Event-by-event investigation of the two-particle source function with 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:

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

  - $\psi_Q(r)$: 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:

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

- 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, anomalous diffusion, jet fragmentation
- $D(\boldsymbol{r})$ is autocorrelation of $S(\boldsymbol{r})$:
  $S(\boldsymbol{r}) = \mathcal{L}(\alpha, R; \boldsymbol{r}) \rightarrow D(\boldsymbol{r}) = \mathcal{L}(\alpha, 2^{\frac{1}{\alpha}}R; \boldsymbol{x})$

2. Analysis

EPOS event generator

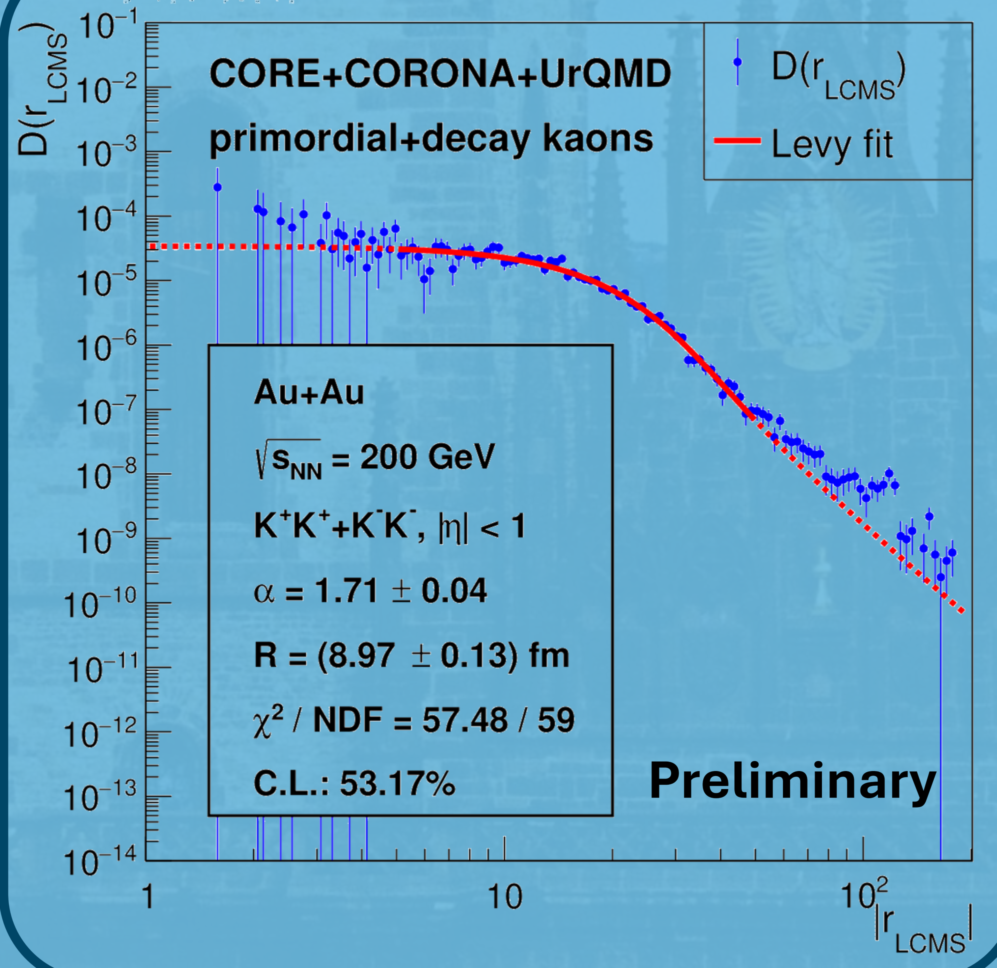
- Phenomenological model using Monte Carlo techniques [5]
- Core-Corona division
- The three stages of evolution:
  - Initial interactions described by Parton-based Gribov-Regge theory
  - Viscous Hydrodynamical evolution
  - Hadronic rescattering, based on UrQMD

Method of analysis

- $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions generated by EPOS359
- Angle-averaged one-dimensional distance distribution:
  $D(r_{LCMS}) = \int D(\boldsymbol{r}_{LCMS}, t)\, d\Omega_{LCMS}\, dt$
  LCMS: Longitudinal co-moving system
- Limited statistics: event-by-event investigation by combining multiple histograms
- The Lévy parameters are calculated from thousands of fits
- Measurements in 4 centrality and 5 k_T classes
- Study of 2 different cases:
  - CORE with primordial kaons
  - CORE+CORONA+UrQMD with primordial + decay kaons

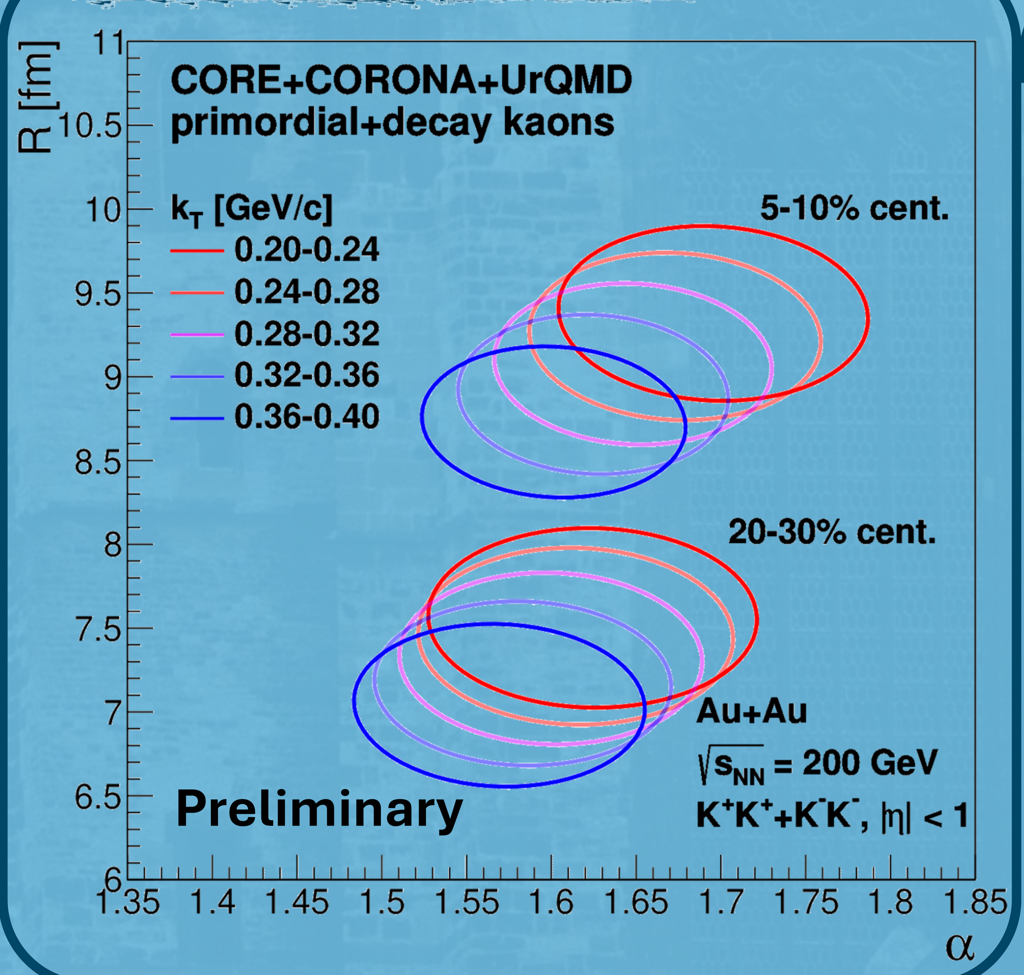
3. Results

Example fit

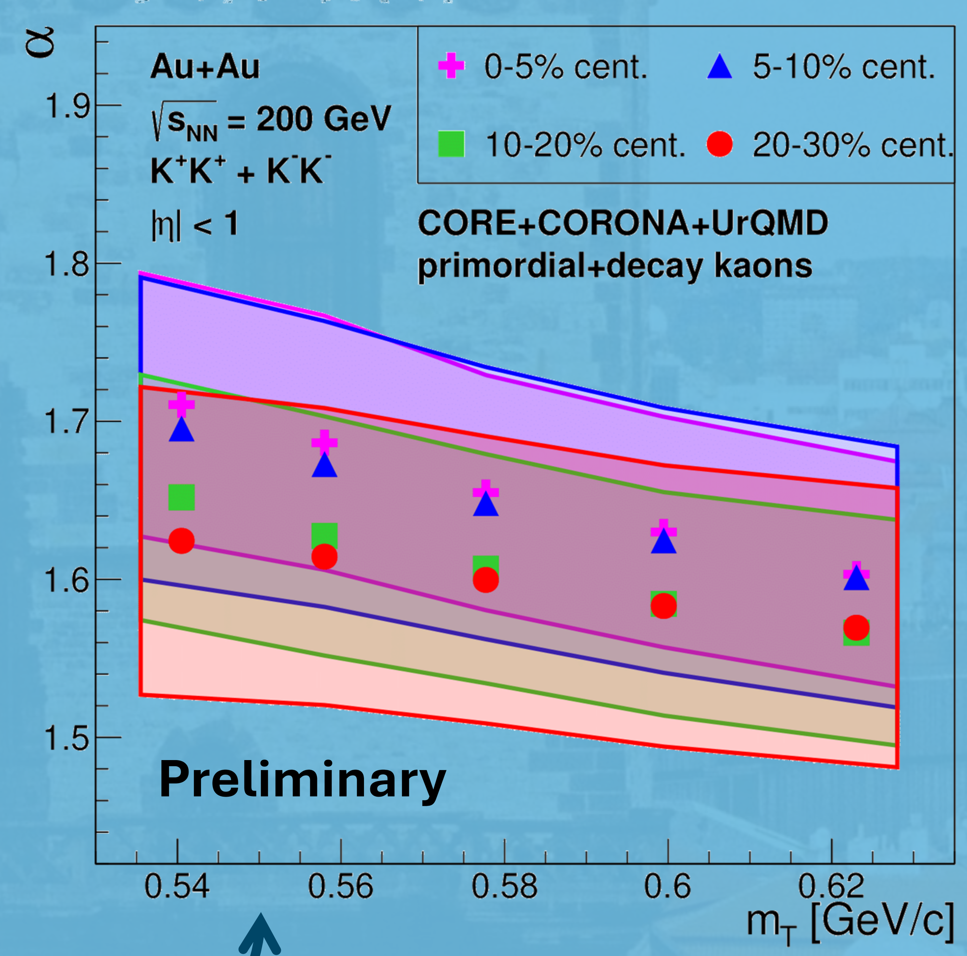


Fit results loaded into a 2D histogram

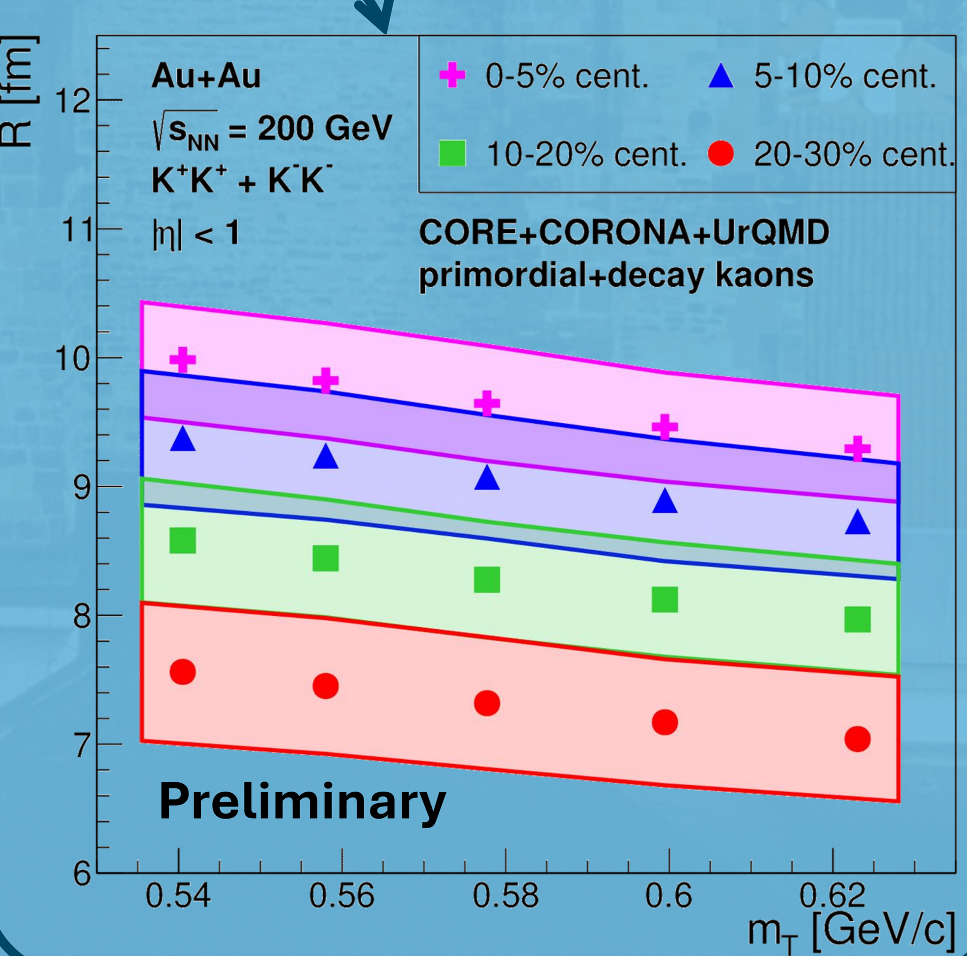
1 σ contours of R vs. α dist.



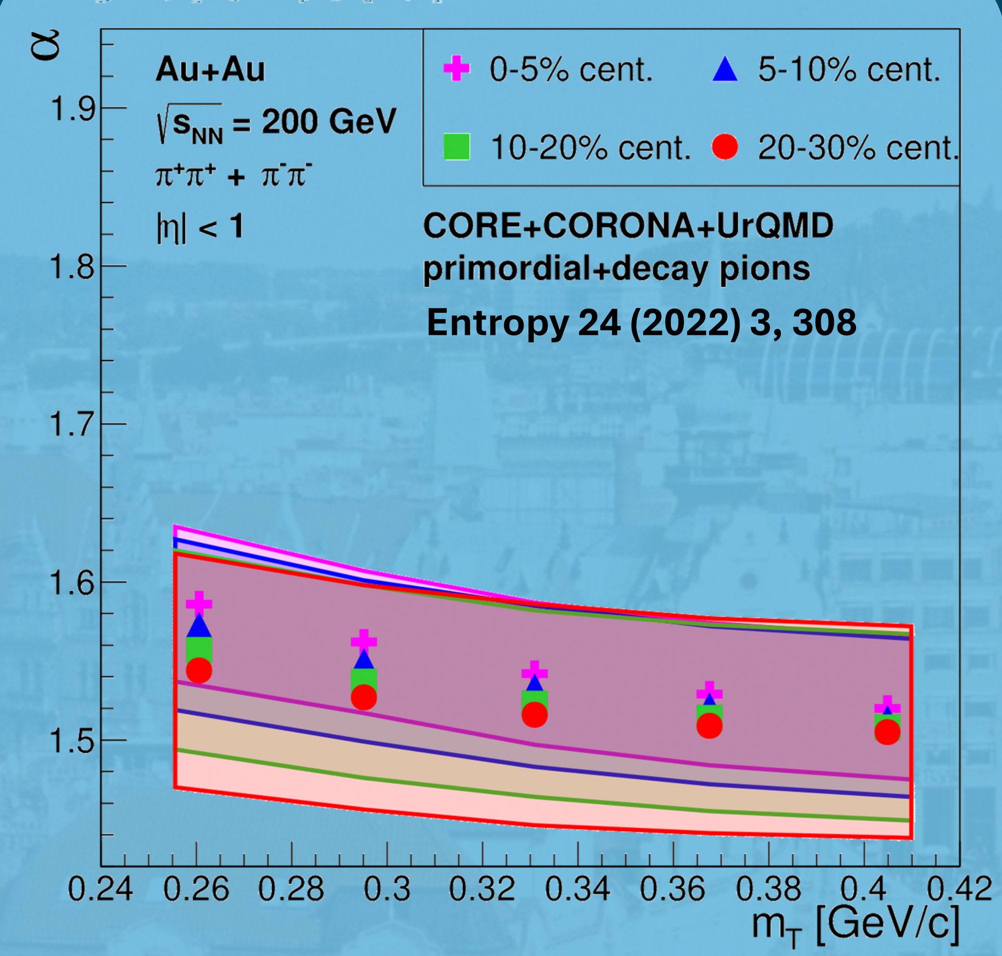
Lévy parameters - Kaons



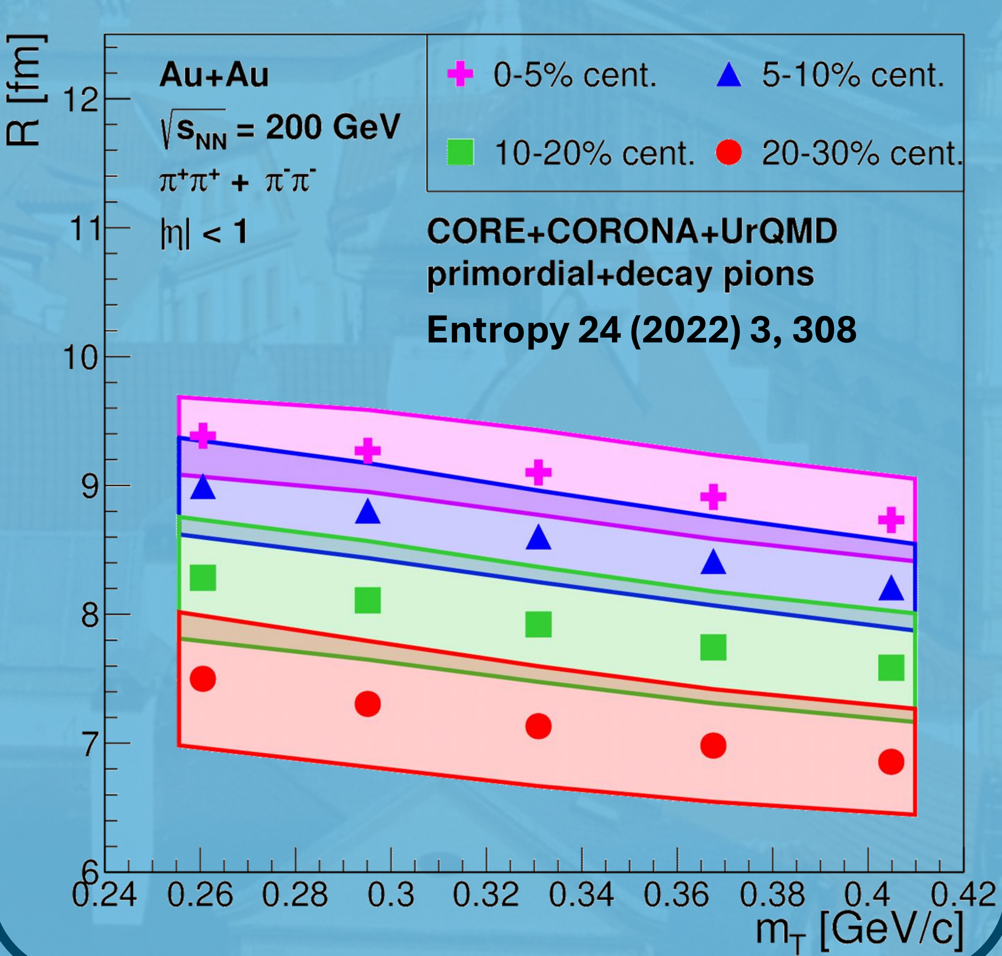
Extracted mean and variance values of the parameters



Lévy parameters – Pions [6]



- $\alpha(K^{\pm}) \geq \alpha(\pi^{\pm})$, contrary to expectations [7]
- $R(K^{\pm}) \geq R(\pi^{\pm})$ despite larger m_T



4. Endnote

Summary

- Kaon-kaon and pion-pion pair sources fitted with Lévy function
- **CORE with primordial particles: Gaussian source for both kaons and pions**
- **CORE+CORONA+UrQMD with primordial + decay particles:**
  - $\boldsymbol{\alpha(K^{\pm}) > \alpha(\pi^{\pm})}$, anomalous diffusion suggests opposite [7]
  - $\boldsymbol{R(K^{\pm}) \geq R(\pi^{\pm})}$ despite larger m_T, R decreases with m_T and cent.
- Lévy sources observed from SPS through RHIC to LHC [8]
- EPOS analysis conducted for kaons, pions, and protons at $\sqrt{s_{NN}} = 2.76$ TeV [9]
- No agreement with PHENIX kaon preliminary results [10]

References

[1] Csörgő, Hegyi, Zajc , Eur.Phys.J . C36;
[2] Csörgő, Hegyi, Novák, Zajc, AIP Conf.Proc. 828;
[3] Metzler, Klafter, Physics Reports 339 (2000) 1-77
[4] Csörgő, Hegyi, Novák, Zajc, Acta Phys.Polon. B36
[5] Werner, K. et al., Phys. Rev.C82, 044904 (2010)
[6] D. Kincses, M. Stefaniak and M. Csanád, Entropy 24 (2022) 3, 308
[7] M. Csanád, T. Csörgő, M. Nagy, Braz.J.Phys. 37 (2007) 1002
[8] M. Csanád, D. Kincses, Universe 10 (2024) 2, 54
[9] B. Kóródi, D. Kincses, M. Csanád, Phys.Lett.B 847 (2023), 138295
[10] L. Kovács for the PHENIX Collaboration, Universe 9 (2023) 7, 336