Charged-kaon femtoscopy in $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions at STAR

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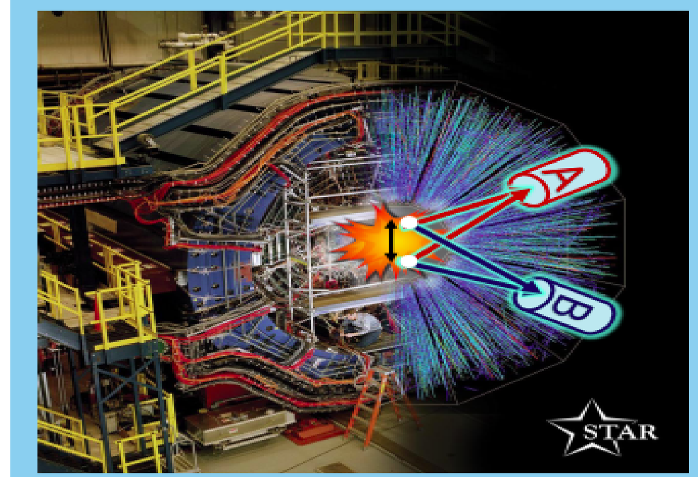
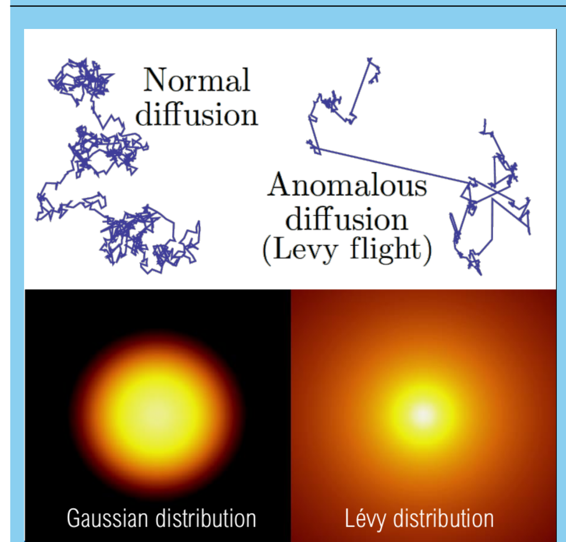
The STAR experiment at RHIC



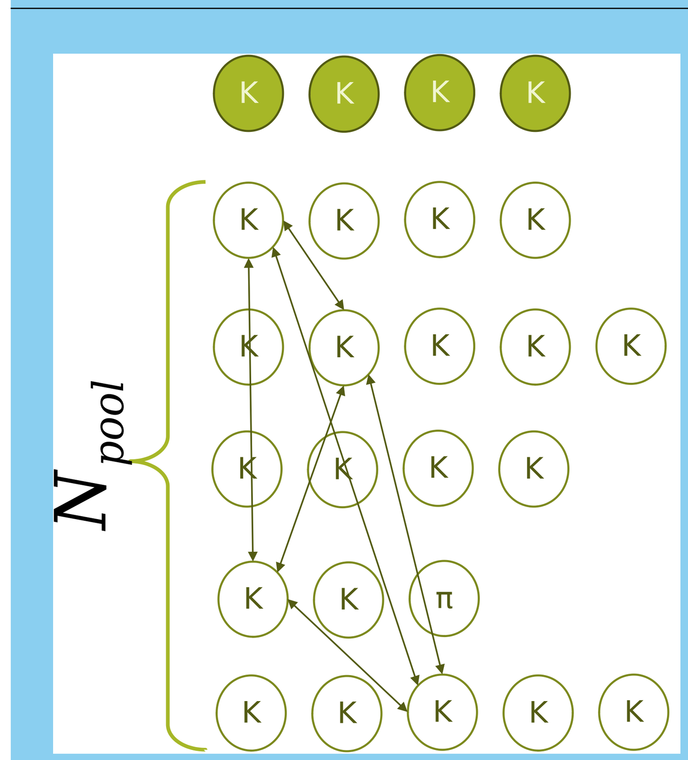
- STAR - Solenoidal Tracker At RHIC
- Colliding ^{238}U, ^{197}Au, ^{63}Cu, ^{96}Zr, ^{96}Ru, ^{27}Al, ^{3}He, d and p
- Multiple centre-of-mass energies ($\sqrt{s_{NN}}$) can be achieved for BES-I & BES-II
- Measurement: RHIC BES with Au+Au collisions at 200 GeV (2016)
- PID: dE/dx for K$^+$, K$^-$

Charged-kaon femtoscopy



- Momentum correlations of identical charged-kaon pairs → can map out source-geometry
- Momentum correlation $C(q) = 1 + \tilde{D}(q)$, where $\tilde{D}(q)$: Fourier transformed of pair source $D(r)$
- Usually assumed source shape for $D(r)$: Gaussian
- Generalization – Lévy distribution: $\mathcal{L}(r;\lambda,R) = \frac{1}{2\pi}\int_{-\infty}^{\infty} e^{-(RQ)^\alpha} e^{iQr} dQ$
- R: Lévy-scale, λ: correlation strength, α: Lévy-exponent, Q: integration variable
- $\alpha = 2$: Gaussian; $\alpha < 2$: power-law; $\alpha = 1$: Cauchy
- Possible reasons for non-Gaussian sources:
  - Proximity to CEP[1]: not relevant at 200 GeV
  - Jet fragmentation[2]: not relevant in A+A collisions
  - Anomalous diffusion[3,4]: possible in A+A at 200 GeV

Measurement methodology



- Momentum (q) measured in Longitudinally Co-Moving System: $q_{LCMS} = |\vec{p}_1 - \vec{p}_2|_{LCMS}$
- Spherical symmetry in q_{LCMS} ideal for 1D analysis of 3D system
- $A(q)$ - kaon pairs from actual (same) event
- $B(q)$ - kaon pairs from mixed event
- Mixed event created by randomly selecting kaon-pairs from pool
- $C(q)$ - correlation function = $A(q)/B(q)$
- 3 m_T bins used – $m_T = \sqrt{m^2 + (k_T/c)^2}$
- Lévy-type corr. func.: $C(q) = 1 + \lambda \cdot e^{-(Rq)^\alpha}$

References

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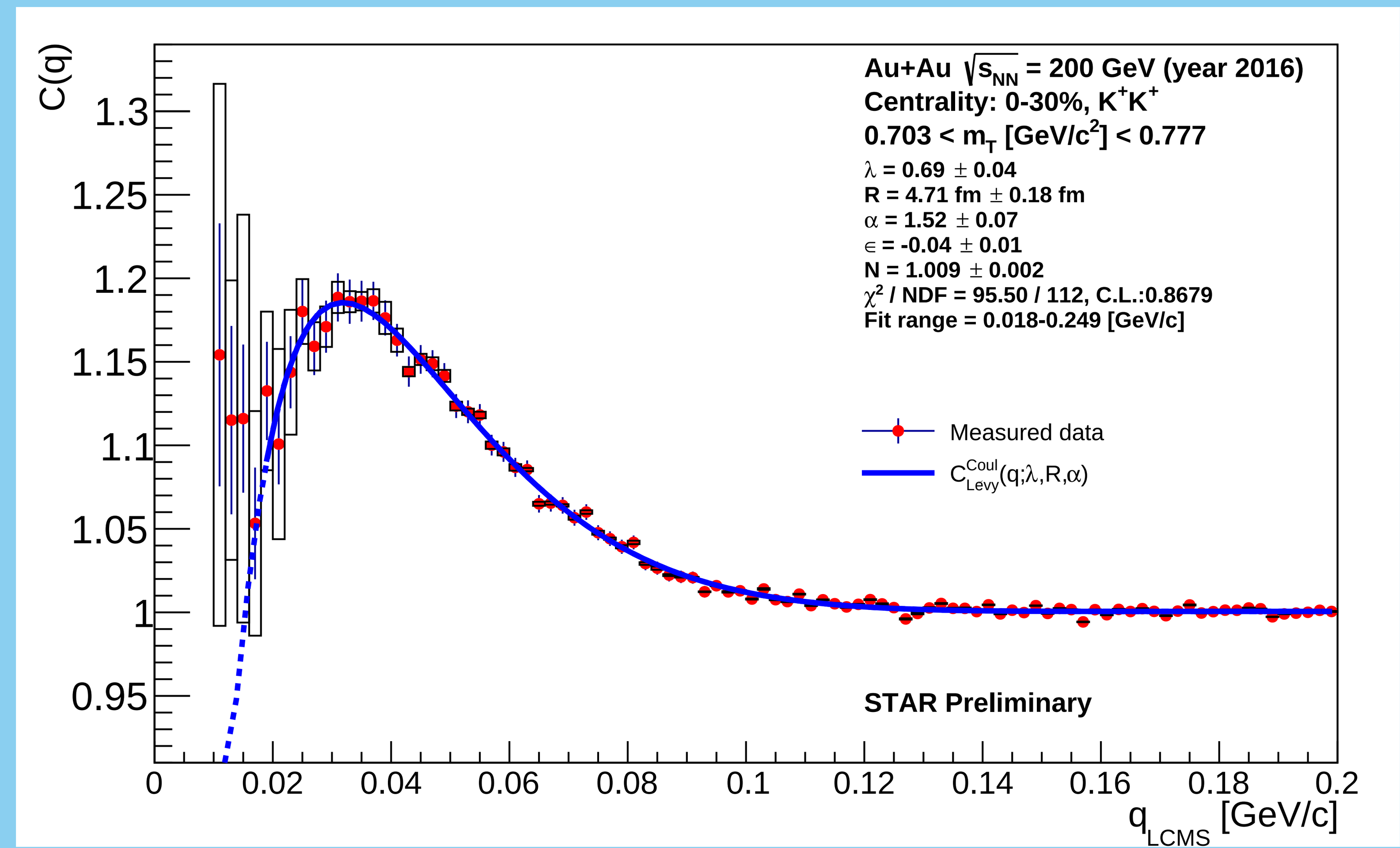
Correlation function

- Correlation function shows Bose-Einstein-peak and Coulomb-hole



- Measured $C(q)$ agrees quantitatively with best-fit Lévy func. over entire q-range

Lévy fitting

- Bowler-Sinyukov formula[6] for like-sign kaons experiencing Coulomb repulsion:

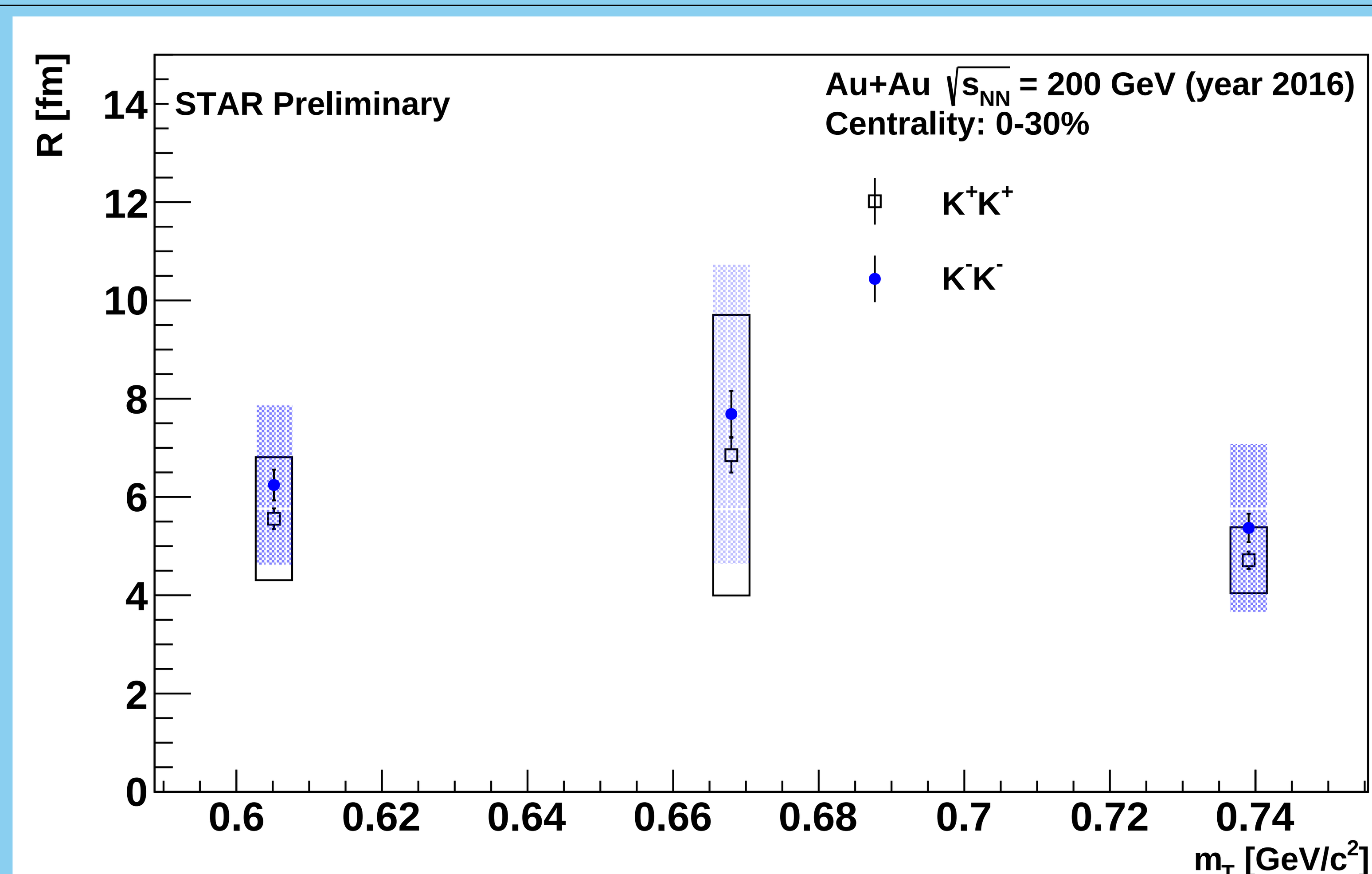
$$C(q) = \left[1 - \lambda + \lambda \cdot K(q) \cdot (1 + e^{-(Rq)^\alpha})\right] \cdot N \cdot (1 + \varepsilon q)$$

- assumed linear background: $N \cdot (1 + \varepsilon q)$
- Coulomb correction[8]:

$$K(q;\alpha,R) = \frac{\int D(r)|\psi^{\text{Coul}}(r)|^2 dr}{\int D(r)|\psi^0(r)|^2 dr} \rightarrow \text{calculated numerically}$$

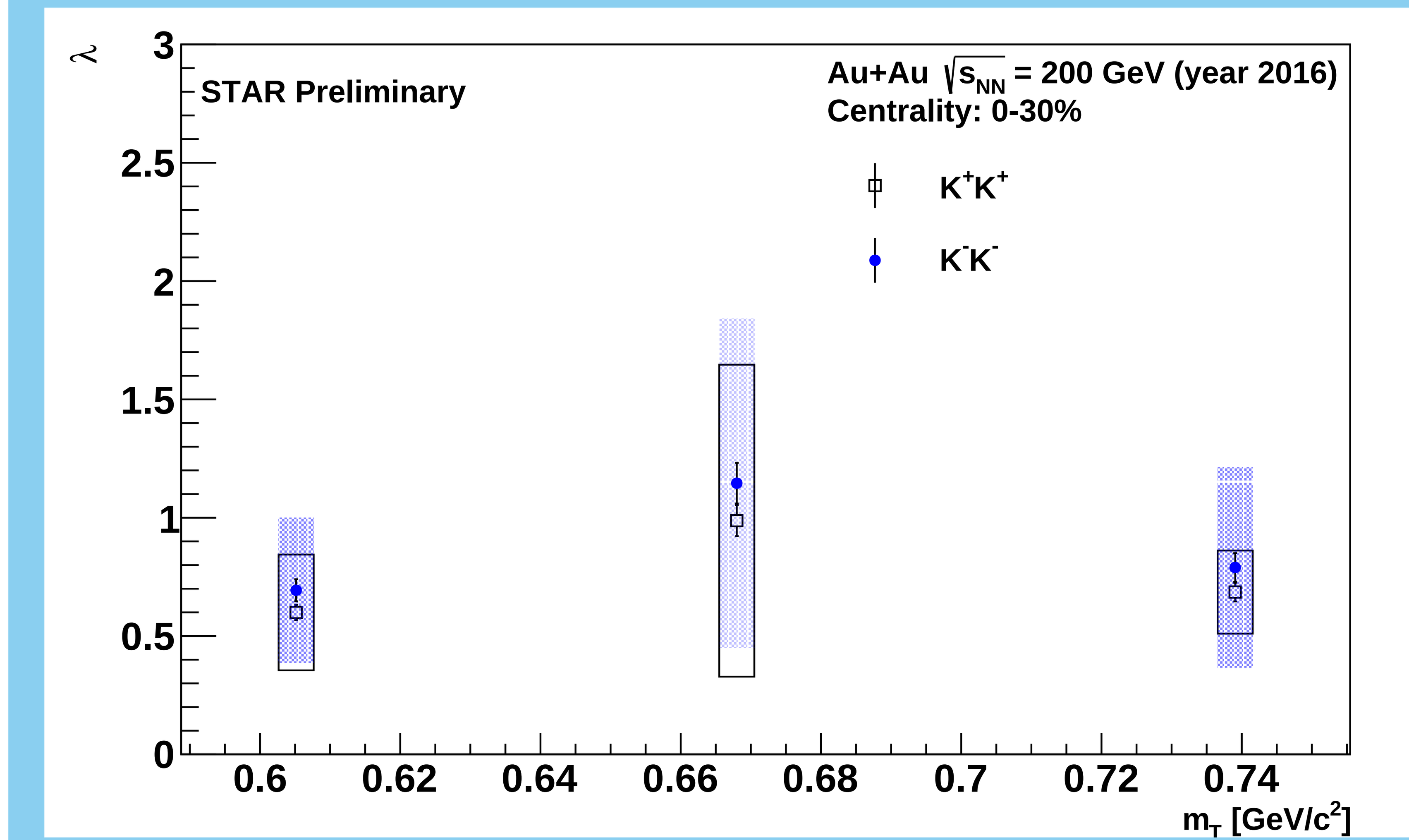
- $D(r)$: spatial pair-distribution, ψ^0: 2-particle, plane-wave, ψ^{Coul}: Coulomb-wave

Lévy-scale R



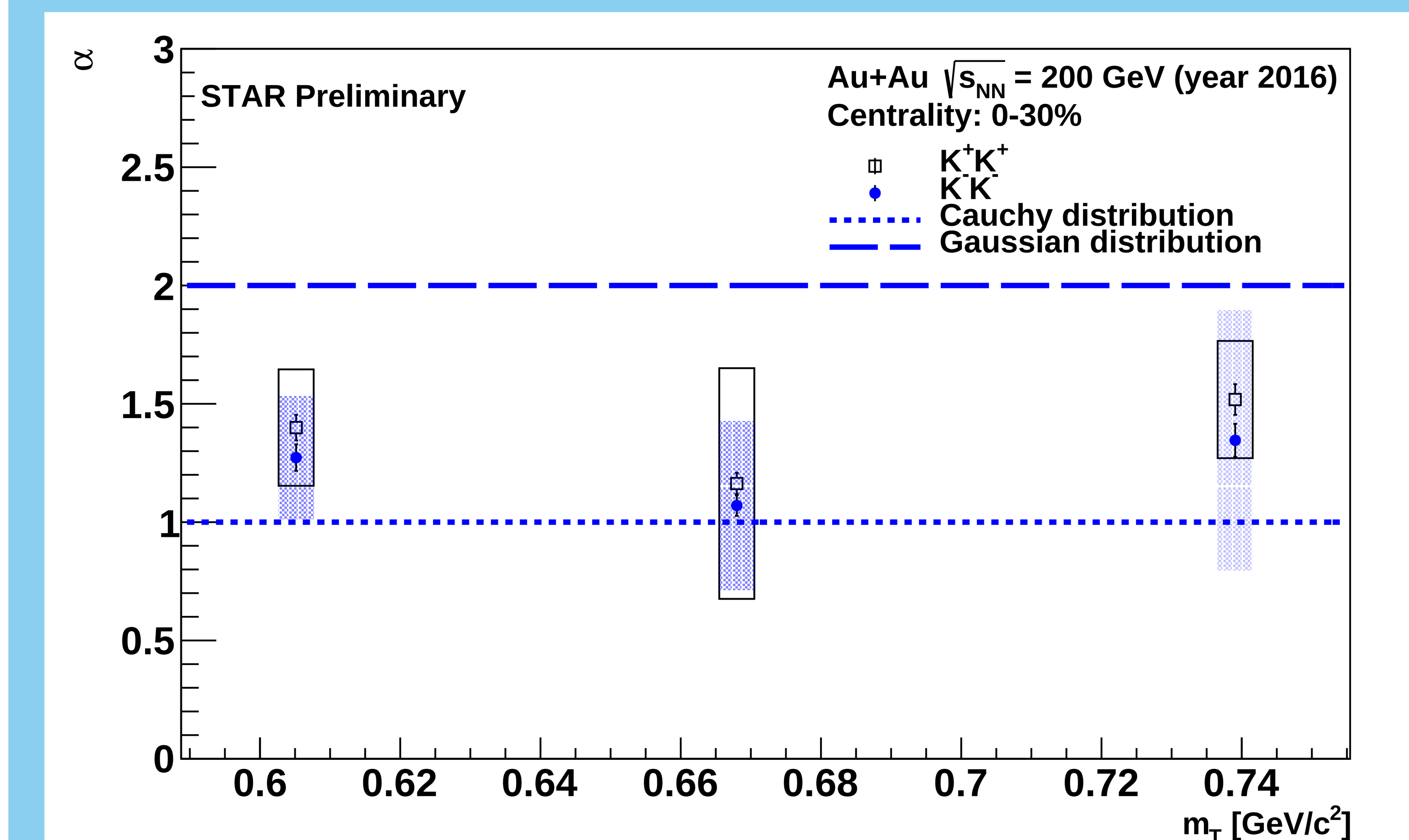
- Kaon-homogeneity length: very weak dependence on m_T – large uncertainties
- Possible slight decrease → not contradicting hydro predictions
- Comparable to PHENIX π data at same m_T[5]: $R_\pi(m_T{=}0.6{-}0.7\ \text{GeV}/c^2) \approx 5{-}7$ fm

Correlation strength λ



- Intercept of correlation function → Core-Halo model[7]: $\lambda = N_C/(N_C + N_H)$
- Values close to unity, in line with expected small fraction of decay-kaons

Lévy-exponent α



- May describe extent of anomalous diffusion
- $\alpha \approx 1.0 - 1.5$ for kaons, similar to PHENIX pion results[5]: $\alpha_\pi \approx 1.2$
- Suggesting non-Gaussian source for charged kaons, similar to pions

Summary

- Preliminary analysis suggests a non-Gaussian source for K$^\pm$K$^\pm$ pairs.
- Lévy-stability exponent α comparable to that of pions.
- A full systematic uncertainty analysis required to achieve definitive conclusions.
- Similar measurements at lower $\sqrt{s_{NN}}$ would be interesting as probes for CEP.

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The STAR Collaboration
https://drupal.star.bnl.gov/STAR/presentations

Analysis details

Event processing

- STAR's PicoDST file-storage has 3.06 billion events from the 2016 RHIC beam-energy scan (BES) at 200 GeV.
- Trigger cuts (VPD, TPC etc.) are applied, which bring the no. of events down to 2.59 billion.
- The 0-30% centrality cut further reduces the events to 776 million.
- Out of these, 52.8% have been processed, *i.e.*, they have provided the particle-tracks for the analysis.

Calculating correlations

Track processing

- Tracks are read in and cut (PID check, etc.), following which pair-correlations amongst particles from the same event are calculated as functions of $q_{\mathrm{LCMS}} = \sqrt{(p_{1x} - p_{2x})^2 + (p_{1y} - p_{2y})^2 + q^2_{\mathrm{long,LCMS}}}$ to obtain $A(q)$.
- The pair cuts - FMH, SL & $\Delta z - \Delta u$ are applied at this stage.
- Particles from the current event are stored in a background pool and event-mixing is performed by randomly selecting particles from stored events.
- Over-weighting of events is avoided by selecting only one particle from one background event.
- In the mixed event thus created, pair-correlations are calculated - after applying the pair cuts again - to obtain $B(q)$. The ratio of $A(q)$ & $B(q)$ gives $C(q)$.
- $C(q)$ is fit with the Coulomb-corrected Lévy function: $\left[1 - \lambda + \lambda \cdot K(q) \cdot (1 + e^{-|Rq|^\alpha})\right] \cdot N \cdot (1 + \varepsilon q)$.
- The Coulomb correction, $K(q; \alpha, R)$, is calculated numerically.
- Finally, the resulting fit parameters - R, λ & α - are extracted and plotted; along with their systematic uncertainties.

Coulomb's correction & linear contribution

- Coulomb correction: $K(q;\alpha,R)=\frac{\int D(r)|\psi^{\mathrm{Coul}}(r)|^2dr}{\int D(r)|\psi^0(r)|^2dr}$
- For $D(r), r=$ spatial separation,
  obtained from $S(x), x=$ spatial location
- $S(x)$: phase-space density of emitter, obtained from Core-Halo model as:
  $S(x,p)=S_{\mathrm{Core}}(x,p)+S_{\mathrm{Halo}}(x,p)$
- Linear background: $N\cdot(1+\varepsilon q)$
- $N\approx 1$ from fitting
- $\varepsilon\approx 0$ from fitting
- Linear contribution negligible