Υ, χ_c and ψ' production and nuclear modifications from PHENIX

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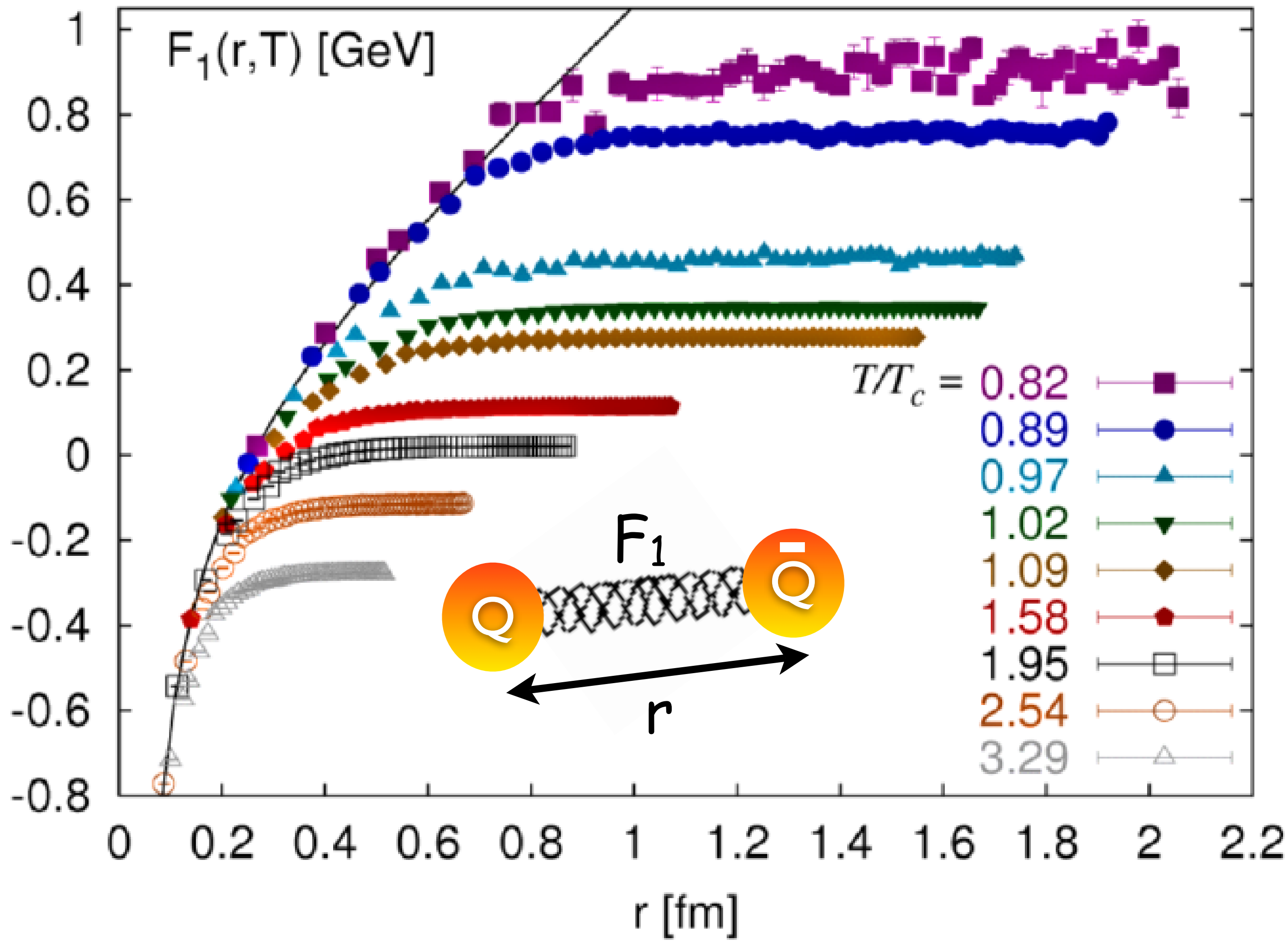
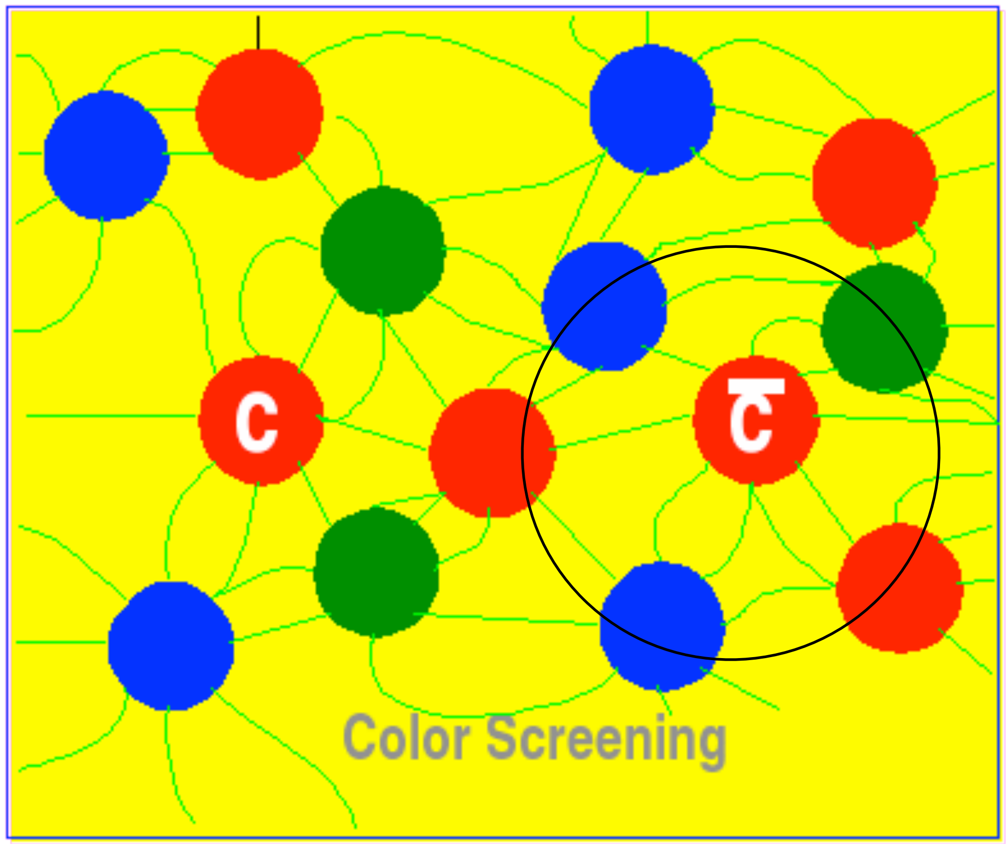
LOS ALAMOS NATIONAL LAB
for the PHENIX Collaboration

WWND 2012 - San Juan, Porto Rico

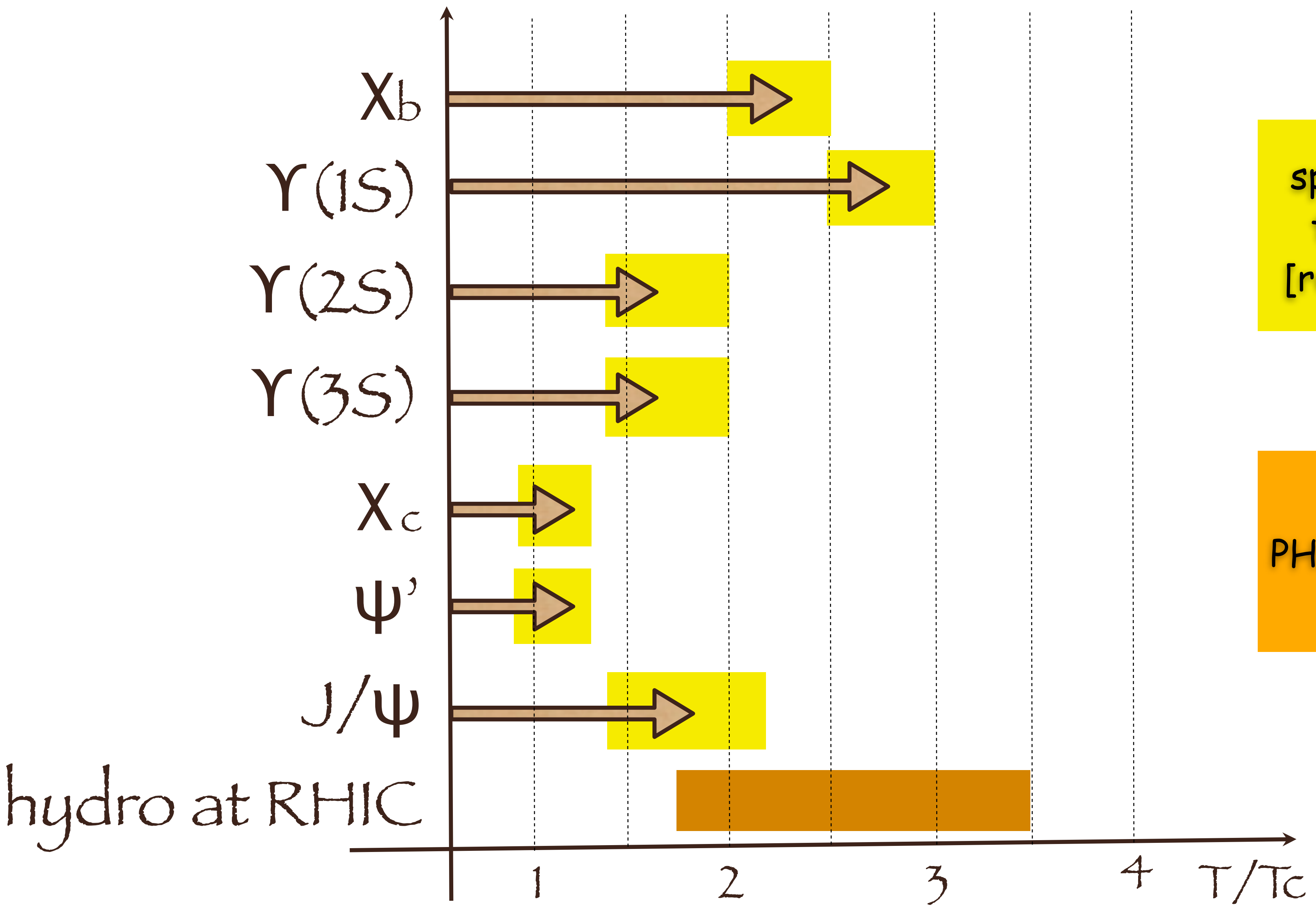
Color Screening





State	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ'_b	Υ''
Mass (GeV)	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
ΔE (GeV)	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
ΔM (GeV)	0.02	−0.03	0.03	0.06	−0.06	−0.06	−0.08	−0.07
r_0 (fm)	0.50	0.72	0.90	0.28	0.44	0.56	0.68	0.78

QGP Thermometer



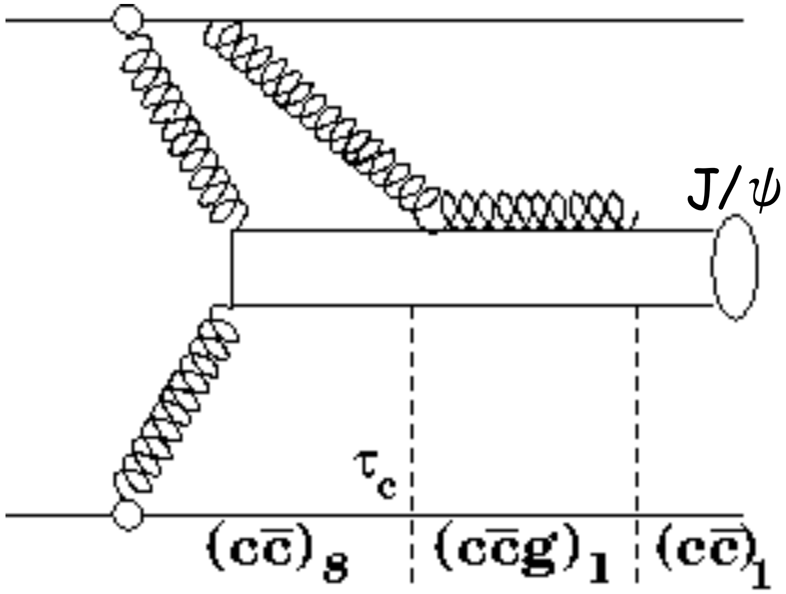
spectral functions at finite temperature estimations [references in backup slide]

hydro models fitted to PHENIX thermal photon data (assuming Tc=170MeV)

quarkonia is much more than a QGP signature

However …

- J/ψ and Υ(1S) have feed-down from excited states
- what quarkonium cross the nucleus?
  - a final state (J/ψ, ψ') or a pre-resonant state



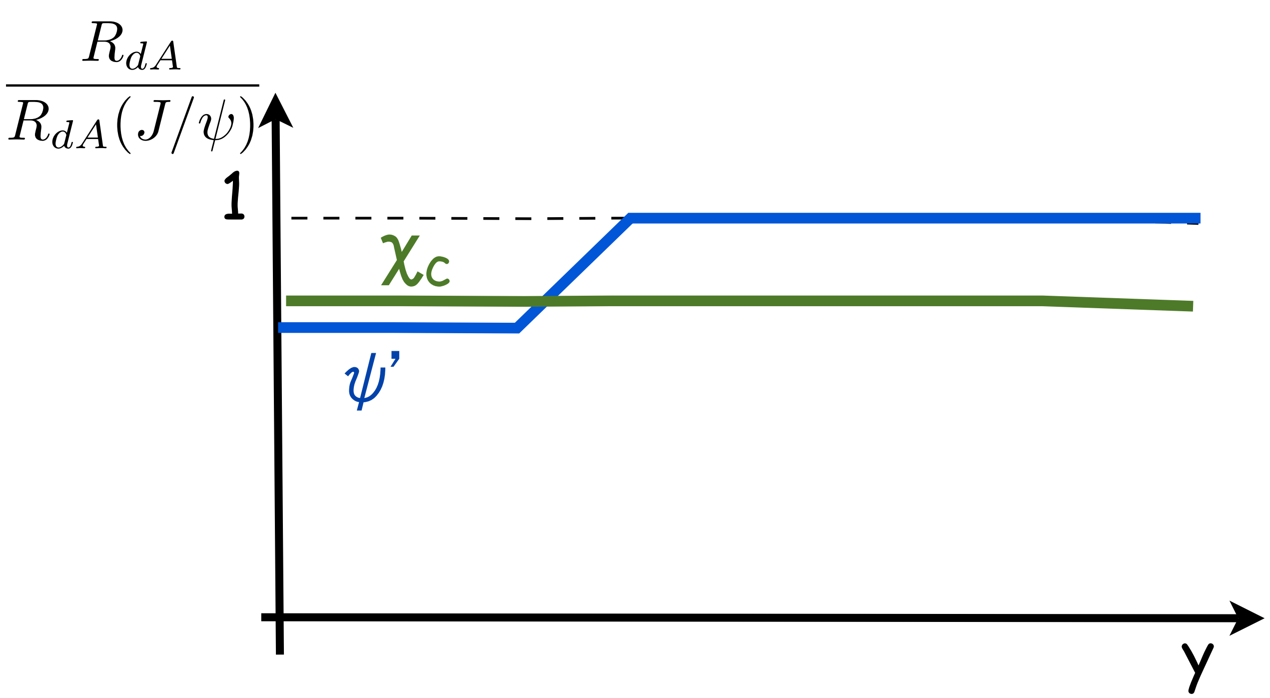
- charmonium is a pre-resonant object above y ~ -2 in p+A collisions at RHIC [K.Tuchin, D.Kharzeev, Nucl.Phys.A770,40(2006)]

- χ_c is formed as a color singlet (no pre-resonant stage)
- bottomonia states also can have pre-resonant stages

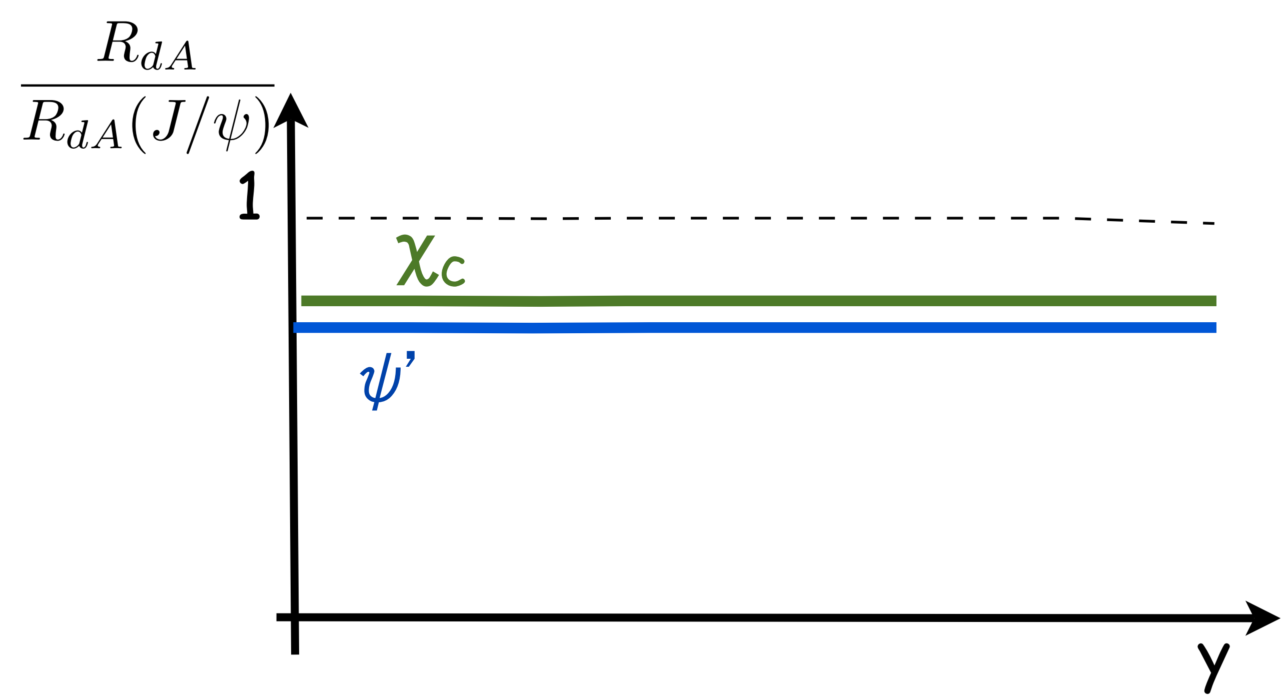
How to check if pre-resonant stage exist

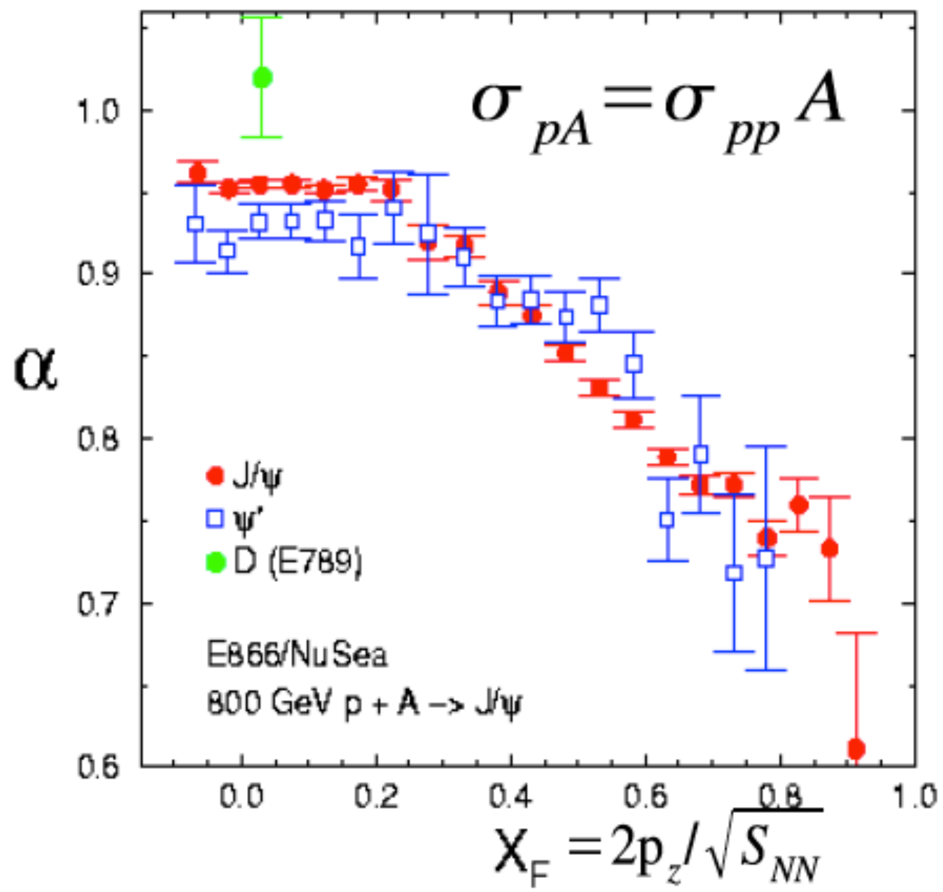
- initial states are the same for J/ψ and ψ'
- ψ' almost 2x larger than J/ψ, binding energy 13x weaker, breakup cross section should be very different
  - $R_{dA}(\psi') < R_{dA}(J/\psi)$ if they cross the nucleus as final states

pre-resonant charmonium scenario

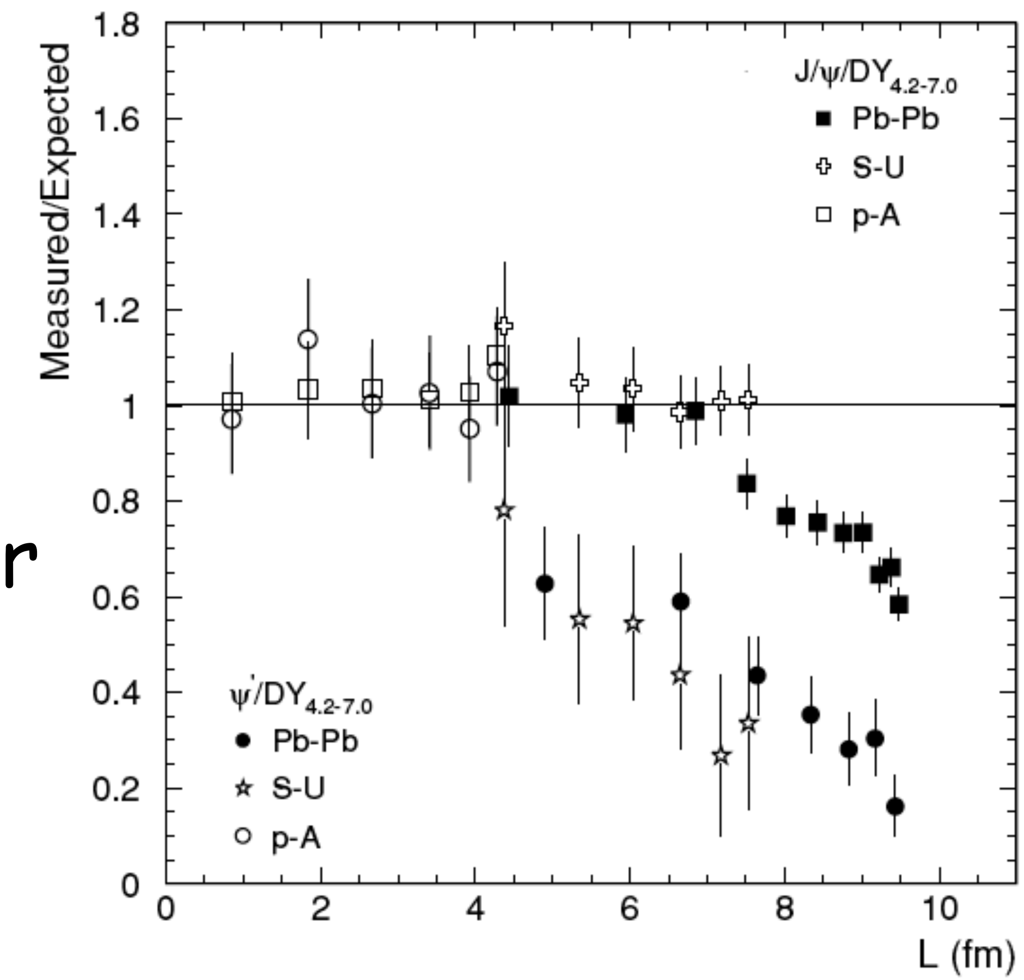


no pre-resonant charmonium



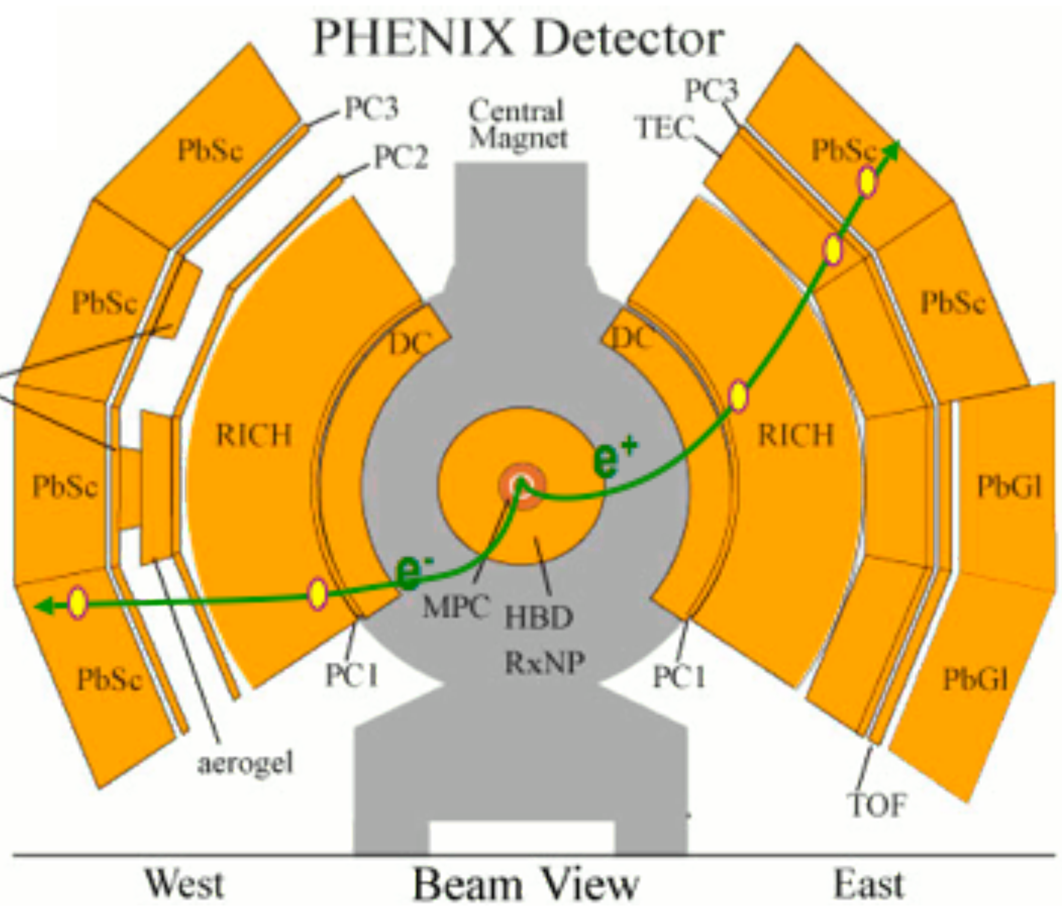


- pre-resonant state for x_F>0.3 in E866 ?

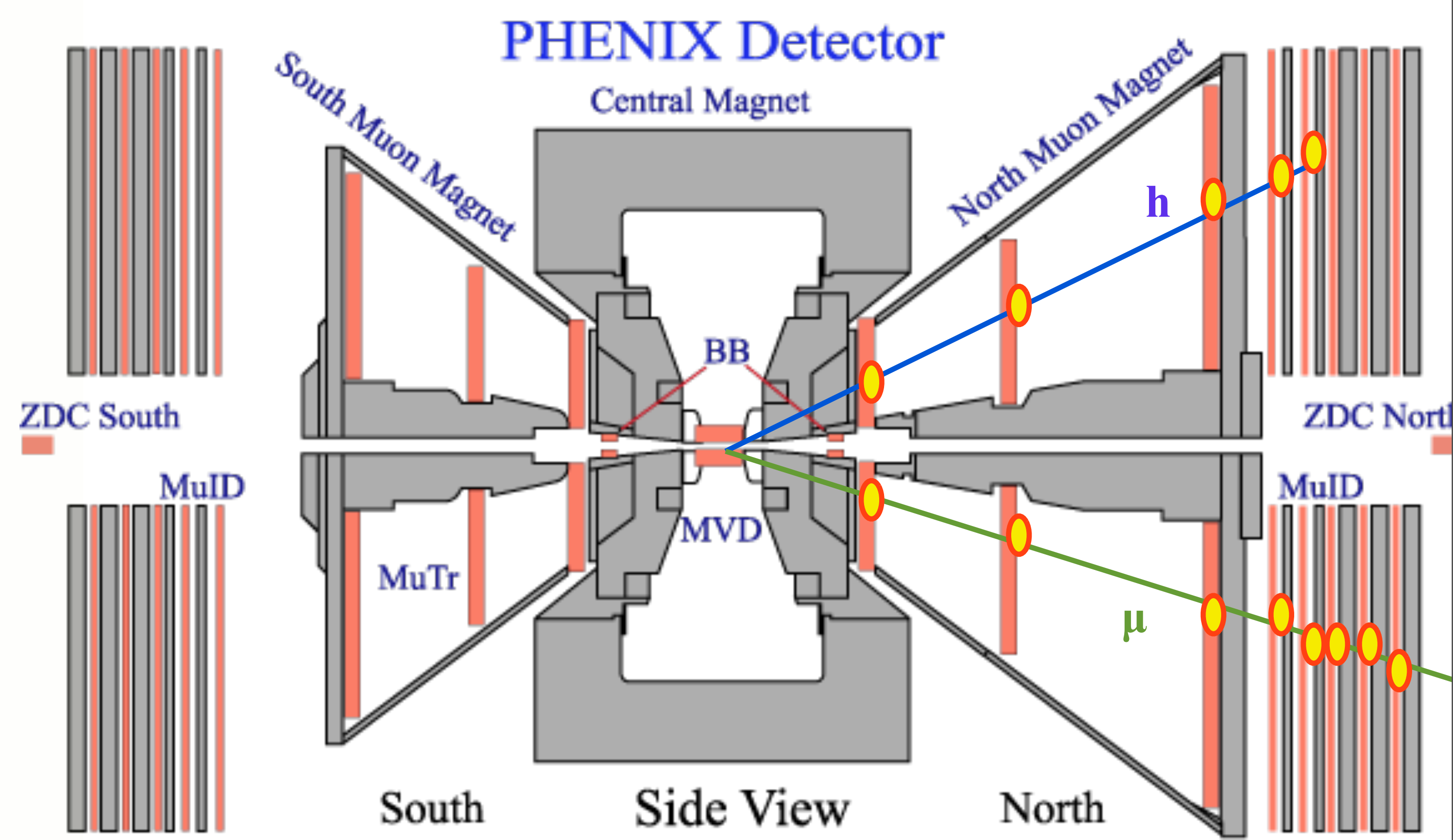


- NA38/NA50 has pre-resonant behavior in p+A and final state charmonium behavior in A+A

- what about RHIC ?
- needs R_{dA} of χ_c to confirm the pre-resonant picture



$|y|<0.35$ $\Delta\Phi \approx 2\times\pi/2$



$1.2<|y|<2.2$ $\Delta\Phi \approx 2\pi$

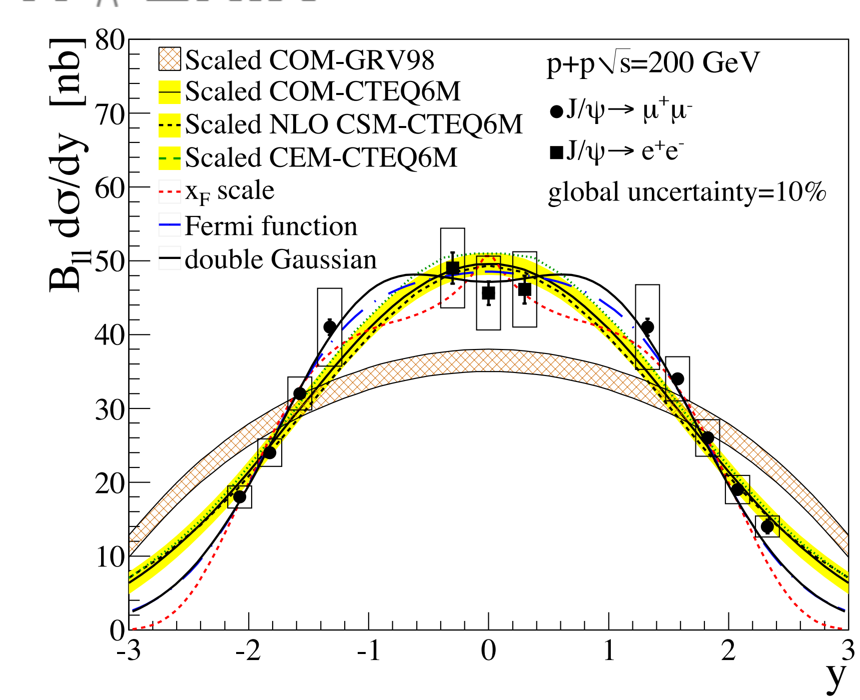
dilepton decays: J/ψ, ψ', Υ(1S+2S+3S)

radiative decays: $\chi_c \rightarrow e^+e^-\gamma$

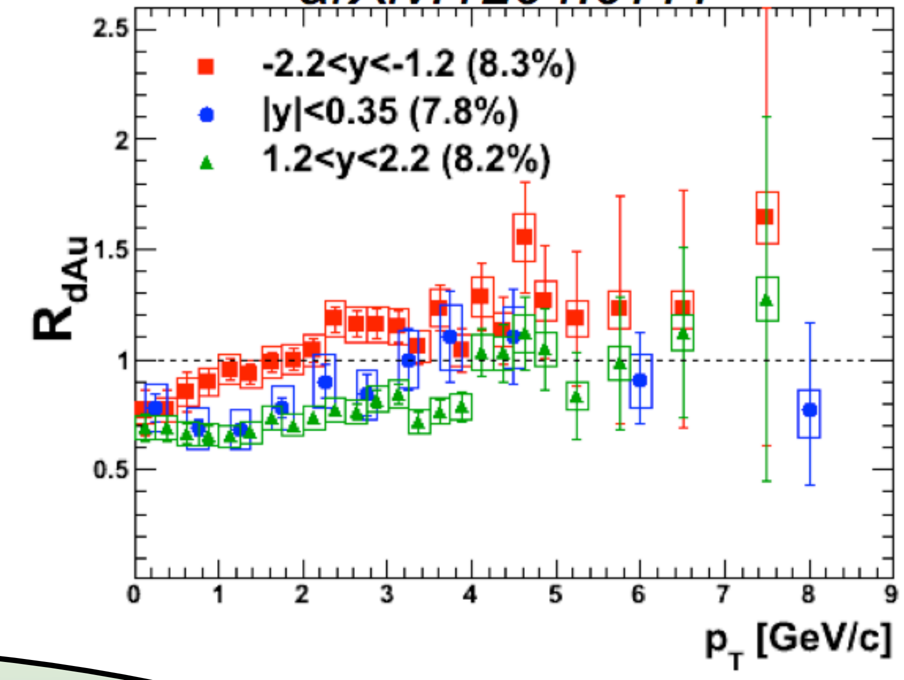
Charmonium

	$\lvert y\rvert < 0.35$	$1.2 < \lvert y\rvert < 2.2$
$J/\psi \rightarrow e^+e^-$	p+p,d+Au, Cu+Cu,Au+Au	
$J/\psi \rightarrow \mu^+\mu^-$		p+p,d+Au, Cu+Cu,Au+Au
$\psi' \rightarrow e^+e^-$	p+p,d+Au	
$\chi_{c1,2} \rightarrow J/\psi + \gamma$	p+p,d+Au	

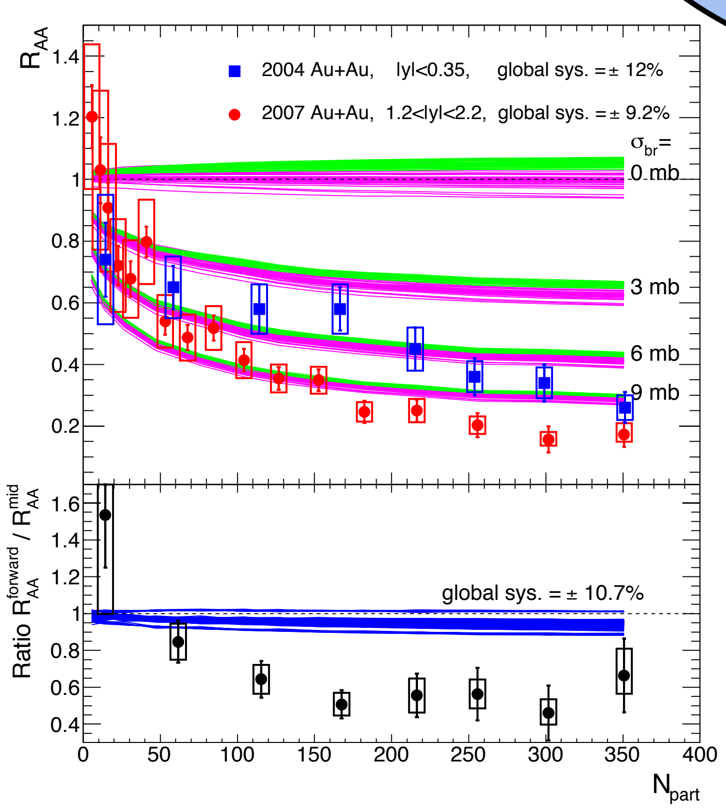
PHENIX

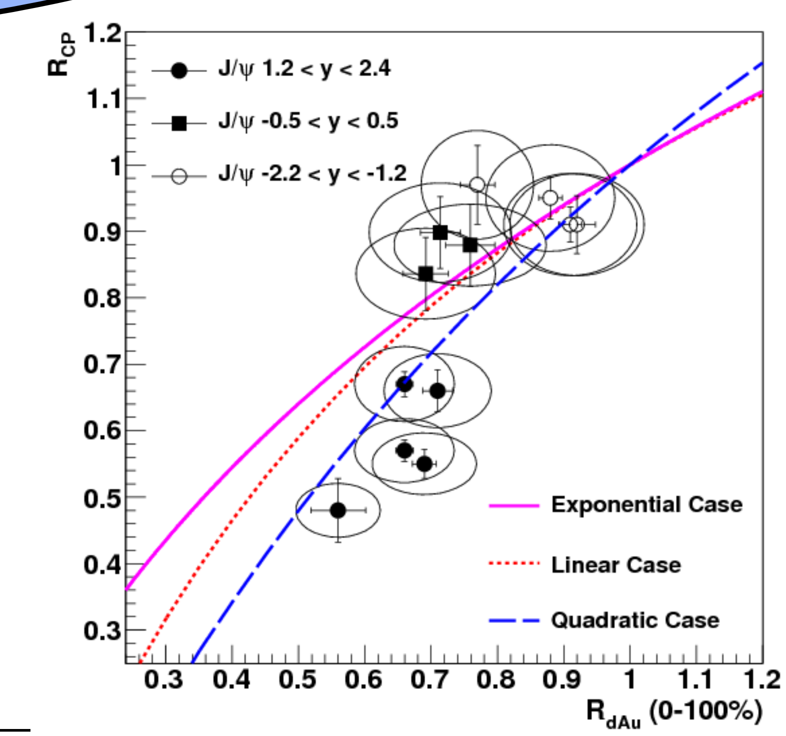


arXiv:1204.0777



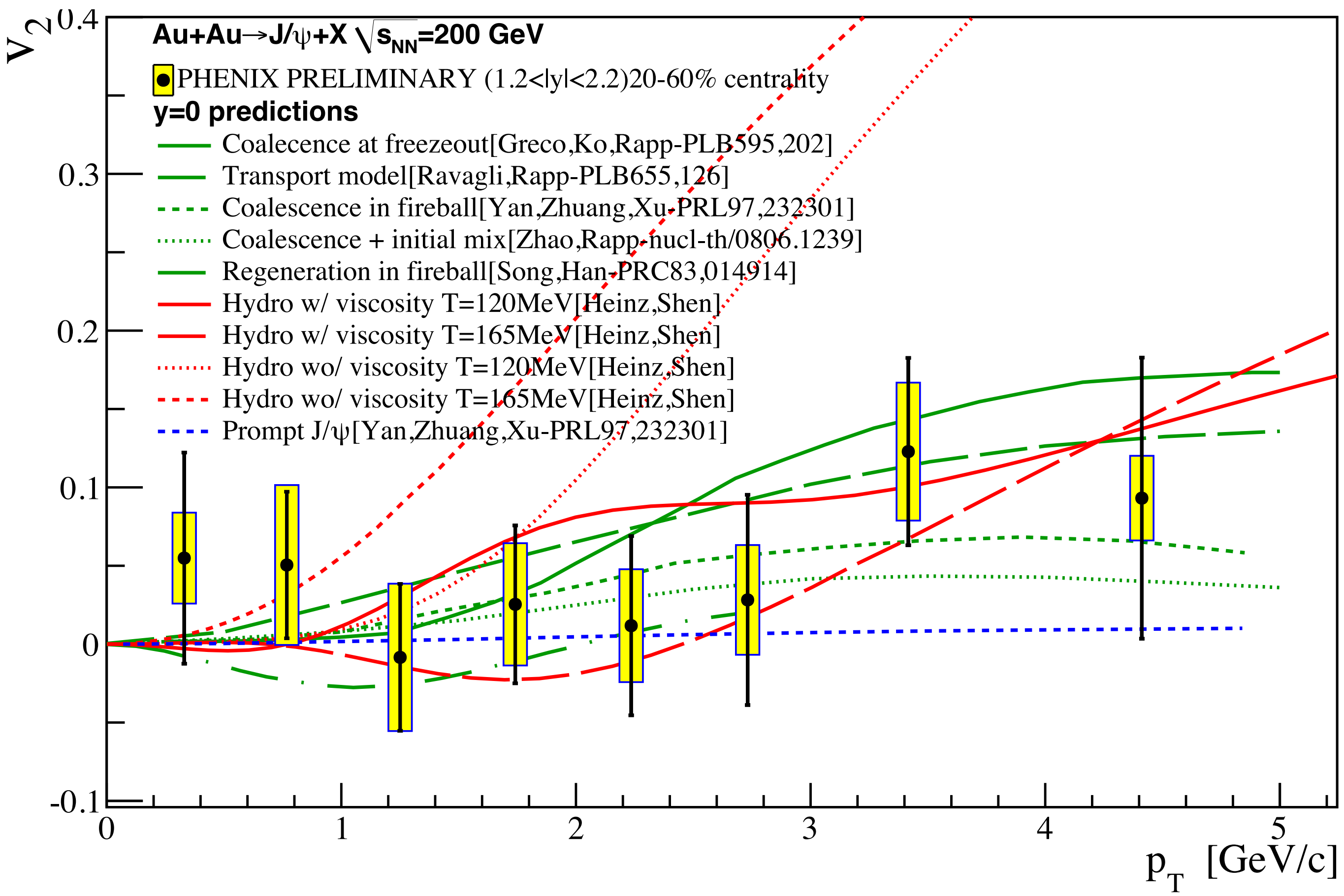
Detailed
study of the ground
state of charmonium (J/ψ)

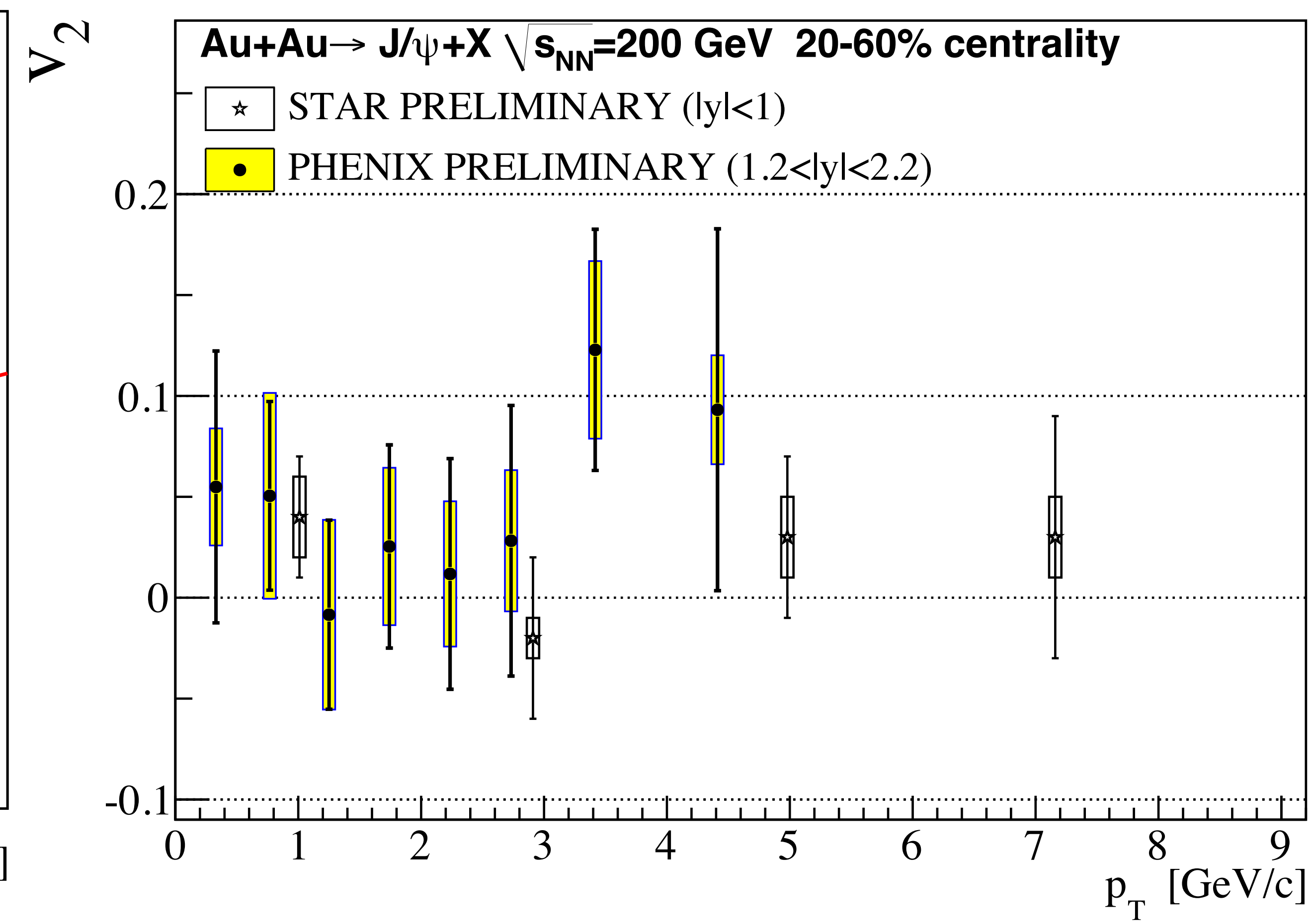




new J/ψ v_2 at large rapidity

and the results keep coming ...





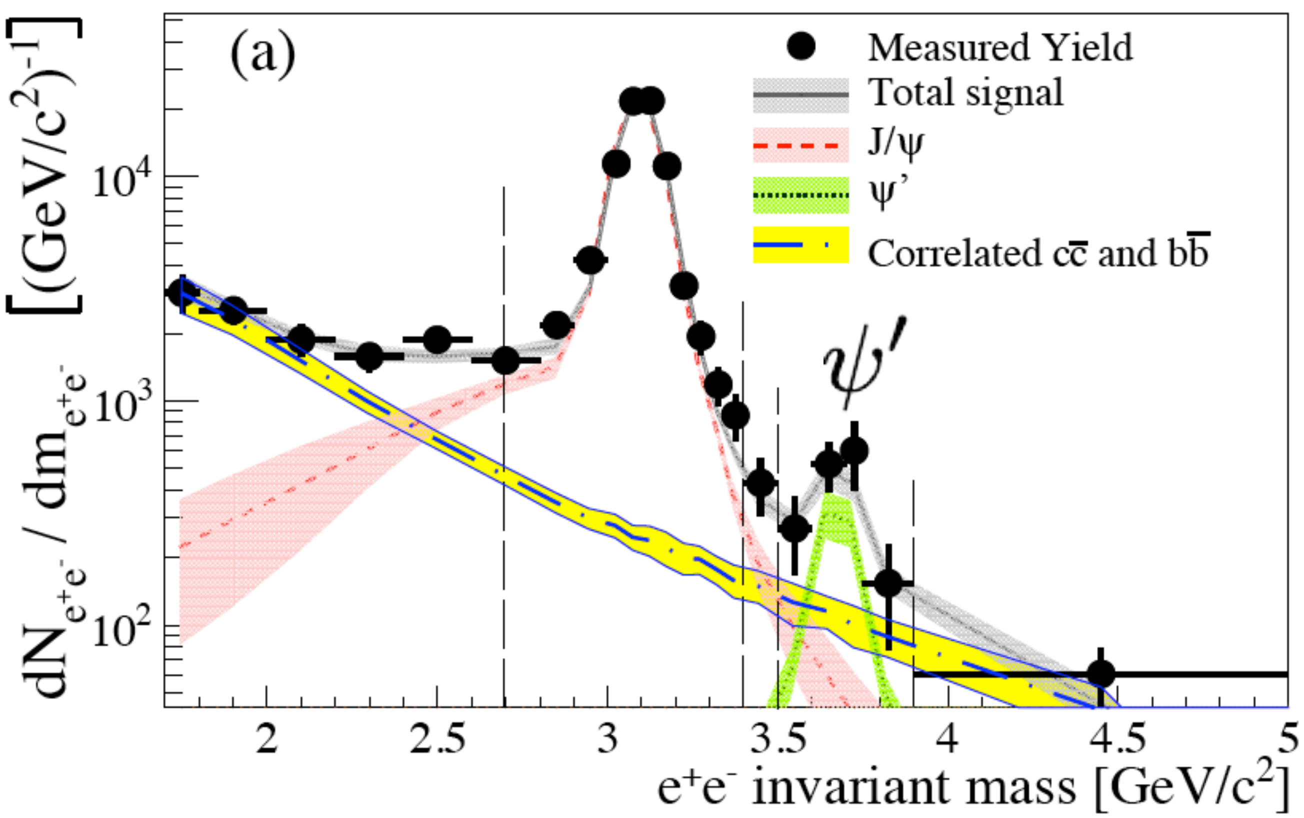
agreement with several coalescence models for mid-rapidity

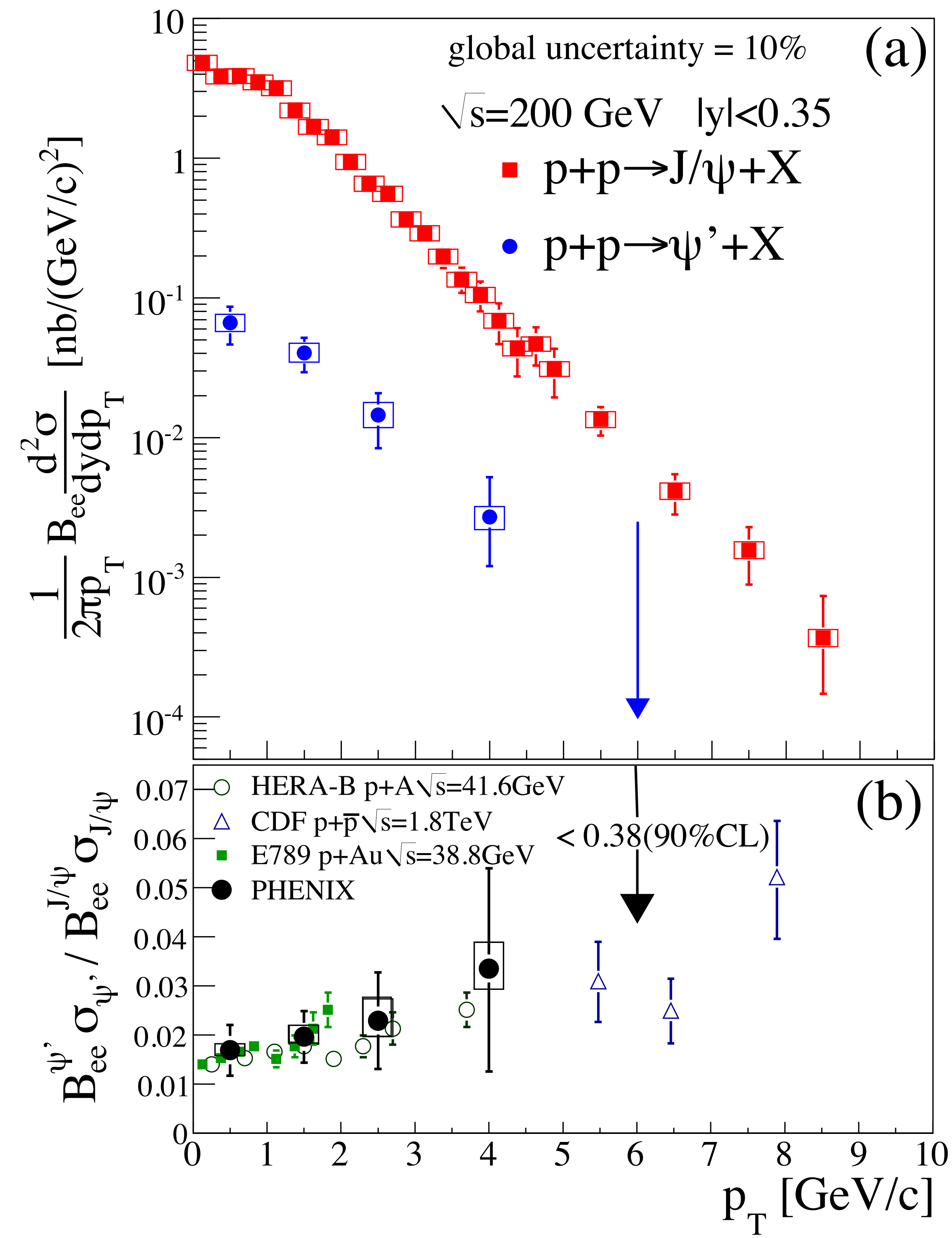
or some path length dependence of R_{AA} ?

PHENIX

$p + p \rightarrow \psi' \rightarrow e^+e^- \quad \sqrt{s} = 200GeV \quad |y| < 0.35$

arXiv:1105.1966 approved for PRD





$$F^{J/\psi}_{\psi'} = \frac{B^{\psi'}_{J/\psi}\sigma_{\psi'}}{\sigma_{J/\psi}} = (9.6 \pm 2.4)\%.$$

PHENIX

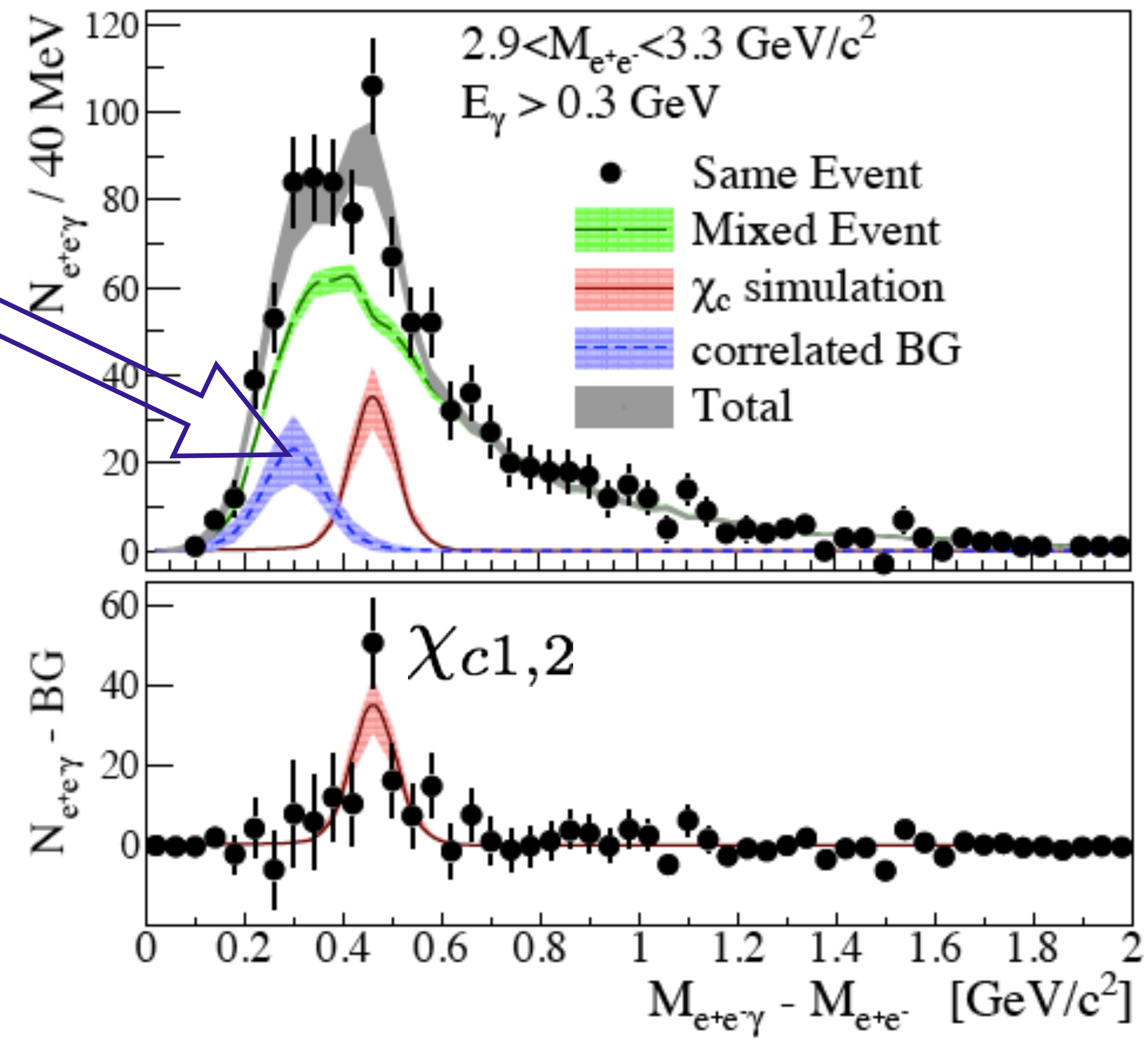
$\chi_c \rightarrow J/\psi + \gamma \rightarrow e^+e^- + \gamma$

γ measured in EMCal (Eγ >300 GeV)

Eγ from χ_c ~600 MeV

arXiv:1105.1966 approved for PRD

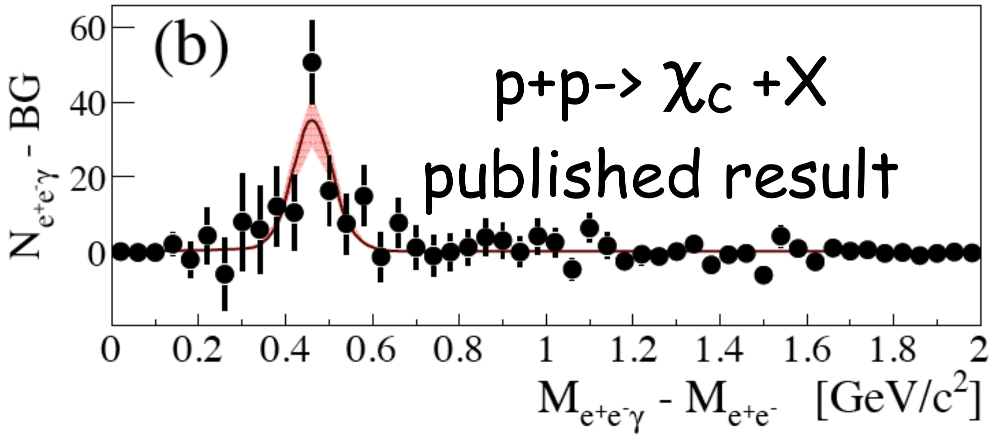
$p + p \quad \sqrt{s} = 200GeV \quad |y| < 0.35$

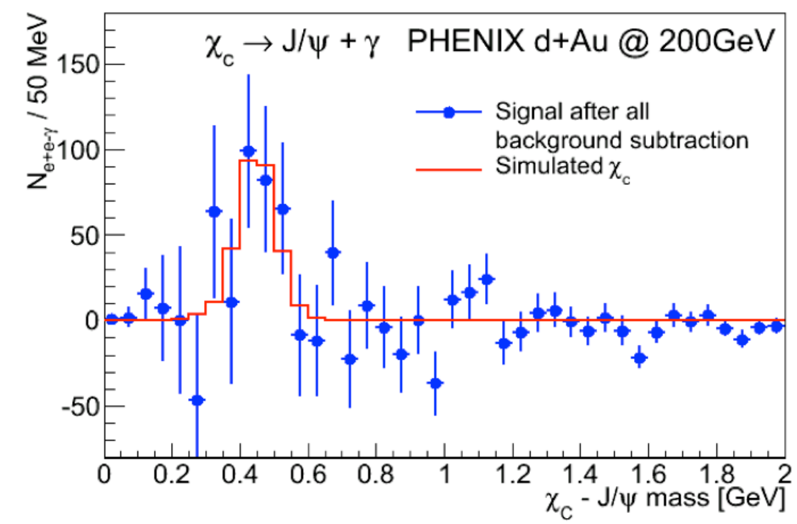


Correlated background

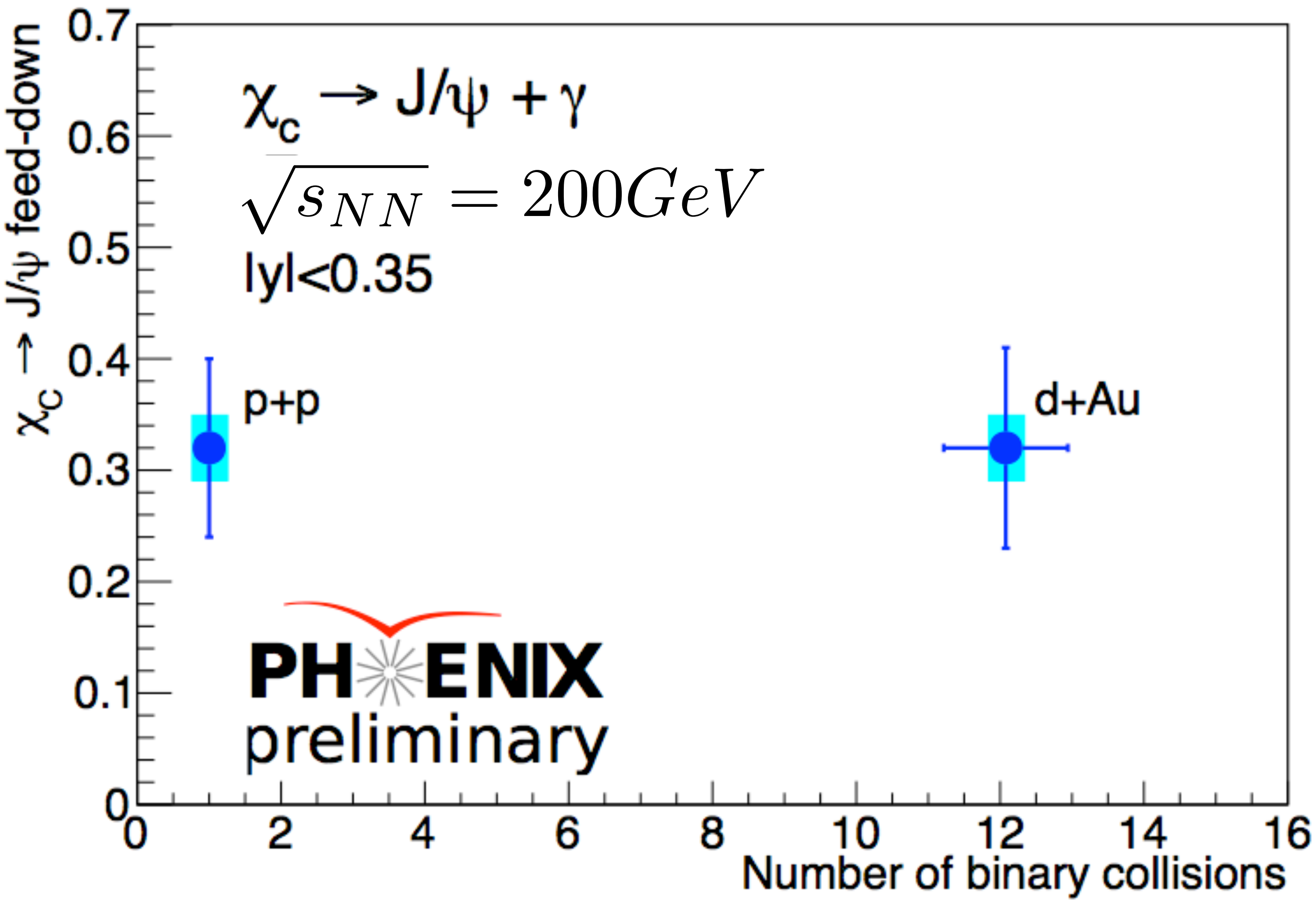
- $J/\psi \rightarrow e^+e^-\gamma$ (radiative decay)
- electron bremsstrahlung
- $e^+e^-\gamma$ (from jets)
- $\psi' \rightarrow J/\psi + n\pi^0, J/\psi + \eta$
- $gg \rightarrow J/\psi + \gamma + gg$ (NNLO $c\bar{c}$)
- $B \rightarrow J/\psi + n\gamma$

Feed-down fraction



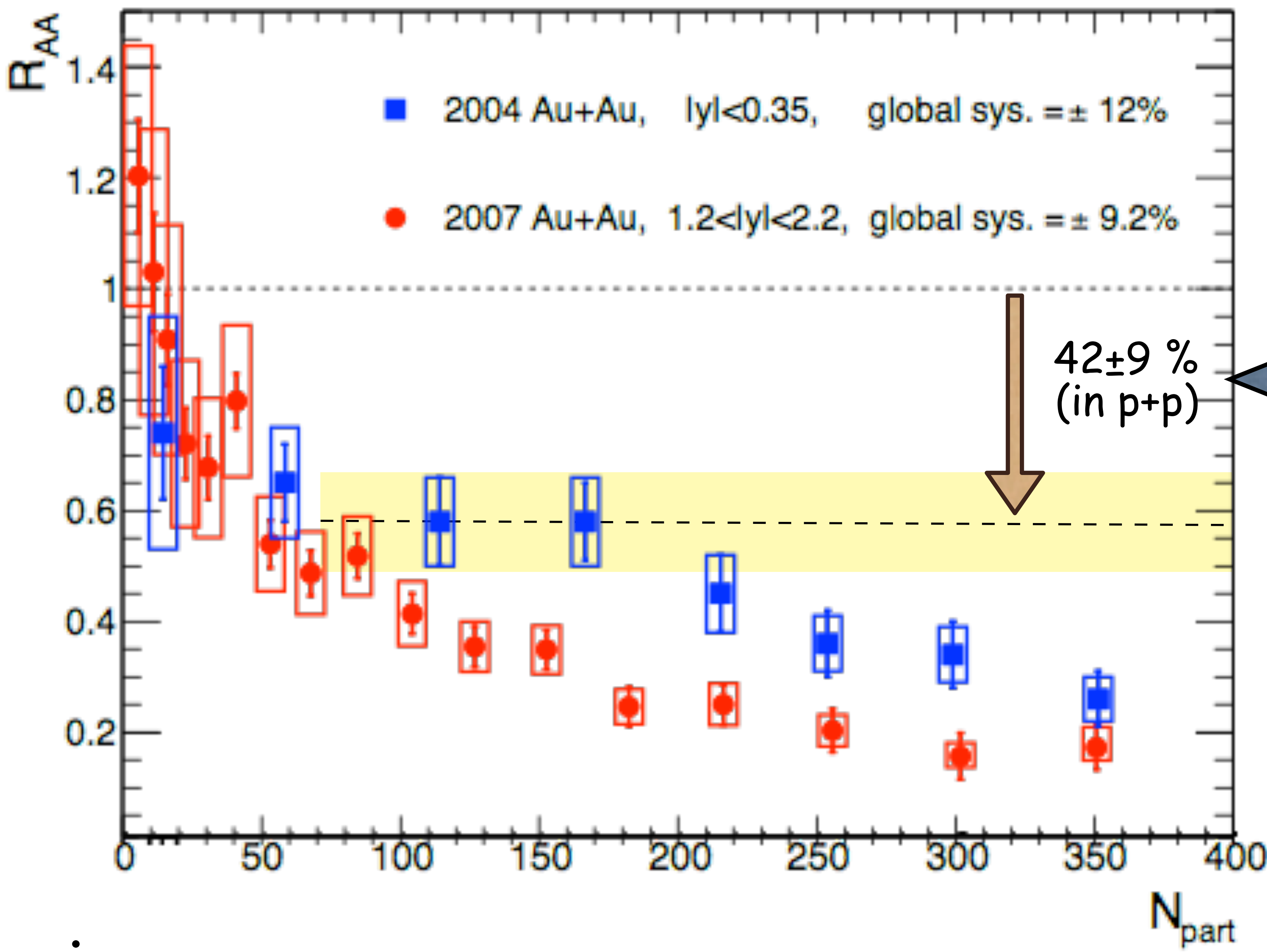


$$F_{\chi_c}^{J/\psi} = \frac{N_{\chi_c}}{N_{J/\psi}} \frac{1}{\langle \varepsilon_{\chi_c} / \varepsilon_{J/\psi} \rangle}$$



- feed-down fraction should go down in d+Au if breakup of χ_c is larger than of J/ψ
- no significant modification given the large uncertainties

[PRC84, 054912 (2011)]



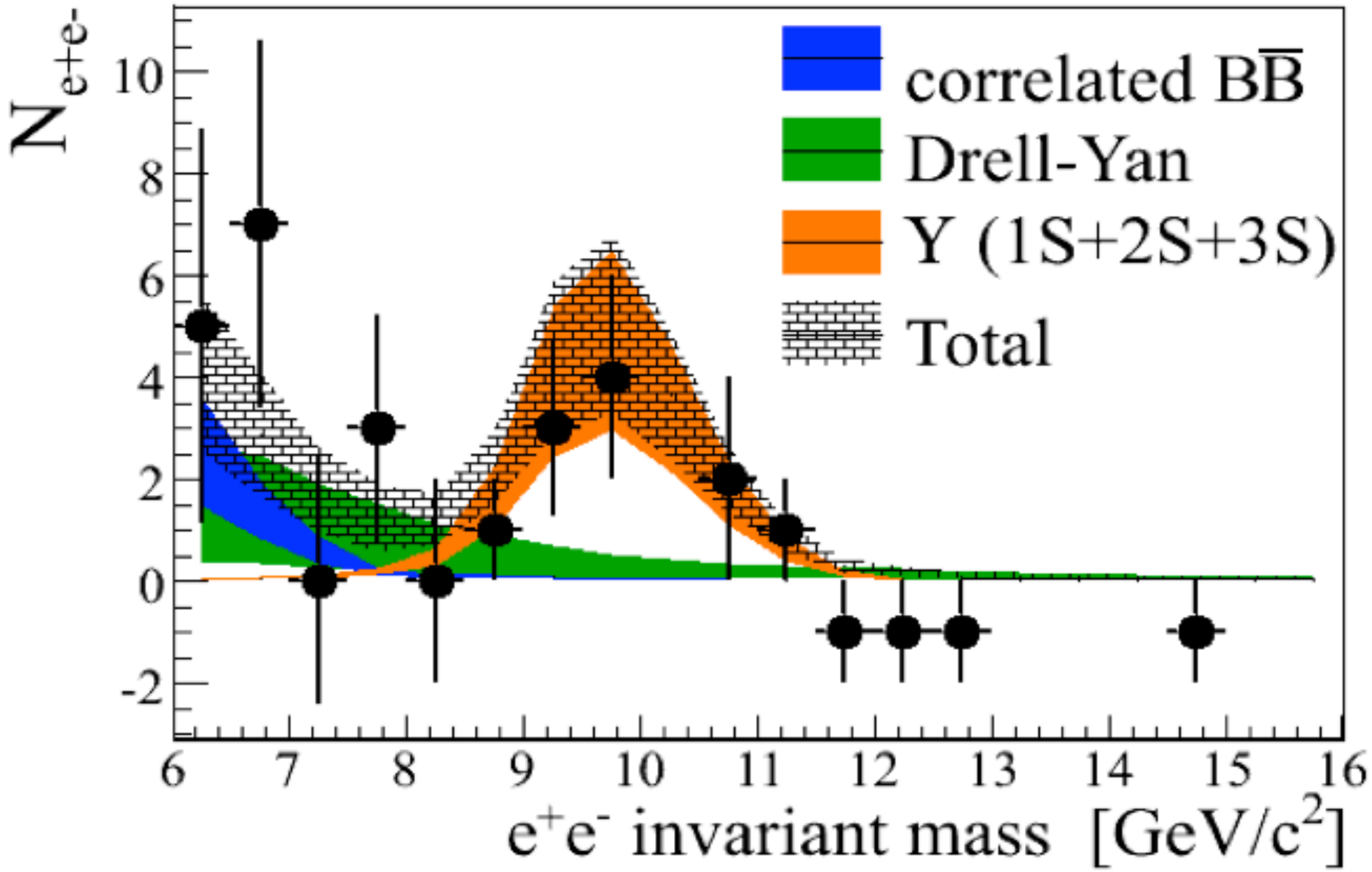
$\chi_c + \psi'$ feed-down

- assuming
  - final state charmonium crossing the medium
  - total suppression of χ_c and ψ'
- room for J/ψ suppression, but needs to also consider Cold Nuclear Matter

Bottomonium

	$\|y\| < 0.35$	$1.2 < \|y\| < 2.2$
$\Upsilon(1S+2S+3S) \rightarrow e^+e^-$	p+p,d+Au, Au+Au	
$\Upsilon(1S+2S+3S) \rightarrow \mu^+\mu^-$		p+p,d+Au, Au+Au

What ϒ we measure ?



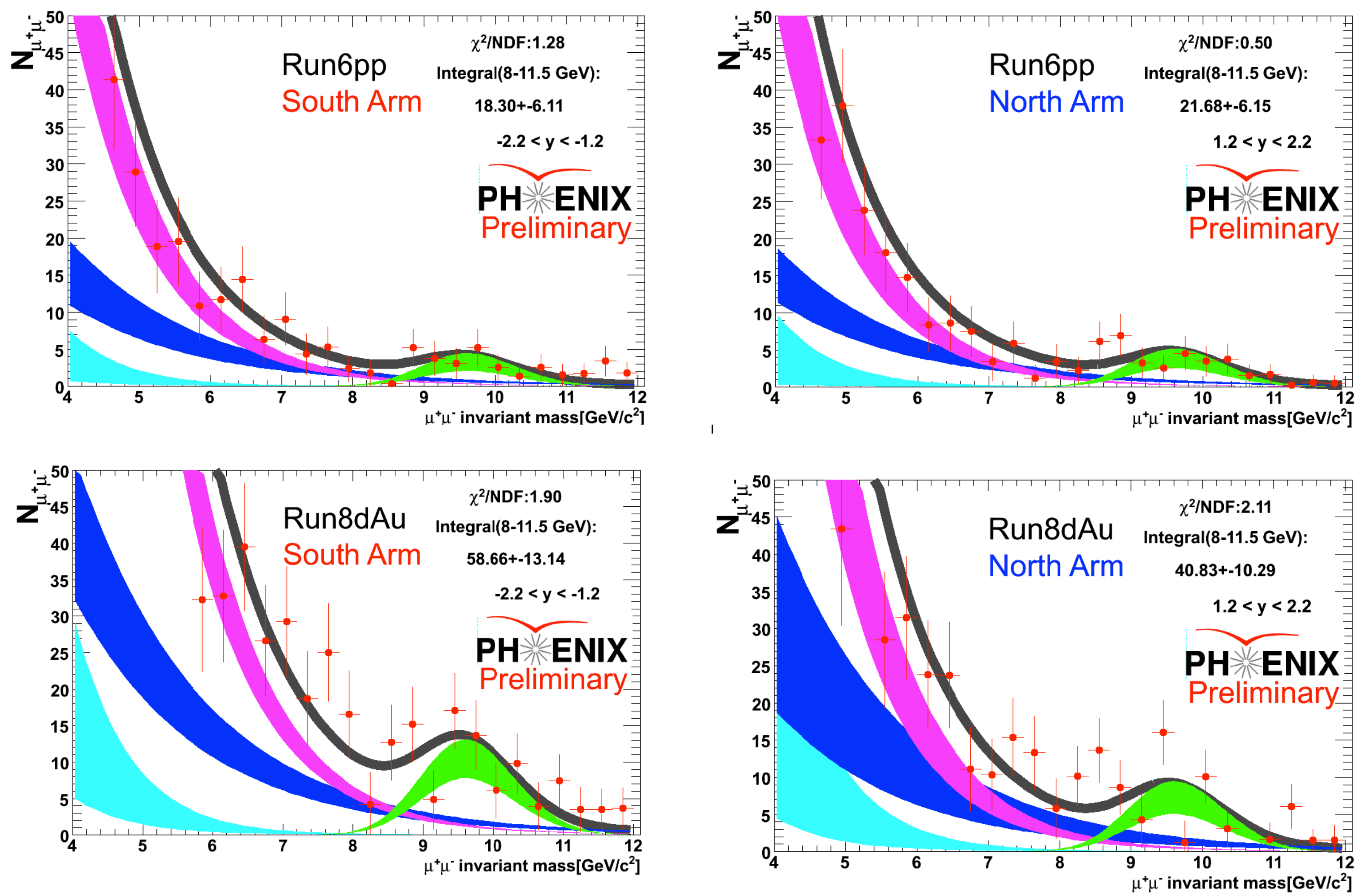
	mass [GeV/c^2]	contribution*
ϒ(1S)	9.5	73%
ϒ(2S)	10.0	17%
ϒ(3S)	10.4	10%

* from CDF data

	feed-down fraction to ϒ(1S)**
prompt ϒ(1S)	~51%
χ_b (1P+2P)	~37%
ϒ(2S)	~11%
ϒ(3S)	~1%

* from CDF data

Background in Υ region



$c\bar{c}$

$b\bar{b}$

mass shape from:
- PYTHIA (mostly back-to-back)
- random opening angle

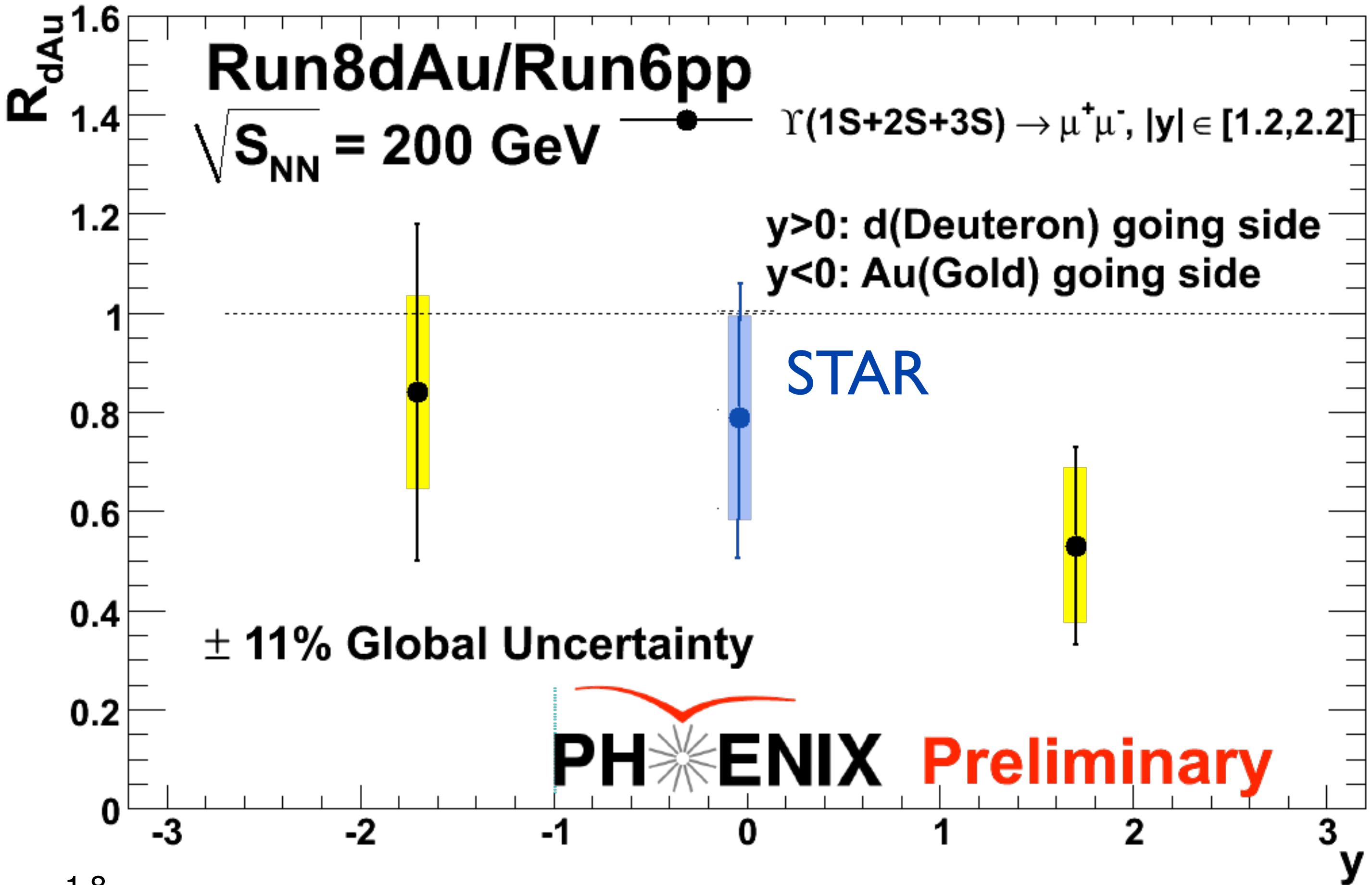
normalization from fit to inv. mass

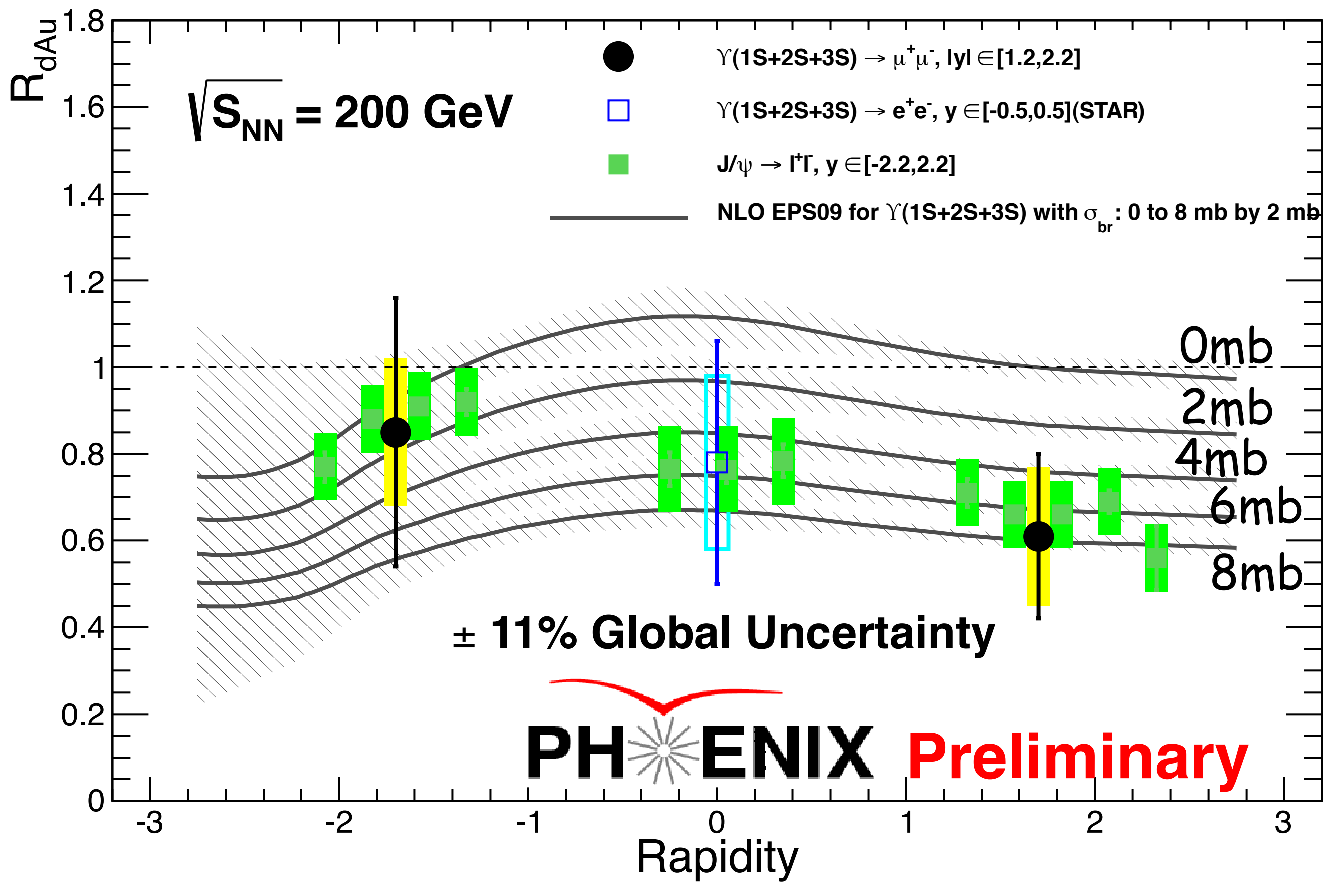
Drell Yan

$\Upsilon(1S + 2S + 3S)$

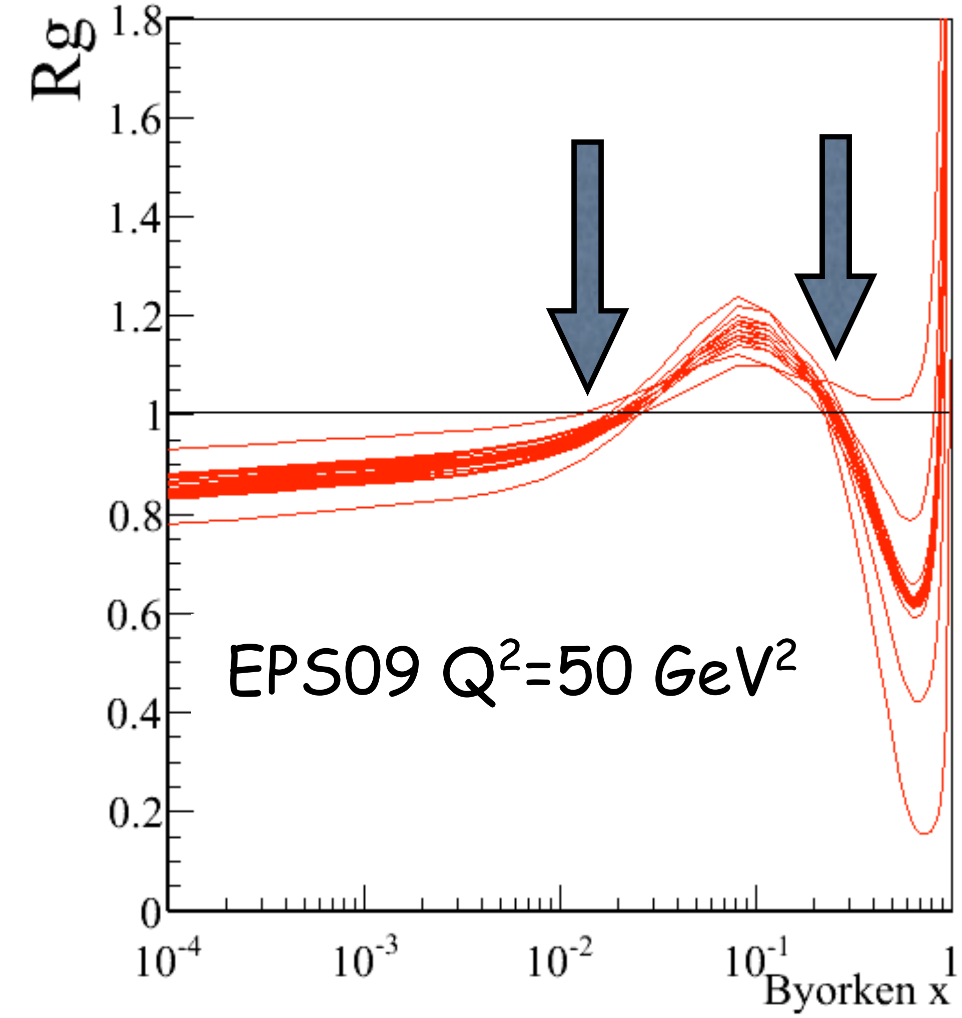
mass shape and normalization from
- PYTHIA, NLO calculations in p+p
- NLO + initial state effects + isospin effect (Ivan Vitev)

Cold Nuclear Matter Effects



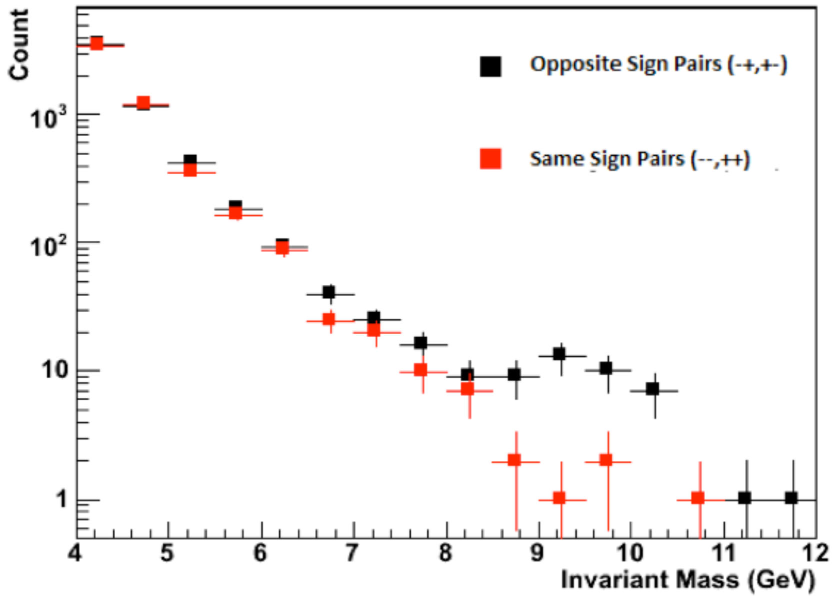


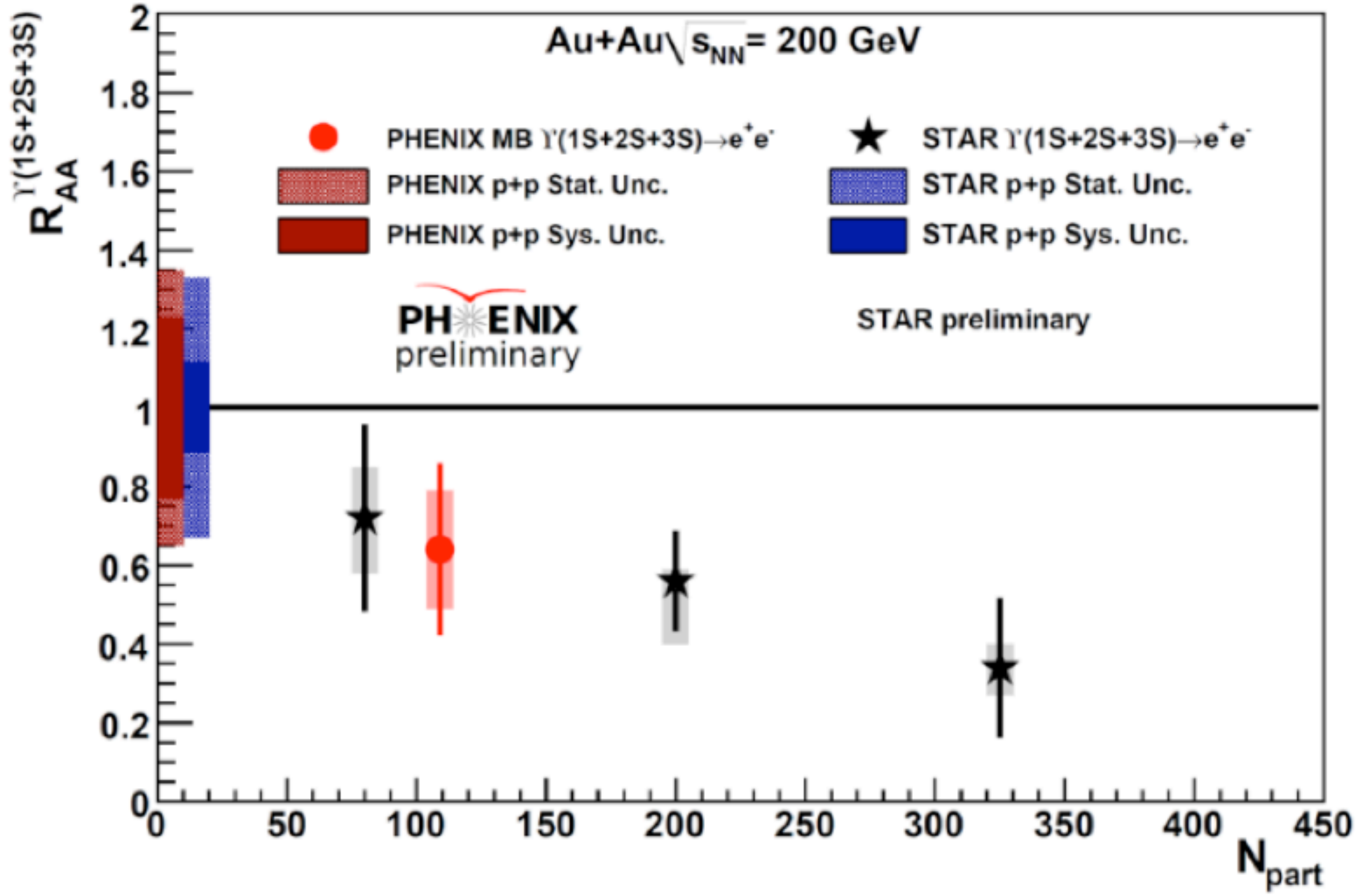
Eskola, Paukkunen, Salgado, JHEP04 (2009) 065



- large uncertainties but overall suppression consistent with J/ψ
- better agreement w/ nPDF + some breakup cross section

CNM + QGP effects

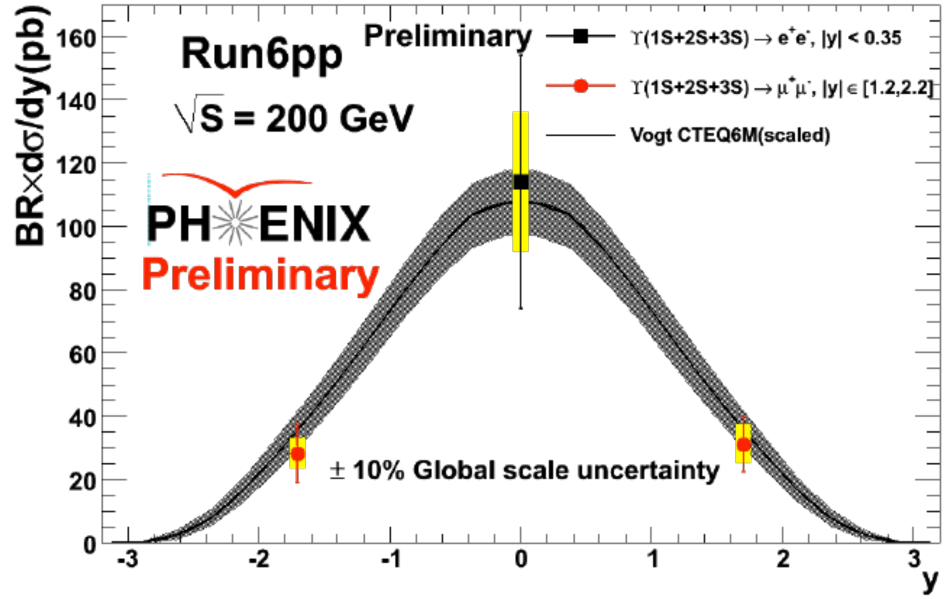




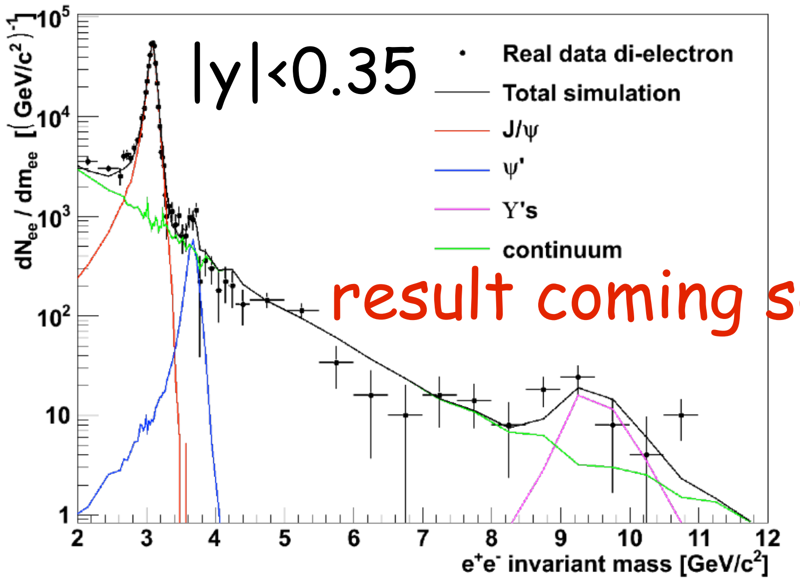
- consistent with STAR result
- R_{AA}~0.64 if Υ(2S) and Υ(3S) melt (no CNM)
- R_{AA}~0.37 if Υ(2S), Υ(3S) and χ_b (1P+2P) melt (no CNM)
- needs better handle of CNM and feed-down fractions for confirmations

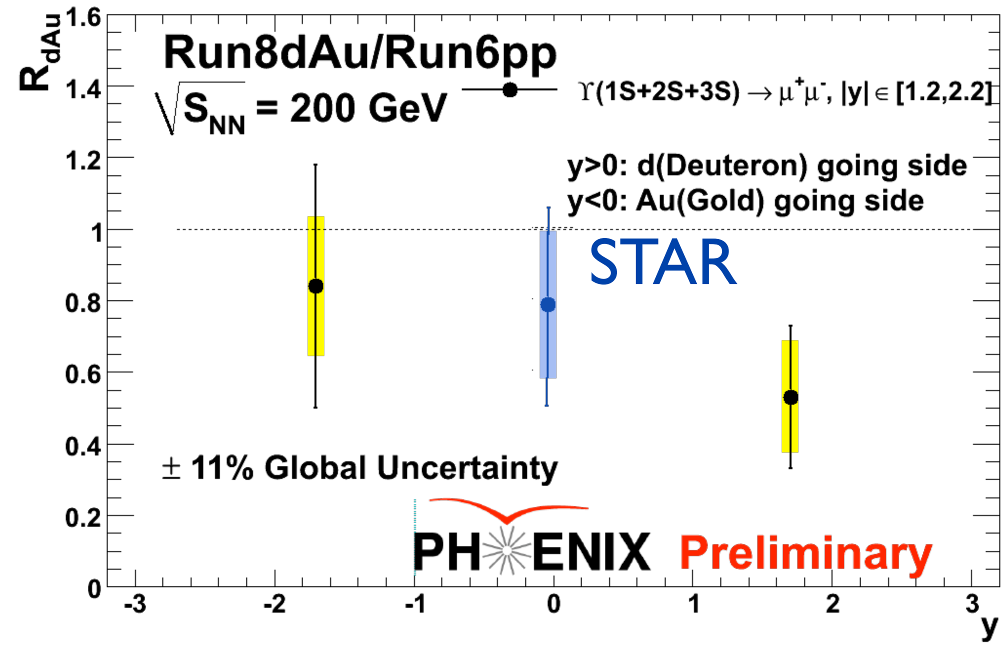
ϒ(1S+2S+3S) signal and results

p+p

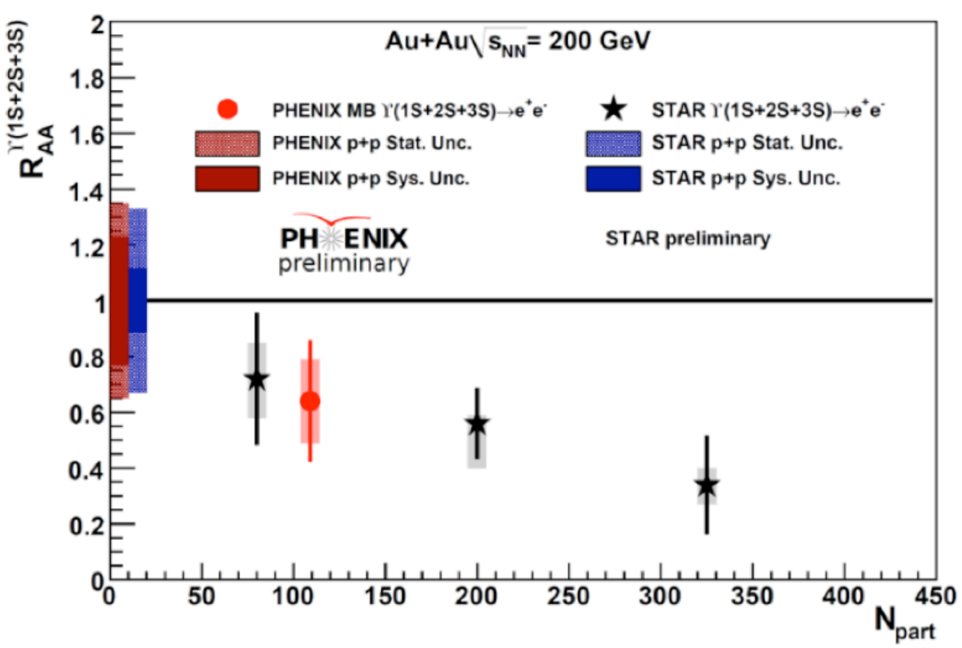


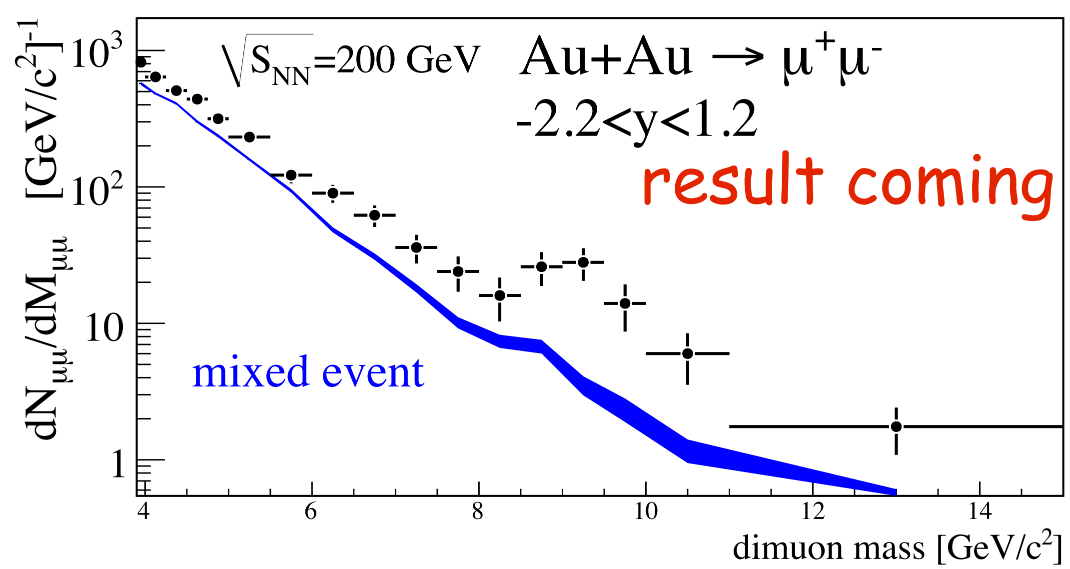
d+Au





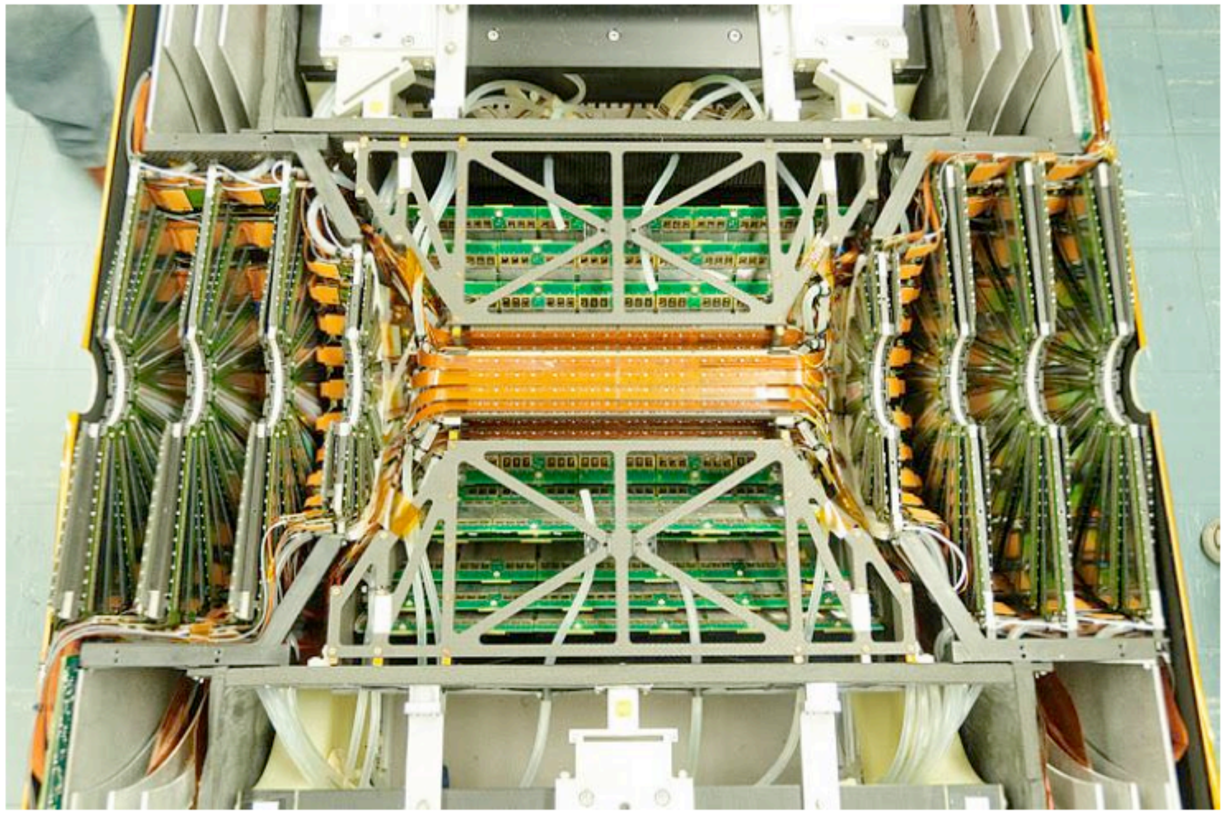
Au+Au

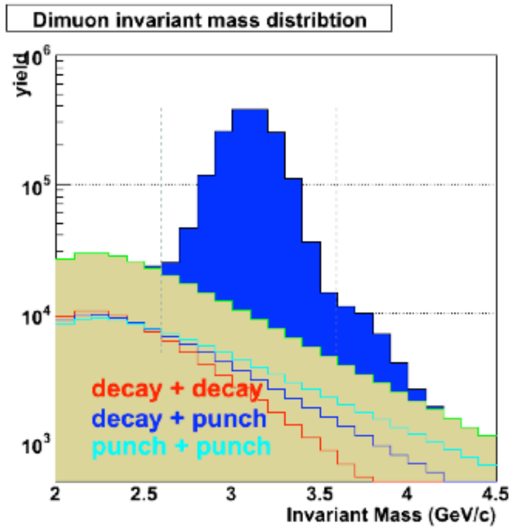


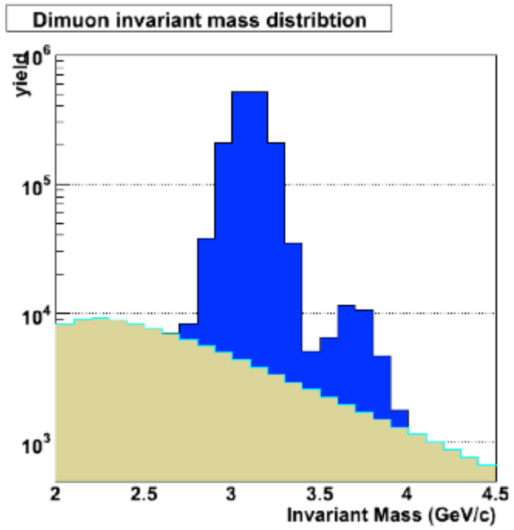


PRESENT and FUTURE

Installed vertex detectors: VTX and FVTX



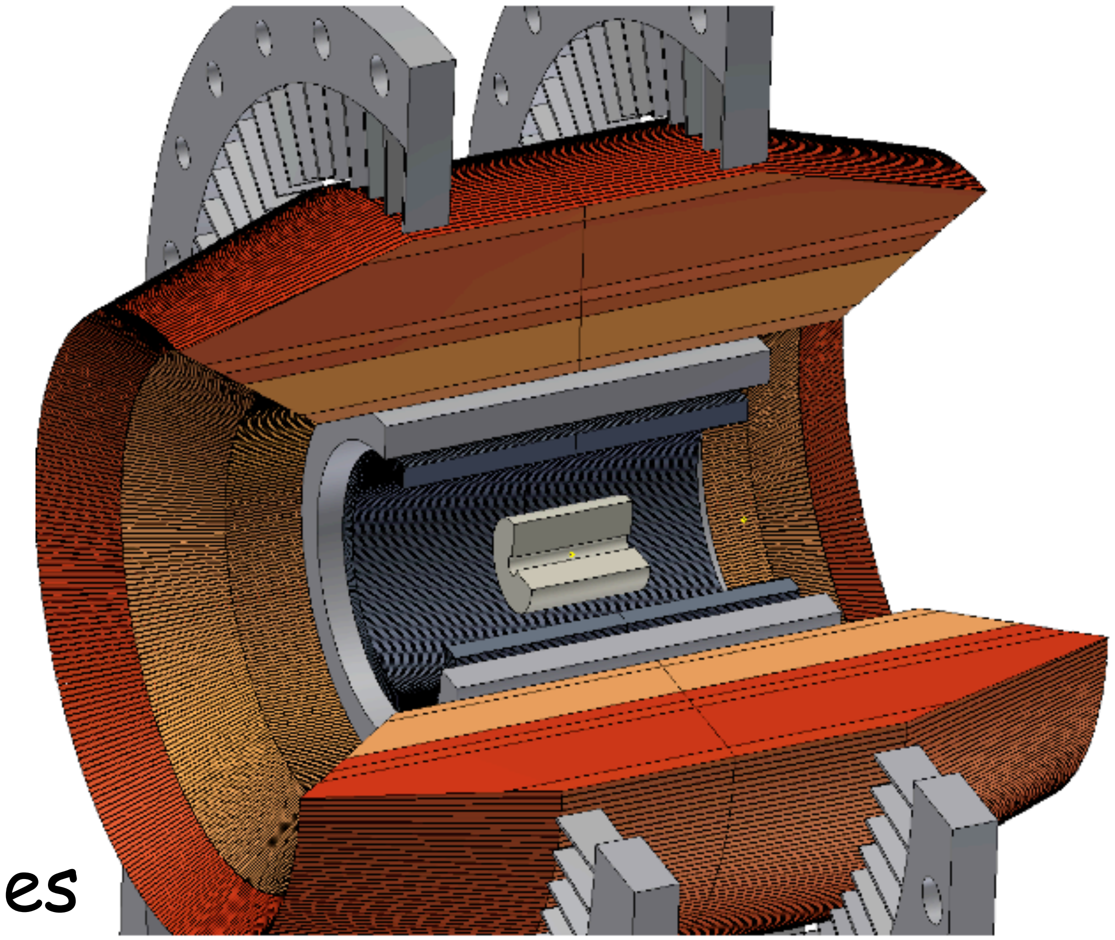


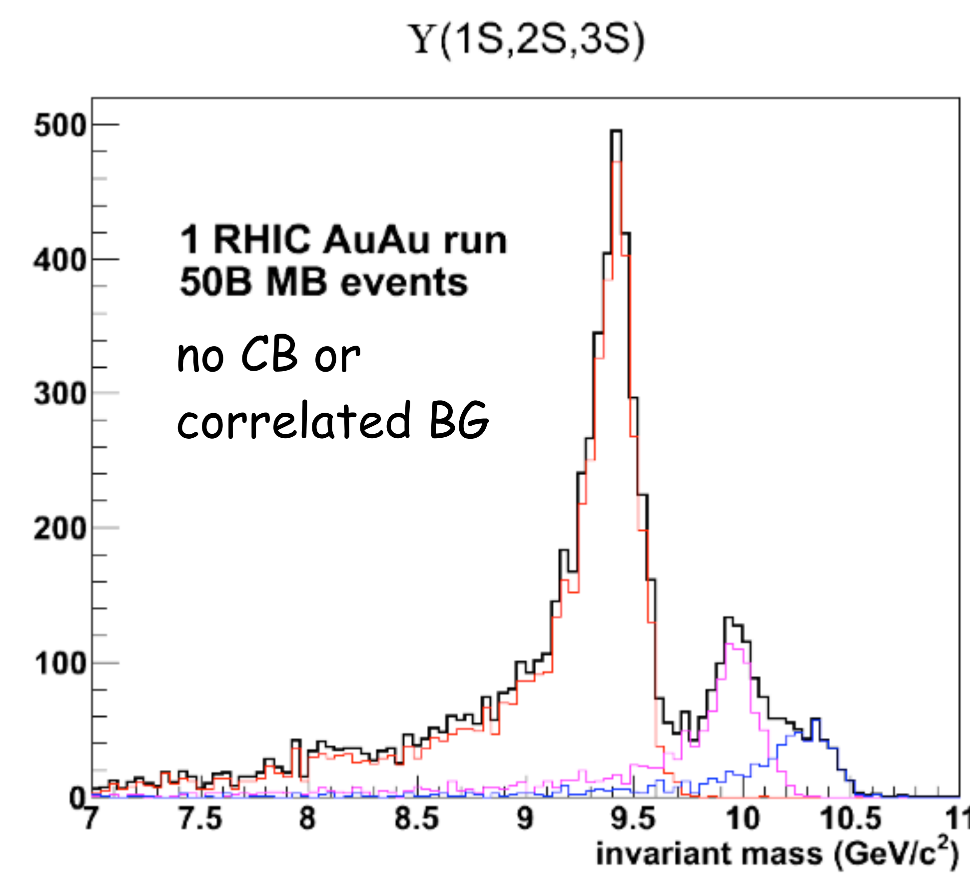


- measure open heavy flavor
  - quarkonia R_{AA} relative to HF can cancel out initial state effects
- better measurement of dimuon opening angle at large rapidity:
  - J/ψ, ψ' separation
  - first studies of pre-resonant stages when looking rapidity dependence
- open the possibility to study radiative decay of χ_c using γ conversions in VTX

FUTURE

solenoidal PHENIX (sPHENIX)





- high luminosities
- full azimuthal, $-1.1 < \eta < 4$ coverage

- calorimetry at large y will allows rapidity dependence of χ_c measurement
- 2T solenoid allows $\Upsilon(1S)$, $\Upsilon(2S+3S)$ separation at mid- and forward rapidity
- more details in Ali Hanks and Kenneth Barish talks

Thanks for your attention

BACKUP SLIDES

PHENIX

List compiled by Kei Suzukia, Philipp Gublerb, Kenji Moritac, and Makoto Okaa - arXiv:1204.1173v1

Charmonium:
Lattice QCD [4, 5, 6, 7, 8, 9, 10, 11, 12, 13],
QCD sum rules [14, 15, 16, 17, 18],
AdS/QCD [19, 20, 21, 22],
resummed perturbation theory [23, 24],
effective field theories [25, 26]
potential models [11, 27, 28, 29, 30, 31, 32, 33].

Bottominum:
[12, 17, 27, 29, 33, 34,35]

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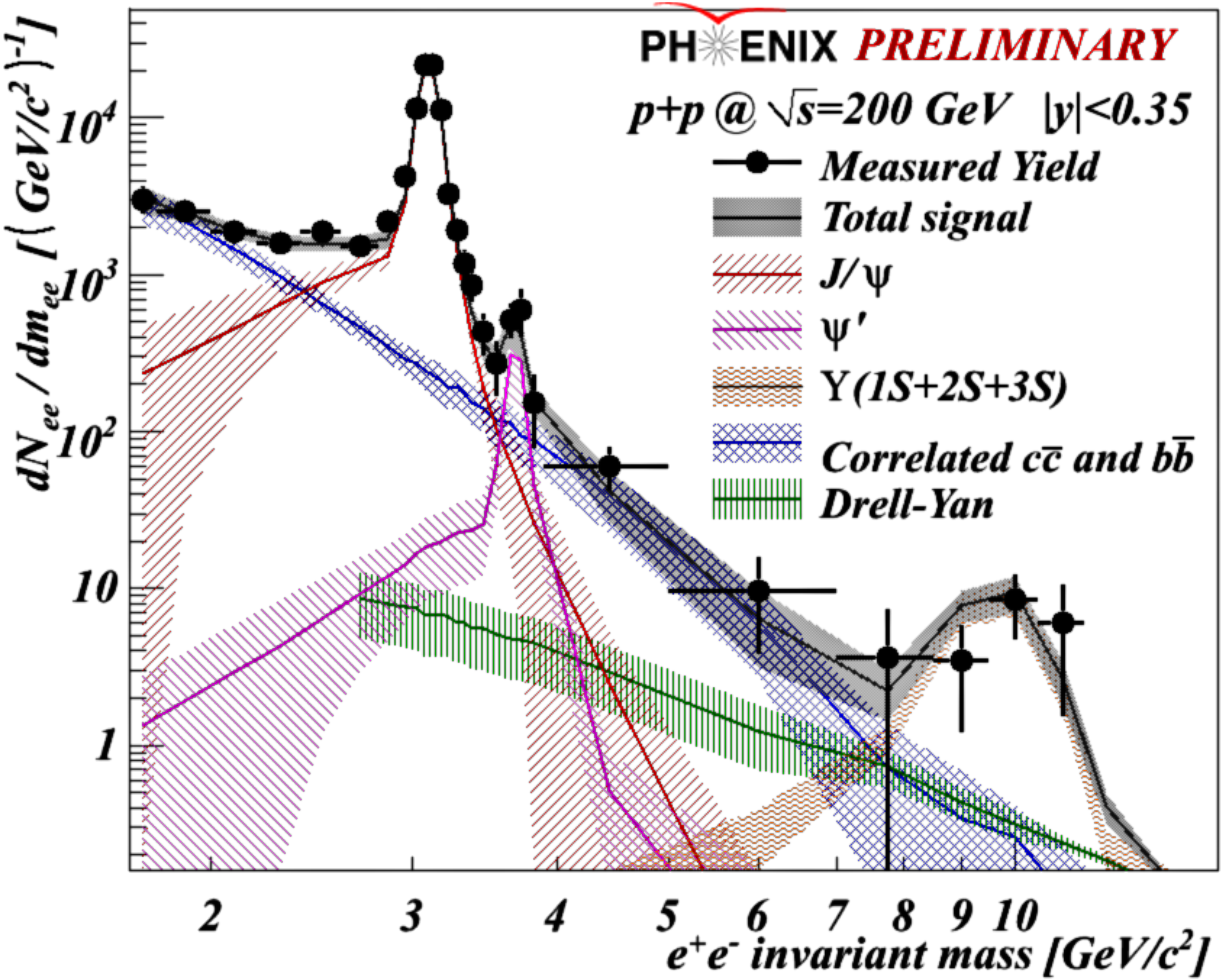
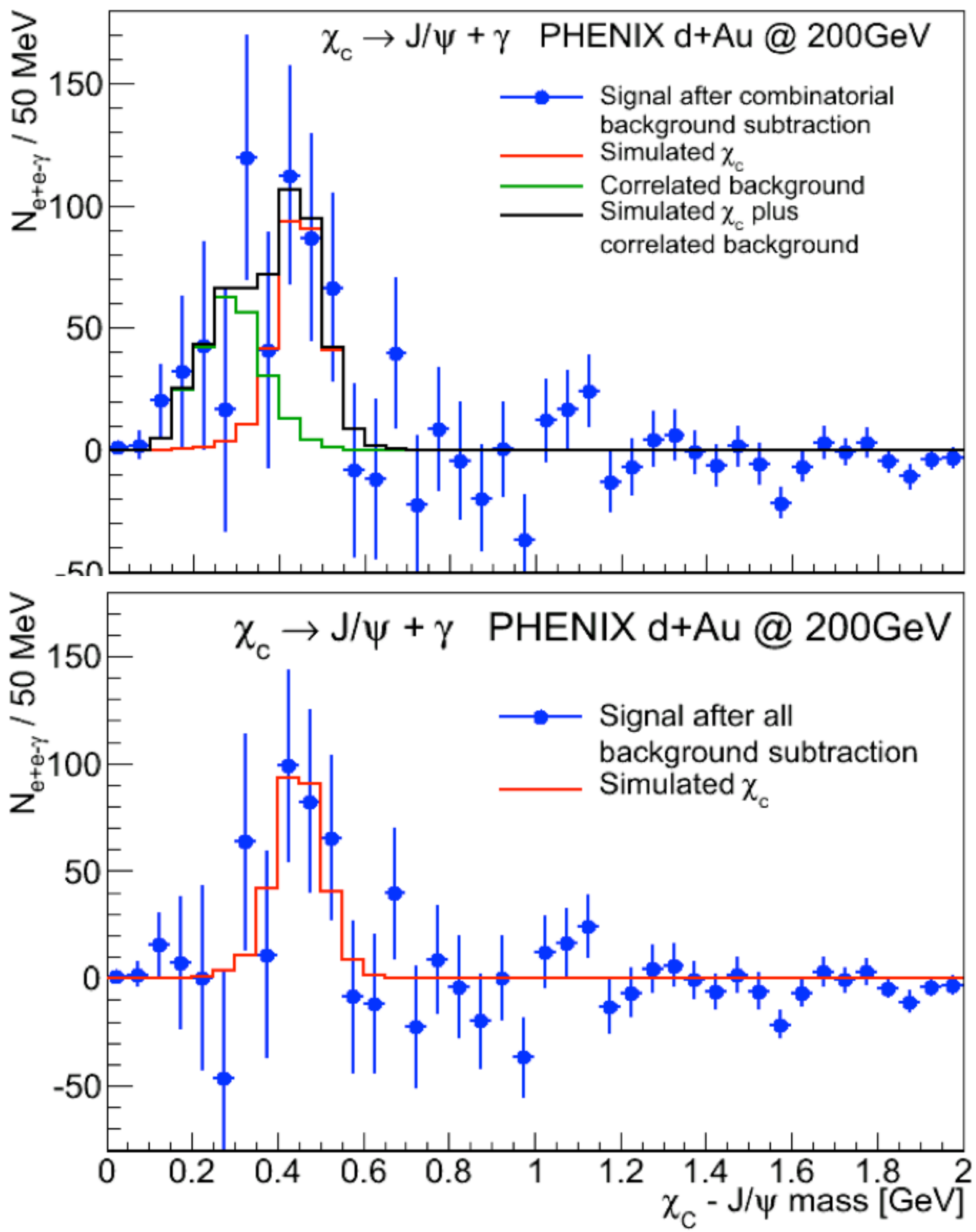

PHENIX PRELIMINARY
p+p @ √s=200 GeV |y|<0.35
Measured Yield
Total signal
J/ψ
ψ'
Υ(1S+2S+3S)
Correlated cc̄ and bb̄
Drell-Yan
dN_ee / dm_ee [(GeV/c²)⁻¹]
10⁴
10³
10²
10
1
2
3
4
5
6
7
8
9
10
e⁺e⁻ invariant mass [GeV/c²]



$\chi_c \rightarrow J/\psi + \gamma$ PHENIX d+Au @ 200GeV
Signal after combinatorial background subtraction
Simulated χ_c
Correlated background
Simulated χ_c plus correlated background
$N_{e+e-\gamma}$ / 50 MeV
150
100
50
0
-50
$\chi_c \rightarrow J/\psi + \gamma$ PHENIX d+Au @ 200GeV
Signal after all background subtraction
Simulated χ_c
$N_{e+e-\gamma}$ / 50 MeV
150
100
50
0
-50
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
χ_C - J/ψ mass [GeV]