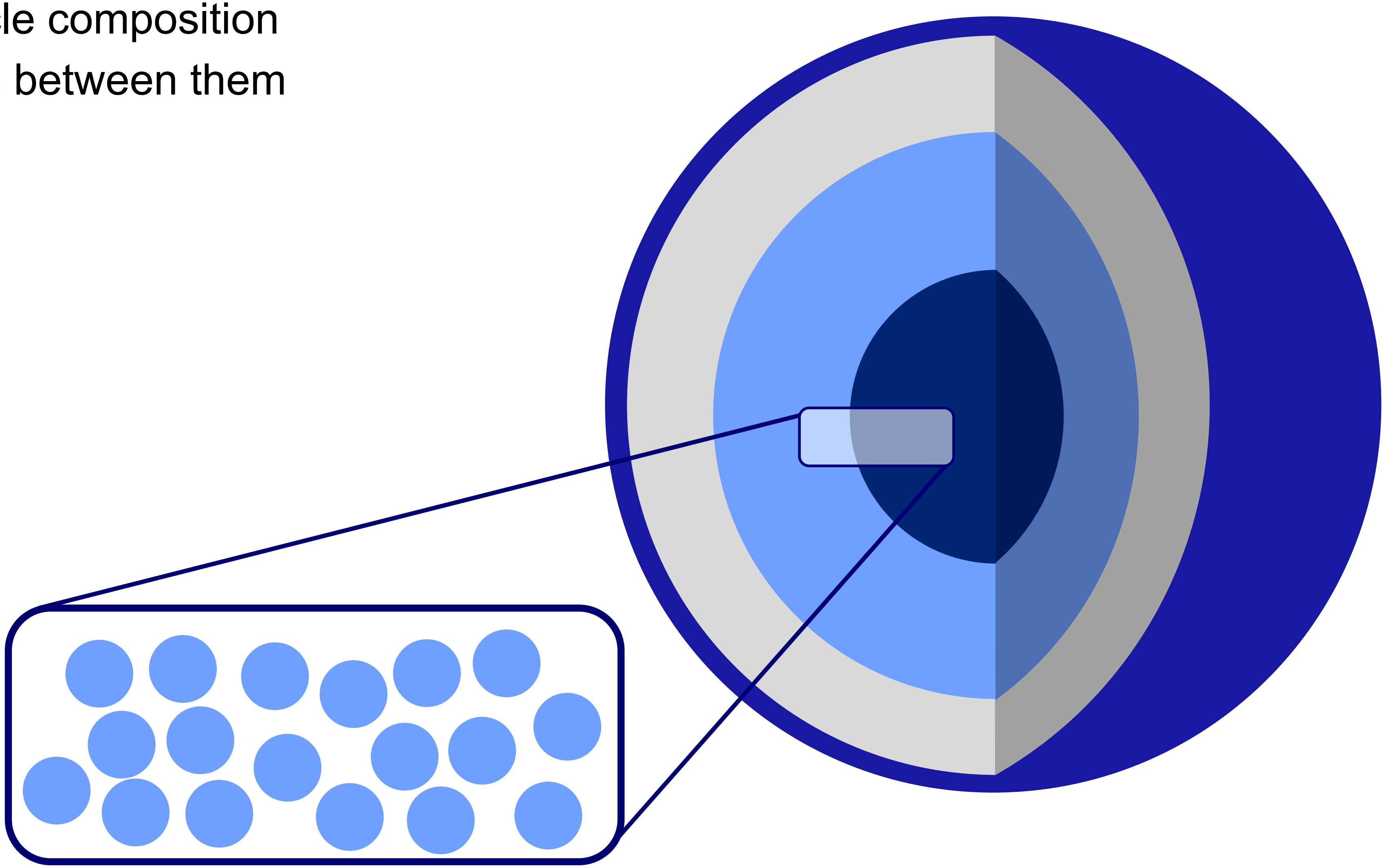
- Physics of neutron stars driven by their equation of state (EoS)



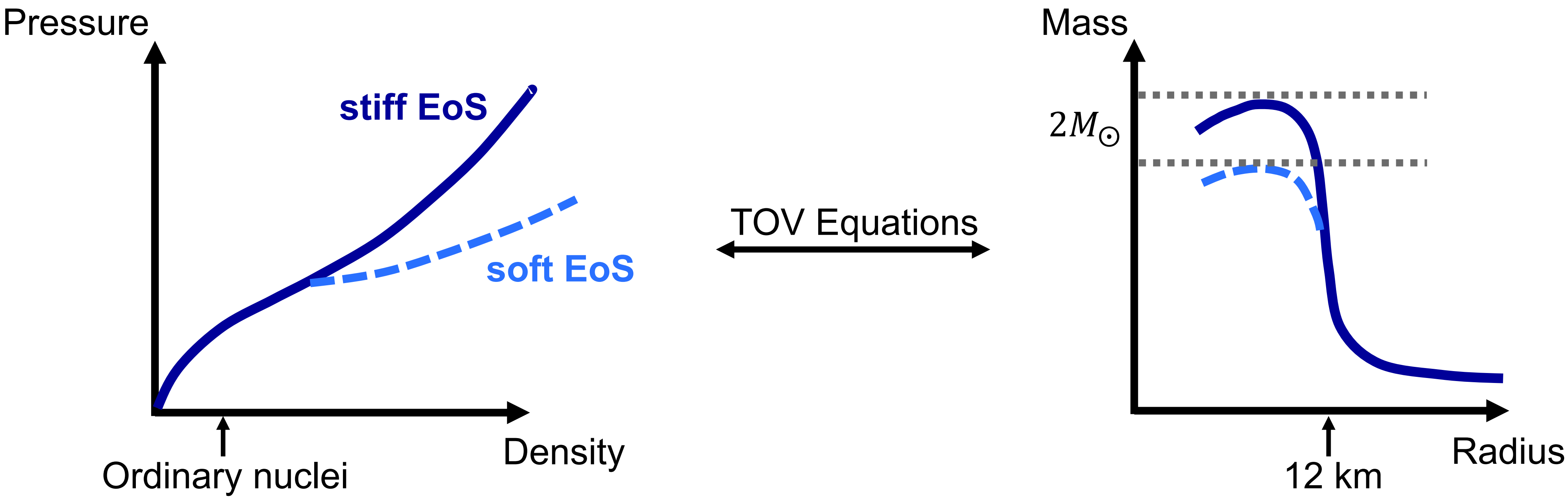
Neutron Stars

- EoS dependent on the particle composition and the possible interactions between them



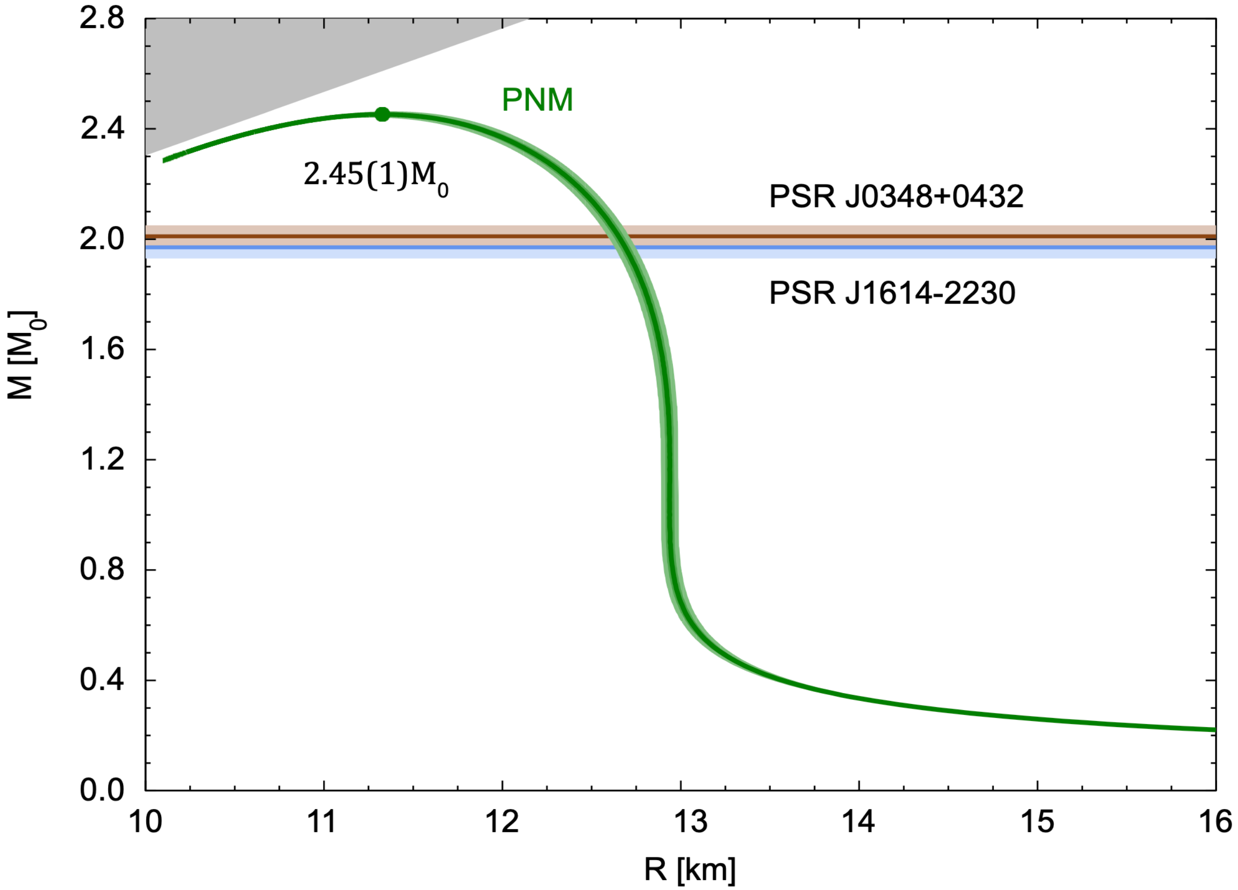
Neutron Stars

- EoS dependent on the particle composition and the possible interactions between them
- EoS linked to masses and radii of neutron stars via TOV equations



Neutron Stars

- EoS dependent on the particle composition and the possible interactions between them
- EoS linked to masses and radii of neutron stars via TOV equations
- Pure neutron matter (PNM) supports heavy neutron stars of $2M_{\odot}$

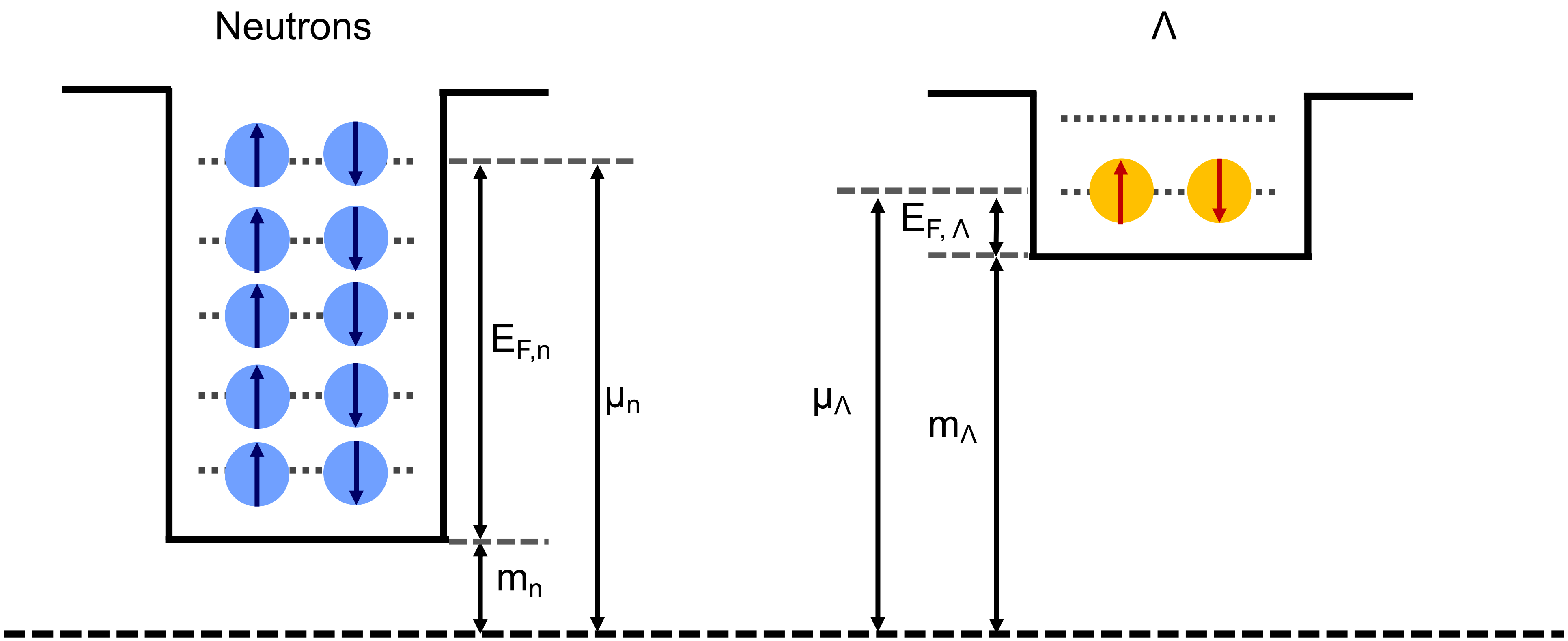


Adapted from D. Lonardoni et al., PRL 114, 092301 (2015)

Neutron Stars and the Hyperon Puzzle

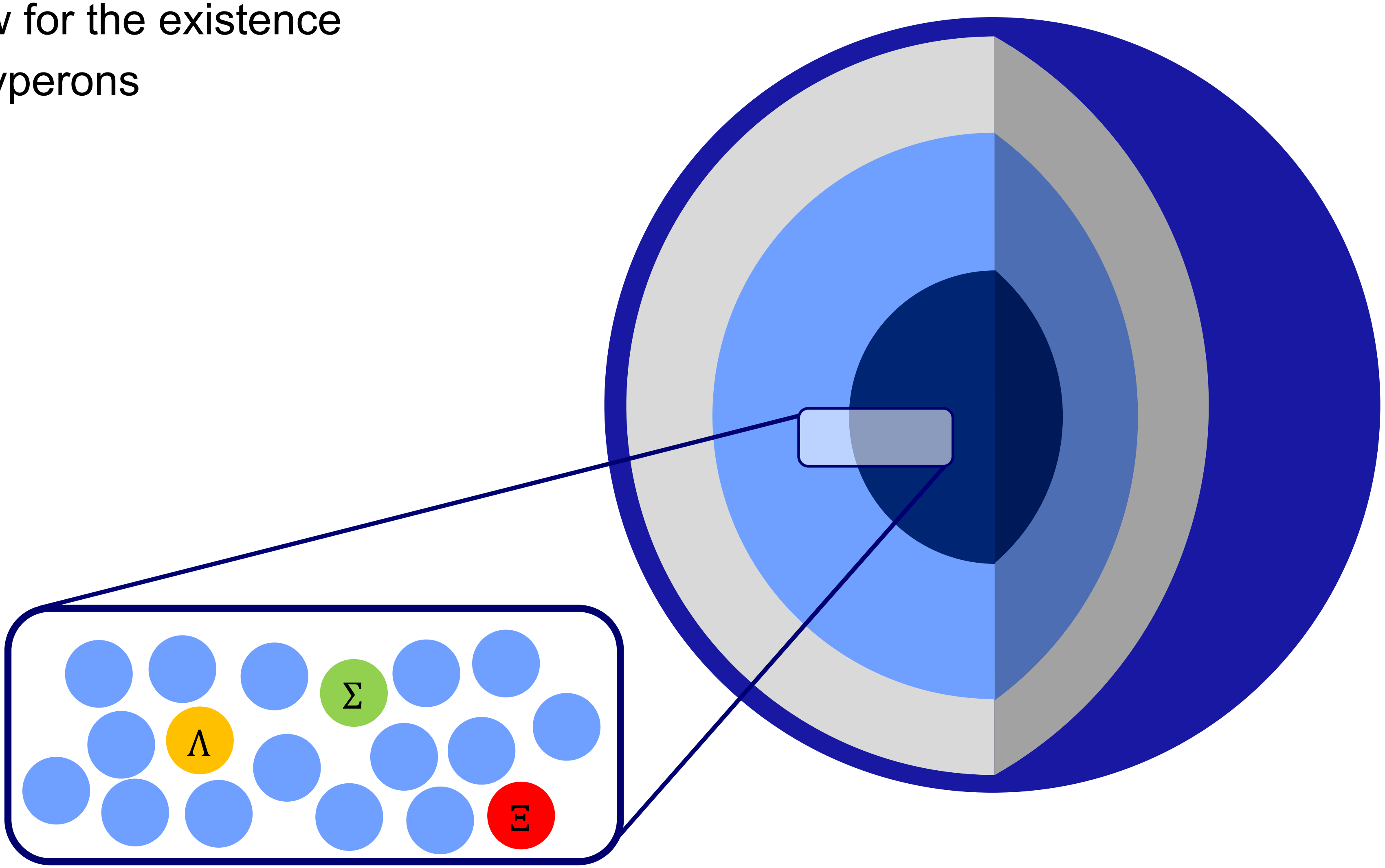
- Chemical potential μ = m + Fermi energy
- Fermi energy increases with density

→ $\mu_n = \mu_\Lambda$: conversion into baryons with strangeness (hyperons)



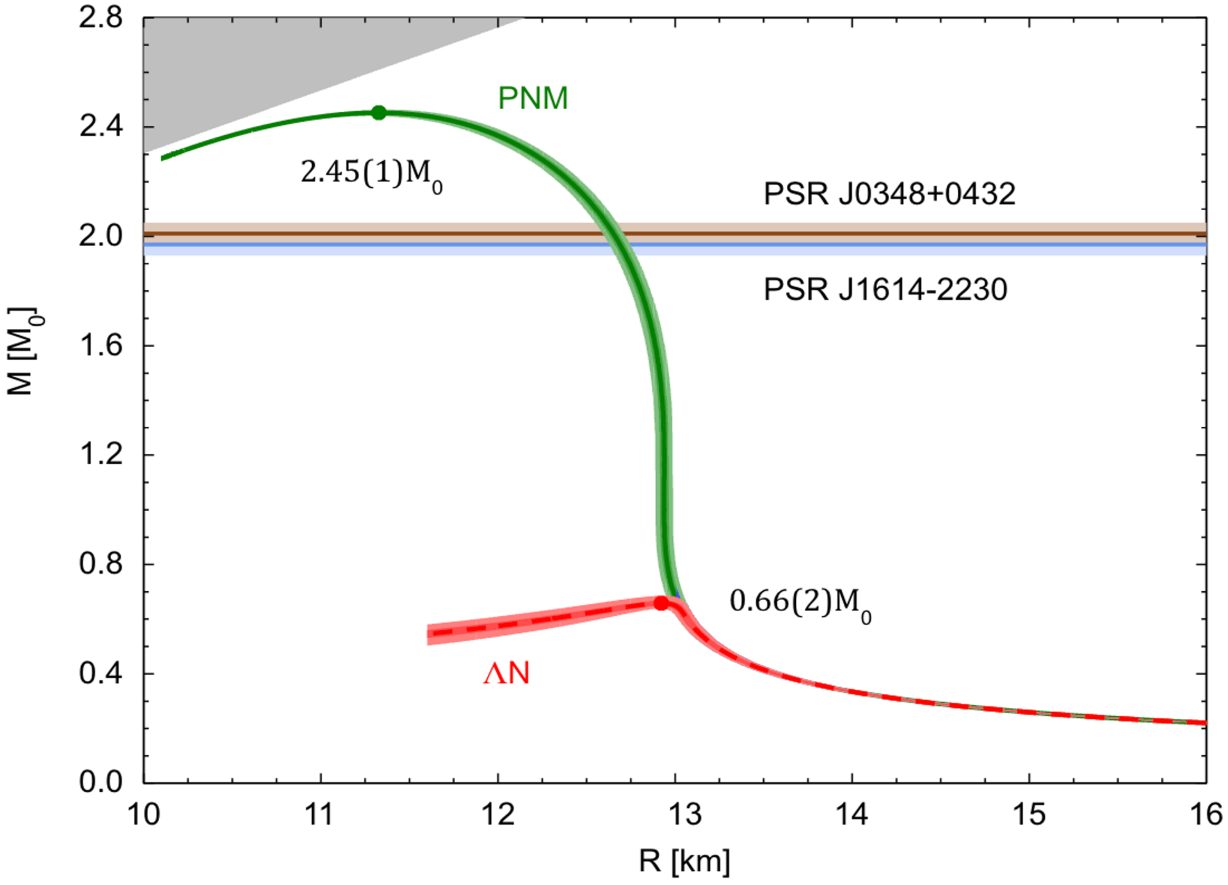
Neutron Stars and the Hyperon Puzzle

- High baryonic densities allow for the existence of strange particles, e.g. Λ hyperons



Neutron Stars and the Hyperon Puzzle

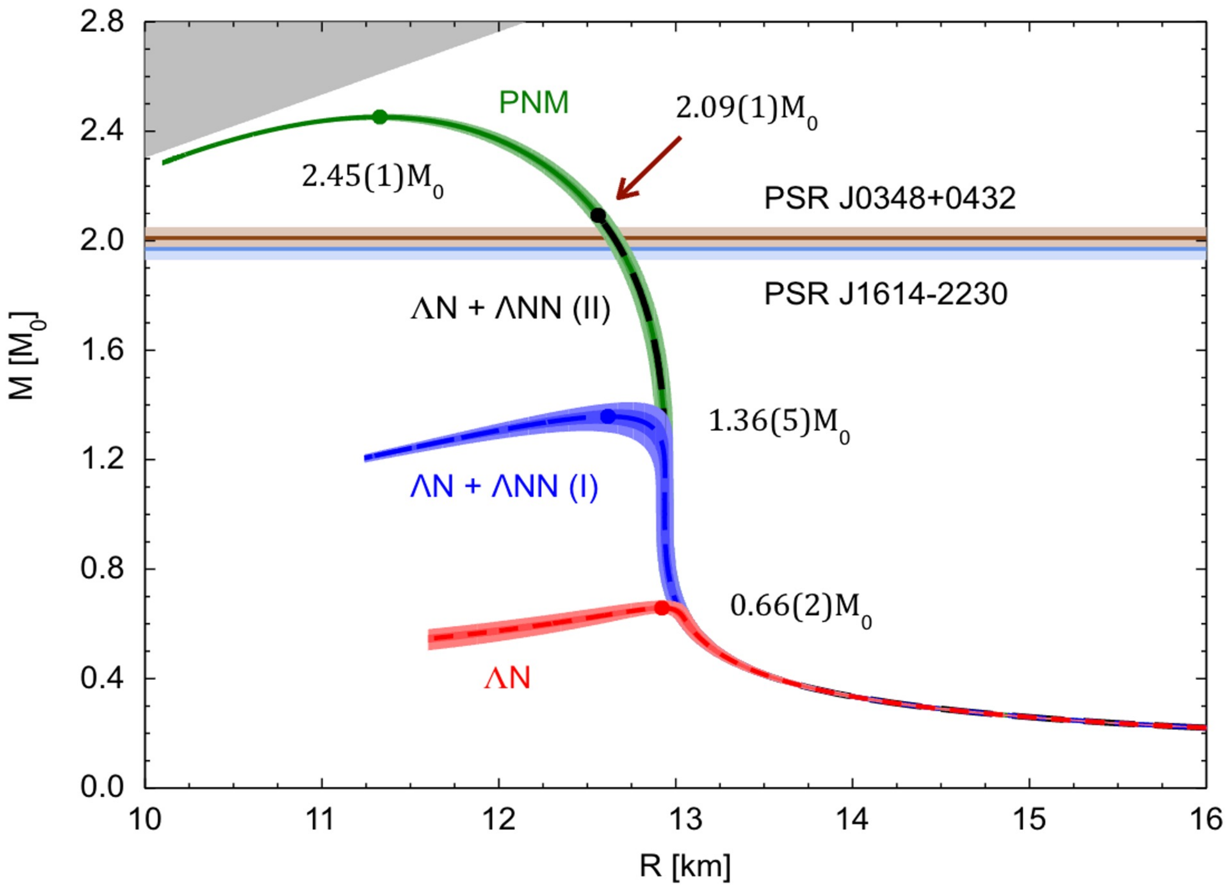
- High baryonic densities allow for the existence of strange particles, e.g. Λ hyperons
- However: EoS softens with appearance of Λ hyperons
  → cannot support heavy neutron stars



Adapted from D. Lonardoni et al., PRL 114, 092301 (2015)

Neutron Stars and the Hyperon Puzzle

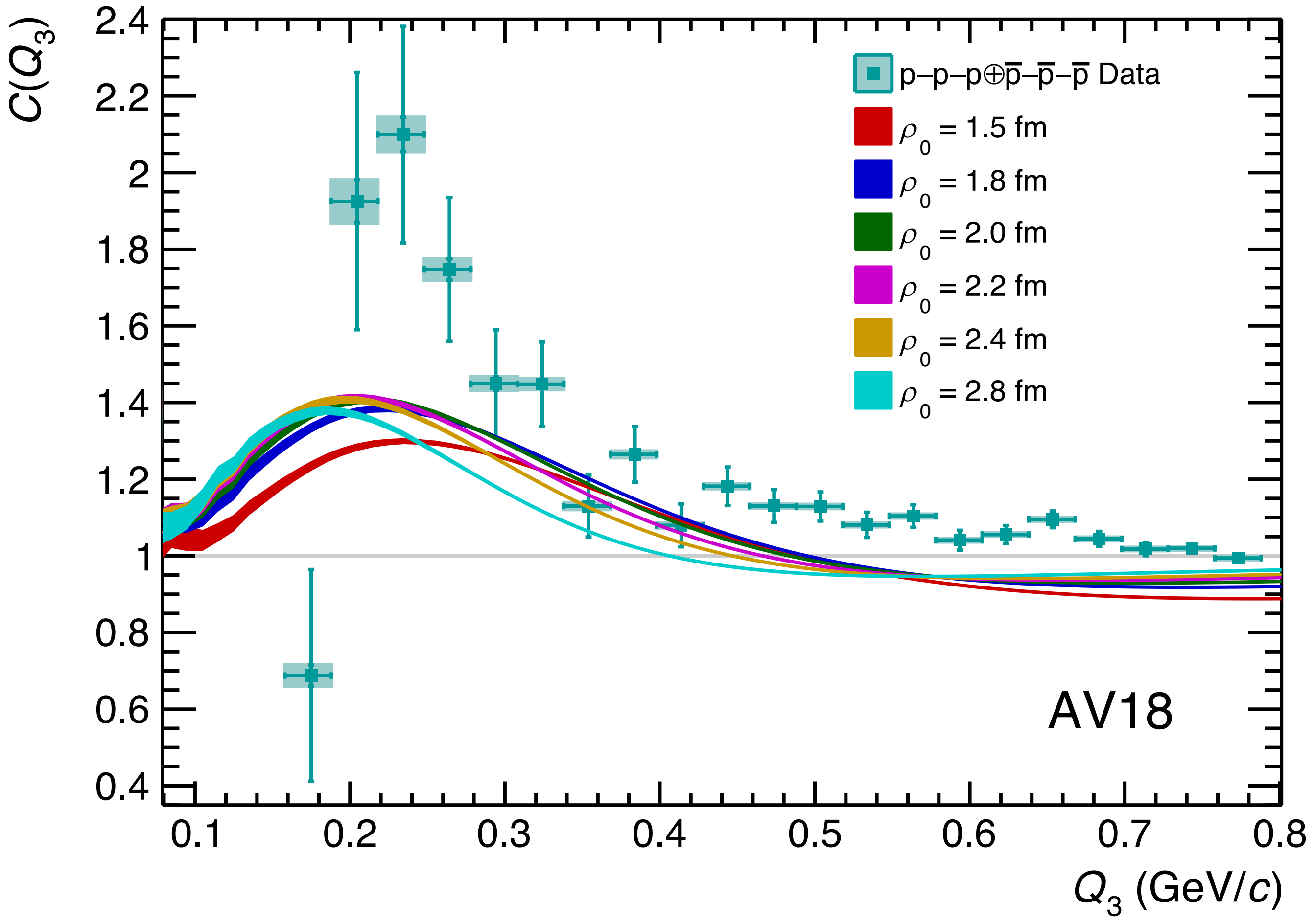
- High baryonic densities allow for the existence of strange particles, e.g. Λ hyperons
- However: EoS softens with appearance of Λ hyperons
  → cannot support heavy neutron stars
- Three-body interactions such as ΛNN play an important role



Adapted from D. Lonardoni et al., PRL 114, 092301 (2015)

Three-body hadronic interactions with ALICE

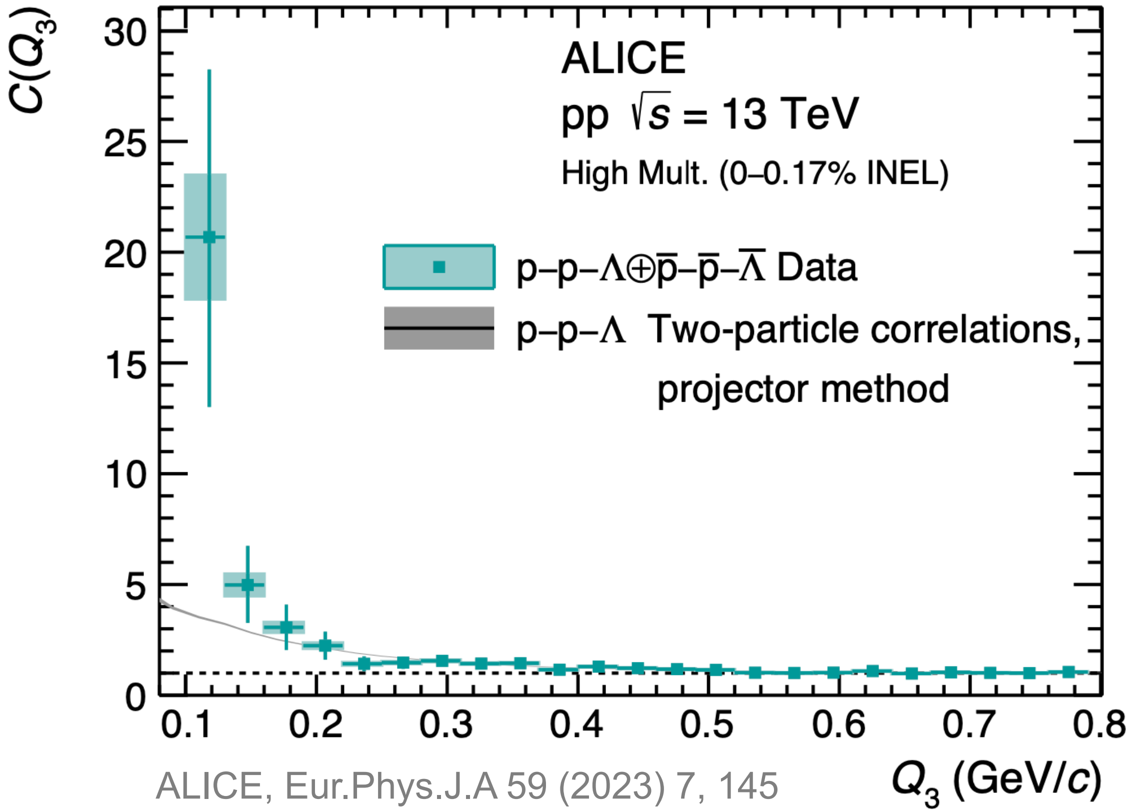
- Three-hadron interactions of ppp & $pp\Lambda$ are currently studied in ALICE with femtoscopy
  ALICE, Eur. Phys. J. A 59 (2023) 145
- Results of ppp from Run2 have first comparisons with theory
  A. Kievsky, E. Garrido, M. Viviani, L.E. Marcucci, L. Serksnyte, R. Del Grande, arXiv:2310.10428, accepted by PRC
- Calculations of $\mathrm{pp}\Lambda$ are currently on the way



A. Kievsky, E. Garrido, M. Viviani, L.E. Marcucci, L. Serksnyte, R. Del Grande, arXiv:2310.10428, accepted by PRC

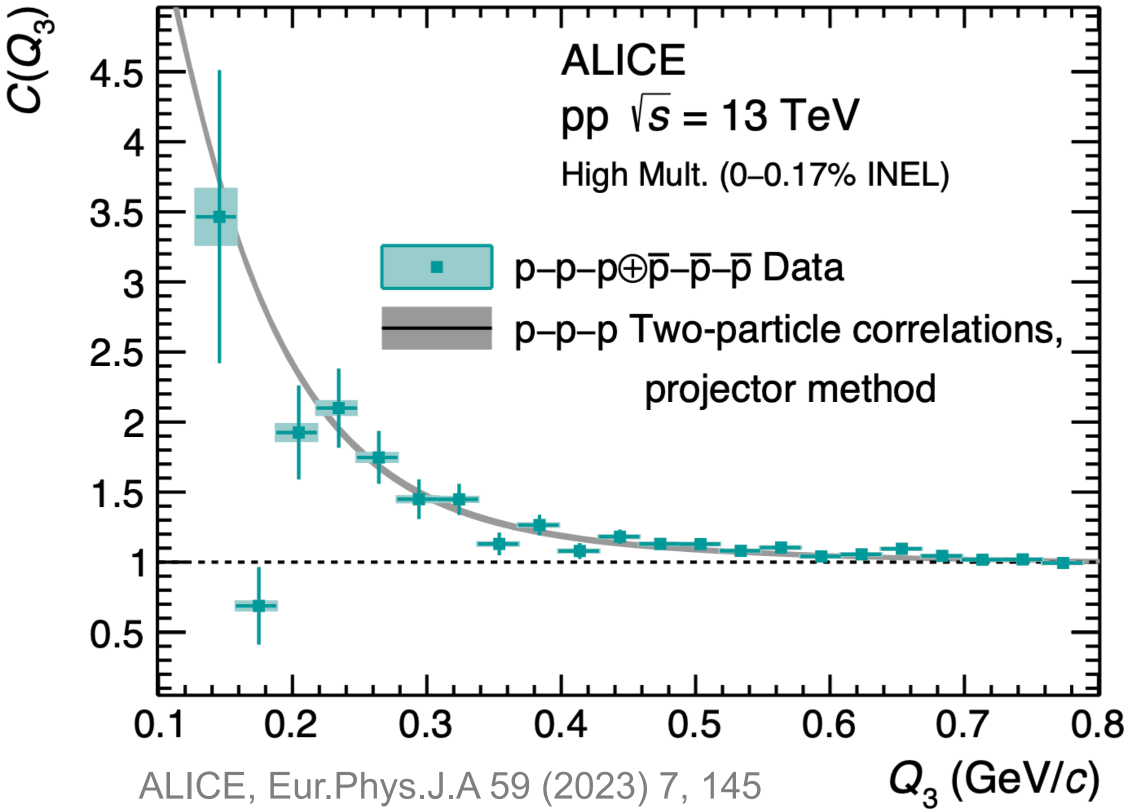
Other Three-Body Studies

p-p-Λ



ALICE, Eur.Phys.J.A 59 (2023) 7, 145

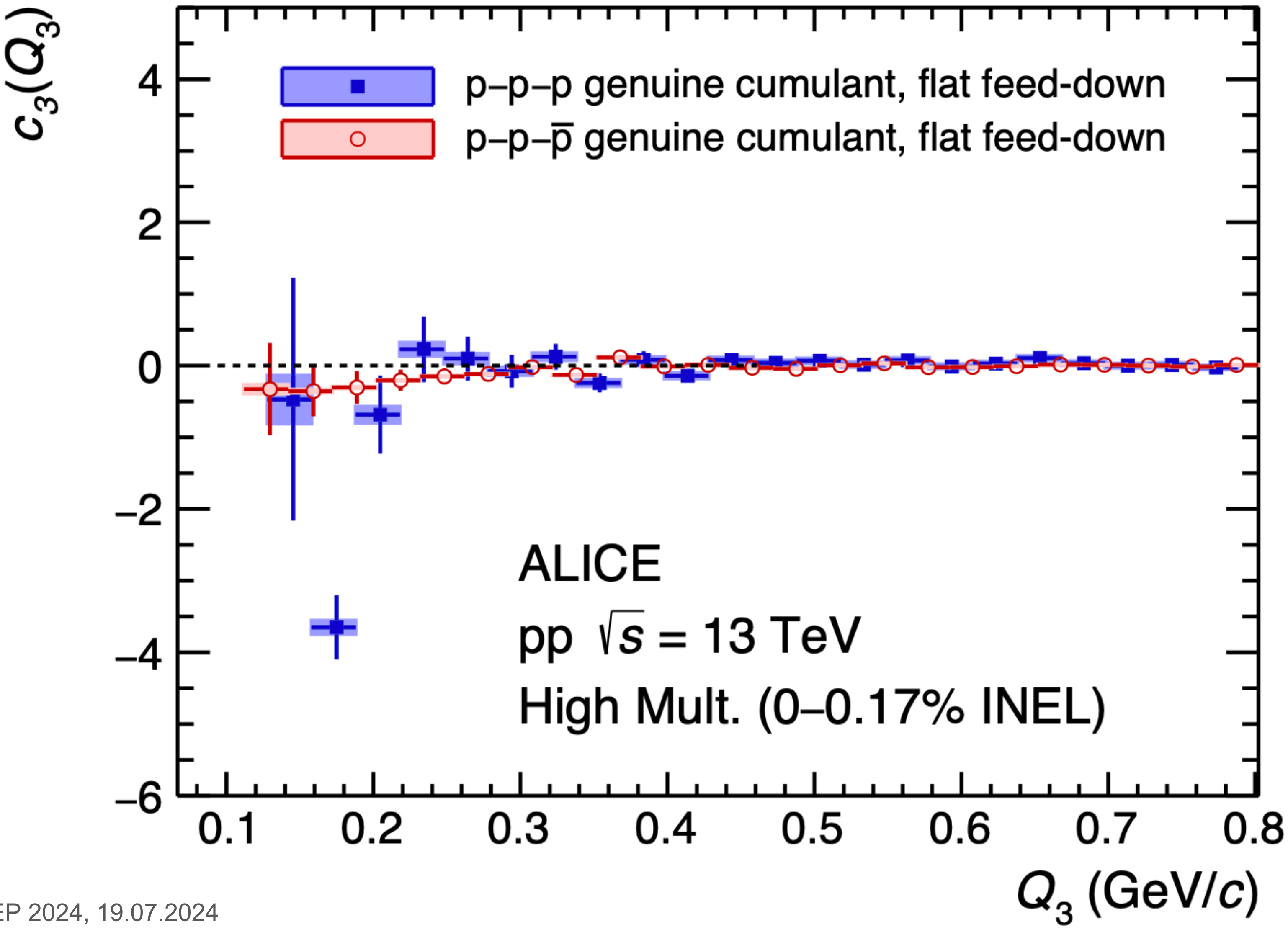
p-p-p



ALICE, Eur.Phys.J.A 59 (2023) 7, 145

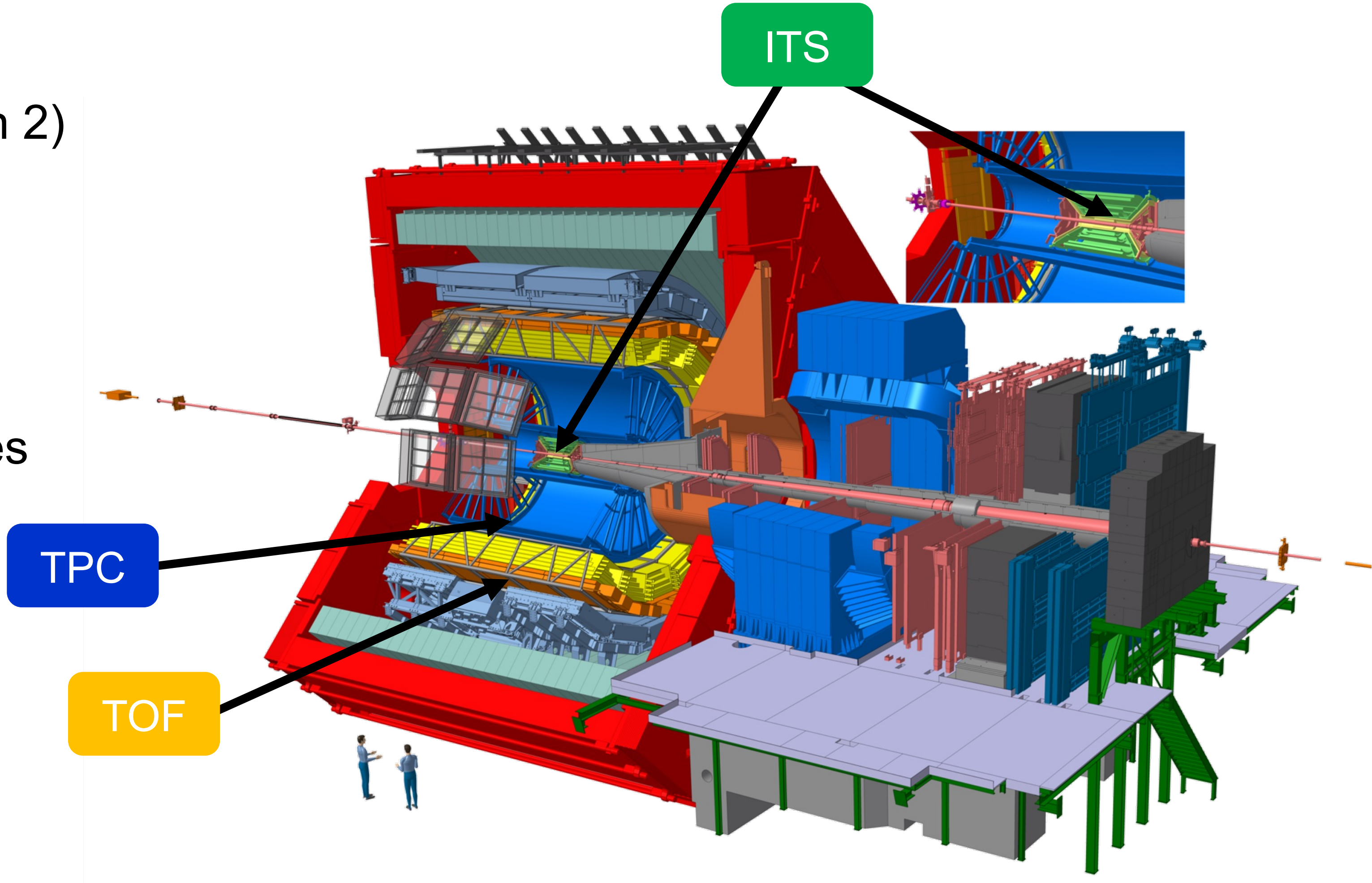
Other Three-Body Studies

ALICE, Eur.Phys.J.A 59 (2023) 7, 145



ALICE - A Large Ion Collider Experiment

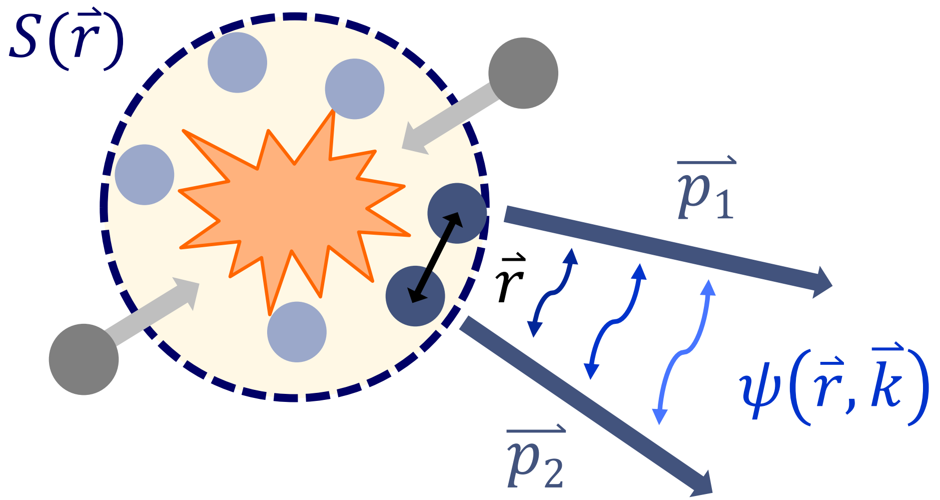
- pp at $\sqrt{s}$ = 13 TeV
- 10^9 high-multiplicity (HM) events (Run 2)
- Direct detection of charged particles (protons, kaons, pions, deuterons)
- Very good PID capabilities of the detector resulting in very pure samples (protons ~ 98%, pions 99%)



A. Tauro, "ALICE Schematics" (2017), CERN CDS

Two-body femtoscopy

L. Fabbietti and V. Mantovani Sarti and O. Vazquez Doce, Study of the Strong Interaction Among Hadrons with Correlations at the LHC, Annu. Rev. Nucl. Part. Sci. (2021) 71:377-402



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

theoretical definition — experimental definition

Relative momentum $\vec{k}^* = \frac{1}{2}\mid \vec{p}_1^* - \vec{p}_2^* \mid$ and $\vec{p}_1^* + \vec{p}_2^* = 0$

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

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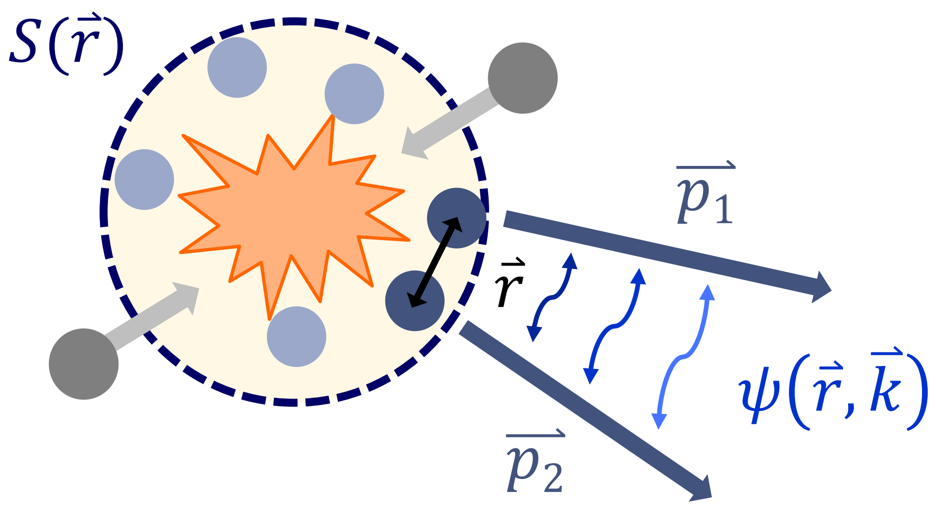

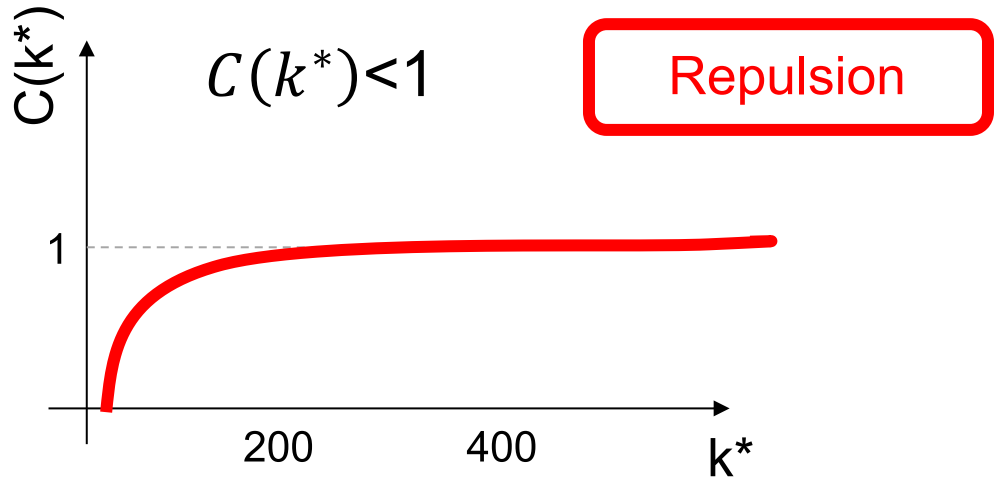

$$C(k^*) = \int S(\vec{r}^*)\left|\psi(\vec{k}^*,\vec{r}^*)\right|^2 d^3\vec{r}^* = \mathcal{N}\frac{\mathrm{N}_{\mathrm{same}}(k^*)}{\mathrm{N}_{\mathrm{mixed}}(k^*)}$$

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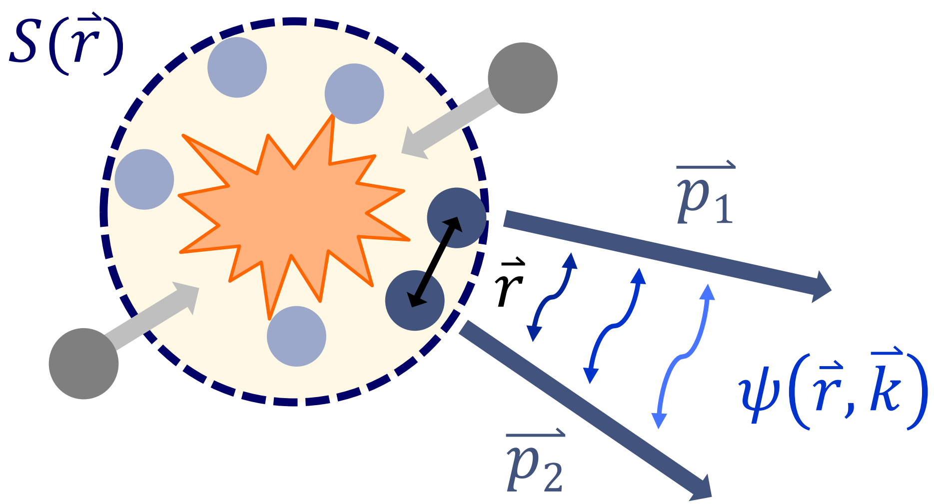

$$C(k^*) = \int S(\vec{r}^*)\left|\psi(\vec{k}^*,\vec{r}^*)\right|^2 d^3\vec{r}^* = \mathcal{N}\frac{N_{same}(k^*)}{N_{mixed}(k^*)}$$

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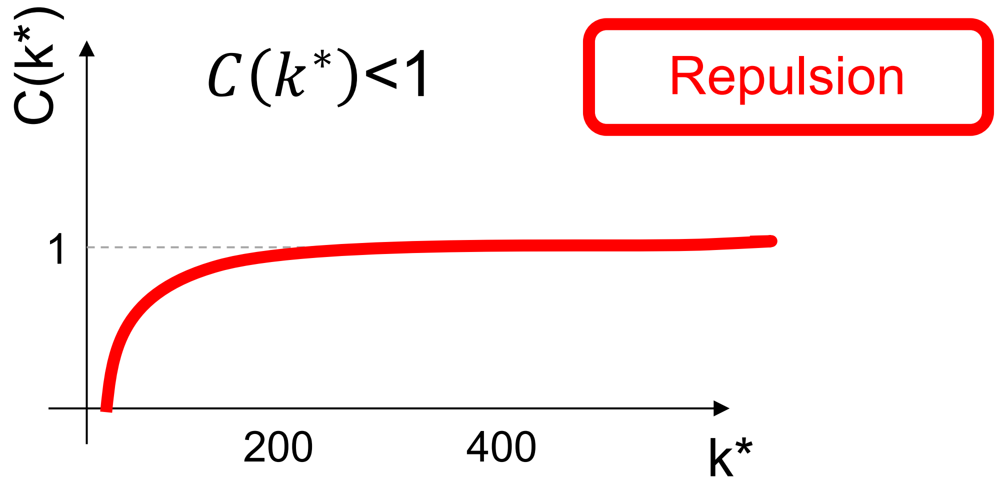
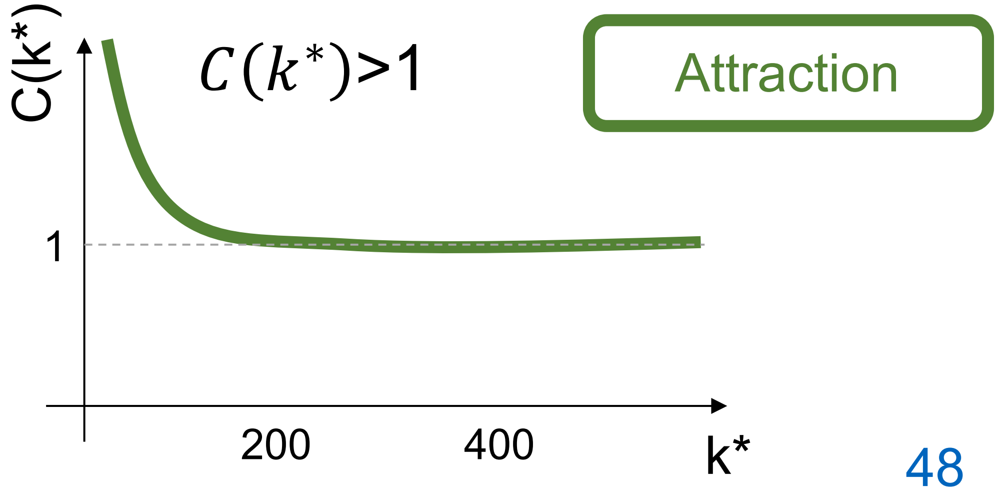
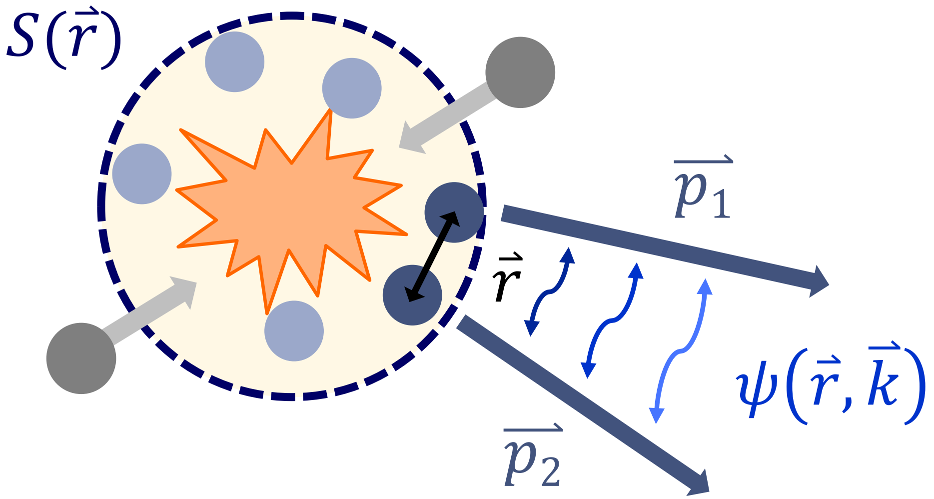




Two-body Femtoscopy

- Observed femtoscopic correlation functions depend on
  - Final-state interaction $\left|\psi(\vec{k}^*, \vec{r}^*)\right|^2$
  - Particle emitting source $S(\vec{r}^*)$
- The study of the interactions, especially also of exotic pairs, need a well constrained source!



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

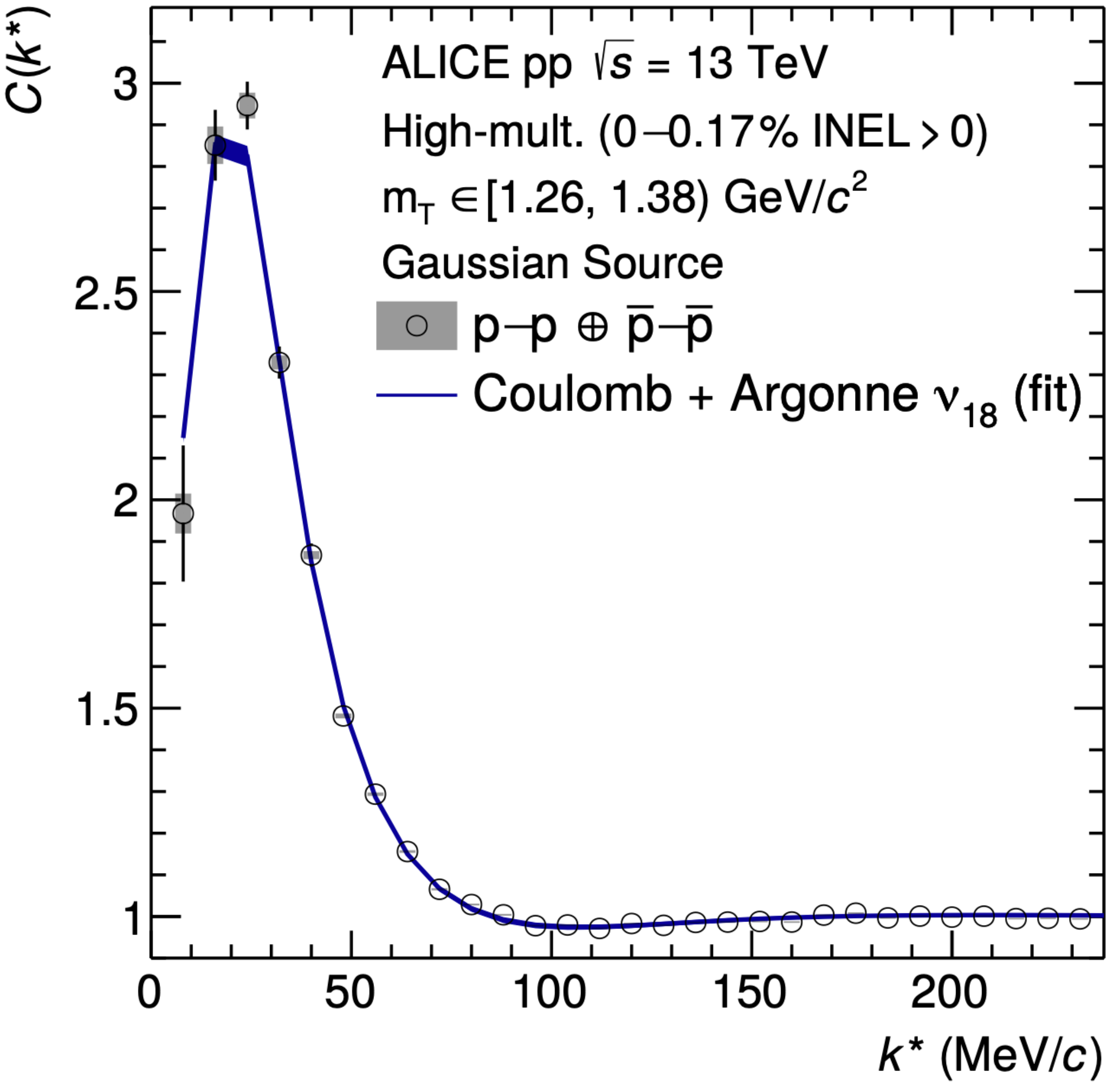
The Source for Baryon Pairs

- pp and $p\Lambda$ correlations in HM pp collisions at $\sqrt{s}$ = 13 TeV
- Known interaction allows the extraction of the source size
- Source modelled as a gaussian

$$S(r) = \frac{1}{(4\pi r_{eff}^2)^{3/2}} \exp\left(-\frac{r^2}{4r_{eff}^2}\right)$$

- r_{eff} as free fit parameter

ALICE, Phys. Lett. B 811 (2020) 135849



A Common Baryon Source?

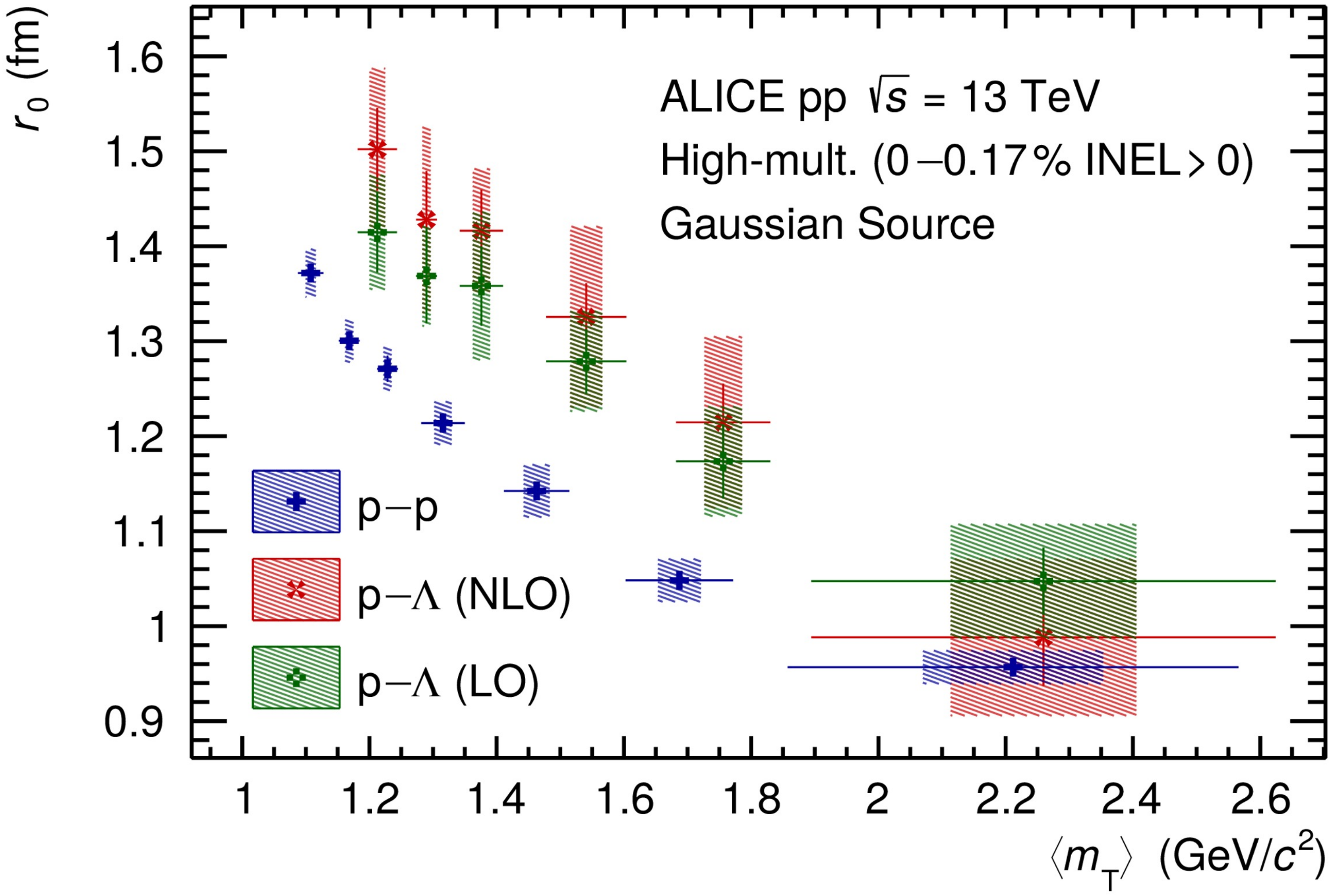
- Effective source size for different transverse mass bins, with

  $$m_{\mathrm{T}} = \sqrt{\bar{m}^2 + k_T^2}$$

  and $\vec{k}_{\mathrm{T}} = \frac{1}{2}\left[\vec{p}_{\mathrm{T},1} + \vec{p}_{\mathrm{T},2}\right]$

- Different effective source size for pp and $p\Lambda$ pairs!

ALICE, Phys. Lett. B 811 (2020) 135849

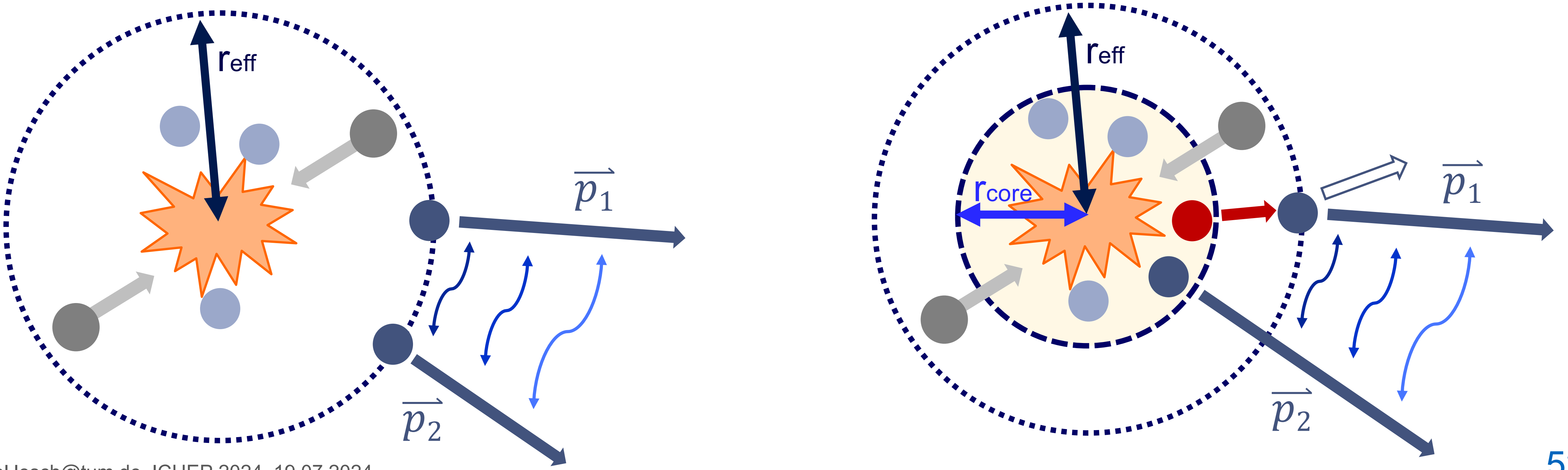


A Common Baryon Source?

- Effective source not taking short-lived resonances into account
- Proper source modelling

$$S(r) = \frac{1}{(4\pi r_{core}^2)^{3/2}} \exp\left(-\frac{r^2}{4r_{core}^2}\right) \otimes \text{(Resonance Contributions)}$$

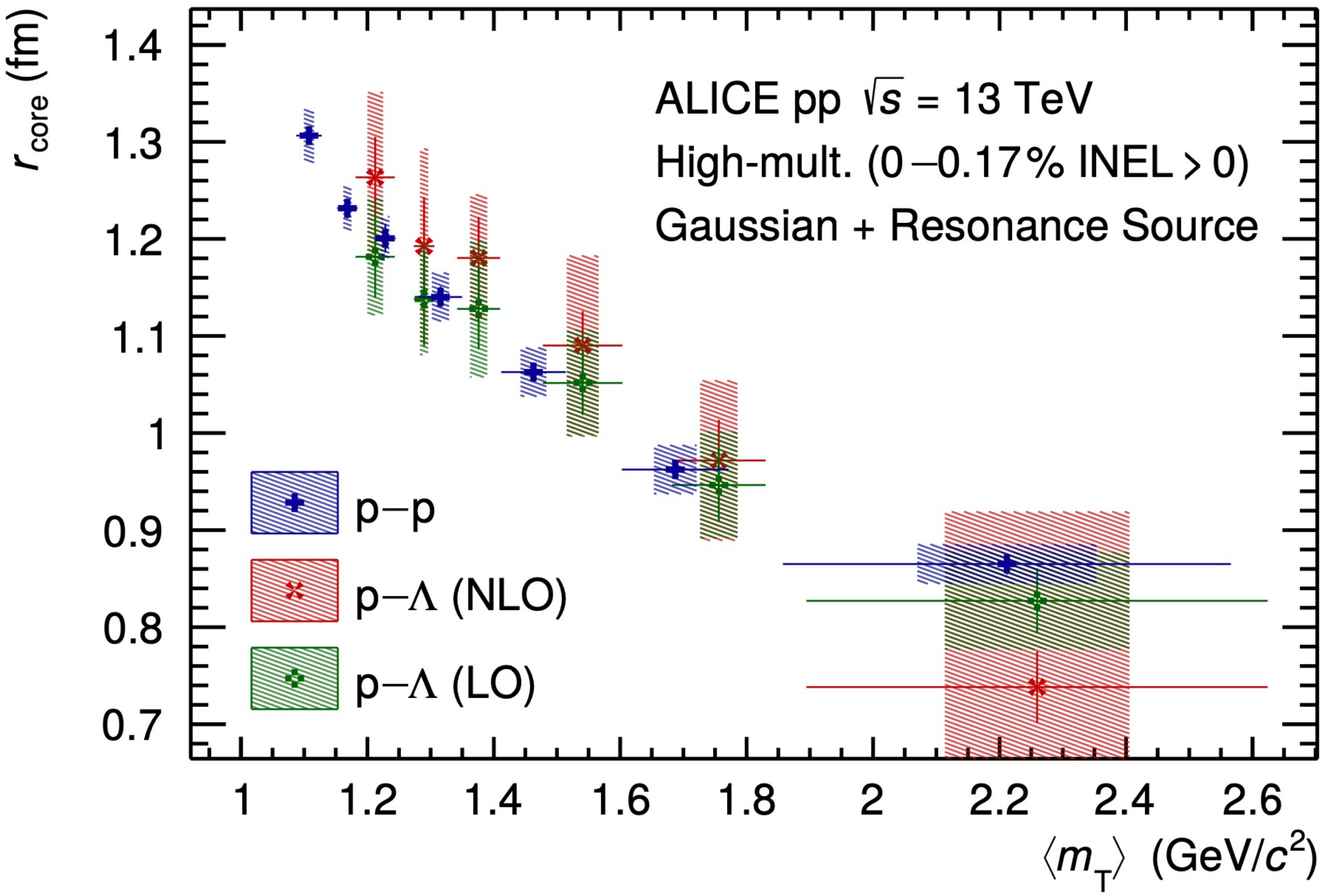
- Resonance contributions fixed from statistical hadronization model and EPOS



A Common Baryon Source!

- Source distribution of particles from Gaussian core (r_{core}) and decay of short-lived particles
- Different effective source size for pp and $p\Lambda$ pairs **BUT**
- Common core source of primordial baryons!

ALICE, Phys. Lett. B 811 (2020) 135849

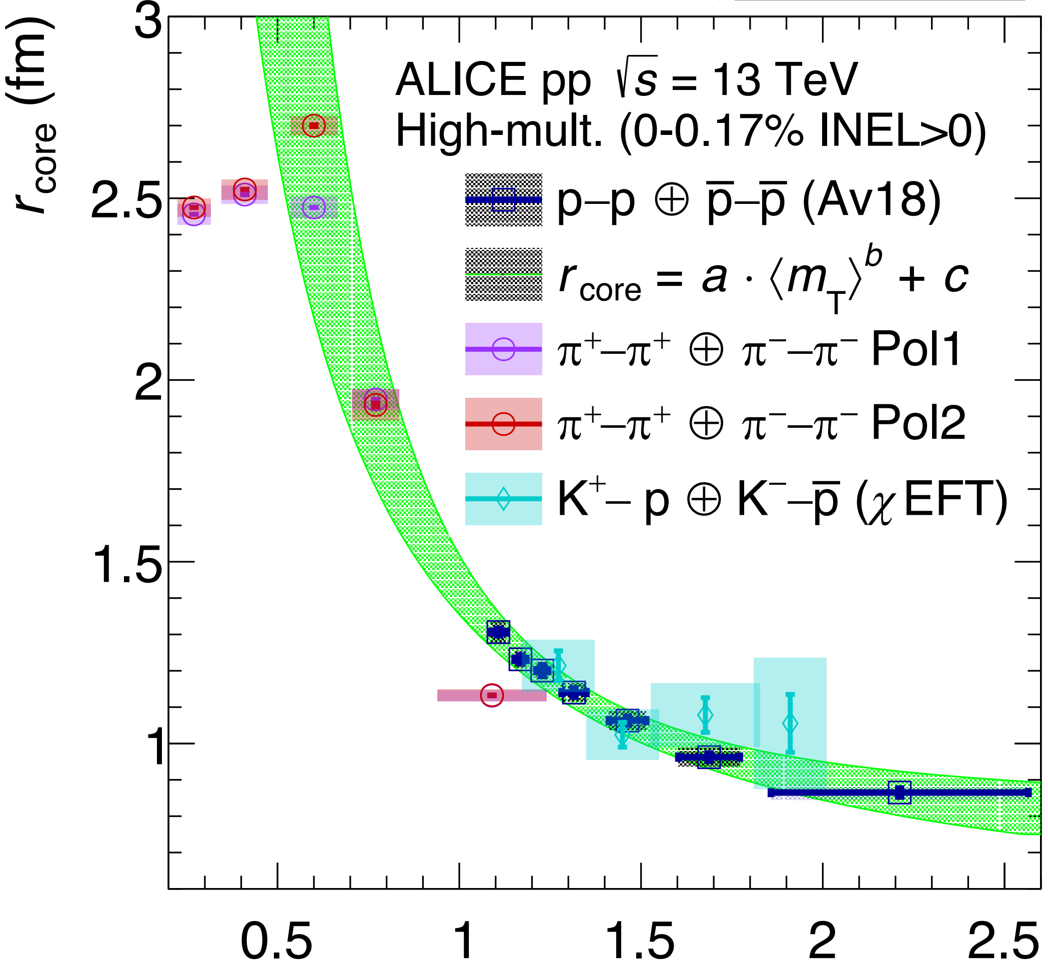


A Common ~~Baryon~~ Hadron Source!

- Particle emission source studied with
  - pp ALICE, PLB, 811 135849, 2020
  - pK^+ ALICE, arXiv:2311.14527
  - $\pi^\pm\pi^\pm$ ALICE, arXiv:2311.14527
- Common source for all hadrons!
- Scaling allows to extract the source size of particle pairs with unknown interaction

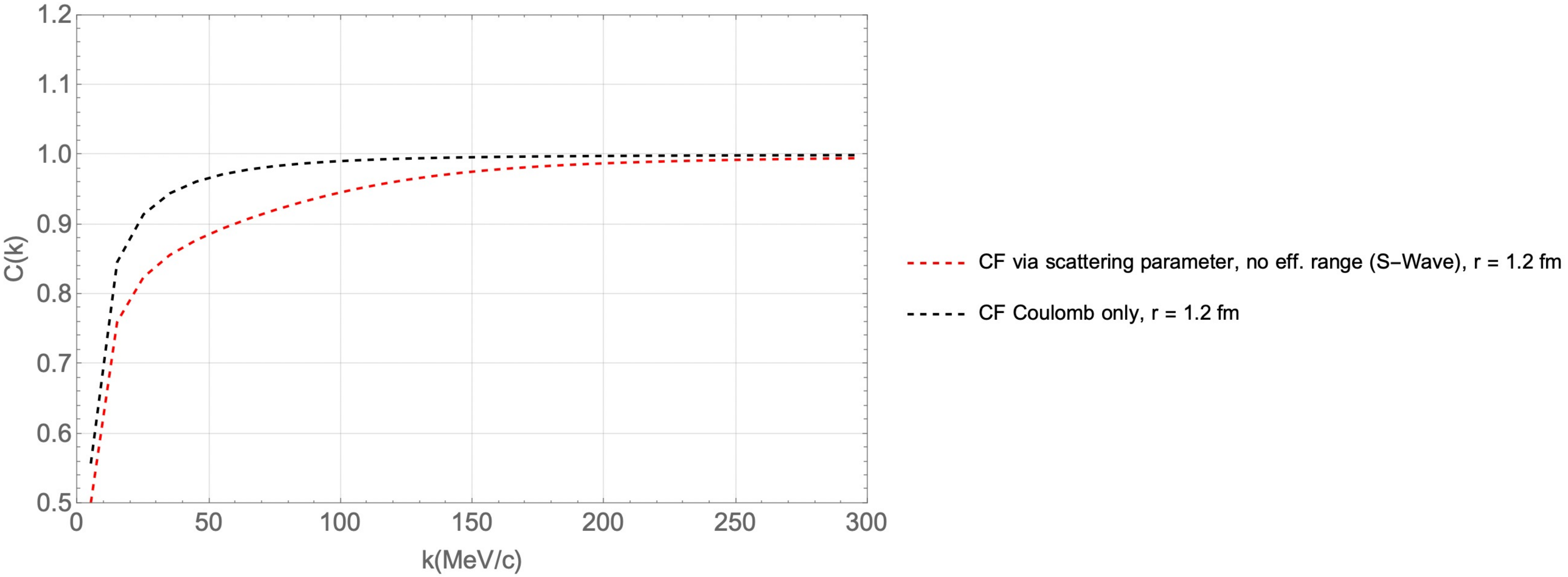
→ Possibility to study interaction for exotic pairs (strange and charm sector)

ALICE, arXiv:2311.14527



$m_{\mathrm{T}} = \sqrt{\overline{m}^2 + k_T^2}$ and $\langle m_{\mathrm{T}} \rangle$ (GeV/c^2)

$\vec{k}_{\mathrm{T}} = \frac{1}{2}\left[\vec{p}_{\mathrm{T},1} + \vec{p}_{\mathrm{T},2}\right]$



1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
C(k)
0
50
100
150
200
250
300
k(MeV/c)
CF via scattering parameter, no eff. range (S–Wave), r = 1.2 fm
CF Coulomb only, r = 1.2 fm

Fitting of data $p\pi^+$

$$C_{\text{total}} = \mathcal{N} \times C_{\text{bckg}} \times [\lambda_{\text{Gen}} C_0 + (1 - \lambda_{\text{Gen}})] + N_\Delta PS(p_\text{T}, T) \times Sill(M_\Delta, \Gamma_\Delta)$$

- Background C_{bckg} via MC templates, controlled by w_c
- Interaction $C_0(r_{\text{core}})$ Coulomb + strong interaction (fixed from scattering lengths)

  M. Hoferichter et al, Phys.Rept. 625 (2016) 1-88
  M. Hennebach et al, Eur.Phys.J.A 50 (2014) 12, 190
- Sill distribution $Sill(M_\Delta, \Gamma_\Delta)$, M_Δ fixed to 1215 MeV

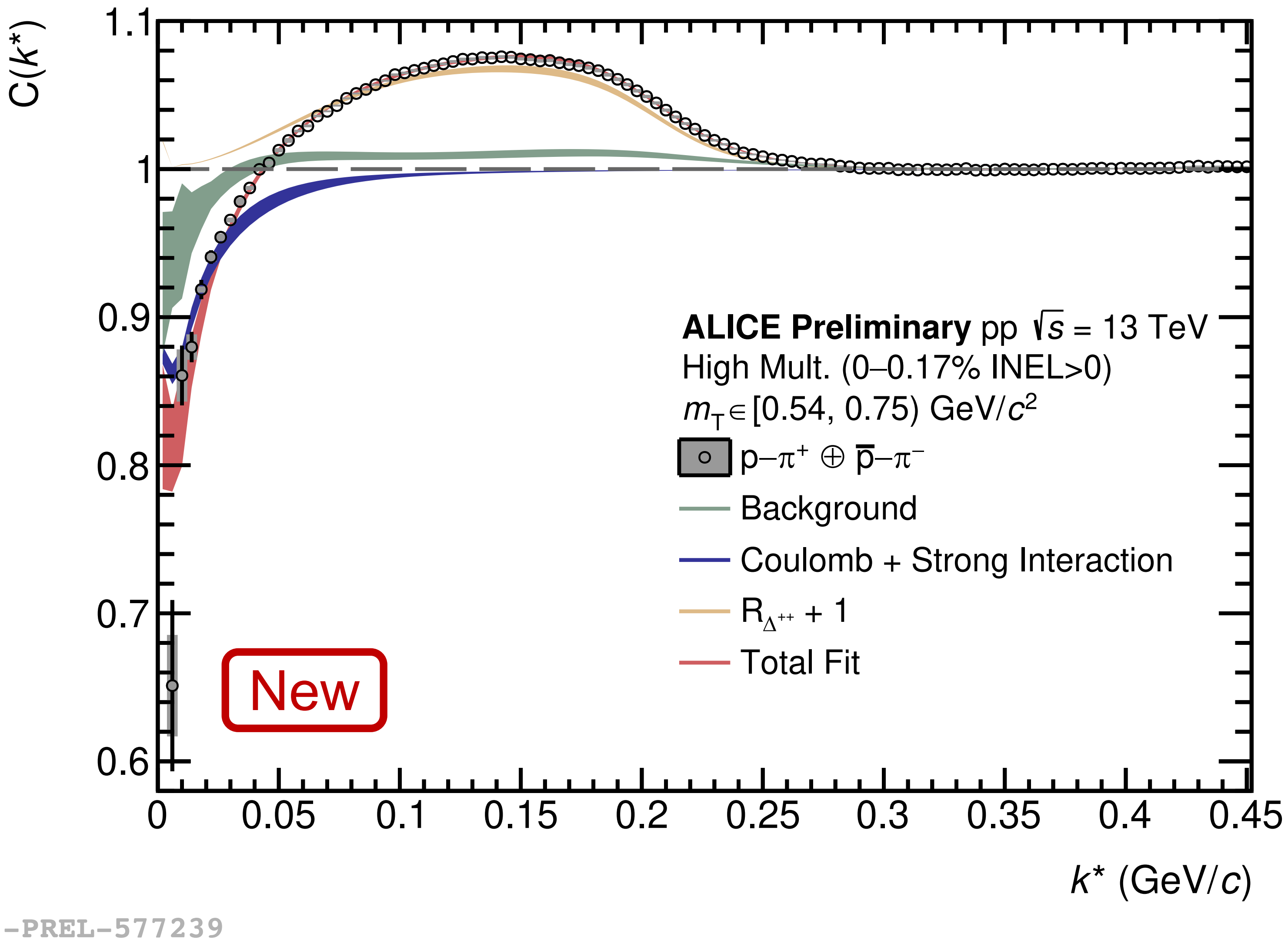
  F. Giacosa et al, Eur.Phys.J.A 57 (2021) 12
- $PS(p_\text{T}, T)$ phase-space factor

$$PS(p_\text{T}, T) \propto \frac{m}{\sqrt{m^2 + p_\text{T}^2}} \times \exp\left(-\frac{\sqrt{m^2 + p_\text{T}^2}}{T}\right)$$

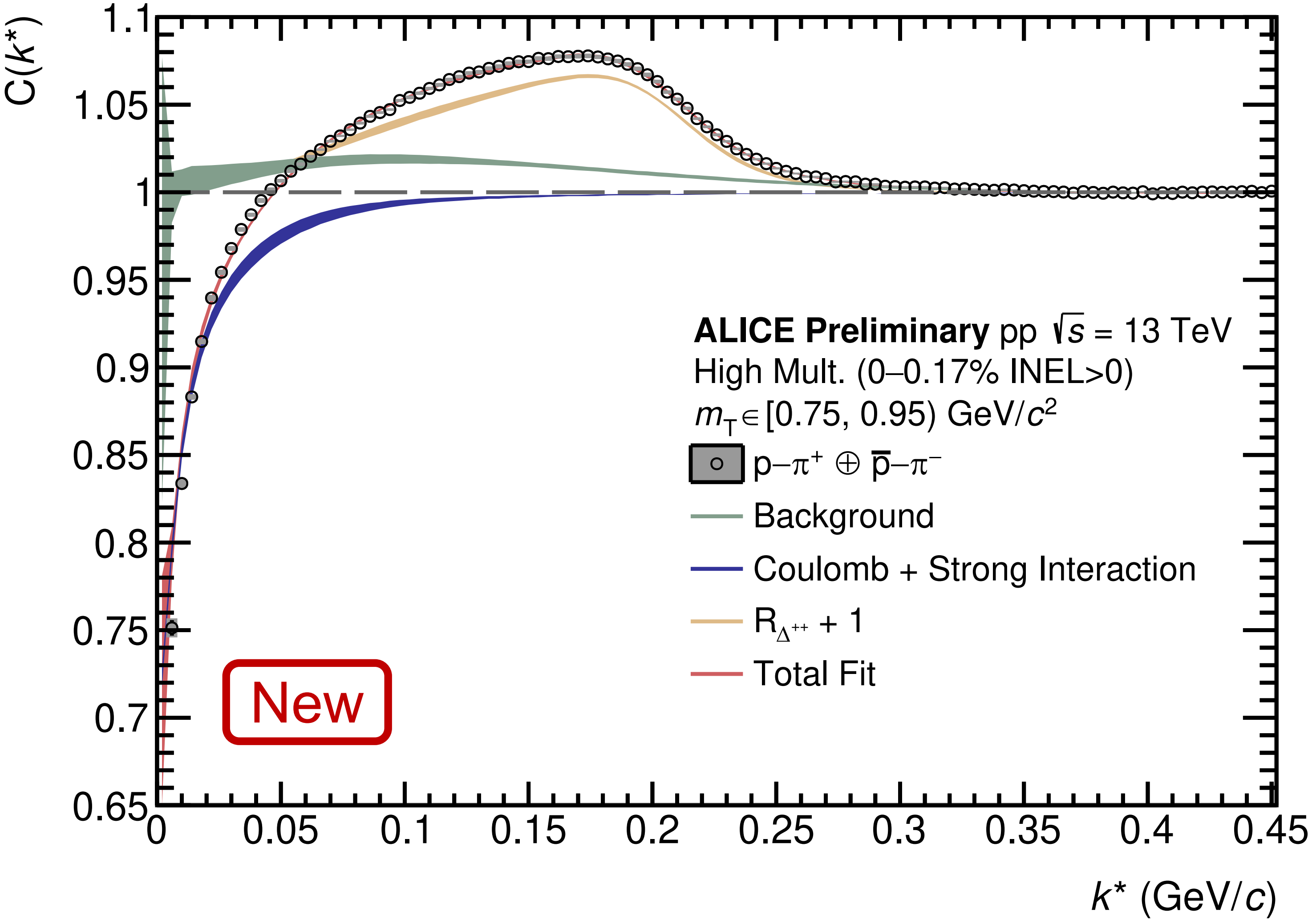
- Fit between between 0 and 450 MeV in k*

Free Parameters of the fit:
- Overall normalisation N
- w_c
- r_{core}
- Scaling of Δ^{++} N_Δ
- T (kinetic decoupling temp.)
- Width of Δ^{++}

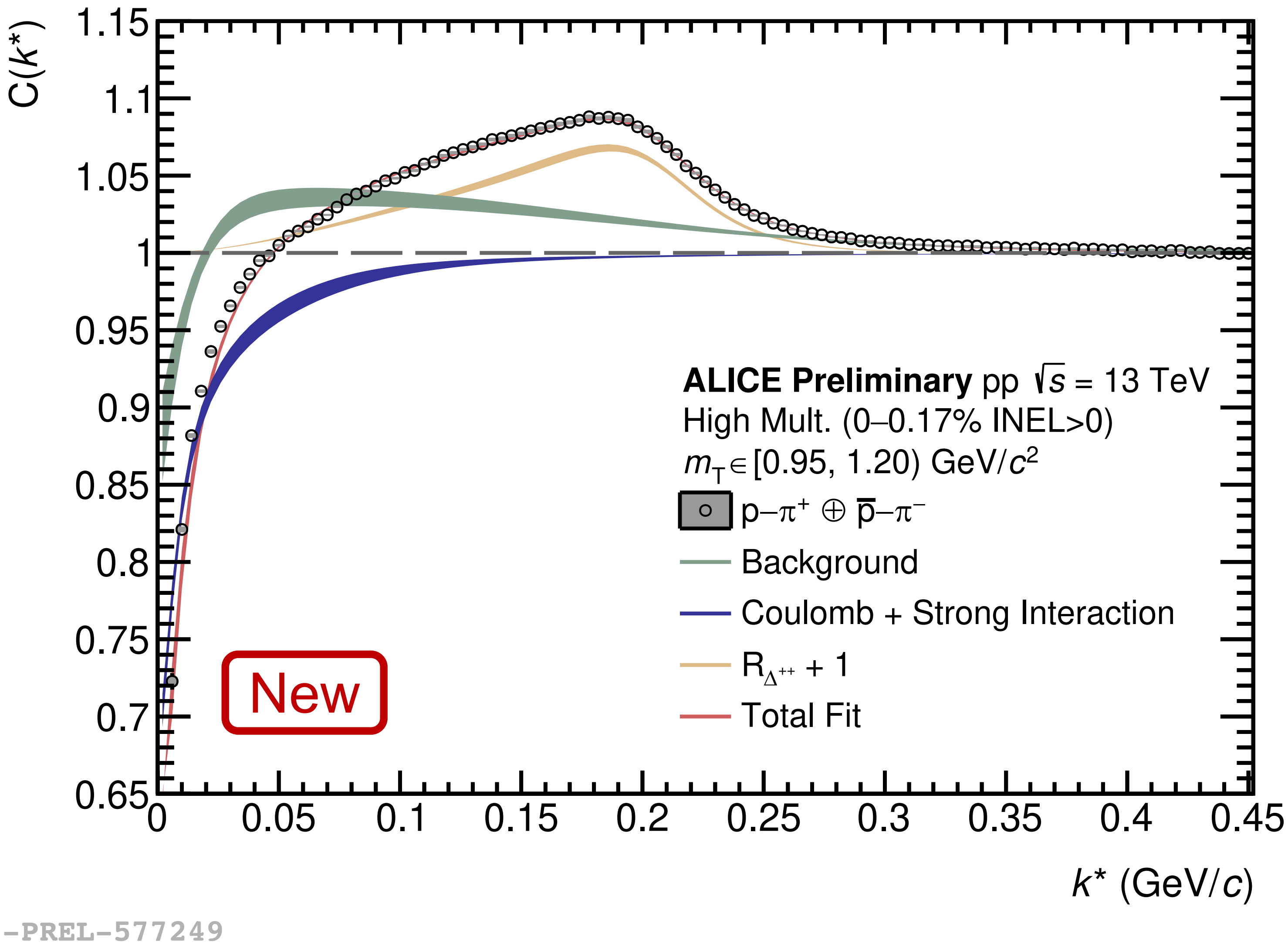
$p\pi^+$ - m_T interval 1



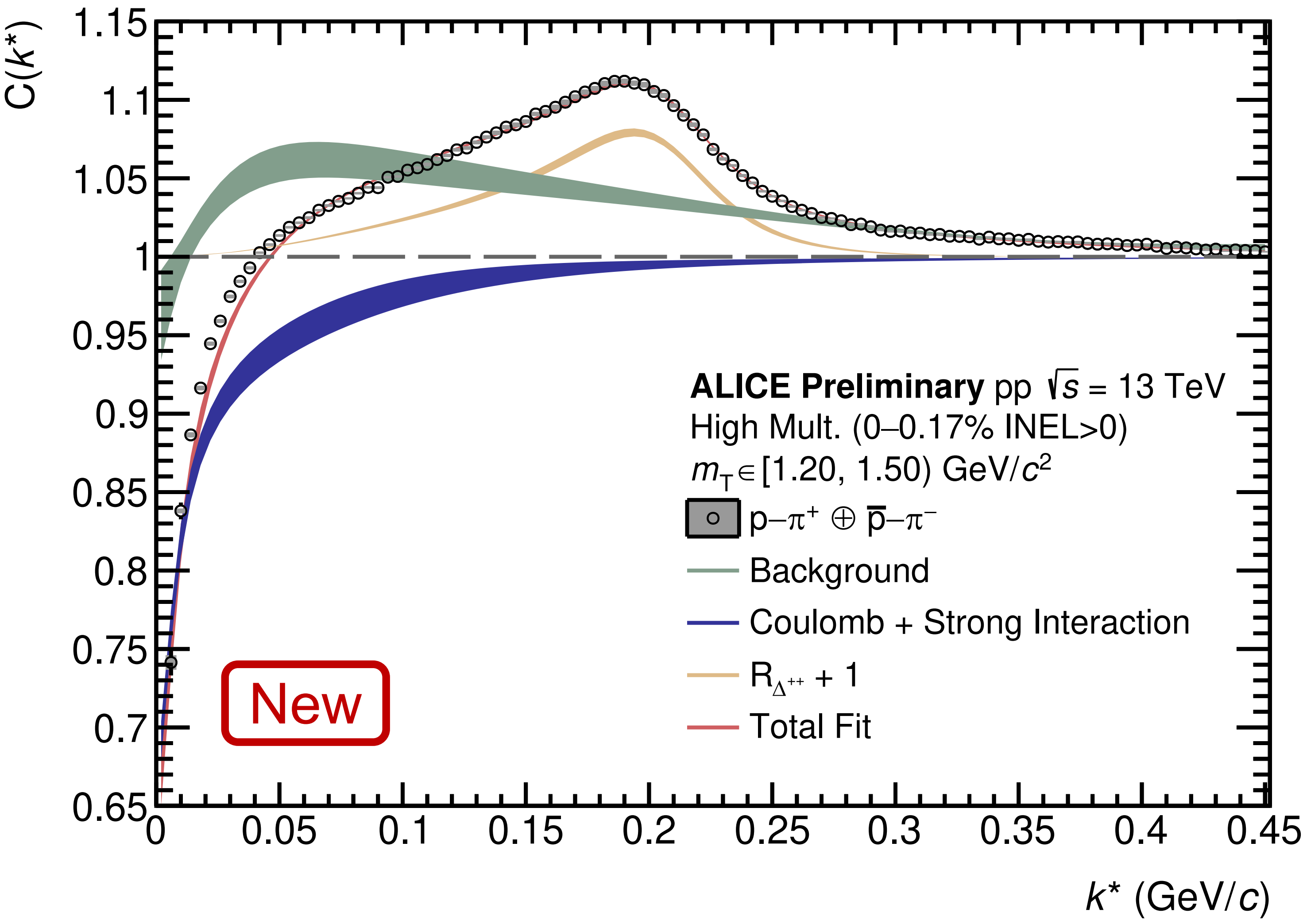
pπ$^+$ - m_T interval 2



$p\pi^+$ - m_T interval 3

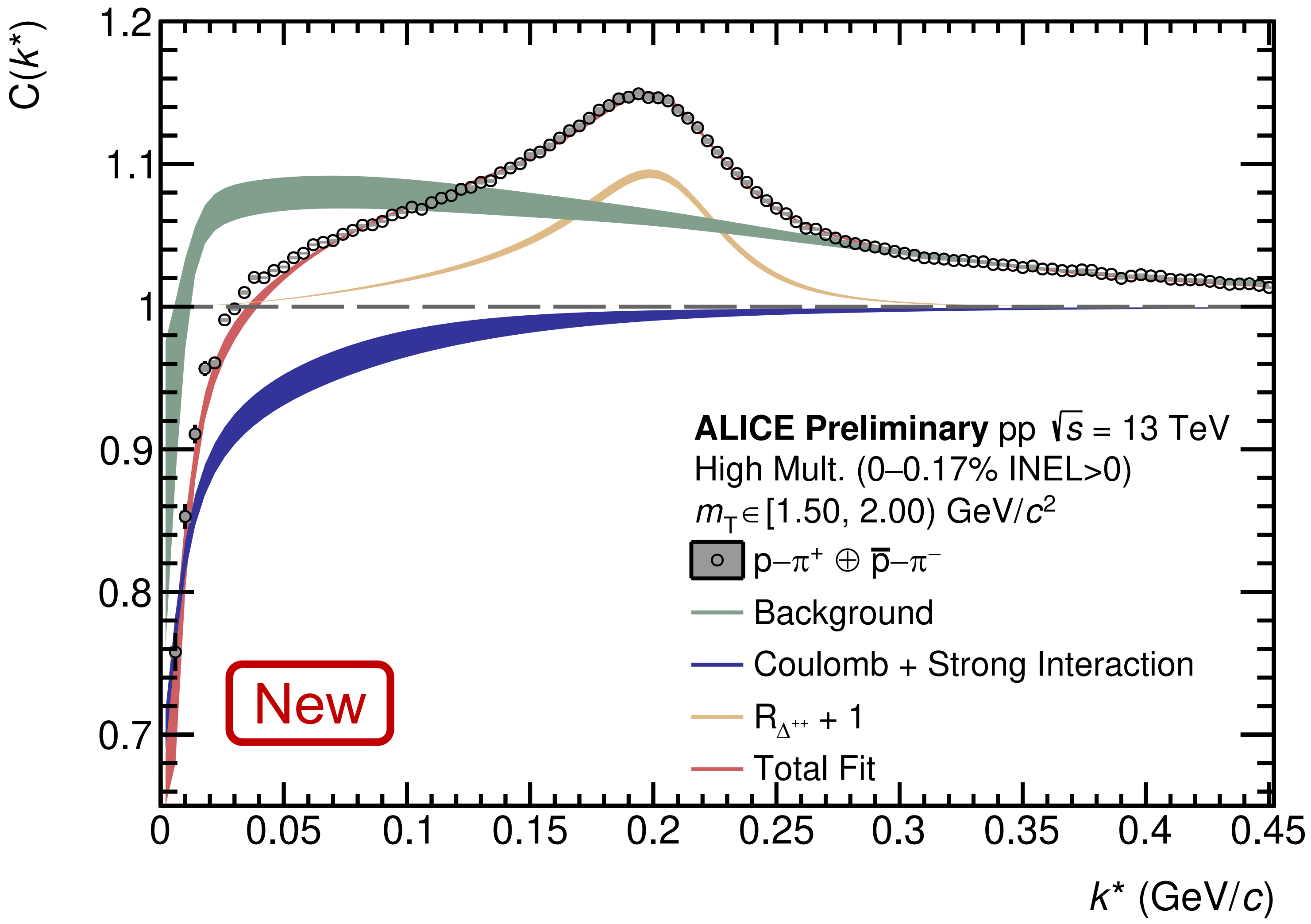


$p\pi^+$ - m_T interval 4



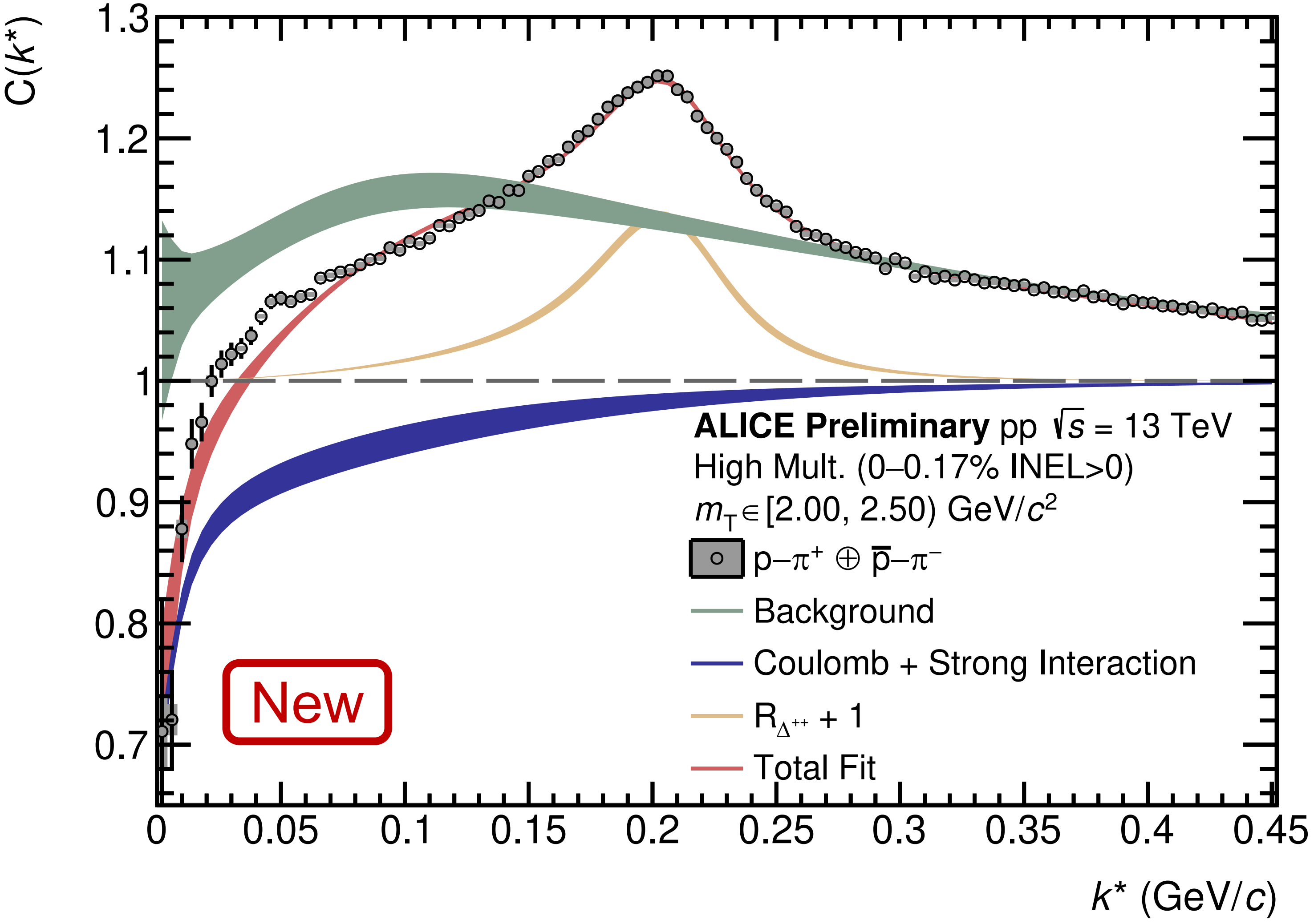
ALI-PREL-577254

$p\pi^+$ - m_T interval 5



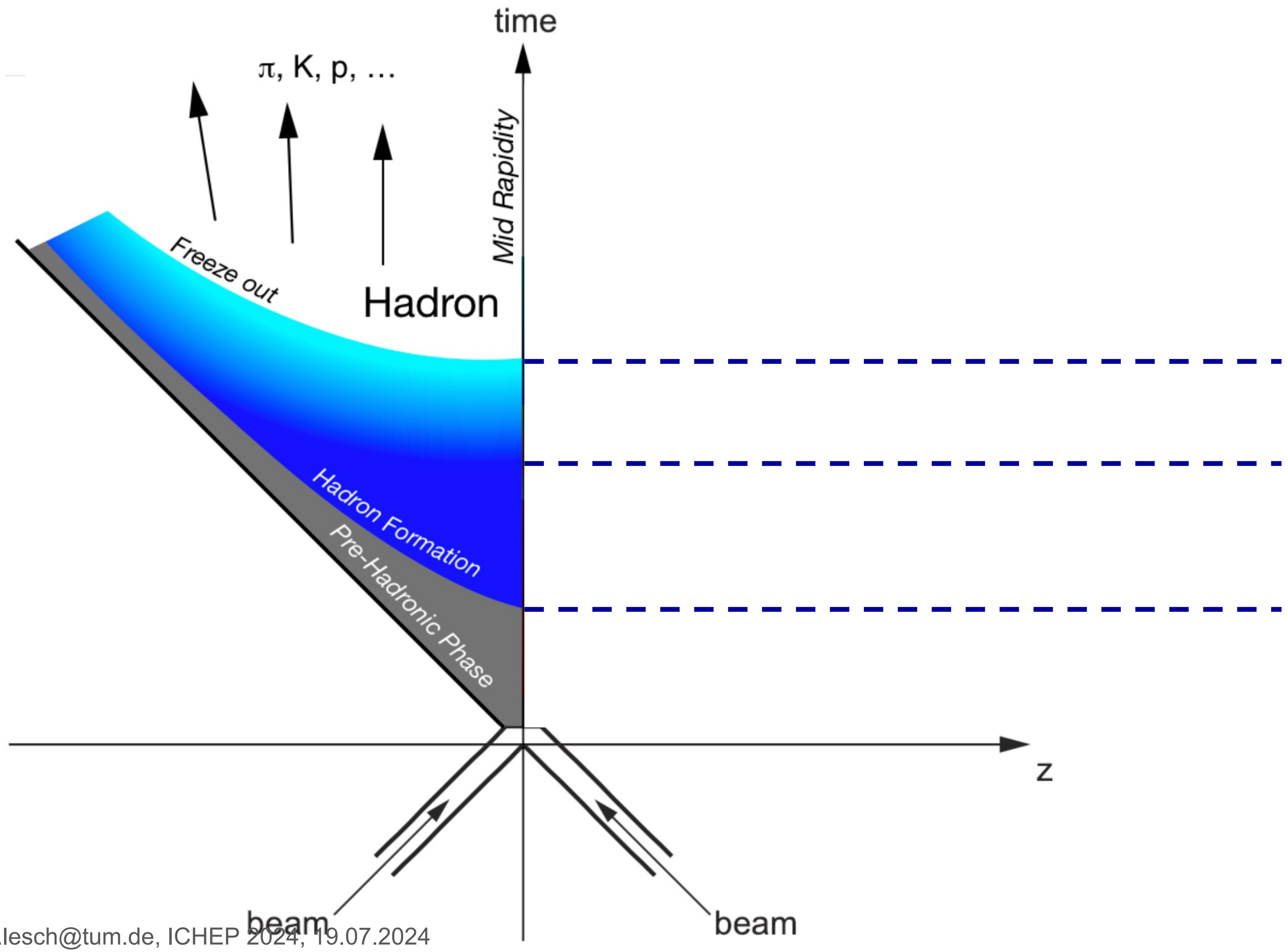
ALI-PREL-577259

$p\pi^+$ - m_T interval 6



ALI-PREL-577264

About the life of the Δ^{++}

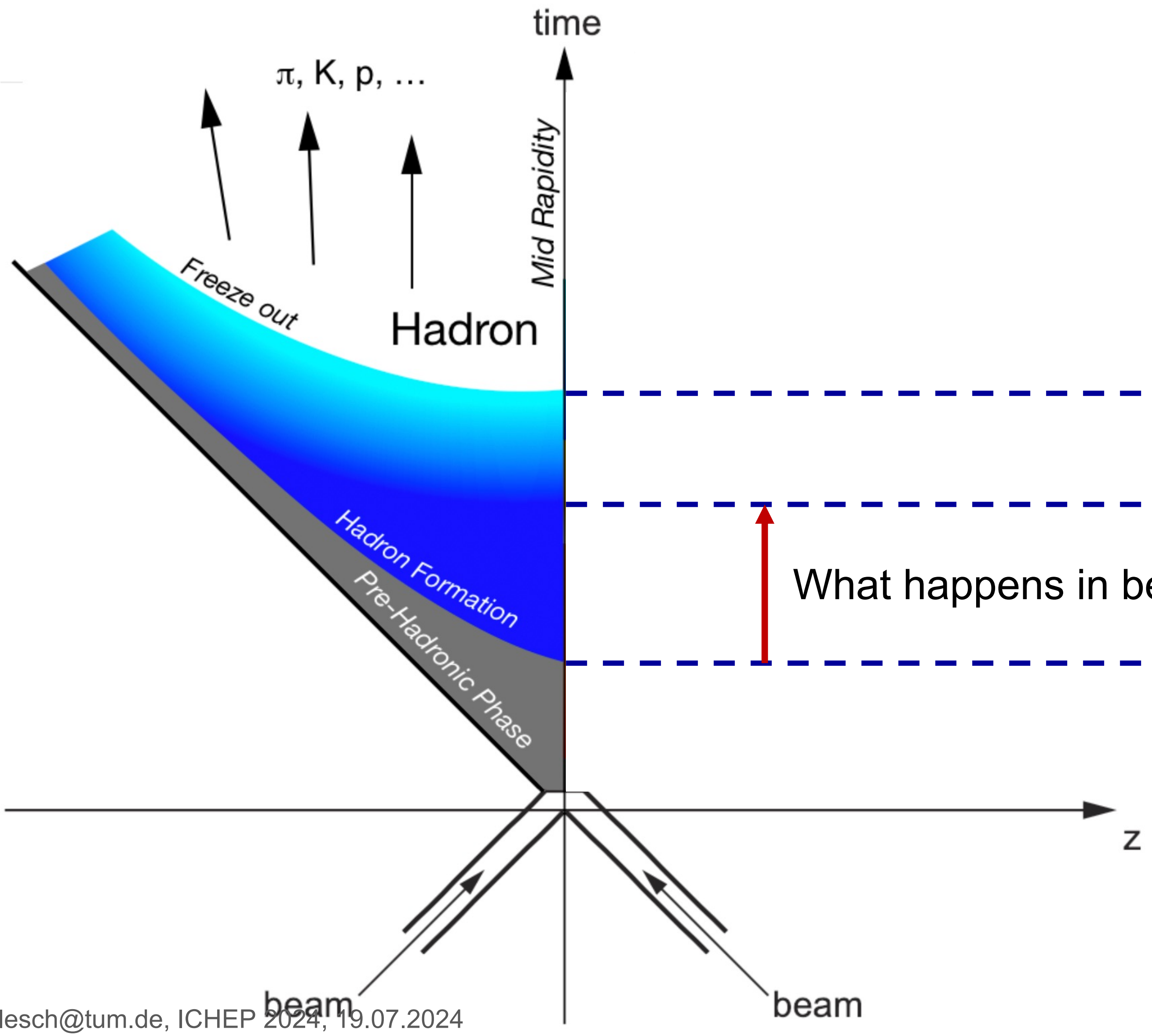


Kinetic freezout
→ characterized by T_{ch}

Decay of the $\Delta^{++} \rightarrow p\pi^{+}$

Formation of the Δ^{++}
(and all other hadrons)
→ characterized by T_{ch}

About the life of the Δ^{++}



What happens in between?

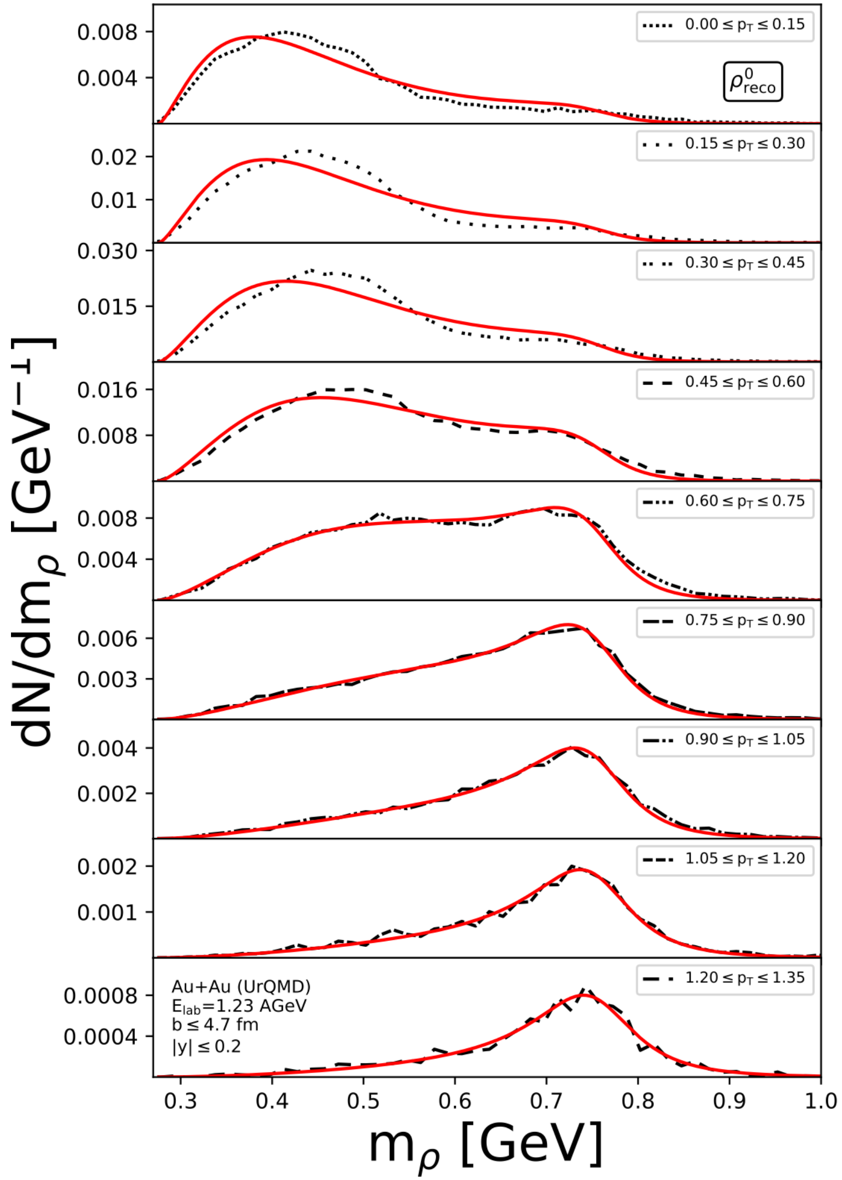
Kinetic freezout
→ characterized by T_{ch}

Decay of the $\Delta^{++} \rightarrow p\pi^{+}$

Formation of the Δ^{++}
(and all other hadrons)
→ characterized by T_{ch}

Rescattering of the Δ^{++}

- Paper: Tom Reichert, Marcus Bleicher, [Nucl.Phys.A 1028 (2022) 122544]
- Study of kinetic mass shifts of ρ(770) and K*(892) in Au+Au reactions at E_{beam} = 1.23 AGeV with UrQMD
- Fitting of Data with PS x BW
- However: Temperature not fixed to chemical freezout but free parameter



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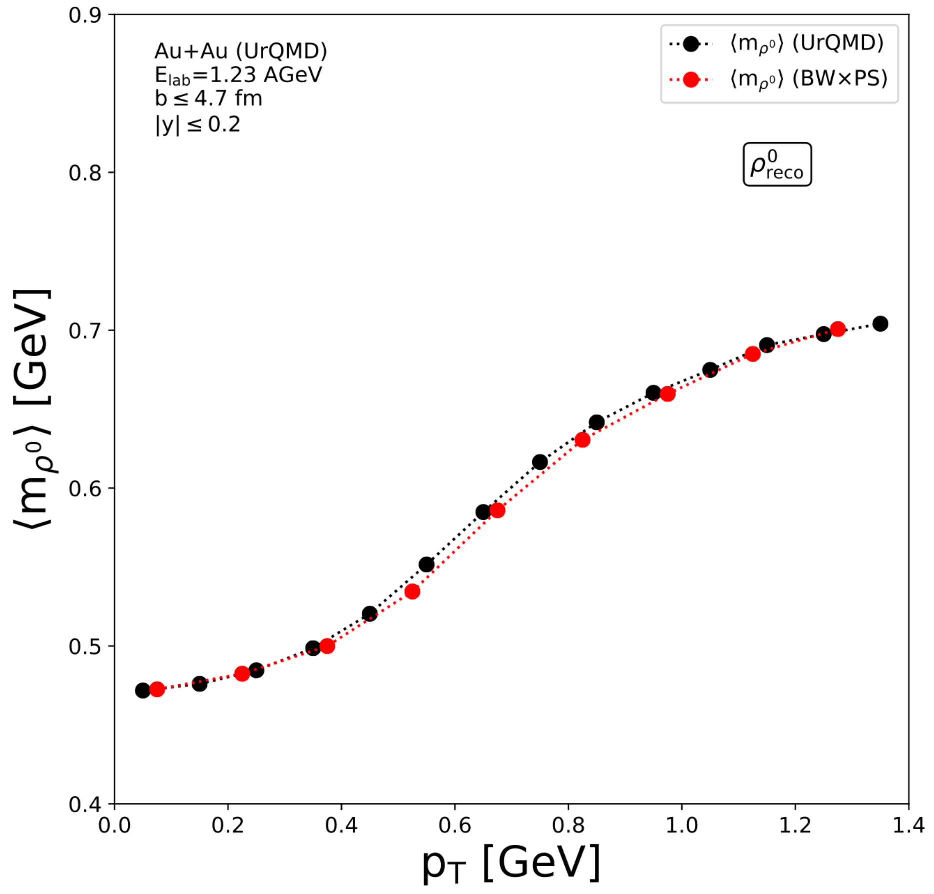
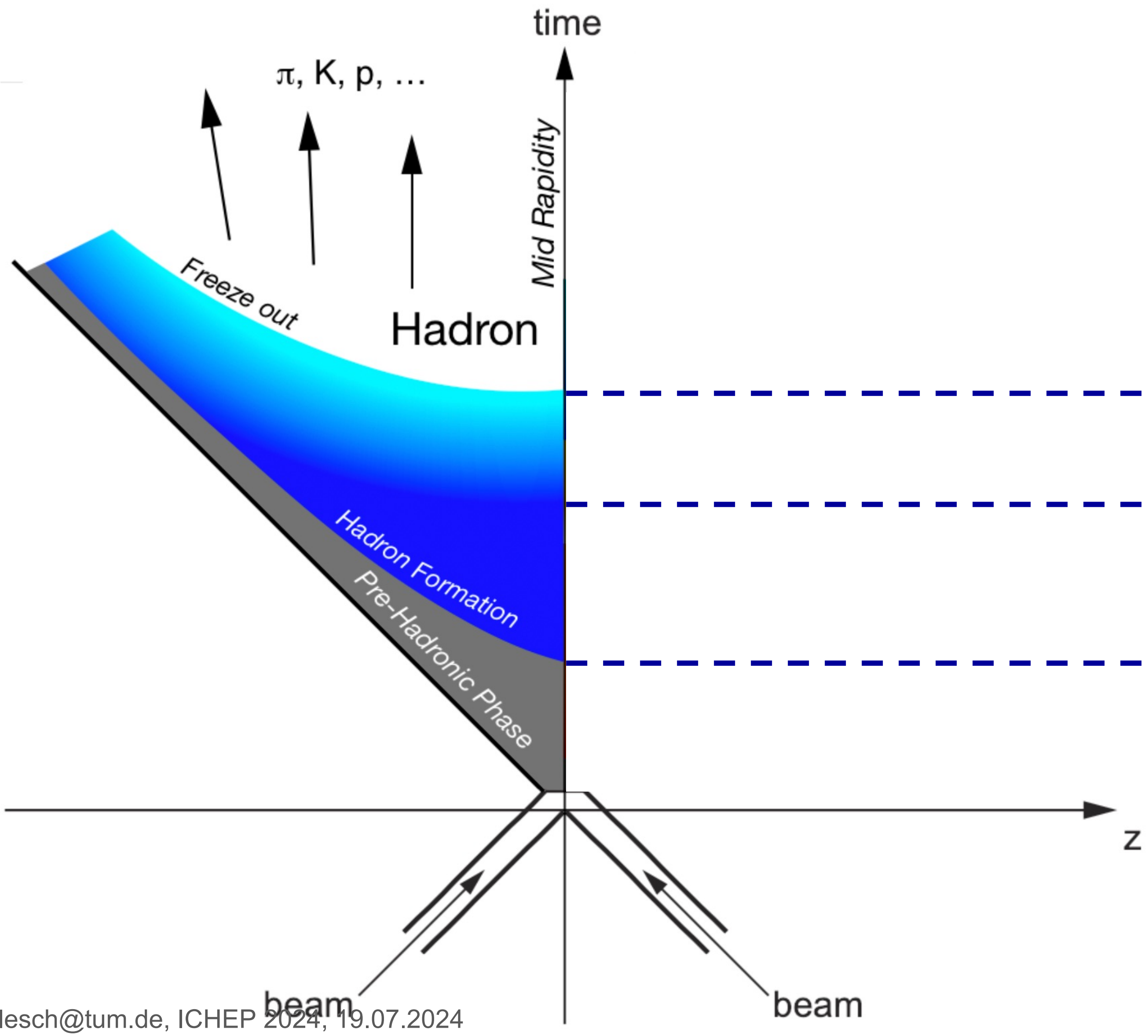
- Fitting of Data with PS x BW
- However: Temperature not fixed to chemical freezout but free parameter ("Kinetic Decoupling Temperature")
  → good agreement between UrQMD and fit



About the life of the Δ^{++}



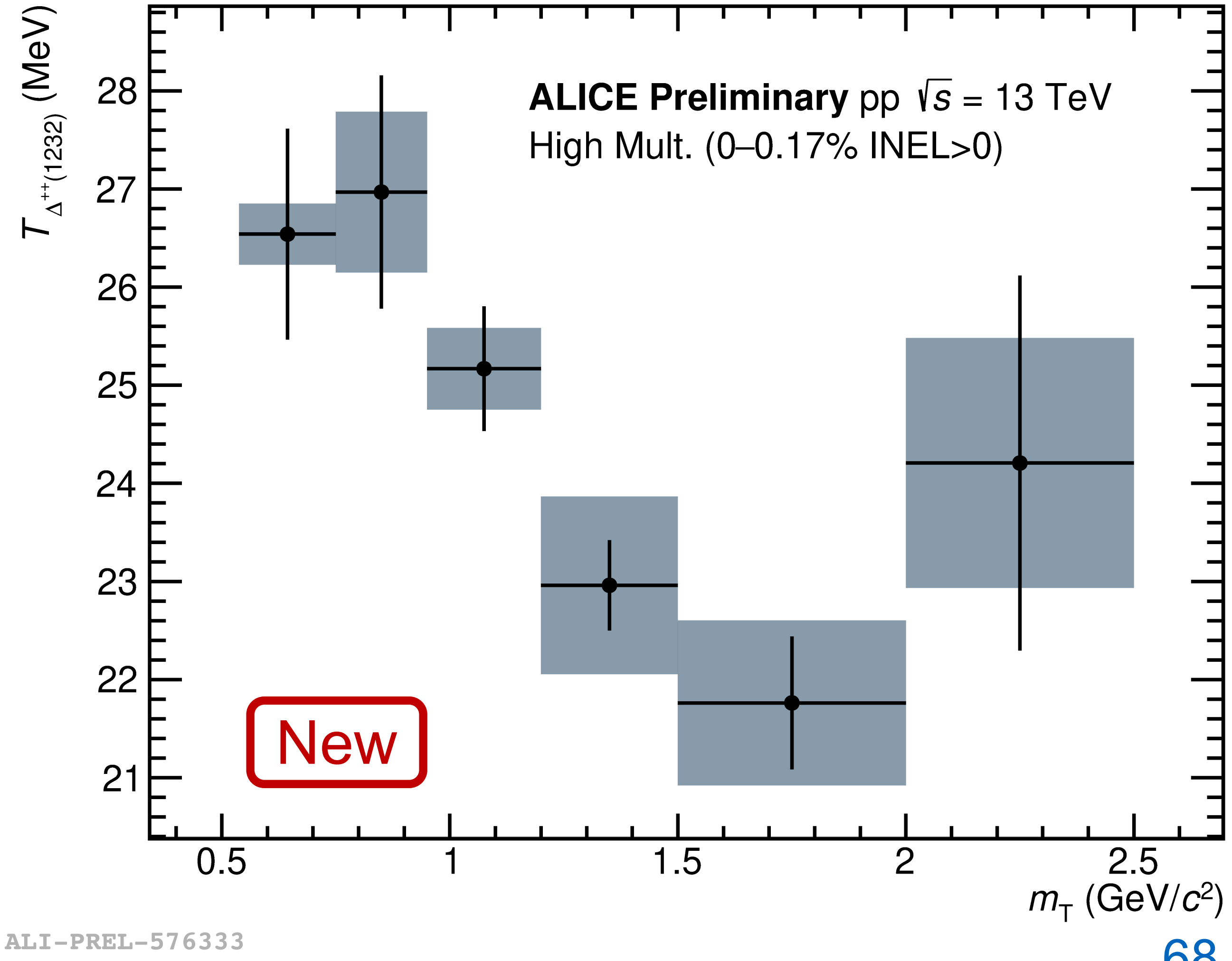
Kinetic freezout
→ characterized by T_{ch}

Decay of the $\Delta^{++} \rightarrow p\pi^{+}$
→ characterized by T_{dec}

Formation of the Δ^{++}
(and all other hadrons)
→ characterized by T_{ch}

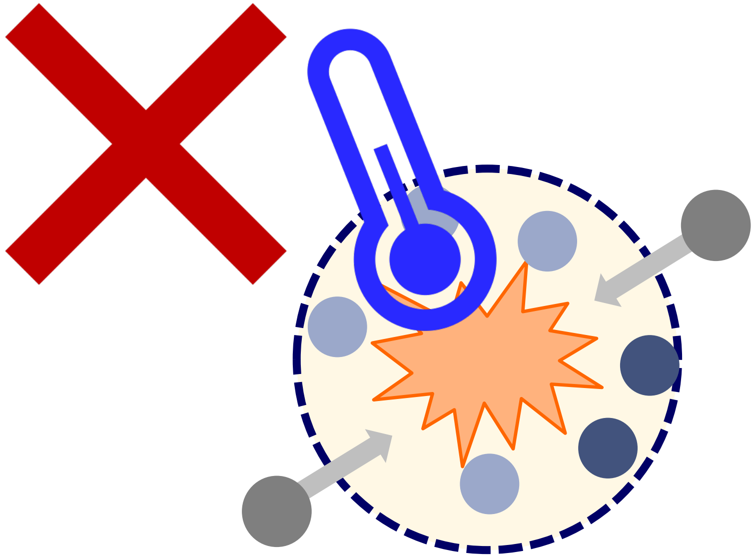
Kinetic decoupling temperature Δ^{++}

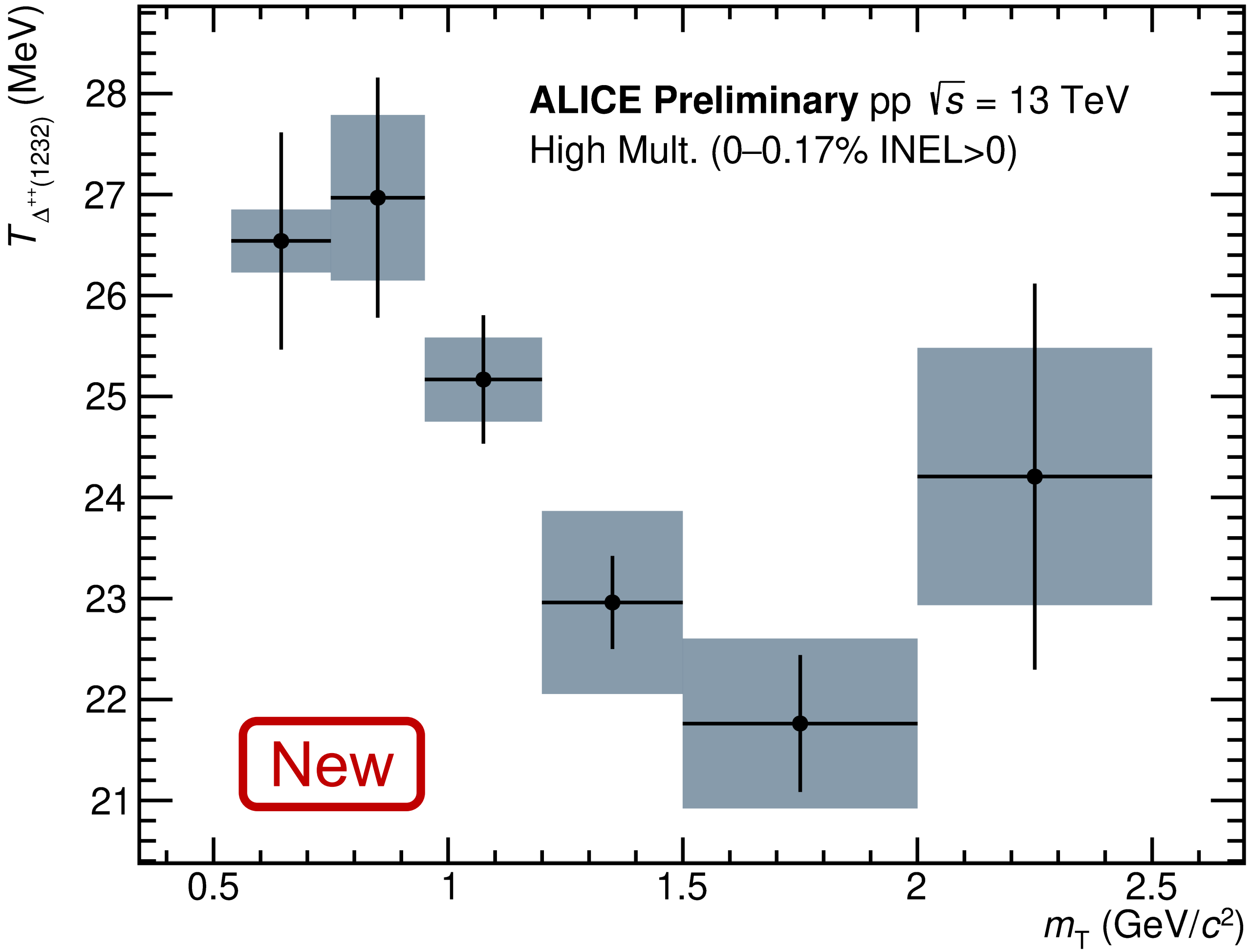
- Low "decoupling temperature" of about 25 MeV



Kinetic decoupling temperature Δ^{++}

- Low “decoupling temperature” of about 25 MeV
- This does not mean that pp collisions are cold!

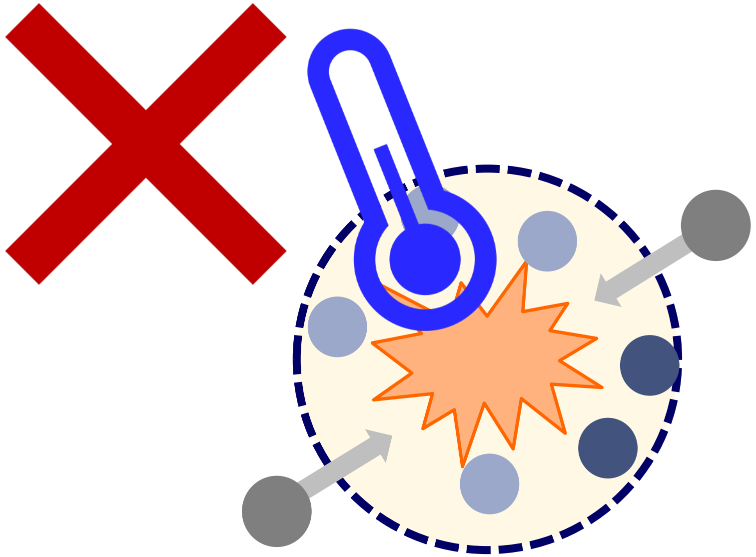




Kinetic decoupling temperature Δ^{++}

- Low "decoupling temperature" of about 25 MeV
- This does not mean that pp collisions are cold!
- We see a modification of the phase space of resonance

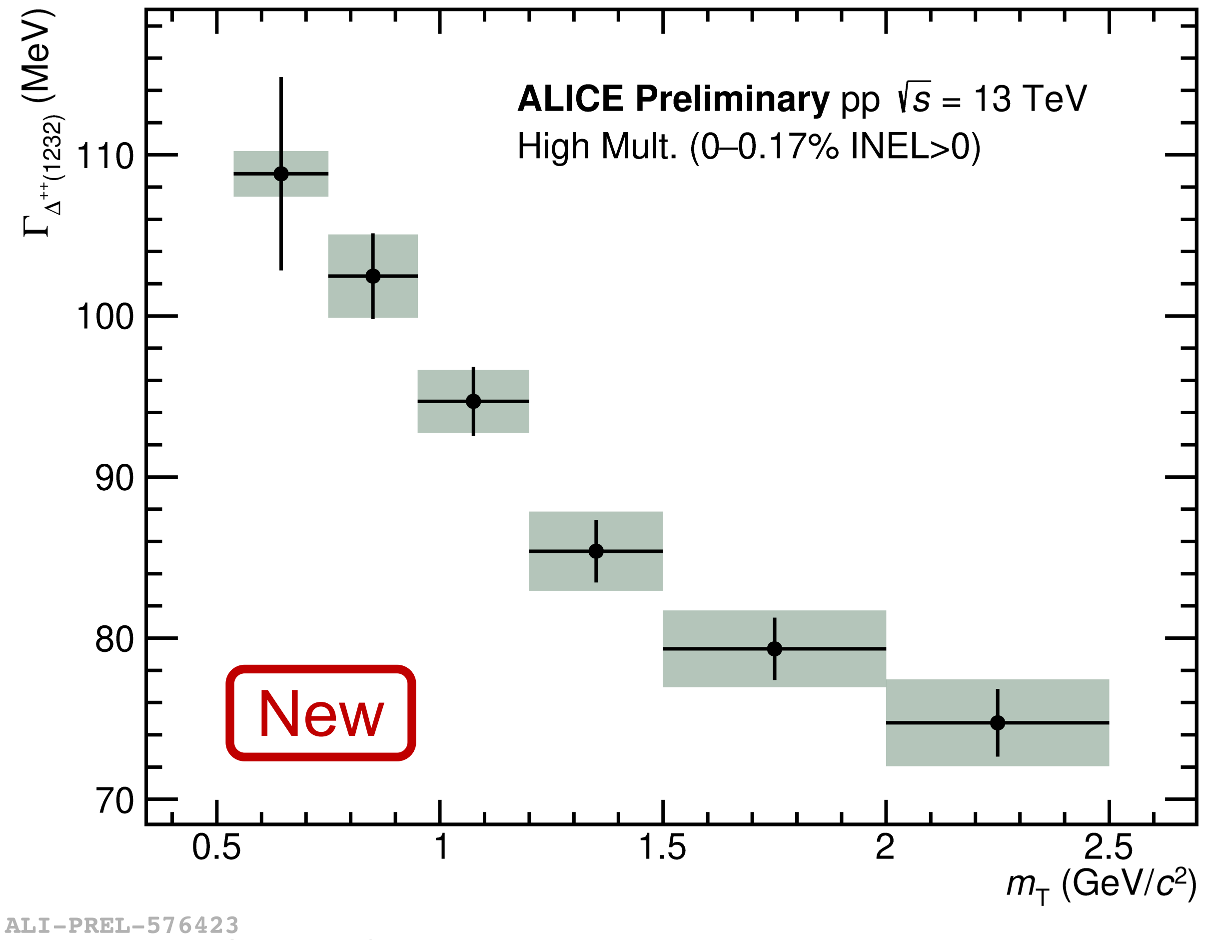
→ hadronic moshpit for the Δ^{++}

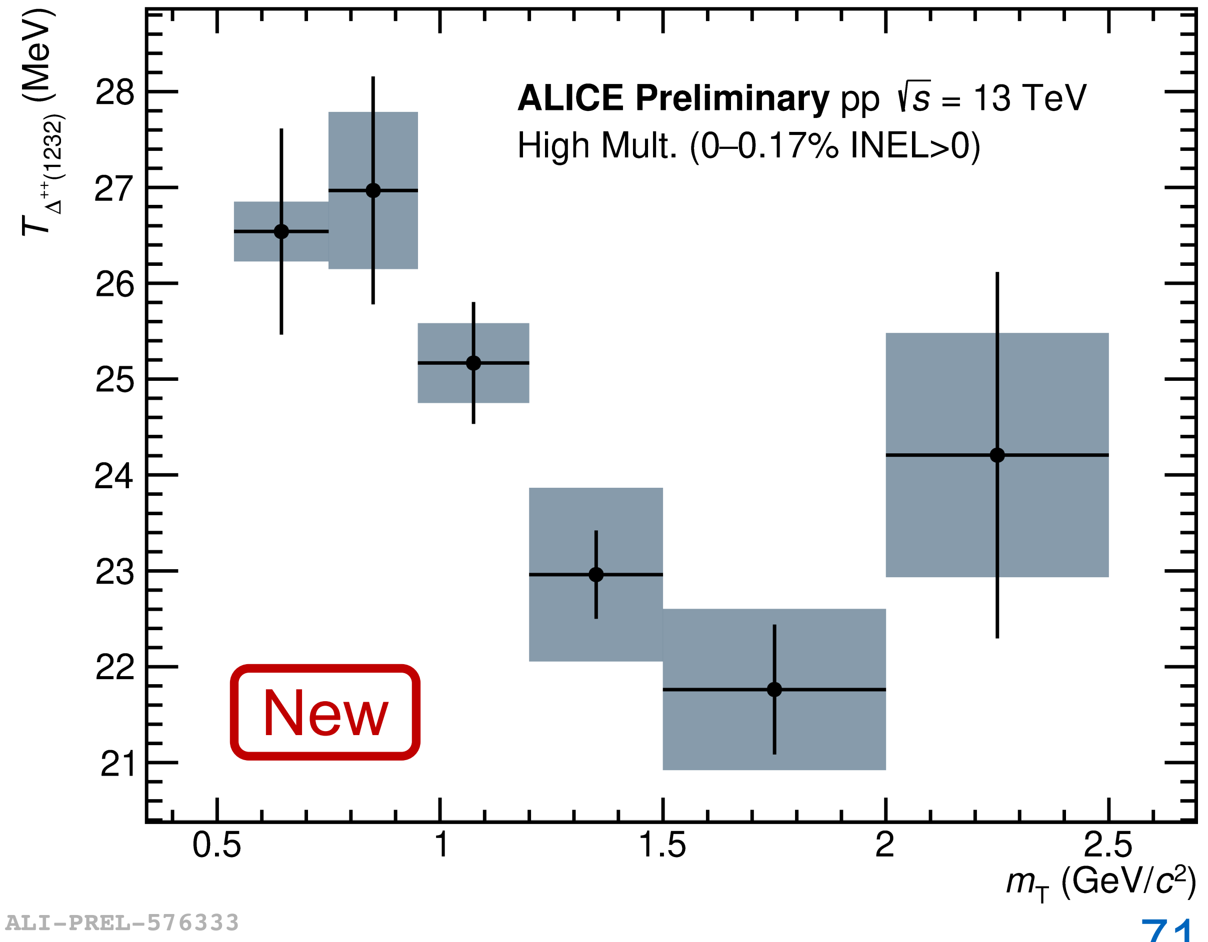


Thanks to Berkin and his AI friends!

Width & kinetic decoupling temperature Δ^{++}

- Width constant ~ 90 MeV
- Low "decoupling temperature" → modification of the phase space of resonance





Fitting of data $p\pi^-$

$$C_{\text{total}} = N \times C_{\text{bckg}} \times [\lambda_{\text{Gen}} C_0 + (1-\lambda_{\text{Gen}})] + N_\Delta PS(p_{\text{T}}, T) \times Sill(M_\Delta, \Gamma_\Delta) + N_\Lambda Gaus(M_\Lambda, \Gamma_\Lambda)$$

- Background $C_{\text{bckg}} = [\, 1 + N_{\text{B}}(w_{\text{c}} C_{\text{c}} + (1-w_{\text{c}}) C_{\text{NC}} - 1) + Sill(M_2, \Gamma_2) + Sill(M_3, \Gamma_3)]$
- Interaction C_0 Coulomb + strong interaction (fixed from scattering lengths)

  M. Hoferichter et al, Phys.Rept. 625 (2016) 1-88.
  M. Hennebach et al, Eur.Phys.J.A 50 (2014) 12, 190
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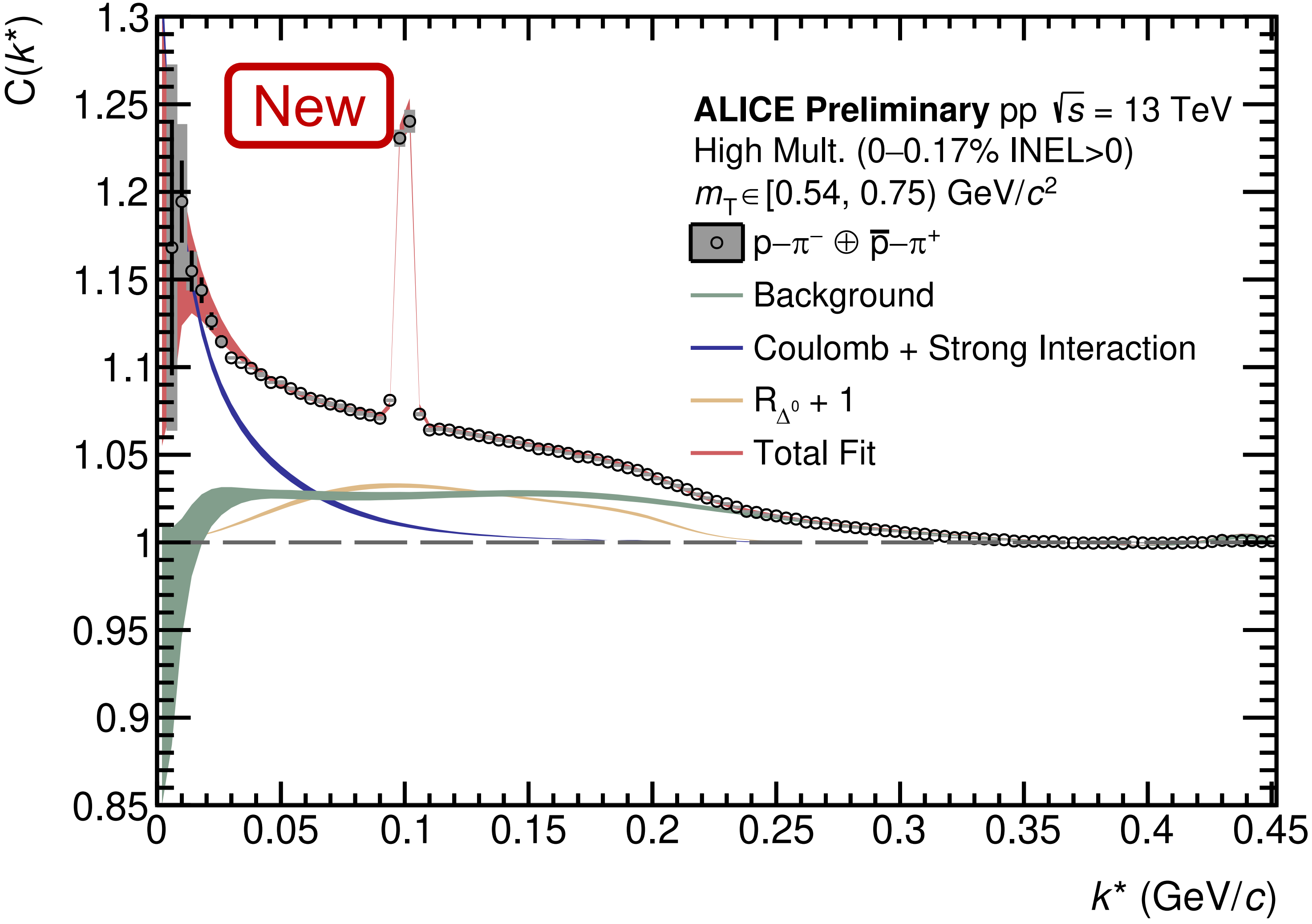
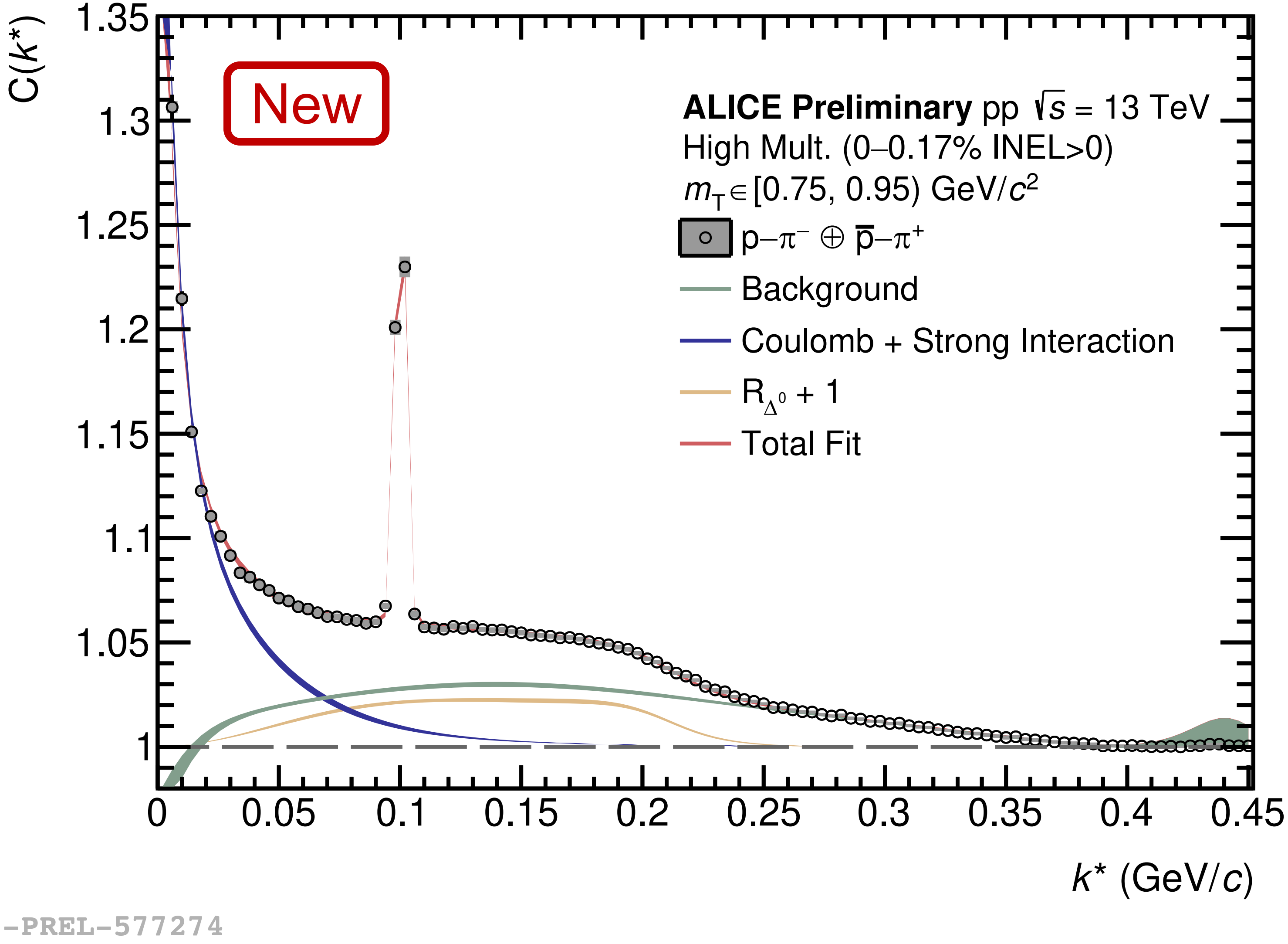
- r_{core}
- Scaling of Δ^0 N_Δ
- T (kinetic decoupling temp.)
- Width of Δ^0
- Scaling of Λ N_Λ
- Mass of Λ
- Width of Λ

$p\pi^-$ - m_T interval 1

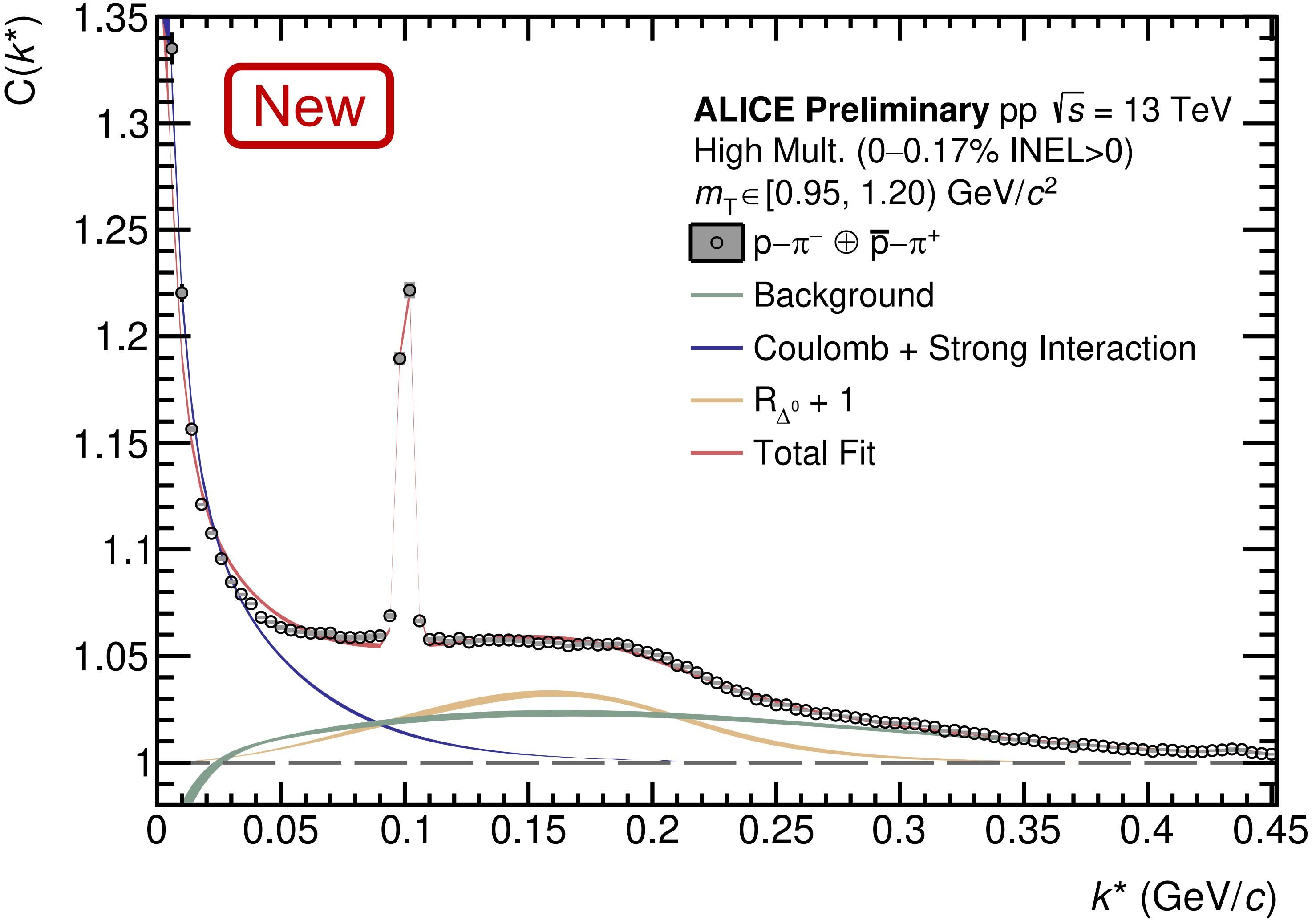


ALI-PREL-577269

$p\pi^-$ - m_T interval 2



$p\pi^-$ - m_T interval 3



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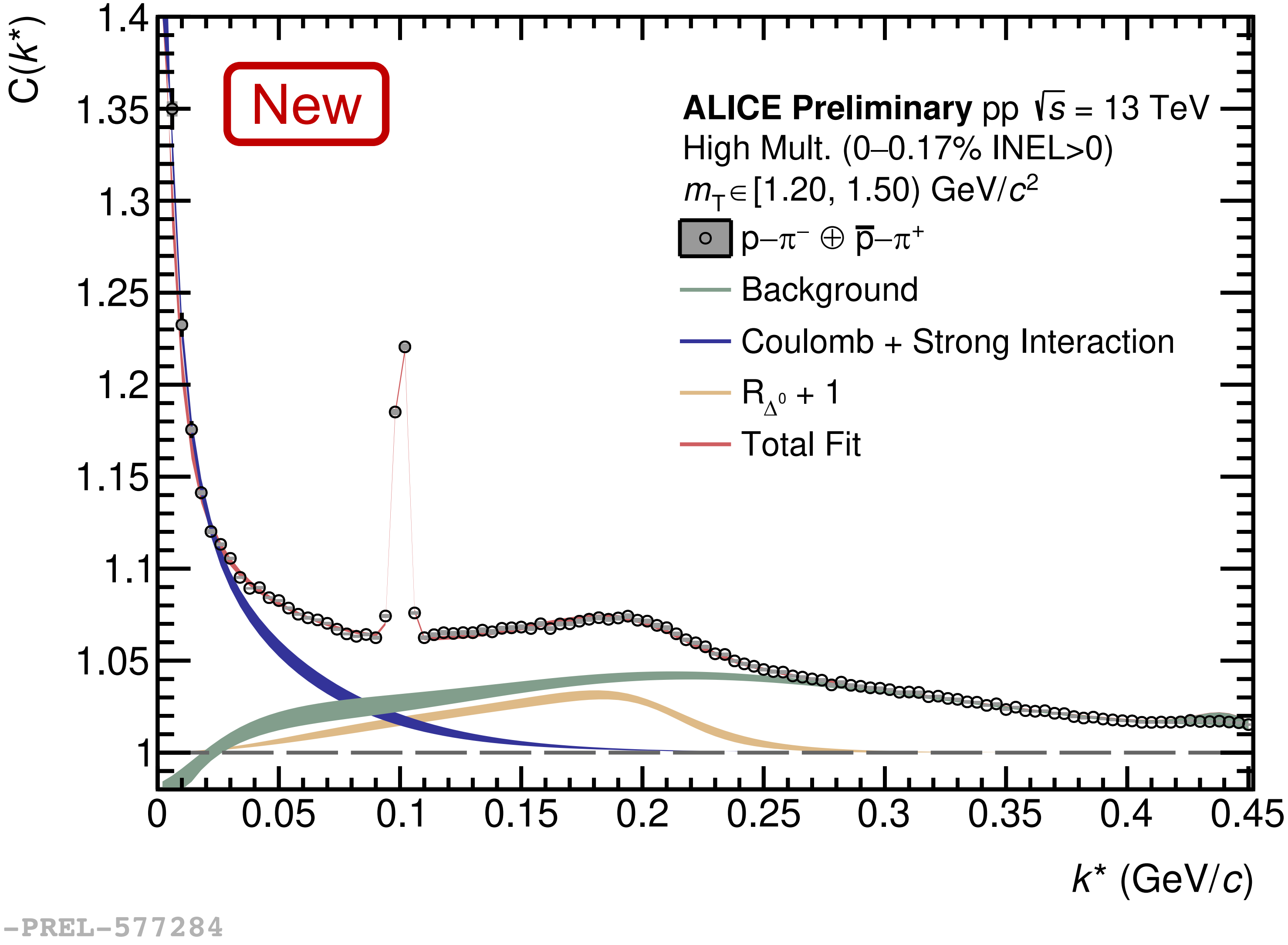
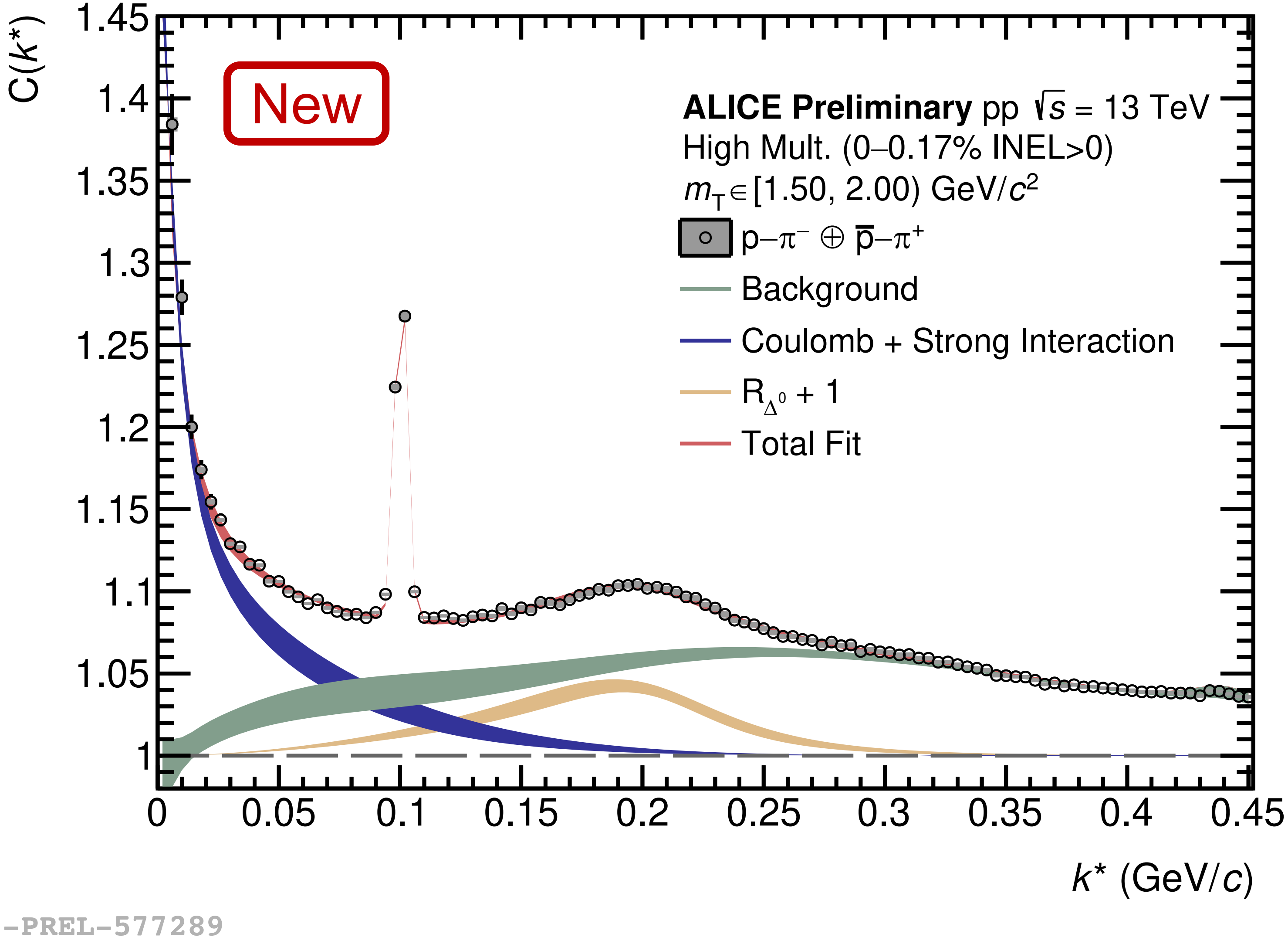
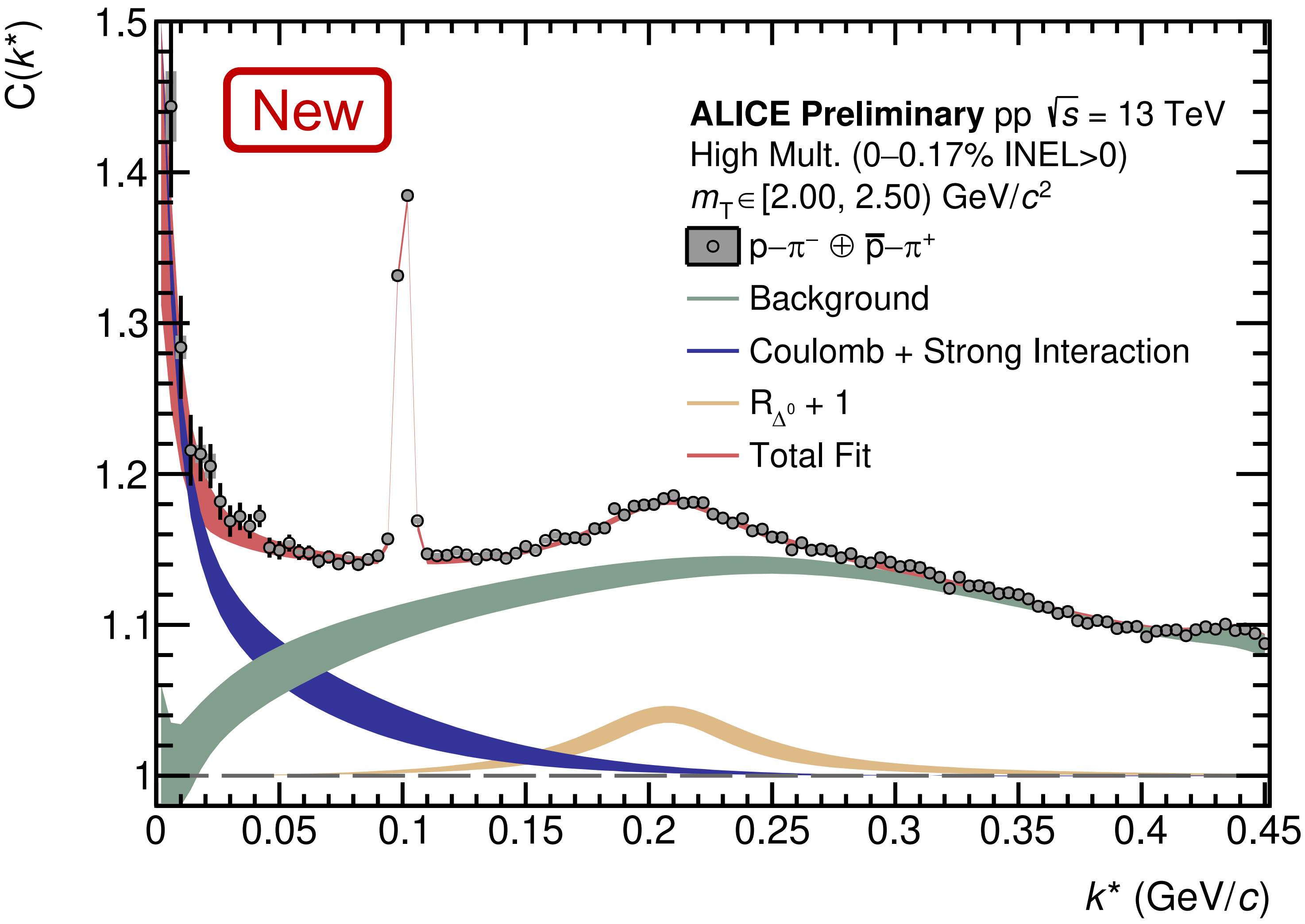
$p\pi^-$ - m_T interval 4



$p\pi^-$ - m_T interval 5



$p\pi^-$ - m_T interval 6



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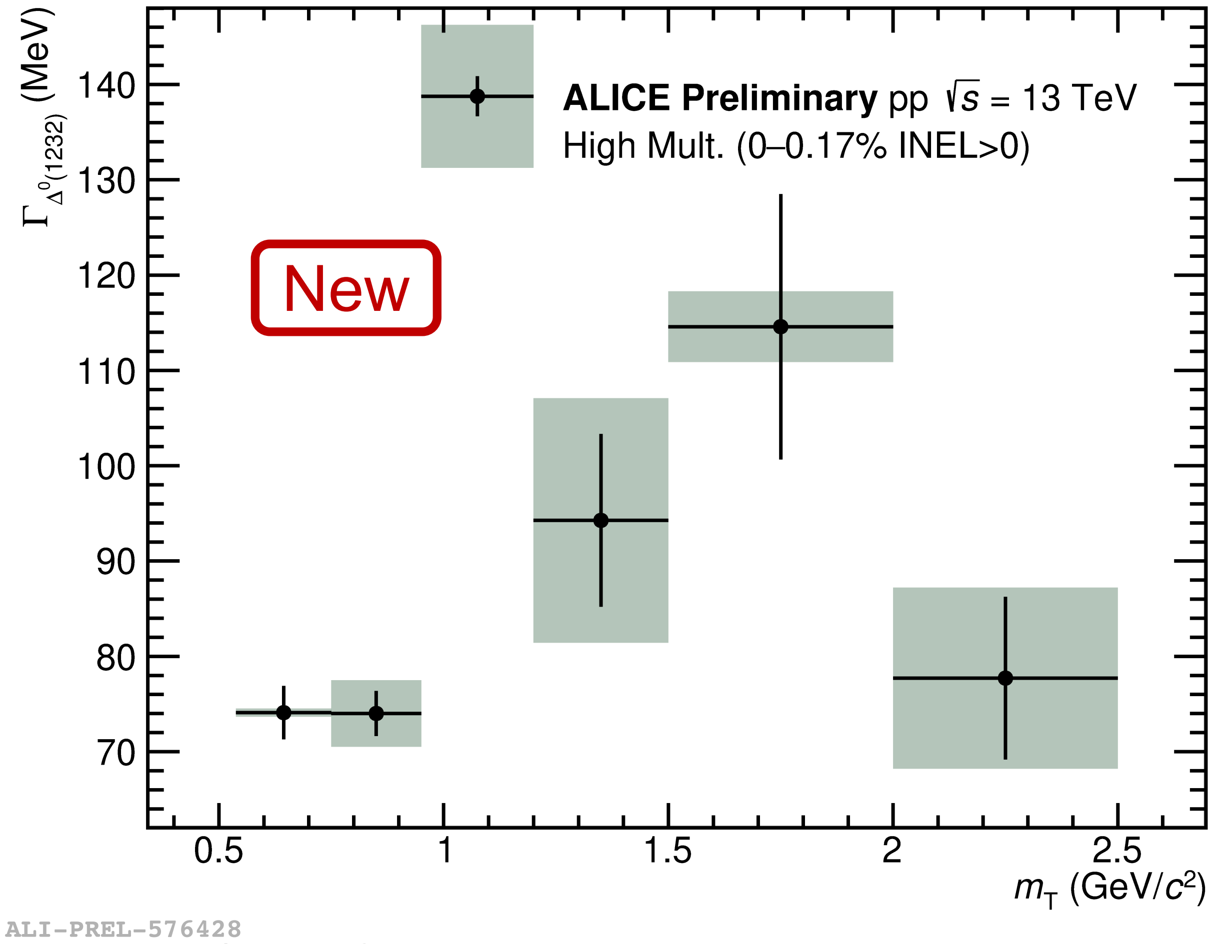
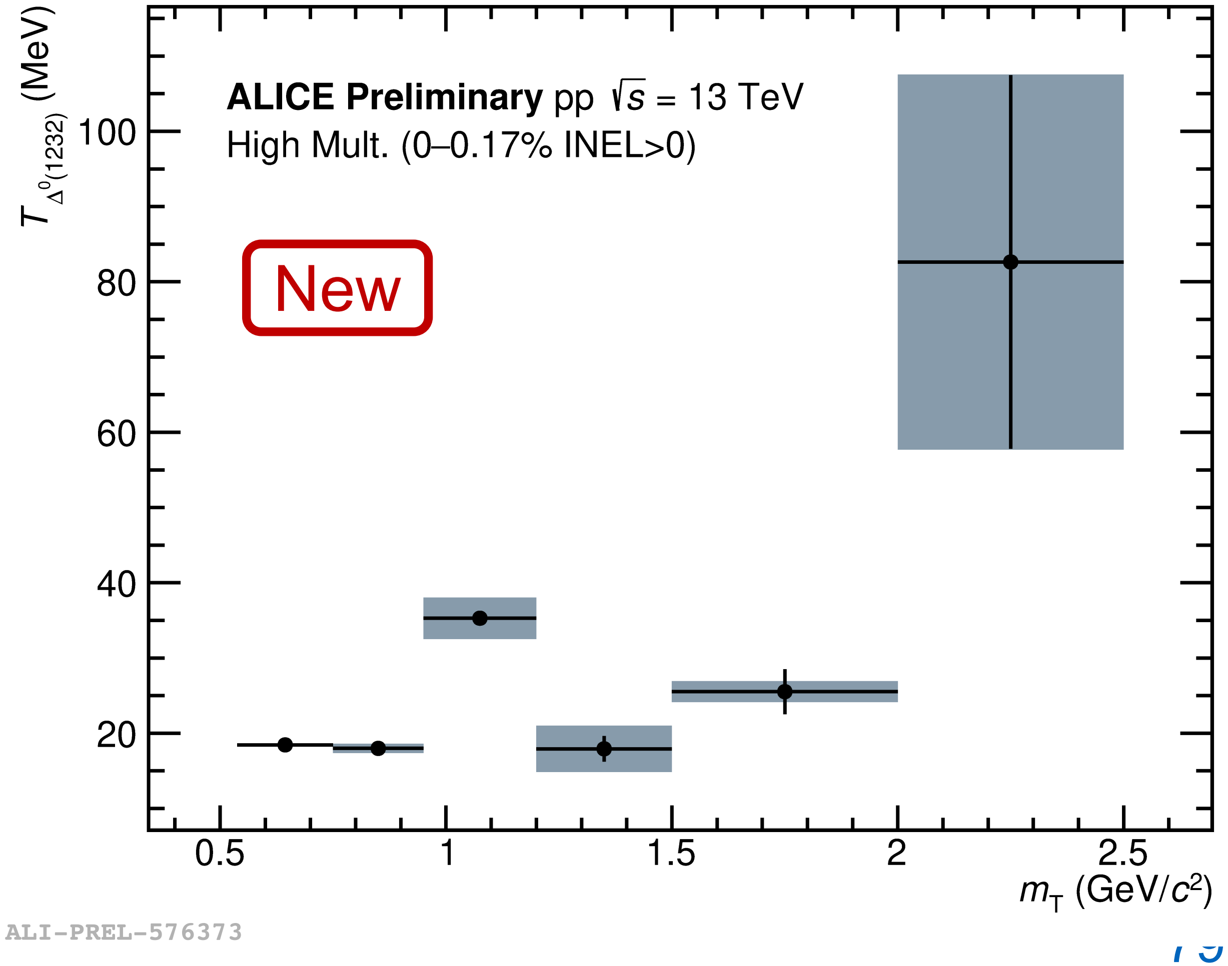
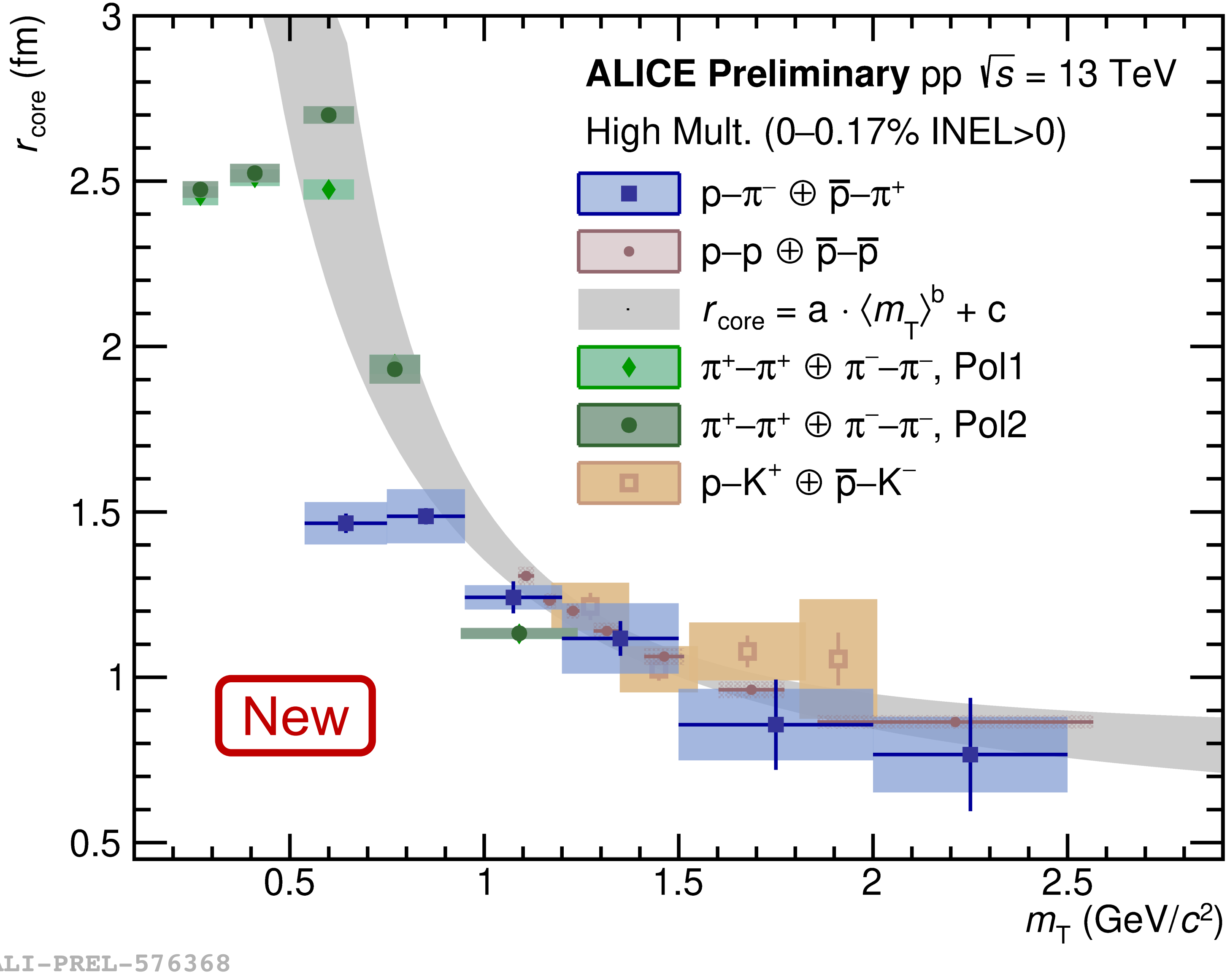
Width & kinetic decoupling temperature Δ^0

- Width constant ~ 90 MeV
- Low “decoupling temperature” → modification of the phase space of resonance





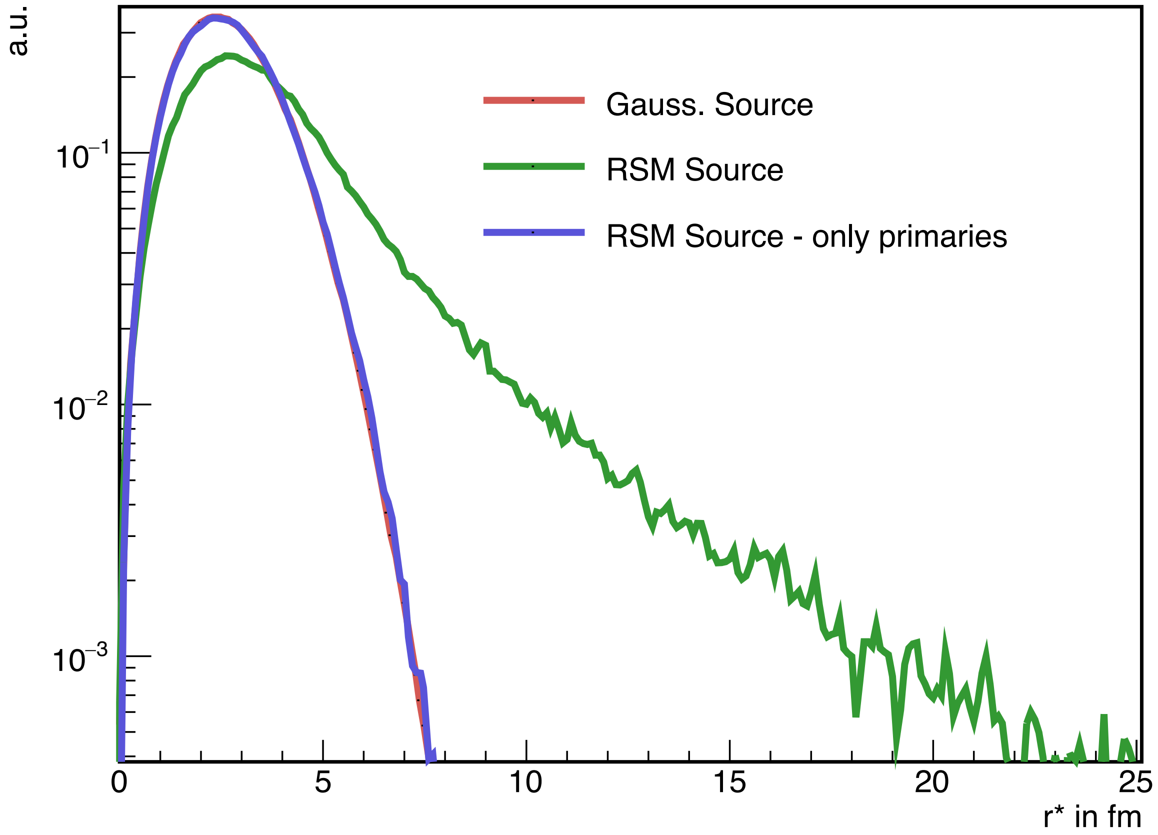


ALICE Preliminary pp $\sqrt{s}$ = 13 TeV
High Mult. (0–0.17% INEL>0)
p–π⁻ ⊕ p̄–π⁺
p–p ⊕ p̄–p̄
$r_{core} = a \cdot \langle m_T \rangle^b + c$
π⁺–π⁺ ⊕ π⁻–π⁻, Pol1
π⁺–π⁺ ⊕ π⁻–π⁻, Pol2
p–K⁺ ⊕ p̄–K⁻
New
r_{core} (fm)
m_T (GeV/c^2)
0.5
1
1.5
2
2.5
3
ALI-PREL-576368

Source

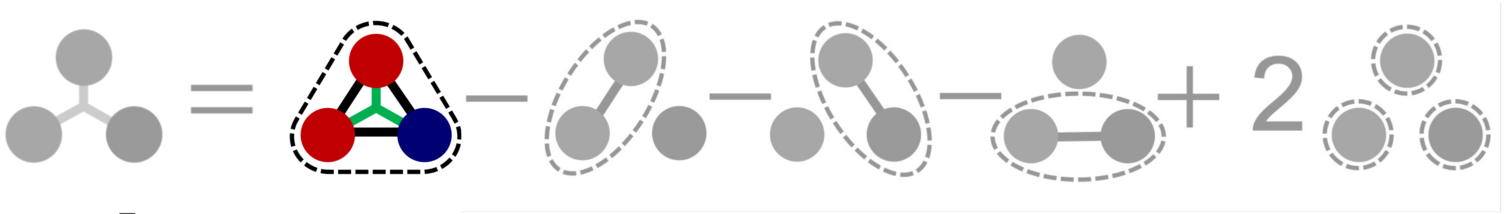
- Source from resonance source model

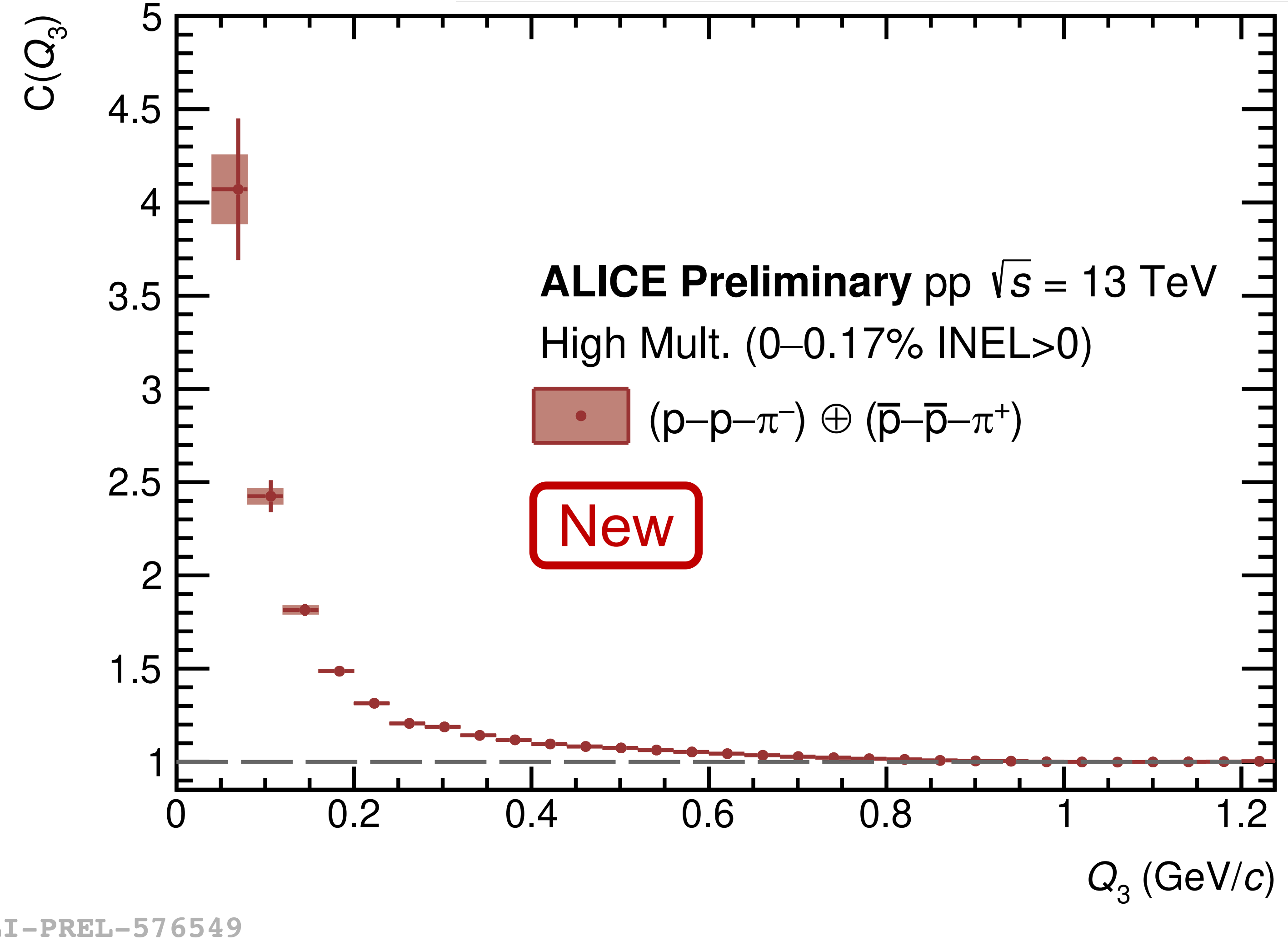
Property	Value
Proton Effective Resonance mass $\langle m \rangle_{eff,p}$	1.360 GeV
Proton Effective Resonance life-time $\langle \tau \rangle_{eff,p}$	1.65 fm
Proton Primordial Fraction	0.357
Pion Effective Resonance mass $\langle m \rangle_{eff,\pi}$	1.124 GeV
Pion Effective Resonance life-time $\langle \tau \rangle_{eff,\pi}$	1.5 fm
Pion Primordial Fraction	0.39



Three-particle correlation function of ppπ^-

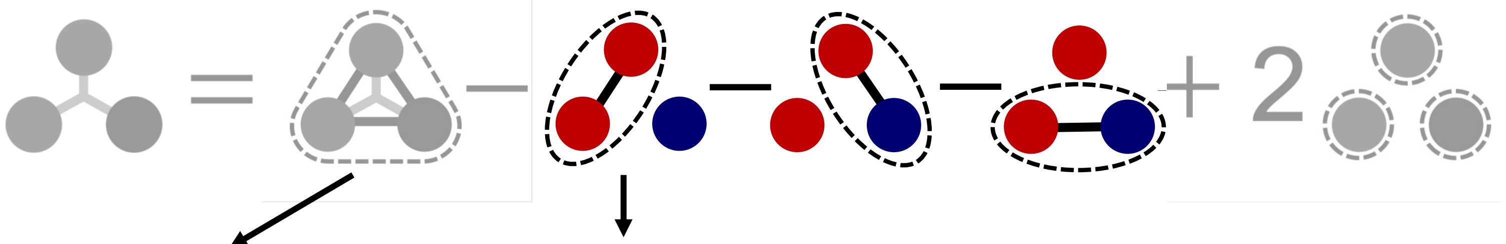
- Overall attractive effects in triplet correlation function
- Signal consisting of two-body and potential three-body effects

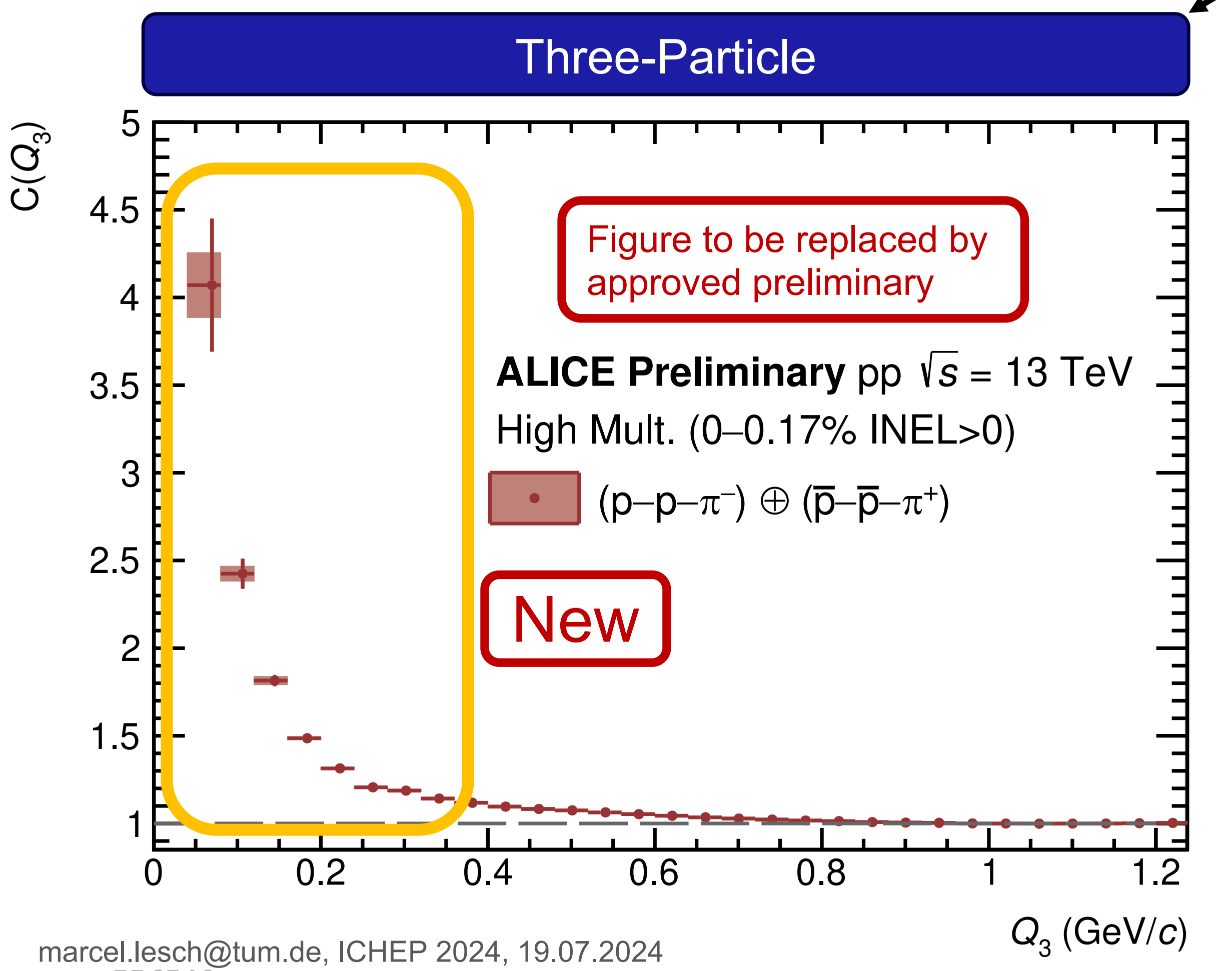


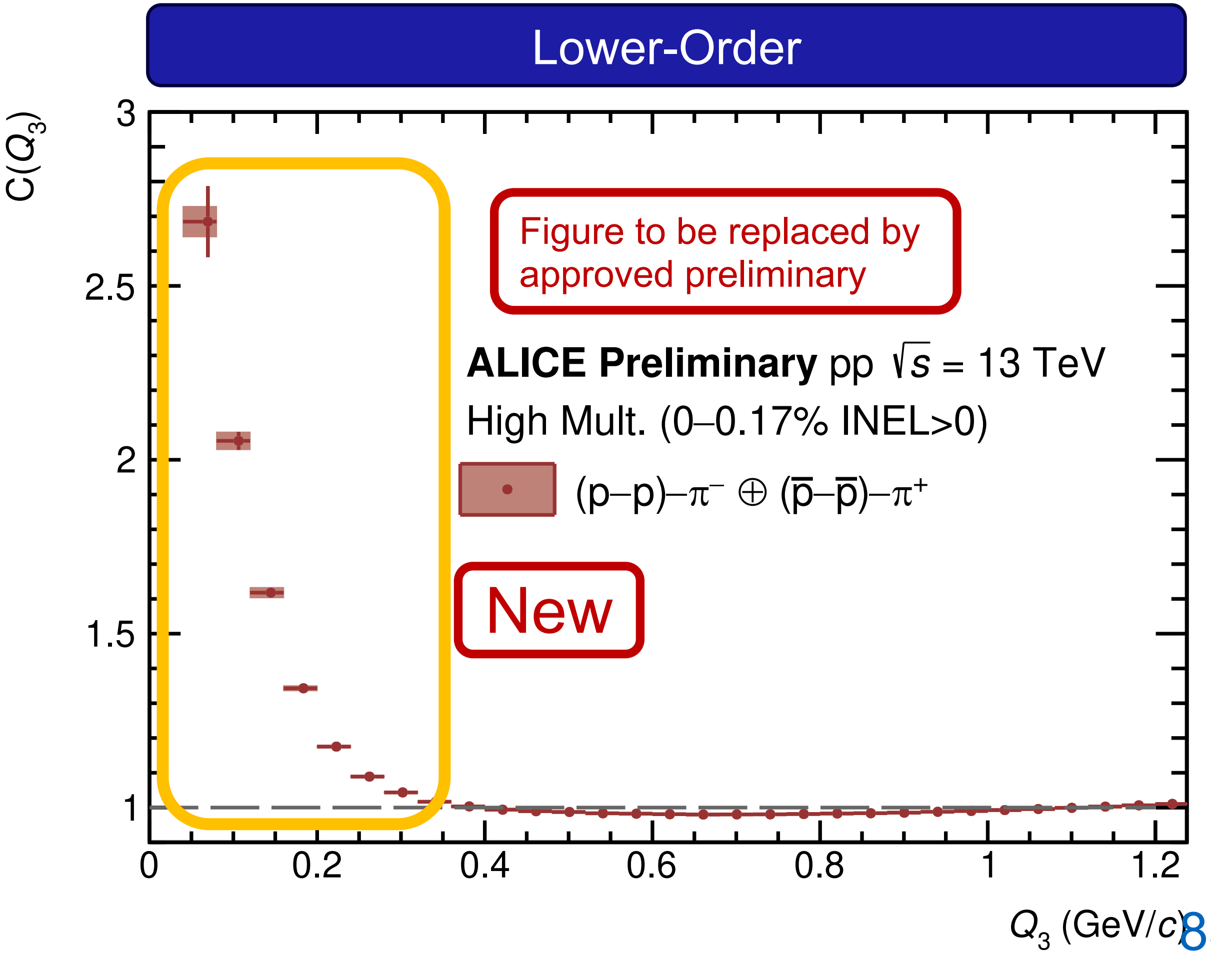


Two-particle contributions of $pp\pi^-$

- Contribution from attractive strong interaction of pp







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Two-body contributions of ppπ^-

- Visible contribution from $\Lambda \rightarrow p\pi^-$