Λ-p femtoscopy

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Outline

- **Two particle correlations: Definition**

- **Proton-proton correlations**

  ➡ Corrections and results from comparison with models

- **Lambda-proton correlations**

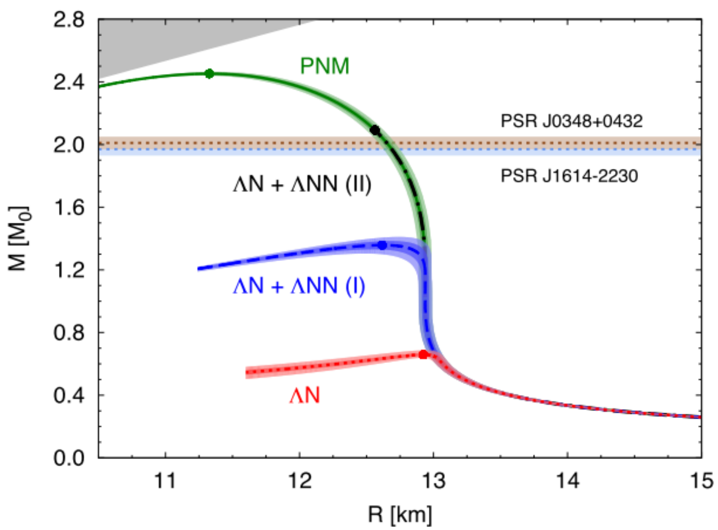
  ➡ Use of proton-proton results to investigate the interaction of Λp pairs

- **Summary and outlook**

Motivation

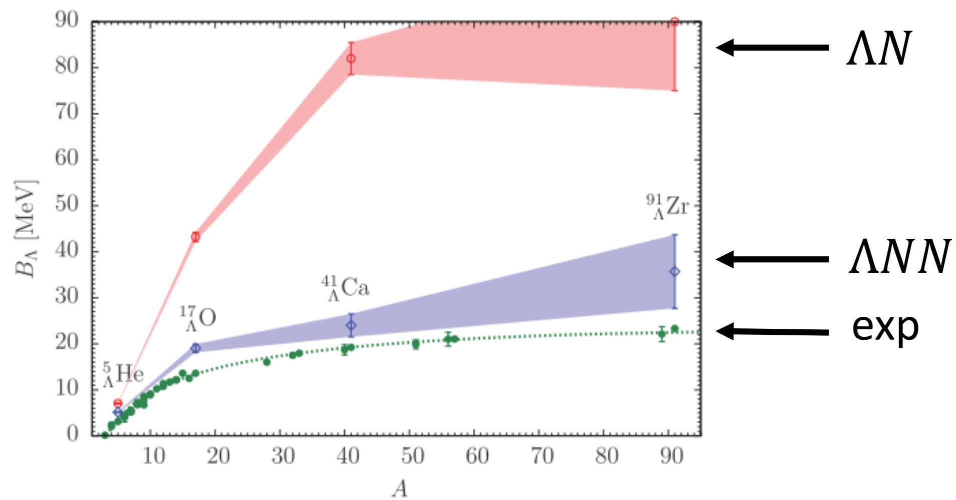
Detailed information needed to describe various systems:

Neutron stars



Lonardoni et al., Phys. Rev. Lett. 114, 092301

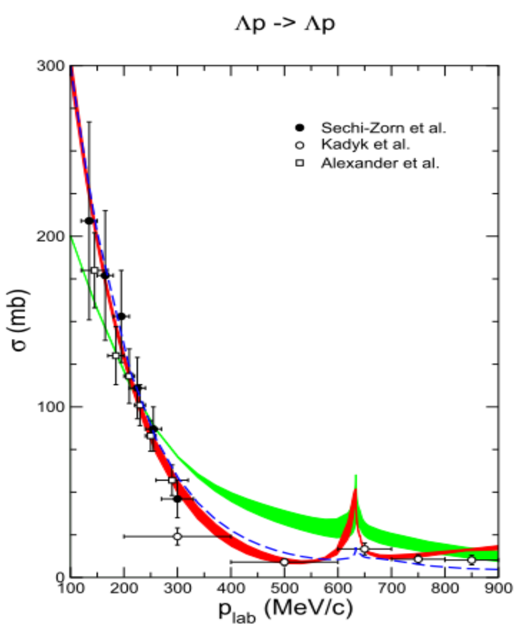
Hypernuclei

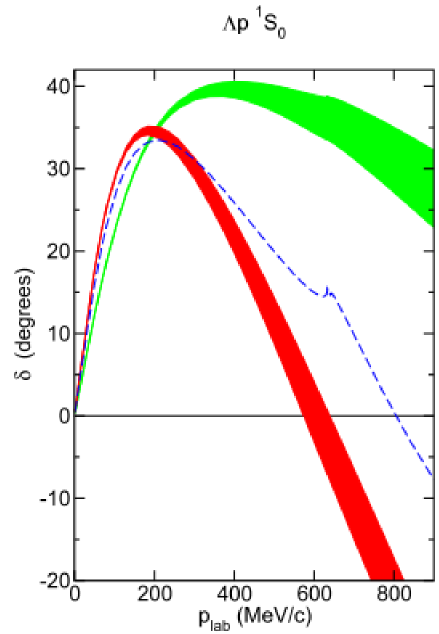


Lonardoni et al., Phys.Rev. C87 (2013) 041303

Motivation

Experimental data is quite scarce





(no phaseshift data at all)

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Introduction

Theoretical correlation function:

$$C^{ab}(\mathbf{P},\mathbf{q}) = \frac{\mathcal{P}(\vec{p}_a,\vec{p}_b)}{\mathcal{P}(\vec{p}_a)\mathcal{P}(\vec{p}_b)} = \int d^3r' S_{\mathbf{P}}(\mathbf{r}')|\phi(\mathbf{q},\mathbf{r}')|^2$$

Source function:
Distribution of relative distance between the particle pairs (in CMS)

Wave function of particle pair:
Includes the interactions

Experimental correlation function:

$$C(k) = \frac{A(k)}{B(k)}$$

$k = \frac{1}{2}|\mathbf{p}_1 - \mathbf{p}_2|$

$\mathbf{p}_1 + \mathbf{p}_2 = 0$ **Pair reference frame (PRF)**

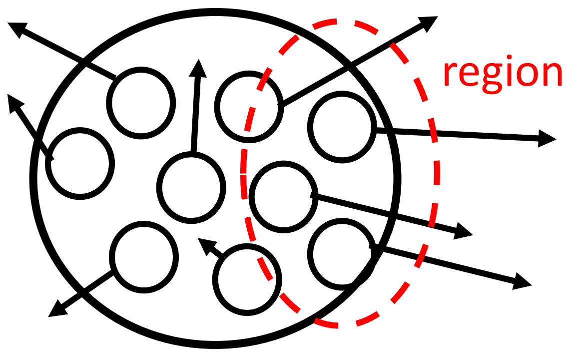
- **Same:** relative momentum dist. of particles in the same event
- **Mixed:** particles from different events (not correlated)
- **Normalized to unity**: $C(k > 100\ \mathrm{MeV/c}) \equiv 1$

Introduction

Strategy of analysis – two steps:

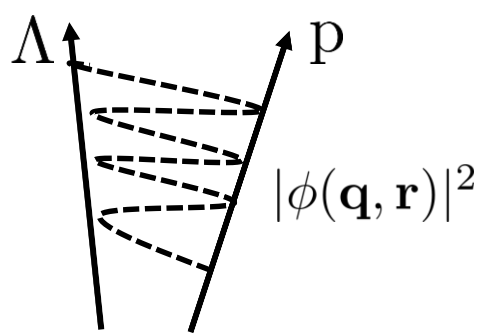
$$C^{ab}(\mathbf{P},\mathbf{q}) = \frac{\mathcal{P}(\vec{p}_a,\vec{p}_b)}{\mathcal{P}(\vec{p}_a)\mathcal{P}(\vec{p}_b)} = \int d^3r' \underbrace{S_{\mathbf{P}}(\mathbf{r}')}_{\textbf{1.}} \underbrace{|\phi(\mathbf{q},\mathbf{r}')|^2}_{\textbf{2.}}$$

1. Understand the emission profile of the pNb system



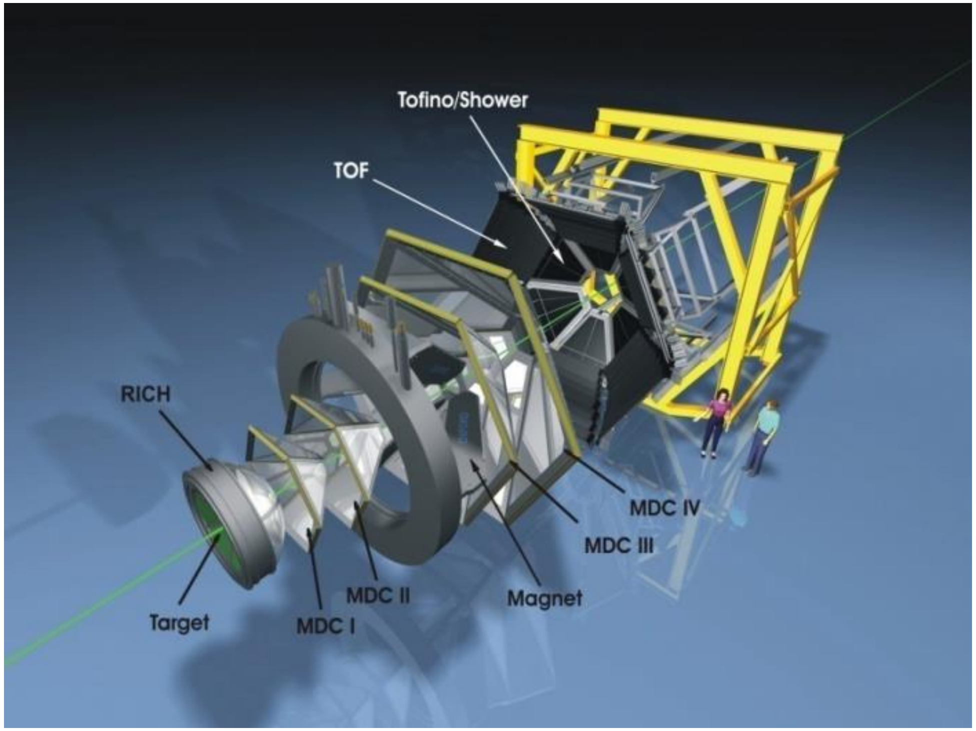
region of homogeneity == „Source“ $S_{\mathbf{P}}(\mathbf{r})$

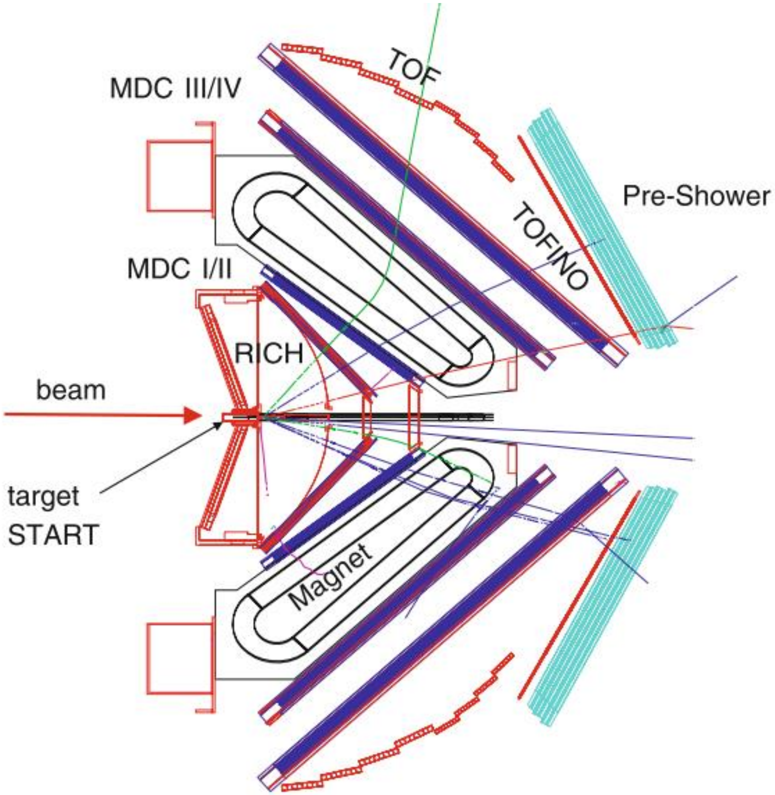
2. Use the information of point 1 to investigate particle interactions which are not well known



Experiment

High **A**cceptance **D**i-**E**lectron **S**pectrometer **- HADES:**





Features of HADES:

- Large geometric acceptance $\phi \in [0, 2\pi] \,, \Theta \in [15°, 85°]$
- Momentum resolution $\sim 2 - 6\%$

Reaction

System under investigation:

$$\mathrm{p} + {}^{93}_{41}\mathrm{Nb} \rightarrow \mathrm{P} + \mathrm{X}$$

$$\mathrm{P} = \mathrm{pp}, \pi^{\pm}\pi^{\pm}, \ldots$$

Beam:

$\xrightarrow{\mathrm{p}}$

$\sim 2 \cdot 10^6/\mathrm{s}$

$T_p = 3.5\ \mathrm{GeV}$

$\sqrt{s_{NN}} = 3.18\ \mathrm{GeV}$

Target:

12-fold segmented target of ${}^{93}\mathrm{Nb}$ discs

2.8% interaction probability

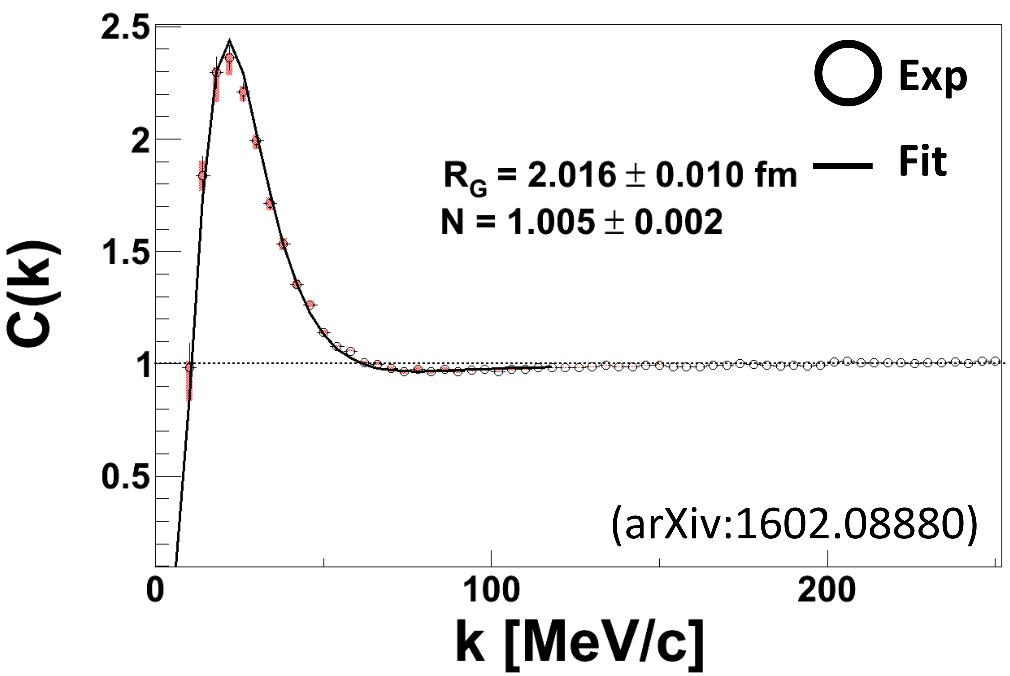
$\langle A_{part} \rangle \sim 2.7$

Femtoscopy in a small system!

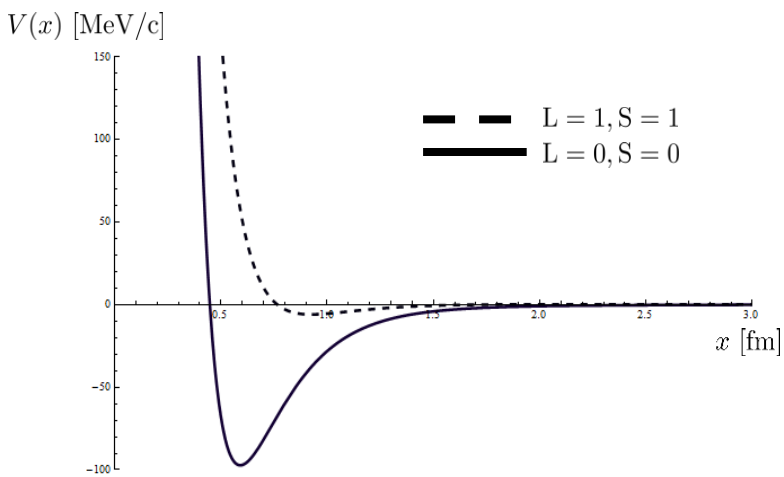
Source Size (pp)

Information about the source: proton-proton correlation function:

Extract source size: $C^{ab}(k) = N \int d^3r' S_{\mathbf{P}}(\mathbf{r}')|\phi(\mathbf{k},\mathbf{r}')|^2$



Potential used for strong interaction:



B. D. Day, Phys. Rev. C 24, (1981), 1203

$$\frac{d^2w}{d\rho^2} + \left[1 - \frac{2\eta}{\rho} - \frac{l(l+1)}{\rho^2} - \frac{2\mu}{k^2}V(\rho)\right] = 0$$

$$S(r) \sim \exp(-r^2/4R_G^2)$$

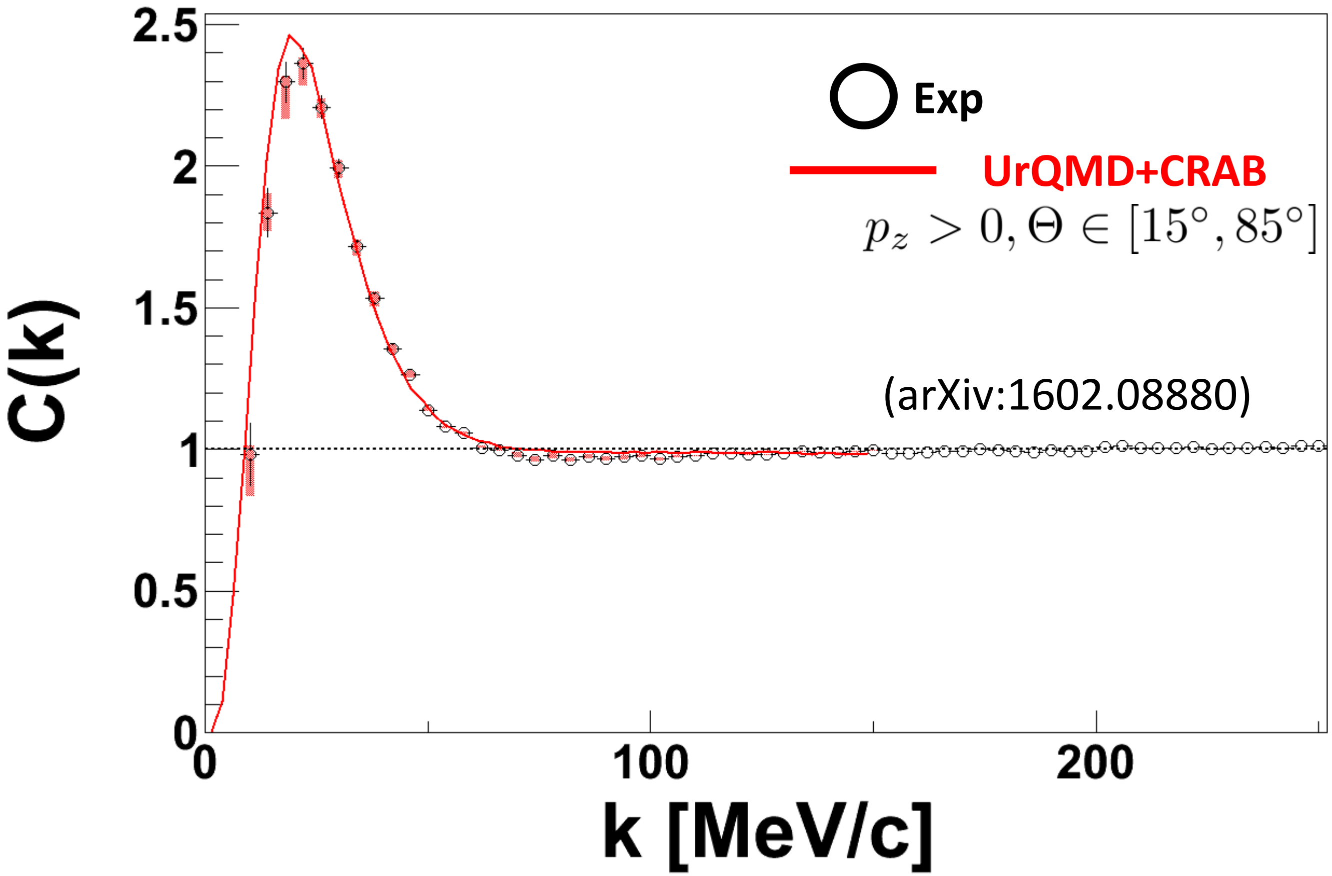
$$R_G = 2.016 \pm 0.010^{+0.109}_{-0.118}\ \text{fm}$$

Model Comparison (pp)

Source comparison to transport theory (same potential used as for the fit):

In one dimension:

Calculation of UrQMD correlation function with help of CRAB



UrQMD gives a good source description for protons

Interaction (Λp)

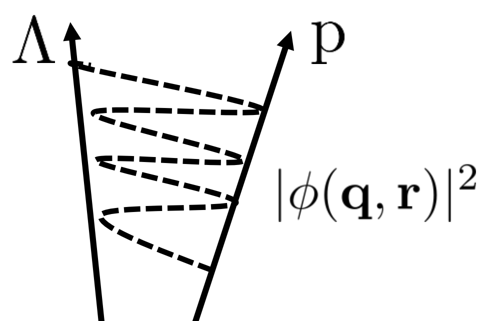
Strategy of analysis:

$$C^{ab}(\mathbf{P},\mathbf{q}) = \frac{\mathcal{P}(\vec{p}_a,\vec{p}_b)}{\mathcal{P}(\vec{p}_a)\mathcal{P}(\vec{p}_b)} = \int d^3r' S_{\mathbf{P}}(\mathbf{r'})|\phi(\mathbf{q},\mathbf{r'})|^2$$

2.

1. Understand the emission profile of the pNb system

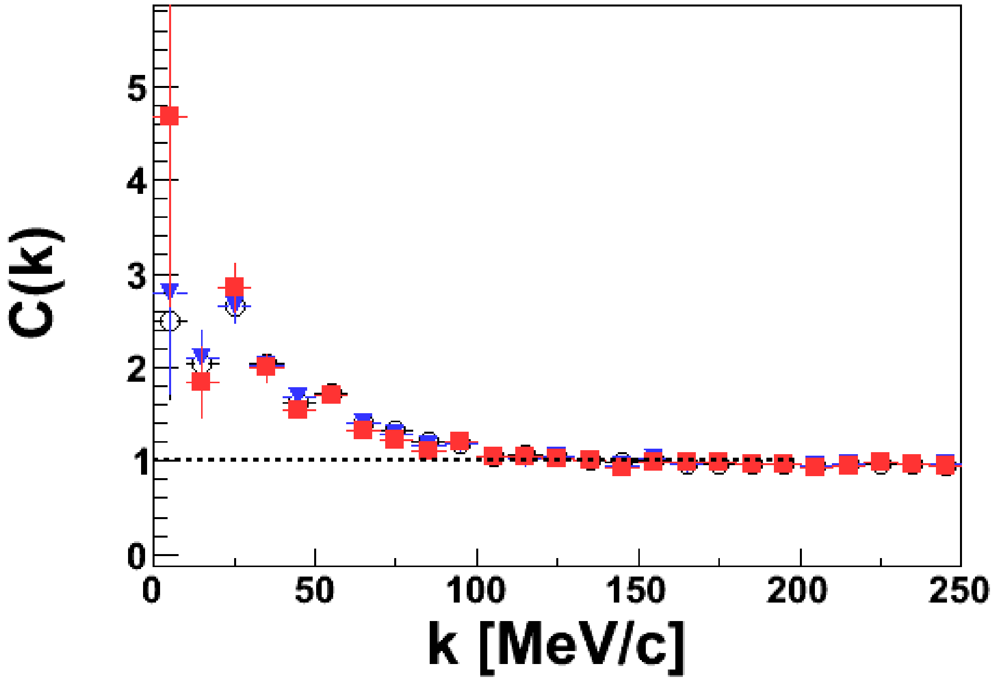
2. Use the information of point 1 to investigate particle interactions of not well known type



Interaction (Λp)

Apply corrections – investigate systematics:

Correlation function after application of all corrections



(arXiv:1602.08880)

Lednicky's model:

$$C(k) = 1+\sum_S \rho_S \left[\frac{1}{2} \left| \frac{f^S(k)}{R_G^{\Lambda p}} \right|^2 \left(1 - \frac{d_0^S}{2\sqrt{\pi} R_G^{\Lambda p}} \right) + 2 \frac{\mathcal{R} f^S(k)}{\sqrt{\pi} R_G^{\Lambda p}} F_1(Q R_G^{\Lambda p}) - \frac{\mathcal{I} f^S(k)}{R_G^{\Lambda p}} F_2(Q R_G^{\Lambda p}) \right]$$

R. Lednický and V. L. Lyuboshitz, Sov. J. Nucl. Phys. **35**, 770 (1982), [Yad. Fiz.35,1316(1981)].

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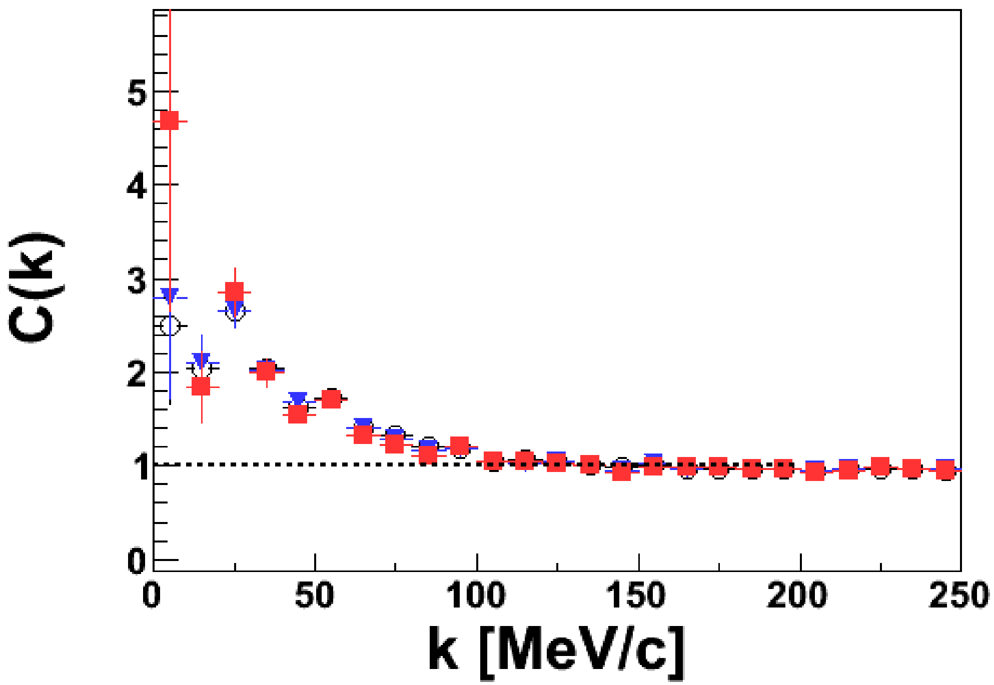

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R. Lednicky and V. L. Lyuboshits, Sov. J. Nucl. Phys. **35**, 770 (1982), [Yad. Fiz.35,1316(1981)].

Can we use the pp measurement to fix it?

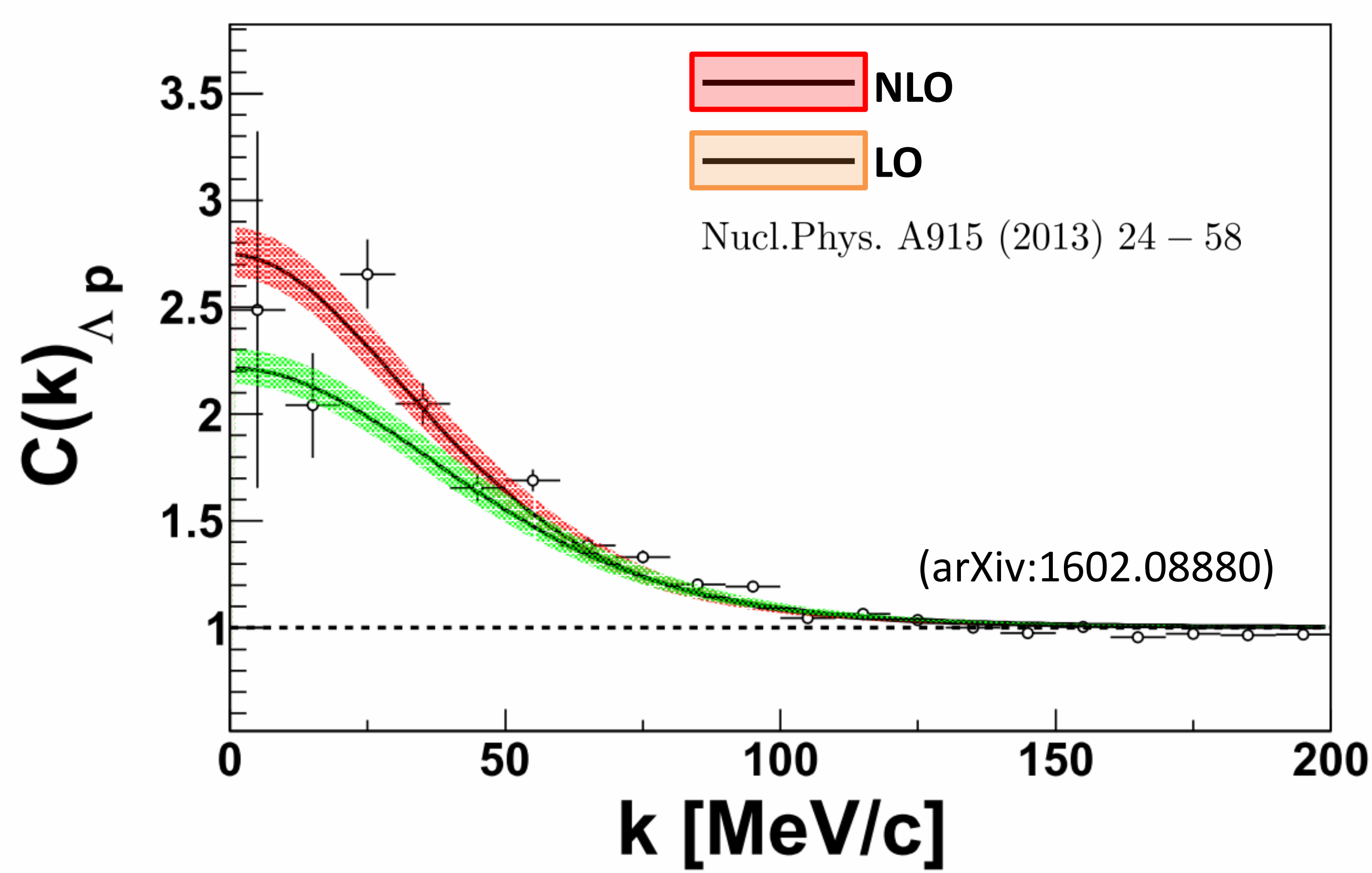
Interaction (Λp)

Comparison to models:

$$\mathrm{RF} = \frac{R_{\mathrm{inv}}^{pp}}{R_{\mathrm{inv}}^{\Lambda p}} = 1.184$$

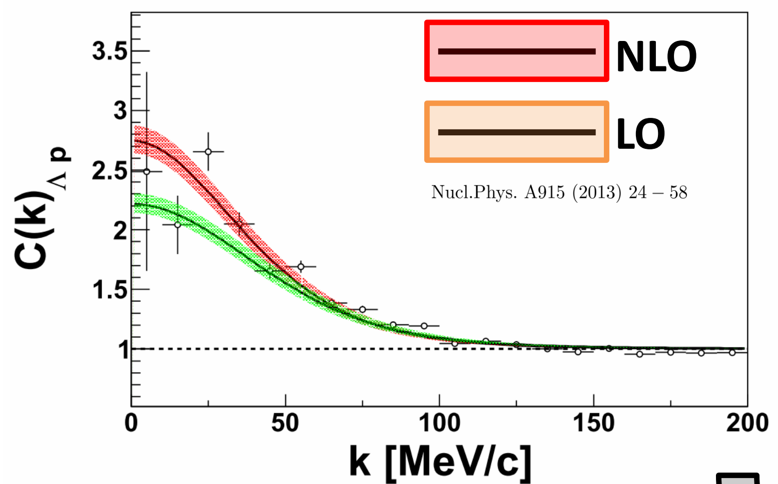
$$R_G = 2.016 \pm 0.010^{+0.109}_{-0.118}\ \mathrm{fm}$$

$$R_G^{\Lambda p} = R_G^{pp} / RF$$

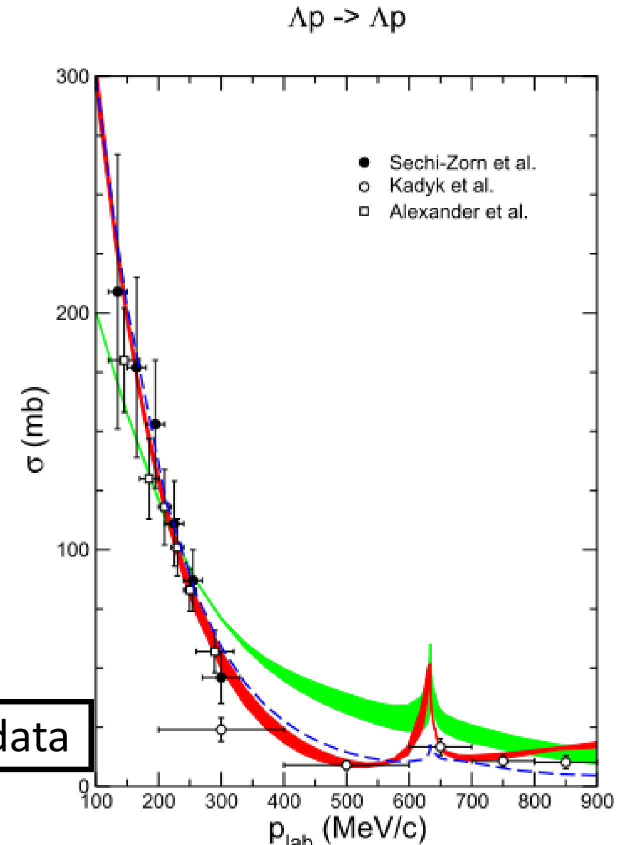


Interaction (Λp)

Comparison to models:



no data



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„Closing the gap"

Summary

- Source size of emission region in pNb system determined with pp-pairs

- Knowing the source size allows to study final state interactions of not well known type

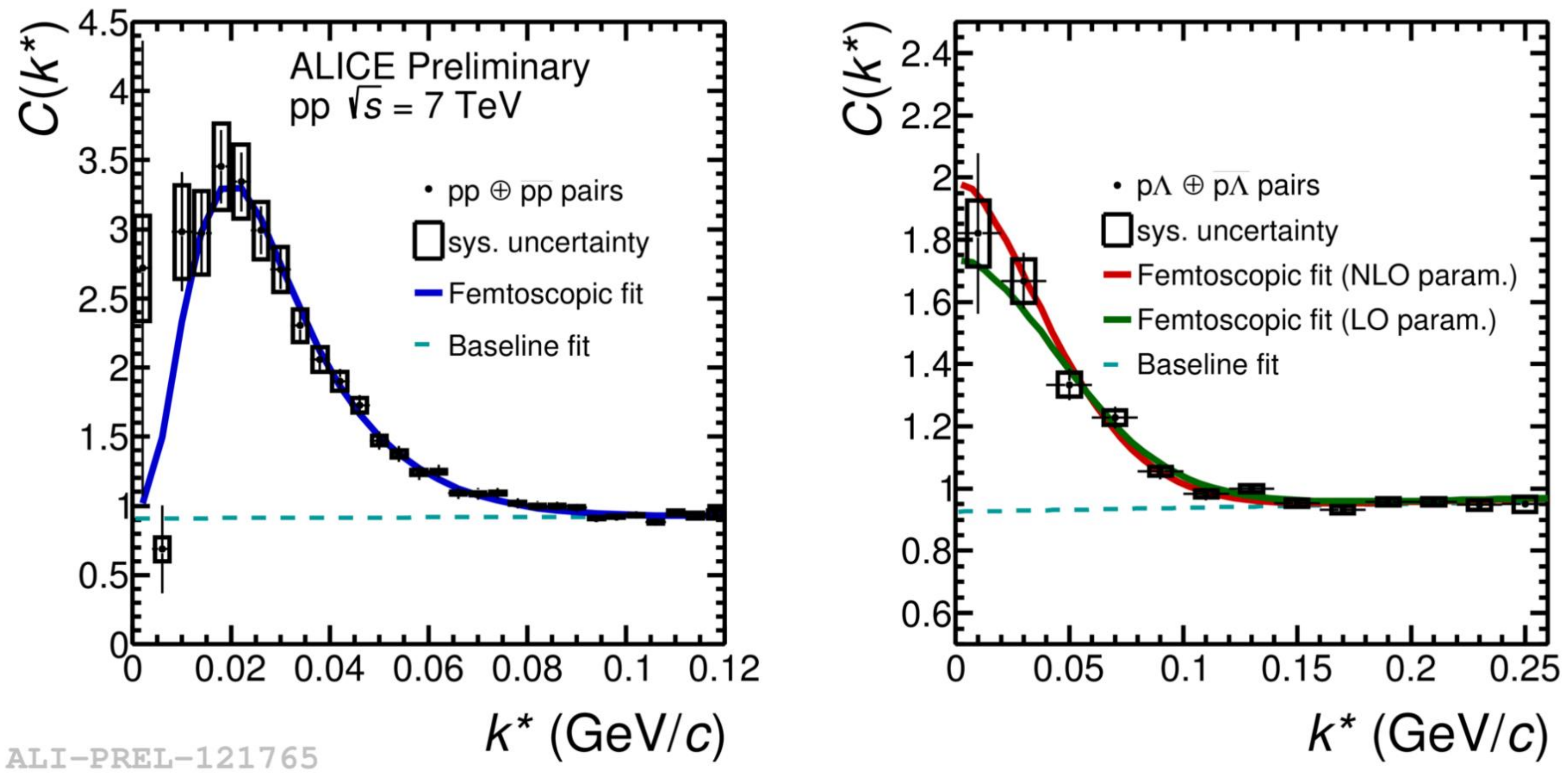
⇨ „Closing the gap“: No scattering data at very low relative momenta

Article for detailed information:

J. Adamczewski-Musch *et al.* (HADES Collaboration)
Phys. Rev. C 94, 025201

Outlook

- Apply the same technique to **ALICE** data.
  Currently investigating the **pp 7 TeV** data (*Oliver Arnold*).



Outlook

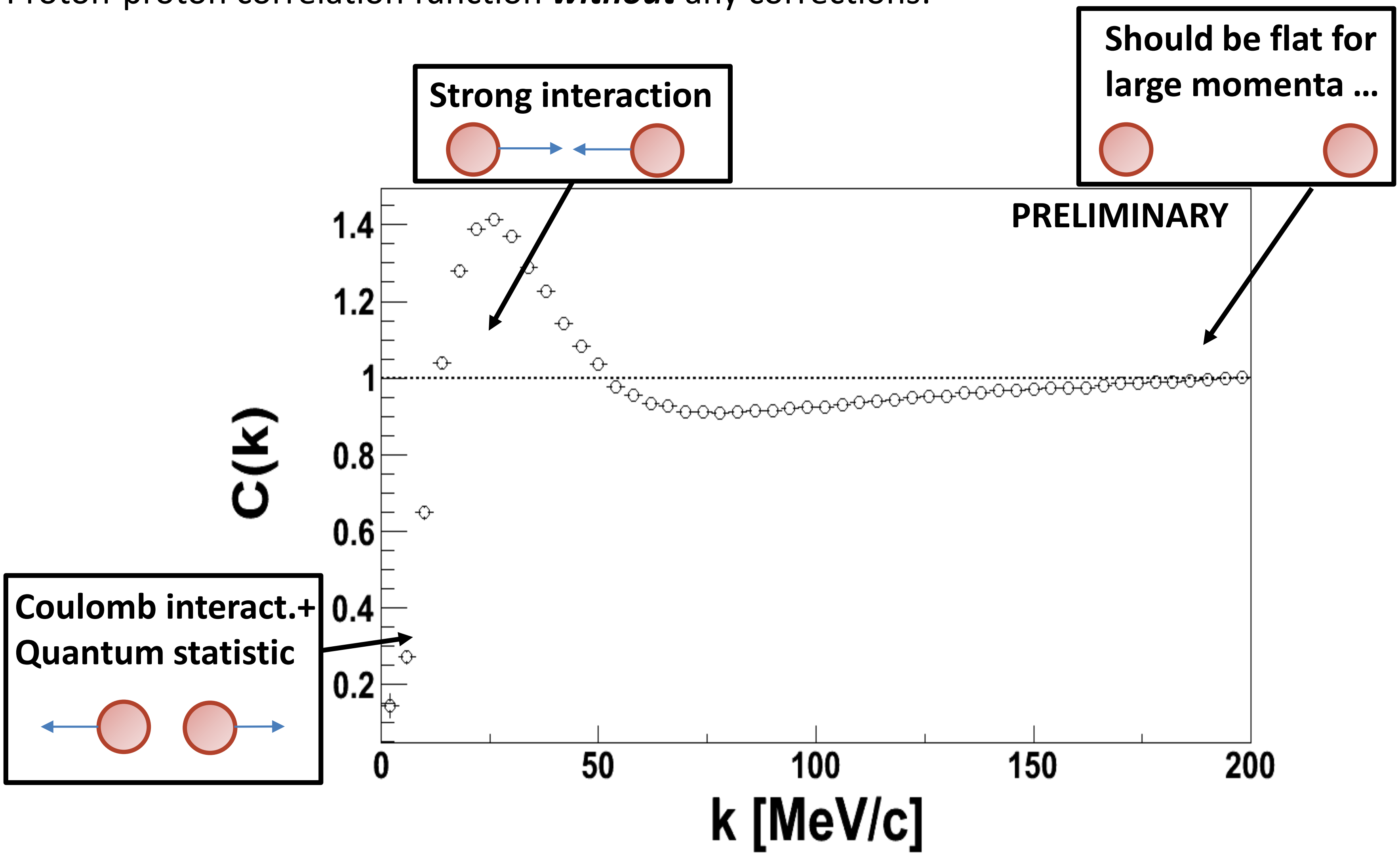
- Currently developing a ***C**orrelation **A**nalysis **T**ool using the **S**chrödinger equation* (CATS).
(*Dimitar Mihaylov*)

- Attempt to perform multi-particle femtoscopy.
(*Ante Bilandzic*)


Thank You For
Your Attention
Munich, Germany

Correlation Function (pp)

Information about the source: proton-proton correlation function:
Proton-proton correlation function ***without*** any corrections:

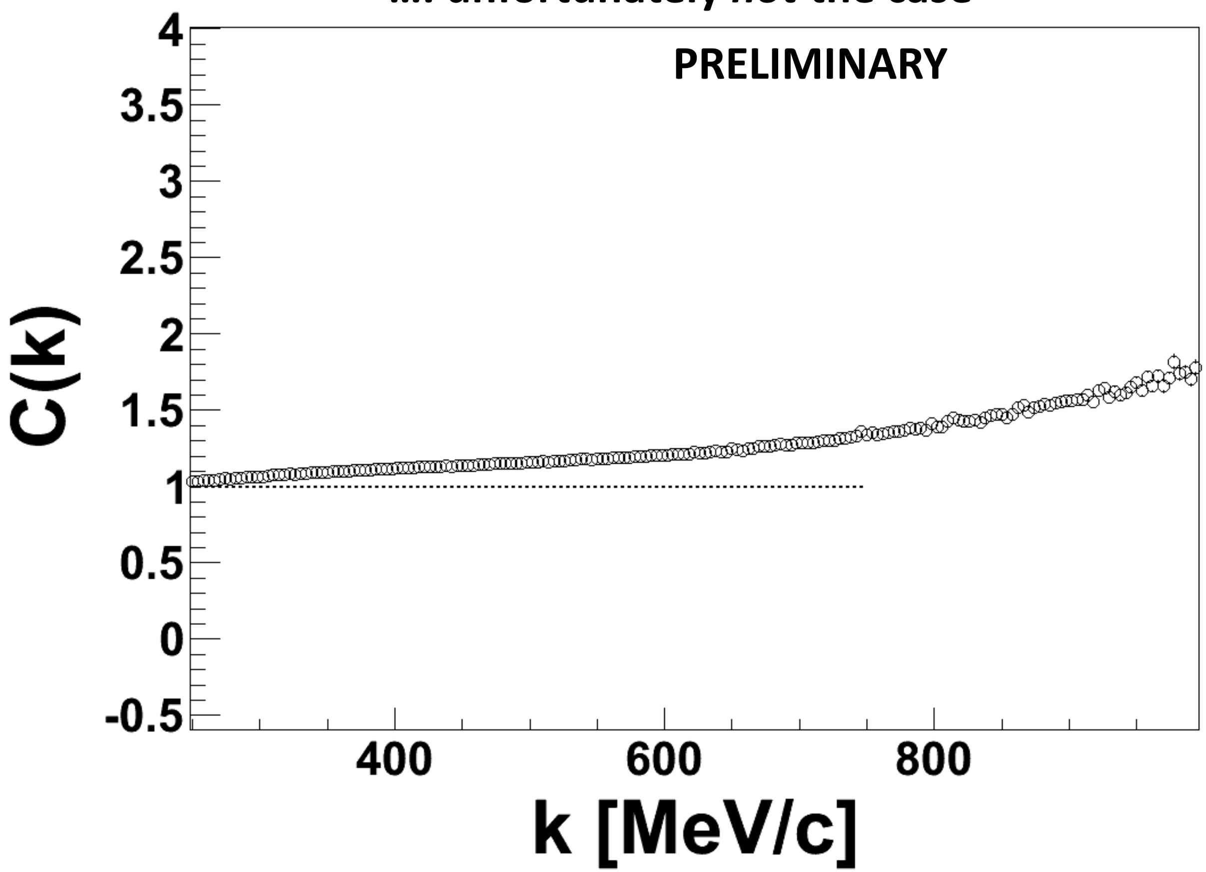


Correlation Function (pp)

Information about the source: proton-proton correlation function:
Proton-proton correlation function ***without*** any corrections:

Should be flat for large momenta …

…. unfortunately *not* the case

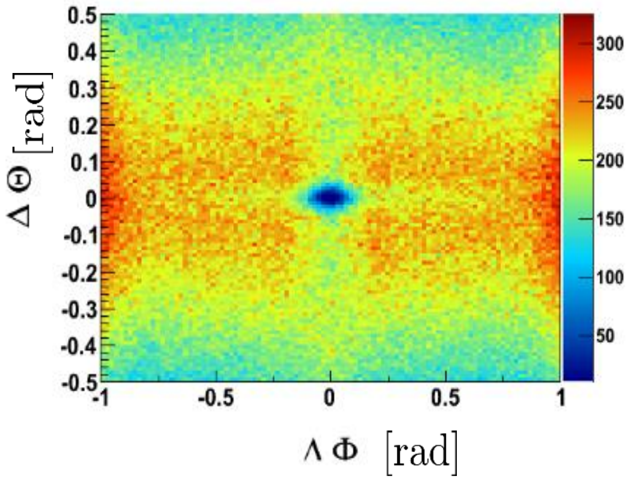


Correlation Function (pp)

Information about the source: proton-proton correlation function:

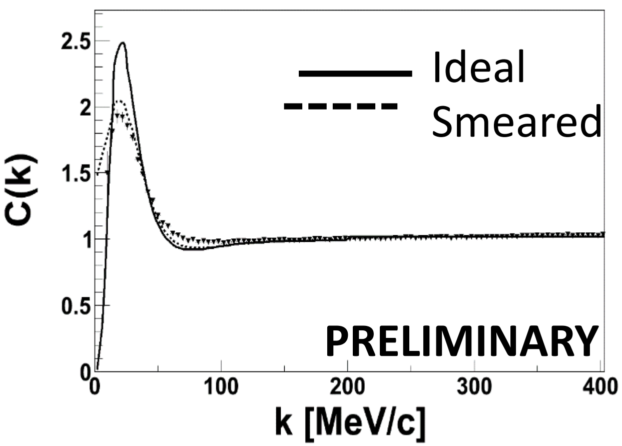
Corrections

Reject pairs which are too close together



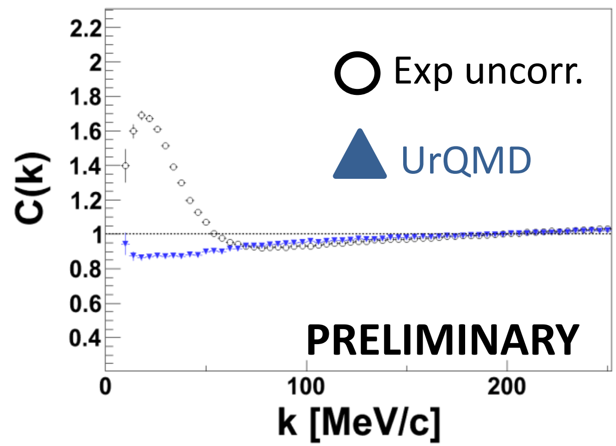
$$|\Delta\phi| > 3 \times 0.039 \text{ rad}$$
$$|\Delta\Theta| > 3 \times 0.015 \text{ rad}$$

Correct for finite momentum resolution



$$\frac{C_{\mathrm{real}}(k)}{C_{\mathrm{measured}}(k)} = \frac{C_{\mathrm{ideal}}(k)}{C_{\mathrm{smeared}}(k)}$$

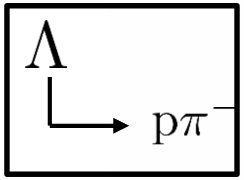
Correct for long range correlations



$$C(k) \equiv C_{\mathrm{raw}}(k)/C_{\mathrm{UrQMD}}(k)$$

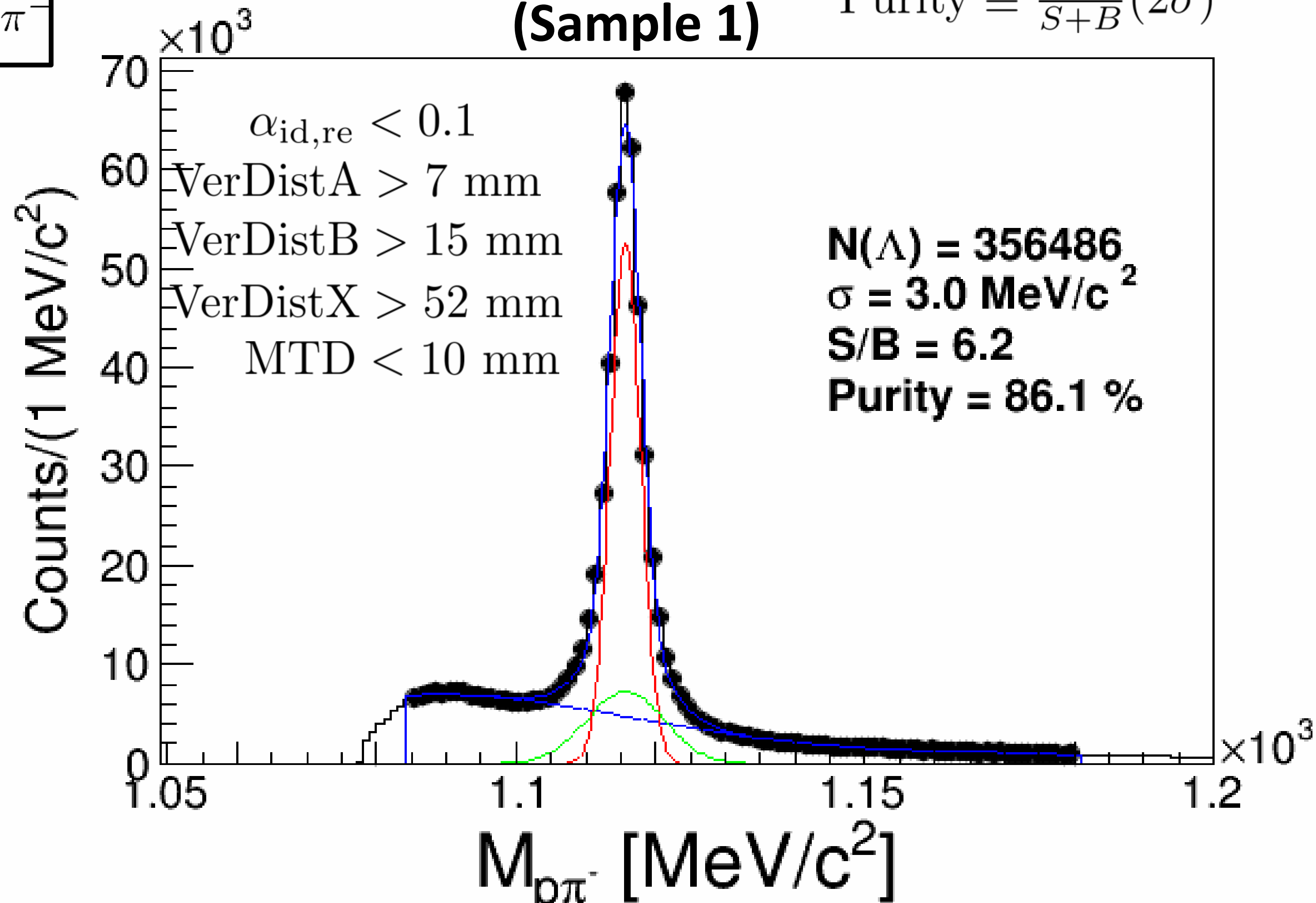
Interaction (Λp)

Select $\Lambda's$ with large purity – different cut combinations to investigate systematics:



(Sample 1)

$\text{Purity} \equiv \frac{S}{S+B}(2\sigma)$



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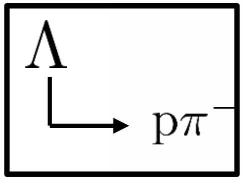
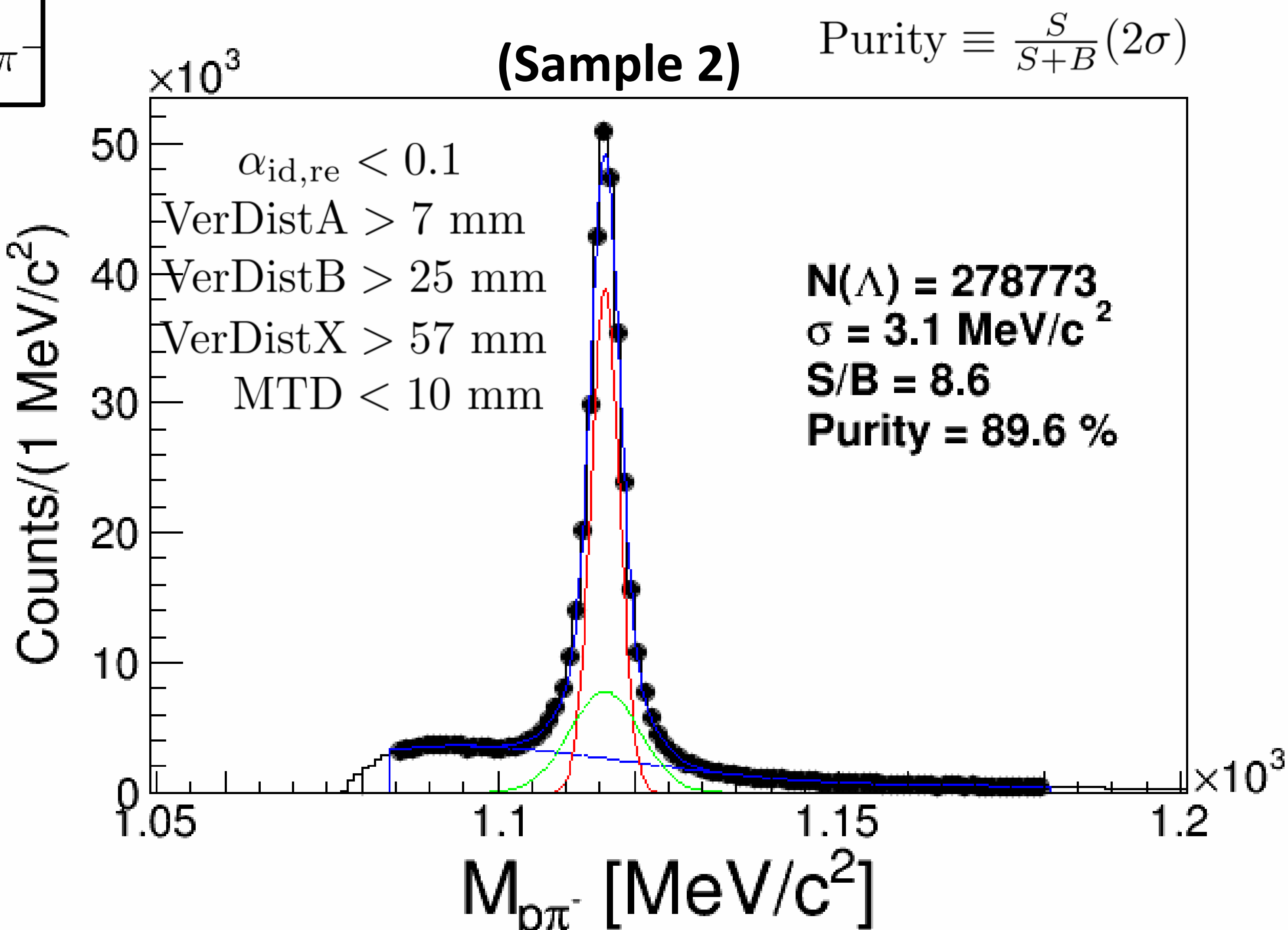
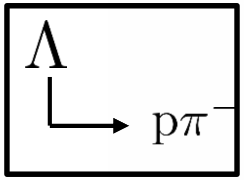
Select $\Lambda's$ with large purity – different cut combinations to investigate systematics:





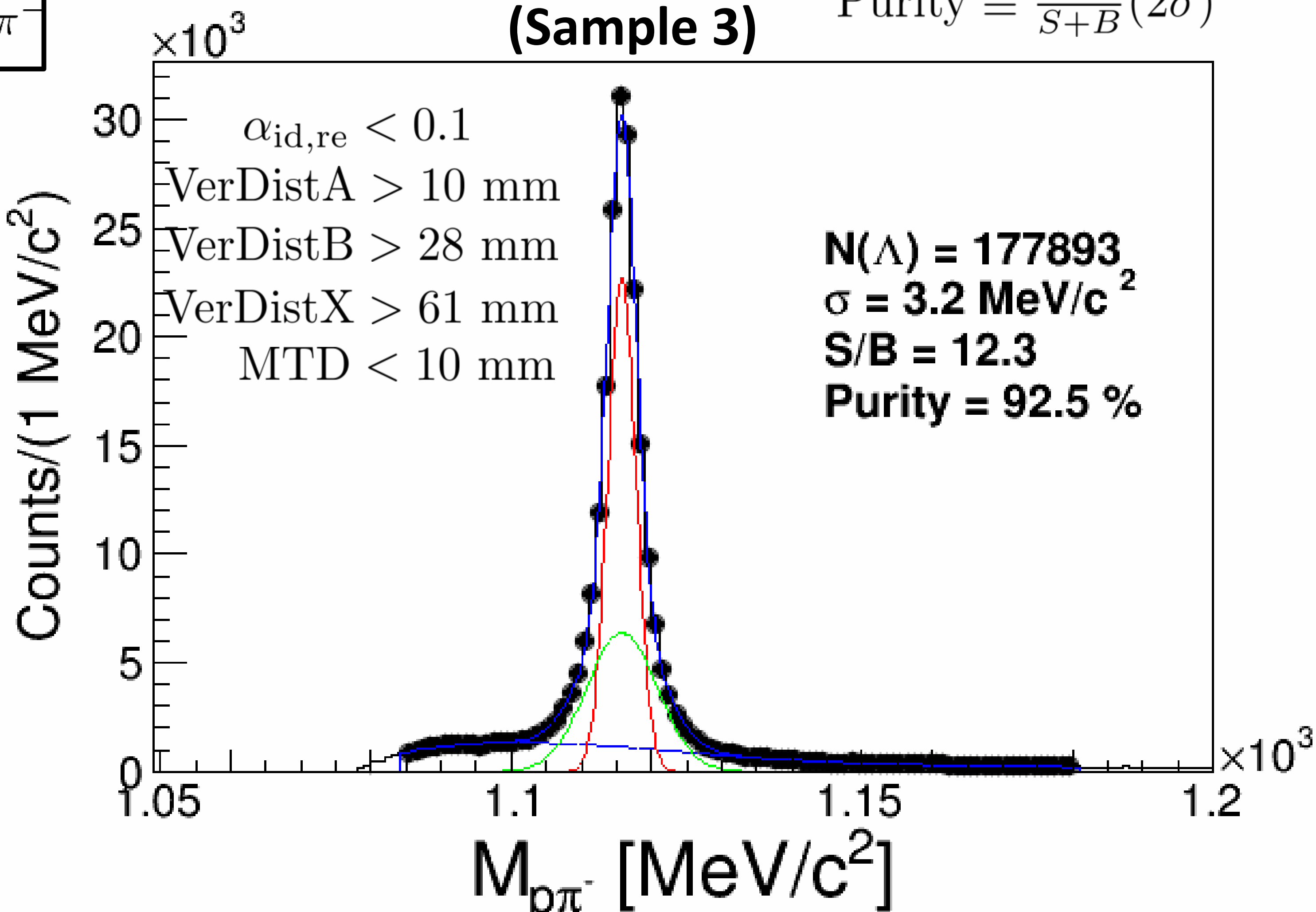
Interaction (Λp)

Select $\Lambda's$ with large purity – different cut combinations to investigate systematics:



(Sample 3)

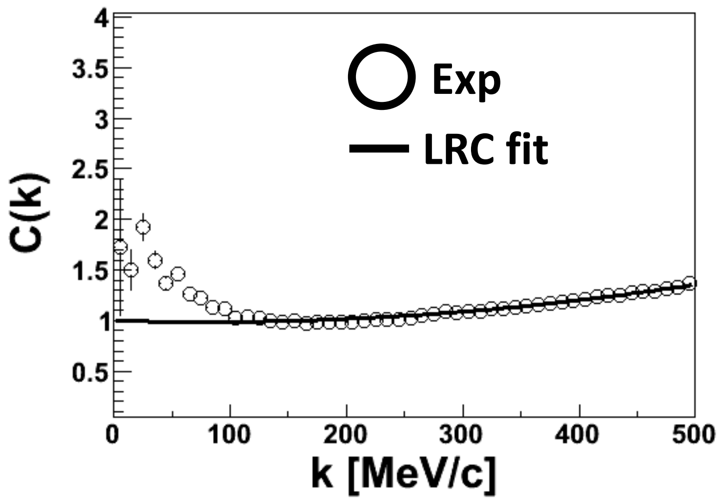
$$\text{Purity} \equiv \frac{S}{S+B}(2\sigma)$$



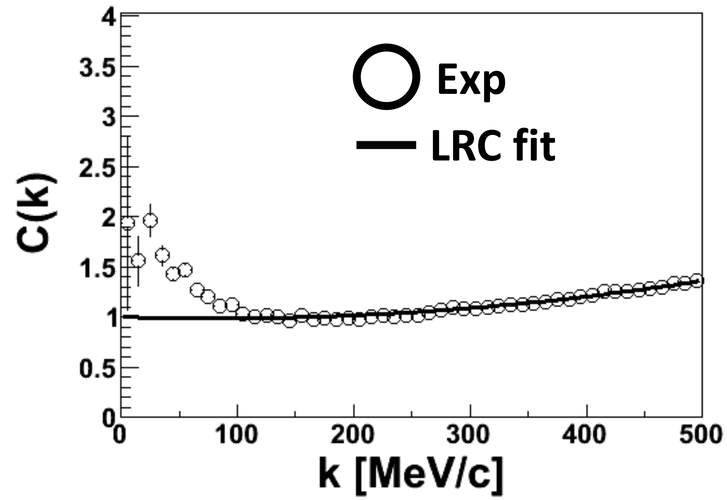
Interaction (Λp)

Again corrections: Influence of long range correlations for all three cut combinations:

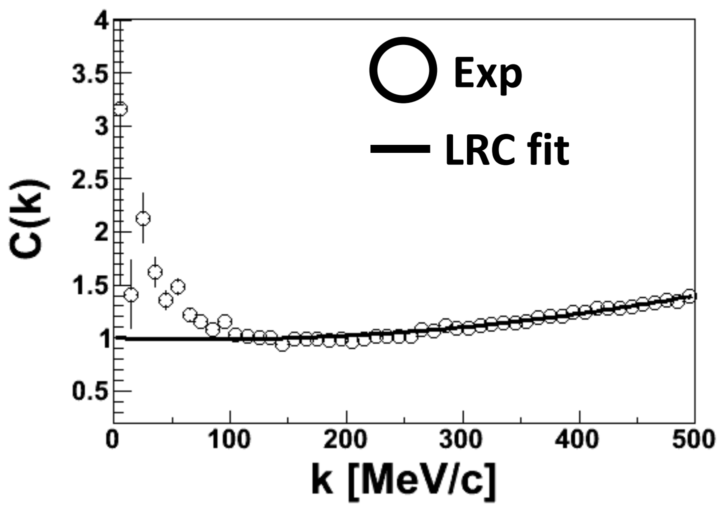
combo1



combo2



combo3



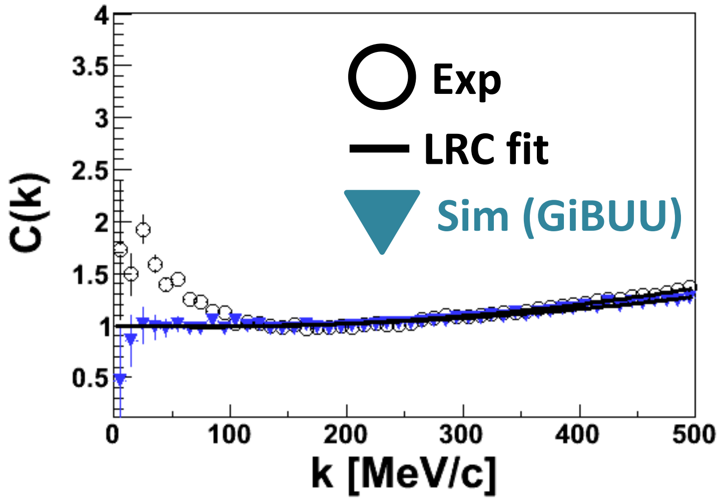
Model the long-range part with a polynomial

$$C_{\mathrm{LRC}} = 1 + ak + bk^2 \quad k \in [250, 600]\ \mathrm{MeV/c}$$

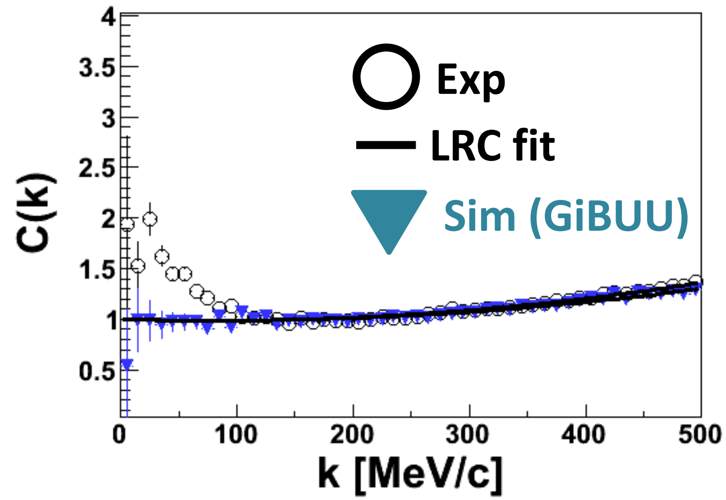
Interaction (Λp)

Again corrections: Influence of long range correlations for all three cut combinations:

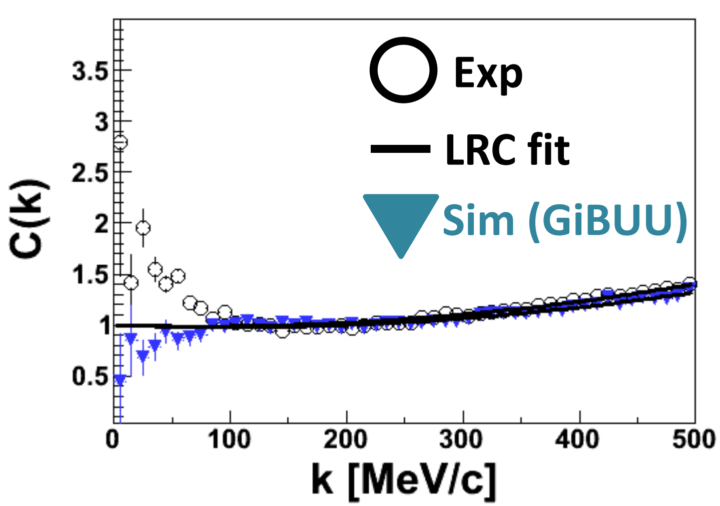
combo1



combo2



combo3



Model the long-range part with a polynomial

$$C_{\mathrm{LRC}} = 1 + ak + bk^2 \quad k \in [250, 600]\ \mathrm{MeV/c}$$

Simulation confirms trend of the fit from the long-range part also at small relative momenta

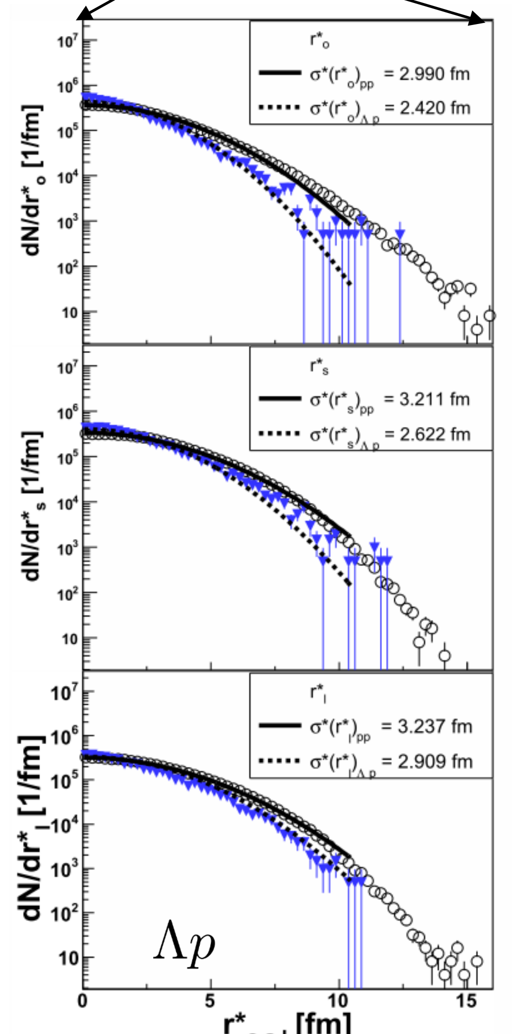
Interaction (Λp)

Source extraction from transport theory (UrQMD) - LCMS:

$$C^{ab}(k) = \int d^3r' S_{\mathbf{P}}(\mathbf{r}')|\phi(\mathbf{k},\mathbf{r}')|^2 \qquad k < 30 \text{ MeV/c}$$

▼ Λp

○ pp



Fit function used:

$$\sim \exp(-r^2/2\sigma^2)$$

$$R_{\text{inv}} = \sqrt{\frac{{R^*_{\text{out}}}^2 + {R^*_{\text{side}}}^2 + {R^*_{\text{long}}}^2}{3}}$$

$$\text{RF} = \frac{R^{pp}_{\text{inv}}}{R^{\Lambda p}_{\text{inv}}} = 1.184$$

(arXiv:1602.08880)