Pion femtoscopy in p+Au and d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV in the STAR experiment

Eugenia Khyzhniak
(for the STAR collaboration)
National Research Nuclear University MEPhI
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Outline

- Motivation
- Femtoscopy
- Correlation functions and their fits
- Systematic uncertainty
- $k_T$ dependence of $R_{inv}$ and $\lambda$
- System comparison
Motivation

Examination of the spatial and temporal scales of the particle-emitting source is one of the ways to study the process of particle production.

M. Podgoretky 1989 Particles & Nuclei 20 630-68

In small systems (like p+p or d+Au) a collision area size is sensitive to fluctuations of initial conditions. Therefore, the detailed nature of particle production becomes important.

**Femtoscopy**

- **Femtoscopy allows one to measure:**
  - Size of the emission source
  - Source shape & orientation
  - Lifetime & Emission duration

- **System expansion dynamics are influenced by:**
  - Transport properties
  - Phase transition/Critical point
  - Initial-state event shape

Extracted radii measure the homogeneity lengths of the source

Analysis technique

Construction of the correlation function:

\[ C(Q_{\text{inv}}) = \frac{A(Q_{\text{inv}})}{B(Q_{\text{inv}})} \]

\[ Q_{\text{inv}} = \sqrt{(p_1^2 - p_2^2)^2 - (E_1 - E_2)^2} \]

\[ A(Q_{\text{inv}}) - Q_{\text{inv}} \text{ distribution with Bose-Einstein statistics (and final-state interactions – Coulomb and strong)} \]

\[ B(Q_{\text{inv}}) - Q_{\text{inv}} \text{ distribution without it (reconstructed by event-mixing technique)} \]

Fit of the correlation function:

\[ C(Q_{\text{inv}}) = N \left( 1 - \lambda + \lambda K_{\text{Coul}}(Q_{\text{inv}})(1 + G(Q_{\text{inv}})) \right) D(Q_{\text{inv}}) \]

\[ G(Q_{\text{inv}}) = e^{-q_{\text{inv}}^2 R_{\text{inv}}^2} \]

1) Schematic view

2) Fit of the correlation function:

- \( N \) - normalization factor
- \( \lambda \) - correlation strength parameter
- \( K_{\text{Coul}} \) - is a squared like-sign pion pair Coulomb wave-function integrated over a spherical Gaussian source


\[ D(Q_{\text{inv}}) = 1 \text{ (in this analysis) – Non-femtoscopic correlations} \]
The STAR experiment

- **Colliding systems:**
  - d+Au@200 GeV
  - p+Au@200 GeV

- **Pion identification:**
  - Time Projection Chamber (TPC) - main tracking detector, $|\eta| < 1.0$, full azimuth
Correlation functions and their fits look reasonable.

**Lorentzian fit assumption:** 
\[ G(Q_{inv}) = e^{-q_{inv}^2 R_{inv}^2} \]

**Gaussian fit assumption:** 
\[ G(Q_{inv}) = e^{-q_{inv}^2 R_{inv}^2} \]

**d+Au and p+Au systems comparison**

\[ \vec{k}_T = \frac{\vec{p}_{1T} + \vec{p}_{2T}}{2} \]
Statistical and systematic uncertainty

- For almost all cases statistical uncertainty smaller than marker size

- Sources of the systematic uncertainty:
  - Selection criteria of the events (position of the primary vertex): < 5%
  - Selection criteria of the tracks (momentum of the tracks, tracking efficiencies): < 6%
  - Selection criteria of the pairs (two track effects – merging, splitting): < 2%
  - Fit range: < 3%
  - Coulomb radius: < 3%

- Plan to investigate single track momentum resolution
$k_T$ dependence of $R_{inv}$ and $\lambda$

- Radii decrease with increasing $k_T$
- Radii increase with increasing particle multiplicity
- Correlation strength parameter $\lambda$ decreases with particle multiplicities
  - Influence of the resonances increases?

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$d+Au@200GeV$

$p+Au@200GeV$
System comparison ($R_{inv}$ vs. $k_T$)

- Radii increase with increasing size of the colliding system
- Weak radius dependence on colliding system (especially for $k_T > 0.35$ GeV/c)

- The femtoscopic radii difference between colliding species becomes smaller with increasing $k_T$
Summary

- Femtoscopic parameters were obtained for p/d+Au systems

- The $k_T$ dependence of the $R_{inv}$ shows the collective dynamics of the system (system expansion) and allows to probe the different regions of the homogeneity in both p/d+Au systems

- Radii increase with increasing particle multiplicity

- The femtoscopic radii difference between colliding species becomes smaller with increasing $k_T$
Thank you for your attention!
Back-up slide
## Selection criteria

<table>
<thead>
<tr>
<th>Event cuts</th>
<th>Track cuts</th>
<th>Pair cuts</th>
<th>Pion TPC cuts</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>Z_{TPC}</td>
<td>&lt; 40$</td>
<td>$N_{Hits} &gt; 15$</td>
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<tr>
<td>$\sqrt{X_{TPC}^2 + Y_{TPC}^2} &lt; 2$</td>
<td>$N_{Hits}/N_{HitsFit} &gt; 0.51$</td>
<td>0.15 &lt; $k_t$ (GeV/c) &lt; 1.05</td>
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<tr>
<td>$</td>
<td>Z_{TPC} - Z_{VPD}</td>
<td>&lt; 5$</td>
<td>DCA &lt; 2 cm</td>
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<td></td>
<td>$</td>
<td>η</td>
<td>&lt; 0.5$</td>
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<tr>
<td></td>
<td>0.15 &lt; $p$ (GeV/c) &lt; 0.8</td>
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