Comparison of source shapes from EPOS and momentum correlations from CRAB

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1. Introduction

Femtoscopy

➢ Study of momentum difference correlations of identical bosons on the femtometer scale

➢ Correlation function:

$$C(q,K) = \int D(r,K)\ \left|\psi_q(r)\right|^2 d^4r$$

➢ Pair source distribution:

$$D(r,K) = \int S\left(\rho + \frac{r}{2}, K\right) S\left(\rho - \frac{r}{2}, K\right) d^4\rho$$

- $\psi_q(r)$: symmetrized pair wave function
- S(x,p): single-particle freeze-out distribution (source)
- r: pair separation four-vector
- ρ: pair center of mass four-vector
- K: average momentum of the pair

Lévy-type of distribution

➢ Generalization of Gaussian → Lévy distribution:

$$\mathcal{L}(\alpha, R^2, \boldsymbol{r}) = \frac{1}{(2\pi)^3} \int d^{3}\boldsymbol{q}\ \ e^{i\boldsymbol{q}\boldsymbol{r}}\, e^{-\frac{1}{2}\left|\boldsymbol{q}^T R^2 \boldsymbol{q}\right|^{\alpha/2}}$$

➢ Lévy exponent α:
$\alpha = 2$ → Gaussian shape, $\alpha < 2$ → Power-law

➢ Lévy scale parameters: Geometry of the source

$$R^2 = \mathrm{diag}\left(R^2_{\mathrm{out}}, R^2_{\mathrm{side}}, R^2_{\mathrm{long}}\right)$$

➢ Reasons for the appearance of Lévy-type sources: Critical behavior, Lévy walk, jet fragmentation [1]

➢ Assuming a Lévy-source, it follows that:

$$C_2^{(0)}(\boldsymbol{q}) = 1 + \lambda \cdot e^{-\left|\boldsymbol{q}^T R^2 \boldsymbol{q}\right|^{\alpha/2}}$$

➢ Correlation strength parameter (λ) comes from the core-halo model

2. Methods

CRAB

➢ Analyzed data: $\sqrt{s_{\mathrm{NN}}} = 200\ GeV$ Au+Au collisions generated by EPOS3, $\pi^+\ \pi^+$ correlations in the 0-10% centrality class [3]

➢ EPOS3 => S(x,p) without Bose-Einstein correlations [3,4]

➢ CRAB: adds correlations and calculates the correlation function $C_2^{(0)}(\boldsymbol{q})$ [5]

- Creates mixed events for better statistics
- Choses random pairs for A(q) and B(q)
- 3D binning in q
- Cuts in K => 1 run for every K bin

Fitting

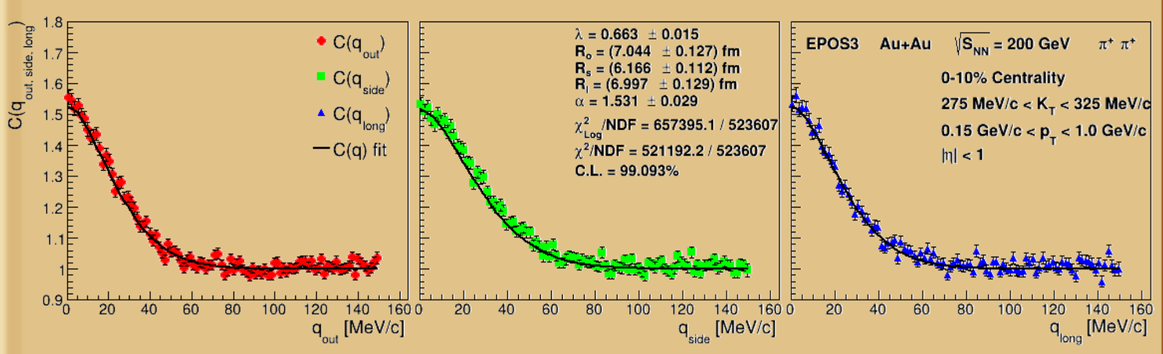
➢ Fitting the Lévy-correlation function in 3D (5 parameters: α, Rout Rside Rlong λ)

➢ Finding the optimal fit with log likelihood error function:

$$\chi^2_{\log} = -2 \sum \left[A \cdot \ln\left(\frac{f(A+B)}{A(1+f)}\right) + B \cdot \ln\left(\frac{A+B}{B(1+f)}\right)\right]$$

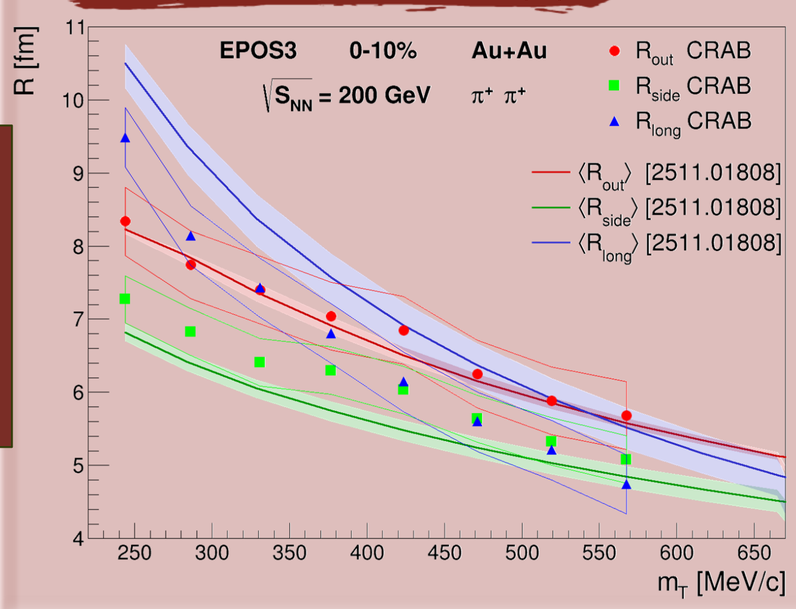
- A => A(q), B => B(q), f => fitted corr. Function

➢ Visualization of the fit by projecting the original and fitted values along the 3 axes:

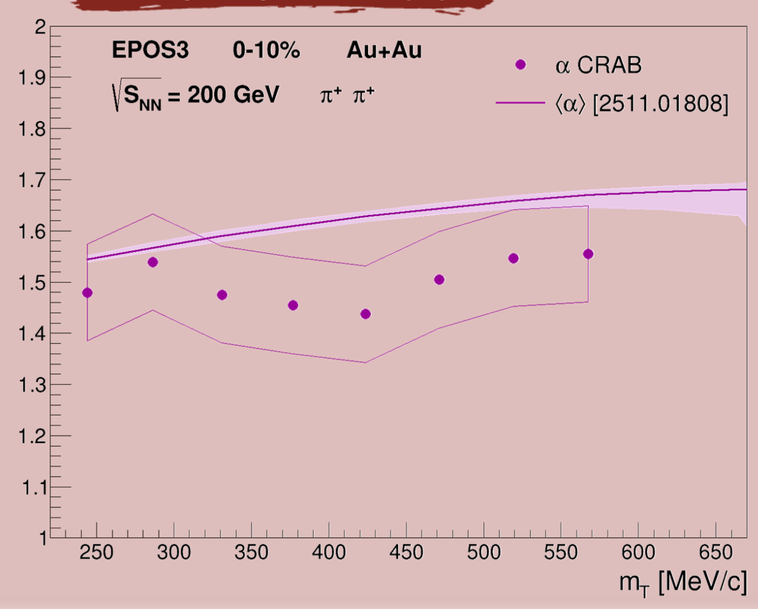


3. Results

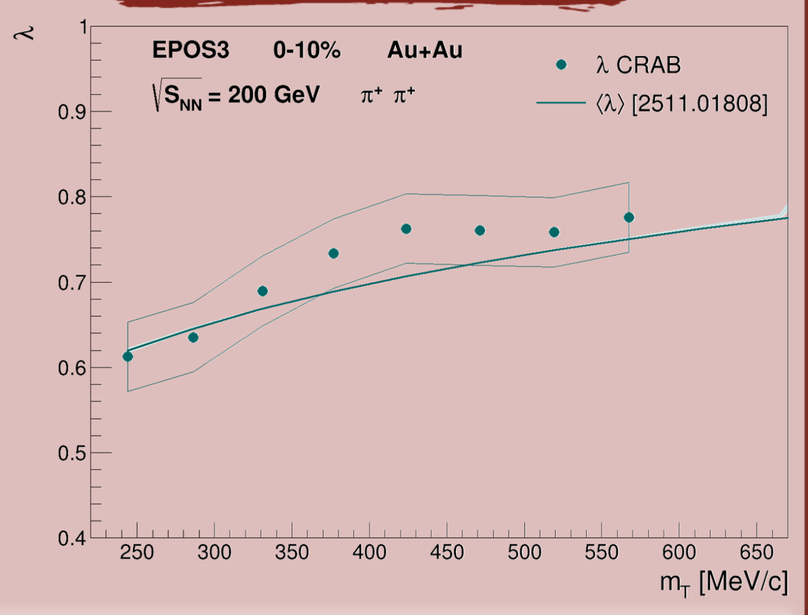
Lévy-scale parameter (R)



Lévy-exponent (α)



Correlation strength (λ)



➢ My results are compared to those of Ref. [2], which analyzed the same dataset, extracting the Lévy source parameters via fitting $D(r,K)$

➢ The trends agree with the independent analysis, although the oscillations — likely from event mixing — and the large systematics remain under investigation.

4. Endnote

Summary

➢ 3D $\pi^+\ \pi^+$ femtoscopy analysis on central Au+Au collisions generated by EPOS3

➢ Added Bose–Einstein correlations and calculated the correlation function using CRAB

➢ Fitted 3D correlation function assuming Lévy-type source

➢ The trends of the results agree well with those of Ref. [2]

➢ But the oscillations and large systematics require further investigation

References

[1] Kincses D., Nagy M., Csanád M. (2025), Lévy walk of pions in heavy-ion collisions, Commun. Phys. 8(1):55
[2] Kincses D., Árpási E., Kovács L. et al., arXiv:2511.01808
[3] K. Werner, I. Karpenko, T. Pierog, M. Bleicher, K. Mikhailov, Phys. Rev. C 82, 044904(2010), 1004.0805
[4] D. Kincses, M. Stefaniak, M. Csanád, Entropy 24, 308 (2022), 2201.07962
[5] S. Pratt et al., Nucl. Phys. A 566, 103C (1994)