Partially funded by

Two-Pion Femtoscopic Correlations in Au+Au Collisions at $\sqrt{s_{NN}} = 3$ GeV from STAR

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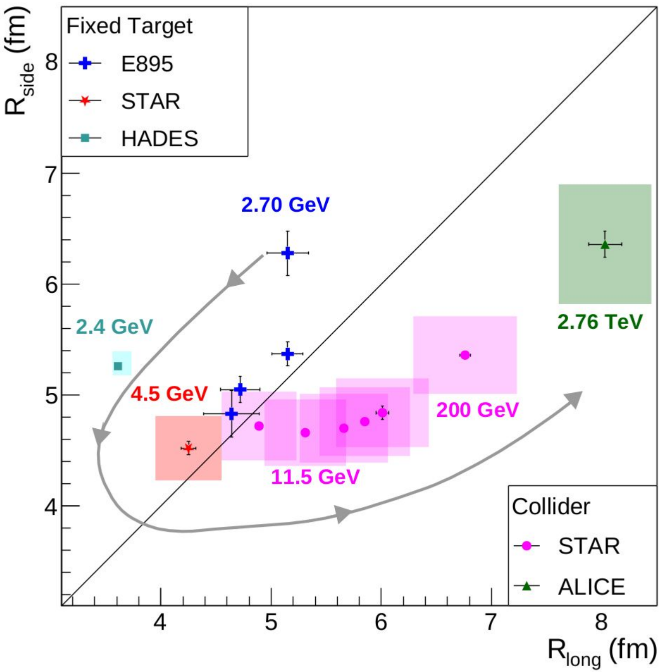
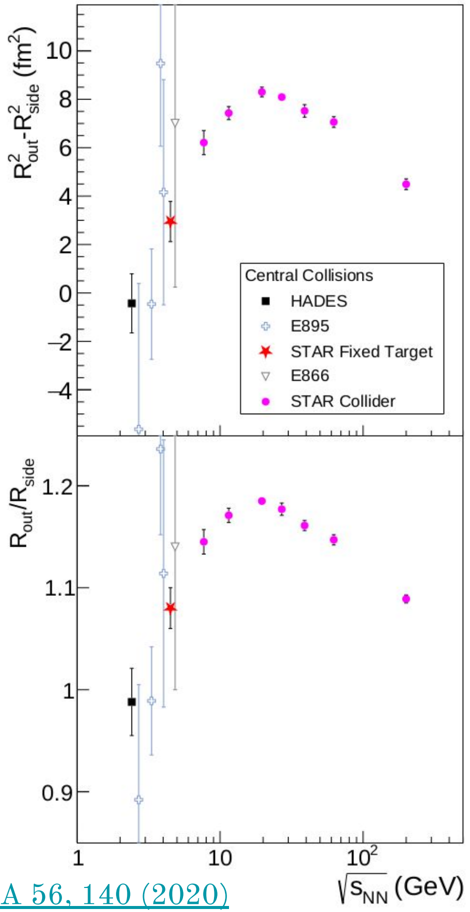
Motivation:

- The correlation femtoscopy technique can reveal the structure of homogeneity region
- The energy dependence of source size may reveal fundamental insights into the equation of state of strongly-interacting matter
- Measurements of the emission region characteristics not only at midrapidity, but also at the backward (forward) rapidity can provide new information about the source and make it possible to impose constraints on the heavy-ion collision models

M. S. Abdallah et al. (STAR Collaboration) Phys. Rev. C 103, 2021



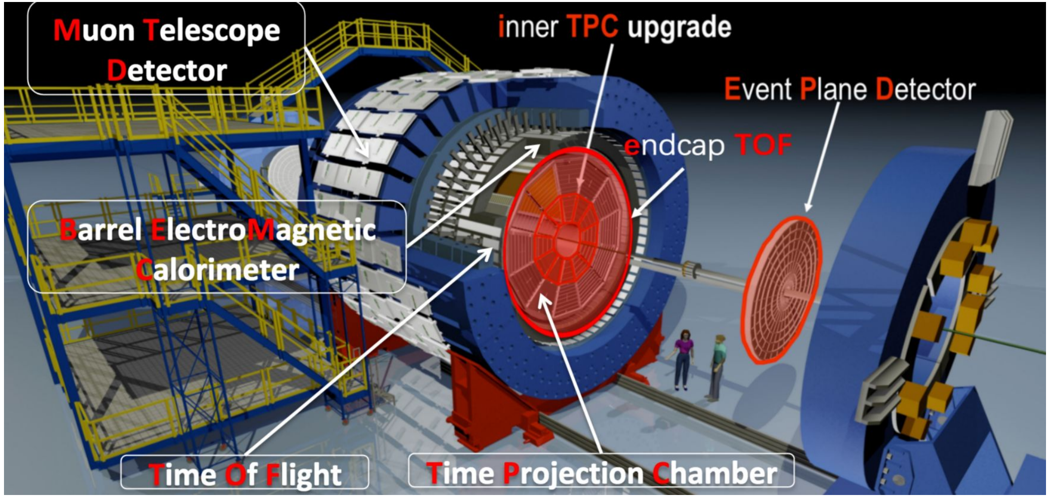


Experiments:
HADES: J. Adamczewski-Musch et al., Eur. Phys. J. A 56, 140 (2020)
ALICE: A. Aamodt et al., Phys. Lett. B 696, 328 (2011)
STAR: L. Adamczyk et al., Phys. Rev. C 92, 014904 (2015)
E895: M. A. Lisa et al., Phys. Rev. Lett. 84, 2798 (2000)

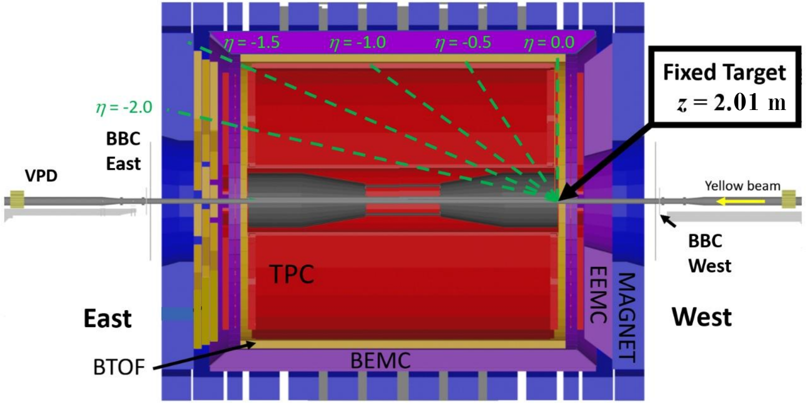
Goals:

- Estimation of spatial and temporal parameters of the particle-emittion region in Au+Au collisions at $\sqrt{s_{NN}} = 3$ GeV using the STAR data

The STAR Experiment

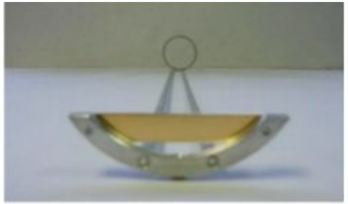


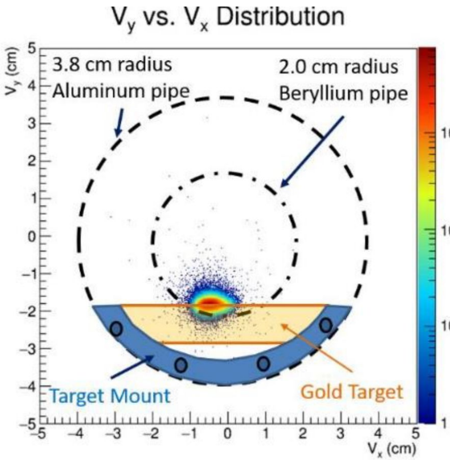
Fixed-target program



Fixed-target program:

- Gold target of thickness 1.93 g/cm^2 (0.25 mm)
- Located 200.7 cm from the center of the Time Projection Chamber (TPC)
- Gold beam of energy 3.85 GeV/n





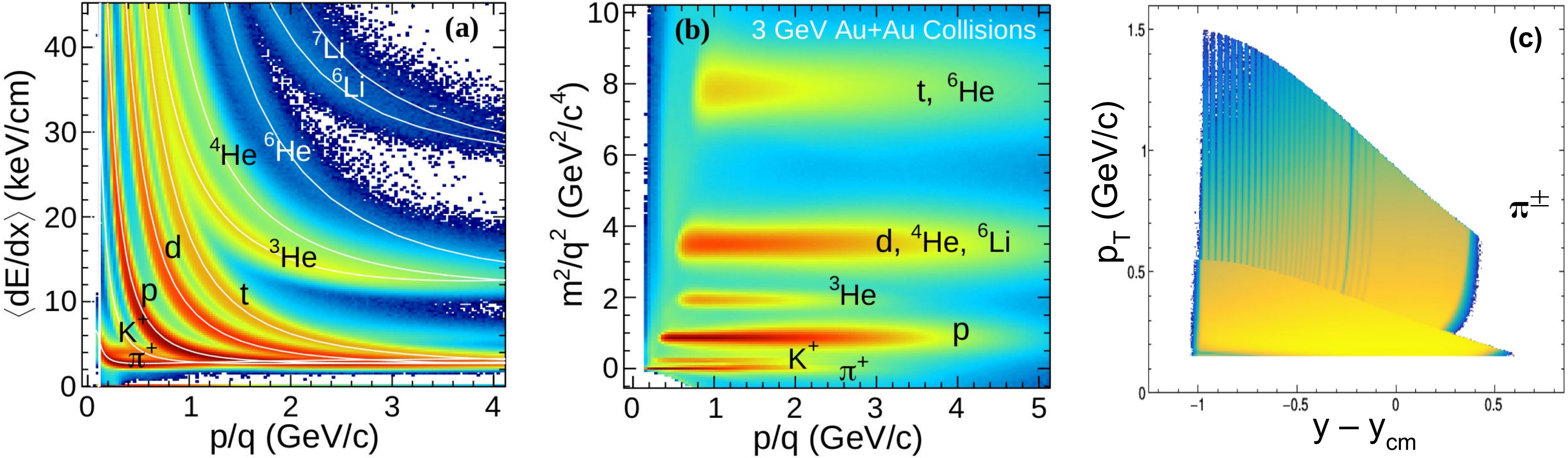
Datasets:

- **$\pi^{\pm}$**: $\sqrt{s_{NN}} = 3$ GeV FXT 2018
- **K^{+}, K^{0}_{s}**: $\sqrt{s_{NN}} = 3, 3.2, 3.5, 3.9$ GeV FXT 2018 – 2020

Tracks:

- $-2 < \eta < 0$ ($\pi^{\pm}$, K^{0}_{s}), $-1.85 < \eta < 0$ (K^{+})
- $0.15 < p_T < 1.5$ GeV/c ($\pi^{\pm}$),
  $0.2 < p_T < 1.8$ GeV/c (K^{0}_{s}),
  $0.2 < p < 2$ GeV/c (K^{+})

TPC PID TOF PID



$\pi^{\pm}$: $0.15 < p < 0.55$ GeV/c: TPC; $0.55 < p < 1.5$ GeV/c: TPC+TOF. Purity $> 98\%$

K^{+}: $0.2 < p < 2$ GeV/c: TPC+TOF. Purity $> 95\%$

K^{0}_{s}: $p < 1$ GeV/c: TPC; $p > 1$ GeV/c: TPC+TOF. K^{0}_{s} are reconstructed using invariant mass method

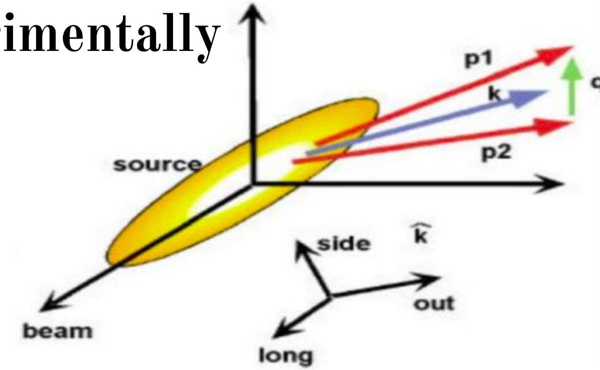
Measuring two-particle correlation function (CF) experimentally

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

$A(q)$ - formed using pairs where both tracks come from the same event. It contains correlations due to quantum-statistics (QS) and final state interactions (FSI, Coulomb dominated).

$B(q)$ - obtained via mixing technique, where the two tracks come from separate events. Femtoscopic correlations are absent

q - relative momentum

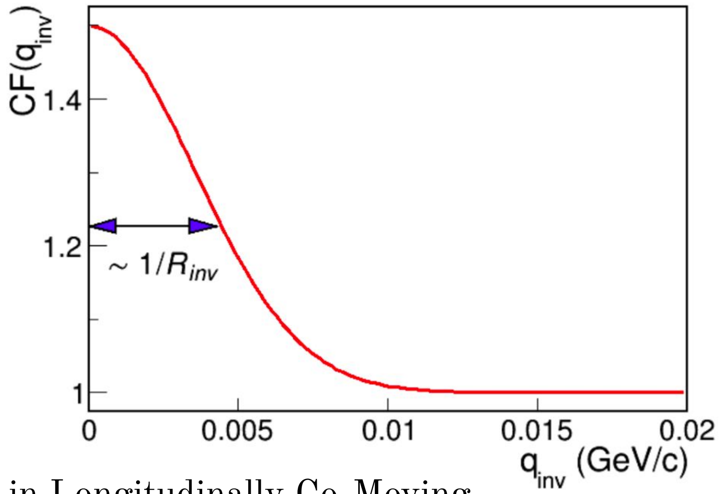


The relative pair momentum can be projected onto the Bertsch-Pratt, out-side-long system:

q_{long} - along the beam direction,

q_{out} - along the transverse momentum of the pair,

q_{side} - perpendicular to longitudinal and outward directions



S. Pratt, Phys. Rev. D 33 (1986) 1314

G. Bertsch, Phys. Rev. C 37 (1988) 1896

CF are constructed in Longitudinally Co-Moving System (LCMS), where $p_{1,z} + p_{2,z} = 0$

Femtoscopic radii are extracted by fitting C(q) with Bowler-Sinyukov:

$$C(q) = N[(1-\lambda) + \lambda K(q)(1+G(q))]$$, where

$$G(q) = \exp(-q_{out}^2 R_{out}^2 - q_{side}^2 R_{side}^2 - q_{long}^2 R_{long}^2 - 2q_o q_l R_{ol}^2)$$

N - normalization factor,

K(q) - Coulomb correction factor,

λ - correlation strength,

R_{side} ~ geometrical size of the particle emission source,

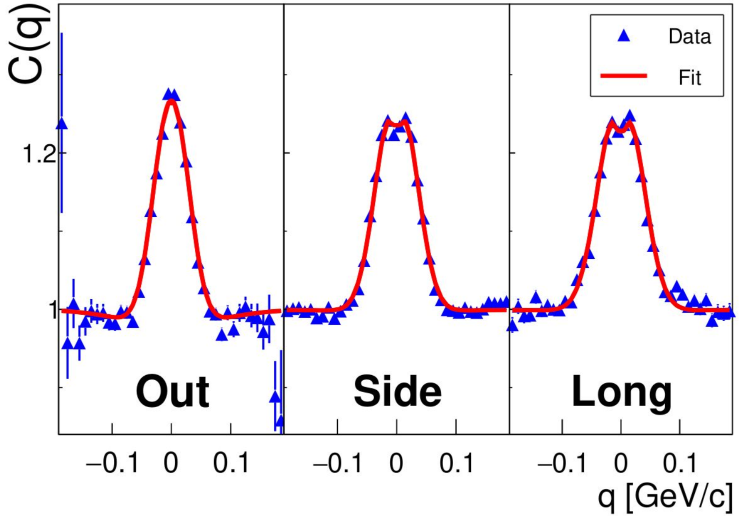
R_{out} ~ geometrical size + particle-emitting duration

R_{long} ~ medium lifetime,

$R^2_{out\text{-}long}$ – tilt of the CF in the q_{out} — q_{long} plane, depending on the degree of asymmetry of the rapidity acceptance w.r.t. midrapidity.

Yu. Sinyukov et al. Phys. Lett. B 432 (1998) 248
M. Bowler Phys. Lett. B 270 (1991) 69

Fit example:

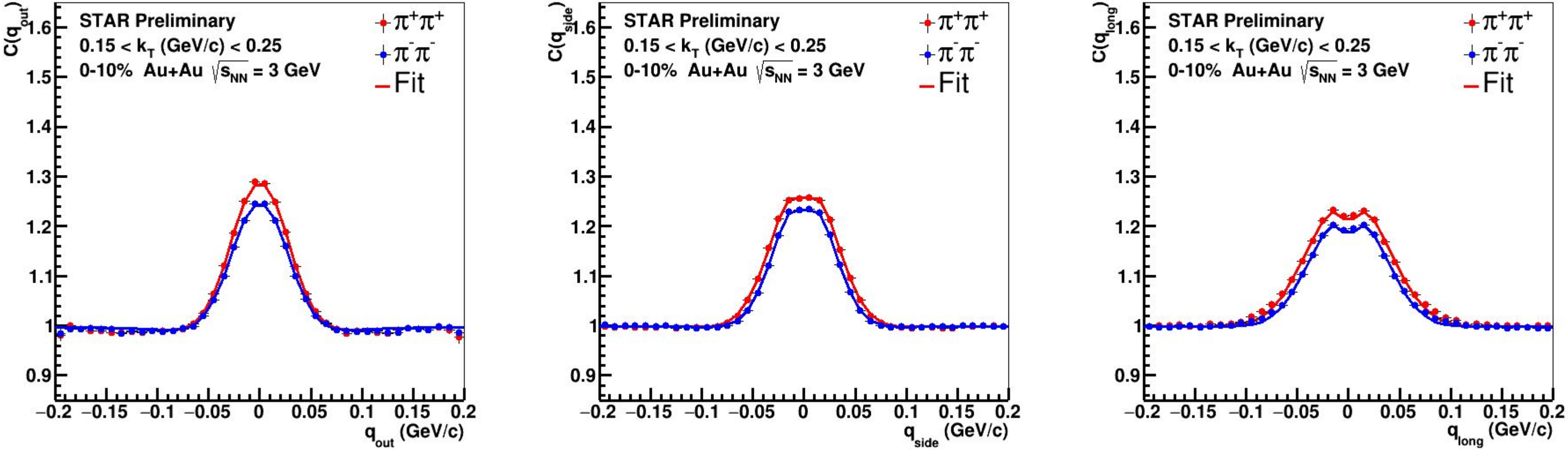


Fit using Log-likelihood method: Phys. Rev. C 66 (2002) 054906

$$\chi^2 = -2\left[A\, ln\left(\frac{C(A+B)}{A(C+1)}\right) + B\, ln\left(\frac{A+B}{B(C+1)}\right)\right], C = \frac{A}{B}$$

Correlation functions of positive and negative pions pairs at centrality 0-10% in range $0.15<k_T<0.25$ GeV/c of momentum

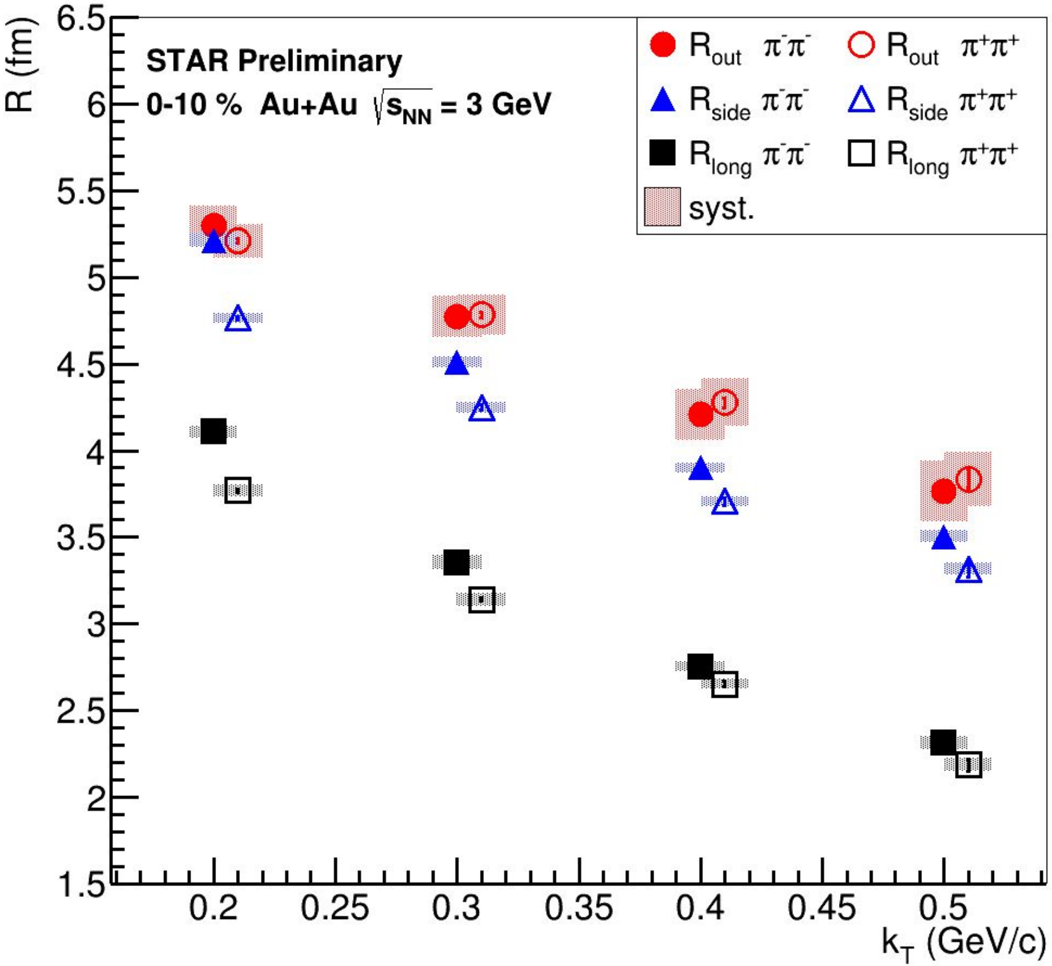
$$\vec{k}_T = (\vec{p}_{1,T} + \vec{p}_{2,T})/2$$



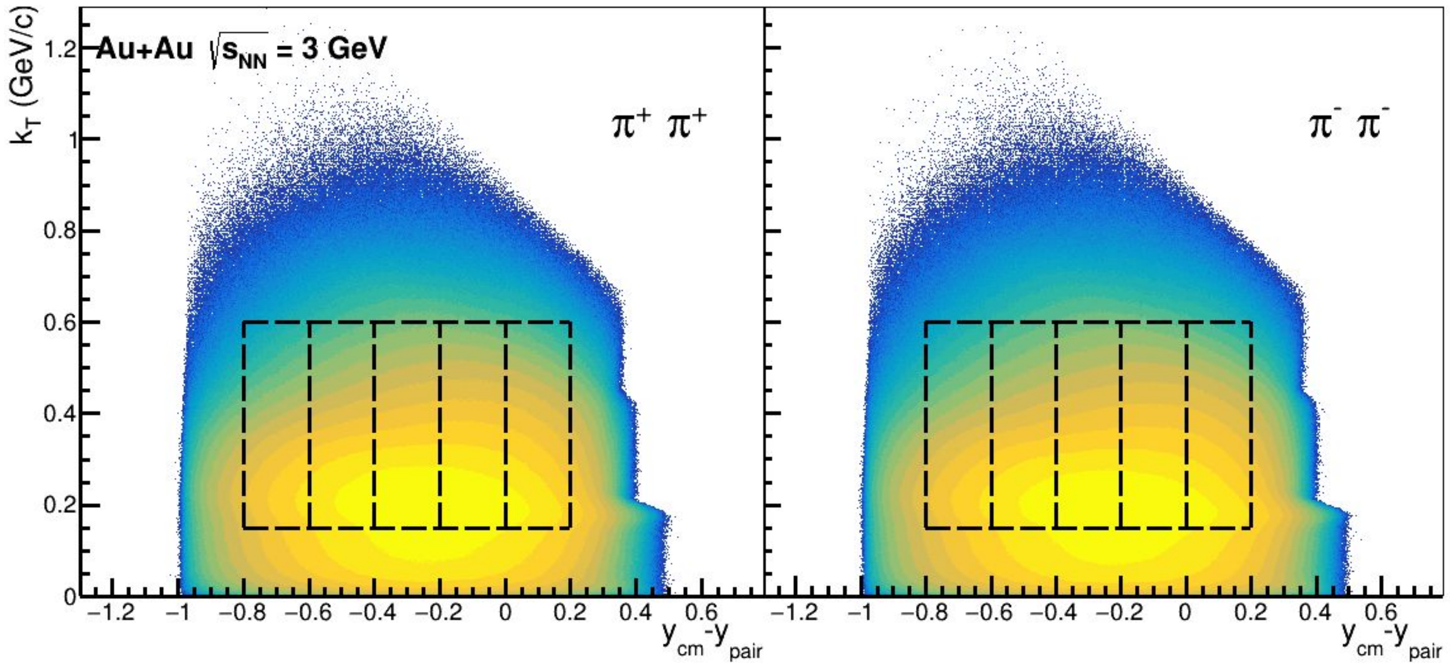
- The correlation functions of identical pions were constructed for all ranges in k_T
- Correlation functions of positive and negative pions differ slightly for small k_T, which may be due to residual electric charge
- Femtoscopic radii are extracted by fitting correlation function with Bowler-Sinyukov

Charged pion femtoscopic radii

- **The femtoscopic radii** of the emission region in the out, side and long projections for positive and negative pions **decrease with increasing transverse momentum of pairs** due to a decrease in the emission region of the system due to transverse flow
- Femtoscopic radii of positive and negative pions differ considerably for side and long projections

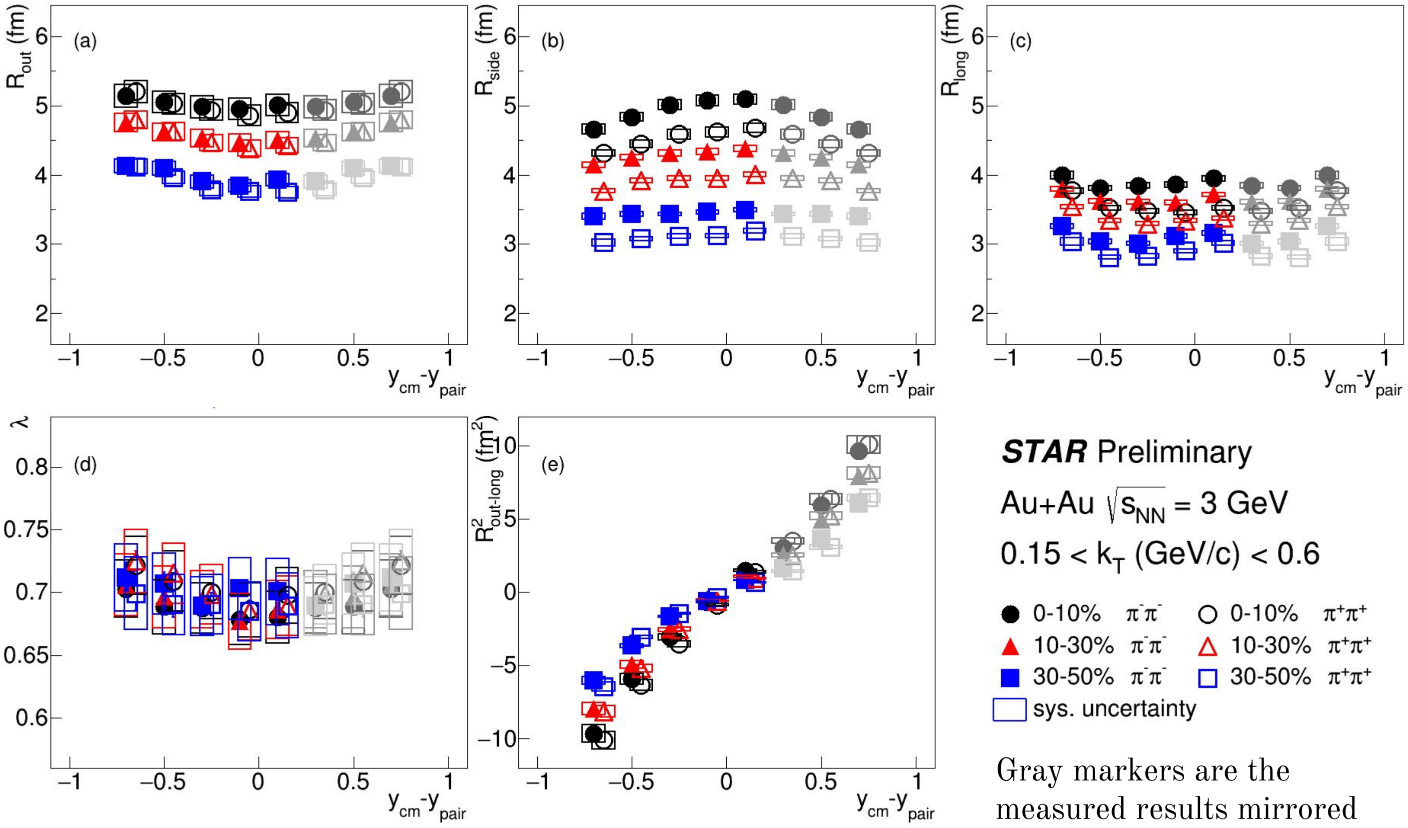


Rapidity analysis



Acceptance of positively (left panel) and negatively (right panel) charged pion pairs for Au+Au collisions at $\sqrt{s_{NN}} = 3$ GeV. Dashed lines denote the selected rapidity windows for the rapidity-differential analysis

Rapidity dependence of charged pion femtoscopic radii



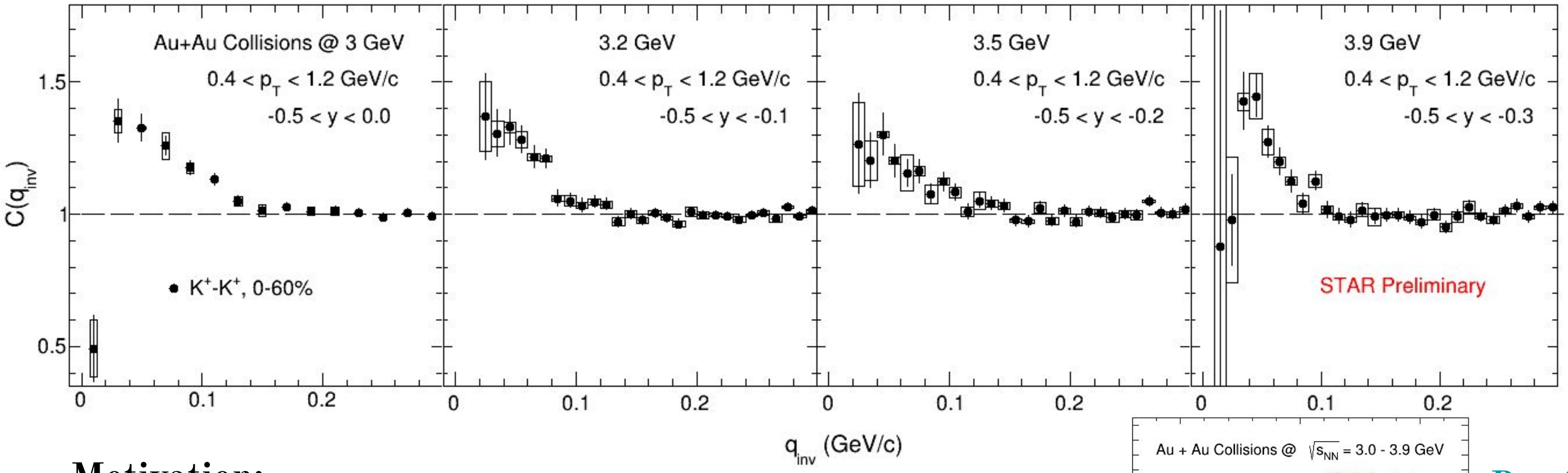
Gray markers are the measured results mirrored w.r.t. midrapidity (y_{cm}-y_{pair} = 0)

R_{side} decreases with going out of midrapidity:
➔ **Hints on boost-invariance breaking**

Clear rapidity dependence of $R^2_{out-long}$:
➔ **Asymmetric rapidity window in analysis, could give rise to non-zero values in rapidity integrated measurement**

R_{out}, R_{side} and R_{long} increase from peripheral to central collisions reflecting the geometry of the overlapping region.

K^+K^+ femtoscopic correlations



1D CF

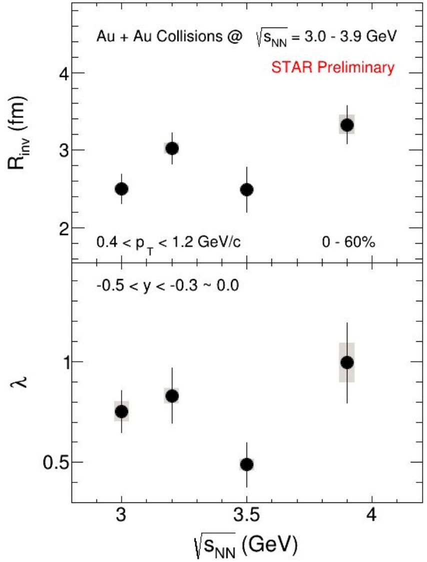
Motivation:

Kaons can provide more accurate information about the source of particle emission than pions due to

- ➔ less contribution from long lifetime resonances
- ➔ smaller rescattering cross-section

Results:

- ➔ No clear energy dependence was observed for source ra and correlation strength

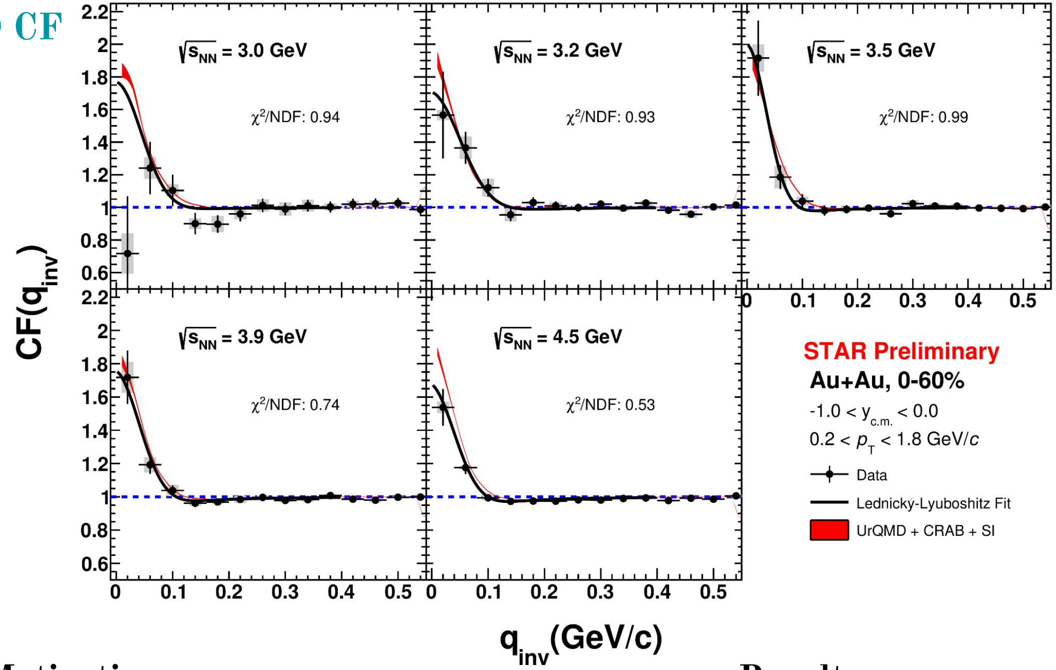


R_{inv} & λ

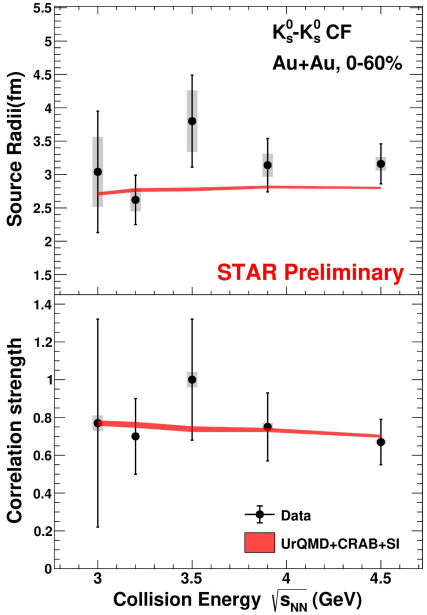
R_{inv} corresponds to the length of homogeneity in 1D case

$K^0_s K^0_s$ femtoscopic correlations

1D CF



R_{inv} & λ



Motivation:

The correlation function of $K^0{}_s K^0{}_s$ can provide information about particle emission source and final state interaction (FSI) between $K^0 K^0, \bar{K}_0 \bar{K}_0, K_0 \bar{K}_0$

Results:

- Particle emission source parameters can be described by UrQMD+CRAB model calculations
- No clear energy dependence was observed for source radii and correlation strength

Summary

- Femtoscopic measurements of charged pions produced in Au+Au collisions at $\sqrt{s_{NN}} = 3$ GeV were presented
- The transverse momentum dependence of emitting source radii (R_{out}, R_{side}, R_{long}) was measured:
    - Femtoscopic radii for pions decrease with increasing k_T due to transverse flow
- The dependence of the λ, R_{out}, R_{side}, R_{long}, $R^2_{out-long}$ on the pair rapidity and centrality (0-10%, 10-30%, 30-50%) was presented:
    - Clear rapidity dependence of $R^2_{out-long}$
    - Decrease of R_{side} with increasing rapidity shows a hint of the boost-invariance breaking
- Femtoscopic measurements of K^+K^+ and $K^0_sK^0_s$ produced in Au+Au collisions at $\sqrt{s_{NN}} = 3 - 3.9$ GeV were presented:
    - The dependence of the λ and R_{inv} on the collision energy was evaluated:
        - No clear energy dependence for R_{inv} and λ