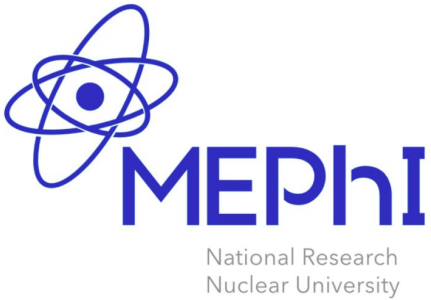


Bose–Einstein correlations of charged pions in Au+Au collisions at $\sqrt{s_{NN}} = 3$ GeV from UrQMD

Anna Kraeva, Grigory Nigmatkulov
National Research Nuclear University MEPhI
ICPPA-2022. December 01, 2022

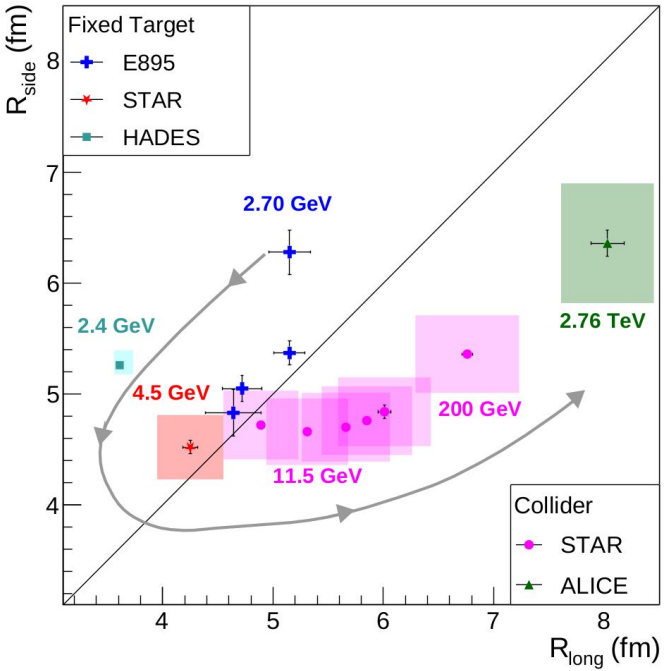
Motivation:

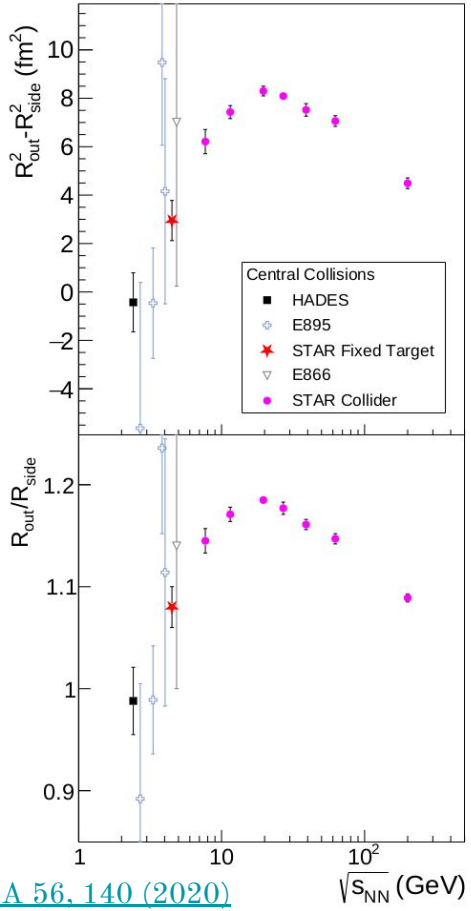
- The energy dependence of femtoscopic scales may reveal fundamental insights into the QGP equation of state
- The low energy results help to reveal the structure of particle-emission region, where deconfinement is not expected

Goals:

- Estimation of spatial and temporal parameters of the particle-emittion region in Au+Au collisions at $\sqrt{s_{NN}} = 3$ GeV using the UrQMD model
- The results from UrQMD will be used in future to compare with the data from STAR experiment.

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)

Fundamentals of femtoscopy:

$\frac{d\sigma(p_1)}{dp_1}$ – the probability of a particle emission from some area with momentum p_1

$\frac{d^2\sigma(p_1,p_2)}{dp_1 dp_2}$ – probability of emission of 2 particles with momentum p_1 and p_2

$$R(p_1,p_2) = R(q,p) = \frac{\sigma_{in} d^2\sigma/dp_1 dp_2}{d\sigma/dp_1 \cdot d\sigma/dp_2}$$ - **correlation function (CF) of 2 particles**

$\vec{p} = \vec{p_1} + \vec{p_2}$

$\vec{q} = \vec{p_1} - \vec{p_2}$

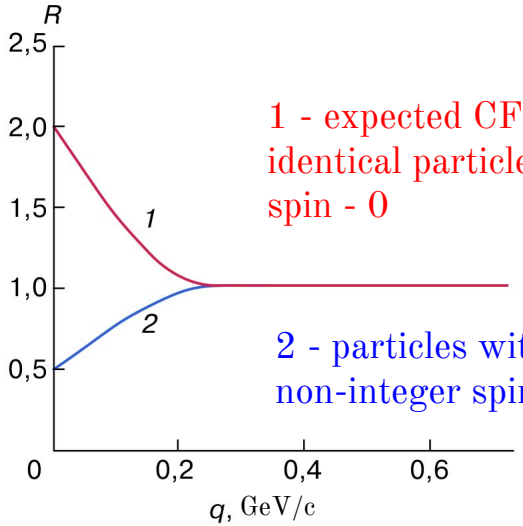
if the particles are emitted **<u>independently</u>** from each other

$$\frac{d^2\sigma}{dp_1 dp_2} = \frac{d\sigma}{dp_1}\frac{d\sigma}{dp_2}$$

$$R \equiv 1$$

in case of any **<u>correlation</u>**

$$R \neq 1$$



1 - expected CF of two identical particles with spin - 0

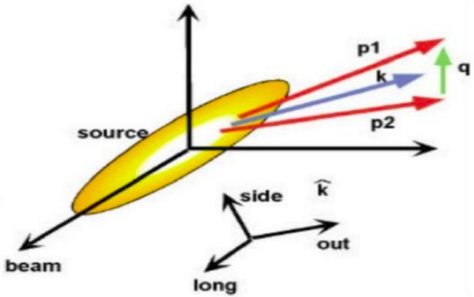
2 - particles with non-integer spin

How to construct the two-particle correlation function?

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

$A(q)$ - formed using pairs, where both tracks are from the same event. It contains quantum-statistical correlations (QS)

$B(q)$ - formed using pairs, where QS are absent



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

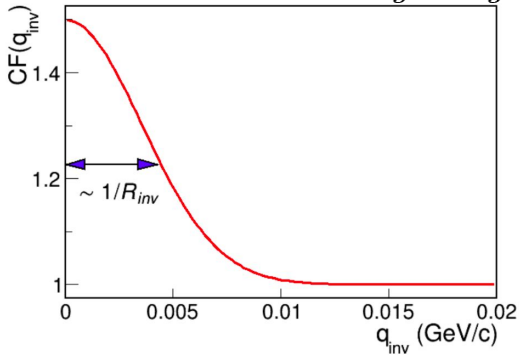
MC generators do not contain QS correlations. Femtoscopic weight could be added as: $1 + \cos(q\Delta r)$ where Δr is a relative four-coordinate of particles from a pair.

G. Bertsch, M. Gong, and M. Tohyama Phys. Rev. C 37, 1896 (1988)
S. Pratt, Phys. Rev. Lett. 53, 1219 (1984)

Femtoscopic radii are extracted by fitting C(q):

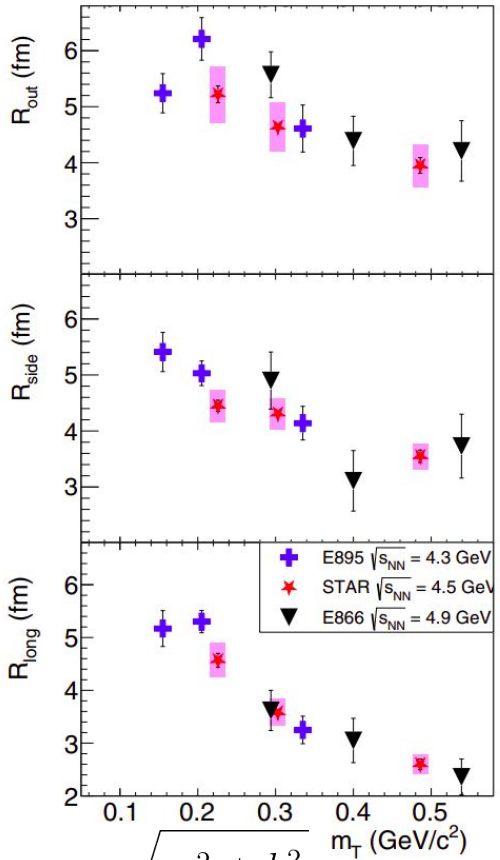
$$C(q_{out}, q_{side}, q_{long}) = N[1 + \lambda \cdot exp(-R^2_{out}q^2_{out} - R^2_{side}q^2_{side} - R^2_{long}q^2_{long})]$$

N - normalization factor,
λ - correlation strength,
q_{long} - along the beam direction,
q_{out} - along the transverse momentum of the pair,
q_{side} - perpendicular to longitudinal and outward directions
R_{side} ~ geometrical size of the particle emission source,
R_{out} ~ geometrical size + particle-emitting duration
R_{long} ~ medium lifetime



LCMS system was used, where $p_{1,z} + p_{2,z} = 0$

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



$$m_T = \sqrt{m_\pi^2 + k_T^2}$$

Experimentally observed:

- R_{side} and R_{out} decrease with increasing m_T due to transverse flow
- R_{long} decrease due to longitudinal flow

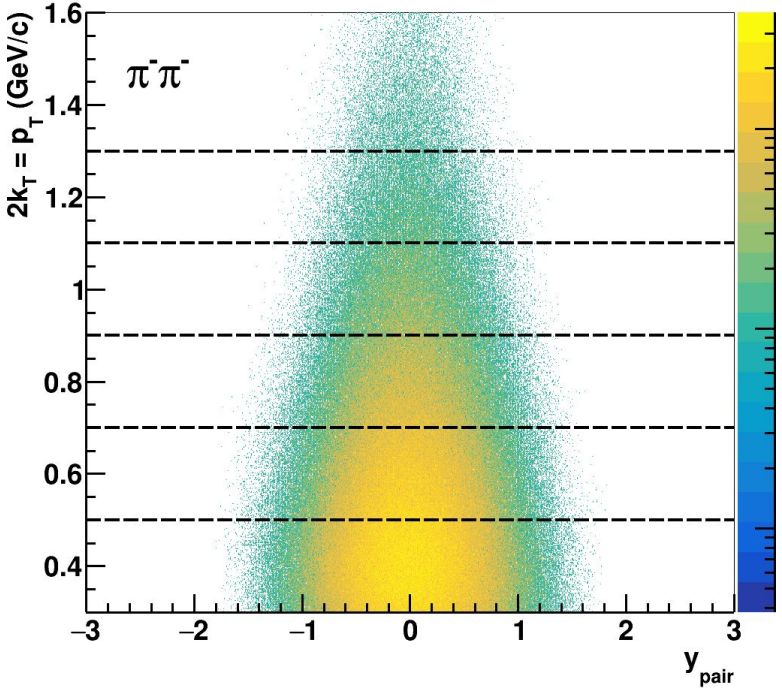
Theoretical basis:

- correspond to regions of homogeneity

What will be presented in this analysis?

The k_T and centrality dependencies of R_{out}, R_{side}, R_{long}

1st step of analysis:
integrated rapidity ranges of pairs

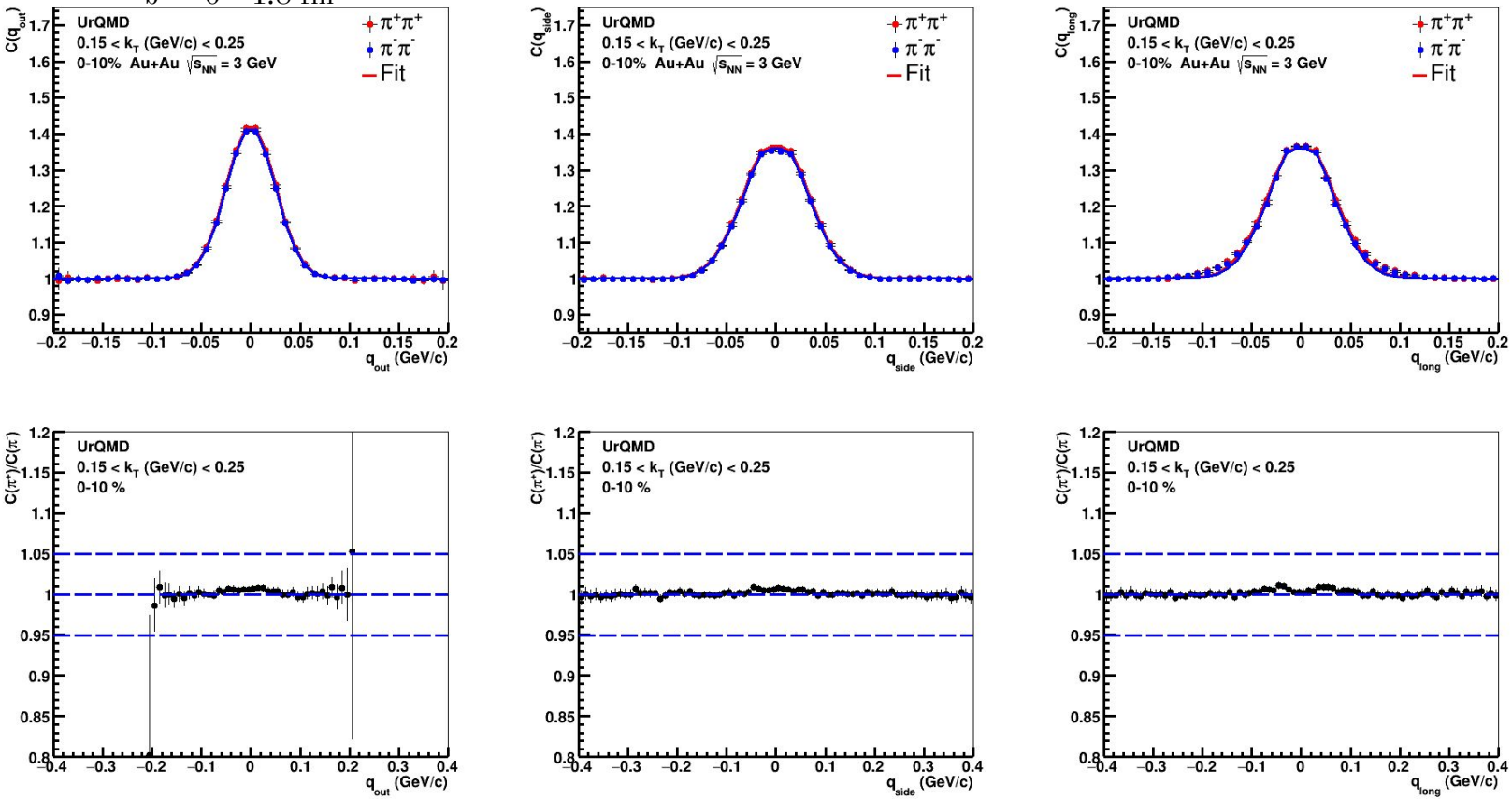


Chosen k_T ranges:
(0.15, 0.25), (0.25, 0.35), (0.35, 0.45), (0.45, 0.55), (0.55, 0.65) GeV/c

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

CF of positive and negative pion pairs and their ratio

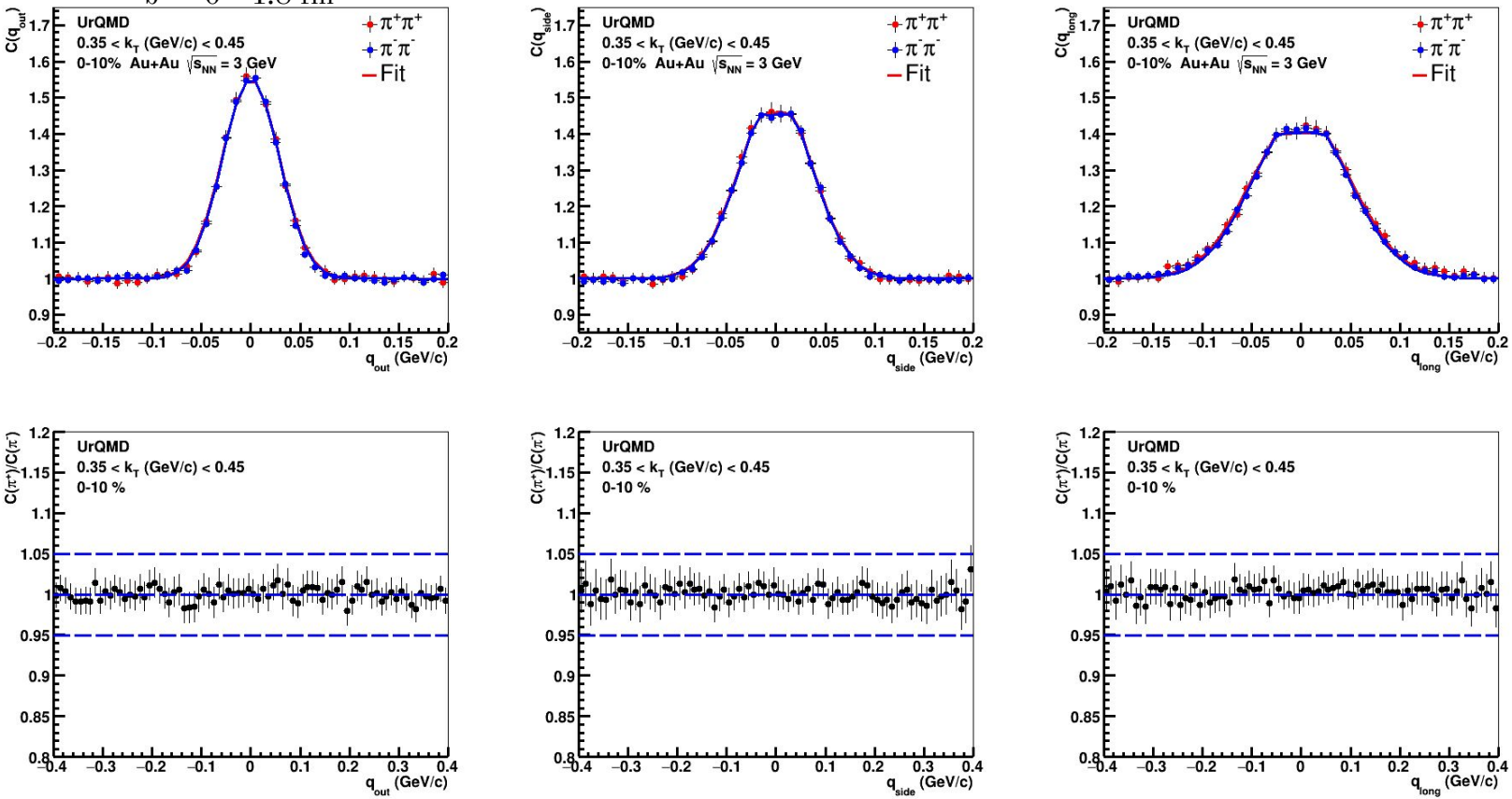
b = 0 - 4.8 fm



The correlation functions of identical positive and negative pions are similar.

CF of positive and negative pion pairs and their ratio

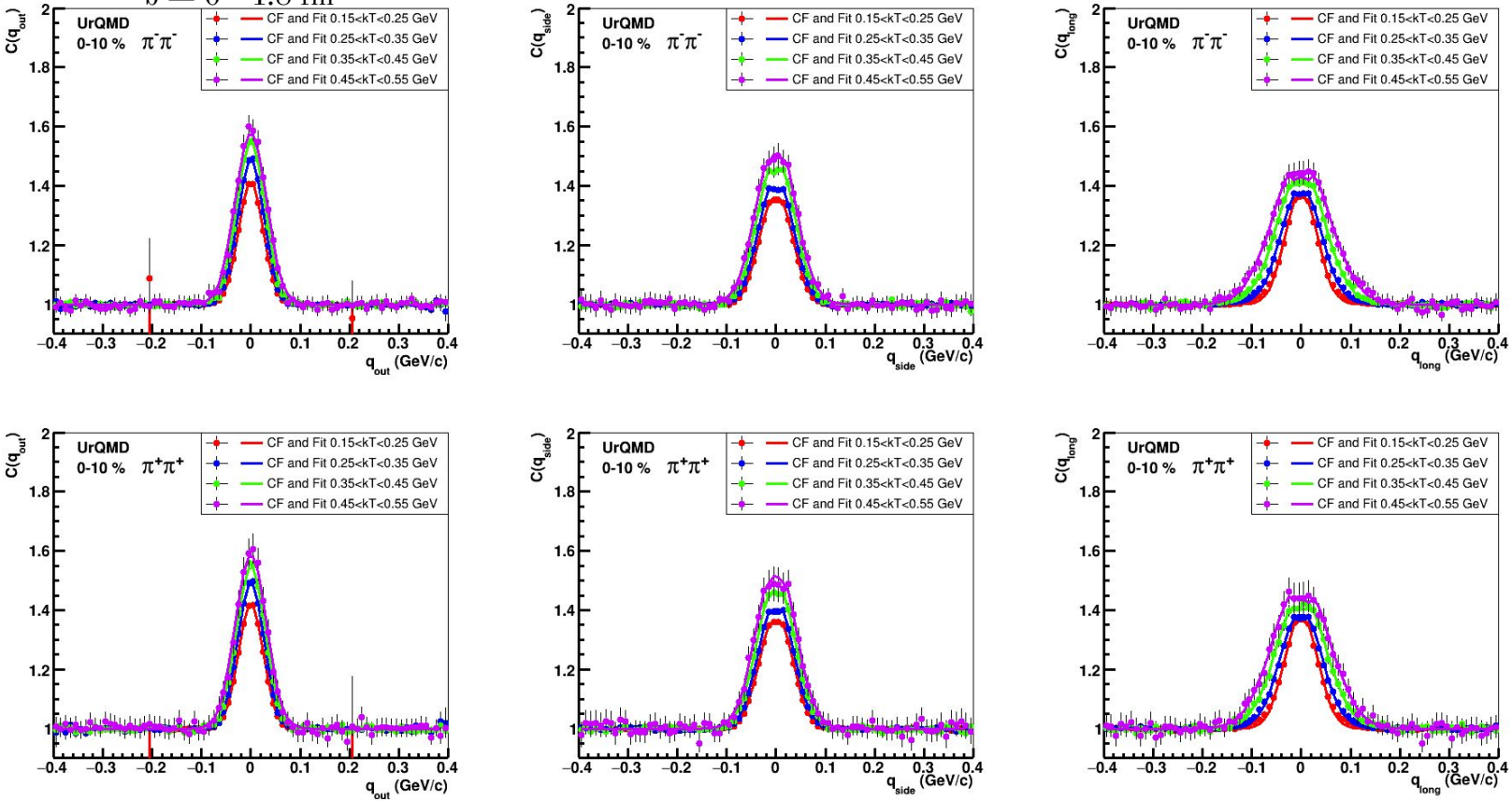
b = 0 - 4.8 fm



The correlation functions of identical positive and negative pions agree with each other within the uncertainties

k_T-dependence of CF of positive and negative pion pairs

b = 0 - 4.8 fm



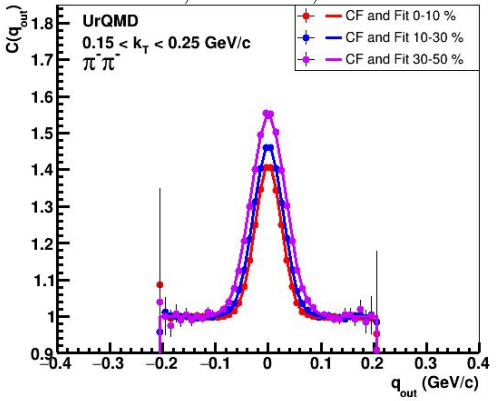
$\pi^-\pi^-$

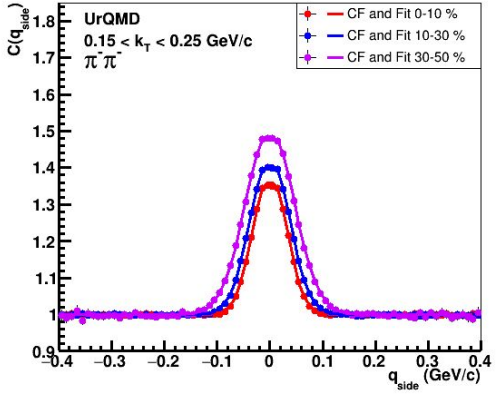
$\pi^+\pi^+$

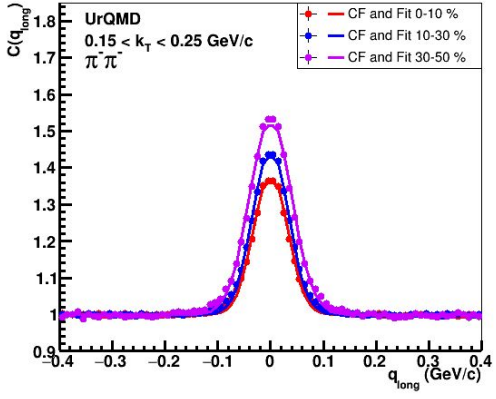
It is observed that the larger the k_T, the greater the width of CF

Centrality dependence of CF of positive and negative pion pairs

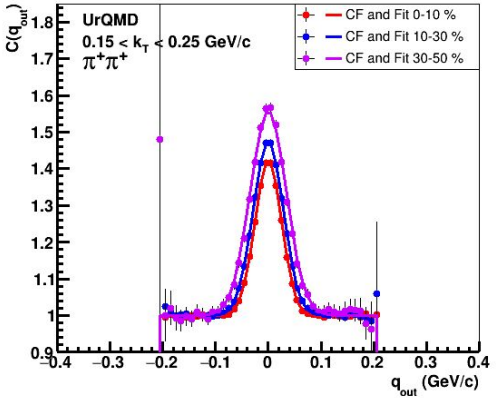
b = 0 - 4.8, 4.8 - 8.4, 8.4 - 10.8 fm

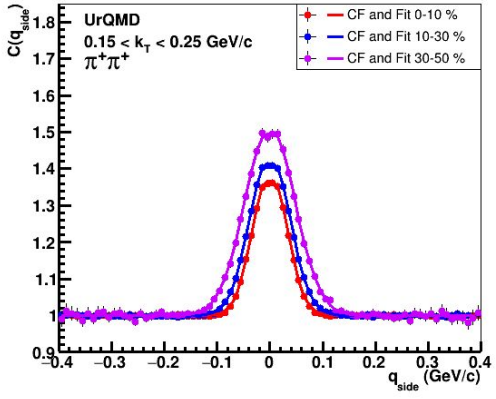


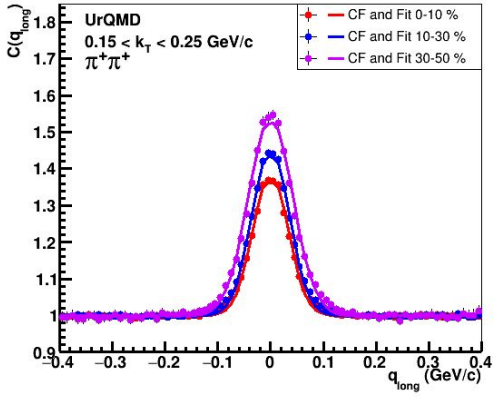




$\pi^-\pi^-$



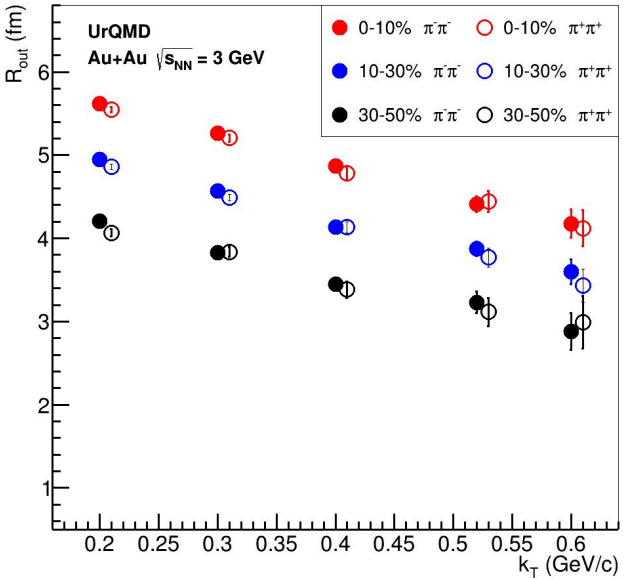


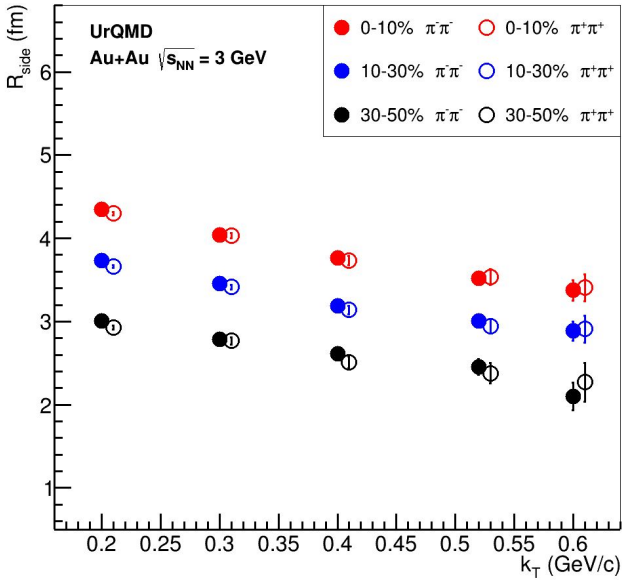


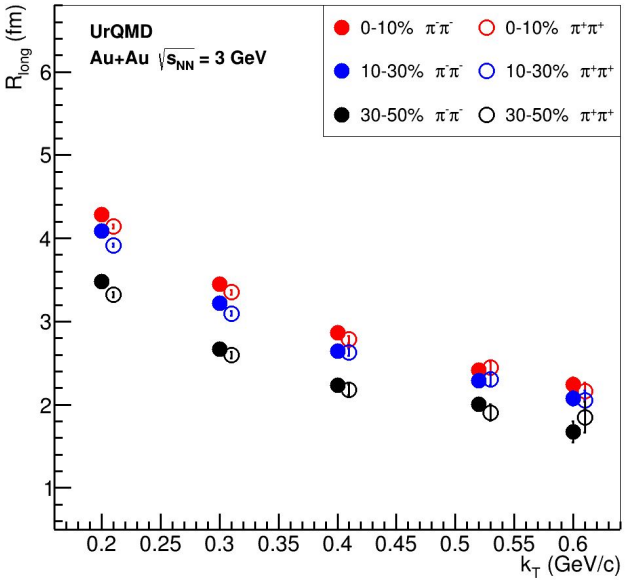
$\pi^+\pi^+$

It is observed that the larger the centrality, the greater the width of CF

Charged pion femtoscopic radii







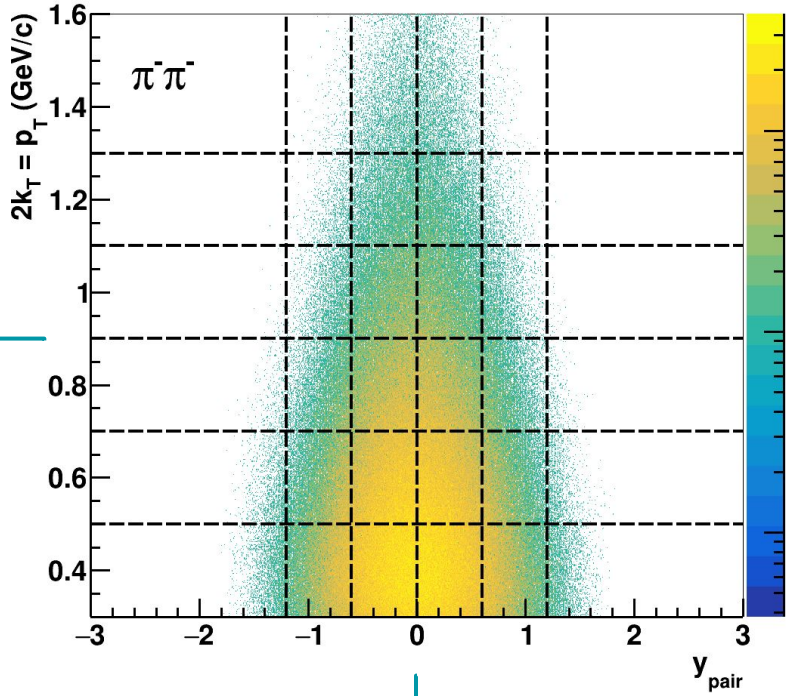
Estimated **femtoscopic radii** for positive and negative pions **decrease with increasing k_T. Femtoscopic radii depend on centrality**: the smaller the centrality, the greater the radius.

What will be presented in this analysis?

The k_T and rapidity dependencies of R_{out}, R_{side}, R_{long}

2nd step of analysis:

double differential analysis for rapidity and k_T



k_T ranges:

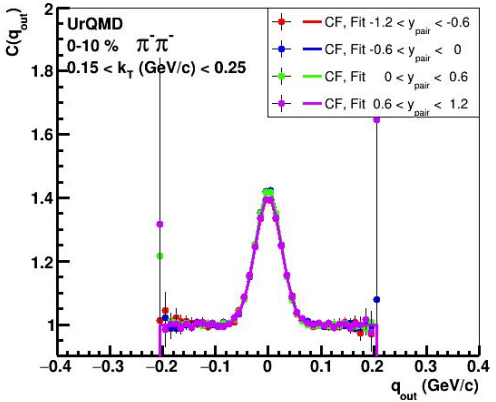
(0.15, 0.25), (0.25, 0.35), (0.35, 0.45), (0.45, 0.55), (0.55, 0.65) GeV/c

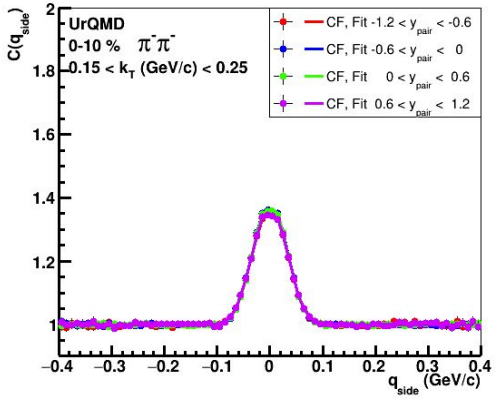
Rapidity ranges:

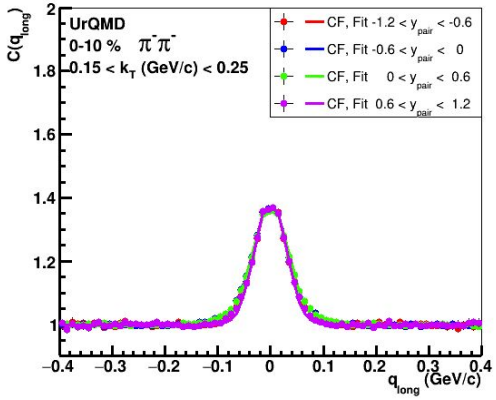
(-1.2, -0.6), (-0.6, 0), (0, 0.6), (0.6, 1.2)

Rapidity dependence of CF of positive and negative pion pairs

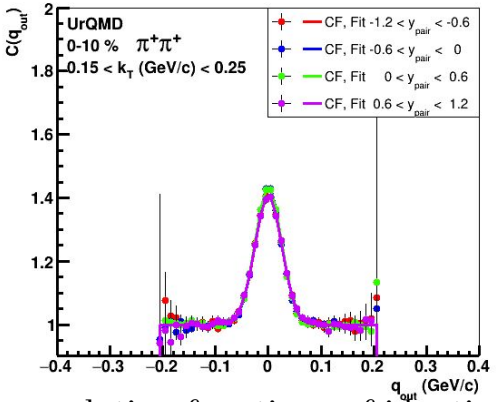
b = 0 - 4.8 fm

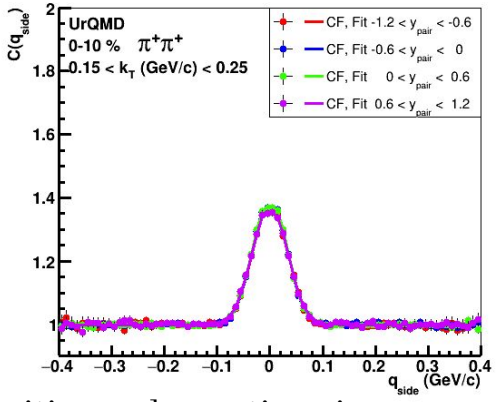


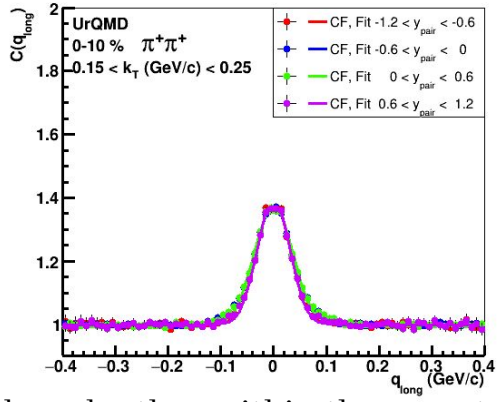




$\pi^-\pi^-$



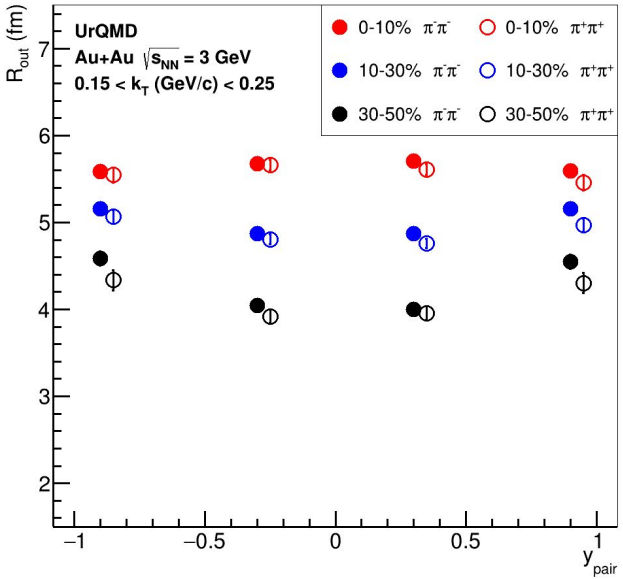


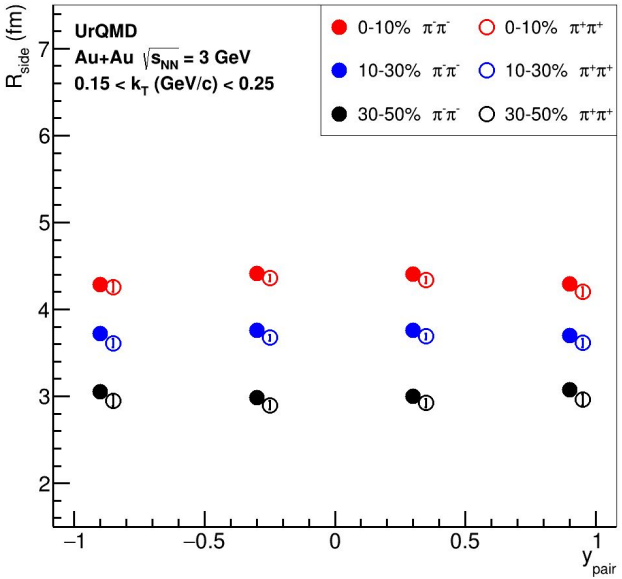


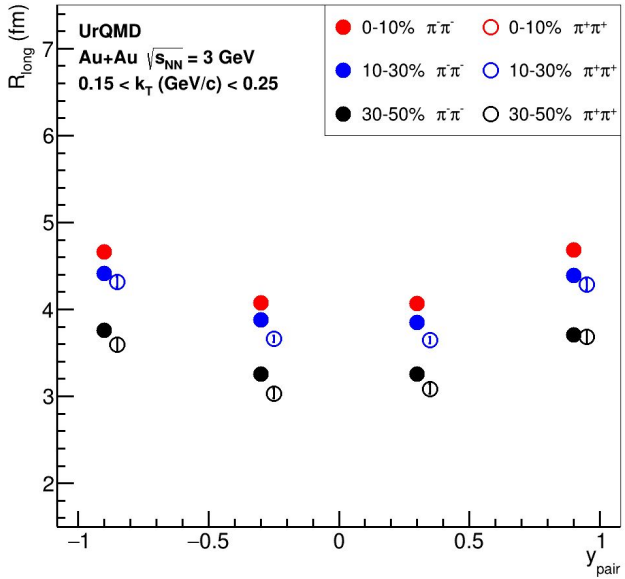
$\pi^+\pi^+$

The correlation functions of identical positive and negative pions agree with each other within the uncertainties.
CF of pions have weak (if any) rapidity dependence.

Charged pion femtoscopic radii in rangers of pair rapidity







- **R_{out}, R_{side}** for positive and negative pions have **weak rapidity dependence**
- **R_{long}** seems **to have rapidity dependence**

Summary

- Femtoscopic analysis of charged pions produced in Au+Au collisions at $\sqrt{s_{NN}} = 3$ GeV was performed using UrQMD
- Three-dimensional correlation functions of identical charged pions are studied for 5 k_T bins, for 3 centrality bins and for 4 pair rapidity intervals
- The transverse momentum and rapidity dependence of femtoscopic radii (R_{out}, R_{side}, R_{long}) was estimated:
  - *k_T-dependence*: radii decrease with increasing k_T due to flow
  - *y-dependence*:
    - R_{out} and R_{side} - weak (if any) rapidity dependence
    - R_{long} seems to have weak rapidity dependence.