Femtoscopic measurements of strange hadrons in Au+Au collisions at the STAR experiment

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Abstract
Relativistic heavy-ion collisions can study properties of nuclear matter in high-energy experiments like the STAR experiment. Femtoscopy, which relies on information carried by the particles produced in the collisions, is one of methods to learn about the bulk matter. By studying the quantum statistical effects and final state interactions between two particles, one can study spatial and temporal extents of particle emitting source. For the case of kaons, the correlation functions are sensitive to the early stage of the collision evolution and provide different information about particle-emitting sources compared to pions. Information on the final state interactions amongst the particles under study can also be extracted from the measurement. Especially, in the case of strange particle correlations, one could investigate hyperon-nucleon interactions which is little known.

Supported in part by the
Hard Probes 2020 Austin, Texas
Neutral kaon selection criteria

<table>
<thead>
<tr>
<th>Cuts</th>
<th>200 GeV</th>
<th>39 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_T$ [GeV/c]</td>
<td>0.4 - 2.0</td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>\eta</td>
<td>$</td>
</tr>
<tr>
<td>DCA $V^0$ to PV [cm]</td>
<td>0.0 – 0.3</td>
<td></td>
</tr>
<tr>
<td>DCA of daughters [cm]</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>decay lengh [cm]</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Armenteros $q_T$ [GeV/c]</td>
<td>0.12 – 0.22</td>
<td></td>
</tr>
<tr>
<td>Armenteros $</td>
<td>\alpha</td>
<td>$</td>
</tr>
<tr>
<td>mass range [GeV/c$^2$]</td>
<td>0.488 – 0.51</td>
<td>0.475 - 0.525</td>
</tr>
</tbody>
</table>

Armenteros-Podolanski plot

dE/dx for pions

Numbers of events

<table>
<thead>
<tr>
<th>Energy/centrality</th>
<th>0-10%</th>
<th>10-70%</th>
<th>0-70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 GeV</td>
<td>-107M</td>
<td>-154M</td>
<td>-261M</td>
</tr>
<tr>
<td>39 GeV</td>
<td>-12M</td>
<td>-71M</td>
<td>-83M</td>
</tr>
</tbody>
</table>
**Basics of femtoscopy**

**Femtoscopy** – method to examine the particle emitting source sizes (of the order of $10^{-15}$ fm and lifetime $10^{-23}$ s) by measurements of relative momentum characteristics.

**The correlation function (CF)** – the ratio of probability of observing two particles with specific momenta $p_1$ and $p_2$ at the same place and time to the product of probabilities to find them separately:

$$ CF(p_1, p_2) = \frac{P_2(p'_1, p'_2)}{P_1(p_1)P_1(p_2)} $$

**The experimental correlation function:**

$$ CF(q_{inv}) = \frac{A(q_{inv})}{B(q_{inv})} $$

$$ q_{inv} = \sqrt{(p_1 - p_2)^2 - (E_1 - E_2)^2} $$

$A(q_{inv})$ – the signal distribution, $B(q_{inv})$ - the background distribution.

**Neutral kaons correlations**

The correlation function depends on:
- **Quantum statistics (QS)**
- **Final State Interactions (FSI)**
  - Coulomb Interaction (COUL)
  - Strong Interaction (SI)
Gaussian density distribution (includes only QS effects): \( CF(q_{\text{inv}}) = 1 + \lambda e^{-R_{\text{inv}}^2 q_{\text{inv}}^2} \)

\( \lambda \) – the correlation strength, \( R_{\text{inv}} \) - the size of the particle-emitting source.


\[
CF(q_{\text{inv}}) = 1 + \lambda \left( e^{-R_{\text{inv}}^2 q_{\text{inv}}^2} + \frac{1}{2} \left[ \frac{f(k^*)}{R_{\text{inv}}} \right]^2 + \frac{4R f(k^*)}{\sqrt{\pi} R_{\text{inv}}} F_1(q_{\text{inv}} R_{\text{inv}}) - \frac{2 S f(k^*)}{\sqrt{\pi} R_{\text{inv}}} F_2(q_{\text{inv}} R_{\text{inv}}) \right)
\]

strong FSI through the \( f_0(980) \) and \( a_0(980) \) resonances

\[
f(k^*) = \frac{1}{2} [f_0(k^*) + f_1(k^*)], \quad f_1(k^*) = \frac{Y_r}{m_r - s - iY_r k^* - iy_r k^*}, \quad s = 4(m_R^2 + k^2)
\]

<table>
<thead>
<tr>
<th>( m_{f_0} ) [GeV/c^2]</th>
<th>( \Gamma_{f_0 \bar{K}K} )</th>
<th>( \Gamma_{f_0 \pi\pi} )</th>
<th>( m_{a_0} ) [GeV/c^2]</th>
<th>( \Gamma_{a_0 \bar{K}K} )</th>
<th>( \Gamma_{a_0 \pi\pi} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antonelli [1]</td>
<td>0.973</td>
<td>2.763</td>
<td>0.5283</td>
<td>0.985</td>
<td>0.4038</td>
</tr>
<tr>
<td>Achasov2001 [2]</td>
<td>0.996</td>
<td>1.305</td>
<td>0.2684</td>
<td>0.992</td>
<td>0.5555</td>
</tr>
<tr>
<td>Achasov2003 [3]</td>
<td>0.996</td>
<td>1.305</td>
<td>0.2684</td>
<td>1.003</td>
<td>0.8365</td>
</tr>
<tr>
<td>Martin [4]</td>
<td>0.978</td>
<td>0.792</td>
<td>0.1990</td>
<td>0.974</td>
<td>0.3330</td>
</tr>
</tbody>
</table>

Results

Summary:
- The strong final-state interaction has a significant effect on the $K_s^0 K_s^0$ correlation due to the near-threshold $f_0(980)$ and $a_0(980)$ resonances.
- The radii of the source depend on centrality and increase with increasing collision energy.
- Comparison with model calculations shows better compatibility for UrQMD model.

Future plans: $K_s^0 K^{ch}$ correlation functions.

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**Strong FSI through the $f_0(980)$ and $a_0(980)$ resonances**

**Results**

- **STAR Preliminary**
  - Au+Au collisions @ 39 GeV
  - Au+Au collisions @ 200 GeV