Femtoscopy with kaons at the STAR experiment

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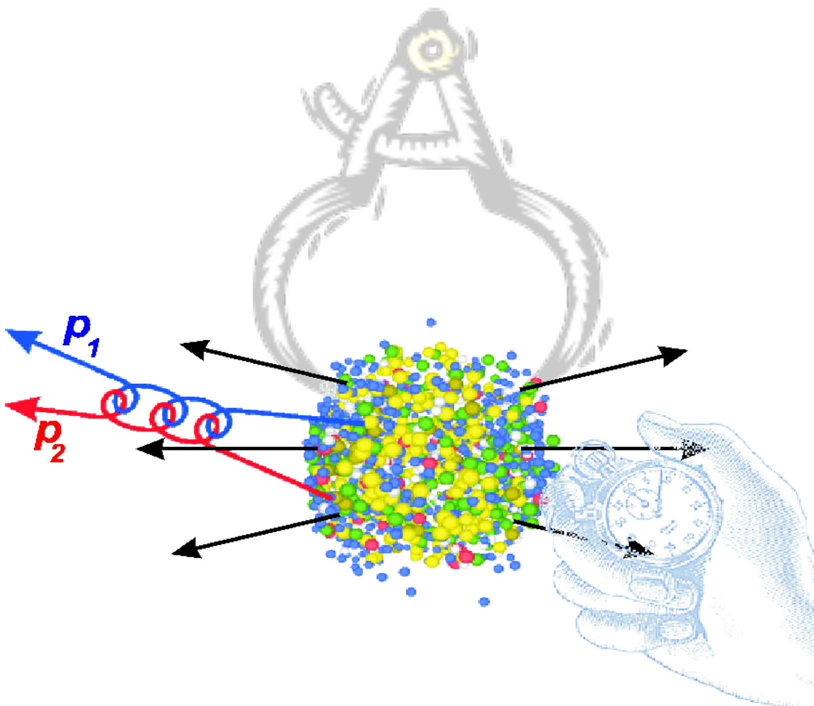
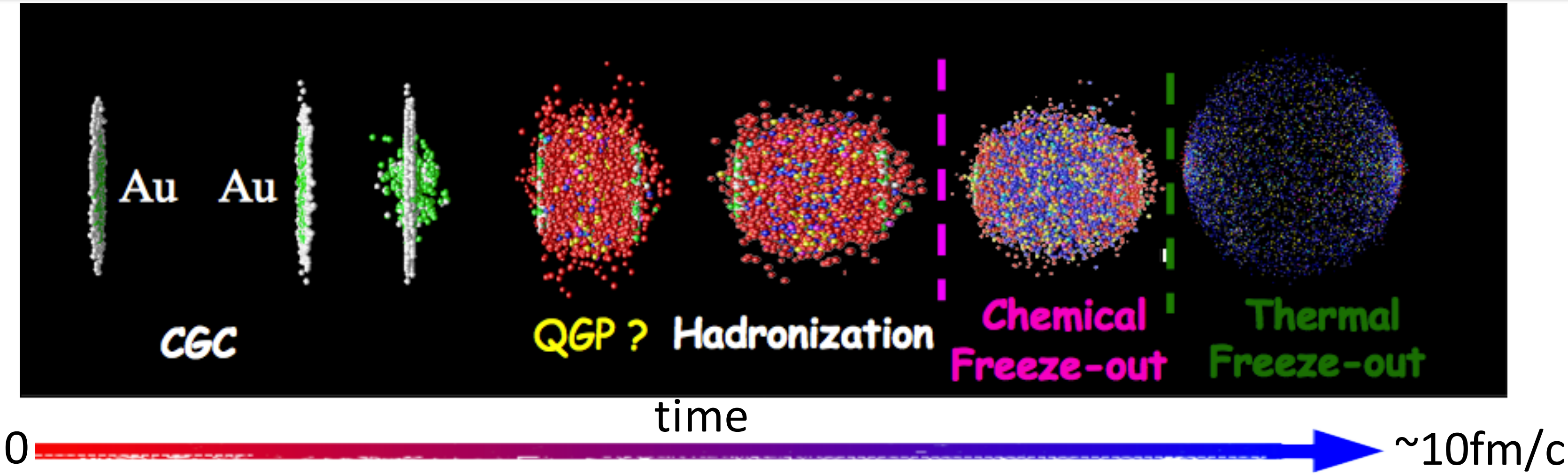
Outline

- Introduction into femtoscopy
- RHIC Beam Energy Scan and motivation for kaon femtoscopy
- Like-sign kaon femtoscopy for Beam Energy Scan
- Femtoscopy with unlike-sign kaons
- Conclusion

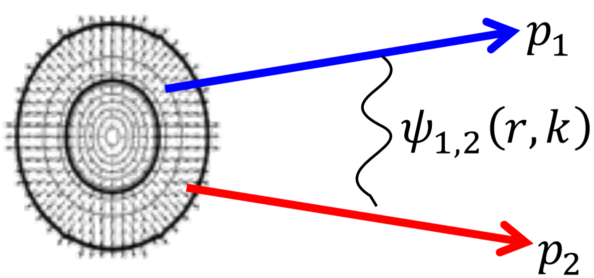


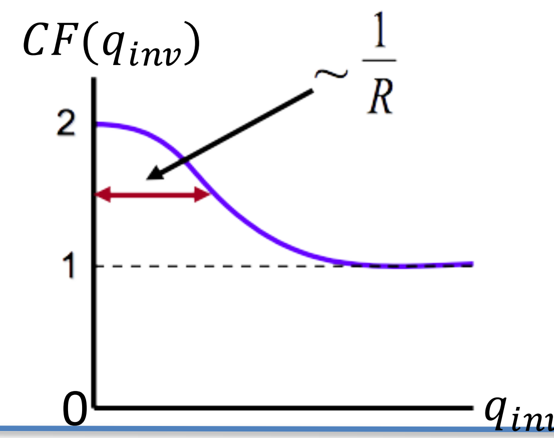
Femtoscopy



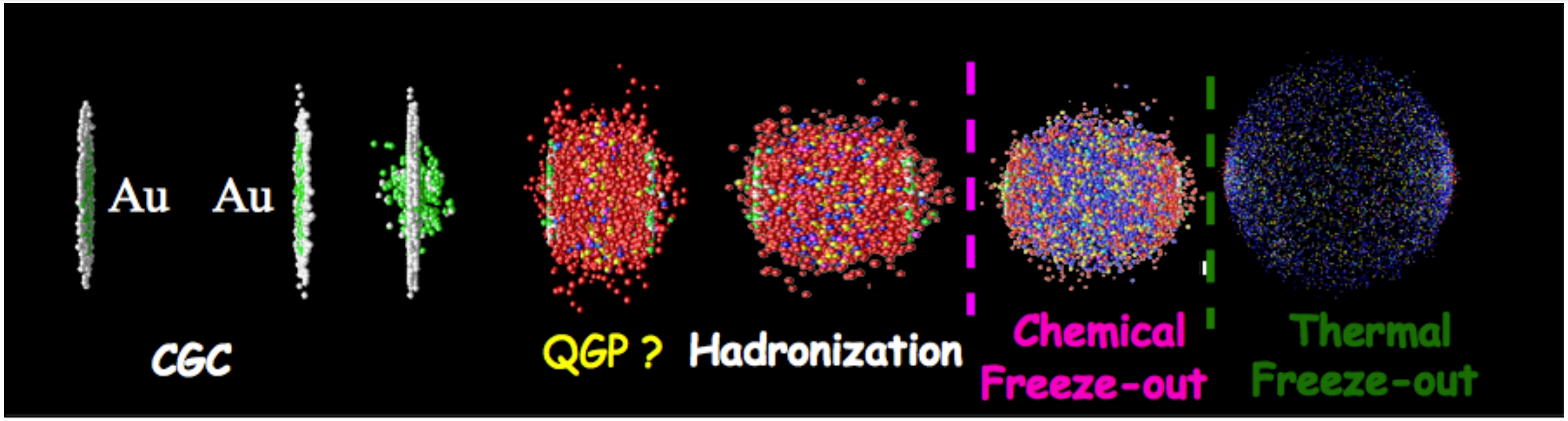
- Study source size and its dynamical properties – shape and timescale of the emission zone
- Correlation function: $CF(p_1, p_2) = \int d^3 r S(r,k) \left| \psi_{1,2}(r,k) \right|^2$

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





Femtoscopy



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

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

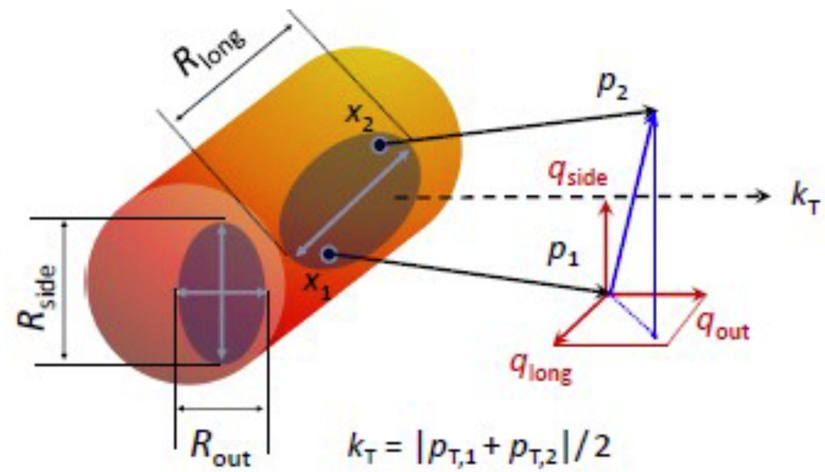
1D + identical non-interacting particles

+ assumption – source is parameterized by the Gaussian

$$CF(\vec{q}) = 1 \pm \lambda \exp(-q_{inv}^2 R_{inv}^2)$$

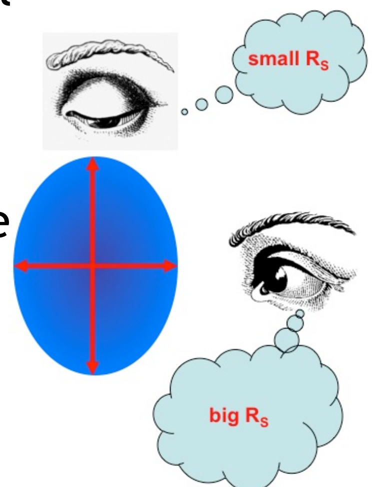
3D – Longitudinal Co-Moving System (LCMS)

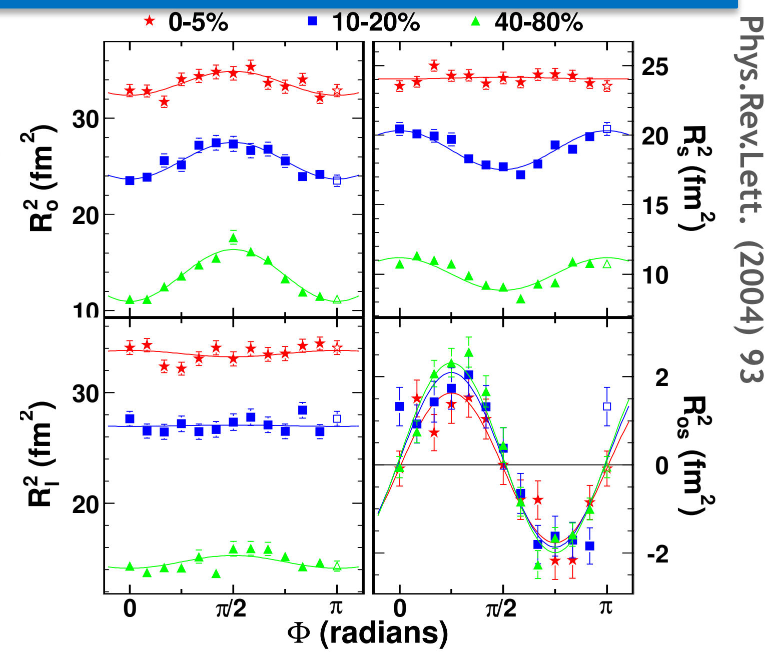
$$CF(\vec{q}) = 1 + \lambda \exp\left(-q_o^2 R_o^2 - q_s^2 R_s^2 - q_l^2 R_l^2\right)$$



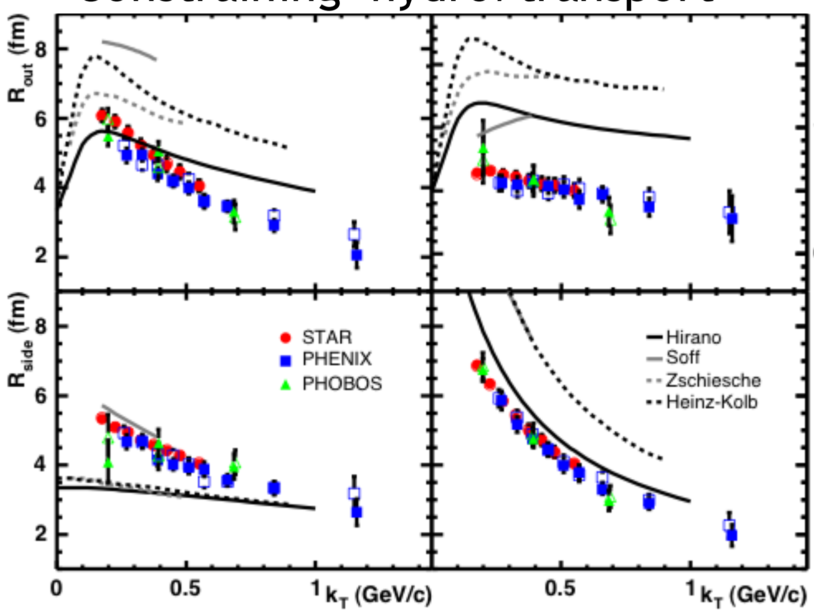
Femtoscopy - what information can we obtain?

- HBT radii depend on dynamical properties of source, e.g. EoS, order of phase transition, flow... → Studying dynamical properties of source

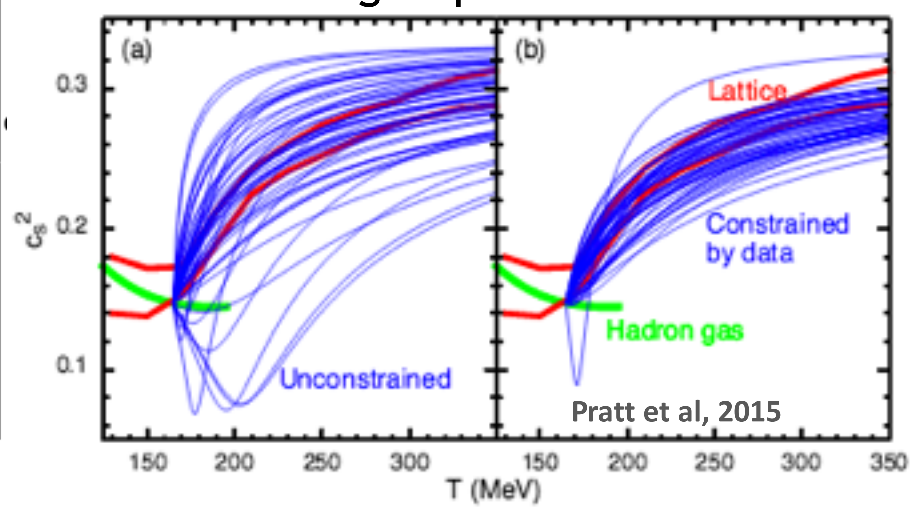




Constraining hydro/transport



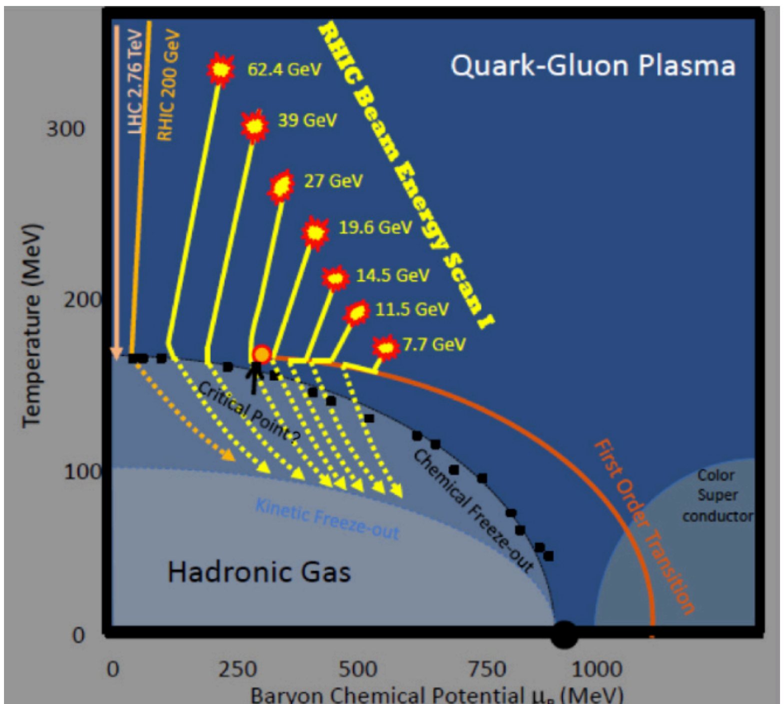
Constraining Equation of state

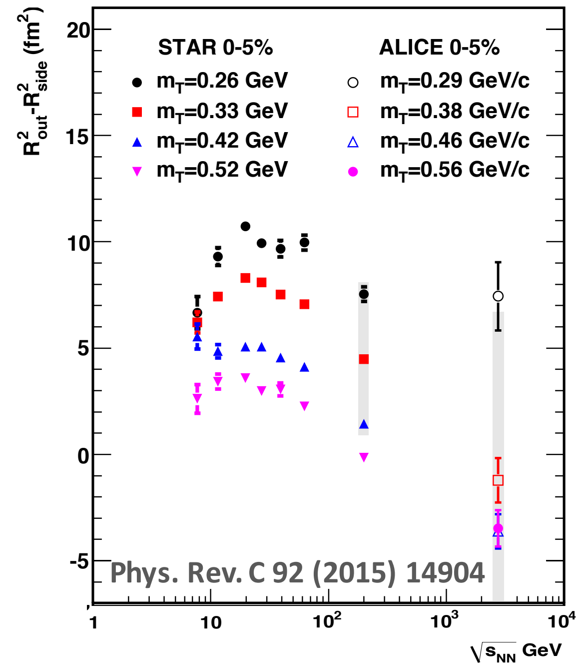


RHIC Beam Energy Scan (BES) and kaon femtoscopy for BES

RHIC Beam Energy Scan & Femtoscopy

- BES is one of the main physics program at the RHIC
- The goal of BES is study phase diagram of nuclear matter
  - Find the QCD critical point
  - 1st order phase transition signs
  - Turn-off of sQGP signatures





Femtoscopy for BES:

- Longer emission duration is expected in case of 1st order phase transition
  Rischke & Gyulassy, nucl-th/9606039
- Non-monotonicity $R^2_{out} - R^2_{side}$ may indicate changes in dynamics

Femtoscopy with kaons - a cleaner probe

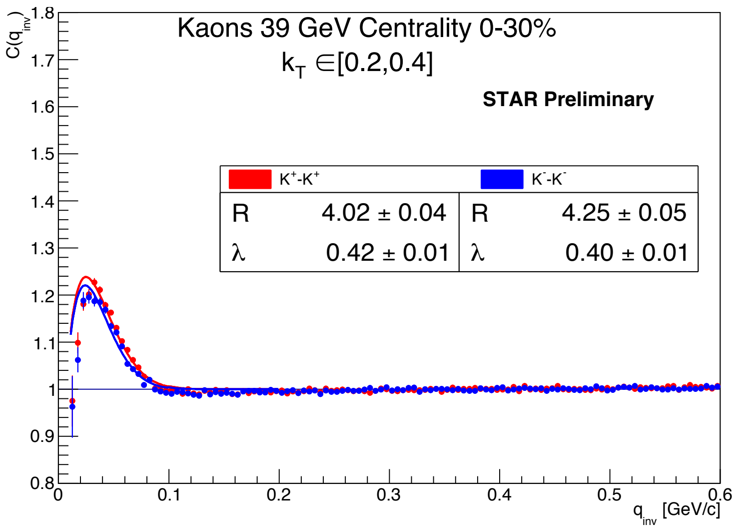
In comparison with pions, there are following advantages:

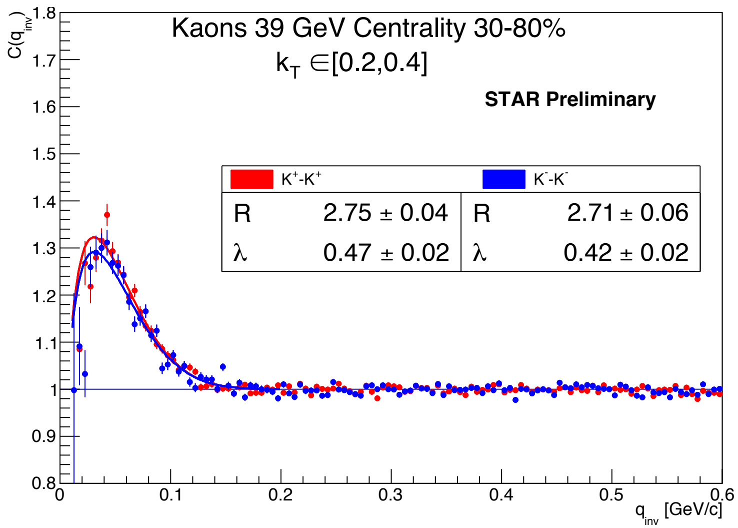
- Less feed-down – smaller contamination with non-primary kaons from weakly decaying resonances
- Smaller cross section – information about a different stage of the collision evolution
- Kaons contain strange quark – different production process if QGP is formed
- More difficult due to ~10x smaller statistics

Like-sign kaon femtoscopy for BES

Martin Girard from WUT

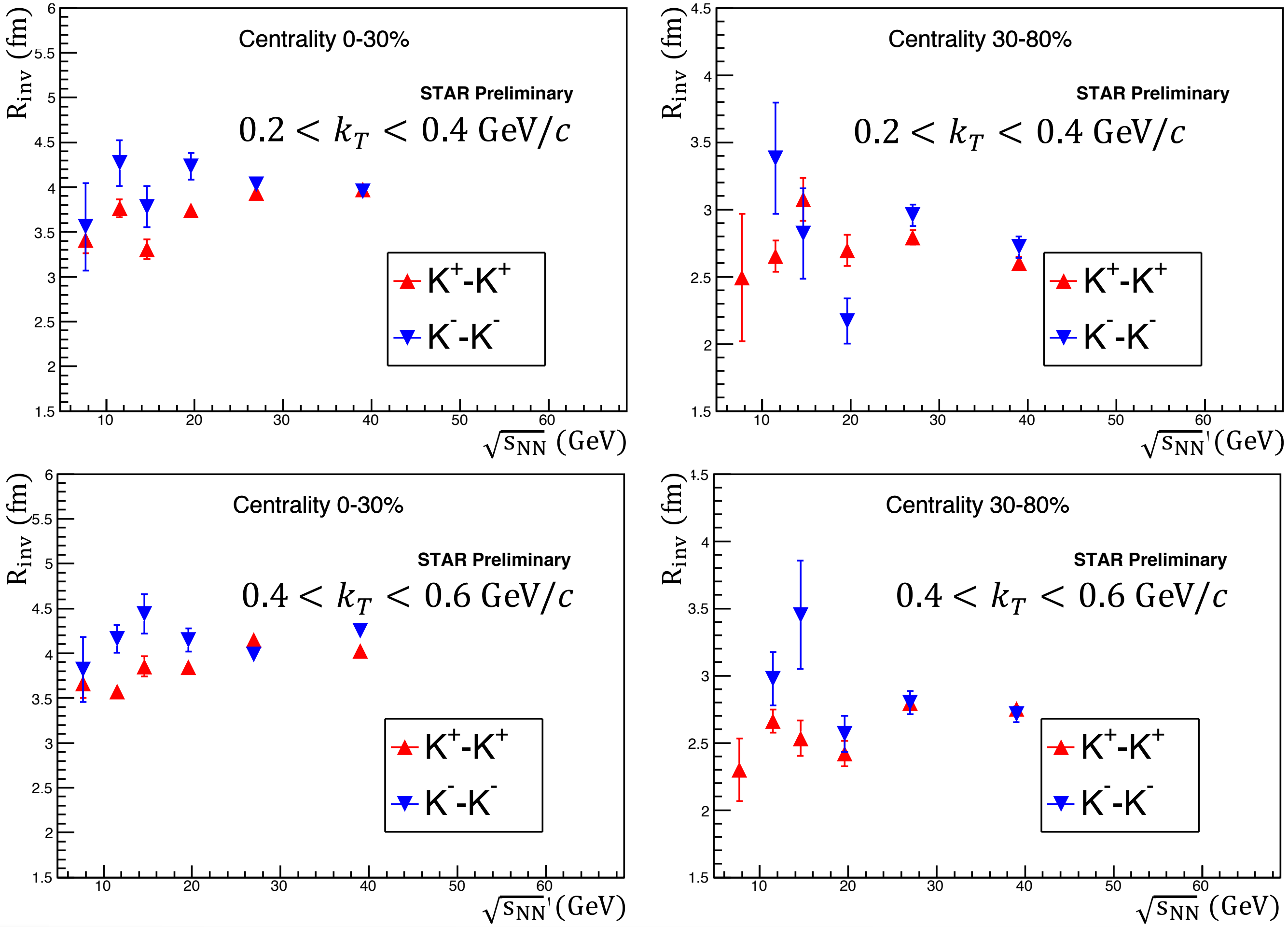
- 1D femtoscopic analysis of charged kaons
- 6 energies: 7.7, 11.5, 14.5, 19.6, 27, 39 GeV
- 2 centrality bins (0-30, 30-80%) and 2 k_T bins (0.2-0.4, 0.4-0.6 GeV/c)
- Fitting function: $CF(q_{inv}) = \left[(1-\lambda) + \lambda K(q_{inv}) e^{-R_{inv}^2 q_{inv}^2}\right]\mathcal{N}$,
  where λ - correlation strength, $K(q_{inv})$ - Coulomb function and $\mathcal{N}$ - normalization





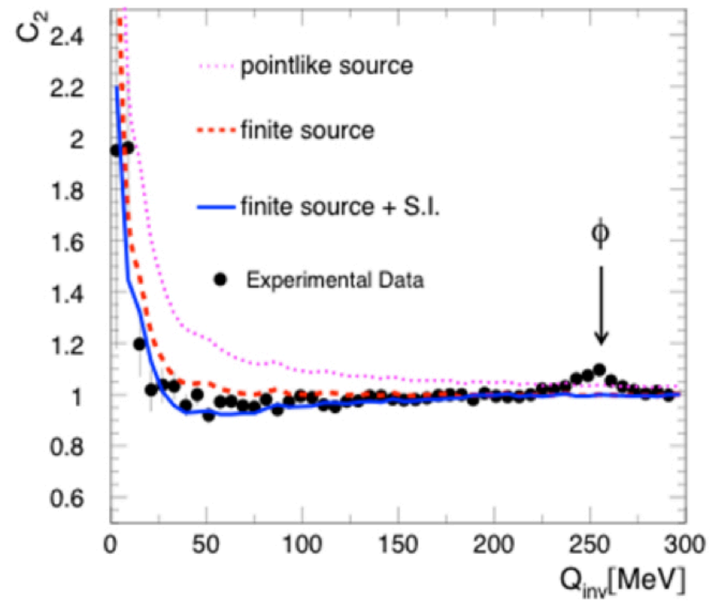
Like-sign kaon femtoscopy for BES - results

- Extraction of source radii R_{inv} from 1D correlation function
- Source radii R_{inv} as function of energy - 7.7, 11.5, 14.5, 19.6, 27, 39GeV
- No clear beam energy dependence visible



Femtoscopy with unlike-sign kaons at 200 GeV

- Au+Au collisions at 200 GeV - data were recorded by the STAR in 2011
  – larger available statistics + ToF for PID

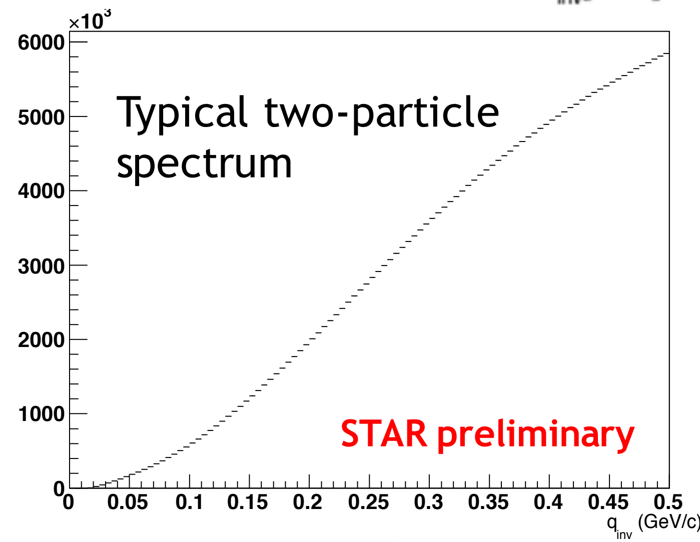


Unlike-sign kaons

- Coulomb and strong final-state interaction (FSI)
- $\boldsymbol{\phi}(\mathbf{1020})$ **resonance:**
  $k^* = 126\,\text{MeV}/c\,,\,\Gamma = 4.3\text{ MeV}$

Use strong FSI in region of resonance:
Lednicky: Phys.Part.Nucl. 40 (2009) 307-352
Pratt et al.: PRC 68 (2003) 054901

- More sensitive to source spatial extent than measurement at low q_{inv}
- Statistically advantageous



Unlike-sign 1D CF for Au+Au collisions at 200 GeV

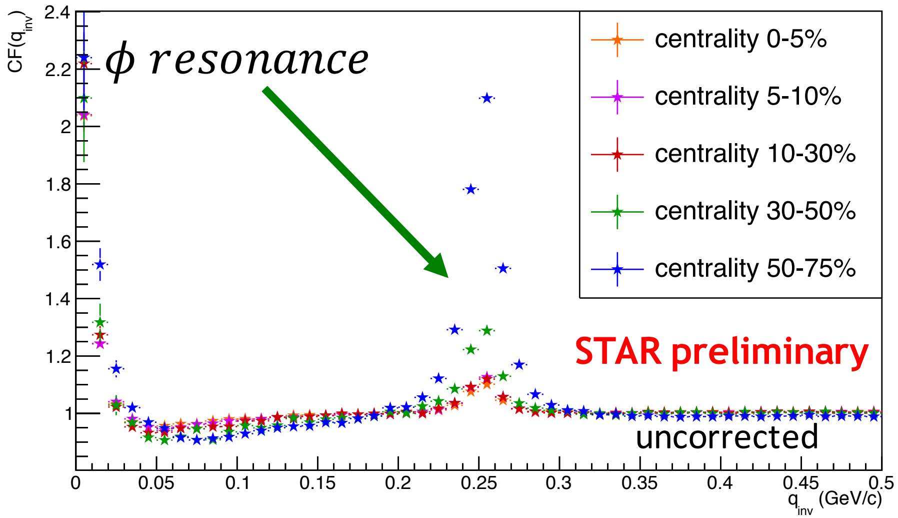
Centrality dependence

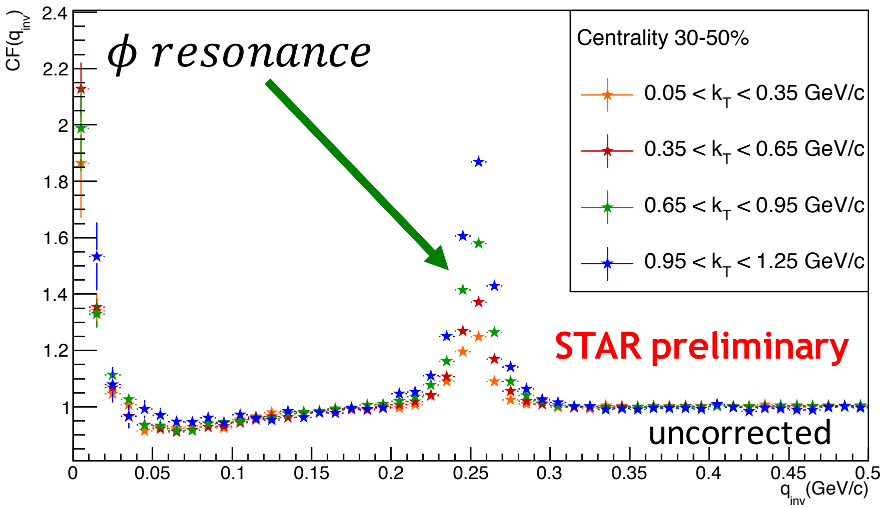
- Significant dependence is observed in $\phi(1020)$ region (CF are integrated over k_T)

k_T dependence

- Significant dependence is observed in $\phi(1020)$ region for all centralities

$$q_{inv} = p_1 - p_2 = 2k^*$$





Unlike-sign 1D CF for Au+Au collisions at 200 GeV

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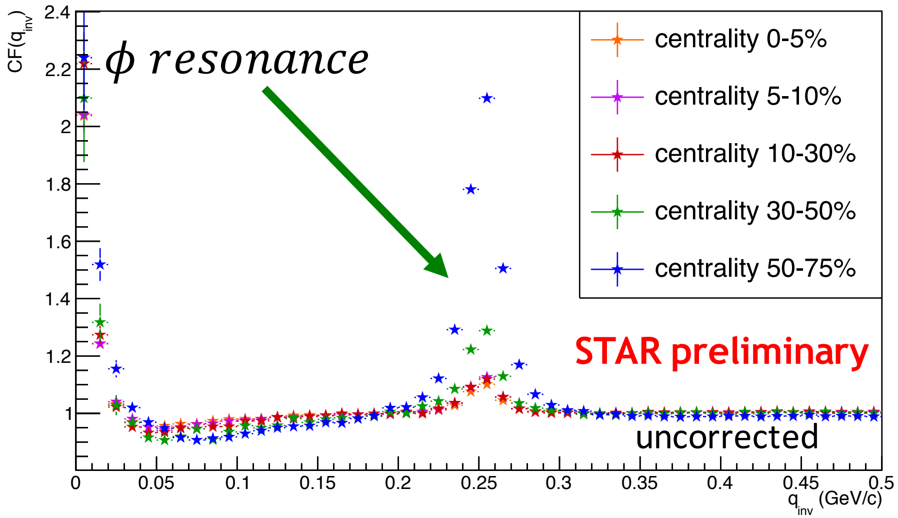

k_T dependence

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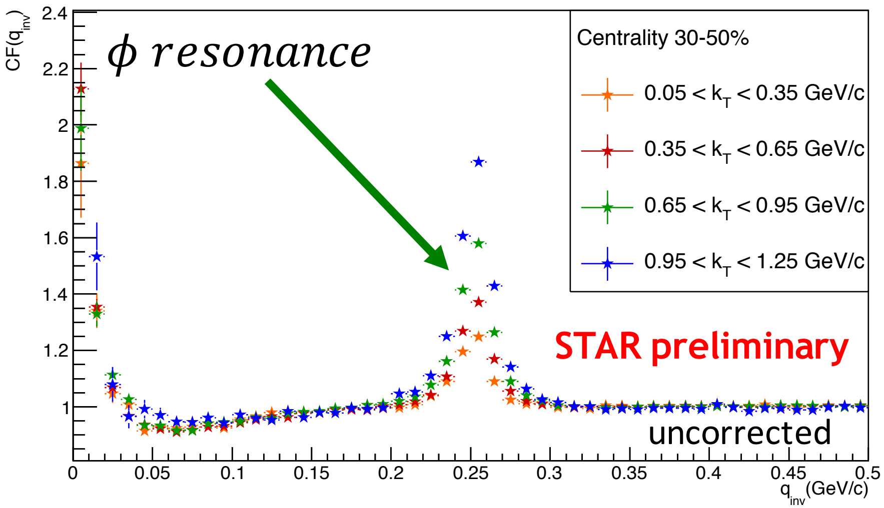
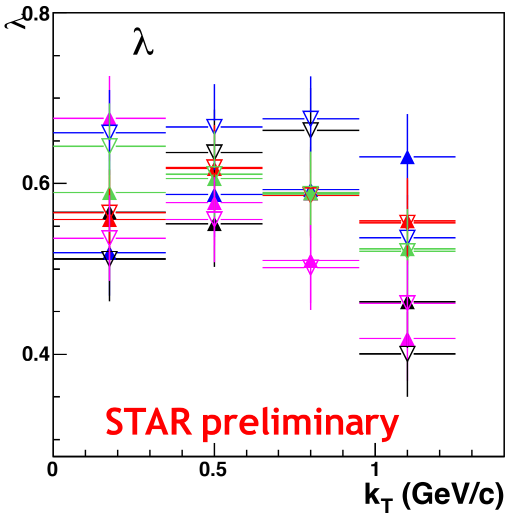


- In order to **compare** experimental correlation function to **theoretical predictions**, **extraction of kaon source radii R_{inv} and λ** from fitting **like-sign correlation function** is needed

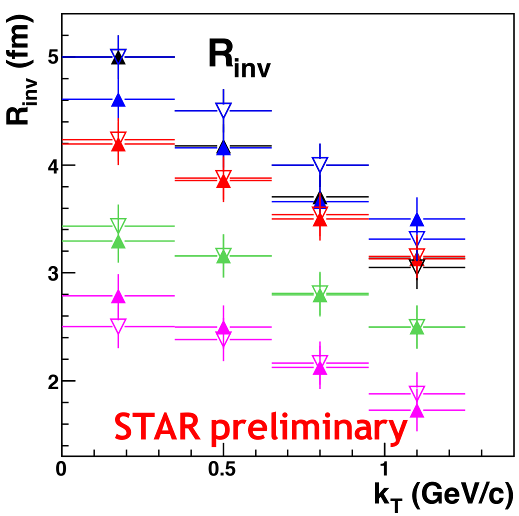
Kaon source parameters from K^+K^+ & K^-K^- correlations

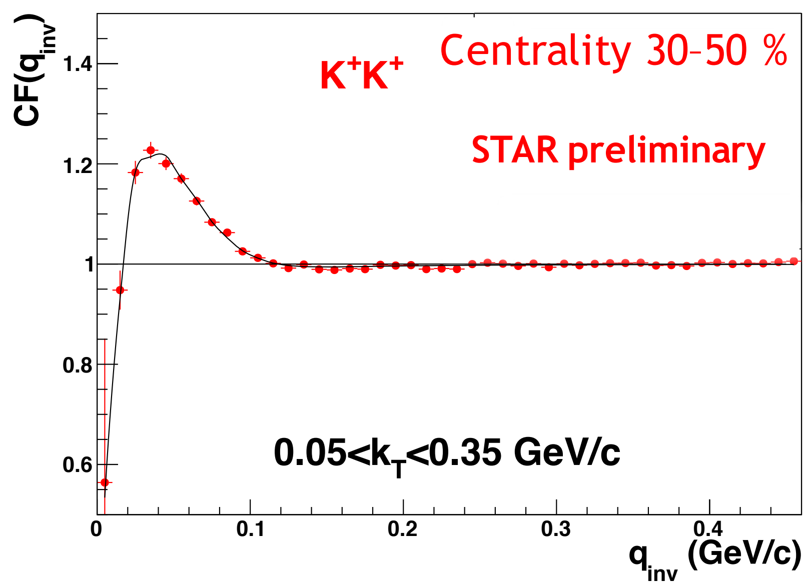


1D Kaon HBT parameters

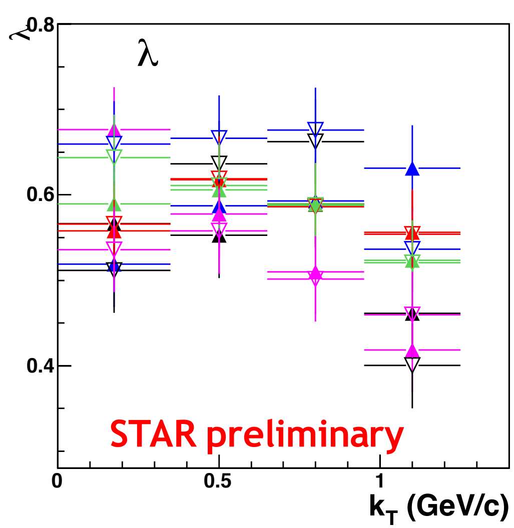
K^+K^+	K^-K^-
▲ 0-5%	▽ 0-5%
▲ 5-10%	▽ 5-10%
▲ 10-30%	▽ 10-30%
▲ 30-50%	▽ 30-50%
▲ 50-75%	▽ 50-75%

- λ and source size R_{inv} are extracted from fitting like-sign CF
- Uncertainty is dominated by systematic error, which is obtained by varying the fit range
- The source radii R_{inv} increase with the centrality and decrease with pair transverse momentum k_T





Comparison of unlike-sign 1D correlation function to Lednicky model



- **Lednicky model** includes the treatment of ϕ resonance due to the FSI as well as generalized smoothness approximation *Lednicky: Phys.Part.Nucl. 40 (2009) 307-352*

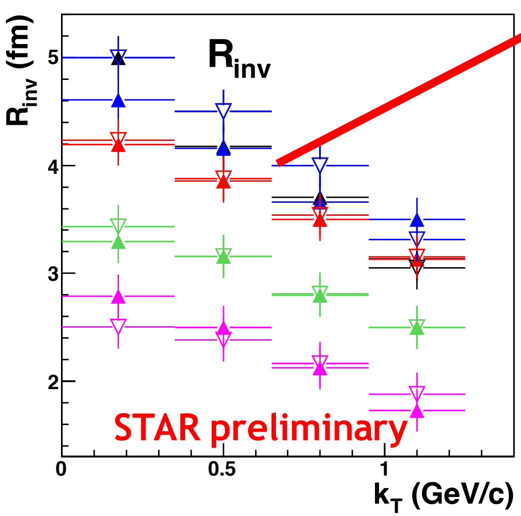
$$CF(p_1,p_2) = \int d^3 r S(r,k)\left|\psi_{1,2}(r,k)\right|^2$$

  - 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:

$$CF^{exp} = \left(CF^{theor} - 1\right)\lambda + 1,$$

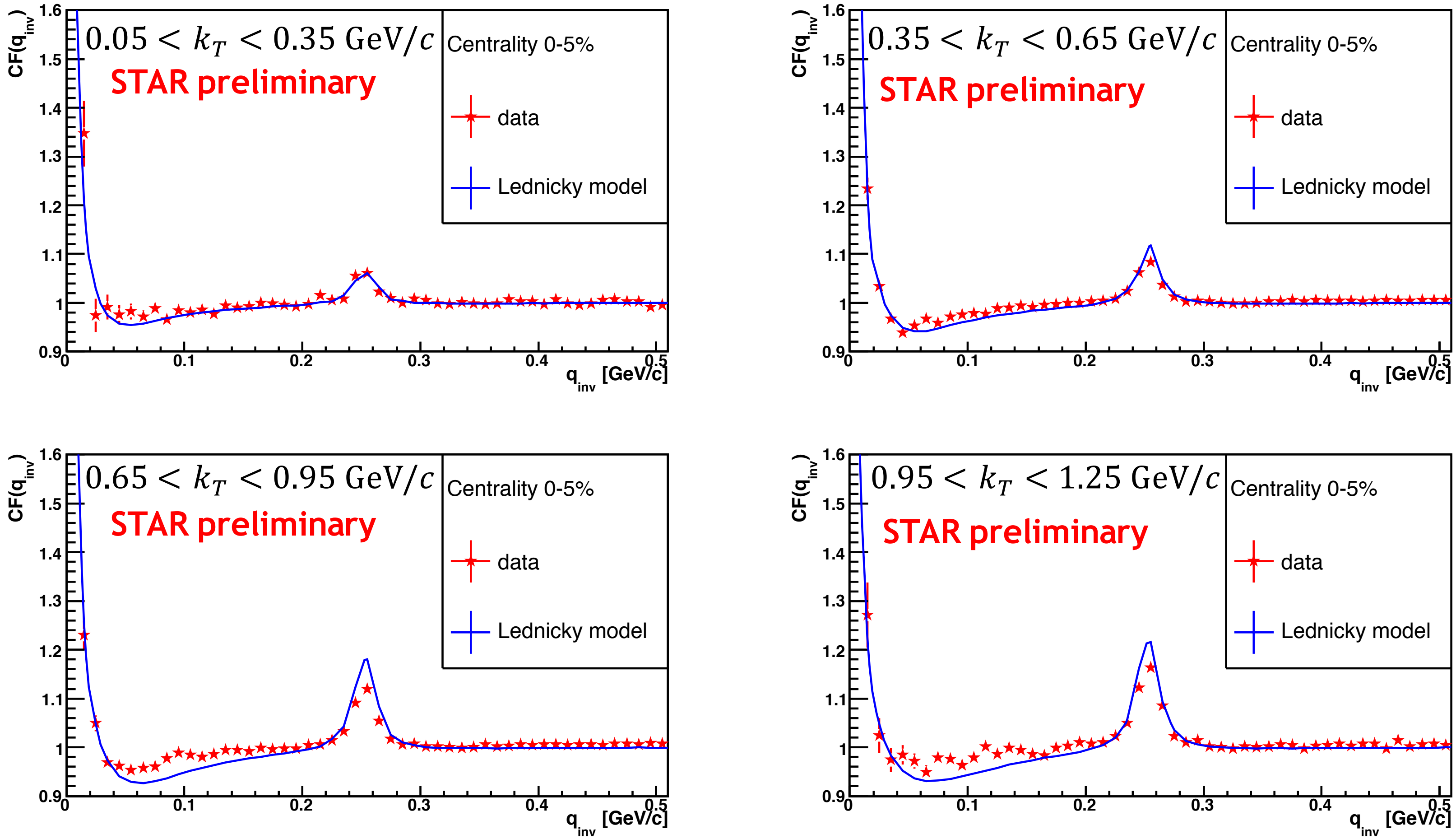
  in order to compare to an experimental correlation function, which is corrected for misidentification of kaons



Comparison of unlike-sign 1D correlation function to Lednicky model

Centrality 0-5 %

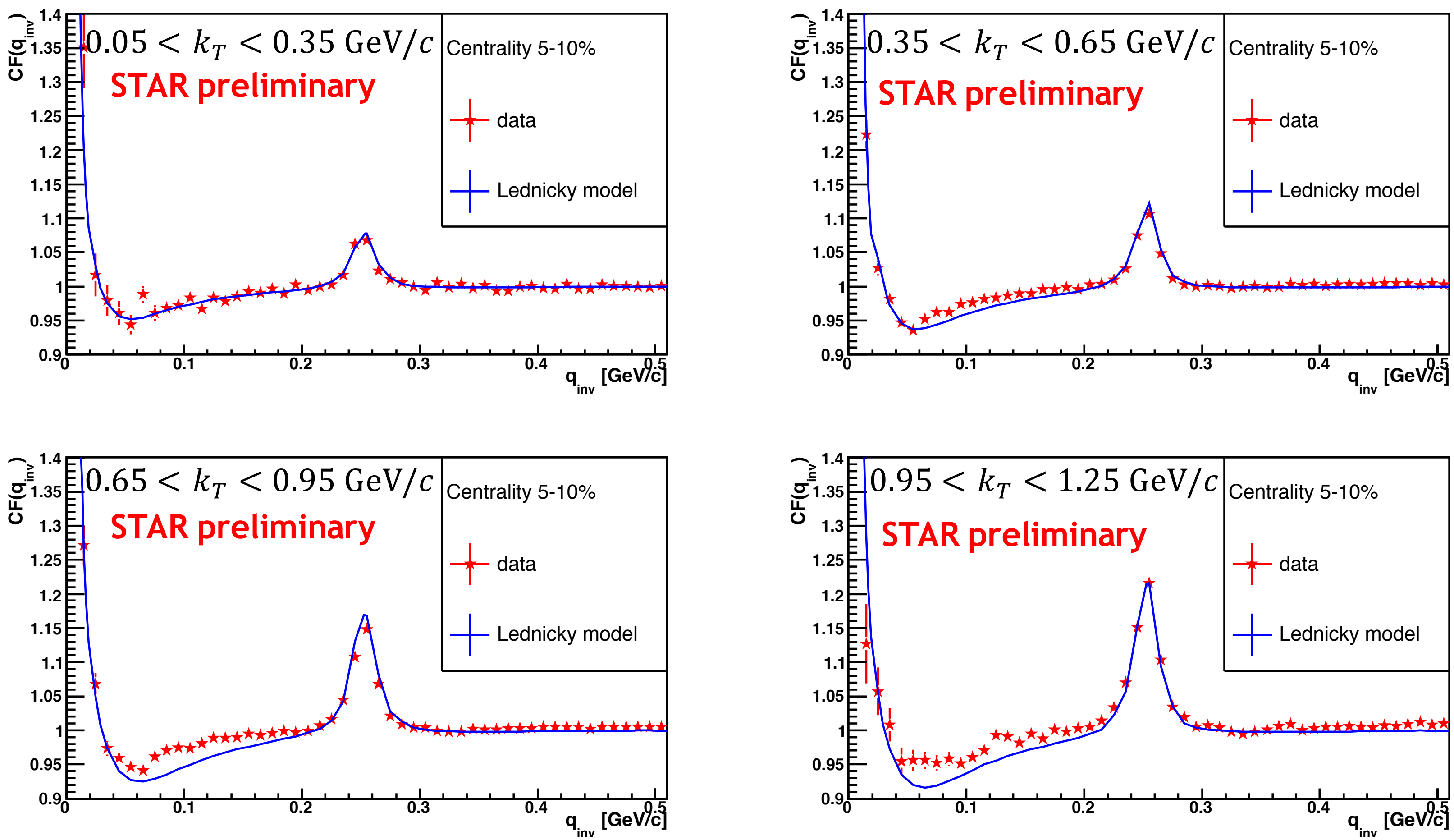
- The Lednicky's model reproduces overall structure of the observed correlation function



Comparison of unlike-sign 1D correlation function to Lednicky model

Centrality 5-10 %

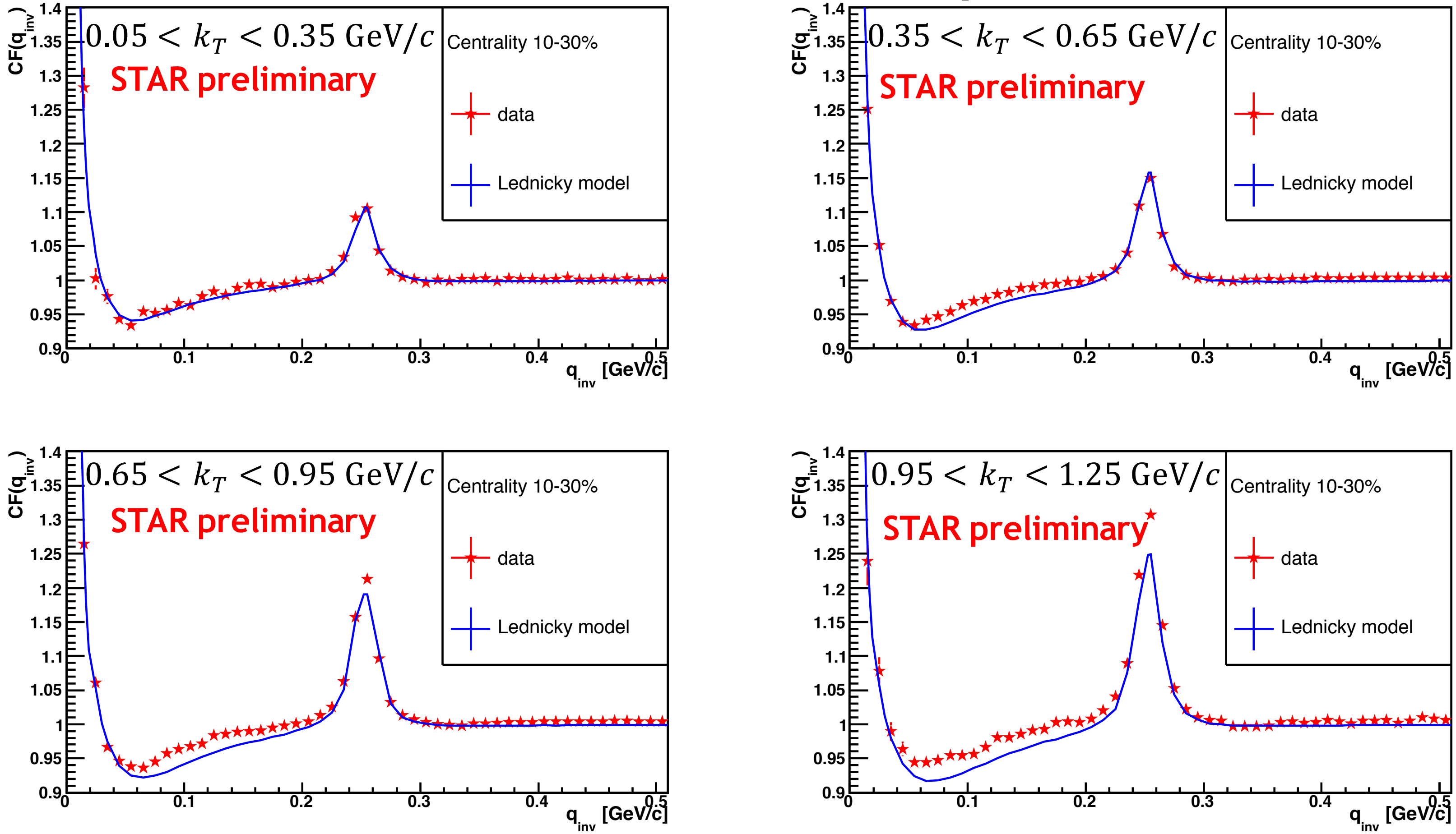
- The Lednicky's model reproduces overall structure of the observed correlation function



Comparison of unlike-sign 1D correlation function to Lednicky model

Centrality 10–30 %

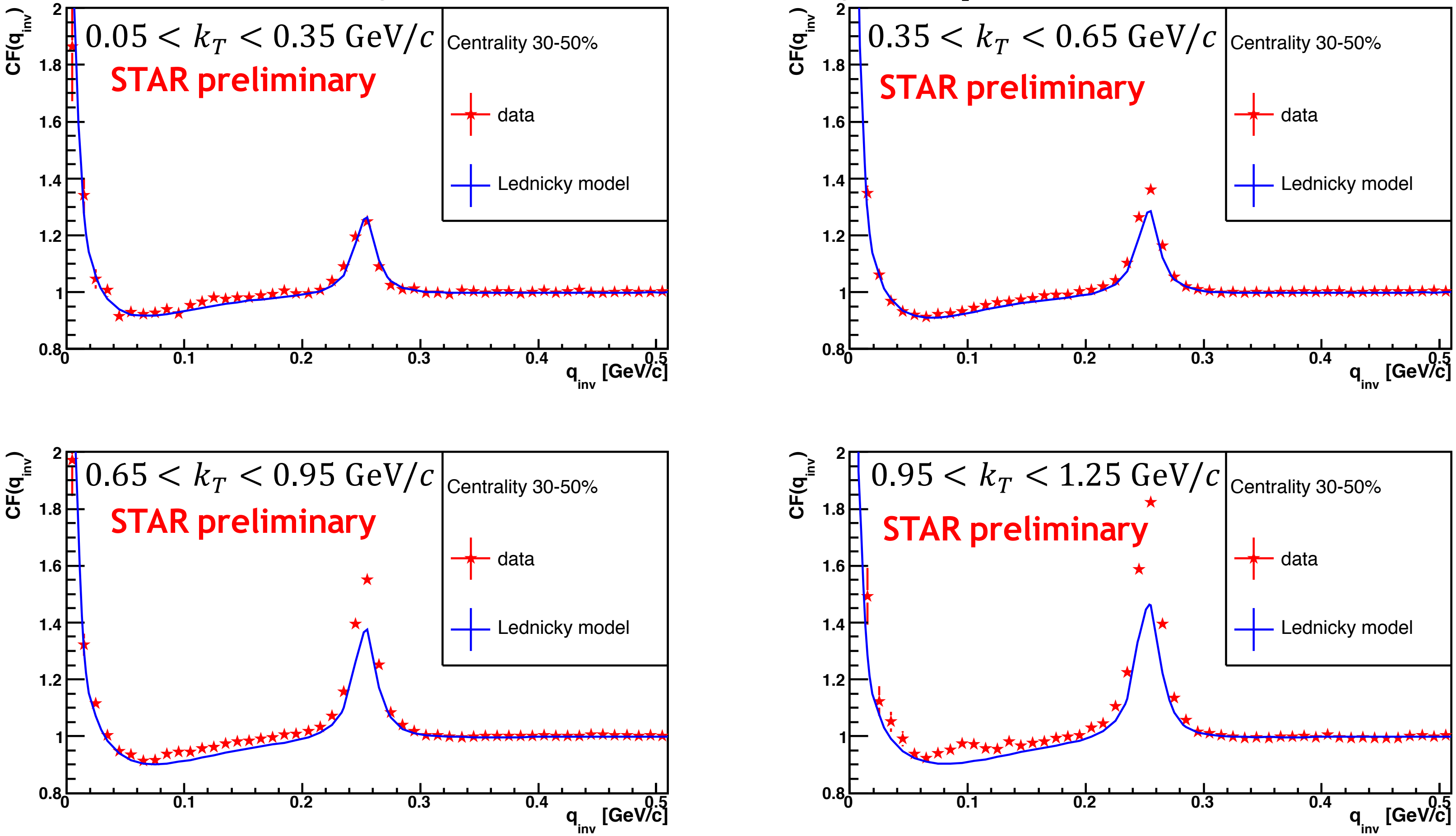
- The Lednicky's model reproduces overall structure of the observed correlation function, but model under predicts the strength of the correlation functions in the region of resonance for higher k_T



Comparison of unlike-sign 1D correlation function to Lednicky model

Centrality 30-50 %

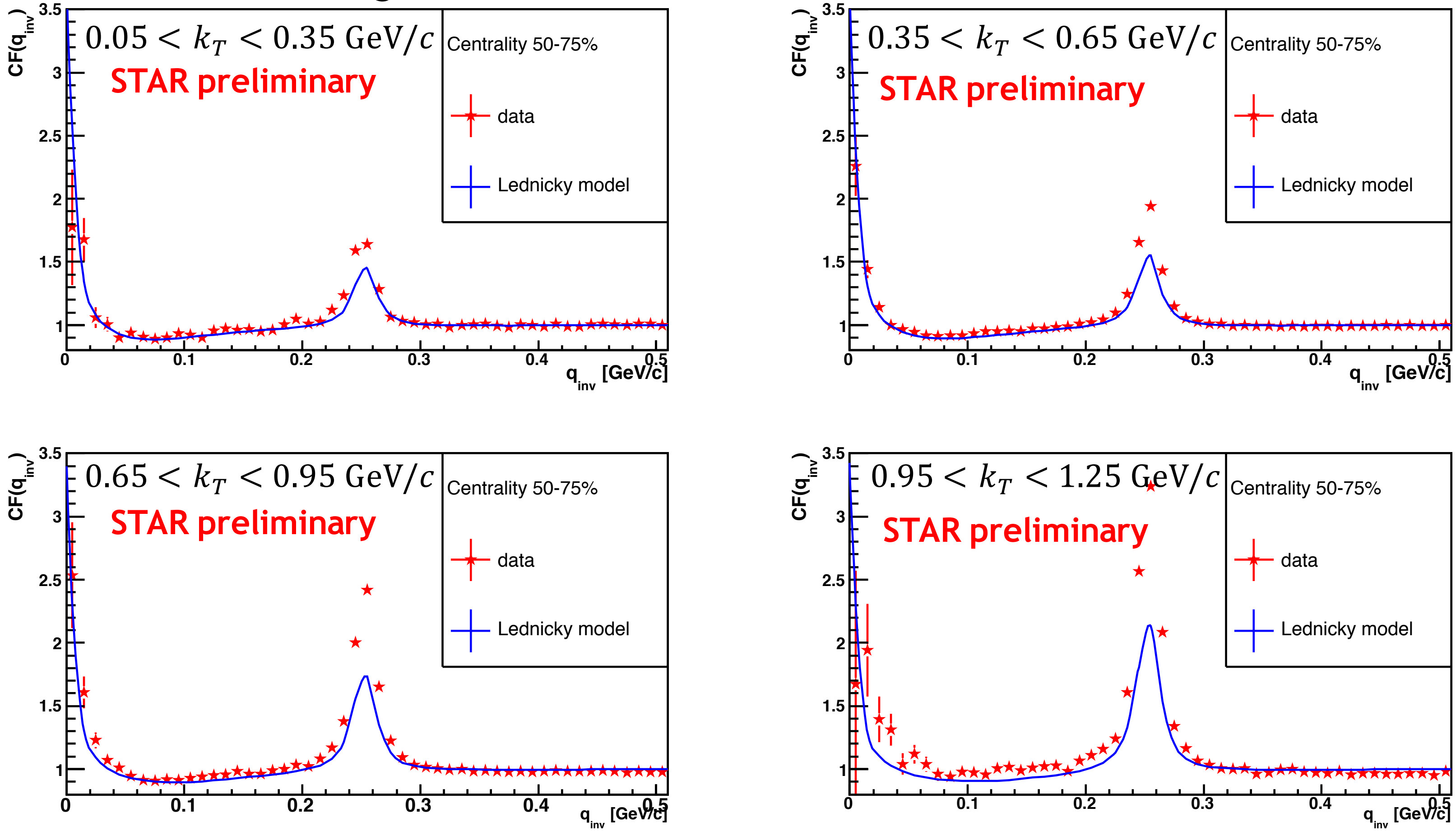
- The Lednicky's model reproduces overall structure of the observed correlation function, but model under predicts the strength of the correlation functions in the region of resonance for higher k_T



Comparison of unlike-sign 1D correlation function to Lednicky model

Centrality 50-75 %

- The Lednicky's model reproduces overall structure of the observed correlation function, but model under predicts the strength of the correlation functions in the region of resonance



Summary

STAR results on kaon femtoscopy:

Like-sign kaon femtoscopy for RHIC Beam Energy Scan

- Extraction of source radii R_{inv} from 1D correlation function

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

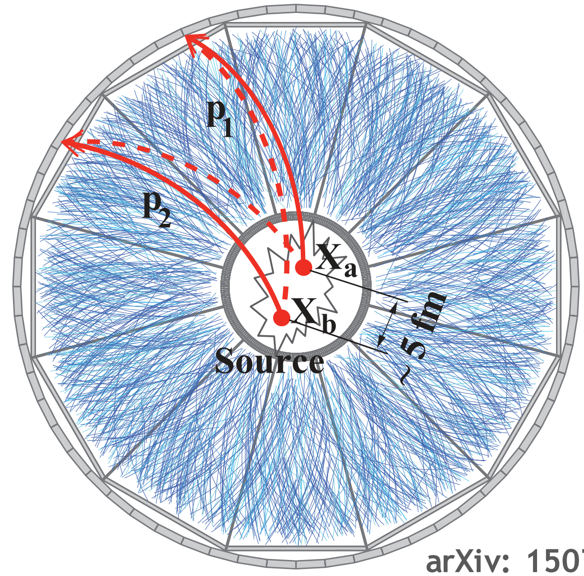
Thank you for your attention

Back-up

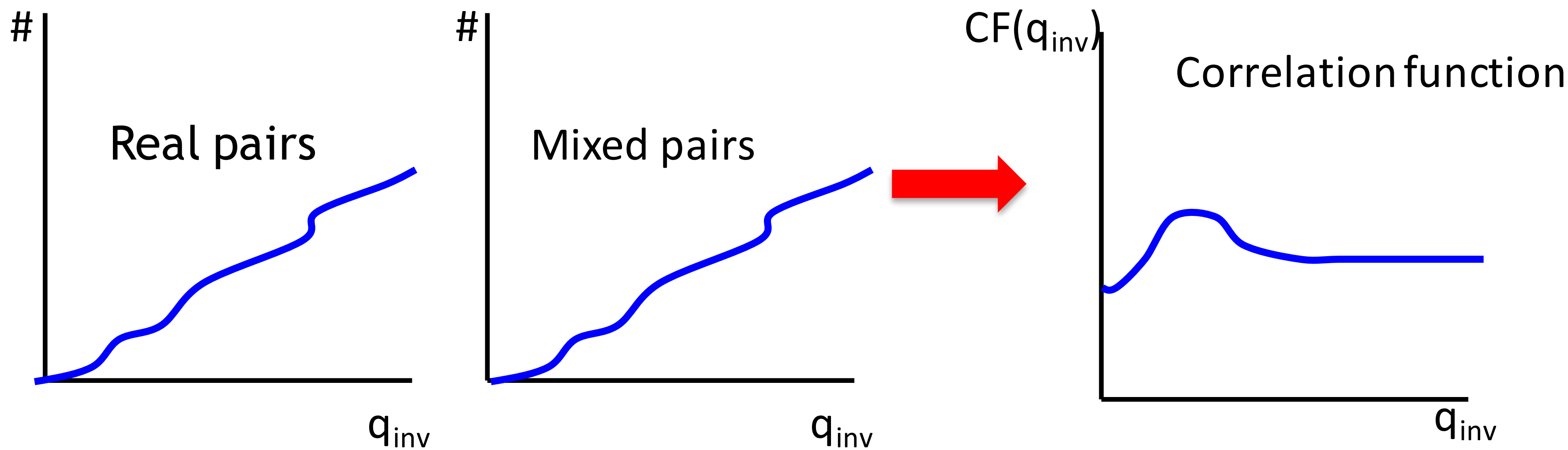
Back-up: Experimental correlation function

Experimentally:

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



arXiv: 1507.07158



Back-up: Kaon source imaging

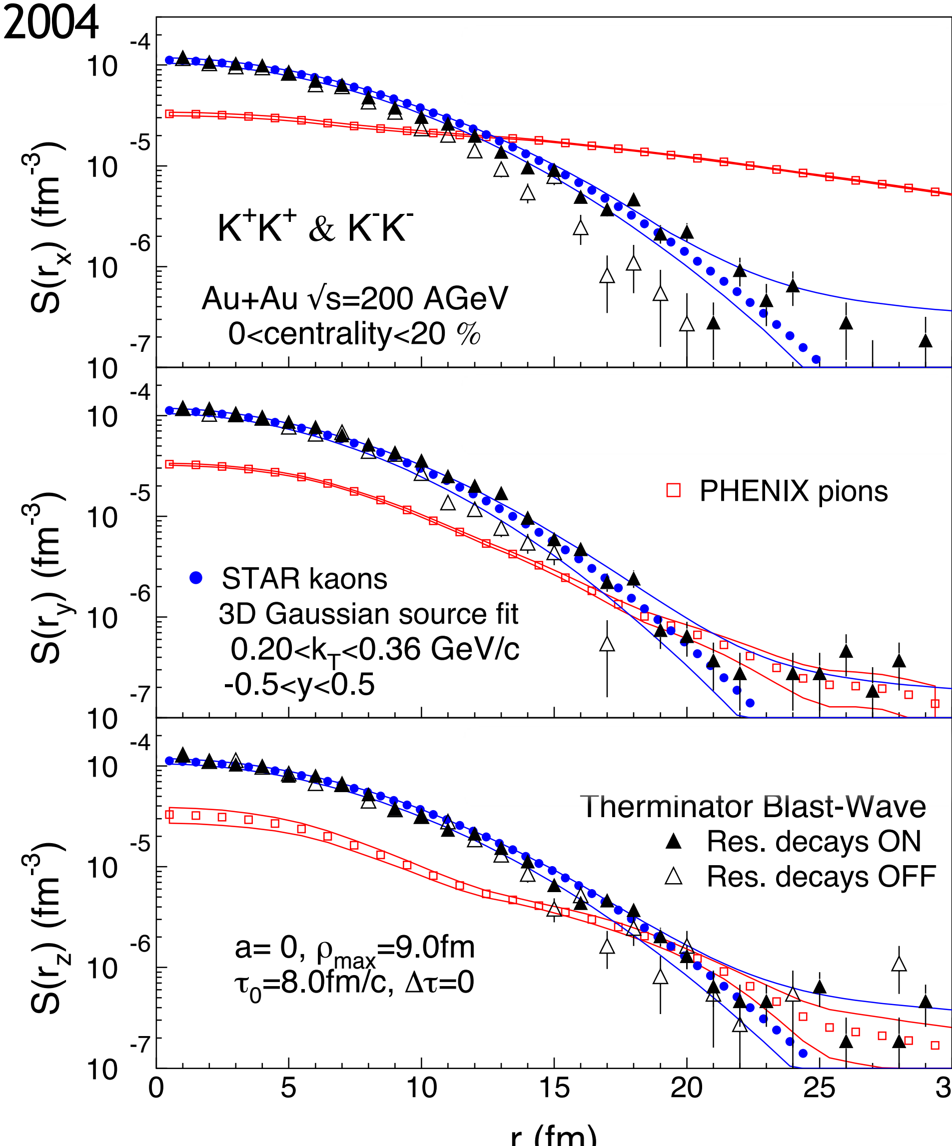
- Au+Au collision at 200 GeV recorded in 2004 and 2007 – only TPC for PID

Source imaging - technique to obtain $S(r,k)$ directly

- Numerical inversion of the equation

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

- advantageous: no assumptions for the shape of source
- challenges: statistics, no analytical solutions → some limitations and approximations
- **Kaon source can be well described by Gaussian shape**



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