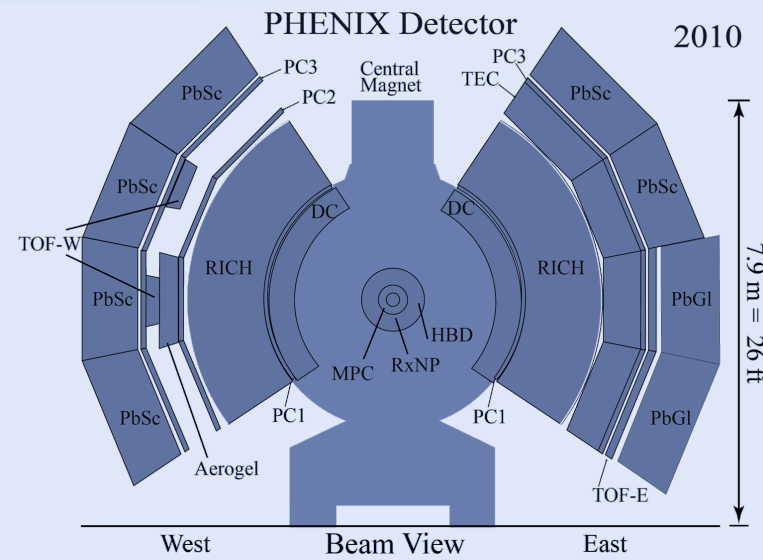


Abstract

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

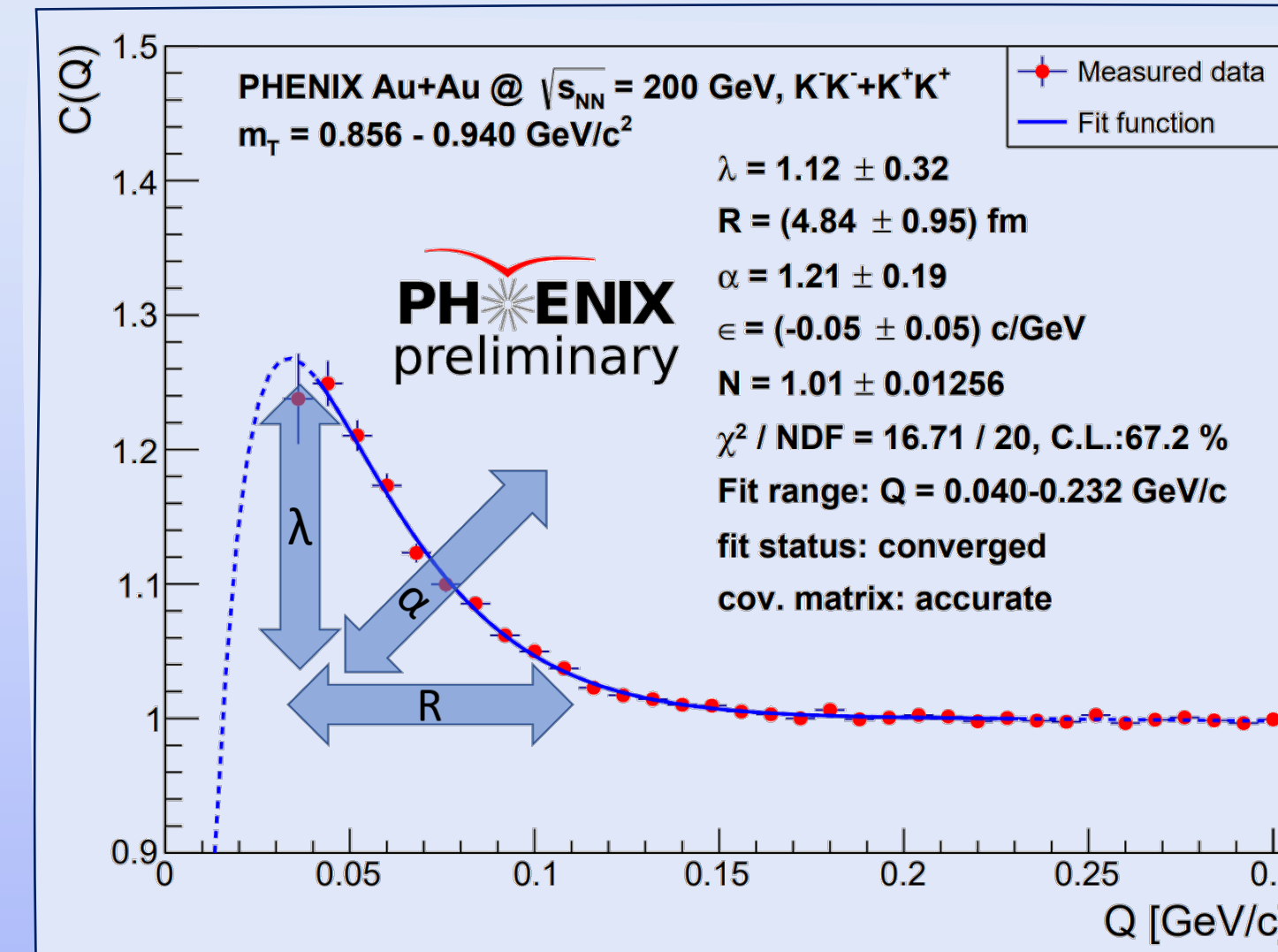
- Used dataset: PHENIX 200 GeV Au+Au 7.3 billion events MinBias data
- Pair distributions measured
- Bose-Einstein correlation function: actual / background pair distribution
- Background pair distributions: event mixing
- PID cuts: 2.5σ for K, 2.5σ veto for π
- Two track cuts to rule out merging and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



Bose-Einstein correlation function with Lévy source

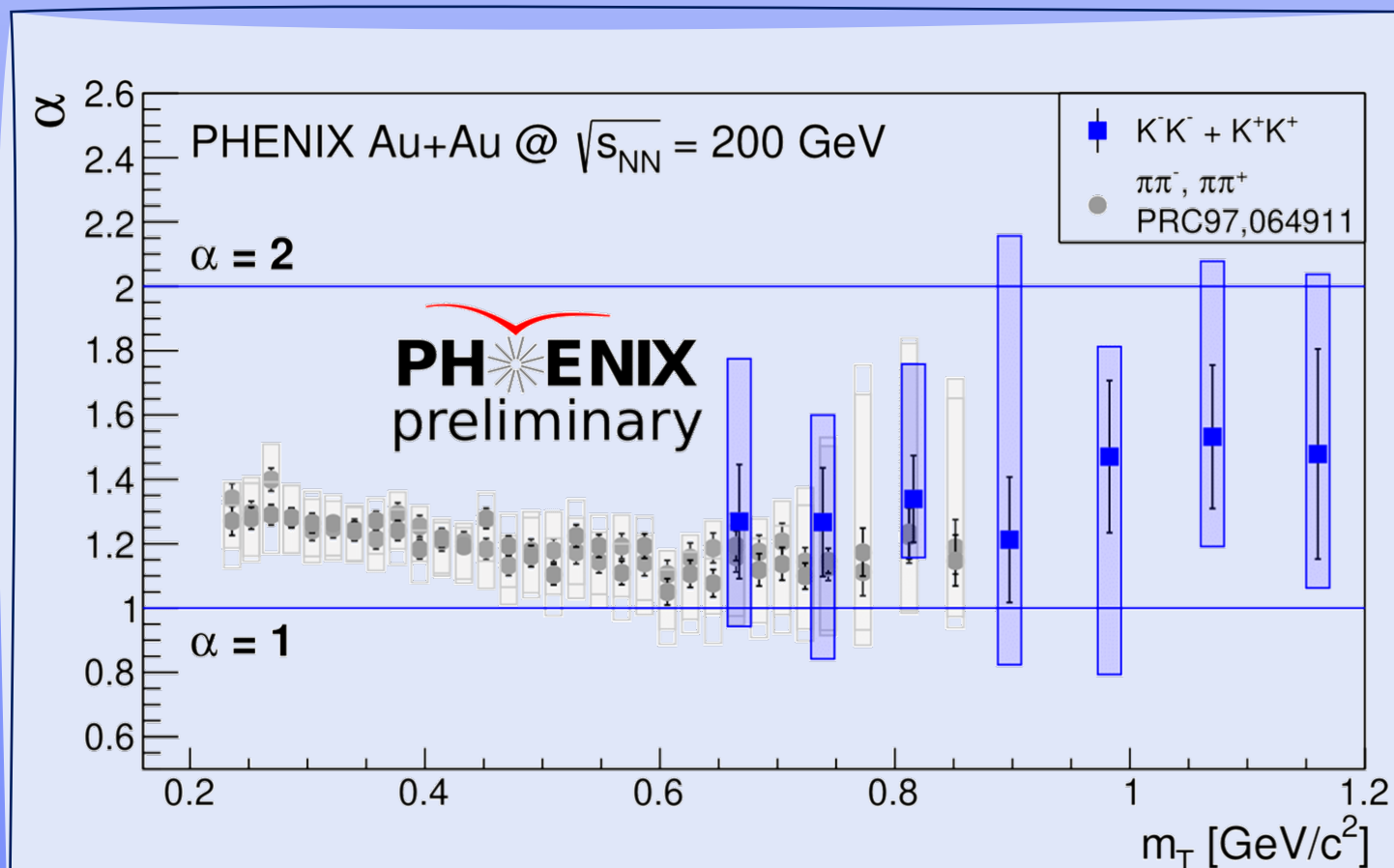
- Lévy-shaped $S(x,p)$ particle emitting source assumed, generalization of Gaussian: $\mathcal{L}(\alpha, R; x) = (2\pi)^{-3} \int d^3q e^{iqx} e^{-\frac{1}{2}|qR|^\alpha}$, Gaussian: $\alpha = 2$, Cauchy: $\alpha = 1$
- Correlation function given with invariant momentum distribution $N_1(p)$: $C_2(p_1, p_2) = \frac{N_2(p_1, p_2)}{N_1(p_1)N_1(p_2)}$, where $N_1(p) = \int S(x, p) |\Psi(x)|^2 d^4x$ and $N_2(p_1, p_2) = \int \int S(x_1, p_1) S(x_2, p_2) |\Psi_{p_1-p_2}(x_1 - x_2)|^2 d^4x_1 d^4x_2$ [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]: $C_2(q, K) \cong 1 + \frac{|\tilde{S}(q, K)|^2}{|\tilde{S}(0, K)|^2}$, 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



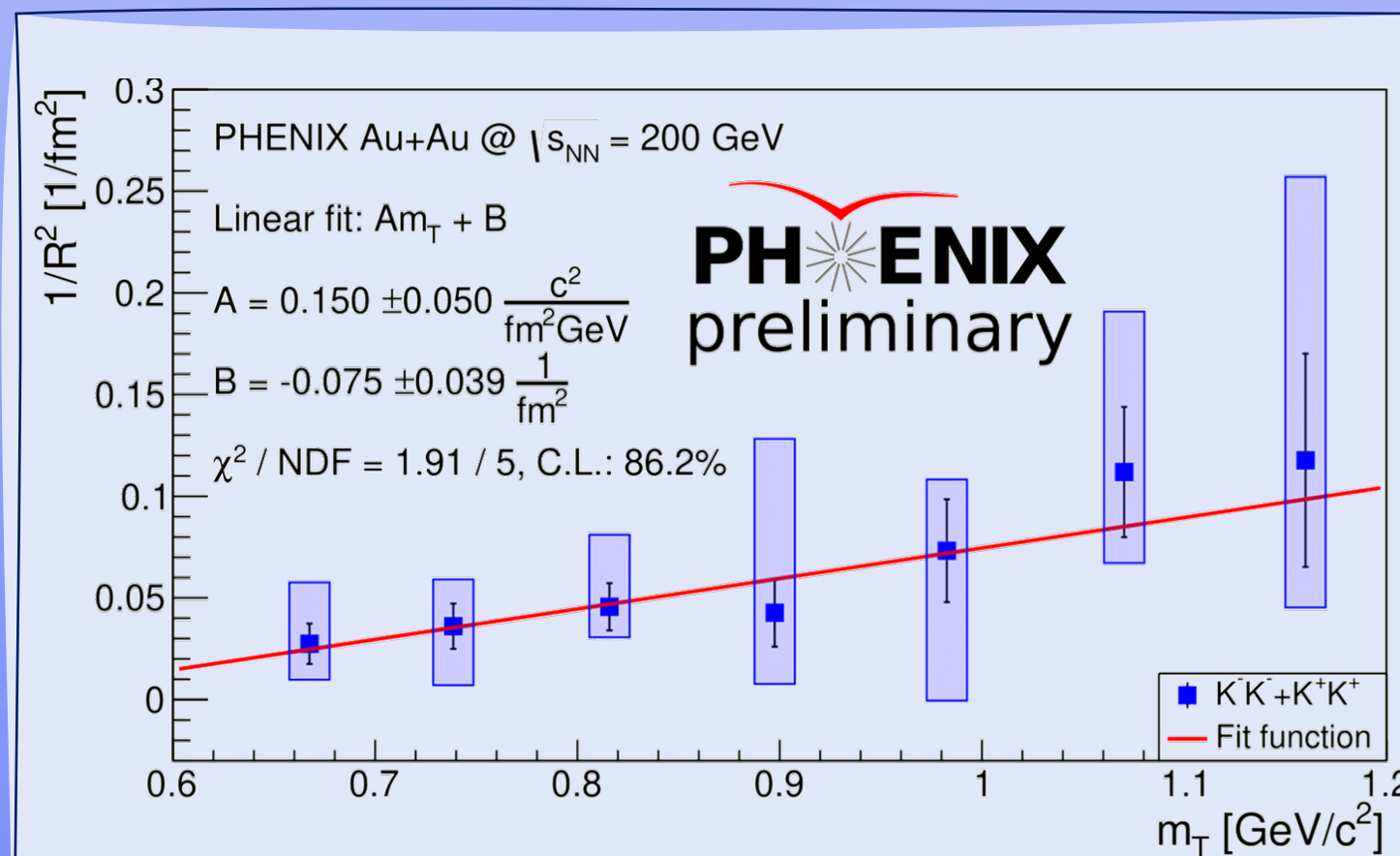
- Correlation functions measured in 7 m_T bins
- Linear background $N \cdot (1 + \epsilon Q)$ assumed
- Fit is acceptable if:
 - Confidence level is at least 0.1%
 - The fit status converges
 - Covariance matrix is accurate
- λ : correlation strength
- α : Lévy shape parameter
 - determined by anomalous 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



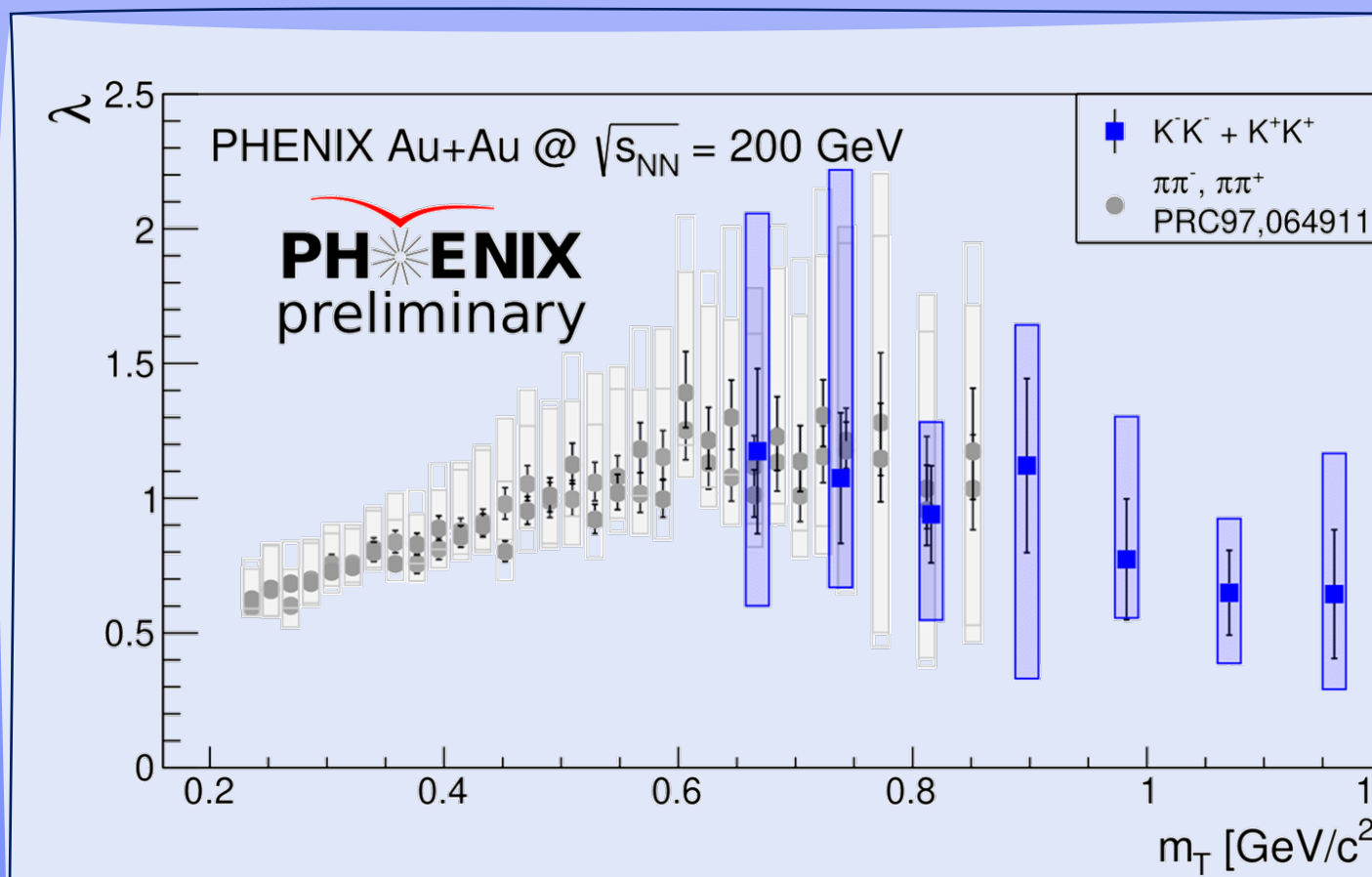
- Does not exhibit strong dependence on transverse mass
- K^\pm α consistent with π^\pm , weak $\alpha(K^\pm) > \alpha(\pi^\pm)$ indication
- Anomalous diffusion suggests $\alpha(K^\pm) < \alpha(\pi^\pm)$ [5]

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: $\lambda = [N_{core} / (N_{core} + N_{halo})]^2$
- 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

- [1] F.B. Yano, S.E. Koonin, Phys. Lett. 78B, 556 (1978)
- [2] Csörgő et al., EPJ C36 (2004) 67
- [3] A. Adare et al., Phys. Rev. C97, 064911 (2018)
- [4] T. Csörgő, B. Lörstad, Phys. Rev. C54, 1390 (1996)
- [5] M. Csanád, T. Csörgő, M. Nagy, Braz.J.Phys. 37 (2007) 1002

Additional information: Bose - Einstein correlation function

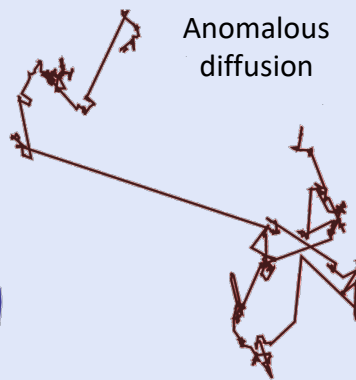
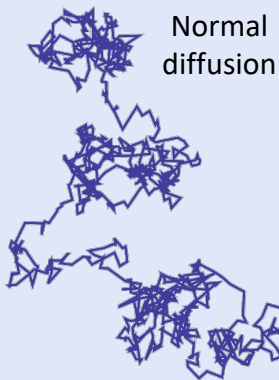
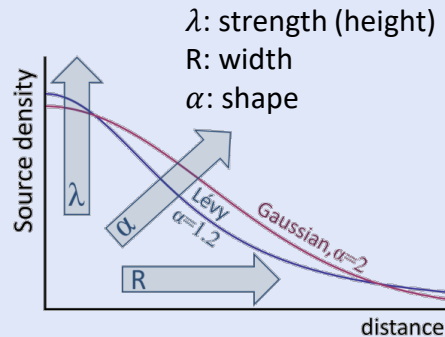
Lévy-type of distribution and anomalous diffusion

- Increasing mean free path: anomalous diffusion
- Lévy-distribution from generalized central limit theorem could be valid [1-3]

$$\mathcal{L}(\alpha, R; \mathbf{x}) = (2\pi)^{-3} \int d^3 q e^{i\mathbf{q}\mathbf{x}} e^{-\frac{1}{2}|\mathbf{q}R|^\alpha}$$

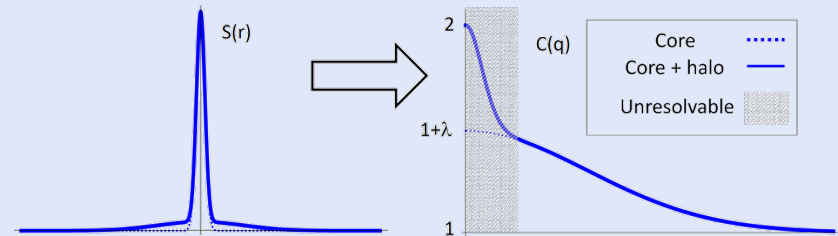
$\alpha = 2$ (Gaussian dist.)
→ normal diffusion

$0 < \alpha < 2$
→ anomalous diffusion



Distortion effects on the correlation function

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



References:

- [1] R. Metzler, E. Barkai, J. Klafter, Phys. Rev. Lett. 82, 3563 (1999)
- [2] T. Csörgő, S. Hegyi, W.A. Zajc, Eur. Phys. J. C36, 67 (2004)
- [3] M. Csanád, T. Csörgő, M. Nagy, Braz. J. Phys. 37, 1002 (2007)
- [4] T. Csörgő, Heavy Ion Phys. 15, 1 (2002)

Additional information: Methodology

- Correlation function variable:

- $$Q = |q_{LCMS}| = \sqrt{(p_{1x} - p_{2x})^2 + (p_{1y} - p_{2y})^2 + q_{long,LCMS}^2}$$

- $$q_{long,LCMS}^2 = \frac{4(p_{1zE2} - p_{2zE1})}{(E_1 + E_2)^2 - (p_{1z} + p_{2z})^2}$$

- 3D source nearly spherical in LCMS $\rightarrow q_{LCMS}$ proper 1D variable
- Particle identification:
 - time-of-flight data from TOF e/w, momentum, flight length
 - 2.5σ cuts on invariant mass distribution
- Event cuts: $|z_{vtx}| < 30$ cm, no centrality cut
- Varied track cuts
 - Kaon PID cut: $2.0 \sigma - 2.5 \sigma - 3.0 \sigma$
 - Pion PID veto: $3.0 \sigma - 2.5 \sigma - 2.0 \sigma$
 - PC3 matching cut: 2σ or no cut
 - EMCal/TOF matching cut: $1.5 \sigma - 2.0 \sigma - 2.5 \sigma$
- Pair-cuts:
 - customary shaped cuts on $\Delta\phi - \Delta z$ plane for DCH, ToF e/w, EMCal

