ALICE quarkonia

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Outline:

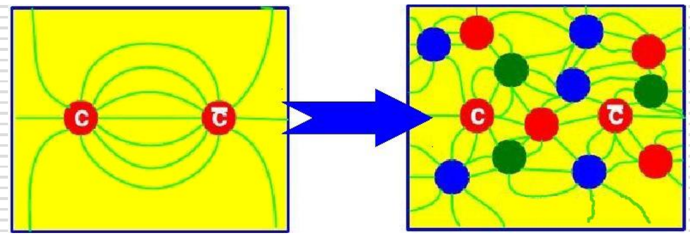
- introduction
- review of Pb-Pb results: J/ψ, ψ(2S), Υ
- new results in p-Pb: J/ψ and Υ
- conclusions and prospects

BIRMINGHAM SQM 2013

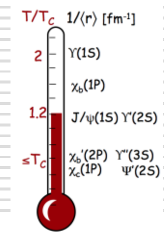
ALICE talks on Quarkonia

- Lizardo Valencia Palomo: "*Charmonium production measurements in Pb-Pb collisions with ALICE at the LHC*", Quarkonia/HF - Friday 16:50
- Igor Lakomov: "*J/ψ production in p-Pb collisions with ALICE at the* LHC", pA collisions - Friday 15:00
- Fiorella Fionda "*Measurements of J/ψ →ee with the ALICE Experiment at the LHC*" Quarkonia/HF - Friday 16:30
- Palash Khan "*Upsilon Production in Pb-Pb Collisions at Forward Rapidity with ALICE at the LHC*" Quarkonia/HF - Friday 17:10

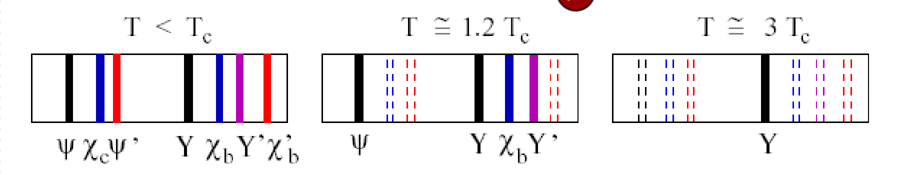
Introduction (i)



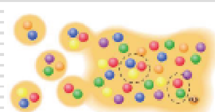
- Charmonium suppression via colour screening → probe of deconfinement
  - Matsui and Satz, PLB 178 (1986) 416

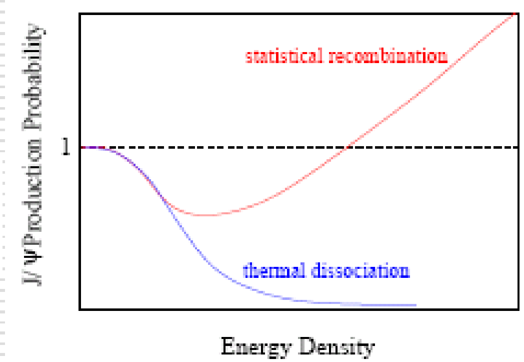


- Sequential suppression of the quarkonium states
  - Digal, Petreczky, Satz, PRD (2001) 0940150



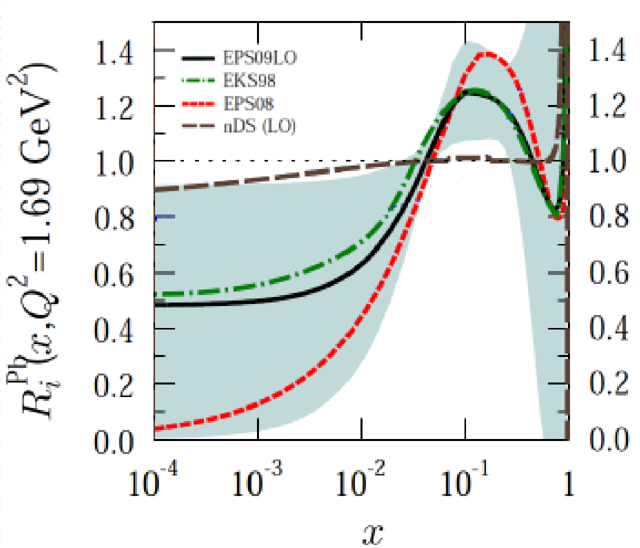
- Enhancement via (re-)generation of charmonia, due to the large multiplicity of $c\bar{c}$ pairs
  - P. Braun-Munzinger and J. Stachel, PLB 490 (2000) 196
  - R.L. Thews et al. PRC 63 (2001) 054905





Introduction (ii)

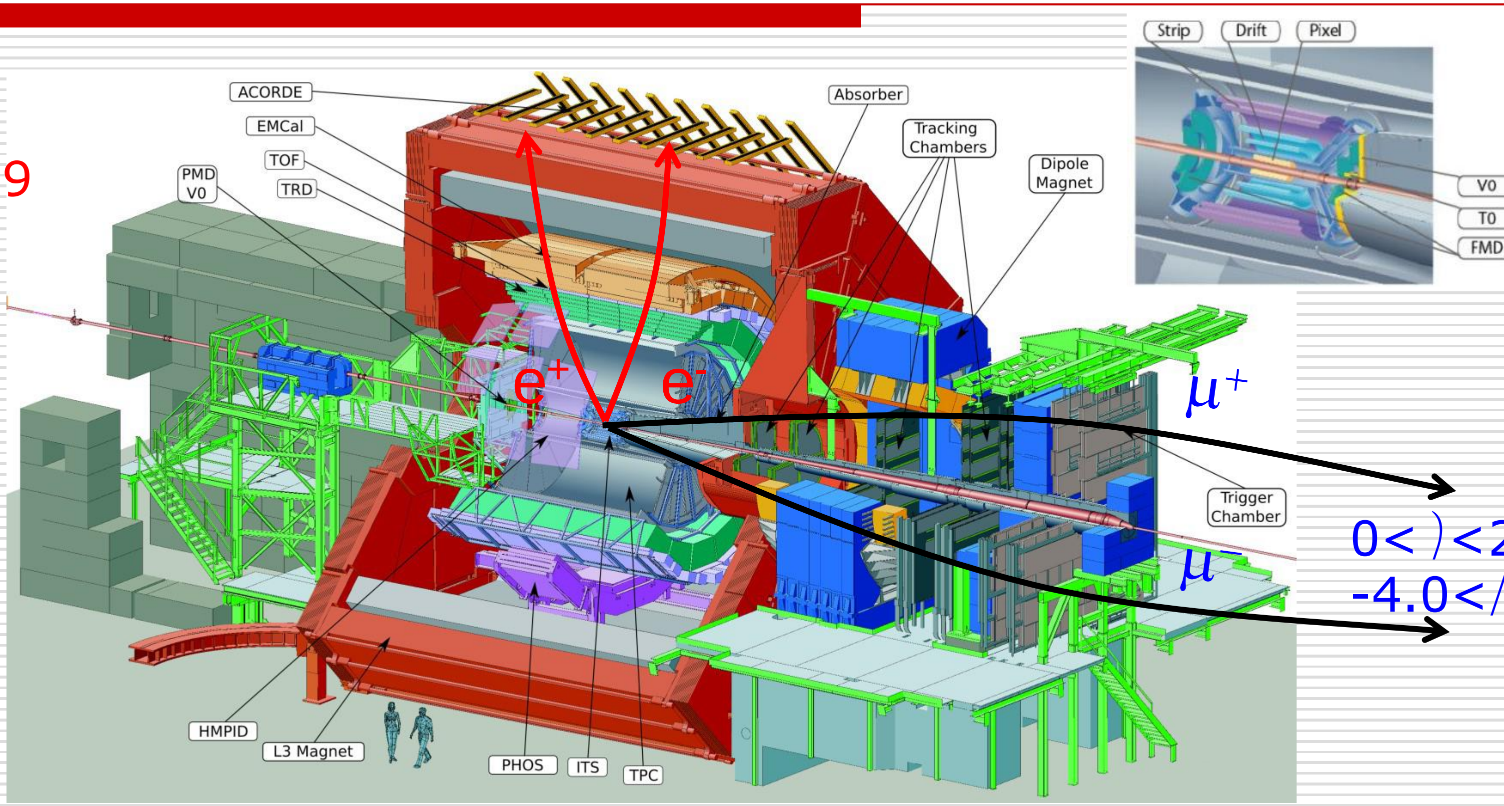
- Cold nuclear effects. What do we expect at LHC ?
  - Nuclear absorption
    - at LHC, quarkonia formation time >> collision time
    → small absorption expected
  - Gluon shadowing
    - at LHC (= small x) a large shadowing expected but huge uncertainty on nPDFs at low Q^2
    … or gluon saturation
  - Initial state energy loss
    - energy loss of the incoming parton: typically, constant fraction in each collision
    - new approach (Peignè, Arleo): *coherent energy loss* arXiv:1212.0434



- *Hot* nuclear effects in pA?
  - Multiplicity in pA@LHC ~ that of semi-central AA at lower energies

Quarkonia with ALICE

$0<\varphi<2\pi$
$|\eta_e| < 0.9$

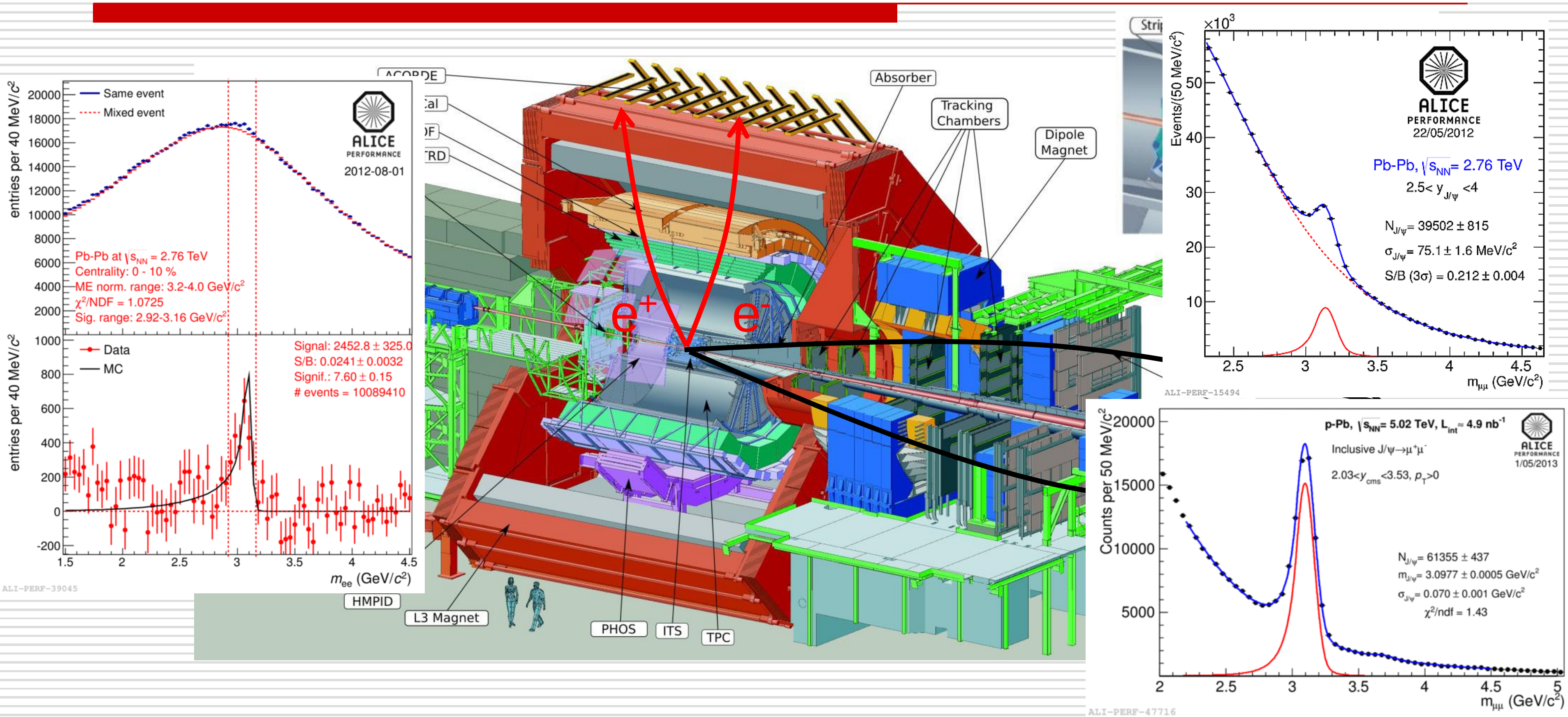


$0<\varphi<2\pi$
$-4.0<\eta_\mu<-2.5$

- measured in two ways in ALICE:
  - in the central barrel in the e^+e^- channel ($|y|<0.9$)
  - in the forward spectrometer in the $\mu^+\mu^-$ channel ($2.5<y<4$)

down to $p_T=0$ in both channels

Quarkonia with ALICE



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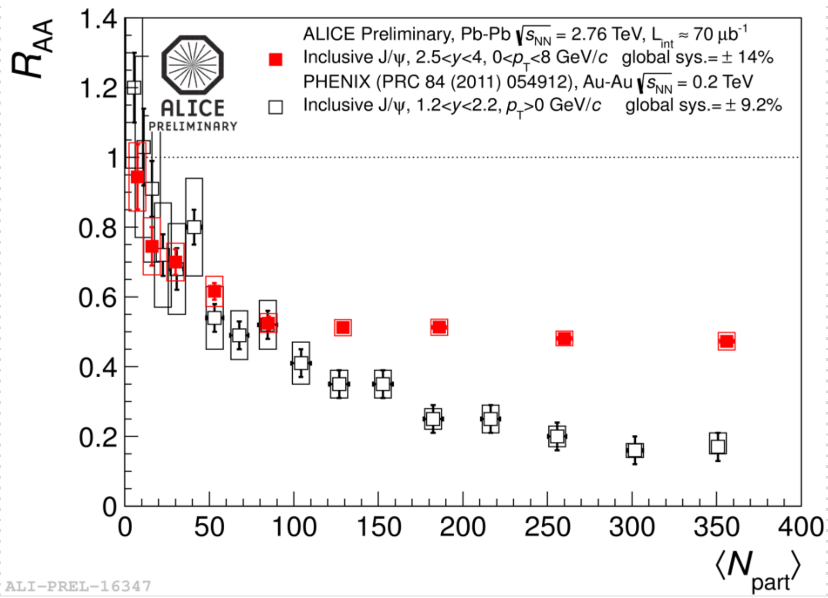
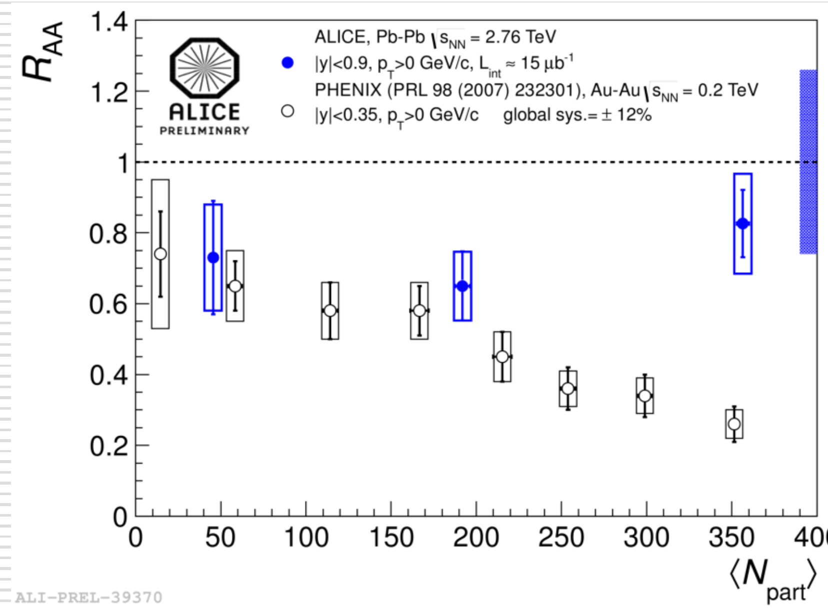
R_{AA} of J/ψ vs centrality



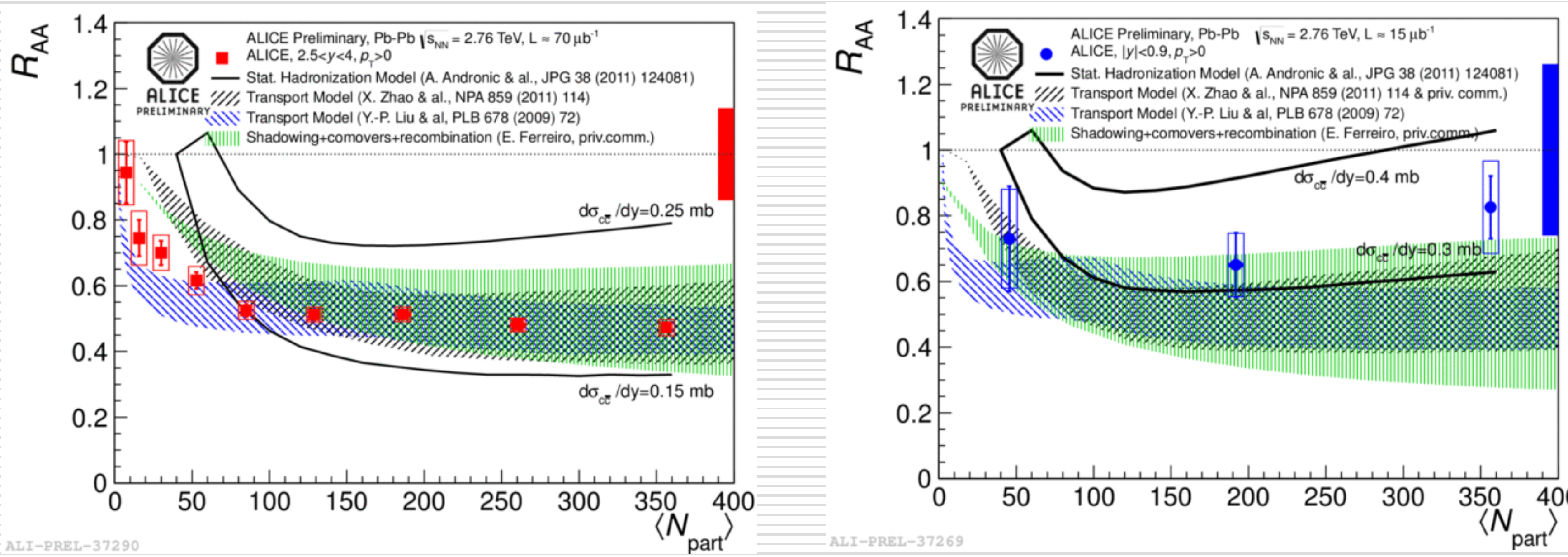


Comparison with PHENIX:

- Stronger centrality dependence at lower energy
- Systematically larger R_{AA} values for central events in ALICE

as qualitatively expected in a (re-)generation scenario

R_{AA} of J/ψ vs centrality



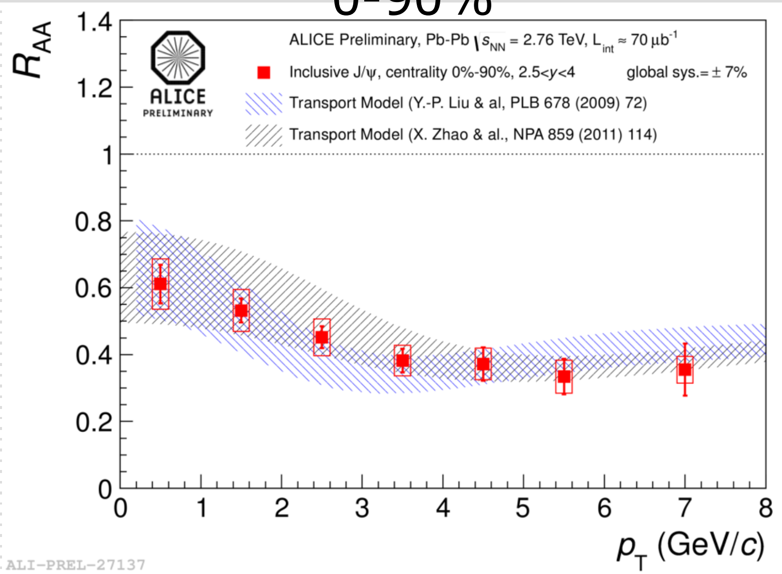
Comparison with models:

- main model uncertainties from shadowing and $s_{c\bar{c}}$ (see, e.g., stat. Hadronization Model)
- (re-)combination looks necessary

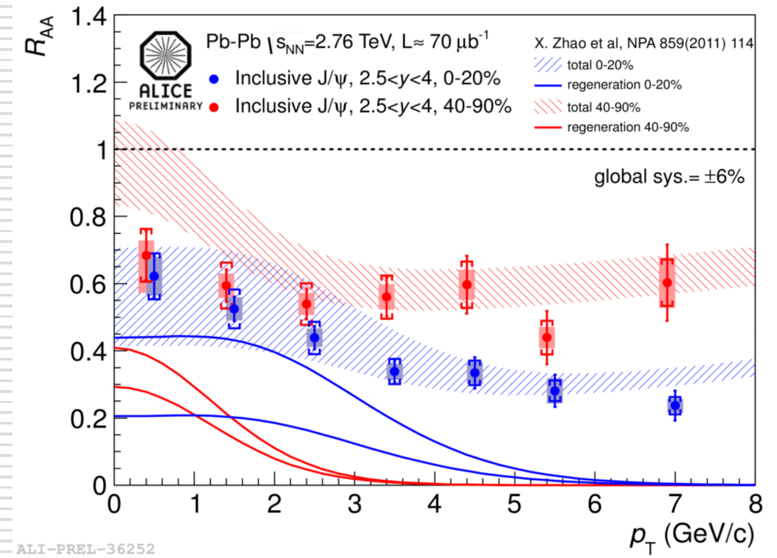
→ measure p-Pb (and $s_{c\bar{c}}$)

R_{AA} of J/ψ vs p_T

0-90%

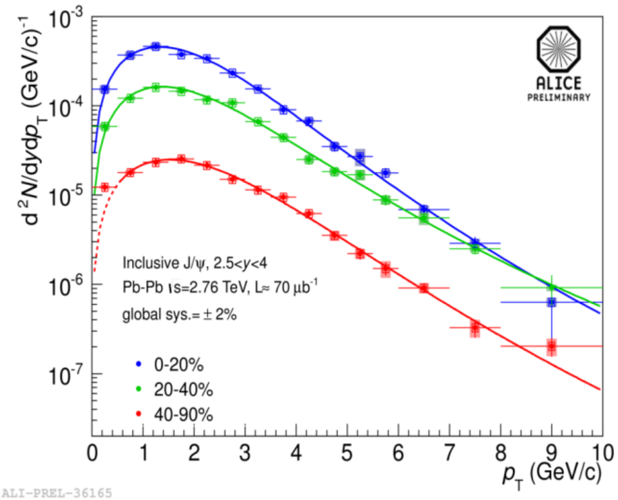


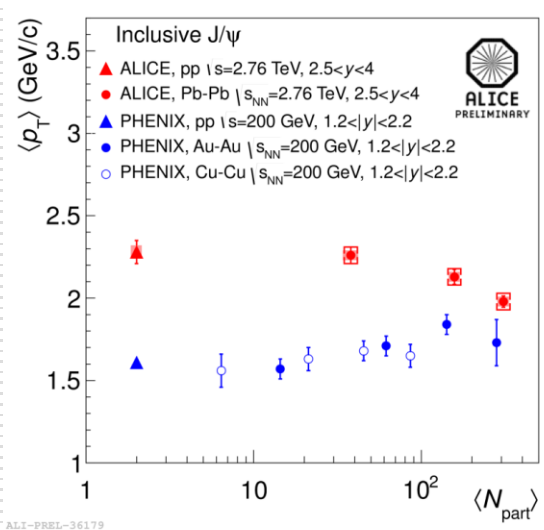
0-20% vs 40-90%

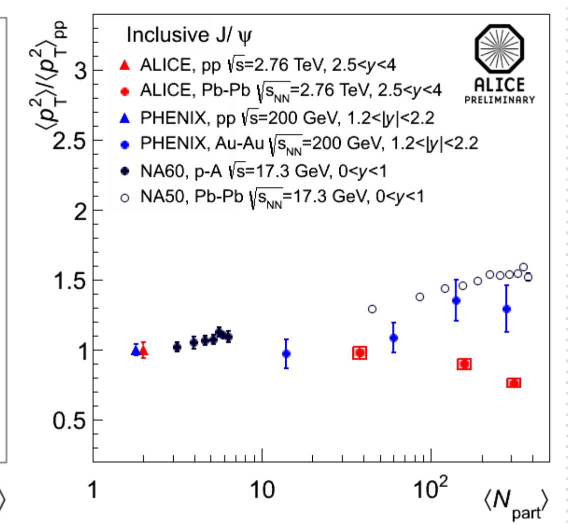


- suppression stronger at high-p_T
- difference low vs. high-p_T more pronounced for central collisions
- fair agreement data vs. models with sizable contribution from (re-)combination
  - a bit worse for peripheral at low p_T

$\langle p_T \rangle$ and $\langle p_T^2 \rangle$ of J/ψ





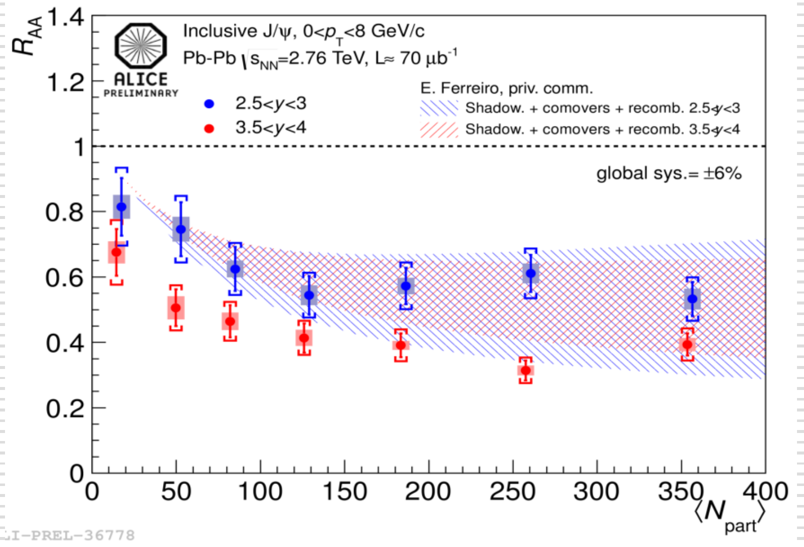


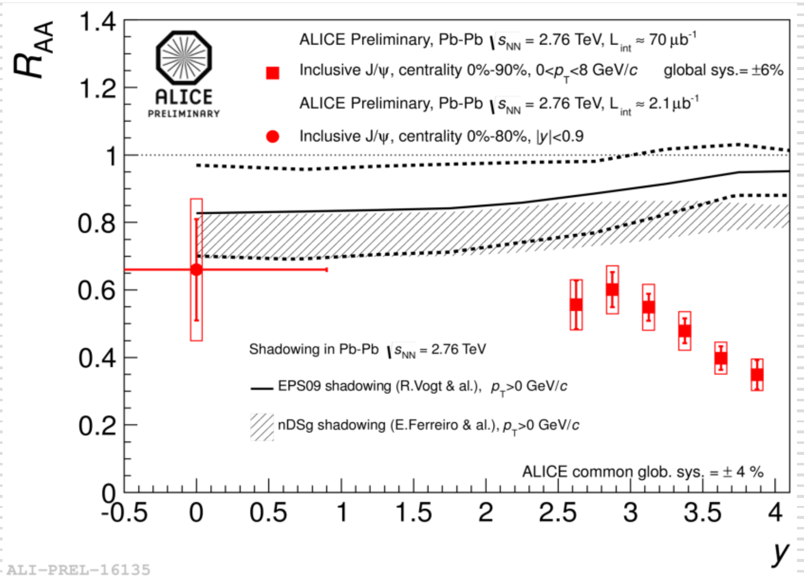
- The J/ψ $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ decrease with centrality, confirming the observation that low-p_T J/ψ are less suppressed in central collisions

- the trend is different w.r.t. to the one observed at lower energies, where an increase of the $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ with centrality was obtained

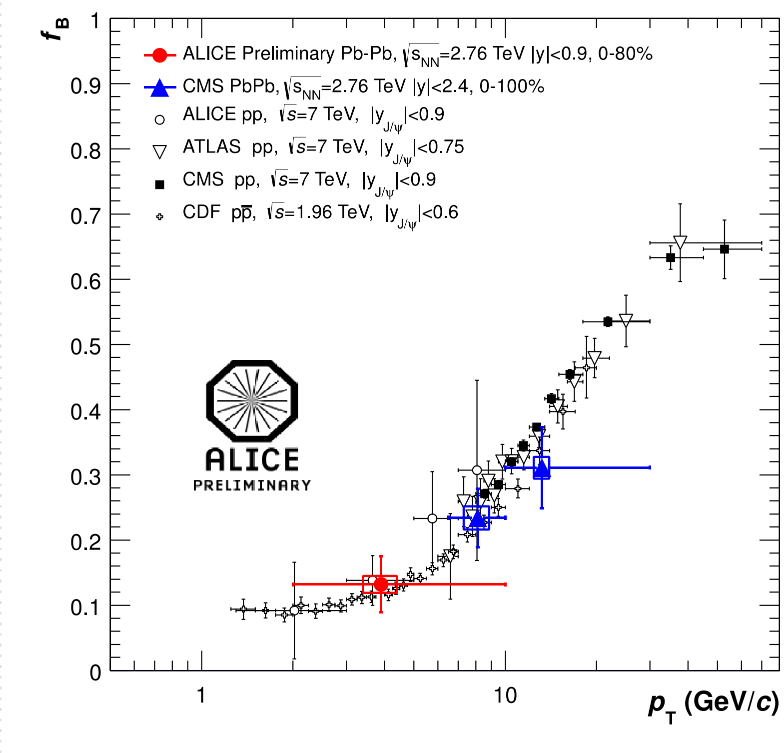
R_{AA} of J/ψ: rapidity dependence

- R_{AA} decreases by 40% from y=2.5 to y=4
- Comover+regeneration model shows a weaker rapidity dependence
- Suppression beyond the current shadowing estimates
  →look at p-Pb



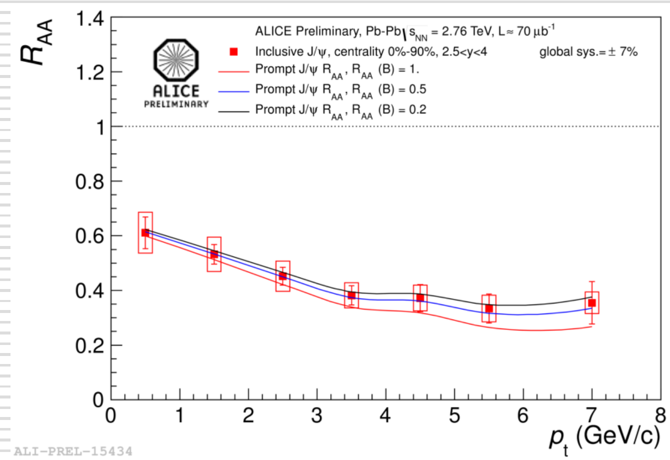


non-prompt J/ψ in Pb-Pb at low p_T

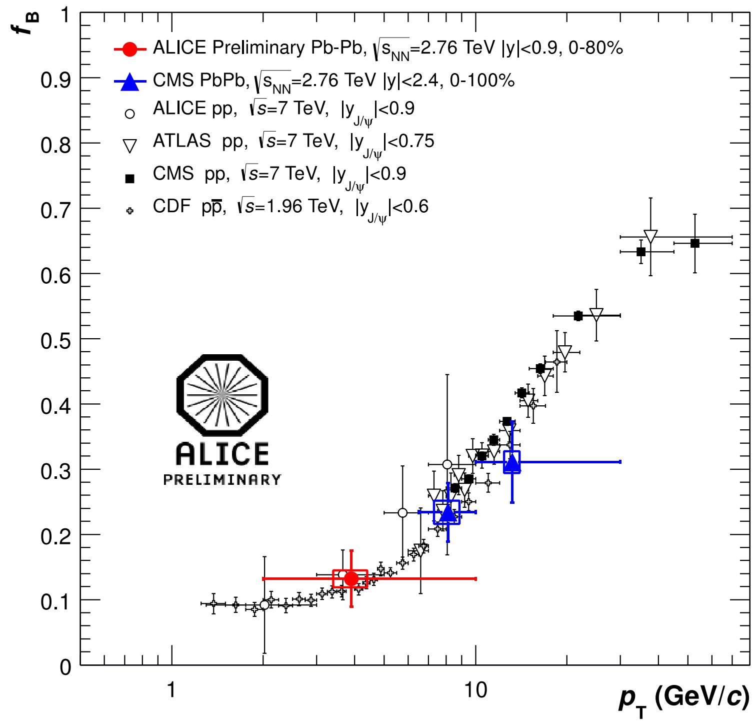


- ALICE p_T coverage:
  - $2 < p_T < 10$ GeV/c
  - complementary to CMS (p_T>6.5 GeV/c)
- similar trend of f_B as a function of p_T in pp and Pb-Pb

- now more confident that non-prompt J/ψ have negligible effects on the measured R_{AA}



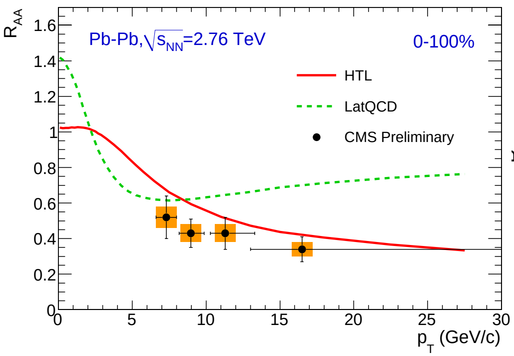
non-prompt J/ψ in Pb-Pb at low p_T



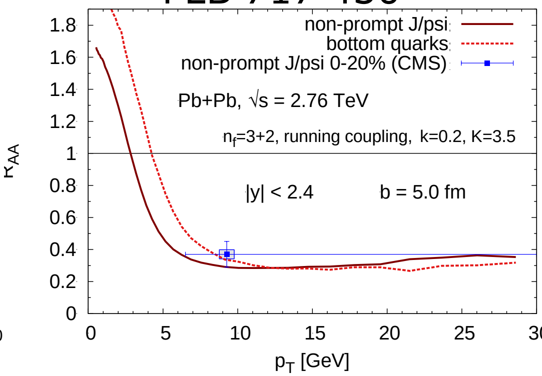
- ALICE p_T coverage:
  - 2 < p_T < 10 GeV/c
  - complementary to CMS (p_T>6.5 GeV/c)
- similar trend of f_B as a function of p_T in pp and Pb-Pb

- R_{AA} of non-prompt J/ψ at low p_T coming soon
  - study beauty energy loss down to p_T close to 0

W.M. Alberico et al. arXiv1305.7421

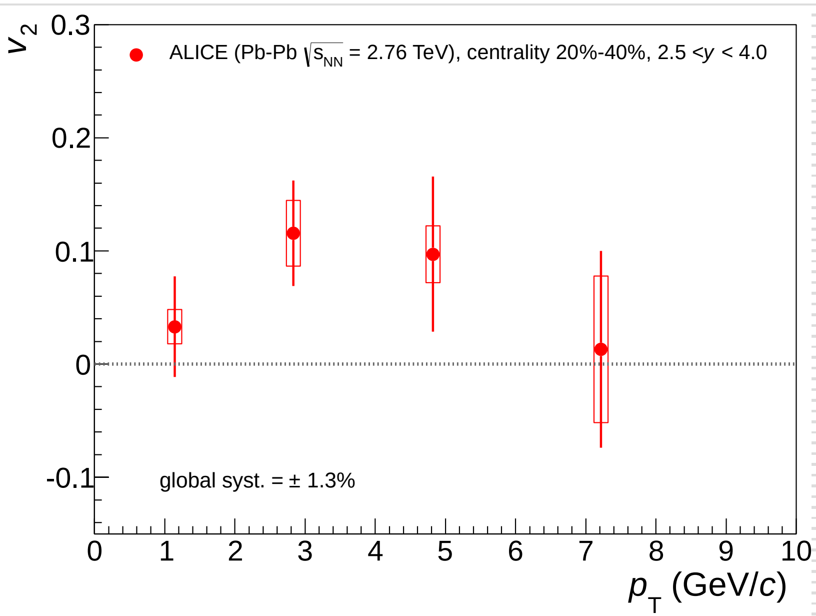


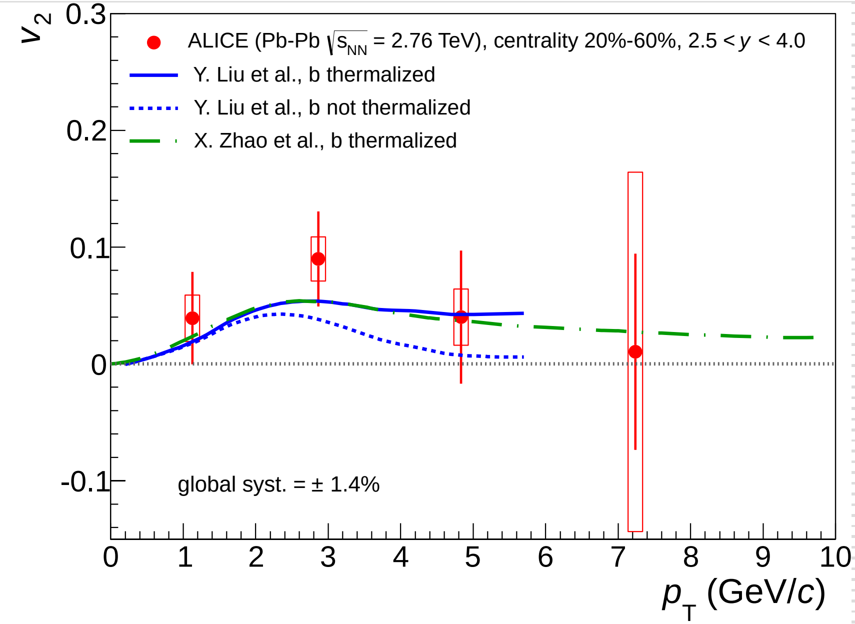
J. Uphoff et al. PLB 717 430



J/ψ elliptic flow

arXiv:1303.5880





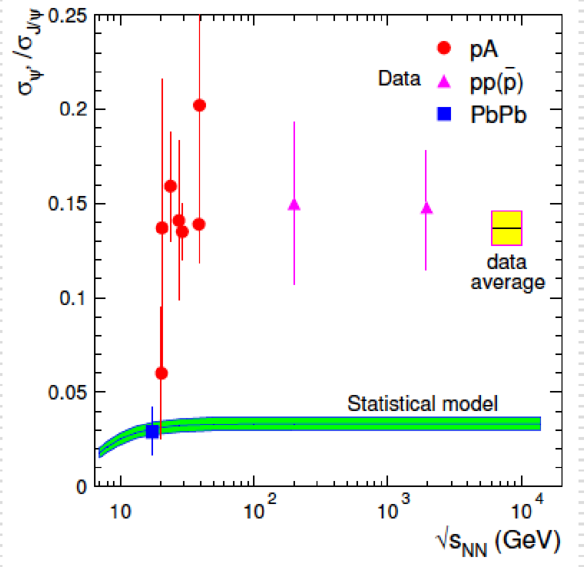
- indication of non zero flow, which favors the scenario of a significant fraction of J/ψ production from charm quarks in a deconfined partonic phase

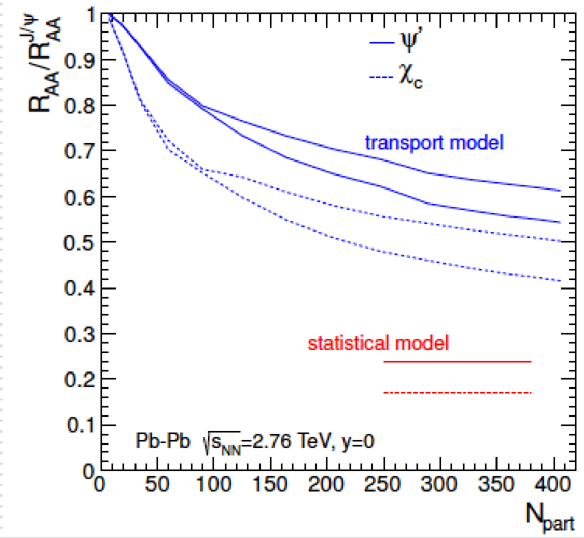
ψ(2S)

- how ?

$$R = \frac{N^{\psi(2S)}_{\rm Pb-Pb} / N^{J/\psi}_{\rm Pb-Pb}}{N^{\psi(2S)}_{\rm pp} / N^{J/\psi}_{\rm pp}} = \frac{R^{\psi(2S)}_{\rm AA}}{R^{J/\psi}_{\rm AA}}$$

- why ?
  - *R* is weakly-dependent on charm production cross section employed in models for Pb-Pb collisions
  - R < 1 expected in both *transport* (NPA 859 114) and *statistical* (PLB 490 196) model, but different magnitudes predicted

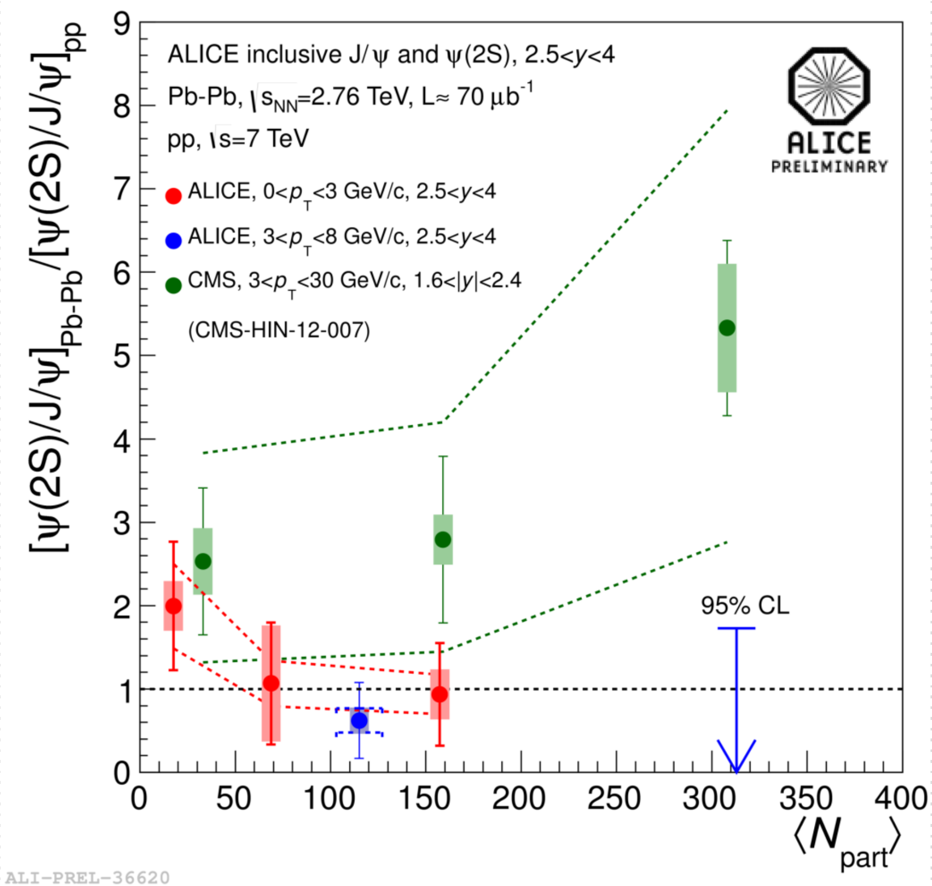




At SPS (NA50): R=0.24

$[\psi(2S)/J/\psi]_{Pb\text{-}Pb}$ / $[\psi(2S)/J/\psi]_{pp}$

- Dashed lines show the error on the pp reference:
  - CMS → □s = 2.76 TeV
  - ALICE → □s =7 TeV
    - √*s*- and *y*-dependence accounted for in the systematics
- Main systematic uncertainties from signal extraction and MC input for acceptance calculation

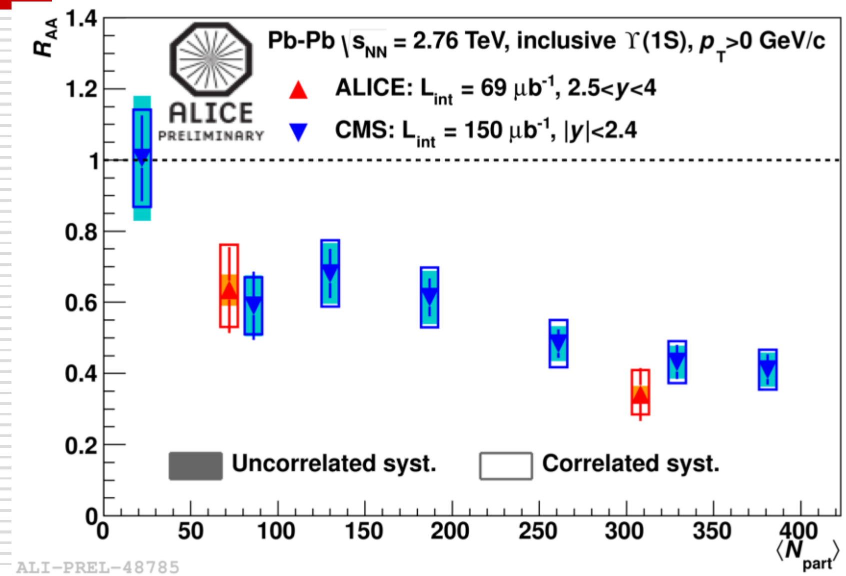


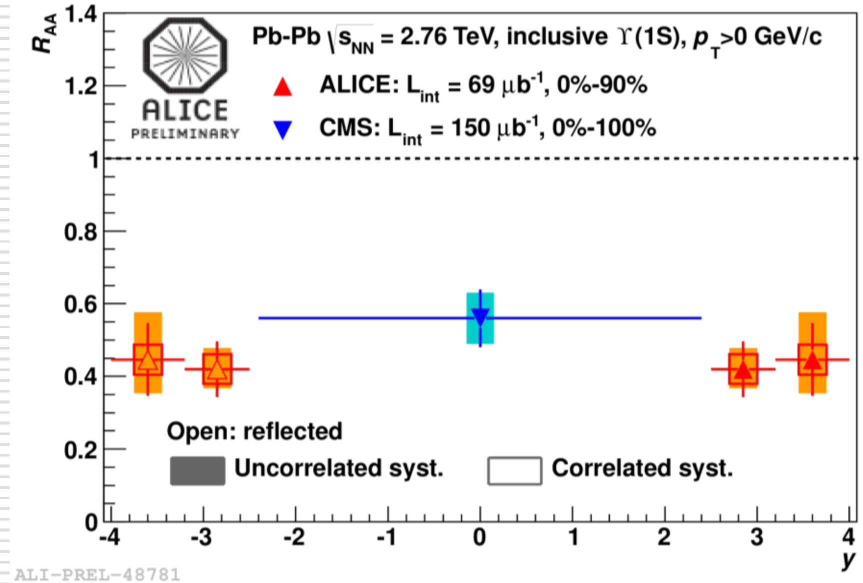
ALICE excludes large enhancement in the most central collisions

ALICE upgrade → precision measurement to discriminate among models

Υ(1S) R_{AA}

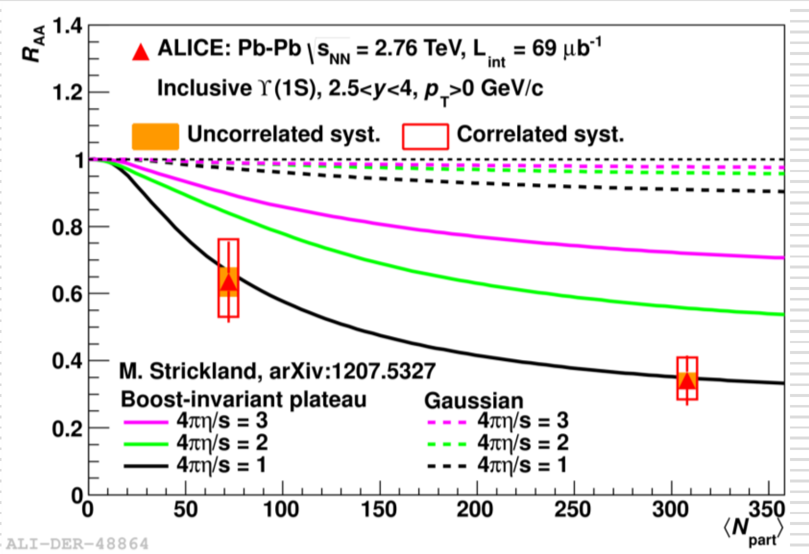
- pp cross section at 2.76 TeV from an interpolation procedure
- suppression looks stronger for central collisions
- no evidence of rapidity dependence
  - even when comparing with CMS mid-rapidity data



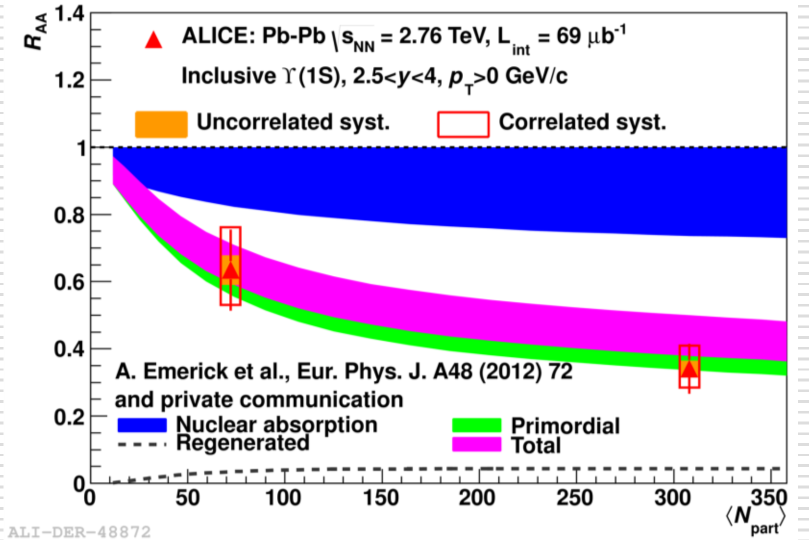


Υ(1S) R_{AA}: comparison to models

- Different approaches:
  - Strickland → hydro-like evolution, feed-down from higher mass states, no CNM effect
  - Emerick et al.→ rate equation model with regeneration, CNM parameterized through an absorption cross-section



- both models in fair agreement with data
  - several handles inside the models →try to put as many constraints as possible
    - e.g., Strickland already uses a temperature profile which can also describes J/ψ v_2 (B. Schenke et al arXiv:1102.0575)
    - next: CNM constrained from p-Pb measurements



p-Pb collisions

- data collected in February/March 2013
- Beam energy: $\sqrt{s_{NN}}$ = 5.02 TeV
  - Energy asymmetry of the LHC beams (E_p = 4 TeV, E_{Pb}= 1.58 A□TeV)
    → rapidity shift Δy= 0.465 in the proton direction
- Collected statistics:
  - ~130 million MB events / 50 μb^{-1}
    - MB trigger efficiency ~99% for NSD events
  - ~31 nb^{-1} triggered, in particular:
    - di-muon trigger ~ 19 nb^{-1}
    - TRD rare trigger ~ 1.4 nb^{-1}
- I will show results for the di-muon channel in
  - p-Pb ($2.03<y_{CMS}<3.53$) - L_{int} ~ 5 nb^{-1}
  - Pb-p ($-4.46<y_{CMS}<-2.96$) - L_{int} ~ 6 nb^{-1}

Which observable for nuclear effects ?

- Nuclear modification factor R_{pA}
  - full coverage of the ALICE muon spectrometer $2.5<y_{LAB}<4$ exploited
  - based on an estimate of the σ^{QQ}_{pp} reference at $\sqrt{s_{NN}}$=5.02TeV

$$R_{pPb}^{Q\bar{Q}} = \frac{Y_{pPb}^{Q\bar{Q}}}{\langle T_{pPb} \rangle \sigma_{pp}^{Q\bar{Q}}}$$

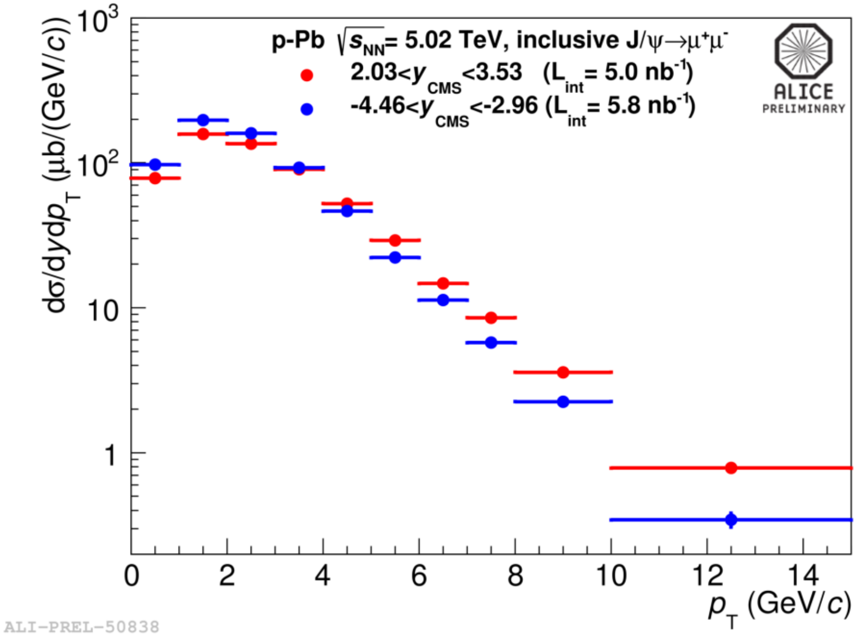
$Q\bar{Q}$ = J/ψ or Υ

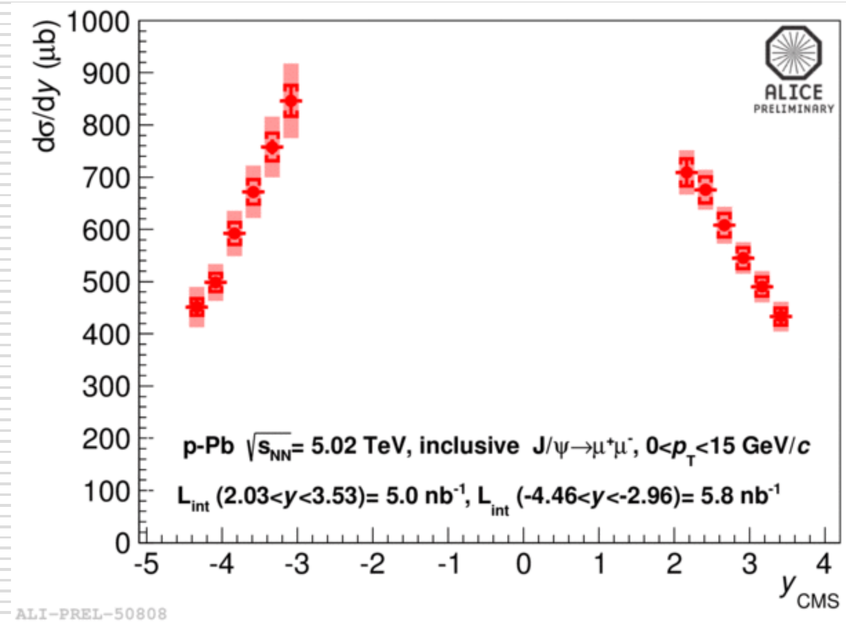
$$Y_{pPb}^{Q\bar{Q}} = \frac{N_{Q\bar{Q}}}{(A \times \varepsilon) N_{MB}}$$

- Forward to backward ratio R_{FB}
  - computed in the common (restricted) y_{CMS} range $2.96< |y_{CMS}|< 3.53$
  - σ^{QQ}_{pp} reference at $\sqrt{s_{NN}}$=5.02TeV not needed, some systematics cancel out
  - less sensitive to the physics behind the models

$$R_{FB} = \frac{R_{pPb}}{R_{Pbp}} = \frac{Y_{Q\bar{Q}}^{Forward}}{Y_{Q\bar{Q}}^{Backward}}$$

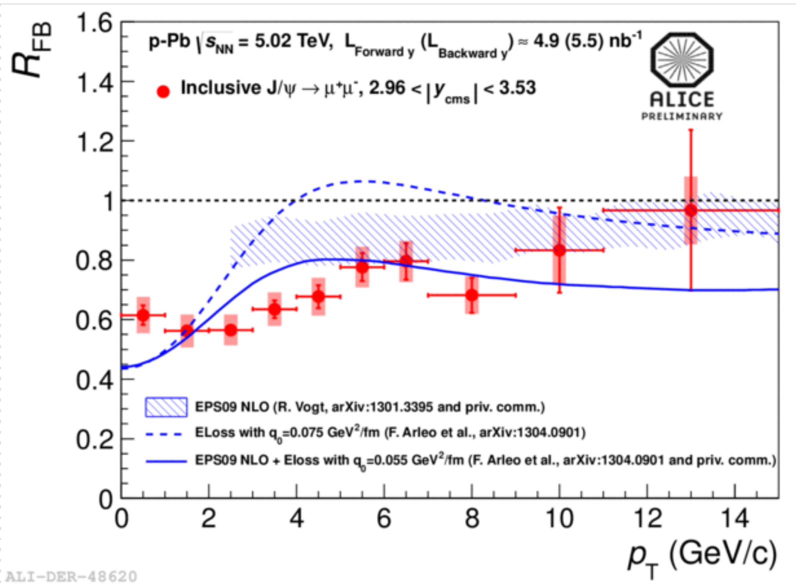
J/) production in p-Pb: $\frac{ds^{J/y}}{dydp_T}$ and $\frac{ds^{J/y}}{dy}$

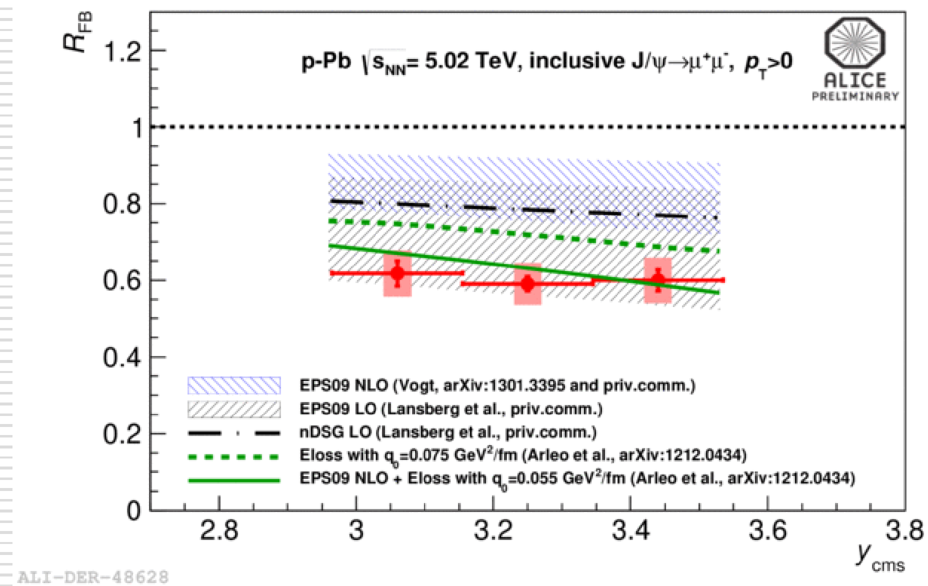




- precise measurement: systematic errors of about 6-8%, statistical errors negligible
- coverage: $0<p_T<14$ GeV/c,$-4.5<y_{cms}<-3$ & $2<y_{cms}<3.5$
- cross section higher in the backward rapidity region (Pb-p)

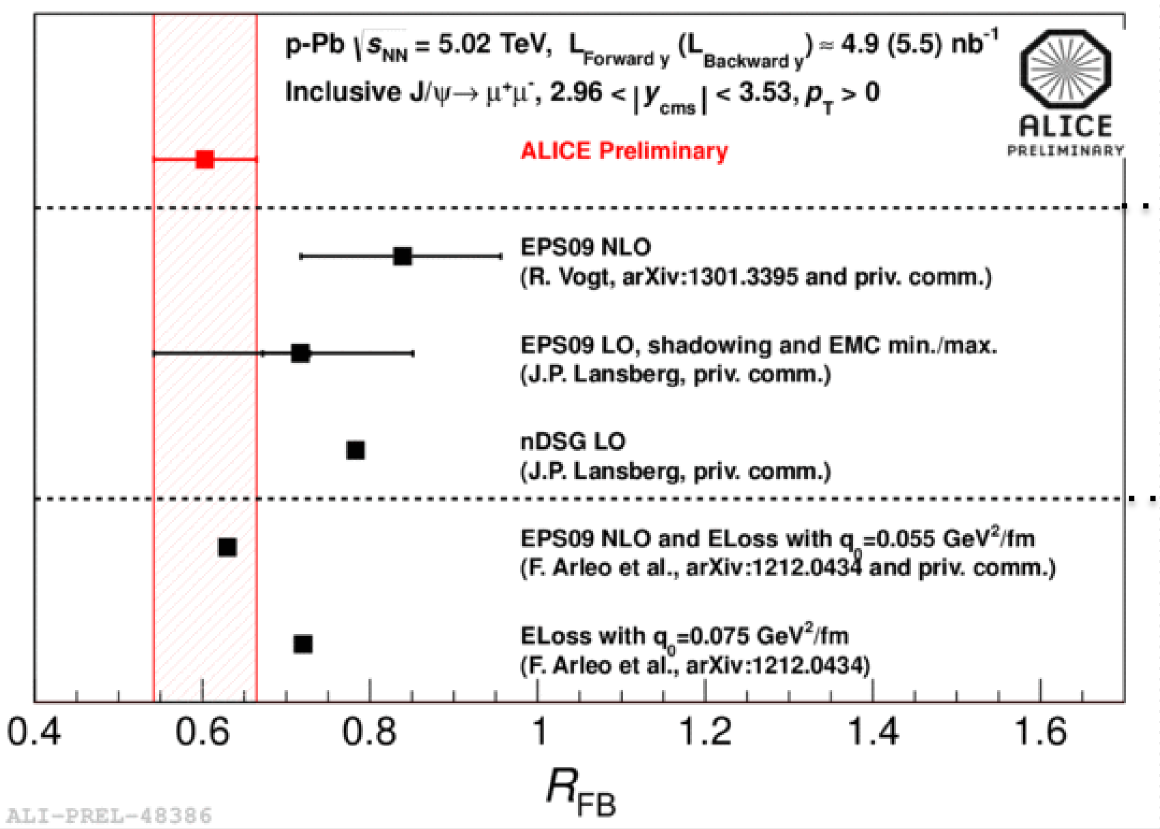
R_{FB} of J/ψ vs. p_T and y_{cms}





- stronger suppression at low p_T
- weak (if any) evidence of y_{cms} dependence in this small rapidity range
- models including shadowing and energy loss show strong nuclear effects at low p_T
  - in fair agreement with the data, but p_T-dependence looks smoother than from model with *coherent* energy loss

Integrated R_{FB} of J/ψ vs. models



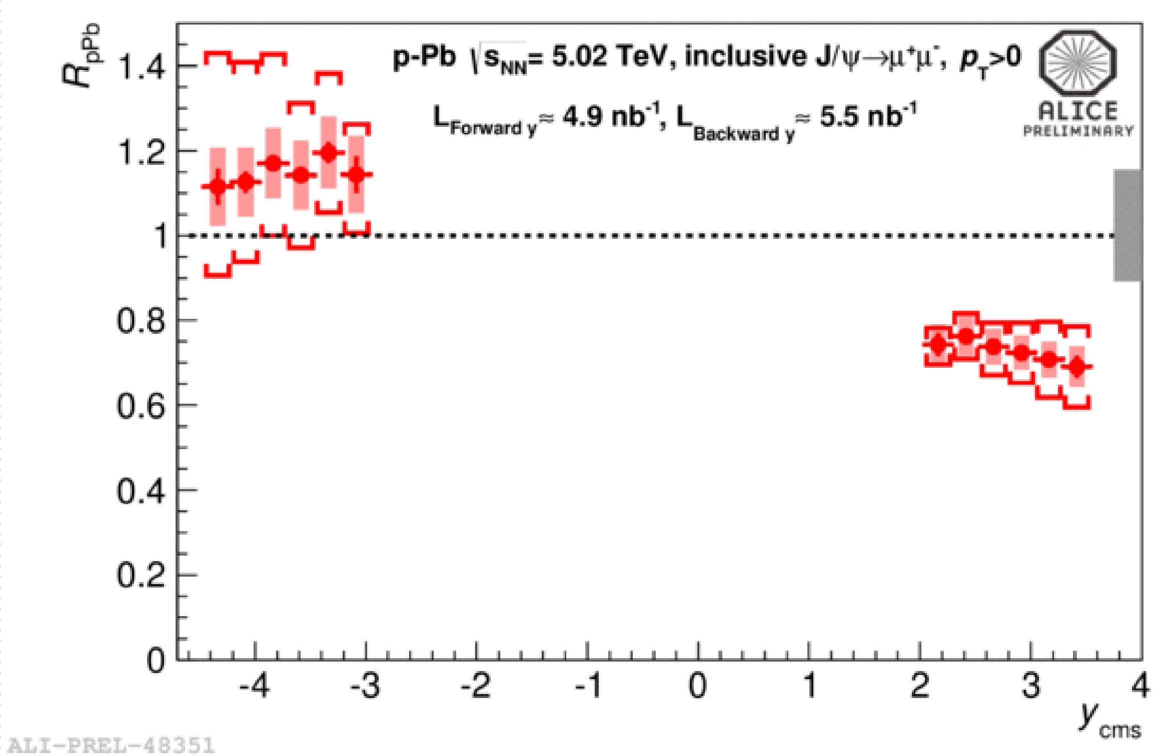
- pure shadowing slightly overestimate the data
- better agreement for model including energy loss

R_{pPb} of J/ψ

Systematic uncertainties:

- boxes→ *uncorrelated*
- brackets → *largely correlated*
- grey box at unity→ *fully correlated*

- dominant uncertainty, of about ~25% (18%) at backward (forward) rapidity from the pp reference
  - details in I. Lakomov's talk on friday



integrated over y_{cms}

R_{pA} $(2.03<y_{CMS}<3.53)$=
0.732 ± 0.005(stat) ± 0.059(syst) + 0.131(syst. ref) – 0.101(syst.ref)

R_{pA} $(-4.46<y_{CMS}<-2.96)$=
1.160 ± 0.010 (stat) ± 0.096(syst) + 0.296(syst. ref) – 0.198(syst.ref)

R_{pPb} of J/ψ vs. models

Systematic uncertainties:

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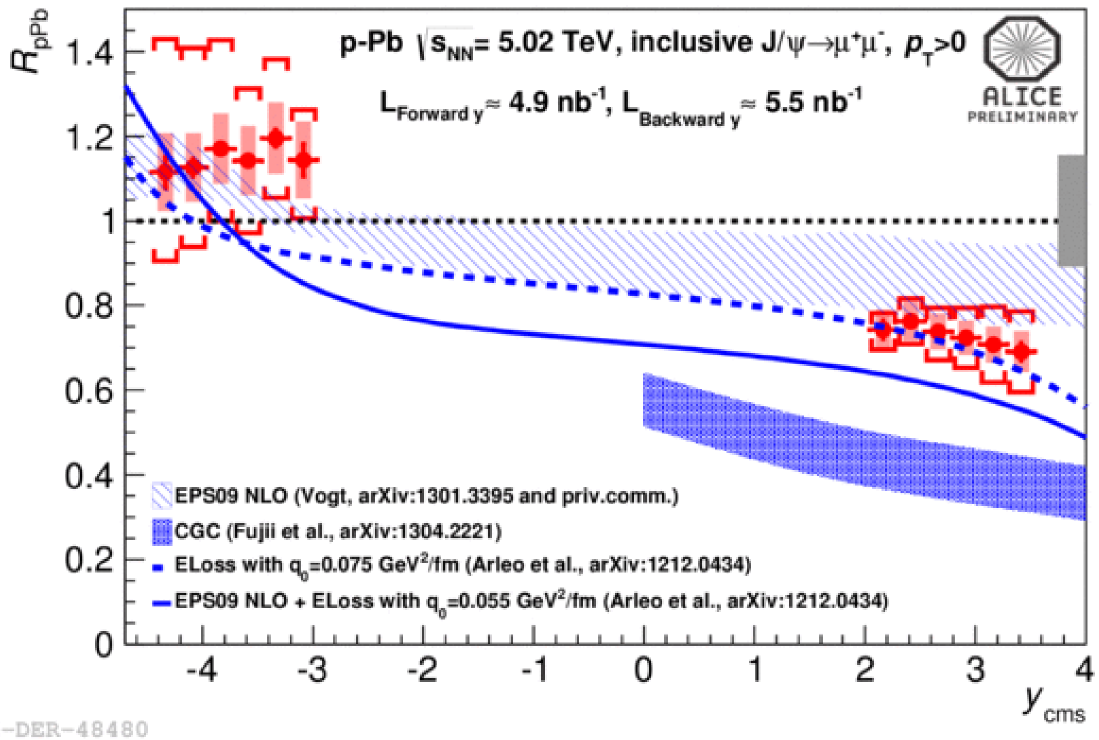
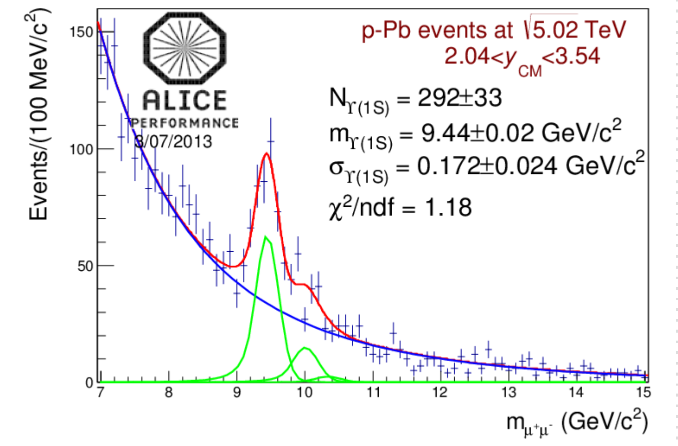


- large (pp) uncertanties prevent firm conclusions between only shadowing or shadowing + energy loss
- CGC calculations disfavored by data

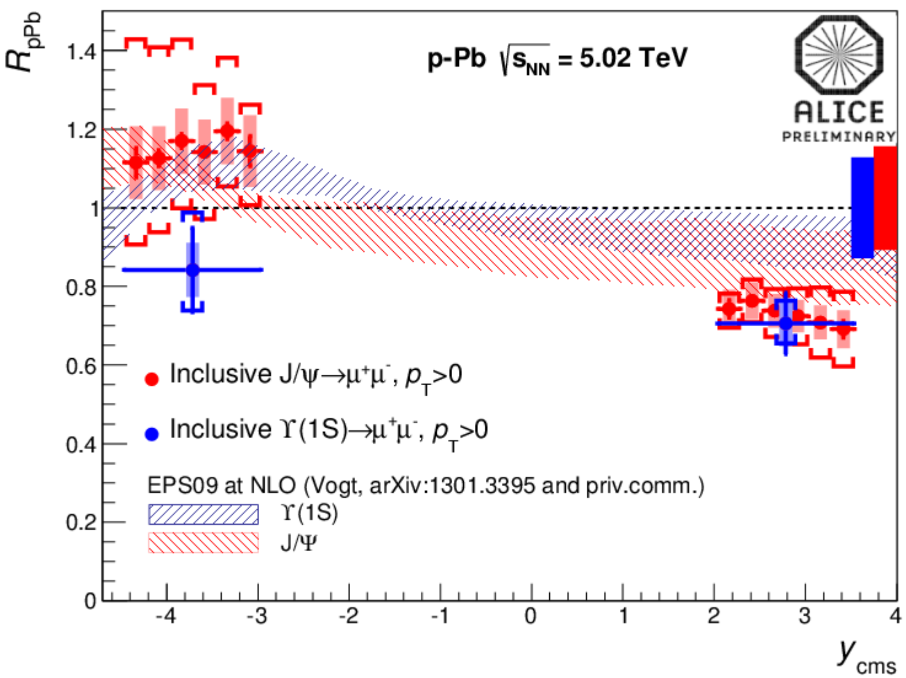
Υ(1S) in p-Pb: R_{pPb}

- large uncertainties
  - again largest contribution from pp
  - statistical error ~17%

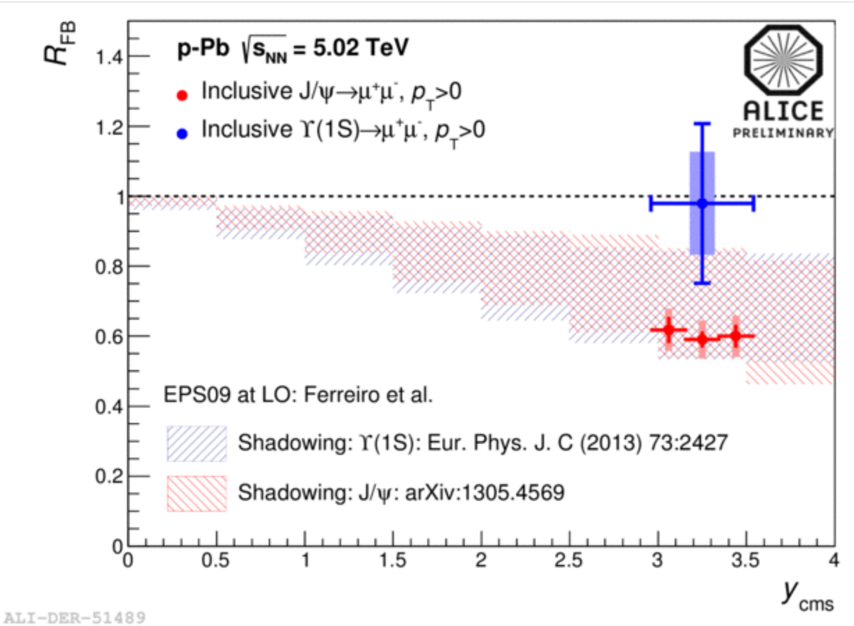


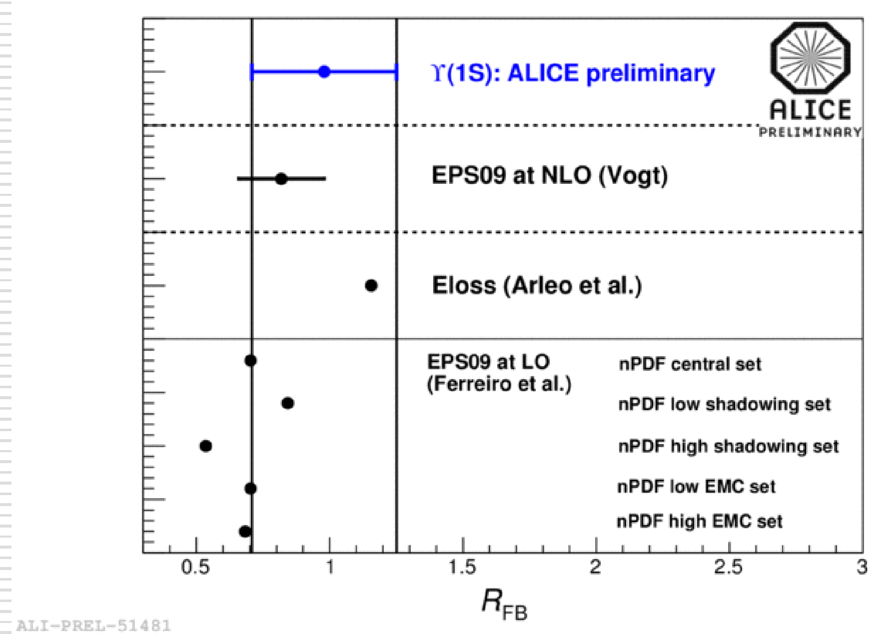
- data suggest suppression of Υ at forward rapidity

- EPS09 calculation at NLO describes well the J/ψ and also the Υ trend



Υ(1S) in p-Pb: R_{FB}





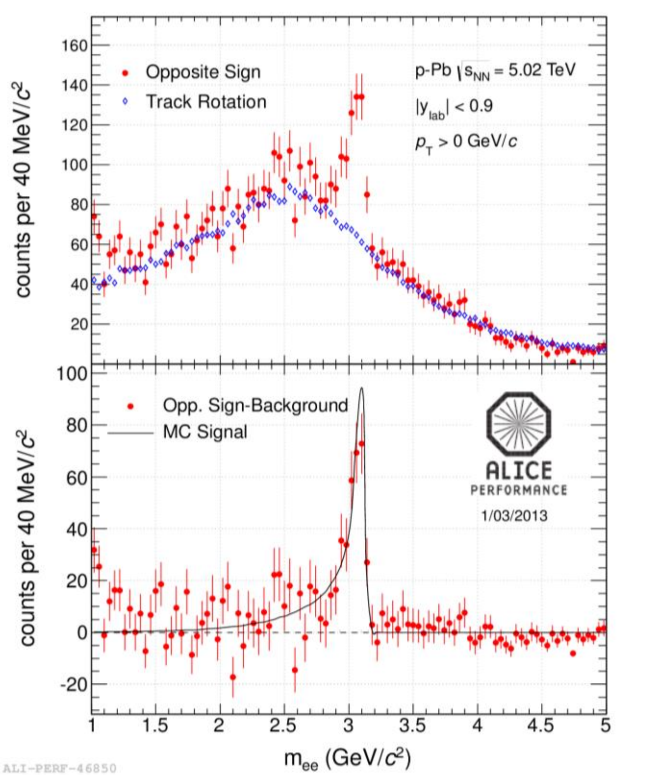
- R_{FB} of Υ close to 1 and larger than that of J/ψ
- within the large uncertainties in agreement with most models

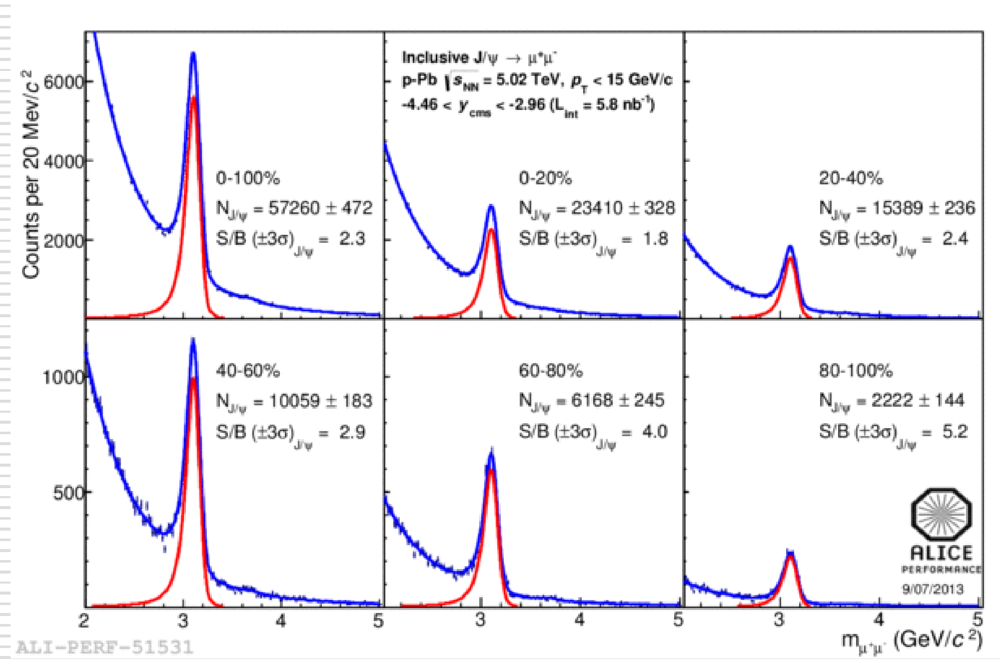
Conclusions

- **Pb-Pb**
  - detailed measurement of **J/ψ** production vs. p_T and rapidity
    - Models including J/ψ production via (re-)combination describe ALICE results on R_{AA} and v_2
  - **ψ(2S)**: ALICE data exclude strong enhancement in central Pb-Pb collisions
  - fraction of **J/ψ from B** hadrons measured down to p_T=2 GeV/c
    - complementary to CMS ; similar trend vs. p_T as in pp
  - Υ: suppression stronger in central collisions, no rapidity dependence within uncertainties

- **p-Pb**
  - inclusive production of **J/ψ** and Υ measured at backward and forward rapidities
    - R_{FB} of J/ψ decreases at low p_T down to ~0.5 in fair agreement with models including coherent energy loss
    - but nuclear shadowing accounts already for most of the observed R_{FB} (R_{pPb});
    - CGC calculations look disfavored

… and prospects





- other results still to be extracted from the 2013 p-Pb data:
  - e.g., J/ψ at mid-rapidity, centrality dependence of J/ψ at forward rapidity, ψ(2S)

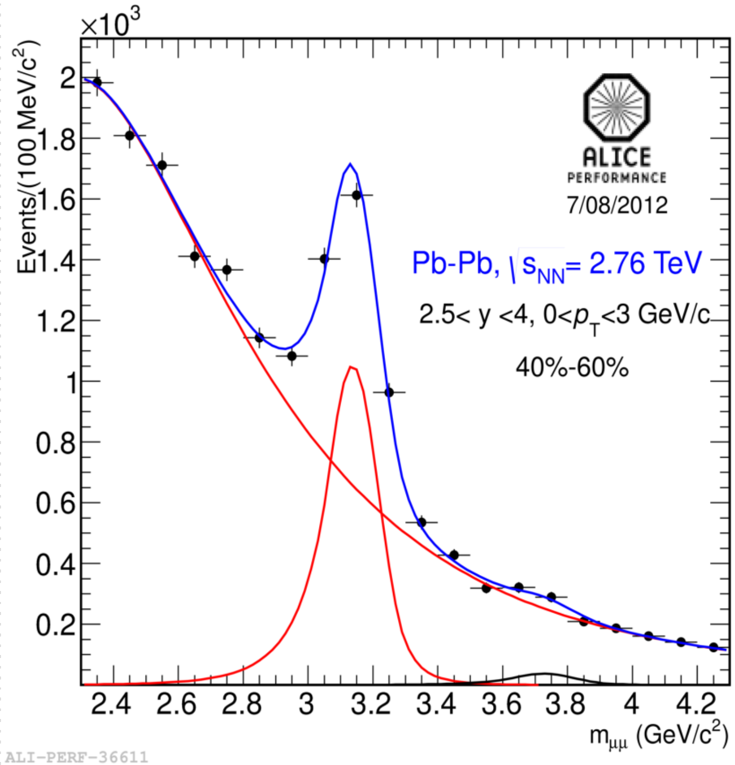
  and in Pb-Pb: e.g., R_{AA} for non-prompt J/ψ

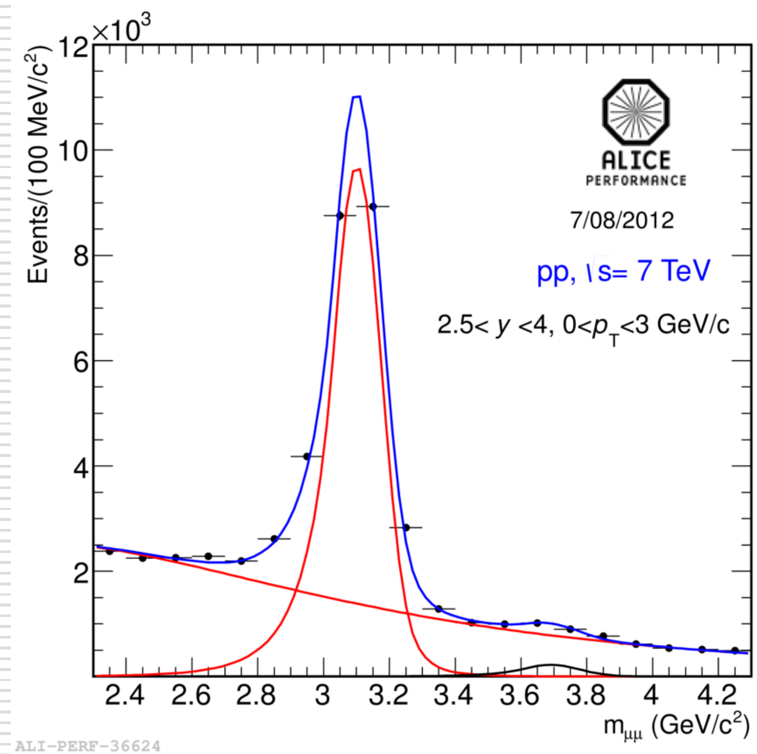
ALICE talks on Quarkonia

- Lizardo Valencia Palomo: "*Charmonium production measurements in Pb-Pb collisions with ALICE at the LHC*", Quarkonia/HF - Friday 16:50
- Igor Lakomov: "*J/ψ production in p-Pb collisions with ALICE at the* LHC", pA collisions - Friday 15:00
- Fiorella Fionda "*Measurements of J/ψ →ee with the ALICE Experiment at the LHC*" Quarkonia/HF - Friday 16:30
- Palash Khan "*Upsilon Production in Pb-Pb Collisions at Forward Rapidity with ALICE at the LHC*" Quarkonia/HF - Friday 17:10

Spares

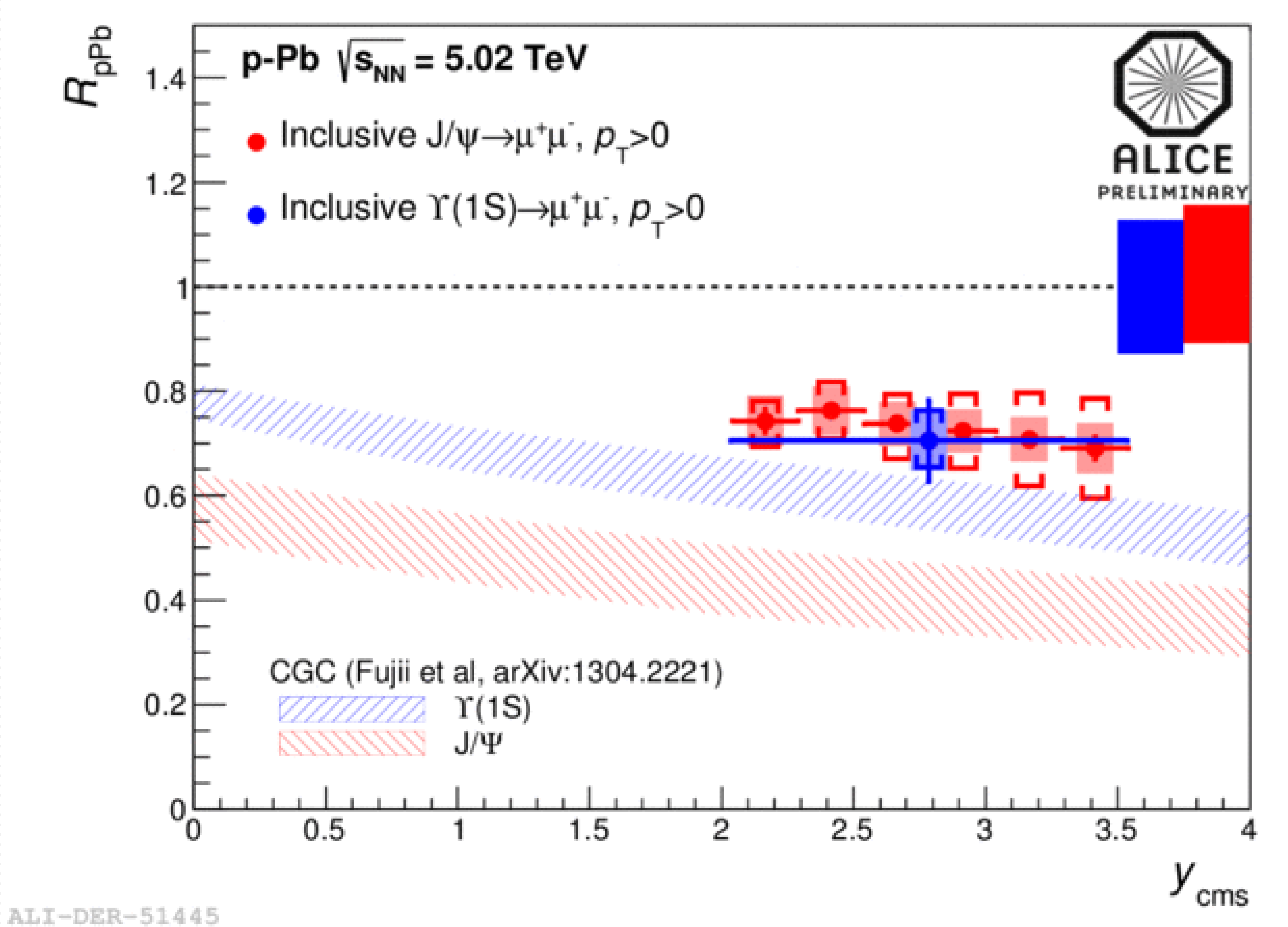
$[\psi(2S)/J/\psi]_{Pb\text{-}Pb} / [\psi(2S)/J/\psi]_{pp}$





- signal extraction only possible in 2 p_T bins:
  - 0 < p_T < 3 GeV/c: 20-40%, 40-60% and 60-90%
  - 3 < p_T < 8 GeV/c : 0-20% and 20-60%.

J/ψ and Υ R_{pPb} compared to CGC



The pp reference at √s = 5.02 TeV

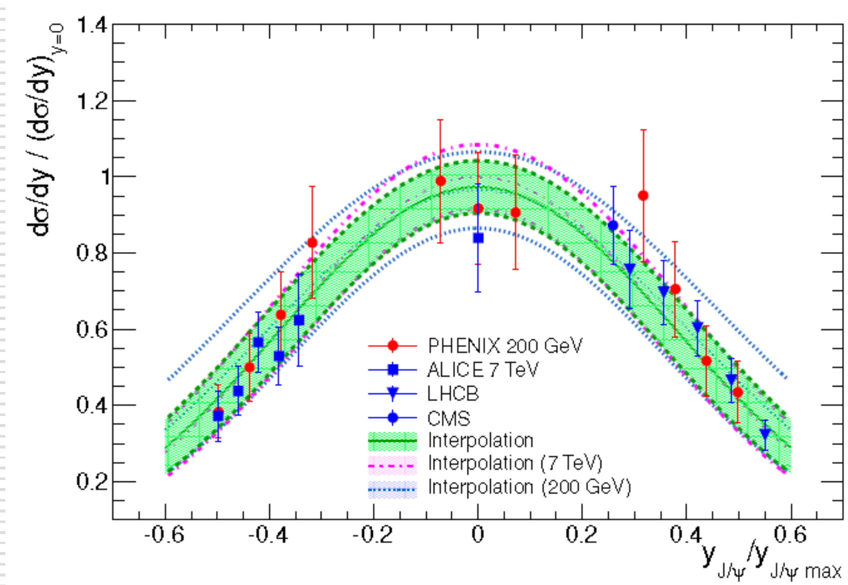
- pp data at □s = 5.02 TeV are not available
  - reference cross section $\sigma_{J/\psi}^{pp}$ obtained through an interpolation procedure (based on F. Bossu' et al., arXiv:1103.2394)
  - $\sigma_{J/\psi}^{pp}$ energy and rapidity dependence interpolated from CDF (√s = 1.96 TeV), PHENIX (√s = 200 GeV), ALICE, LHCb (√s = 2.76 and 7TeV) and CMS (√s = 7TeV) data
- Energy dependence: pp cross section ad mid-rapidity
  - Interpolation based on a phenomenological shape (power-law) gives, at √s = 5.02 TeV

$$BR \times \left.\frac{d\sigma^{pp}}{dy}\right|_{y=0} = 362 \pm 6(stat) + 55(syst) - 37(syst)\, nb$$

  - Systematic uncertainties evaluated fitting test distributions obtained moving data points according to a Gaussian distribution with a width corresponding to 2.5 × their systematic uncertainties (randomly for uncorrelated ones, same direction for correlated ones)
  - Results are in agreement with FONLL and LO CEM calculations

The pp reference at √s = 5.02 TeV

- Rapidity dependence
  - phenomenological approach, based on the observation that PHENIX, ALICE and LHCb and CMS results on $(d\sigma^{pp}/dy)/d\sigma^{pp}/dy|_{y=0}$ vs $y_{J/\psi}/y_{J/\psi,\max}$ are independent on √s

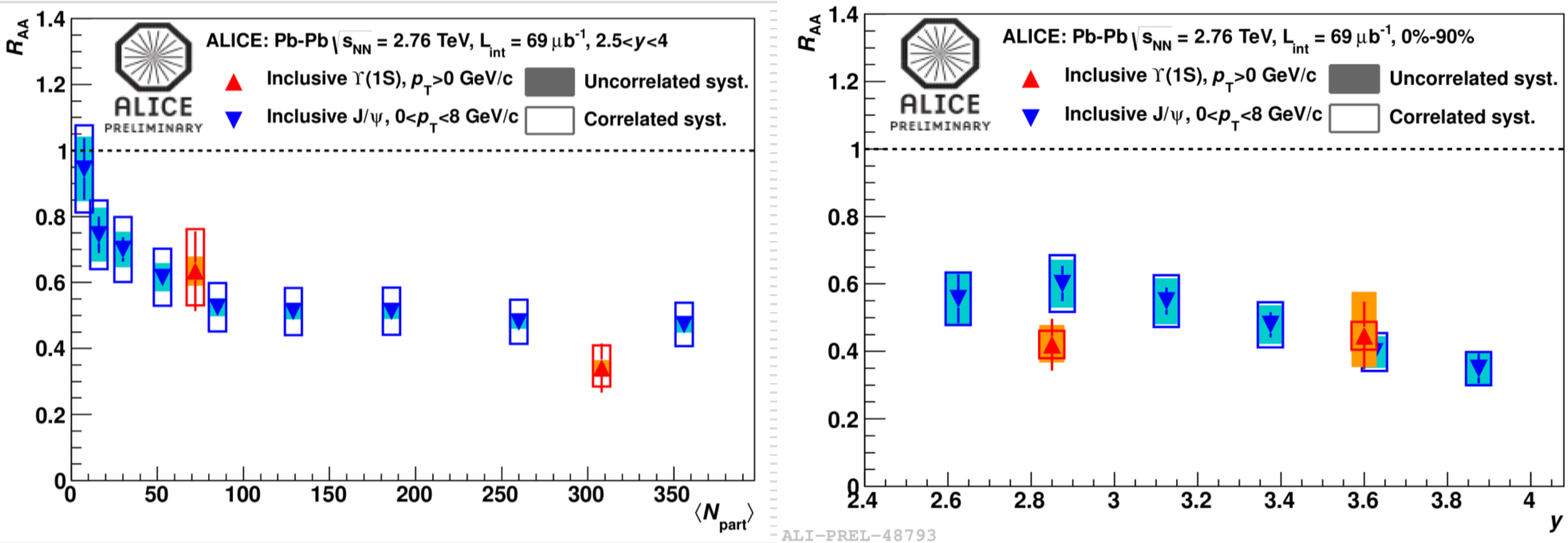


  - The distribution is fitted with a Gaussian shape
  - Systematic uncertainties obtained with the same procedure adopted for the mid-*y* result. The chosen 2.5 sigma cut accommodate results based on FONLL and LO CEM calculations

$$BR´\ ds^{pp}_{J/y}/dy\left(2.03<y_{CMS}<3.53\right)=231+41(syst)-32(syst)\,nb$$

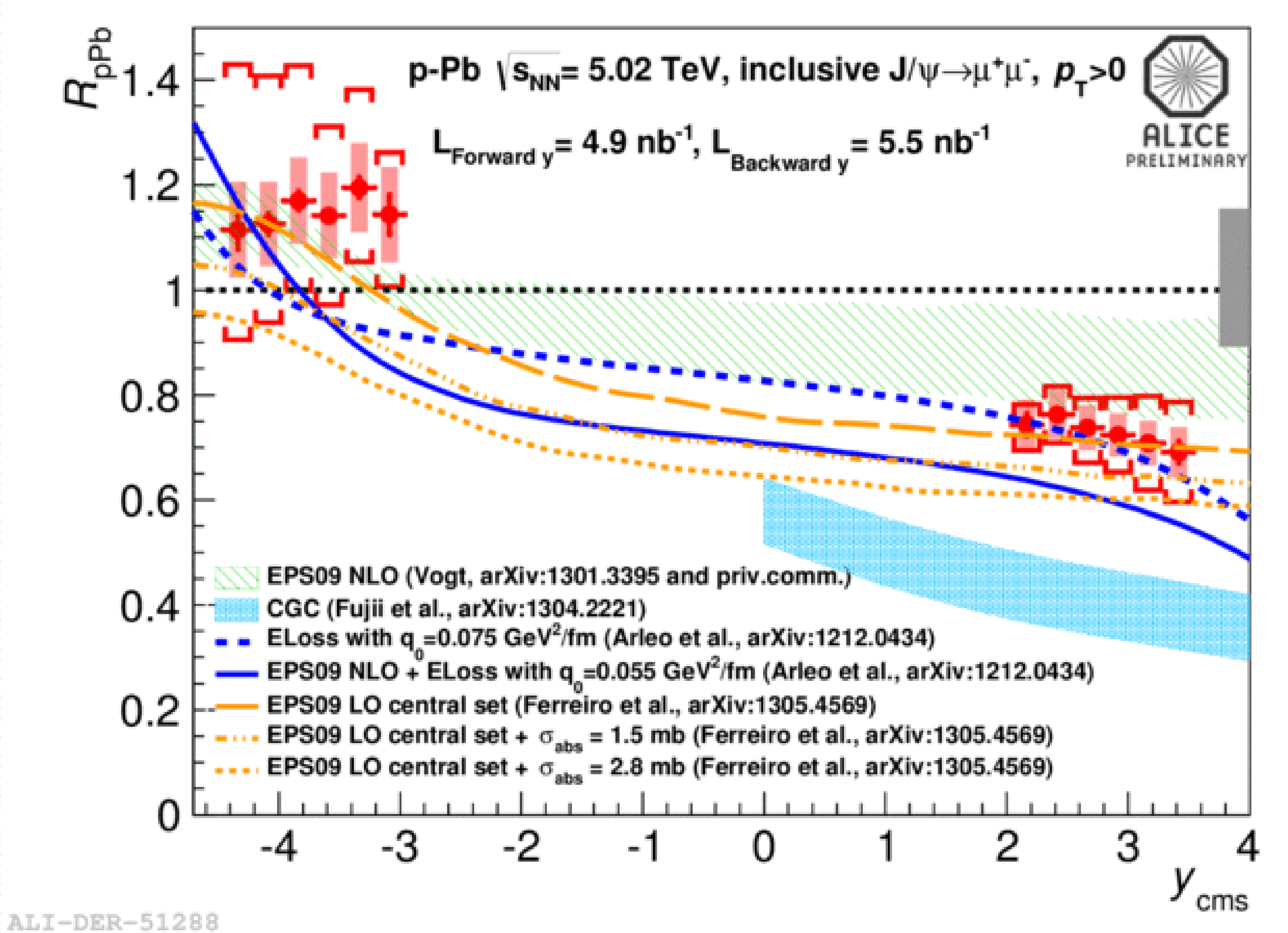
$$BR\times d\sigma^{pp}_{J/\psi}/dy\,(-4.46<y_{CMS}<-2.96)=159+40(syst)-27(syst)\,nb$$

R_{AA}: J/ψ vs. Υ



- surprisingly similar suppression of inclusive J/ψ and Υ, but one may argue that:
  - Υ should be much less subjected to regeneration than J/ψ
  - inclusive Υ suppressed because of the the "sequential melting", as observed by CMS
    - Feed down from higher excited states Υ(2S), Υ(3S), χ_b, χ_b' ~ 50 %

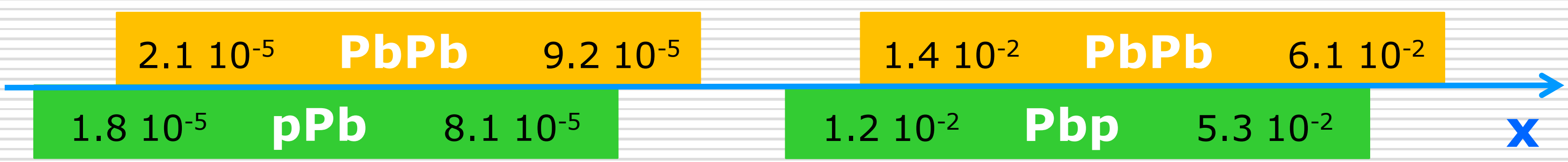
R_{pPb} of J/ψ vs. several models



From p-Pb to Pb-Pb…

- p-Pb results will provide information on the size of CNM effects in Pb-Pb
  - Pb-Pb: $2.5<|y_{CMS}|<4$, $\sqrt{s_{NN}}$ = 2.76TeV
  - p-Pb: slightly different kinematic domain and energy
    $2.04<y_{CMS}<3.54$, $2.96<y_{CMS}<4.46$, $\sqrt{s_{NN}}$ = 5.03TeV

…but Bjorken x regions shifted by only ~10%.
In a 2→1 production mechanism (at p_T~0):



- Work in progress to quantify size of CNM effects in Pb-Pb results!