Particle-species dependence of the two-particle source function in EPOS

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1. Introduction

Femtoscopy

- Study of momentum correlations of identical bosons
- Correlation function: $C(Q) = \int D(r)|\psi_Q(r)|^2 \, d^4r$
- Pair source distribution:

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

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

Lévy-type of distribution

- Generalization of Gaussian → Lévy distribution:

$$\mathcal{L}(r,R_x,R_y,R_z,\alpha) = \frac{1}{(2\pi)^3}\int d^3q\, e^{iqr} e^{-\frac{1}{2}|q_x^2R_x^2+q_y^2R_y^2+q_z^2R_z^2|^{\frac{\alpha}{2}}}$$

- Lévy exponent α:
  $\alpha = 2 \rightarrow$ Gaussian shape, $\alpha < 2 \rightarrow$ Power-law
- Lévy scale R: Geometry of the source
- Reasons for the appearance of Lévy-type sources [1-4]:
  Critical behavior, Lévy walk, jet fragmentation
- $D(\boldsymbol{r})$ is autocorrelation of $S(\boldsymbol{r})$:

$$S(\boldsymbol{r}) = \mathcal{L}(\alpha,R;\boldsymbol{r}) \rightarrow D(\boldsymbol{r}) = \mathcal{L}(\alpha,2^{\frac{1}{\alpha}}R;\boldsymbol{r})$$

EPOS event generator

- Phenomenological model using Monte Carlo techniques [5]
- Core-Corona division
- The three stages of evolution:
  - Initial interactions described by Parton-based Gribov-Regge theory
  - Viscous Hydrodynamical evolution
  - Hadronic rescattering, based on UrQMD

2. Analysis

Method of analysis [6]

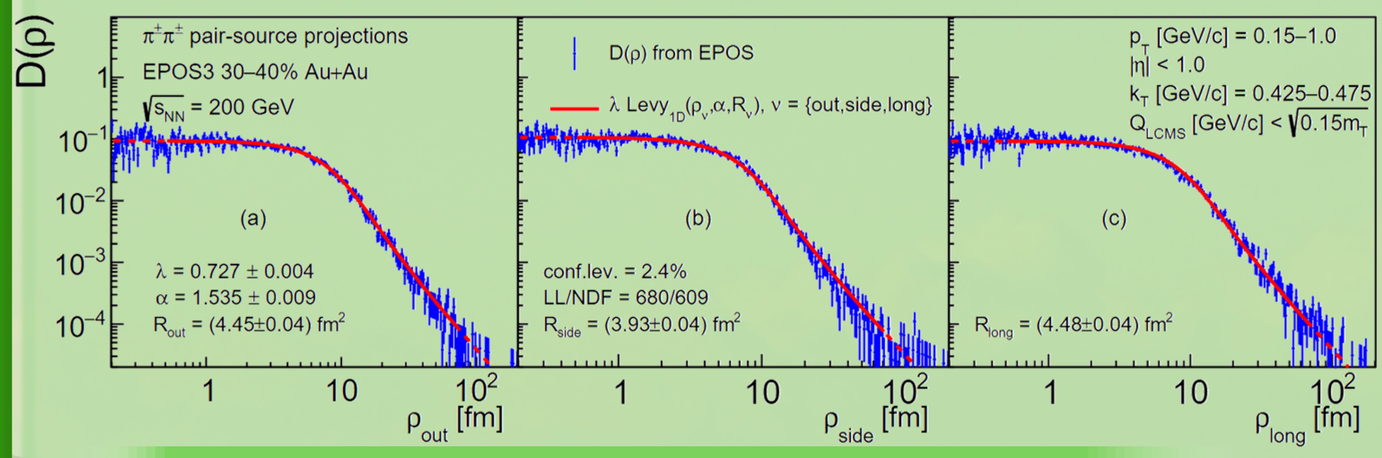
- $\sqrt{s_{\mathrm{NN}}} = 200$ GeV Au+Au collisions generated by EPOS359
- 3D separation vector $\boldsymbol{\rho}$ from freeze-out coordinates, boosted to the Longitudinal Co-Moving System (LCMS)
- Normalized 1D projections of the 3D $D(\boldsymbol{\rho})$ source are fitted simultaneously using Bertsch–Pratt coordinates
- The 1D projections are also Lévy
- Studied the centrality and m_{T} dependence of the source, where $m_T = \sqrt{m^2+k_T^2}$
- Fit function defined as: $D_{c,c} = \lambda\mathcal{L}^{1D}(\rho_\nu,\alpha,R_\nu)$, where $D_{c,c}$ is the core-core source function
- Investigated particles: pions, kaons, protons

Systematic uncertainties

- Number of events averaged
- Pair kinematic limit
  - $Q_{LCMS}^{max} = \sqrt{A*m_T}$ ← To consider the fit limit of the correlation function in experiments
- Fit range
  - $\rho = B/\sqrt{m_T}$ ← Total systematic uncertainty: squared sum of the individual sources

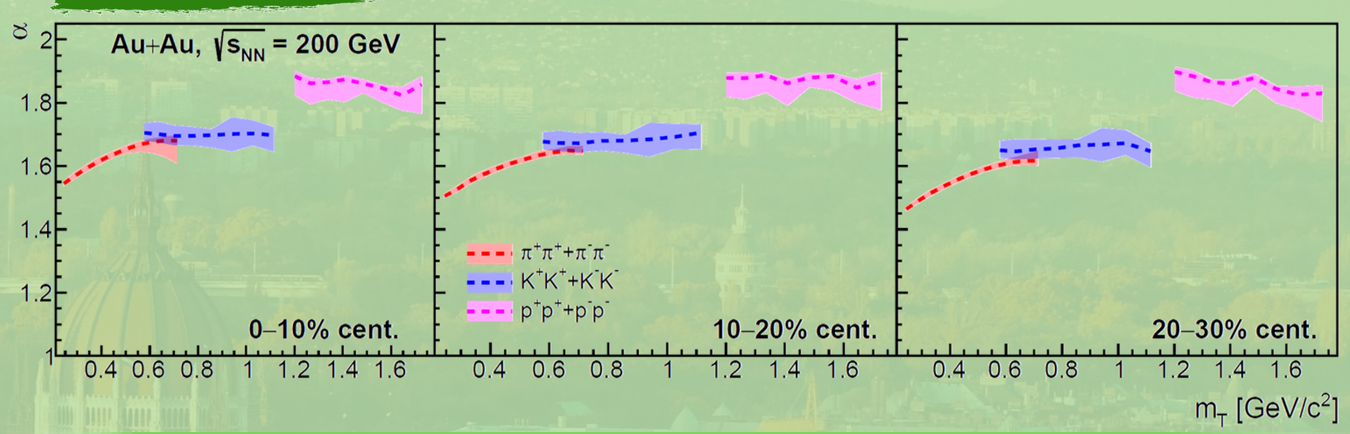
3. Results

Example fits [7]



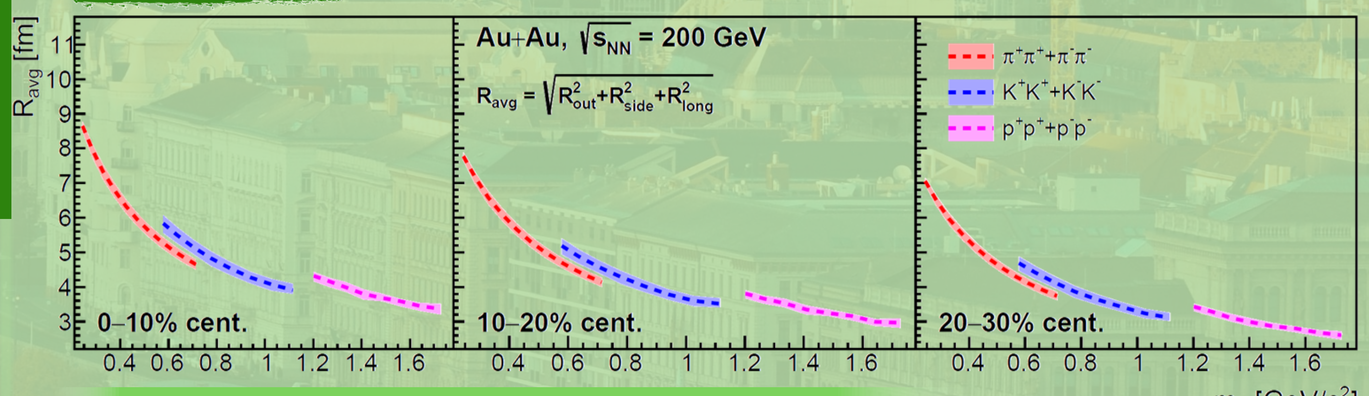
- Out direction: aligned with the pair's average transverse momentum
- Long direction: alinged with the beam direction
- Side direction: perpendicular to out & long

Parameter α



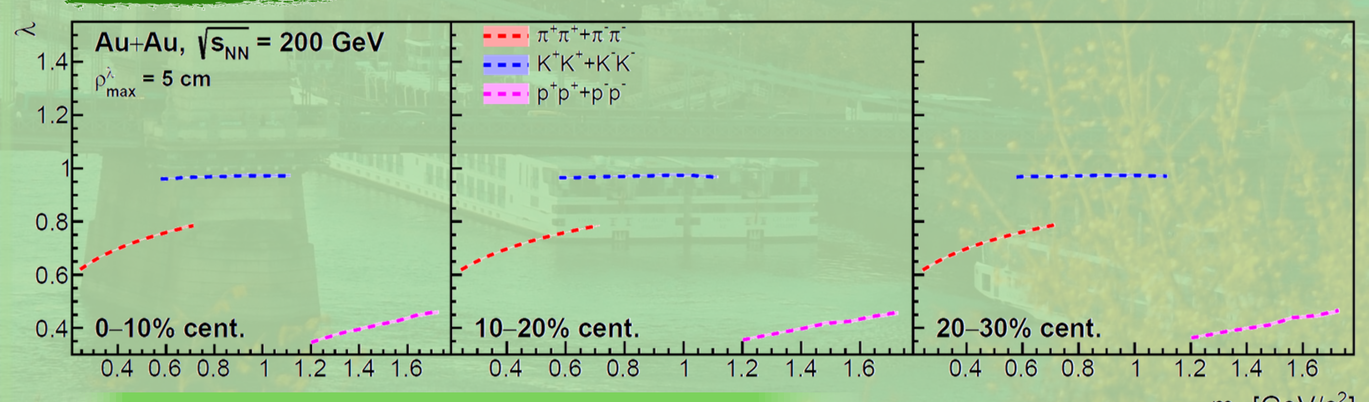
- Expectation based on elastic scattering dominated Lévy walk: α(K) < α(π) < α(p)
- Relation obtained in the simulation, contrary to expectations: α(π) ≤ α(K) < α(p) [8]
- Probably due to inelastic scattering processes or resonance decays

Parameter R



- Decreases with transvers mass, as predicted by hydro
- Depends on particle species, probably due to UrQMD

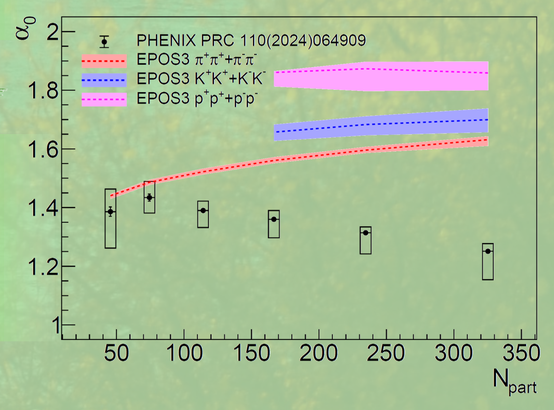
Parameter λ



- $\lambda(K) \approx 1$: few decay contributions to kaons
- Low $\lambda(p)$: strong feed-down from hadron decays

⟨α(m$_T$)⟩ vs number of participants

- Decreasing trend with increasing N_{part} in EPOS3
- Opposite trend seen in the experiment
- Possible reason: scattering of charged particles induced by the Coulomb interaction not incorporated in EPOS3



4. Endnote

Summary

- Kaon-kaon, pion-pion, proton-proton 3D pair sources fitted with Lévy function
- ***α***: α(K) ≤ α(π) < α(p), unlike expectation for elastic scattering dominated Lévy walk [8]
- ***R***: decreases with m_{T} and centrality, weak particle-species dependence
- ***λ***: $\lambda(K) \approx 1$ → weak feed-down; $\lambda(\pi)$ intermediate; low $\lambda(p)$ → strong feed-down
- **⟨α(m$_T$)⟩**: Experiment and simulation show opposite trends [9]
- Lévy sources observed from SPS through RHIC to LHC [8]
- EPOS analysis conducted for kaons, pions, and protons at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV [10]

References

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