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Estimation of pion emission source characteristics in Au+Au collisions at $\sqrt{s_{NN}} = 3$ GeV in the STAR experiment

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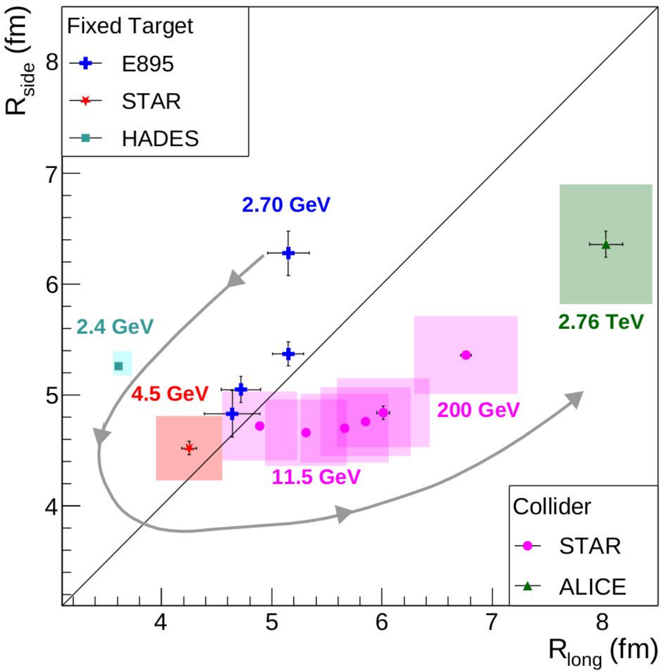
Motivation:

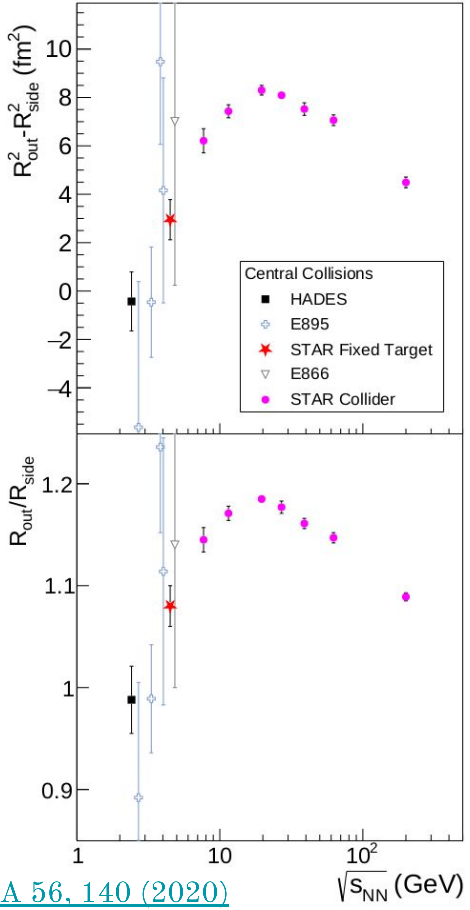
- The correlation femtoscopy technique can reveal the structure of homogeneity region
- The energy dependence of source size may reveal fundamental insights into the equation of state of strongly-interacting matter
- Measurements of the emission region characteristics not only at midrapidity, but also 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

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

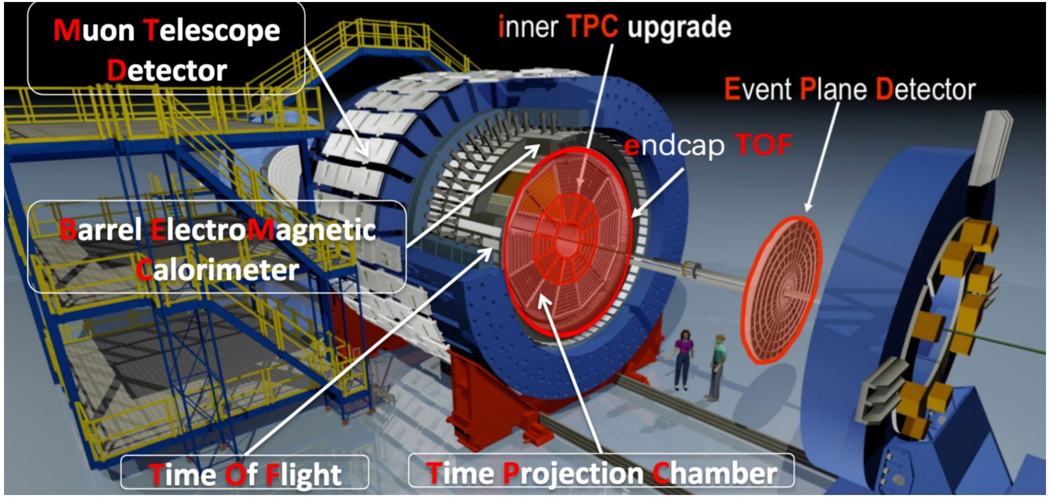
M. S. Abdallah et al. (STAR Collaboration)
Phys. Rev. C 103, 2021



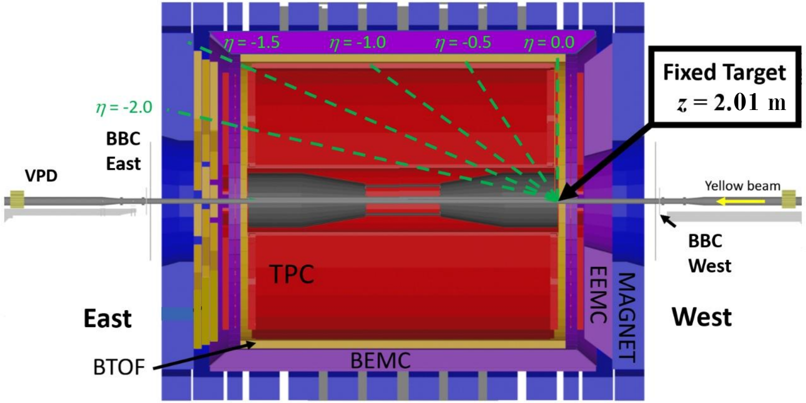


Experiments:
HADES: J. Adamczewski-Musch et al., Eur. Phys. J. A 56, 140 (2020)
ALICE: A. Aamodt et al., Phys. Lett. B 696, 328 (2011)
STAR: L. Adamczyk et al., Phys. Rev. C 92, 014904 (2015)
E895: M. A. Lisa et al., Phys. Rev. Lett. 84, 2798 (2000)

The STAR Experiment

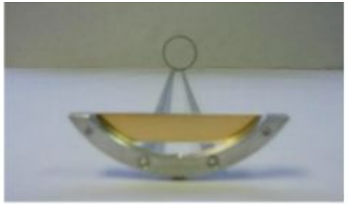


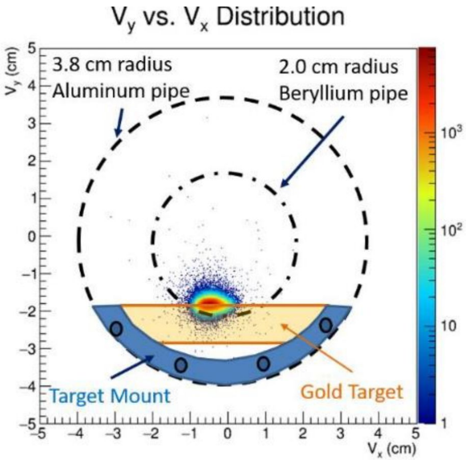
Fixed-target program



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
- Fixed target program has other energies as well





Dataset:

- $\sqrt{s_{NN}} = 3$ GeV Fixed-Target 2018
- $\sim 2.6 \cdot 10^{8}$ events

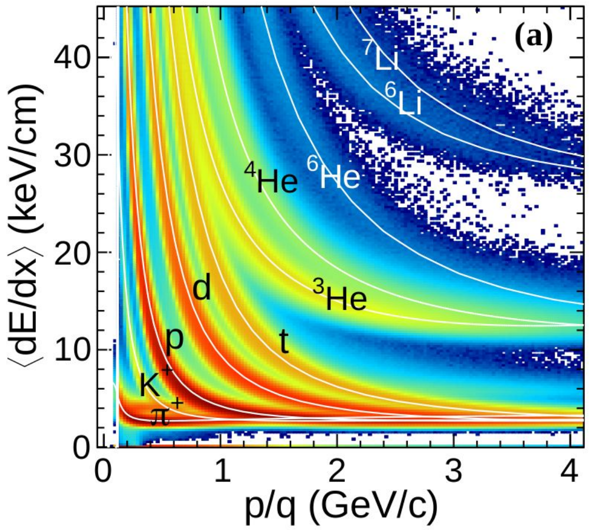
Tracks:

- $-2 < \eta < 0$
- $0.15 < p_T < 1.5$ GeV/c

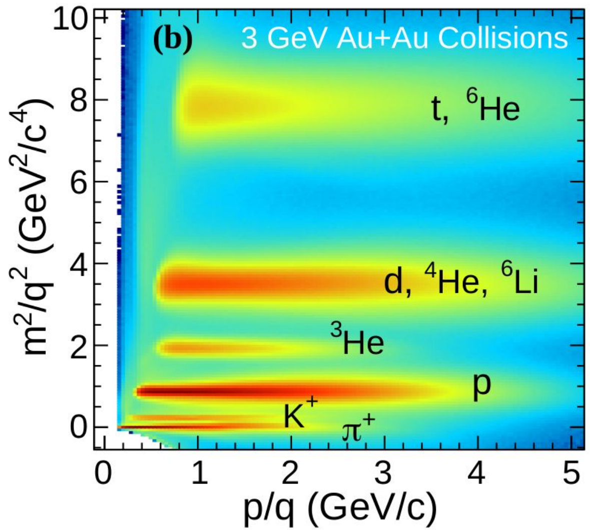
Identification of particles:

$0.15 < p < 0.55$ GeV/c: TPC; $0.55 < p < 1.5$ GeV/c: TPC+TOF

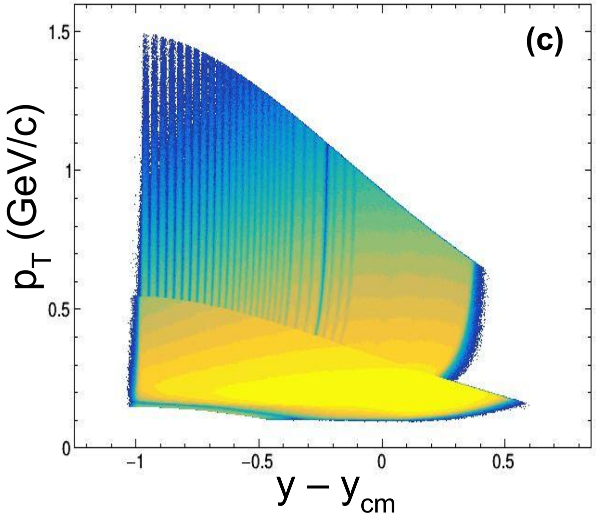
TPC PID



TOF PID

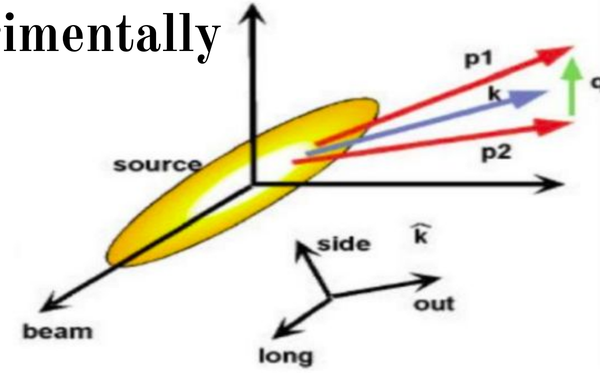


Pion acceptance:



Pion identification was carried out in a wide range of momentum $0.15 < p < 1.5$ GeV/c.
The purity of pions is not lower than 98%.

Measuring two-particle correlation function (CF) experimentally

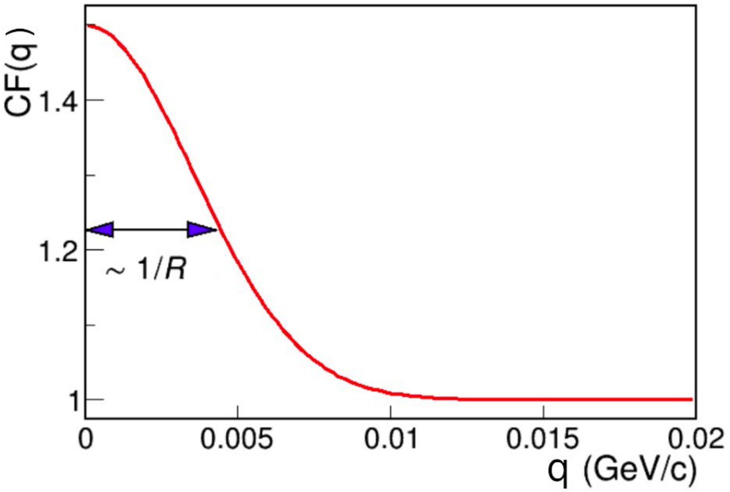


$$C(q) = \frac{A(q)}{B(q)}$$

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

$B(q)$ - 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

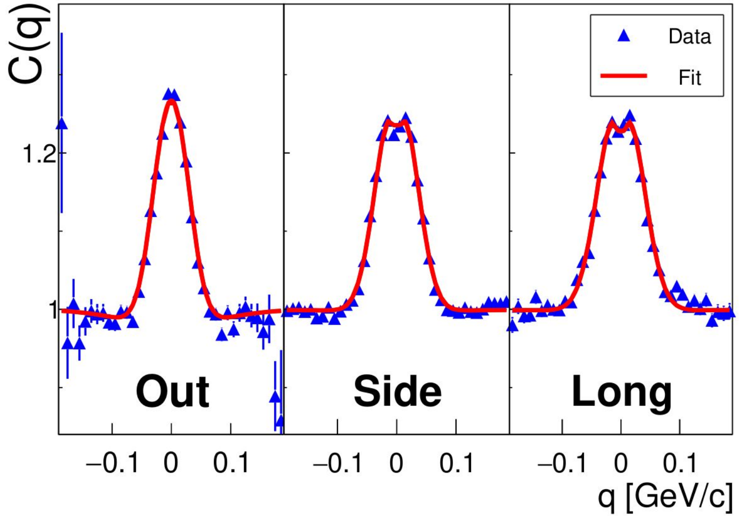
R_{long} ~ medium lifetime,

$R^2_{out\text{-}long}$ – 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:

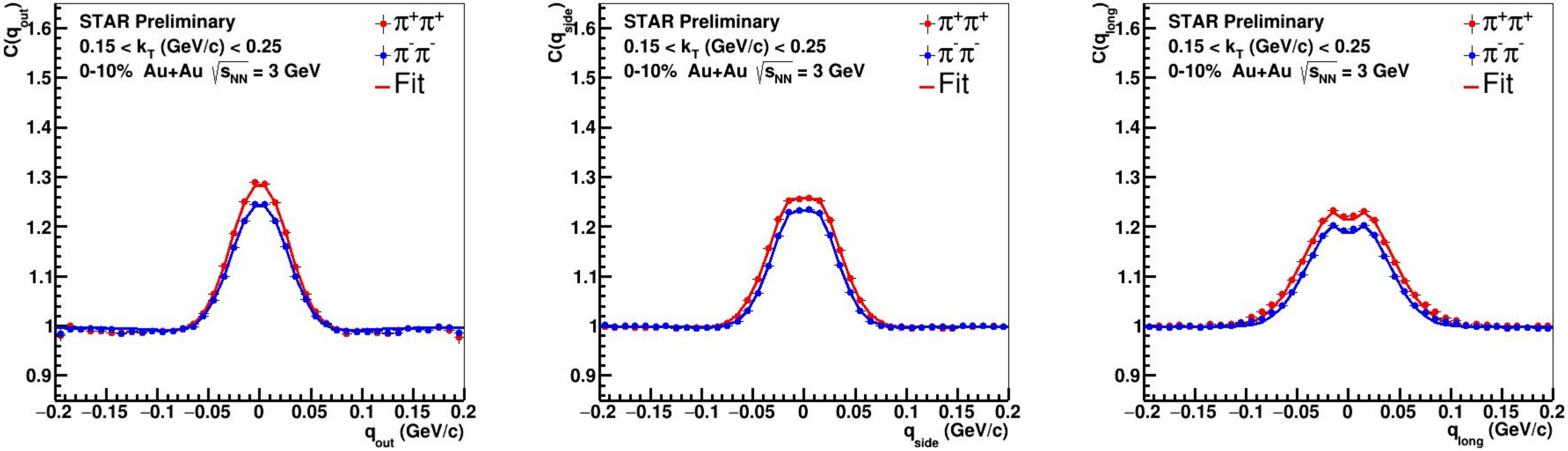


Fit using Log-likelihood method: Phys. Rev. C 66 (2002) 054906

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

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

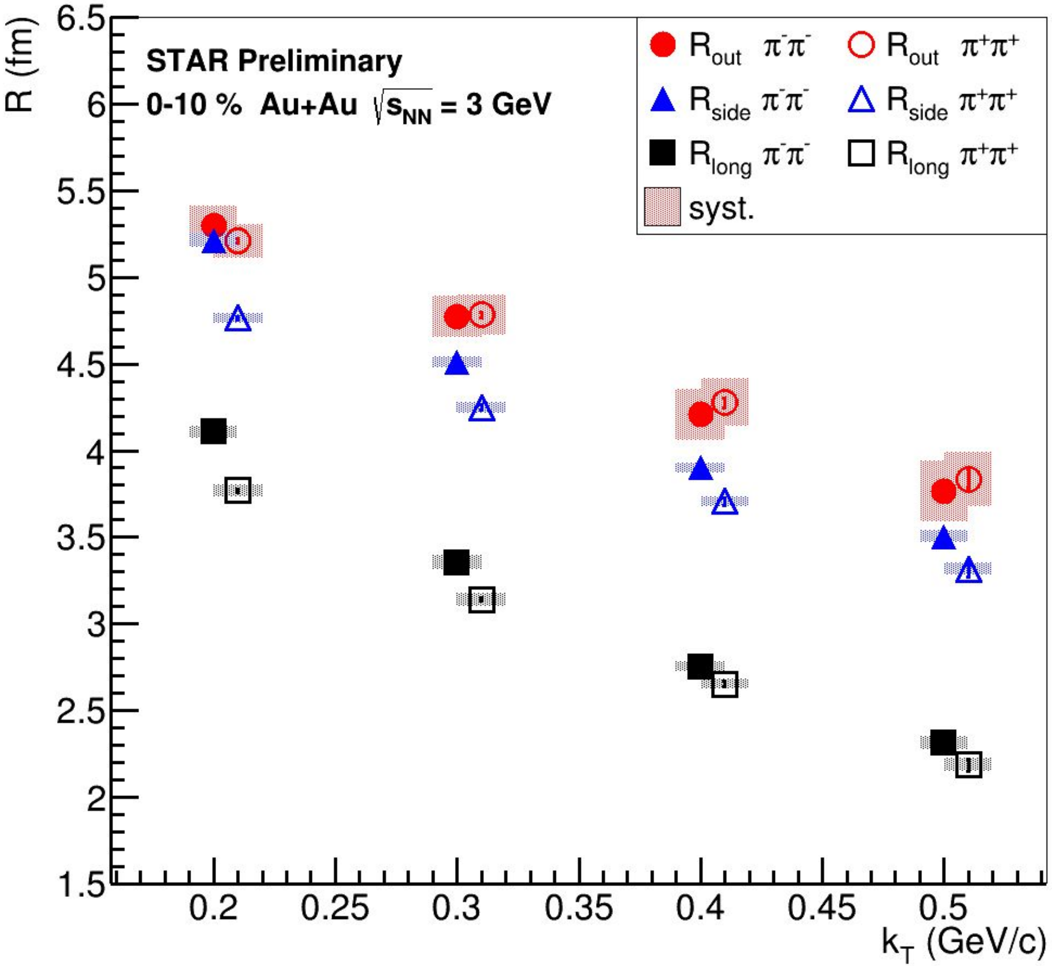
$$\vec{k}_T = (\vec{p}_{1,T} + \vec{p}_{2,T})/2$$



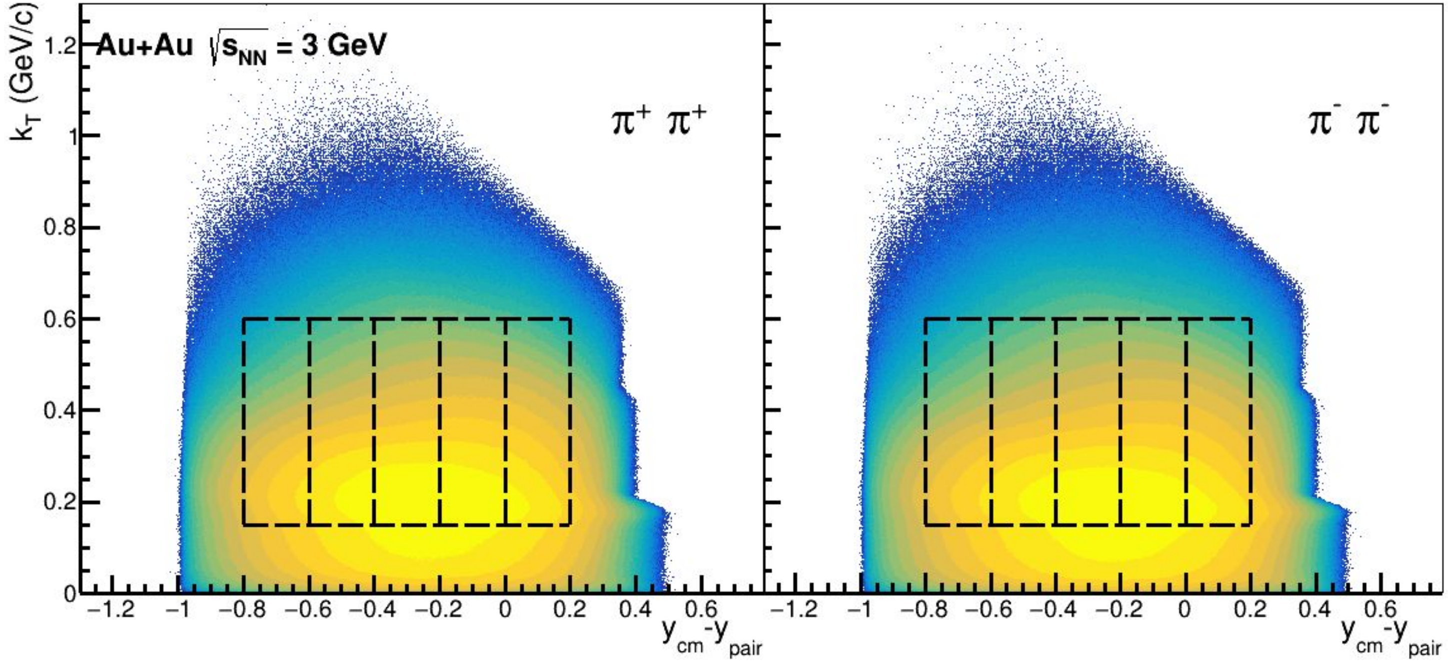
Correlation functions of positive and negative pions differ slightly for small k_T, which may be due to residual electric charge

Charged pion femtoscopic radii

- The radii R_{out}, R_{side} and R_{long} 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

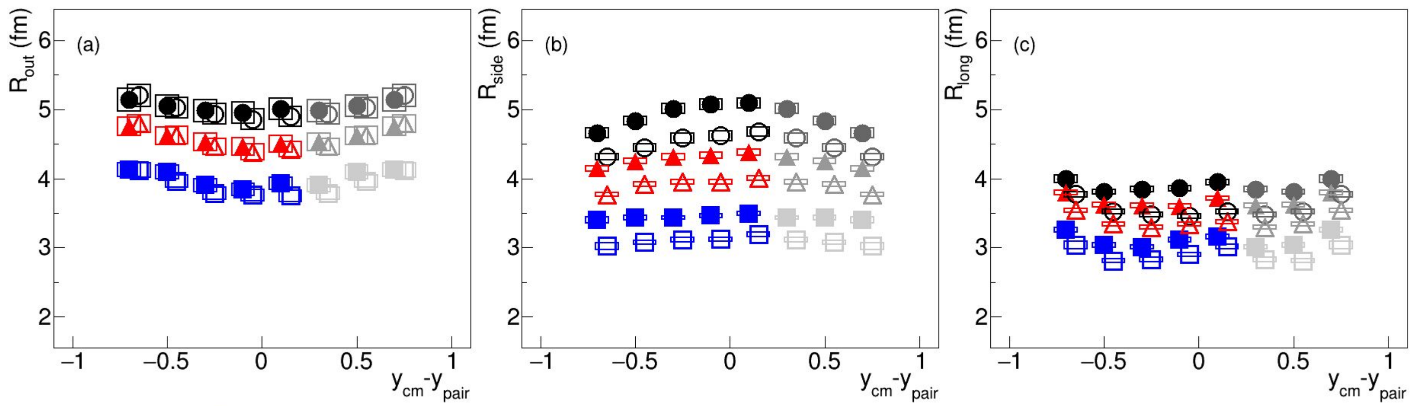


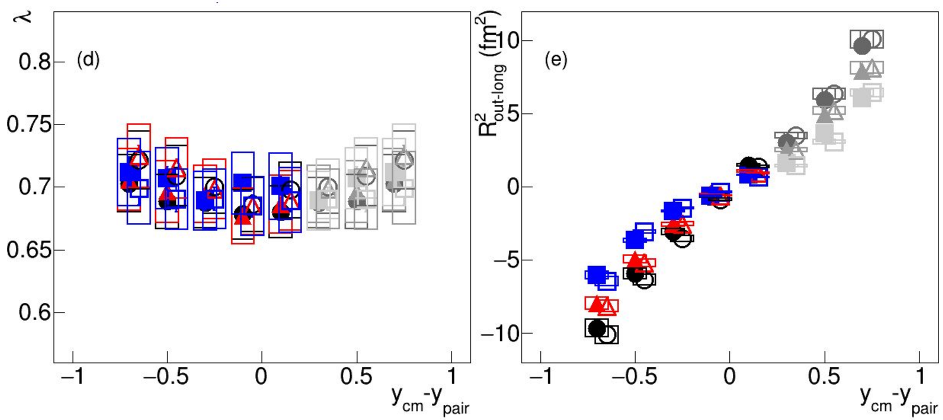
Rapidity analysis

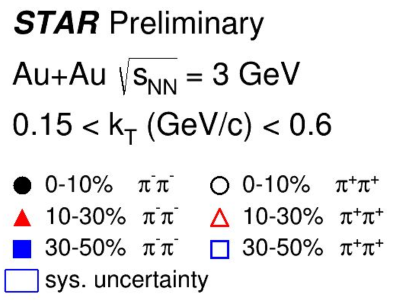


Acceptance of positively (left panel) and negatively (right panel) charged pion pairs for Au+Au collisions at $\sqrt{s_{NN}} = 3$ GeV. Dashed lines denote the selected rapidity windows for the rapidity-differential analysis

Rapidity dependence of charged pion femtoscopic radii







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

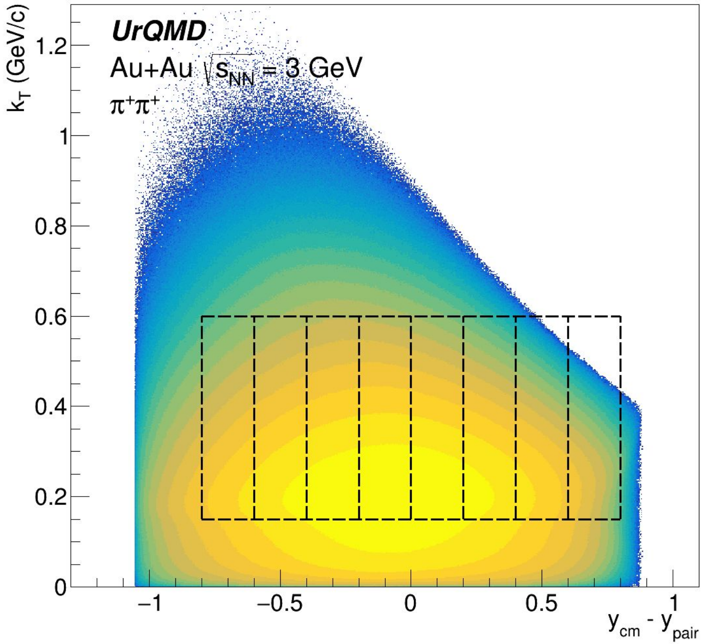
R_{side} decreases with going out of midrapidity:

➔ **Hints on boost-invariance breaking**

Clear rapidity dependence of $R^2_{out\text{-}long}$ due to symmetry in longitudinal direction.

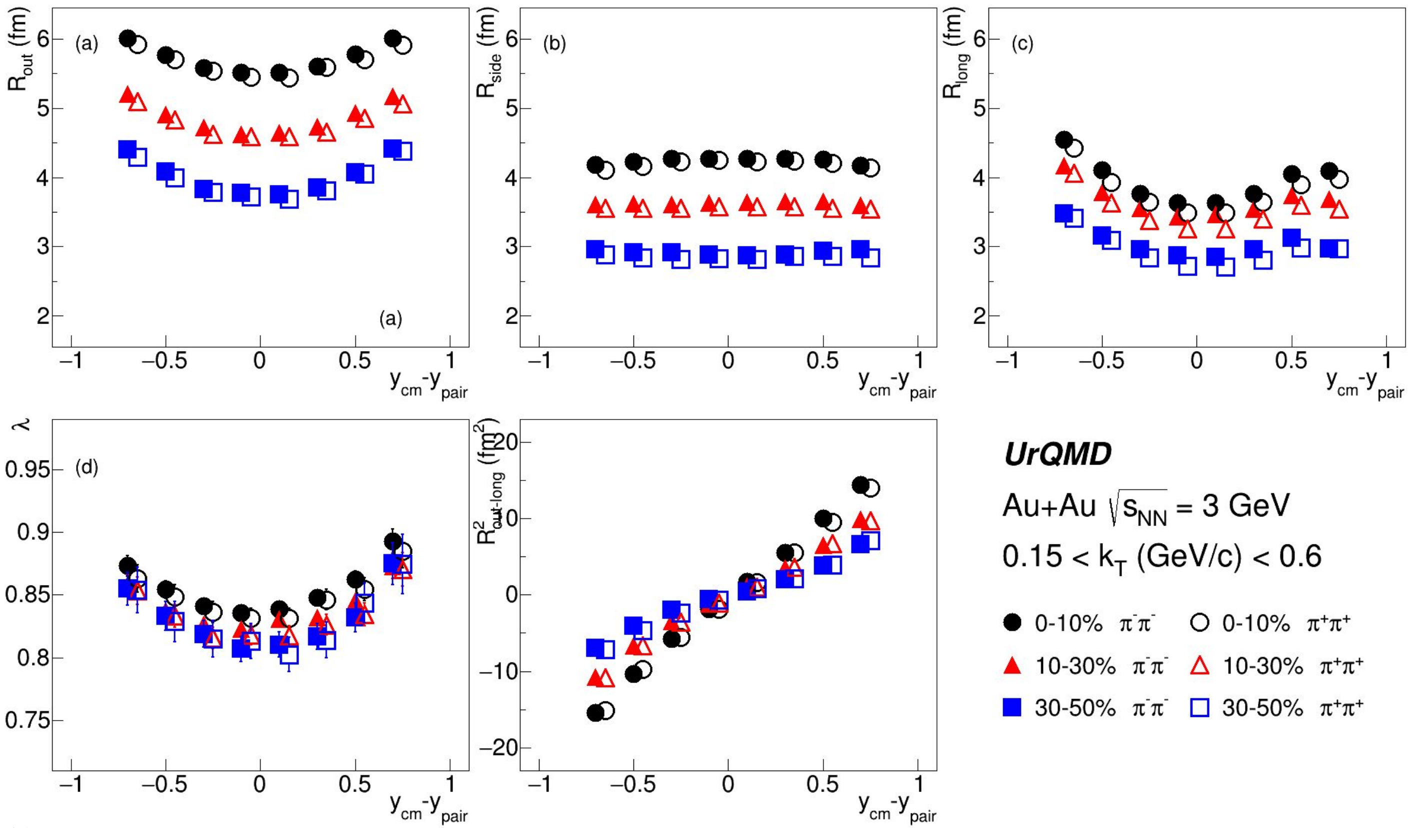
R_{out}, R_{side} and R_{long} increase from peripheral to central collisions reflecting the geometry of the overlapping region.

Rapidity analysis in UrQMD



Acceptance of positively charged pion pairs for Au+Au collisions at $\sqrt{s_{NN}} = 3$ GeV in UrQMD. Dashed lines denote the selected rapidity windows for the rapidity-differential analysis

Rapidity dependence of charged pion femtoscopic radii from UrQMD



- UrQMD qualitatively describes experimental observables
- UrQMD overestimates R_{out}, $R^2_{out-long}$ and λ:
  - overestimated emission duration
  - resonance decay contributions
- R_{side} from UrQMD are smaller than those from the data, and have a weak y-dependence:
  - geometrical size of particle emission is underestimated
  - no hint for boost-invariance breaking

Summary

- Femtoscopic measurements of charged pions produced in Au+Au collisions at $\sqrt{s_{NN}} = 3$ GeV are presented
- Correlation functions of positive and negative pions differ slightly for small k_T, which may be due to residual electric charge
- R_{out}, R_{side}, R_{long} decrease with pair transverse momentum due to transverse flow
- The dependence of the λ, R_{out}, R_{side}, R_{long}, $R^2_{out\text{-}long}$ on the pair rapidity and centrality (0-10%, 10-30%, 30-50%) was presented:
  - Rapidity dependence of $R^2_{out\text{-}long}$ is due to symmetry in longitudinal direction
  - Decrease of R_{side} with increasing rapidity shows a hint of the boost-invariance breaking
- UrQMD calculations:
  - Qualitatively reproduce experimental data
  - Demonstrate overestimation of emission duration and underestimation of geometrical size
  - Show no hints of boost-invariance breaking