Quarkonium production in U+U, Cu+Au, energy dependent Au+Au in PHENIX

Anthony D Frawley Florida State University

On behalf of the **PHENIX** collaboration

QWG 2014 November 13, 2014





PHENIX charmonium detection

Dielectron measurements at midrapidity and dimuon measurements at forward/backward rapidity cover most of the kinematic region of interest at 200 GeV.

D, B $\rightarrow \mu^{\pm}$ $J/\psi \rightarrow \mu^+\mu^-$ D, B $\rightarrow e^{\pm}$ $J/\psi \rightarrow e^+e^-$ -2.2 < y < -1.2-0.35 < y < 0.351.2<y<2.4 $\Lambda \Phi = 2\pi$ $\Delta \Phi = \pi$ PHENIX Detector 2008 North Muon Magn 2008 PHENIX Detector Central Magnet Muon Magner Central Magnet TEC PES MPC ZDC South ZDC North TOF-W RICH MuID MuID PhG RxNP MuTr PCI PCI Aerogel Side View South North Beam View West East

Centrality measurement

The Beam-Beam Counters cover $3.0 < |\eta| < 3.9$.

Detect soft charged particles produced in a collision, and provide:

- The minimum bias event trigger
- The collision Z vertex (from Δt between BBC North and South)
- The collision **centrality** (from the signal size)

In **d+Au** collisions, the signal from only the **Au-going** BBC is used for centrality.

In all other cases the combined BBC signal is used.



PHENIX J/ ψ measurements

200 GeV

- Au+Au
- Cu+Cu
- Cu+Au
- U+U (prelim.)
- 62.4 GeV
 - Au+Au
- **39 GeV**
 - Au+Au

Au+Au J/ ψ at 200 GeV

- 200 GeV
 - Au+Au
 - Cu+Cu
 - Cu+Au
 - U+U (prel.)
- 62.4 GeV
 - Au+Au
- 39 GeV
 - Au+Au

The suppression is strongest at forward rapidity

- Energy density is slightly smaller at forward rapidity
- But CNM effects are different
- Also, underlying charm is smaller at forward rapidity



PHENIX PRC 84 054912 (2011)

N_{part}

Au+Au J/ψ vs energy

- 200 GeV
 - Au+Au
 - Cu+Cu
 - Cu+Au
 - U+U (prel.)
- 62.4 GeV
 - Au+Au
- 39 GeV
 - Au+Au

The suppression seems to be:

- Strongest at 200 GeV
- Weaker at 64 GeV
- Weaker again at 39 GeV



Au+Au J/ ψ vs energy - theory comparison

- 200 GeV
 - Au+Au
 - Cu+Cu
 - Cu+Au
 - U+U (prel.)
- 62.4 GeV
 - Au+Au
- 39 GeV
 - Au+Au

Model: the suppression is similar because at 200 GeV the increased suppression is compensated by increased regeneration.



PHENIX 200 GeV & ALICE 2.76 TeV data

The ALICE J/ψ results show that at LHC energies the suppression is much reduced (compare blue with red).

This is due to a much smaller R_{AA} at low p_T at RHIC energy.

• Combined with large v₂ at LHC, but not at RHIC, suggests **coalescence** is important at LHC.



So 200 GeV Au+Au seems to be close to a **minimum of R**_{AA} (at low p_T) for the J/ ψ .

forward rapidity



$J\!/\psi$ R_{AA} vs system size

- 200 GeV
 - Au+Au
 - Cu+Cu
 - Cu+Au
 - U+U (prel.)
- 62.4 GeV
 - Au+Au
- 39 GeV
 - Au+Au

A hint that U+U is less suppressed than Au+Au.

• Higher energy density does not translate to stronger suppression



Asymmetric collisions - Cu+Au

- 200 GeV
 - Au+Au
 - Cu+Cu
 - Cu+Au
 - U+U (prel.)
- 62.4 GeV
 - Au+Au
- 39 GeV
 - Au+Au

Au-going direction similar to Au+Au. Cu-going direction is more strongly suppressed.

- Qualitatively, what we would expect from shadowing
- Taking the ratio would cancel some systematics..



Cu+Au forward/backward ratio

- 200 GeV
 - Au+Au
 - Cu+Cu
 - Cu+Au
 - U+U (prel.)
- 62.4 GeV
 - Au+Au
- 39 GeV
 - Au+Au

The ratio cancels systematics.

The calculation is **very** simple just $\sigma_{abs} = 4 \text{ mb} + \text{EPS09}$ shadowing

• Effectively shows the **ratio of shadowing effects** at forward/backward rapidity



PHENIX ψ ' measurements

Observation of unexpectedly strong suppression of the Ψ ' in d+Au collisions. Difference from J/ Ψ can not be explained by (any known) CNM effects.

Remarkably, the Ψ ' suppression at RHIC and LHC energies is very similar.

Still an open question what causes this. Comoving matter in the final state?



12

PHENIX Y(1S+2S+3S) measurements

The PHENIX mass resolution does **not** allow us to resolve the Upsilon states in $Y \rightarrow e^+e^-$

Additionally, the small cross section at RHIC makes this a statistically challenged measurement.

Presently we have measurements of the combined yields in p+p and in Au+Au.



PHENIX Y(1S+2S+3S) in p+p & Au+Au

In p+p we have data at all three rapidities covered by PHENIX.

In Au+Au we have only midrapidity data.

So we can make the R_{AA} at midrapidity.



Y(1S+2S+3S) in Au+Au - comparison with CMS

15

Unlike the J/ ψ case, the suppression we see is similar to that seen by CMS at LHC energy.

Roughly consistent with what would be expected from strong suppression of the excited states only.



Y(1S+2S+3S) in Au+Au - theory comparisons

Potential model with rate equation by Emerick, Zhao and Rapp, Eur. Phys. J A48, 72 (2012).

Includes CNM estimates and regeneration effects (small at RHIC).

Potential model with finite momentum space anisotropy by Strickland and Barzov, NP A 879, 23(2012). Does not include CNM effects or regeneration.

The data do not provide much constraint on the theory parameters.



Y(1S+2S+3S) in Au+Au - theory comparisons

Potential model with rate equation by Emerick, Zhao and Rapp, Eur. Phys. J A48, 72 (2012).

Includes CNM estimates and regeneration effects (small at RHIC).

Potential model with finite momentum space anisotropy by Strickland and Barzov, NP A 879, 23(2012). Does not include CNM effects or regeneration.

Adding the STAR data helps, but we obviously need a much better measurement at RHIC



Near future quarkonia measurements with PHENIX

In the 2014 run (completed) have very large luminosity **Au+Au** data set

• Will improve Y(1S+2S+3S) yield significantly.

The **FVTX** detector was installed in front of the muon arms for the 2012 run. It improves the momentum resolution so that the ψ ' can now be separated from the J/ ψ in the muon arms.

- We will have ψ' vs multiplicity data in 500 GeV p+p collisions at mid and forward rapidity from 2013 run data.
- We will have ψ' / J/ψ ratio data vs centrality in Cu+Au collisions from 2012 run data.



18

Near future quarkonia measurements with PHENIX¹⁹

In the 2015 RHIC run we will take p+Au and p+Cu data -

- J/ψ systematics with target mass
- ψ ' at three rapidities in p+Au

Statistical precision estimates



Longer term: sPHENIX Upsilons

For quarkonia, our major goal has always been the characterization of the Debye screening as a function of temperature. The SPS, RHIC and LHC J/ψ results have already shown the value of high quality data covering a broad range of initial temperatures.

The proposed large acceptance **sPHENIX** detector, will make good **separated Upsilon measurements** for comparison with LHC data.



Backups

But different collision energy leads to different CNM effects!

Direct comparison of R_{AA} data at different energies and for different systems is inconclusive - CNM effects are known to vary strongly.

JHEP 0902:014 (2009) 12 $\sigma_{abs}^{J/V}$ ($\mathbf{y}_{cms} = \mathbf{0}$) [mb] EKS98 O NA3 J/w A NA50-400 10-= 158 GeV NA50-450 0.28<v<0.78 E866 NA60 HERA-B PHENIX ... = 400 GeV V<0.35 -0.17<y<0.33 6 power-law 200 20 80 140 100 120 160 180 √S_{NN} [GeV]



Centrality dependence of J/ψ modification in d+Au

Strong centrality dependence **not** expected from EPS09s or breakup. CGC model seems to get it at forward rapidity.



Wednesday, November 12, 14

But do we believe the centrality measurement?

Yes.

Detailed discussion of method used by PHENIX, and comparison with a HIJING study in arXiv:1310.4793.

Conclusion: Bias corrections are fairly small, and under control.



J/ψ vs HF lepton modification in d+Au collisions

Comparison of p_T dependence of J/ψ modification with that for **open HF** leptons is instructive (**Matt Durham's** talk, today)

Caveat: Different kinematics!

The J/ ψ suppression at **backward rapidity** is much stronger than for HF.

• Implies J/ψ is suppressed **beyond** the underlying HF production.

At forward rapidity they are similar.

• Implies J/ψ suppressed at forward rapidity **because** the underlying HF is suppressed.

Consistent with

- Breakup at backward rapidity
- A process like energy loss of a colored dipole in CNM at forward rapidity.



J/ψ modification at forward rapidity in d+Au

Models of parton radiative energy loss (Arleo et al., JHEP 1305 (2013) 155; Sharma and Vitev, Phys.Rev. C87 (2013) 044905) and absorption (Kopeliovich et al., Nucl.Phys. A864 (2011) 203; Ferriero et al., Few Body Syst. 53 (2012) 27).

These seem to describe J/ψ data over a **broad CM energy range**.



Wednesday, November 12, 14

What were we expecting?

If ψ ' suppression was due to breakup of a colorless expanding meson by nucleons, it should be **identical to the J/\psi suppression**:

• At y=0 at 200 GeV, τ is so short the final meson size difference between J/ ψ and ψ ' does not come into play.



Possible explanations of strong ψ ' suppression?



But there seems to be a systematic increase of ψ ' to J/ ψ relative modification with multiplicity.

NA38 p+A

NA50 p+A HERA-B p+A

PHENIX d+Au MB

100

dN_{ch}/dŋ|^{HIJING}

1000

NA50 Pb+Pb NA38 S+U

- hot matter effect?

10



Wednesday, November 12, 14

1.8