Kaon femtoscopy at the STAR experiment

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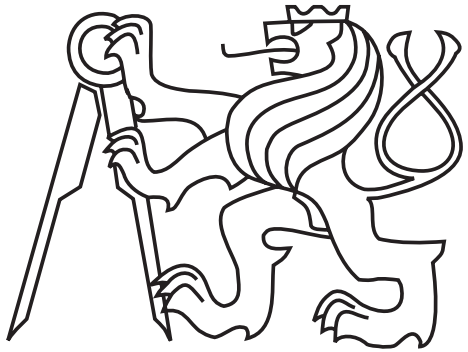
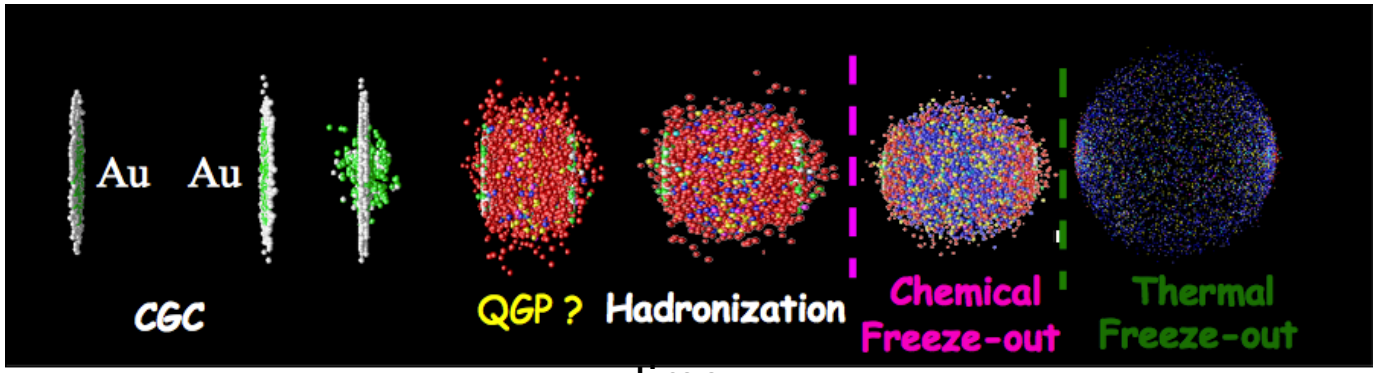
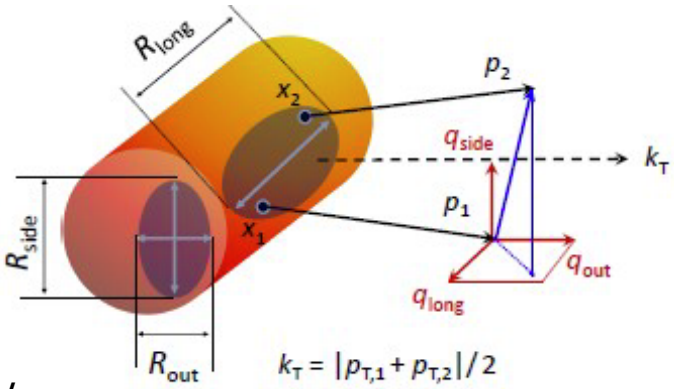
5^{th} – 6^{th} October 2016



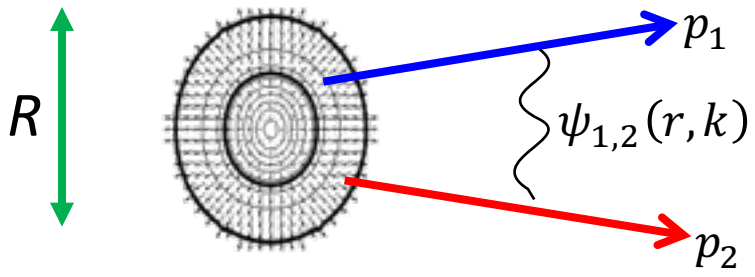
Femtoscopy

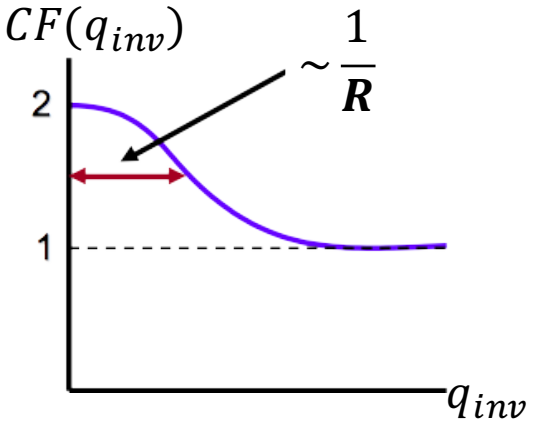




- Study space-time extents of the source at the thermal freeze-out
- Correlation function: $CF(p_1, p_2) = \int d^3r S(r,k) \left|\psi_{1,2}(r,k)\right|^2$

$$r = x_1 - x_2 \quad q_{inv} = p_1 - p_2 = 2k^*$$





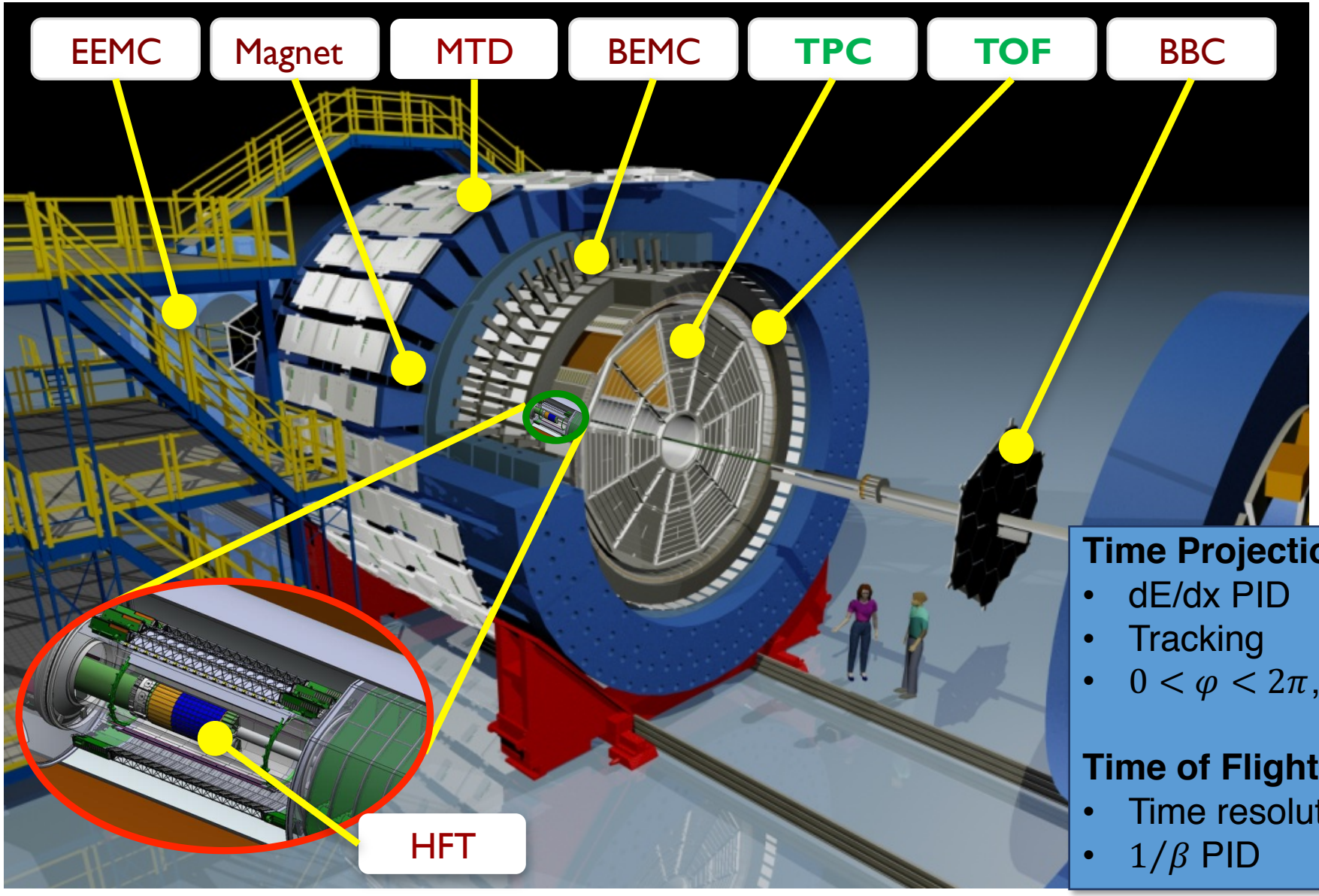
Femtoscopy with kaons – a cleaner probe

In comparison with the most abundant pions, there are following advantages

- Less feed-down – smaller contamination with non-primary kaons from resonance decays
- Smaller cross section – information about a different stage of the collisions evolution
- Kaons contain strange quark

However, more difficult due to ~10 smaller statistics

STAR Experiment at RHIC



Time Projection Chamber
- dE/dx PID
- Tracking
- $0 < \varphi < 2\pi$, $|\eta| < 1$

Time of Flight
- Time resolution < 80ps
- $1/\beta$ PID

Charged kaon femtoscopy for BES

RHIC Beam Energy Scan

- One of the main physics program at the RHIC
- The goal of Beam Energy Scan:
  - Find the QCD critical point
  - 1st order phase transition signs
  - Turn-off sQGP signatures

$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	#Events	#Weeks	Year
200	20	350 M	11	2010
62.4	70	67 M	1.5	2010
39.0	115	130 M	2	2010
27.0	155	70 M	1	2011
19.6	205	36 M	1.5	2011
14.5	260	20 M	3	2014
11.5	315	12 M	2	2010
7.7	420	4 M	4	2010

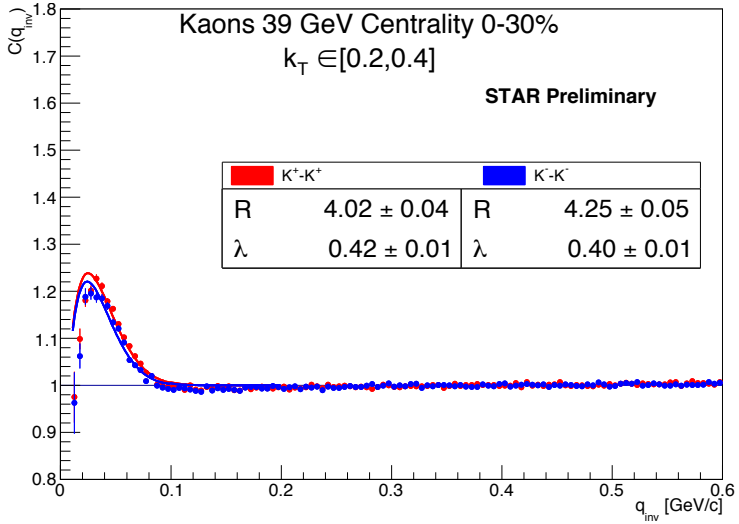
1D femtoscopic analysis of charged kaons

- Motivation: Is there a different between K^+ and K^- source?
- 6 energies: 7.7, 11.5, 14.5, 19.6, 27 and 39 GeV
- 2 centrality bins (0-30% and 30-80%)
- 2 k_T bins (0.2-0.4 GeV/*c* and 0.4-0.6 GeV/*c*)
- Fitting function: *Phys. Lett., B270:69–74, 1991*

$$CF(q_{inv}) = \left[(1-\lambda) + \lambda K(q_{inv}, R_{inv})(1 + e^{-R_{inv}^2 q_{inv}^2})\right]\mathcal{N},$$

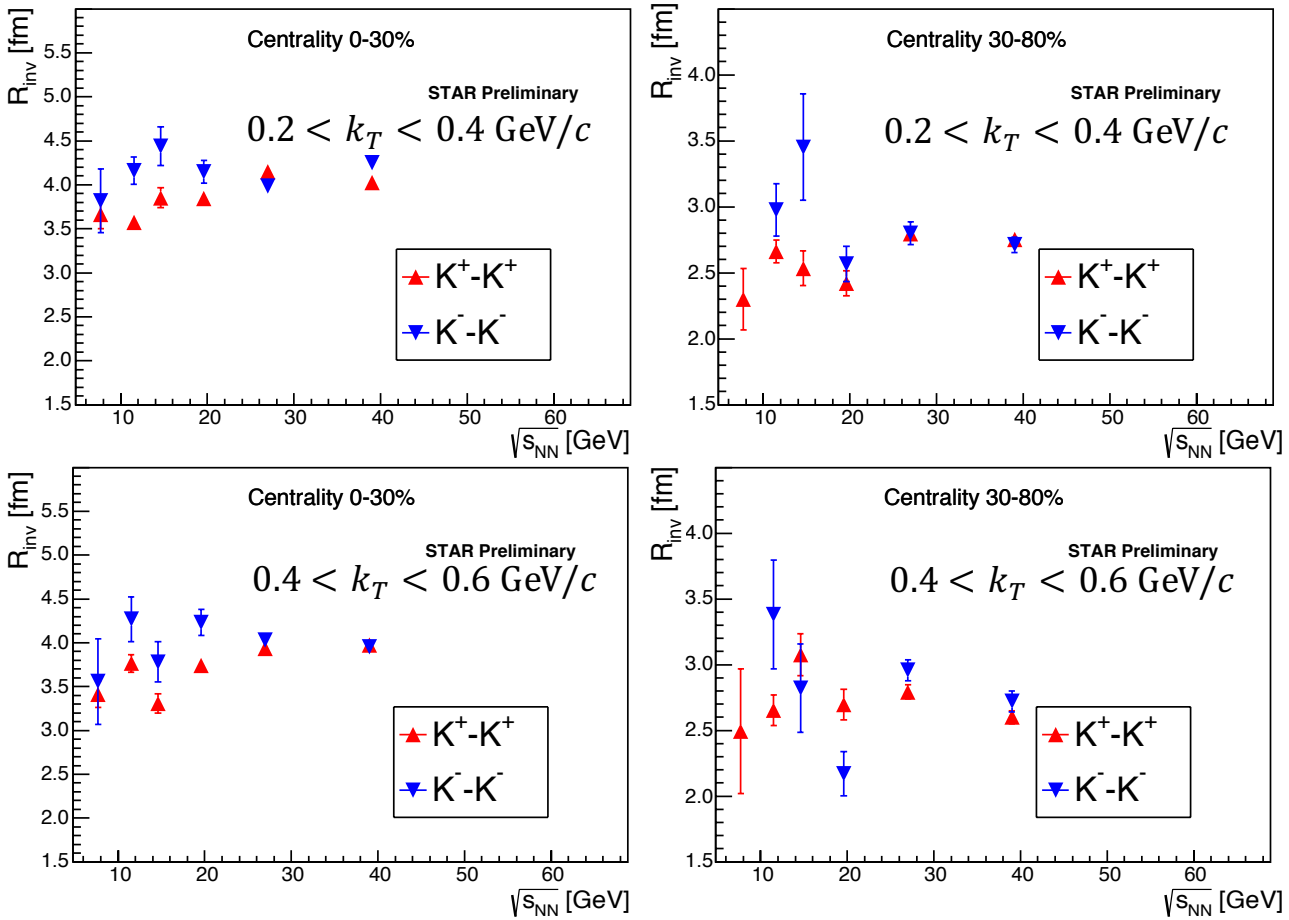
where R_{inv}– source radii, λ – correlation strength, $K(q_{inv}, R_{inv})$ – Coulomb function and $\mathcal{N}$ – normalization

Martin Girard from WUT



Results from kaon femtoscopy for BES

- No clear beam energy dependence visible
- Possible different behavior for K^+ and K^- for energy 10-20 GeV ?



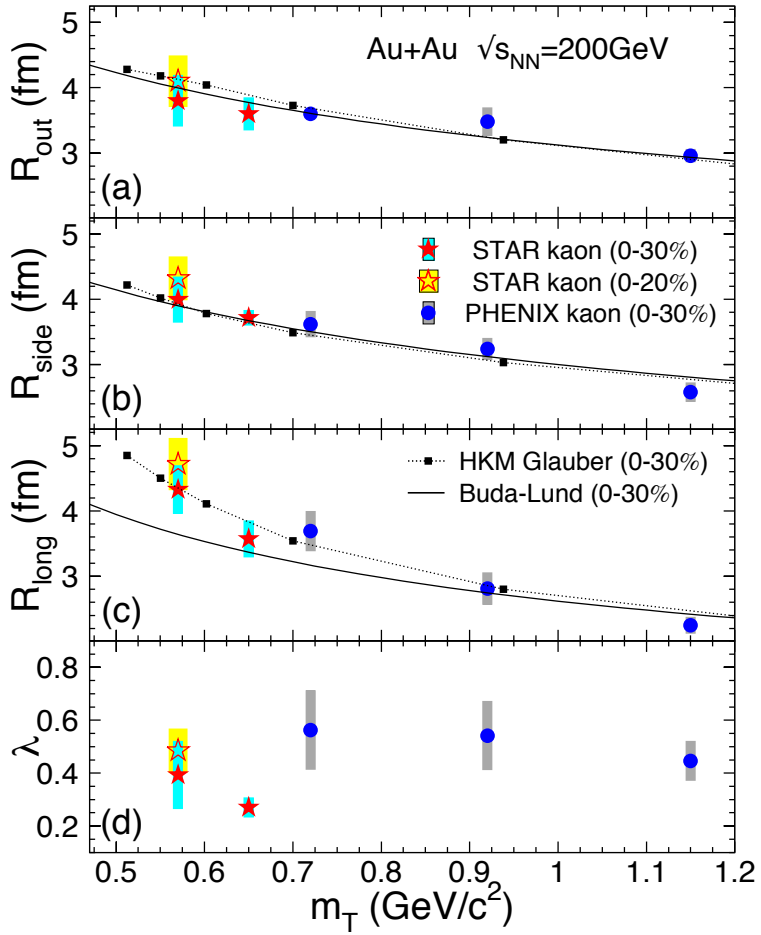
Kaon femtoscopy at top RHIC energy

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

In the past, STAR has already performed the first measurements with kaons

Phys. Rev. C88 (2013) 34906

- Used data were recorded in 2004 and 2007
- Only TPC for PID
- Data favor models that break the m_T −scaling



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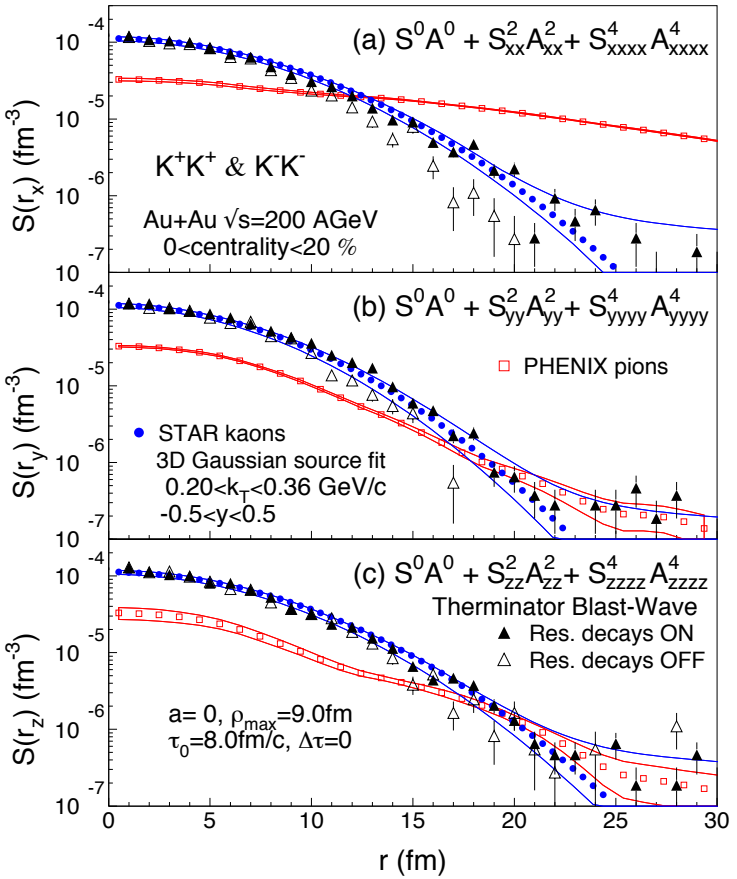
- Only TPC for PID
- Data favor models that break the m_T −scaling
- **Source imaging** was also performed
  - Technique to obtain kaon source function $S(r,k)$ directly

-> Kaon source can be well described by Gaussian shape



Kaon femtoscopy at top RHIC energy

Now, higher statistics which allow more precise measurements

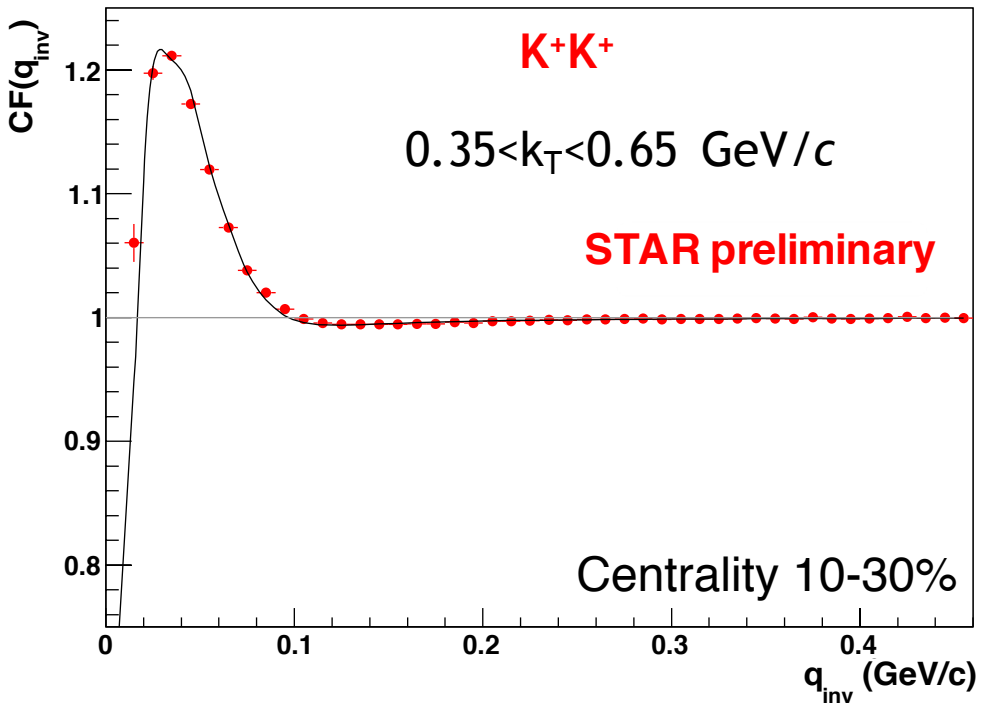
- Data were recorded by the STAR in 2011
- One of the largest available statistics
- Time of Flight detector improves PID and extends identification to higher momenta

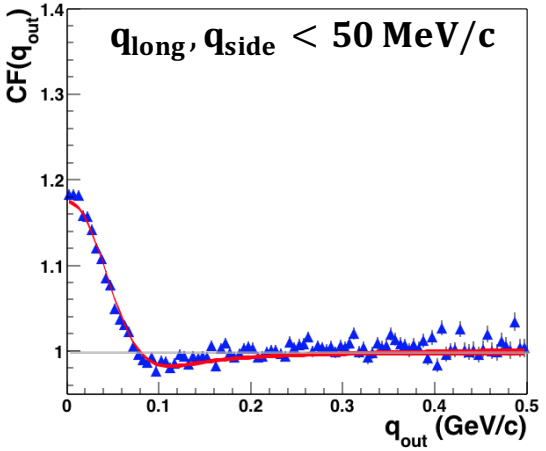
1D & 3D femtoscopic analysis of charged kaons

- 1D: 5 centrality bins: 0-5%, 5-10%, 10-30%, 30-50% and 50-75%
- 3D: 4 centrality bins: 0-10%, 10-30%, 30-50% and 50-75%
- 4 k_T bins: (0.05-0.35)GeV/c, (0.35-0.65) GeV/c, (0.65-0.95) GeV/c and (0.95-1.25) GeV/c

Fitting – extraction of source size

- Applied corrections for detector effects: kaon misidentification and momentum resolution
- **Fit example:** 1D correlation function & projection of 3D correlation function
  - data (points) vs the best fit (lines)
  - good agreement with data



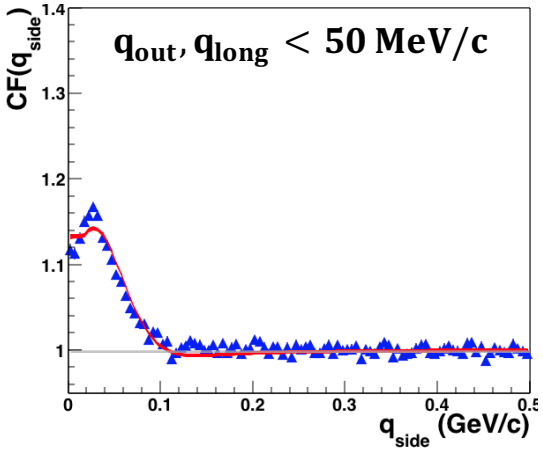


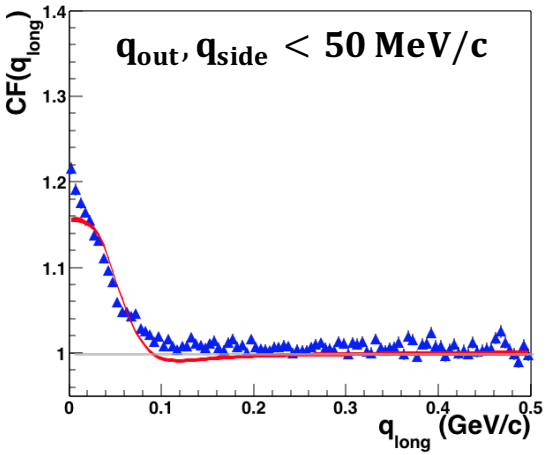
Centrality 0-10%

K^+K^+

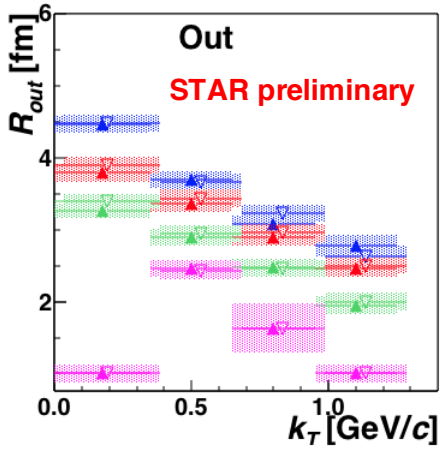
$0.35<k_T<0.65$ GeV/c

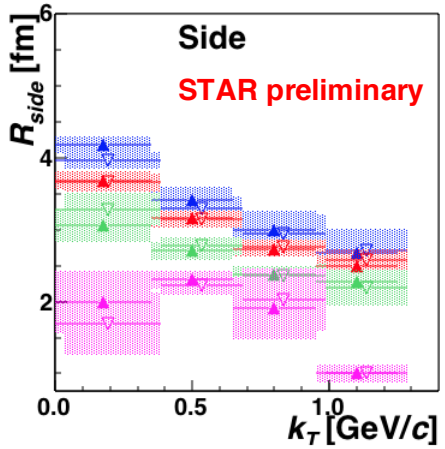
STAR preliminary

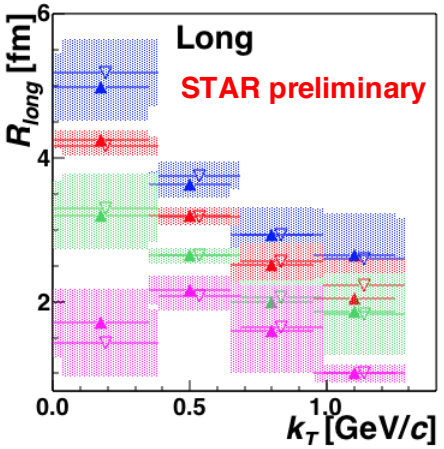




Results – extracted source size

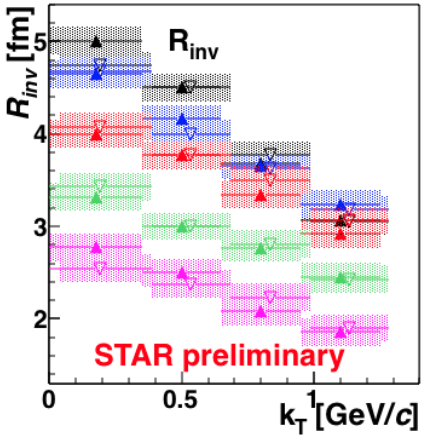






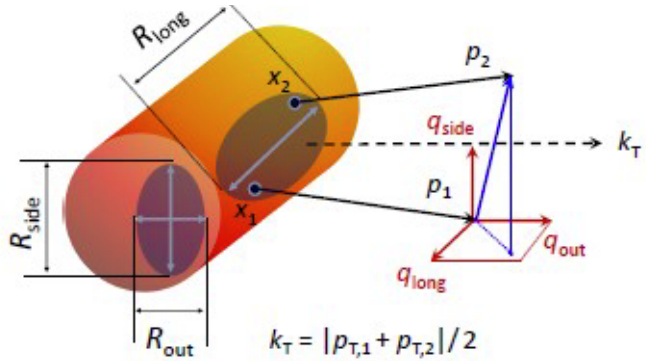
3D Kaon HBT parameters

K^+K^+	K^-K^-
▲ 0-10%	▽ 0-10%
▲ 10-30%	▽ 10-30%
▲ 30-50%	▽ 30-50%
▲ 50-75%	▽ 50-75%



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

K^+K^+	K^-K^-
▲ 0-5%	▽ 0-5%
▲ 5-10%	▽ 5-10%
▲ 10-30%	▽ 10-30%
▲ 30-50%	▽ 30-50%
▲ 50-75%	▽ 50-75%

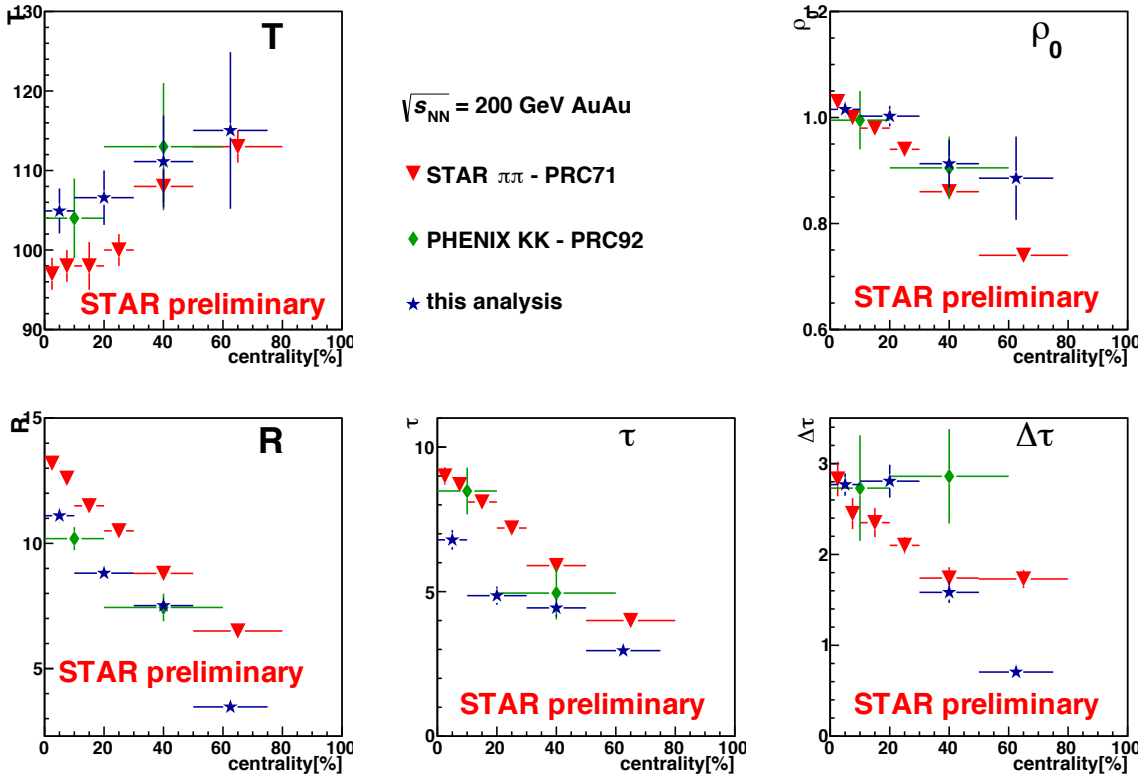


$$k_T = \left(\frac{\overrightarrow{p_1} + \overrightarrow{p_2}}{2}\right)_T$$

- **k_T and centrality dependence of HBT radii is observed**
  - Source radii increase with the centrality and decrease with pair transverse momentum
- 1D & 3D: Uncertainty is dominated by systematic error, which is obtained by varying the fit range

Results – KK radii & Blast-wave model

- Blast-wave parameterization can provide additional insight into the freeze-out configuration
- Simultaneous fit of kaon source radii and particle spectra (*Phys. Rev., C69:034909, 2004*)



- Only statistical error; systematic errors are under study
- Comparison of PHENIX results with these results – consistent within errors
- Difference between pion and kaon parameters can indicate earlier decoupling of kaons

Femtoscopy with unlike-sign kaons

Higher statistics also allow new possibilities:

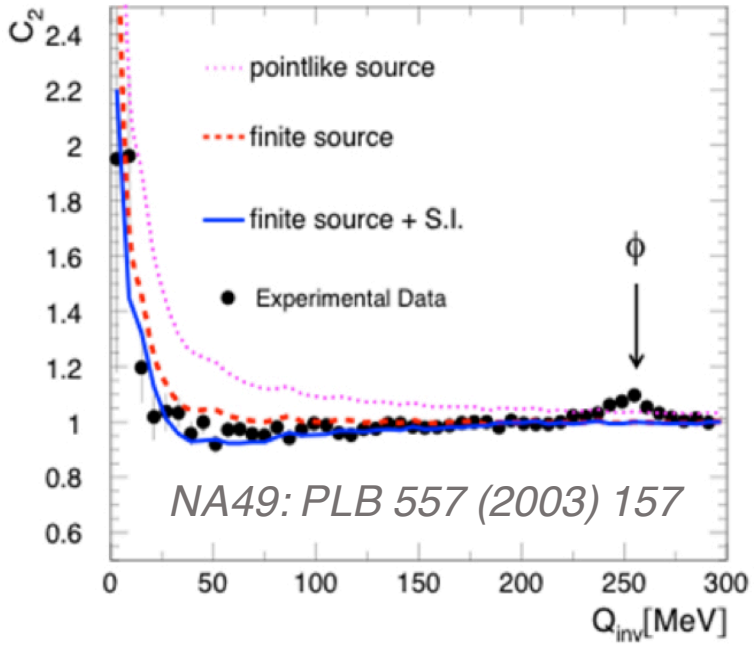
Femtoscopy with narrow resonance

Lednicky: Phys.Part.Nucl. 40 (2009) 307-352
Pratt et al.: PRC 68 (2003) 054901

- Using strong final-state interaction via the resonance decay
  - Predicted to be sensitive to source spatial extent than measurement at low q_{inv}
  - Statistically advantageous
- Challenge - extension of femtoscopic formalism to higher q_{inv}

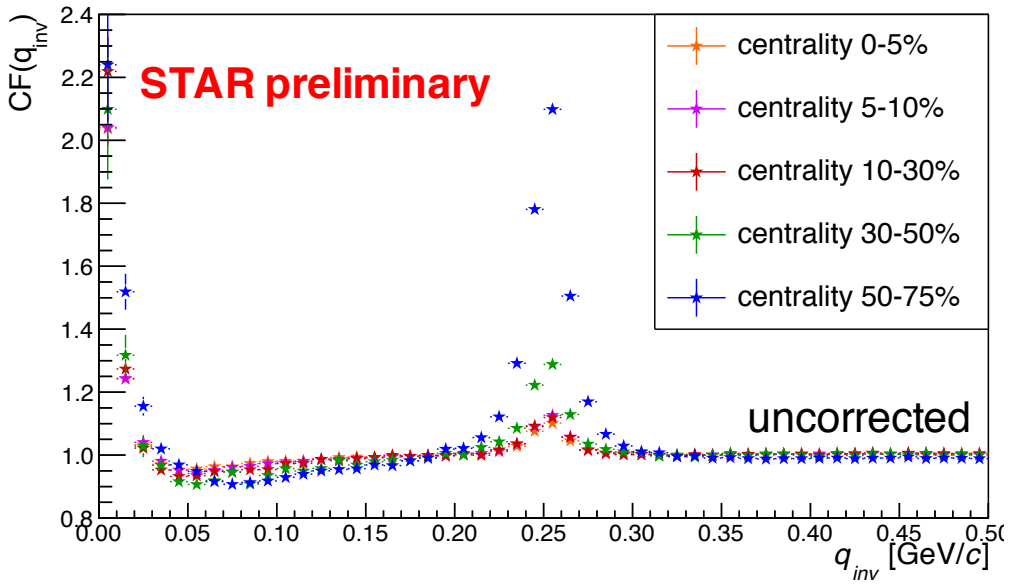
K^+K^- correlations:

- Coulomb and strong final state interaction
- $\phi(1020)$ resonance
  - $k^* = 126\,\mathrm{MeV}/c$, $\Gamma = 4.3$ MeV
- First systematic study

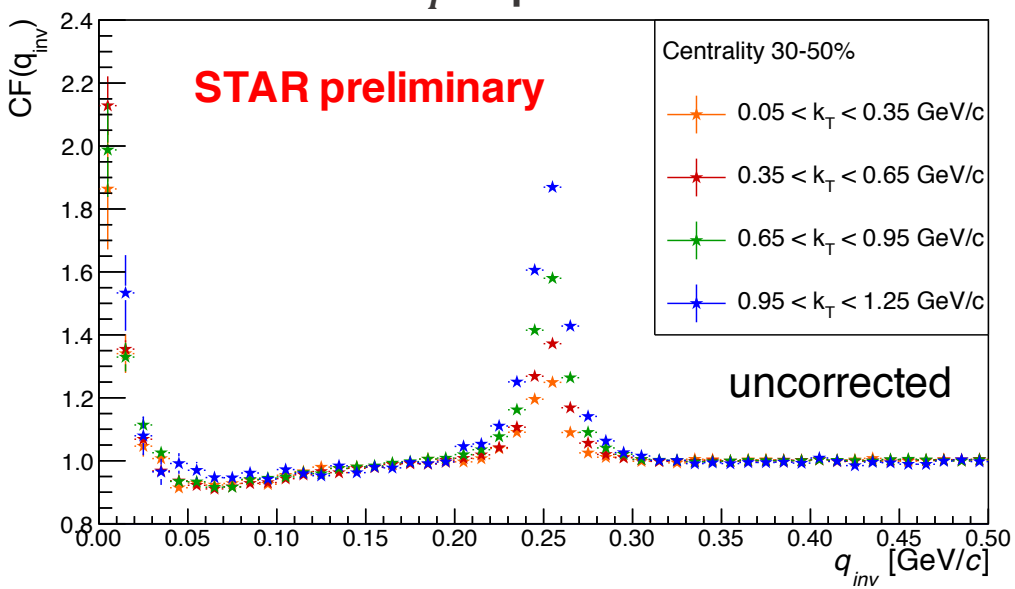


Raw unlike-sign kaon correlation functions

Centrality dependence



k_T dependence



- CFs are sensitive to the source size
- In particular, **unlike-sign kaon CF is sensitive in the region of the resonance**
- In order to **compare experimental** unlike-sign kaon correlation functions to **theoretical predictions**, **the purity corrections** were done

Comparison of 1D unlike-sign to theoretical model

- Extracted radii from like-sign kaon femtoscopy are used for theoretical calculation of unlike-sign correlation function

- **Gauss + Lednický model of final-state interaction**

  Lednicky: Phys.Part.Nucl. 40 (2009) 307-352

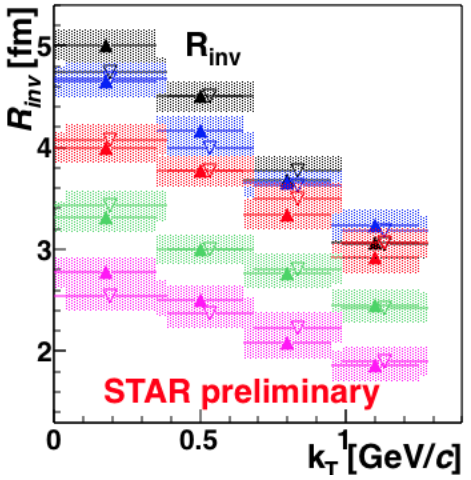
  - Includes $\phi(1020)$ resonance due to the FSI

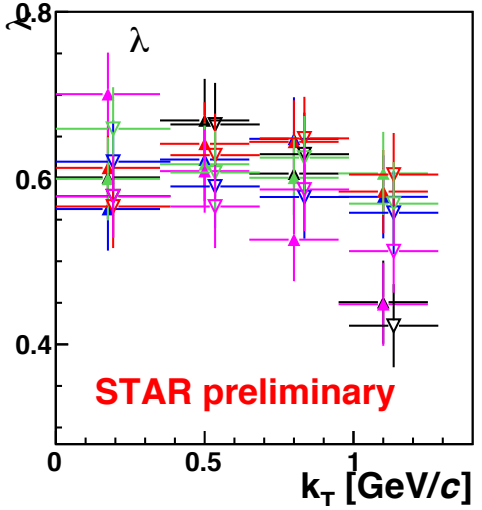
    $$CF(p_1,p_2) = \int d^3r S(r,k)\left|\psi_{1,2}(r,k)\right|^2$$

  - Gaussian parameterization of source size – source size R_{inv} is extracted from the like-sign correlation function fit

  - The theoretical function is transformed to the experimental one via:
    $CF^{exp} = \left(CF^{theo} - 1\right)\lambda + 1$
    in order to compare to an experimental correlation function, which is corrected for impurities

Experimental data for theoretical calculation

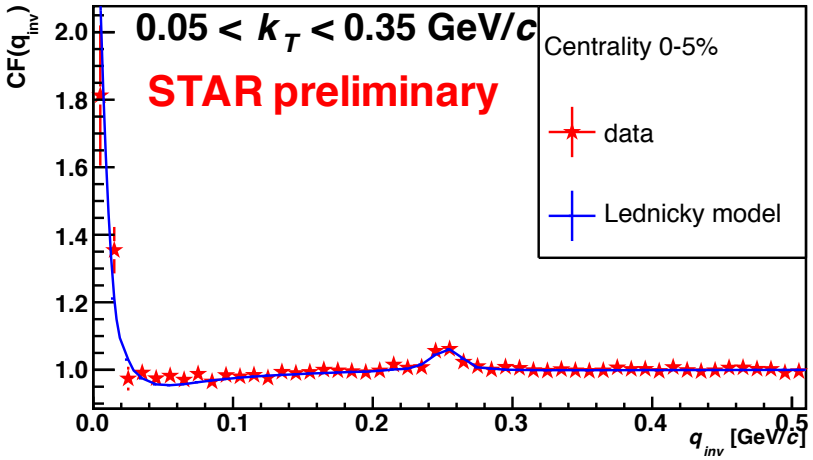


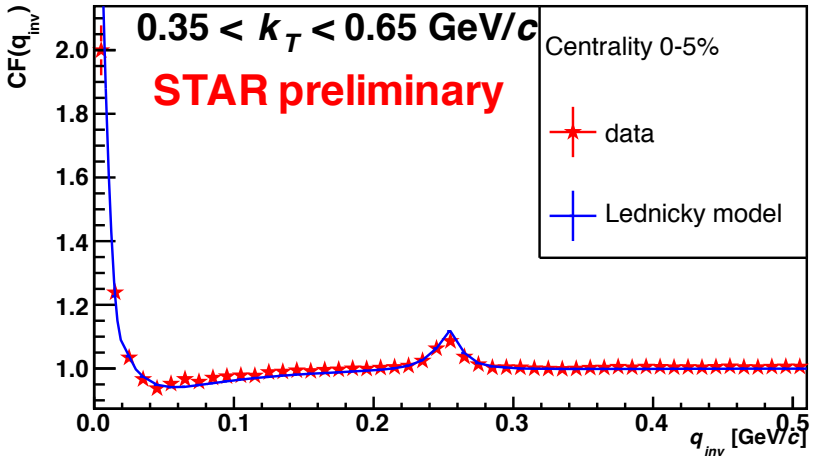


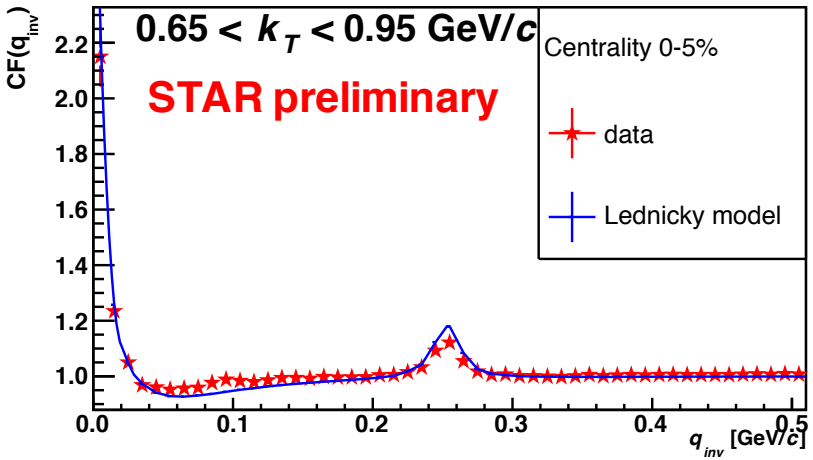
Comparison of 1D unlike-sign to Lednický model

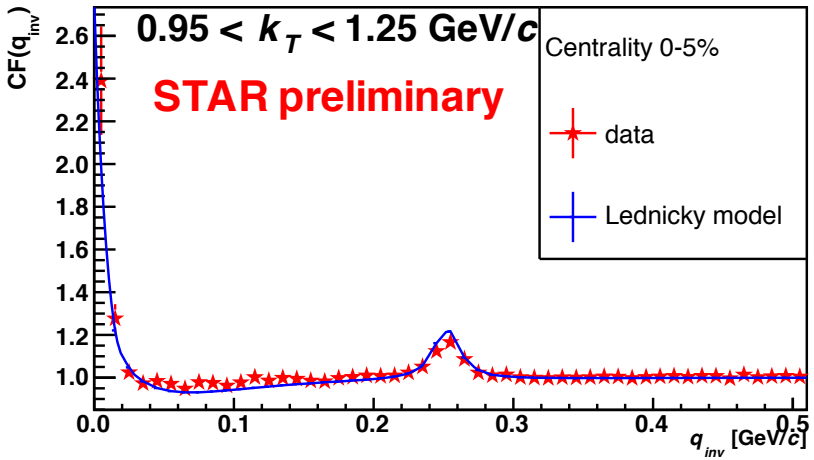
- Lednický model reproduces overall structure of the observed correlation function

Centrality 0-5 %





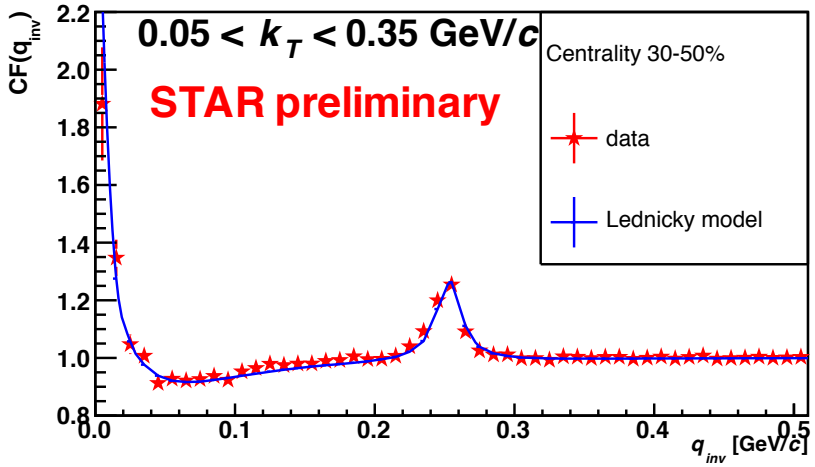


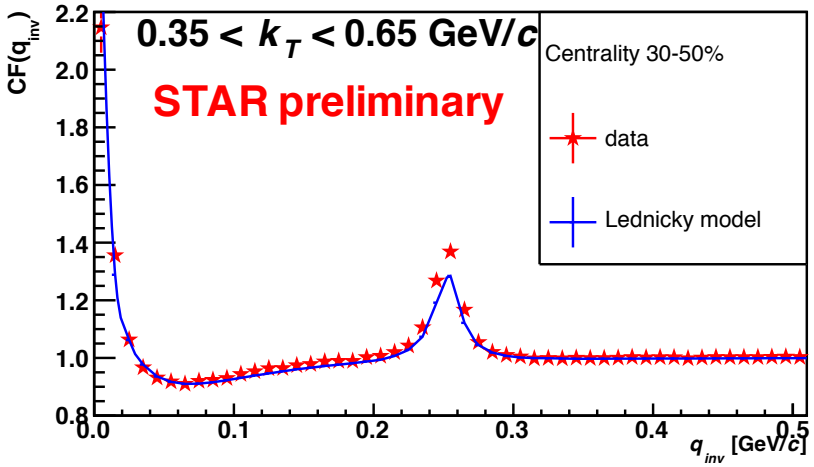


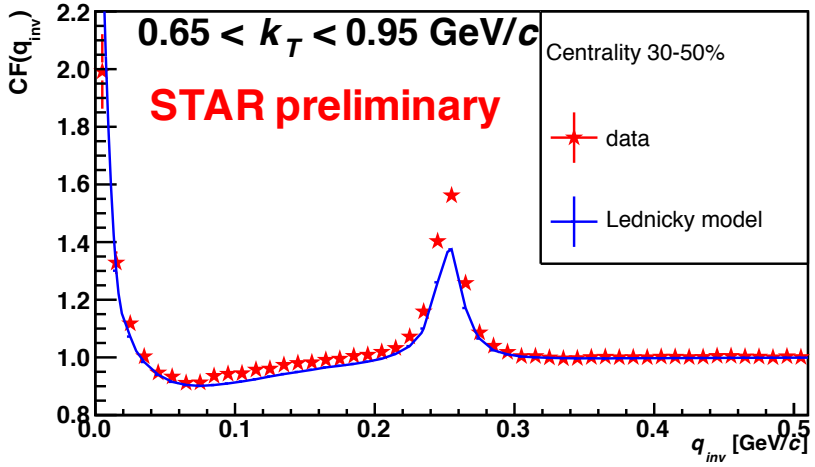
Comparison of 1D unlike-sign to Lednický model

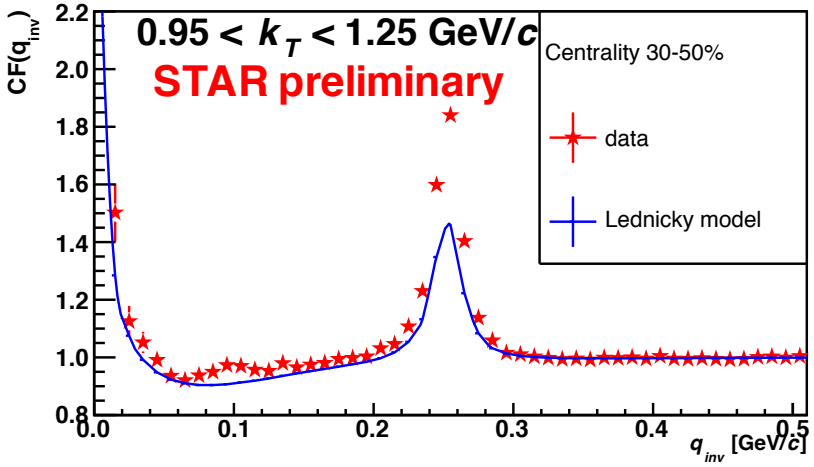
- Model under predicts the strength of the correlation functions in the region of resonance for smaller source – it can be interpreted as a breakdown of femtoscopic formalism in region of resonance

Centrality 30-50 %









Conclusions

Charged kaon femtoscopy for RHIC Beam Energy Scan

- Extraction of source radii R_{inv} from 1D correlation function
- Possibly different emitting source radii for K^+ and K^- for energy below 20 GeV

Measurement of K^+K^+ & K^-K^- correlations in Au+Au collisions at 200 GeV

- Extraction of source radii R_{out}, R_{side} and R_{long} from 3D CF
- **Performed kaon source imaging**
  - Study kaon source function in Au+Au collisions at 200 GeV
  - Source can be well described by Gaussian shape
- Source radii used for Blast-wave model to extract freeze-out configuration
  - Results show difference between pion and kaon parameters

Measurement of K^+K^- correlations in Au+Au collisions at 200 GeV

- Strong centrality dependence in $\phi(1020)$ region
- k_T dependence in $\phi(1020)$ region
- Comparison of unlike-sign CF to Lednický model
  - Comparison indicates a breakdown of femtoscopic formalism in region of resonance in peripheral collisions

Thank you for your attention

- Femtoscopy
- Kaon femtoscopy
- STAR Experiment
- Kaon femtoscopy for BES
- Results from BES
- Kaon femtoscopy at top RHIC energy
- Results from 200 GeV
- K^+K^- femtoscopy
- Model comparison
- Conclusions