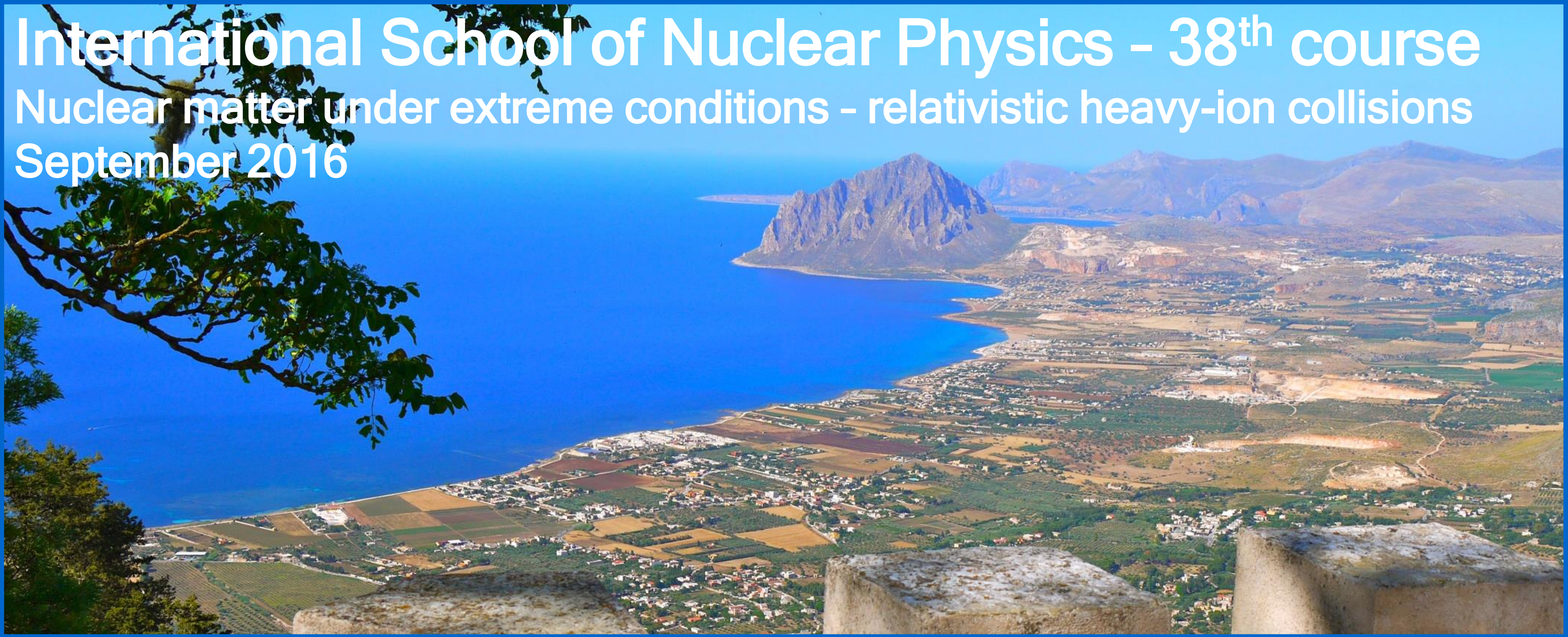
International School of Nuclear Physics - 38th course

Nuclear matter under extreme conditions - relativistic heavy-ion collisions

September 2016



Quarkonium results in pA & AA: from RHIC to LHC

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International School of Nuclear Physics – 38th course

Nuclear matter under extreme conditions – relativistic heavy-ion collisions

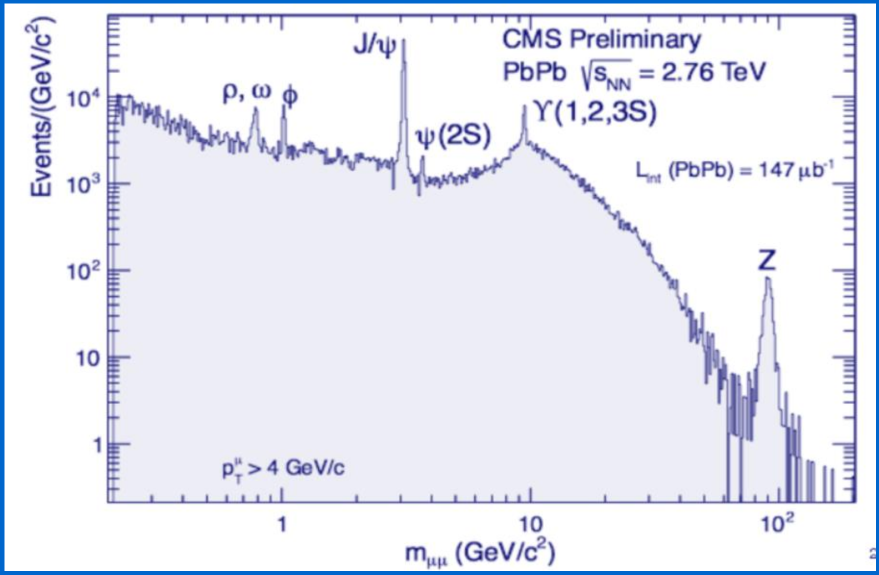
September 2016

Outlook:

Selection on results on

- Charmonium: J/ψ and ψ(2S)
- Bottomonium: ϒ(1S), ϒ(2S), ϒ(3S)

in p-A, d-A and A-A collisions at RHIC and LHC energies



AA: hot matter effects

the original idea

quarkonium production suppressed via color screening in the QGP

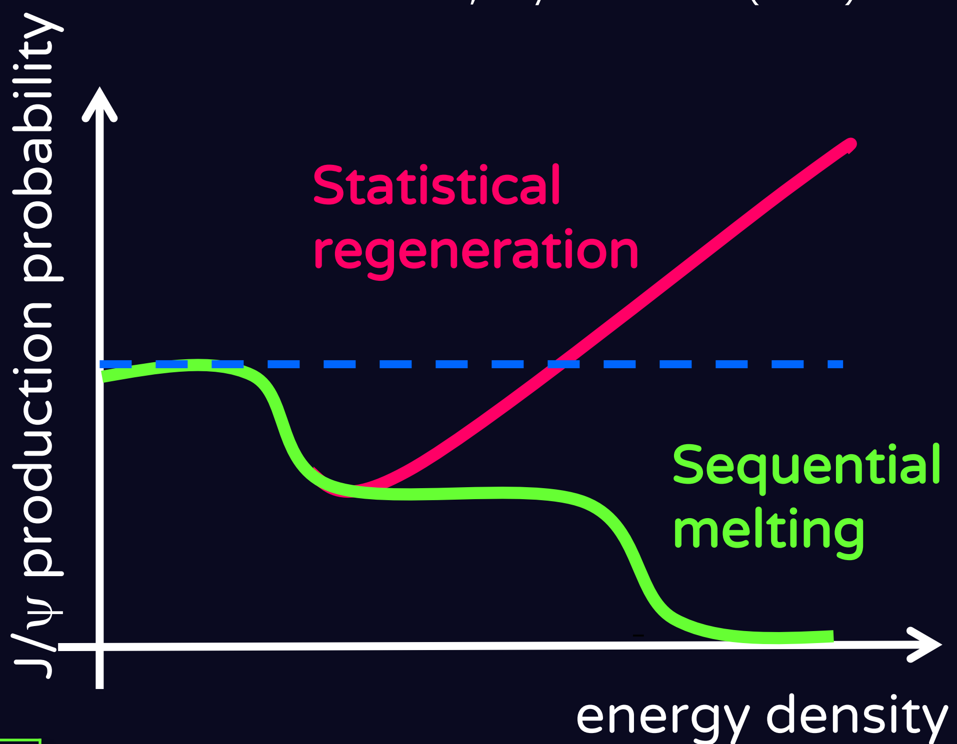
T.Matsui and H.Satz, Phys.Lett.B178 (1986) 416

sequential melting

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

(re)combination

enhanced quarkonium production through (re)combination during QGP phase or at hadronization



Central AA collisions	SPS 20 GeV	RHIC 200 GeV	LHC 2.76TeV	LHC 5.02TeV
N_{ccbar}/event	~0.2	~10	~85	~115

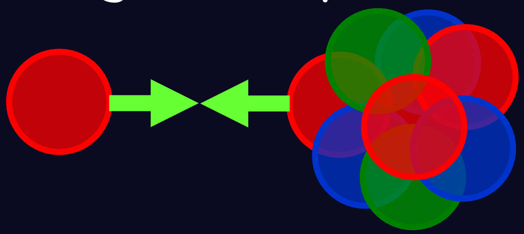
P. Braun-Muzinger,J. Stachel, PLB 490(2000) 196
R. Thews et al, Phys.Rev.C63:054905(2001)

pA: CNM effects

Cold nuclear matter effects: might affect quarkonium production on top of hot matter mechanisms

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

investigated in p-A collisions



the assessment of the size of these effects is fundamental to interpret quarkonium A-A results

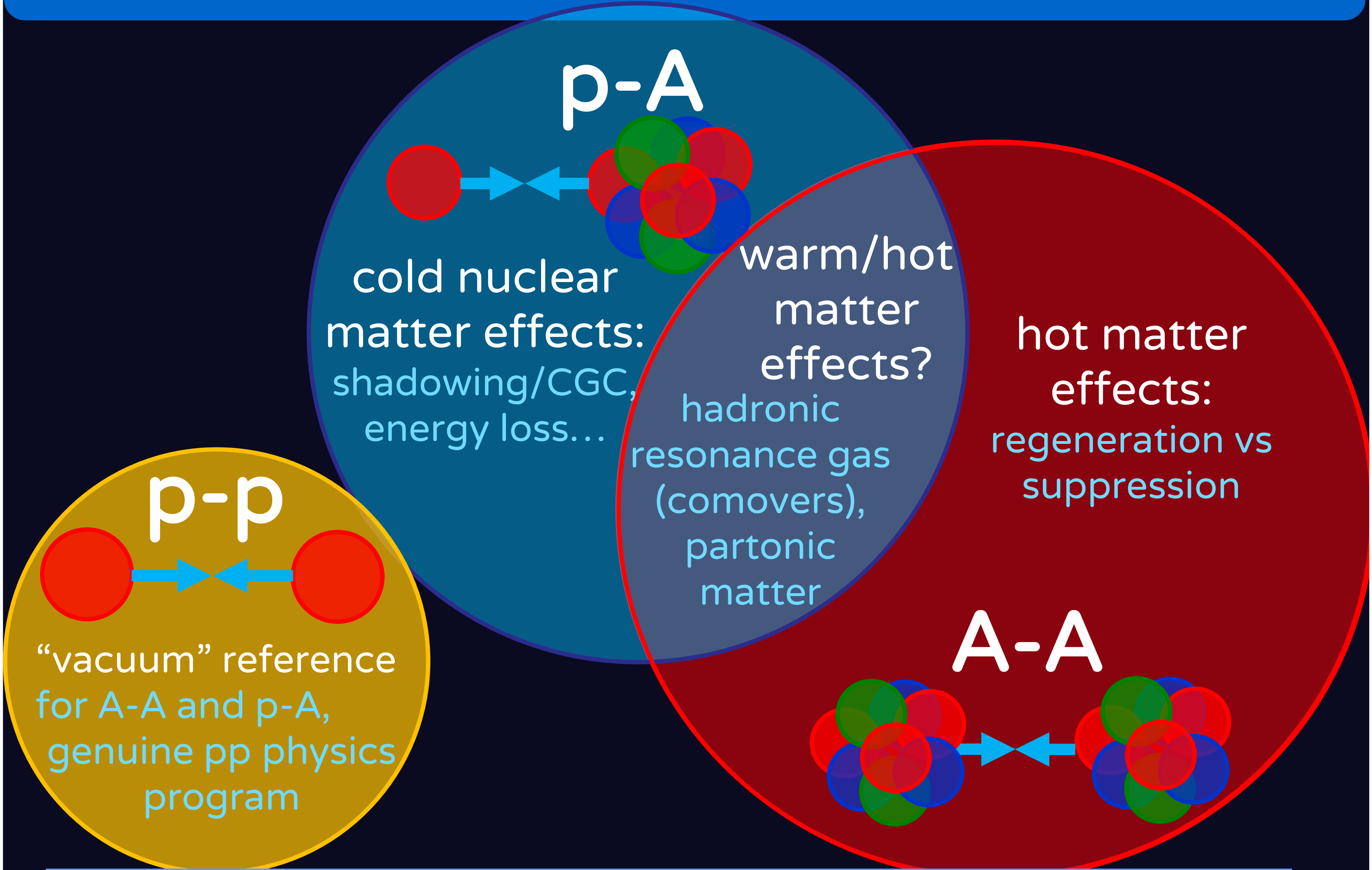
Nuclear modification factor

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

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

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

Quarkonium in HI



Quarkonium at RHIC & LHC

Facility	Experiment	System	$\sqrt{s_{NN}}$ (GeV)	Data taking
RHIC	PHENIX STAR	Au-Au, Cu-Cu, Cu-Au, U-U	200, 193, 62, 39	2000-2016
		p-A, d-Au	200	
		pp	200-500	
LHC	ALICE ATLAS CMS LHCb	Pb-Pb	2760 5020	2010-2012 2015
		p-Pb	5020 (8000)	2013 (2016)
		pp	2760, 7000, 8000, 13000	2010-2016

Quarkonium at RHIC & LHC

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RHIC	PHENIX STAR	Au-Au, Cu-Cu, Cu-Au, U-U	200, 193, 62, 39	2000-2016
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LHC	ALICE ATLAS CMS LHCb	Pb-Pb	2760 5020	2010-2012 2015
				2013 (2016)
			13000	10-2016

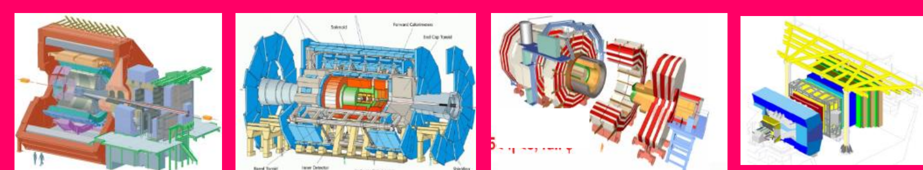
Quarkonium production investigated via collisions:

- with different beam species
- at various energies

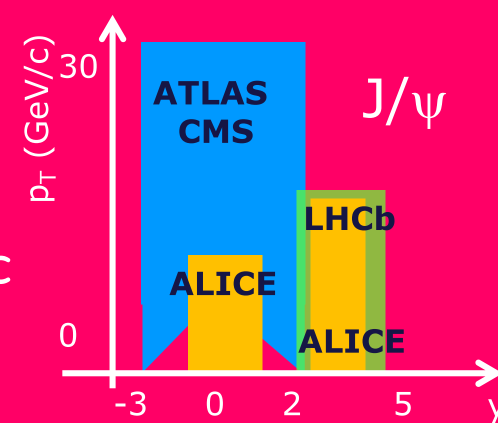
Quarkonium at RHIC & LHC

Facility	Experiment	System	$\sqrt{s_{NN}}$ (GeV)	Data taking
RHIC	PHENIX STAR	Au-Au, Cu-Cu, Cu-Au, U-U	200, 193, 62, 39	2000-2016
		p-A, d-Au	200	
LHC	ALICE ATLAS CMS LHCb			

All LHC experiments investigate quarkonium production



→ complementary results due to different kinematic coverages



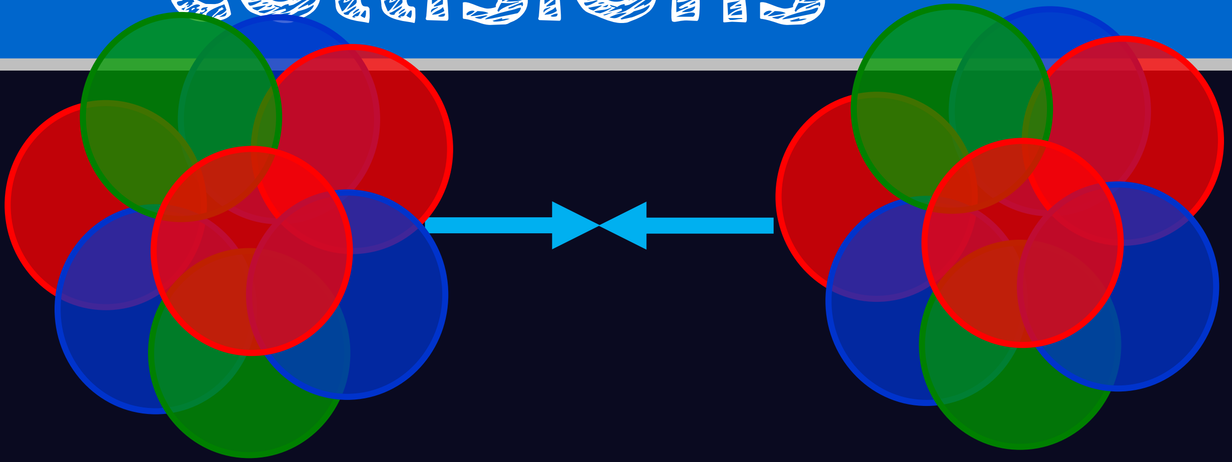
Quarkonium at RHIC & LHC

Facility	Experiment	System	$\sqrt{s_{NN}}$ (GeV)	Data taking
RHIC	PHENIX	Au-Au, Cu-Cu, u-Au, U-U	200, 193, 62, 39	2000-2016
		-A, d-Au	200	
		pp	200-500	
LHC	ALICE ATLAS CMS LHCb	Pb-Pb	2760 5020	2010-2012 2015
		p-Pb	5020 8000	2013 (2016)
		pp	2760 5020 7000 8000 13000	2010-2016

LHC Run-1

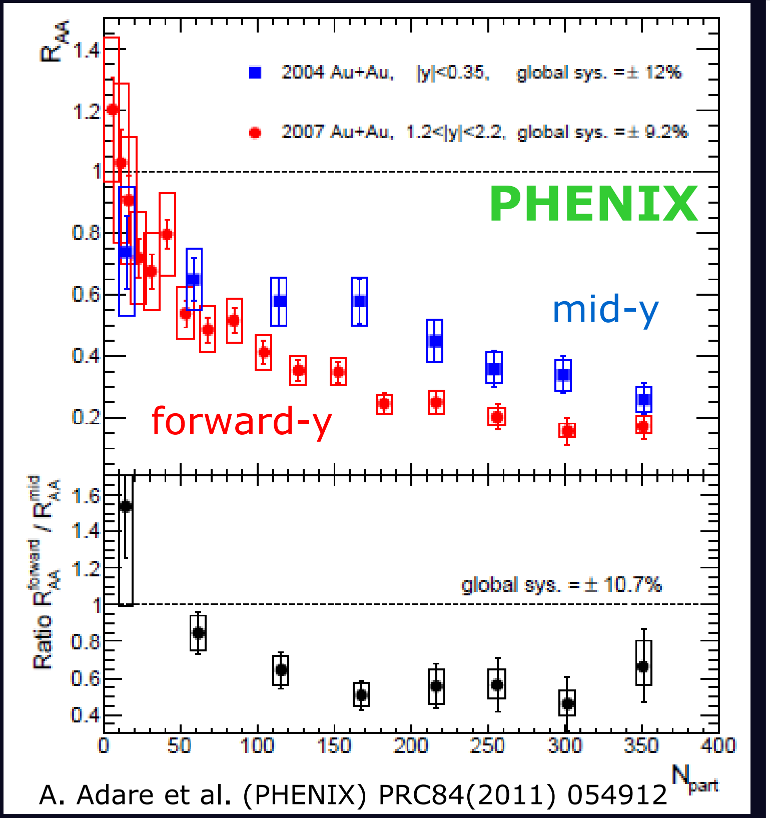
LHC Run-2

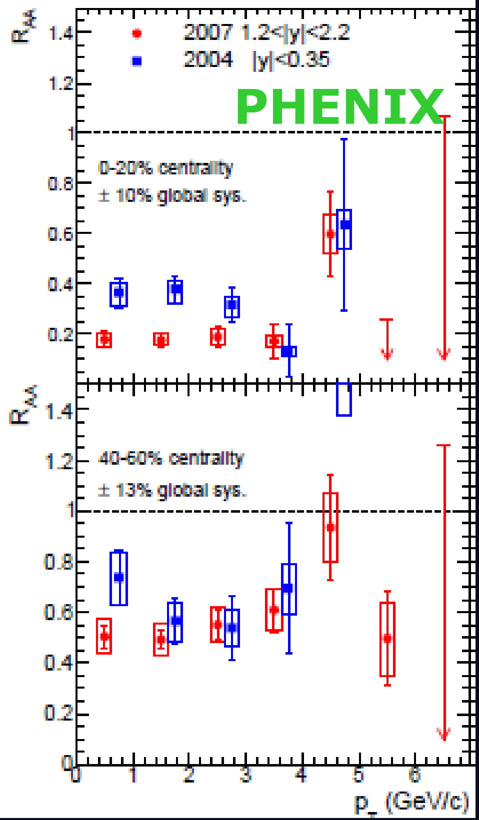
Quarkonium in AA collisions

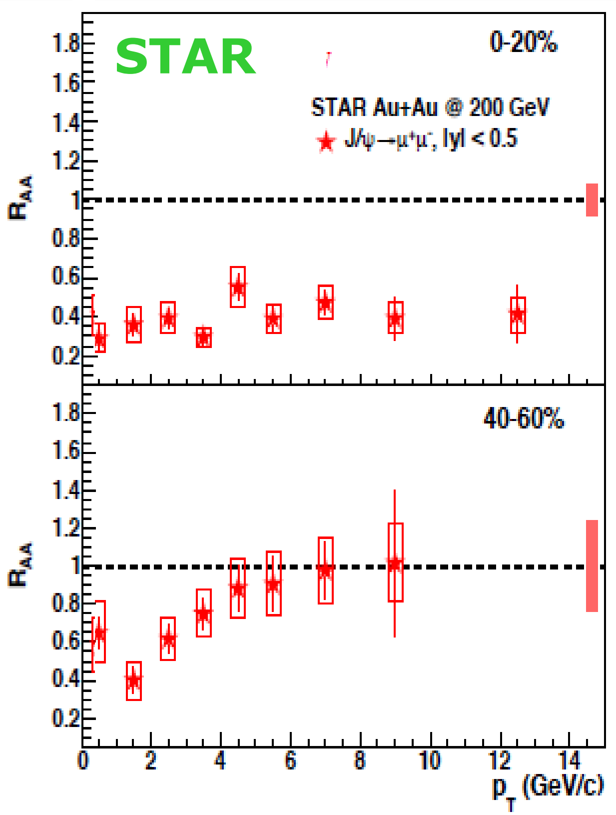


J/ψ suppression at RHIC

Stronger J/ψ suppression at forward-y wrt mid-y in AuAu@200GeV

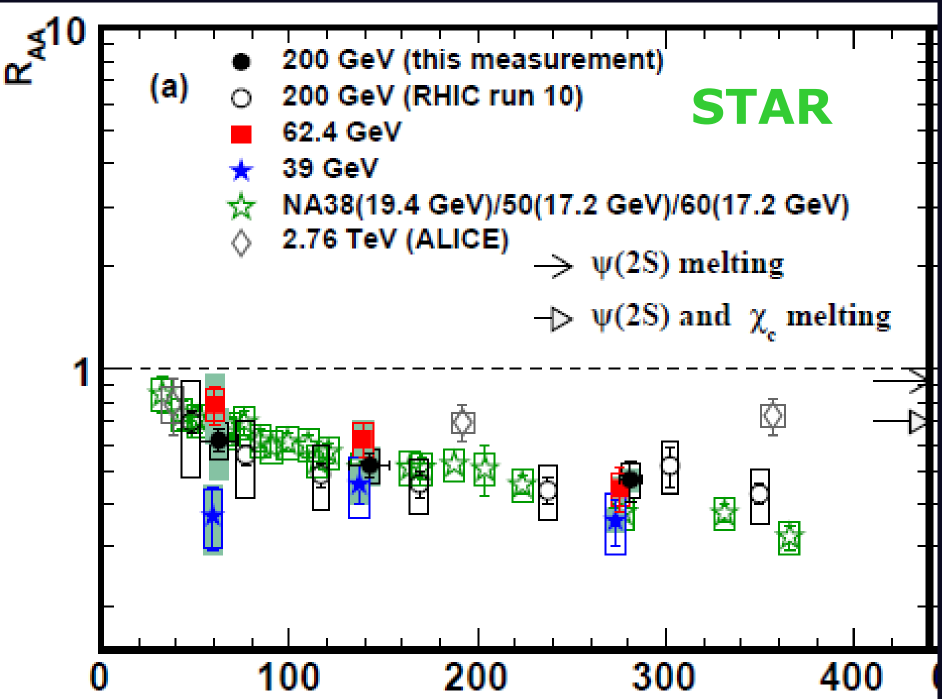




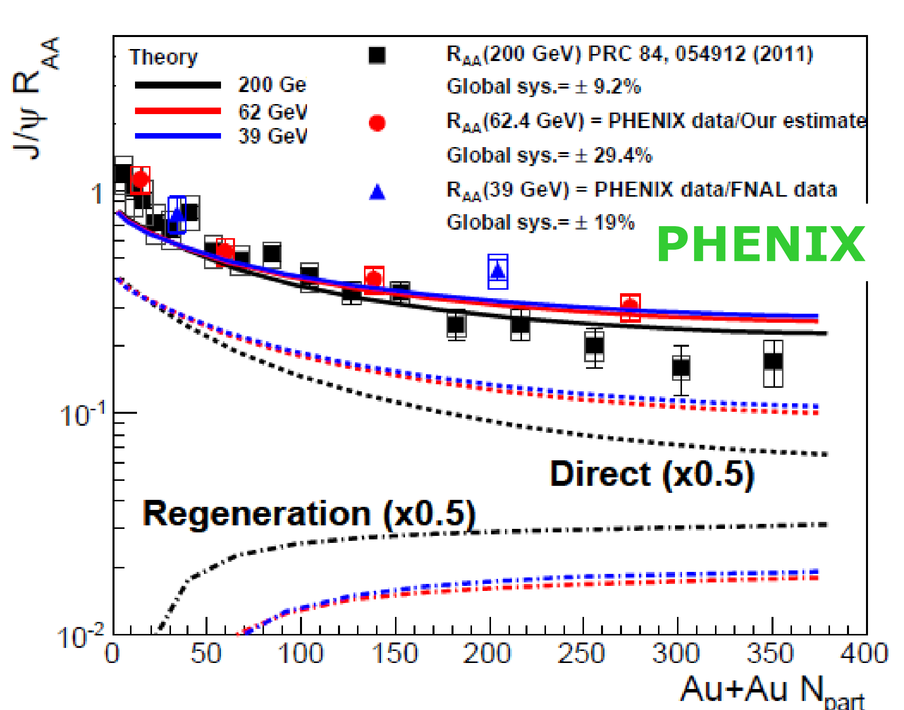


- Strong centrality and low-p_T suppression
- Qualitative agreements with suppression + recombination models

Energy scan at RHIC



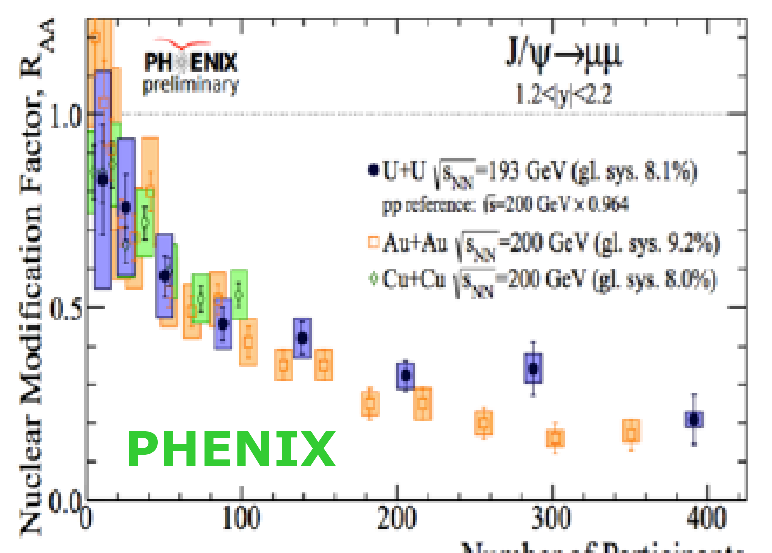
A. Adamczyk et al. (STAR) arXiv:1607.0751



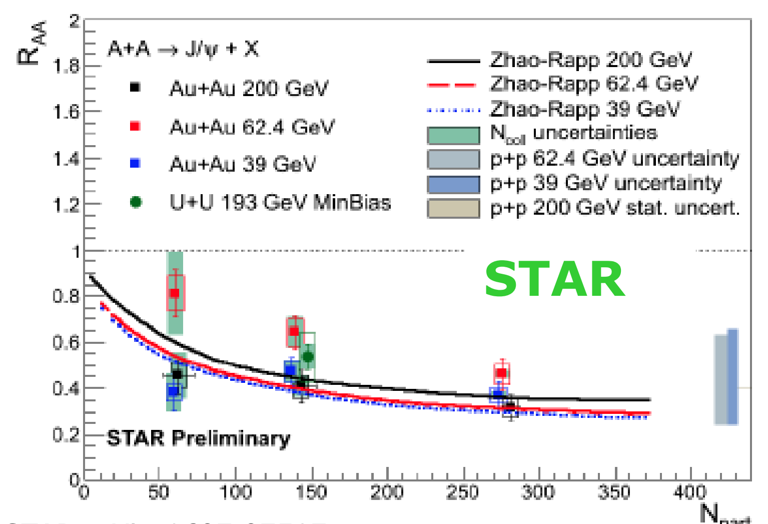
A. Adare et al. (PHENIX) PRC86(2012) 064901

- R_{AA} suppression visible at all energies
- No significant energy dependence, including SPS!
- Qualitative agreements with suppression + recombination models
  → pp reference at 39 & 62.4 GeV needed for quantitative comparison

System scan at RHIC



PHENIX PRC93(2016) 034903



STAR arXiv:1607.07517

- Various systems studied:
  - rather similar suppression observed
  - hint for a weaker suppression in U-U

in central U-U collisions:

1) stronger color screening suppression

$\varepsilon_{AuAu} \sim$ 80-85% ε_{UU}

2) J/ψ recombination favoured by 25% larger N_{coll} in U-U

$$N_{J/\psi}^{stat} \sim N_c^2 \sim N_{coll}^2$$

- Dominant recombination in U-U over suppression?
- Quantitative conclusions depend on U Woods-Saxon description

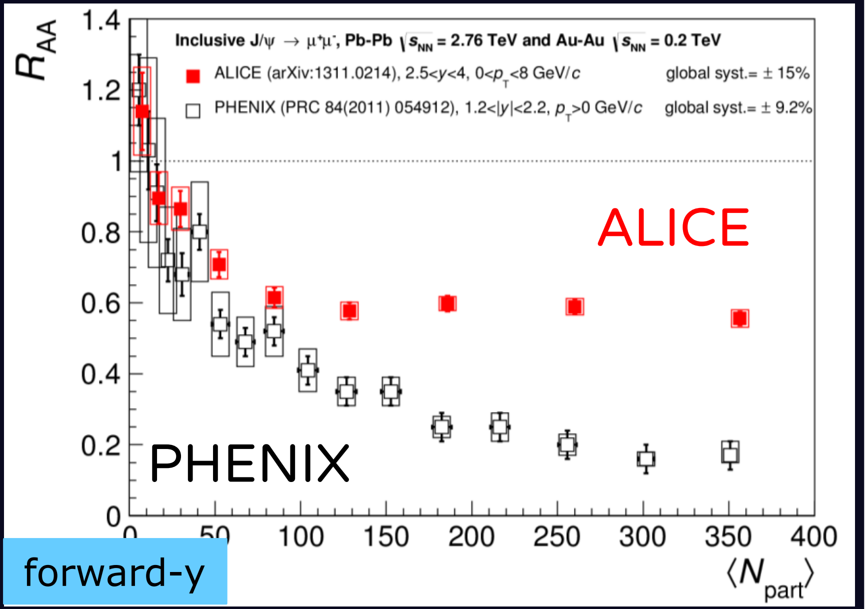
J/ψ: LHC Run1 results

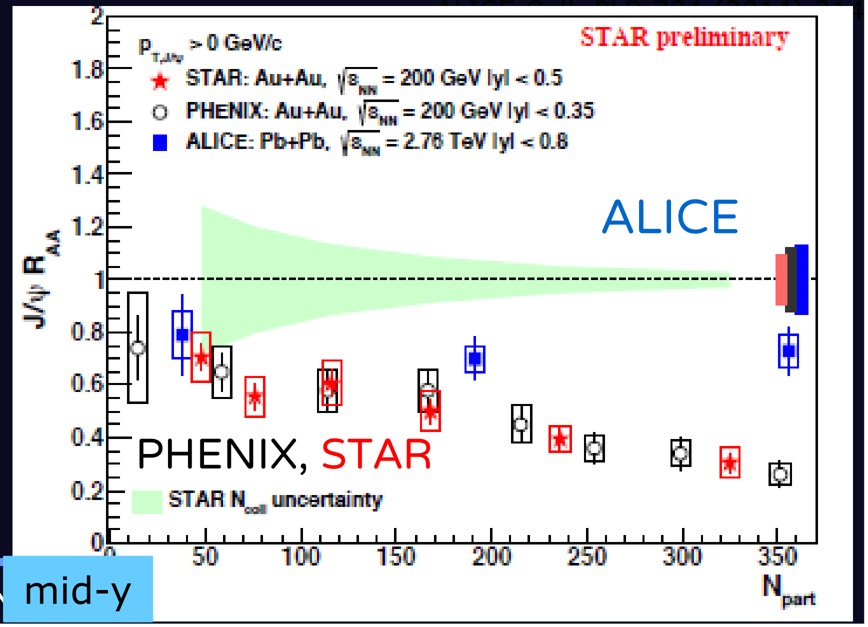
Evidence of recombination for low p_T J/ψ at LHC

Observation validated by the comparison of LHC results with

1) lower energy experiments

J/ψ suppression vs centrality is stronger in PHENIX/STAR than in ALICE, in spite of the LHC larger energy densities





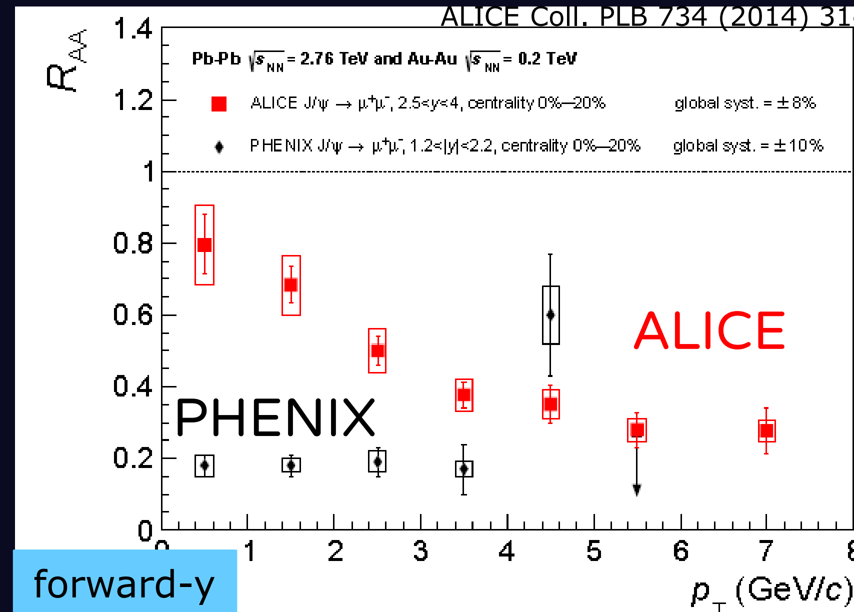
J/ψ: LHC Run1 results

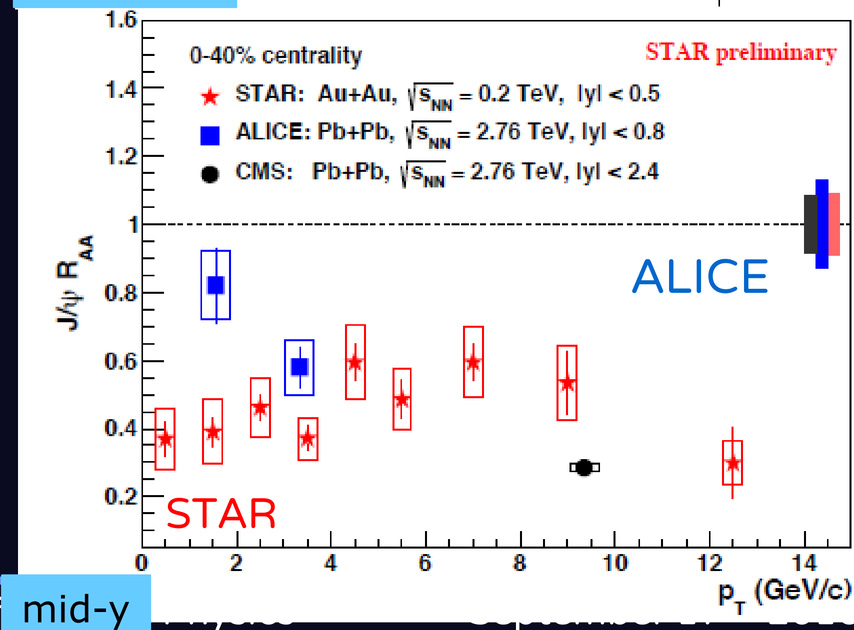
Evidence of recombination for low p_T J/ψ at LHC

Observation validated by the comparison of LHC results with

1) lower energy experiments

weaker suppression at low p_T observed by ALICE



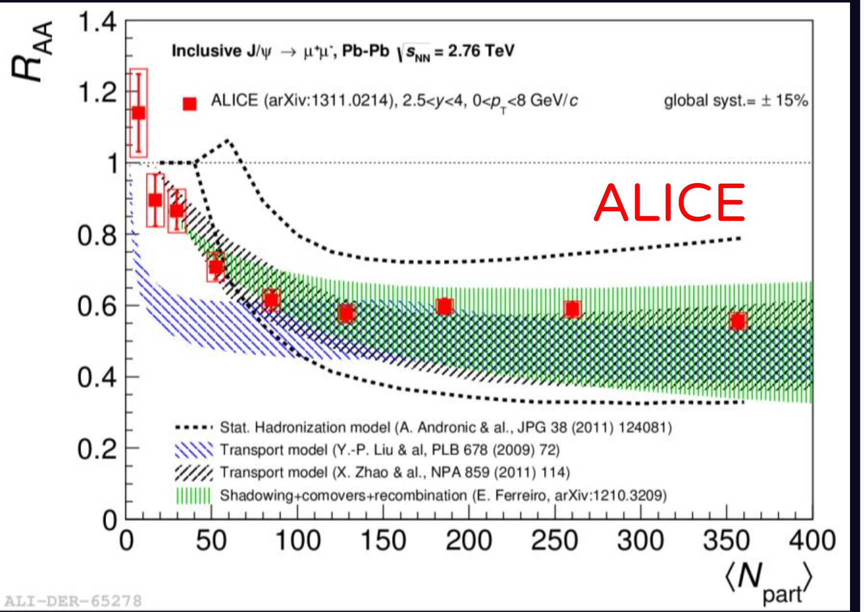


J/ψ: LHC Run1 results

Evidence of recombination for low p_T J/ψ at LHC

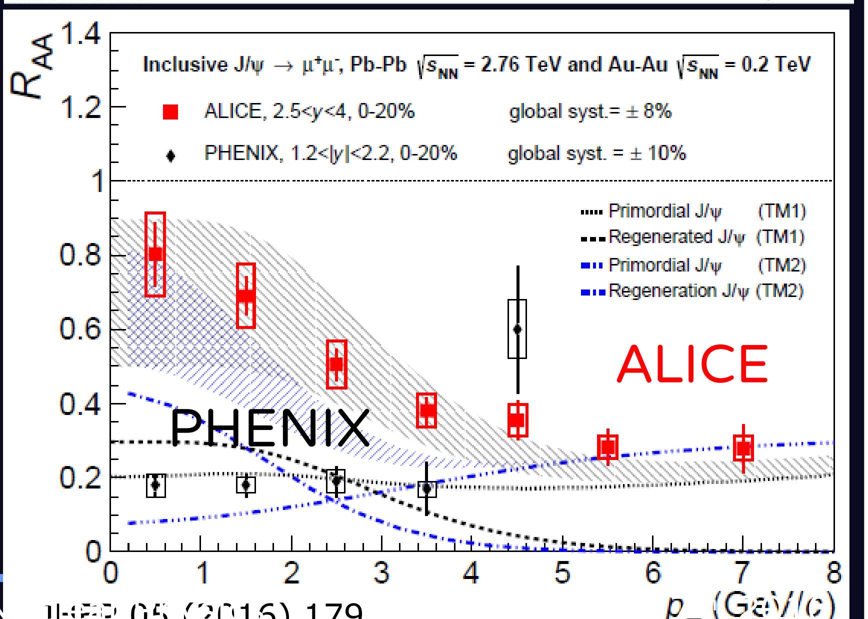
Observation validated by the comparison of LHC results with

1) lower energy experiments
2) theoretical models



models including (re)combination of J/ψ in QGP or in the hadronic phase provide a reasonable description of ALICE results

still rather large theory uncertainties: models will benefit from a precise measurement of σ_{cc} and CNM effects



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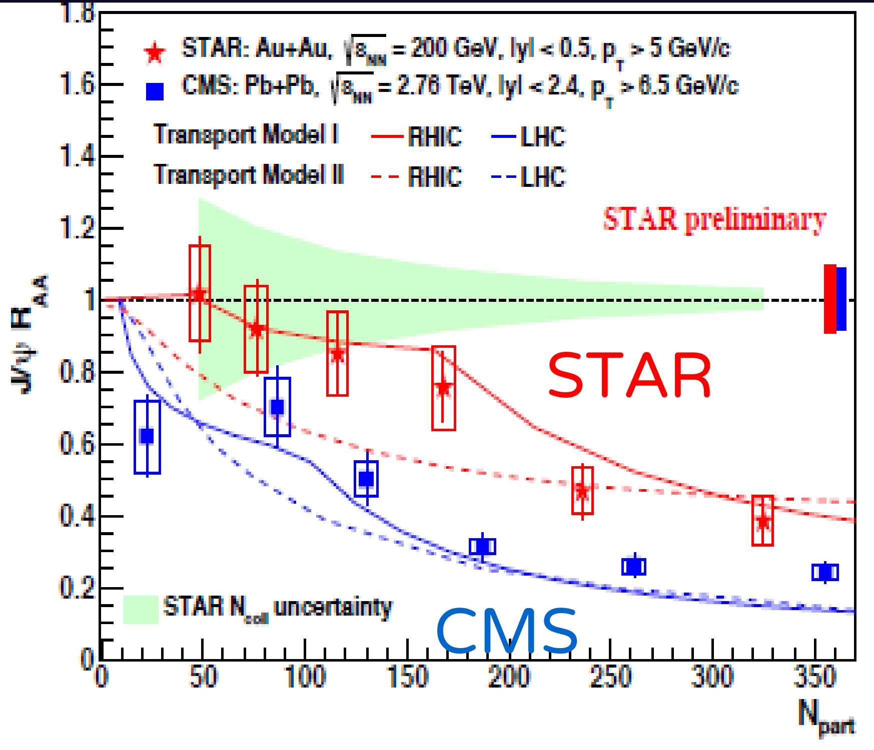
J/ψ: LHC Run1 results

Evidence of recombination for low p_T J/ψ at LHC

Observation validated by the comparison of LHC results with

1) lower energy experiments
2) theoretical models
3) **high p_T J/ψ results**



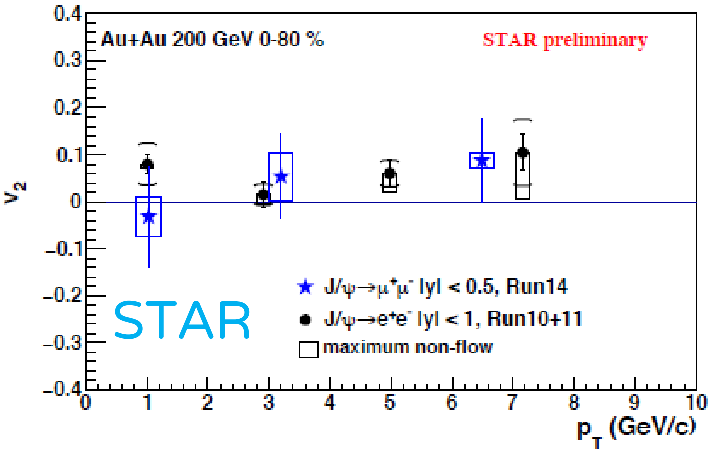
- suppression stronger at higher √s, as expected from QGP dissociation
- opposite J/ψ behavior compared to low-p_T results
- negligible re(combination) effects expected at high p_T

Transport model:
Model I at RHIC: PLB 678 (2009) 72
Model I at LHC: PRC 89 (2014) 054911
Model II at RHIC: PRC 82 (2010) 064905
Model II at LHC: NPA 859 (2011) 114

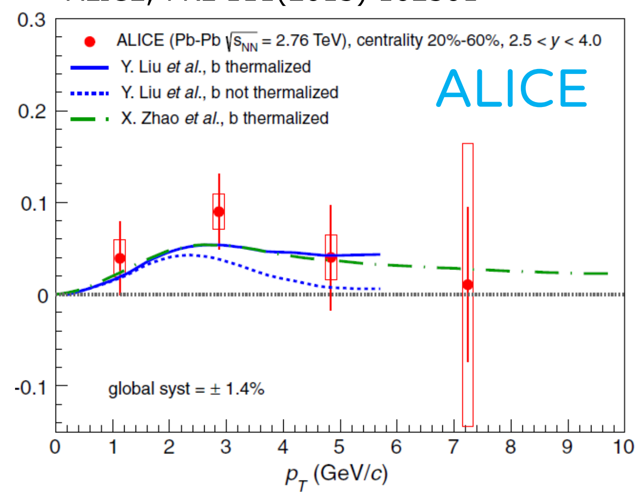
J/ψ flow

If c quarks participate to QGP collective motion, they should acquire elliptic flow
→ J/ψ from (re)combination should inherit the flow of c quarks

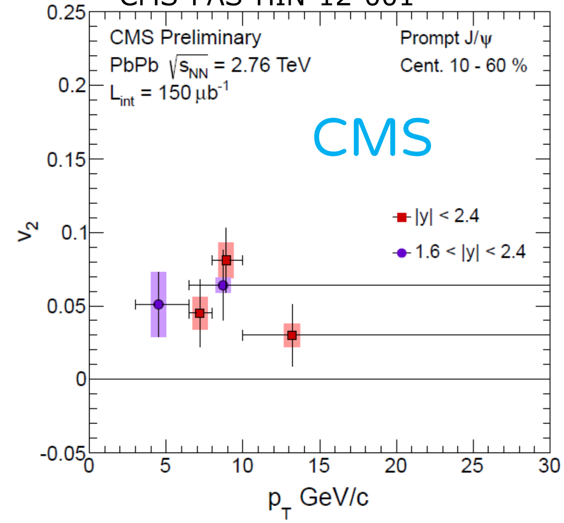
STAR, PRL 052301(2013)



ALICE, PRL 111(2013) 162301



CMS-PAS-HIN-12-001



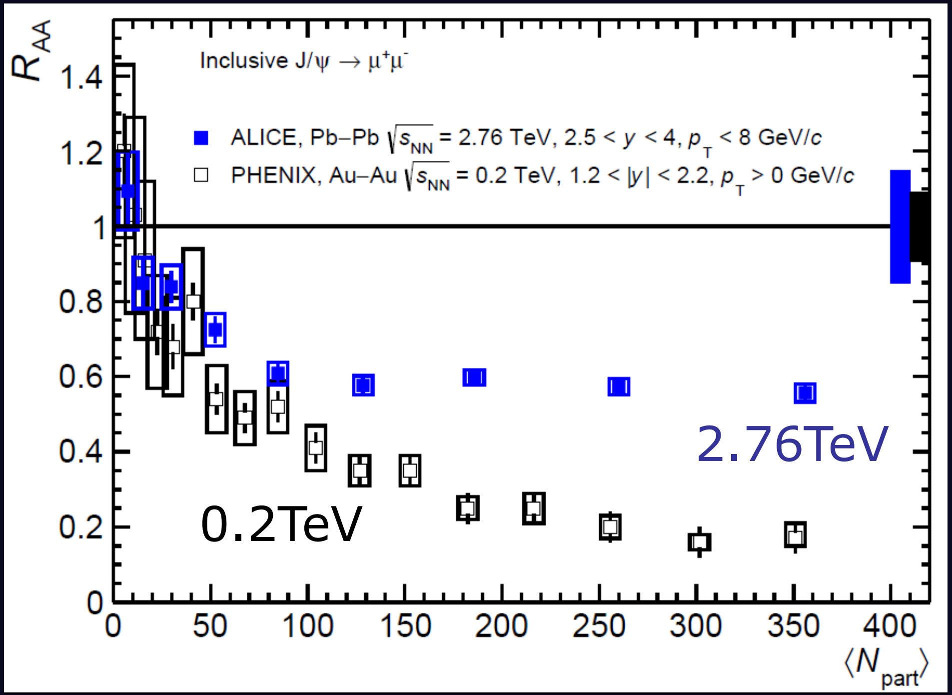
Hint for J/ψ flow at LHC, contrary to v_2~0 observed at RHIC!

ALICE: qualitative agreement with transport models including regeneration

CMS: path-length dependence of energy loss?

J/ψ results from LHC Run-2

LHC: Pb-Pb collisions @ $\sqrt{s_{NN}}$=5.02TeV

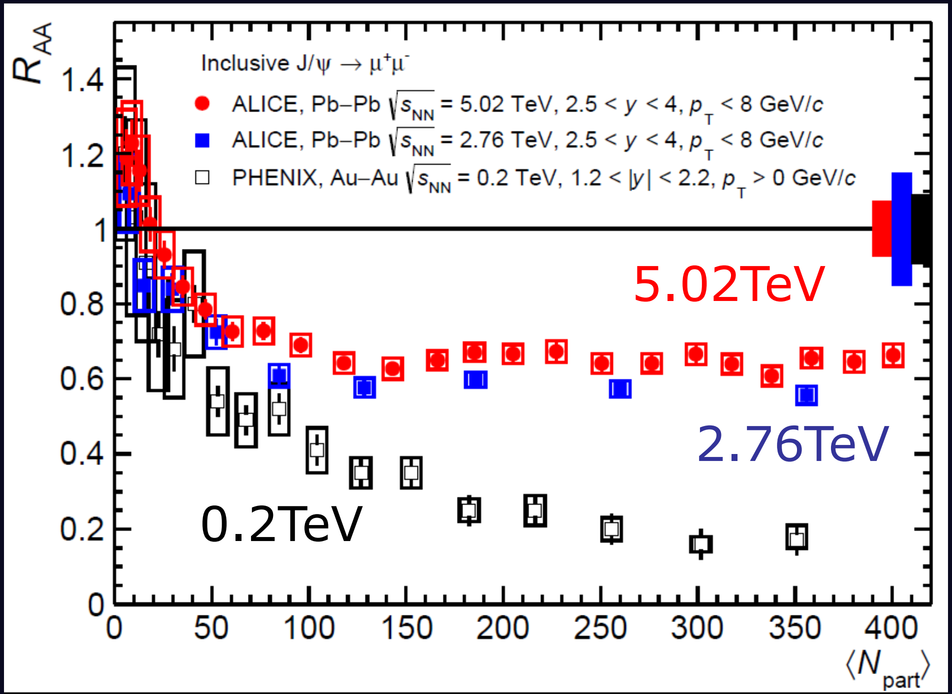


arXiv:1606.08197

J/ψ results from LHC Run-2

LHC: Pb-Pb collisions @ $\sqrt{s_{NN}}$=5.02TeV

High statistics Run-2 allows the R_{AA} evaluation in narrow centrality bins



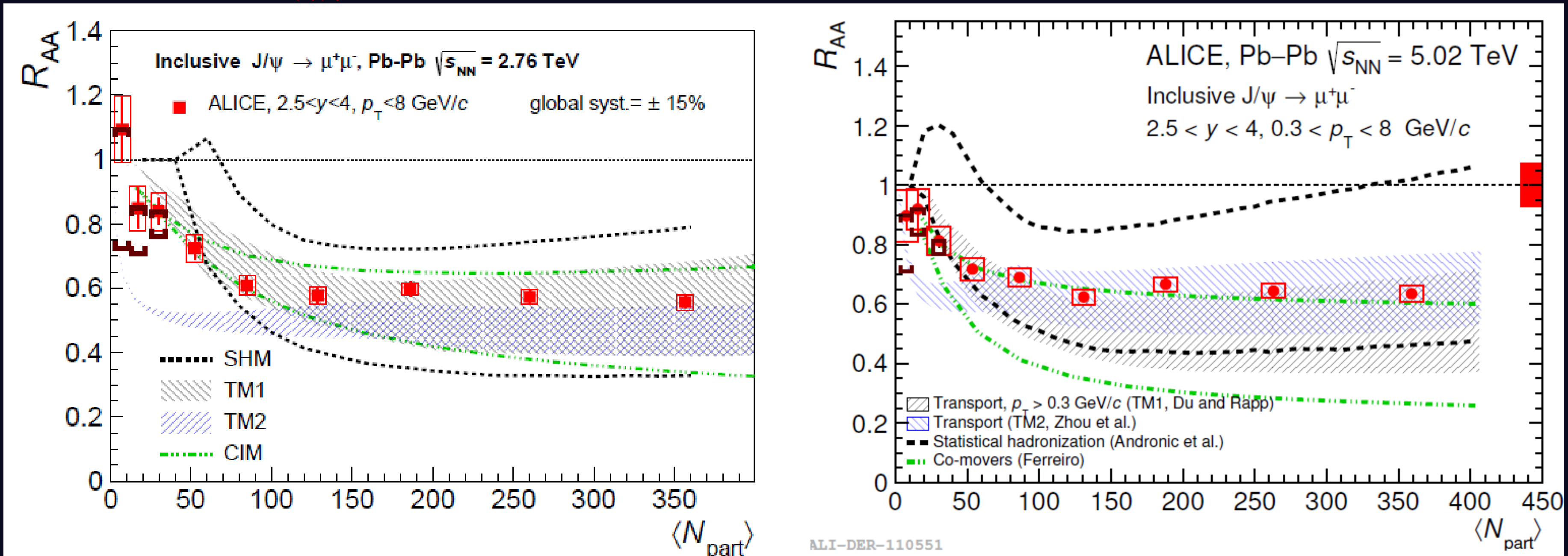
- Similar centrality dependence at the two energies, with an increasing suppression up to N_{part}~100, followed by a plateau

- R_{AA} @ 5.02TeV is ~15% higher than the one at 2.76TeV, even if within uncertainties

arXiv:1606.08197

J/ψ theory models

$\sqrt{s_{NN}}$=2.76TeV $\sqrt{s_{NN}}$=5.02TeV



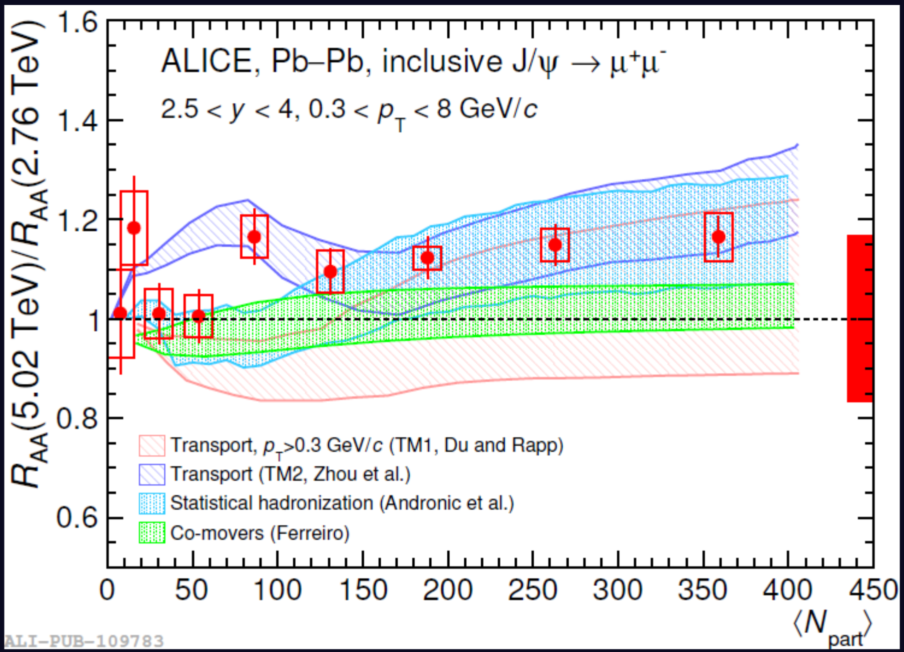
Brackets represents the possible range of variation of the hadronic J/ψ

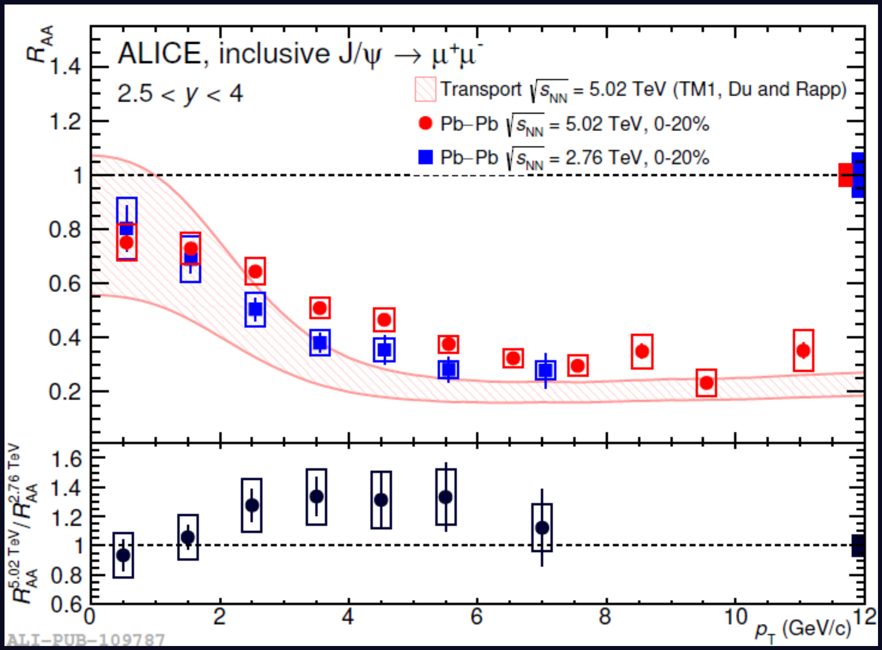
Comparison of same theory models at the two energies:

TM1, TM2 (Du et al, Zhou et al): rate equation of suppression/regeneration in QGP
SHM (Andronic et al): J/ψ produced by stat. hadronization at phase boundary
CIM (Ferreiro): suppression by the comoving partonic medium and regeneration

- Data are compatible with theory models at both energies
- Still large uncertainties mainly due to the choice of σ_{cc}

Run-2 J/ψ results



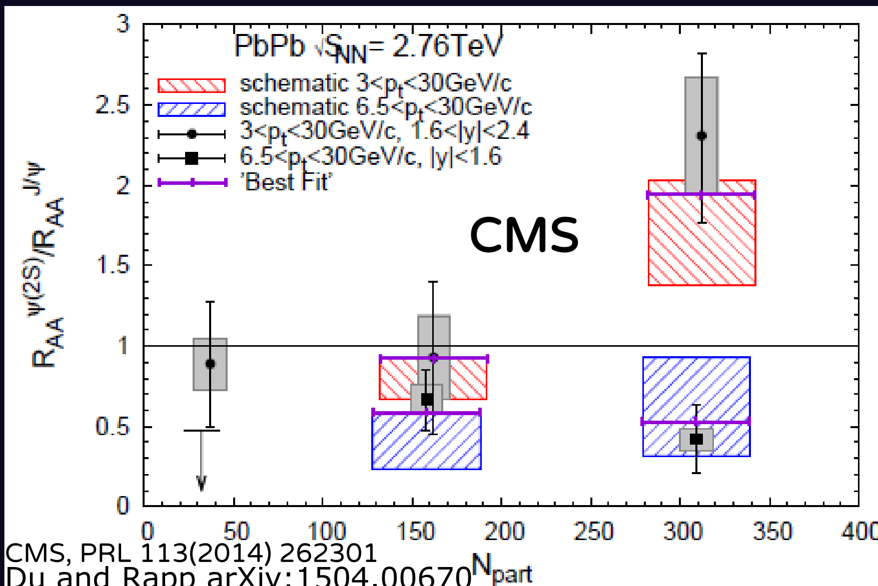


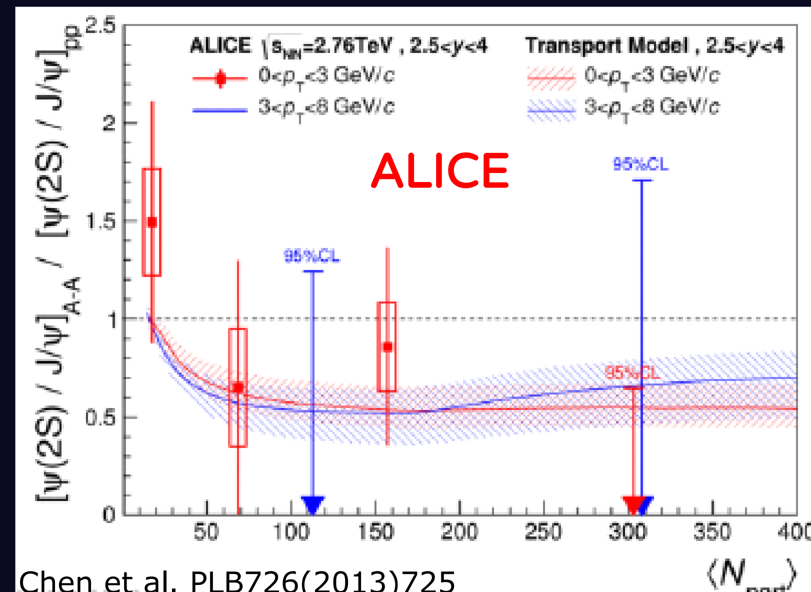
- Theoretical and experimental uncertainties reduced in the R_{AA} double ratio
- Centrality dependence of the R_{AA} ratio is rather flat
- R_{AA} increases with p_T, at both energies, as expected in a regeneration scenario
- Hint for an increase of R_{AA}, at 5.02TeV, in $2<p_T<6$ GeV/c

Also $\sqrt{s_{NN}}$=5.02TeV results support a picture where a combination of J/ψ suppression and (re)combination occurs in the QGP

ψ(2S) in AA collisions

- ψ(2S) production modified in AA with a strong kinematic dependence





Fw-y, $3<p_T<30GeV/c$ → $R_{AA}^{J/\psi} < R_{AA}^{\psi(2S)}$

- later ψ(2S) regeneration, when radial flow is stronger, might explain the rise

Mid-y $6.5<p_T<30GeV/c$ → $R_{AA}^{J/\psi} > R_{AA}^{\psi(2S)}$

- stronger suppression of ψ(2S) wrt J/ψ

Fw-y, $0<p_T<3GeV/c$ → $R_{AA}^{J/\psi} > R_{AA}^{\psi(2S)}$

- ALICE trend agrees with transport models and stat. hadronization approach

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- Run1 data not precise enough to conclude on ψ(2S) behavior
Run2 results eagerly awaited!

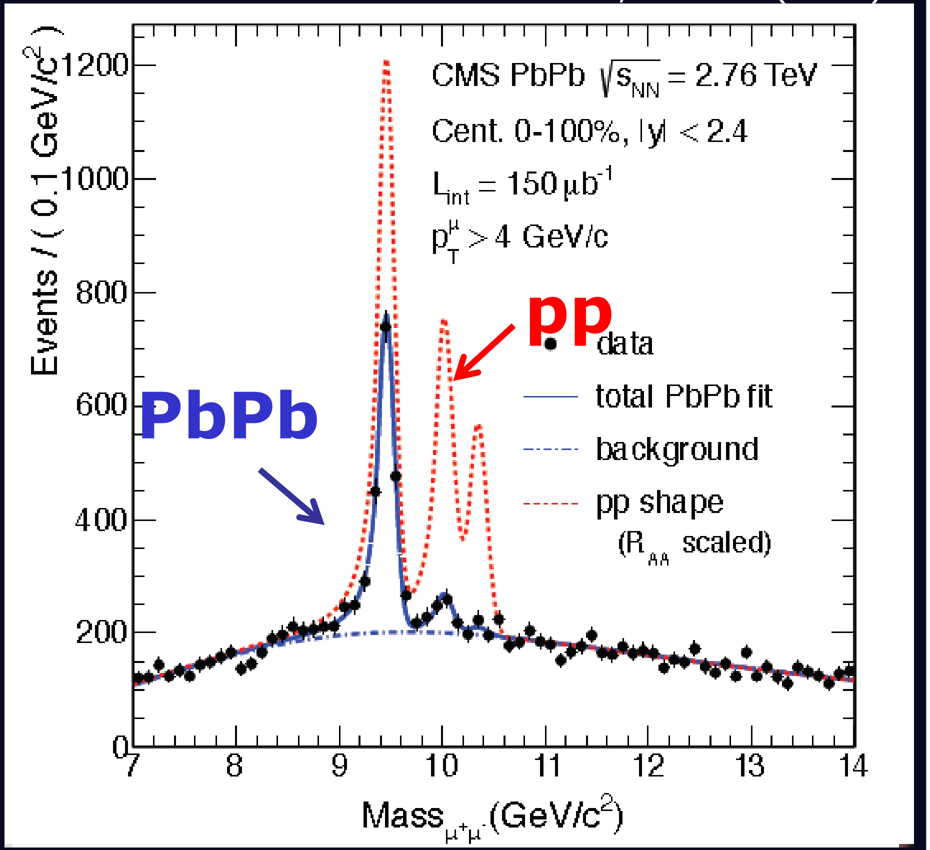
Υ(ns) production in AA

PRL 109, 222301 (2012)

➡ Main features of bottomonium production wrt charmonium:

- no B hadron feed-down
- smaller gluon shadowing effects
- negligible (re)combination
- more robust theoretical predictions due to the higher b quark mass

with a drawback…smaller production cross-section



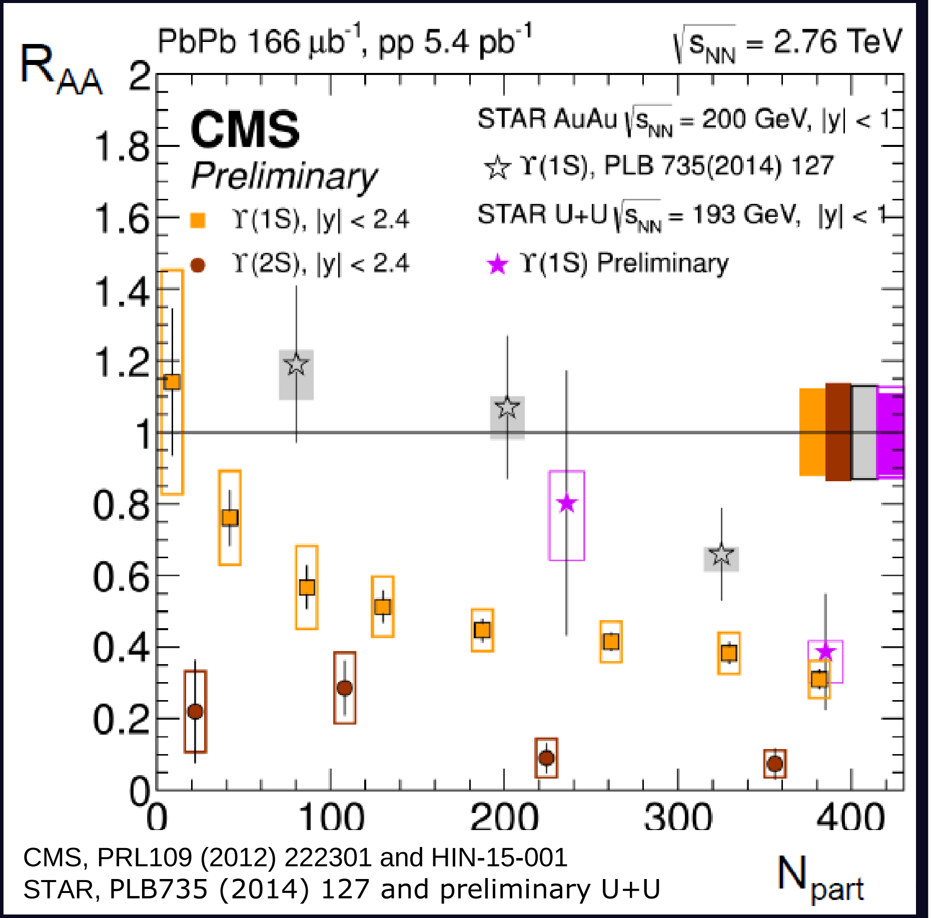
➡ Clear suppression of Υ states in PbPb at LHC energies with respect to pp collisions

Run-1 Υ(ns): where we stand?

Sequential suppression observed at LHC in Run 1:

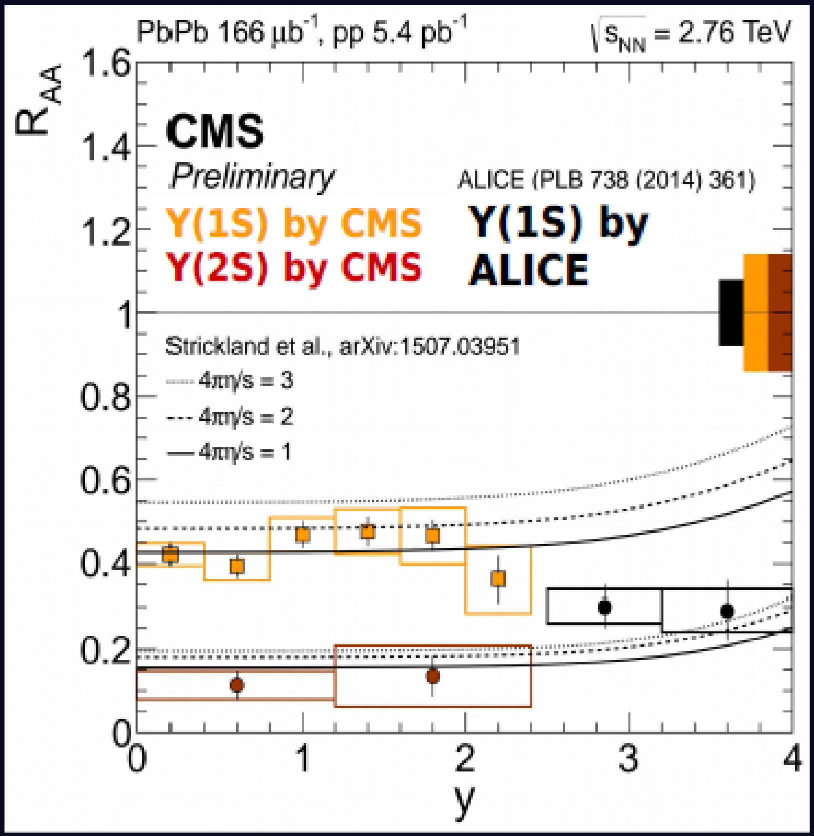
$$R_{AA}^{\Upsilon(3S)} < R_{AA}^{\Upsilon(2S)} < R_{AA}^{\Upsilon(1S)}$$

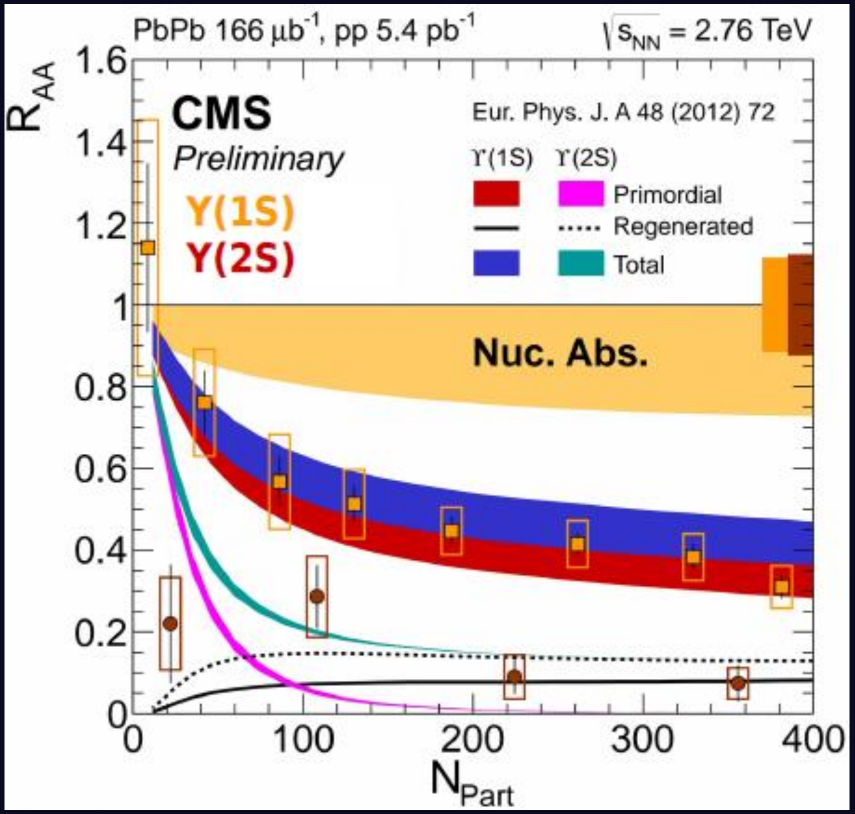
$R_{AA}(\Upsilon(1S)) = 0.43 \pm 0.03 \pm 0.07$
$R_{AA}(\Upsilon(2S)) = 0.13 \pm 0.03 \pm 0.02$
$R_{AA}(\Upsilon(3S)) < 0.14$ at 95% CL



- centrality dependent suppression for Υ(1S) and Υ(2S)
- at LHC Υ(1S) is already suppressed in semiperipheral collisions, while at RHIC only in the central ones
- feed-down from excited states + CNM are enough to explain the observed Υ(1S) suppression?

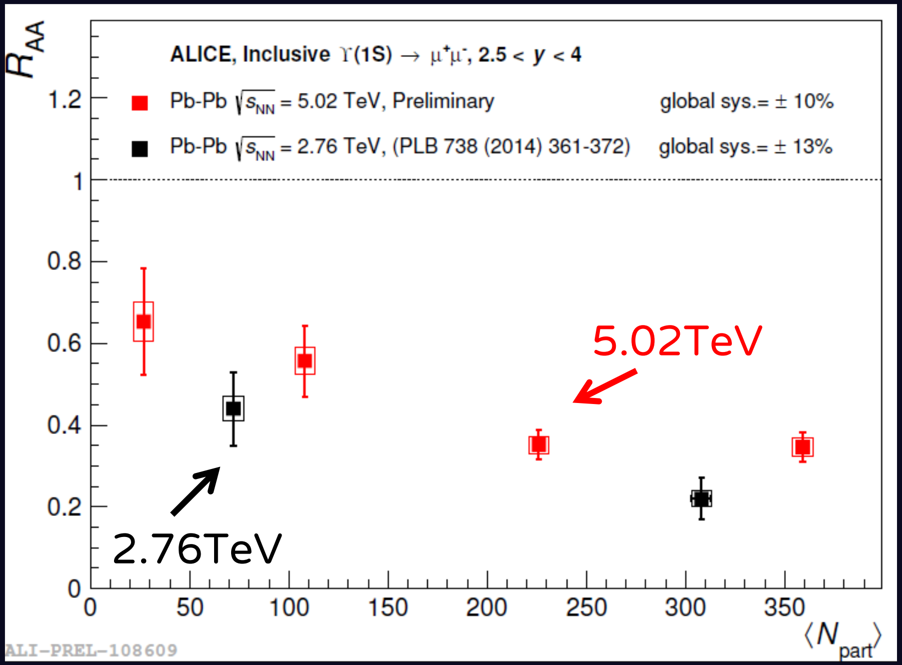
LHC Run-1 Υ(ns) results

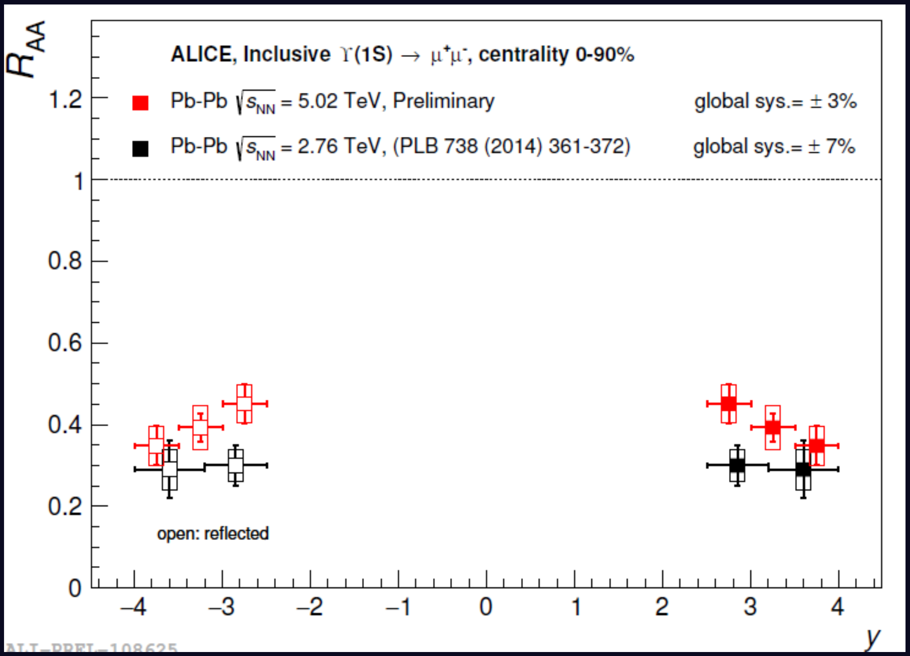




- no p_T or y dependence of the Υ(1S) and Υ(2S) suppressions
- models reproduce the p_T and centrality dependence
- rapidity description still needs tuning

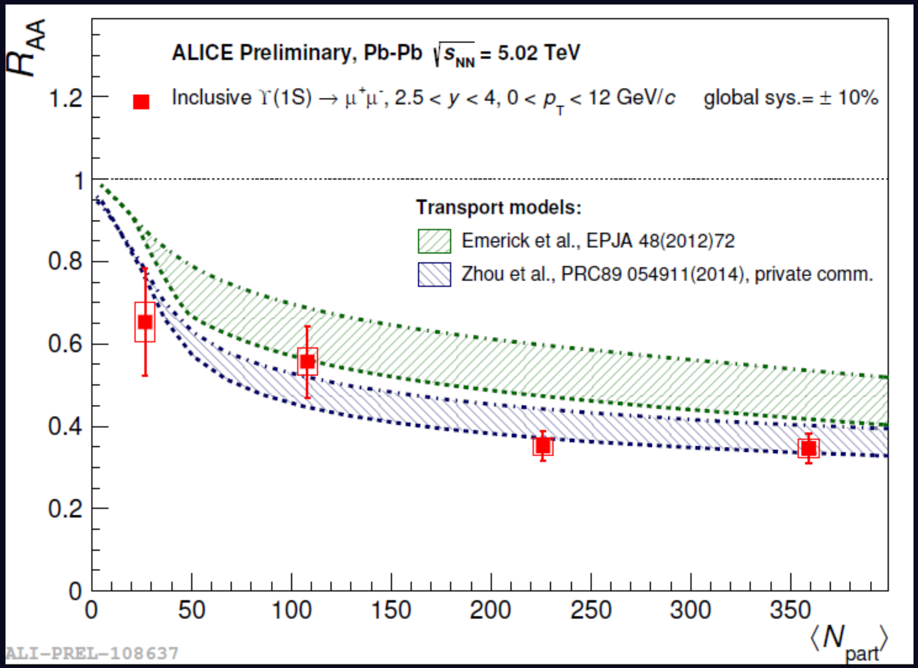
LHC Run-2 ϒ(ns) results

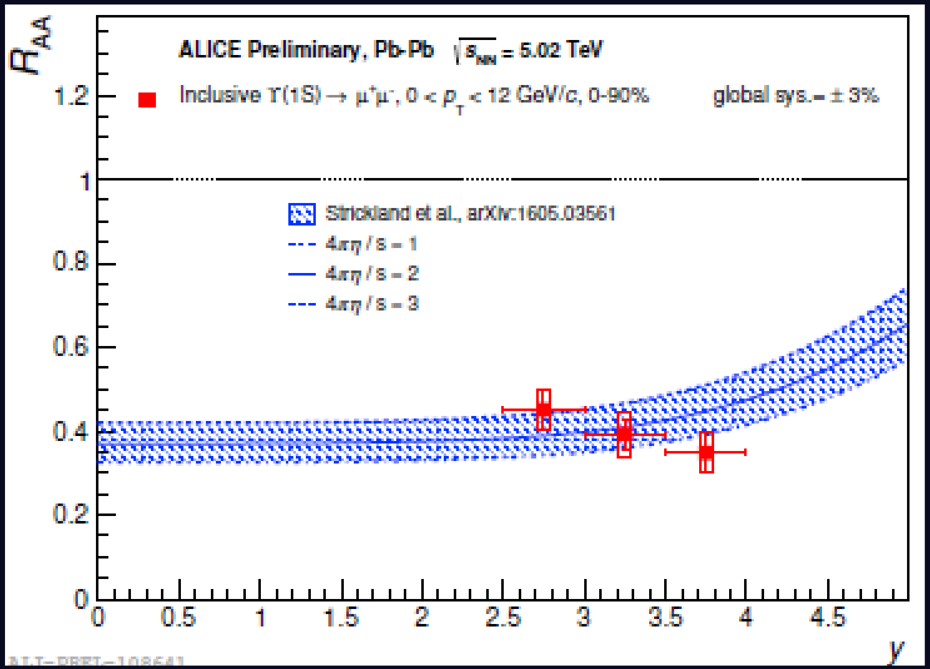




- Centrality dependent ϒ(1S) R_{AA} suppression observed also at $\sqrt{s_{NN}}$=5.02TeV
- No firm conclusion on the R_{AA} energy dependence within the current uncertainties

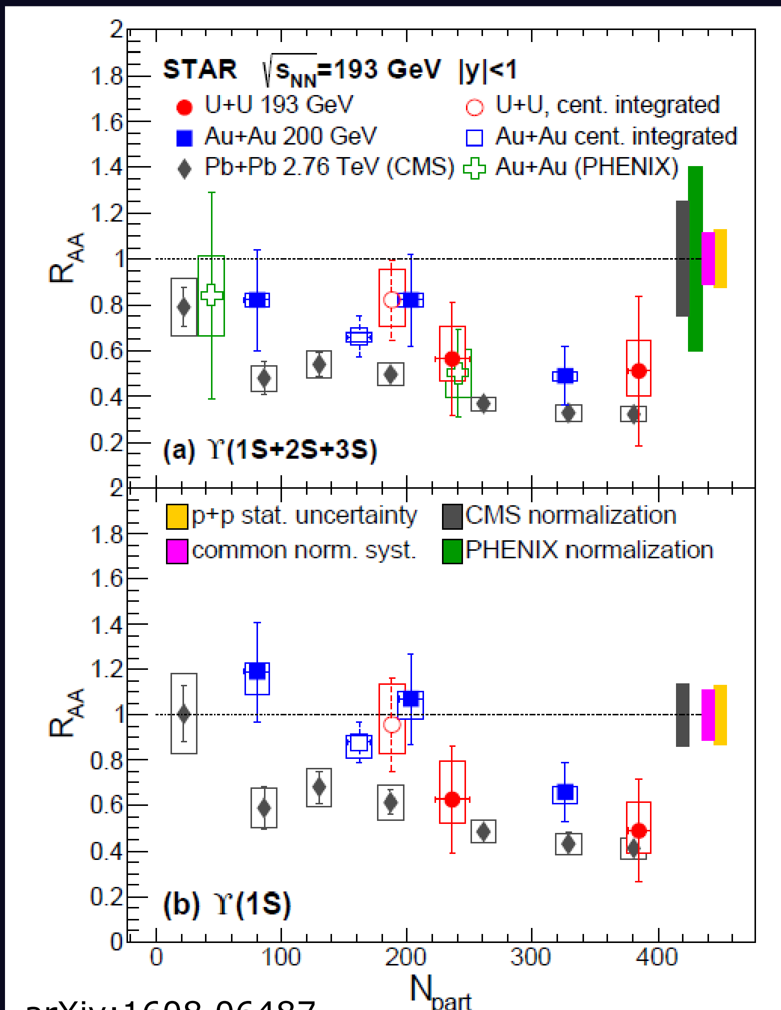
ϒ(ns) theory models





- Theory models, with (Emerick et al.) or without (Zhou et al.) regeneration component, qualitatively reproduce the data within uncertainties
- Different trend in data and theory for most forward-y?

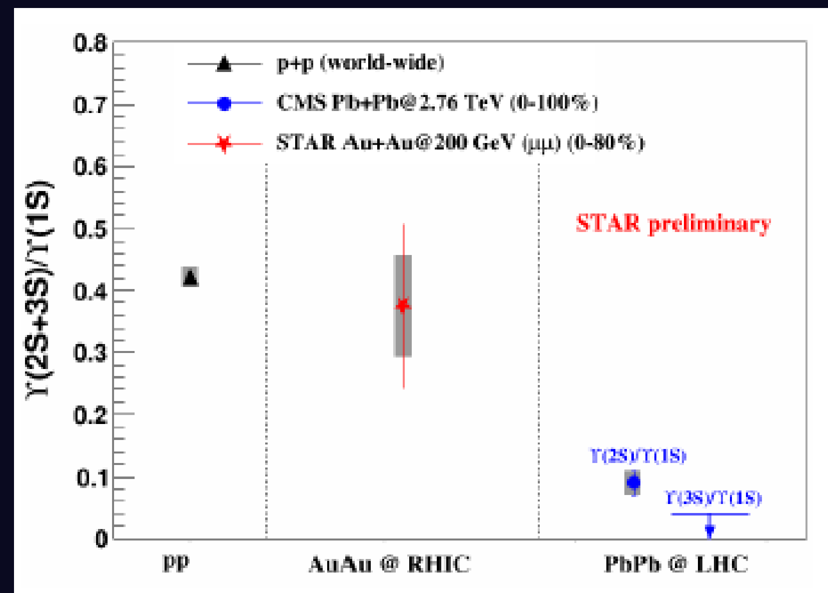
Υ(ns) at RHIC



arXiv:1608.06487

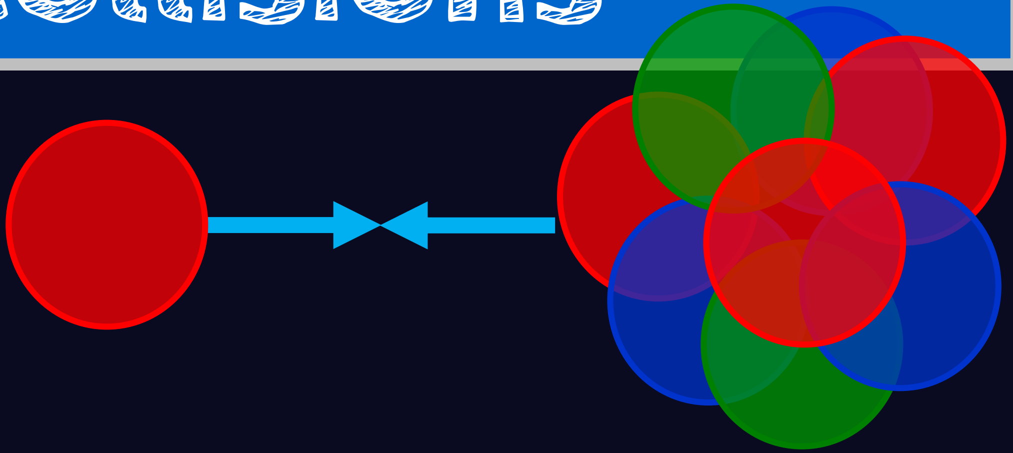
- Υ(1S) is also suppressed at RHIC, in central collisions, even if less wrt LHC

$R_{AA}(\Upsilon(1S))$= 0.63±0.13±0.09 (AuAu+UU)

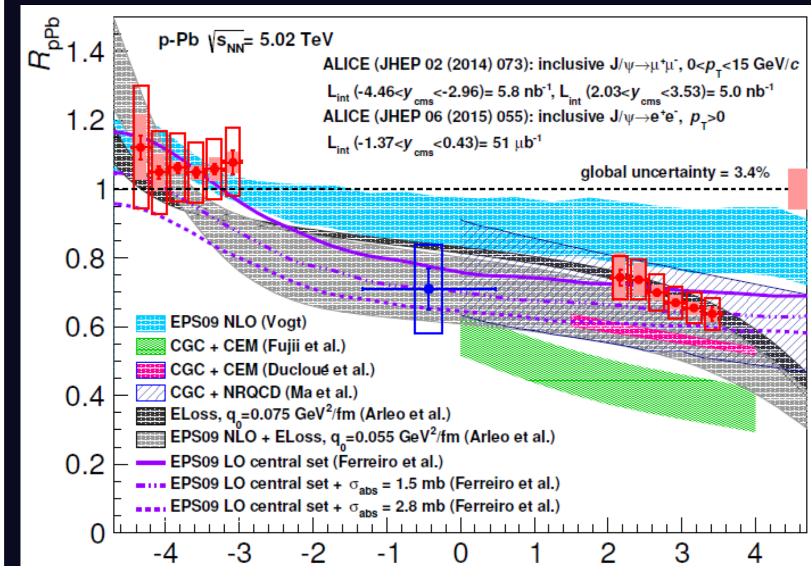


- STAR: excited states accessible in the muon channel
- Hint of less suppression of excited states wrt LHC

Quarkonium in p-A collisions



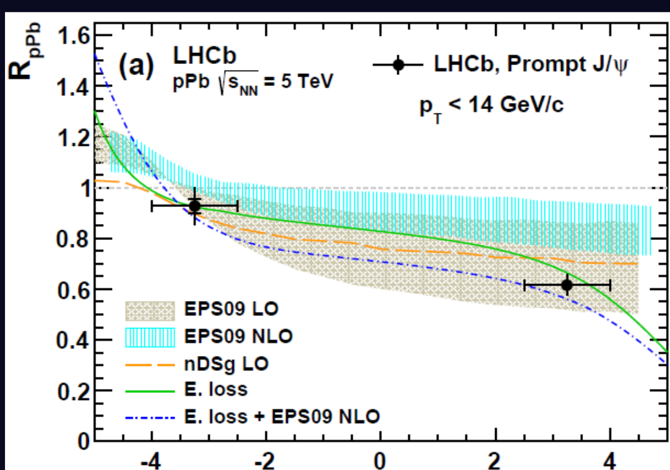
pA J/ψ results at LHC



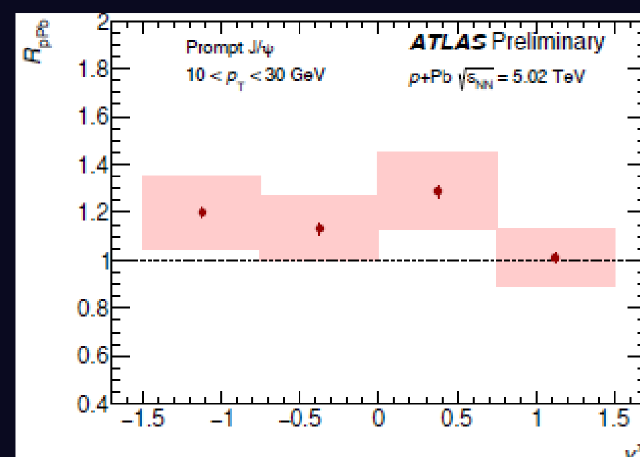
JHEP 02(2014)073, JHEP 06(2015)055

J/ψ affected by CNM effects, with a strong y and p_T dependence:
→ R_{pA} decreases towards forward y

- data consistent with shadowing and coherent parton energy loss models
- agreement with CGC depends on implementation
- good agreement between ALICE and LHCb (similar kinematic range)
- different behavior at mid-y for low and high p_T J.ψ



JHEP 02(2014)072

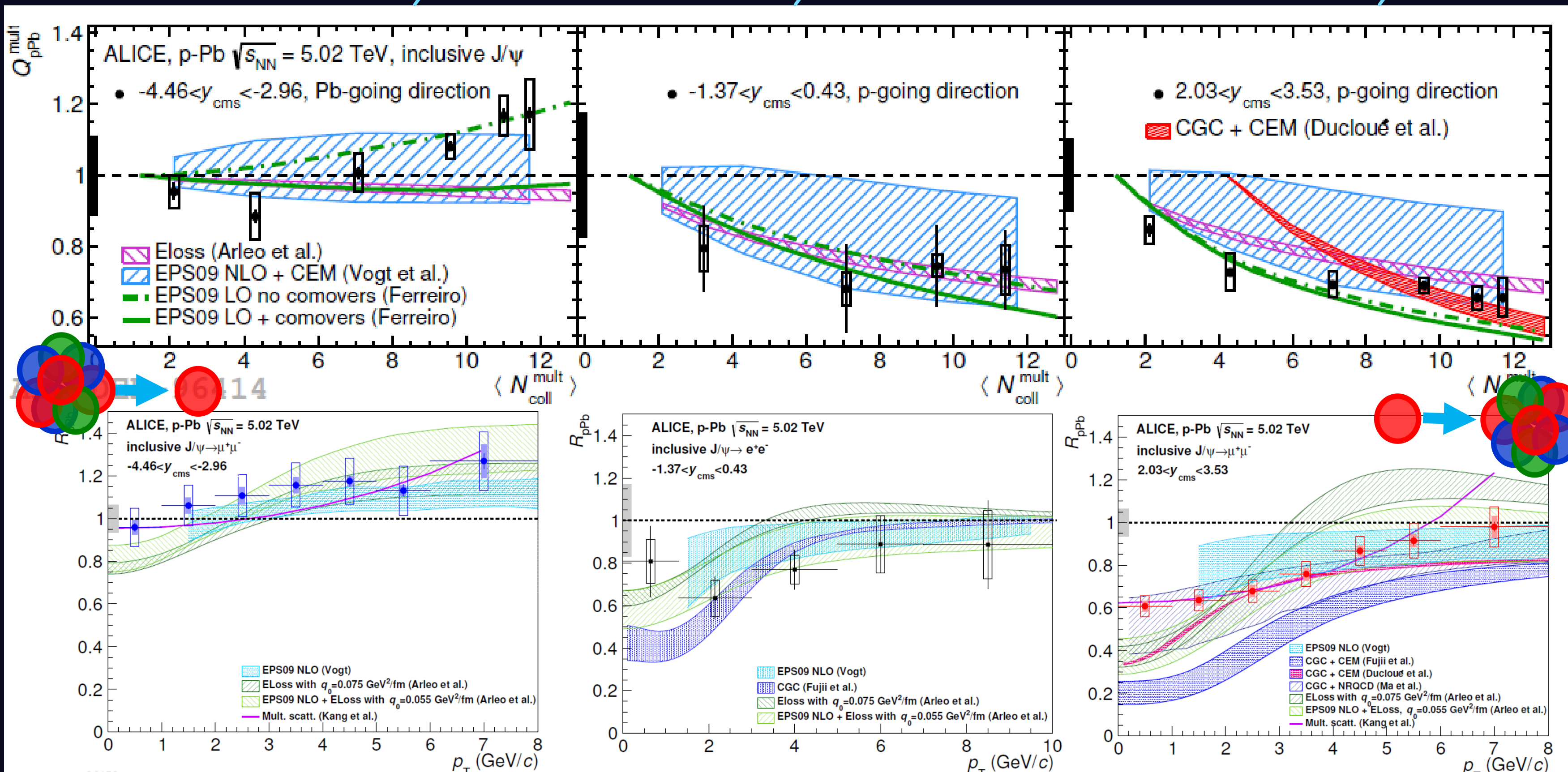


J/ψ vs pT and centrality

backward-y mid-y forward-y

centrality

transv. momentum



mid and fw-y: suppression increases vs centrality and is larger at low p_T

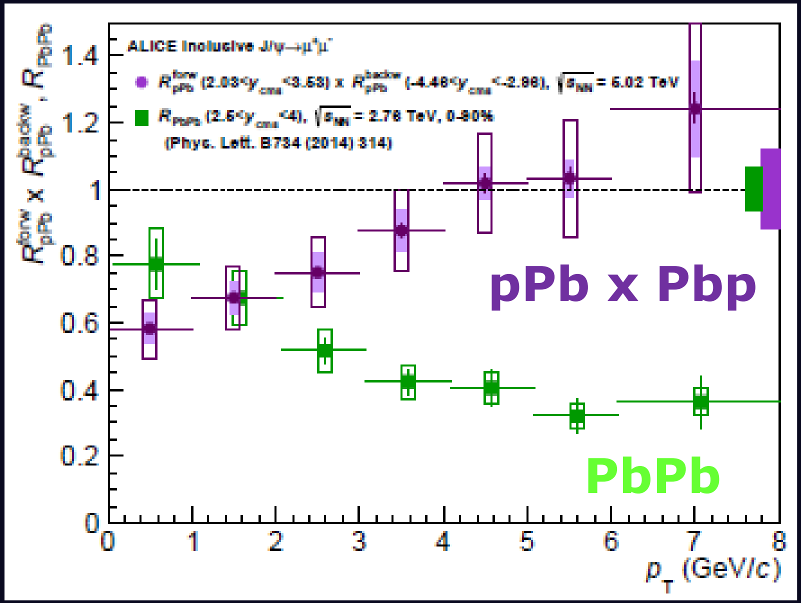
backward-y: hint for increasing Q_{pA} vs centrality, with rather flat p_T trend

➡ Shadowing and coherent energy loss models in fair agreement with data

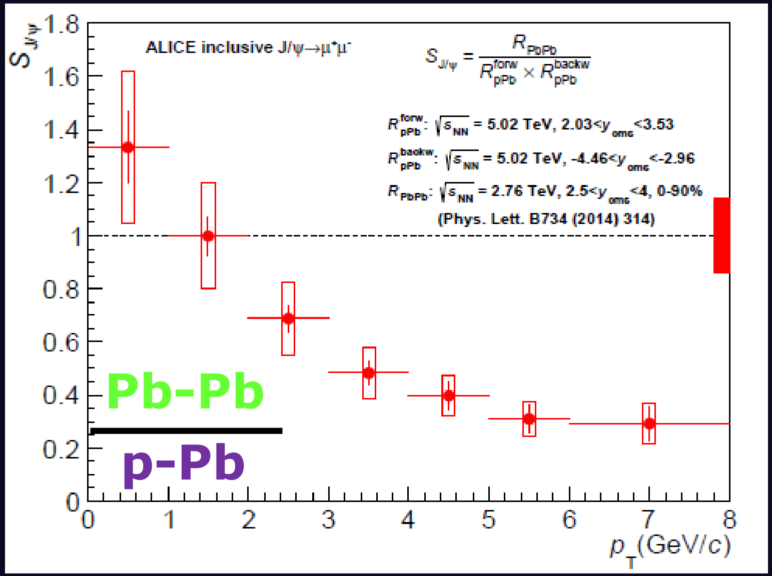
From pA to AA

Once CNM effects are measured in pPb, 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}, similar x-coverage as PbPb



we get rid of CNM effects with AA / pA x Ap



CNM effects not enough to explain PbPb data at high p_T

Evidence for hot matter effects in Pb-Pb!

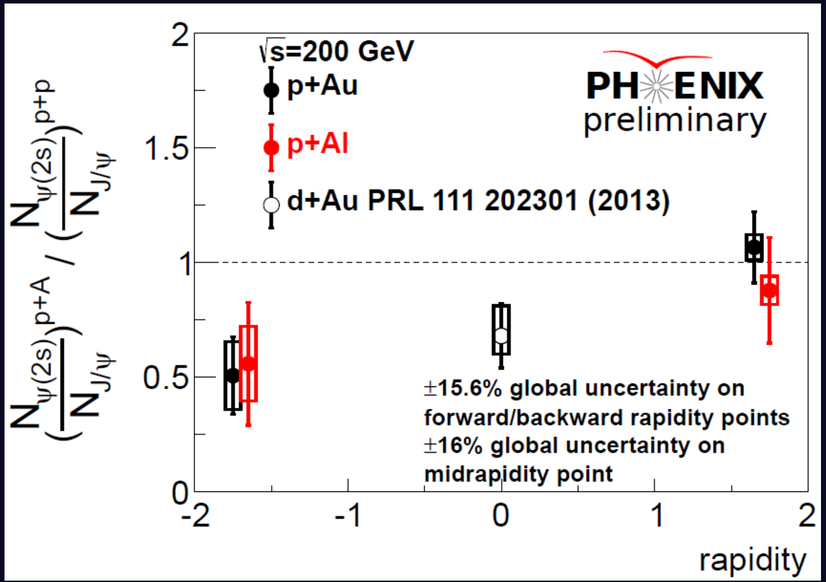
ψ(2S) production in pA, dA

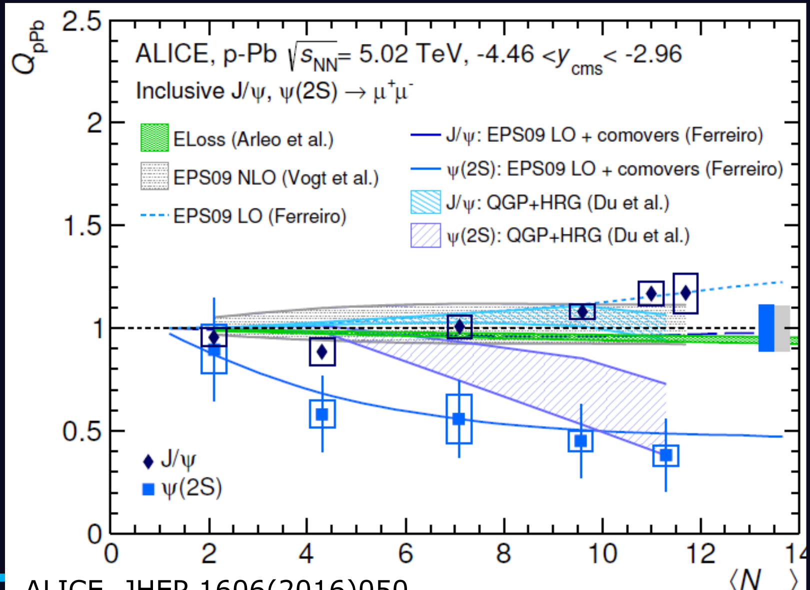
ψ(2S) suppression is stronger than the J/ψ one, both at RHIC and LHC

→ unexpected since time spent by the cc in the nucleus (τ_c) is shorter than charmonium formation time (τ_f)

→ shadowing and energy loss, almost identical for J/ψ and ψ(2S), do not account for the different suppression

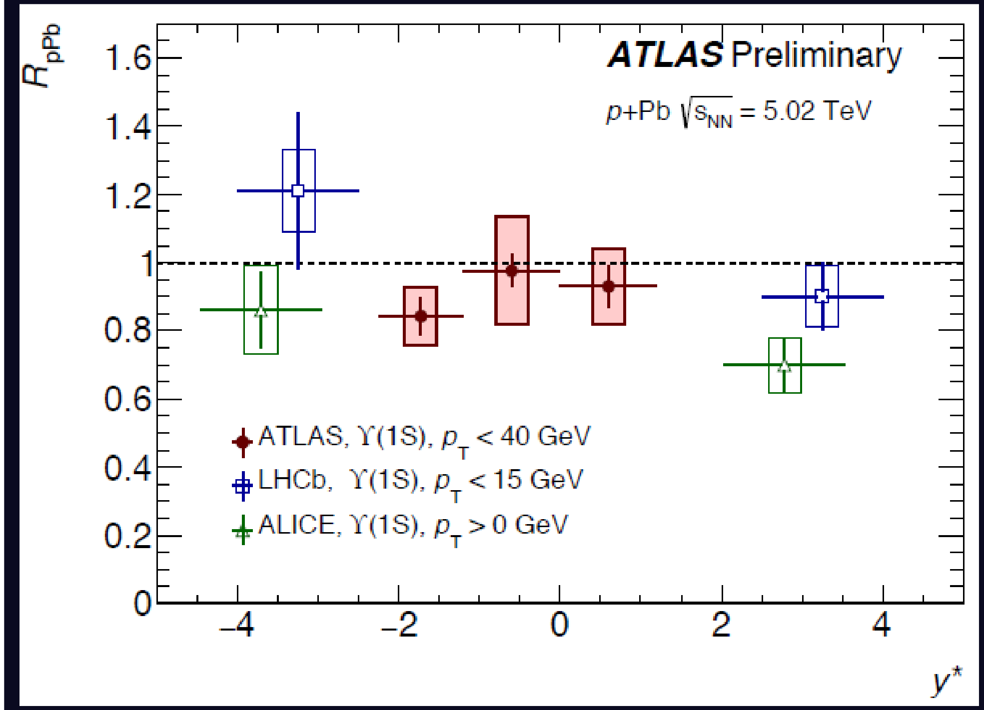
Only models including QGP + hadron resonance gas or comovers describe the stronger ψ(2S) suppression





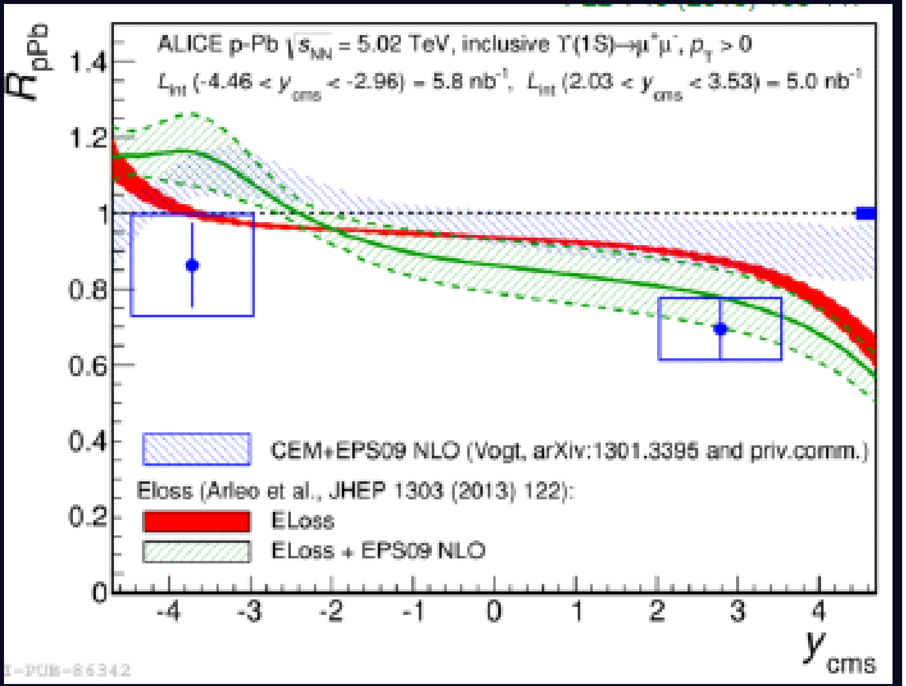
ALICE, JHEP 1606(2016)050

Υ(1s) in pA collisions



- No significant rapidity dependence of Υ(1S) R_{pA} (ALICE and LHCb agree within uncertainties)

- Shadowing and energy loss models are compatible at forward-y
  At backward-y smaller anti-shadowing is suggested

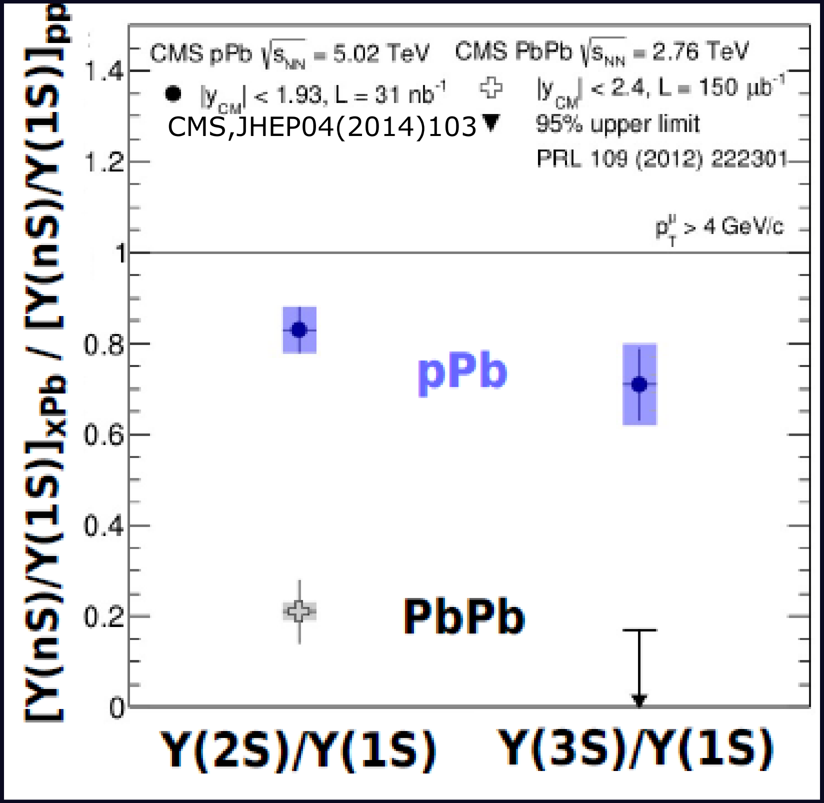


ALICE, Phys. Lett. B 740 (2015) 105
ATLAS-CONF-2015-050 ,LHCb, JHEP 07(2014)094

Υ excited states in pA

p-Pb vs pp @mid-y:
Stronger excited states suppression with respect to Υ(1S)
Initial state effects similar for the three Υ states
→ Final states effects in p-Pb?

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



➡ 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

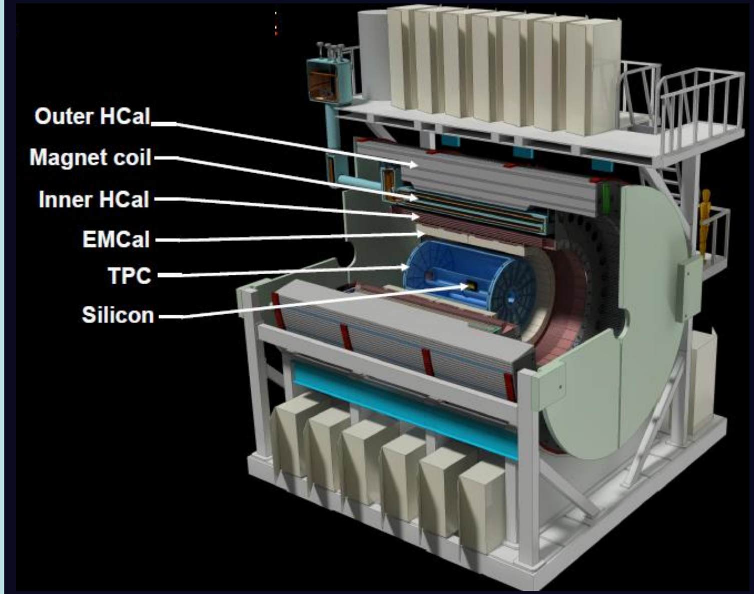
compatible with pp results
0.26 ± 0.08 (ALICE, pp@7TeV)

➡ Rapidity dependent final state effects at play?

RHIC and LHC Prospects

sPHENIX (>2020)

Precision Υ spettroscopy (80MeV resolution expected)

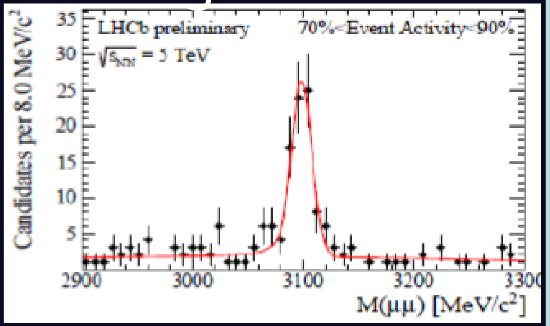


LHC heavy-ion program

2016: pA at $\sqrt{s_{NN}}$ = 5.02 and 8 TeV
2018: PbPb
2021 - 2023: LHC Run3 – L_{int} > 10nb^{-1} for PbPb (is ~1nb^{-1} in Run2)
2026 – 2029 : LHC Run4

LHCb

Joined the PbPb data taking in 2015: covers peripheral semi-periph. Range



SMOG: fixed target pA program at LHC, up to $\sqrt{s}$ =110 GeV

Conclusions

A large sample of quarkonium results in various systems and at various energies is now available from both RHIC and LHC!

- A combination of suppression and regeneration mechanisms affects J/ψ production at RHIC and LHC
- Theory models qualitatively describe the data, but still large uncertainties (open charm cross section)
- CNM effects (mainly shadowing and energy loss) play an important role, as observed in pA collisions
- Bottomonium results might be compatible with sequential suppression in QGP

Thanks!

Conclusions

A large sample ... t

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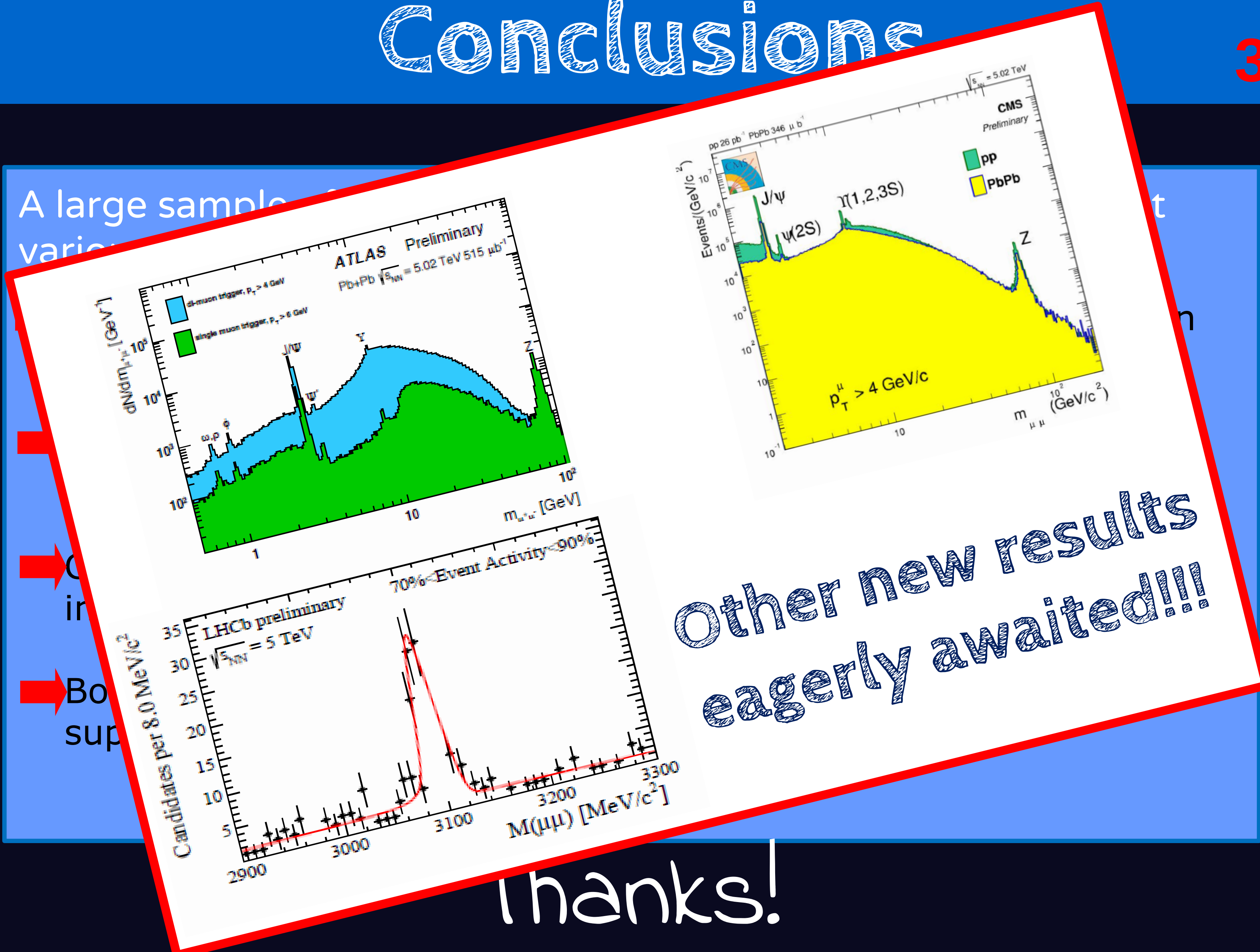
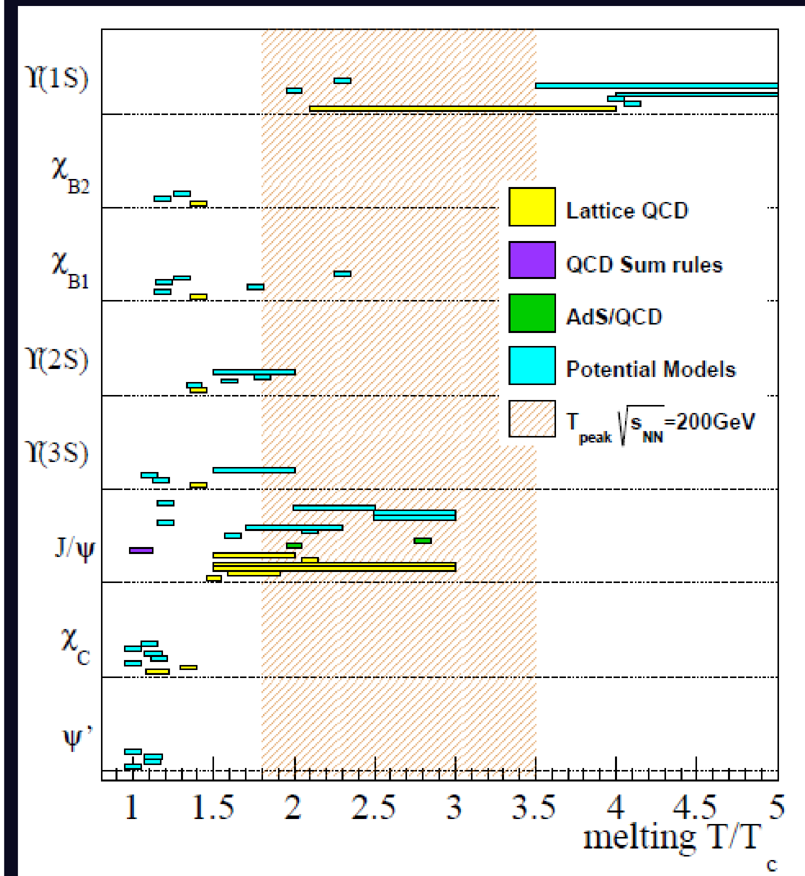


Thanks!

Backup slides

AA: from suppression...



PHENIX, Phys.Rev C91, 024913

the original idea:

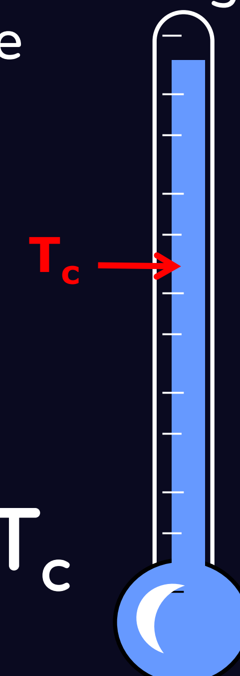
quarkonium production suppressed via color screening in the QGP

sequential melting

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

ψ(2S) J/ψ Υ(1S)

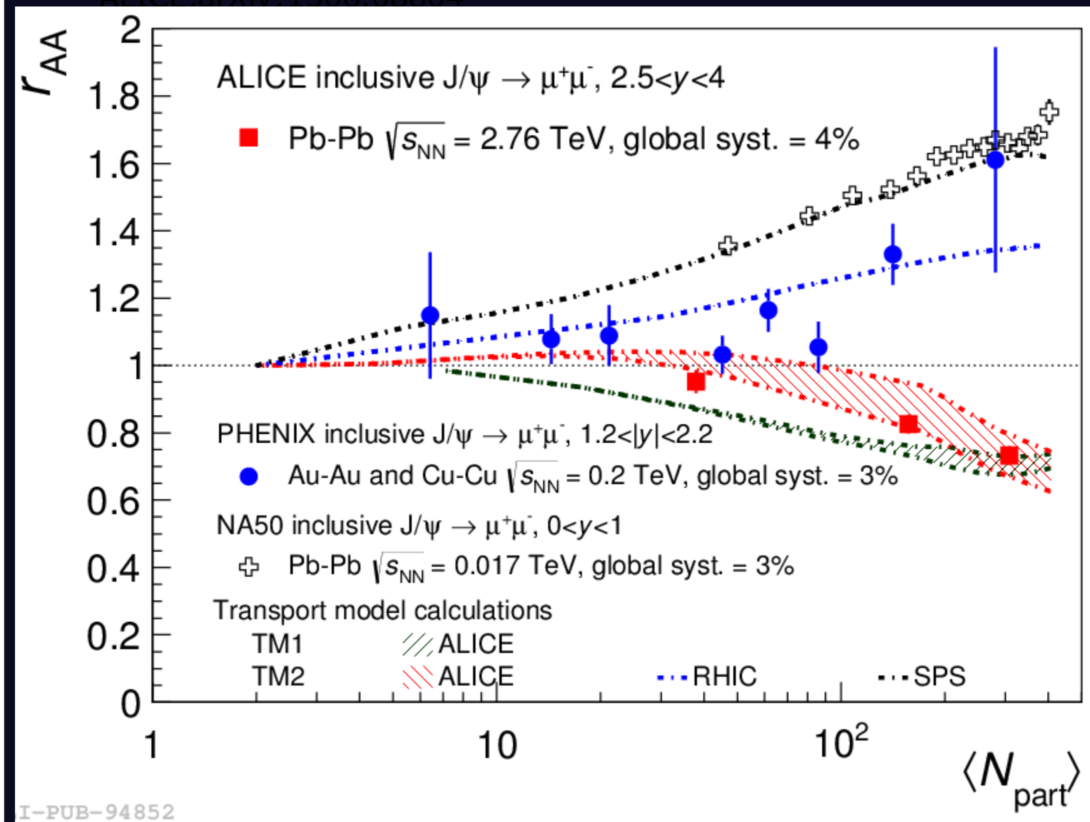
$T>>T_c$

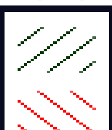


Quarkonium as QGP thermometer

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

ALICE arXiv:1506.08804





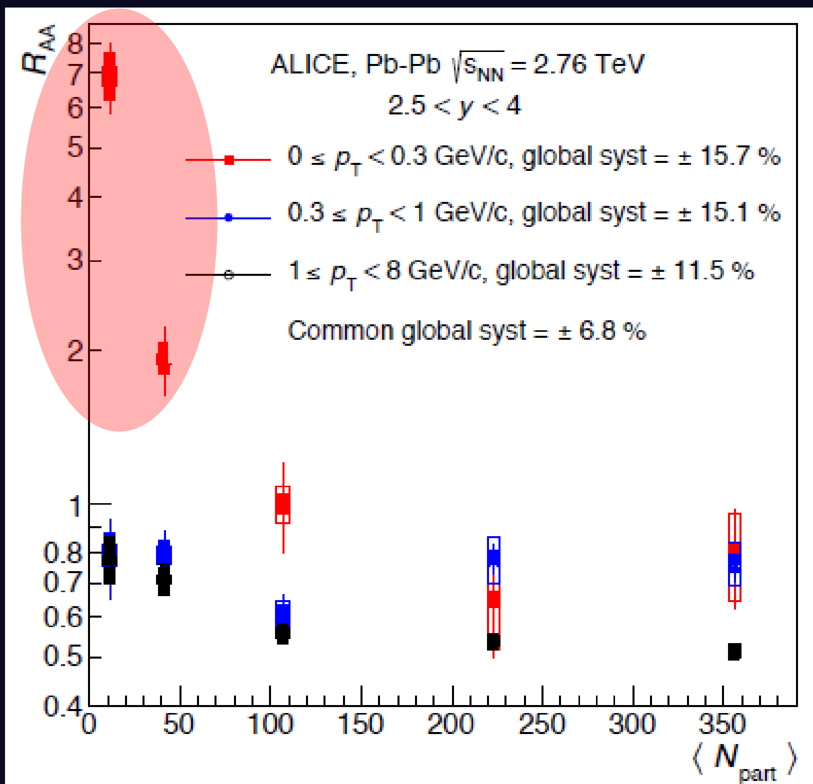
TM1: Zhao et al., Nucl.Phys.A859 (2011) 114
TM2: Zhou et al. Phys.Rev.C89 (2014)054911

$$r_{AA} = \frac{\langle p_T^2 \rangle_{AA}}{\langle p_T^2 \rangle_{pp}}$$

- r_{AA} centrality evolution strongly depends on √s
- decreasing r_{AA} trend, observed at LHC
  → due to (re)combination, which dominates J/ψ production at low p_T
- transport models, already describing J/ψ R_{AA}, also reproduce the r_{AA} evolution

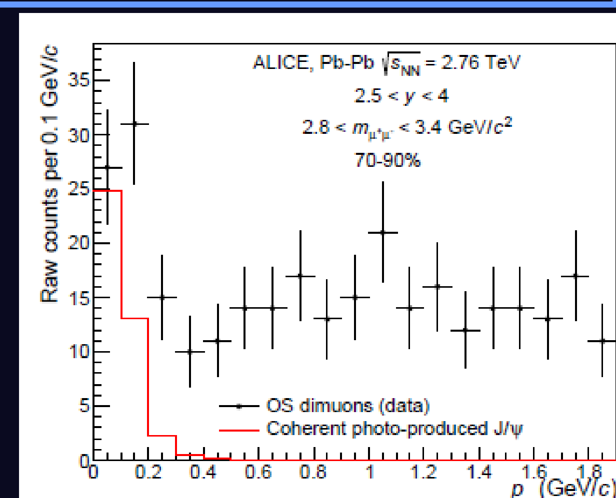
J/ψ at very low p_T

- Strong R_{AA} enhancement in peripheral collisions for $0<p_T<0.3$ GeV/c



- significance of the excess is 5.4 (3.4)σ in 70-90% (50-70%)
- behaviour not predicted by transport models

- excess might be due to coherent J/ψ photoproduction in PbPb (as measured also in UPC)

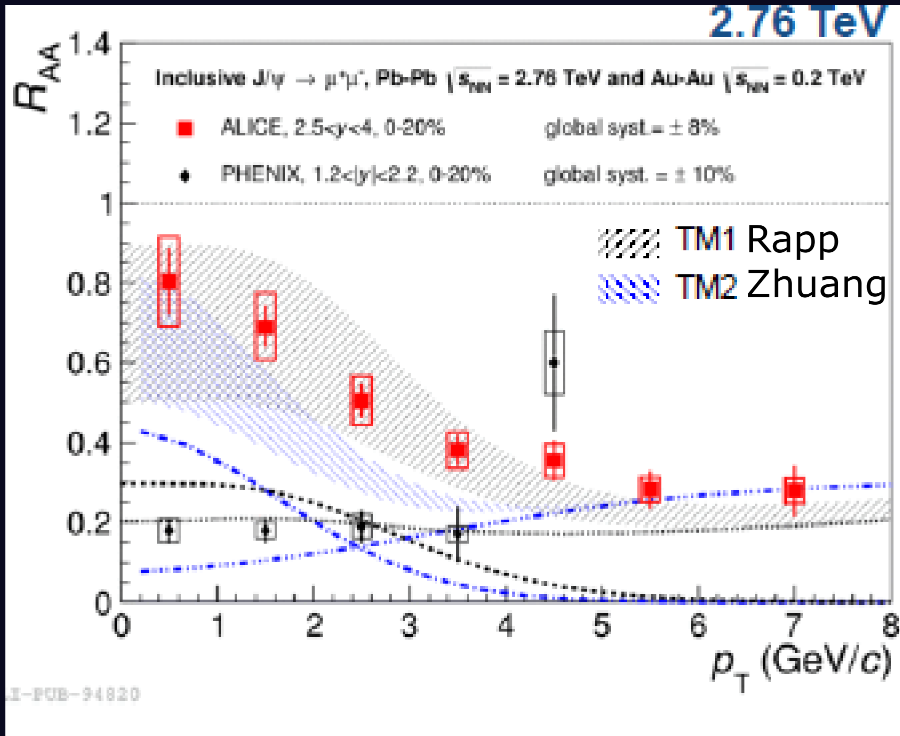


- if excess is "removed" requiring $p_T^{J/\psi}$>0.3GeV/c → ALICE R_{AA} lowers by 20% at maximum (in the most peripheral bin)

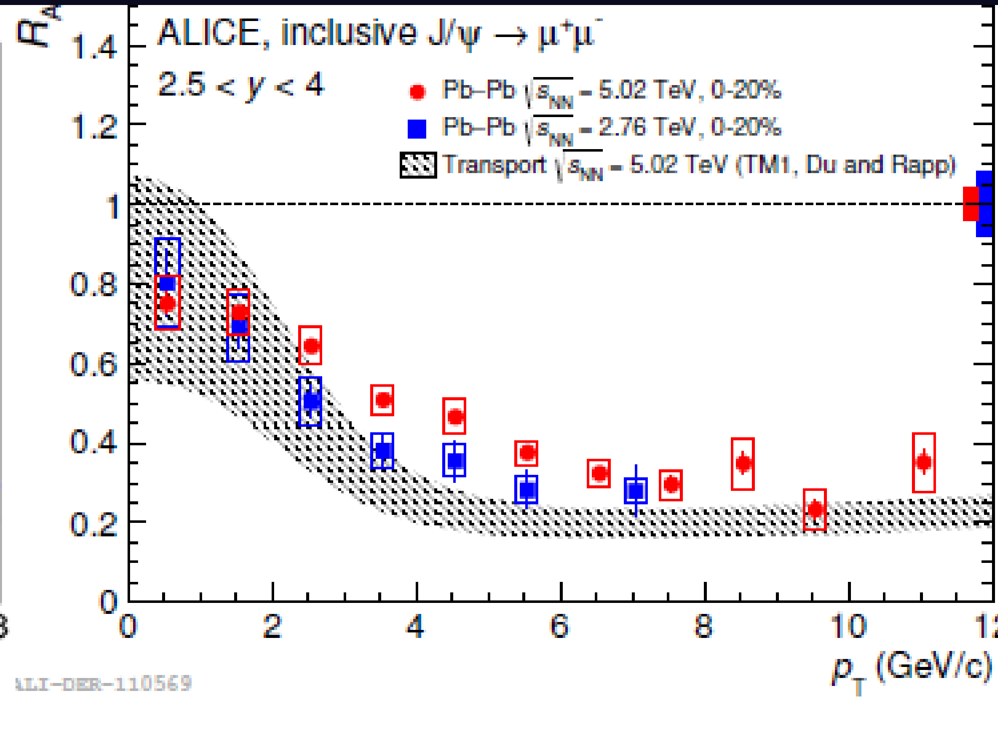
RAA vs pT

ALICE, PLB 734 (2014) 314, JHEP 07(2015)051, arXiv:1506.08804

2.76TeV



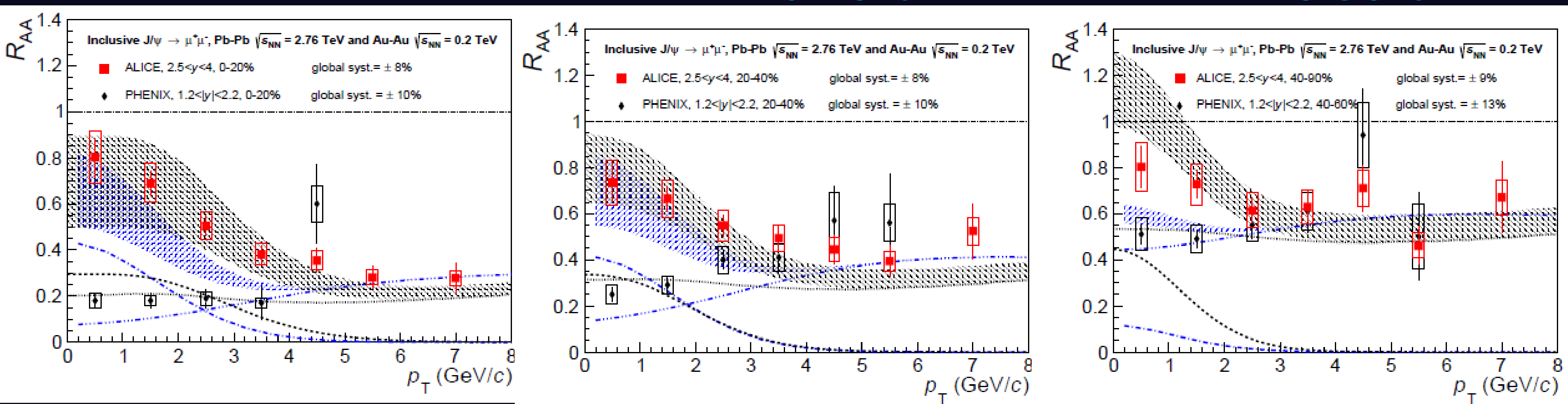
5.02TeV



Multi-differential J/ψ studies

- p_T-centrality multi-differential studies allows detailed comparison with theory models

0-20% 20-40% 40-90%



TM1 Zhao et al., Nucl.Phys.A859 (2011) 114

TM2 Zhou et al. Phys.Rev.C89 (2014)054911

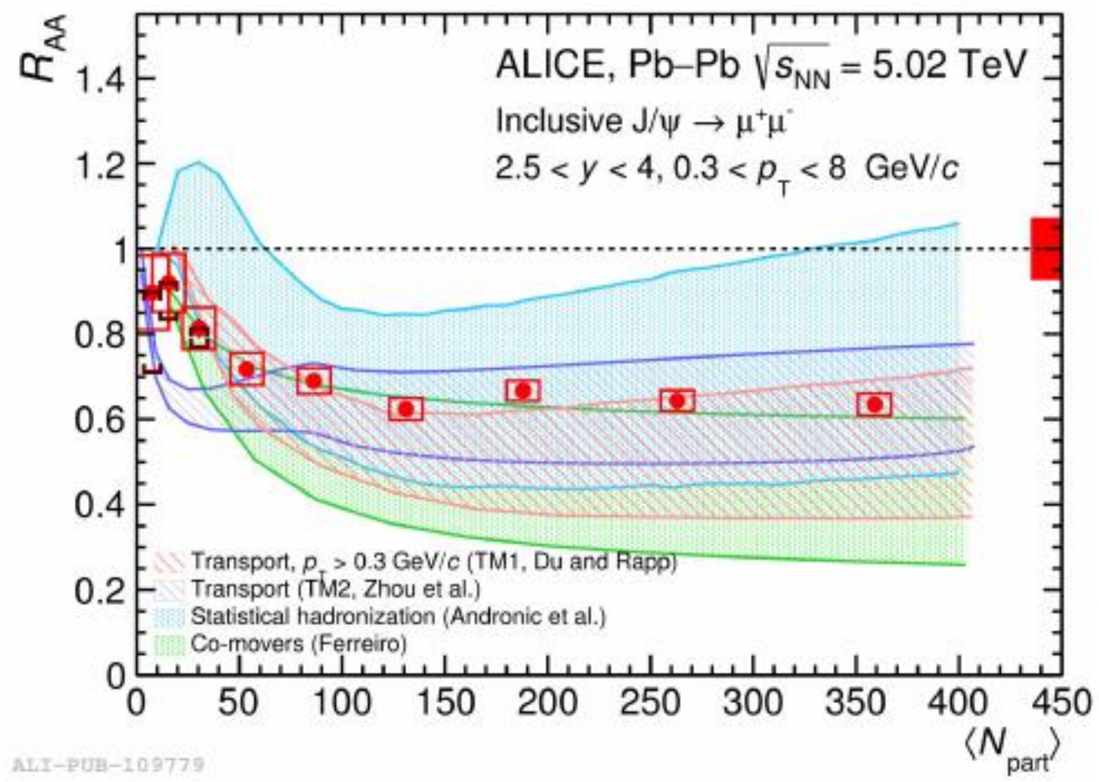
ALICE, arXiv:1506.08804

- Primordial J/ψ (TM1)
- Regenerated J/ψ (TM1)
- Primordial J/ψ (TM2)
- Regeneration J/ψ (TM2)

- Model provide a fair description of the data, even if with different balance of primordial/regeneration components

Still rather large theory uncertainties: models will benefit from precise measurement of σ_{cc} and CNM effects

LHC Run-2 J/ψ results

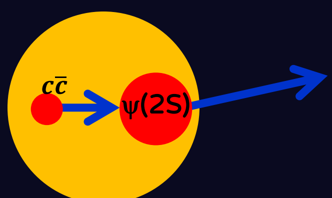


model	$\sigma_{c\bar{c}}$	N-N $\sigma_{J/\psi}$	comover $\sigma_{J/\psi}$	Shadowing
Transport(Rapp)	0.57 mb	3.14 μb	-	EPS09
Transport(Zhou)	0.82 mb	3.5 μb	-	EPS09
Stat. hadronization	0.45 mb	-	-	EPS09
Comovers	[0.45,0.7] mb	3.53 μb	0.65 mb	Glauber-Gribov theory

ψ(2S) production in pA

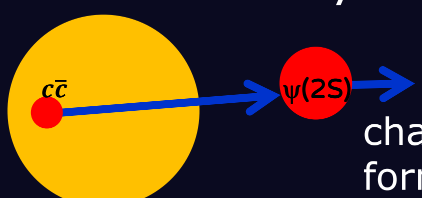
- Being more weakly bound than the J/ψ, the ψ(2S) is an interesting probe to have further insight on the charmonium behaviour in pA
- Low energy ψ(2S) p-A results from NA50, E866 and HERA-B:

<u>mid-*y* (x_F~0)</u>:
ψ(2S) suppression stronger than J/ψ one, interpreted via pair break-up
→ fully formed resonances traversing the nucleus



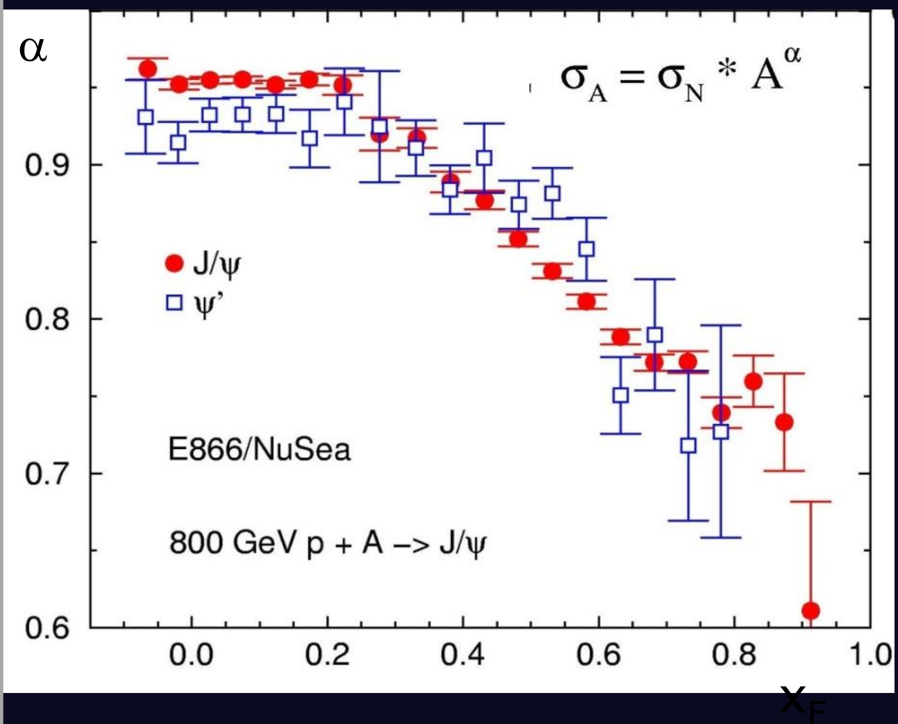
charmonium
formation time<crossing time

<u>forward-*y* (high x_F)</u>:
suppression becomes identical
→ dominated by energy loss

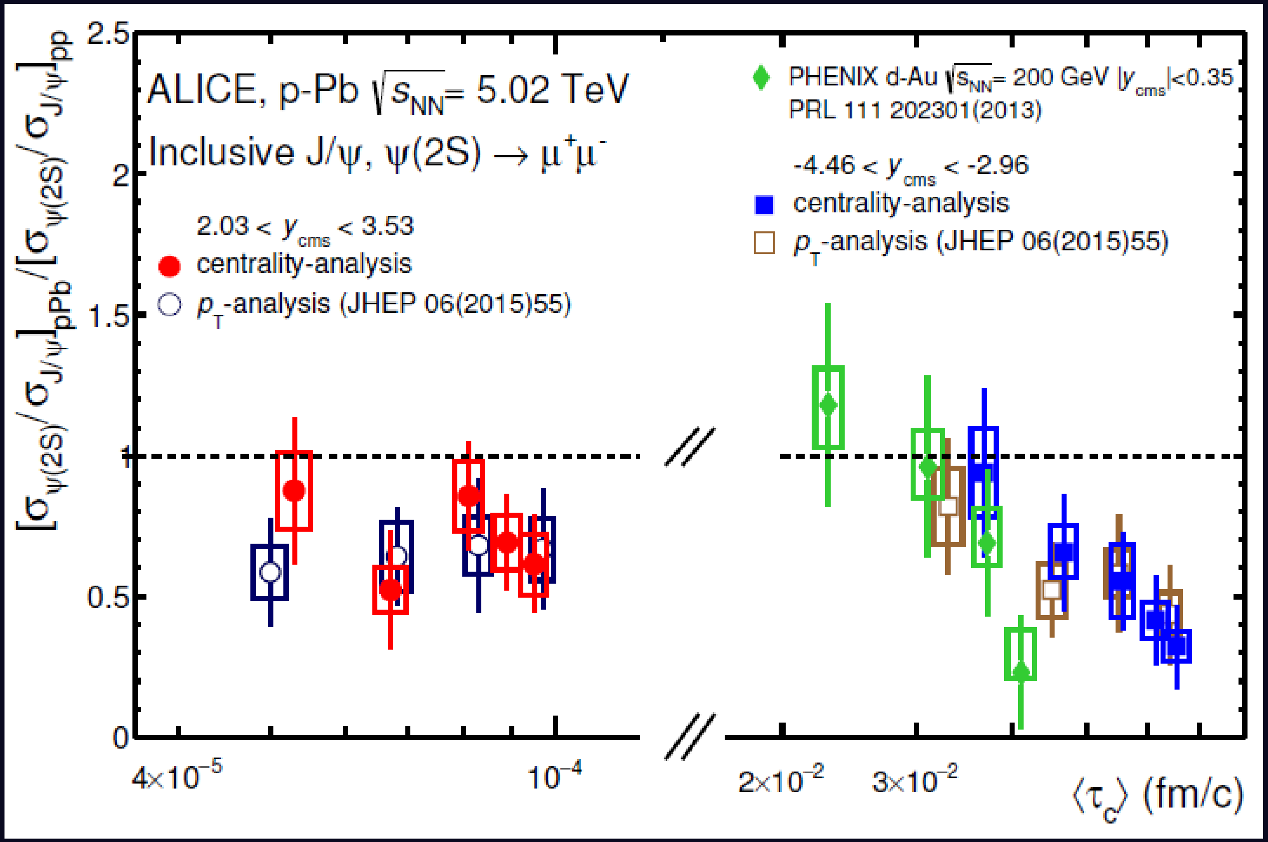


charmonium
formation time>crossing time

E866 Collab., PRL 84 (2000) 3256



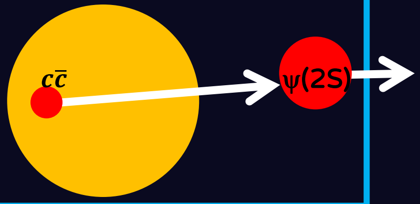
$\psi(2S)$ versus crossing time



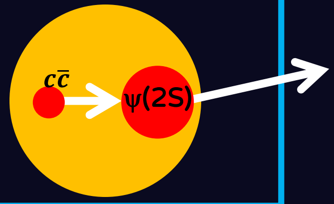
$$\tau_c = \frac{\langle L \rangle}{(\beta_z \gamma)}$$

D. McGlinchey, A. Frawley and R.Vogt, PRC 87,054910 (2013)

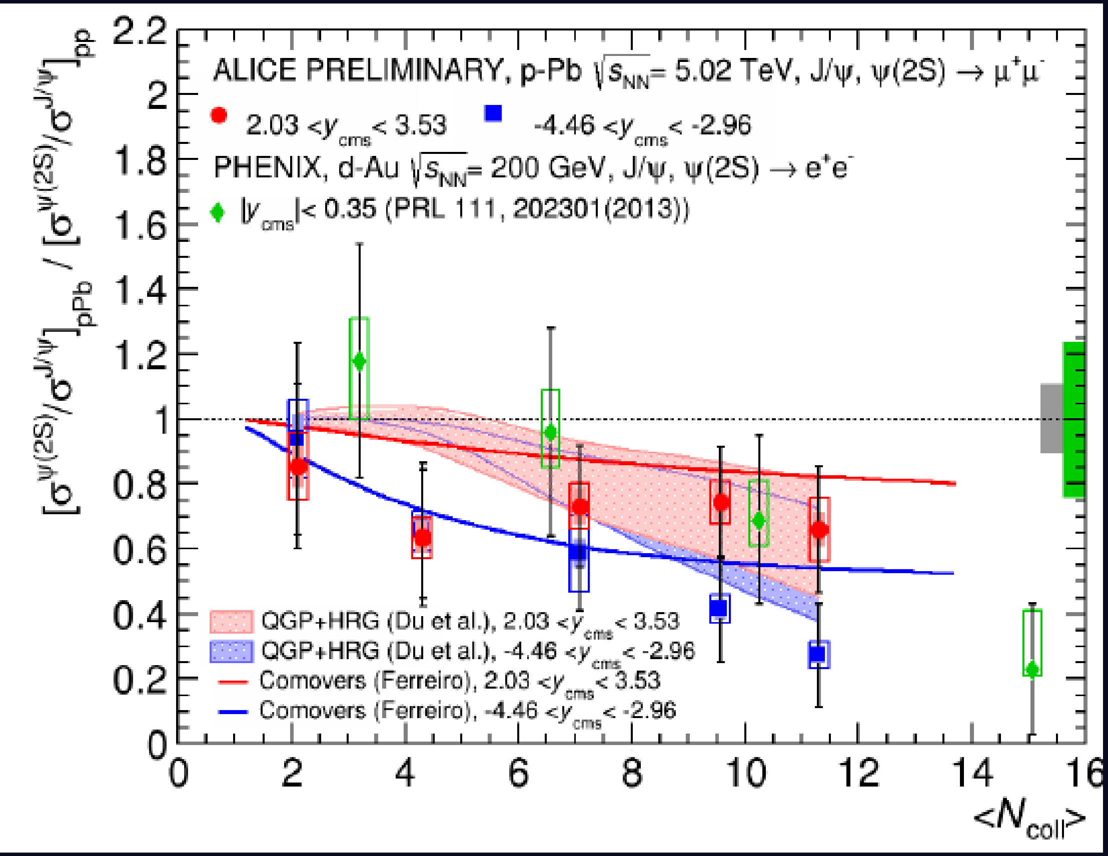
Forward-y: $\tau_c << \tau_f$
interaction with nuclear matter cannot play a role



Backward-y: $\tau_c \lesssim \tau_f$
indication of effects related to break-up in the nucleus?



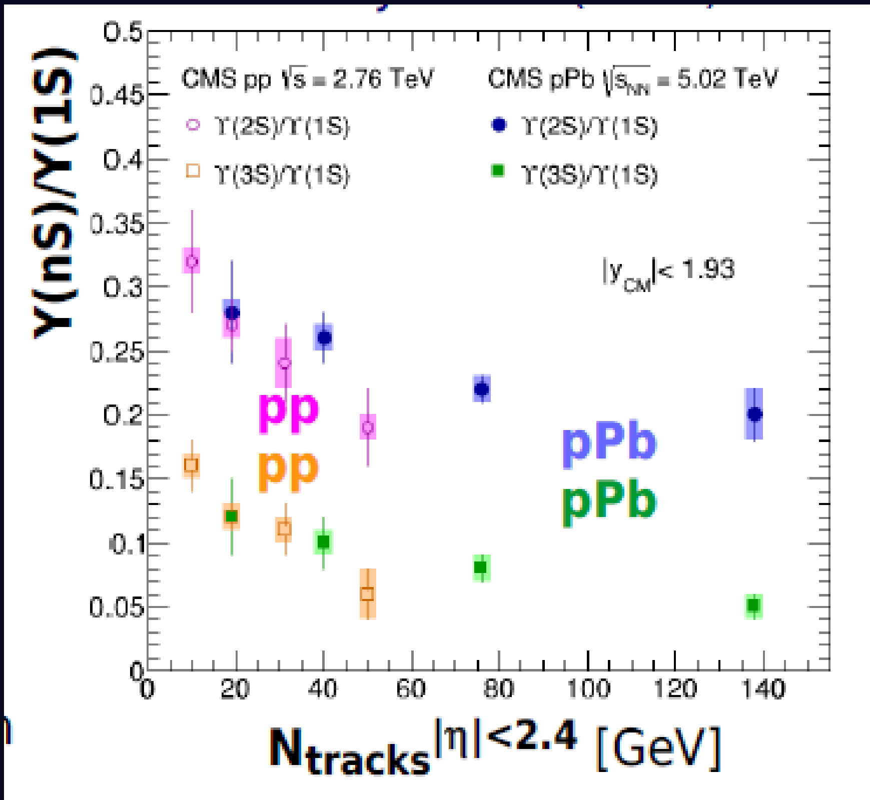
ψ(2S) / J/ψ double ratio



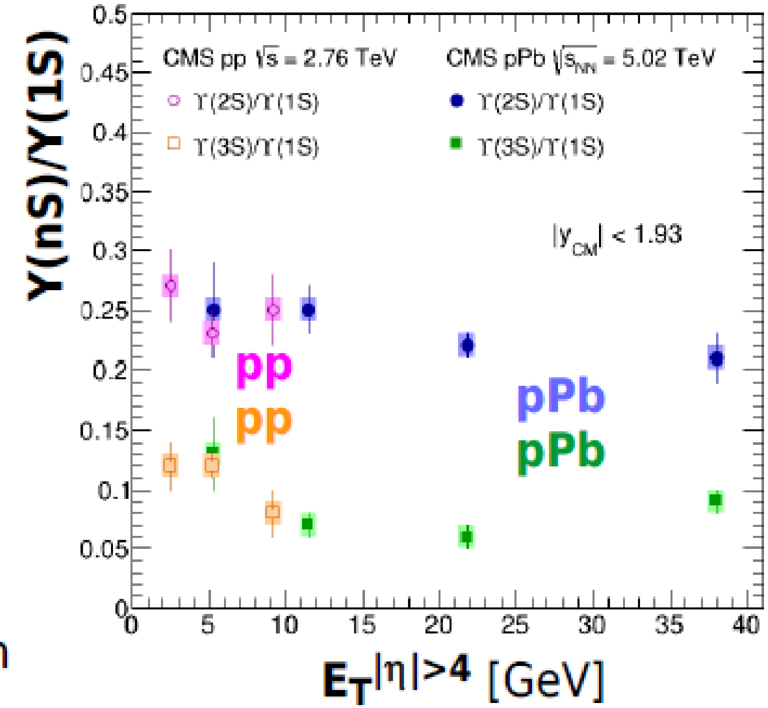
Similar suppression trend observed versus centrality, by both ALICE and PHENIX

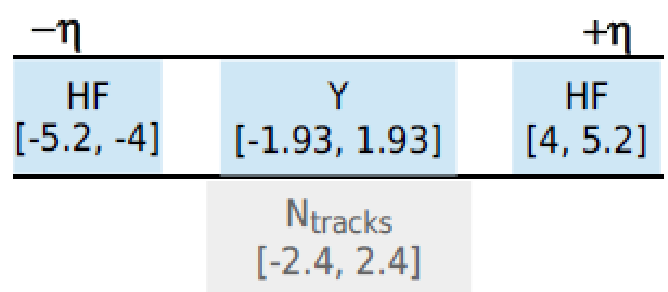
➡ QGP+hadron resonance gas (Rapp) or comovers models (Ferreiro) describe the observed suppression

Υ vs ev. activity



JHEP 04 (2014) 103

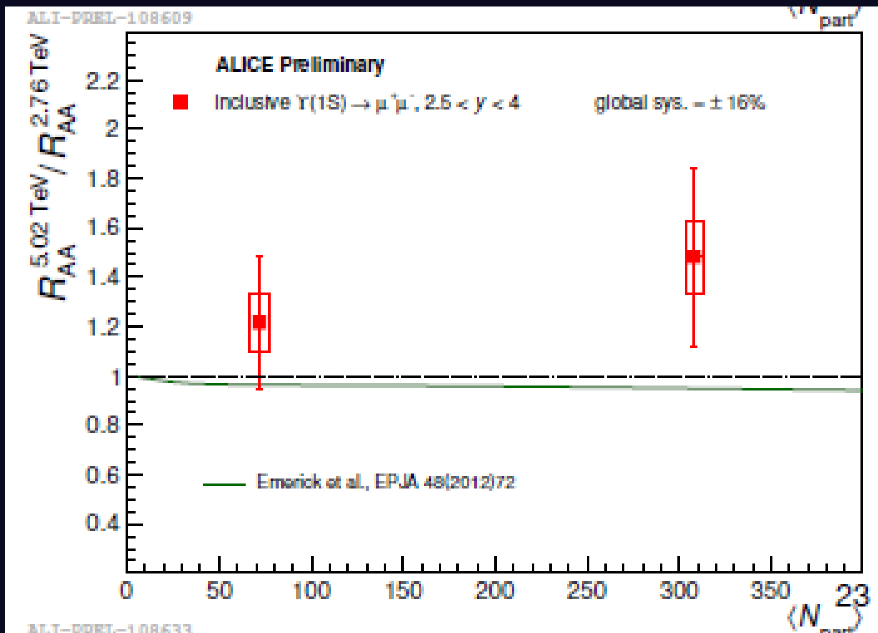


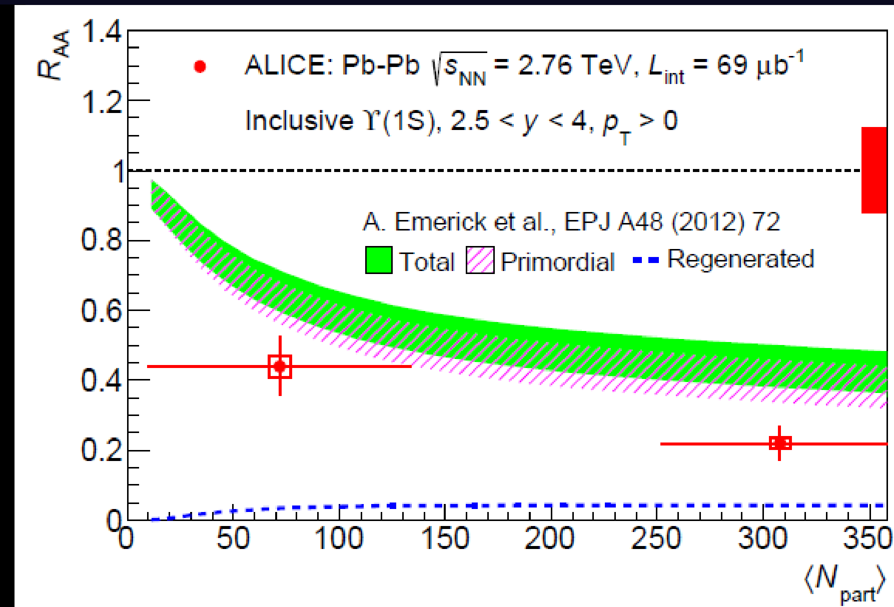


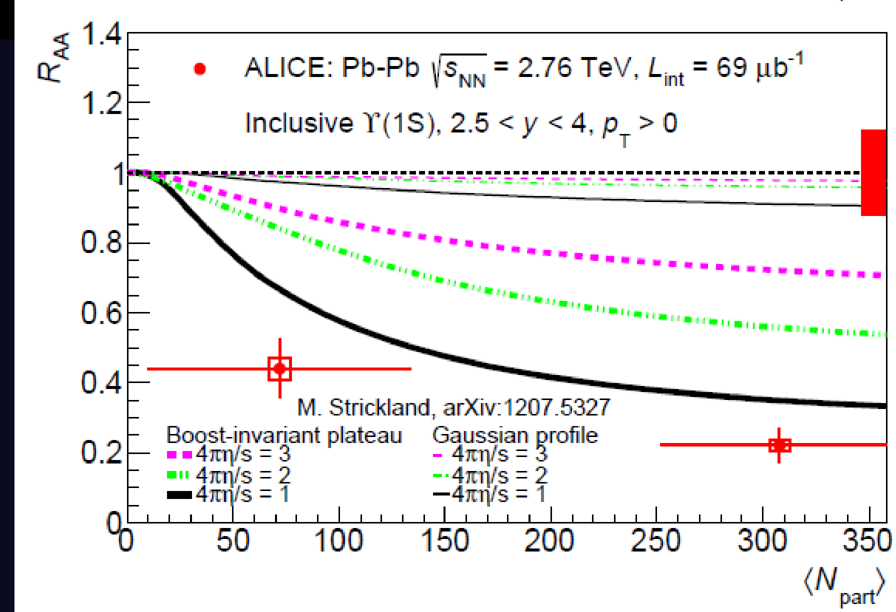
- Υ(nS)/Υ(1S) ratios fall with event-activity
  - Is the multiplicity affecting the Υ(nS)?
  - Are the Υ(nS) produced differently with multiplicity?

CMS

ϒ compared to theory

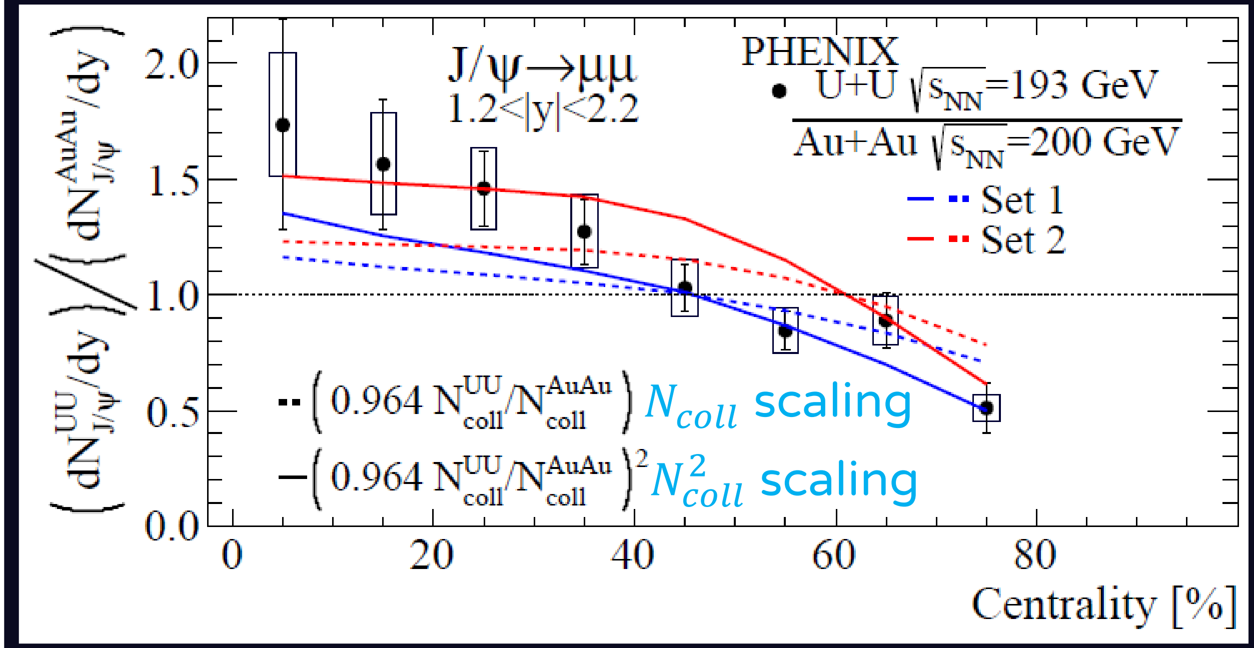






J/ψ production at RHIC

(re)combination/suppression role investigated comparing U-U and AuAu



in central U-U collisions:

1) stronger suppression due to color screening

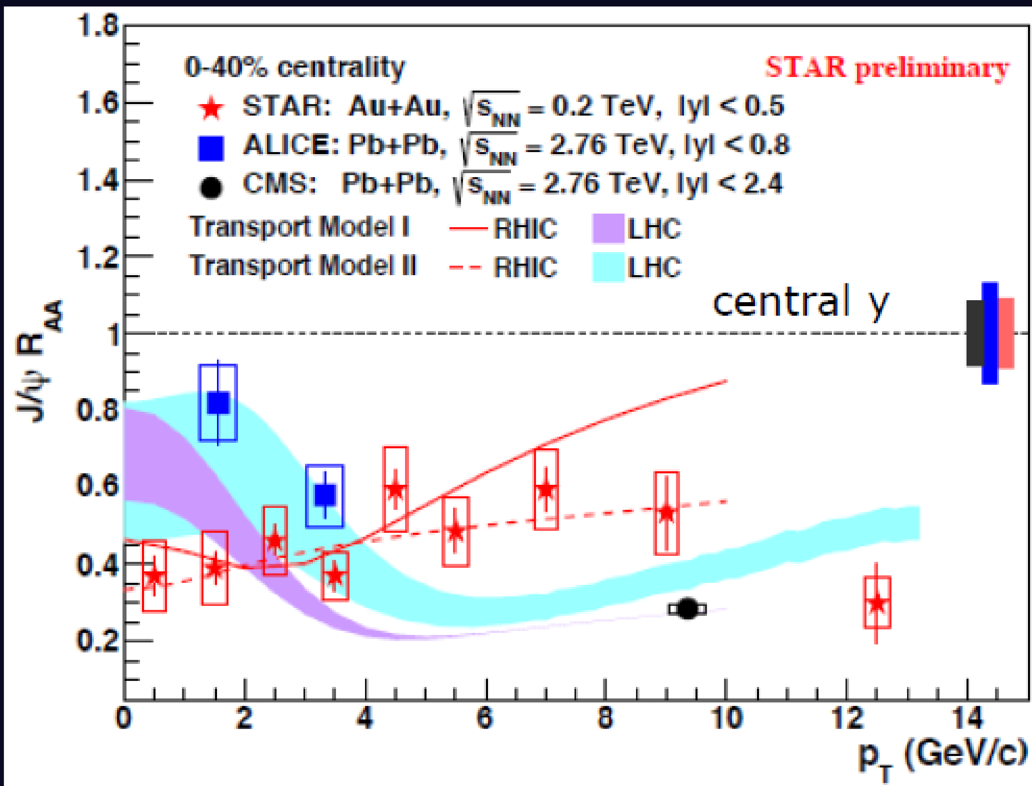
$\varepsilon_{AuAu} \sim 80\text{-}85\%\ \varepsilon_{UU}$

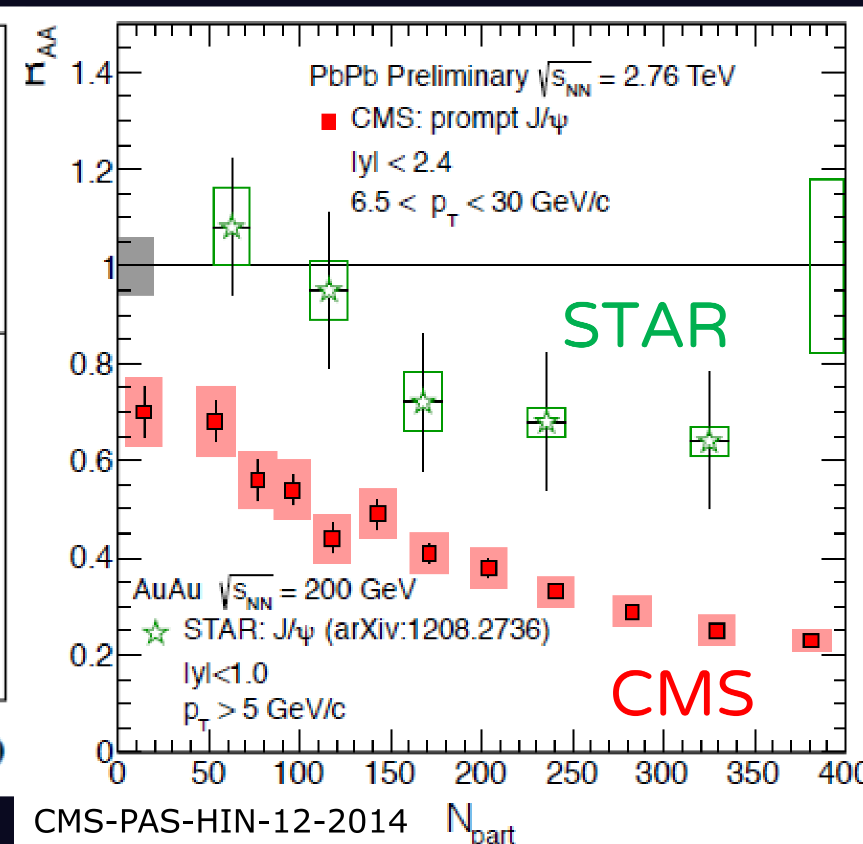
2) J/ψ recombination favoured by 25% larger N_{coll} in UU

$N^{stat}_{J/\psi} \sim N_c^2 \sim N_{coll}^2$

- results slightly favour N_{coll}^2 scaling → dominant (re)combination over suppression when going from central U-U to Au-Au collisions
- quantitative comparison depends on the choice of the uranium Woods-Saxon parametrizations

PHENIX, arXiv:1509.05380


0-40% centrality
STAR preliminary
STAR: Au+Au, $\sqrt{s_{NN}}$ = 0.2 TeV, |y| < 0.5
ALICE: Pb+Pb, $\sqrt{s_{NN}}$ = 2.76 TeV, |y| < 0.8
CMS: Pb+Pb, $\sqrt{s_{NN}}$ = 2.76 TeV, |y| < 2.4
Transport Model I — RHIC LHC
Transport Model II - - RHIC LHC
central y
J/ψ R_{AA}
p_T (GeV/c)


PbPb Preliminary $\sqrt{s_{NN}}$ = 2.76 TeV
CMS: prompt J/ψ
|y| < 2.4
6.5 < p_T < 30 GeV/c
STAR
AuAu $\sqrt{s_{NN}}$ = 200 GeV
STAR: J/ψ (arXiv:1208.2736)
|y|<1.0
p_T > 5 GeV/c
CMS
R_{AA}
N_{part}
CMS-PAS-HIN-12-2014

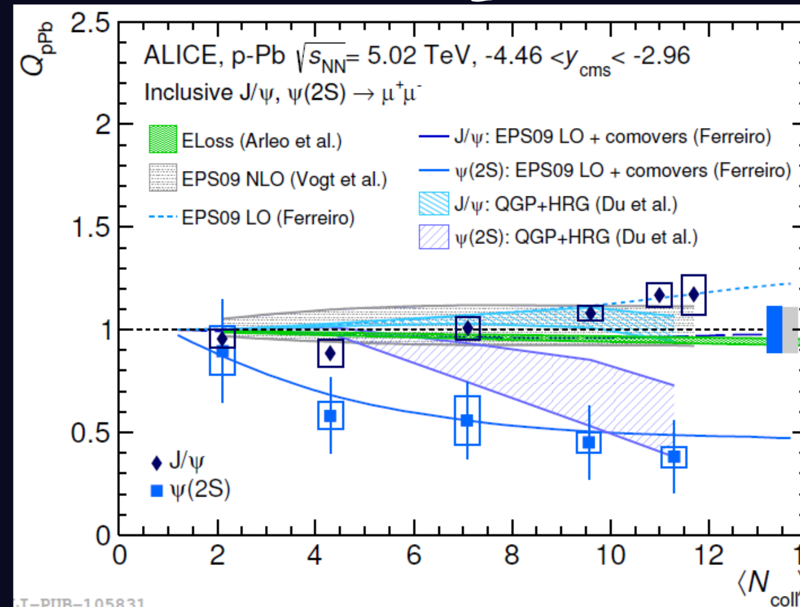
ψ(2S) production in pA

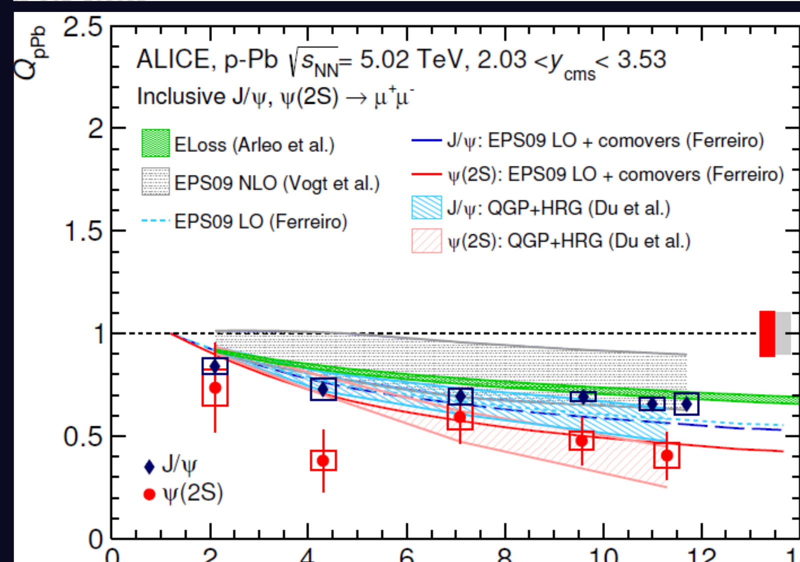
ψ(2S) suppression is stronger than the J/ψ one, both at RHIC and LHC

→ unexpected since time spent by the cc in the nucleus (τ_c) is shorter than charmonium formation time (τ_f)

→ shadowing and energy loss, almost identical for J/ψ and ψ(2S), do not account for the different suppression

Only models including QGP + hadron resonance gas or comovers describe the stronger ψ(2S) suppression

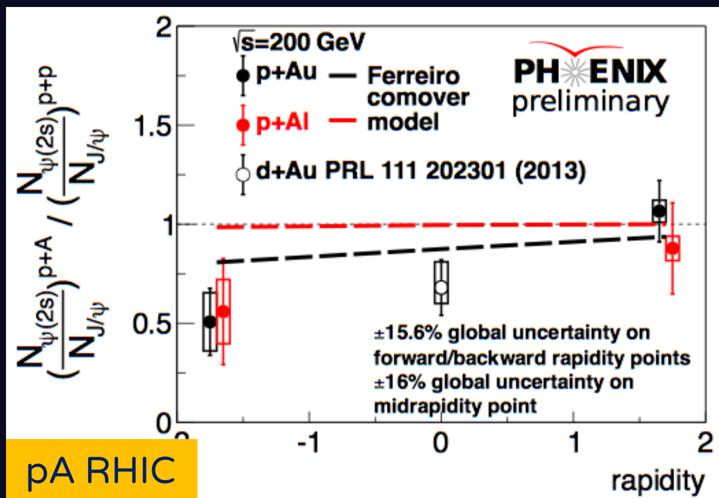


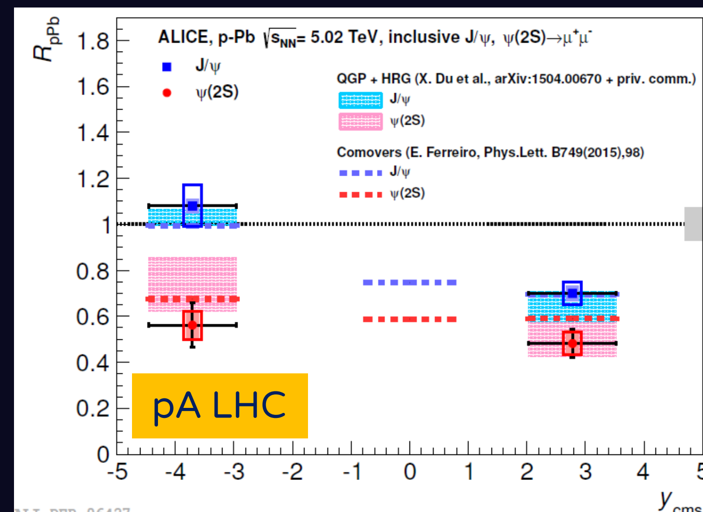


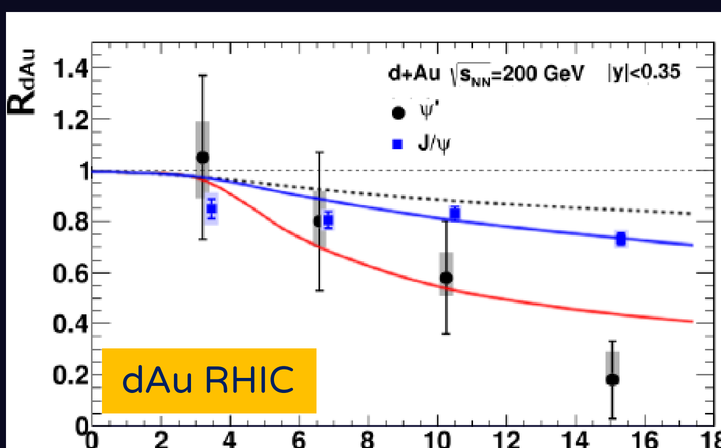
ALICE, JHEP 1606(2016)050

Comparison to theoretical models

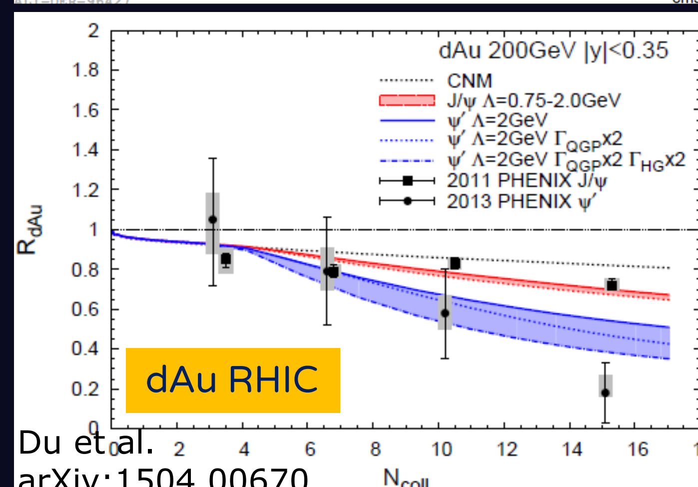
- QGP+hadron resonance gas (Rapp) or comovers models (Ferreiro) reasonably describe both J/ψ and ψ(2S) suppression at RHIC and LHC





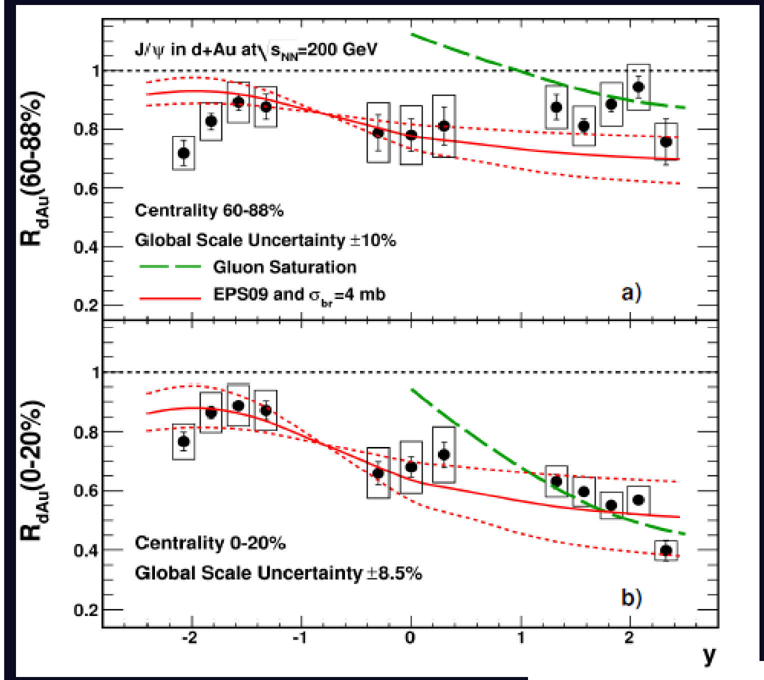


Ferreiro, PLB 749(2015)98

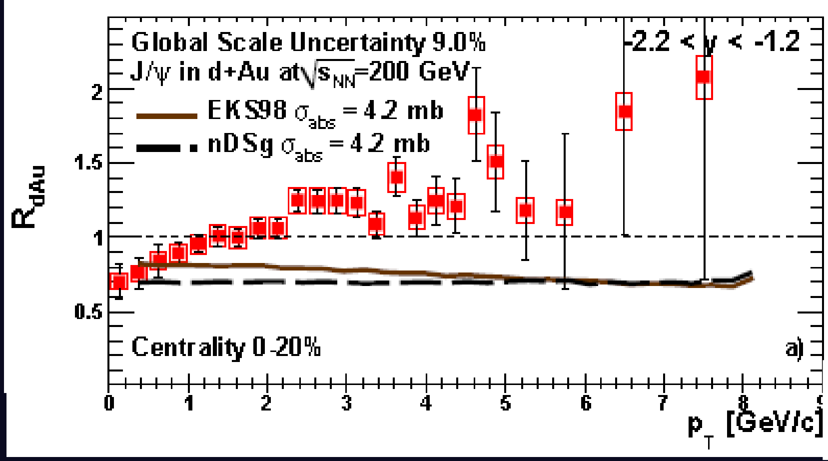


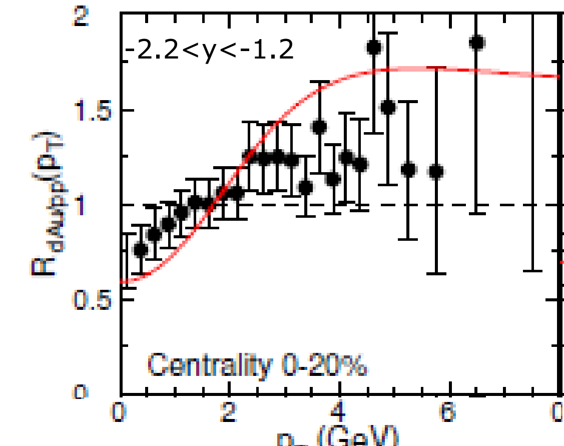
Du et al. arXiv:1504.00670

CNM effects at RHIC



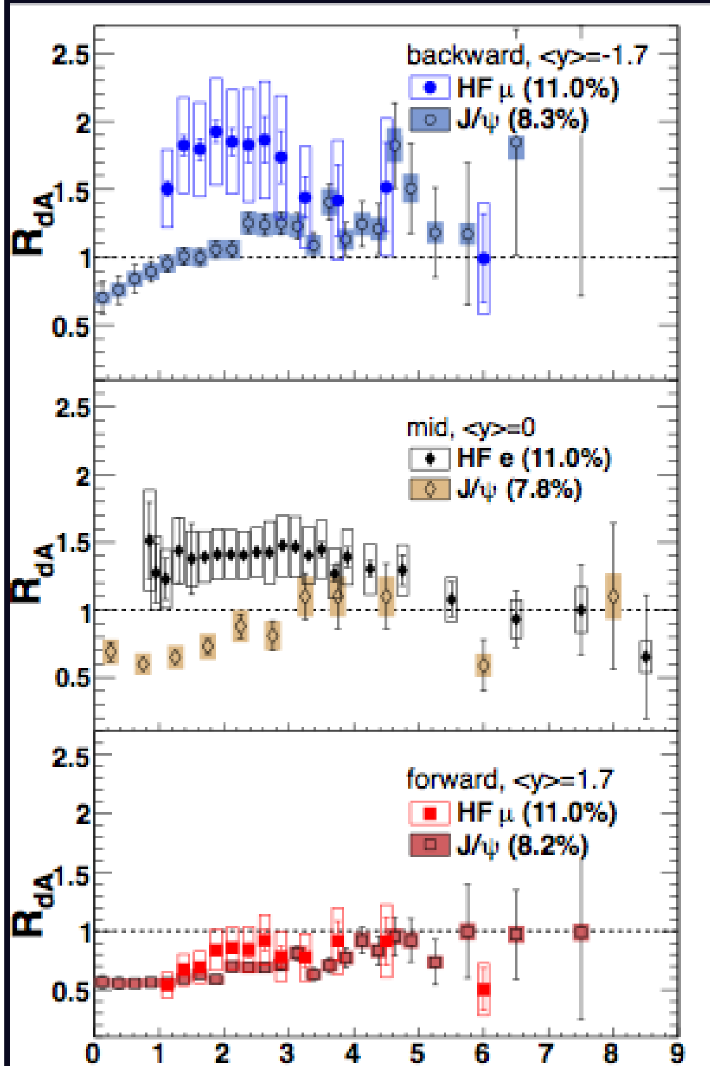
- Disentangling CNM mechanisms is challenging
- shadowing + cc break-up describe R_{dAu} vs y, but meets some difficulties for R_{dAu} vs p_T
- coherent energy loss contribution induces a less flat R_{dAu} dependence on p_T





Arleo et al. JHEP1305 (2013) 155

CNM effects at RHIC



PHENIX: PRC 87 034904
PHENIX: PRL 112 252301

Comparison between heavy flavor and quarkonium:

R_{dA} of HF muon and J/ψ are consistent at forward rapidity, but clearly different at backward rapidity

- charm production is enhanced but J/ψ production is significantly suppressed due to nuclear breakup inside dense comovers at backward rapidity
- Contrarily to LHC, at RHIC energies a contribution from J/ψ breakup in nuclear matter could be present ($\sigma_{J/\psi\text{-}N}$ ~ 4mb)