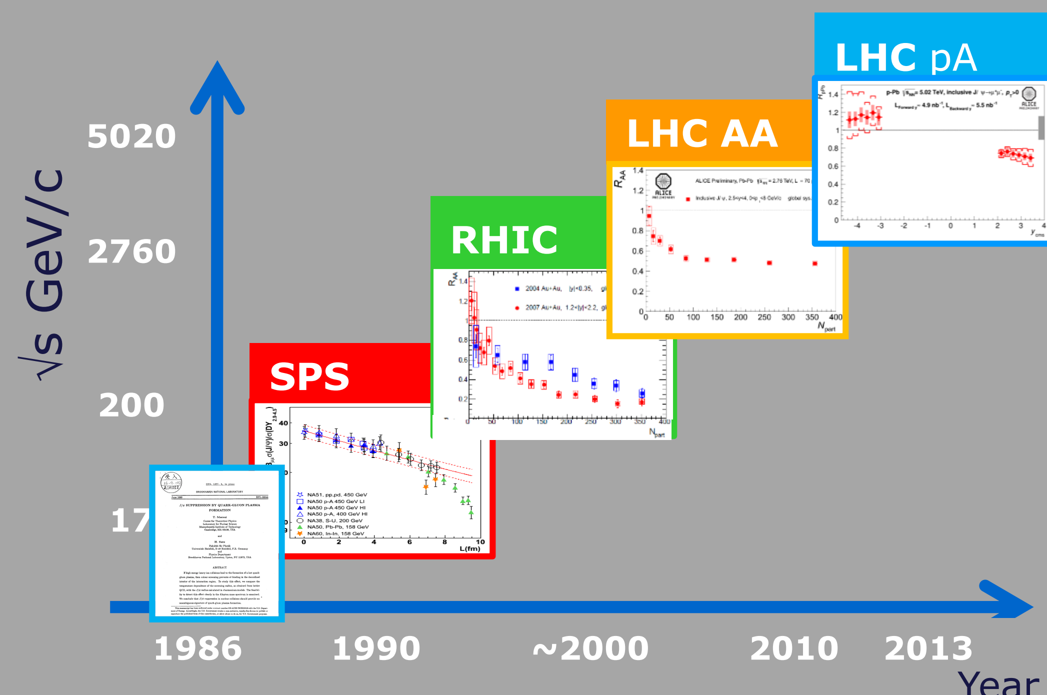
J/ψ production in heavy-ion collisions and related items

Roberta Arnaldi
INFN Torino

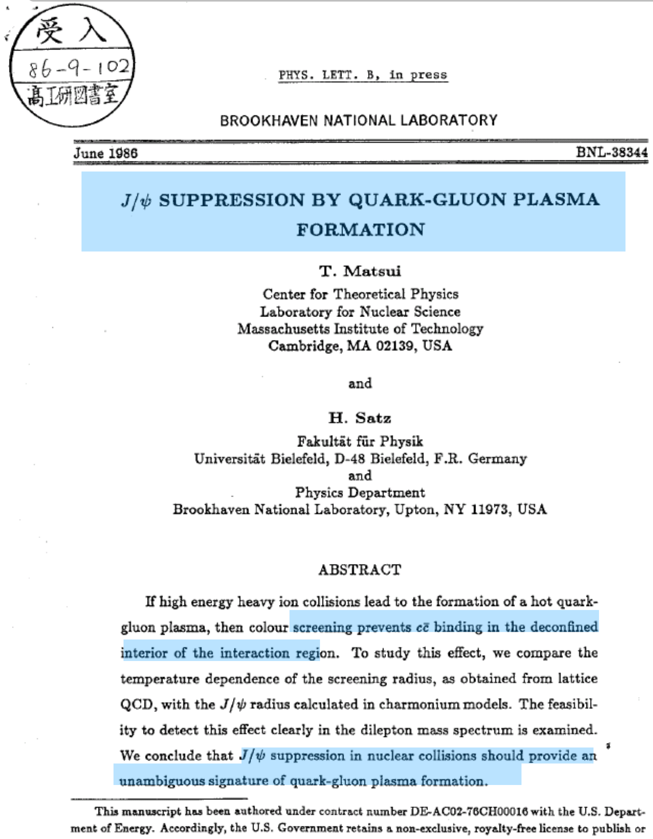
Outlook:

charmonium production
in pA and AA collisions
from

SPS → RHIC → LHC



Quarkonium in a hot medium



受入
86-9-102
高工研図書室

PHYS. LETT. B, in press

BROOKHAVEN NATIONAL LABORATORY

June 1986 BNL-38344

J/ψ SUPPRESSION BY QUARK-GLUON PLASMA FORMATION

T. Matsui
Center for Theoretical Physics
Laboratory for Nuclear Science
Massachusetts Institute of Technology
Cambridge, MA 02139, USA

and

H. Satz
Fakultät für Physik
Universität Bielefeld, D-48 Bielefeld, F.R. Germany
and
Physics Department
Brookhaven National Laboratory, Upton, NY 11973, USA

ABSTRACT

If high energy heavy ion collisions lead to the formation of a hot quark-gluon plasma, then colour screening prevents $c\bar{c}$ binding in the deconfined interior of the interaction region. To study this effect, we compare the temperature dependence of the screening radius, as obtained from lattice QCD, with the J/ψ radius calculated in charmonium models. The feasibility to detect this effect clearly in the dilepton mass spectrum is examined. We conclude that J/ψ suppression in nuclear collisions should provide an unambiguous signature of quark-gluon plasma formation.

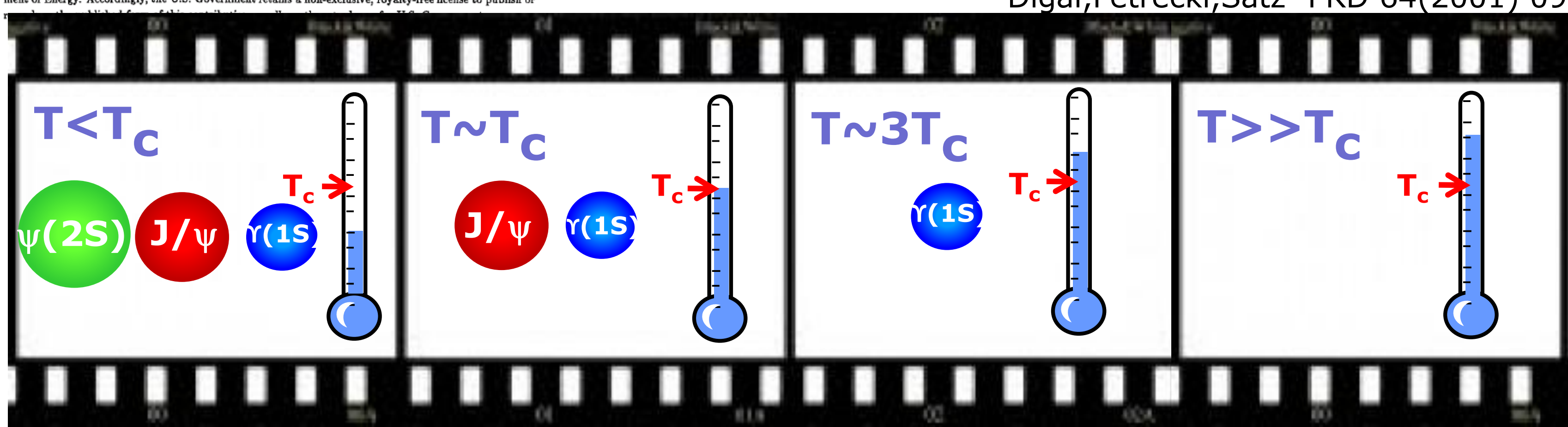
This manuscript has been authored under contract number DE-AC02-76CH00016 with the U.S. Department of Energy. Accordingly, the U.S. Government retains a non-exclusive, royalty-free license to publish or

Sequential melting

Differences in the binding energies of the quarkonium states lead to a sequential melting of the states with increasing temperature

Quarkonium is a thermometer of the initial QGP temperature

Digal,Petrecki,Satz PRD 64(2001) 0940150



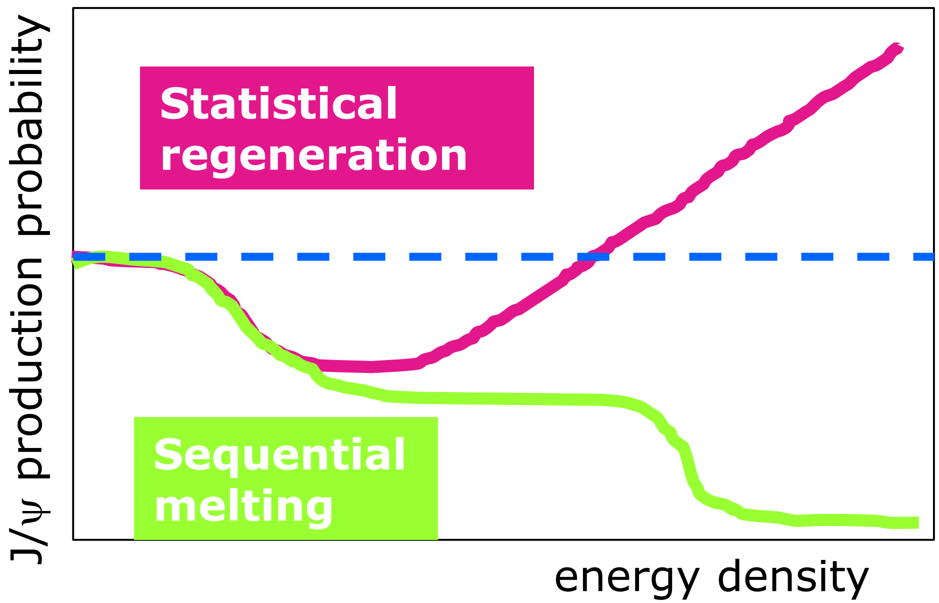
Quarkonium in a hot medium

(Re)combination

Increasing the collision energy the cc pair multiplicity increases

Central AA collisions	SPS 20 GeV	RHIC 200 GeV	LHC 2.76TeV
N_{ccbar}/event	~0.2	~10	~75

➡ enhanced quarkonia production via (re)combination at hadronization or during QGP stage



P. Braun-Muzinger,J. Stachel, PLB 490(2000) 196
R. Thews et al, Phys.Rev.C63:054905(2001)

Cold Matter Effects

Cold Matter Effects (CNM)

on top of mechanisms related to hot matter, other effects have to be taken into account to interpret quarkonium A-A results:

- nuclear parton shadowing
- energy loss
- $c\bar{c}$ in medium break-up

investigated through p-A collisions

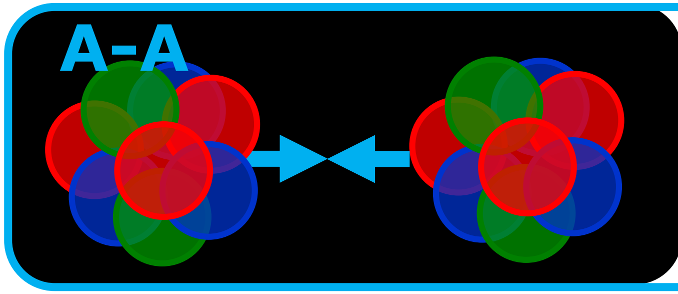
Nuclear modification factor

Medium effects are quantified comparing the quarkonium yield in AA with the pp one, scaled by a geometrical factor (from Glauber model)

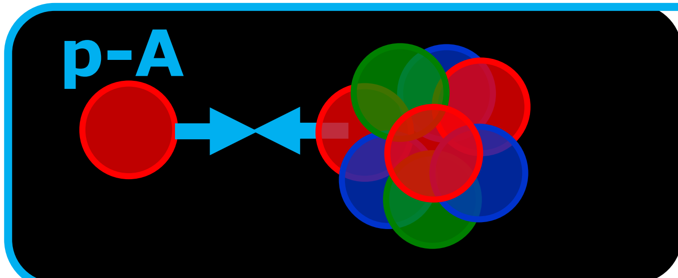
$$R_{AA}^{J/\psi} = \frac{Y_{AA}^{J/\psi}}{\langle T_{AA} \rangle \sigma_{pp}^{J/\psi}}$$

- $R_{AA} = 1$ → no medium effects
- $R_{AA} \neq 1$ → hot/cold matter effects

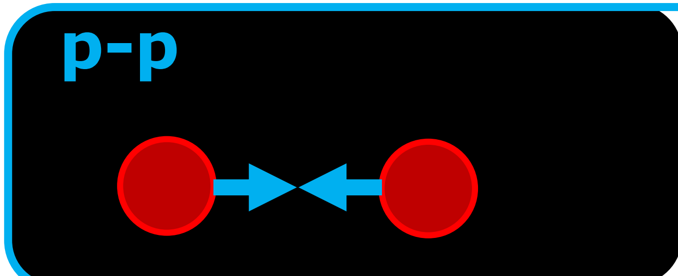
Quarkonium studies in Heavy-Ion collisions



- Quarkonium as a probe of the hot medium created in the collision (QGP)
- Suppression vs (re)combination



- Investigation of cold nuclear matter effects (shadowing, energy loss…)
- Crucial tool to disentangle genuine QGP effect is AA collisions



- Reference process to understand behaviour in pA, AA collisions
- Useful to investigate production mechanisms (NRQCD, CEM models...)

Quarkonium in Heavy-Ion collisions

Facility	Experiment	System	$\sqrt{s_{NN}}$ (GeV)	Data taking
SPS	NA38	S-U	19	1986-1992
	NA50	Pb-Pb	17	1995-2003
		p-A	27-29	
	NA60	In-In	17	2003-2004
		p-A	17-27	
RHIC	PHENIX/STAR	Au-Au, Cu-Cu, Cu-Au, U-U	200, 193, 62, 39	2000-2015
		p-Au, d-Au	200	
LHC	ALICE/ATLAS/ CMS/LHCb	Pb-Pb	2760	2010-2012
		p-Pb	5020	2013

➡ pp collision program has also been scheduled at RHIC and LHC

Quarkonium in Heavy-Ion collisions

Facility	Experiment	System	$\sqrt{s_{NN}}$ (GeV)	Data taking
SPS	NA38	S-U	19	1986-1992
	NA50	Pb-Pb	17	1995-2003
		p-A	2[illegible]	
	NA60	In-In	17	2003-2004
		p-A	17-27	
RHIC	PHENIX/STAR	Au-Au, Cu-Cu, Cu-Au, U-U	200, 193, 62, 39	2000-2015
		d-Au	200	
LHC	ALICE/ATLAS/ CMS/LHCb	Pb-Pb	2760	2010-2011
		p-Pb	5020	2013

~30 years long story

➡ pp collision program has also been scheduled at RHIC and LHC

Quarkonium in Heavy-Ion collisions

Facility	Experiment	System	$\sqrt{s_{NN}}$ (GeV)	Data taking
SPS	NA38	S-U	19	1986-1992
	NA50	Pb-Pb	17	1995-2003
			27-29	
	NA60		17	2003-2004
		p-A	17-27	
RHIC	PHENIX/STAR	Au-Au, Cu-Cu, Cu-Au, U-U	200, 193, 62, 39	2000-2015
		d-Au	200	
LHC	ALICE/ATLAS/ CMS/LHCb	Pb-Pb	2760	2010-2011
		p-Pb	5020	2013

More than a factor ~100 increase in energy

➡ pp collision program has also been scheduled at RHIC and LHC

Quarkonium in Heavy-Ion collisions

Facility	Experiment	System	$\sqrt{s_{NN}}$ (GeV)	Data taking
SPS	NA38	S-U	19	1986-1992
	NA50	Pb-Pb	17	1995-2003
		[illegible]	[illegible]	
	NA60	In-In	17	2003-2004
		p-A	17-27	
RHIC	PHENIX/STAR	Au-Au, Cu-Cu, Cu-Au, U-U	200, 193, 62, 39	2000-2015
LHC	ALICE/ATLAS/CMS/LHCb	Pb-Pb	2760	2010-2012
		p-Pb	5020	2013

Fixed target experiments

Collider experiments

➡ pp collision program has also been scheduled at RHIC and LHC

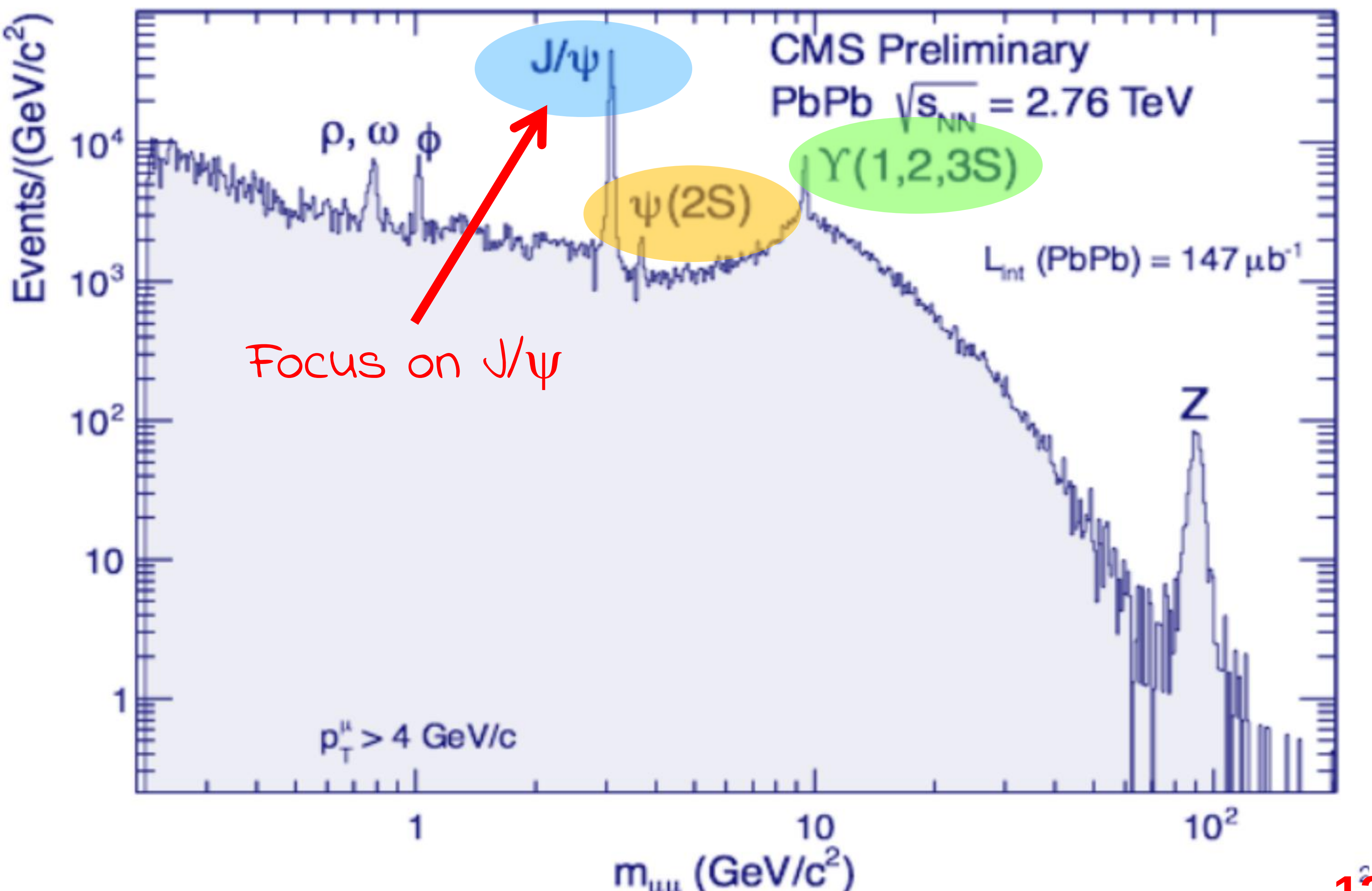
Quarkonium in Heavy-Ion collisions

Facility	Experiment	System	$\sqrt{s_{NN}}$ (GeV)	Data taking
SPS	NA38	S-U	19	1986-1992
	NA50	Pb-Pb	17	1995-2003
		p-A	27-29	
		In-In	17	2003-2004
		p-A	17-27	
RHIC	PHENIX/STAR	Au-Au, Cu-Cu, Cu-Au, U-U	200, 193, 62, 39	2000-2015
		d-Au	200	
LHC	ALICE/ATLAS/ CMS/LHCb	Pb-Pb	2760	2010-2011
		p-Pb	5020	2013

For all experiments, the AA program is followed by the pA one

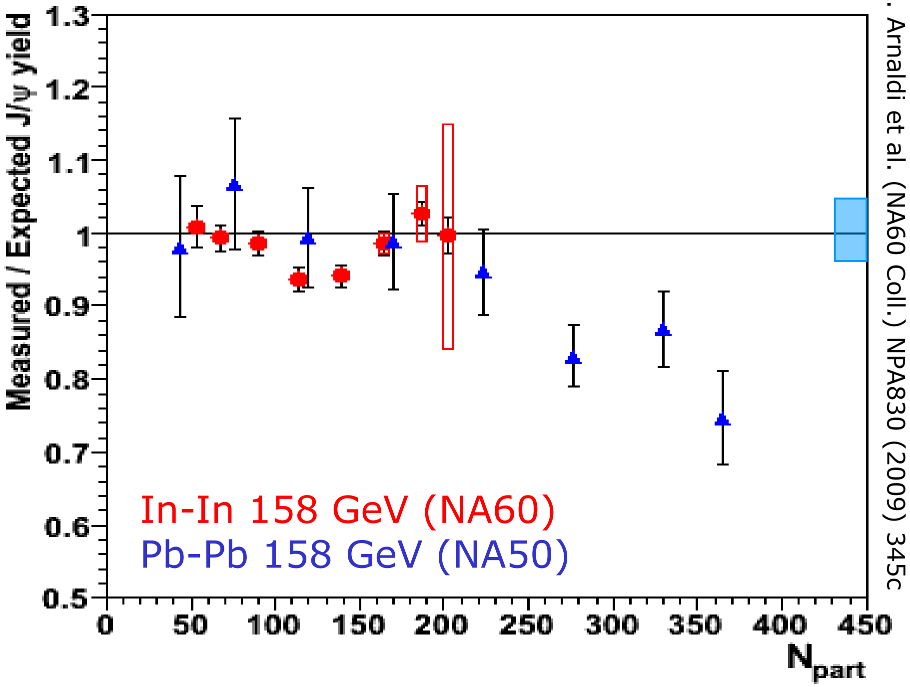
➡ pp collision program has also been scheduled at RHIC and LHC

Quarkonium resonances



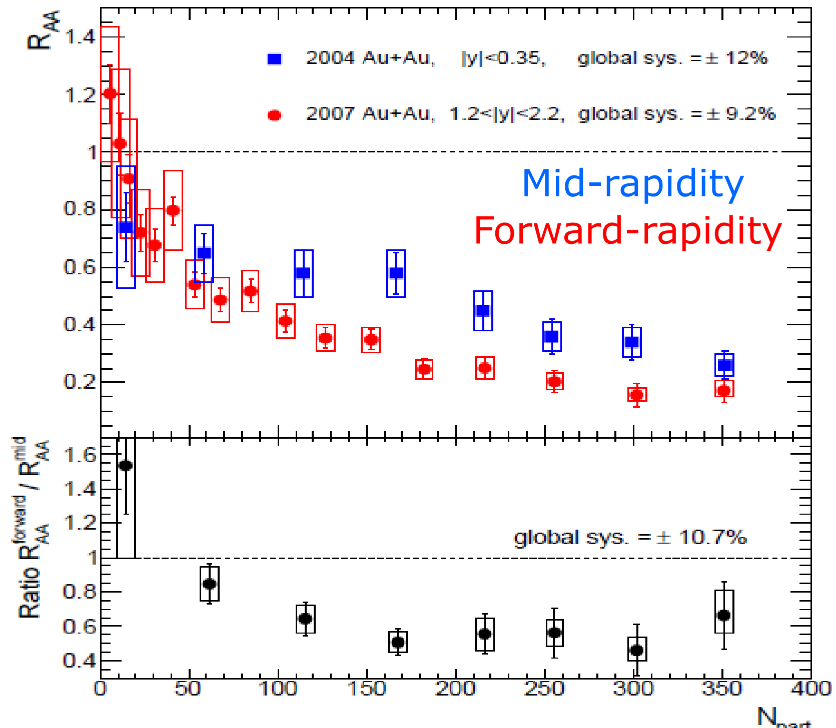
First J/ψ measurements at low energy

SPS (NA38, NA50, NA60)
$\sqrt{s_{NN}}$ = 17 GeV



R. Arnaldi et al. (NA60 Coll.) NPA830 (2009) 345c

RHIC (PHENIX,STAR)
$\sqrt{s_{NN}}$ =39,62.4,200GeV

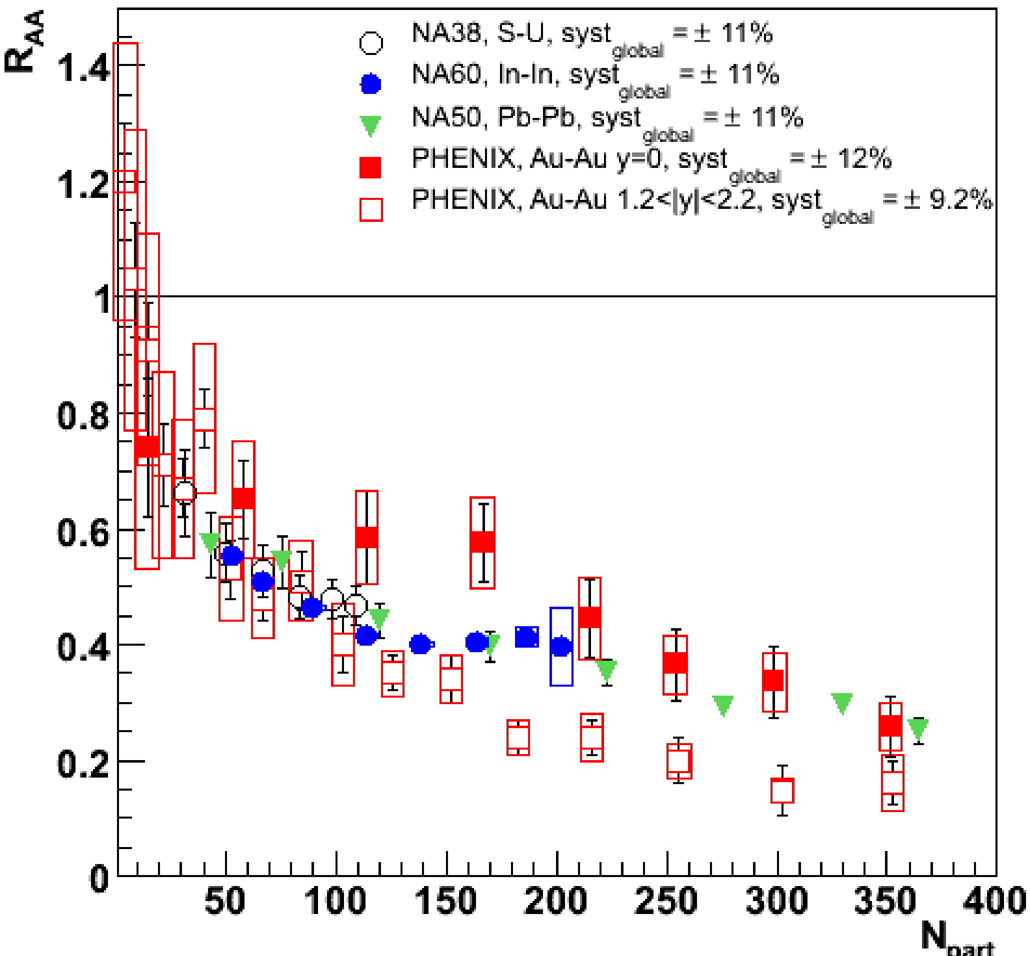


RA. Adare et al(PHENIX Xoll.), PRC84 (2011) 054912

SPS:
first evidence of anomalous suppression (i.e. beyond CNM expectations) in Pb-Pb
~30% suppression compatible with ψ(2S) and χ_c decays

RHIC:
suppression, strongly rapidity dependent, in Au-Au at √s= 200 GeV
Stronger suppression at forward y
(not expected if suppression increases with energy density, larger at mid-y)

From SPS and RHIC results to LHC



N.Brambilla et al. (QWG) EPJC71 (2011) 1534

- Puzzles from SPS and RHIC
  - **RHIC**: stronger suppression at forward rapidities
  - **SPS vs. RHIC**: similar R_{AA} pattern versus centrality
- Hint for (re)combination at RHIC?

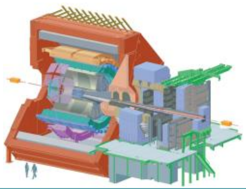
  No final theoretical explanation

Decisive inputs expected from LHC results, having access to:

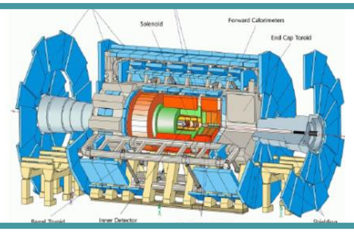
higher energies
→ stronger suppression?
more charm
→ larger (re)combination?
more bottom
→ Υ can be investigated

Quarkonium at LHC

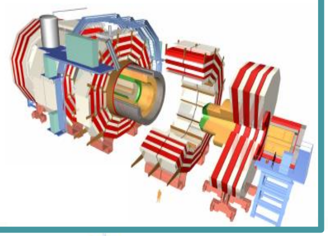
ALICE J/ψ, $\psi(2S) \rightarrow \mu^+\mu^-$
$\Upsilon \rightarrow \mu^+\mu^-$
$J/\psi \rightarrow e^+e^-$



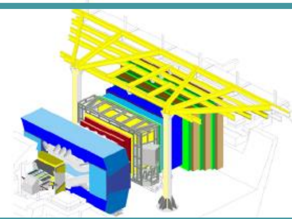
ATLAS $J/\psi \rightarrow \mu^+\mu^-$



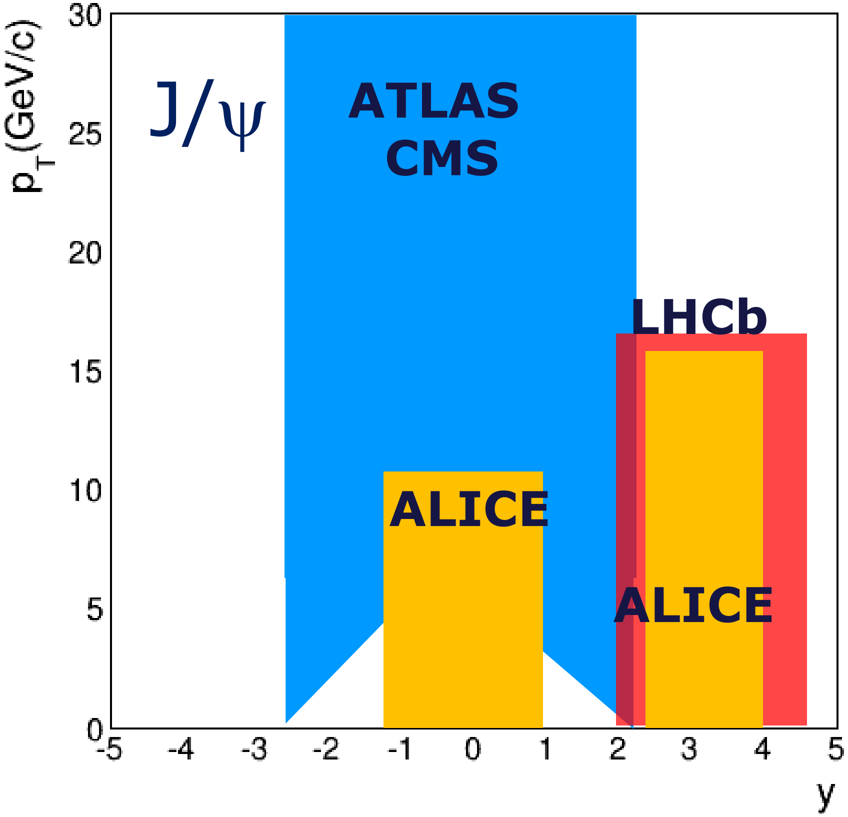
CMS J/ψ, $\psi(2S) \rightarrow \mu^+\mu^-$
$\Upsilon \rightarrow \mu^+\mu^-$



LHCb J/ψ, $\Upsilon \rightarrow \mu^+\mu^-$
(no heavy ion physics program)

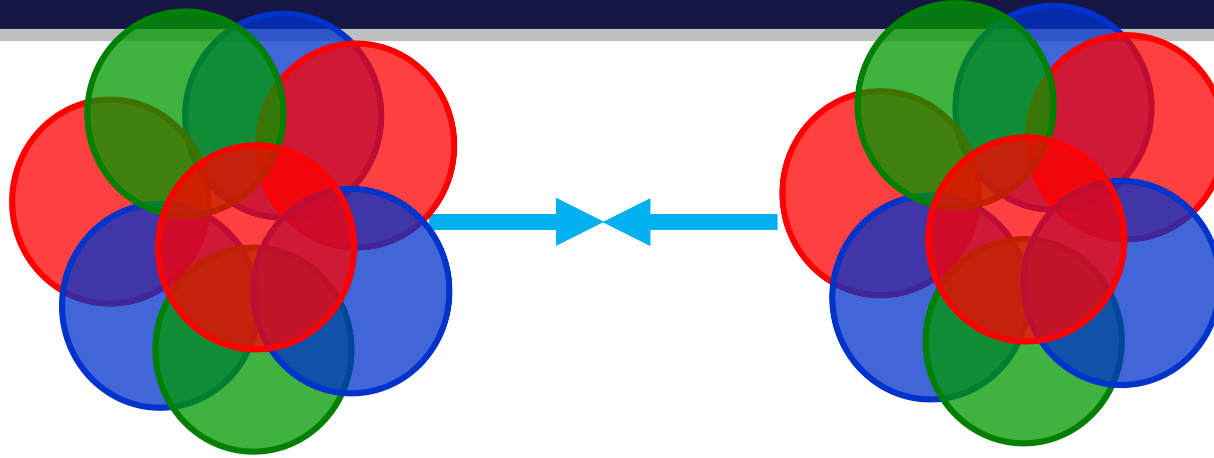


➡ Kinematic coverage of quarkonium measurements:



➡ Complementary quarkonium results from LHC experiments!

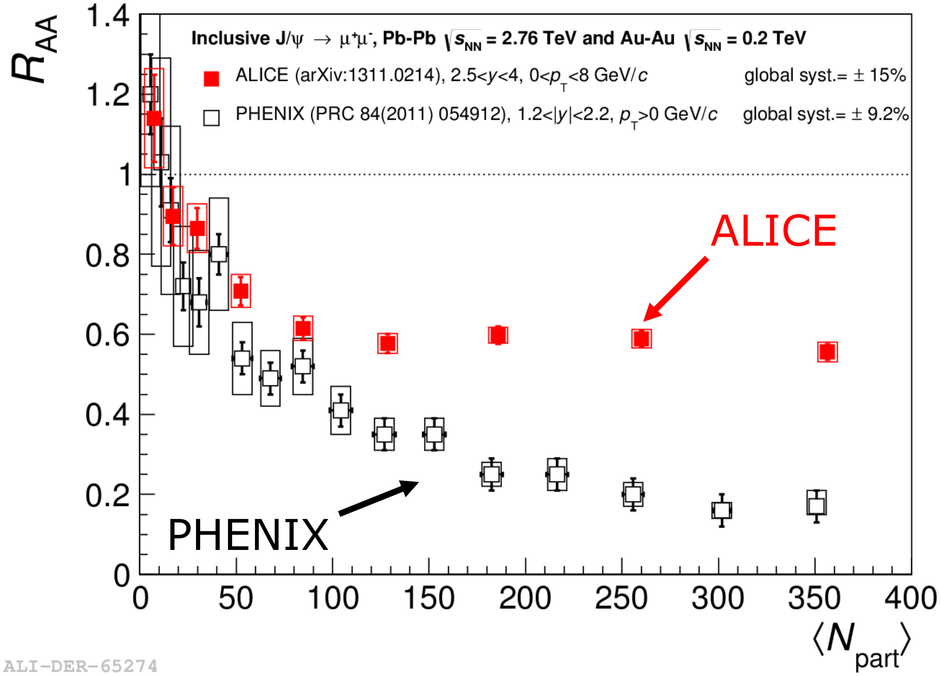
J/ψ in AA collisions at LHC

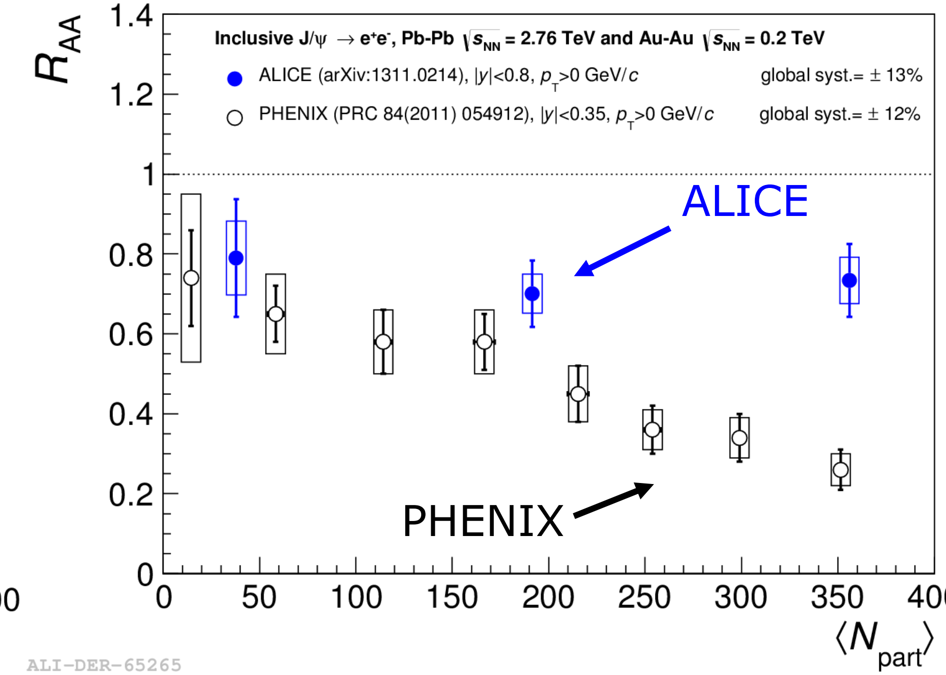


J/ψ R_{AA} vs centrality: ALICE vs PHENIX

- Centrality dependence of the J/ψ inclusive R_{AA} studied by ALICE in both central and forward rapidities down to zero p_T

ALICE Coll. PLB 734 (2014) 314





ALICE results:

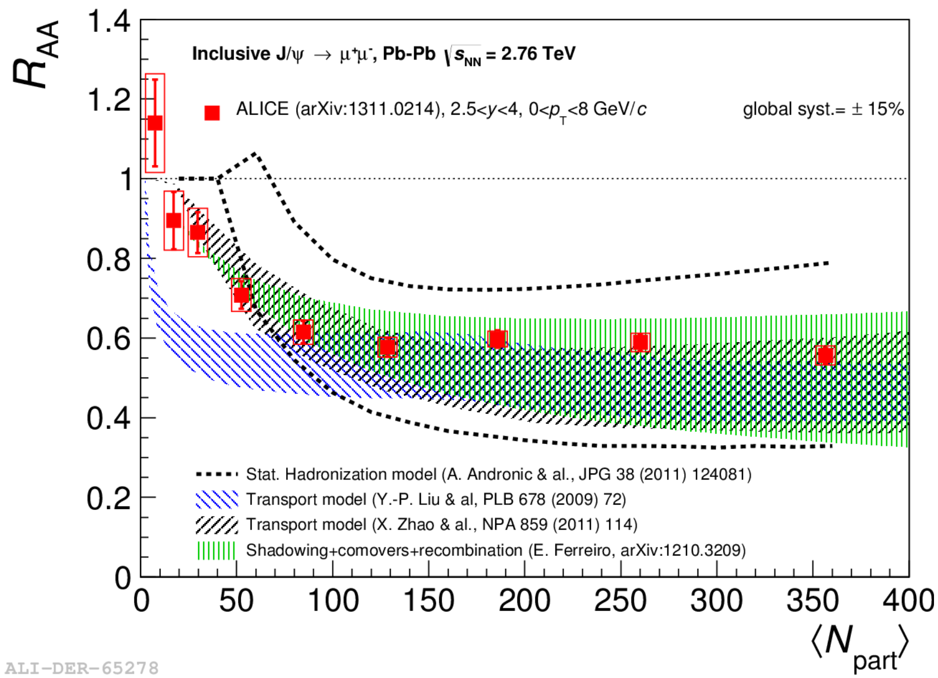
→ clear J/ψ suppression with almost no centrality dependence for N_{part}>100

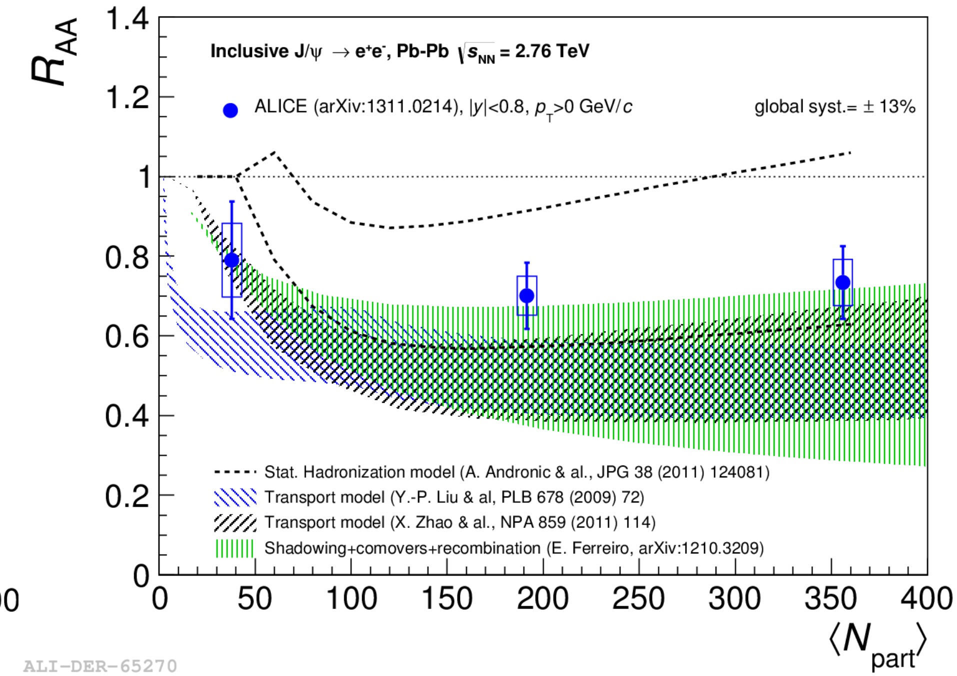
Comparison with PHENIX:

→ ALICE results show weaker centrality dependence and smaller suppression for central events

- behaviour expected in a (re)combination scenario

J/ψ R_{AA} vs centrality: ALICE vs PHENIX



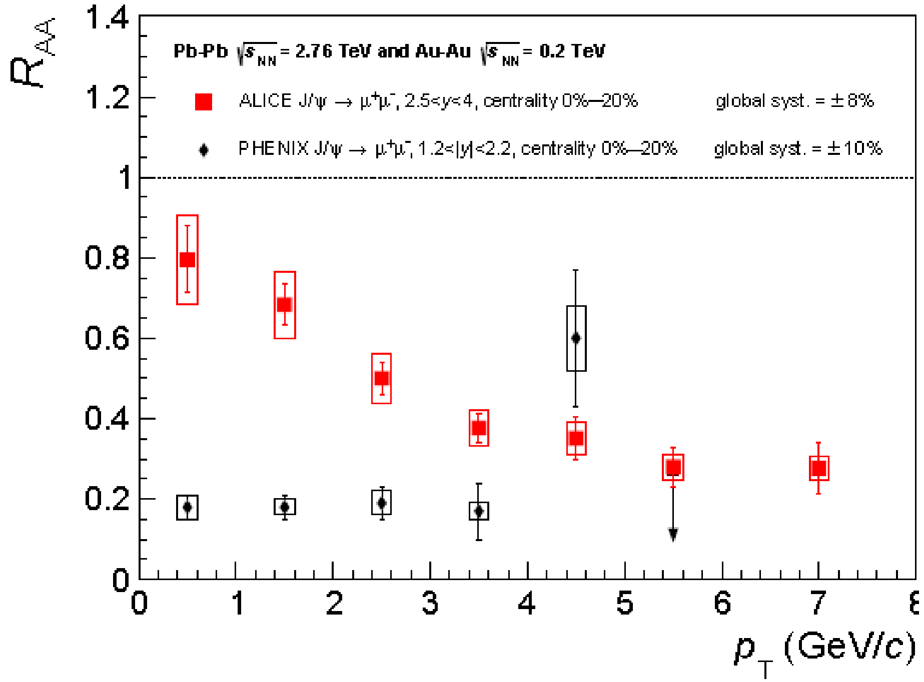


Comparison to theory calculations:

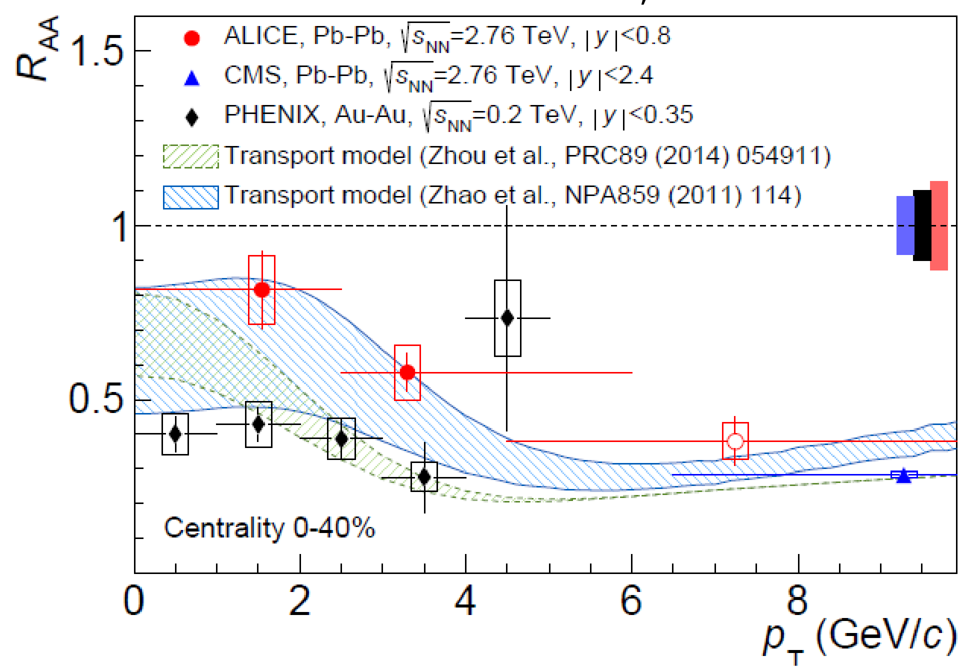
- Models including a large fraction (> 50% in central collisions) of J/ψ produced from (re)combination or models with all J/ψ produced at hadronization provide a reasonable description of ALICE results
- Still rather large theory uncertainties: models will benefit from a precise measurement of σ_{cc} and from cold nuclear matter evaluation

Low p_T J/ψ: ALICE & PHENIX

- J/ψ production via (re)combination should be more important at low transverse momentum (p_T region accessible by ALICE)



ALICE Coll., arXiv:1504.07151

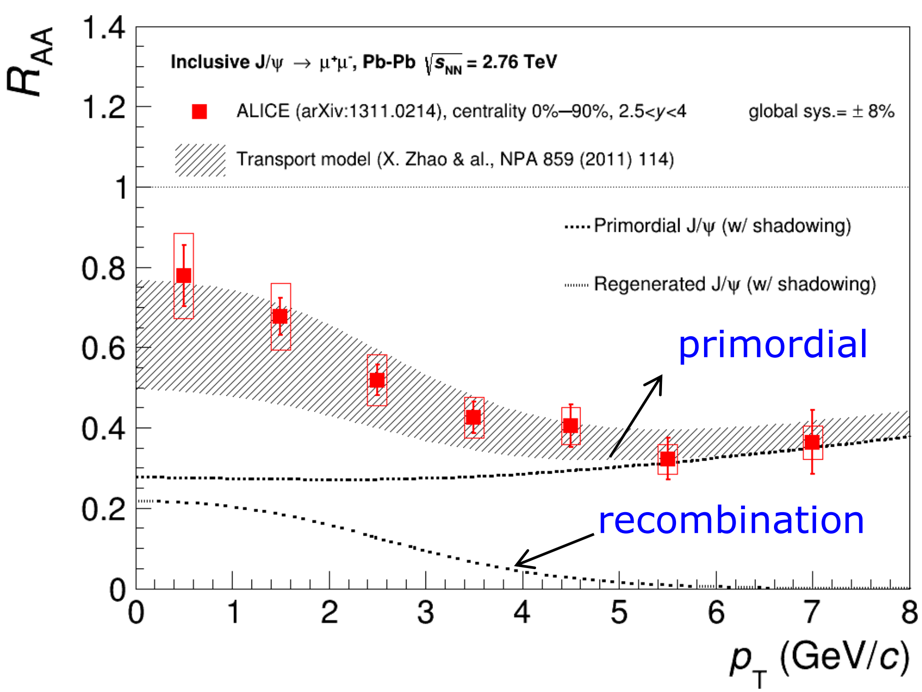


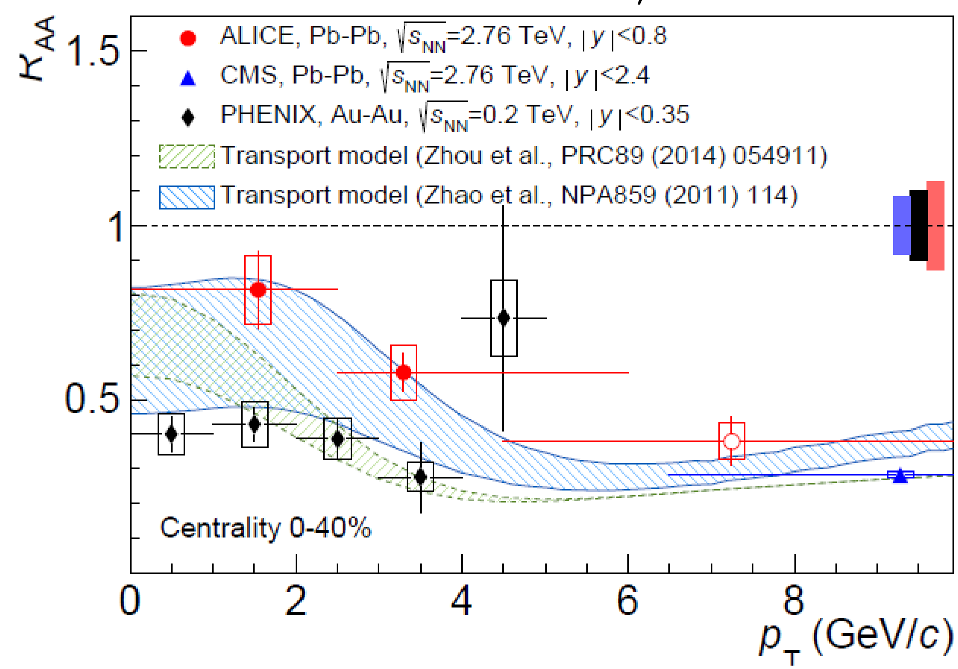
- Different suppression for low and high p_T J/ψ
  → Smaller R_{AA} for high p_T J/ψ
- Striking difference, at low p_T, between PHENIX and ALICE patterns

Low p_T J/ψ: ALICE & PHENIX

- J/ψ production via (re)combination should be more important at low transverse momentum (p_T region accessible by ALICE)

ALICE Coll., arXiv:1504.07151

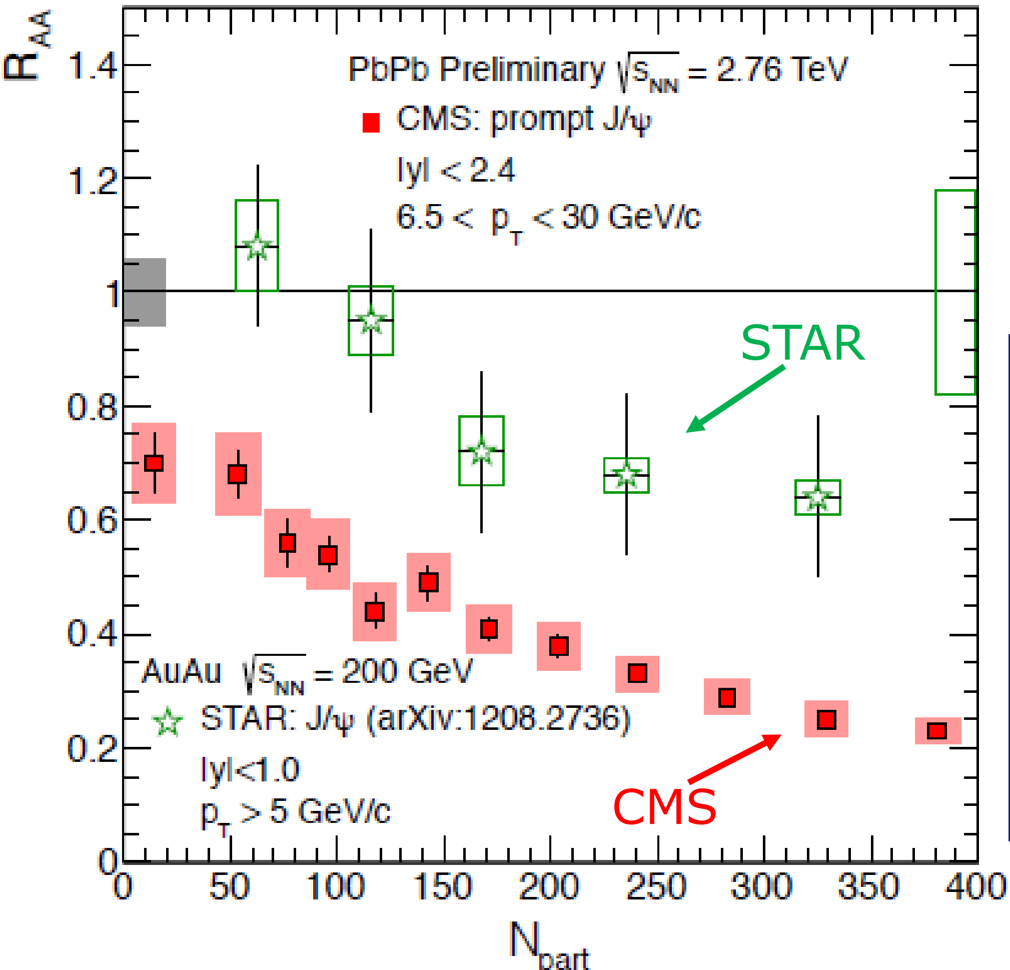




- Different suppression for low and high p_T J/ψ
  - → Smaller R_{AA} for high p_T J/ψ
- Models: ~50% of low-p_T J/ψ are produced via (re)combination, while at high p_T the contribution is negligible

High-p_T J/ψ: CMS & STAR

- At LHC high p_T J/ψ have been investigated by CMS



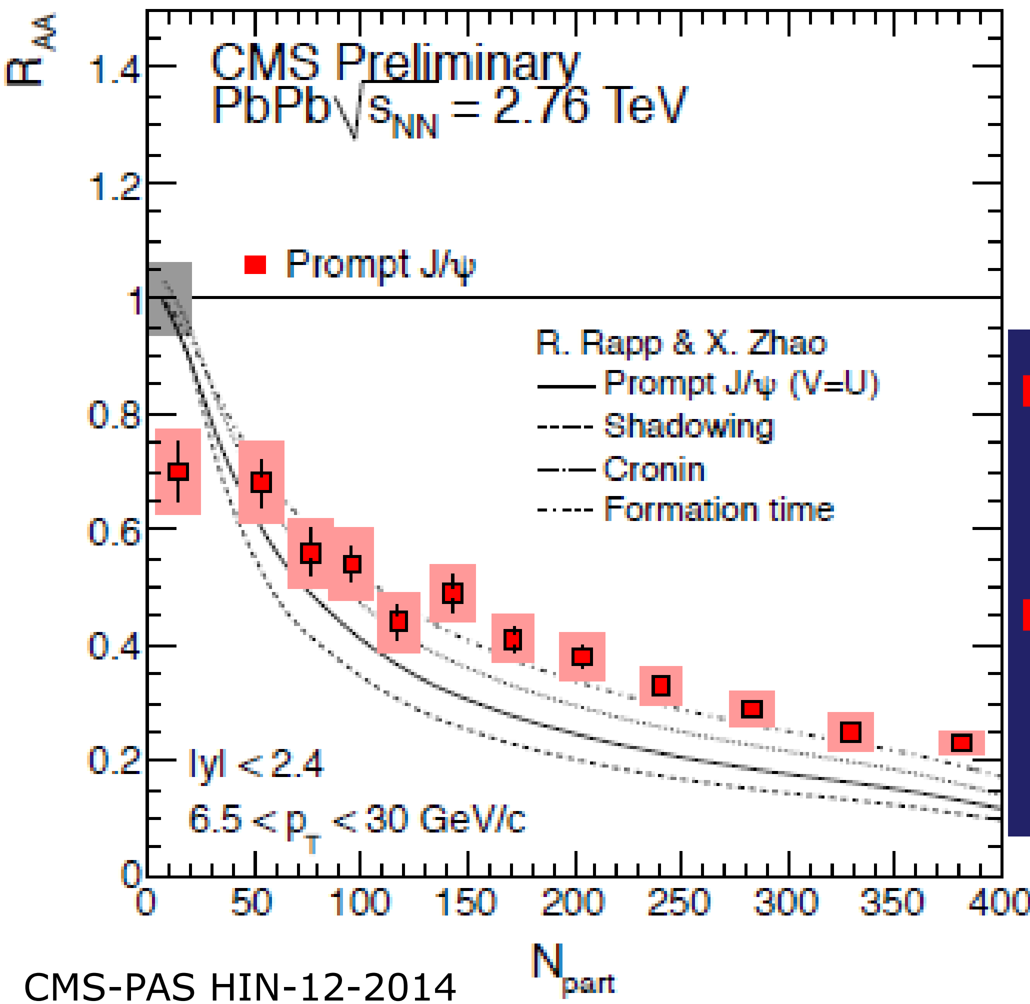
- Limits in the CMS low-p_T J/ψ acceptance since muons need to overcome the magnetic field and energy loss in the absorber:
  - mid-y: p_T>6.5 GeV/c
  - forward y: p_T>3 GeV/c

- Opposite behavior when compared to ALICE low-p_T results
- Suppression is stronger at LHC energy (by a factor ~3 compared to RHIC for central events)

CMS-PAS HIN-12-2014

High-p_T J/ψ: CMS & STAR

- At LHC high p_T J/ψ have been investigated by CMS



CMS-PAS HIN-12-2014

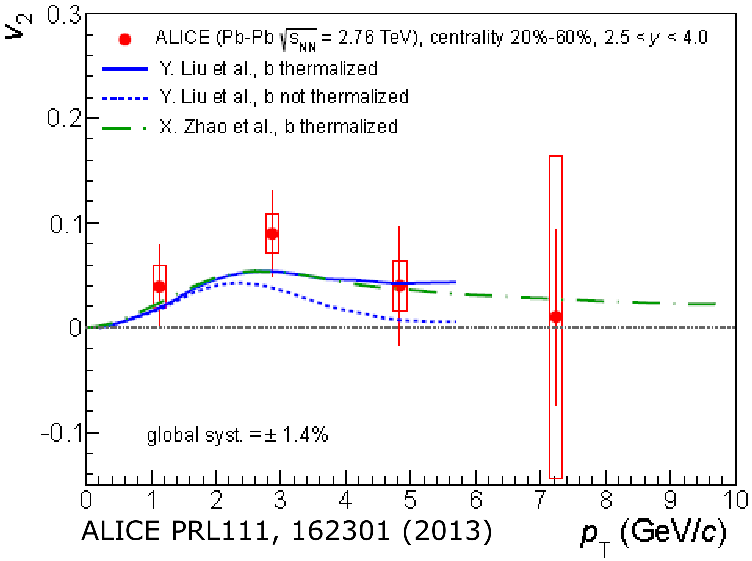
- Limits in the CMS low-p_T J/ψ acceptance since muons need to overcome the magnetic field and energy loss in the absorber:
  - mid-*y*: p_T>6.5 GeV/c
  - forward *y*: p_T>3 GeV/c

- Opposite behavior when compared to ALICE low-p_T results
- Suppression is stronger at LHC energy (by a factor ~3 compared to RHIC for central events)

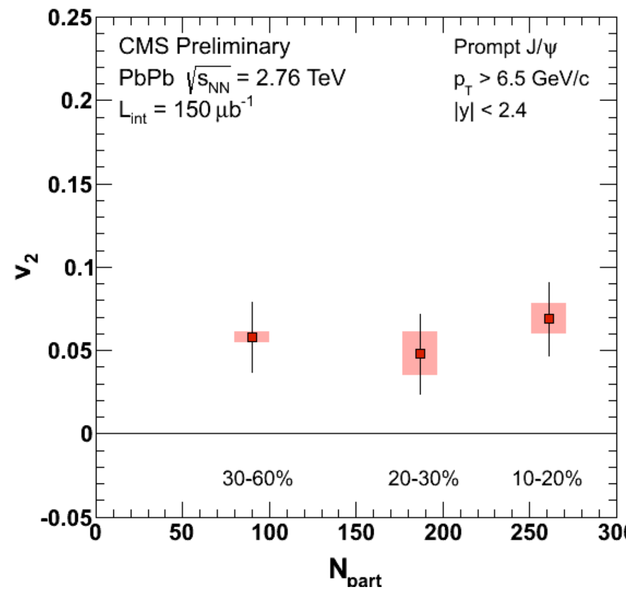
- negligible (re)generation effects expected at high p_T

J/ψ flow

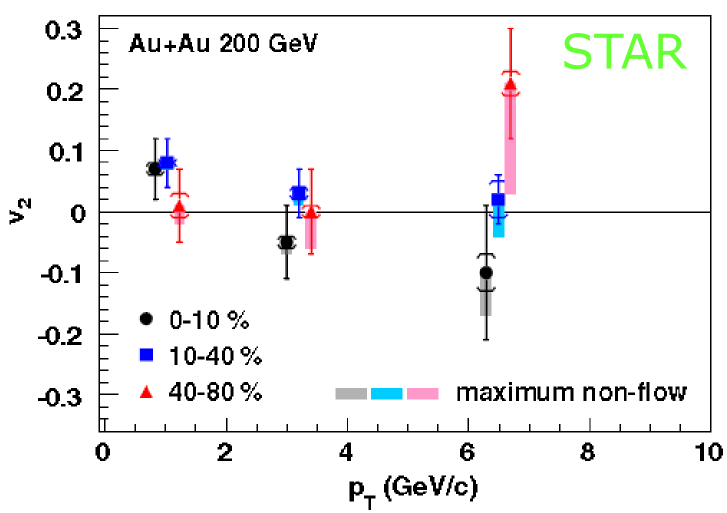
- The contribution of J/ψ from (re)combination should lead to a significant elliptic flow signal at LHC energy



ALICE PRL111, 162301 (2013)



D.Moon, HP2013

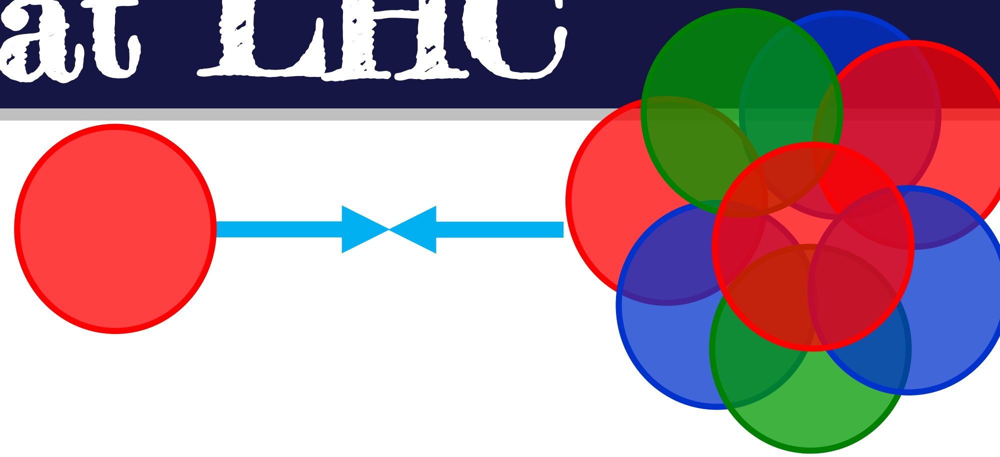


STAR, PRL 052301(2013)

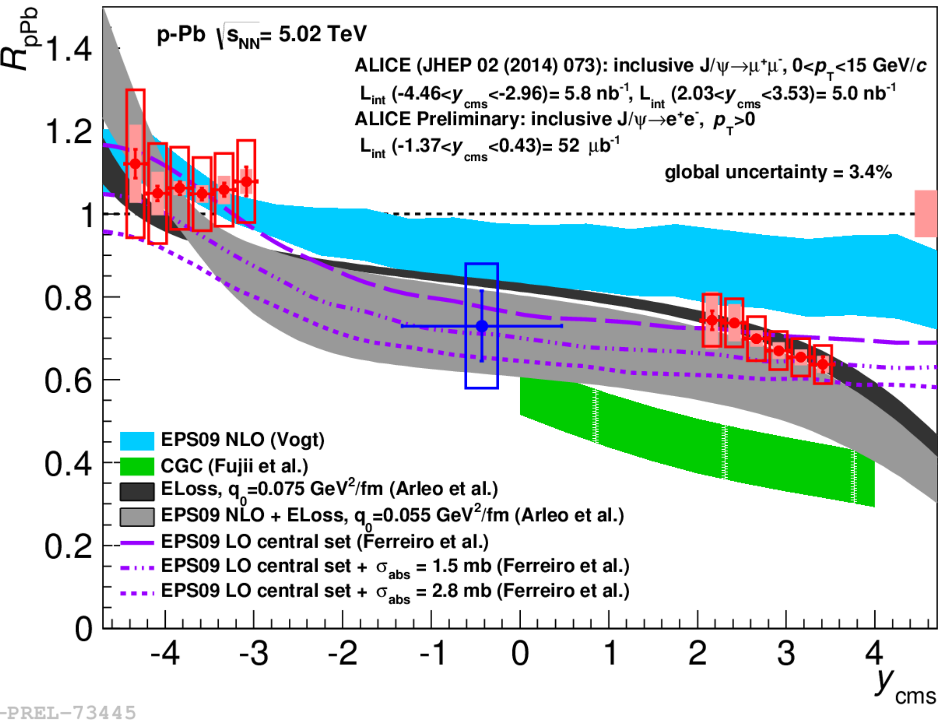
- Hint for J/ψ flow at LHC, contrary to v_2~0 observed at RHIC!

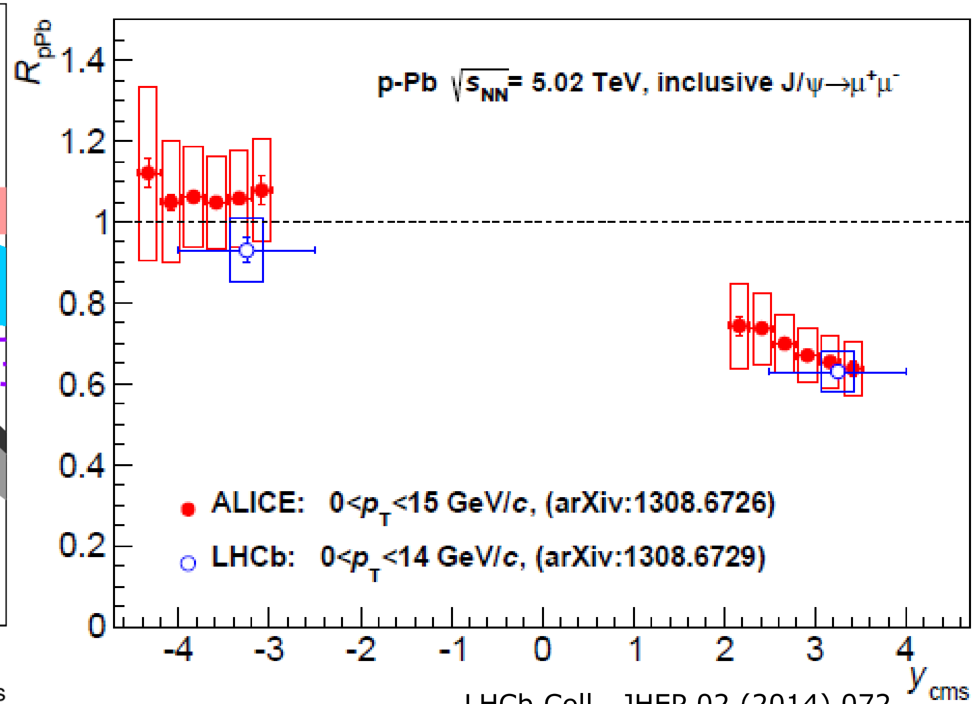
- ALICE: qualitative agreement with transport models including regeneration
- CMS: path-length dependence of energy loss?

J/ψ in pA collisions at LHC



J/ψ in p-Pb collisions

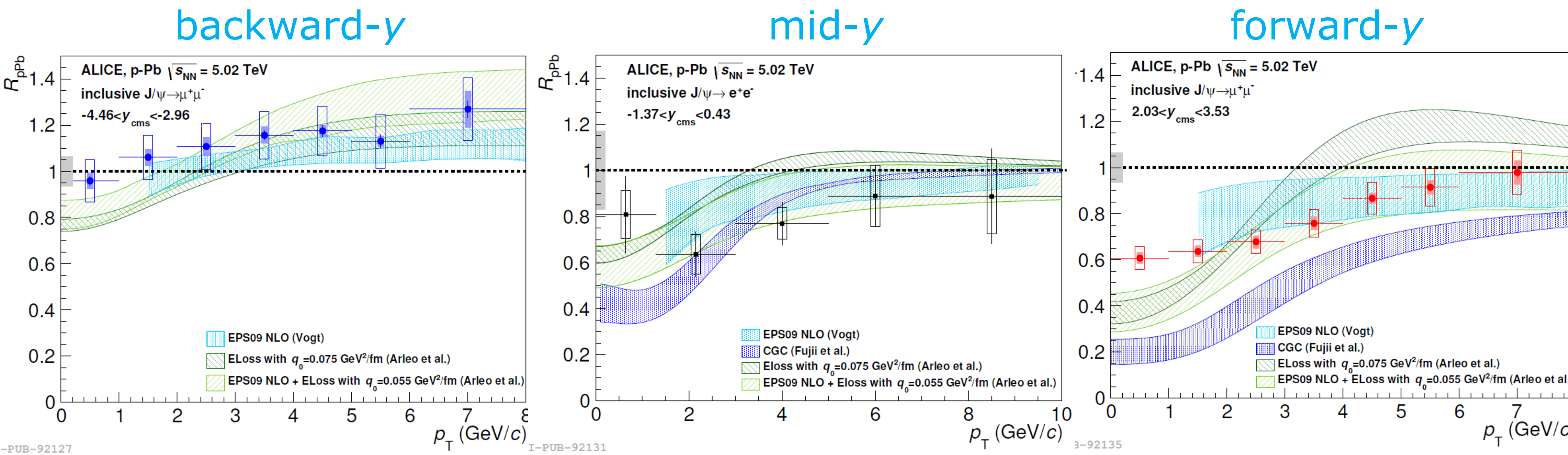




LHCb Coll., JHEP 02 (2014) 072
ALICE Coll., JHEP 02 (2014) 073

- J/ψ production in modified also in pA because of CNM effects:
  → R_{pA} decreases towards forward *y*
- Theoretical predictions: reasonable agreement with
  - shadowing calculations and models including coherent parton energy loss
  - CGC description seems not to be favoured

p-Pb: role of CNM effects on J/ψ



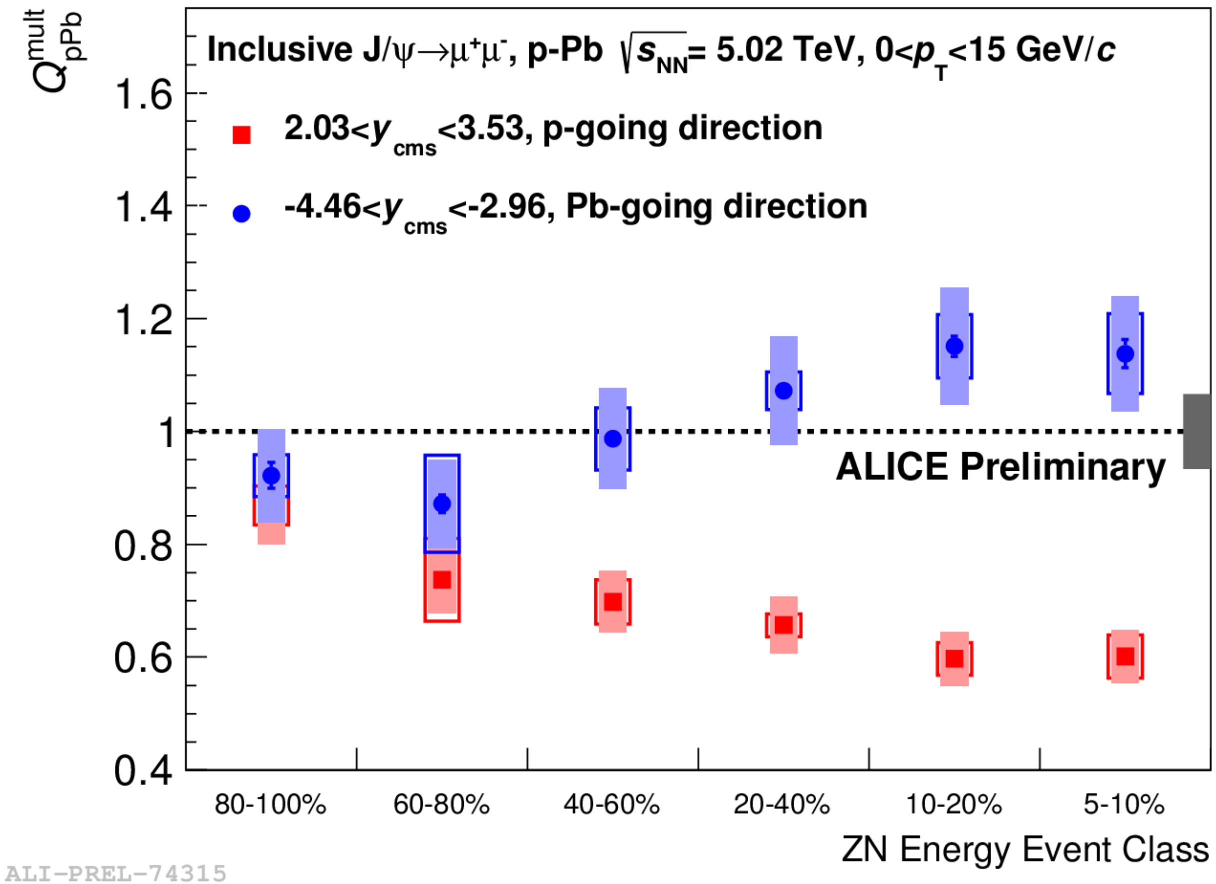
- R_{pA} p_T dependence in 3 y ranges:
  - Backward-*y*: negligible p_T dependence, R_{pA} compatible with unity
  - Mid-*y*: small p_T dependence, R_{pA} ~1 for p_T>3GeV/c
  - Forward-*y*: R_{pA} increases with p_T

- Comparison with theoretical models:

fair agreements with models based on shadowing + energy loss (except at forward-*y* and low p_T)

ALICE Coll. arXiv:1503.07179

J/ψ versus event activity



Q_{pA} is a nuclear modification factor with a possible influence due to potential bias in the event activity estimator, not related to nuclear effects

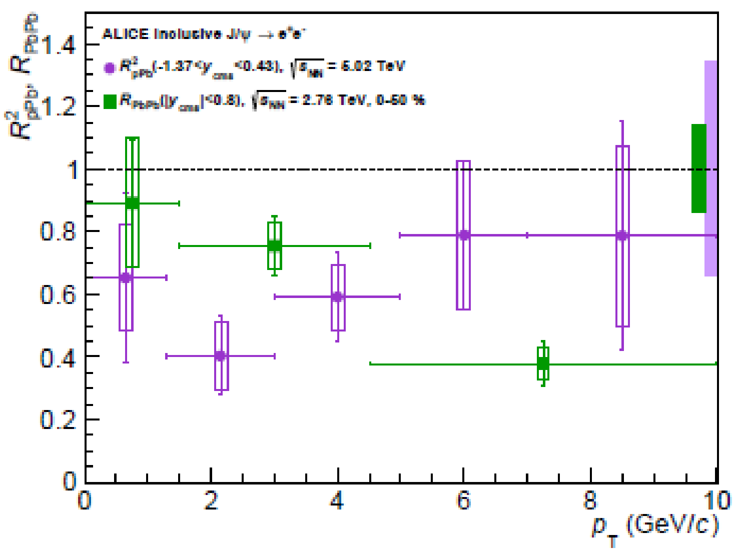
$$Q_{pA}^{J/\psi} = \frac{Y_{pA}^{J/\psi}}{\langle T_{pA} \rangle \sigma_{pp}^{J/\psi}}$$

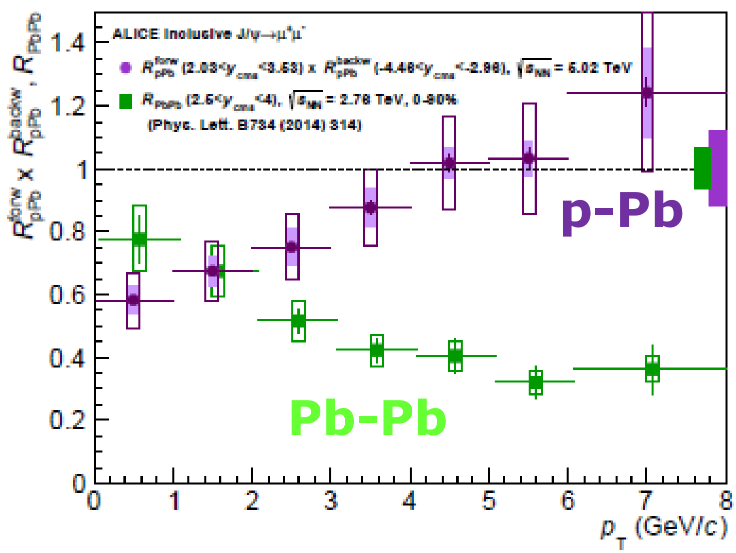
- At forward-y, strong J/ψ Q_{pA} decrease from low to high event activity
- At backward-y, Q_{pA} consistent with unity, with a feeble event activity dependence

CNM effects from pPb to PbPb

➡ Once CNM effects are measured in pA, what can we learn on J/ψ production in PbPb?

Hypothesis:
- 2→1 kinematics for J/ψ production
- CNM effects (dominated by shadowing) factorize in p-A
- CNM obtained as R_{pA} x R_{Ap} (R_{pA}^2), similar x-coverage as PbPb





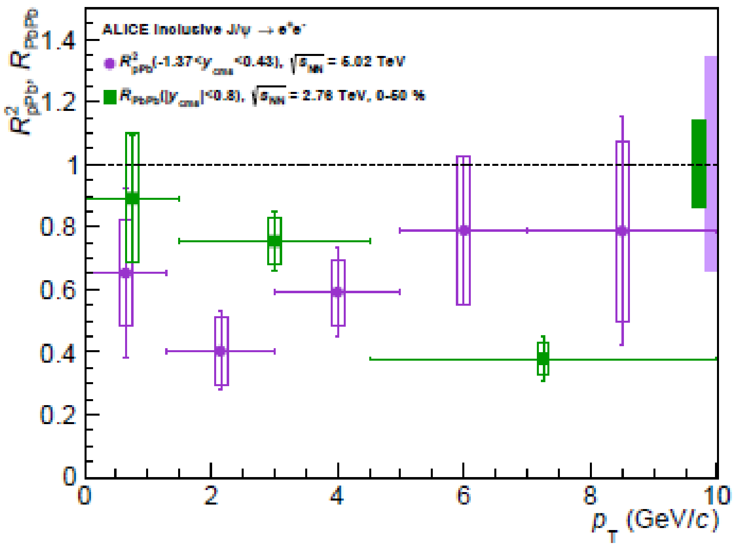
➡ Sizeable p_T dependent suppression still visible
→ CNM effects not enough to explain AA data at high p_T

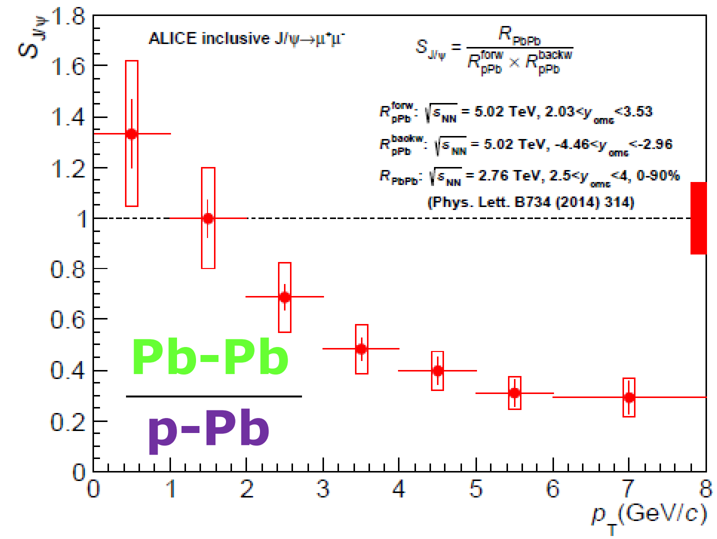
➡ we get rid of CNM effects, by doing the ratio AA / pA

CNM effects from pPb to PbPb

Once CNM effects are measured in pA, what can we learn on J/ψ production in PbPb?

Hypothesis:
- 2→1 kinematics for J/ψ production
- CNM effects (dominated by shadowing) factorize in p-A
- CNM obtained as R_{pA} x R_{Ap} (R_{pA}^2), similar x-coverage as PbPb



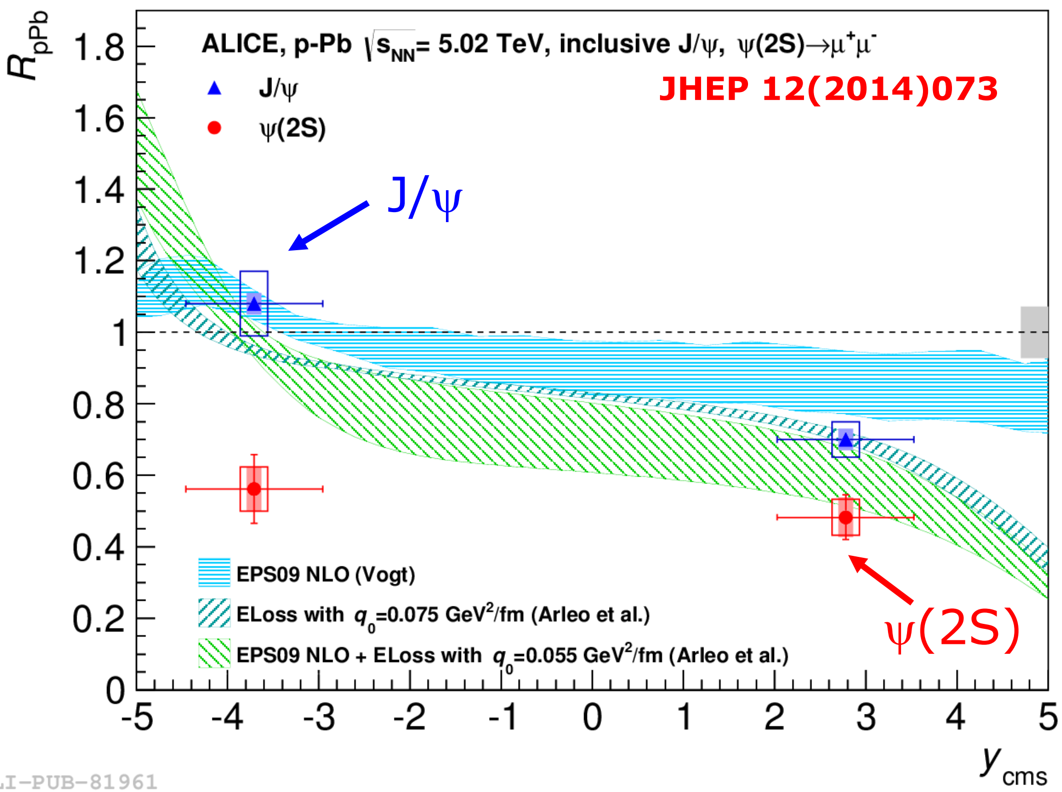


- Sizeable p_T dependent suppression still visible
  → CNM effects not enough to explain AA data at high p_T

- we get rid of CNM effects, by doing the ratio AA / pA

ψ(2S) vs J/ψ in p-A collisions

Being a more weakly bound state than the J/ψ, the ψ(2S) is an interesting probe to investigate charmonium behaviour in the medium



A strong decrease of the ψ(2S) production in p-Pb, relative to J/ψ, is observed with respect to the pp measurement ($2.5<y_{cms}<4$, $\sqrt{s}$=7TeV)

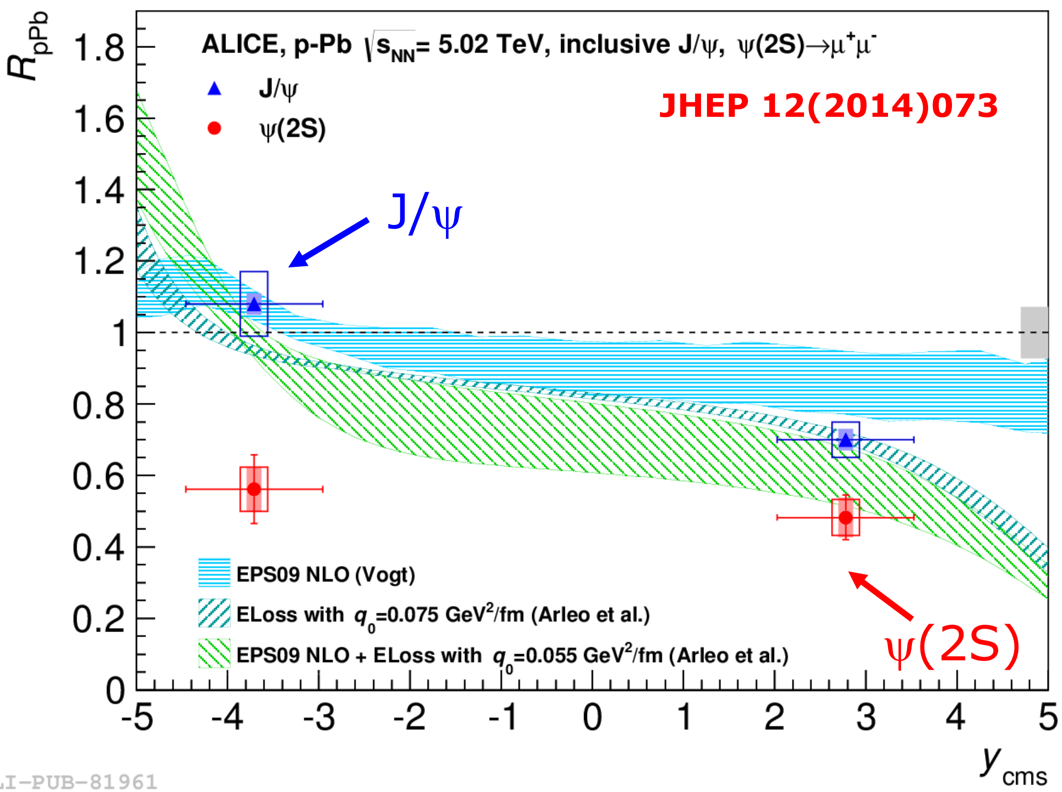
Similar effect seen by PHENIX in d-Au at $\sqrt{s_{NN}}$=200 GeV

same initial state CNM effects (shadowing & coherent energy loss) for J/ψ and ψ(2S)

theoretical predictions in disagreement with ψ(2S) result

ψ(2S) vs J/ψ in p-A collisions

Can the stronger ψ(2S) suppression be due to break-up of the fully formed resonance in CNM?



possible if:

formation (τ_f) < crossing time (τ_c)

forward-*y*:	backward-*y*:
$\tau_c \sim 10^{-4}$ fm/c	$\tau_c \sim 10^{-1}$ fm/c

while τ_f ~0.05-0.15 fm/c

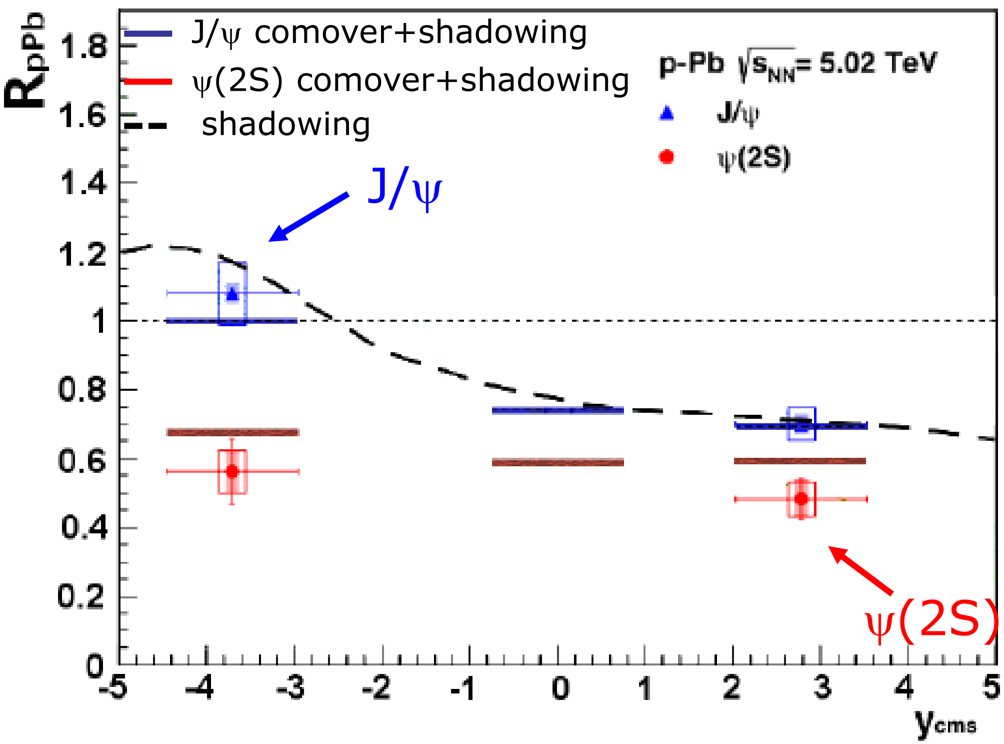
forward-*y*:
break-up effects excluded

backward-*y*:
$\tau_f \sim \tau_c$, hence break-up in CNM hardly explains the strong J/ψ and ψ(2S) difference

Final state effects related to the (hadronic) medium created in the p-Pb collisions?

ψ(2S) vs J/ψ in p-A collisions

Final state effects related to the (hadronic) medium created in the p-Pb collisions?



Charmonium interaction with comoving particles:

- Comovers dissociation affects more strongly the loosely bound ψ(2S) than the J/ψ
- Comovers density larger at backward rapidity

E. Ferreiro arXiv:1411.0549

J/ψ in heavy ion collisions: where are we?

Large wealth of results at LHC complementing SPS and RHIC measurements!

Two main mechanisms at play in AA collisions

1. Suppression in a deconfined medium
2. (charmonium) re-combination at high $\sqrt{s}$ and low p_T

Qualitatively explanation of the main features of the results

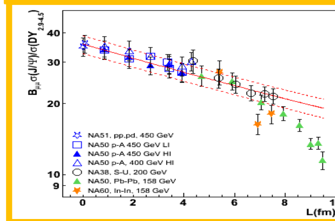
In p-A collisions:

- interplay of shadowing and coherent energy loss can satisfactorily describe the J/ψ results
- loosely bound ψ(2S) is likely influenced by the hadronic final state

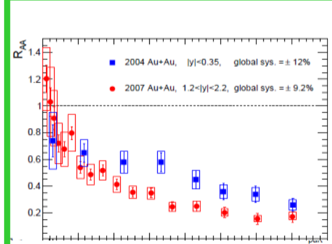
Results from LHC Run2 eagerly awaited!

- Energy increase ($\sqrt{s_{NN}}$=5TeV) will allow for confirmation of the (re) combination role at low p_T
- Statistics increase will allow to sharpen Run-I results

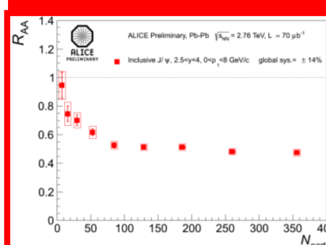
SPS



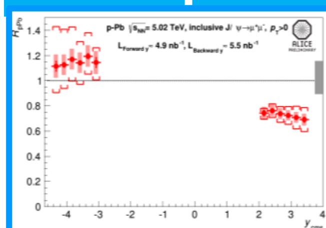
RHIC dA, AA



LHC AA



LHC pA



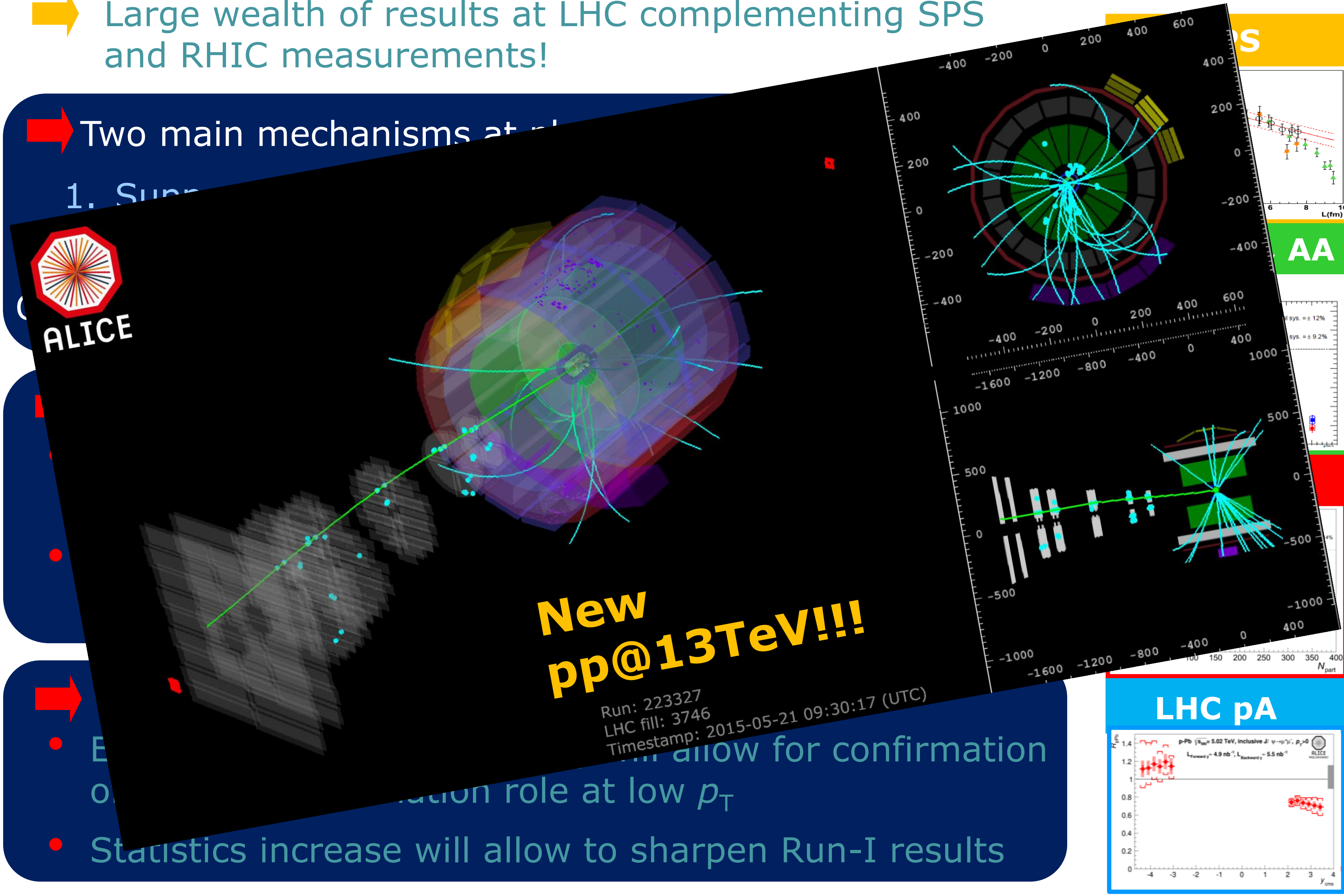
J/ψ in heavy ion collisions: where are we?

- Large wealth of results at LHC complementing SPS and RHIC measurements!

Two main mechanisms at pl

1. Supp

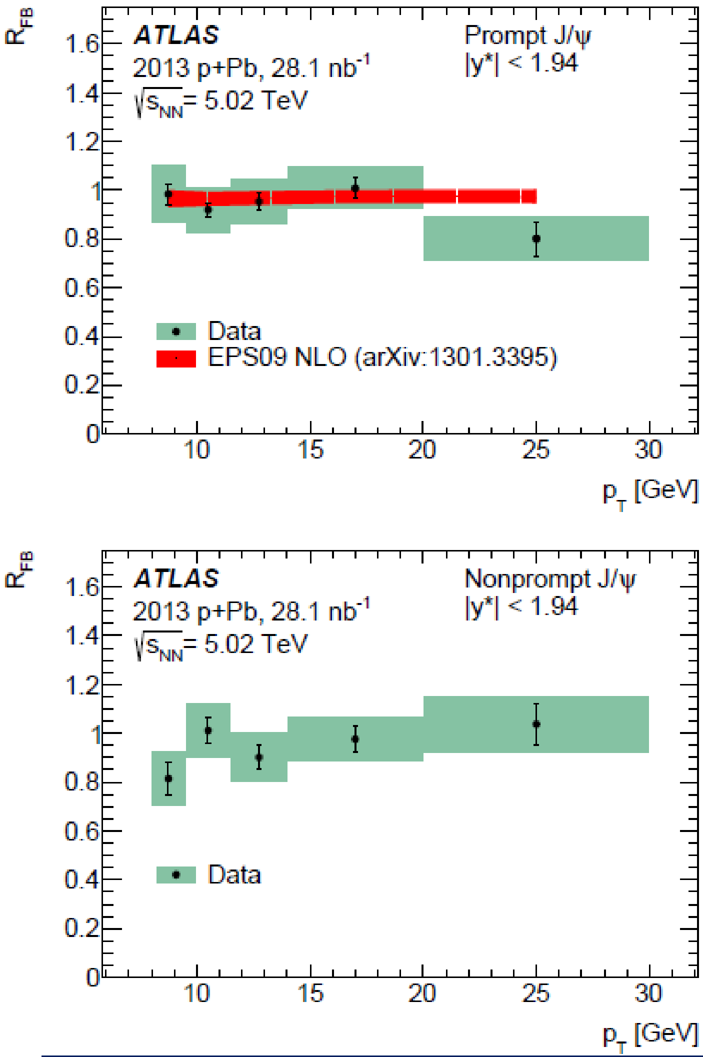
- E… allow for confirmation o… ation role at low p_T
- Statistics increase will allow to sharpen Run-I results



Backup slides

p-Pb: role of CNM effects on J/ψ

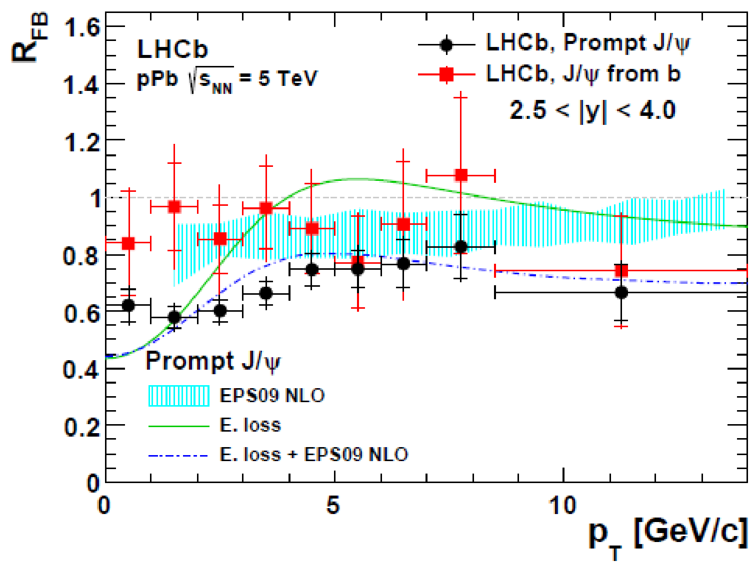
ATLAS: |y|<1.94, 8<p_T<30GeV/c



ATLAS Coll. arXiv:1505.08151

- ATLAS and LHCb measure the forward to backward cross section ratio, R_{FB}, for
  - Prompt J/ψ
  - Non prompt J/ψ from B decay
- Similar shadowing/saturation expected for quarkonia and b quarks

LHCb: 2.5<|y|<4, 0<p_T<14GeV/c



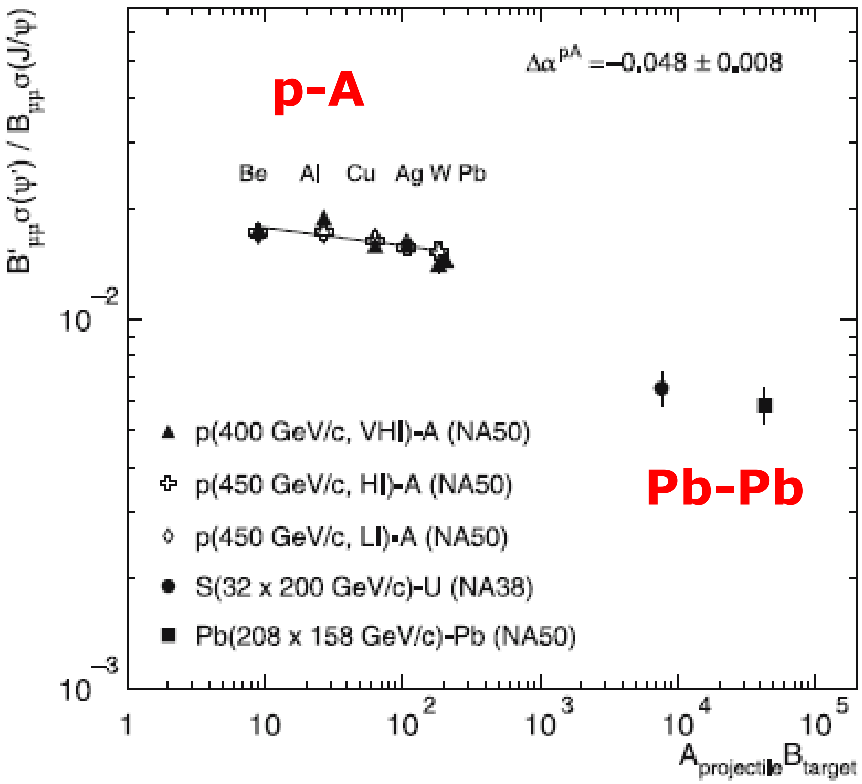
LHCb Coll. arXiv:1308.6729

- ATLAS/LHCb results indicate a strong kinematic dependence of CNM for both charmonium and b quark production

LOW ENERGY RESULTS: ψ(2S) FROM SPS & RHIC

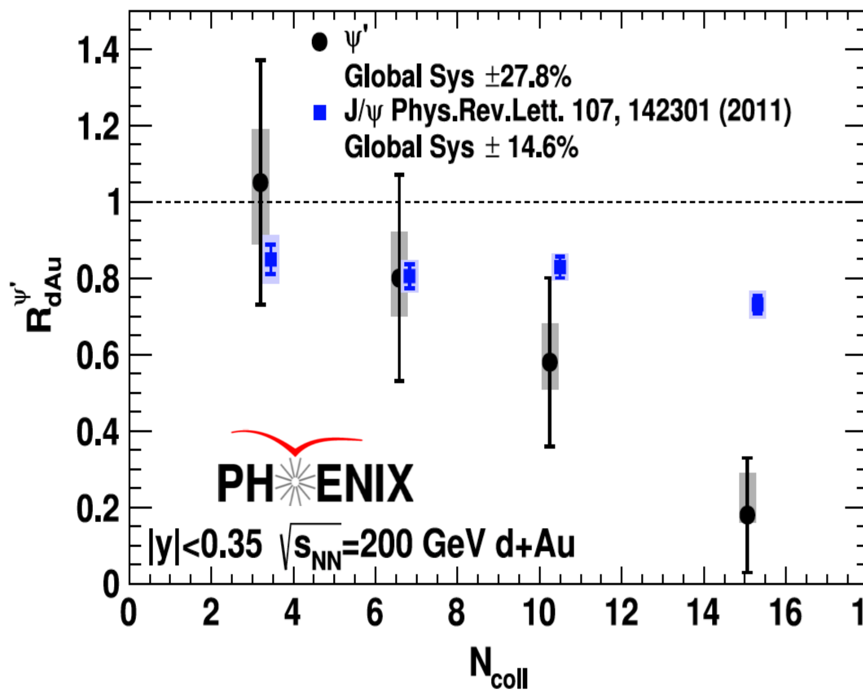
SPS (NA50) pA, AA @ $\sqrt{s_{NN}}$ = 17 GeV

Eur. Phys. J. C 49, 559 (2007)



RHIC (PHENIX) d-Au @ $\sqrt{s_{NN}}$ = 200 GeV

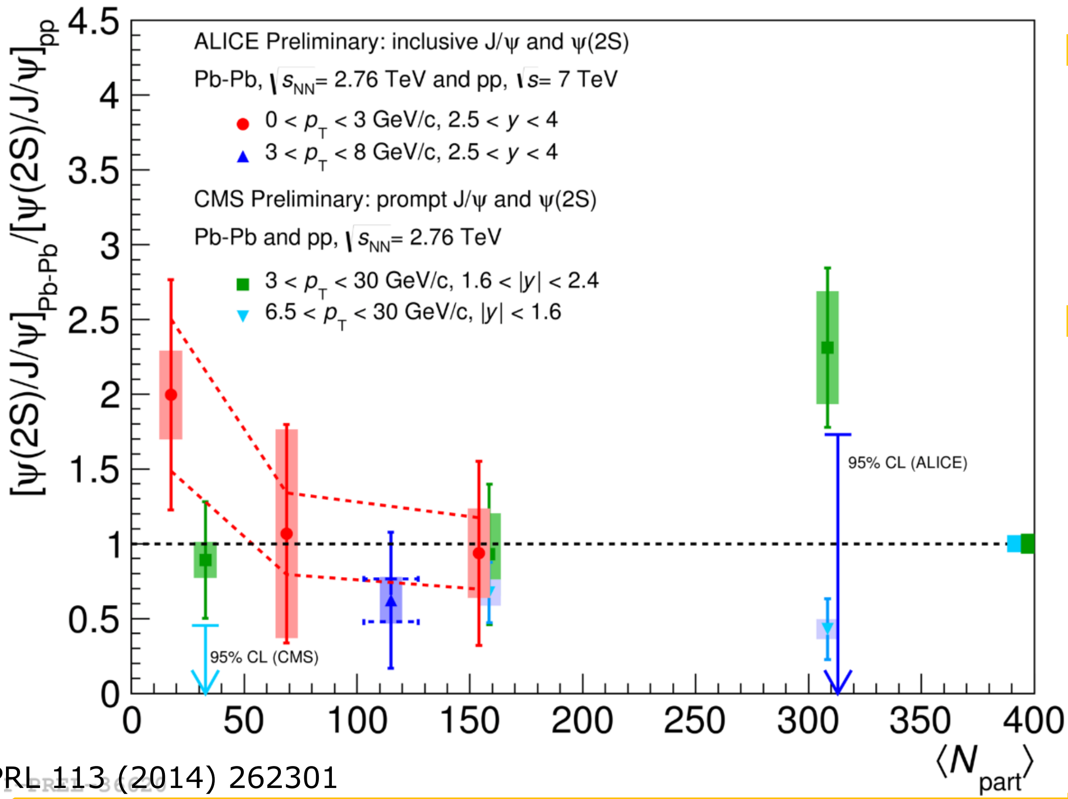
PRL 111, 202301 (2013)



- ψ(2S) is more suppressed than J/ψ already in pA collisions and the suppression increases in Pb-Pb
- unexpected ψ(2S) suppression, stronger than the J/ψ one in d-Au

ψ(2S)/J/ψ IN PB-PB @LHC

- Being a more weakly bound state than the J/ψ, the ψ(2S) is another interesting probe to investigate charmonium behaviour in the medium
- The ψ(2S) yield is compared to the J/ψ one in Pb-Pb and in pp



PRL 113 (2014) 262301

- ALICE: reference pp@√s=7TeV

  low p_T ($0<p_T<3$GeV/c) → ψ(2S) more suppressed than J/ψ

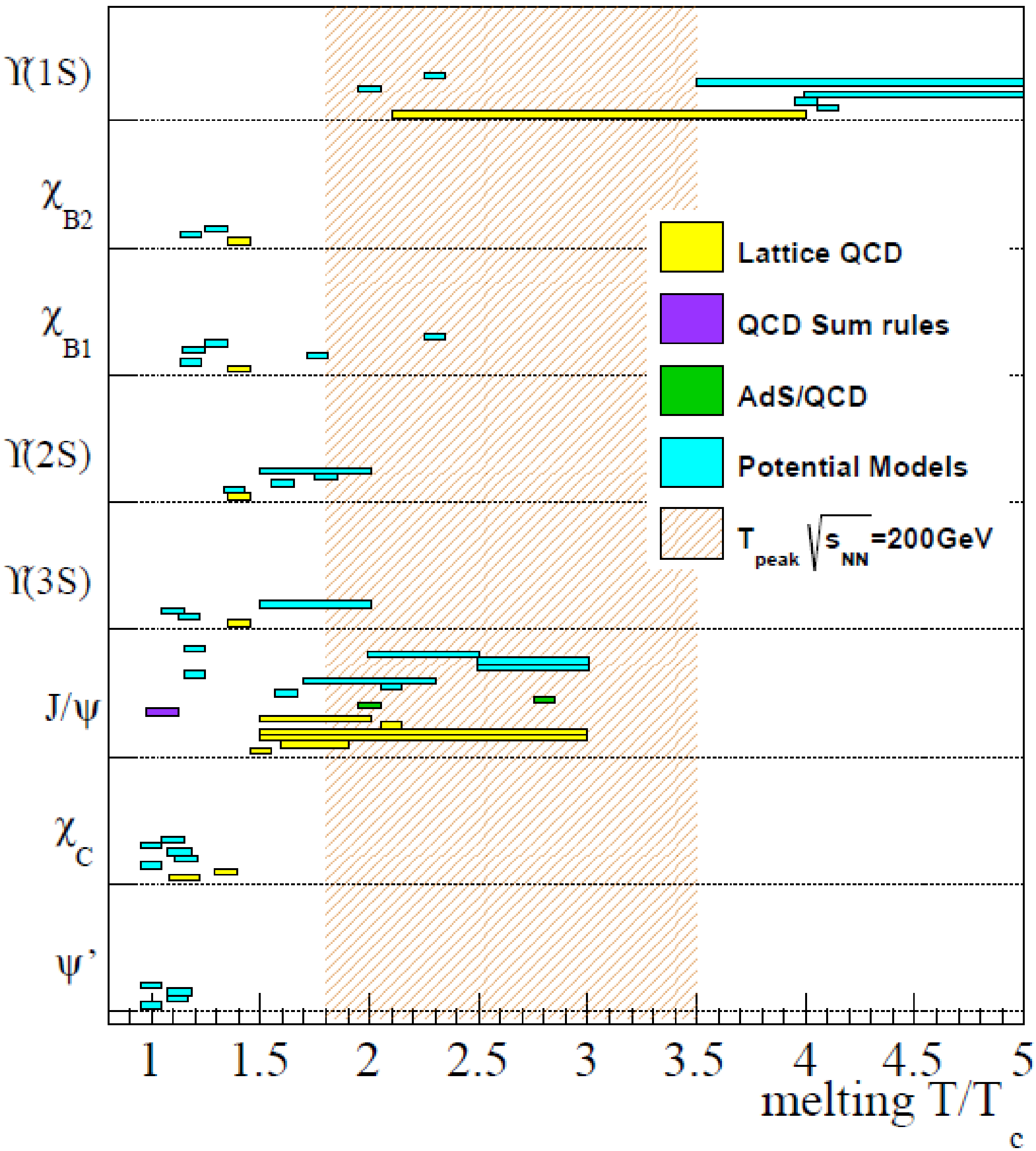
- CMS: reference pp@√s=2.76TeV

  $p_T>3$ GeV/c & $1.6<|y|<2.4$ → ψ(2S) less suppressed than J/ψ

  $p_T>6.5$ GeV/c & $|y|<1.6$ → ψ(2S) more suppressed than J/ψ

- Improved agreement between ALICE and CMS data (new pp CMS reference)
- Large statistics and systematic uncertainties prevent a firm conclusion on the ψ(2S) trend vs centrality

DISSOCIATION TEMPERATURES



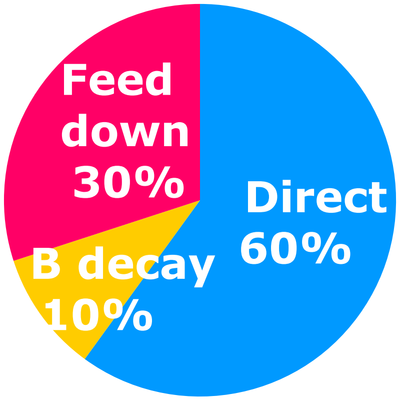
arXiv:1404.2246

Quarkonium production and decay

J/ψ production

Quarkonium production can proceed:

- directly in the interaction of the initial partons
- via the decay of heavier hadrons (feed-down)



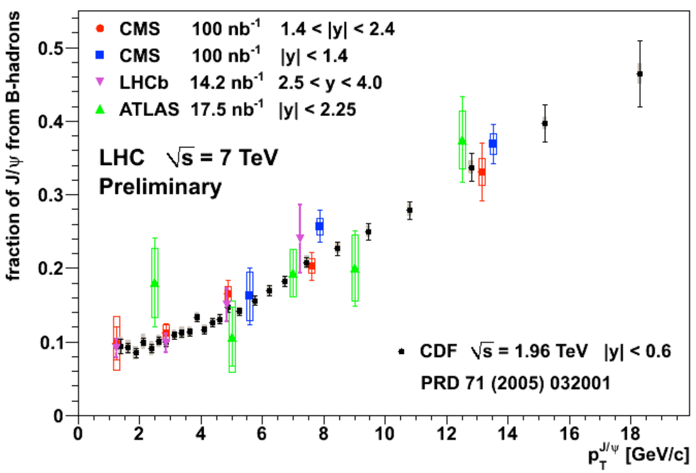
For J/ψ (LHC energies) the contributing mechanisms are:

Prompt

- Direct production
- Feed-down from higher charmonium states:
  ~ 8% from ψ(2S), ~25% from χ_c

Displaced

- B decay
  contribution is p_T dependent
  ~10% at p_T~1.5GeV/c



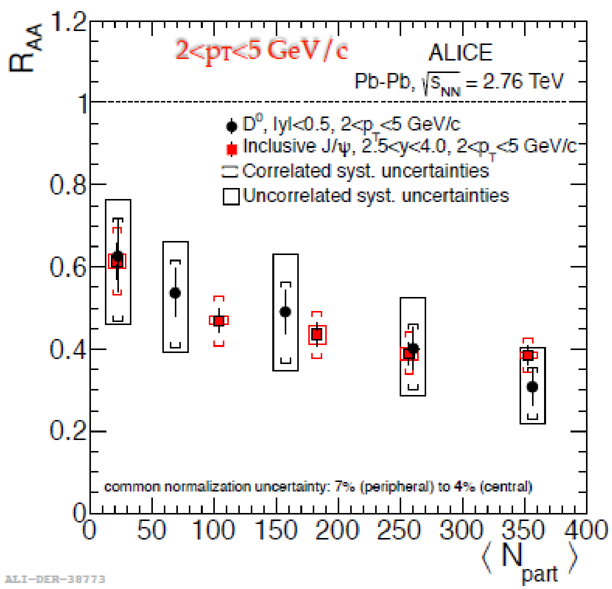
J/ψ decay

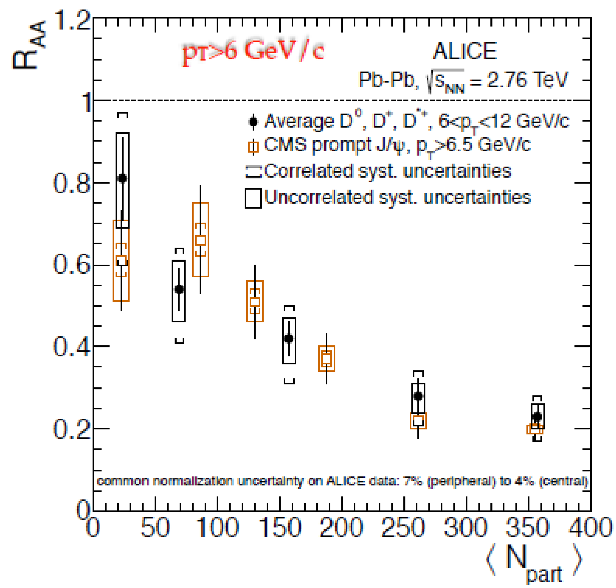
J/ψ can be studied through its decays:

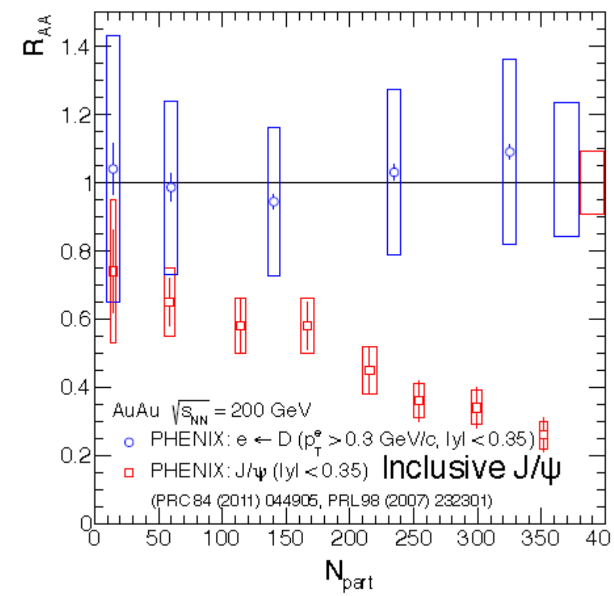
$J/\psi \rightarrow \mu^+\mu^-$ **$J/\psi \rightarrow e^+e^-$** (~6% branching ratio)

J/ψ vs D in AA collisions

- Open charm should be a very good reference to study J/ψ suppression (a` la Satz)







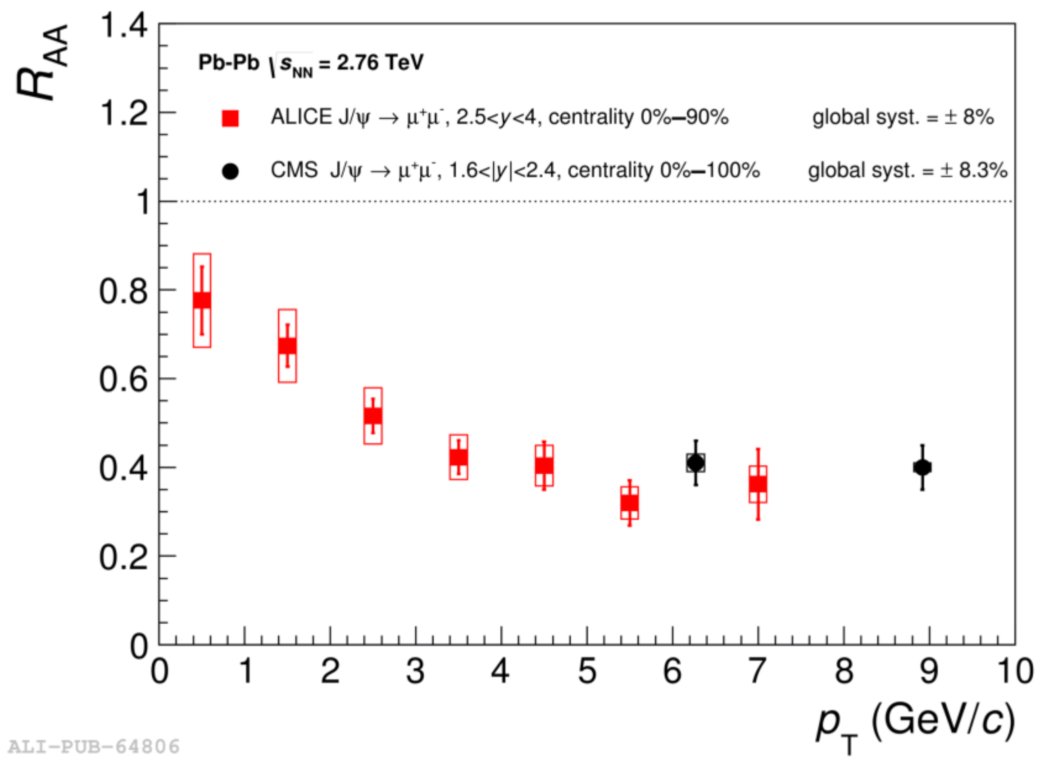
- Interesting comparison between ALICE and CMS J/ψ compared to D

Caveat:
complicate to compare J/ψ and D R_{AA} at LHC because of restricted kinematic regions.
Low p_T D not accessible for the moment

- Different trend observed at low p_T at RHIC.
At high p_T trend is similar to the LHC one

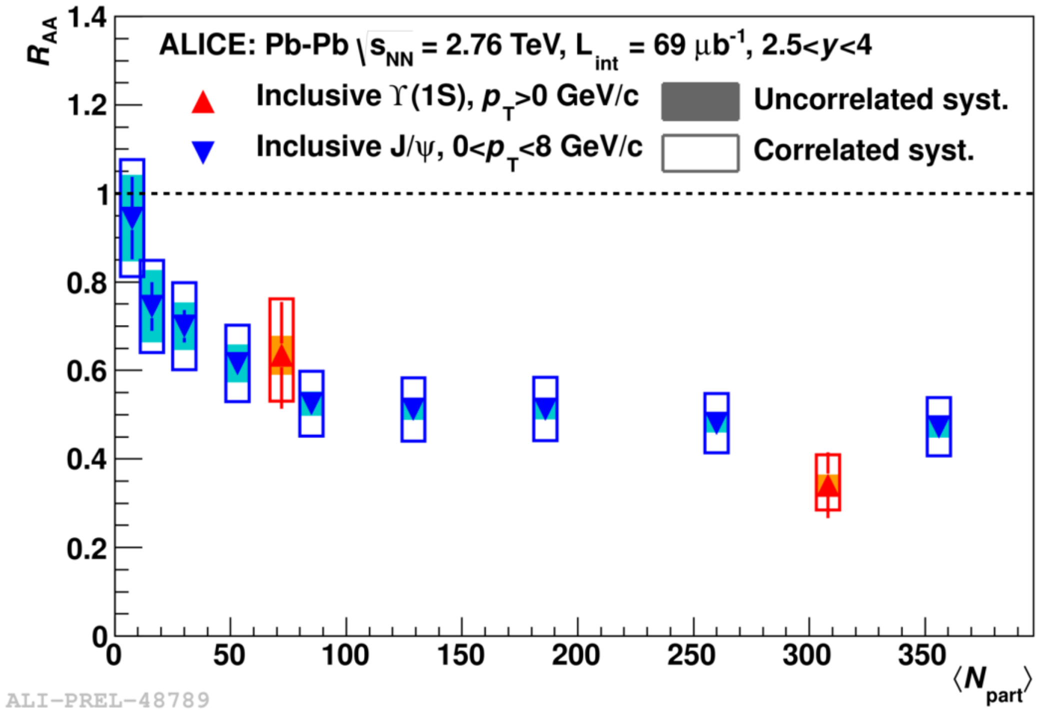
CMS: high p_T J/ψ

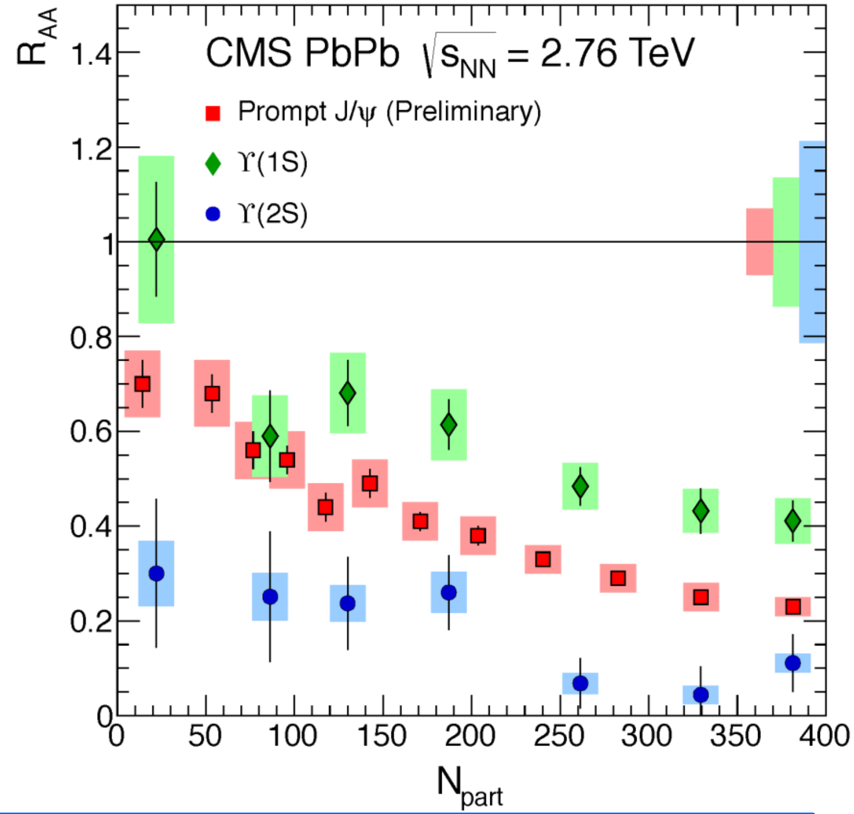
- The high p_T region can be investigated by CMS!



- Good agreement with ALICE (at high p_T) in spite of the different rapidity range

Comparison Υ and J/ψ

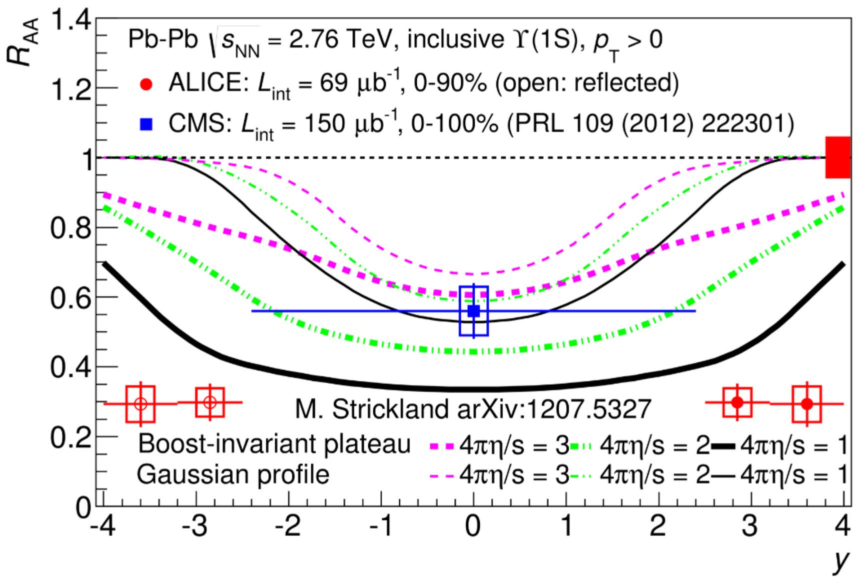


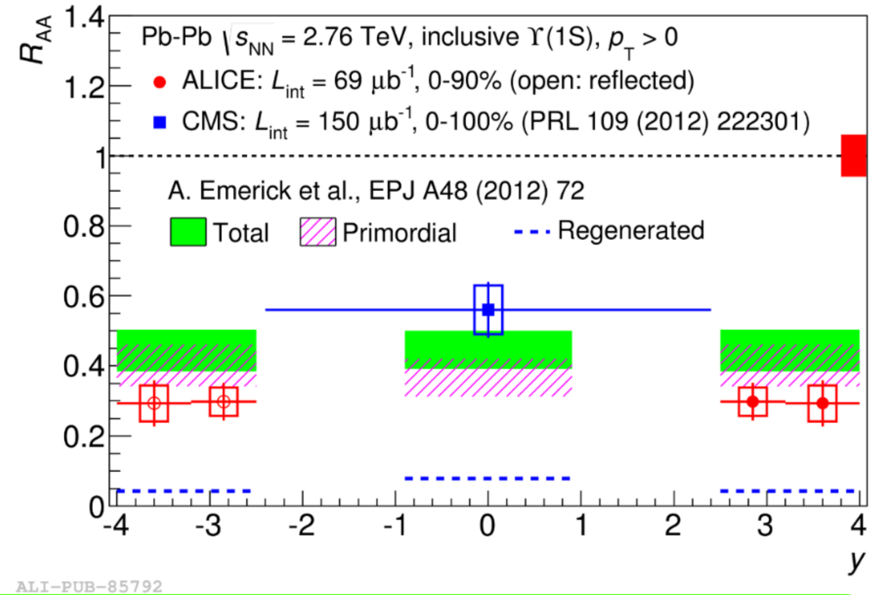


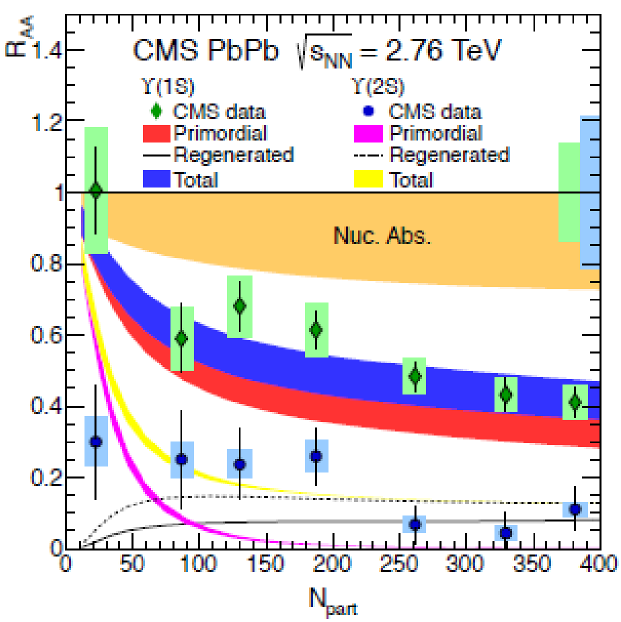
- Similar R_{AA} for low p_T inclusive J/ψ and Υ(1S)
- Sequential suppression observed for prompt J/ψ and Υ(nS) at high p_T

→ interplay of the competing mechanisms for J/ψ and Υ can be different and dependent on kinematics!

COMPARISON WITH THEORY



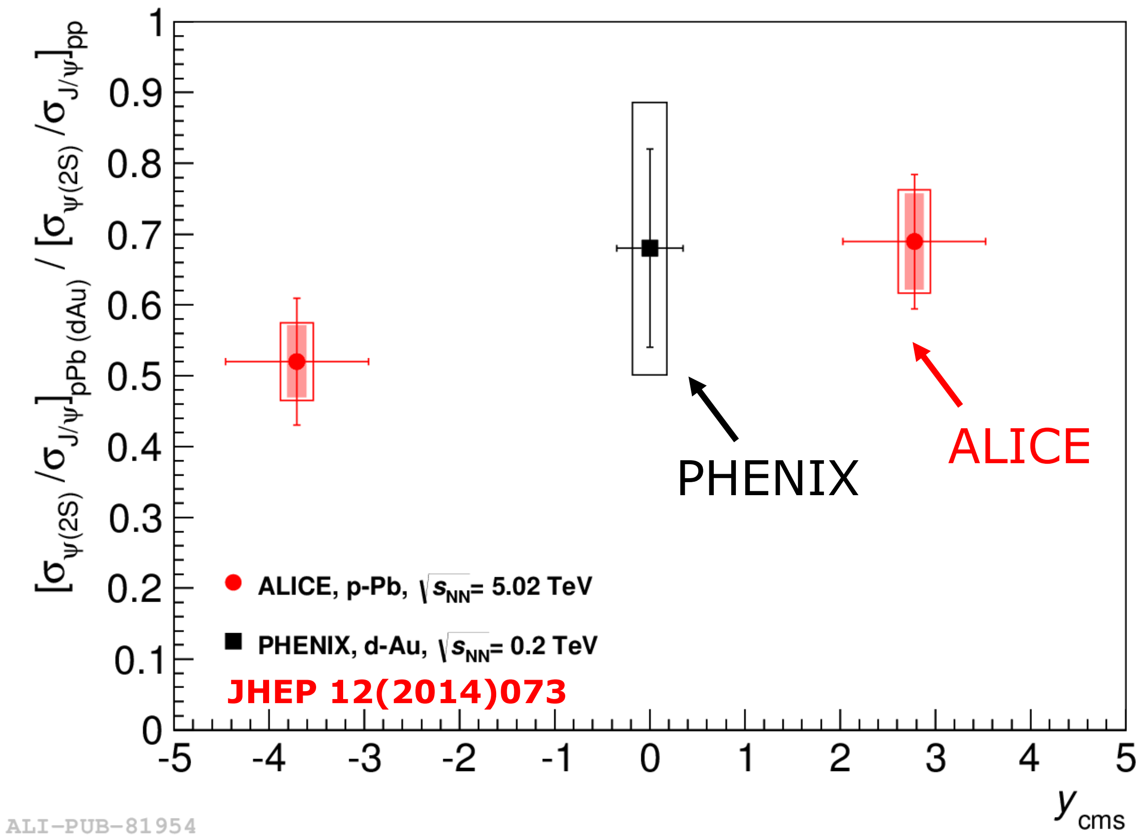




- Stronger suppression at forward rapidity (ALICE) than at mid-rapidity (CMS)
- Theory still meets difficulties in describing simultaneously the R_{AA} centrality and rapidity dependence (suppression slightly overestimated at forward-y, while better reproduced at mid-y)

ψ(2S)/J/ψ in p-Pb

A strong decrease of the ψ(2S) production in p-Pb, relative to J/ψ, is observed with respect to the pp measurement ($2.5<y_{cms}<4$, $\sqrt{s}$=7TeV)



Double ratio allows a direct comparison of the J/ψ and ψ(2S) production yields between experiments

Similar effect seen by PHENIX in d-Au collisions, at mid-y, at $\sqrt{s_{NN}}$=200 GeV

$[\psi(2S)/J/\psi]_{pp}$ variation between ($\sqrt{s}$=7TeV, 2.5<y<4) and ($\sqrt{s}$=5.02TeV, 2.03<y<3.53 or -4.46<y<-2.96) based on CDF and LHCb data (~8% included in the systematic uncertainty)

$\Upsilon(1S)$ PRODUCTION IN PB-PB COLLISIONS

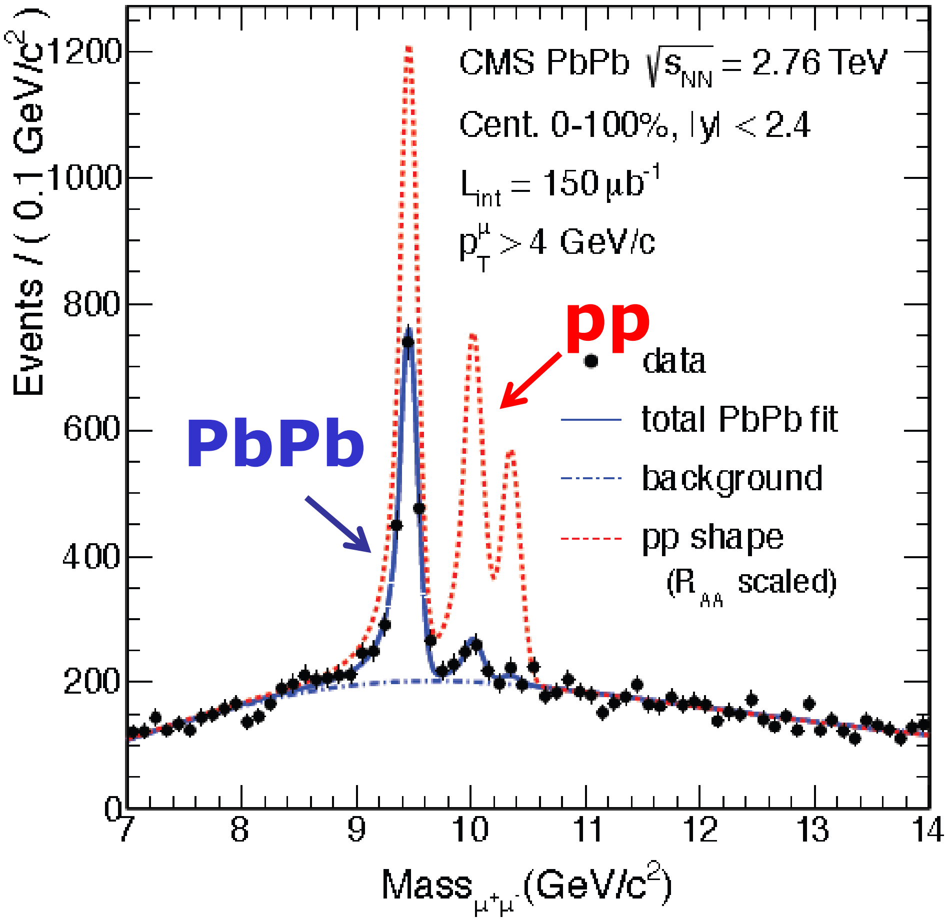
LHC is the machine for studying bottomonium in AA collisions

Main features of bottomonium production wrt charmonia:

- no B hadron feed-down
- gluon shadowing effect are smaller
- (re)combination expected to be smaller
- theoretical predictions more robust due to the higher mass of b quark

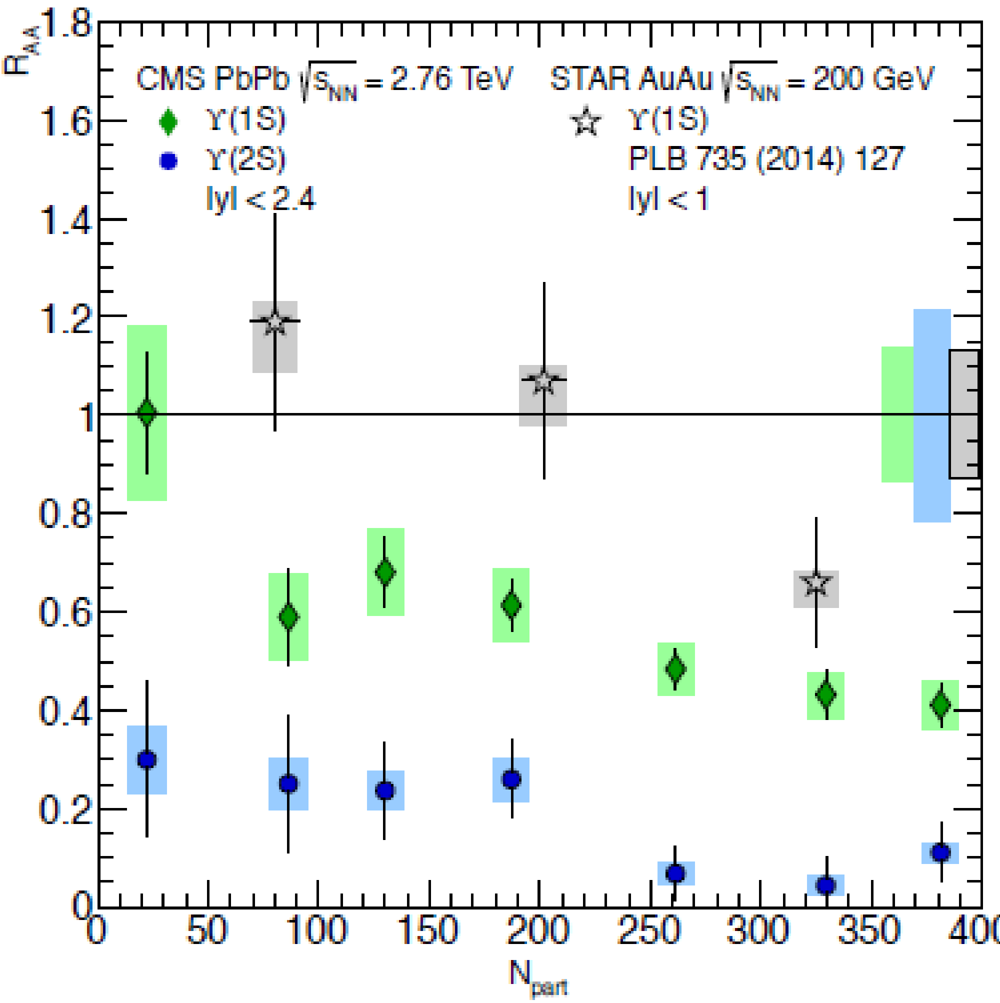
with a drawback…smaller production cross-section

PRL 109, 222301 (2012)



Clear suppression of Υ states in PbPb with respect to pp collisions

ϒ(1S) PRODUCTION IN PB-PB COLLISIONS



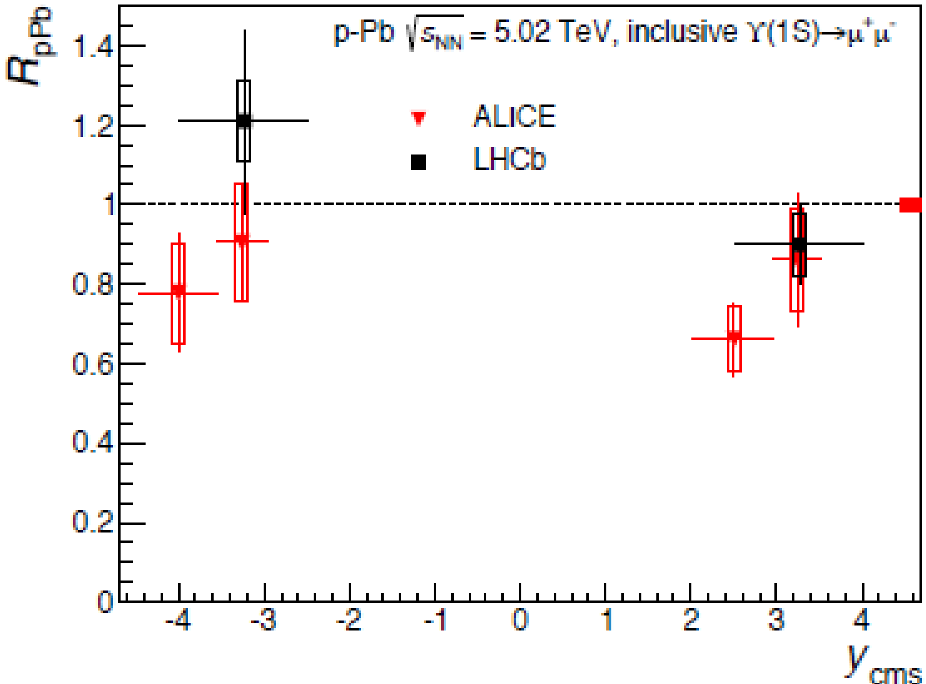
- Clear suppression of ϒ(2S)
- ϒ(1S) suppression compatible with suppression of excited states (50% feed-down)
- Sequential suppression of the three ϒ states according to their binding energy:

$$\mathbf{R}_{AA}^{\Upsilon(3S)} < \mathbf{R}_{AA}^{\Upsilon(2S)} < \mathbf{R}_{AA}^{\Upsilon(1S)}$$

R_{AA}(ϒ(1S)) = 0.56 ± 0.08 (stat) ± 0.07 (syst)
R_{AA}(ϒ(2S)) = 0.12 ± 0.04 (stat) ± 0.02 (syst)
R_{AA}(ϒ(3S)) <0.1 (at 95% C.L)

- Suppression at LHC is stronger than at RHIC

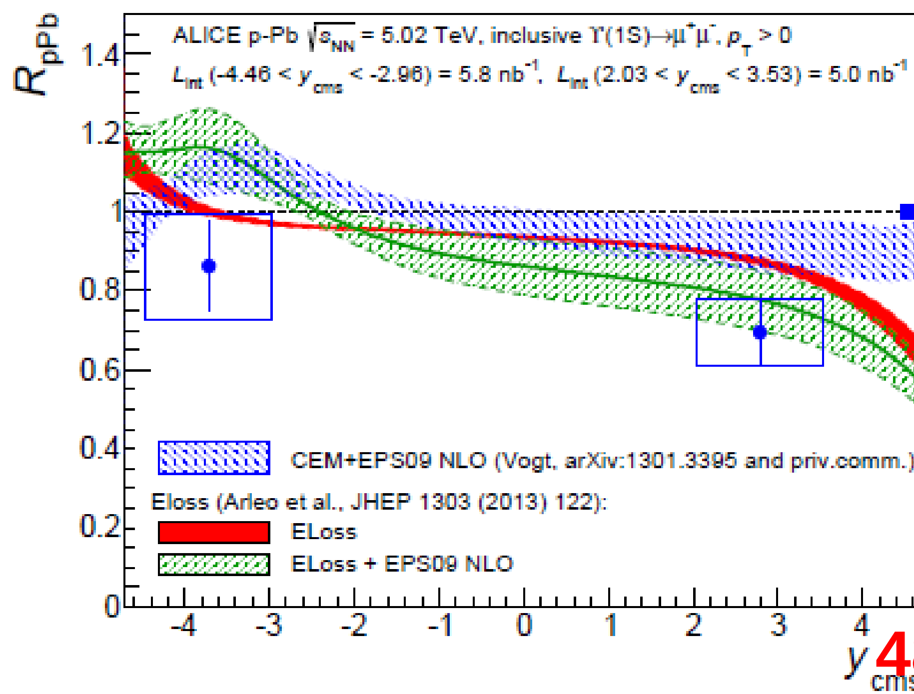
ϒ(1S) PRODUCTION IN p-Pb



- ϒ(1S) measured at mid-*y* by CMS and at forward-*y* by both ALICE and LHCb

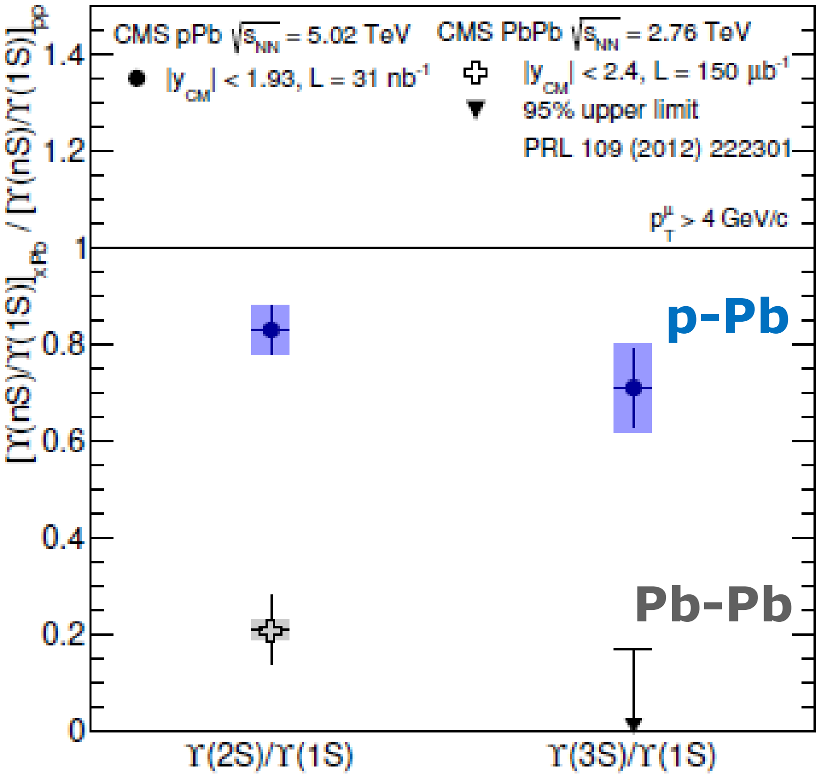
  → Compatible R_{pA} results within uncertainties (but LHCb systematically higher)

- Hint for stronger suppression at forward-*y* (similarly to J/ψ)
- Theoretical calculations based on initial state effects seem not to describe simultaneously forward and backward *y*



ALICE: arXiv:1410.2234, accepted by PLB
LHCb: JHEP 07(2014)094

Υ(nS)/Υ(1S) PRODUCTION IN p-Pb



Initial state effects similar for the three Υ states

p-Pb vs pp @mid-y: different/stronger final states effects in p-Pb affecting the excited states

p-Pb vs PbPb @mid-y : even stronger suppression of excited states in PbPb

CMS HIN-13-003, JHEP 04 (2014) 103, PRL 109 (2012)

ALICE (and LHCb) observes:

Υ(2S)/Υ(1S) (ALICE)
$2.03<y<3.53$: 0.27±0.08±0.04
$-4.46<y<-2.96$: 0.26±0.09±0.04

Compatible with pp results
0.26±0.08 (ALICE, pp@7TeV)

CMS analyses the double ratio $[\Upsilon(2S)/\Upsilon(1S)]/[\Upsilon(nS)/\Upsilon(1S)]_{pp}$ and finds

0.83±0.05±0.05