Kaon femtoscopy in STAR
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Beam Energy Scan program

Beam Energy Scan (BES) - a comprehensive program conducted by all experiments of the RHIC complex, launched in 2010 to study the Quantum Chromodynamics Phase Diagram at different chemical potential ($\mu_b$) and temperature ($T$) values using collisions of Au ions at collision energies from 7.7 GeV to 200 GeV [1, 2].

The main goals:
- To study the QCD Phase Diagram at different collision energies and to find areas in which QGP signatures are turned off,
- To find a Critical Point between crossover and the first-order phase transition,
- To examine the area between the hadronic and Quark Gluon Plasma matter.

Fig. 1 The Quantum Chromodynamics Phase Diagram [3].

Femtoscopy

Femtoscopy - a method to examine the particle emitting source sizes (of the order of $10^{-15}$ m) by measurements of relative momentum characteristics [4].

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 [5]:

$$CF(p_1, p_2) = \frac{P_1(p_1) P_1(p_2) d^4 p_1 d^4 p_2}{P_1(p_1) P_2(p_2) d^4 p_2 d^4 p_1}$$

The experimental correlation function:

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

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

Kaon correlation function

The correlation function depends on:
- Quantum statistics (QS)
- Final state interactions (FSI):
  - Coulomb interaction (Coul)
  - Strong interaction (SI)

Like-sign charged kaons -> dominant quantum statistical effects together with Coulomb interaction
Neutral kaons -> absent Coulomb interaction but strong interaction need to be taken into account together with quantum statistical effects

Fig. 2 CF of the like-sign charged kaons from the Thermator model for central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

Gaussian density distribution (includes only QS effects):

$$CF(q_{cm}) = 1 + \exp(-R_{cm}^2/q_{cm}^2)$$

$\lambda$ - the correlation strength
$R_{cm}$ - the size of the particle-emitting source

Lednicky and Lyuboshitz model: includes strong FSI was also using to fit the K$^+$K$^-$ correlation functions [6].

Armenteros-Podolanski plot

The kinematic properties of the $V^0$ candidates.

$K^+_0 \rightarrow \pi^+ + \pi^-$

$\pi^+$ and $\pi^-$ have the same mass and their momenta are distributed symmetrically on average

Neutral kaon results

| $p_0$ [GeV/c] | $|n|$ | DCA $V^0$ to the PV [cm] | DCA of daughter [cm] | decay length [cm] | mass range [GeV/c] |
|--------------|------|--------------------------|----------------------|------------------|-------------------|
| 0.2-1.5      | < 0.5| < 0.3                    | < 0.3                | > 2              | 0.488 - 0.51      |

Fig. 3 CF of the neutral kaon pairs from the Thermator model for central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

Charged kaons results

- $k_t$ and centrality dependence of HBT radii observed
- Source sizes increase with the centrality and decrease with the pair transverse momentum

Fig. 5 Radial of the source from the K$^+$K$^-$ and K$^+$K$^+$ correlation function in different $k_t$ ranges [8].

Fig. 6 Neutral kaons CF with Gaussian fit

Fig. 7 Comparison with previous STAR result.

Summary

- Kaon femtoscopy – a complementary method to pion femtoscopy
- Less affected by resonance decays than pions
- Allows one to learn about the final state interaction
- Source size ~5 fm for the most central collisions

References