A SCENIC OVERVIEW OF J/ψ PRODUCTION IN HEAVY ION COLLISIONS AT PHENIX

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Introduction

- This is an overview of the PHENIX J/ψ results in hot nuclear matter, ie QGP.
- I'll be showing R_{AA} and v_2 in Au+Au collisions, as well as R_{AA} from Cu+Cu collisions.
- Hopefully by the end you'll have a nice overview of the current landscape.

Why J/ψs?

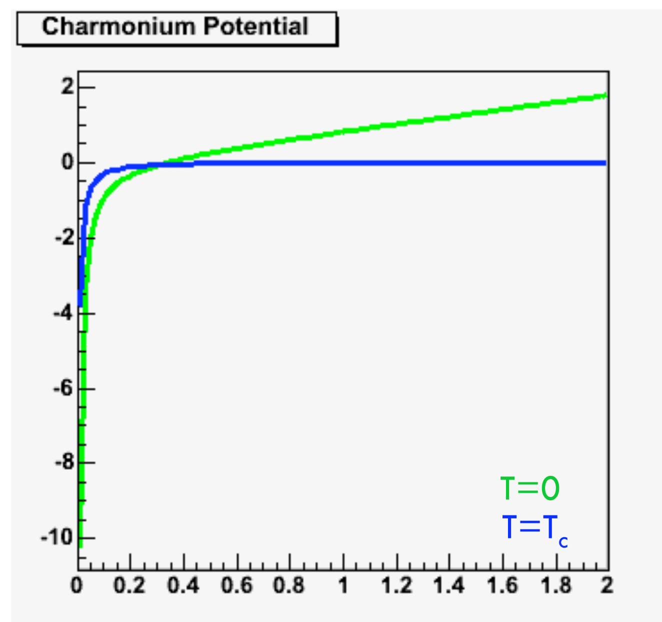
- *"If high energy heavy ion collisions lead to the formation of a hot quark-gluon plasma, then colour screening prevents $c\bar{c}$ binding in the deconfined interior of the interaction region."*

  \- Matsui & Satz, 1986

- Debye screening (from EM plasmas) is a modification a particle's potential due to the charge density of the surrounding medium.

- One way to look at it is that the charmonium potential well is modified in the medium to become much shallower.

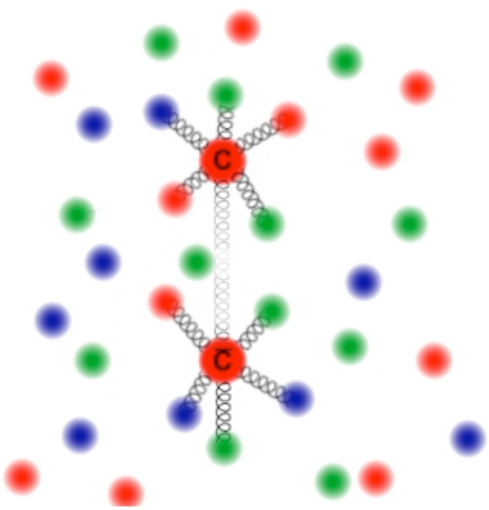
$$V(r) = \kappa r - \frac{\alpha_{eff}}{r} \longrightarrow V(r) = -\frac{\alpha \, e^{-r/\lambda_D}}{r}$$



J/ψs Unbound

- Another view is that the energetic short-range interactions in the QGP overwhelm the charmonium binding interaction.

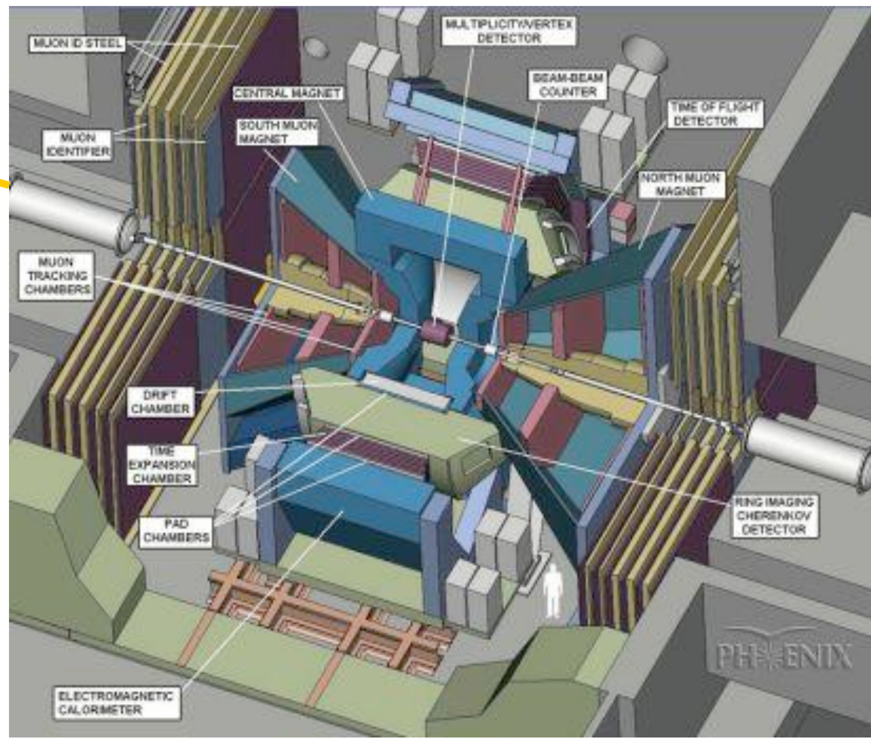
- The charm and anti-charm become unbound, and may combine with light quarks to emerge as open charm mesons.



The PHENIX Detectors

Drift Chamber, Pad Chamber, EMCal & RICH detect $J/\psi \rightarrow ee$ at mid-rapidity.

Au ion
$y<0$



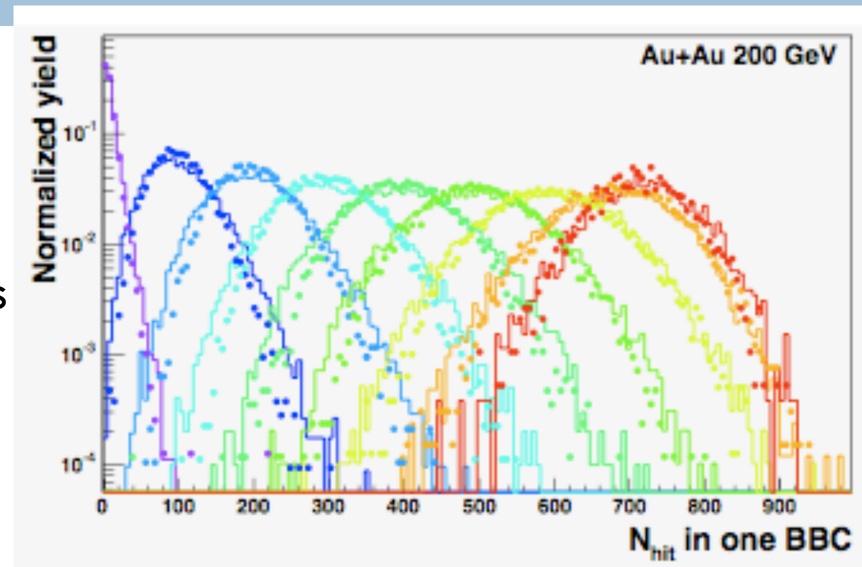
Beam-Beam Counter used to measure centrality and collision z-position.

MuTr and MuID detect $J/\psi \rightarrow \mu\mu$ at forward rapidities.

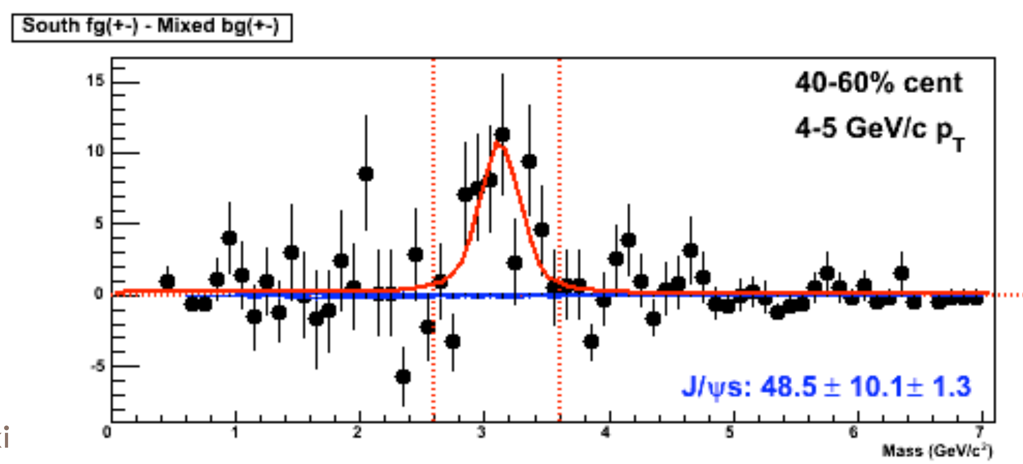
Au ion
$y>0$

Measuring the J/ψ at PHENIX

- Use a Glauber model combined with a Negative Binomial distribution of particles going into the BBC ($3<|\eta|<3.9$) to map centrality classes to N_{part}, N_{coll}, etc.



- Extract J/ψ by removing the combinatoric background either through like-sign subtraction or event mixing, then fitting the remaining peak.



Studying J/ψ Suppression with R_{AA}

R_{AA}

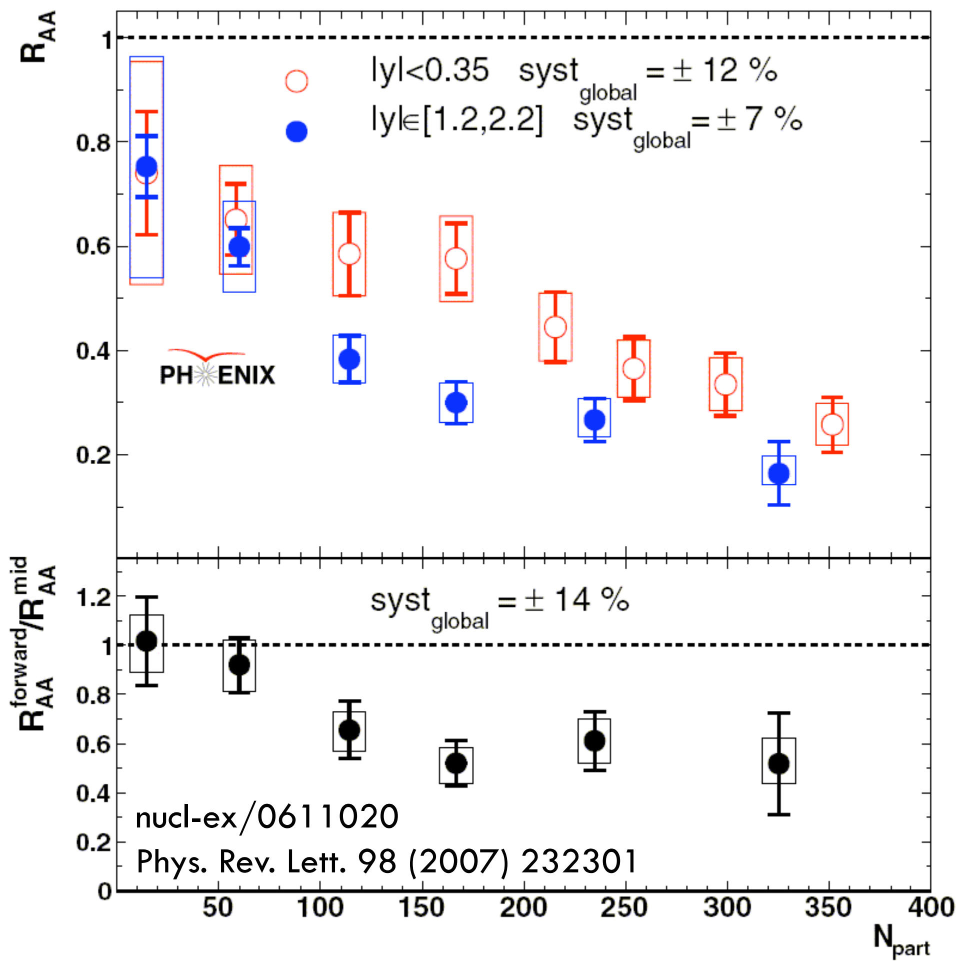
- Take the yields from nuclear collisions and divide by p+p yields, scaled by the appropriate number of binary collisions (N_{coll}).

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN^{AuAu}/dy}{dN^{pp}/dy}$$

- Deviations from unity should first be compared to CNM effects. Any remaining suppression can be attributed to the deconfined medium (QGP).

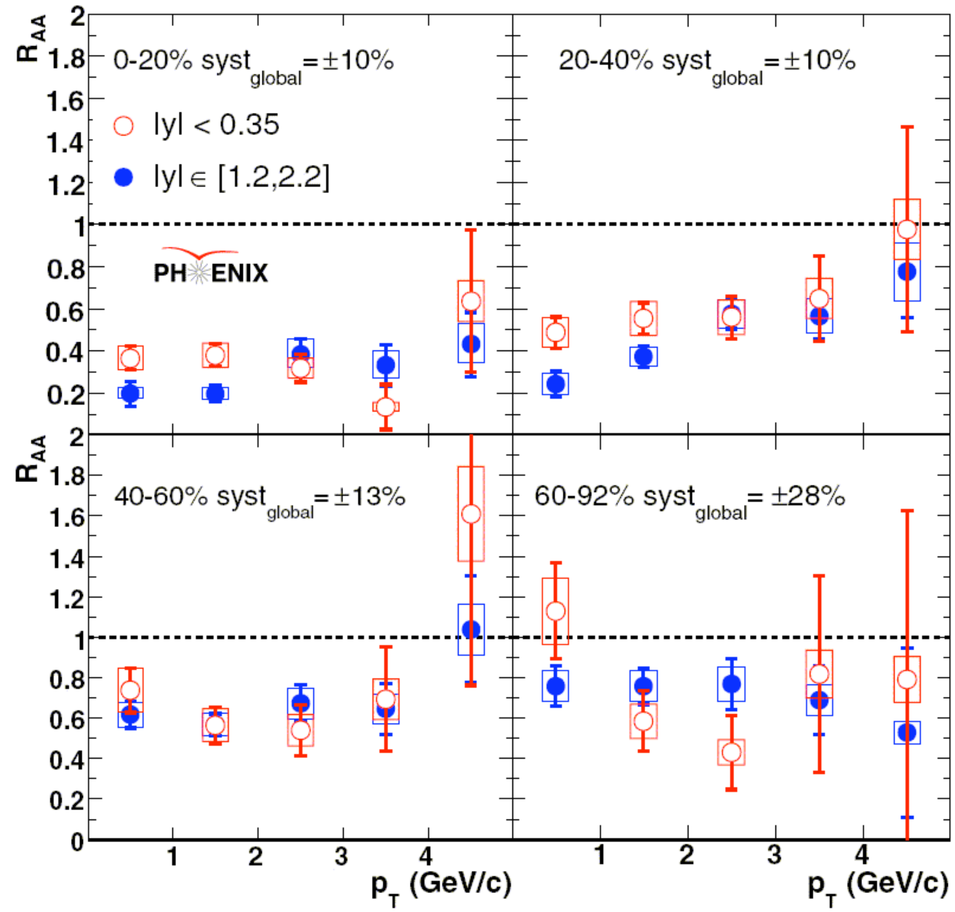
R_{AA} vs. N_{part} in 200GeV Au+Au

- Obvious suppression in more central collisions (larger N_{part}).
- Larger suppression at forward rapidity than mid-rapidity.
- Need better CNM constraints to ***really*** test QGP screening. Hopefully Run 8 d+Au data will provide that.



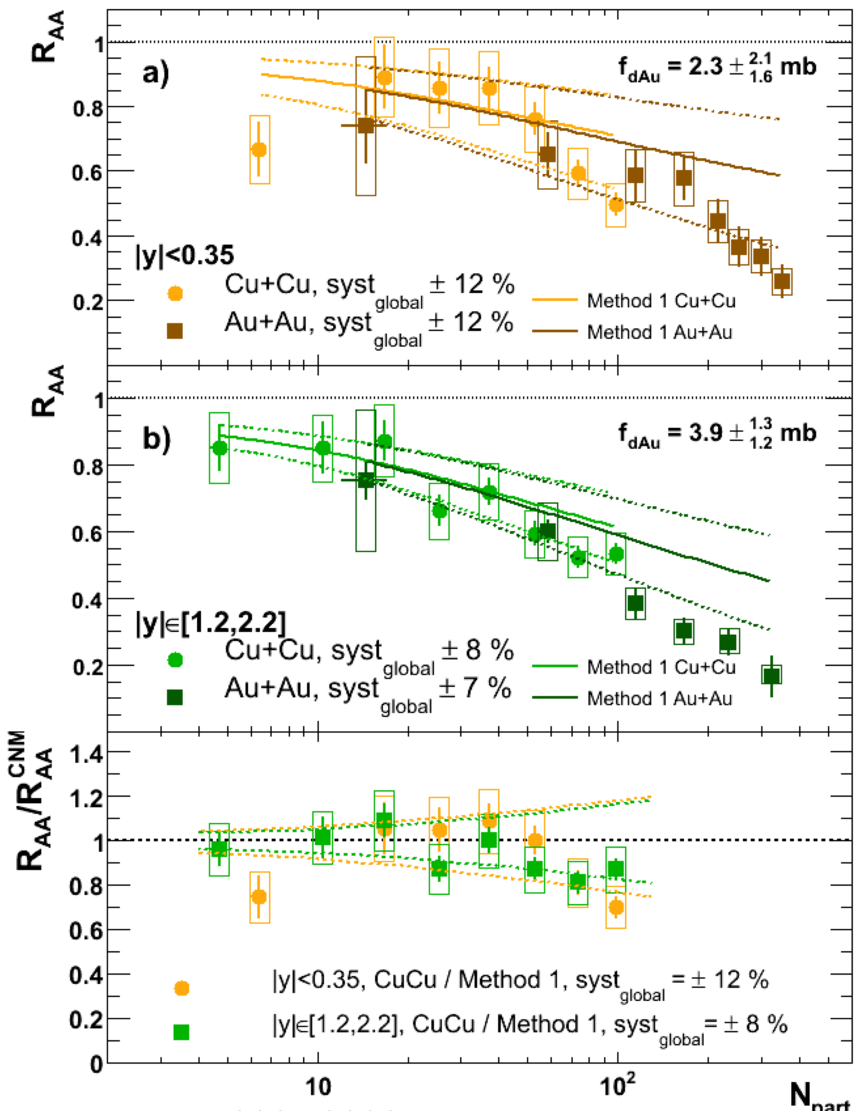
R_{AA} vs. p_T in 200GeV Au+Au

- Less suppression at higher p_T in 20-60% central.
- Much interest in p_T dependence recently, esp. at higher p_T. See for example:
  Zhao & Rapp, arXiv:0806.1239
  Z. Tang (STAR) arXiv:0804.4846
- We hope to push higher in p_T with Run 7, but still very hard with current statistics.



nucl-ex/0611020
Phys. Rev. Lett. 98 (2007) 232301

R_{AA} vs. N_{part} in 200GeV Cu+Cu



arXiv: 0801.0220

- Run 5 Cu+Cu J/ψ results available on the arxiv and accepted by PRL.

- Cu+Cu R_{AA} is in line with CNM projections from d+Au (central lines in panels a &b), while Au+Au is further suppressed.

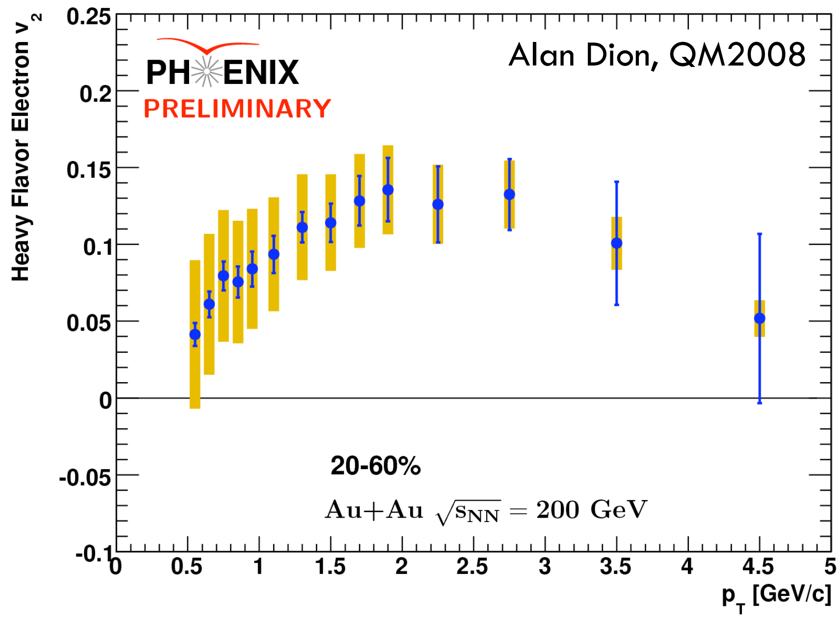
Studying J/ψ Formation with v_2

Elliptic Flow

- Precise measurements of the flow of heavy quarks could tell us about how they thermalize with the medium, as well as how many J/ψs come from recombination.

- We expect J/ψs which are formed via recombination to inherit the flow properties of the individual charm quarks. And, we already know that open charm mesons flow.

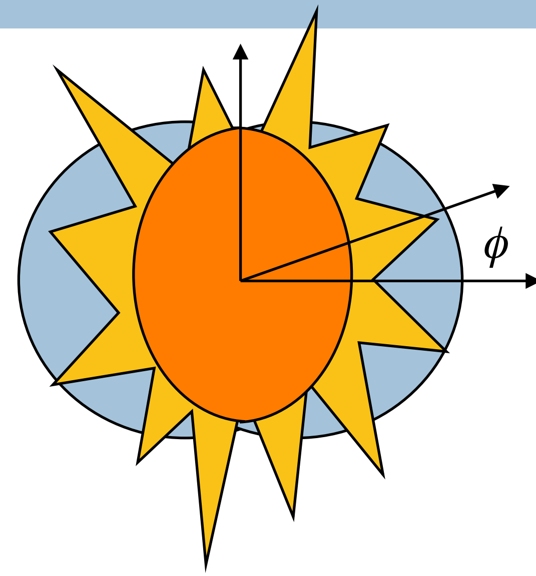
- So a large J/ψ v_2 could indicate that most J/ψs are coming from recombination. Could also manifest as a difference between forward and mid-rapidity.

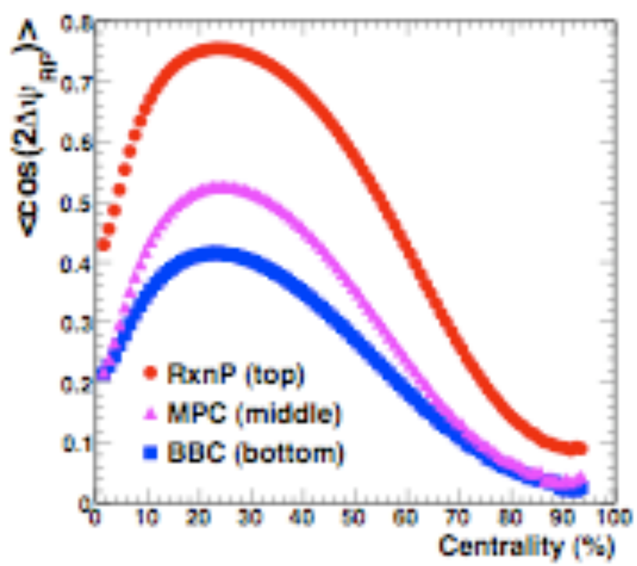


Reaction Plane and v_2

$$v_2 = \langle cos2(\phi - \Psi_{RP}) \rangle$$

$$v_2^{actual} = v_2^{meas} / \langle cos2(\Psi_{RP}^{actual} - \Psi_{RP}^{meas}) \rangle$$



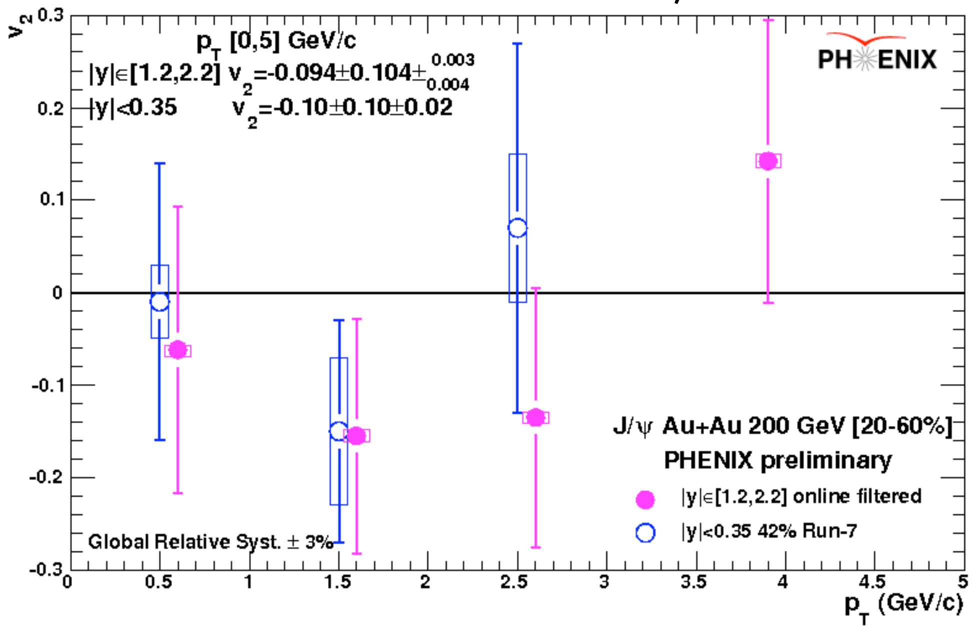


- In Run 7, PHENIX used the new Reaction Plane Detector, allowing for almost a factor of 2 improvement in reaction plane resolution.

J/ψ v_2 in Run 7 Au+Au collisions

- A bit underwhelming at the moment. A small improvement to the dimuon result is expected from analyzing the minimum-bias sample.

Catherine Silvestre, Hard Probes 2008



- For dielectrons, this is only 42% of the Run 7 data, so a larger improvement could be had, but still $\sim\sqrt{2}$.

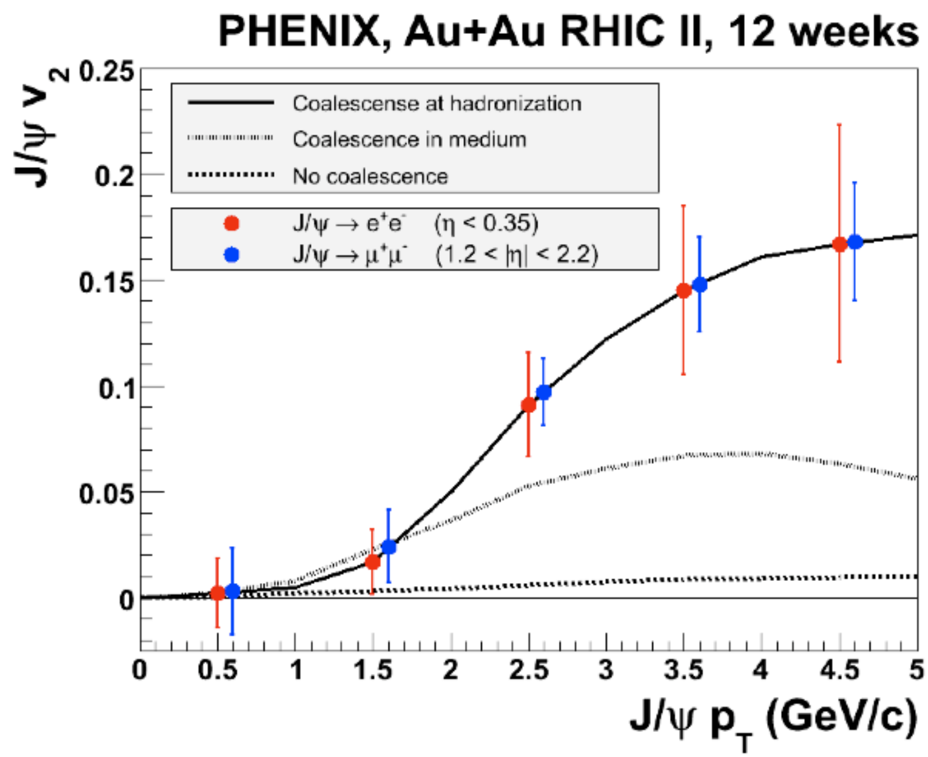
- Most consistent with zero or negative v_2.

- Really need RHIC II luminosities to make a precise measurement.

Projections for RHIC II

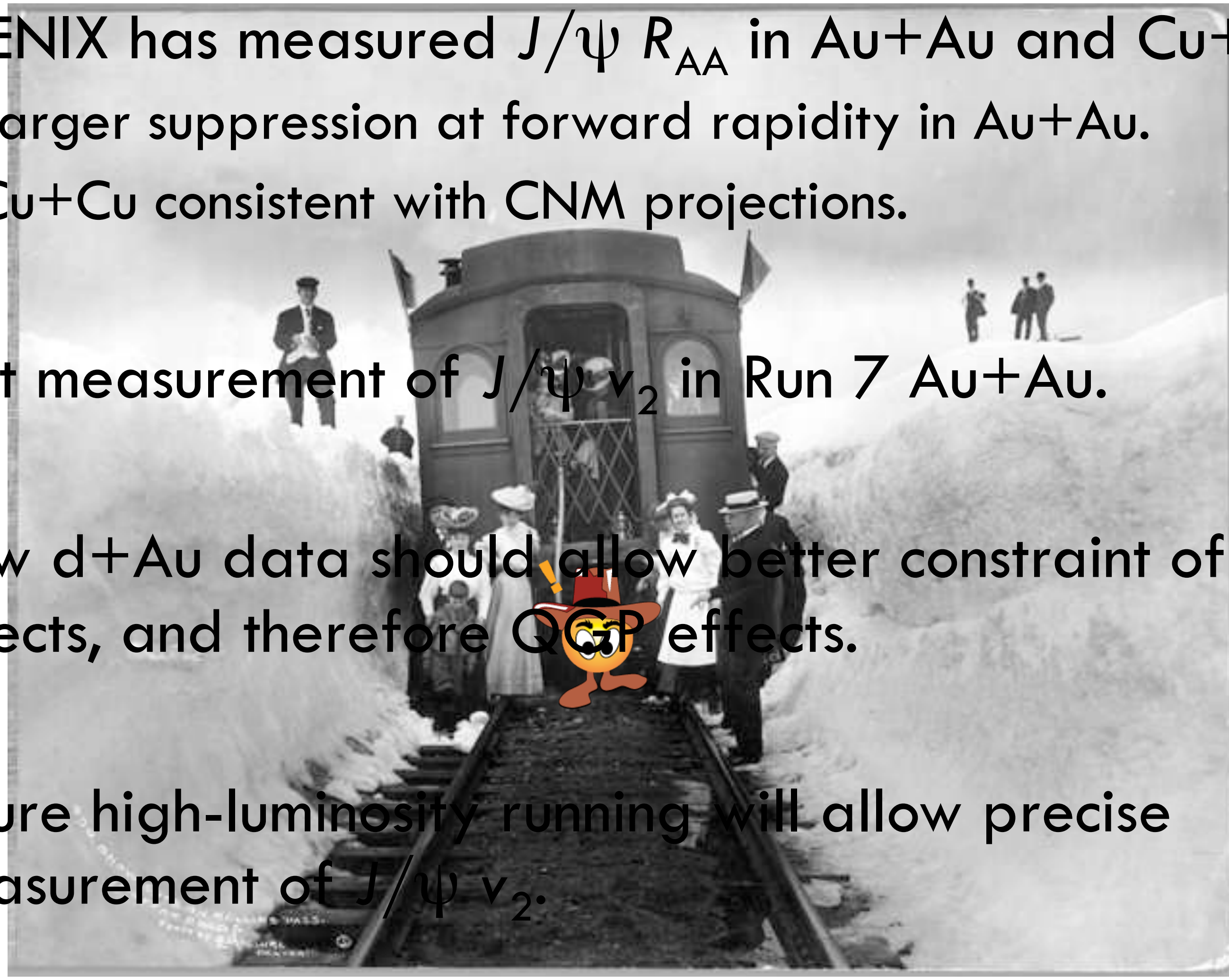
- We can use a simple MC or an analytic expression to estimate the error on v_2 for a given sample size (RHIC II projection).

- Also incorporate PHENIX RP resolution and J/ψ signal/background.



$$\delta(v_2) = \sqrt{\frac{1-2v_2^2}{2N}} \approx \frac{1}{\sqrt{2N}}$$

Summary



- PHENIX has measured J/ψ R_{AA} in Au+Au and Cu+Cu.
  - Larger suppression at forward rapidity in Au+Au.
  - Cu+Cu consistent with CNM projections.
- First measurement of J/ψ v_2 in Run 7 Au+Au.
- New d+Au data should allow better constraint of CNM effects, and therefore QGP effects.
- Future high-luminosity running will allow precise measurement of J/ψ v_2.

*All wildlife photos taken in Rocky Mountain National Park

Backups

v_2 Statistical Error

We'll call our randomly distributed variable X:

$$X = cos2\Phi$$

Now we can write down some basic statistical quantities:

$$\langle X \rangle = \langle cos2\Phi \rangle = v_2 \quad \langle X^2 \rangle = \langle cos^2 2\Phi \rangle = \frac{1}{2}$$

$$Var(X) = \langle X^2 \rangle - \langle X \rangle^2 = \frac{1}{2} - v_2$$

But we'll be taking multiple samples, so our measurement is the mean of X, and the statsistcal error is the sqrt of the variance.

$$Var(\bar{X}) = \frac{1}{N} Var(X) \qquad \delta(\bar{X}) = \sqrt{\frac{1 - 2v_2^2}{2N}}$$

PHENIX 200 GeV

Assumes one NCC arm in 2011, two NCC arms in 2013.

Species	Signal	$\|\eta\|$	To Date	2009	2011	2013
pp	$J/\psi \to e^+e^-$	< 0.35	$\sim$ 1,500	30,000	29,000	46,000
	$J/\psi \to \mu^+\mu^-$	$1.2 - 2.4$	$\sim$ 8,000	256,000	249,000	393,000
	$\psi' \to e^+e^-$	< 0.35	–	540	530	830
	$\psi' \to \mu^+\mu^-$	$1.2 - 2.4$	–	4,600	4,500	7,100
	$\chi_c \to e^+e^-\gamma$	< 0.35	–	2,000	1,900	3,000
	$\chi_c \to \mu^+\mu^-\gamma$	$1.2 - 2.4$	–		37,000	116,000
	$\Upsilon \to e^+e^-$	< 0.35	–	115	110	180
	$\Upsilon \to \mu^+\mu^-$	$1.2 - 2.4$	$\sim$ 27	290	280	440
	$B \to J/\psi X \to e^+e^-$	< 0.35	–	160	155	240
	$B \to J/\psi X \to \mu^+\mu^-$	$1.2 - 2.4$	–	1,600	1,500	2,400
Au+Au	$J/\psi \to e^+e^-$	< 0.35	$\sim$ 800	13,500	14,600	22,400
	$J/\psi \to \mu^+\mu^-$	$1.2 - 2.4$	$\sim$ 7,000	119,000	129,000	198,000
	$\psi' \to e^+e^-$	< 0.35	–	240	260	400
	$\psi' \to \mu^+\mu^-$	$1.2 - 2.4$	–	2,150	2,300	3,600
	$\chi_c \to e^+e^-\gamma$	< 0.35	–	890	960	1,500
	$\chi_c \to \mu^+\mu^-\gamma$	$1.2 - 2.4$	–		19,000	59,000
	$\Upsilon \to e^+e^-$	< 0.35	–	120	130	200
	$\Upsilon \to \mu^+\mu^-$	$1.2 - 2.4$	–	310	340	520
	$B \to J/\psi X \to e^+e^-$	< 0.35	–	170	190	290
	$B \to J/\psi X \to \mu^+\mu^-$	$1.2 - 2.4$	–	1,700	1,900	2,900