Femtoscopy with unlike-sign kaons at STAR in 200 GeV Au+Au collisions

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Workshop on Particle Correlations and Femtoscopy
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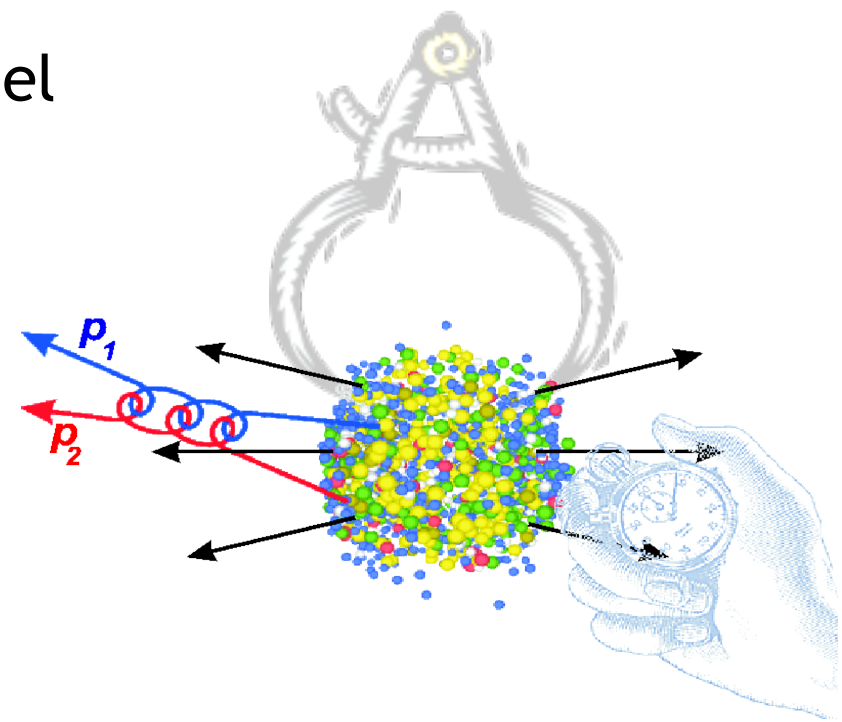
Outline

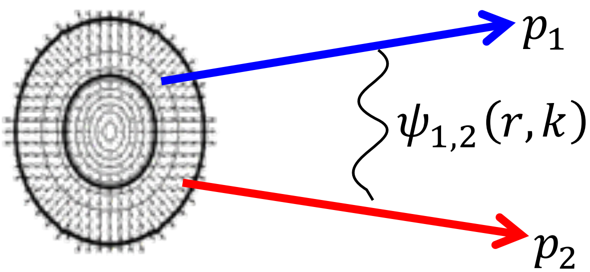
- Motivation for unlike-sign kaon femtoscopy
- STAR detector
- Preliminary results
- Purity corrections from fitting like-sign correlation function
- Comparison to Lednicky model
- Conclusion

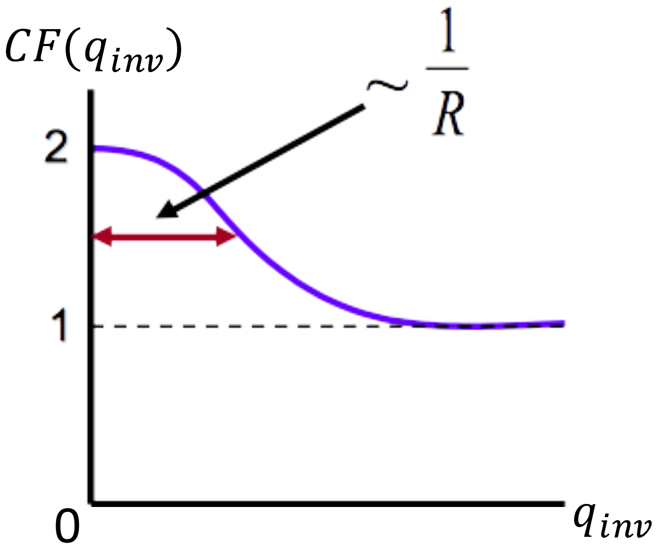


Standard HBT measurements

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

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





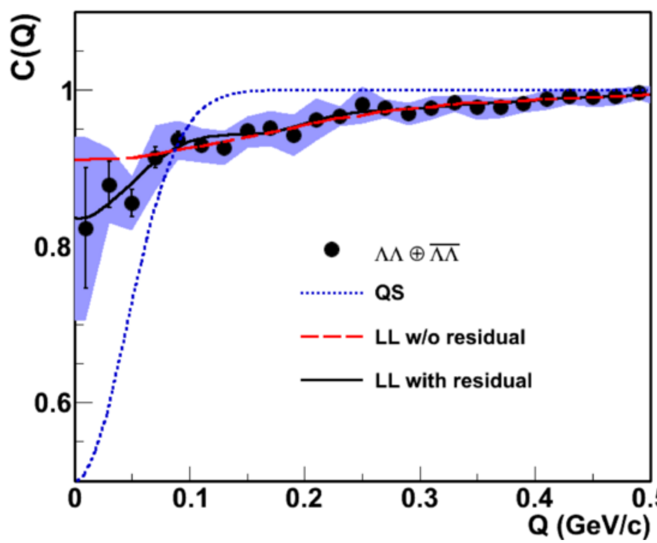
- Measurements with identical non-interacting particles
  - Only quantum statistics for description of their interaction

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

  - Study source size and its dynamical properties – shape and timescale of the emission zone

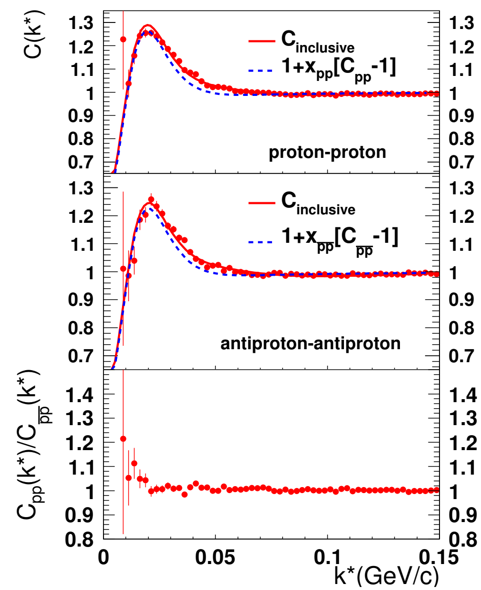
Two-particle measurements

- Measurements with interacting particles
  - Coulomb interaction and strong final-state interaction
  - Sensitive to source size and measurements of particles' interactions



$\Lambda\Lambda$ correlation function in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

Phys. Rev. Lett. 114, 022301 (2015)



Measurements of interaction between antiprotons

STAR Nature 2015

- In all these cases, the correlation function is sensitive to the pertinent physics **at very low** q_{inv}

HBT with narrow resonances

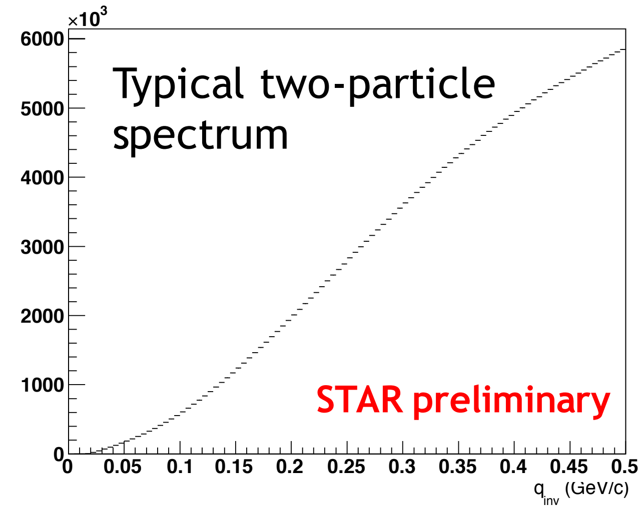
Use strong FSI in region of resonance:
Lednicky: Phys.Part.Nucl. 40 (2009) 307-352
Pratt et al.: PRC 68 (2003) 054901

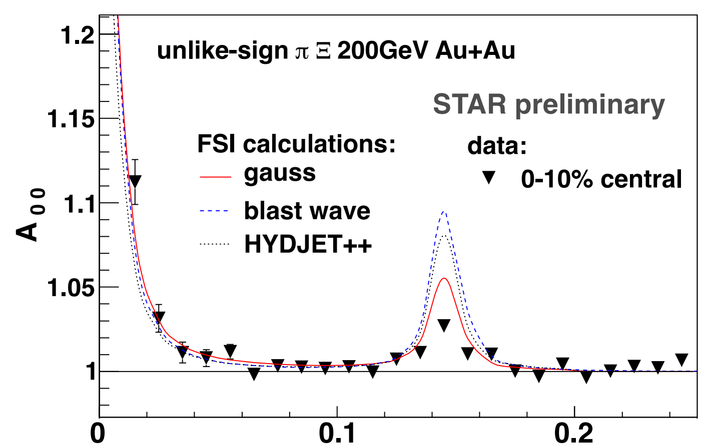
- More sensitive
- Statistically advantageous

Challenges for HBT formalism:
- Extension of HBT formalism to higher q_{inv}
- Smoothness assumption

  Lednicky et al.: Prog.Theor.Phys.Suppl. 193 (2012) 335-339
- Equal-time approximation
- "Double counting" – direct vs FSI treatment
  (Lisa, WPCF2013)

System with narrow resonances near threshold:
- $\pi\Xi$ and K^+K^-





Braz.J.Phys 37(2007)925

HBT with kaons

- Coulomb and strong final-state interaction (FSI)

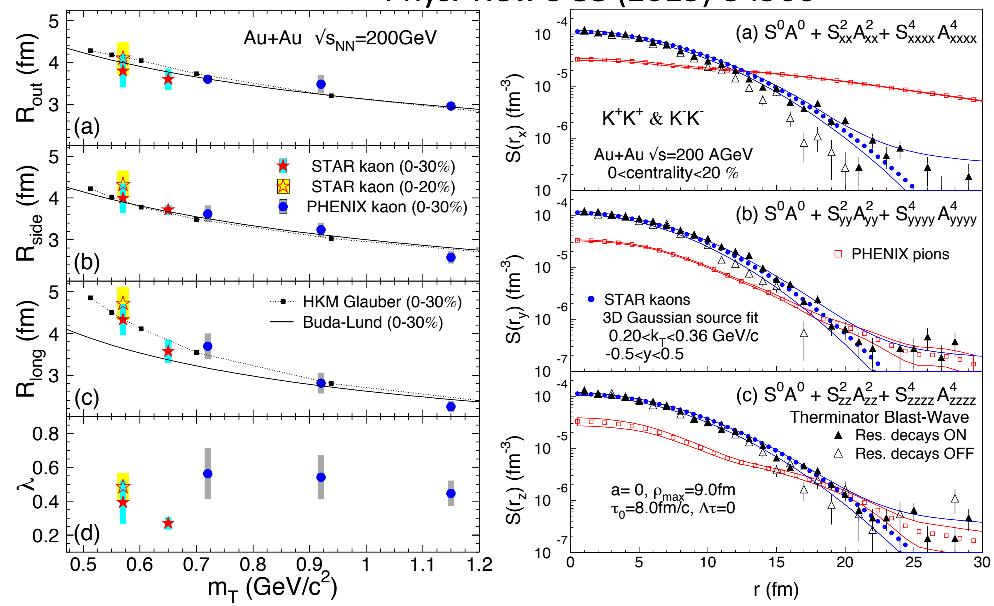
- $\phi(1020)$ resonance:
  $k^* = 126\,\mathrm{MeV}/c\,,\,\Gamma = 4.3\,\mathrm{MeV}$

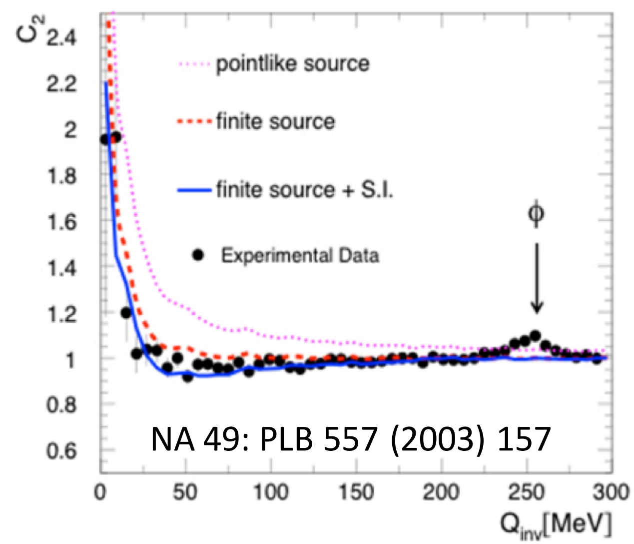
- Narrow resonance – separation of emission and FSI

Advantages of using kaons:

- higher statistics
- low feed-down
- source is well known (imaging)

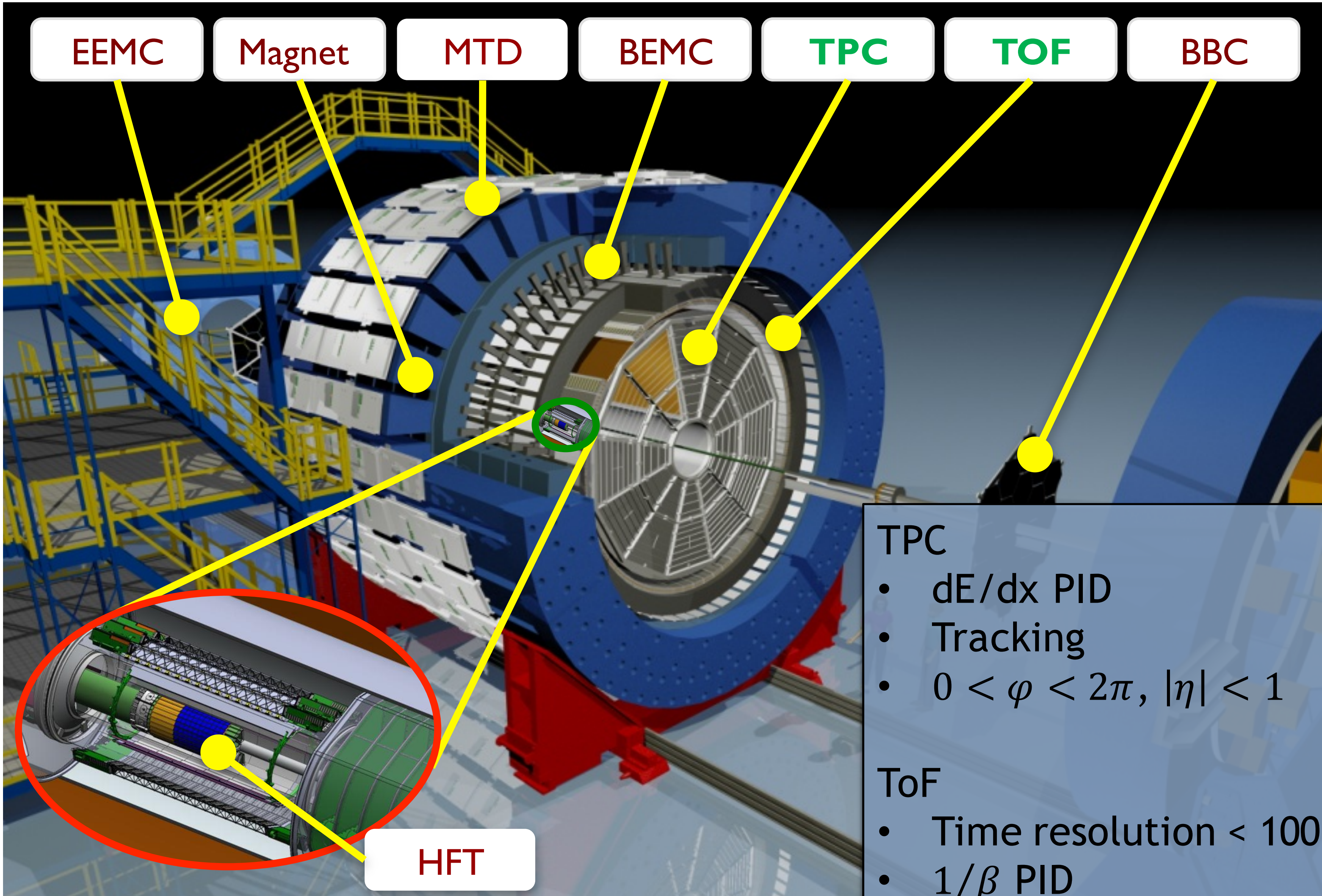
Phys. Rev. C **88** (2013) 34906





NA 49: PLB 557 (2003) 157

STAR Experiment at RHIC



TPC

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

ToF

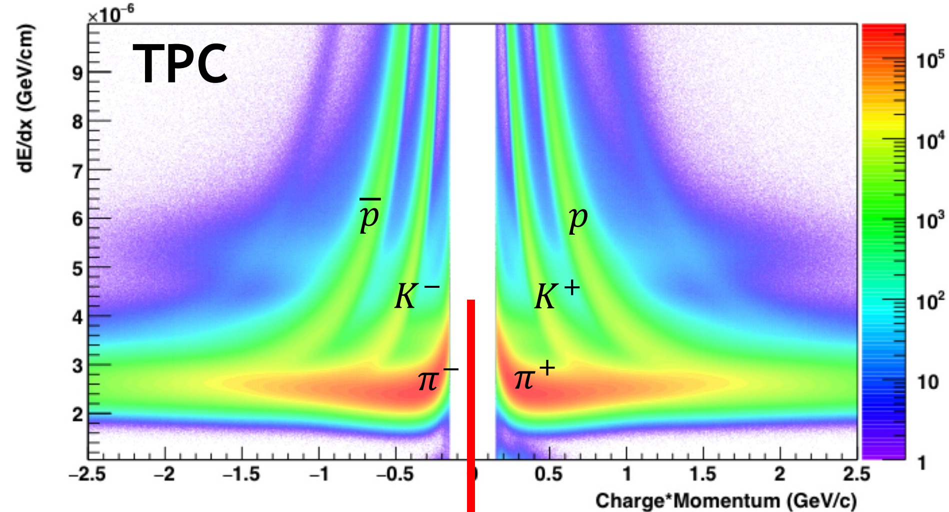
- Time resolution < 100 ps
- $1/\beta$ PID

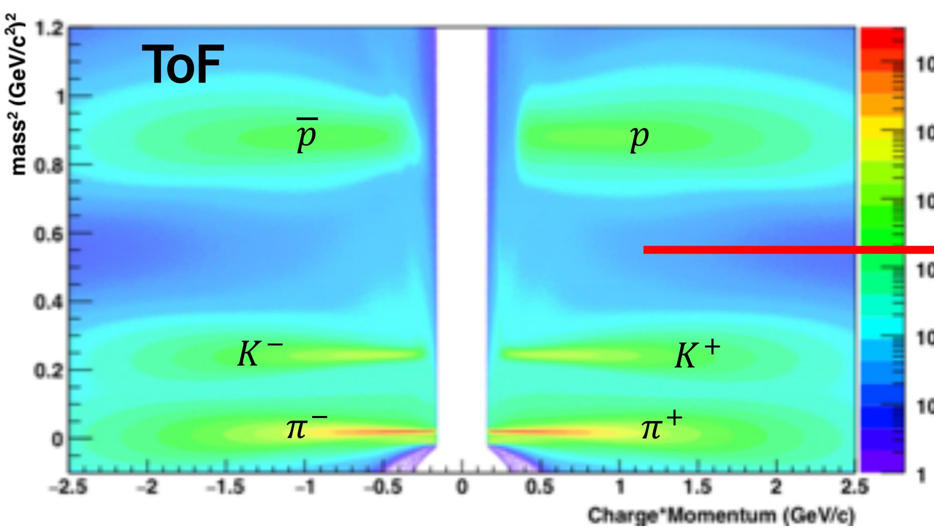
Data sample & Selection criteria

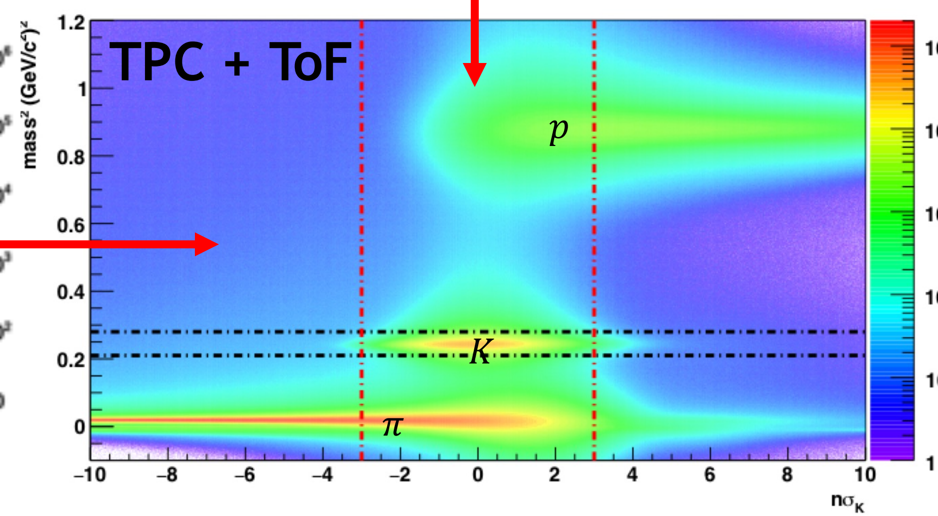
- Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV taken in 2011, used 300M events

Event cut
- Vertex z Position: $|V_Z| < 30$ cm
- Pile-up rejection: $\left|V_Z^{vpd} - V_Z^{TPC}\right| < 5$ cm

Kaon identification
- At midrapidity $|\eta| < 1$
- Using ToF and TPC information
- $0.15 < p < 1.55\ \mathrm{GeV}/c$
- TPC: $|n\sigma_{kaon}| < 3$
- ToF: $0.21 < m^2 < 0.28\ \mathrm{GeV}^2/c^4$





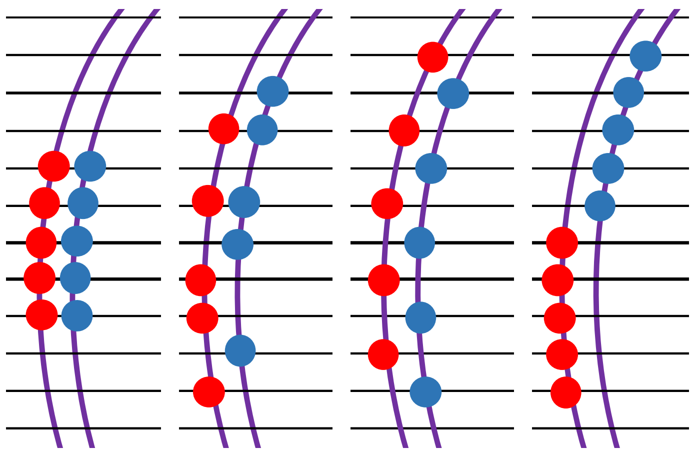


Extraction of correlation function

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



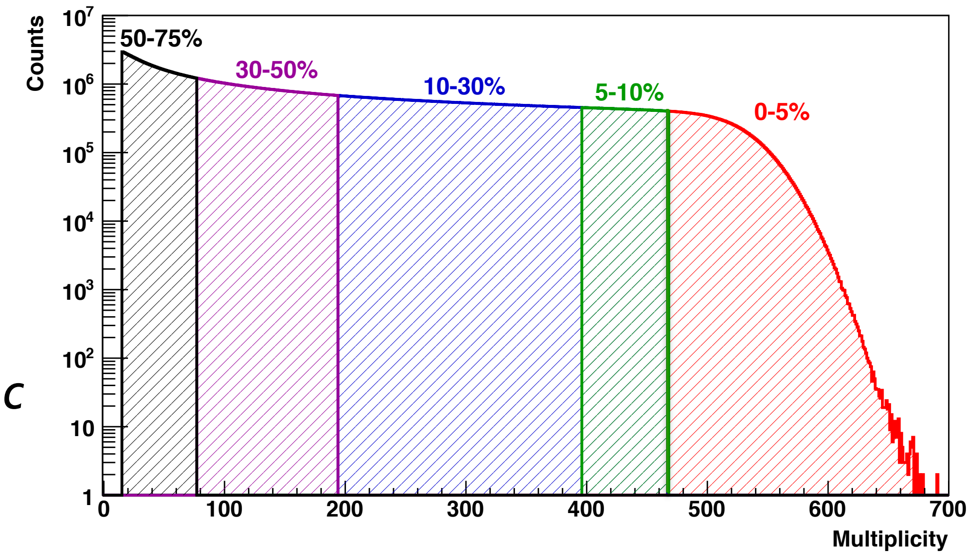
Event mixing

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

Binning

- 5 centralities: 0-5%, 5-10%, 10-30%, 30-50%, 50-75%
- 4 k_T: [0.05, 0.35], [0.35, 0.65], [0.65, 0.95], [0.95, 1.25] GeV/c

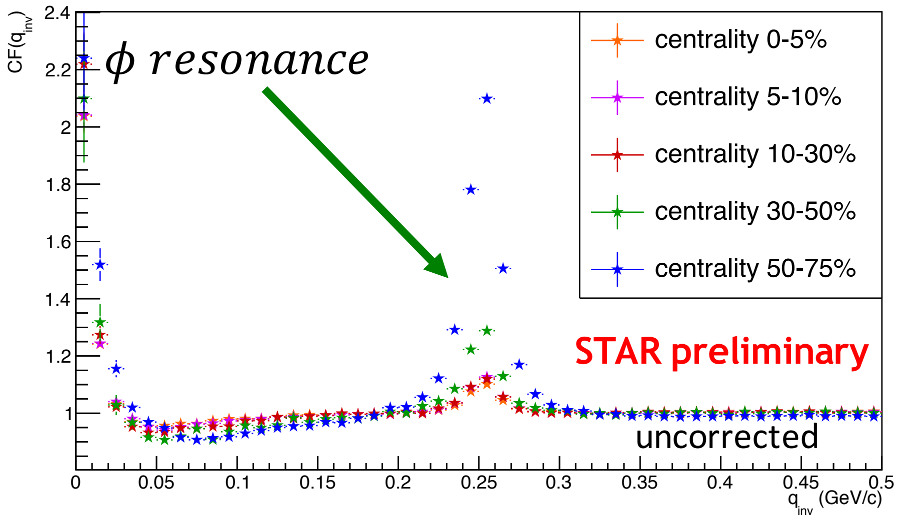
$$k_T = \left(\frac{\vec{p_1} + \vec{p_2}}{2}\right)_T$$



Unlike-sign 1D correlation function

Centrality dependence

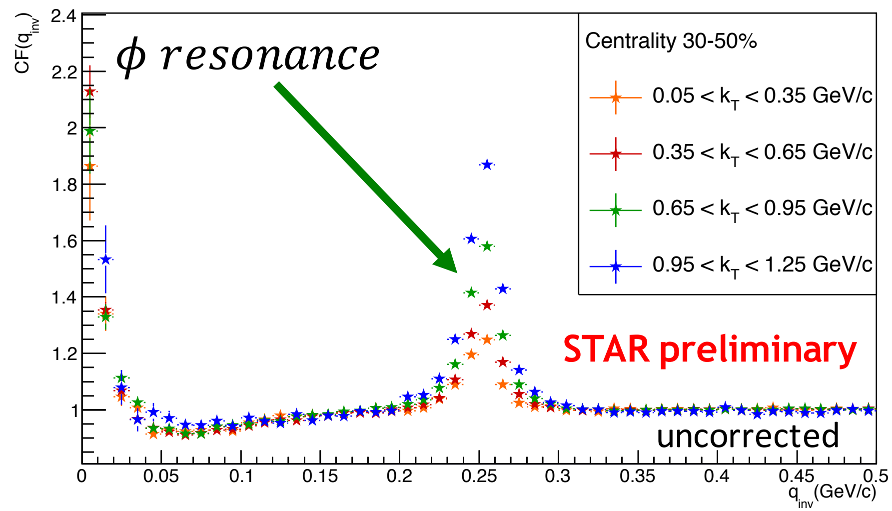
- Significant dependence is observed in $\phi(1020)$ region (CF are integrated over k_T)



k_T dependence

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

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



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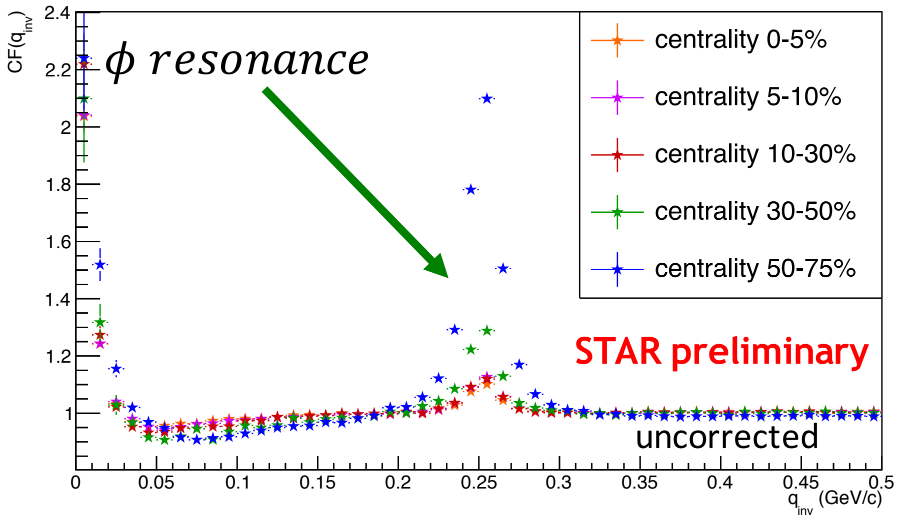
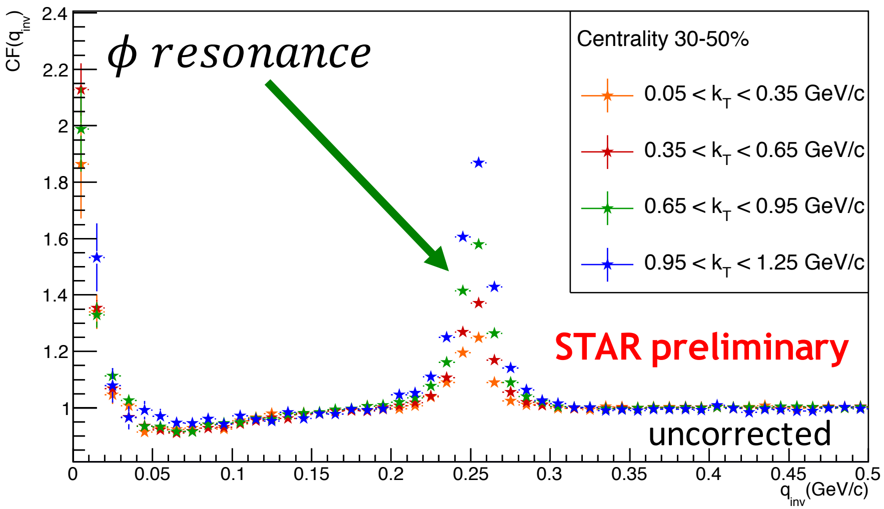




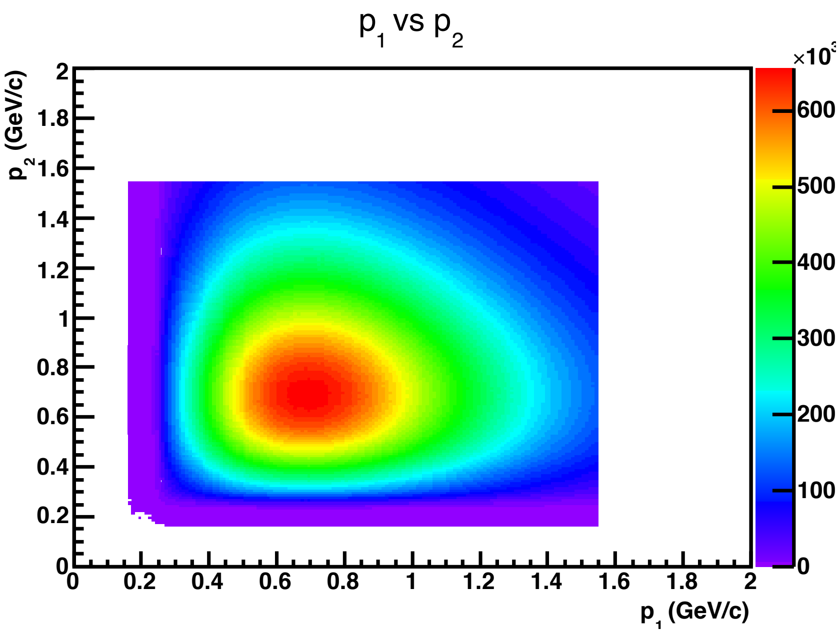
- In order to **compare** experimental correlation function to **theoretical predictions, the corrections are needed**
  - **Purity correction**
  - **Correction via λ parameter** from fitting **like-sign** correlation function

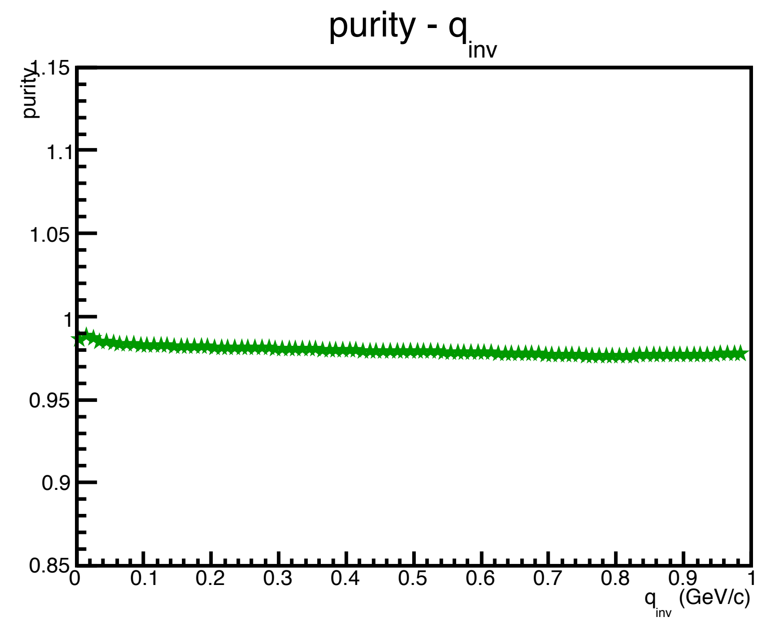
PairPurity correction

- Correction for misidentification of kaons
- Due to excellent tracking ability of STAR detector very high purity

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

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





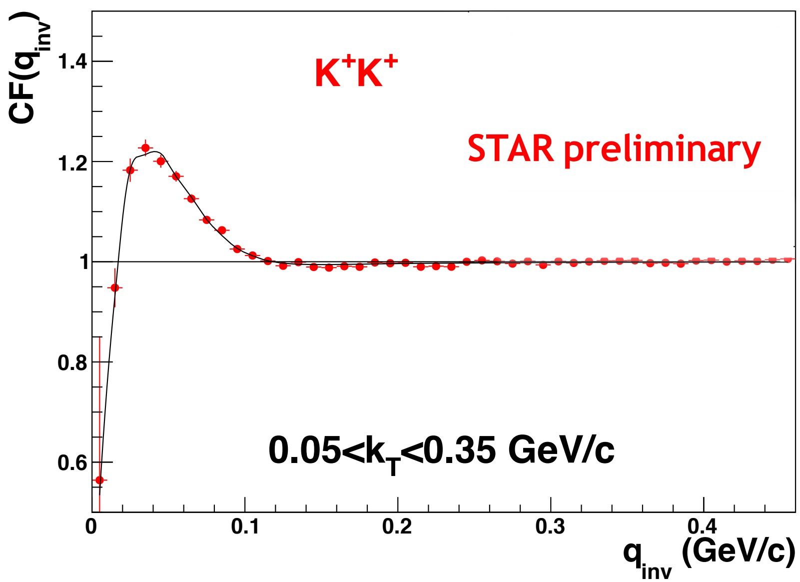
- PairPurity ~98% ➡ very small correction

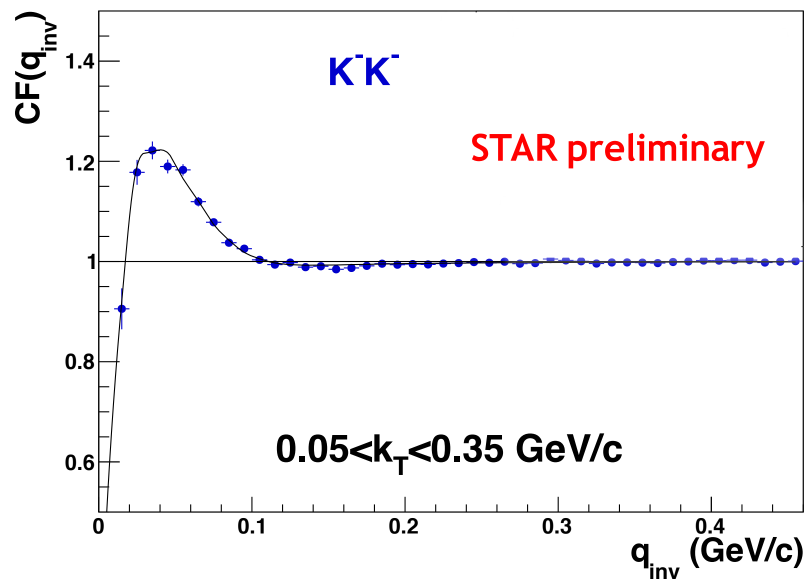
Like-sign 1D correlation function and fitting

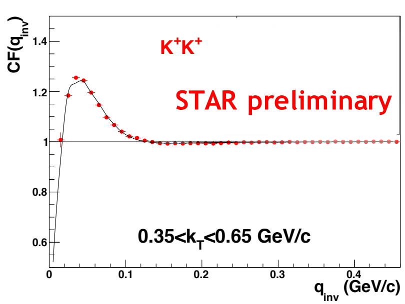
- Used for extraction of kaon emission source size R_{inv} and λ
- Fitting function: $CF(q_{inv}) = \left[(1-\lambda) + \lambda K(q_{inv}) e^{-R_{inv}^2 q_{inv}^2}\right]\mathcal{N}$,

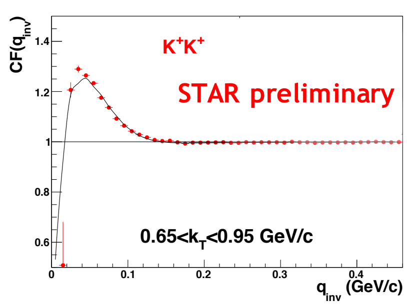
  where λ - correlation strength, $K(q_{inv})$ - Coulomb function and $\mathcal{N}$ - normalization

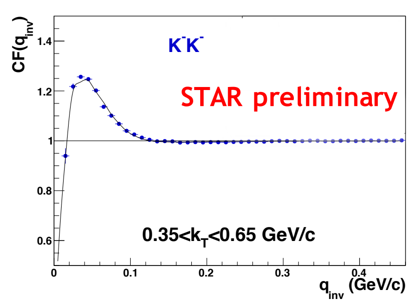
Centrality 30-50 %

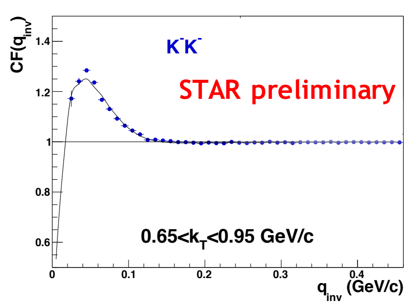




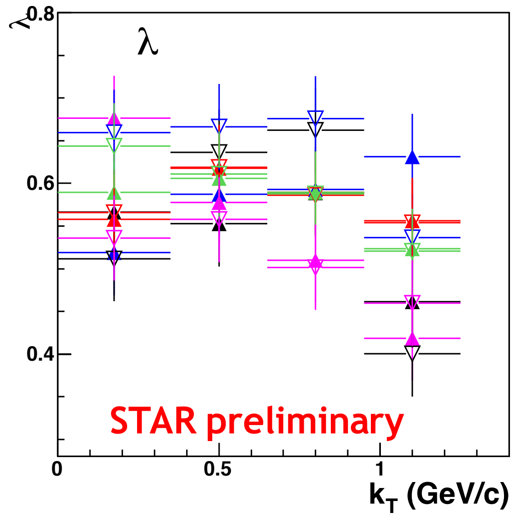






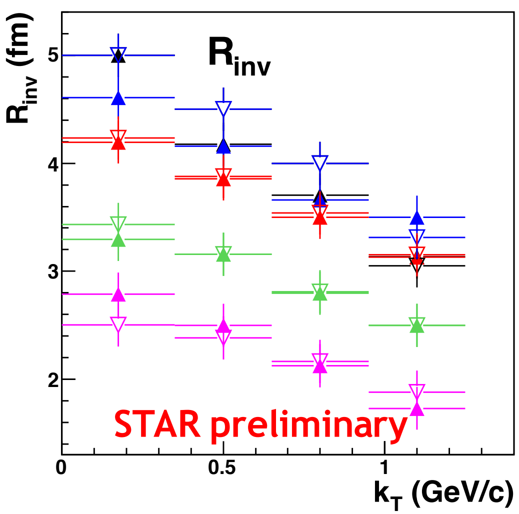


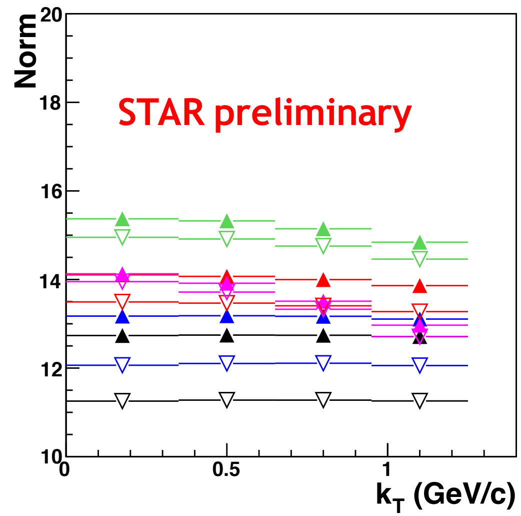
Like-sign 1D correlation function and fitting



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%



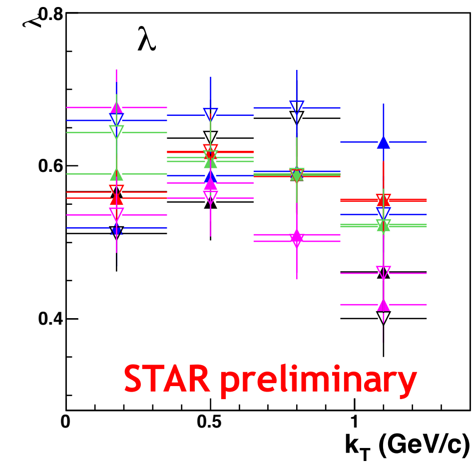


- λ, R_{inv} and normalization $\mathcal{N}$ are parameters of fit
- Uncertainty is dominated by systematic error, which is obtained by varying the fit range
- The source radii R_{inv} increase with the centrality and decrease with pair transverse momentum k_T

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

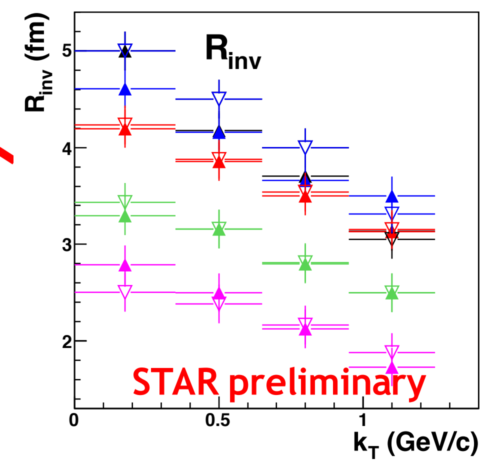
- **Lednicky model** includes the treatment of ϕ resonance due to the FSI as well as generalized smoothness approximation
  Lednicky: Phys.Part.Nucl. 40 (2009) 307-352

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



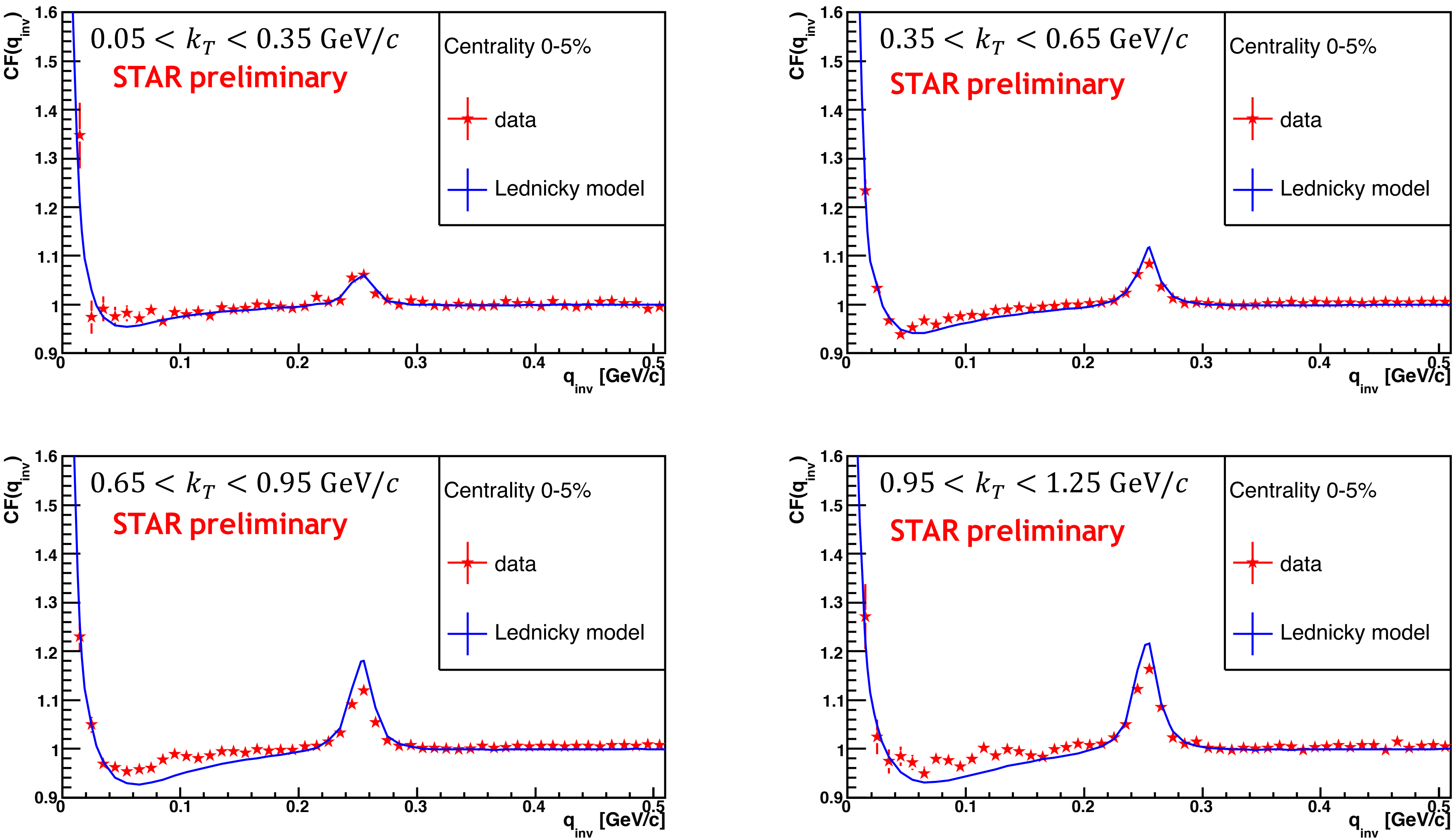
- Gaussian parameterization of source size – source size R_{inv} is extracted from fitting like-sign correlation function

- The theoretical function is transformed to a experimental one via:
  $CF^{exp} = (CF^{theor} - 1)\lambda + 1$,
  in order to compare to an experimental correlation function, which is corrected for impurities



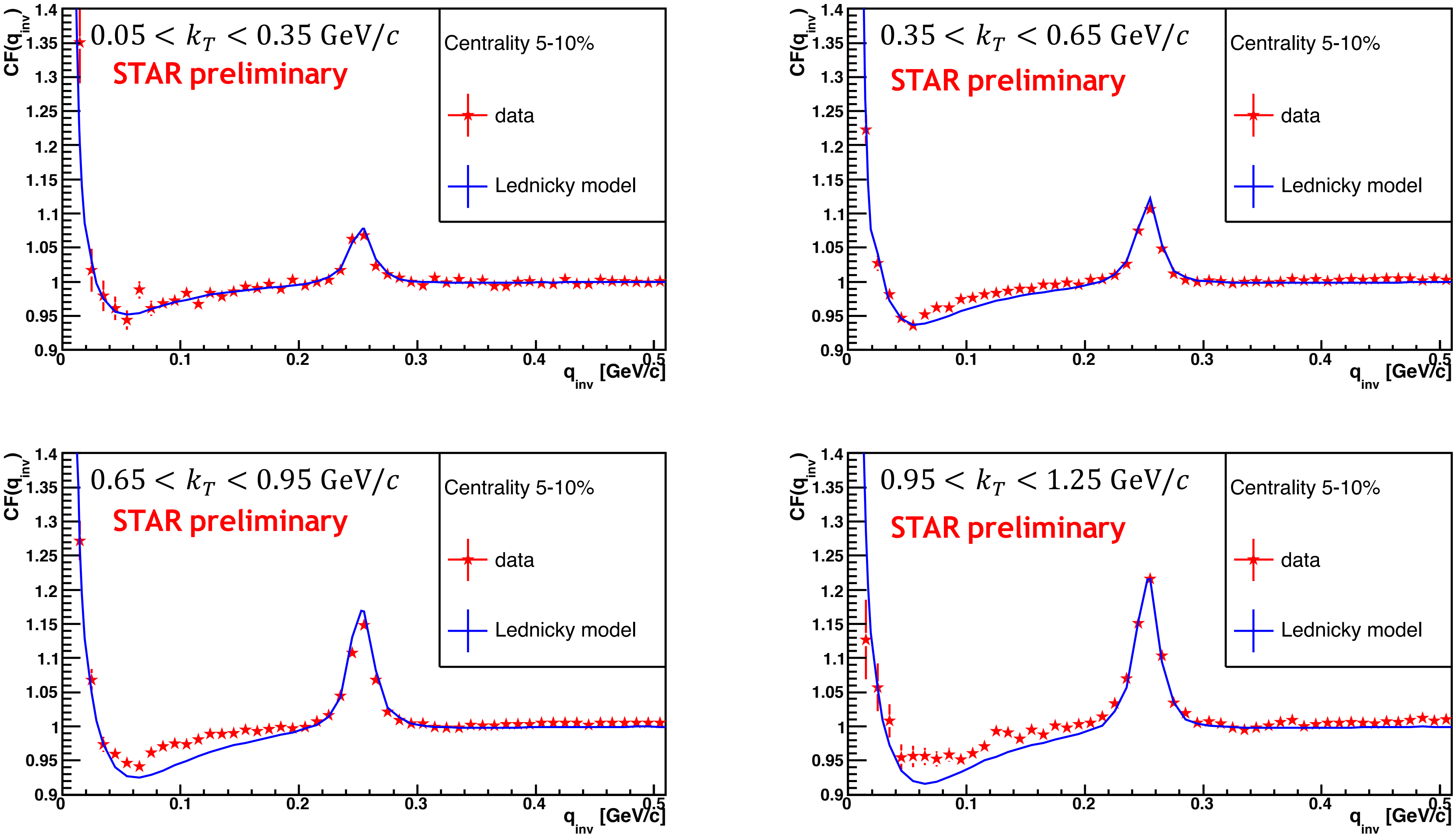
Comparison of unlike-sign 1D correlation function to Lednicky model

Centrality 0-5 %



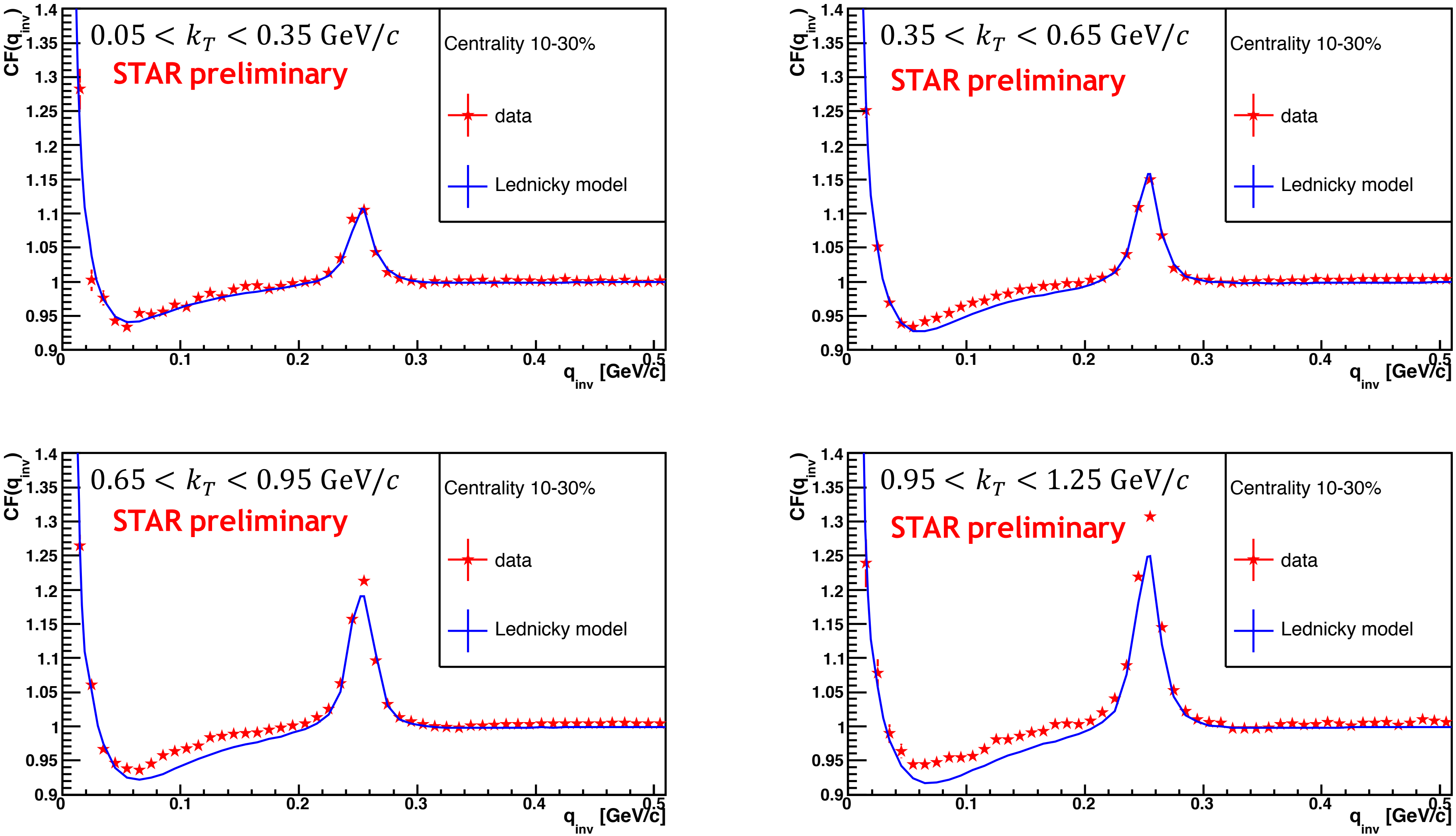
Comparison of unlike-sign 1D correlation function to Lednicky model

Centrality 5–10 %



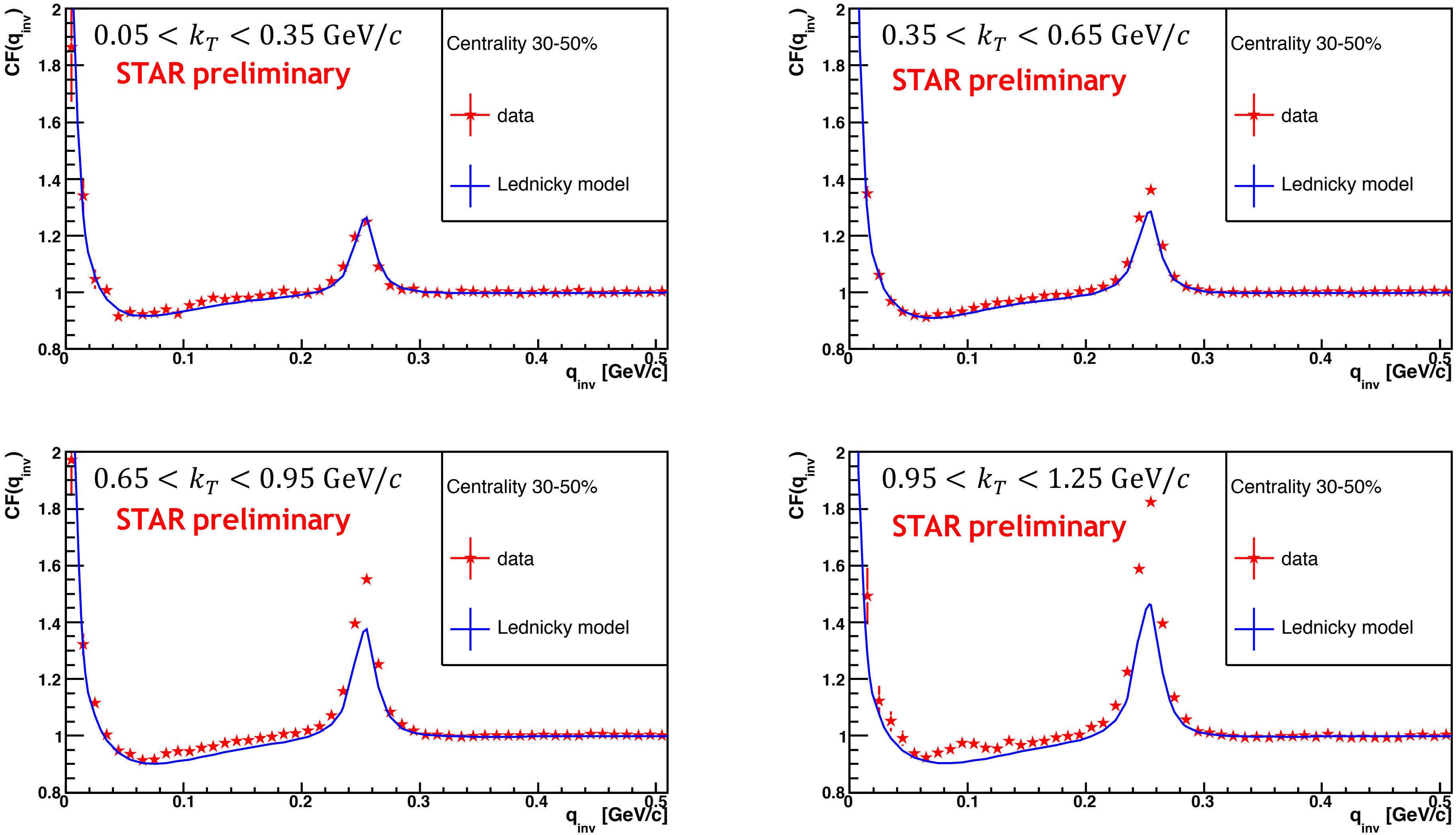
Comparison of unlike-sign 1D correlation function to Lednicky model

Centrality 10-30 %



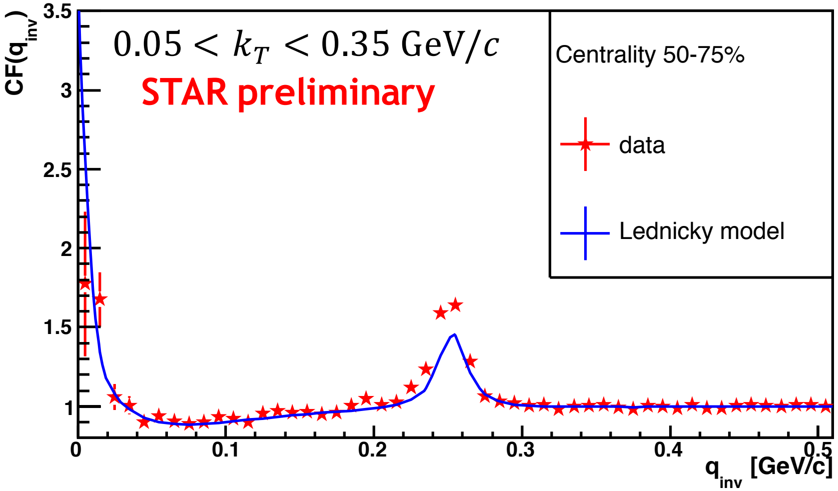
Comparison of unlike-sign 1D correlation function to Lednicky model

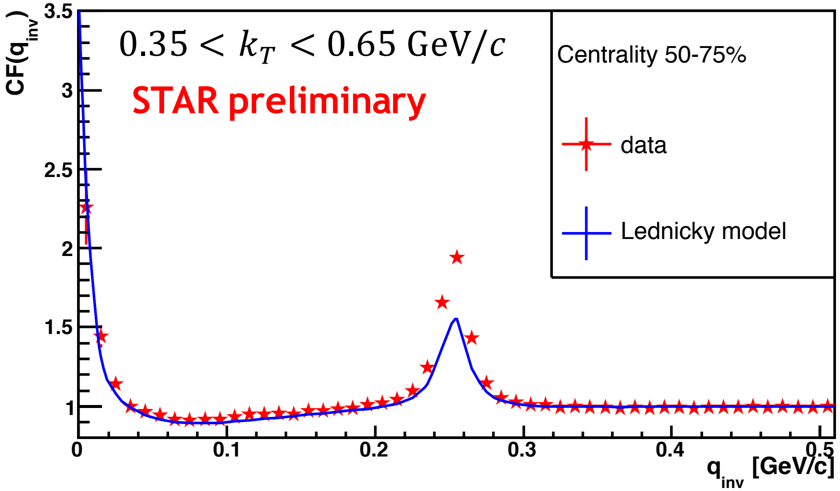
Centrality 30-50 %

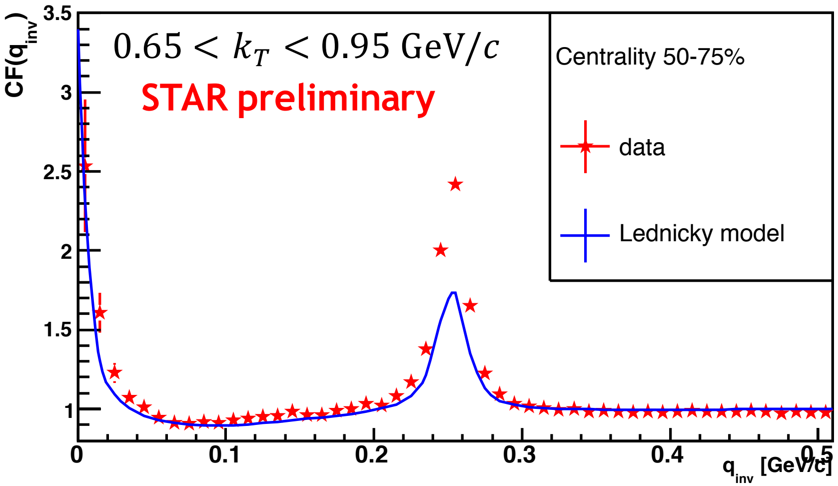


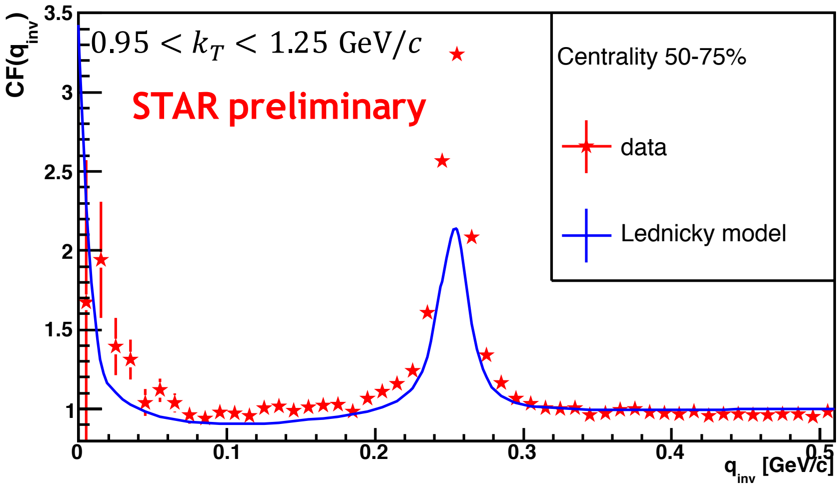
Comparison of unlike-sign 1D correlation function to Lednicky model

Centrality 50–75 %



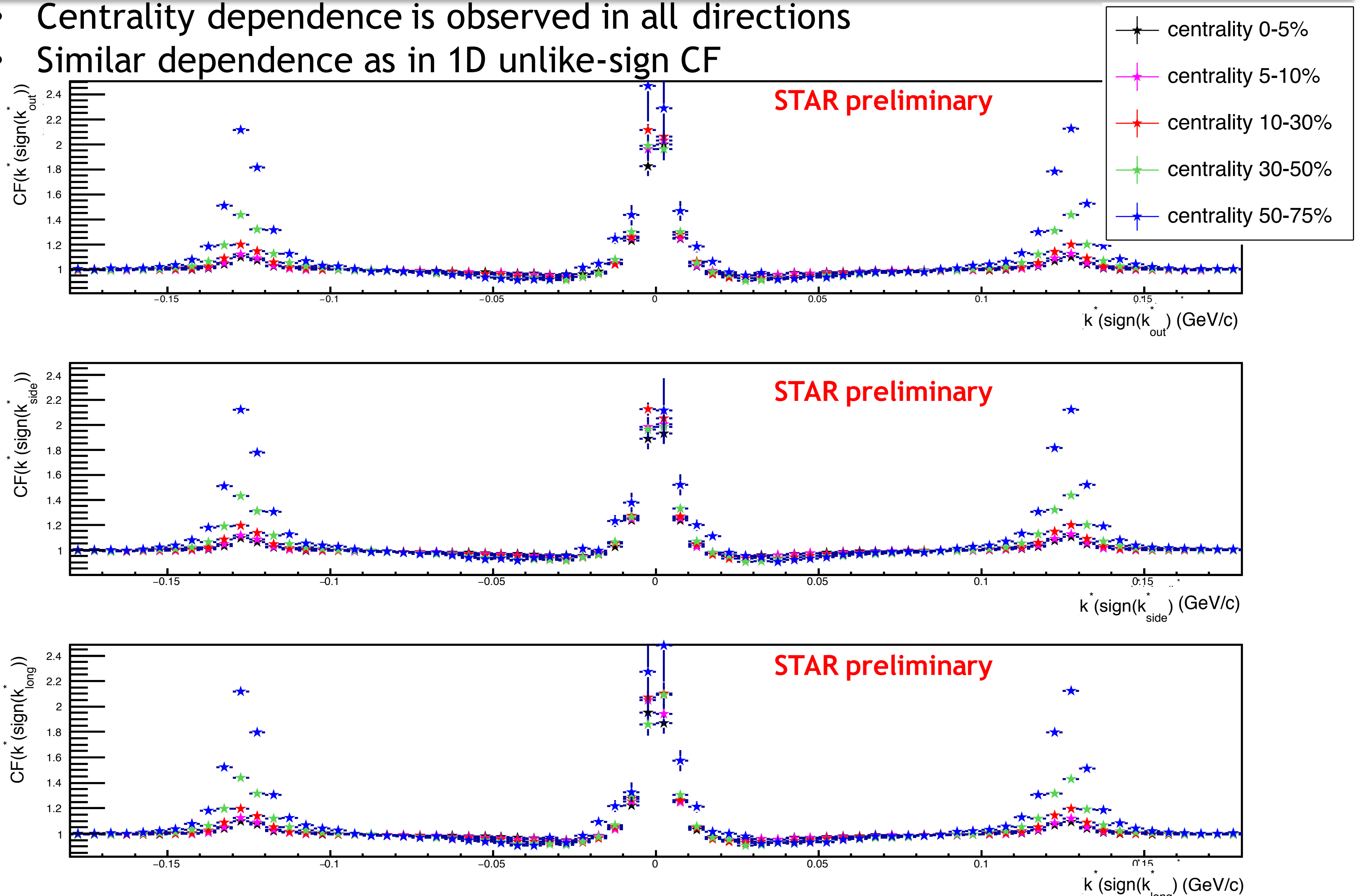






First look at 3D unlike-sign CF

- Centrality dependence is observed in all directions
- Similar dependence as in 1D unlike-sign CF



Conclusion

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

Extraction of λ parameter and source radii R_{inv} from like-sign CF in Au+Au collisions at 200 GeV

Comparison of unlike-sign correlation function 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.

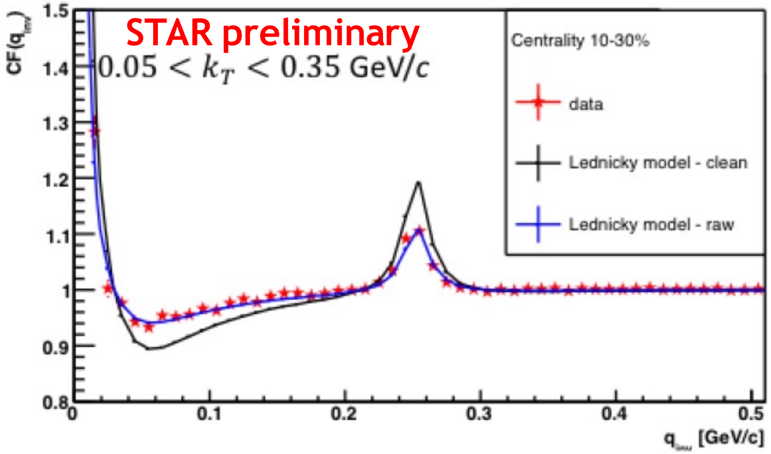
Thank you for your attention

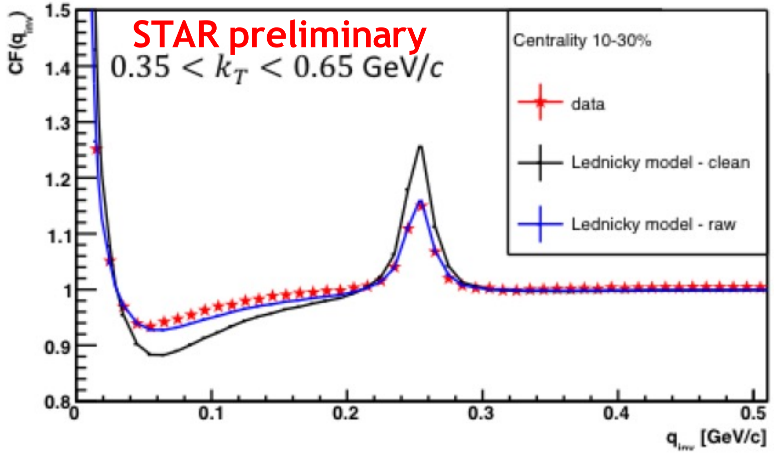
Back-up

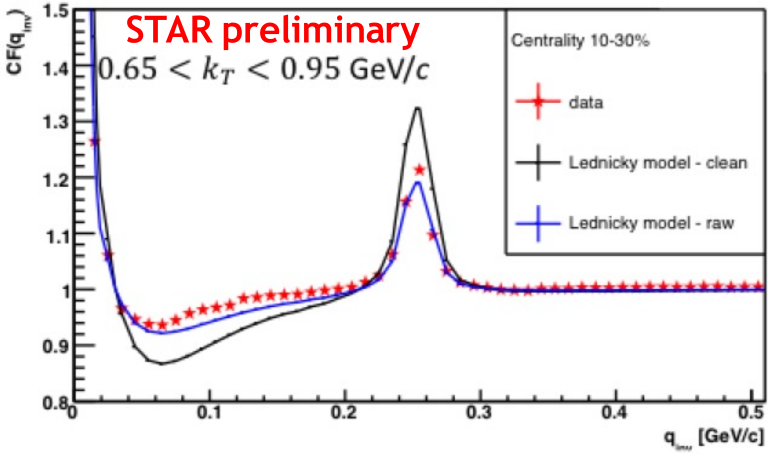
Back-up

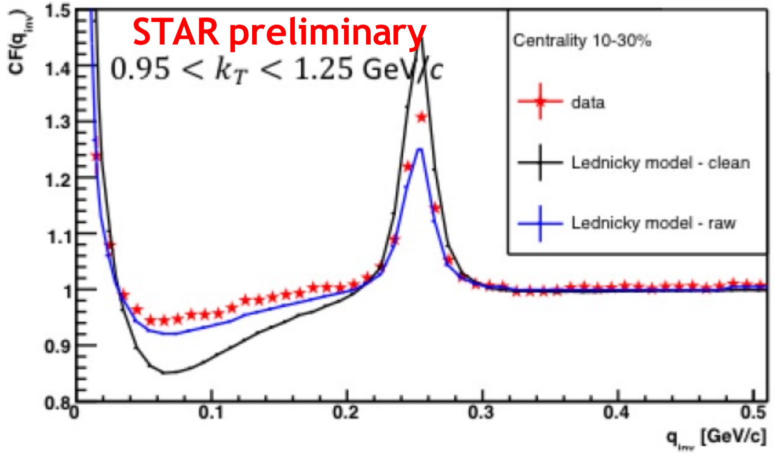
- The theoretical function is transformed to a experimental one via: $CF^{exp} = (CF^{theor} - 1)\lambda + 1$, in order to compare to an experimental correlation function

Centrality 10–30 %









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Centrality 30–50 %