Quarkonium production at the LHC: experimental overview

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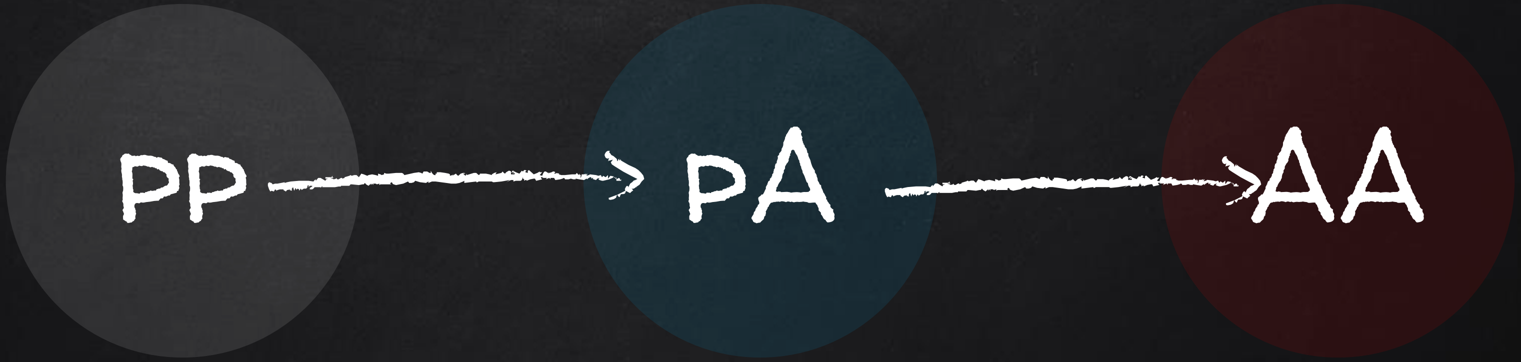
EMMI Rapid Reaction Task Force:
Suppression and (re)generation of quarkonium in heavy-ion collisions at the LHC
16 December 2019

Overview

- ✓ wrap-up of the most recent charmonium and bottomonium results (after-QM19)
- ✓ At the end of Run-2, precise results from the LHC experiments are available, in all systems and over a broad kinematic range



GOAL: compare results, check compatibility
Do we have a coherent picture?

Observables

Nuclear modification factor R_{AA}

Medium effects quantified comparing AA particle yield with pp cross section, scaled by a geometrical factor ($\propto N_{coll}$)

$$R_{AA} = \frac{Y_{AA}}{\langle T_{AA} \rangle \sigma_{pp}}$$

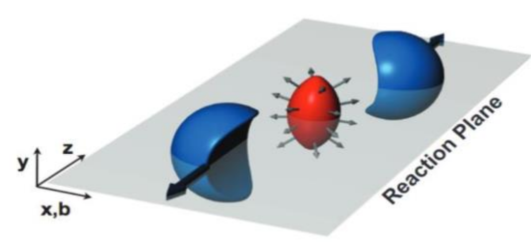
- hot/cold matter effects
  → $R_{AA} \neq 1$

Azimuthal anisotropy v_2

Multiple interactions in the medium convert initial geometric anisotropy into particle momenta anisotropy

→ elliptic flow (v_2) is the 2nd coeff. of the Fourier expansion of the azimuthal distributions of the produced particles, wrt the event plane

$$v_2 = \langle \cos 2(\phi_{particle} - \Psi_{EP}) \rangle$$



Where are we?

p-A	RHIC	LHC (mid-y)	LHC (fw-y)
J/ψ R_{pA}	✓ (green)	✓ (green)	✓ (green)
$\psi(2S)$ R_{pA}	✓ (yellow)	✓ (green)	✓ (green)
$\Upsilon(1S)$ R_{pA}	✓ (yellow)	✓ (green)	✓ (green)
$\Upsilon(2S,3S)$ R_{pA}	✗	✓ (yellow)	✓ (yellow)
J/ψ v_2	✗	✓ (green)	✓ (green)
$\psi(2S)$,$\Upsilon(nS)$ v_2	✗	✗	✗

R_{pA}: available J/ψ, $\psi(2S)$ and $\Upsilon(nS)$ results, over a broad kinematic range, at RHIC and LHC

v_2: results only for J/ψ at LHC

Precision still limited for excited states

Where are we?

A–A	RHIC	LHC (mid-y)	LHC (fw-y)
J/ψ R_{AA}	✓ (green)	✓ (green)	✓ (green)
ψ(2S) R_{AA}	✓ (red)	✓ (green)	✓ (yellow)
Υ(1S) R_{AA}	✓ (yellow)	✓ (green)	✓ (green)
Υ(2S,3S) R_{AA}	✓ (yellow)	✓ (green)	✓ (yellow)
J/ψ v_2	✓ (yellow)	✓ (green)	✓ (green)
Υ(1S) v_2	✗	✓ (yellow)	✓ (yellow)
J/ψ polarization	✗	✗	✓ (green)

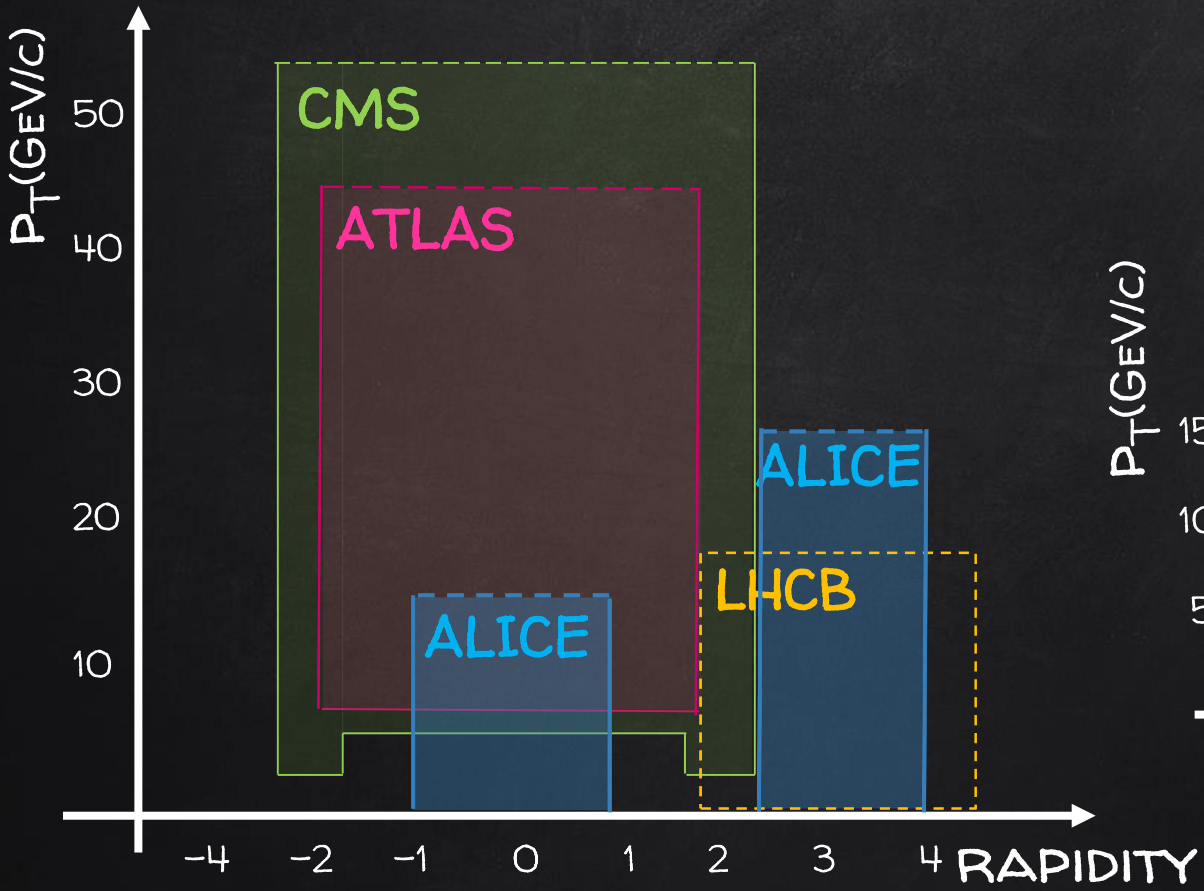
R_{AA}: high precision reached for ground states, but statistics still limited for excited states

v_2: precise J/ψ results at LHC

New observables: polarization

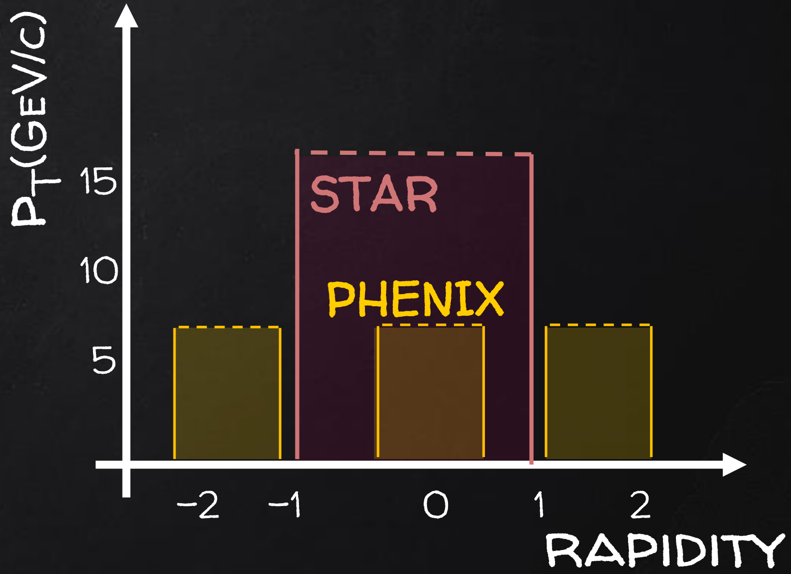
New resonance: X(3872)

J/ψ KINEMATIC COVERAGE

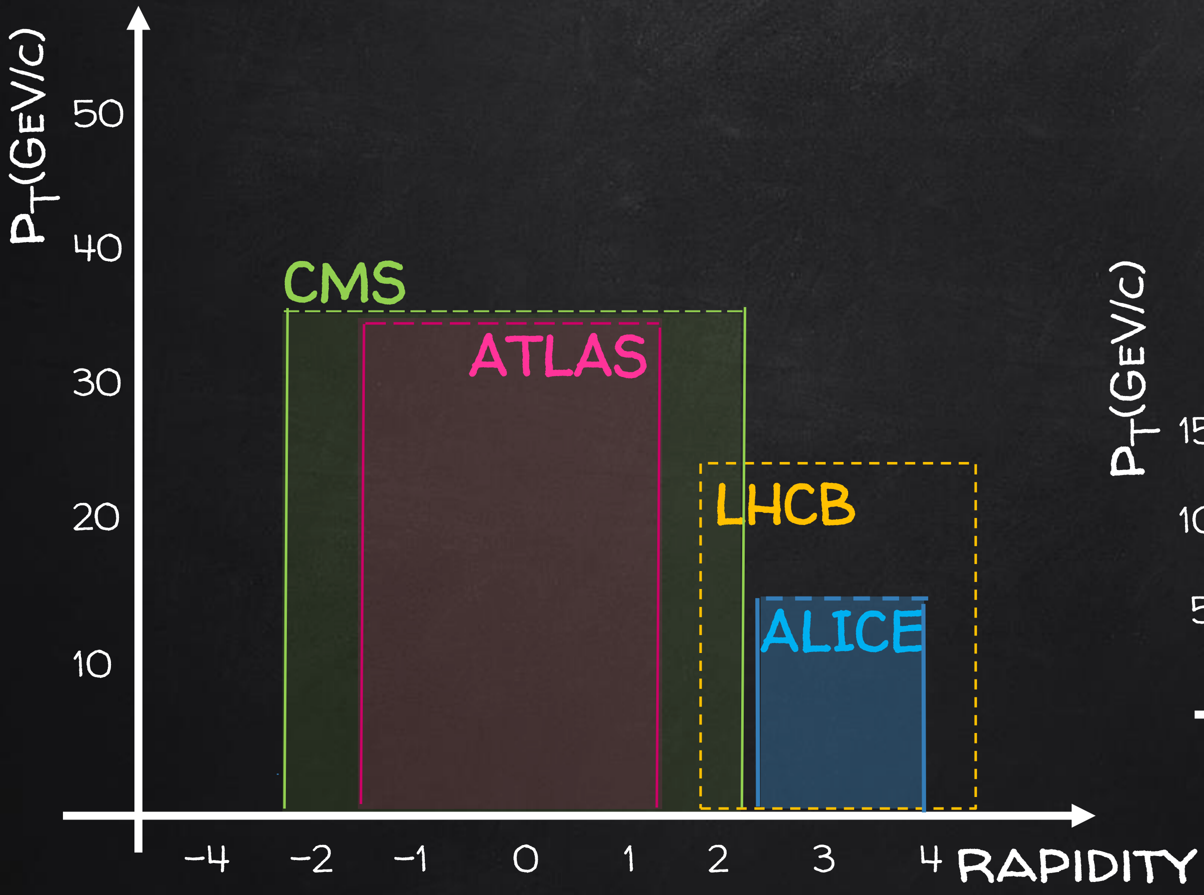


AA (pA for LHCb)

(p_T reach based on the most recent measurements)



Υ kinematic coverage



AA (pA for LHCb)

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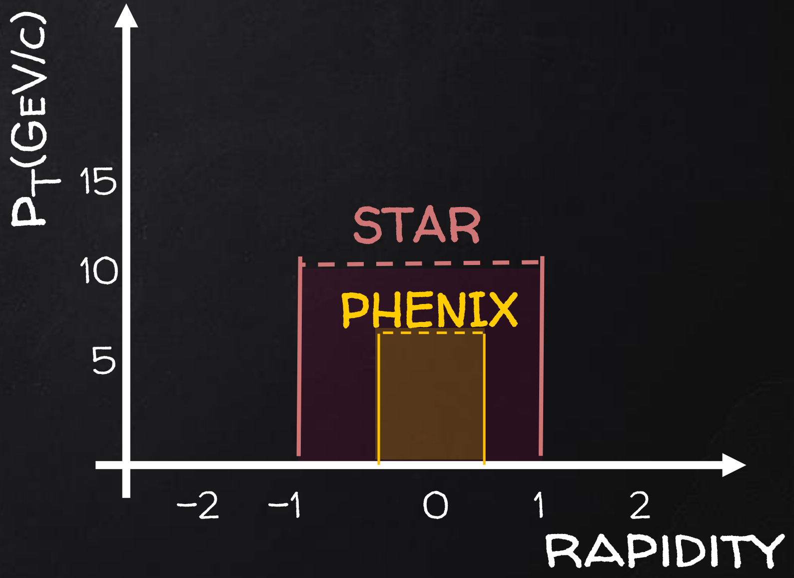


News from QM2019

Focus on pA and AA new preliminary or final results

ATLAS

- Υ in PbPb @ 5.02 TeV (2018) (ATLAS-CONF-2019-54)

CMS

- Υ(nS) production in pPb @ 5.02TeV (HIN-18-005)
- Υ v_2 in PbPb @ 5.02 TeV (2018) (HIN-19-002)
- X(3872) in PbPb @ 5.02 TeV (HIN-19-005)

LHCb

- X(3872) vs ev. activity in pp @ 8TeV (LHCb-CONF-19-005)

ALICE

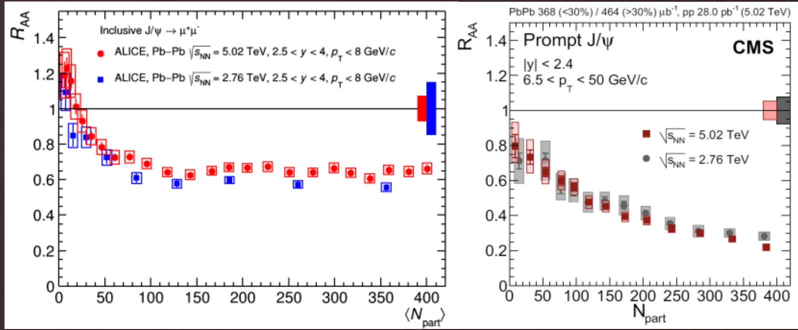
- J/ψ Q_{pA} vs centrality in pPb @ 5.02 TeV
- Υ(1S) and Υ(2S) production in pPb @ 8.16TeV (arXiv:1910.14405)
- J/ψ R_{AA}, v_2 at mid-y in PbPb @ 5.02 TeV (2015-2018 data) (arXiv:1910.14404)
- J/ψ R_{AA} at forward-y, in PbPb @ 5.02 TeV (2018), vs pT and multi-differential
- J/ψ polarization in PbPb @ 5.02 TeV
- Υ R_{AA} and v_2 at forward-y in PbPb @ 5.02 TeV (2018)

CAVEAT

- ✓ CMS and ATLAS results are for prompt J/ψ, ψ(2S) and ϒ(nS)
- ✓ ALICE results are for inclusive J/ψ (fraction of J/ψ from B is ~10% for $p_T < 5$ GeV/c and 30% for $p_T \sim 10$ GeV/c)

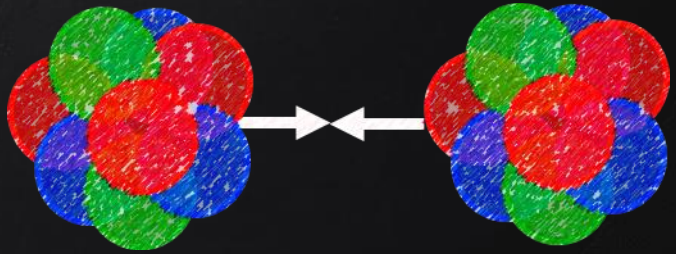
$$R_{AA}^{prompt} = \frac{R_{AA}^{incl} - R_{AA}^{non-prompt} F_B}{1 - F_B}$$

- ✓ In some comparison plots LHC Run1 and Run2 results ($\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV) are superimposed, assuming a negligible $\sqrt{s_{NN}}$ dependence



Most recents data points taken “by hand”

AA collisions

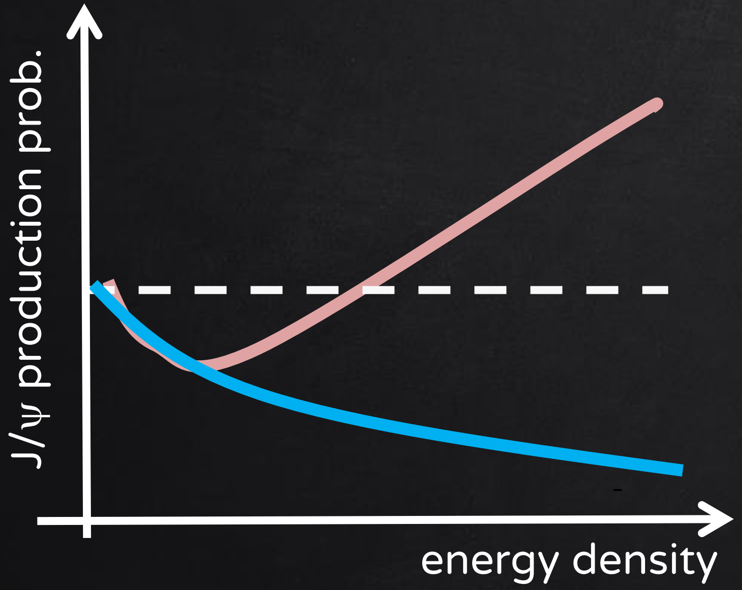


Hot matter effects

The original idea:

quarkonium production suppressed via color screening in QGP

(T.Matsui,H.Satz, PLB178 (1986) 416)



Recombination

$Q\bar{Q}$ abundance increases with $\sqrt{s_{NN}}$

Central AA coll	$N_{c\bar{c}}$ per ev.	$N_{b\bar{b}}$ per ev.
RHIC, 200GeV	~10	-
LHC, 5.02 TeV	~115	~3

→ (re)combination at hadronization or in QGP enhances charmonium production

→ small contribution for bottomonium (also at LHC)

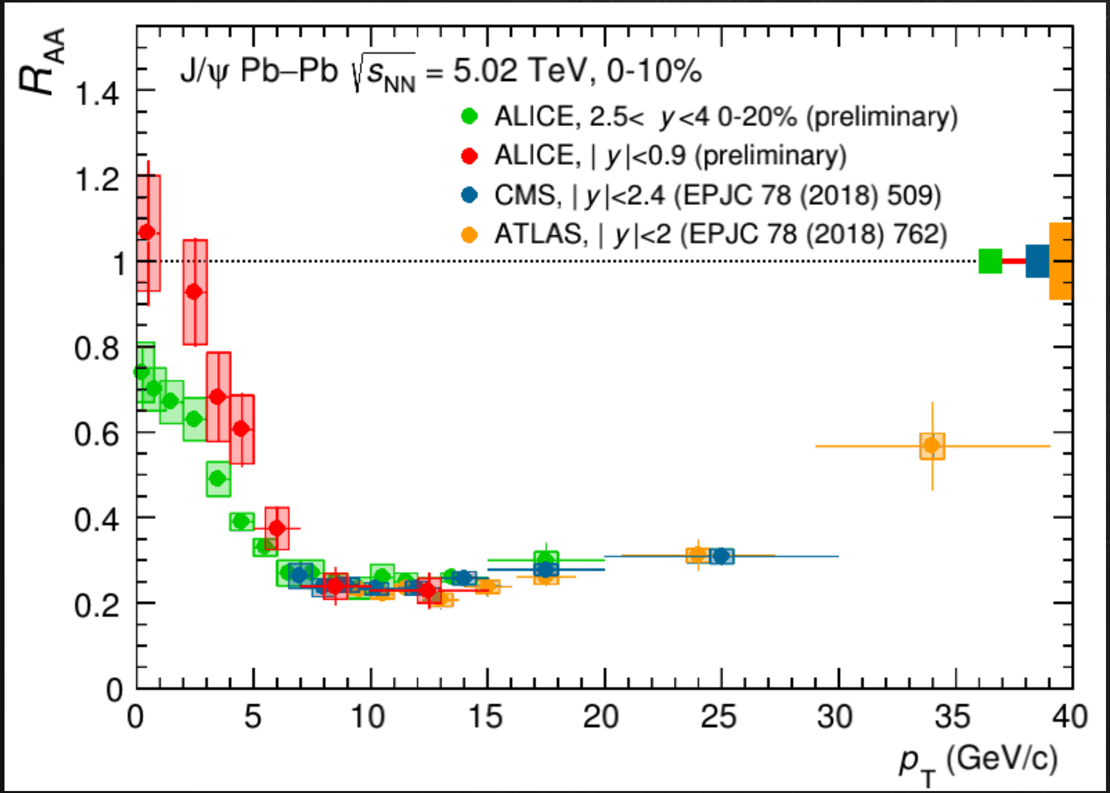
P. Braun-Muzinger,J.Stachel, PLB490(2000)196,
R.Thews et al, PRC63:054905(2001)

Sequential melting

differences in quarkonium binding energies lead to a sequential melting with increasing temperature

Digal,Petreczky,Satz PRD 64(2001) 0940150

J/ψ R_{AA} vs. p_T



Very broad p_T range (up to 40 GeV/c) now accessible

Low p_T

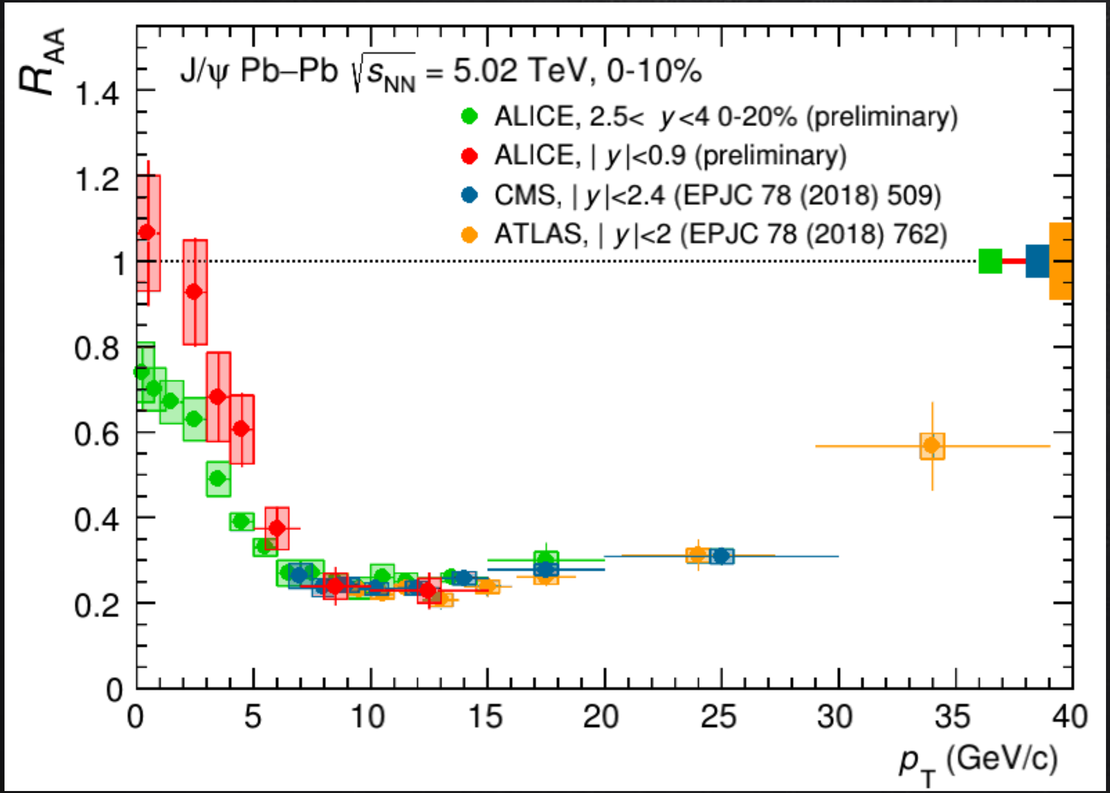
Strong rapidity dependence

High p_T

- Common behavior, independent on rapidity
- Very good compatibility of results from different experiments

Low p_T → High p_T → Very high p_T

J/ψ R_{AA} vs. p_T



Low p_T → High p_T → Very high p_T

Low p_T

Recombination mechanism plays a role clearly depending on y

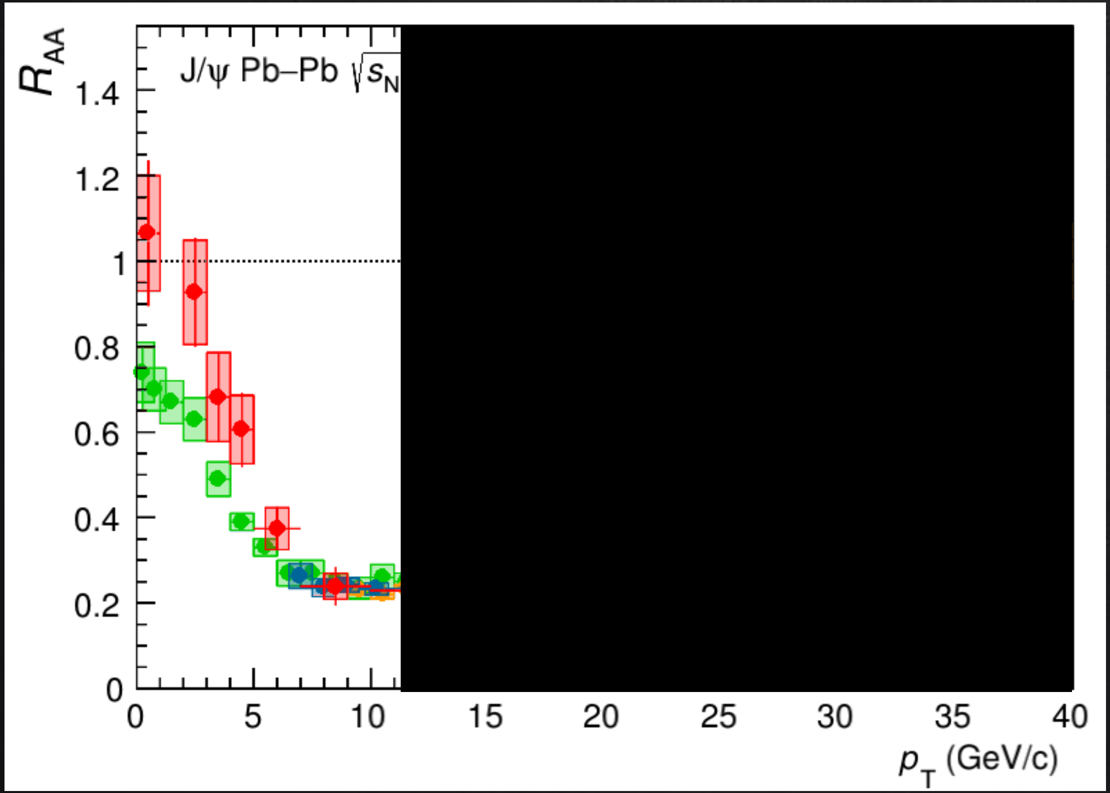
High p_T

- Suppression is the dominant process
- similar R_{AA} independent on the rapidity range

Very high p_T

R_{AA} rise due to energy loss mechanism?

J/ψ R_{AA} vs. p_T



Low p_T → High p_T → Very high p_T

Low p_T

Recombination mechanism plays a role clearly depending on y

High p_T

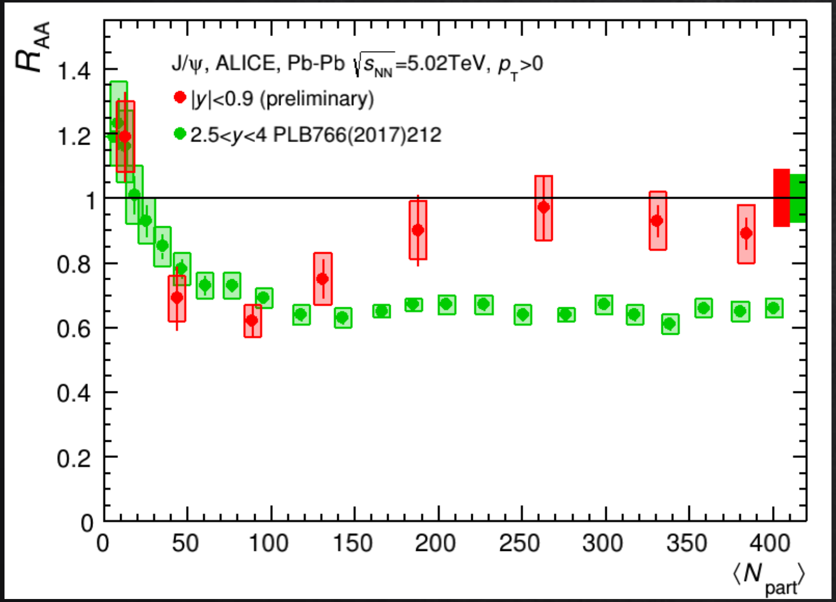
- Suppression is the dominant process
- similar R_{AA} independent on the rapidity range

Very high p_T

R_{AA} rise due to energy loss mechanism?

Low p_T J/ψ: mid vs fw-y

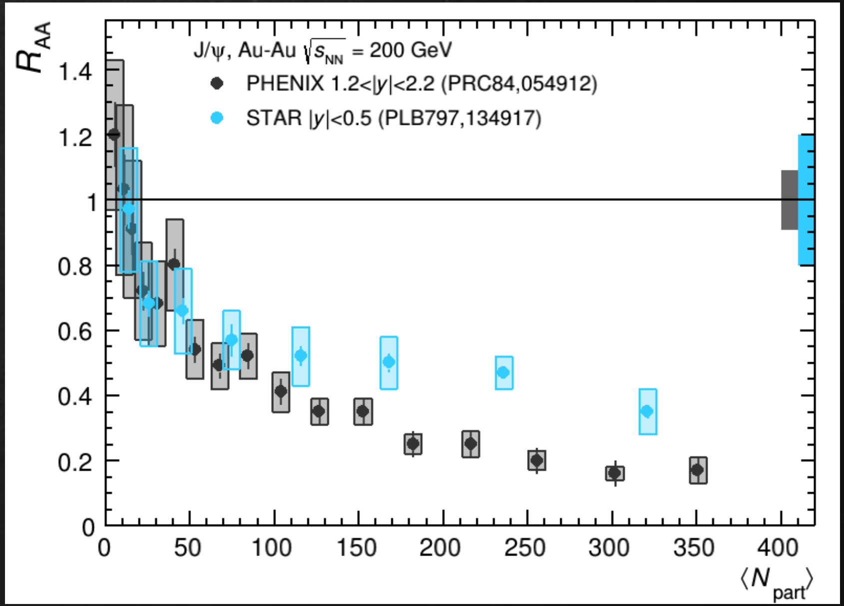
LHC



MID-Y

FW-Y

RHIC

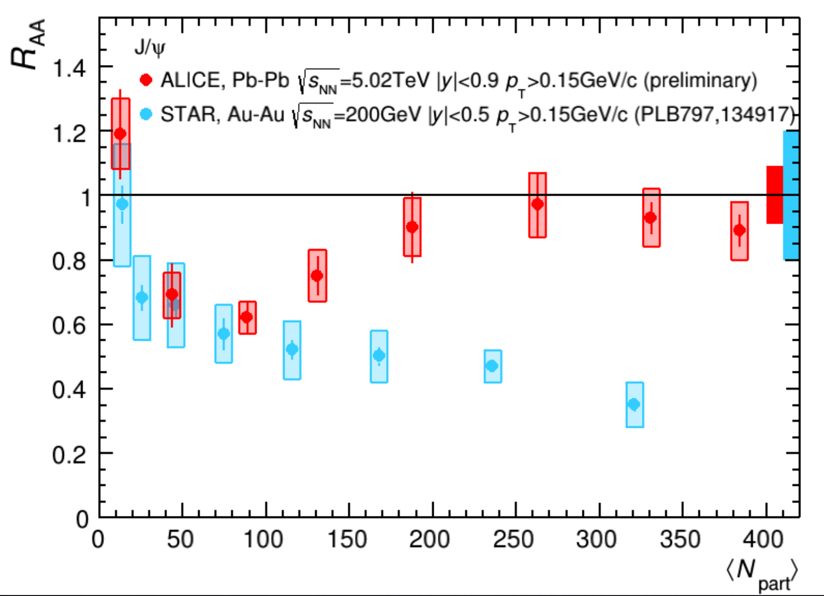


Higher R_{AA} at mid-rapidity wrt forward-y, in central events

Similar y-dependence already observed at lower energies

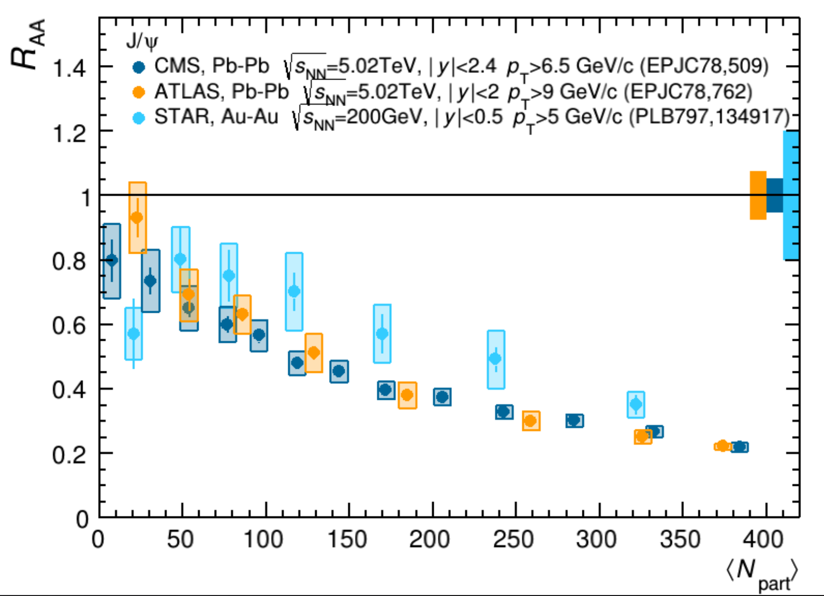
J/ψ: RHIC vs LHC

Low p_T J/ψ



$\sqrt{s_{NN}}$

High p_T J/ψ

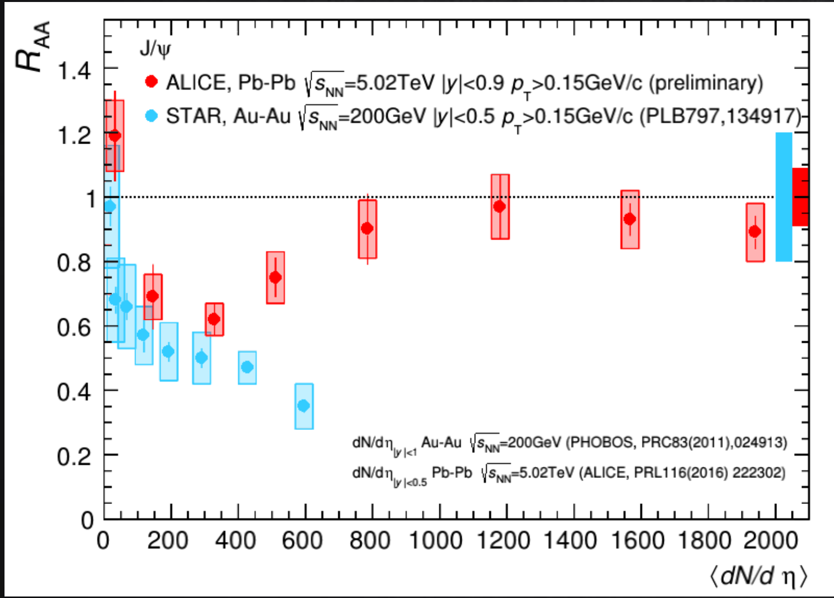


Significant difference in central collisions

R_{AA} at the two $\sqrt{s_{NN}}$ are closer, with slightly higher values at RHIC

J/ψ: RHIC vs LHC

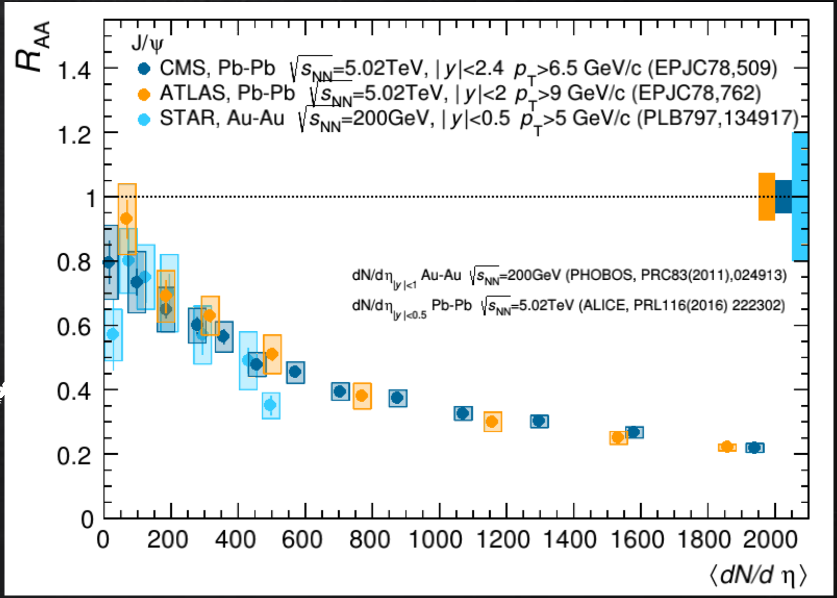
Low p_T J/ψ



Significant difference in central collisions

$\sqrt{s_{NN}}$

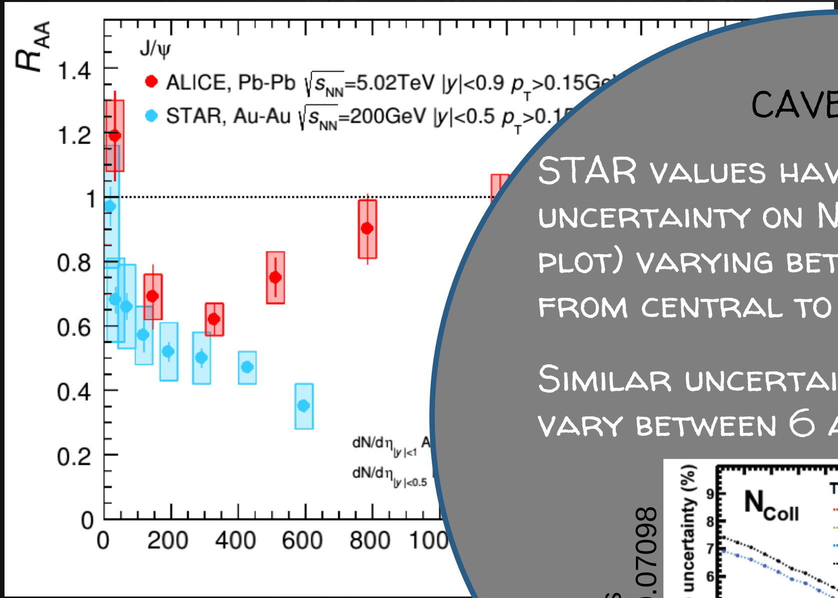
High p_T J/ψ



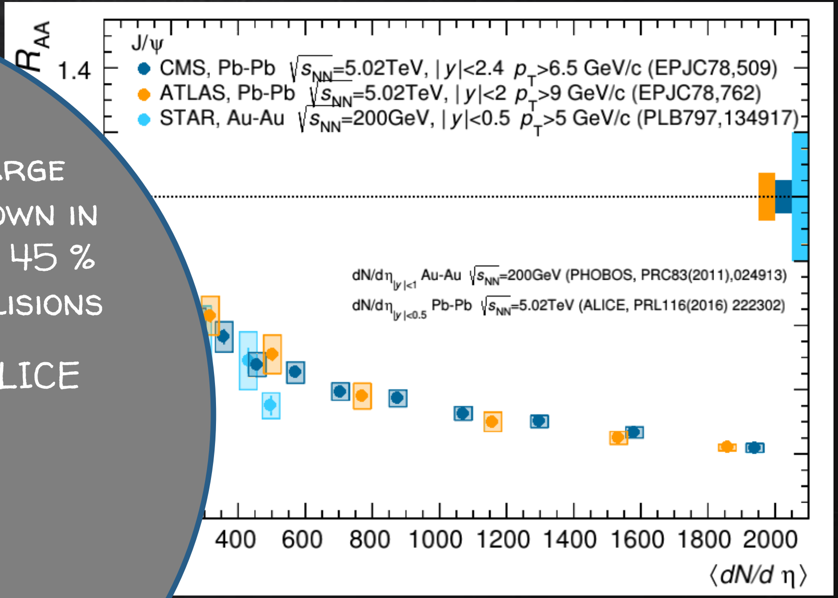
R_{AA} trend is rather smooth when shown vs dN/dη

J/ψ: RHIC vs LHC

Low p_T J/ψ



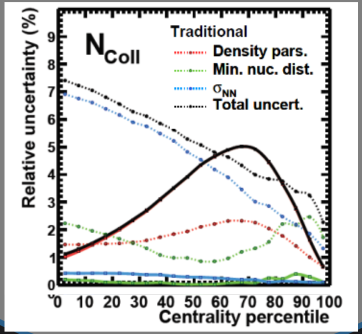
High p_T J/ψ



CAVEAT

STAR values have a very large uncertainty on N_{coll} (not shown in plot) varying between 3% to 45 % from central to periph. collisions

Similar uncertainties for ALICE vary between 6 and 3%

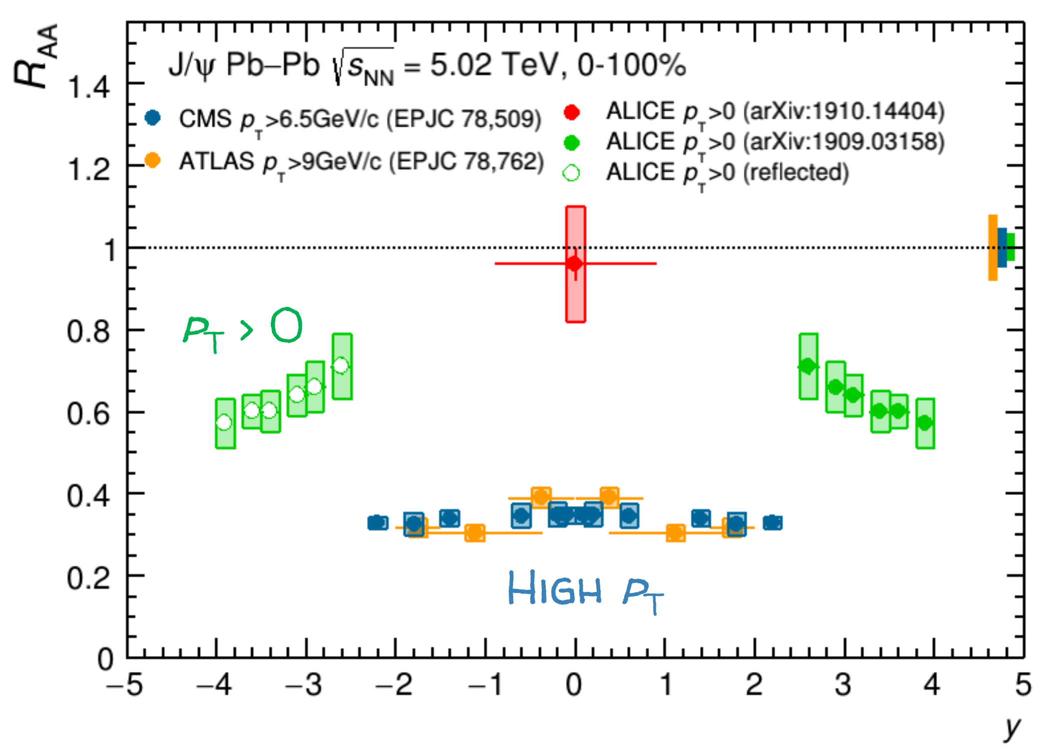


C. Loizides
arXiv:1710.07098

Significant dif... in central collis...

...rend is rather smooth when ...wn vs dN/dη

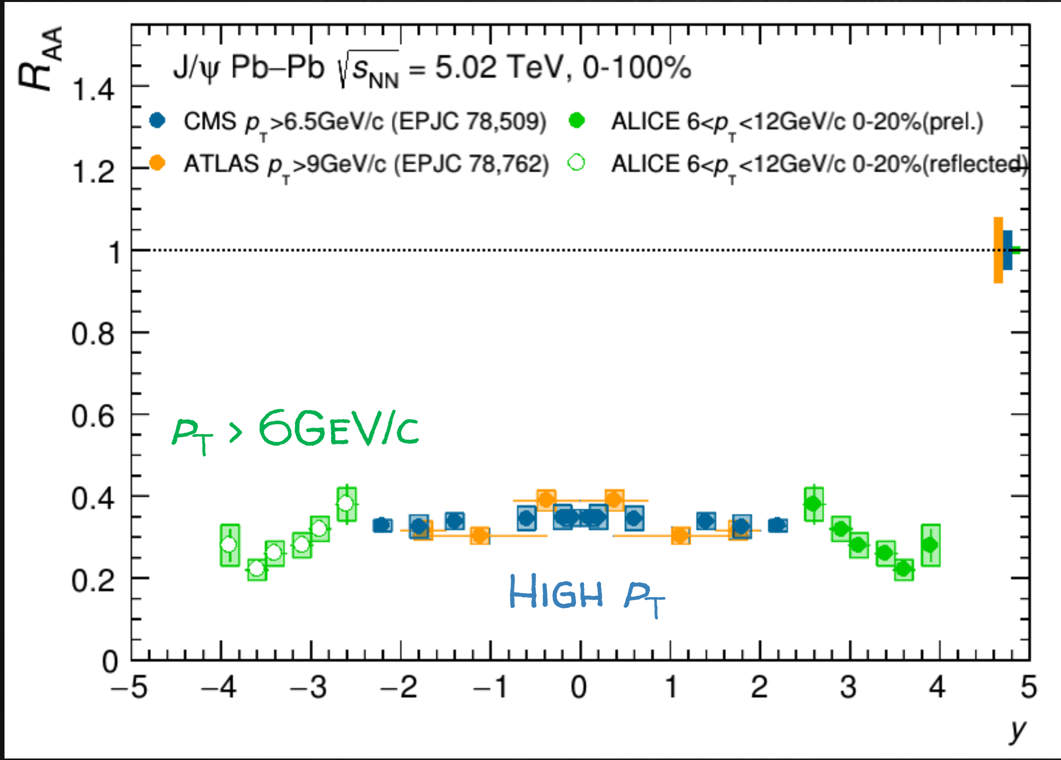
J/ψ: rapidity dependence



At low p_T R_{AA} shows a strong rapidity dependence

Significant difference at mid-y, due to the different pT coverage

J/ψ: rapidity dependence



At low p_T R_{AA} shows a strong rapidity dependence

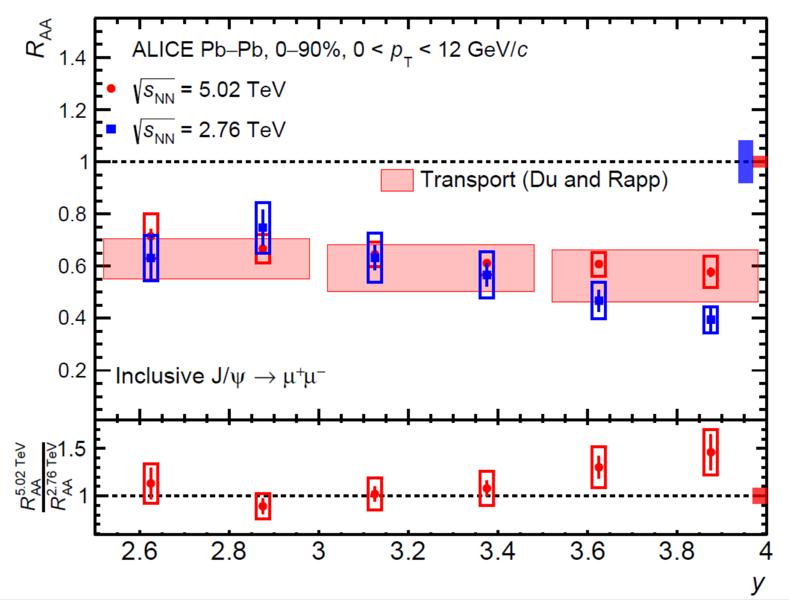
Significant difference at mid-y, due to the different p_T coverage

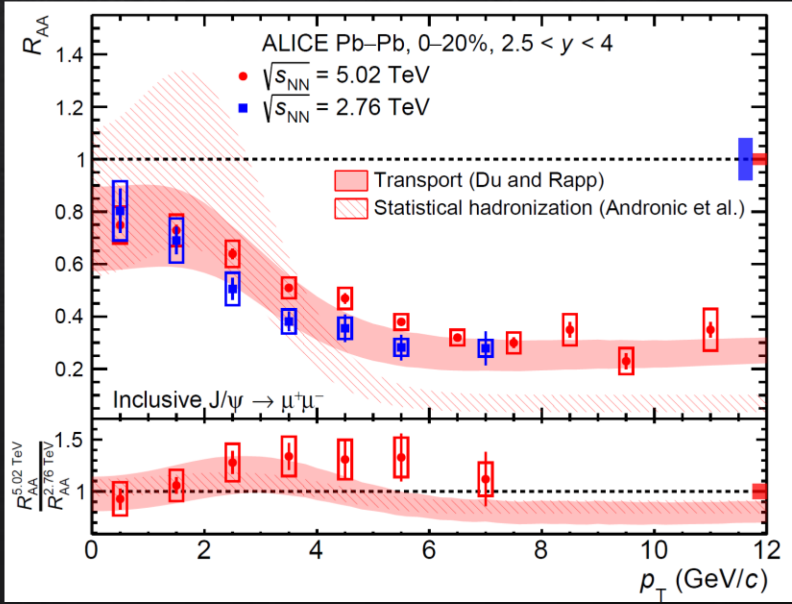
Also the difference at forward-y is driven by the p_T range

LHC: 2.76 vs 5.02 TeV

Overall good agreement between LHC results from Run1 and Run2

There are differences in the R_{AA} at very forward-y or intermediate p_T. Physics origin or fluctuations?



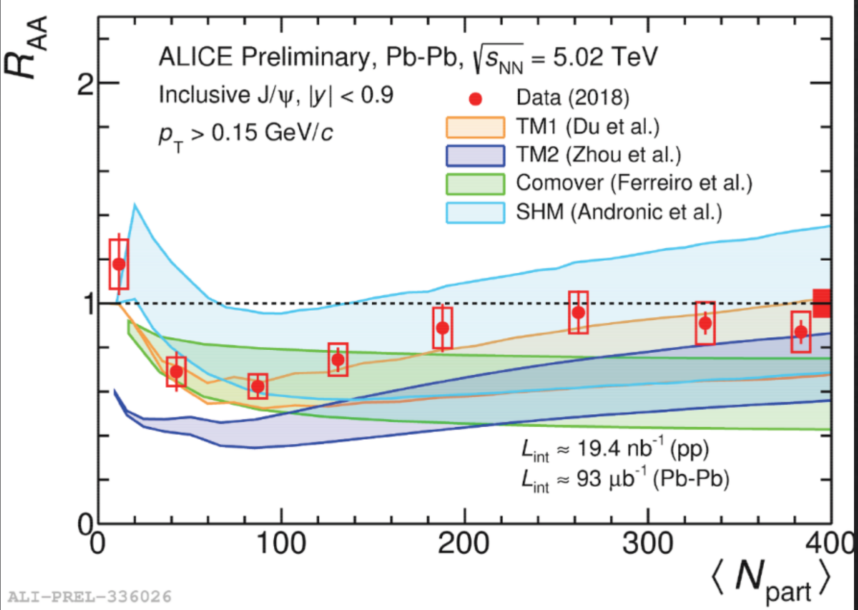


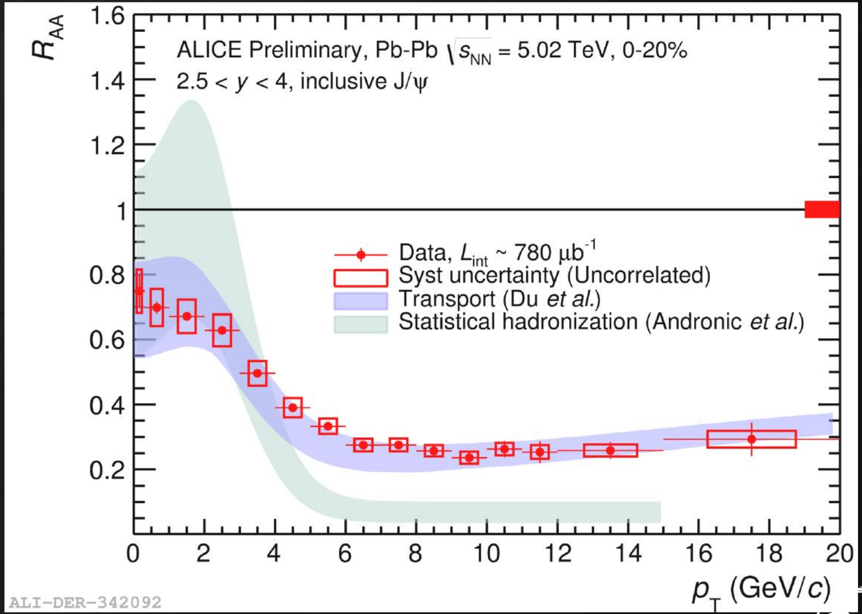
ALICE, arXiv: 1909.03158

COMPARISON TO THEORY

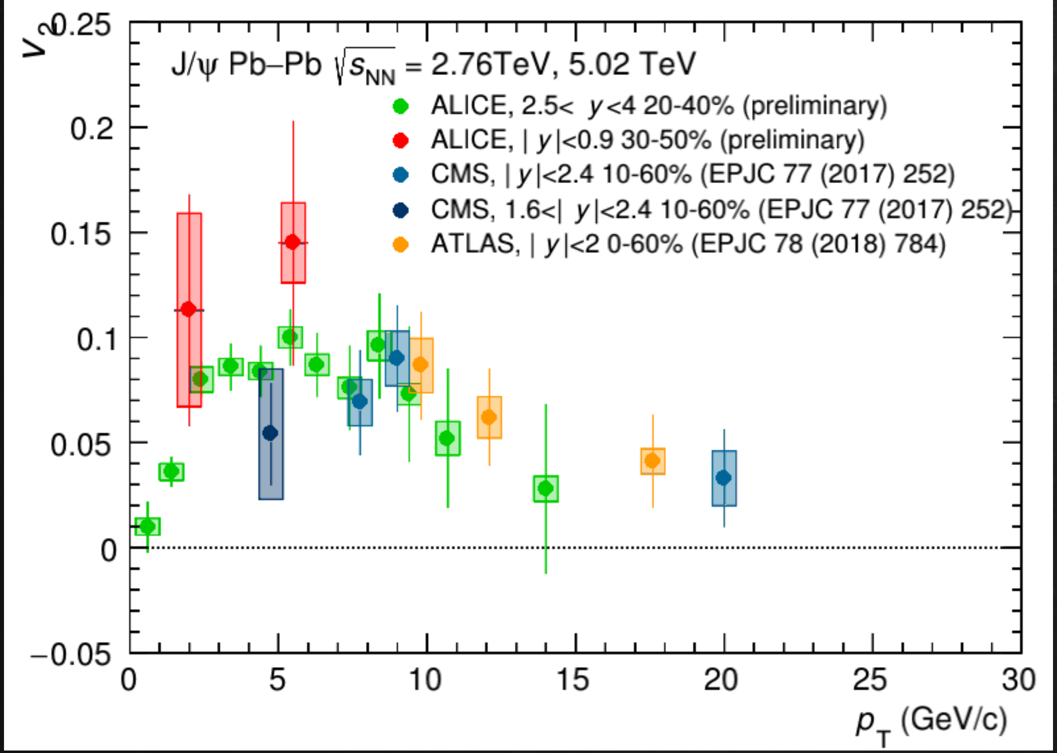
Data are described by models based on suppression+regeneration mechanisms

Regeneration dominates at low pT and high energy





J/ψ v_2



v_2 provides complementary information on J/ψ production

→ J/ψ from recombination should inherit thermalized charm flow

J/ψ v_2 measured up to p_T=30 GeV/c

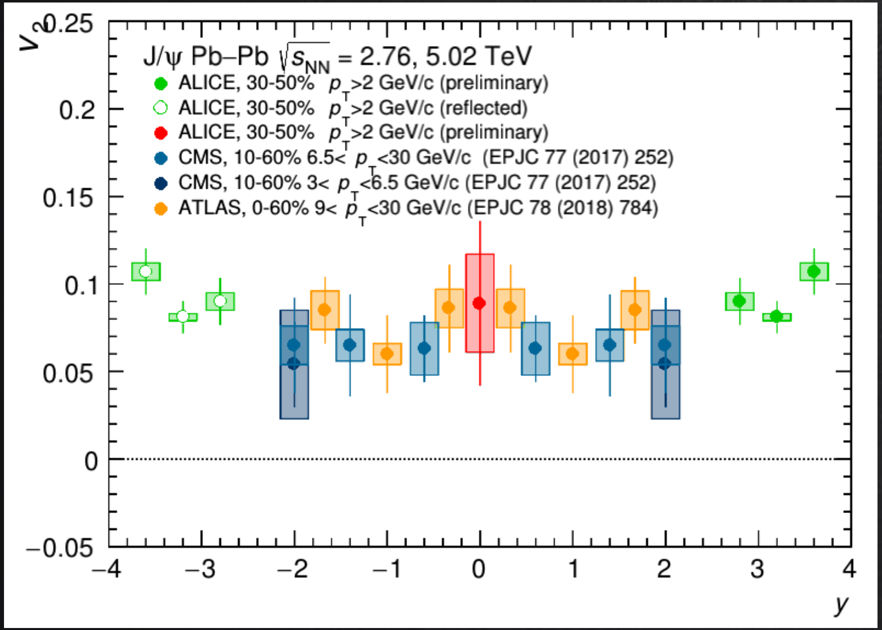
Low p_T:

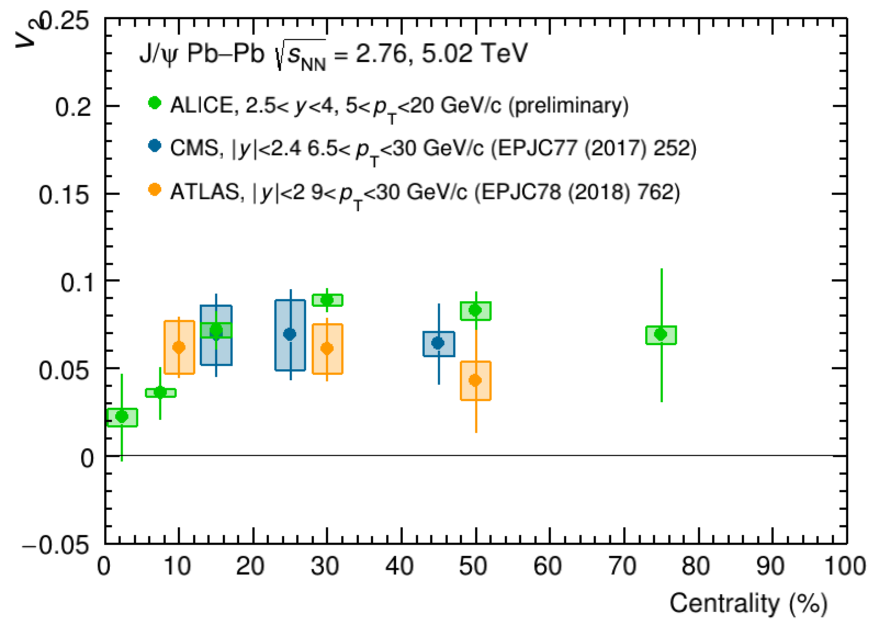
evidence for non-zero flow (ALICE, 7σ effect in 4<p_T<6 GeV/c)

High p_T:

$v_2 \neq 0$ (ATLAS and CMS)

J/ψ v_2

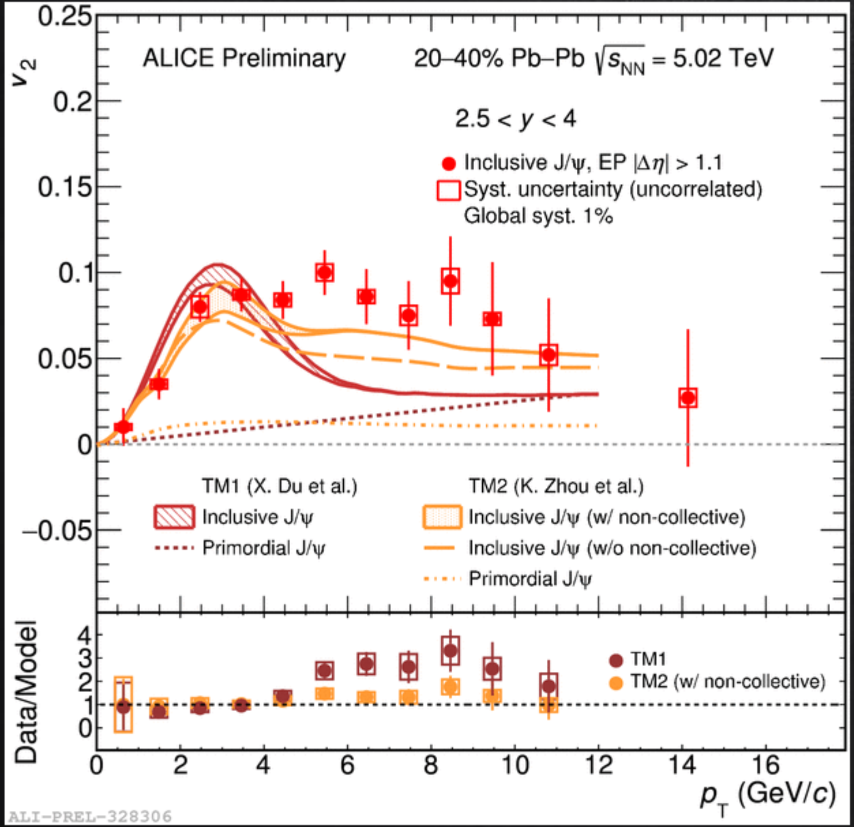




No significant difference in J/ψ v_2 between mid and forward-rapidity (different p_T ranges though)

v_2 is larger for intermediate centralities

THEORY COMPARISON



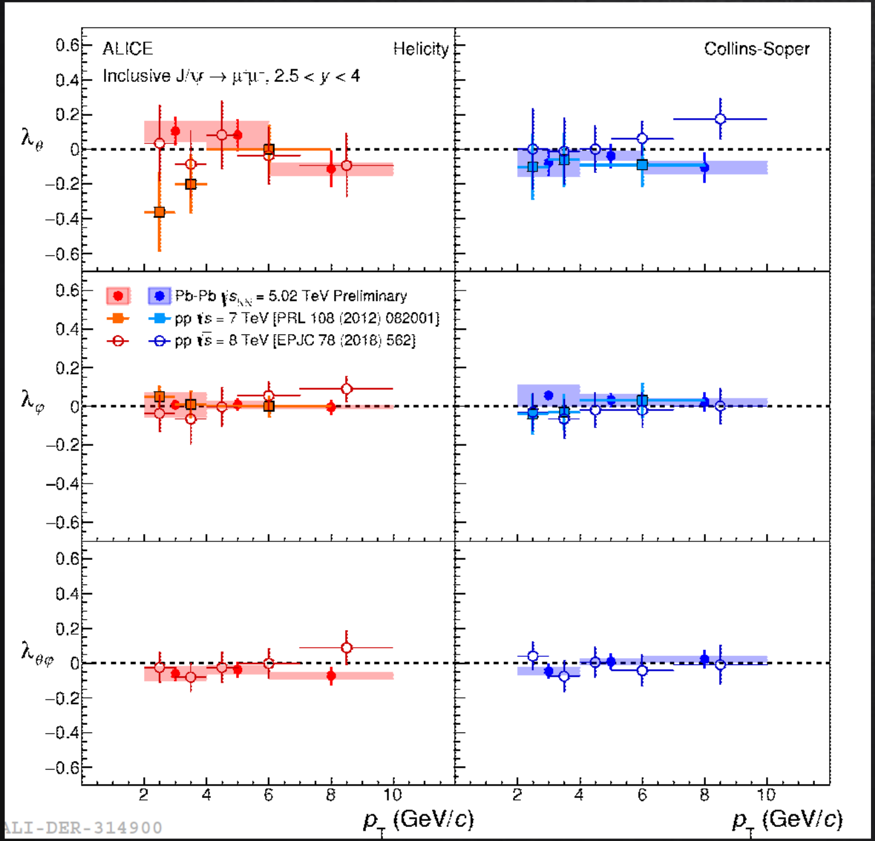
LOW p_T:

Size of v_2 reproduced by models including a large J/ψ regeneration component

HIGH p_T:

path-length effects play a role, but v_2 still underestimated

J/ψ polarization



First J/ψ polarization measurement in PbPb collisions at LHC

$$W(\cos\theta,\varphi) \propto \frac{1}{3+\boldsymbol{\lambda_\theta}} \cdot \left(1 + \boldsymbol{\lambda_\theta} \cos^2\theta + \boldsymbol{\lambda_\varphi} \sin^2\theta \cos 2\varphi + \boldsymbol{\lambda_{\theta\varphi}} \sin 2\theta \cos\varphi\right)$$

Polarization parameters consistent with zero almost over the whole p_T range

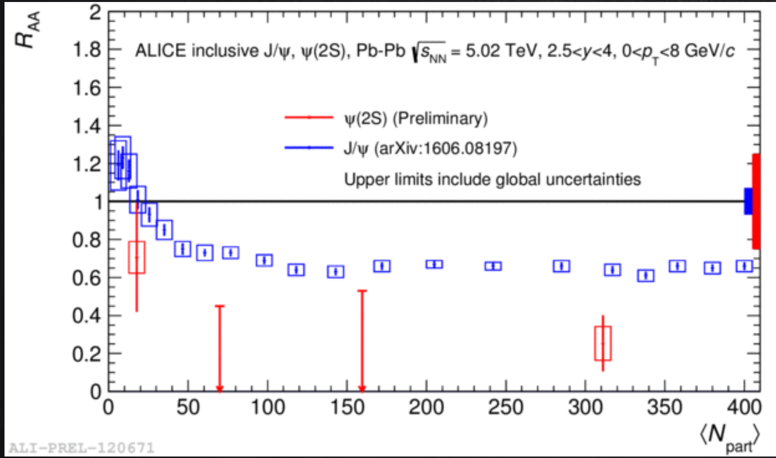
No significant difference between PbPb and pp results

Should the J/ψ be sensitive to the magnetic field present early in the collision history?

ψ(2S)

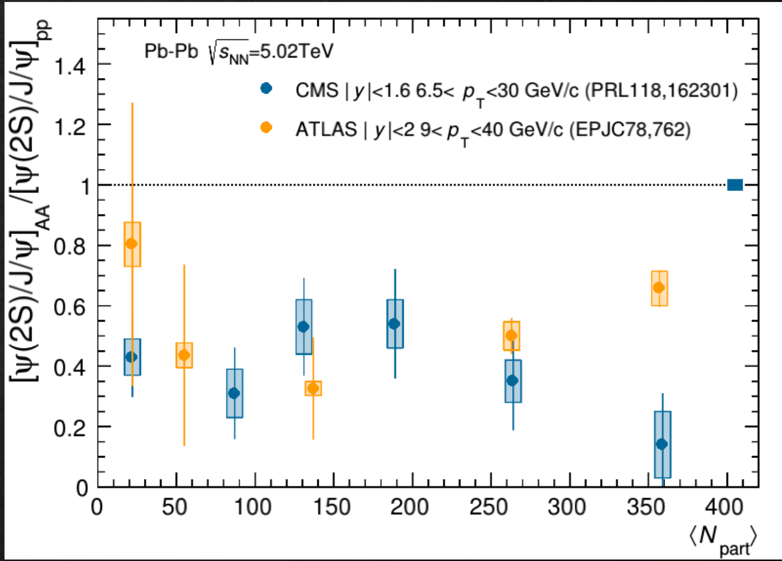
ψ(2S) loosely bound state, binding energy: ψ(2S)~60 MeV, J/ψ ~640MeV

Low p_T



ψ(2S) is strongly suppressed in central collisions, but size of uncertainties prevents a detailed comparison with J/ψ

High p_T



ψ(2S) suppression stronger than J/ψ

Tension in central events between ATLAS and CMS

Bottomonium in AA

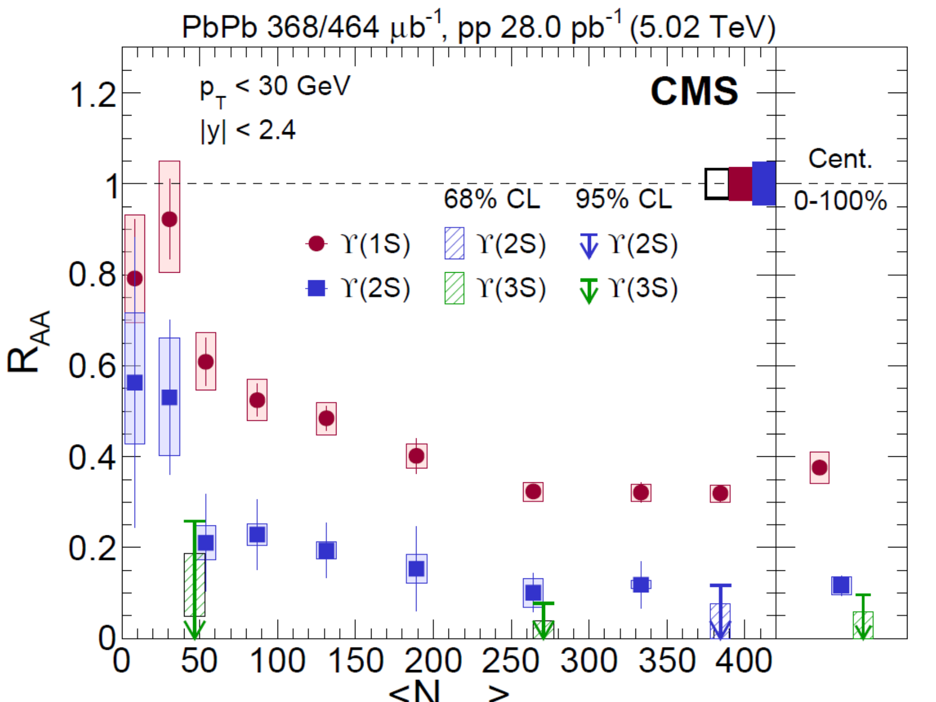
Three Υ states with different sensitivity to the medium

↓

Limited recombination and no B feed-down (but large feed down from excited states)

↓

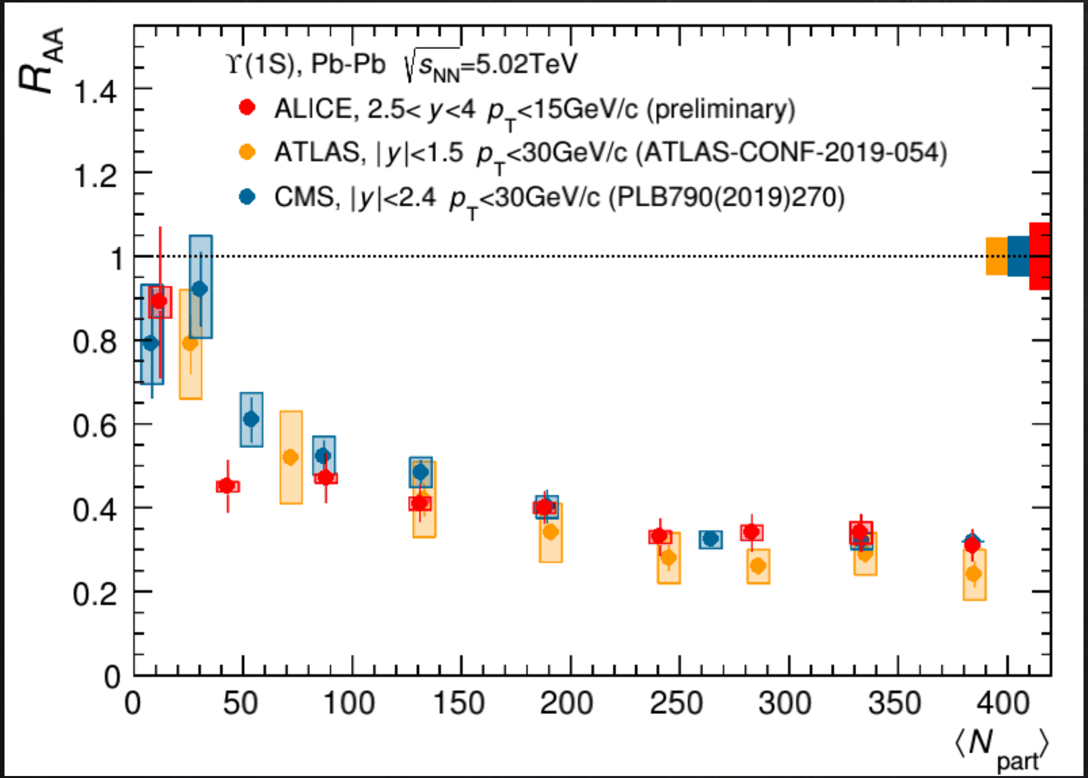
Interesting for studies on sequential suppression



CMS, PLB790 (2019) 270

Strong centrality suppression for all Υ(nS) (factor ~2.5 for Υ(1S), ~7 for Υ(2S))

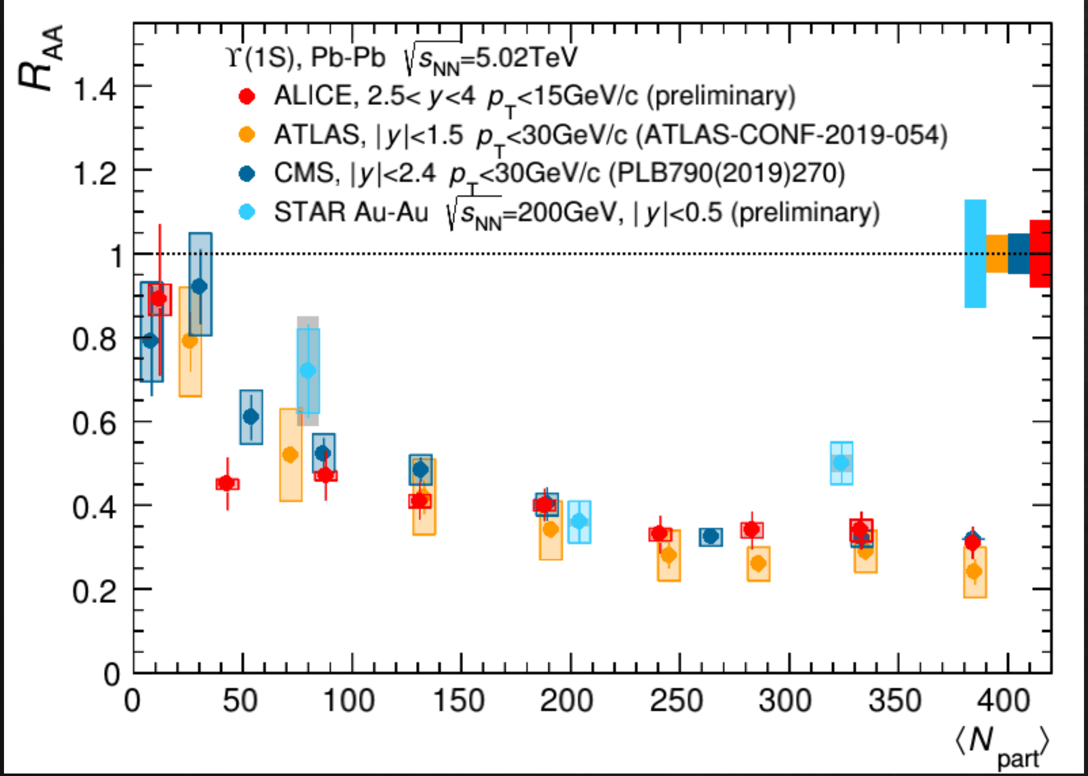
$\Upsilon(1S)$ R_{AA}



Compatible R_{AA} values for all the LHC experiments

Strong centrality-dependent $\Upsilon(1S)$ suppression

Υ(1S) R_{AA}: RHIC vs LHC



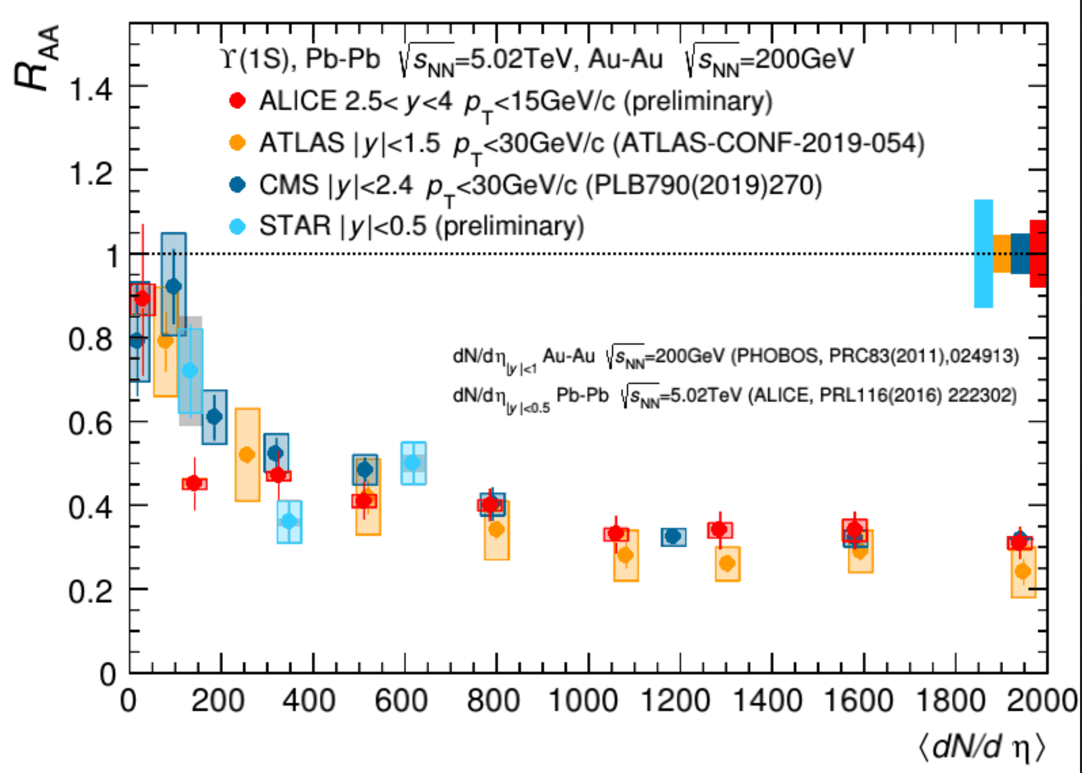
Compatible R_{AA} values for all the LHC experiments

Strong centrality-dependent Υ(1S) suppression

Similar Υ(1S) suppression also at low $\sqrt{s_{NN}}$?

Could be expected if direct Υ(1S) are not suppressed at LHC

$\Upsilon(1S)$ R_{AA}: RHIC vs LHC

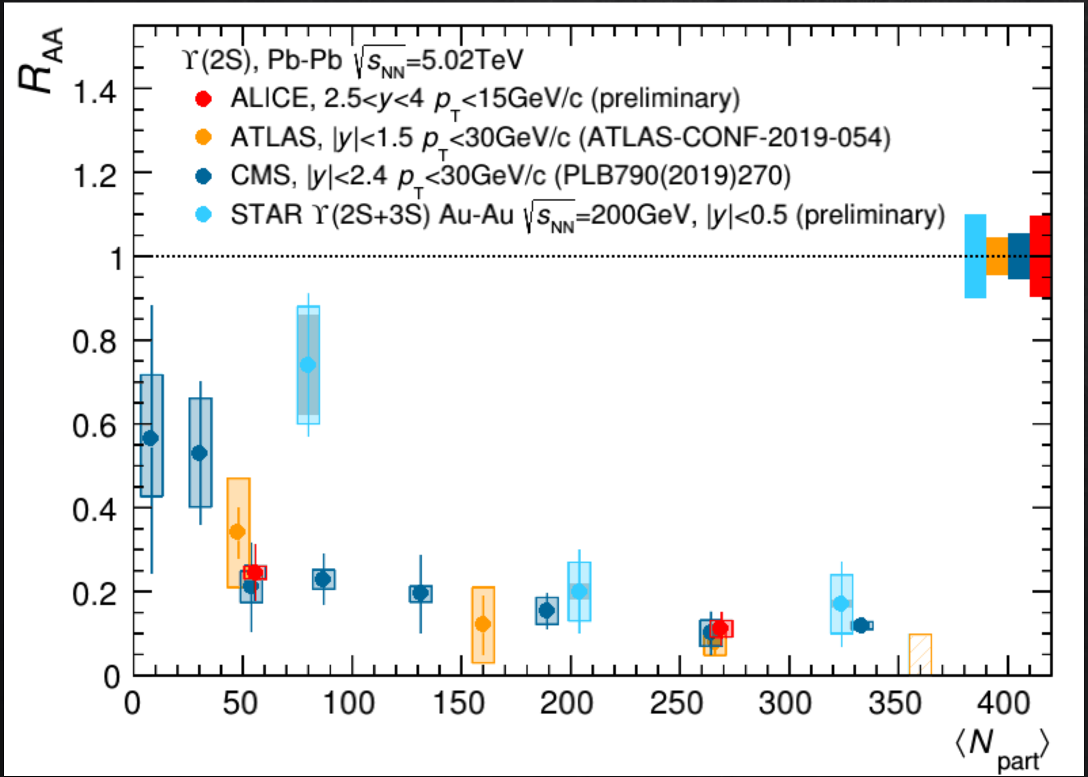


Compatible R_{AA} values for all the LHC experiments

Strong centrality-dependent $\Upsilon(1S)$ suppression

Plotting versus dN/dη suggests a smooth evolution with fluctuations in the centrality dependence of RHIC results

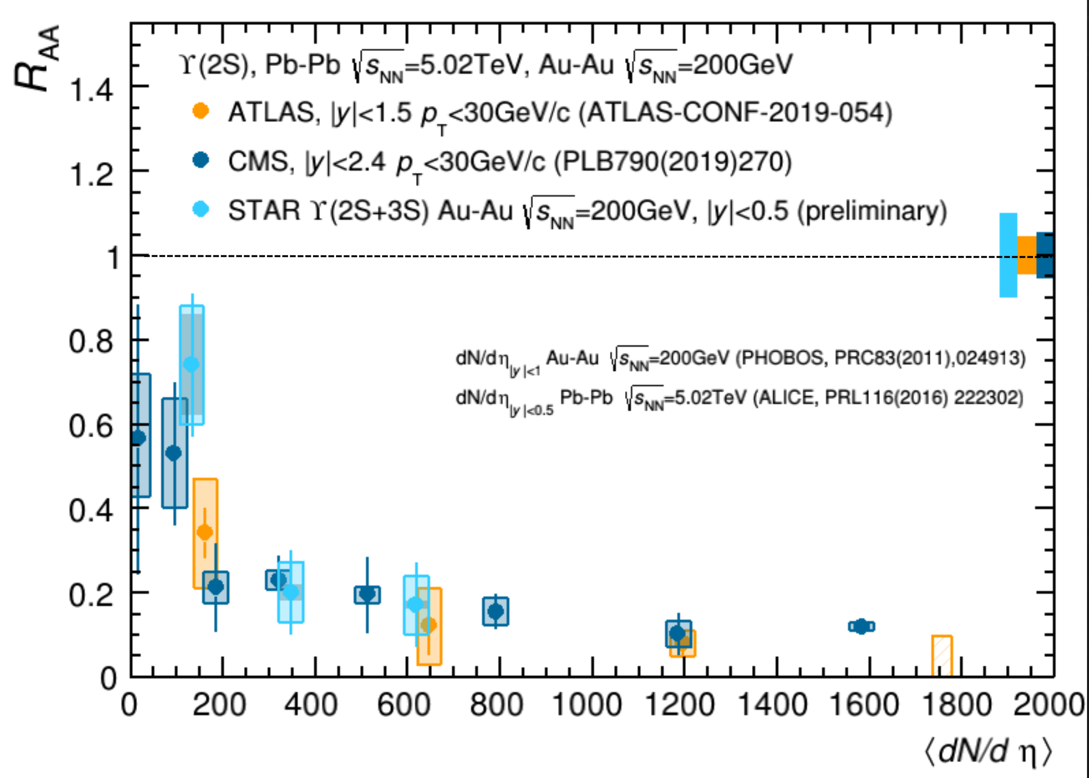
$\Upsilon(2S)\ R_{AA}$



Υ(2S) suppression is stronger than the Υ(1S) one

Suppression at RHIC is slightly lower in peripheral collisions, but similar in the central ones, wrt LHC

$\Upsilon(2S)$ R_{AA}

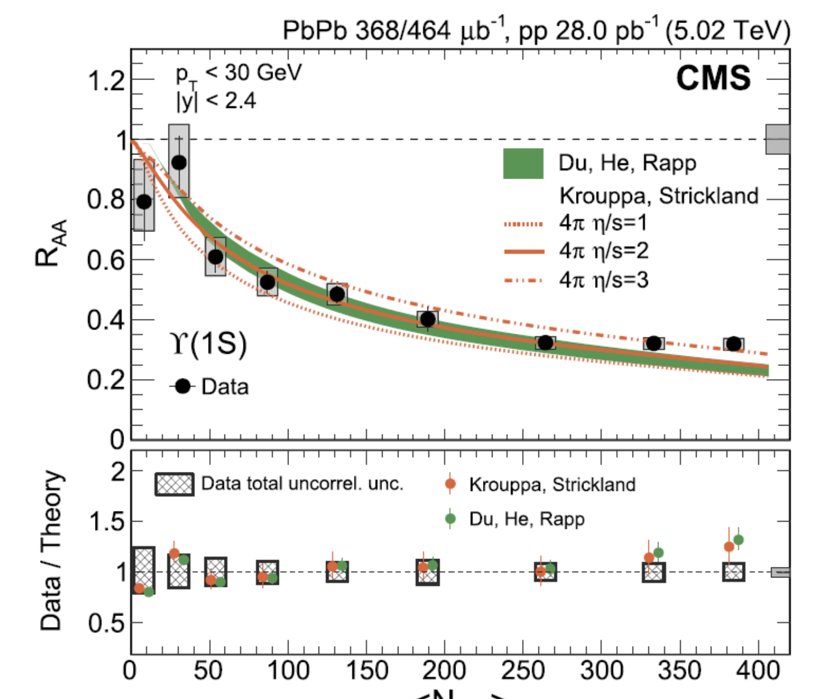


$\Upsilon(2S)$ suppression is stronger than the $\Upsilon(1S)$ one

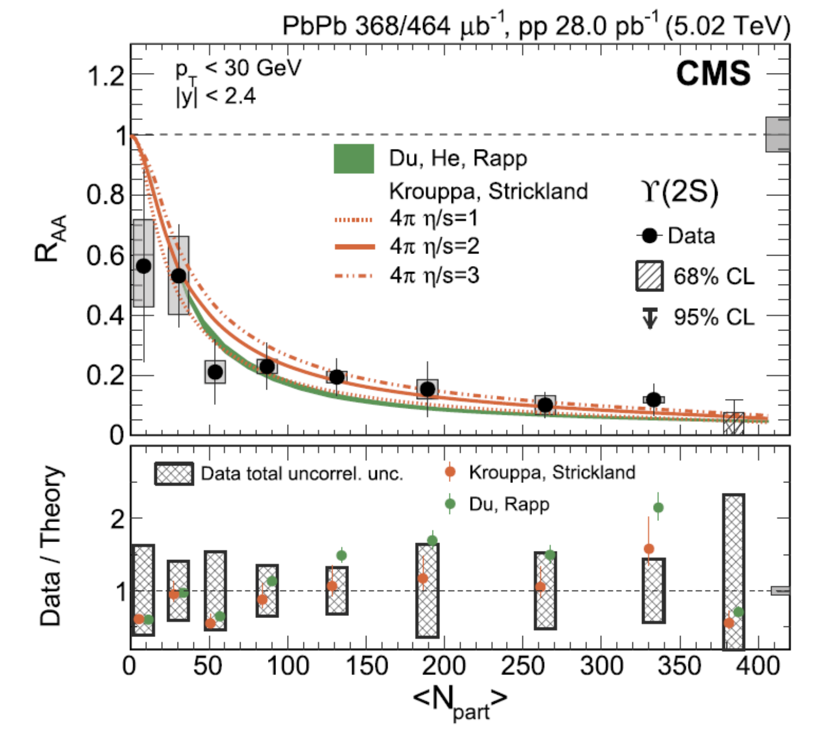
Plotting versus $dN/d\eta$ leads to a smooth trend

Strong suppression of the excited states at both energies

Theory comparison

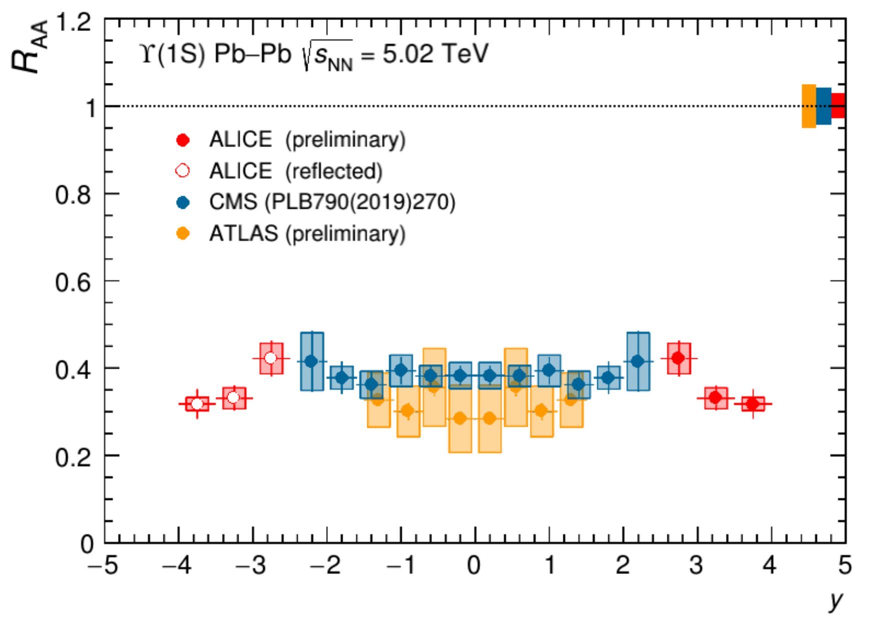


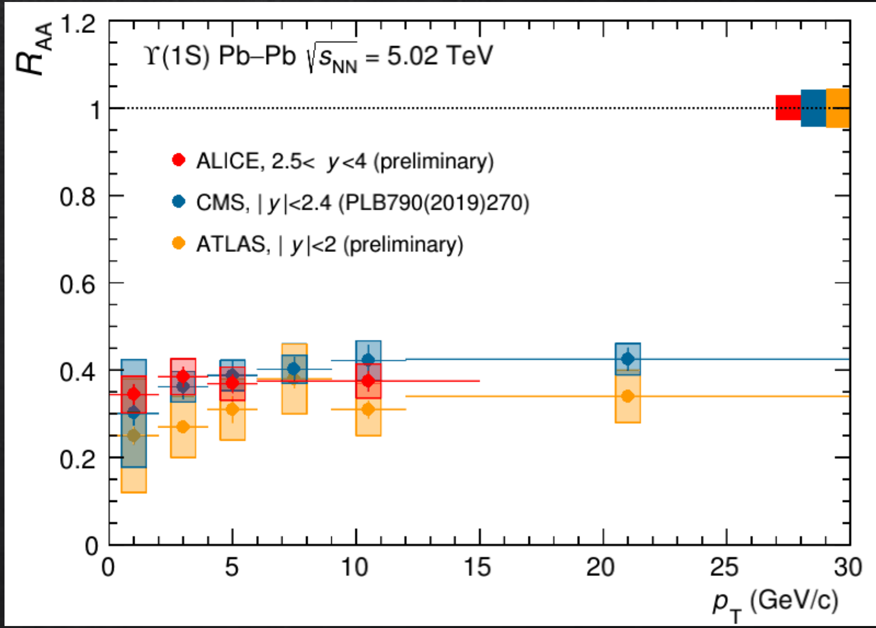
PLB790(2019)270



Data are described by models including color screening and feed-down from decay of heavier quarkonia (+regeneration)

$\Upsilon(1S)$ R_{AA} vs y and p_T

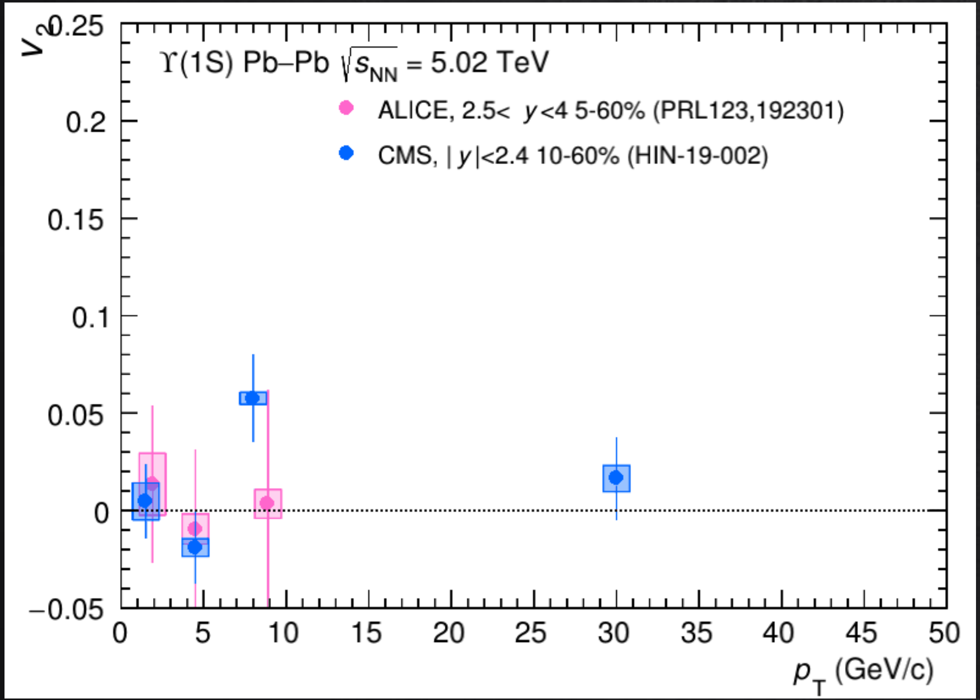




Broad rapidity coverage

Rather flat rapidity dependence, but significant decrease at forward-y (recombination-signature?) however no small p_T increase of R_{AA}

Υ(1S) v_2



First measurement of Υ(1S) v_2 in AA collisions

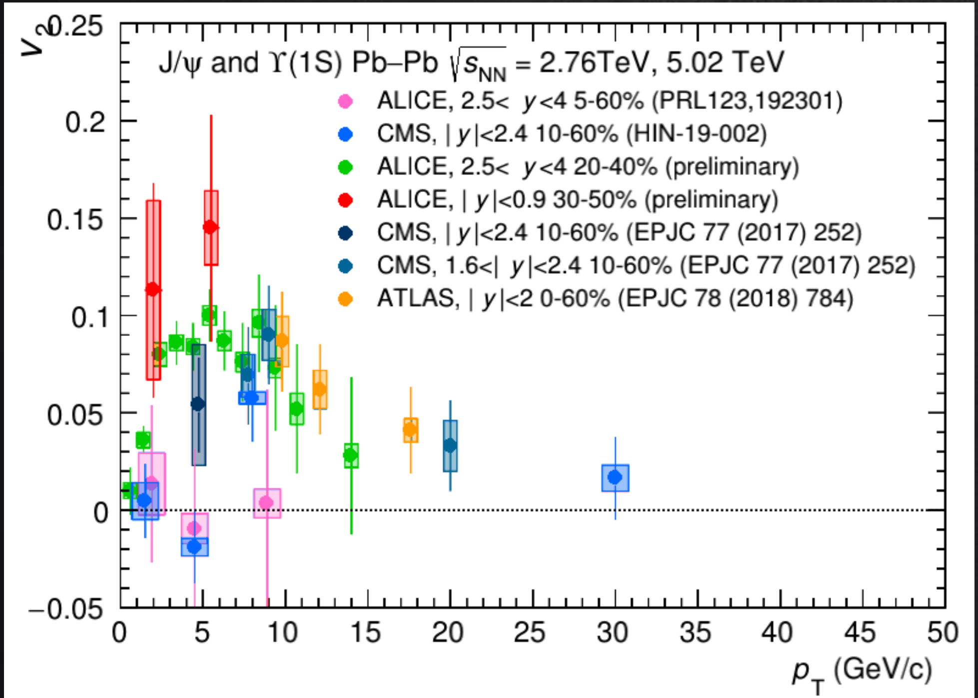
Υ(1S) v_2 is consistent with zero over the full p_T range and over all centralities, with a maximum offset of 2.5σ

No significant rapidity dependence

Υ(2S) v_2 also measured in 10–90%:

−0.063 ± 0.085 (stat) ± 0.037 (syst)

Υ(1S) v_2



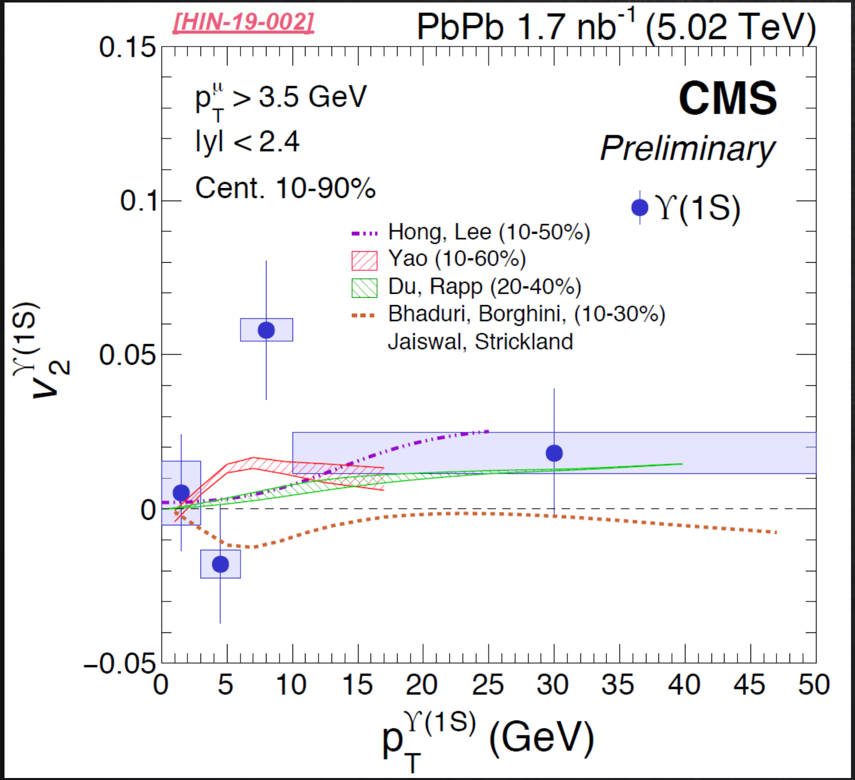
First measurement of Υ(1S) v_2 in AA collisions

Υ(1S) v_2 is lower than the J/ψ one as expected from:

- Negligible regeneration component
- Υ(1S) dissociation occurring early in the fireball evolution (high T) when path length differences in the suppression are small

(Rapp, PRC96,054901)

Comparison to theory



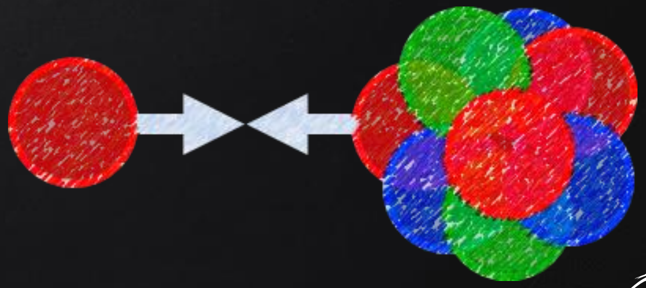
v_2 is compatible with the small values predicted by theory models including or not a regeneration contribution

Overall agreement, but much more precise data are needed to discriminate between approaches

More inputs might come from precise measurement of Υ(2S) v_2

→ being suppressed at lower T, Υ(2S) should be sensitive to path length effects, inducing a larger v_2 wrt Υ(1S) (Rapp, PRC96,054901)

pA COLLISIONS

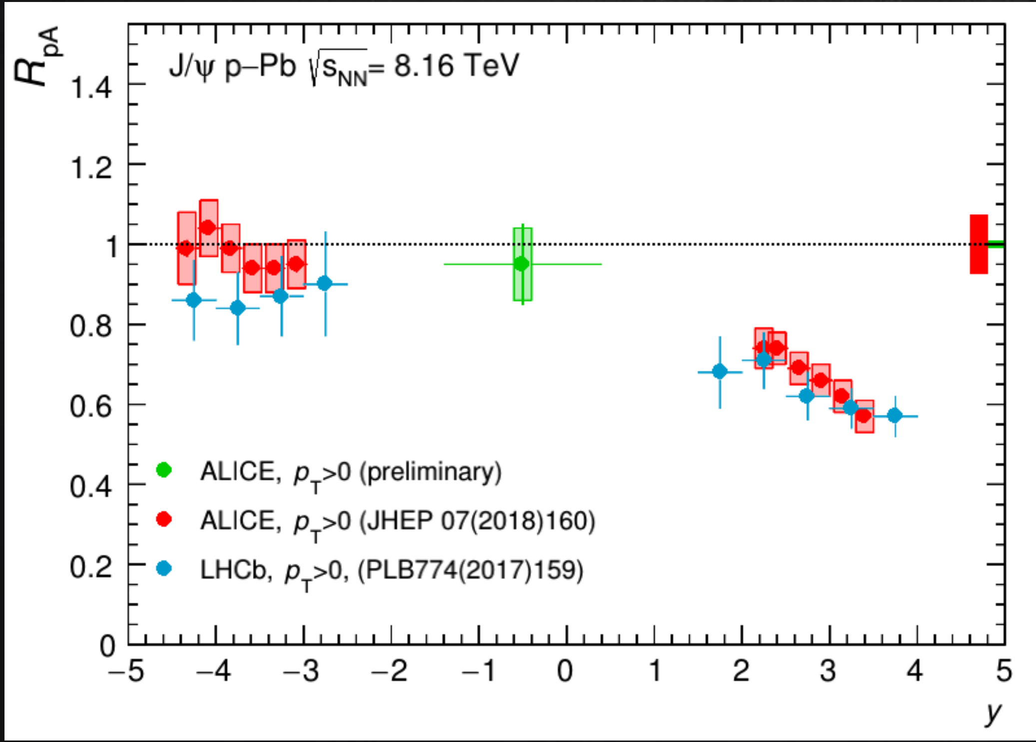


COLD MATTER EFFECTS

ADDRESSED VIA pA COLLISIONS, TO INVESTIGATE

- ROLE OF THE VARIOUS CNM CONTRIBUTIONS, WHOSE IMPORTANCE DEPENDS ON KINEMATIC AND ENERGY OF THE COLLISIONS
- SIZE OF CNM EFFECTS, FUNDAMENTAL TO INTERPRET QUARKONIUM AA RESULTS
- PRESENCE OF POSSIBLE HOT MATTER EFFECTS

J/ψ in pA

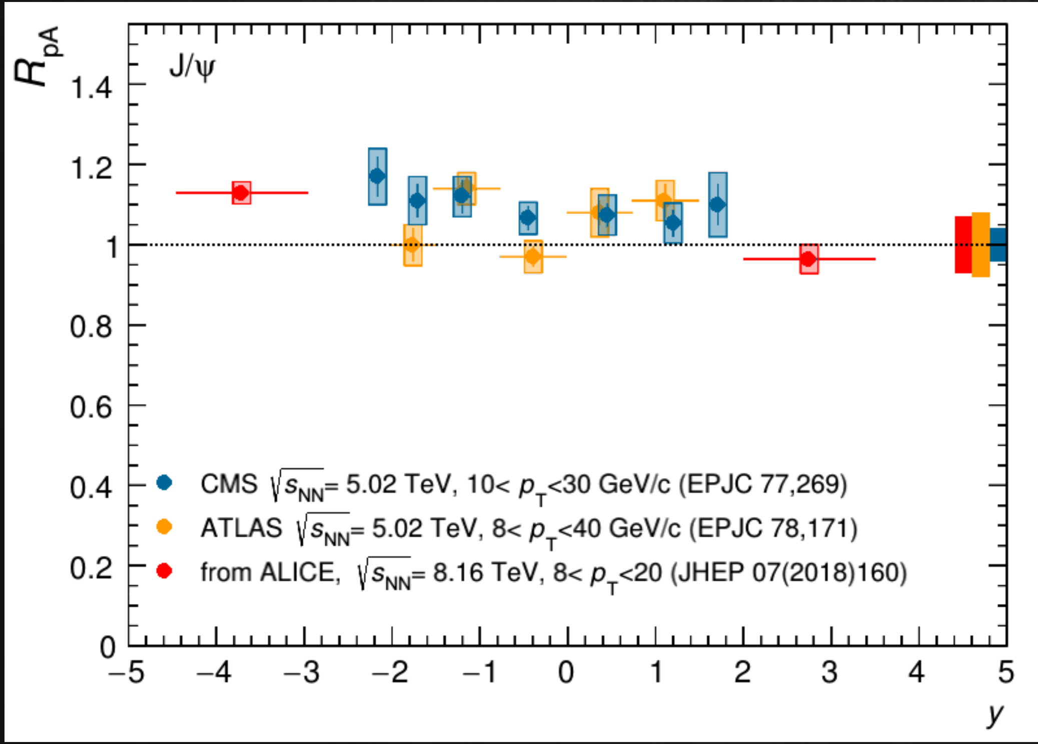


Low p_T

J/ψ R_{pA} shows a strong rapidity dependence, with the J/ψ production significantly suppressed at forward-y

ALICE p-going direction: $2.3\ 10^{-5}<x<1.5\ 10^{-4}$
Pb-going direction: $1.5\ 10^{-2}<x<10^{-1}$

J/ψ in pA



Low p_T

J/ψ R_{pA} shows a strong rapidity dependence, with the J/ψ production significantly suppressed at forward-y

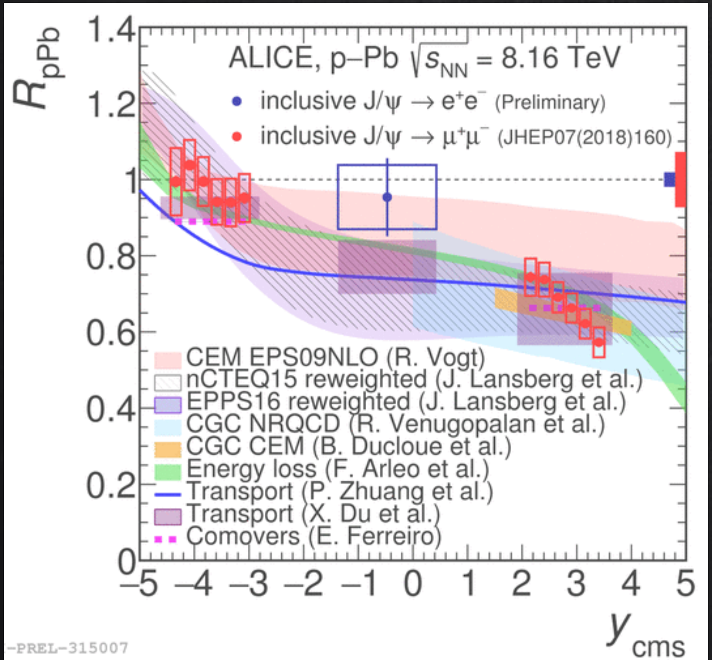
High p_T

R_{pA} is rather flat and close to unity (or slightly higher)

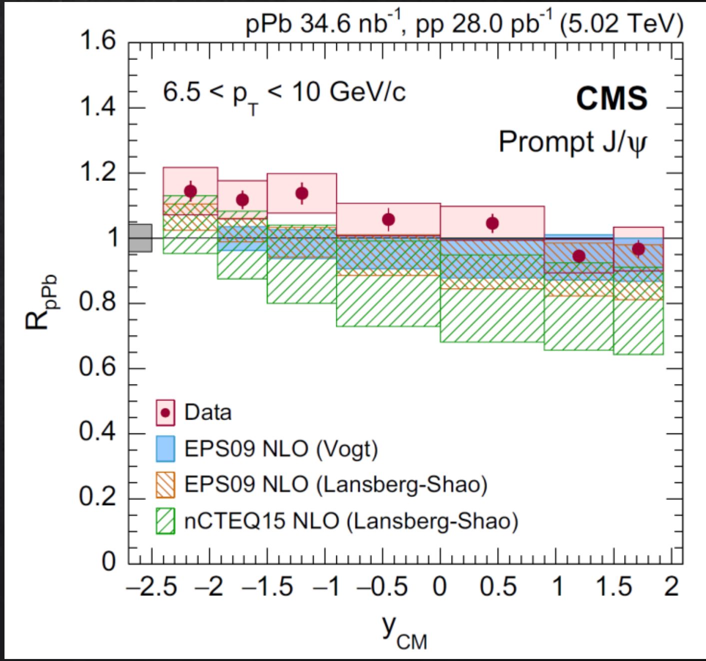
Comparison to theory

CNM models, based on shadowing, CGC, energy loss describe the data

Low p_T

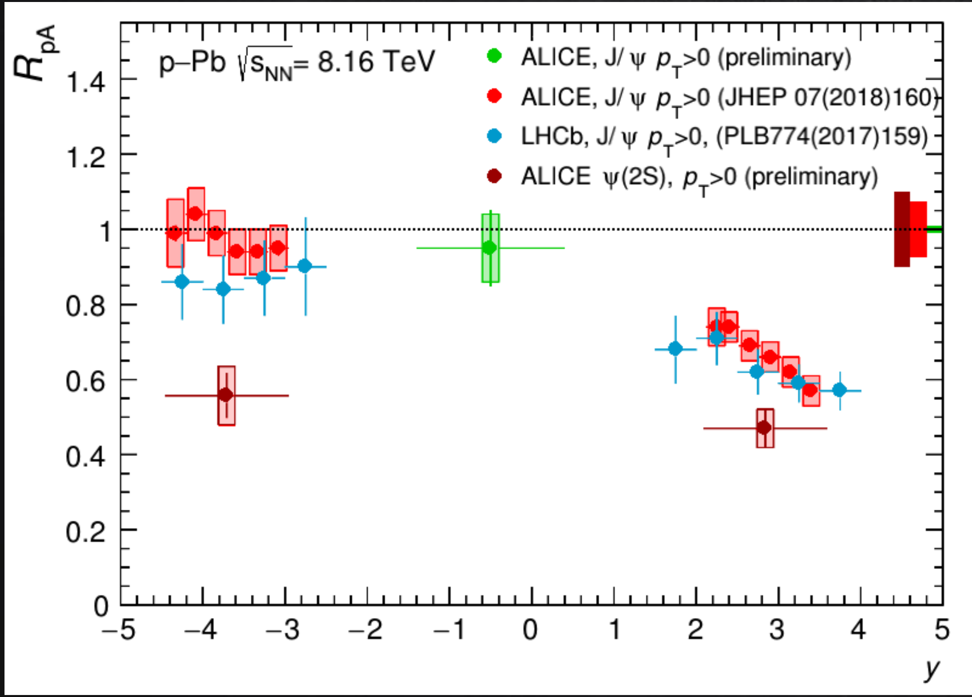


High p_T



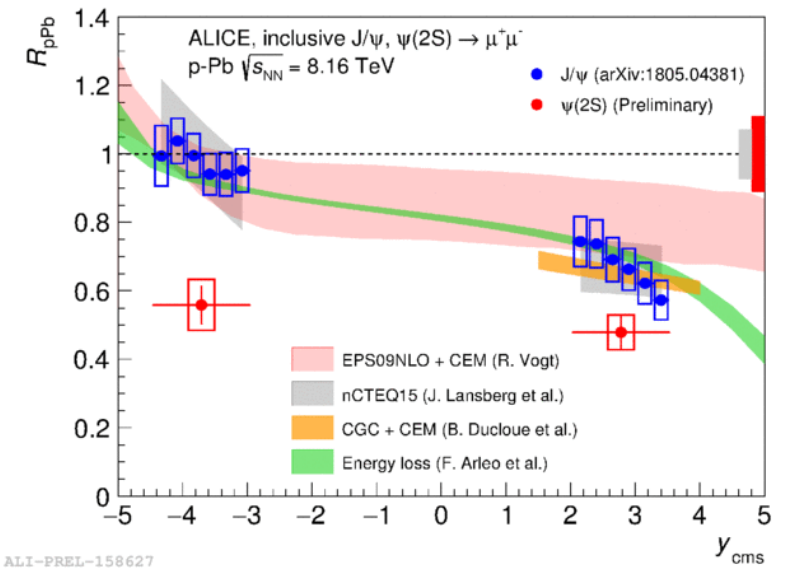
→ Reweighting of nPDF (dijets, open charm, quarkonia?) might help reducing the uncertainties (P. Paakkinen, QM19, J.P. Lansberg PRL121,052004)

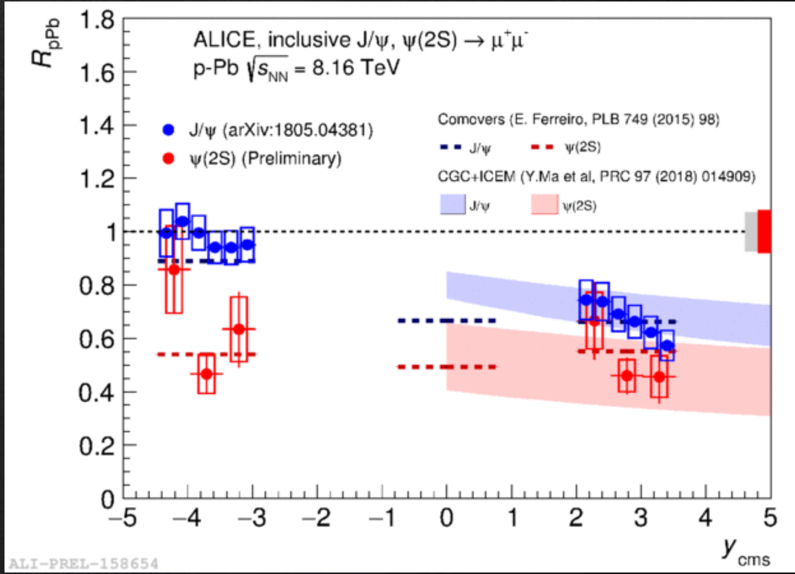
Excited charmonium states



ψ(2S) suppression is stronger than the J/ψ one, in particular at backward-y

Comparison to theory

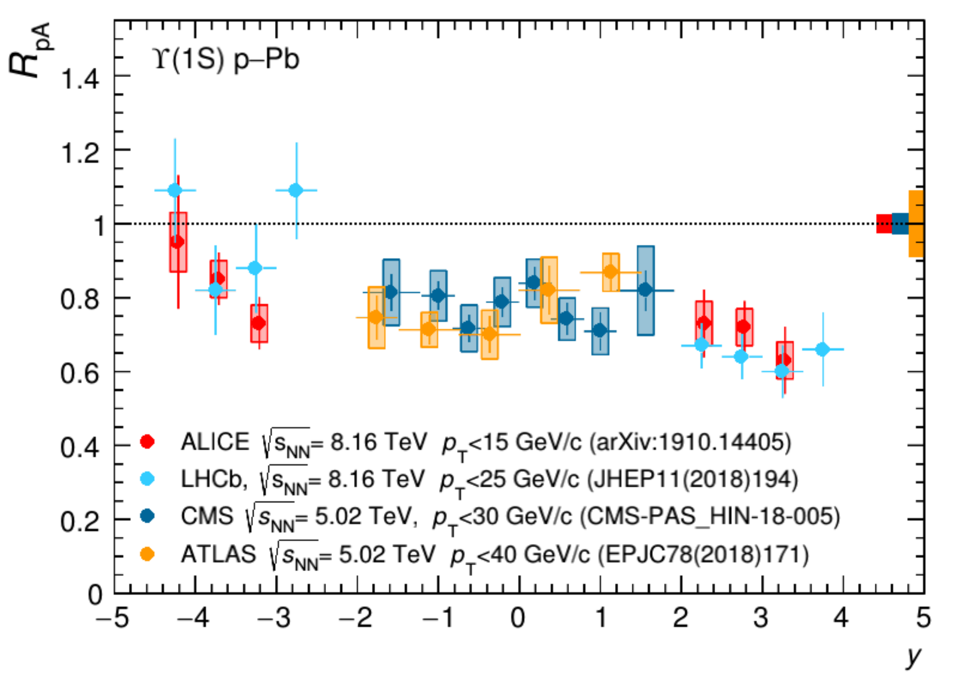




At LHC energies
Formation time > crossing time
same effects were expected for the two resonances

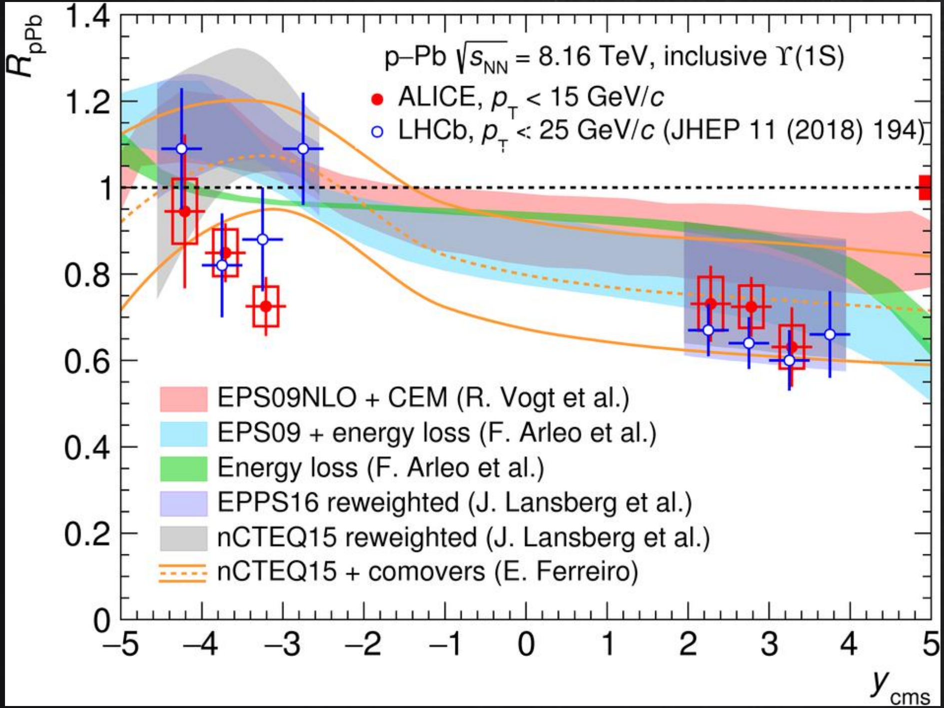
additional final state effects (interactions with hadron comovers) needed to describe the data

ϒ(1S) in pA



ϒ(1S) R_{pA} shows a hint for a (weak) rapidity-dependence

Υ(1S) in pA



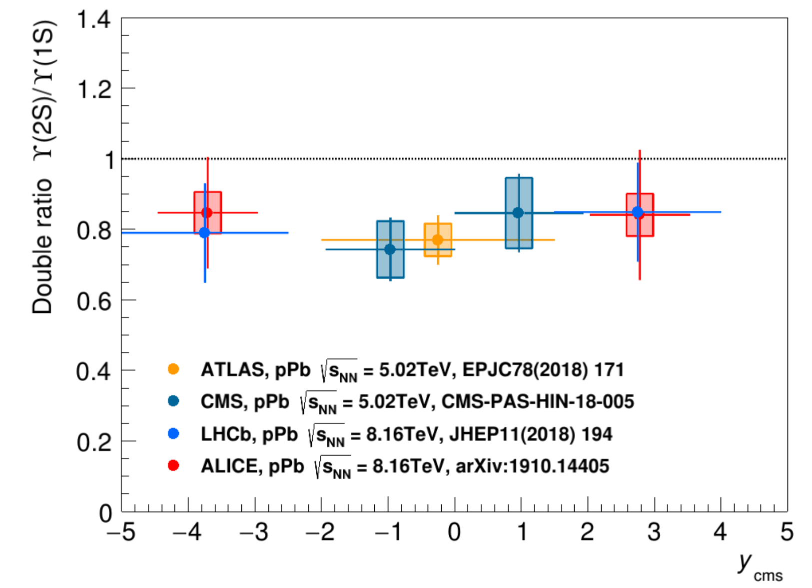
Υ(1S) R_{pA} shows a hint for a (weak) rapidity-dependence

Also in this case, models based on shadowing or energy loss describe the data

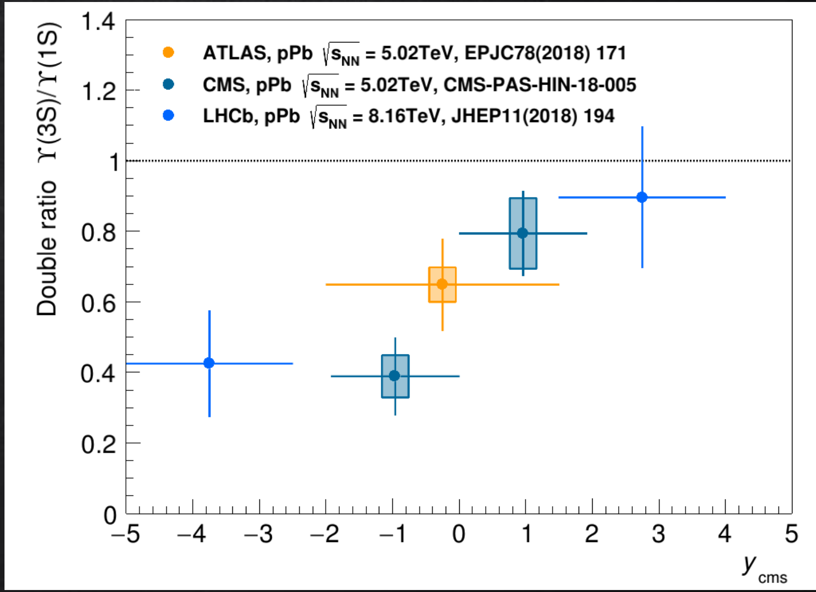
Do models slightly overestimate data at backward-y?

Excited bottomonium states

ϒ(2S)/ϒ(1S)



ϒ(3S)/ϒ(1S)

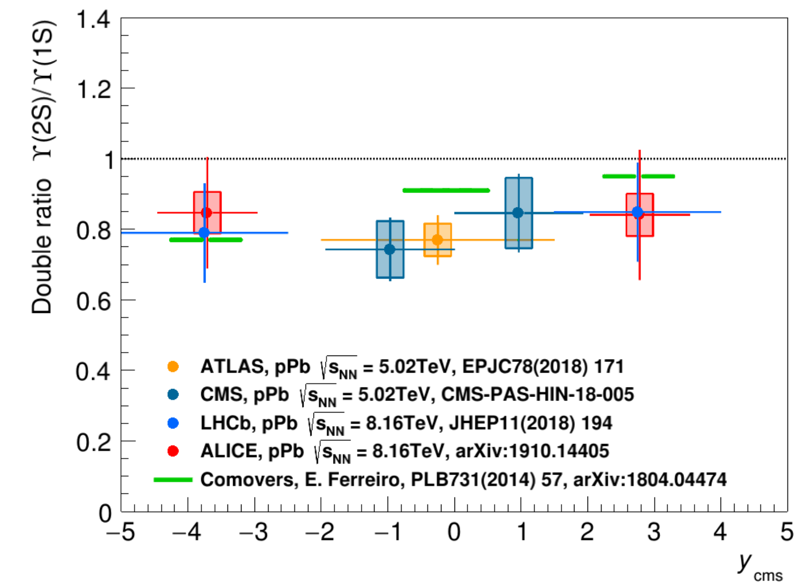


Excited states show a strong suppression than ϒ(1S) in pA wrt pp

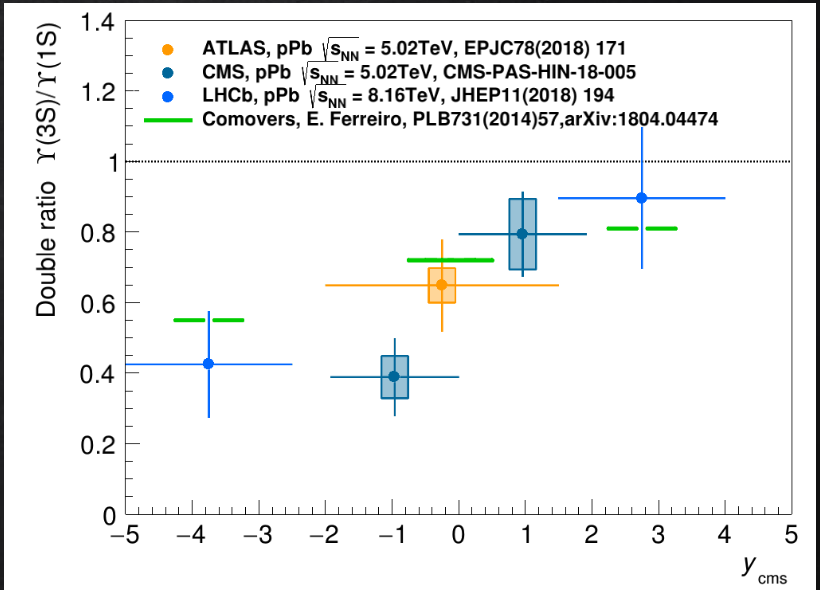
The ϒ(2S) modification does not show a rapidity dependence, while the ϒ(3S) (as expected?) is strongly suppressed at backward-y

Excited bottomonium states

Υ(2S)/Υ(1S)



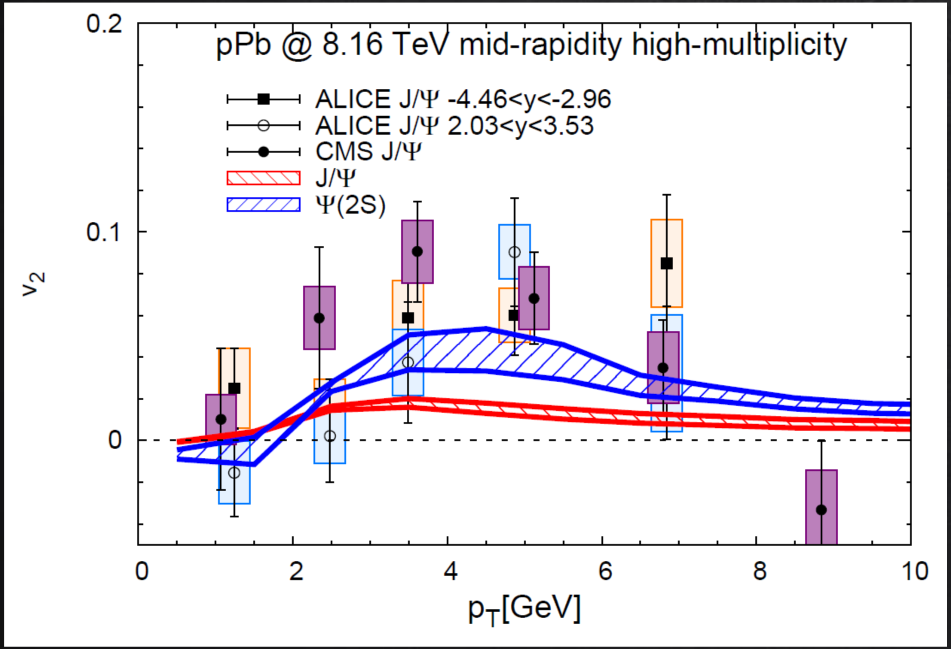
Υ(3S)/Υ(1S)



Excited states show a strong suppression than Υ(1S) in pA wrt pp

Υ(2S) has 20% suppression relative to Υ(1S)
Should one expect a similar effect for J/ψ (similar binding energy)?

J/ψ v_2 in pA

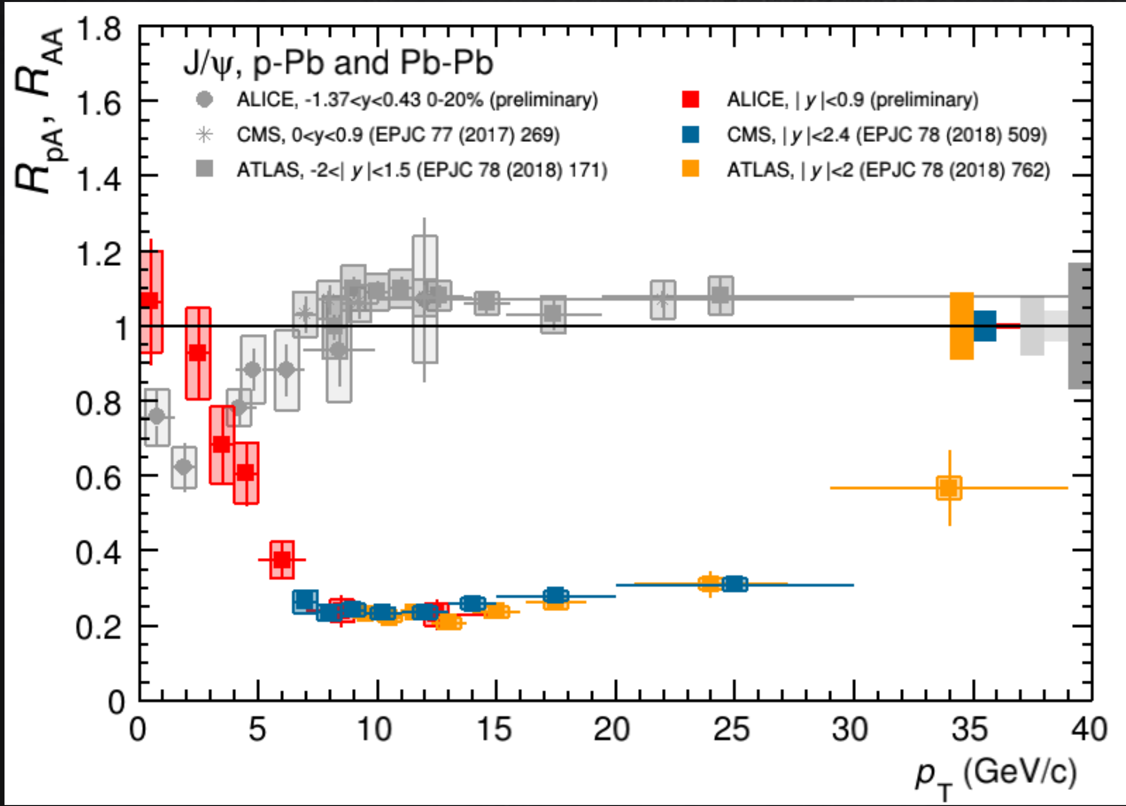


A significant non-zero v_2 is observed in high-multiplicity p-Pb

- Size of v_2 similar to the one measured in PbPb
- However, usual v_2 interpretation for PbPb, based on regeneration or path lengths effects, doesn't work in pPb
- Models where v_2 originates from final state effects in the fireball (dissociation, regeneration) underestimate the data

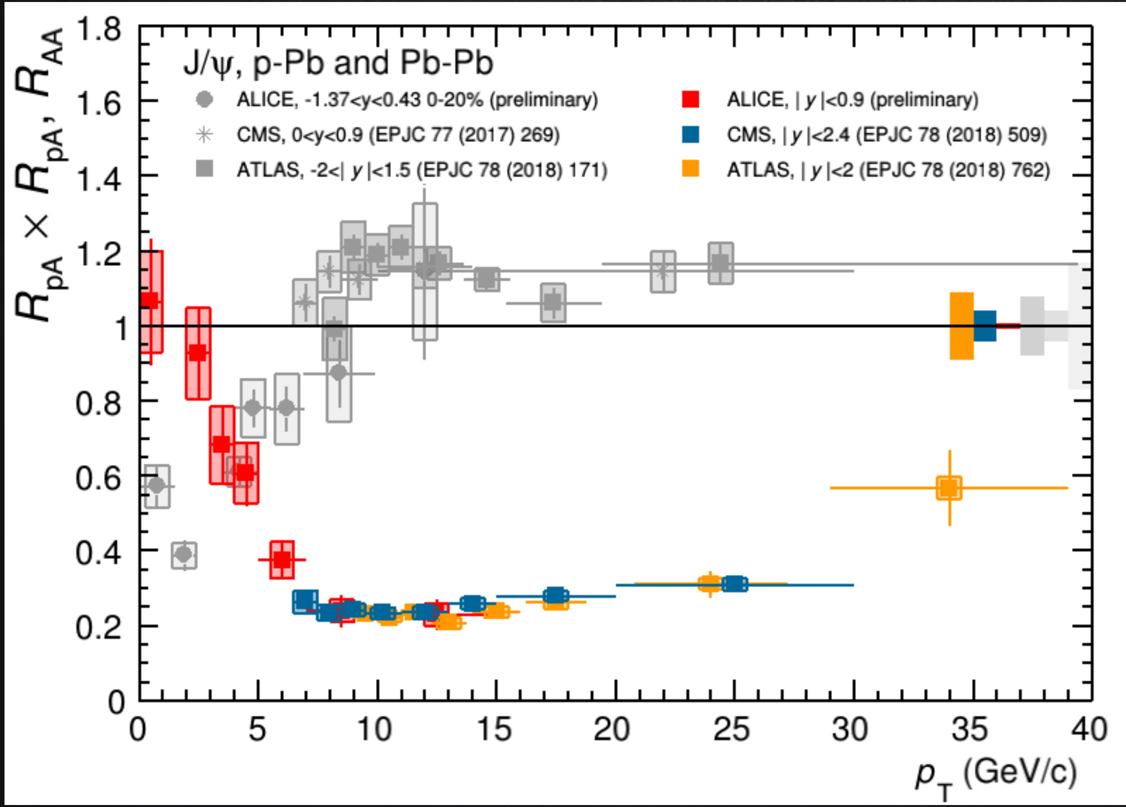
ALICE, PLB 780 (2018) 7
CMS, PLB791(2019)172
Rapp et al, JHEP03(2019)015

pA and AA: J/ψ



Significant difference between J/ψ R_{pA} and R_{AA} over all the p_T range

pA and AA: J/ψ

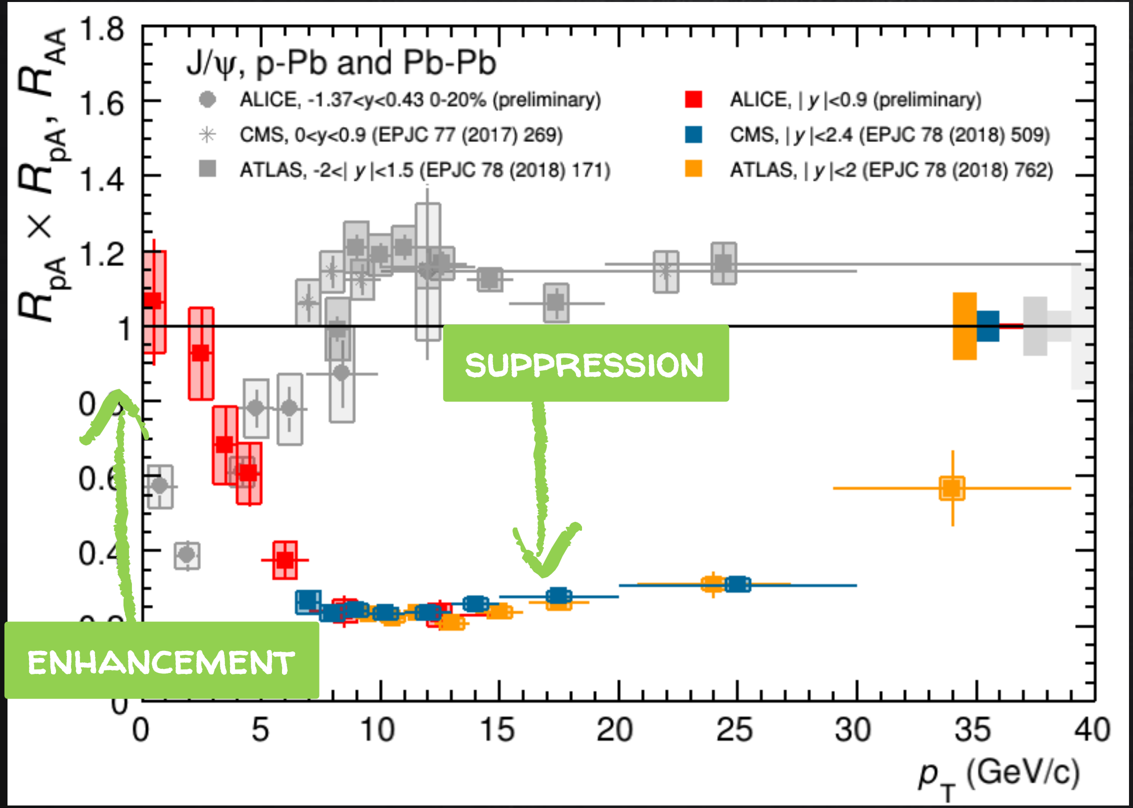


Significant difference between J/ψ R_{pA} and R_{AA} over all the p_T range

Under the assumption that shadowing is the main CNM effect at mid-y:

$$R_{AA}^{CNM} = {R_{pA}}^2$$

pA and AA: J/ψ



Significant difference between J/ψ R_{pA} and R_{AA} over all the p_T range

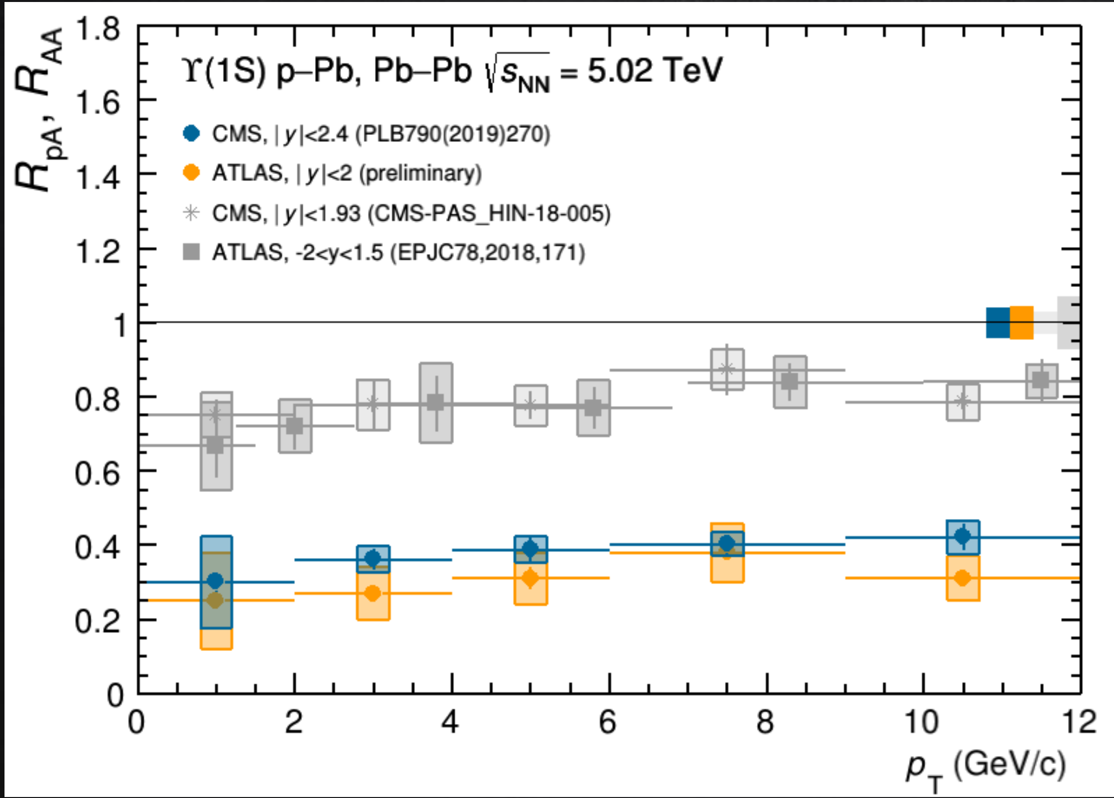
Under the assumption that shadowing is the main CNM effect:

$$R_{AA}^{CNM} = R_{pA}^2$$

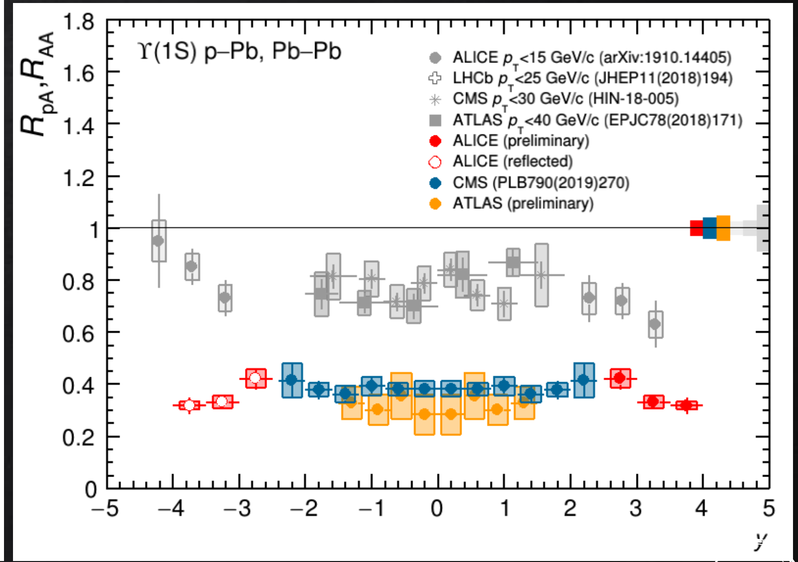
Clear R_{AA} enhancement at low p_T and suppression at high p_T

Crossing between suppression and enhancement at $p_T \sim 4$ GeV/c

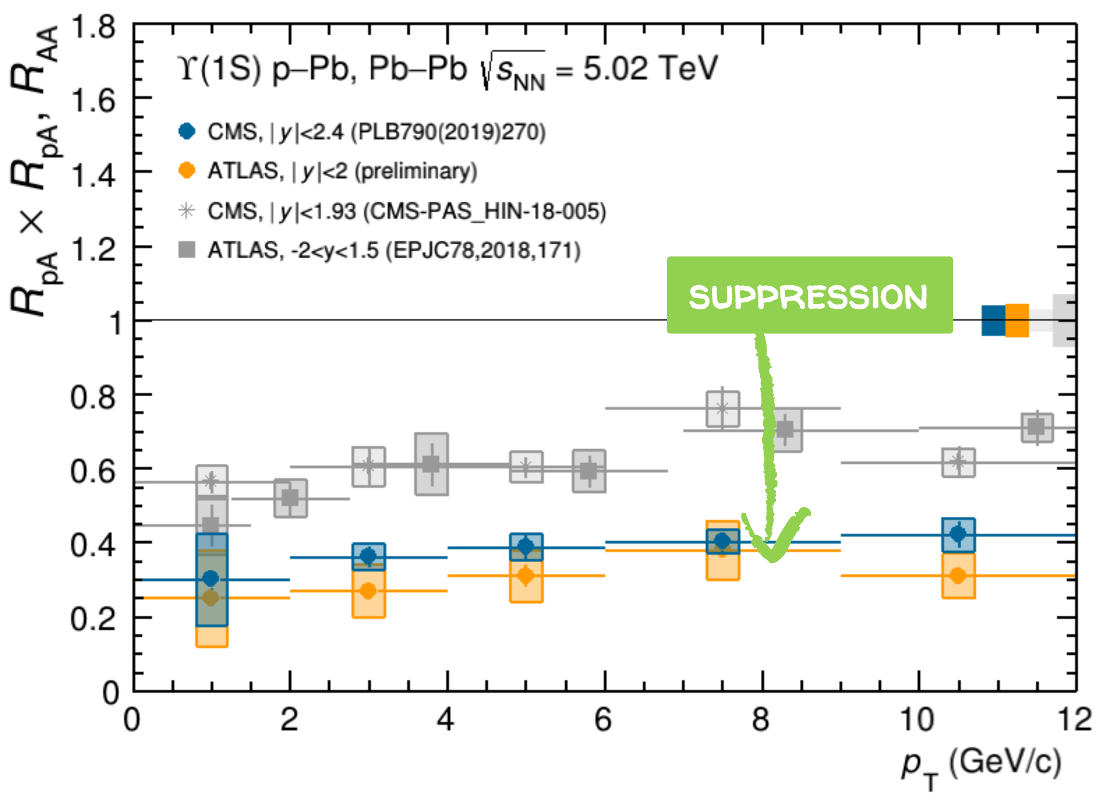
pA and AA: Υ(1S)



Υ(1S) R_{pA} is higher than R_{AA} over the whole y and p_T range



pA and AA: Υ(1S)



Υ(1S) R_{pA} is higher than R_{AA} over the whole y and p_T range

If shadowing is the main CNM effect at mid-y:

$$R_{AA}^{CNM} = R_{pA}{}^2$$

- ✓ Sizeable CNM effects over all the p_T range
- ✓ R_{pA} always higher than R_{AA}, i.e. there is an additional suppression at all p_T on top of CNM effects

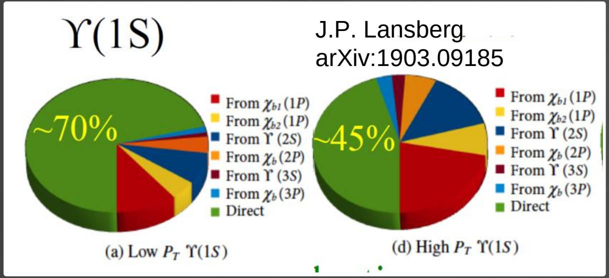
Direct Υ(1S)

Υ(1S) is clearly suppressed in PbPb collisions

To understand if direct Υ(1S) are suppressed, we need a precise assessment of
- size of CNM effects
- feed-down from S and P states

Υ(1S) inclusive R_{AA} (mid-y, 0-90%): 0.38 +/- 0.04 (stat+syst) (CMS PLB790,270)

Feed-down ~30% at low p_T



Direct Υ(1S) R_{AA}:
0.38/0.7 ~0.54 +/- 0.05
(assuming no uncertainty on feed-down)

CNM evaluated from (CMS HIN-2018-005)
R_{pA} = 0.77 +/- 0.07 (stat+syst)

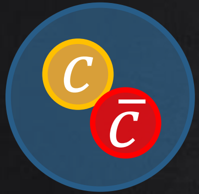
→ R_{AA}(CNM) ~ R_{pA}^2 ~0.60 +/- 0.06

Observed Υ(1S) suppression compatible with CNM and suppression of higher states?

X(3872)

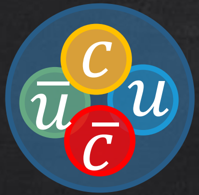
- ✓ First observed in 2003 by BELLE
- ✓ Quantum numbers: $J^{PC} = 1^{++}$
- ✓ Nature of this state not yet understood:

Charmonium



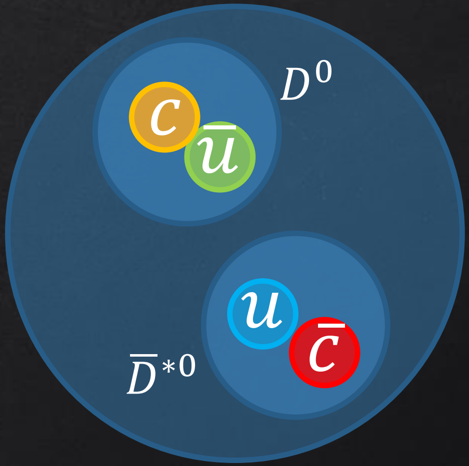
Wrong mass predicted with $J^{PC} = 1^{++}$

Tetraquark



R~0.3fm

D^0–$\bar{D}^{*0}$ molecule



R>5 fm, small binding energy

(Yen-Jie Lee, QM2019)

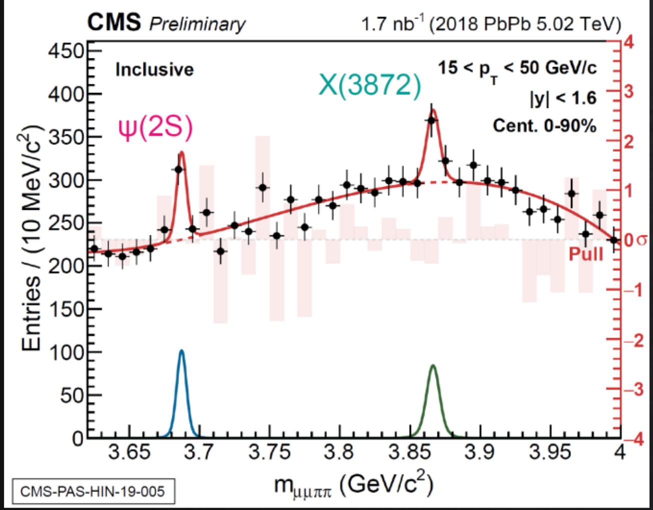
Production in heavy ions might provide insight on its inner structure

X(3872)

Study the ratio of prompt X(3872) to ψ(2S) reconstructed via

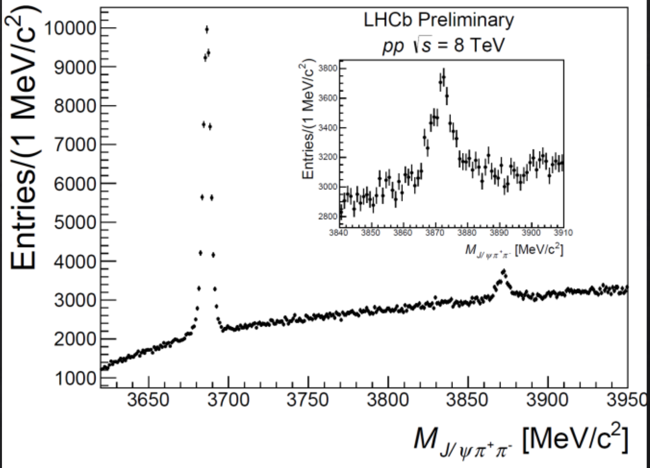
$\psi(2S), X(3872) \rightarrow J/\psi\pi\pi \rightarrow \mu\mu\pi\pi$

First X(3872) evidence in PbPb @ 5.02 TeV



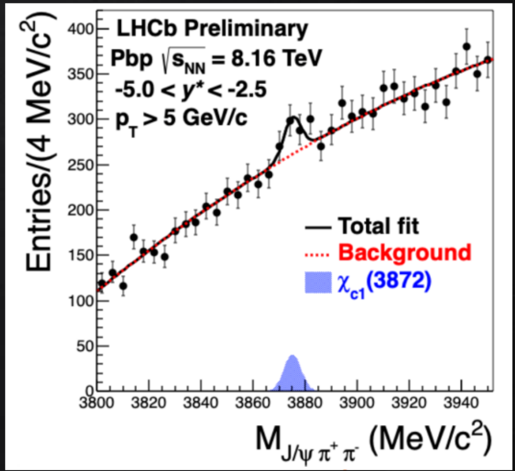
$15 < p_T < 50$ GeV/c, $|y| < 1.6$

X(3872) multiplicity dependence in pp @ 8TeV

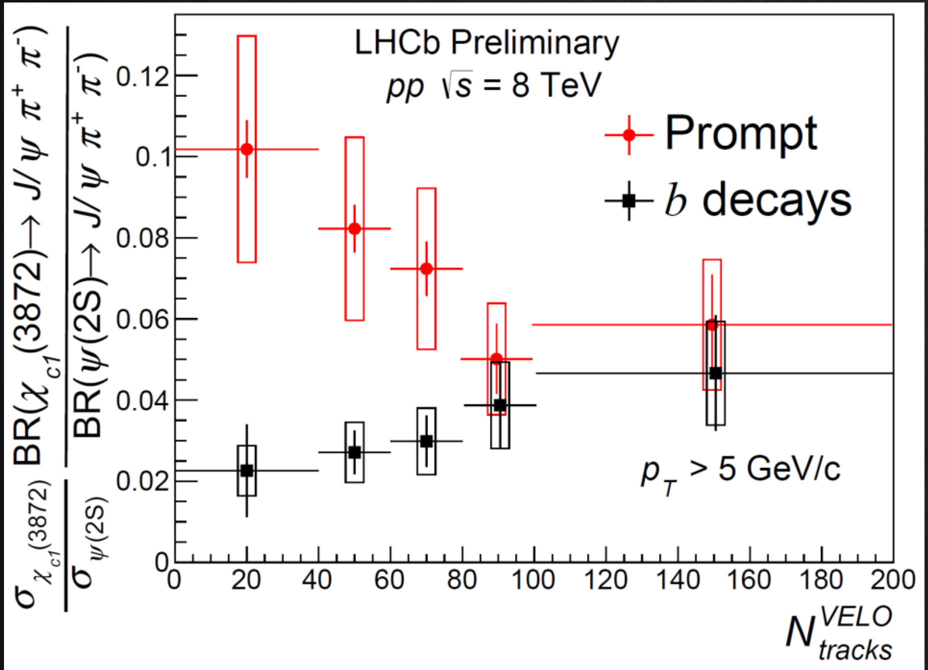


$p_T > 5$ GeV/c, $2 < y < 4.5$

X(3872) in pPb @ 8.16TeV



X(3872) in pp@8TeV

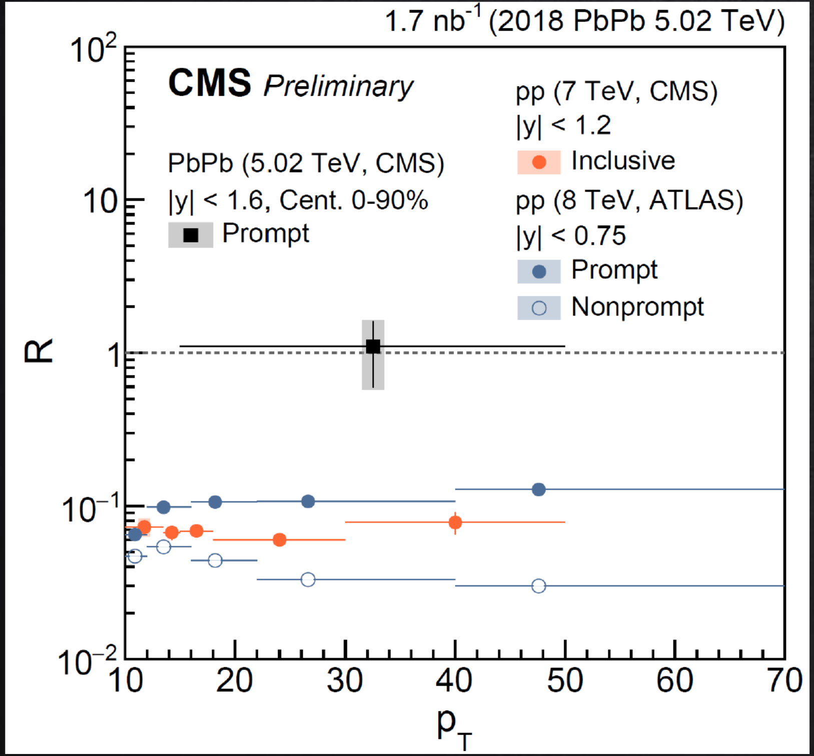


LHCb-conf-2019-005

Significant decrease of prompt X(3872)/ψ(2S) vs event activity

- ✓ Expected in a scenario where X(3872) is a weakly bound state more easily broken by comoving hadrons than ψ(2S)
- ✓ Non-prompt ratio has a weak dependence on event multiplicity, as expected for in vacuum decays

X(3872) in PbPb



$R = X(3872) / \psi(2S)$

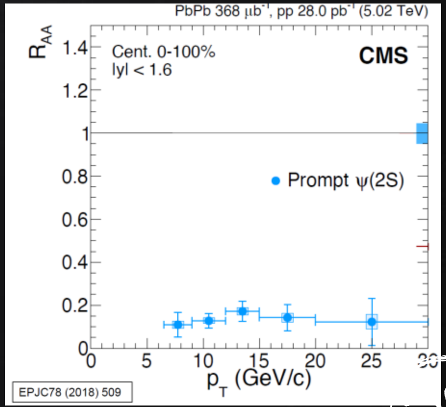
Ratio of corrected prompt yield

R = 1.10 +/− 0.51 (stat) +/− 0.53 (syst)

Hint for an enhancement of X(3872) production in AA, wrt pp collisions

ψ(2S) significantly suppressed in PbPb:

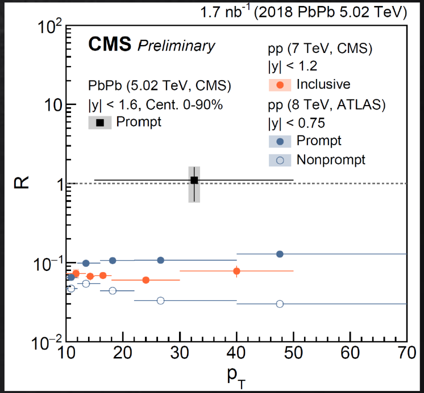
R_{AA} = 0.14 +/− 0.06 (stat) +/− 0.02 (syst) ($15 < p_T < 20$ GeV/c)



X(3872) in PbPb

Let's try to estimate $R_{AA}^{X(3872)}$:

$$R_{AA}^{X(3872)} = R_{AA}^{\psi(2S)} \times \frac{[X(3872)/\psi(2S)]_{AA}}{[X(3872)/\psi(2S)]_{pp}}$$



$R_{AA}^{\psi(2S)}$ =
0.14 +/− 0.06 (stat) +/− 0.02 (syst)
($15<p_T<20$ GeV/c)

$[X(3872)/\psi(2S)]_{AA}$ = 1.10 +/− 0.51 (stat) +/− 0.53 (syst)

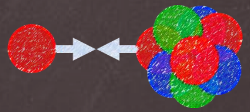
$[X(3872)/\psi(2S)]_{pp}$ = 0.106 +/− 0.008 (stat) +/− 0.004 (syst)
($16<p_T<22$ GeV/c) ATLAS, JHEP01,117

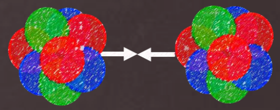
$$R_{AA}^{X(3872)} = 1.46 \pm 0.92\ (\text{stat}) \pm 0.73\ (\text{syst})$$

Very large uncertainties:
Compatible with either a compact state hardly affected by the medium or a loose state mainly created by coalescence?

CONCLUSIONS

At the end of Run2, very precise quarkonium results are available, in pA and AA, over a broad kinematic range





Results from all the LHC experiments show an overall good compatibility and should give strong constraints to theory models

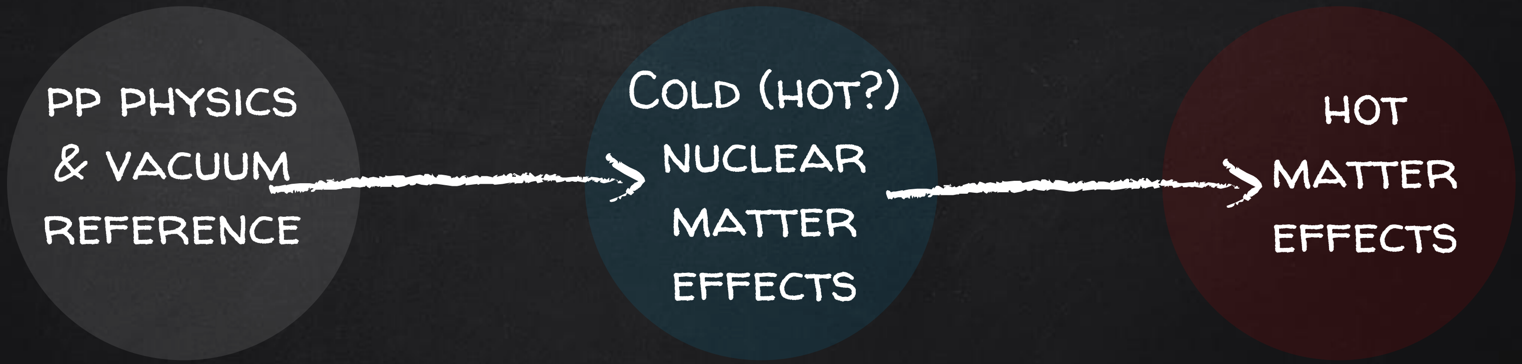
We wish you fruitful discussions and we expect you to solve all the remaining misteries!

Thank you!

Backup

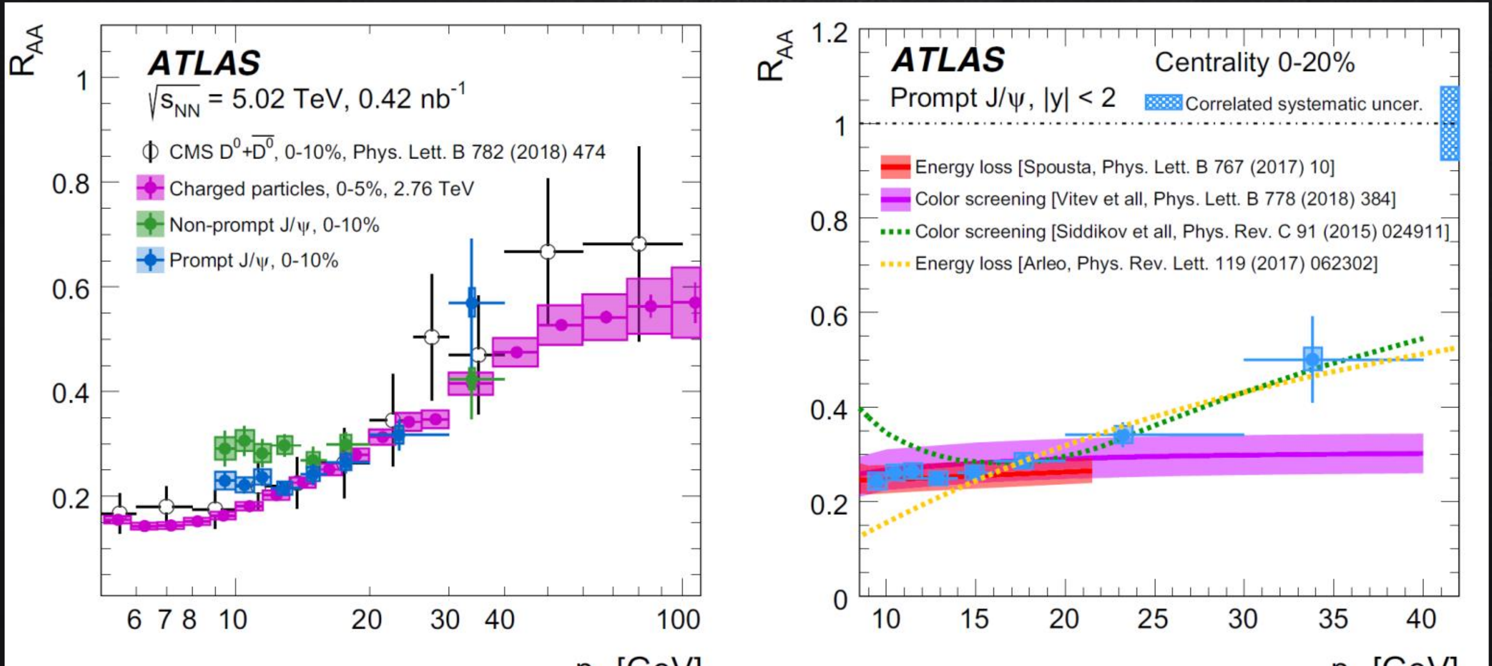
Overview

(After-QM) wrap-up of the most recent results on charmonium and bottomonium at the end of LHC Run2



Main observables: nuclear modification factor and flow

J/ψ R_{AA} – very high p_T

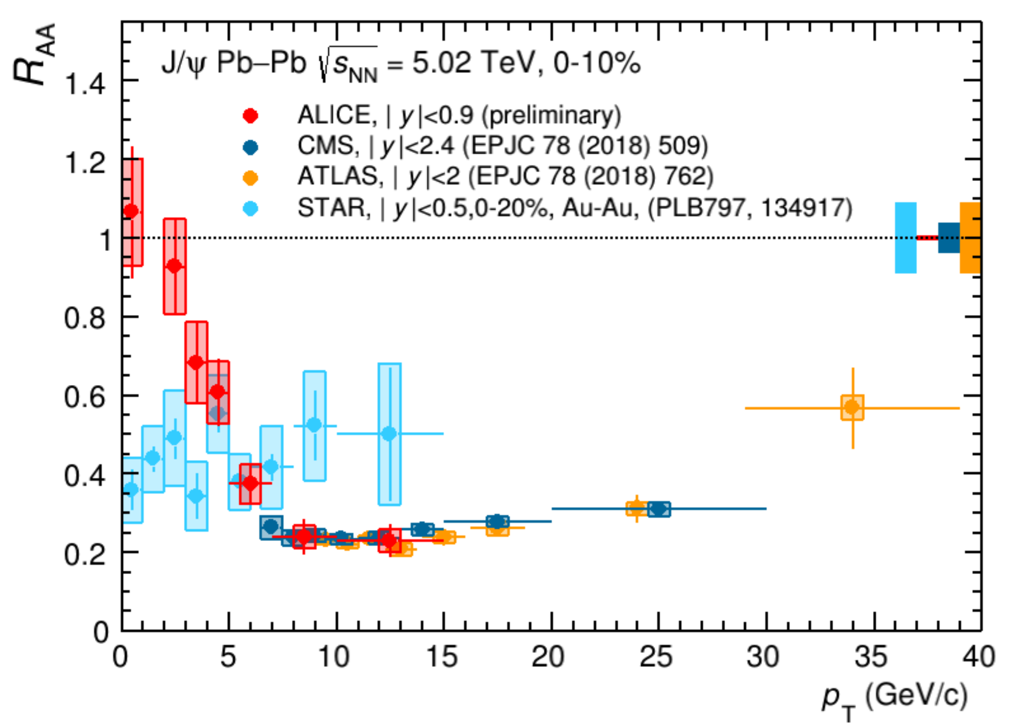


ATLAS, EPJC78(2018) 762

Indication of a high p_T rise, as for charged hadrons or D mesons

→ weak regeneration expected, parton energy-loss at play?

LOW – HIGH $\sqrt{s_{NN}}$



Significantly different R_{AA} p_T dependence at low and high $\sqrt{s_{NN}}$

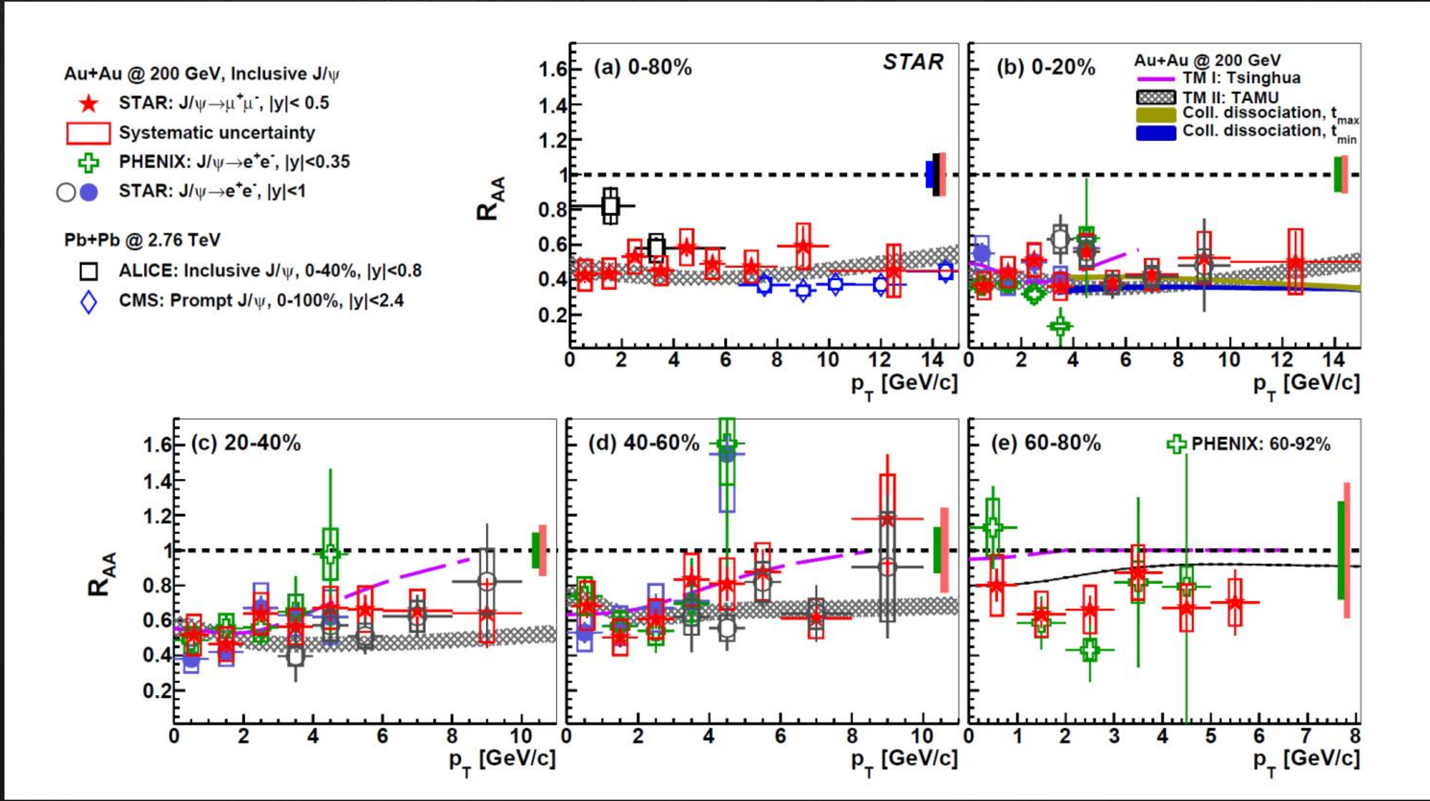
At RHIC energies

→ R_{AA} is rather flat versus p_T

→ at low p_T, R_{AA} is significantly smaller wrt LHC results

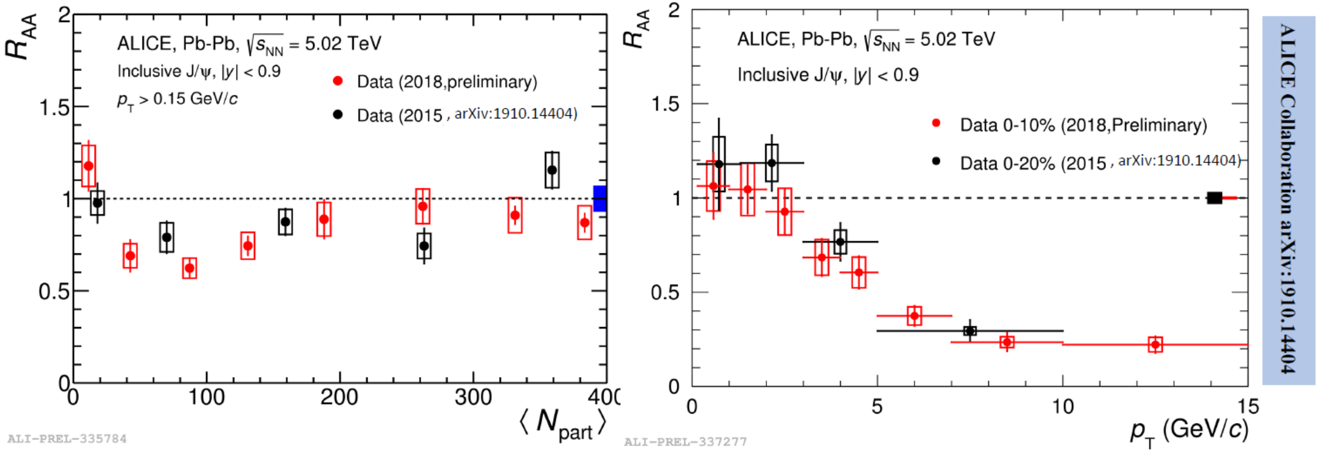
→ at high p_T, R_{AA} is slightly higher than the results at LHC energy, but uncertainties are still large

J/ψ – comparison to theory



J/ψ comparison RUN1 vs RUN2

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



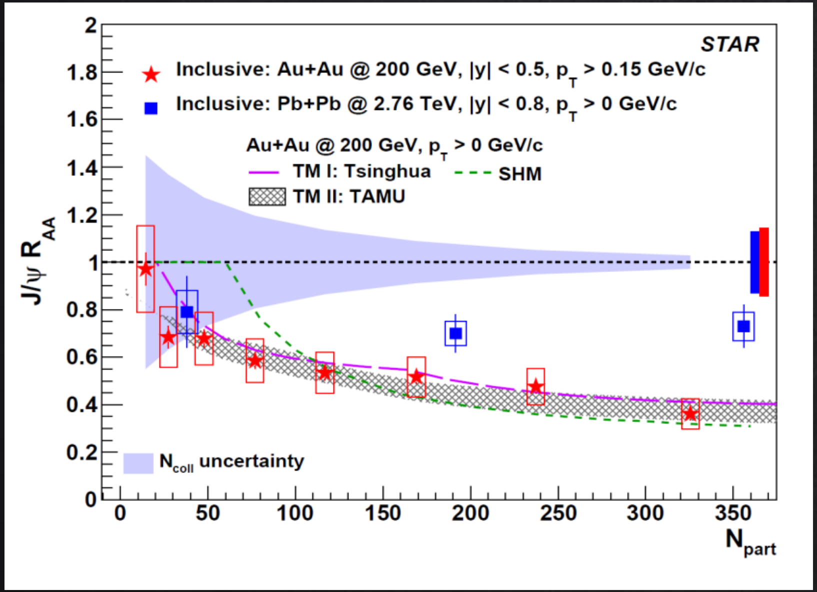
New preliminary (2018), new publication (2015)

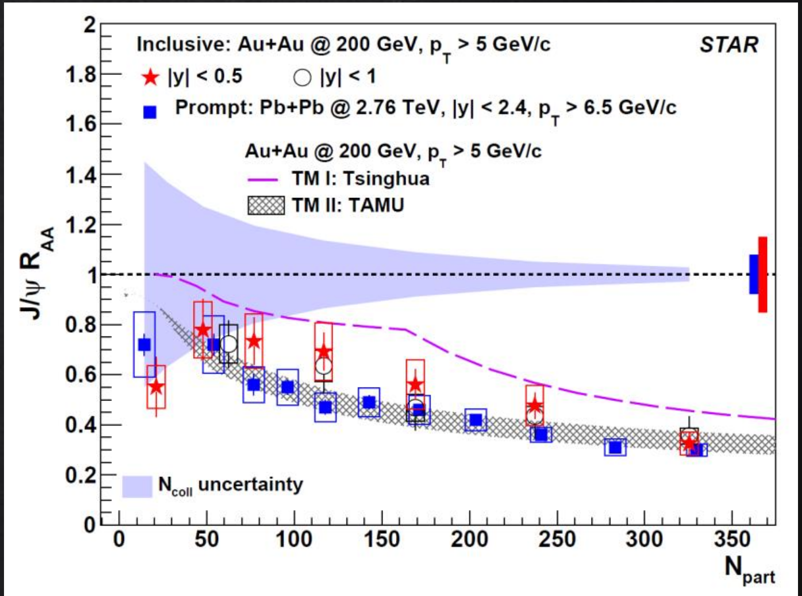
p_T

- New measurements based on high statistics data (~10 x for 0-10%, ~ 4 x for 30-50% compared to 2015)
- Significantly better precision and larger p_T coverage w.r.t the previous measurements

COMPARISON TO THEORY

Same models describe also low $\sqrt{s_{NN}}$ results

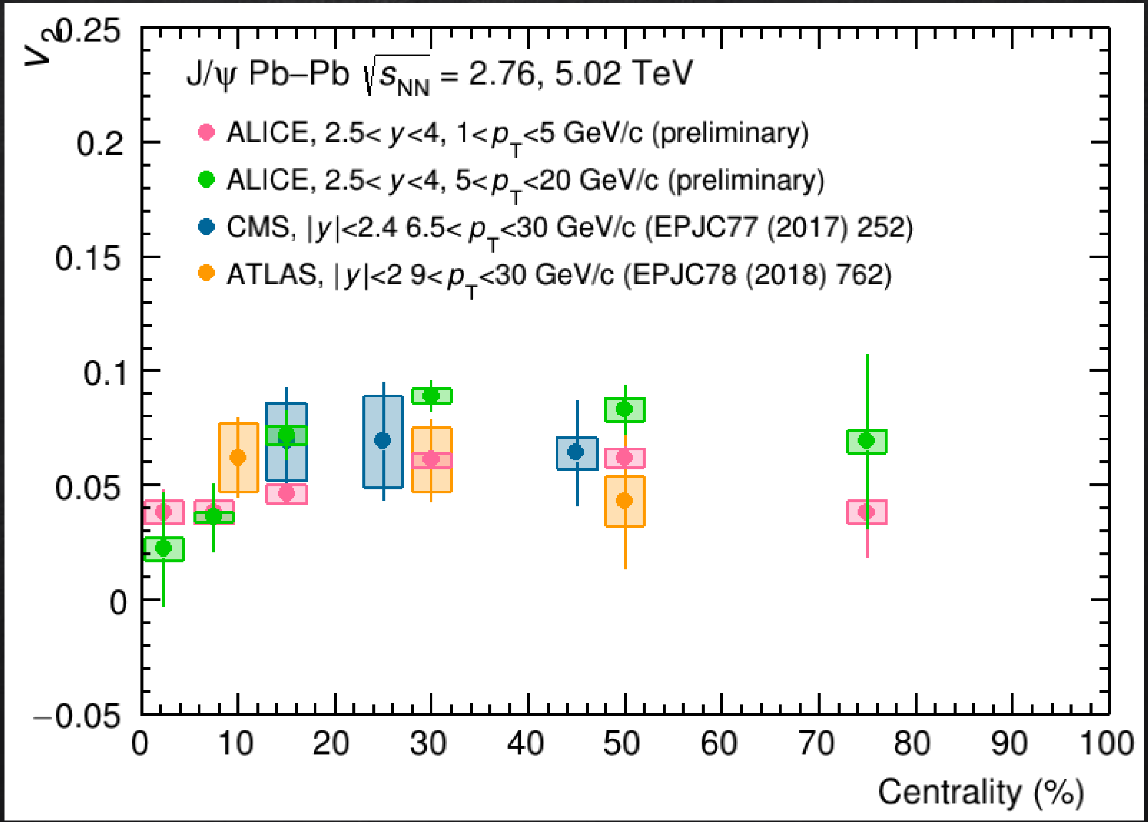




Still large uncertainties mainly due to charm cross section and shadowing

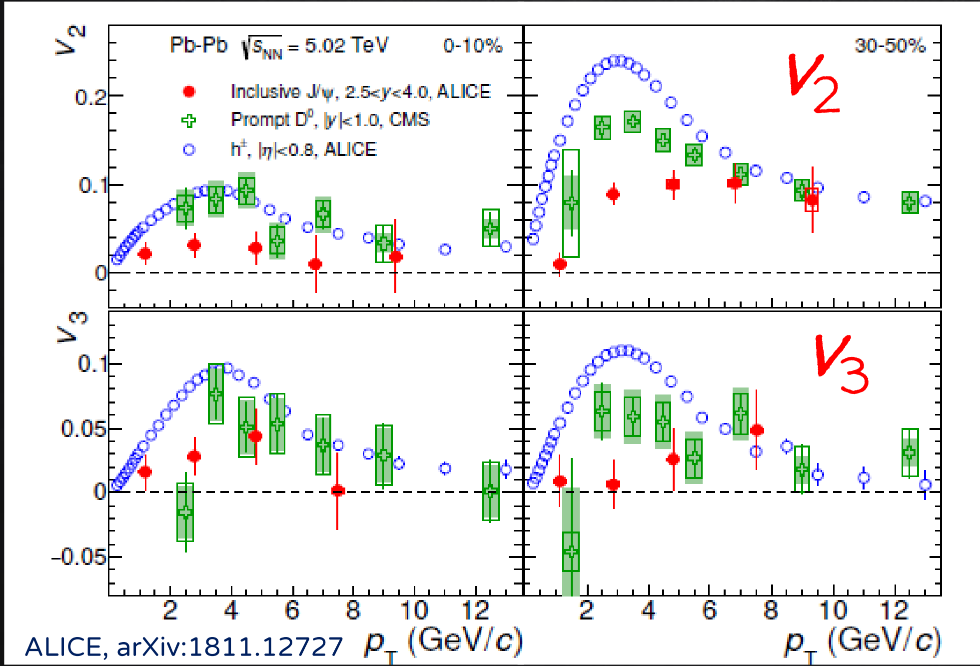
→ in many cases, data precision better than theory one

J/ψ v_2



v_2
J/ψ Pb–Pb $\sqrt{s_{NN}}$ = 2.76, 5.02 TeV
ALICE, 2.5< y<4, 1<p_T<5 GeV/c (preliminary)
ALICE, 2.5< y<4, 5<p_T<20 GeV/c (preliminary)
CMS, |y|<2.4 6.5<p_T<30 GeV/c (EPJC77 (2017) 252)
ATLAS, |y|<2 9<p_T<30 GeV/c (EPJC78 (2018) 762)
0.25
0.2
0.15
0.1
0.05
0
−0.05
0
10
20
30
40
50
60
70
80
90
100
Centrality (%)

J/ψ v_2 and v_3



First measurement of inclusive J/ψ v_3

3.7σ significance for a positive v_3 over the full p_T range

Low-intermediate p_T (intermediate centralities)

Both v_2 and v_3 suggests an ordering between charged hadrons, D^0 and J/ψ

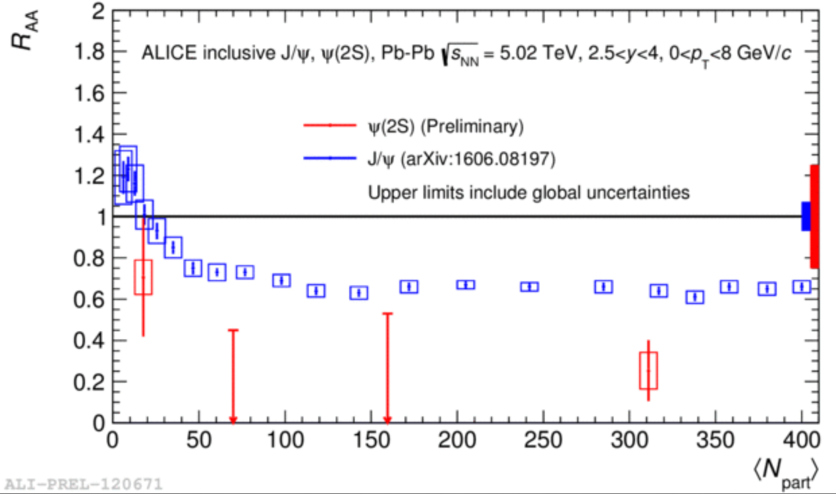
High p_T

v_2 converge to similar values for all particles, as expected by path length effects

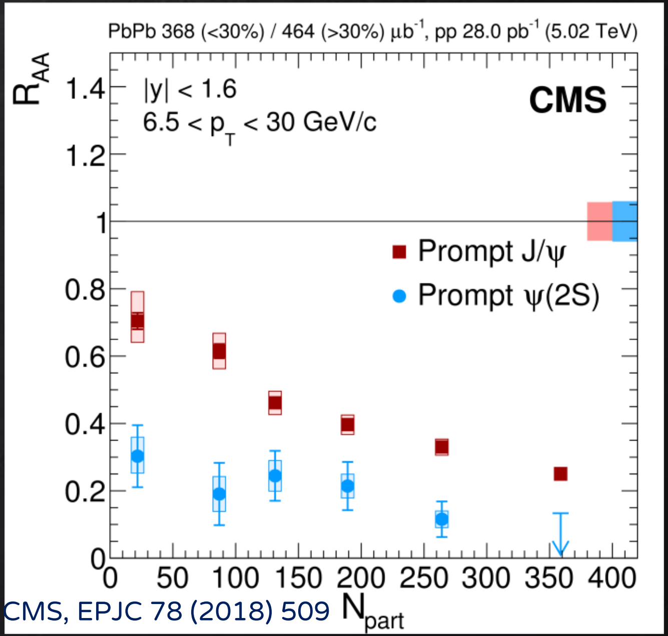
ψ(2S)

ψ(2S) loosely bound state: binding energy: ψ(2S)~60 MeV, J/ψ ~640MeV

Low p_T



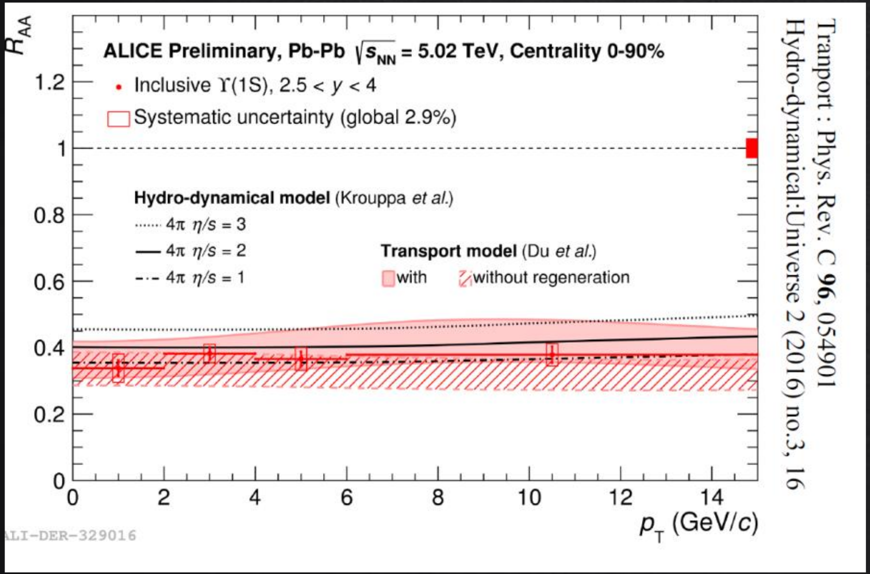
High p_T

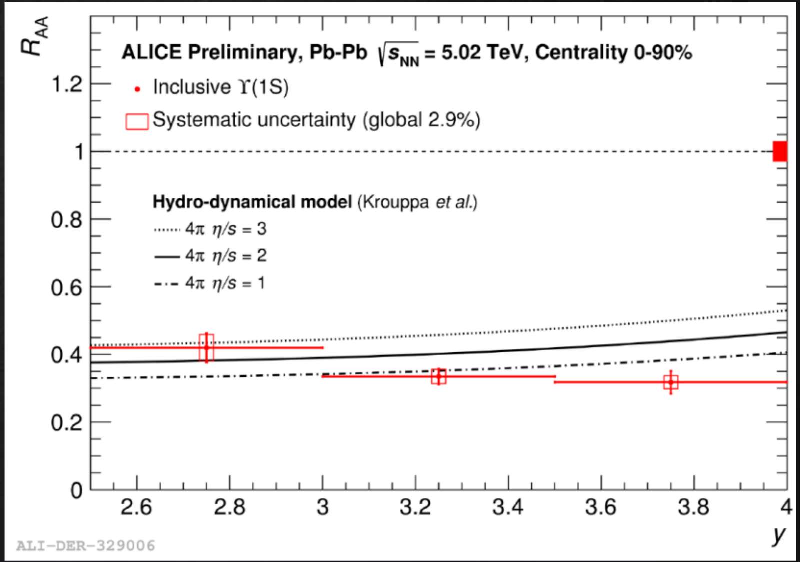


ψ(2S) is strongly suppressed in central collisions, but size of uncertainties prevents a detailed comparison with J/ψ

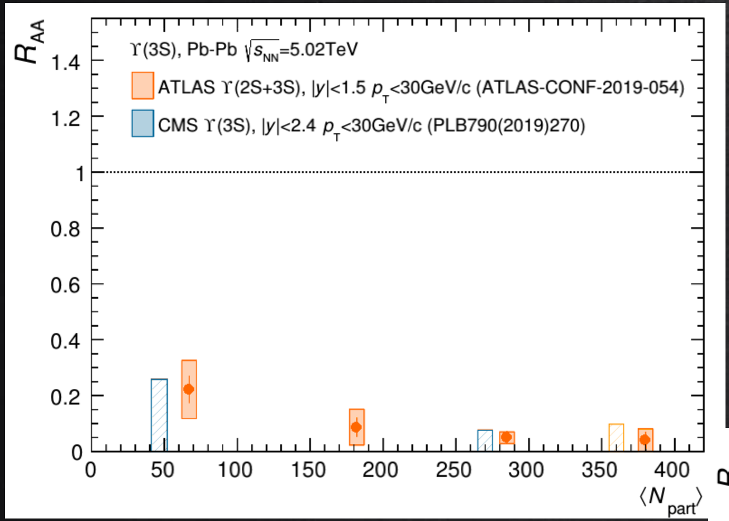
ψ(2S) suppression stronger than J/ψ, as expected in a sequential suppression scenario

Υ(1S) vs pT and rapidity

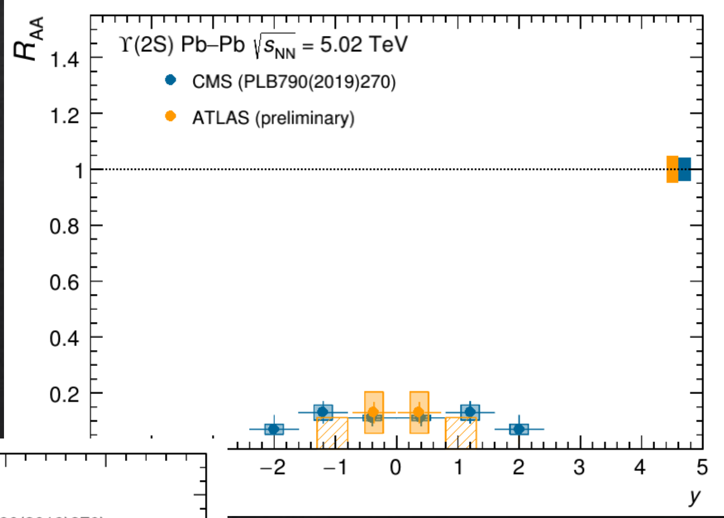




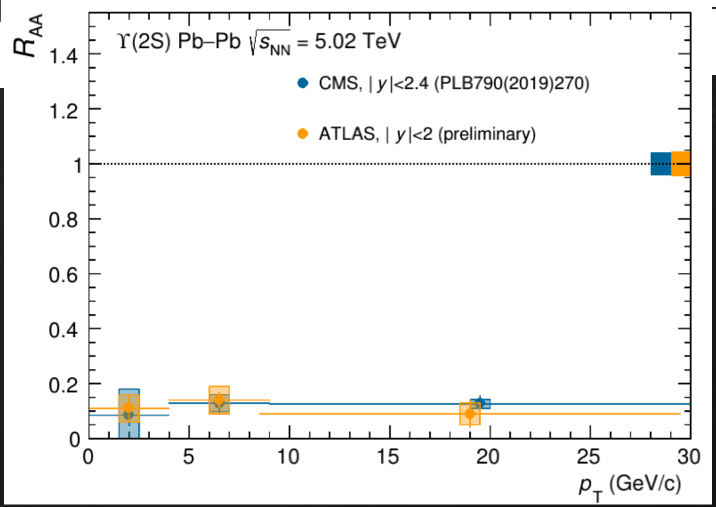
ϒ(2S) and ϒ(3S)



R_{AA}
ϒ(3S), Pb-Pb $\sqrt{s_{NN}}$=5.02TeV
ATLAS ϒ(2S+3S), |y|<1.5 p_T<30GeV/c (ATLAS-CONF-2019-054)
CMS ϒ(3S), |y|<2.4 p_T<30GeV/c (PLB790(2019)270)
⟨N_{part}⟩

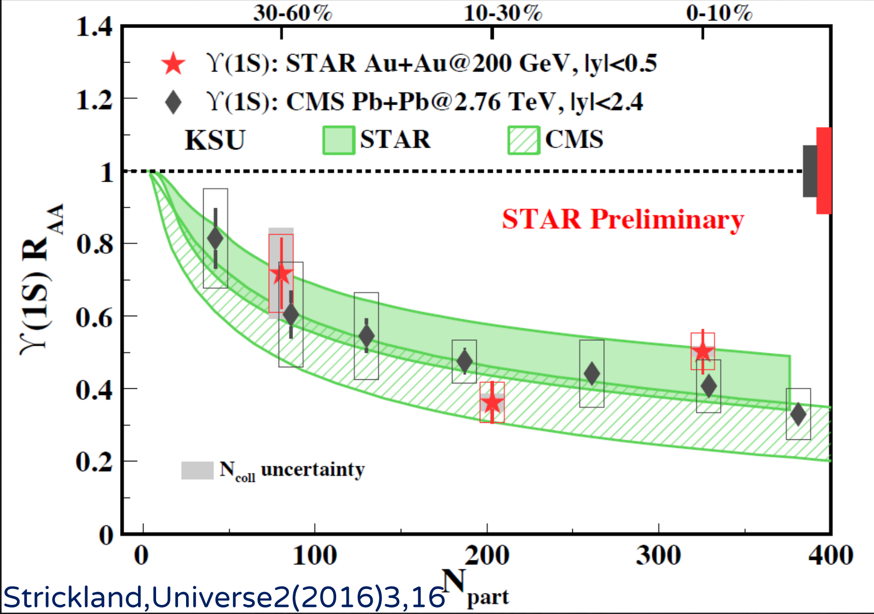


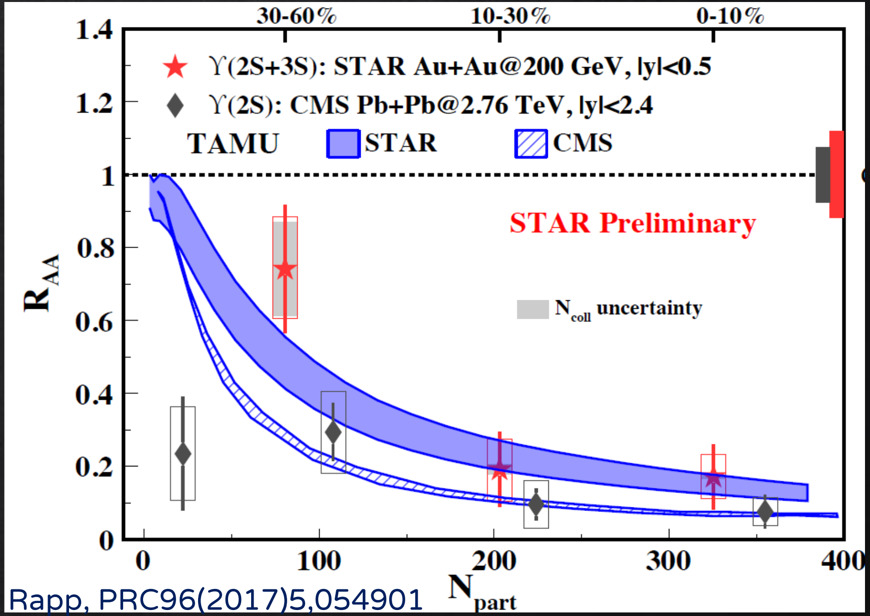
R_{AA}
ϒ(2S) Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV
CMS (PLB790(2019)270)
ATLAS (preliminary)
y



R_{AA}
ϒ(2S) Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV
CMS, | y |<2.4 (PLB790(2019)270)
ATLAS, | y |<2 (preliminary)
p_T (GeV/c)

Theory comparison

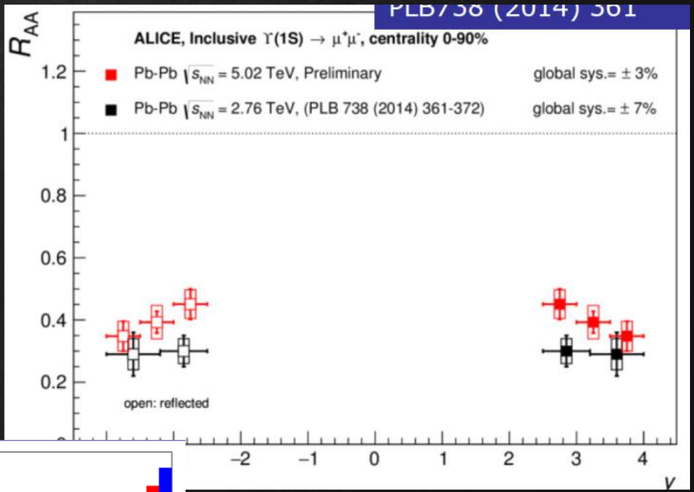


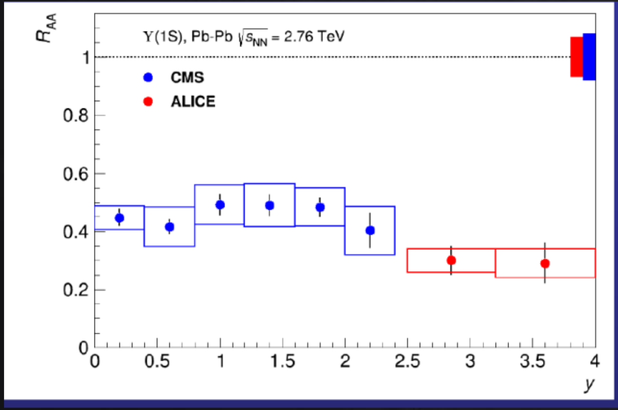


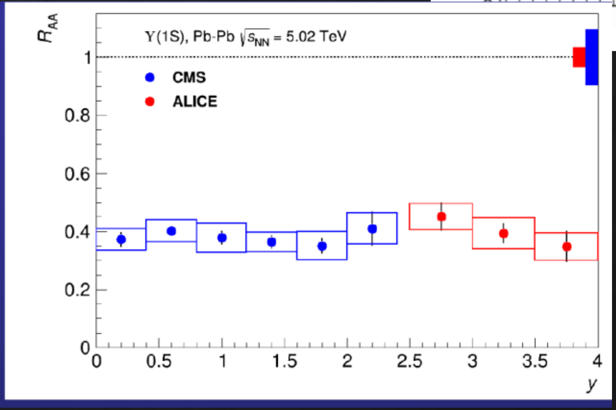
Models including suppression (+regeneration) fairly describe the data

However, models foresee a difference in the ϒ(nS) R_{AA} at low ad high $\sqrt{s_{NN}}$, not observed in data

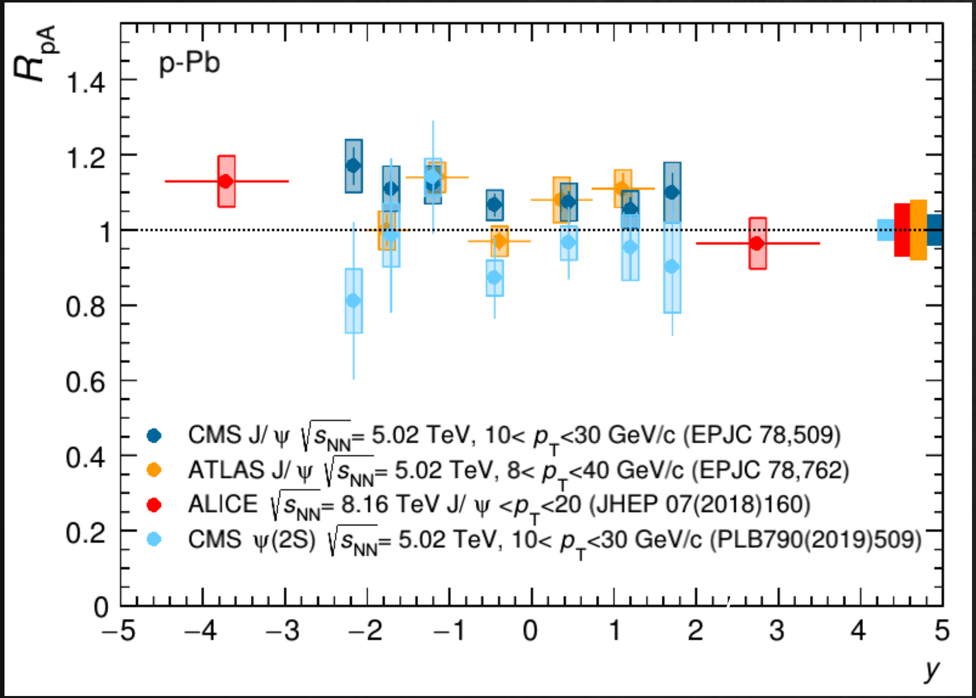
ϒ(1S) vs rapidity







Excited charmonium states



Low p_T

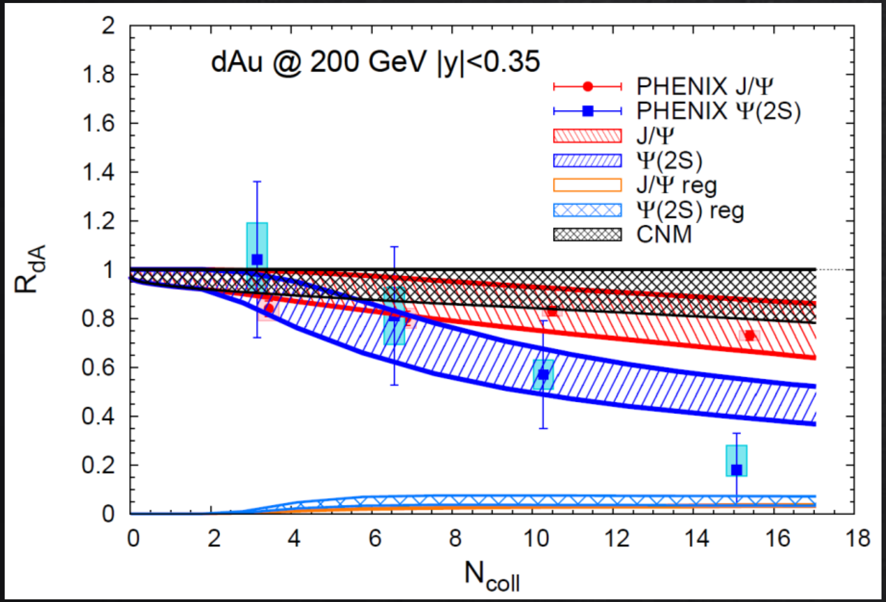
ψ(2S) suppression is stronger than the J/ψ one, in particular at backward-y

High p_T

The difference between the ψ(2S) and J/ψ suppression is less significant

→ Difference between J/ψ and ψ(2S) R_{pA} is larger at low pt and backward-y

ψ(2S) in pA



dAu @ 200 GeV |y|<0.35
PHENIX J/Ψ
PHENIX Ψ(2S)
J/Ψ
Ψ(2S)
J/Ψ reg
Ψ(2S) reg
CNM
R_dA
N_coll
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
2
4
6
8
10
12
14
16
18

EPPS16 reweighted with CMS dijet $R_{pPb}^{norm.}$

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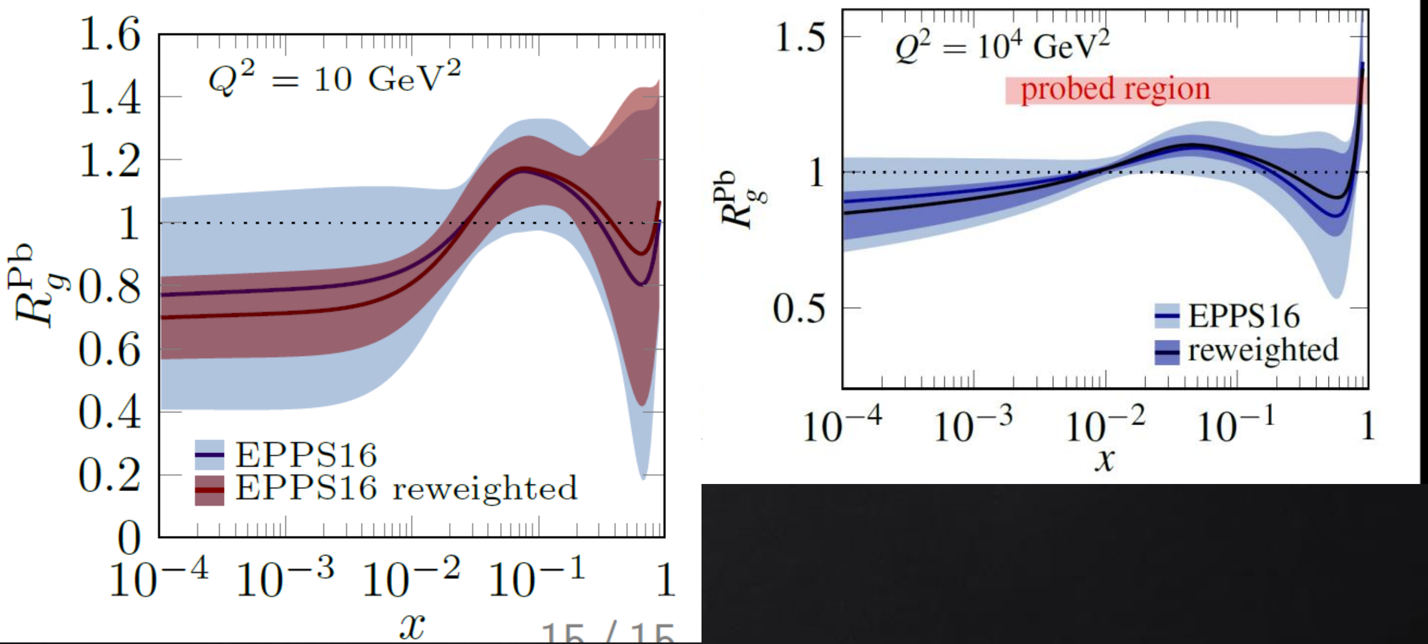
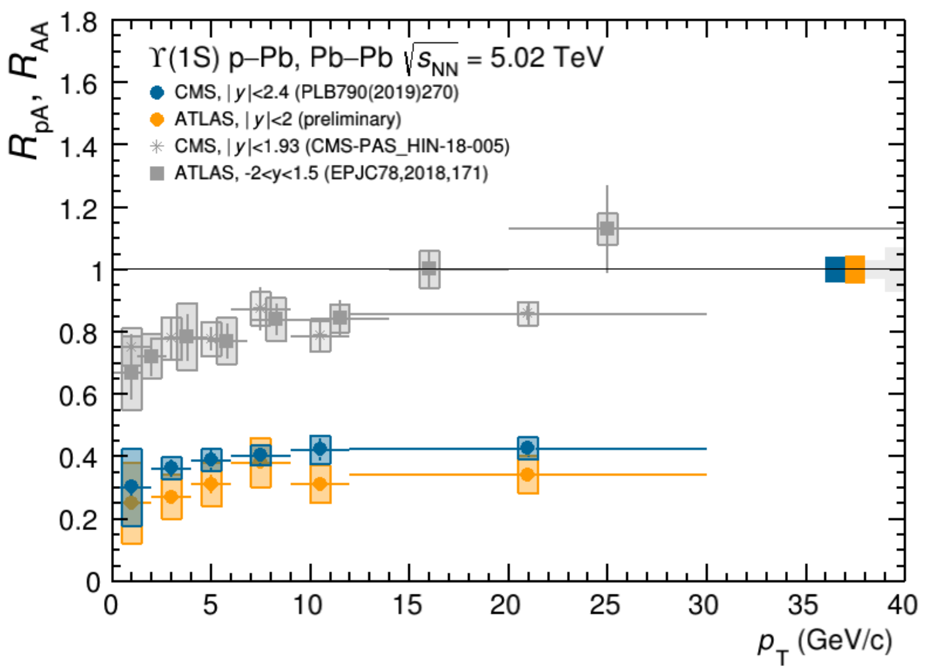
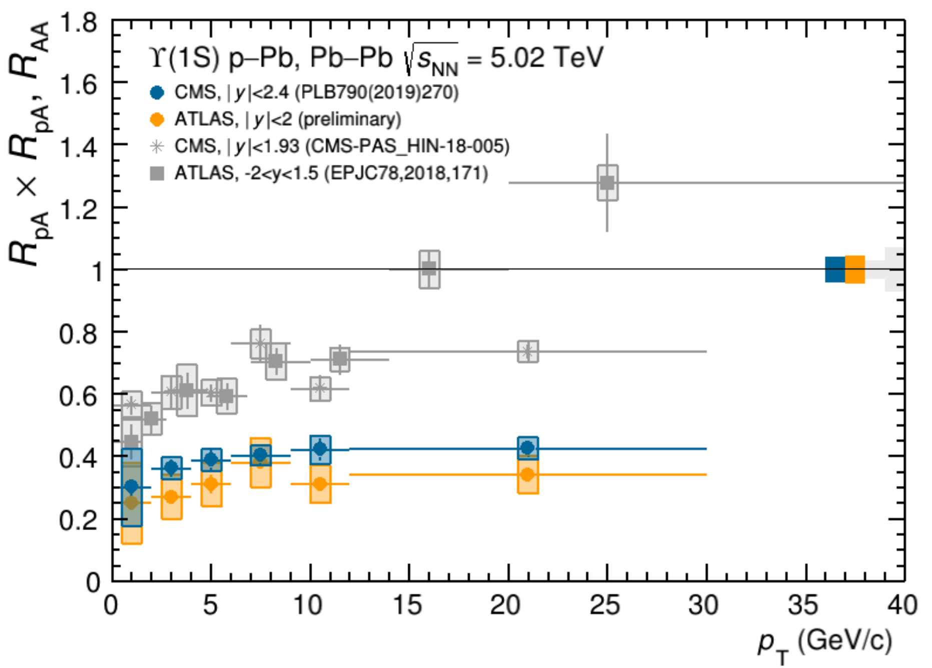
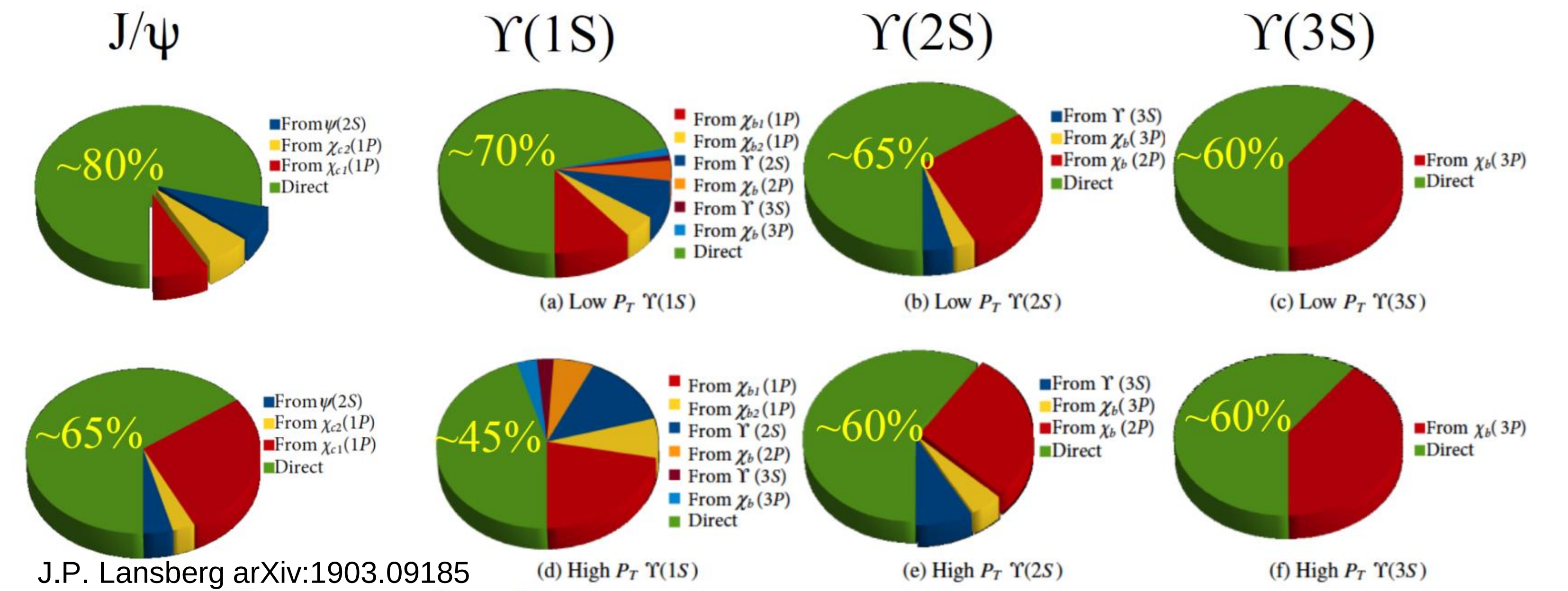


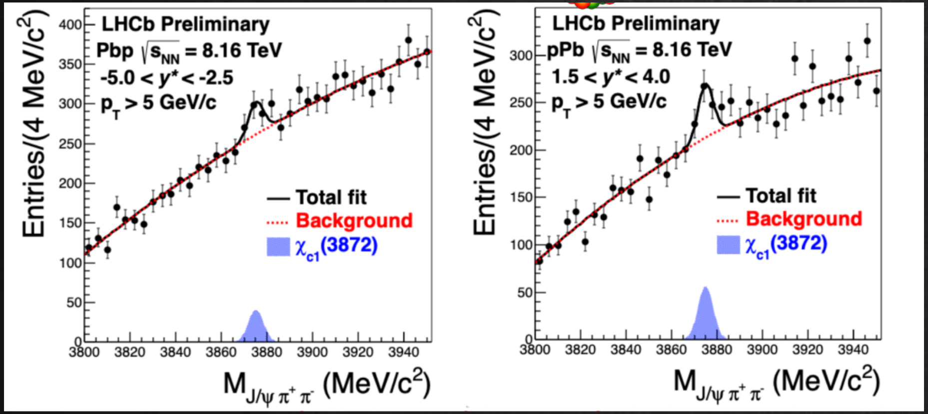

Υ(1S) p–Pb, Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV
CMS, |y|<2.4 (PLB790(2019)270)
ATLAS, |y|<2 (preliminary)
CMS, |y|<1.93 (CMS-PAS_HIN-18-005)
ATLAS, -2<y<1.5 (EPJC78,2018,171)
R_{pA}, R_{AA}
p_T (GeV/c)


Υ(1S) p–Pb, Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV
CMS, |y|<2.4 (PLB790(2019)270)
ATLAS, |y|<2 (preliminary)
CMS, |y|<1.93 (CMS-PAS_HIN-18-005)
ATLAS, -2<y<1.5 (EPJC78,2018,171)
$R_{pA} \times R_{pA}$, R_{AA}
p_T (GeV/c)

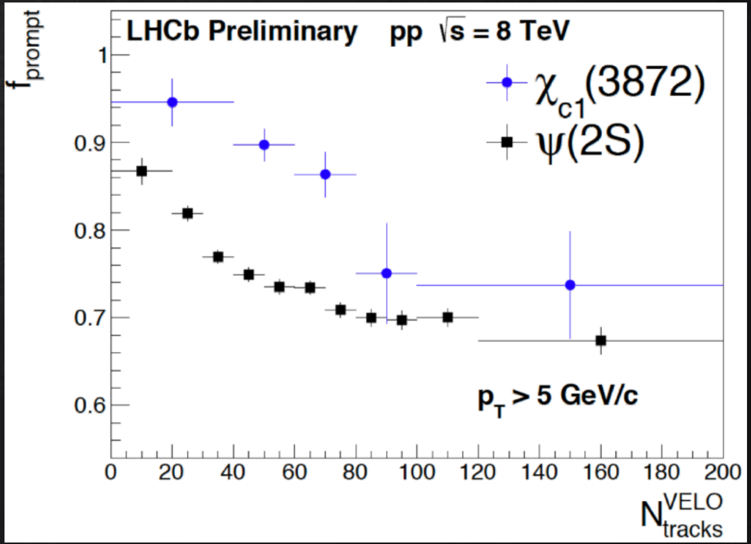


J.P. Lansberg arXiv:1903.09185

X(3872) in pp and pPb



Significant decrease of prompt fraction for both X(3872) and ψ(2S), vs event activity



state	η_c	J/ψ	χ_{c0}	χ_{c1}	χ_{c2}	ψ'	X(3872) ($D\bar{D}^*$ *Molecule*)
mass [GeV]	2.98	3.10	3.42	3.51	3.56	3.69	3.872
ΔE [GeV]	0.75	0.64	0.32	0.22	0.18	0.05	0.00001± 0.00027

Satz, J. Phys. G 32 (3) 2006

LHCb-conf-2019-005

Chi_c in pPb

Analysis of $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ in 2016 pPb data is ongoing.
LHCb tracking allows separation of the two χ_c peaks using converted photons even in a nuclear environment (left plot). On the other hand calorimeters provide larger statistics (right plot).