Nuclear modification factors of $\pi^0$ and $\eta$ mesons in U+U collisions at $\sqrt{s_{NN}}=192$ GeV

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Abstract. Extensive study of heavy ion collisions at RHIC resulted in the discovery of a strongly coupled Quark Gluon Plasma (sQGP). Since then, the RHIC experiments main effort was directed towards detailed study of the new state of matter using more differential and precise measurements. One of the signatures of sQGP formation is the jet quenching effect, which is observed as a suppression of high transverse momenta ($p_T$) hadron yields in heavy-ion ($A+A$) collisions compared to ones measured in elementary proton-proton ($p+p$) collisions, which is quantified with the nuclear modification factor ($R_{AA}$). This paper presents results of $\pi^0$ and $\eta$ mesons invariant $p_T$-spectra and $R_{AA}$ measured in U+U collisions at $\sqrt{s_{NN}} = 192$ GeV in different centrality intervals with PHENIX experiment at RHIC. The $\pi^0$ and $\eta$ mesons production in U+U collisions is similarly suppressed within uncertainties and shows similar suppression pattern as the one measured in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV in central and semi-central collisions. In peripheral collisions $\pi^0$ and $\eta$ mesons are slightly more suppressed in U+U collisions then in Au+Au.

1. Introduction

Strongly interacting quark-gluon plasma (sQGP) is an ideal liquid-like phase of nuclear matter under the extreme conditions of temperature with quarks and gluons (partons) as its degrees of freedom. The sQGP production was established in central heavy-ion ($A+A$) collisions at RHIC in 2005 [1-4]. The jet quenching [5] is the one of the main sQGP signatures and manifests by a suppressed production of hadron yields at high transverse momenta ($p_T > 5$ GeV/c) relative to the yields measured in elementary proton-proton ($p+p$) collisions. The effect is related to the energy loss of hard-scattered partons traversing the dense and hot strongly interacting medium created in $A+A$ collisions.

Nuclear modification factor ($R_{AA}$) is used to quantify the medium effects and is calculated as:

$$ R_{AA}(p_T) = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}(p_T)}{dN_{pp}(p_T)} $$

(1)

where $dN_{AA}(p_T)/dN_{pp}(p_T)$– the particle yield, measured in $A+A$ ($p+p$) collisions, $\langle N_{coll} \rangle$– the average number of binary inelastic nucleon-nucleon collisions.

This paper presents invariant $p_T$-spectra and nuclear modification factors of $\pi^0$ and $\eta$ mesons measured in U+U collisions at $\sqrt{s_{NN}} = 192$ GeV at RHIC. The measurement of $\eta$ and $\pi^0$ meson production spectra allows to study jet-quenching effect with a good precision, because $\eta$ and $\pi^0$ can be identified up to the highest $p_T$ with relatively small uncertainties. $\eta$ mesons have hidden strangeness thus measurement of its production serves as a responsible tool of the parton energy loss study as a function of flavor and mass of the fragmented hadron. The U+U collision system provides the largest energy density available at RHIC. Also, the uranium nucleus is highly asymmetric, which leads to different...
parametrizations of the U+U collision geometry [6, 7]. All these features make the U+U system important for the systematic study of the jet quenching and give a unique possibility to obtain additional restrictions on the parameters of various parton energy loss theoretical models.

2. Data Analysis

All analyzed data was collected with the PHENIX spectrometer [8] central arms each covering \( \pi/2 \) in azimuth and \( |\eta| < 0.35 \) in pseudorapidity and contain \( 9 \times 10^8 \) collision events. The \( \pi^0 \) and \( \eta \) meson production is measured with respect to the collision centrality and meson \( p_T \). The collision centrality is measured with the beam-beam counters (BBC, \( 3.0 < |\eta| < 3.9 \)) [9]. The collisions with centrality 0-20% correspond to central collisions with large nuclei overlap region, the collisions with centrality 60-80% correspond to peripheral collisions where only few nucleons interact. A Glauber model [10] is used to estimate the average numbers of participating nucleons (\( \langle N_{part} \rangle \)) and binary nucleon-nucleon collisions (\( \langle N_{coll} \rangle \)) for each centrality bin. Two sets of \( \langle N_{part} \rangle \) and \( \langle N_{coll} \rangle \) (Glauber sets hereafter) are used to calculate \( \pi^0 \) and \( \eta \) meson nuclear modification factors. The Glauber sets differ from each other by the Wood-Saxon distribution parametrizations [11]. Glauber sets 1 and 2 are published in [6] and [7], respectively.

The \( \pi^0 \) and \( \eta \) mesons measurement is obtained in a \( \pi^0(\eta) \rightarrow \gamma \gamma \) decay channel. The photon reconstruction is performed with the electromagnetic calorimeter (EMCal), detailed description of which, including the construction and calibrations, can be found elsewhere in [12]. The meson yield extraction is performed with the analysis of the \( \gamma \gamma \) pairs invariant mass (\( m_{\gamma \gamma} \)) distributions formed with respect to the meson \( p_T \) and collision centrality. To form the distributions photons are required to satisfy several analysis cuts. The minimum EMCal cluster energy cut (\( E_{\gamma} > 0.4 \) GeV) is applied to suppress the hadron clusters contribution in the EMCal. An asymmetry cut \( \left| E_{\gamma_1} - E_{\gamma_2} \right| / \left( E_{\gamma_1} + E_{\gamma_2} \right) < 0.8 \) is applied to photon energies of each \( \gamma \gamma \) pair to improve a signal-to-background ratio.
Figure 2. Comparison of $R_{AA}$ values in U+U Glauber 1 (●), U+U Glauber 2 (■) ($\sqrt{s_{NN}} = 192$ GeV) and Au+Au (● – RHIC Run Year-2002 [13], ○ – RHIC Run Year-2007 [14]) ($\sqrt{s_{NN}} = 200$ GeV) collisions at similar $N_{coll}$ for 0-20% (a), 20-40% (b), 40-60% (c), and 60-80% (d) U+U centrality intervals. Error bars and open boxes show statistical and systematic uncertainties, respectively. Boxes at unity show scaling uncertainty.

The resulted distributions are fitted to a combination of Gaussian (for signal and the second order polynomial (for the residual background). The meson yield values are estimated as a difference between the distribution bin-counts sum in the $2\sigma$ region around the meson peak and the polynomial integral in the same region. Measured yields are corrected for the limited acceptance and detector effects with the reconstruction efficiency obtained using GEANT3 [15] Monte-Carlo simulation. Simulated $\pi^0$ and $\eta$ mesons are embedded into the real U+U events to account for high occupancy effects in the detector.

3. Results

Figure 1 shows the $\eta$ invariant $p_T$-spectra obtained in four different centrality intervals and minimum bias collisions. The spectra are measured in a large transverse momentum range: up to 14 GeV/c in minimum bias, and up to 14 GeV/c in central and semi central U+U collisions. The major contribution in the measurement systematic uncertainty comes from the meson yields extraction (12% at low $p_T$, 7% intermediate $p_T$ to 10% at high $p_T$).

Figure 2 compares $\eta$ nuclear modification factors measured as a function of $p_T$ and collision centrality in U+U and Au+Au [13, 14] collisions at $\sqrt{s_{NN}} = 192$ GeV and $\sqrt{s_{NN}} = 200$ GeV with similar $\langle N_{coll} \rangle$, respectively. Production of $\eta$ is strongly suppressed in central, semi-central and semi-peripheral collision for both colliding systems. In peripheral U+U collisions the $\eta$ meson yields are slightly more suppressed than in Au+Au, but still consistent within large uncertainty. The $\eta$ meson nuclear modification factors obtained with the Glauber set 1 are slightly larger than ones obtained with the Glauber set 2, but both results are consistent within uncertainties.
Figure 3. Integrated nuclear modification factor of $\pi^0$ Glauber set 1 (●) and $\eta$ Glauber set 1 (▲) mesons in U+U collisions at $p_T>5$ GeV/c as a function of numbers of participants. Error bars and open boxes show statistical and systematic uncertainties, respectively. Boxes at unity show scaling uncertainty.

Figure 3 presents $\eta$ and $\pi^0$ integrated $R_{AA}$ measured in U+U collisions versus $N_{part}$. One can see that $\eta$ meson yields are suppressed in the same way as $\pi^0$ in U+U collisions at similar $N_{part}$ and collision energy.

4. Summary

PHENIX has measured $\eta$ meson production in U+U collisions at $\sqrt{s_{NN}}=192$ GeV at mid rapidity in the transverse momentum range of $2<p_T<14$ GeV/c, using RHIC Run-12 data. In central collisions the meson yield is suppressed by a factor of $\sim 5$ at $p_T>5$ GeV/c compared to the binary scaled $p+p$ reference. Suppression of $\eta$ yields in U+U is the same as in Au+Au at similar energy and the numbers of binary collisions in central collisions within uncertainties. In peripheral U+U collisions low $p_T$ $\eta$ mesons seem to be slightly more suppressed but still agree within uncertainties. Production of $\pi^0$ and $\eta$ mesons is similarly suppressed for all measured numbers of participants, which suggests that suppression occurs at the parton level followed by fragmentation in vacuum.

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