Kaon femtoscopy in 200 GeV Au+Au collisions at the STAR experiment

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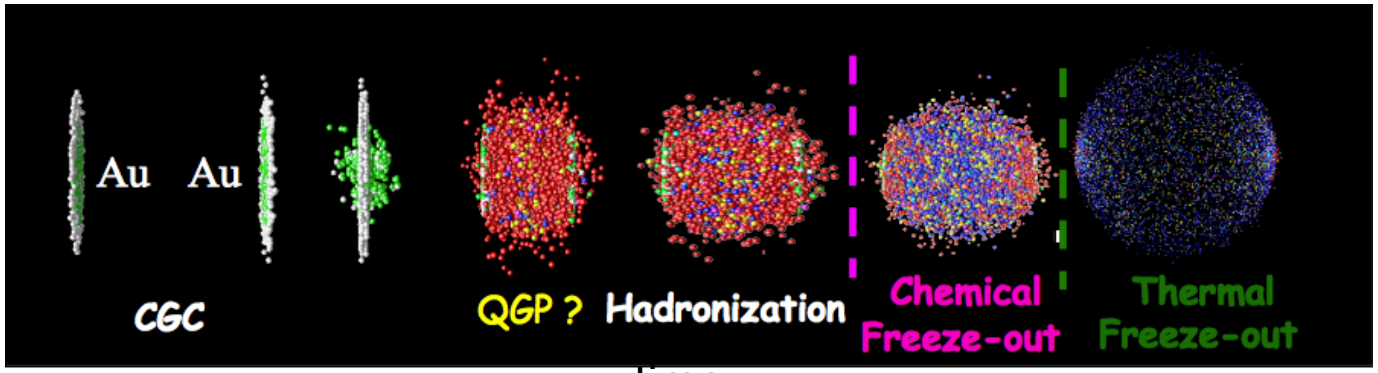
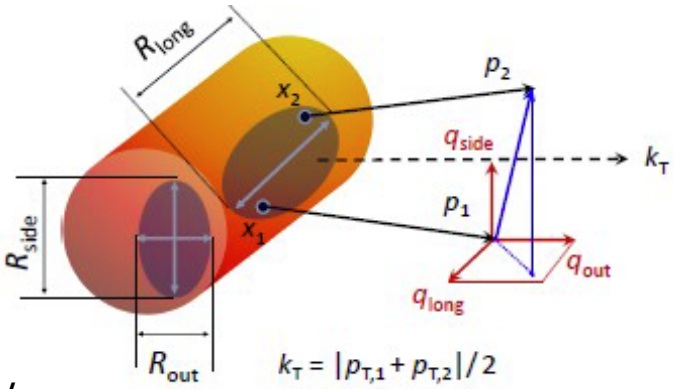
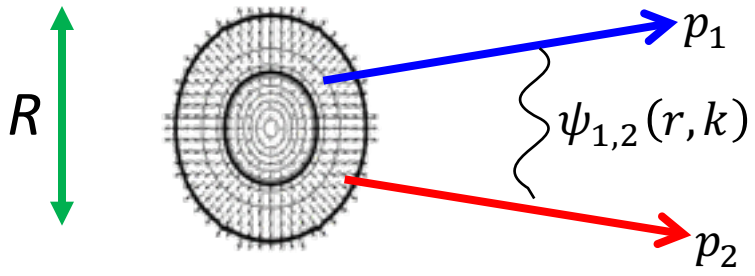
Femtoscopy

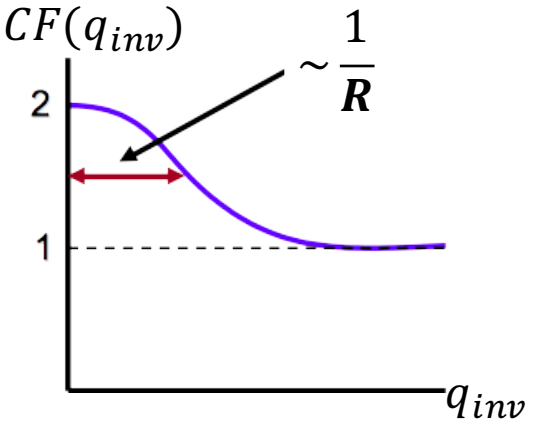




- Study space-time extents of the source at the thermal freeze-out
- Correlation function: $CF(p_1,p_2) = \int d^3r S(r,k)\left|\psi_{1,2}(r,k)\right|^2 = \frac{\text{real pairs}}{\text{mixed pairs}}$

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





Motivation for kaon femtoscopy

In comparison with the standard pion femtoscopy, kaons provide following advantages

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

However, more difficult due to lower number of kaon pairs per event

This talk:

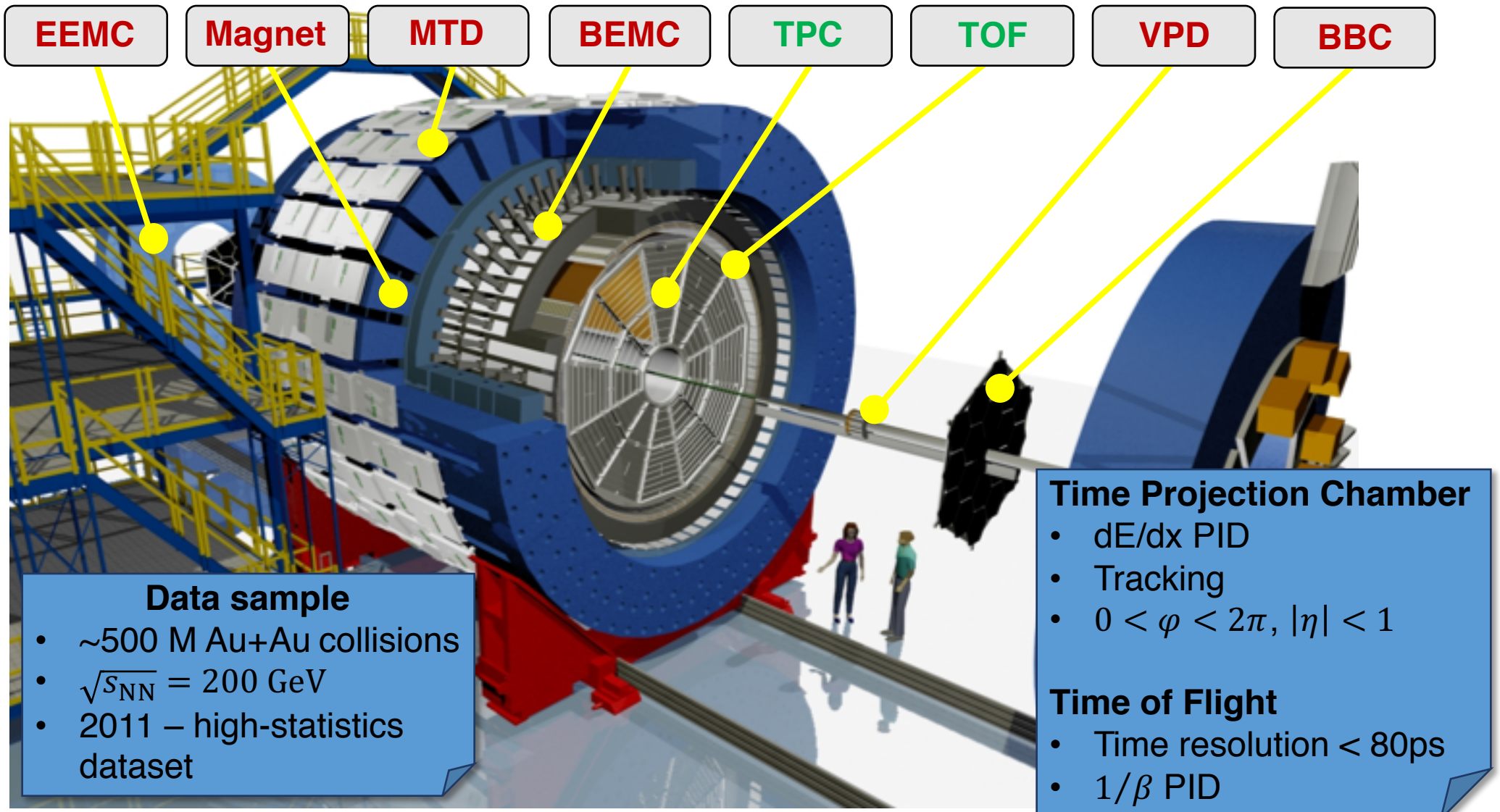
Part I: Identical charged kaon femtoscopy

- Kaon pairs: Quantum statistics and Coulomb interaction dominate at low q_{inv}
- Goal: Extraction of space-time characteristic and kinetic freeze-out parameters

Part II: Non-identical charged kaon femtoscopy

- Kaon pairs: Coulomb interaction and strong interaction in *s* and *p*-wave
- Goal: Can we measure space-time characteristic in the region of the resonance?

STAR Experiment at RHIC



Data sample
- ~500 M Au+Au collisions
- $\sqrt{s_{\mathrm{NN}}} = 200$ GeV
- 2011 – high-statistics dataset

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

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

Identical charged kaon femtoscopy

Part I:

Identical charged kaon femtoscopy

Extraction of source radii from CF

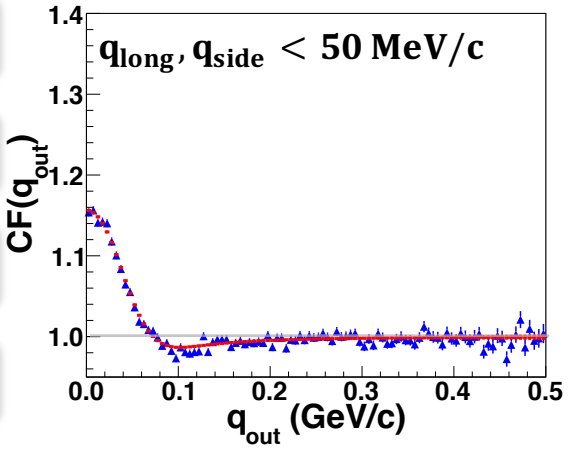
- Bowler-Sinyukov fitting procedure: *Bowler PLB 270:69–74, 1991*

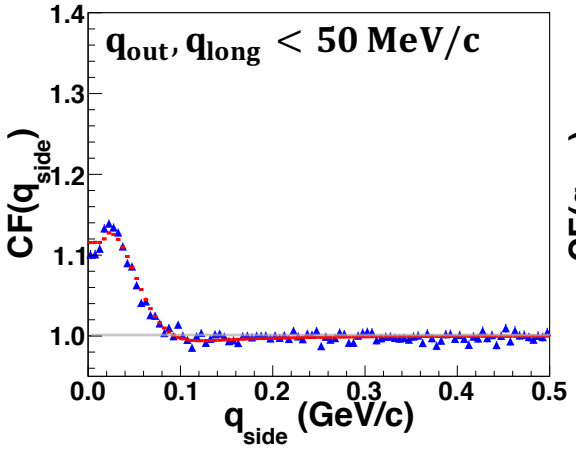
3D: $CF(q_o, q_s, q_l) = \left[(1-\lambda) + \lambda K(q_{inv}, R_{inv})\left(1 + \exp\left(-q_o^2 R_o^2 - q_s^2 R_s^2 - q_l^2 R_l^2\right)\right)\right]\mathcal{N}$,

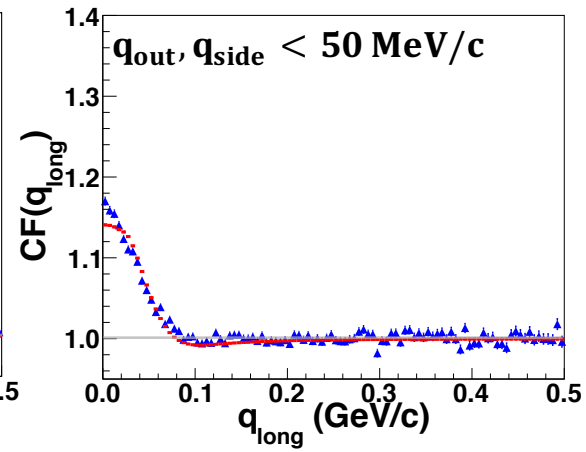
  - R_o, R_s, R_l – source radii
  - λ parameter – correlation strength
  - $\mathcal{N}$ – normalization
  - $K(q_{inv}, R_{inv})$ – Coulomb function

- Fit using log-likelihood method *PRC 66 (2002) 054906*

- **Fit example:** projection of 3D correlation function
  - data (points) vs the best fit (red lines)
  - good agreement with data







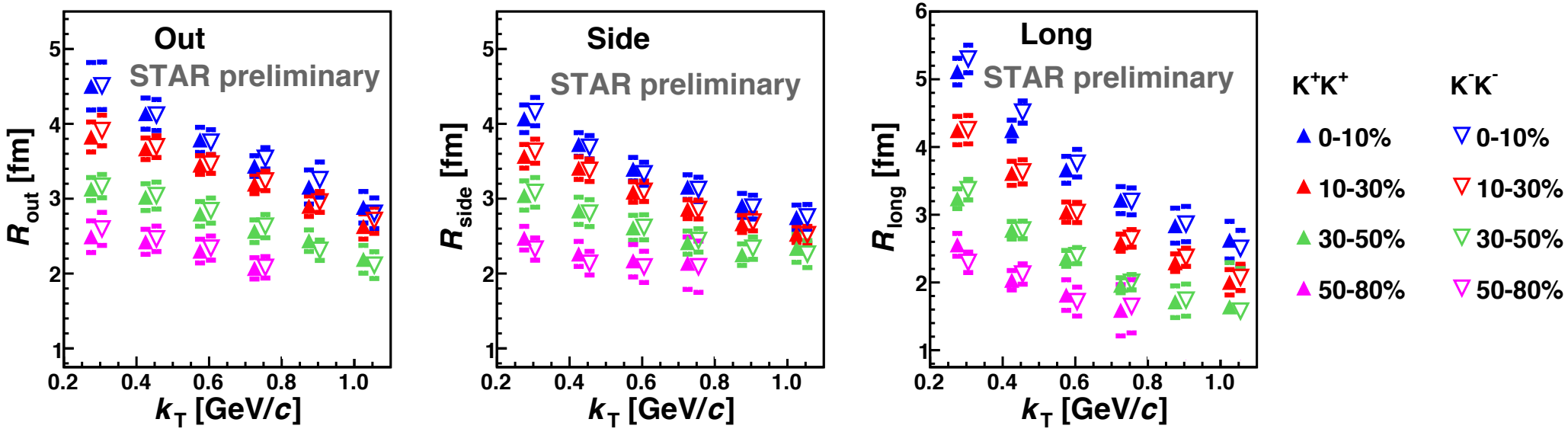
STAR preliminary

200 GeV K^+K^+

Centrality 0-10%

0.45 <k_T<0.60 GeV/c

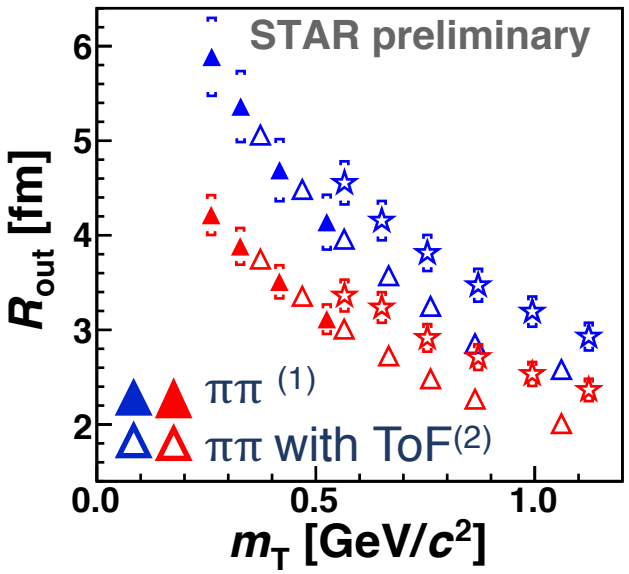
Results from 200 GeV: 3D Kaon source radii

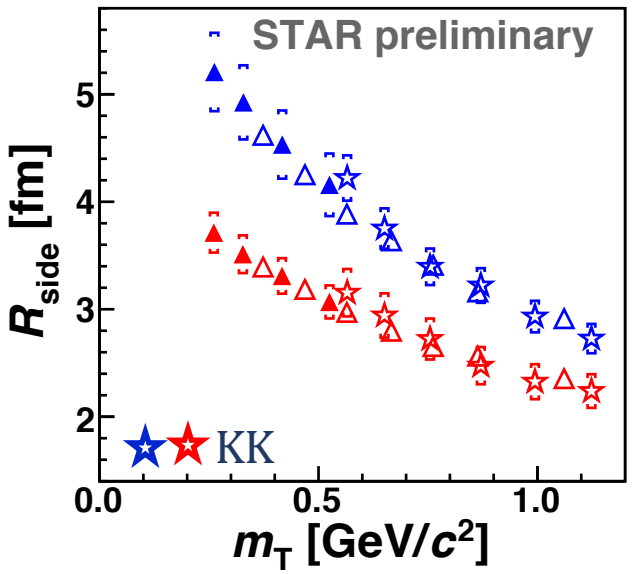


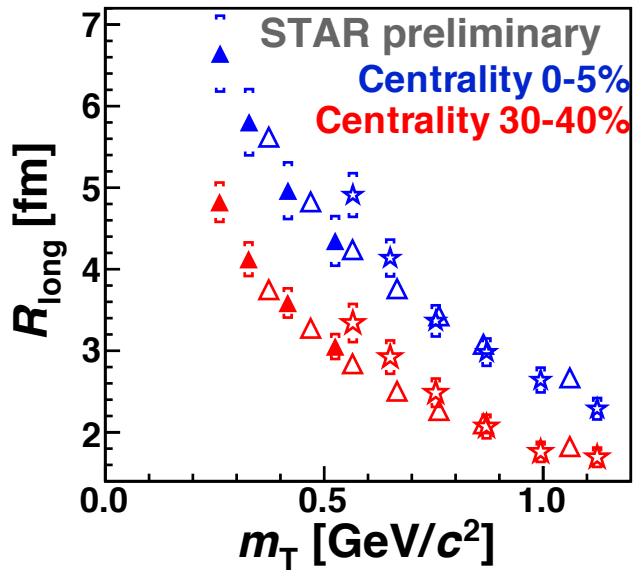
$$k_T = \left(\frac{\overrightarrow{p_1} + \overrightarrow{p_2}}{2}\right)_T$$

- **Most precise measurement of kaon source radii so far**
- **Extracted source radii - k_T and centrality dependence is observed**
  - Source radii increase with the centrality and decrease with pair transverse momentum
- Uncertainty is dominated by systematic error - varying the fit range, Coulomb corrections and PID

Results from 200 GeV: Kaon vs Pion source radii







- R_{side} for kaons follows the same trends as pions
- R_{out} for kaons is larger than for pions for the same m_{T}
- R_{long} for kaons has different trend than pions

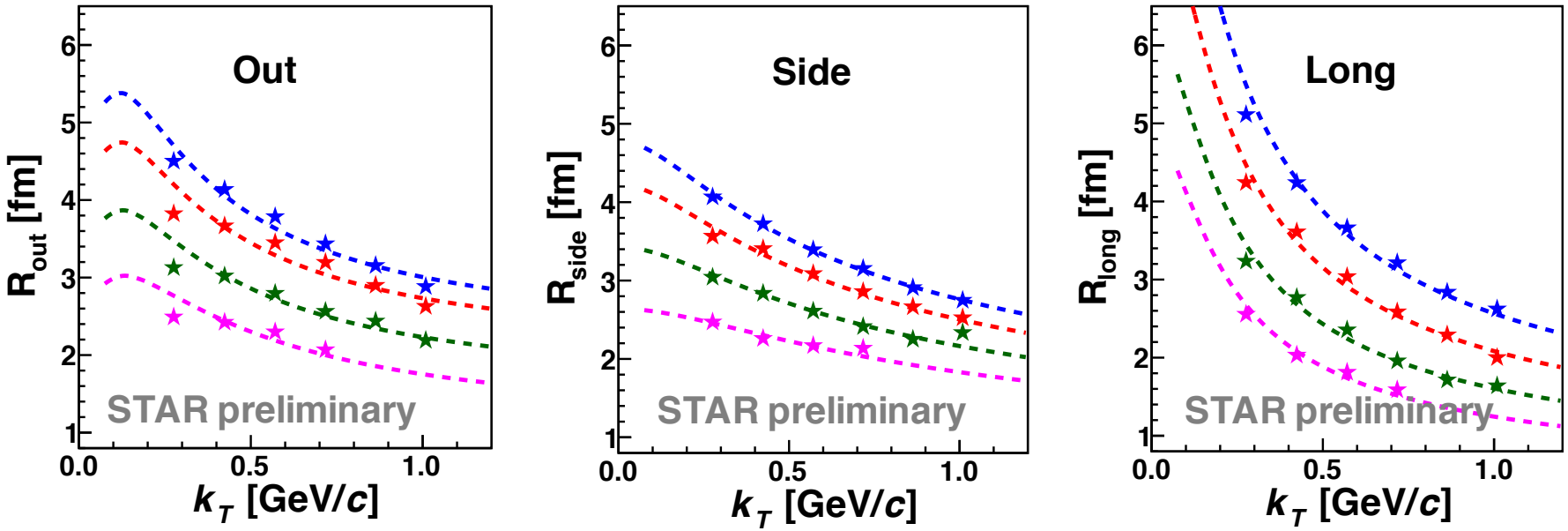
$$m_{\mathrm{T}} = \sqrt{k_{\mathrm{T}}^2 + m^2}$$

Kaon and pion source radii, especially the R_{out} follow different m_{T}

References: (1) STAR PRC **92** (2015) 14904, (2) STAR preliminary

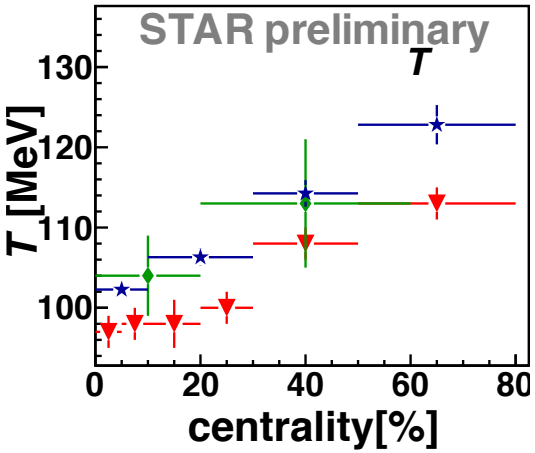
Results – Kaon radii & Spectra & Blast-wave model

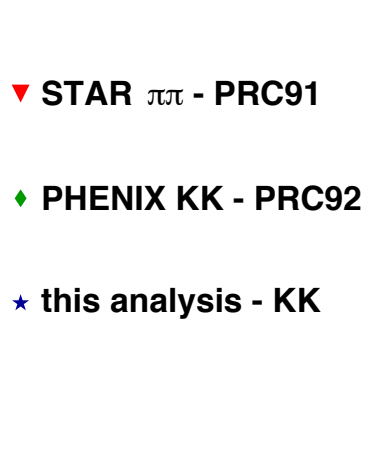
- Blast-wave parameterization can provide additional insight into the freeze-out parameters *Lisa, Retiere PRC 70:044907, 2004*
- Simultaneous fit of kaon source radii and particle spectra *Phenix PRC 69:034909, 2004*
- Parameters of Blast-wave fit are:
  - freeze-out temperature T
  - maximum transverse rapidity ρ_0
  - radius of the source R
  - system proper time τ
  - emission duration $\Delta\tau$

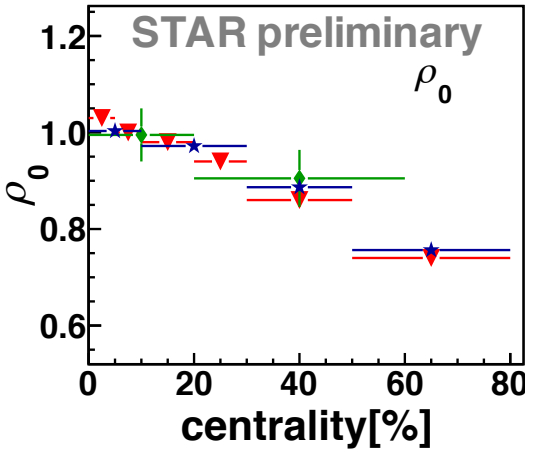


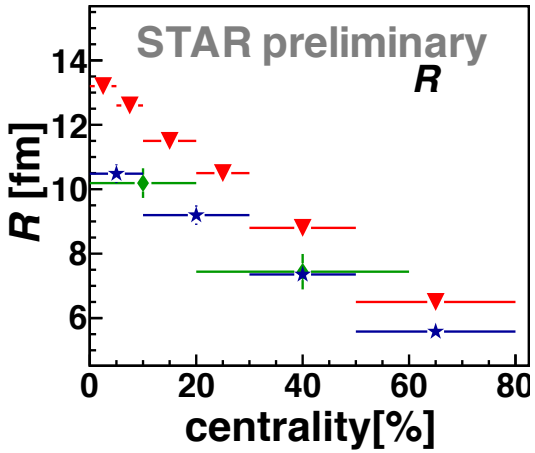
- Points – only statistical errors
- Lines – best BW fit

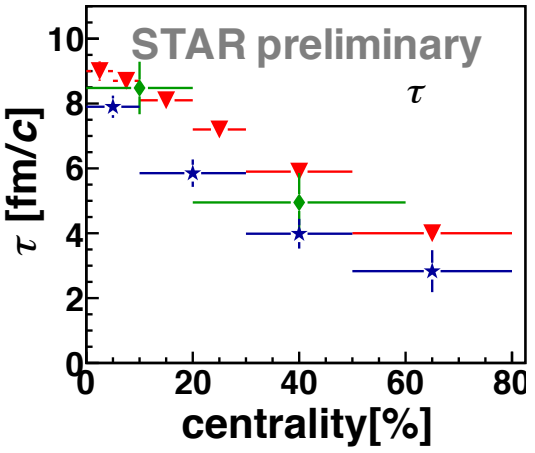
Results – Kaon radii & Spectra & Blast-wave model

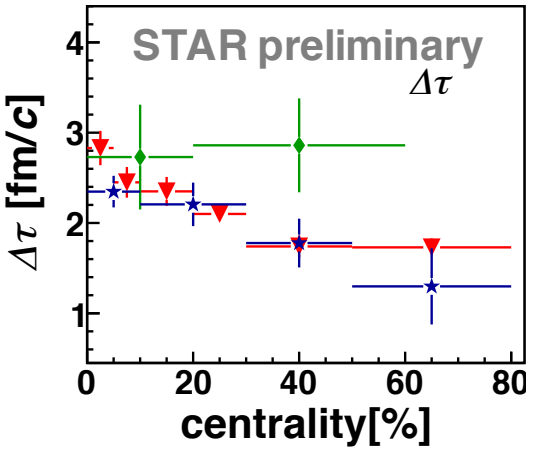












- Study of systematic errors is underway
- Parameters of freeze-out configuration are different for kaon and pion within BW

World systematics of kaon femtoscopic measurements

Results from RHIC Beam Energy Scan I:

- Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, 62.5

  BES: centrality 0-20%, $0.20 < k_T < 0.50$ GeV/c

  200 GeV: centrality 0-10%, $0.05 < k_T < 0.35$ GeV/c

+ results from ALICE *Nucl.Phys. A956 (2016) 373-376*

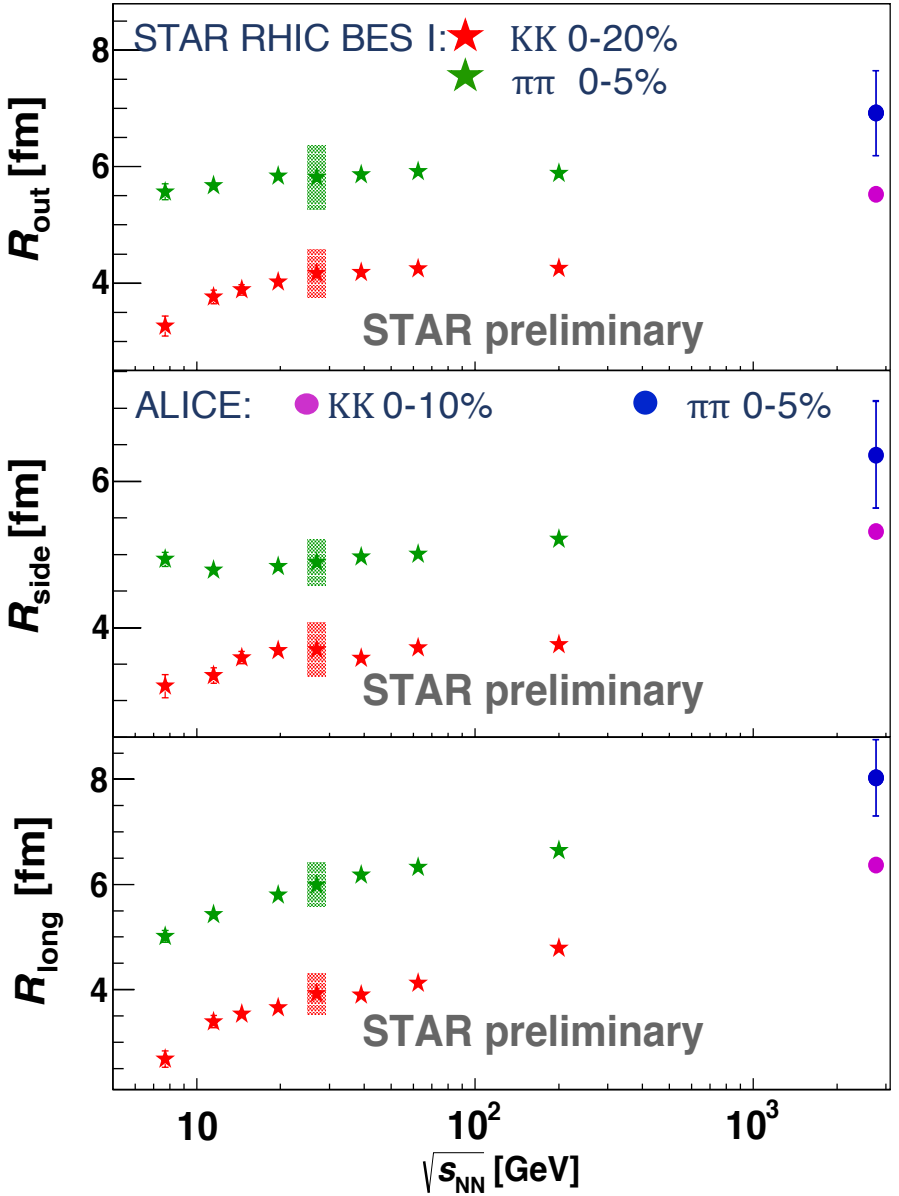
2.76 TeV: centrality 0-10%, $< k_T > \sim 0.35$ GeV/c

- Systematic errors for STAR points similar at all energies

- The available data will allow detailed study as already is performed for Au+Au $\sqrt{s_{NN}}$ = 200 GeV

More info: Grigory Nigmatkulov's talk

References: Pion femtoscopy - STAR PRC **92** (2015) 14904



Non-identical charged kaon femtoscopy

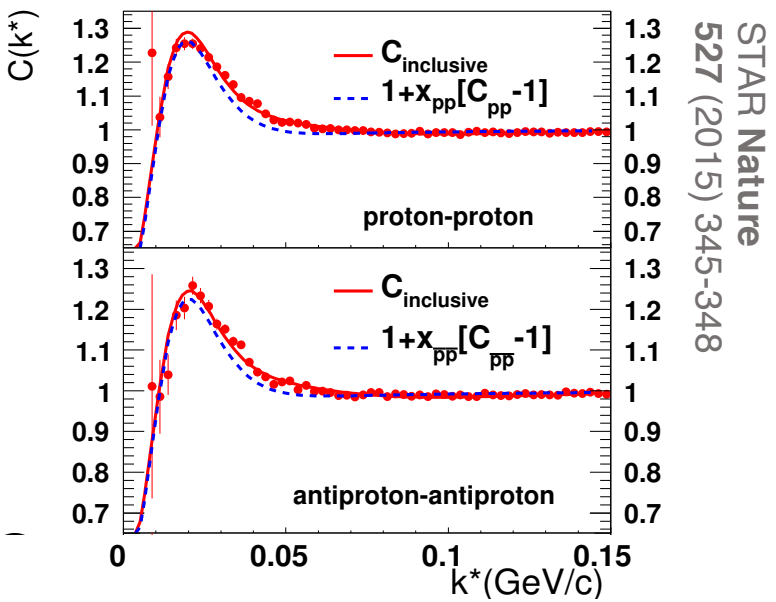
Part II:

Non-identical charged kaon femtoscopy

Non-identical charged kaon femtoscopy

Femtoscopic formalism is already well tested for various measurements at low q_{inv}

Can we use femtoscopic formalism for measurements at higher q_{inv}, in the region of resonance?



STAR Nature 527 (2015) 345-348

Femtoscopy with a narrow resonance

- 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 - test of femtoscopic formalism for measurement at higher q_{inv}

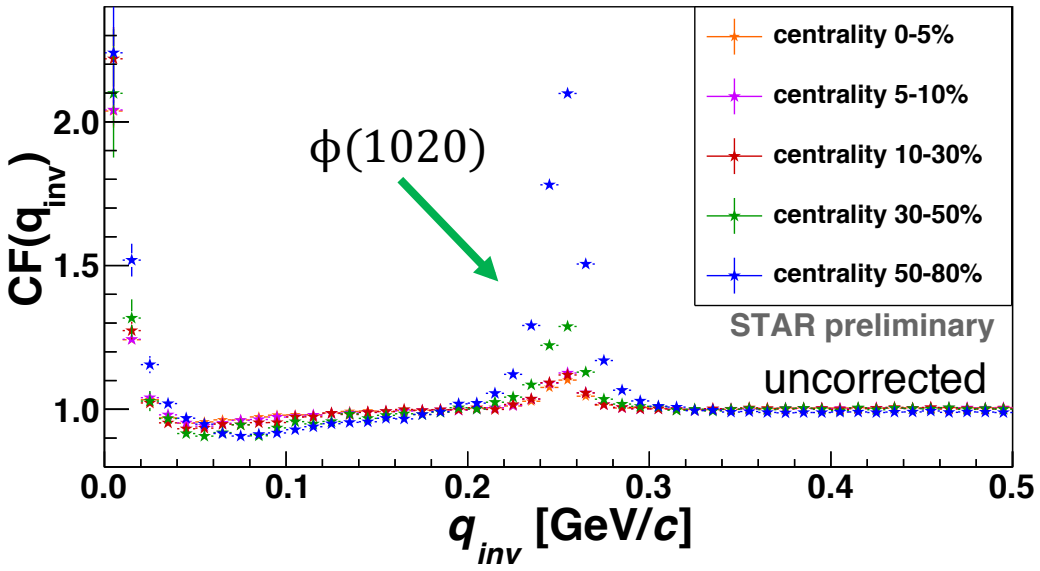
Lednicky: Phys.Part.Nucl. 40 (2009) 307-352
*Pratt et al.: PRC **68** (2003) 054901*

K^+K^- correlations:

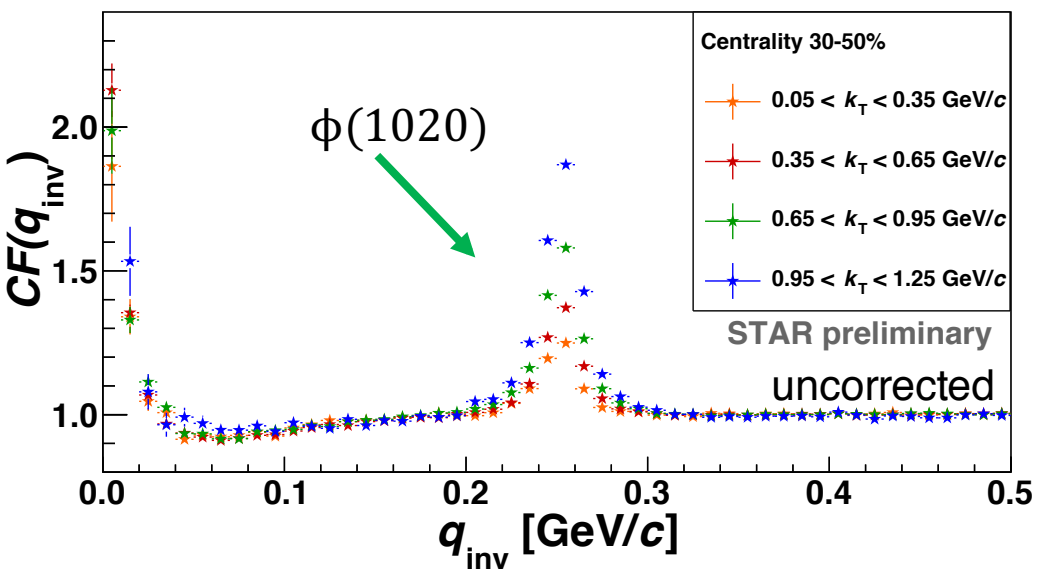
- Coulomb and strong final state interaction
- $\phi(1020)$ resonance
  - $k^* = 126\,\mathrm{MeV}/c$, $\Gamma = 4.3\ \mathrm{MeV}/c^2$
- First systematic study

Raw K^+K^- correlation functions

Centrality dependence



k_T dependence



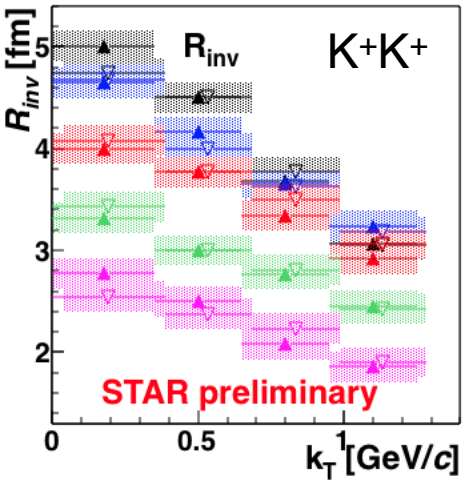
200 GeV Au+Au collisions

- CFs are sensitive to the source size
- In particular, **non-identical kaon CF is sensitive in the region of the resonance**
- In order to **compare experimental** unlike-sign kaon correlation functions to **theoretical predictions**, **the influence of momentum resolution and purity were studied**

Comparison of 1D K^+K^- to theoretical model

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

Experimental data for theoretical calculation



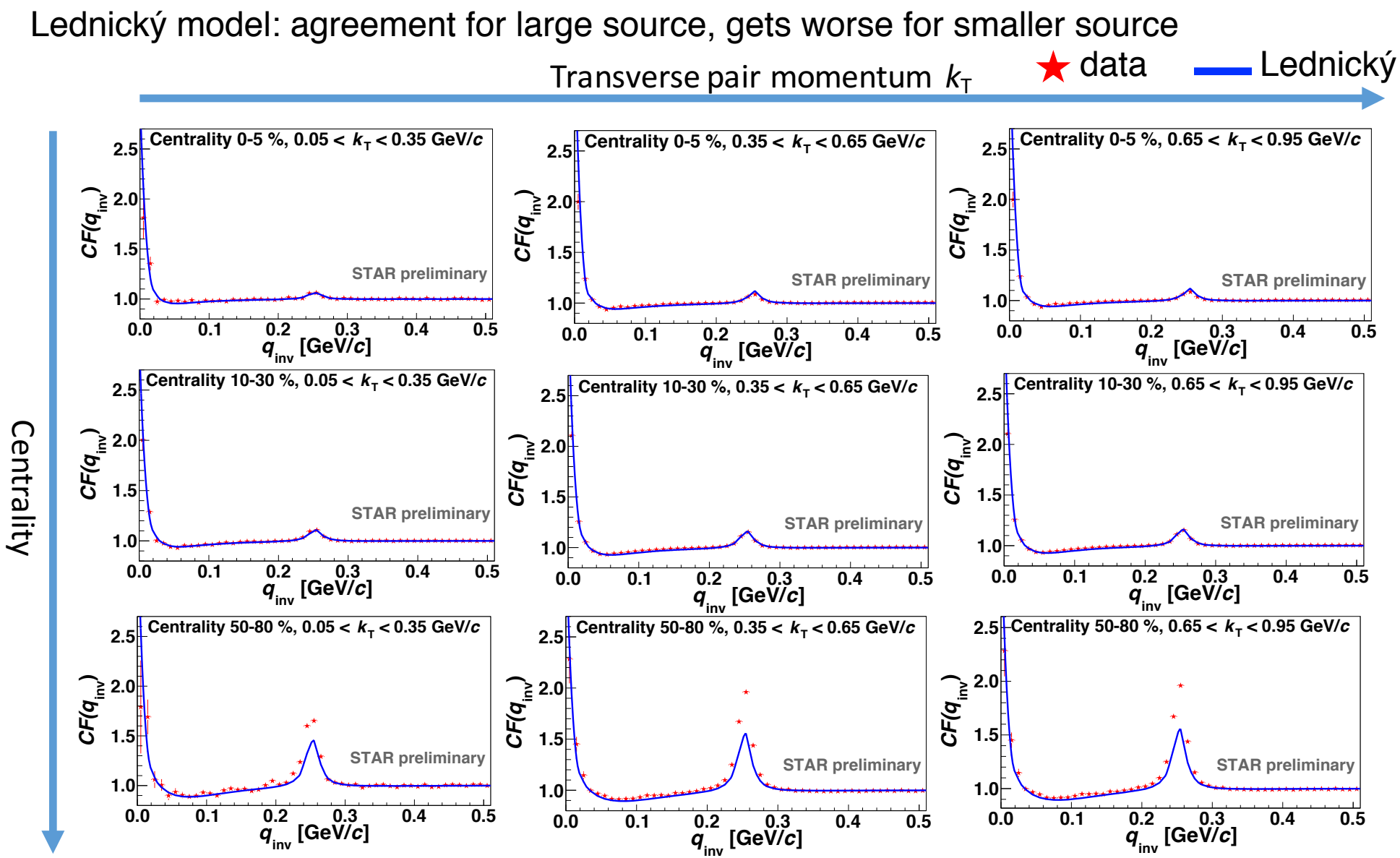
- **Gauss + Lednický model of final-state interaction**
  Lednicky: Phys.Part.Nucl. 40 (2009) 307-352
  - Includes $\phi(1020)$ resonance due to the FSI

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

  - Gaussian parameterization of source size – source size R_{inv} is extracted from the like-sign correlation function fit
    - Gaussian shape is suggested by kaon source imaging
      STAR: PRC **88** (2013) 34906
  - 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

Comparison of 1D K^+K^- to Lednický model

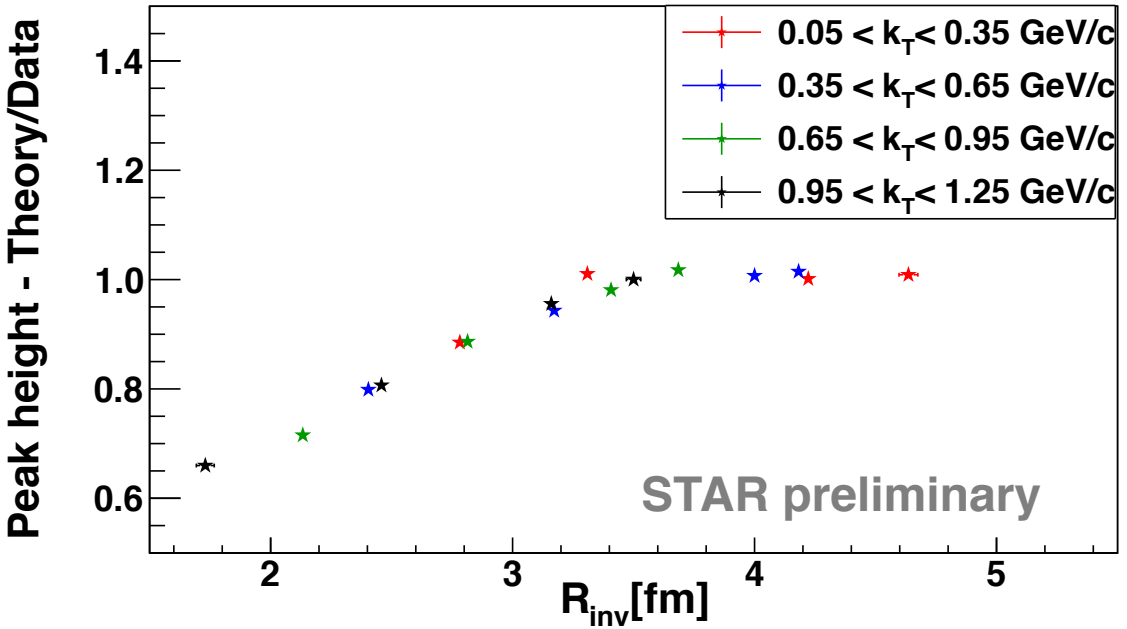
- Lednický model: agreement for large source, gets worse for smaller source



Comparison of 1D K^+K^- to Lednický model

Observations:

- The model underpredicts the strength of the correlation functions in the region of resonance with decreasing R_{inv}
- Model *fails* for smaller system (~3fm and smaller)



Only statistical errors (smaller than point size)

- Can this behavior be interpreted as a breakdown of the smoothness approximation?
- Ongoing work: source parameterized by Blast-Wave model
  - more realistic description of the source
  - influence of the presence of $r^* - k^*$ correlations ?

Conclusions

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

✓ Comparison of K and π source radii:

R_{side} - similar trend

R_{out} and R_{long} - different trend

We observe that at the $0.4 < m_T < 0.9$ GeV/c^2, kaon radii are larger than that of the pions in 200GeV Au+Au collisions

✓ Kinetic freeze-out parameters were extracted by Blast-wave parameterization

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

✓ Strong centrality and k_T dependence in $\phi(1020)$ region

✓ Possible breakdown of femtoscopic formalism for small systems

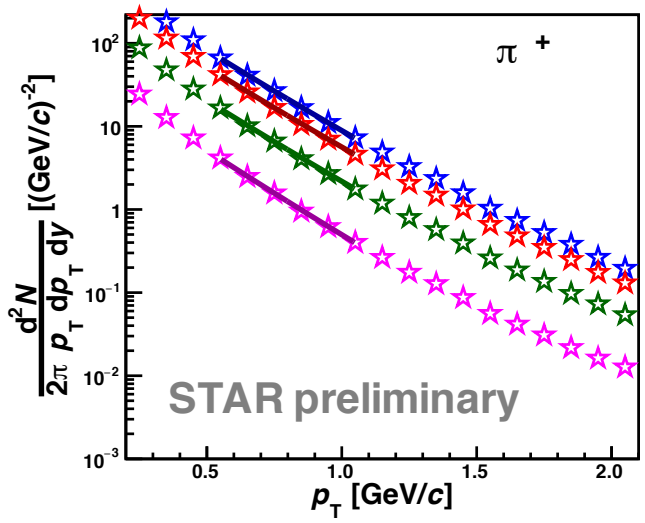
The End

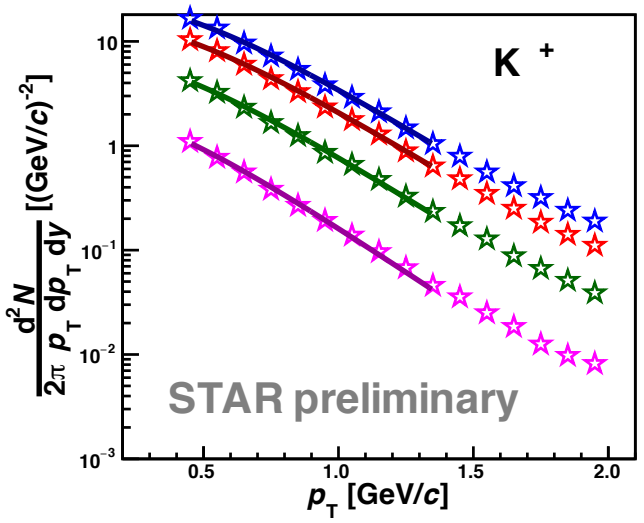
Thank you for your attention

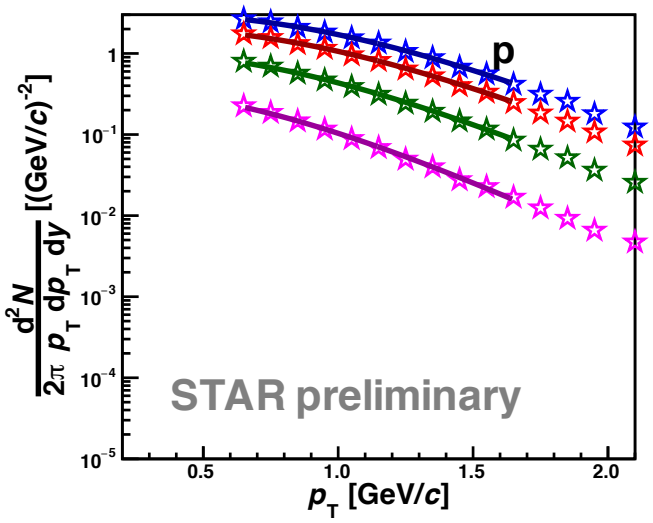
The End

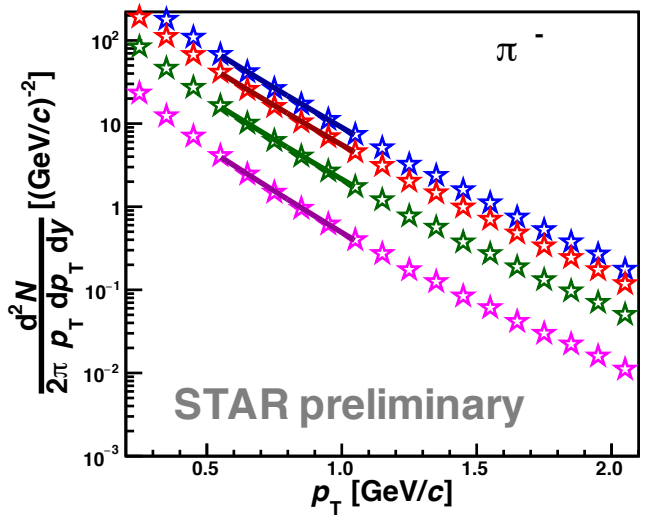
Back-up slides

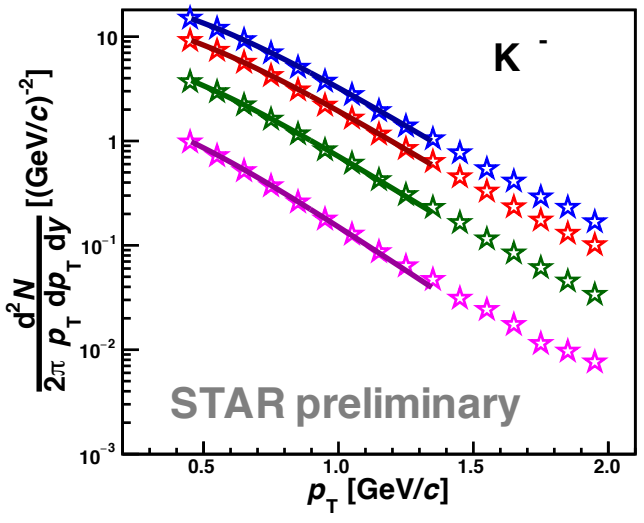
Blast-wave model – spectra fit

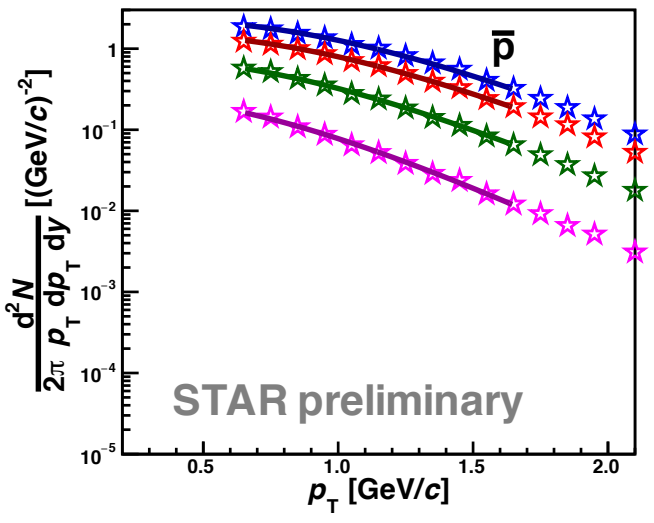




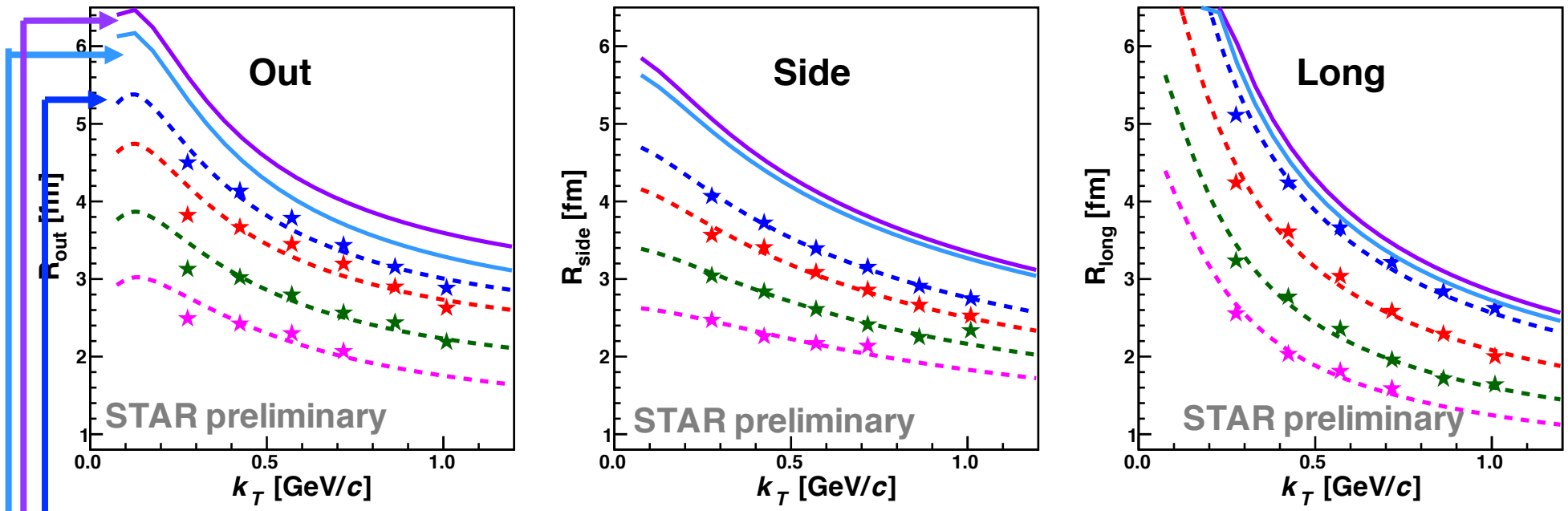








Blast-wave model – kaon vs pion results



Particle	Centrality[%]	T[MeV]	R[fm]	ρ_0	τ [fm/c]	$\Delta\tau$[fm/c]
Kaon	0-10	102±1	10.5±0.3	1.003±0.001	7.9±0.3	2.3±0.2
Pion(1)	0-5	97±2	13.2±0.2	1.03±0.01	9.0±0.3	2.83±0.19
Pion(1)	5-10	98±2	12.6±0.2	1.00±0.01	8.7±0.2	2.45±0.17

References: (1) Phys. Rev. C **71** (2005) 44906