Charged kaon femtoscopy with Lévy sources in $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions at PHENIX

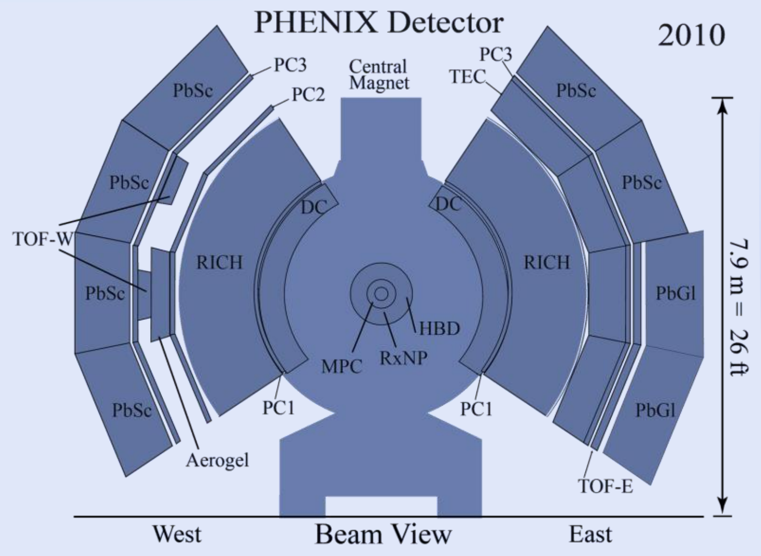
László Kovács (Eötvös University, Budapest), for the PHENIX Collaboration

Abstract

The PHENIX experiment measured two-particle Bose- Einstein quantum-statistical correlations of charged kaons in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV collision. The correlation functions are parametrized assuming that the source emitting the particles has a Lévy-shape, characterized by the α Lévy exponent and the R Lévy scale. By introducing the λ intercept parameter we account for the core-halo fraction. The parameters are investigated as the function of transverse mass. The comparison of the parameters measured for charged kaons to those measured from pion-pion correlation may clarify the connection of Lévy parameters to physical processes.

Measurement details

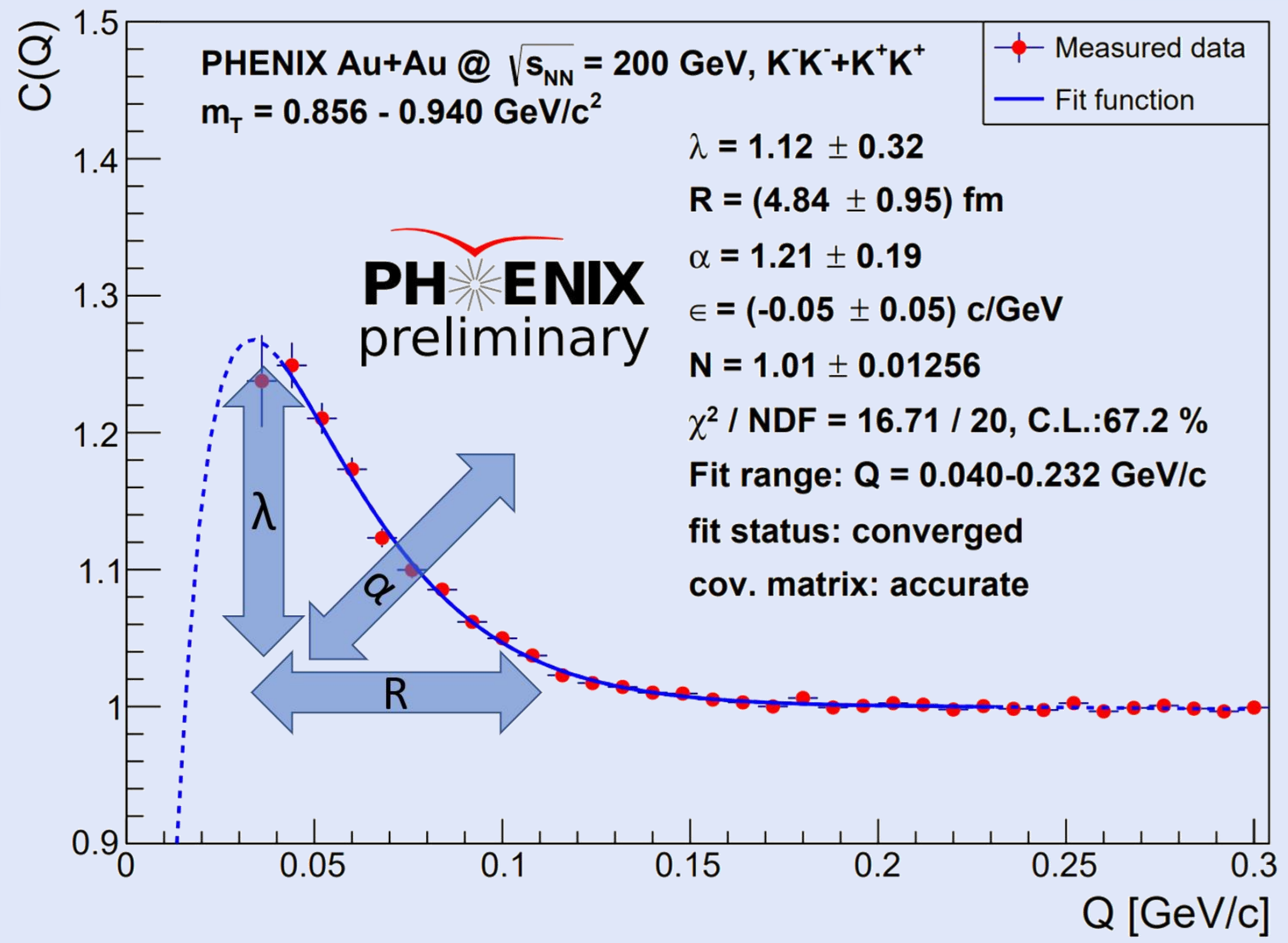
- Used dataset:
  PHENIX
  200 GeV Au+Au
  7.3 billion events
  MinBias data
- Pair distributions measured
- Bose-Einstein correlation function:
  actual / background pair distribution
- Background pair distributions: event mixing
- PID cuts: 2.5σ for K, 2.5σ veto for π
- Two track cuts to rule out merging and splitting
- Final state Coulomb interaction calculated for kaons



Bose-Einstein correlation function with Lévy source

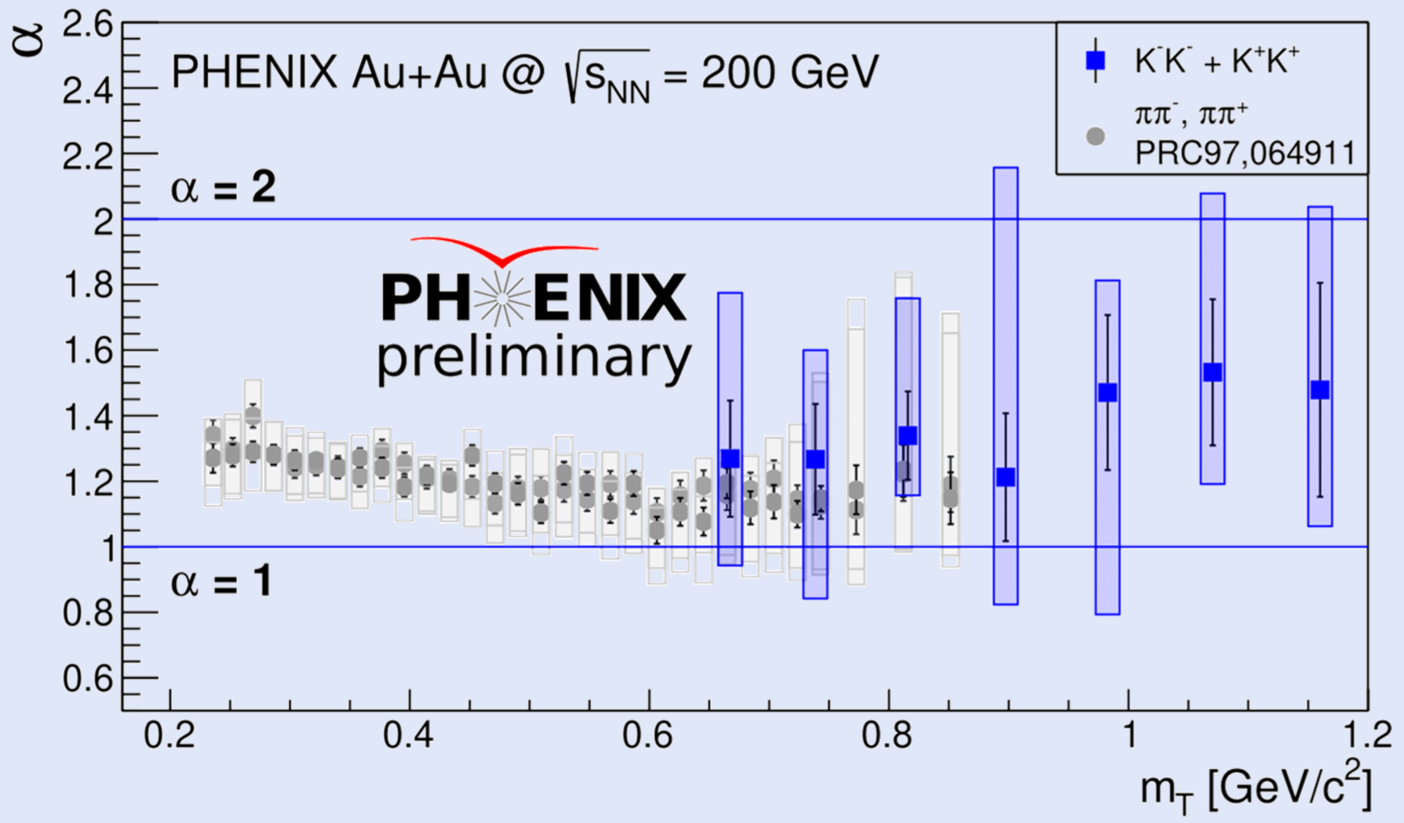
- Lévy-shaped *S(x,p)* particle emitting source assumed, generalization of Gaussian:
  $\mathcal{L}(\alpha, R; \boldsymbol{x}) = (2\pi)^{-3}\int d^3\boldsymbol{q} e^{i\boldsymbol{q}\boldsymbol{x}} e^{-\frac{1}{2}|\boldsymbol{q}R|^{\alpha}}$, Gaussian: $\alpha = 2$, Cauchy: $\alpha = 1$
- Correlation function given with invariant momentum distribution $N_1(p)$:
  $C_2(p_1,p_2) = \frac{N_2(p_1,p_2)}{N_1(p_1)N_1(p_2)}$, where $N_1(p) = \int S(x,p)|\Psi(x)|^2\, d^4x$
  and $N_2(p_1,p_2) = \int S(x_1,p_1)S(x_2,p_2)|\Psi_{p_1-p_2}(x_1-x_2)|^2\, d^4x_1 d^4x_2$ [1]
- If source Lévy and $p_1 \approx p_2 \approx K = (p_1+p_2)/2$, then $C_2(q,K)$ defined as [2]:
  $C_2(q,K) \cong 1 + \left|\frac{\tilde{S}(q,K)}{\tilde{S}(0,K)}\right|^2$, where $q = p_1 - p_2$, $\tilde{S} = \int e^{iqx} S(x,K)$
- Correlation function can be expressed as a function of Q [3]:
  $Q = |q_{LCMS}|$, where q is measured in the Longitudinal Co-Moving System $C_2(Q) = 1 + \lambda e^{-|QR|^{\alpha}}$, with Coulomb: $C_2(Q) = 1 - \lambda + \lambda \cdot K_C(Q) \cdot (1 + e^{-|QR|^{\alpha}})$

Example fit



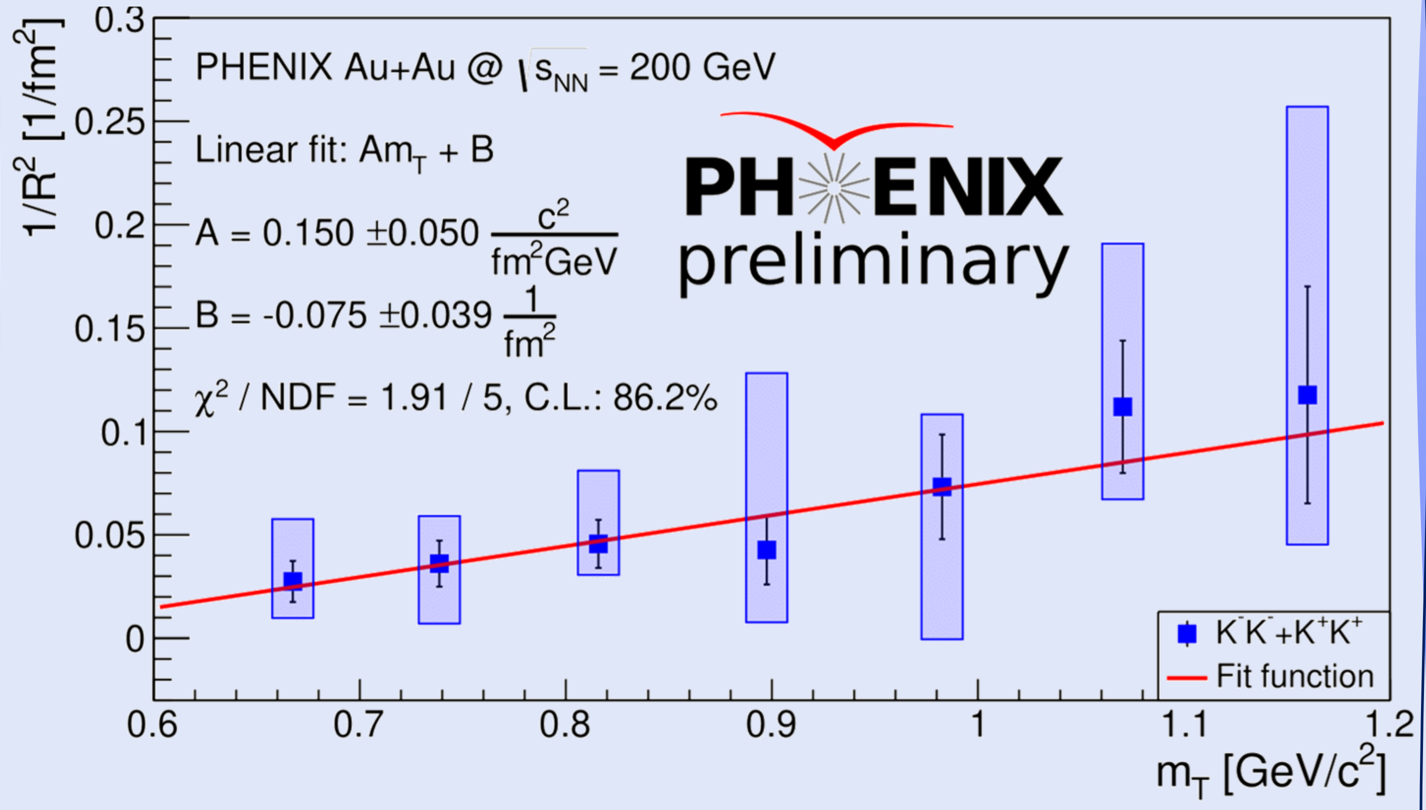
- Correlation functions measured in 7 m_T bins
- Linear background $N\cdot(1+\epsilon Q)$ assumed
- Fit is acceptable if:
  - Confidence level is at least 0.1%
  - The fit status converges
  - Covariance matrix is accurate
- λ: correlation strength
- α: Lévy shape parameter
  - determined by anomalous diffusion?
- R: Lévy scale parameter
  - related to the width of the corr. func.
  - not the same as Gaussian radius, RMS
  - hydro scaling behavior [4]: $R \sim 1/\sqrt{m_T}$?

α: Lévy shape parameter



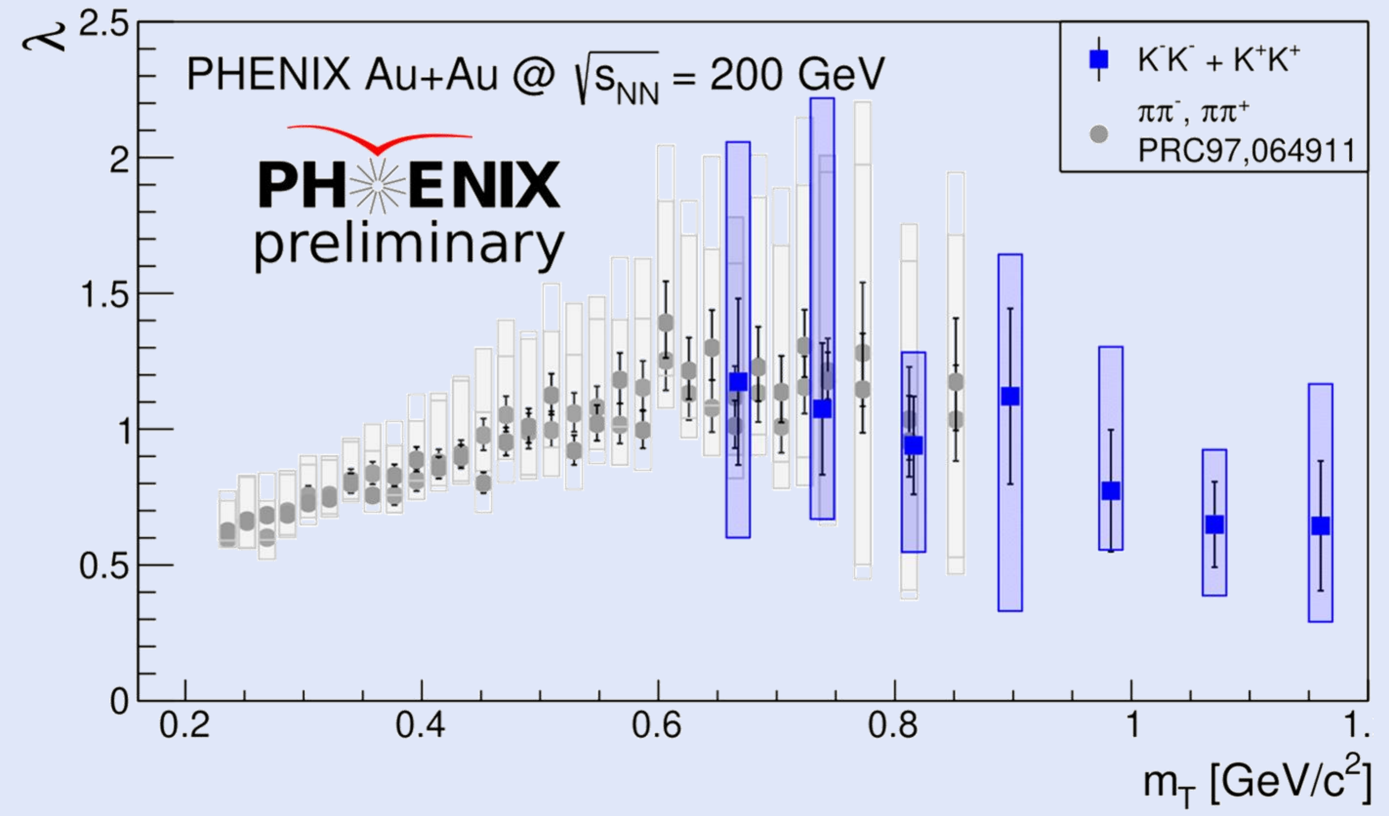
- Does not exhibit strong dependence on transverse mass
- $K^{\pm}$ α consistent with $\pi^{\pm}$, weak $\alpha(K^{\pm}) > \alpha(\pi^{\pm})$ indication
- Anomalous diffusion suggests $\alpha(K^{\pm}) < \alpha(\pi^{\pm})$ [5]

R: Lévy scale



- Linear scaling of $1/R^2$ predicted for Gaussian radii by hydro
- $R_{Lévy}$ shows the same behaviour

λ: correlation strength



- Core-halo ratio: $\lambda = [N_{\mathrm{core}}/(N_{\mathrm{core}} + N_{\mathrm{halo}})]^2$
- Slight decrease with m_T, maybe due to worsening PID

Summary

- Lévy source fit of Bose-Einstein correlations works well
- $\alpha(K^{\pm}) > \alpha(\pi^{\pm})$, but anomalous diffusion suggests opposite, other physical processes affect value of α, further investigations need to be done
- Kaon λ consistent with pions
- $R_{Lévy}$ parameter shows geometric behavior, although $R_{Lévy} \neq R_{Gauss}$

References

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Additional information: Bose - Einstein correlation function

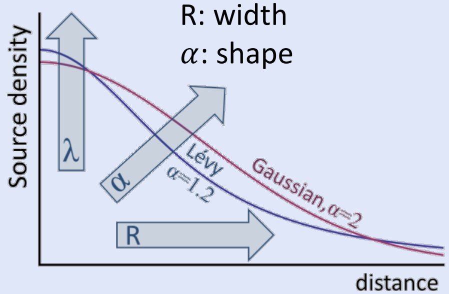
Lévy-type of distribution and anomalous diffusion

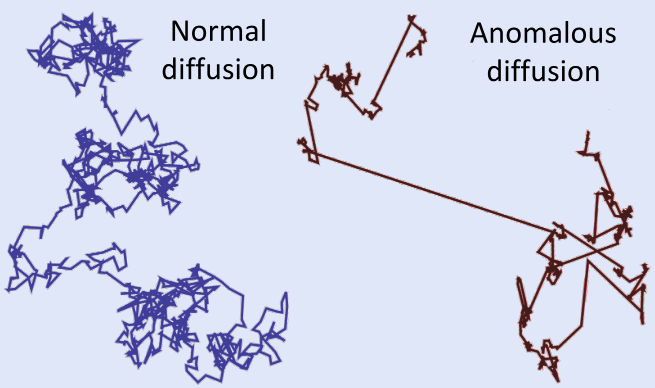
- Increasing mean free path: anomalous diffusion
- Lévy-distribution from generalized central limit theorem could be valid [1-3]
- $\mathcal{L}(\alpha, R; \boldsymbol{x}) = (2\pi)^{-3} \int d^3\boldsymbol{q} e^{i\boldsymbol{q}\boldsymbol{x}} e^{-\frac{1}{2}|\boldsymbol{q}R|^{\alpha}}$

λ: strength (height)
R: width
α: shape

α = 2 (Gaussian dist.)
→ normal diffusion

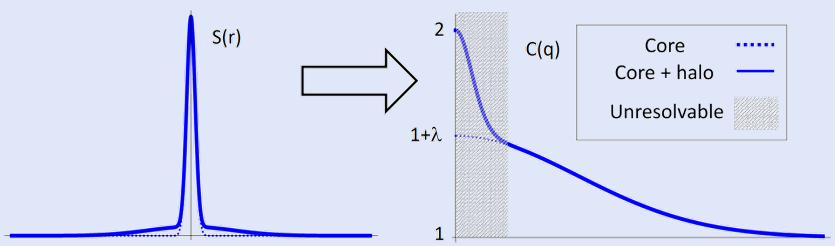
0 < α < 2
→ anomalous diffusion





Distortion effects on the correlation function

- Like-charged kaons → Coulomb correction needed:
  - $C_{meas}(Q) = K(Q) \cdot C_{B\text{-}E}(Q)$
  - Solved with numerical method
- Effect of the resonance kaons → core-halo model [4]:
  - $S = S_{core} + S_{halo}$
  - Long-lived resonances contribute to the halo
  - Introducing the core/halo ratio: $\lambda = [N_{core}/(N_{core} + N_{halo})]^2$
  - Fit func.: $C_2(Q) = 1 - \lambda + \lambda \cdot K(Q) \cdot C_{B\text{-}E}(Q)$



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Additional information: Methodology

- Correlation function variable:
  - $Q = |q_{LCMS}| = \sqrt{(p_{1x} - p_{2x})^2 + (p_{1y} - p_{2y})^2 + q^2_{long,LCMS}}$
  - $q^2_{long,LCMS} = \frac{4(p_{1z}E_2 - p_{2z}E_1)}{(E_1+E_2)^2 - (p_{1z}+p_{2z})^2}$
  - 3D source nearly spherical in LCMS → q_{LCMS} proper 1D variable
- Particle identification:
  - time-of-flight data from TOF e/w, momentum, flight length
  - 2.5 σ cuts on invariant mass distribution
- Event cuts: |zvtx|<30 cm, no centrality cut
- Varied track cuts
  - Kaon PID cut: 2.0 σ – 2.5 σ – 3.0 σ
  - Pion PID veto: 3.0 σ – 2.5 σ – 2.0 σ
  - PC3 matching cut: 2 σ or no cut
  - EMCal/TOF matching cut: 1.5 σ – 2.0 σ – 2.5 σ
- Pair-cuts:
  customary shaped cuts on $\Delta\phi - \Delta z$ plane for DCH, ToF e/w, EMCal