Pion and kaon Bose-Einstein correlations from the BES program at STAR

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Motivations

- Measurement of space-time parameters of 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 are measured in the Beam Energy Scan program at RHIC (AGS, SPS, LHC, …)
- Pion interferometry in Au+Au collisions 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
- Kaon femtoscopy: provides complementary information because they are less affected by resonance decays, contain strange quark, heavier than pions

Correlation function

- Two-particle correlation function:

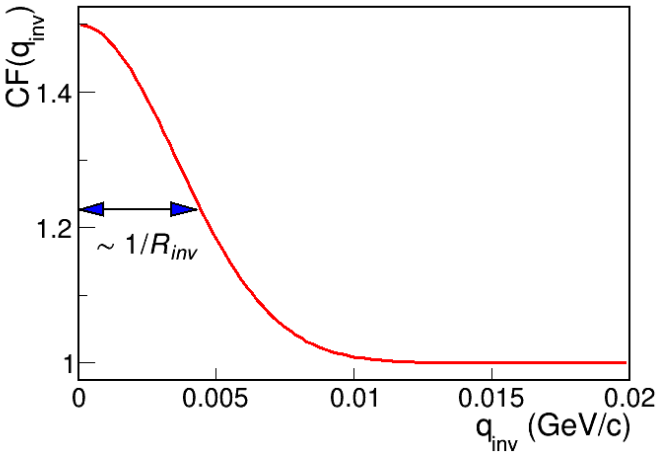
$$CF(p_1, p_2)=\int d^3r\, S(r, k)\, |\Psi_{1,2}(r, k)|^2$$

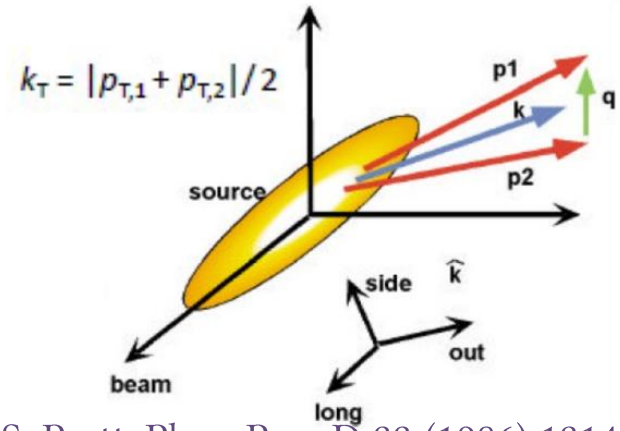
$$r=x_1-x_2 \text{ and } q\equiv q_{inv}= p_1 - p_2$$

- 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):

$$C_2(q_{out}, q_{side}, q_{long}) = N(1-\lambda+\lambda K(q_{inv})(1+\exp(-R_{out}^2 q_{out}^2 - R_{side}^2 q_{side}^2 - R_{long}^2 q_{long}^2))$$

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

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

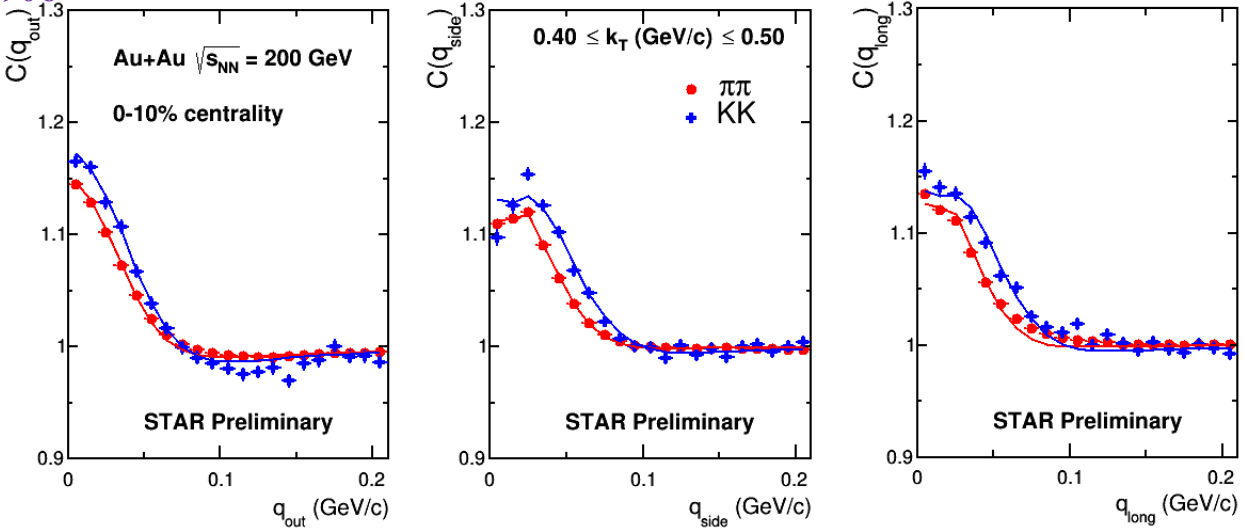
- Fit using Log-likelihood method:
  E-802. Phys. Rev. C 66 (2002) 054906

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

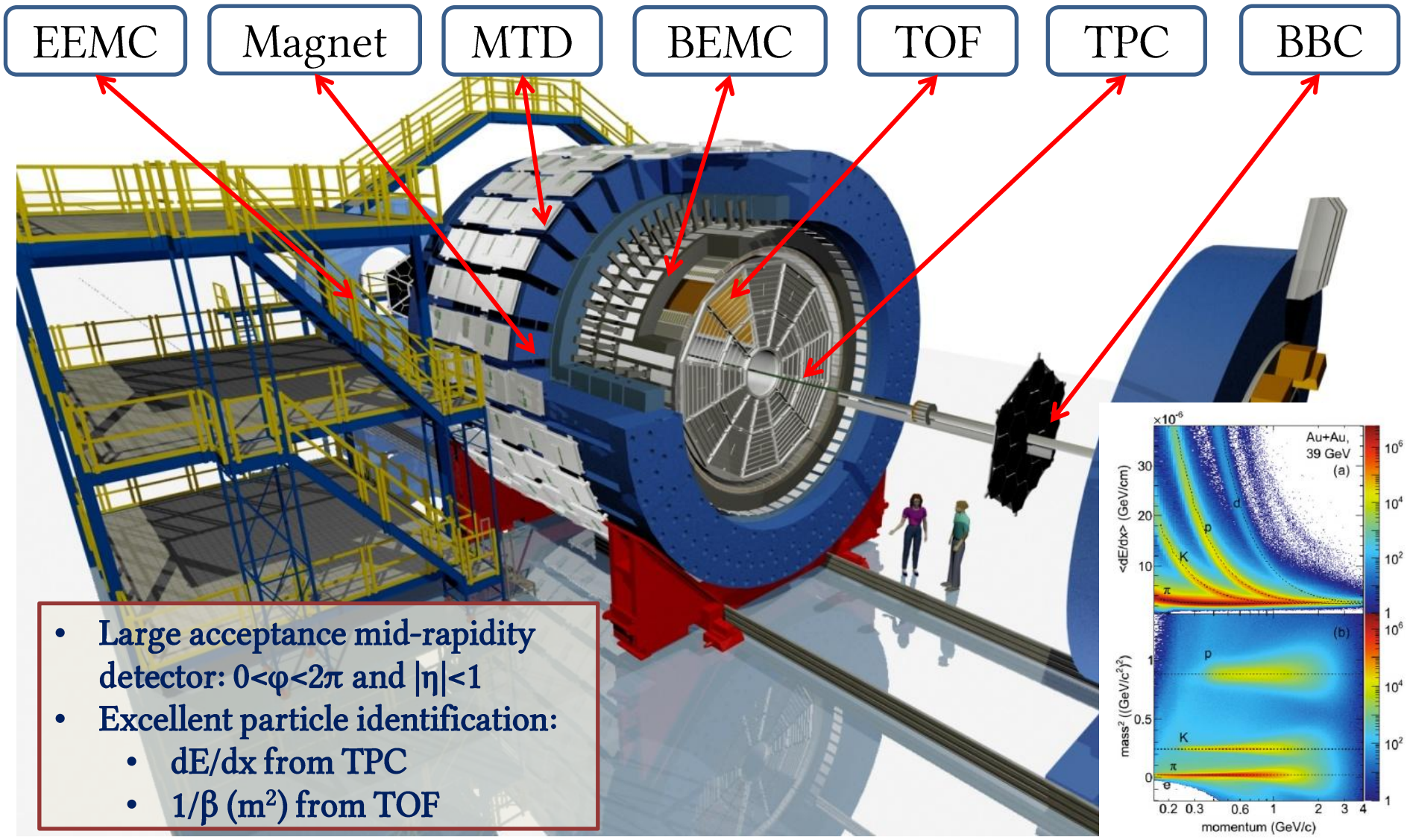
- Fit example →

Out, side and long projections of 3D ππ and KK correlation functions

Fit shows a good description of the data



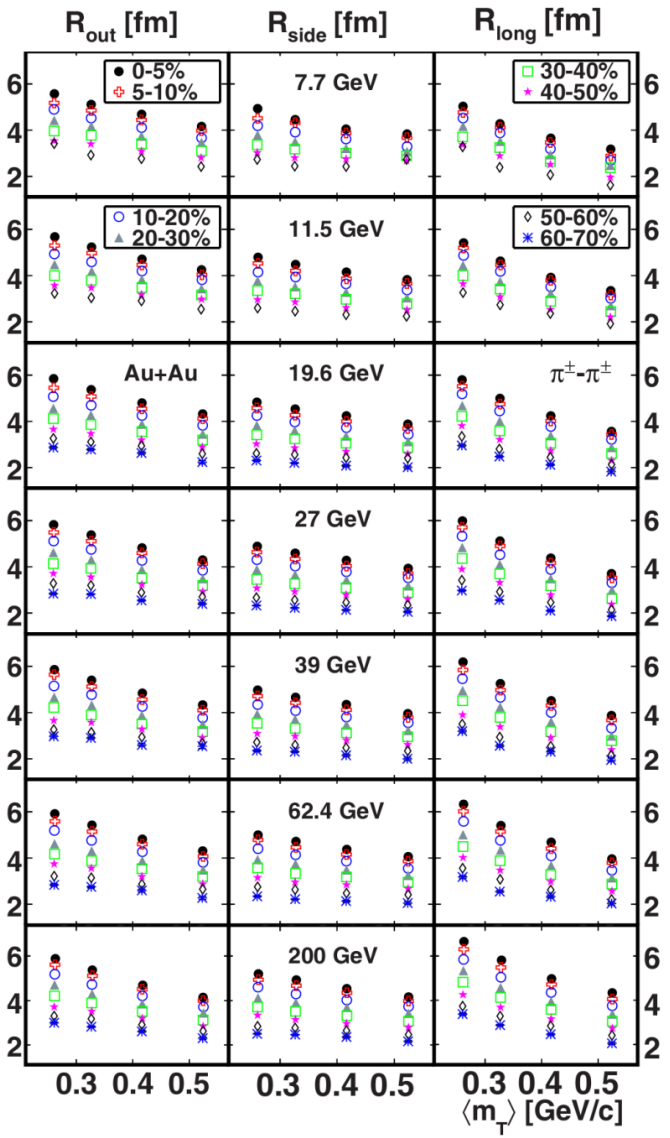
Solenoidal Tracker At RHIC



- 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

Pion femtoscopy in STAR

STAR, PRC 92 (2015) 014904

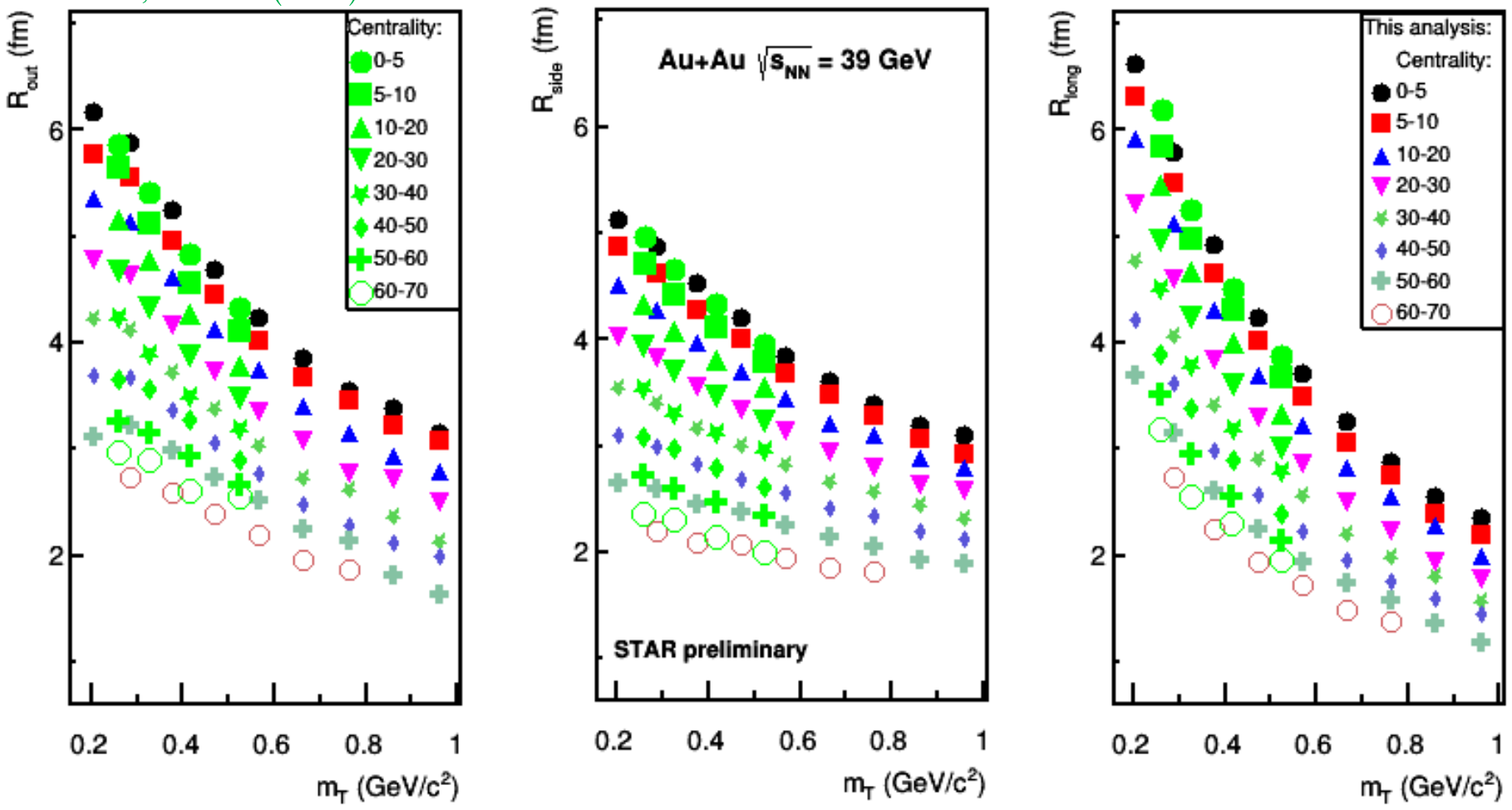


- Pion correlations have been extensively measured in STAR
- The decrease of the femtoscopic radii with increasing transverse mass $m_T = \sqrt{k_T^2 + m^2}$ is attributed to the hydrodynamic flow in heavy-ion collisions
- To make the comparison with kaons, the extension to the higher m_T is needed.
- 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: $\|n\sigma_K\|<3$, $0.20 < m_K^2$ $(GeV/c^2)^2 < 0.32$

Comparison to the published data

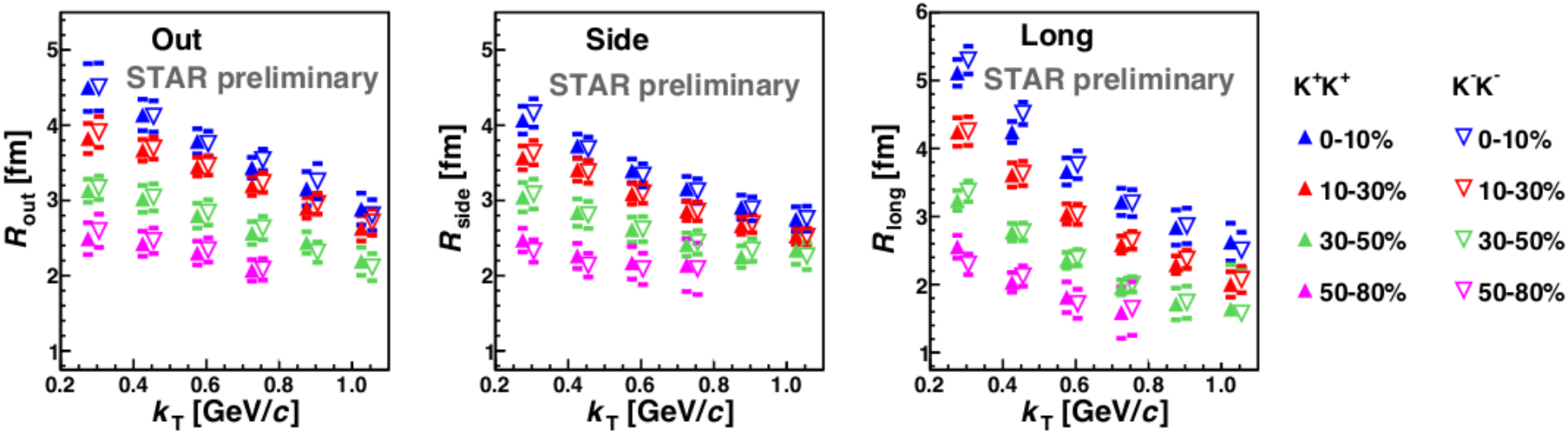
STAR, PRC 92 (2015) 014904



1. Extracted femtoscopic parameters are in a good 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

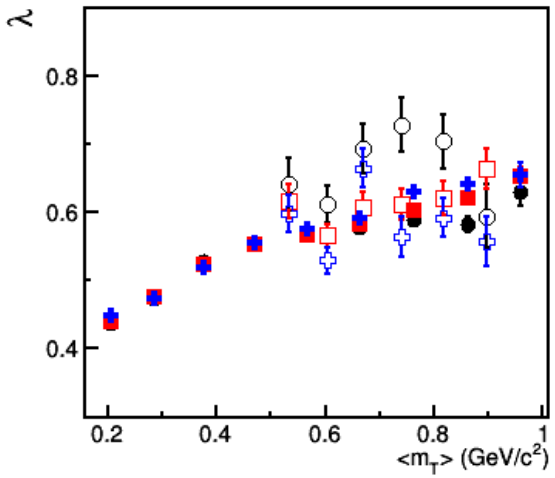
Charged kaons

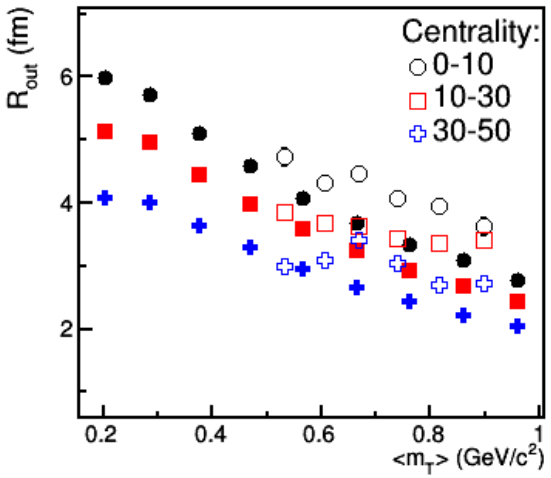
Au+Au $\sqrt{s_{NN}}$ = 200 GeV

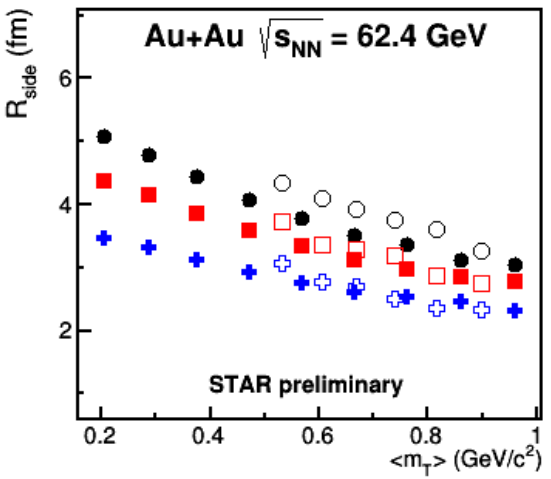


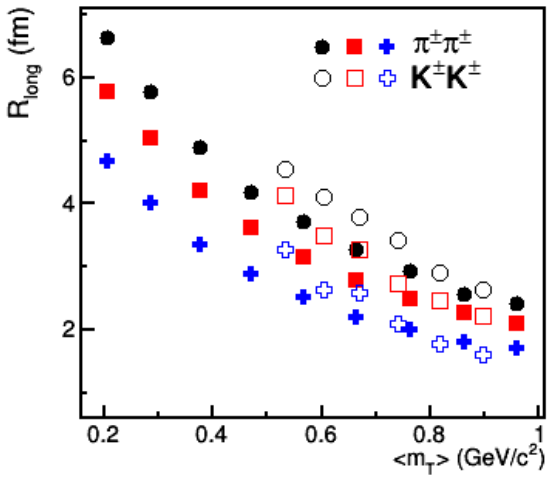
1. Measured femtoscopic radii for positive and negative kaon pairs agree with each other within the uncertainties
2. Extracted radii decrease with increasing transverse momentum – influence of the collective radial flow S. Akkelin et al. Phys. Lett. B 356 (1995) 525

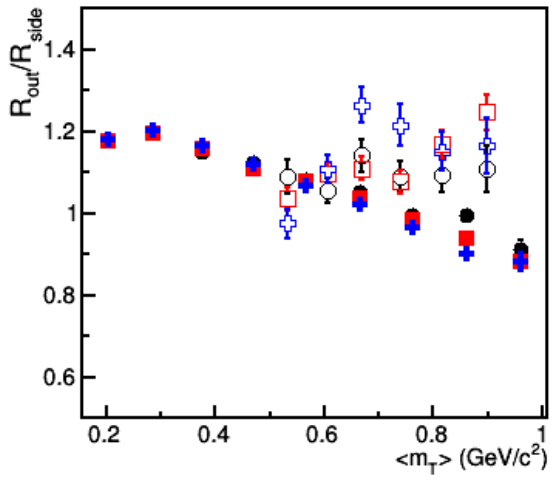
KK and ππ femtoscopy at $\sqrt{s_{NN}}$=62.4 GeV







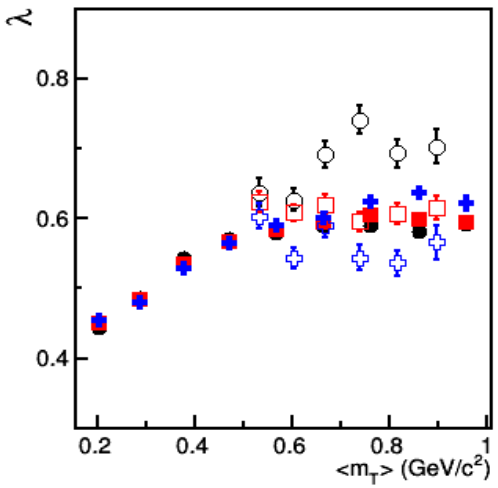


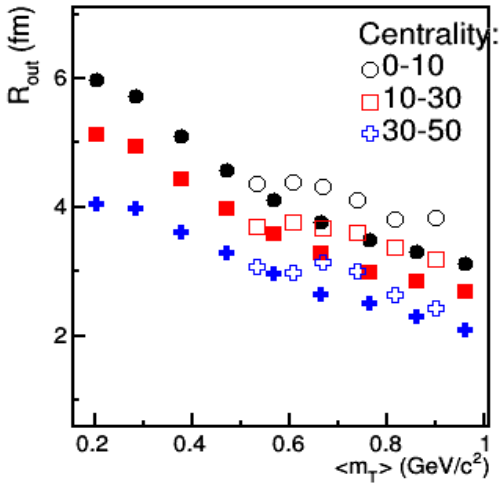


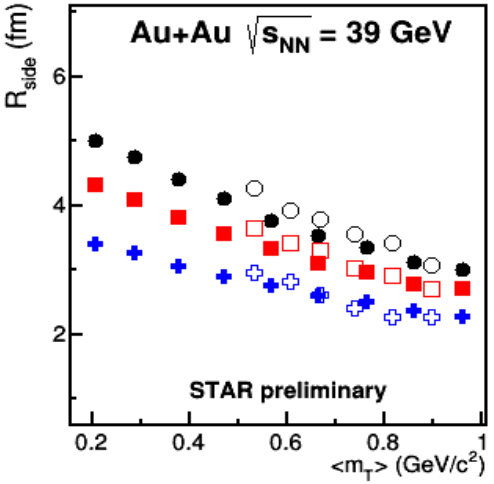
Statistical errors only

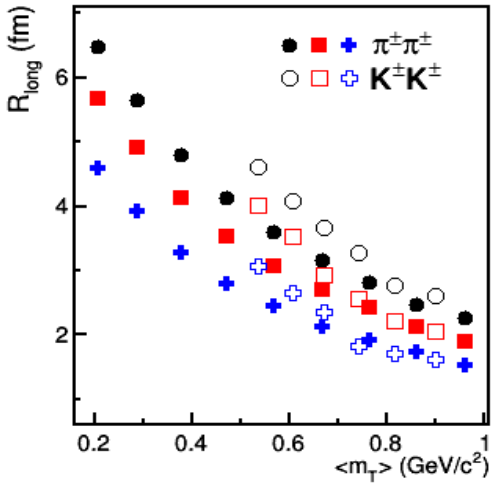
- Kaon femtoscopic radii in outward and longitudinal directions are generally larger than those for pions at the same m_T → breaking of the m_T-scaling
- In the sideward direction, the pion and kaon radii are similar

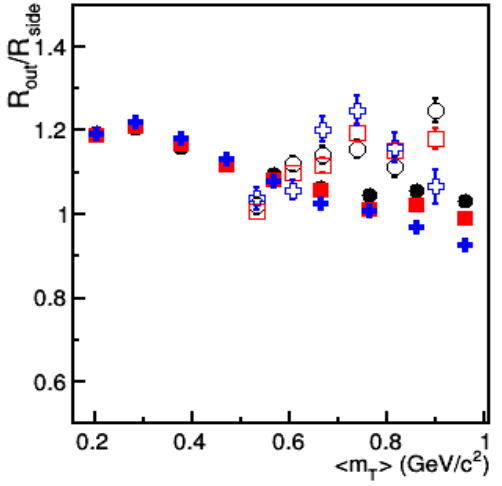
KK and ππ femtoscopy at $\sqrt{s_{NN}}$=39 GeV











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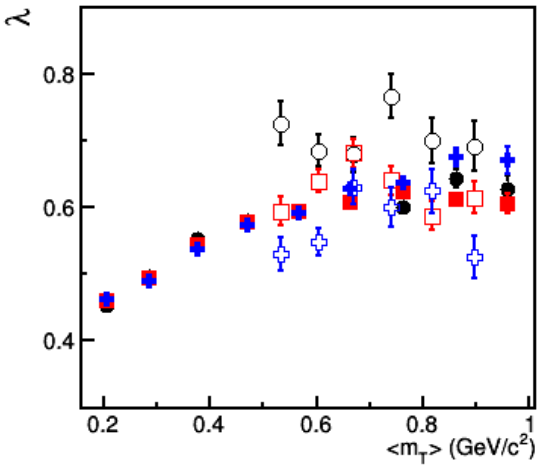
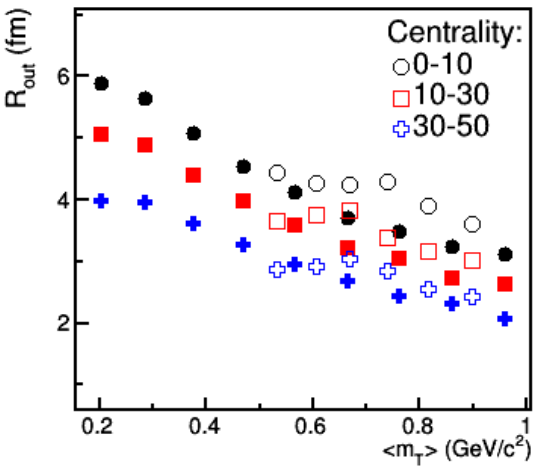
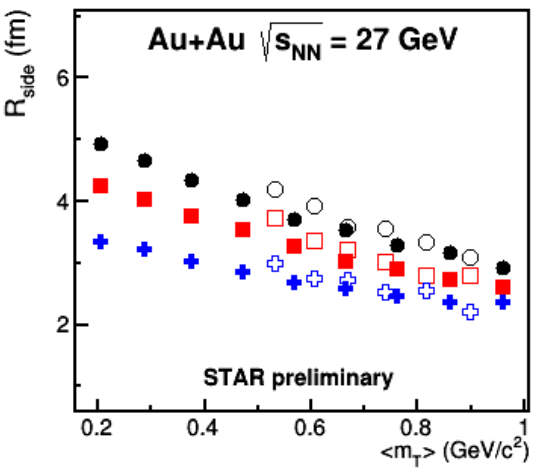
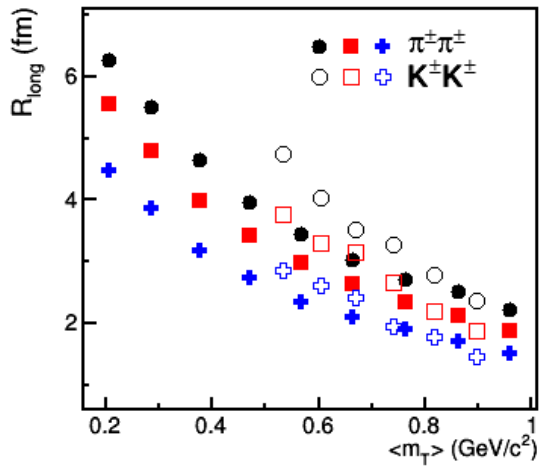
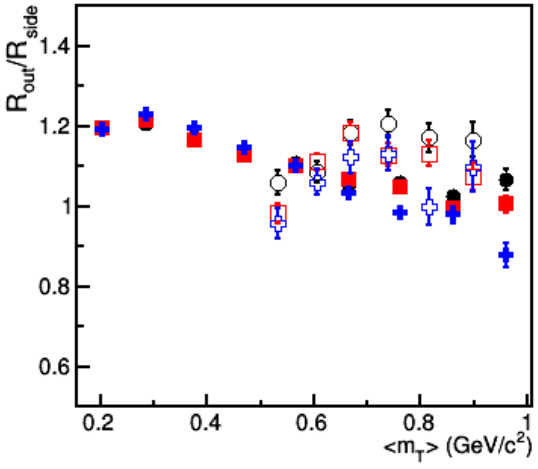
KK and ππ femtoscopy at $\sqrt{s_{NN}}$=27 GeV











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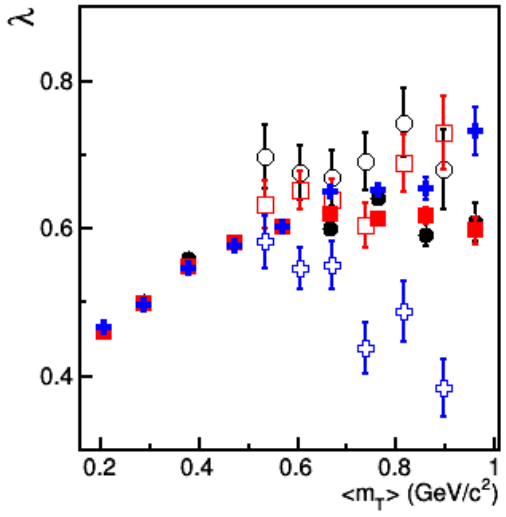
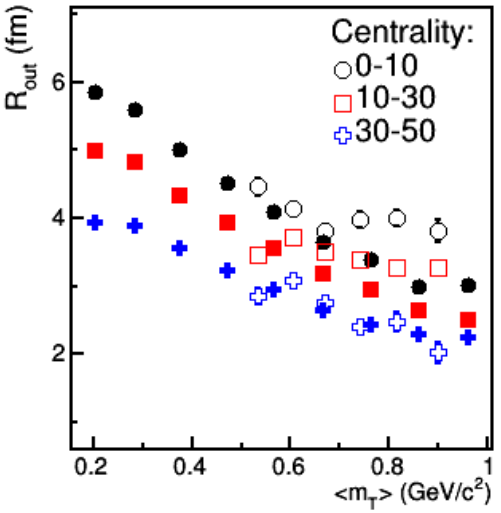
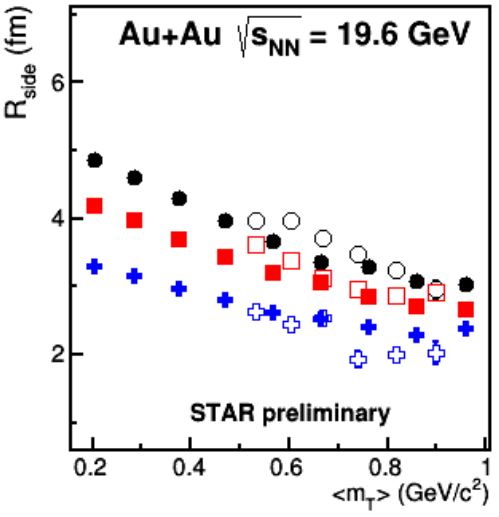
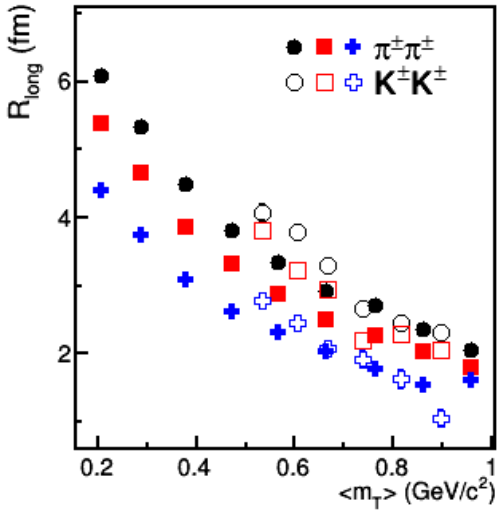
- In the sideward direction, the pion and kaon radii are similar

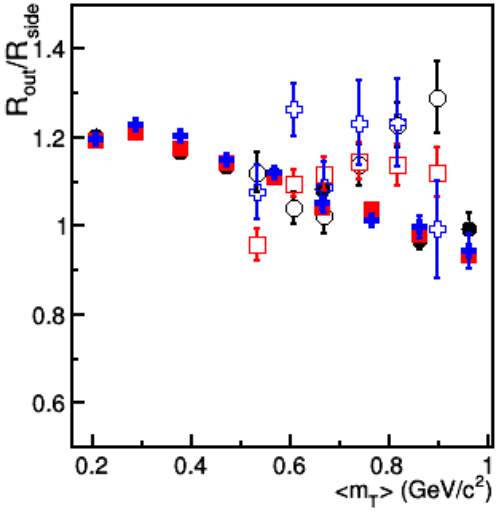
KK and ππ femtoscopy at $\sqrt{s_{NN}}$=19.6 GeV







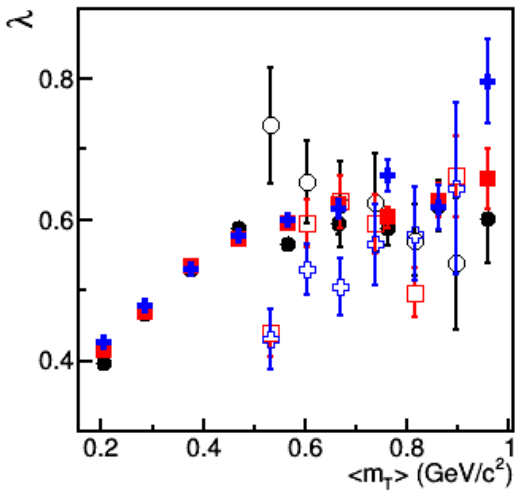


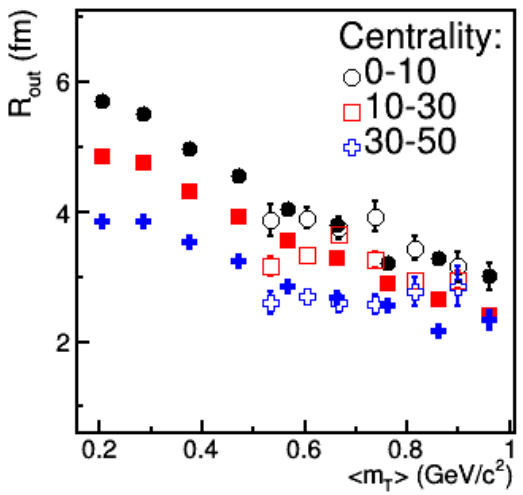


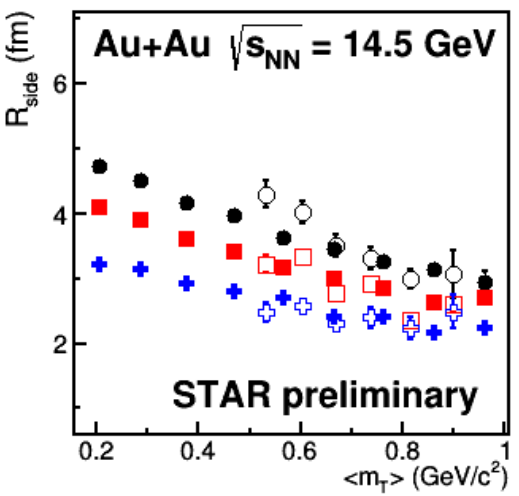
Statistical errors only

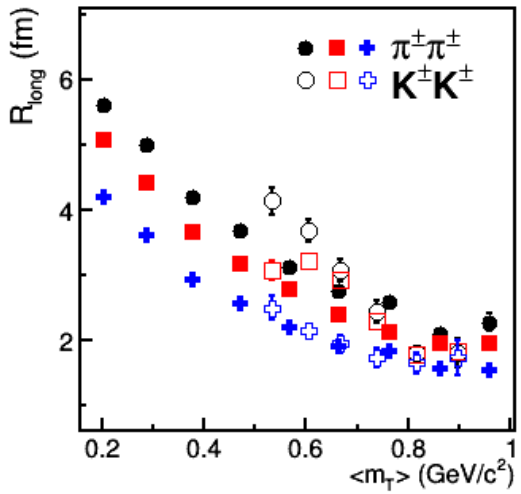
- Less differences between kaon and pion femtoscopic parameters at energies below 19.6 GeV

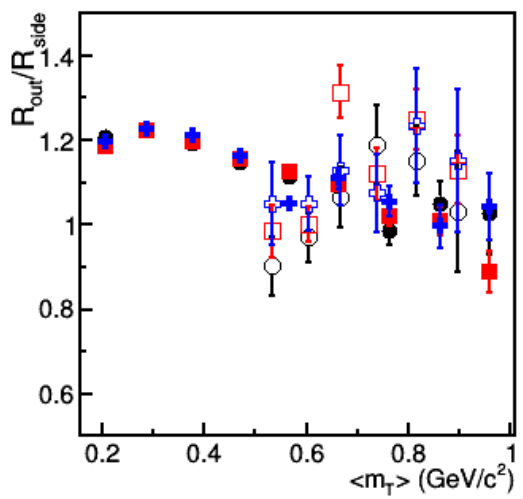
KK and ππ femtoscopy at $\sqrt{s_{NN}}$=14.5 GeV







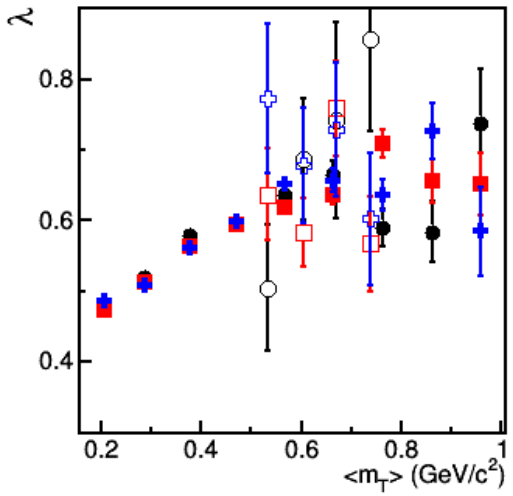


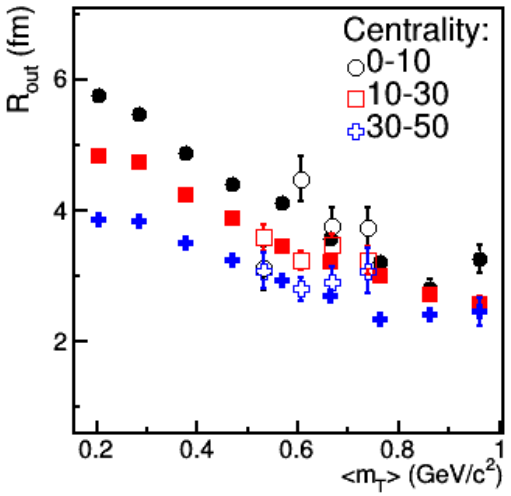


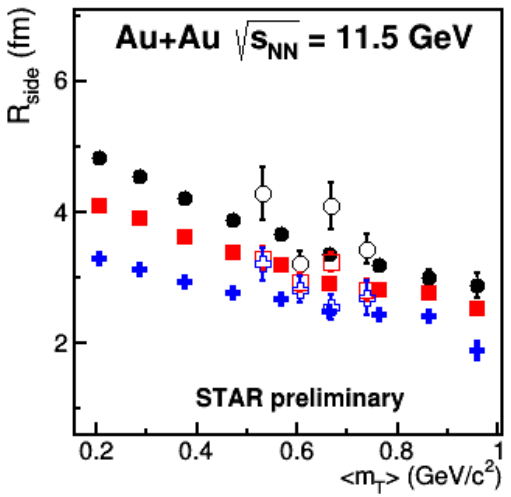
Statistical errors only

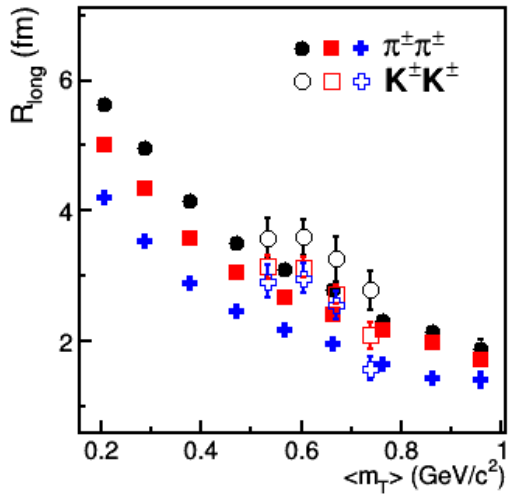
- Less differences between kaon and pion femtoscopic parameters at energies below 19.6 GeV

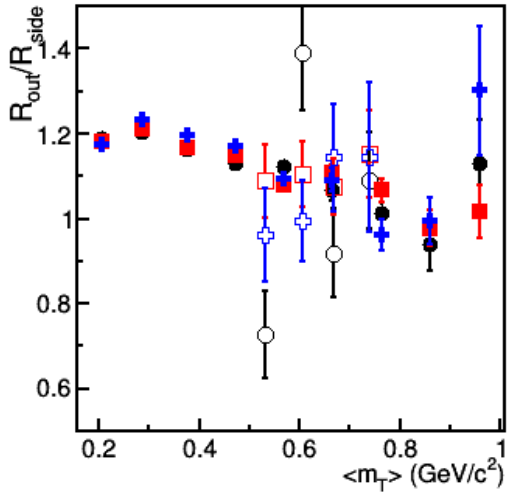
KK and ππ femtoscopy at $\sqrt{s_{NN}}$=11.5 GeV







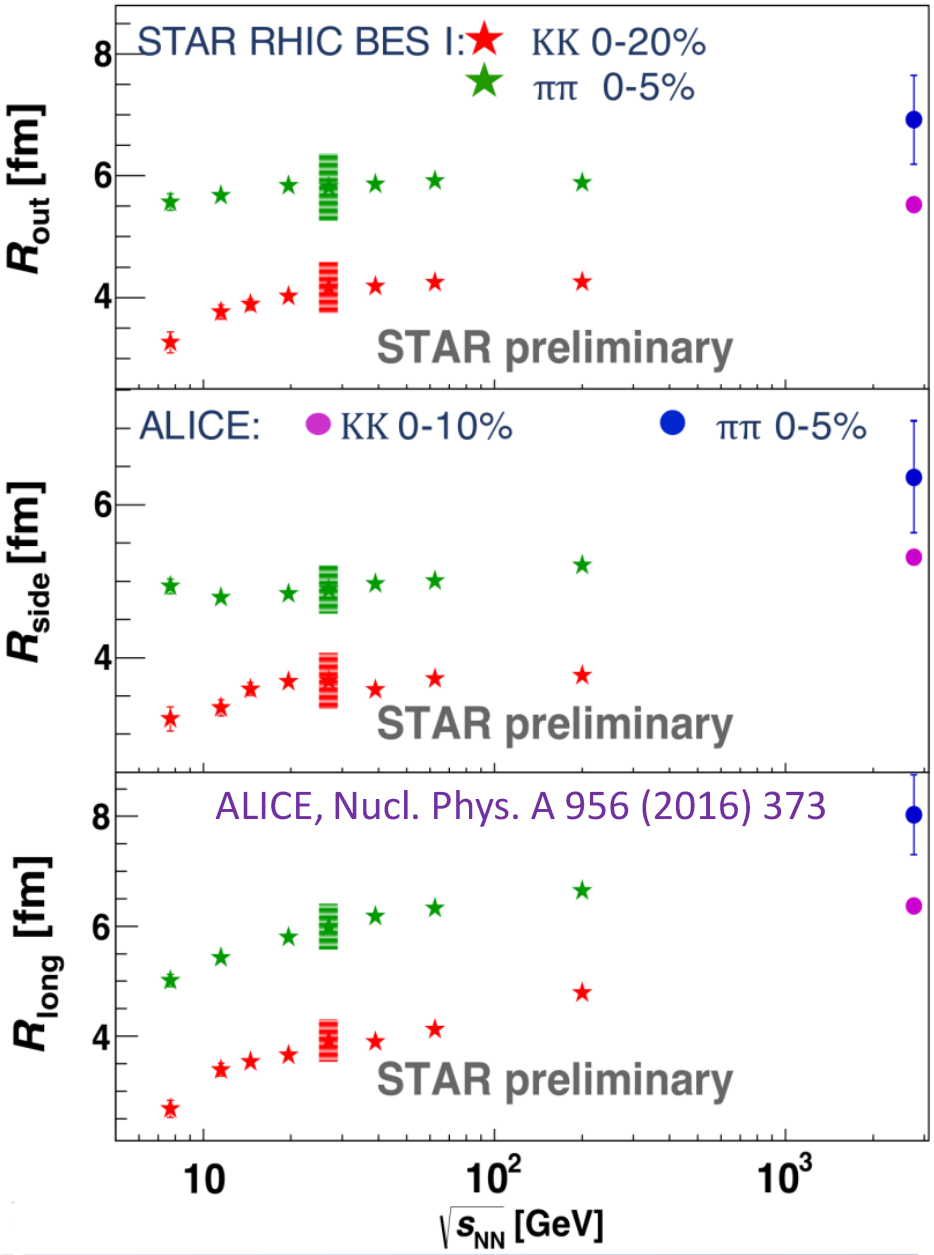




Statistical errors only

- Less differences between kaon and pion femtoscopic parameters at energies below 19.6 GeV

Results from the BES phase-I



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 rise at the LHC

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

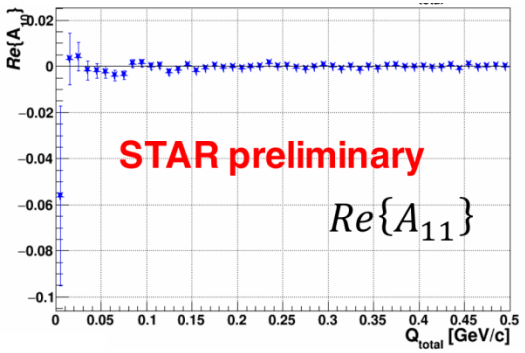
Summary:

- Centrality dependence of the ππ and KK femtoscopic parameters is measured for Au+Au collisions at 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 dependencies
- R_{out}, R_{side} and R_{long} for pions and kaons smoothly increase with increasing energy

Backup slides

Search for the differences in K^+K^+ and K^-K^-

Spherical harmonic decomposition of the K^+K^- correlation function (by Jindřich Lidrych at 16th Zimányi school)



- Example of SHD of CF
- For all BES energies $Re\{A_{1,1}(Q_{total})\}$ vanish within errors
- There isn't asymmetry between particle sources -> we can merge K^+K^+ & K^-K^- pairs for BES energies