Kaon femtoscopy in Au+Au collisions from the Beam Energy Scan at the STAR experiment

Jindřich Lidrych for the STAR Collaboration

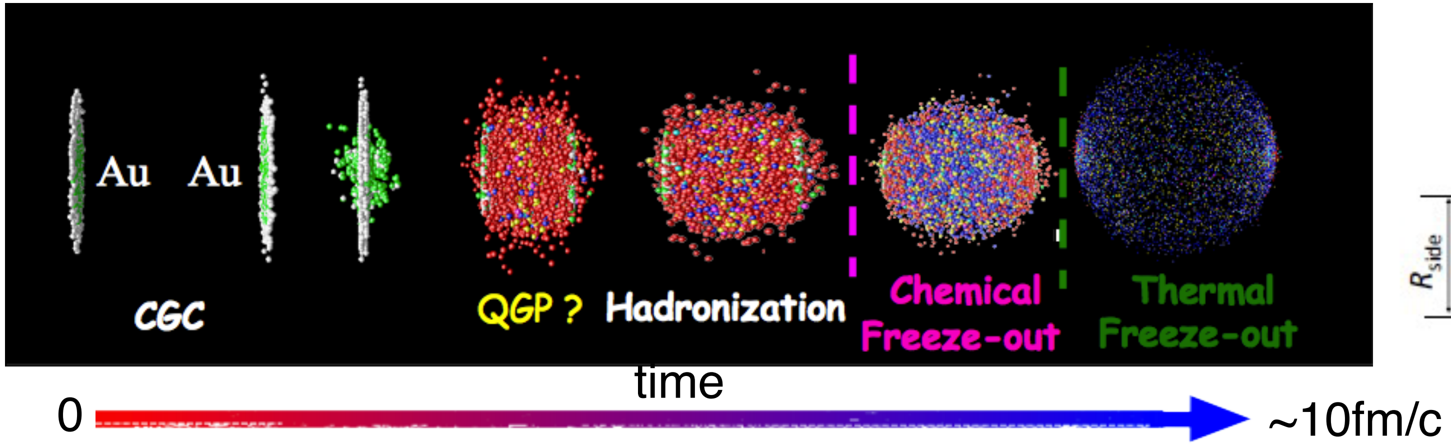
Faculty of Nuclear Sciences and Physical Engineering
Czech Technical University in Prague

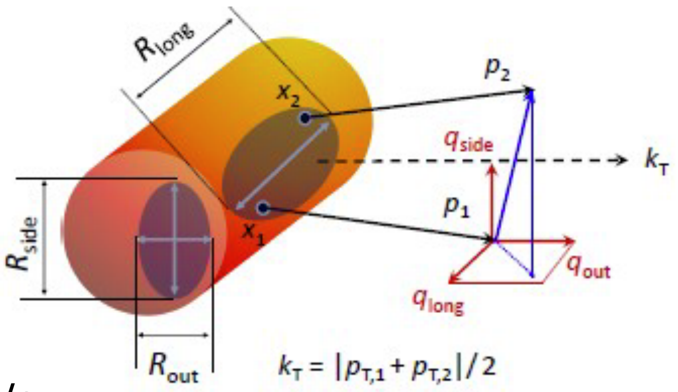
17th International Conference

Strangeness in Quark Matter

10th – 15th July 2017

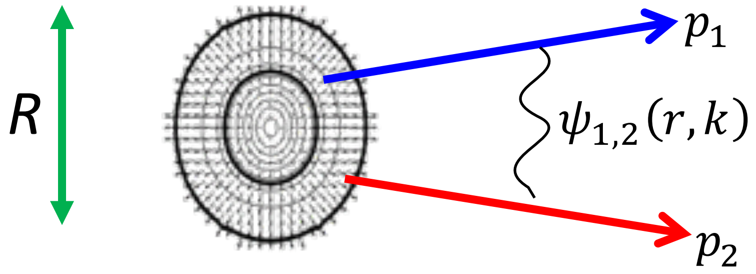
Femtoscopy

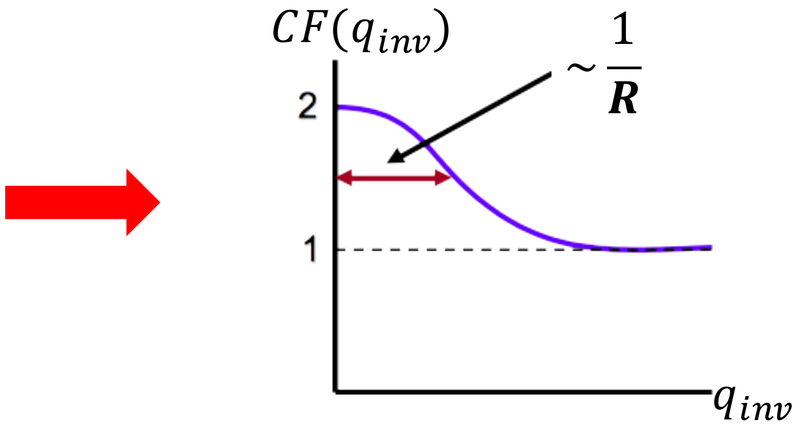




- Study space-time extents of the source at the thermal freeze-out
- Correlation function: $CF(p_1, p_2) = \int d^3r S(r,k) |\psi_{1,2}(r,k)|^2 = \frac{\text{real pairs}}{\text{mixed pairs}}$

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





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

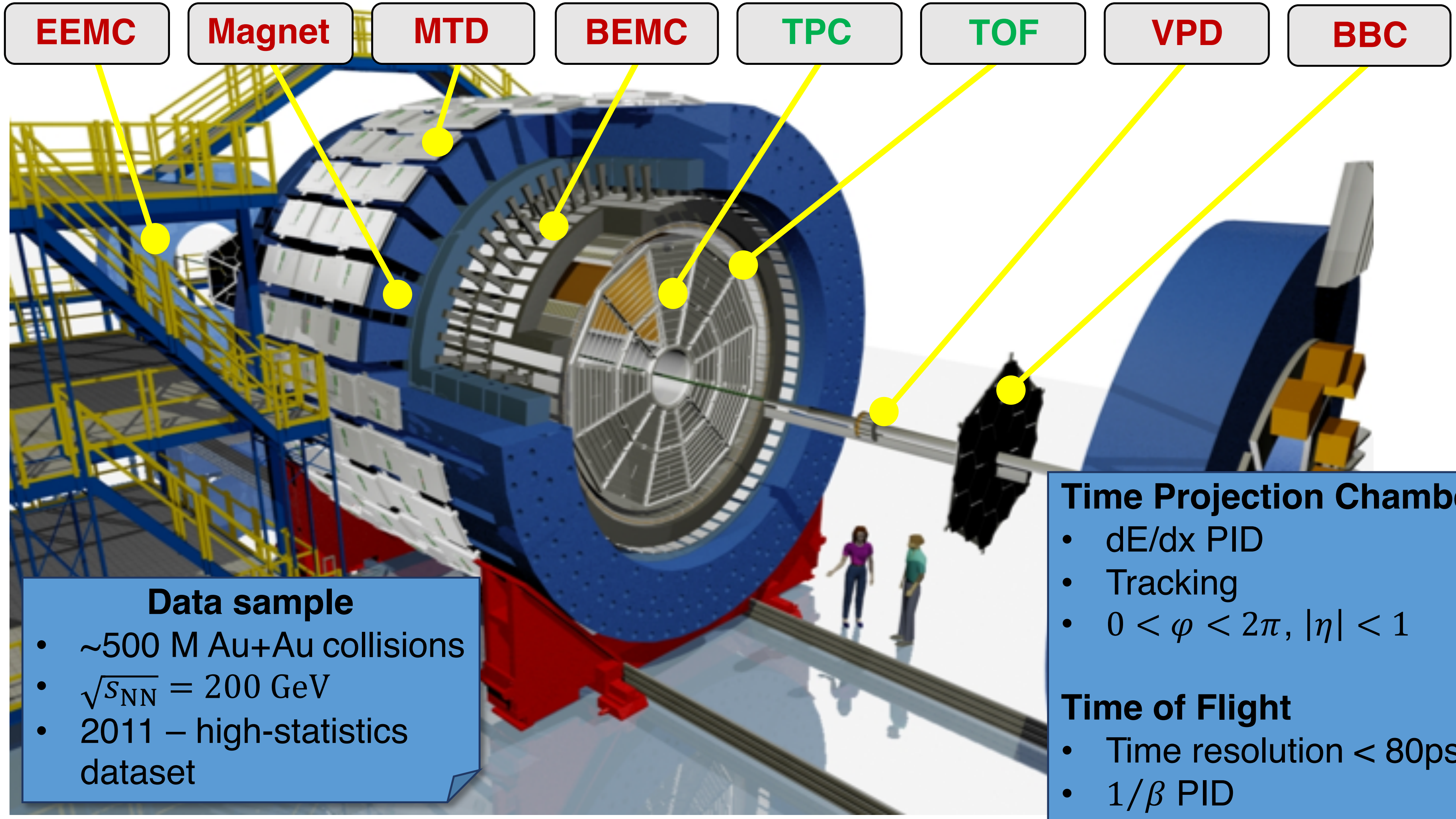
- Kaon pairs: Quantum statistics and Coulomb interaction dominate at low q_{inv}
- Goal: Extraction of space-time characteristics and kinetic freeze-out parameters

Part II: Non-identical charged kaon femtoscopy

- Kaon pairs: Coulomb interaction and strong interaction in *s* and *p*-wave
- Goal: Extract space-time characteristics in the region of the resonance

STAR Experiment at RHIC

- Femtoscopy
- Kaon femtoscopy
- **STAR Experiment**
- Methods
- Results from 200 GeV
- BW Fit
- Results from BES
- K^+K^- femtoscopy
- Model comparison
- Conclusions



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

Part I:

Identical charged kaon femtoscopy

Extraction of source radii from CF

- Bowler-Sinyukov fitting procedure:

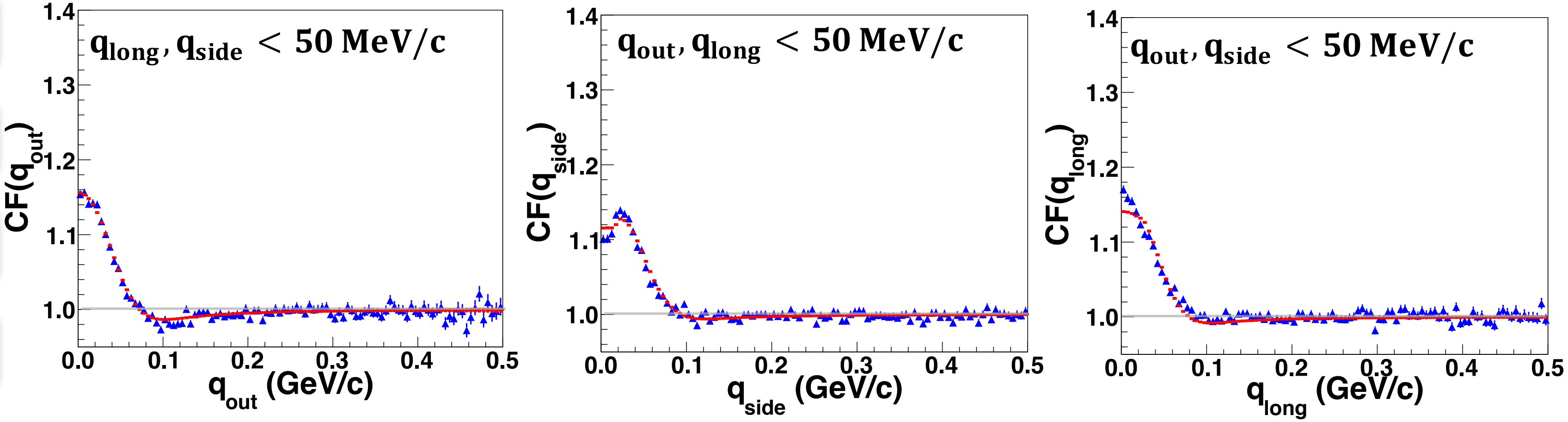
Bowler PLB 270:69–74, 1991
Sinyukov PLB 432:248-257, 1998

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

  - 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 (lines)
  - good agreement with data



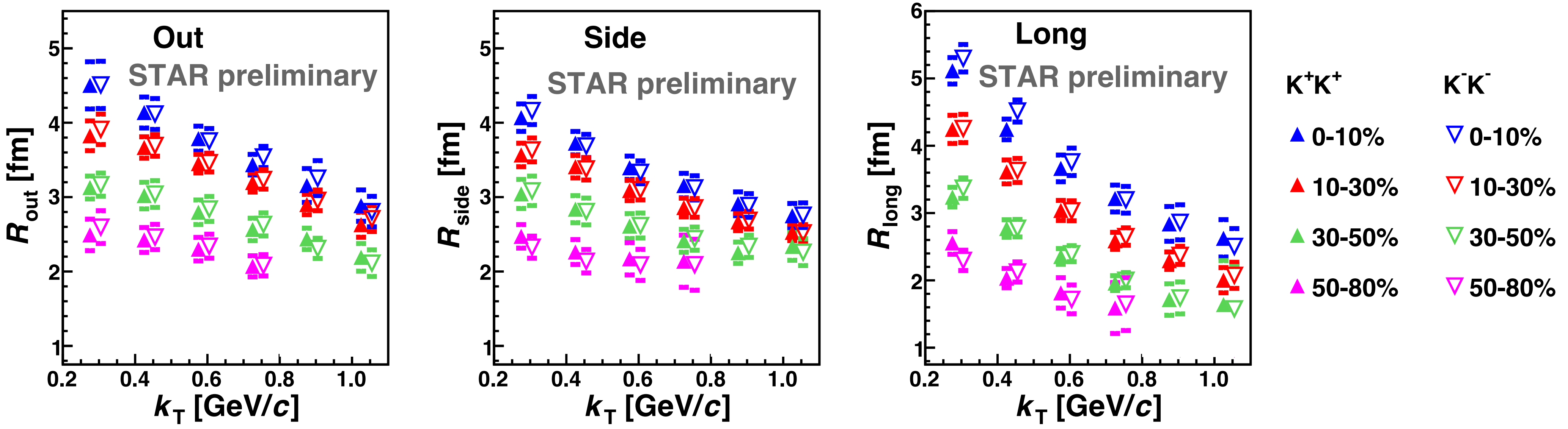
STAR preliminary

200 GeV K^+K^+

Centrality 0-10%

0.45 $<k_T<$ 0.60 GeV/c

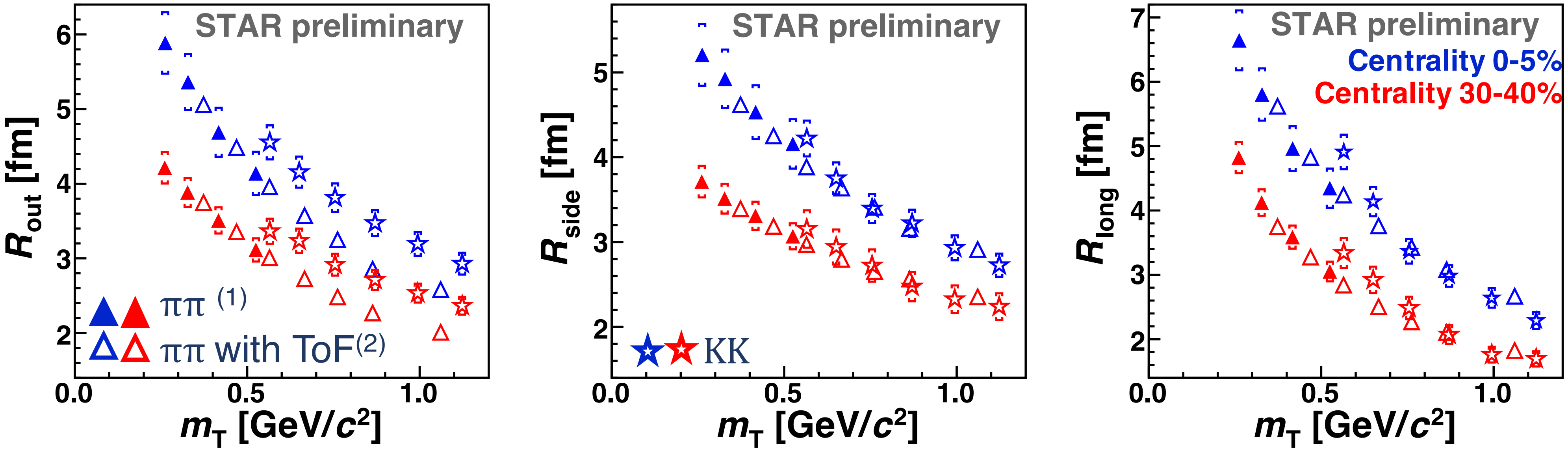
Results from 200 GeV: 3D Kaon source radii



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

- **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 uncertainties - varying the fit range, Coulomb corrections and PID

Results from 200 GeV: Kaon vs Pion source radii



- R_{side} trend for kaons is similar to that of pions
- R_{out} for kaons is larger than for pions for the same m_{T}
- R_{long} for kaons has different trend than pions

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

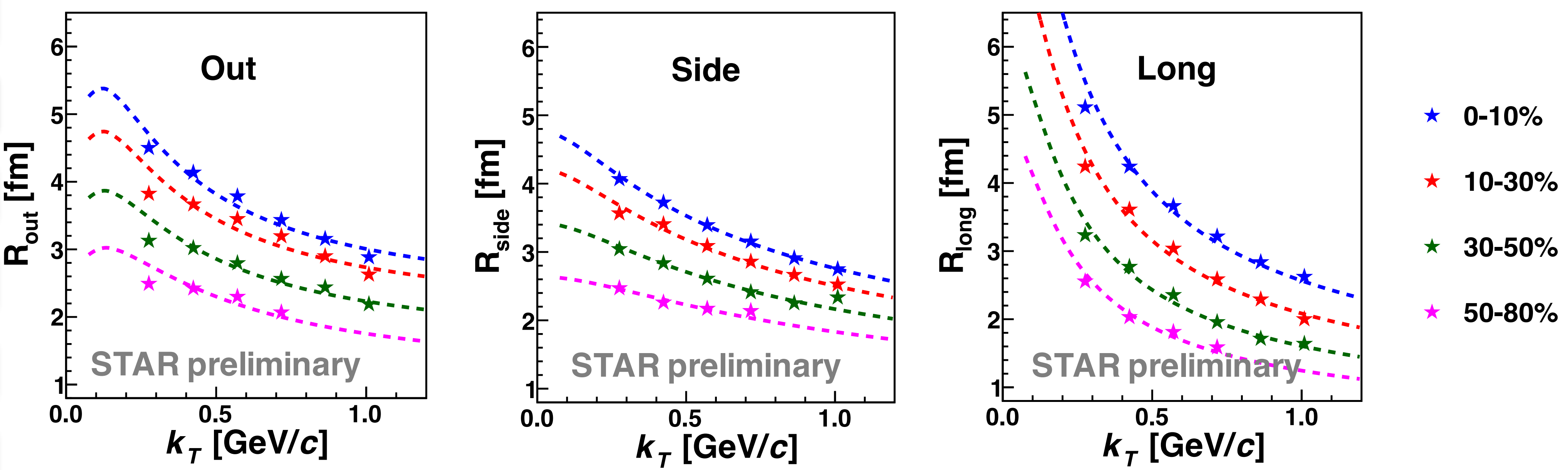
Kaon and pion source radii, especially the R_{out} follow different m_{T} dependence

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

Results – Kaon radii & Spectra & Blast-wave model

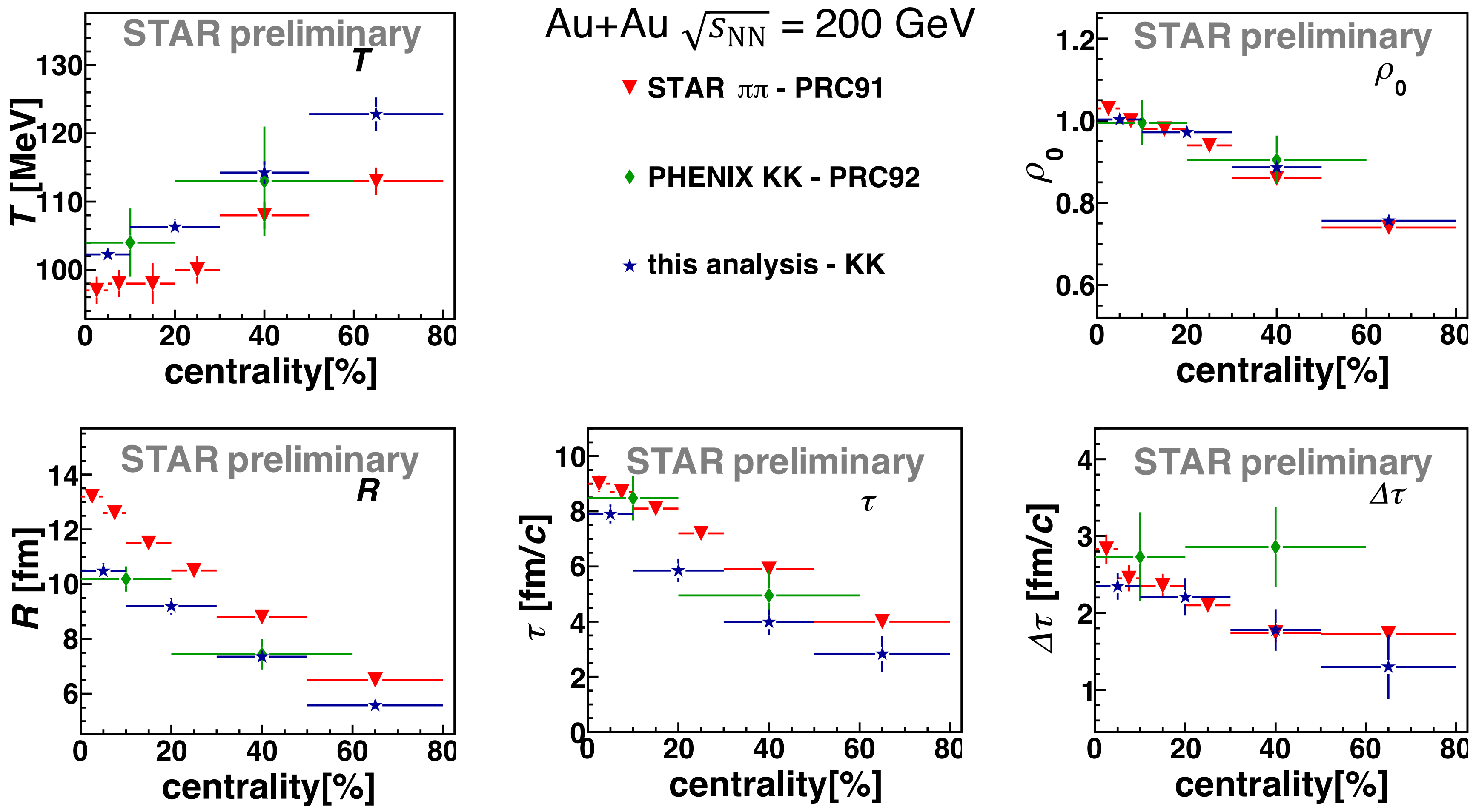
- Blast-wave parameterization can provide additional insight into the freeze-out parameters *Lisa, Retiere PRC 70:044907, 2004*
- Simultaneous fit of kaon source radii and particle spectra(π/K/p) *PHENIX PRC 69:034909, 2004*
- Parameters of Blast-wave fit are:
  - freeze-out temperature T
  - radius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

Au+Au $\sqrt{s_{NN}}$ = 200 GeV



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

Results – Kaon radii & Spectra & Blast-wave model



- Study of systematic uncertainties 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, 62.4

  Kaon:

  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*

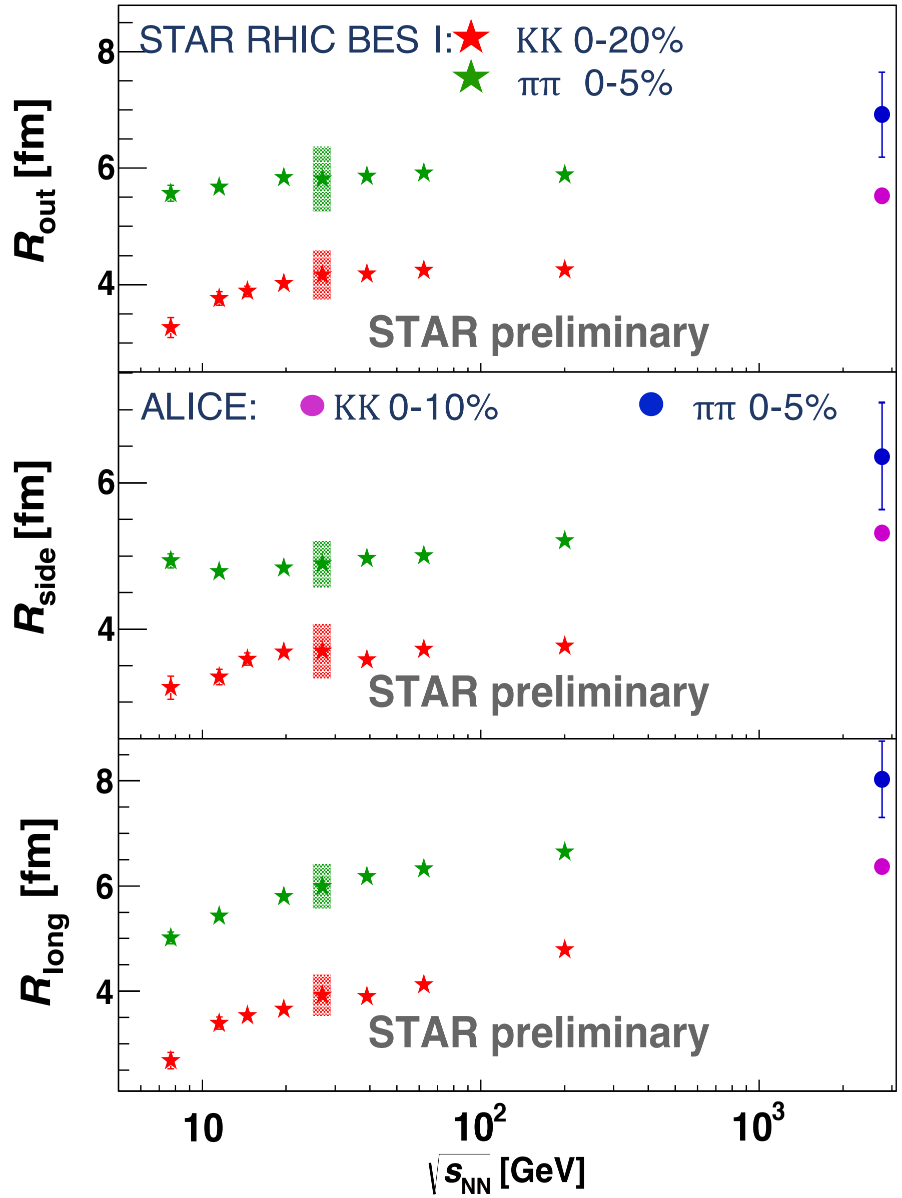
  2.76 TeV: centrality 0-10%, $< k_T > \sim 0.35$ GeV/c

  Pion:

  BES + 200 GeV: centrality 0-5%, $< k_T > \sim 0.22$ GeV/c

- Systematic uncertainties for STAR results at all energies have similar sizes as the ones shown for 27 GeV as shaded areas

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



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

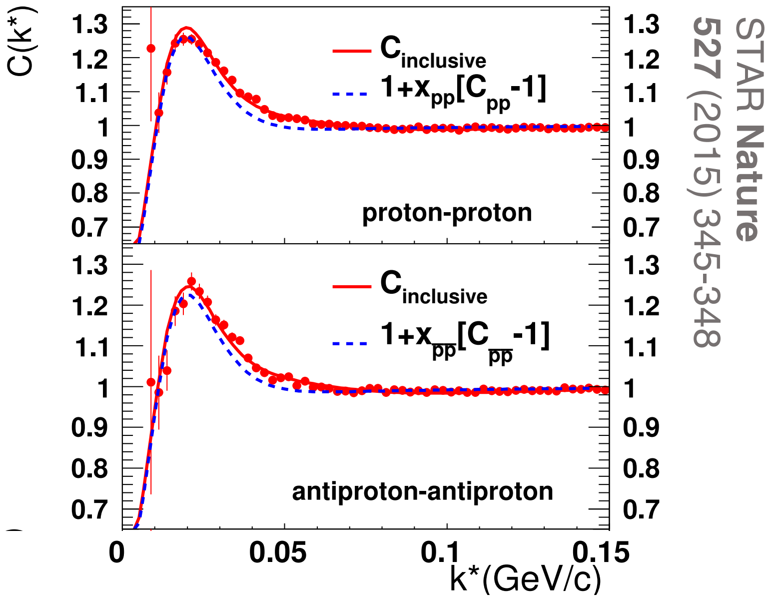
Non-identical charged kaon femtoscopy

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?

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}

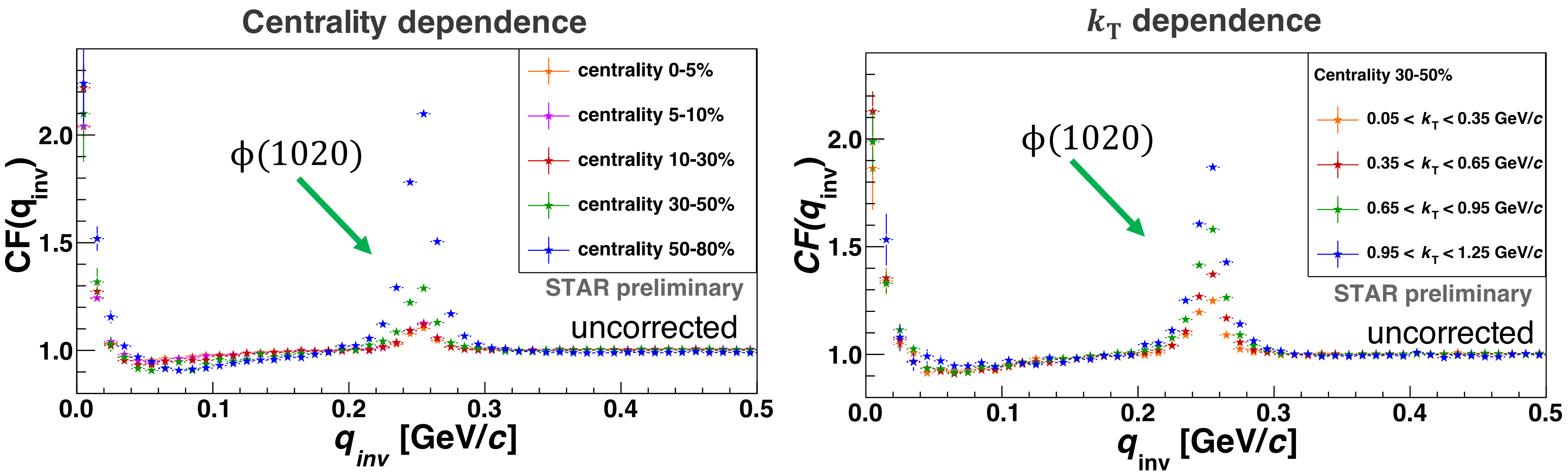
Lednicky: Phys.Part.Nucl. 40 (2009) 307-352
*Pratt et al.: PRC **68** (2003) 054901*

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

- Femtoscopy
- Kaon femtoscopy
- STAR Experiment
- Methods
- Results from 200 GeV
- BW Fit
- Results from BES
- **K^+K^- femtoscopy**
- Model comparison
- Conclusions



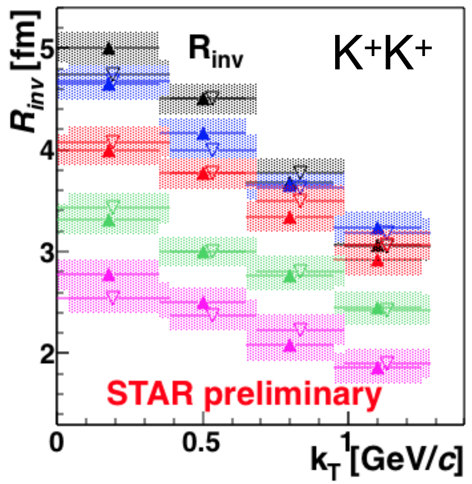
200 GeV Au+Au collisions

- 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 was 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



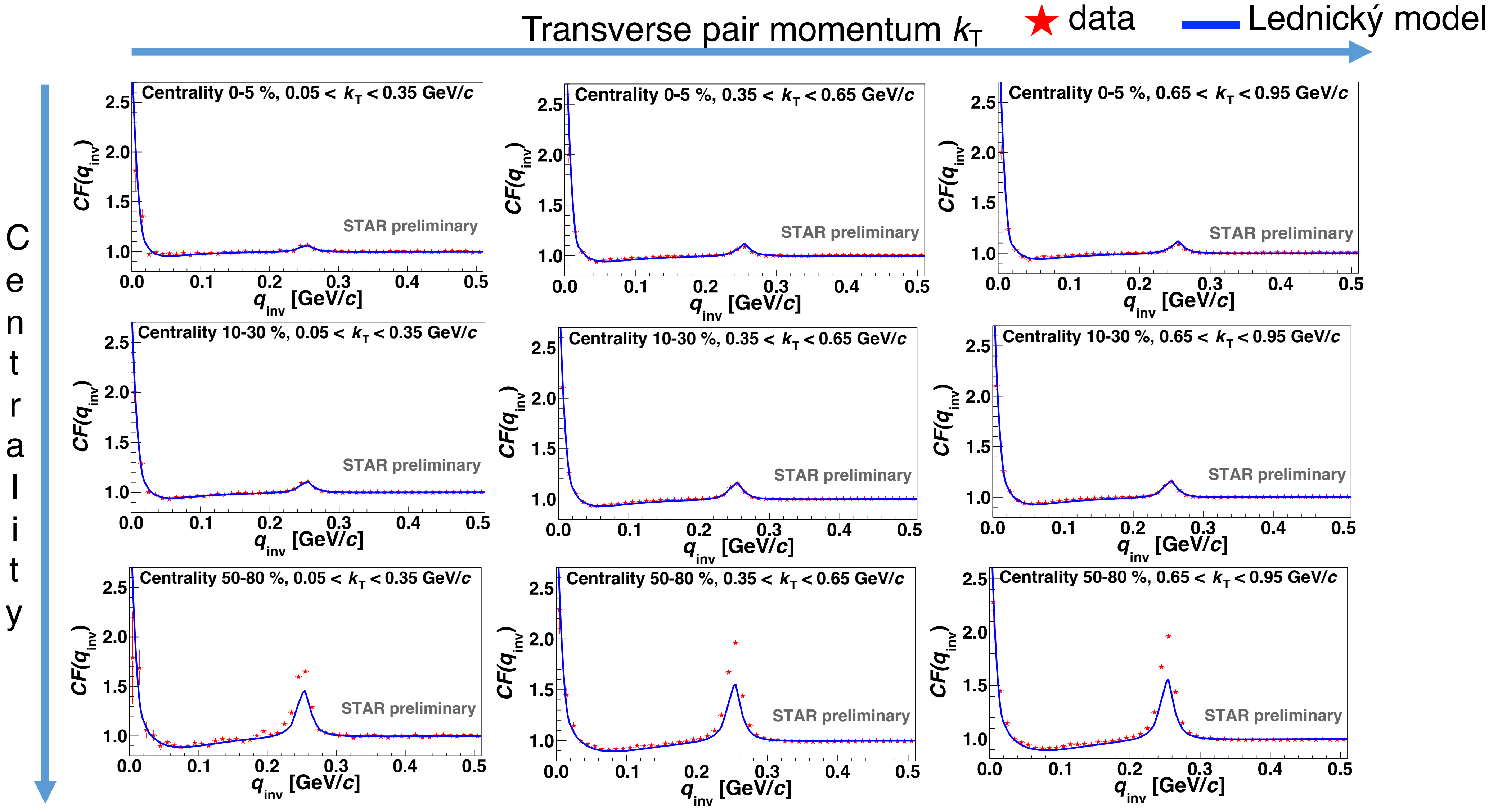
- **Gauss + Lednický model of final-state interaction**
  Lednicky: Phys.Part.Nucl. 40 (2009) 307-352
  - Includes $\phi(1020)$ resonance due to the FSI

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

  - 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:
    $CF^{exp} = (CF^{theo} - 1)\lambda + 1$
    in order to compare to an experimental correlation function, which is corrected for impurities

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

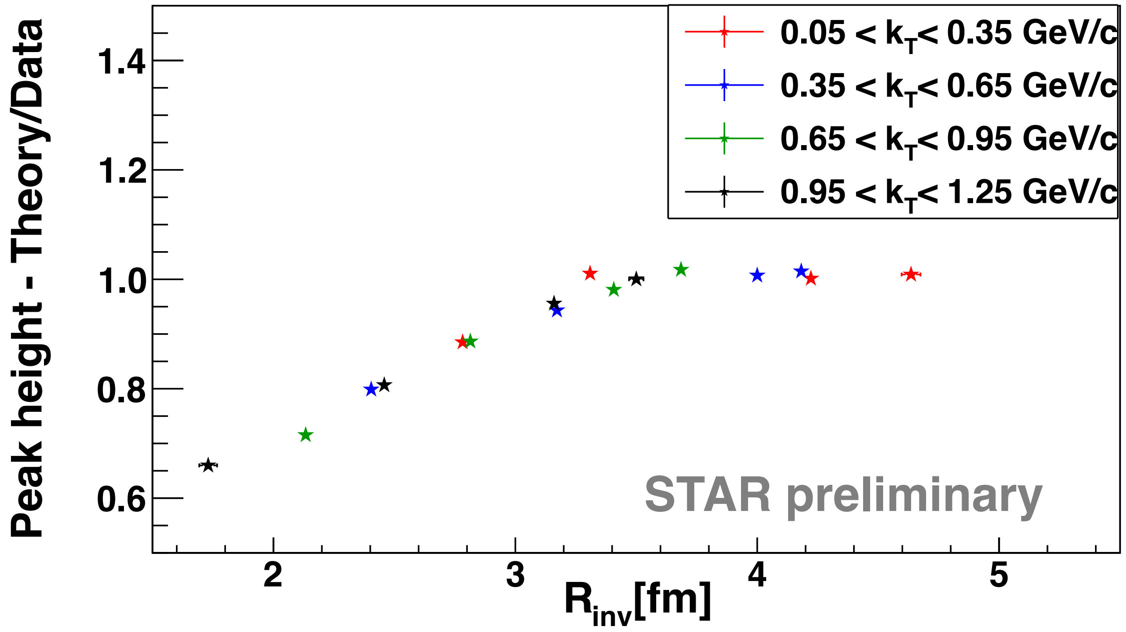
- Lednický model: agreement for large source, gets worse for smaller source



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 uncertainties (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 using the 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 the femtoscopic formalism for small systems

The End

Thank you for your attention

Utrecht 2017

The End

Back-up slides

Utrecht 2017

Blast-wave model – spectra fit