Heavy quarkonia production at STAR

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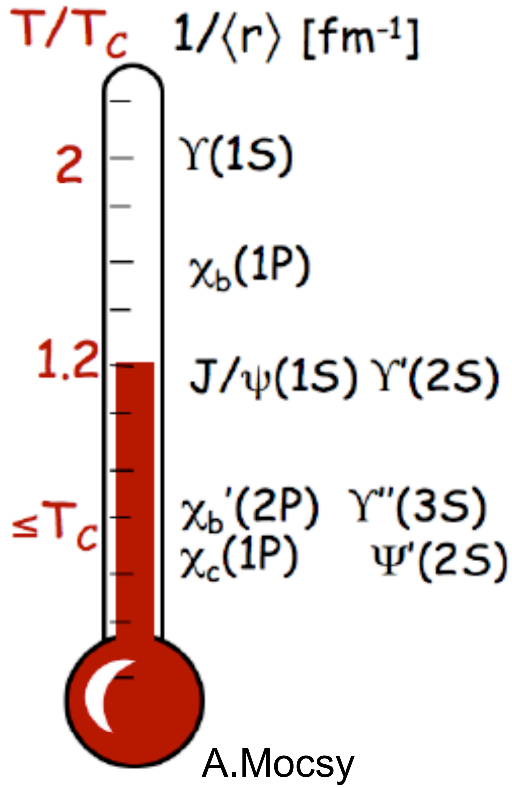
Why heavy quarks?

- Large mass = early production (at RHIC)
- Quarkonia family:
  $c\bar{c}$: J/ψ, ψ', χ_c ...
  $b\bar{b}$: ϒ(1S), ϒ(2S), ϒ(3S) ...
- J/ψ suppression → classic QGP signature
  T. Matsui, H. Satz, Phys. Lett. B178, 416 (1986).
  - due to the color screening of the binding potential
- Quarkonia suppression pattern → QGP temperature
  - T and binding energy determine suppression
  - model dependent



A.Mocsy
Eur.Phys.J.C61:
705-710,2009

J/ψ suppression: complications

- Production mechanism in p+p not well understood
  - no model describes p_T spectrum and polarization simultaneously (Int.J.Mod.Phys.A21:3857-3916,2006, arXiv:hep-ph/0602091v2)

- Feed-down (up to 50% of all J/ψ) (C. da Silva, arXiv:0907.4696v2)

- ”Cold” matter effects:
  - shadowing, nuclear absorption, co-mover absorption ...

  (E. G. Ferreiro at al: arXiv:0903.4908v1, A. D. Frawley at al: arXiv:0806.1013v2)

- “Hot” matter effects:
  - regeneration, dissociation by gluons, ...

  (R.Rapp, arXiv:0807.2470v2)

Basic strategy

– baseline - **p+p**

– “normal” suppression - **d+Au**

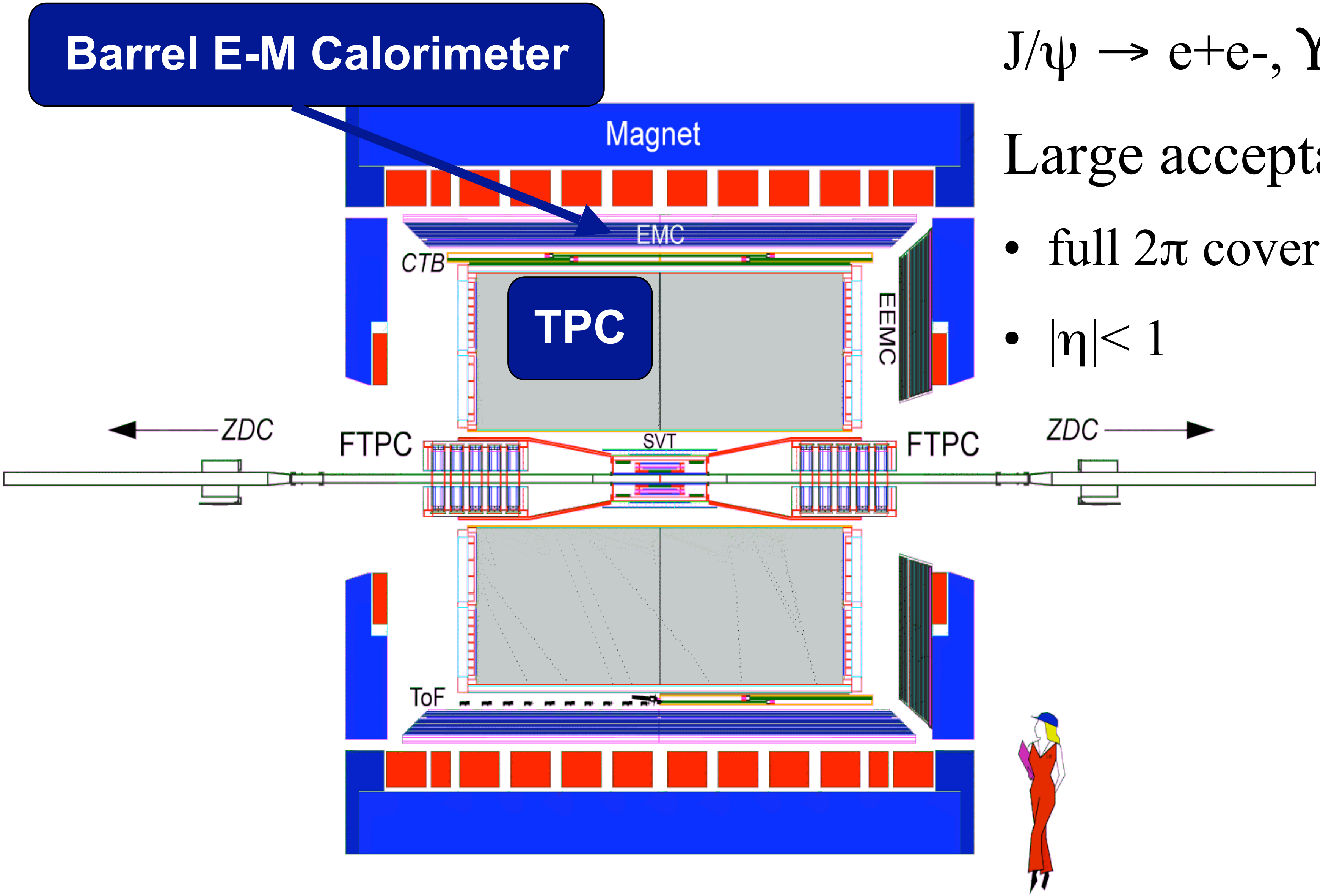
$$R_{dAu} = \frac{1}{\langle N_{coll} \rangle} \frac{dN/dy^{dAu}}{dN/dy^{pp}}$$

$R_{AA\ (dAu)} = 1$ if no modification of the production in the medium

– “anomalous” suppression - **Au+Au**

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

STAR detector



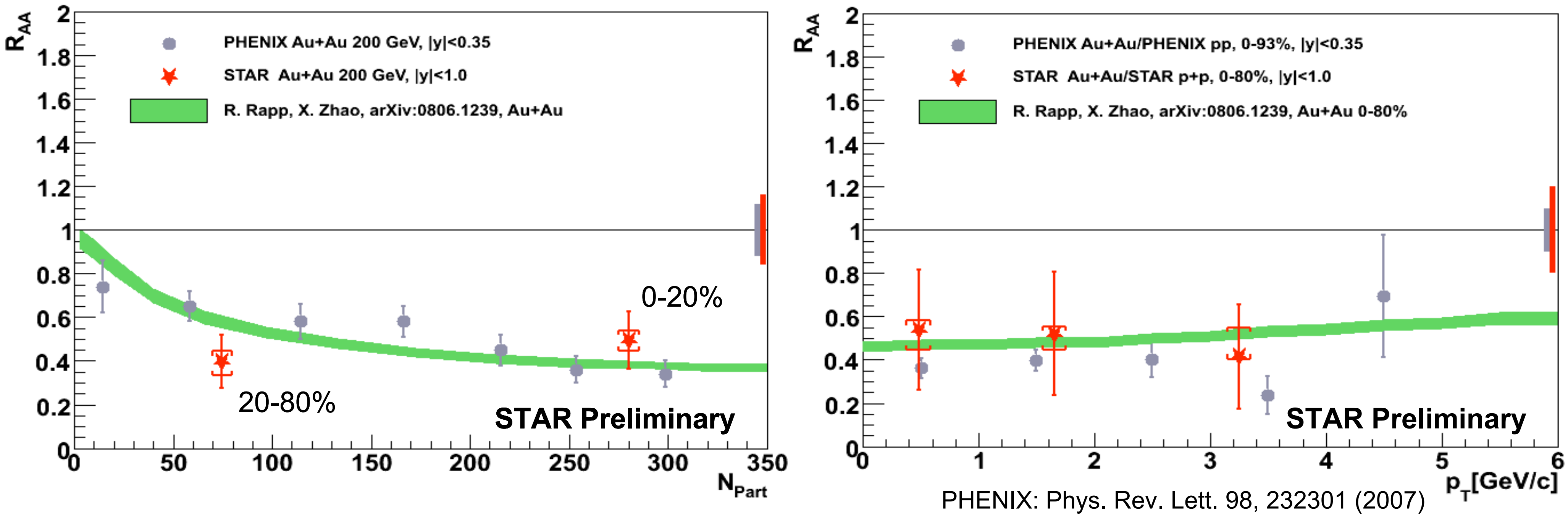
$J/\psi \rightarrow e+e-$, $\Upsilon \rightarrow e+e-$

Large acceptance:

- full 2π coverage in ϕ
- $|\eta| < 1$

J/ψ production at STAR

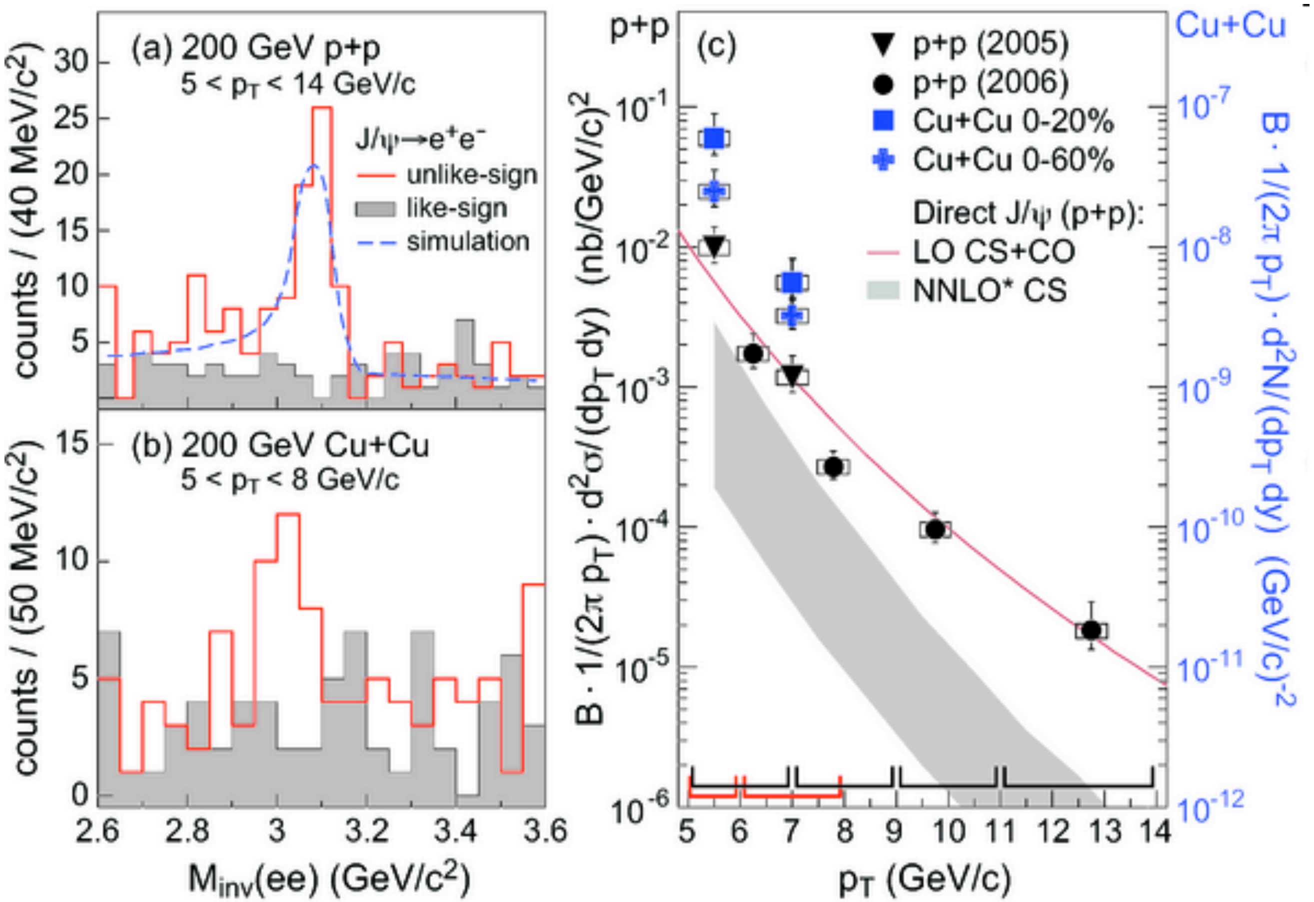
Low-p_T J/ψ in Au+Au 200 GeV



PHENIX: Phys. Rev. Lett. 98, 232301 (2007)

- Model (green band) includes: color screening in QGP, dissociation in hadronic phase, statistical recombination, B → J/ψ feed-down and formation time effects
- New Au+Au results with minimum inner material soon (5x higher statistics)

J/ψ production test: high-p_T measurements



Phys.Rev.C80:041902,2009

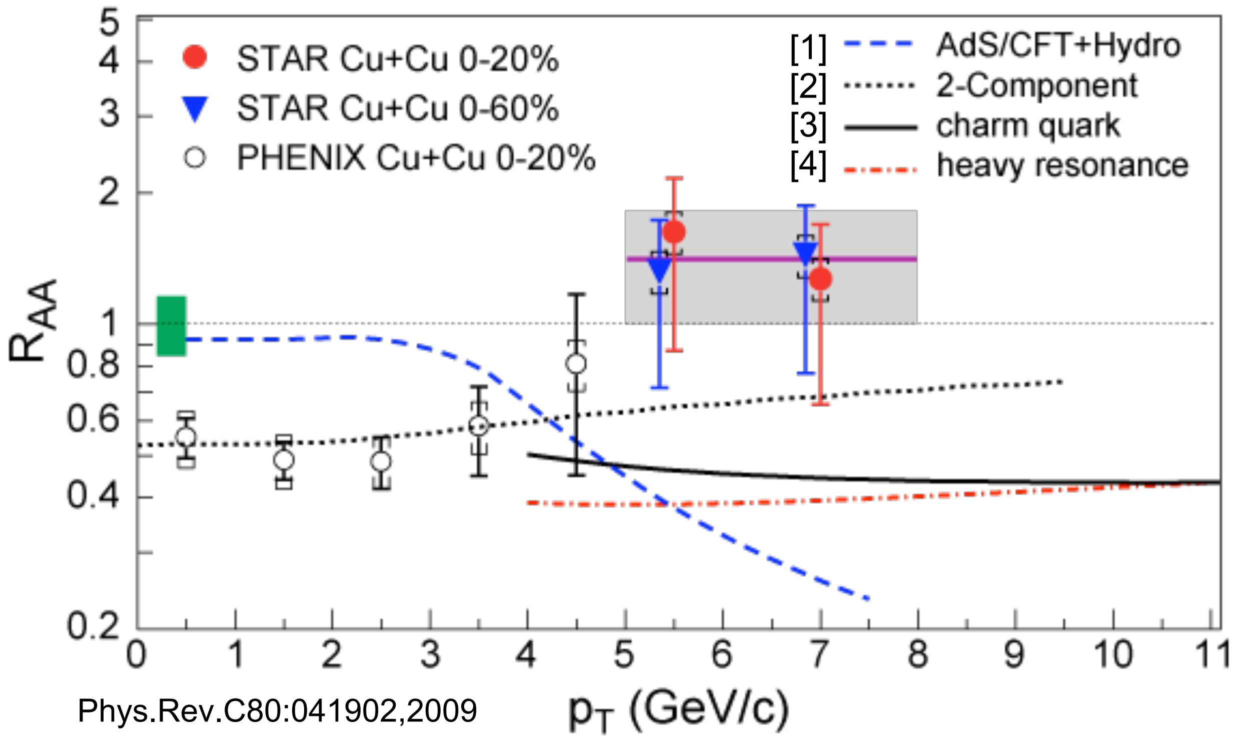
NRQCD (LO CO+CS) – describes data well, little room for feed down from ψ' , χ_c, B

G. C. Nayak, M. X. Liu, and F. Cooper, Phys. Rev. D68, 034003 (2003), and private communication

NNLO CS predicts a steeper p_t dependence

P. Artoisenet et al., Phys. Rev. Lett. 101, 152001 (2008), and J.P. Lansberg private communication

J/ψ production test: high-p_T measurements



Phys.Rev.C80:041902,2009

No suppression at high p_T

$R_{AA}(p_T > 5\ GeV/c) =$

$1.4 \pm 0.4 \pm 0.2$

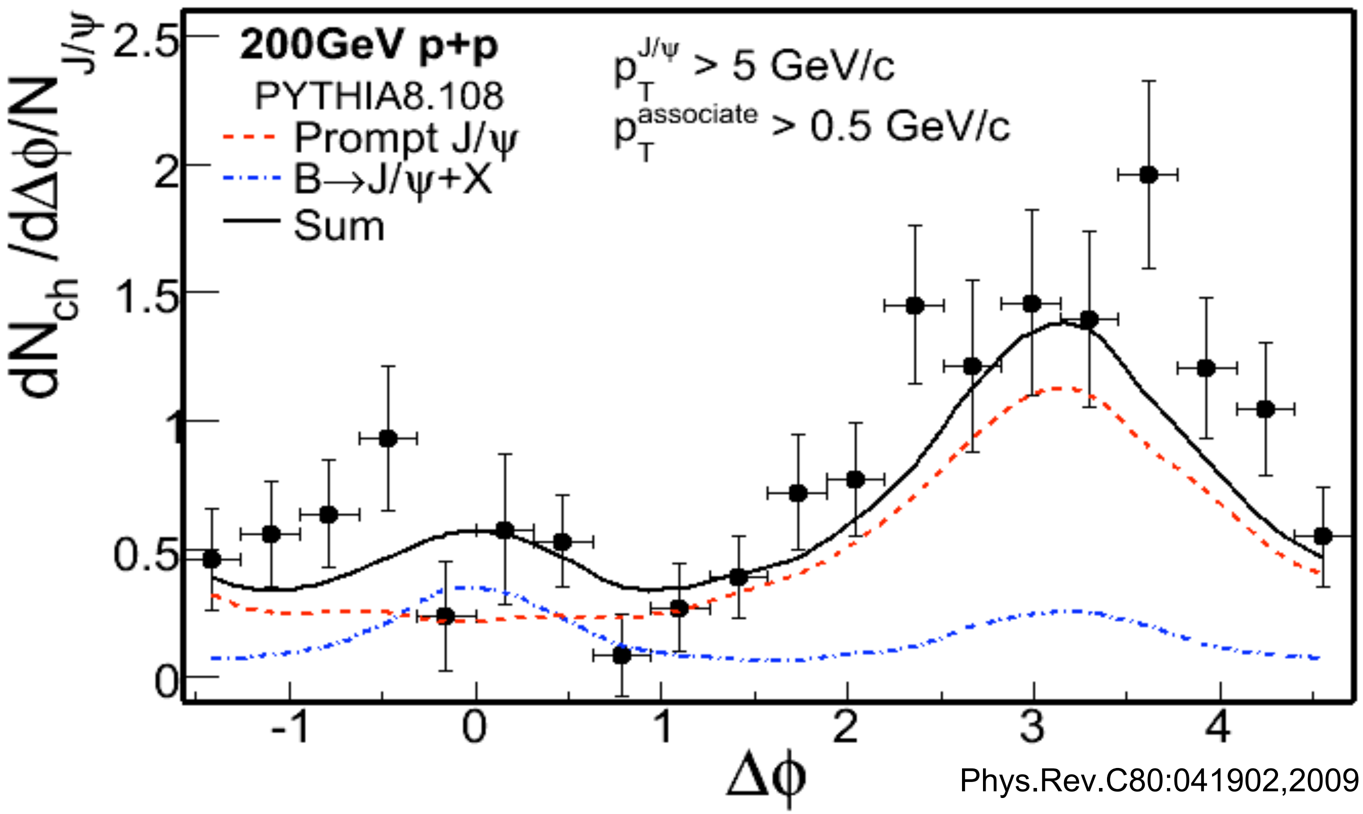
- Contrast to strong suppression of open charm

B.Abedev et al.,Phys.Rev.Lett. 98 (2007), 192301, S.Adler et al., Phys.Rev.Lett. 96(2006) 032301, [4] A. Adil and I. Vitev, Phys. Lett. B649, 139 (2007), and I. Vitev private communication; [3] S. Wicks et al., Nucl. Phys. A784, 426 (2007), and W. A. Horowitz private communication.

- Rising trend reproduced when B feed-down and formation time effects included [2] R. Rapp, X. Zhao, nucl-th/0806.1239

How important is B → J/ψ feed-down ?

J/ψ - hadron azimuthal angle correlation



Phys.Rev.C80:041902,2009

- If B → J/ψ then strong near side correlation
- No significant near side correlation observed
- B meson's contribution to J/ψ yield : (13 ± 5)% for $p_T^{J/\psi}$ > 5 GeV/c


Next level: Υ

Υ

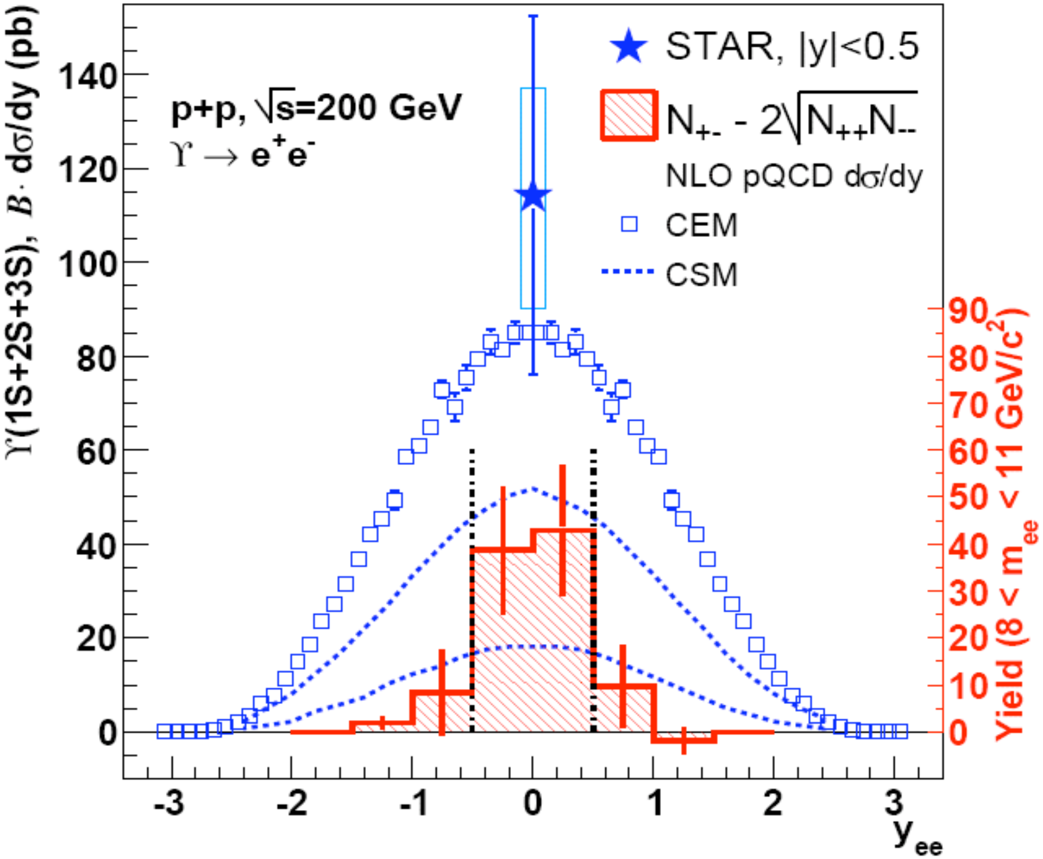
The Good

- Small regeneration and co-mover absorption
  (Z.W. Lin and C.M Ko PLB 503:104 (2001), R. Rapp at all arXiv:0807.2470v2)
- Low combinatorial background

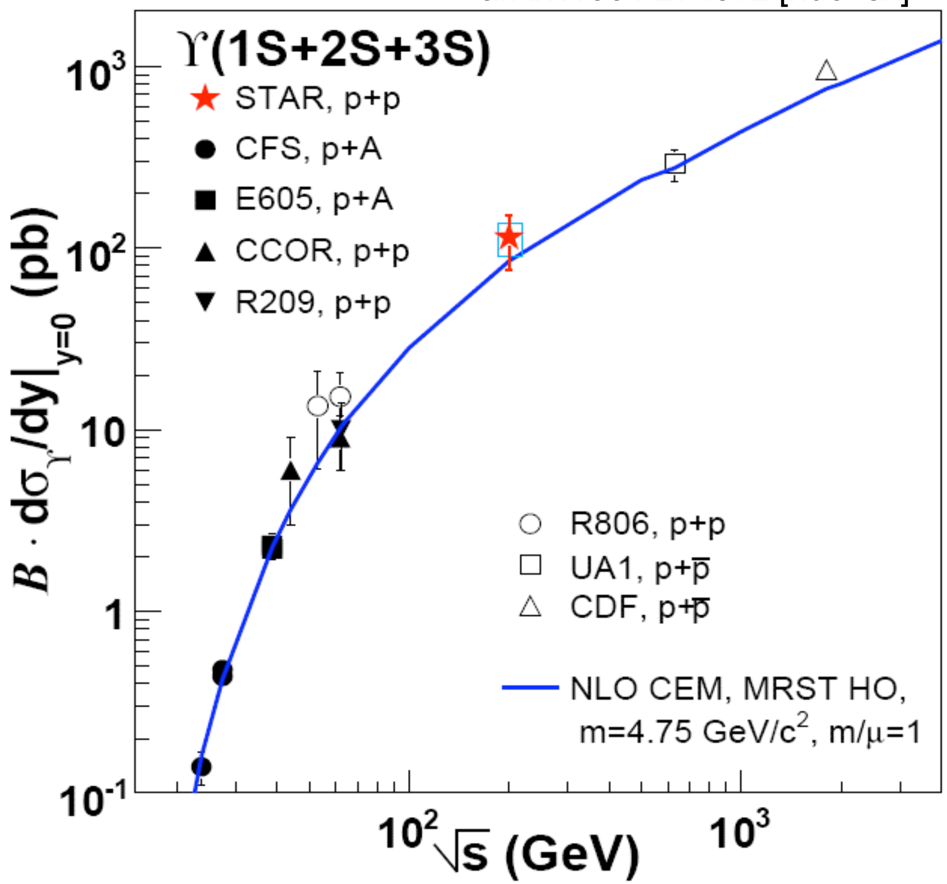
The Bad

- Low production rate
  10^{-9}/min-bias pp (3 orders of magnitude smaller than $\sigma_{J/\psi}$)
- Separation of Υ(1S), Υ(2S), Υ(3S) requires good mass resolution

baseline: ϒ in p+p 200 GeV



arXiv:1001.2745v2 [nucl-ex]

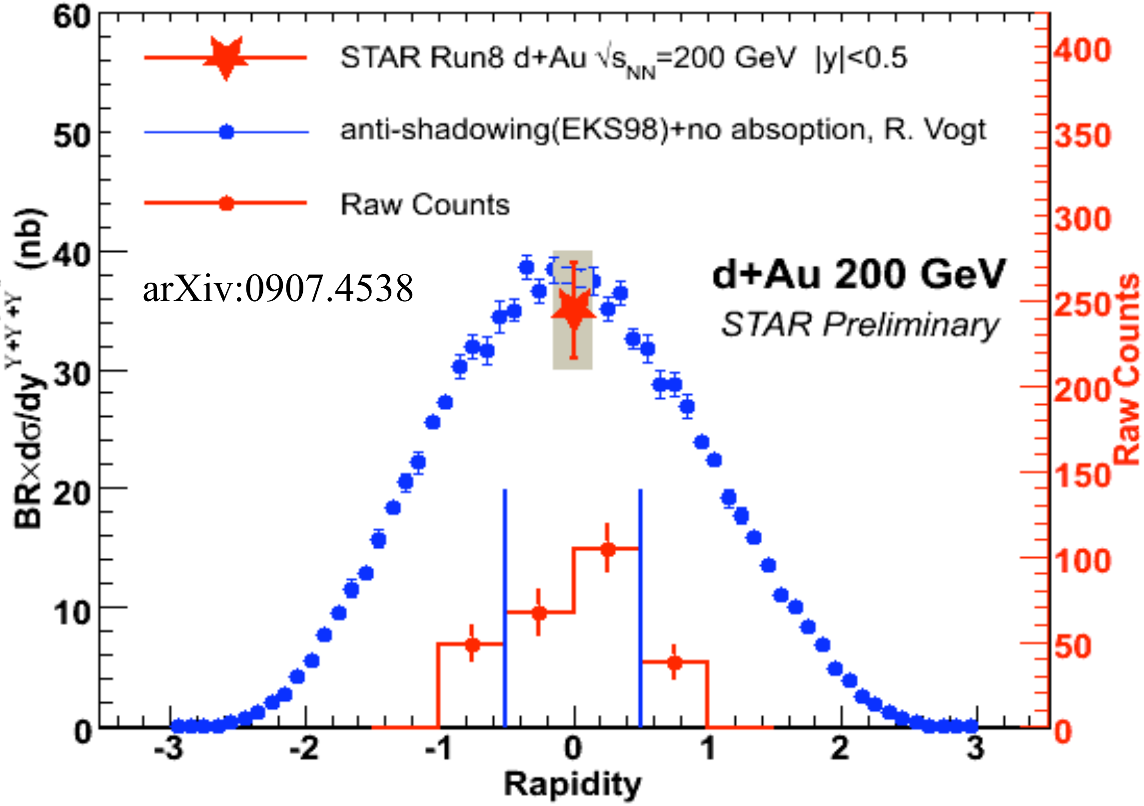


$$\sum_{n=1} \mathcal{B}(nS) \times \sigma(nS) = 114 \pm 38 \,^{+23}_{-24} \text{ pb}$$

Color Singlet Model (CSM)
PRL 100, 032006(2008),
Color Evaporation Model (CEM)
Phys. Rept. 462, 125 (2008)

Consistent with CEM, (inconsistent with CSM: ~ 2σ)
Consistent with world data trend

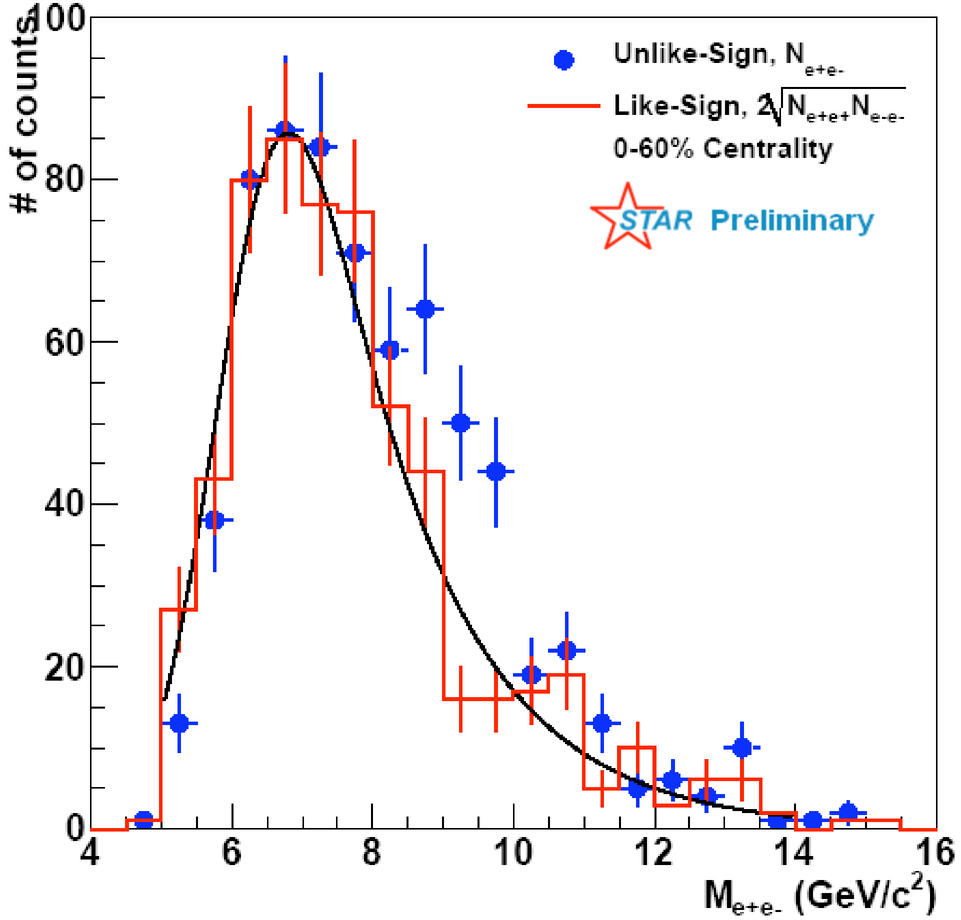
Cold nucl. matter: Υ in d+Au

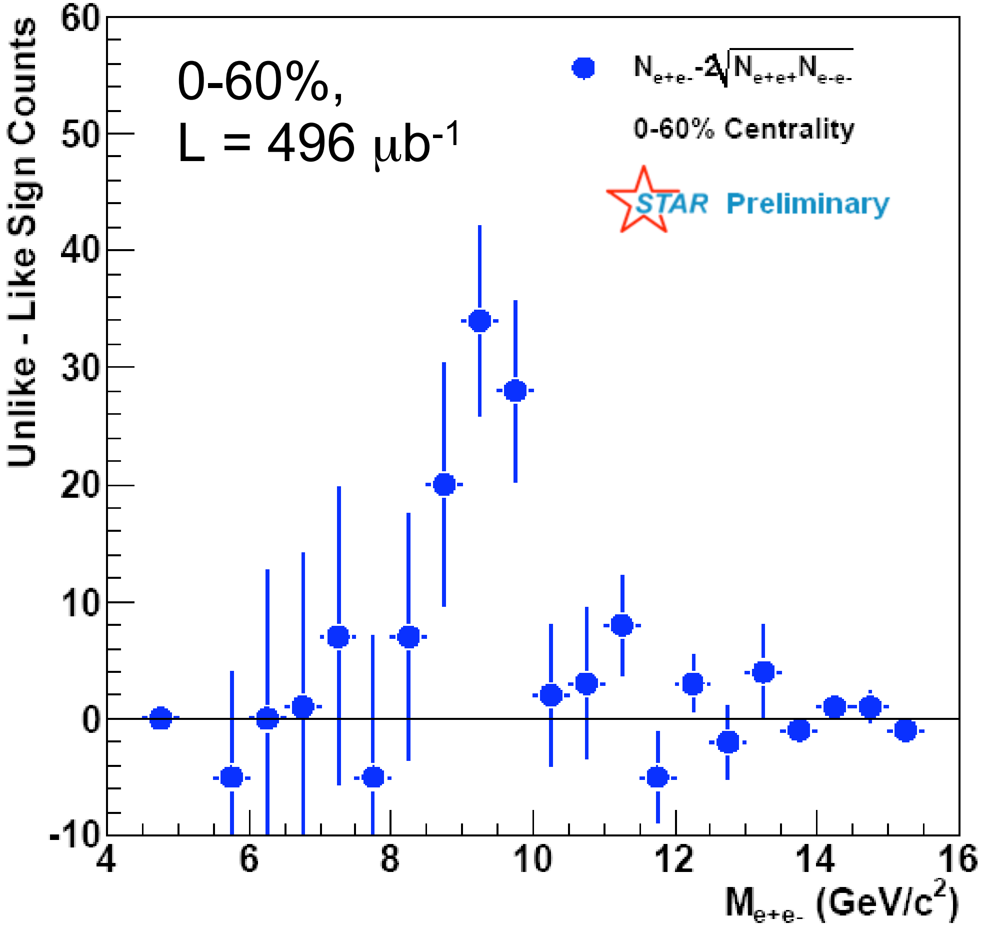


$$R_{dA} = 0.78 \pm 0.28(\text{stat.}) \pm 0.20(\text{sys.})$$

- Consistent with N_{bin} scaling
- Cold Nuclear Matter effects (shadowing) are rather small

ϒ in Au+Au 200 GeV





- 4.6σ significance, 95 Signal counts in $8 < m < 11$ GeV/c^2
- Includes ϒ, Drell-Yan + $b\bar{b}$
- Analysis in progress

Summary and Outlook

- High-p_T J/ψ measurement in p+p - a crucial test of quarkonia production in QCD
- (B → J/ψ) / J/ψ = (13 ± 5)% for p_T > 5 GeV/c
- No J/ψ suppression at high-p_T in Cu+Cu 200GeV: $R_{AA} \sim 1$
- First ϒ cross section measurements at RHIC energies:
  - p+p results consistent with Color Evaporation Model
  - d+Au: R_{dAu} = 0.78 ± 0.28 (stat.) ± 0.20 (sys.)

- Outlook
  - new p+p and Au+Au 200 GeV data with new ToF available soon (5x higher statistics)
  - high-p_T J/ψ in Au+Au and ϒ R_{AA} in Au+Au

Backup

Heavy quarks = early production

Interpenetration time: $t \approx 2R/\gamma$

$m_c \approx 1.3$ GeV

SPS: $t \geqslant 1 fm$

$m_b \approx 4.2$ GeV

RHIC: $t \leqslant 0.2 fm$

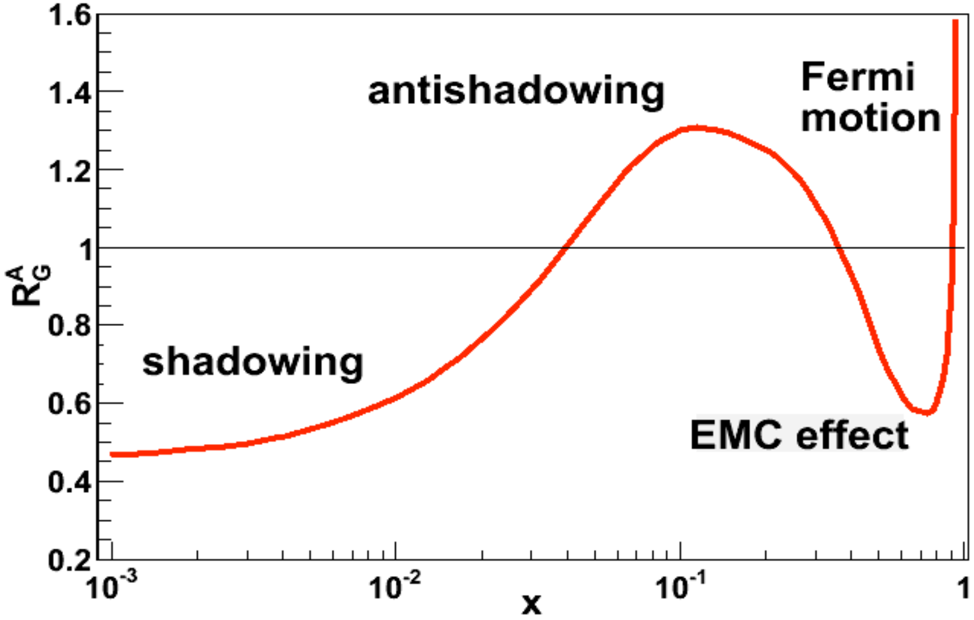
$t_c^{production} = 1/2m_c \leqslant 0.1 fm$

LHC: $t \leqslant 5 \times 10^{-3} fm$

Cold Nuclear Matter Eff.

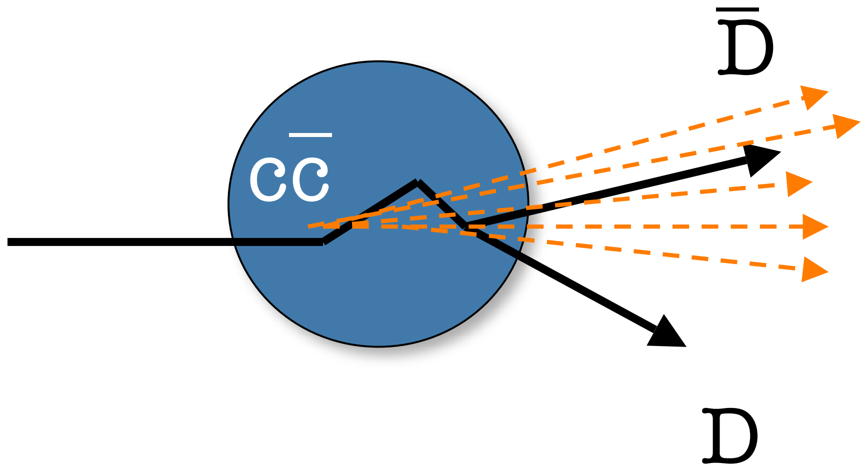
Initial state (Before $c\bar{c}$ formation)

1. Shadowing



2. Initial parton energy loss

Final state



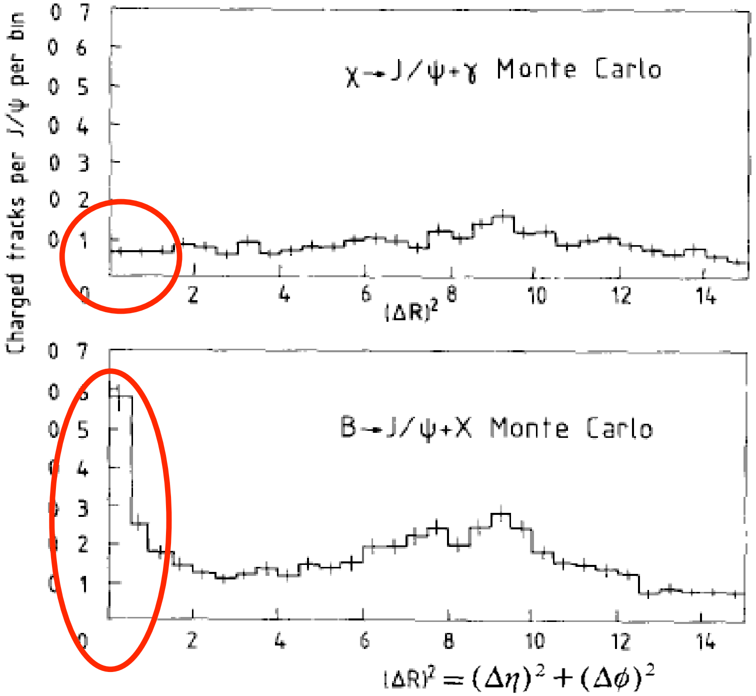
Nuclear absorption and/or co-movers interaction

Quarkonia family

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

H. Satz, J. Phys. G 32 (2006) R25

Disentangle contributions via Correlations



UA1:PLB 200, 380(1988) and PLB 256,112(1991)

1) $g + g \longrightarrow \chi + g$

$\quad \Rightarrow J/\psi + \gamma$

No near side correlation

2) $g + g \longrightarrow b + \bar{b}$

$\quad \Rightarrow B_{hadron} + X$

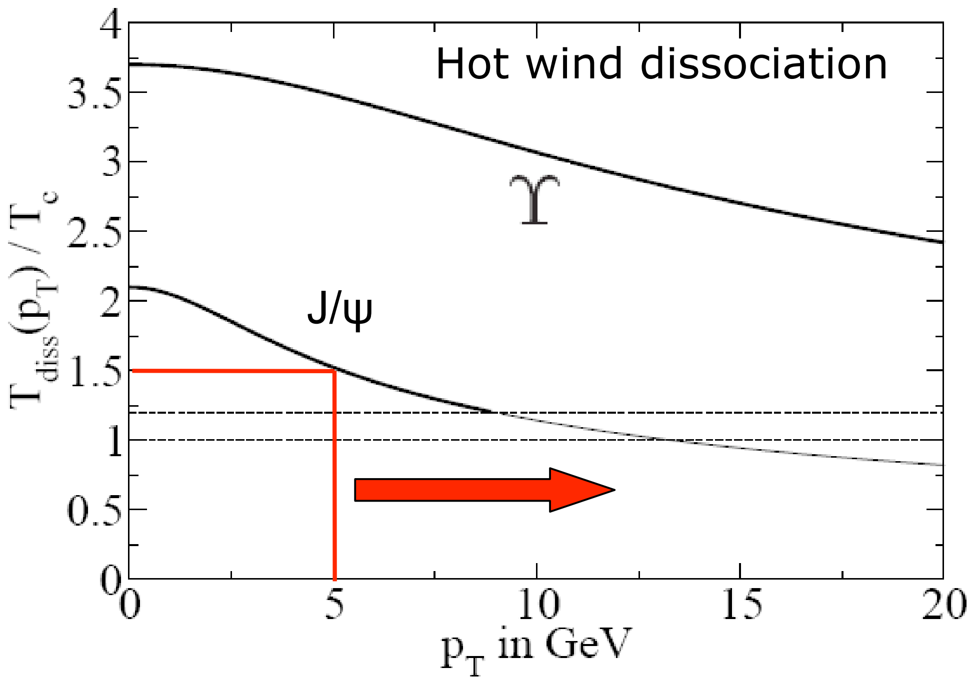
$\quad \Rightarrow J/\psi + X$

Strong near side correlation

J/ψ-hadron correlation can shed light on different contribution to J/ψ production

Hot wind dissociation

- Hot wind dissociation → high p_T direct J/ψ suppression
- (H. Liu, K. Rajagopal and U.A. Wiedemann, PRL 98, 182301(2007) and hep-ph/0607062, M. Chernicoff, J. A. Garcia, A. Guijosa hep-th/0607089)



AdS+CFT with hydro