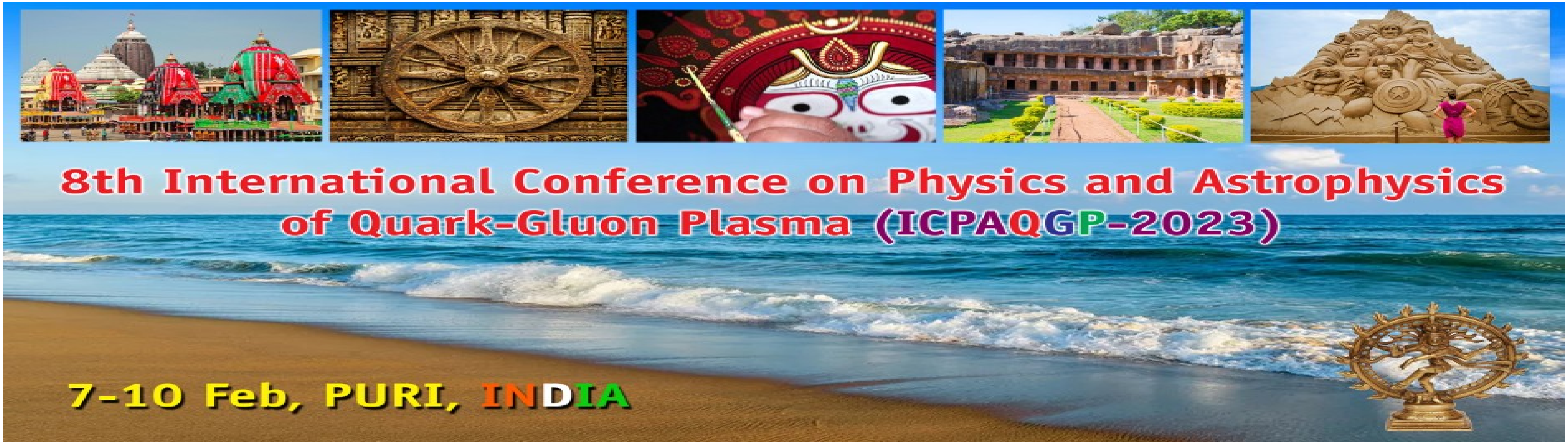
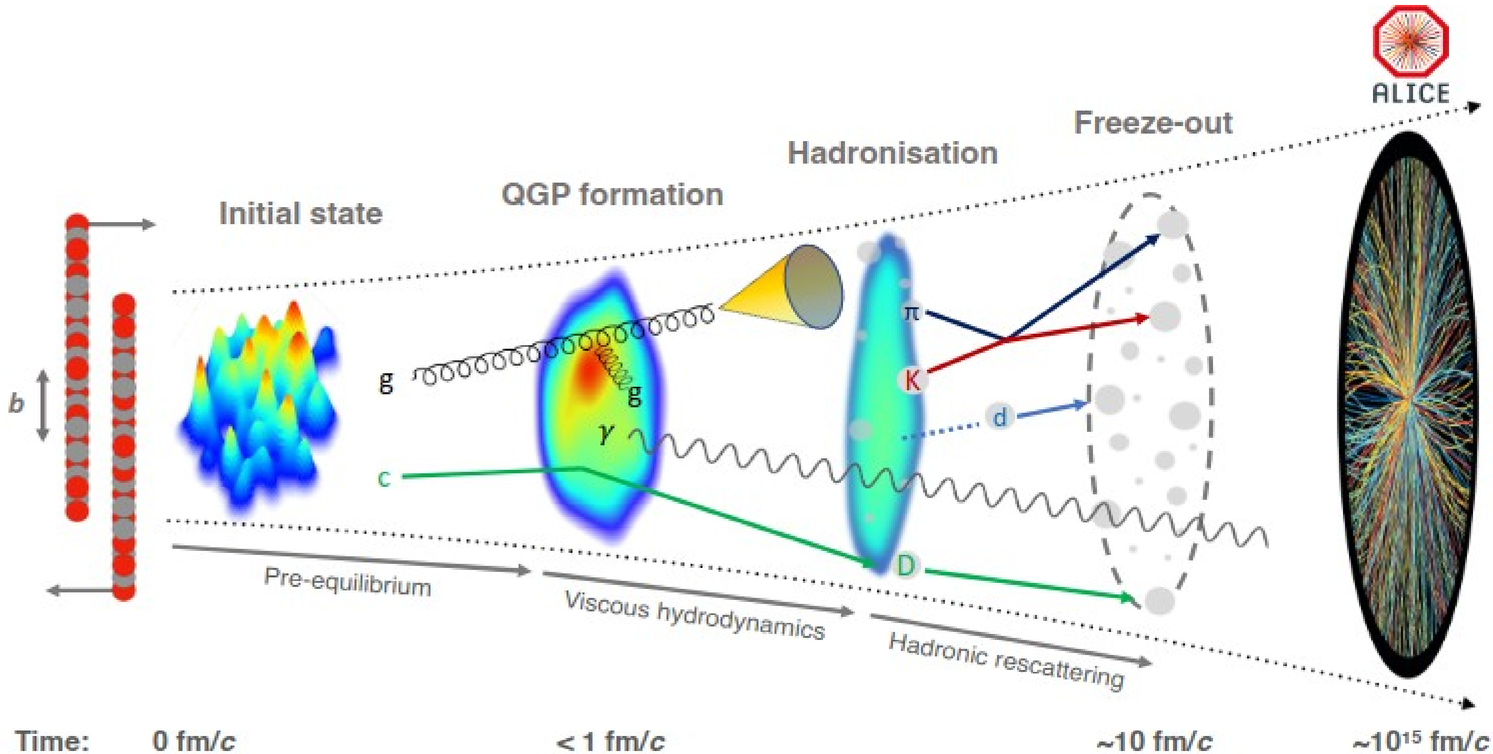
Υ production at LHC energies

Subikash Choudhury
SINP



Evolution of a heavy ion collision



arXiv:2211.04384

What are Quarkonia?

– Bound states of heavy flavor quarks-antiquark pair, charmonium ($c\bar{c}$) and bottomonium ($b\bar{b}$)

– Produced very early in collisions from initial hard scattering

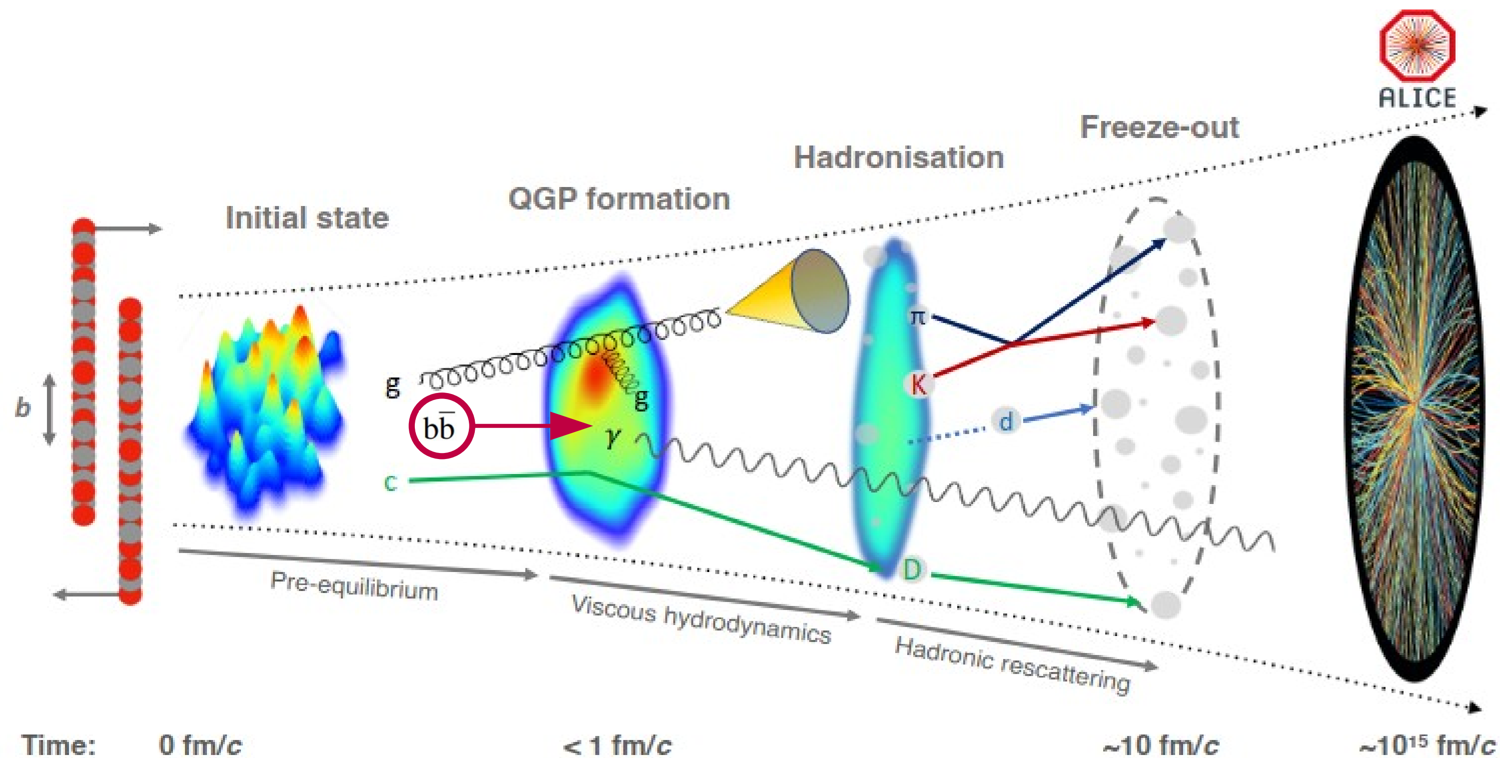
Why important ?

– Benchamark for non-perturbative and perturbative aspects of QCD

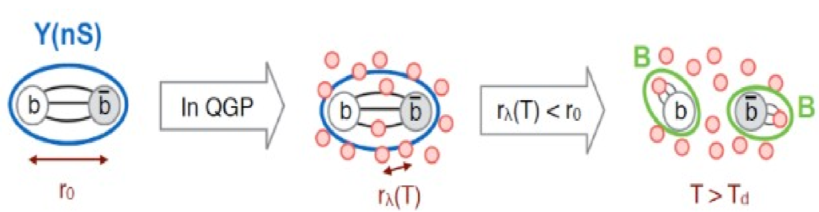
– Sensitive to partonic deconfinement

Why Quarkonia/Bottomonia ?

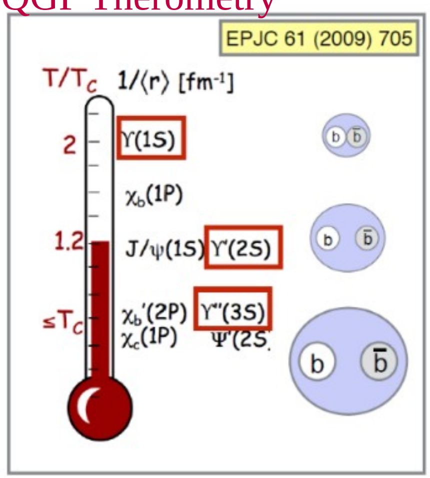
arXiv:2211.04384



Color screening



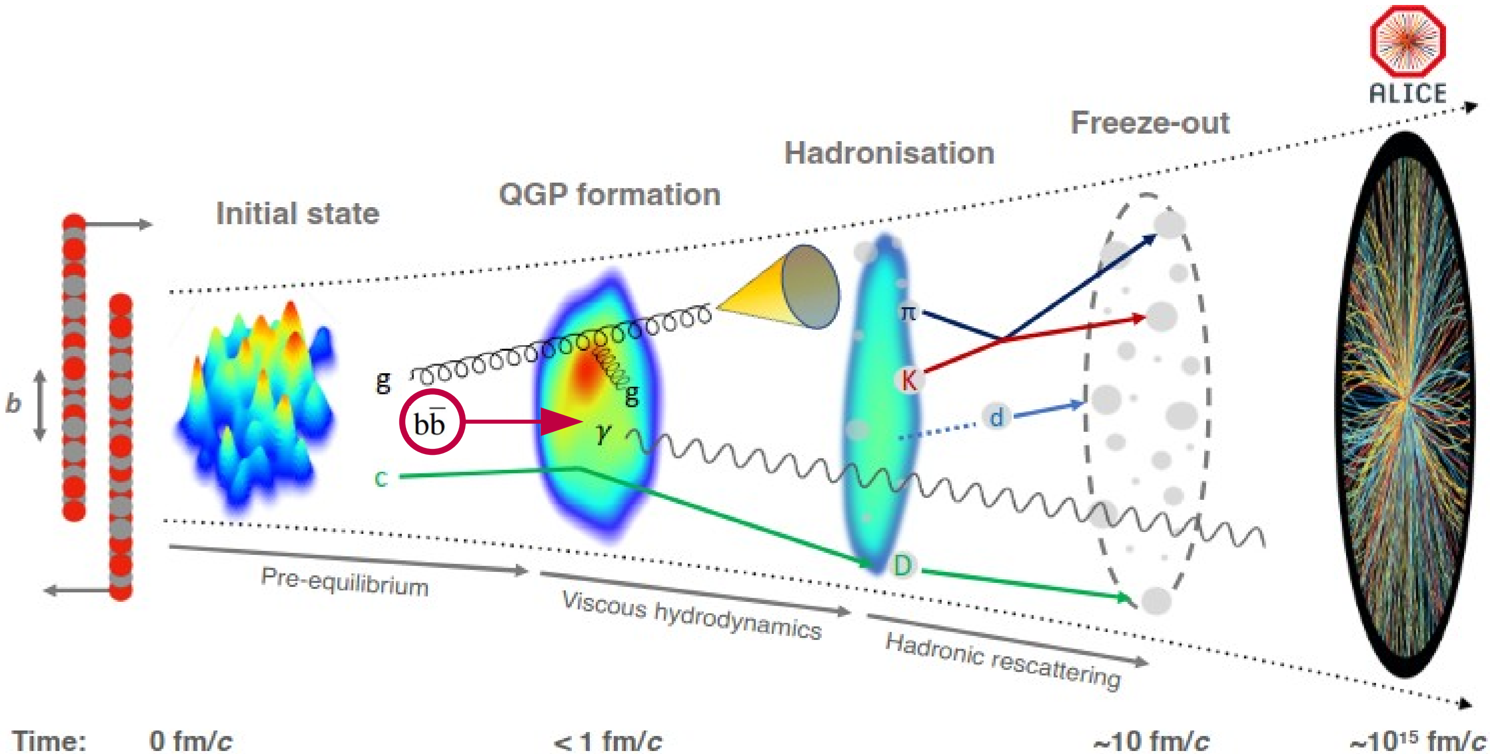
QGP Therometry



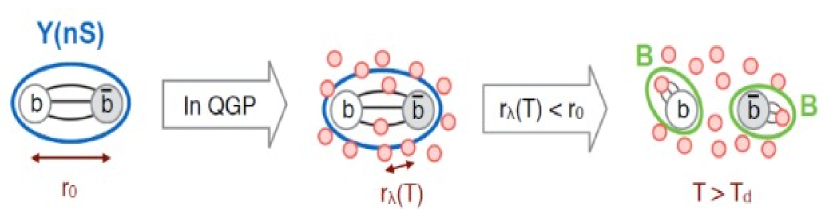
Static dissociation and sequential melting

Why Quarkonia/Bottomonia ?

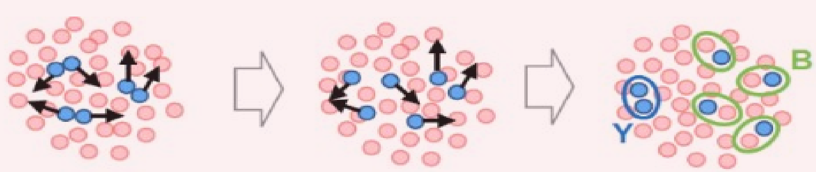
arXiv:2211.04384



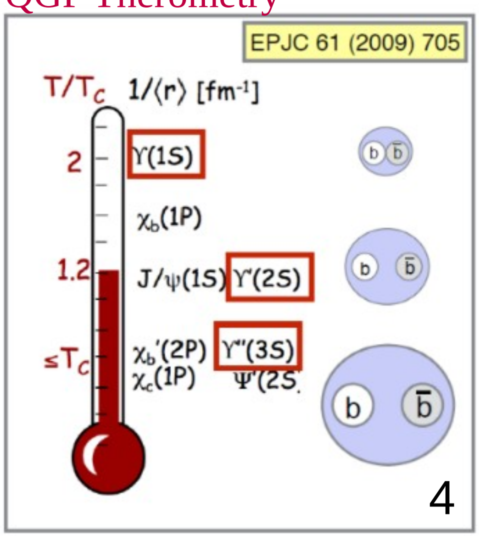
Color screening (sequential melting)



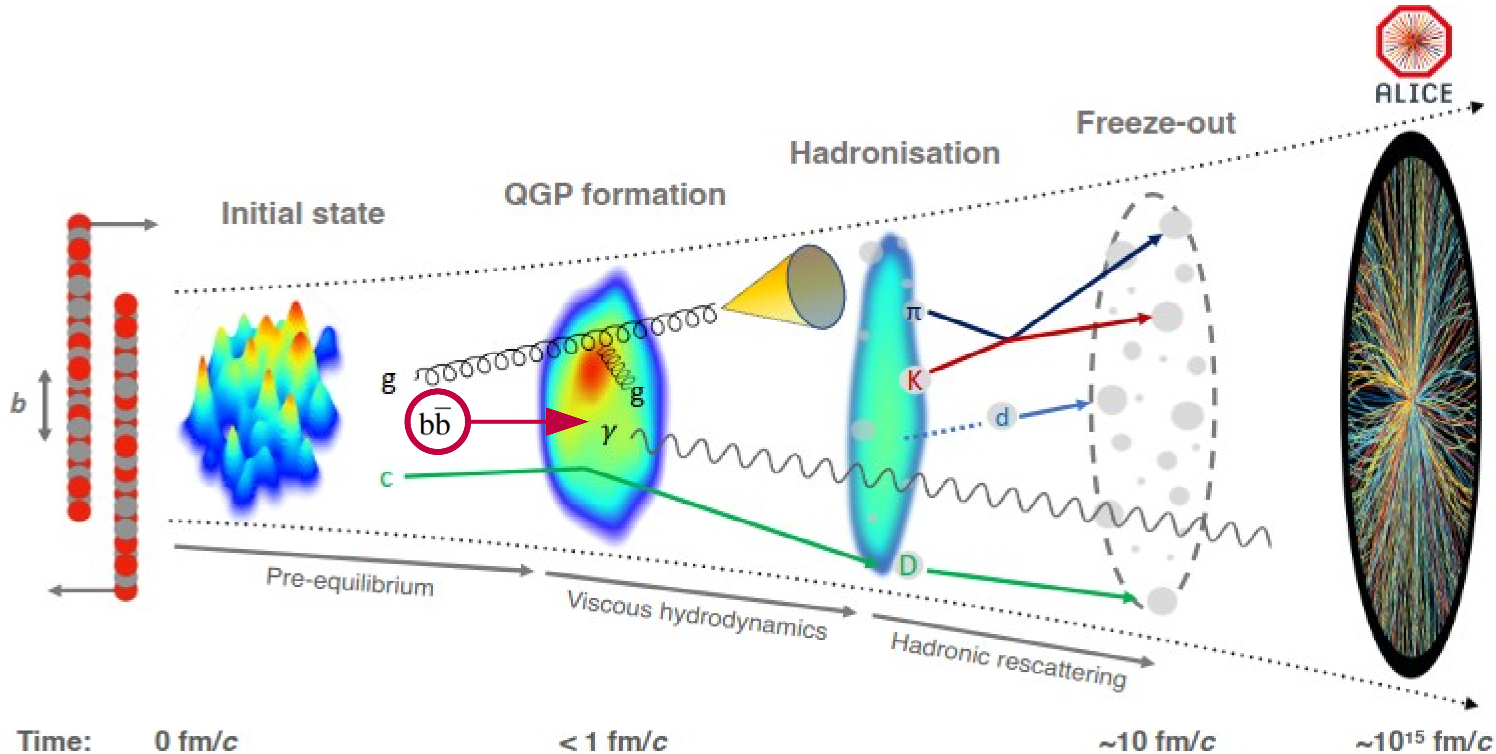
Regeneration (unlikely for Υ)



QGP Therometry



Why Quarkonia/Bottomonia ?



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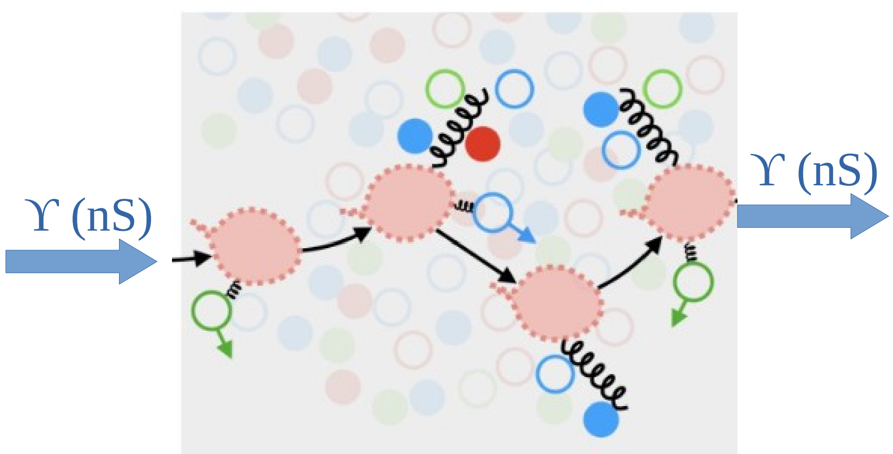
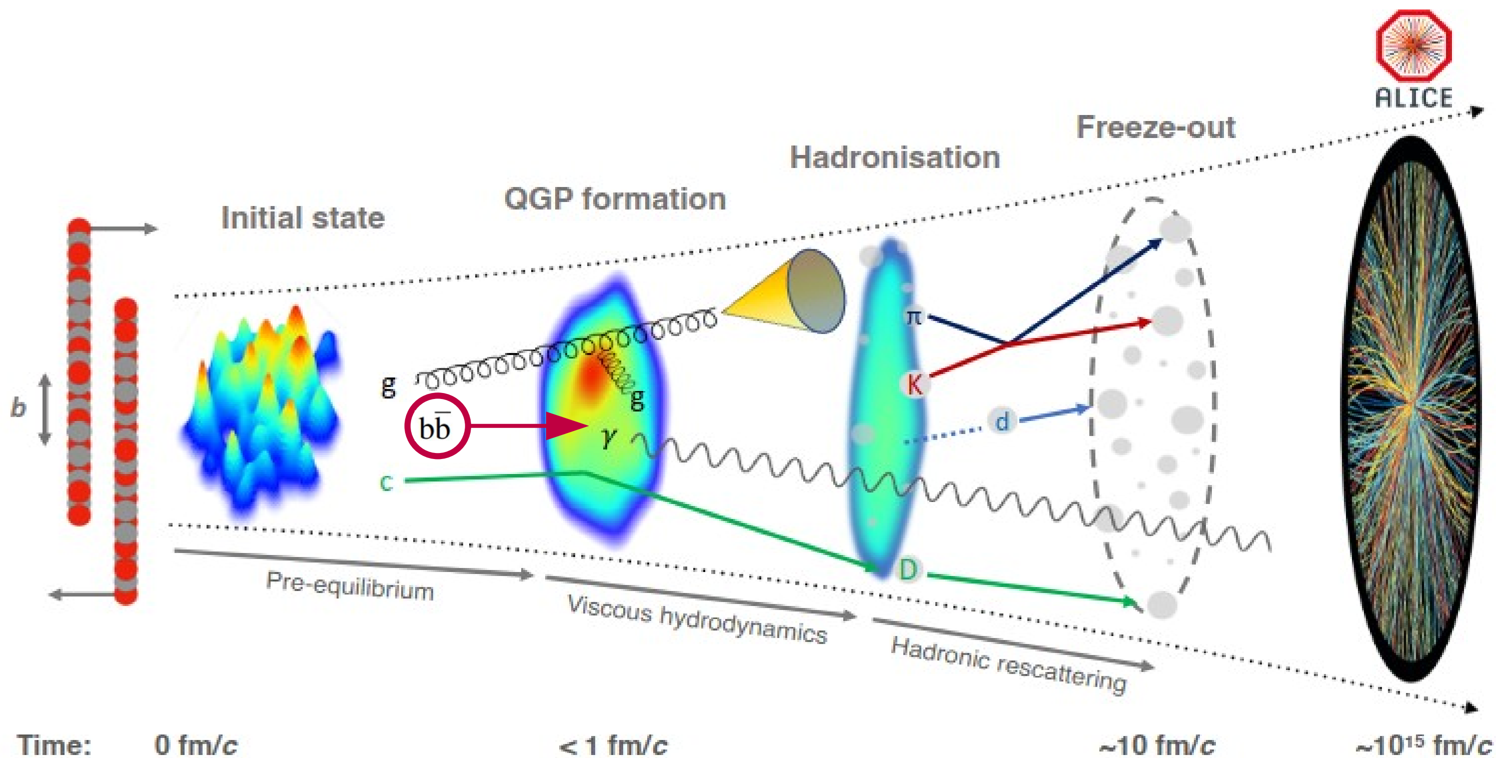


Information on thermalization
– picks up flow (v_2) ?

Why Quarkonia/Bottomonia ?



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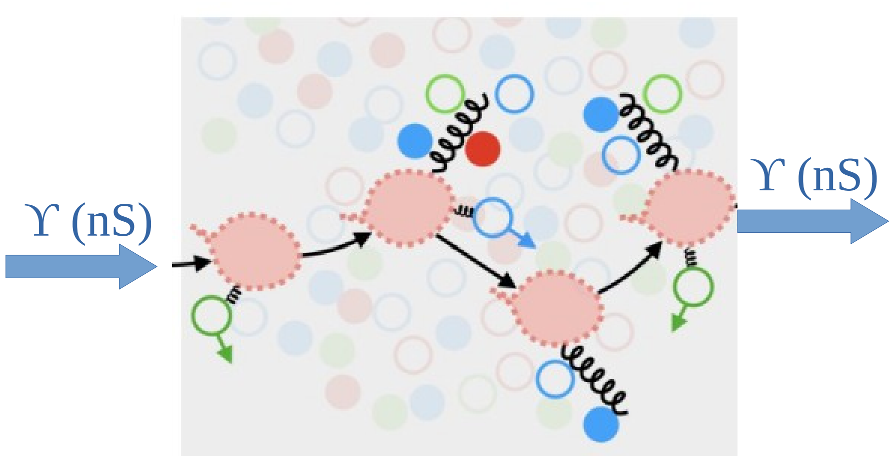
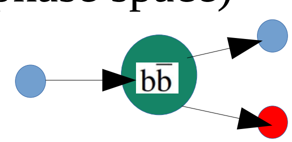


Information on thermalization
– picks up flow (v_2) ?

What else ?
– Dynamic dissociation (co-mover/close in phase space)



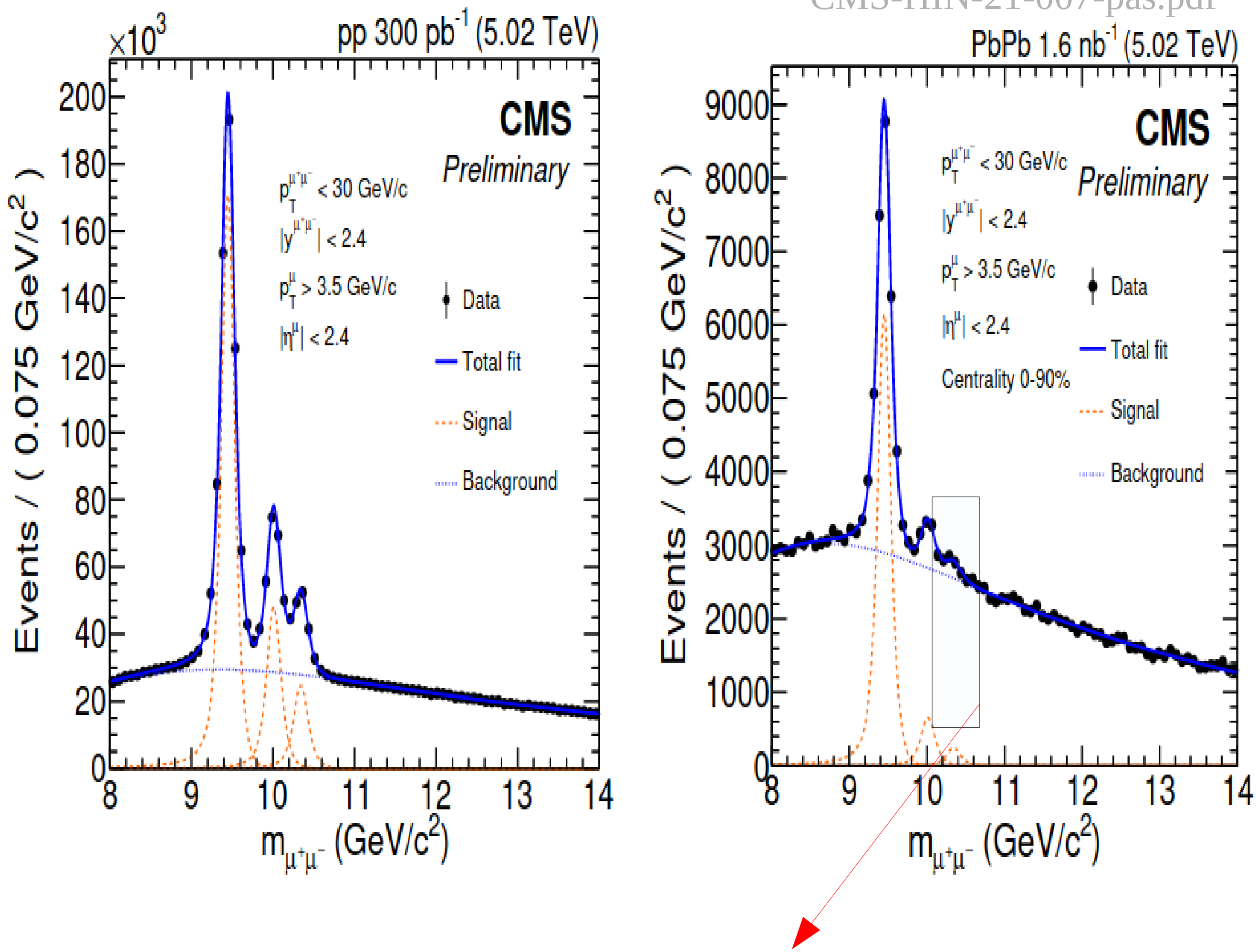
Signal Extraction

Selection:
$\Upsilon(nS) \rightarrow \mu^+\mu^-$
In detector acceptance

Signal :
Crystal Ball

Background:
2nd order polynomial/
Double Exponential

CMS-HIN-21-007-pas.pdf



1st observation of Υ(3S) in PbPb

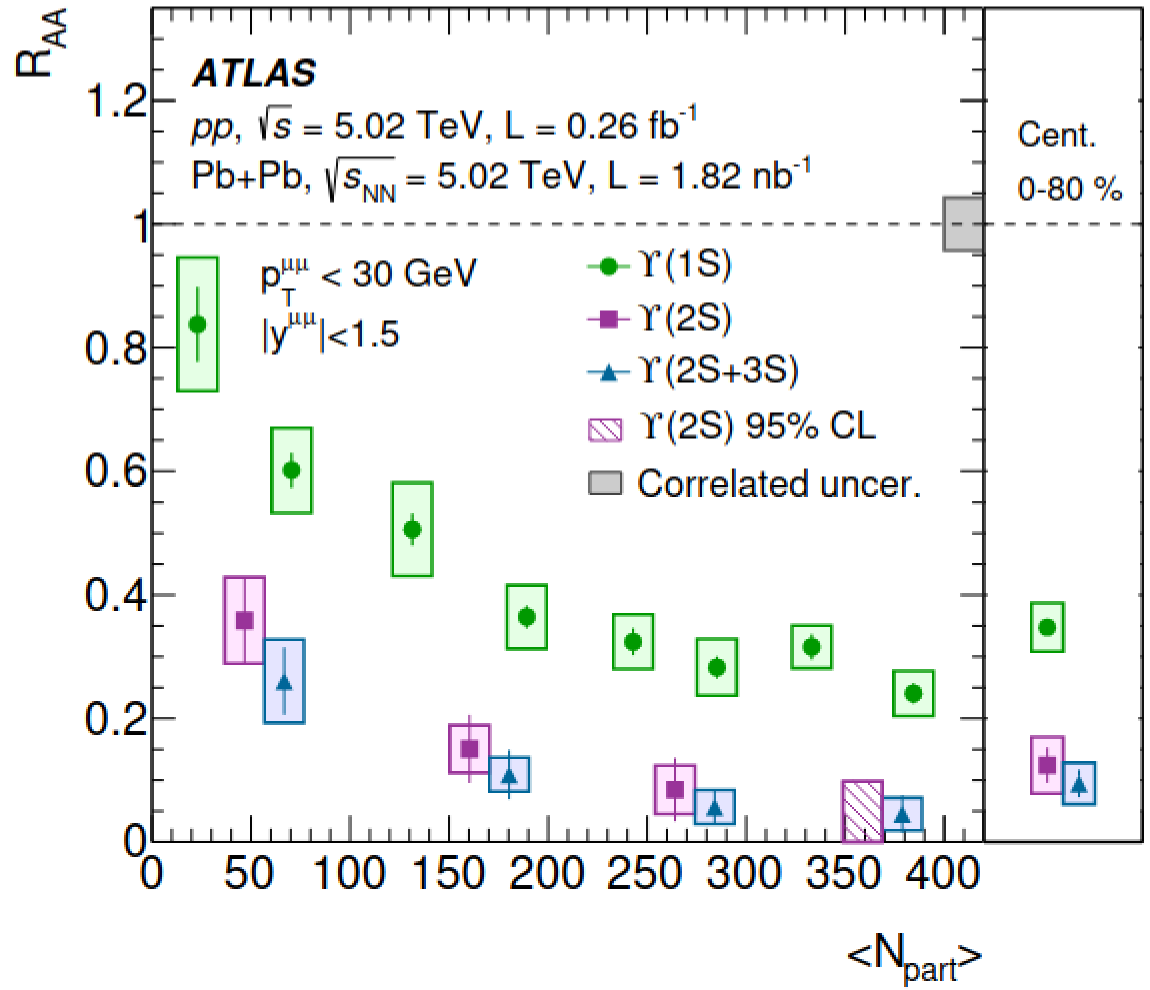
Nuclear Modification factor, R_{AA}

2205.03042

$$R_{AA} = \frac{N_{AA}}{\langle T_{AA} \rangle \times \sigma^{pp}}$$

$R_{AA} = 1$: AA equivalent to pp
$R_{AA} < 1$: signature of QGP

Ordering in R_{AA} :
$\Upsilon(1S) > \Upsilon(2S) > \Upsilon(2S{+}3S)$



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Ordering in R_{AA} :
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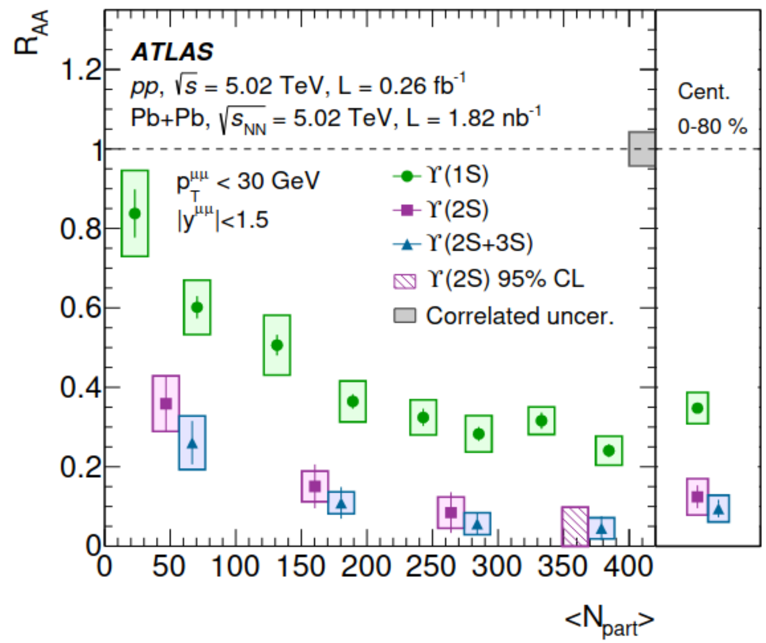
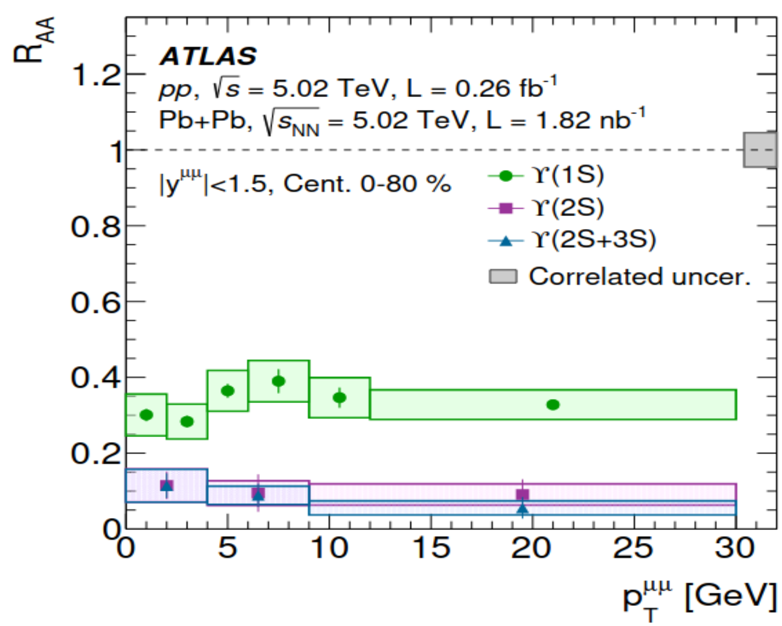
No strong p_T dependence

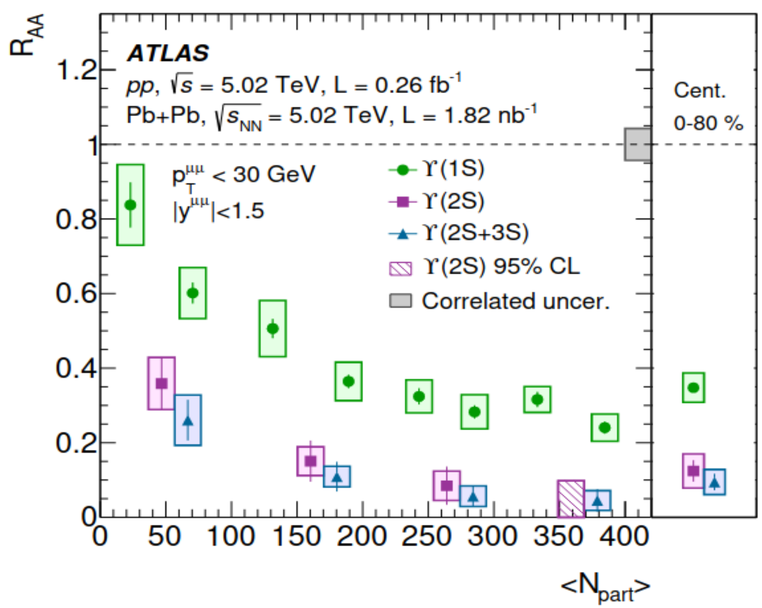
Evidence of sequential melting

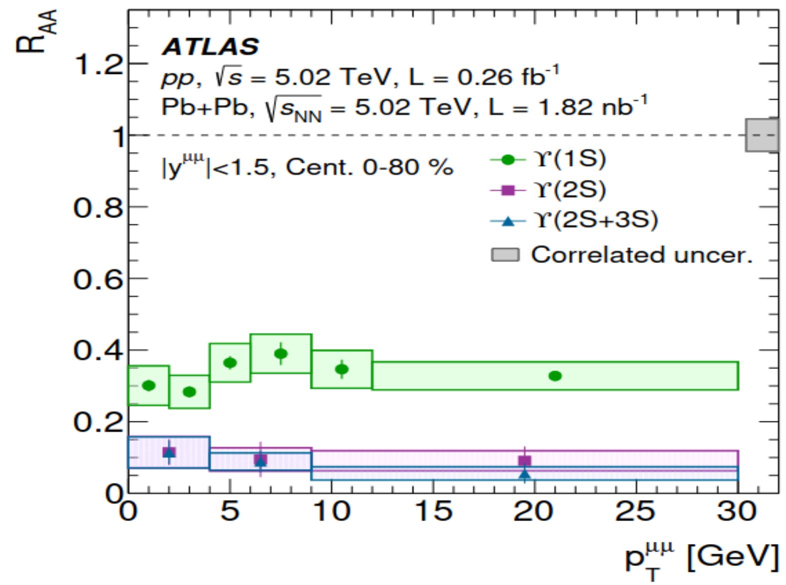




Nuclear Modification factor, R_{AA}

CMS-HIN-21-007-pas.pdf
2207.06568





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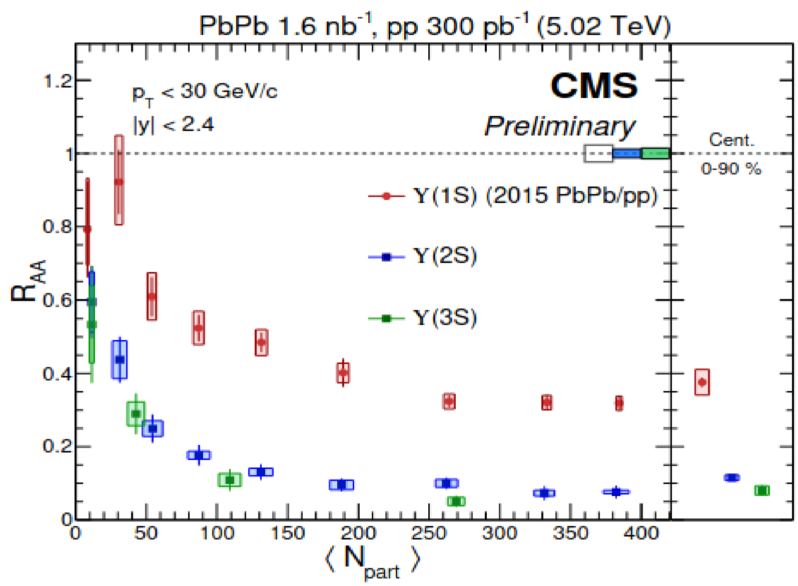
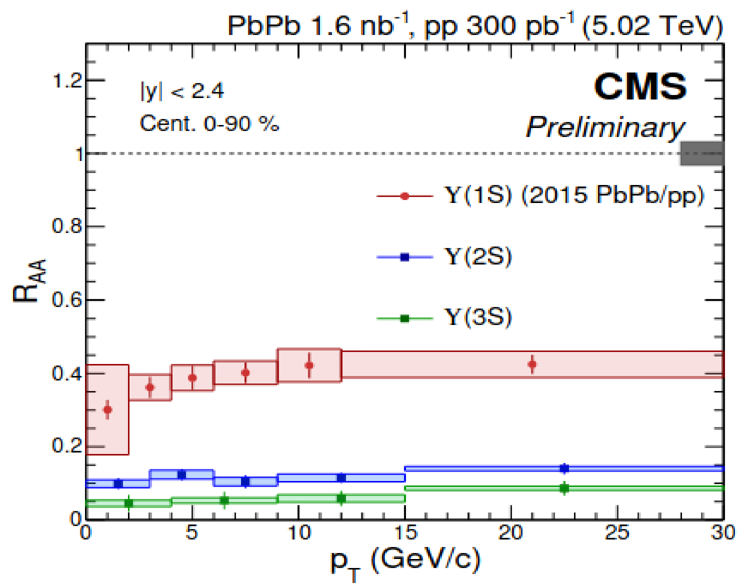
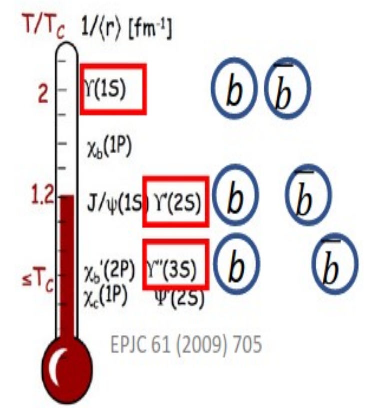




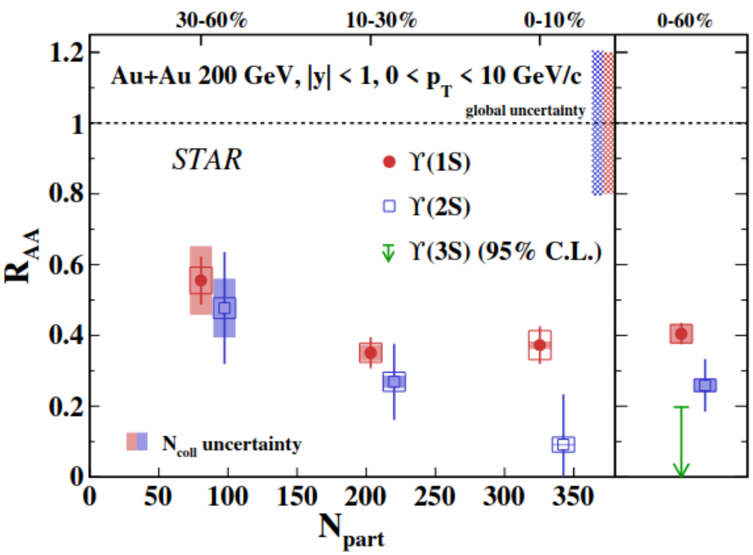


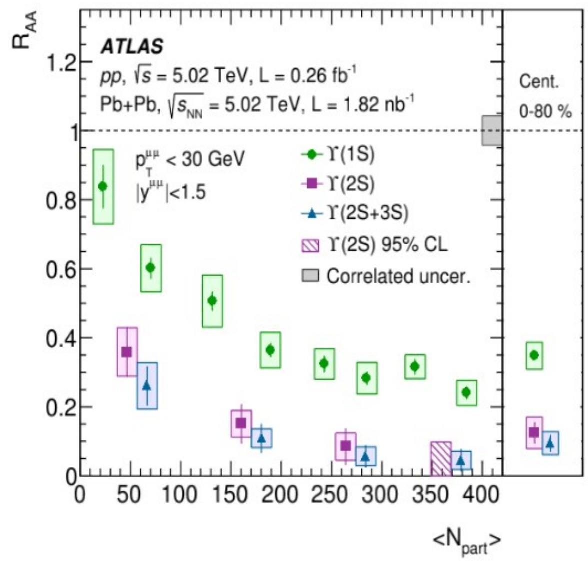
Clear evidence of sequential melting

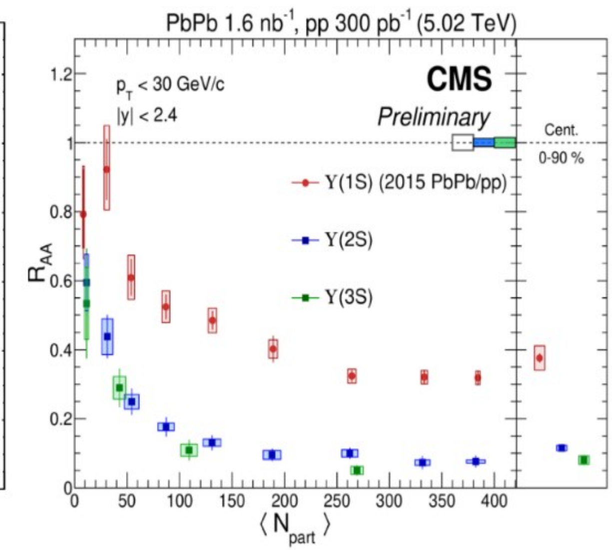
Nuclear Modification factor, R_{AA}

CMS-HIN-21-007-pas.pdf
2207.06568
2205.03042

From RHIC (200 GeV) to LHC (5020 GeV)







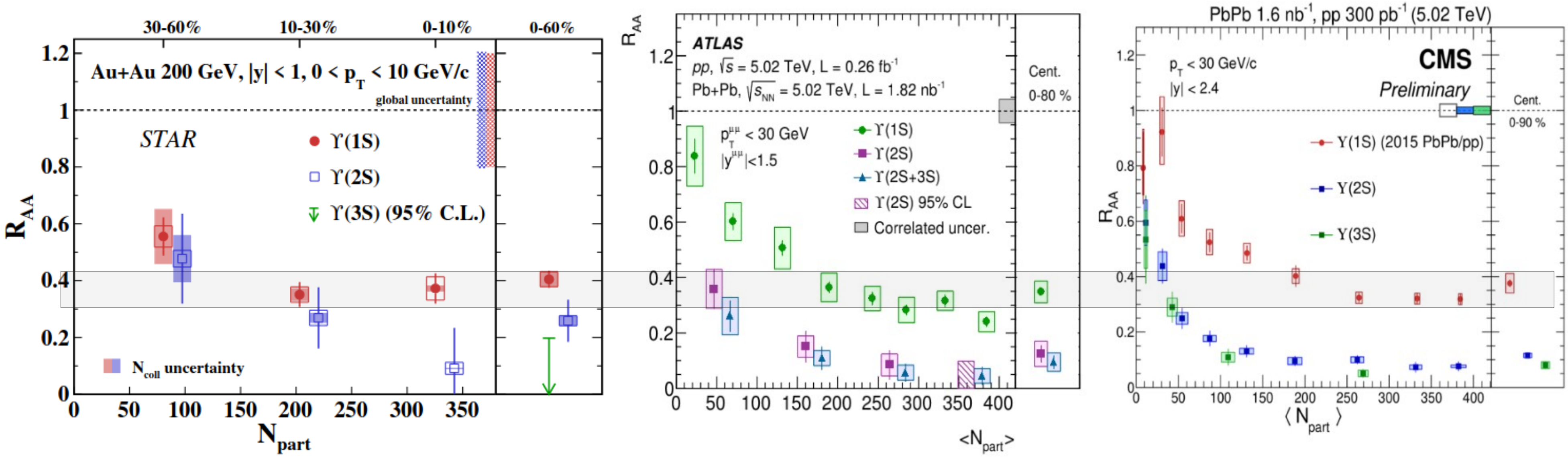
Clear indication sequential melting both at RHIC and LHC

Ordering in R_{AA} :
Υ(1S) > Υ(2S) > Υ(2S+3S / 3S)

Nuclear Modification factor, R_{AA}

CMS-HIN-21-007-pas.pdf
2207.06568
2205.03042

From RHIC (200 GeV) to LHC (5020 GeV)



Clear indication sequential melting both at RHIC and LHC

Important to note:
– ϒ(1S) has same order of suppression both at RHIC & LHC
– ϒ(2S) is more suppressed at LHC than RHIC

Model calculation simultaneously explains RHIC and LHC data with: medium temperature
– 455 MeV at RHIC
– 630 MeV at LHC

Model predictions for R_{AA}

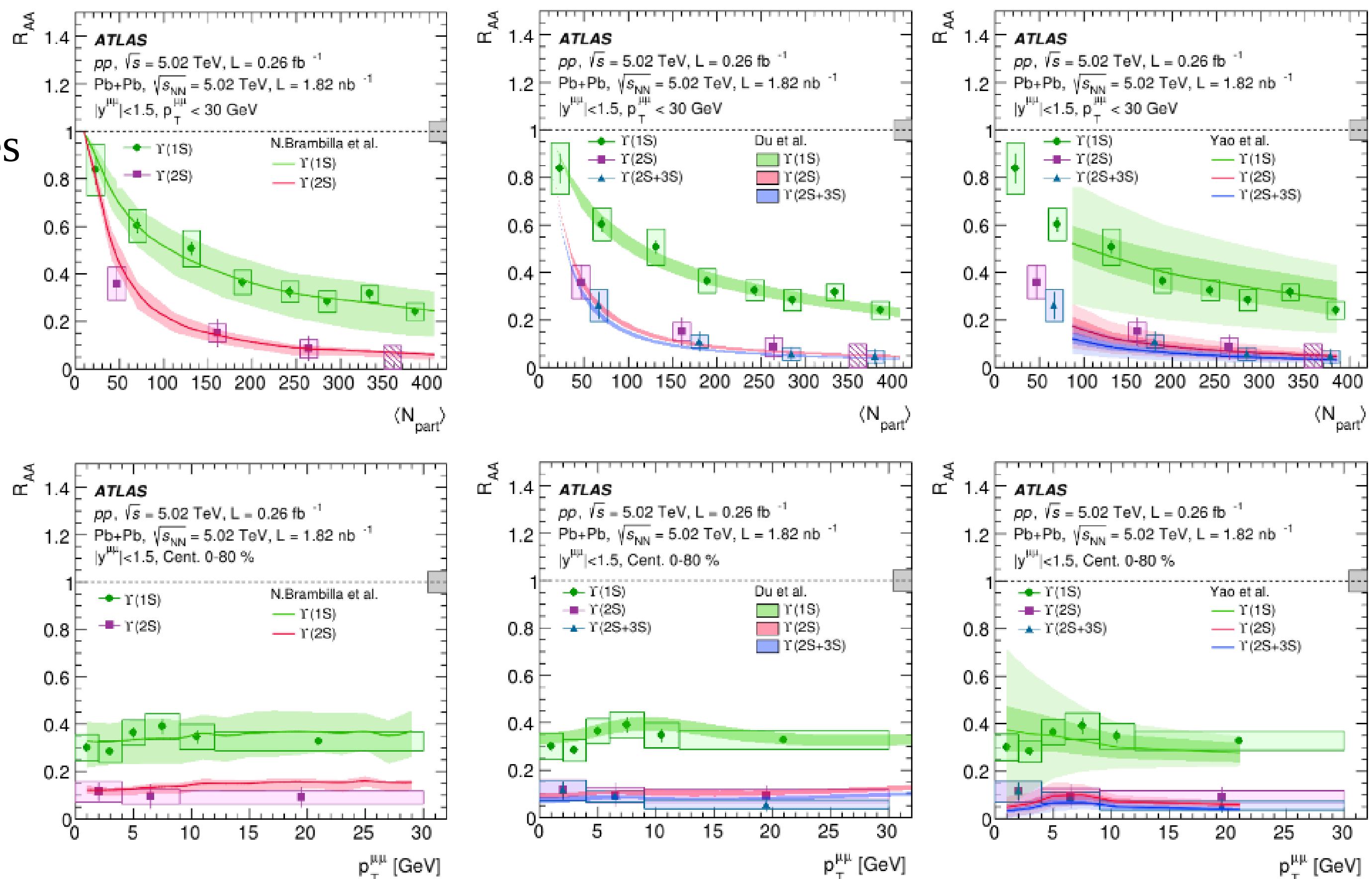
2205.03042

Models use different approaches but agrees well with data

Key ingradient in all models is deconfinement

LHC data suggests strong BE of $\Upsilon(1S)$ that can survive upto T_{avg} ~ 500 MeV

$\Upsilon(2S)$ melts at ~ 250 MeV



N.Brambilla et al., PRD 104 (2021) 094049

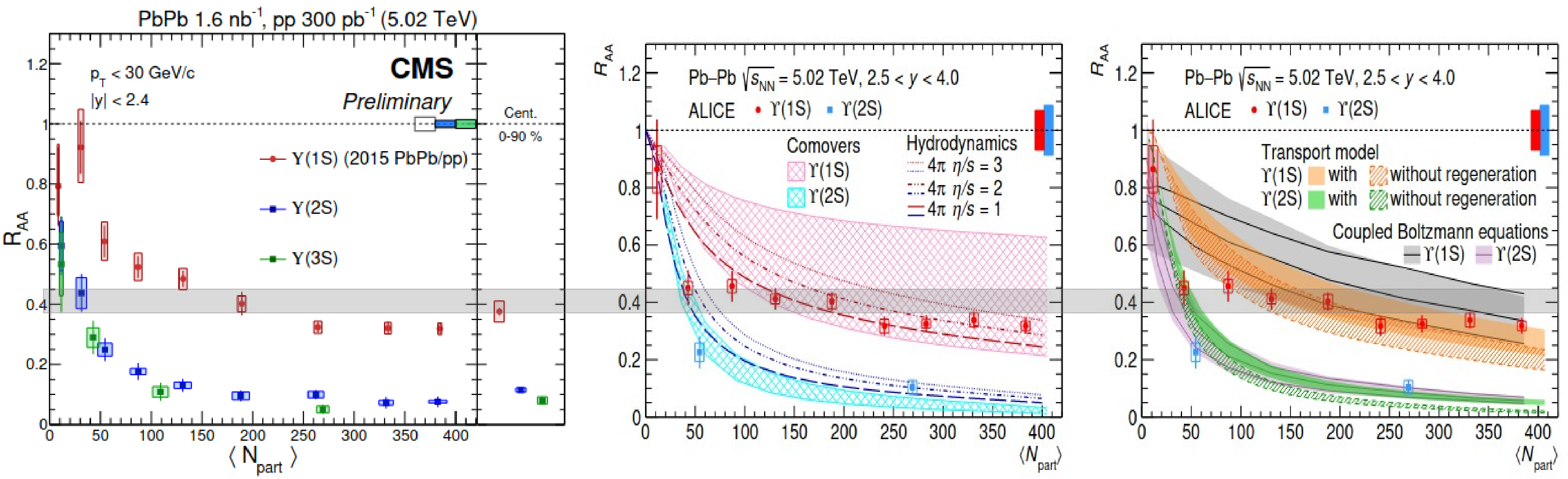
M.H.X. Du and R. Rapp, PRC 96 (2017) 054901

X. Yao et al., JHEP 2021 (2021) 46

Nuclear Modification factor, R_{AA}

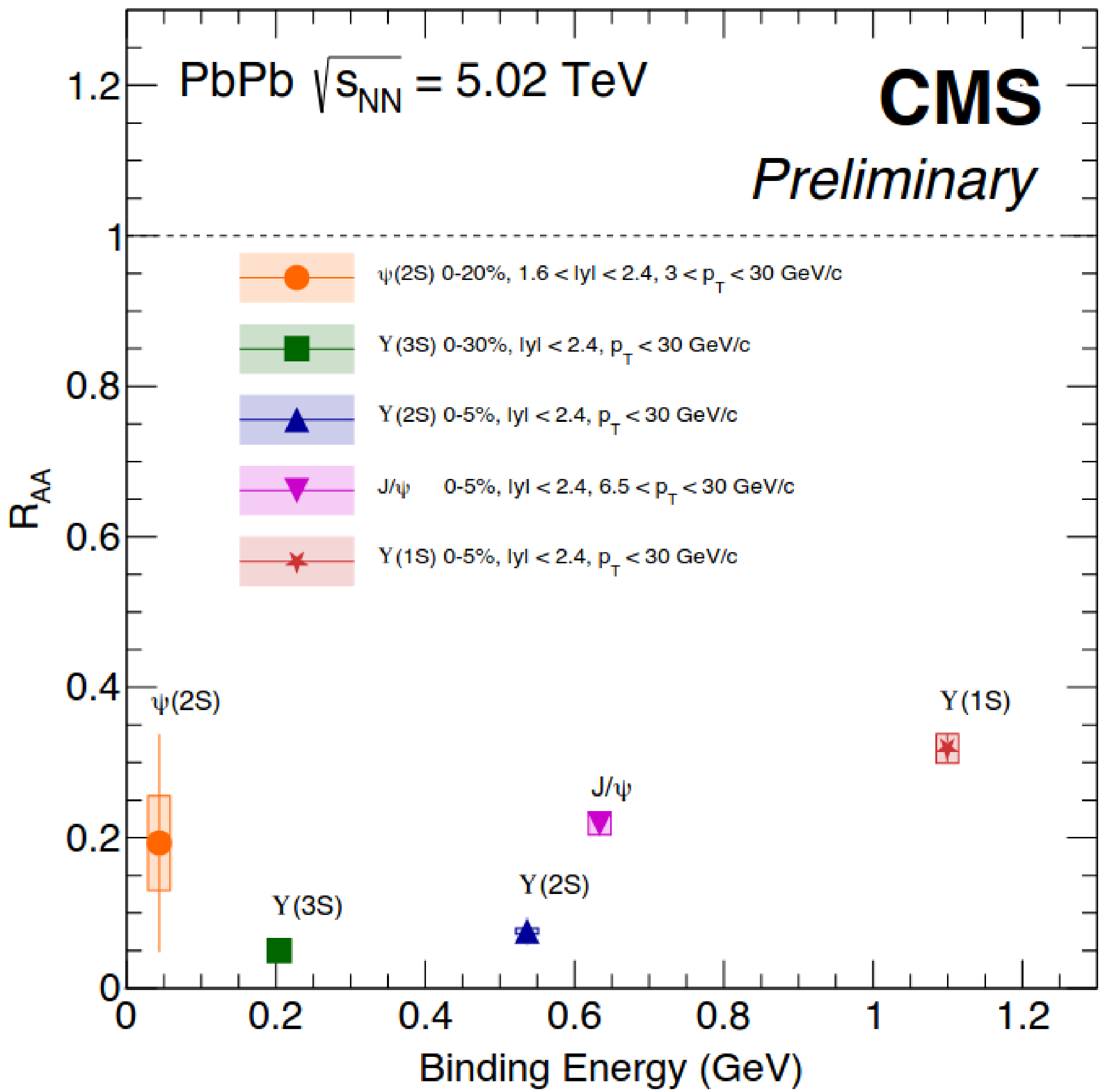
From mid rapidity to forward rapidity

CMS-HIN-21-007-pas.pdf
2011.05758



– Sequential suppression both at mid and forward rapidity
– No rapidity dependence
– Model calculations suggest regenaration effect is insignificant

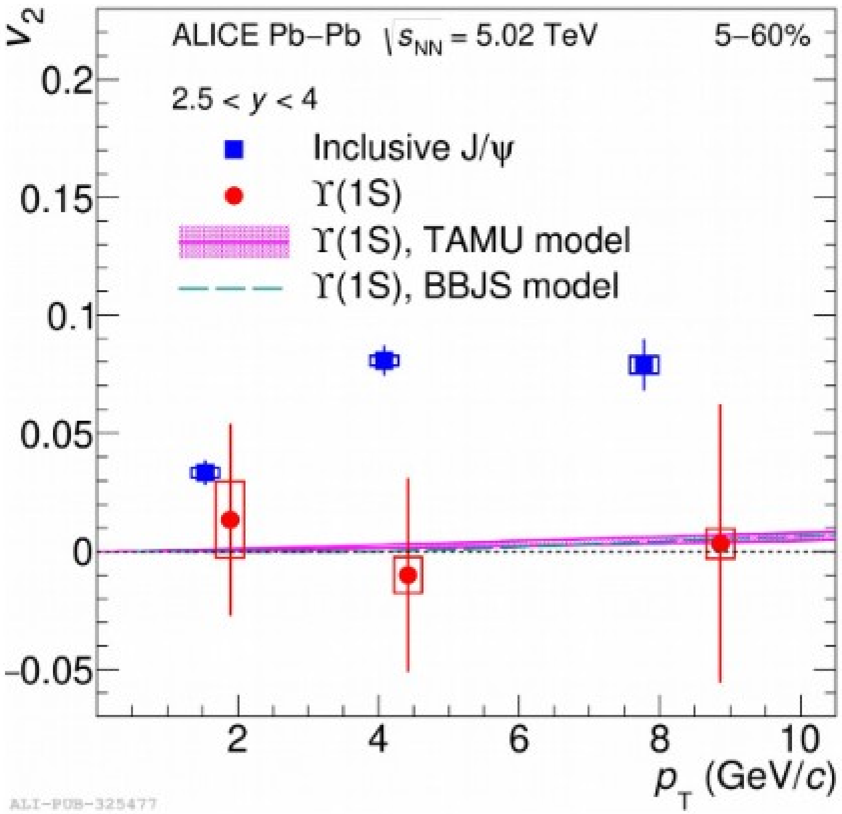
Binding energy relation of Quarkonia R_{AA}



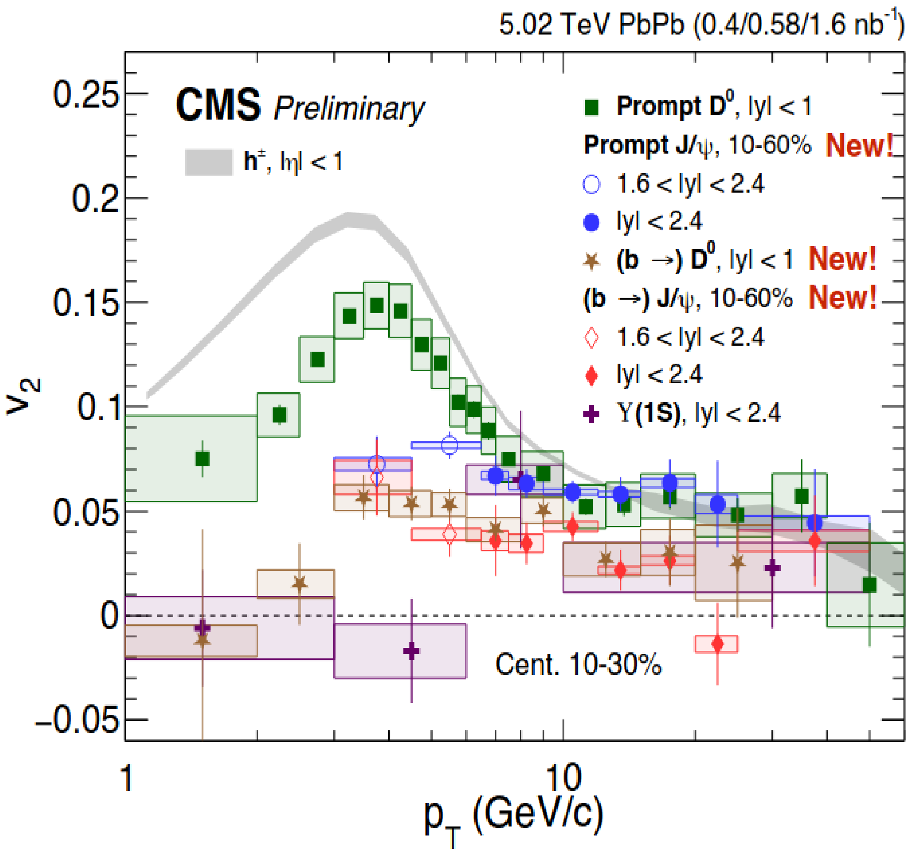
EPJC 78 (2018) 509
CMS PAS HIN 21 007

Collective flow

PRL 123 (2019) 192301



PbPb @ 5.02 TeV

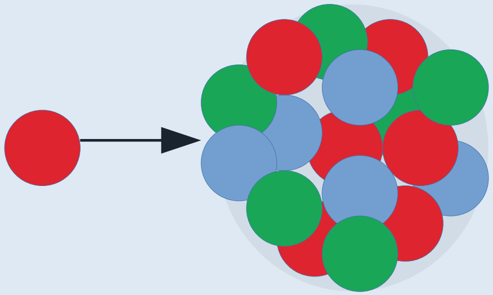


ϒ(1S) v_2 consistent with zero, model calculations predict very small value

– Leaves the medium very early

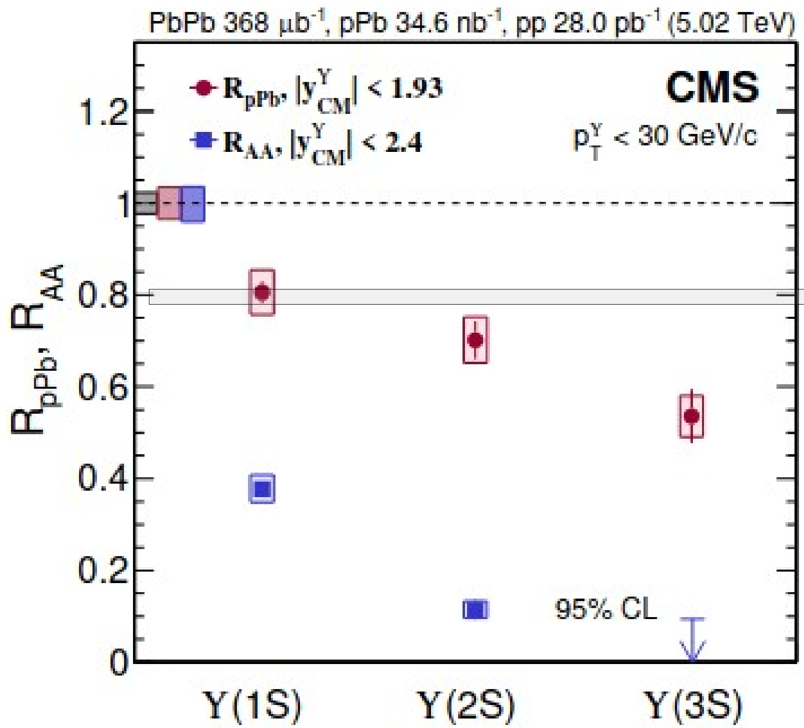
Simultaneous description of R_{AA} & v_2 can constrain model parameters better

Small System (pA)



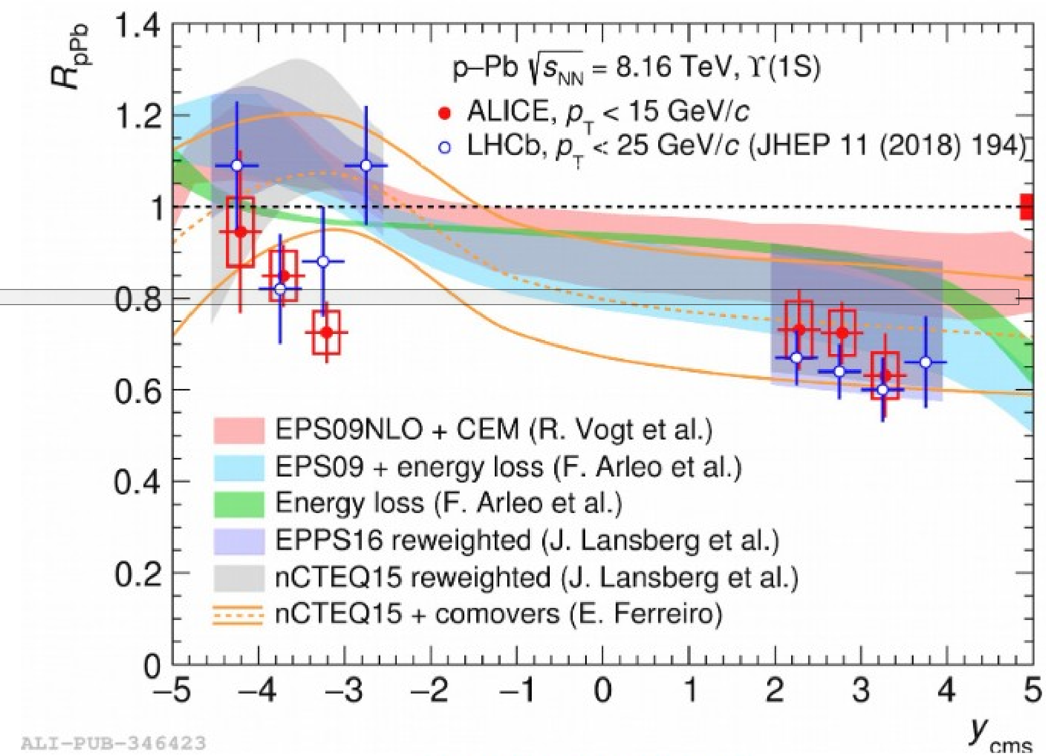
Nuclear Modification factor, R_{pA}

2202.11807



PLB 806 (2020) 135486

Pb

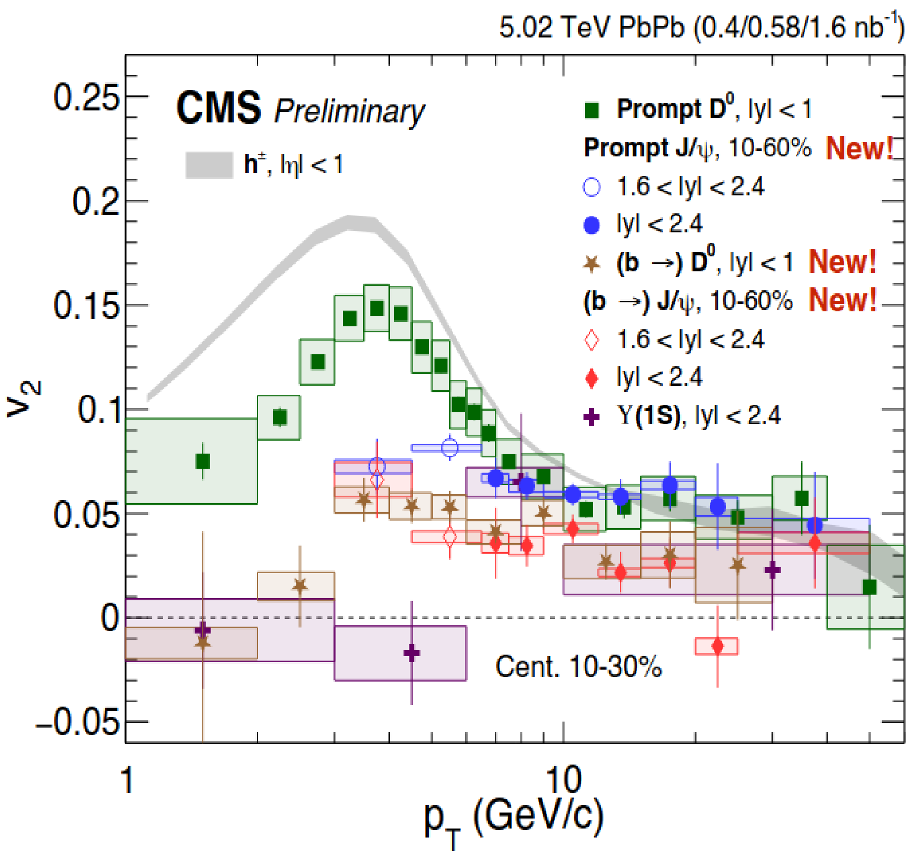


- $R_{pPb} < R_{AA}$
- R_{pPb} exhibit ordering same as R_{AA}
- Presence of final state interactions, consistent with "co-mover" scenario

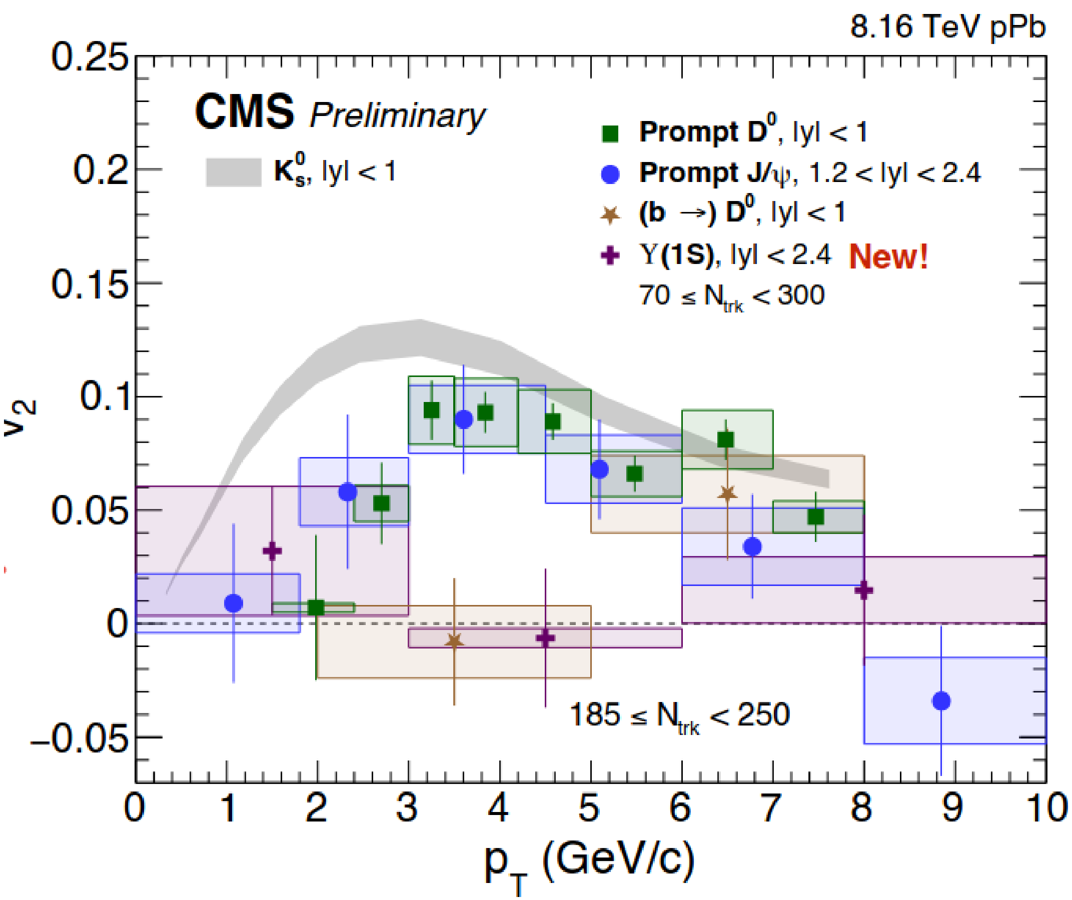
- Υ(1S) order of suppression is same at mid and forward rapidity
- Pb going direction shows more suppression
- Agrees with "co-mover" scenario

Collective flow

PbPb @ 5.02 TeV

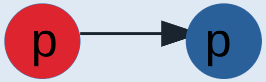


pPb @ 8.16 TeV



Υ(1S) v_2 is consistent with zero both in AA and pA collisions

Smaller System (pp)



ϒ(nS)/ϒ(1S) with Event Activity (EA)

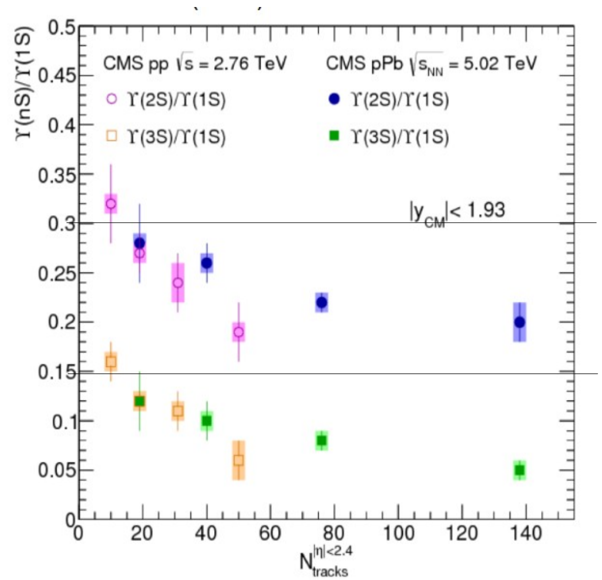
JHEP 04 (2014) 103
JHEP 11 (2020) 011

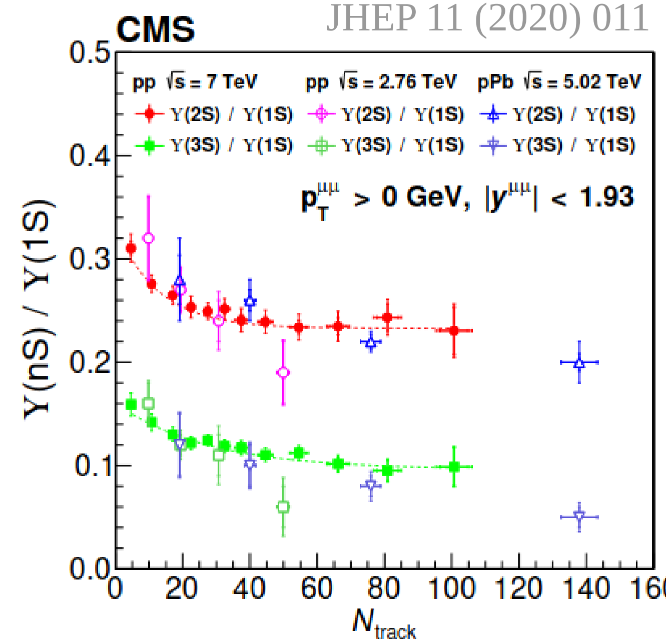
EA is the measure of number particles produced in an event

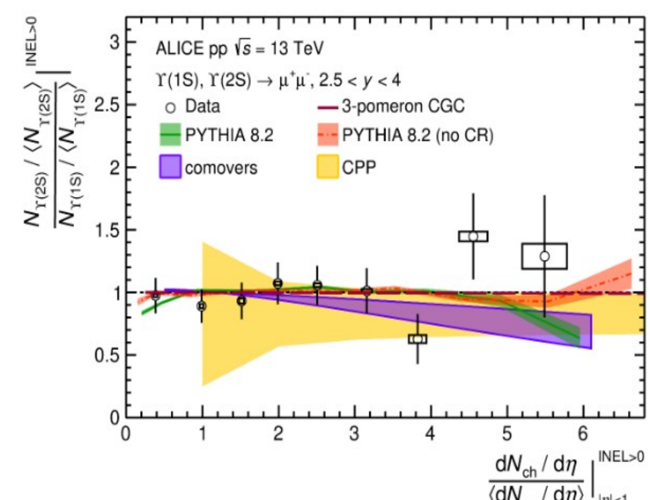
ϒ(nS)/ϒ(1S) vs EA
is analogous to R_{AA} or R_{pA}

CMS results at mid-rapidity and high multiplicity shows a suppression
– Hint of final state interaction?

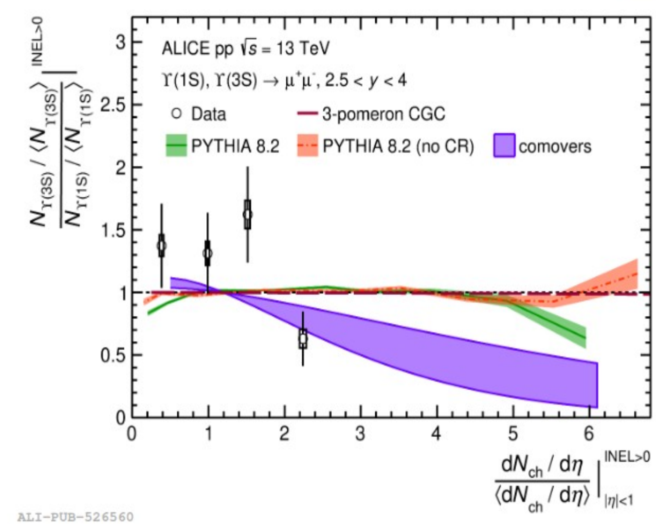
No EA dependence at forward y
– Consistent with PYTHIA
– Comover model underestimates







2209.04241



Υ(nS) < p_T> vs EA

JHEP 11 (2020) 011

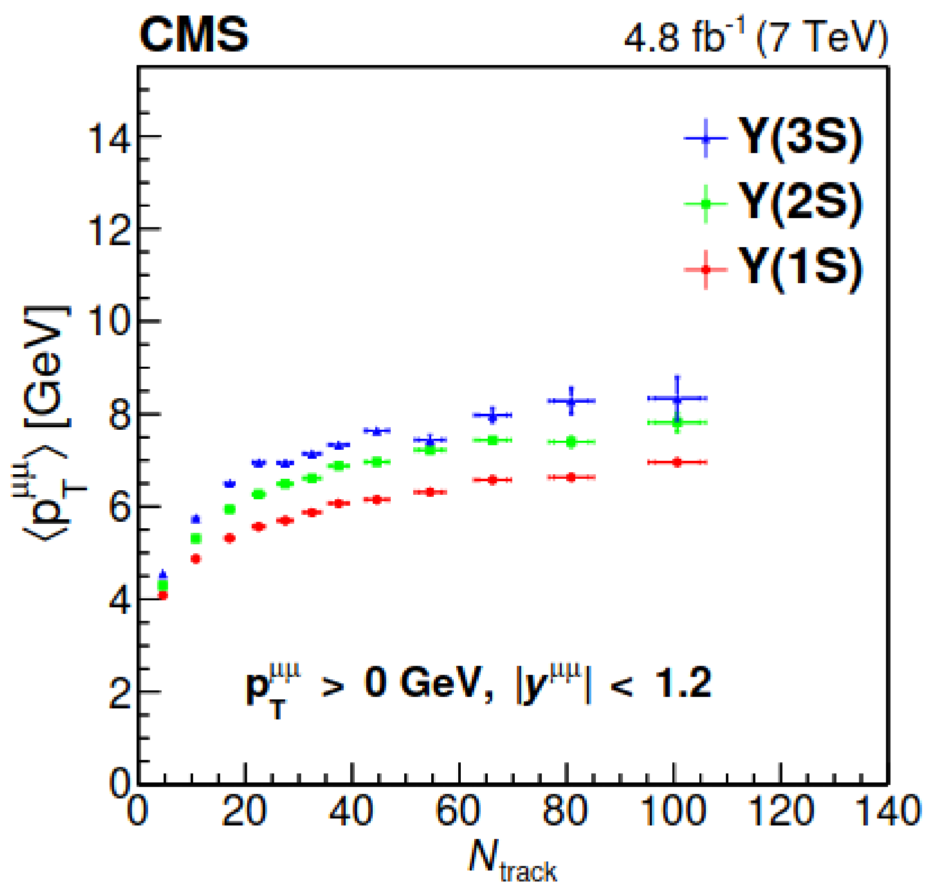
A clear mass ordering

– <p_T> of Υ(3S) > Υ(2S) > Υ(1S)

– Is the reason same as it is for π,K & p? Mass ordering due to radial flow-like effect

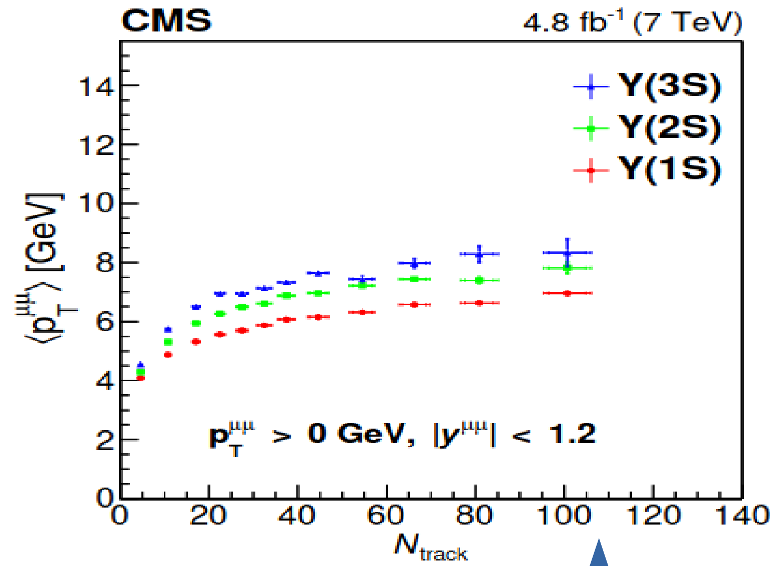
What can be other explainations ?

– Can co-movers/dynamic dissociation explain ?



Υ(nS) < p_T> vs EA

JHEP 11 (2020) 011



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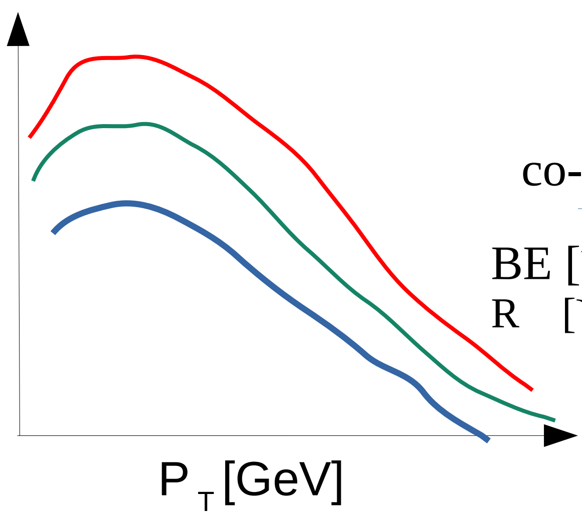
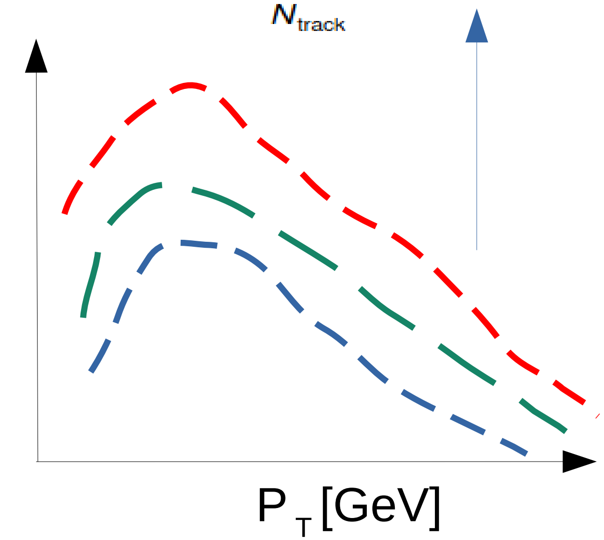


co-mover/dynamic disso.

BE [Υ(3S) <Υ(2S) <<Υ(1S)]

R [Υ(3S) >Υ(2S) >>Υ(1S)]

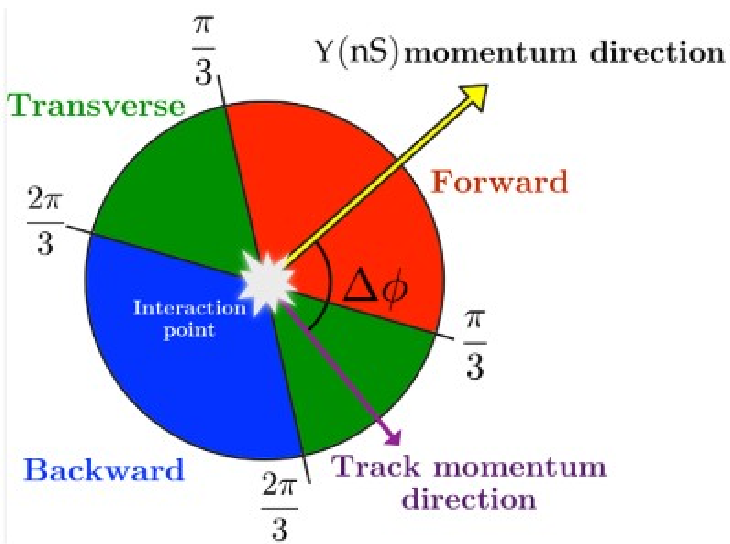


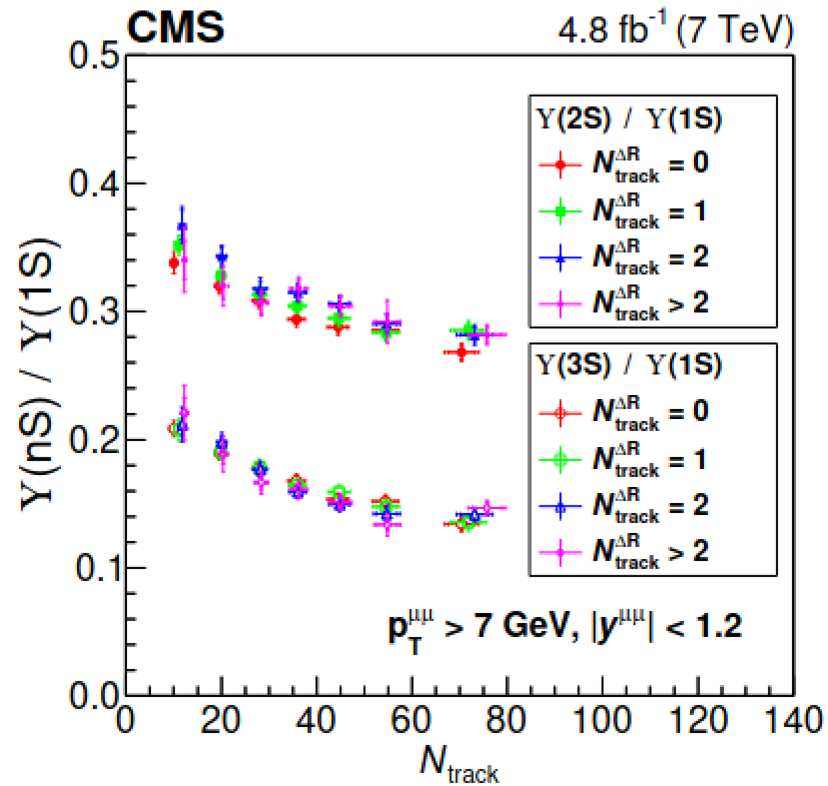
Low p_T yield depleted, high p_T yield roughly same

More weightage from high p_T bins, <p_T> shifts to a higher value

Test of co-mover idea

JHEP 11 (2020) 011





Υ(nS) / Υ(1S) vs N_{track} calculated for # of tracks in a cone around Υ(nS)

- In co-mover scenario ratio should depend N_{track} around Υ(nS)
- Results is contrary to the expectation
- Some thing more is happening

A novel and unconventional measurement from ATLAS

ATLAS-CONF-2022-023.pdf

ATLAS measured < n_{ch} > for different $\Upsilon(nS)$:

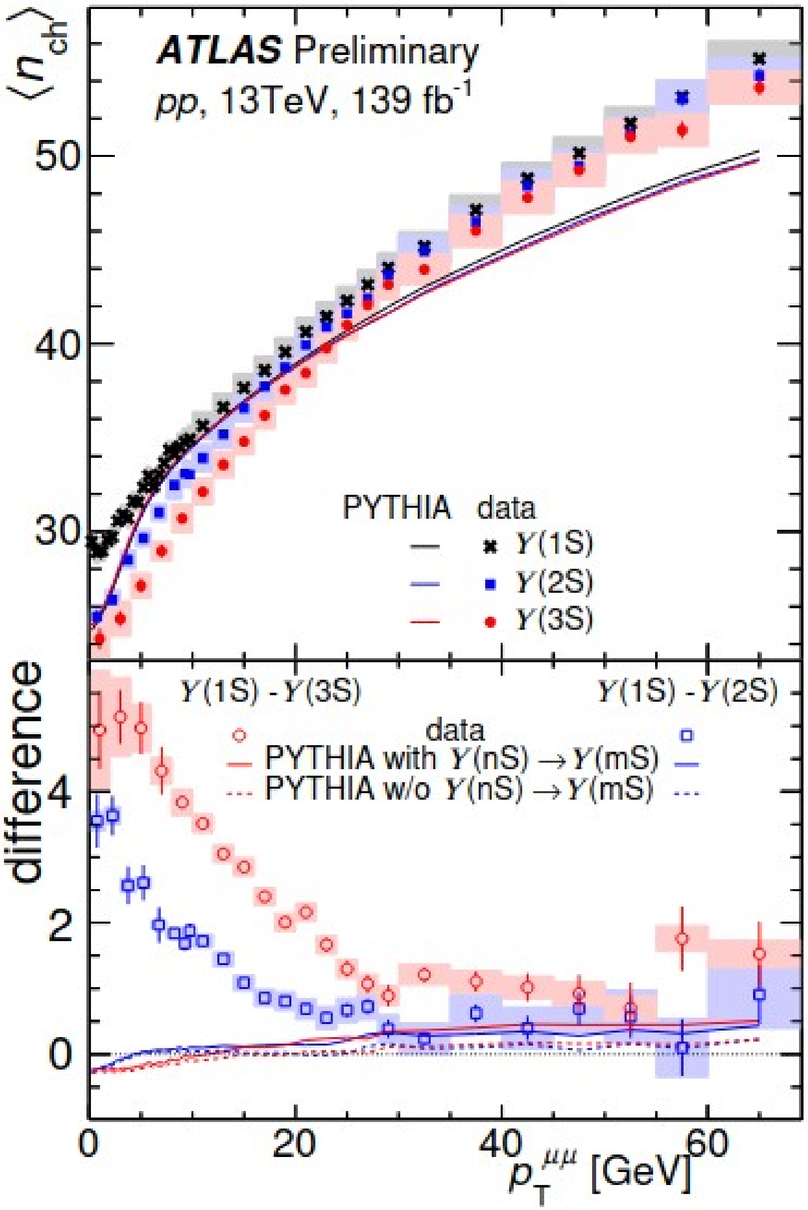
– < n_{ch} > is different for different $\Upsilon(nS)$ states

– Event with $\Upsilon(2S)$ has ~3 tracks less than events that has $\Upsilon(1S)$

– Event with $\Upsilon(3S)$ has ~5 tracks less than events that has $\Upsilon(1S)$

– More dominant at low-p_T

– No such effect in PYTHIA



Trivial interpretation:
Energy penalty is more producing massive particle

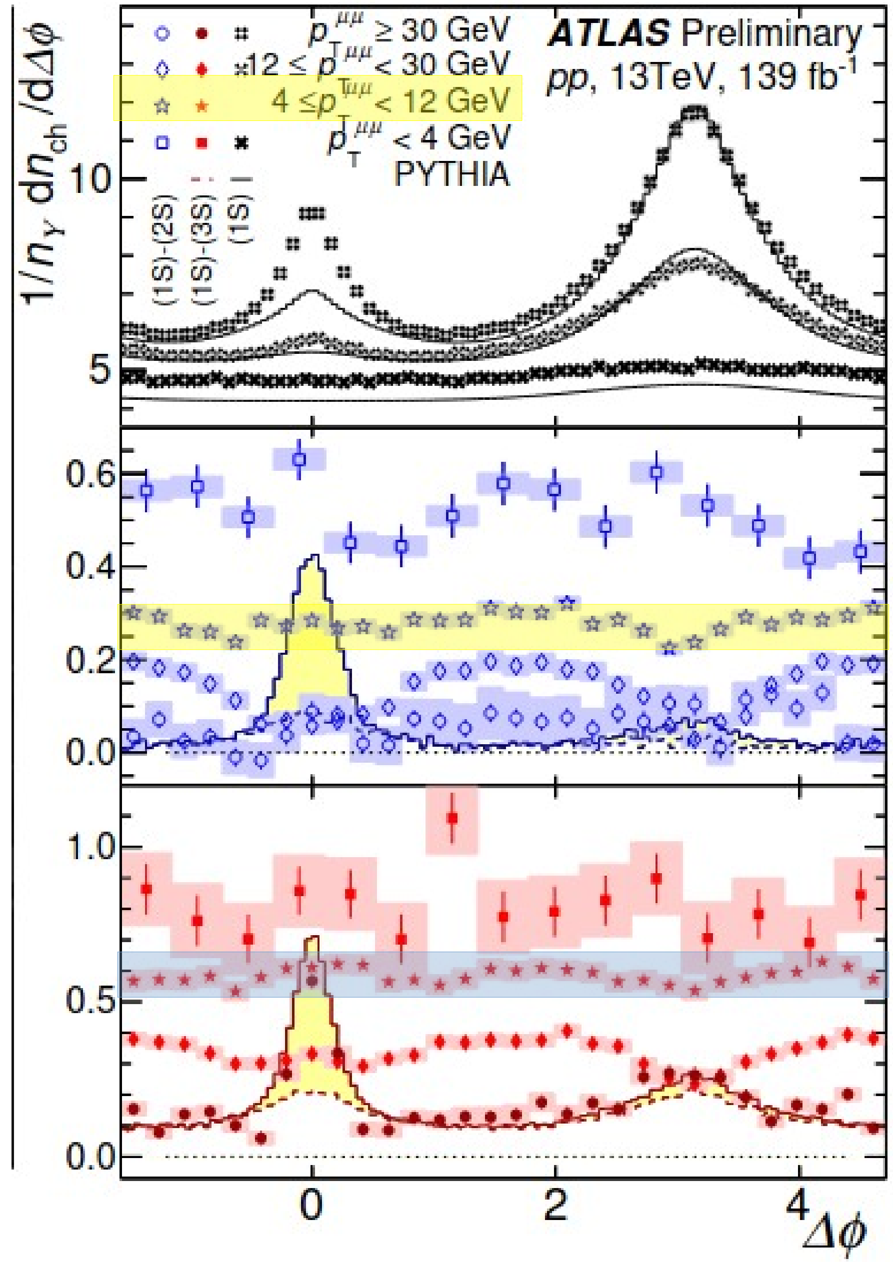
A novel and unconventional measurement from ATLAS

ATLAS-CONF-2022-023.pdf

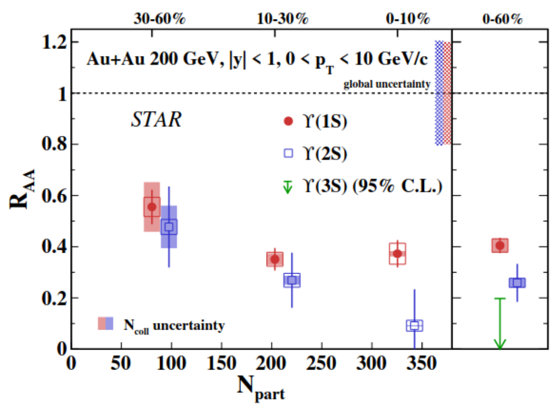
Excess in < n_{ch} >is not only around Υ(1S) direction

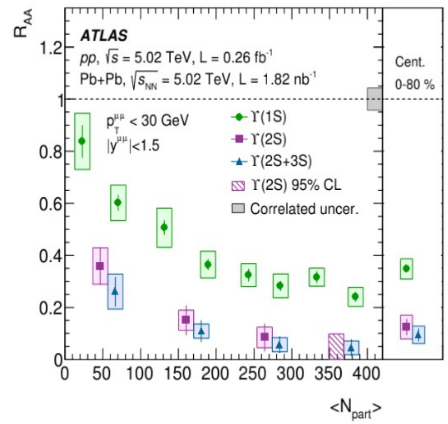
It is spread over entrire $\Delta\phi$

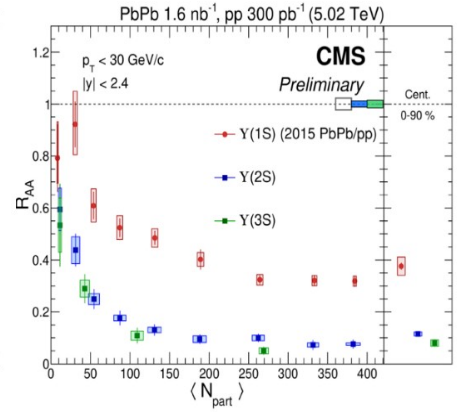
Something interesting must be happening



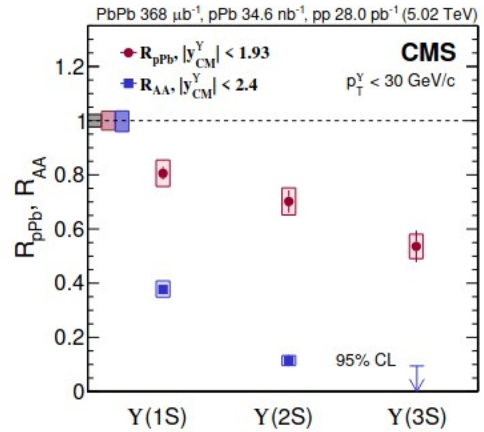
Summary

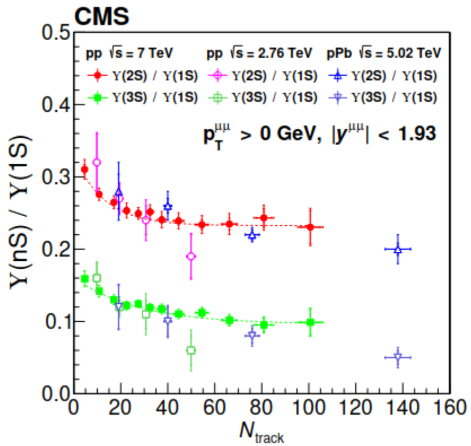


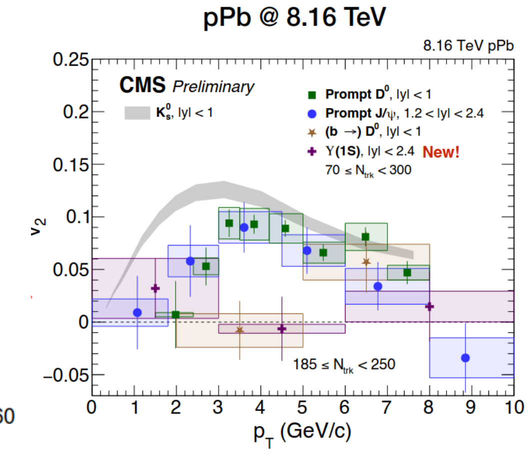




AA collisions







pA/pp collisions

Sequential (like) suppression observed in AA (pA) collisions both at RHIC and LHC

Medium effect in pA, most likely effect of dynamic dissociation

v_2 of ϒ(1S) consistent with zero

Thank You