PHENIX results on Levy analysis of Bose-Einstein correlation functions

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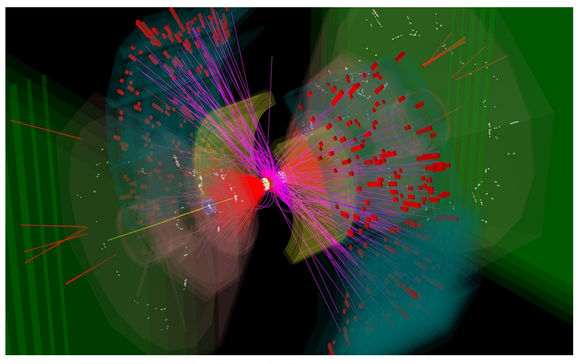
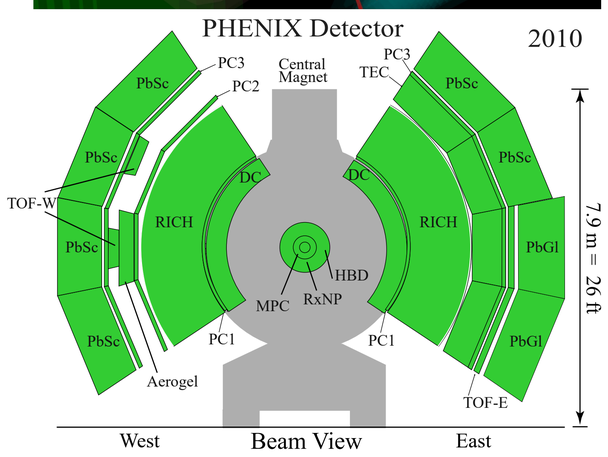
Máté Csanád (Eötvös University, Budapest) for the PHENIX Collaboration

The PHENIX experiment at RHIC





- Observing collisions of p, d, Cu, Au, Al, He, U
- Charged pion ID from ~ 0.2 to 2 GeV/c

Introduction to Bose-Einstein correlations

- $N_1(p), N_2(p)$ - invariant momentum distributions, the definition of the correlation function:

$$C_2(p_1,p_2) = \frac{N_2(p_1,p_2)}{N_1(p_1)N_1(p_2)}, \text{ where } N_2(p_1,p_2) = \int S(x_1,p_1)S(x_2,p_2)|\Psi_2(x_1,x_2)|^2 d^4x_2 d^4x_1 \quad (1)$$

- $S(x,p)$ source function (usually assumed to be Gaussian - Levy is more general)
- Ψ_n n-particle wave function - interaction free case: $|\Psi_2|^2 = 1+\cos(qx)$
- If $p_1 \simeq p_2$: $C_2 \to$ inverse Fourier-trf. $\to S$

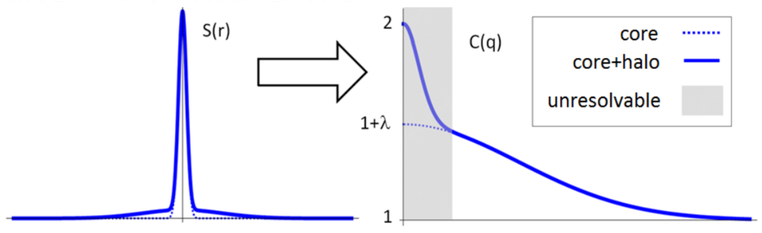
$$C_2(q,K) \simeq 1 + \left|\frac{\widetilde{S}(q,K)}{\widetilde{S}(0,K)}\right|^2, \quad \widetilde{S}(q,k) = \int S(x,k)e^{iqx}d^4x$$

$$K = (k_1+k_2)/2$$

$$x = x_1 - x_2, \; q = k_1 - k_2$$

Final state interactions, resonances

- Identical charged pions - Coulomb interaction distort the simple picture
  - different methods of handling, e.g. Coulomb-correction: $C_{B\text{-}E}(q) = K(q)\cdot C_{\text{meas.}}(q)$
  - An other possibility to fit with the effect incorporated in the fitted function
- Resonance pions reduce the corr. function [1, 2]
- $S = S_C + S_H$
- Primordial pions - Core $\lesssim 10$ fm
- Resonance pions - from very far regions - Halo



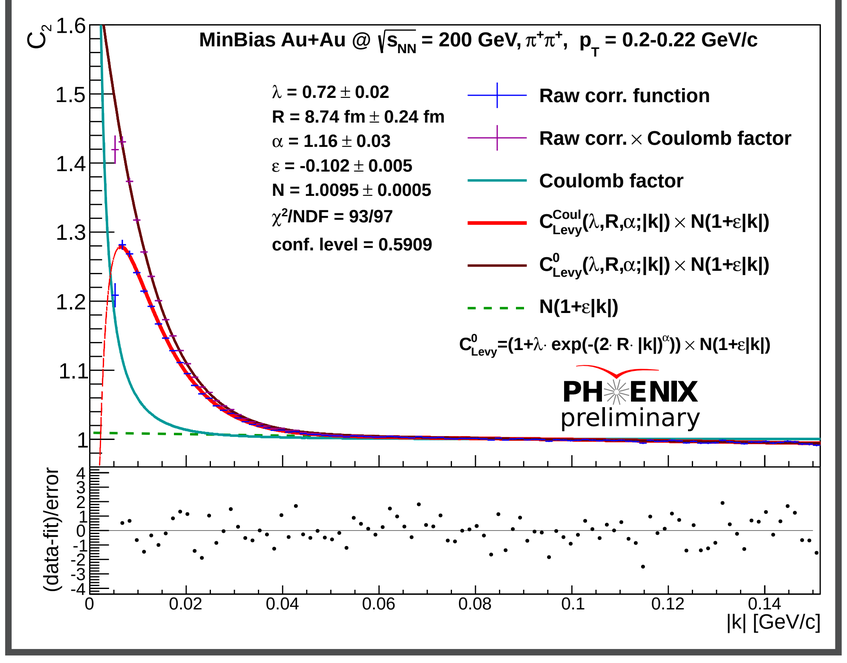
The Levy-distribution and the critical point

- Generalized Gaussian from anomalous diffusion: Levy-distribution, $\alpha = 2$: Gauss, $\alpha = 1$: Cauchy

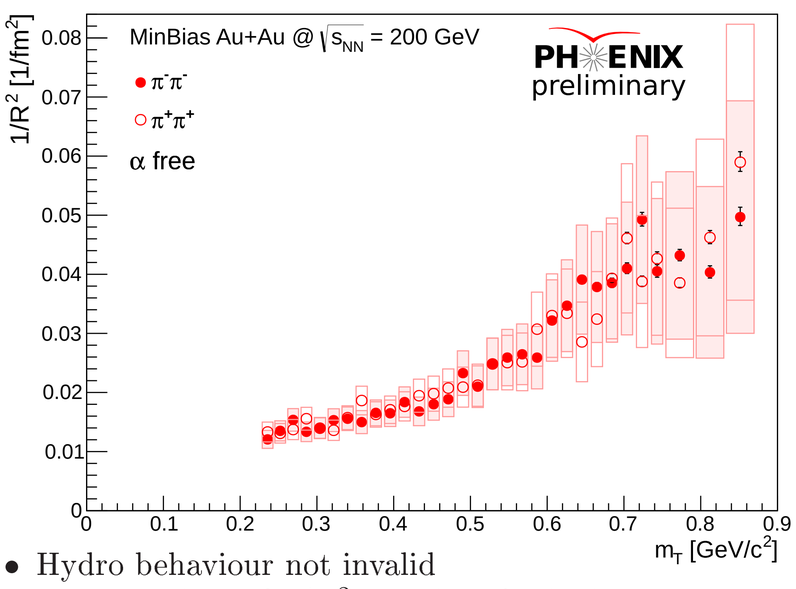
$$\mathcal{L}(\alpha,R,r) = \frac{1}{(2\pi)^3}\int d^3q e^{iqr} e^{-\frac{1}{2}|qR|^\alpha} \quad (2)$$

- Shape of the corr. func. with Levy source [3]: $C_2(|k|) = 1 + \lambda\cdot e^{-(2R|k|)^\alpha}$ with $|k| = |q|/2$
- Critical behaviour $\to$ described by critical exponents
- Spatial corr. $\propto r^{-(d-2+\eta)} \to$ defines η exponent
- Symmetric stable distributions (Levy) $\to$ spatial corr. $\propto r^{-1-\alpha}$ $\Big\}$ $\alpha \equiv$ critical exponent η
- QCD universality class $\leftrightarrow$ 3D Ising [4, 5] $\begin{cases}\eta(\text{CEP}) = 0.03631(3) \text{ from 3D Ising [6]} \\ \eta(\text{CEP}) = 0.5 \pm 0.05 \text{ from rfd.3D Ising [7]}\end{cases}$

Example correlation function

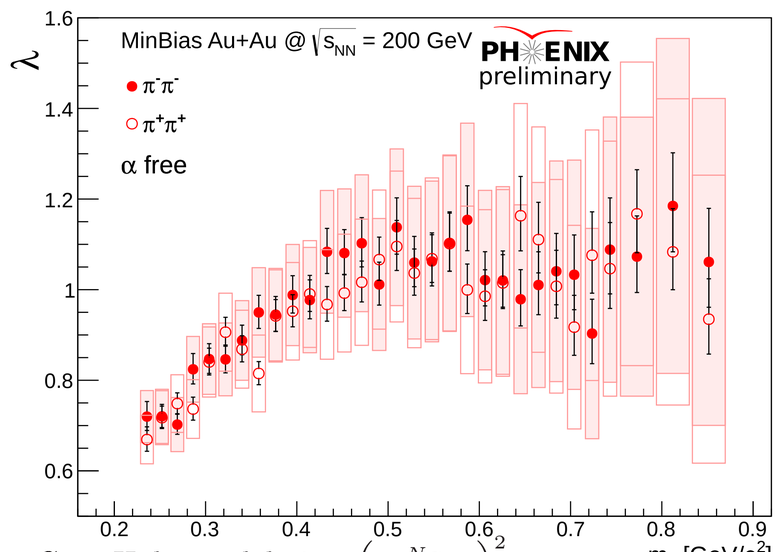


Levy scale parameter R vs. m_T



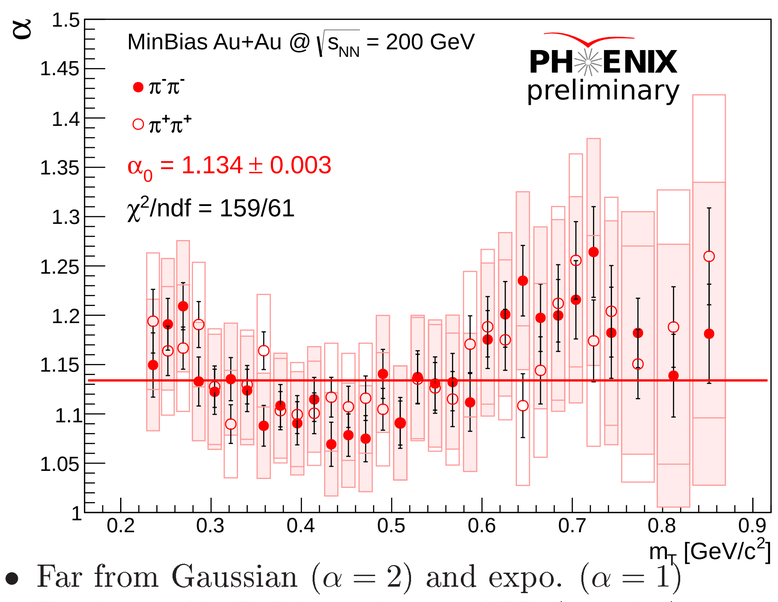
- Hydro behaviour not invalid
- Linear scaling of $1/R^2$ not clear for high m_T

Correlation strength λ vs. m_T



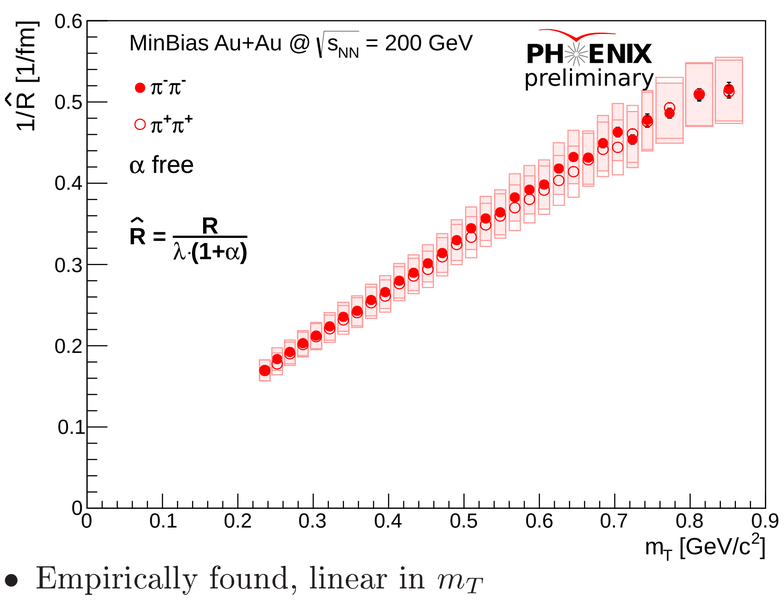
- Core-Halo model: $\lambda = \left(\frac{N_C}{N_C+N_H}\right)^2$
- Decrease at small $m_T \to$ increase of halo frac.

Levy exponent α vs. m_T



- Far from Gaussian ($\alpha = 2$) and expo. ($\alpha = 1$)
- Far from rfd.3D Ising value at CEP ($\alpha = 0.5$)

Newly found scale param. $\widehat{R}$ vs. m_T



- Empirically found, linear in m_T
- Physical interpretation still an open question

Summary

- Bose-Einstein corr. with Levy-source
  - Good agreement with data
  - Levy exponent $\alpha \equiv$ critical exponent η
  - Motivation for precise Levy HBT measurement!
- Preliminary Levy HBT results
  - α at $\sqrt{s_{NN}} = 200$GeV~ 1.134
  - Hydro not invalid even with $\alpha \neq 2$
  - With fixed α the linearity of $1/R^2$ holds
  - Decrease of λ at small m_T
    - Resonance effects?
    - Partially coherent particle production?
  - New scaling parameter $1/\widehat{R} = (\lambda(1+\alpha))/R \propto m_T$
- Future plans
  - Lower energies, search for the critical point
  - Three-pion correlations
  - Pion-kaon comparison

References

References

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