Hyperon-nucleon and hyperon-hyperon interaction studied via two-particles correlations

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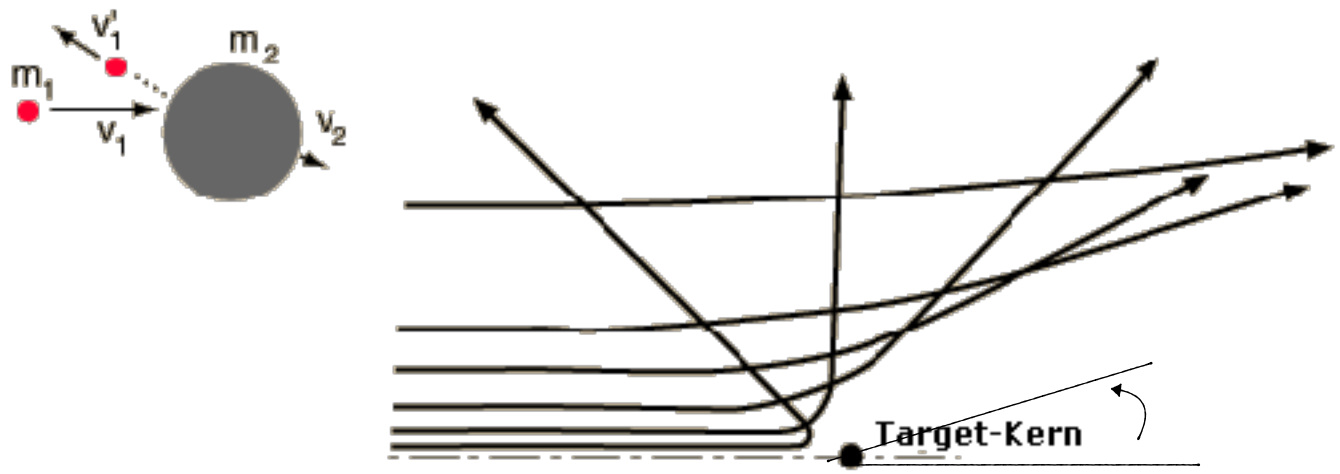
Outline

- Hadron interactions
- The measurement of Hadron Hadron Correlations
- Experimental Results: RUN1 and RUN2
  - pp Collisions at 7 TeV, 5 TeV and 13 TeV, p-Pb at 5.02 TeV measured by ALICE
  - pp, pΛ , pΞ^-, pK($\overline{\text{K}}$) Correlations
- Outlook

Hadron Interactions

Scattering Data and Interaction Parameters

Scattering experiments -> Extraction of the differential cross section



$$\longrightarrow \quad \frac{d\sigma}{d\Omega}$$

Partial Wave Expansion:

$$\sigma = \frac{4\pi}{k^2} \sum_l (2l+1) \sin^2(\delta_l).$$

δ_l = phase shifts

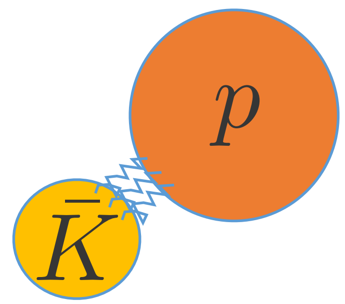
Scattering Length

$$f_0 = -\lim_{k \to 0} \frac{1}{k} \tan \delta_0(k)$$

l=0, s-wave Only!

Which information does the scattering length carry?

Kaon-Nucleon:

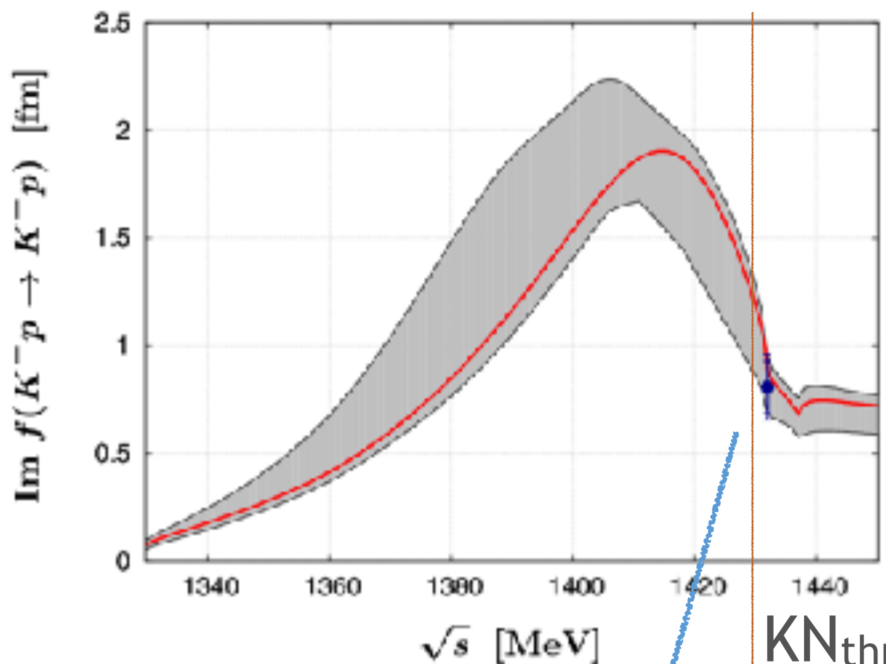


Bound state?

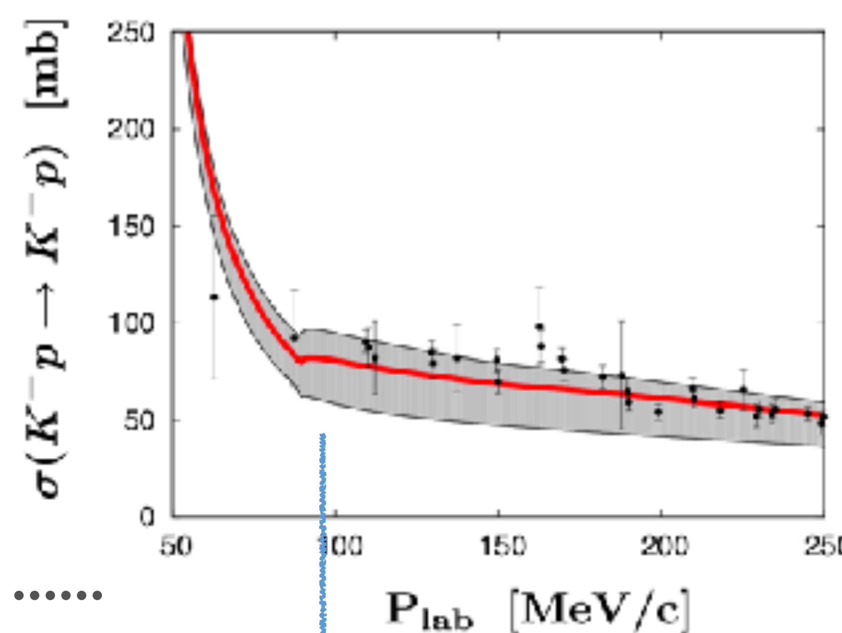
$\Lambda(1405)$

Ant

At and Below Threshold



Above Threshold



...... $KN_{threshold}$

$p_{lab} = 0$

kaonic atoms

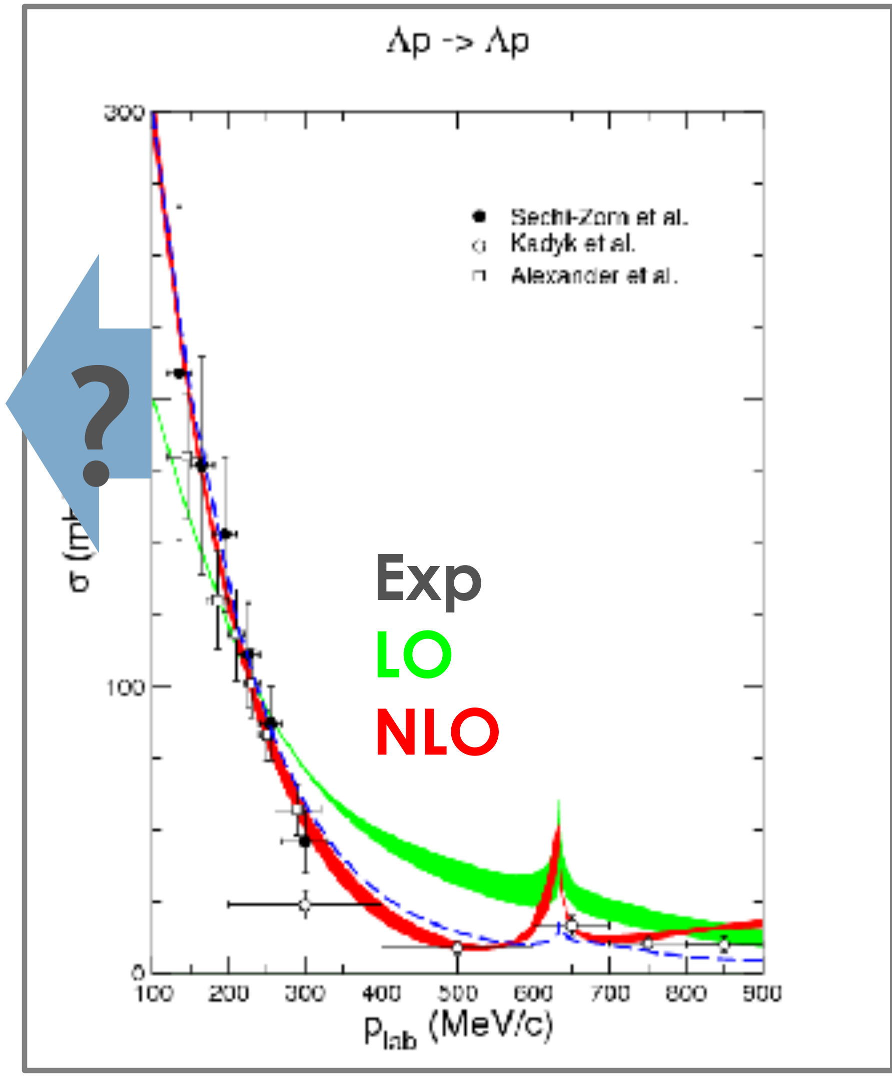
Siddharta er al. Phys.Lett. B704 (2011)

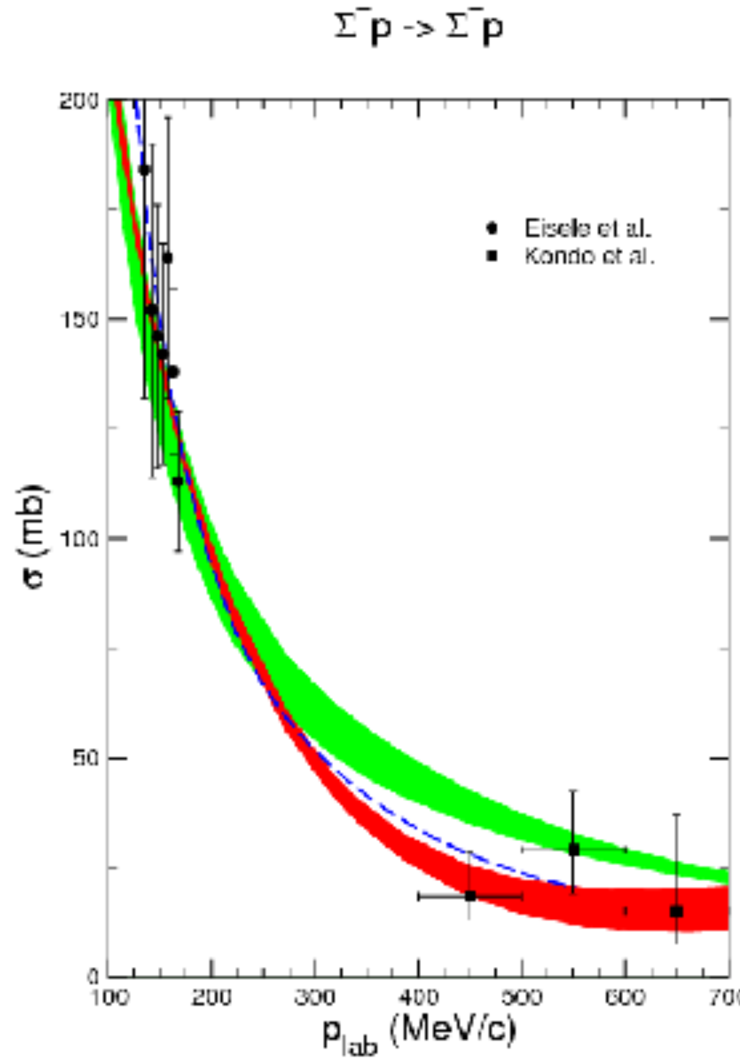
Scattering data

G.S. Abrams *et al.* Phys.Rev. 139 (1965) B454-B457

Y. Ikeda et al Nucl.Phys. A881 (2012) 98-114

Hyperon-Nucleon Scattering





LO: H. Polinder, J.H., U. Meißner, NPA 779 (2006) 244
NLO: J.Haidenbauer., N.Kaiser, et al., NPA 915 (2013) 24

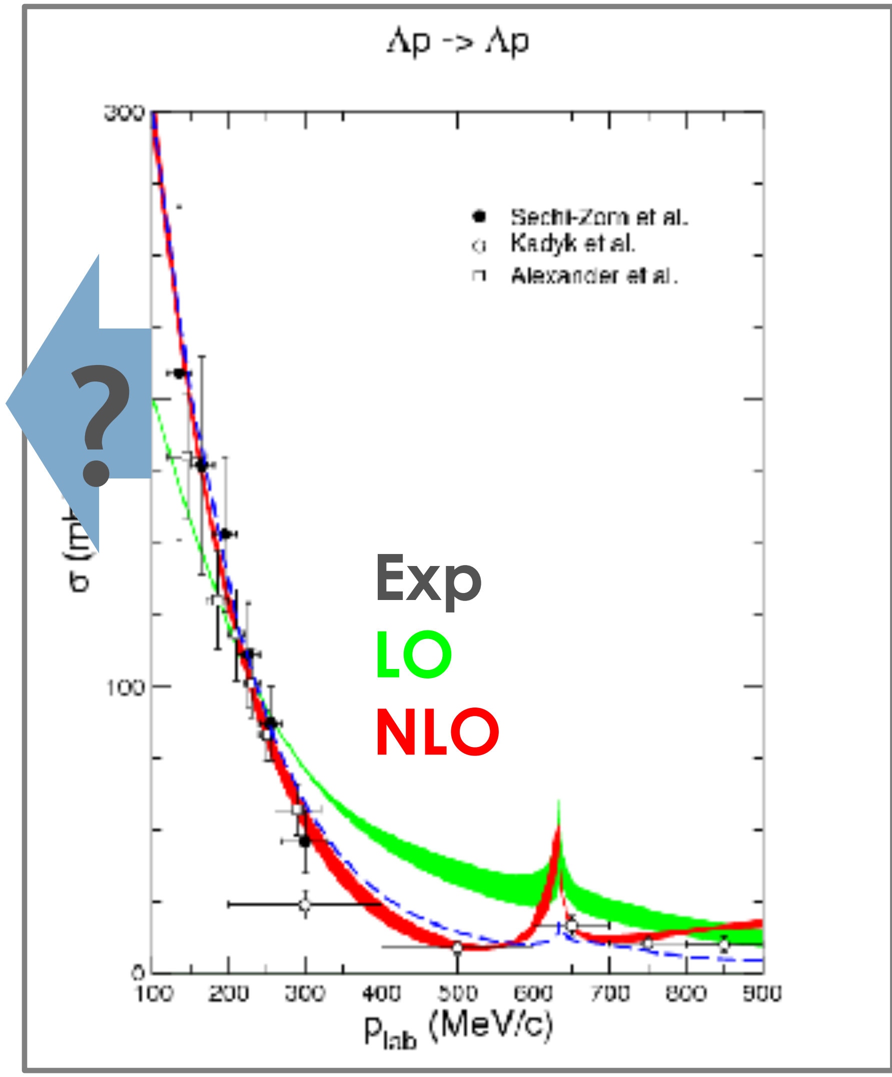
Data from scattering experiments and bubble chambers detectors from 1968 and 1971

$K^- + p \rightarrow \Sigma^0 + \pi^0,\ \Sigma^0 \rightarrow \Lambda + \gamma$

$K^- + p \rightarrow \Sigma^- + \pi^+ \ldots$

Production Threshold for $\Lambda's:\ p \geq 100\, MeV$

Hyperon-Nucleon Scattering



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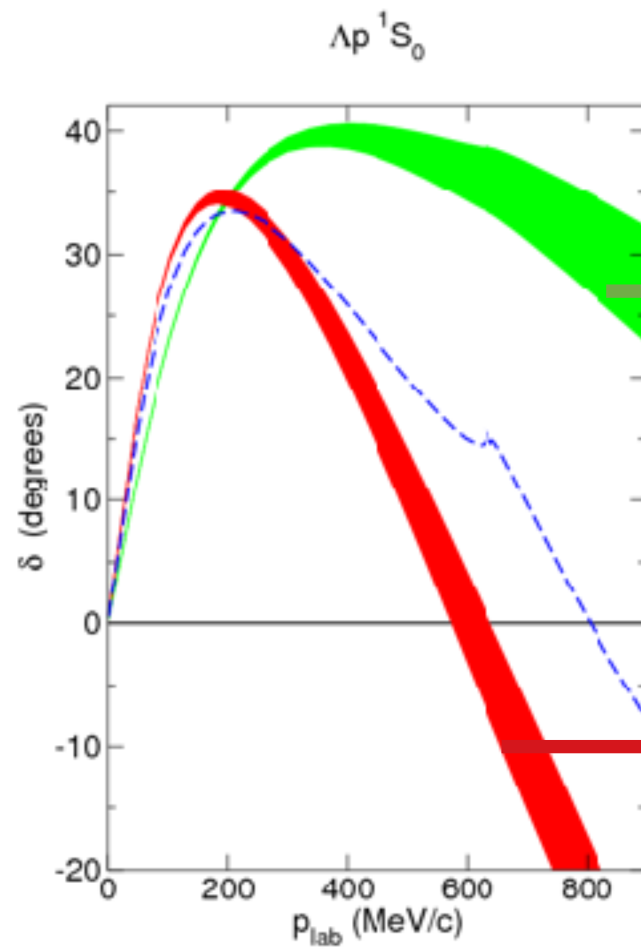
LO less attractive than **NLO**

$a^1S_0 = -1.91\,fm$ $a^1S_0 = -2.91\,fm$



Interaction always attractive

Interaction becomes repulsive
Repulsive core of the interaction

Data from scattering experiments and bubble chambers detectors from 1968 and 1971

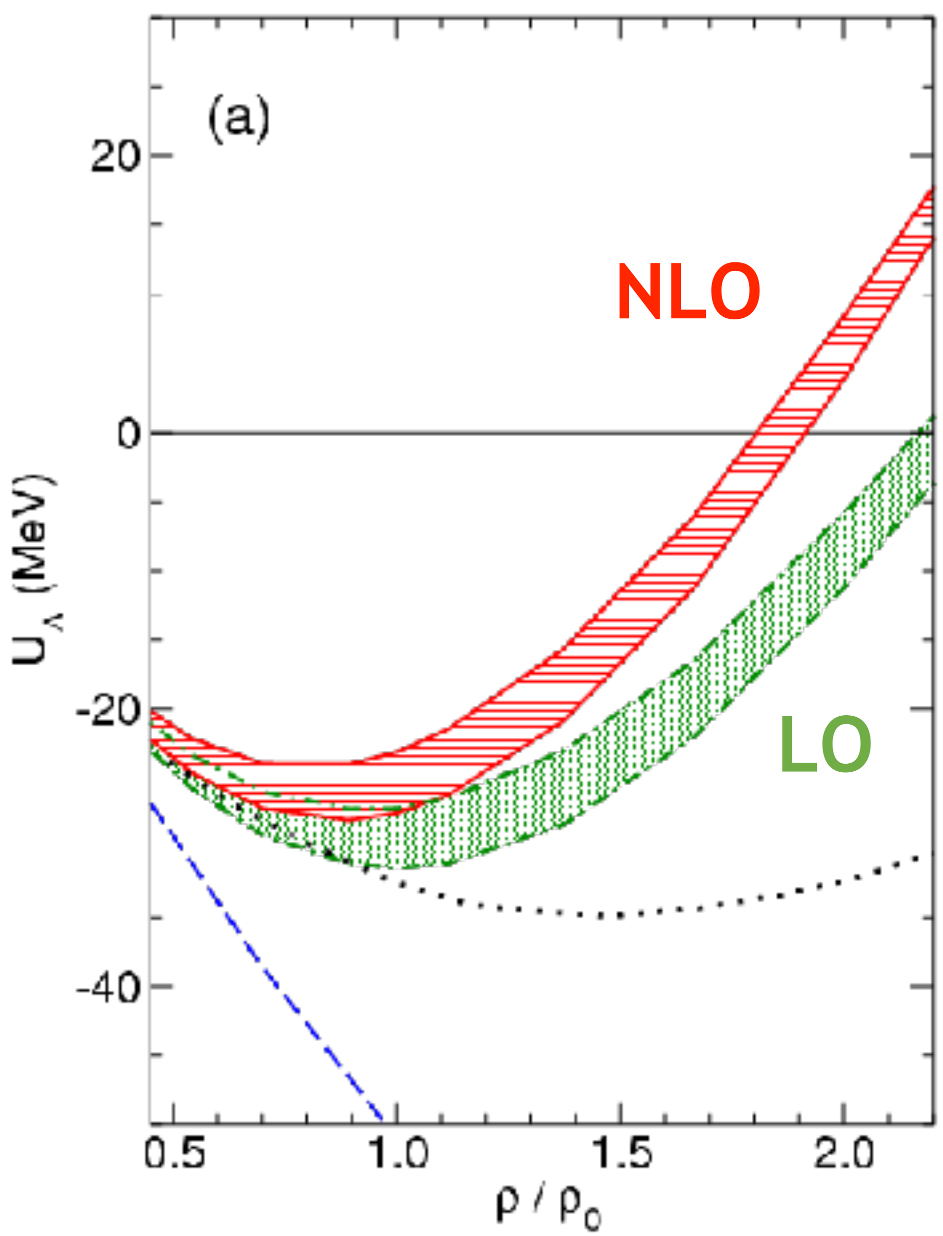
$K^- + p \rightarrow \Sigma^0 + \pi^0,\ \Sigma^0 \rightarrow \Lambda + \gamma$

$K^- + p \rightarrow \Sigma^- + \pi^+ \ldots$

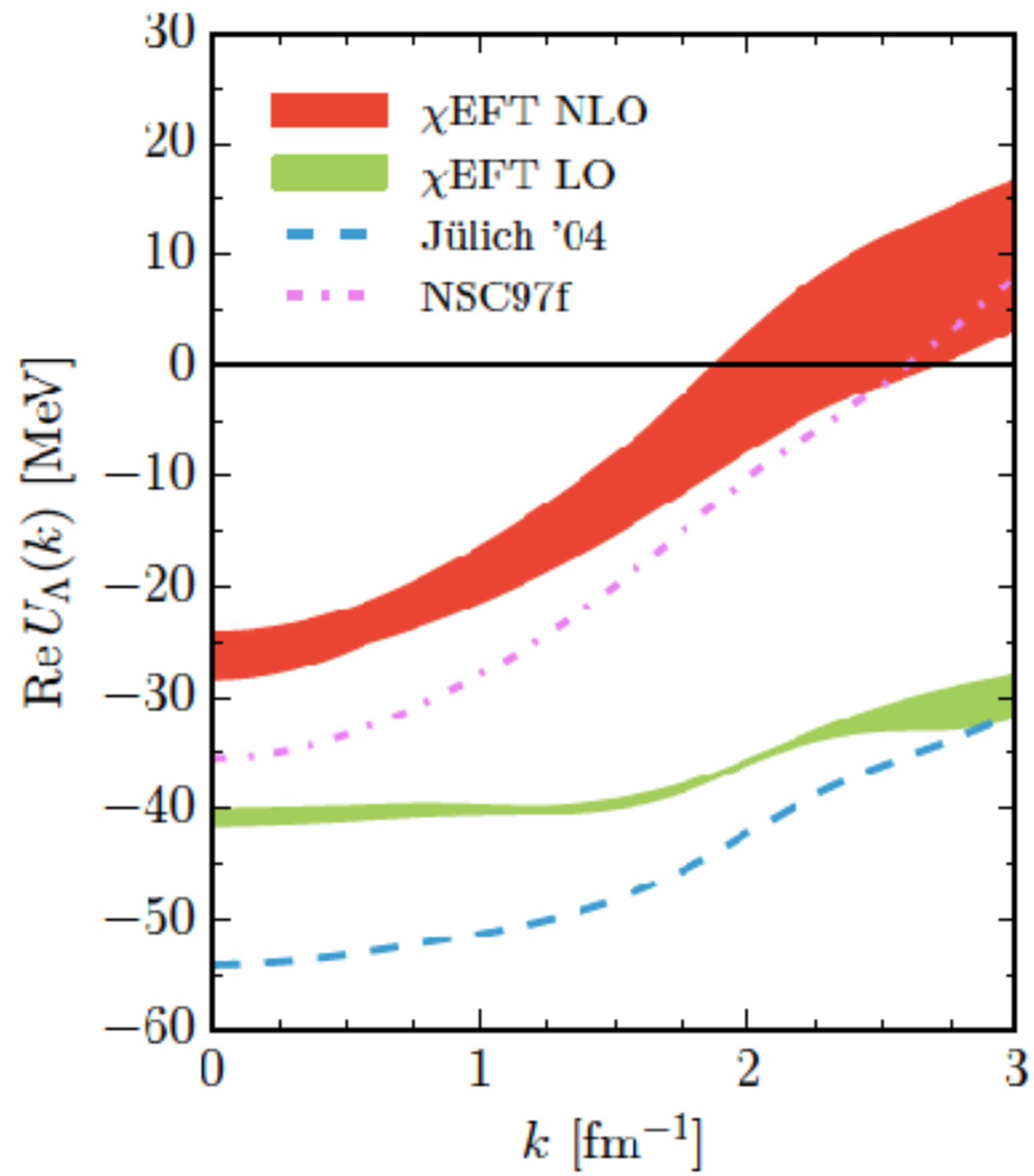
Production Threshold for $\Lambda's:\ \ p \geq 100\,MeV$

Single Particle Potential

Two particle interactions are fundamental to extract the behaviours of hyperons within nuclear matter



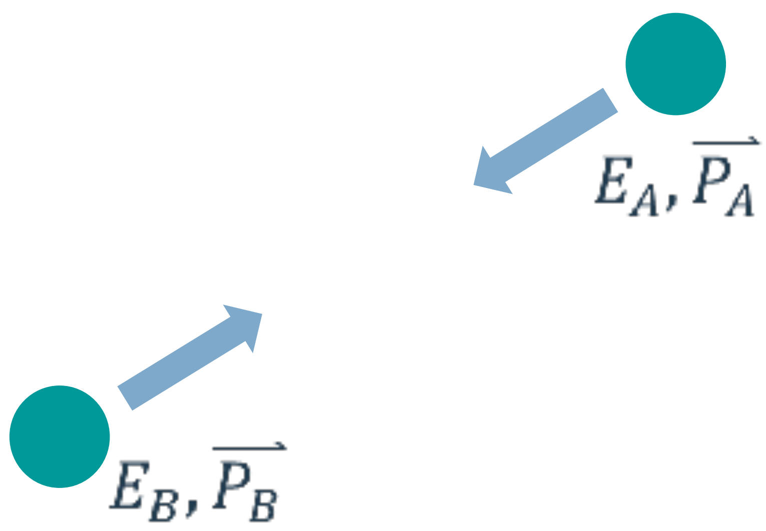
Haidenbauer et a. Eur.Phys.J. A53 (2017) no.6, 121



Petschauer et al. Eur.Phys.J. A52 (2016) no.1, 15

The measurement of Hadron Hadron Correlations

Nuclear Collisions



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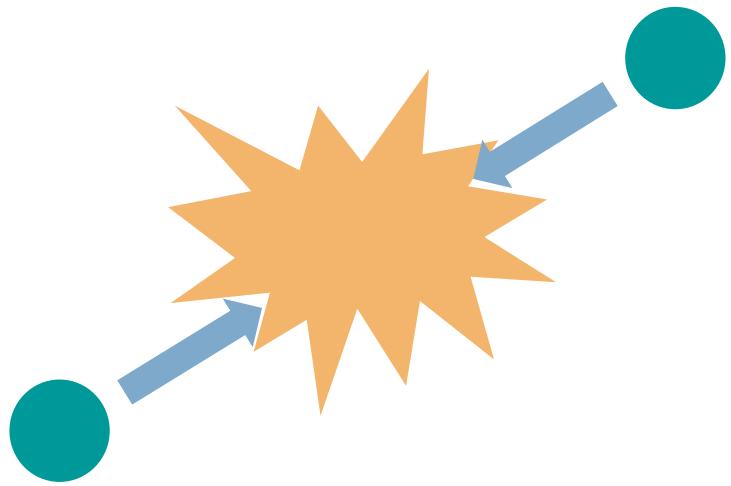
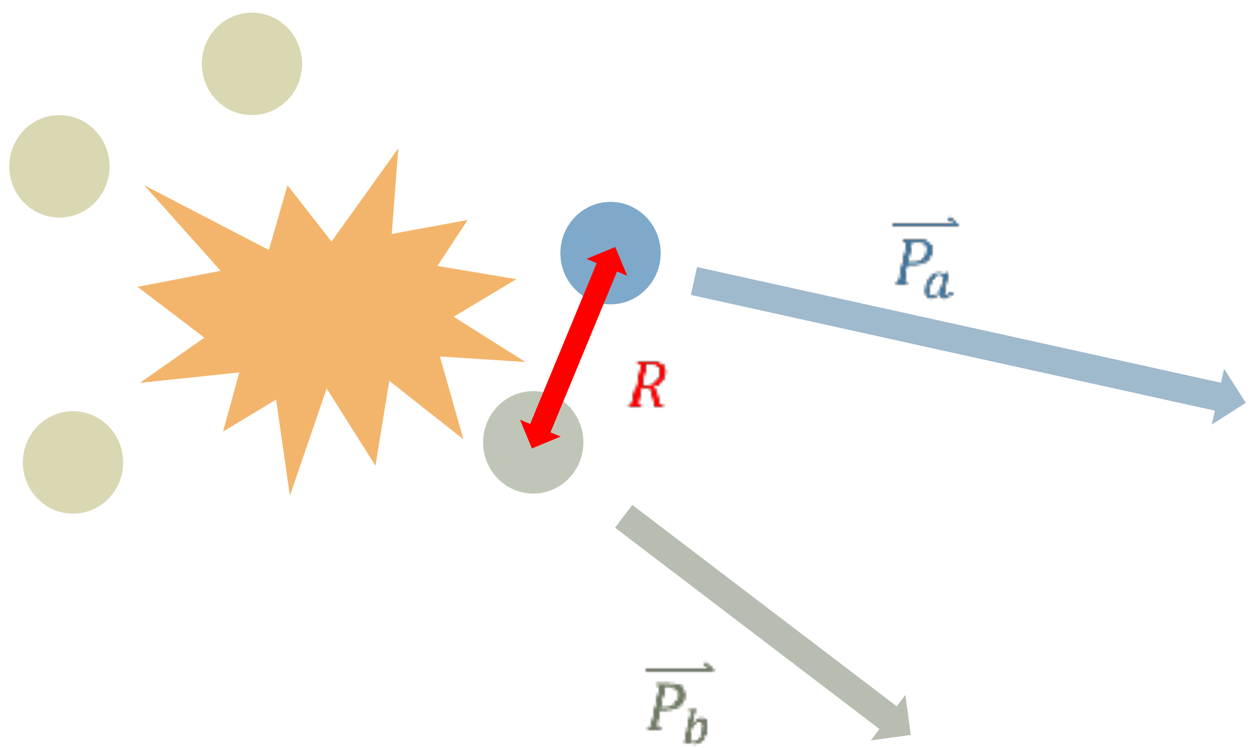
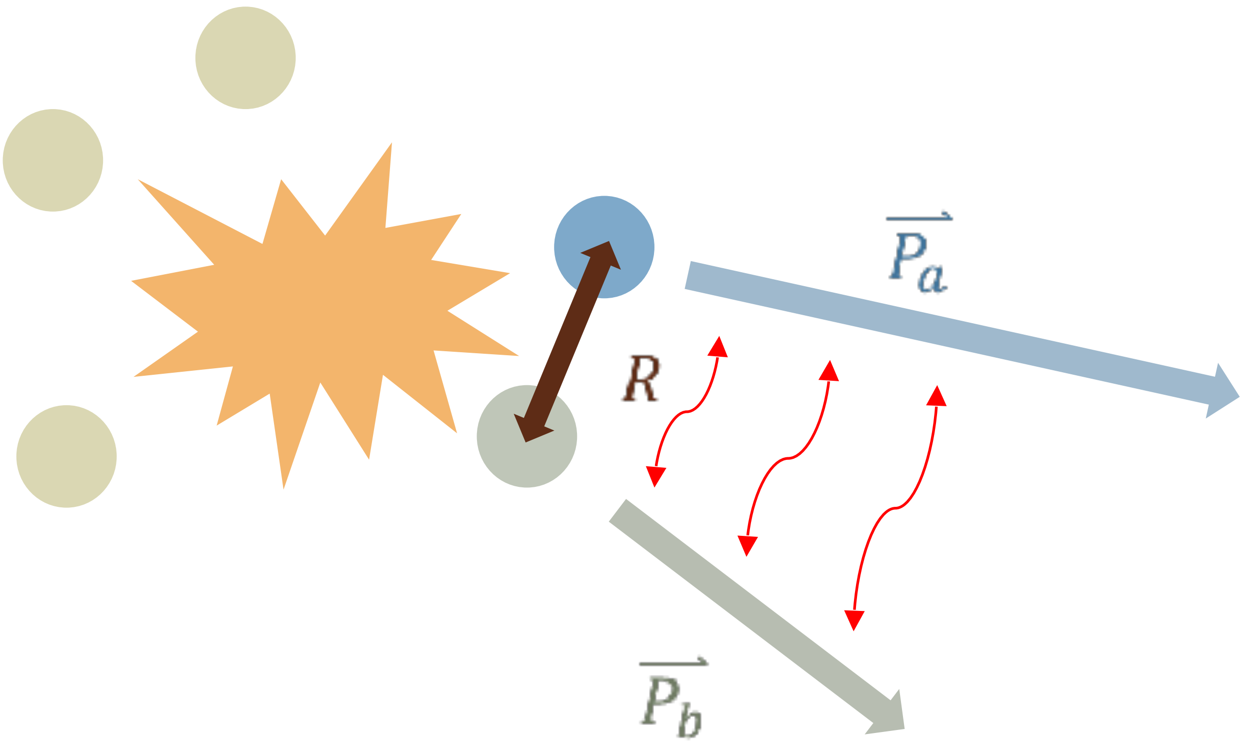


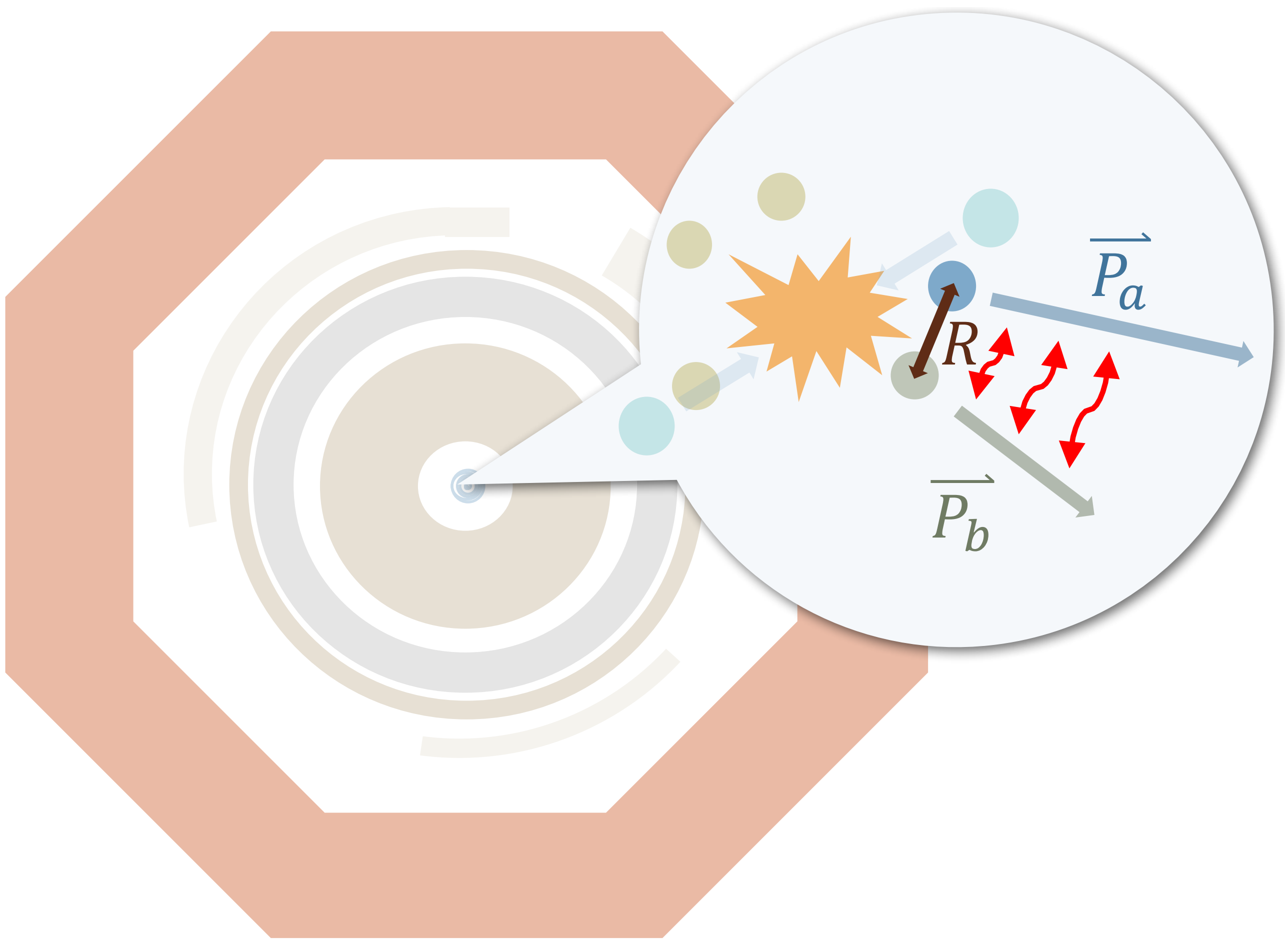
Particle Production



Particle Propagation



The ALICE Data Set



We measure **pp**, **pΛ**, **ΛΛ**, **pΞ**, **pK**

Proton and Pion identification with TPC and TOF

Reconstruction of hyperons

$\Lambda \rightarrow p\pi^-$ (BR ~ 64%)

$\Xi^- \rightarrow \Lambda\ \pi^-$ (BR ~ 100%)

Datasets:

- pp 7 TeV: 3.4 · 10^8 MB Events
- pp 5 TeV: 10 · 10^8 MB Events
- pp 13 TeV: 10 · 10^8 MB Events
- p-Pb 5.02 TeV: 6.0 · 10^8 MB Events

The Correlation Function

The correlation function:

$$C(k^*) = \frac{P(\boldsymbol{p}_a, \boldsymbol{p}_b)}{P(\boldsymbol{p}_a)P(\boldsymbol{p}_b)},$$

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Experimentally obtained as:

$$C(k^*) = \mathcal{N} \frac{N_{Same}(k^*)}{N_{Mixed}(k^*)}$$

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Given by:

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

$k^* \to \infty$: 1

Source

Relative Wave Function

$$k^* = \frac{|\boldsymbol{p}_a^* - \boldsymbol{p}_b^*|}{2} \text{ and } \boldsymbol{p}_a^* + \boldsymbol{p}_b^* = 0$$

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$\xrightarrow{k^* \to \infty} 1$

Source → $S(\boldsymbol{r}, k^*)$

Relative Wave Function → $\psi(\boldsymbol{r}, k^*)$

$$k^* = \frac{|\boldsymbol{p}_a^* - \boldsymbol{p}_b^*|}{2} \text{ and } \boldsymbol{p}_a^* + \boldsymbol{p}_b^* = 0$$

Assumption of a **common source** with **Gaussian shape** for the **pp, pΛ, pΞ**, $\Lambda\Lambda$ and pK Correlation Function

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Assumption of a **common source** with **Gaussian shape** for the **pp**, **p**Λ, **p**Ξ, $\Lambda\Lambda$ and pK Correlation Function

Strong constraint

The Correlation Function

(D.L.Mihaylov et al. Eur.Phys.J. C78 (2018) no.5,394)

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$\xrightarrow{k^* \to \infty}$ 1

Source

Relative Wave Function

$$k^* = \frac{|\boldsymbol{p}_a^* - \boldsymbol{p}_b^*|}{2} \text{ and } \boldsymbol{p}_a^* + \boldsymbol{p}_b^* = 0$$

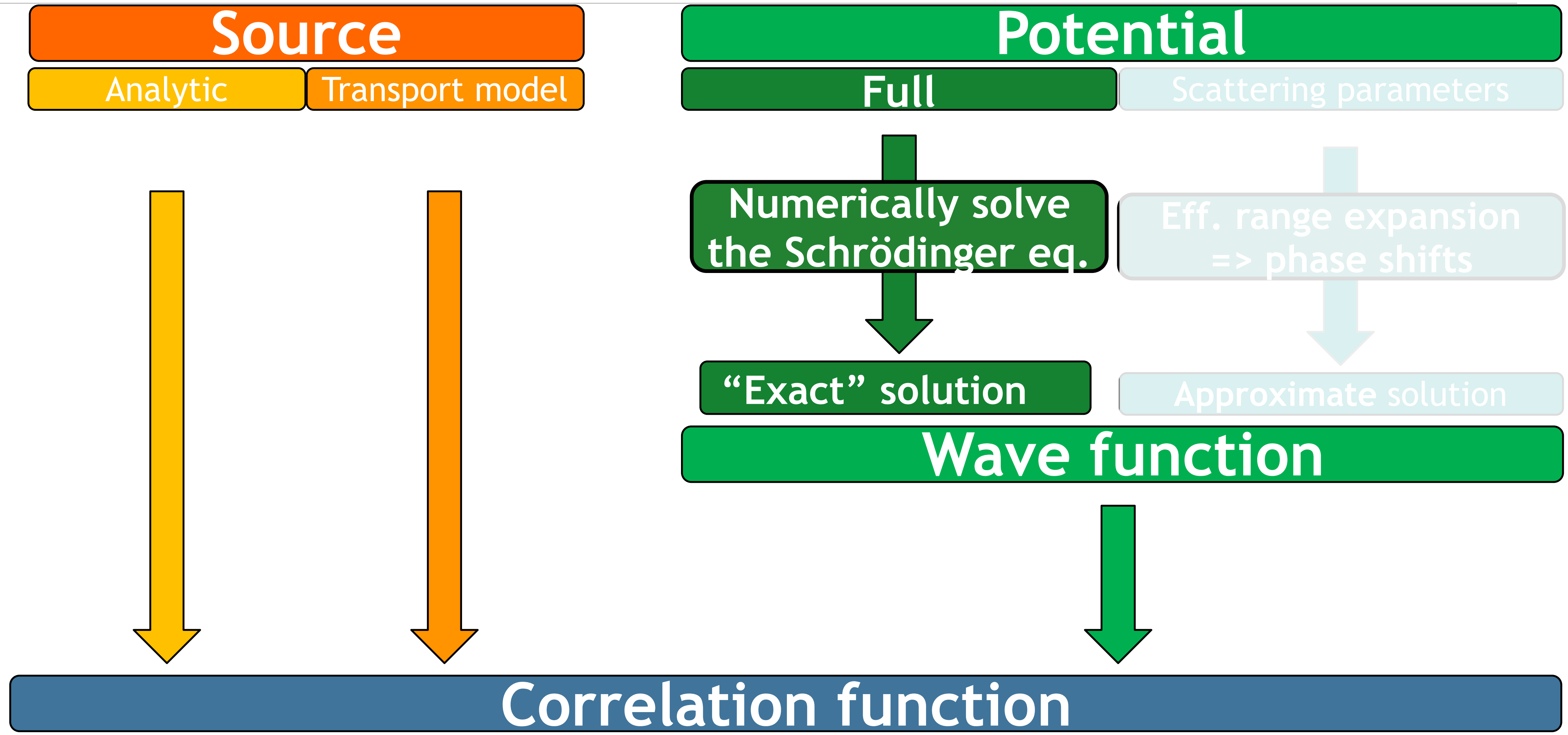
Assumption of a **common source** with **Gaussian shape** for the **pp, pΛ, pΞ**, $\Lambda\Lambda$ and pK Correlation Function

Strong constraint

correlations functions allow to study the interactions

CATS – Correlation Analysis Tool Using the Schrödinger Equation

(D.L.Mihaylov et al. Eur.Phys.J. C78 (2018) no.5,394)



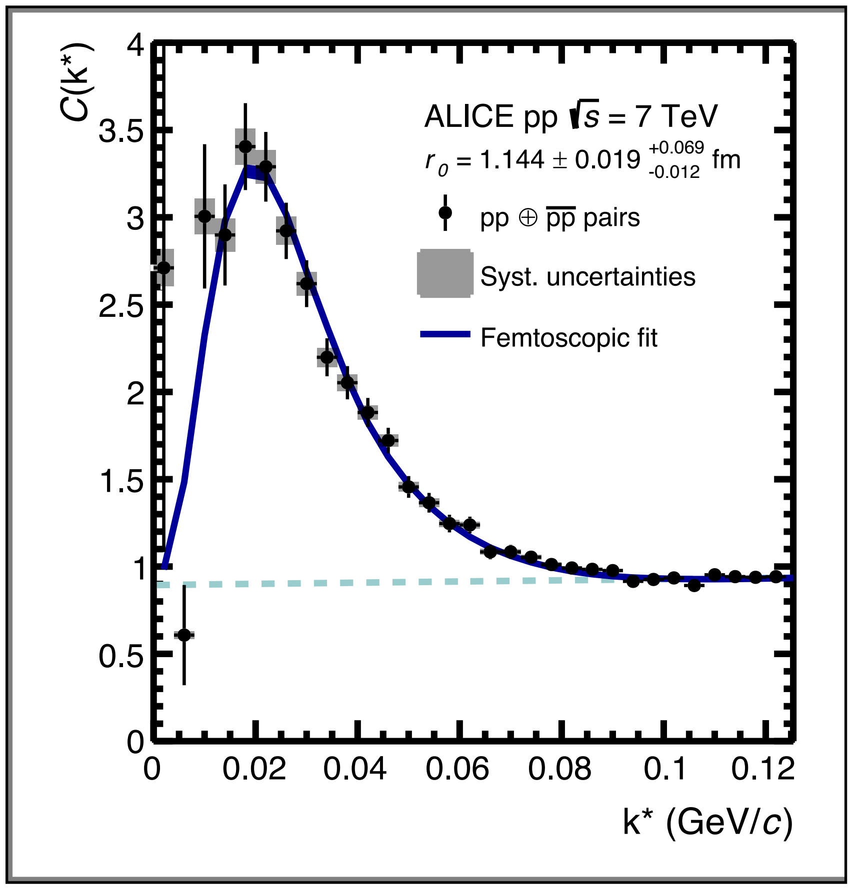
$$C(k) = \int S(\vec{r},k)\,|\psi(\vec{r},k)|^2\, d\vec{r} \xrightarrow{k\to\infty} 1$$

Experimental Results: RUN1 and RUN2

Fit of the pp, Λp and ΛΛ Correlation Function

pp 7 TeV   RUN1 ~ 2,5 * 10[8] evt   ALICE Coll. arXiv:1805.12455

pp



Interplay between the strong attractive and Coulomb repulsive interactions

Fit to the experimental with CATS

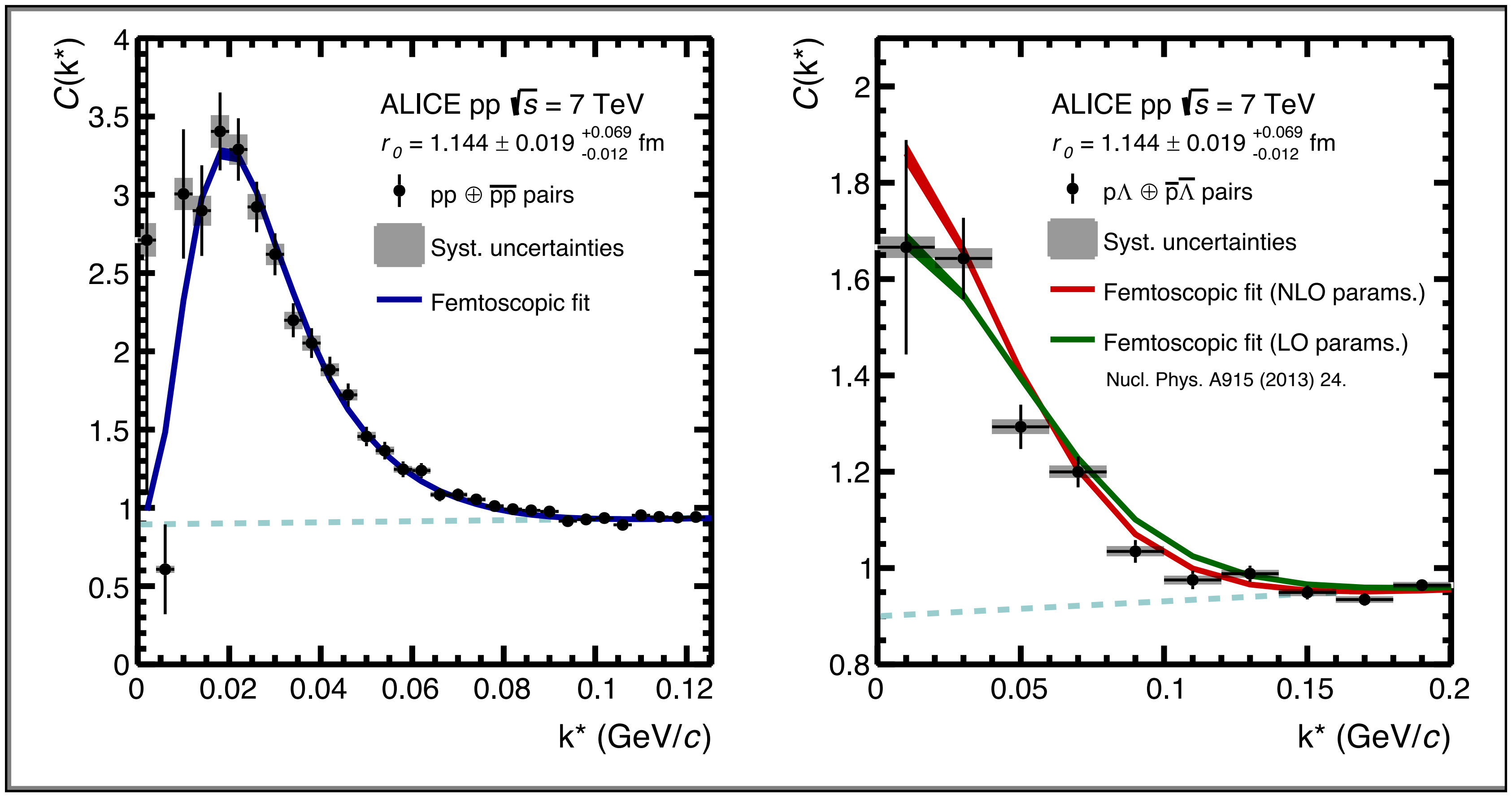
AV18 Potential
Gaussian Source
Common to ALL pairs (same procedure for p-Pb data as well)

$$C(k) = \int dr^3 \phi^2_{rel}(r,k) \exp\left(-\frac{r^2}{4R_G^2}\right)$$

Fit of the pp, Λp and ΛΛ Correlation Function

pp 7 TeV RUN1 ~ 2,5 * 10^8 evt ALICE Coll. arXiv:1805.12455

pp Λp

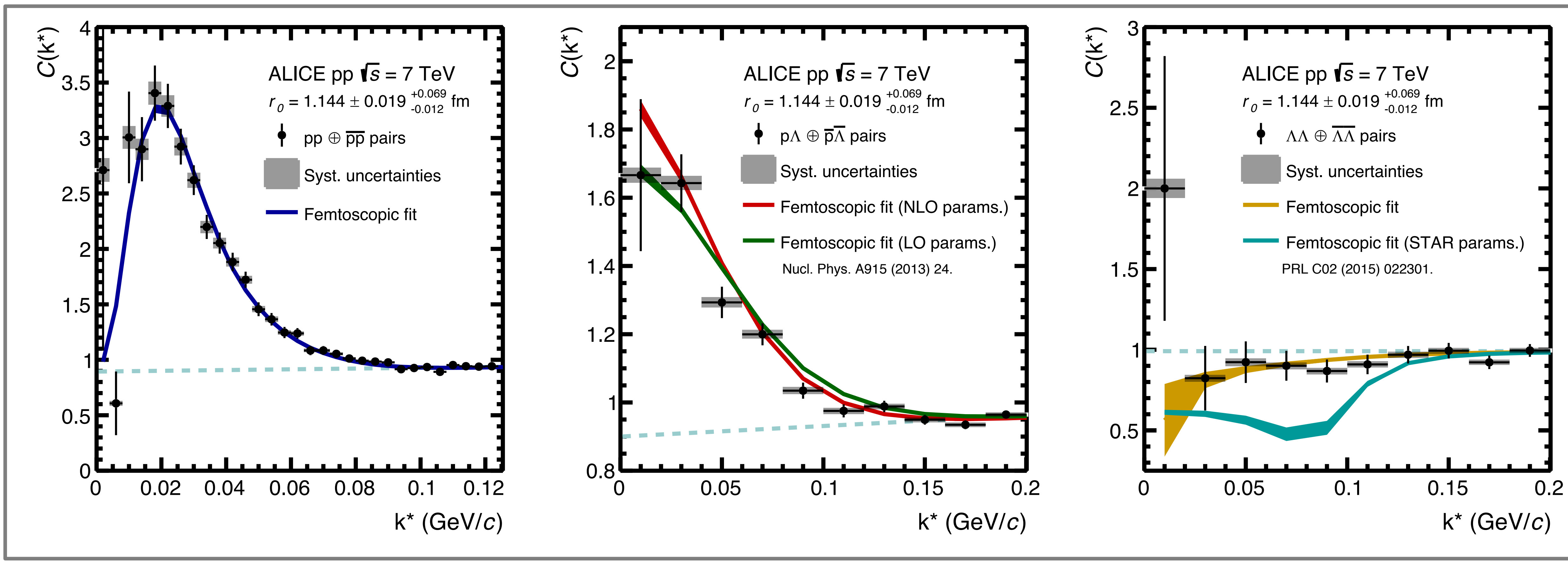


Lednicky fits with scattering parameters
CATS for NLO also possible
Evident attractive interaction

Fit of the pp, Λp and ΛΛ Correlation Function

pp 7 TeV RUN1 ~ 2,5 * 10^8 evt ALICE Coll. arXiv:1805.12455 accepted by PRC

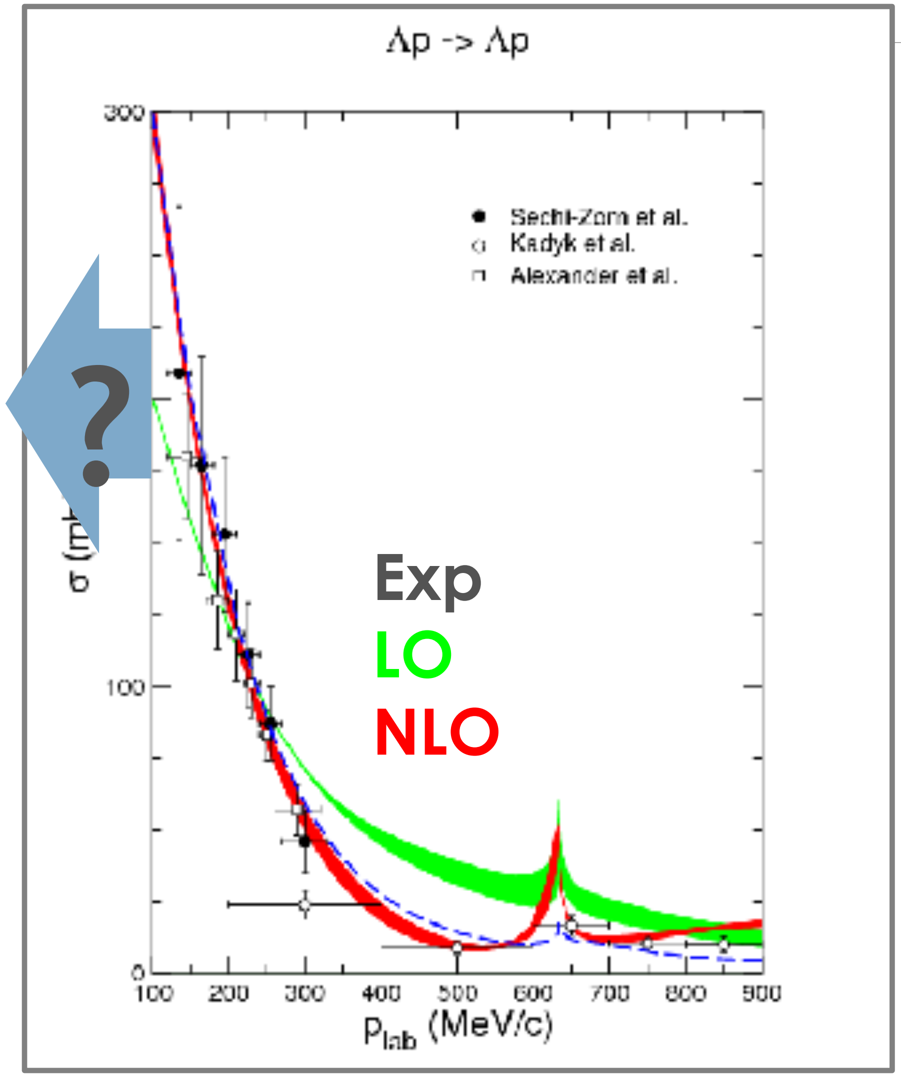
pp Λp $\Lambda\Lambda$



Different baseline because of quantum statistics

Lednicky fit carried out
too large error yet on the scattering parameters

Proton-Λ : Scattering vs Femtoscopy Data



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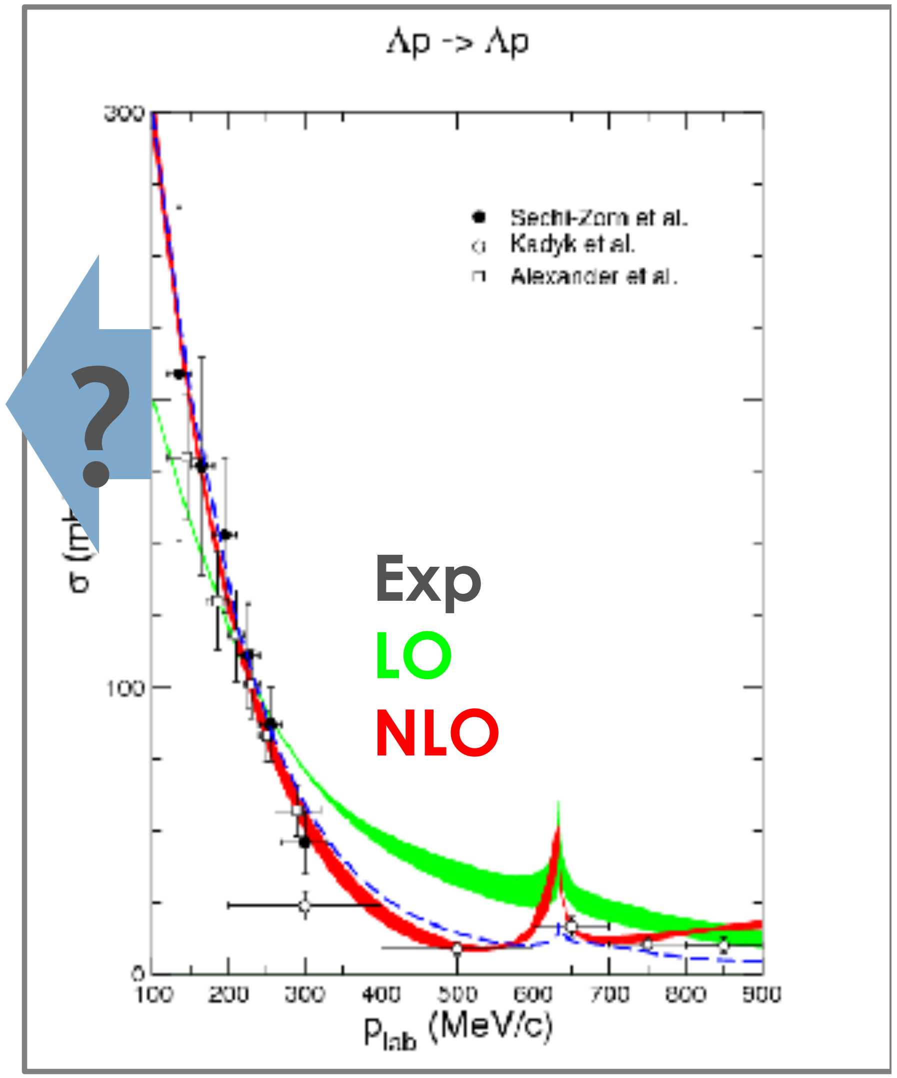
Proton-Λ : Scattering vs Femtoscopy Data



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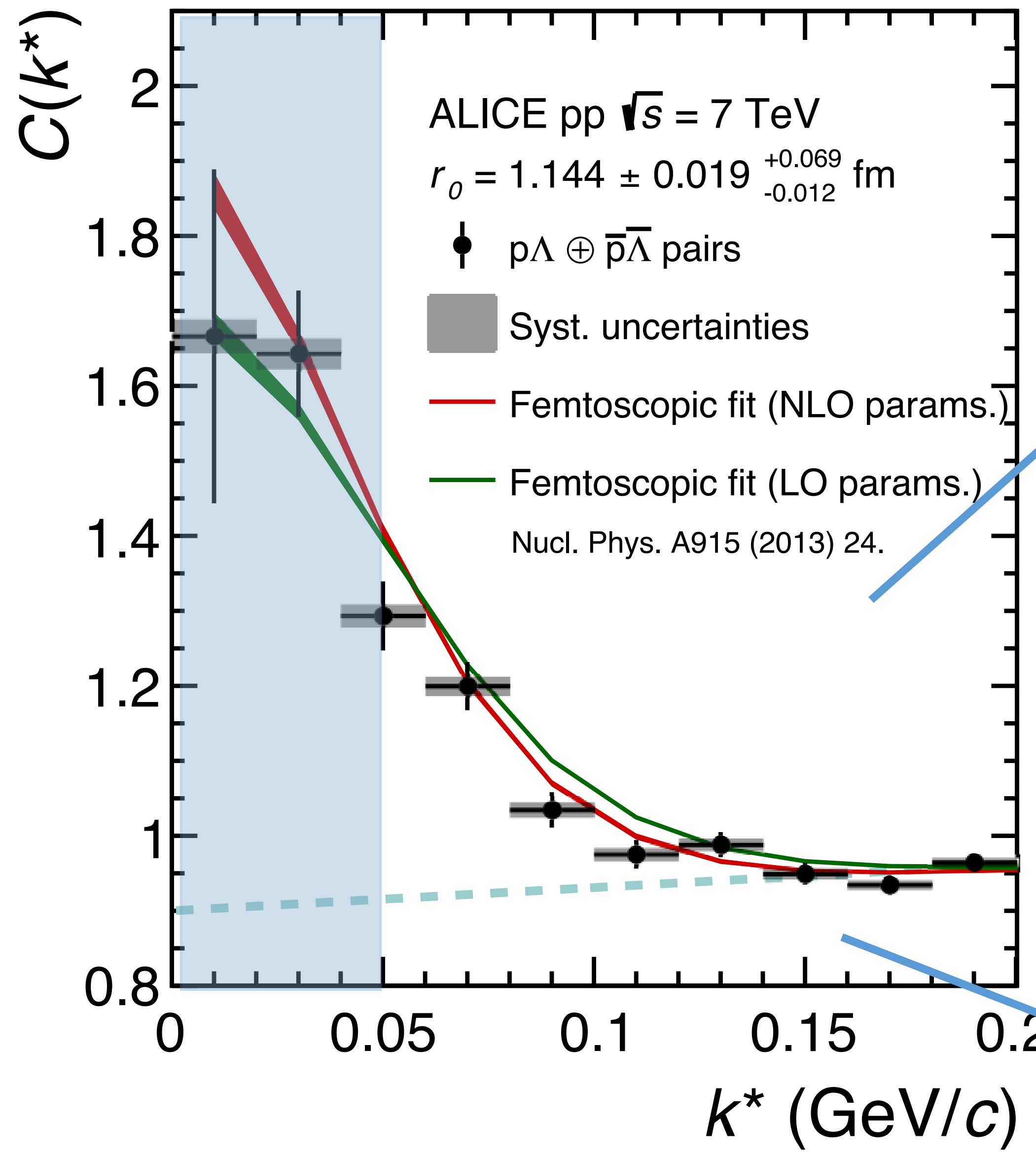


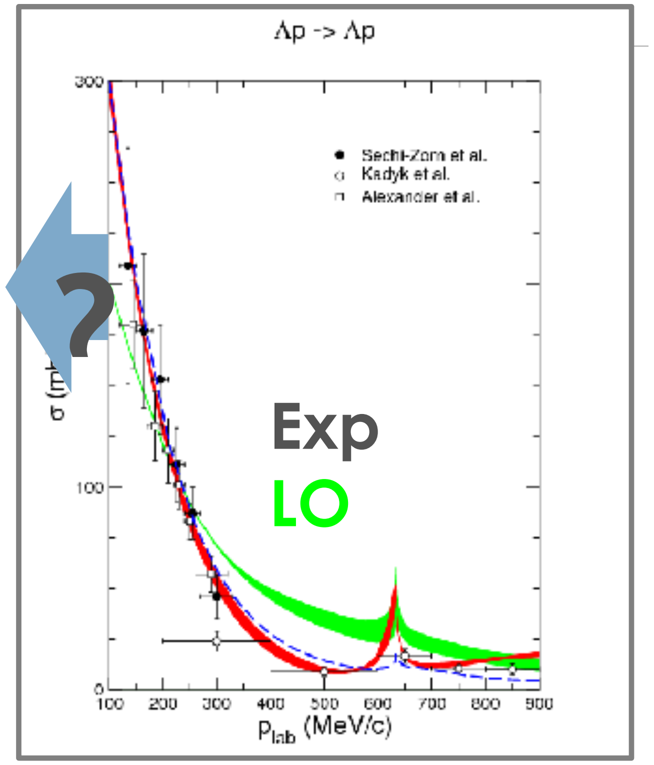
C(k*)> 1: Attractive interaction

C(k*) <1: Repulsive interaction

ALICE Coll. arXiv:1805.12455

- Combination of spin singlet and triplet
- * Extension to the low momentum regime
- * Statistics not sufficient to test different models

Proton-Λ : Scattering vs Femtoscopy Data



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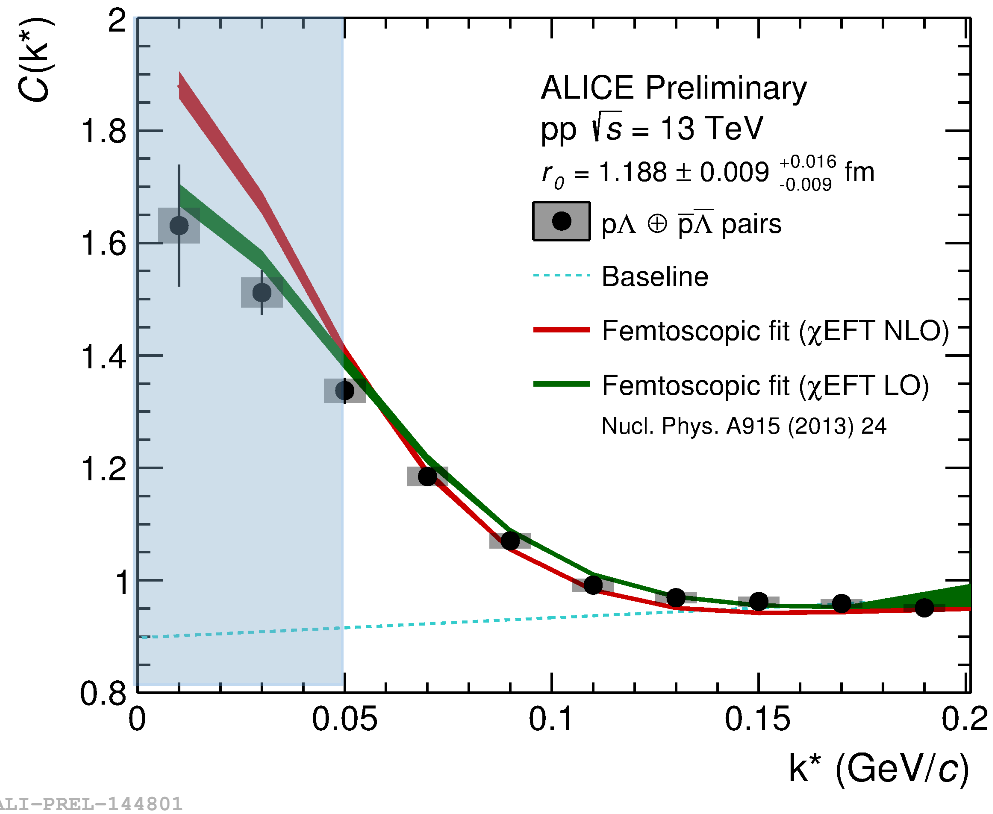
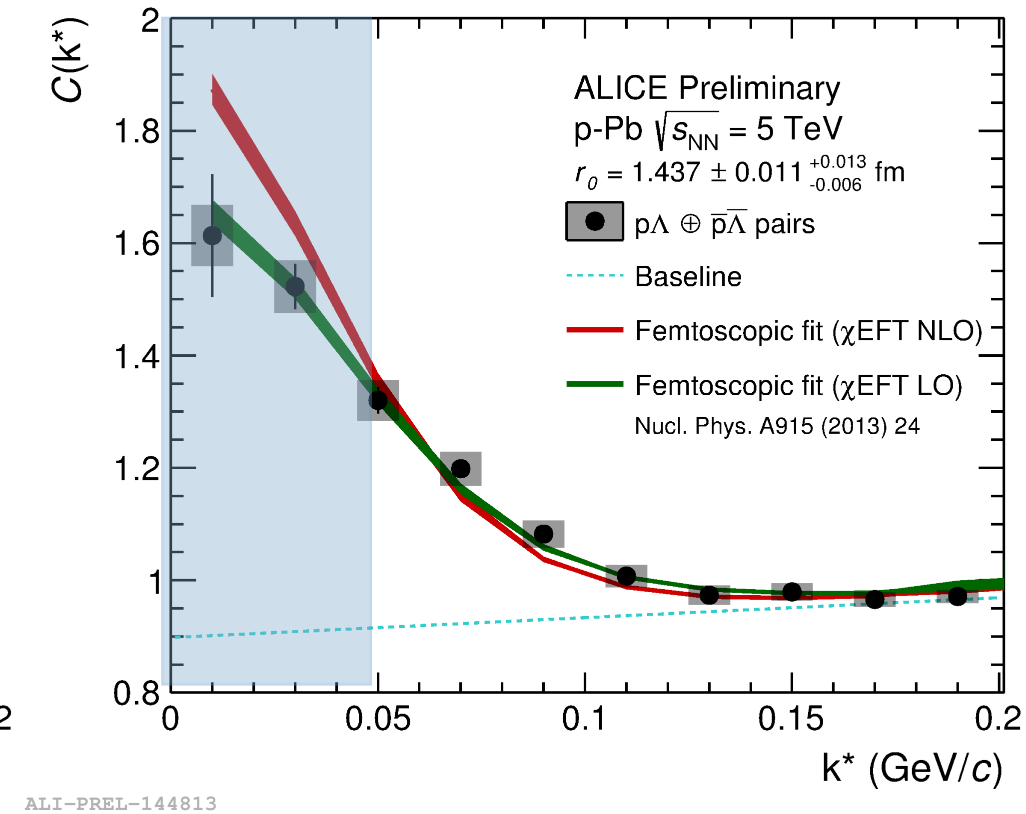




RUN2 data: 10^9 evt for pp and 5* 10^8 evt for p-Pb
* Extension to the low momentum regime
* Statistics **sufficient** to test different models

Under the assumption of a common **Gaussian source** smaller scattering lengths are favoured

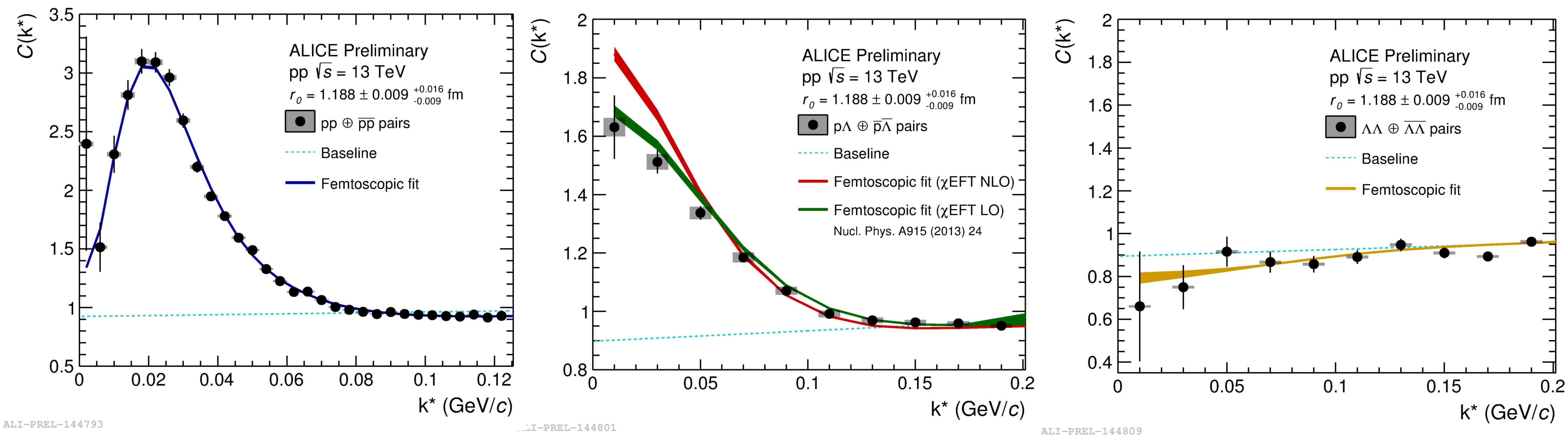
LO less attractive than **NLO**

$a^1S_0 = -2.91\,fm$ $a^1S_0 = -1.91\,fm$

Fit of the pp, Λp and $\Lambda\Lambda$ Correlation Function

RUN2 ~ 10^9 evt

pp Λp $\Lambda\Lambda$



Gaussian source and Argonne v_{18} potential describes the p-p correlation function

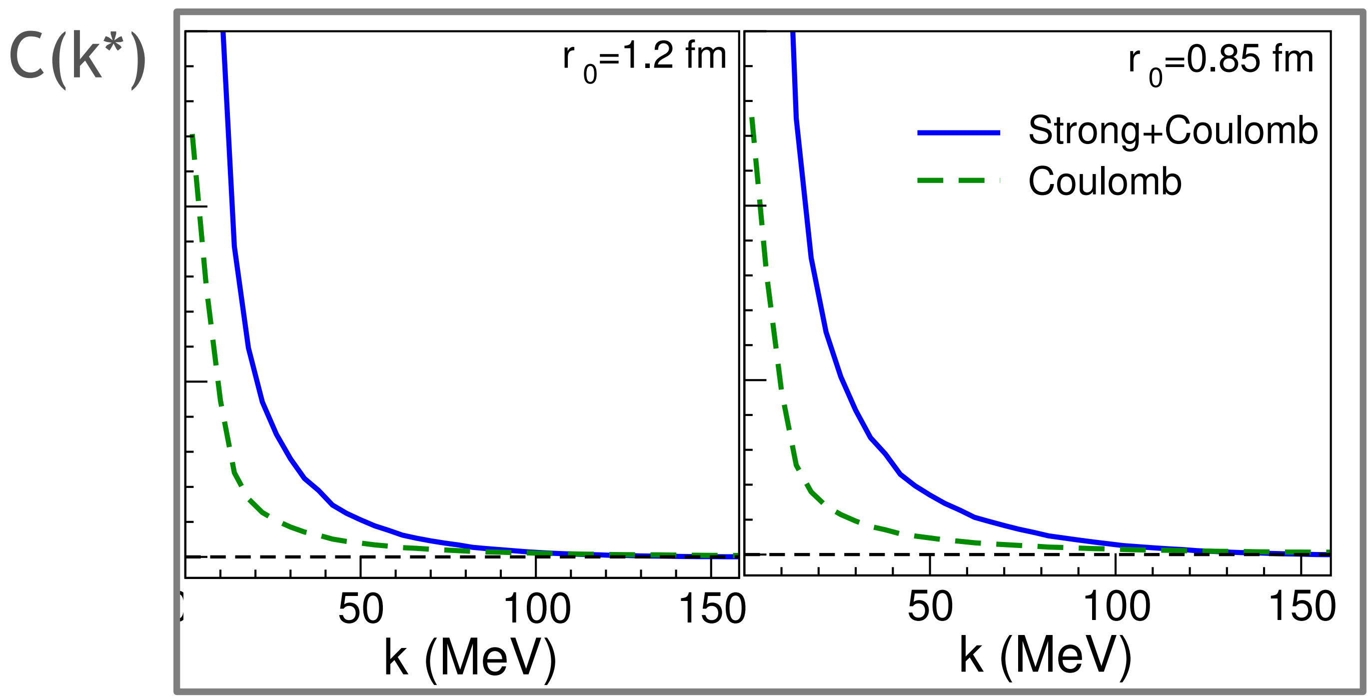
- Source size of the **pp (7 TeV)** system **r_0=1.14 fm** <u>**(ALICE Coll. arXiv:1805.12455)**</u>
- Source size of the **pp (13 TeV)** system **r_0=1.19 fm**
- Source size of the **p-Pb (5.02 TeV)** system **r_0=1.44 fm**

Ξ^-

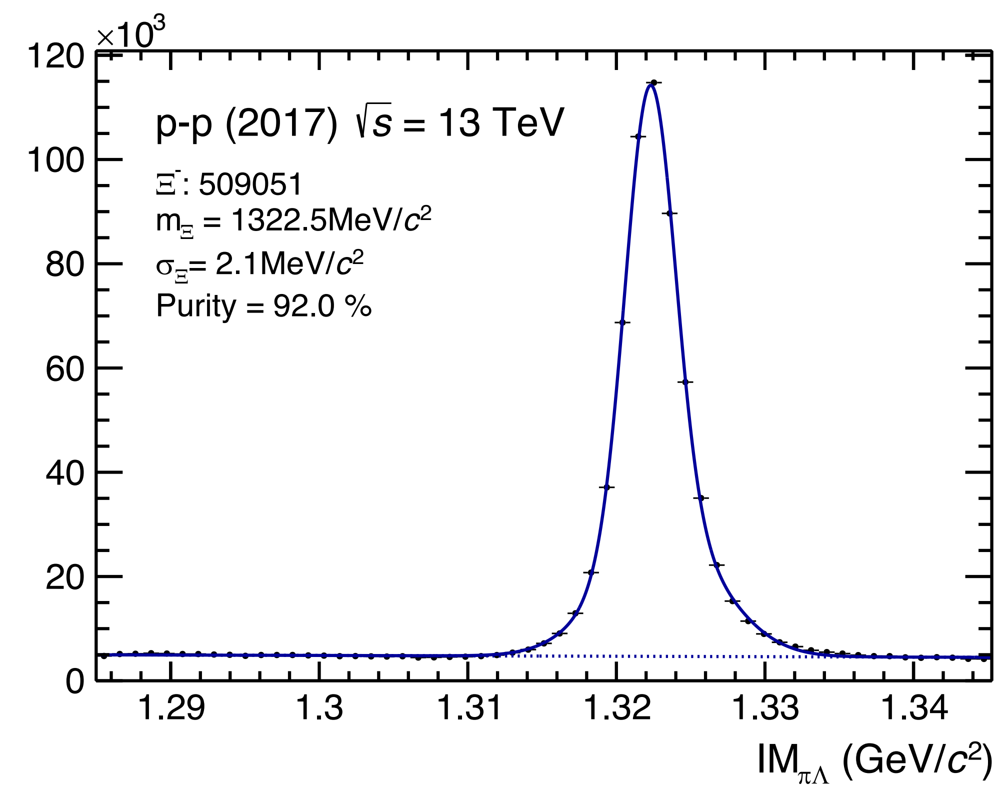
- **Preliminary** calculations by the HAL QCD Collaboration
- Taking the strong interaction into account creates a significantly different Correlation function than Coulomb only

- Decay mode $\Xi^{\pm} \rightarrow \Lambda + \pi$

$$p + \pi$$



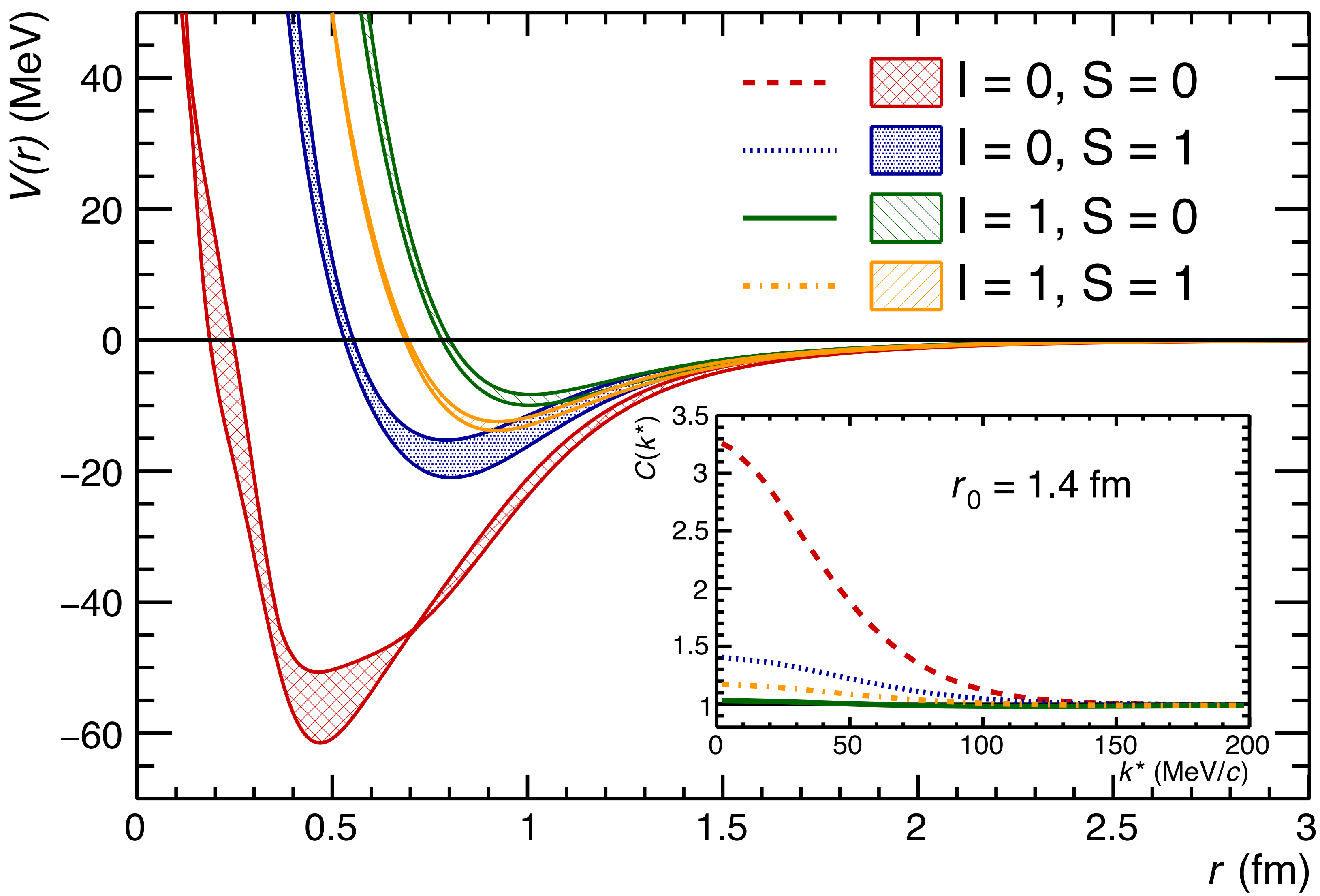
arXiv:1702.06241 , Nuclear Physics A 967 (2017) 856–859



CATS (D.L.Mihaylov et al. Eur.Phys.J. C78 (2018) no.5,394)

Lattice Interaction

(Potential from Hatsuda et al., NPA967 (2017) 856, PoS Lattice2016 (2017) 116)

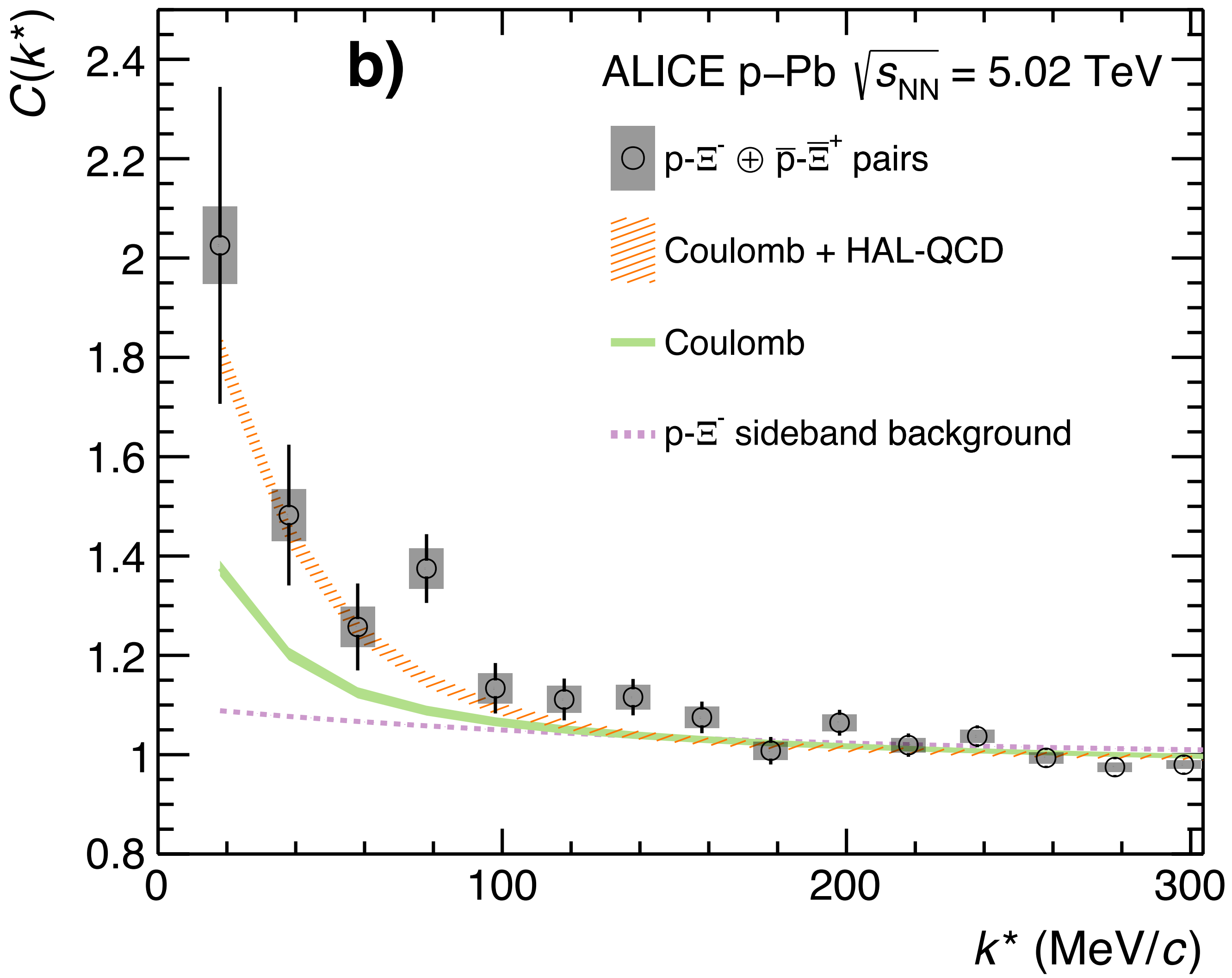


Errors due to different integration times

Each Potential can be converted in a correlation function via CATS

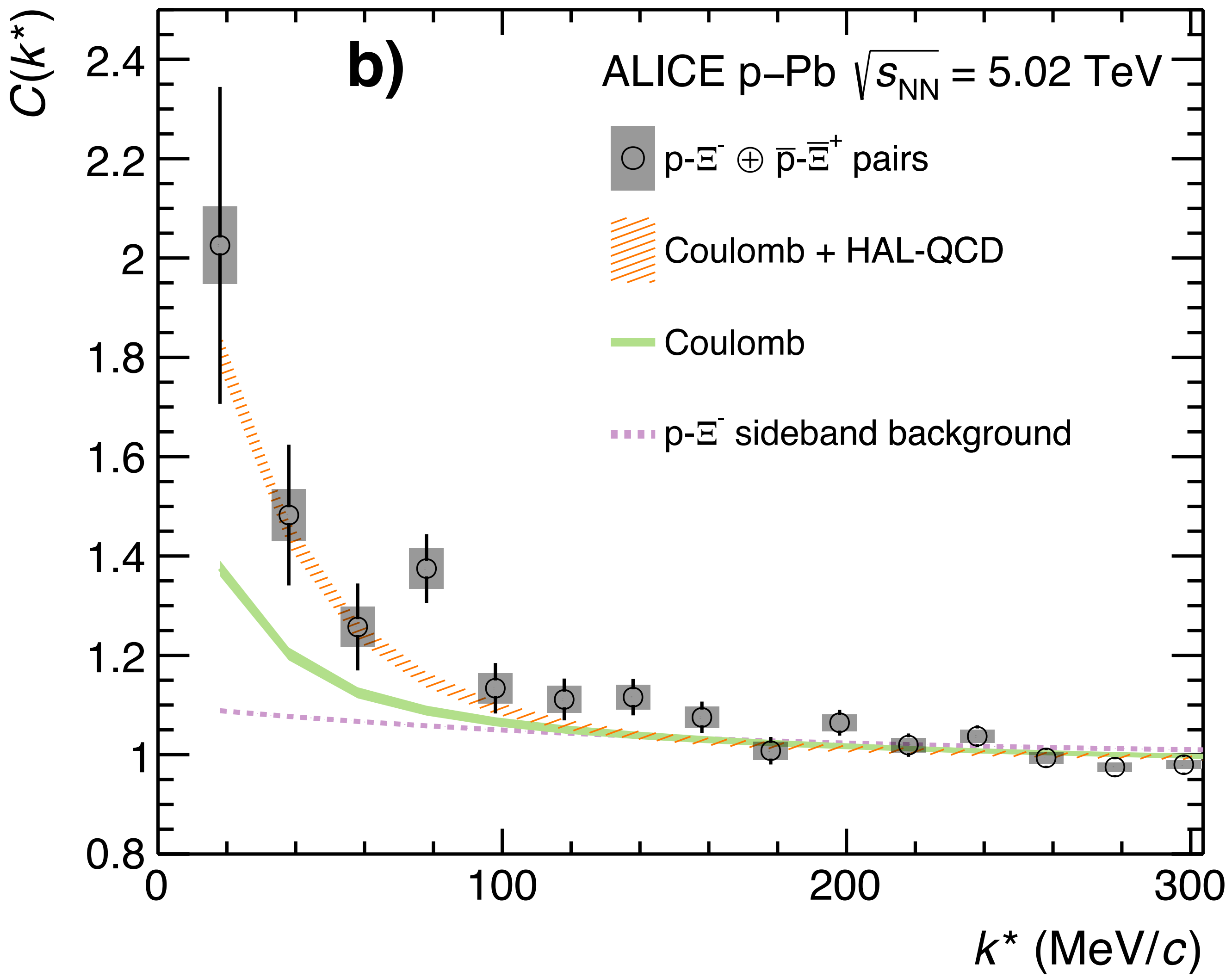
$$C(k^*) = \frac{1}{8}\left(C_{I=0}^{S=0} + C_{I=1}^{S=0}\right) + \frac{3}{8}\left(C_{I=0}^{S=1} + C_{I=1}^{S=1}\right)$$

proton-Ξ^- Correlation Function



First observation of strong attractive interaction in p-Ξ^-

proton-Ξ⁻ Correlation Function



<u>First observation of strong attractive interaction in p-Ξ⁻</u>

modeled with preliminary QCD strong potential by the HAL QCD collaboration

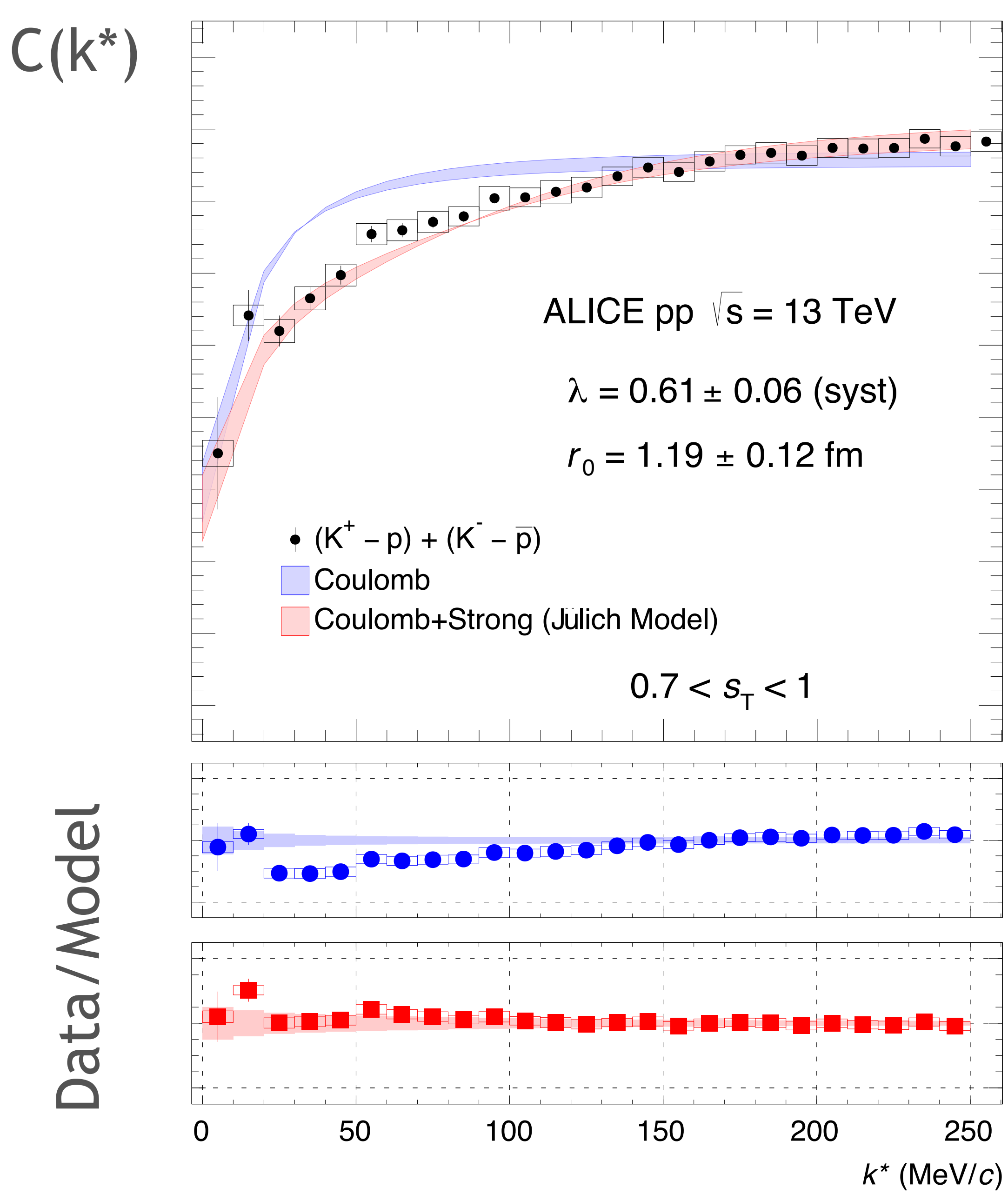
(Hatsuda et al., NPA967 (2017) 856, PoS Lattice2016 (2017) 116)

$$C(k^*) = \frac{1}{8}\left(C_{I=0}^{S=0} + C_{I=1}^{S=0}\right) + \frac{3}{8}\left(C_{I=0}^{S=1} + C_{I=1}^{S=1}\right)$$

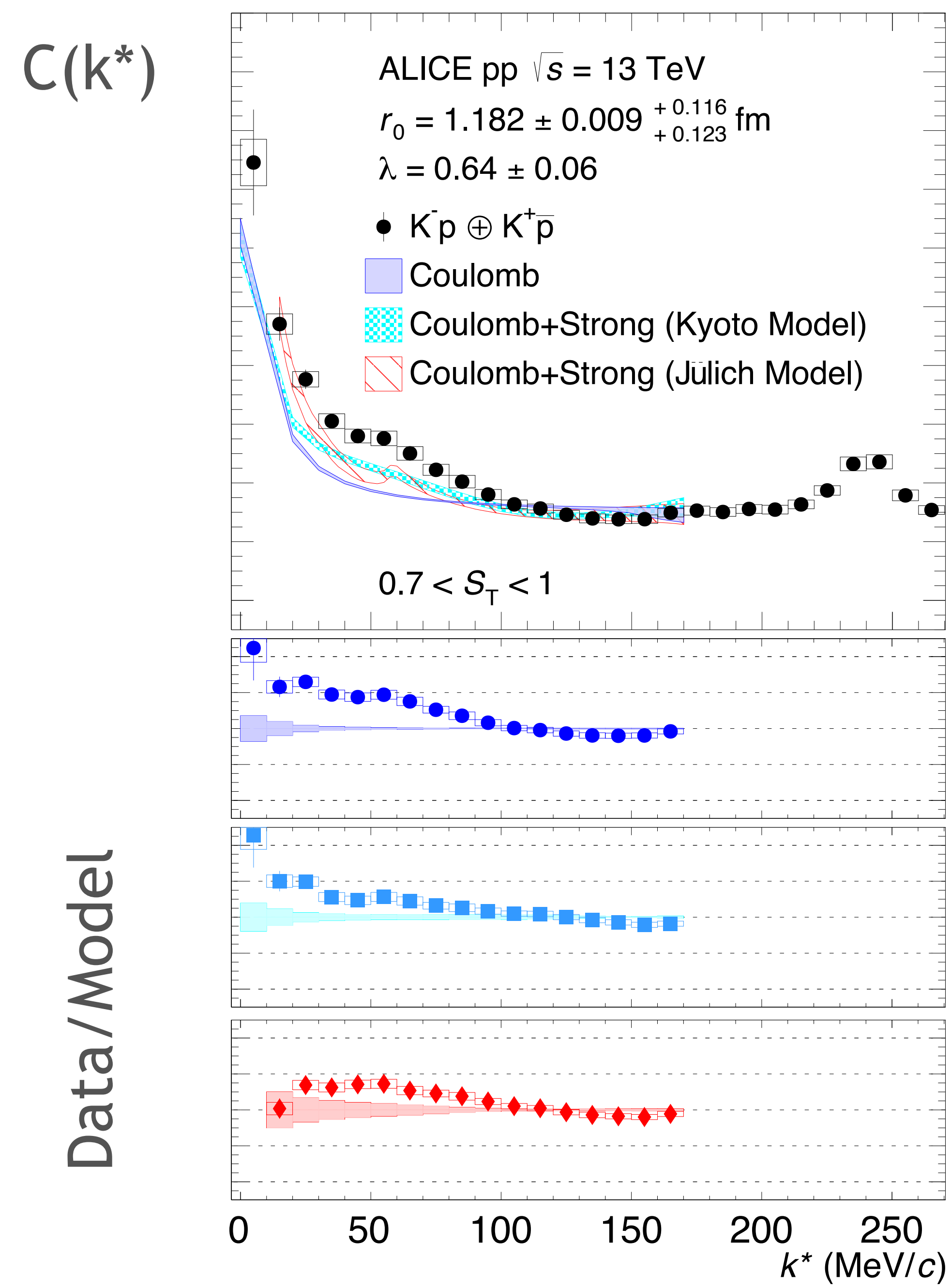
Coulomb-only hypothesis excluded at around 4 σ

Kp and $\overline{\text{K}}$p correlations

K^+p: **Repulsive** Strong Interaction

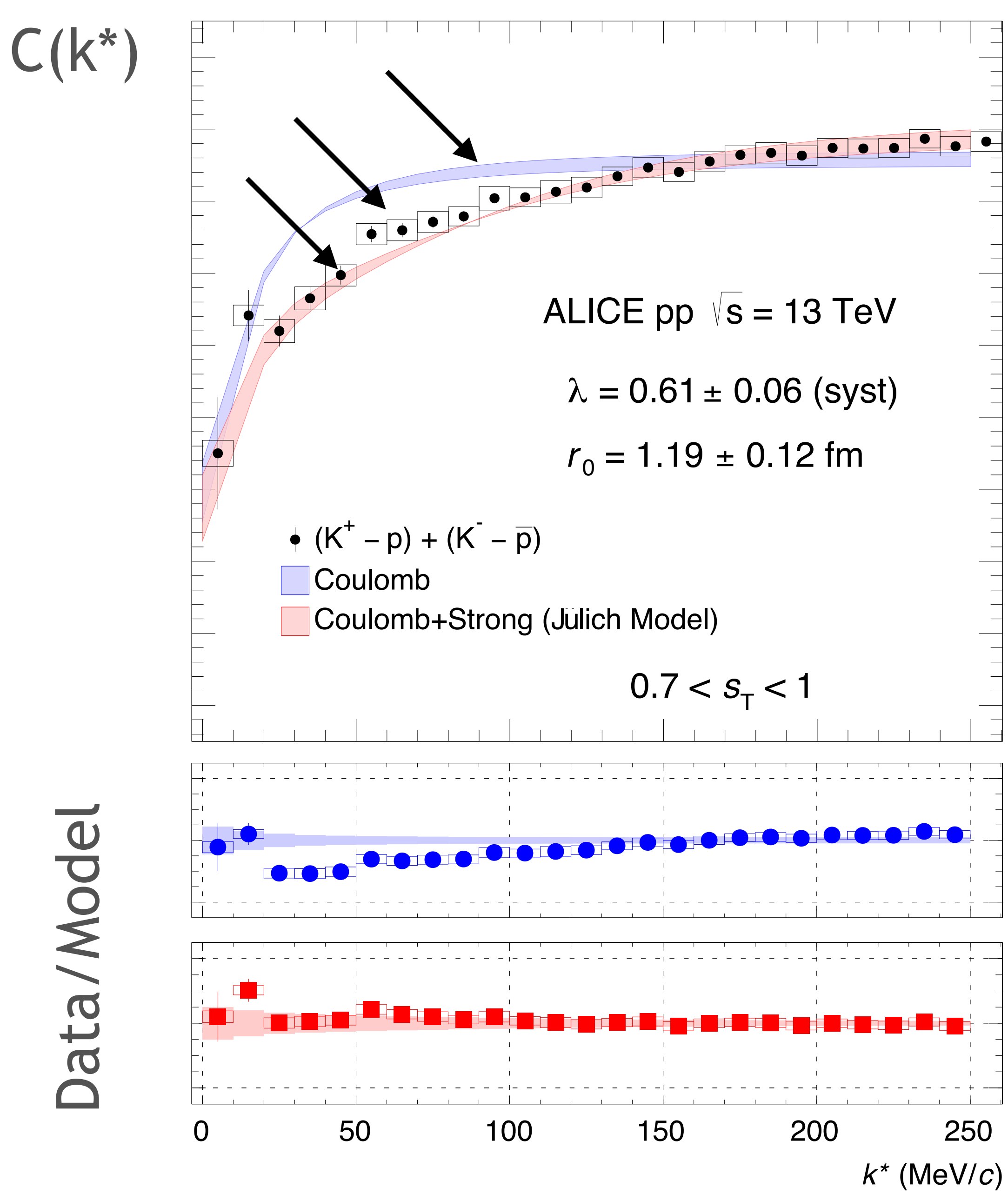


K^-p: **Attractive** Strong Interaction

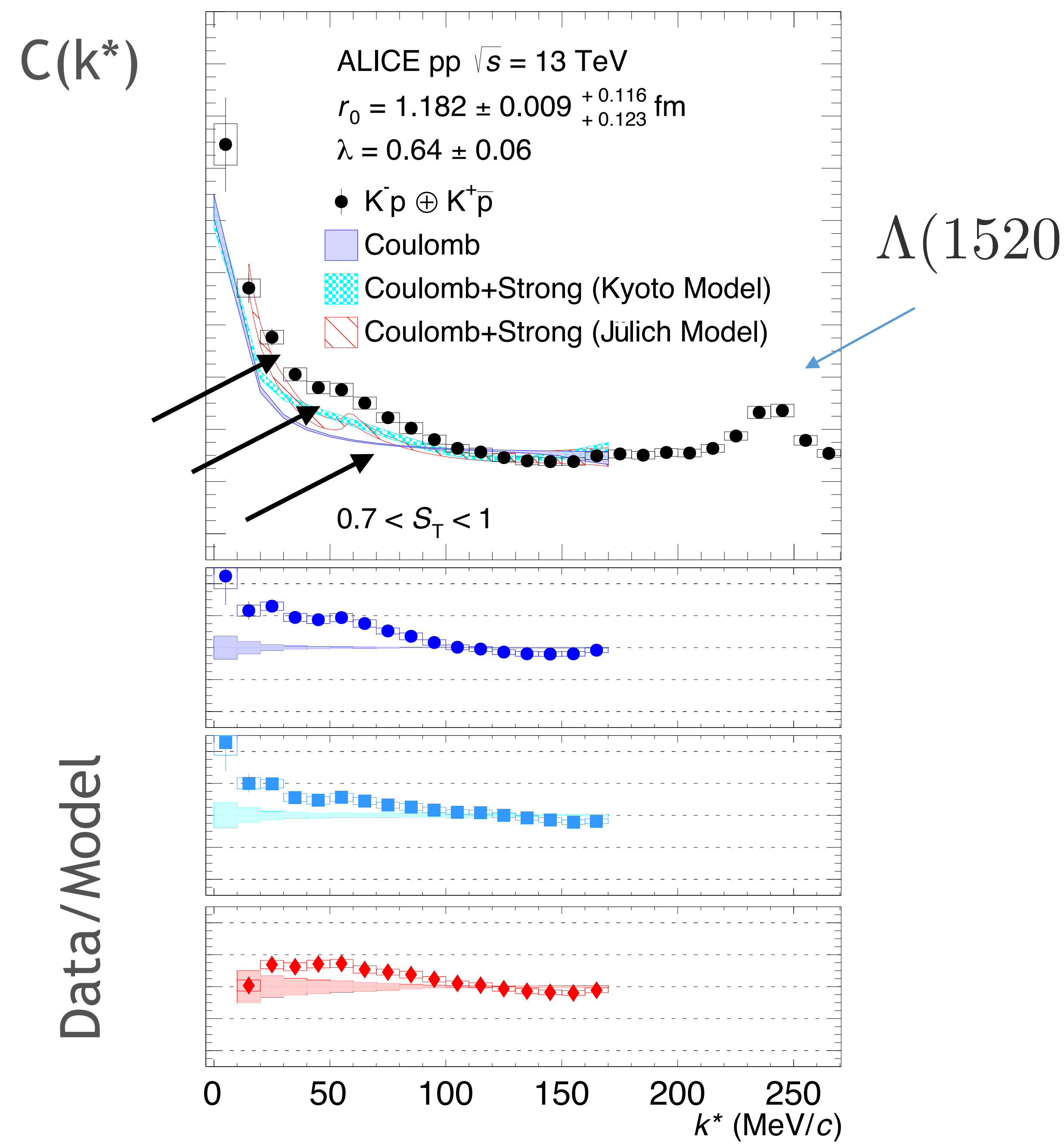


Kp and $\overline{\text{K}}$p correlations

K⁺p: **Repulsive** Strong Interaction

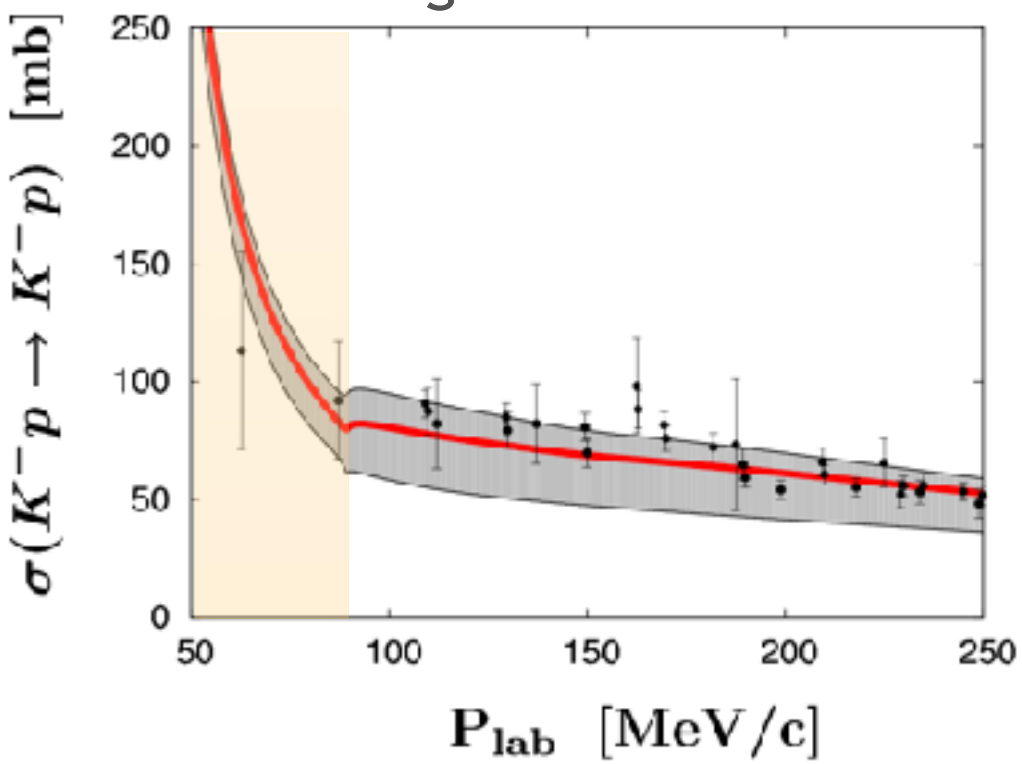


K⁻p: **Attractive** Strong Interaction



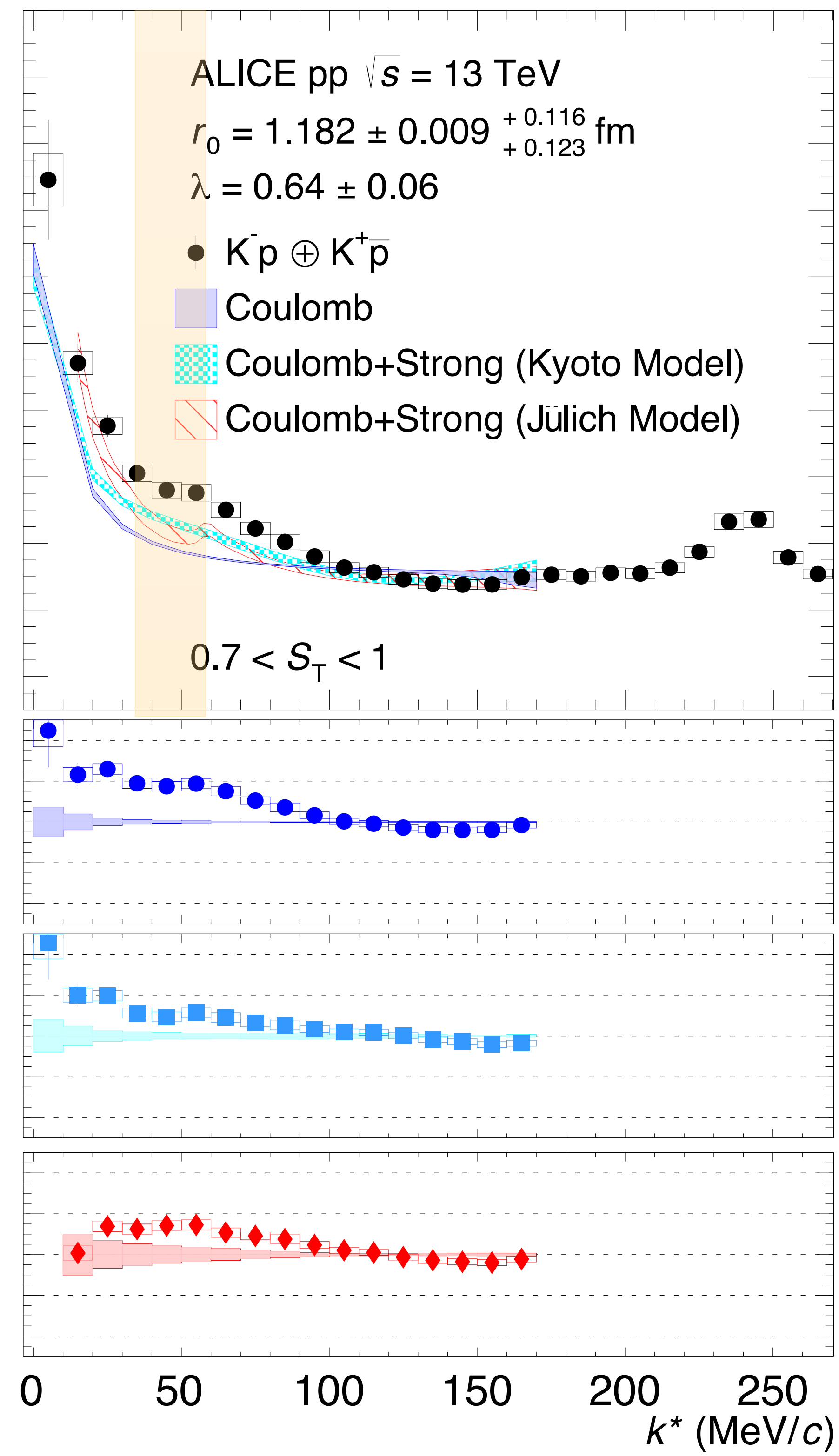
$\bar{K}p$ Interaction

Scattering Data



G.S. Abrams *et al.* Phys.Rev. 139 (1965) B454-B457

Correlation Data



Clear effect of the opening of the $\bar{K}^0N$ channel

$$\bar{K}^0N \to K^-p$$

Unprecedented constrains for low energy QCD

Summary of recent Results (2017-2018)

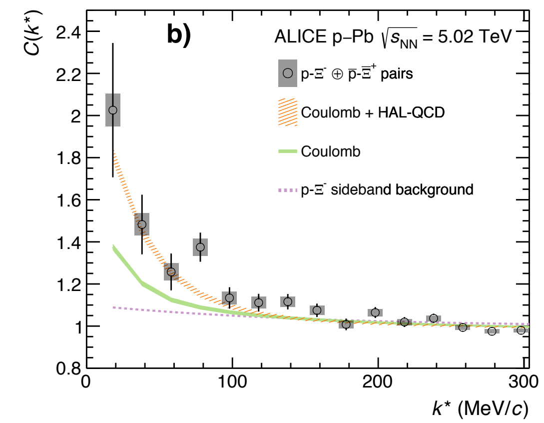
1) ALICE Coll. arXiv:1805.12455 accepted by PRC

ALICE

CERN EP 2018 XXX
Day Month 2018

2) **First observation of the attractive interaction between a proton and a multi-strange baryon**

ALICE Collaboration*

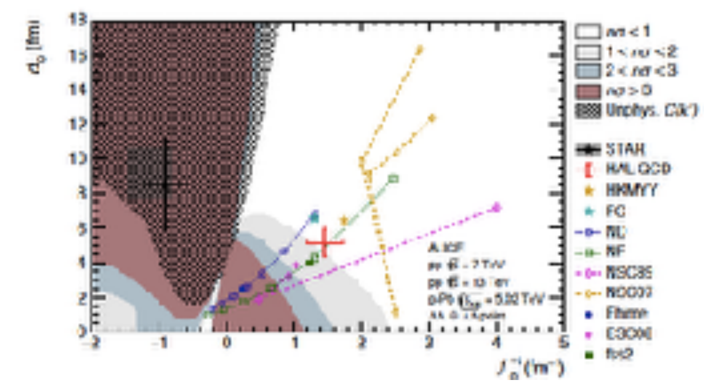


3) ALICE

CERN-EP-2018-XXX
Day Month 2018

Study of the Λ–Λ interaction with femtoscopy correlations in pp and p–Pb collisions at the LHC

ALICE Collaboration*

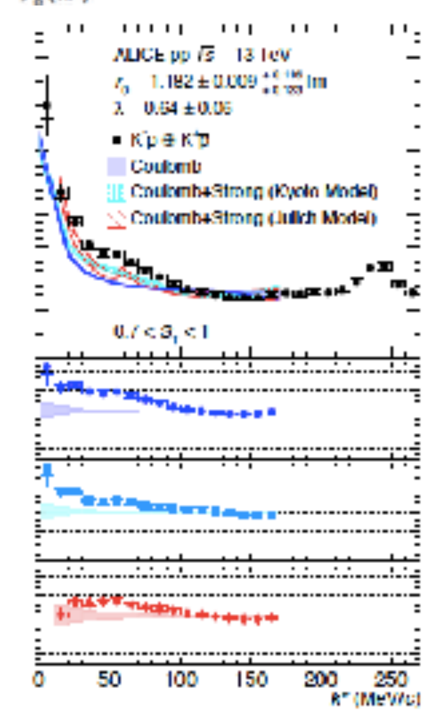


4) ALICE

CERN-EP-2018-XXX
Day Month 2018

Low-energy kaon-proton scattering with femtoscopy in proton-proton collisions at the LHC

ALICE Collaboration*



Future prospects

Finalise RUN2 Analysis (2018 data)

-> Detailed study of Λp
-> Preliminary results for $\mathrm{p}\Sigma$ and $\mathrm{p}\Omega$
-> Ongoing analysis of $\mathrm{dK}(\overline{\mathrm{K}})$
-> Extraction of cross-sections and comparison to theoretical predictions
-> Work on three particle correlations

In RUN3 (from 2021 on) we expect factor 100 in statistics

FEMTO GANG