Proton-Proton and Lambda-proton correlations in p+Nb reactions at 3.5 GeV

arXiv:1602.08880

Laura Fabbietti and Oliver Arnold

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Technische Universität München

Excellence Cluster *Universe*

Outline

- **What is a particle correlator?**

- **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:

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

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

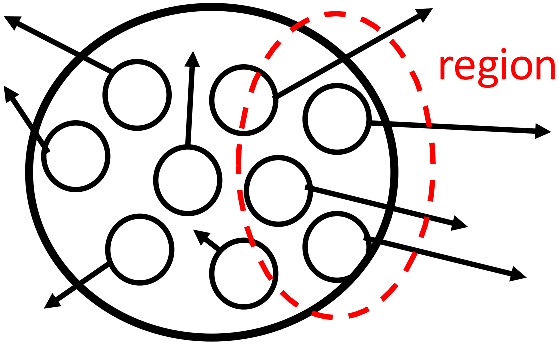
$\mathbf{p}_1 + \mathbf{p}_2 = 0$ **Pair reference frame (PRF)**

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

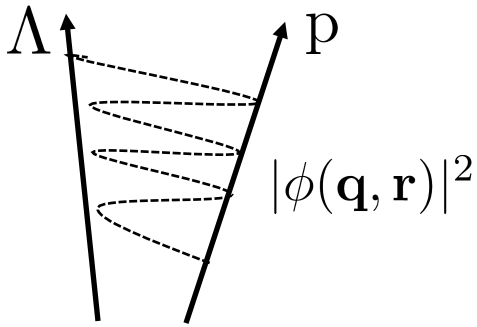
Strategy of analysis:

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

1. Understand the emission profile of the pNb system

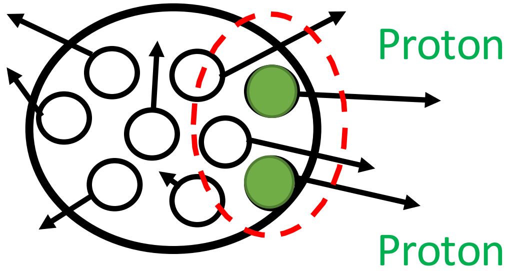


2. Use the information of point 1 to investigate particle interactions which are not well known

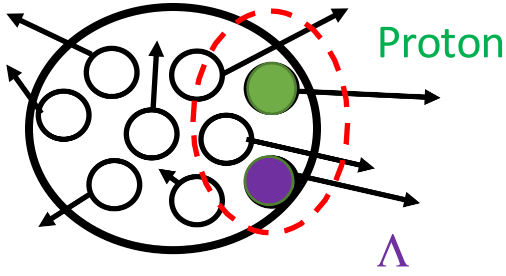


Method

Benchmark Channel



Investigated Channel



$$C^{pp}(P,q) = \int d^3r' \, S(r') \, |\varphi(q,r')|^2$$

Method 1:
- Known Interaction
- Assumption that the source is Gaussian (R_0)
- Calculation of the Correlation Function and comparison to the Data

Method 2:
- UrQMD Simulation for particle production
- CRAB Afterburner to account for the Final State Interaction among the emitted particles.

Method

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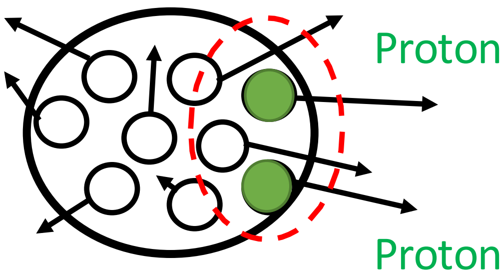

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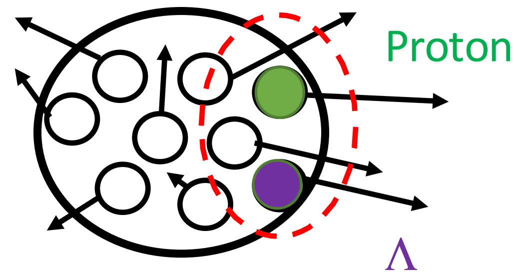

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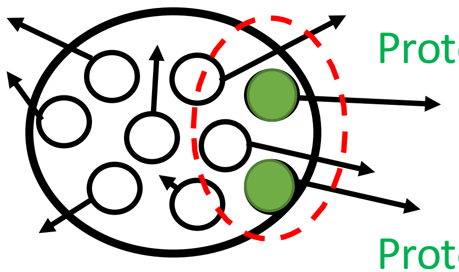
Check that the same assumption about the source is valid → Take the UrQMD ‘prediction for the Λp Source

Benchmark Channel



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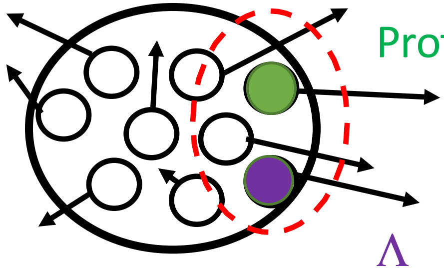

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Method 1:
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Method 1:
- Lednicky Model: Correlation Formula as a function of the Λp scattering length and source Radius R_0 .
- Test different scattering length

Method 2:
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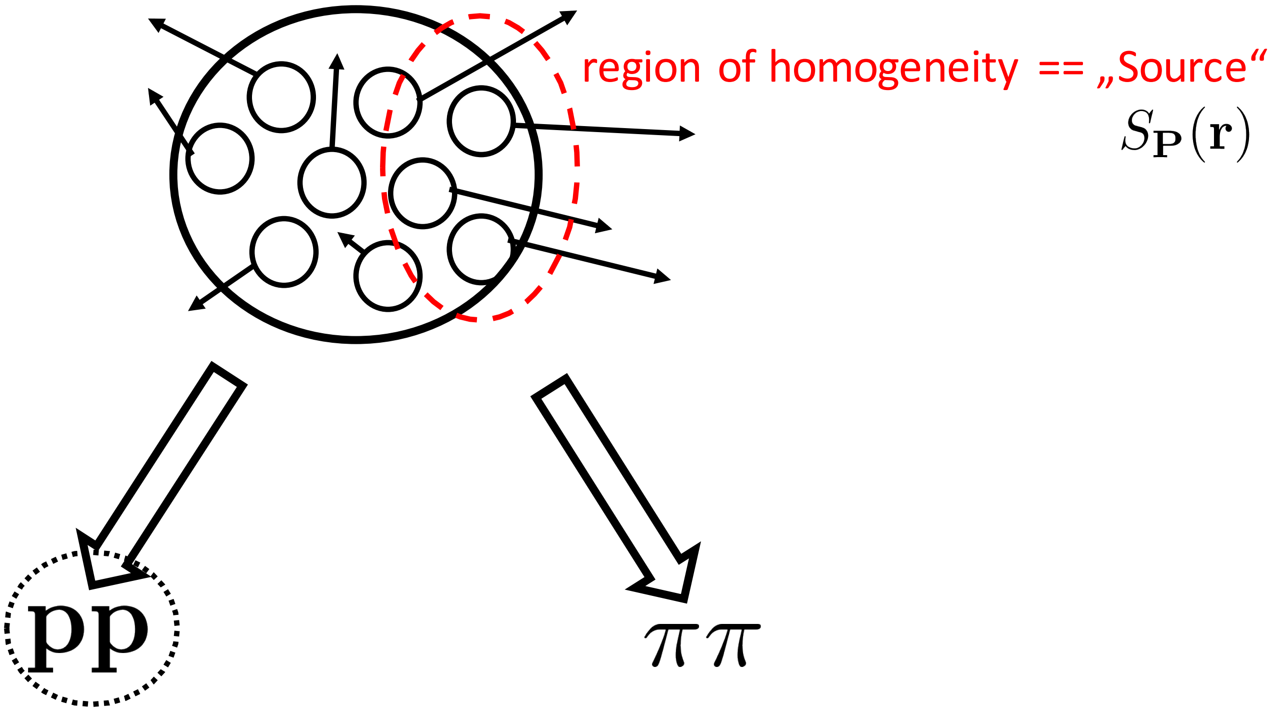
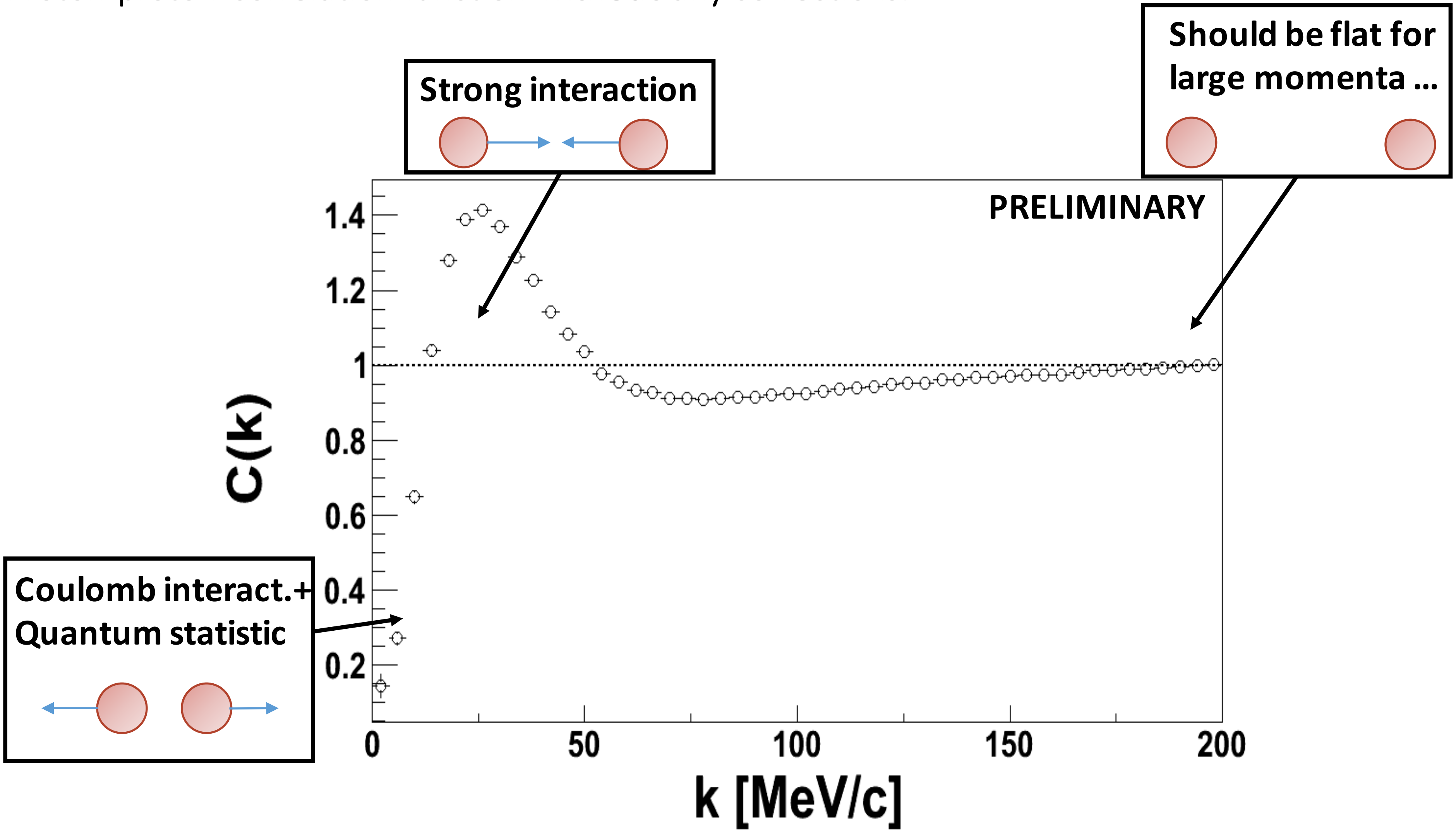


Correlation Function

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

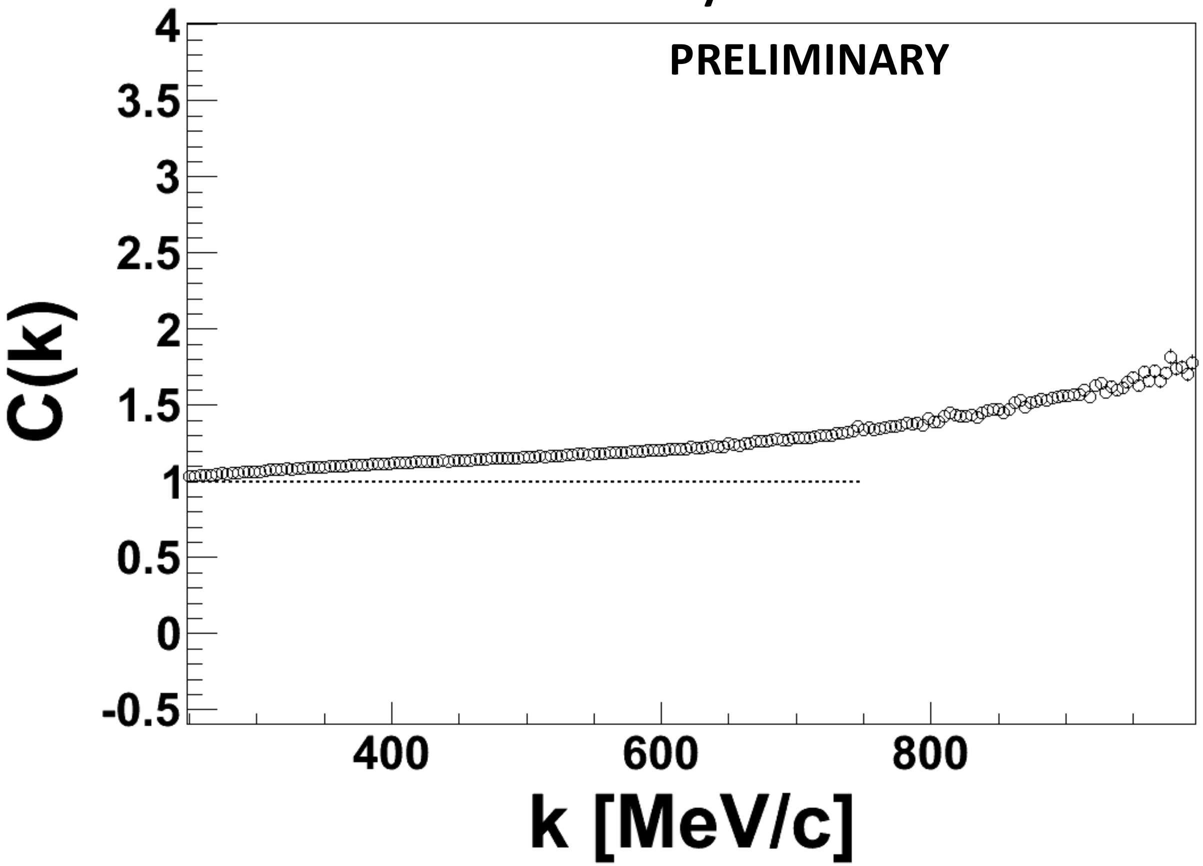


Correlation Function

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

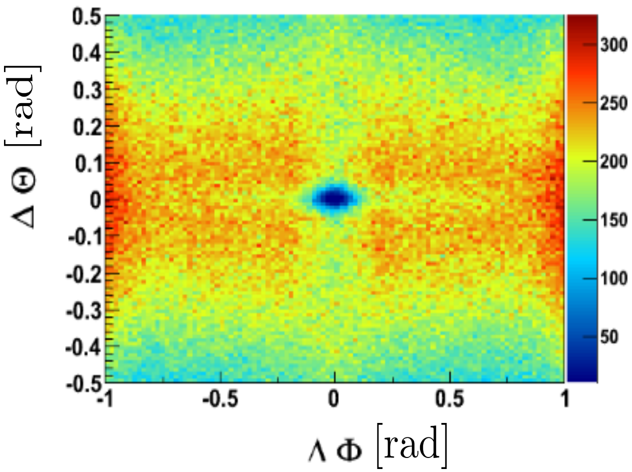


Correlation Function

Information about the source – proton proton correlation function:

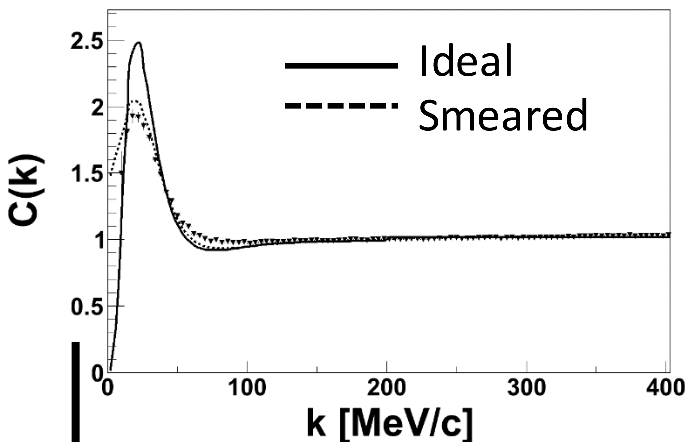
Corrections

Reject pairs which are too close together



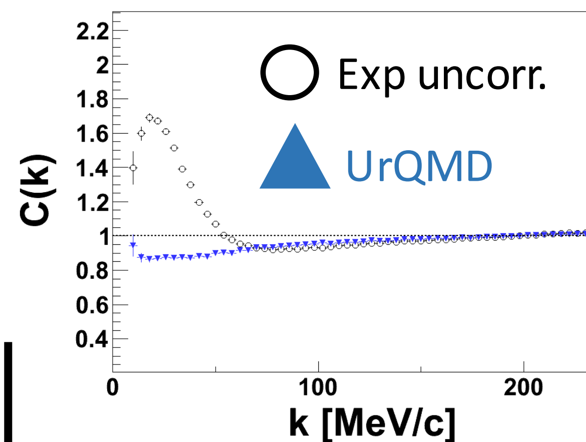
$$|\Delta\phi| > 3 \times 0.039 \text{ rad}$$
$$|\Delta\Theta| > 3 \times 0.015 \text{ rad}$$

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



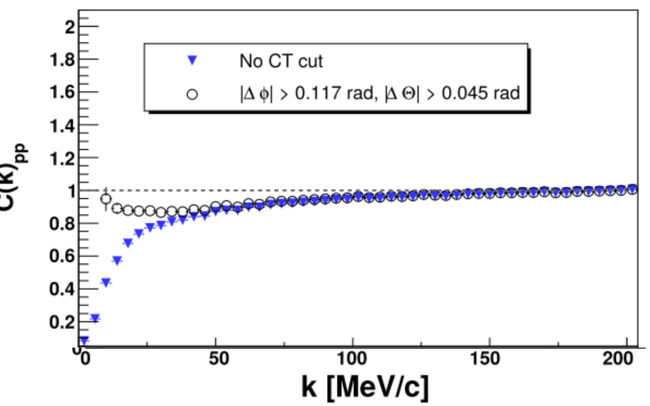
$$C(k) \equiv C_{\text{raw}}(k)/C_{\text{UrQMD}}(k)$$

Correlation Function

Information about the source – proton proton correlation function:

Corrections

Reject pairs which are too close together



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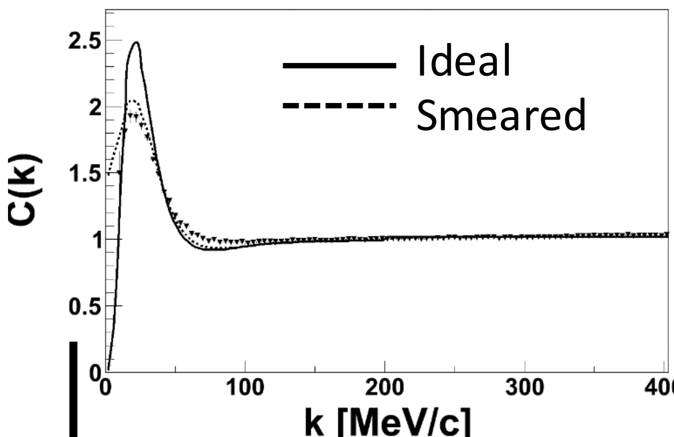

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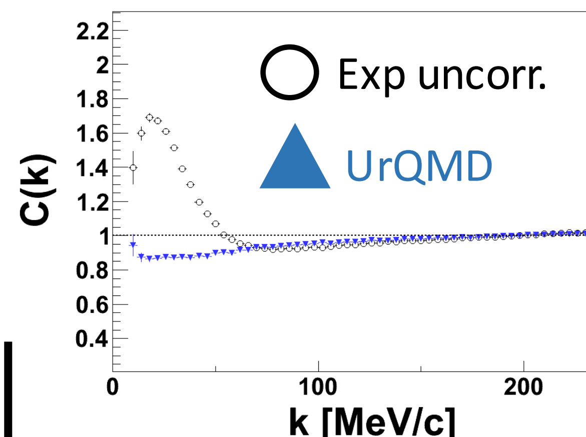
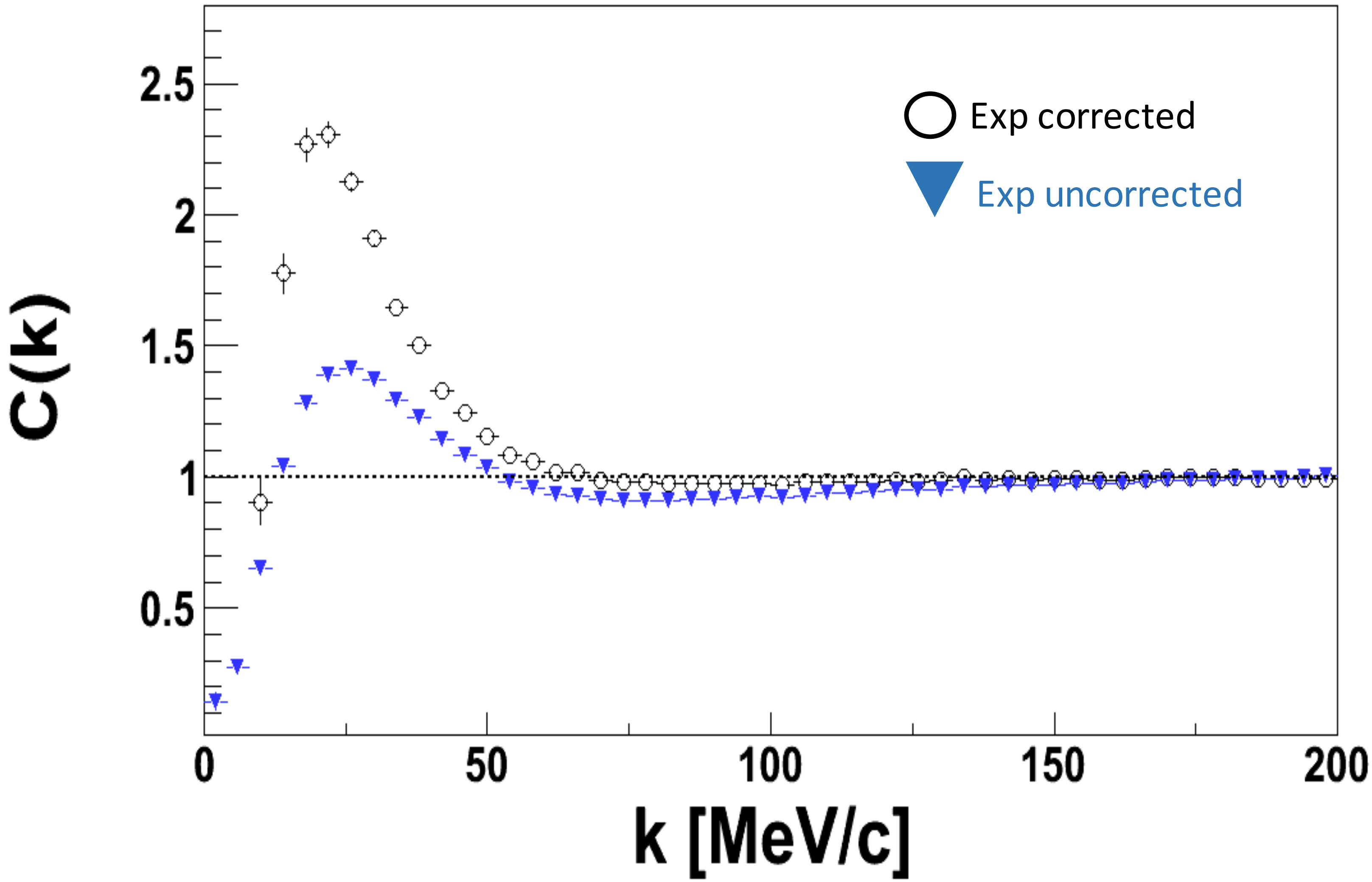


$$C(k) \equiv C_{\text{raw}}(k)/C_{\text{UrQMD}}(k)$$

Information about the source – proton proton correlation function:

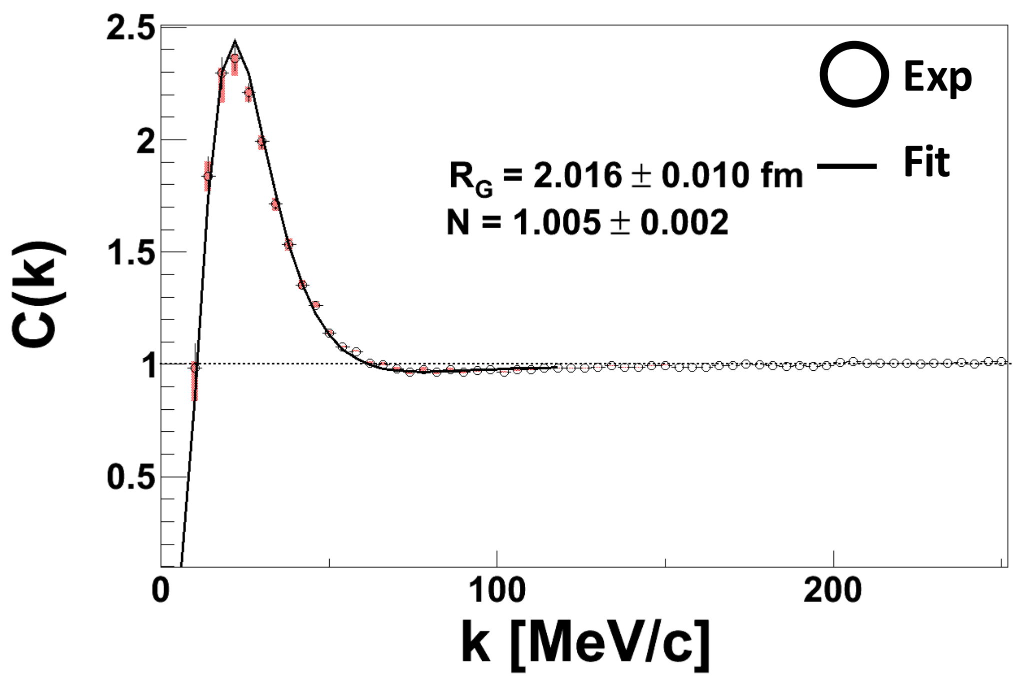
Proton-proton correlation function corrected for all efficiencies:



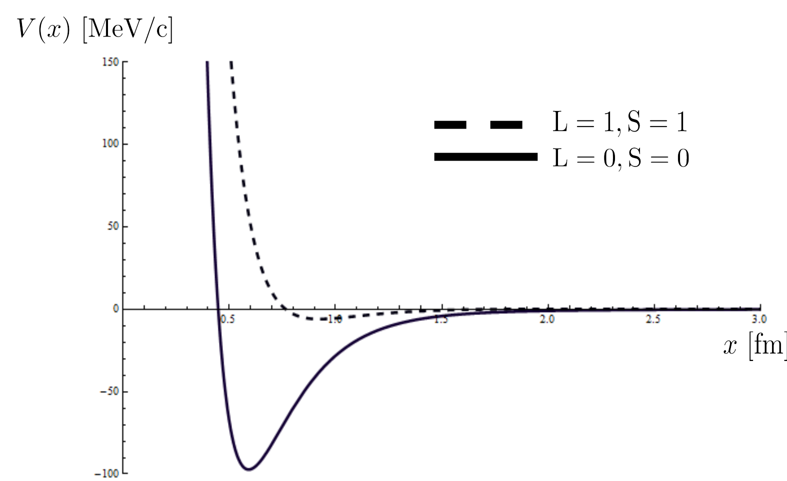
Correlation Function

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

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

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

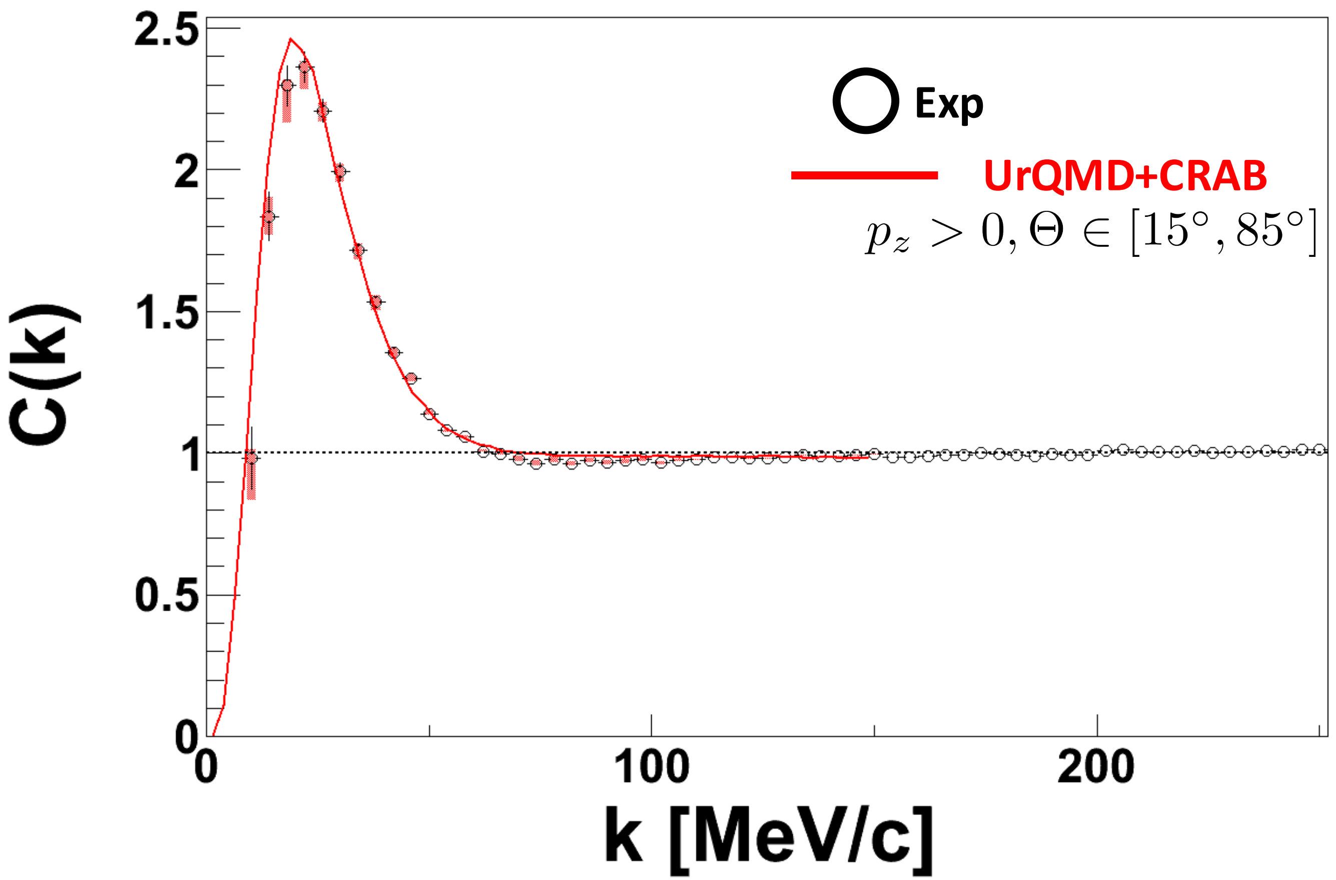
$$R_G = 2.016 \pm 0.010^{+0.039}_{-0.027}\ \mathrm{fm}$$

Interaction

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

In one dimension:

Calculation of UrQMD correlation function with help of CRAB

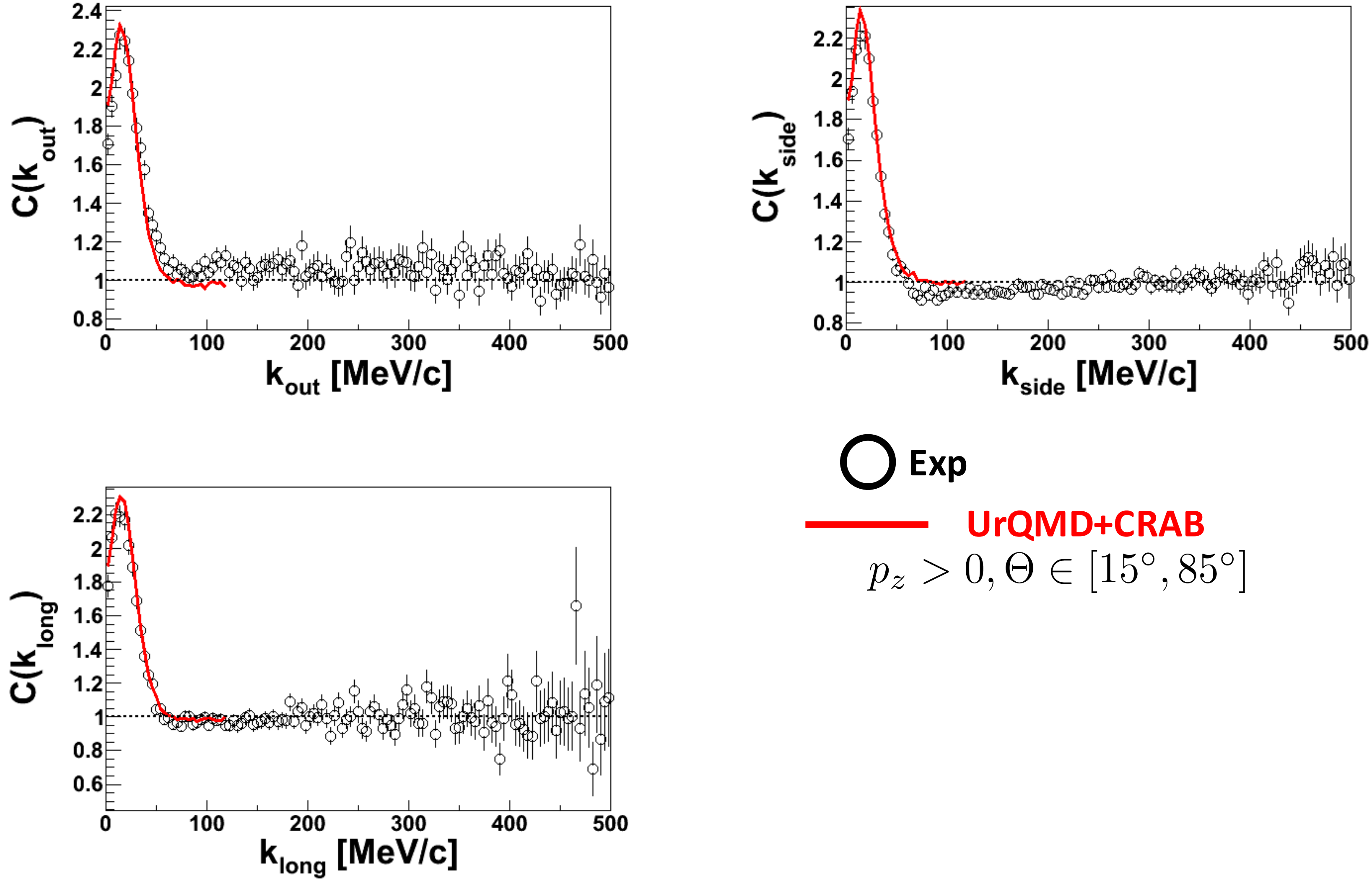


UrQMD gives a good source description for protons

Interaction

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

In three dimensions:



Interaction

Strategy of analysis:

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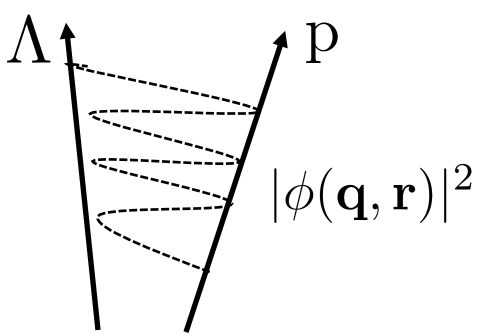
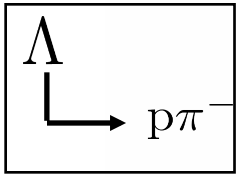
1. **2.**

1. Understand the emission profile of the pNb system

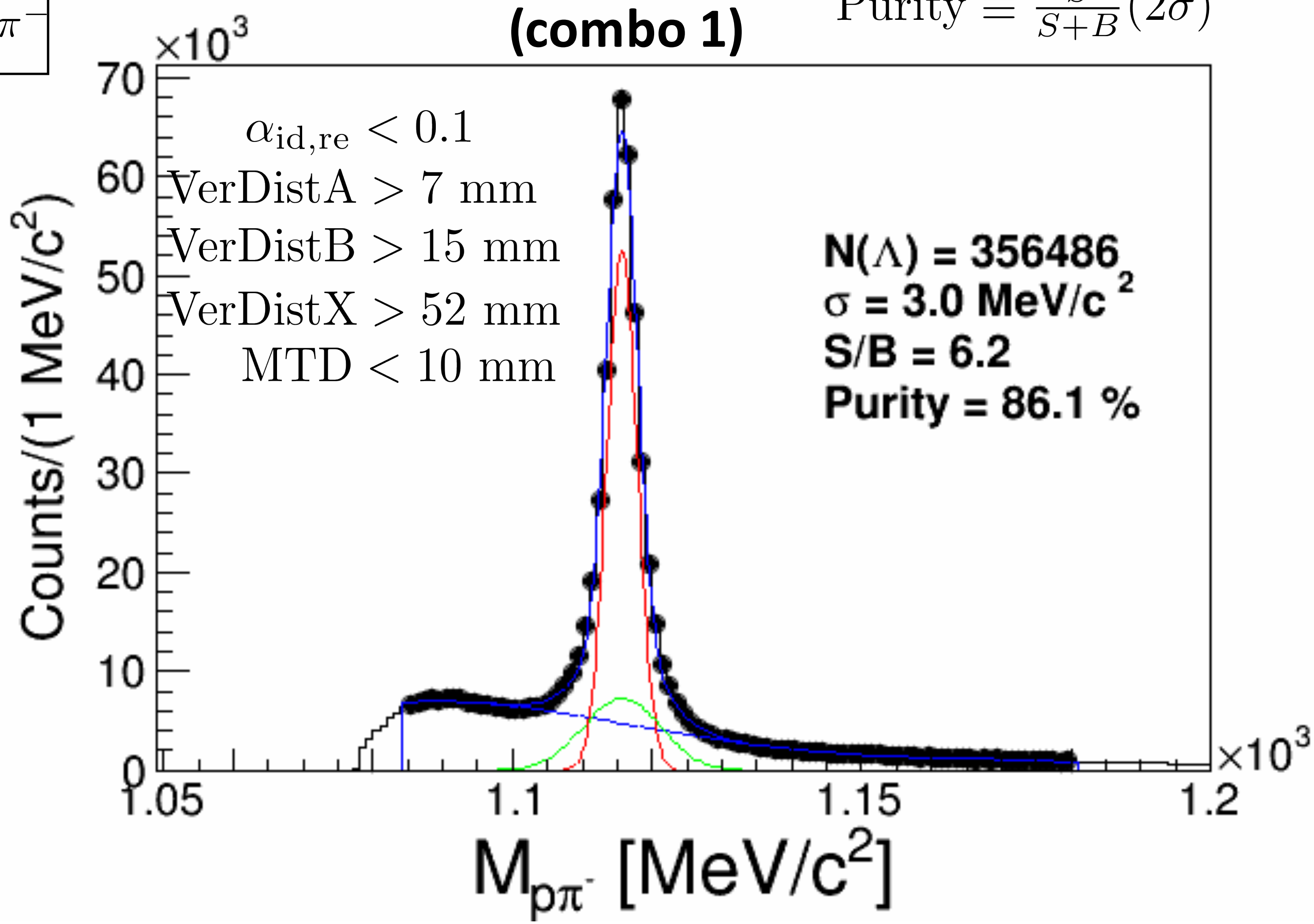
2. Use the information of point 1 to investigate particle interactions of not well known type



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



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



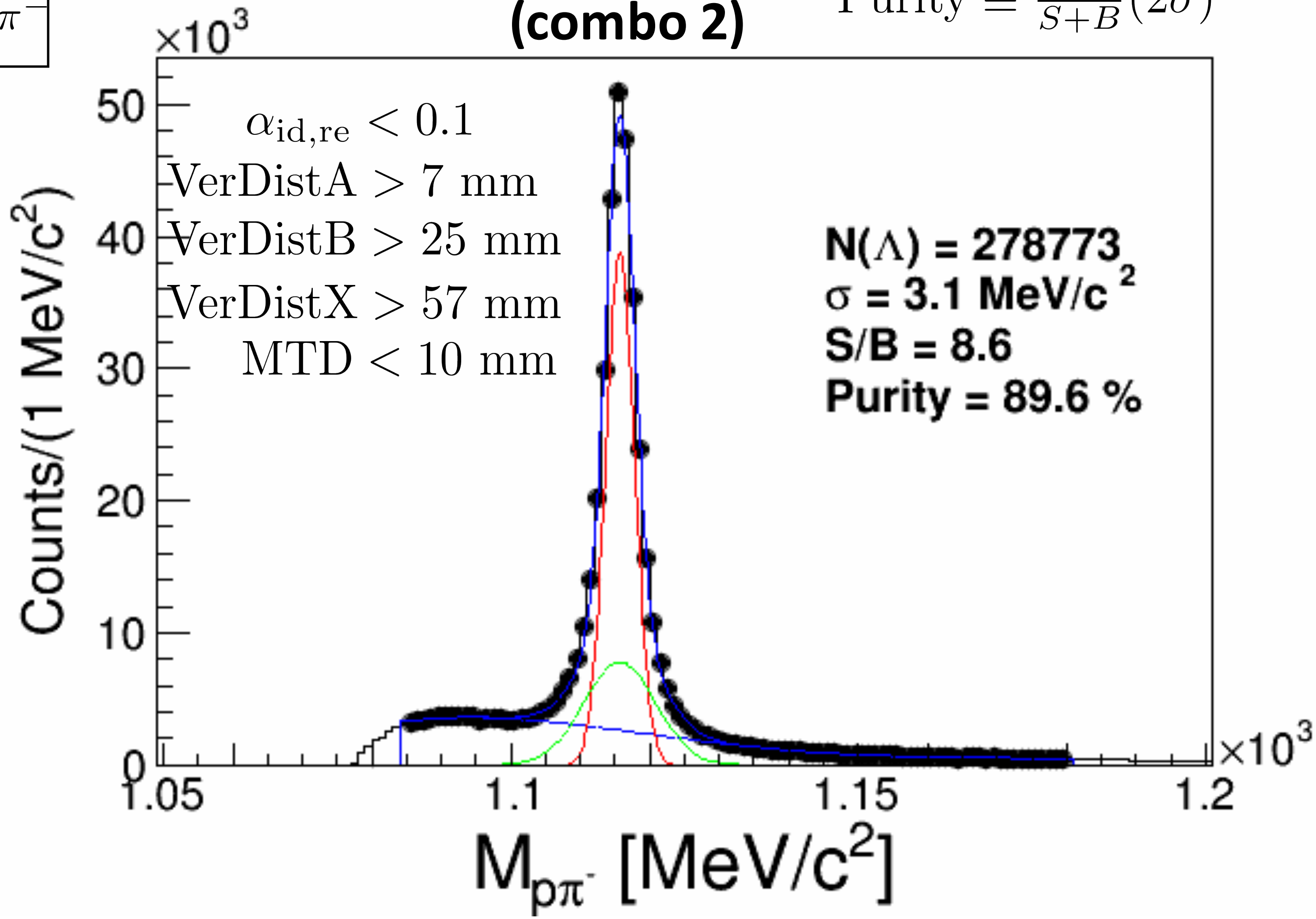
Interaction

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

$\Lambda \rightarrow p\pi^-$

(combo 2)

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



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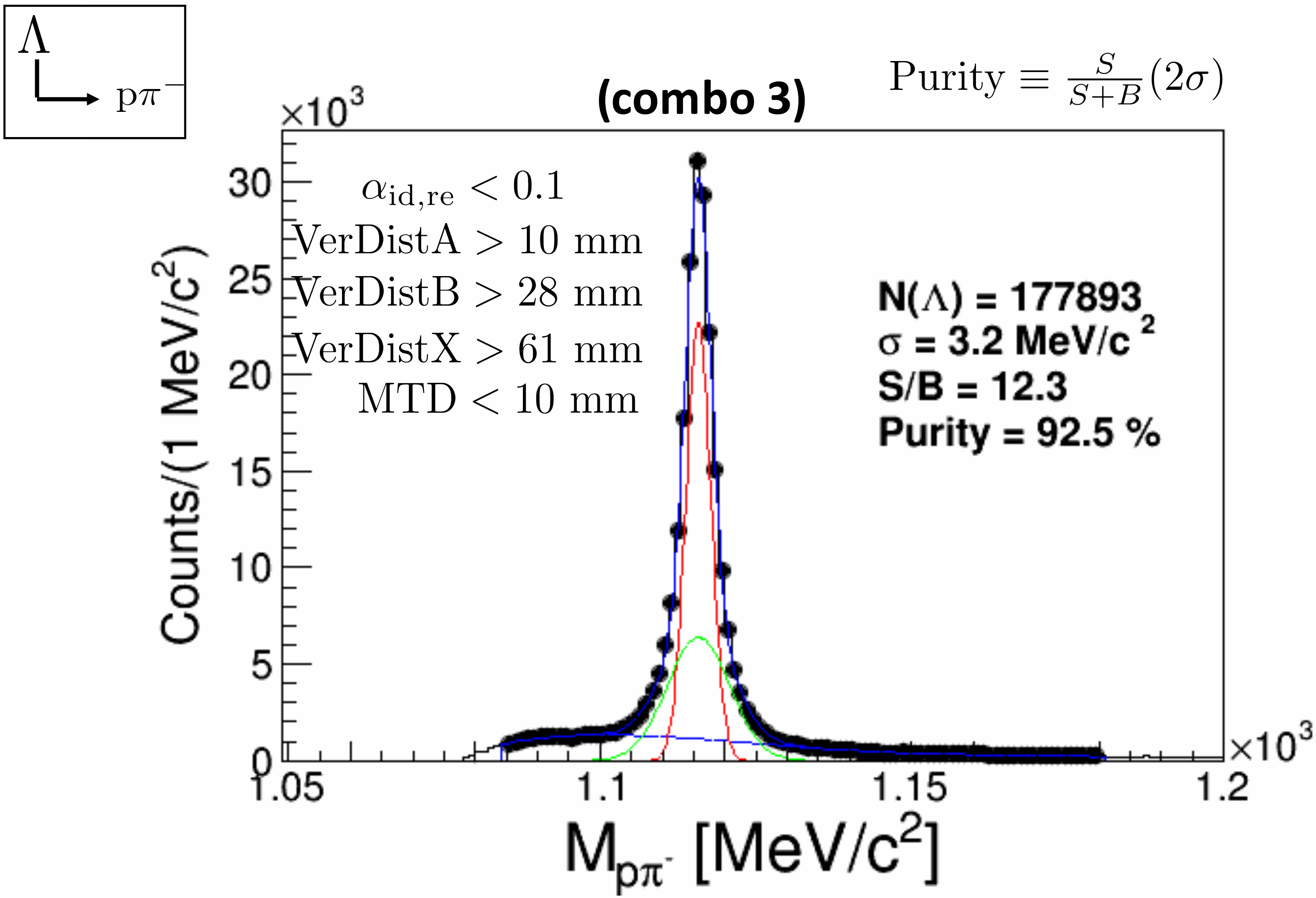
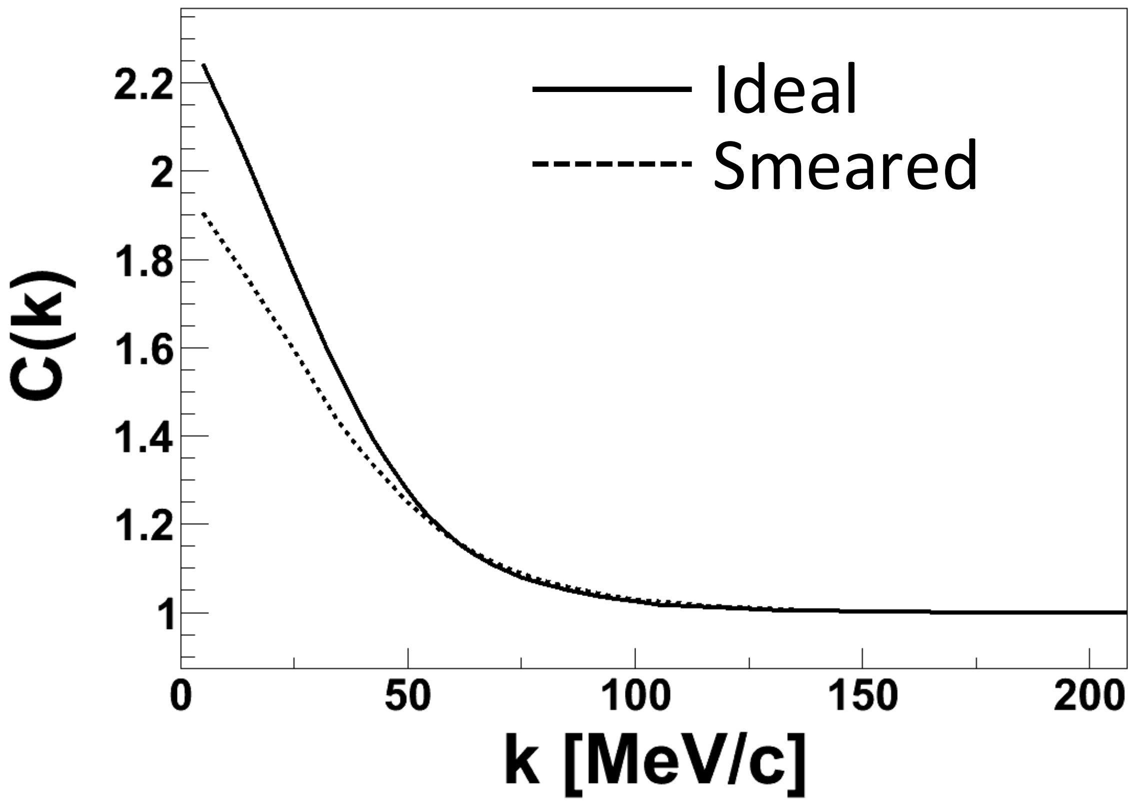


Interaction

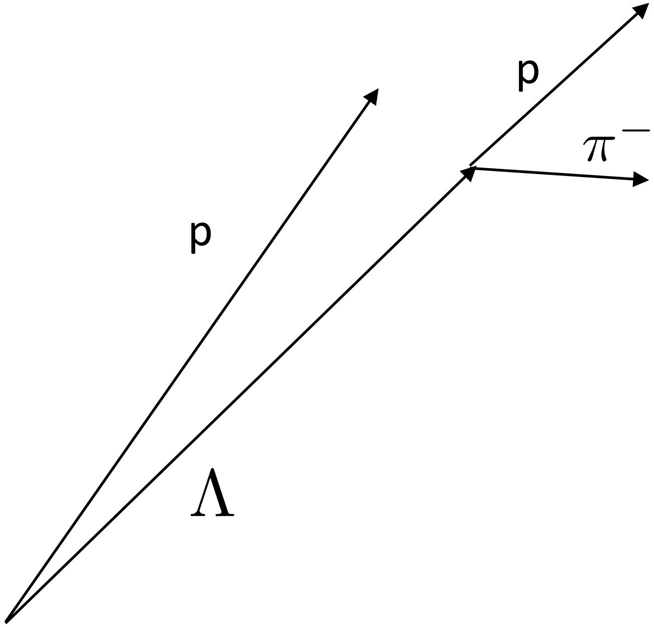
Again corrections: Influence of finite momentum resolution:



The momentum resolution suppresses slightly the correlation signal

Again corrections: Influence of close track efficiency:

Topology for correlated pairs:



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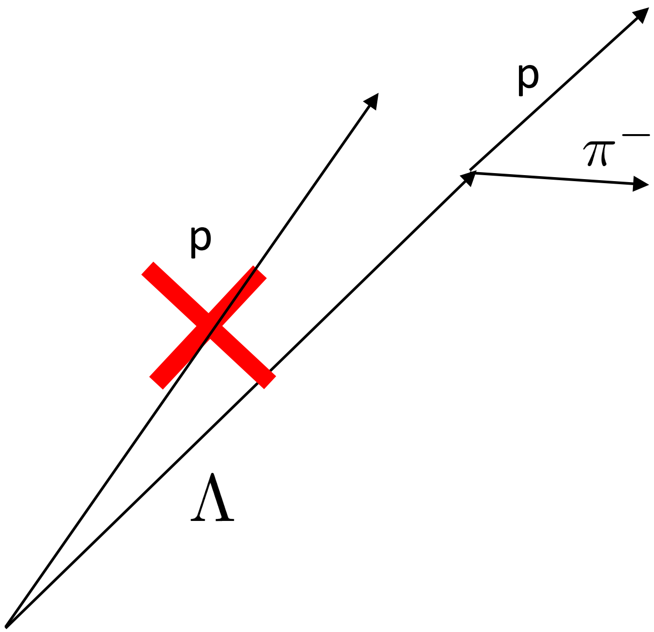

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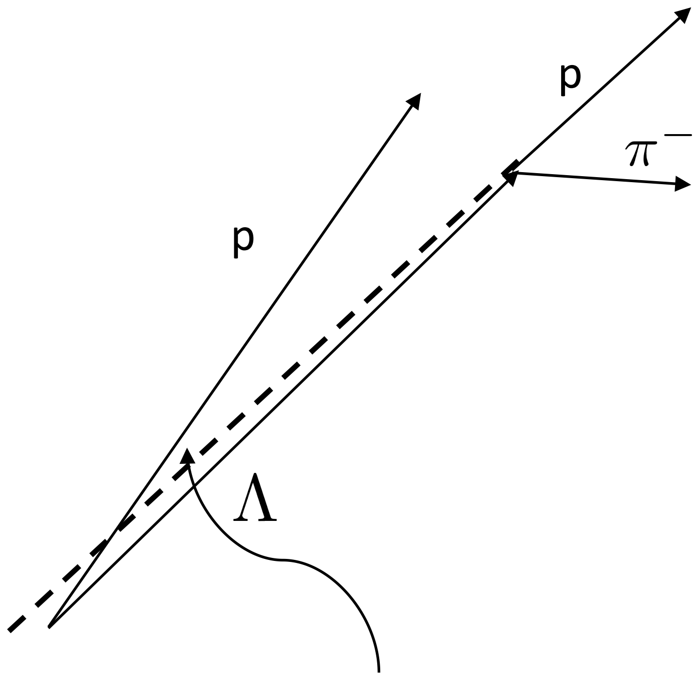
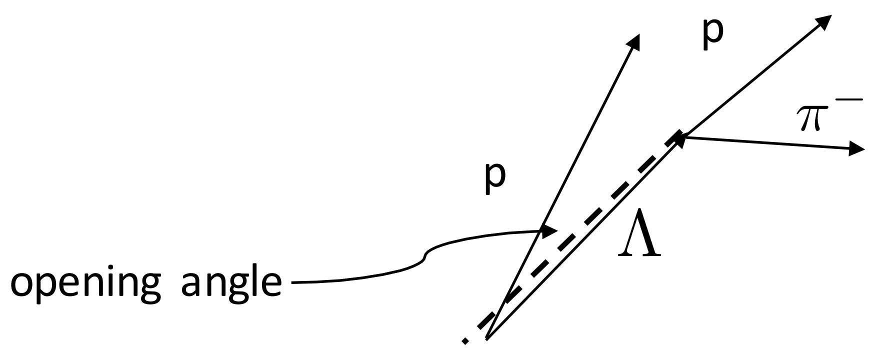
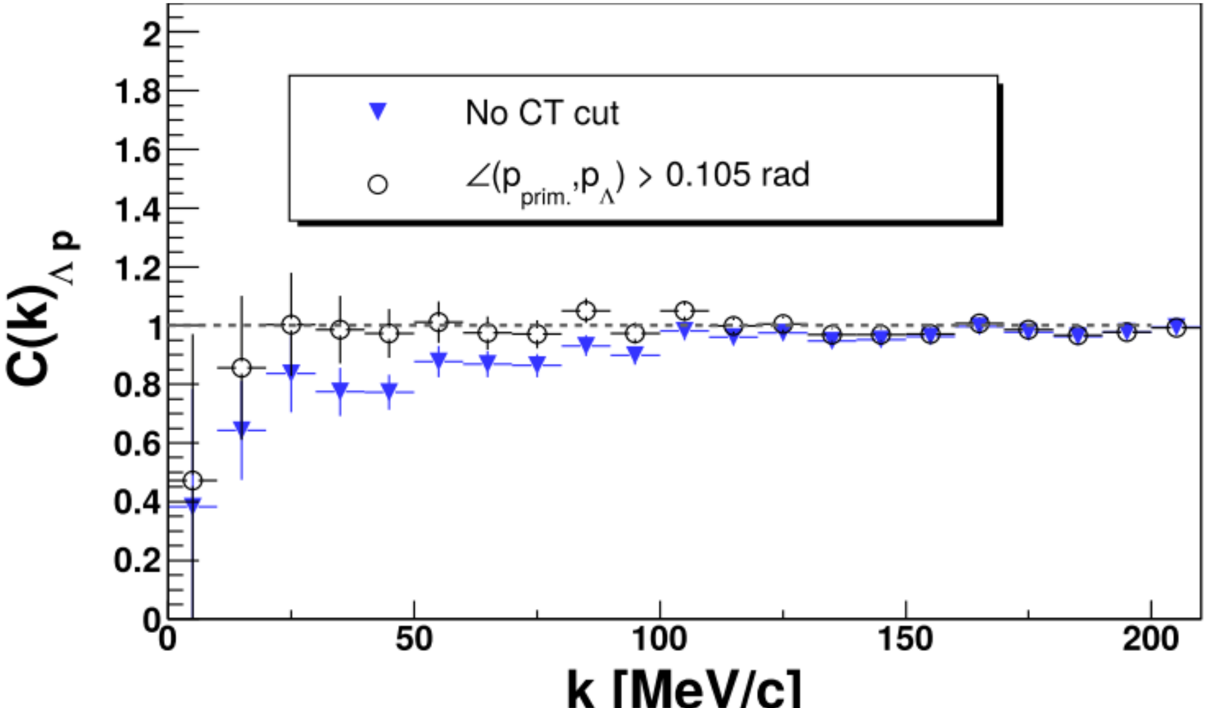


Minimum opening angle

Again corrections: Influence of close track efficiency:



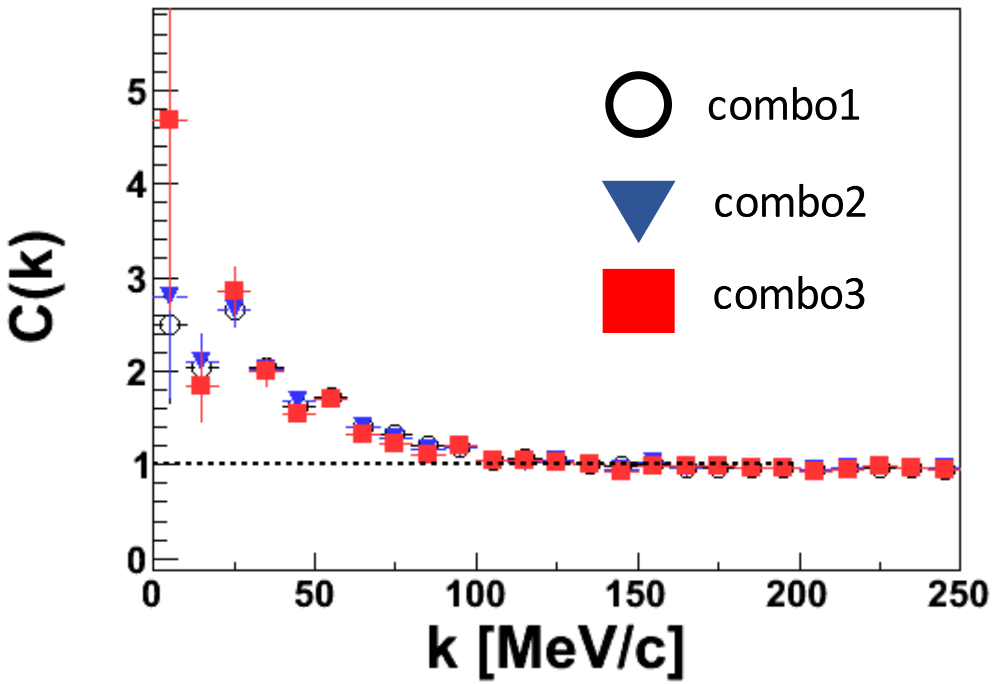
(GiBUU Sim)



Interaction

Apply corrections – investigate systematics:

Correlation function after application of all corrections



Lednicky's model:

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

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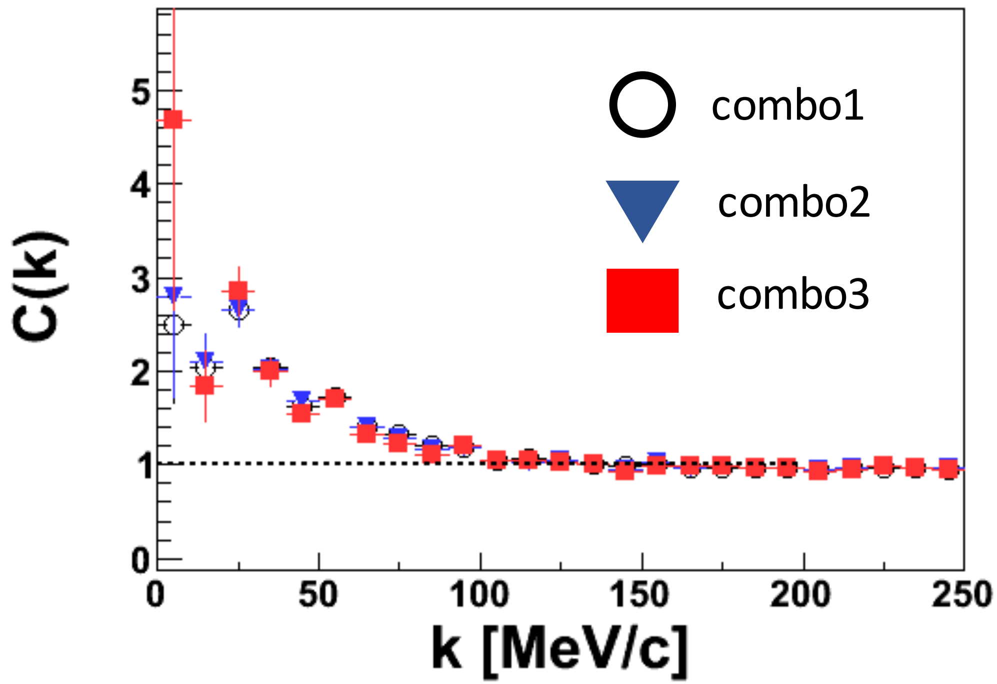

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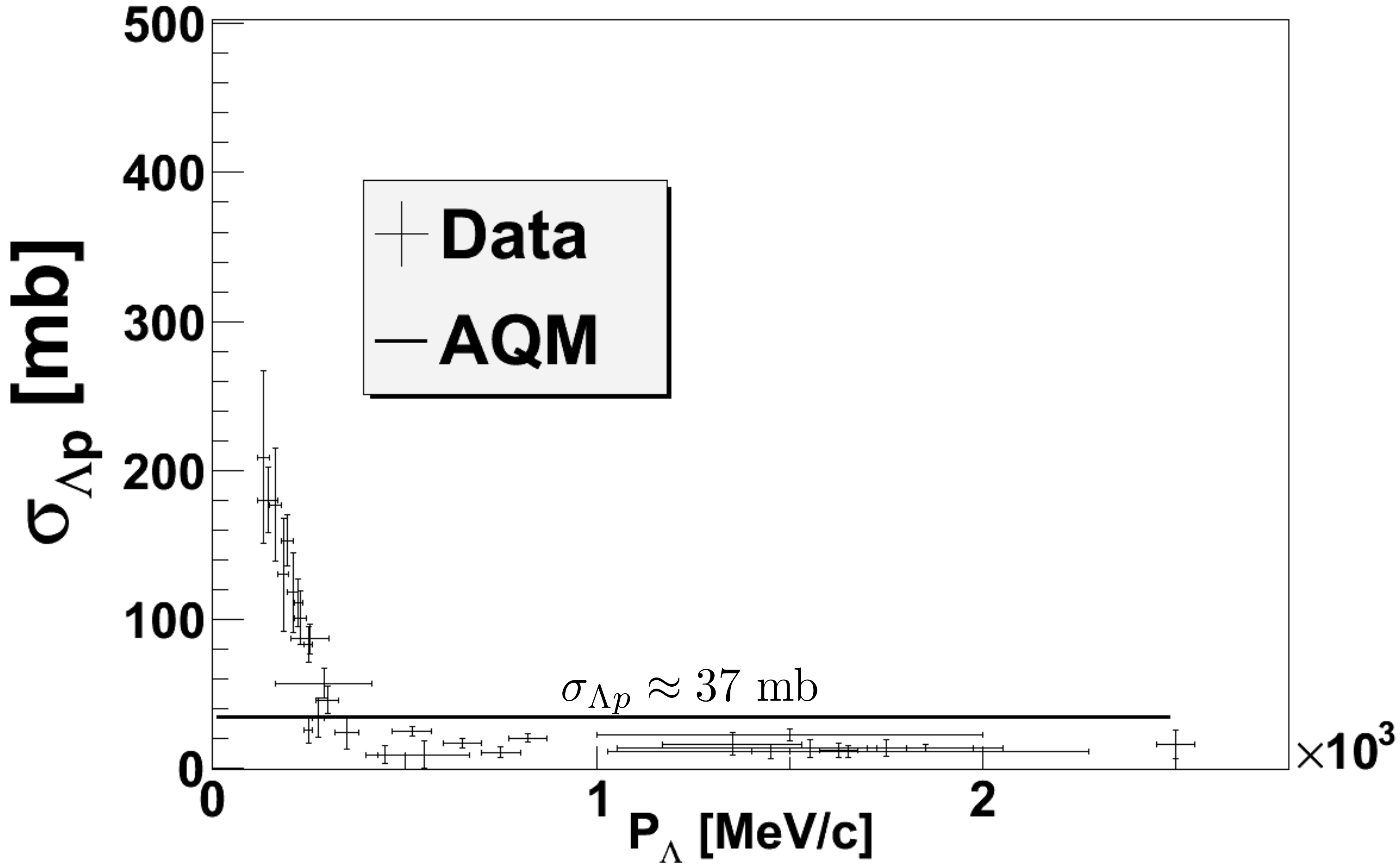
Can we use the pp measurement to fix it?

Interaction

Source comparison from transport theory:

Improved UrQMD for the scattering part of Lambdas

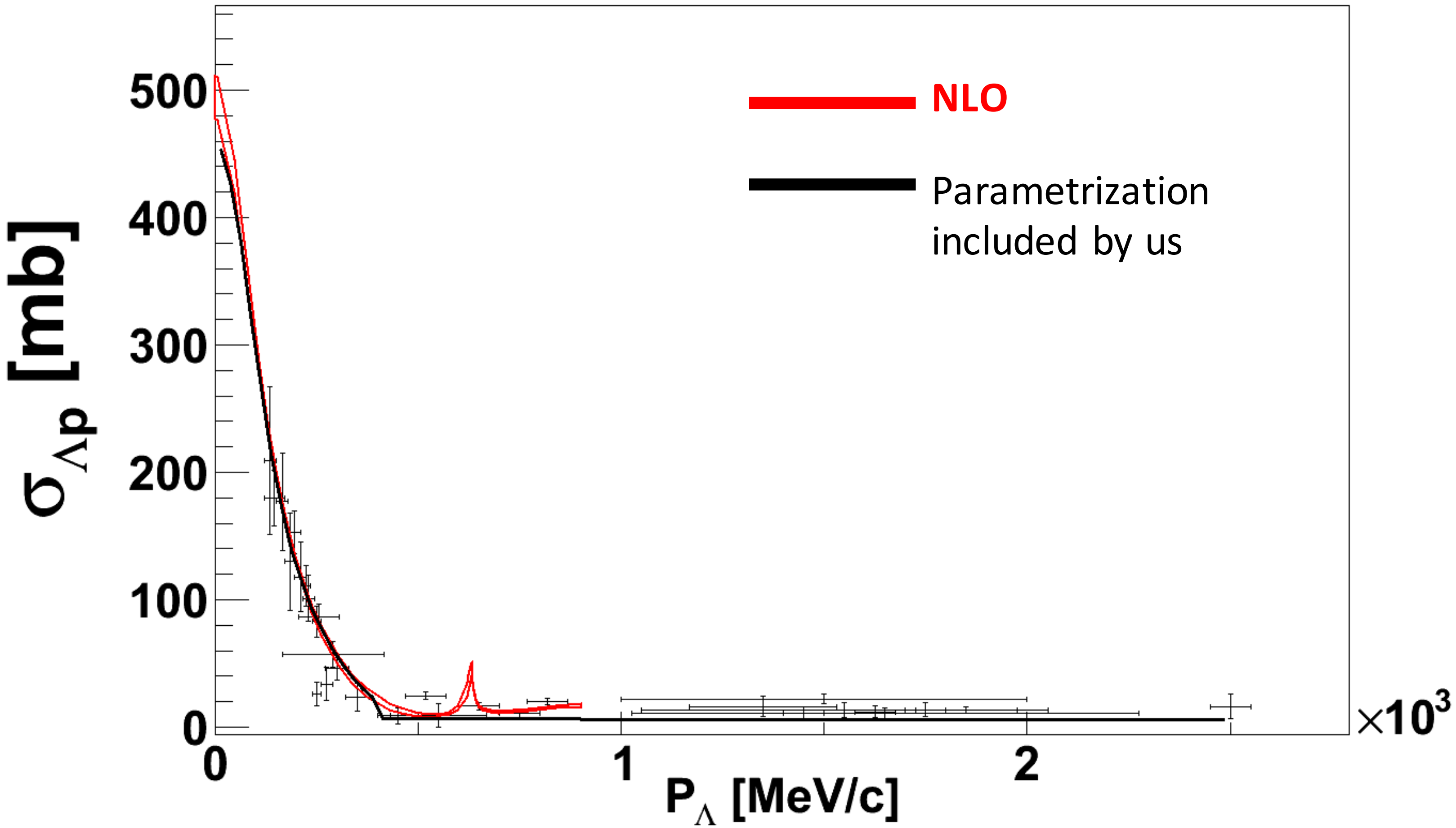


Improvement for low energies necessary

Interaction

Source comparison from transport theory:

Improved UrQMD for the scattering part of Lambdas



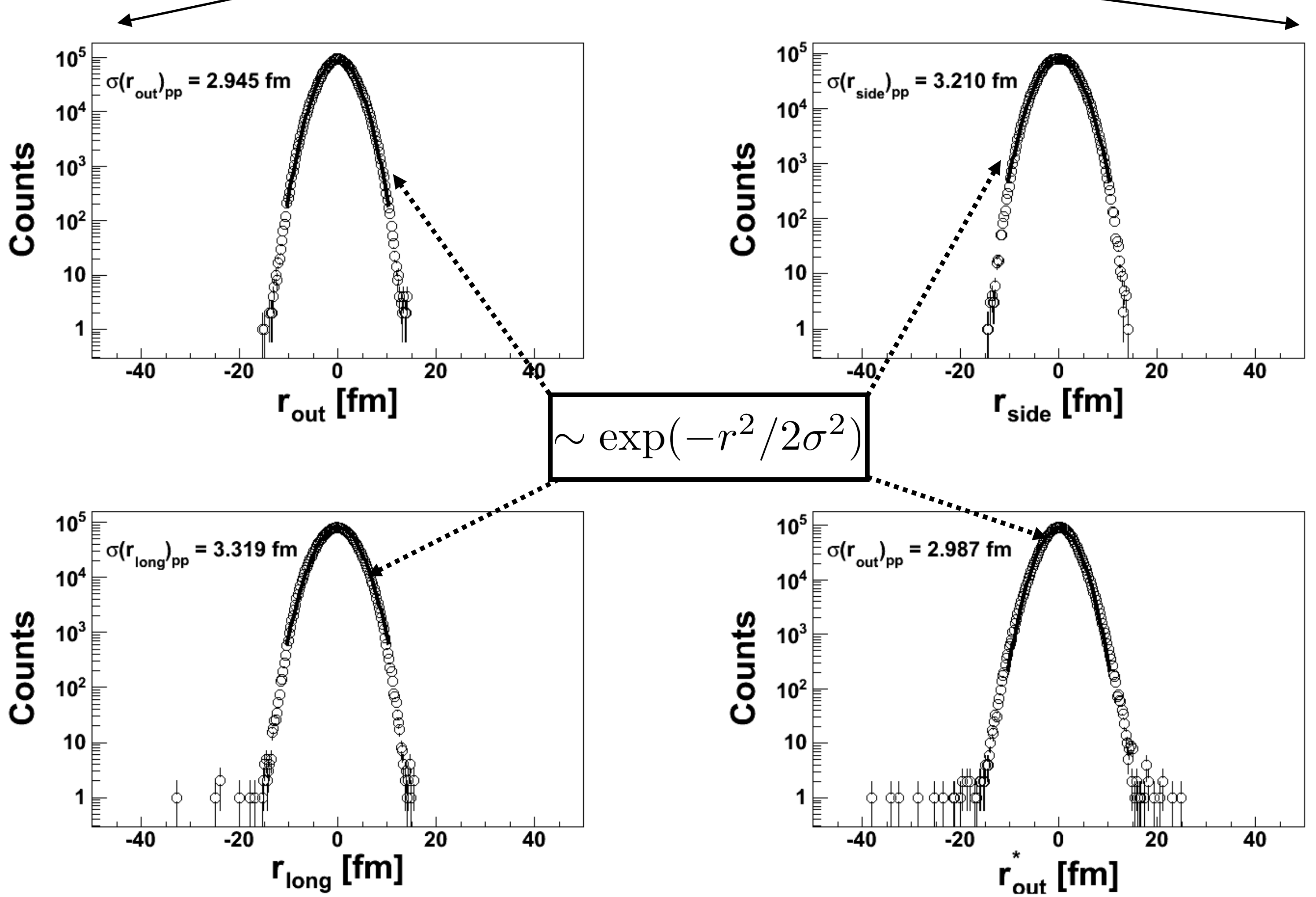
Will also affect dN/dy spectra in pNb

Interaction

Source extraction from transport theory (UrQMD) - LCMS:

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

Proton-Proton



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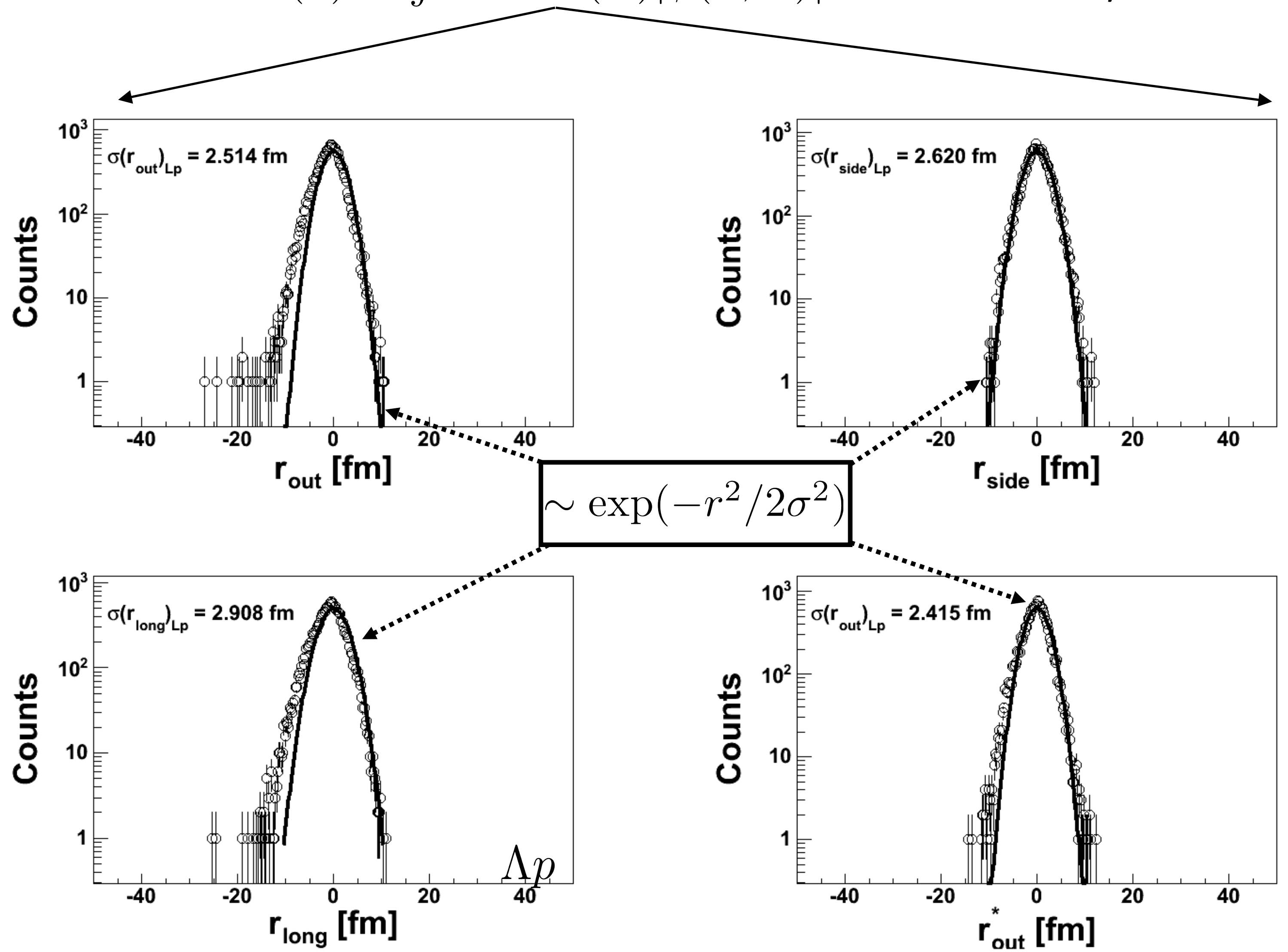
Λp



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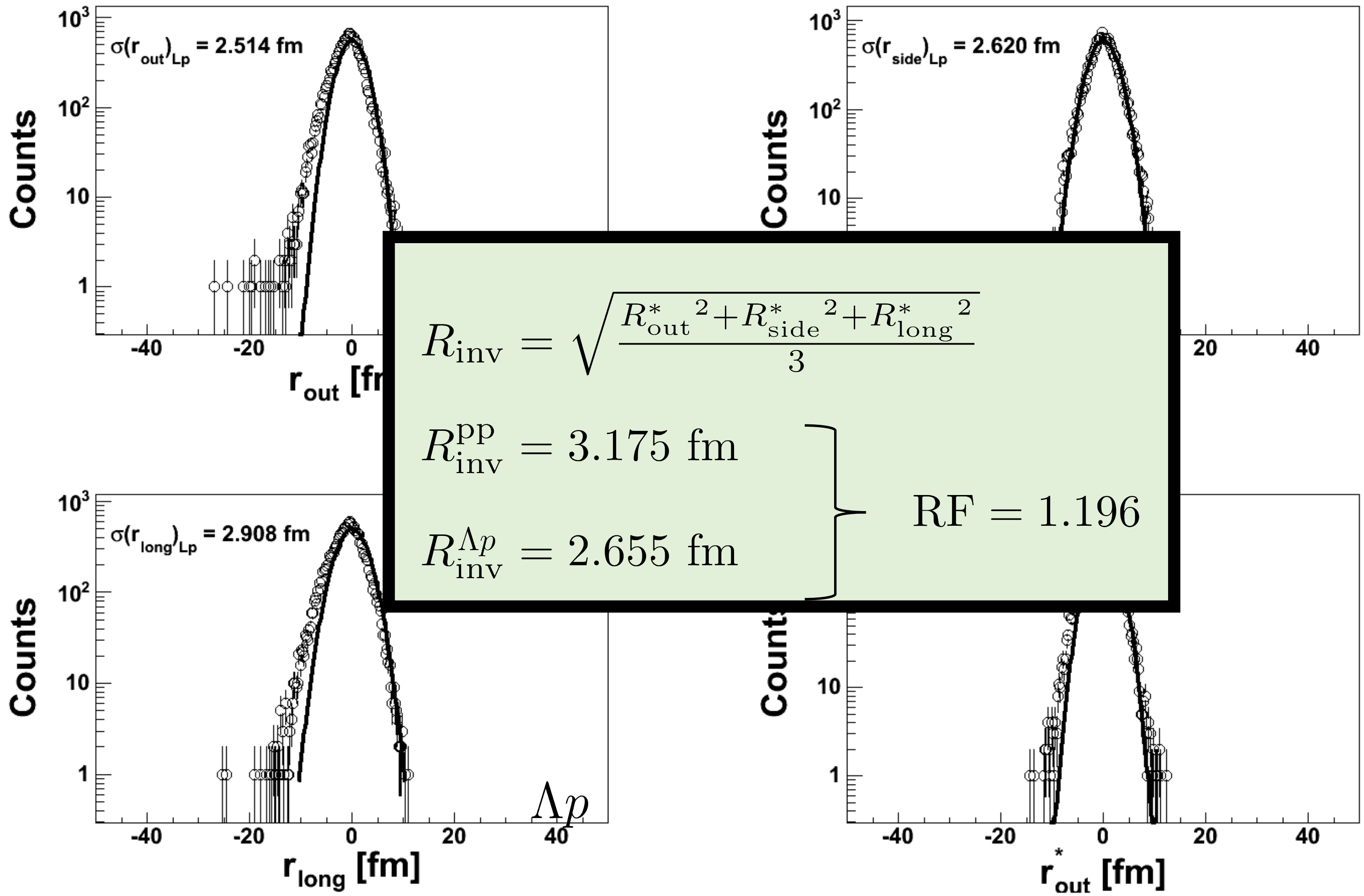
Λp



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

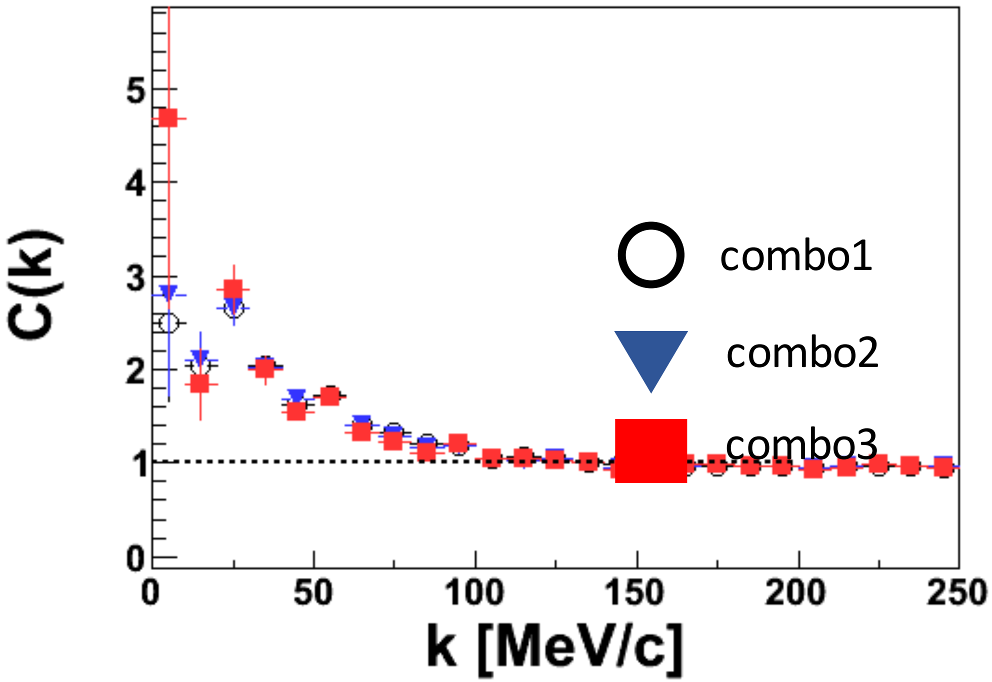
$$R^{\text{pp}}_{\text{inv}} = 3.175\ \text{fm}$$

$$R^{\Lambda p}_{\text{inv}} = 2.655\ \text{fm}$$

$$\text{RF} = 1.196$$

Interaction

Correlation function after application of all corrections



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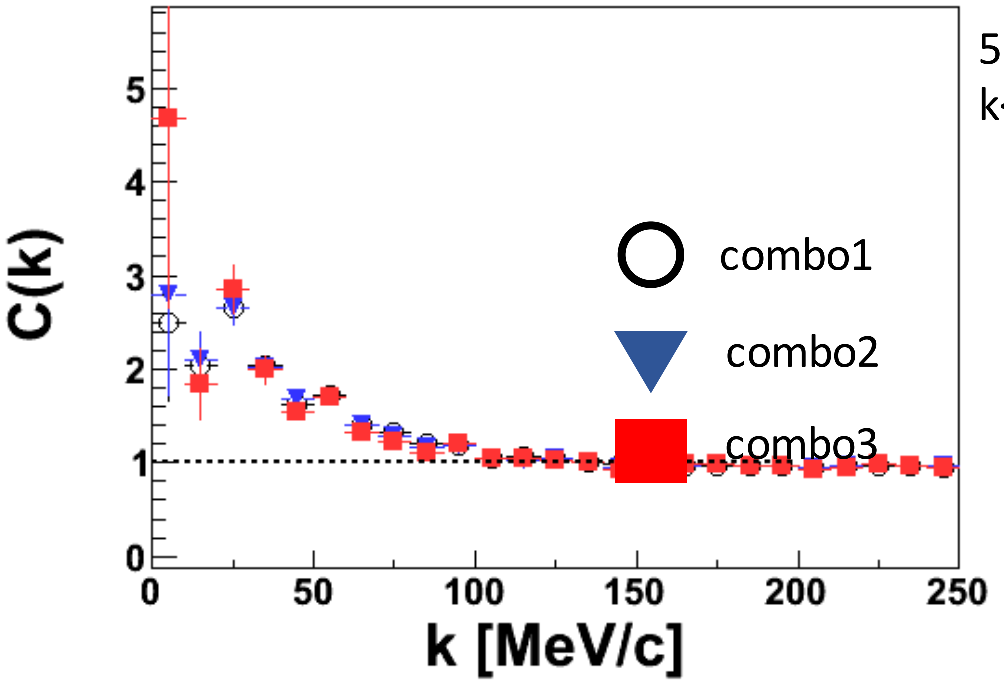
UrQMD +pp Fit used to fit $R_G^{\Lambda p}$

Interaction

Correlation function after application of all corrections



50.000 Λp pairs with k< 100 MeV/c

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Effective Range expansion of the complex scattering amplitude

$$f^S(k) = \left(\frac{1}{f_0^S} + \frac{1}{2 d_0^S k^2} - ik\right)^{-1}$$

f_0^S : Scattering length

d_0^S Effective range

Interaction

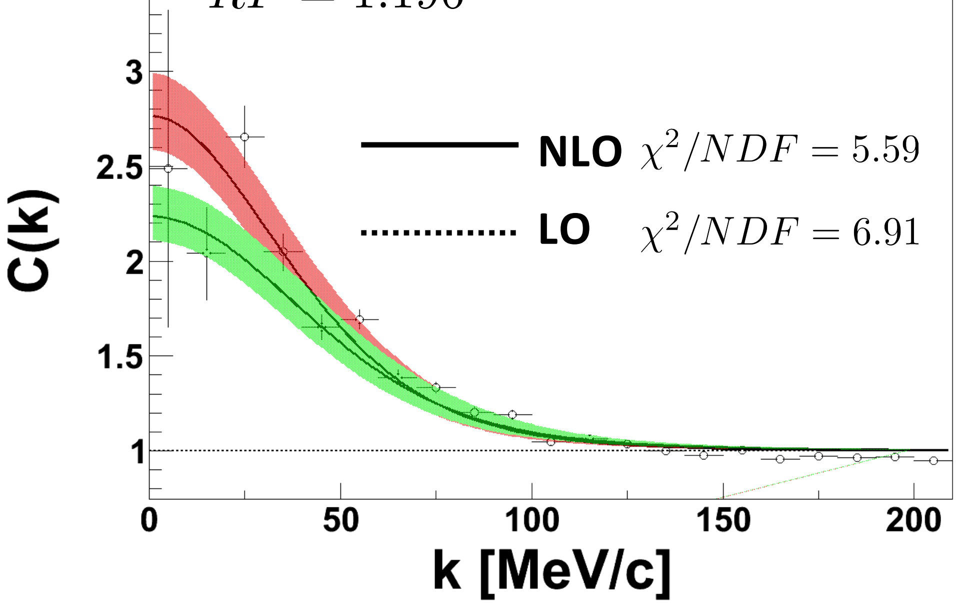
arXiv:1602.08880

Comparison to models:

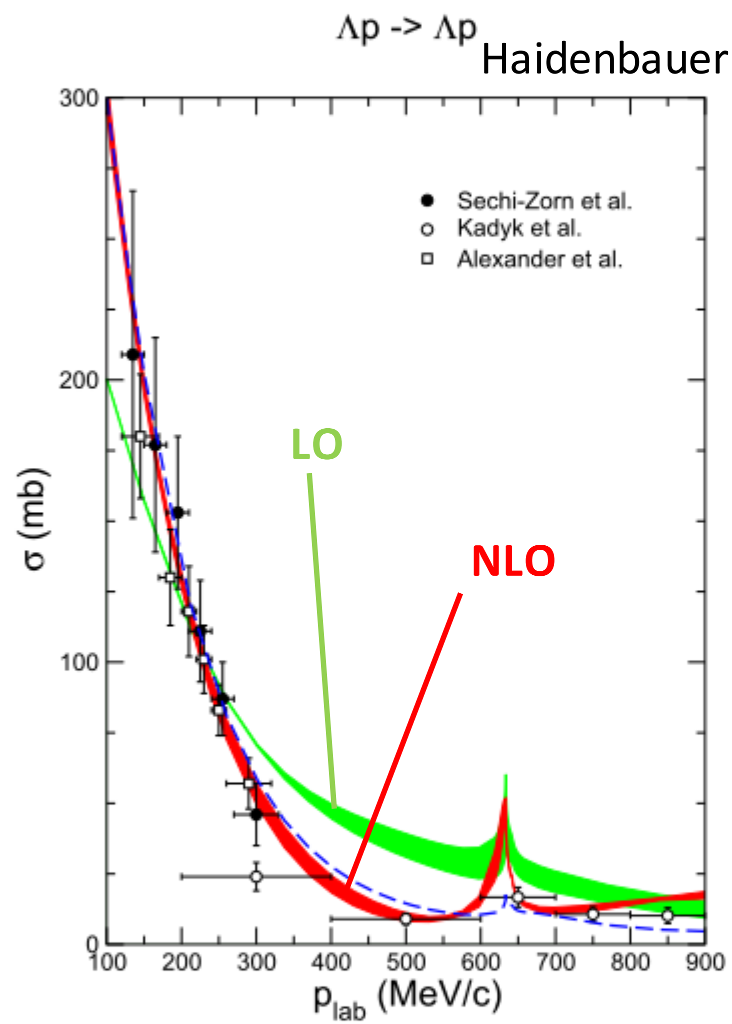
Correlation function obtained by using the NLO and LO scatttering length and effective range results

$$R_G = 2.016 \pm 0.010^{+0.039}_{-0.027}\ \text{fm}$$

$$R_G^{\Lambda p} = R_G^{pp}/RF$$
$$RF = 1.196$$



Haidenbauer et al.



Valid alternative to scattering experiments

Summary

- Correlation function calculated and source size for proton pairs extracted
- Study interaction of Lambda-proton pairs. Comparison to model predictions.

New Measurements

* Factor 10 for Λ-p correlation (2019)
p+Nb at 3.7 GeV (3 weeks)
3 KHz compared to actual 70 kHz
$3*10^6$ = beam intensity

* Σ^0-p correlation with the calorimeter (2019)

50% additional reduction wrt Λ (with 6 sectors)

- Evaluate the background to the Λp correlation quantitatively
- Measure for the first time the Σ^0-p scattering length

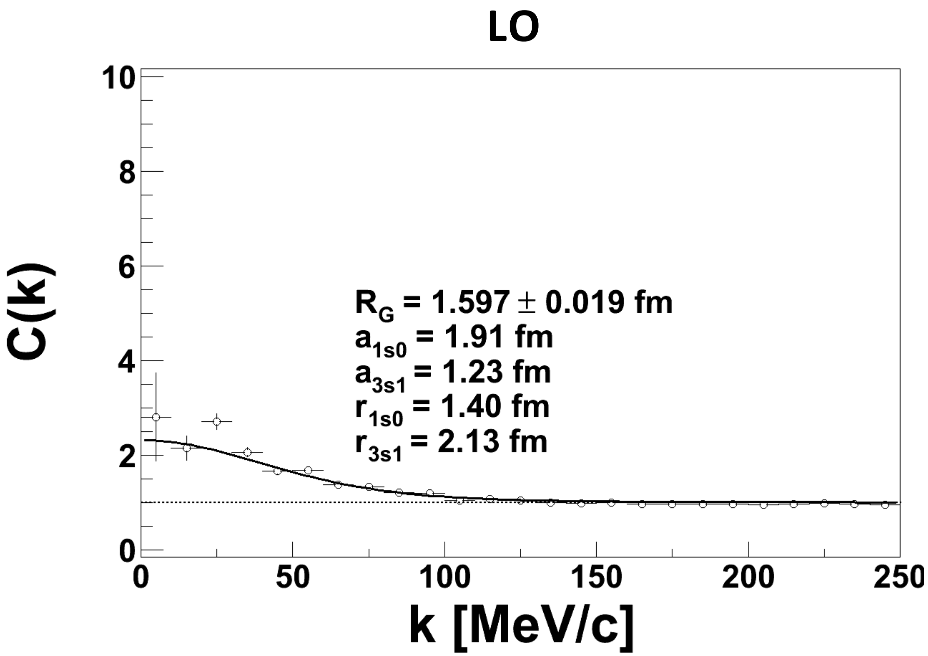
- Go to 3-body correlation Λ-p-p: the more the merrier
- Ξ-p ?? Simulations are needed

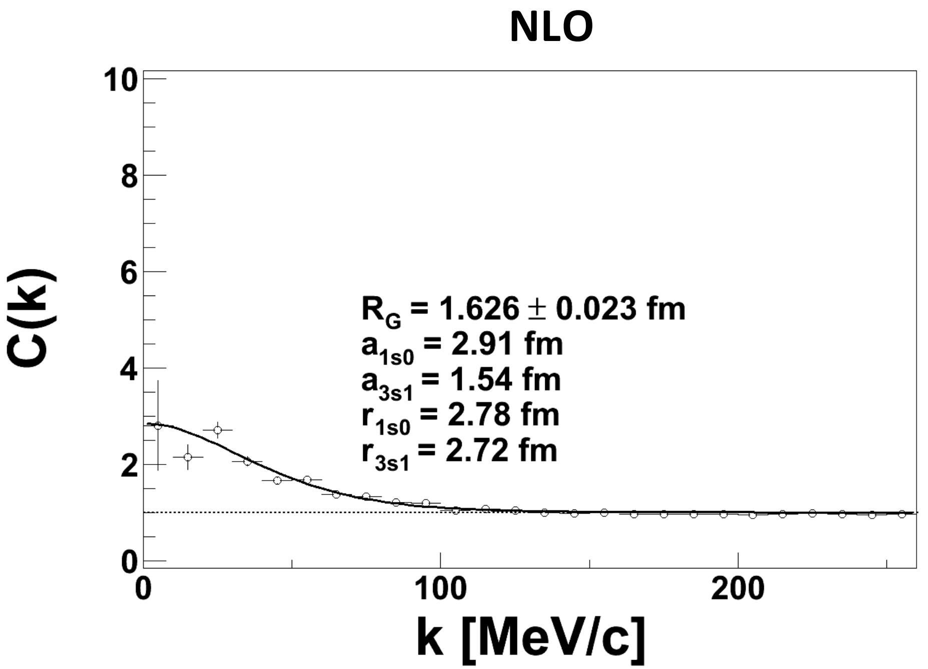
BACKUP

Interaction

Comparison to models:

Question: Effect on source size extraction?





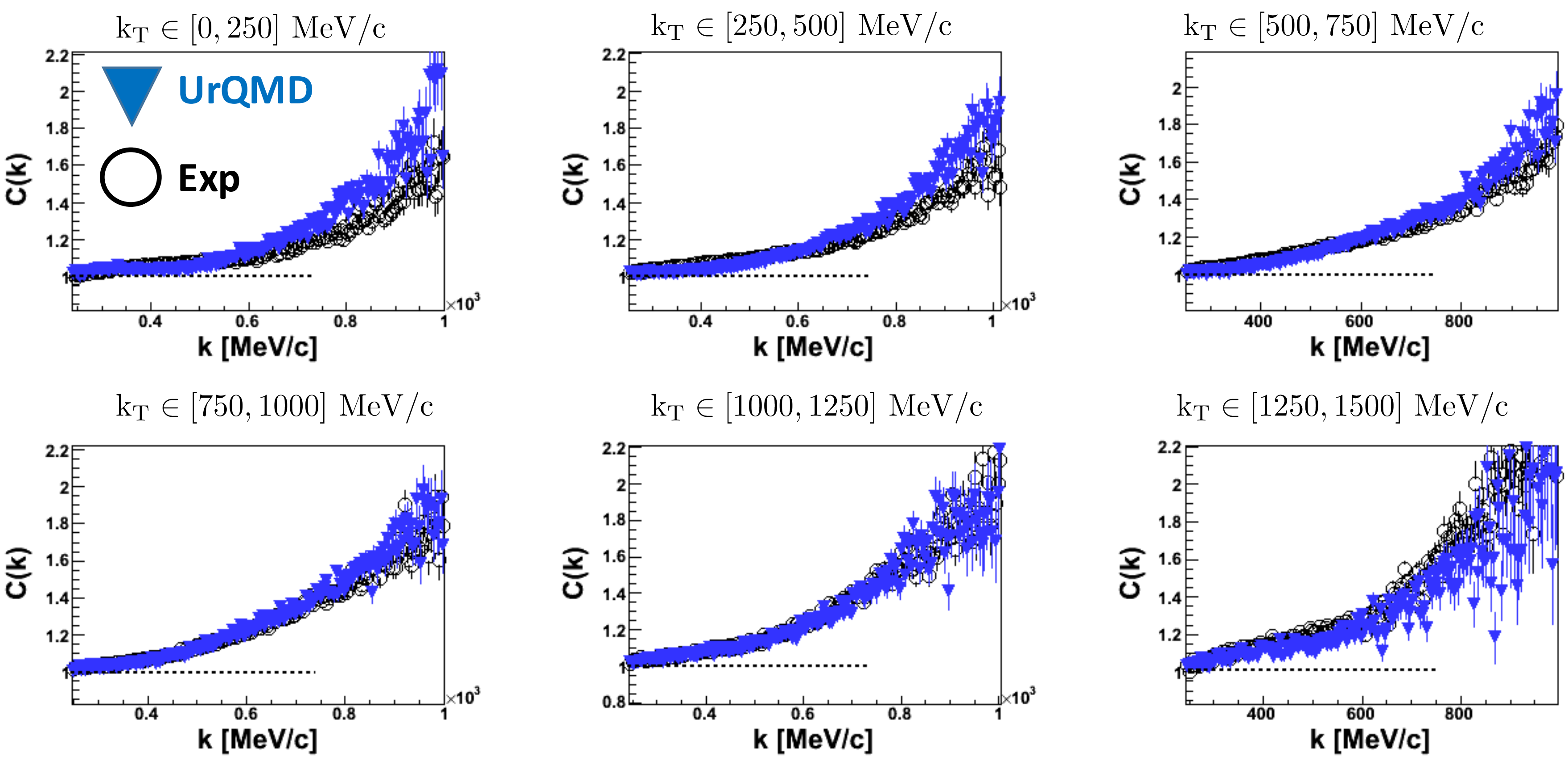
→ Small on source size

Backup

Results from pNb femtoscopy – Correlation function (angle integrated):

Can we model them (LRC)?

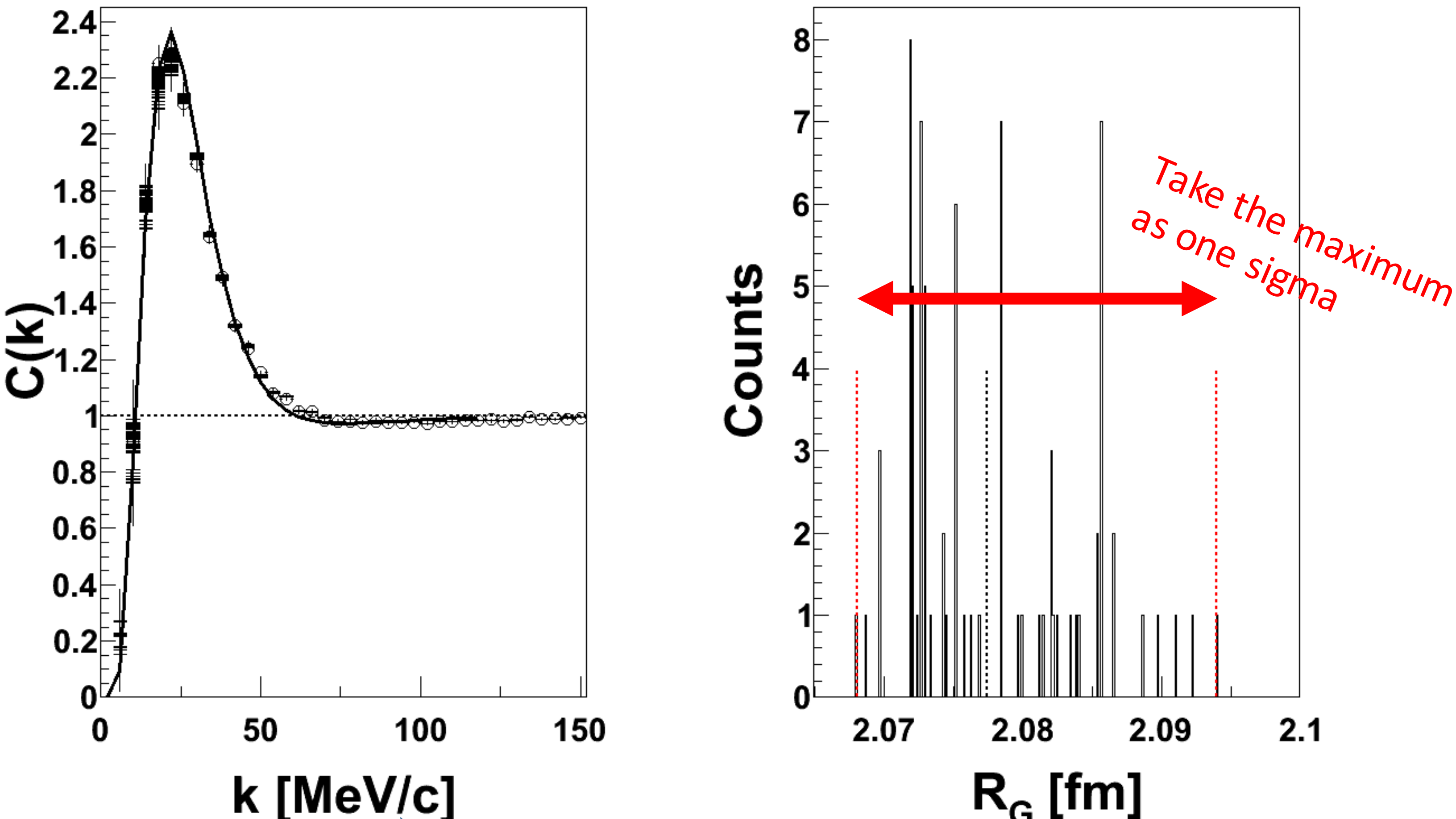
Baseline: as a function of pair transverse momentum $k_T = |\mathbf{p}_{1T} + \mathbf{p}_{2T}|$



Backup

Systematic errors on pp correlation function – close track efficiency:

Errors from pp source size – Variation of close track efficiency cut
(use 35 different cut combinations on $\Delta\phi, \Delta\Theta$):

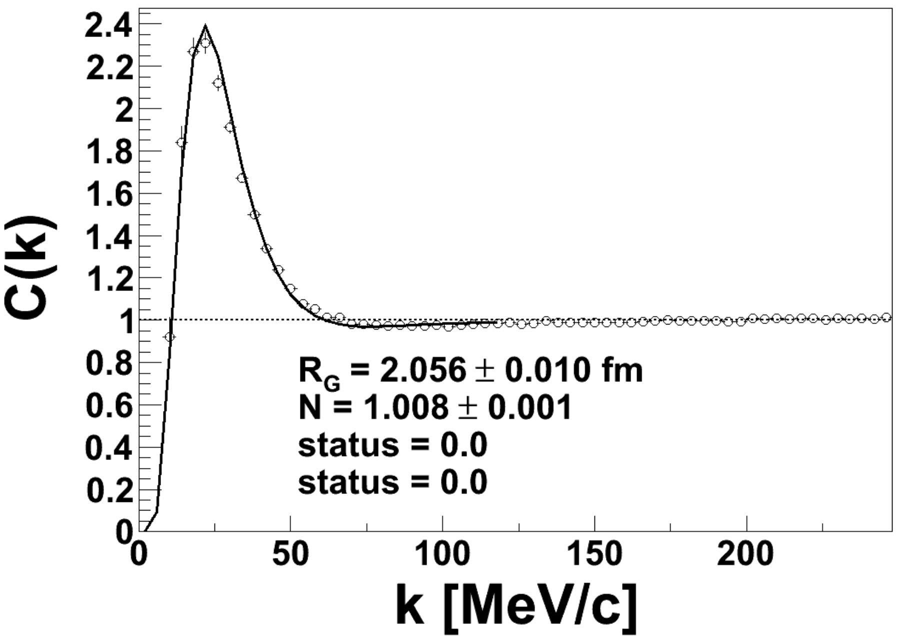


$$R_G = 2.078 \pm 0.010^{+0.016}_{-0.010} \text{ fm}$$

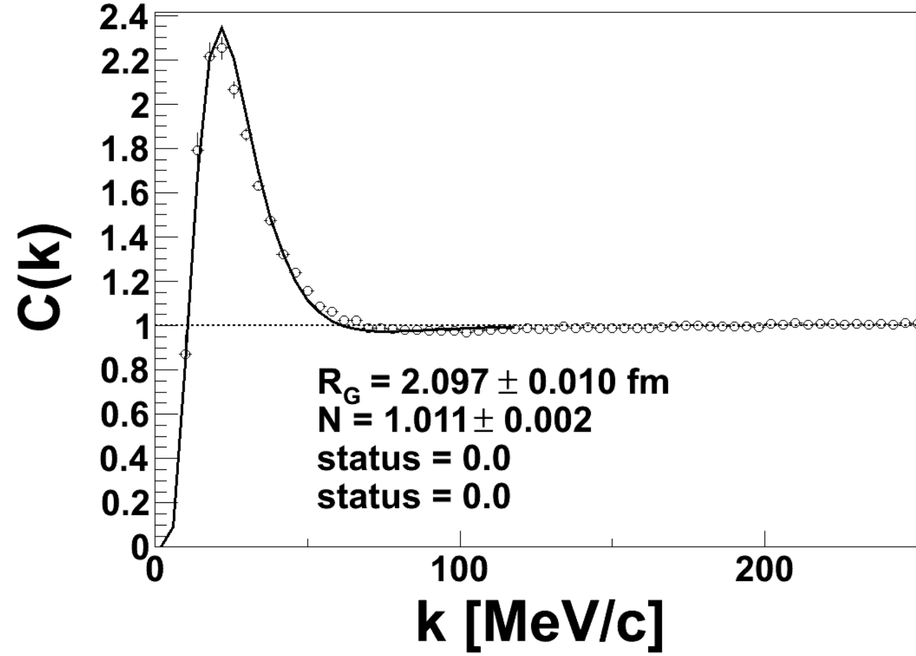
Systematic errors on pp correlation function – momentum resolution:

Use a variation of 10% around the chosen mean source size of 2.2 fm

$2.2\ \mathrm{fm} - 10\%$



$2.2\ \mathrm{fm} + 10\%$



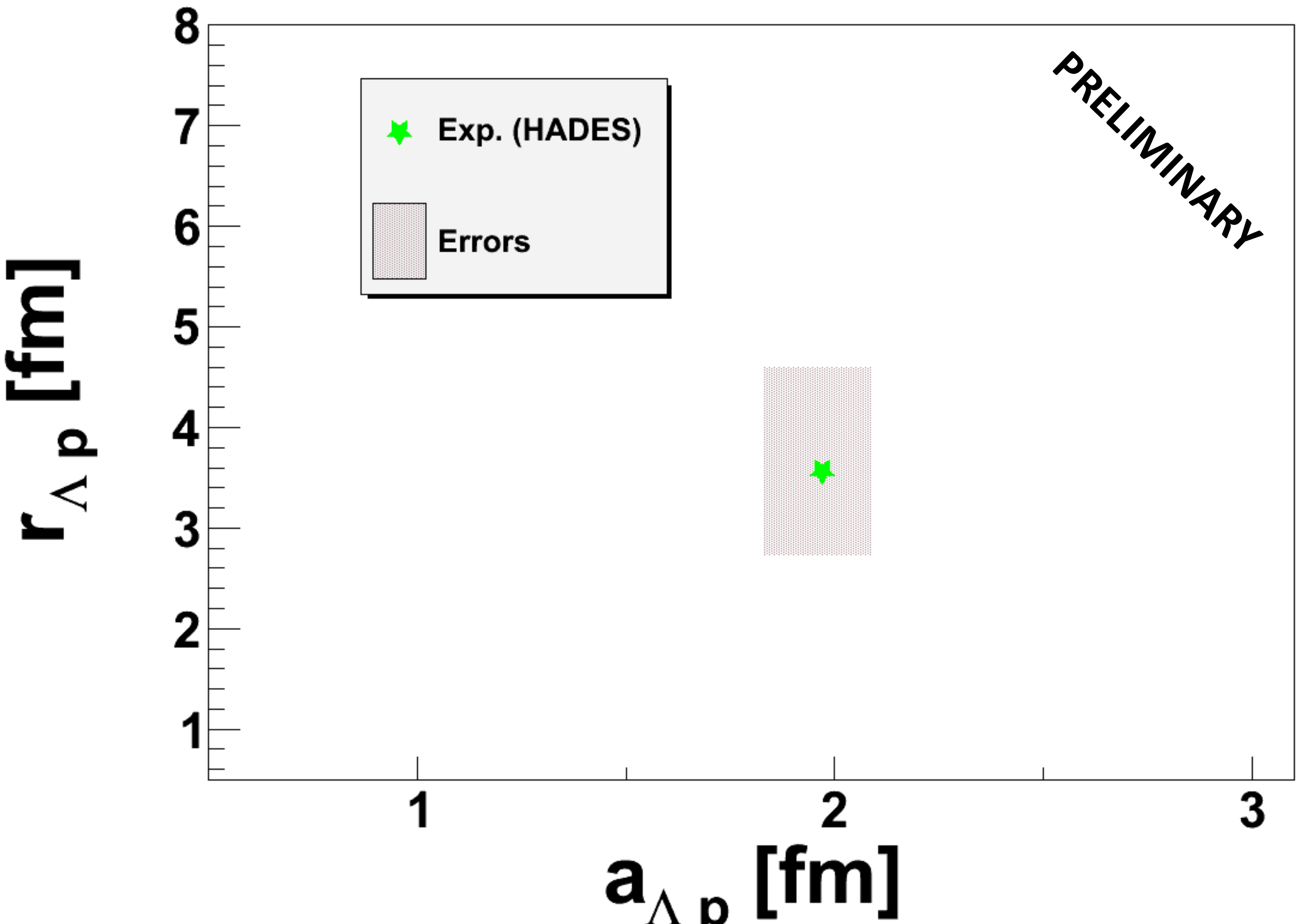
statistics   close track   momentum resolution

$$R_G = 2.078 \pm 0.010\ (\mathrm{stat})^{+0.016}_{-0.010}\ (\mathrm{sys})^{+0.019}_{-0.022}\ (\mathrm{sys})\ \mathrm{fm}$$

Interaction

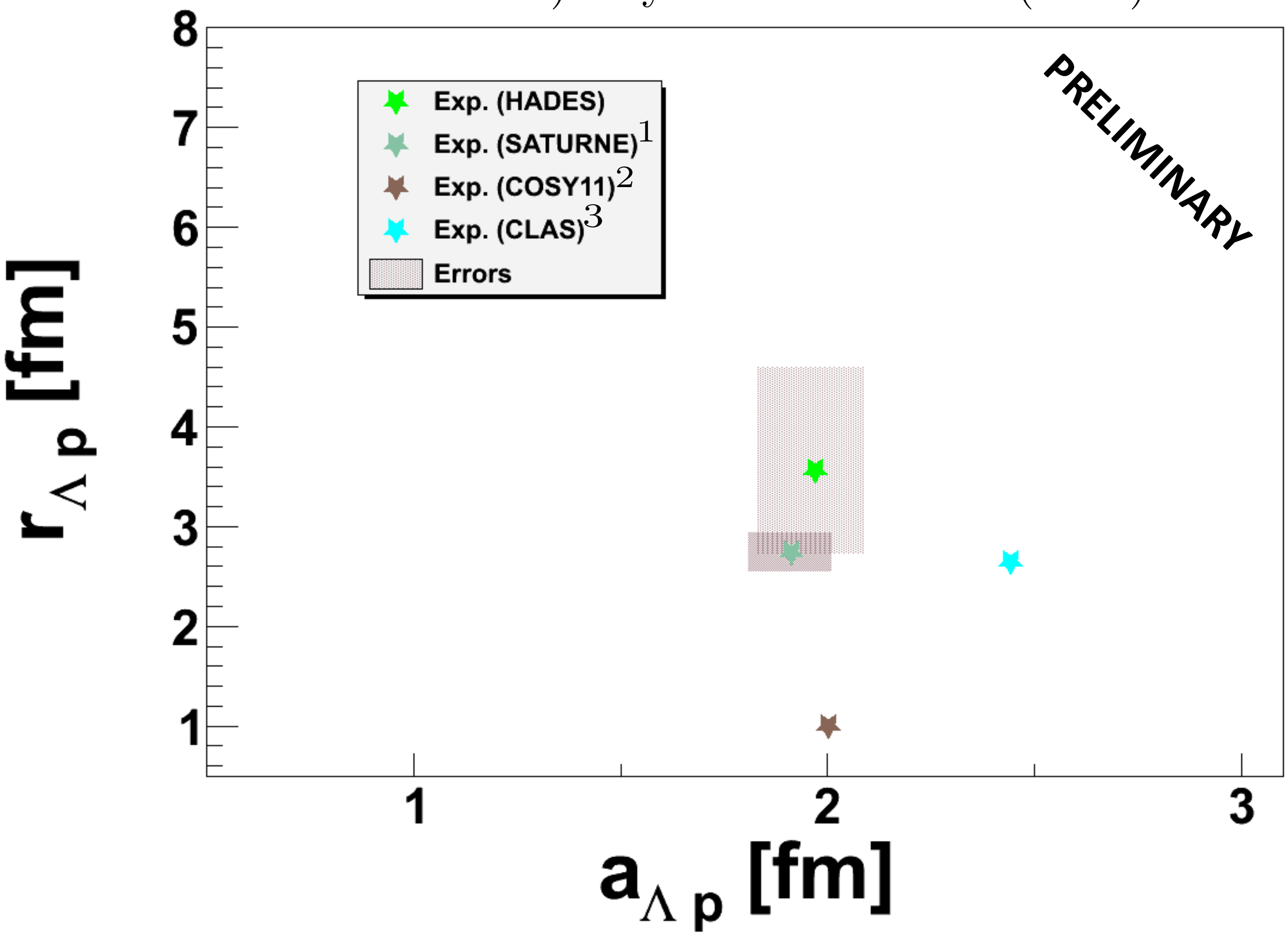
Comparison to other measurements and to models:

Only effective scattering length measured (no information about spin)



Comparison to other measurements and to models:

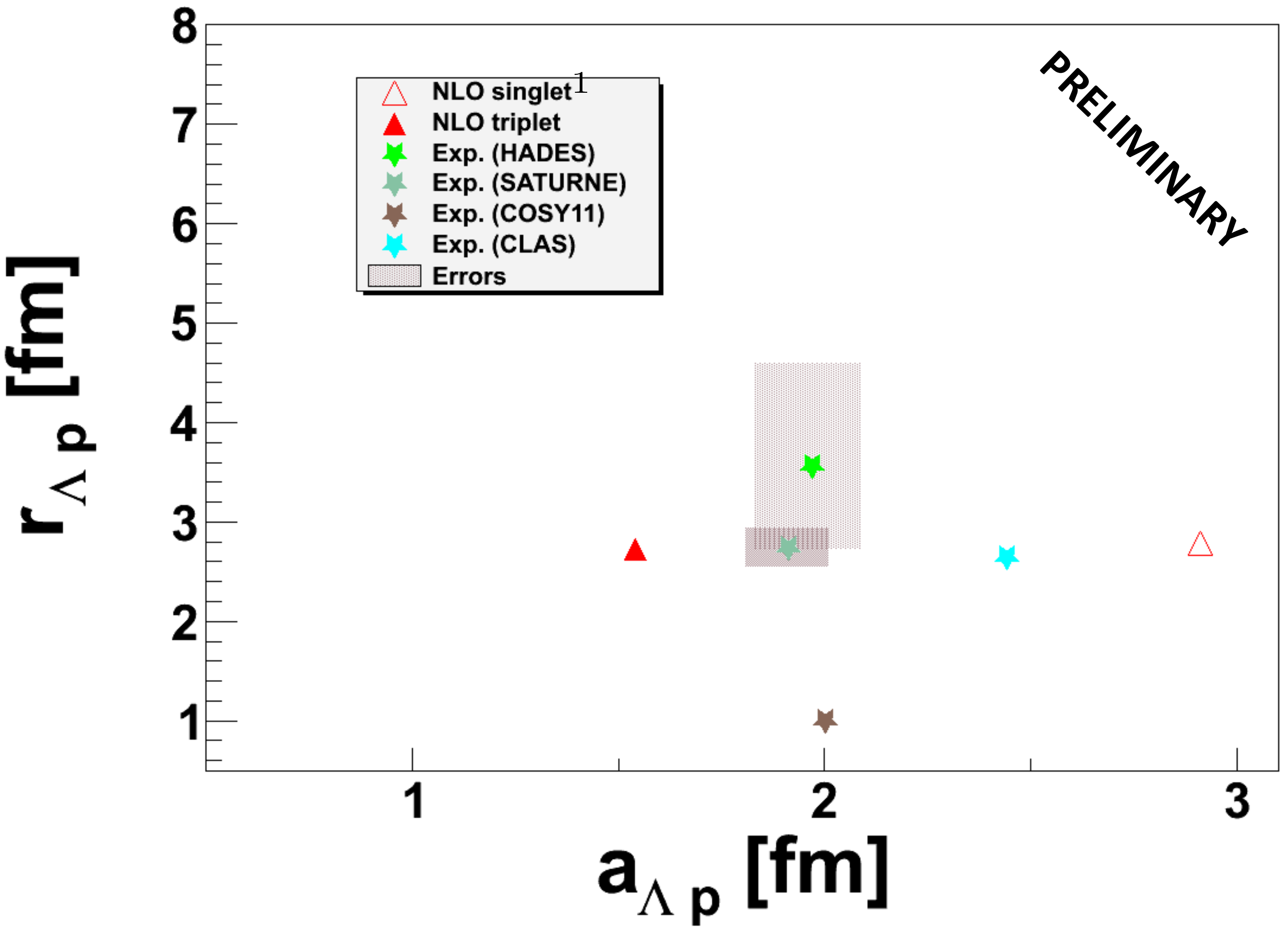
1) Eur.Phys.J. A21 (2004) 313 – 321
2) Eur.Phys.J. A2 (1998) 99 – 104
3) Phys.Atom.Nucl. 72 (2009) 668 – 674



Interaction

Comparison to other measurements and to models:

1) Nucl.Phys. A915 (2013) 24 – 58



Comparison to other measurements and to models:

1) Nucl.Phys. A915 (2013) 24 – 58
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