Charmonia production in heavy ion collisions, from SPS to LHC

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Introduction

- Motivations
  - Suppression of quarkonia is a prediction of lattice QCD calculations, for instance :

H. Satz, J. Phys. G 32 (2005)

state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	> 4.0	1.76	1.60	1.19	1.17

- Experimental setup
  - SPS/CERN NA38, NA50 and NA60 experiments ($\sqrt{s_{NN}}$ = 17 – 30 GeV)
    - Fixed target experiments
    - **Large statistic** (100 000's J/ψ)
    - **Many data set of different types** (p+A w/ A=p, d, Be, Al, Cu, Ag, W, Pb; S+U, In+In, Pb+Pb)
    - Small rapidity coverage (typically y ∈ [0,1])
  - RHIC/BNL Phenix experiment ($\sqrt{s_{NN}}$ = 200 GeV)
    - Collider experiments
    - Smaller statistic : 1000's J/ψ (10000's since 2007)
    - Fewer number of data set of different types (p+p, d+Au, Cu+Cu, Au+Au)
    - **Large rapidity coverage** (y ∈ [-0.5,0.5], y ∈ [-2.2,-1.2] and y ∈ [1.2,2.2])
  - LHC/CERN experiments ($\sqrt{s_{NN}}$ = 5,5 TeV)
    - Collider experiments
    - **Large statistic** (100000's J/ψ)
    - Few number of data set of different types (p+p, Pb+Pb, p+Pb)
    - **Large rapidity coverage** (|y|<2.5 ATLAS/CMS, |y|<0.9 and -4.0 < y < -2.5 ALICE)

Charmonium production at SPS

NA38, NA51, NA50, NA60

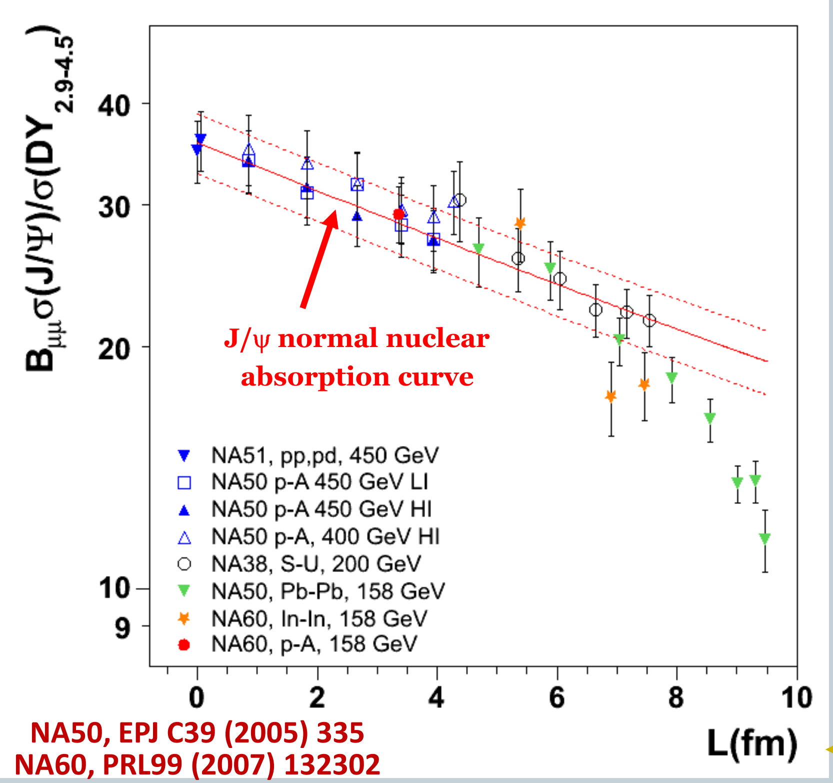
Two major results :

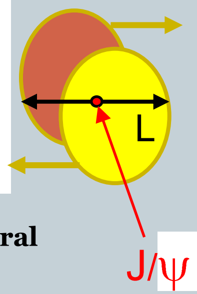
1. Observation of **Cold Nuclear Matter effects** : Absorption by nuclear matter
   - Suppression observed from p+p to peripheral Pb+Pb
   - J/ψ survival probability :

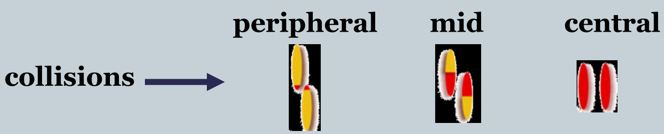
$$S(J/\psi) \propto e^{-\rho\sigma_{abs}L}$$

   - Fit to data: σ_{abs}=4.18 ±0.35 mb

2. Observation of **Anomalous suppression** in Pb+Pb (NA50) and In+In (NA60) central collisions when compared with Cold Nuclear Matter effects.



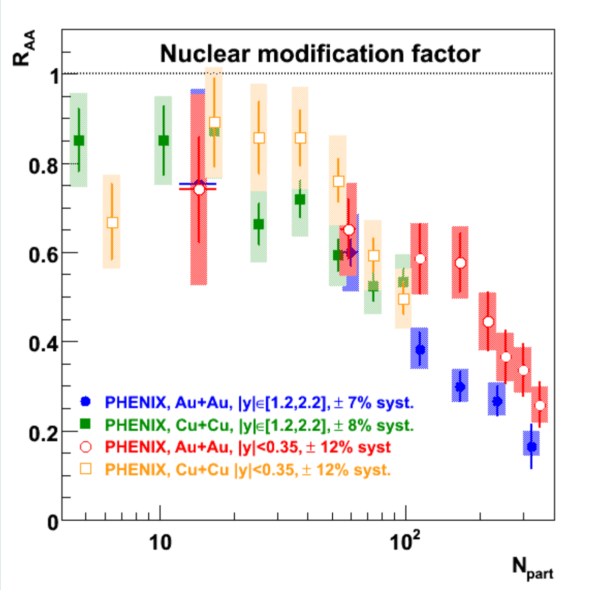


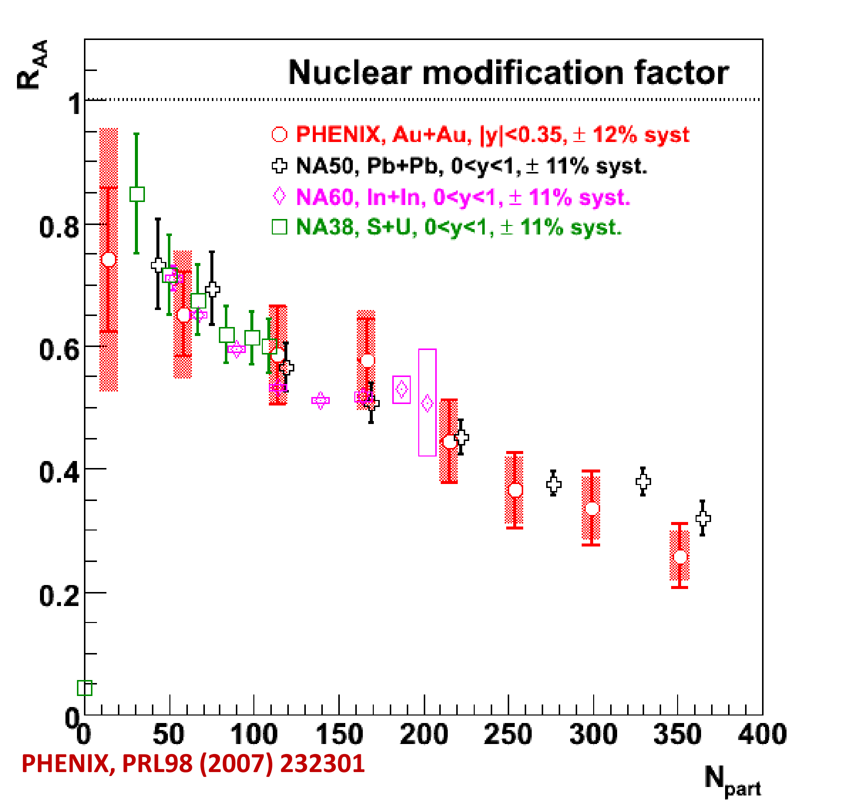


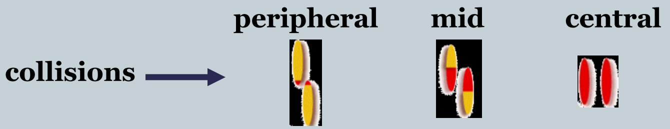
Charmonium production at RHIC

- PHENIX
  - **Two experimental stricking observations**
    - Point 1 : similar behavior SPS.vs.RHIC at mid-rapidity
      - At a given N_{part}, expect different energy densities
      - Don't expect same CNM effects

N_{part} = number of participant nucleons

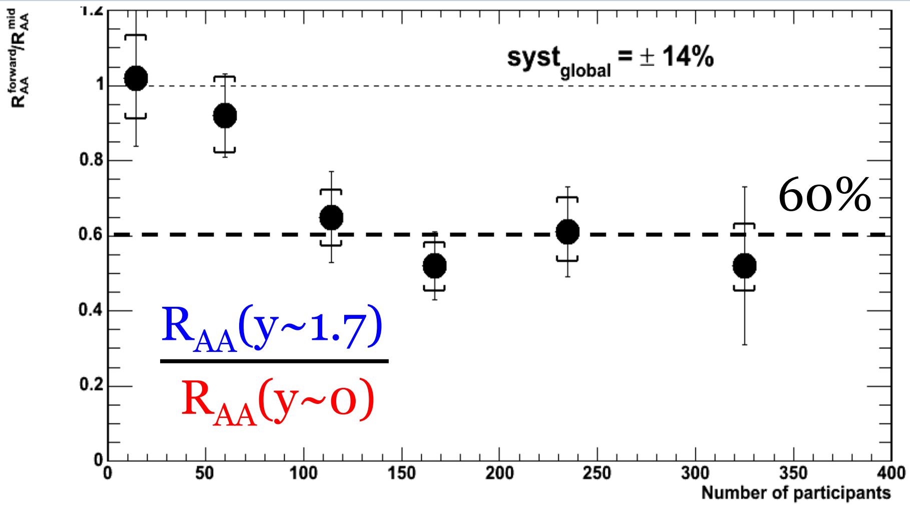




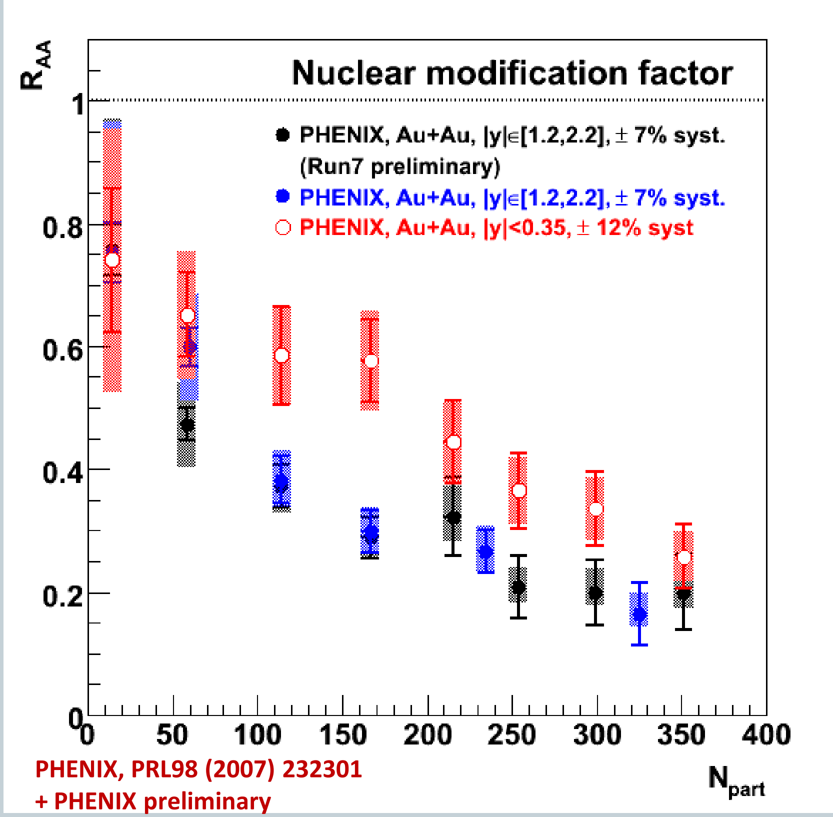


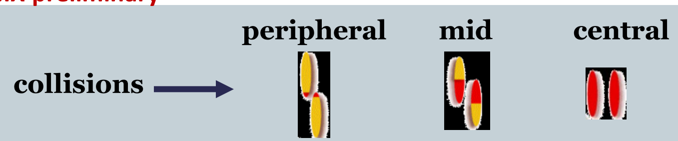
Charmonium production at RHIC

- PHENIX
  - **Two experimental stricking observations**
    - Point 1 : similar behavior SPS.vs.RHIC at mid-rapidity
    - Point 2 : larger suppression at forward rapidity compared to mid-rapidity (confirmed with recent data)



N_{part} = number of participant nucleons



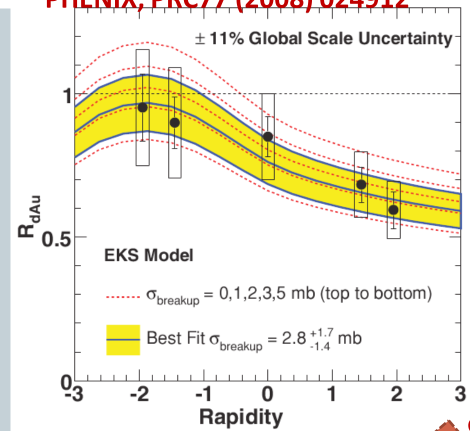


SPS .vs. RHIC at mid-rapidity

Cold Nuclear Matter effects

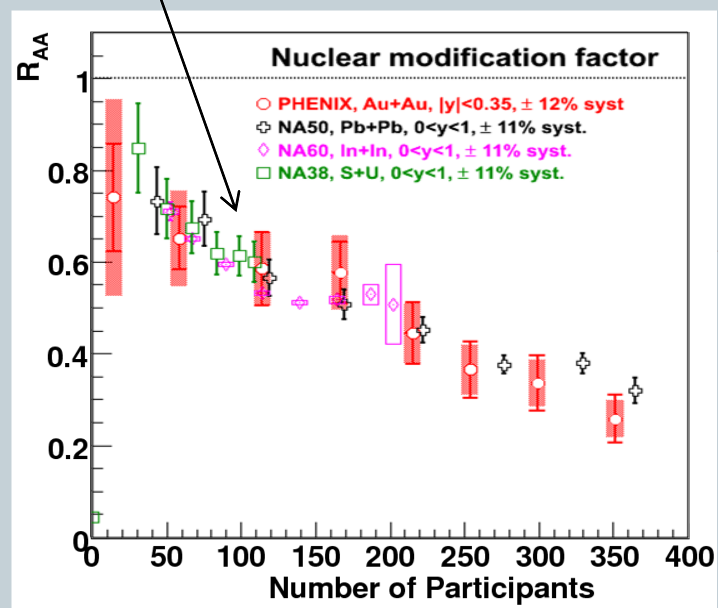
- Measured R_{AA} include
  - Hot and Dense Matter effects (HDM)
  - Cold Nuclear Matter effects (CNM)
- Need to remove CNM effects
  - At SPS : use p+A data (σ_{abs} = 4.2 mb)
  - At RHIC : use d+Au data
    - Shadowing (modification of PDFs) could play a role
    - Absorption can be smaller
  - due to **large uncertainties in d+Au data** at RHIC can't tell weither CNM effects are the same or not.
- Need more precise CNM effect measurements at RHIC
  - run 8 : ~30 x more data (ongoing analysis)

PHENIX, PRC77 (2008) 024912



d+Au

σ_{abs} = 4.2 mb

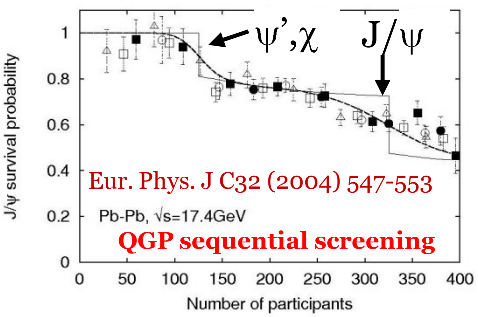


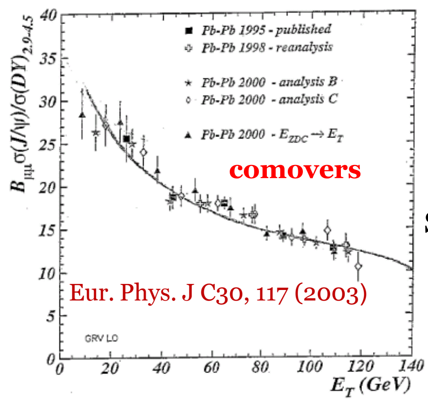
Au+Au

SPS .vs. RHIC and RHIC mid.vs.fwd

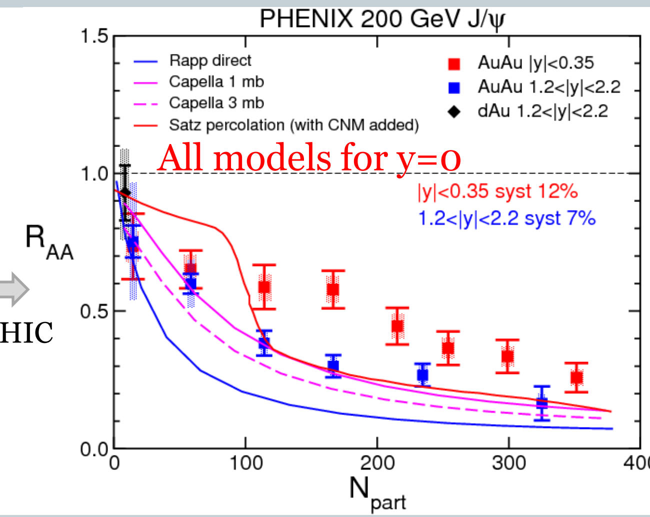
Hot and Dense Matter effects : suppression models

- suppression models which reproduce SPS data overestimate the suppression at RHIC…

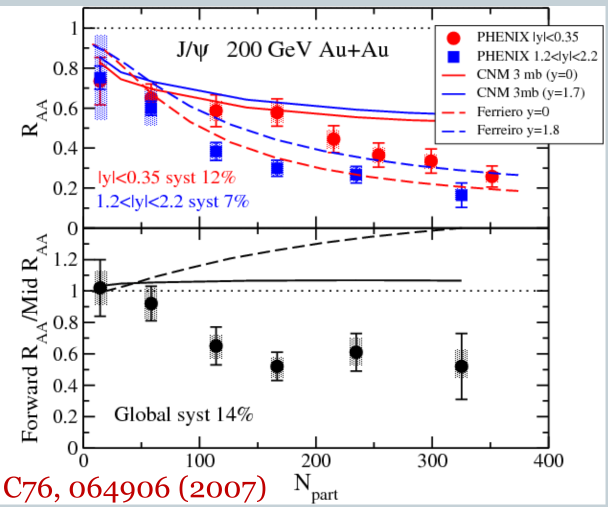




SPS → RHIC



- … Fwd.vs.mid in comovers model
  - Comovers density is larger at mid-rapidity → larger suppression expected at mid-rapidity
  - Fails to reproduce the data

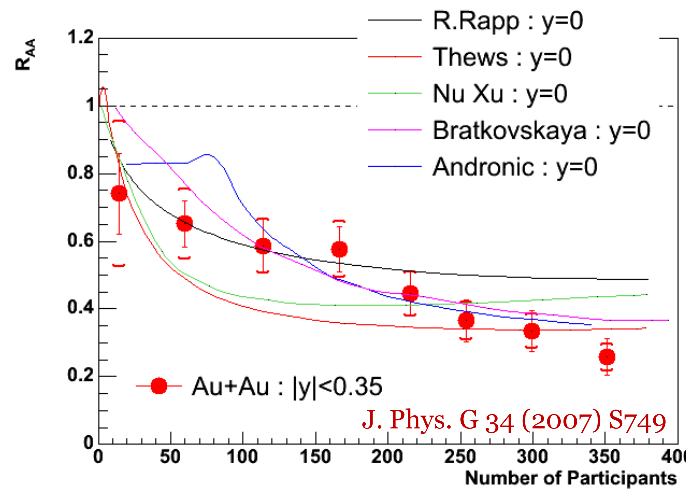


Phys. Rev. C76, 064906 (2007)

RHIC mid.vs.fwd

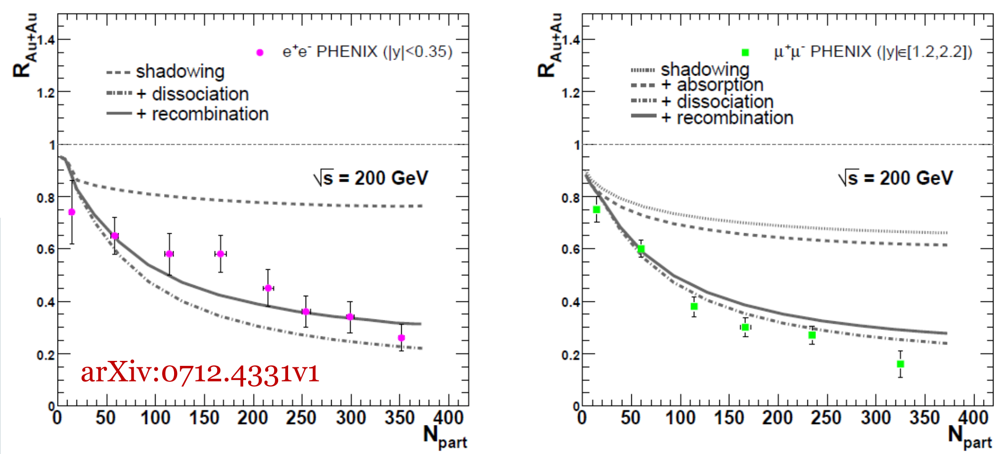
Hot and Dense Matter effects : recombination

- recombination models
  - Recombination (regeneration) is a mechanism which leads non-correlated c and $\bar{c}$ quarks to combine into a $c\bar{c}$ bound state (such as J/ψ) : $c+\bar{c} \rightarrow J/\psi + g$
  - Compensate direct suppression



- Recombination .vs. Rapidity
  - Adding recombination to comovers
  - More recombination at mid-rapidity

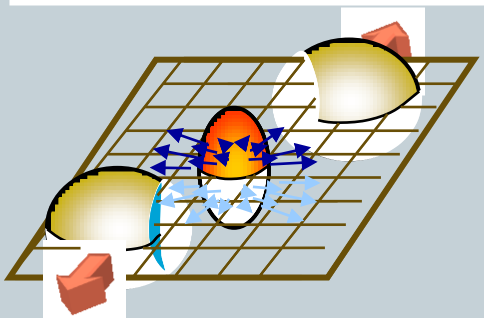
How to test recombination ?



Testing recombination

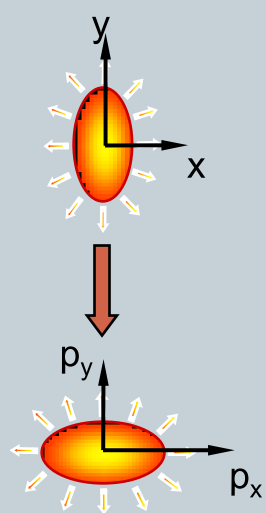
PHENIX J/ ow measurement

- Non photonic electrons (charm+beauty) flow at RHIC. **If J/ψ are regenerated**, they **should inherit from charm-quark flow**.
- Current measurements are not precise enough to discriminate.

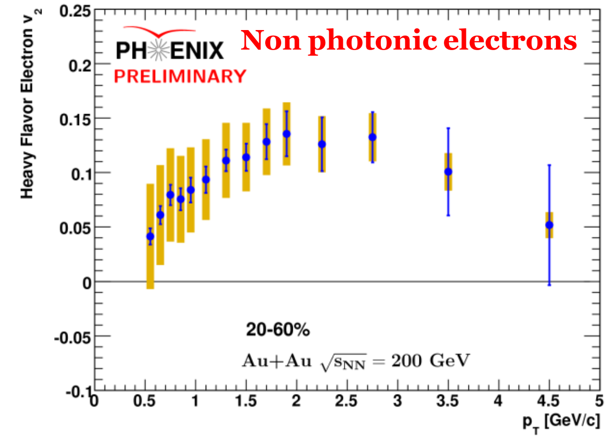


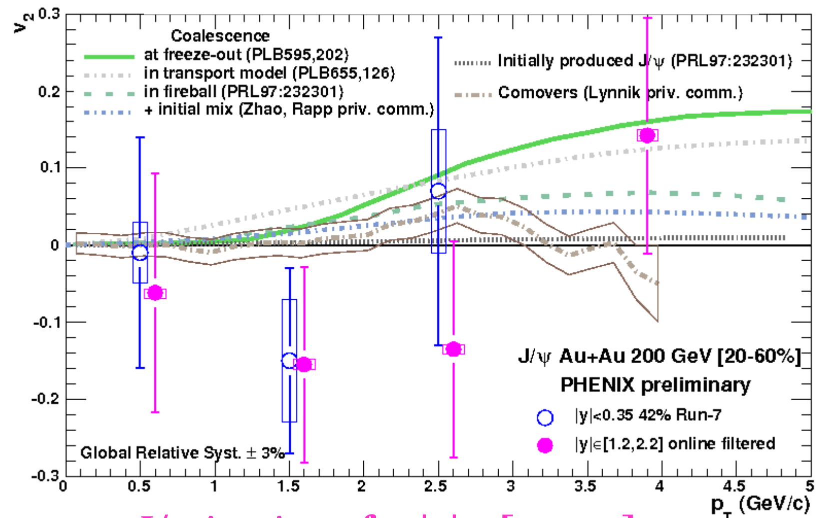
v_2 characterizes the azimuthal anisotropy of particle emission with respect to the collision reaction plane

$$\frac{dN}{d\varphi\, dp_T} = 1 + 2v_2(p_T)\cos(2\varphi)$$



Positive v2 ➔ thermalization of the medium



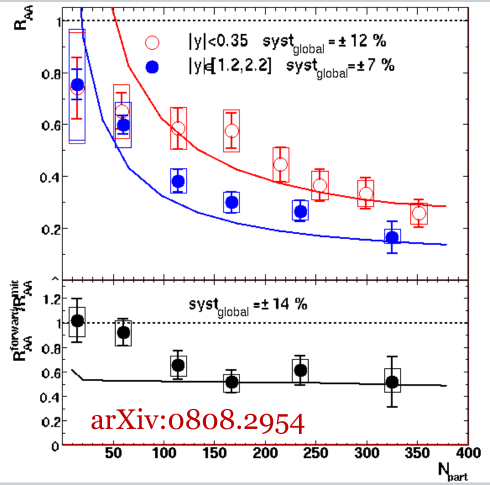


J/ψ Au+Au v_2 for |y| ∈ [1.2,2.2]

J/ψ Au+Au v_2 for |y| < 0.35

RHIC mid.vs.fwd
back to CNM effects

- Could the difference mid.vs.fwd come from CNM effects ?
  - CGC (gluon saturation)
    - Enhancement of 3 gluons fusion in J/Ψ production mechanism
    - Absolute amount of suppression is fitted on semi-peripheral data
    - Ratio fwd/mid comes from the model

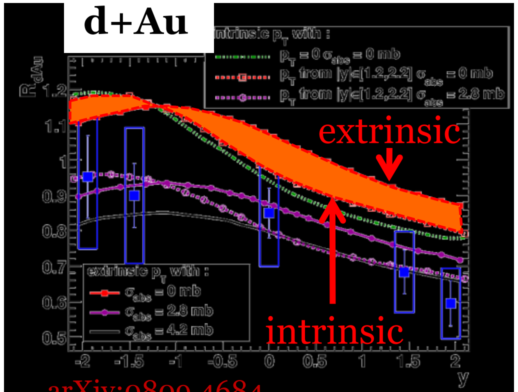


arXiv:0808.2954

- Shadowing (modification of PDFs) based on new g+g→J/ψ

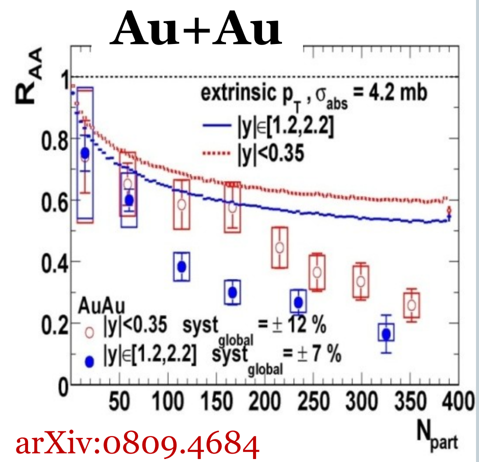
extrinsic : g+g → J/ψ + g + X
intrinsic : g+g → J/ψ + X

d+Au



arXiv:0809.4684

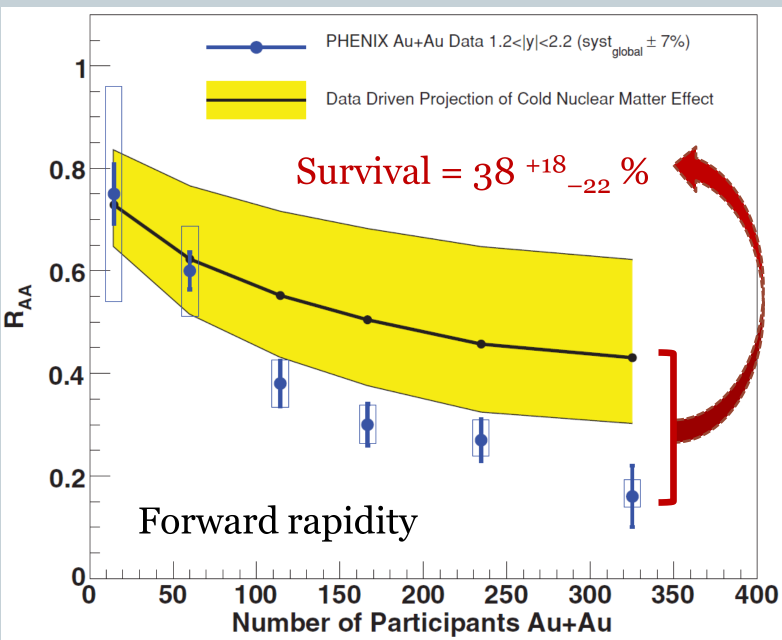
Au+Au

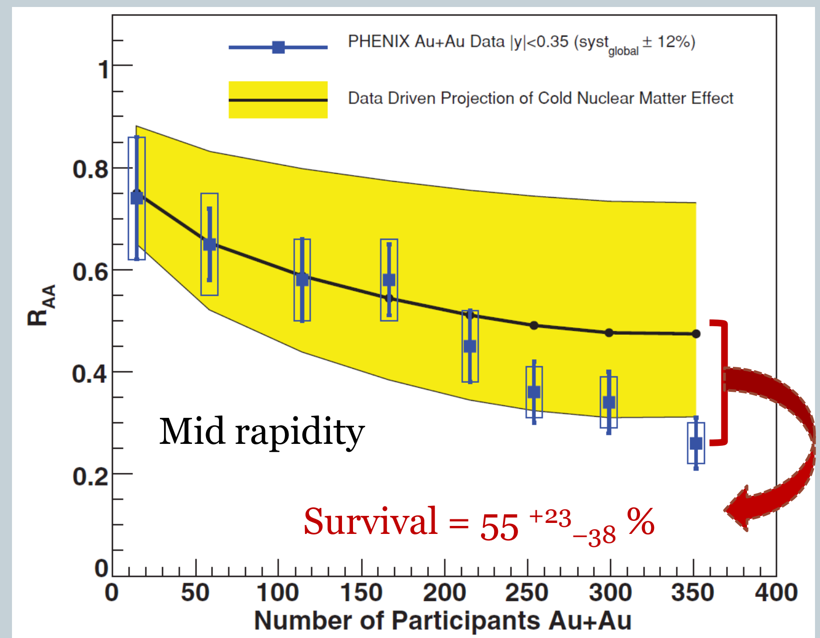


arXiv:0809.4684

Point 2 : RHiC mid.vs.fwd
back to the data

- Extrapolate CNM effects from d+Au to Au+Au with data driven method
  - Fit d+Au data as a function of centrality (impact parameter)
  - Extrapolate to Au+Au
  - Within errors, the suppression could be the same at forward and mid rapidity
  - Need better statistics in d+Au → run 8 (2008) d+Au





Conclusion
for SPS and RHIC

- Summary of SPS and RHIC
  - Comparable R_{AA} at mid-rapidity between SPS and RHIC
  - Larger suppression observed by PHENIX at forward rapidity compared to mid rapidity ➔ several explanations ; not discriminate yet.
  - CNM effects are not well constrained at RHIC. Need better measurement ➔ run 8 d+Au data (~ 80 000 J/Ψ) ; may need other systems.

- Next at RHIC
  - **RHIC luminosities advance**

Species	Energy	Units	Up to 2008 Obtained	2009 Projected	2011 Projected	2013 Projected
Au+Au	200	μb^{-1}	380	610	1450	1820
pp	200	pb^{-1}	7.0	14.6	31.1	40
pp	500	pb^{-1}	–	36.5	78	100

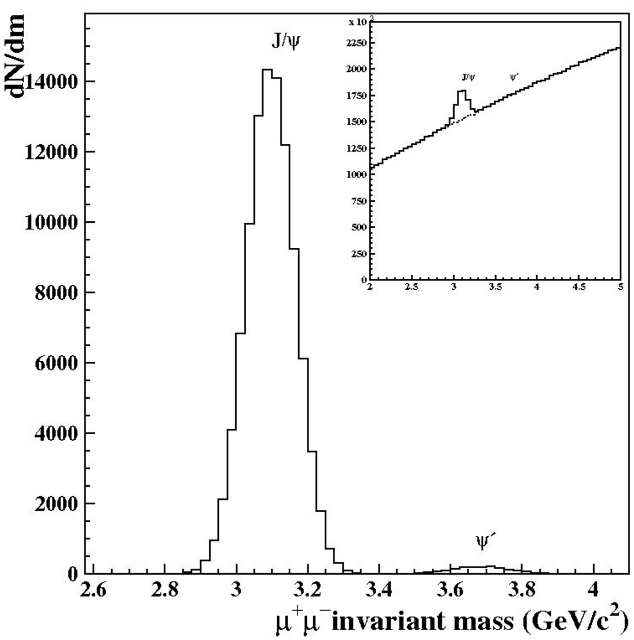
  - **Detector upgrades**
    - PHENIX : barrel and endcap silicon vertex detector
    - STAR : DAQ upgrade + tracking upgrade (silicon pixel sensors + silicon strip pad sensors)
  - **Impact on physics**
    - Better mass resolution, better signal/background ratio
    - Ψ', χ_c measurements (J/Ψ ~ 0.6 J/Ψ + 0.3 χ_c → J/Ψ + 0.1 Ψ'→J/Ψ) ?

Outlook
for LHC

- ## ATLAS

A. Lebedev - QM08

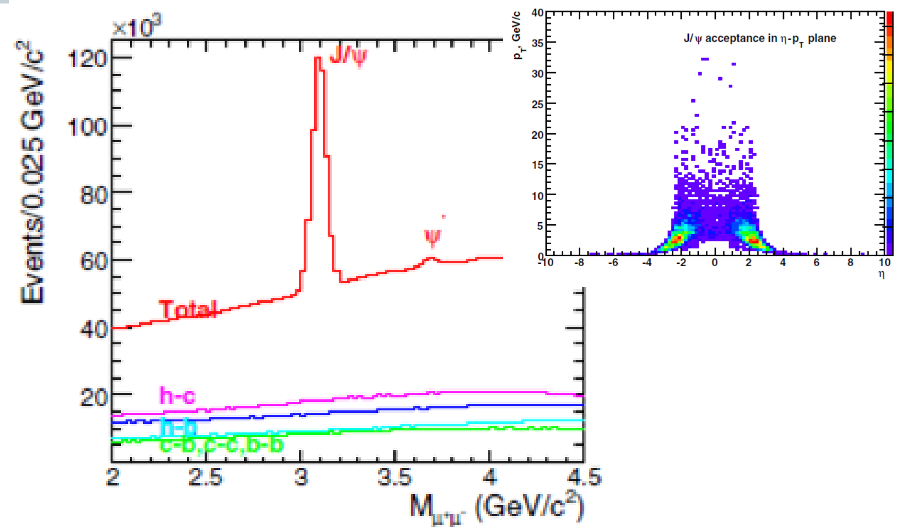
  - Large rapidity acceptance : |y| < 2.5
  - Good mass resolution (σ=68 MeV/c²)
  - Signal/bkg ~ 1
  - Difficult to reconstruct μ's with p_T<2.5 GeV



- ## CMS

J. Phys. G: Nucl. Part. Phys. 34 (2007) 2307-2455

  - Large rapidity acceptance |η| < 2.4
  - Very good mass resolution (σ=35 MeV/c²)
  - Signal/bkg ~ 0.6
  - Limited acceptance at low p_T



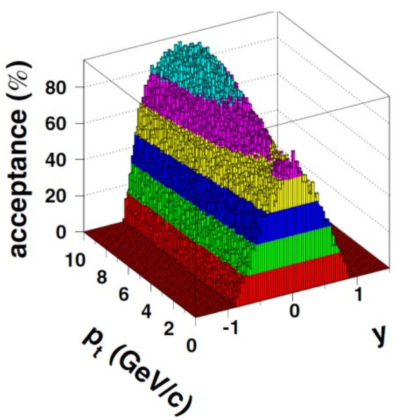
One month Pb+Pb (0.5 nb⁻¹)

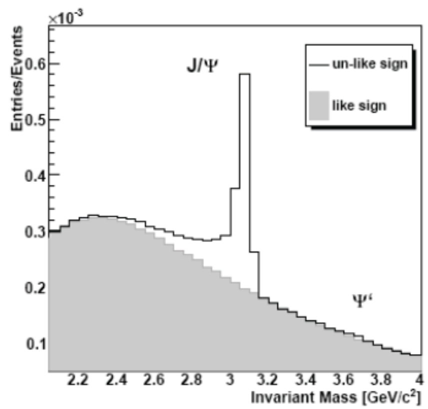
$dN_{ch}/d\eta\|_{\eta=0}$, Δη	S/B	N(J/ψ)	S/B	N(Υ)	N(Υ′)	N(Υ″)
2500, |η| < 2.4	1.2	184 000	0.12	26 000	7300	4400
2500, |η| < 0.8	4.5	11 600	0.97	6400	2000	1200
5000, |η| < 2.4	0.6	146 000	0.07	20 300	5900	3500
5000, |η| < 0.8	2.8	12 600	0.52	6000	1800	1100

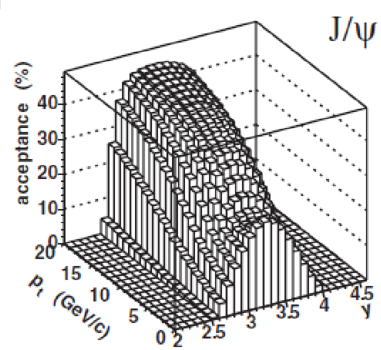
Outlook
for LHC

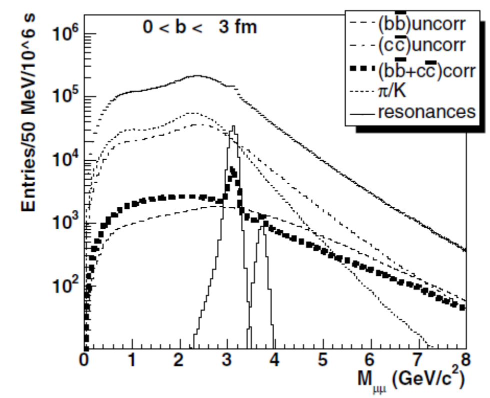
- ALICE mid (e^+e^-)
  - J/ψ → dielectron (|y|<0.9)
  - Resolution: σ=30 MeV/c²
  - Signal/Bkg: ~1.2
  - Expected rate (one month, 10^6s): 120k

- ALICE forward ($\mu^+\mu^-$)
  - J/ψ → dimuon (-4<y<-2.5)
  - Resolution: s=70 MeV/c²
  - Signal/bkg ~ 0.2
  - Expected rate (one month) : 680k









J. Phys. G: Nucl. Part. Phys. 32 (2006) 1295–2040

Outlook
upsilon

- In the future, new observable : bottonium states

state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	> 4.0	1.76	1.60	1.19	1.17

- Expected rates

PHENIX 12 weeks Au+Au

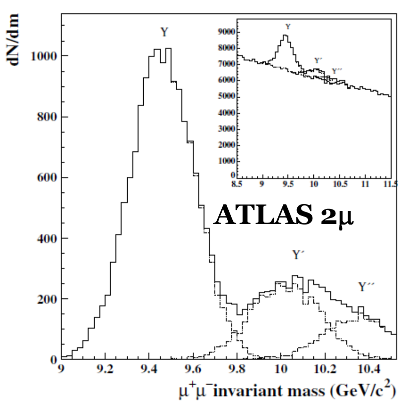
Signal	$\lvert\eta\rvert$	To Date	2009	2011	2013
$\Upsilon \to e^+e^-$	< 0.35	–	120	130	200
$\Upsilon \to \mu^+\mu^-$	$1.2 - 2.4$	–	310	340	520

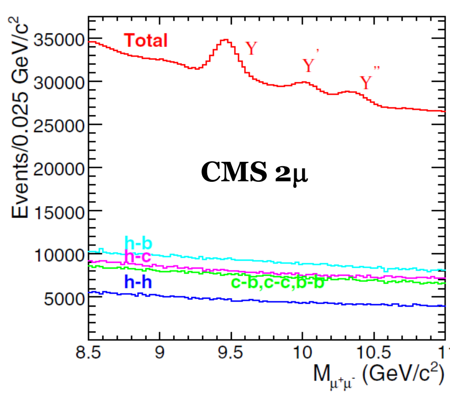
STAR 12 weeks Au+Au

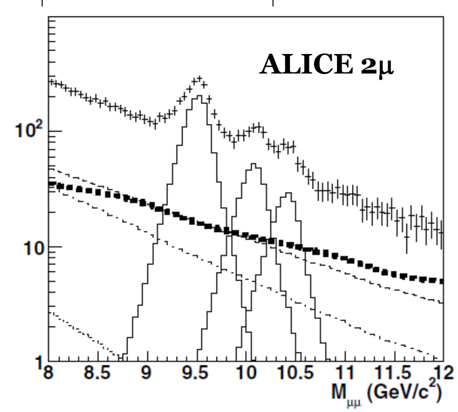
Signal	$\lvert\eta\rvert$	To Date	2009	2011	2013
$\Upsilon \to e^+e^-$		–	5,800	13,800	9,700

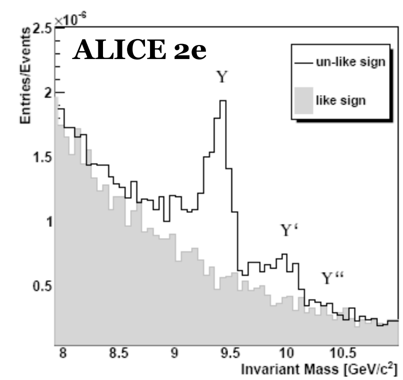
LHC 1 month

Signal	ALICE	$\lvert\eta\rvert$	CMS	$\lvert\eta\rvert$	ATLAS	$\lvert\eta\rvert$
$\Upsilon \to \mu^+\mu^-$	9,600	$2.5 - 4$	37,700	< 2.4	15,000 (21,200)	< 2.0 (< 2.5)
$\Upsilon \to e^+e^-$	1,800	< 0.9				









Charmonia production in HIC
conclusion

- Many results already got from SPS and RHIC
  - Still difficult to get a satisfying overall picture
  - Lack of CNM effects understanding at RHIC (so far)
- New results from RHIC upgrades should help to make progress
  - Larger statistic (Au+Au 2007, d+Au 2008 and futur)
  - Better heavy flavor study (thanks to upgrades)
  - Ψ' and χ_c ?
- LHC experiments should provide a complementary view
  - Much higher energy (from 5.5 TeV in Pb+Pb to 14 TeV in p+p) and high statictics
  - Very good detector performances
  - But …
    - Only one month of Heavy Ion Collisions per year
    - Different energy regimes (constant Z/A*Energy)
      - p+p @ 14 TeV (can do p+p @ 5.5 TeV, but taken on HIC one month program)
      - Pb+Pb @ 5.5 TeV
      - p+Pb or Pb+p @ 8.8 TeV (ALICE has (only) one muon spectrometer)
    - Asymetric beam energy implies shift of rapidity window (0.5 unit for p+Pb compared to Pb+Pb) → issues for CNM effects
  - … it will take some time