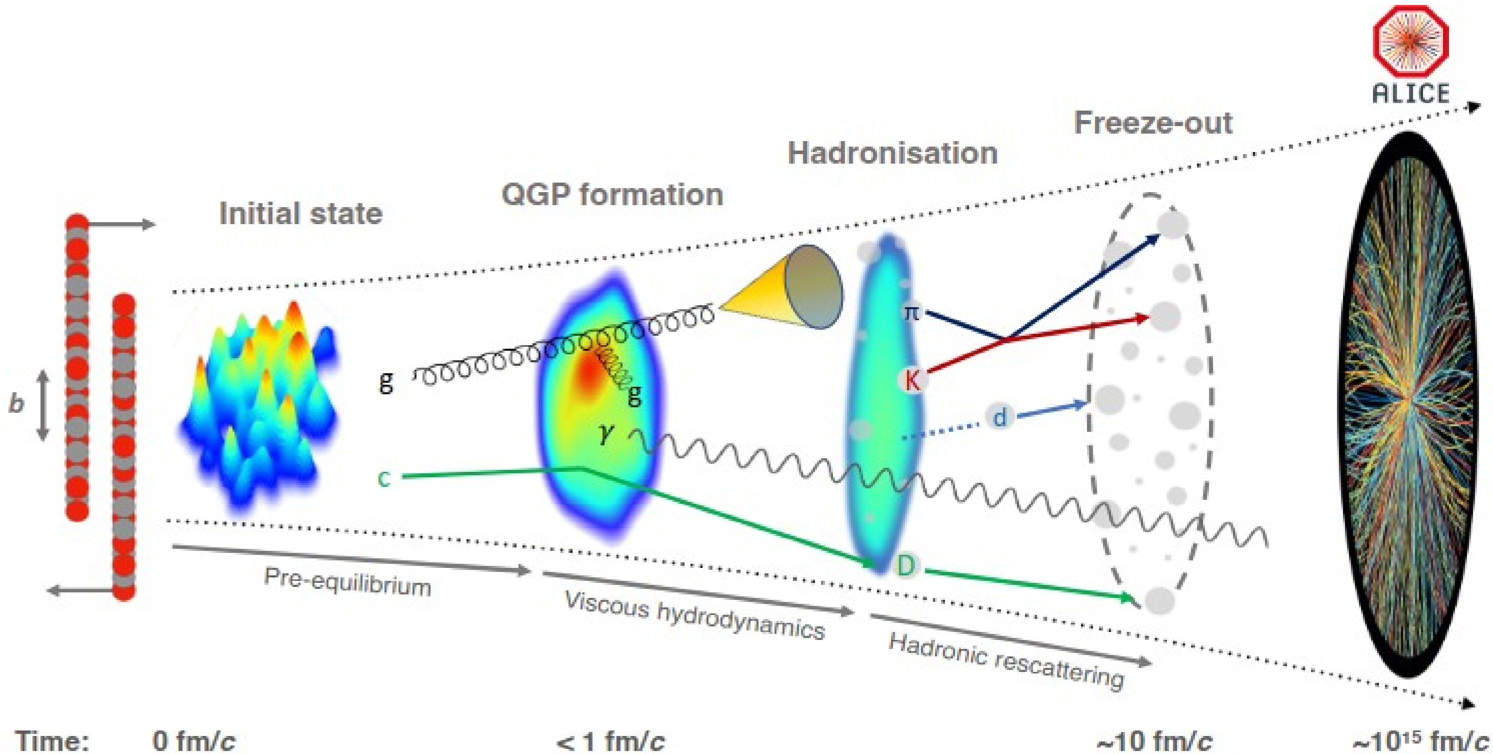
Recent results on bottomonium production

Subikash Choudhury
Saha Institute of Nuclear Physics

DAE-BRNS symposium on "Contemporary and Emerging Topics in High Energy Nuclear Physics (CETHENP 2022)"

Evolution of a heavy ion collision



arXiv:2211.04384

What are Quarkonia?

– Bound states of heavy flavor quark-antiquark pairs; charmonium ($c\bar{c}$) and bottomonium ($b\bar{b}$)

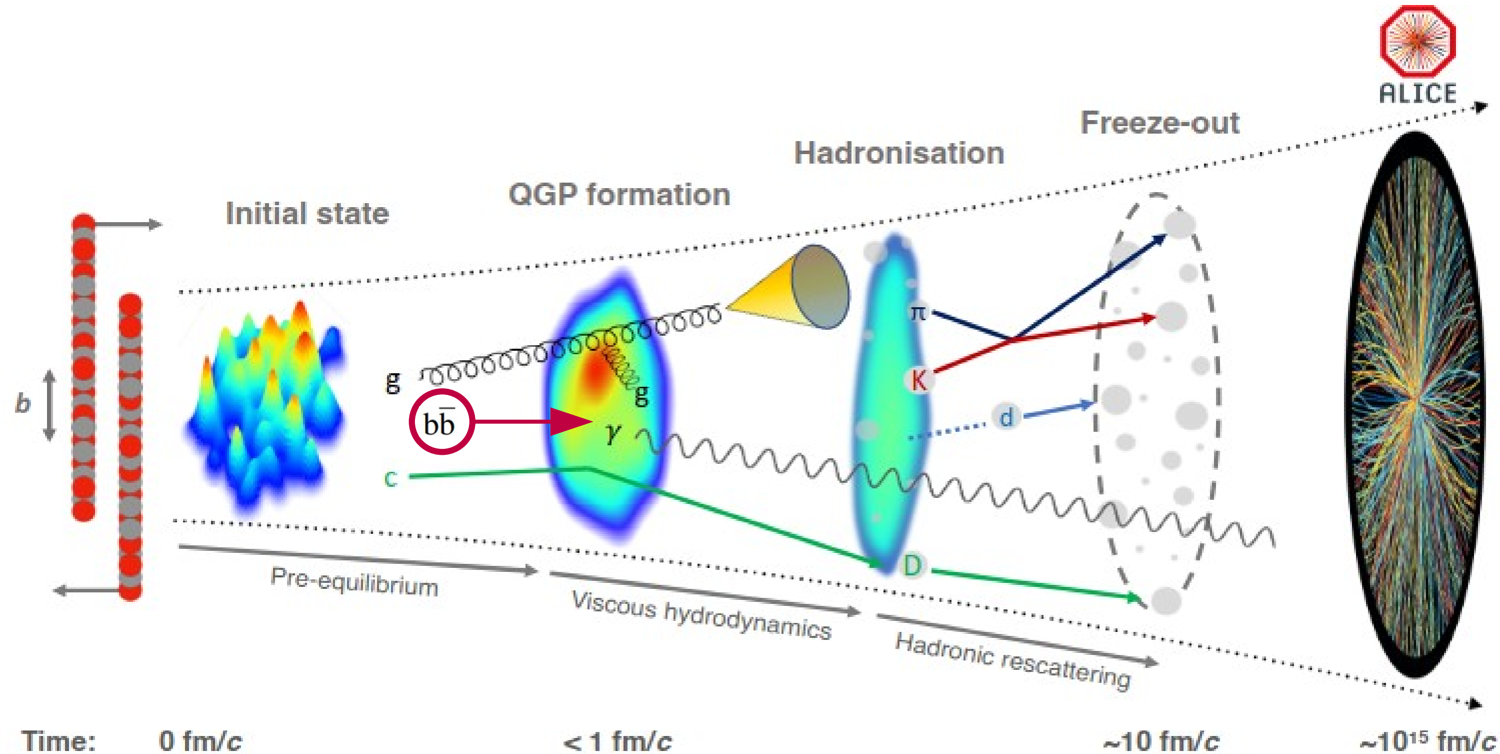
– Produced very early in collisions from initial hard scattering

Why important ?

– Benchamark for non-perturbative and perturbative aspects of QCD

– Sensitive to partonic deconfinement

Why Quarkonia/Bottomonia ?



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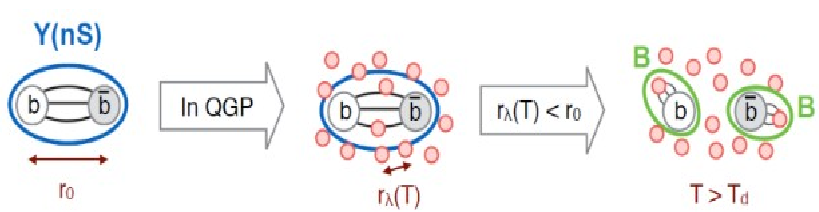
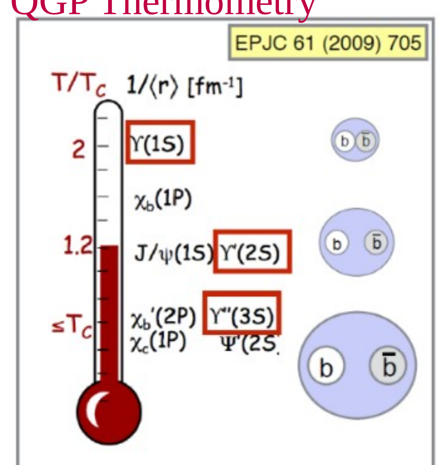
Color screening



Static dissociation and sequential melting

QGP Thermometry



Why Quarkonia/Bottomonia ?

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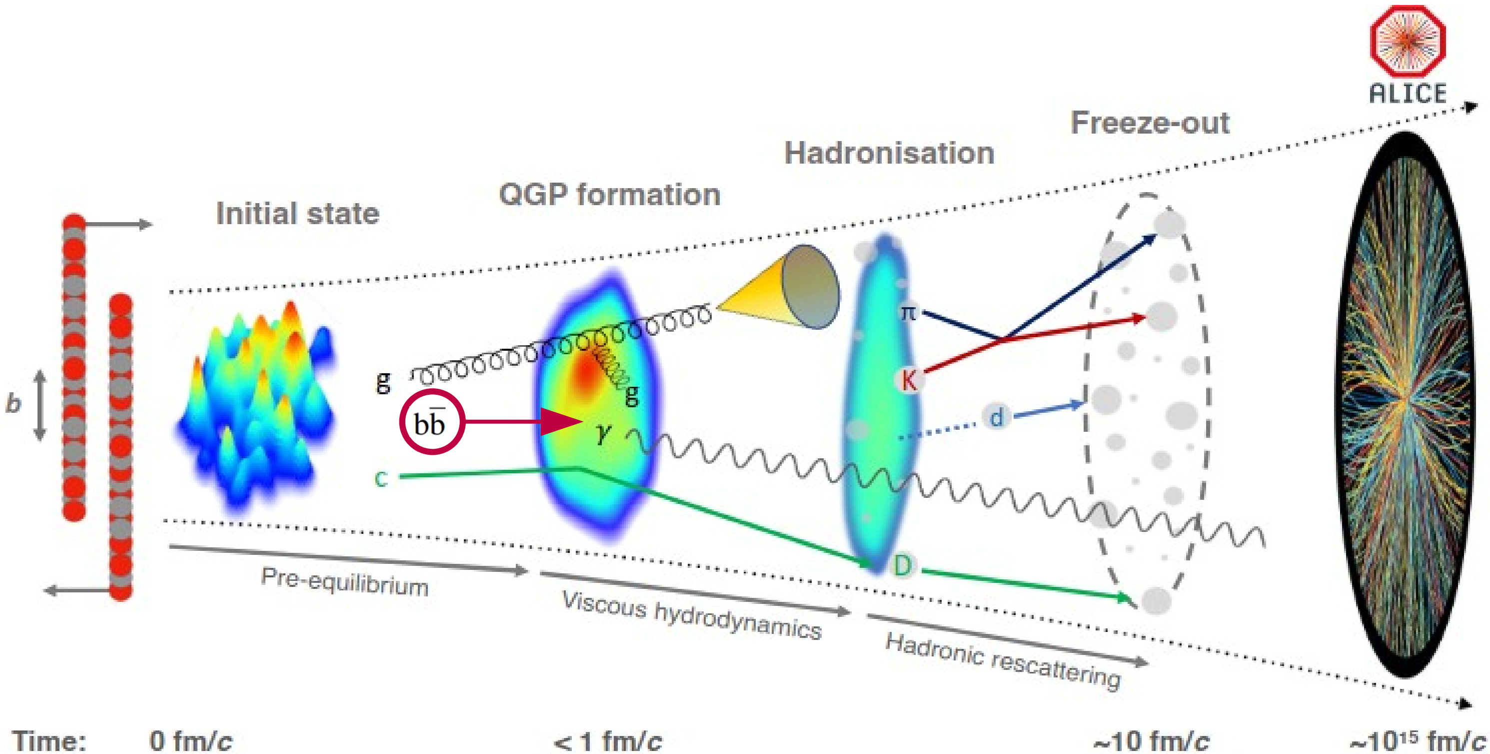
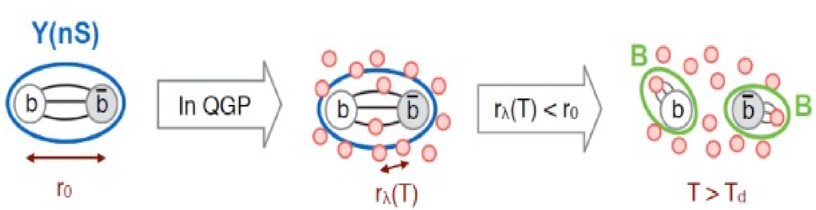
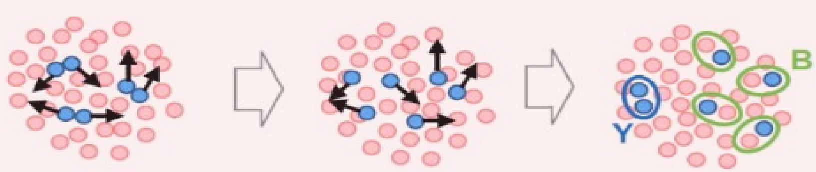


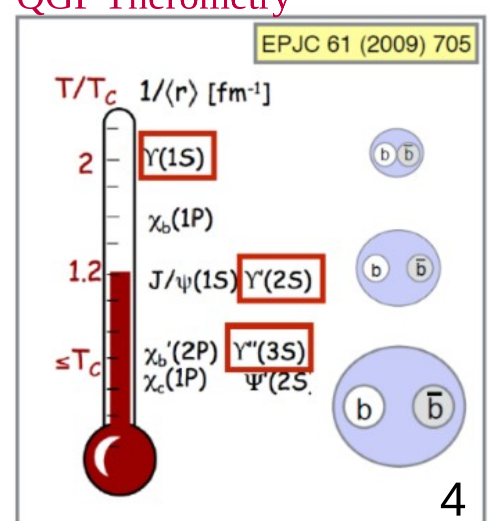
QGP Therometry

Color screening (sequential melting)

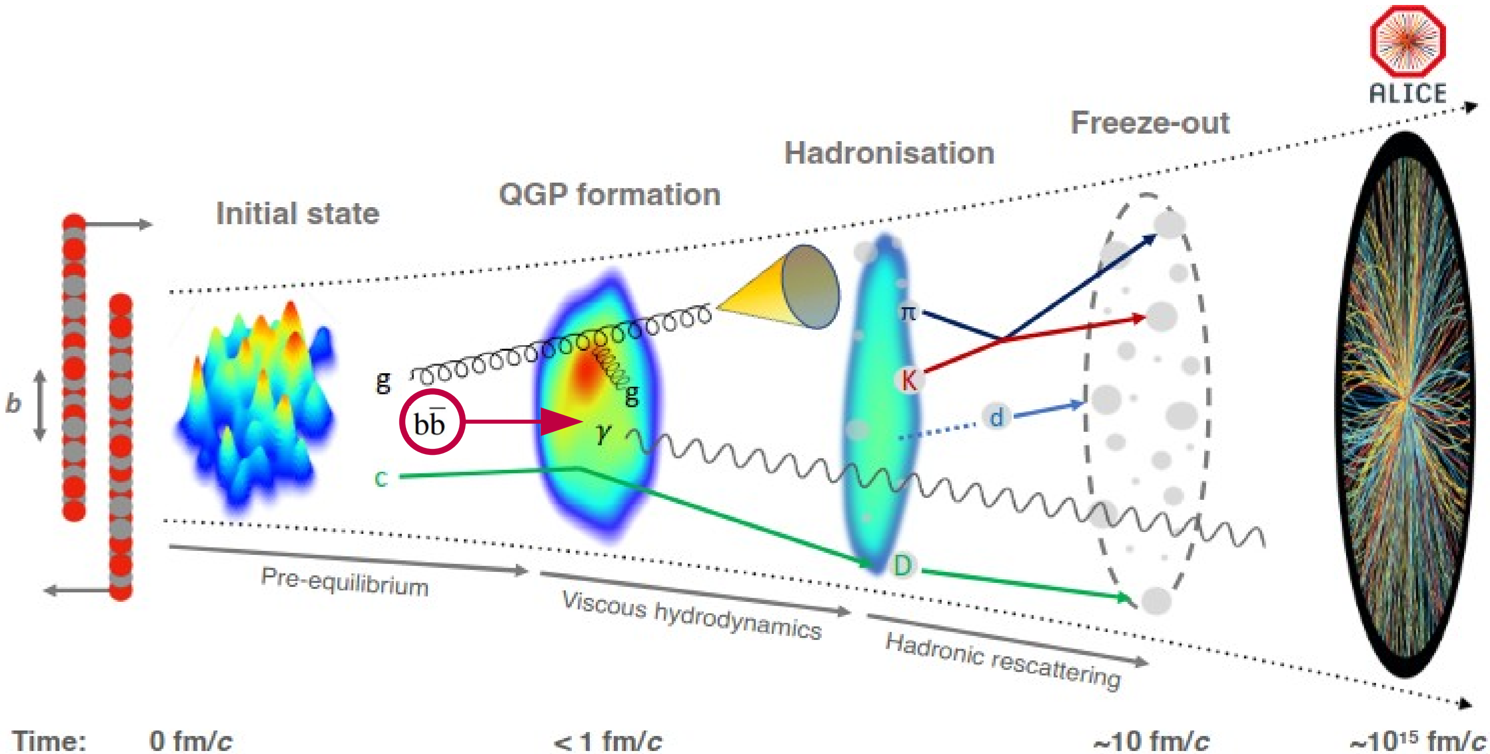


Regeneration (unlikely for Υ)





Why Quarkonia/Bottomonia ?



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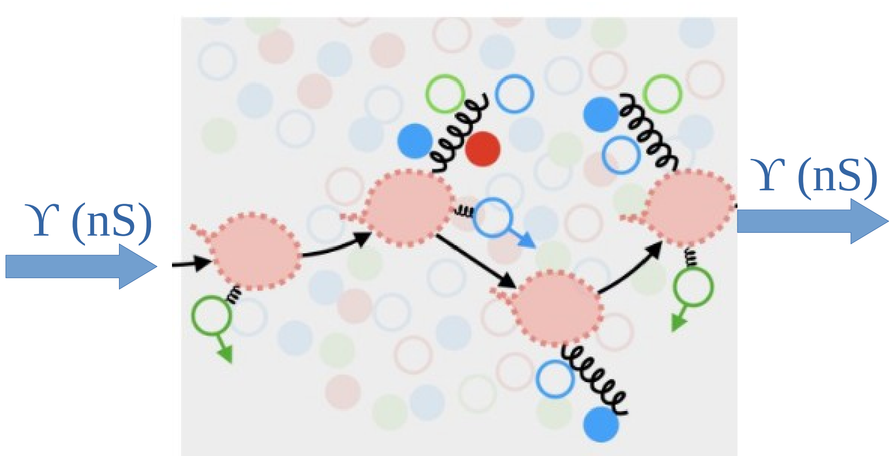
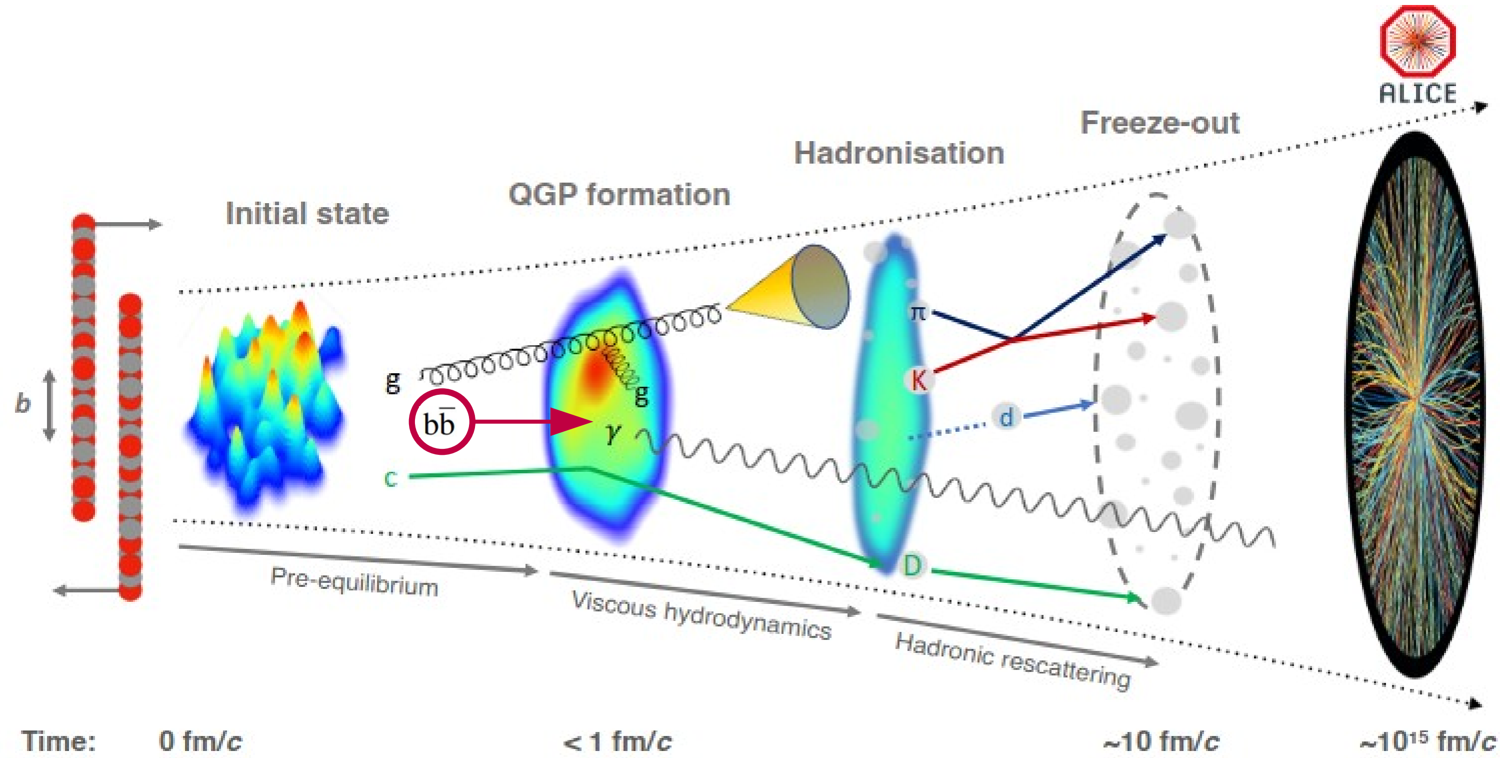
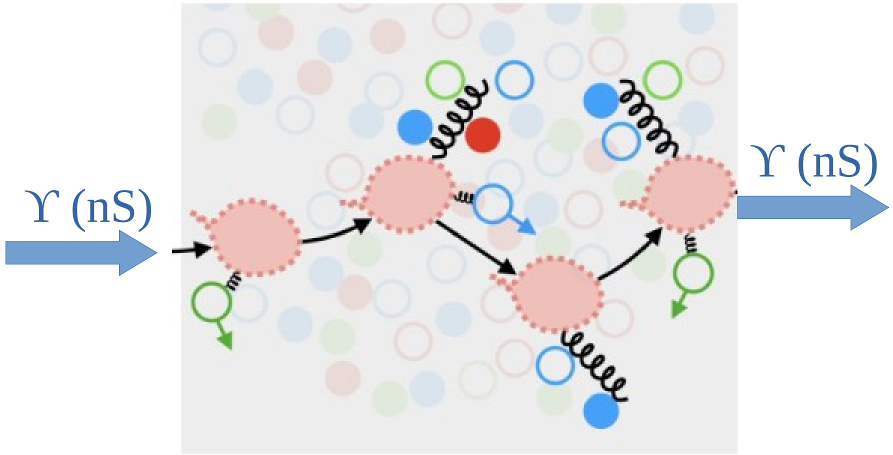


Information on thermalization
– picks up flow (v_2) ?

Why Quarkonia/Bottomonia ?

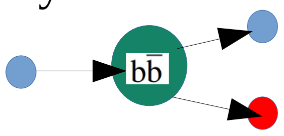
arXiv:2211.04384





Information on thermalization
– picks up flow (v_2) ?

What else ?
– Dynamic dissociation (co-mover)



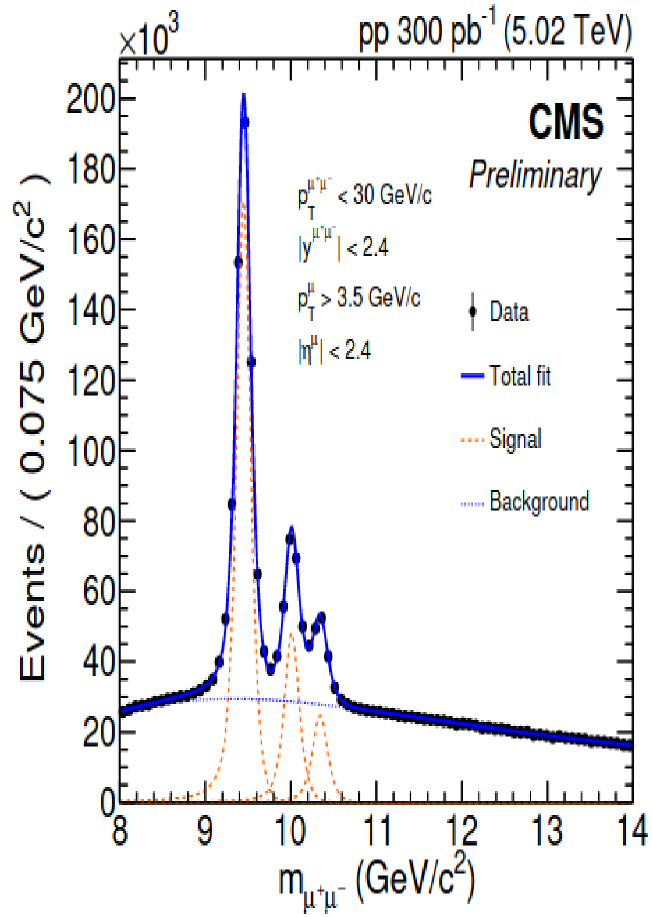
Signal Extraction

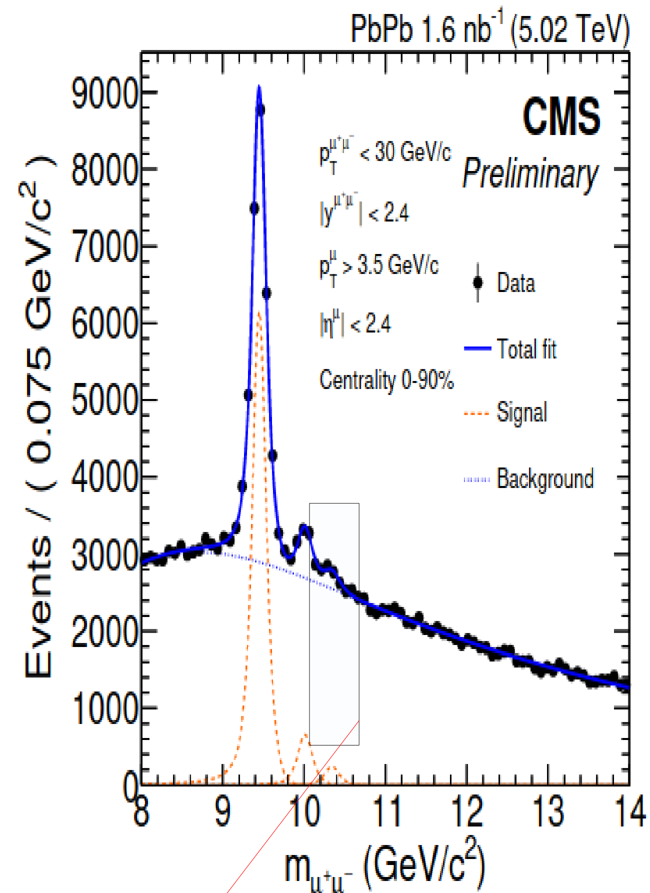
CMS-HIN-21-007-pas.pdf

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

Signal :
Crystal Ball

Background:
2nd order polynomial/
Double Exponential





1st observation of $\Upsilon(3S)$ in PbPb

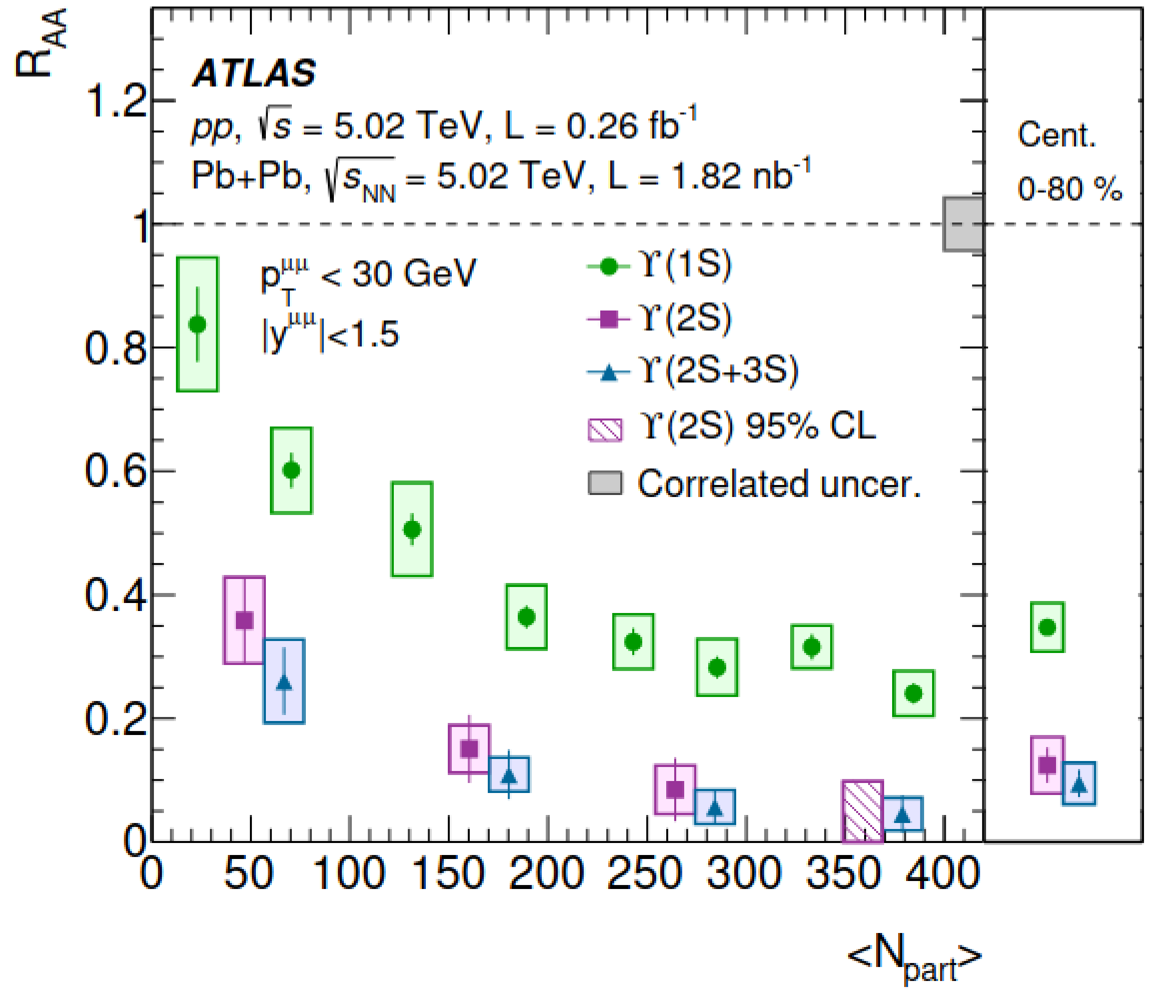
Nuclear Modification factor, R_{AA}

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} :
Υ(1S) > Υ(2S) > Υ(2S+3S)



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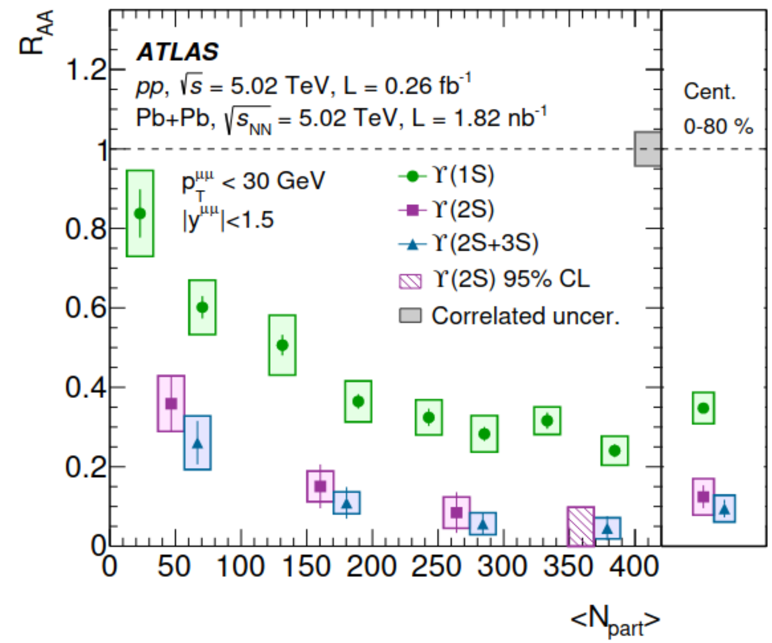
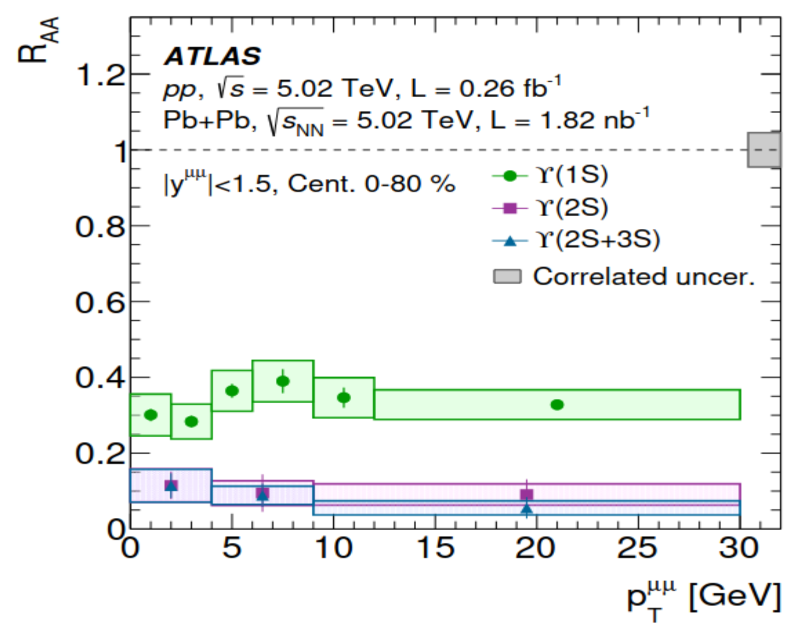


Ordering in R_{AA} :

ϒ(1S) > ϒ(2S) > ϒ(2S+3S)

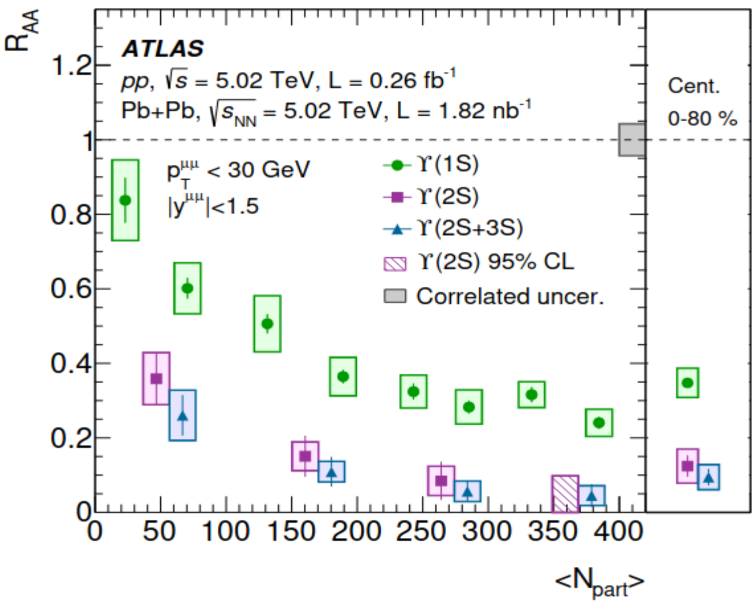


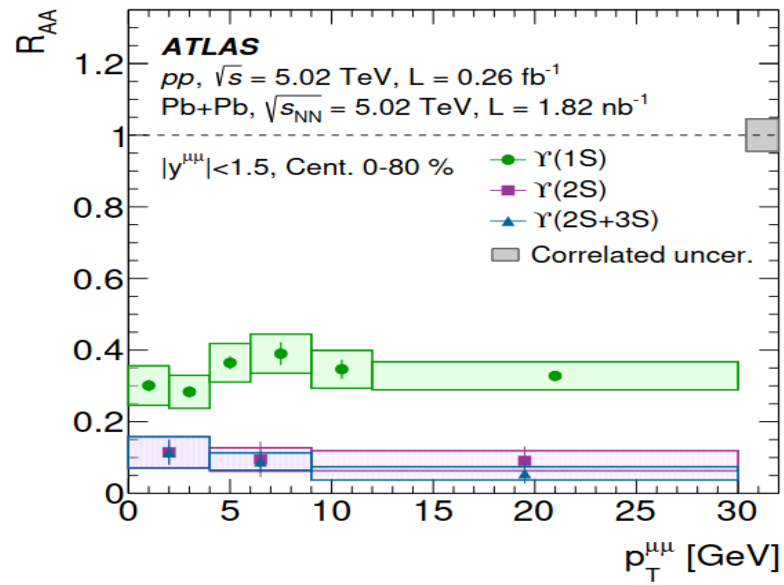
No strong p_T dependence

Evidence of sequential melting

Nuclear Modification factor, R_{AA}

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





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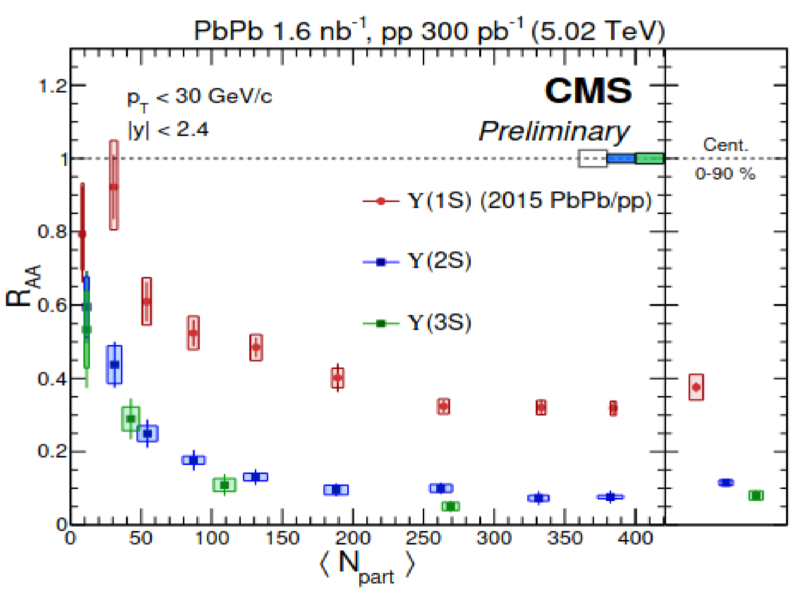

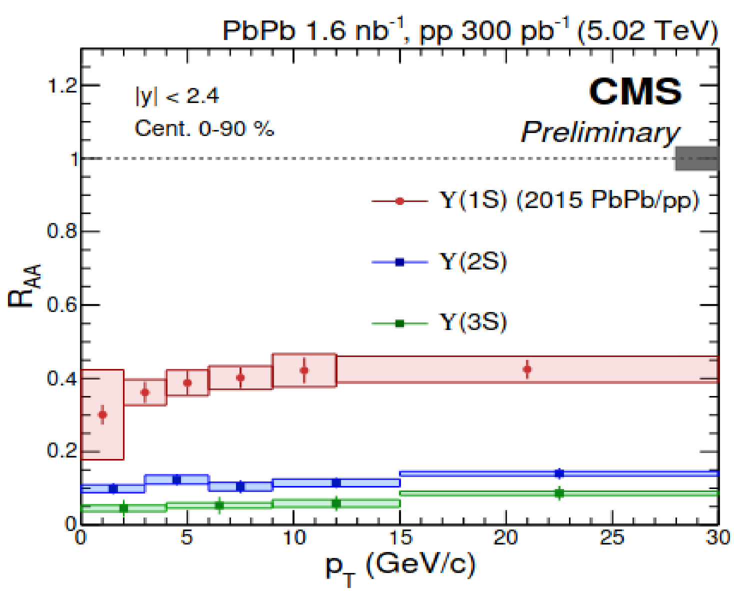

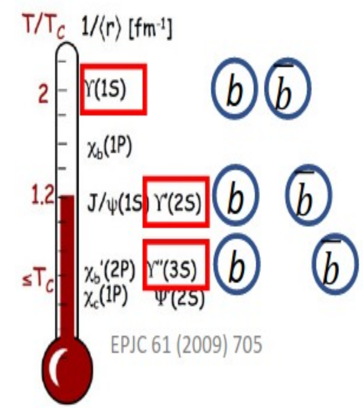

Clear evidence of sequential melting

Nuclear Modification factor, R_{AA}

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

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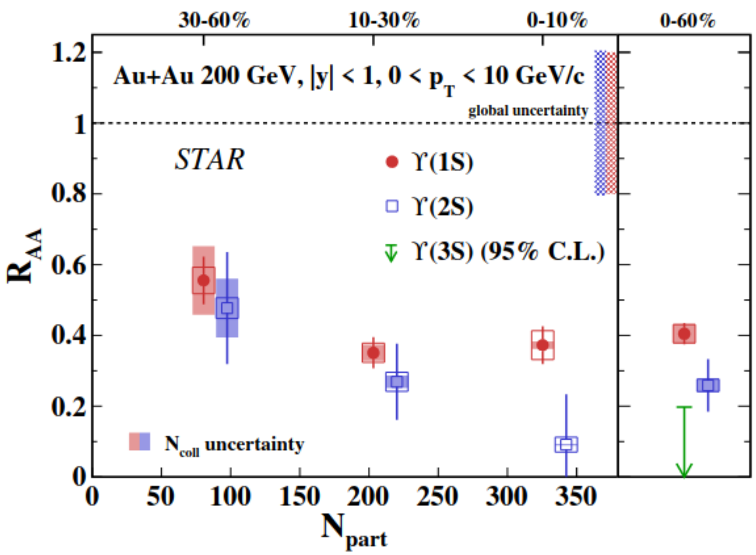

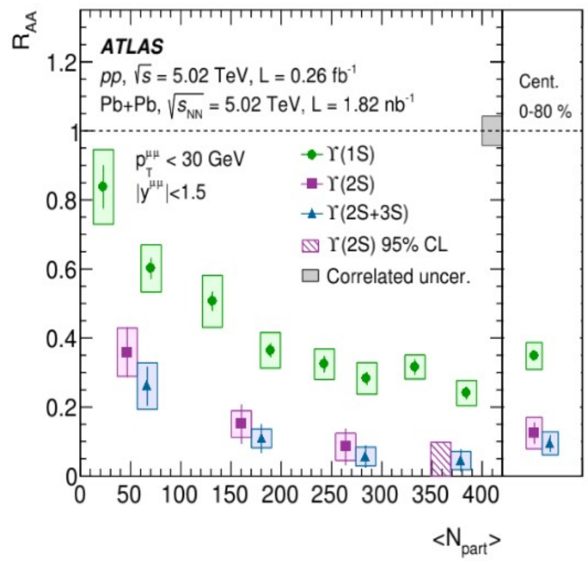

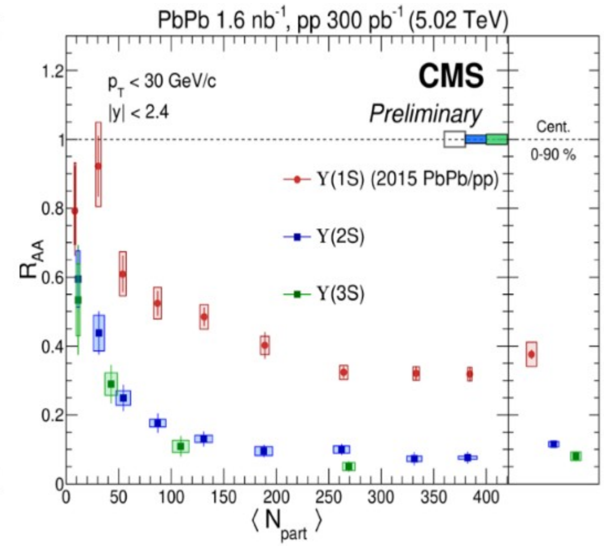

Clear indication sequential melting both at RHIC and LHC

Ordering in R_{AA} :

Υ(1S) > Υ(2S) > Υ(2S+3S / 3S)

Nuclear Modification factor, R_{AA}

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

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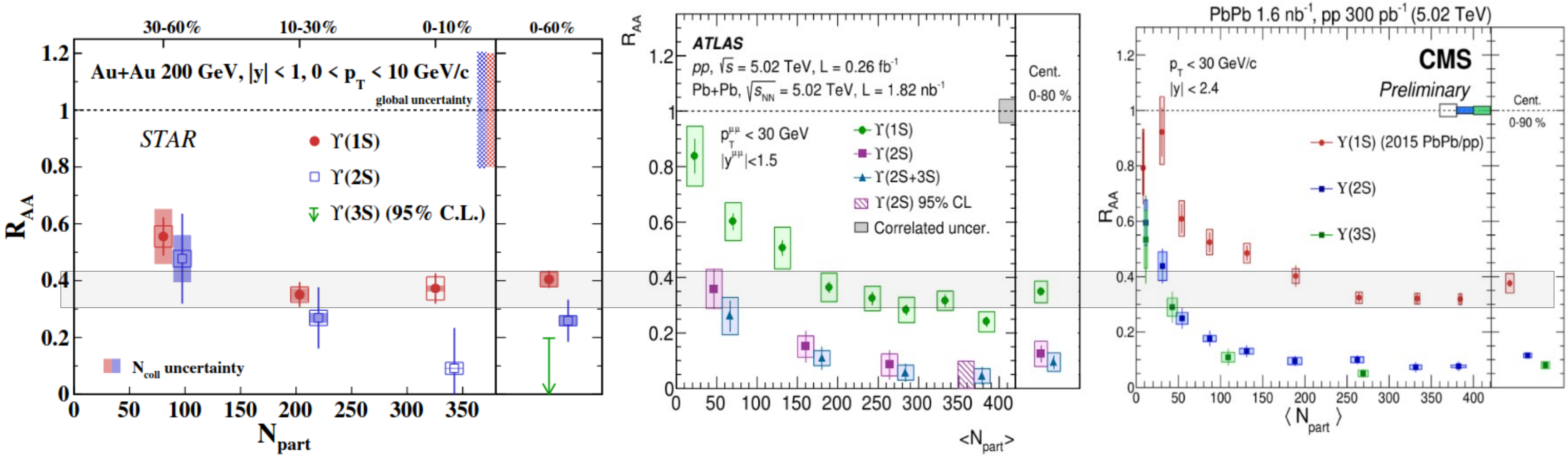


2205.10289 , PRD 104 (2021) 094049

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 at LHC data with: medium temperature
– 455 MeV at RHIC
– 630 MeV at LHC

Model predictions

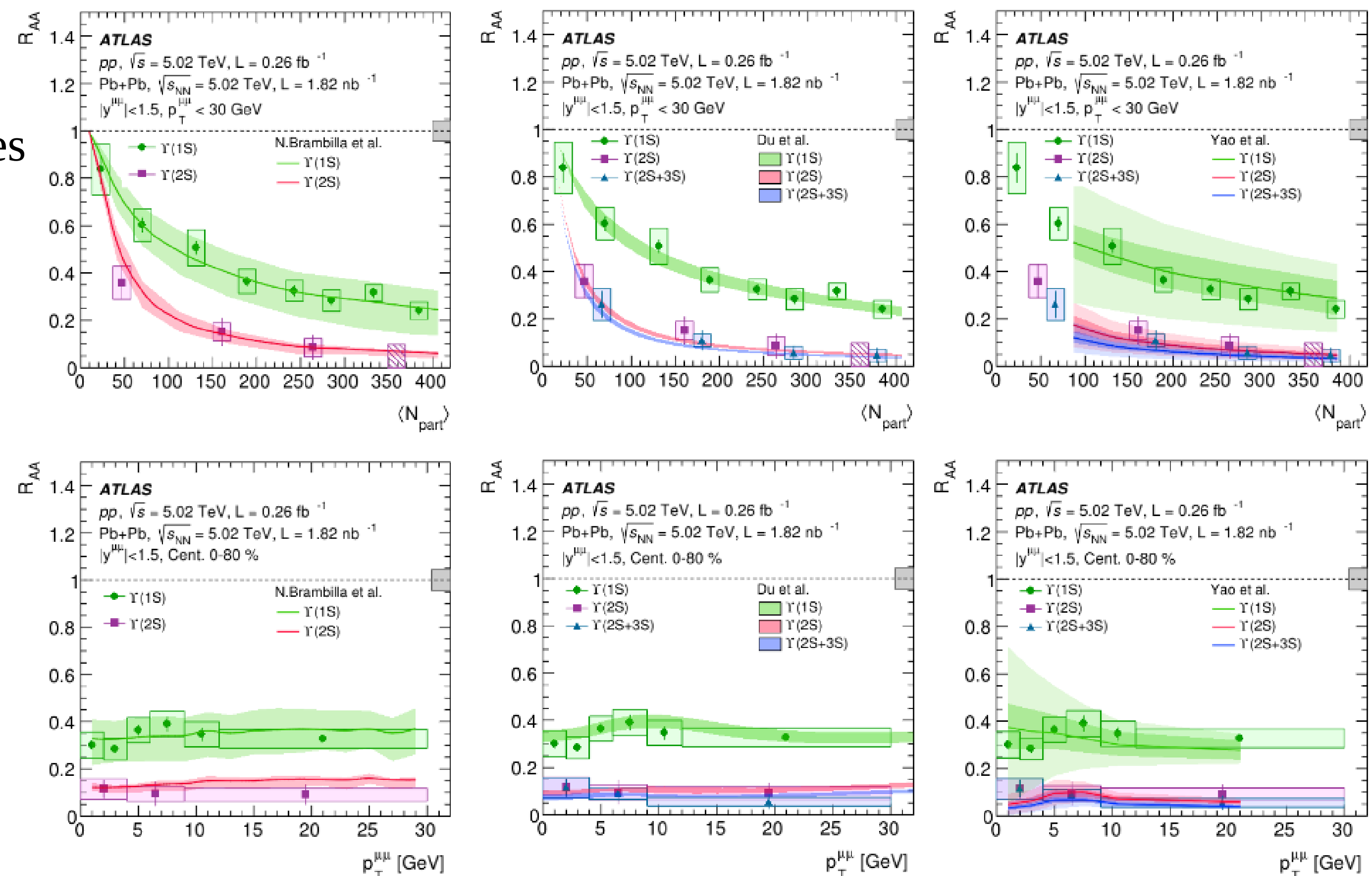
Models use different approaches but agrees well with data

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

2205.03042



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

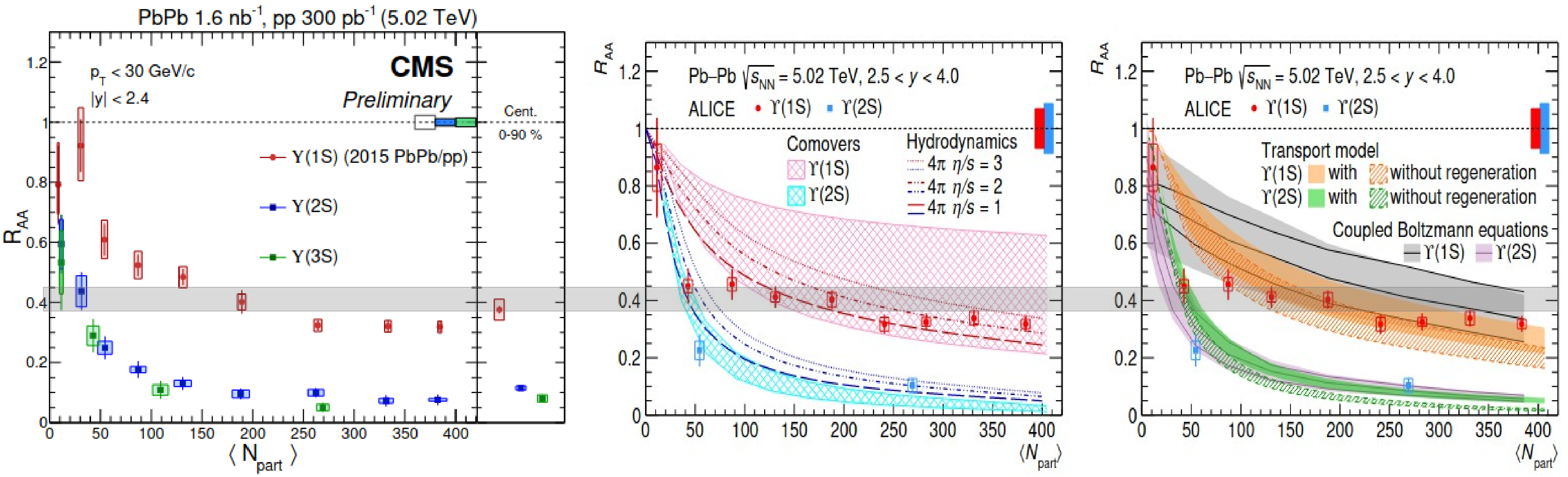
M.H.X. Du and R. Rapp, PRC 96 (2017) 054901

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

Nuclear Modification factor, R_{AA}

From mid rapidity to forward rapidity

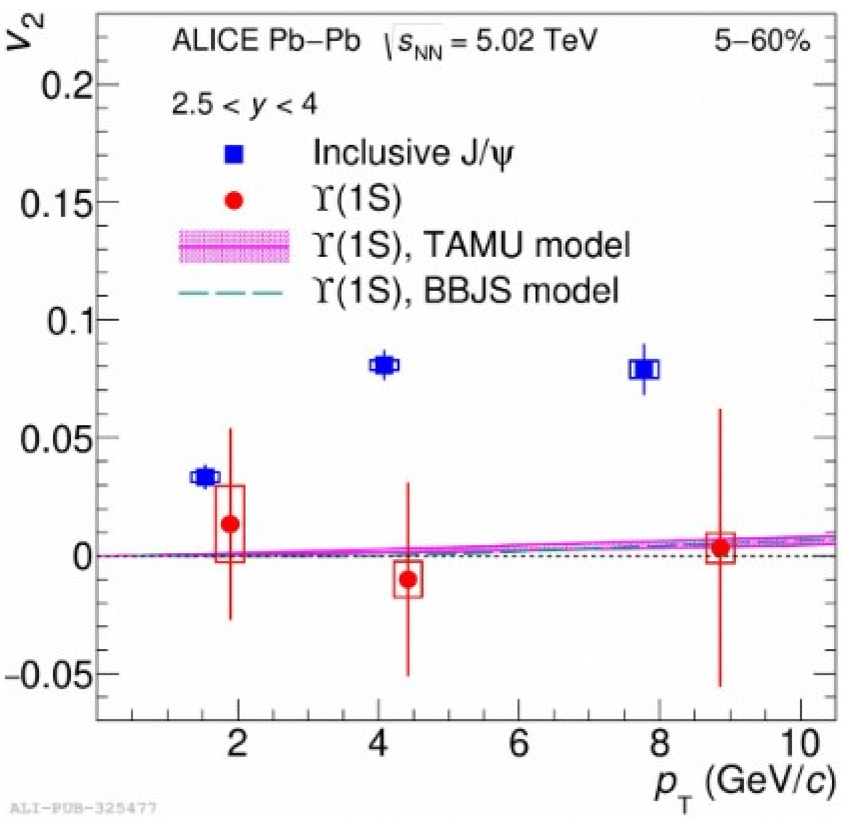
CMS-HIN-21-007-pas.pdf
2011.05758

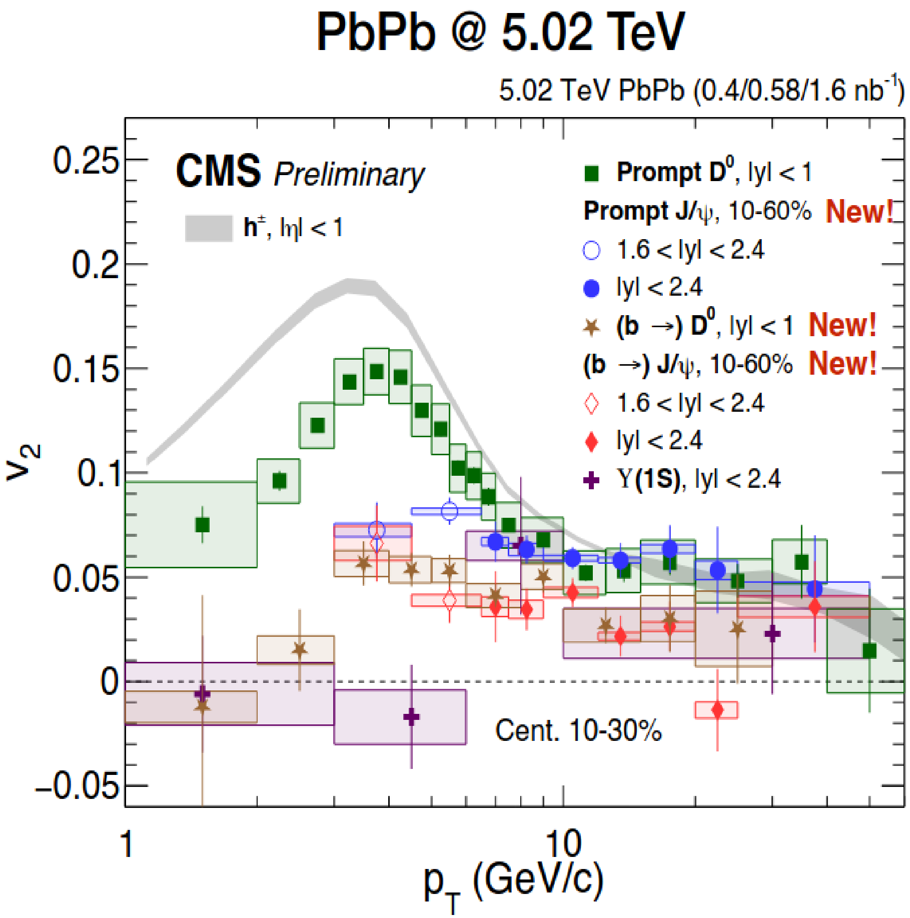


– Sequential suppression both at mid and forward rapidity
– No rapidity dependence
– Model calculations suggest regenaration effect is insignificant

Collective flow

PRL 123 (2019) 192301



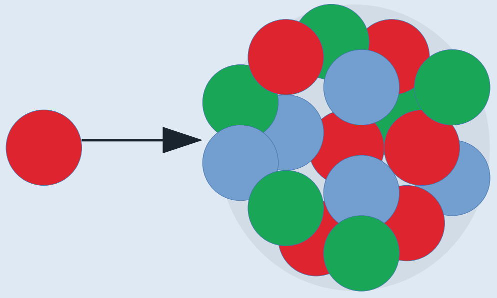


ϒ(1S) v_2 consistent with zero, model calculations predict very small value

– Leaves the medium very early

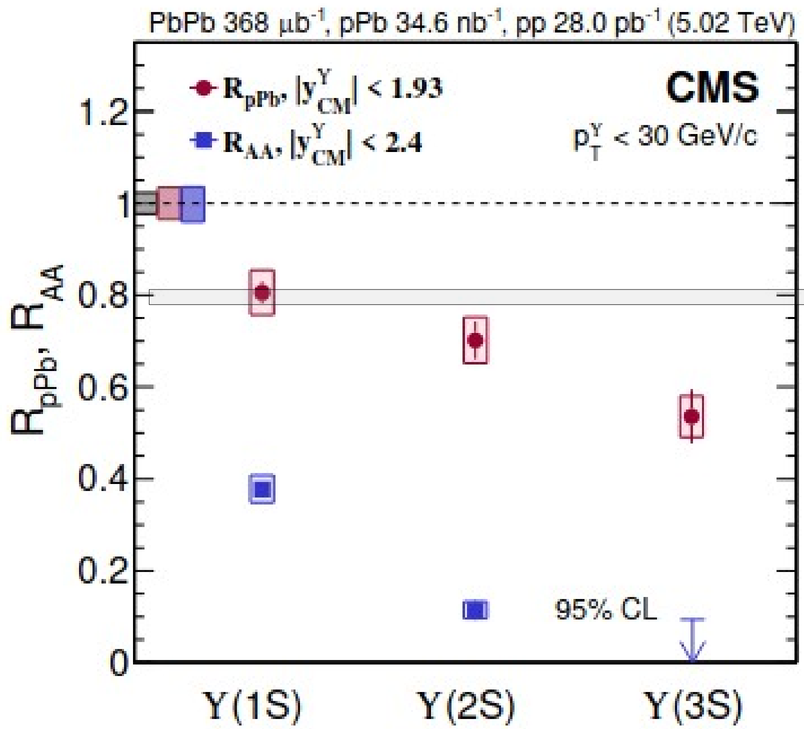
Simultaneous description of R_{AA} & v_2 can constrain model parameters better

Small System (pA)



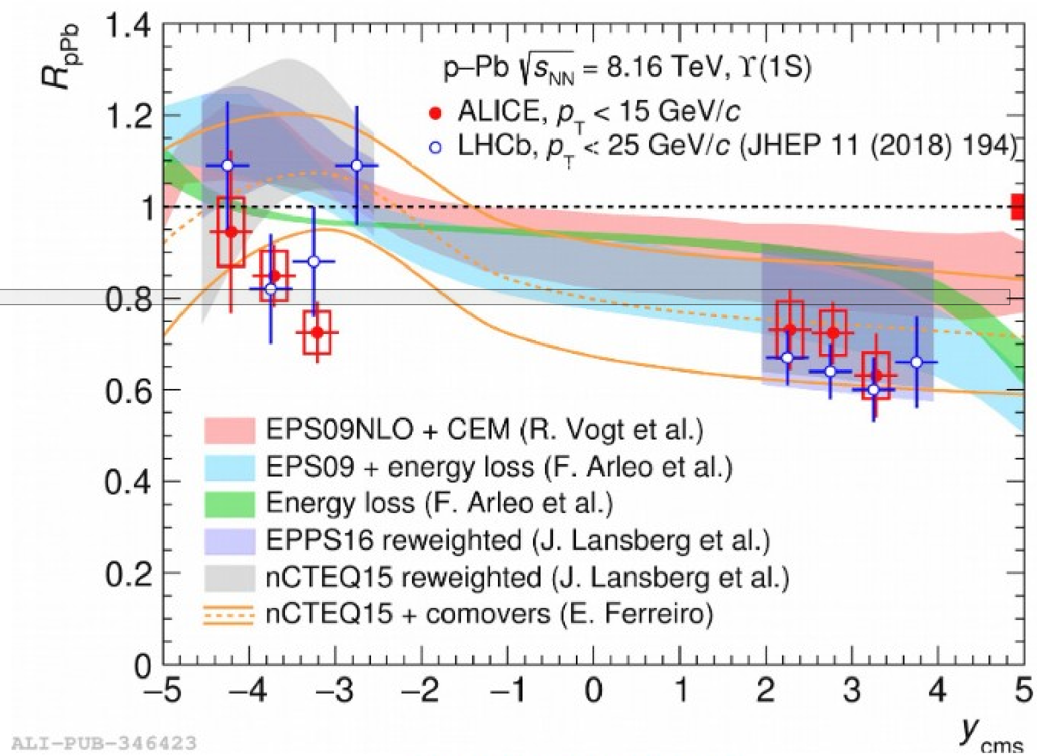
Nuclear Modification factor, R_{pA}

2202.11807



PLB 806 (2020) 135486

Pb →

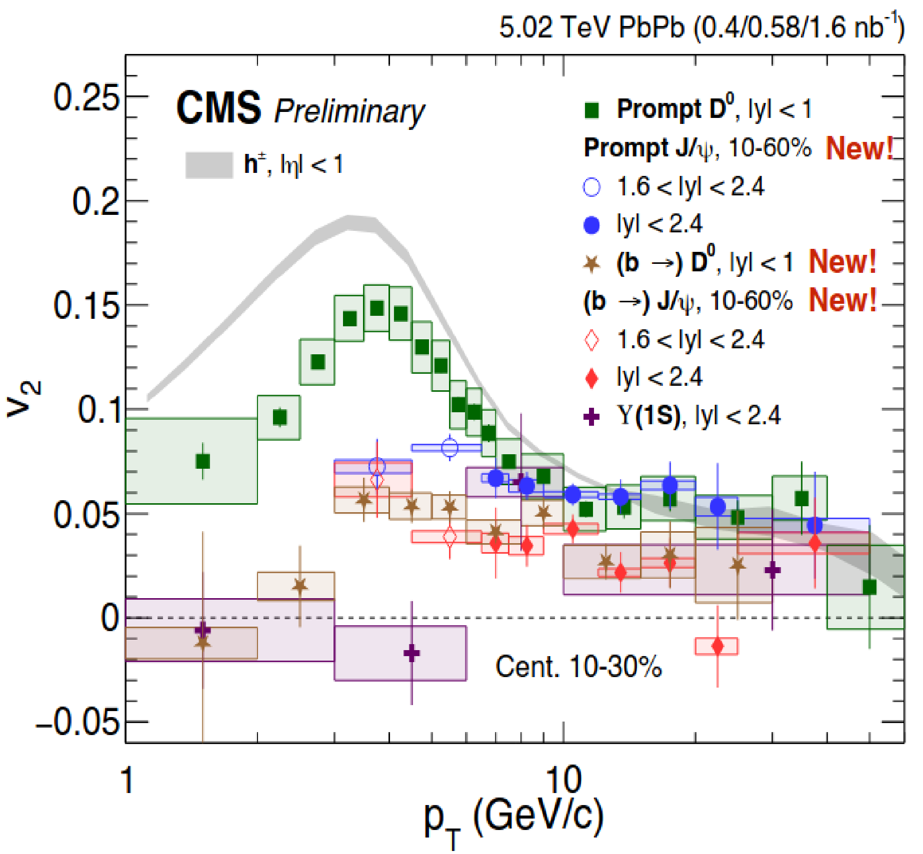


– R_{pPb} > R_{AA}
– R_{pPb} exhibit ordering same as R_{AA}
– Presence of final state interactions, consistent with “co-mover” scenario

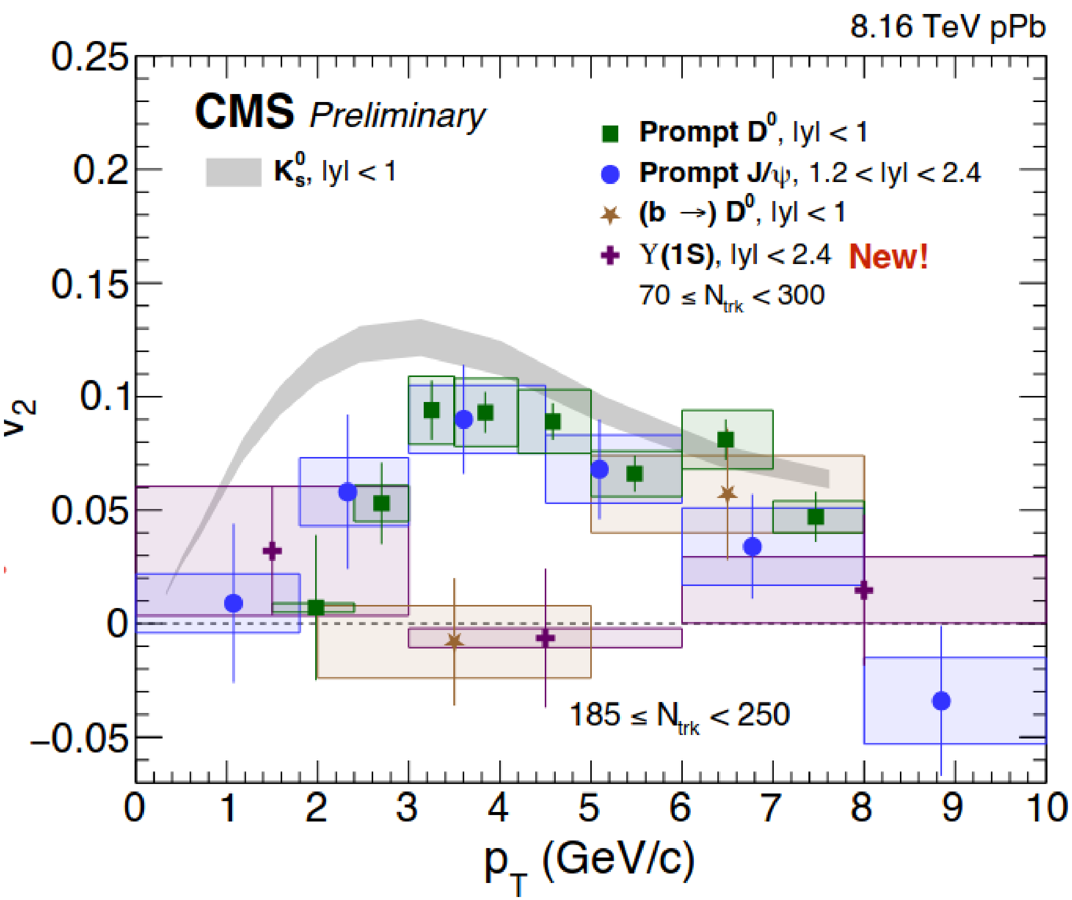
– Υ(1S) order of suppression is same at mid and forward rapidity
– Pb going direction shows more suppression
– Agrees with “co-mover” scenario

Collective flow

PbPb @ 5.02 TeV

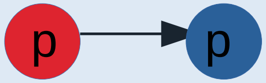


pPb @ 8.16 TeV



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)

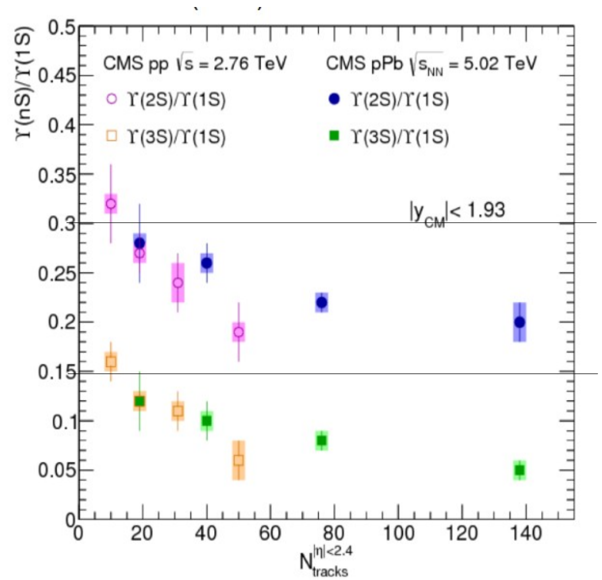
JHEP 04 (2014) 103
JHEP 11 (2020) 011

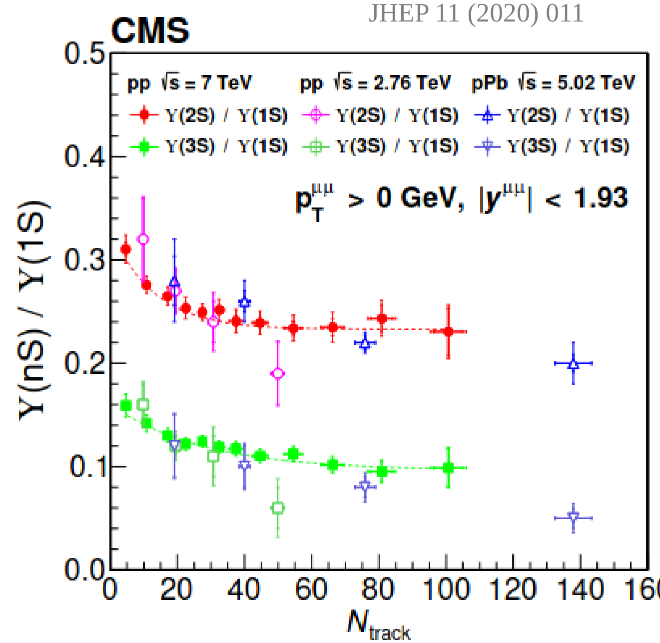
EA is the measure of number particles produced in an event

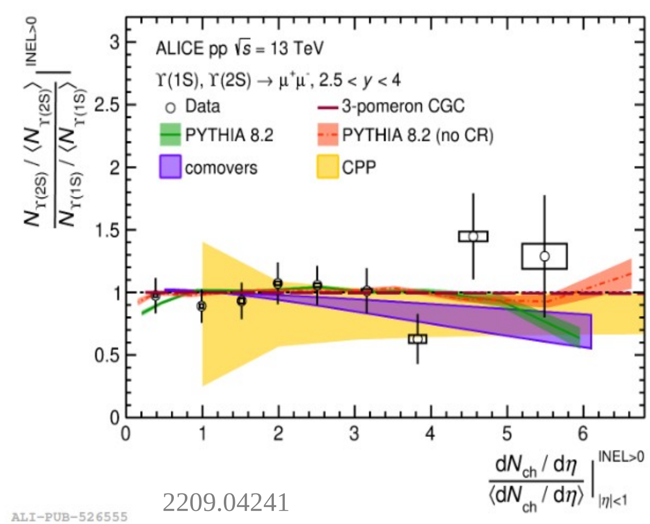
Υ(nS)/Υ(1S) vs EA
is analogous to R_{AA} or R_{pA}

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







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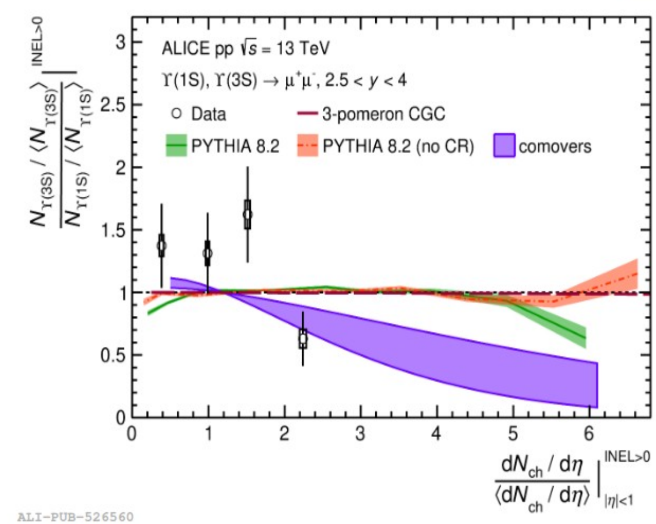


$\Upsilon(nS)$ < p_T> vs EA

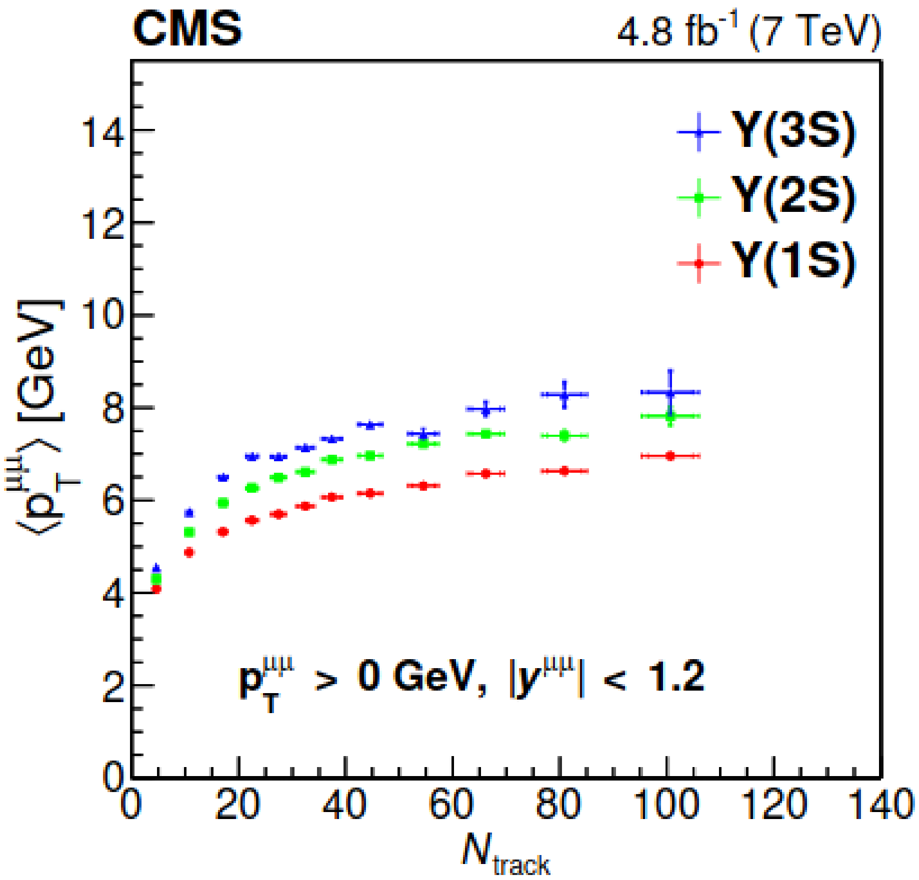
A clear mass ordering

– <p_T> of $\Upsilon(3S) > \Upsilon(2S) > \Upsilon(1S)$

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

What can be other explainations ?

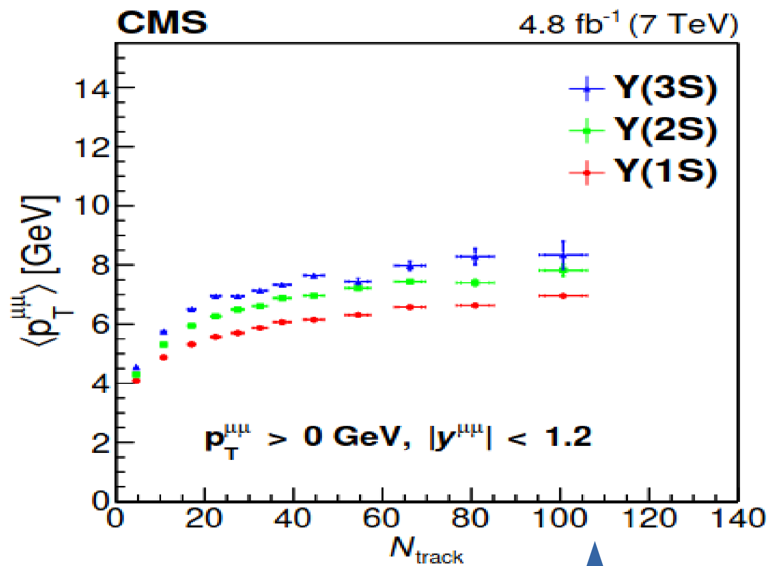
– Can co-movers explain ?



JHEP 11 (2020) 011

$\Upsilon(nS)$ < p_T> vs EA

JHEP 11 (2020) 011



A clear mass ordering
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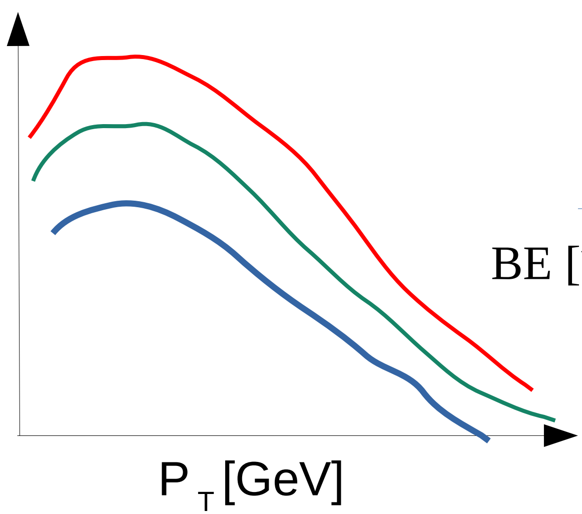
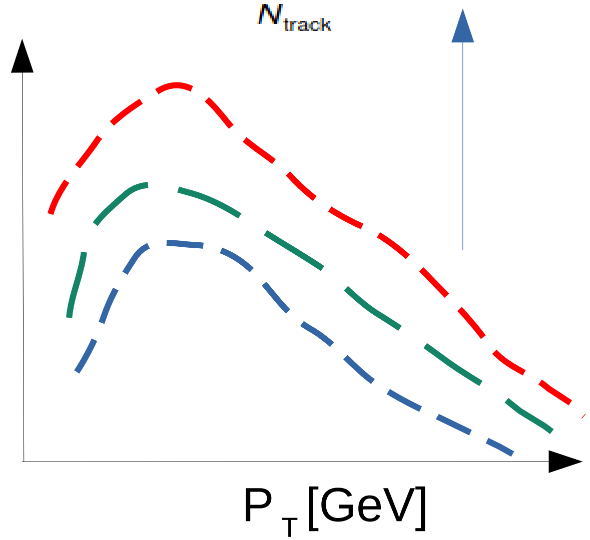


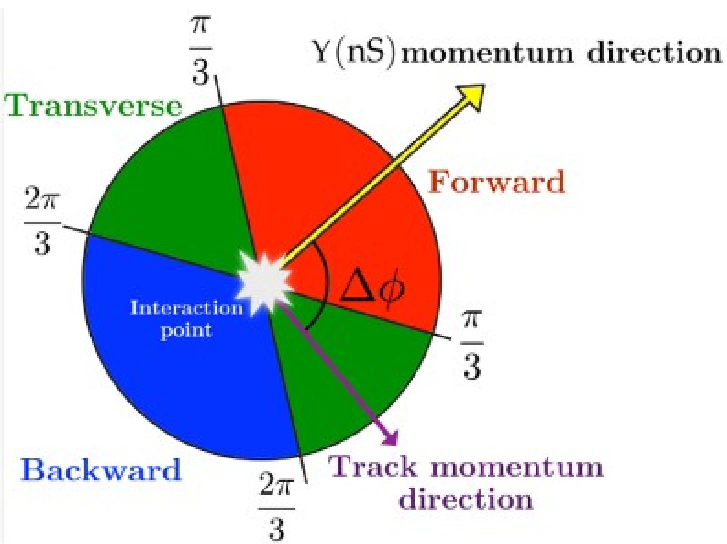
co-mover

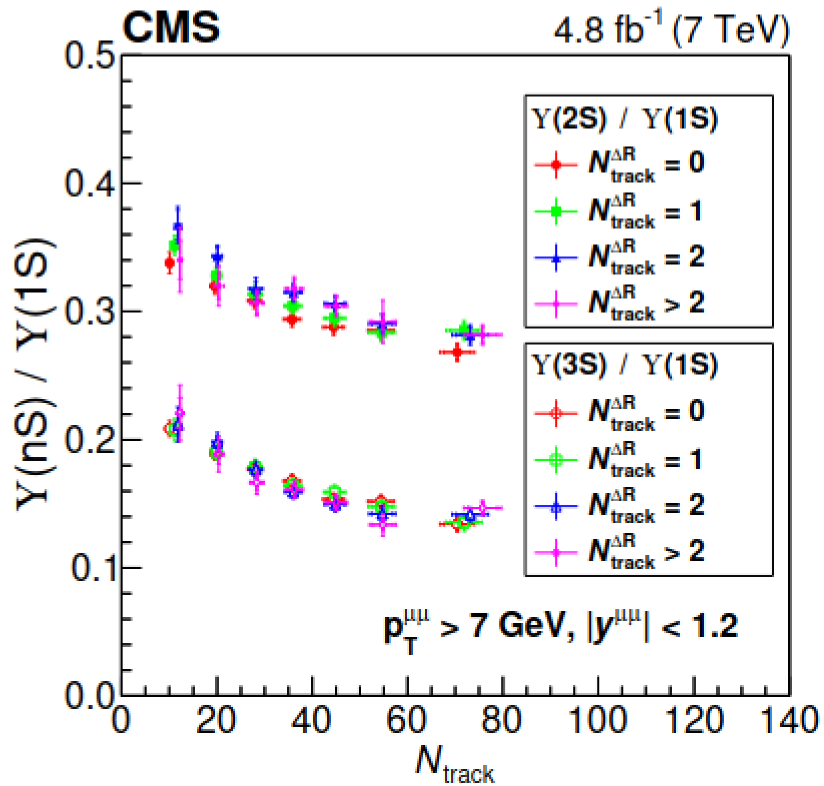
BE [$\Upsilon(3S) < \Upsilon(2S) << \Upsilon(1S)$]



Low p_T yield depleted, high p_T yield roughly same
More weightage from high p_T bins, <p_T> shifts to high value

Test of co-mover idea



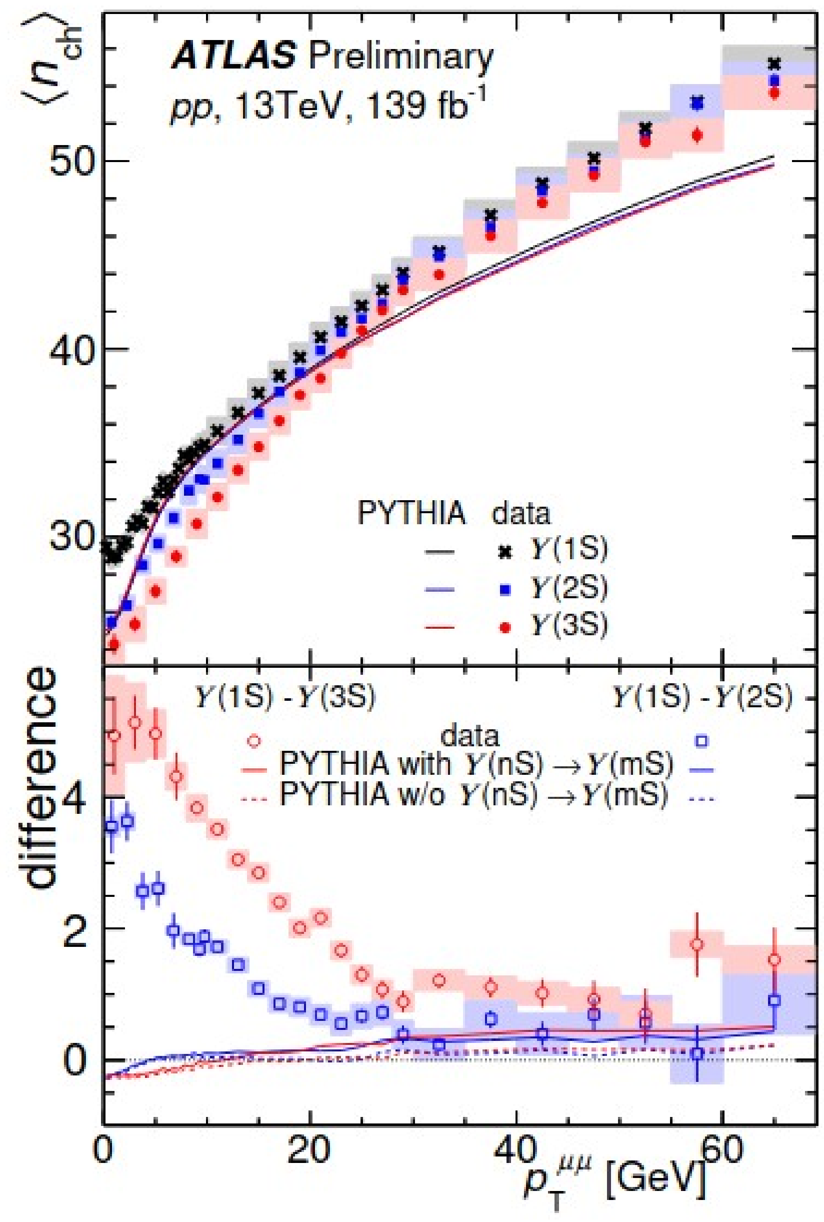


Υ(nS) / Υ(1S) vs N_{track} calculated for # of tracks in a cone around Υ(nS)

- 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 $\Upsilon(1S)$

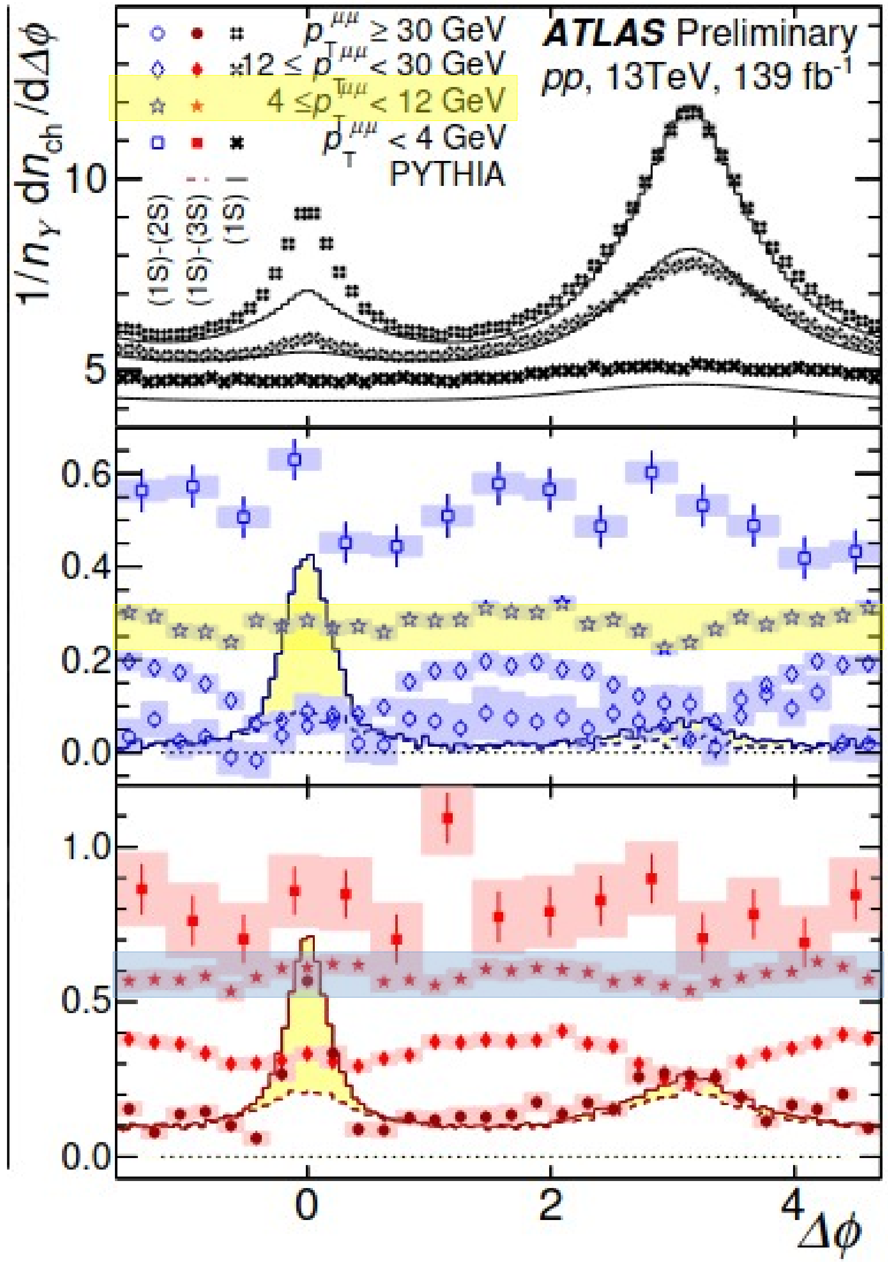
– More dominant at low-p_T

– 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

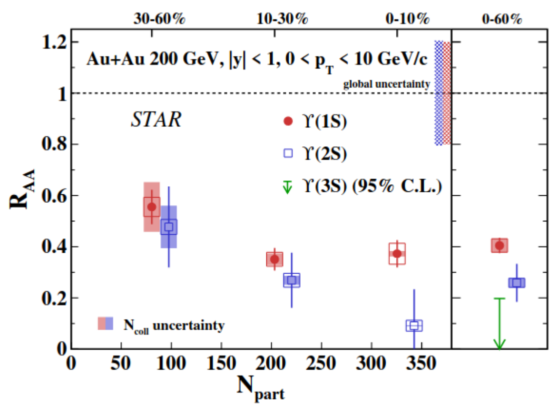


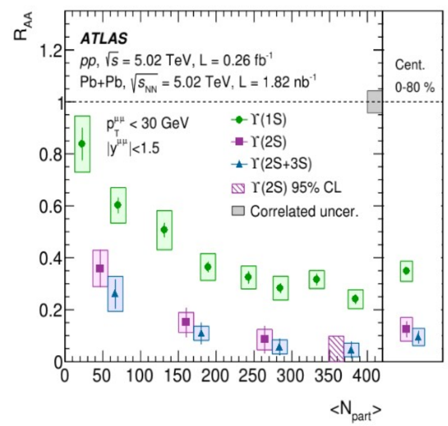
Excess in $< n_{ch} >$is not only around Υ(1S) direction

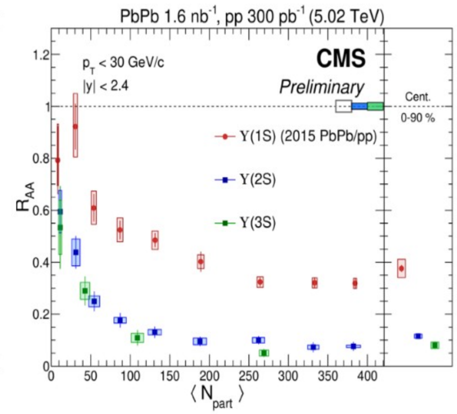
It is spread over entrire $\Delta\phi$

Something interesting must be happening

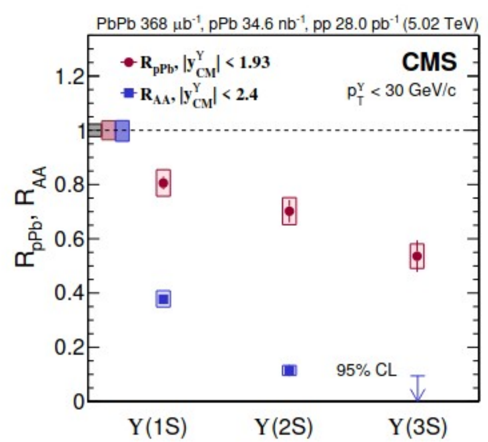
Summary

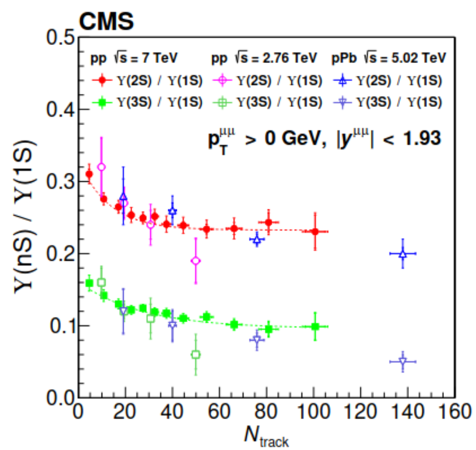


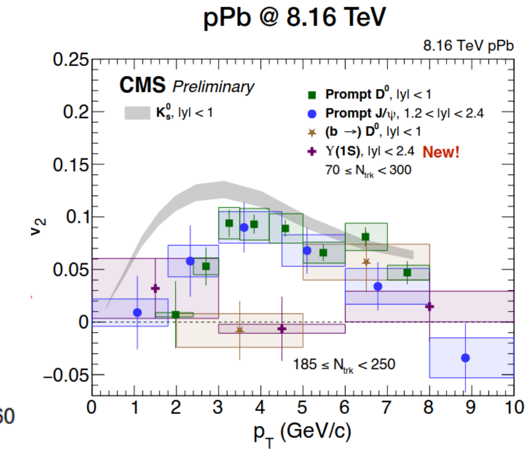




AA collisions







pA/pp collisions

Sequential (like) suppression observed in AA (pA) collisions both at RHIC and LHC
Medium effect in AA, most likely effect of dynamic dissociation
v_2 of ϒ(1S) consistent with zero

Thank You