Neutral pion production in $\sqrt{s_{NN}}$=200 GeV Cu+Au collisions at PHENIX

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Abstract. Cu+Au collisions at RHIC generate asymmetric initial geometries and densities in both azimuth and rapidity. High p_T π^0s produced in $\sqrt{s_{NN}} = 200$ GeV Cu+Au collisions provide new environments to study parton energy loss in the Quark Gluon Plasma, including very central events where the Cu nucleus is enveloped by the Au nucleus. By measuring π^0 yields in ϕ relative to the event plane, we can probe different core-corona regions in these very central events and study the path length dependence of energy loss in various lopsided initial geometries. PHENIX has observed the suppression of π^0s as a function of the azimuthal angle with respect to the event plane in $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions and found it consistent with a larger than quadratic path length dependence suggesting a non-perturbative energy loss model applies. The unique collision geometries available in Cu+Au provide new settings to explore and possibly confirm this path length dependence. The status of the Cu+Au π^0 analysis is presented.

1. Introduction

High p_T neutral pions serve as a proxy for the jet because the leading particles of a jet are a good measure of jet energy. The suppression of high p_T pions in heavy ion collisions is understood as a consequence of jet quenching in the quark gluon plasma. By considering the reaction plane dependence of high p_T neutral pion production, we can study the path length dependence of the energy loss of the hard parton as it travels through the medium. Furthermore by comparing the neutral pion measurements to reconstructed jet measurements we can study how fragmentation is modified by the medium. In addition to highlighting the novel collision configurations available at RHIC, Cu+Au collisions create asymmetric initial geometries and densities that can test the path length dependence of parton energy loss. This proceeding first discusses the measurements of neutral pions in PHENIX and provides Au+Au results for context. Then the measurements in the Cu+Au collision system are presented.

2. Measuring neutral pions at PHENIX

Neutral pions are measured using photon showers in PHENIX's central arm electromagnetic calorimeters. The calorimeters consist of six sectors of PbSc and two sectors of PbGl calorimeters. Photon shower identification requires a minimum energy of 400 MeV with a shower shape selection in the PbSc. Photon showers in the same sector with an asymmetry, $(E1 - E2)/(E1 + E2)$, of less than 0.8 are combined to form pion candidates. Combinatorial background pairs are determined and statistically subtracted using event mixing with a side-band normalization region. Fig. 1 presents the uncorrected neutral pion yield in various fine

centrality bins. While the efficiency corrections are not yet applied, this measurement extends out to p_T values of between 10 and 15 GeV/c depending on the centrality.
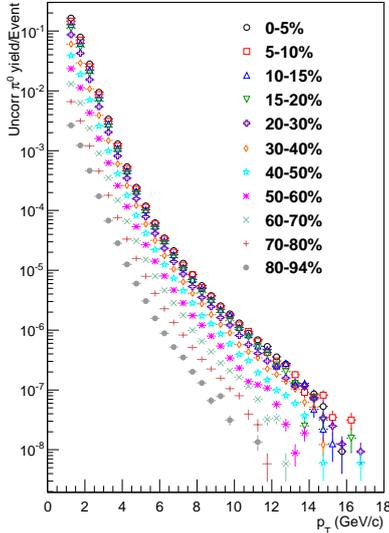
Figure 1. The uncorrected neutral pion yield per event in Cu+Au centrality bins. The centrality bins are as follows: 0-5%(black open circles), 5-10%(red squares), 10-15%(blue upward triangles), 15-20%(green downward triangles), 20-30%(purple open crosses), 30-40%(orange diamonds), 40-50%(cyan stars), 50-60%(magenta asterisk), 60-70%(grey-green x), 70-80%(brown cross), and 80-94%(grey solid circles).

One of the goals of this analysis is the reaction plane dependence of the nuclear modification factor, $R_{AA}(p_T, \Delta\phi)$ where $\Delta\phi$ is the azimuthal angle relative to the event plane. This is done by first measuring the inclusive $R_{AA}(p_T)$ and then determining the relative modulation of the yield in $\Delta\phi$, $F(p_T, \Delta\phi)$ for each p_T value, according to Equation 1.

$$R_{AA}(p_T, \Delta\phi) = R_{AA}(p_T)F(p_T, \Delta\phi) \tag{1}$$

$F(p_T, \Delta\phi)$ is the ratio of the number of counts for a given $\Delta\phi$ over the total number of counts at all $\Delta\phi$. This ratio also contains a correction for the event plane resolution determined from raw v_2^{raw} and the resolution-corrected v_2^{corr} via the factor $(1 + 2v_2^{corr}cos(2\Delta\phi))/(1 + 2v_2^{raw}cos(2\Delta\phi))$.

2.1. Au+Au results
PHENIX has measured the neutral pion $R_{AA}(p_T, \Delta\phi)$ in $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions out to 17 GeV/c in 10% centrality bins [1]. The in-plane R_{AA}, with a $\Delta\phi$ from 0 to 15°, shows less suppression than the out-of-plane R_{AA}, with a $\Delta\phi$ from 75 to 90°. The separation between the in-plane and out-of-plane R_{AA} decreases as number of participants in the collision, N_{Part}, increases and the eccentricity of the overlap region decreases.

In Fig. 2, the PHENIX in-plane and out-of-plane π^0 R_{AA} is compared to various energy loss models, including AMY, higher twist corrections to deep inelastic scattering processes (HT), ASW calculations and ASW with AdS/CFT soft processes(ASW-AdS/CFT). AMY, HT and ASW all show a quadratic path length dependence, while ASW-AdS/CFT has a cubic path length dependence. One recent study suggests that including multiple soft processes will result in a linear path length dependence [2]. However, in this comparison the PHENIX data is best represented by the ASW-AdS/CFT curves suggesting a higher than quadratic path length dependence [1].

3. Cu+Au results
Neutral pion measurements in Cu+Au collisions provide an opportunity to further test these models in a new collision system. Asymmetric Cu+Au collisions generate unique collision
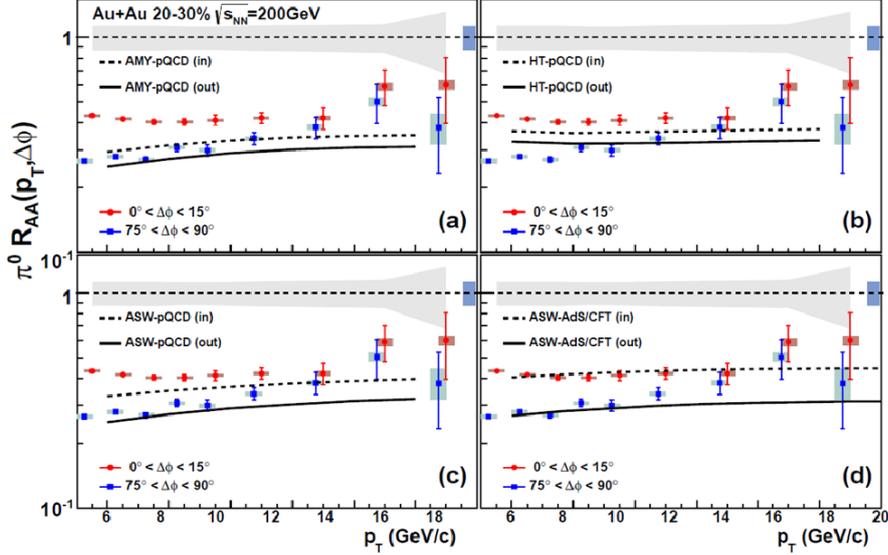
Figure 2. The π^0 R_{AA} in 20-30% Au+Au collisions. Both the in-plane and out-of-plane R_{AA} are shown and are compared to various energy loss theories, including AMY (a), higher twist corrections to deep inelastic scattering processes (b), ASW calculations (c) and ASW with AdS/CFT soft processes (d) [1].

geometries including asymmetric overlap regions, pressure gradients, density profiles and path lengths. Furthermore, measurements of the transverse energy as a function of the number of participants shows that Cu+Au collisions provide access to high energy densities, Fig. 3. The asymmetric nature of Cu+Au collisions were expected to result in angular particle distributions that contain odd flow harmonics not attributed to fluctuations in the initial state. A large positive charged pion v_1 component is measured, Fig. 4. This means that more particles are emitted from the Au-side of the overlap region. This large imbalance in particle production is not seen in symmetric collision systems.

Alternatively, the measured charged hadron v_3 in Cu+Au collisions is small. It shows no significant centrality dependence and comparisons with the charged hadron v_3 in Au+Au and Cu+Cu collisions show no clear system-size dependence. Initially this was surprising as we expected more higher-order odd harmonics, however, AMPT calculations show that the average third-order eccentricity in the Cu+Au system are similar to those in the Au+Au and Cu+Cu systems [4]. In contrast, a large v_2 is measured in Cu+Au collisions for charged hadrons and identified charged pions and protons. The pion and proton v_2 show mass ordering at low p_T and follow valence quark number scaling in all centrality bins. These characteristics, including the v_2 centrality dependence, are all similar to the behavior seen in Au+Au collisions. A clear system-size dependence in the charged hadron v_2 is seen where the v_2 in Au+Au collisions is larger than that in Cu+Au at the same number of participants, N_{Part}. The v_2 in both Au+Au and Cu+Au collisions are larger than the corresponding v_2 in Cu+Cu collisions. These charged hadron and charged pion and proton flow measurements extend out to a p_T of 3 and 2.5 GeV/c respectively. The neutral pion measurements will be able to extend our measurements out to higher p_T, specifically to a p_T of 6 GeV/c for v_1 and v_2.

The Cu+Au charged pion p_T spectrum and R_{AA} is also measured out to a p_T of 2.6 GeV/c. The suppression of charged pions in Cu+Au collisions is very similar to the suppression seen in Au+Au collisions at the same number of participants, N_{part}, and number of binary collisions,
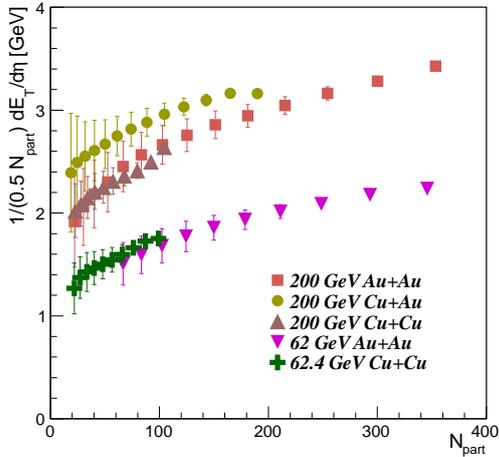
Figure 3. The $1/(0.5N_{Part})dE_T/d\eta$ as a function of the number of participants, N_{Part}, in $\sqrt{s_{NN}}$ = 200 GeV Cu+Au collisions. The Cu+Au results (circles) are compared to the measurements in Au+Au and Cu+Cu collisions at 200 and 62 GeV.
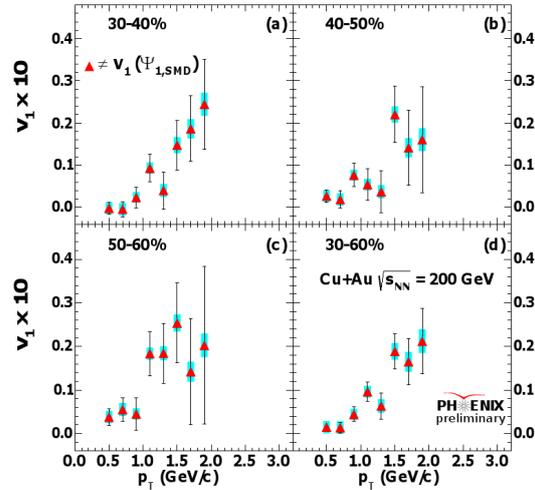
Figure 4. The charged pion v_1 as a function of p_T in the 30-40%, 40-50%, 50-60% and 0-60% centrality bins in Cu+Au collisions is shown. The v_1 is determined relative to the Ψ_1 event plane measured in the SMD, $\Psi_{1,SMD}$ [3].

N_{Coll}. The neutral pion R_{AA} will determine whether this agreement holds out at higher p_T. We expect the π^0 R_{AA} to extend out to a p_T of at least 10 GeV/c.

The unique geometries available in Cu+Au collisions consist of more than asymmetric overlap regions. It is also possible to have events where the Cu-nucleus is embedded in the Au-nucleus. The Cu-nucleus should have very few, almost zero, spectator neutrons resulting in very few hits in PHENIX's Cu-going Zero Degree Calorimeter (ZDC). Looking in the central collisions, in 1% centrality bins, we see that the concentration of events that have no hits in the Cu-going ZDC increases as events become more central. In the most central bin of 0-1%, 70% of the events have no hits in the Cu-going ZDC. Measurement of the π^0 yield in these very central bins will provide access to varying concentrations of these Cu-embedded events and shed light on the medium effects resulting from this unusual geometry.

4. Conclusions

Neutral pion production in Cu+Au collisions is capable of testing our current understanding of energy loss models and determine if the asymmetric behaviors seen at low p_T in charged hadrons extend out to high p_T. Simulations and efficiency corrections are on-going. Of particular interest is the measurement of the nuclear modification factor with respect to the event plane. The possibility of using very central centrality bins and event plane engineering to further study the novel collision geometries available in Cu+Au is very promising.

References

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