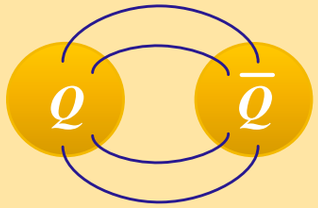
Quarkonium measurement in pp, pPb and PbPb collisions at 5.02 TeV with CMS

JaeBeom Park, Korea University

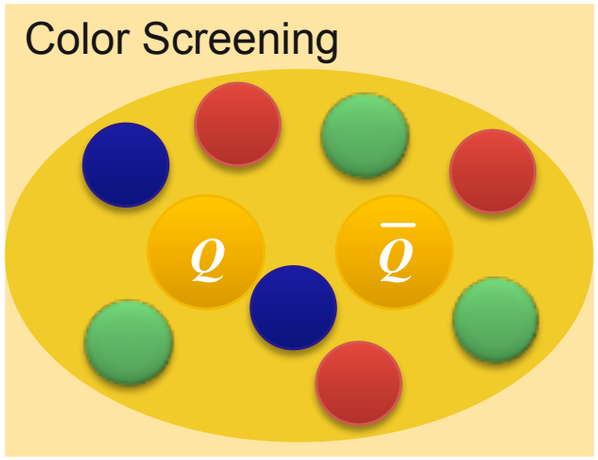
Motivation

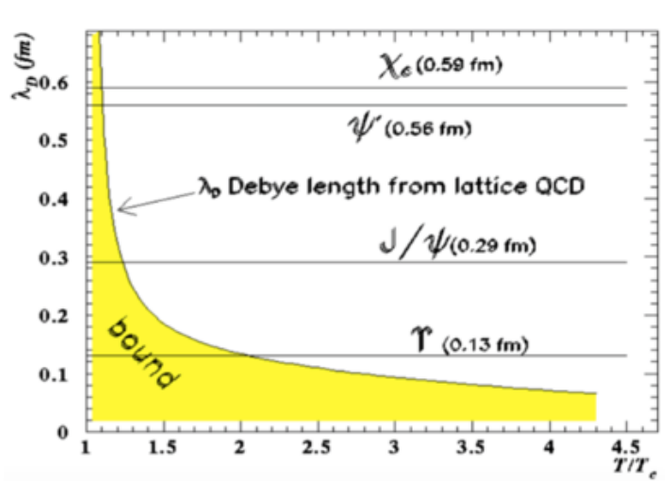
- **Quarkonium : Bound states of one quark and its anti quark**
  - **One of the most important probes in heavy ion collisions**

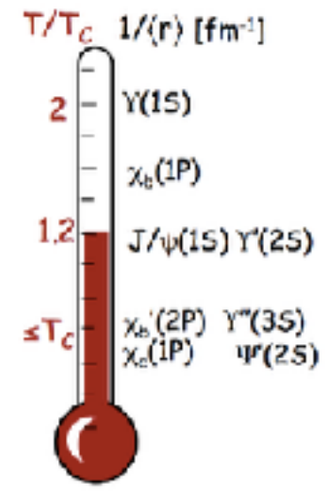
Vacuum



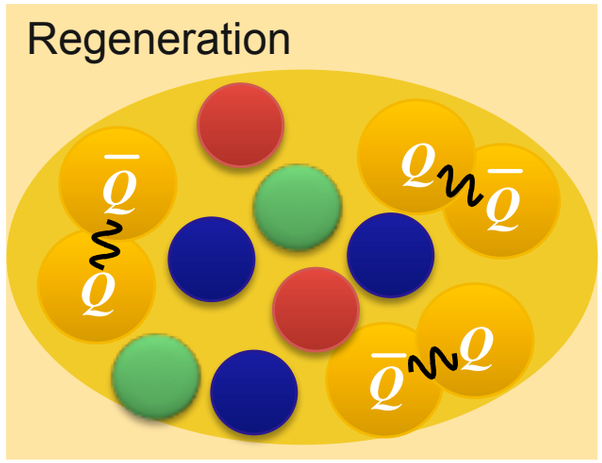
Color Screening

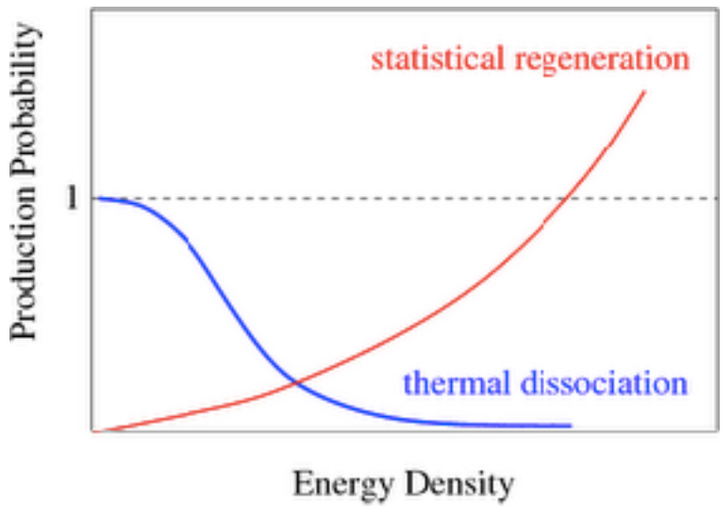






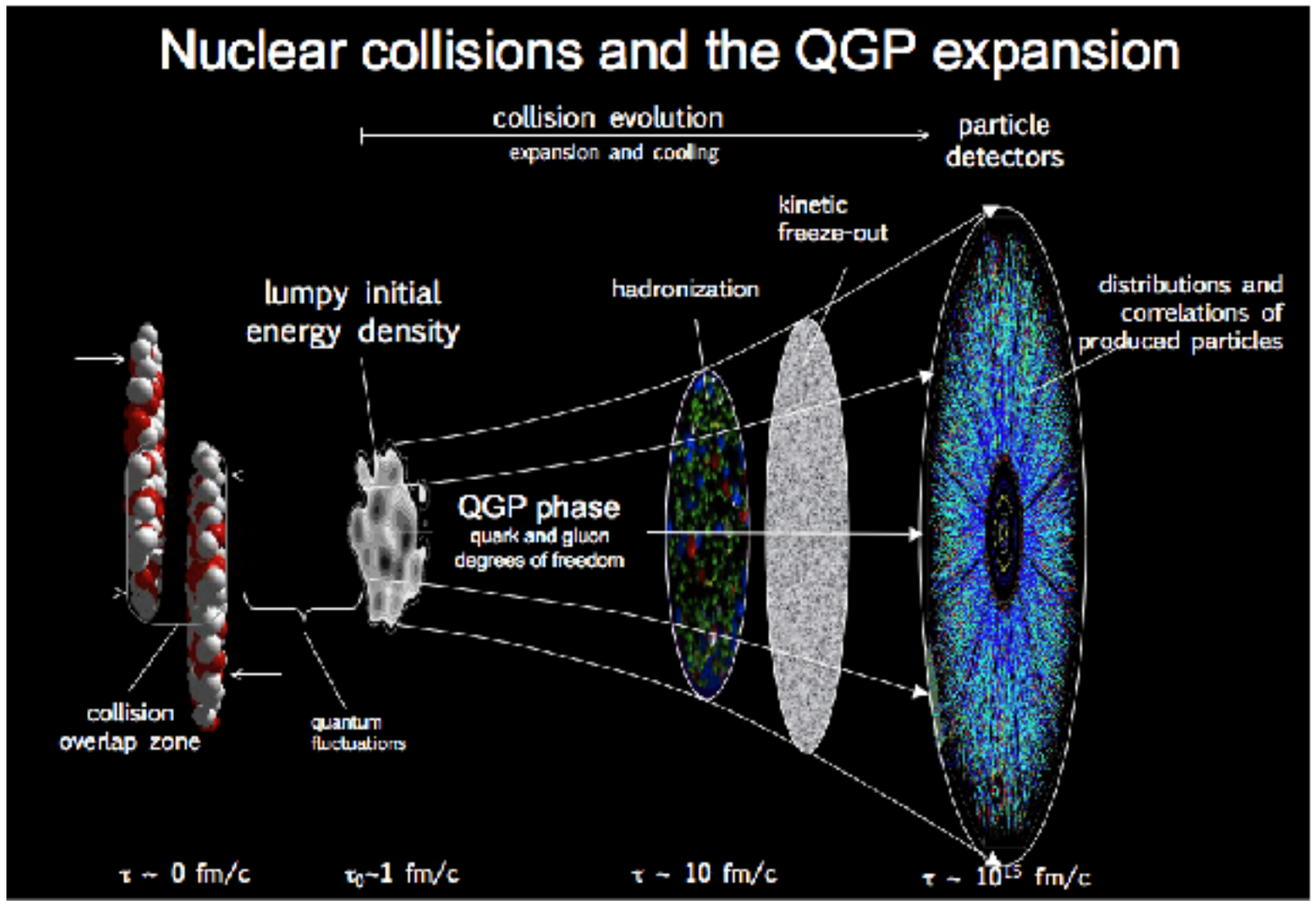
Regeneration





Motivation

- **Quarkonium : Bound states of one quark and its anti quark**
  - **Produced by hard scattering at the early stage in the collision**



$$\tau_{\text{formation}}(q\bar{q}) < \tau_{\text{formation}}(\text{QGP}) < \tau_{\text{life}}(\text{QGP}) < \tau_{\text{life}}(q\bar{q})$$

Quarkonia in HI CMS

Charmonia

- R_{AA} J/ψ in PbPb at 2.76 TeV
  [EPJC 77 (2017) 252]
- Double Ratio in PbPb at 2.76 TeV
  [PRL 113 (2014) 262301]
- J/ψ in pPb at 5.02 TeV
  [EPJC 77 (2017) 269]

Run 1

- ψ(2S) in pPb at 5.02 TeV
  [arXiv:1805.02248] [Submitted to PLB last week]

Run 2

- Double Ratio in PbPb at 5.02 TeV
  [PRL 118 (2017) 162301]
- R_{AA} charmonia in PbPb at 5.02 TeV
  [arXiv:1712.08959] [Submitted to EPJC]

Bottomonia

- Double ratio of Y(nS) in PbPb at 2.76 TeV
  [PRL 107 (2011) 052302]
- R_{AA} of Y(nS) in PbPb at 2.76 TeV
  [PLB 770, 357(2017)]

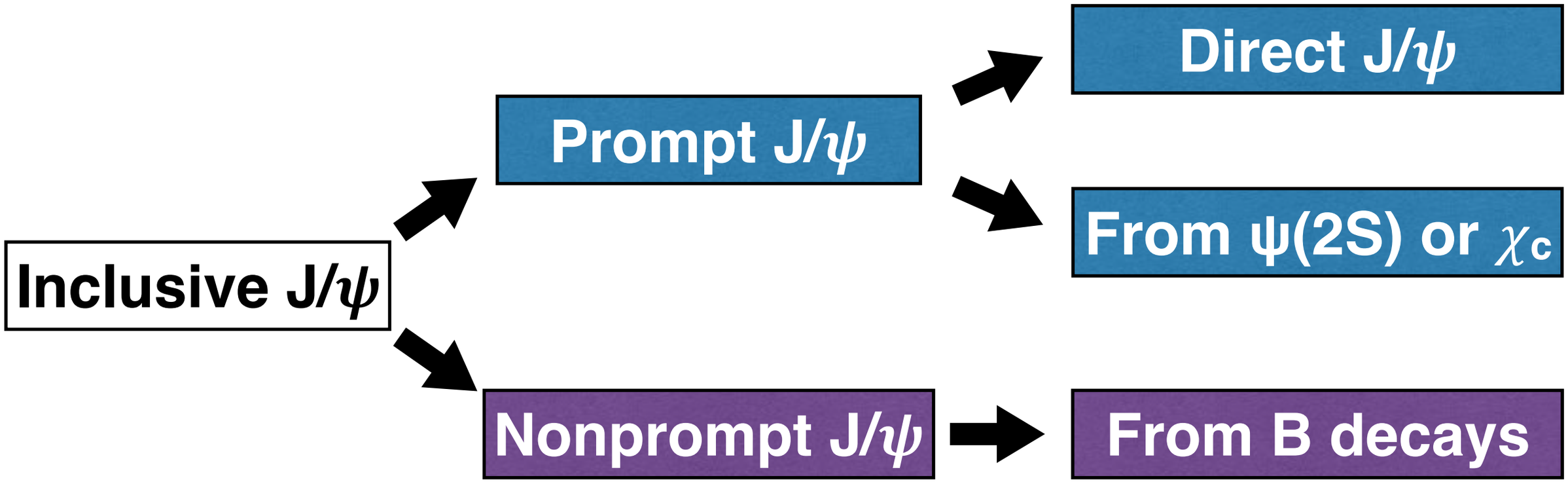
Run 1

- Single & Double Ratio in pPb at 5.02 TeV
  [JHEP 04 (2014) 103]

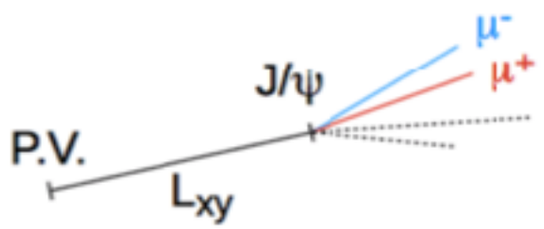
Run 2

- Double Ratio in PbPb at 5.02 TeV
  [PRL 120 (2018) 142301]
- R_{AA} of Y(nS) in PbPb at 5.02 TeV
  [arXiv:1805.09215] [Submitted to PLB yesterday]

Prompt & Nonprompt J/ψ



$$l_{J/\psi} = L_{xy} \frac{m_{J/\psi}}{p_T}$$



- **Prompt J/ψ : Nuclear effects on quarkonium production**
- **Nonprompt J/ψ : Information on open heavy flavor (b-quark)**

Outline

- **Quarkonia in PbPb collision**
  - **Charmonia**
  - **Bottomonia**
- **Quarkonia in pPb collision**
  - **Charmonia**
  - **Bottomonia**
- **Summary**

Outline

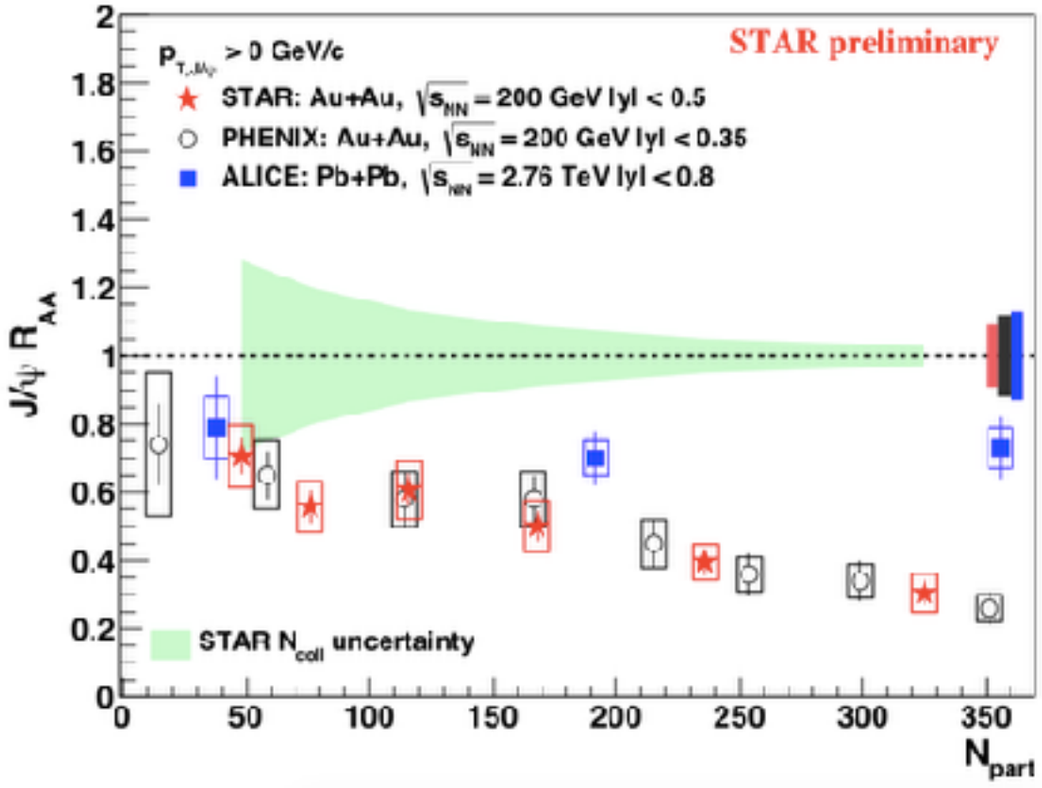
- **Quarkonia in PbPb collision**
  - **Charmonia**
  - **Bottomonia**
- **Quarkonia in pPb collision**
  - **Charmonia**
  - **Bottomonia**
- **Summary**

Regeneration of J/ψ in PbPb

mid |y|

ALICE : PLB 734, 314(2014)

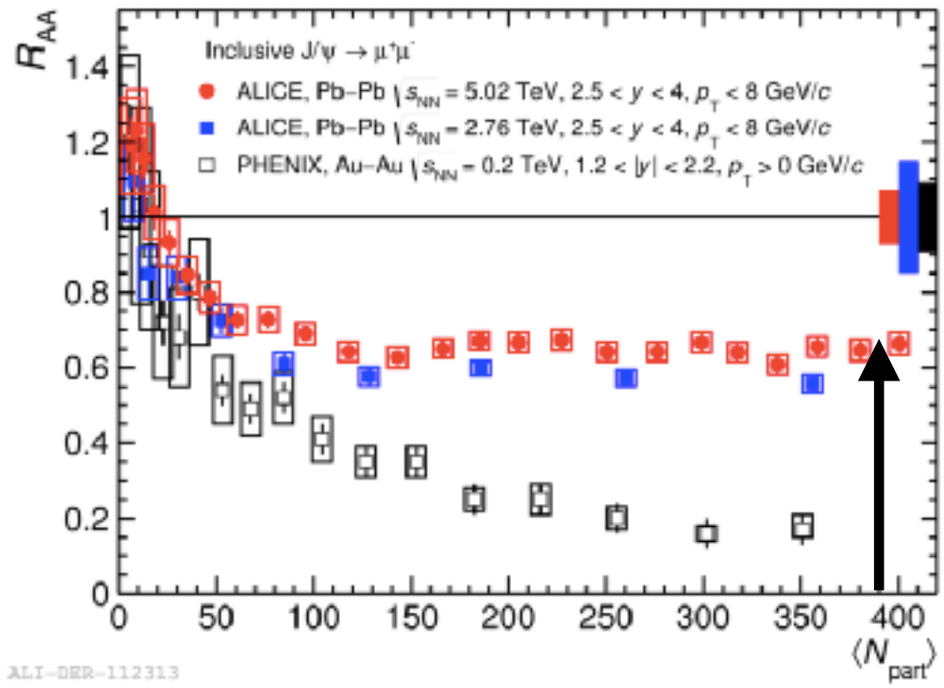
PHENIX : PRL 98 (2007) 232301



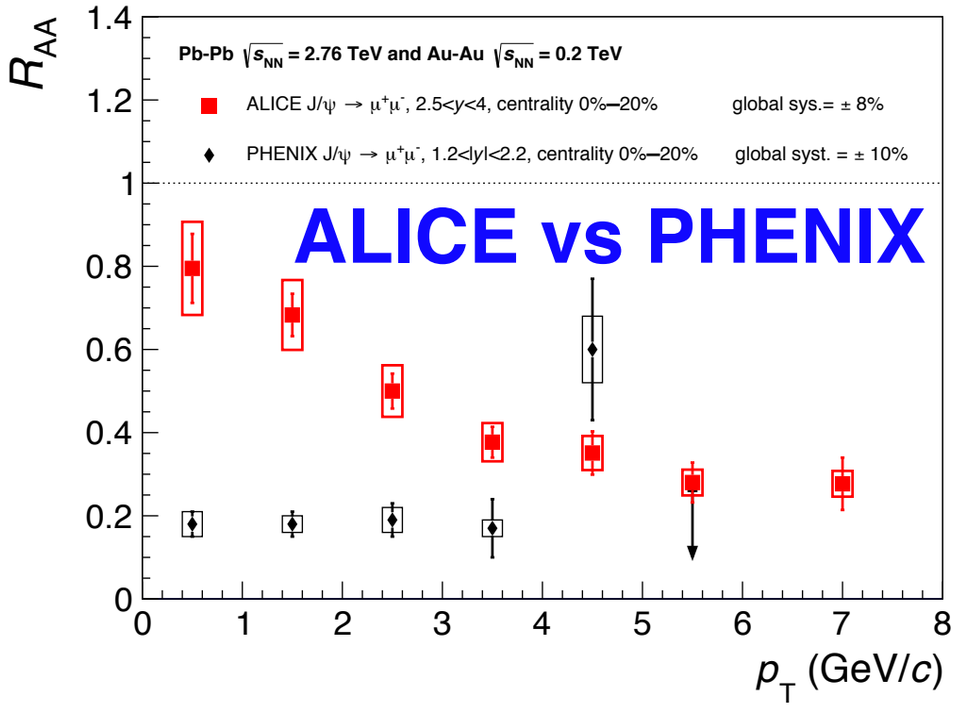
forward |y|

ALICE : PLB 766 (2017) 212

PHENIX : PRC 84 (2011) 054912



higher $\sqrt{s_{NN}}$ Regeneration?

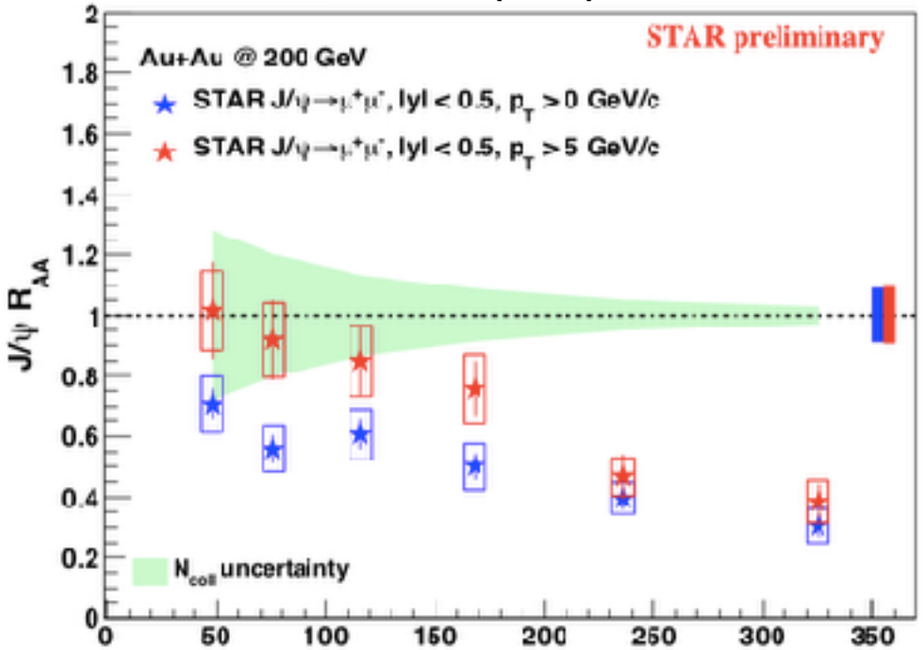


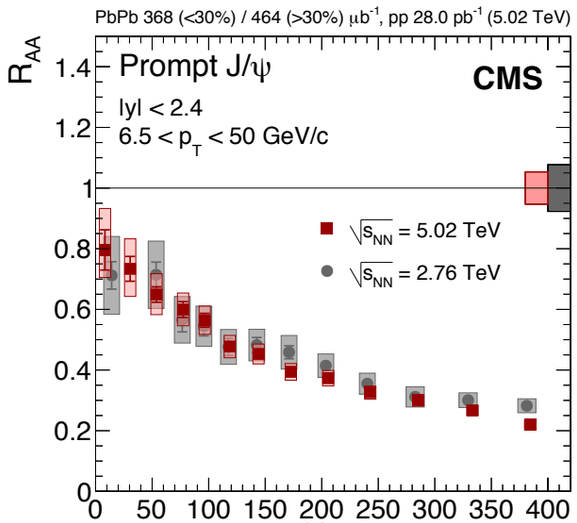
- **Larger suppression in RHIC than ALICE**
- **J/ψ regeneration in low p_T?**

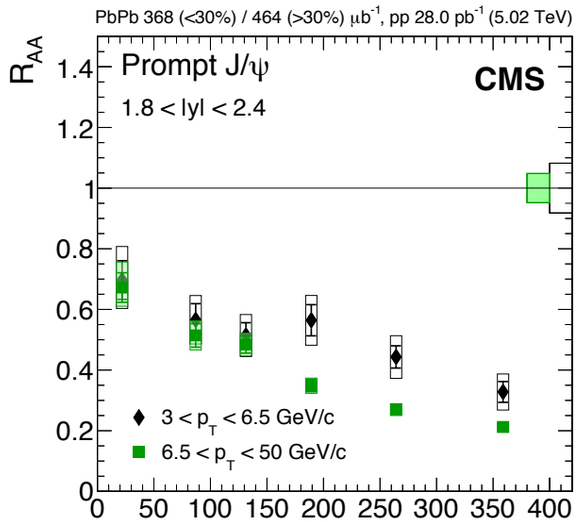
J/ψ in PbPb with CMS

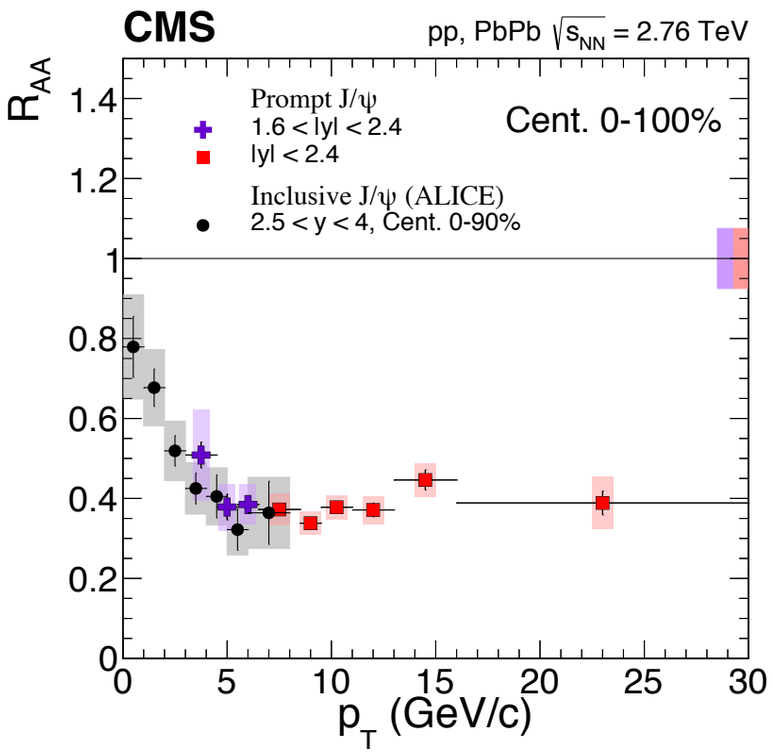
5.02 TeV : arXiv:1712.08959

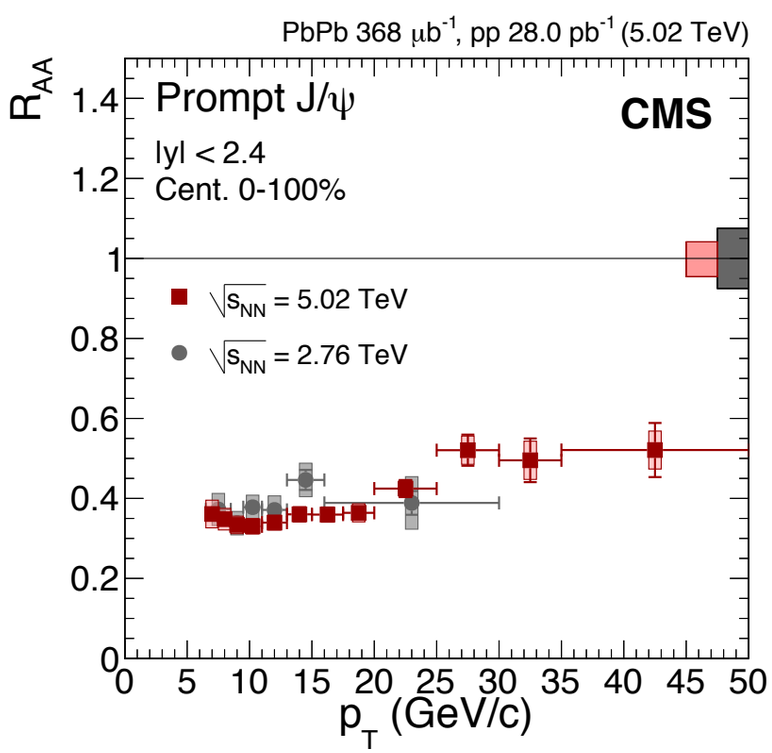
2.76 TeV : EPJC 77 (2017) 252







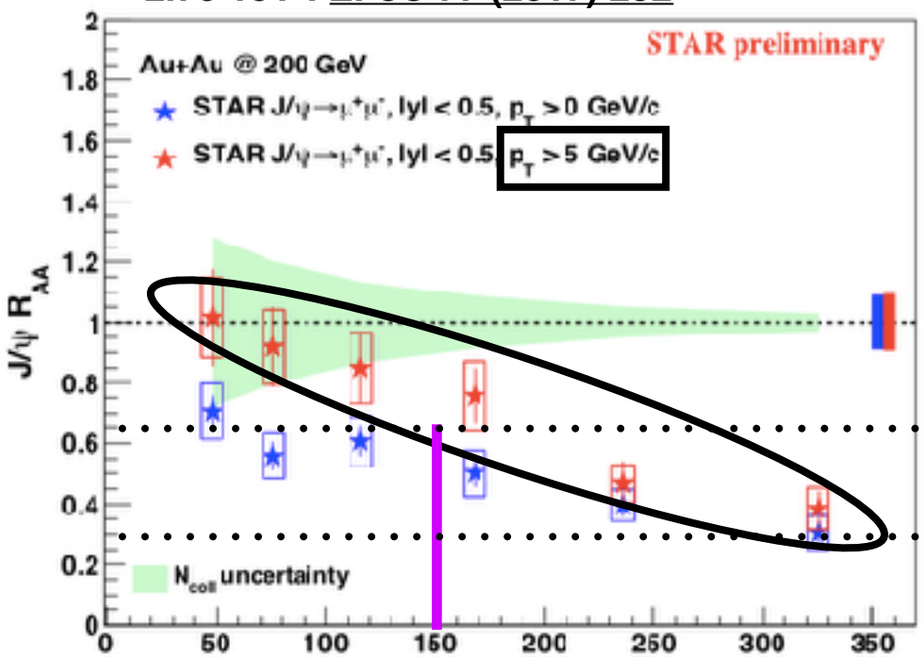




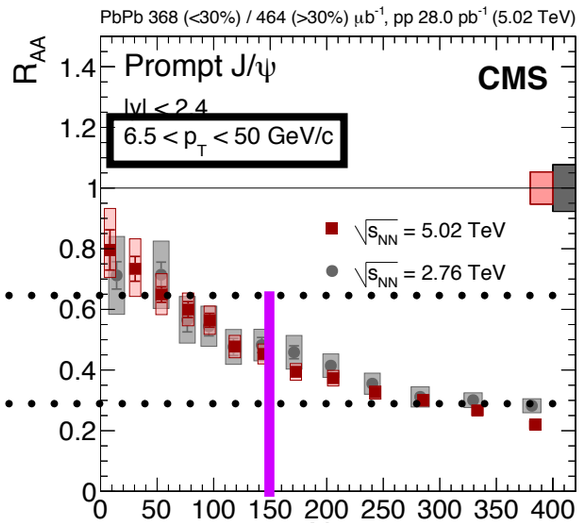
J/ψ in PbPb with CMS

5.02 TeV : arXiv:1712.08959

2.76 TeV : EPJC 77 (2017) 252



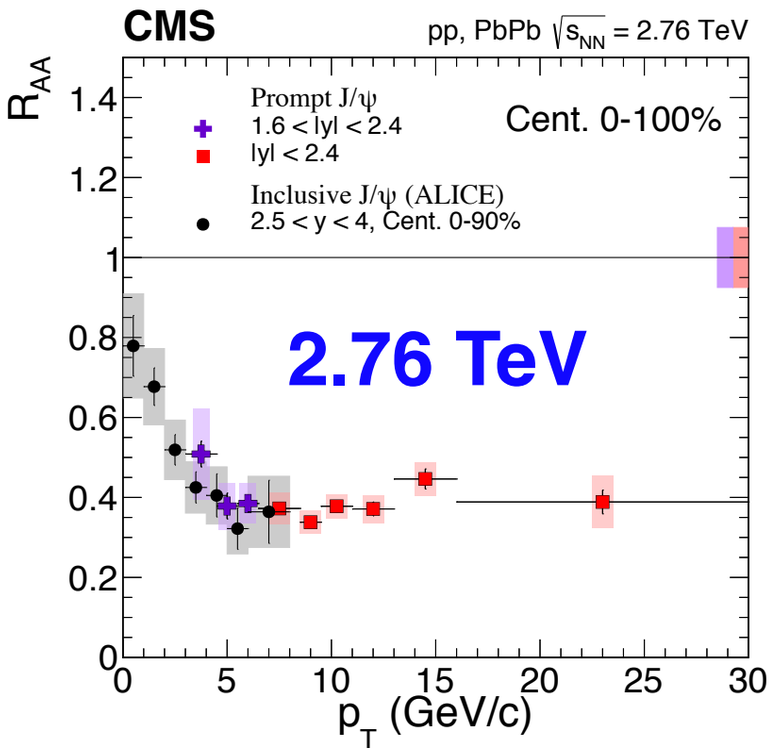
2.76 vs 5.02 TeV
p_T > 6.5 GeV/c

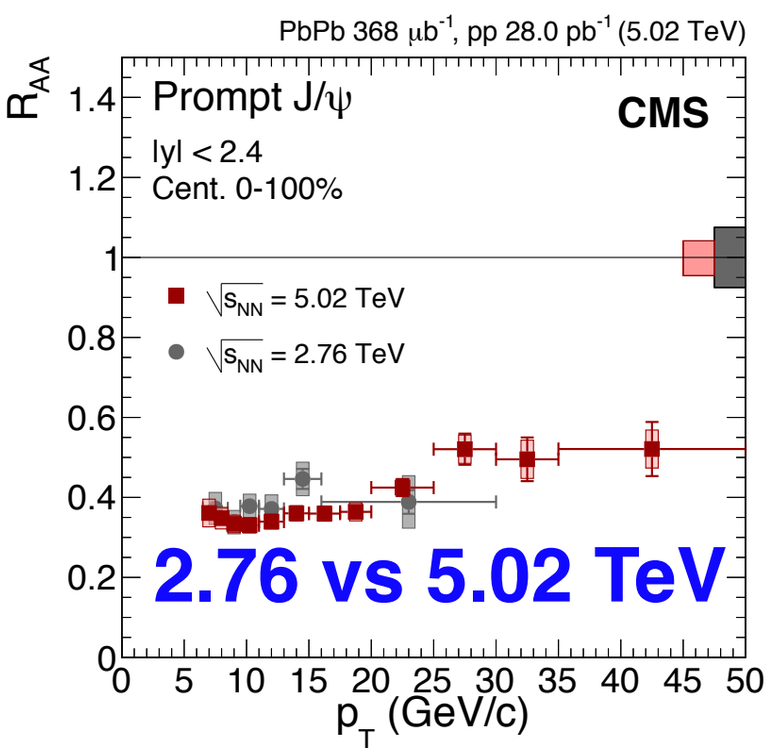


- **Larger suppression with CMS compared to STAR**
- **No strong $\sqrt{s_{NN}}$ dependence**

J/ψ in PbPb with CMS

5.02 TeV : arXiv:1712.08959
2.76 TeV : EPJC 77 (2017) 252



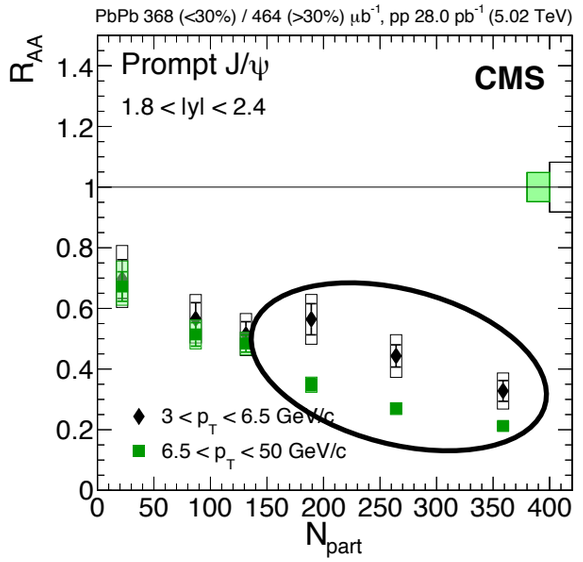


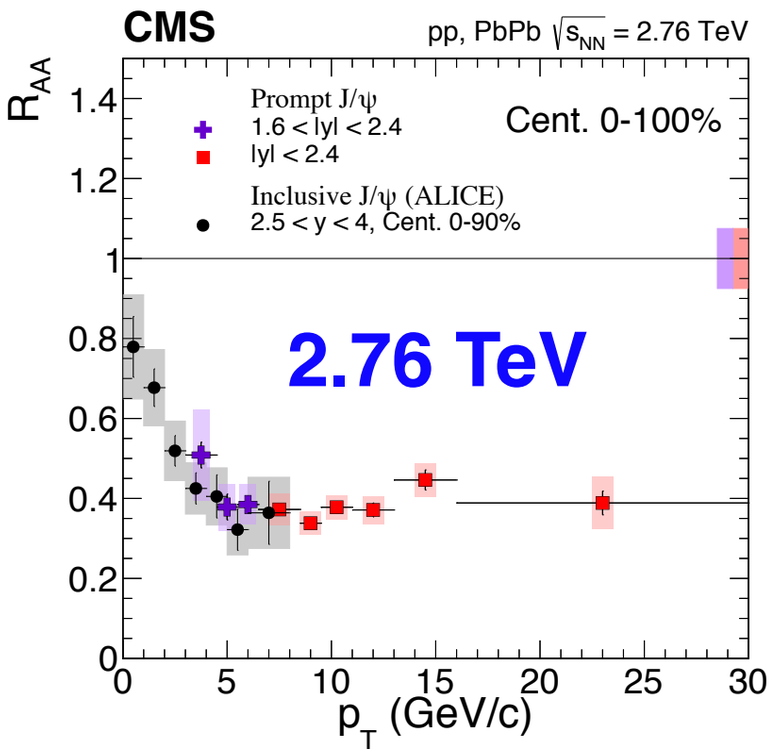
- **Compatible trend at low p_T with ALICE**
- **No strong $\sqrt{s_{NN}}$ dependence**

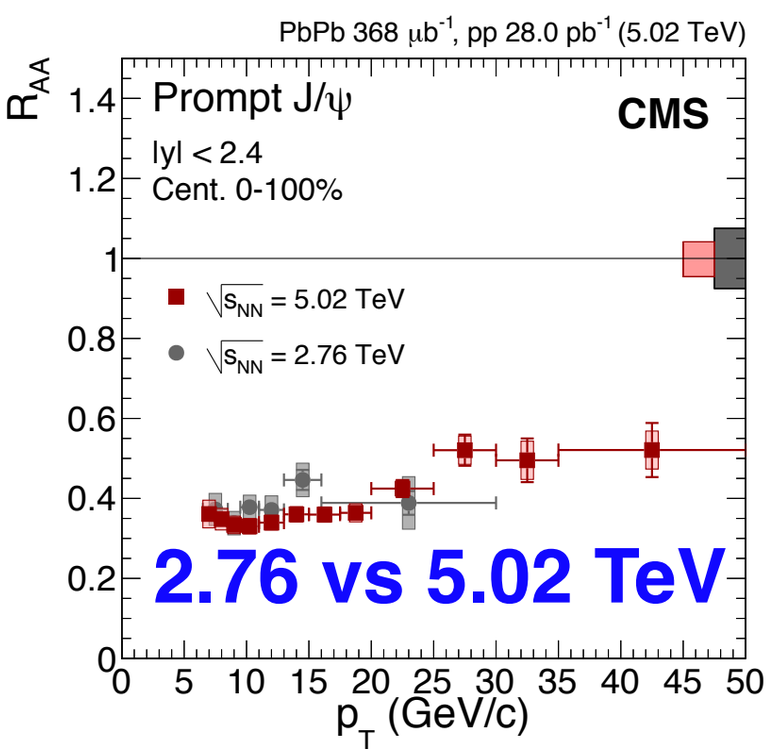
J/ψ in PbPb with CMS

5.02 TeV : arXiv:1712.08959
2.76 TeV : EPJC 77 (2017) 252

5.02 TeV forward |y|



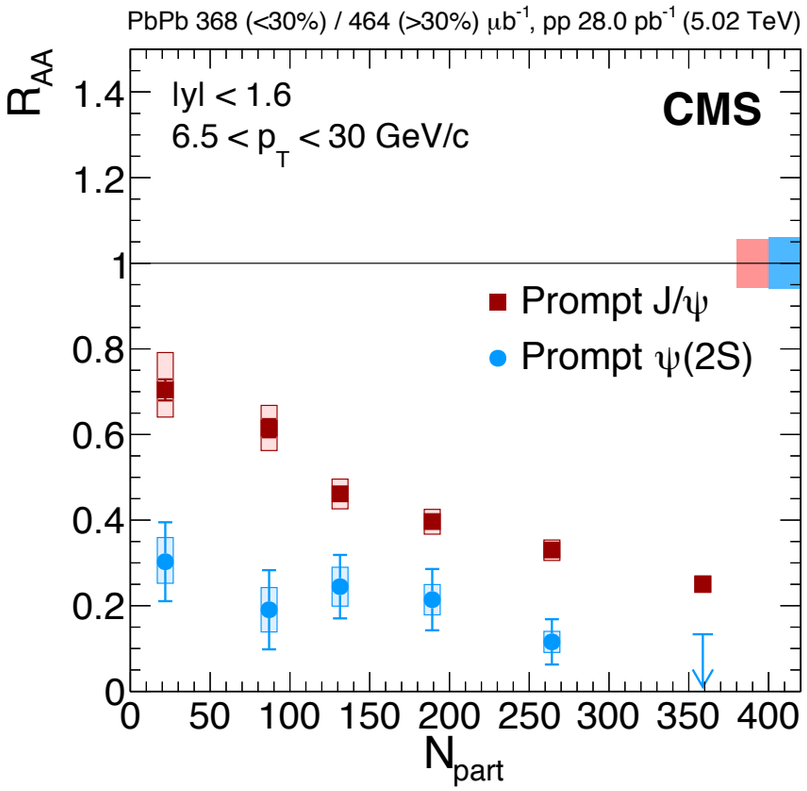


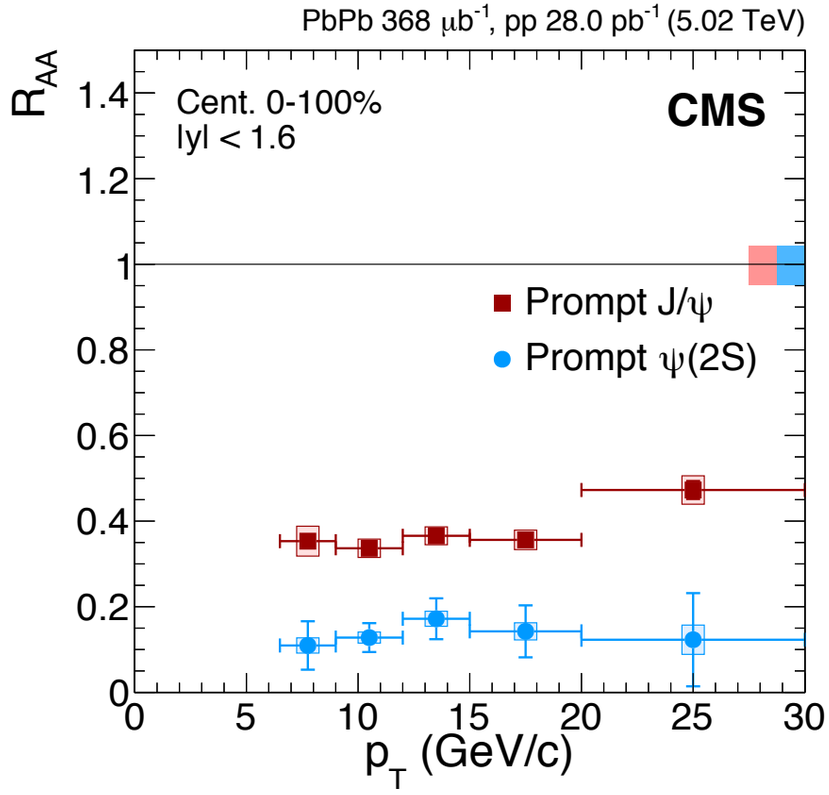


- **Compatible trend at low p_T with ALICE**
- **No strong $\sqrt{s_{NN}}$ dependence**
- **Less prompt J/ψ suppression at low pT**

ψ(2S) in PbPb

arXiv:1712.08959

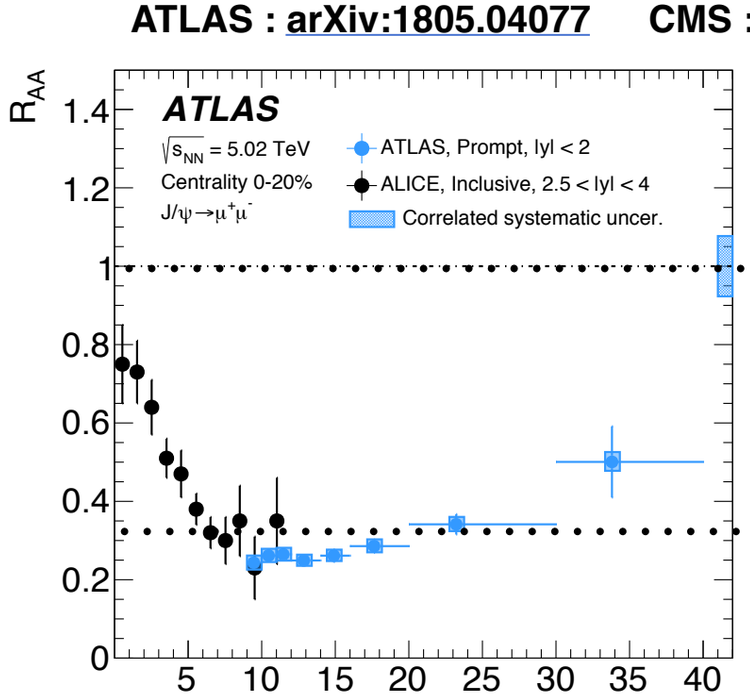


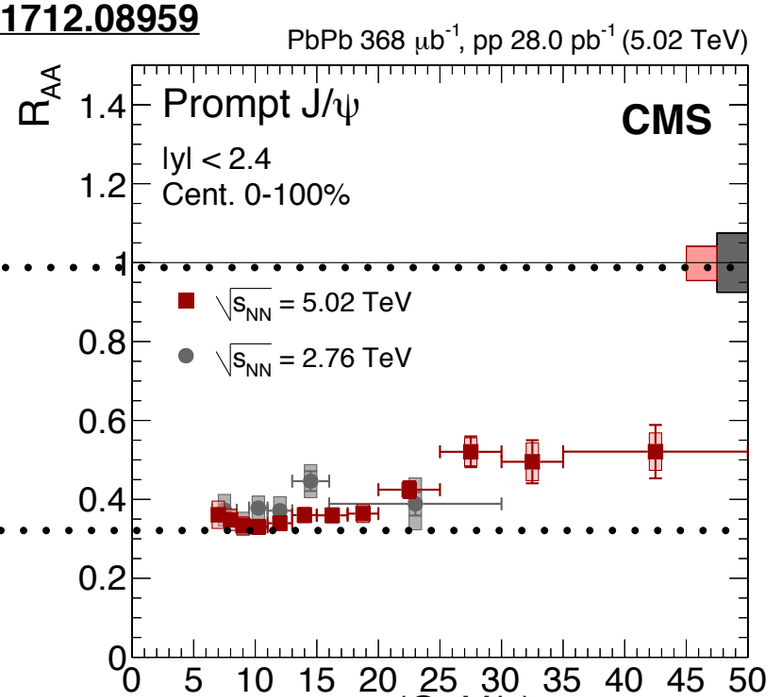


- **Larger suppression of J/ψ for all centrality and p_T bins**
- **ψ(2S) is suppressed in all centrality events**
- **no clear p_T dependence of ψ(2S)**
- **ψ(2S) still suppressed in high p_T region**

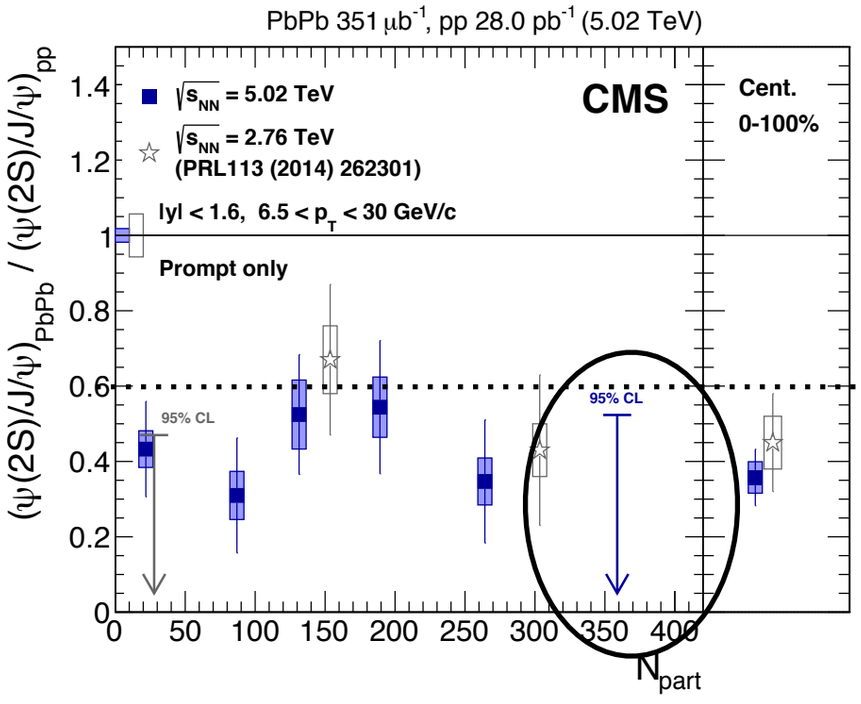
ATLAS vs CMS

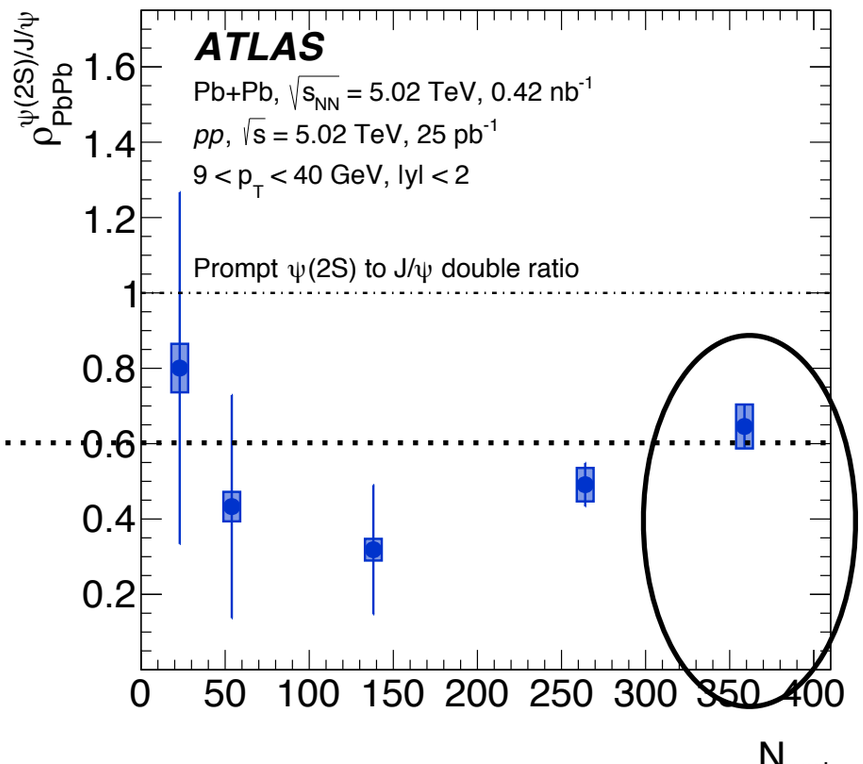
ATLAS : arXiv:1805.04077 **CMS : arXiv:1712.08959**





- **Indication of increasing R_{AA} vs p_T for J/ψ**

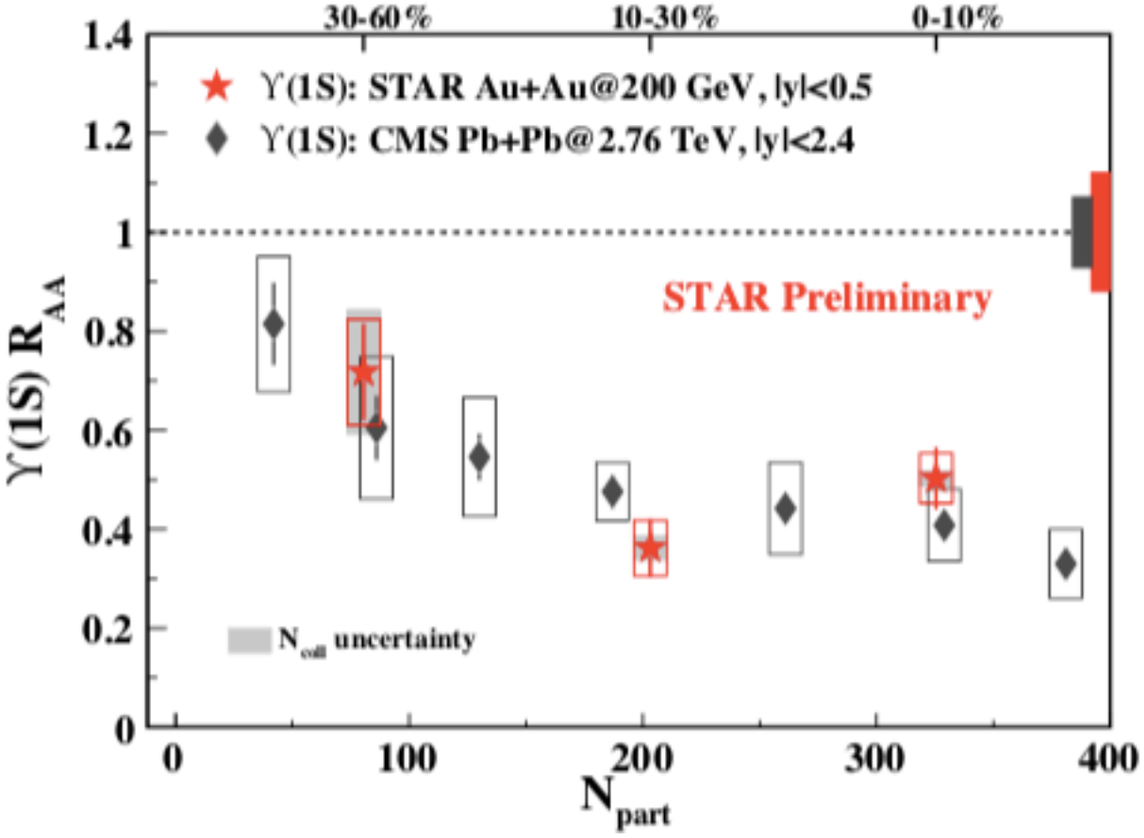


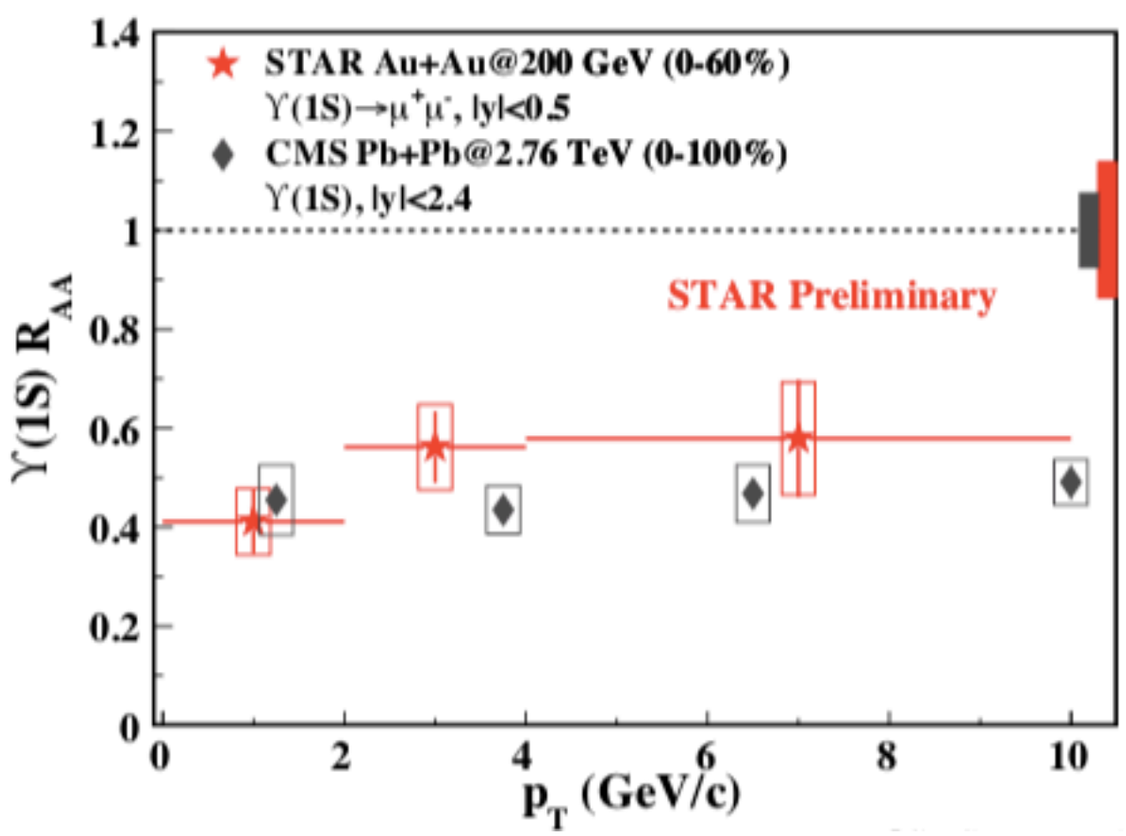


- **Sequential suppression across p_T and cent. bins**

What about bottomonia?

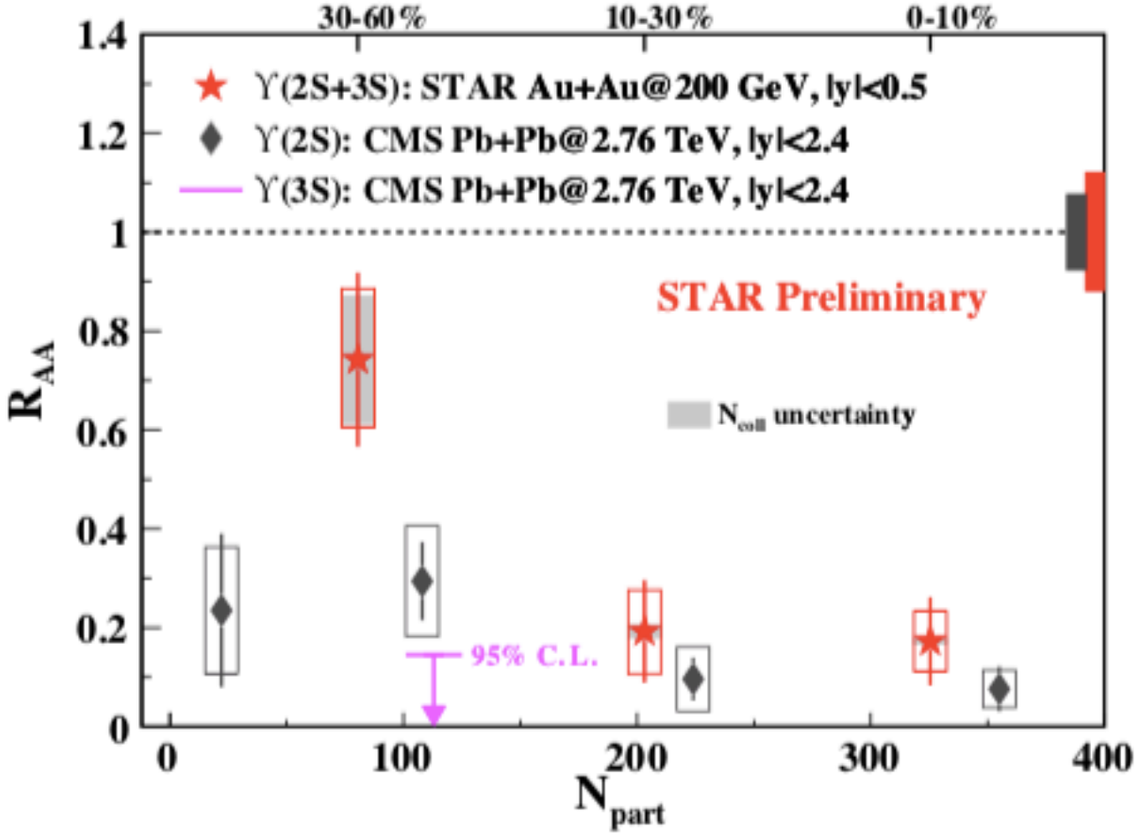
RHIC vs LHC Υ(1S)

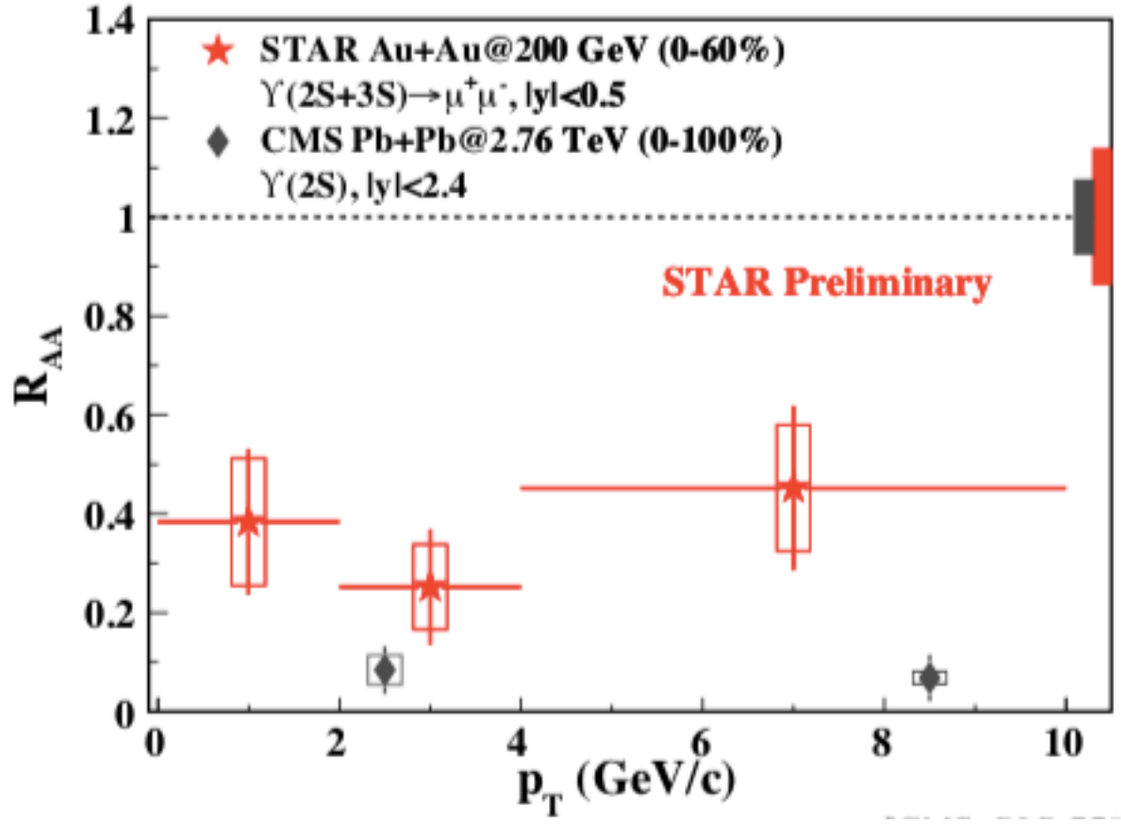




- **Compatible with CMS and STAR data for Y(1S)**
- **CNM + Regeneration effect?**

RHIC vs LHC excited states

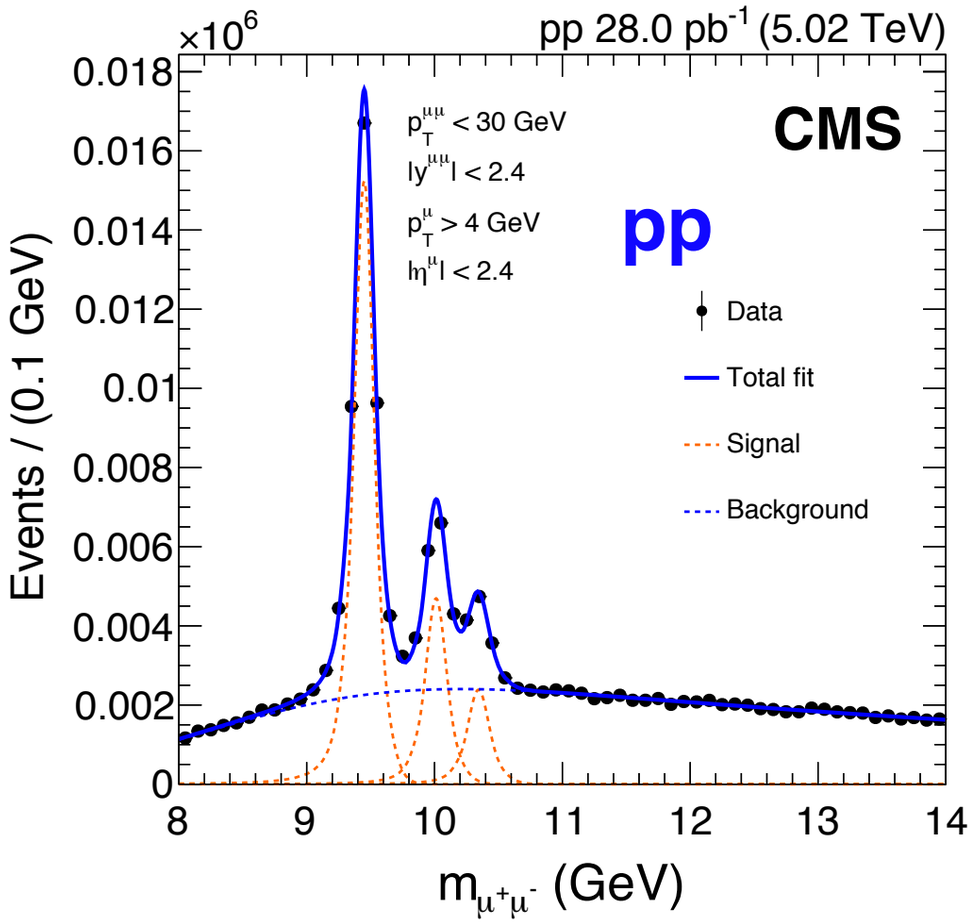


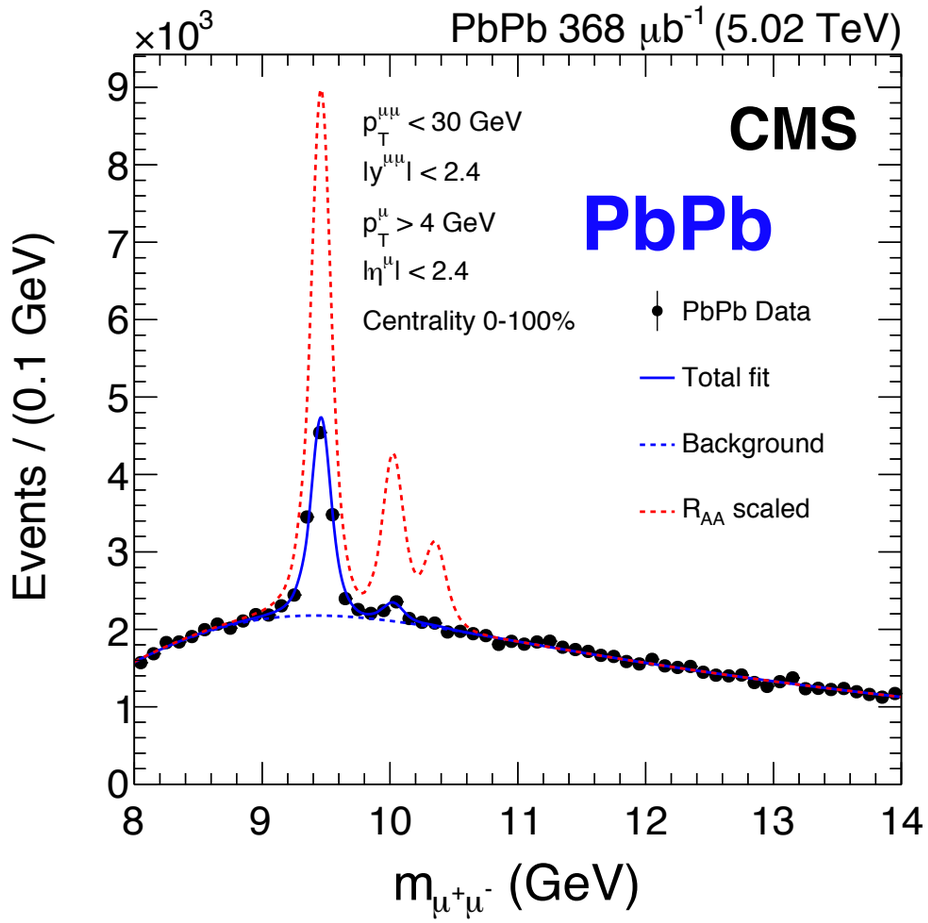


- **Indication of more suppression for excited states at LHC**
- **Sequential suppression for both STAR and CMS data**
- **What about 5.02 TeV? feed down component?**

Y(nS) in PbPb 5.02 TeV

arXiv:1805.09215

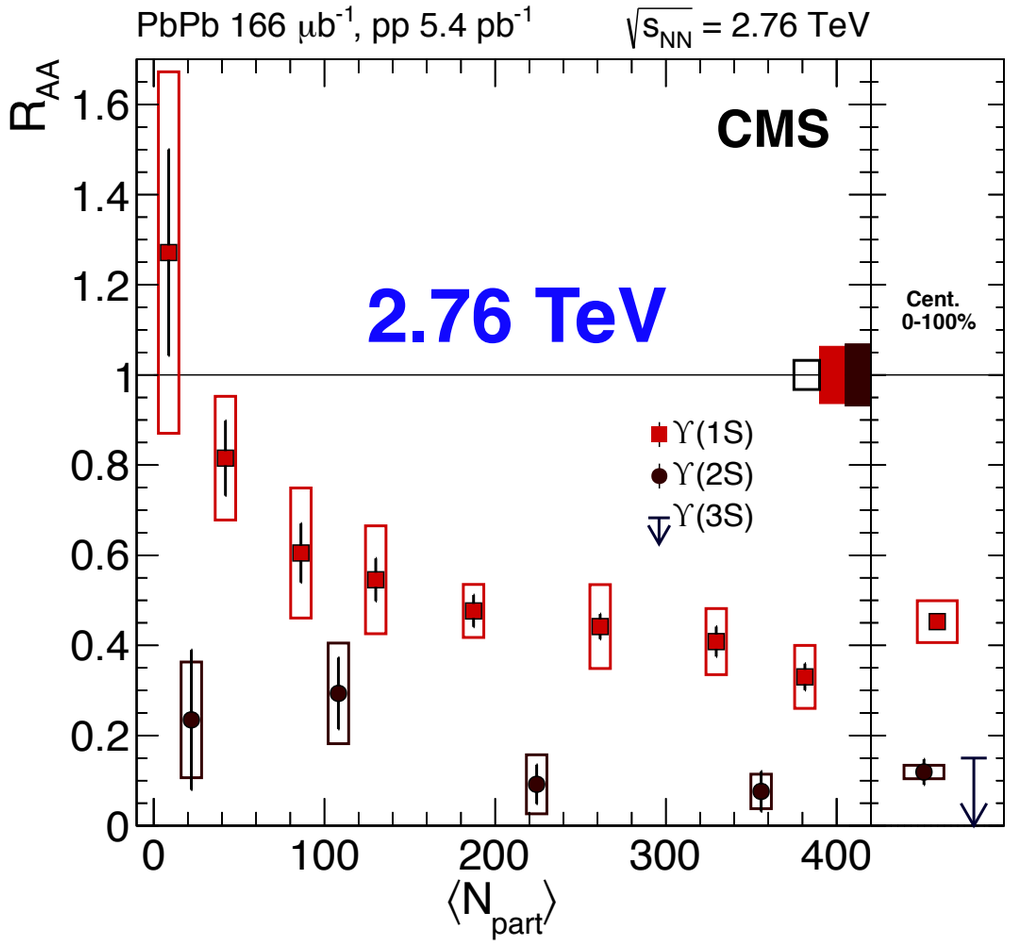




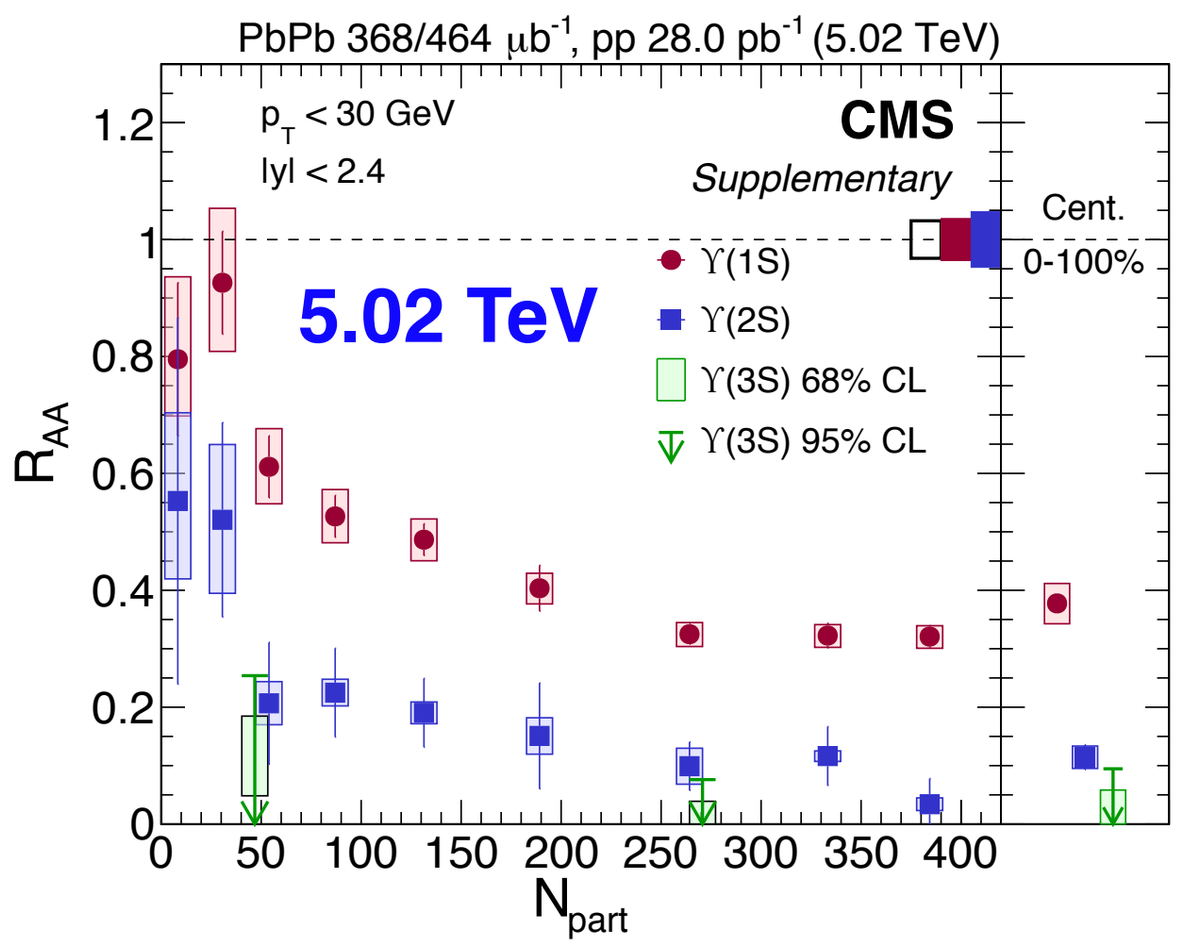
- **Large suppression of Y(1S), Y(2S) and Y(3S)**
- **No visible peak of Y(3S) in given statistics**

Y(nS) in PbPb 2.76 vs 5.02 TeV

PLB 770, 357(2017)



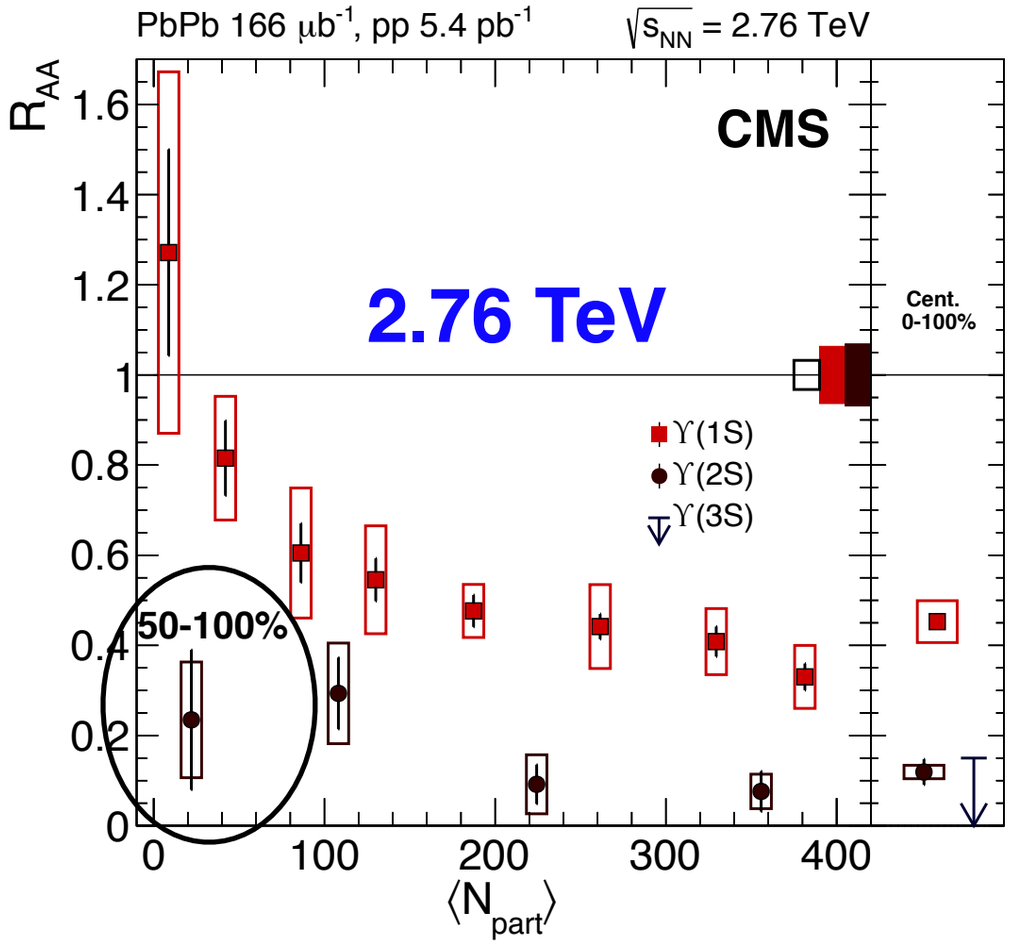
arXiv:1805.09215



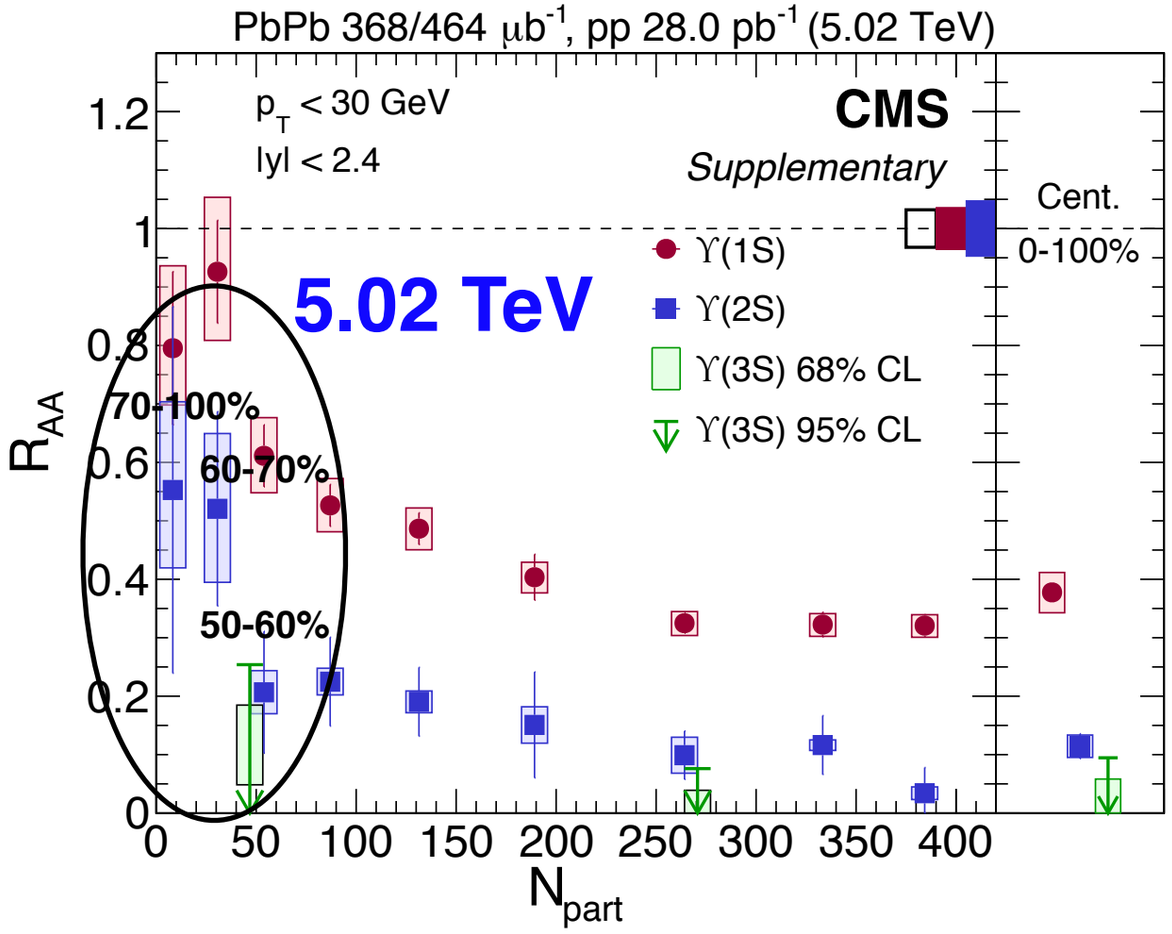
- **Sequential suppression for Upsilons in both 2.76 & 5.02 TeV**
- **More precise measurement of Y(2S) in peripheral events at 5.02 TeV**
- **Y(3S) suppressed in all centrality bins**

Y(nS) in PbPb 2.76 vs 5.02 TeV

PLB 770, 357(2017)



arXiv:1805.09215



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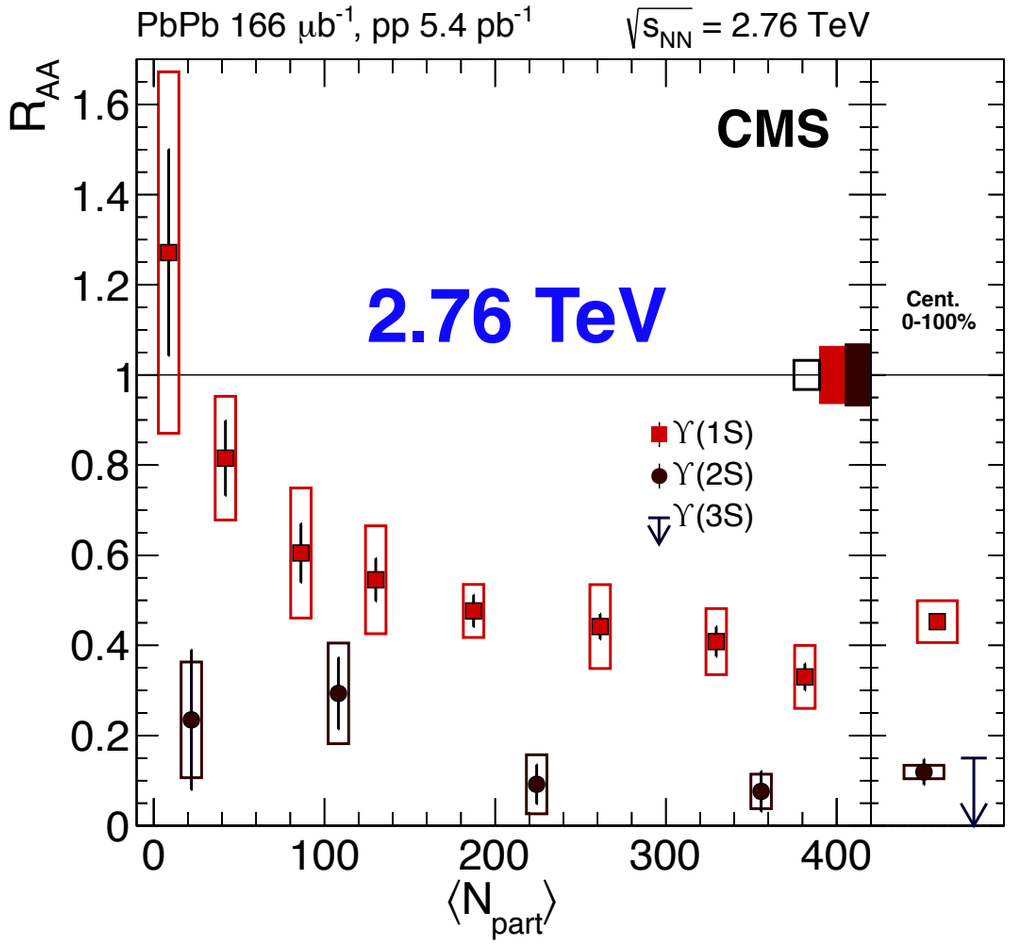
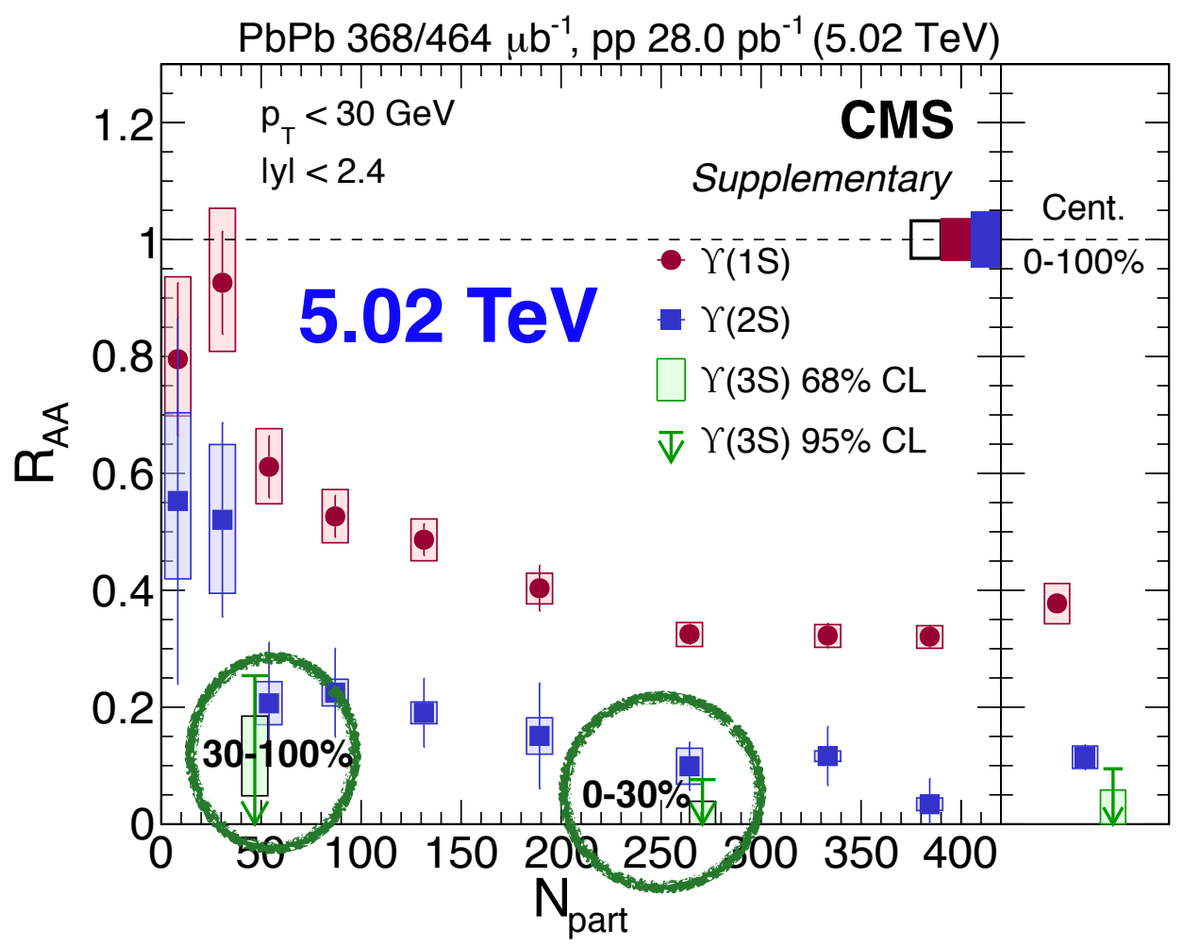
Y(nS) in PbPb 2.76 vs 5.02 TeV

PLB 770, 357(2017)



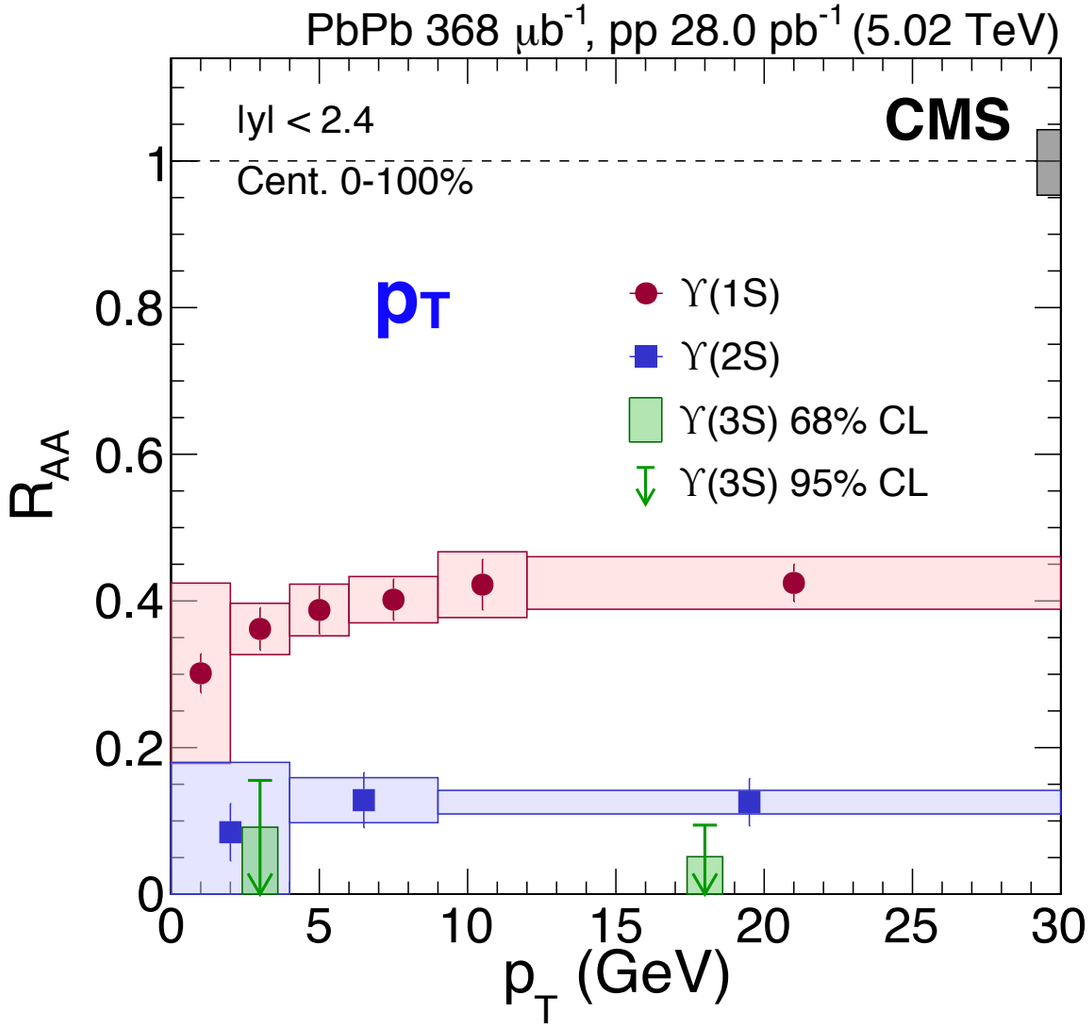
arXiv:1805.09215

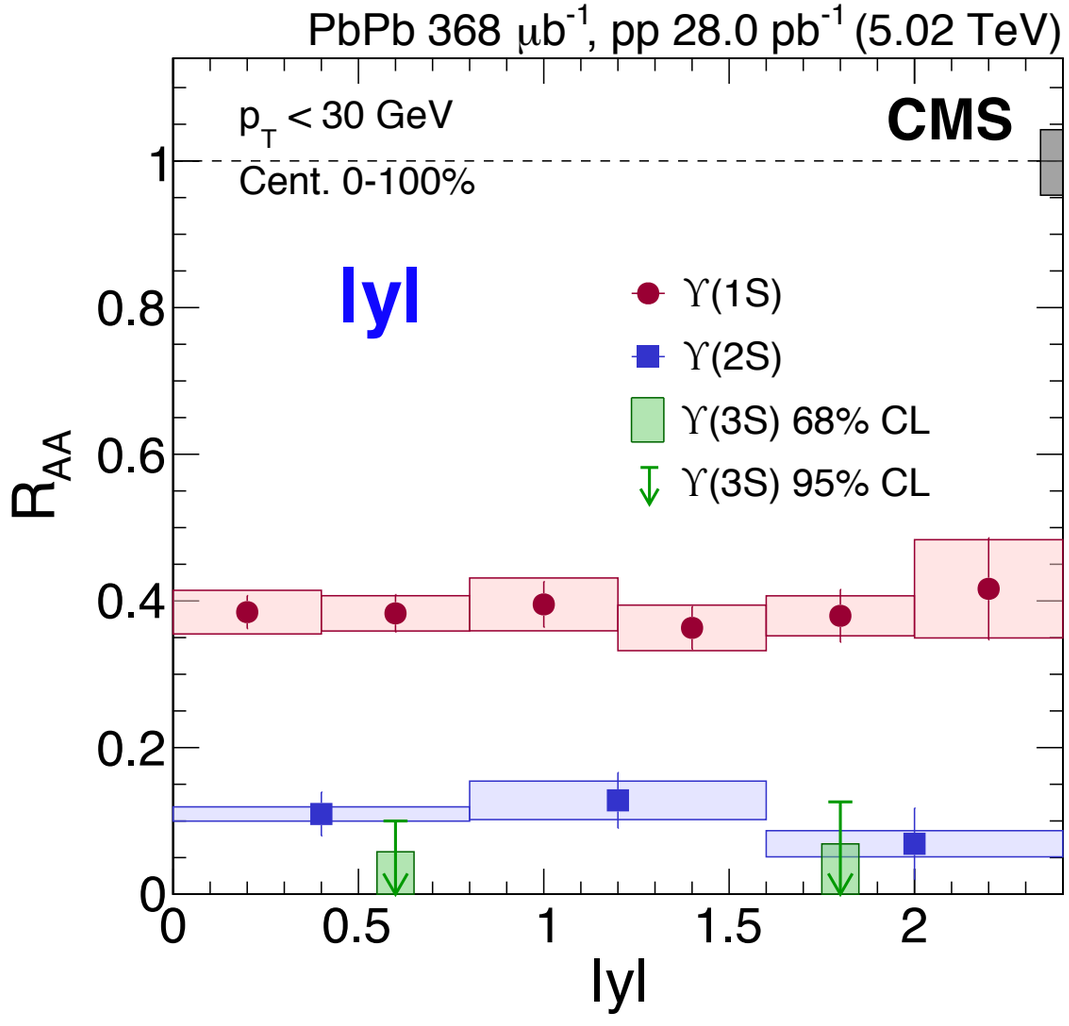


- **Sequential suppression for Upsilons in both 2.76 & 5.02 TeV**
- **More precise measurement of Y(2S) in peripheral events at 5.02 TeV**
- **Y(3S) suppressed in all centrality bins**

Υ(nS) RAA vs p_T, y at 5.02 TeV

arXiv:1805.09215



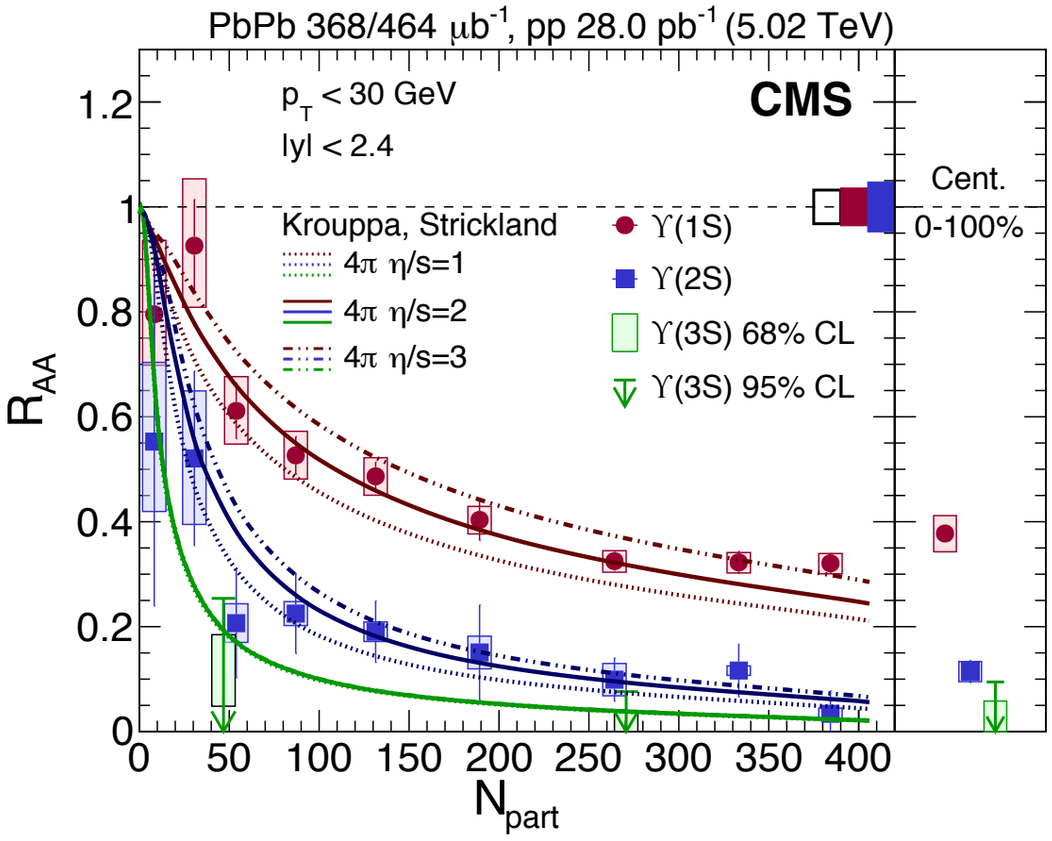


- **No significant dependence in both kinematic variable s**
- **Sequential suppression of Y mesons**

Model comparison vs N_{part}

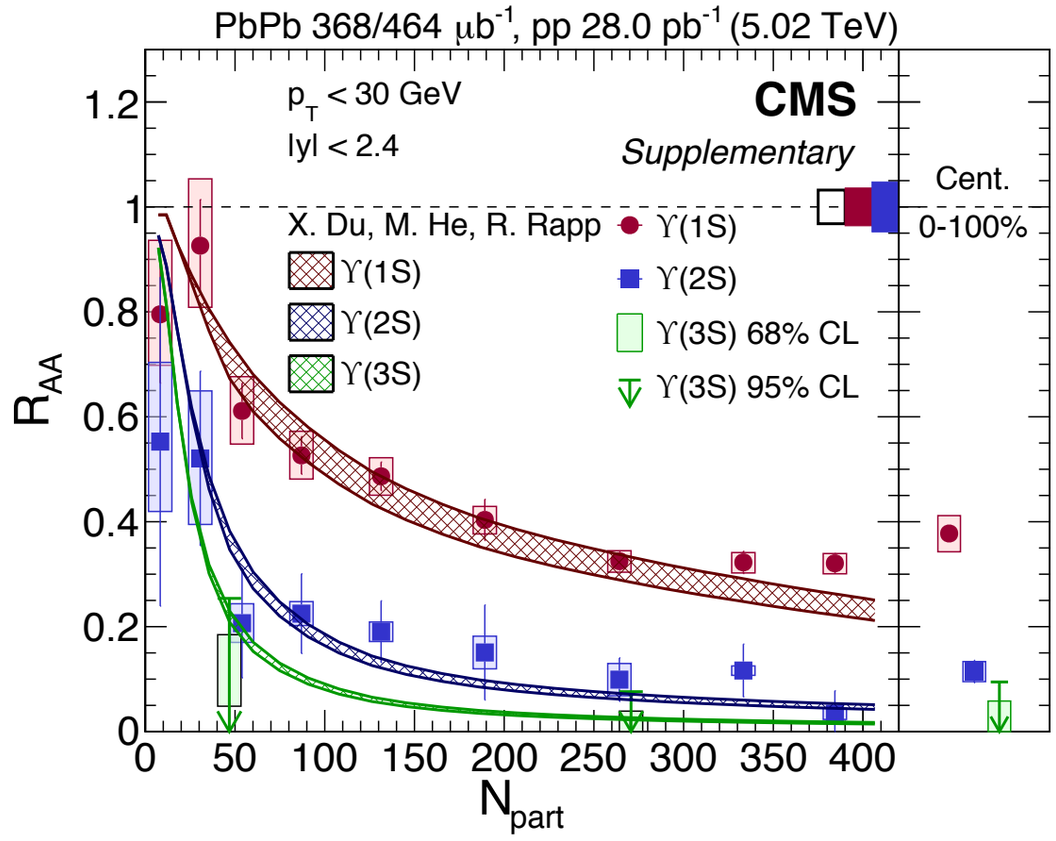
arXiv:1805.09215

Krouppa, Strickland



- **Melting temperatures:**
  Y(1S, 2S, 3S) : 600, 230, 170 MeV
- **No regeneration**
- **Initial temperature:**
  2.76 TeV: 544 - 552 MeV
  5.02 TeV: 629 - 641 MeV (16% increase)
- **Y(1S) R_{AA} : ~25% decrease**

Du, Rapp

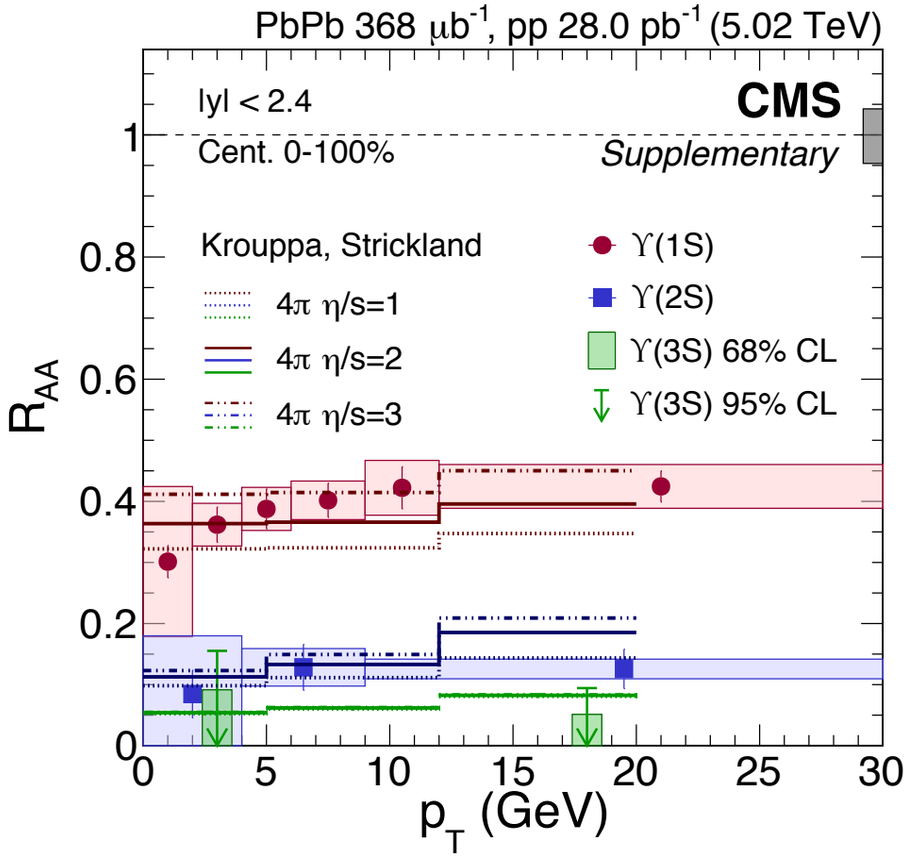


- **Melting temperatures:**
  Y(1S, 2S, 3S) : 500, 240, 190 MeV
- **Including regeneration**
- **Initial temperature:**
  2.76 TeV: 520 - 750 MeV
  5.02 TeV: 550 - 800 MeV (7% increase)
- **Y(1S) R_{AA} : slight decrease**

Model comparison vs p_T

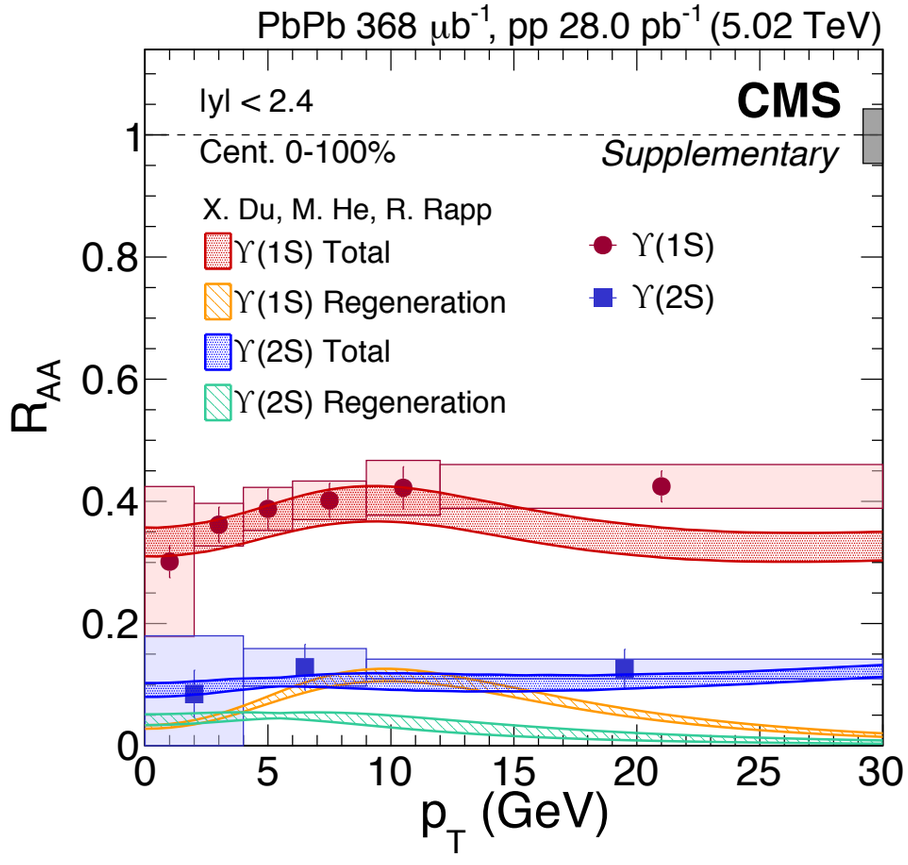
arXiv:1805.09215

Krouppa, Strickland



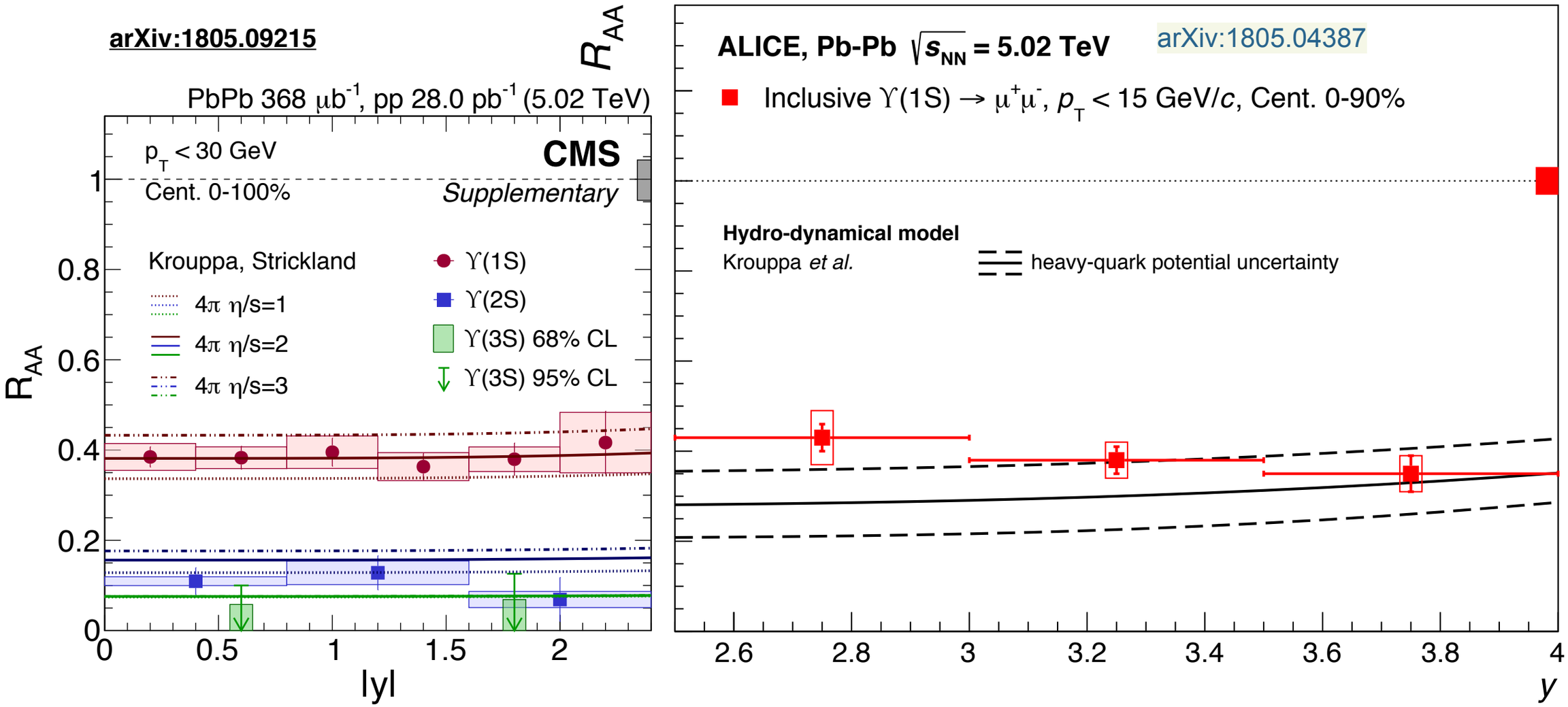
- Strickland et al. calculation
  : Increasing R_{AA} with p_T
  - ➡ High β QGP escape before significant modification
- Compatible with data

Du, Rapp



- Rapp et al. calculation
  : p_T dependent regeneration contribution
  - ➡ expect slight increase of Y(1S) from p_T zero up to ~10 GeV/c
  - ➡ Not visible within uncertainty
- Compatible with data

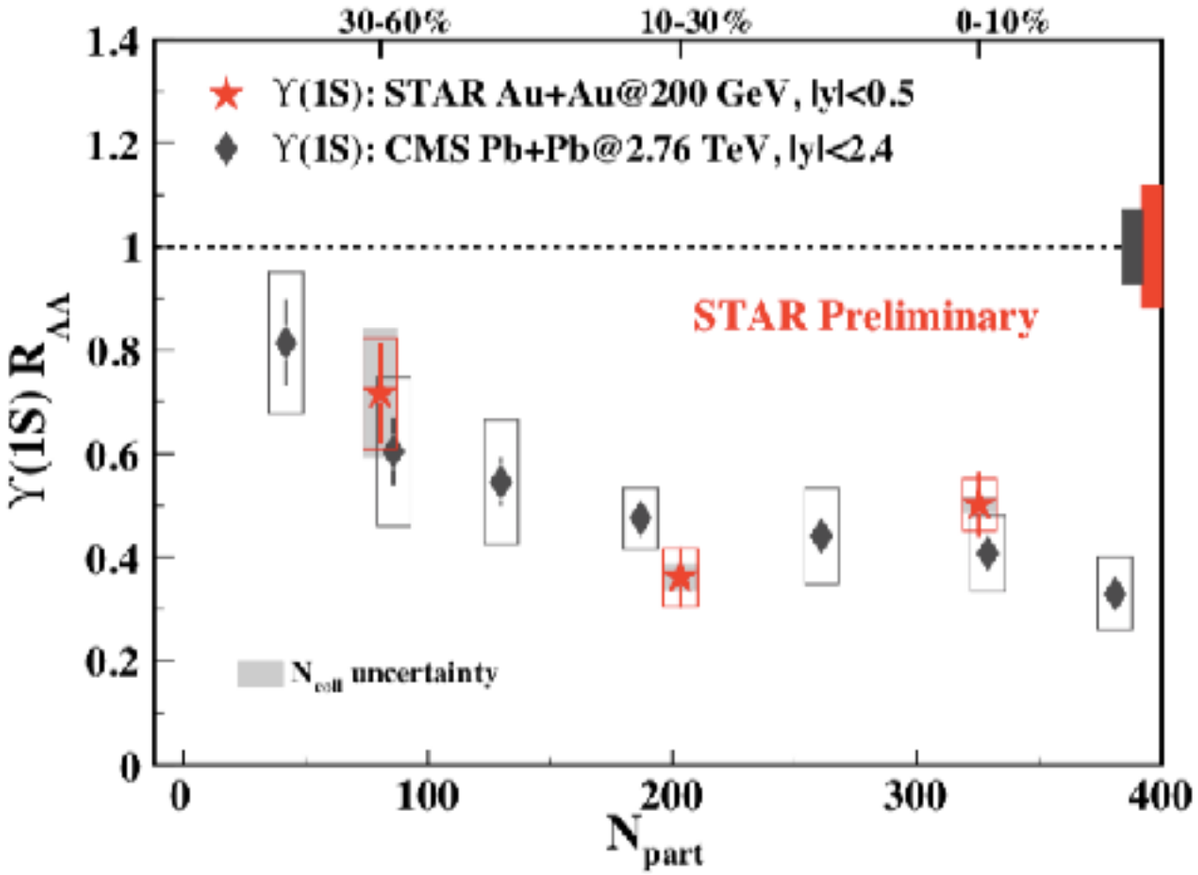
Model comparison vs y

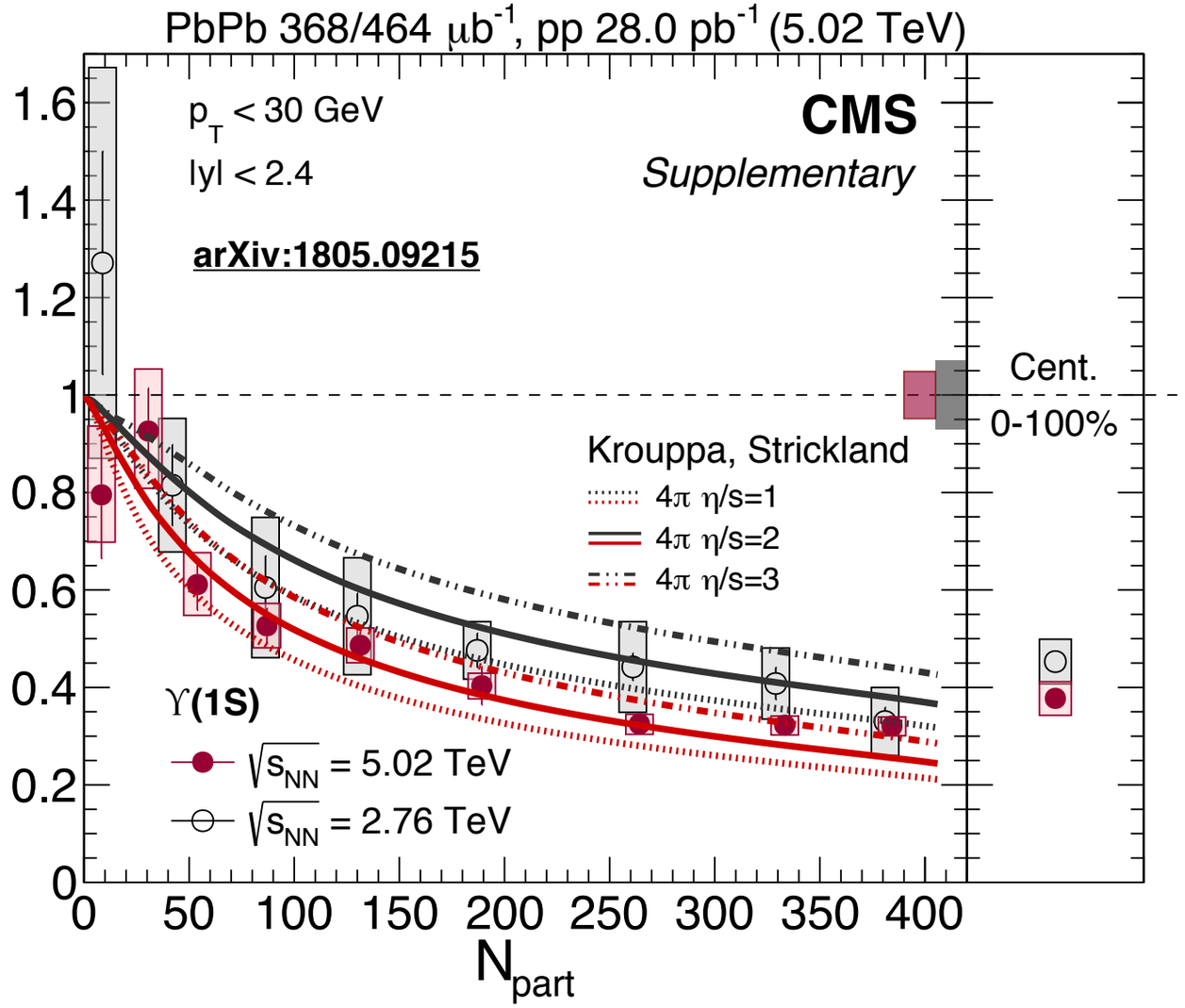


- **CMS data agrees with Strickland et al. perturbative potential**
- **No strong rapidity dependence up to y=4 including ALICE data**

200 GeV vs 2.76 TeV vs 5.02 TeV

CMS : PLB 770, 357(2017)

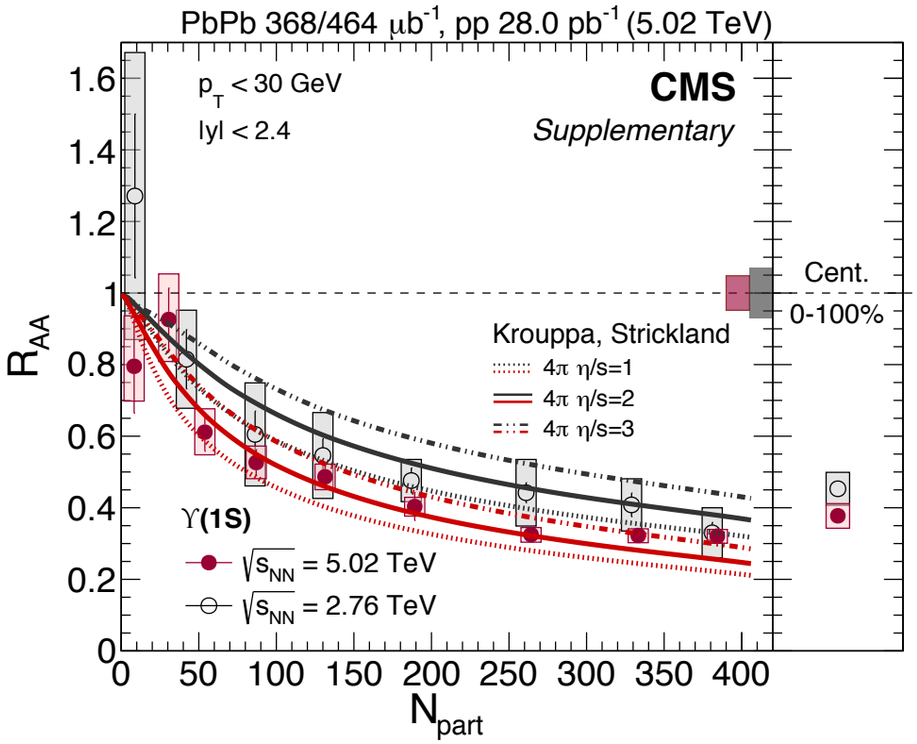


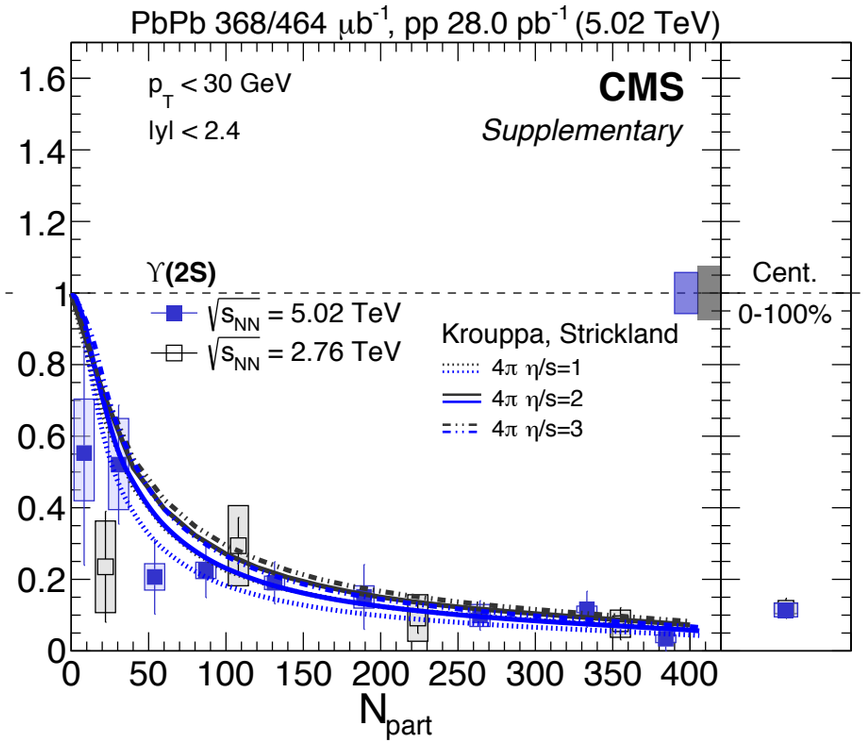


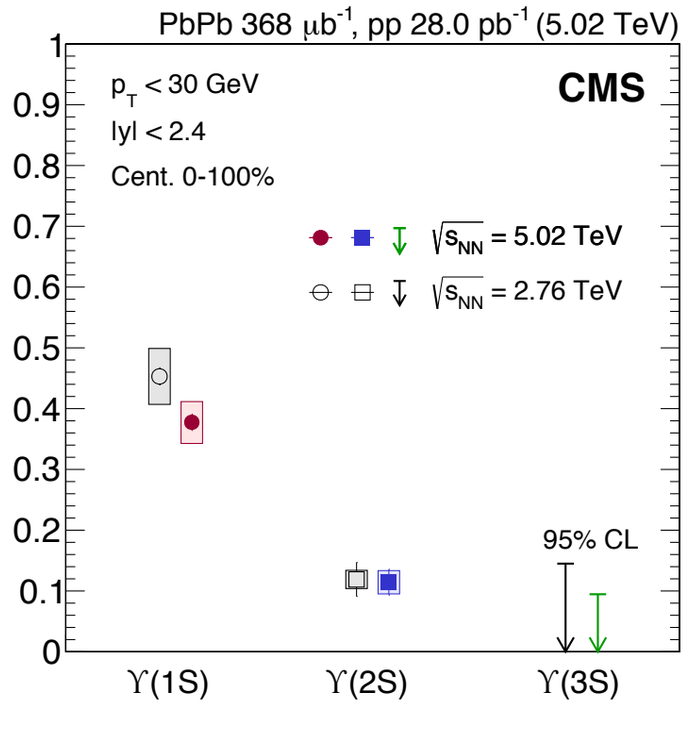
- **Y(1S) : R_{AA}(RHIC) ~ R_{AA}(LHC 2.76) ≥ R_{AA}(LHC 5.02)**
- **Indication of larger suppression for Y(1S) but compatible within unc. R_{AA}(2.76) / R_{AA}(5.02) = 1.2 +/- 0.15 (unc.)**
- **Suppression of direct Y(1S)? Need more input : feed-down, v2 etc.**

Summary of 2.76 vs 5.02 TeV

arXiv:1805.09215





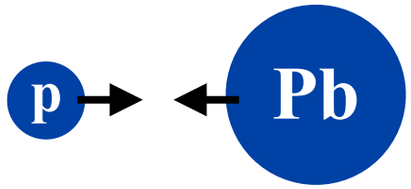


- **Sequential suppression for both energies**
- **Y(1S) : R_{AA}(LHC 2.76) ≥ R_{AA}(LHC 5.02)**
- **Similar suppression for the excited states at 2.76 & 5.02 TeV**
- **Model agrees with data for each corresponding energy**

Outline

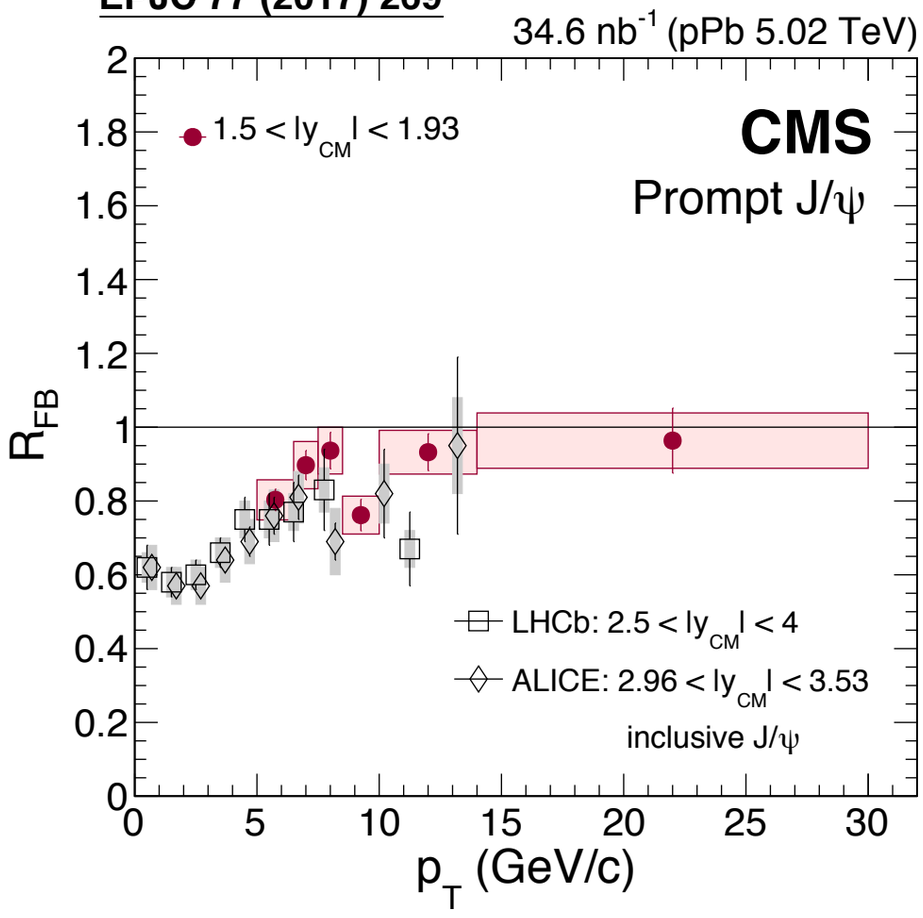
- Quarkonia in PbPb collision
  - Charmonia
  - Bottomonia
- **Quarkonia in pPb collision**
  - **Charmonia**
  - **Bottomonia**
- Summary

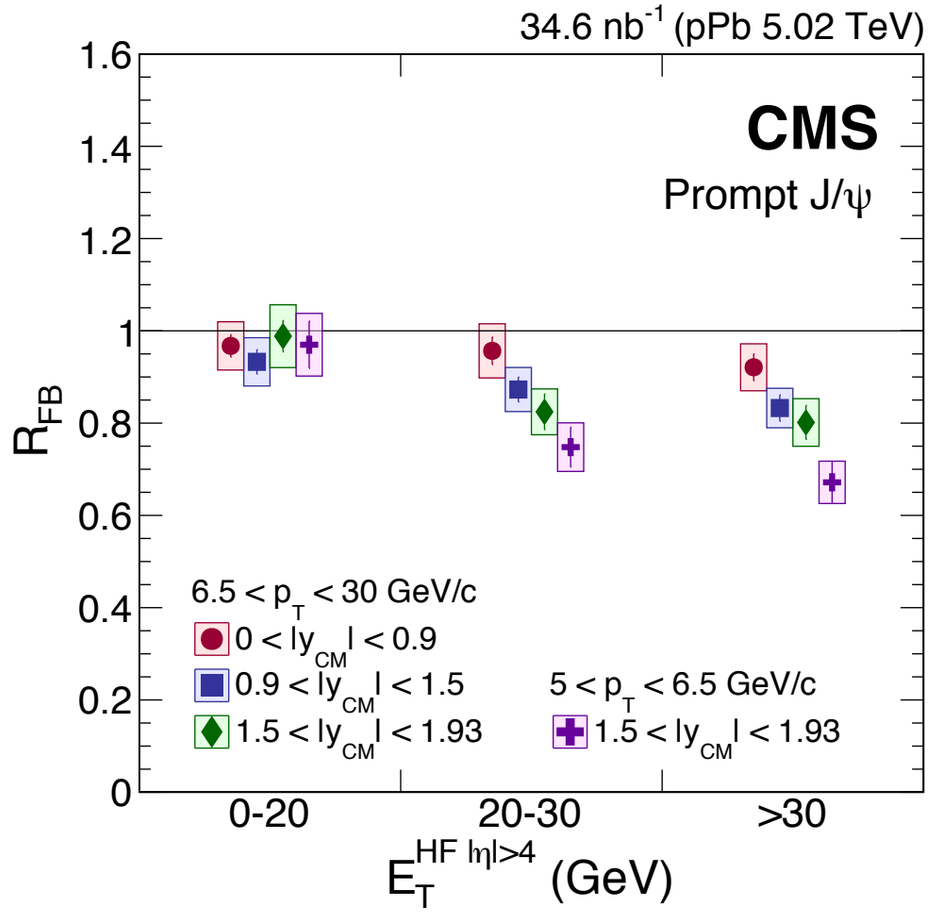
J/ψ in pPb



- **p-going side : forward & low x**
- **Pb-going side : backward & high x**

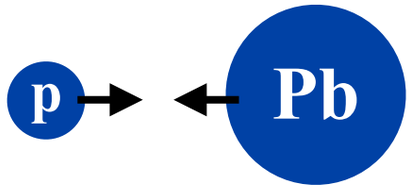
EPJC 77 (2017) 269





- **R_{FB} below 1 at forward low p_T**
- **Compatible with other experiment data**
- **Enhanced nuclear effect for increasing central pPb collisions**

J/ψ in pPb



- **p-going side : forward & low x**
- **Pb-going side : backward & high x**

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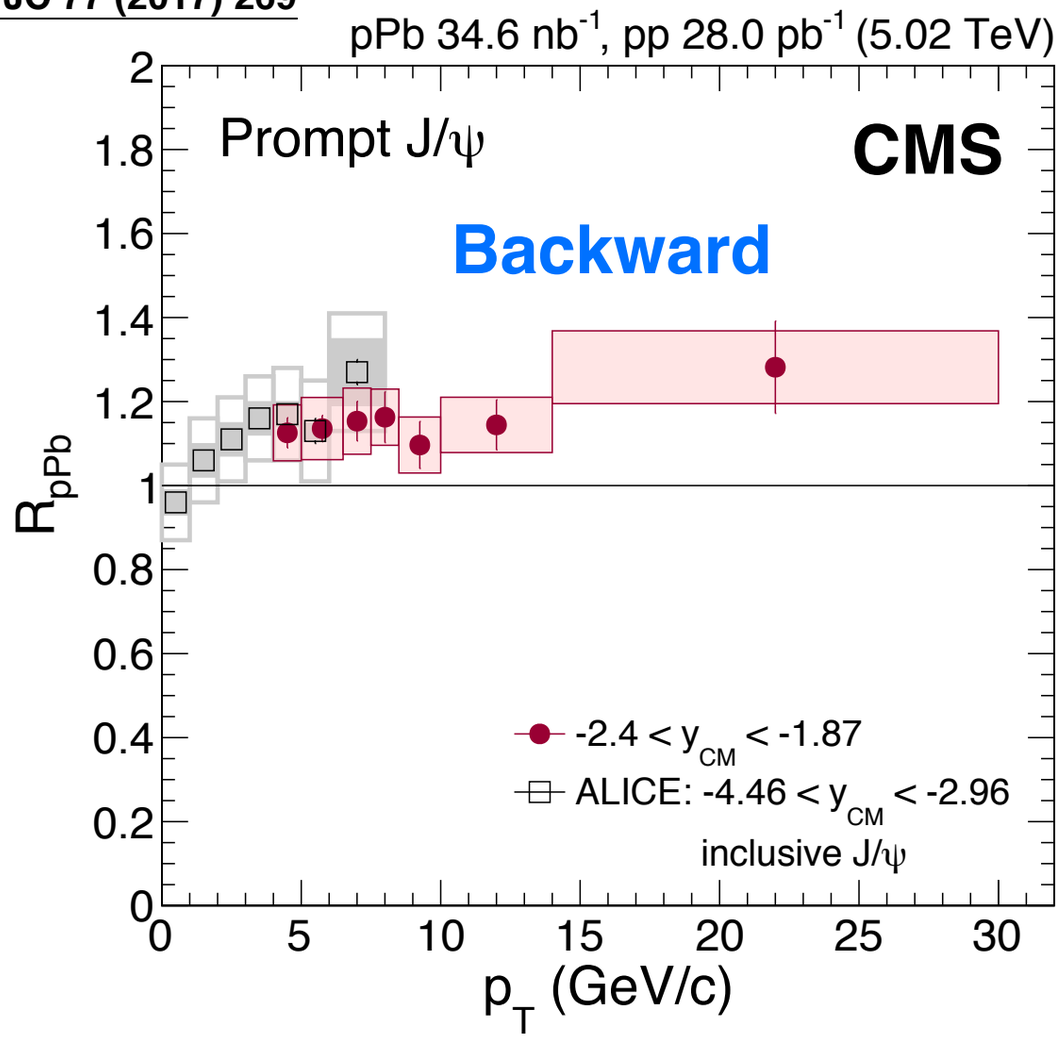
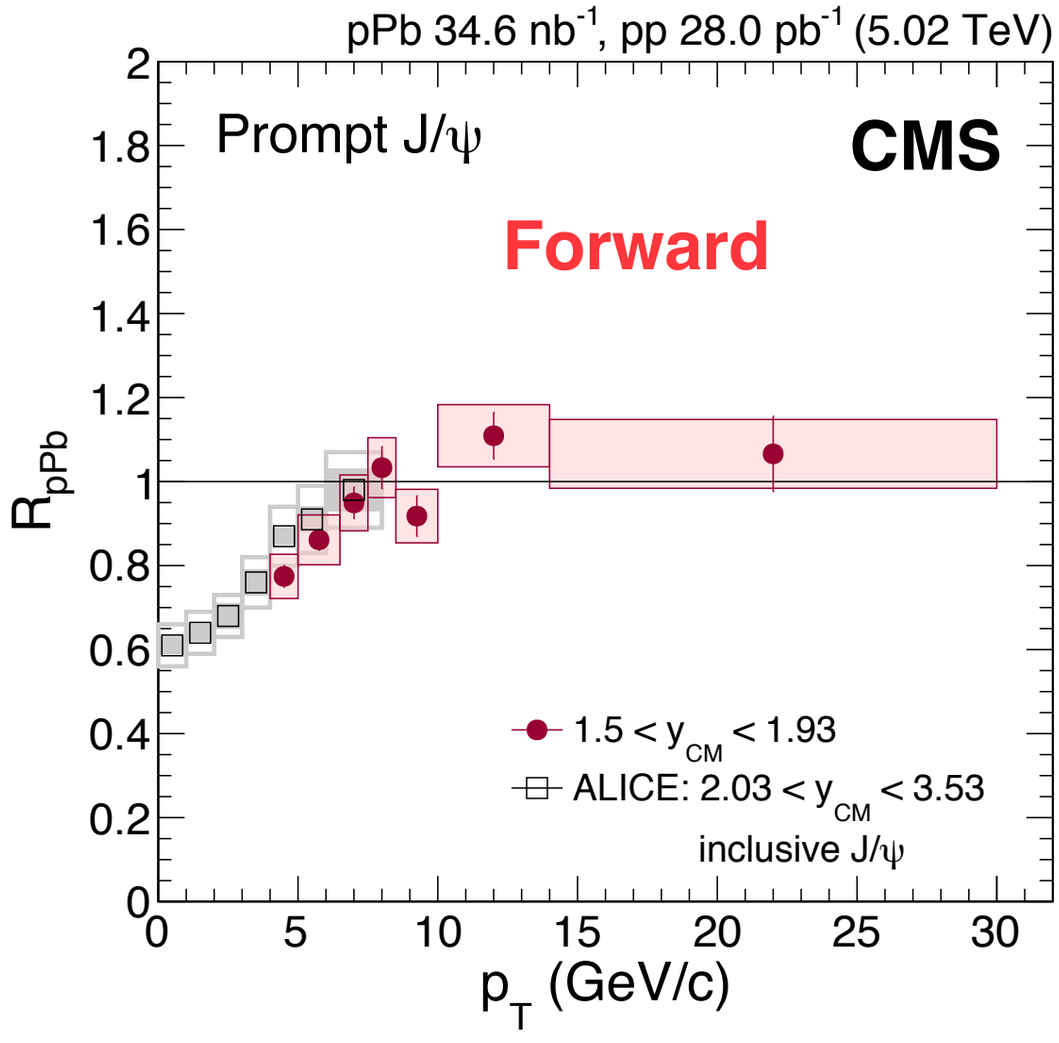
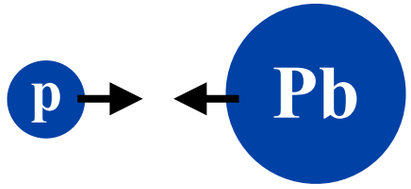




- **Suppression at forward low p_T**
- **CMS data above unity in backward region**

J/ψ in pPb



- **p-going side : forward & low x**
- **Pb-going side : backward & high x**

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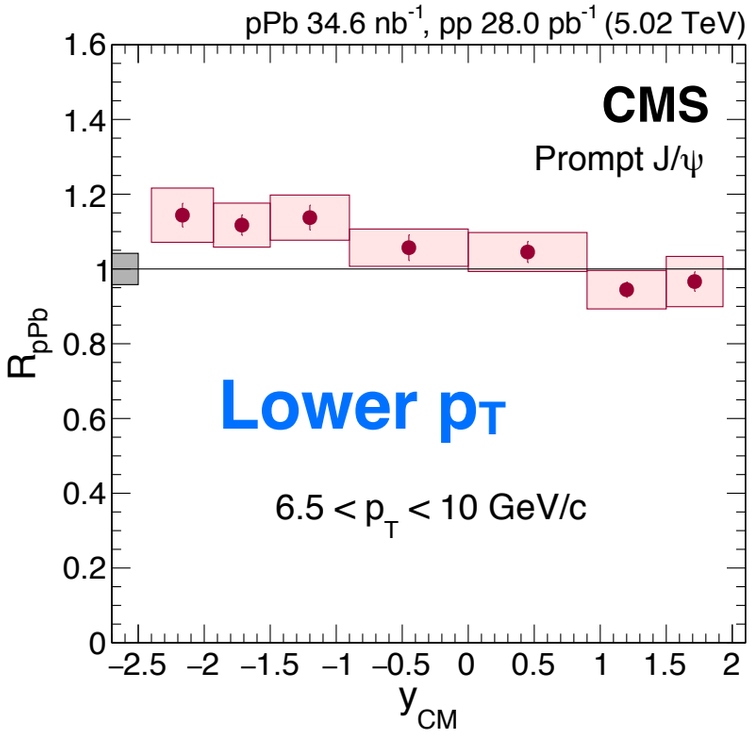

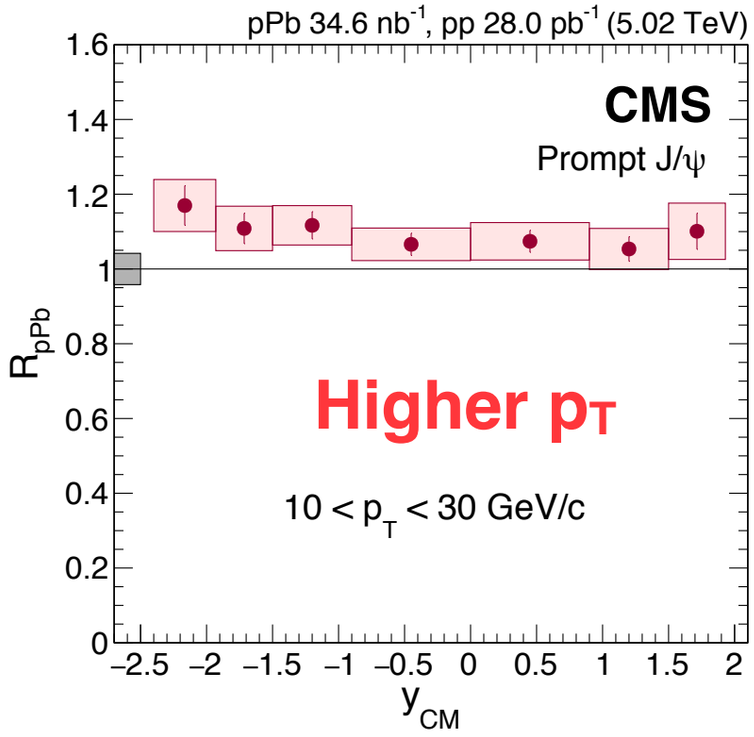

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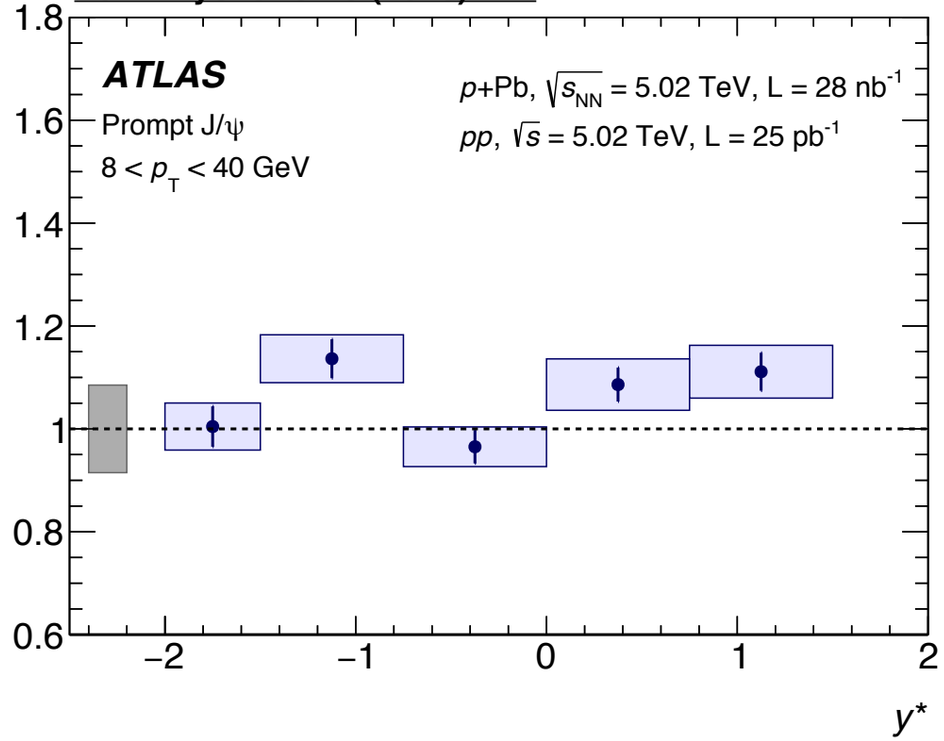
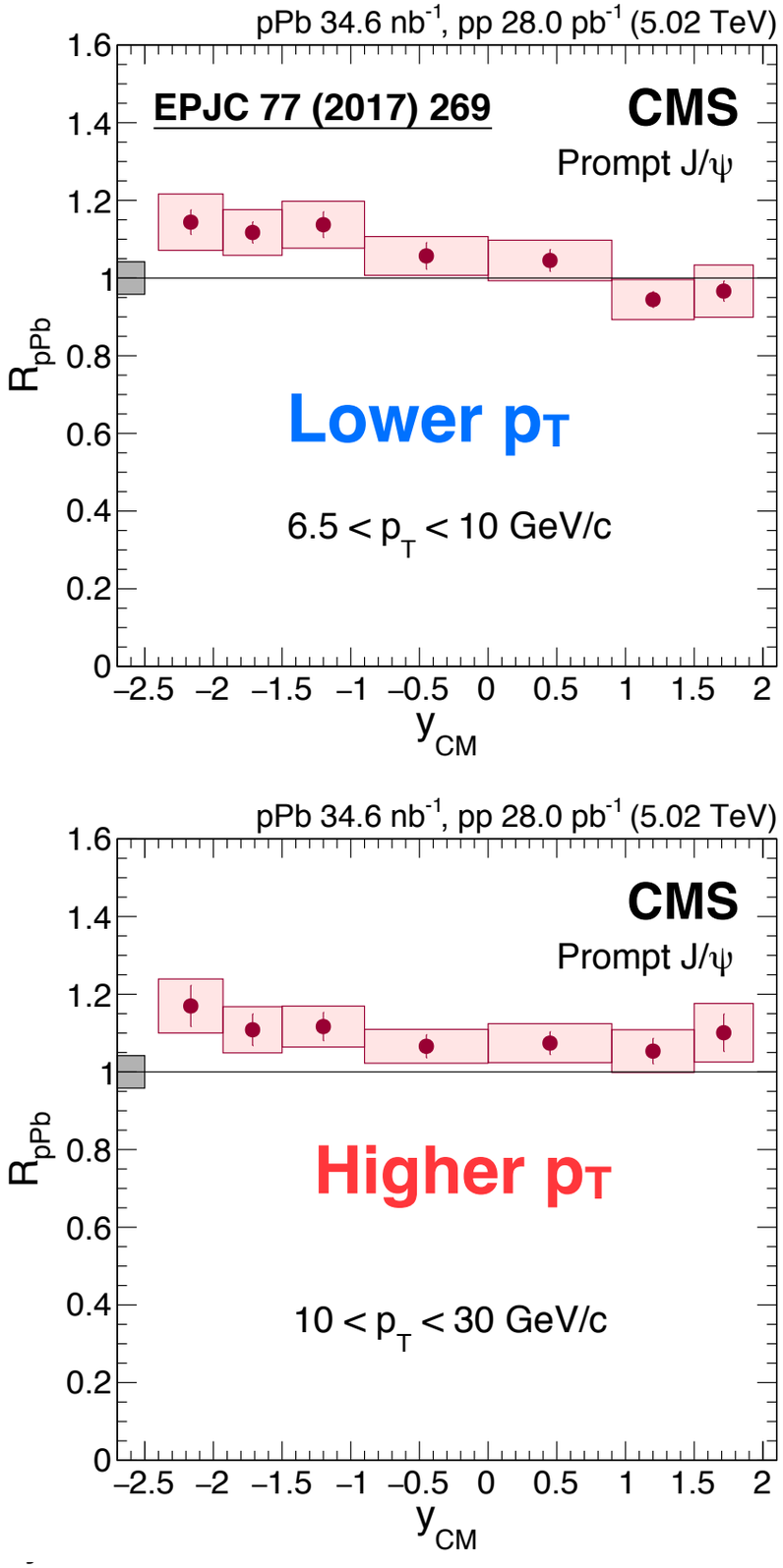
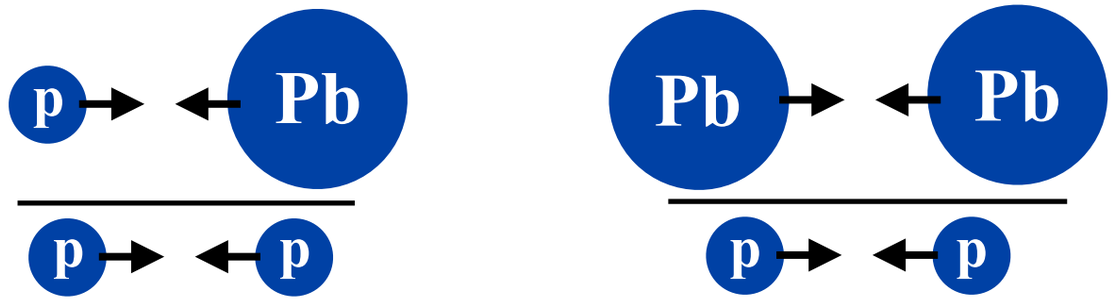


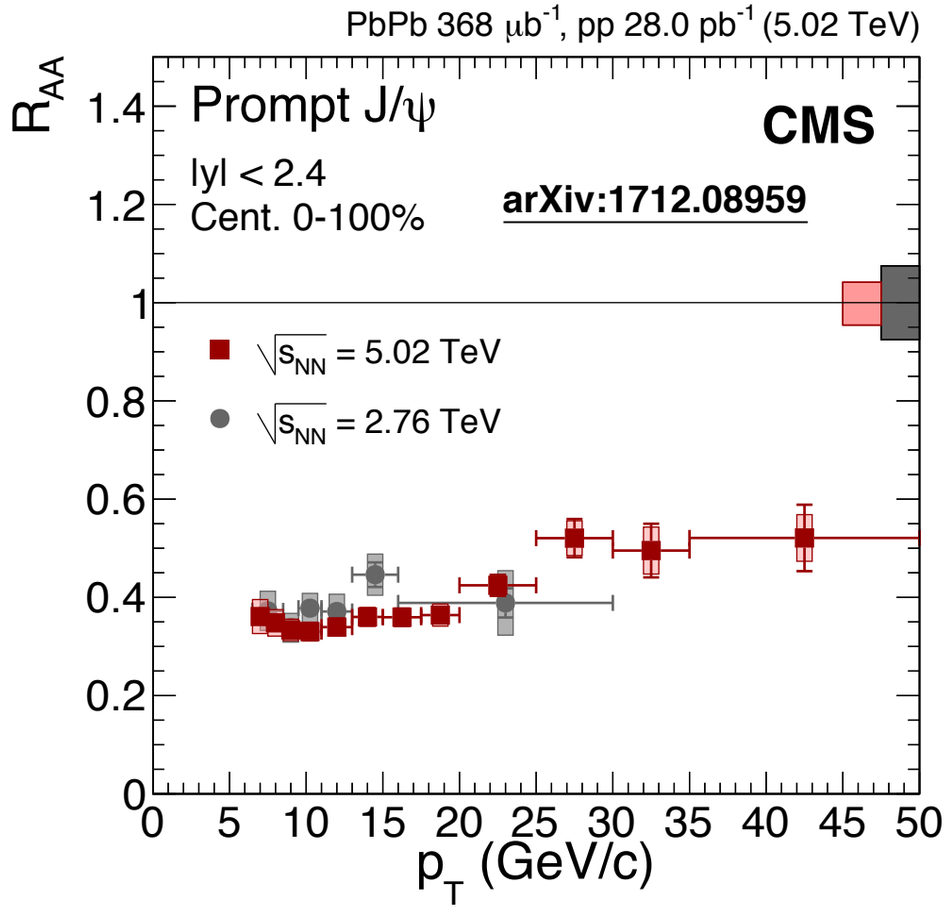
- **CMS data :**
  - ➡ **Decrease in low p_T with toward forward rapidity**
  - ➡ **Above unity in higher p_T range**
- **ATLAS data : no strong rapidity dependence observed**

J/ψ R_{pPb} vs R_{AA}

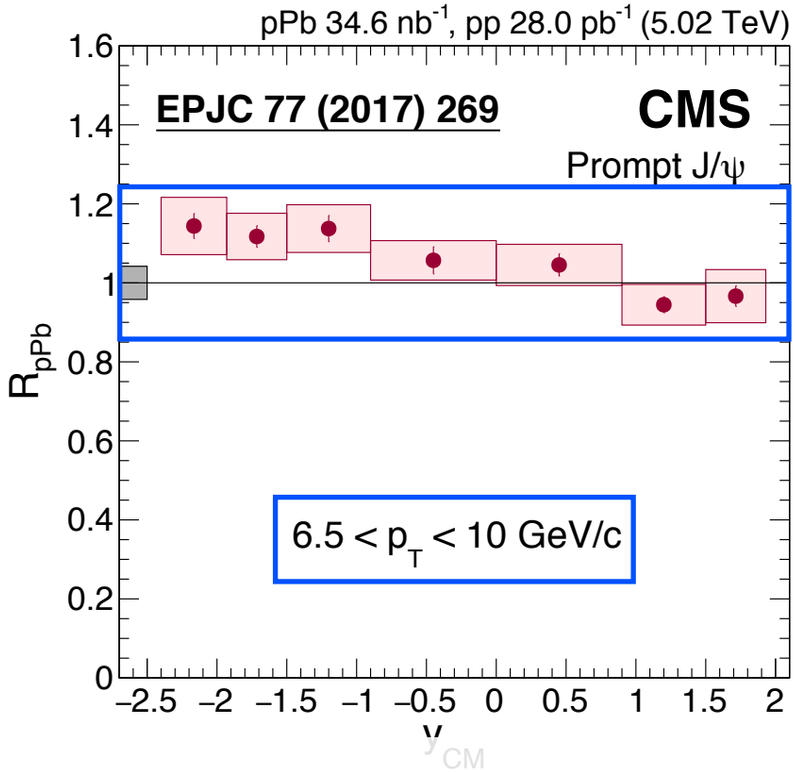


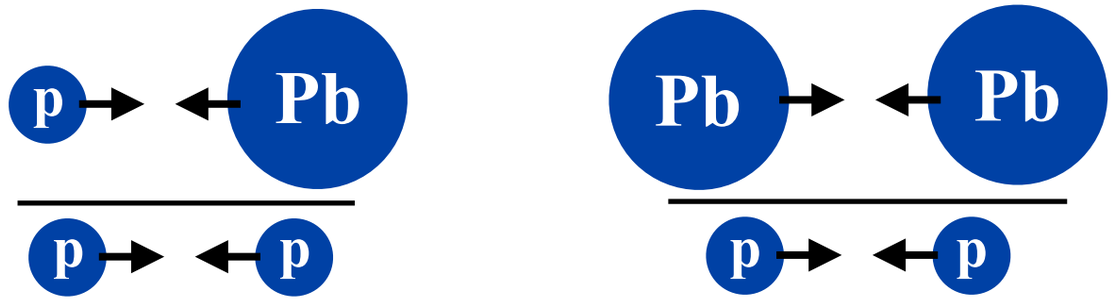


▶ R_{pPb} vs R_{AA}

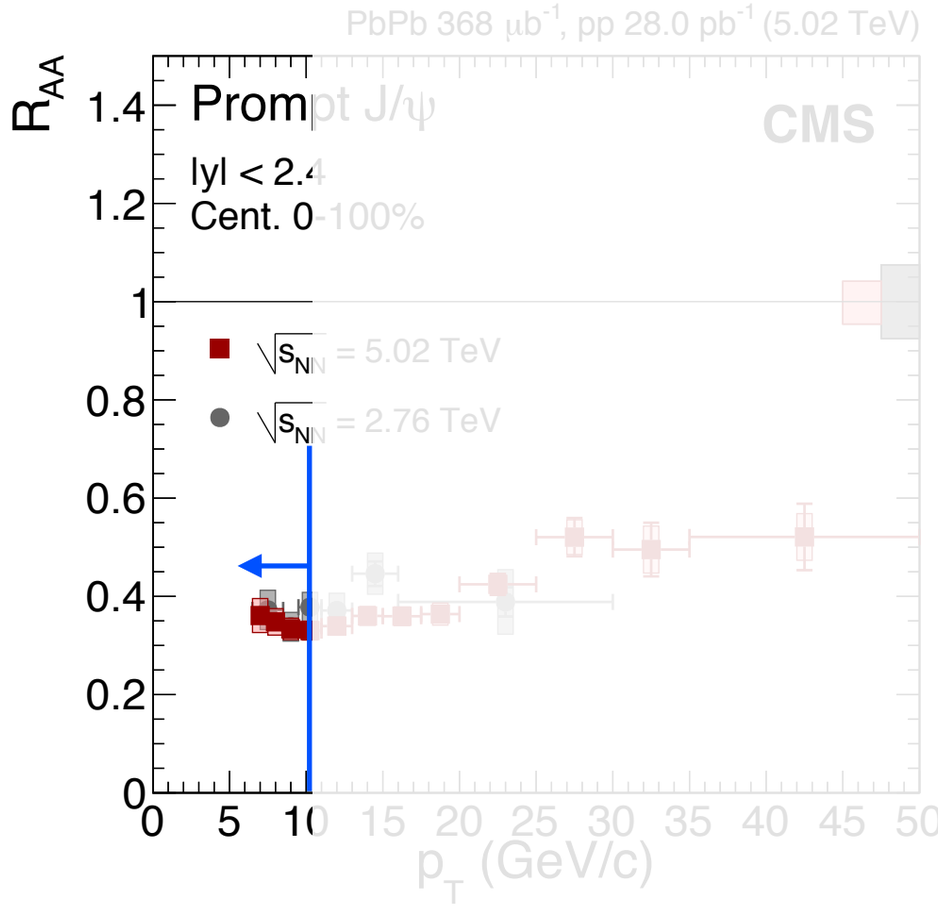


J/ψ R_{pPb} vs R_{AA}



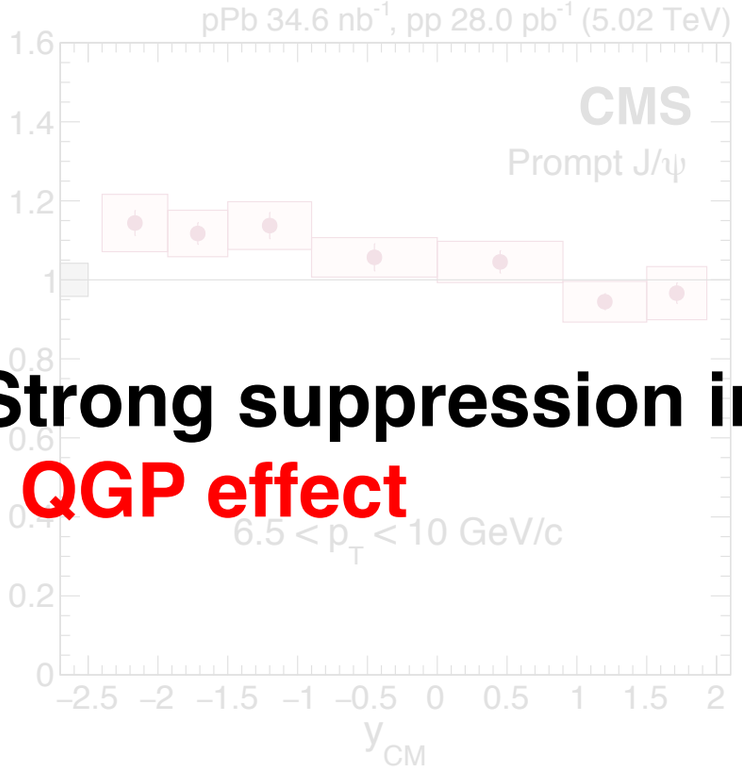


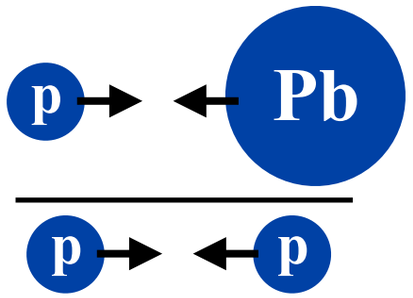
- **R_{pPb} vs R_{AA}**

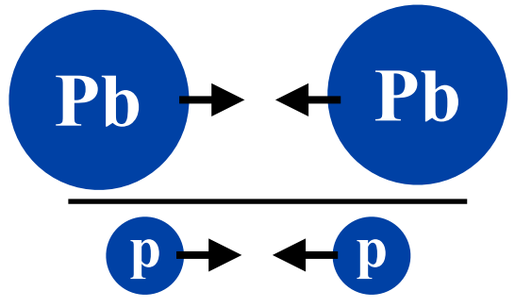


- **Strong suppression in PbPb : QGP effect**

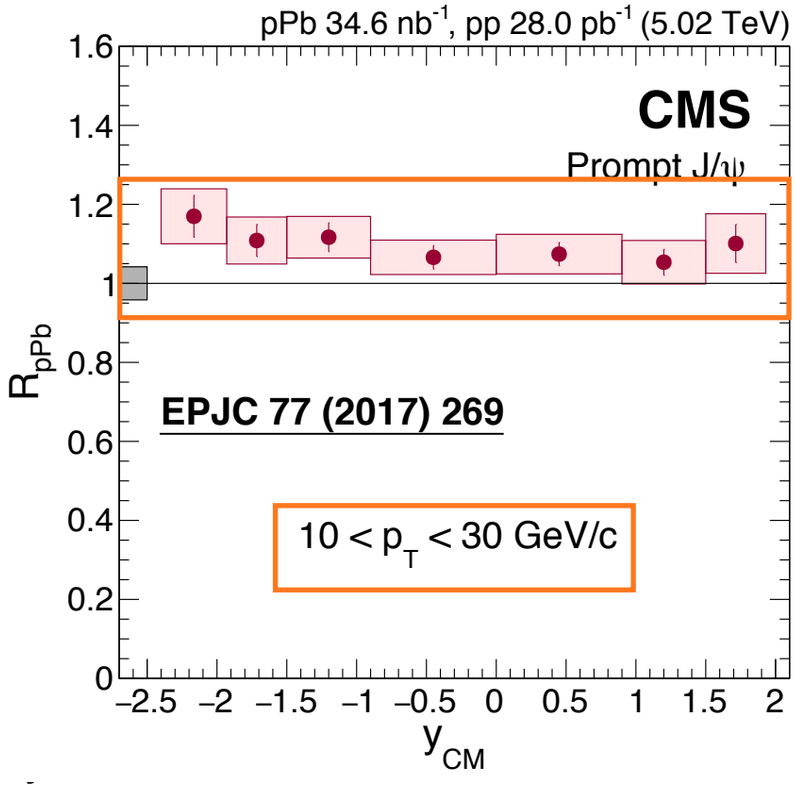
J/ψ R_{pPb} vs R_{AA}



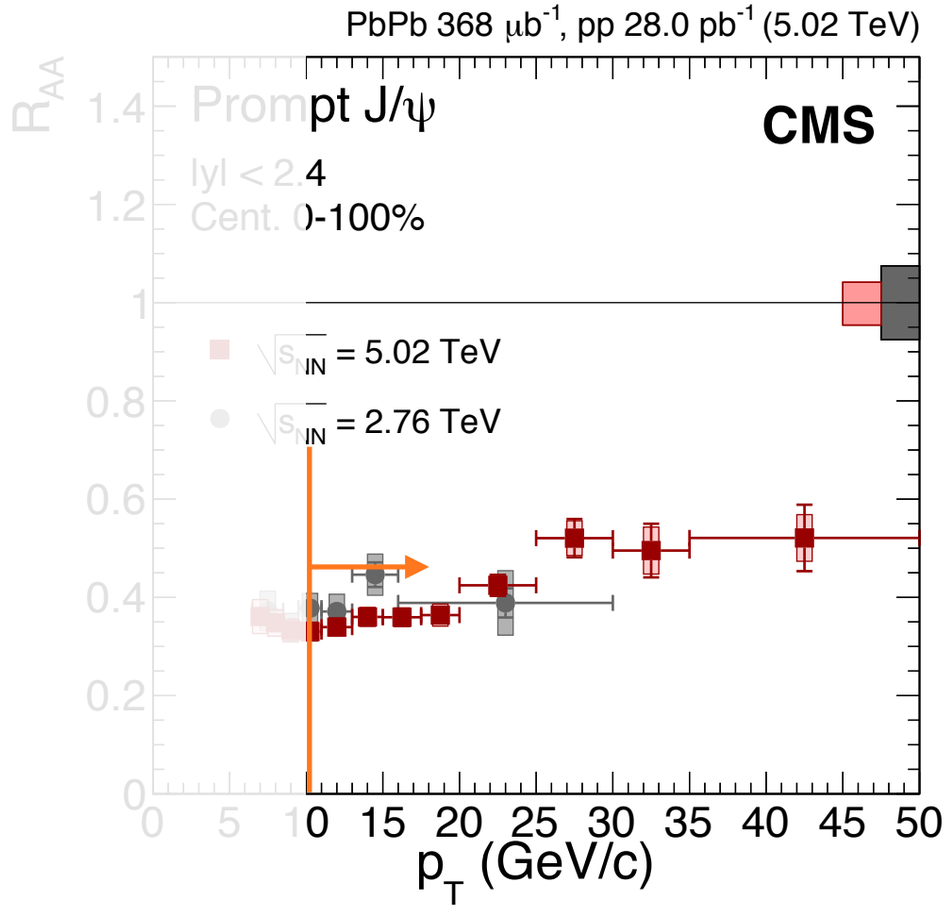




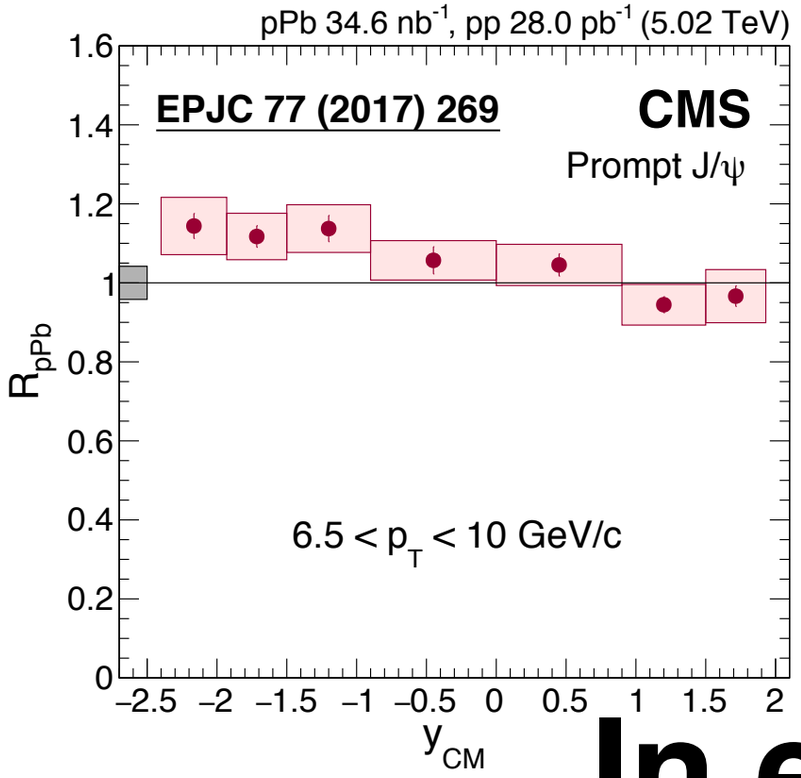
- **Strong suppression in PbPb : QGP effect**

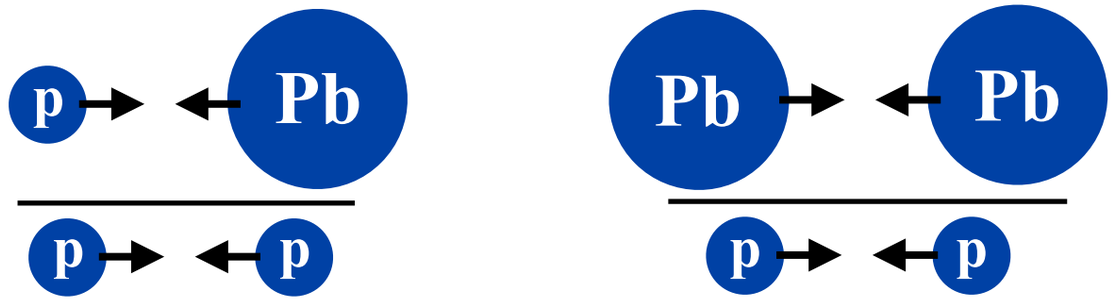


- R_{pPb} vs R_{AA}

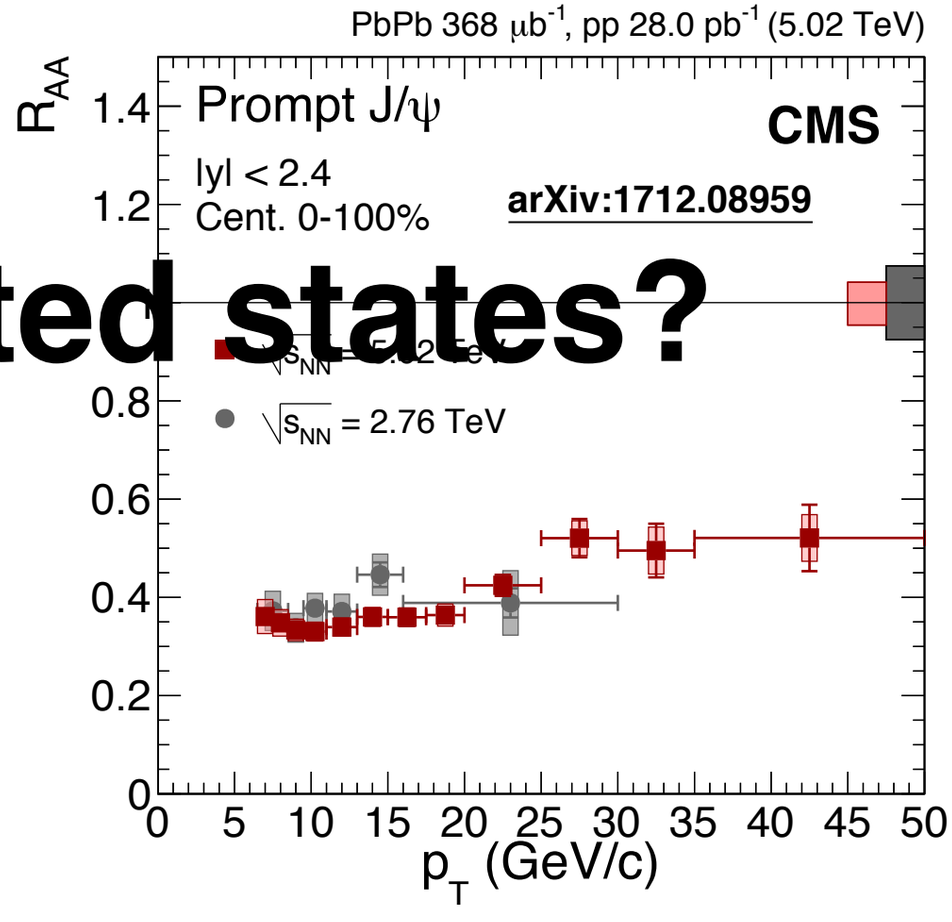


J/ψ R_{pPb} vs R_{AA}

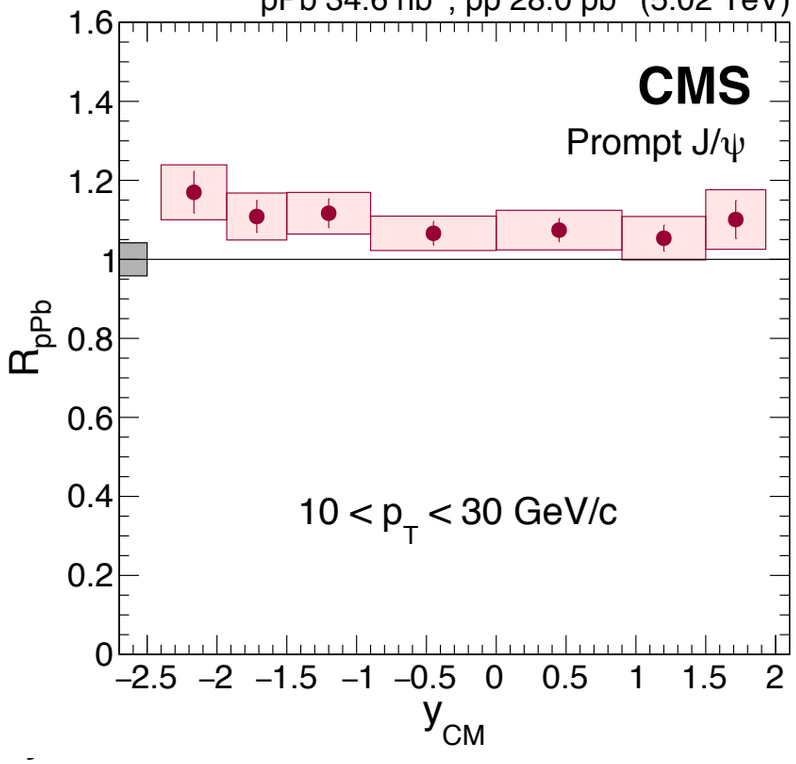




- R_{pPb} vs R_{AA}

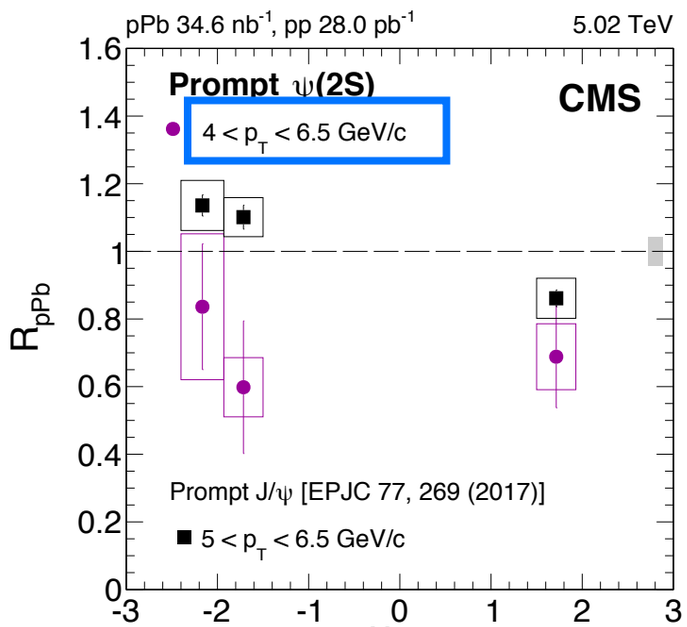


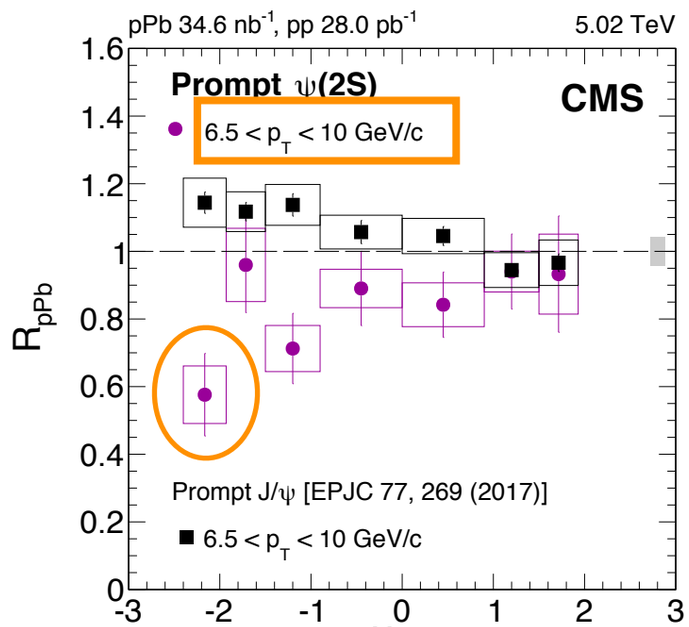
In excited states?



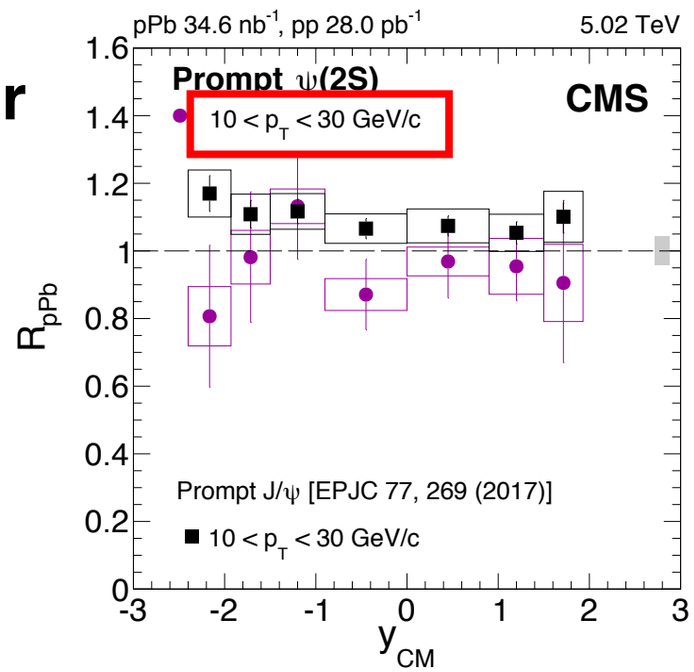
ψ(2S) R_{pPb} in CMS

arXiv:1805.02248



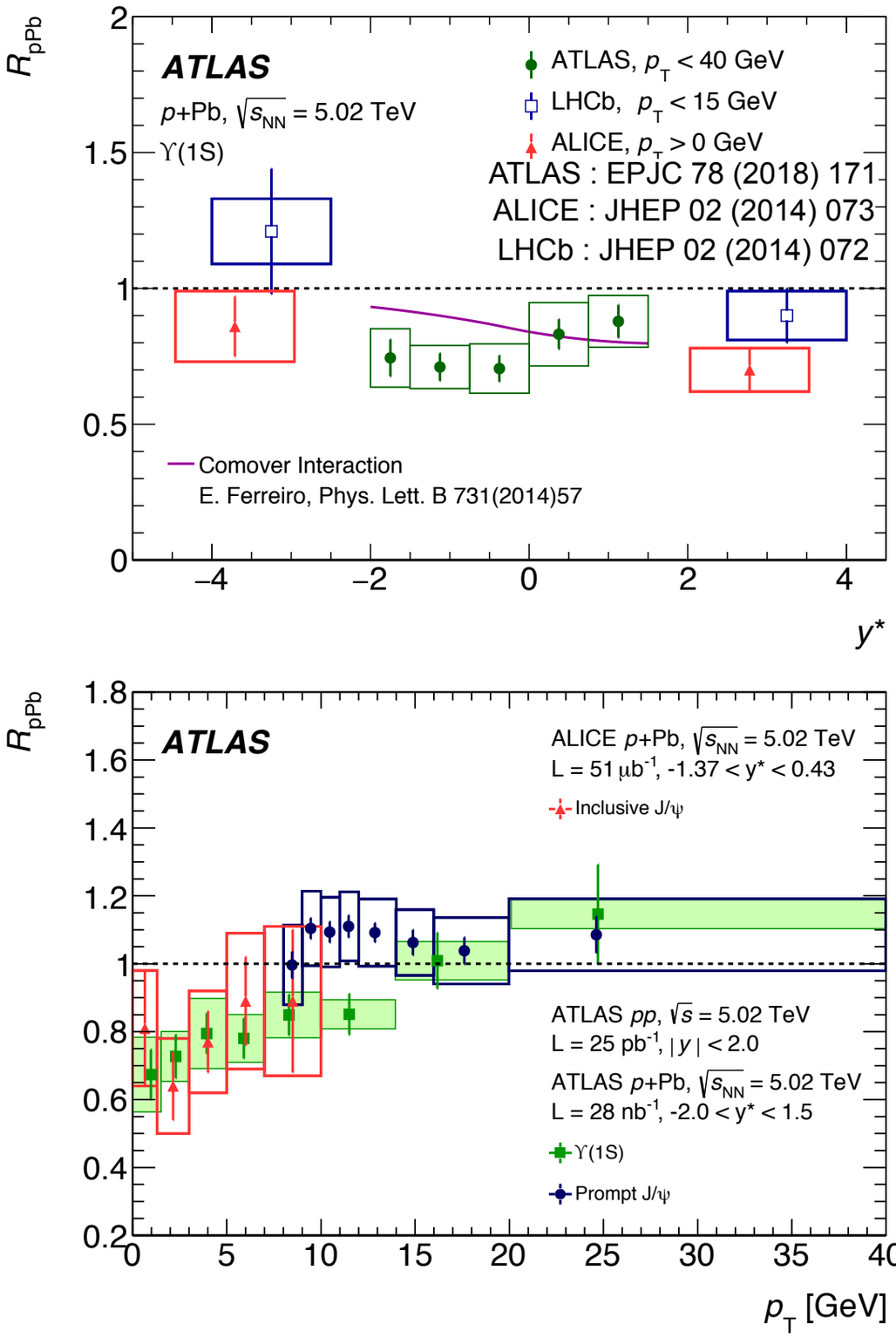


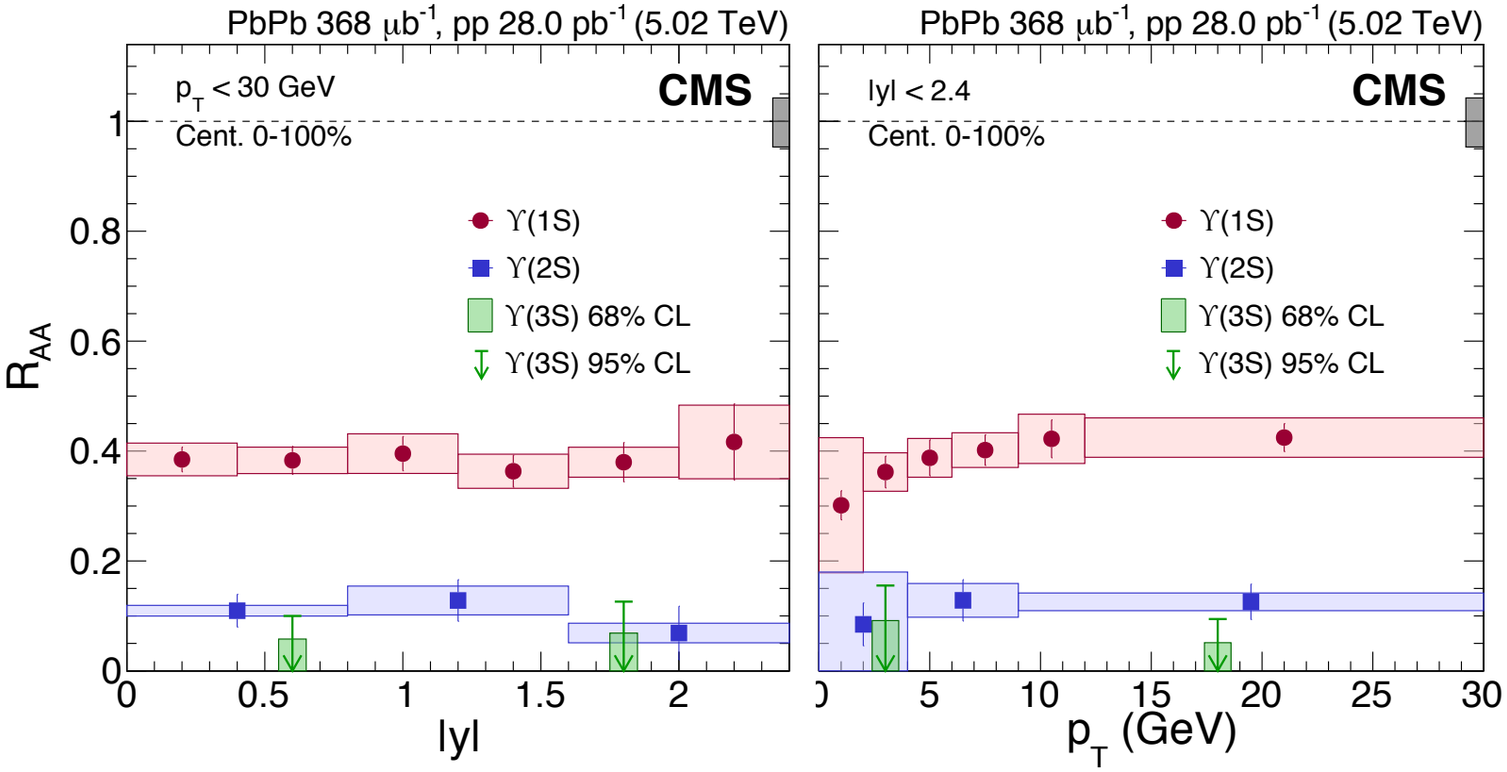
- **Larger suppression for ψ(2S) than J/ψ**
- **Still suppressed for high p_T**



- **Indication of final state effect?**
- **Co-mover breakup?**
- **Need input to understand CNM effect : Flow harmonics etc.**

Bottomonia in pPb

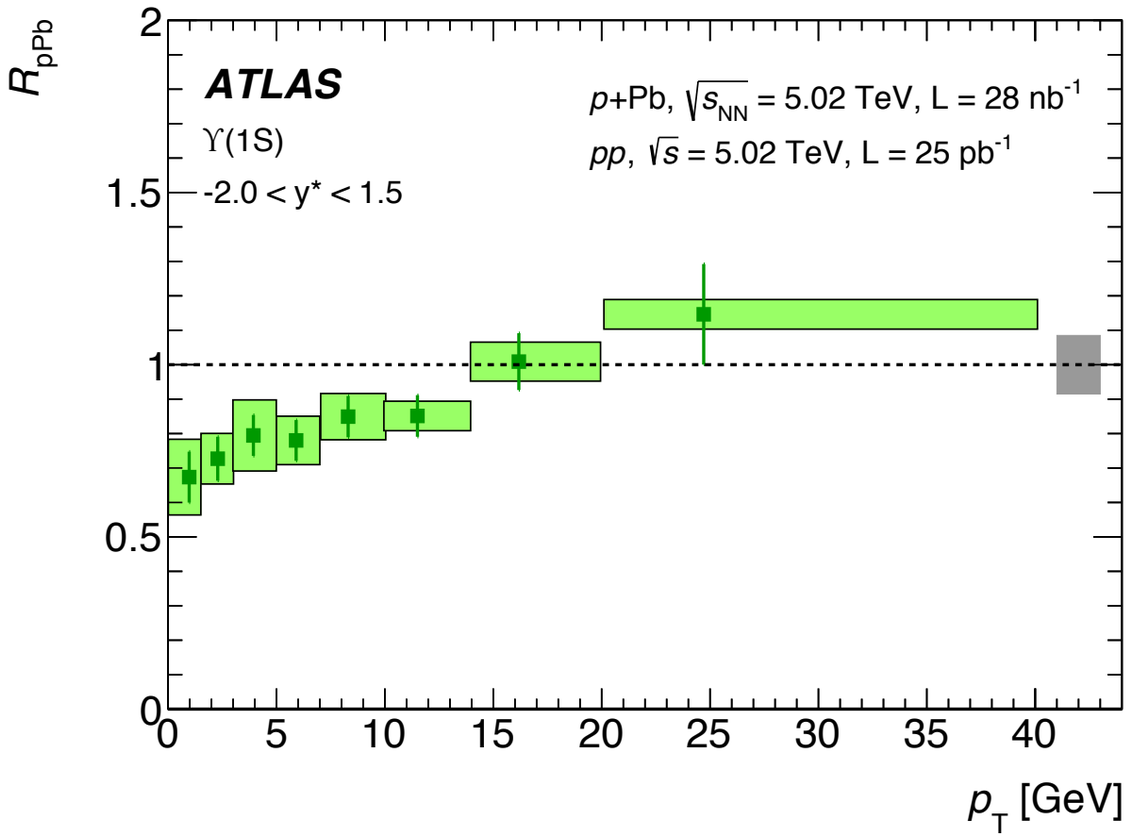


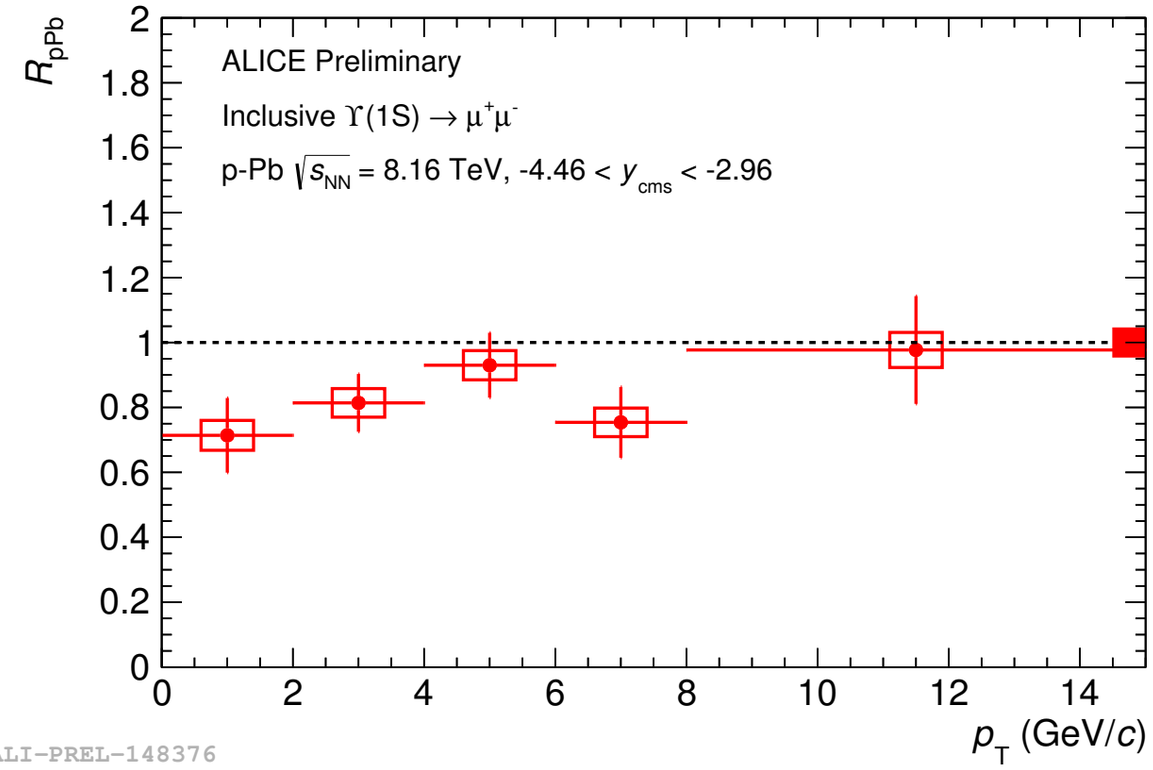


- **R_{pPb} & R_{FB} of Y(1S), Y(2S), Y(3S) with CMS**
- **CNM effect, understanding of Y production**
- **CMS-HIN-18-005**
- **… will be shown in future conference soon**

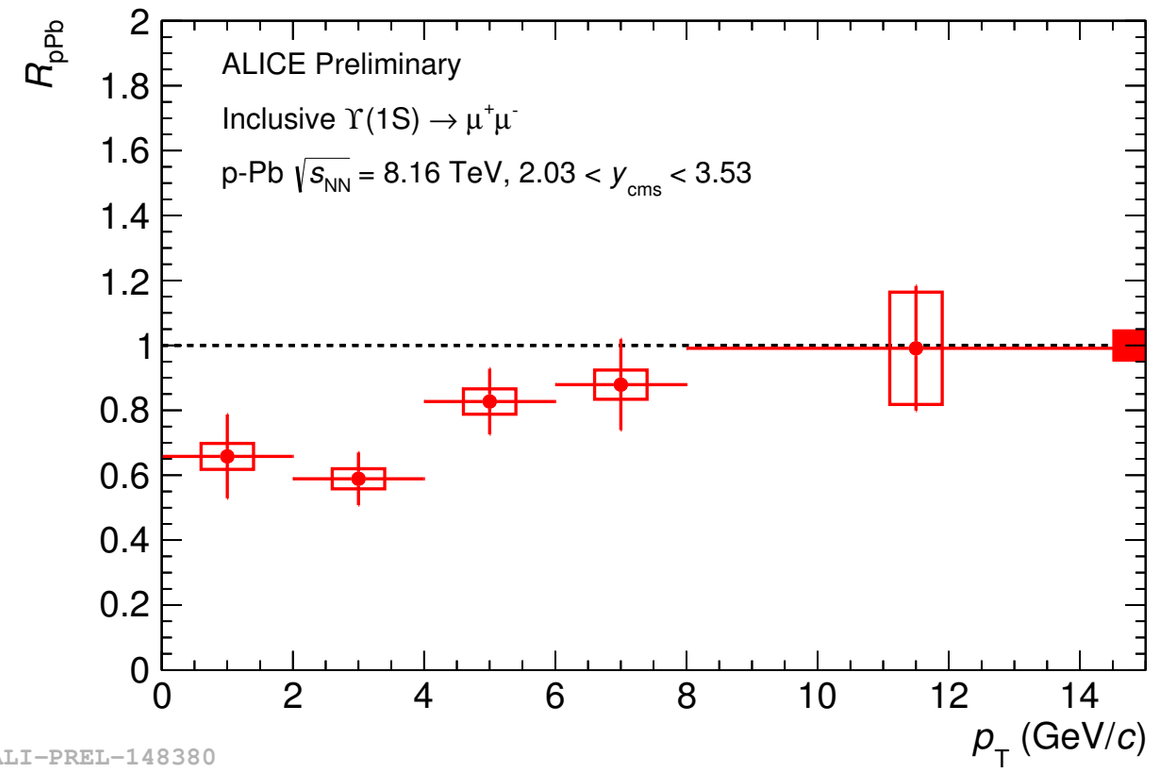
Quarkonium in QM 2018

Bottomonia in pPb





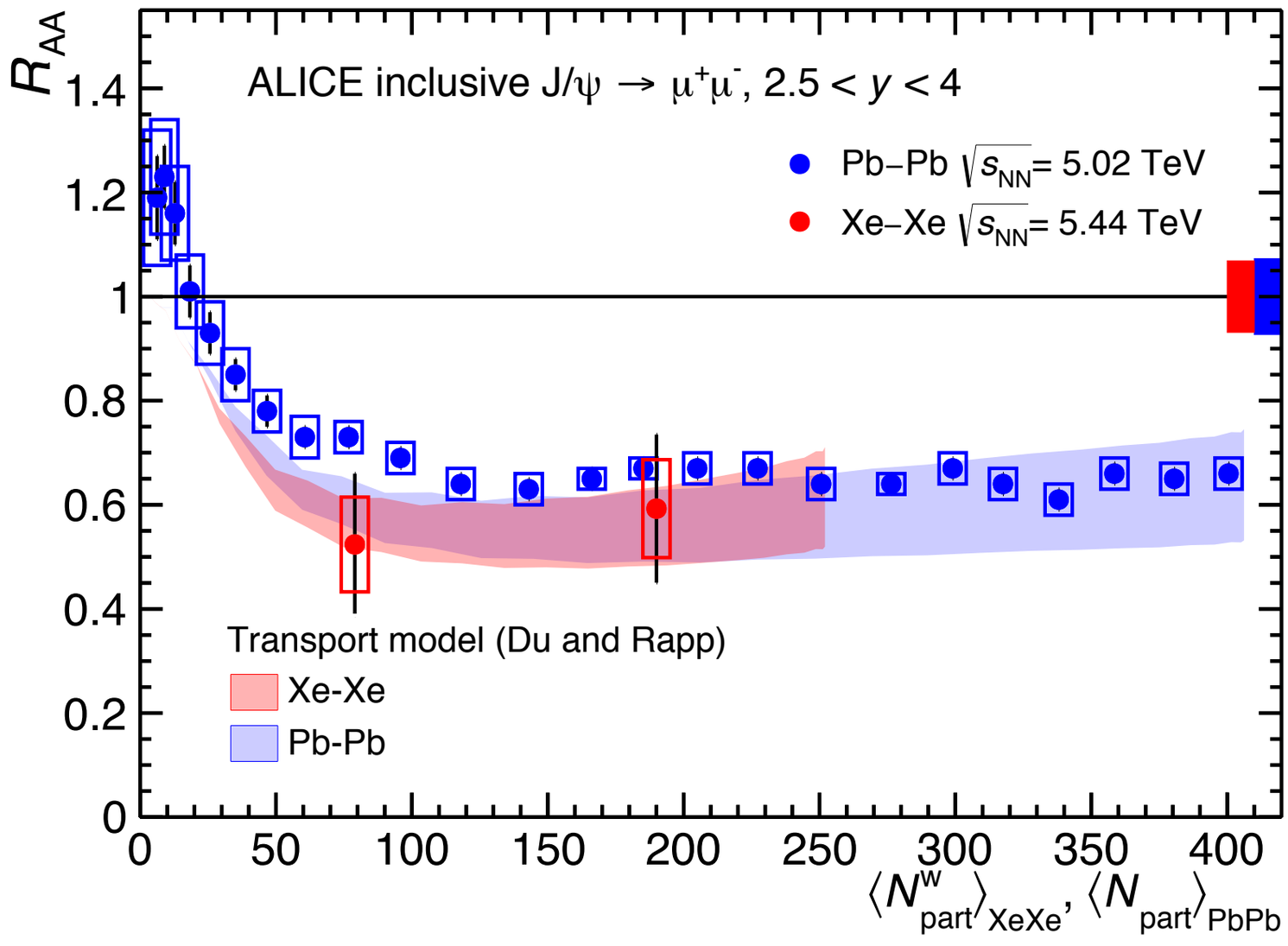
ALI-PREL-148376



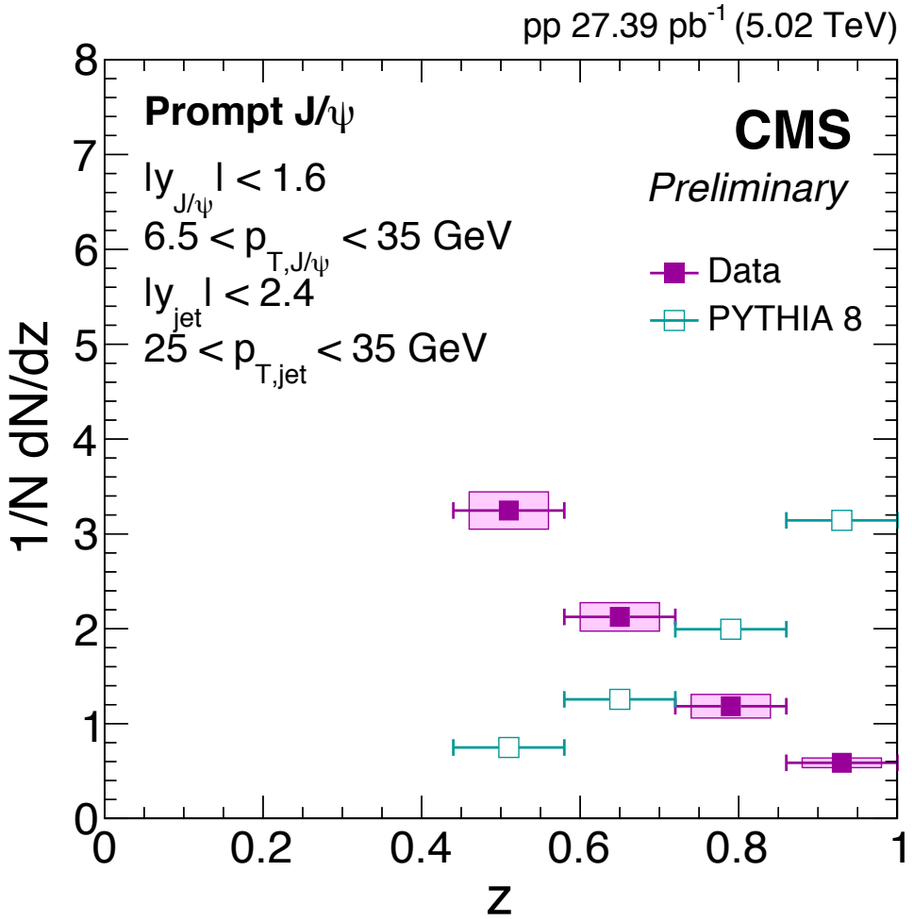
ALI-PREL-148380

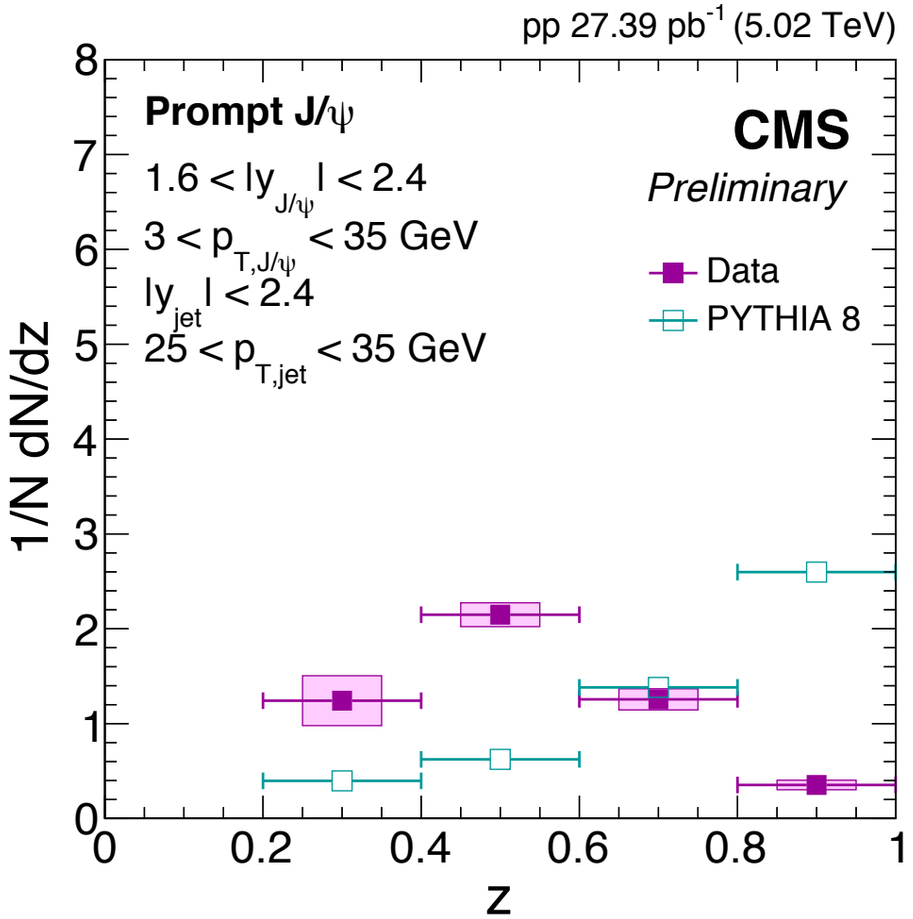
J/ψ in XeXe 5.44 TeV

arXiv:1805.04383



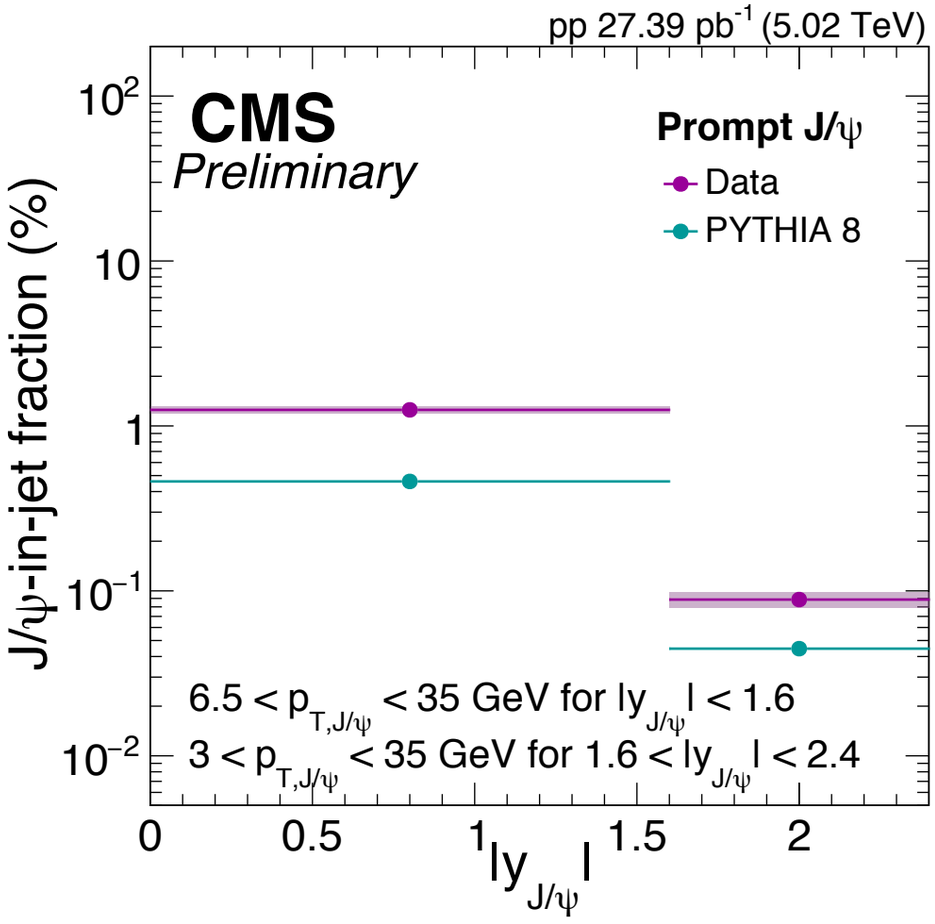
J/ψ in Jets at 5.02 TeV pp

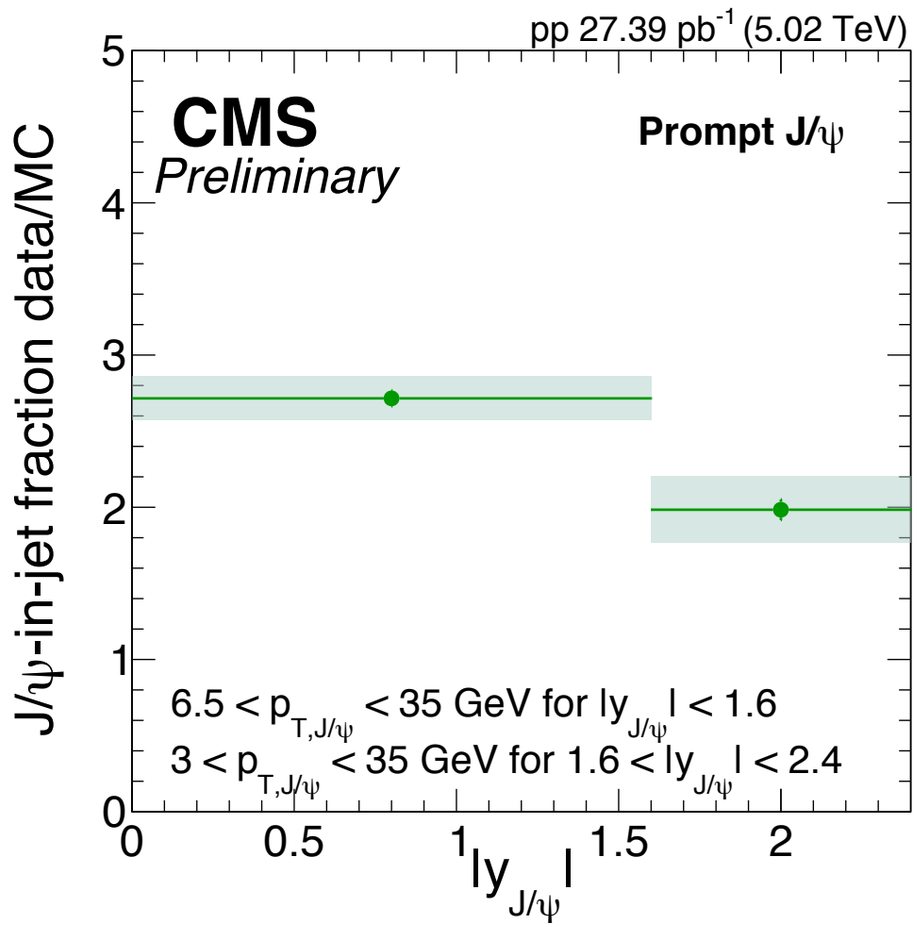




- **Prompt J/ψ distribution is different in mid and forward rapidity**
- **PYTHIA does not describe the J/ψ production in pp**
- **Prompt J/ψ less isolated in data**

J/ψ in Jets at 5.02 TeV pp

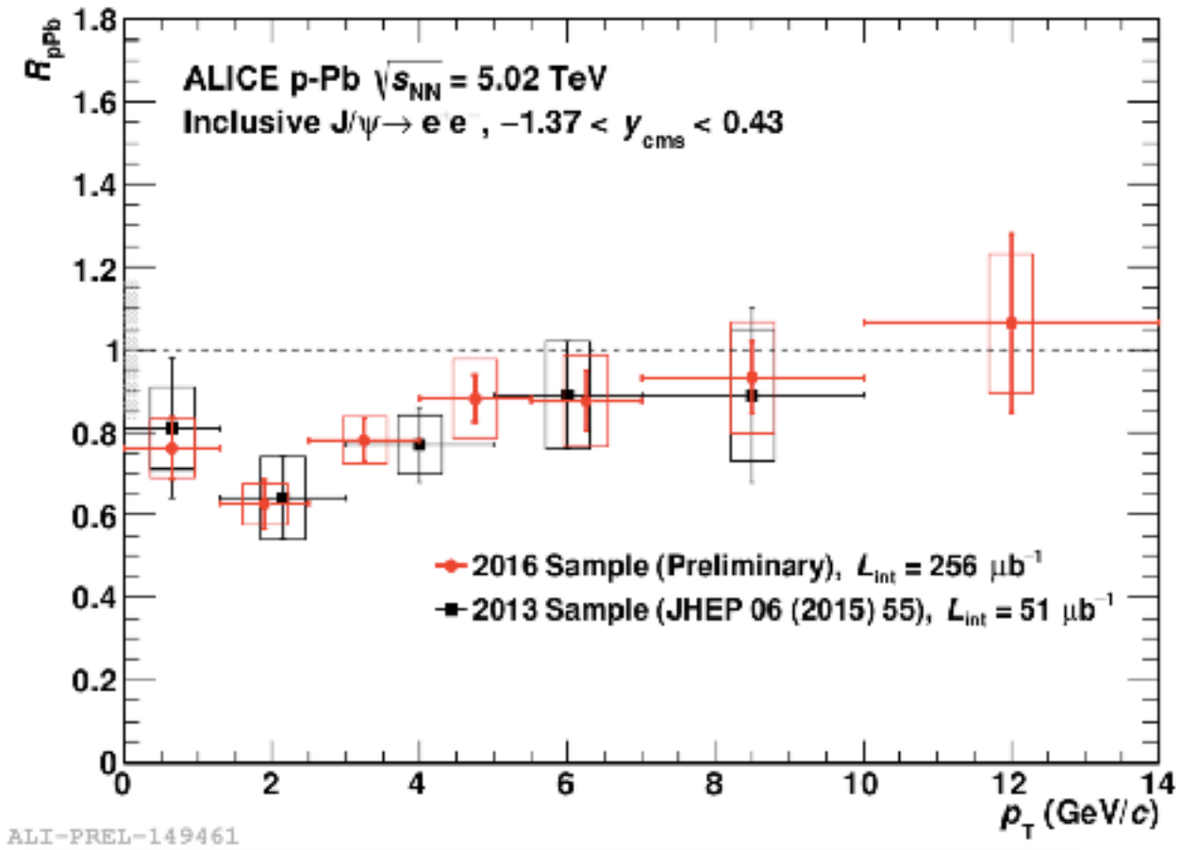


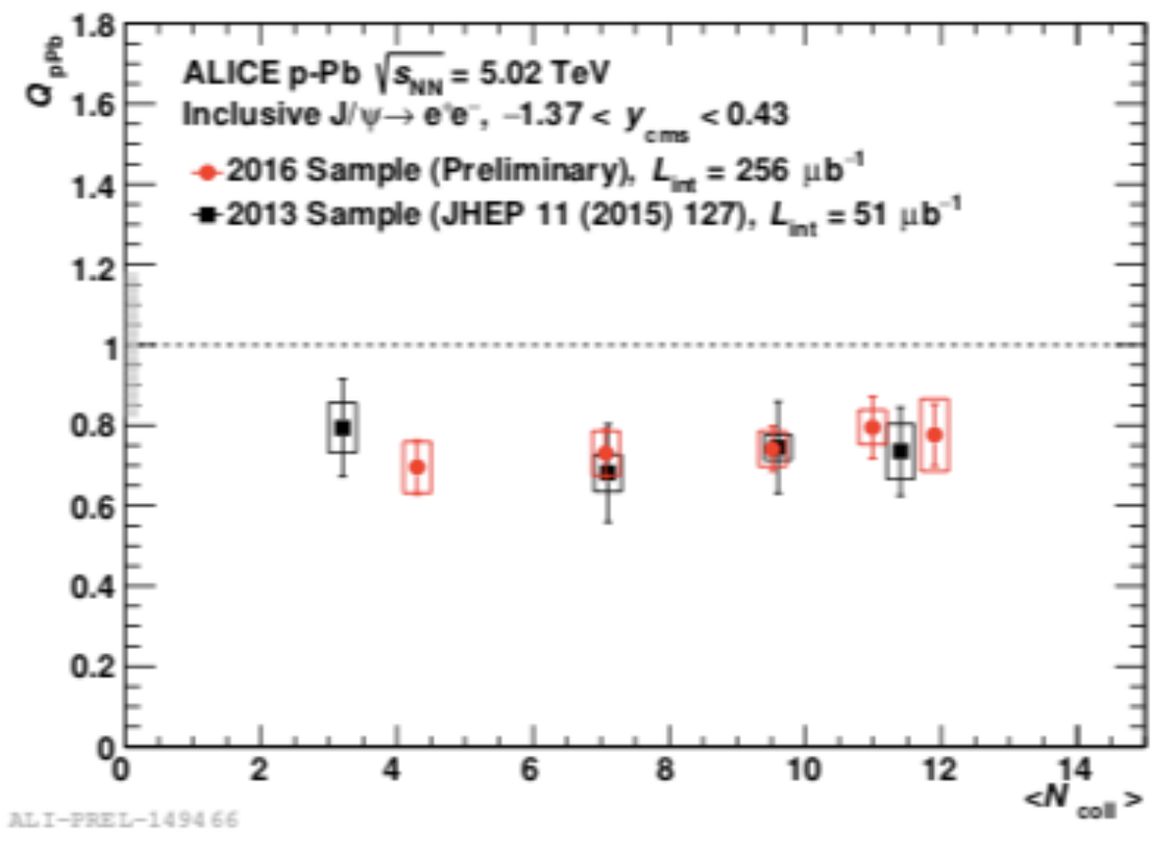


- **Fraction of prompt J/ψ is less than ~1%**
- **Larger fraction of J/ψ in jets in data than in MC**
- **In heavy ion collision : May need to link J/ψ to jet-quenching**

J/ψ in pPb 2016 data at 5 TeV

ALICE-PUBLIC-2018-007

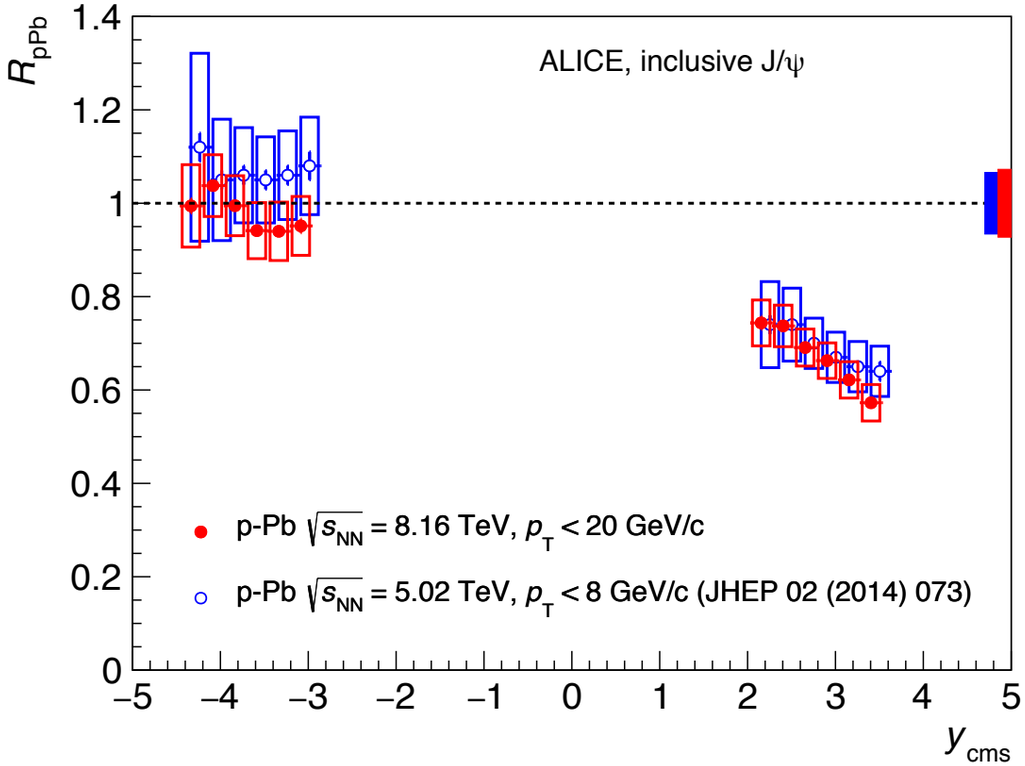


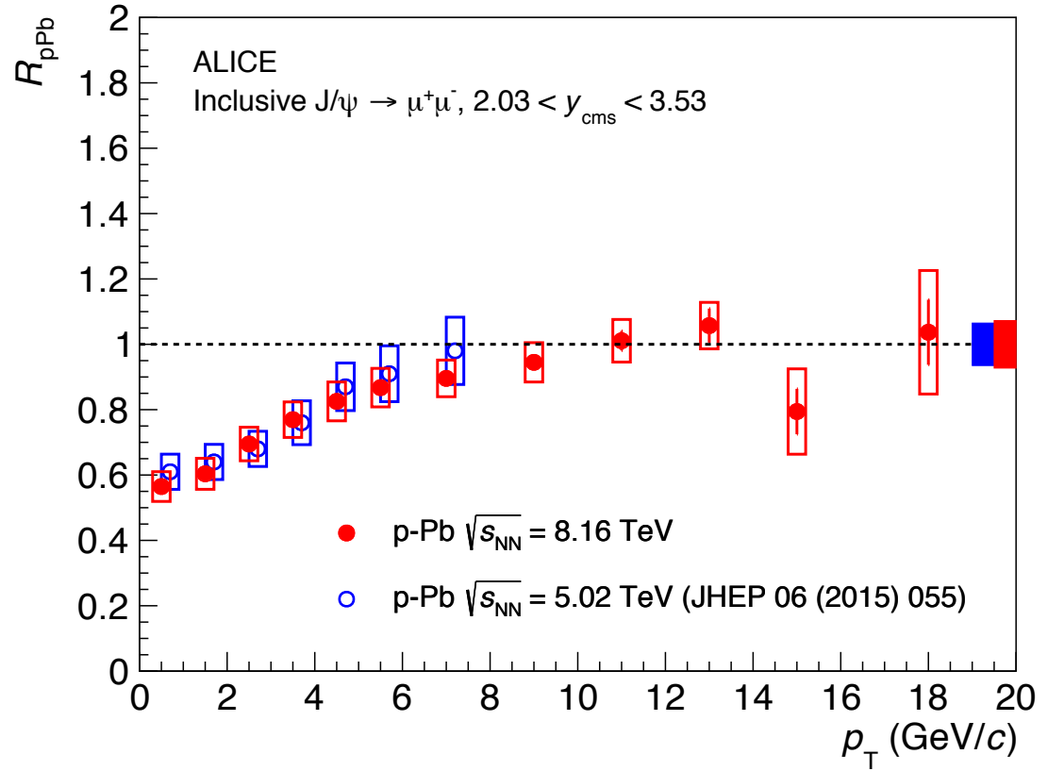


- **2016 data agrees with sample of 2013**
- **More precise measurement, reduction of uncertainty**
- **Suppression at low pT**
- **No strong dependence on collision centrality**

J/ψ in pPb at 8 TeV

arXiv:1805.04381

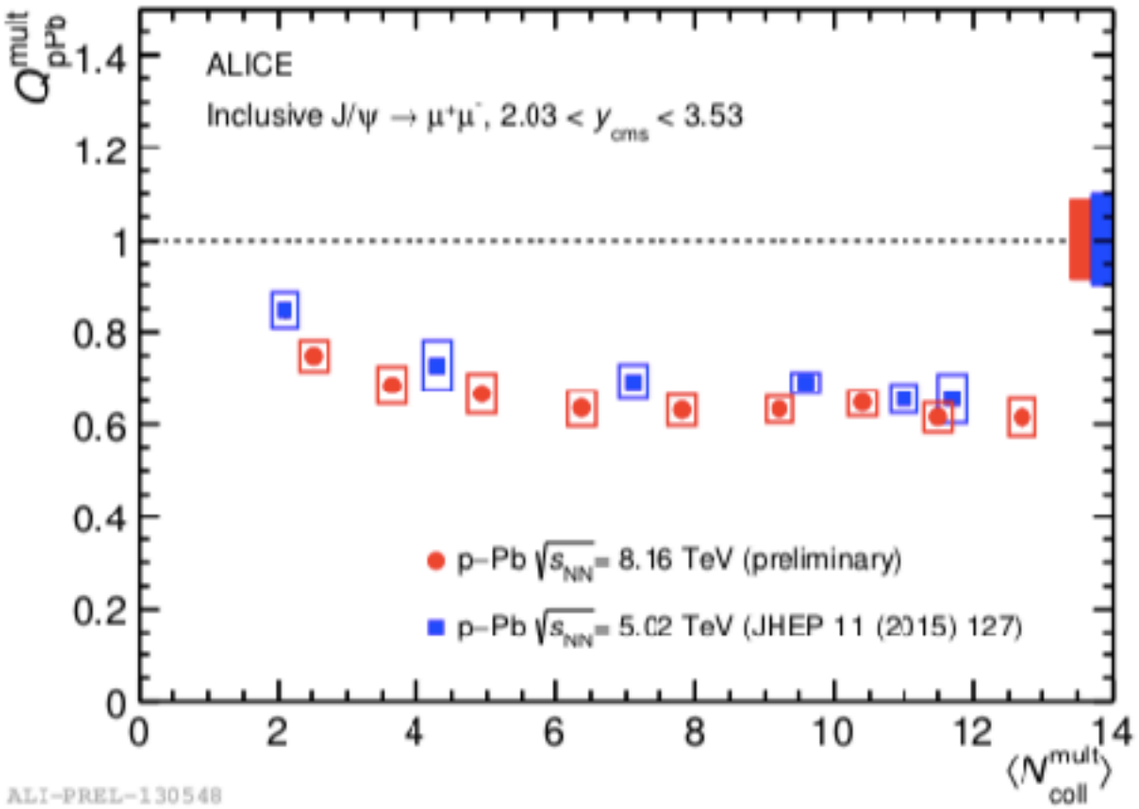


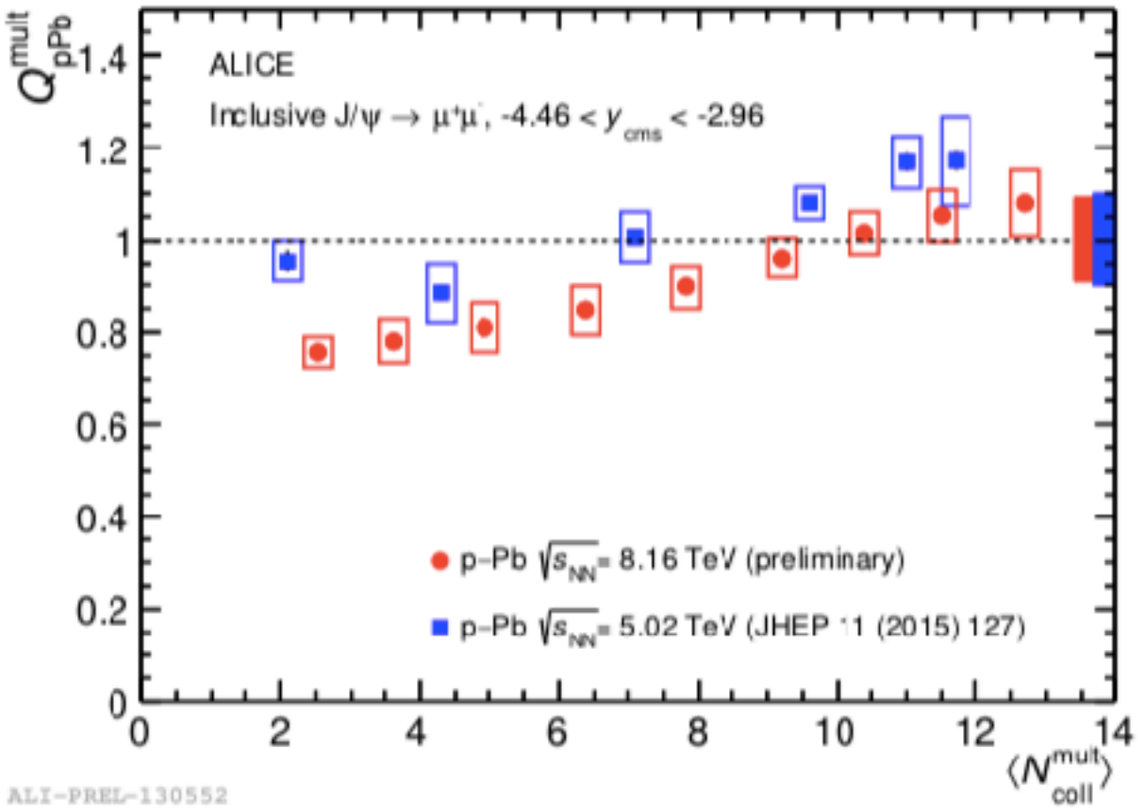


- **Strong y dependence between forward and backward**
- **No strong energy dependence**

J/ψ in pPb at 8 TeV

ALICE_PUBLIC-2017-007

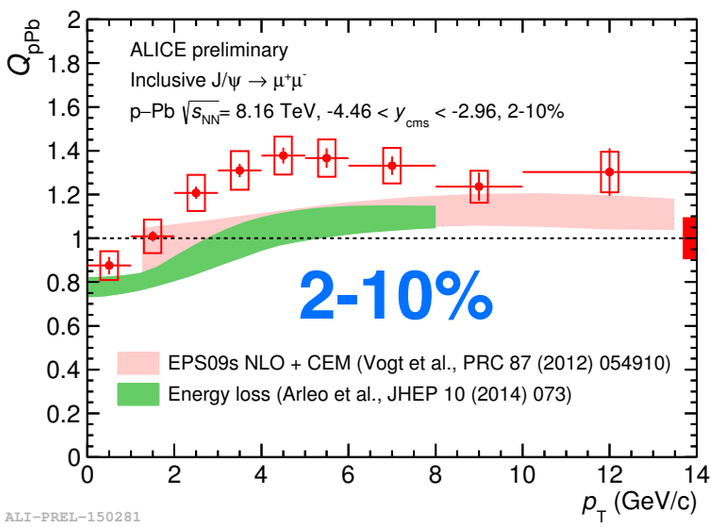


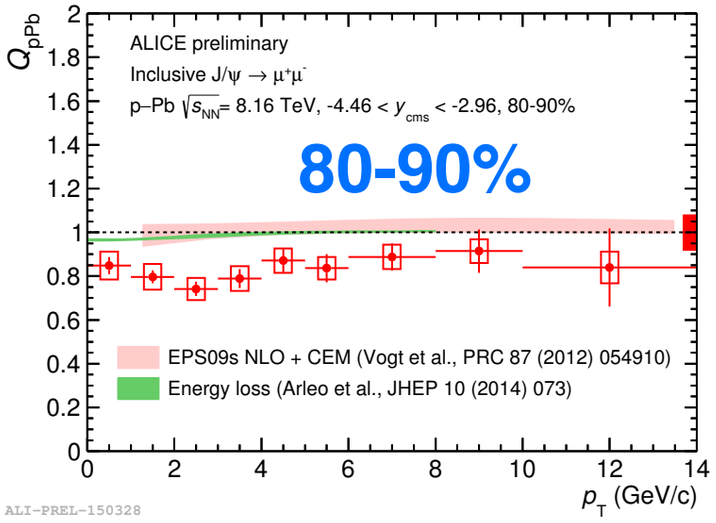


- **More suppression toward central collisions at forward rapidity**
- **Decreasing Q_{pPb} with more central events at backward rapidity**
- **Compatible with 5.02 TeV results**

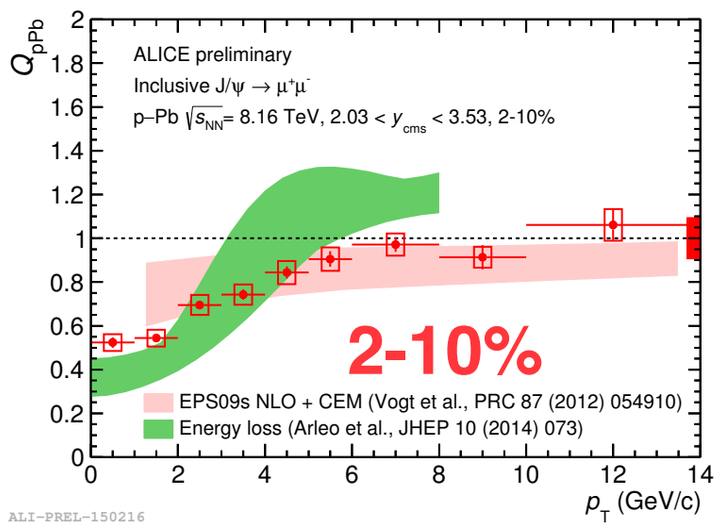
J/ψ in pPb at 8 TeV

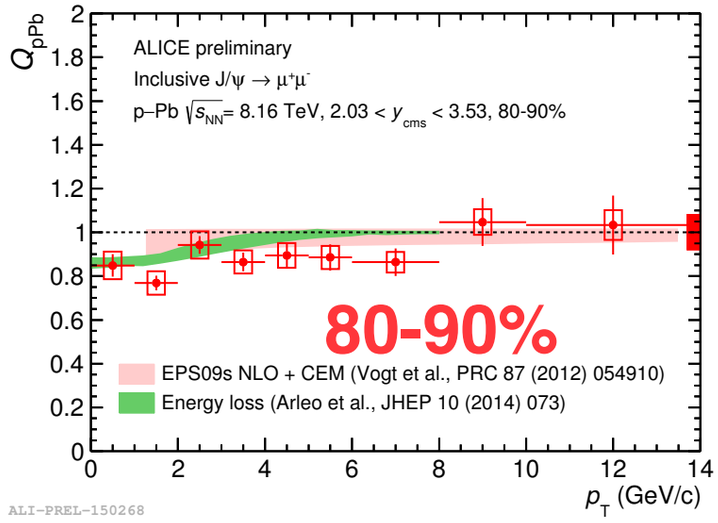
Backward





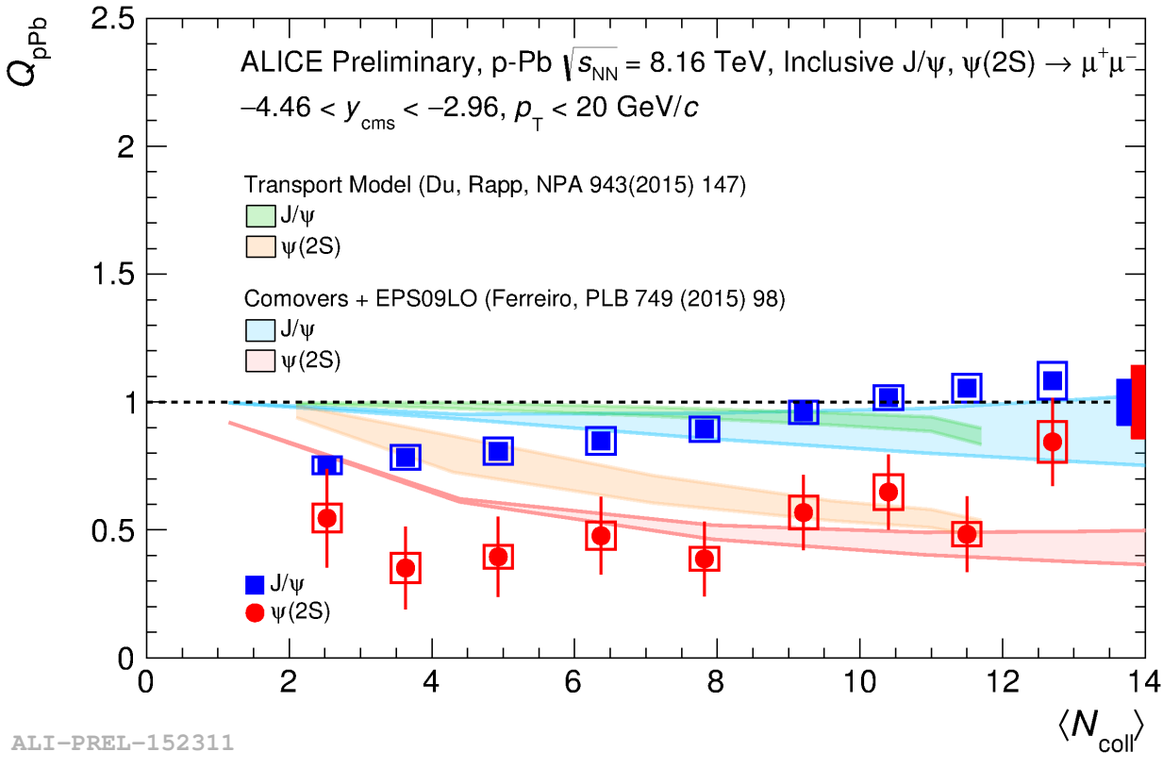
Forward

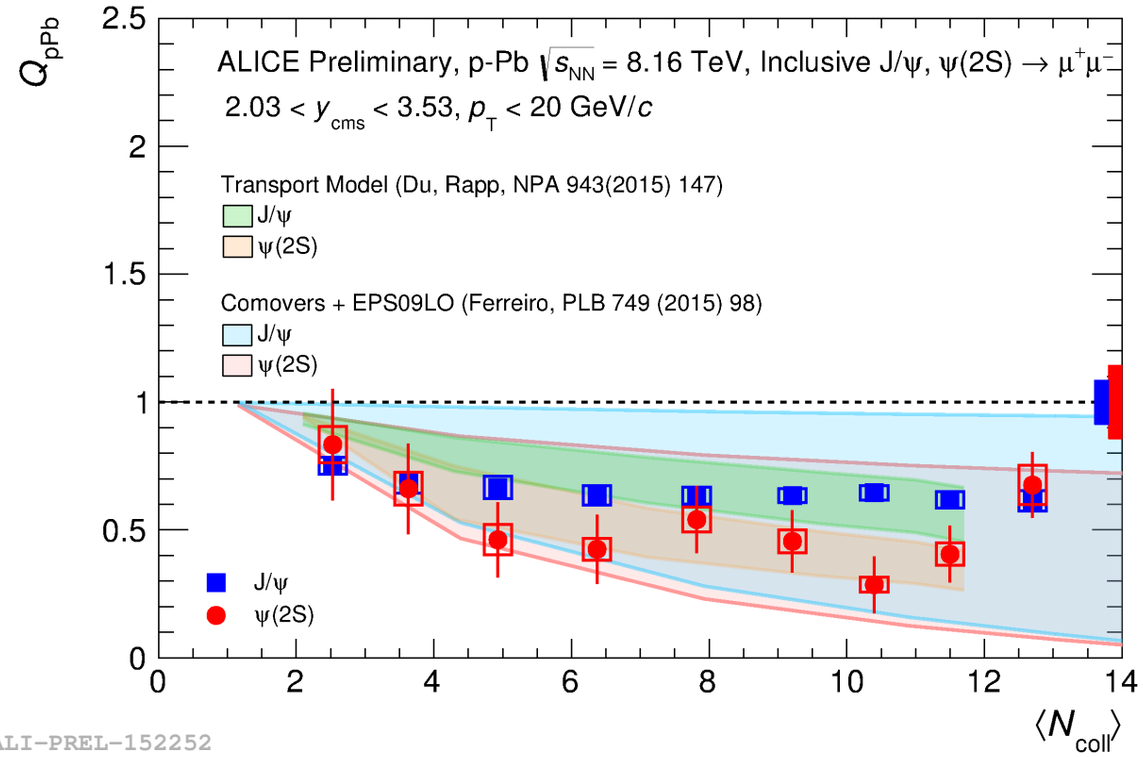




- **Energy Loss and Shadowing model : not able to reproduce J/ψ modification in central collisions**
- **Compatible with calculations in peripheral events within uncertainties**

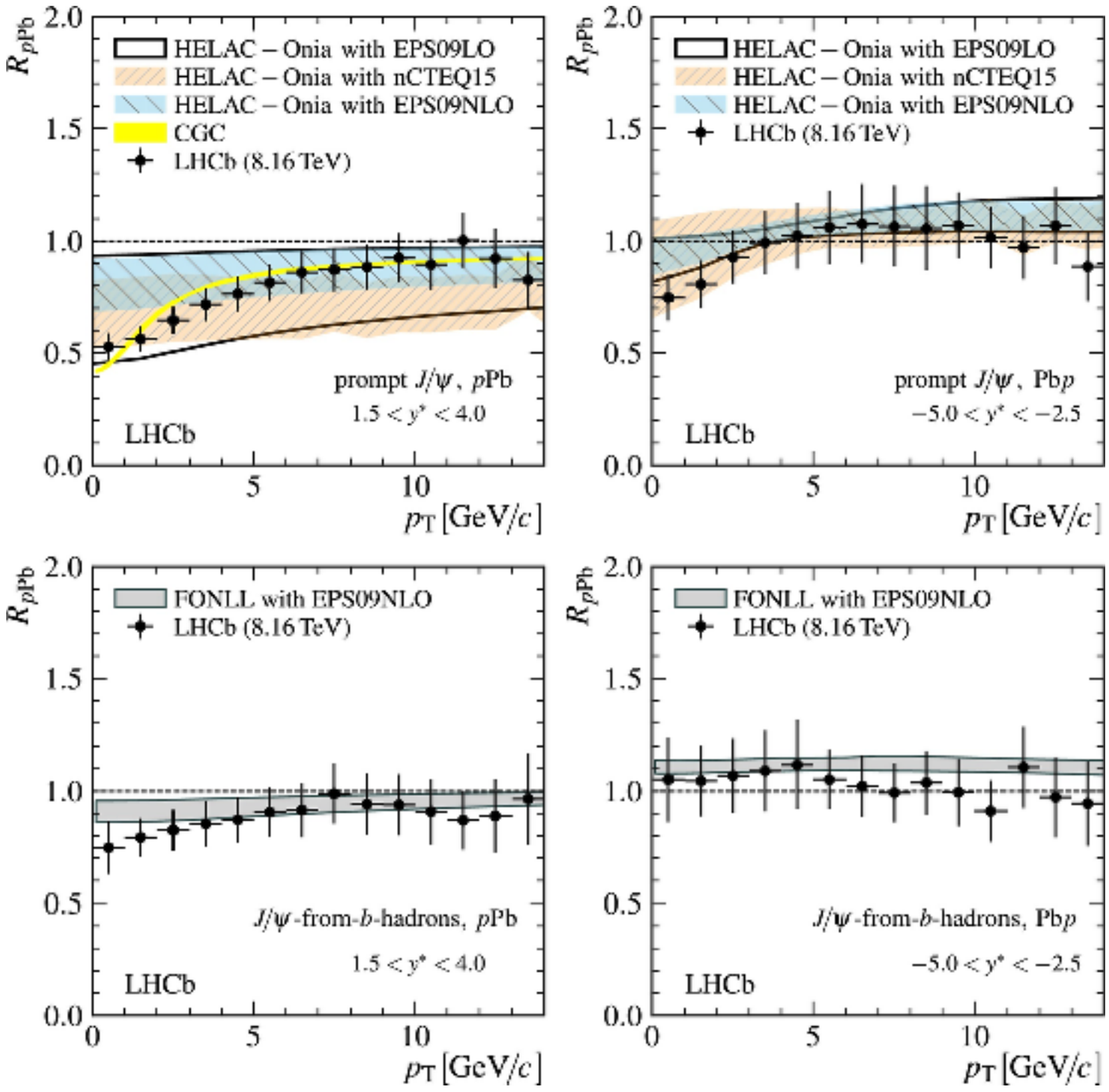
J/ψ & ψ(2S) in pPb at 8 TeV





- **Larger suppression of ψ(2S) compared to J/ψ**
- **Less suppression with increasing central collisions at backward region**
- **No strong centrality dependence of ψ(2S) at forward rapidity**

J/ψ in pPb at 8 TeV



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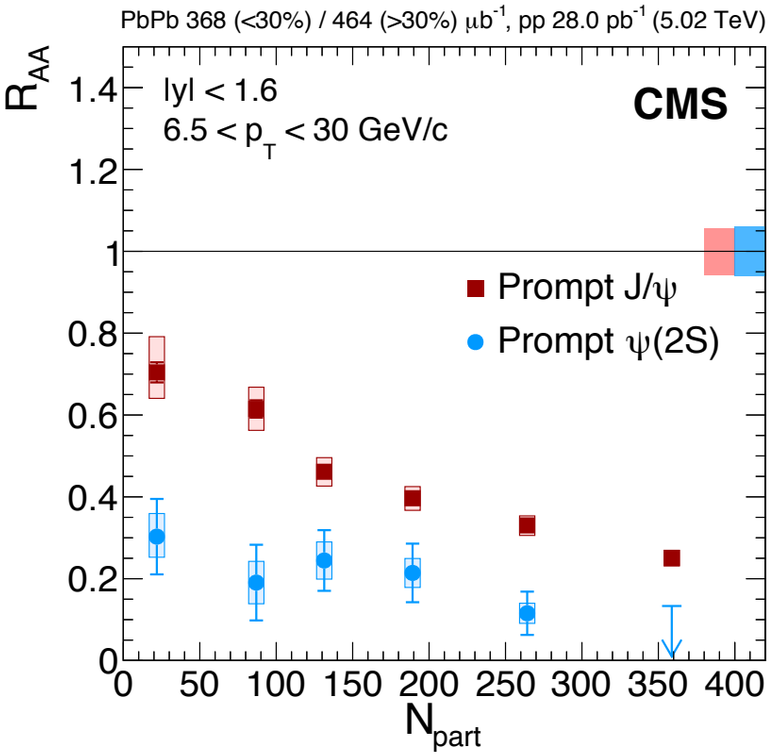
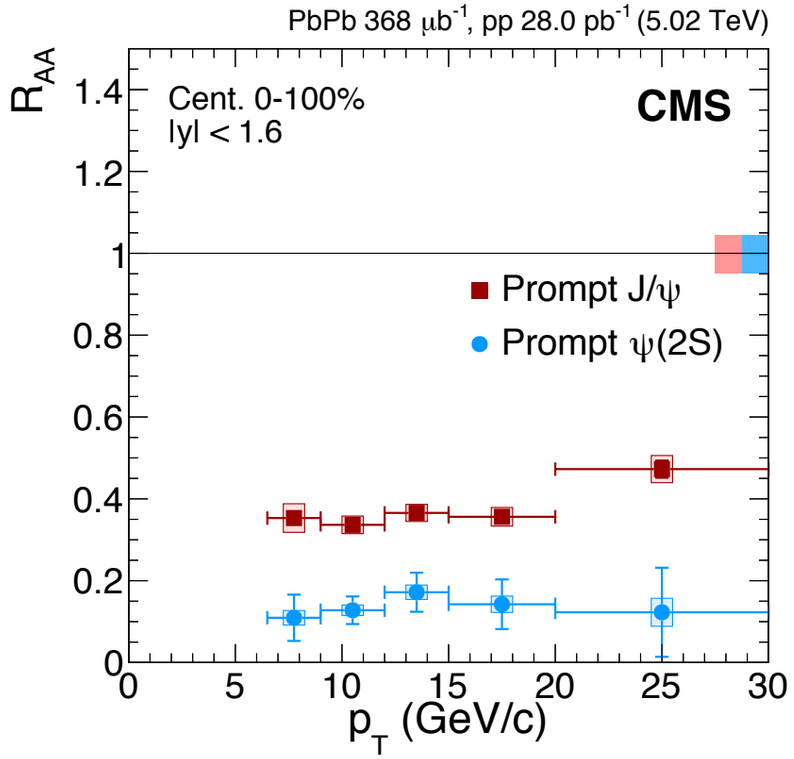
- **Prompt J/ψ suppression at low pT for both forward and backward**
- **Nonprompt J/ψ suppressed at forward low pT which consistent with unity in backward rapidity**
- **Measurement provide constraints on gluon distribution in low-x region**

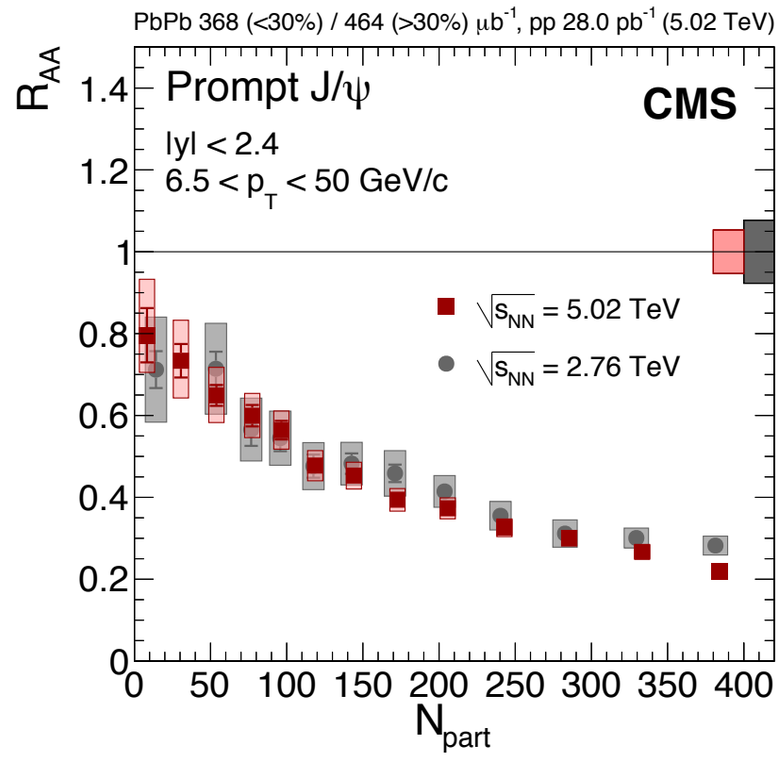
Outline

- Quarkonia in PbPb collision
  - Charmonia
  - Bottomonia
- Quarkonia in pPb collision
  - Charmonia
  - Bottomonia
- **Summary**

Charmonia in PbPb

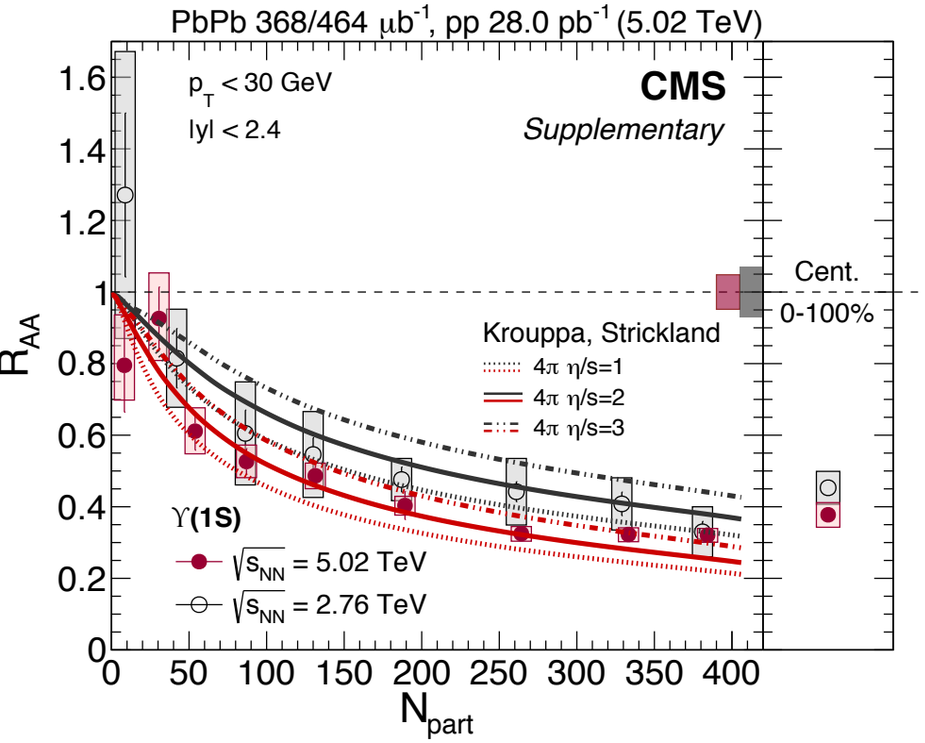


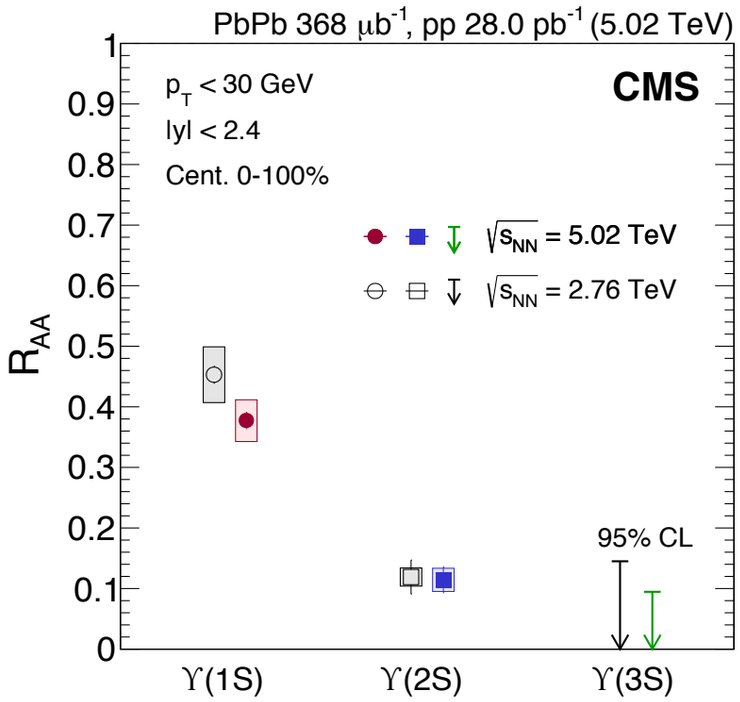


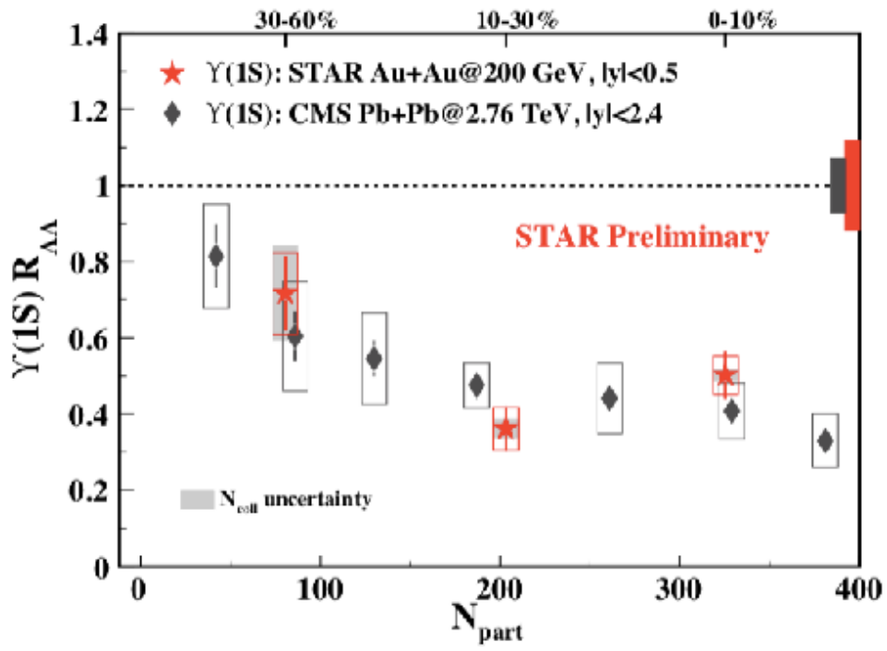


- **$R_{AA}^{\psi(2S)} < R_{AA}^{J/\psi}$**
- **Prompt ψ(2S) still suppressed up to 30 GeV/c**
- **Similar suppression with 2.76 TeV and 5.02 TeV**

Bottomonia in PbPb

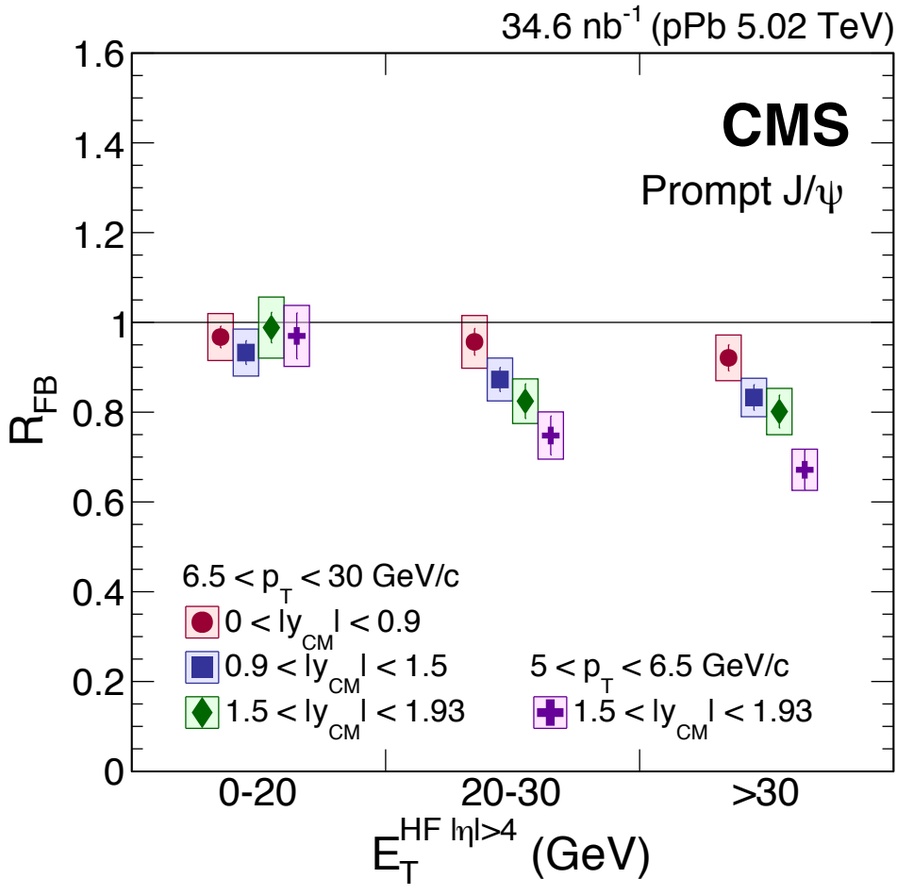


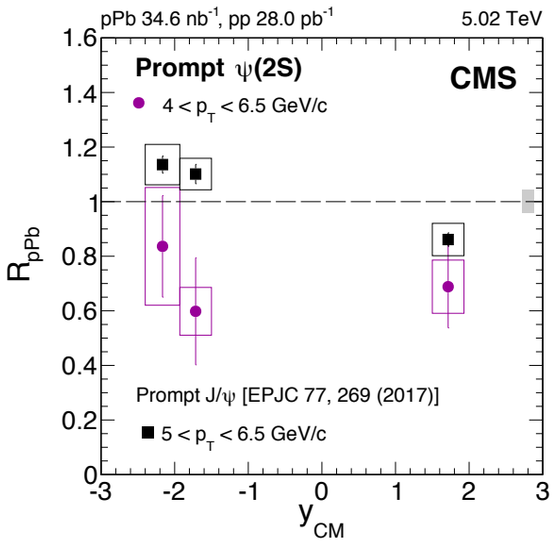


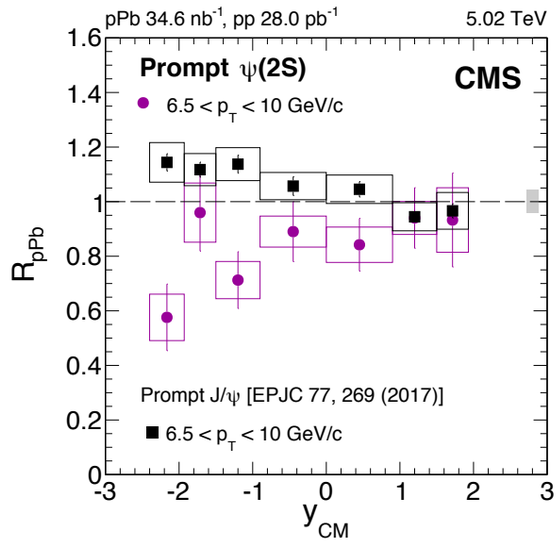


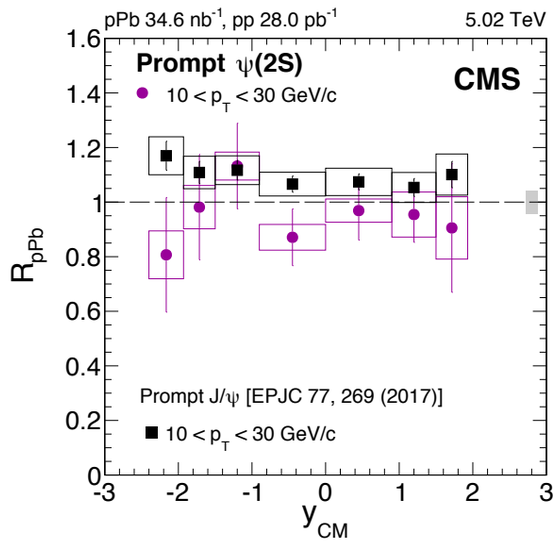
- **Sequential suppression of each Upsilon state**
- **Larger suppression of Y(1S) at 5.02 TeV but compatible within uncertainty**
- **Y(1S) : R_{AA}(RHIC) ~ R_{AA}(LHC 2.76) ≥ R_{AA}(LHC 5.02)**

Charmonia in pPb



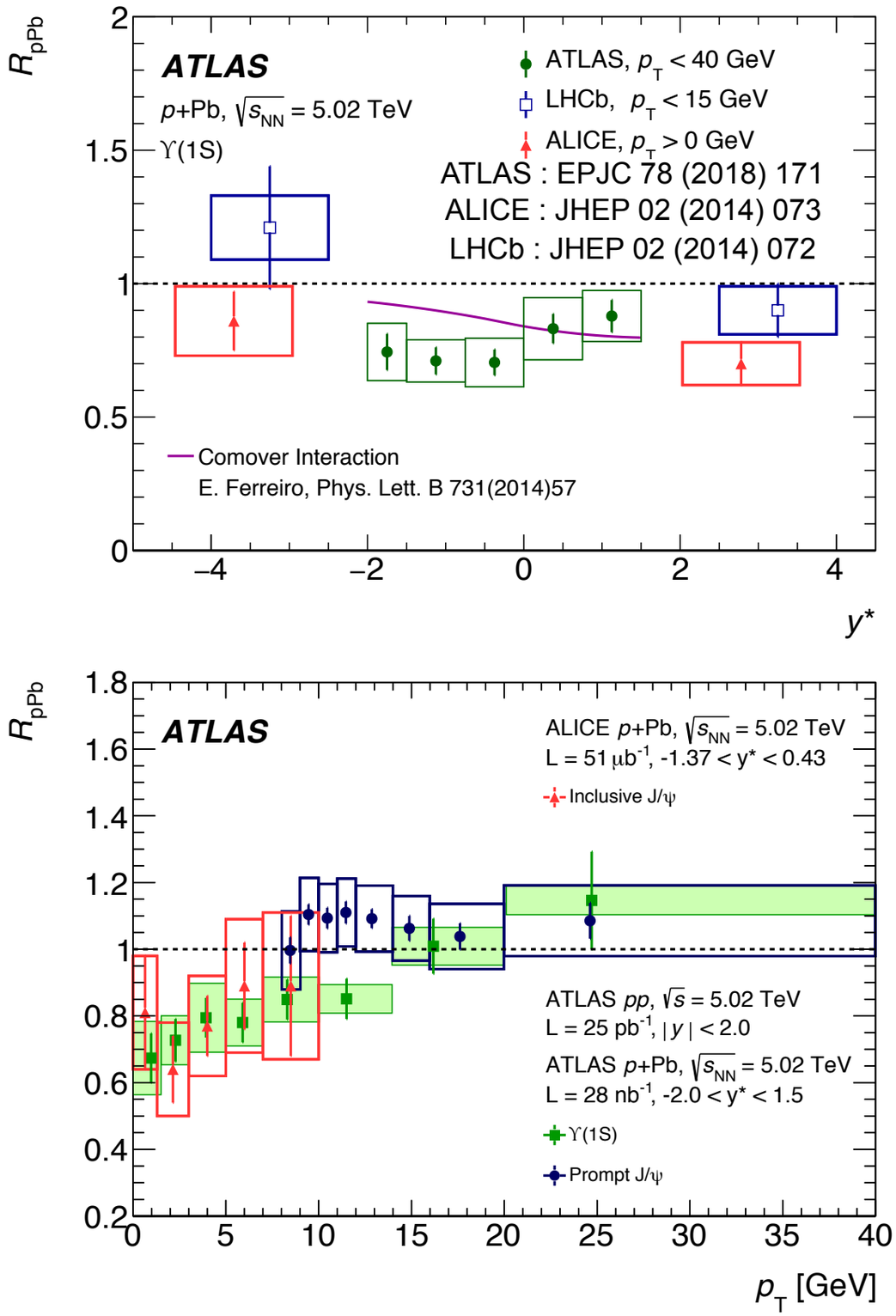


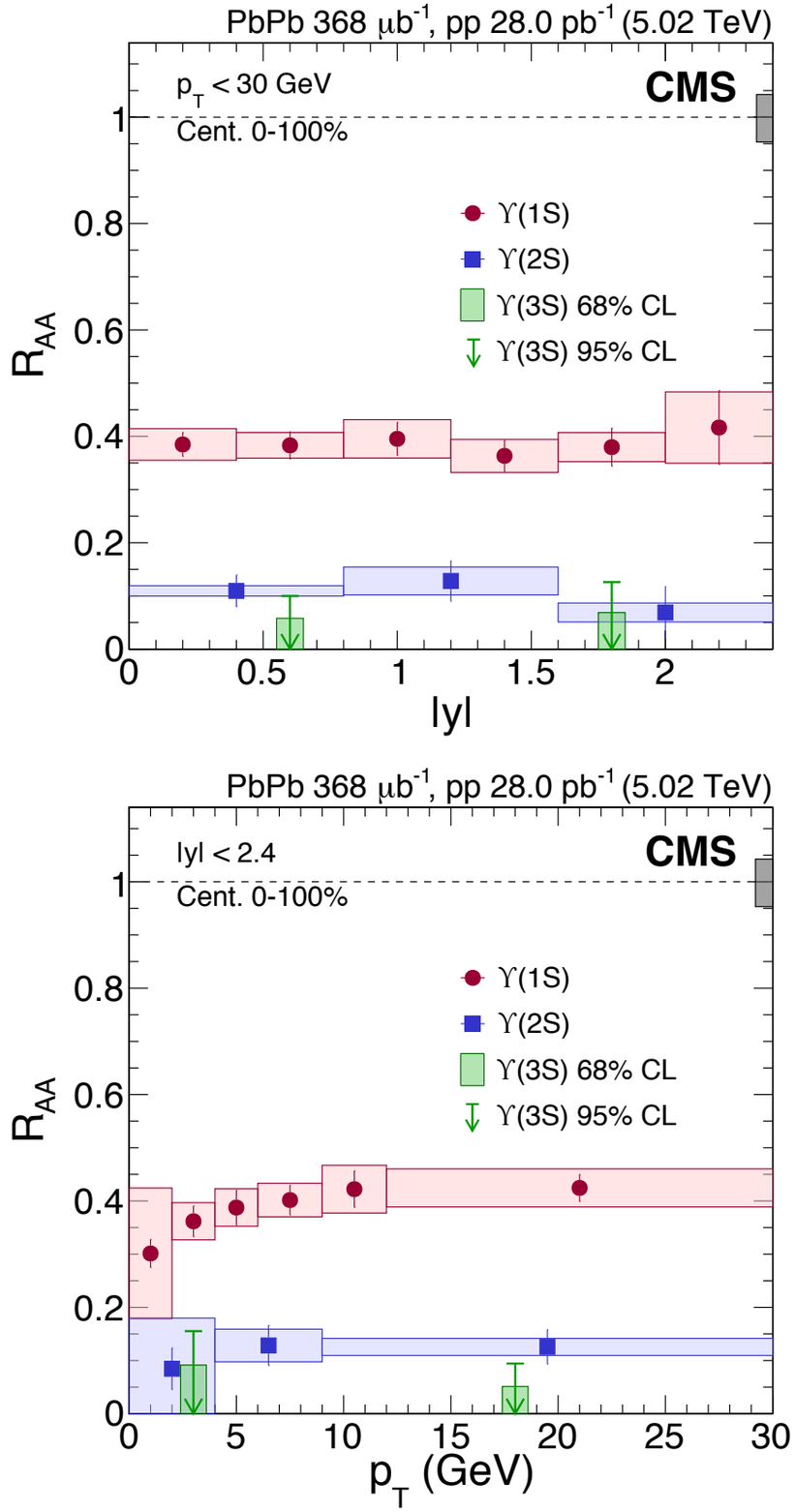




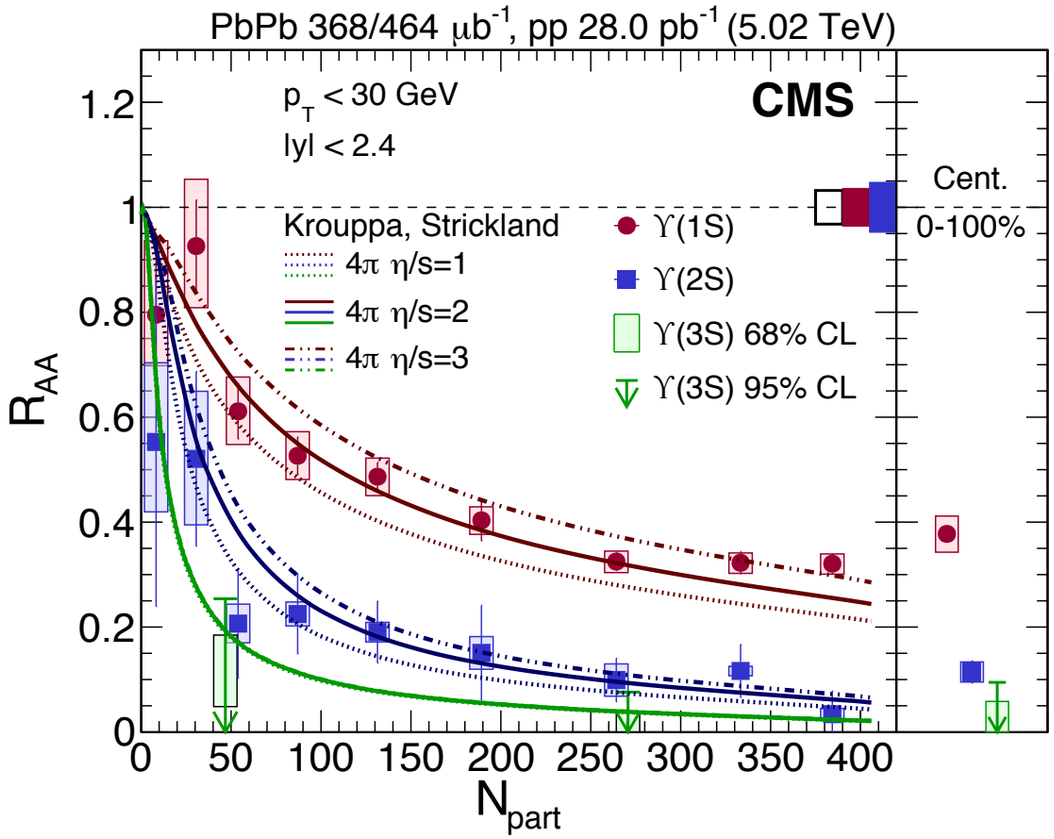
- **Enhanced nuclear matter effects for increasingly central pPb collisions**
- **Larger suppression of ψ(2S) than J/ψ**
- **Possible final state effect?**

Bottomonia in pPb





Discussion

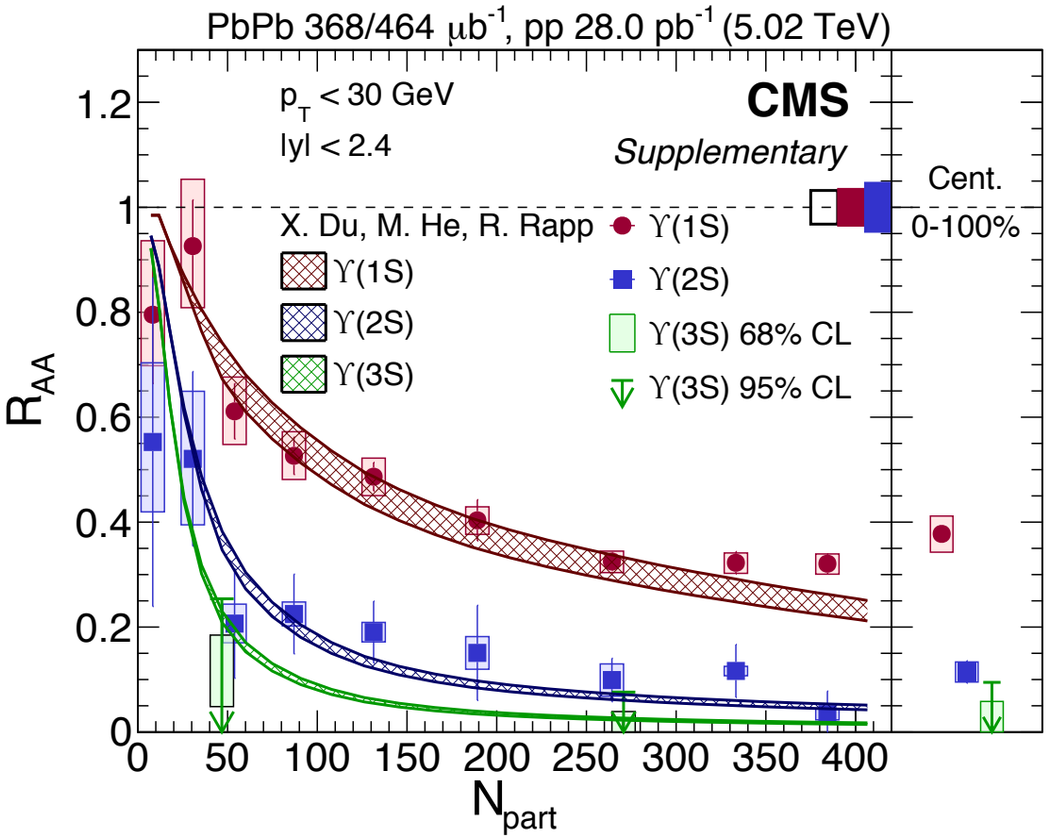


- **Initial temperature:**

  2.76 TeV: 544 - 552 MeV

  5.02 TeV: 629 - 641 MeV (16% increase)

- **Y(1S) R_{AA} : ~25% decrease**



- **Initial temperature:**

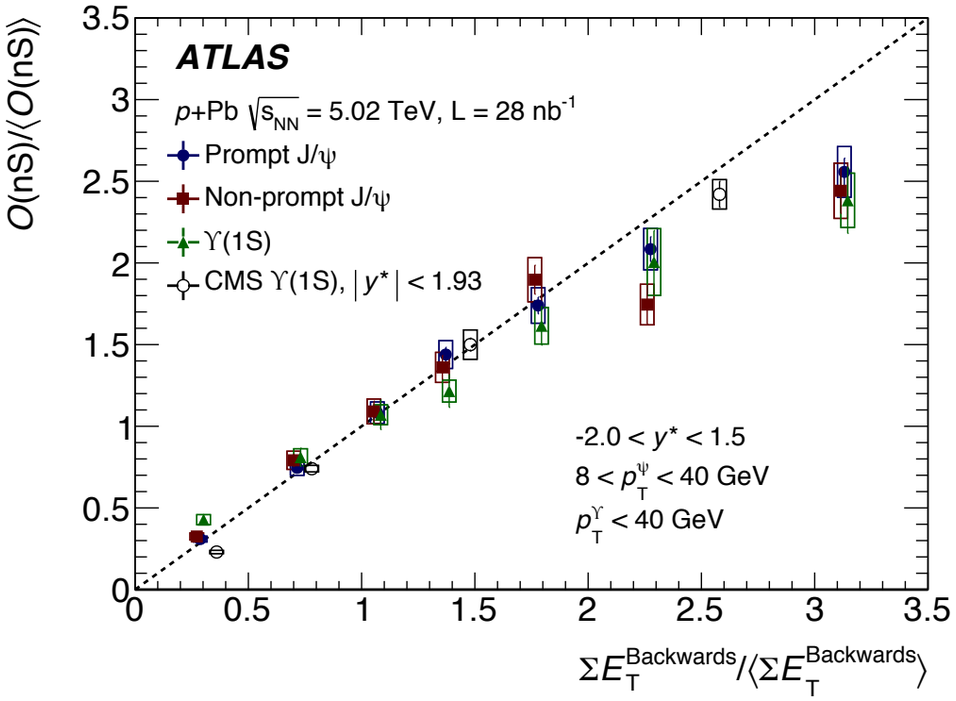
  2.76 TeV: 520 - 750 MeV

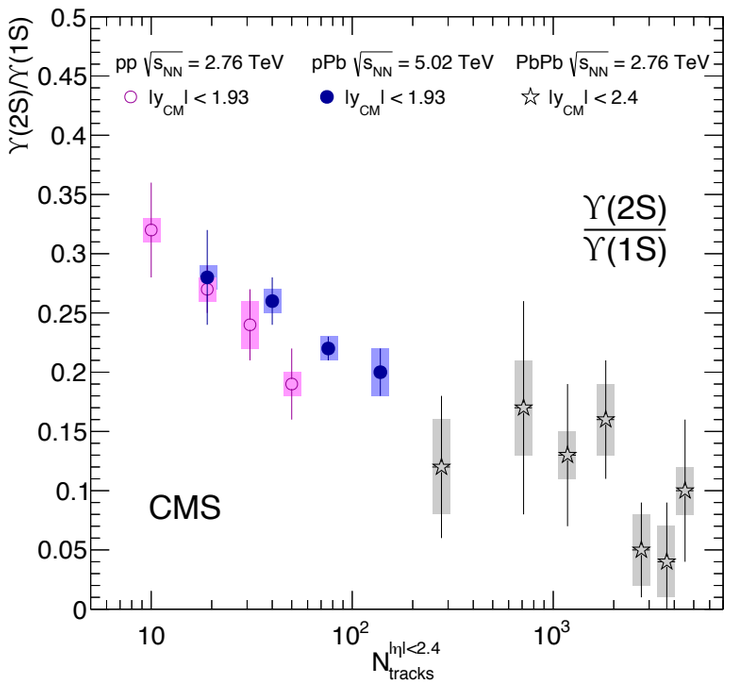
  5.02 TeV: 550 - 800 MeV (7% increase)

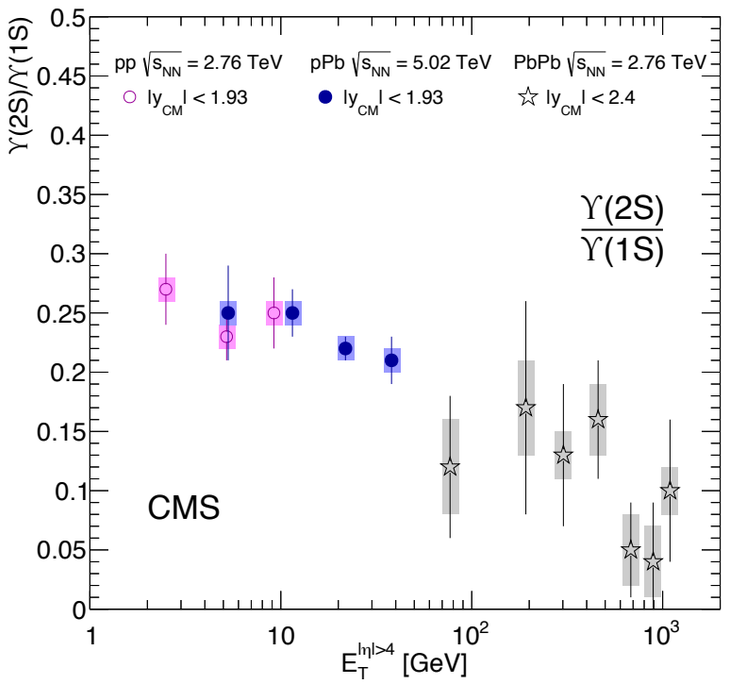
- **Y(1S) R_{AA} : slight decrease**

- **How can we extract the medium temperature?**
- **Need additional observable? Excited states? Y v2? …**

Discussion

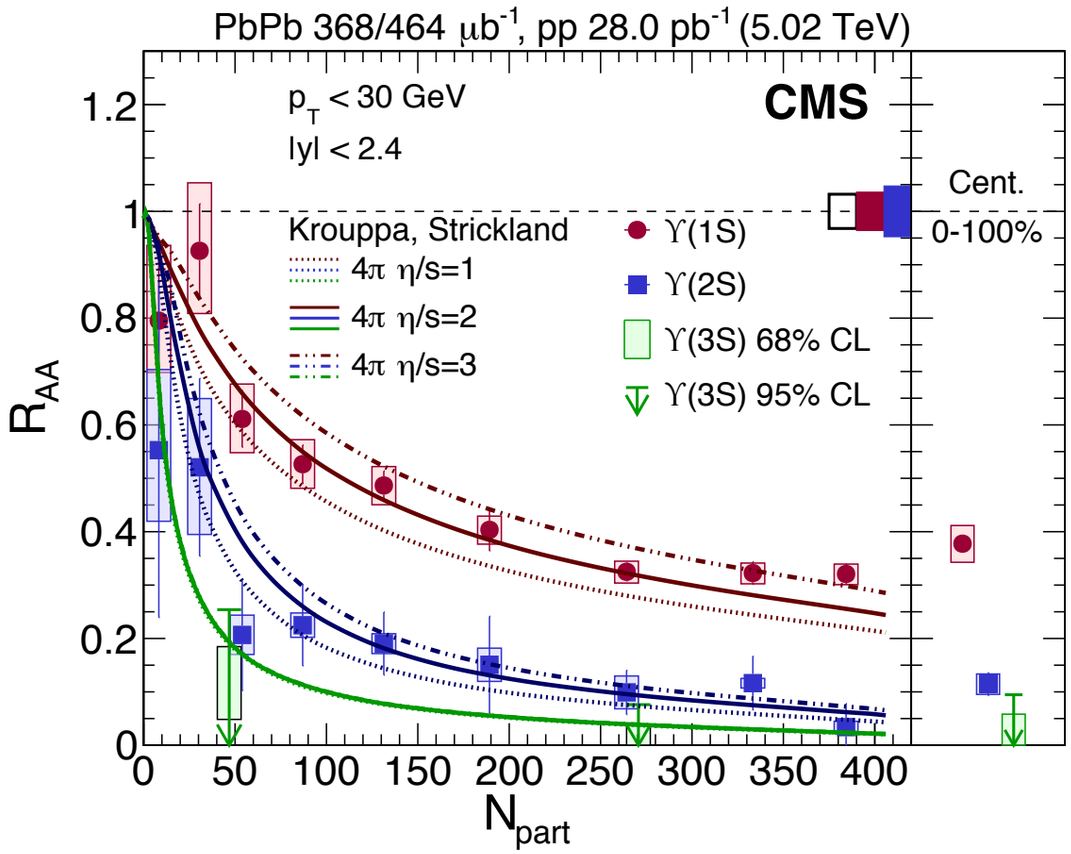




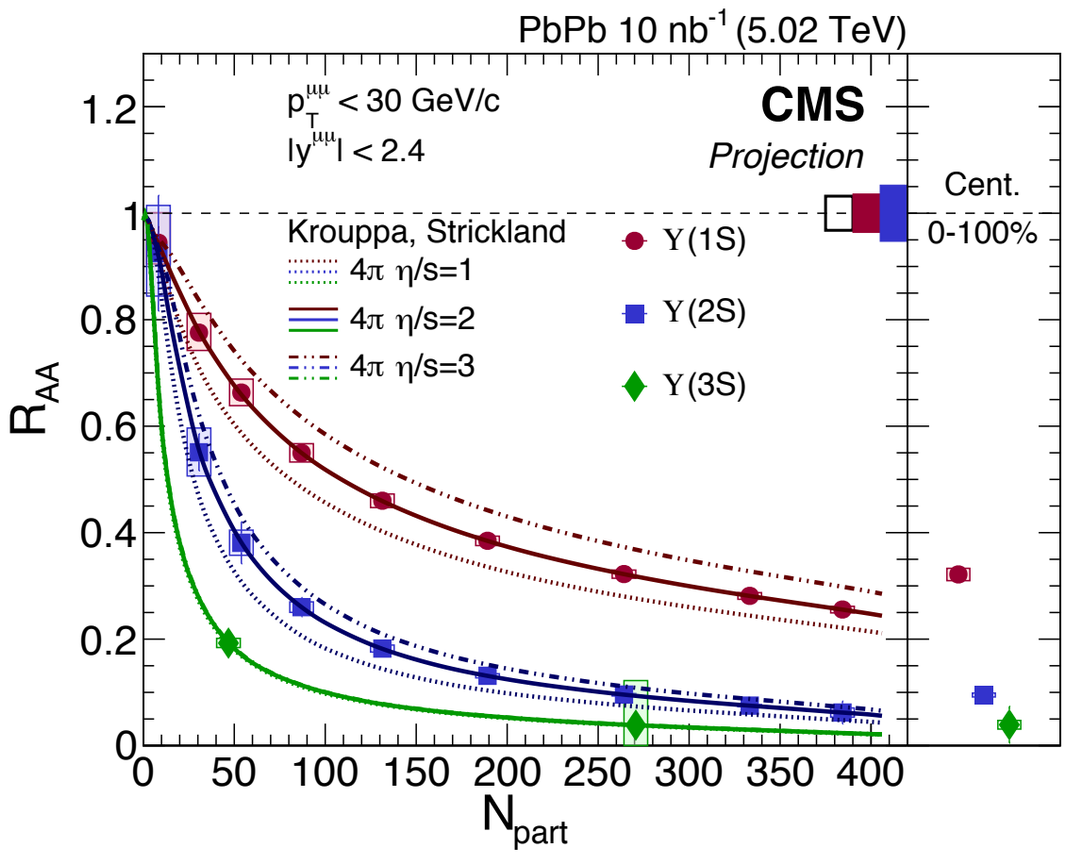


- **Why suppression of excited states for increasing event activity even in pp and pPb?**
- **Looking forward with all quarkonium including J/ψ and ψ(2S) with more statistics in pp, pPb and PbPb collisions**

Discussion



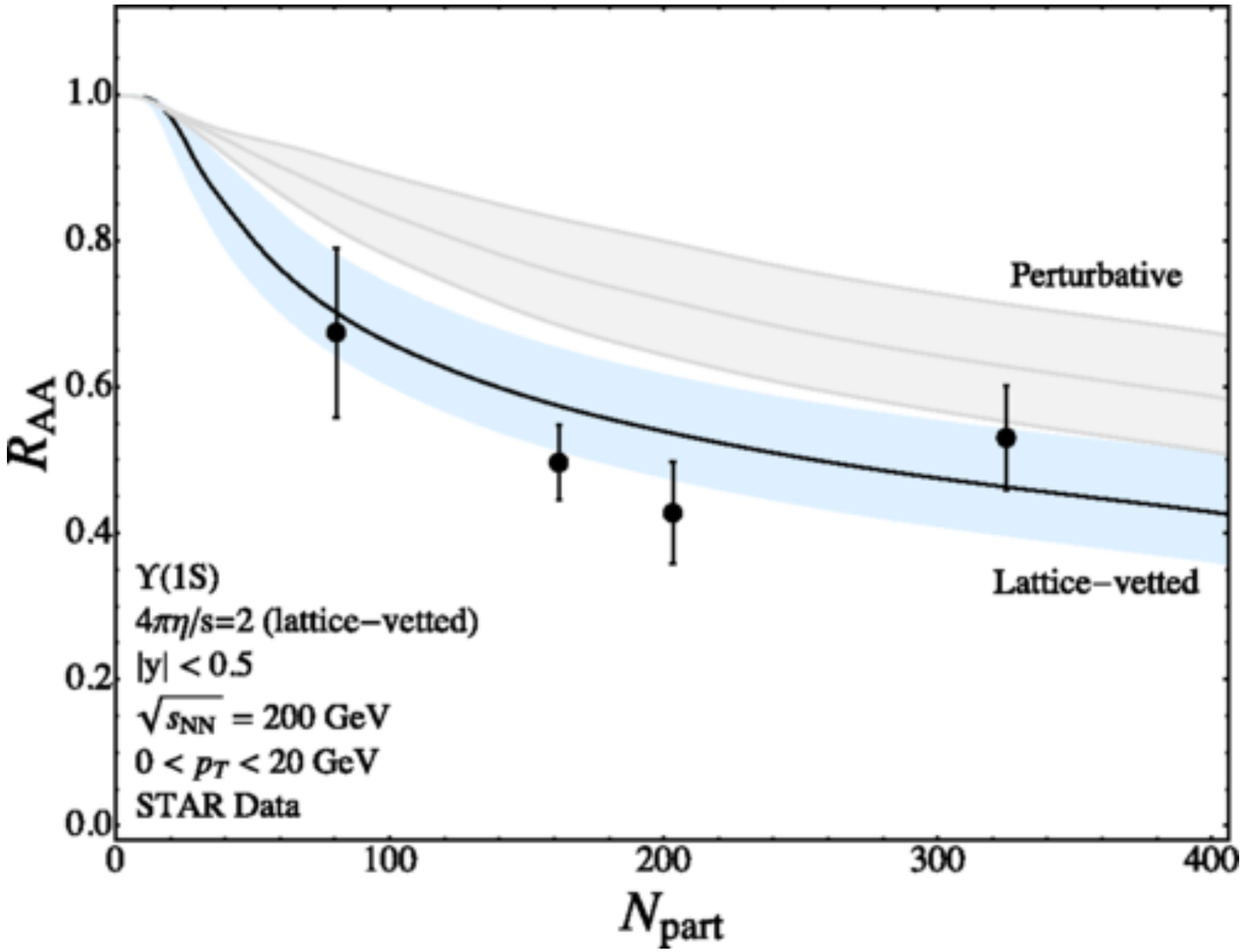
CMS-PAS-FTR-17-002



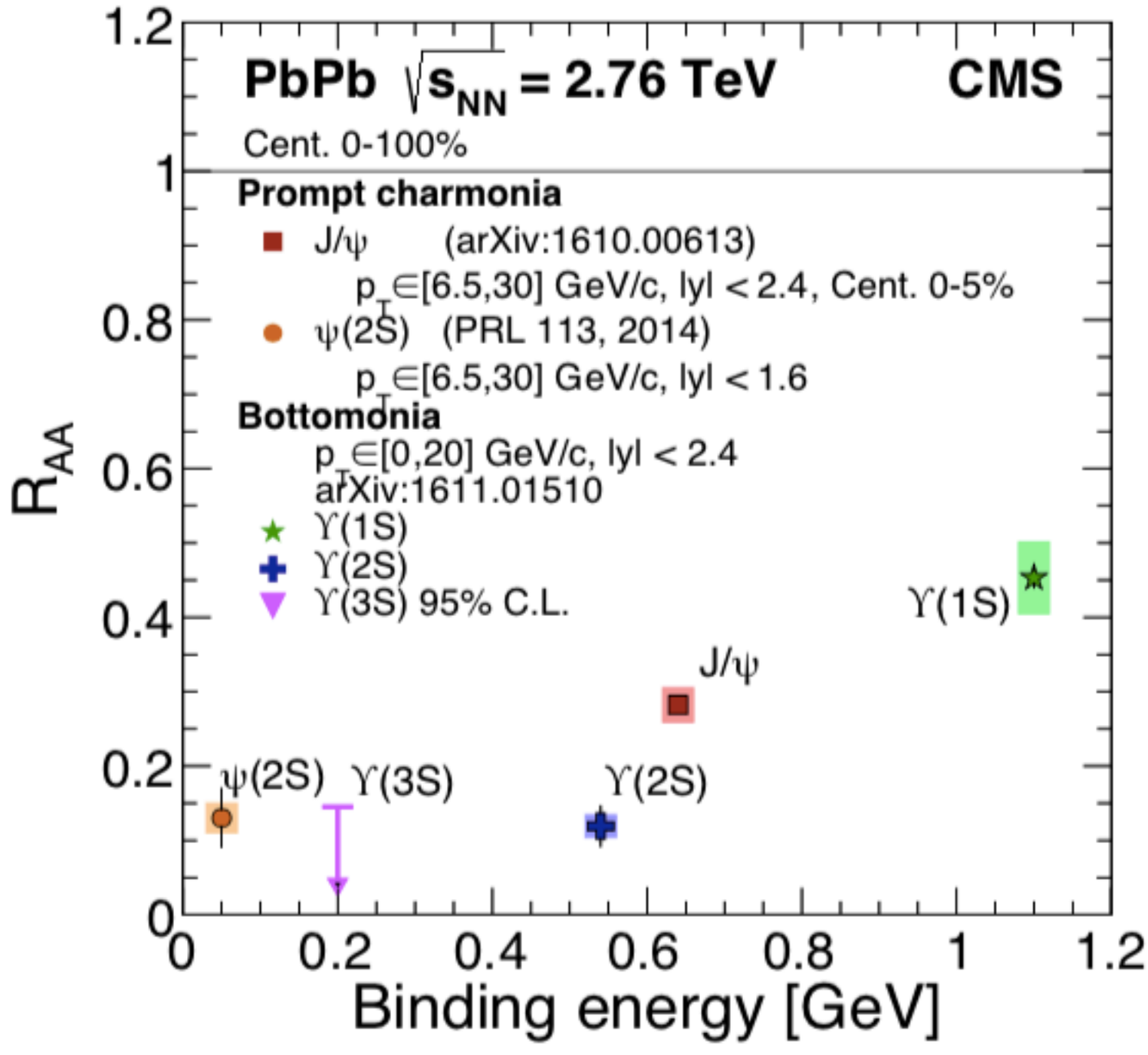
- **Y(3S) dissociated? Physics or Statistics?**
- **Way of reducing systematic uncertainty? (correlation b/w global unc.)**

Thank you

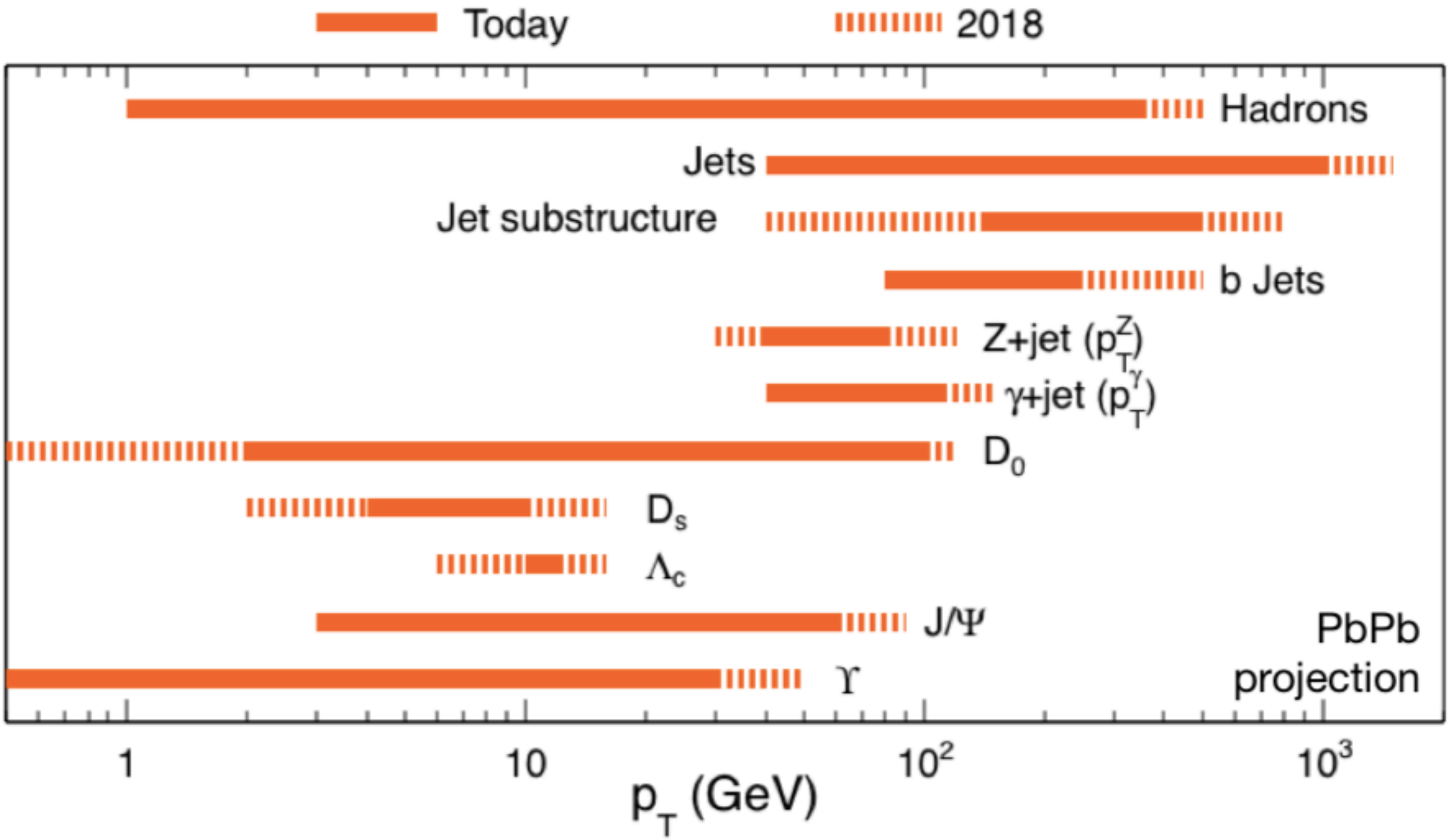
Charmonia in PbPb



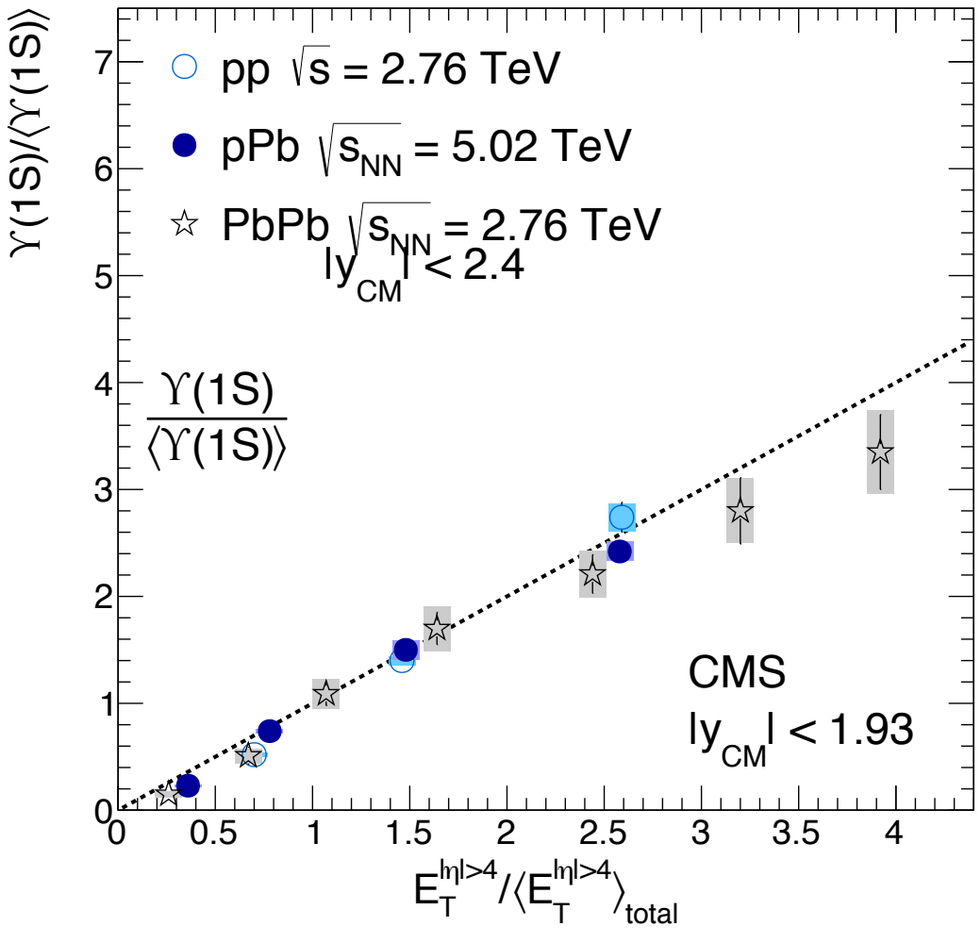
Charmonia in PbPb

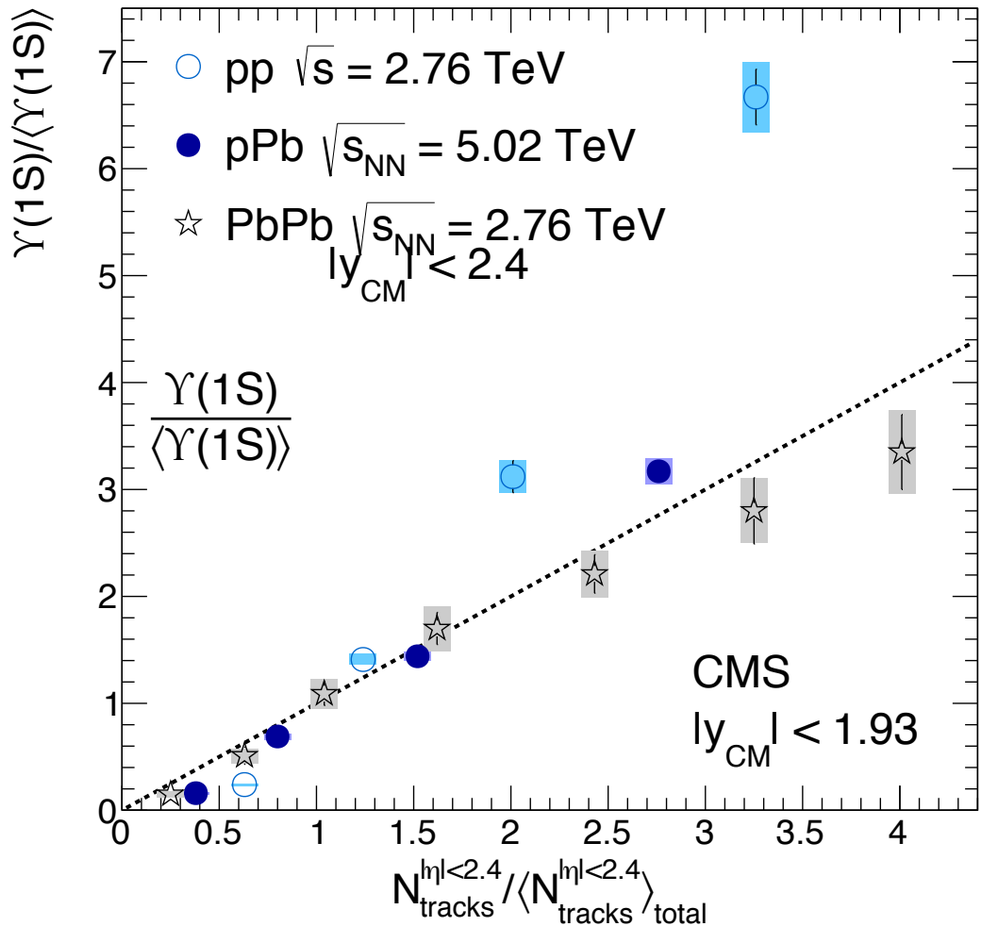


Kinematic acceptance

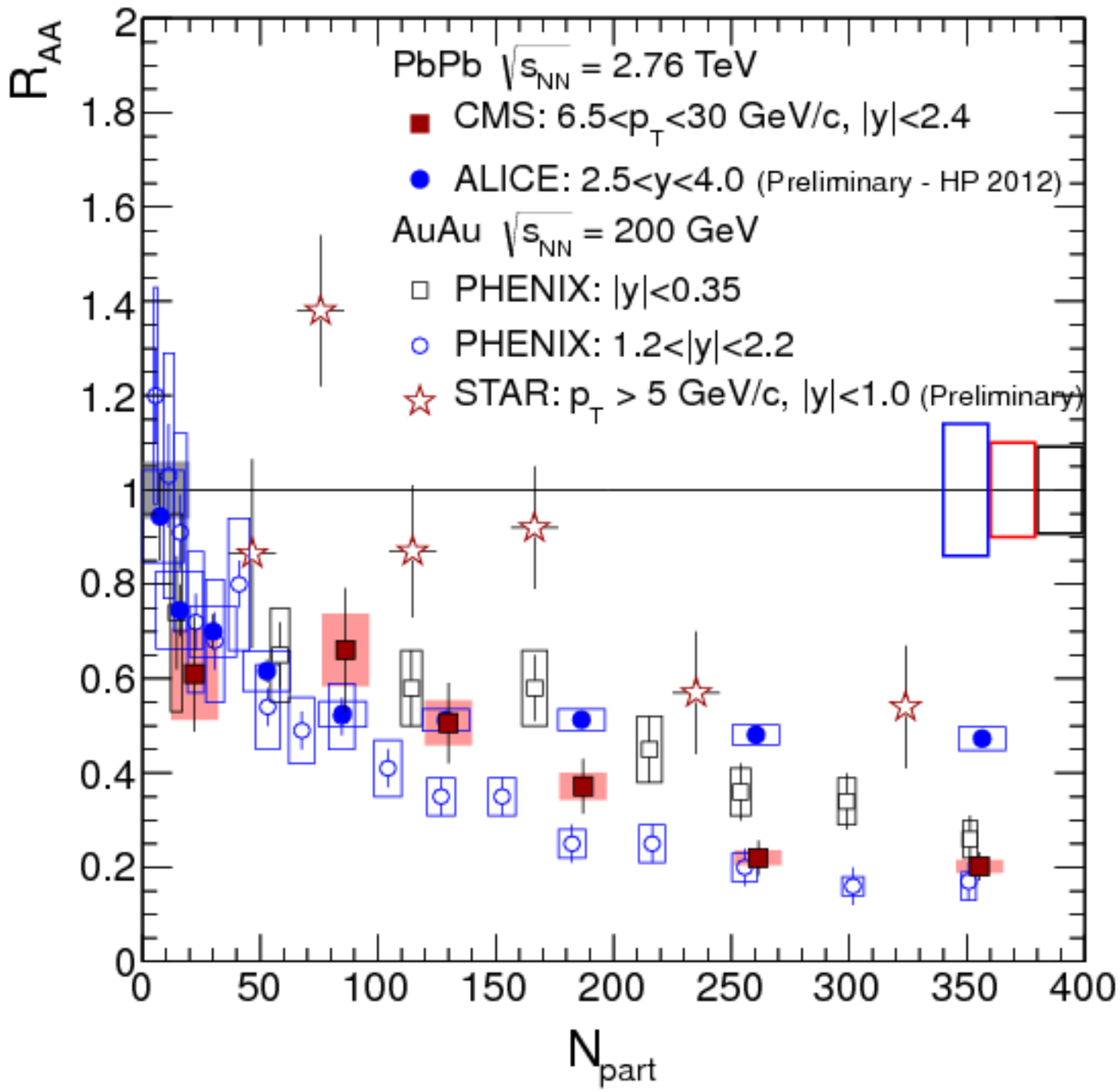


Event Activity





R_{AA} in p_T, y


R_AA
PbPb √s_NN = 2.76 TeV
CMS: 6.5<p_T<30 GeV/c, |y|<2.4
ALICE: 2.5<y<4.0 (Preliminary - HP 2012)
AuAu √s_NN = 200 GeV
PHENIX: |y|<0.35
PHENIX: 1.2<|y|<2.2
STAR: p_T > 5 GeV/c, |y|<1.0 (Preliminary)
N_part