Non-identical kaon femtoscopy at STAR experiment

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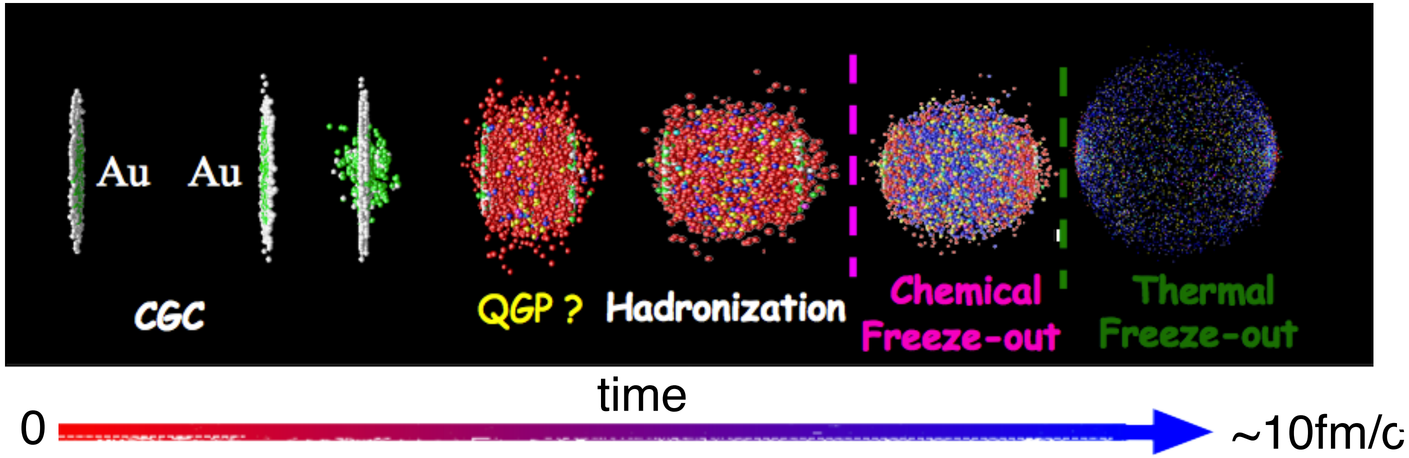
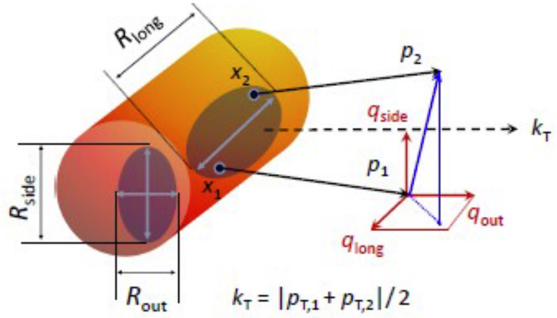
7. Česko-slovenská studentská konference ve fyzice

24th May 2016

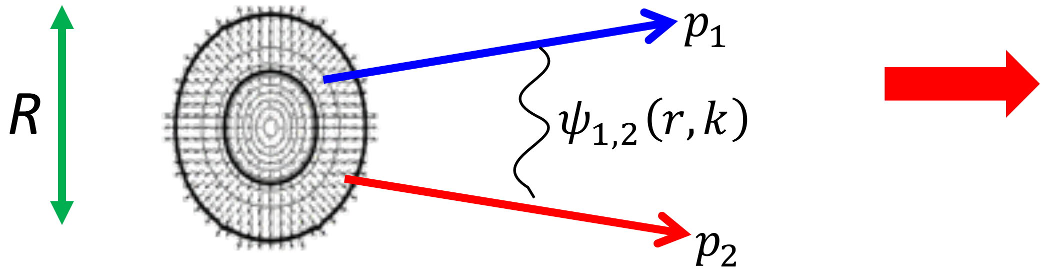
Femtoscopy

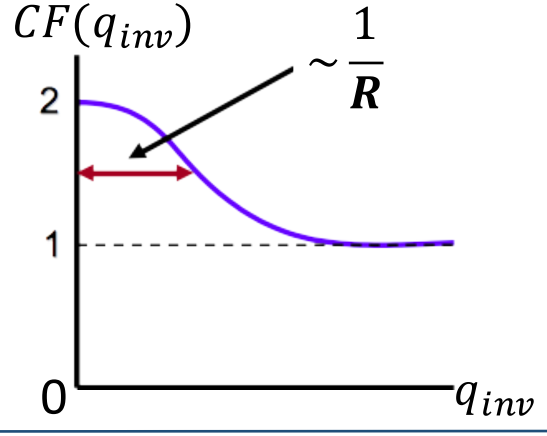




- Study space-time extents of the source at the thermal freeze-out
- Correlation function: $CF(p_1,p_2) = \int d^3r S(r,k) \left|\psi_{1,2}(r,k)\right|^2$

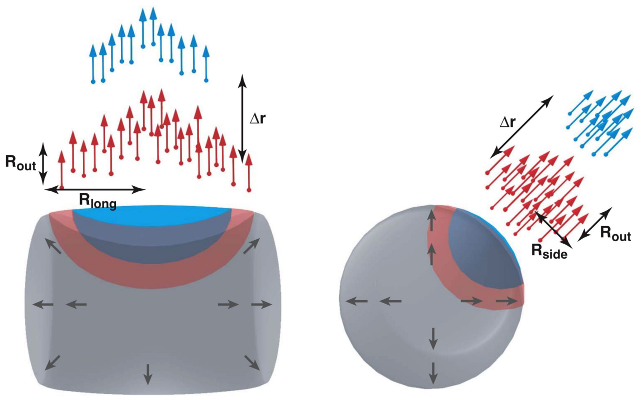
$$r = x_1 - x_2 \quad q_{inv} = p_1 - p_2 = 2k^*$$

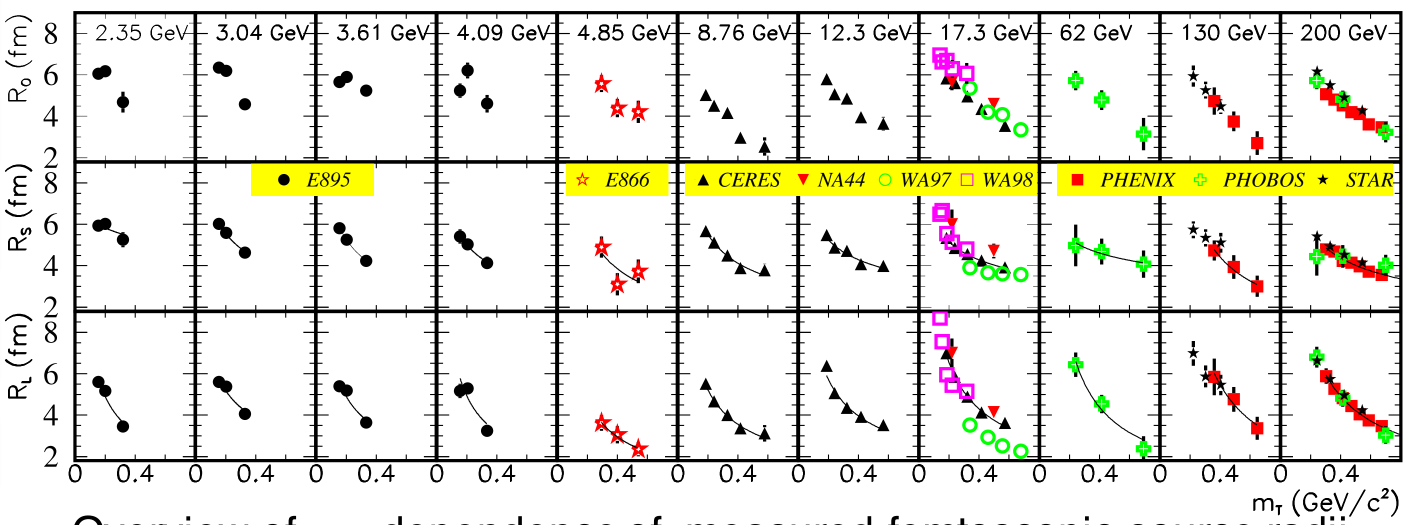




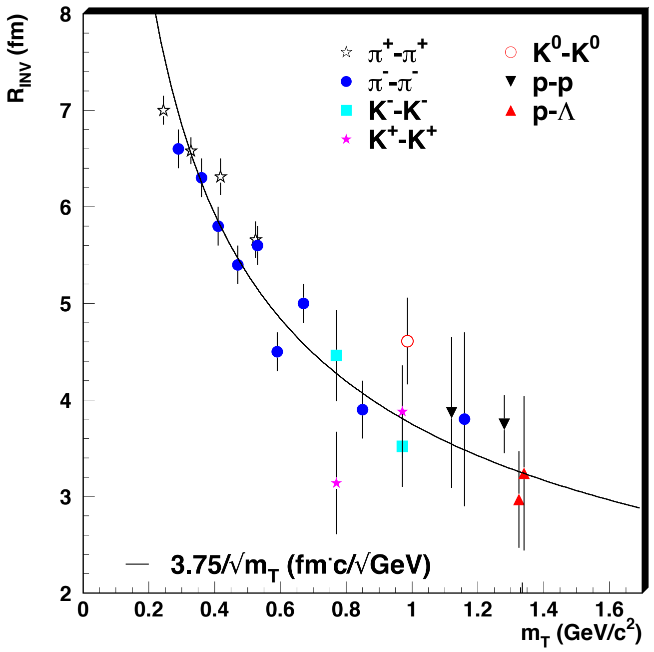
Femtoscopy

- Dynamical properties are encoded in femtoscopic radii
- Typical m_T scaling indicates expansion and evolution of the measured system





Overview of m_T dependence of measured femtoscopic source radii from $\pi^{\pm} - \pi^{\pm}$ correlation



m_T scaling for different particle species

Kaon femtoscopy

In comparison with typical pion femtoscopy, there are following advantages:

- Kaons contain strange quark
- Smaller cross section with hadronic matter
- More difficult due to ~ 10 smaller statistics

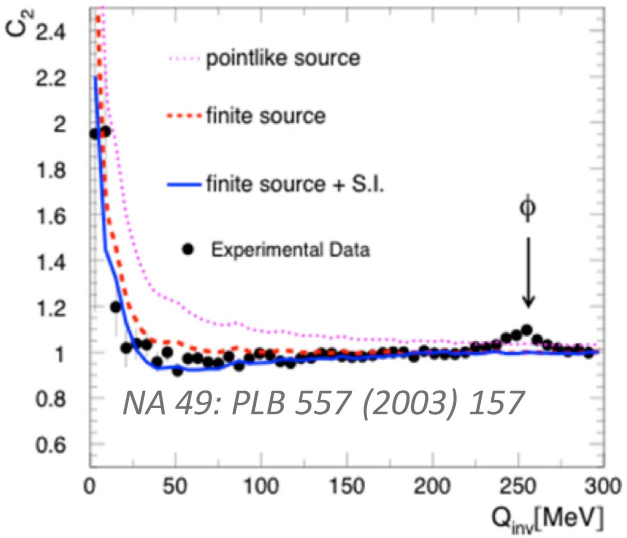
K^+K^+ & K^-K^- - “standard femtoscopy” at low q_{inv}

- Extraction of source radii

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

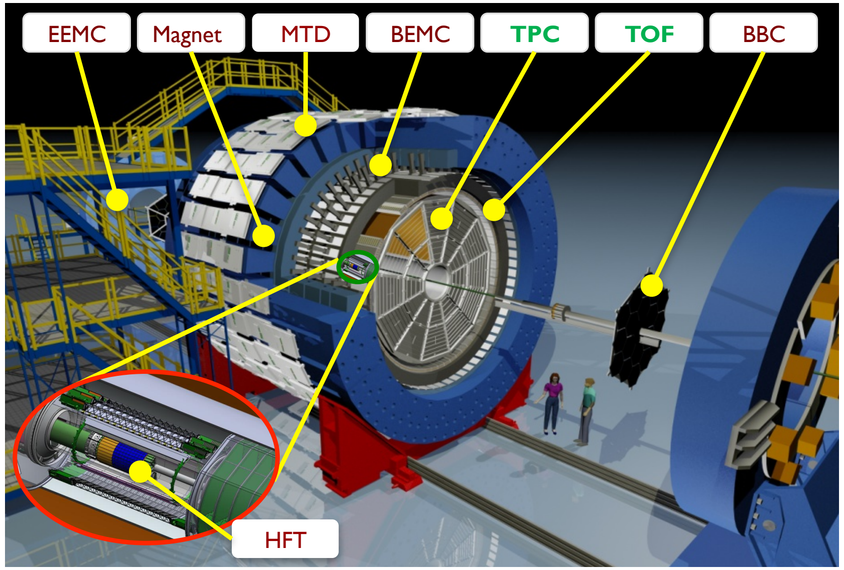
K^+K^- correlations - femtoscopy with narrow resonance

- Using strong final-state interaction via $\phi(1020)$ resonance
  - Predicted to be sensitive to the source size
  - Statistically advantageous
- Challenge - extension of femtoscopic formalism to higher q_{inv}
- First systematic study



NA 49: PLB 557 (2003) 157

Data sample



The Solenoidal Tracker at RHIC (STAR)

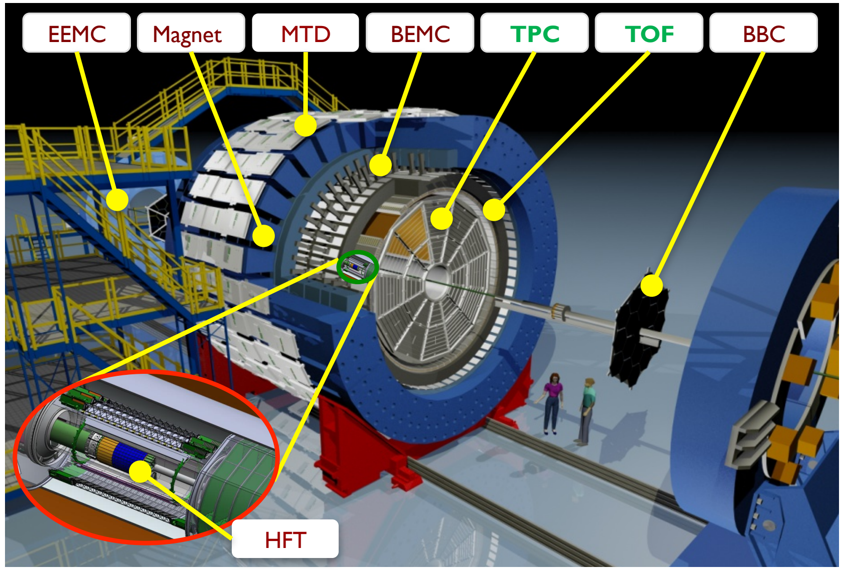
- PID at mid-rapidity with full coverage in azimuthal angle

Main subdetectors used for this analysis:

- Time Projection Chamber (TPC)
- Time of Flight (ToF)

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

Kaon identification



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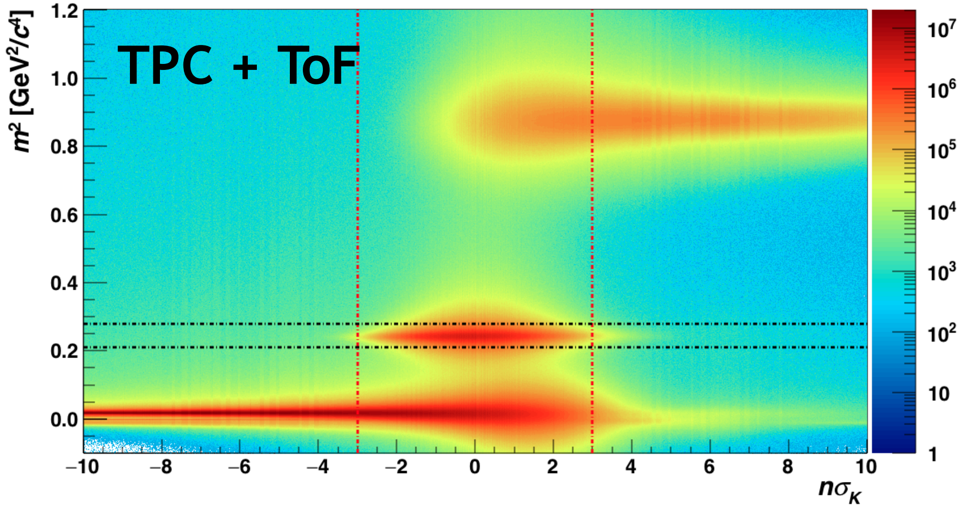
Kaon identification

- $0.15 < p < 1.55$ GeV$/c$
- TPC: $|n\sigma_{kaon}| < 3$
- ToF: $0.21 < m^2 < 0.28$ GeV$^2/c^4$

$$n\sigma_K = \ln\left(\frac{dE/dx^{meas}}{dE/dx^{theo}}\right)/\sigma_{dE/dx}$$

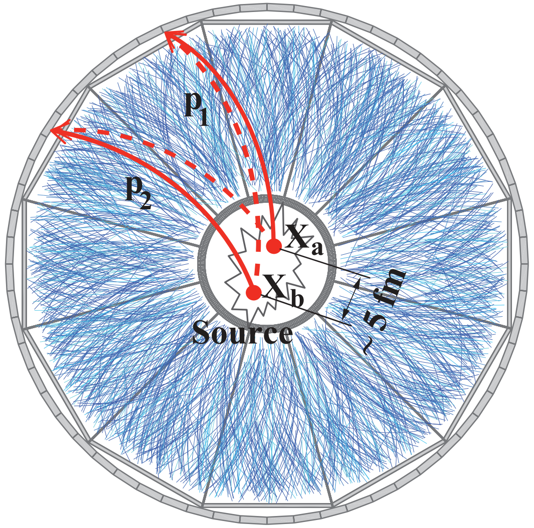
$$m = \frac{p_{TPC}}{c}\sqrt{\left(\frac{1}{\beta_{ToF}}\right)^2 - 1}$$



Construction of correlation function

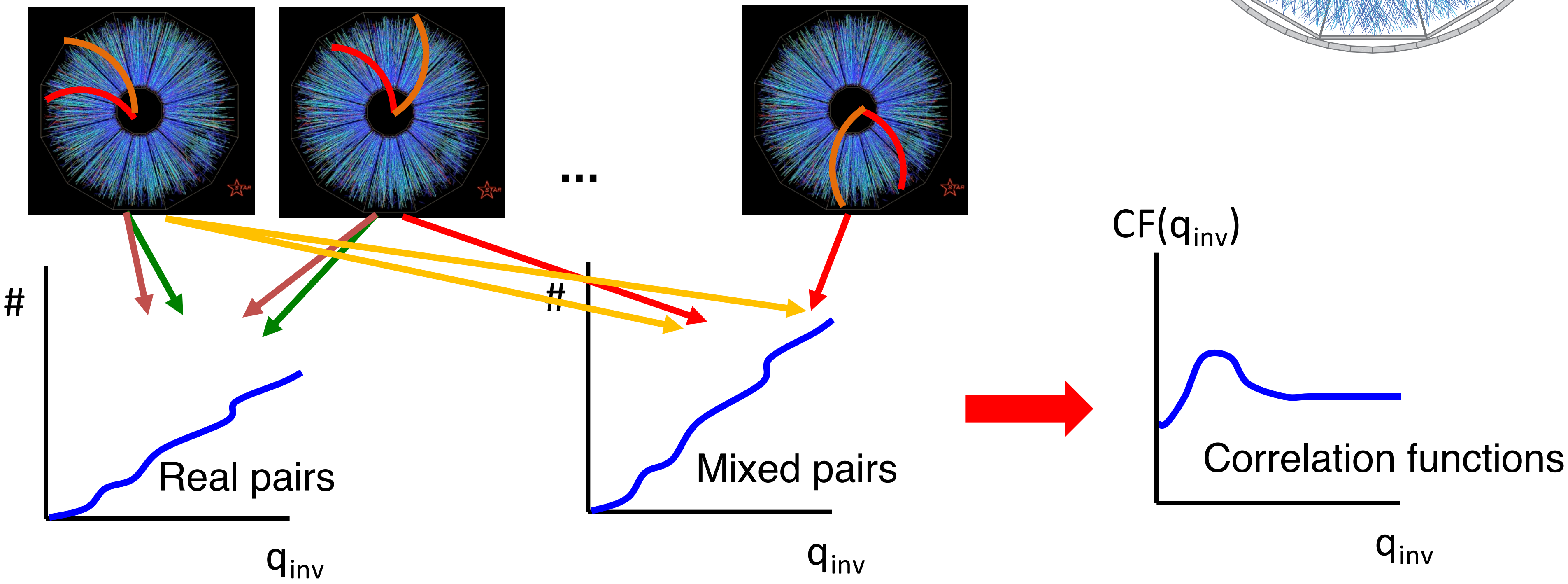
Experimental correlation function:

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



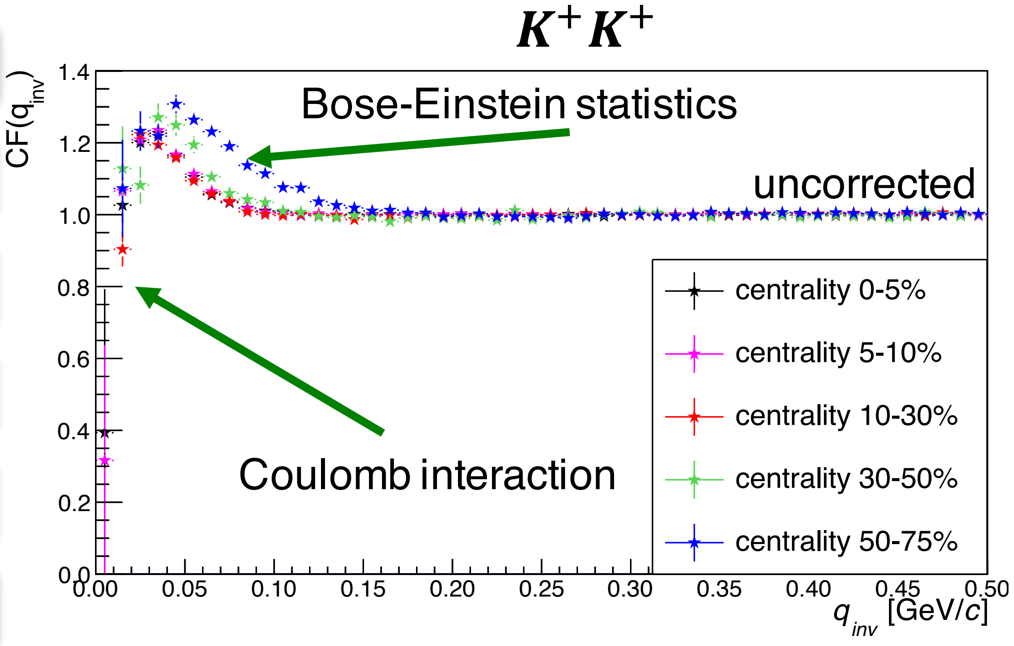
Event mixing:

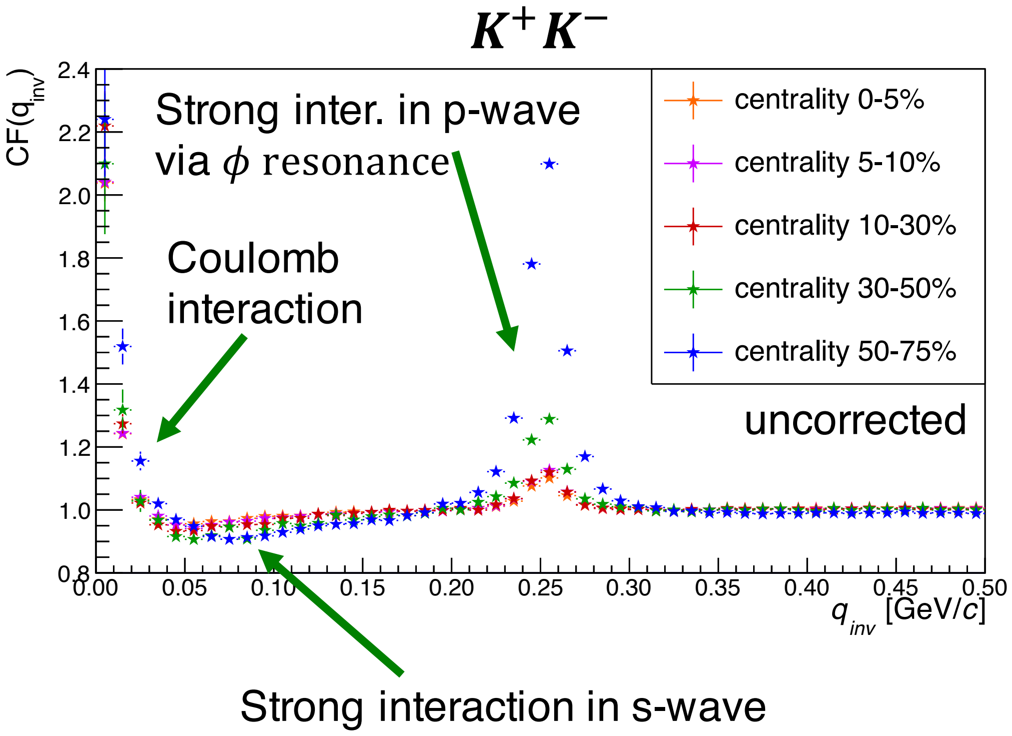
- V_Z – 10 mixing bins: 6 cm
- Multiplicity: 100 per bin



Raw correlation functions

- Femtoscopy
- Kaon femtoscopy
- Data sample
- Kaon identification
- Construction of CF
- **Raw correl. function**
- Corrections
- Fitting
- Results
- Model comparison
- Conclusions





- CFs are sensitive to the source size
- In particular, unlike-sign kaon CF is sensitive in the region of the resonance

Corrections

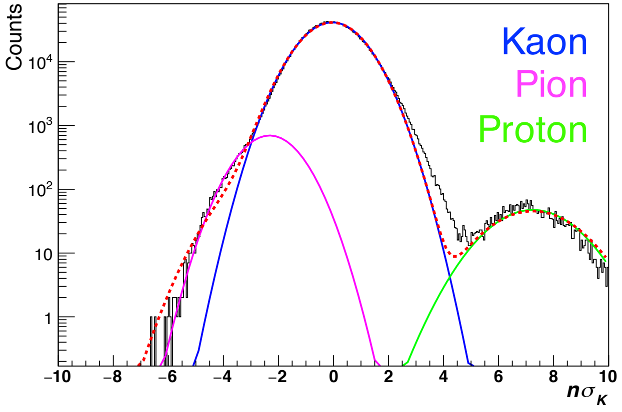
- **Purity Correction**
  - Corrections for misidentification of kaons

$$PairPurity(q_{inv}) = \sum_{p_1,p_2} Purity(p_1)Purity(p_2)Prob(q_{inv}|p_1p_2)$$

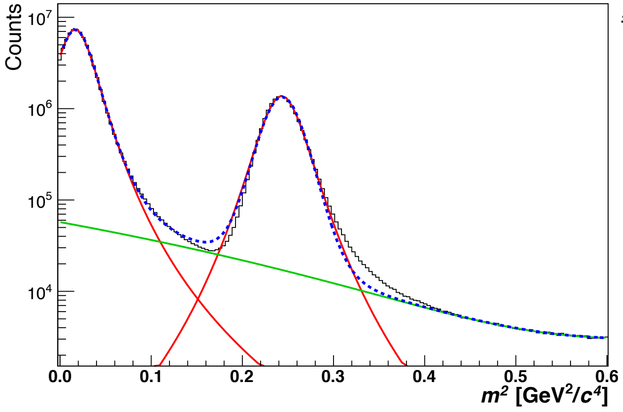
$$Purity(p_i) = Purity_{TPC}(p_i)Purity_{TOF}(p_i)$$

- Due to excellent PID ability of STAR detector **very high purity**

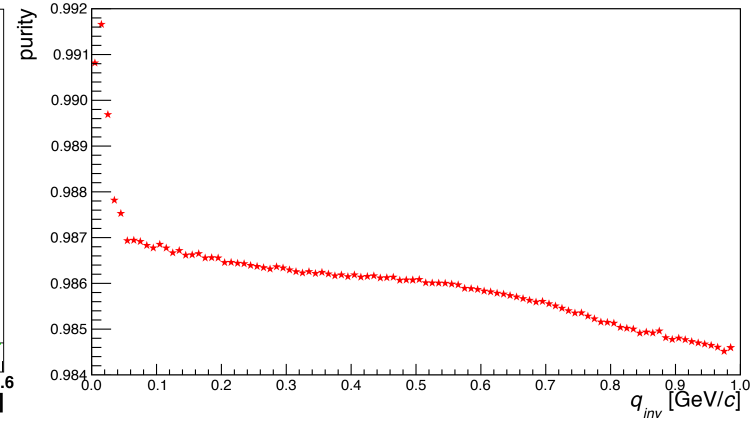
TPC purity



ToF purity



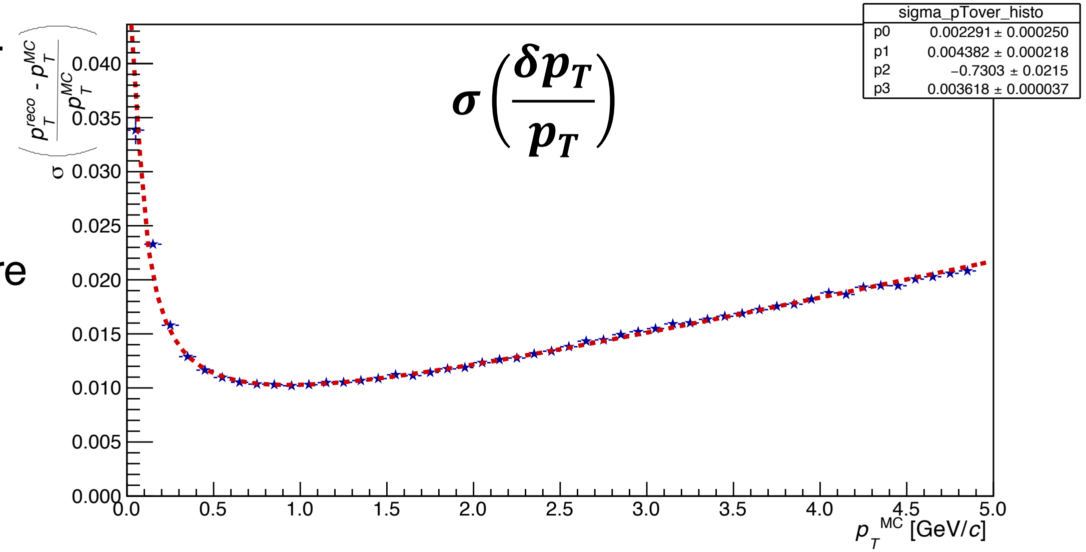
PairPurity

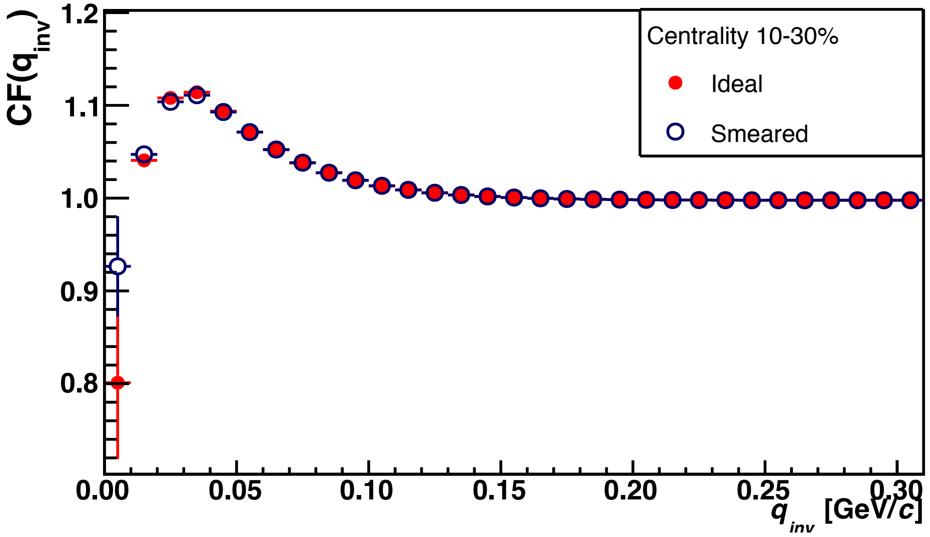


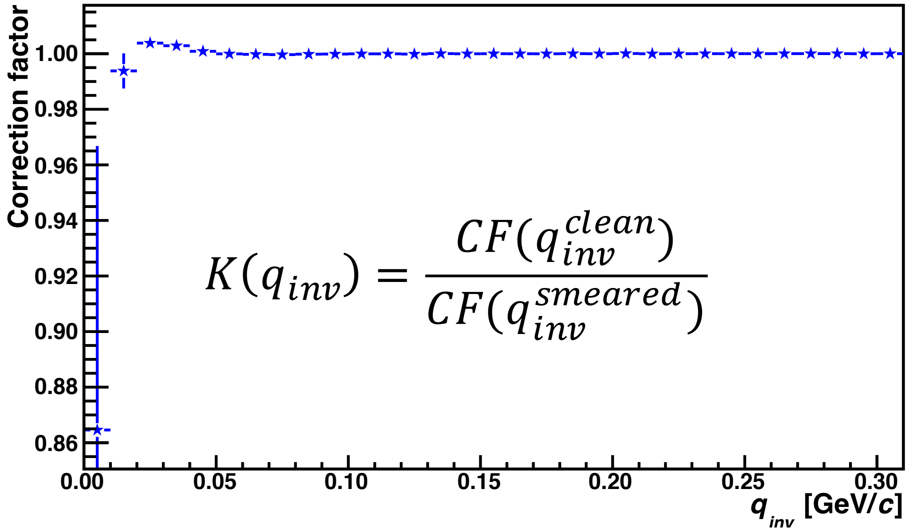
Corrections

- **Momentum resolution**
  - Correction for detector effect – limited single-particle momentum resolution in TPC
  - Parameters of momentum resolution were obtained by fitting **Monte-Carlo simulations**
  - Then, ideal and smeared theoretical CFs were calculated
  - Finally, the correction factor was obtained

STAR TPC resolution from MC simulations







Fitting – extraction of source size

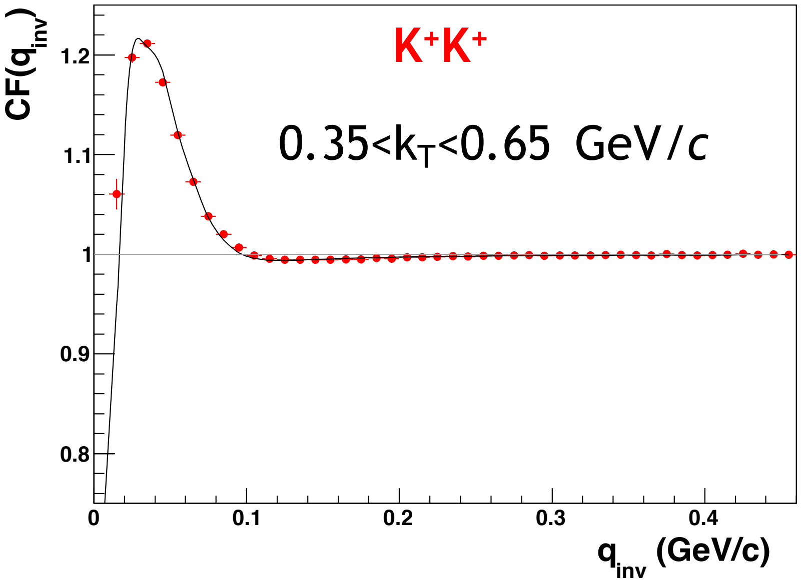
- Fitting of 1D & 3D CF + **Gaussian source**
- “standard” Bowler-Sinyukov method:

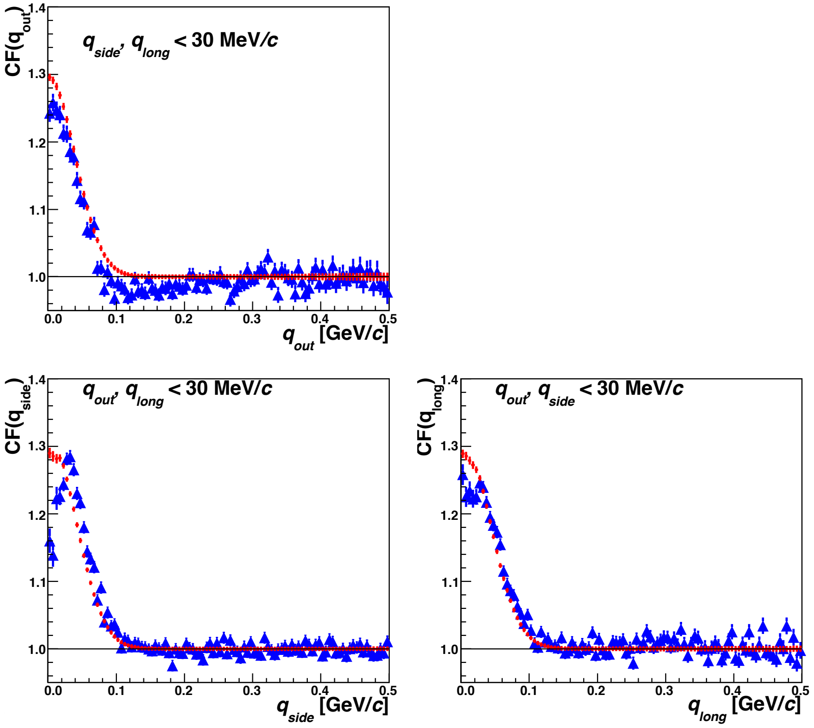
Phys. Lett., B270:69–74, 1991

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

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

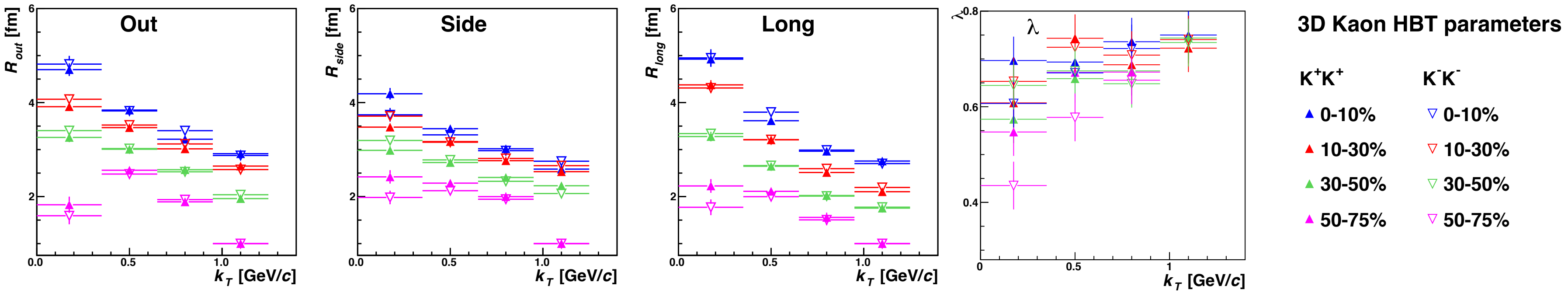
- Fit example: 1D correlation function & projection of 3D correlation function



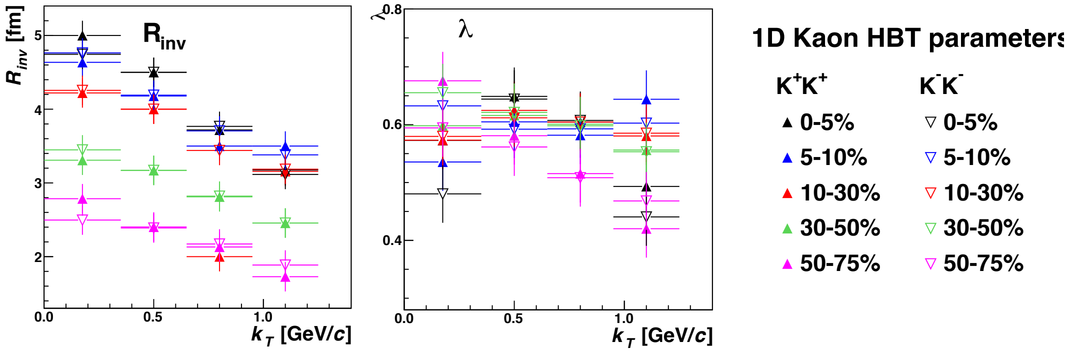


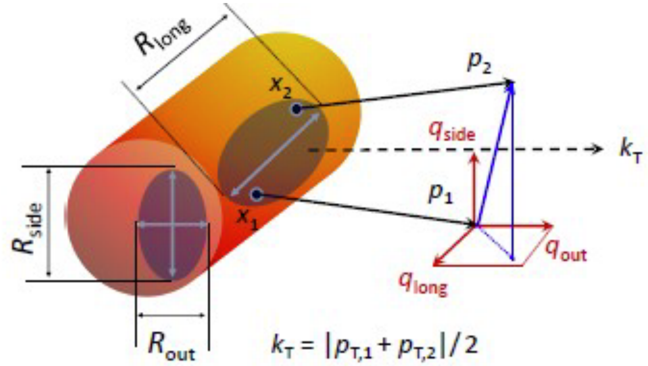
Results

3D



1D



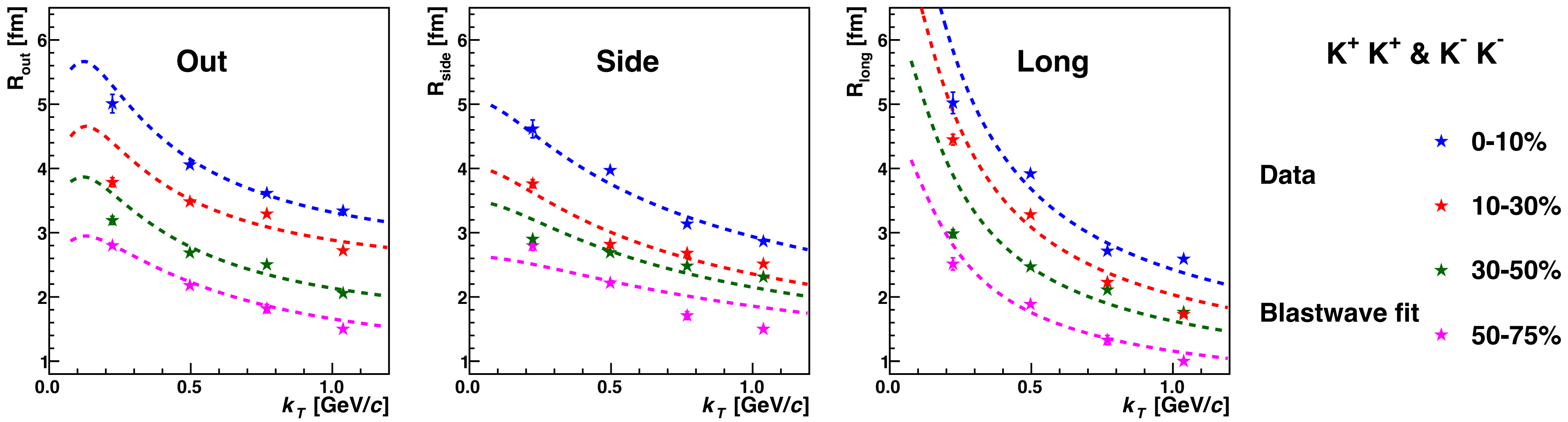


- Typical k_T and centrality dependence of HBT radii is observed
  - The transverse expansion -> falling of R_{out} and R_{side}
  - The longitudinal expansion -> falling of R_{long}

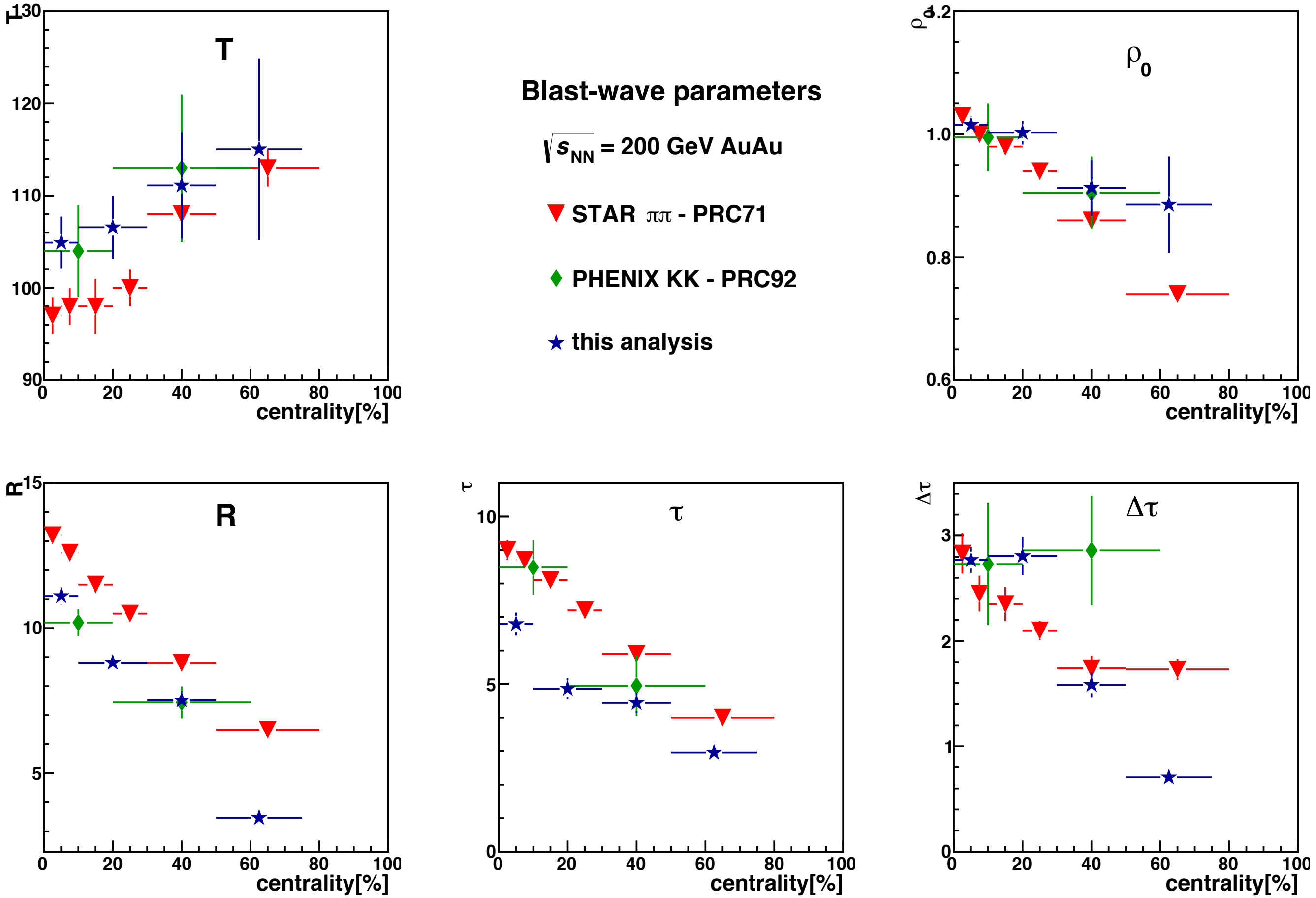
$$k_T = \left(\frac{\vec{p_1} + \vec{p_2}}{2}\right)_T$$

Results: Kaon HBT radii & Blast-wave

- Blast-wave parameterization can provide additional insight into the freeze-out configuration of studied system *Phys.Rev., C70:044907, 2004*
- Simultaneous fit of spectra and HBT radii
- Parameters of fits:
  - freeze-out temperature T
  - radius of the source R
  - emission duration $\Delta\tau$
  - maximum transverse rapidity ρ_0
  - system proper time τ



Results: Kaon HBT radii & Blast-wave



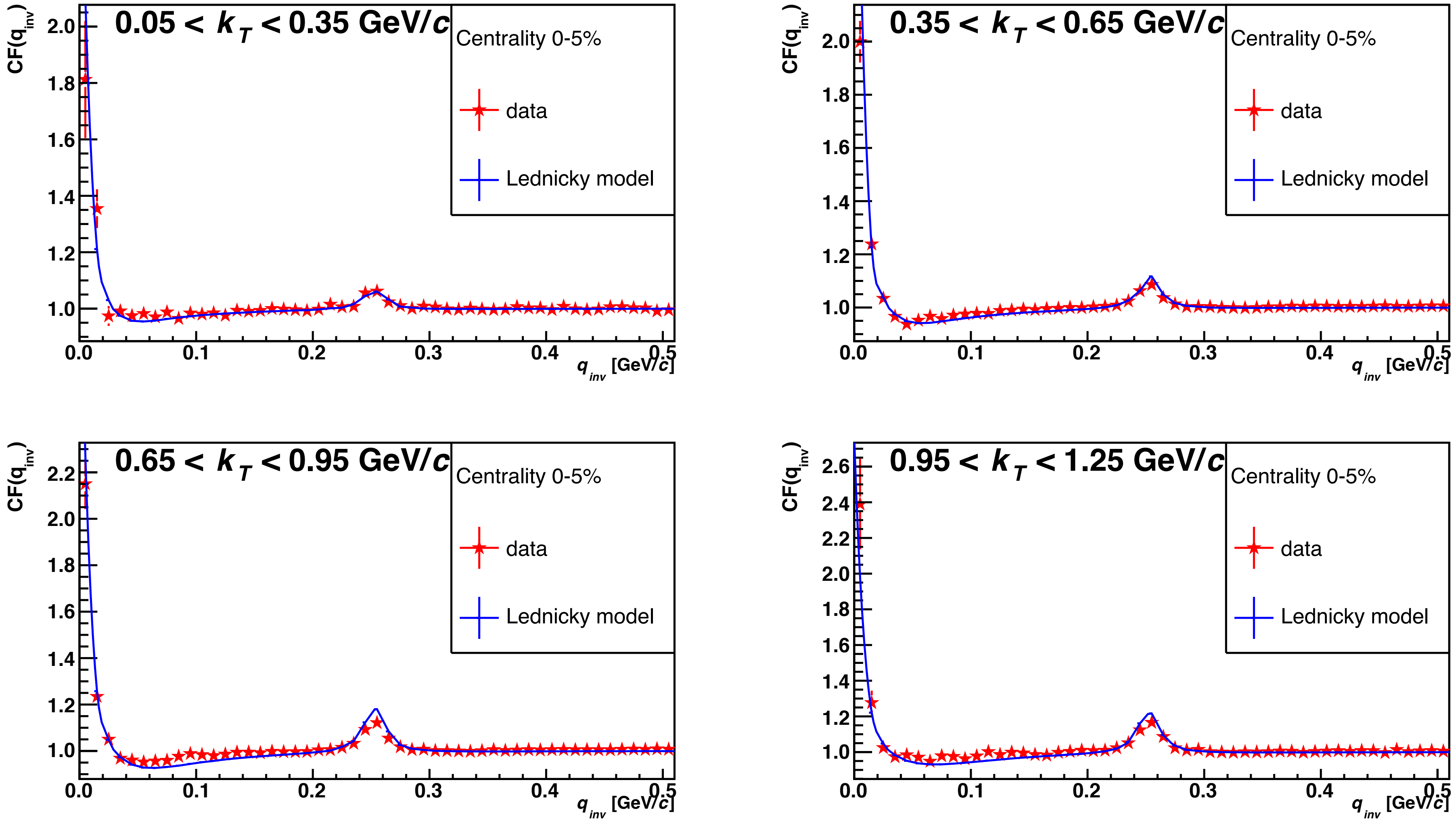
- Comparison of PHENIX results with my results – consistent within errors
- Difference between pion and kaon parameters can indicate earlier emission of kaons
- Not systematic errors yet - understudy

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
- In my work, following theoretical and hydrodynamics models were used:
  - **Lednický model of final-state interaction** *Lednicky: Phys.Part.Nucl. 40 (2009) 307-352*
    - Includes $\phi(1020)$ resonance
    - Gaussian parameterization of source
  - **THERMINATOR 2 –** THERMal heavy IOn collisions generaTOR 2 *arXiv:1102.0273*
    - Statistical production of particles + resonances decay
    - Blast-wave parameterization of the freeze-out configuration
    - No FSI
    - In this work interaction is described by Lednicky model

Comparison of 1D unlike-sign to Lednicky model

Centrality 0-5 %



- Momentum resolution – ongoing work

Comparison of 1D unlike-sign to Lednicky model

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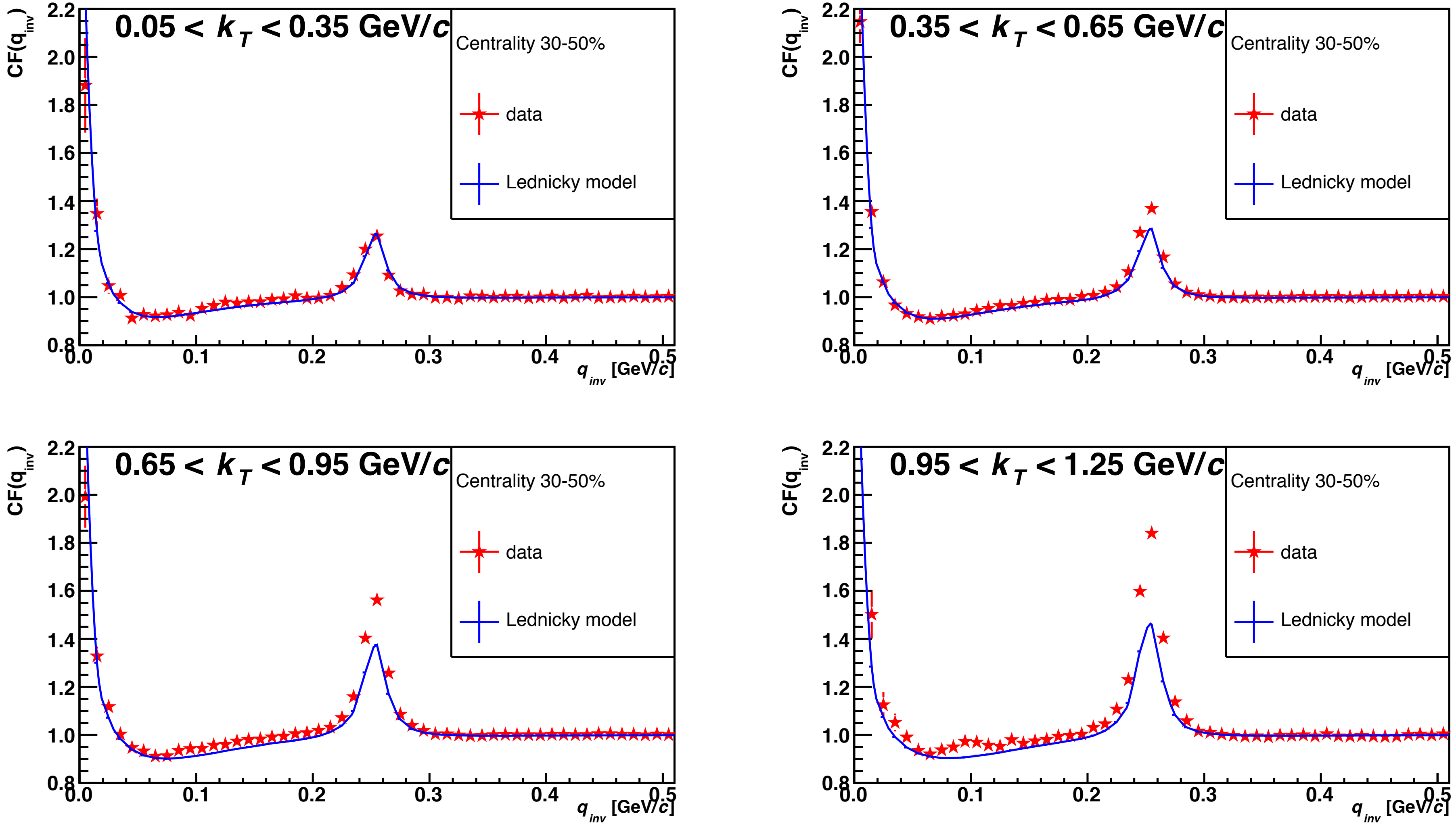
Centrality 30-50 %



- Momentum resolution – ongoing work

Conclusions

Measurement of **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
- Performed blast-wave fit - freeze-out configuration is extracted

First 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
- Experimental correlation function are compared to the theoretical calculation and hydro-based models prediction

Outlook:

- Master Thesis defense in June 2016
- Estimation of the systematic errors
- Paper proposal

End

Thank you for your attention

End

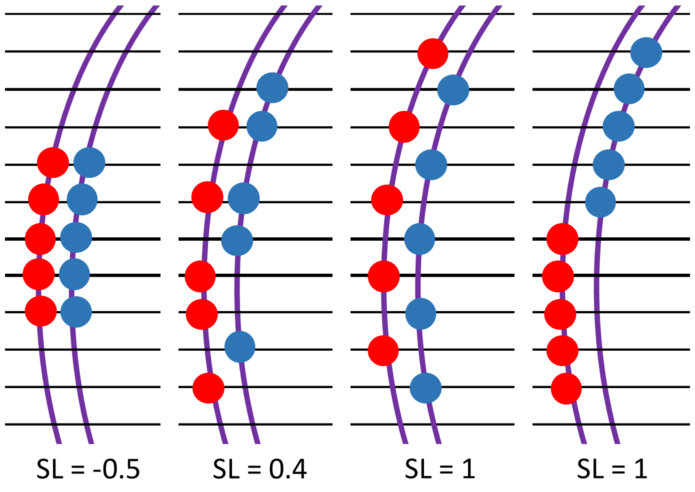
Back-up slides

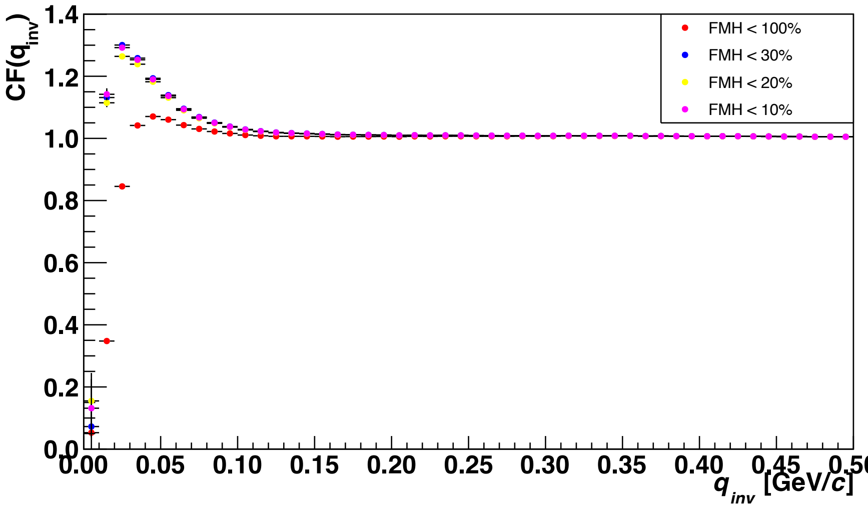
Construction of correlation function – Pair cuts

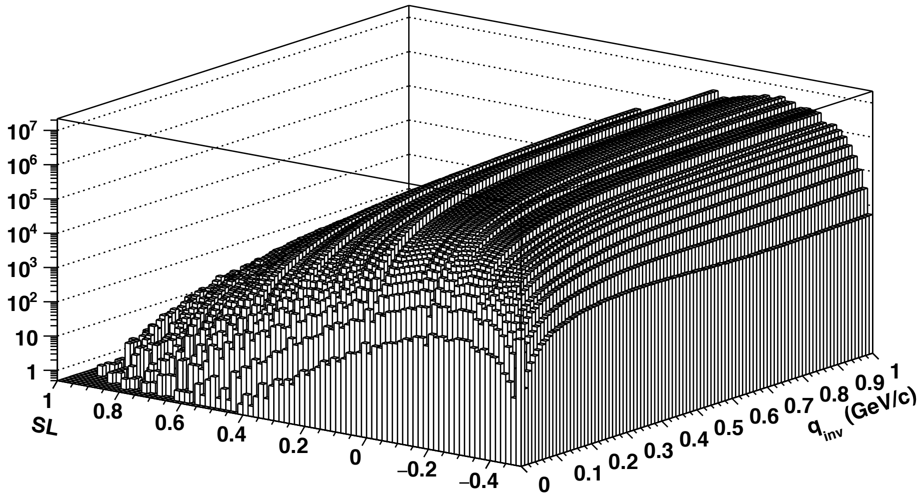
Experimentally, $CF(q_{inv}) = \frac{real\,pairs}{mixed\,pairs}$

Pair cut

- -0.5 < Split Level < 0.6 Phys. Rev. C **71** (2005) 44906
  - To remove track splitting – one track reconstructed as two tracks
- Fraction of Merged Hits < 0.05
  - To remove merged tracks – two tracks with low q_{inv} reconstructed as one track





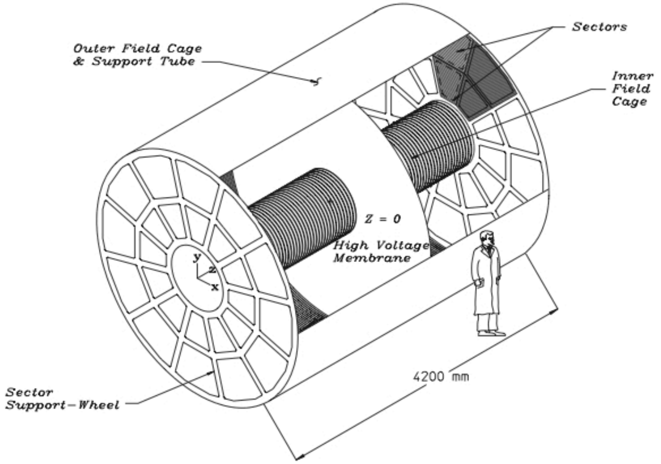


Momentum resolution in more detail

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

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

- CFs are smeared



How to remove this effect:

- TPC measures: p_T – transverse momentum
  φ – azimuthal angle
  θ – polar angle

- The components of $\vec{p}$ are expressed as:

$$p_x = p_T \cos\varphi$$
$$p_y = p_T \sin\varphi$$
$$p_z = \frac{p_T}{\tan\theta}$$

- The **deviations** of these components from the ***real*** components can be expressed as

$$\delta p_x = p_x \frac{\delta p_T}{p_T} - p_y \delta\varphi$$
$$\delta p_y = p_y \frac{\delta p_T}{p_T} + p_x \delta\varphi$$
$$\delta p_z = p_z \frac{\delta p_T}{p_T} + p_T \frac{\delta\theta}{(\sin\theta)^2}$$

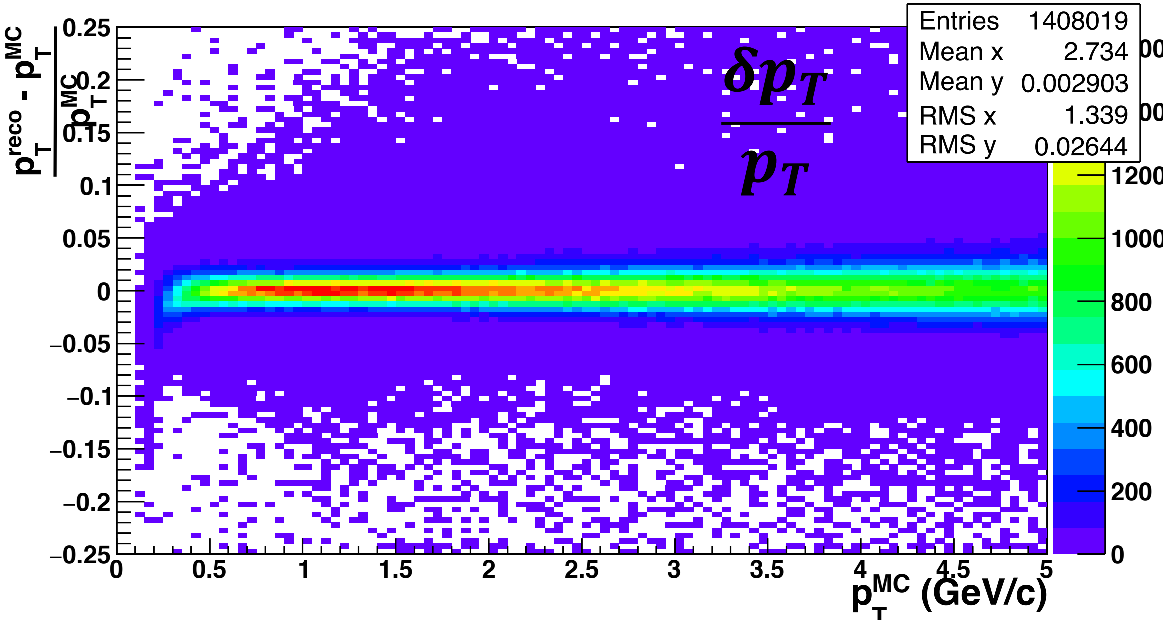
- $\boldsymbol{\frac{\delta p_T}{p_T}}$, $\boldsymbol{\delta\varphi}$ and $\boldsymbol{\delta\theta}$ are obtained from **embedding**

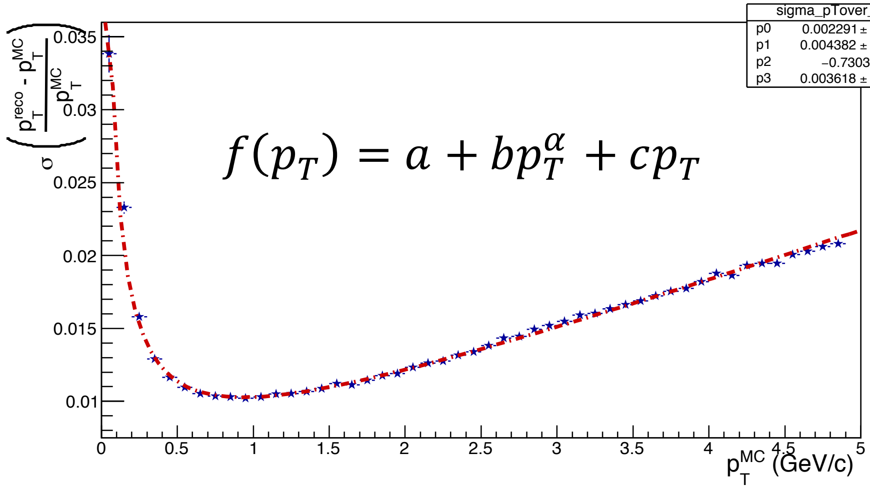
- Calculate CF with and without smearing

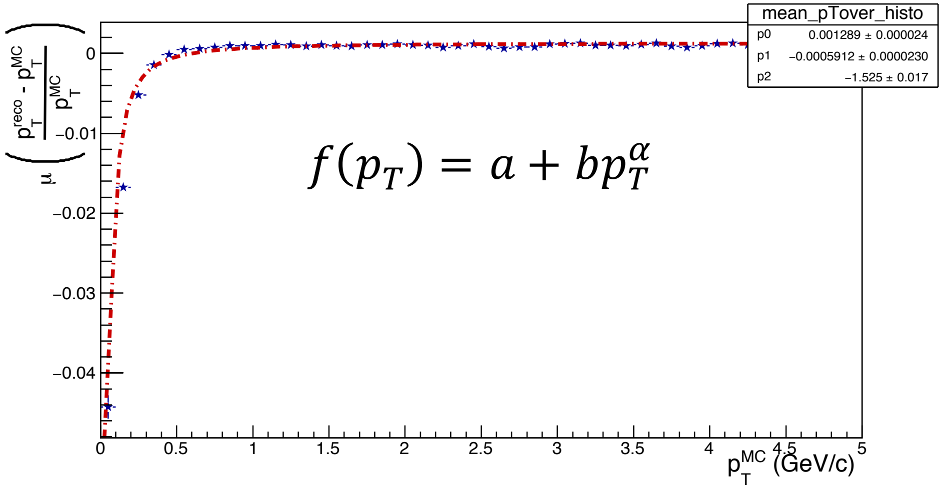
- Obtain the correction factor

$$K(q_{inv}) = \frac{CF(q_{inv}^{ideal})}{CF(q_{inv}^{smeared})}$$

Momentum resolution in more detail – parameters from MC







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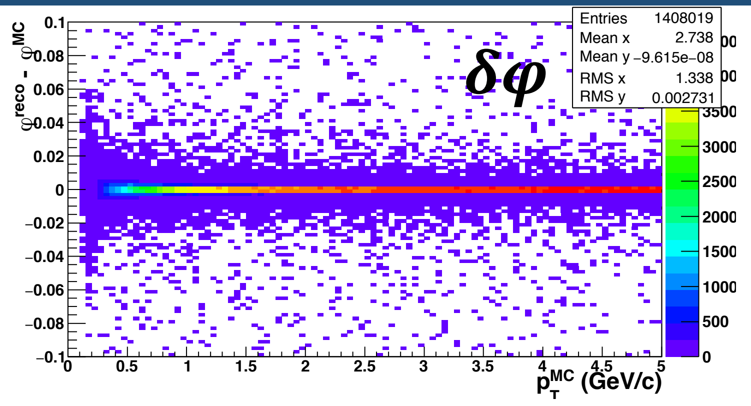
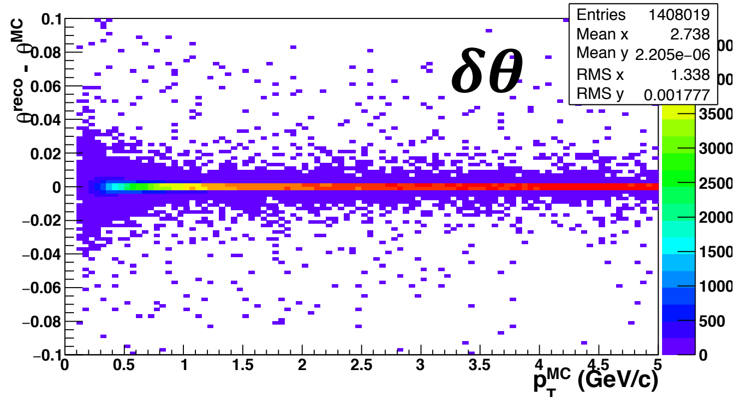
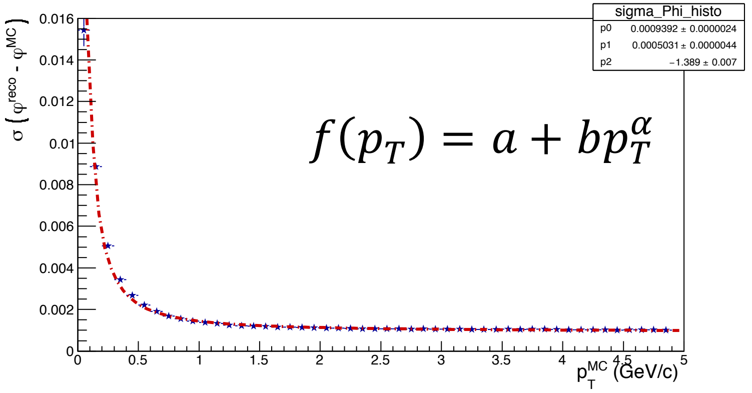
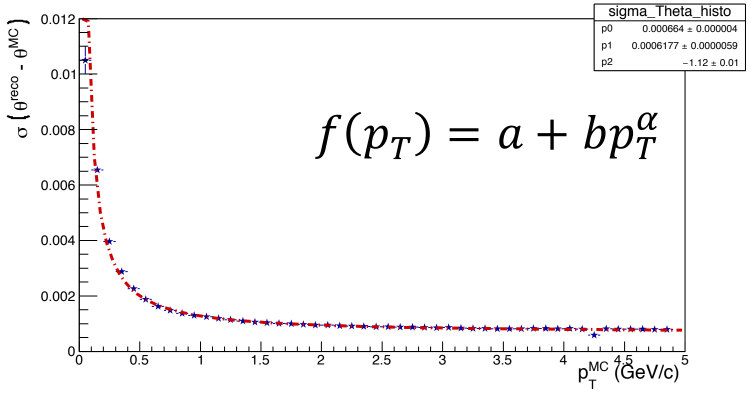
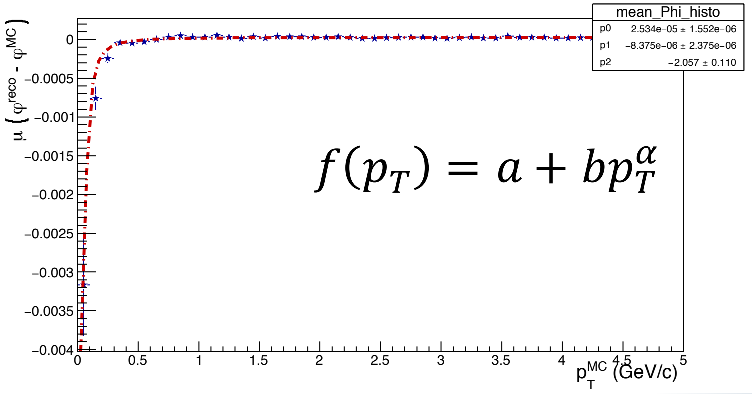
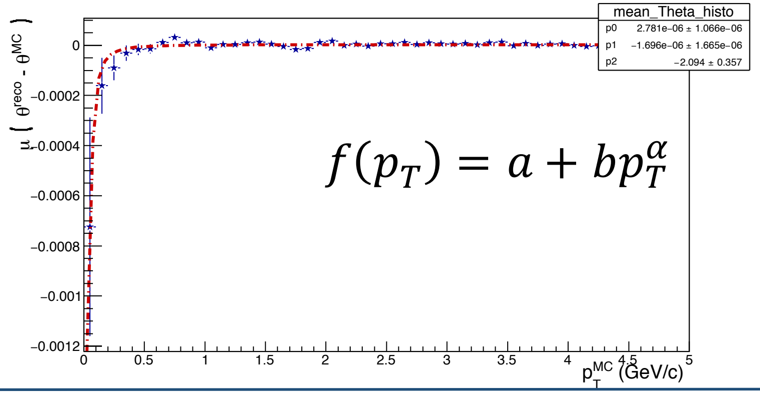






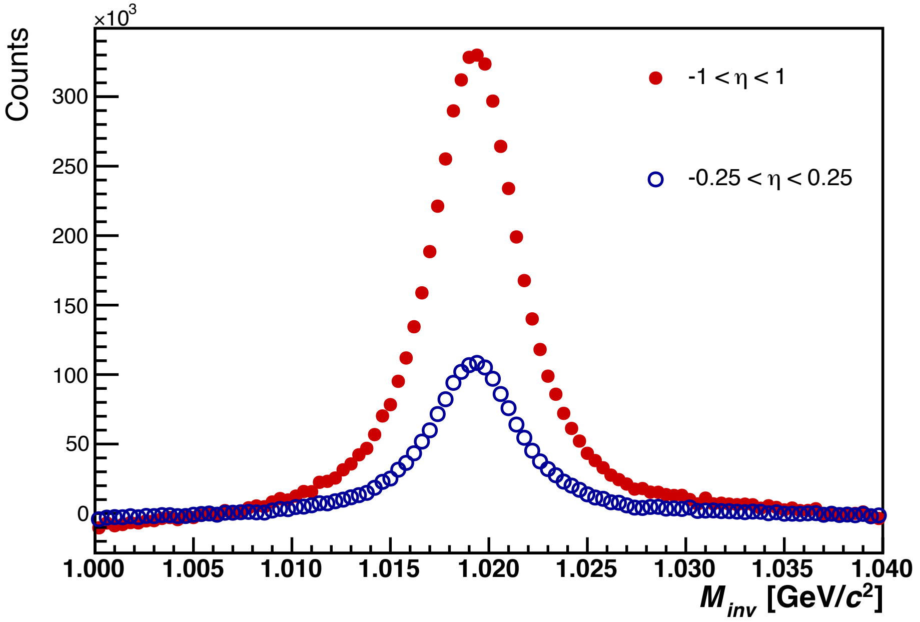


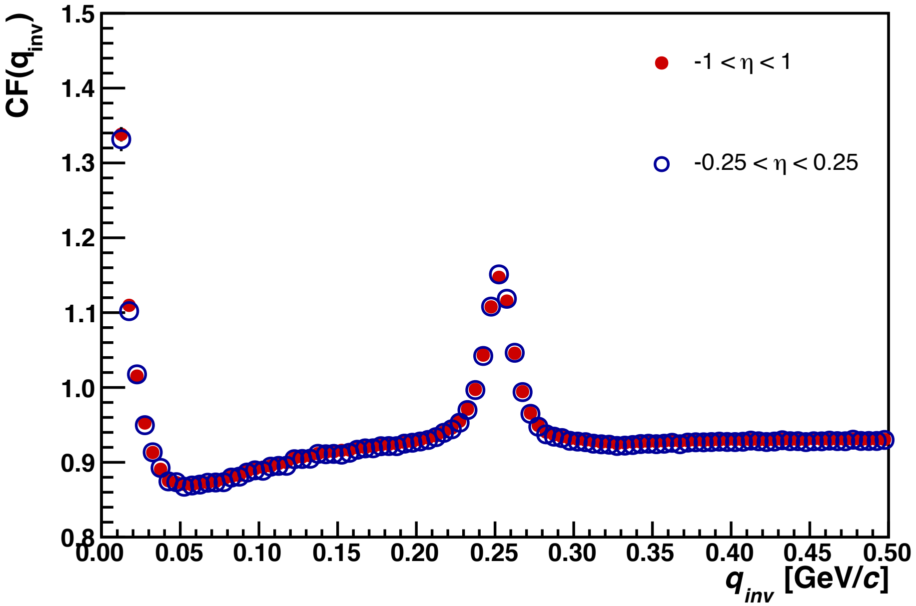




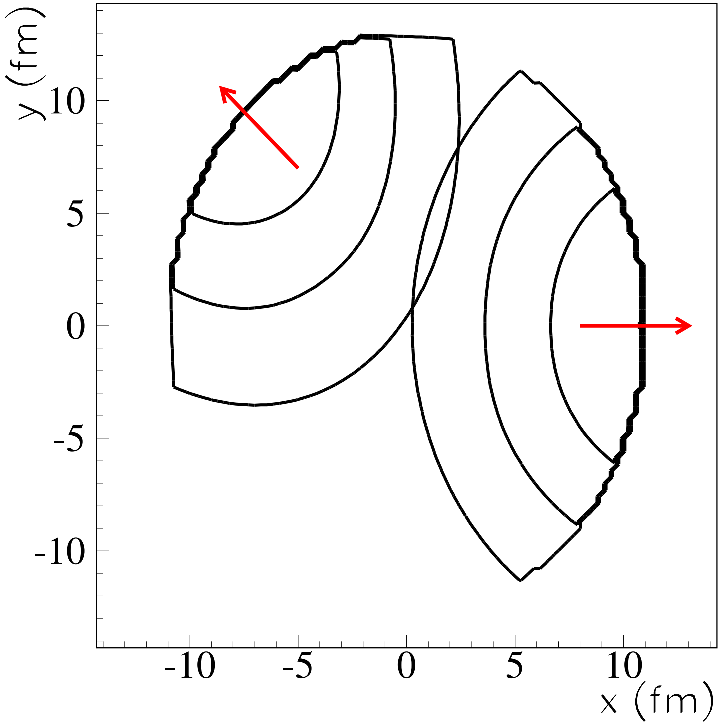
Detector acceptance and unlike-sign correlation function

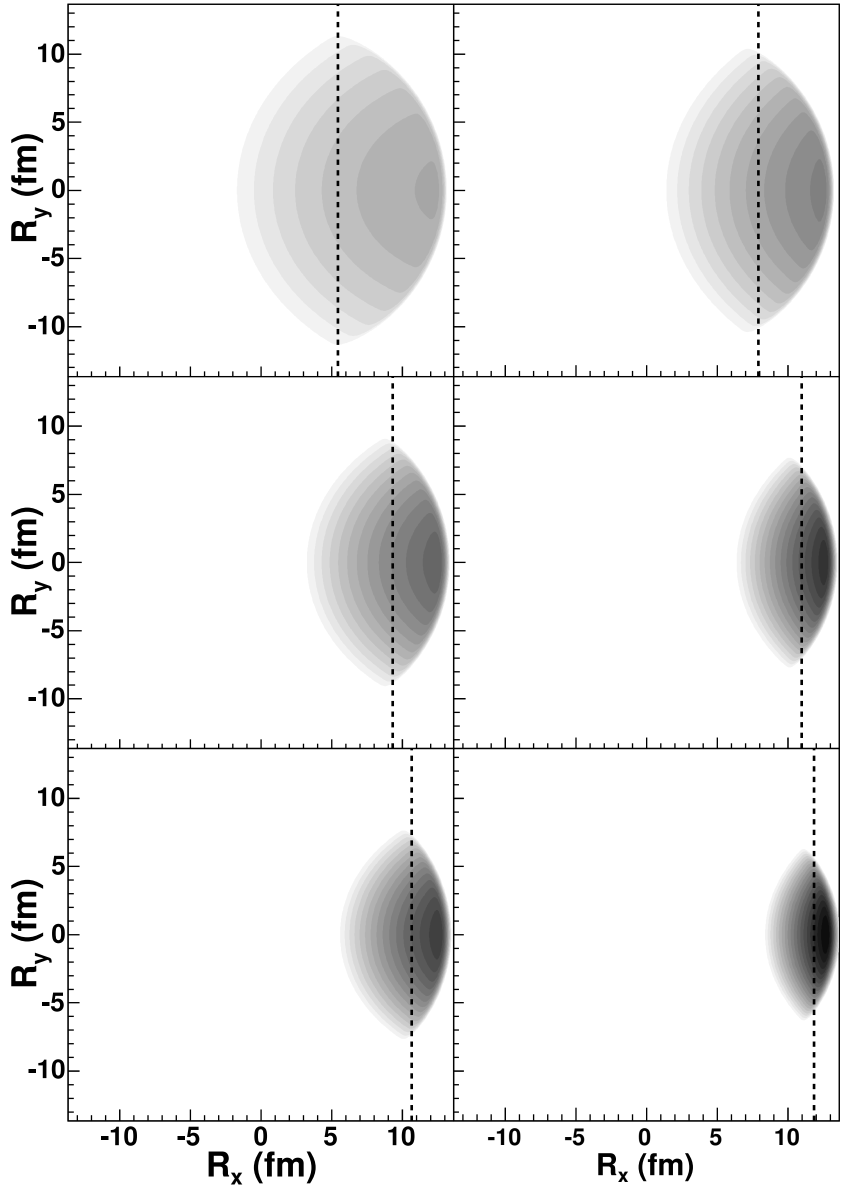
- Different cut on pseudorapidity = different number of kaons from $\phi(1020)$ decay
- Peak height is the same for different cut = CF is sensitive to volume of the system





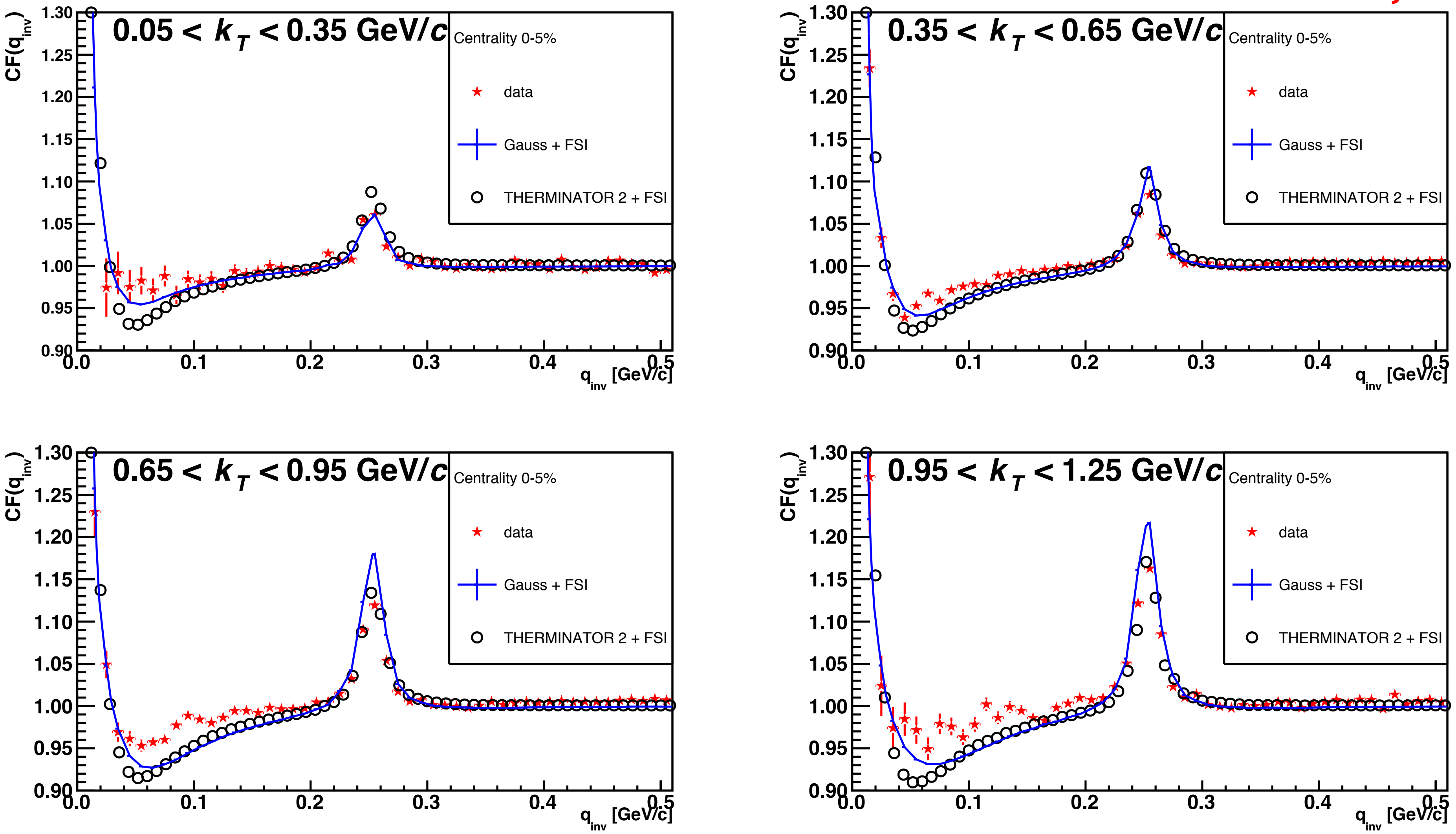
Blast-wave model





Comparison of 1D unlike-sign to THERMINATOR 2

Centrality 0-5 %



- Momentum resolution – ongoing work

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Centrality 50-75 %