Proton-Proton and Proton-Lambda correlations measured in p+Nb collisions at 3.5 GeV with HADES

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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

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)

Wavefunction 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)**

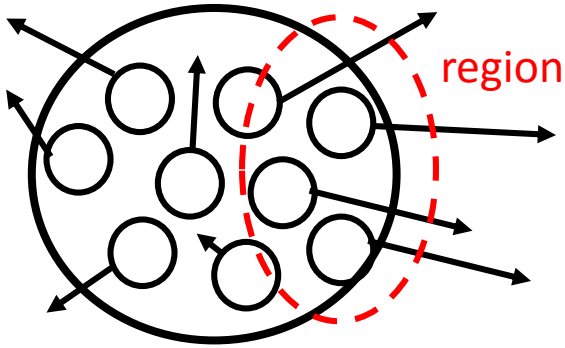
- **Same:** relative momentum dist. of particles in the same event
- **Mixed:** particles from different events (not correlated)
- **Normalized to unity**: $C(k > 100\ \mathrm{MeV/c}) \equiv 1$

Introduction

Strategy of analysis – two steps:

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

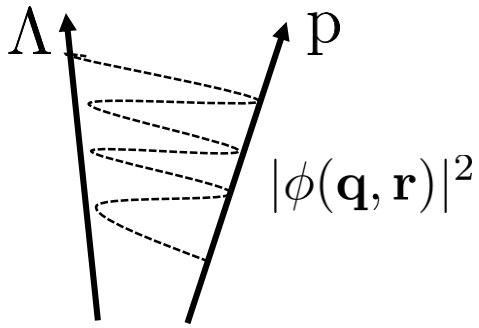
1. Understand the emission profile of the pNb system



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

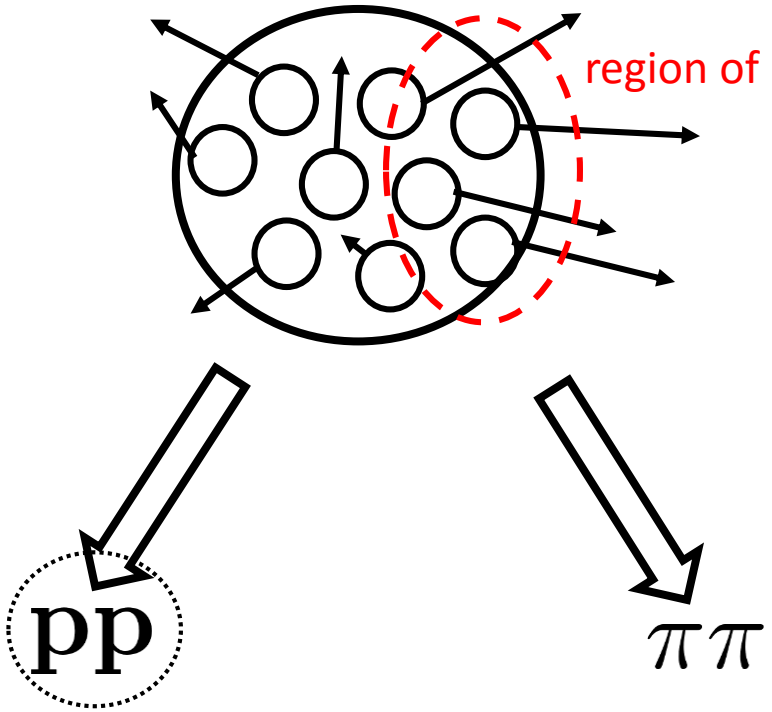


Introduction

Strategy of analysis – two steps:

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

1. Understand the emission profile of the pNb system



Use $\mathbf{pp}$ pairs since we have plenty of protons and we know their interaction

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:

p ⟶

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

$T_p = 3.5$ GeV

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

Target:

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

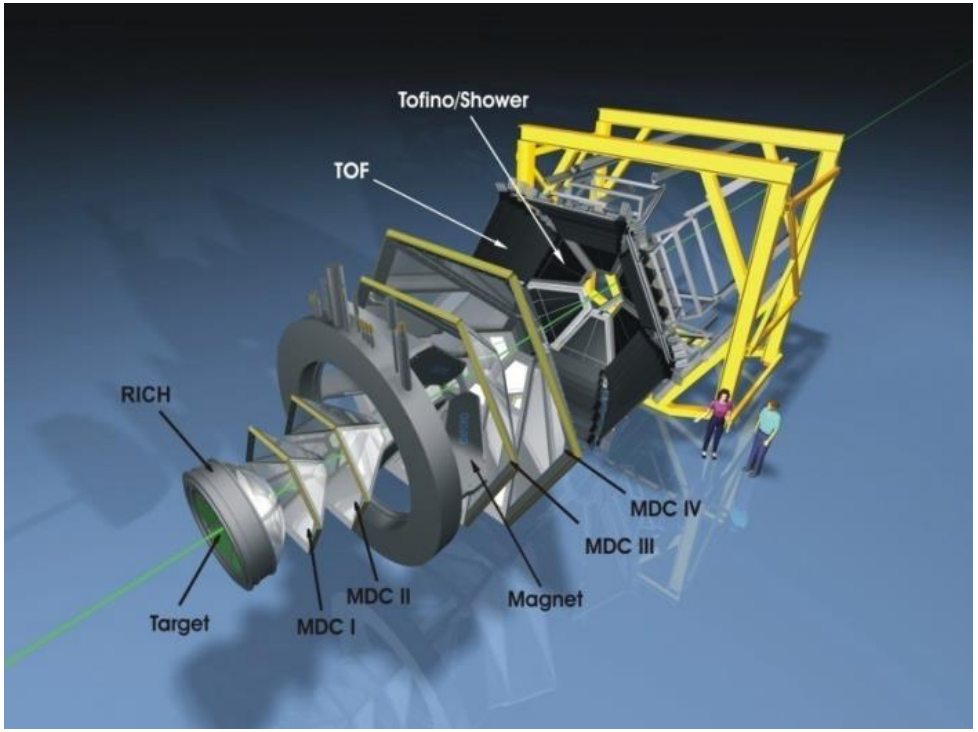
2.8% interaction probability

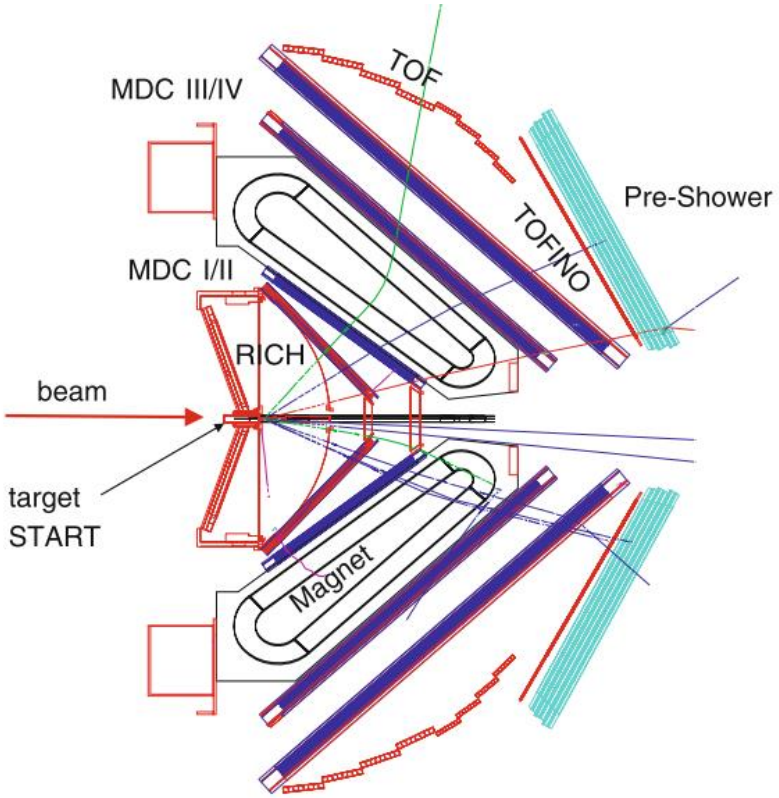
$\langle A_{part} \rangle \sim 2.7$

Femtoscopy in a small system!

Experiment

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



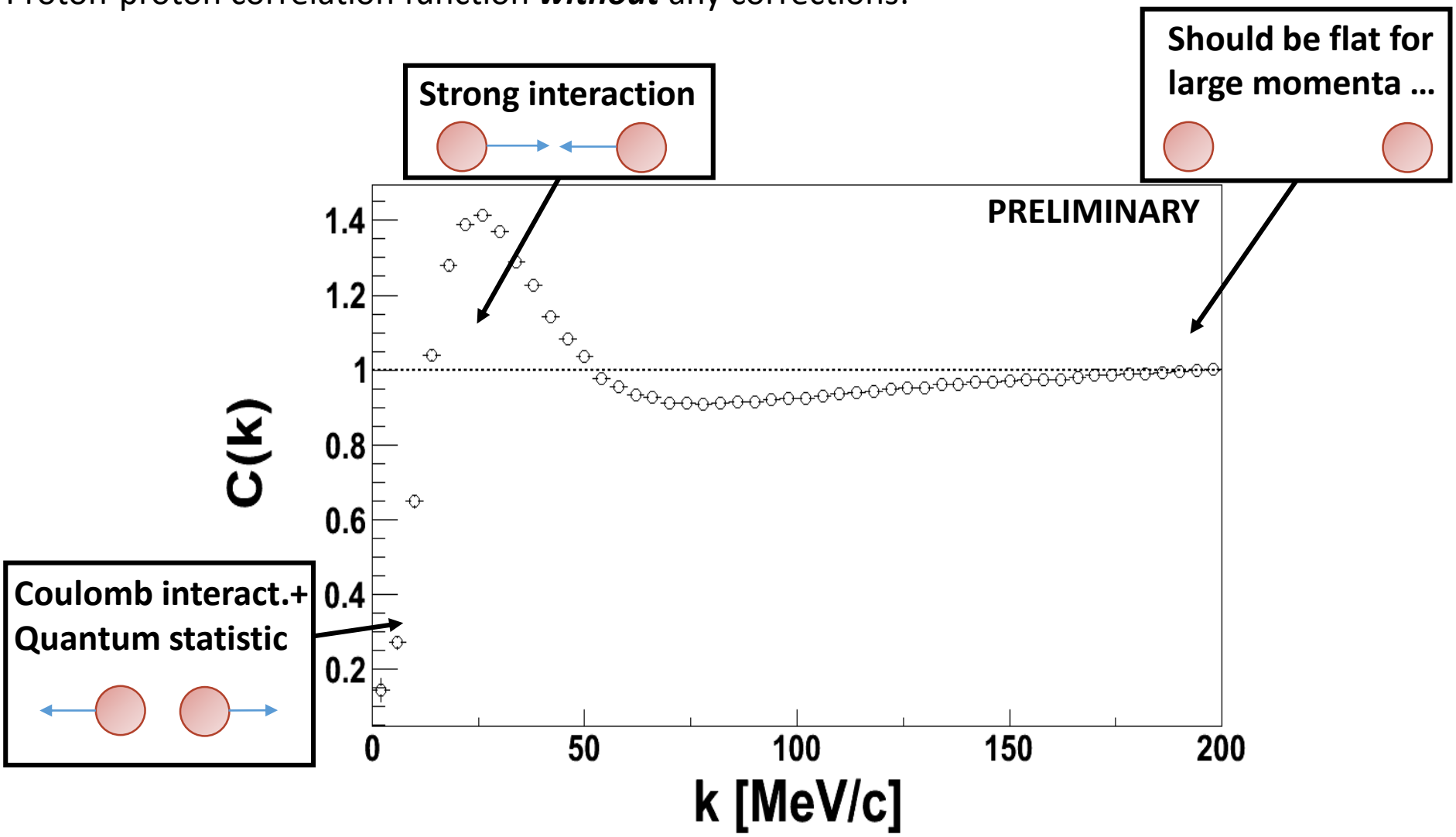


Features of HADES:

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

Correlation Function

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

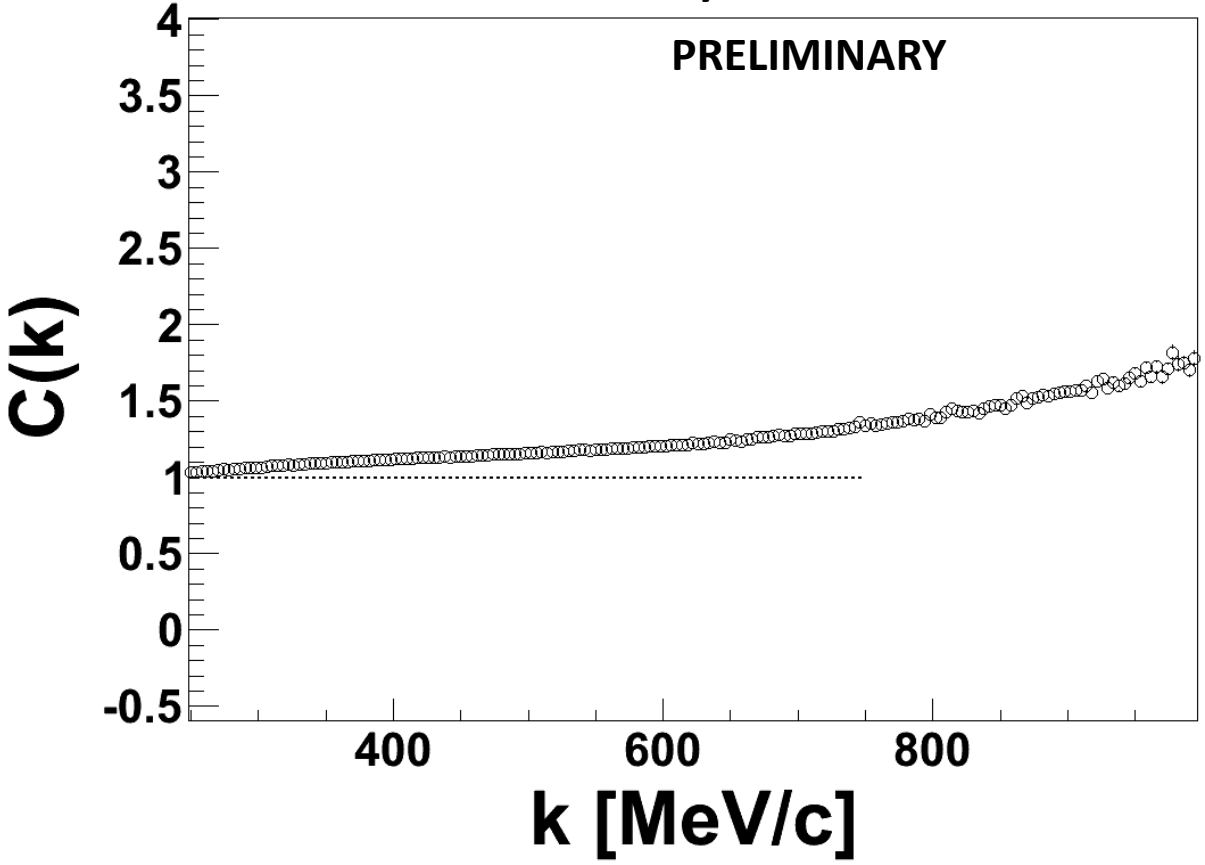


Correlation Function

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

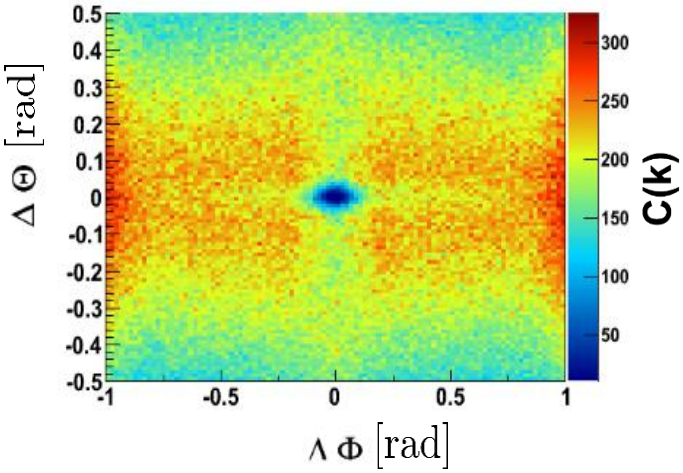


Correlation Function

Information about the source – proton proton correlation function:

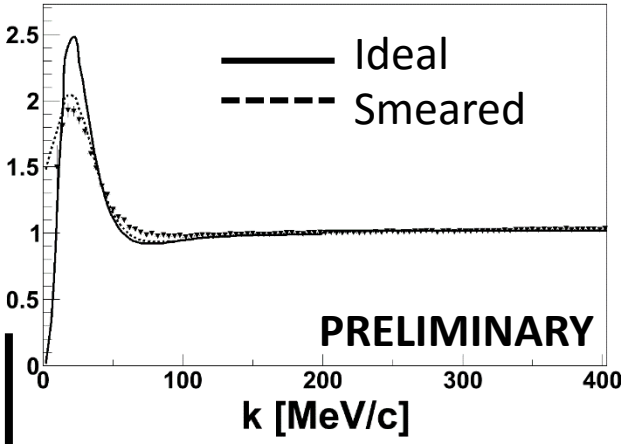
Corrections

Reject pairs which are too close together



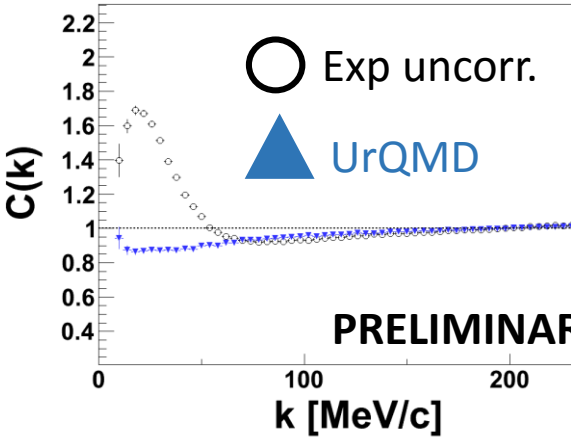
$$|\Delta\phi| > 3 \times 0.039 \text{ rad}$$
$$|\Delta\Theta| > 3 \times 0.015 \text{ rad}$$

Correct for finite momentum resolution



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

Correct for long range correlations

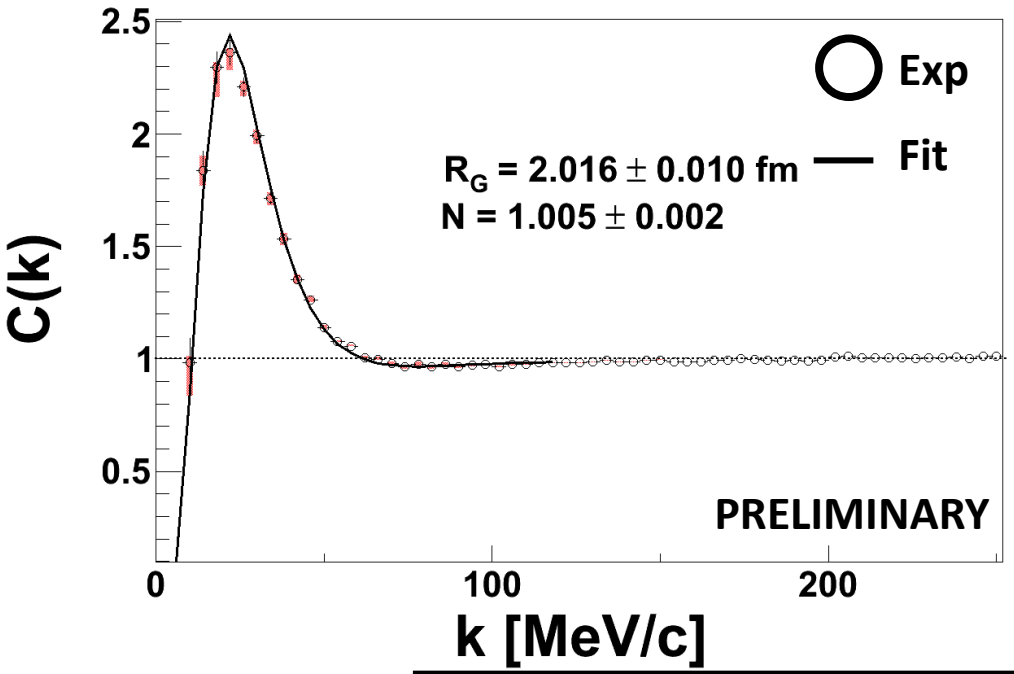


$$C(k) \equiv C_{\text{raw}}(k)/C_{\text{UrQMD}}(k)$$

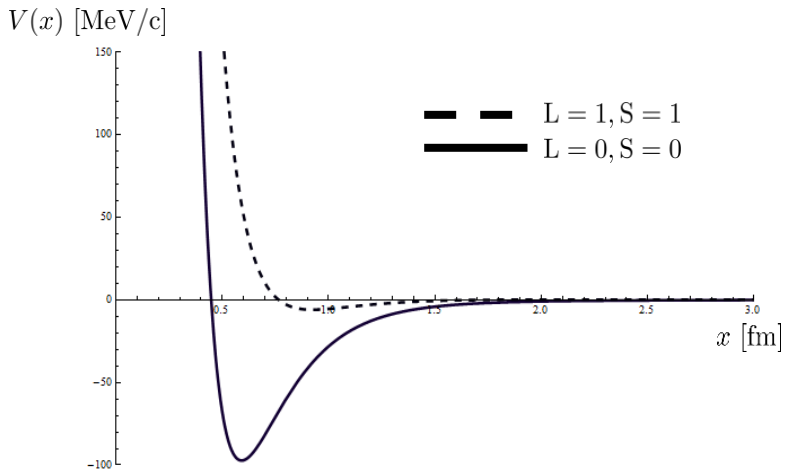
Source Size

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

$$\frac{d^2w}{d\rho^2} + \left[1 - \frac{2\eta}{\rho} - \frac{l(l+1)}{\rho^2} - \frac{2\mu}{k^2} V(\rho)\right] = 0 \qquad S(r) \sim \exp(-r^2/4R_G^2)$$

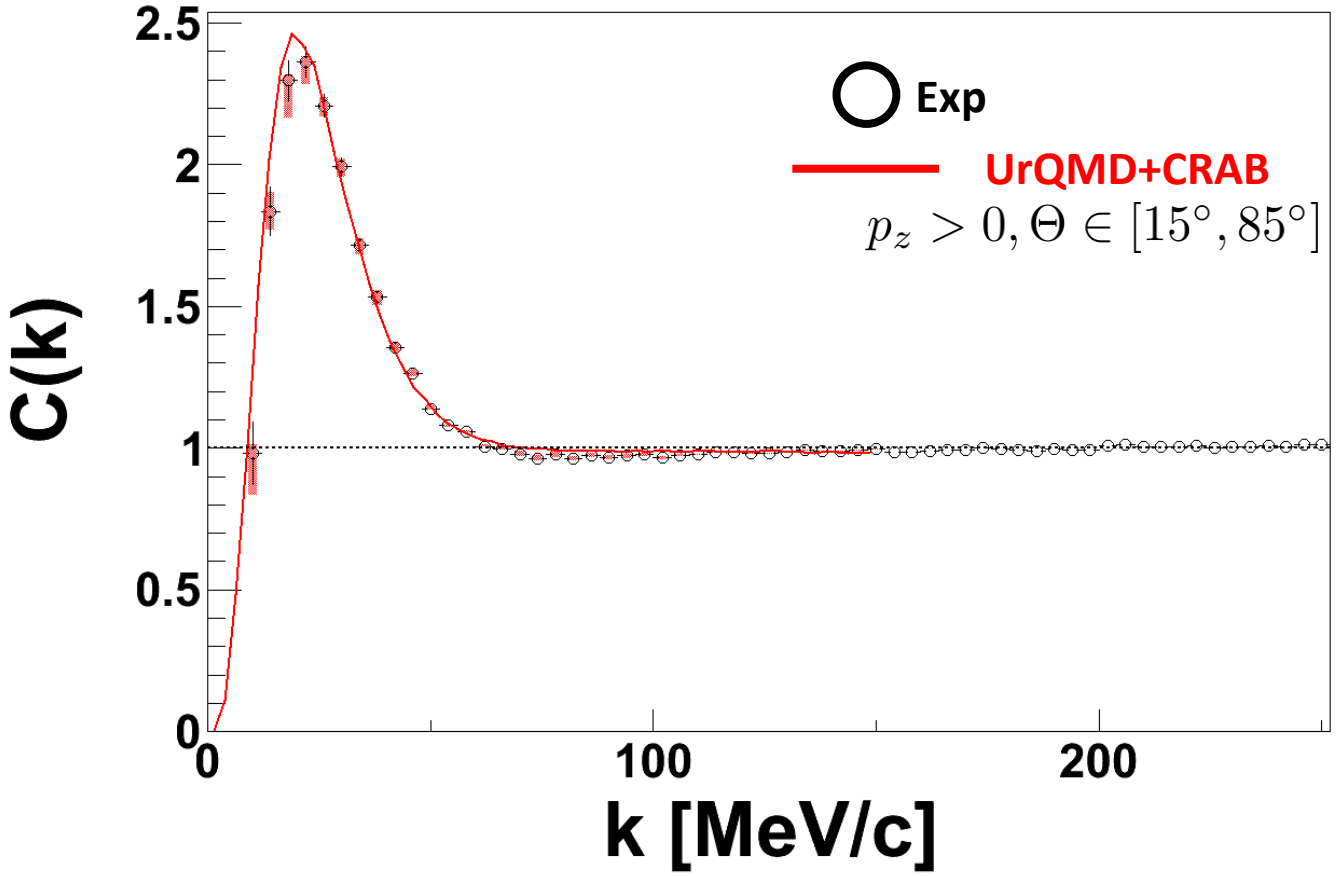
$$R_G = 2.016 \pm 0.010^{+0.109}_{-0.118} \text{ fm}$$

Model comparison

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

In one dimension:

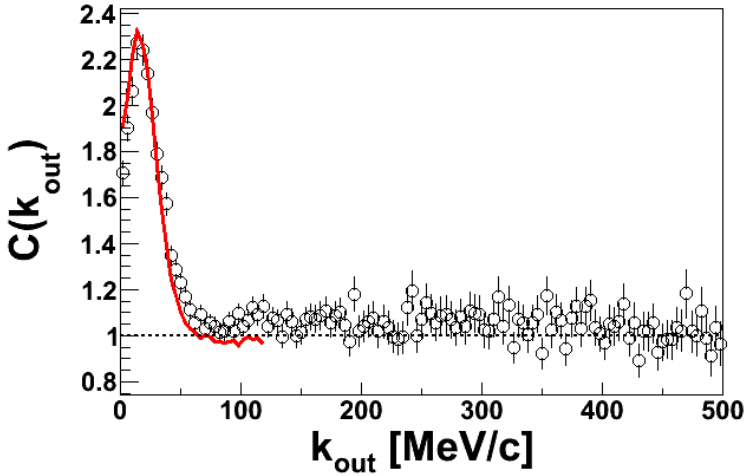
Calculation of UrQMD correlation function with help of CRAB

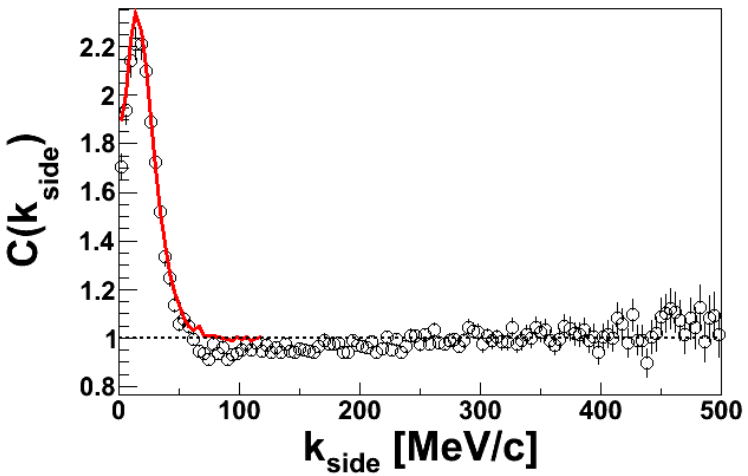


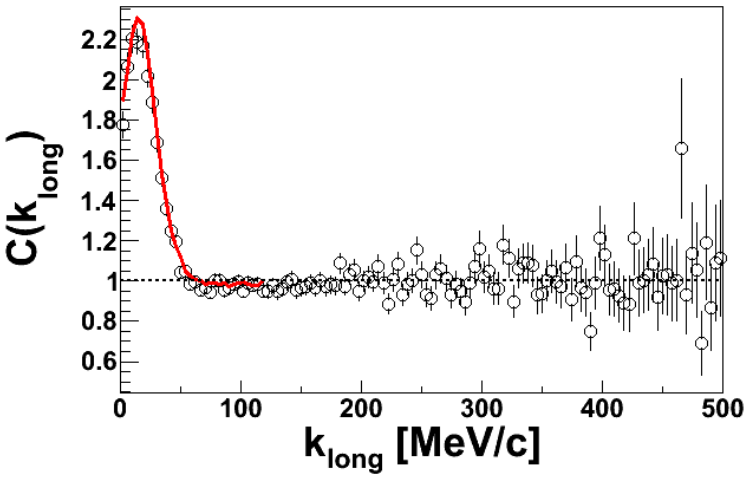
Model comparison

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

In three dimensions:







Exp

UrQMD+CRAB

$p_z > 0, \Theta \in [15°, 85°]$

UrQMD gives a good source description for protons

Interaction

Strategy of analysis:

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

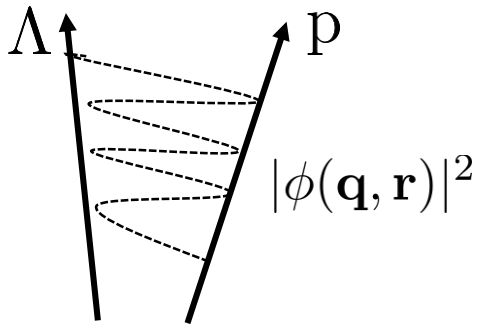
2.

1. Understand the emission profile of the pNb system

region of homogeneity == „Source“

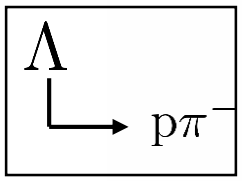
$S_{\mathbf{P}}(\mathbf{r})$

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



Interaction

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



(combo 1)

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

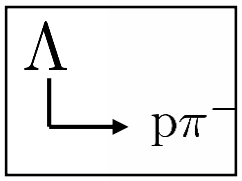
$\alpha_{\text{id,re}} < 0.1$
VerDistA > 7 mm
VerDistB > 15 mm
VerDistX > 52 mm
MTD < 10 mm

N(Λ) = 356486
σ = 3.0 MeV/c²
S/B = 6.2
Purity = 86.1 %

Counts/(1 MeV/c²)
$M_{p\pi^-}$ [MeV/c²]

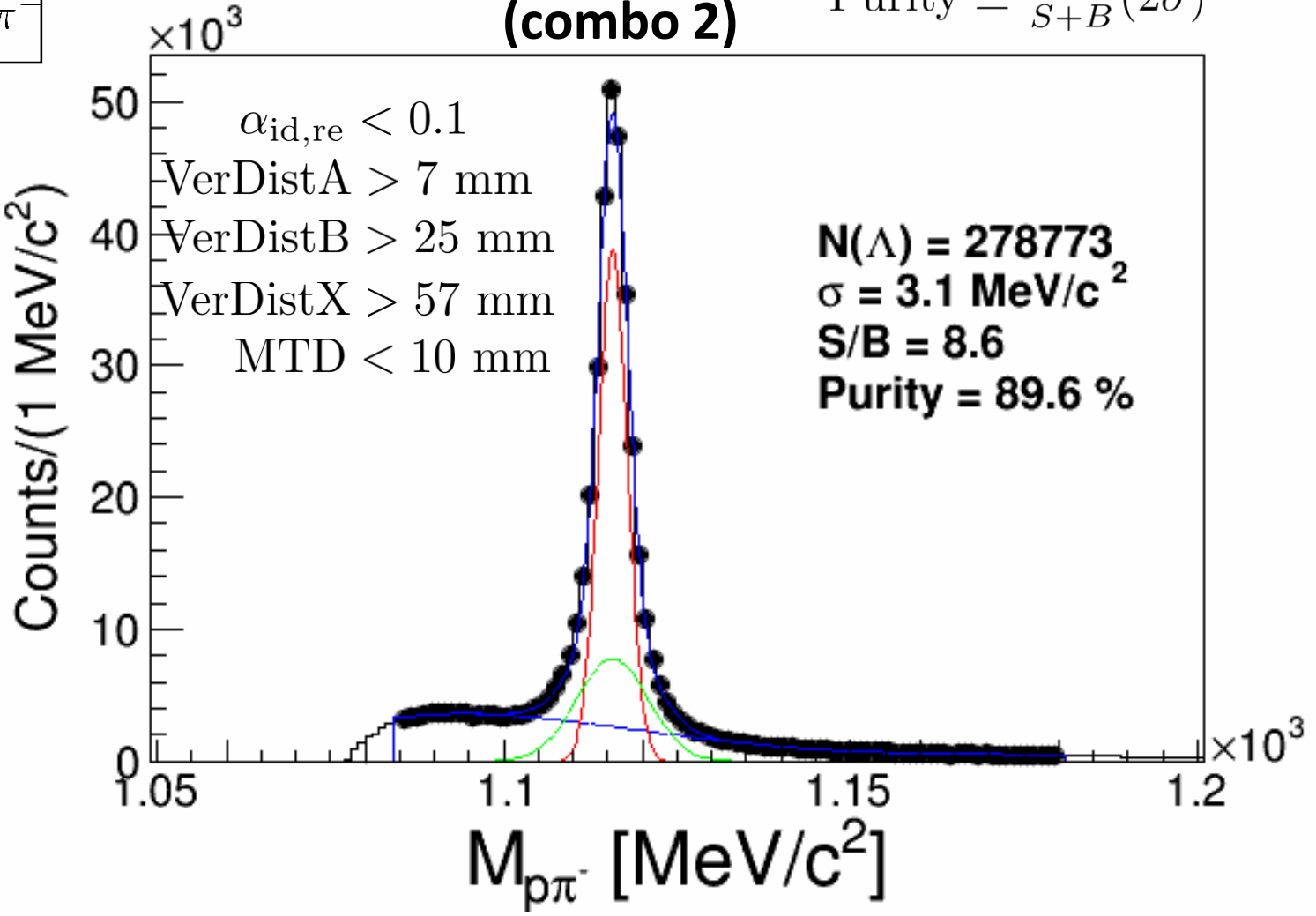
Interaction

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



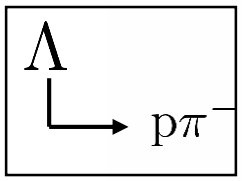
(combo 2)

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



Interaction

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

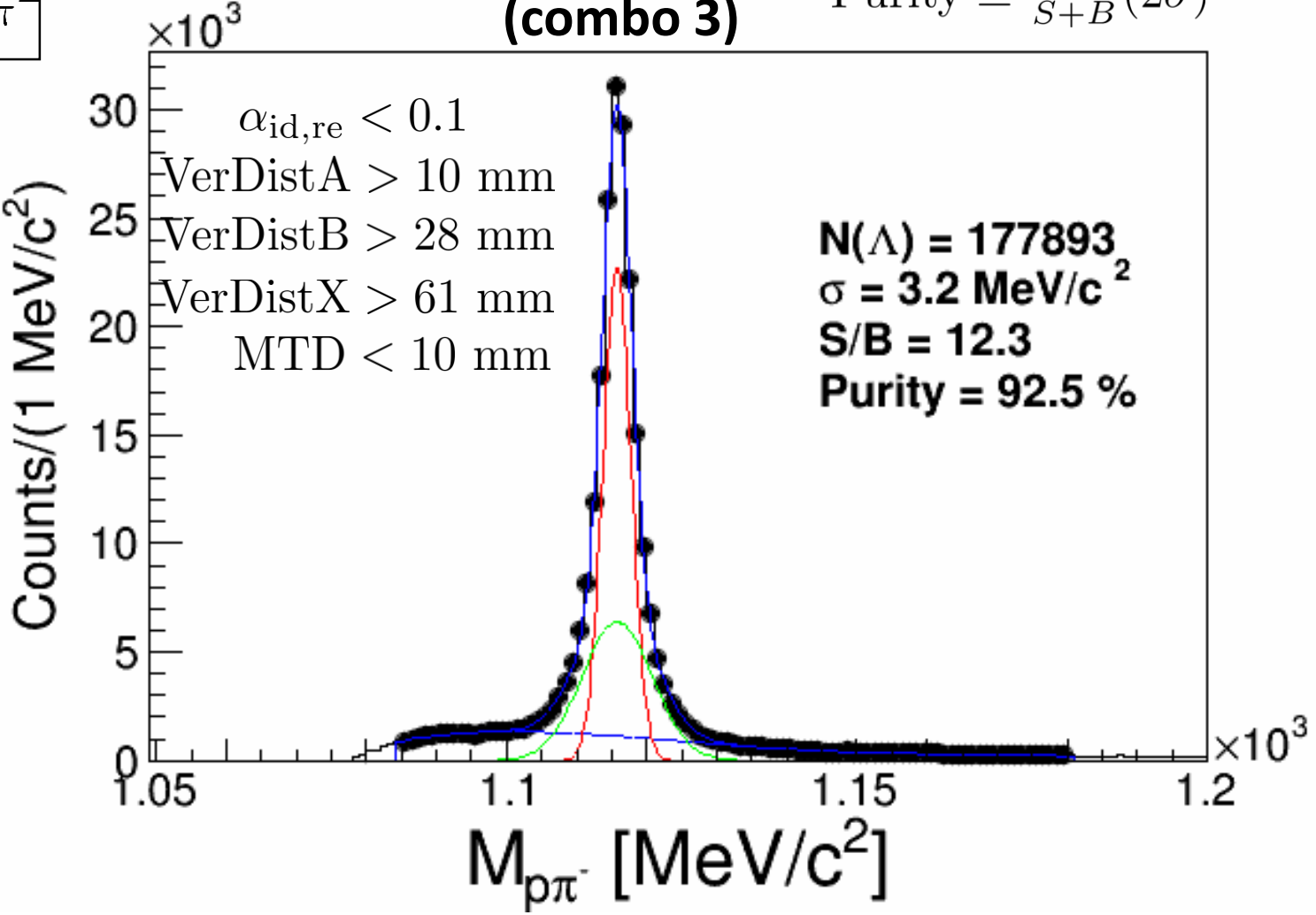


(combo 3)

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

$\alpha_{\text{id,re}} < 0.1$
$\text{VerDistA} > 10$ mm
$\text{VerDistB} > 28$ mm
$\text{VerDistX} > 61$ mm
$\text{MTD} < 10$ mm

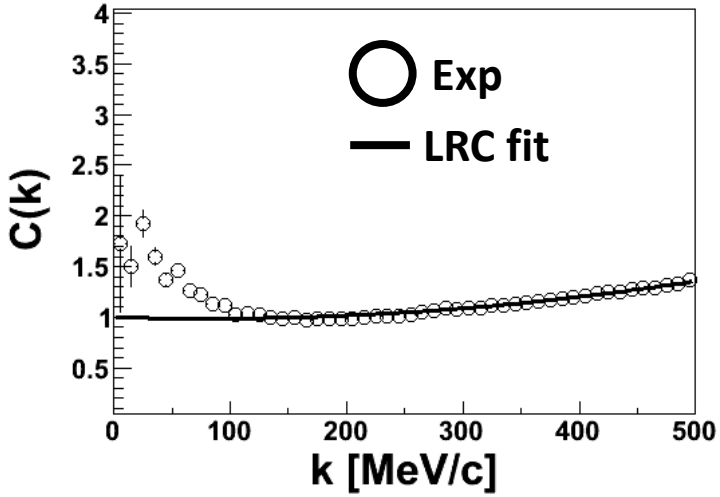
N(Λ) = 177893
σ = 3.2 MeV/c²
S/B = 12.3
Purity = 92.5 %



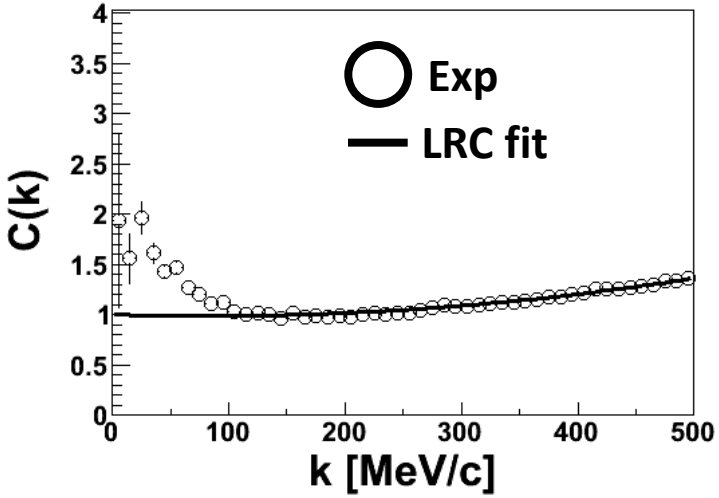
Interaction

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

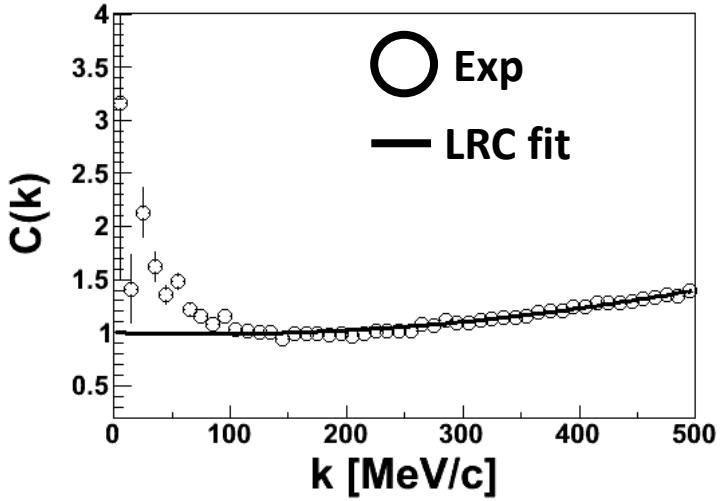
combo1



combo2



combo3



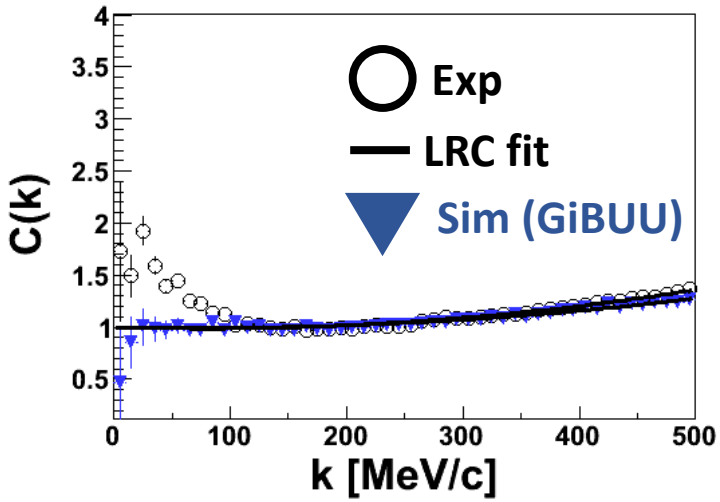
Model the long-range part with a polynomial

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

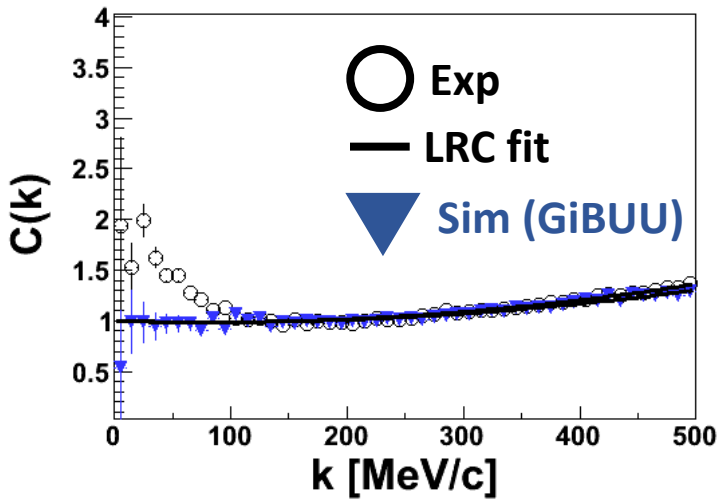
Interaction

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

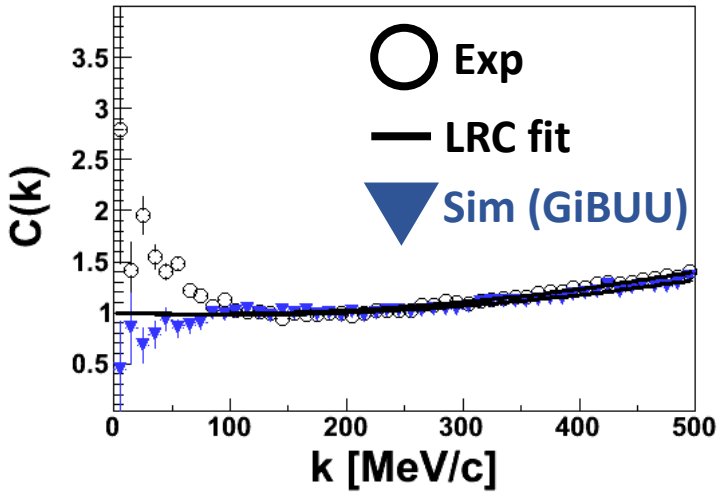
combo1



combo2



combo3



Model the long-range part with a polynomial

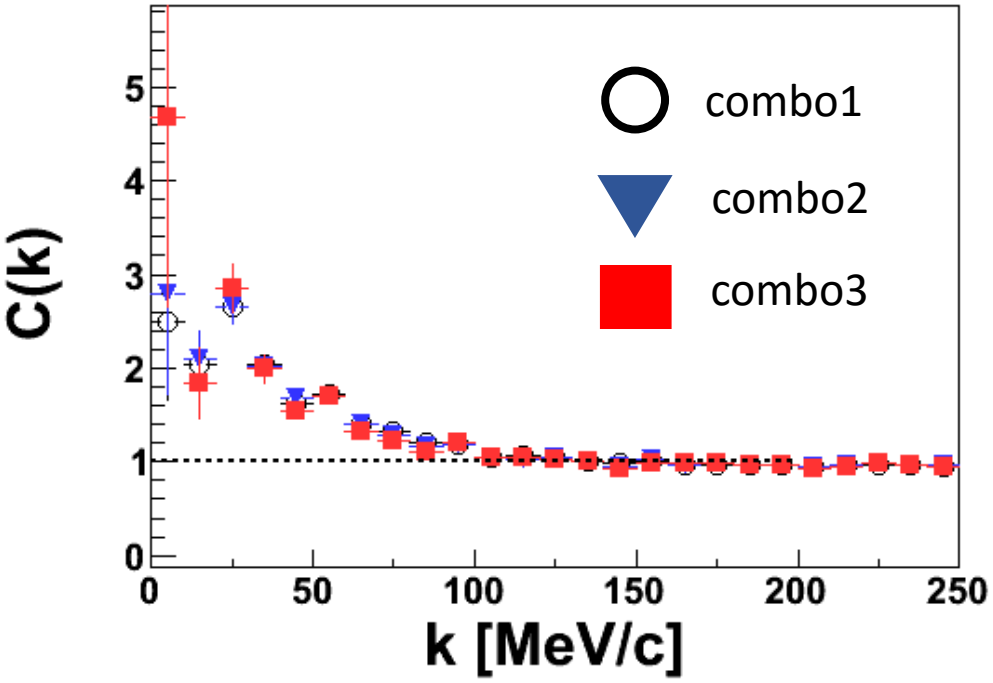
$$C_{\mathrm{LRC}} = 1 + ak + bk^2 \quad k \in [250, 600]\ \mathrm{MeV/c}$$

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

Interaction

Apply corrections – investigate systematics:

Correlation function after application of all corrections



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

Interaction

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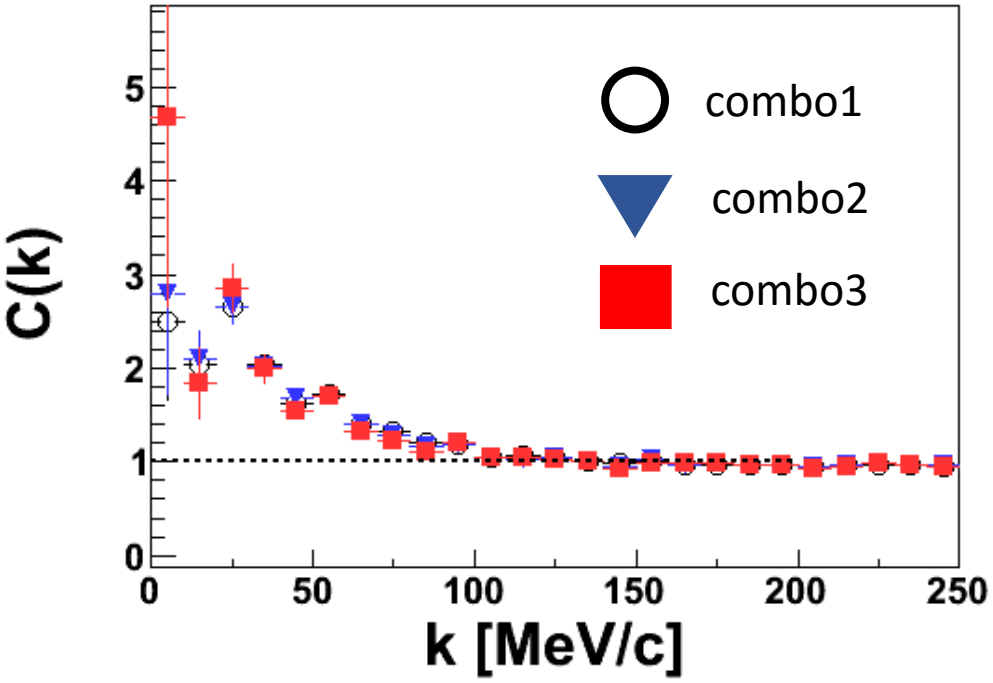

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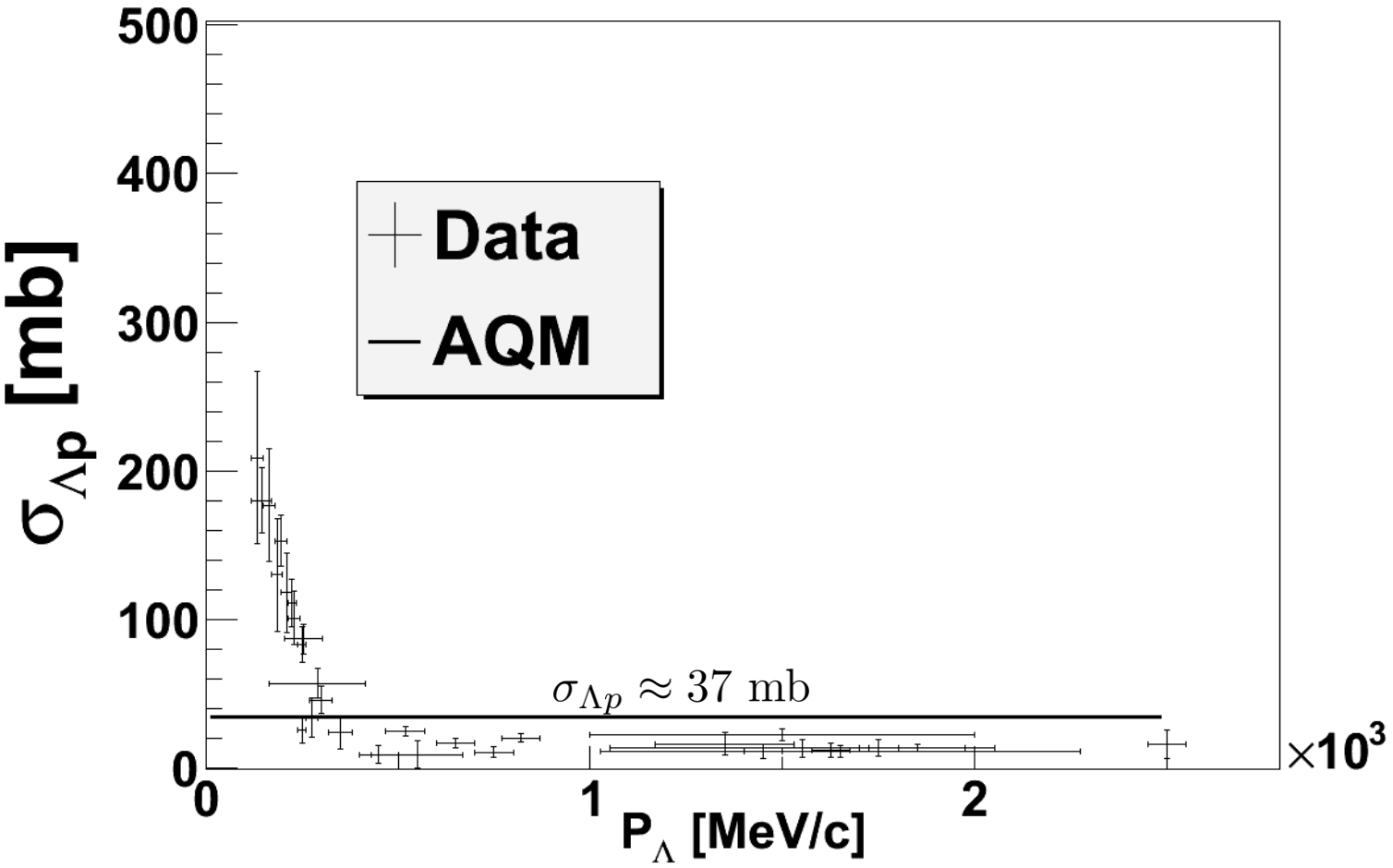
R. Lednicky and V. L. Lyuboshits, Sov. J. Nucl. Phys. **35**, 770 (1982), [Yad. Fiz.35,1316(1981)].

Can we use the pp measurement to fix it?

Interaction

Source function extraction from transport theory (UrQMD):

Improve UrQMD for the scattering of Lambdas

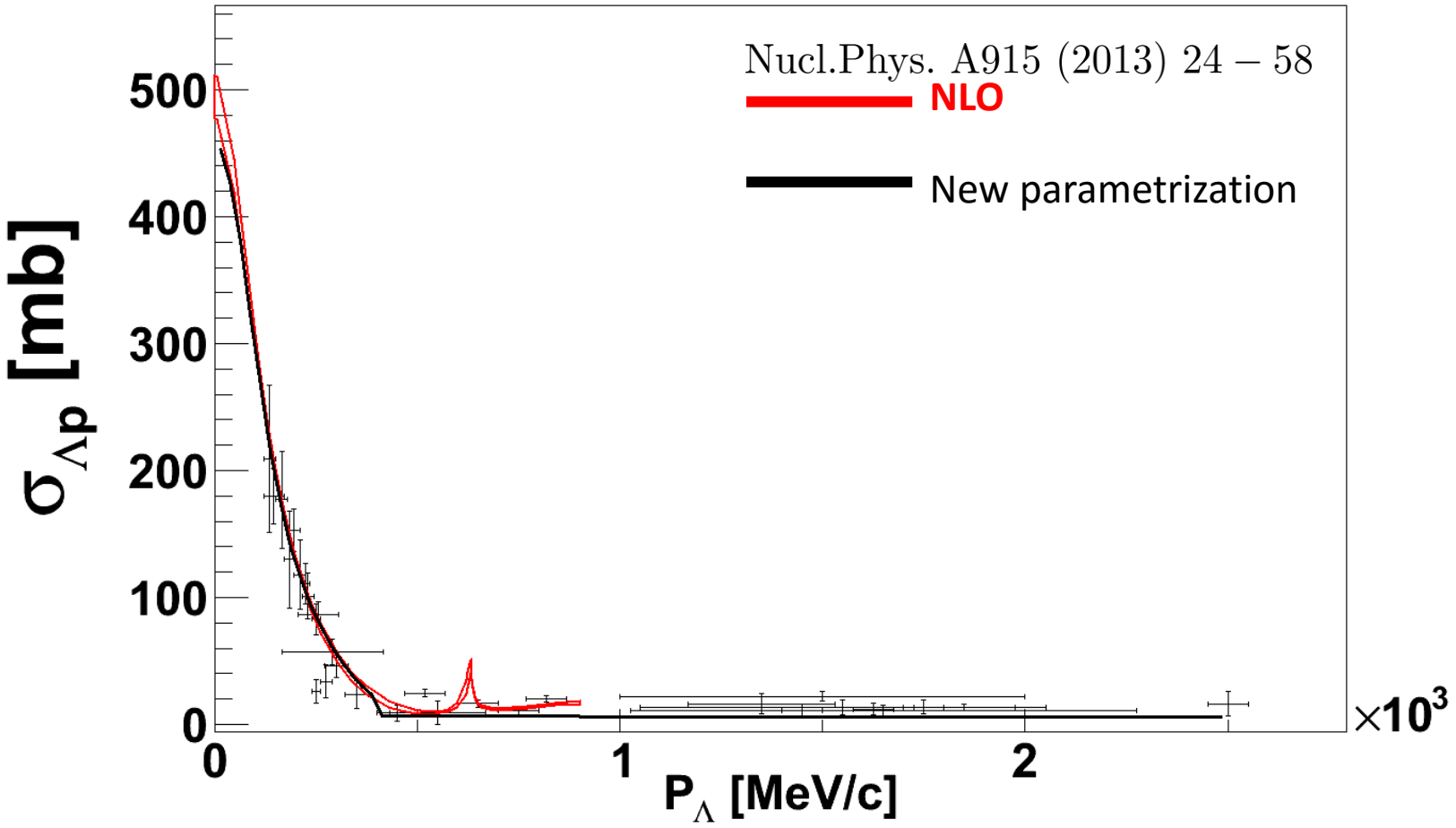


Improvement for low energies necessary

Interaction

Source function extraction from transport theory (UrQMD):

Improve UrQMD for the scattering of Lambdas



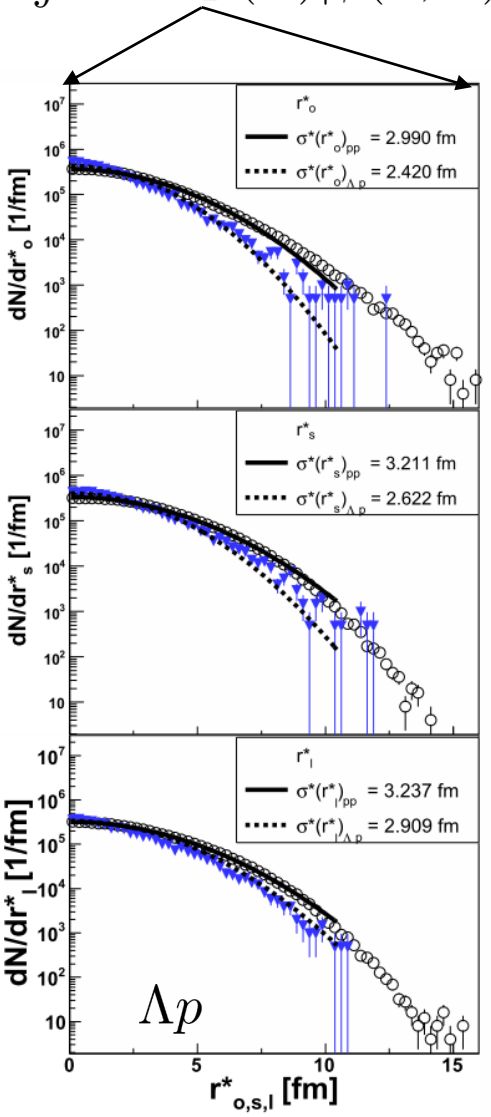
Interaction

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:

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

Interaction

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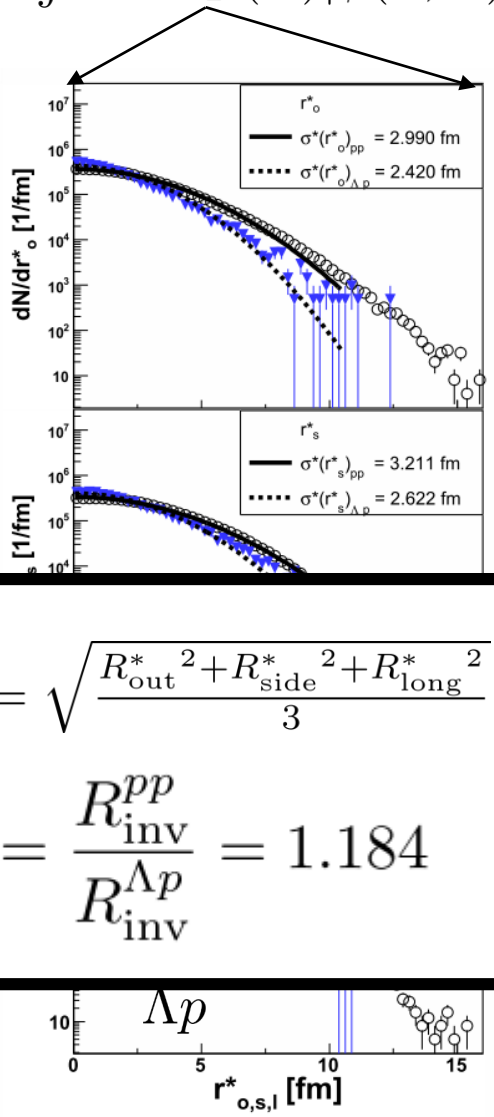


Fit function used:

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

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

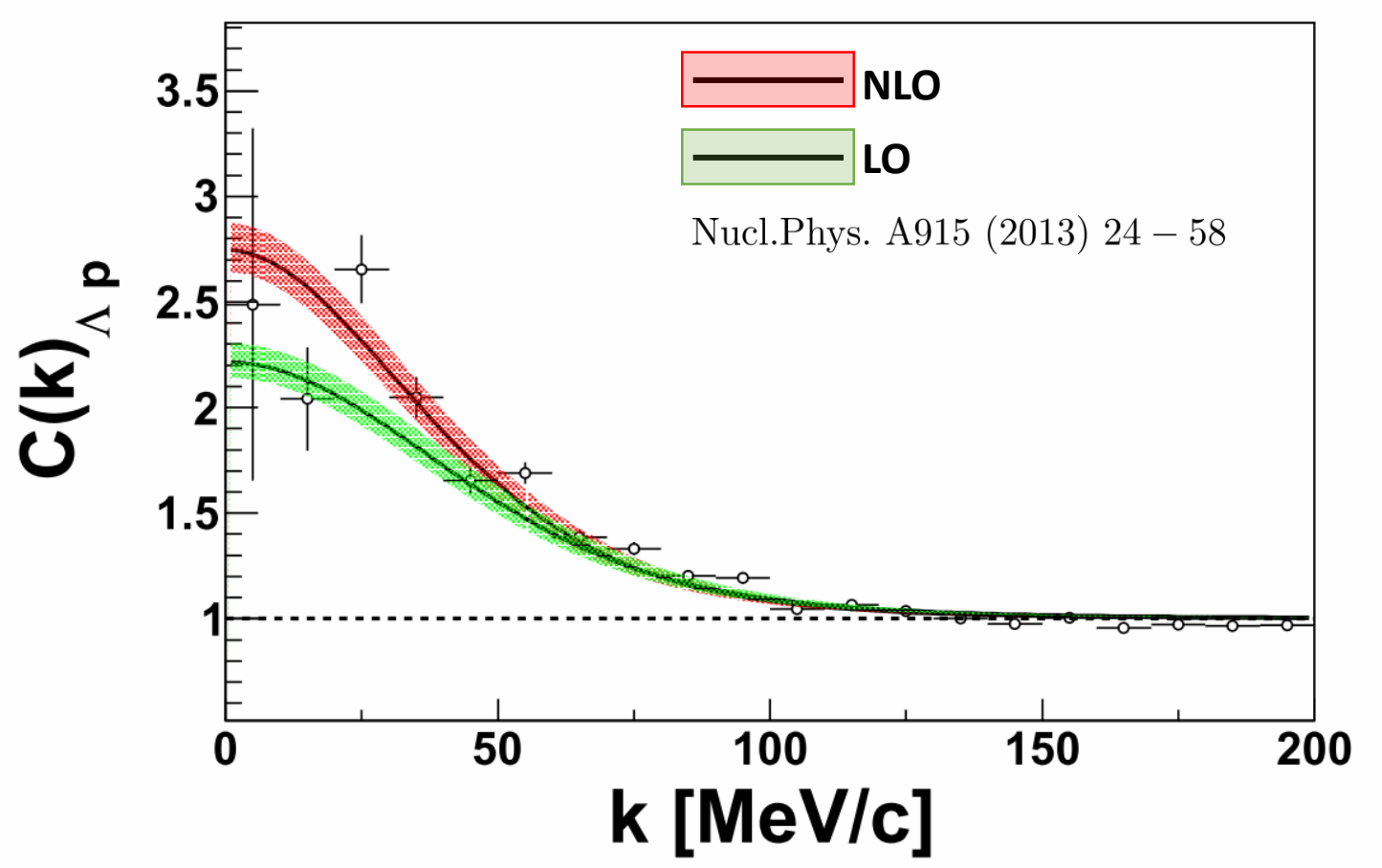
$$\text{RF} = \frac{R^{pp}_{\text{inv}}}{R^{\Lambda p}_{\text{inv}}} = 1.184$$

Interaction

Comparison to models:

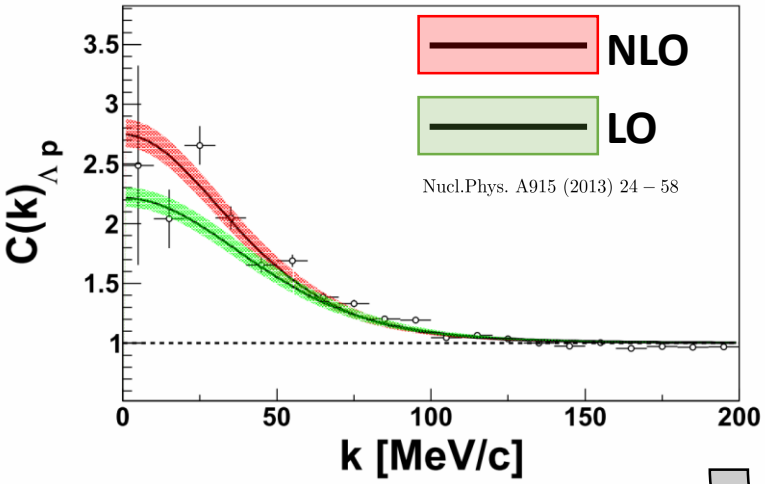
$$R_G = 2.016 \pm 0.010^{+0.109}_{-0.118} \text{ fm}$$

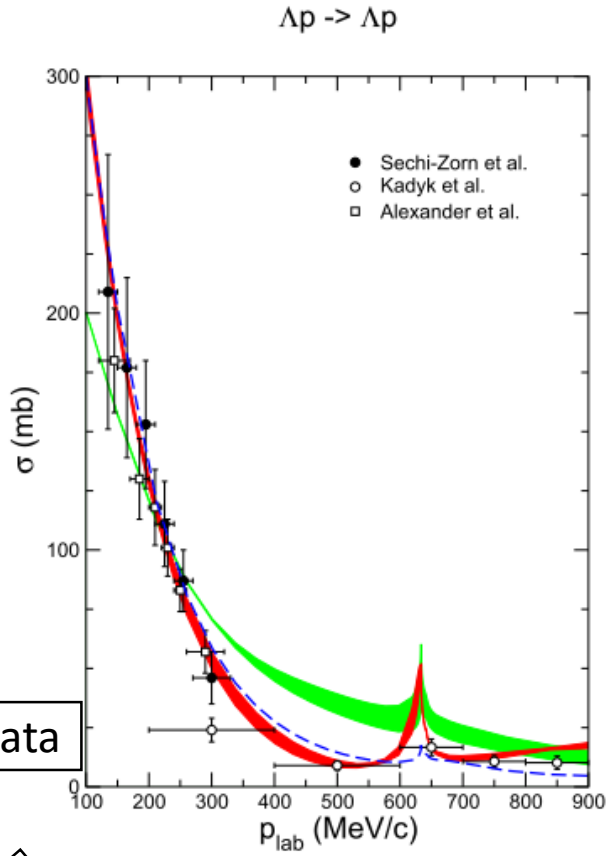
$$R_G^{\Lambda p} = R_G^{pp} / RF$$



Interaction

Comparison to models:





no data

„Closing the gap“

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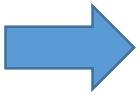
Summary

- 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