Two-pion and two-kaon femtoscopic correlations in Au+Au collisions from STAR BES and 200 GeV data

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Outline

- Motivation
- Femtoscopy
- The STAR experiment at RHIC
- Results
- Summary

Motivation

- Access to the spatial and temporal information about the particle-emitting source at kinetic freeze-out
- Different particle species are sensitive to various effects (Final State Interactions (FSI), transport properties, asymmetries, etc…)
- Pion femtoscopic parameters were measured in a Beam Energy Scan program at RHIC (and at AGS, SPS, LHC, …)
  - Add Au+Au at $\sqrt{s_{NN}}$ = 14.5 GeV (not yet published)
- Extending transverse mass region (up to 1 GeV/c^2) using particle identification from the Time-Of-Flight detector

Correlation function

- Two-particle correlation function:

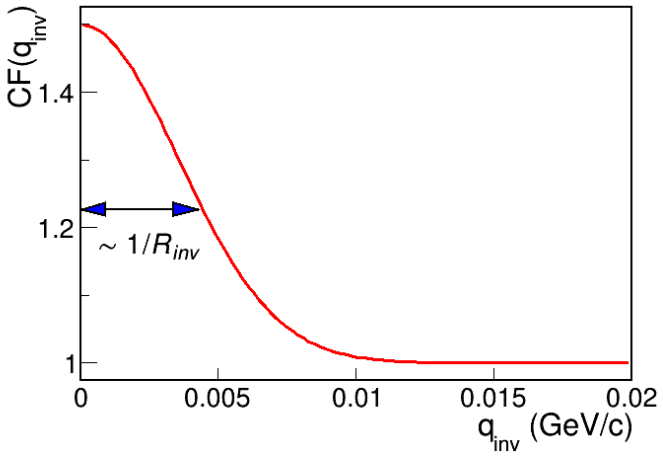
$$CF(p_1, p_2)=\int d^4r\, S(r, k)\, |\Psi_{1,2}(r, k)|^2$$

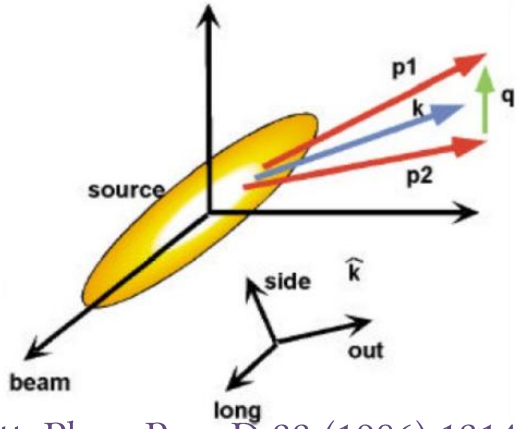
$$r=x_1-x_2 \text{ and } q\equiv q_{inv}= p_1 - p_2$$

- Experimentally:

$$CF(q) = A(q)/B(q)$$

  - A(q) – contain quantum statistical (QS) correlations and final state interactions (FSI)
  - B(q) – obtained via mixing technique (does not contain QS and FSI)





S. Pratt. Phys. Rev. D 33 (1986) 1314
G. Bertsch. Phys. Rev. C 37 (1988) 1896

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

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

Fitting procedure

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

$$C(q_{out}, q_{side}, q_{long}) = N\left[1 - \lambda + \lambda K(q_{inv})\left(1 + \exp(-R_{out}^2 q_{out}^2 - R_{side}^2 q_{side}^2 - R_{long}^2 q_{long}^2)\right)\right]$$

N – normalization factor
λ – correlation strength
$K(q_{inv})$ – Coulomb correction
R_{side} ~geometrical size of the system
R_{out} ~ geometrical size + particle emission duration
R_{long} ~ medium lifetime

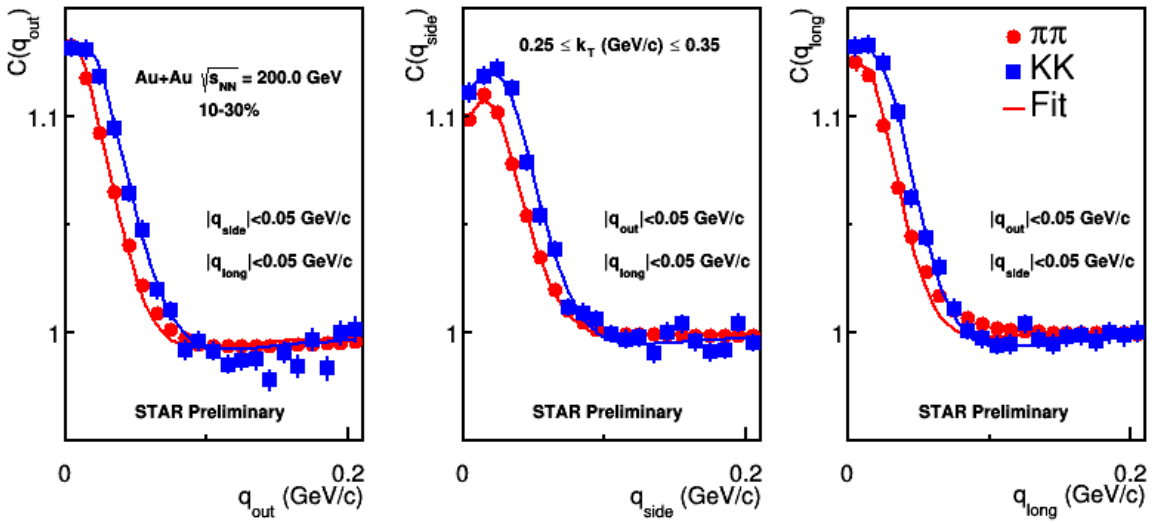
M. Bowler. Phys. Lett. B 270 (1991) 69
Yu. Sinyukov et al. Phys. Lett. B 432 (1998) 248

- Fit using Log-likelihood method
  E-802. Phys. Rev. C 66 (2002) 054906

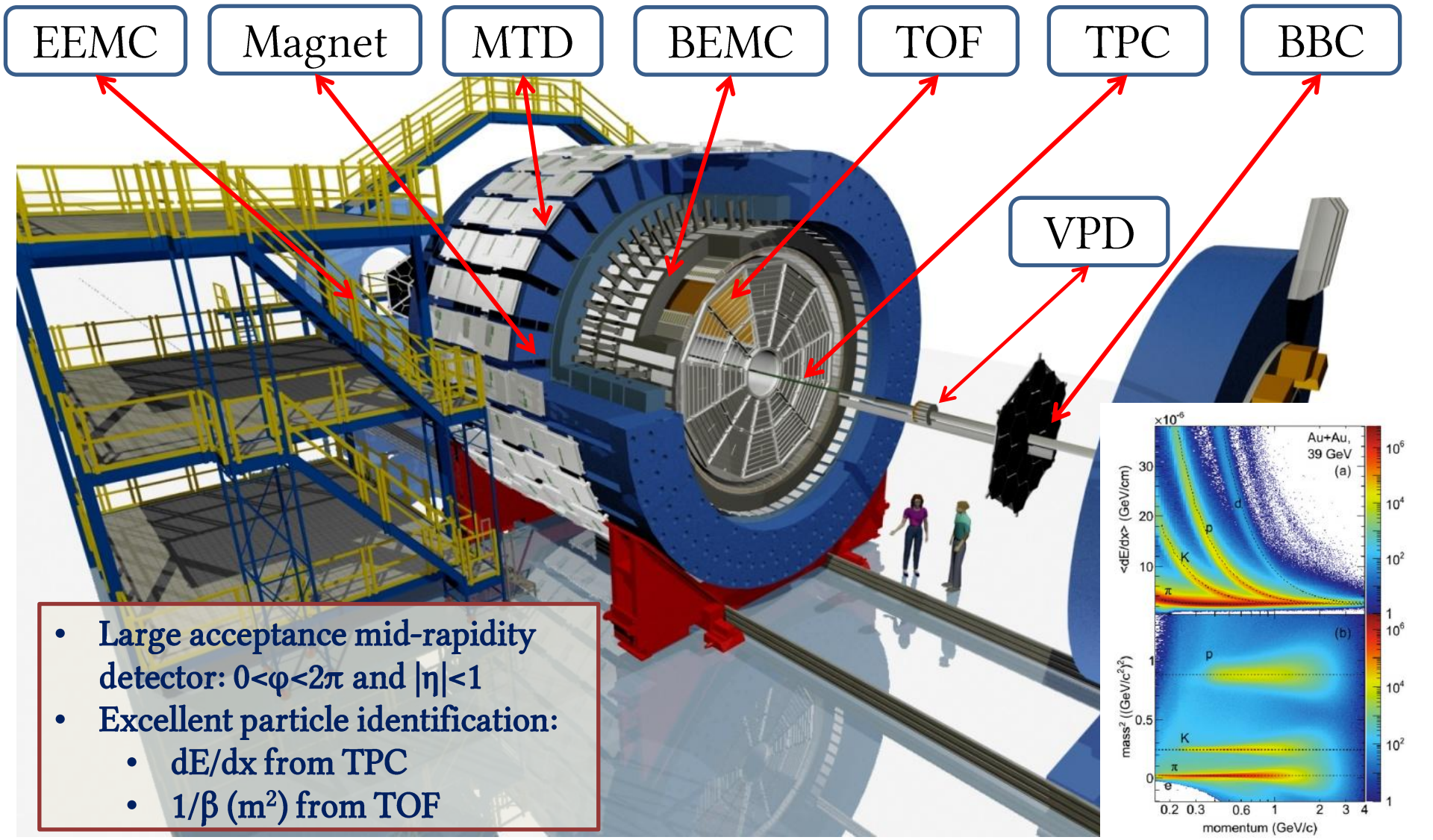
$$\chi^2 = -2\left[A\ln\left(\frac{C(A+B)}{A(C+1)}\right) + B\ln\left(\frac{A+B}{B(C+1)}\right)\right], C = \frac{A}{B}$$

- Fit example

Out, side and long projections of ππ and KK correlation functions and fits



The Solenoidal Tracker At RHIC



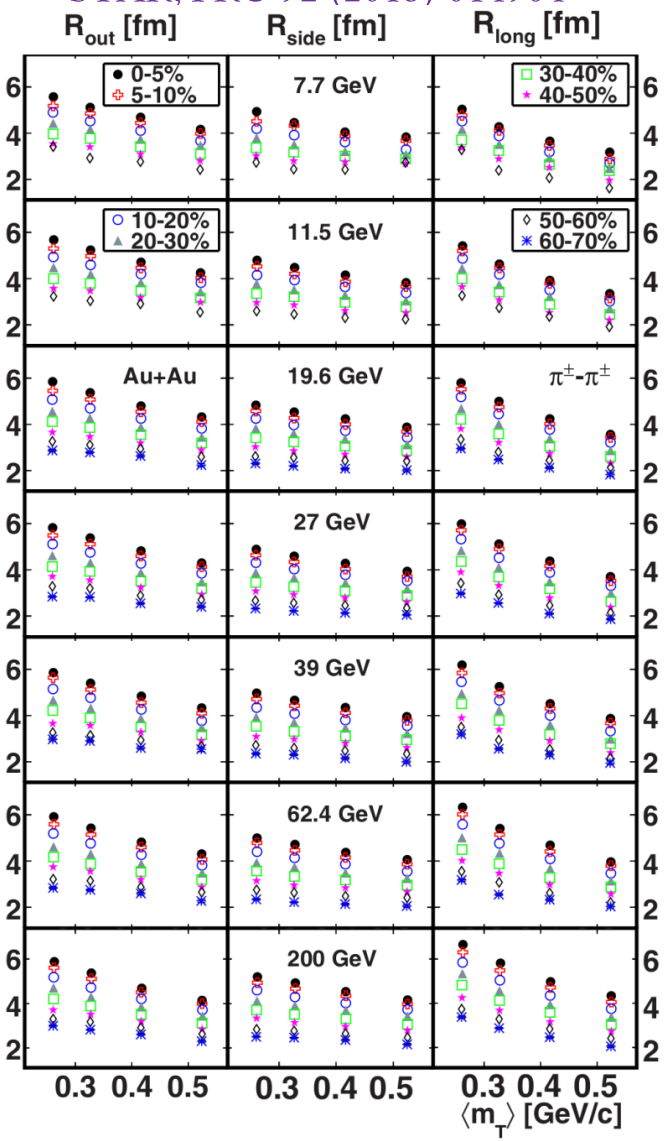
- Large acceptance mid-rapidity detector: $0<\varphi<2\pi$ and $|\eta|<1$
- Excellent particle identification:
  - dE/dx from TPC
  - $1/\beta$ (m^2) from TOF

Previous pion results from STAR

- Pion correlations have been extensively measured in STAR
- The decrease of the femtoscopic radii with increasing transverse mass $m_T = \sqrt{k_T^2 + m^2}$ is attributed to the hydrodynamic flow in heavy-ion collisions
- To make the comparison with kaons, the extension to the higher m_T is needed.
- Particle identification with TPC and TOF

Event and pair cuts	Same as in STAR, PRC 92 (2015) 014904
Track cuts:	$\|\eta\|<1$, nHits>15
PID: if no TOF (dE/dx)	$0.15 < p\ (GeV/c) < 0.45$ π: $\|n\sigma_\pi\|<2$, $\|n\sigma_{other}\|>2$ K: $\|n\sigma_K\|<2$, $\|n\sigma_{other}\|>2$
PID: If TOF (m^2+dE/dx)	$0.15 < p\ (GeV/c) < 1.45$ π: $\|n\sigma_\pi\|<3$, $-0.02 < m_\pi^2\ (GeV/c^2)^2 < 0.062$ K: $\|n\sigma_K\|<3$, $0.20 < m_K^2\ (GeV/c^2)^2 < 0.32$

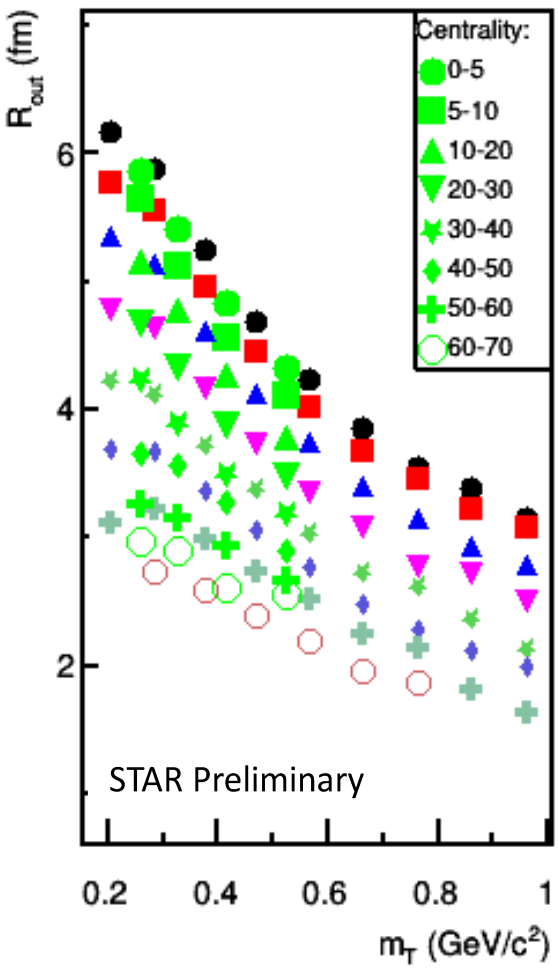
STAR, PRC 92 (2015) 014904

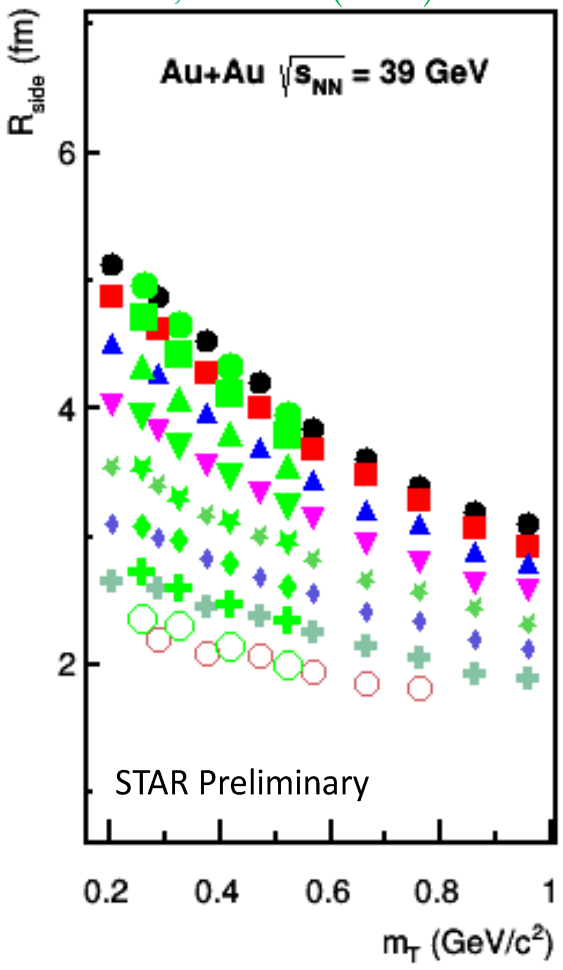


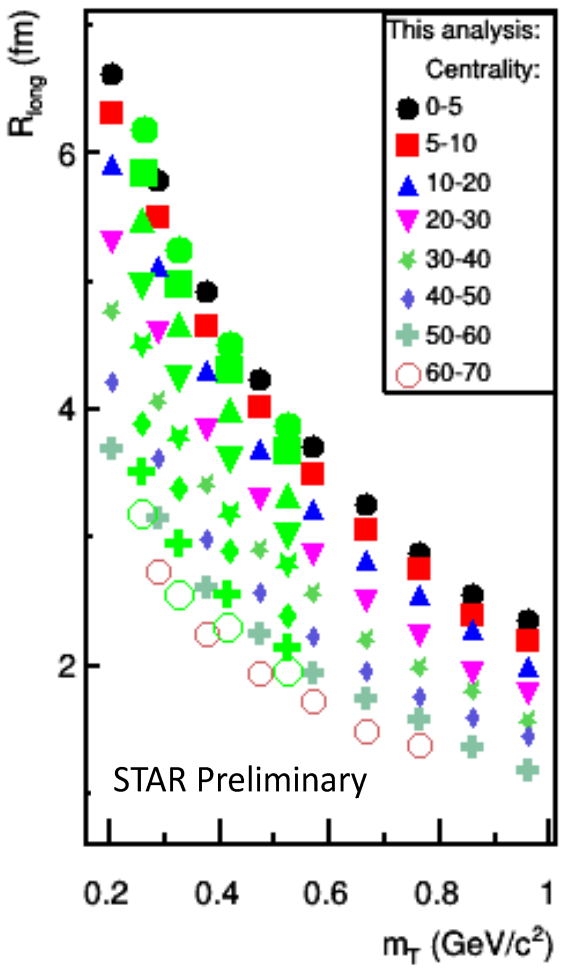
Comparison to the published data

Only statistical uncertainties

STAR, PRC 92 (2015) 014904



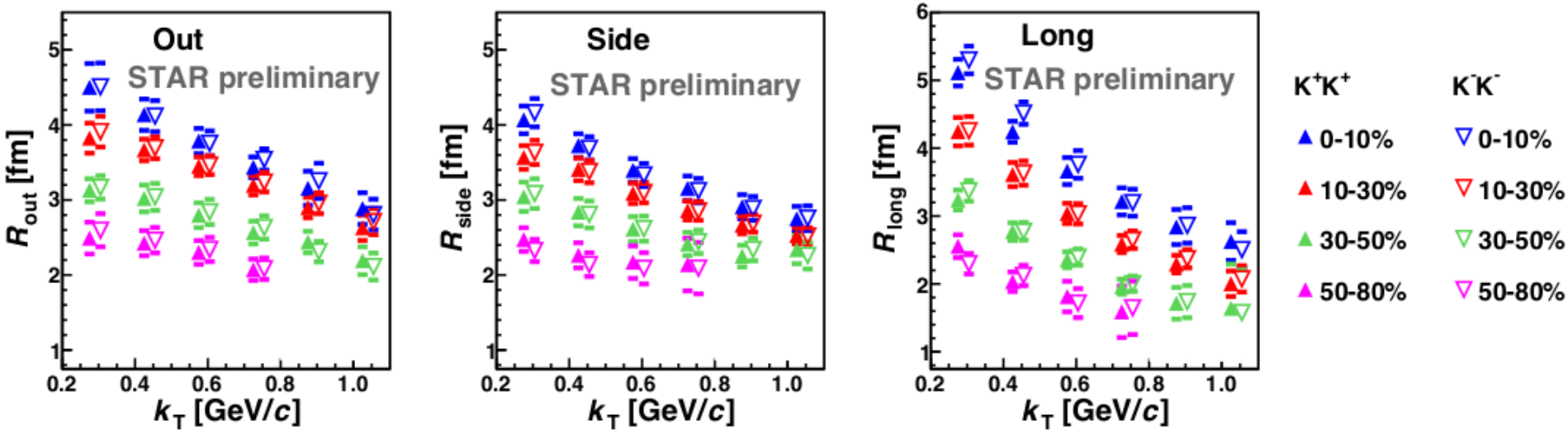




1. Extracted femtoscopic parameters are in agreement with the published data for all collisions centralities and transverse mass intervals
2. Can be done for all BES energies: 7.7, 11.5, 14.5, 19.6, 27, 39, 62.4, 200 GeV

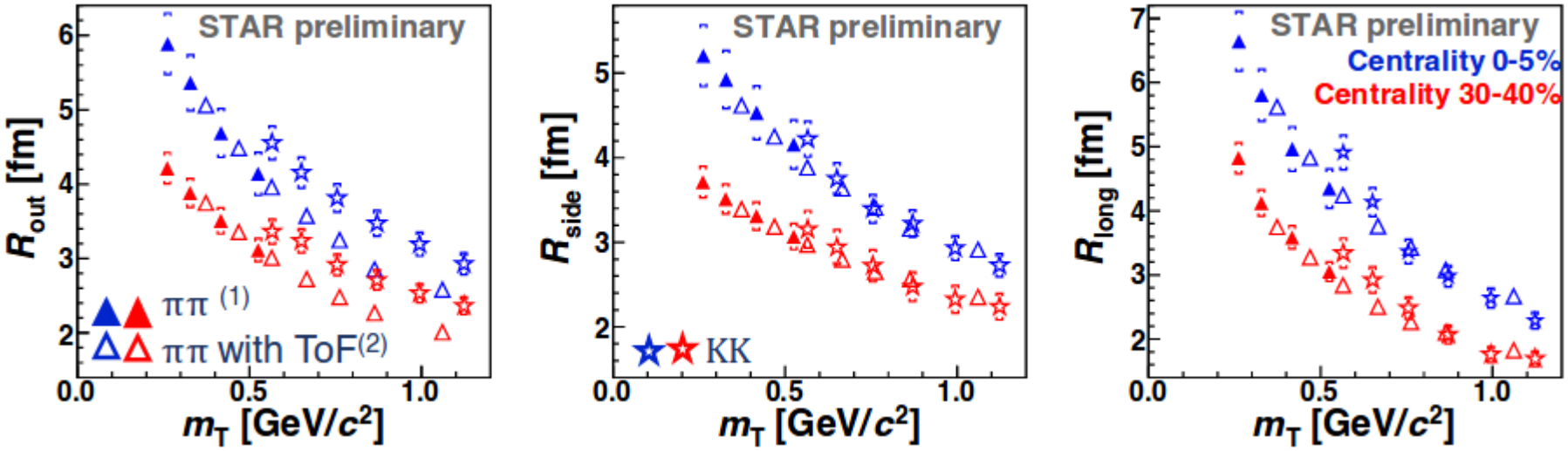
Charged kaons at top RHIC energy

Au+Au $\sqrt{s_{NN}}$ = 200 GeV



1. Measured femtoscopic radii for positive and negative kaon pairs agree with each other within the uncertainties
2. Extracted radii decrease with increasing transverse momentum – influence of the collective radial flow S. Akkelin et al. Phys. Lett. B 356 (1995) 525

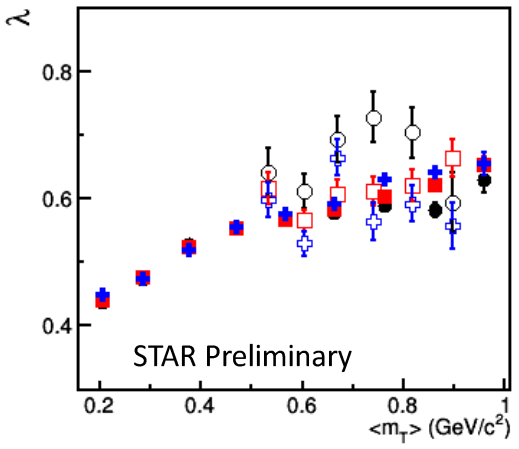
Results from 200 GeV

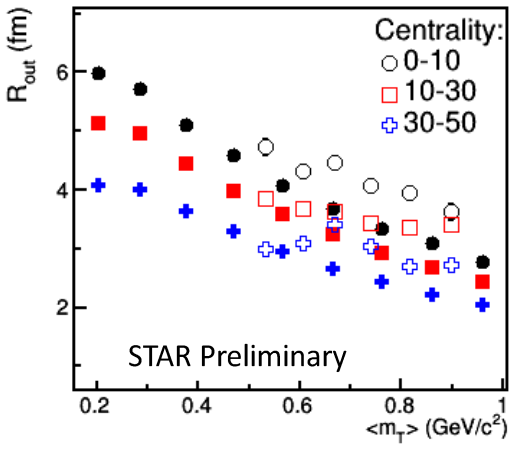


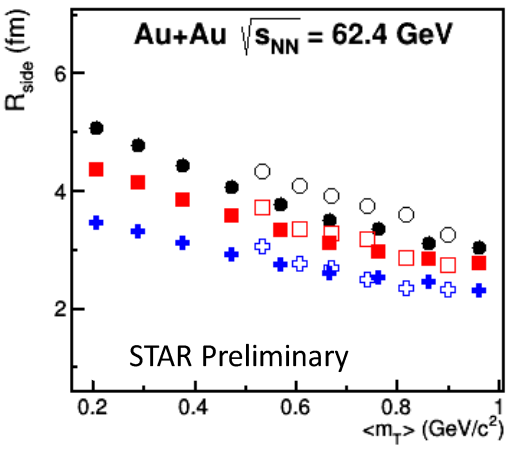
- Extending transverse mass region (up to 1 GeV/c^2) using particle identification from the Time-Of-Flight detector
- Pion results are consistent with the previous analysis(1)
- R_{side} trend for kaons is similar to that of pions
- R_{out} and R_{long} of pion and kaon source radii follow different m_T dependences
- $R_{long}(K) > R_{long}(\pi)$
  - Contribution from long-lived resonances at the kinetic freeze-out? (3)

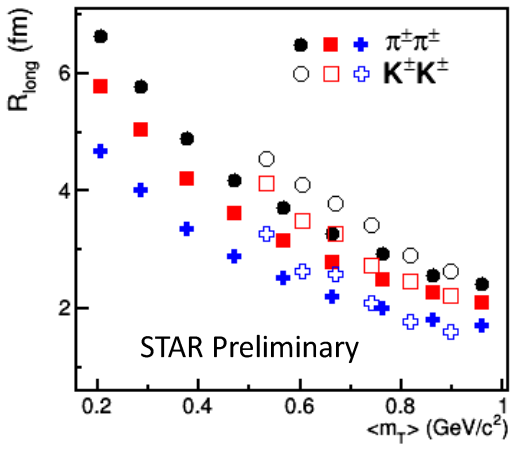
(1) STAR, Phys. Rev. C 92 (2015) 014904
(2) This analysis: STAR Preliminary
(3) Yu.M. Sinyukov, et al. Nucl. Phys. A 946 (2015) 227

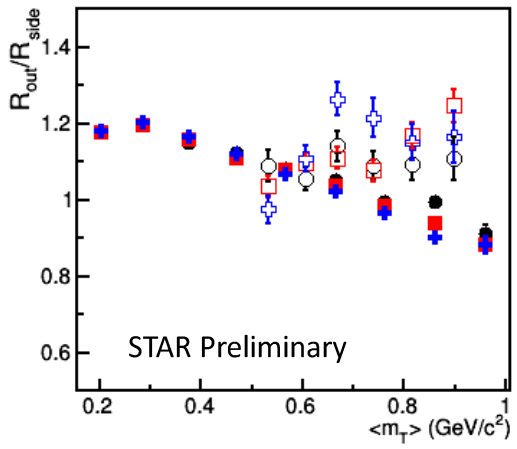
Results from 62.4 GeV







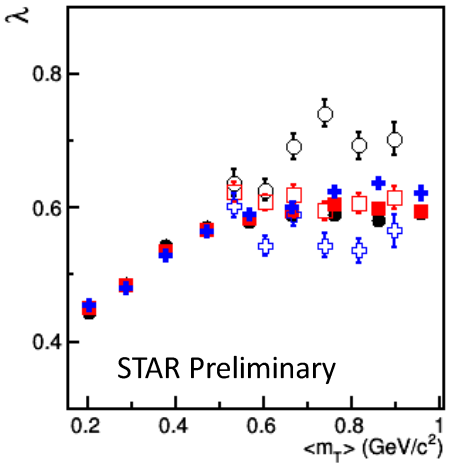


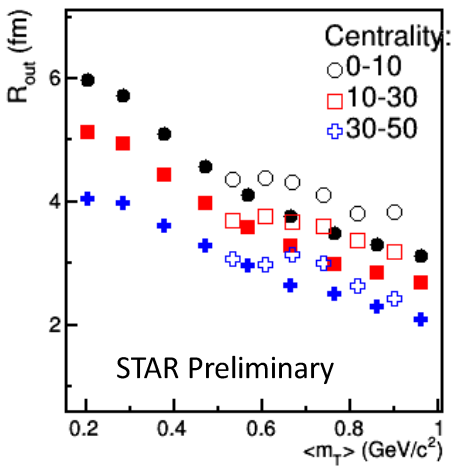


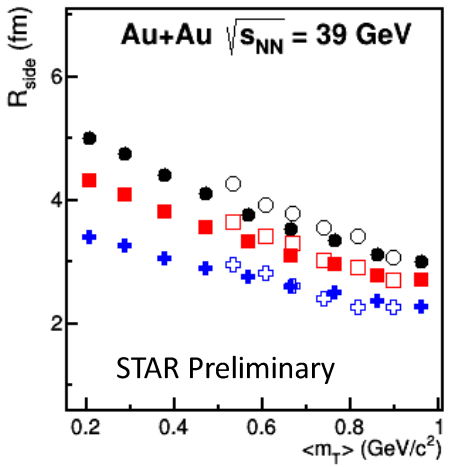
Only statistical uncertainties

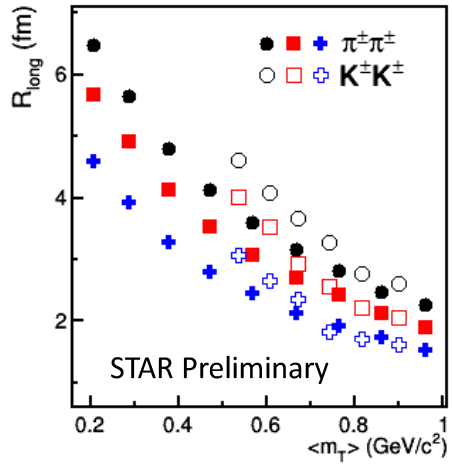
- Kaon femtoscopic radii in outward and longitudinal directions are generally larger than those for pions at the same m_T → breaking of the m_T-scaling
- In the sideward direction, the pion and kaon radii are closer than in other directions

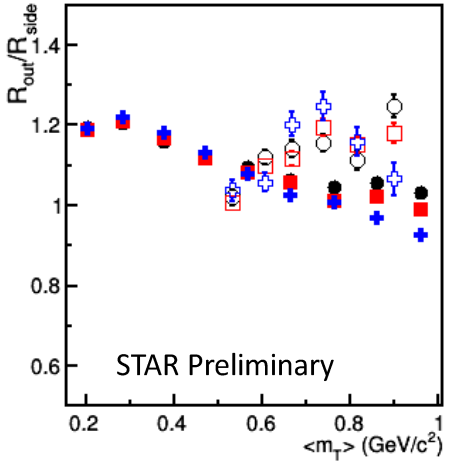
Results from 39 GeV







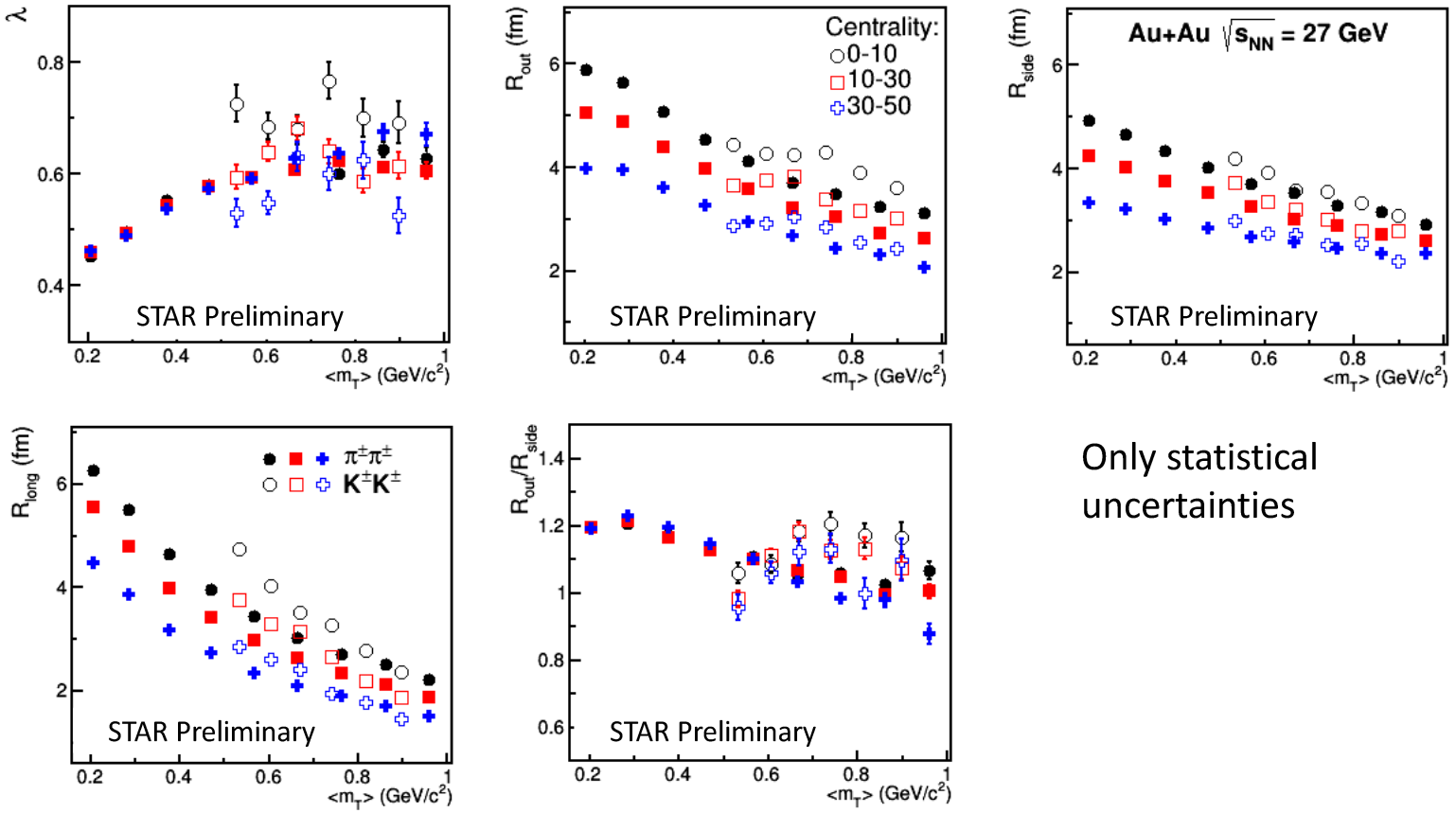




Only statistical uncertainties

- Kaon femtoscopic radii in outward and longitudinal directions are generally larger than those for pions at the same m_T → breaking of the m_T-scaling
- In the sideward direction, the pion and kaon radii are similar

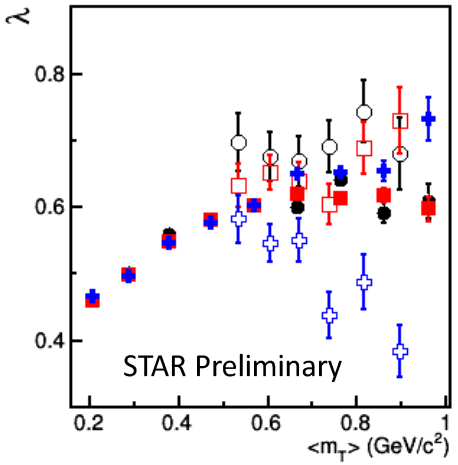
Results from 27 GeV

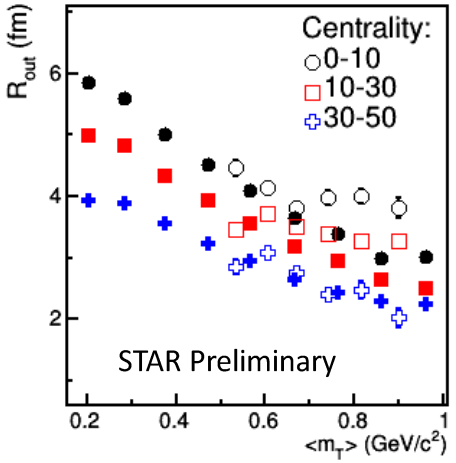


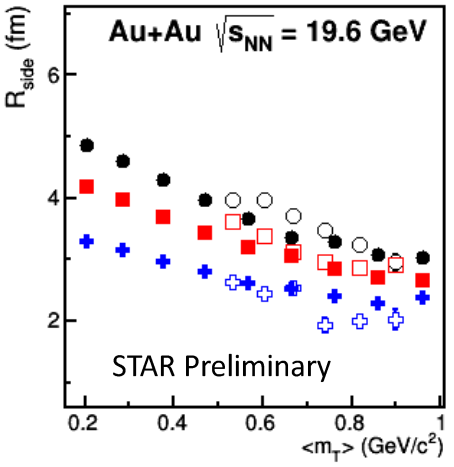
Only statistical uncertainties

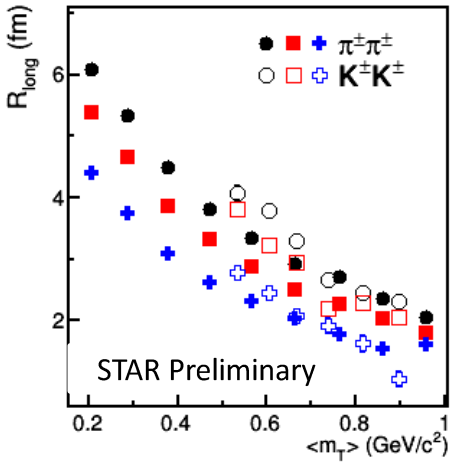
- Kaon femtoscopic radii in outward and longitudinal directions are generally larger than those for pions at the same m_T → breaking of the m_T-scaling
- In the sideward direction, the pion and kaon radii are similar

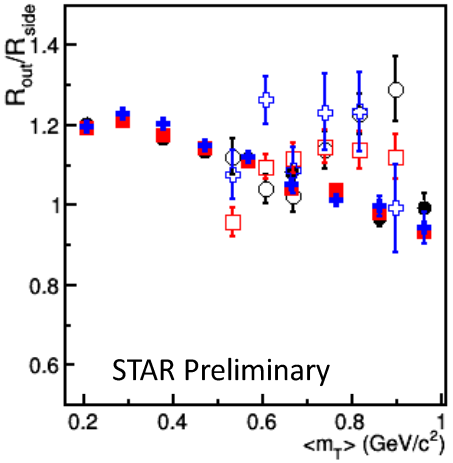
Results from 19.6 GeV







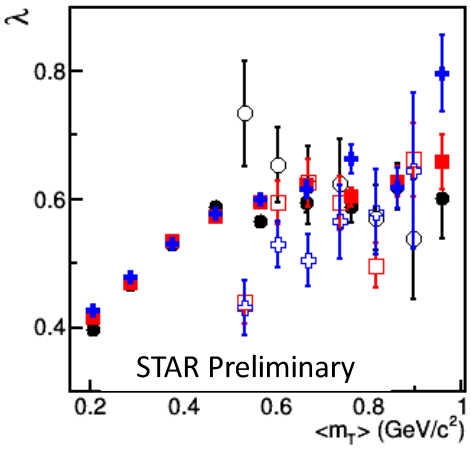


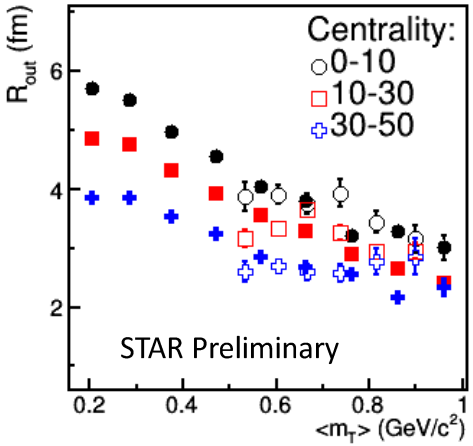


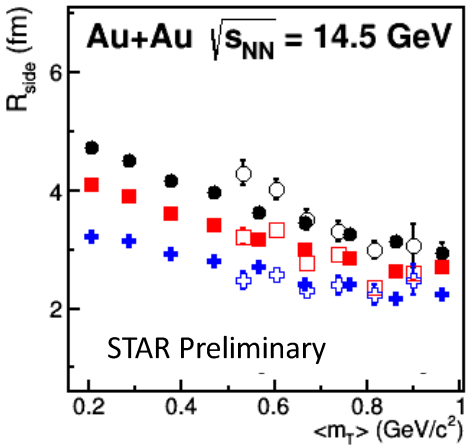
Only statistical uncertainties

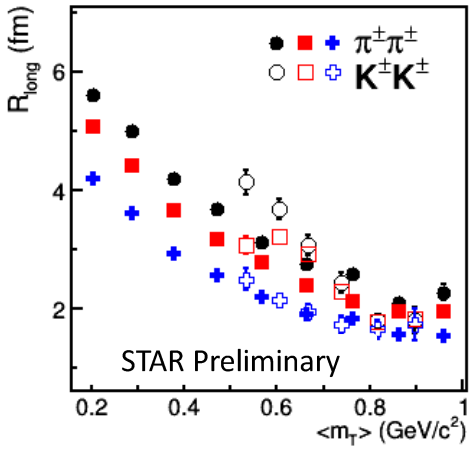
- Less differences between kaon and pion femtoscopic parameters in outward and sideward directions compared to the higher energies

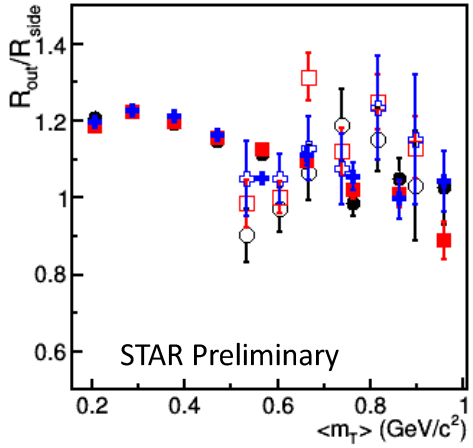
Results from 14.5 GeV







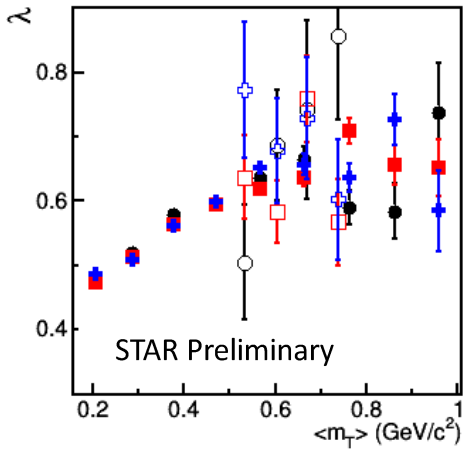


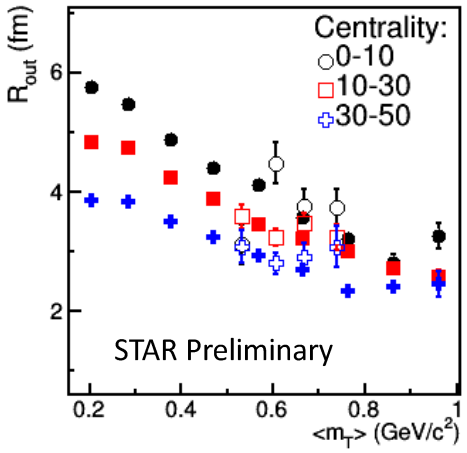


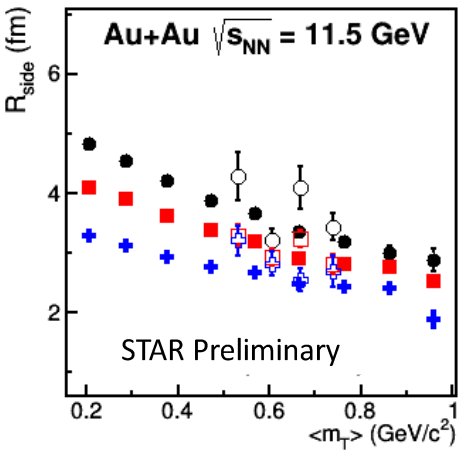
Only statistical uncertainties

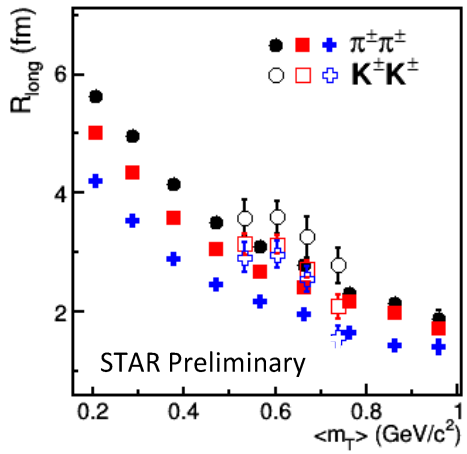
- Less differences between kaon and pion femtoscopic parameters in outward and sideward directions compared to the higher energies

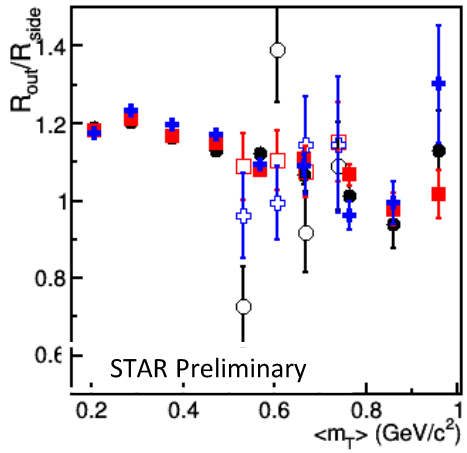
Results from 11.5 GeV











Only statistical uncertainties

- Less differences between kaon and pion femtoscopic parameters in outward and sideward directions compared to the higher energies

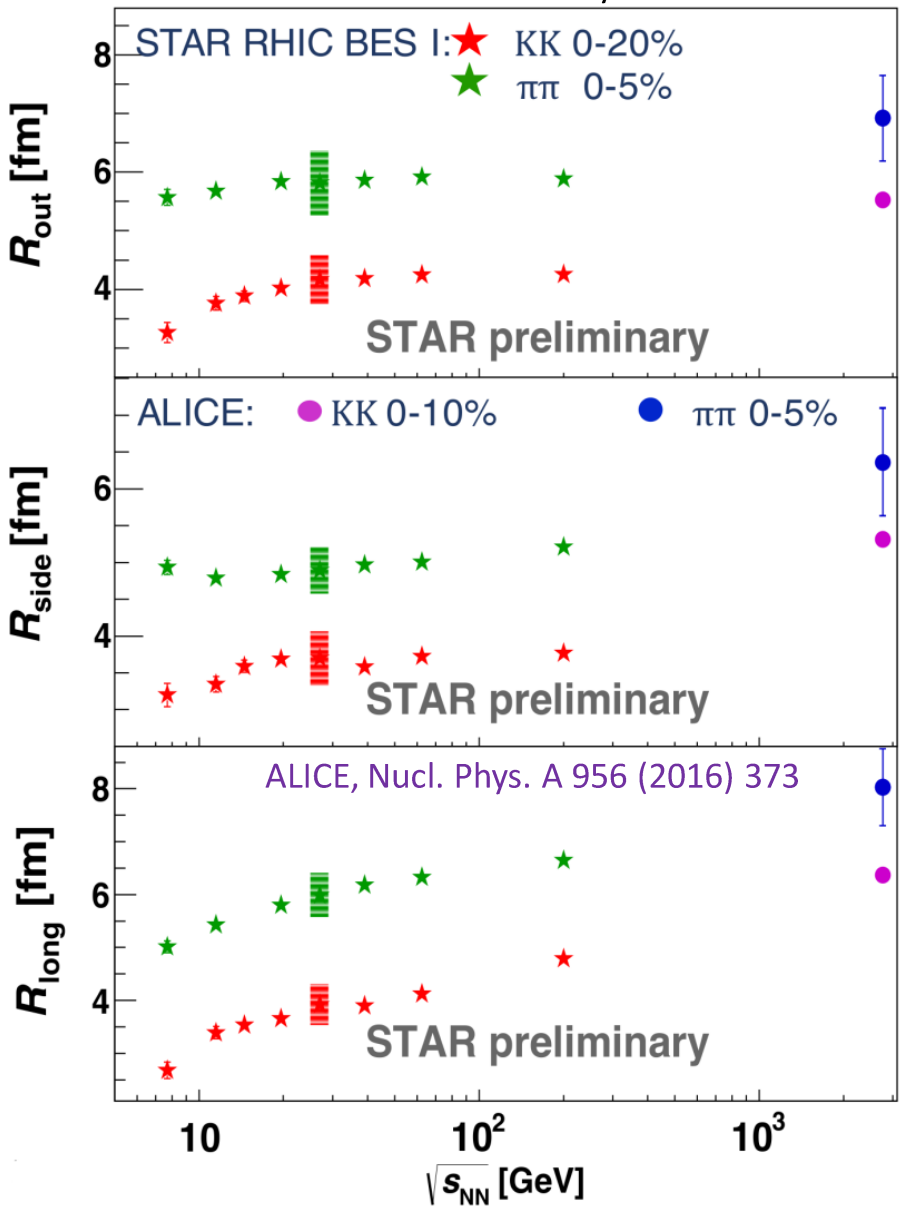
Radii from Beam Energy Scan I

Shaded boxes represent systematic uncertainties

The extracted femtoscopic radii smoothly increase with increasing collision energy

The values of R_{out} and R_{side} for both pions and kaons show a very small increase at the RHIC energies and slightly larger at the LHC

The values of R_{long} suggest that the system lives longer at the LHC energy



Summary

- Centrality dependence of the ππ and KK femtoscopic parameters is measured for Au+Au collisions at 7.7, 11.5, 14.5, 19.6, 27, 39, 62.4 and 200 GeV

- Pion results (with the extended m_T region) are consistent with the published data

- Pion and kaon radii seem to follow different m_T dependence
  - Need model comparisons (iHKM, vHLLE, UrQMD, …)

- R_{out}, R_{side} and R_{long} for pions and kaons smoothly increase with increasing energy at RHIC