PROCEEDINGS OF SCIENCE

Recent Results from The PHENIX Collaboration At RHIC

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The PHENIX experiment at RHIC has collected a huge amount of data on proton-proton, proton-nucleus, and nucleus-nucleus collisions in a wide range of collision energies. The variety of observables which can be measured by the PHENIX detector allowed for detailed and systematic study of the properties of hot and dense nuclear matter, and the conditions necessary for the creation of Quark-Gluon plasma. In this talk I will review the most interesting results from the PHENIX experiment with the focus on recent results on charm/bottom separation, quarkonia suppression, and jet measurements in various colliding systems.

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1. Jets in PHENIX

Jets in proton-proton collisions were measured using anti-k_T algorithm with R=0.3. Figure 1 shows jet p_T spectra in p+p and d+Au collisions measured by PHENIX [1]. On the same figure a prediction for p+p collisions made using perturbative QCD approach [2] is shown as a magenta band. The insert at the bottom shows model to data ratio. As one can see, the prediction is in good agreement with the data. The jet measurement in proton-proton collisions was used a a baseline for Jet study in nucleus-nucleus collisons.

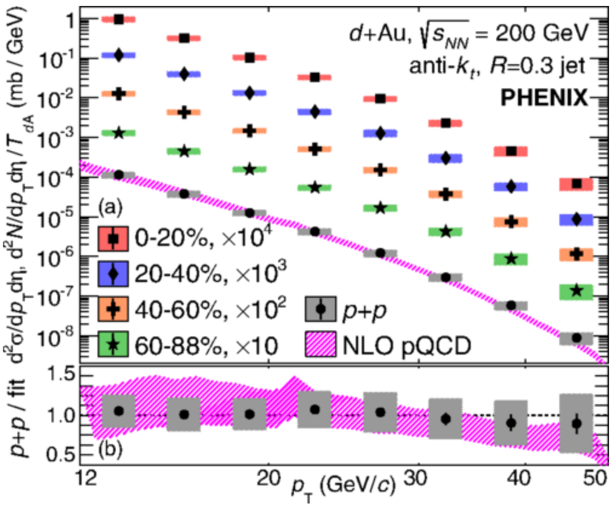

Figure 1: Jet p_T distributions in p+p and d+Au collisions measured by PHENIX (data points), and pQCD prediction [2] for the p+p collisions (megenta band). The inset at the bottom shows data and theory divided by the fit to the data.

Figure 2 shows jet R_{dAu} as a function of p_T for minimum bias d+Au collisions (left), and various centrality d+Au collisions (right). While for minimum bias d+Au collisions the results are consistent with no nuclear modification, in most central collisions the jets appear to be suppressed, but in periferal collisons a rather strong enhancement is observed. One of the possible explanations is scaling of R_{dAu} with parton x. A proton with a high-x parton is effectibvely smaller than average, and will strike fewer nucleons in the nucleus. Smaller than expected number of binary collisions will cause R_{dAu} to be greater than one. Several theoretical efforts are now being launched in this direction [3, 4, 5].

Figure 3 shows jet ispectra in Cu+Au collisions (left) and jet R_{dAu} for various centrality collisions (right). Jet measurement in Cu+Au collisions is complicated by a very large backgropund. To reduce background, smaller ($R = 0.2$) raidus was used in anti-k_T algorithm for jet search. Data-driven underlying event determination was used in order to subtract remaining background. In this method jets were reconstructed from randomly shuffled tracks and clusters. Rate of fake jets was determined to be $\sim 30\%$ at 15 GeV, and dropped down to $\sim 5\%$ at 25 GeV. Suppression factor of about 2 was observed in most central Cu+Au collisions, while most peripheral collisions exibit a hint of enhancement. Inprovement in both statistical and systematic uncertainties is necessary to make final conclusions.

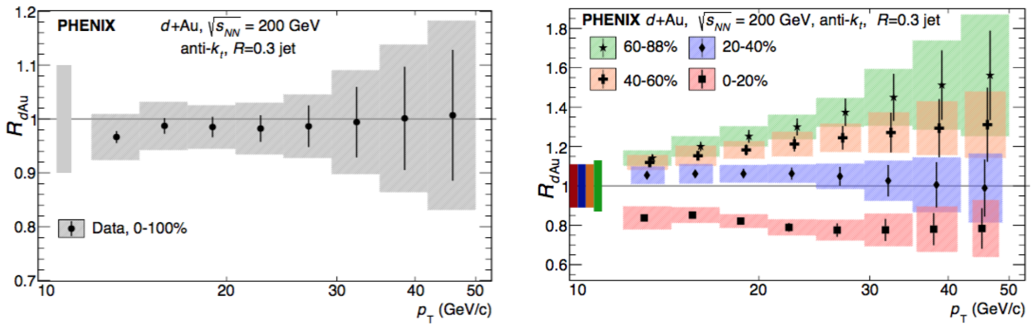

Figure 2: Jet R_{dAu} for minimum bias (left) and various centrality collisions (right).

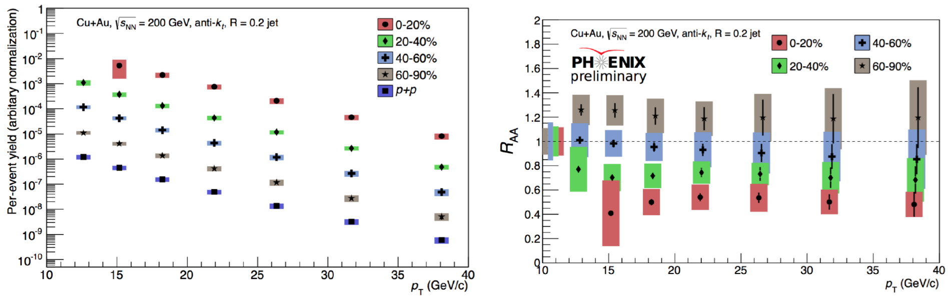

Figure 3: Jet ispectra in Cu+Au collisions (left) and jet R_{dAu} for various centrality collisions (right).

2. Quarkonia in PHENIX

2.1 $\psi(2S)$ to J/ψ ratio in p+Au collisions

Heavy charm quarks are produced in initial hard scatterings, and their production can be calulated in perturbative QCD approach, so the initial state effects are well under control. $c\bar{c}$ pairs form J/ψ and $\psi(2S)$ at the later stages of the collisions. Binding energies of these two charmonium states are very different (640MeV and 50MeV). Thus, the difference between these two states can help us to understand the final state effects in nucleus-nucleus collisions.

The PHENIX experiment has measured previously [6] $\psi(2S)$ nuclear modification factor in d+Au collisions at $\sqrt{s} = 200$ GeV/c. The measurement was done at mid-rapidity. The magnitude and the trend with centraility of $\psi(2S)$ meson suppression turned out to be very different than that of J/ψ [7]. In most central d+Au collisions $\psi(2S)$ suppression was measured to be almost 3 times larger than that of J/ψ. Since the initial state factors in a nucleus, such as shadowing and energy loss, should be the same or very similar for $c\bar{c}$ precursor pairs for both $\psi(2S)$ and J/ψ, something different must be happening in the later stages of the collision.

The new PHENIX measurement of $\psi(2S)$ production in p+p, p+Au and p+Al collisions at $\sqrt{s} = 200$ GeV/c at forward/bacward rapidity may shed light on the relatively large suppression of $\psi(2S)$. Fig. 4 shows the fraction of $\psi(2S)$/J/ψ as a function of transverse momentum (p_T) in proton-proton collisions. Integrated over all p_T, this fraction is around 2%, which is in agreement with the world data (see Fig. 5). This measurement serves as a baseline for the proton-nucleus measurements.

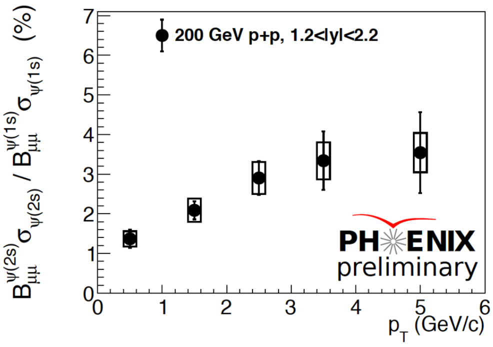

Figure 4: Fraction of $\psi(2S)/J/\psi$ as a function of transverse momentum in proton-proton collisions.

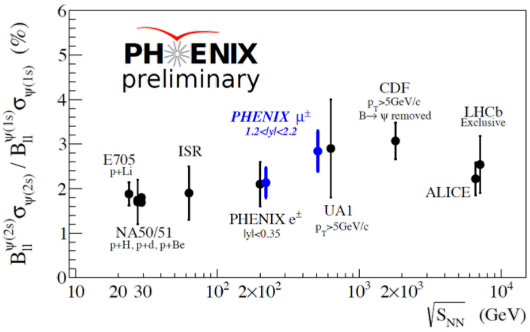

Figure 5: Integrated over p_T $\psi(2S)/J/\psi$ fraction as a function of $\sqrt{s}$.

Fig. 6 shows relative suppression of $\psi(2S)/J/\psi$ as a function of rapidity for p+Au and p+Al collisions, as well as the old d+Au result at mid-rapidity. In the proton-going direction (positive rapidity) suppression of $\psi(2S)$ is, essentially, the same as that of J/ψ, while in the nucleus-going direction (negative rapidity) $\psi(2S)$ are much more suppressed both in p+Au and p+Al collisions. In other words, $\psi(2S)$'s are strongly suppressed in both directions, while J/ψ's are strongly suppressed in proton-going direction, and moderately in nucleus-going direction.

Fig. 7 shows relative suppression of $\psi(2S)/J/\psi$ as a function of transverse momentum. As one can see, the slowest J/ψ, which spend the most time with soft co-movers are completely gone. Thus looks qualitatively different from similar results from the ALICE experiment [8], where little or no dependence on J/ψ transverse momentum is observed. However, both results agree within rather large experimental uncertainties.

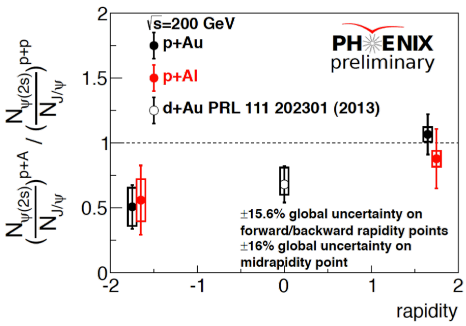

Figure 6: Relative $\psi(2S)/J/\psi$ suppression as a function of rapidity.

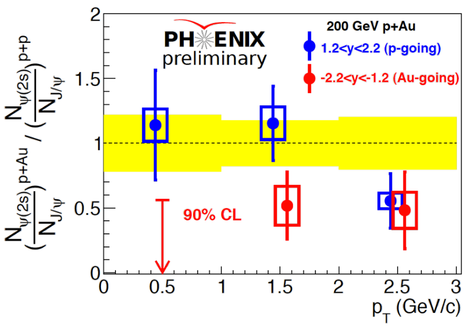

Figure 7: Relative $\psi(2S)/J/\psi$ suppression as a function of transverse momentum.

2.2 $B \to J/\psi$ in p+p and Cu+Au collisions

In nucleus-nucleus collisions J/ψ's produced in B-meson decays are sensitive to different initial and final state effects than directly produced J/ψ's. In p+p collisions $B \to J/\psi$ measurement can help to constrain gluon PDFs in different regions of x and Q^2. The PHENIX experiment has measured $B \to J/\psi$ in p+p and Cu+Au collisions using precise measurement of distance of closest approach (DCA) in the plane perpendicular to the beam using forward silicon vertex detector (FVTX). The measurement was done at forward rapidity ($1.2 < |\eta| < 2.2$).

Fig. 8(left) shows how $B \to J/\psi$ measurement was performed. Black data points show the measured DCA distribution, while curves indicate the background. After background subtraction the DCA distribution for J/ψ coming from B-meson decays remains and is shown in green. Fig. 8(right) shows the measured by PHENIX fraction of J/ψ coming from B-meson decays (red square) compared to the world data.

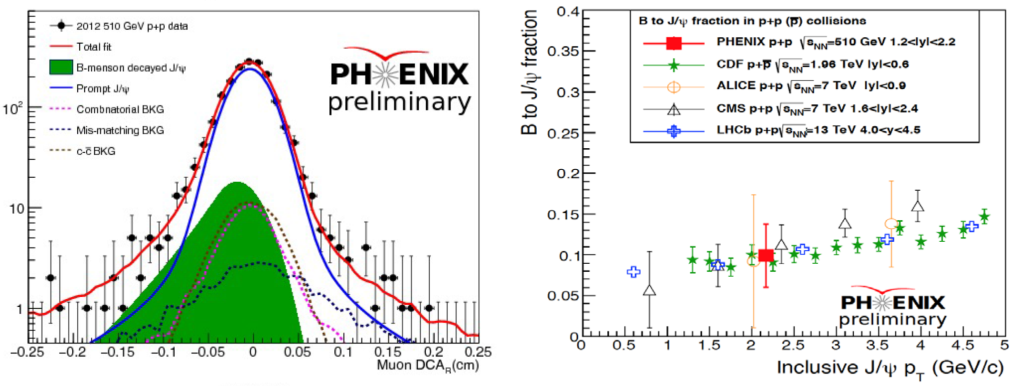

Figure 8: (Left) DCA distribution in p+p collisions. (Right) Fraction of J/ψ coming from B-meson decays measured by PHENIX (red square) compared to the world data.

$B \to J/\psi$ measurement in Cu+Au collisions is compicated by larger background, but is still possible. Fig. 9(left) shows the DCA distribution in Cu+Au collisions, while Fig. 9(right) shows J/ψ R_{AA} minimum bias Cu+Au collisions in Cu-going and Au-going directions. The R_{AA} was calculated from corresponding fractions of J/ψ coming from B decays and assuming that in p+p collisions this fraction is 0.1. Both points are consistent with no suppression, which indicates that B-mesons are less suppressed than J/ψ.

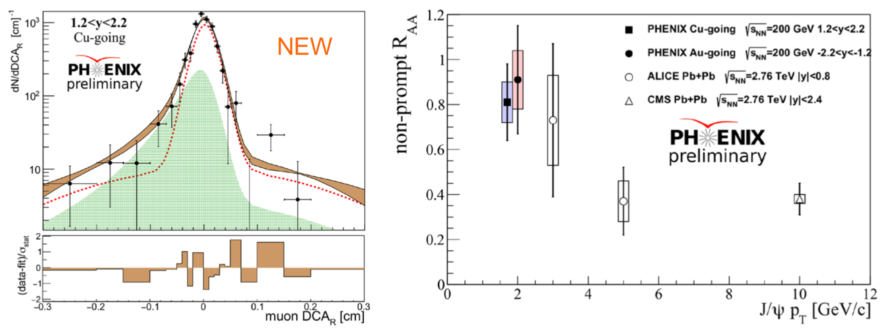

Figure 9: (Left) DCA distribution in Cu+Au collisions. (Right) R_{AA} for J/ψ coming from B-meson dacays compared to the world data.

3. Direct photons in PHENIX

Direct photons don't interact with the hot and dense nuclear matter created in high energy heavy ion collisions, and thus carry undistorted information about the collisions. They are emitted from the earliest time to the final stages of the collision and provide signal from the whole event. Direct photon measurement is compilcated by the large background from hadronic decays.

The PHENIX experiment uses two different methods of direct photon measurement. One is based on photon converstions and involves an analysis of di-electron invariant mass distributions, and the other one uses clusters in the PHENIX Electromagnetic Calorimeter (EMCal) after applying charged particle veto and shower shape cuts.

Direct photon yield and flow are shown in Fig. 10 along with several hydrodynamic model predictions. Simultaneous description of the measured yield and flow pose a serious problem for the theory. Large values of the flow indicate that many direct photons come from the late stages of the collision, when the flow has developed.

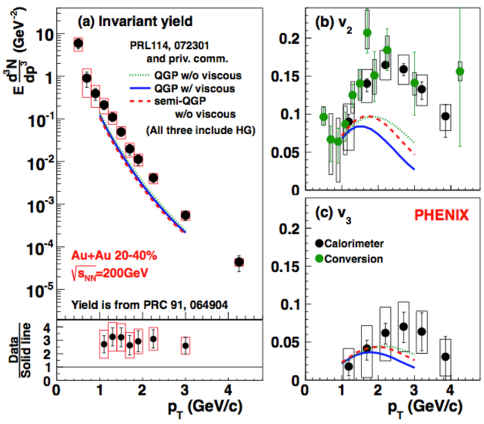

Figure 10: Direct photon yield (left) and flow (right) as a function of transverse momentum. Black data points indicate calorimeter method results, green data points indicate conversion method results.

4. Conclusions

The PHENIX experiment has measured jets in p+p, d+Au, and Cu+Au collisions at $\sqrt{s} = 200 GeV$. Significant enhancement of jets in peripheral d+Au collisions is observed.

In central Cu+Au collisions jets are suppressed by a factor of 2. A hint of enhancement can be seen in most peripheral collisions.

In p+A collisions ψ' suppression is larger than that of J/ψ in Au going direction, and same in p-going direction. Very strong ψ' suppression is observed at low p_T. This indicates the importance of quarkonia breakup by co-movers.

Measured $B \to J/\psi$ fraction in p+p collisions is consistent with that at different $\sqrt{s}$. Small modification in Cu+Au is observed.

Direct photons yield and flow are larger than expected from models. Large flow indicates thjat many direct photons are produced in the late stages of the collision, when the flow has developed.

References

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