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

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Outline

- Motivation
- Femtoscopcy
- 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. Podgoretsky 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

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Extracted radii measure the homogeneity lengths of the source
Analysis technique

Construction of the correlation function:

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

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

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

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

Fit of the correlation function:

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

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

\[ N \] – 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:**
  - \( d + \text{Au} @ 200 \ \text{GeV} \)
  - \( p + \text{Au} @ 200 \ \text{GeV} \)

- **Pion identification:**
  - Time Projection Chamber (TPC) - main tracking detector, \(|\eta| < 1.0\), full azimuth
Example of the correlation functions and fits

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

d+Au and p+Au systems comparison

Correlation functions and their fits look reasonable

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

Lorentzian fit assumption: \( G(Q_{inv}) = e^{-q_{inv} R_{inv}} \)
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 $\lambda$**

- **d+Au@200GeV**
  - Radius decreases with increasing $k_T$
  - Radius increases with increasing particle multiplicity
  - Correlation strength parameter decreases with particle multiplicities
    - Influences of the resonances increases?

- **p+Au@200GeV**
System comparison ($R_{\text{inv}}$ Vs. $k_T$)

- Weak radius dependence on colliding system
- Radii increase with increasing size of the colliding system
- The femtoscopic radii difference between colliding species becomes smaller with increasing $k_T$
Femtoscopic parameters were obtained for p/d+Au systems.

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

Radius increases 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>$</td>
<td>Z_{TPC}</td>
<td>$ (cm) &lt; 40</td>
<td>$N_{Hits} &gt; 15$</td>
</tr>
<tr>
<td>$\sqrt{X_{TPC}^2 + Y_{TPC}^2}$ (cm) &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>$</td>
<td>Z_{TPC} - Z_{VPD}</td>
<td>$ (cm) &lt; 5</td>
<td>DCA &lt; 2 cm</td>
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<tr>
<td>$</td>
<td>\eta</td>
<td>&lt; 0.5$</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>$0.15 &lt; p$ (GeV/c) &lt; 0.8</td>
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</tbody>
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