Upsilon Suppression as a Probe of Hot Medium

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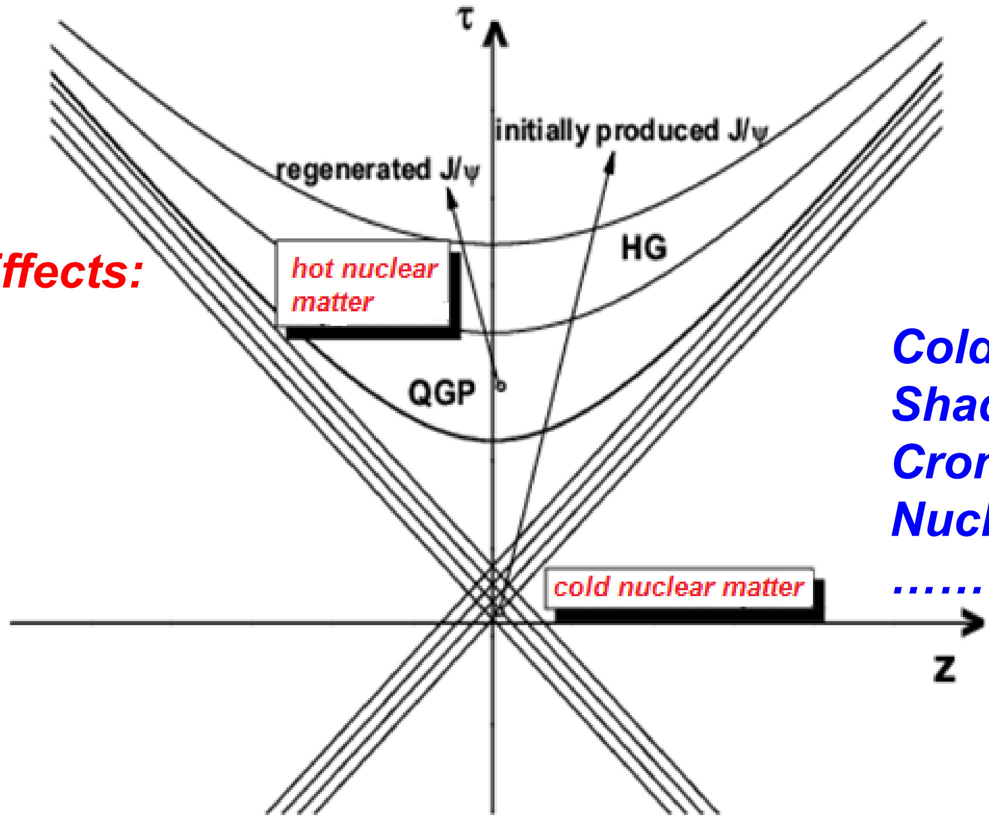
- *Why Upsilon*
- *A dynamic transport approach*
- *Yield and transverse momentum distributions*

Thanks to Dr. Nu Xu and Kai Zhou

Quark Matter 2014, May 19-24, Darmstadt

Cold and Hot Medium Effects on Quarmonium Production

Hot Medium Effects:
Dissociation,
Regeneration,
……



Cold Medium Effects:
Shadowing effect,
Cronin effect,
Nuclear absorption,
……

Can we simplify the system and focus on the hot medium (QGP) effects?

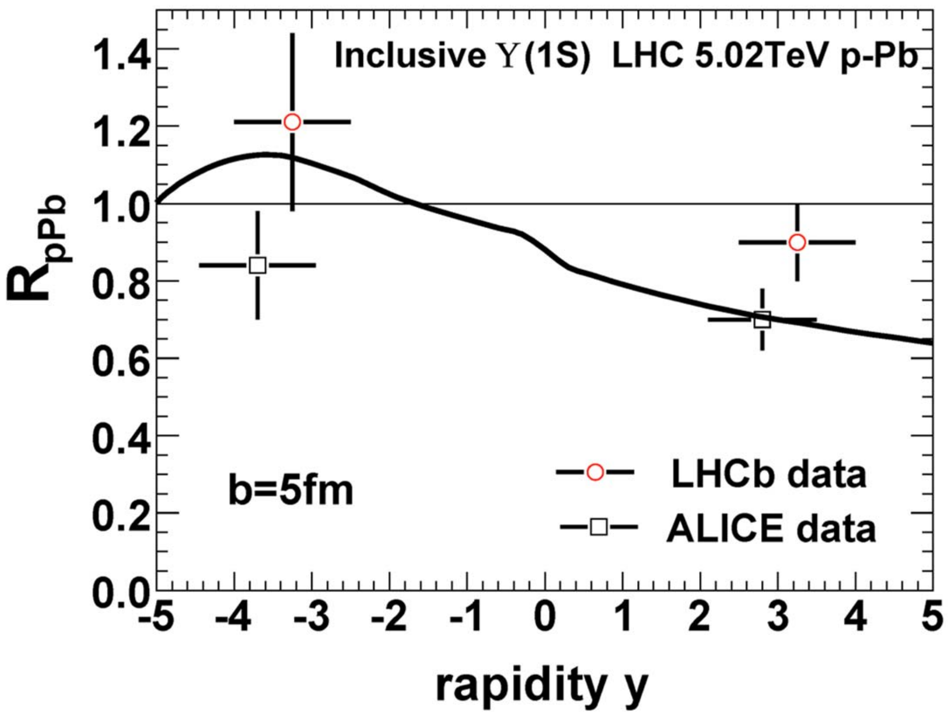
Why Upsilon ?

In comparison with J/ψ,

1) Υ regeneration in hot medium is weak, the production calculations with perturbative QCD become dominant and more reliable;

2) Υ is so heavy, there is no feed-down contribution at RHIC and LHC;

3) the cold medium effect is weak from the pA data.



ALICE: ArXiv：1405.1177
LHCb: talk by Yang this morning
LHCb-PAPER-2013-015

Υ is controlled by hot medium effects !

A Dynamic Transport Approach for Quarkonia in HIC

- ***QGP evolution***

$$\partial_\mu T^{\mu\nu} = 0, \qquad \partial_\mu n^\mu = 0$$ **+ *equation of state***

- ***quarkonium motion*** $(\Psi = J/\psi,\ \psi',\ \chi_c)$

gluon dissociation cross section by OPE and quarkonium size by potential model

$$\sigma(T) = \sigma(0)\langle r^2\rangle(T)/\langle r^2\rangle(0)$$

$$\partial f_\Psi/\partial\tau + \mathbf{v}_\Psi\cdot\nabla f_\Psi = -\alpha_\Psi f_\Psi + \beta_\Psi.$$

detailed balance

$$\alpha_\Psi(\mathbf{p}_t,\mathbf{x}_t,\tau|\mathbf{b}) = \frac{1}{2E_\Psi}\int\frac{d^3\mathbf{p}_g}{(2\pi)^3 2E_g}W_{g\Psi}^{c\bar{c}}(s)f_g(\mathbf{p}_g,\mathbf{x}_t,\tau)\Theta\left(T(\mathbf{x}_t,\tau|\mathbf{b})-T_c\right),$$

$$\beta_\Psi(\mathbf{p}_t,\mathbf{x}_t,\tau|\mathbf{b}) = \frac{1}{2E_\Psi}\int\frac{d^3\mathbf{p}_g}{(2\pi)^3 2E_g}\frac{d^3\mathbf{p}_c}{(2\pi)^3 2E_c}\frac{d^3\mathbf{p}_{\bar{c}}}{(2\pi)^3 2E_{\bar{c}}}W_{c\bar{c}}^{g\Psi}(s)f_c(\mathbf{p}_c,\mathbf{x}_t,\tau|\mathbf{b})f_{\bar{c}}(\mathbf{p}_{\bar{c}},\mathbf{x}_t,\tau|\mathbf{b})$$
$$\times(2\pi)^4\delta^{(4)}(p+p_g-p_c-p_{\bar{c}})\Theta\left(T(\mathbf{x}_t,\tau|\mathbf{b})-T_c\right),$$

- ***cold medium effects (for instance, EKS98) modify not only the initial quarkonium distribution but also the regeneration!***

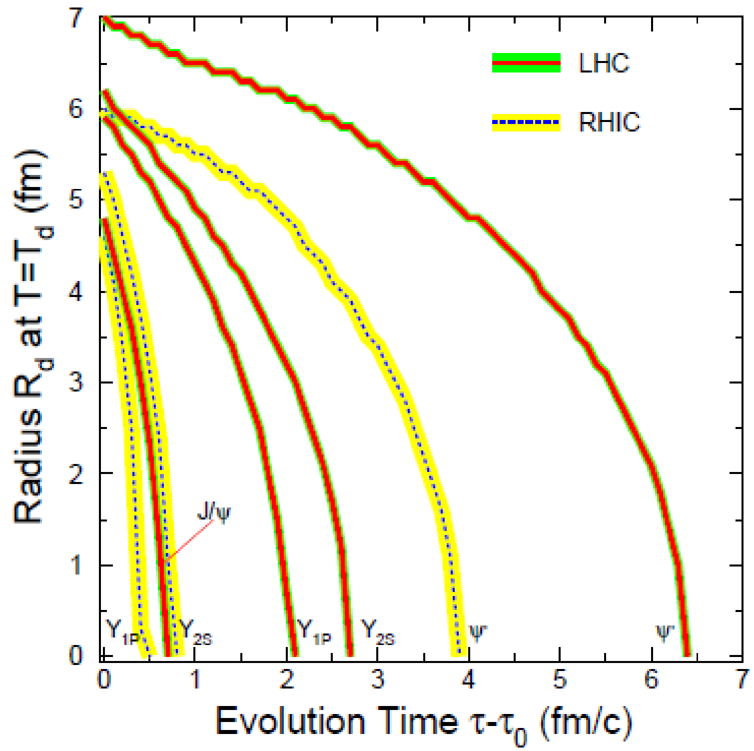
- ***assumption: thermalized gluon and heavy quark distributions***

Quarkonium Surviving Region

potential model (V=U, H.Satz):

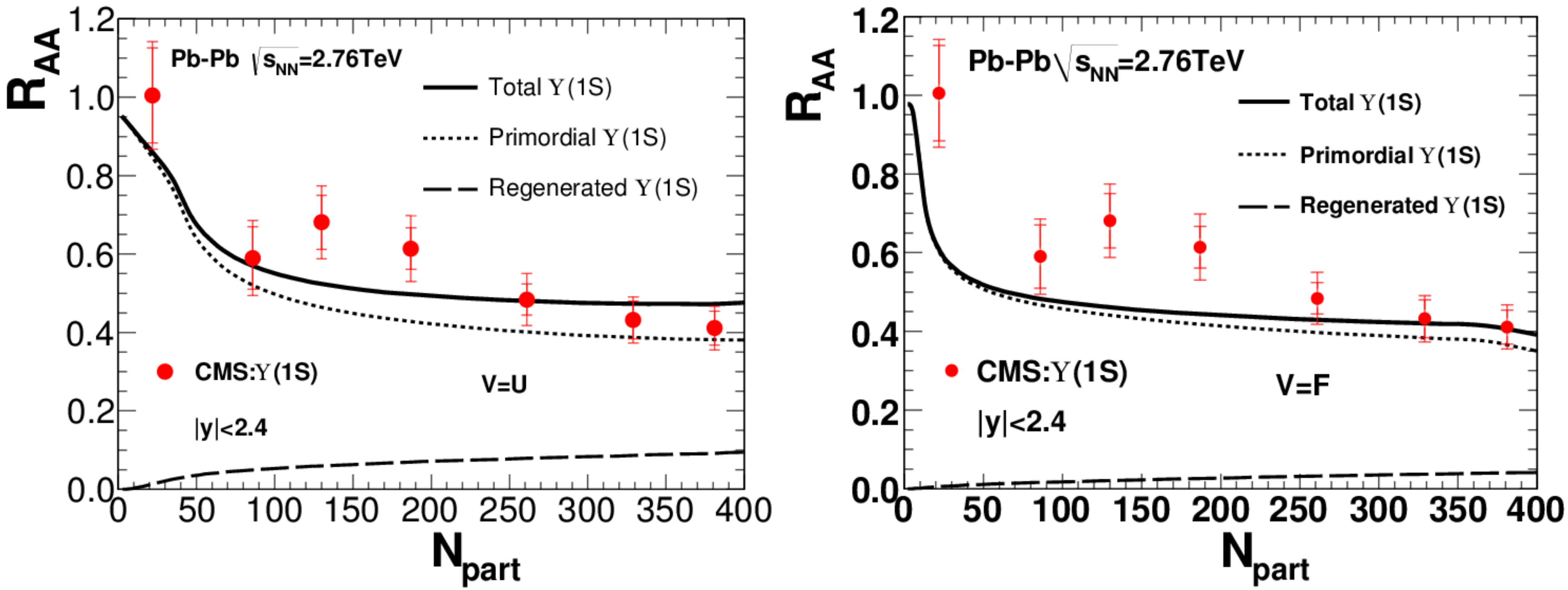
state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	>4.0	1.76	1.60	1.19	1.17

hydrodynamics: $T(R_d, y, \tau) = T_d$



potential model (V=F): lower dissociation temperature

Upsilon(1s) at mid rapidity



dσ(1s)/dy=40 nb (PYTHIA, CDF(1.8TeV) and CMS(7 TeV))

dσ(bb)/dy=20 ub (FONLL)

CMS data: NPA910, 91(2013)

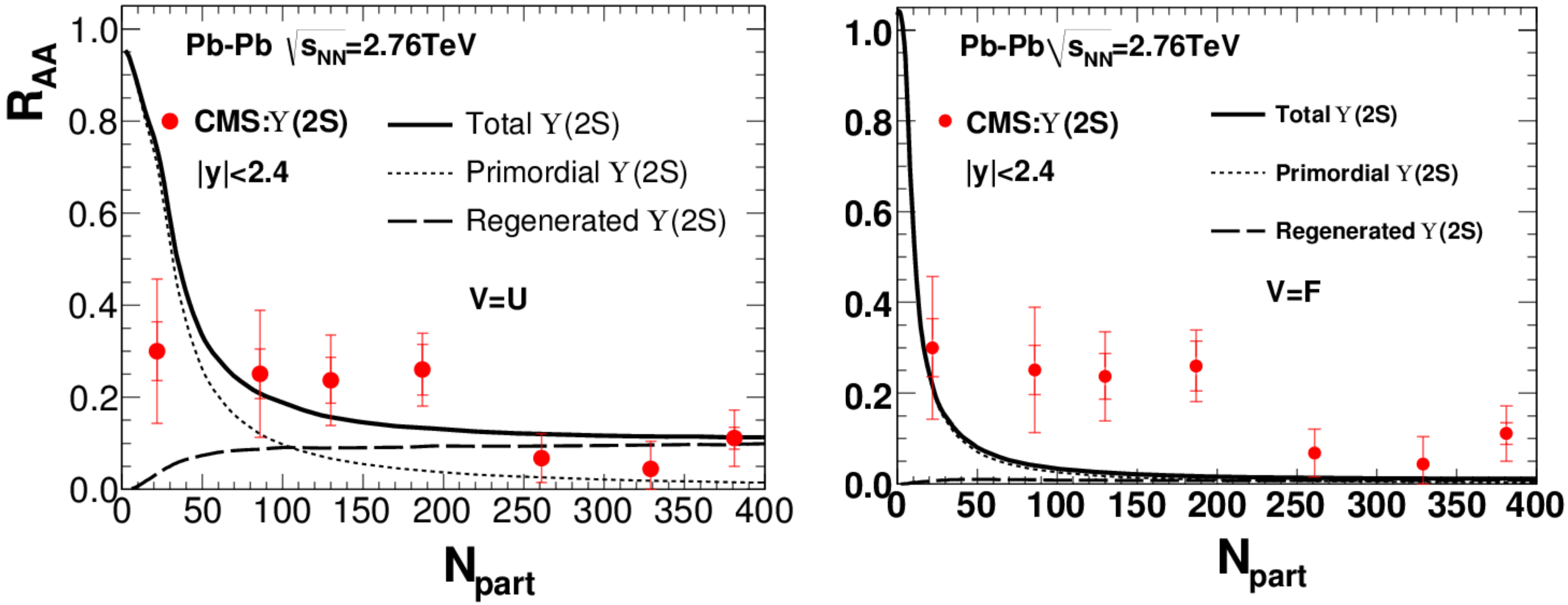
in central collisions:

1) T(2s)<T<T(1s) for both V=U and V=F, excited states are eaten up but ground state is not affected, R_AA=0.5;

2) small regeneration.

ground state is not sensitive to the hot medium !

Upsilon(2s) at mid rapidity



in central collisions:

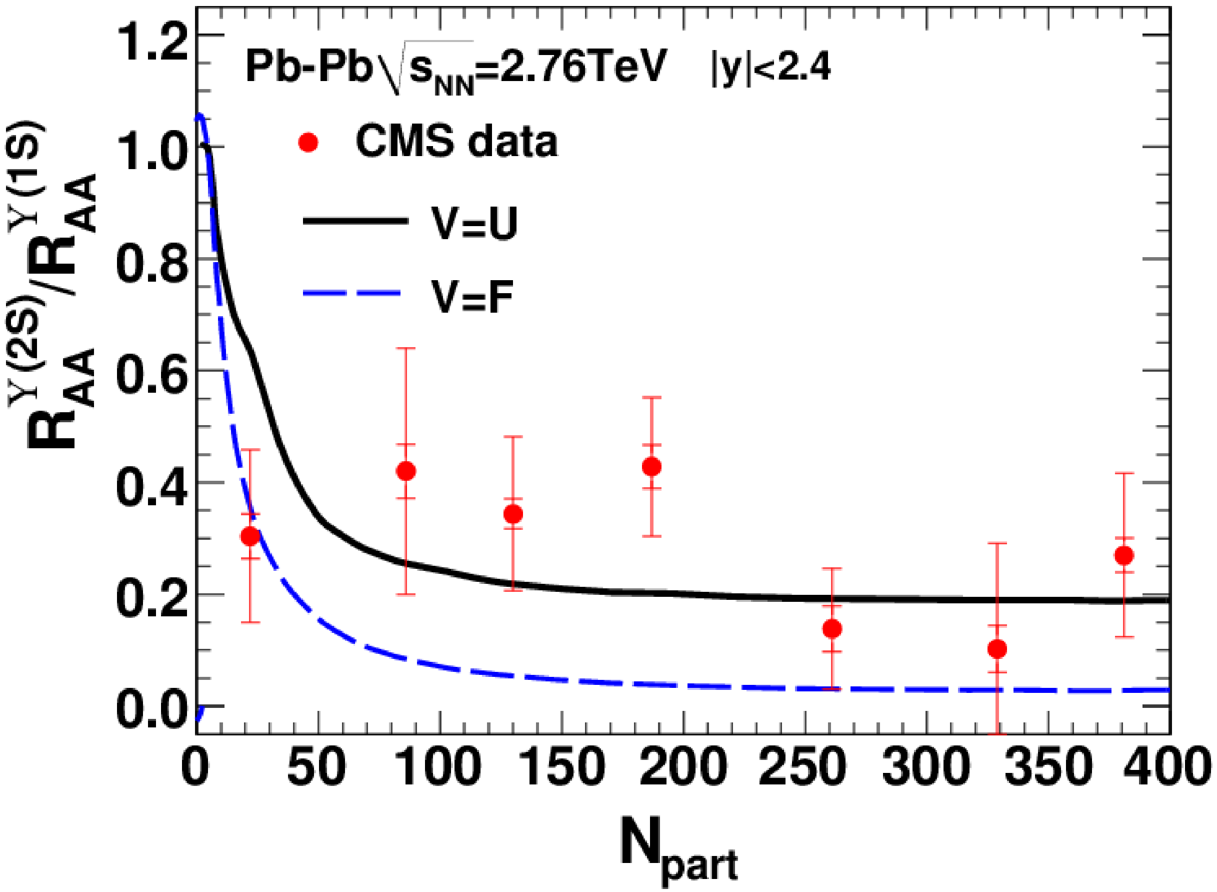
1) initial production is eaten up by the hot medium, the small regeneration becomes dominant!

2) for V=F, T(2s)~Tc, regenerated Upsilon(2s) is again eaten up by the medium !

3) the data favor V=U.

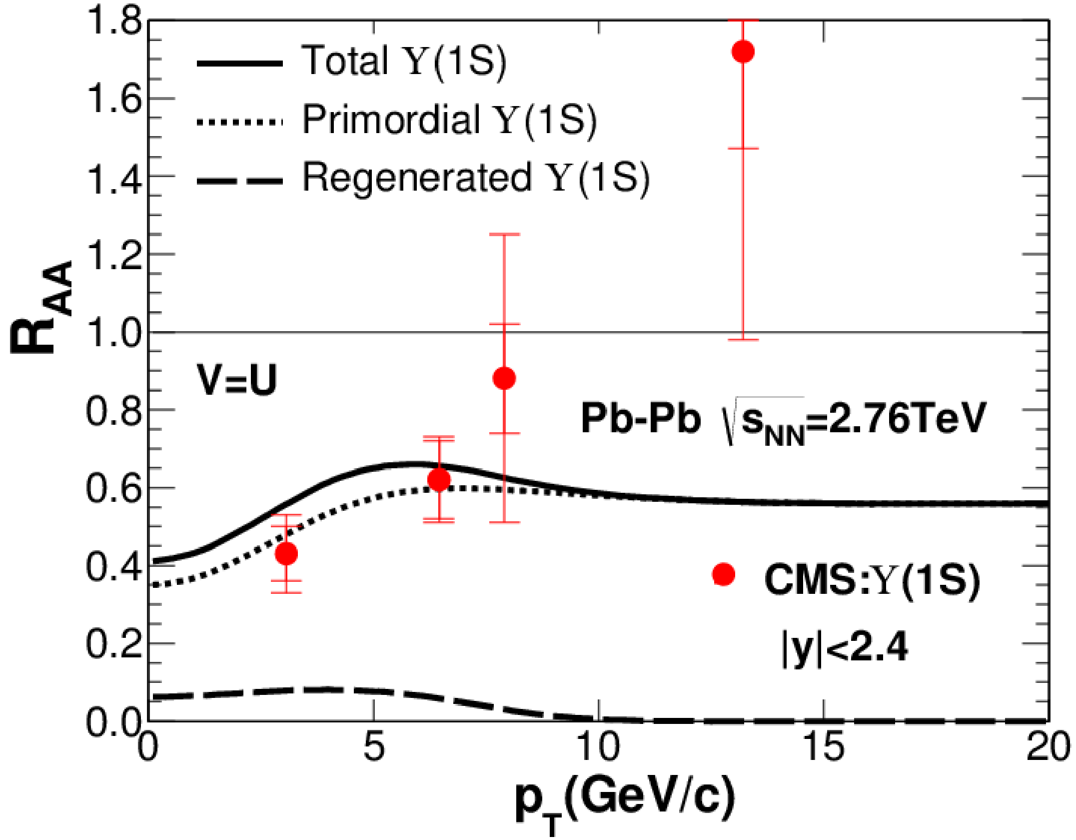
excited states are sensitive to the hot medium !

Double Ratio



the data favor V=U

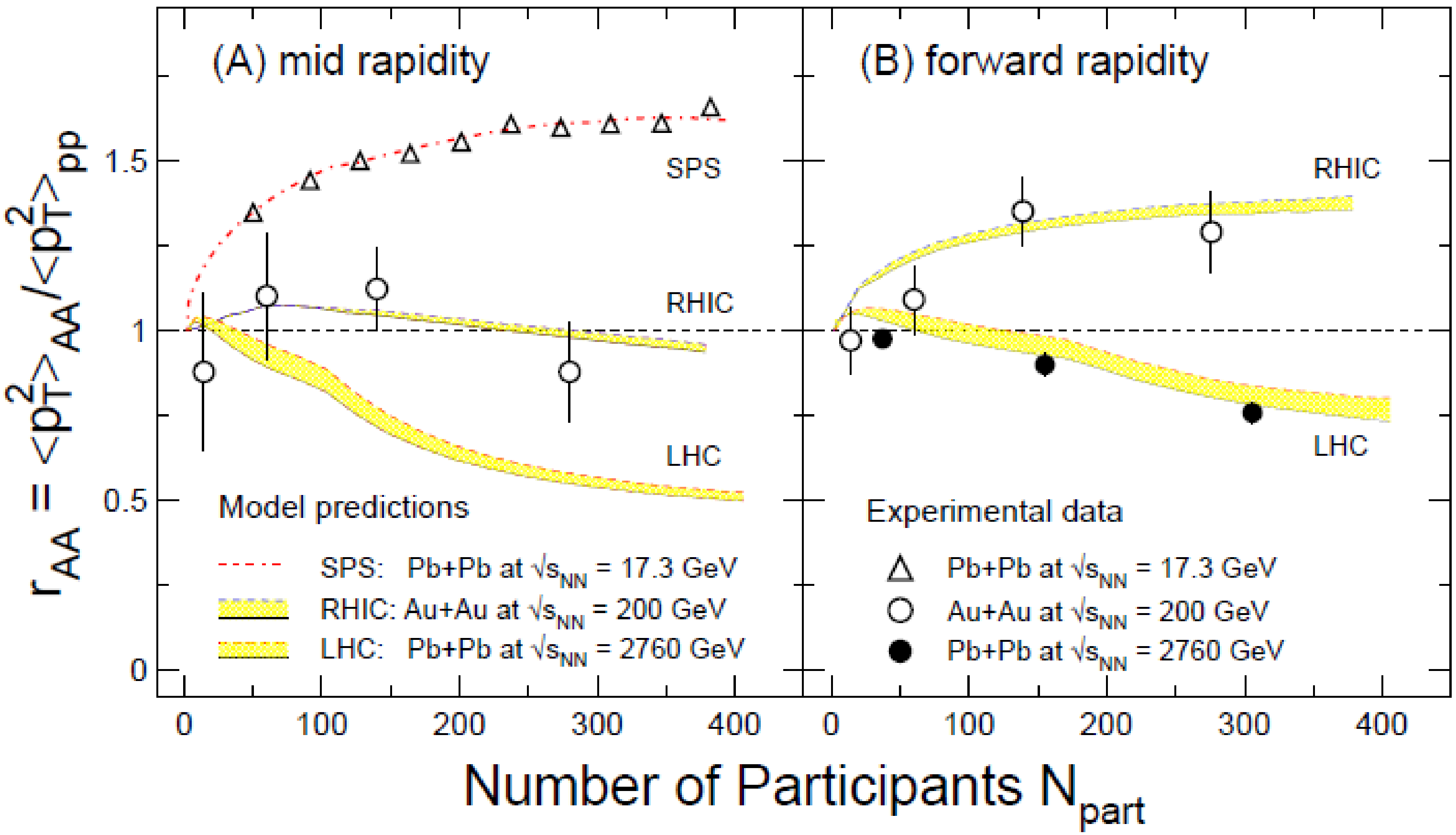
Pt distribution



the calculation cannot reach the data at high pt

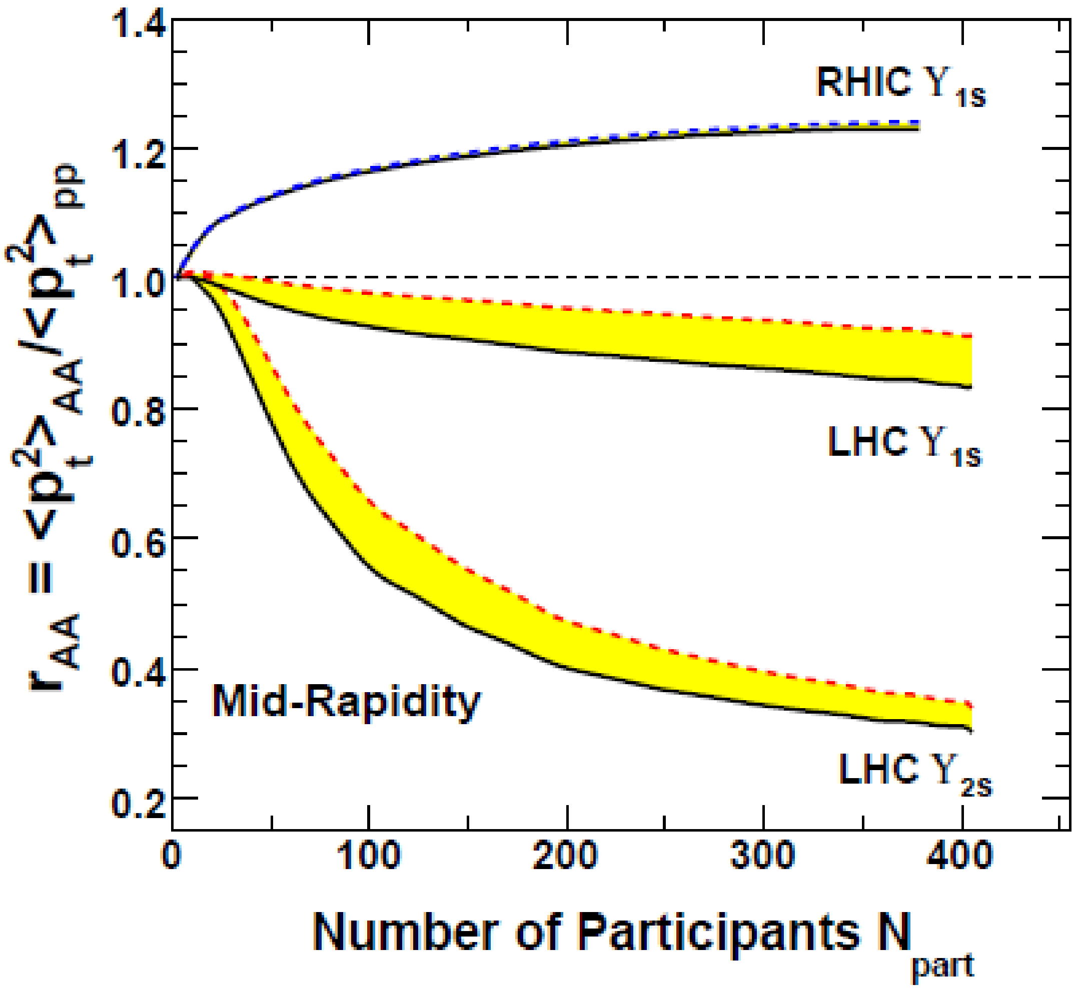
P_t Ratio (J/ψ)

$$r_{AA} = \frac{\langle p_t^2 \rangle_{AA}}{\langle p_t^2 \rangle_{pp}}.$$



J/ψ r_AA is sensitive to the hot medium !

P_t Ratio (Upsilon)



the excited Upsilon states are sensitive to the hot medium !

Conclusions

● ***while the ground state is nearly medium independent, the excited states are sensitive to the hot medium (very small R_AA and r_AA).***

● ***while the regeneration is very small, it controls the behavior of the excited states.***

● ***the CMS data favor V=U.***

Backup

Input

- **medium evolution**

$$RHIC: \ \tau_0 = 0.6\ fm, \quad \sigma_{\mathrm{pp}} = 41\ mb, \quad T_0 = 344\ \mathrm{MeV}$$

$$LHC: \ \tau_0 = 0.6\ fm, \quad \sigma_{\mathrm{pp}} = 62\ mb,$$

$$T_0 = 430 \text{ and } 484\ \mathrm{MeV} \text{ for forward and mid rapidity}$$

- **initial production**

$$RHIC: \ \sigma_{abs} = 0, \ a_{gN} = 0.1\ \mathrm{GeV}^2 / fm,$$

$$d\sigma_{pp}^{J/\psi} / dy = 0.42 \text{ and } 0.74\ \mu\mathrm{b} \text{ for forward and mid rapidity}$$

$$LHC: \ \sigma_{abs} = 0, \ a_{gN} = 0.15\ \mathrm{GeV}^2 / fm,$$

$$d\sigma_{pp}^{J/\psi} / dy = 2.22, \ 3.35, \ 4.10\ \mu\mathrm{b} \text{ for rapidity } [2.5, 4], [1.6, 2.4], [0, 1.6]$$

$r_B = 0.27 \pm 0.04$ for J/ψ and $r_B = 0.38 \pm 0.0$

$Q = 0.35^{+0.10}_{-0.07}$

- **regeneration**

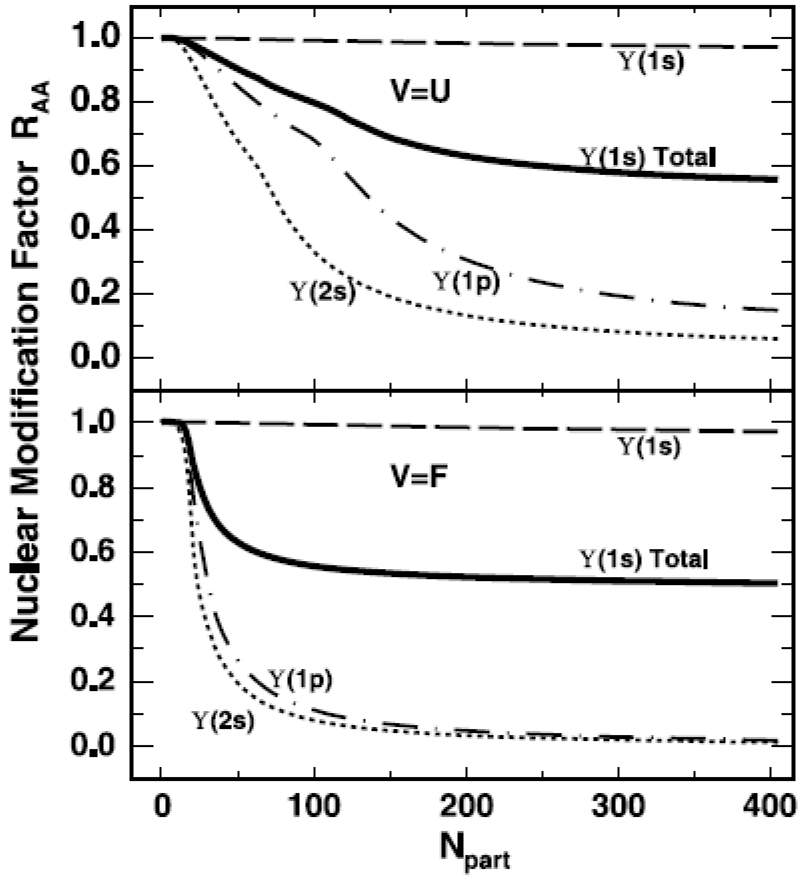
$$RHIC: \ d\sigma_{pp}^{c\bar{c}} / dy = 0.04 \text{ and } 0.12 mb \text{ for forward and mid rapidity}$$

$$LHC: \ d\sigma_{pp}^{c\bar{c}} / dy = 0.40 \text{ and } 0.65\ mb \text{ for forward and mid rapidity}$$

V=U: $T_d = 2.3 T_c$ for J/ψ and $1.1 T_c$ for ψ' and χ_c

Υ at RHIC: $R_{AA}(N_p)$

Y.Liu, B.Chen, N.Xu, PZ,PLB2011

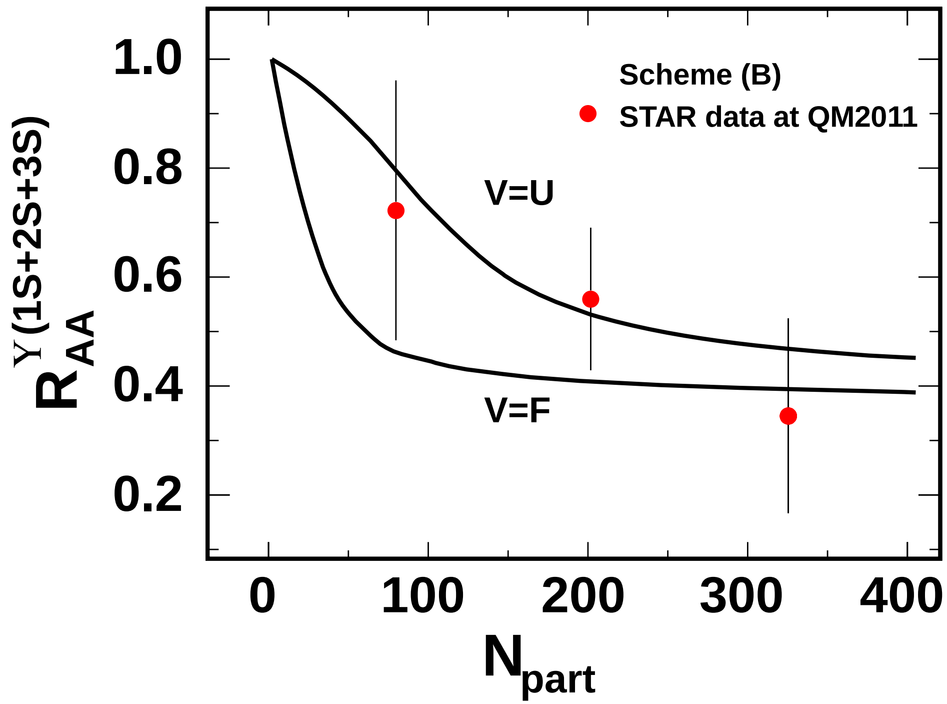


for minimum bias events:

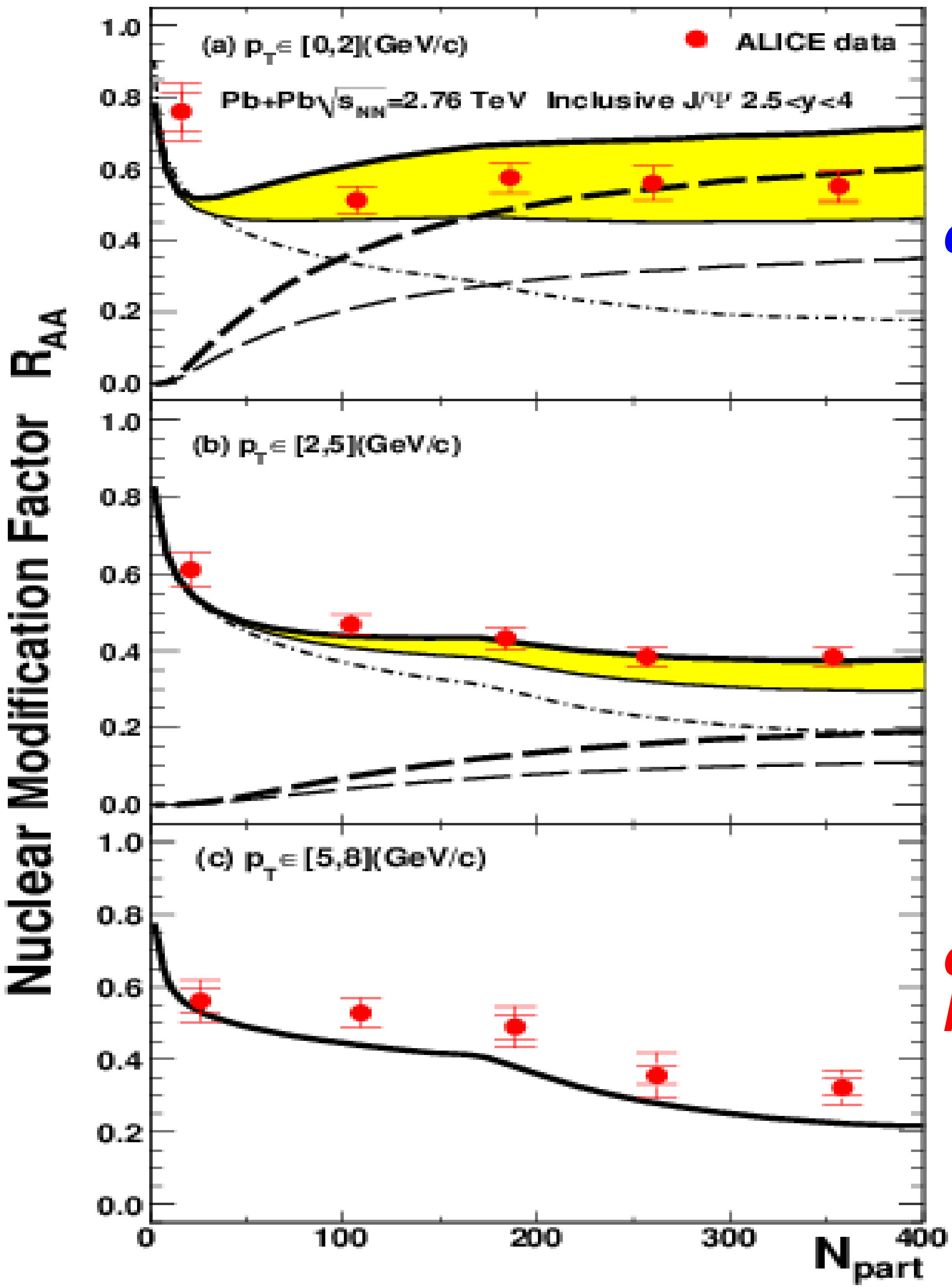
PHENIX dada: R_{AA}<0.64 (NPA2009)

our result: R_{AA} = 0.63 for V=U

R_{AA} = 0.53 for V=F



● *from the comparison with data, V is close to U.*

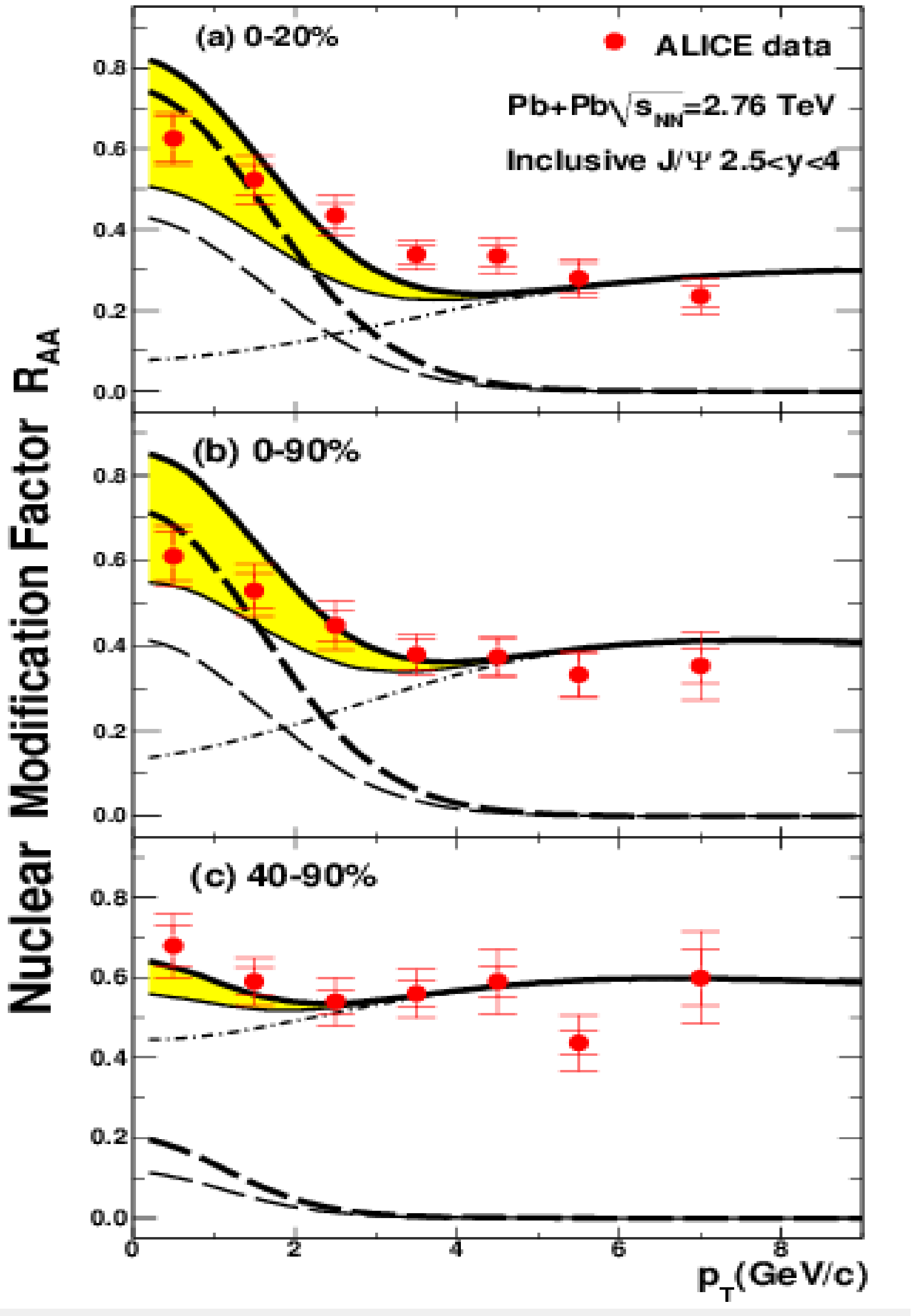


R_{AA} (N_p) in different p_t bins

dominant regeneration at low p_t

the band comes from the uncertainty in charm quark cross section

dominant initial production at high p_t



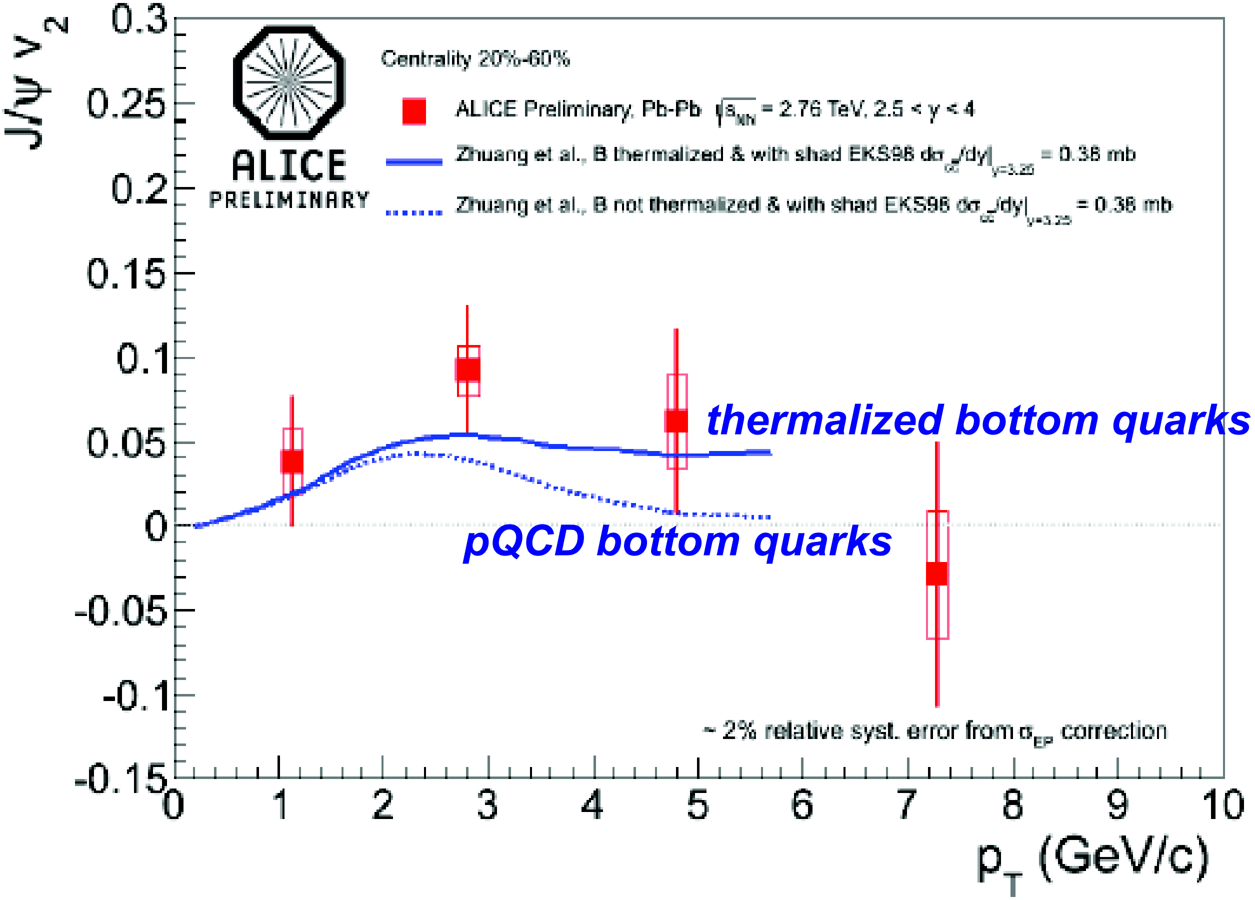
R_{AA} (p_t) in different centrality bins

dominant regeneration in central collisions

the band comes from the uncertainty in charm quark cross section

dominant initial production in peripheral collisions

Elliptic Flow

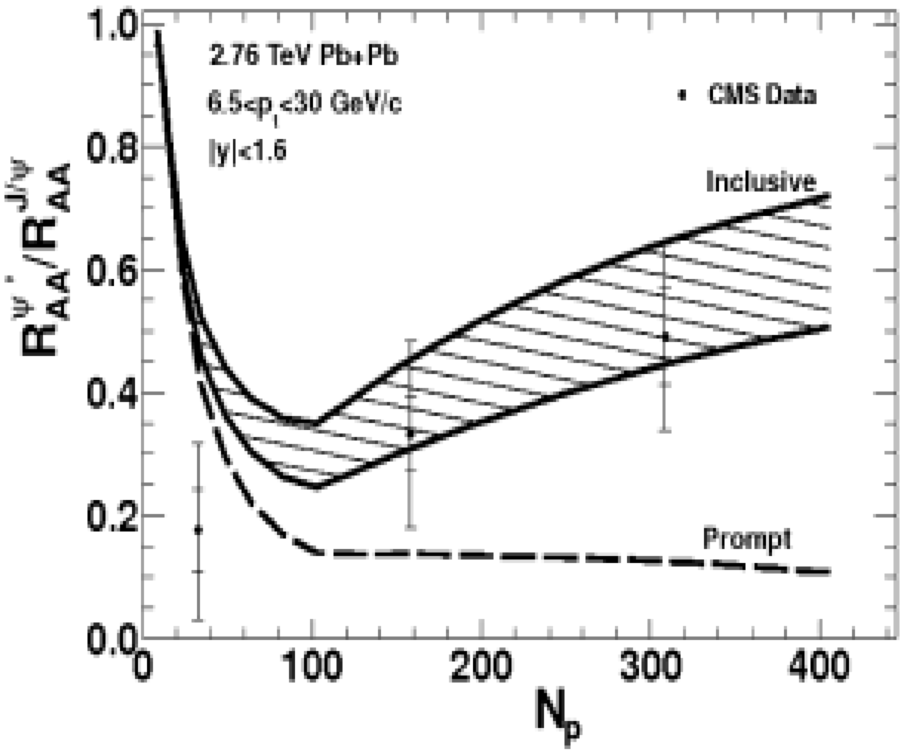


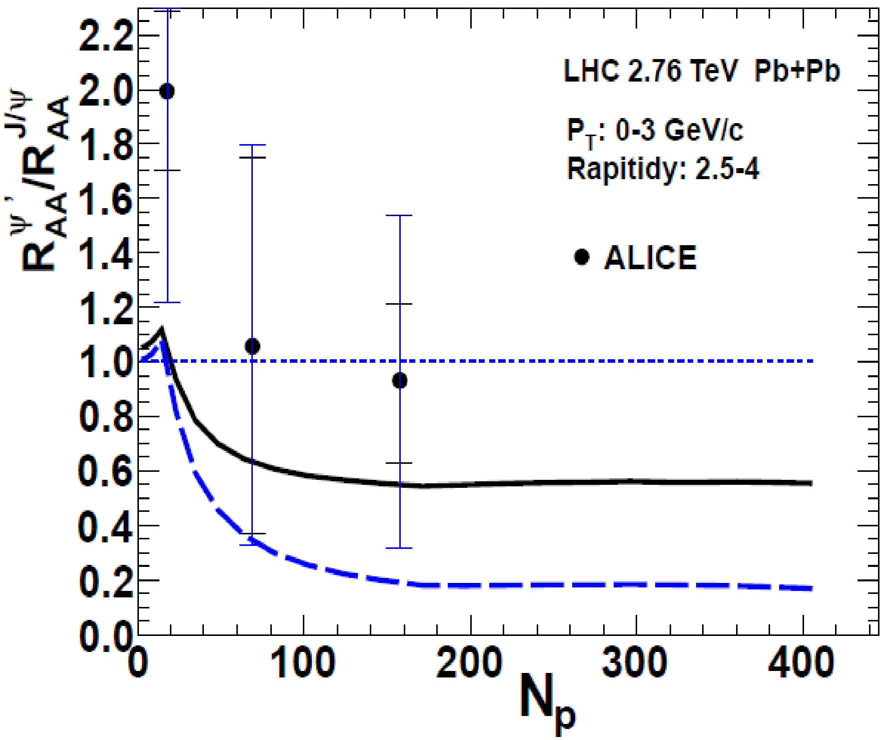
no regeneration, no collective flow !

regeneration + charm quark thermalization lead to J/Ψ v_2 !

Excited States

B decay is important for excited charmonium states at LHC





the band comes from the uncertainty in B decay fraction

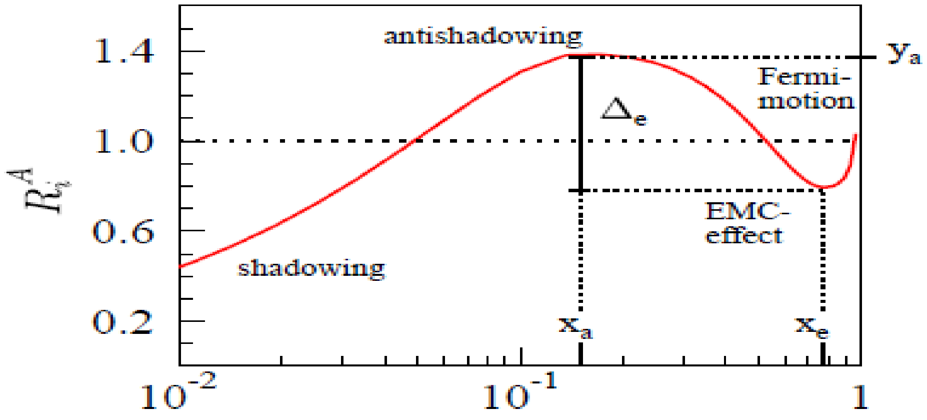
Shadowing Effect

parton distribution function (PDF) in a nucleus is different from a simple superposition (Glauber model) of the PDF in a free nucleon.

shadowing correction factor:

$$R_i^A(x,\mu_F) = \frac{f_i^A(x,\mu_F)}{A f_i^{nucleon}(x,\mu_F)}, \quad f_i = q, \bar{q}, g$$

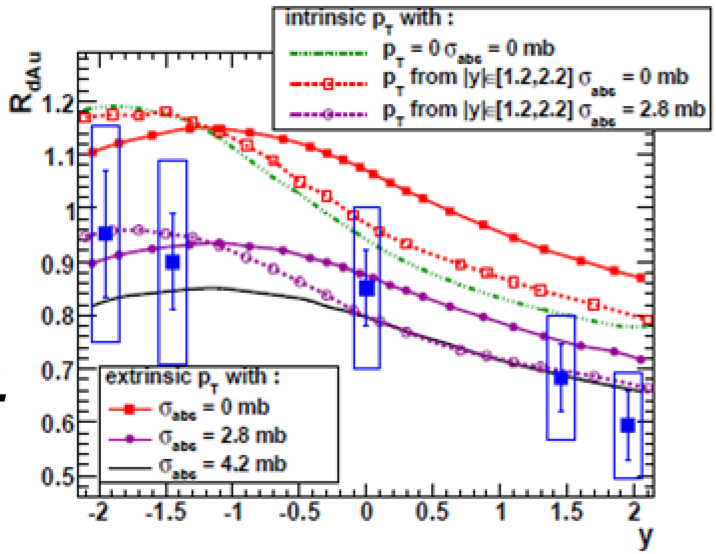
x: momentum fraction,
$\sqrt{\mu_F}$: transverse momentum



$$\frac{d^2\sigma_{AB\to J/\psi X}}{dy_\Psi dp_t d\vec{x}_t} = \int_0^1 dx_1 dx_2 \int d\vec{x}_t dz_A dz_B \mathcal{F}_g^A(x_1,\vec{x}_t,z_A,\mu_F)\, \mathcal{F}_g^B(x_2,\vec{x}_t-\vec{b},z_B,\mu_F) 2\hat{s}p_t \frac{d\sigma_{gg\to J/\psi+g}}{d\hat{t}} \delta(\hat{s}+\hat{t}+\hat{u}-M^2)\, S_{abs}$$

$$\mathcal{F}_g^A(x_1,\vec{x}_t,z_A,\mu_F) = \rho_A(\vec{x}_t,z_A)\mathcal{R}_g^A(\vec{x}_t,x_1,\mu_F)g(x_1,\mu_F)$$

usual PDF



shadowing effect + nuclear absorption can explain the pA data at RHIC energy.