Quarkonia and vector mesons in d+Au collision at forward rapidity in PHENIX

Kwangbok Lee

Korea University

for PHENIX collaboration

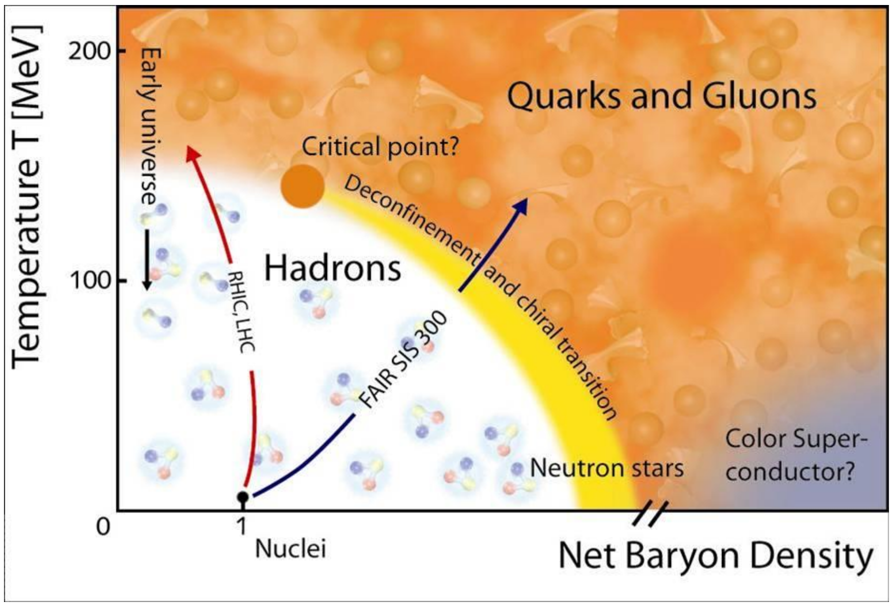
Outline

- Heavy Ion physics
  - A + A collision
    -> J/psi, heavy quarkonia
  - *p*(*d*) + A collision (Cold nuclear matter)
    -> Shadowing effect, nuclear absorption, gluon saturation, initial state energy loss

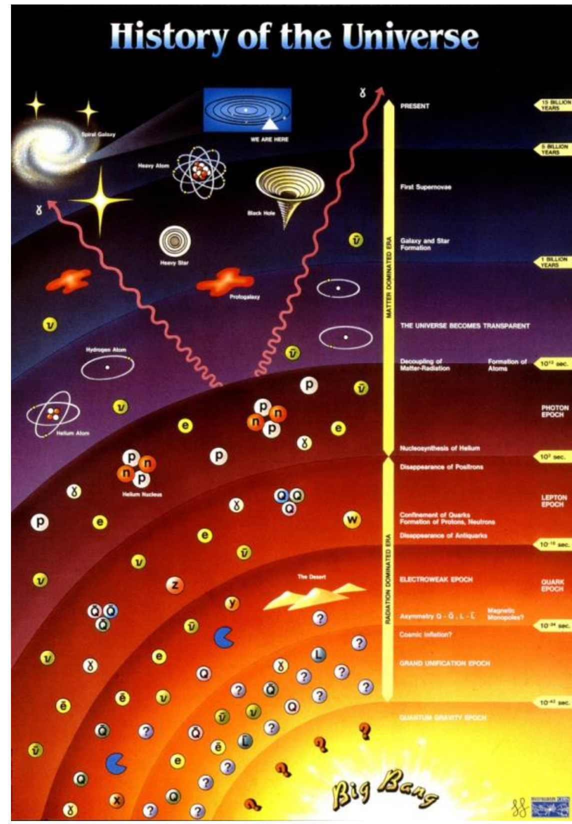
- Quarkonia measurement
- Light vector mesons measurement

- Summary

Heavy Ion physics



The phase diagram of QCD matter



present

First Supervovae

Galaxy & Star Formation

Atom Formation

He Formation

WI & QED Separate

Quark Gluon Plasma

EW & QCD Separate (GUT)

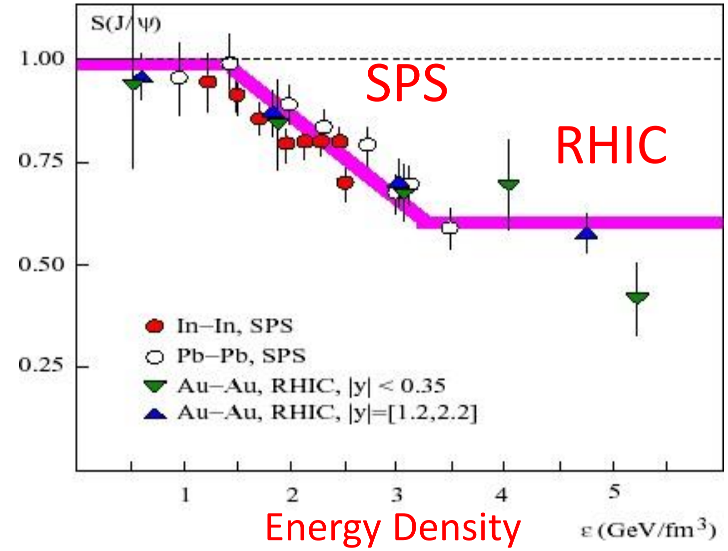
Big Bang

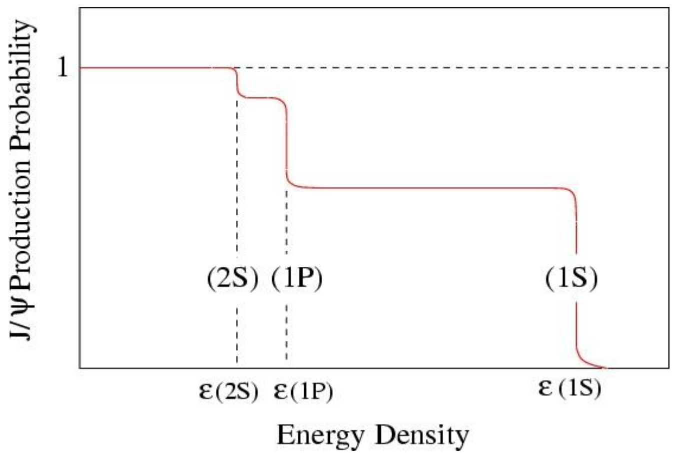
History of the Universe

J/psi suppression

Several scenarios may contribute:

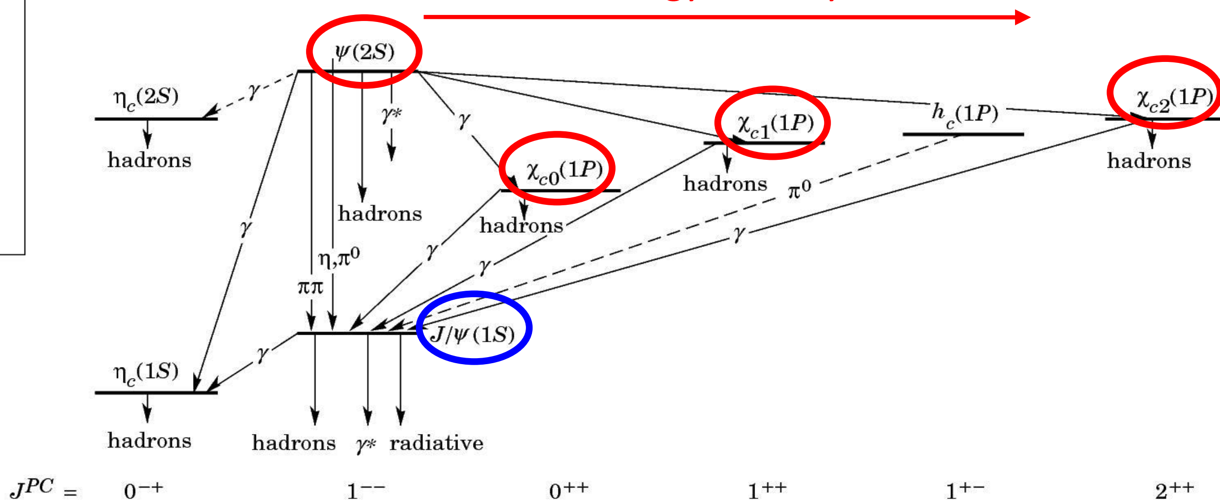
- Suppression by the color screening
- Cold nuclear matter (CNM) effect
- Regeneration effect





Satz, hep-ph/0512217

Sequential J/ψ suppression by colour screening



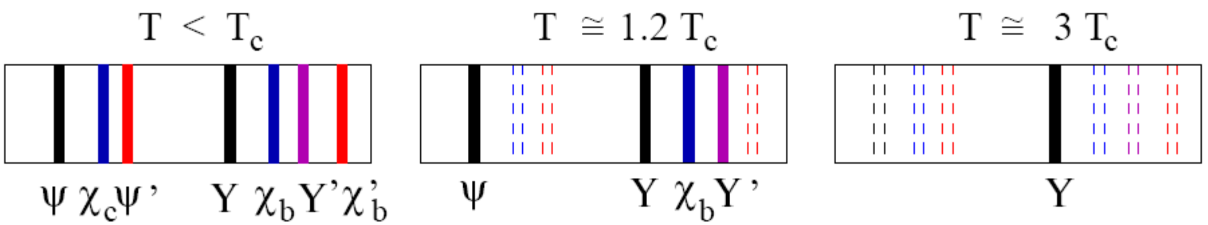
Charmonium system

Quarkonia & Color deconfinement

state	J/ψ (1S)	χ_c (1P)	Υ (1S)	Υ (2S)	Υ (3S)
	$c\bar{c}$		$b\bar{b}$		
mass [GeV]	3.10	3.53	9.46	10.02	10.36
radius [fm]	0.25	0.36	0.14	0.28	0.39
T_d/T_c	2.10	1.16	> 4.0	1.60	1.17

hep-ph/0609197v1 H. Satz

- Each quarkonium has different binding radius.



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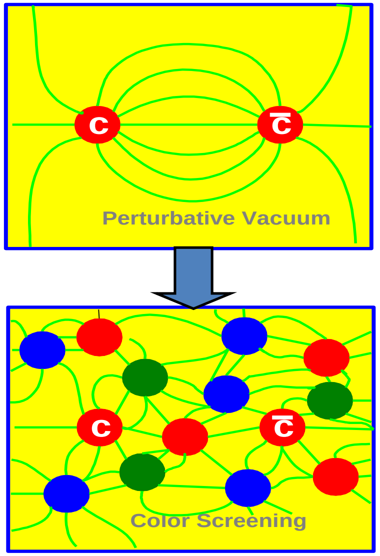
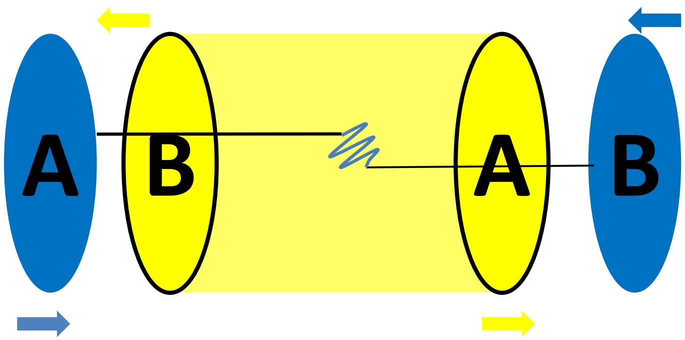


Schematic of color screening

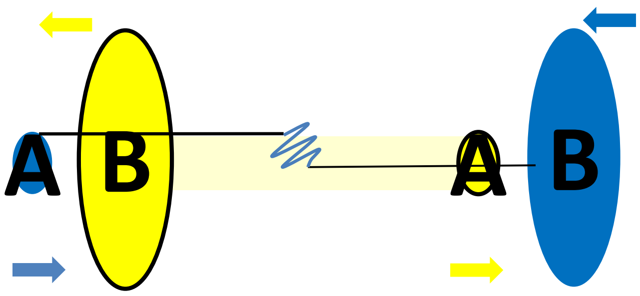
- At RHIC, Υ(3S) melts and the Υ(2S) is likely to melt, the Υ(1S) is expected to survive. - S. Digal et.al., Phys. Lett. B 514 (2001) 57.
  C-Y Wong, Phys. Rev. C 72 (2005) 034906.

Cold Nuclear Matter (CNM)

- Since, in *p*(*d*)A collisions, no hot and dense medium is expected to be created, the matter created is called cold nuclear matter (CNM).
- The CNM can provide the quantitative comparison to the measurement of A + A collision so can provide a better understanding of the effects beyond CNM from hot and dense nuclear matter.
- CNM is an interesting matter itself.

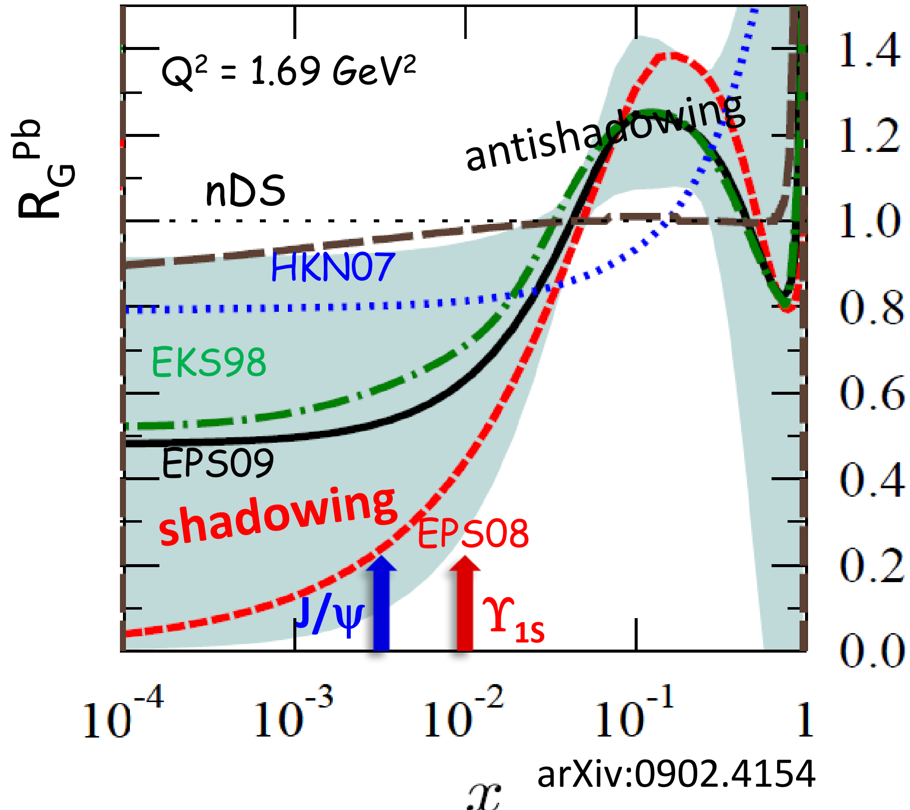


Schematic illustration of Au + Au collision



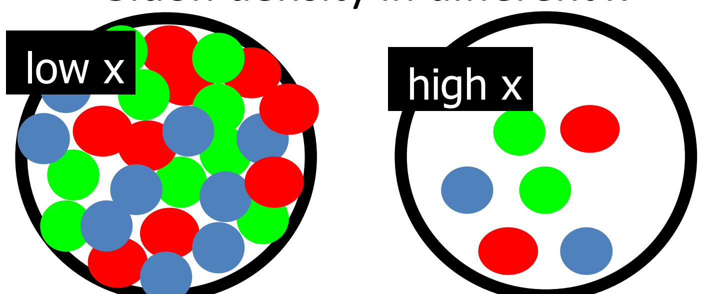
Schematic illustration of *d* + Au collision

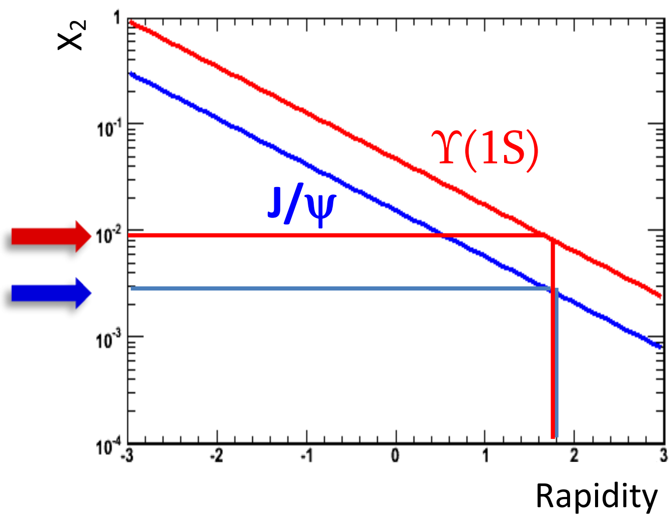
Cold Nuclear Matter (CNM)



- Shadowing model
- Nuclear absorption
- Initial state parton energy loss

Gluon density in different x



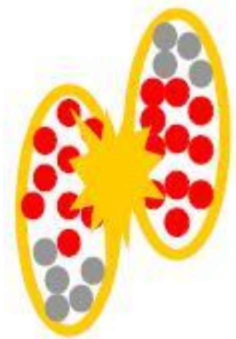


$$x_2 = \frac{m}{\sqrt{s}} e^{-y}$$

Nuclear modification factors

$$R_{dAu} = \frac{N_{inv}^{dAu} / \langle N_{coll}^{dAu} \rangle}{N_{inv}^{pp}}$$

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



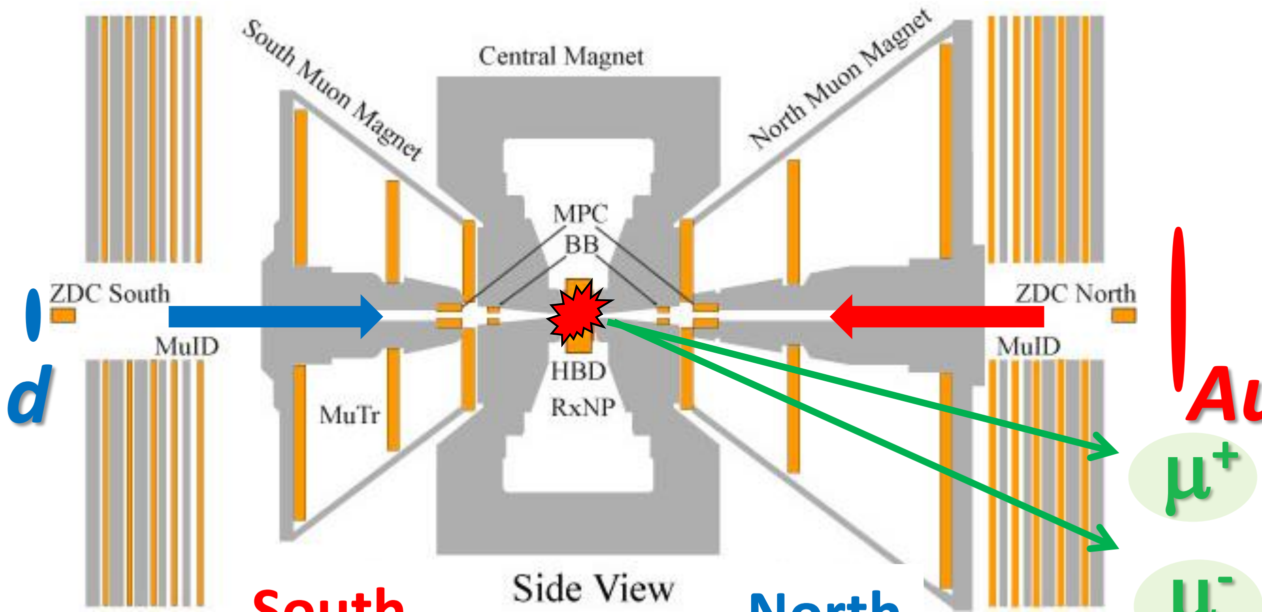
	pp	dAu (all centralities)	dAu (0-20%)	dAu (60-88%)
N_{coll}	1	7.6 ± 0.4	15.1 ± 1.0	3.2 ± 0.2

N_{coll} : number of binary (pp) collisions in one HI collision.

- If the production of AA behaves like in pp,
  $R_{dAu} = R_{cp} = 1$
- If there is suppression, R_{dAu} , $R_{cp} < 1$

PHENIX Muon arm

$$\sqrt{S_{NN}} = 200GeV$$



$$\Upsilon \rightarrow \mu^{+}\mu^{-}$$
$$1.2 < |y| < 2.2$$
$$\Delta\phi = 2\pi$$

$$\rho/\omega\ \phi,\ J/\psi \rightarrow \mu^{+}\mu^{-}$$

South

<y> ~ -1.7, x2 ~ 0.2

Gold going direction

North

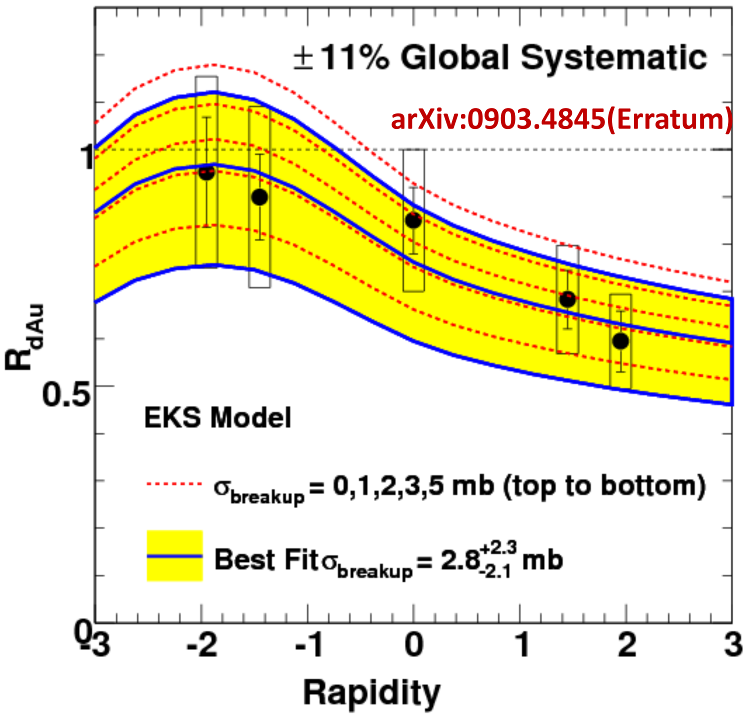
<y> ~ 1.7, x2 ~ 0.01

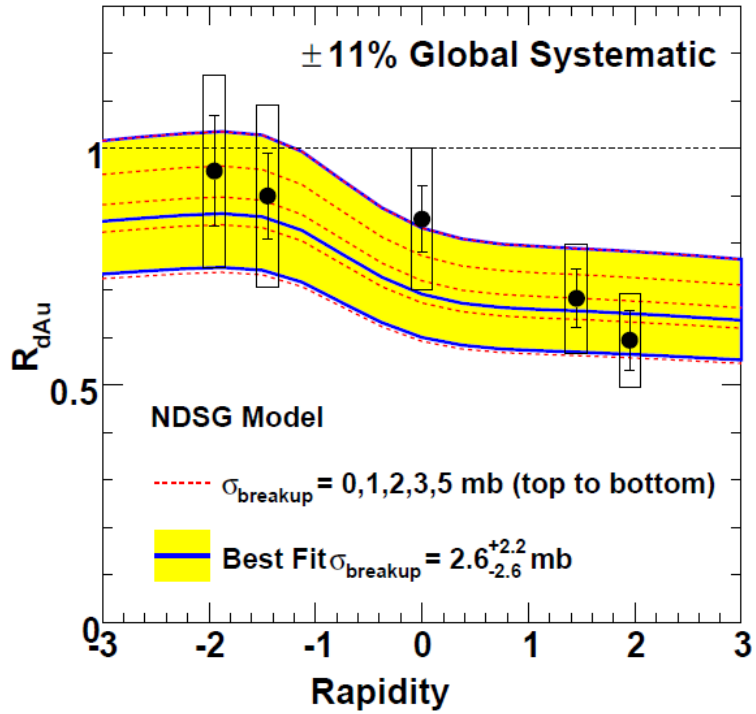
deuteron going direction

thought to be in shadowing region

J/ψ R_{dAu}

Run2003 dAu/Run2005 pp, PRC 79, 059901(E) (2009)





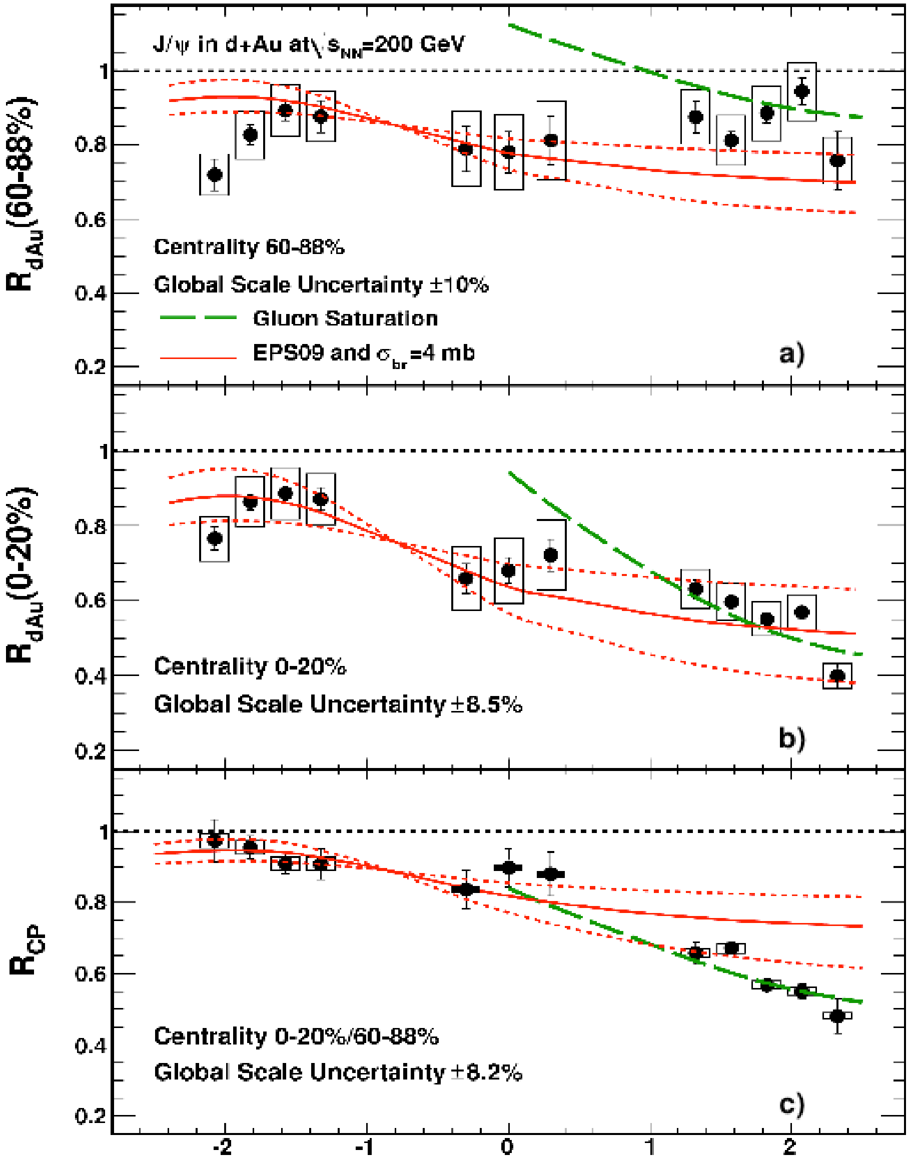
Shadowing model comparison to R_{dAu} values with EKS PDF and fixed breakup cross sections

With NDSG and fixed breakup cross sections

PDF	EKS(mb)	NDSG(mb)
$\sigma_{breakup}$	$2.8^{+2.3}_{-2.1}$	$2.6^{+2.2}_{-2.6}$

Published R_{dAu} vs. rapidity result

New J/ψ R_{dAu}, R_{cp}



- Preliminary result with 2008 d+Au data which has ~30 times statistics than 2003 d+Au data.
- Can't fit the data with fixed breakup cross sections.
- Gluon saturation does not match at mid rapidity
- Need to understand the suppression of shadowing region.

Upsilon analysis

- Run 8 (2008) d+Au data and Run 6 (2006) p+p data are used.

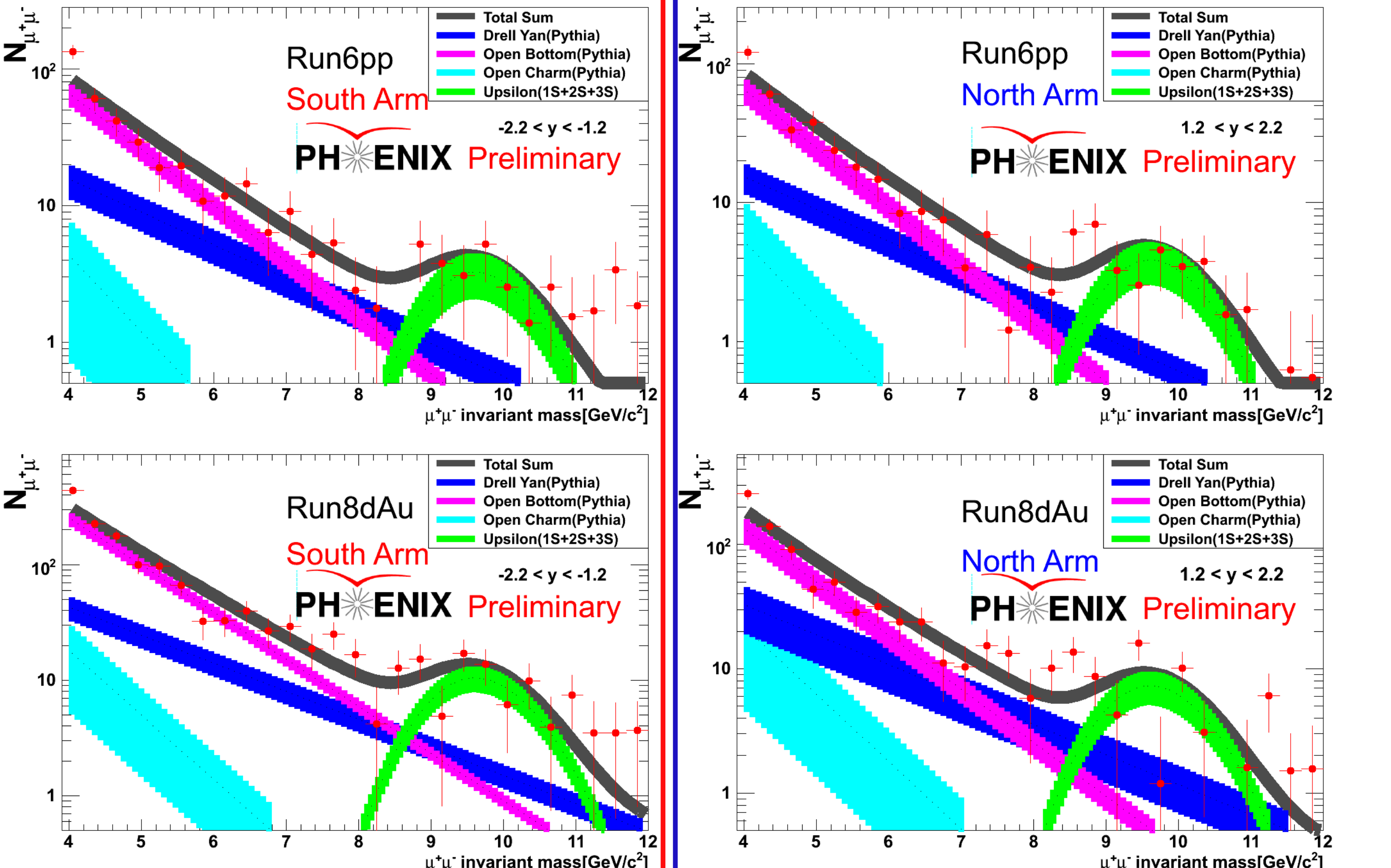
  -> provide Upsilon cross section, σ_{Υ} and Upsilon nuclear modification factor, R_{dAu}.

- Physical backgrounds of Drell Yan, open charm and open beauty

  are simulated and excluded.

	Run06	Run7	Run08	
Collision type	pp	AuAu	pp	dAu
$\sqrt{s_{NN}}$ (GeV/c^2)	200	200	200	200
∫Ldt	10.7 pb-1	0.8 nb-1	5.2 pb-1	80 nb-1

Invariant mass distribution



Gold(Au) going, y<0

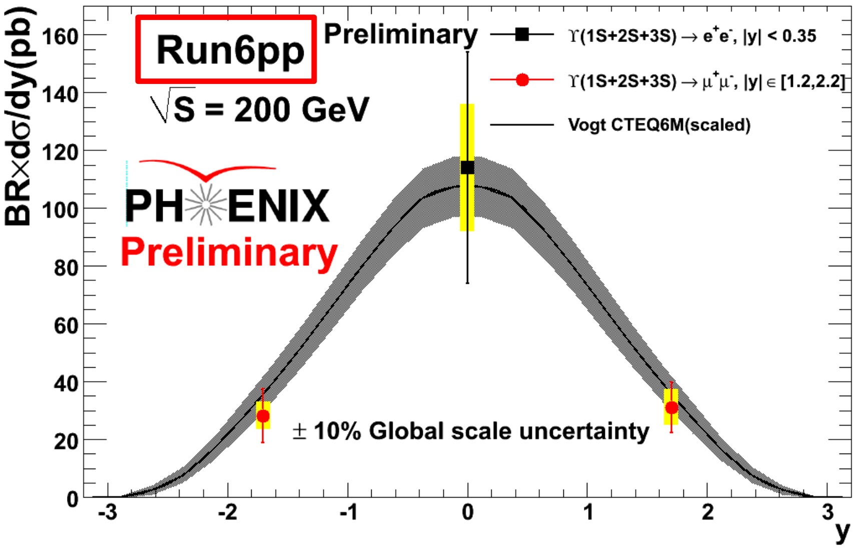
Deuteron(d) going, y>0

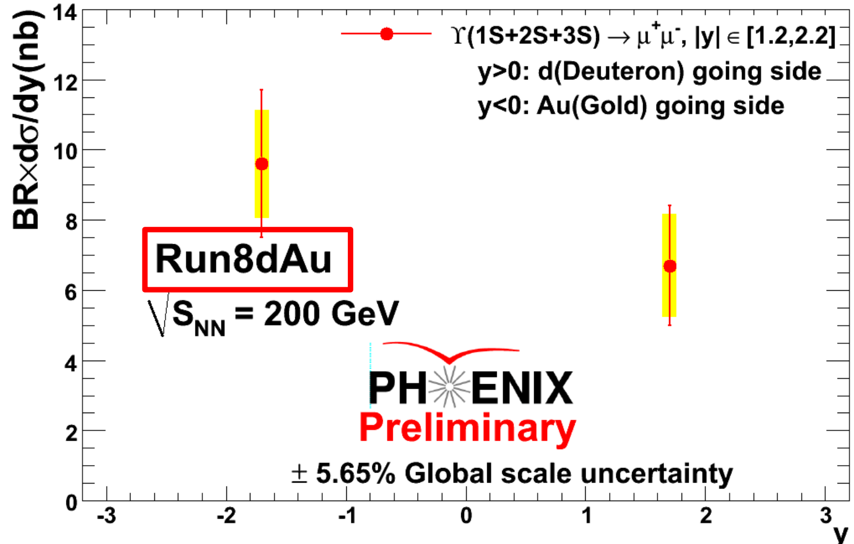
p+p

d+Au

Physical background of Drell Yan, $b\bar{b}$ and $c\bar{c}$ is estimated (pythia)

Upsilon cross sections





BR*dσ/dy = 28.2±9.4(stat.)±4.8(syst.)pb, y ∈[-2.2, -1.2]

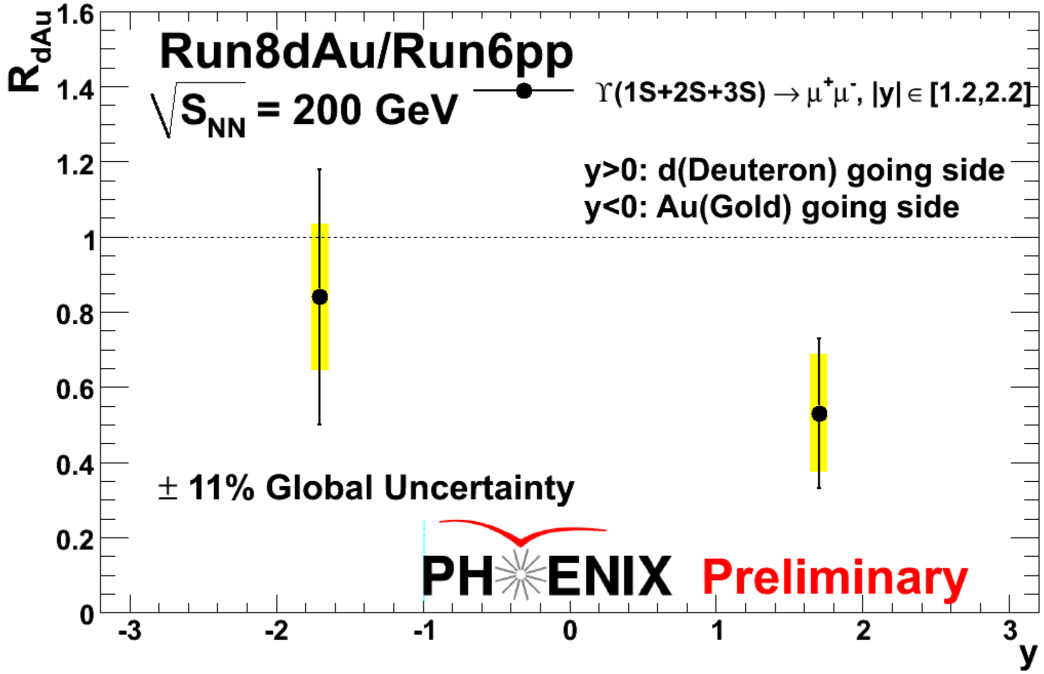
BR*dσ/dy = 31.1±8.7(stat.)±6.2(syst.)pb, y ∈[1.2, 2.2]

BR*dσ/dy = 9.6±2.1(stat.)±1.5(syst.)nb, y ∈[-2.2, -1.2]

BR*dσ/dy = 6.7±1.7(stat.)±1.5(syst.)nb, y ∈[1.2, 2.2]

- pp cross section is reference to comparison to d+Au collision.
- pp cross section vs. rapidity is following the shape of Color Evaporation Model-CTEQ6M(PDF)(scaled down by ~2).
- Cross section vs. rapidity of d+Au collision is asymmetric.

Upsilon R_{dAu}

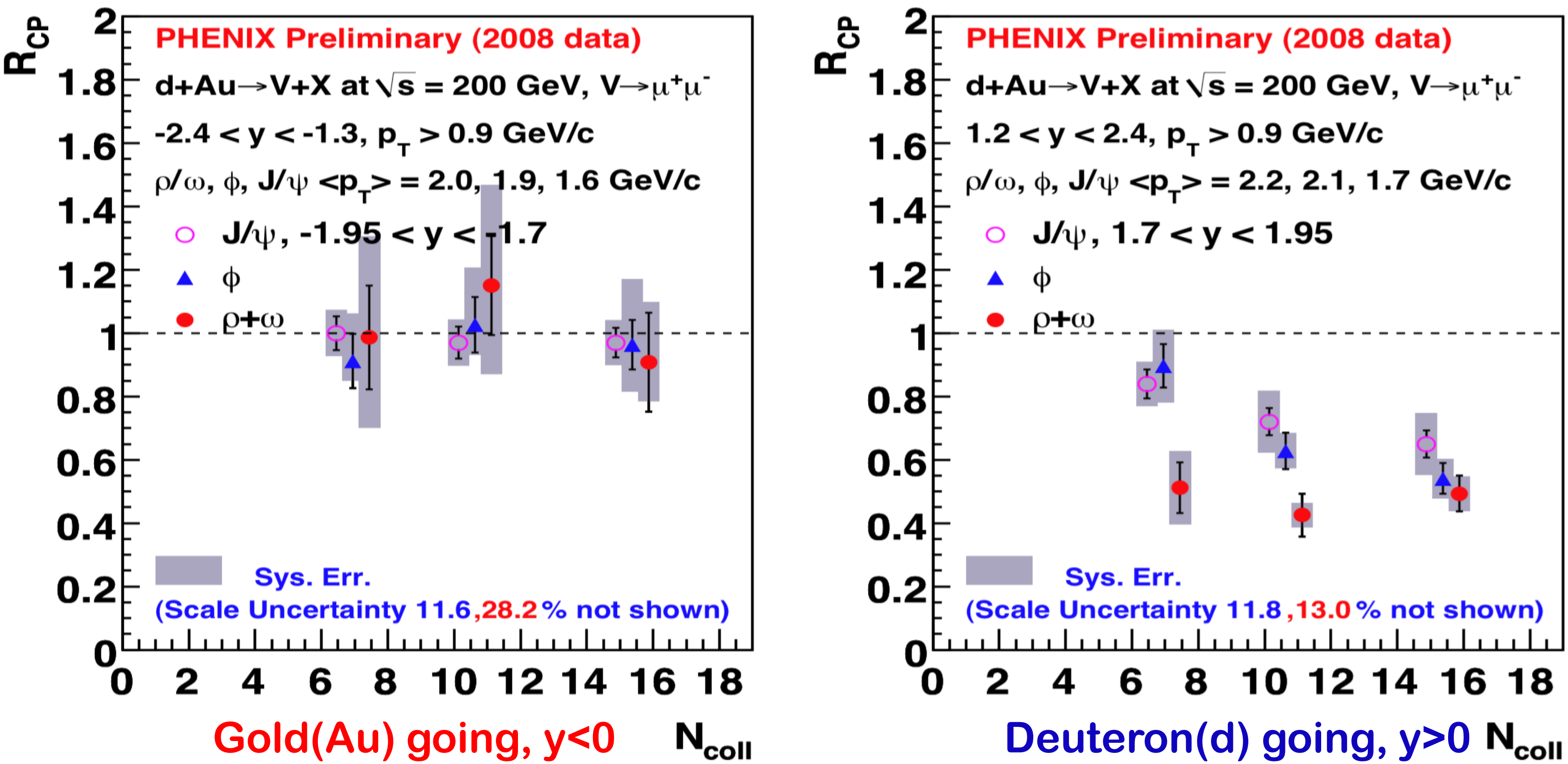


R_{dAu} = 0.84 $\pm$ 0.34(stat.) $\pm$ 0.20(sys.), $y \in$ [-2.2, -1.2]

R_{dAu} = 0.53 $\pm$ 0.20(stat.) $\pm$ 0.16(sys.), $y \in$ [1.2, 2.2]

- First Upsilon R_{dAu} measurement at forward rapidity.
- Showing suppression at small x region.
- Waiting for theoretical comparison.

Light vector mesons R_{cp}



- First nuclear modification factor measurement for low mass vector mesons at forward rapidity.
- Significant suppression at deuteron going direction.
- Stronger suppression for ρ/ω than ϕ and J/Ψ.

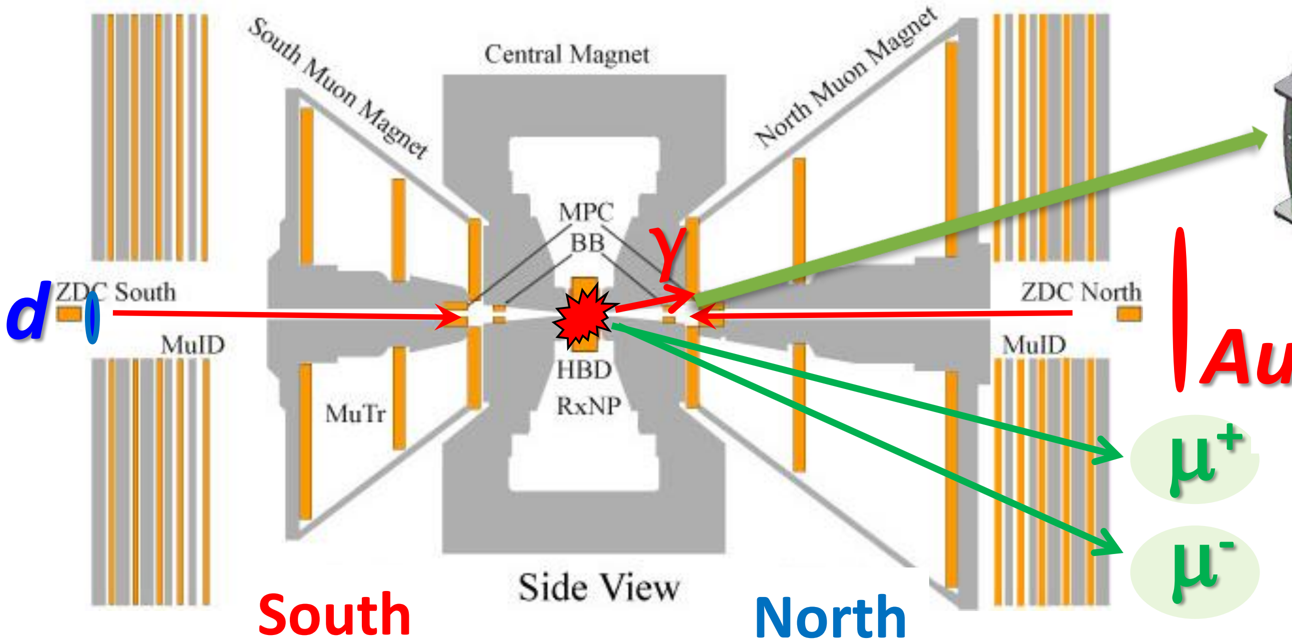
chi_c Analysis

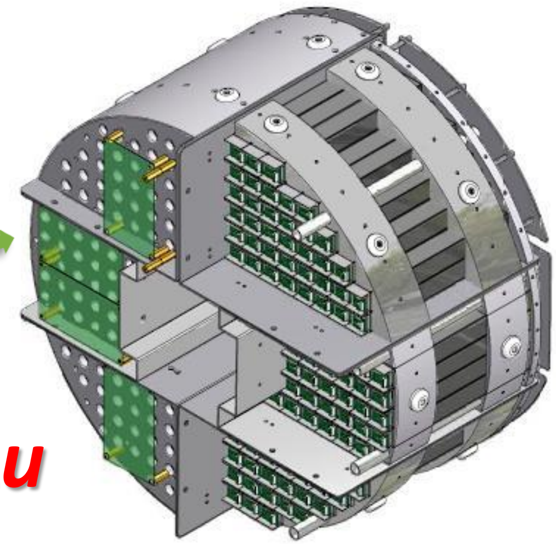
- Higher charmonium state(1P) than $J/\psi(1S)$.
- There are three states of chi_c.
- Radiative decay channel $\chi_c \rightarrow J/\psi + \gamma \rightarrow \mu^+\mu^-(e^+e^-) + \gamma$.
- $R_{\chi c} = (\chi_c \rightarrow J/\psi + \gamma) / (\text{Inclusive } J/\psi)$.
- It would be a good tool to decouple the fraction of decay J/ψ and direct J/ψ.

BR ratio	χ_{c0} (3.41 GeV)	χ_{c1} (3.51 GeV)	χ_{c2} (3.56 GeV)	J/ψ (3.10 GeV)
$\chi_c \rightarrow J/\psi,\gamma$	1.16%	34.4%	19.5%	
$J/\psi \rightarrow \mu^+\mu^-$				5.93%

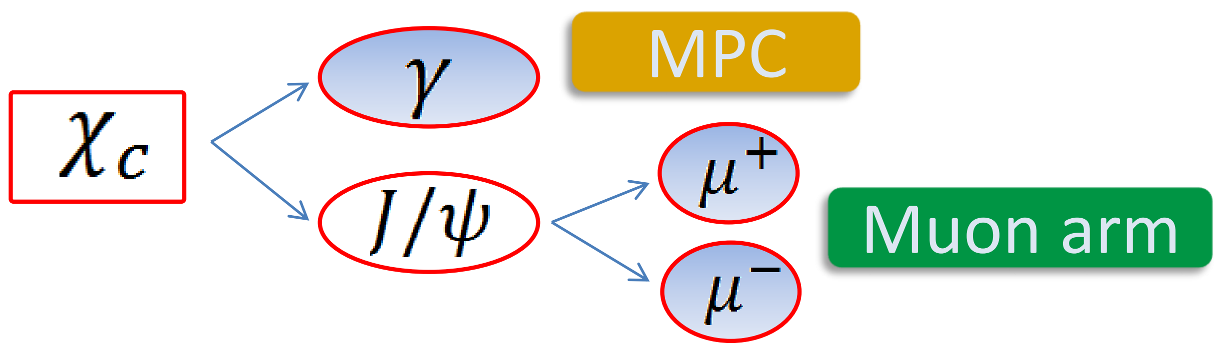
PDG 10’

How can we detect chi_c?

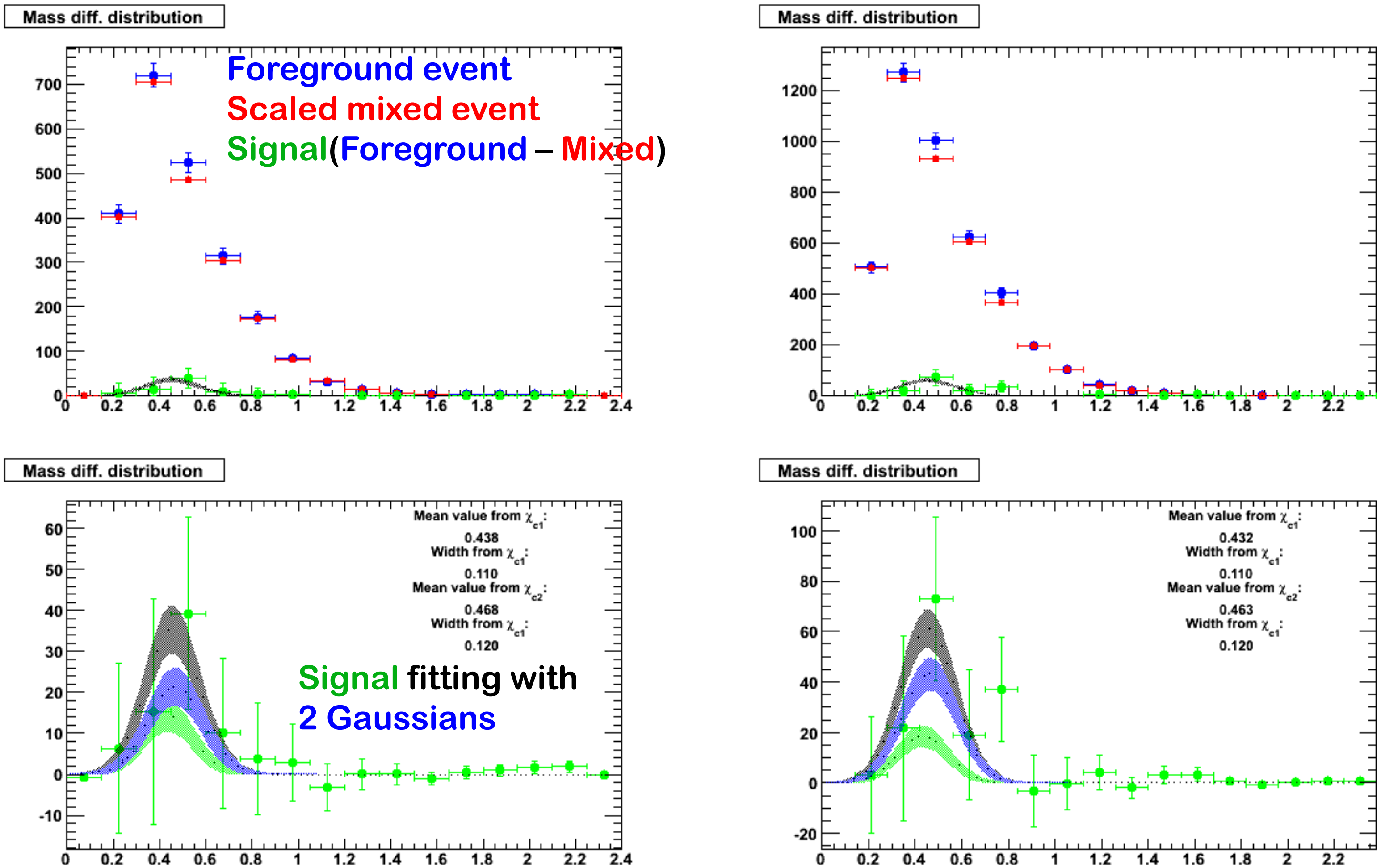




Forward E.M. Calorimeter (MPC)
$3.1 < |y| < 3.8$



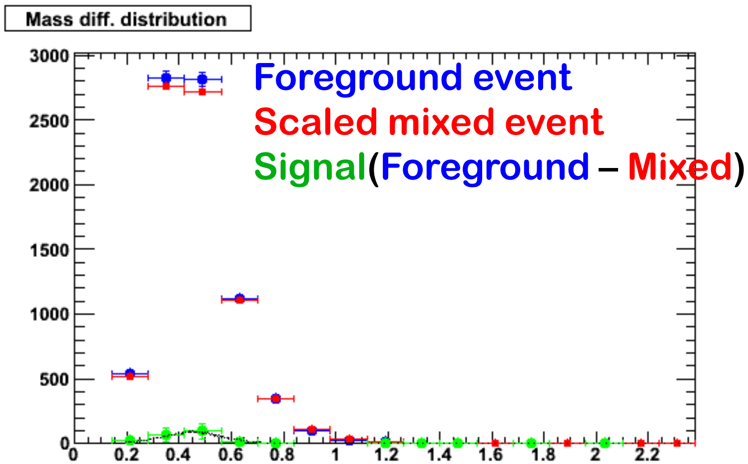
Fitting to real data (p + p data set)

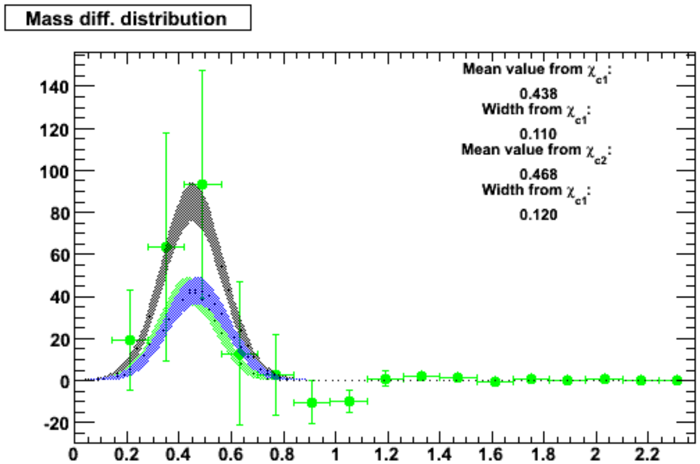


North arm

South Arm

Fitting to real data (d + Au data set)





dAu North

- Peak is visible at small x region.
- South MPC has large background.

Summary

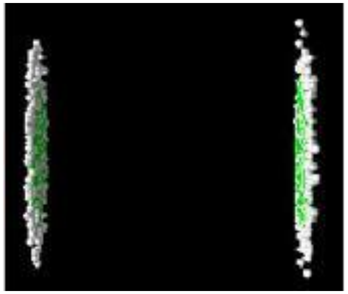
- Nuclear modification factors of Upsilon, J/ψ and light vector mesons are shown.

- They show suppression at low x region but, not clearly understood yet.
- Recent J/ψ R_{cp} result is not explained well with shadowing model and fixed breakup cross sections.
- Upsilon R_{dAu} shows suppression in low x region and need to have theoretical comparison.
- Low mass vector mesons need to understand its production mechanisms.

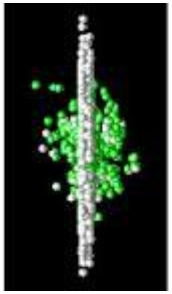
- χ_c feed down to J/ψ measurement is underway and important to decouple the cold nuclear matter effect and QGP state.
- In future, PHENIX FVTX/VTX upgrade will reduce more background and make the ψ' and even Drell-Yan measurement possible.

Back up

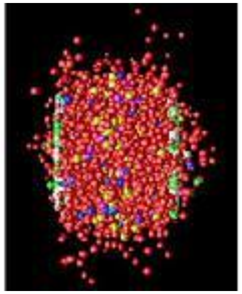
Heavy Ion Collision



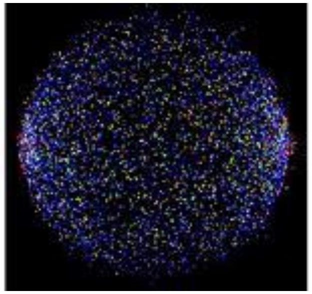
1. About to collide



2. Collide

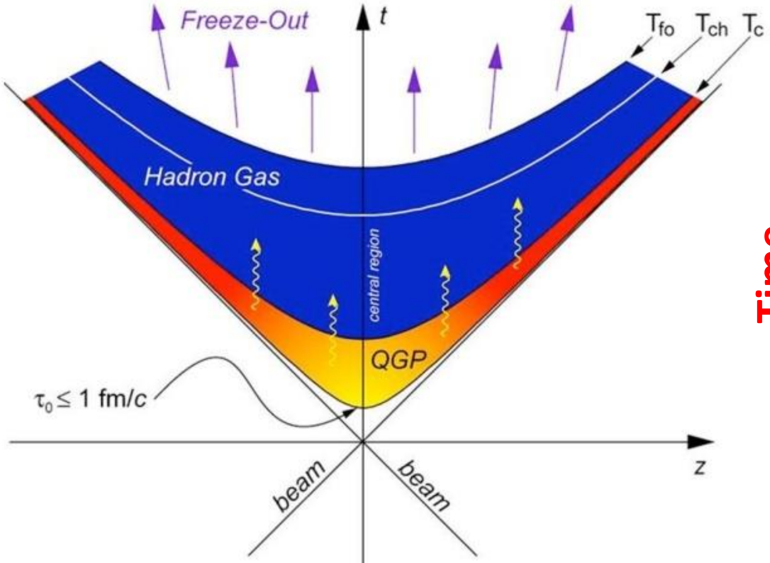


3. QGP

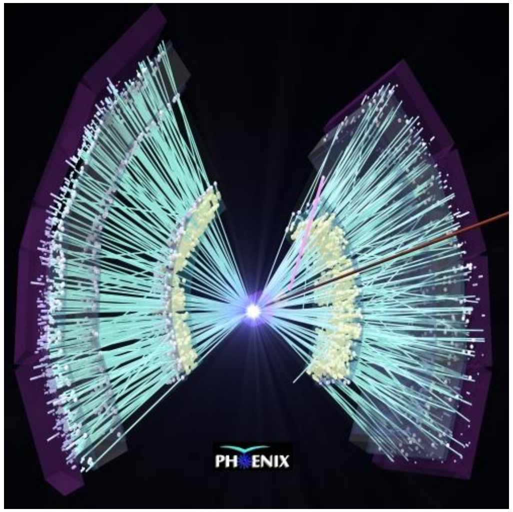


4. Hadronize(Freeze out)

Time

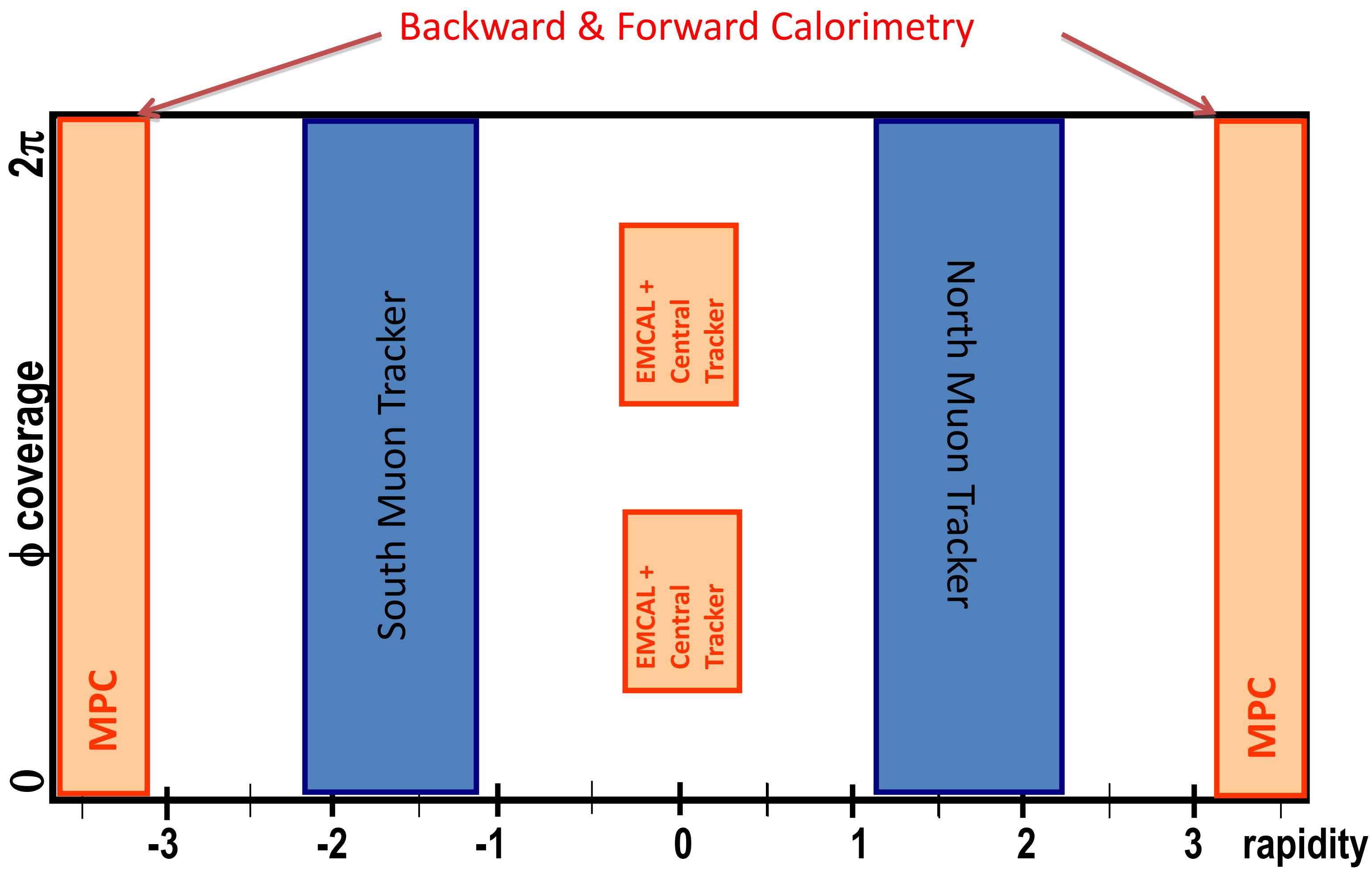


Time



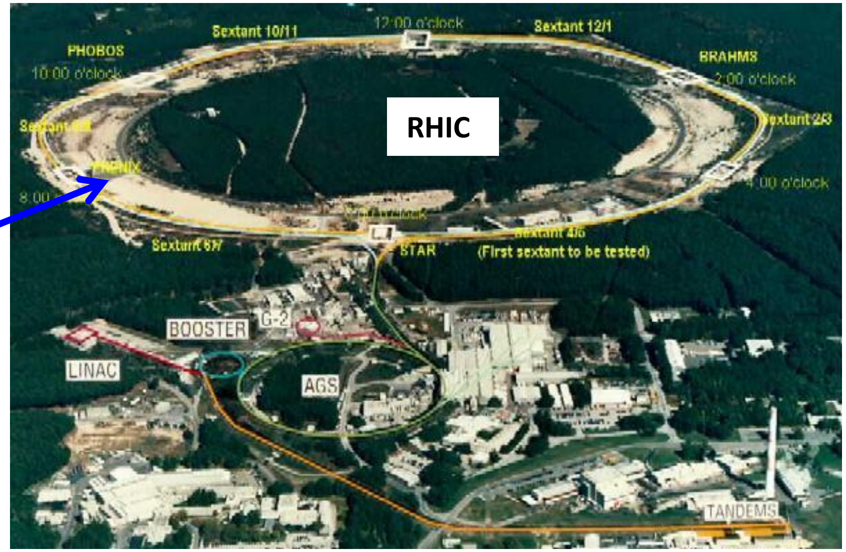
The space-time diagram of a heavy ion collision

PHENIX acceptance

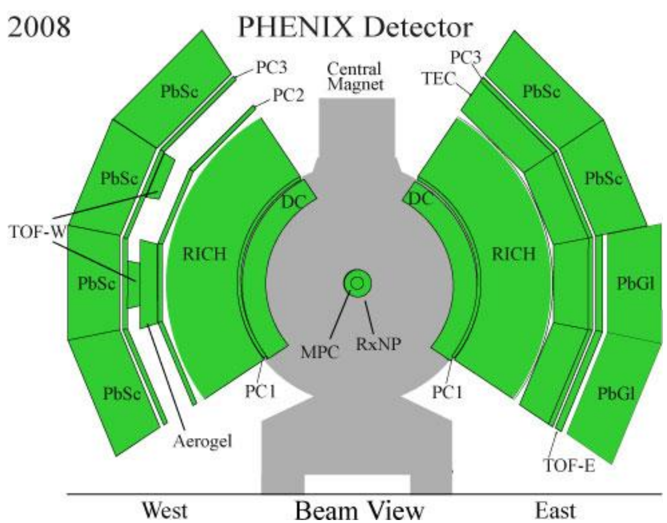


RHIC and PHENIX detector

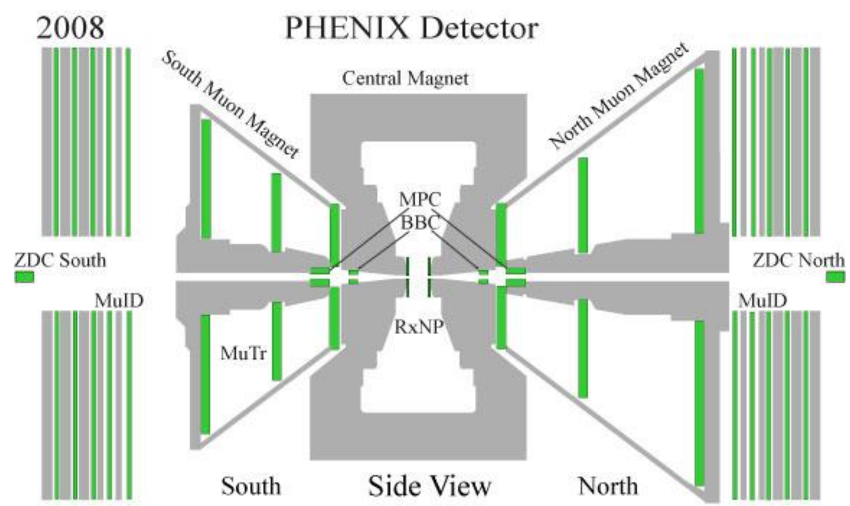
PHENIX



$\sqrt{S_{NN}}$ = 200(7.7 ~ 500) GeV
Collision type = p+p, Au+Au
Cu+Cu, d+Au



Central arm



Muon arm