Measurements of K^+K^+ correlation function in $\sqrt{s_{NN}}$ = 3.0 GeV Au+Au Collisions at RHIC-STAR

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Outline

- Introduction and motivation
- K^+K^+ correlation function
- Systematic uncertainty
- Extracting parameters of correlation function
- Summary and outlook

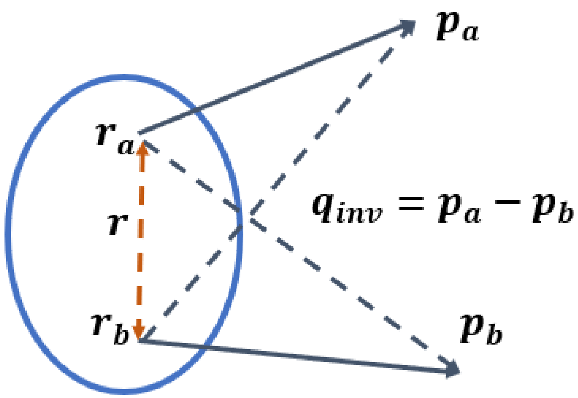
Femtoscopy

Femtoscopy (inspired by Hanbury Brown and Twiss interferometry)

the method to probe geometric and dynamic properties of the source.

Koonin-Pratt equation: $C(q_{\text{inv}}) = \int dr|\psi(q_{\text{inv}}, r)|^2 S(r)$

Steven E. Koonin. PRC,1990,42(6)



Invariant relative momentum: $q_{\text{inv}} = |\Delta \overrightarrow{P^{\mu}}|$

Pair wave function: $\psi(q_{\text{inv}}, r)$

Emission function: $S(r)$

Theory Method

$$C_{\text{theory}}(\overrightarrow{P_{\text{a}}}, \overrightarrow{P_{\text{b}}}) = \frac{P_2(\overrightarrow{P_{\text{a}}}, \overrightarrow{P_{\text{b}}})}{P_1(\overrightarrow{P_{\text{a}}})P_1(\overrightarrow{P_{\text{b}}})}$$

Experimental Method

$$C_{\text{exp}}(q_{\text{inv}}) = \frac{\text{Same events}(q_{\text{inv}})}{\text{Mixed events}(q_{\text{inv}})}$$

Motivation

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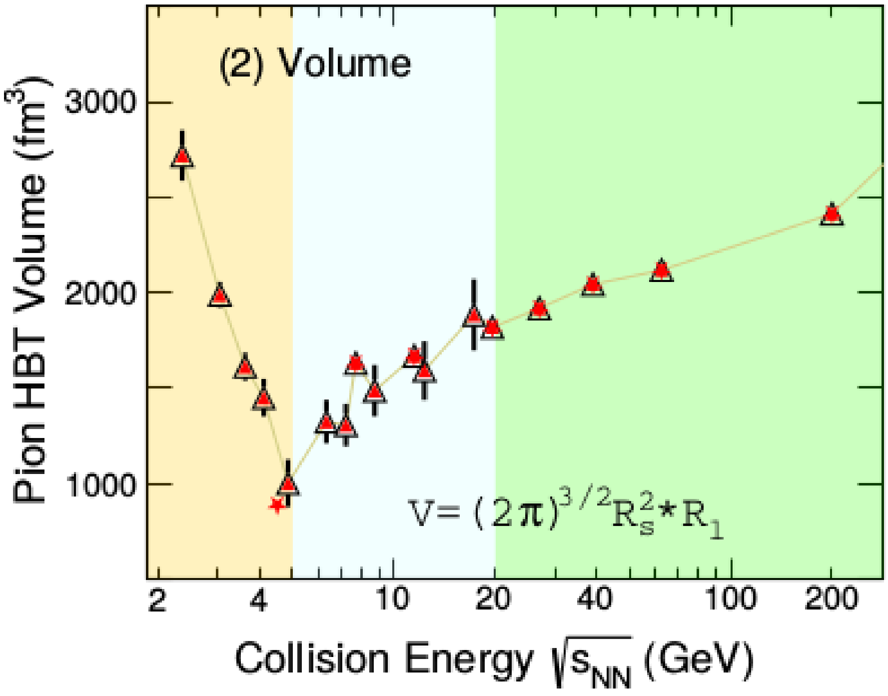
Nonmonotonic energy dependence for pion source size.

Leszek Adamczyk. PRC 92,014904(2015)



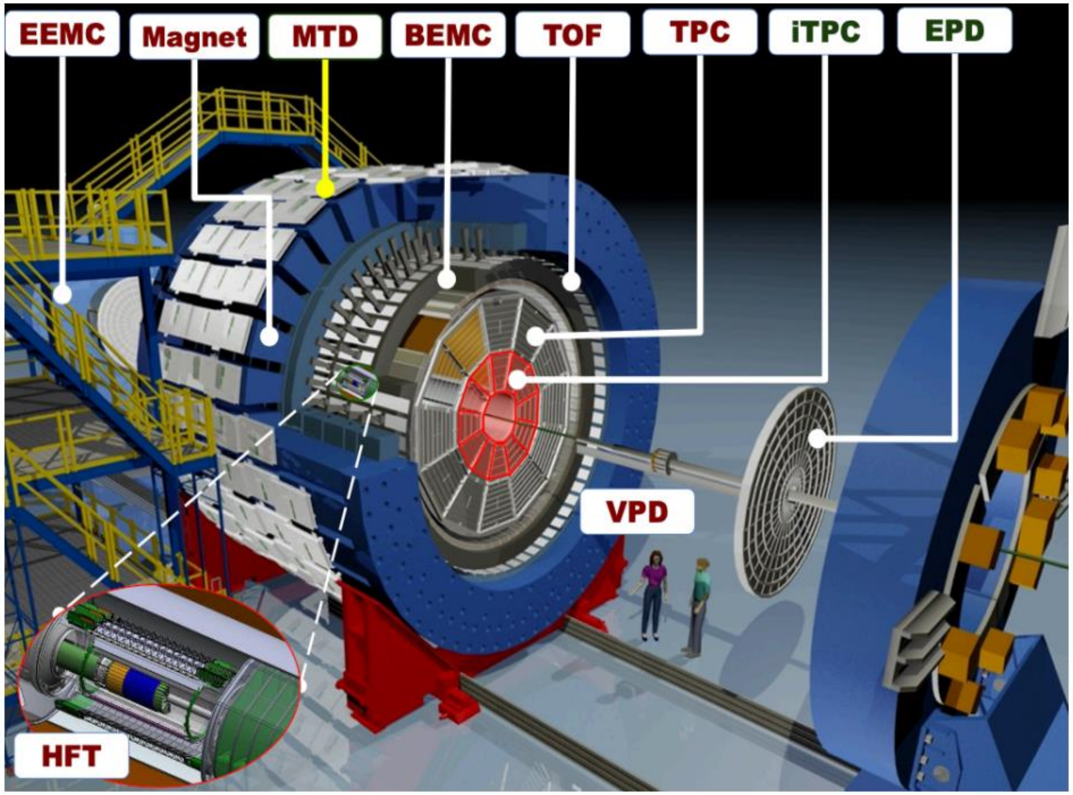
Why do we analyse kaons?

Kaons can provide complementary information to pions:

- Smaller cross section with the hadronic matter.
- Less affected by the feed-down from resonance decays.
- The production of strange quark is related to QGP formation.

How about the collision energy dependence of kaon source size?

STAR detector and dataset



Dataset	Au+Au $\sqrt{s_{NN}}$ = 3.0 GeV
Year	2018
Number of events	~260M

V_z (cm)	198~202
V_r (cm)	< 2
p_T(GeV/c)	0.15~2.0
p(GeV/c)	0.2~5.0
η	-2~0
DCA(cm)	< 3

The STAR Detector

- Full 2π azimuthal coverage
- Large acceptance at midrapidity
- Excellent particle identification

K^{+} selection

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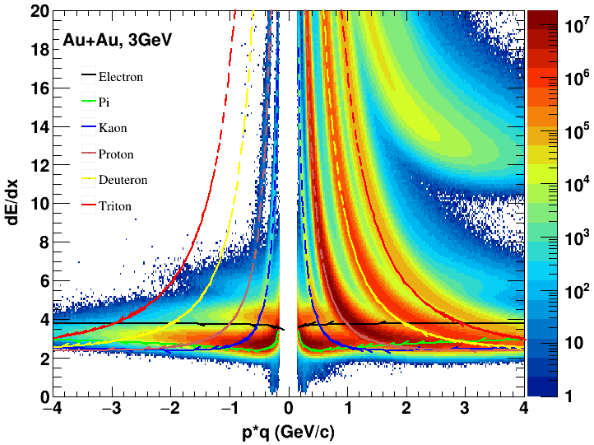
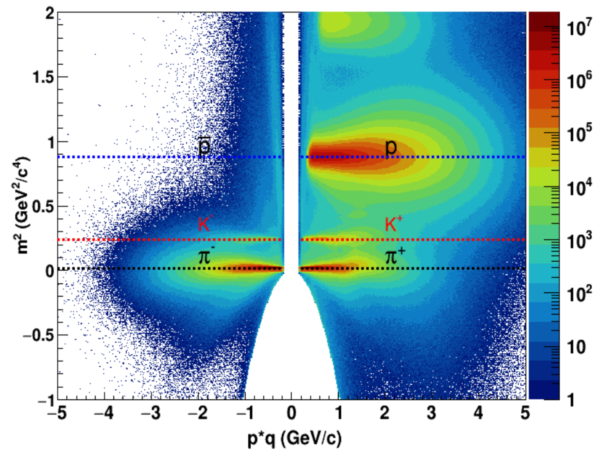
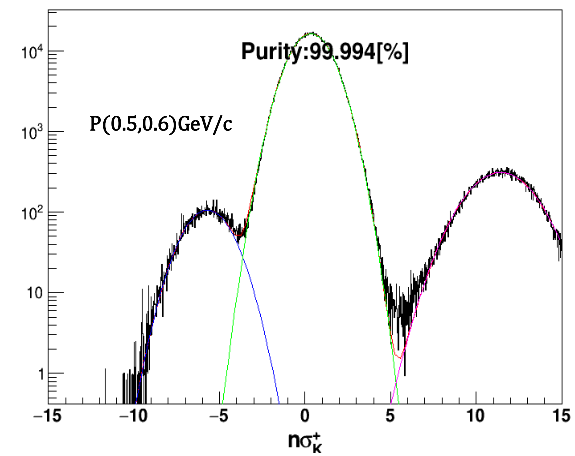
Tri-gaussian ($Gaussian_{blue}$ + $Gaussian_{green}$ + $Gaussian_{purple}$) is used to fit the $n\sigma_{K^{+}}$ distribution.



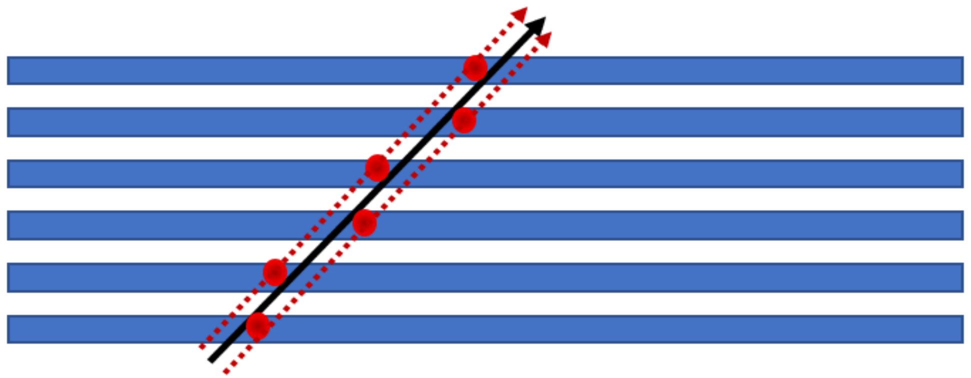




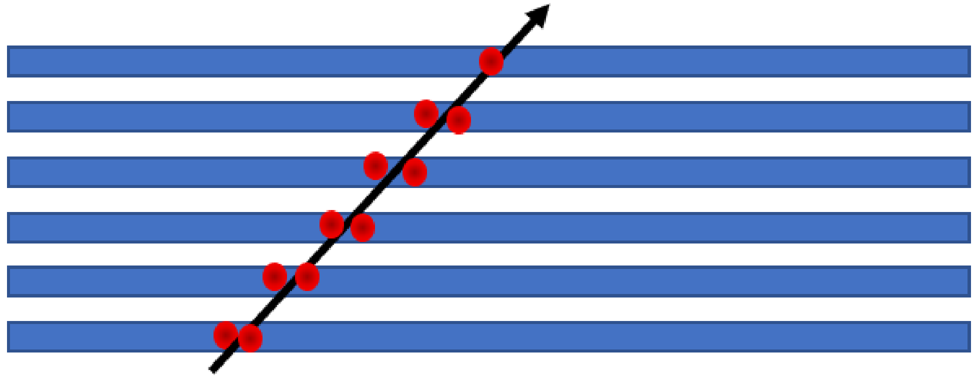
$$\text{Purity} = \frac{\int_{\mu-3}^{\mu+3} \text{Gaussian}(K^{+})}{\int_{\mu-3}^{\mu+3} [\text{Gaussian}(\pi^{+}) + \text{Gaussian}(K^{+}) + \text{Gaussian}(p)]}$$

PID Cuts (Purity >95%)		
$\lvert n\sigma_{K^{+}} \rvert < 3$	$0.16 < mass^2 < 0.36$	for $0.2 < momentum < 2.0$ GeV/c

Track splitting and merging effects



Track splitting: shifts of pad-rows, a single track is reconstructed as two tracks with similar momenta.



Track merging: two tracks with close θ and ϕ are reconstructed as a single one. (θ and ϕ determined by p_x, p_y and p_z)

Momentum smearing effect

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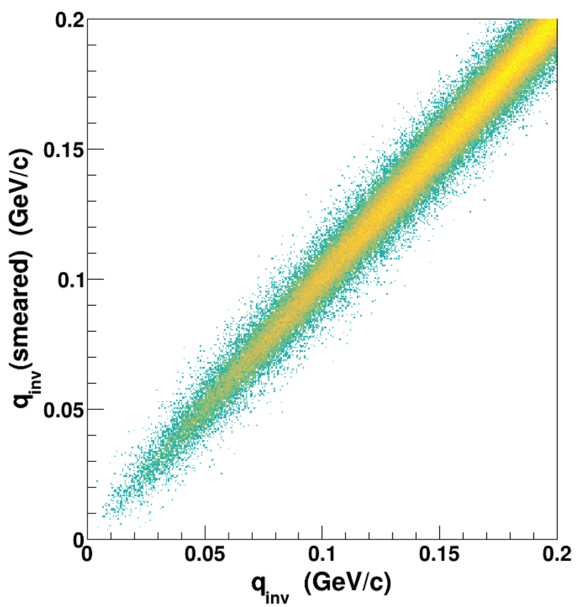
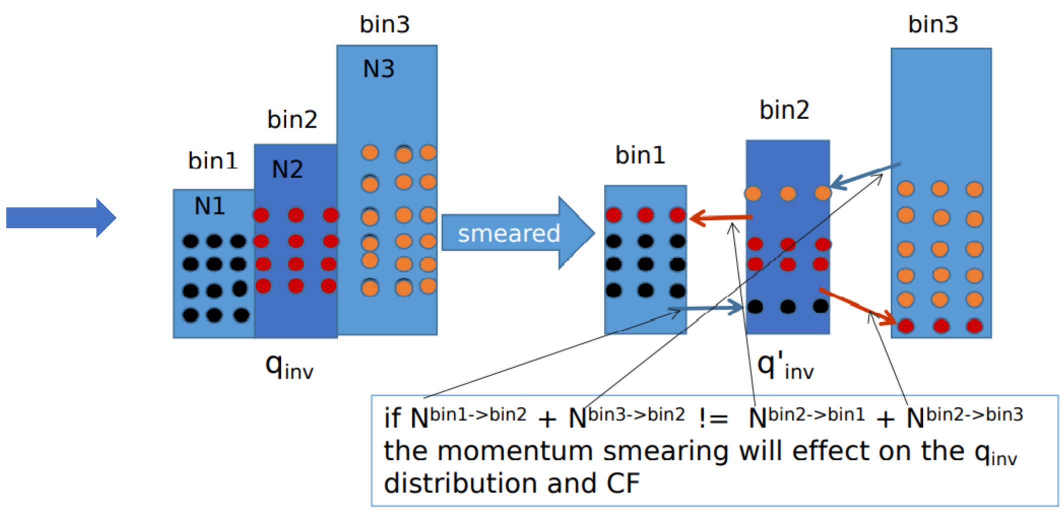
The detector has a momentum resolution for measuring the particle momentum.

$$p_T^{\text{smear}} = p_T^{\text{meas}} + \Delta p_T$$
$$\theta^{\text{smear}} = \theta^{\text{meas}} + \Delta\theta$$
$$\phi^{\text{smear}} = \phi^{\text{meas}} + \Delta\phi$$

The measured q_{inv} is a Gaussian distribution with the real q_{inv} as the mean.

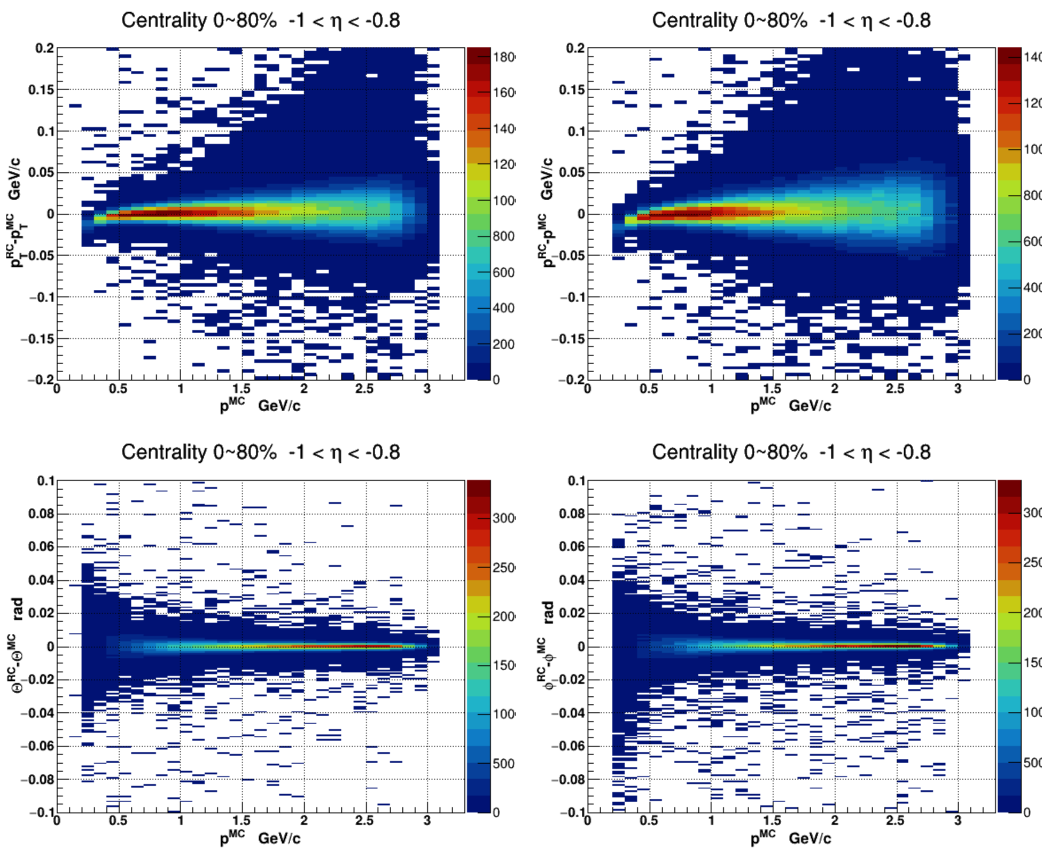




Embedding

MC: Monte-Carlo simulation RC: Detector reconstruction

Number of events from MC:531300



Take the σ of the Gaussian distribution of p_{T} , θ , ϕ as the resolution.

Momentum smearing effect

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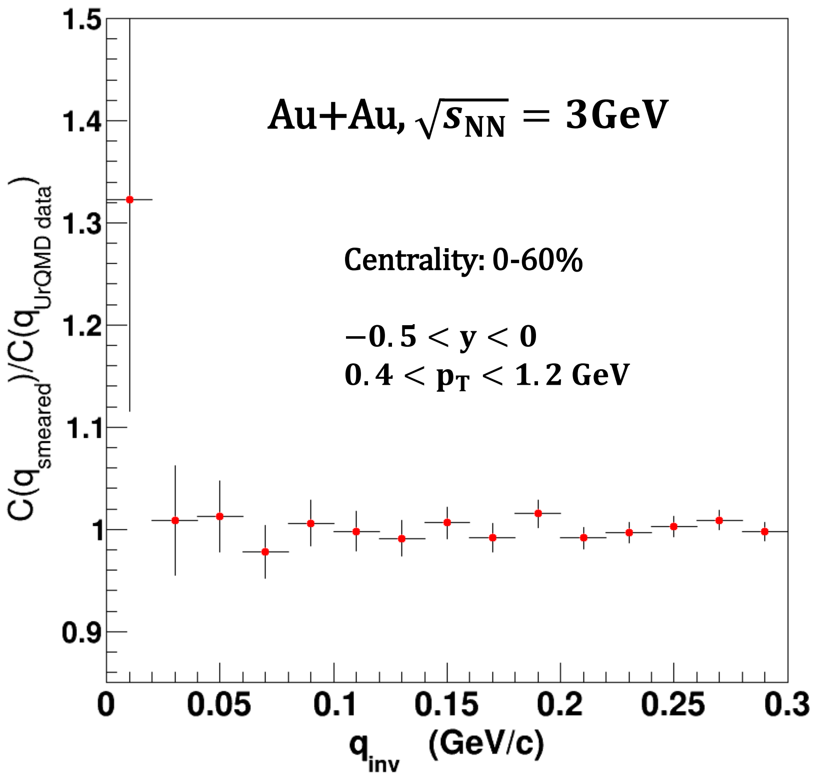


Correction: $CF\,(q_{data}) * \frac{CF\,(q_{smeared})}{CF\,(q_{UrQMD\ data})}$

The momentum smearing effect is tiny, the statistics need to be increased to make corrections.

Systematic uncertainty

sys. error source	dca	nhitsFit	|Δϕ|	|nσ|
Default	< 3 cm	> 23	> 0.005	< 3
Varied	< 2 cm	> 27	> 0.01 > 0.015	< 2

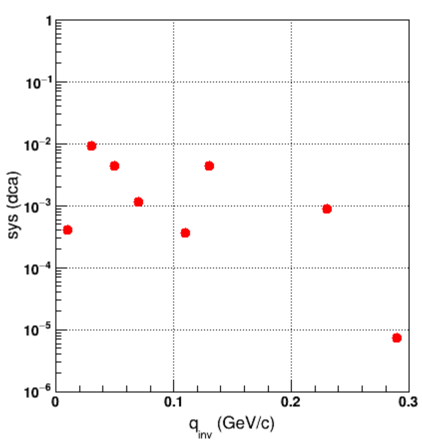
$\Delta\mathrm{CF} = (|\mathrm{CF}_{\mathrm{default}} - \mathrm{CF}_{\mathrm{varied}}|)/\mathrm{CF}_{\mathrm{default}}$

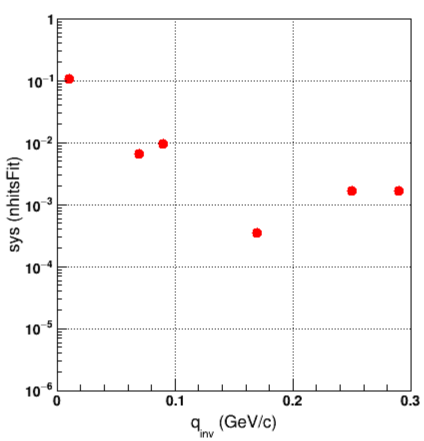
$\Delta\sigma(\mathrm{Stat.\ fluctuation}) = \left(\sqrt{|\mathrm{err}^2_{\mathrm{default}} - \mathrm{err}^2_{\mathrm{varied}}|}\right)/\mathrm{CF}_{\mathrm{default}}$

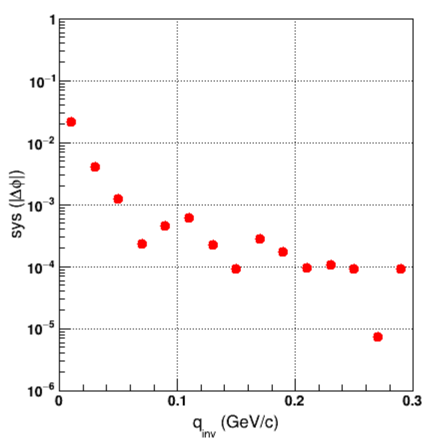
same source with different cut:
$\mathrm{sys.err} = \sqrt{(\mathrm{sys.err}_1^2 + \mathrm{sys.err}_2^2)/2}$

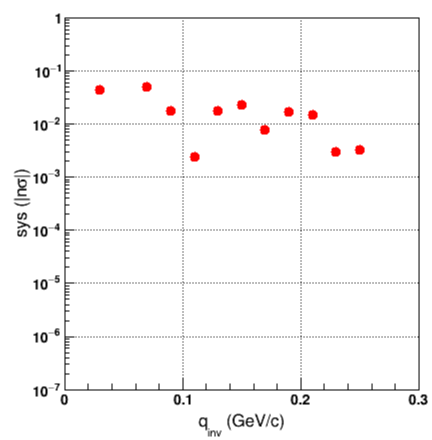
$\mathrm{sys.err} = \Delta\mathrm{CF} - \Delta\sigma$; if $\Delta\mathrm{CF} < \Delta\sigma(\mathrm{Stat.\ fluctuation})$, $\mathrm{sys.err} = 0$

$$sys.\mathrm{err}_{\mathrm{final}} = \sqrt{\mathrm{sys.err}^2_{\mathrm{dca}} + \mathrm{sys.err}^2_{\mathrm{nhitsFit}} + \mathrm{sys.err}^2_{|\Delta\phi|} + \mathrm{sys.err}^2_{|n\sigma|}}$$



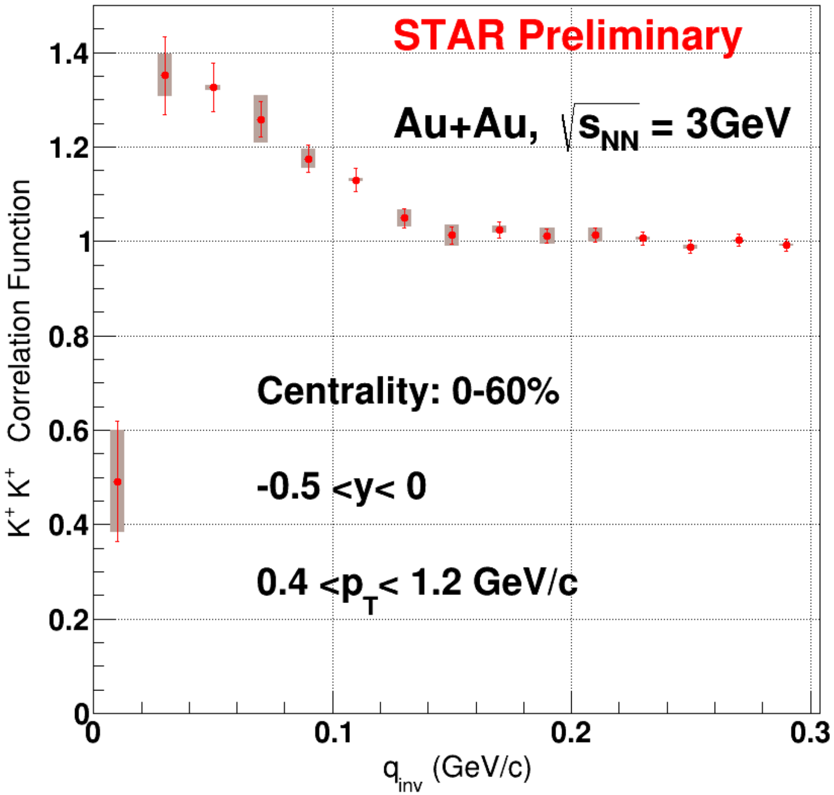






At low q_{inv}, systematic uncertainty of track splitting effect (nhitsFit) dominates.

Correlation function



At $q_{\text{inv}} < 0.02$ GeV/c, Coulomb interaction (repulsive) is dominant.

With the increase of q_{inv}, Coulomb interaction becomes weak, quantum statistics (attractive) is dominant.

At $q_{\text{inv}} > 0.15$ GeV/c, Coulomb interaction and quantum statistics can be ignored.

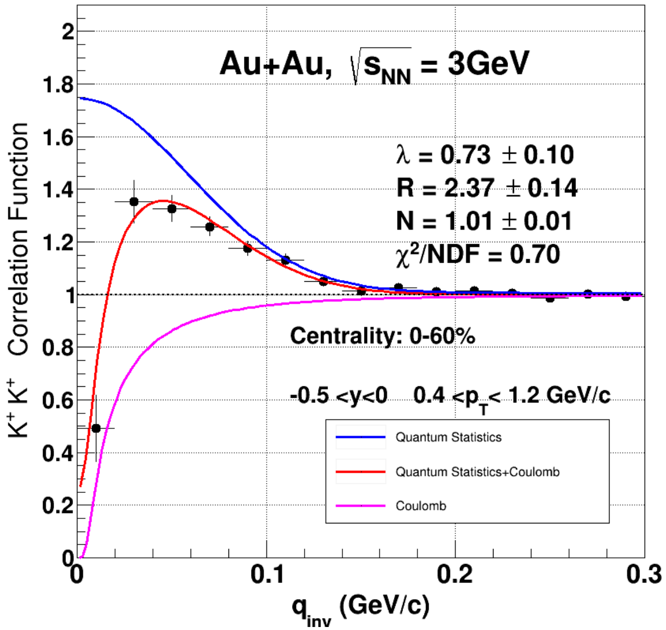
Extraction of R and λ

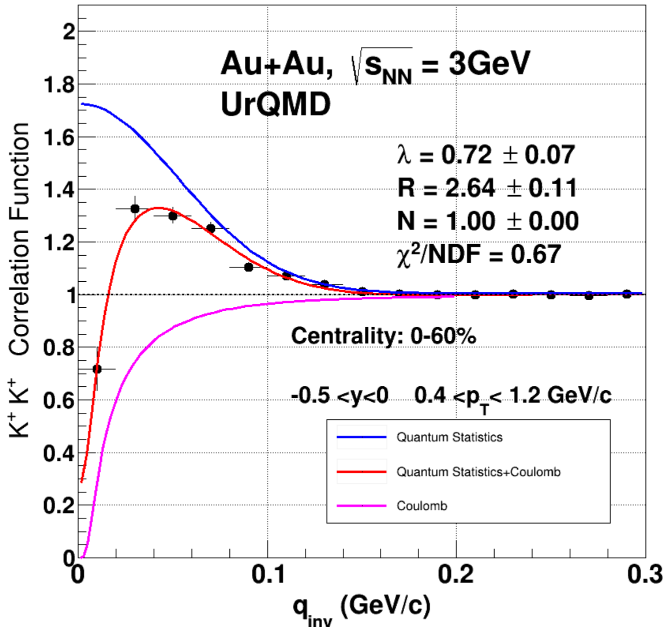
Sinyukov-Bowler method: $C(q) = N\left[(1-\lambda) + K_{\mathrm{coul}}(q,R)\lambda\left(e^{-q^2R^2}+1\right)\right]$

Y. Sinyukov et al. Phys. Lett. B 432 (1998)

λ - correlation strength parameter   R – Gaussian source size   N - normalization factor

Quantum Statistics: $C^{(0)}(q) = N(1+\lambda e^{-q^2R^2})$ - interaction-free particles





Within the statistical error, R and λ extracted from the experiment and model are similar.

Summary and outlook

Summary

- K^+K^+ CF measurements in Au+Au collisions at $\sqrt{s_{NN}} = 3$ GeV
- Extraction of the parameters source size R and λ
- The CF from data can be reproduced by UrQMD model

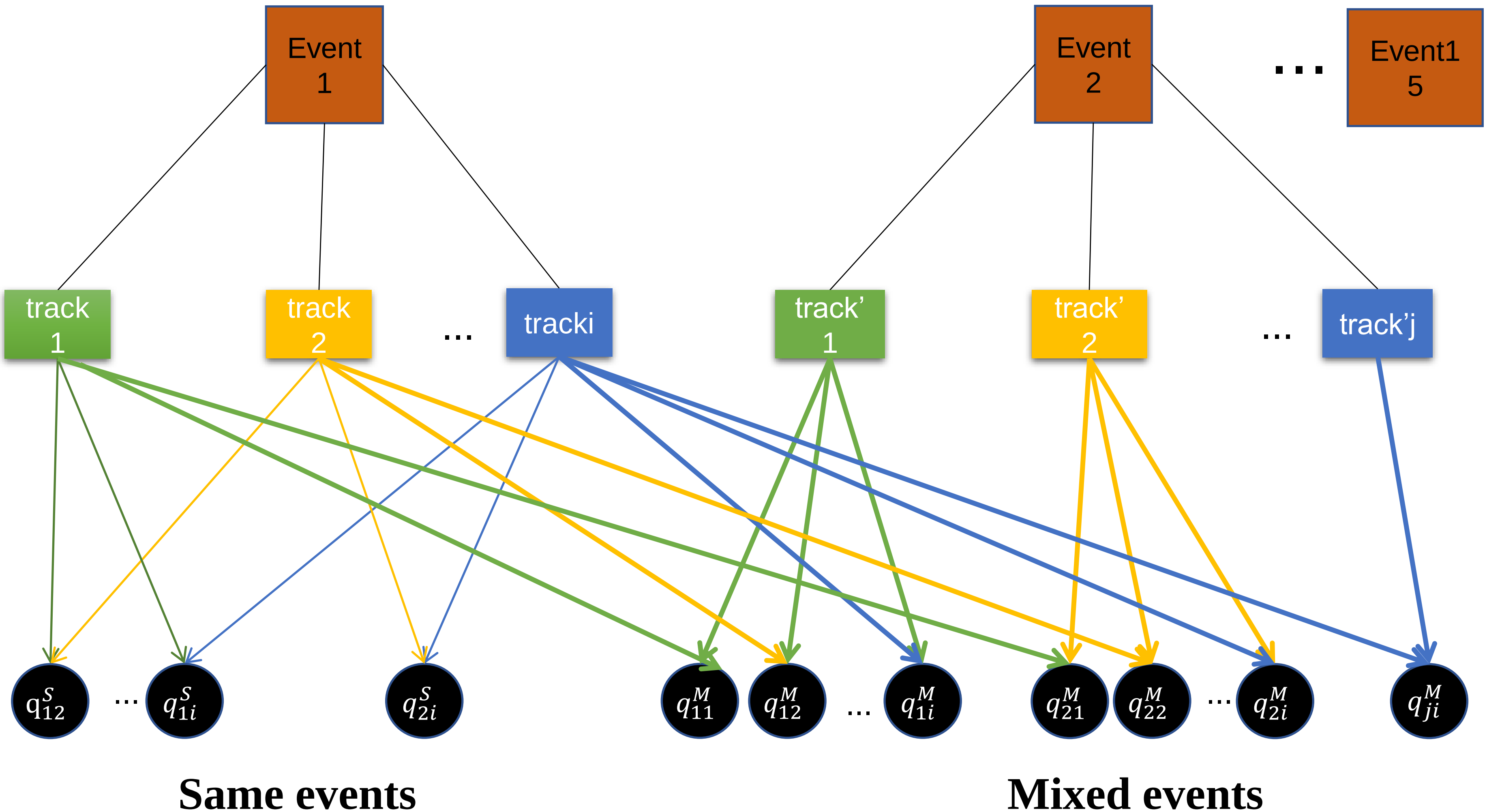
Outlook

- Collision energy dependence

Thanks for your attention!

Backup

We mixed particles from different events which come from same V_z bin and centrality bin. Every 15 events are mixed as a group.



Simulation of correlation function