First ALICE results on quarkonium production at Run-2 energies

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for the ALICE Collaboration

CERN-LHC seminar – Tuesday, July 19 2016

Outline

- Introduction
- J/ψ and ψ(2S) in pp collisions at $\sqrt{s}$ = 13 TeV
- J/ψ in pp and Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
- Υ(1S) in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

Results first shown at the Strangeness in Quark Matter conference, Berkeley, June 27 – July 1st

Outline

- Introduction
- J/ψ and ψ(2S) in pp collisions at $\sqrt{s}$ = 13 TeV — preliminary
- J/ψ in pp and Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV — submitted on June 27
- Υ(1S) in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV — preliminary

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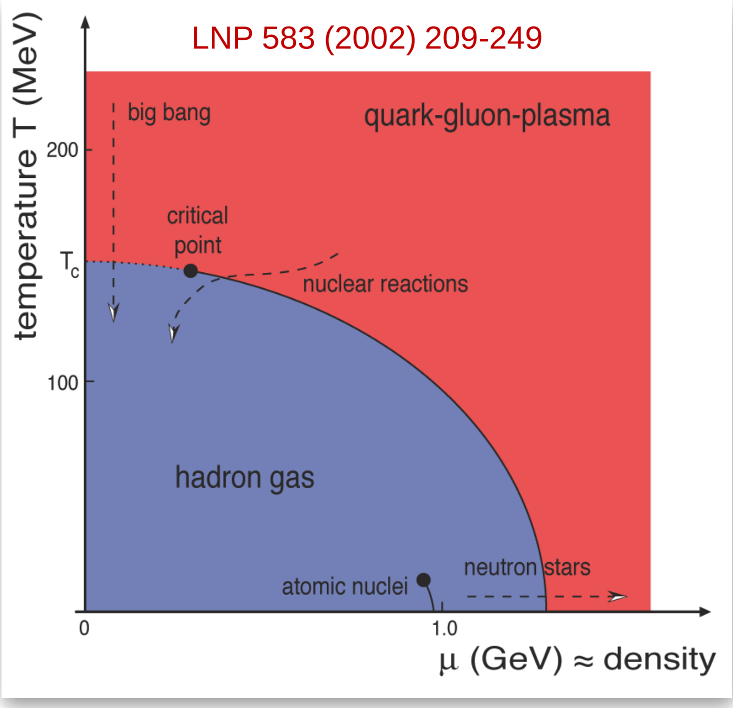
Quark Gluon Plasma

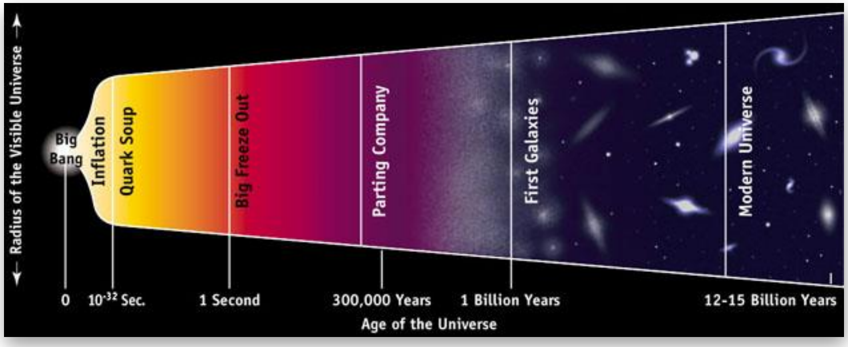
Aim: study the production and properties of a Quark Gluon Plasma in relativistic Heavy Ion collisions



QGP: State of the nuclear matter for which the relevant degrees of freedom are quarks and gluons, as opposed to hadrons

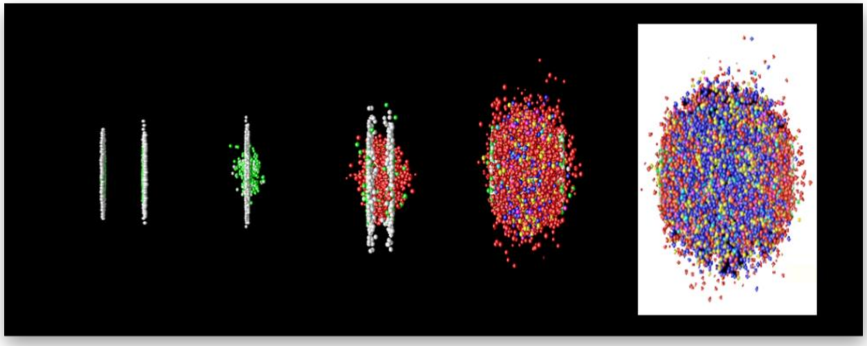
Predicted by Lattice QCD at $T_c \approx 150$ MeV for $\mu = 0$ (2.10^{12} K)

Should correspond to the state of the universe ~1 μs after the big bang



Relativistic Heavy Ion collisions

Relativistic heavy ion collisions should provide a high enough energy density (or temperature) to form a QGP, provided that the collision energy and the ion size are large enough



Such collisions have been studied at

- SPS (CERN) $\sqrt{s_{NN}} \approx 20$ GeV
- RHIC (BNL) $\sqrt{s_{NN}} \approx 200$ GeV
- LHC (CERN) $\sqrt{s_{NN}} \approx 2.76$ TeV, 5 TeV

Typical volume of the QGP: few 10 fm^3

Typical lifetime: few fm/c (10^{-23} s)

$\Rightarrow$ QGP cannot be studied directly
One uses indirect measurements instead

Soft probes:
particles produced in the QGP or at the phase boundary

Typically, low p_T photons, low p_T hadrons

Hard probes:
particles produced before the QGP and travelling through it

Typically, high p_T photons, high p_T hadrons, jets, heavy quarks, quarkonia

Why measure quarkonia

Quarkonia (J/ψ, ψ(2S), Υ(1S)) are bound states of a heavy quark pair (c-cbar or b-bbar)
Their production is understood as the production of the quark pair in a hard-scattering process, followed by the evolution of this pair into a colorless bound state

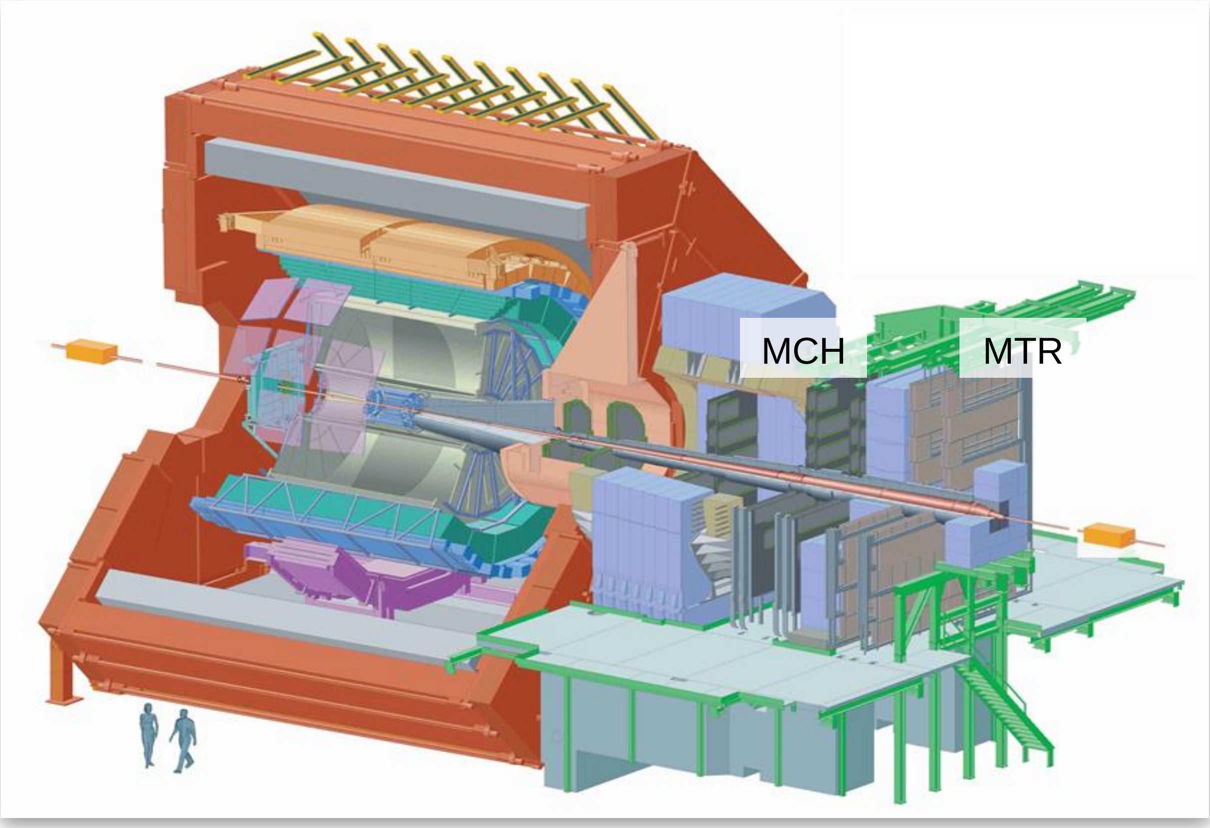
The production of the quark pair
- happens early in the collision (hard probe)
- should be calculable using pQCD

On the other hand, the evolution into a bound state is intrinsically non-perturbative

<u>Quarkonium production measurements are interesting</u>

- in pp, to understand production mechanism, probe parton distribution functions (PDF) in the nucleon and as a reference for Pb-Pb and p-Pb
- in Pb-Pb, to probe the formation and properties of the Quark-Gluon Plasma (color screening, dissociation, recombination)
- in p-Pb, to probe so-called cold nuclear matter effects (modification of the PDFs, saturation, Cronin enhancement, etc.)

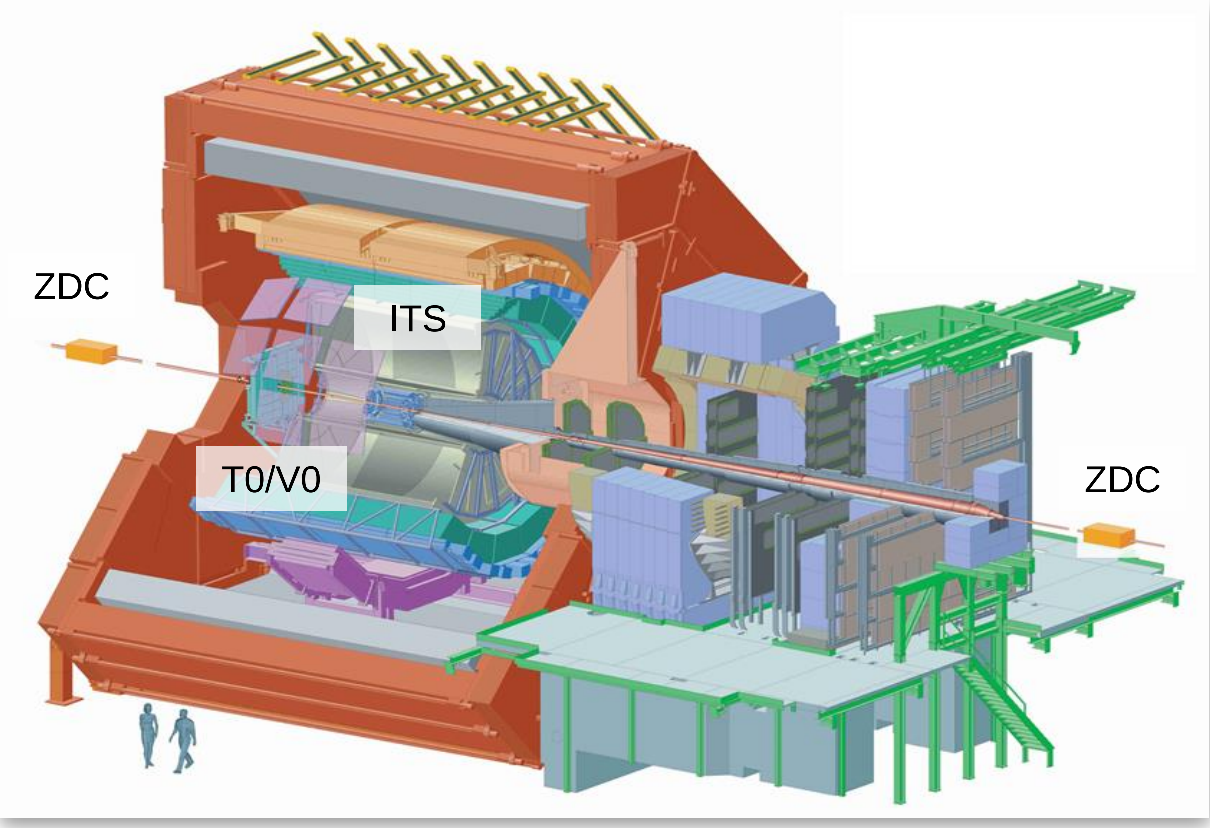
Forward-y quarkonium measurements in ALICE



Quarkonia are measured in the $\mu^+\mu^-$ decay channel, at forward rapidity ($2.5<y<4$) and down to $p_T = 0$ using the Muon System:

- 5 stations of tracking chambers ($-4<\eta<-2.5$)
- 2 stations of trigger chambers
- dipole magnet
- absorbers

Forward-*y* quarkonium measurements in ALICE



<u>Other detectors used in the analysis are</u>:

- ITS for vertex determination
- V0 hodoscopes for triggering (in coincidence with MTR) and for centrality
- V0 and ZDC for background rejection
- T0 Cerenkov detectors for luminosity

Word of caution

All quarkonium measurements presented here are inclusive

They contain:

- direct production
- decay from higher mass resonances (for J/ψ, they are ψ(2S) and χ_c)
- for charmonia, decay from *b*-hadrons (also called non-prompt J/ψ, ψ(2S))

J/ψ and ψ(2S) in pp collisions at $\sqrt{s}$ = 13 TeV

Quarkonium production in pp

In pp, measuring quarkonia probes production mechanism and parton distribution functions

$$d\sigma^{Q} = f_a(x_a).f_b(x_b)\times d\hat{\sigma}_{ab}^{q\bar{q}}\times\left\langle O_{q\bar{q}}^{Q}\right\rangle$$

Quarkonium production cross section has three components

- parton distribution functions: describe the partonic (quark/gluons) content of the proton (soft scale, measured in e.g. DIS experiments)
- partonic cross section: describe how to produce the heavy quark pair from two partons (hard scale, short distances, calculable with pQCD)
- evolution of the heavy quark pair into the quarkonium state Q
(soft scale, large distances and model dependent)

Quarkonium production in pp

$$d\sigma^{Q} = f_a(x_a).f_b(x_b)\times d\hat{\sigma}_{ab}^{q\bar{q}}\times\left\langle O_{q\bar{q}}^{Q}\right\rangle$$

Mainly three approaches used to address the large distance contribution

- Color Evaporation Model (CEM):
  production cross section of a given quarkonium is proportional to the heavy quark pair cross section, integrated between the mass of the quarkonium and twice the mass of the lightest meson containing one heavy quark (D or B). Proportionality factor is independent of y, p_T and $\sqrt{s}$

- Color Singlet model (CSM):
  pQCD is used to describe the heavy quark pair production with the same quantum numbers as the final-state meson (colorless state, CS).

- Non-Relativistic QCD (NRQCD):
  both CS (colorless) and CO (colored) states of the heavy quark pairs are considered. The relative contribution of the states is parametrized using a finite set of universal long range matrix elements (LRME), fitted to a subset of the data (e.g. Tevatron)

Quarkonium production in pp

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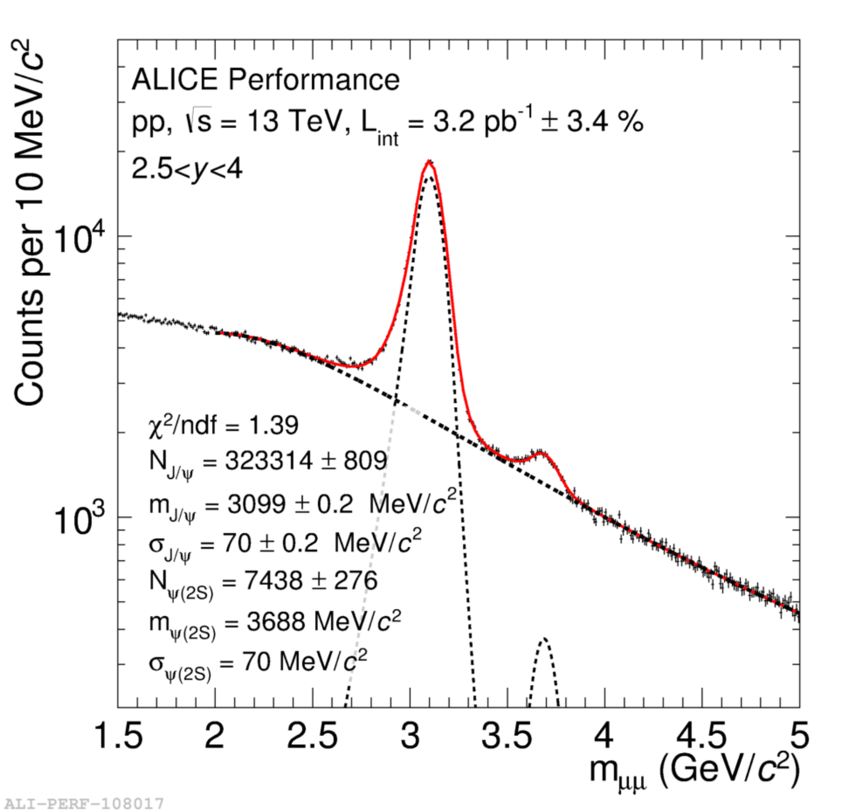
Data analysis

data sample from 2015 pp@13 TeV run at LHC

$L_{int} = 3.2\ pb^{-1} \pm 3.4\%$



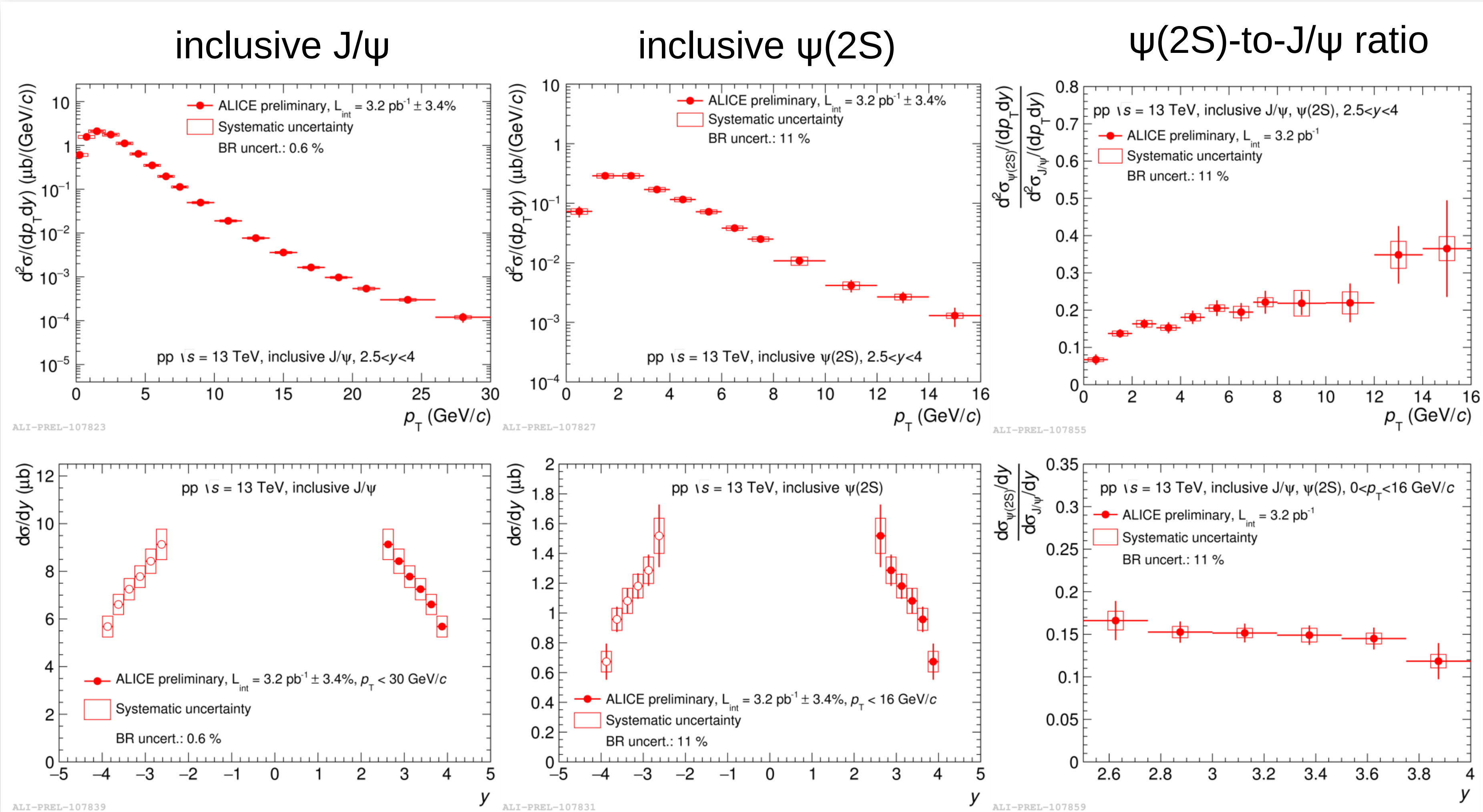
Charmonia are measured using fits to the invariant mass distribution of $\mu^+\mu^-$ pairs detected in the muon system

Corresponds to: $N_{J/\psi} = 325k$
$N_{\psi(2S)} = 7.5k$

$$\sigma_{J/\psi} = \frac{N_{J/\psi}}{BR \times L_{int} \times A.\varepsilon}$$

Systematic uncertainties on cross sections amount to ~7% for J/ψ and ~10% for ψ(2S). They include contributions from signal extraction, acceptance x efficiency corrections and luminosity

Cross sections and particle ratios in pp@13 TeV



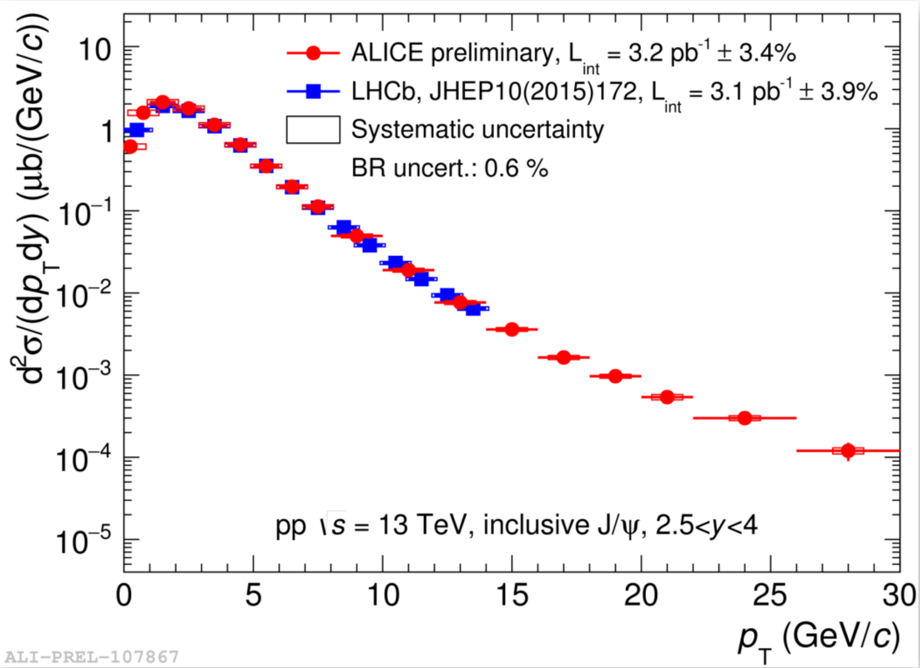
We reach $p_T = 30$ GeV/c for J/ψ, and 16 GeV/c for ψ(2S) as well as ψ(2S)-to-J/ψ ratio

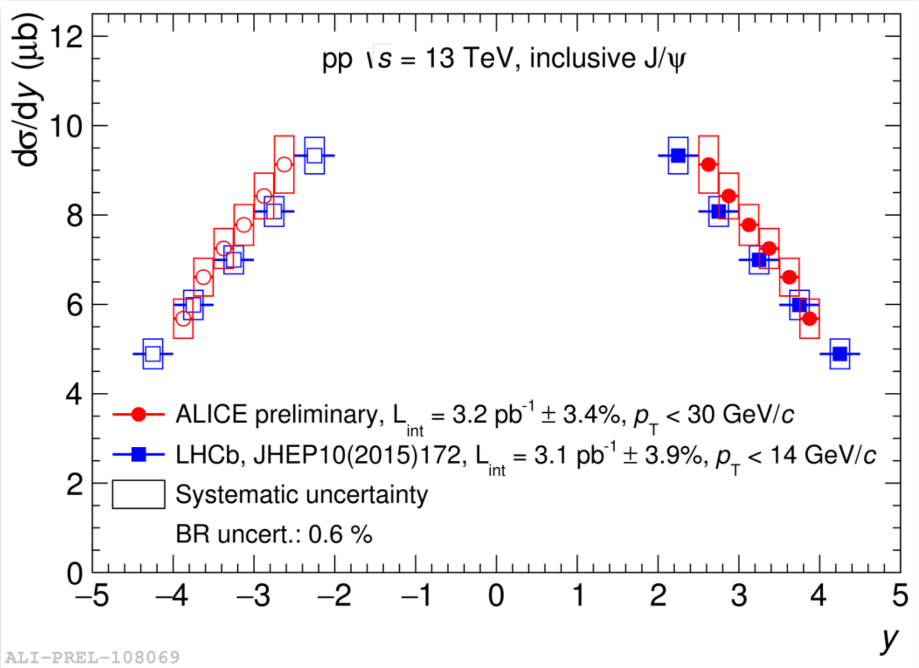
We measure 6 bins in y for 2.5<y<4

Comparison to LHCb

LHCb results from JHEP10 (2015) 172

Quoted values correspond to the sum of the prompt and non-prompt contributions, integrated over the same rapidity range as ALICE (2.5<y<4)

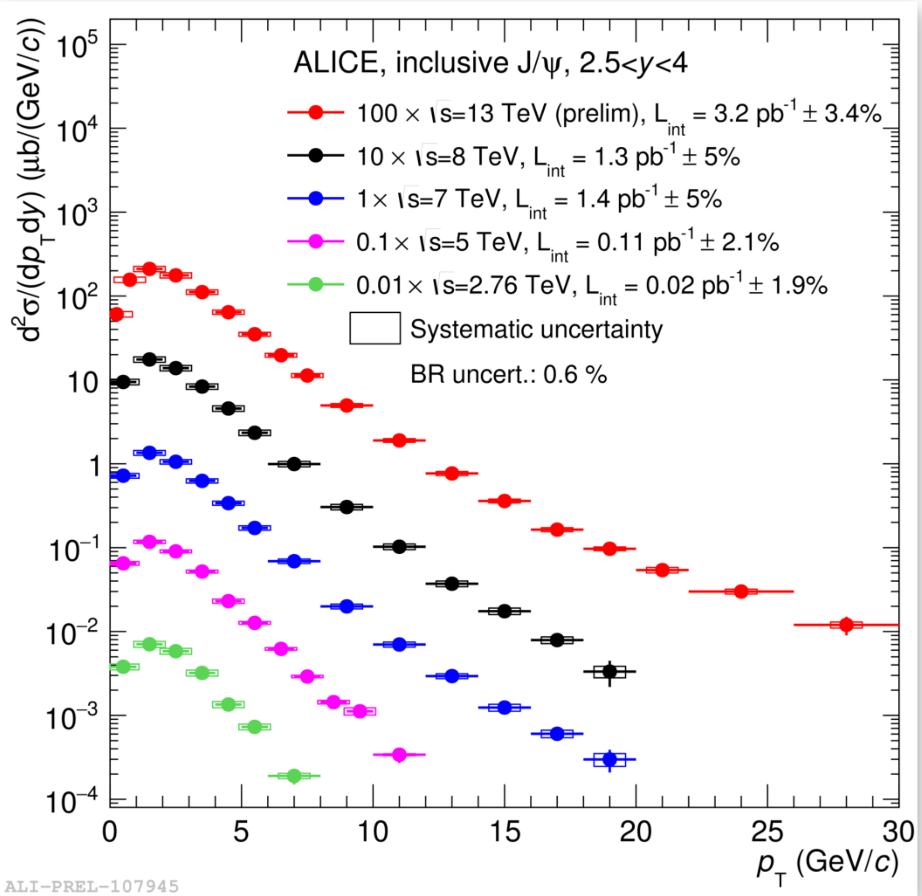




Excellent agreement between the two experiments

All points lie within 1 sigma (stat+syst) one with the other

Comparison to lower energy, J/ψ vs p_T



Comparison to ALICE measurements at $\sqrt{s}$ = 2.76, 5, 7 and 8 TeV

All results published except at 13 TeV

Steady increase of the luminosity and p_T reach with increasing energy

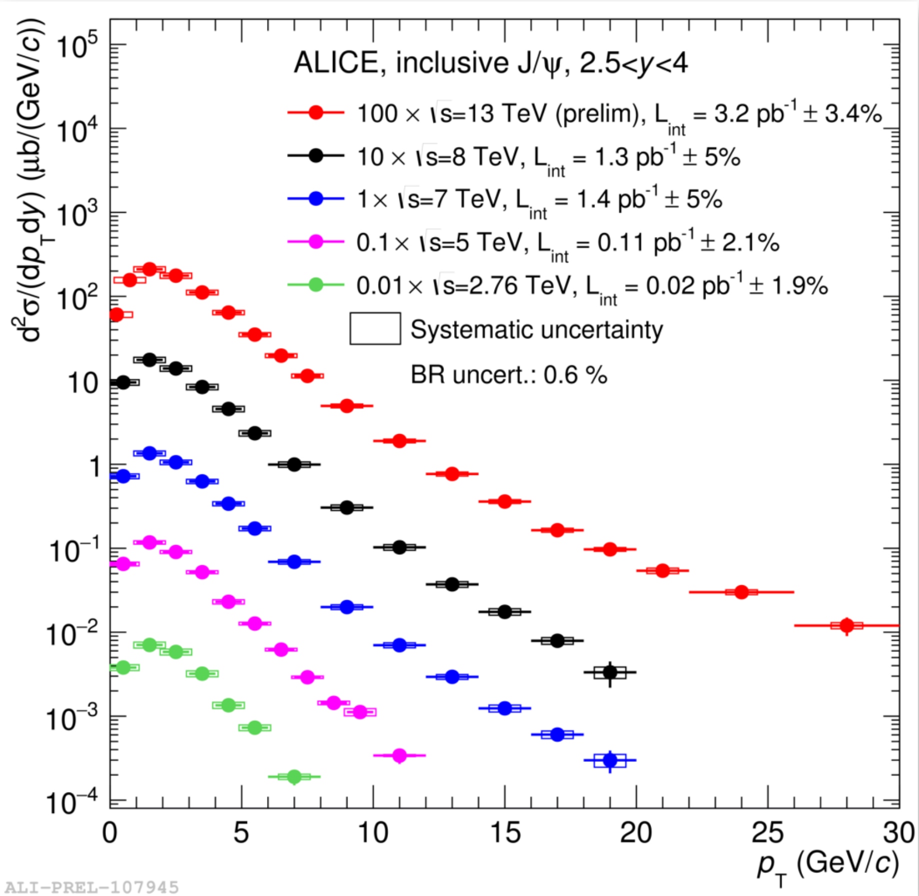
As expected, spectra become harder with increasing energy

Change of slope at high p_T and $\sqrt{s}$ = 13 TeV, attributed to the onset of the non-prompt J/ψ contribution

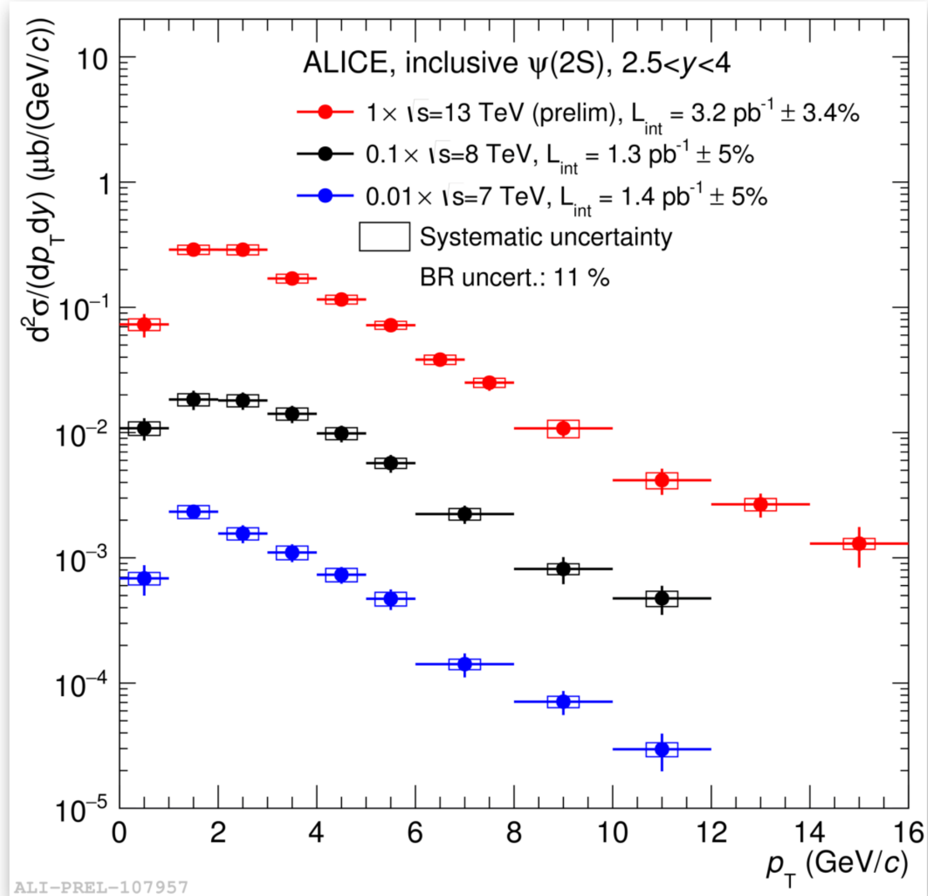
$\sqrt{s}$ = 2.76 TeV PLB 718 (2012) 295
$\sqrt{s}$ = 5 TeV ArXiv:1606.08197
$\sqrt{s}$ = 7 TeV EPJC 74 (2014) 2974
$\sqrt{s}$ = 8 TeV EPJC 76 (2016) 184

Comparison to lower energy, ψ(2S) vs p_T

inclusive J/ψ



inclusive ψ(2S)



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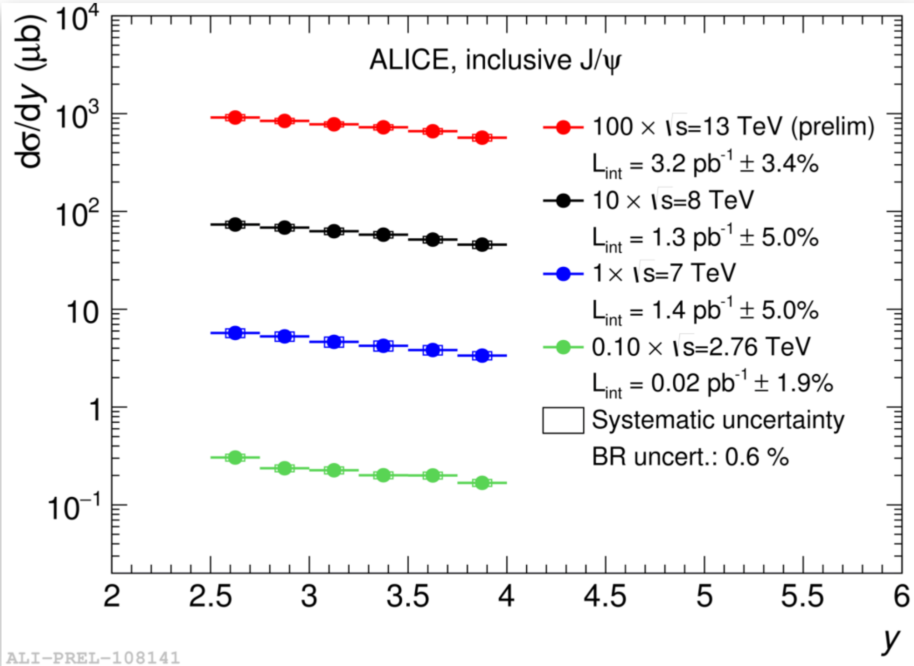
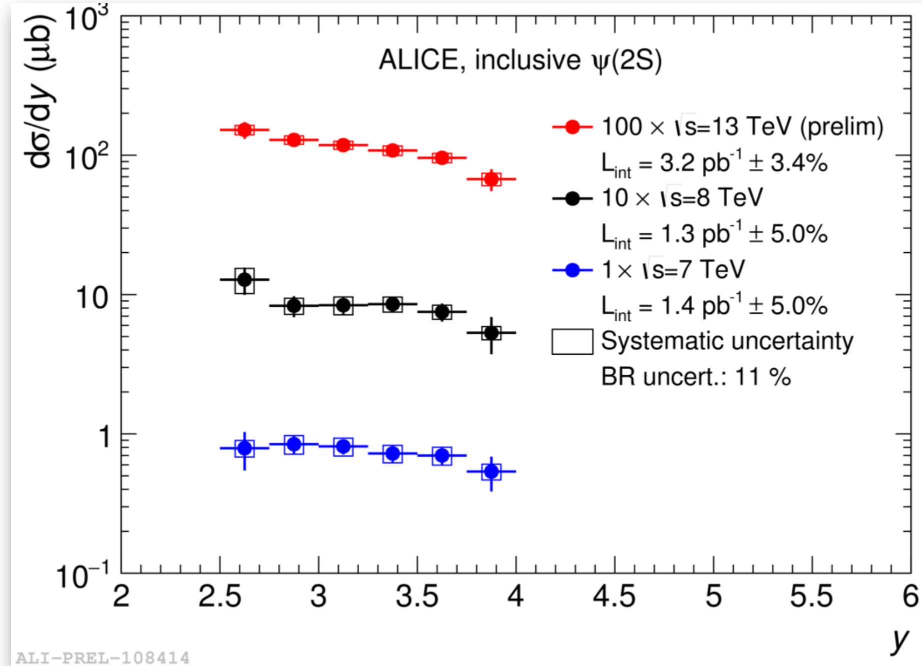
For ψ(2S) we have measurements at $\sqrt{s}$ = 7, 8 and 13 TeV

Comparison to lower energy, J/ψ and ψ(2S) vs *y*

inclusive J/ψ



inclusive ψ(2S)



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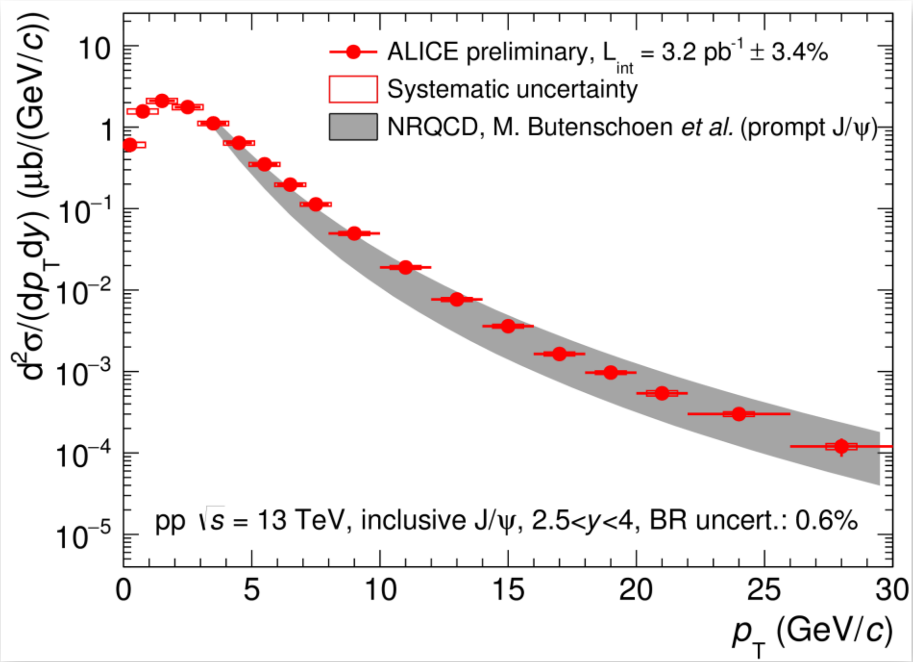
For J/ψ, no visible change in the *y* distribution

For ψ(2S), large uncertainties prevent firm conclusions

Comparison to models, J/ψ vs p_T

NLO NRQCD calculation from Butenschoen and Kniel PRL 106 (2011) 022003 for p_T > 3 GeV/c



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PRL 106 (2011) 042002
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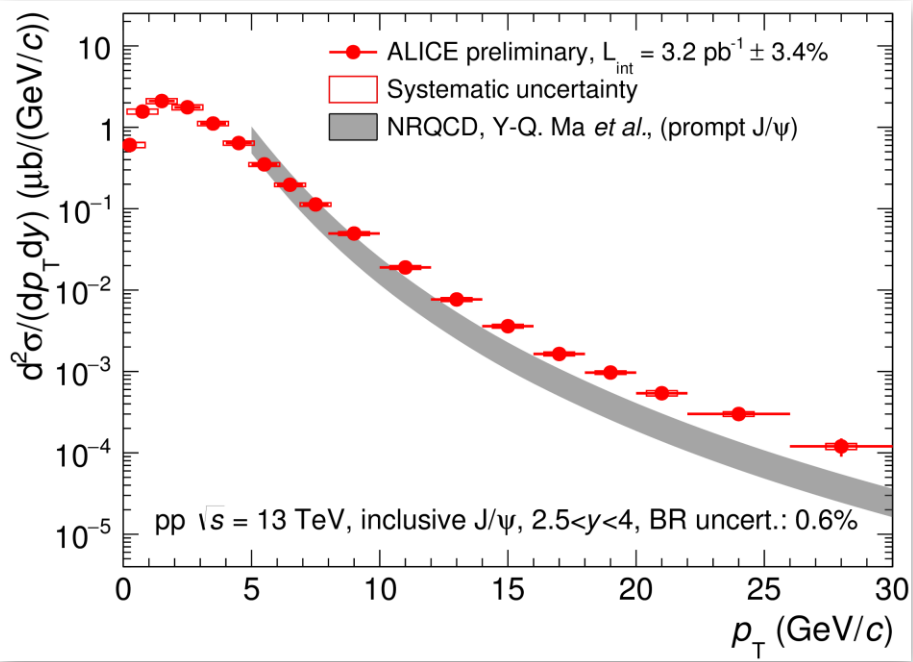

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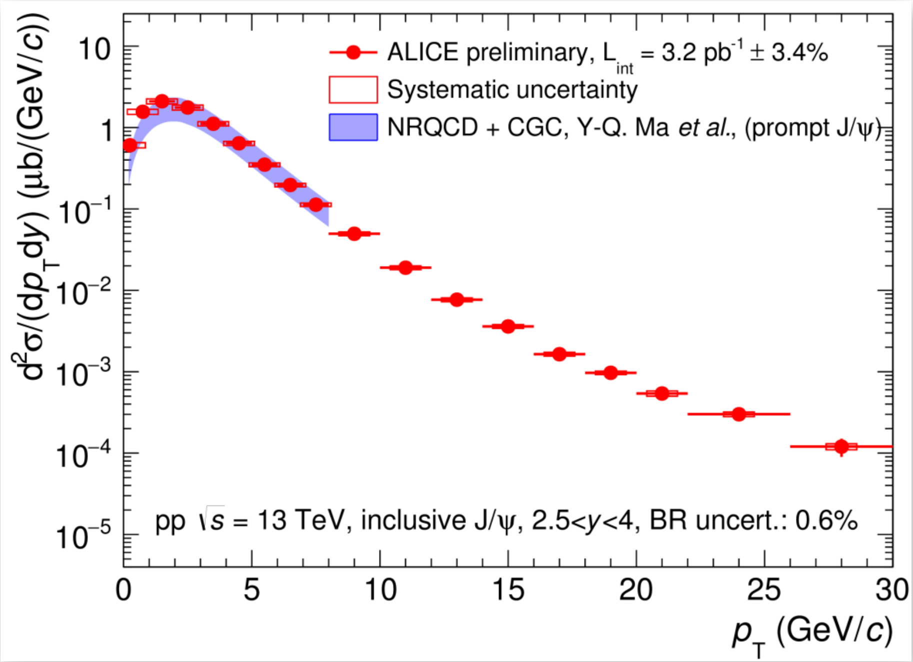

<u>LO NRQCD + CGC</u> from Ma and Venugopalan, PRL 113 (2014) 192301
for 0 < p_T < 7 GeV/c

CGC (Color Glass Condensate) is used to describe low-x gluon saturation in the proton

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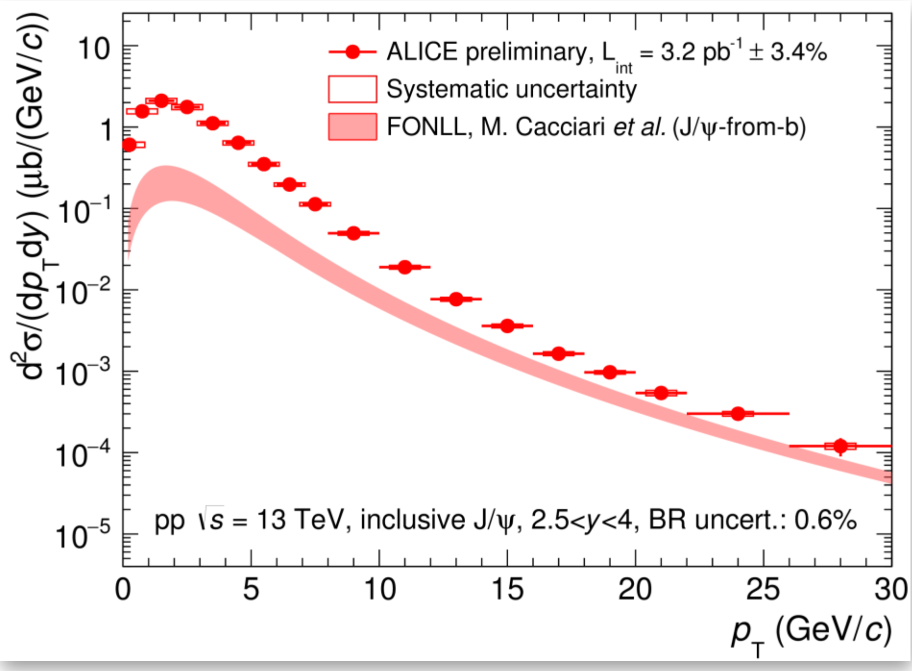

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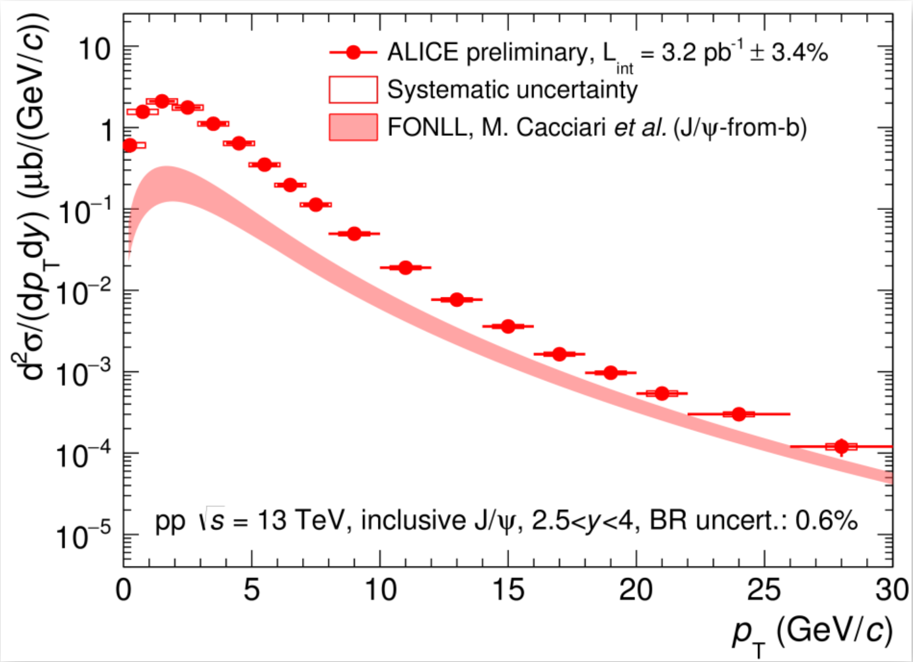
Non-prompt J/ψ from b-hadron decay, using FONLL from
Cacciari *et al.*, JHEP 1210 (2012) 137

Comparison to models, J/ψ vs p_T



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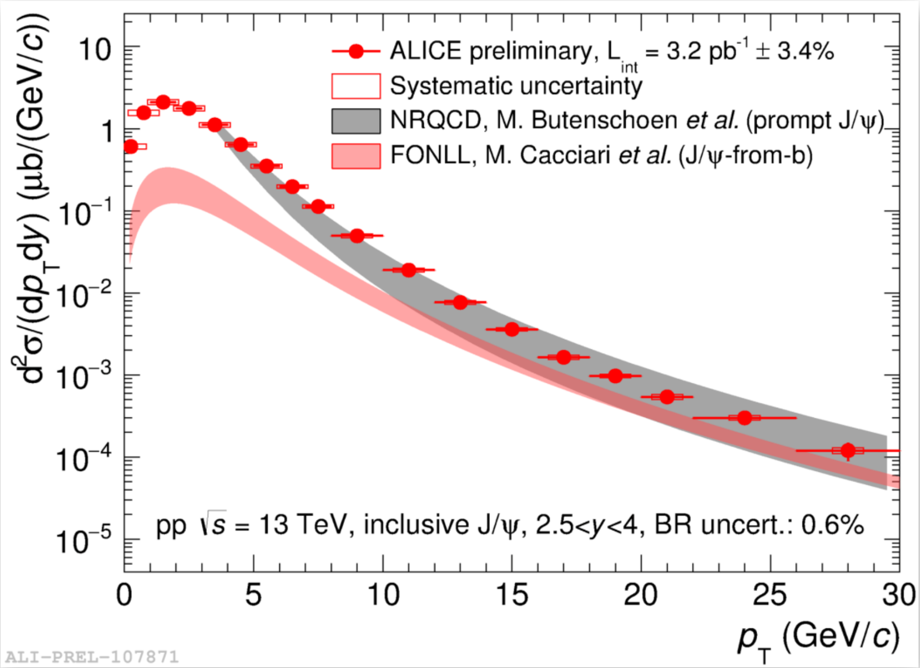
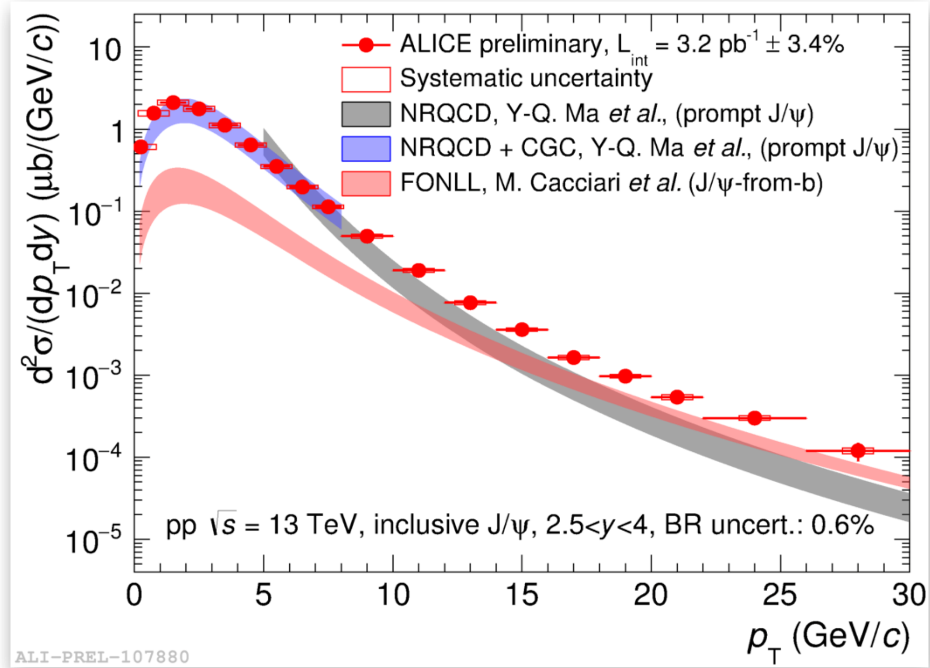
<u>Non-prompt J/ψ from b-hadron decay</u>, using FONLL from Cacciari *et al.*, JHEP 1210 (2012) 137

All models properly account for higher mass resonance decays

Comparison to models, J/ψ vs p_T





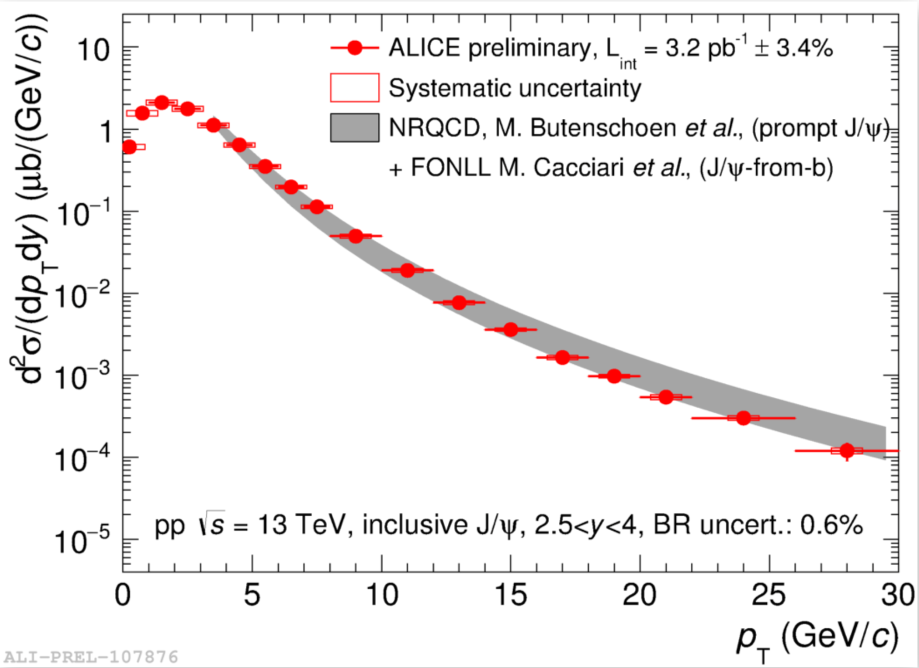
NRQCD (left)	Butenschon and Kniel, PRL 106 (2011) 022003
NRQCD (right)	Ma, Wang and Chao, PRL 106 (2011) 042002
NRQCD+CGC	Ma and Venugopalan, PRL 113 (2014) 192301
FONLL	Cacciari *et al.*, JHEP 1210 (2012) 137

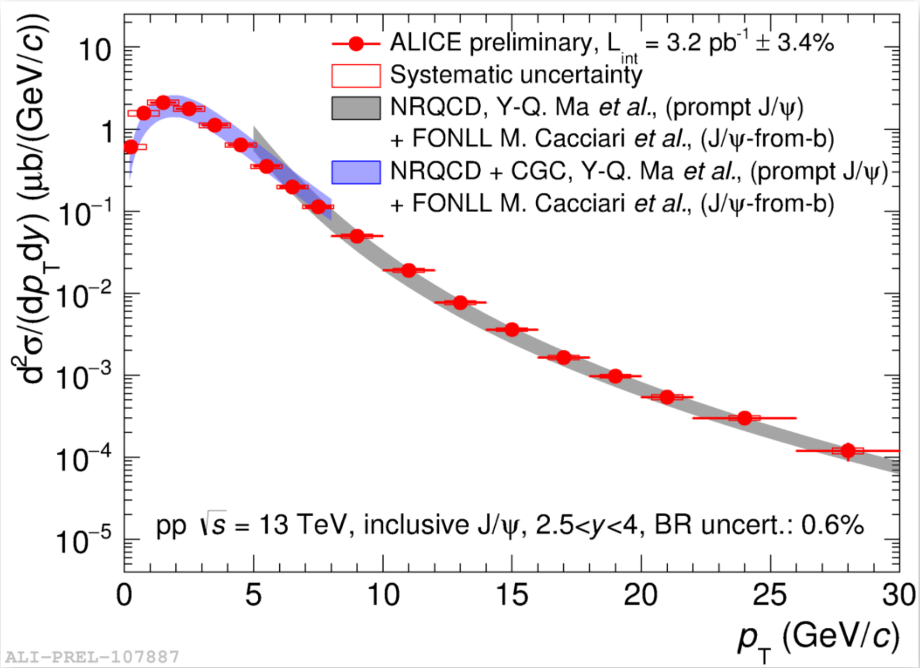
NLO NRQCD models differ in the set of LRME that is used, the p_T at which fits are performed and the datasets considered.

Predictions are quite different at high p_T, but in both cases, non-prompt J/ψ constitute a sizable contribution to the inclusive cross section

Comparison to models, J/ψ vs p_T

As an exercise, we summed NRQCD and FONLL calculations assuming fully uncorrelated uncertainties.

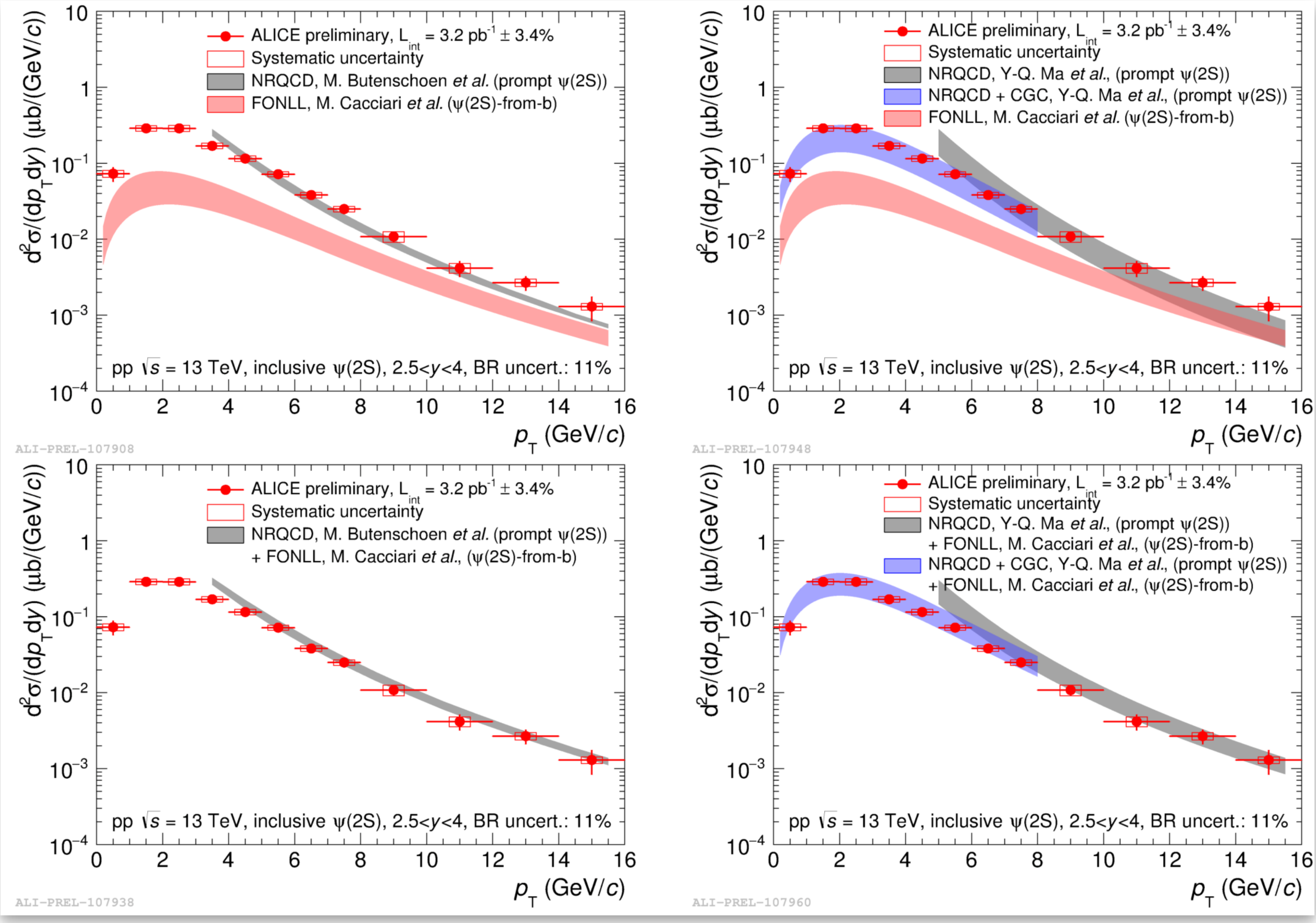




Agreement to the data is much improved, already at intermediate p_T and especially for the calculation from Ma *et al.*

Note that the calculations are completely independent, and that there was no data at this energy and at such high p_T before

Comparison to models, ψ(2S) vs p_T

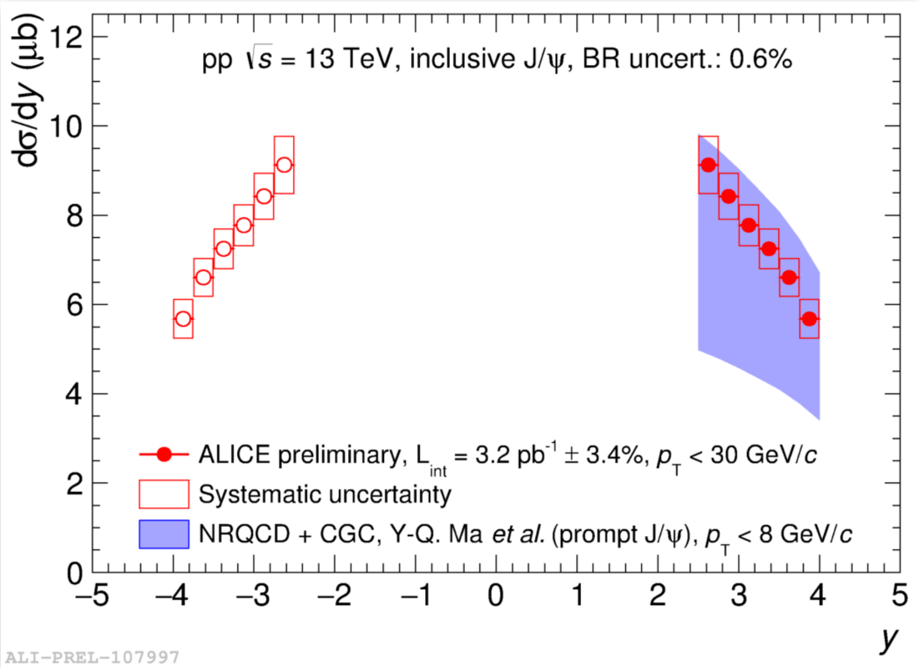


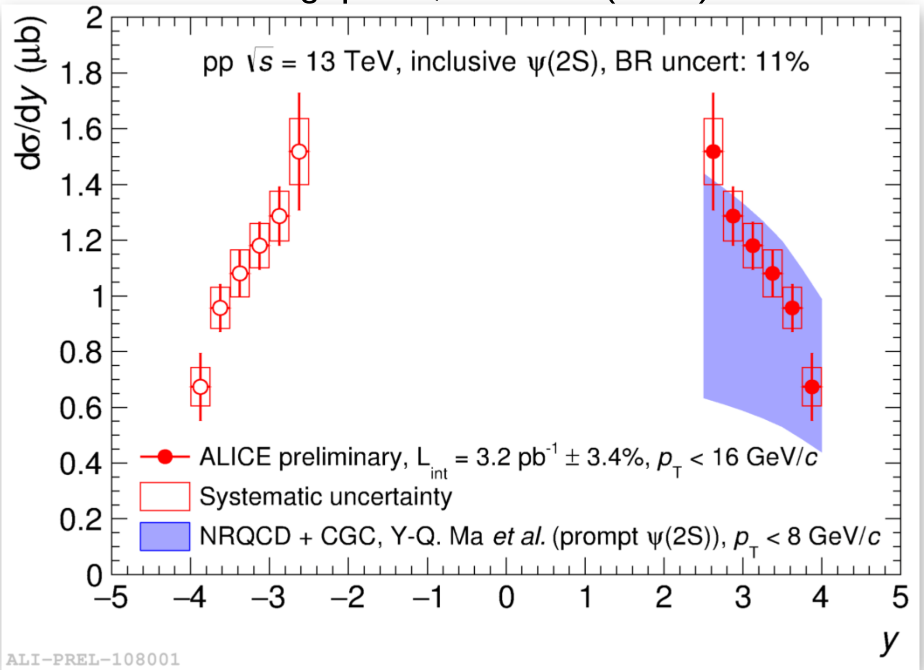
Same conclusions as for the J/ψ case

Rapidity distributions

Since the NRQCD+CGC calculation goes down to $p_T = 0$, it can be compared to our p_T-integrated data vs rapidity

Ma and Venugopalan, PRL 113 (2014) 192301



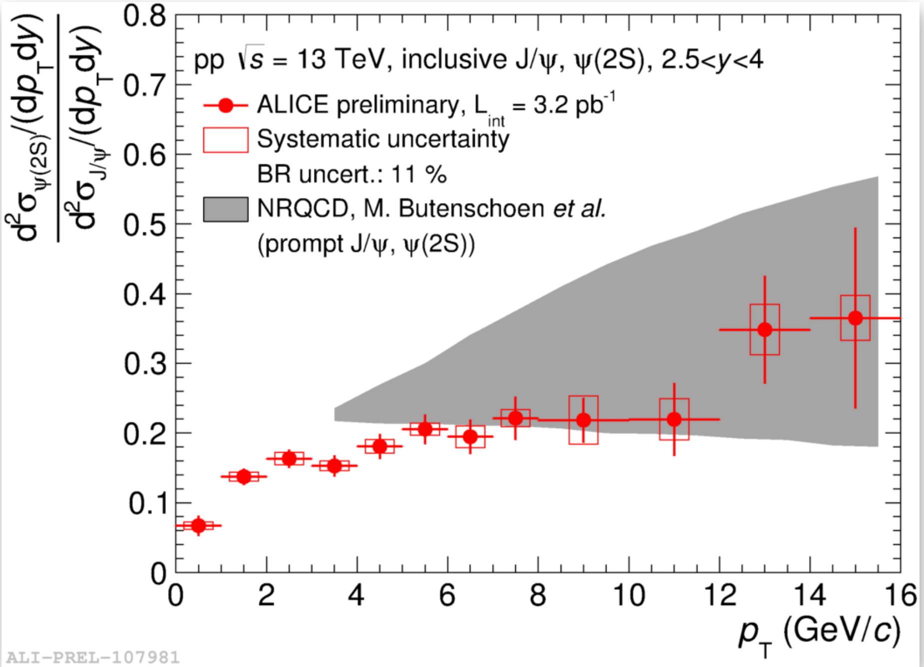


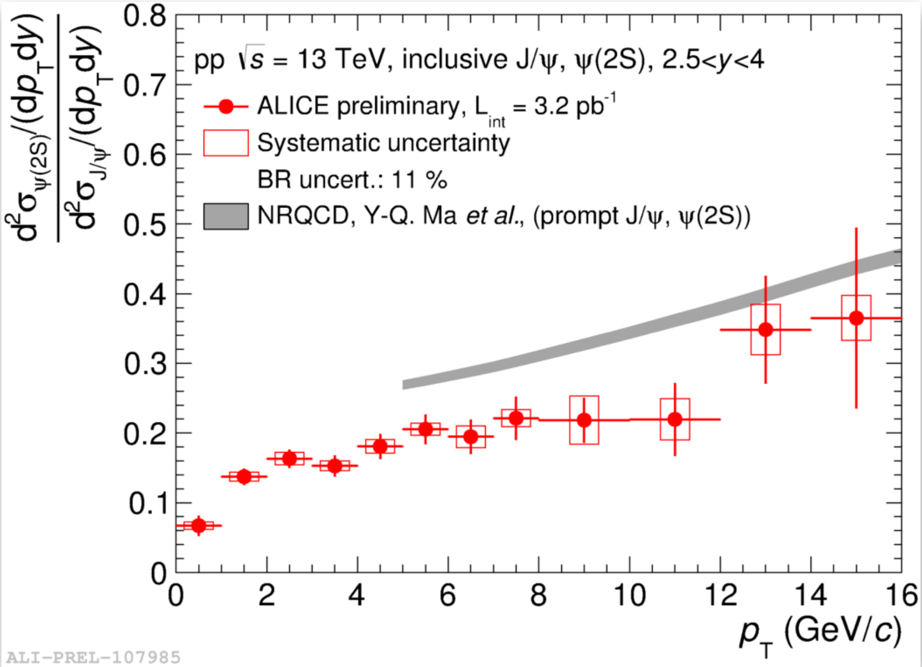
Agreement to the data is reasonable and would be further improved when adding the contribution from non-prompt J/ψ and ψ(2S) (10-15%)

The only other calculation that provides p_T-integrated rapidity distributions is CSM@LO, with significantly larger uncertainties (see ALICE (7TeV) EPJC 74 (2014) 2974)

Particle ratio, comparison to models

Many systematic uncertainties cancel in the particle ratio, for both data and theory





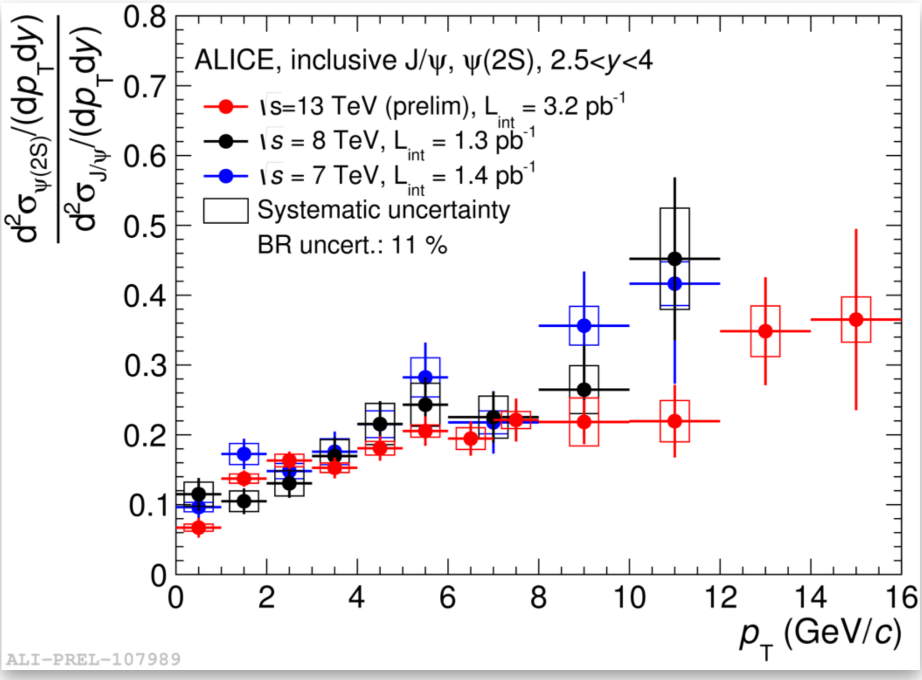
NRQCD (left) Butenschon and Kniel, PRL 106 (2011) 022003
NRQCD (right) Ma, Wang and Chao, PRL 106 (2011) 042002

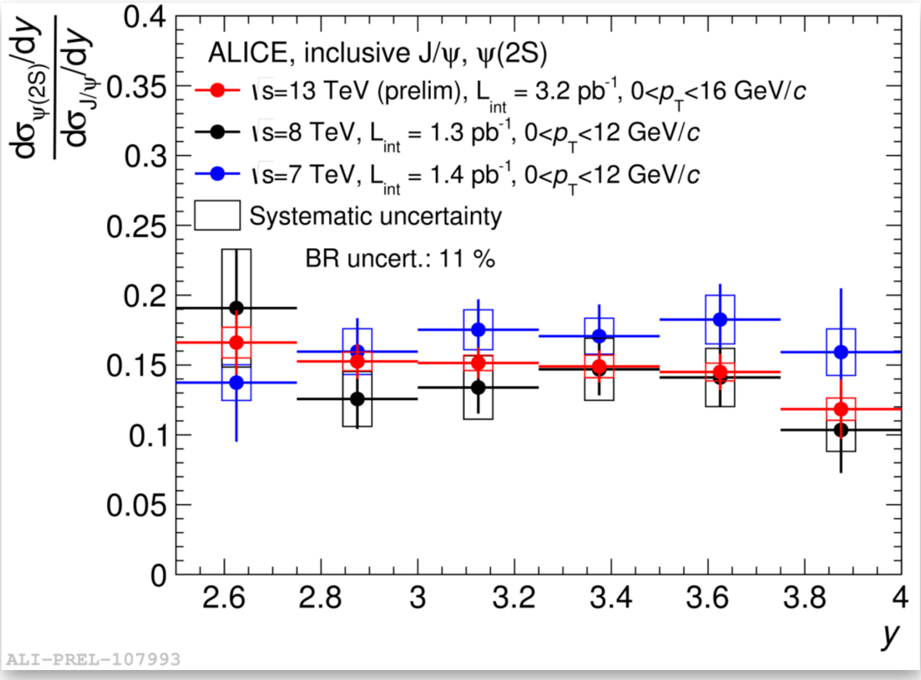
Both calculations follow the same trend but with very different uncertainties. This was already the case at $\sqrt{s}$ = 7 TeV (see ALICE EPJC 74 (2014) 2974)

Calculation from Y-Q Ma *et al.* tends to overestimate the ψ(2S)-to-J/ψ ratio

Contributions from non-prompt J/ψ and ψ(2S) have little impact here because they enter both the numerator and denominator, with a similar (small) magnitude

Particle ratio, energy dependence





$\sqrt{s}$ = 7 TeV EPJC 74 (2014) 2974

$\sqrt{s}$ = 8 TeV EPJC 76 (2016) 184

No visible dependence of the p_T-differential ψ(2S)-to-J/ψ ratio on $\sqrt{s}$

No clear trend either vs rapidity

Summary J/ψ, ψ(2S) in pp

ALICE has measured inclusive J/ψ and ψ(2S) production for all energies available in pp at the LHC

p_T distributions can be reasonably well reproduced by NRQCD calculations, down to $p_T = 0$, provided that higher mass decays and non-prompt contributions are properly accounted for, as well as gluon saturation in the nucleon, at low x

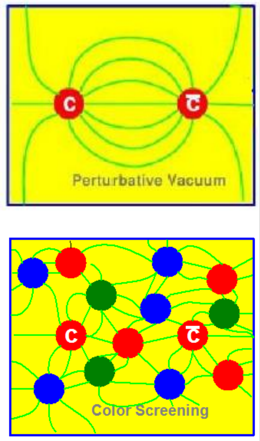
Rapidity distributions are also reasonably well described, albeit with larger uncertainties

Particle ratios are slightly overestimated by models, and show no dependence on collision energy

J/ψ in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

Effects of the QGP on quarkonia

Quarkonium production starts early in the Pb-Pb collision and can be modified by the presence of the Quark-Gluon Plasma

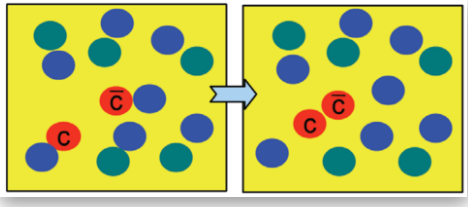


Suppression by color screening (PLB 178 (1986), 416)

Potential between the heavy quarks is screened by surrounding color charges in the QGP

Screening radius (= distance above which the potential is completely screened) decreases with increasing QGP temperature

Less bound quarkonia are suppressed at lower temperature



Regeneration via statistical recombination (PLB 490 (2000) 196)

If the number of heavy quark pairs is large and if heavy quarks thermalize in the QGP, then quarkonia can be formed at phase boundary, by statistical hadronisation, just like other hadrons

This effect goes in the opposite direction as the suppression. It can compensate or even exceed it, if the number of heavy quarks is high enough

Transport models (PRC 63 (2001) 054905)

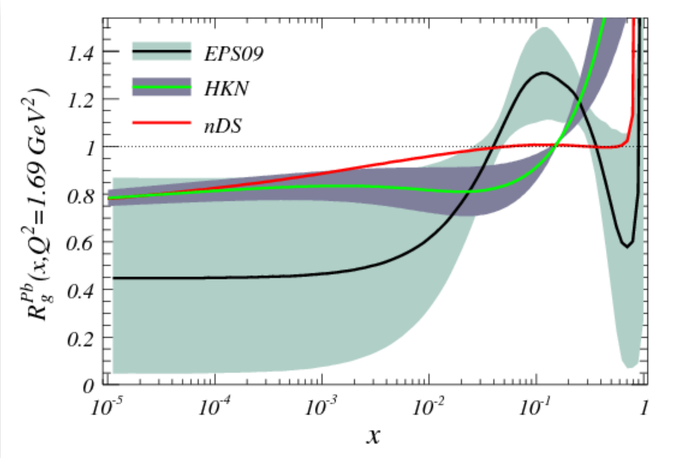
Simultaneous quarkonium suppression and regeneration in the QGP by interaction with the surrounding gluons handled via a rate equation

$$J/\psi + g \leftrightarrow c\,\bar{c}$$

Cold Nuclear Matter effects

Anything that modifies the quarkonium production in heavy-ion collision with respect to pp, in absence of a QGP

J.Phys. G39 (2012) 015010



- Modifications of the parton distribution functions inside the nucleus with respect to free nucleons
  (PRC 88(2013) 047901)

- Gluon saturation at low-x within the CGC
  (Nucl. Phys. 1924(2014) 47-64)

- Energy loss of the incoming partons or the produced heavy quarks
  (PRL 109(2012) 122301)

- Nuclear absorption/dissociation of the quarkonium
  (Nucl. Phys. A700(2002)539)

Measured in p-Pb collisions

Must be included in models that attempt to describe Pb-Pb data, on top of QGP effects

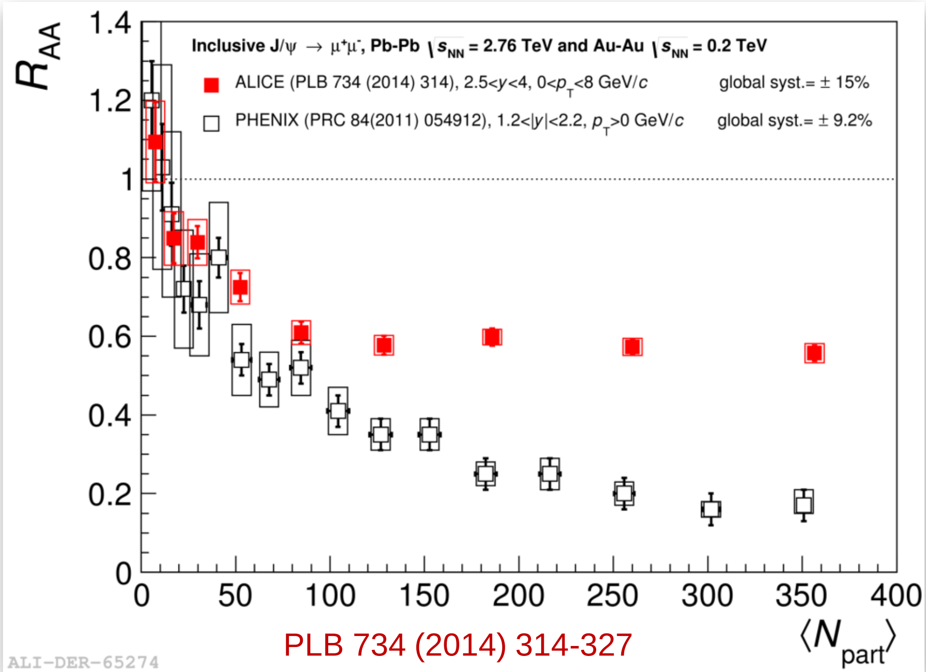
Run-1 results

Nuclear modification factor

$$R_{AA}^{J/\psi} = \frac{Y_{AA}^{J/\psi}}{T_{AA} \cdot \sigma_{pp}^{J/\psi}}$$

T_{AA}: nuclear overlap function, proportional to the number of nucleon-nucleon collisions

R_{AA} = 1 in absence of medium effects



PLB 734 (2014) 314-327

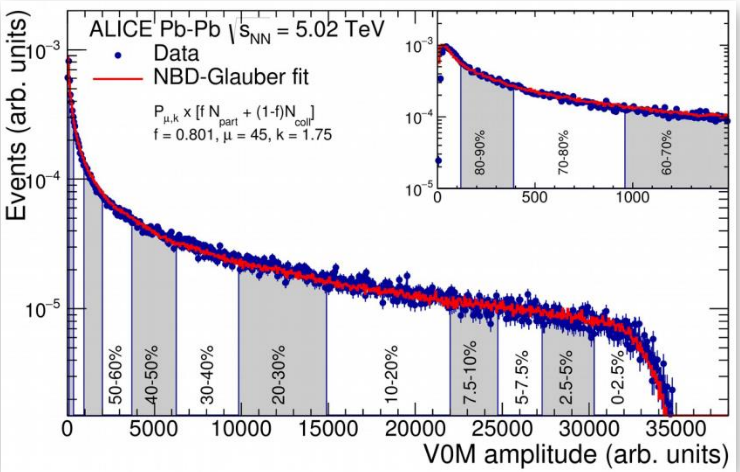
Collision centrality

Related to the transverse distance *b*, between the centers of the colliding nuclei

Also quantified using N_{part}, N_{coll} or T_{AA}

- Peripheral collisions: large *b*, small N_{part}, N_{coll}
- Central collisions: small *b*, large N_{part}, N_{coll}

Measured using fits to energy distribution in a ref detector (here V0) and a geometrical model of the collision



Run-1 results

Nuclear modification factor

$$R_{AA}^{J/\psi} = \frac{Y_{AA}^{J/\psi}}{T_{AA}.\sigma_{pp}^{J/\psi}}$$

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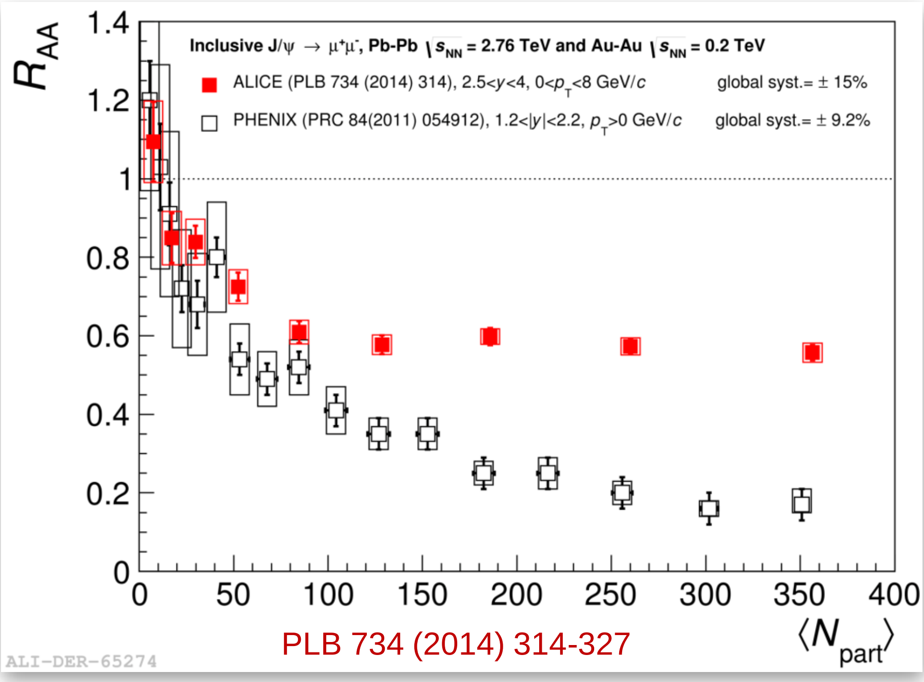


On the figure: J/ψ R_{AA} measured at forward rapidity vs N_{part} at RHIC ($\sqrt{s_{NN}}$ = 0.2 TeV) and at LHC ($\sqrt{s_{NN}}$ = 2.76 TeV)

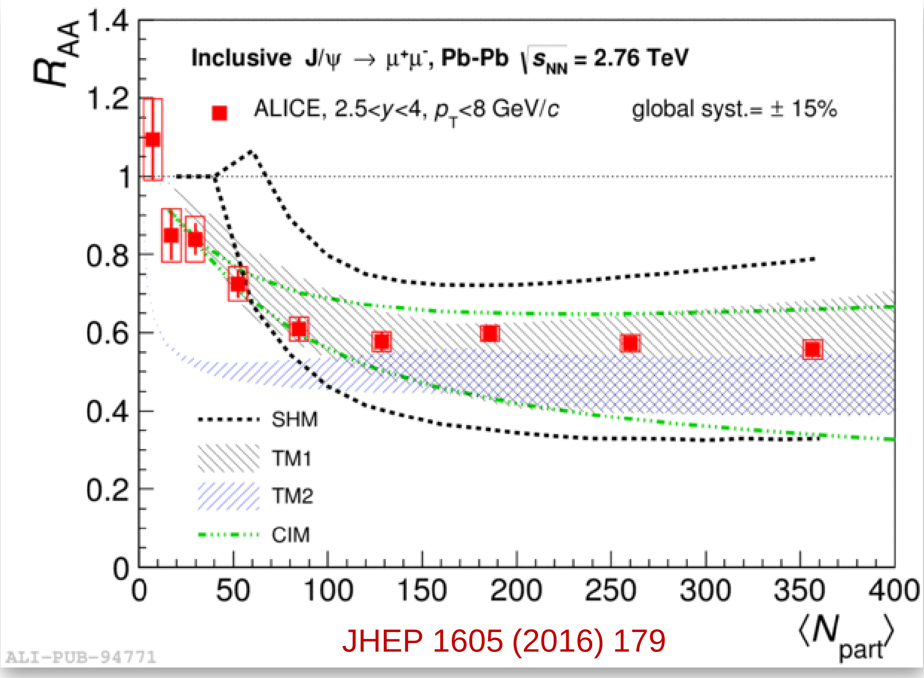
Clear suppression is observed in both cases for mid-central and central collision

Suppression is smaller (larger R_{AA}) at LHC than at RHIC ⇐ recombination

Run-1 results

J/ψ R_{AA} was compared to several models that all include a suppression and a regeneration component, on top of CNM effects

SHM	Andronic et. al., JPG 38 (2011) 124081
TM1	Zhao et. al., NPA 859 (2011) 114–125
TM2	Zhou et. al., PRC 89 (2014) 054911
CIM	Ferreiro, PLB 731 (2014) 57



JHEP 1605 (2016) 179

How the J/ψ R_{AA} is modified when increasing the collision energy by a factor ~2 ?

Are the same models still able to reproduce the new data at 5.02 TeV ?

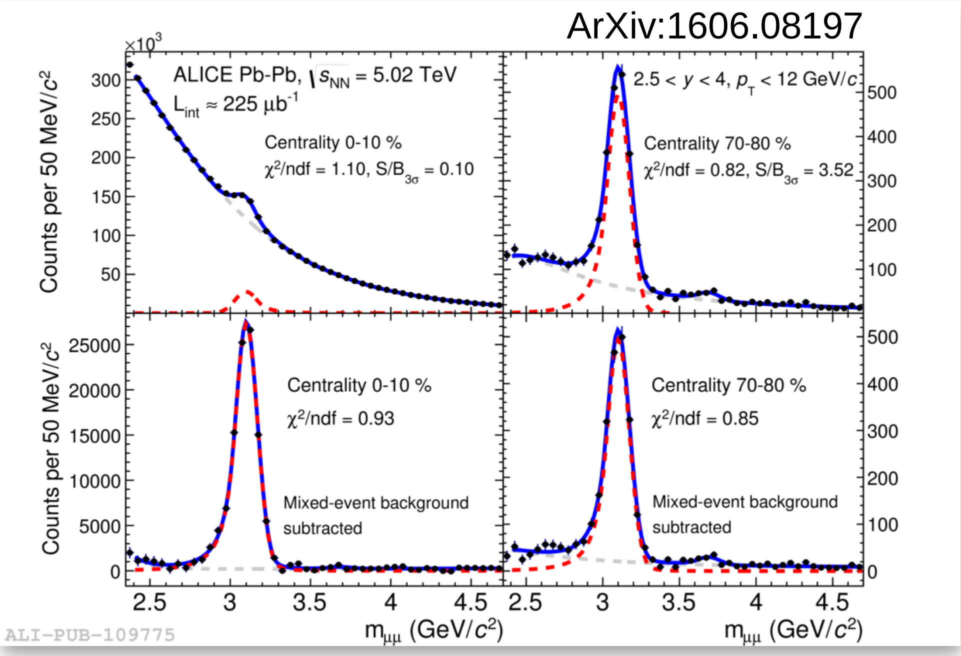
Analysis

Data from fall 2015 (Pb-Pb @ 5.02 TeV)

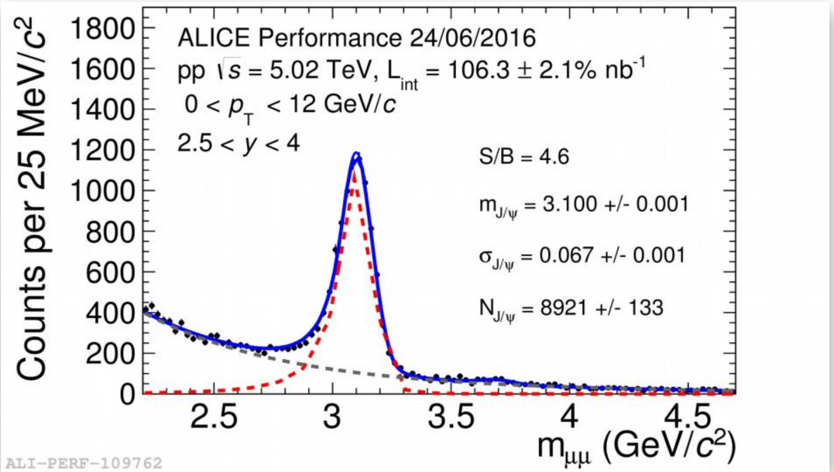
Luminosity: $L_{int} \approx 225\ \mu b^{-1}$

Signal extraction is performed by either

- fitting the invariant mass spectrum directly
- removing the combinatorial background using event mixing, + fit



corresponds to $N_{J/\psi}$ = 285k
(about 7 times Run-1 statistics)



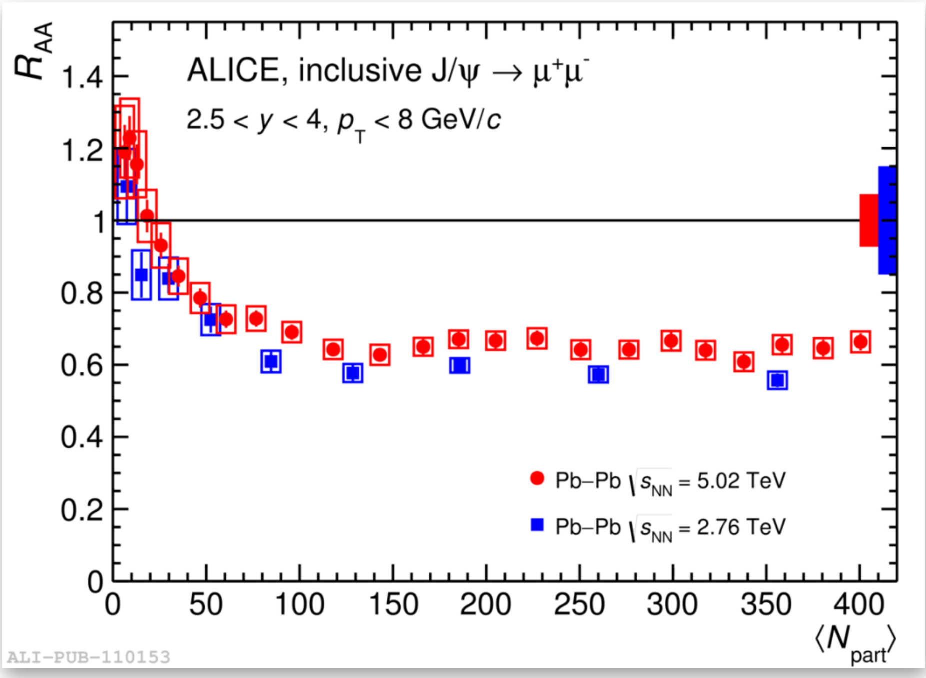
<u>pp reference</u>:

4 days of data taking before the Pb-Pb run

Luminosity: $L_{int} = 106.3\ nb^{-1} \pm 2.1\%$

Run-2 R_{AA} compared to Run-1

ArXiv:1606.08197



Similar centrality dependence at 5 TeV and 2.76 TeV

Difference in magnitude between the two energies is not significant within uncertainties

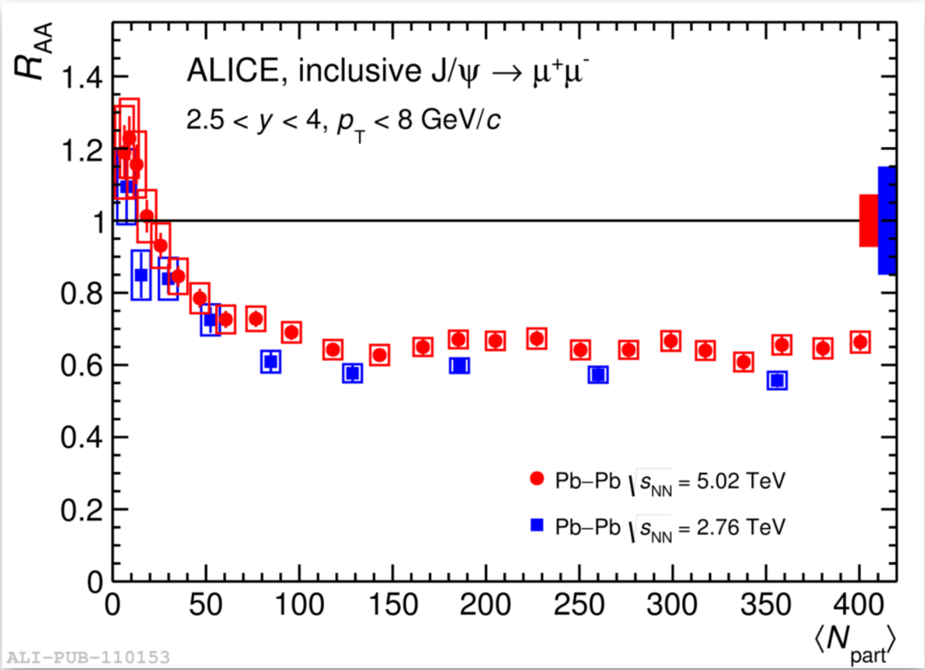
$R_{AA}^{0\text{-}90\%}$ (5.02 TeV) = 0.66 ± 0.01(stat) ± 0.05(syst)

$R_{AA}^{0\text{-}90\%}$ (2.76 TeV) = 0.58 ± 0.01(stat) ± 0.09(syst)

$R_{AA}^{0\text{-}90\%}$ (5.02 TeV)/$R_{AA}^{0\text{-}90\%}$ (2.76 TeV) = 1.13 ± 0.02(stat) ± 0.18(syst)

Run-2 R_{AA} compared to Run-1

ArXiv:1606.08197



Similar centrality dependence at 5 TeV and 2.76 TeV

Difference in magnitude between the two energies is not significant within uncertainties

<u>Contribution from non-prompt J/ψ</u>:

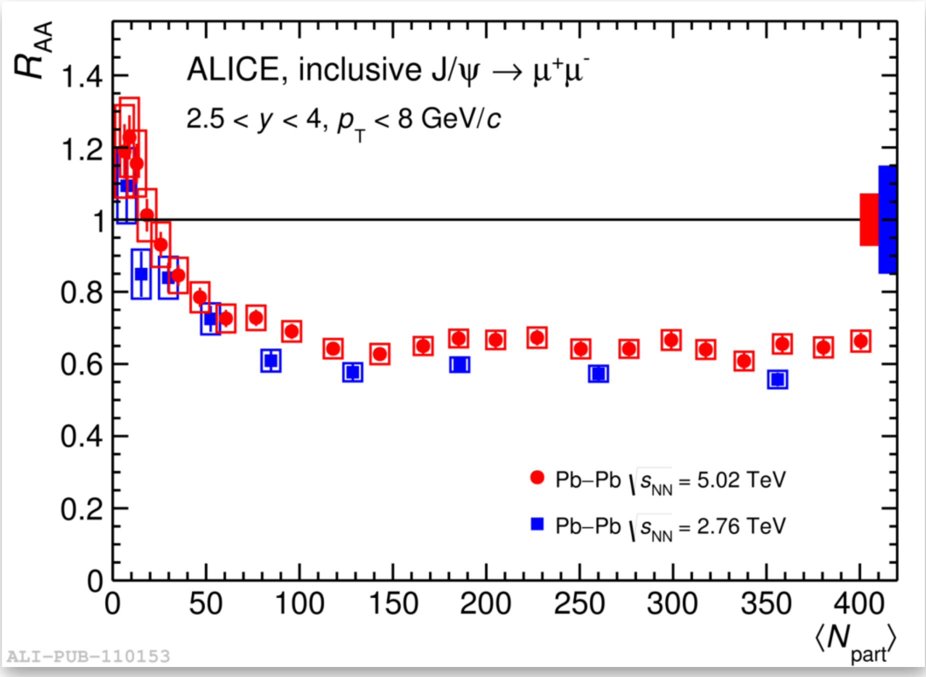
The R_{AA} of prompt J/ψ would be

~ 10% higher if R_{AA}(non-prompt) = 0

~ 5% (1%) smaller if R_{AA}(non-prompt) = 1 for central (peripheral) collisions

Run-2 R_{AA} compared to Run-1

ArXiv:1606.08197



Similar centrality dependence at 5 TeV and 2.76 TeV

Difference in magnitude between the two energies is not significant within uncertainties

<u>J/ψ excess at very low p_T</u>:

For peripheral collisions R_{AA} > 1

This is due to a J/ψ excess observed at very low p_T, possibly originating from photo-production (see ALICE PRL 116 (2016) 222301)

Adding a low p_T cut at 300 MeV/c removes ~80% of this contribution and is better suited for comparison with models

Comparison to models

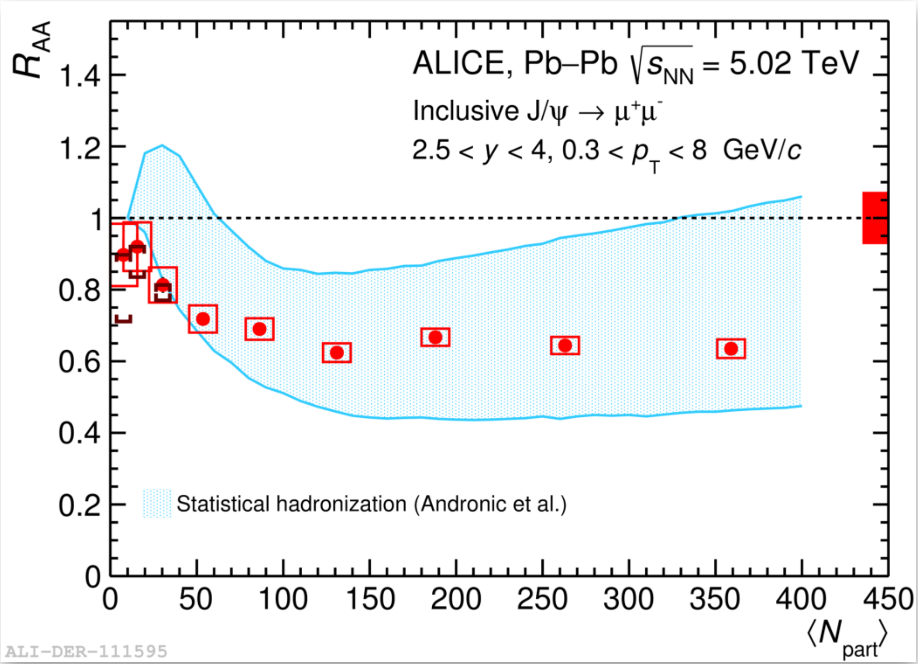
ArXiv:1606.08197

<u>Statistical Hadronization Model (SHM)</u>

Andronic et. al., NPA 904-905 (2013) 535c

Primordial charmonia are completely suppressed in the QGP

Charmonium production occurs at phase boundary by the statistical hadronization of charm quarks



Comparison to models

ArXiv:1606.08197

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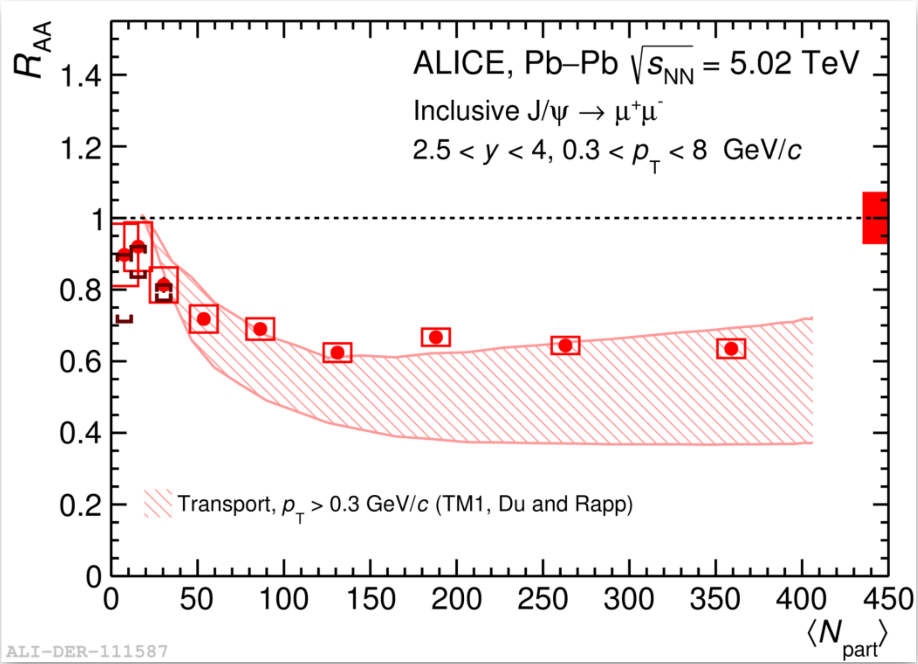

Transport Models (TM)

Continuous charmonium dissociation and regeneration in the QGP, described by a rate equation

Du and Rapp, NPA859 (2011) 114–125

Comparison to models

ArXiv:1606.08197

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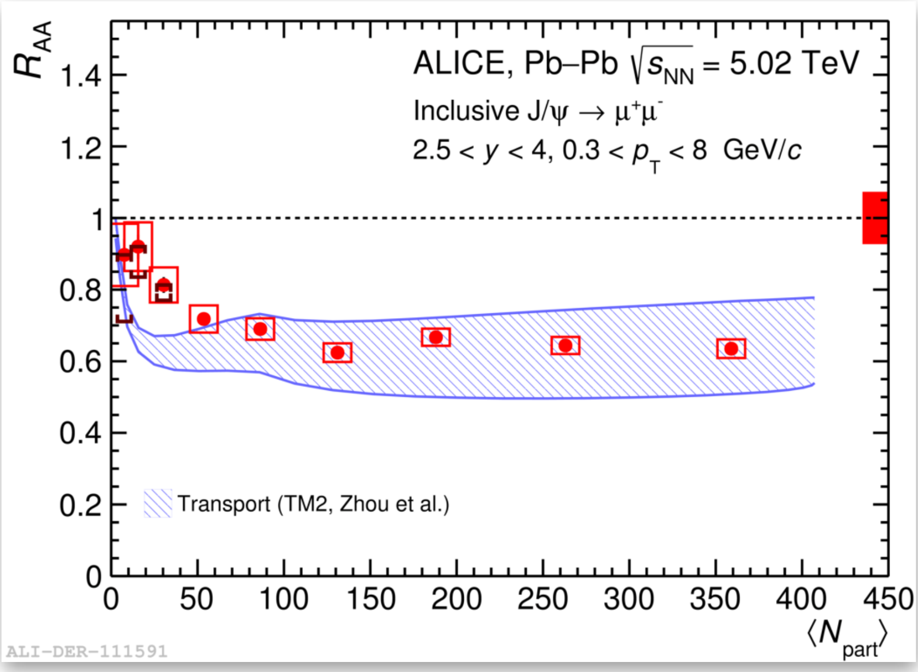

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Zhou et al., PRC89 5, 459 (2014) 054911

Comparison to models

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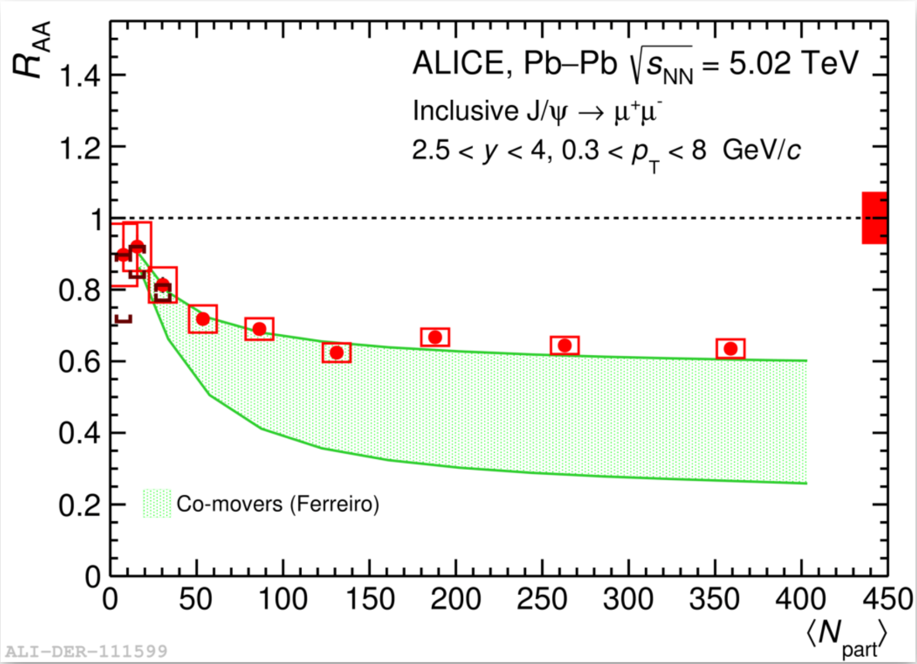

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Continuous charmonium dissociation and regeneration in the QGP, described by a rate equation

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Zhou et al., PRC89 5, 459 (2014) 054911

Comover Interaction Model (CIM)

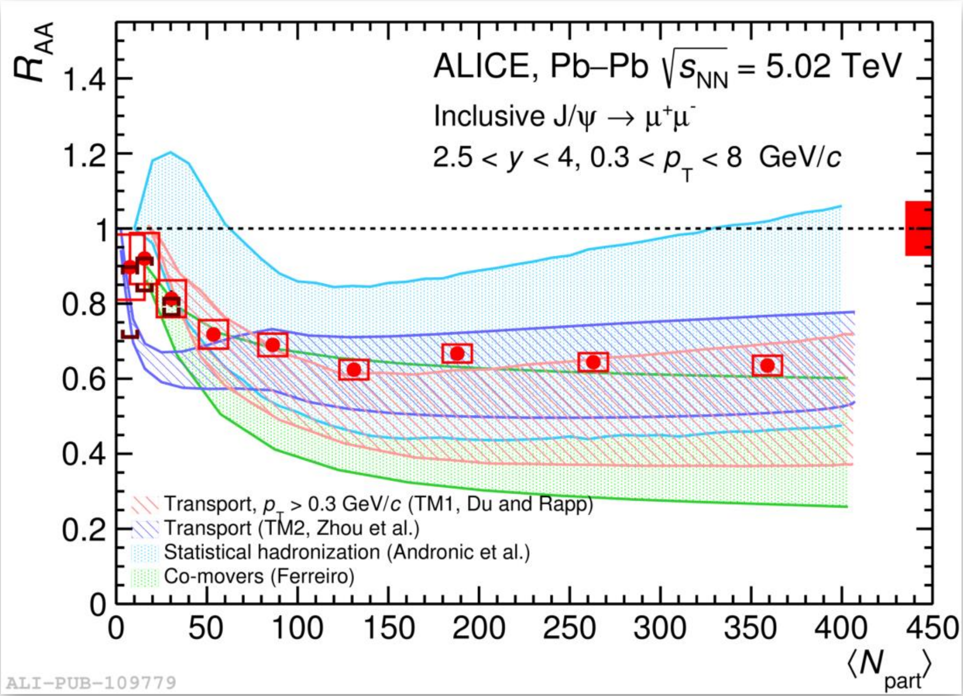
Ferreiro, PLB 731 (2014) 57

Dissociation occurs by interaction with a dense co-moving partonic medium

Regeneration is added as a gain term to the comover dissociation

Comparison to models

ArXiv:1606.08197

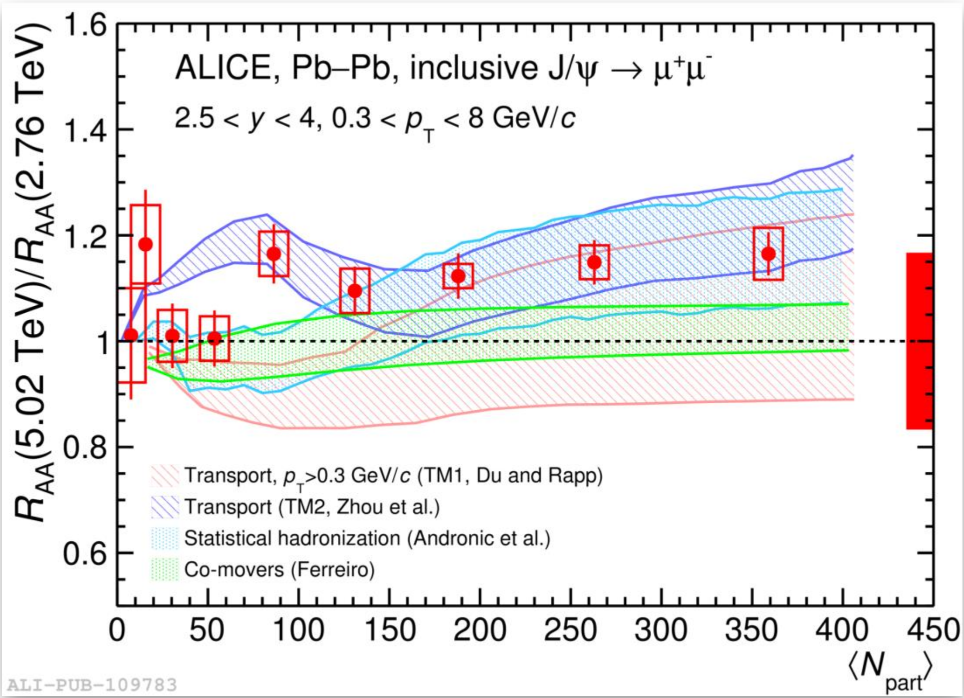


All models that could describe the 2.76 TeV result also describe the new data within large theoretical uncertainties, corresponding to c-cbar cross section and CNM effects

They all contain both a suppression and a regeneration component, on top of cold nuclear matter effects

Run-2/Run-1 ratio compared to models

ArXiv:1606.08197



Forming the ratio between the two energies allows to cancel several uncertainties on the theory side. Remaining uncertainty corresponds to 5% variation of the c-cbar cross section

For the data, only the uncertainty on T_{AA} is cancelled

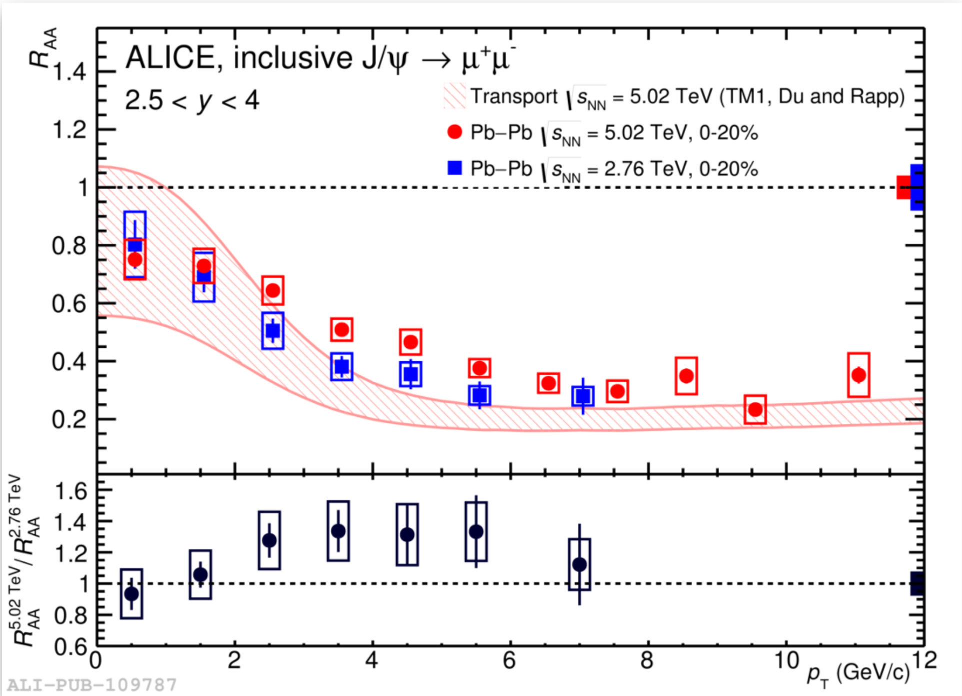
Data show no significant dependence on centrality, nor deviation from unity

Effect from non-prompt J/ψ largely cancels in the ratio and amounts to ~2%

Models are in agreement within uncertainties

R_{AA} vs p_T for central collisions

ArXiv:1606.08197



R_{AA} measurement in central collisions (0-20%) extended up to 12 GeV/c

Hint for an increase of R_{AA} in the intermediate p_T range (2-6 GeV/c), but barely significant

Some tension between model and data at intermediate p_T, whereas reasonable agreement was achieved at 2.76 TeV (see ALICE, JHEP 1605 (2016) 179)

Summary J/ψ in Pb-Pb

J/ψ R_{AA} shows no significant difference between $\sqrt{s_{NN}}$ = 5.02 TeV and 2.76 TeV

Models that could describe the latter can also describe the former,
at least for the p_T-integrated case

Future measurements will include

- more differential studies vs p_T, y and centrality
- measuring ψ(2S) R_{AA} and/or ψ(2S)-to-J/ψ double ratio
- measuring the J/ψ elliptic flow v_2

Also critical would be to decrease the size of the theoretical uncertainties and have a consistent treatment of c-cbar production cross-section, as well as CNM effects

Υ(1S) in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

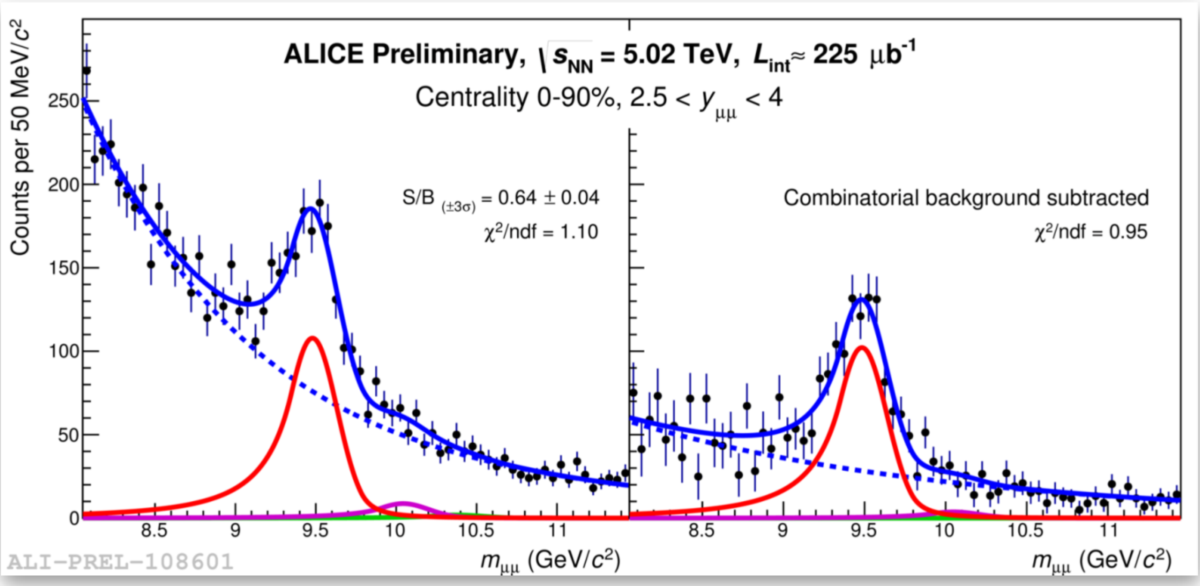
Differences between Υ(1S) and J/ψ

- heavier mass means better control on production (pQCD)
- probe different x in the nucleon
- have no non-prompt contribution
- should be less sensitive to recombination (in central Pb-Pb at LHC, there is about 5 b-bbar pairs, vs 100 c-cbar pairs)
- on the other hand one must still deal with higher-mass decay: ~30% from Υ(2S), Υ(3S) and χ_b

Studying both charmonia (J/ψ) and bottomonia (Υ(1S)) should help disentangle various mechanisms at play (CNM, screening, dissociation, recombination)

Analysis

Same data sample as for the J/ψ analysis
Luminosity: $L_{int} \approx 225\ \mu b^{-1}$



$$N_{\Upsilon(1S)} = 1107 \pm 70\ (\text{stat}) \pm 43\ (\text{syst})$$

Systematic uncertainties on R_{AA} dominated by:

- signal extraction (4-7%)
- interpolated pp cross section (8-12%)

pp reference

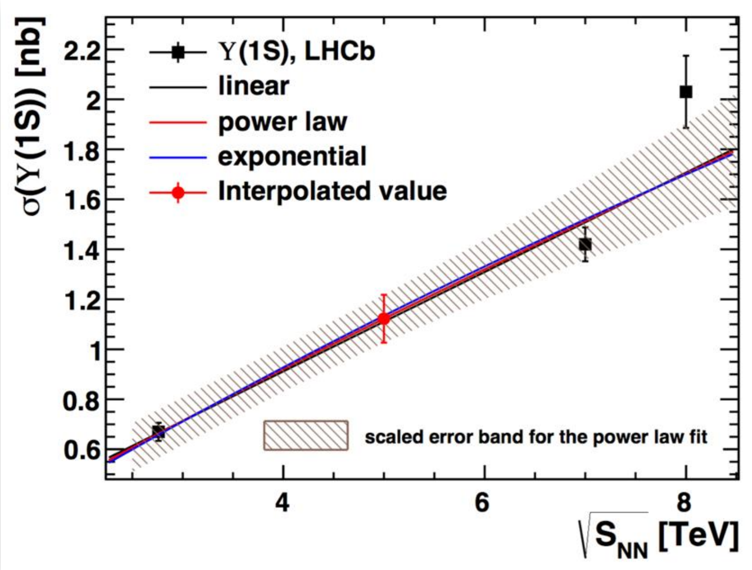
Not enough statistics in pp@5 TeV for a direct measurement

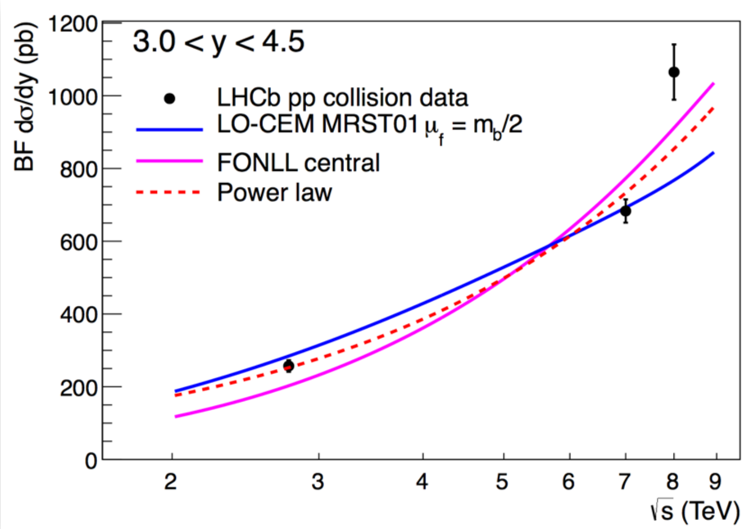
We use an interpolation between LHCb measurements at 2.76, 7 and 8 TeV using several functions:

- two parameters functions (lin, exp, power law)
- Leading order CEM calculation
- FONLL

(same procedure as for p-Pb @ 5 TeV)

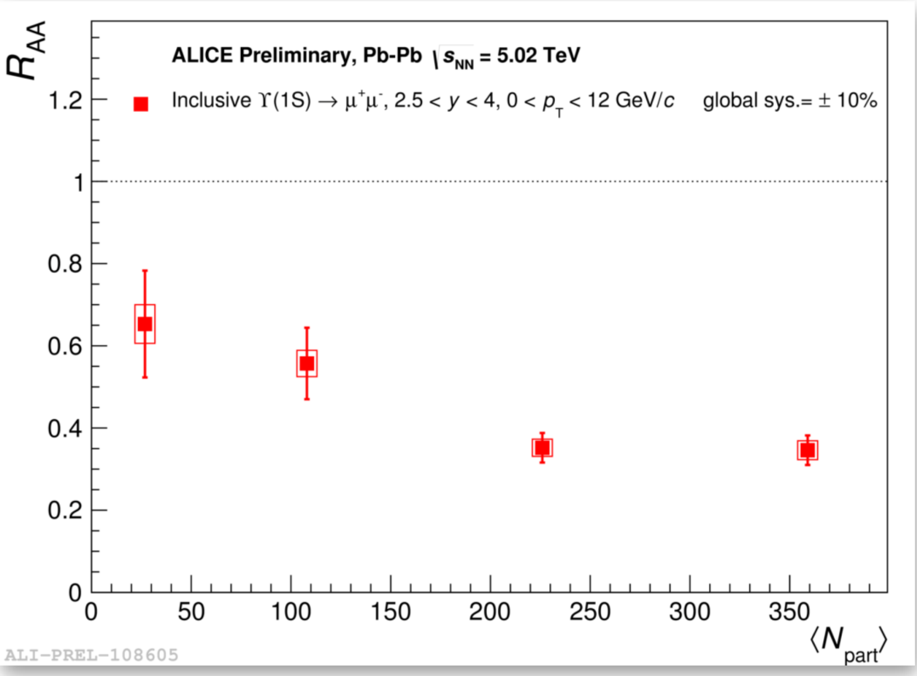
$\sigma_{Y(1S)}$ (2.5 < y <4) = 1.14 ± 0.10 (syst) nb

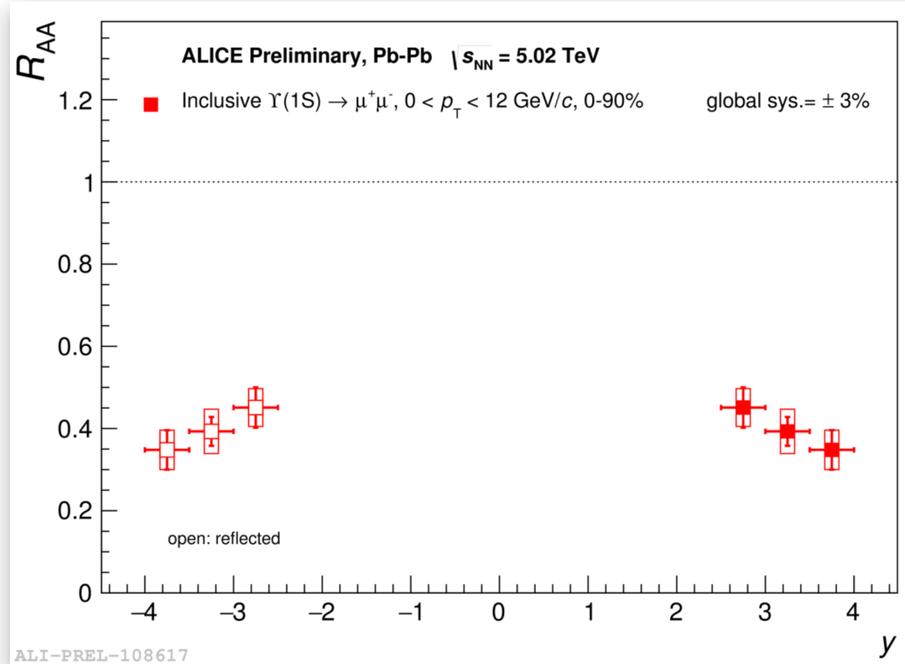




ALICE-PUBLIC-2014-002

Υ(1S) R_{AA} at $\sqrt{s_{NN}}$ = 5.02 TeV

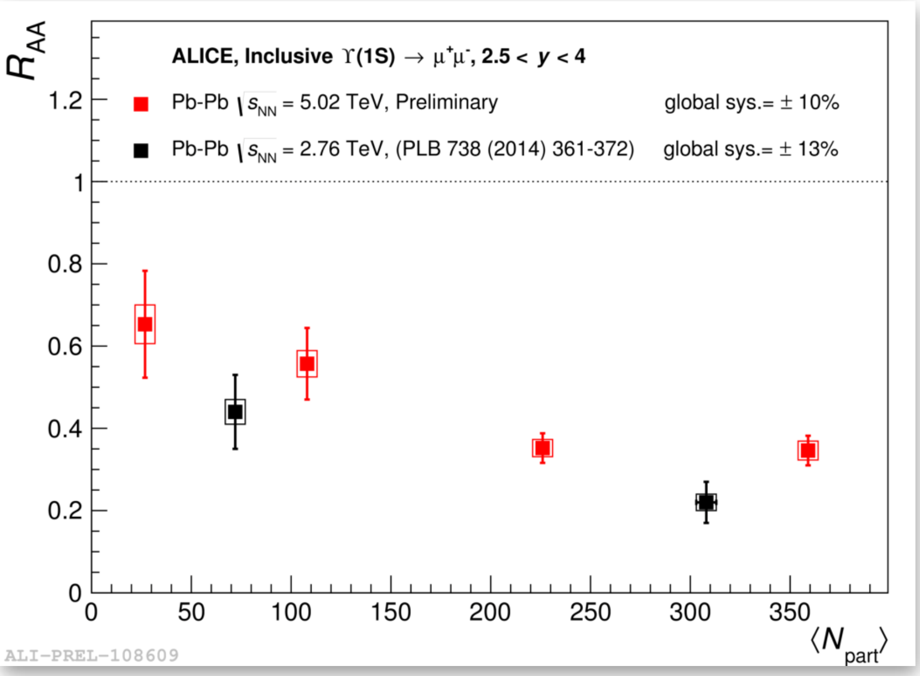


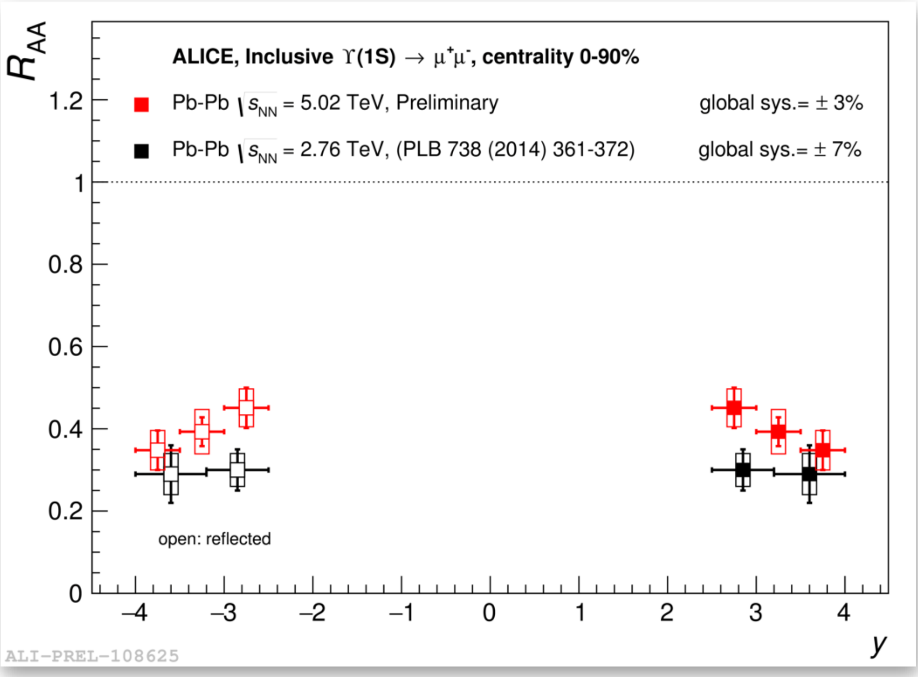


Clear suppression is observed for all centralities. It is stronger (smaller R_{AA}) for more central collisions

Possible decreasing trend with increasing rapidity, but data are also consistent with flat

Comparison to 2.76 TeV





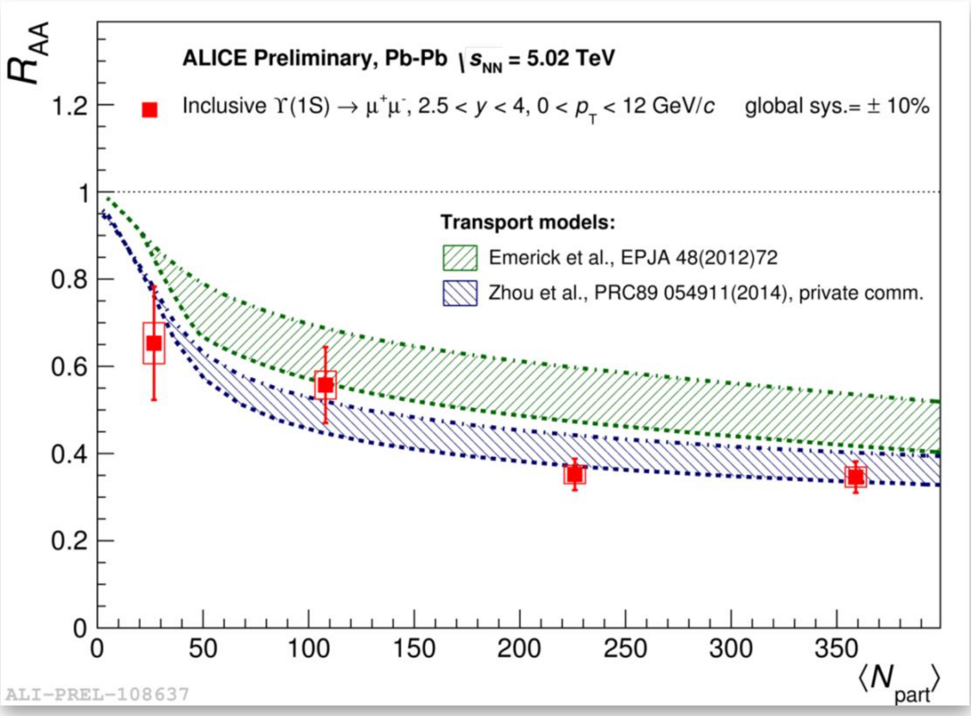
$R_{AA}^{0\text{-}90\%}$ (5.02 TeV) = 0.40 ± 0.03 (stat) ± 0.04 (syst)

$R_{AA}^{0\text{-}90\%}$ (2.76 TeV) = 0.30 ± 0.05 (stat) ± 0.04 (syst)

$R_{AA}^{0\text{-}90\%}$ (5.02 TeV)/$R_{AA}^{0\text{-}90\%}$ (2.76 TeV) = 1.3 ± 0.2 (stat) ± 0.2 (syst)

Difference between the two energies is at the 1 sigma level (stat + syst)

Comparison to models



Two transport models:

Emerick, Zhao and Rapp
(EPJA48 (2012) 72)

uncertainty band corresponds to shadowing hypothesis (0 to 25%)

Feed-down contributions from data (ALICE and LHCb)

Small regeneration component is included

Zhou, N. Xu, Z. Xu and Zhuang
(PRC 89 054911 (2014))

Band corresponds to different sets of feed-down fractions

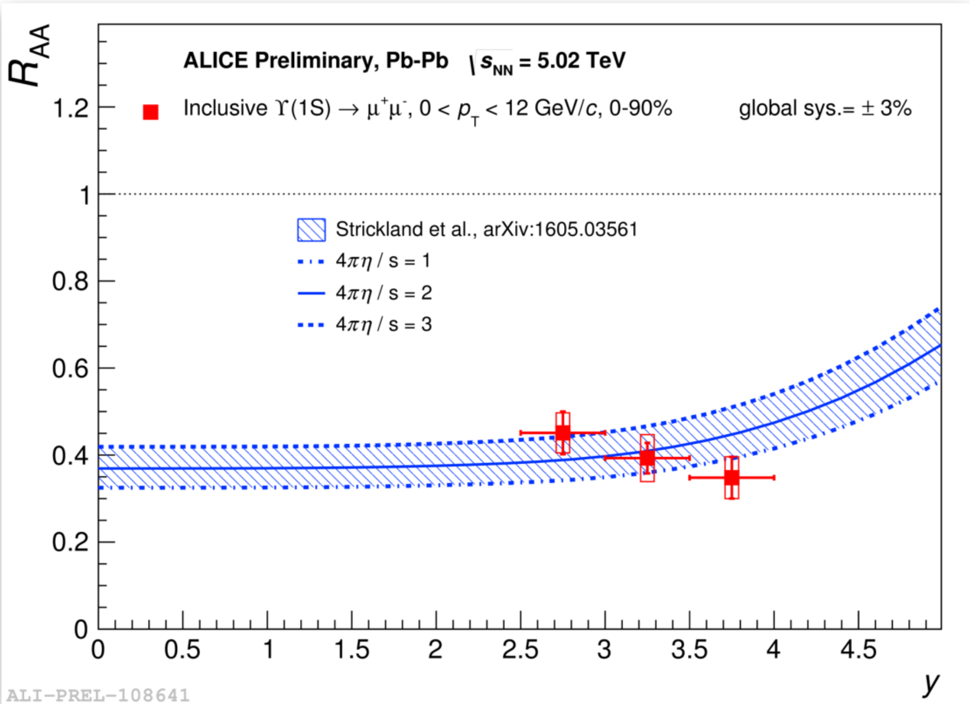
CNM: shadowing from EKS98

No regeneration component

R_{AA} for central collisions is also consistent with a complete suppression of the higher mass resonances (Υ(2S), Υ(3S) and χ_b), and no suppression of Υ(1S)

(considering a feed-down contribution from 30% and CNM effects of ~30%)

Comparison to models



Hydrodynamic model from M. Strickland et al. (arXiv:1605.03561)

thermal suppression in hydrodynamic + anisotropic screening model

uncertainty band corresponds to different values of η/s ratio

initial momentum-space anisotropy $\xi_0 = 0$

no regeneration component

no CNM effects

Model reproduces the magnitude of the suppression

Rapidity dependence seems opposite to that observed in the data

Summary Υ(1S) in Pb-Pb

Inclusive Υ(1S) R_{AA} is below unity and decreases with collision centrality

No significant difference between $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV

No indication of direct Υ(1S) suppression in central collisions

No strong rapidity dependence (to be further constrained with a point at y = 0)

Outlook

<u>in pp collisions</u>:

We have measured J/ψ and ψ(2S) production for all energies available in pp at the LHC

p_T distributions can be well described from p_T = 0 up to 30 GeV/c provided that higher mass decays and non-prompt contributions are properly accounted for, as well as gluon saturation in the nucleon, at low x

<u>in Pb-Pb collisions</u>:

No significant difference between $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV for both J/ψ and Υ(1S)
For J/ψ at least, this is consistent with models

We can learn more by looking at

- more differential results (vs p_T, y and centrality)
- more particles (ψ(2S), Υ(2S), Υ(3S))
- more observables (such as elliptic flow)

In 2016 we will have a p-Pb run at $\sqrt{s_{NN}}$ = 5 TeV and 8 TeV to further constrain CNM effects

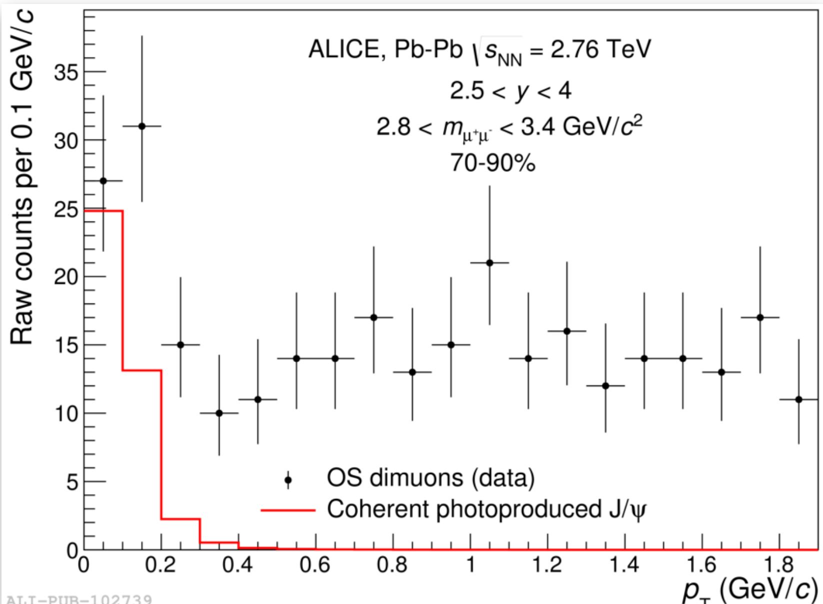
By 2018 we will have a second Pb-Pb run, to consolidate the current data sample
target luminosity $L_{int} = 1\ nb^{-1}$

Backup

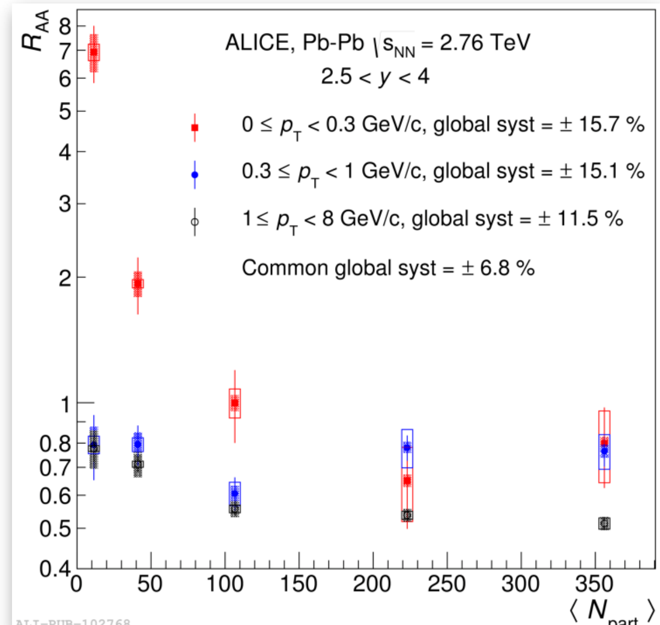
A word on J/ψ photo-production in Run-1

An excess of the J/ψ production has been observed at forward rapidity, low-p_T ($p_T < 300$ MeV/c) and in peripheral collisions

PRL 116 (2016) 222301



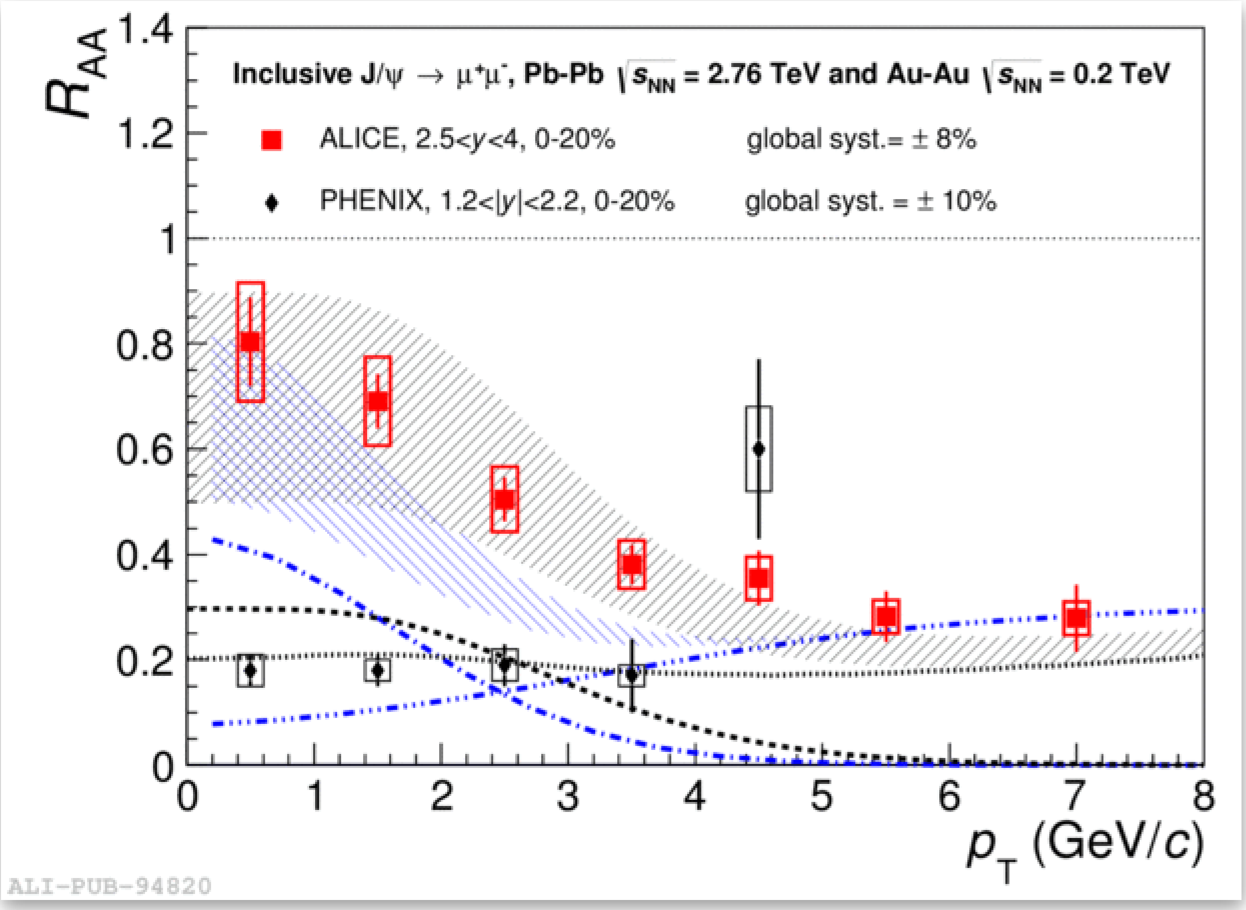
PRL 116 (2016) 222301



It could originate from coherent J/ψ photo-production, as also measured in ultra-peripheral collisions (b>2r) see PLB 718 (2013) 1273, EPJC 73 (2013) 11

It must be properly accounted for (or removed) when interpreting the results on R_{AA} or $\langle p_T \rangle$

J/ψ R_{AA} vs p_T for central collisions in Run-1



black: TM1, Zhao et. al., NPA 859 (2011) 114–125
blue: TM2, Zhou et. al., PRC 89 (2014) 054911