PHENIX results on centrality and beam energy dependent Levy HBT analysis

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Eötvös University, Budapest and EFOP-3.6.1-16-2016-00001, Gyöngyös

XII. Workshop on Particle Correlations and Femtoscopy
Nikhef, Amsterdam, The Netherlands

The conference participation was subsidised by the Talented Student Program of Eötvös Loránd University, Budapest
Outline

- The PHENIX experiment
- Bose-Einstein correlations
- Lévy-type distributions and the critical point
- Centrality dependent results at $\sqrt{s_{NN}} = 200$ GeV, 62 GeV and 39 GeV
- Summary
Observing collision of p+p, p+Al, p+Au, d+Au, h+Au, Cu+Cu, Cu+Au, Au+Au, U+U

Charged pion ID from $\sim 0.2$ to 2 GeV

Typical Au+Au: $\sqrt{s_{NN}} = 130$ GeV, $200$ GeV

Beam energy scan program: 62.4, 39.0, 27.0, 19.6, 14.5, 7.7 GeV
Bose-Einstein correlations

- Correlation function from one- and two-particle momentum distributions:
  \[ C_2(p_1, p_2) = \frac{N_2(p_1, p_2)}{N_1(p_1)N_2(p_2)} \rightarrow C_2(q, K) = 1 + \frac{|\tilde{S}(q, K)|^2}{|\tilde{S}(q = 0, K)|^2} \]

  where \( q = p_1 - p_2 \) and \( K = (p_1 + p_2)/2 \)

- Several effects could modify the correlation functions:
  - Like-charged pions \( \rightarrow \) Coulomb correction needed: \( C_{B-E} = K(q) \cdot C_m(q) \)
  - Strong final state interaction
  - Effect of the resonance pions \( \rightarrow \) core-halo model:
    \[ S = S_{\text{core}} + S_{\text{halo}} \]
    - Long-lived resonances contribute to the halo
    - In-medium \( \eta' \) mass modification \( \rightarrow \) specific, \( m_T \) dependent suppression
  - Partial coherence
  - Squeezed states
  - Aharonov-Bohm-like effect (see our poster :)
    - The hadron gas around the pair could reduce the strength of the correlation
    - Could be treated as an Aharonov-Bohm-like effect

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Lévy-type distribution and the critical point

- Generalized Gaussian – Lévy-distribution
  - Anomalous diffusion
  - Generalized central limit th.

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

- \( \alpha = 2 \) Gaussian, \( \alpha = 1 \) Cauchy, \( 0 < \alpha \leq 2 \) Lévy
- The \( C_2 \) from a symmetric Lévy-source:

\[ C_2(Q) = 1 + \lambda \cdot e^{-(RQ)^\alpha} \]

- Spatial corr. \( \sim r^{-1-\eta} \) in 3D \( \rightarrow \) defines \( \eta \) exponent
- Symmetric stable distribution (Lévy) \( \rightarrow \) spatial corr. \( \sim r^{-1-\alpha} \)
- \( \alpha \) identical to \( \eta \)!
- For details see e.g.:
Searching for the critical point

- QCD universality class ↔ 3D Ising [5],[6]
- At the critical point:
  - random field 3D Ising model [7]: $\eta = 0.5 \pm 0.05$
  - 3D Ising [8]: $\eta = 0.03631(3)$
- Change in $\alpha \rightarrow$ vicinity of the CEP
- Motivation for precise HBT measurements ...
  - ... with different multiplicity $\rightarrow$ centrality dependence
  - ... with different energy: now 200 GeV, 62 GeV, 39 GeV

Lévy exponent $\alpha$ at 200 GeV

- Slightly non-monotonic behavior as a function of $m_T$
- Average has non-monotonic behavior at 200 GeV
- $\alpha = \langle \alpha \rangle$ constant fits were performed with centrality bin dependent value

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PHENIX results on centrality and beam energy dependent Lévy HBT analysis
Lévy exponent $\alpha$ at 62 and 39 GeV

- Lévy exponent $\alpha$ does not seem to depend on $\sqrt{s_{NN}}$
- Fewer centrality bins have to be used due to the statistics
- $\alpha = \langle \alpha \rangle$ constant fits were not done
Lévy scale $R$ at 200 GeV

- Not equivalent with the Gaussian width but show similar trends
- Linear scaling behavior is seen in $1/R^2(m_T)$
- $\alpha$ fix fits reduce the systematic uncertainties
Lévy scale $R$ at 62 and 39 GeV

- Similar decreasing trends with $m_T$ as in the Gaussian case
- Similar trends as at 200 GeV
- Fewer centrality bins have to be used due to statistics
Lévy strength $\lambda$ at 200 GeV

- Decreasing tendency at lower $m_T$ not depend on centrality (as in [9])
- Can be observed clearly in $\lambda/\lambda_{\text{max}}$ with $\alpha$ fix (r.h.s. figure)
- Partial coherence predicts strong centrality dependence
- No centrality dependence of the “hole”

[9] Abelev et al. [STAR collaboration] PRC80, 024905
Lévy strength $\lambda$ at 62 and 39 GeV

- Similar trends as at 200 GeV
- The characteristics of the “hole” do not depend strongly on $\sqrt{s_{NN}}$
- At $\sqrt{s_{NN}} \approx 19.4$ GeV the effect seems to disappear in S+Pb (see [10])

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[10] Beker et al. [NA44 collaboration], PRL74, 3340
New scaling parameter $\hat{R}$ at 200 GeV

- $\frac{1}{\hat{R}} = \frac{\lambda(1+\alpha)}{R}$ scales with $m_T$
- Not sensitive to the $\alpha$ fixation
- May correspond to the area under the correlation function
- Experimentally observed, no theoretical explanation as far as we know
New scaling parameter $\hat{R}$ at 62 and 39 GeV

- Surprisingly good behavior at lower energy
- Linear behavior does still hold
Summary

- Experimentally, a significant deviation from the Gaussian ($\alpha = 2$) case
- Symmetric Lévy shape is a statistically acceptable description
- Lévy parameters connected to rescattering, core/halo model and size
- Lévy exponent $\alpha$: non-monotonic in $N_{\text{part}}$, almost independent of $\sqrt{s_{NN}}$
- Lévy scale $R$: geometric/hydro scaling, similar to Gaussian
- Lévy strength: low-$m_T$ “hole” for $\sqrt{s_{NN}} \geq 39$ GeV, weak centrality dep.
- New par $\hat{R}$: linear scaling for $\sqrt{s_{NN}} \geq 39$ GeV, all investigated centrality

Thank you for your attention!
STAR centrality dependent results (left) and the comparison of STAR results in different $\sqrt{s_{NN}}$ with NA44 data (right)