Quarkonia measurements in p-Pb and Pb-Pb collisions with ALICE

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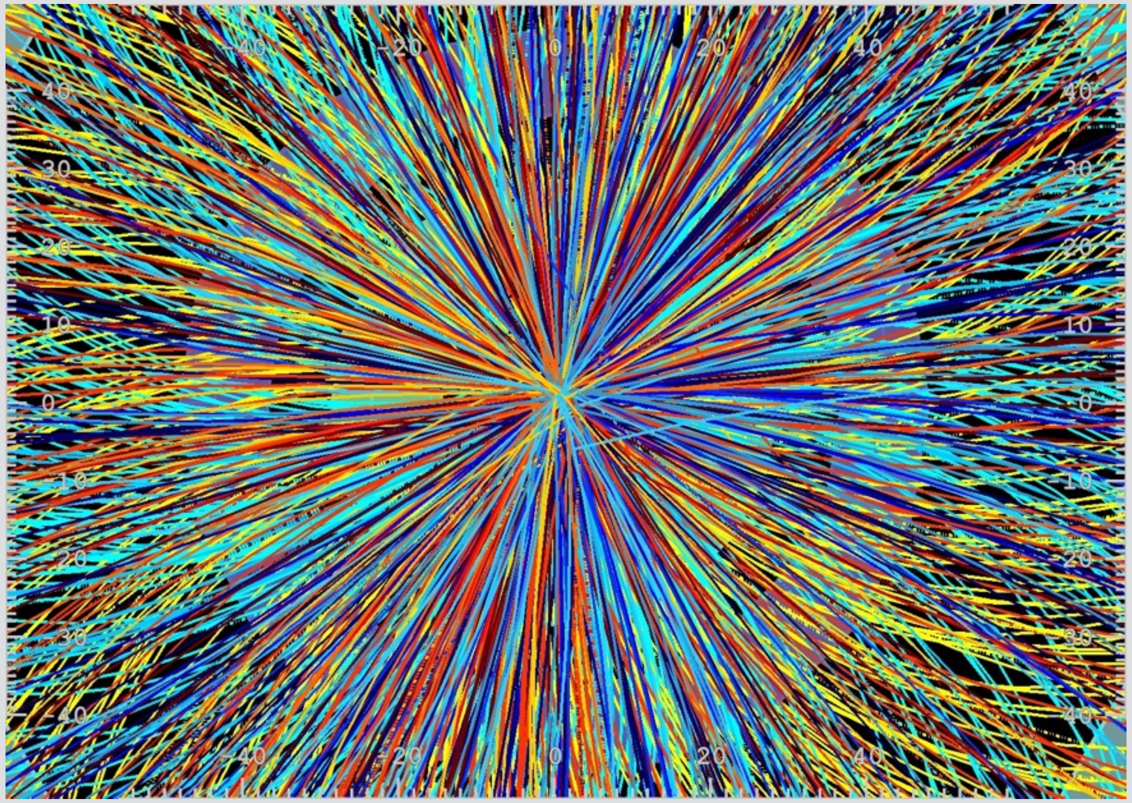
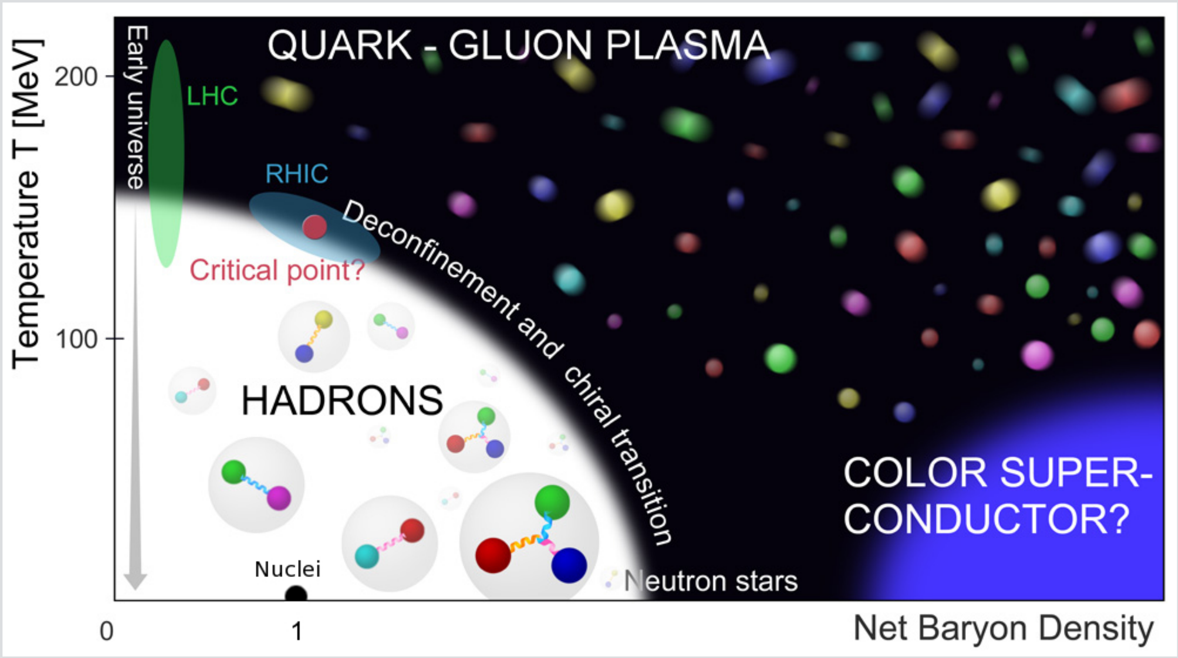
Outline

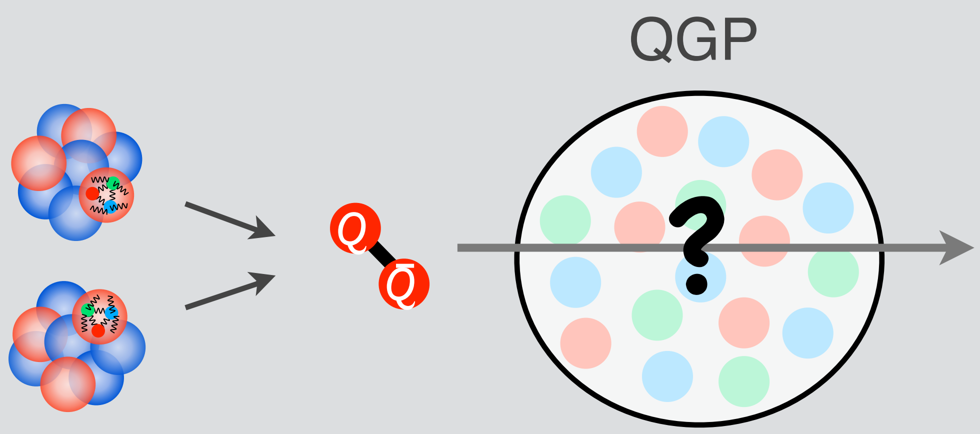
1. Introduction
2. Quarkonia in p-Pb collisions
3. Quarkonia in Pb-Pb collisions
4. Conclusion



Why looking at quarkonia in heavy-ion collisions?



Quark gluon plasma ➙ strongly-interacting QCD system



$Q\bar{Q}$ pairs are produced in the initial hard partonic collisions and $\tau_{Q\bar{Q}} > \tau_{\mathrm{QGP}}$.

Five quarkonium states from two families under study with ALICE:

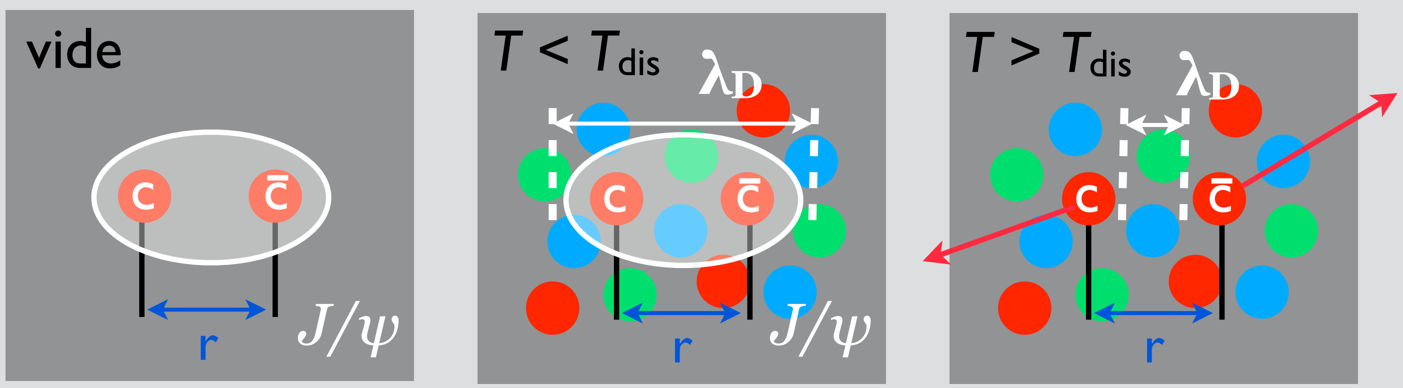
Charmonia		Bottomonia		
J/ψ	$\psi(2S)$	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$

1986 - Matsui & Satz: J/ψ suppression in heavy-ion collisions is a promising probe of QGP.

Heavy quarkonium states are expected to provide information on deconfinement and the QGP properties

Suppression mechanism

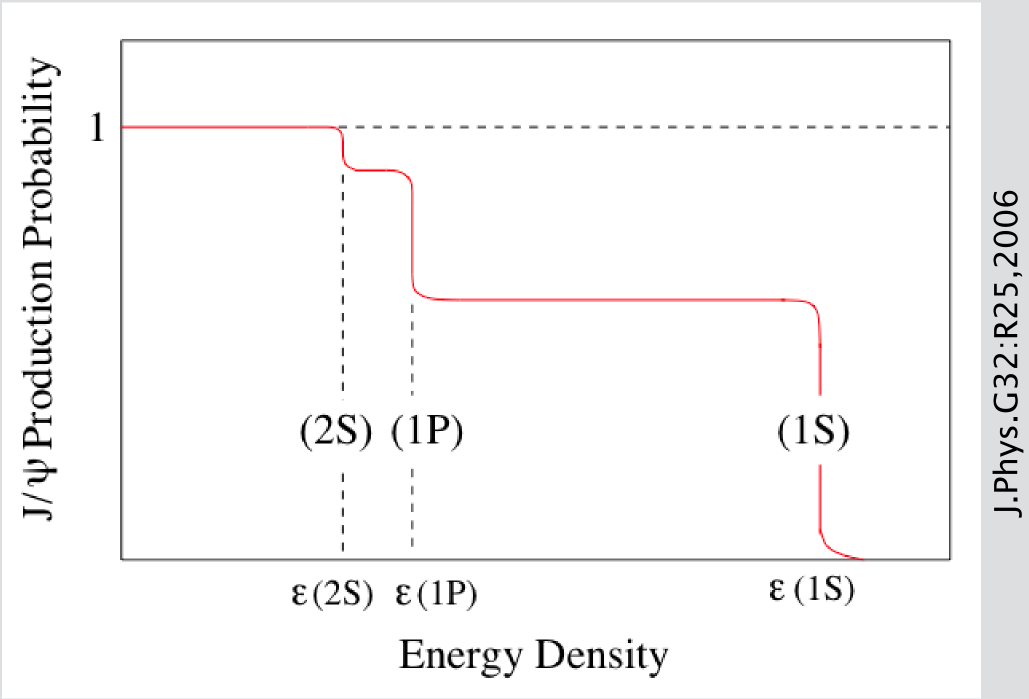
r > Debye radius $\lambda_D(T)$ → Dissociation



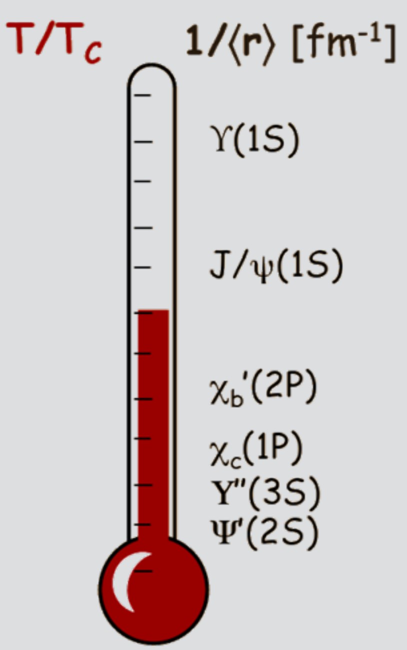
Debye screening

An effective screening of the interquark force is induced by the high density of color charges in QGP

Different binding energy of quarkonium states → sequential suppression?

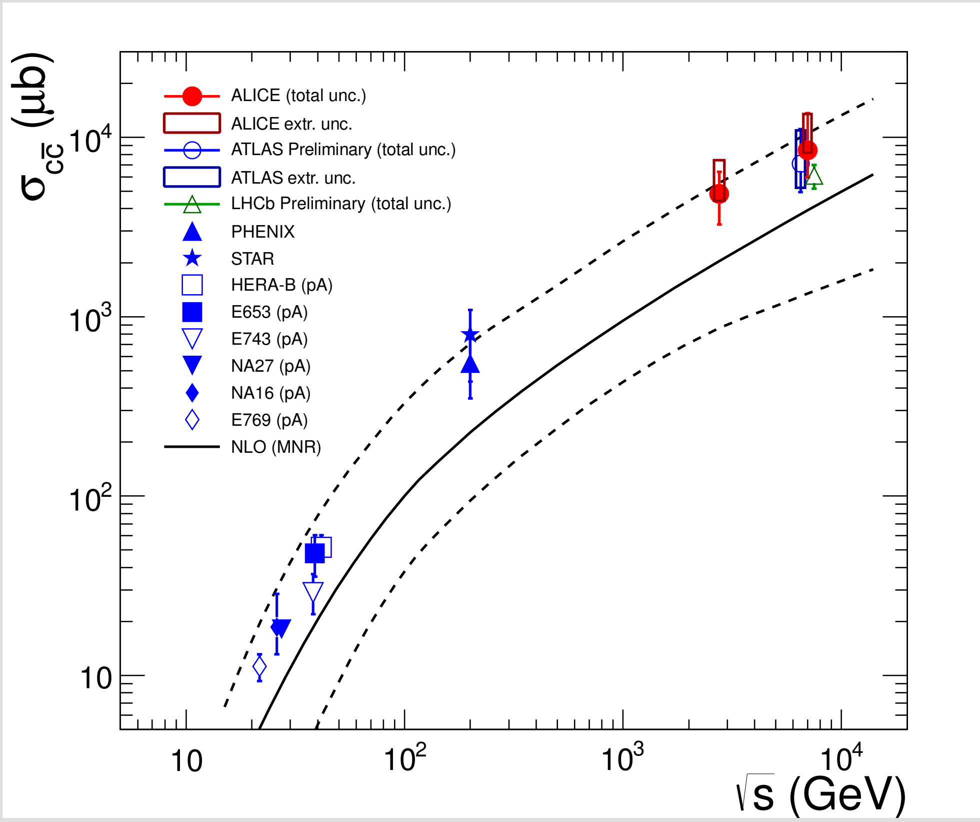


This could provide a measurement of the QGP initial temperature…



Mocsy, EPJC61 (2009) 705

But also regeneration?



JHEP 1207 (2012) 191

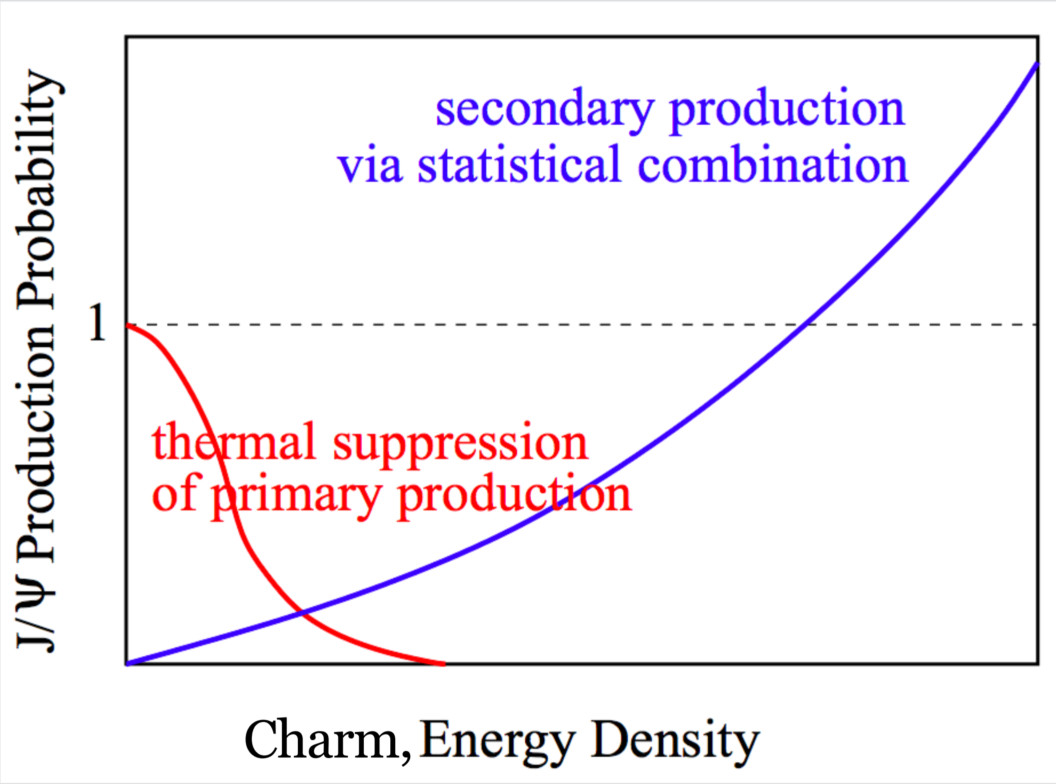
← Large number of charm quarks created in central Pb-Pb collisions at LHC, $N_{c\bar{c}} \approx 100$

Quarkonium production at phase boundary by statistical combinaison of uncorrelated *Q* and $\bar{Q}$ quarks present in the medium

Peculiarity: low p_T production (< 3 GeV/c)

Implication of regeneration:

- Evidence of thermalization
- Evidence of deconfinement
- Enhancement (or compensate suppression)
- Quarkonia as a QGP thermometer?

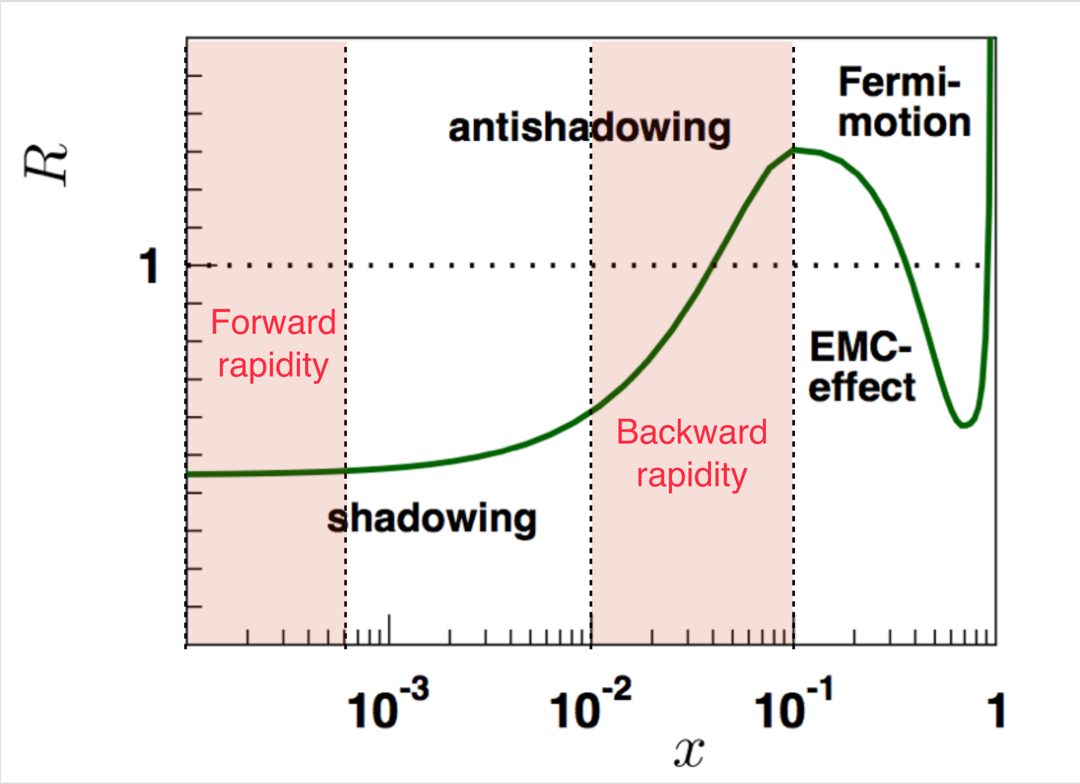


H. Satz, SaporeGravis 2013

And Cold Nuclear Matter effects?

Shadowing: Modification of the Parton Distribution Functions, *f(x,Q²)*, in the nuclei with respect to free nucleons:

$$f^N(x,Q^2) \times A \neq f^A(x,Q^2)$$

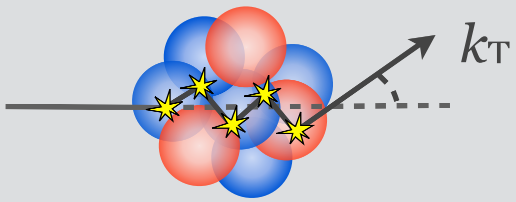


CGC: Saturation via Colour Glass Condensate

E_{loss}: Coherent parton energy loss

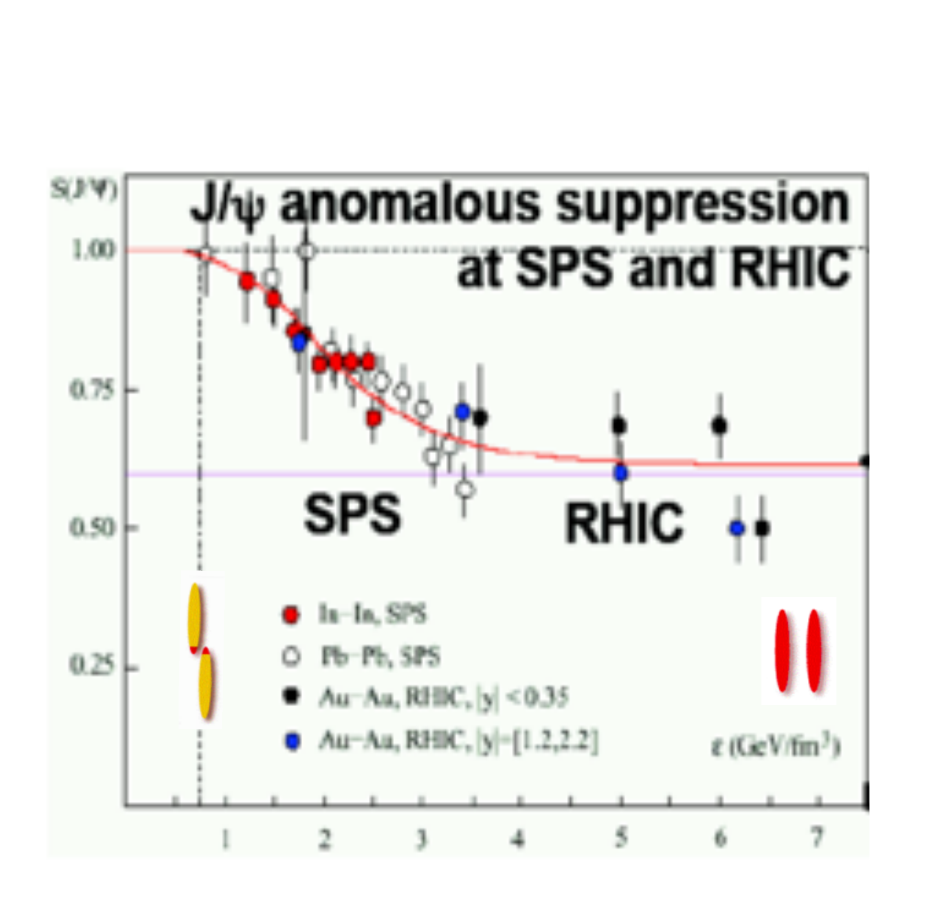
Nuclear absorption: Expected to be negligible at LHC (high coherence distance)

Cronin effect: Multiple parton scattering lead to p_T broadening



p-A collisions used to study CNM effects in the absence of a hot medium

What have we learned from SPS and RHIC?



Prompt *J/ψ* feed-down from higher charmonium states ~ 40%

Clear J/ψ suppression at SPS and RHIC energies with same magnitude!

Nuclear modification factor

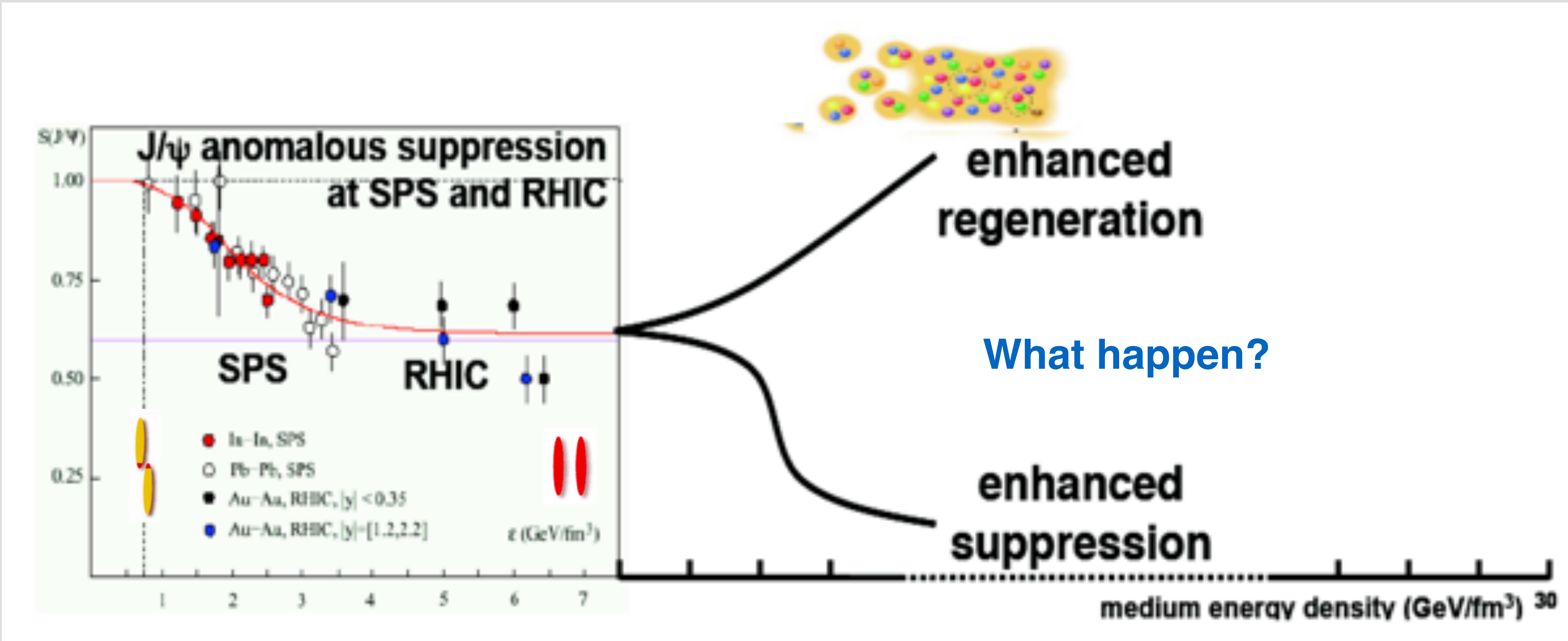
$$R_{\rm AA} = \frac{N_{\rm AA}^{J/\psi}}{\langle N_{\rm coll}\rangle\, N_{\rm pp}^{J/\psi}}$$

= 1 ➙ no medium effect

< 1 ➙ suppression

> 1 ➙ enhancement

At LHC energy?



Charmonia

- Abundantly produced

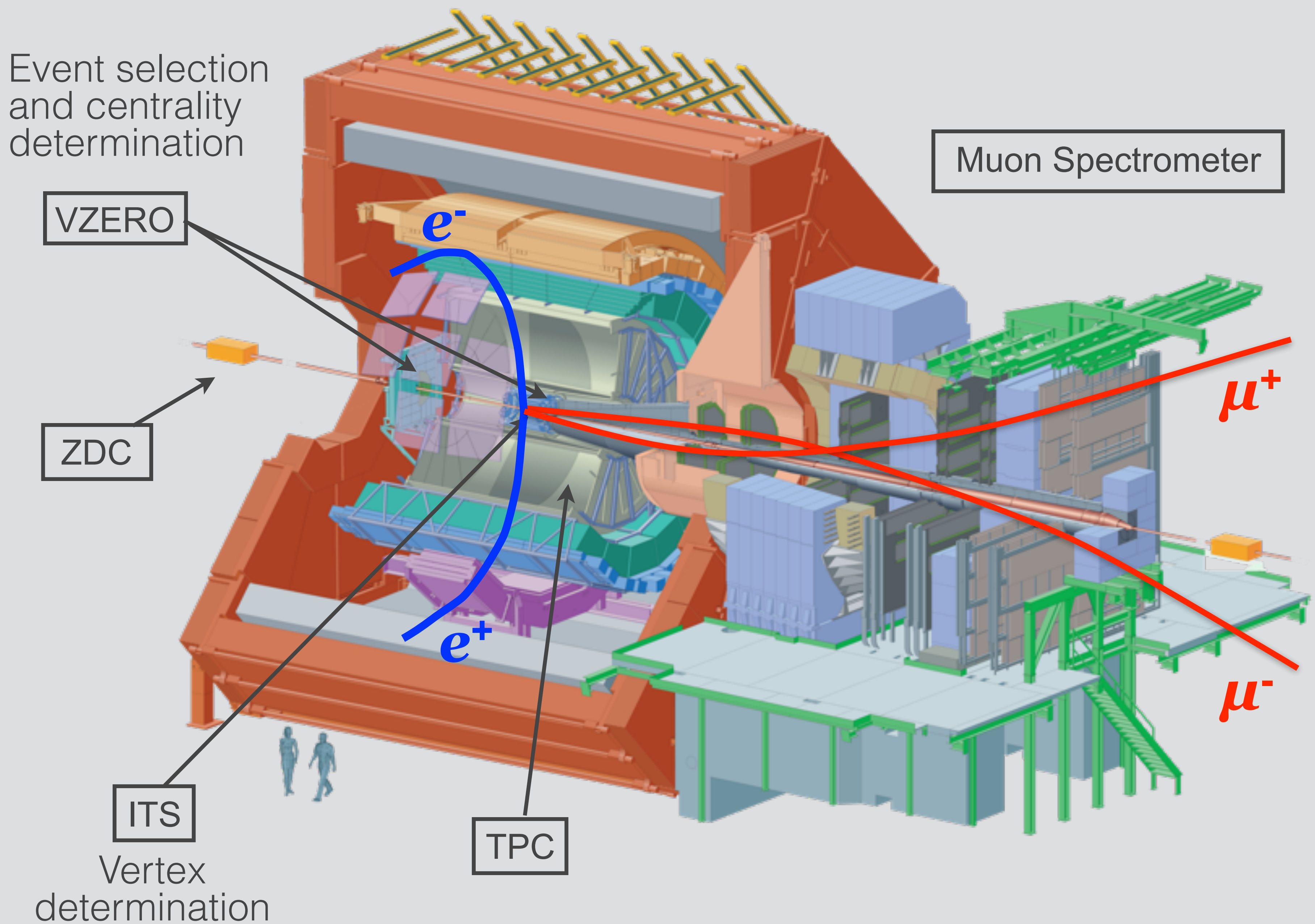
About 200 times more *J/ψ* than *Υ*(1S)

- Regeneration mechanism?

Bottomonia

- Smaller CNM effects than for charmonia (except at very Fwd/Bwd rapidity)
- Regeneration of bottomonia is much smaller than for charmonia
- No feed-down from open flavors

A Large Ion Collider Experiment (ALICE)



Rapidity in p-Pb (5.02 TeV)

$-4.46 < y < -2.96$
($\mu\mu$, Pb-going)
high x-Bjorken

$-1.37 < y < 0.43$
(ee)

$2.03 < y < 3.53$
($\mu\mu$, p-going)
low x-Bjorken

Rapidity in Pb-Pb (2.76 TeV)

$|y| < 0.9$
(ee)

$2.5 < y < 4$
($\mu\mu$)

Quarkonia measurement down to $p_T = 0$

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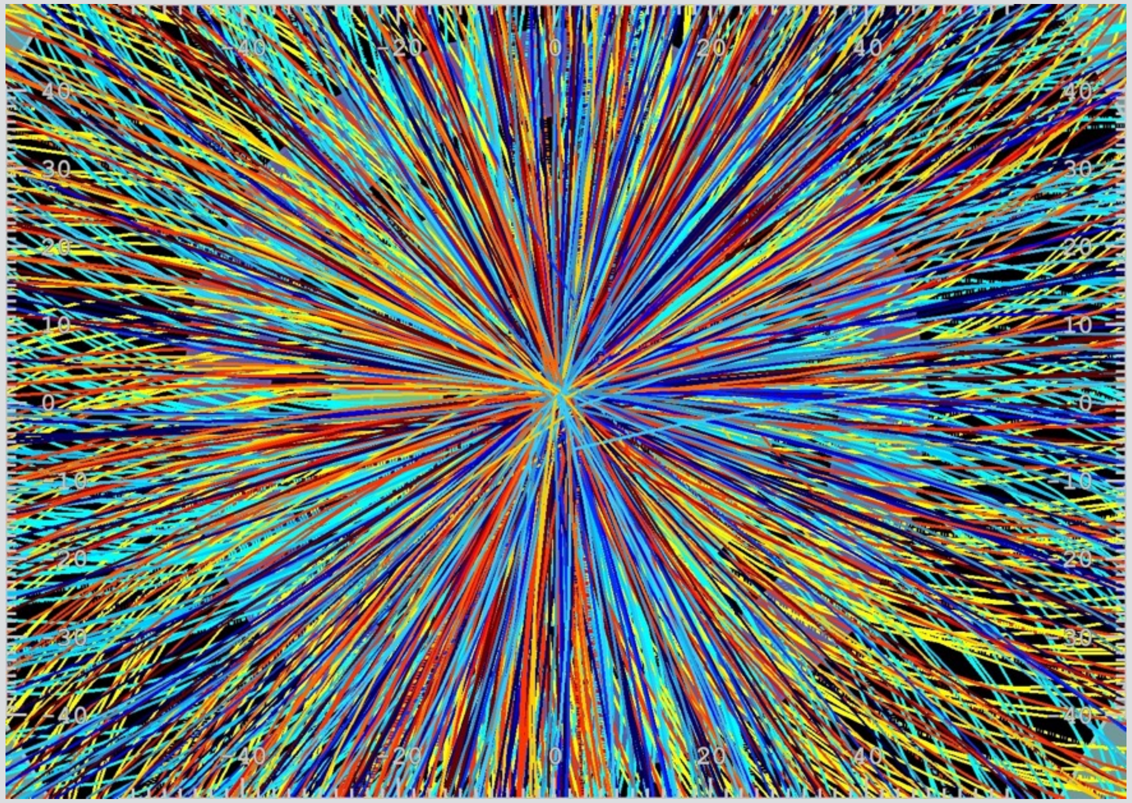
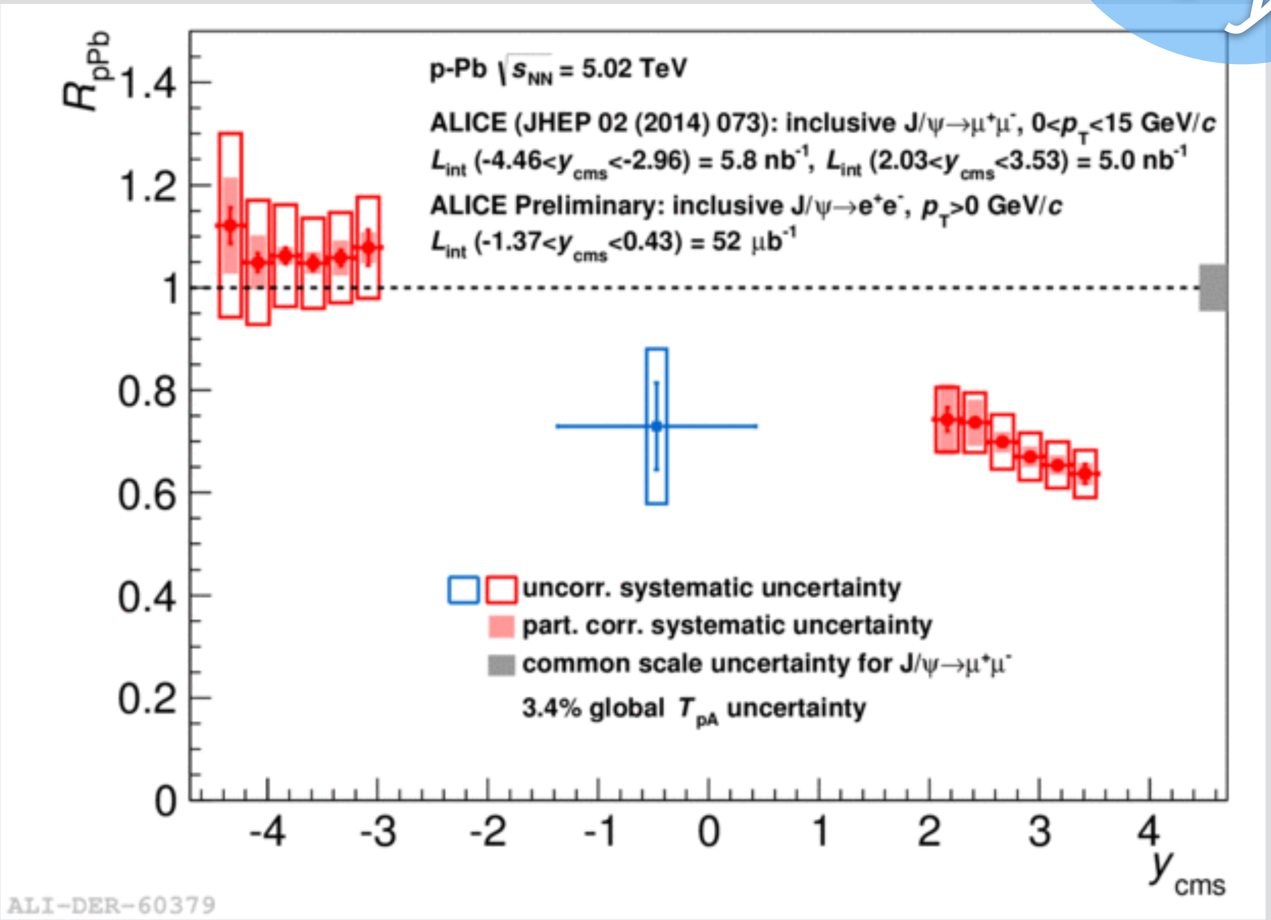


p-Pb: J/ψ

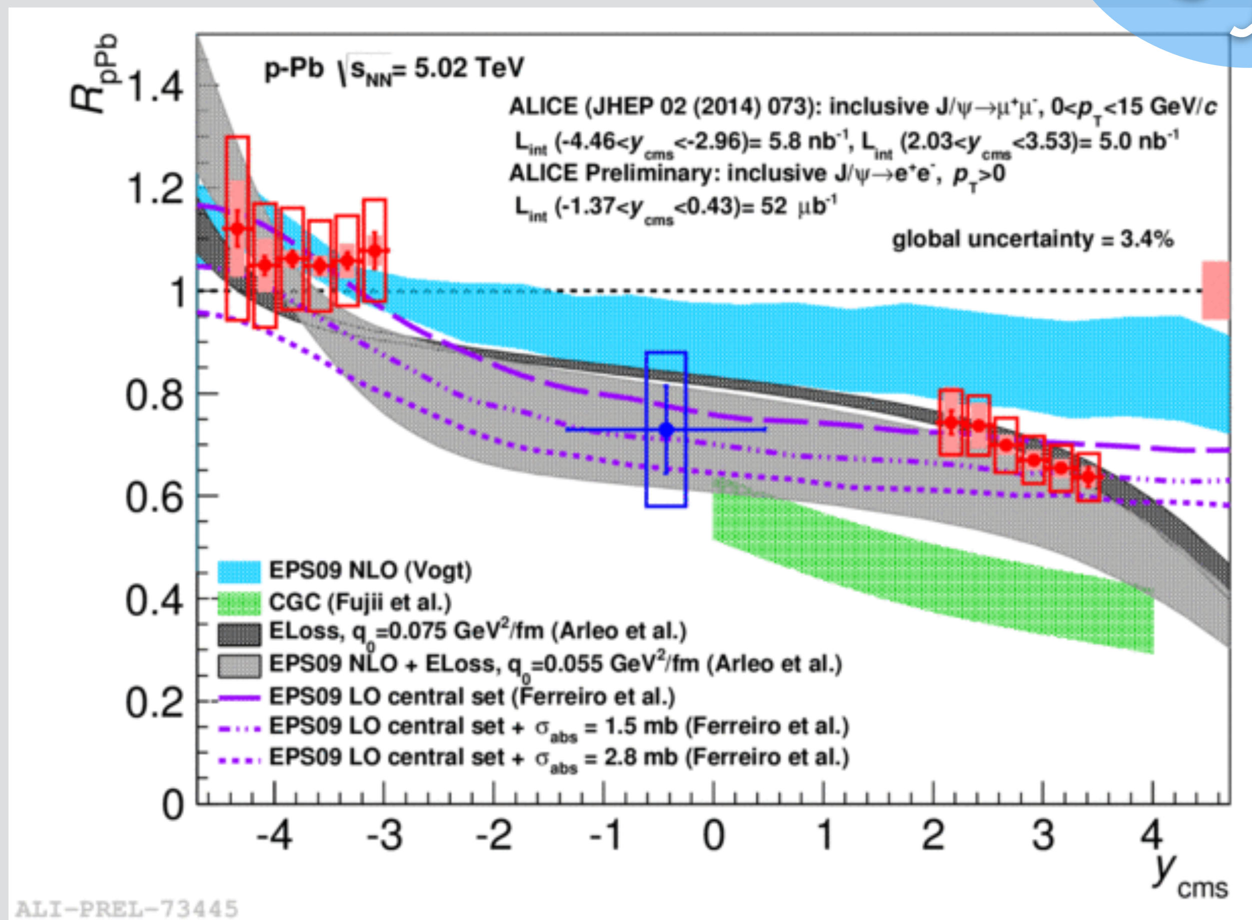
vs y



- Strong suppression at forward rapidity
- Similar suppression a mid- than at forward rapidity
- $R_{p\text{-}Pb}$ is compatible with unity at backward rapidity

p-Pb: J/ψ

vs y



Vogt [arXiv:1301.3395]

CEM production model at NLO,
EPS09 shadowing at NLO

Fair agreement within uncertainties,

Tendency to underestimate suppression at forward rapidity

CGC [NPA 915 (2013) 1]

Disfavored

Arleo et al. [JHEP 1303 (2013) 122]

Contribution from coherent parton energy loss,
With or without shadowing (EPS09)

Fair agreement over the full y- range

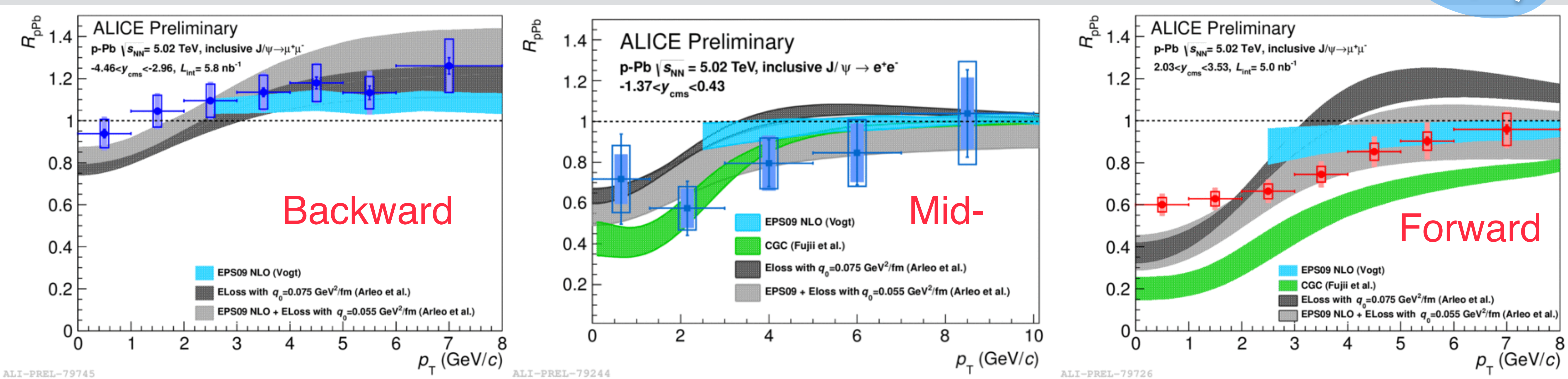
Ferreiro et al. [PRC 88, (2013) 047901]

Generic 2➞2 production model at LO,
EPS09 shadowing at LO

Fair agreement with measured $R_{\text{p-Pb}}$,
Large nuclear absorption disfavored

p-Pb: J/ψ

vs p_T



Strong suppression at mid- and forward rapidity at the low p_T region

$R_{p\text{-}Pb}$ increases with p_T, $\equiv 1$ for $p_T \gtrsim 5$ GeV/c

No suppression at backward rapidity: Small p_T dependence, compatible with unity

Shadowing only model describes trend of data but underestimates suppression at forward rapidity and $2.5 < p_T < 3$ GeV/c

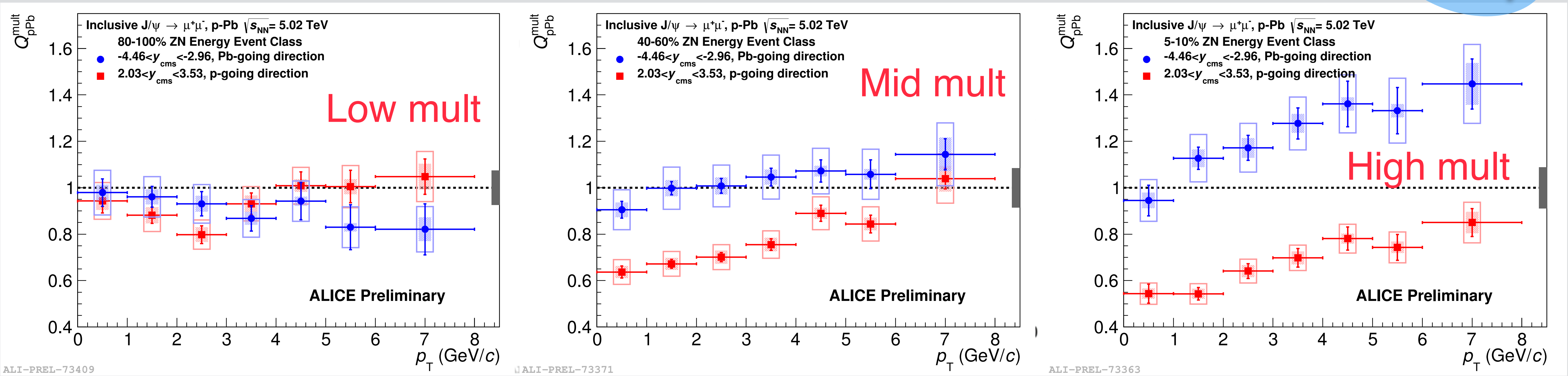
Coherent energy loss only does not describe the observed trends

Coherent energy loss w/ shadowing describes data at high p_T but overestimates suppression at forward rapidity and low p_T

CGC overestimates suppression at forward rapidity

p-Pb: J/ψ

vs p_T



Caveat:

$Q_{\text{p-Pb}}$ stands for $R_{\text{p-Pb}}$ but it is called $Q_{\text{p-Pb}}$ to alert of possible biases in the determination of $<N_{coll}>$:

- multiplicity bias (depends on the estimator used)
- geometrical bias
- jet veto bias

Forward rapidity:

- Decrease of $Q_{\text{p-Pb}}$ for increased event activity
- Clear trend vs p_T: stronger suppression at low-p_T

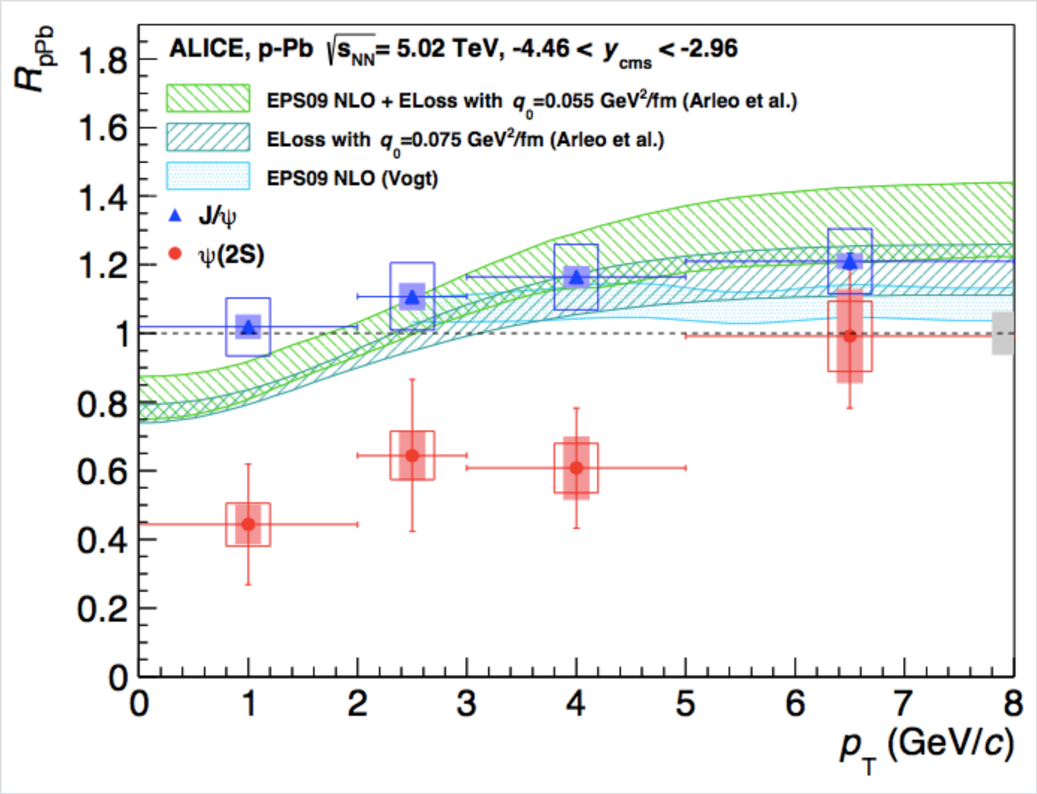
Backward rapidity:

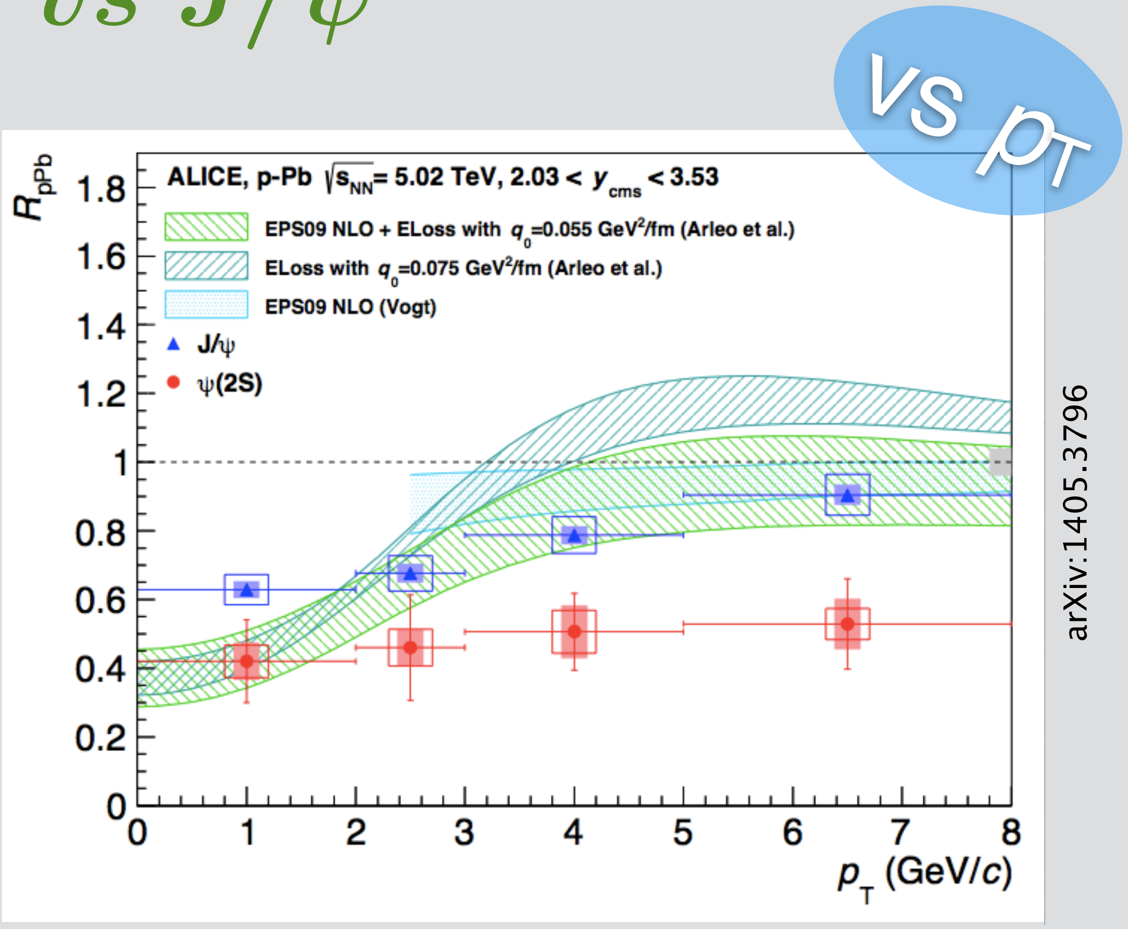
- Increase of $Q_{\text{p-Pb}}$ for increased event activity
- Clear trend vs p_T: stronger enhancement at high-p_T

Impact parameter dependent gluon shadowing effect?

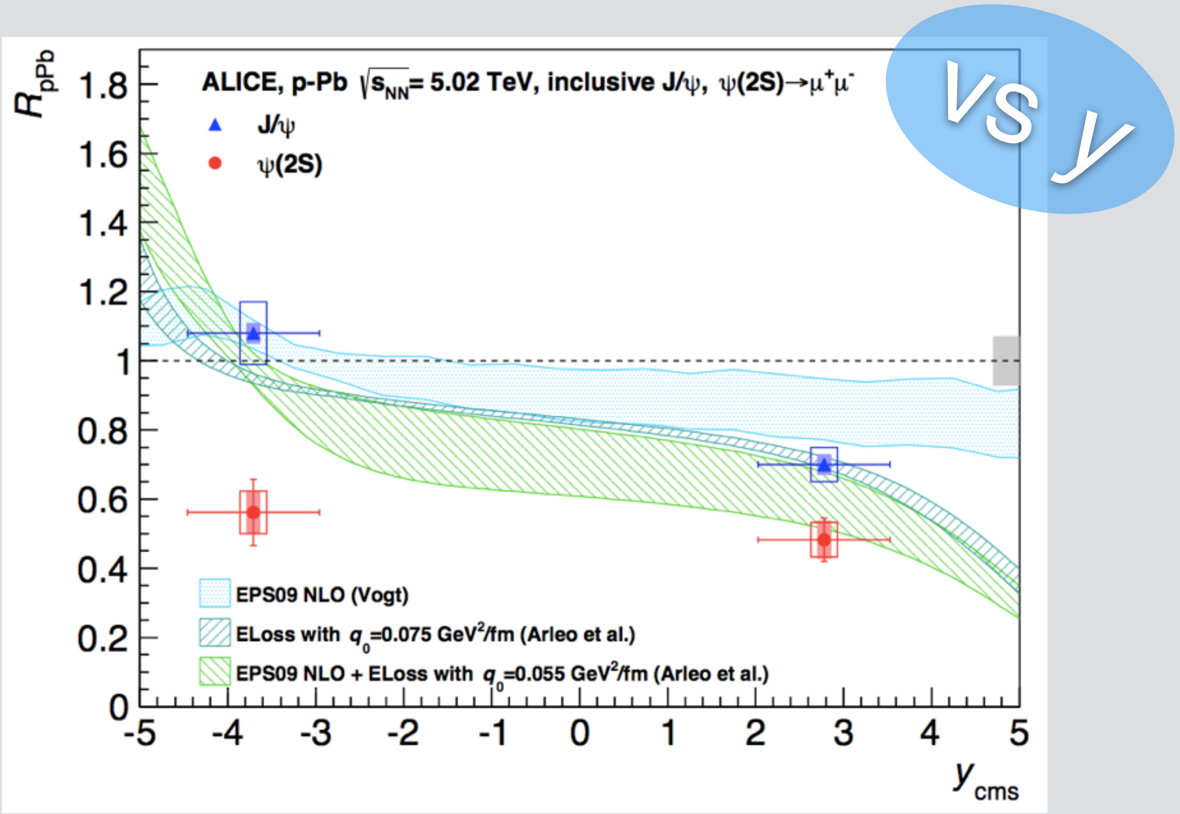
Need to understand the p_T and event-activity dependences in p-Pb

p-Pb: $\psi(2S)$ *vs* J/ψ





arXiv:1405.3796



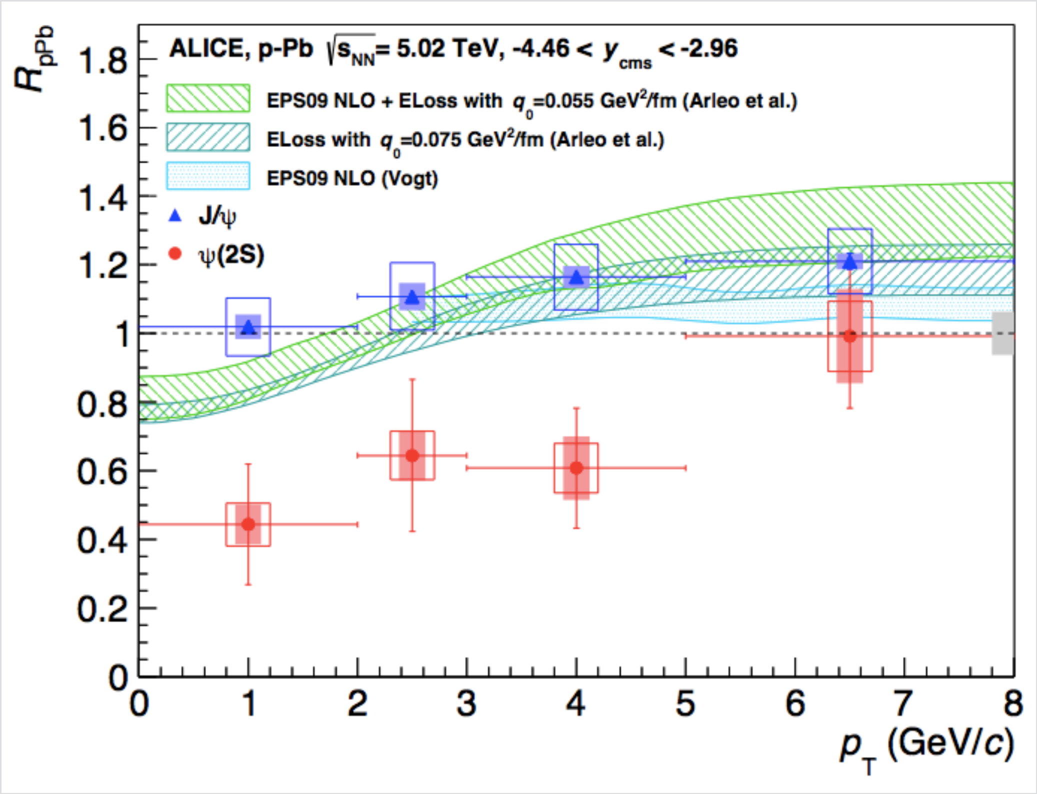
Stronger ψ(2S) suppression than J/ψ!

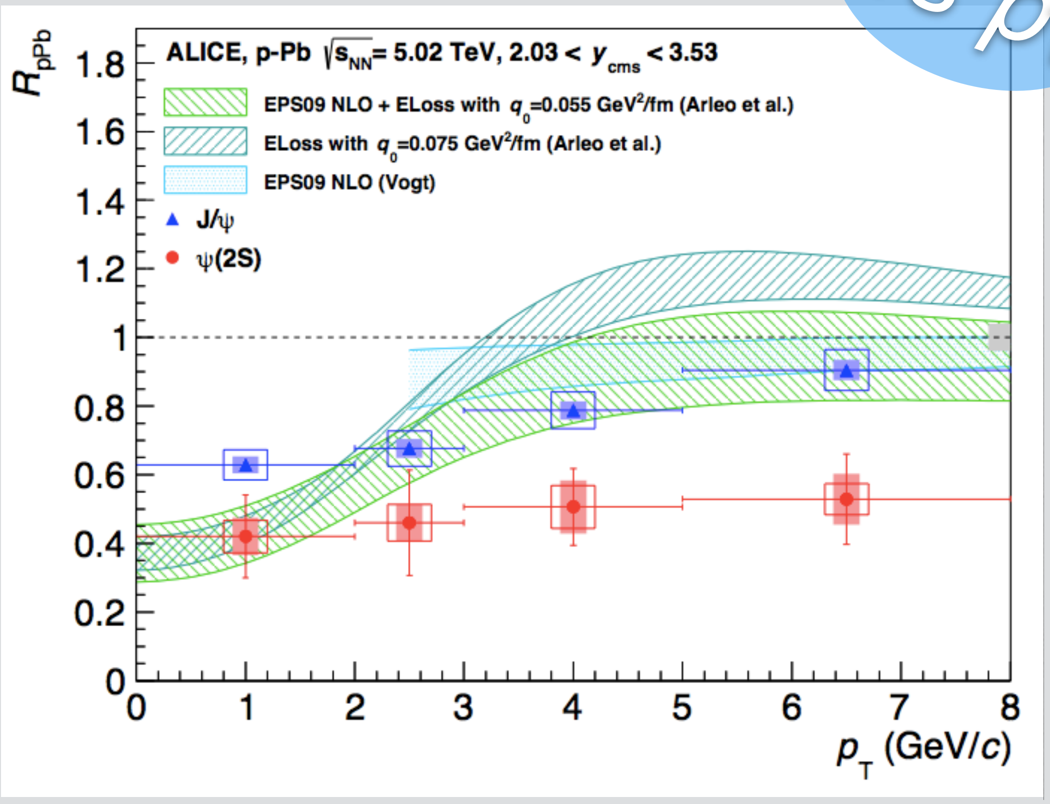
(Already observed at RHIC)

Models including shadowing or/and energy loss underestimate the ψ(2S) suppression
- Similar prediction for both states

p-Pb: $\psi(2S)$ vs J/ψ

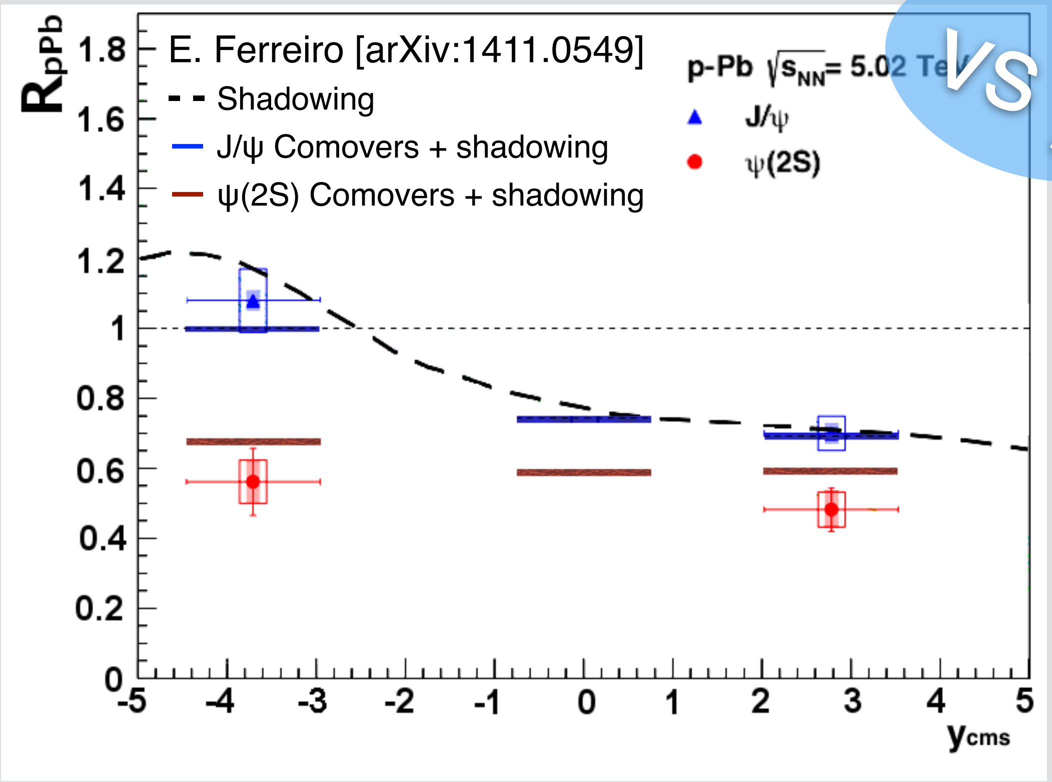
vs p_T





arXiv:1405.3796

vs y



Stronger ψ(2S) suppression than J/ψ!

(Already observed at RHIC)

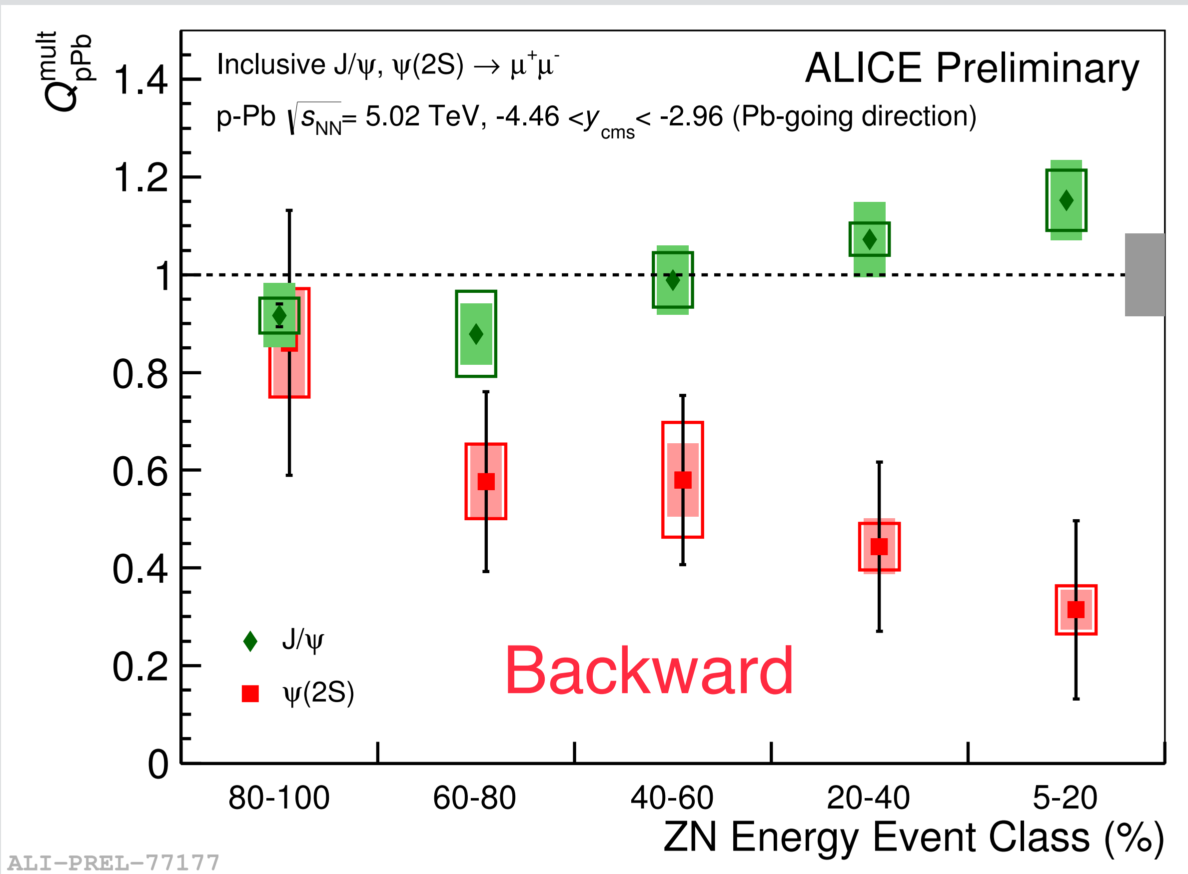
Models including shadowing or/and energy loss underestimate the ψ(2S) suppression

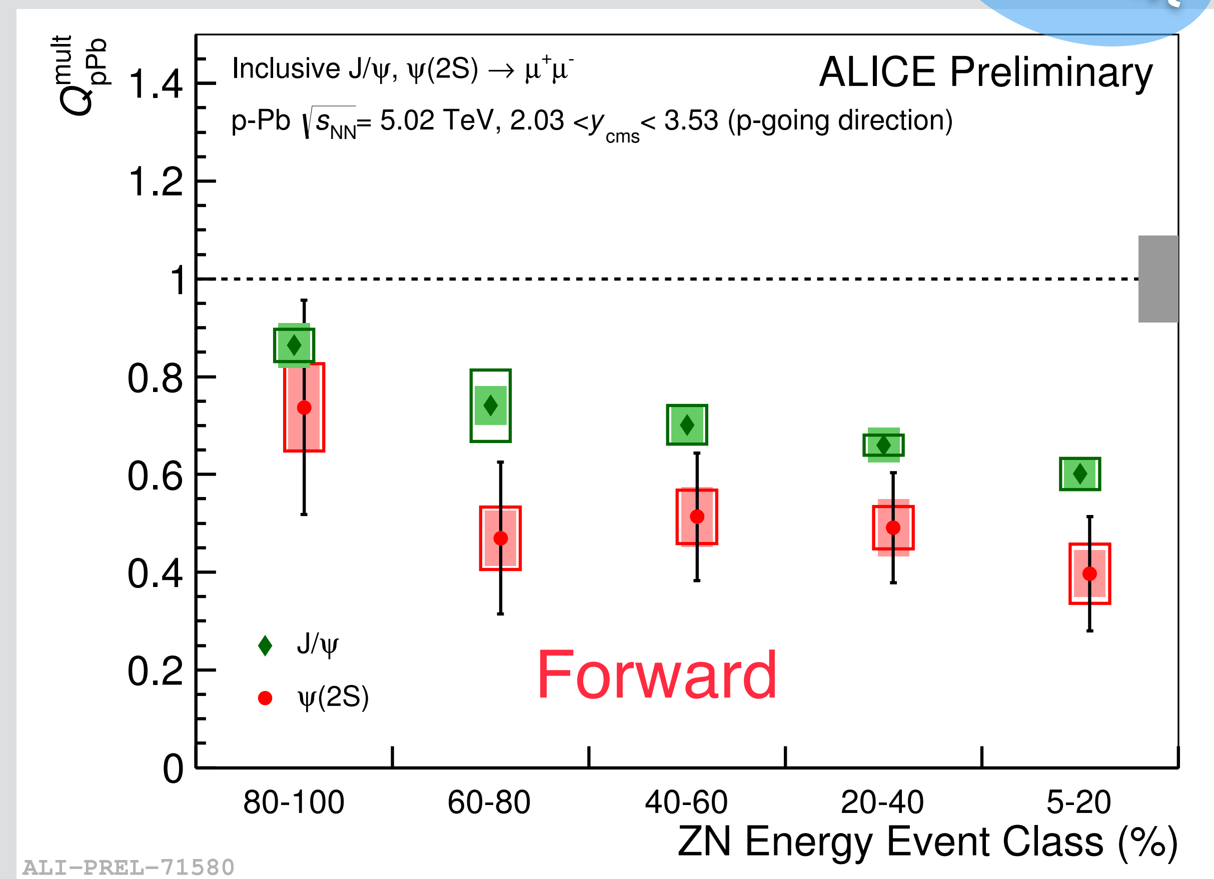
- Similar prediction for both states

Good description by comover model with shadowing at both backward and forward rapidity

p-Pb: $\psi(2S)$ vs J/ψ

vs Mult





Caveat:

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- multiplicity bias (depends on the estimator used)
- geometrical bias
- jet veto bias

Backward rapidity:

- *J/ψ* and *ψ*(2S) clear different behavior,
- *ψ*(2S) is more suppressed in high multiplicity events

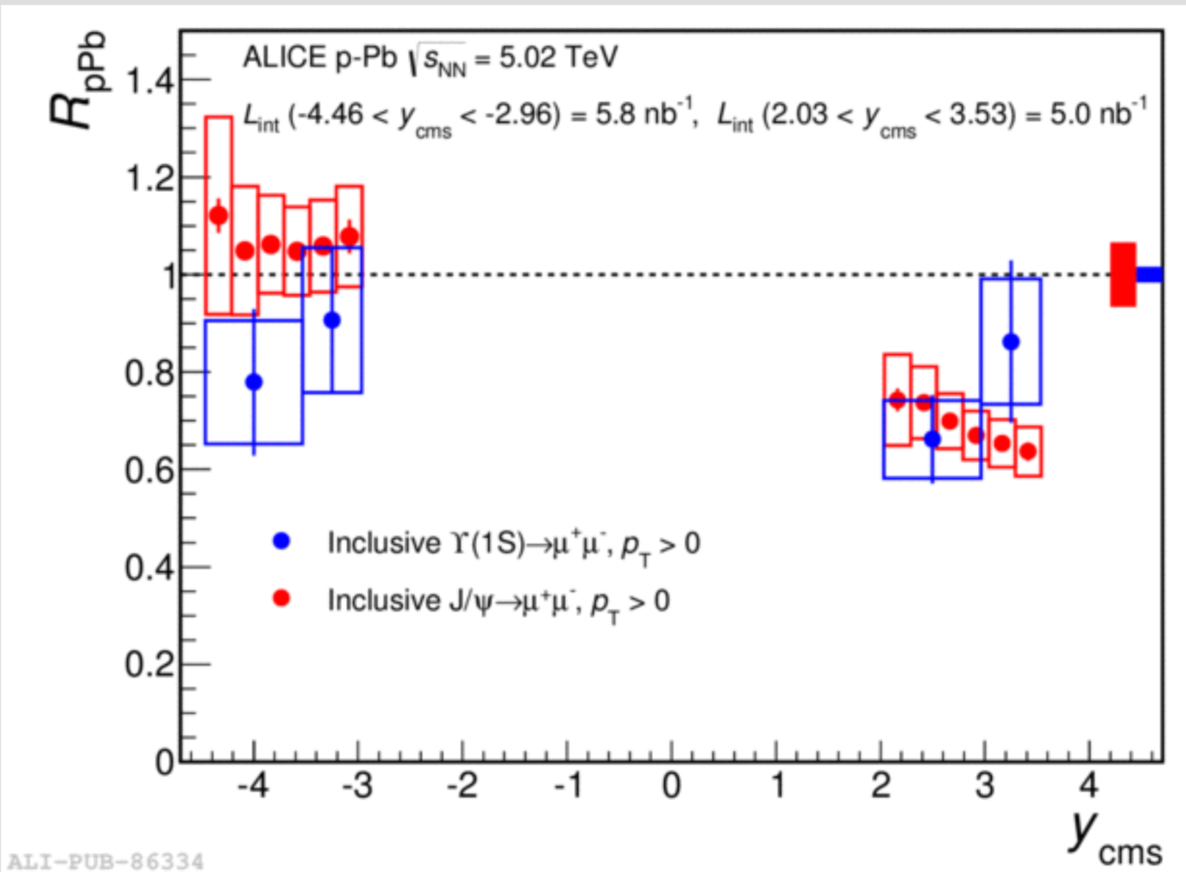
Forward rapidity:

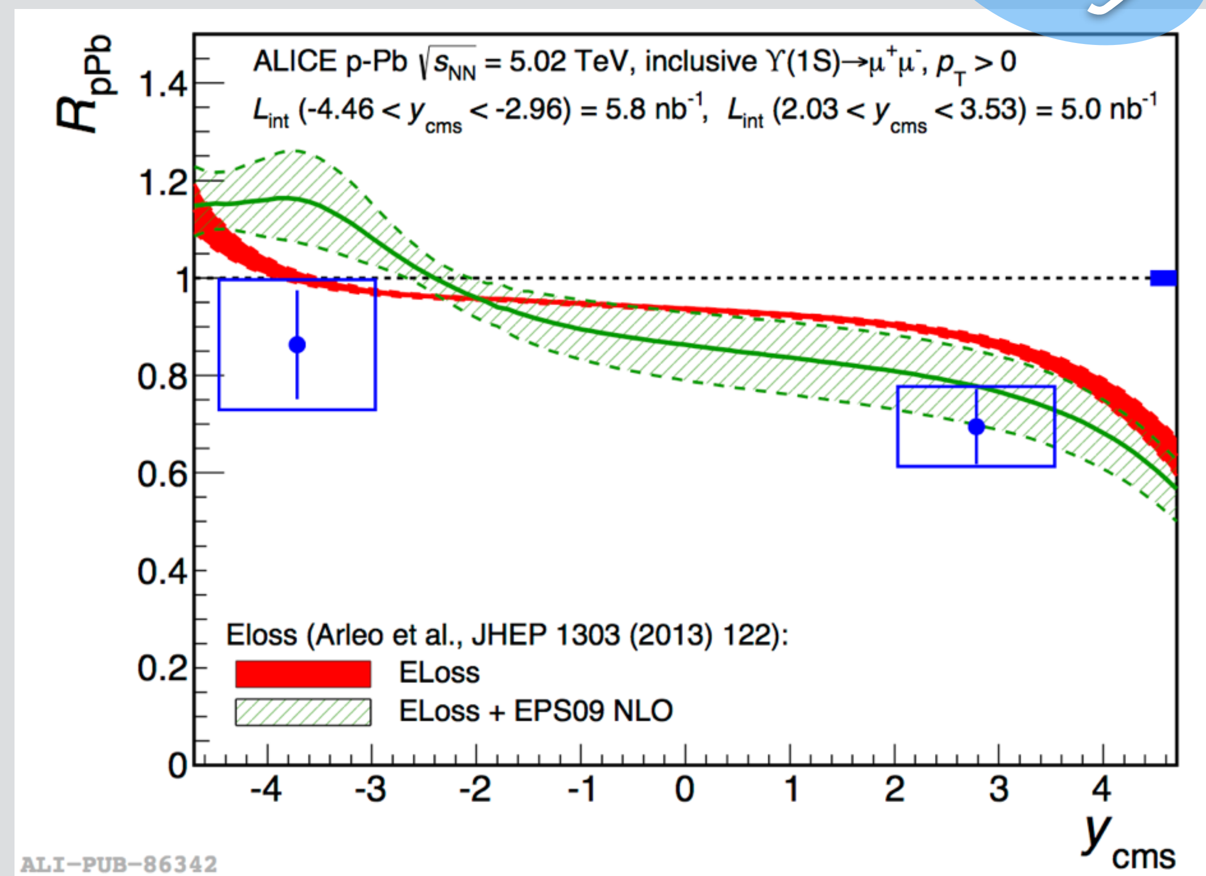
- *J/ψ* and *ψ*(2S) show a similar decreasing trend vs event activity

Need to understand the event-activity dependences in p-Pb

p-Pb : $\Upsilon(1S)$

vs y





PLB 740 (2015) 105

- Consistent with no suppression at backward rapidity
- Indication of similar suppression than *J/ψ* at forward rapidity

Still missing measurement of the *Υ*(2S) and *Υ*(3S) with ALICE

Forward: Better agreement with E_{loss} and shadowing

Backward: Better agreement with E_{loss} only

Model comparisons suggest smaller anti-shadowing than assumed

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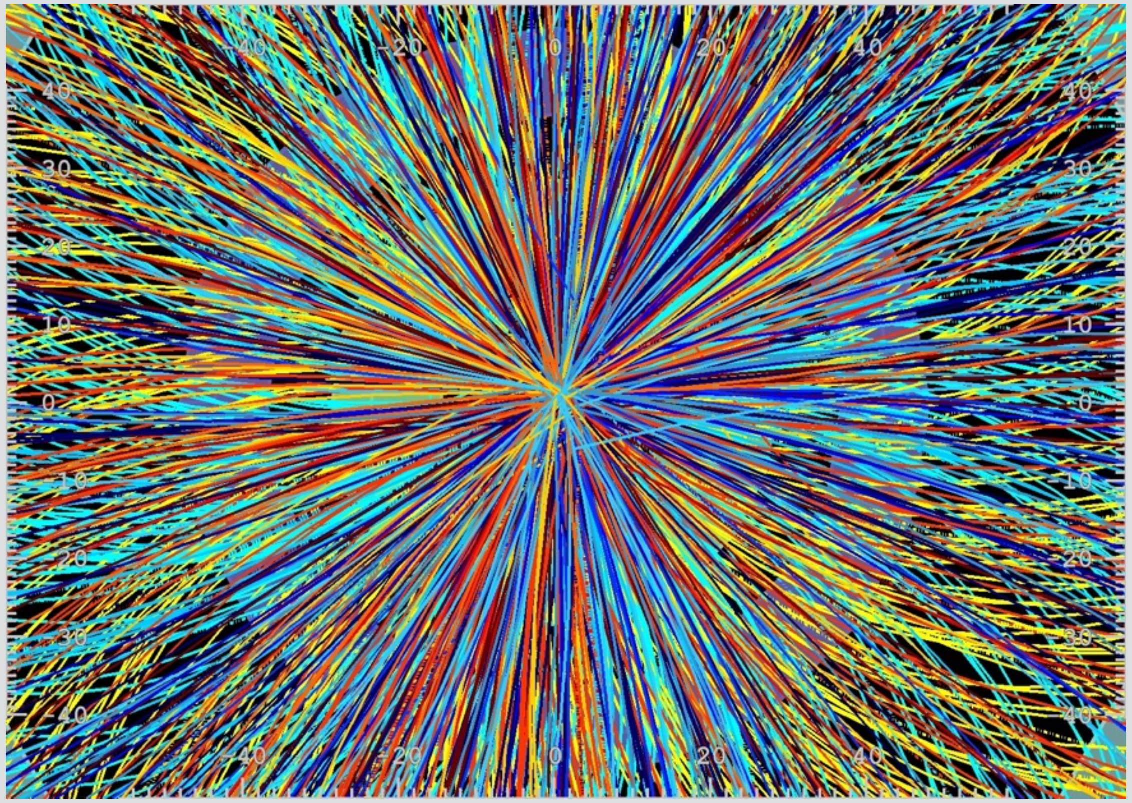
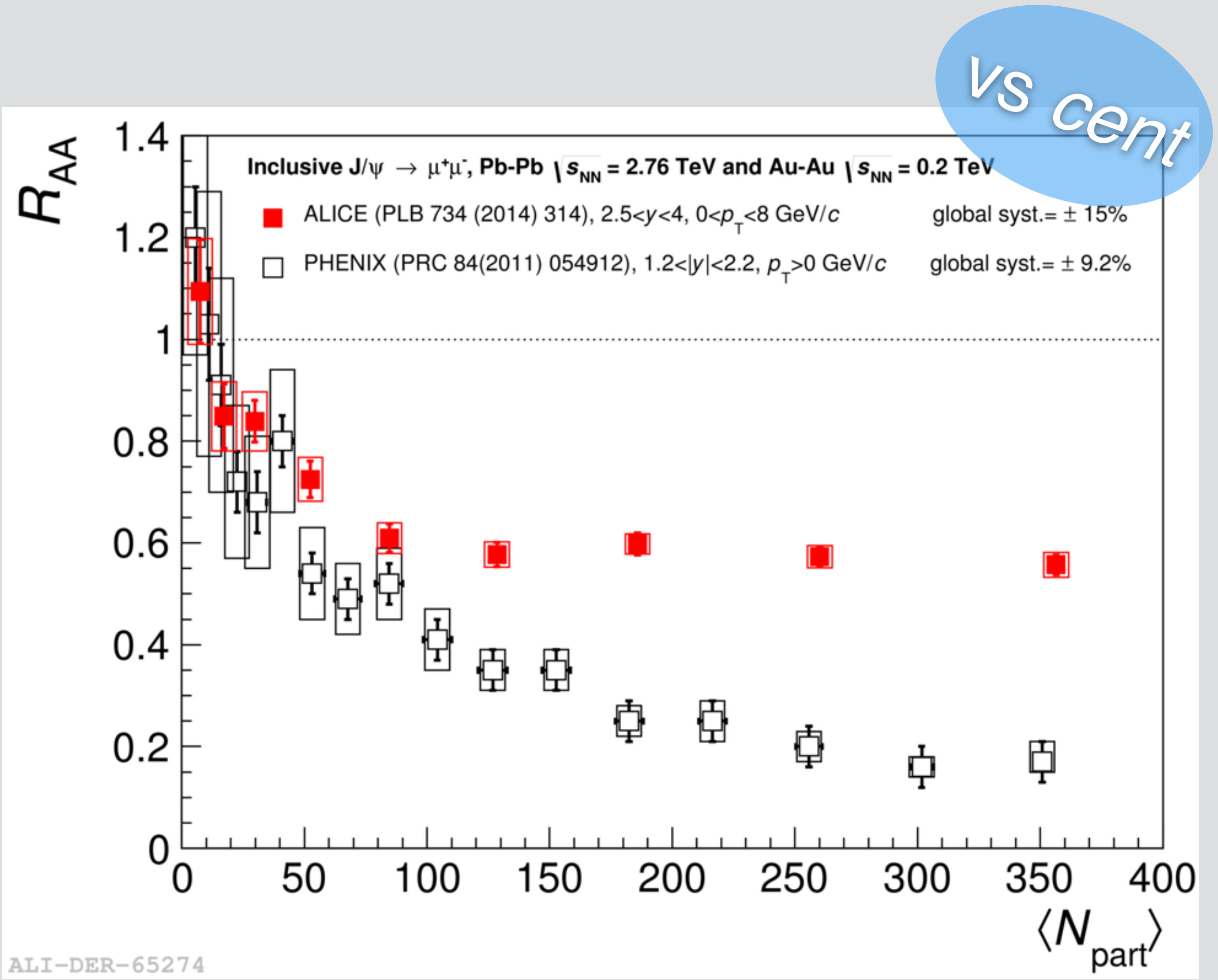
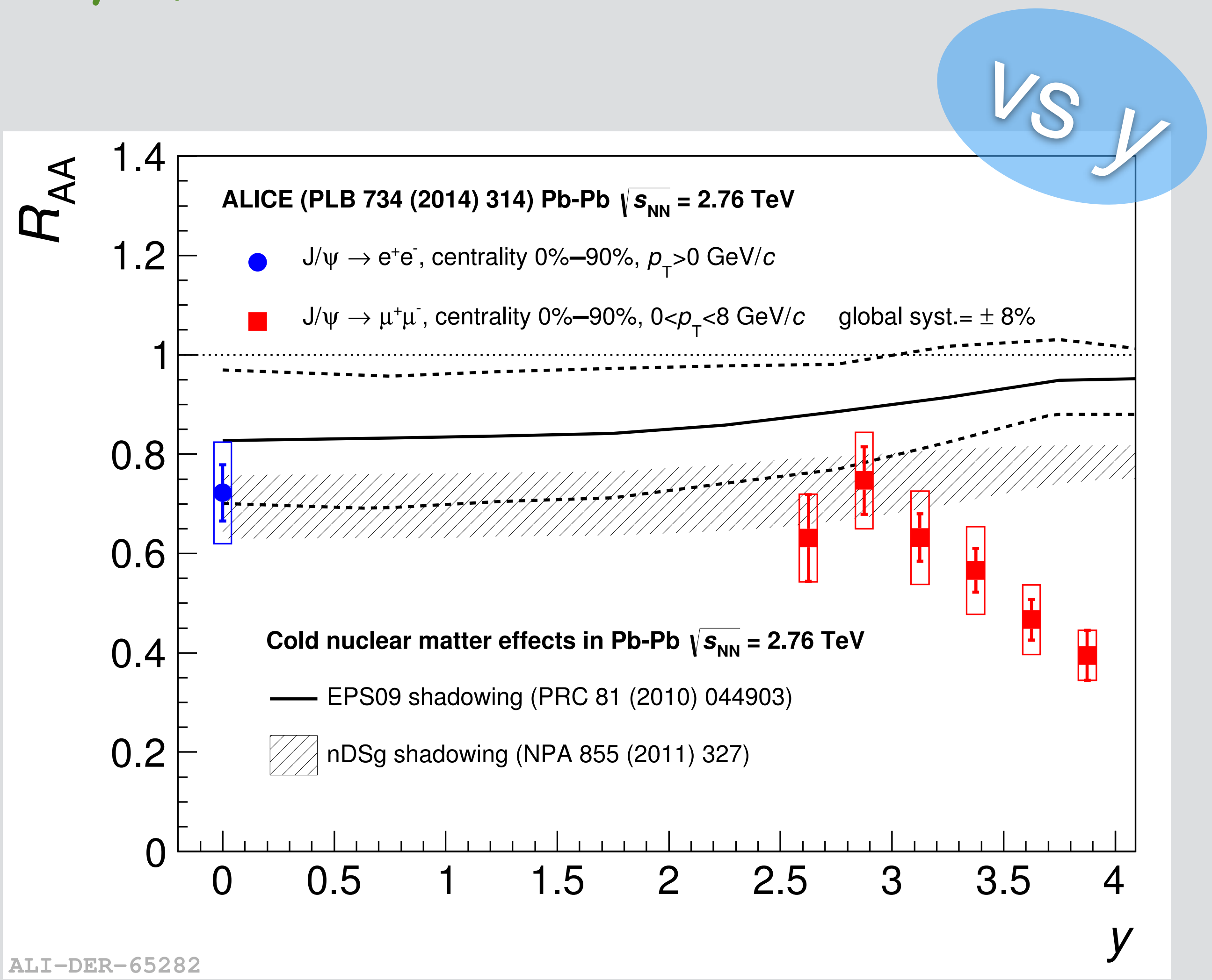


Pb-Pb: J/ψ





J/ψ (inclusive) suppression with almost no centrality dependence for N_{part} >100 for 2.5<*y*<4

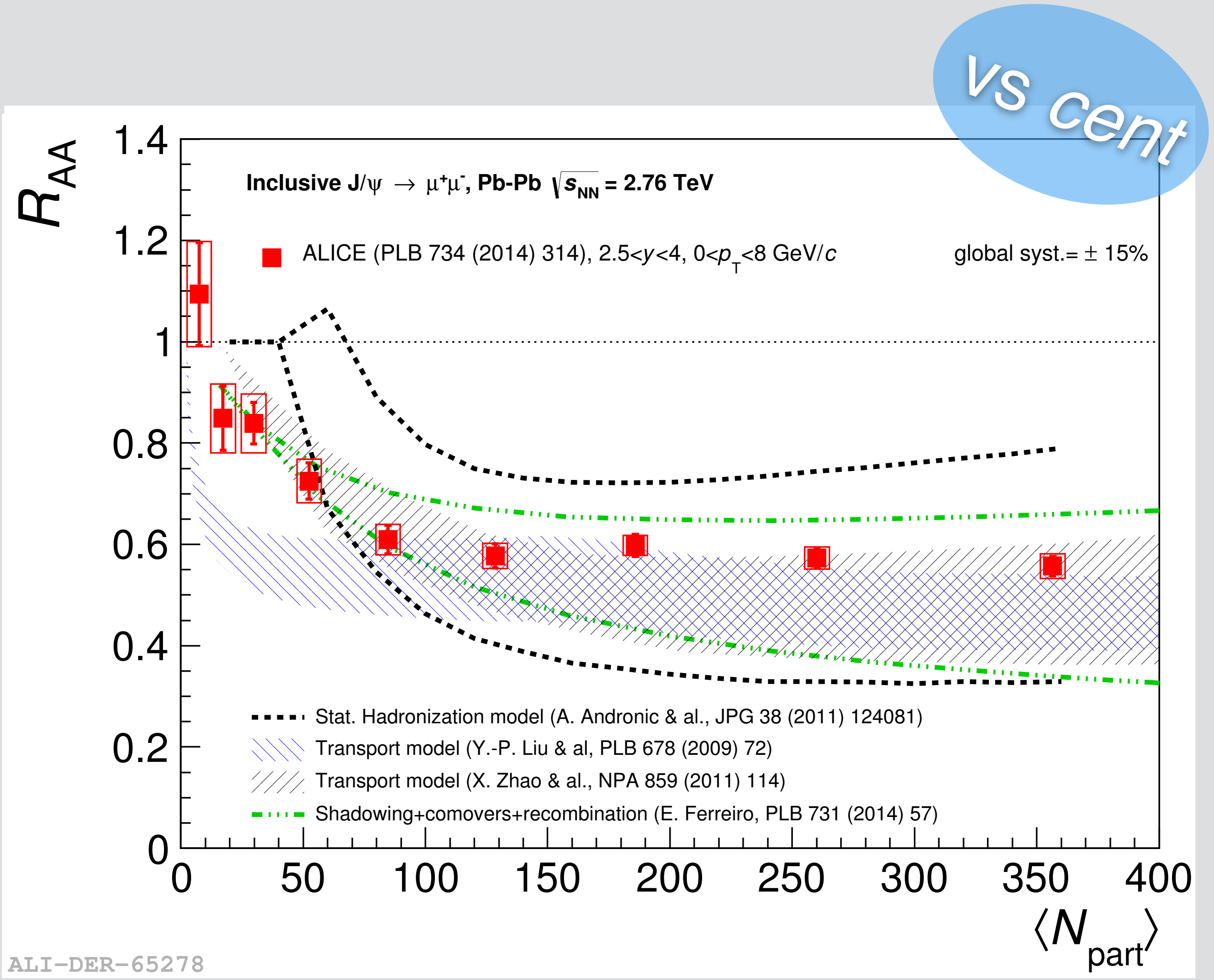
Higher suppression at RHIC energy (200 GeV)

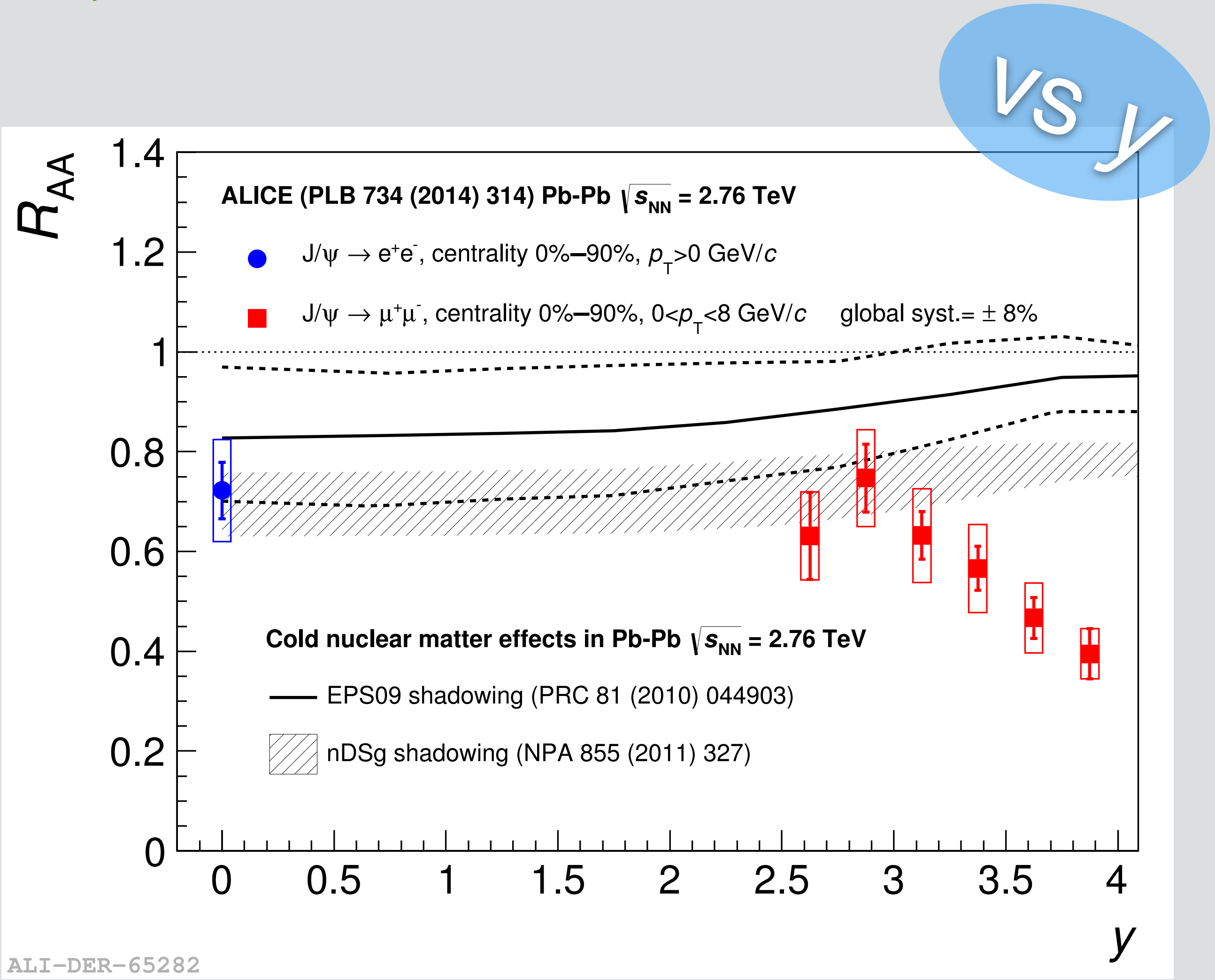
Similar *J/ψ* suppression at y~0 and y~3. Then a decreasing trend appears

Shadowing effects are of the same order of magnitude as the measured *J/Ψ* suppression except at very forward rapidity

The *J/ψ* suppression could be compensated by regeneration mechanisms?

Pb-Pb: J/ψ





J/ψ (inclusive) suppression with almost no centrality dependence for N_{part} >100 for 2.5<*y*<4

Higher suppression at RHIC energy (200 GeV)

All models including *J/ψ* recombination fairly reproduce the ALICE results. Large uncertainties in the calculations (shadowing, $d\sigma_{cc}/dy$)

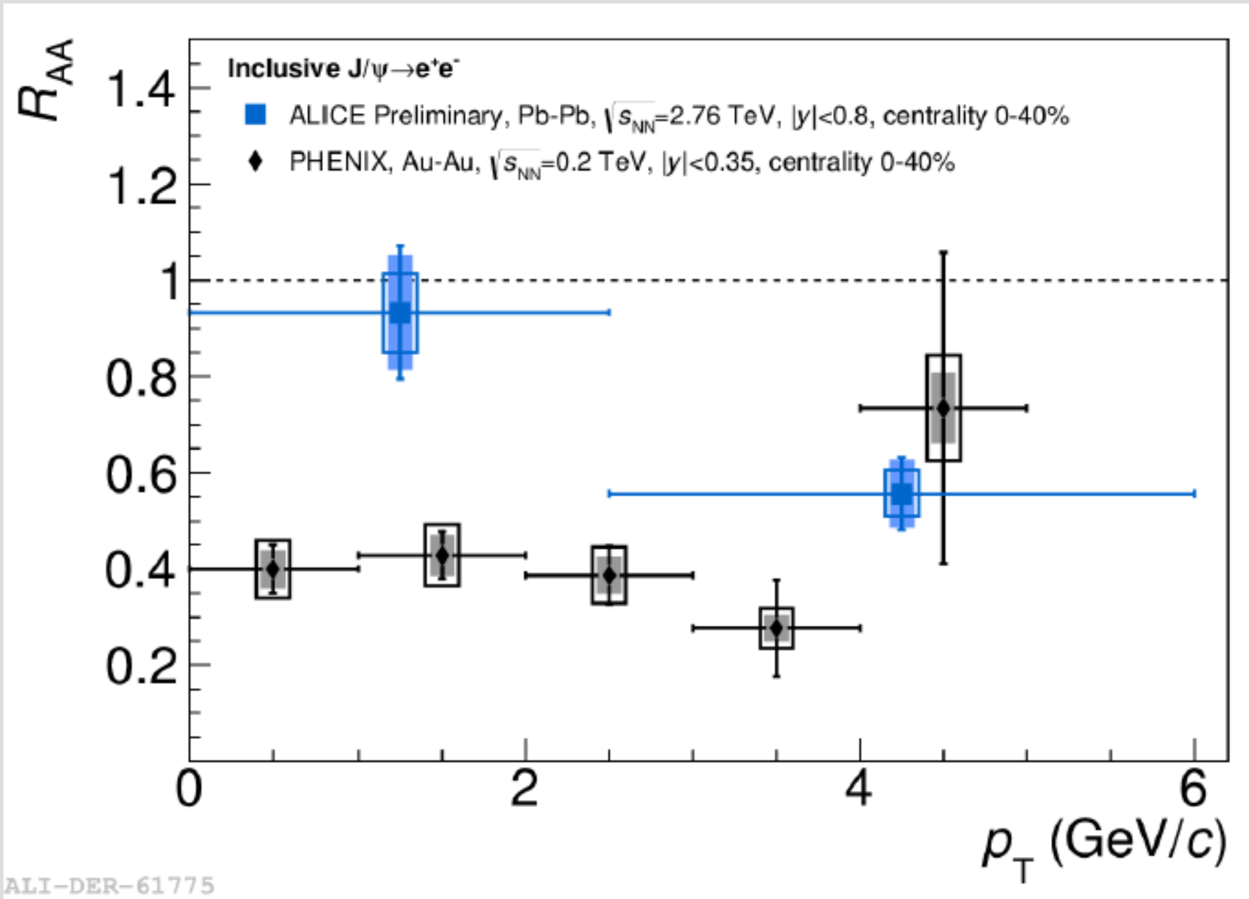
Similar *J/ψ* suppression at y~0 and y~3. Then a decreasing trend appears

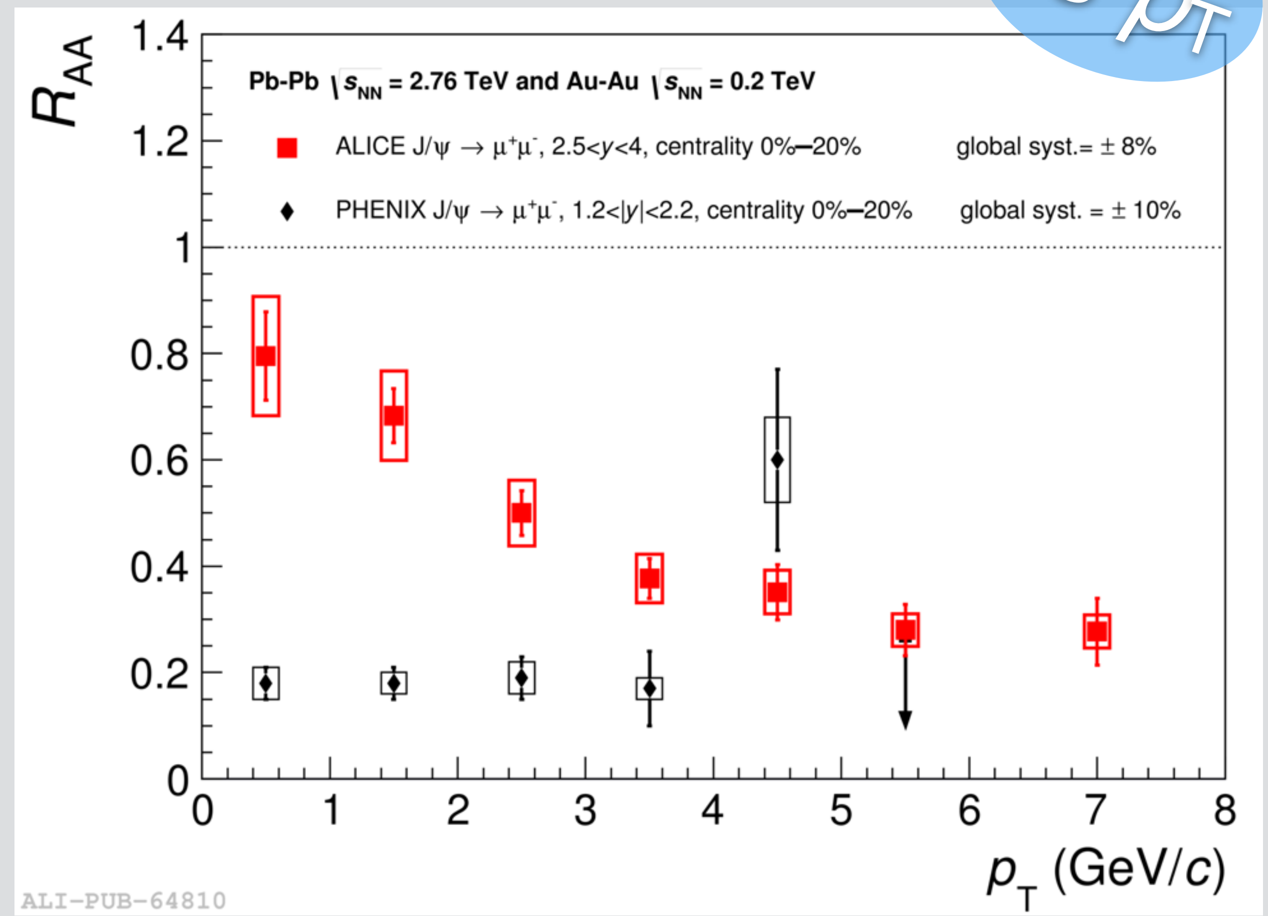
Shadowing effects are of the same order of magnitude as the measured *J/Ψ* suppression except at very forward rapidity

The *J/ψ* suppression could be compensated by regeneration mechanisms?

Pb-Pb: J/ψ

vs p_T

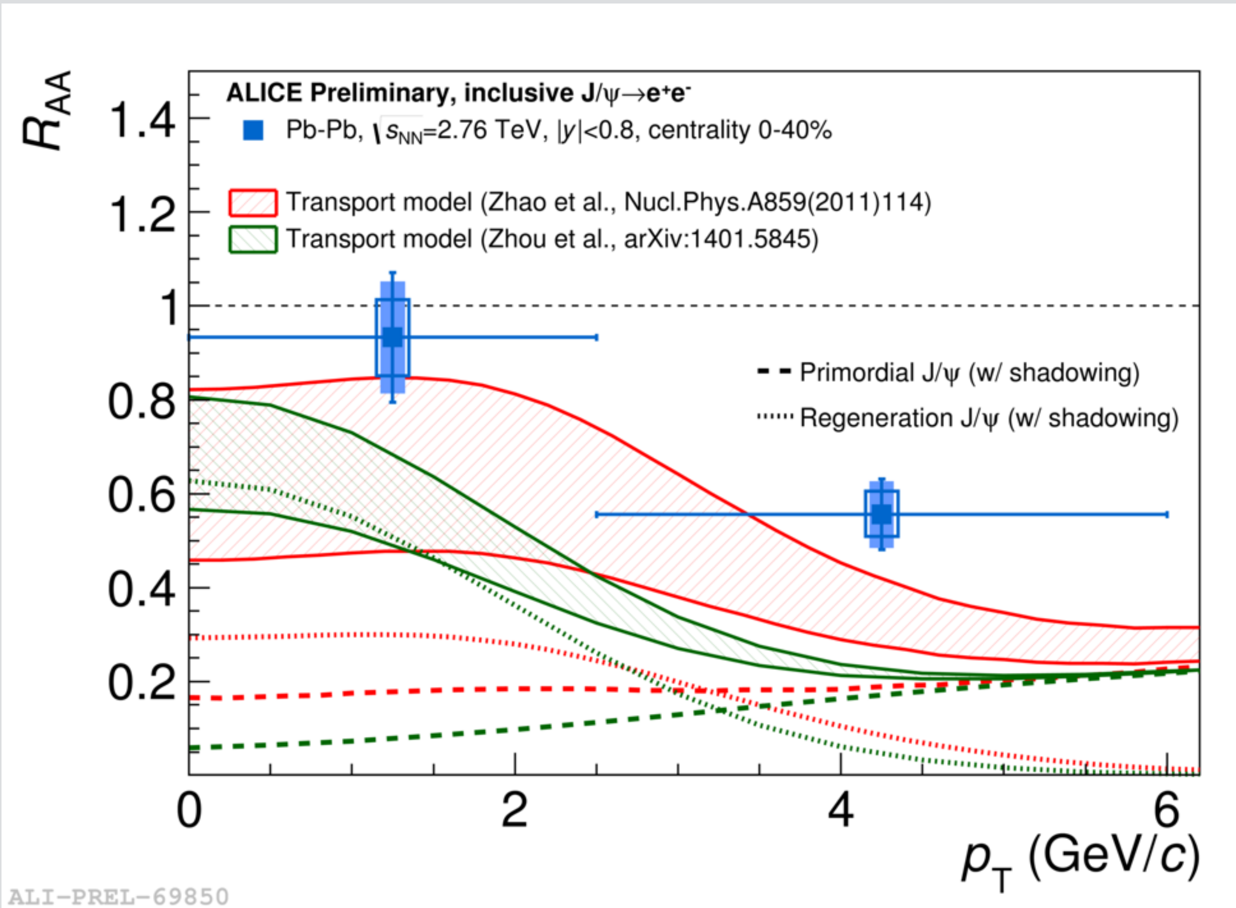


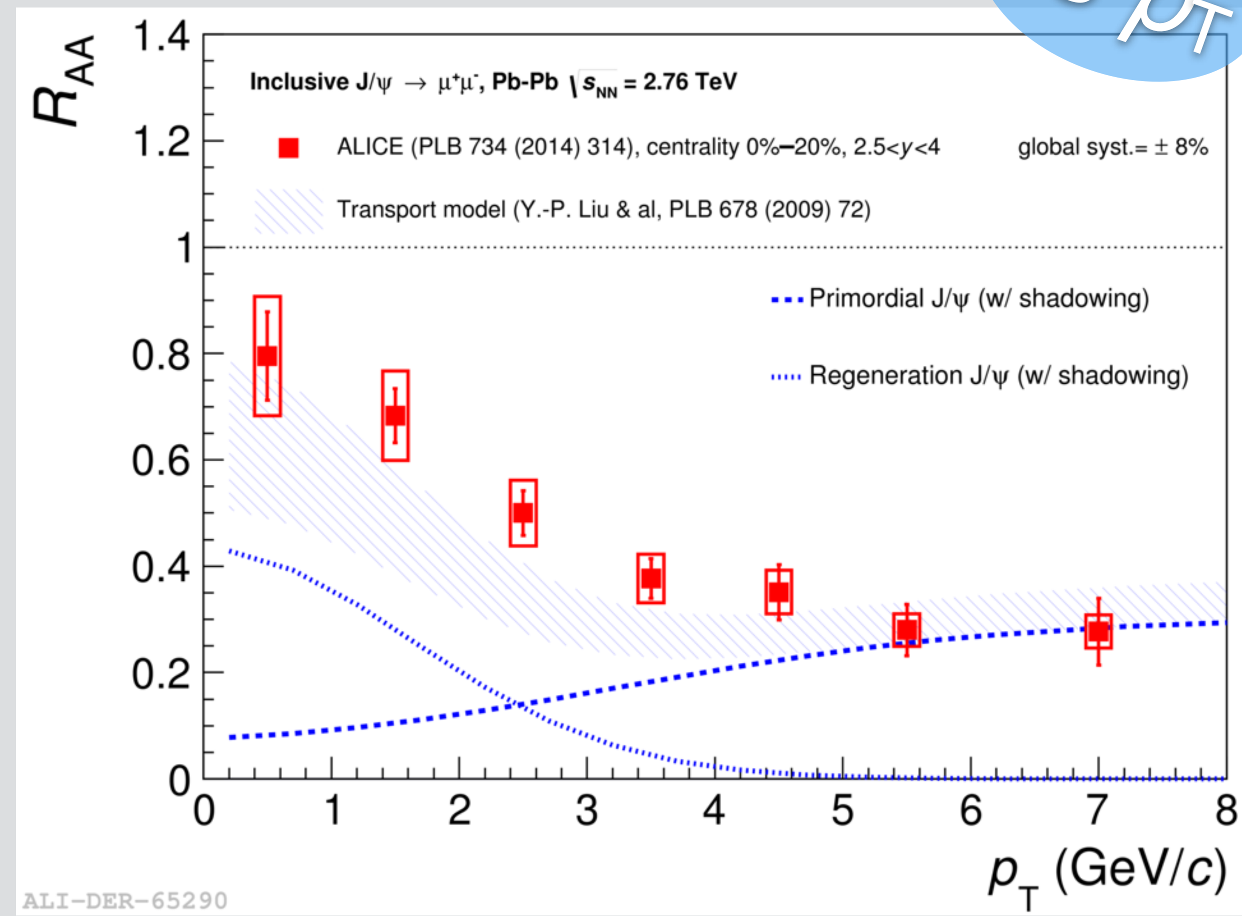


Very large difference in the J/ψ R_{AA} p_T dependence between RHIC and LHC both for central and forward results.

Pb-Pb: J/ψ

vs p_T





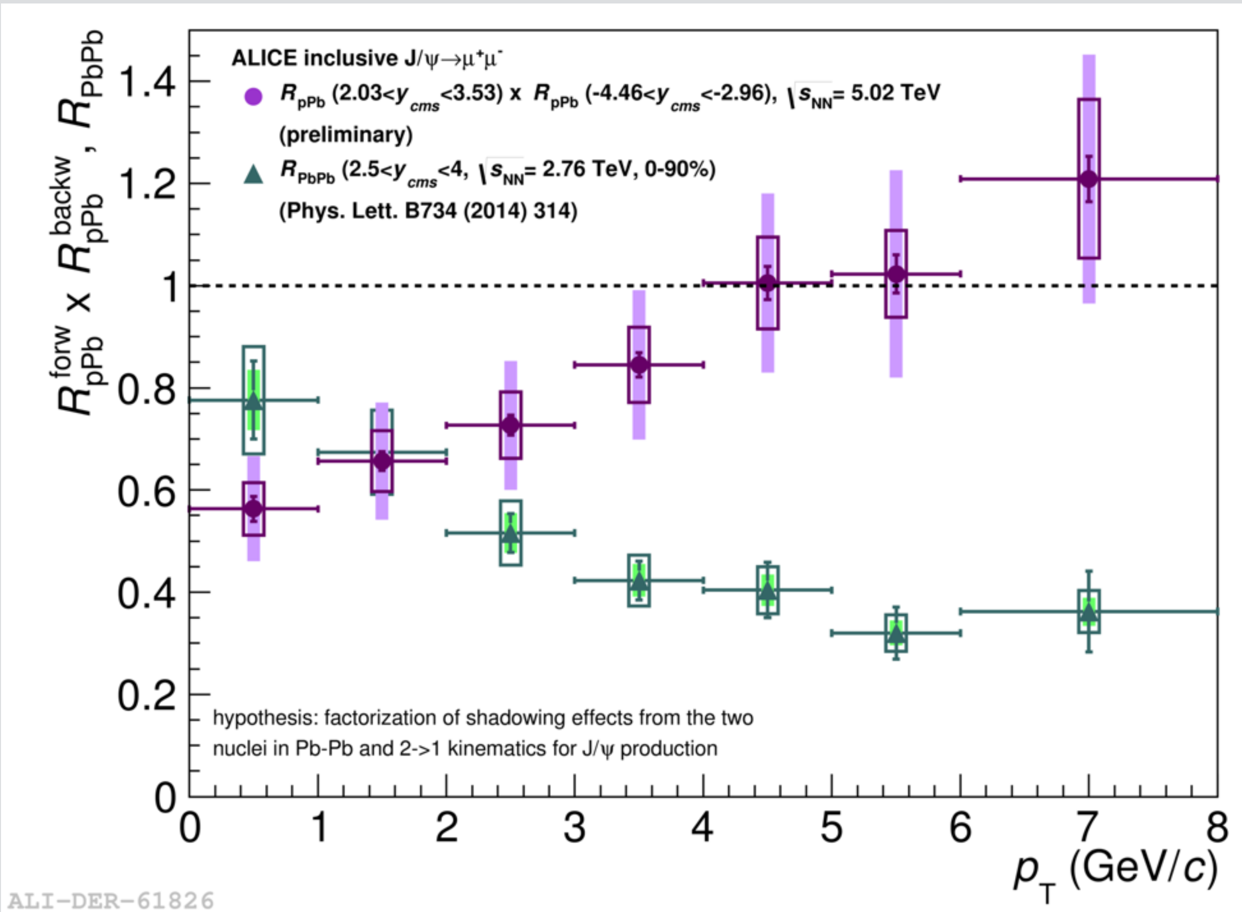
Very large difference in the J/ψ R_{AA} p_T dependence between RHIC and LHC both for central and forward results.

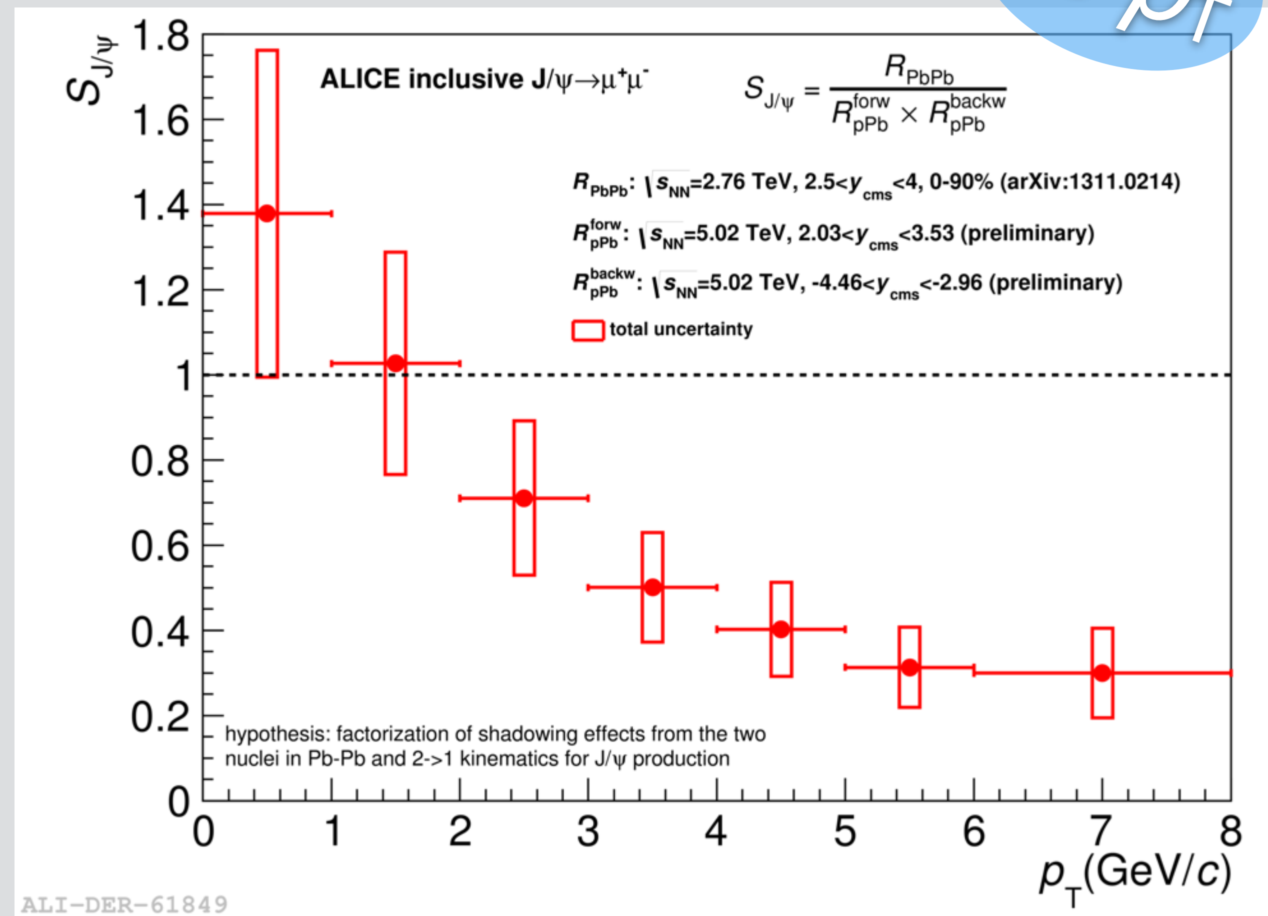
Models with large J/ψ regeneration (important at low-p_T) reproduce fairly well the results
➙ models slightly underestimate the measurements at low-p_T

Large J/ψ R_{AA} at low-p_T fits well with a regeneration scenario

p-Pb & Pb-Pb: J/ψ

vs p_T





Factorize out CNM effects in the J/ψ R_{AA}

CNM evaluated as $R_{p\text{-}Pb}$ x $R_{Pb\text{-}p}$ (similar x-Bjorken coverage as Pb-Pb)

Assumptions:
- 2 → 1 kinematics for J/ψ production ($g+g \rightarrow J/\psi$)
- CNM effects factorize in p-A and are dominated by shadowing

Strong suppression at high p_T due to the hot medium and increase of $S_{J/\psi}$ at low p_T

➙ **Observation that favors regeneration scenario in Pb-Pb**

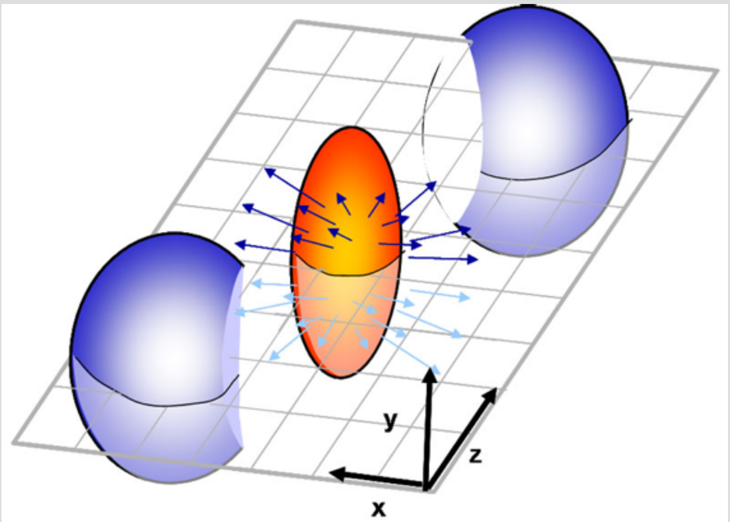
Pb-Pb: J/ψ

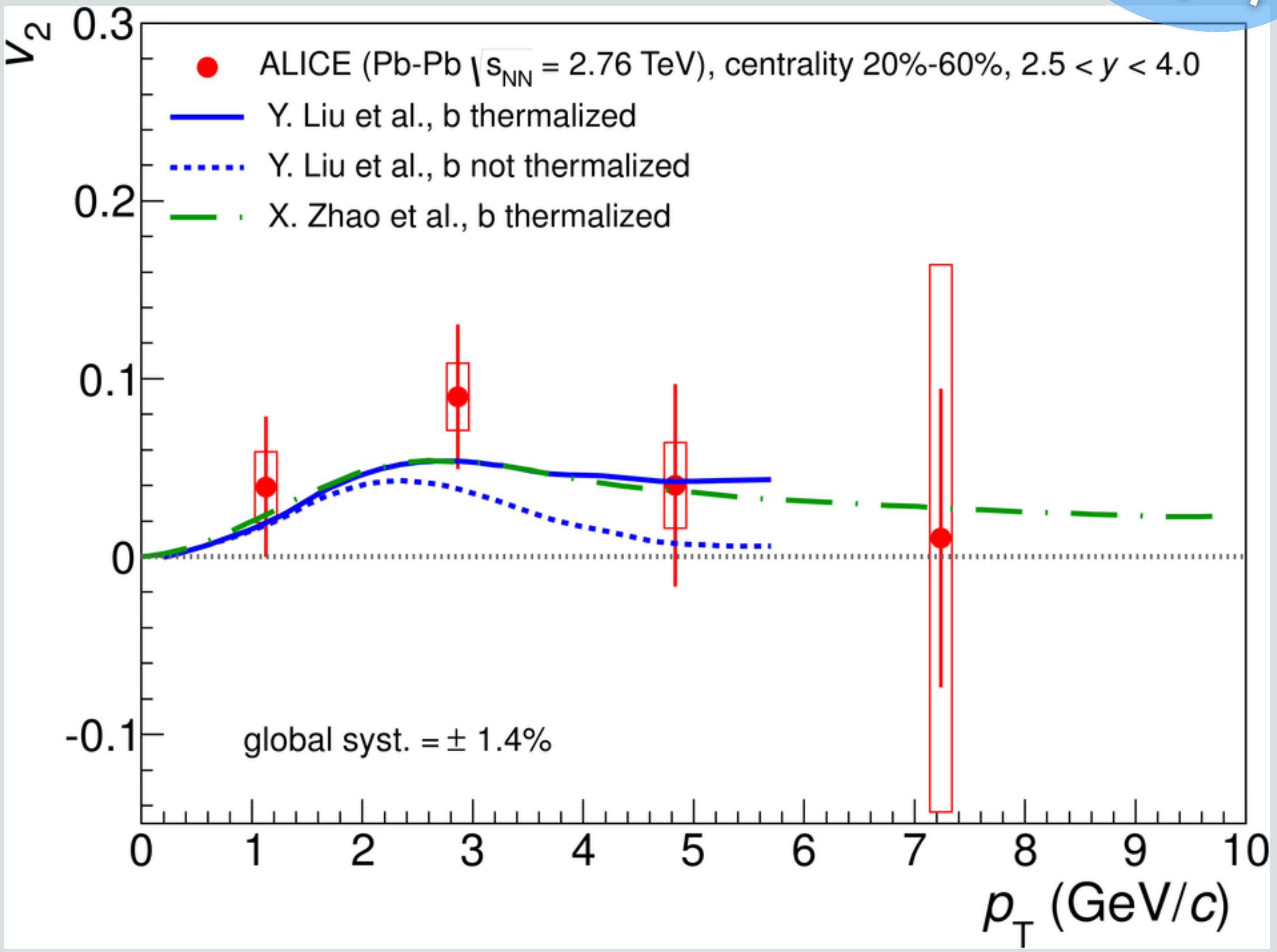
vs p_T

Elliptic flow (v_2)

Pressure gradients in a thermalized medium convert Initial spatial anisotropy into momentum-space anisotropy

$$\frac{dN}{d\phi} = N\left(1 + 2v_2\cos 2(\phi - \psi)\right)$$





PRL 111 (2013) 1662301

Strong elliptic flow observed for light particles and D mesons.

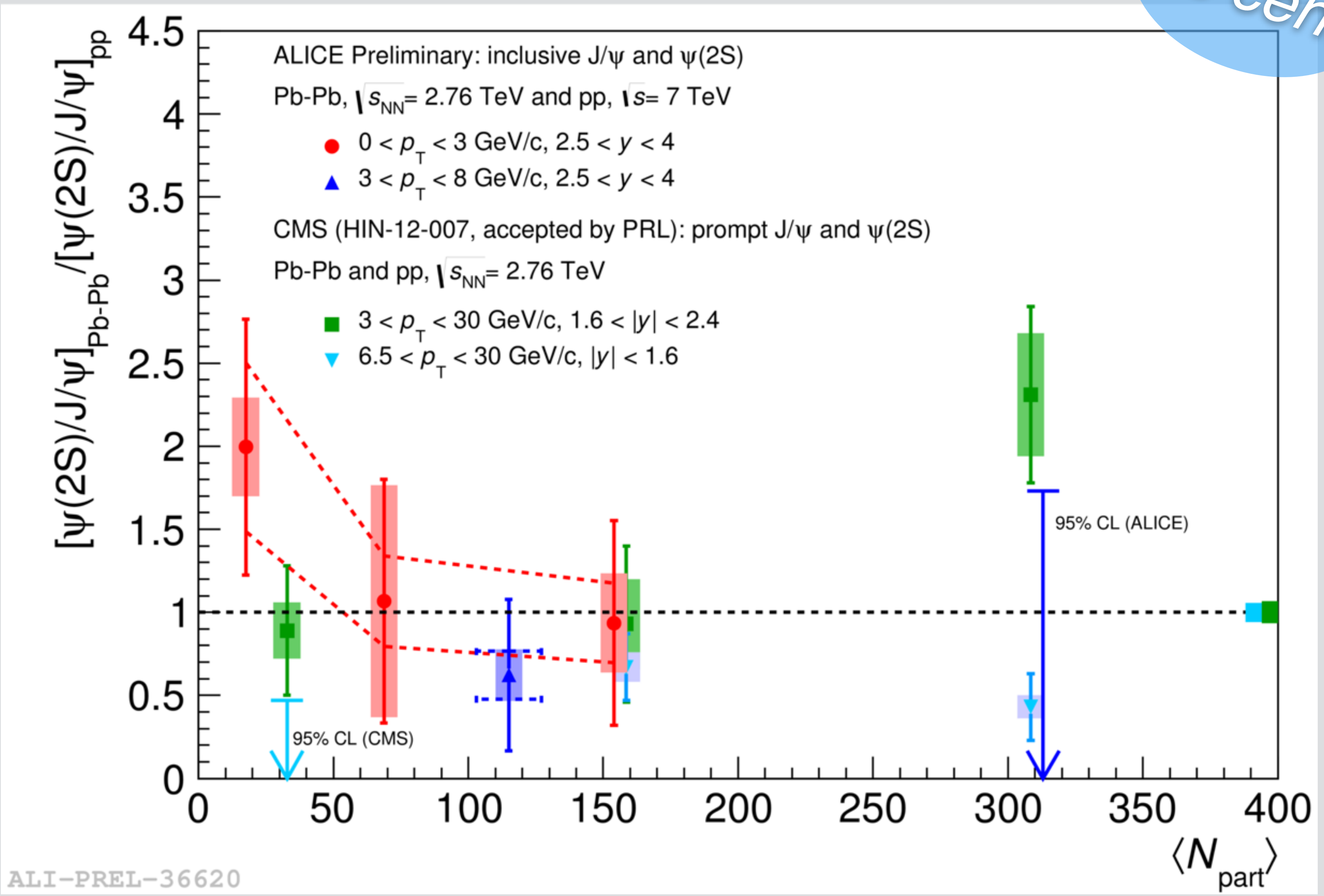
→ Does the J/ψ inherit any of the fireball collective flow via regeneration?

Hint of non-zero J/ψ v_2 seen by ALICE (2.7σ)

In agreement with regeneration mechanism

Pb-Pb: $\psi(2S)$ / J/ψ

vs cent

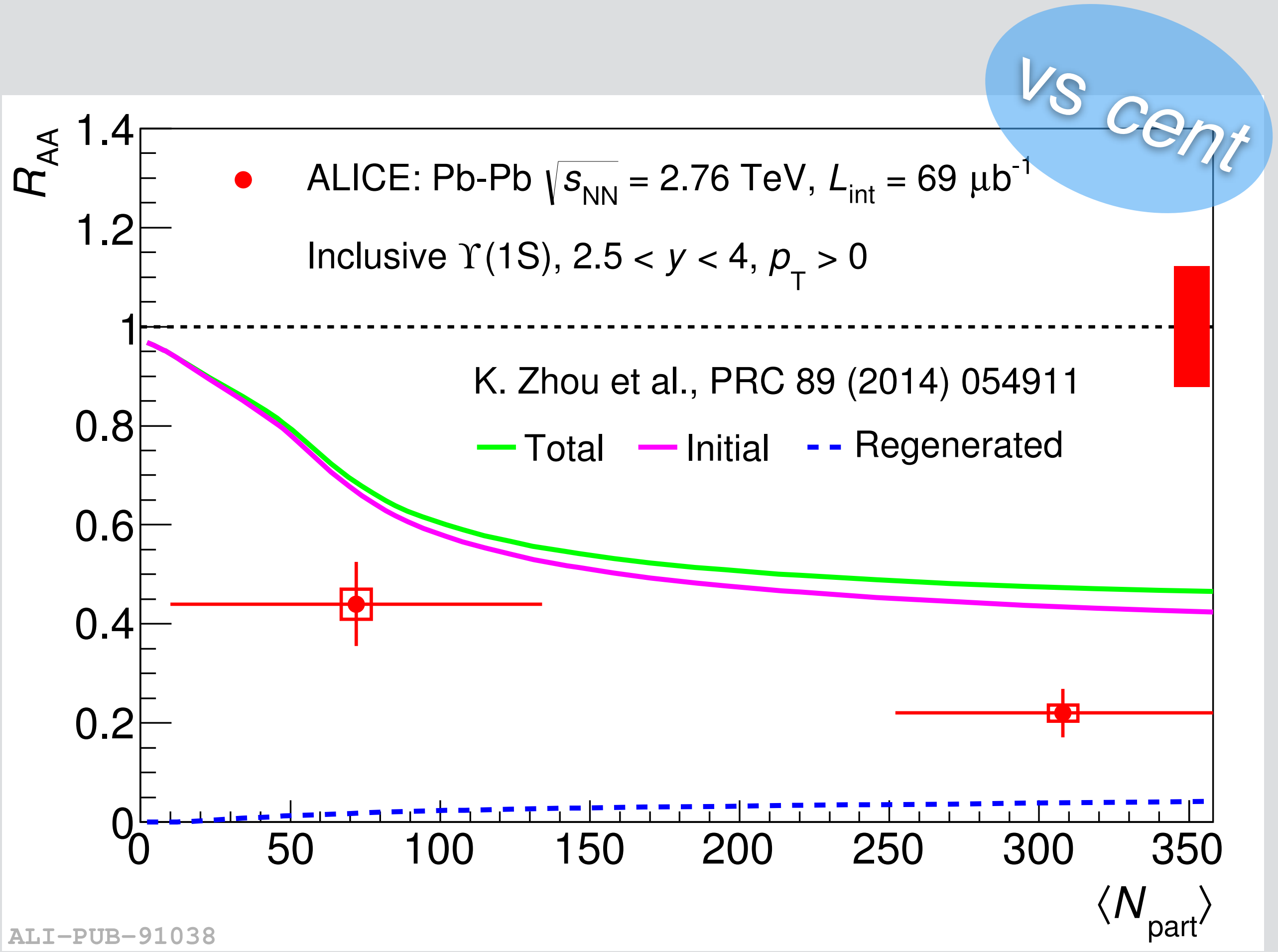


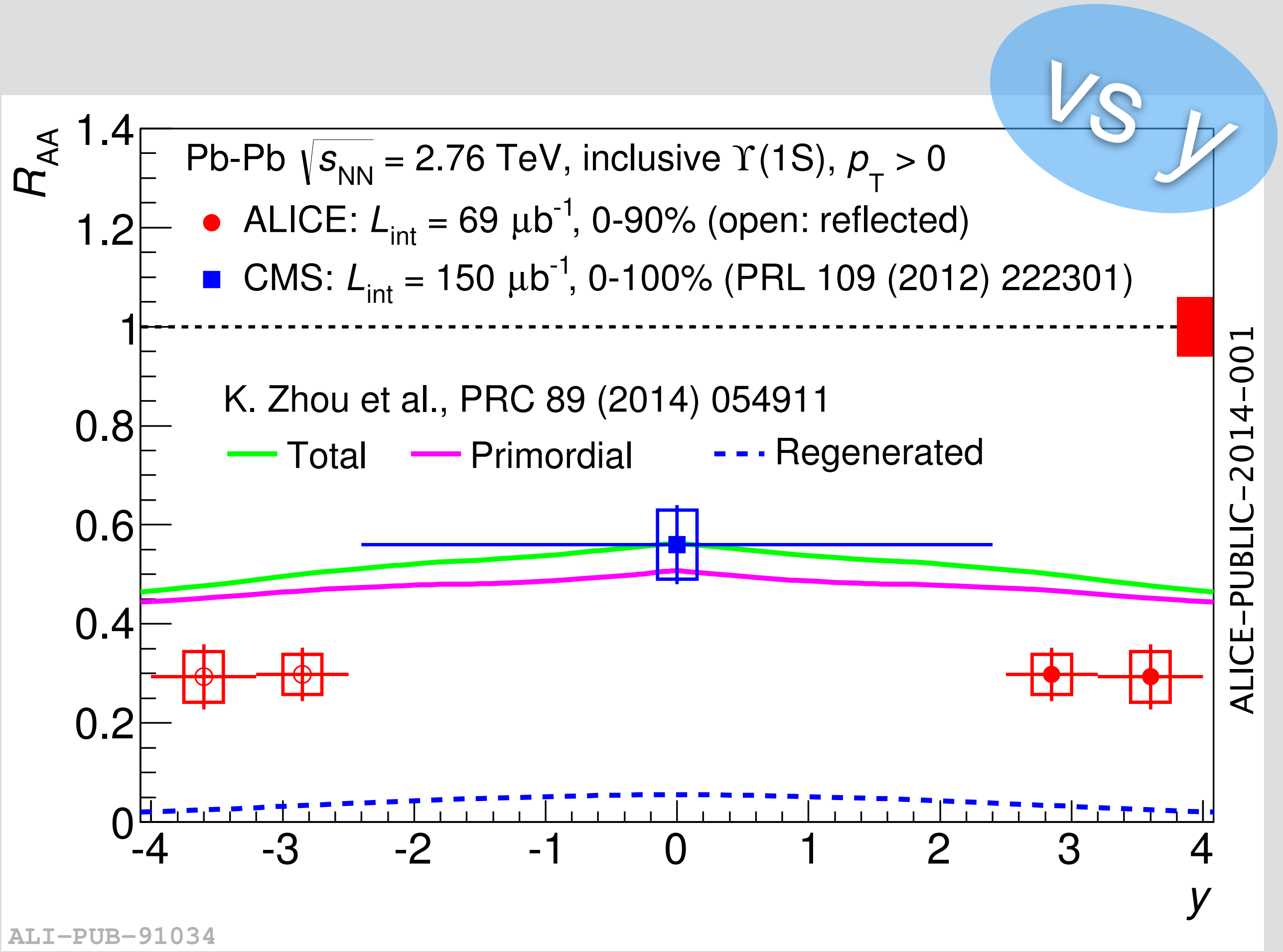
ψ(2S) state is less bound than the J/ψ.
➙ statistical and transport models have rather different predictions for ψ(2S) prod.

In most central Pb-Pb collisions, CMS measures a sizable enhancement
Large uncertainties ➙ interpretation of such effect still unclear.

More data! Wait LHC run-II ...

Pb-Pb: $\Upsilon(1S)$





Clear Y(1S) suppression, increasing from semi-peripheral to central Pb-Pb collisions

Y(1S) feed-down between 30-50%

The model underestimates the observed suppression but reproduce the centrality dependence

Stronger suppression at forward rapidity (ALICE) compare to mid-rapidity (CMS)

The model reproduces well the CMS data but underestimates the higher suppression observed at forward rapidity

Still missing measurement of the *Y*(2S) and *Y*(3S) with ALICE

More data! Wait LHC run-II ...

Summary

p-Pb collisions

- Strong *J/ψ* suppression at mid- and forward rapidity, no suppression at backward rapidity
- Strong multiplicity dependence of *J/ψ* at mid- and forward rapidity
- Stronger *ψ*(2S) suppression than *J/ψ* !
- *Υ*(1S) consistent with no suppression at backward rapidity and similar suppression than *J/ψ* at forward

Pb-Pb collisions

- *J/ψ* (inclusive) suppression with almost no centrality dependence for N_{part}>100 for 2.5<y<4
- Lower suppression than at RHIC energy (200 GeV) and large difference in the p_T dependence
- Hint of non-zero *J/ψ* v_2 seen by ALICE (2.7σ)
- Stronger *Υ*(1S) suppression at forward than at mid-rapidity

Do quarkonia disappear sequentially (thermometer)? Regeneration mechanism?

Three arguments in favor of regeneration from *J/ψ*:
LHC vs RHIC, low p_T less suppressed and non zero flow

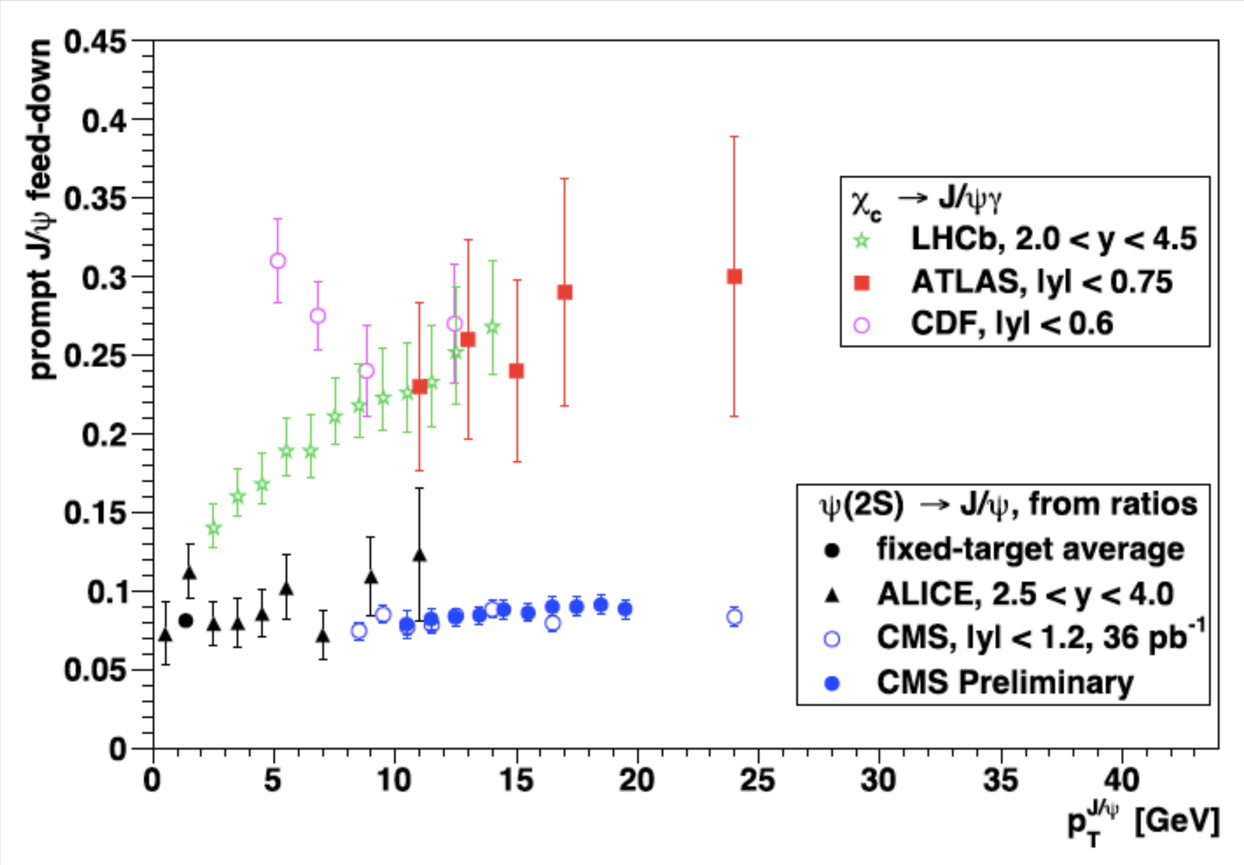
Need to better understand the contribution of CNM effects in p-Pb data and extrapolate them for Pb-Pb data

More data for *ψ*(2S) and bottomonia! Wait LHC run-II ...

Backup slides

And feed-down from higher states?

J/ψ



$\Upsilon(1S)$