Heavy quarkonia production in relativistic d+A and A+A collisions at RHIC, measured by the PHENIX experiment

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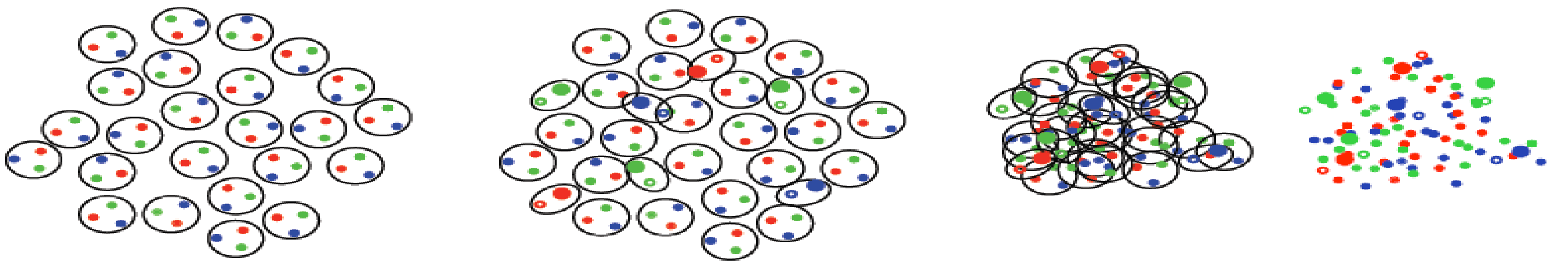
Rencontres de Moriond – March 14, 2010

Outline

- Brief introduction on QGP in Heavy Ion collisions
- Heavy quarkonia production in HI collisions
- Selected J/ψ results in dA and AA collisions
- Selected Υ results in dA and AA collisions

Quark Gluon Plasma in Heavy Ion collisions

Qualitatively:

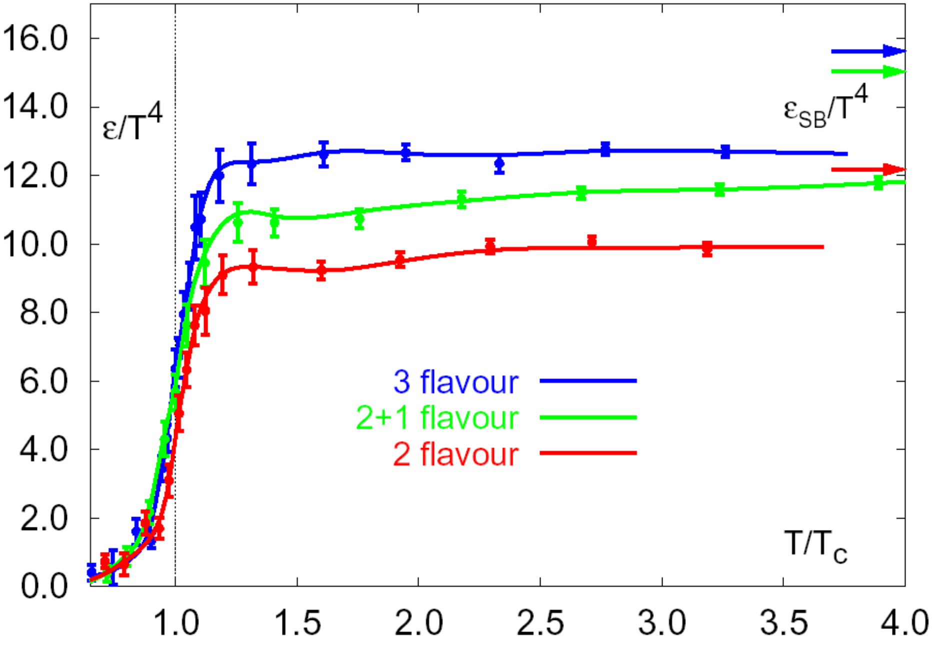


Normal nuclear matter Heating Compression Deconfinment

Lattice QCD calculations:

Number of degrees of freedom in nuclear matter vs Temperature

Exhibits a critical temperature T_c above which quarks and gluons are the correct degrees of freedom that describe the medium



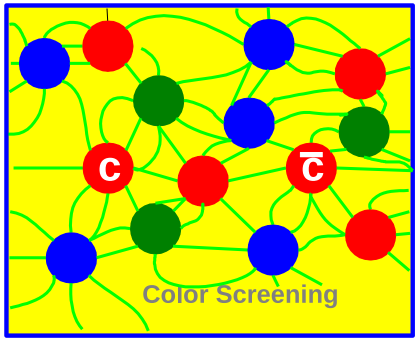
Heavy quarkonia in HI collisions (1)

Heavy quarkonia are good candidates to probe the QGP in heavy ion collisions because:

- they have large masses and are (dominantly) produced at the early stage of the collision, via hard-scattering of gluons.
- they are strongly bound (small radius) and weakly coupled to light mesons.

	mass	radius
J/ψ	3.1 GeV	0.50 fm
ϒ	9.5 GeV	0.28 fm

Sensitive to the formation of a quark gluon plasma via color screening:



State	J/ψ	ϒ
T_{dis}	1.2 T_c	2 T_c

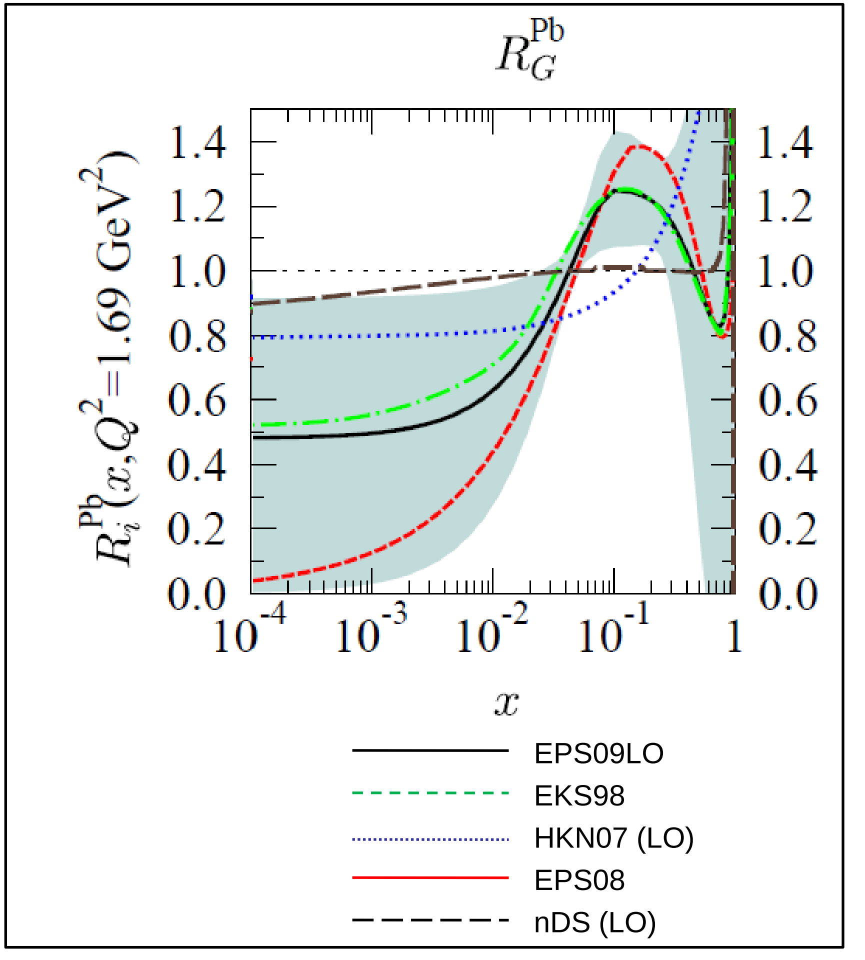
T_c: QGP formation temperature
T_{dis}: quarkonia dissociation temperature

Heavy quarkonia in HI collisions (2)

Cold nuclear matter effects:
Modifications of heavy quarkonia production in absence of a QGP

- Modification of the parton distribution function (pdf) in nuclei
- Dissociation by surrounding hadrons breakup cross-section $\sigma_{breakup}$
- Initial state energy loss
- Cronin effect
- Other mechanisms (gluon saturation/CGC)

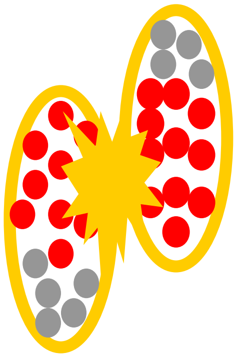
So far, mainly the first two effects (pdf modifications and $\sigma_{breakup}$) have been addressed quantitatively



Tools to study heavy ion collisions (1)

Collision characterization:

Centrality is related to the distance between the center of colliding nuclei (impact parameter b)



Central collisions: small b
Peripheral collisions: large b

N_{part} is the number of nucleons participating to the HI collision
N_{coll} is the number of binary (pp) collisions in one HI collision
Both increase from peripheral to central collisions

Collision	N_{part}	N_{coll}
d+Au (all centralities)		7.6 ± 0.3
Au+Au (all centralities)	109 ± 4	258 ± 25
Au+Au (10% most central)	325 ± 3	955 ± 94

Tools to study heavy ion collisions (2)

Particle production characterization:

$$R_{AA} = \frac{\text{yield in AA (or dA)}}{N_{coll}\text{. yield in pp}}$$

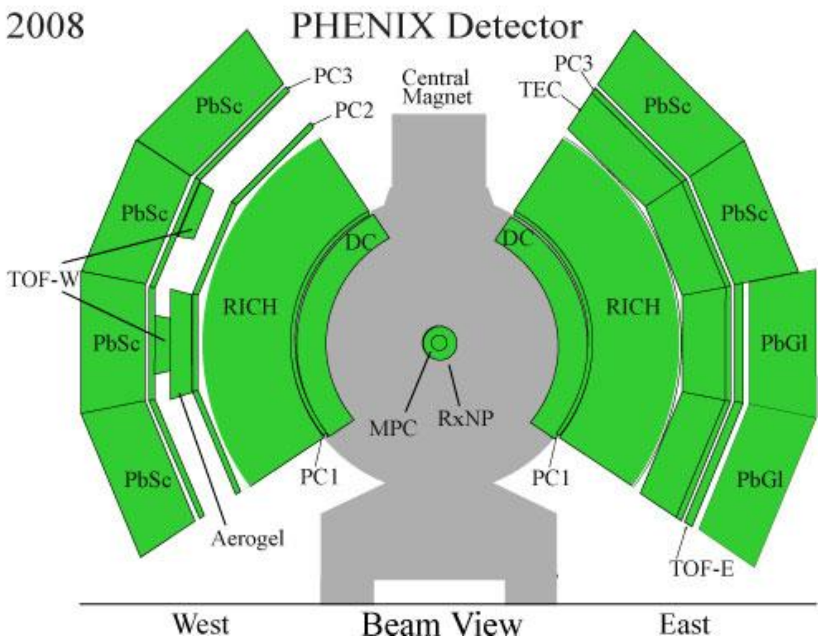
Nuclear modification factor to compare p+p to d+A or A+A

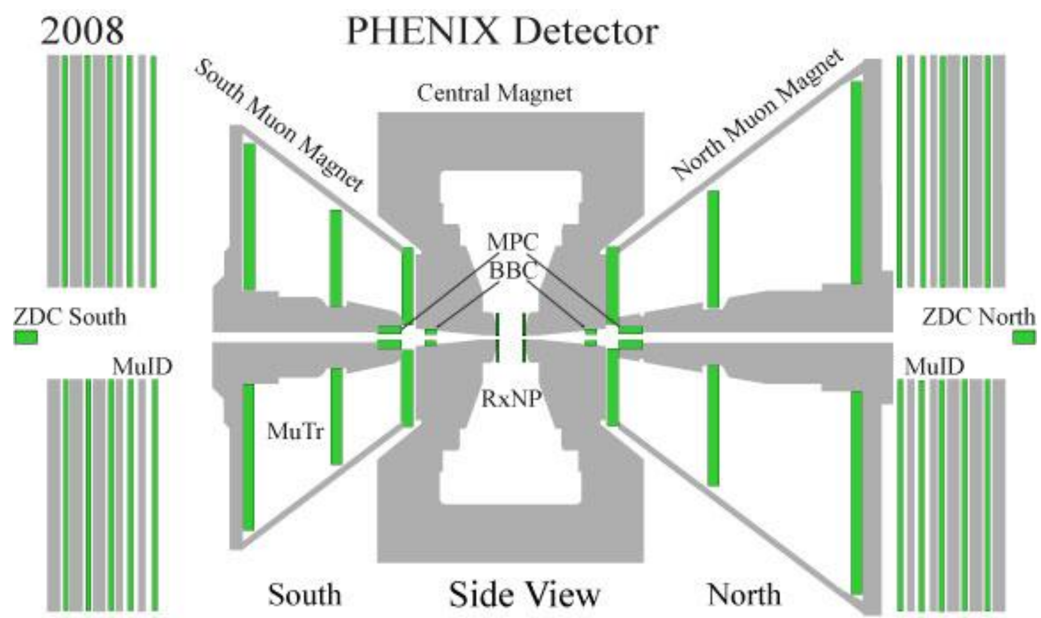
$$R_{CP}^{0-20\%} = \frac{N_{inv}^{0-20\%} \big/ \left\langle N_{coll}^{0-20\%} \right\rangle}{N_{inv}^{60-88\%} \big/ \left\langle N_{coll}^{60-88\%} \right\rangle}$$

Central to peripheral ratio in d+A or A+A (when p+p reference is not available)

For *hard* processes and if everything in AA behaves like in pp, $R_{AA}= R_{cp} = 1$

Heavy quarkonia measurements in PHENIX





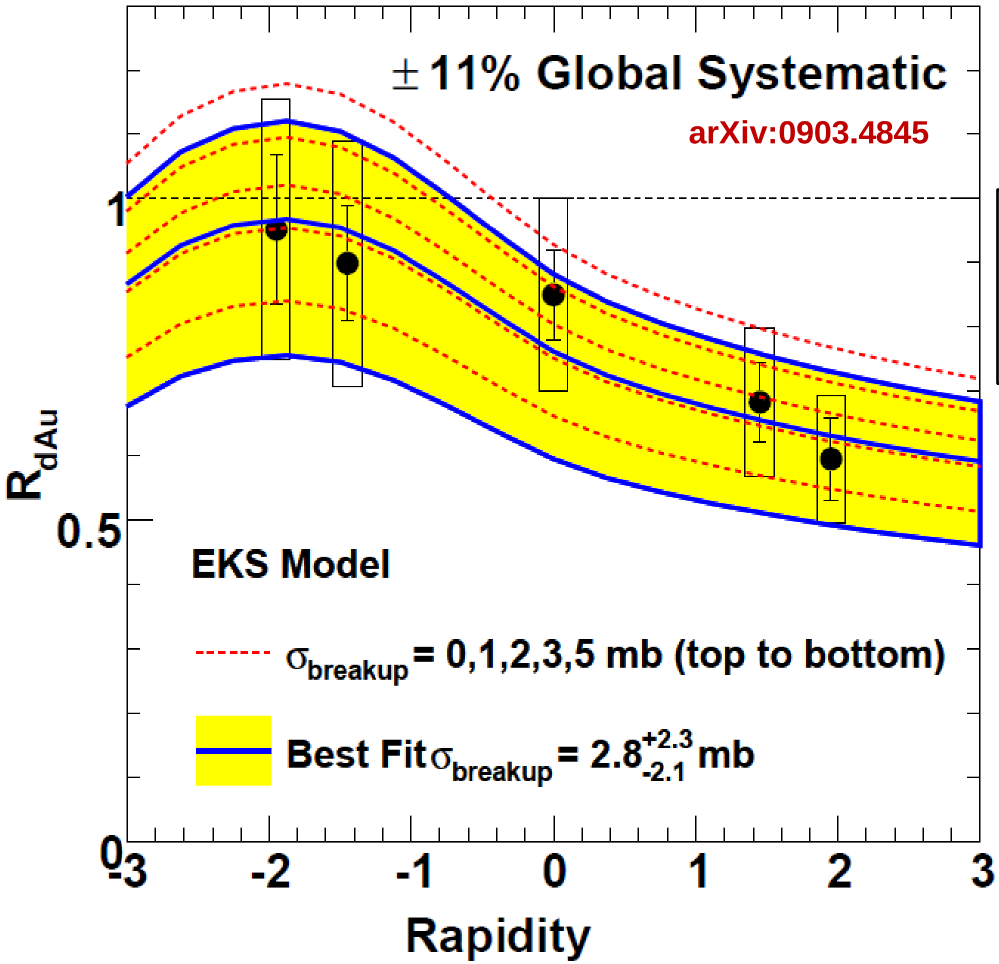
Mid rapidity: **J/ψ,Υ→ e^+e^-**
$|\eta|<0.35$, $\Delta\Phi = 2 \times \pi/2$, $p>0.2$ GeV/c

Forward rapidity: **J/ψ,Υ→ $\mu^+\mu^-$**
$1.2<|\eta|<2.2$, $\Delta\Phi=2\pi$, $p>2$ GeV/c

- Measure quarkonia production in p+p for reference (see talk by D. Jouan)
- Measure in d+A collisions to evaluate Cold Nuclear Matter effects and extrapolate to A+A
- Measure additional effects in A+A to evaluate QGP effects

J/ψ production in d+A and A+A at $\sqrt{s_{NN}}$= 200 GeV

Published R_{dAu} (2003 data) vs rapidity

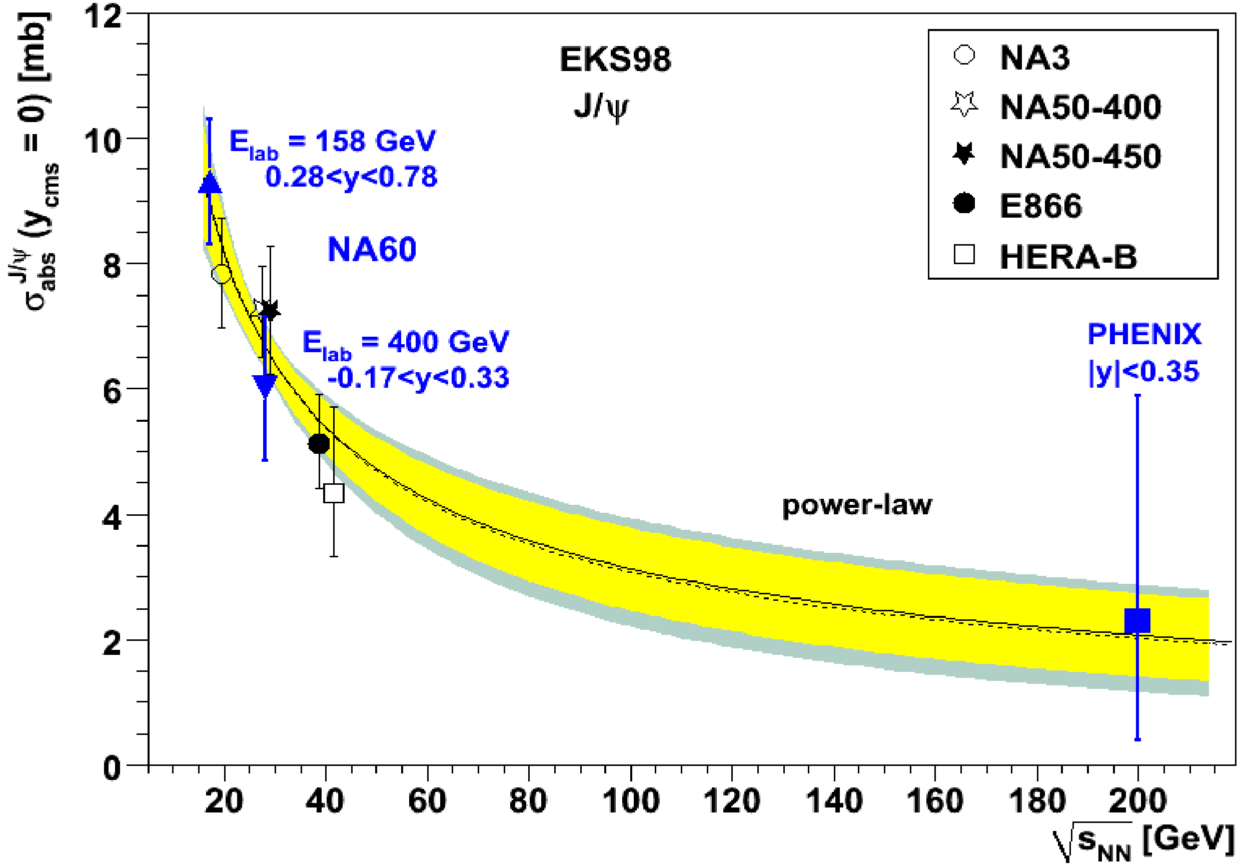


y<0: Au going side. Large x in Au nuclei
y>0: d going side. Small x in Au nuclei, where shadowing is expected

Shadowing models are used together with $\sigma_{breakup}$ from 0 to 5 mb.
Fit to the data gives (here) $\sigma_{breakup} = 2.8^{+2.3}_{-2.1}$ mb

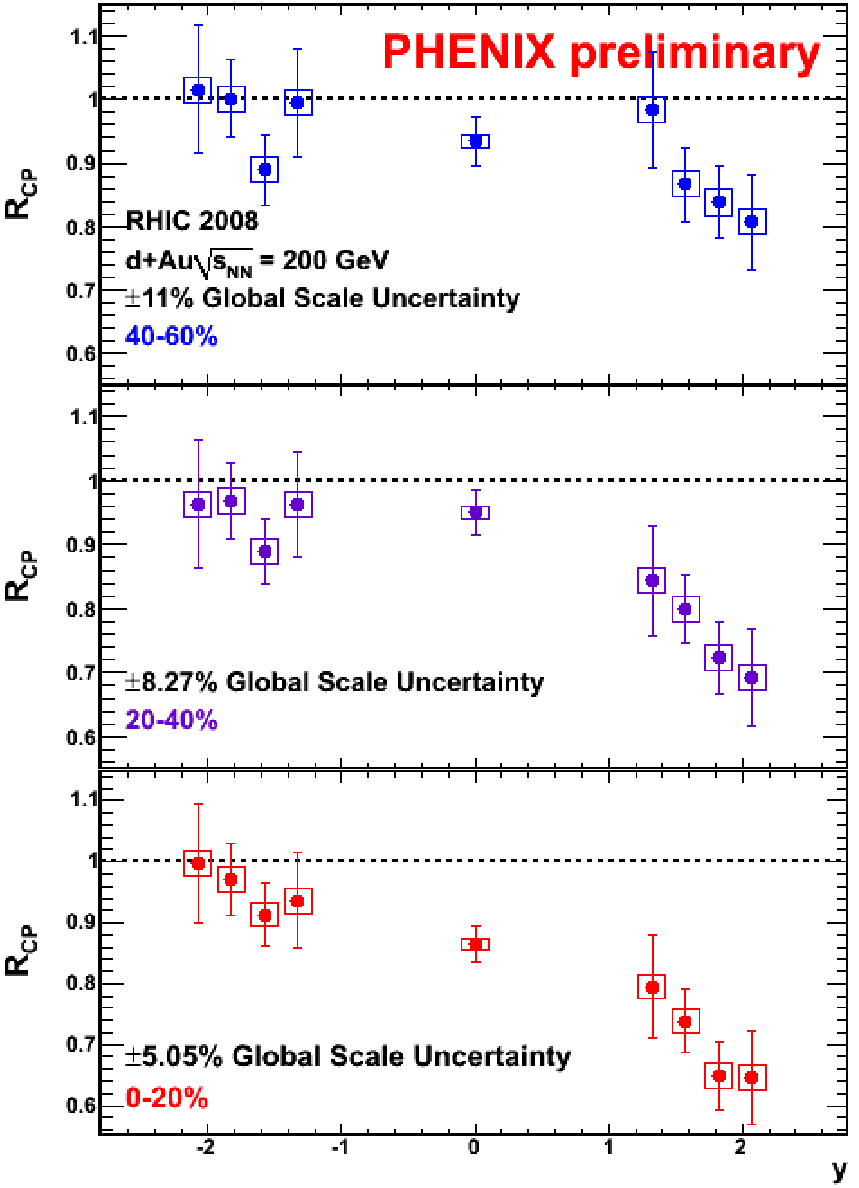
Comparison to other experiments

Lourenco, Vogt, Woehri - arXiv:0901.3054 [hep-ph]



Putting $\sigma_{breakup}$ as a function of $\sqrt{s}$ and comparing to other experiments shows some sort of global trend, yet to be explained theoretically.

Preliminary R_{cp} (2008 data) vs rapidity



2008 d+Au data sample = ~40 times more statistics than 2003 published results.

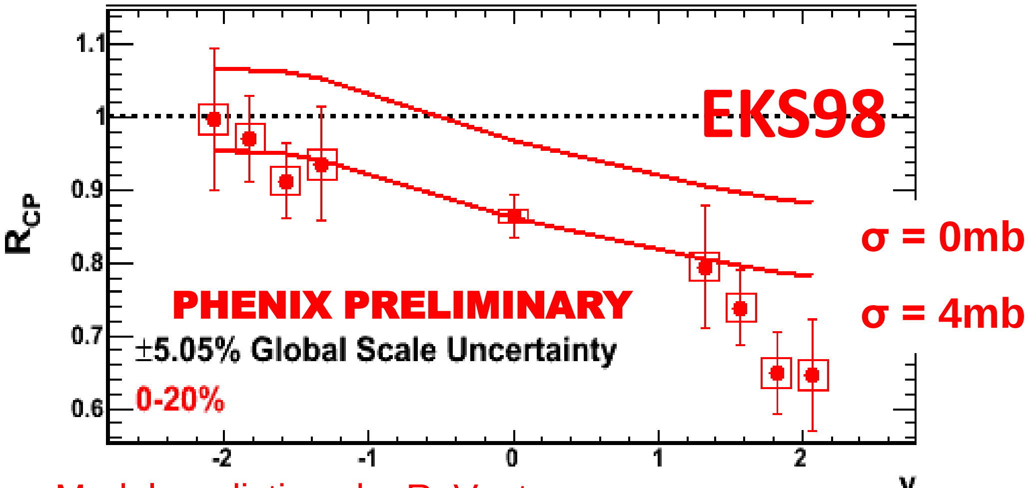
Enough statistics to provide 4 different centrality bins and 9 rapidity bins.

$$R_{CP}^{0-20\%} = \frac{N_{inv}^{0-20\%} \Big/ \left\langle N_{coll}^{0-20\%} \right\rangle}{N_{inv}^{60-88\%} \Big/ \left\langle N_{coll}^{60-88\%} \right\rangle}$$

Systematic errors largely cancel in R_{cp}.

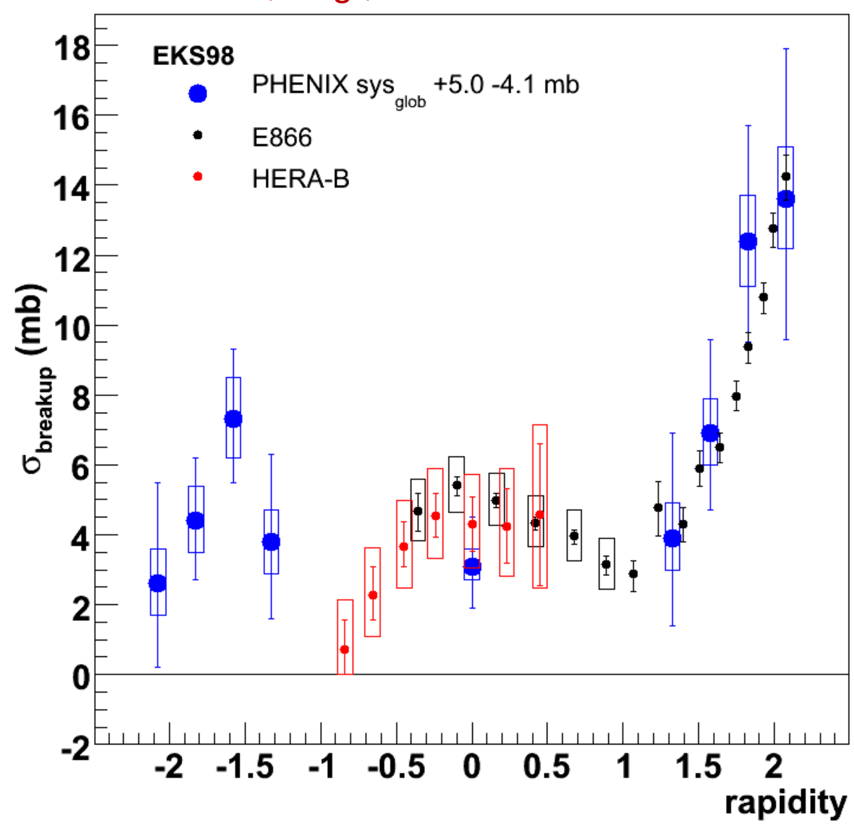
R_{cp} ~1 at negative rapidity
R_{cp} < 1 and decreases with centrality at positive rapidity

Effective break-up cross-section vs rapidity



Model predictions by R. Vogt

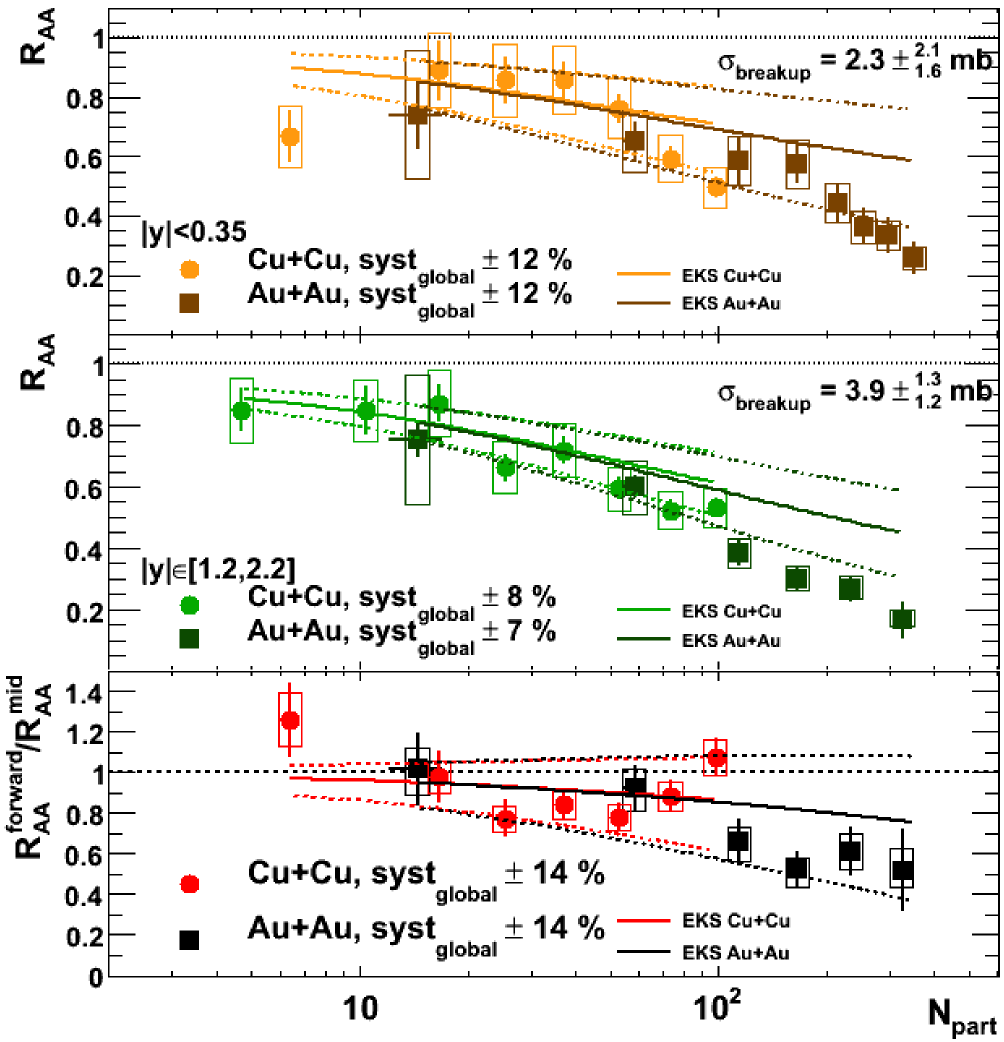
Lourenco, Vogt, Woehri arXiv:0901.3054



- Obviously, shadowing + fixed $\sigma_{breakup}$ don’t match the observed rapidity dependency
- Use d+Au data to extract <u>effective</u> breakup cross section as a function of rapidity to parameterize all the effects that shadowing is missing
- Same trend observed at mid and forward rapidity by E866 and HERA-B

J/ψ R_{AA} vs centrality (N_{part}) in Au+Au and Cu+Cu

arxiv:0801.0220



peripheral → central

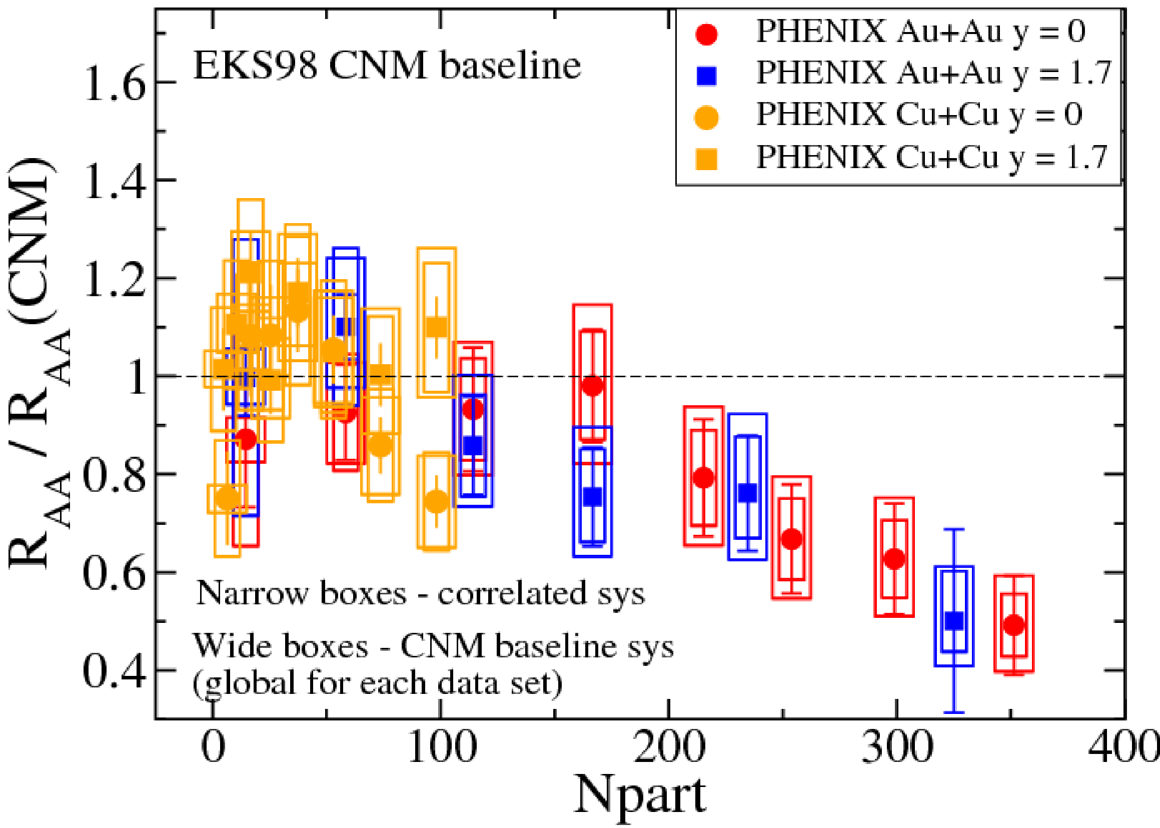
Data are from 2005 Cu-Cu and 2004 Au-Au. Lines are cold nuclear matter effects extrapolated from 2003 d-Au data

Cu-Cu and Au-Au ratios match well where they overlap.
In Au+Au the suppression is larger than expected from CNM

There is more suppression at forward rapidity than at mid-rapidity, although the difference might be absorbed by CNM

J/ψ R_{AA} over CNM in Cu+Cu and Au+Au

Calculations by M.J. Leitch using break-up cross-section and errors estimated from 2008 data

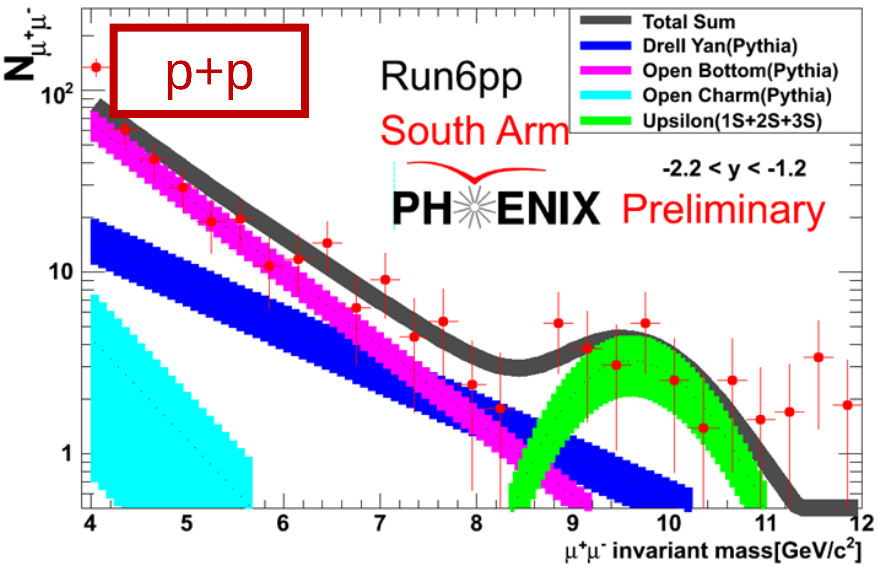


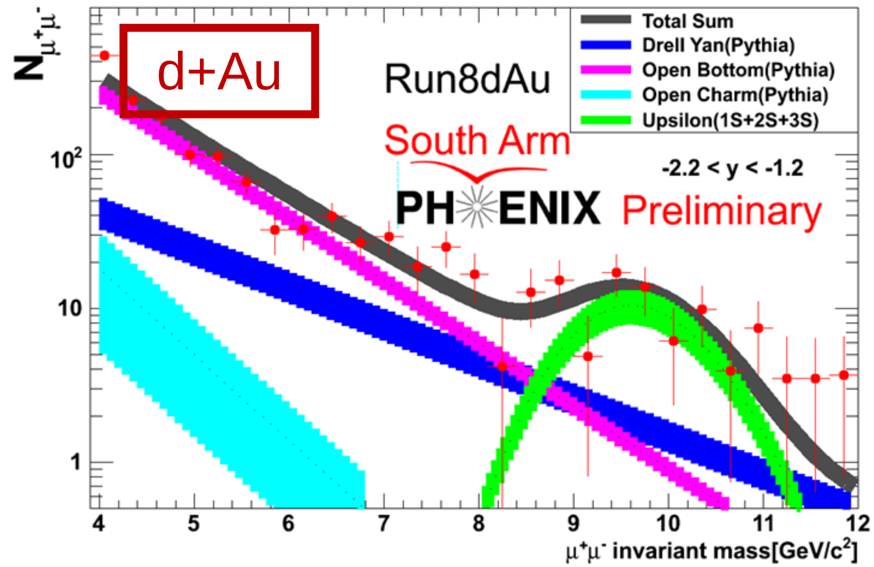
Differences between mid and forward rapidity measurement is washed out.

Suppression beyond cold nuclear matter effects is observed, consistent with de-confinement

Υ production in d+A and A+A at $\sqrt{s_{NN}}$= 200 GeV

Υ at forward rapidity in p+p and d+Au



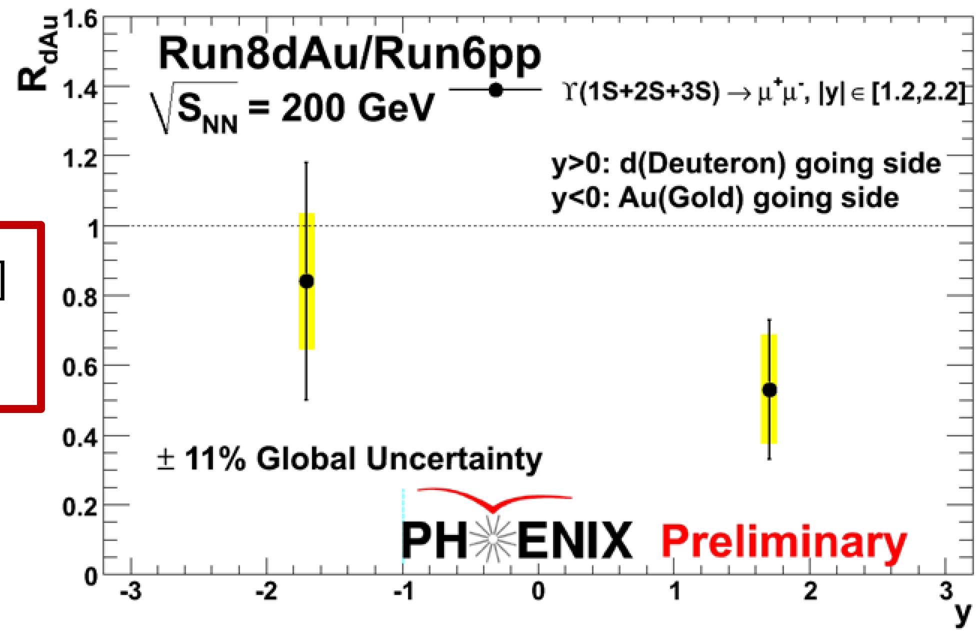


First Υ measurement at forward rapidity (1.2<|y|<2.2) in d+Au collisions

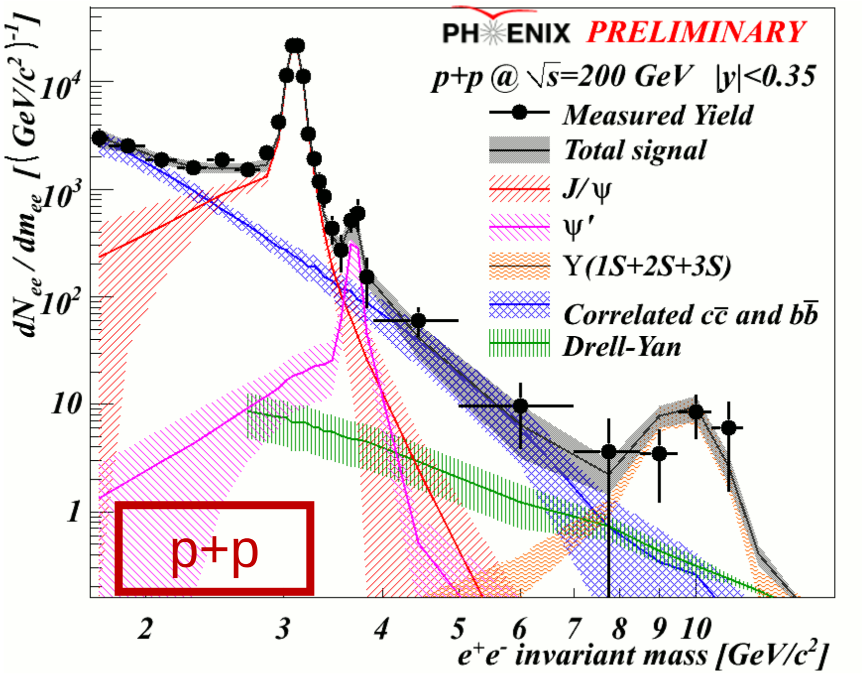
R_{dAu} = 0.84±0.34(stat.)±0.20(sys.), y [-2.2, -1.2]

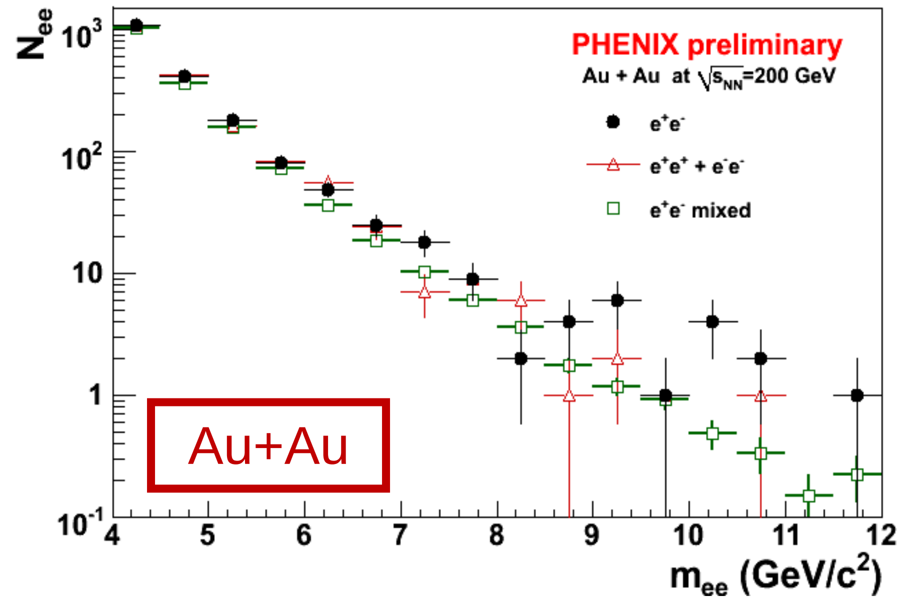
R_{dAu} = 0.53±0.20(stat.)±0.16(sys.), y [1.2, 2.2]

No measurement available (yet) at mid-rapidity



High mass di-lepton R_{AA} in Au+Au



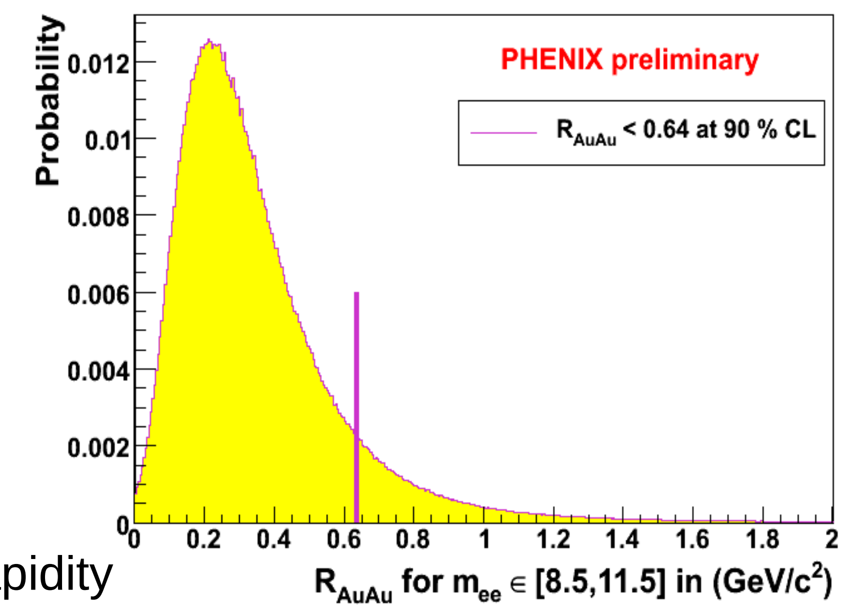


Excess over combinatorial background at high mass (m>8GeV/c^2) attributed to

- Upsilons
- Open beauty
- Drell-Yan

High mass di-lepton R_{AA}:

R_{AuAu} [8.5,11.5] < 0.64 at 90% C.L.



No measurement available (yet) at forward rapidity

Conclusion

- J/ψ have been measured extensively at RHIC (PHENIX) in p+p d+Au and Au+Au collisions. Early results (2003-2005) are being extended using higher statistics data sets (2006-2010).
- A first look at 2008 d+Au data show that Cold Nuclear Matter effects are not well understood in terms of shadowing and break-up cross-sections, notably as a function of rapidity. Need more inputs from theory, more observables (notably p_T dependency), more systems (d+Cu ?)
- in Au+Au a suppression is observed beyond the extrapolated CNM, consistent (notably) with de-confinement. There is ~4 times more statistics available with 2007 data, and about the same using 2010 data.
- Some early Υ measurements are available in p+p, d+Au (forward rapidity) and Au+Au (mid-rapidity), and show a pattern qualitatively similar to the one of the J/ψ.