Quarkonium production in ALICE

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CEA/IRFU

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Contents

- Introduction (Quarkonia, Cold Nuclear Matter Effects, QGP, ALICE)
- New results on quarkonium production in p-Pb collisions
- Review of (some) results on quarkonium production on Pb-Pb collisions

Inclusive measurements:

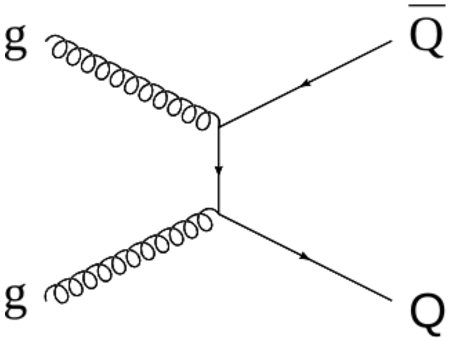
- direct production
- contributions from higher state resonances (ψ(2S) and χ_c)
- contribution from B mesons

Introduction

Heavy Quarkonia

Bound states of charm quarks (J/ψ, ψ’ and χ_c) and beauty quarks (ϒ 1S, 2S and 3S) that are stable for the strong interaction.

Due to their high mass, they can be produced at the early stage of the collision via the hard scattering of gluons:



	Mass (GeV)	Radius (fm)
J/ψ	3.1	0.50
χ_c	3.53	0.72
ψ(2S)	3.68	0.90
ϒ(1S)	9.5	0.28
ϒ(2S)	10.02	0.56
ϒ(3S)	10.36	0.78

hep-ph/0512217

In nuclear collisions, their production can be altered with respect to pp by
- cold nuclear matter effects
- the formation of a Quark Gluon Plasma

They can be *easily* measured via their decay into two leptons

Quarkonium production in Pb-Pb collisions

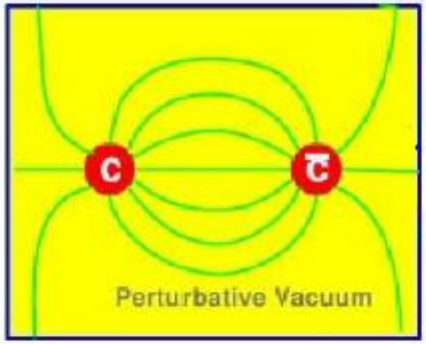
Color Screening **PLB 178, 416 (1986)**

In presence of a QGP, the binding potential of the QQbar pair is screened by the surrounding color charges, at distances $r > r_D$.

r_D becomes smaller for increasing temperature. If smaller than the bound state radius, the latter cannot be formed.

One defines a Debye temperature T_D, above which the bound state is suppressed.

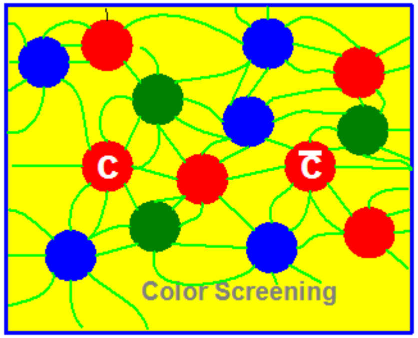
In vacuum



Bound State	J/ψ	χ_c	Ψ’	ϒ(1S)	ϒ(2S)
T_D/T_c	1.2	≤1	≤1	2	1.2

arXiv:0706.2183

In QGP



Recombination **nucl-th/0303036, hep-ph/0306077**

Formation of heavy quarkonia, in the QGP or at the phase boundary, by the coalescence of uncorrelated heavy quarks from the medium.

Recombination rate is proportional to $(dn_Q/dy)^2$. It is therefore crucial to measure the heavy quark production cross-section

Quarkonium production in p-Pb collisions

Cold Nuclear Matter Effects

Effects that can alter the production of quarkonia in heavy ion collisions with respect to pp collisions, even in absence of a QGP.
One must measure and account for such effects in order to evidence the effects of the QGP.

- Gluon shadowing, or saturation (CGC), at small x
  relates to the fact that low x gluon density is smaller in A than in p
- Energy loss and p_T broadening
  In medium gluon radiation of the incoming gluons and ccbar quarks before forming the bound state
- Nuclear absorption
  breakup of the quarkonia by interaction with surrounding nucleons
  small at LHC because the quarkonium formation time is much longer than the crossing time of the colliding nuclei

Studying quarkonium production in pA collisions

- provides insight on the initial state of the nuclear collision
- serves as a reference for nuclear effects that are not due to a QGP

Why measure several quarkonium states

For Cold Nuclear Matter effects

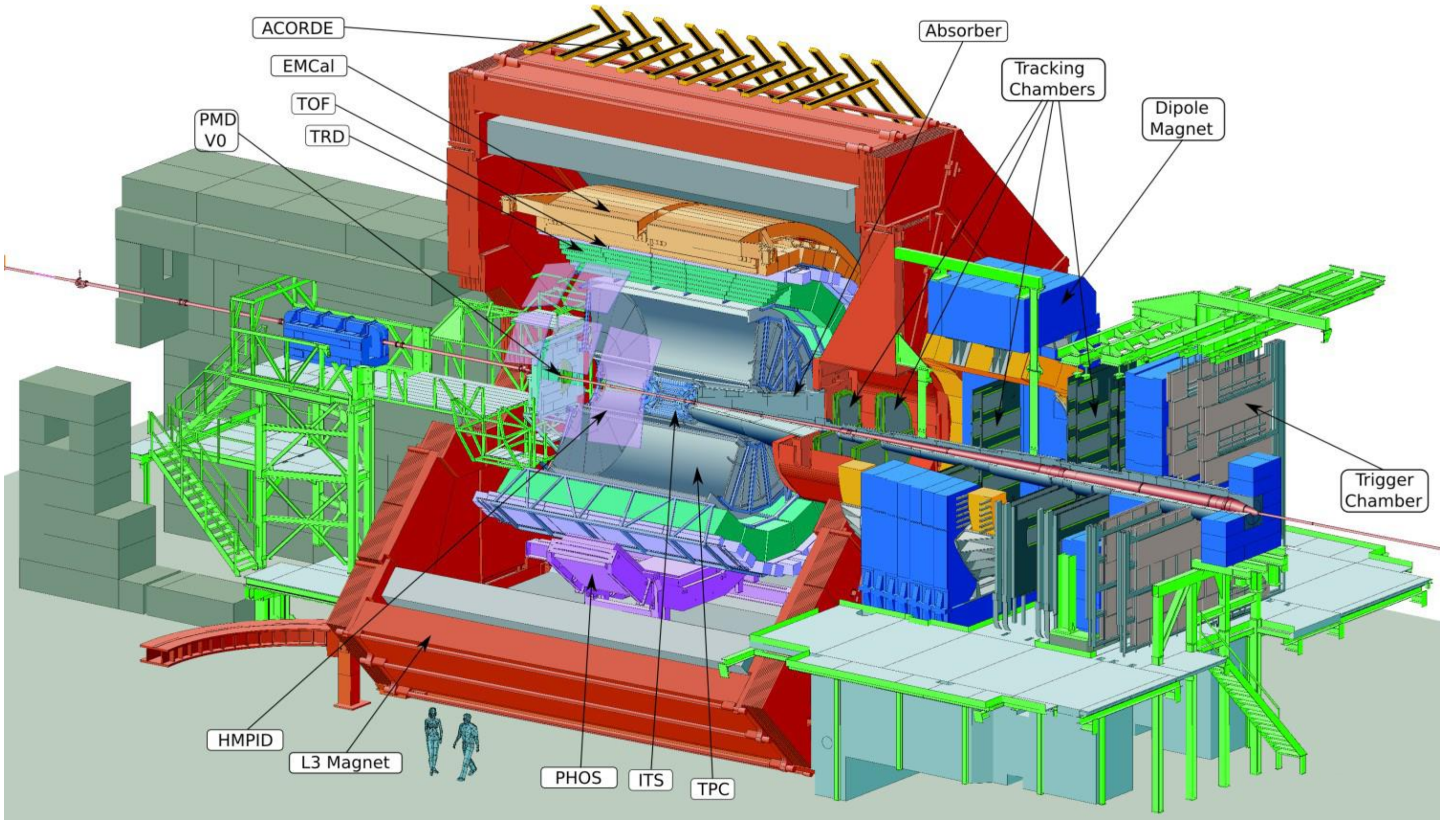
- probe different gluon x ranges in the nucleus (same is true when looking at different rapidity ranges)
- have different formation time
- have different partonic and hadronic cross-sections (for energy loss and nuclear break-up)

For Quark-Gluon Plasma

- have different melting temperatures (because of binding energy)
- have different recombination rates (due to heavy-flavor production cross-sections)

In general, the mechanisms at play should be qualitatively the same, but with different magnitudes.

ALICE



Quarkonia are measured

- at mid rapidity ($|y_{lab}|<0.9$) in the e^+e^- channel, using TPC and ITS
- at forward rapidity ($2.5<y_{lab}<4$) in the $\mu^+\mu^-$ channel, using MCH, MTR and ITS

Trigger systems use VZERO, ITS and MTR

quarkonium Production in p-Pb collisions

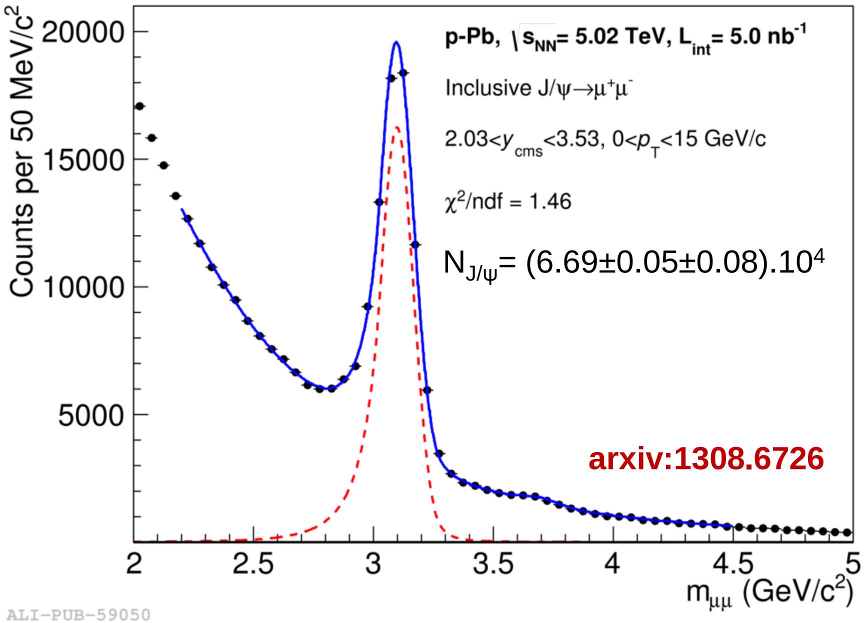
Data samples

Two data taking periods in 2013 ($\sqrt{s_{NN}}$=5.02 TeV)

- p-Pb: muon detector on the p-going side $2.03 < y_{CMS} < 3.53$
  Luminosity: 5 nb^{-1}
- Pb-p: muon detector on the Pb-going side $-4.46 < y_{CMS} < -2.96$
  Luminosity: 5.8 nb-1

Note the rapidity shift between the two configurations due to different energies per nucleon between the two beams

Triggers: Min-Bias (VZERO) + opposite sign di-muon trigger (VZERO+MTR)



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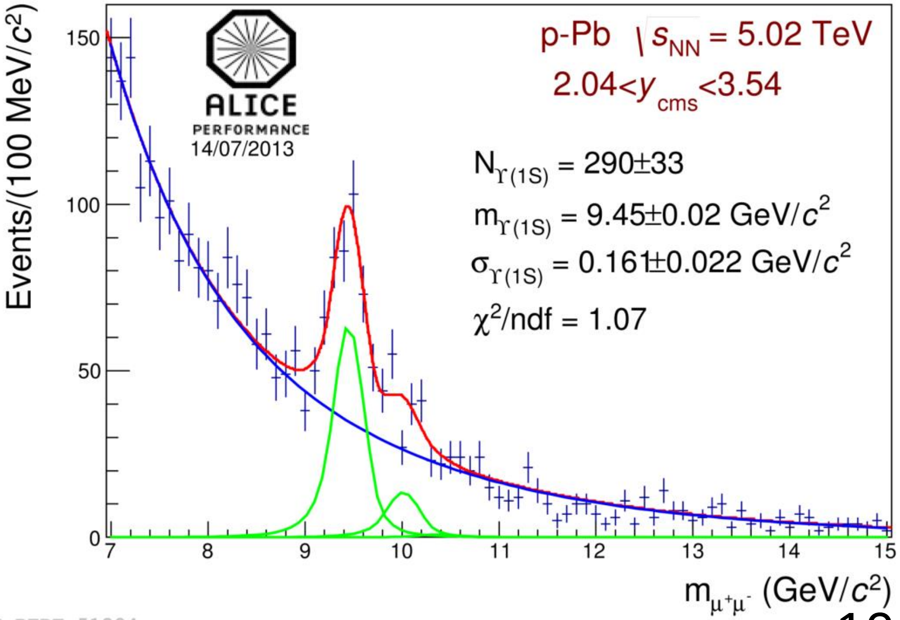

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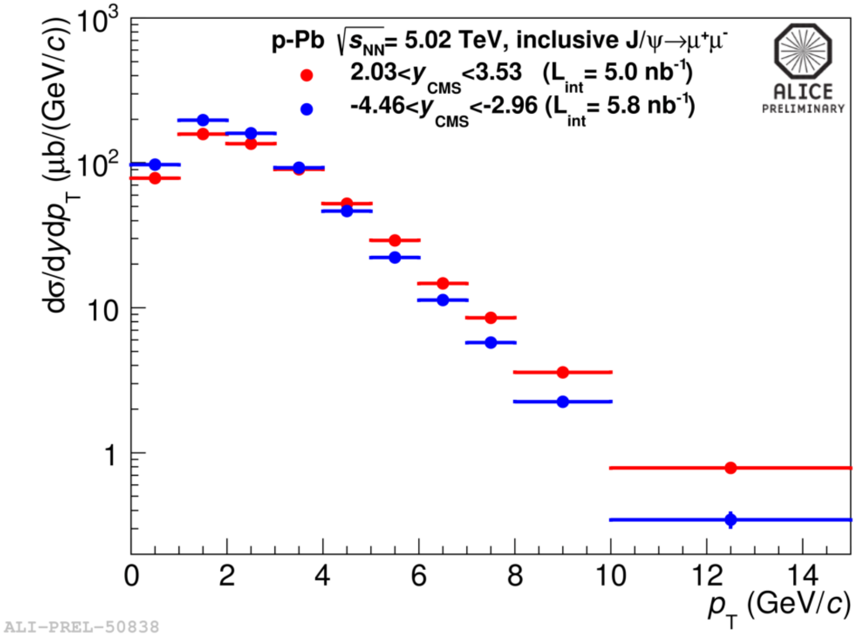
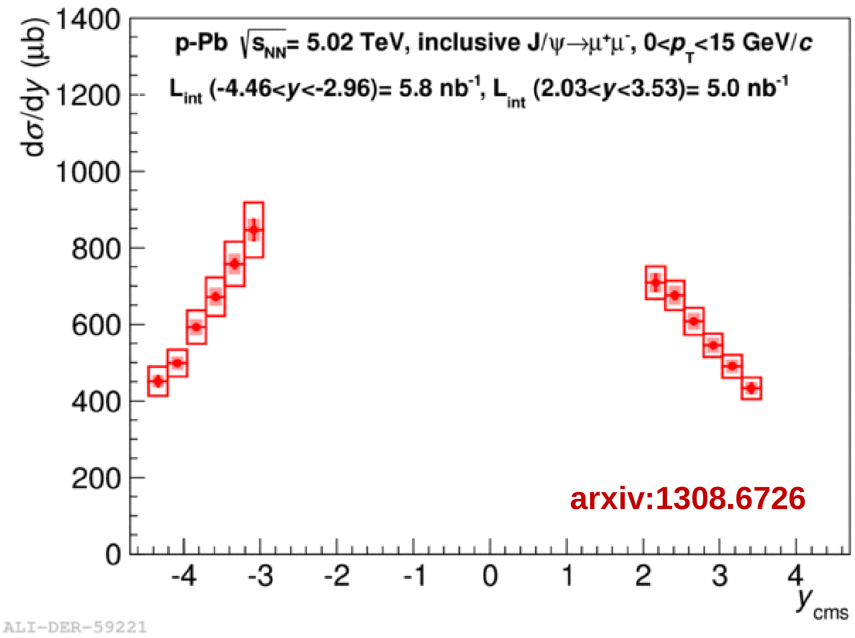
J/ψ production in p-Pb vs p_T and rapidity





y>0 (red) is the p-going direction. Probes small x in the Pb nucleus (~10^{-5})
y<0 (blue) is the Pb-going direction. Probes large x in the Pb nucleus (~10^{-2})

Statistical uncertainties are negligible
Systematic uncertainties (6-8%) are dominated by the tracking efficiency

boxes: uncorrelated systematic uncertainties
shaded area: partially correlated

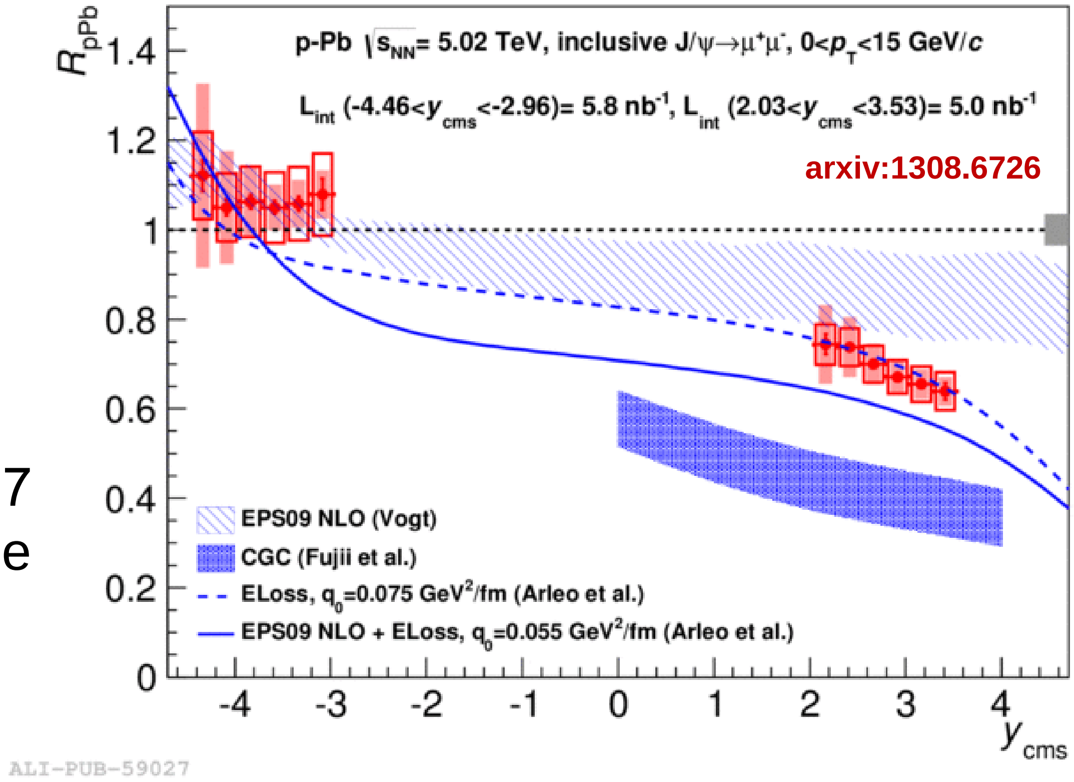
Cross-section is smaller at y>0, and p_T distribution is harder

J/ψ R_{pPb} vs rapidity

$$R_{\mathrm{pPb}}^{J/\Psi} = \frac{Y_{\mathrm{pPb}}^{J/\Psi}}{T_{\mathrm{pPb}} . \sigma_{\mathrm{pp}}^{J/\Psi}}$$

J/ψ cross section in pp is interpolated from ALICE measurements at √s = 2.76 and 7 TeV + fits for rapidity dependence

Introduces a sizable additional systematic uncertainty



A suppression is observed for y>0, consistent with shadowing and energy loss, with no need for nuclear absorption/breakup

The CGC approach overestimates the suppression

Contributions from B meson decays are well within systematic uncertainties, and do not affect the conclusions

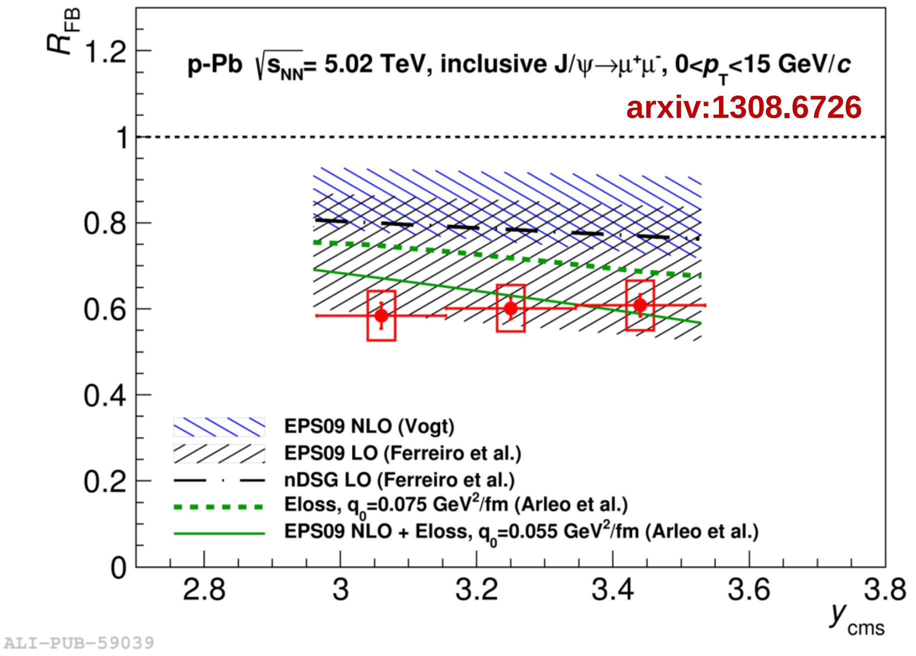
J/ψ Forward/Backward ratio R_{FB}

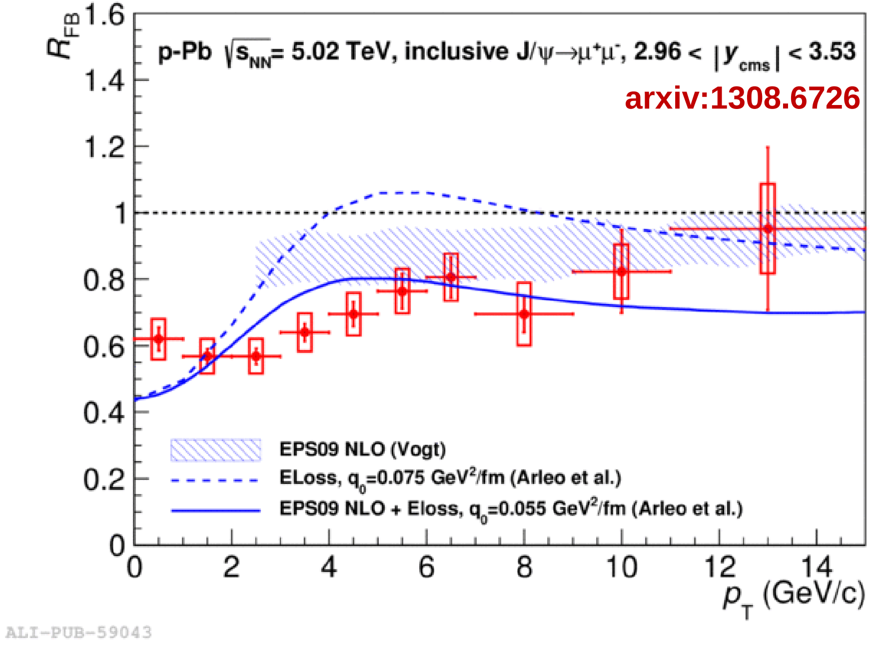
$$R_{\mathrm{FB}}^{J/\Psi} = \frac{Y_{\mathrm{p\text{-}Pb}\,(y>0)}^{J/\Psi}}{Y_{\mathrm{Pb\text{-}p}\,(y<0)}^{J/\Psi}}$$

Several systematic uncertainties cancel in the ratio and there is no need for pp reference

Statistic is decreased because one has to match the rapidity range between the two data sets

Comparison to theory is less stringent than R_{pPb}

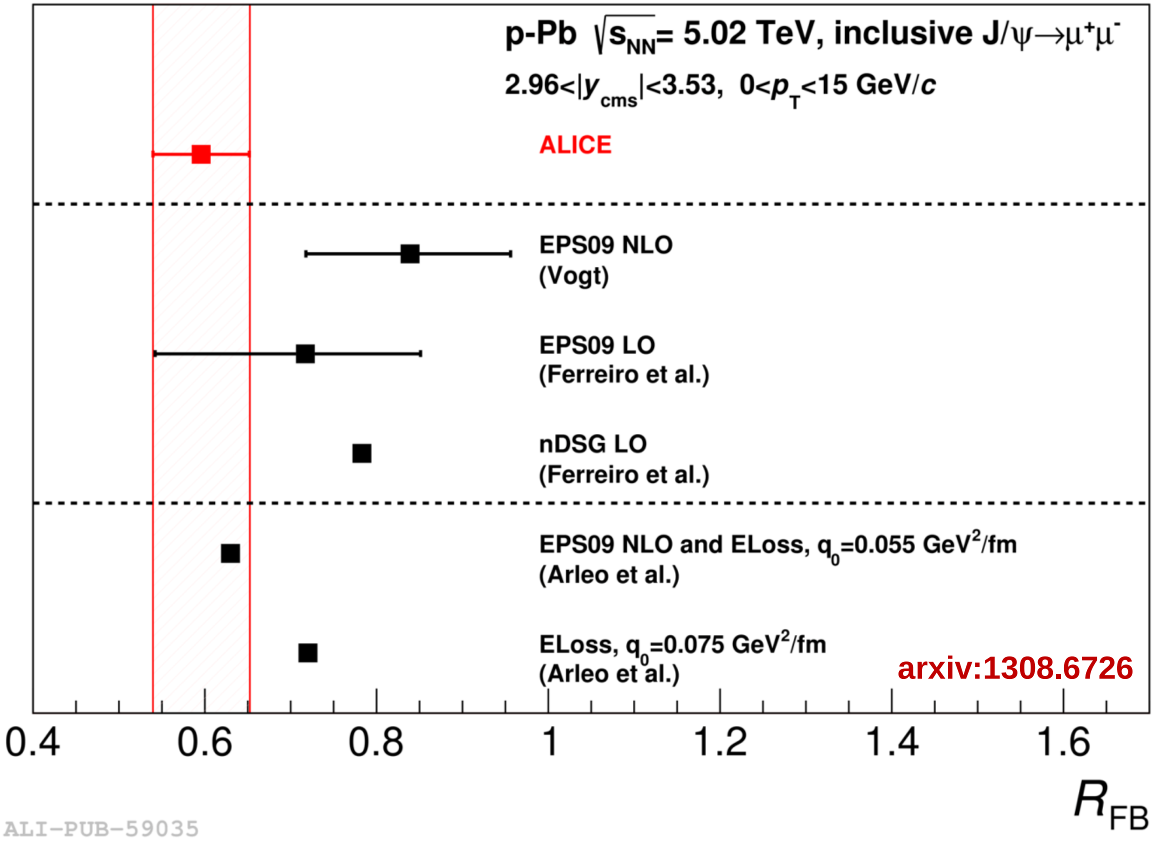




Little to no dependence of R_{FB} on y, qualitatively consistent with models

More suppression at low p_T than at high p_T, but less dependence than energy loss models. R_{FB} is well reproduced for p_T>5 GeV

J/ψ integrated R_{FB} vs models

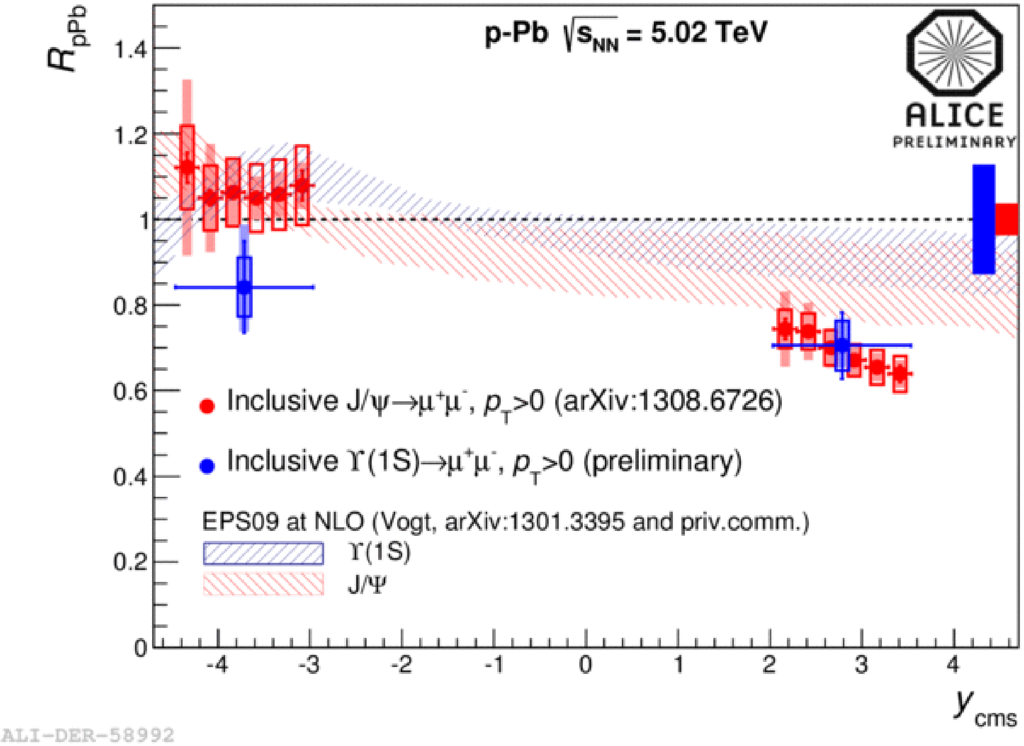


Shadowing models (with different parameterizations of the npdf) overestimate R_{FB}, and have large uncertainties

Adding energy loss improves the agreement with the data

CGC has no prediction at y<0 (large x in Pb) and cannot be compared to R_{FB}

Υ(1S) R_{pPb}



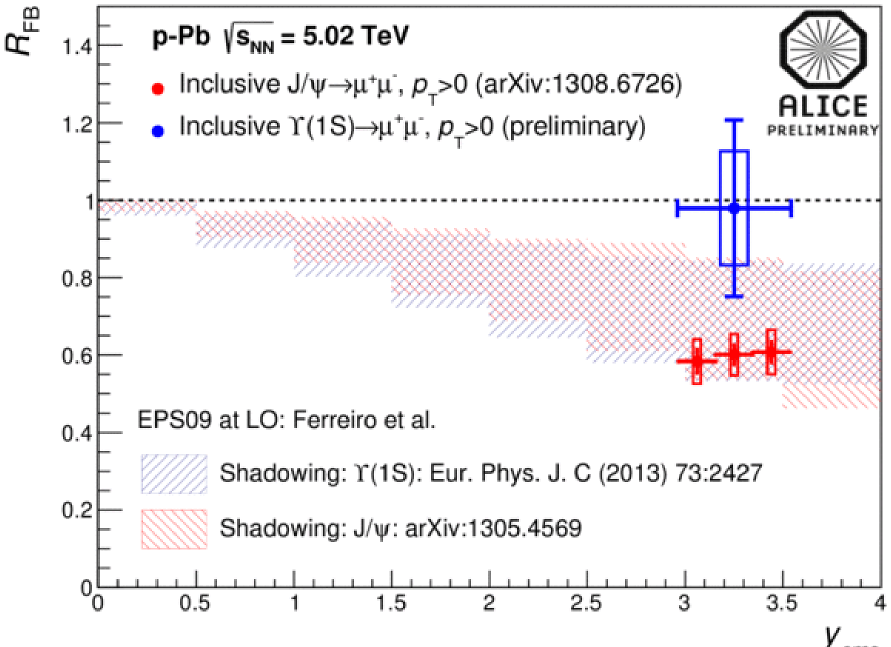
Statistics is limited
Only one bin in rapidity

pp reference obtained by interpolating results from Tevatron (D0) and LHC (CMS and LHCb) + PYTHIA for rapidity dependence

Suppression at y>0 has the same magnitude as for the J/ψ

Shadowing model tends to overestimate the Υ(1S) R_{pPb} on the full y range, but data have large global uncertainties

Υ(1S) R_{FB}



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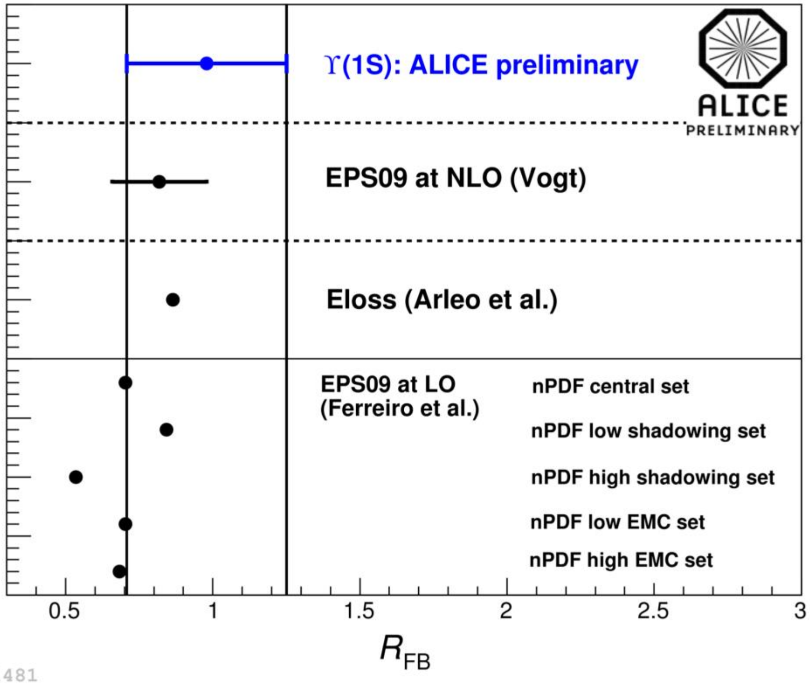

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R_{FB} is compatible with unity, and larger than the J/ψ

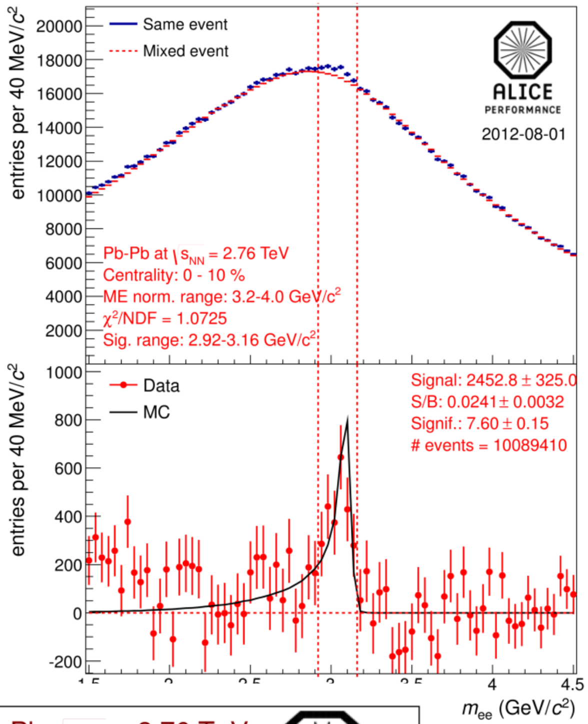
It is compatible with most models

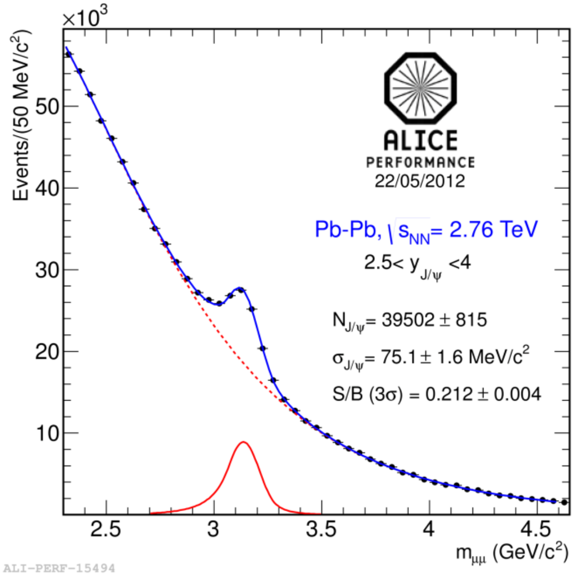
Quarkonium production in Pb-Pb collisions

Data samples

At mid rapidity (|y|<0.9)
2010 + 2011 data sets ($\sqrt{s_{NN}}$ = 2.76 TeV)
Minimum bias trigger (VZERO + ITS)
Centrality triggers (for 2011 dataset)
Luminosity: 27.9 μb^{-1}

At forward rapidity (2.5<y<4)
2011 data set
Minimum bias + opposite sign di-muon trigger
Luminosity: 69.4 μb^{-1}





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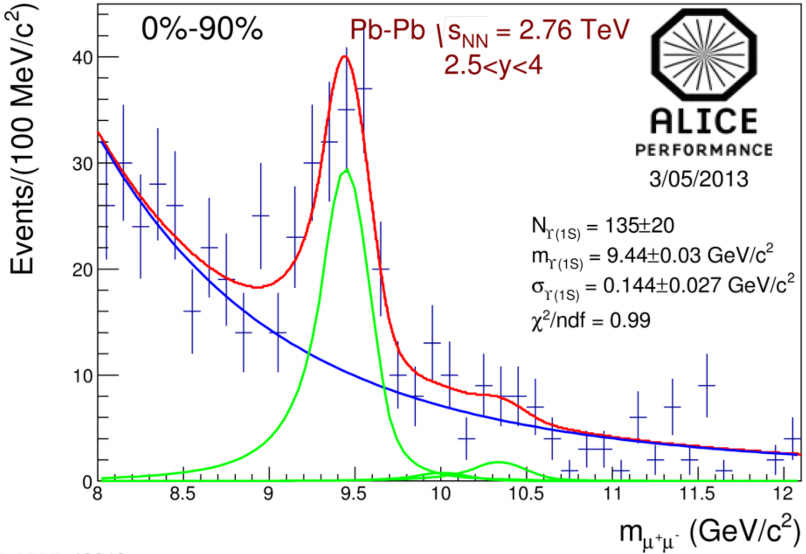

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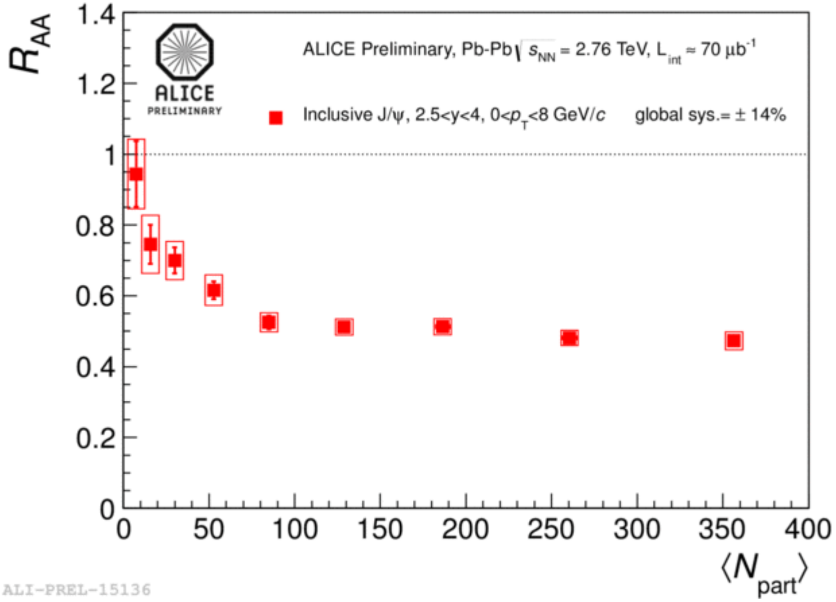
J/ψ R_{AA} vs centrality



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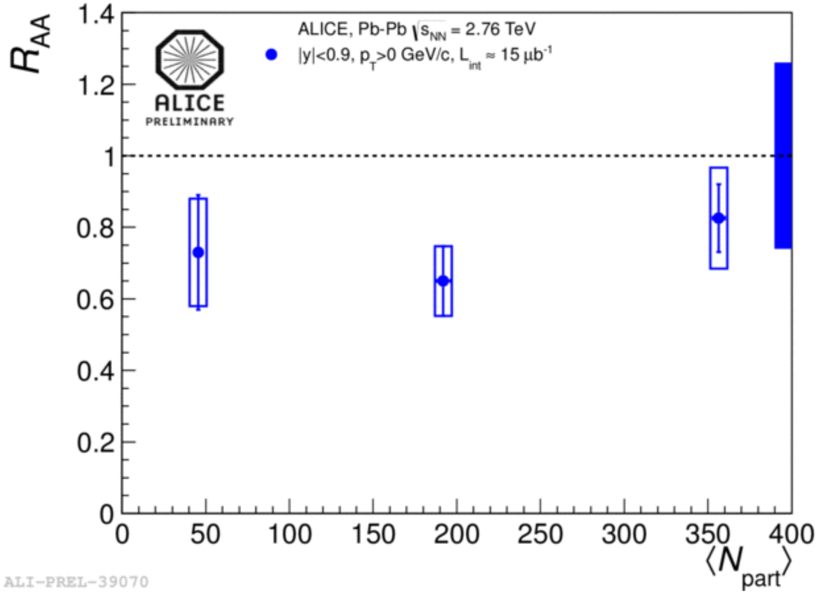

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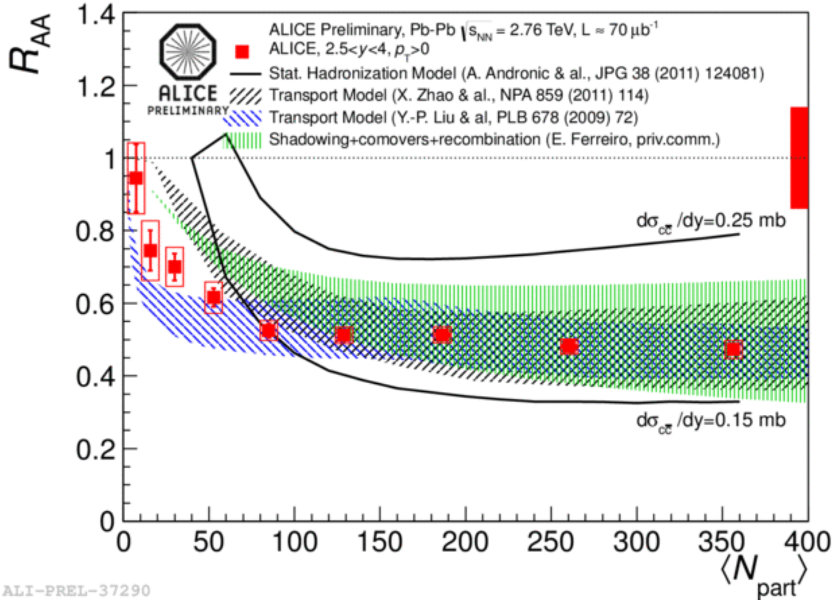
A suppression is observed at both forward- and mid-rapidity for N_{part} > 50 with little dependence on centrality

Contribution from B mesons’ decay ranges from

- -6 to +7% at forward-rapidity
- -9 to +17% at mid-rapidity

J/ψ R_{AA} vs centrality, comparison to models



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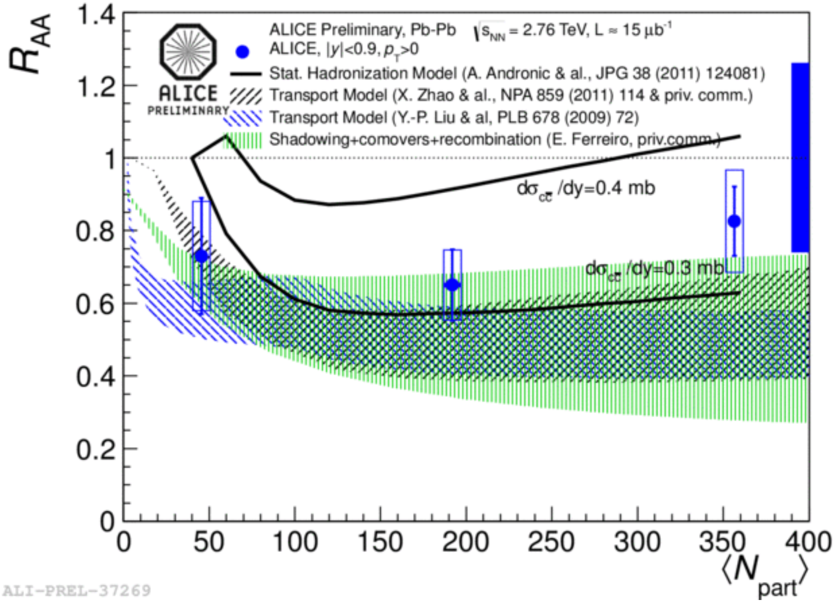

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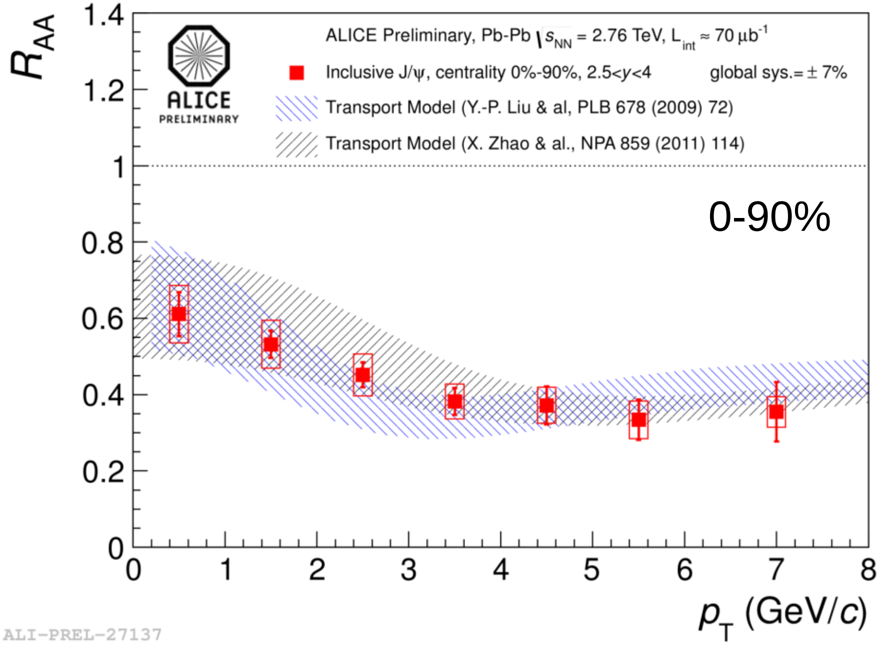
<u>Models</u>:

- Statistical hadronization assumes full suppression of primordial J/ψ and recombination at phase boundary (requires σ_{ccbar})
- Transport models include shadowing, direct suppression and regeneration
- Comover model includes shadowing, interaction with co-moving medium and regeneration

Constraining cold nuclear matter effects is crucial to all these approaches

J/ψ R_{AA} vs p_T



0-90%

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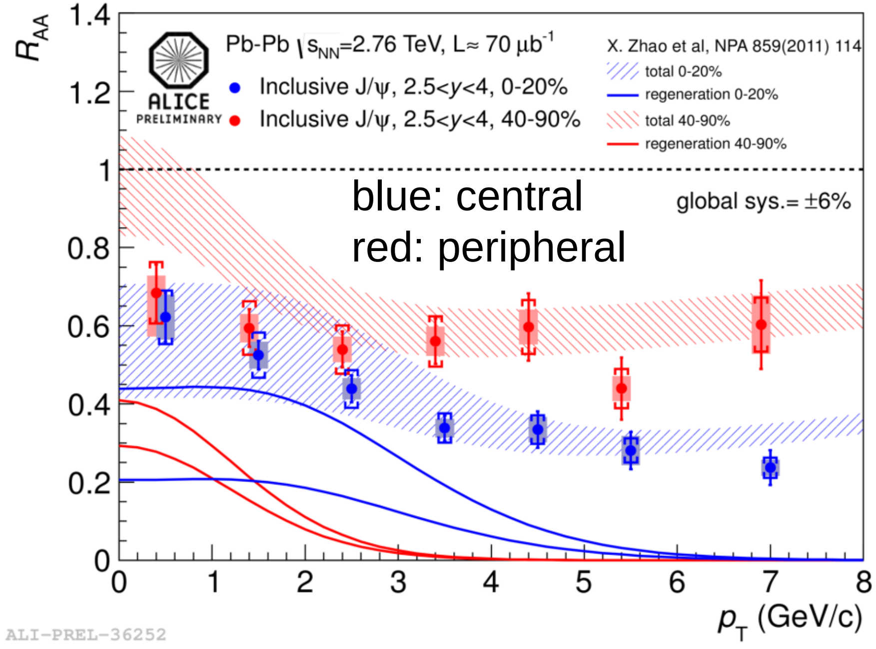


blue: central
red: peripheral

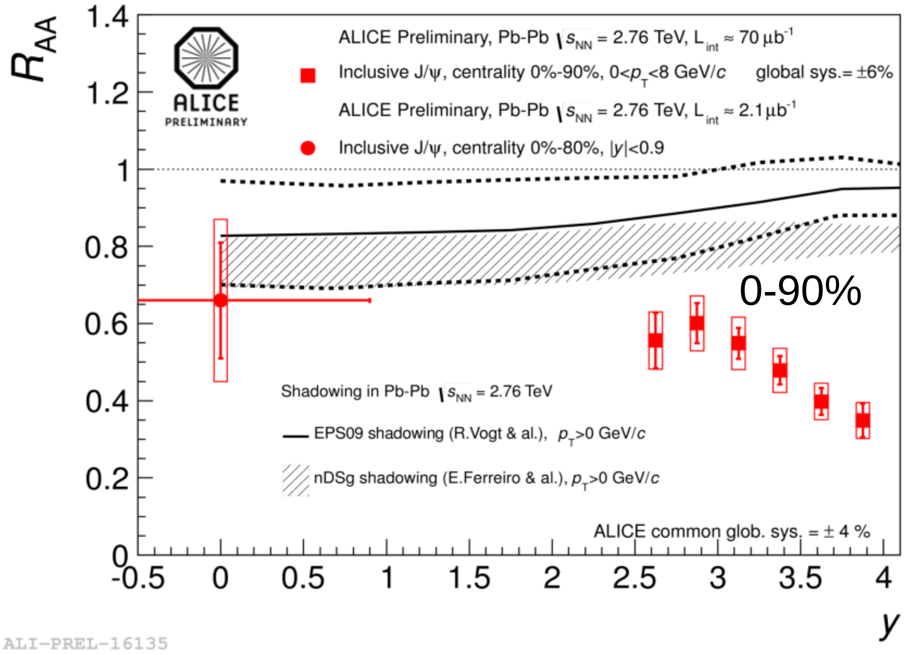
ALI-PREL-36252

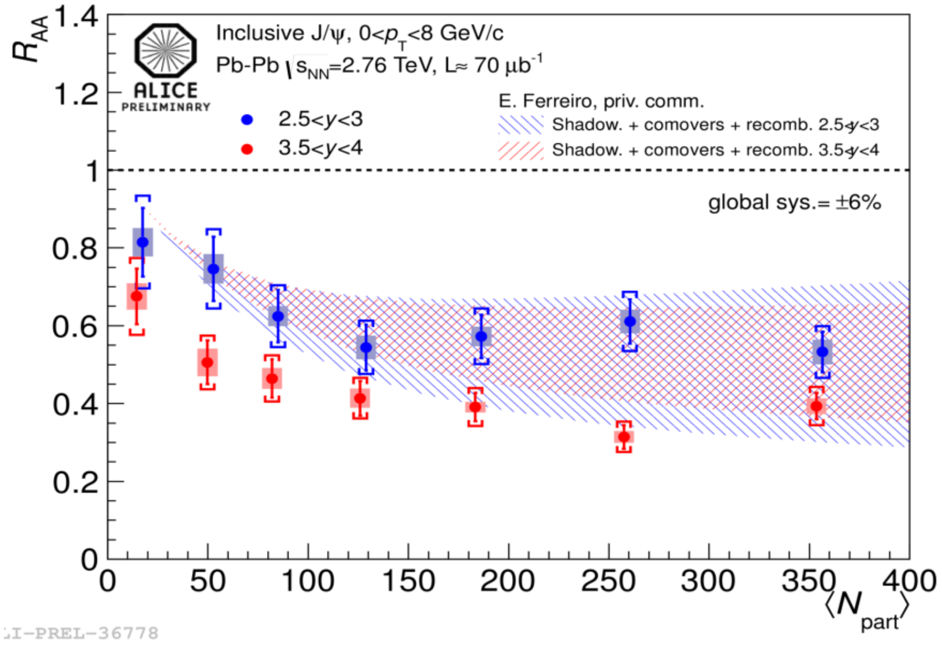
For central collisions, R_{AA} is smaller at high p_T than at low p_T.

This is consistent with regeneration scenarios

As on previous slide, cold nuclear matter effects dominates the theoretical uncertainties (shadowing, effective $\sigma_{breakup}$, etc.)

J/ψ R_{AA} vs rapidity





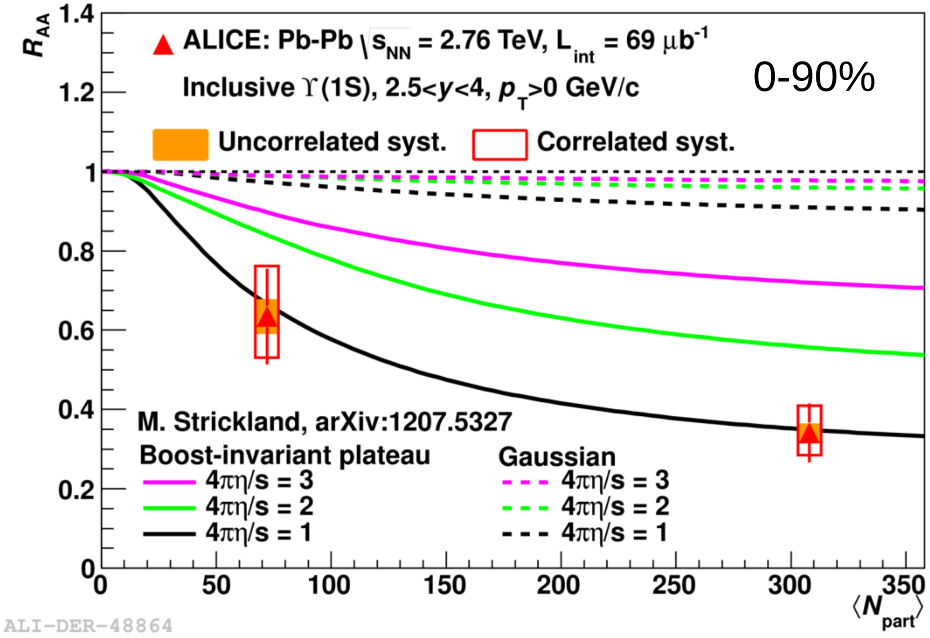
Left

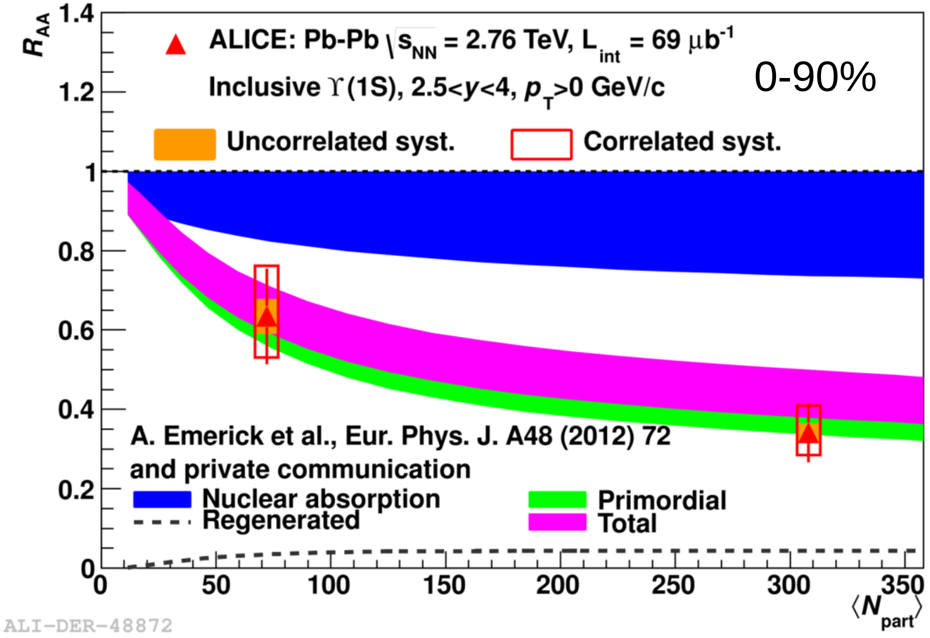
J/ψ R_{AA} vs rapidity for minimum bias collisions compared to estimated cold nuclear matter effects (shadowing). Needs update based on our p-Pb results

Right

J/ψ R_{AA} vs centrality for two bins in rapidity, compared to comover model. R_{AA} is smaller at more forward rapidity, not seen by the model

Υ(1S) R_{AA} vs centrality





Large suppression is observed at forward rapidity for central collisions.

Models:

- Screened potential, hydro-like evolution of the QGP, feed-down from higher mass states, no CNM nor recombination
- Transport model with direct suppression, regeneration and cold nuclear matter effects (using phenomenological absorption cross-section)

Conclusions

Conclusions

Alice has measured J/ψ and Υ(1S) production in p-Pb and Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 and 2.76 TeV

In p-Pb collisions

- A suppression of the J/ψ is observed at y>0 (small x)
  Most of it is accounted for by nuclear shadowing
  Adding energy loss improves the agreement
  CGC calculations overestimate the suppression
- A similar suppression is observed at y>0 for the Υ(1S)
  R_{FB} is consistent with 1, in agreement with shadowing and e-loss predictions

In Pb-Pb collisions

- A suppression of the J/ψ is observed for N_{part}>50, with little dependence on centrality. It is less pronounced at low p_T
  Models that include cold nuclear matter effects, color screening and regeneration can reproduce the data
- A suppression of about the same magnitude is observed for the Υ(1S), with large uncertainties

Most models will benefit from the p-Pb results to better constrain CNM

Perspectives

Things to come

- Cold nuclear matter effects on J/ψ in p-Pb at mid-rapidity
- Centrality dependence of cold nuclear matter effects on J/ψ
- Cold nuclear matter effects on ψ(2S) at forward rapidity
- Update on model calculations in Pb-Pb based on our better knowledge of the CNM

Other presentations on Quarkonia in ALICE:

- L. Aphecetche on Thursday, 6:20 PM, more details on the J/ψ analysis and results in p-Pb collisions
- D. De Gruttola on Friday, 10AM, J/ψ photo-production in ultra-peripheral p-Pb and Pb-Pb collisions

Afterword

Things I have not shown

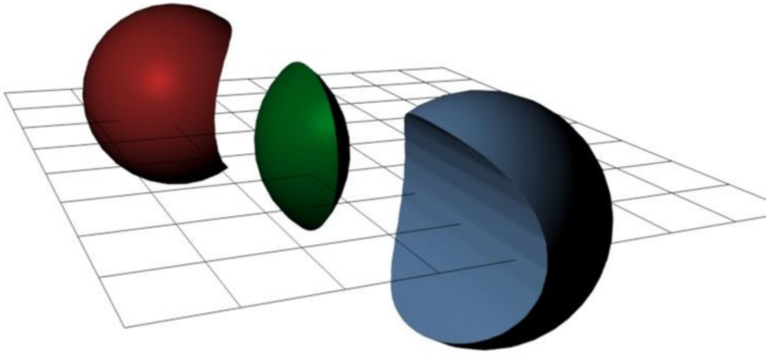
- None of the pp results **arxiv:1205.5880, arXiv:1202.2816, PLB718 (2012) 295, PLB718 (2012) 692–698**
- J/ψ elliptic flow parameter v_2 in Pb-Pb at forward rapidity **arXiv:1303.5880**
- Modifications of the ψ(2S) relative to the J/ψ in Pb-Pb at forward rapidity
- Separation between prompt and non-prompt J/ψ at low p_T in Pb-Pb at mid-rapidity

Thank you

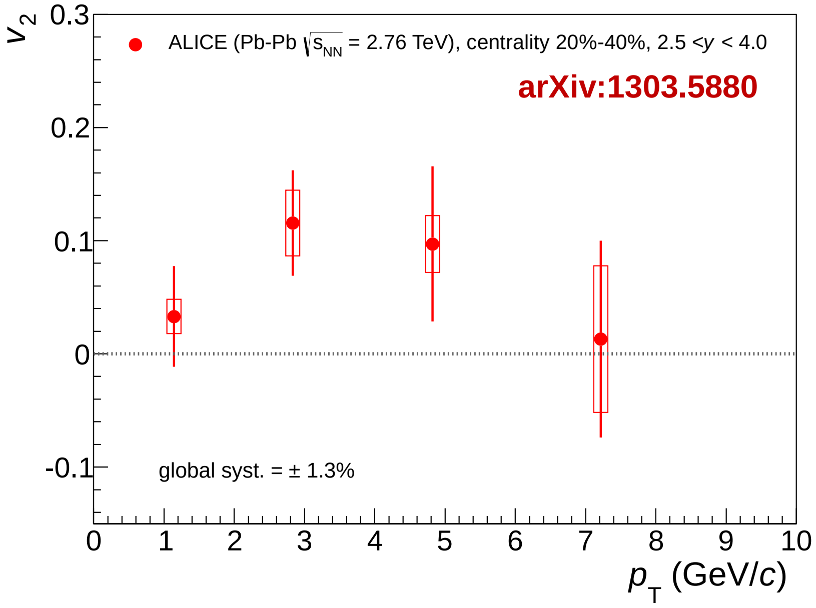
Backups

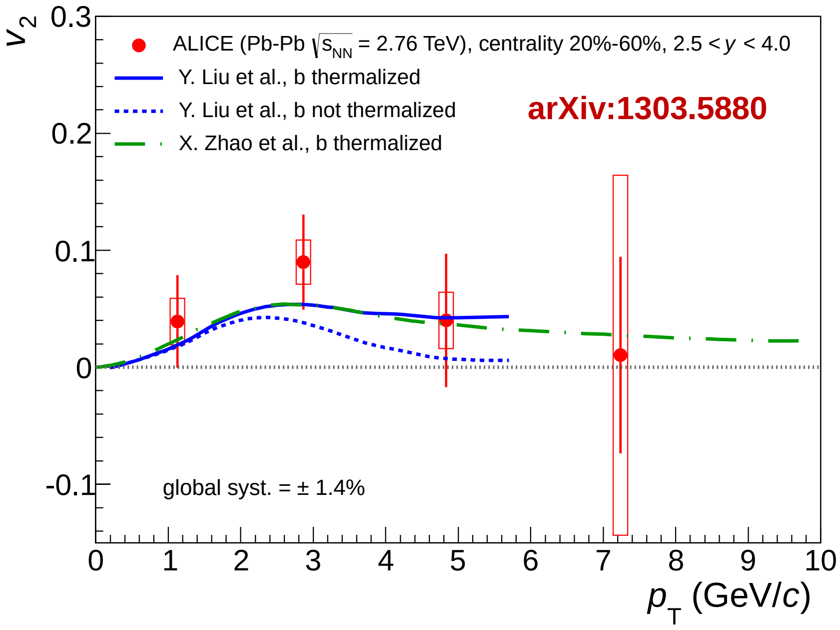
J/ψ elliptic flow parameter v_2 in Pb-Pb

The elliptic flow parameter v_2 characterizes the azimuthal anisotropy of particle emission with respect to the collision's reaction plane.



J/ψ coming from the recombination of uncorrelated + thermalized charm quarks are expected to have a non-zero v_2, originating from the (measured) elliptic flow of the thermalized quarks





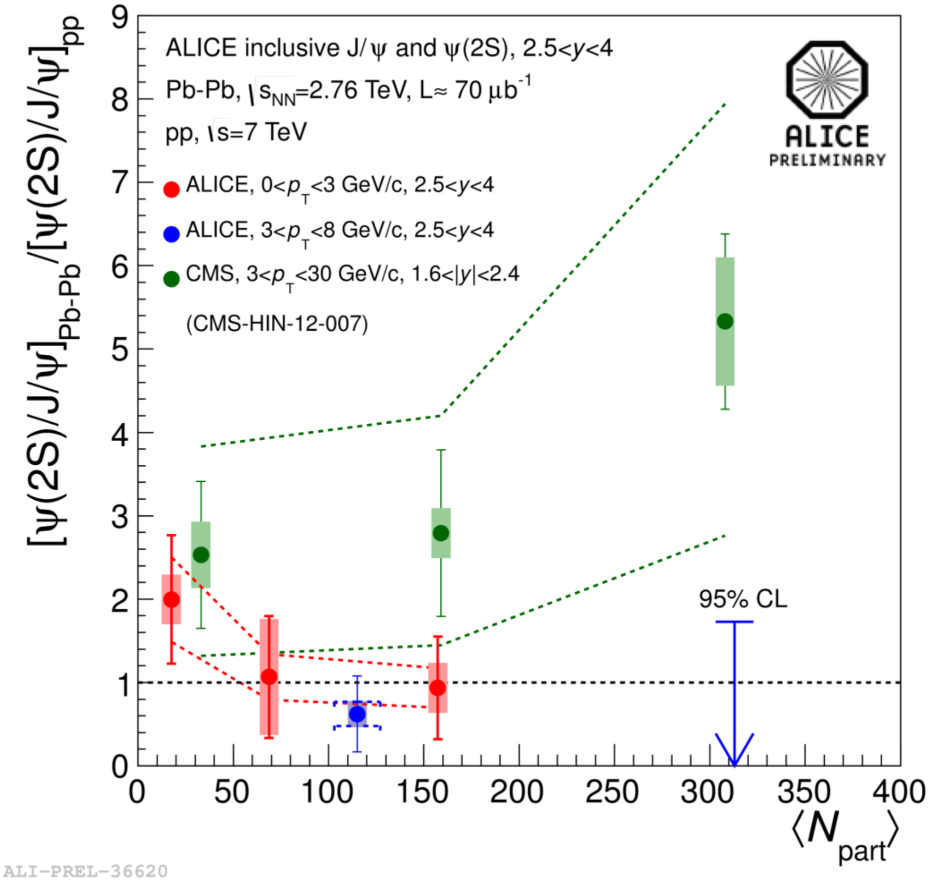
Modification of the ψ(2S) relative to the J/ψ in Pb-Pb

$$R = \frac{R_{\mathrm{AA}}^{\psi(2S)}}{R_{\mathrm{AA}}^{\mathrm{J}/\psi}} = \frac{N_{\mathrm{Pb-Pb}}^{\psi(2S)}}{N_{Pb-Pb}^{J/\psi}} \Big/ \frac{N_{\mathrm{pp}}^{\psi(2S)}}{N_{\mathrm{pp}}^{J/\psi}}$$

pp reference

- results at √s=2.76 TeV for CMS
- results at √s=7 TeV for ALICE
  + energy and rapidity extrapolation

R < 1 is expected in both *transport* (NPA 859 114) and *statistical* (PLB 490 196) model, but different magnitudes predicted



prompt and non-prompt J/ψ in Pb-Pb at mid-rapidity

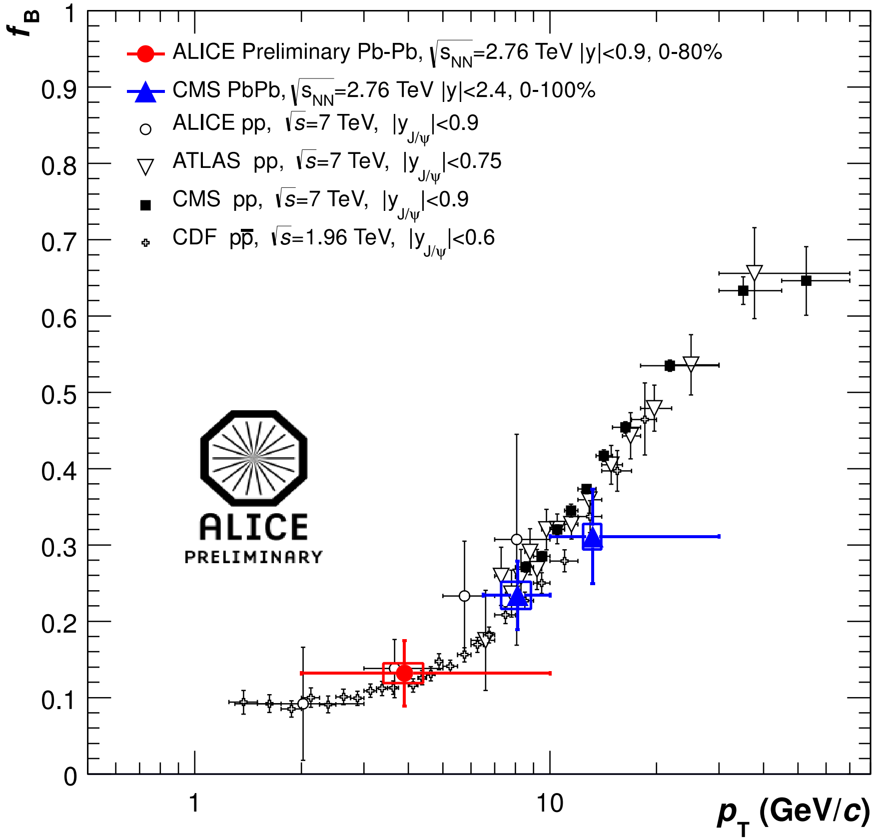
f_B: fraction of the inclusive J/ψ yield that comes from B hadrons decay

Needed to disentangle prompt and non-prompt contributions to the inclusive J/ψ R_{AA}

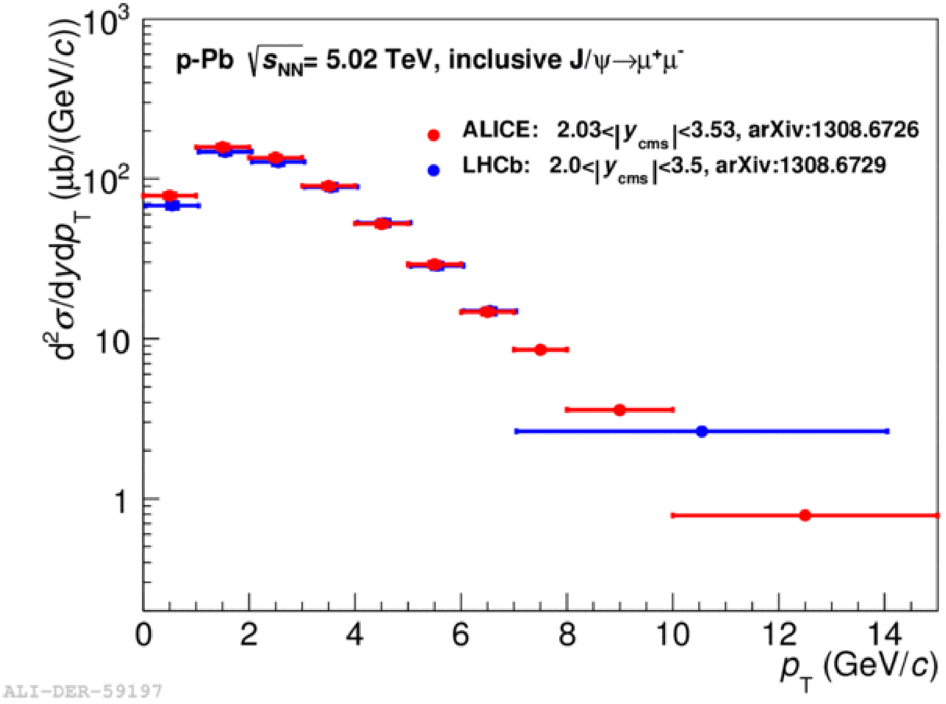
Measured in central barrel, using the pseudo-proper decay length of di-electron pairs:

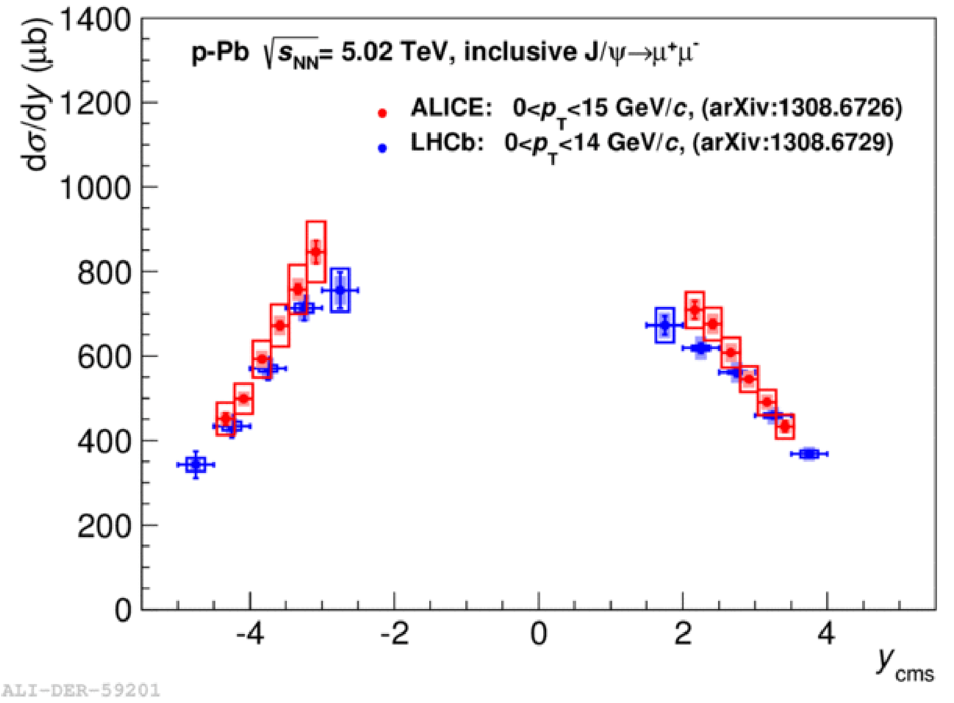
$$x = \frac{c L_{xy} M_{J/\psi}}{p_{\mathrm{T}}}$$

with: $L_{xy} = \vec{L}.\vec{p}_{\mathrm{T}}$



J/ψ cross section in p-Pb, comparison to LHCb





Excellent agreement between the two experiments

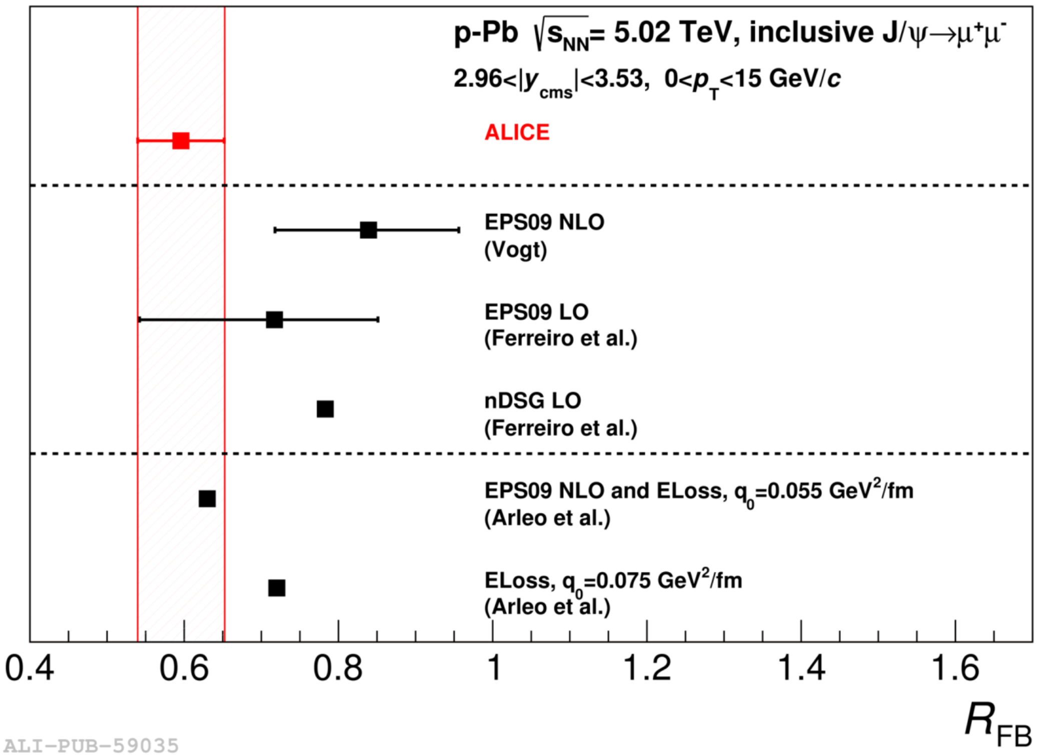
J/ψ Forward/Backward ratio R_{FB}

$$R_{FB}^{J/\Psi} = \frac{Y^{J/\Psi}_{\text{p-Pb}\,(y>0)}}{Y^{J/\Psi}_{\text{Pb-p}\,(y<0)}}$$

Several systematic uncertainties cancel in the ratio and there is no need for pp reference

Statistic is decreased because one has to match the rapidity range between the two data sets

Comparison to theory is less stringent than R_{pPb}



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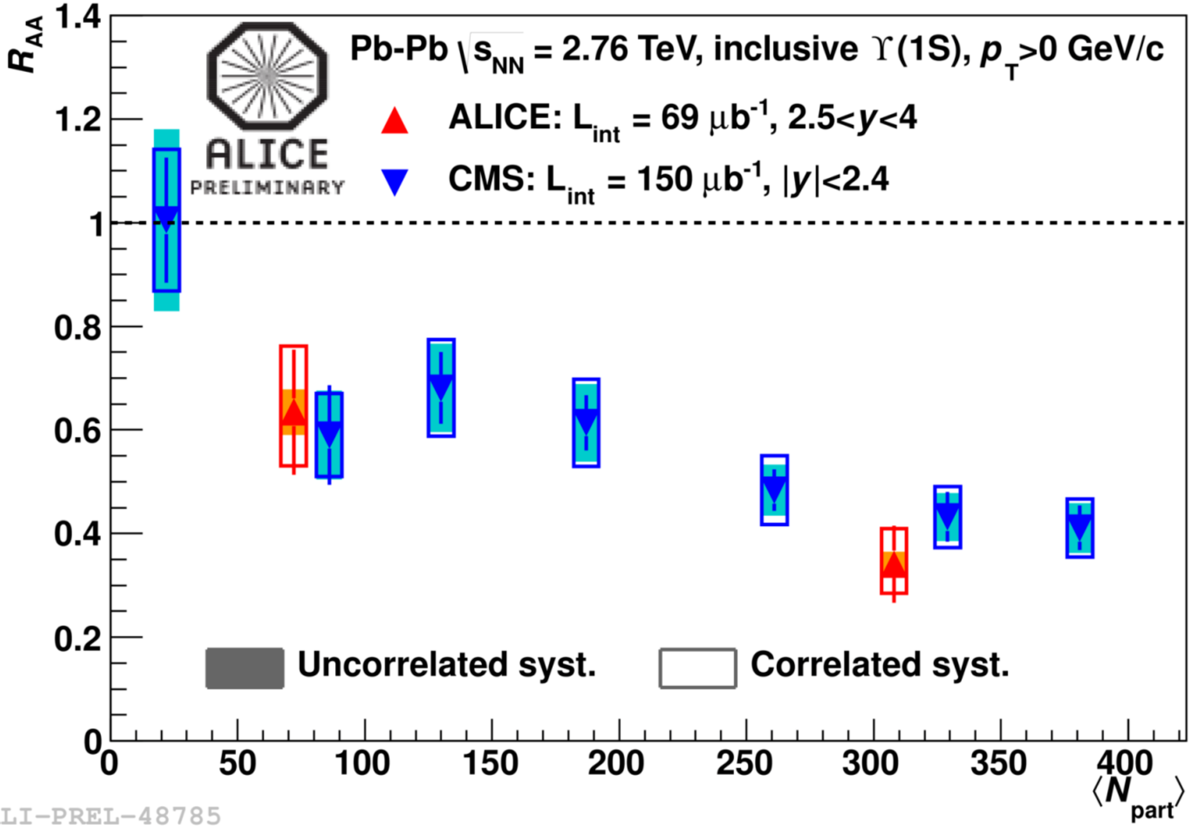
Shadowing models (with different parameterizations of the npdf) overestimate R_{FB}, and have large uncertainties

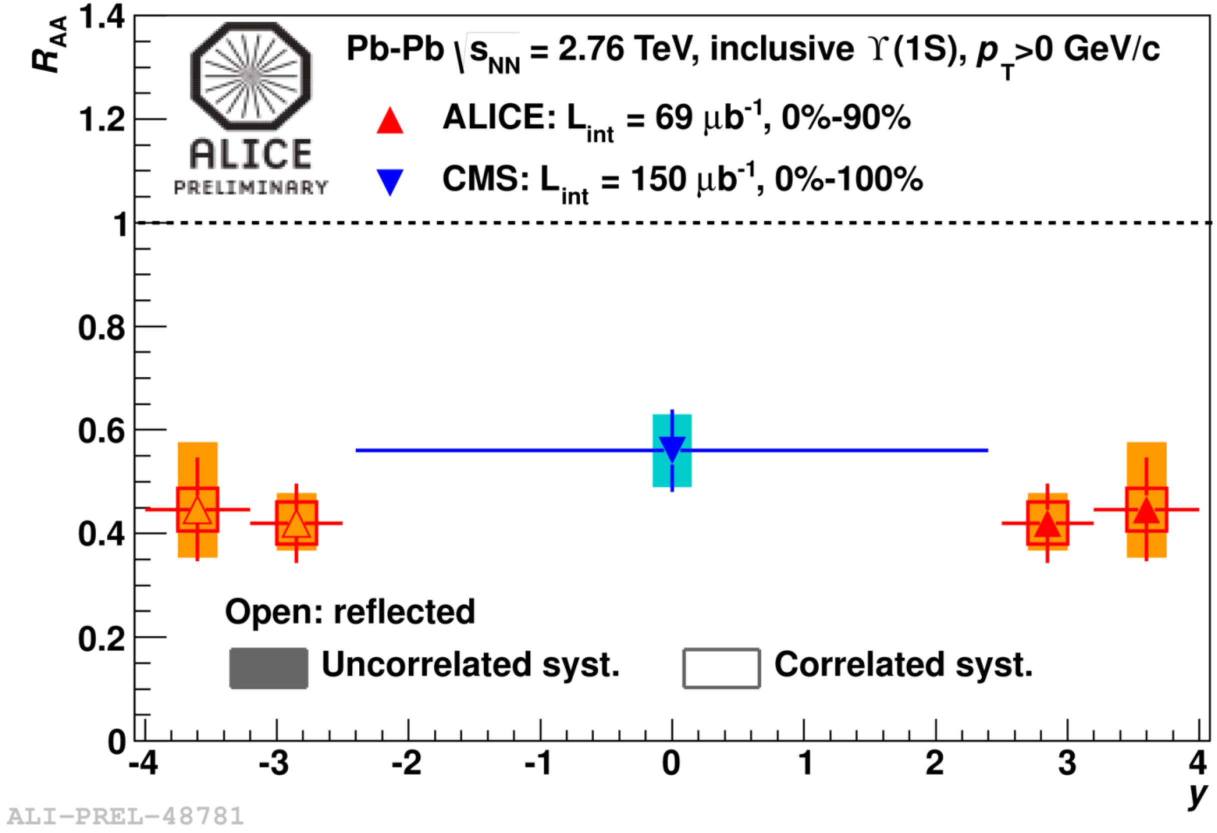
Adding energy loss improves the agreement with the data

CGC has no prediction at y<0 (large x in Pb) and cannot be compared to R_{FB}

Υ(1S) R_{AA} vs centrality, comparison to CMS



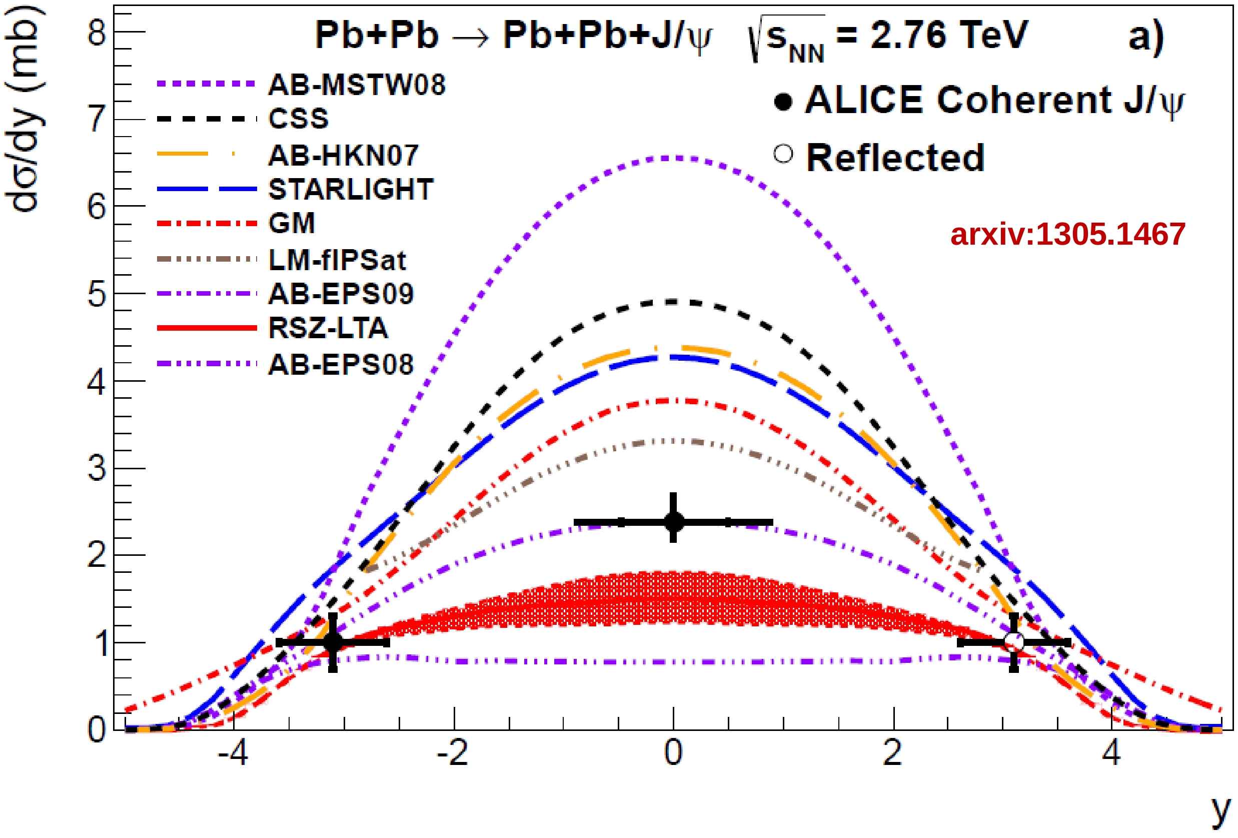
Υ(1S) R_{AA} vs rapidity, comparison to CMS



Interlude: J/ψ production in ultra-peripheral collisions

Measure J/ψ coherent (photo)production in p-Pb and Pb-Pb collisions for which there is minimal hadronic activity

This can be used to constrain low x gluon density in the proton as well as shadowing in the Pb nucleus



See talk by D. De Gruttola on Friday, 10AM