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# Influence of quark content and collision geometry on proton production in heavy ion collisions

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# Influence of quark content and collision geometry on proton production in heavy ion collisions

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**Abstract.** Proton production have been preivously measured in PHENIX experiment in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. It was obtained that protons yields are enhanced over all mesons yields. This phenomenon was called "baryon puzzle". This paper presents mesurements of protons in asymmetric Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV in order to investigate influence of collision geometry. Results in Cu+Au and Au+Au systems were found to be in agreement at similar number of participants, which might indicate that proton production in heavy-ion collision scales with the average size of the nuclear overlap region and do not depends on the details of its shape. In order to investigate influence of quark content on production of protons consisting of three quarks comparison with $\varphi$ , $\pi^0$ -mesons (quark-antiquark pairs) was provided in Cu+Au collisions at the collision energy of 200 GeV. Such information can improve our understanding of quark-gluon plasma and recombination model.

## 1. Introduction

Protons are one of the well-studied baryons, but the process of proton production in relativistic heavy ions collisions is still not well studied. It is possible to study the production of protons in nucleus-nucleus collisions by measuring the factors of nuclear modification ($R_{AB}$ ). $R_{AB}$ is a quantitative characteristic of difference between particle production in nucleus-nucleus (A+A) and proton-proton (p+p) collisions [1].

$R_{AB}$ for protons have been measured in PHENIX experiment [2] in symmetric Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [3]. It was obtained that protons yields are enhanced over all mesons yields. In nucleon-nucleon collisions at $p_T = 3$ GeV/c, only one baryon is produced for every three mesons (1:3), reflecting the larger mass and the requirement of a non-zero baryon number to form the baryon. In Au+Au collisions at RHIC however, baryons and mesons are created in nearly equal proportion (1:1) despite those differences. Therefore, baryon $R_{AB}$ values are enhanced over mesons $R_{AB}$ in Au+Au collisions. This result, known as "Baryon Puzzle", was explained in the frame of recombination models [4]. According to recombination models, partons that are close to each other in phase space (position and momentum) are simply recombined into hadrons. In the frame of recombination models, quarks in QGP are more likely to combine into baryons, than into mesons.

Comparison of Au+Au [5] results with asymmetric Cu+Au system results allows to study the influence of collision geometry on proton production. In order to investigate influence of quark content on production of protons consisting of three quarks, comparison with $\varphi$ , $\pi^0$ -mesons (quark-antiquark pairs) was provided in Cu+Au and Au+Au collisions at the $\sqrt{s_{NN}} = 200$

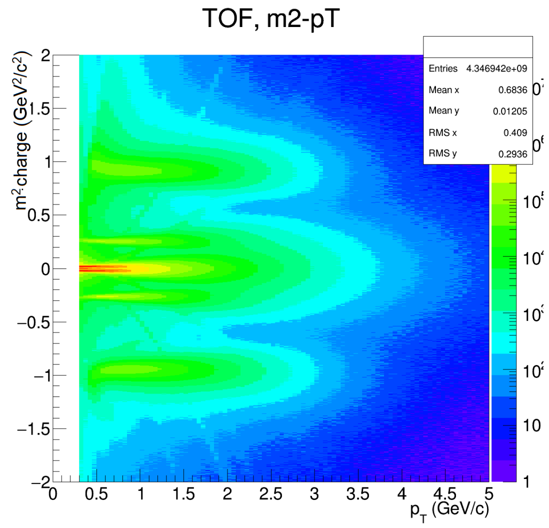


**Figure 1.** 2-d $charge{\cdot}m^2$ distribution

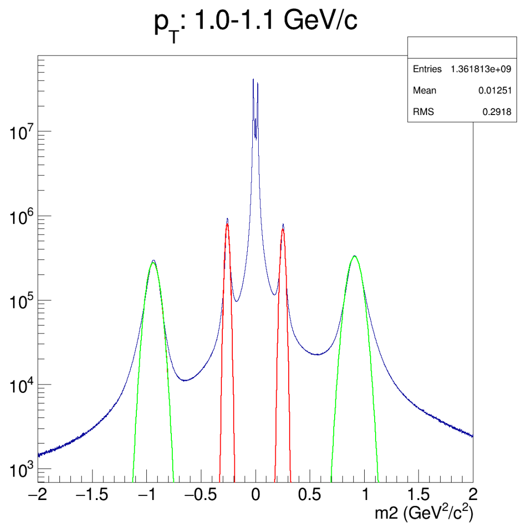


**Figure 2.** Example of 1-d $charge{\cdot}m^2$ distribution for 1.0 GeV/c $< p_T <$ 1.1 GeV/c

GeV. Such information can improve our understanding of quark-gluon plasma hadronization and recombination model.

## 2. Analysis Method

The measurements were done using east PHENIX central arm at mid rapidity ($|y| < 0.35$). Protons are registered in the PHENIX experiment with the help of time of flight detector and drift chambers. Figure 1 shows the distribution of squared mass multiplied by charge of the registered particles versus transverse momentum. The peaks of protons and kaons are well distinguishable and can be approximated by a Gaussian function. An example of such an approximation in the transverse momentum range from 1.0 to 1.1 GeV/c is shown in figure 2. We assume that protons are all particles with a mass in the range of $\pm 2\sigma$ of protons peak. An additional check is also introduced that the particle is not a kaon. That is, the square of its mass does not fall into the $2\sigma$ range of kaons peak.

Obtained protons raw yeilds were used for protons invariant $p_T$ spectra calculation according to the formula:

$$\frac{1}{2\pi p_T}\frac{d^2N}{dp_T\,dy} = \frac{N_p C_{bias}}{2\pi p_T\;N_{evt}\varepsilon_{rec}\Delta p_T\;\Delta y}$$

where $N_{evt}$ is the number of events in a given centrality and $p_T$ , $N_p$ is protons raw yield measured in a given centrality and $p_T$ , $C_{bias} = \varepsilon_{MB}^{BBC}/\varepsilon_p^{BBC}$ , where $\varepsilon_{MB}^{BBC}$ and $\varepsilon_p^{BBC}$ are the beam-beam trigger efficiencies for minimum bias and protons events respectively, $\varepsilon_{rec}$ - the efficiency of protons identification. For $\varepsilon_{rec}$ estimation Glauber Mote-Carlo simulation has been carried out.

As a result, proton $R_{AB}$ can be found as ratio of invariant $p_T$ spectra of protons in A+B collisions ($d^2N_{AB}(p_T)/dydp_T$) and in p+p collisions ($d^2N_{pp}/dydp_T$) normilized by number of binary nucleon-nucleon collisions ($N_{coll}$) according to the formula [1]:

$$R_{AB}(p_T) = \frac{1}{N_{coll}}\frac{d^2N_{AB}(p_T)/dydp_T}{d^2N_{pp}/dydp_T}$$

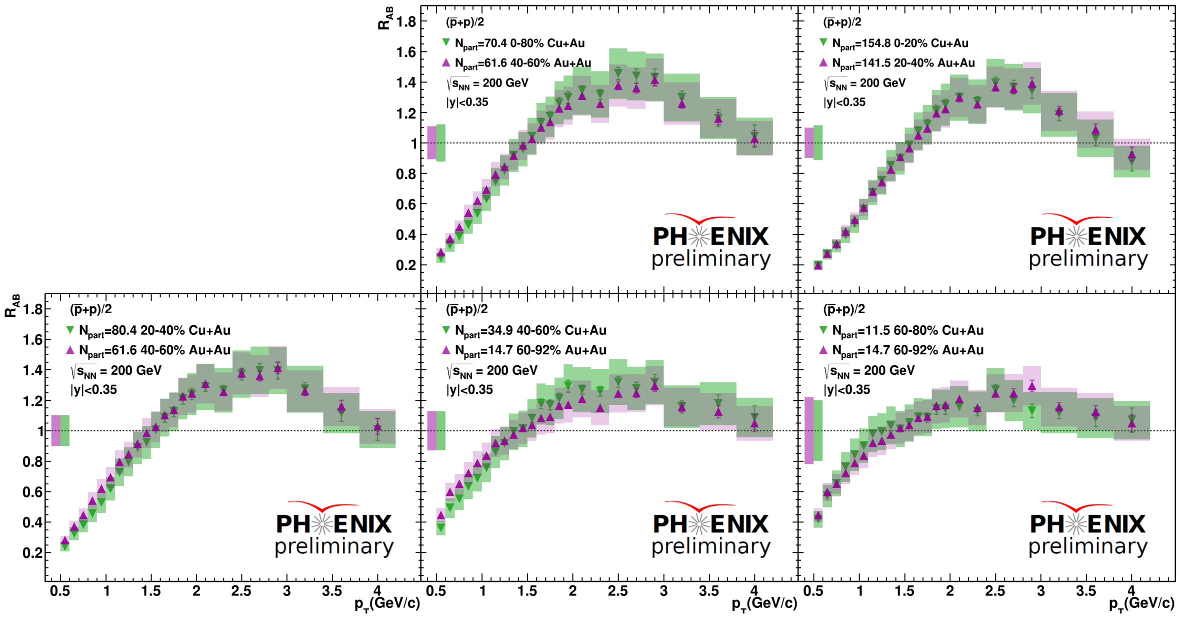


**Figure 3.** Comparison of proton $R_{AB}$ in Cu+Au collisions and Au+Au collisions at $\sqrt{s_{NN}}$ =200 GeV for similar $N_{part}$ values.

## 3. Results

Comparison of protons nuclear modification factors in Cu+Au and AuAu is shown in figure 3. The growth of proton $R_{AB}$ with $p_T$ is explained by the so-called Cronin effect, which leads to an increase in the number of particles with increasing $p_T$ due to multiple rescattering by nucleons of the nucleus [6]. It should be emphasized that the "Cronin peak" is only a qualitative but not quantative explanation of the observed peak. There is no satisfactory description of the dynamic nature of this peak. The results of the research concluded that for Cu+Au and Au+Au collisions $R_{AB}$ values for protons are consistent at similar number of participants. It seems that proton production scales with the average size of the nuclear overlap region and do not depends on the details of its shape.

Another important result is observation of the difference in the protons and mesons $R_{AB}$ [7, 8] in Cu+Au collisions (figure 4). For the most central Cu+Au collisions proton yields are enhanced ($R_{AB} > 1$) at $p_T > 2$ GeV/c, while $\varphi$ and $\pi^0$ -mesons yields are suppressed. Observed difference in $R_{AB}$ values for protons, $\varphi$ and $\pi^0$ -mesons disappears decreasing $N_{part}$.

The ratios of antiprotons to protons are shown in figure 5 are also in good agreement in Cu+Au and Au+Au collisions and weakly depend on the centrality and $p_T$ . The ratio of antiprotons to protons is less than unity, which may be a manifestation of baryon asymmetry.

## 4. Conclusion

Protons invariant $p_T$ spectra and nuclear modification factors have been measured in Cu+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. Proton $R_{AB}$ were found to be in agreement with previous Au+Au results. This fact can indicate that proton production in heavy-ion collision scales with the average size of the nuclear overlap region and do not depends on the details of its shape. Also was observed enhancement of protons $R_{AB}$ over mesons $R_{AB}$ , which disappears from central to peripheral collisions. Such information can improve our understanding of quark-gluon plasma hadronization and recombination model.

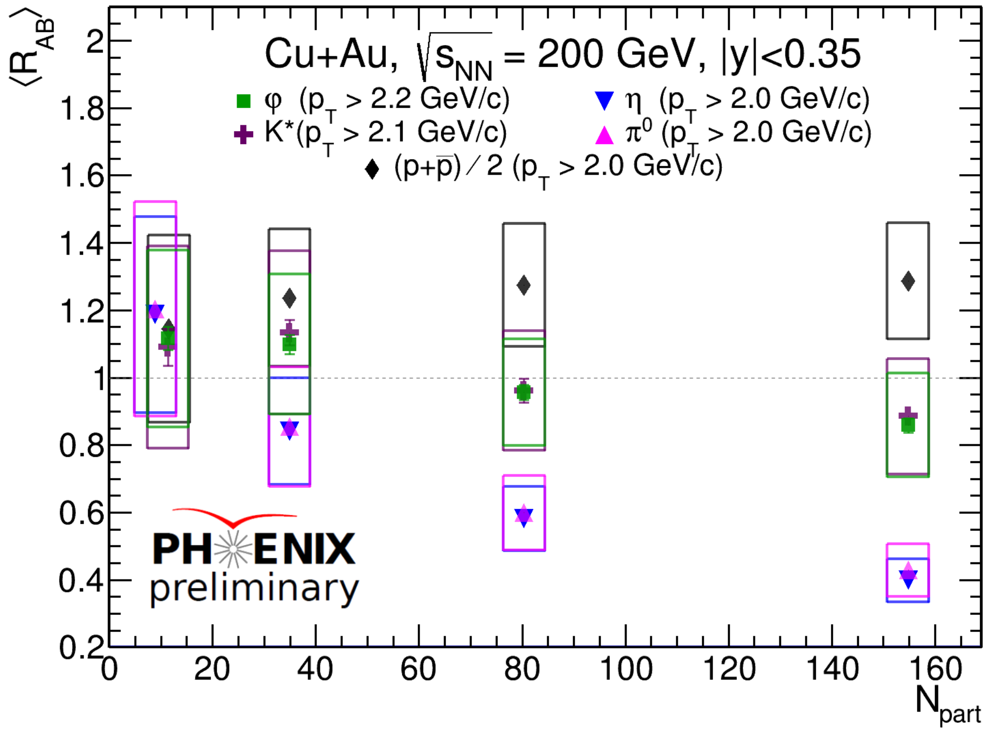


**Figure 4.** Comparison of integrated $\langle R_{AB}\rangle$ for $\varphi, K^*, \eta, \pi^0, (p+\bar{p})/2$ in Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

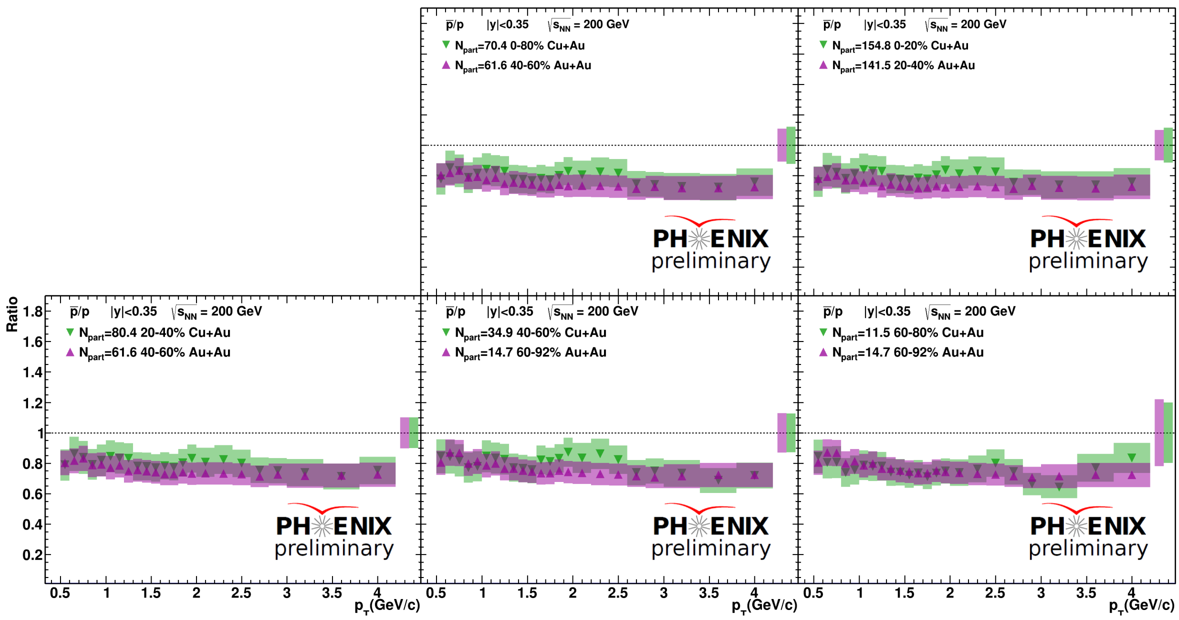


**Figure 5.** Comparison of $\bar{p}/p$ ratos in Cu+Au and Au+Au collisions at 200 GeV at $\sqrt{s_{NN}}$ =200 GeV.

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