Femtoscopy with unlike-sign kaons at the STAR experiment

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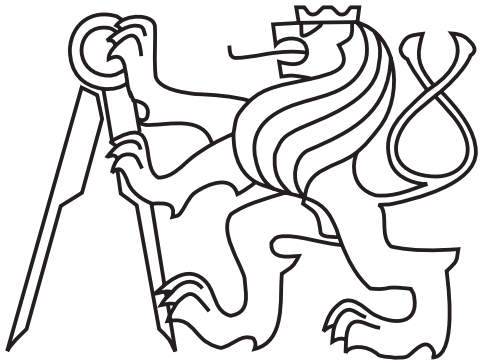
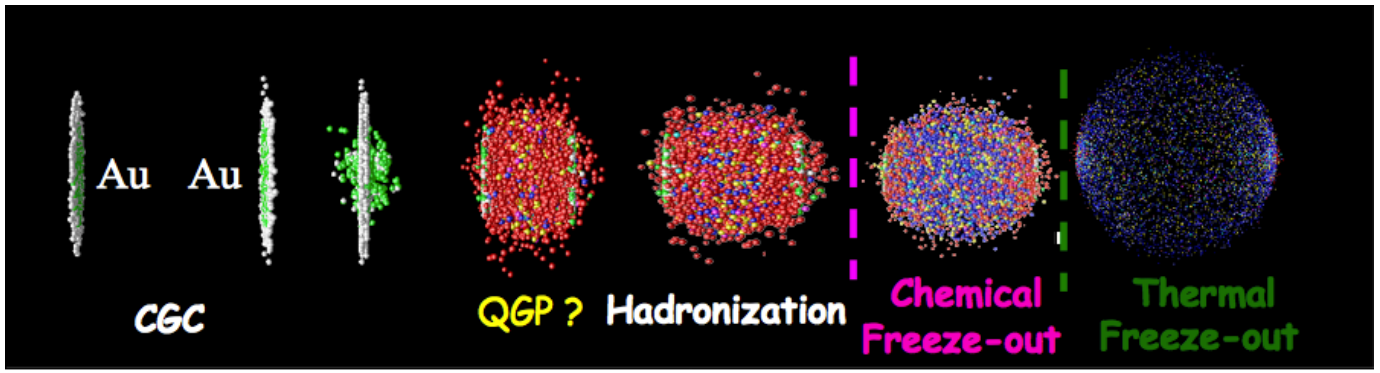
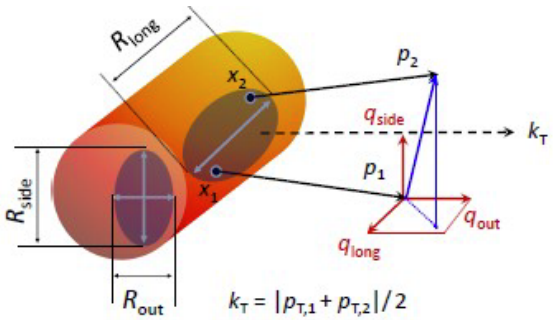


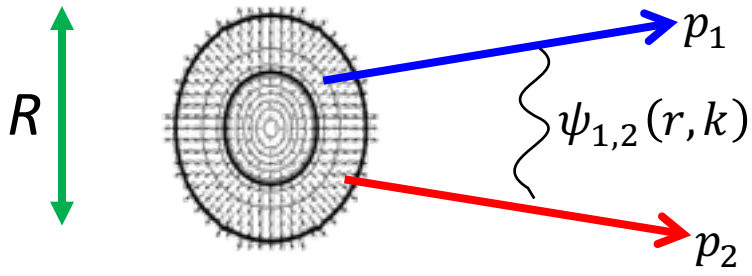
Femtoscopy

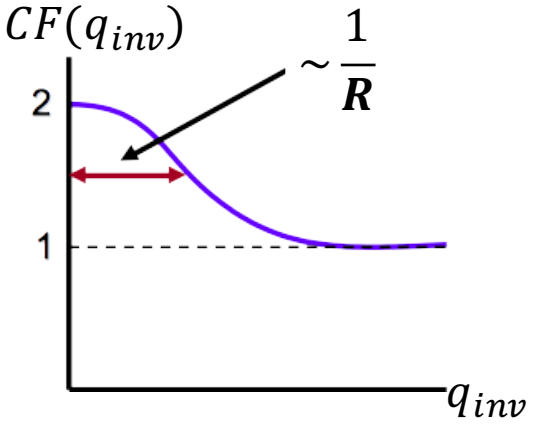




- Study space-time extents of the source at the thermal freeze-out
- Correlation function: $CF(p_1, p_2) = \int d^3r S(r,k) \left|\psi_{1,2}(r,k)\right|^2$

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





Femtoscopy with kaons – a cleaner probe

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

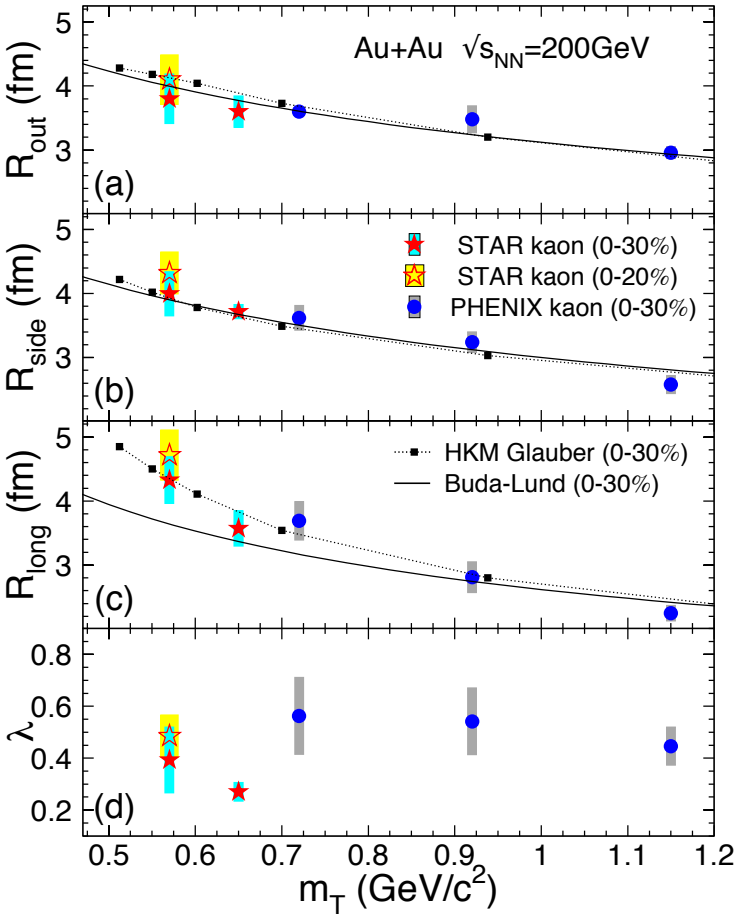
- Less feed-down – smaller contamination with non-primary kaons from weakly decaying resonances
- Smaller cross section – information about a different stage of the collisions evolution

However, more difficult due to ~10 smaller statistics

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

Phys. Rev. C88 (2013) 34906

- Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV recorded in 2004 and 2007
- Only TPC for PID
- The expected trend of femtoscopic radii was observed



Femtoscopy with unlike-sign kaons

Femtoscopy with narrow resonance

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

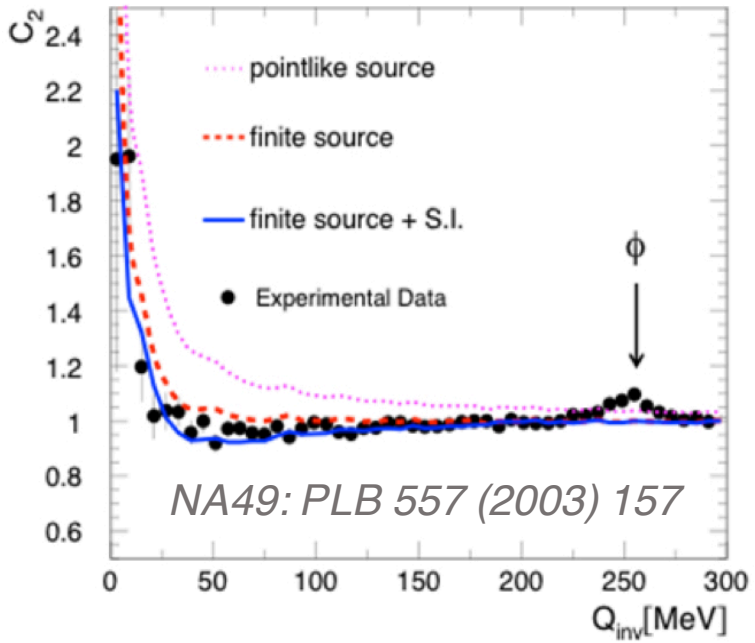
- Using strong final-state interaction via resonance
  - Predicted to be more sensitive to source spatial extent than measurement at low q_{inv}
  - Statistically advantageous
- Challenge - extension of femtoscopic formalism to region of narrow resonance

K^+K^- correlations:

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

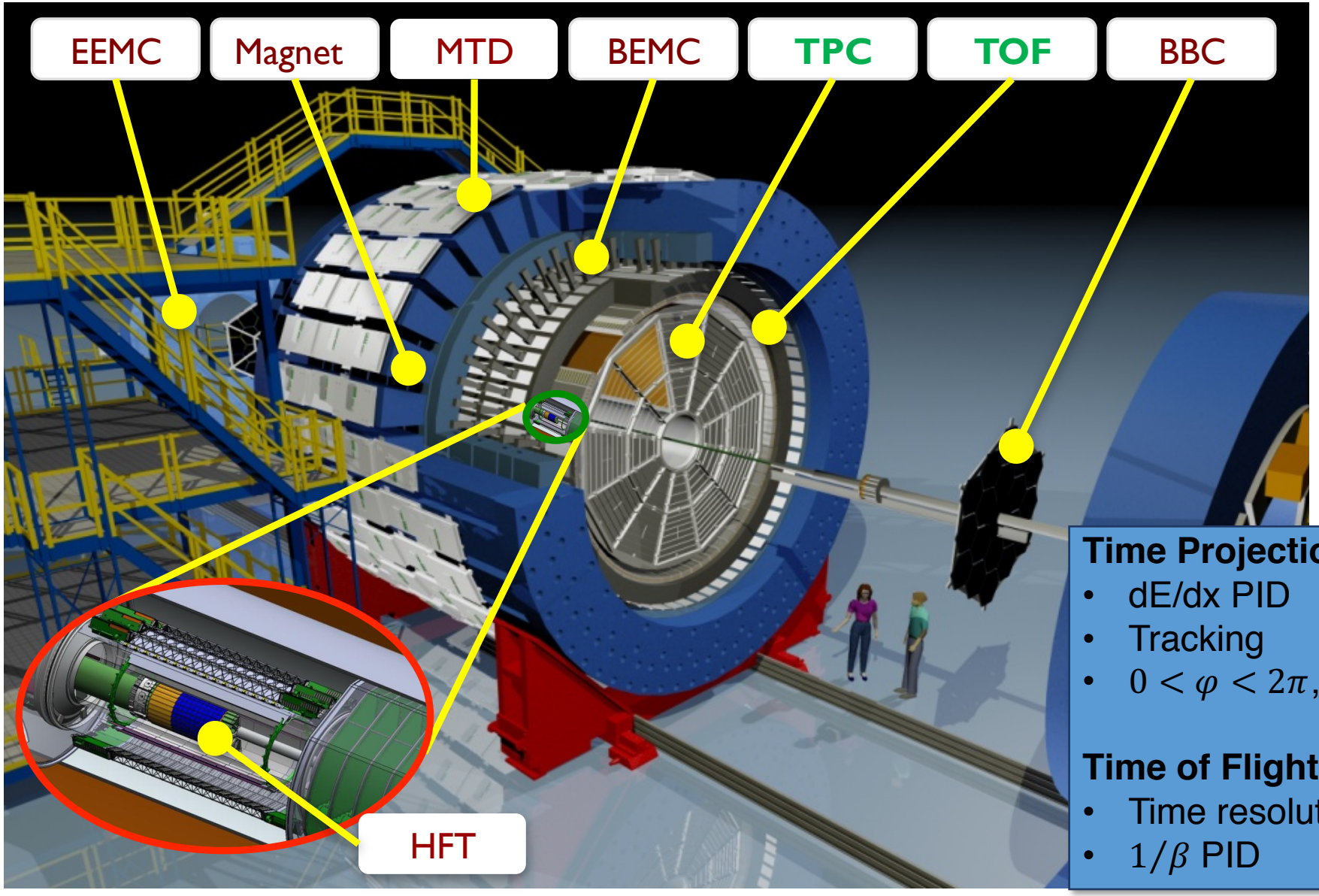
K^+K^+ & K^-K^- correlations:

- "standard femtoscopy" at low q_{inv}
- Extraction of source radii



5% most central Pb+Pb collisions at 158 GeV

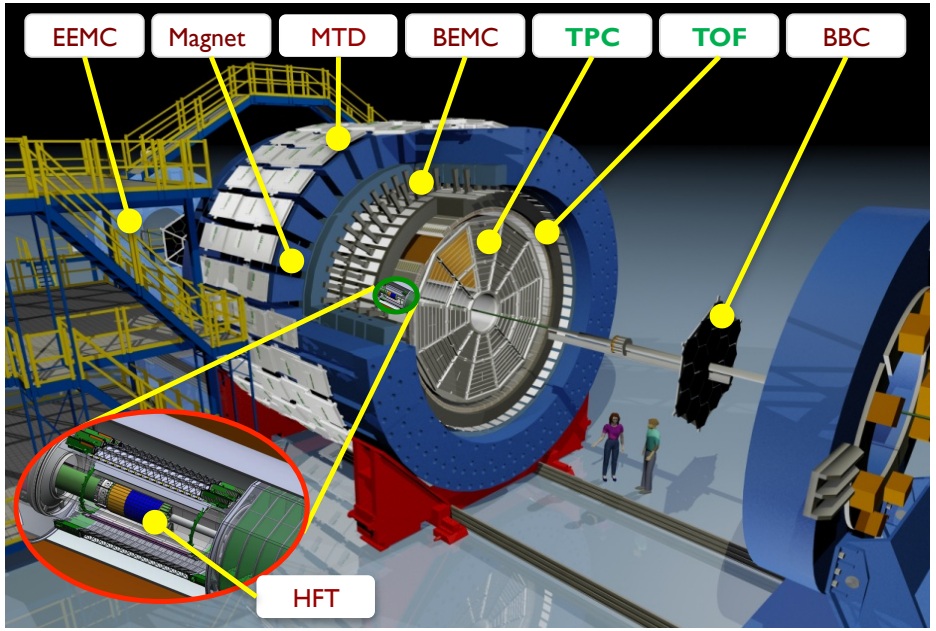
STAR Experiment at RHIC



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

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

Data sample & Kaon identification

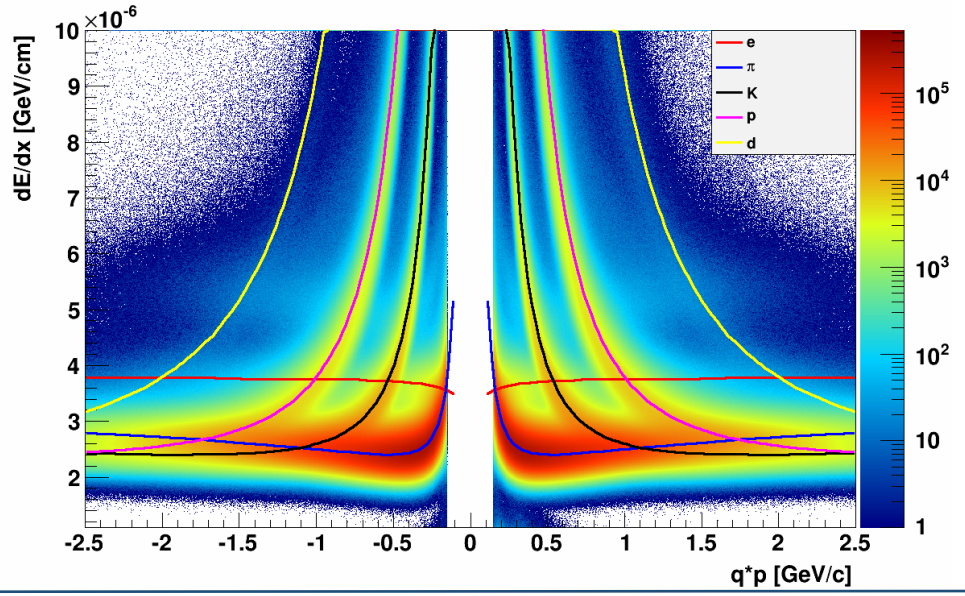


Data sample

- Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV taken in 2011

Kaon identification

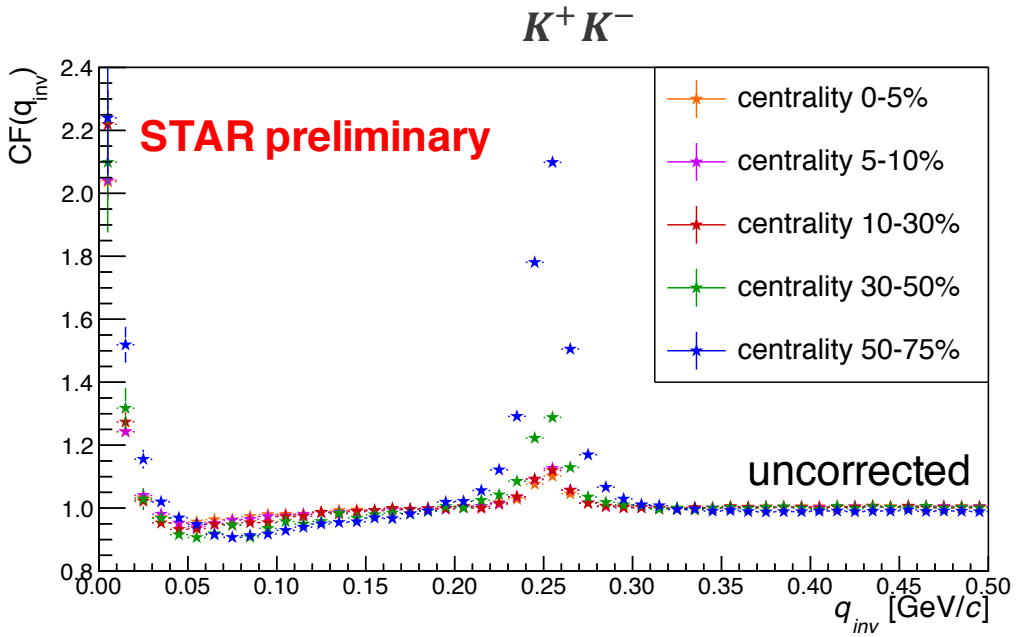
- At midrapidity $|\eta| < 1$
- Using TPC and ToF information
- $0.15 < p < 1.55\ \mathrm{GeV}/c$
- TPC: $|n\sigma_{kaon}| < 3$
- ToF: $0.21 < m^2 < 0.28\ \mathrm{GeV}^2/c^4$

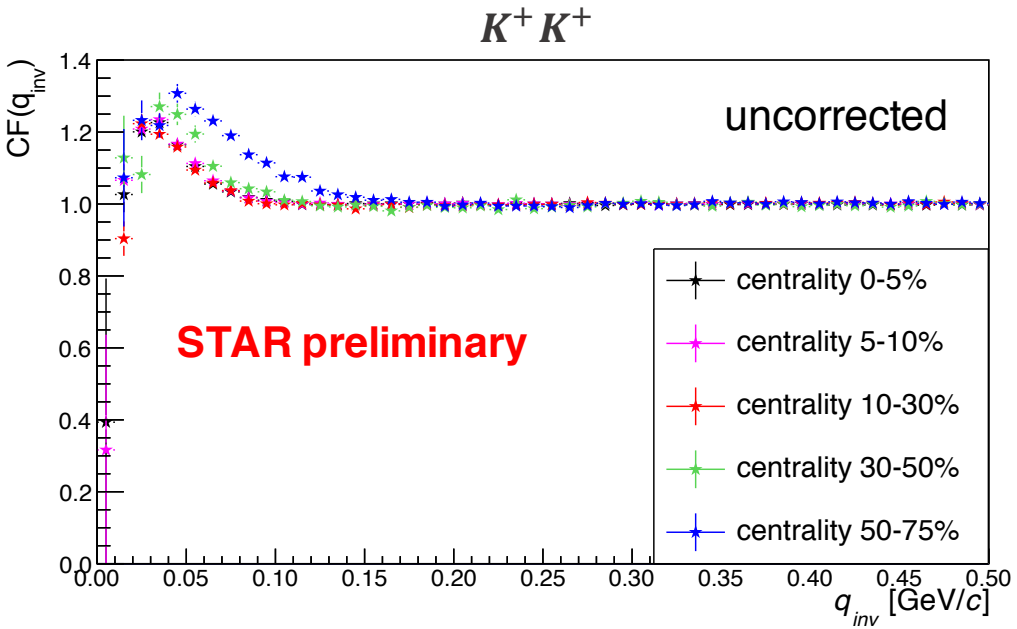


Experimental correlation function:

$$CF(q_{inv}) = \frac{\text{real pairs (correlated)}}{\text{mixed pairs (uncorrelated)}}$$

Raw correlation functions



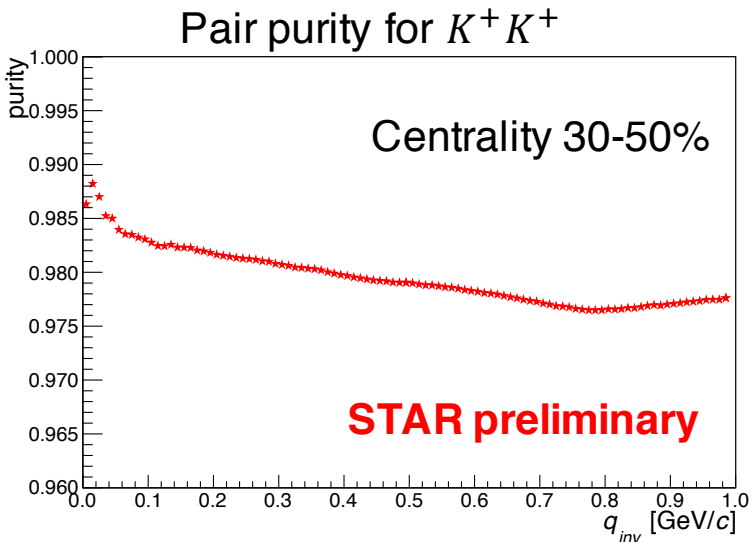


- CFs are sensitive to the source size
- In particular, **unlike-sign kaon CF is sensitive in the region of the resonance**
- In order to **compare experimental** unlike-sign kaon correlation functions to **theoretical predictions**, **the corrections** and **the extraction of space-time extents** from like-sign kaon correlation function are needed

Corrections

Purity Correction

- Corrections for misidentification of kaons
- Due to excellent PID ability of STAR detector very high purity



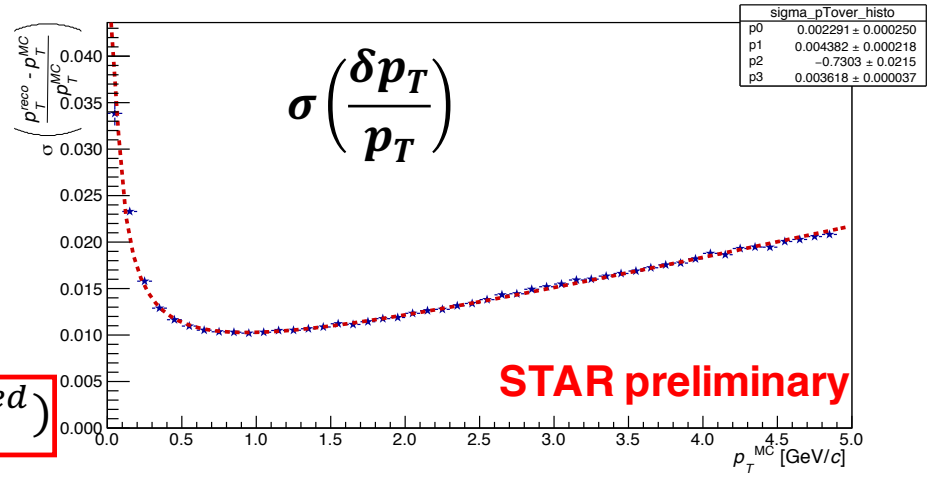
Momentum resolution

- Correction for **detector effect** – **limited** single-particle **momentum resolution in TPC**

$$q_{ivn} + \delta q_{inv} = (p_1 + \delta p_1) - (p_2 + \delta p_2)$$

- Experimental CFs are smeared
- Parameters of momentum resolution were obtained from **Monte-Carlo simulations**
- Then, ideal and smeared theoretical CFs were calculated
- The correction factor $C(q_{inv}) = CF(q_{inv}^{ideal})/CF(q_{inv}^{smeared})$

STAR TPC resolution of kaon transverse momentum from MC simulations



Fitting & Like-sign kaon CF

- Used for extraction of kaon emission source size and λ parameter
- "standard" Bowler-Sinyukov method:

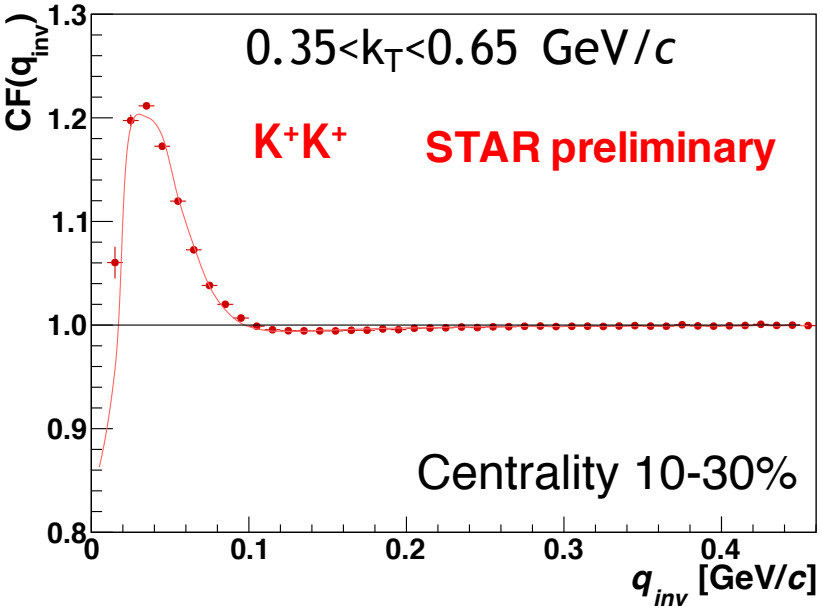
Phys. Lett., B270:69–74, 1991

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

3D: $$CF(q_o, q_s, q_l) = \left[(1-\lambda) + \lambda K(q_{inv}, R_{inv})\left(1 + \exp\left(-q_o^2 R_o^2 - q_s^2 R_s^2 - q_l^2 R_l^2\right)\right)\right]\mathcal{N},$$

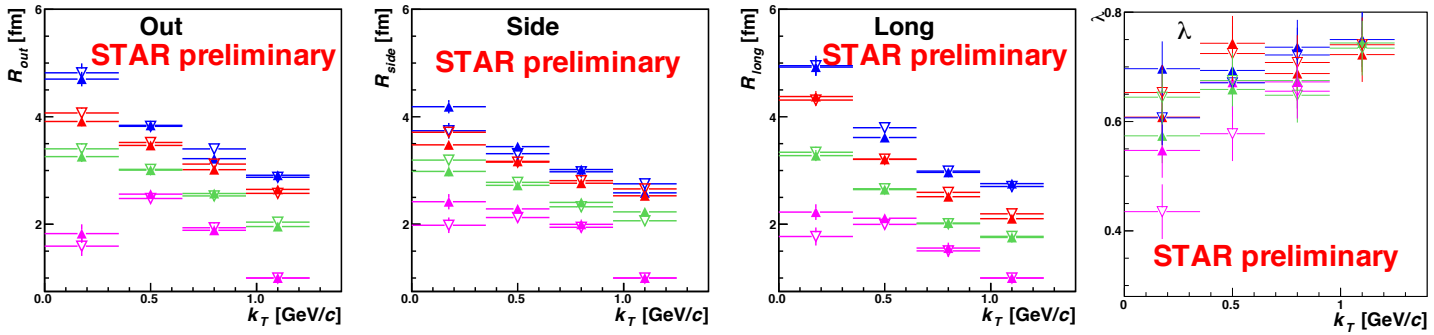
- R_{inv}, R_o, R_s, R_l – source radii
- λ parameter – correlation strength
- $\mathcal{N}$ – normalization
- $K(q_{inv}, R_{inv})$ – Coulomb function

Example of 1D fit: data(points) and the best fit(line)



Results – extracted source size

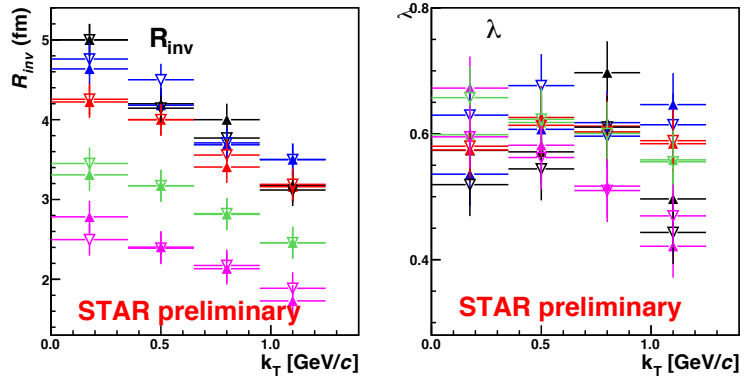
3D



3D Kaon HBT parameters

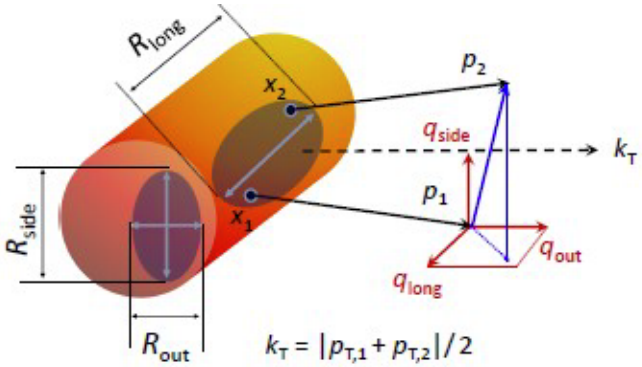
K^+K^+	K^-K^-
0-10%	0-10%
10-30%	10-30%
30-50%	30-50%
50-75%	50-75%

1D



$\sqrt{s_{NN}}$ = 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%



- **Typical k_T and centrality dependence of femtoscopic radii is observed**
  - Source radii increase with the centrality and decrease with pair transverse momentum
- 1D: Uncertainty is dominated by systematic error, which is obtained by varying the fit range
- 3D: Only statistical error; systematic errors understudy

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

Comparison of 1D unlike-sign to theoretical model

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

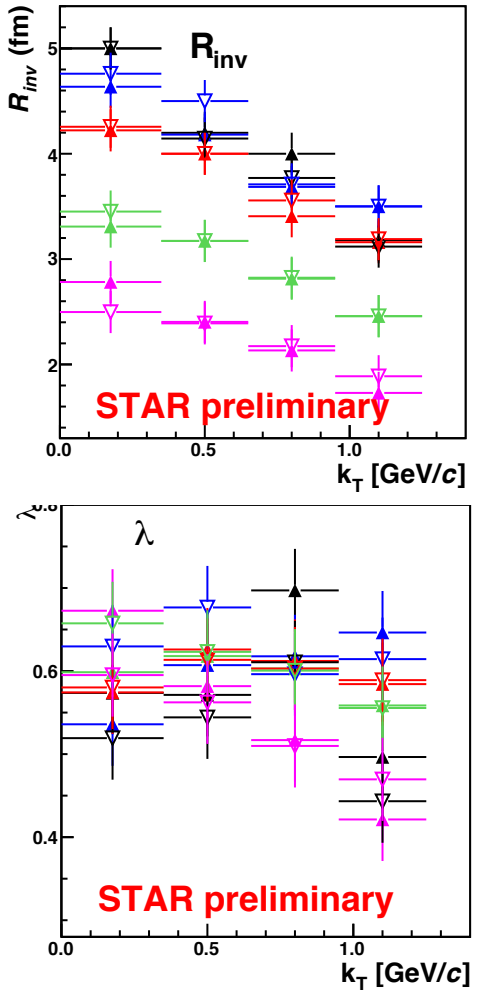
- **Gauss + Lednický model of final-state interaction**
  - Includes $\phi(1020)$ resonance due to the FSI
    Lednicky: Phys.Part.Nucl. 40 (2009) 307-352

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

  - Gaussian parameterization of source size – source size R_{inv} is extracted from fitting like-sign correlation function
  - The theoretical function is transformed to an 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

- **THERMINATOR 2 + Lednický model of final-state interaction**
  - THERMal heavy IoN generATOR 2 *arXiv:1102.0273*
  - Statistical production of particles + resonances decay
  - Blast-wave parameterization of the freeze-out configuration

Experimental data for theoretical calculation

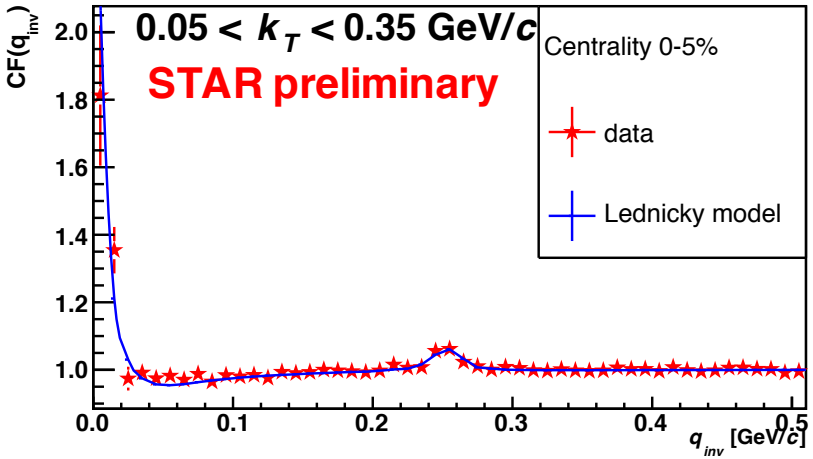


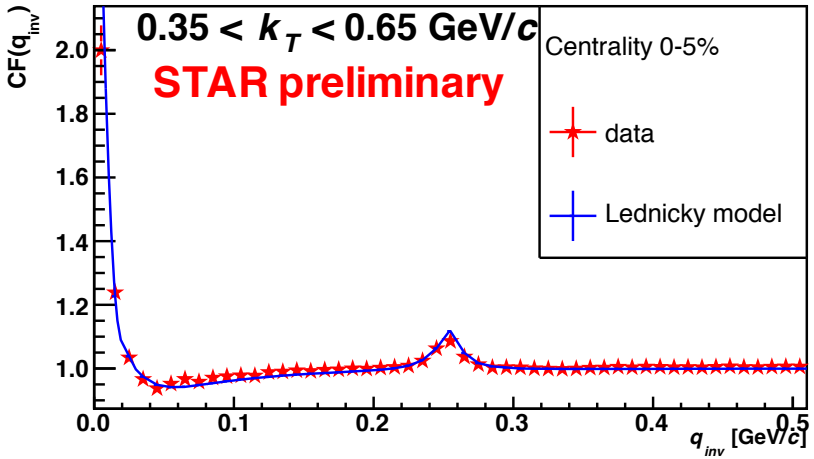
Comparison of 1D unlike-sign to Lednický model

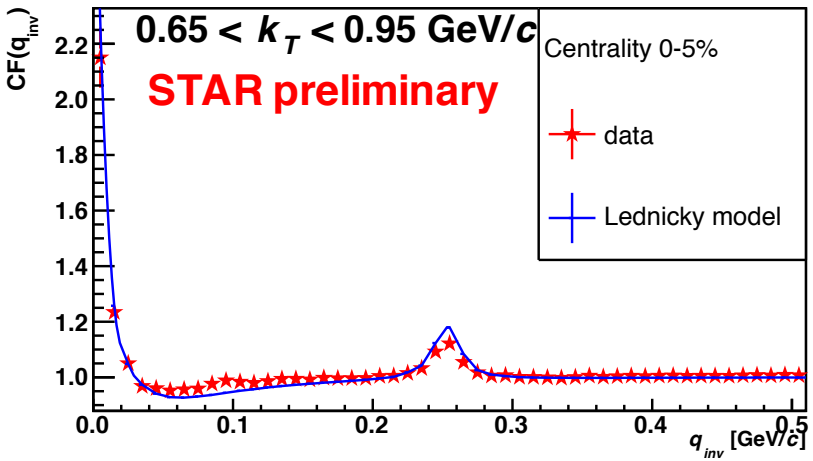
- Lednický model reproduces overall structure of the observed correlation function

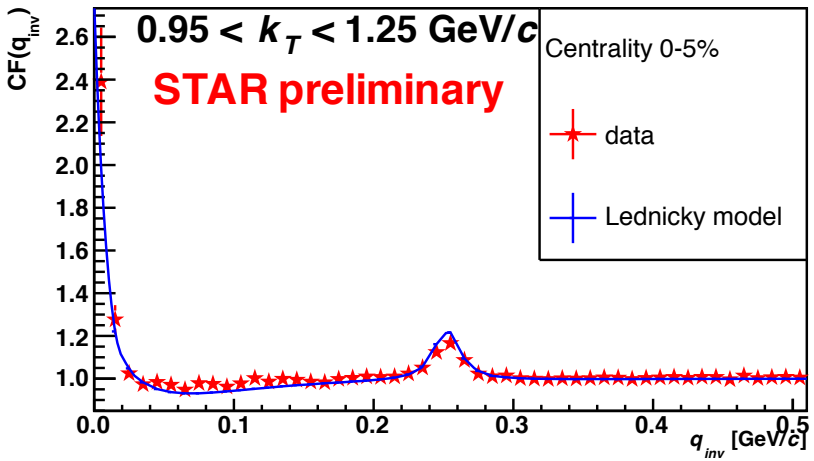
200 GeV Au+Au collisions at RHIC

Centrality 0-5 %





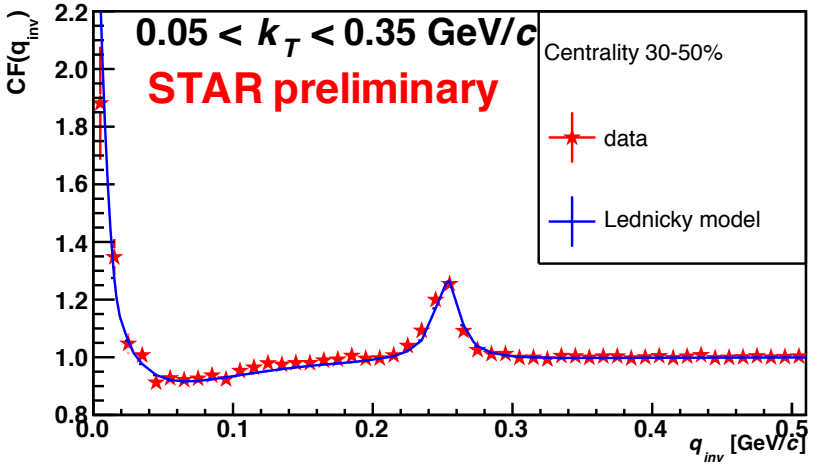


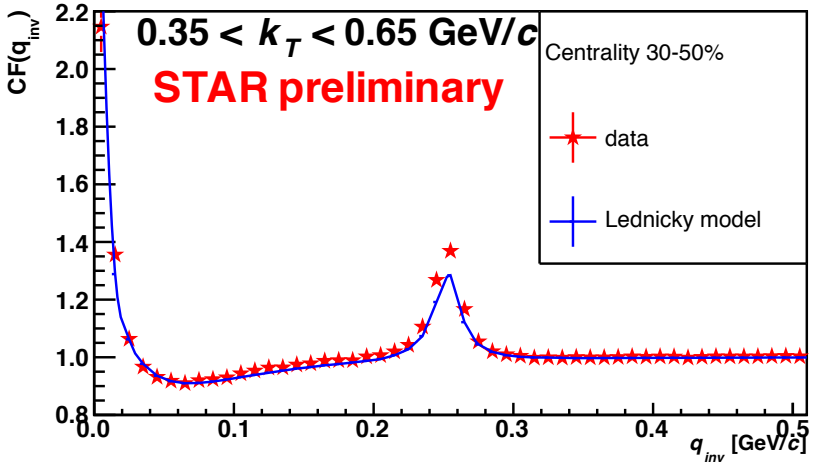


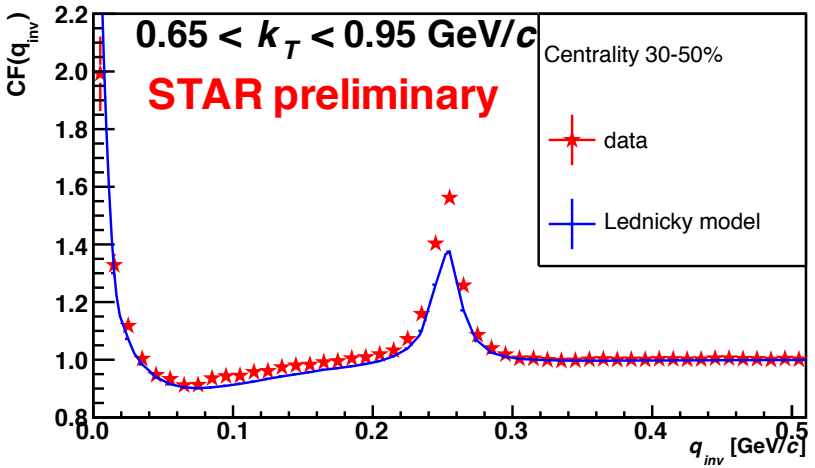
Comparison of 1D unlike-sign to Lednický model

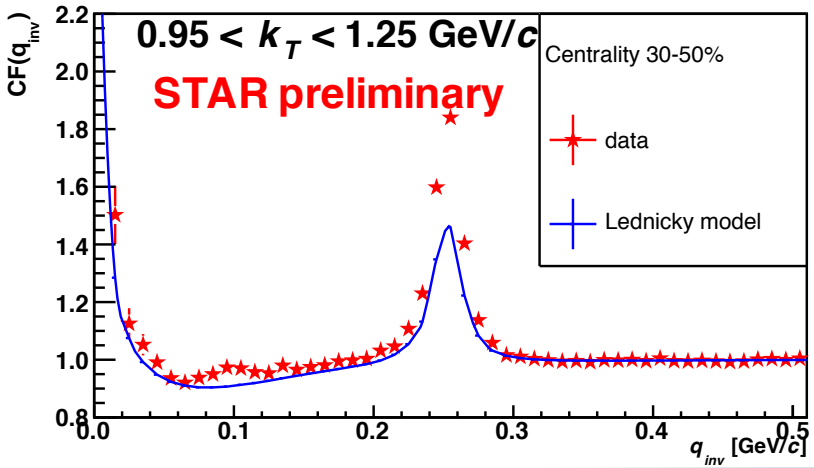
- Lednický model reproduces overall structure of the observed correlation function
- Model under predicts the strength of the correlation functions in the region of resonance for smaller source

200 GeV Au+Au collisions at RHIC, Centrality 30-50 %







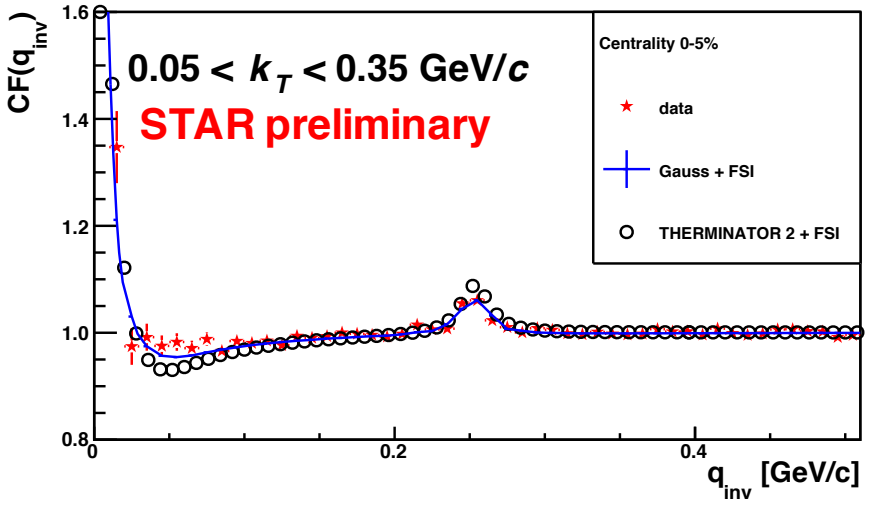


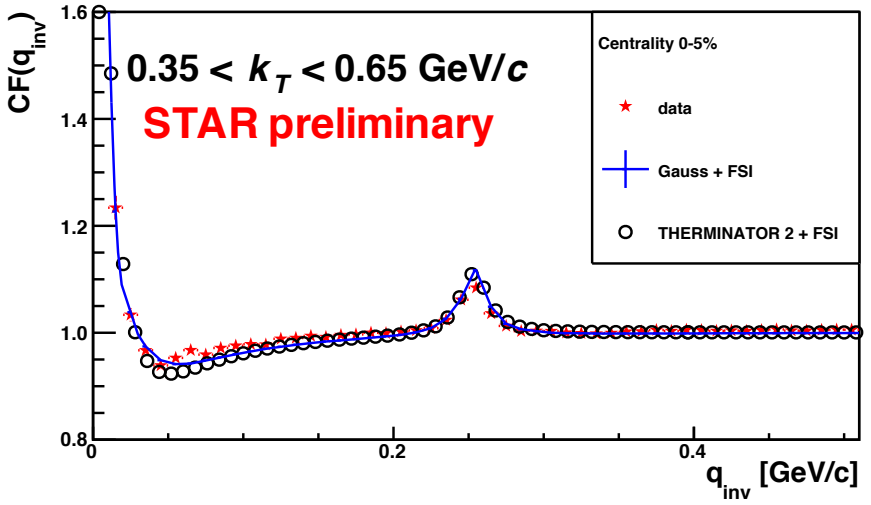
Comparison of 1D unlike-sign to THERMINATOR 2

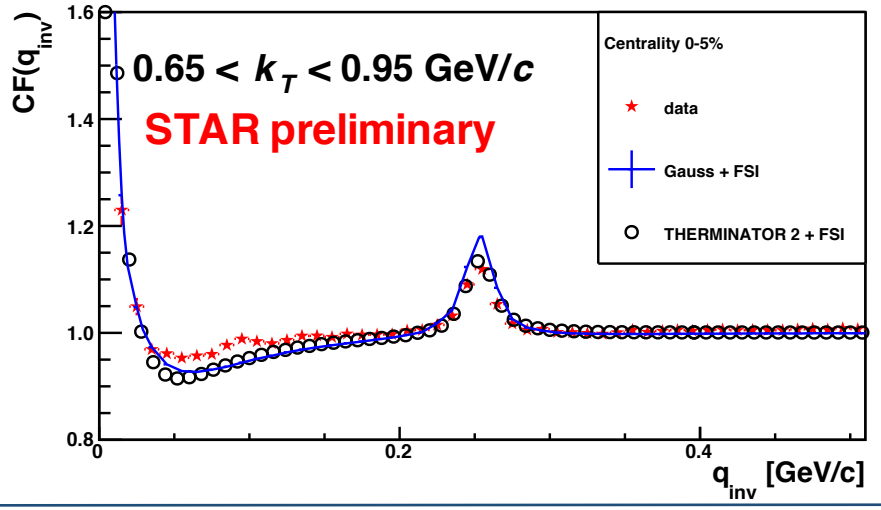
- Model reproduces overall structure of the observed correlation function

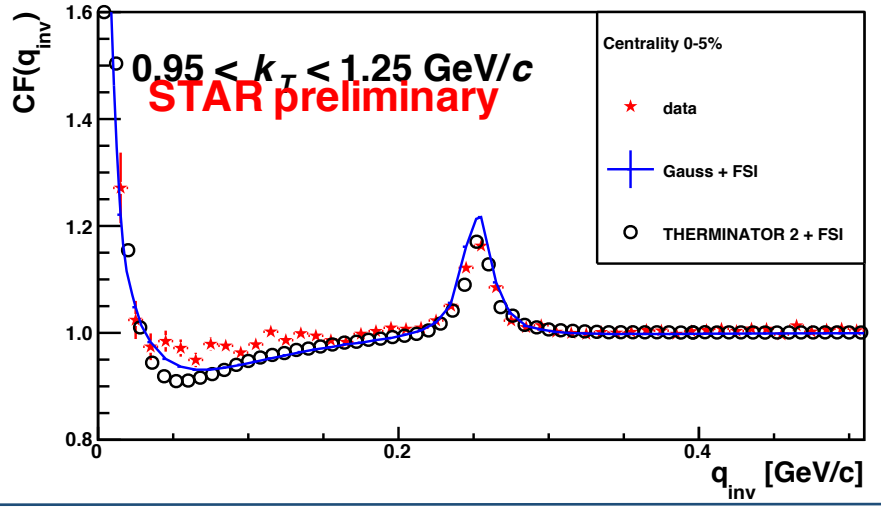
200 GeV Au+Au collisions at RHIC

Centrality 0-5 %









Conclusions

Systematic study 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

Extraction of space-time characteristic of source from $K^+K^+ \& K^-K^-$ correlations in Au+Au collisions at 200 GeV

- Purity and Momentum resolution correction are applied
- Extraction of source radii R_{inv} from 1D CF
- Extraction of source radii R_{out}, R_{side} and R_{long} from 3D CF

Comparison of K^+K^- correlation function to Lednický model

- The Lednický model reproduces overall structure of the observed correlation function
- In the peripheral collisions the model under predicts the strength of the correlation function in the region of resonance

The End

Thank you for your attention