Femtoscopic Measurements of Charged Kaons in Au+Au Collisions at STAR FXT energies

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2. Femtoscopy and STAR detectors
3. Analysis Details
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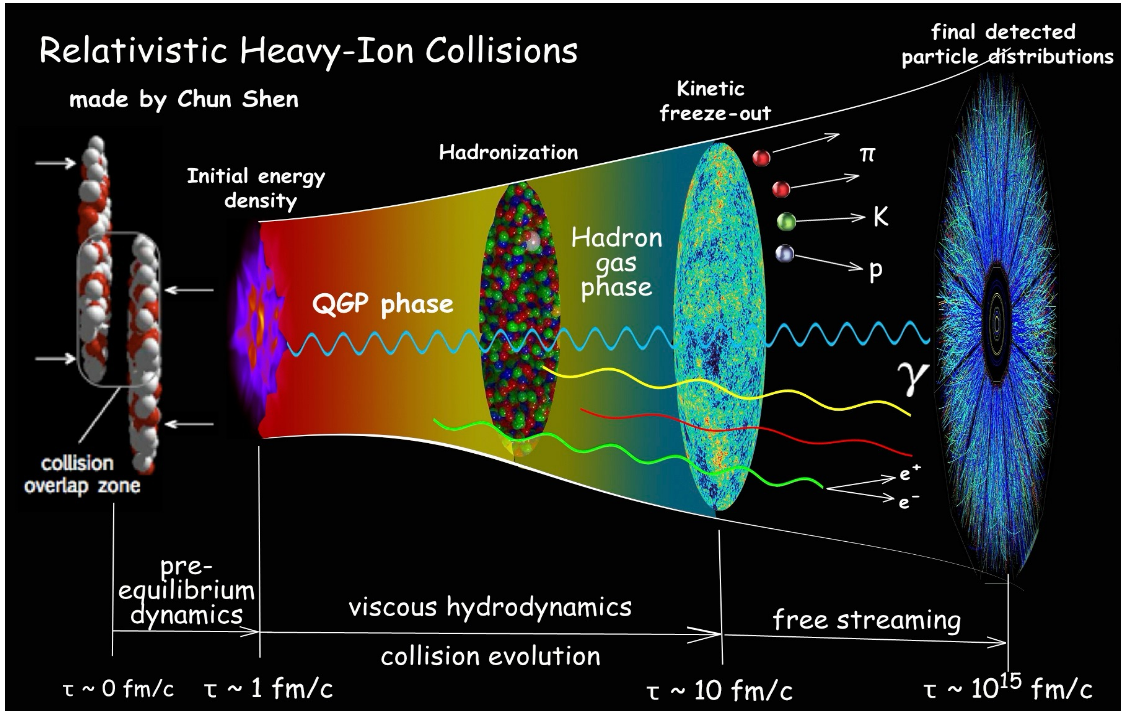
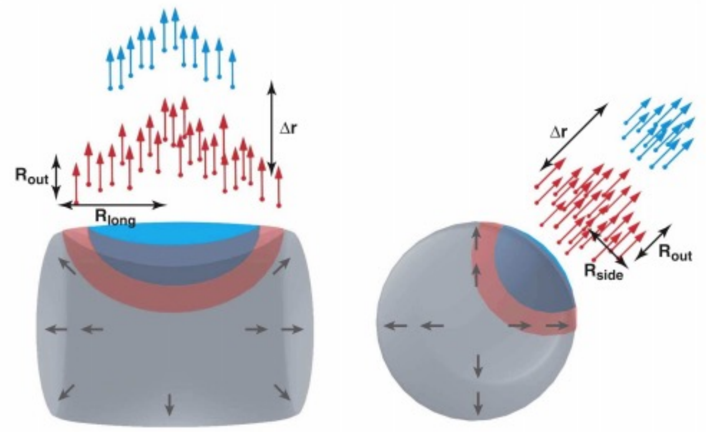
Motivation

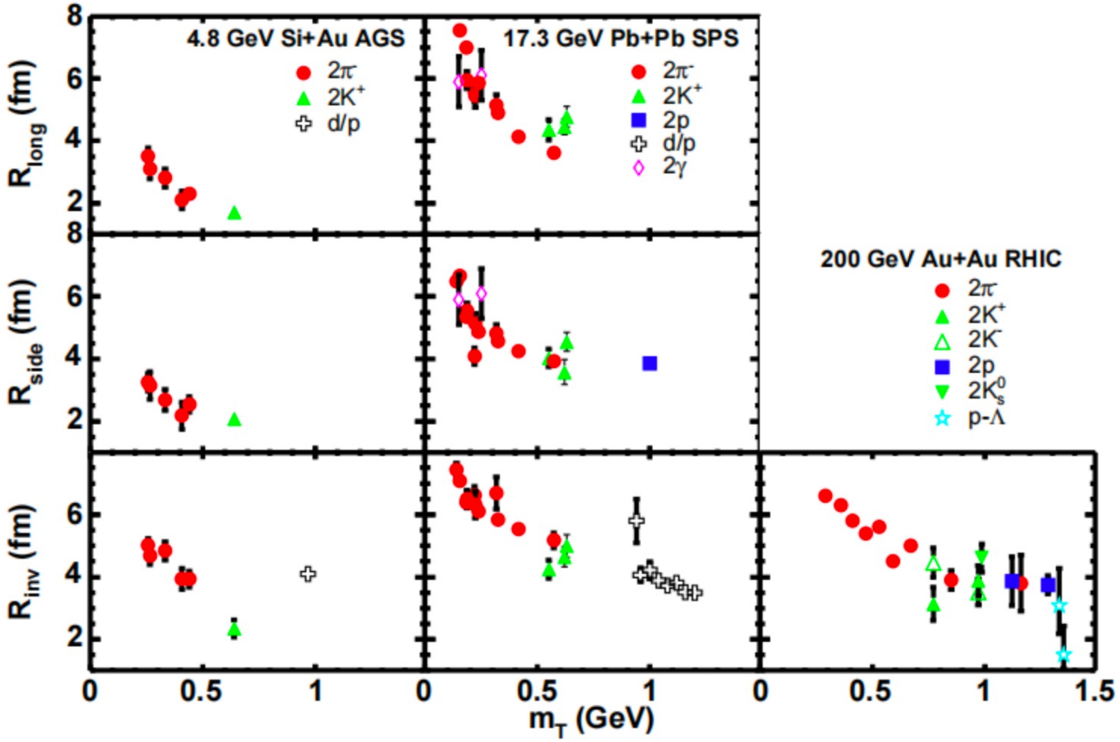


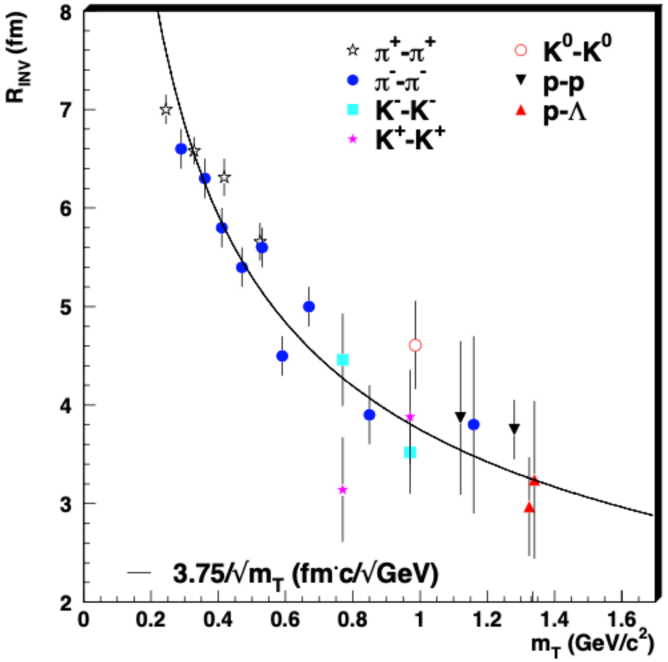
https://u.osu.edu/vishnu/2014/08/06/sketch-of-relativistic-heavy-ion-collisions/

- **Decode space and time evolution of source at kinetic freeze-out.**
- **Why study kaons?**
  1) less contribution from resonances decay
  2) smaller rescattering cross-section
- **Two-particle correlations are sensitive to:**
  1) Quantum Statistics (QS);
  2) Final State Interactions (FSI)



Motivation - m_T-scaling





❖ **High-energy collisions (200 GeV) show universal m_T-scaling of source radii across particle species, consistent with collective hydrodynamic expansion.**

❖ **Does the universal m_T-scaling of source radii survive at lower collision energies?**

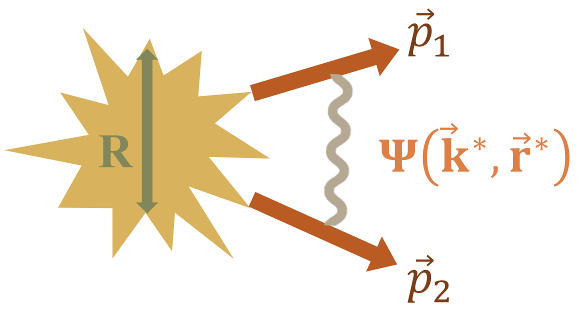
M.A. Lisa, S. Pratt, R. Soltz, and U. Wiedemann. Ann. Rev. Nucl. Part. Sci. 10.55:311, 2005

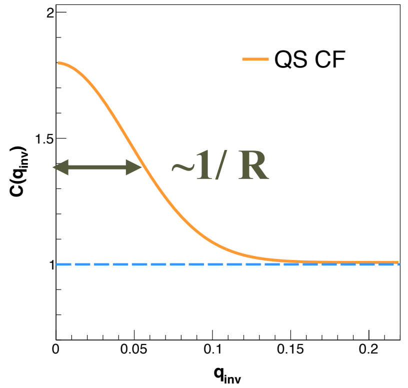
Femtoscopy

$$C(q_{inv}) = \int S(\vec{r}^*)|\Psi(q_{inv}, \vec{r}^*)|^2 d^3\vec{r}^* = \mathcal{N}\frac{N_{same}(q_{inv})}{N_{mixed}(q_{inv})}$$

Assumed Determined Measured

❖ If we assume that we know the **emission function**, the **measured correlation function** can be used to determine **parameters of final state interactions**.





$\vec{r}^*$: relative distance of the emitters in the Pair Rest Frame (PRF: in which frame the total momentum of the pair is zero)

$S(\vec{r}^*)$: emission function

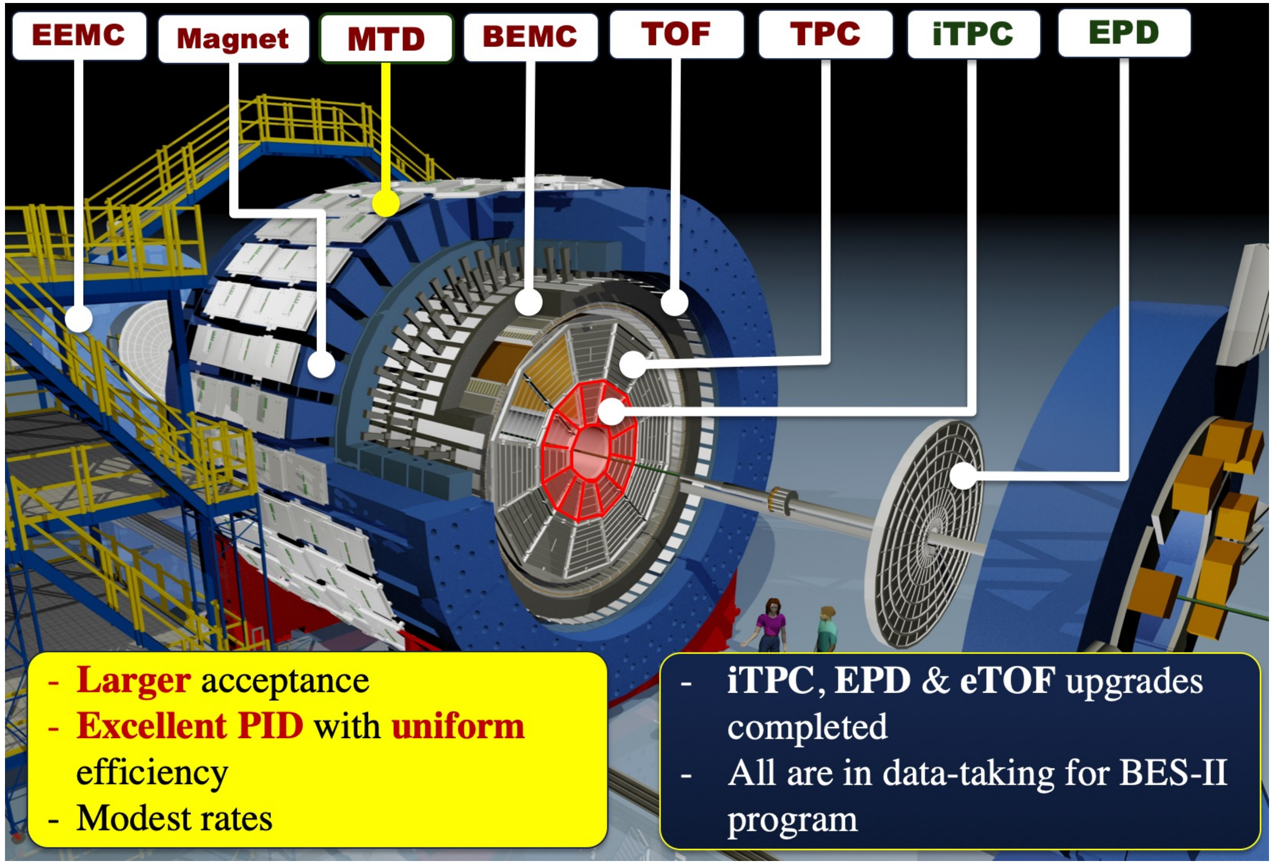
q_{inv}: relative invariant momentum in PRF

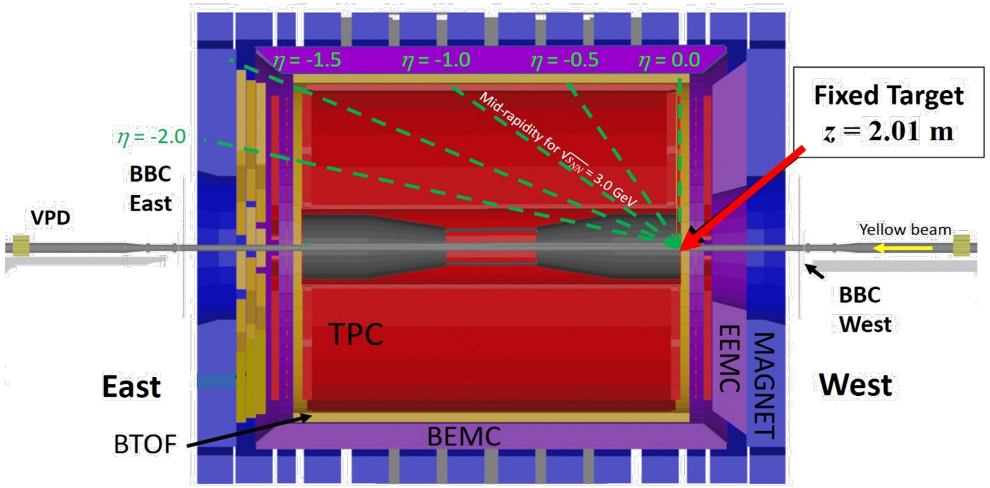
$\Psi(q_{inv}, \vec{r}^*)$: two-particle wave function

$\mathcal{N}\frac{N_{same}(q_{inv})}{N_{mixed}(q_{inv})}$: measured correlation function

[1] Phys. Lett. B, 432(3-4), 248-257 (1998)

STAR Experimental Setup





Main sub-detectors for PID

- Time Projection Chamber (TPC): Ionization energy loss (dE/dx)
- Time of Flight (TOF): m^2

BES-II Upgrades

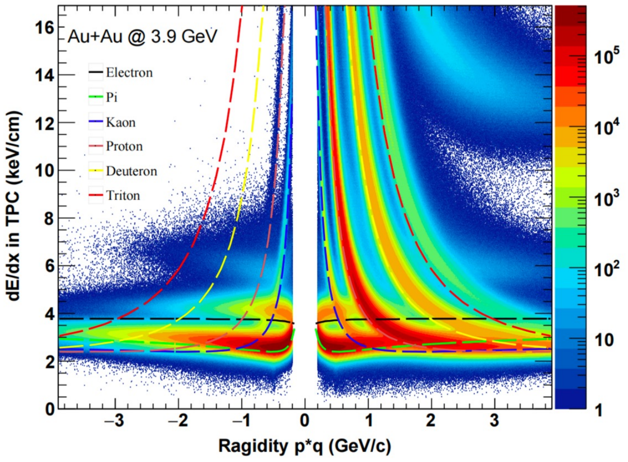
- Inner-Time Projection Chamber (iTPC)
  Extended eta acceptance and improved tracking and dE/dx resolution
- Endcap Time of Flight (eTOF)
  Extended PID coverage
- Event Plane Detector (EPD)
  Improved Event plane resolution

Fixed-Target Experiment

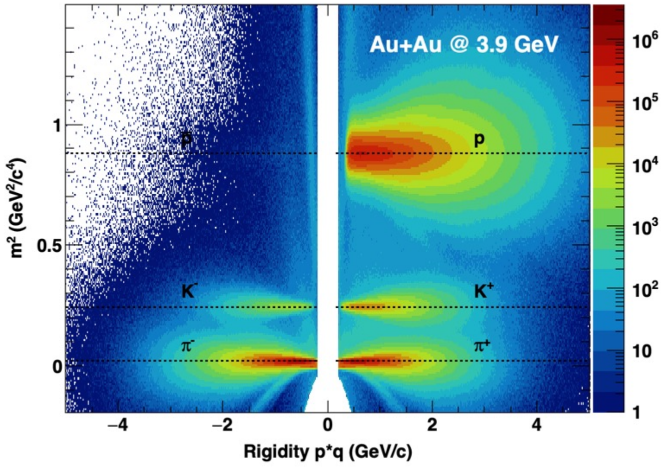
- FXT extends energy reach down to 3 GeV (μ_B = 750 MeV)

Analysis details – PID

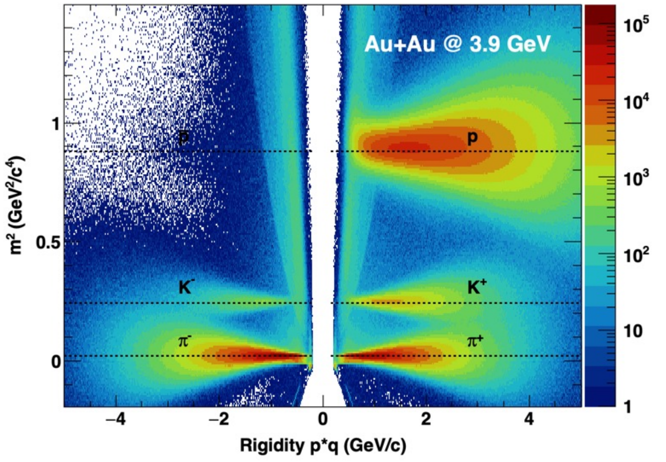
TPC

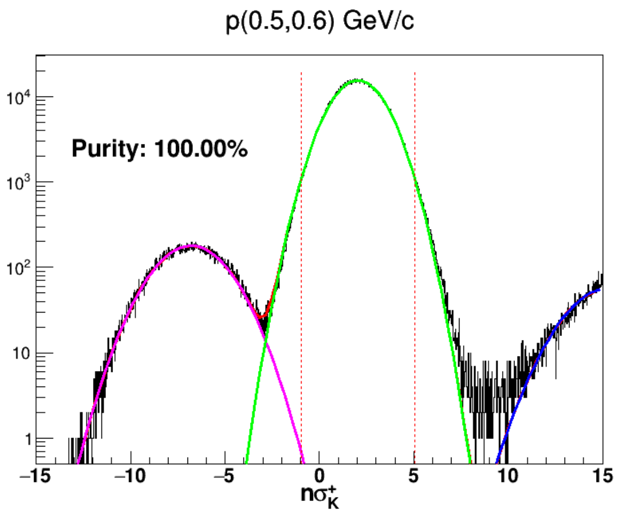


bToF



eToF





Fit function: Tri-Gaussian
K^+ fit function: $Gaussian_{green}$

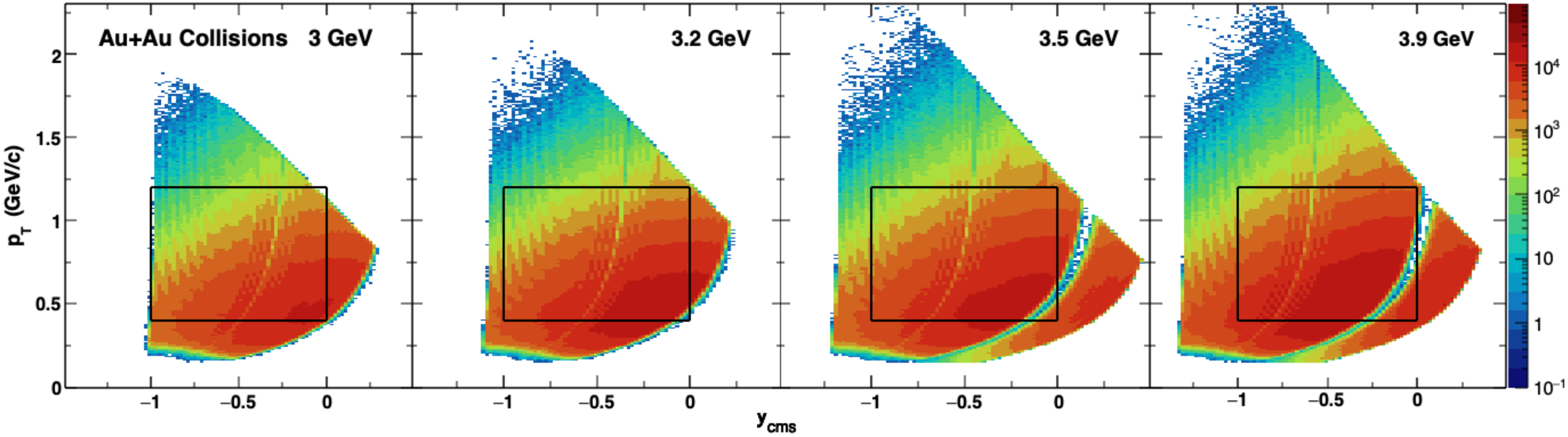
Integral range: (μ-3, μ+3)

For p (0.2, 2) GeV/c, Purity > 95%

- K^+ are identified by TPC and ToF
- Good particle identification capability

Take 3.2 GeV as an example

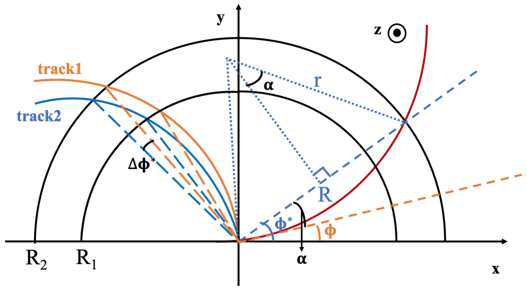
Analysis details – Acceptance

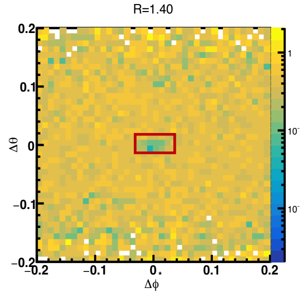


- Analysis window: p_T(0.4, 1.2) GeV/c; y(-1.0, 0.0)
- Good coverage from beam-rapidity to mid-rapidity within eToF

Analysis details – Corrections

$|\Delta\theta| > 0.02 \ || \ |\Delta\phi^*(R = 1.4m)| > 0.05$



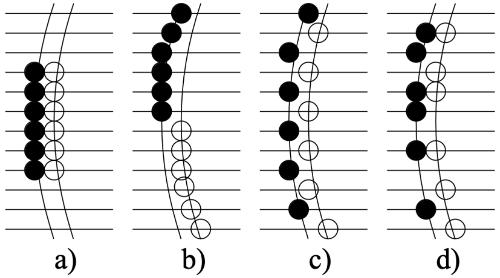


-0.5 < SL < 0.6

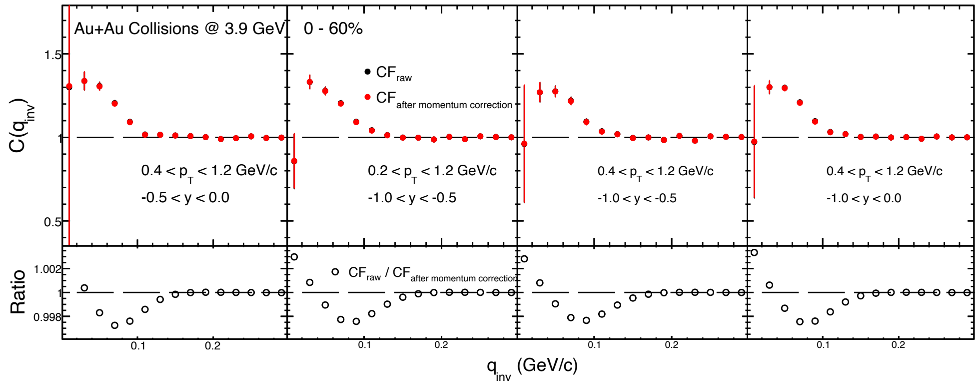
$$\text{Splitting Level (SL)} \equiv \frac{\sum_i S_i}{Nhits_1 + Nhits_2}$$ [1]

S_i = +1: one hit; S_i = -1: two hits; S_i = 0: no hit

Raw CF → **Track splitting** → **Track merging** → **Momentum smearing correction** → **K^+K^+ CF**



SL = -0.5 SL = 1 SL = 1 SL = 0.25

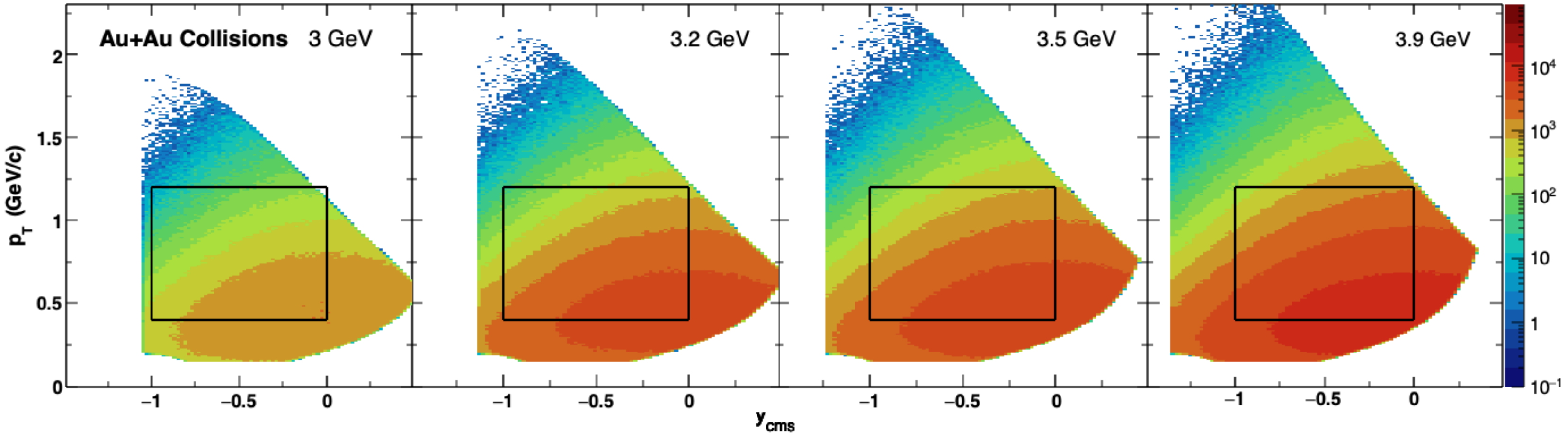


[1] arXiv:nul-ex/0411036

UrQMD Simulation

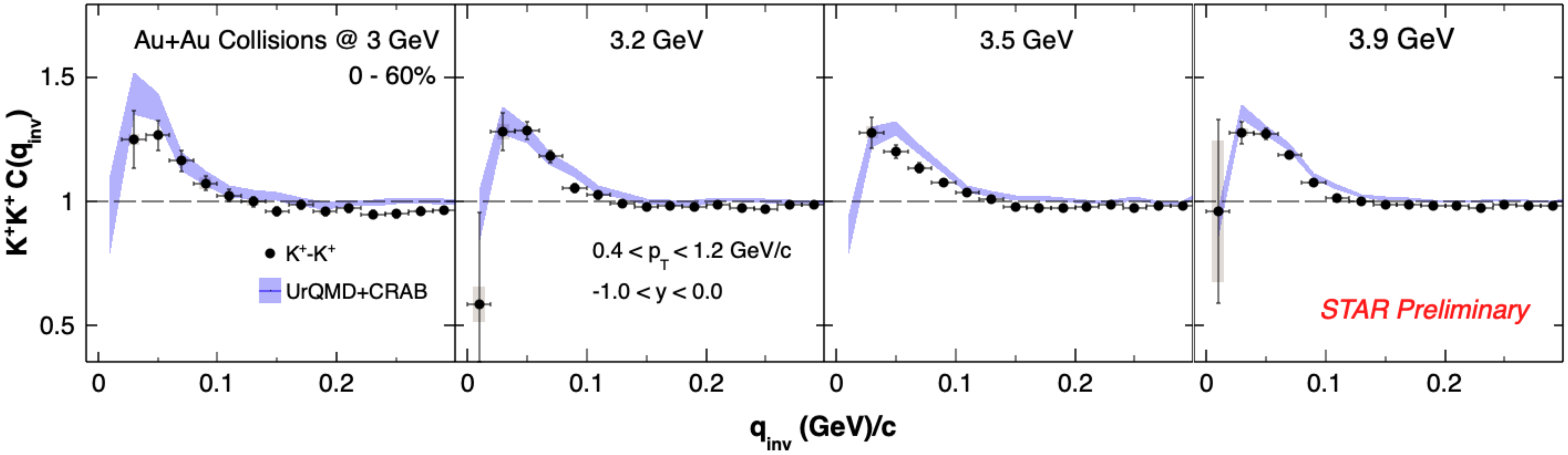
Simulation in UrQMD = Phase space from UrQMD + **FSI** from *Correlation After Burner* (CRAB) for correlations between pair:
- Quantum statistics effects;
- Coulomb interaction.

Acceptance in UrQMD



❖ The same acceptance as the experimental data

Results - Correlation Functions



- ❖ K^+K^+ CF show suppression at very low q_{inv} (Coulomb-dominated), and enhancement at intermediate q_{inv} (Bose-Einstein dominated);
- ❖ UrQMD+Crab consistent well with data.

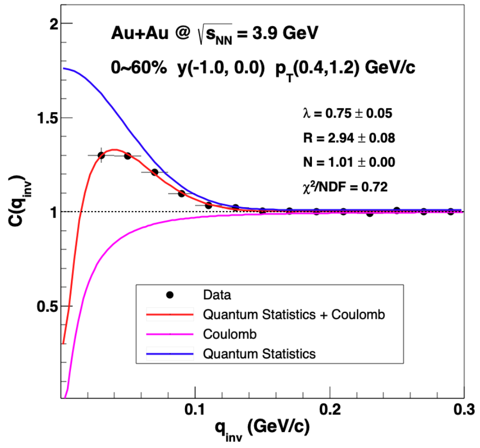
Parametrization

❖ CF including only Quantum Statistical (QS) effect:

$$C^{(0)}(q_{inv}) = N(1 + \lambda e^{-R_G^2 q_{inv}^2})$$

❖ Bowler-Sinyukov[1][2] method to **include Coulomb effect**:

$$C(q_{inv}) = N[(1-\lambda) + \lambda K_{coul}(q_{inv}, R_G)\left(1 + e^{-R_G^2 q_{inv}^2}\right)]$$

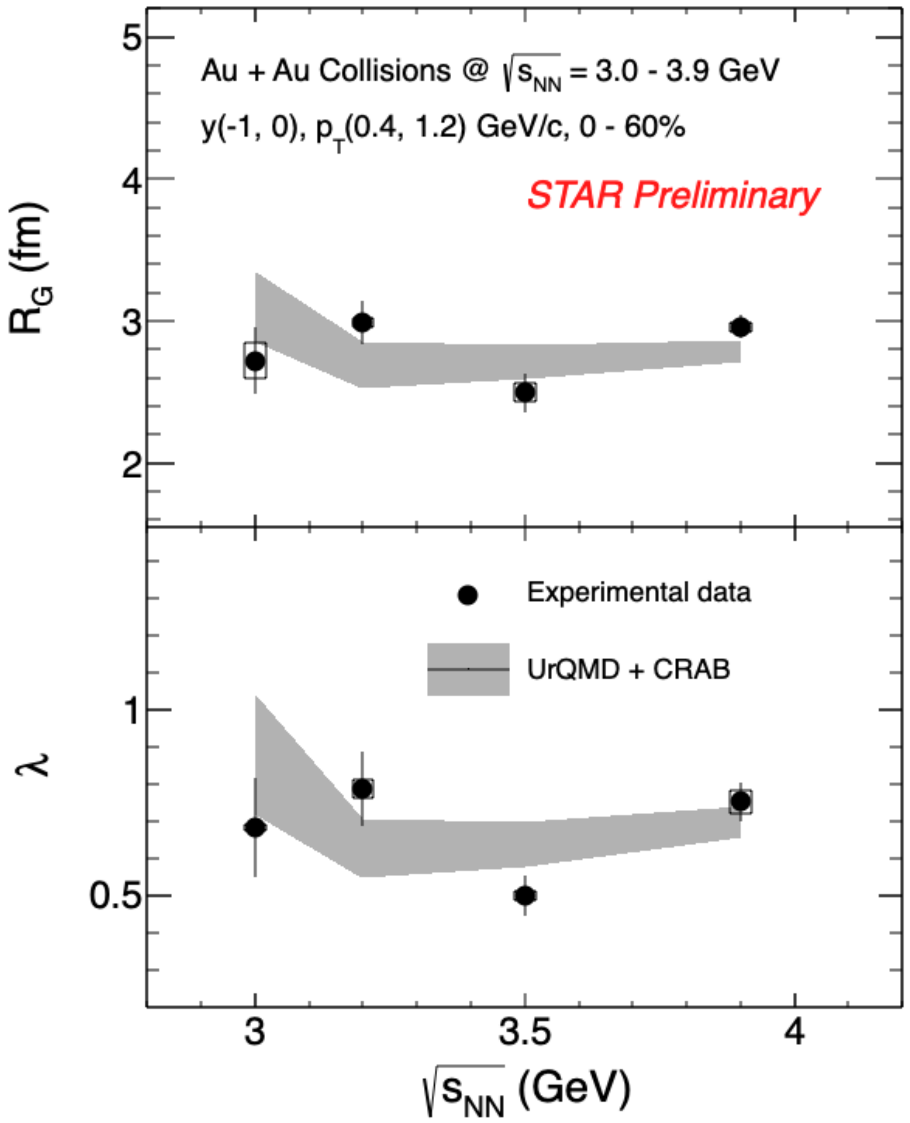


Fitting example

- **λ** – correlation strength; $\boldsymbol{R_G}$ - source radii
- Source function: $S(r) = \frac{\lambda}{(4\pi R_G^3)^{3/2}} e^{-\frac{r^2}{4R_G^2}}$ (Gaussian approximation)
- Coulomb factor: $K_{coul}(q_{inv}, R_G) = \int d^3r S(r) |\psi_{coul}(q_{inv}, r)|^2$ (calculated by Correlation Analysis Tools using the Schrödinger equation (CATS))
- Coulomb wave function: $\psi_{coul}(\vec{r}) = \Gamma(1+i\eta) e^{-\frac{1}{2}\pi\eta} e^{\frac{i}{2}\vec{q}\vec{r}} F\left(-i\eta;\ 1;\ \frac{1}{2}(qr - \vec{q}\vec{r})\right)$, $\eta = \frac{\alpha\mu q_1 q_2}{k^*}$

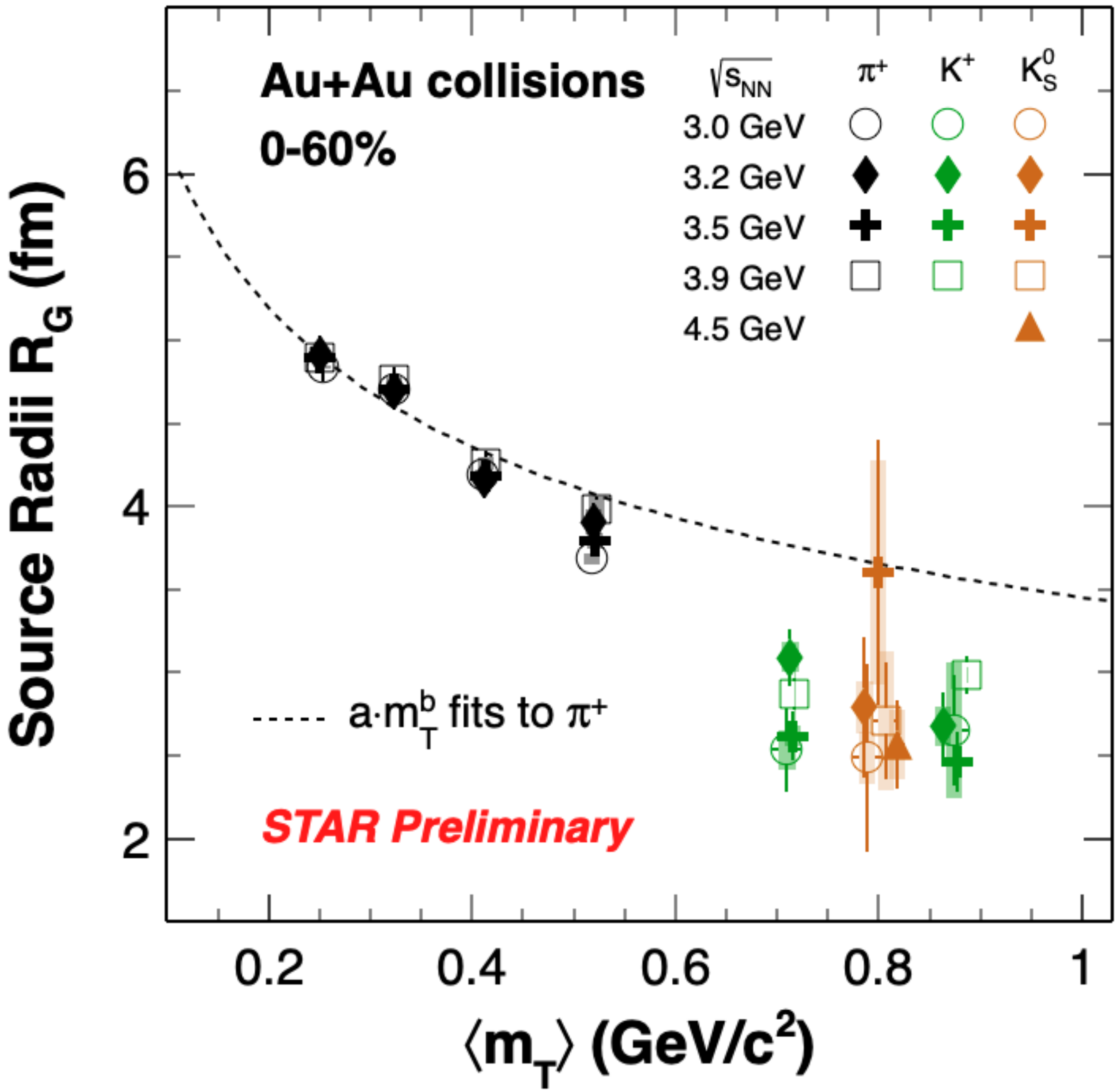
[1] Phys. Lett. B, 432(3-4), 248-257 (1998)
[2] Phys. Lett. B 270, 69 (1991)

Results - Parameters



- ❖ No clear energy dependence for R_G and λ;
- ❖ Model consistent with data

m_T-scaling between kaon & pion



- ❖ R_G of kaons smaller than that of pions;
- ❖ R_G of kaons do not follow m_T - scaling of pions', implying no equilibrium amongst pions and kaons at high baryon density.

Summary and Outlook

Summary:

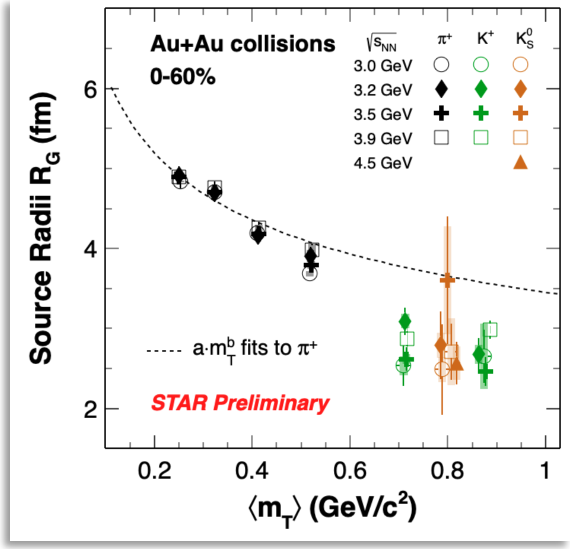
❖ First measurement of kaon femtoscopy at high baryon density

❖ For $\sqrt{s_{NN}}$ = 3.0 – 3.9 GeV:

1) No clear energy dependence of R_G and λ

2) UrQMD+Crab describe well with data

3) R_G of kaons do not follow m_T - scaling of pion's, implying no equilibrium amongst pions and kaons



Outlook:

❖ Analysis on 3D femtoscopy using run21 3GeV data