Charged kaon and pion femtoscopy in the RHIC Beam Energy Scan at the STAR experiment

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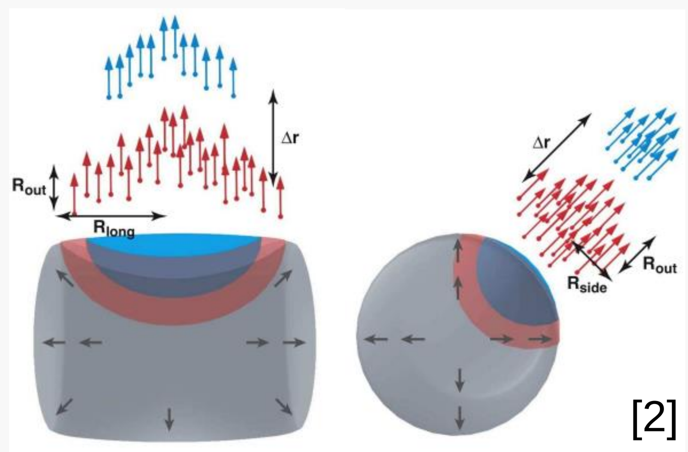
This study presents the first comprehensive femtoscopic analysis of identical kaons and pions produced in Au+Au collisions at $\sqrt{s_{NN}}$ = 14.6 - 200 GeV from the RHIC Beam Energy Scan phases I and II, focusing on charge, transverse momentum, and centrality-dependent properties. The charge-dependent analysis reveals differences at the level of correlation functions for both kaons and pions for the first time at these energies. This observation is consistent with Coulomb field effect due to residual charge after the collision and hadronic final state effects, as implemented in UrQMD. The three-dimensional femtoscopic analysis reveals that the extracted radii, assuming Gaussian distribution for emission source, increase with collision energy, decrease with transverse mass, and are generally larger for kaons compared to pions under the same conditions. The study compares experimental data with model scenarios and discusses the implications of the trend of the extracted size and lifetime of the particle source with the change of collision energy. An analysis of one-dimensional two-pion correlations in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, utilizing Levy-stable distributions for the source shapes, is also presented. The current analysis status of the extracted Levy source parameters, including their dependence on average transverse mass and centrality, is reported.

Femtoscopy

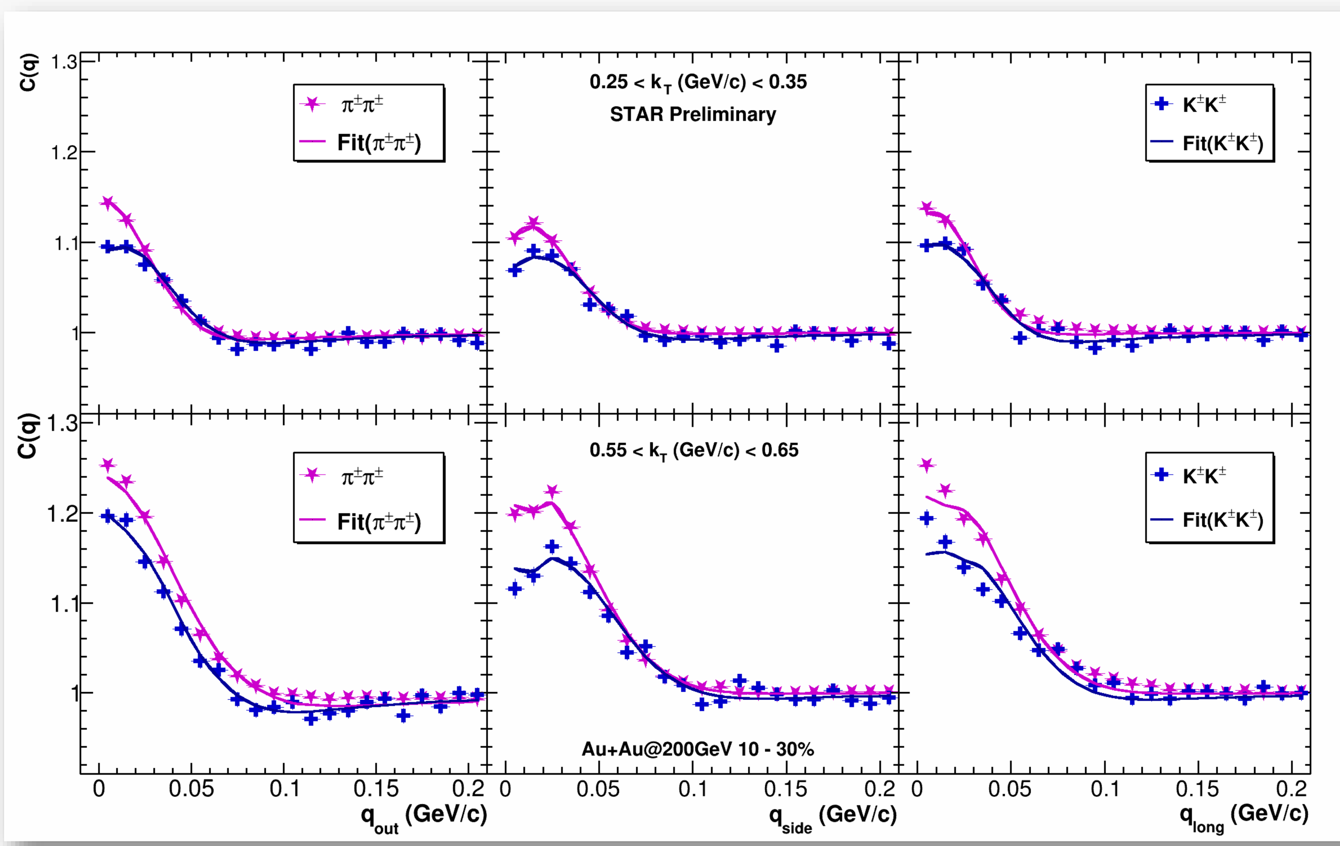
- The correlation femtoscopy technique is a useful tool to study the spatial and temporal scales of systems that have the size of the femtometer scale
- Information about the size, shape, lifetime of the particle-emitting source in heavy-ion collisions
- The correlations determine the region of homogeneity, which is the phase space cloud of outgoing particles with a given velocity magnitude and direction [1-2].



Correlation function

$C(\boldsymbol{q}) = \frac{A(\boldsymbol{q})}{B(\boldsymbol{q})}$

here $A(\boldsymbol{q})$ is the pair distribution in momentum difference $\boldsymbol{q} = \boldsymbol{p_1} - \boldsymbol{p_2}$ for pairs of particles from the same event and $B(\boldsymbol{q})$ is the corresponding distribution for pairs of particles from different events



Approximation of the correlation function

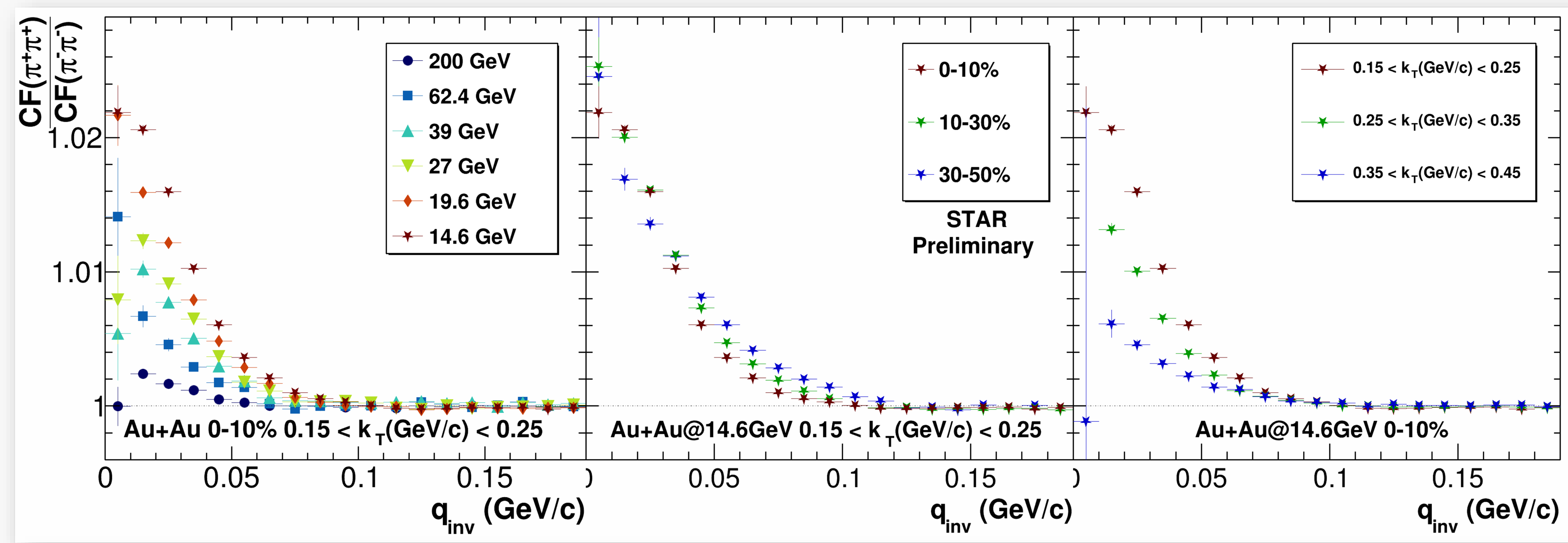
$C(q) = N(1-\lambda) + NK(q)\lambda exp\left[-\sum_{i,j=o,s,l}(q_i q_j R_{ij}^2)^{\alpha/2}\right]$

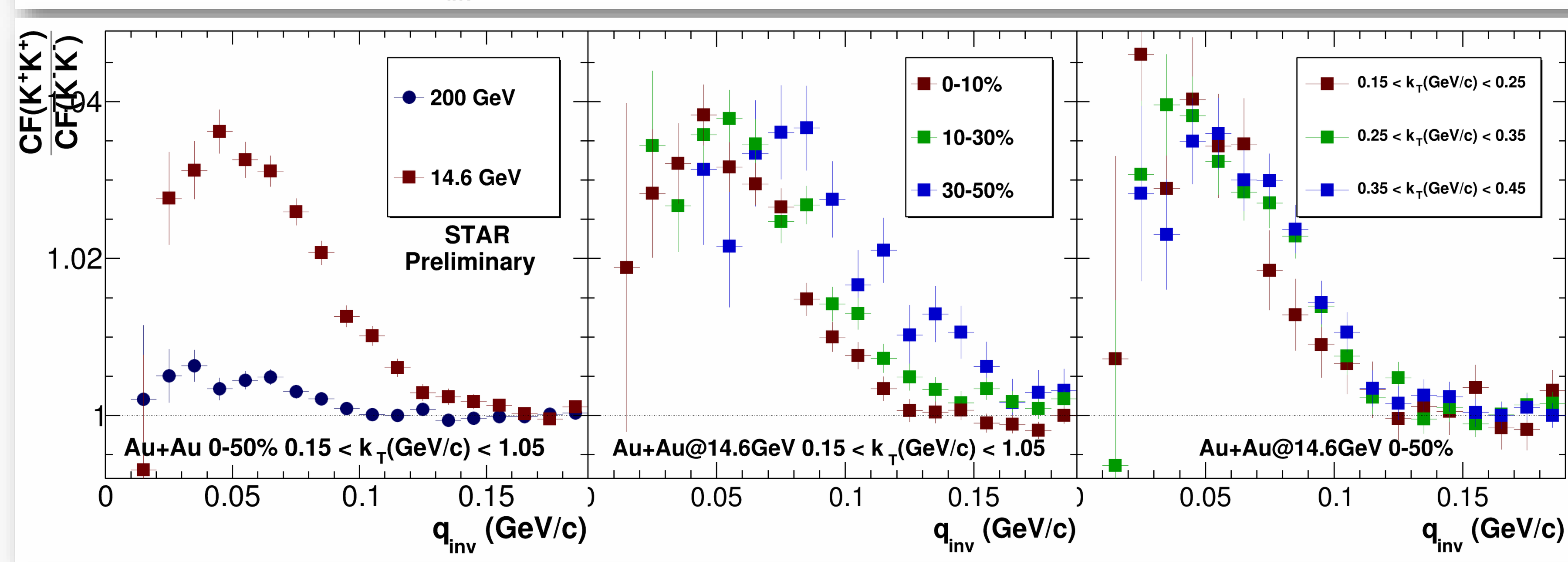
N is the normalization factor, λ characterizes the correlation strength, $K(q)$ accounts for Coulomb effect, $\alpha = 2$ – Gaussian (standard approach in femtoscopy) or free parameter in "Levy-stable source" approach

$$k_T = \frac{|\boldsymbol{p_{T,1}} + \boldsymbol{p_{T,1}}|}{2}$$

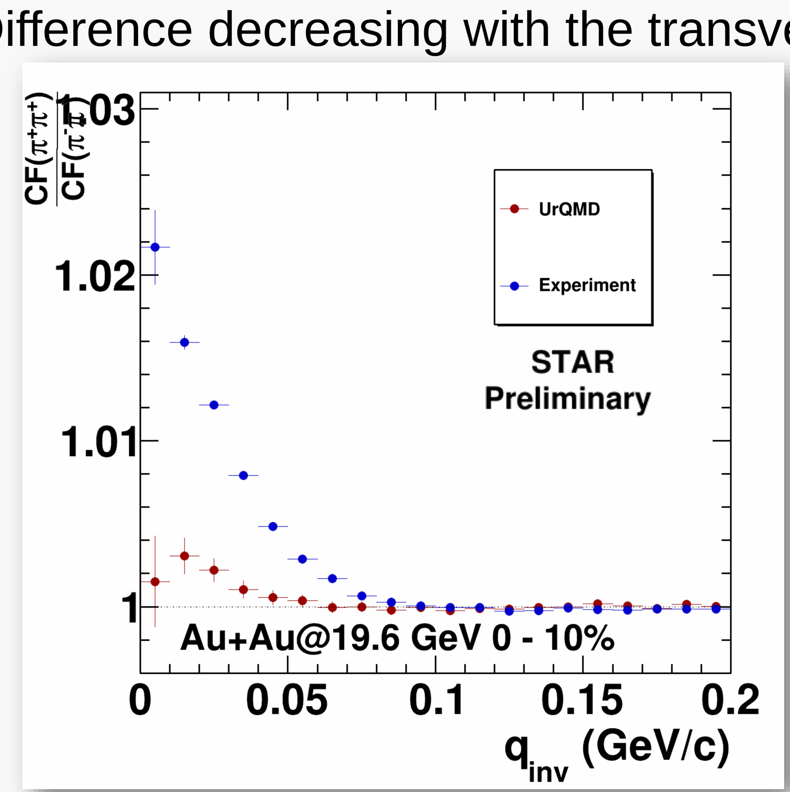
- Correlation for charged kaon pairs is smaller than those for pions
- Coulomb effect for kaons is stronger than for pions

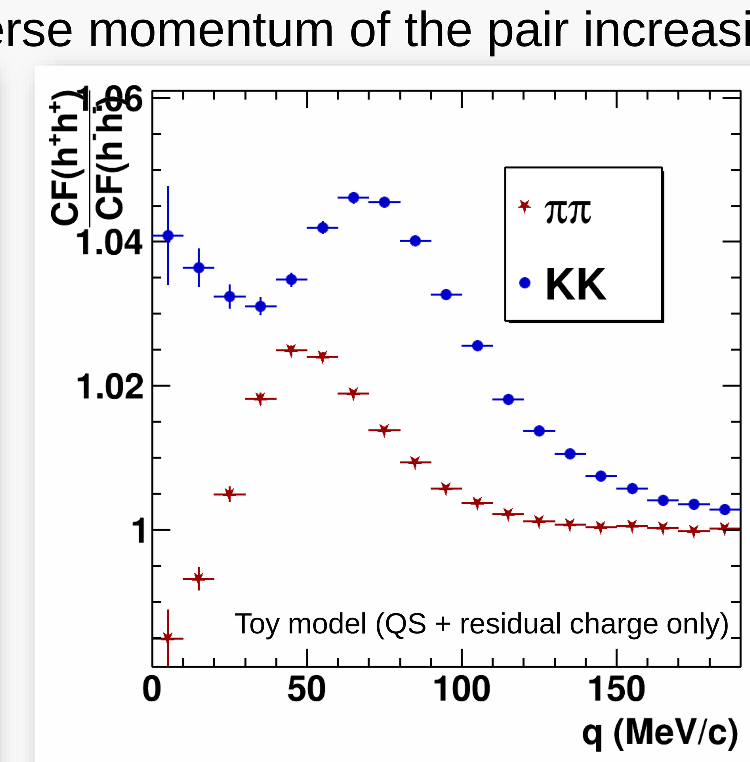
Charge-dependent correlations





- One dimensional analysis revealed difference between correlations of positive and negative pion and kaon pairs
- Difference increases with the energy decreasing
- Difference decreasing with the transverse momentum of the pair increasing

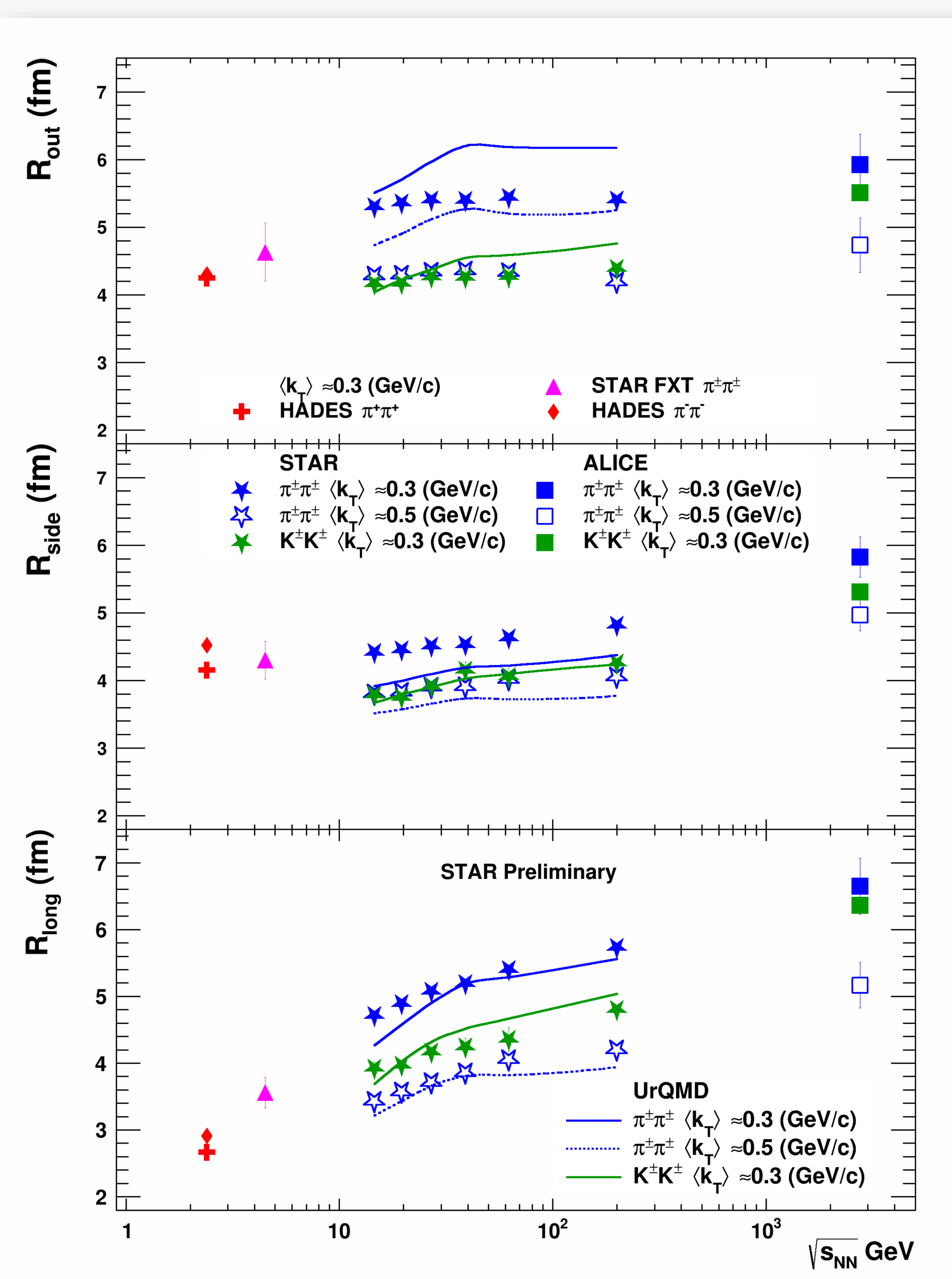


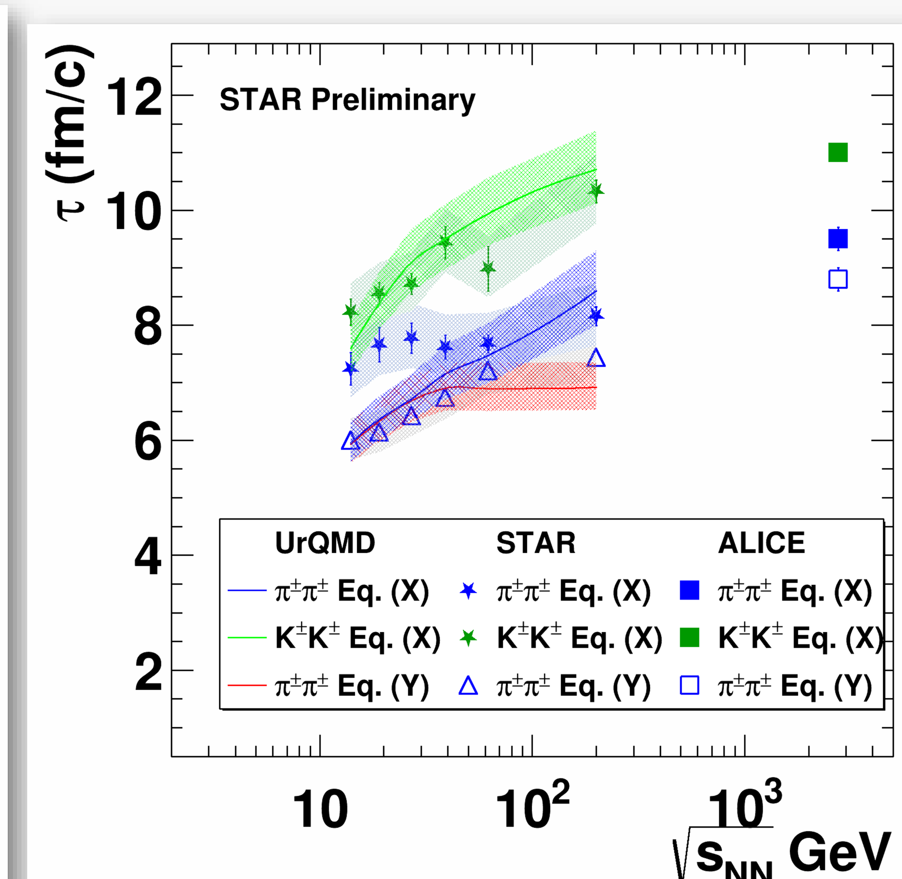


Positive pairs having bigger correlations over the negative pairs reproduced by:

- Hadronic final state effects (UrQMD)
- Coulomb effect from residual source (Toy model)

Extracted parameters





$$\text{Eq. (X)} \quad R^2_{long} = \tau^2_{max}\frac{T_{max}}{m_T \cosh y_T}\left(1+\frac{3T_{max}}{2m_T \cosh y_T}\right)$$

$$\text{Eq. (Y)} \quad R_{long} = \tau\sqrt{\frac{T}{m_T}\frac{K_2(m_T/T)}{K_1(m_T/T)}}$$

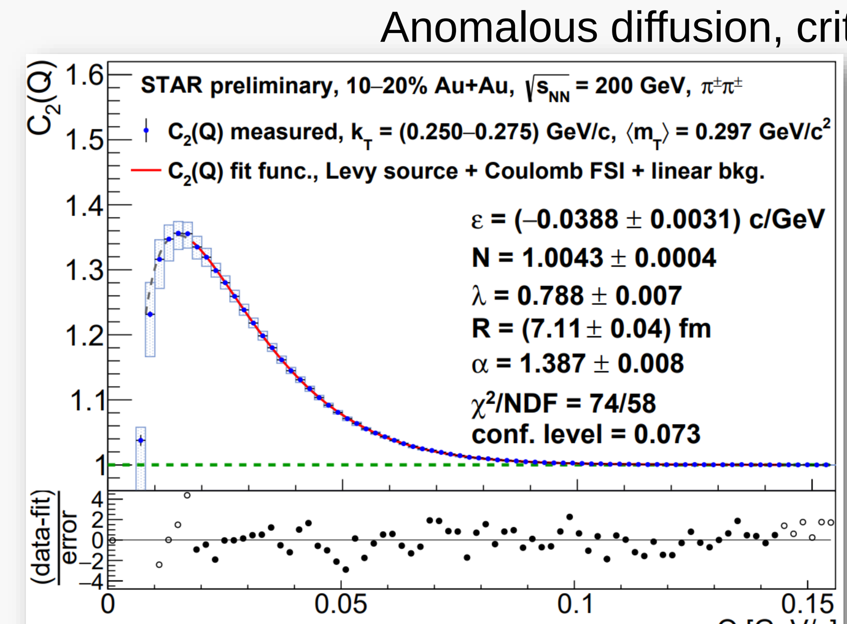
The three-dimensional femtoscopic analysis reveals

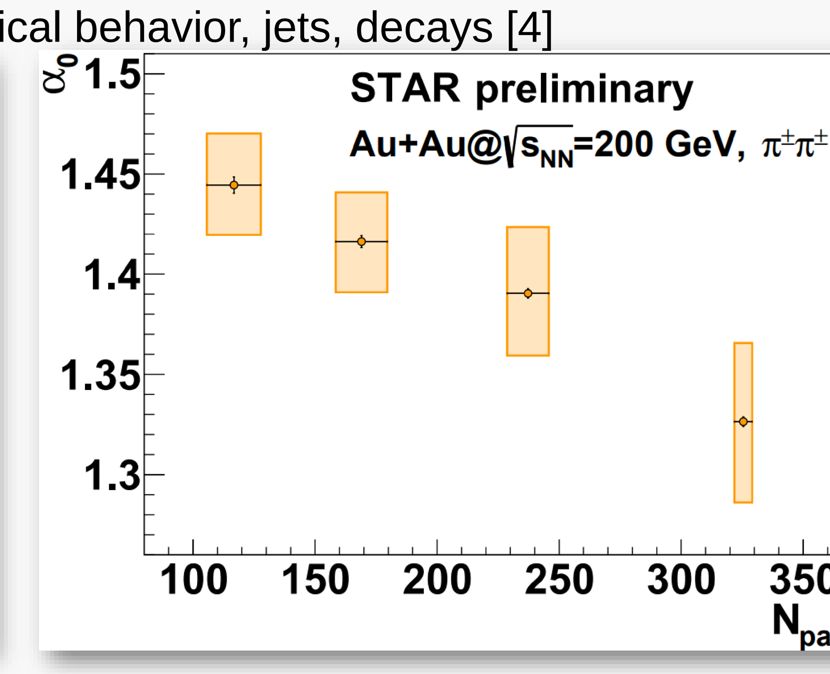
- Extracted radii increase with collision energy
- Decrease with transverse mass
- Are generally larger for kaons compared to pions under the same conditions
- UrQMD in good qualitative agreement with the data

- The time of emission of kaons from the source is longer than the time of emission of pions
  - Influence of resonance (K*) decays [3]
- The emission time of both pions and kaons increases with increasing energy
- The UrQMD model is in agreement with the data

Levy-stable sources

Anomalous diffusion, critical behavior, jets, decays [4]





- Good description of the correlation function under the Levy-stable source assumption
- α decreasing with N_{part}

Summary

- Difference between correlation functions for positive and negative pairs of pions and kaons was noticed for the first time at these energies
  - Consistent with Coulomb field effect due to residual charge after the collision and hadronic final state effects, as implemented in UrQMD

Extracted radii

- Increase with collision energy
- Decrease with transverse mass
- Are generally larger for kaons compared to pions under the same condition
- UrQMD can describe data qualitatively

Levy-stable source

- Source is not strictly Gaussian: $\alpha = 1.3 - 1.5$, decreasing with N_{part}

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The STAR Collaboration
https://drupal.star.bnl.gov/STAR/presentations

References
[1] Phys.Lett.B 356 (1995) 525-530
[2] Ann.Rev.Nucl.Part.Sci. 55 (2005) 357-402
[3] Nucl. Phys. A929 (2014) 1–8
[4] Phys.Rev.C 97 (2018) 6, 064911