Open and closed heavy-flavor suppression in heavy-ion collisions with CMS

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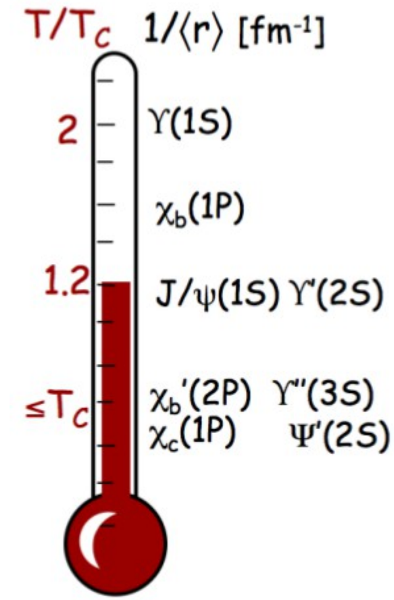
(Korea University)
for the CMS Collaboration

Strangeness in Quark Matter, Birmingham, UK
23 July, 2013

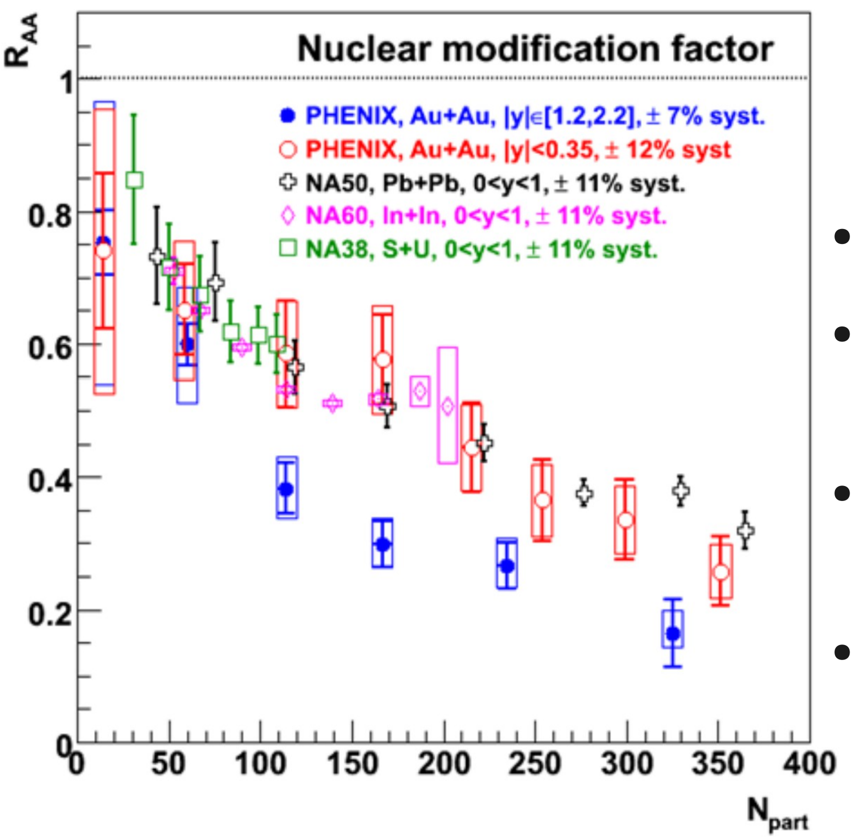
Quarkonia in hot and dense medium

- Heavy quarks are produced at early stage of collision
- Debye screening in Quark-Gluon Plasma leads to melting of quarkonia
- Quarkonia states have different binding energies
- Sequential melting of states is expected with increasing medium temperature

Mocsy, EPJ C 61 (2009) 705



Matsui & Satz, PLB 178 (1986) 416



$$R_{AA} = \frac{1}{N_{coll}} \frac{N_{PbPb}(J/\psi)}{N_{pp}(J/\psi)}$$

- J/ψ R_{AA} similar at SPS and RHIC energies
- More suppression at forward rapidity than at midrapidity
- Mix of shadowing, melting, and regeneration?
- What happens at the LHC with higher energy, luminosity?

PHENIX: PRL 98 (2007) 232301, PRC 84 (2011) 054912
SPS from Scomparin @ QM06

Open heavy-flavor in hot and dense medium

- Quarks interact with medium and lose energy
- Inelastic scattering – radiative energy loss
- Elastic scattering – collisional energy loss
- Dead-cone effect
  - Small-angle gluon radiation is reduced for heavy quarks

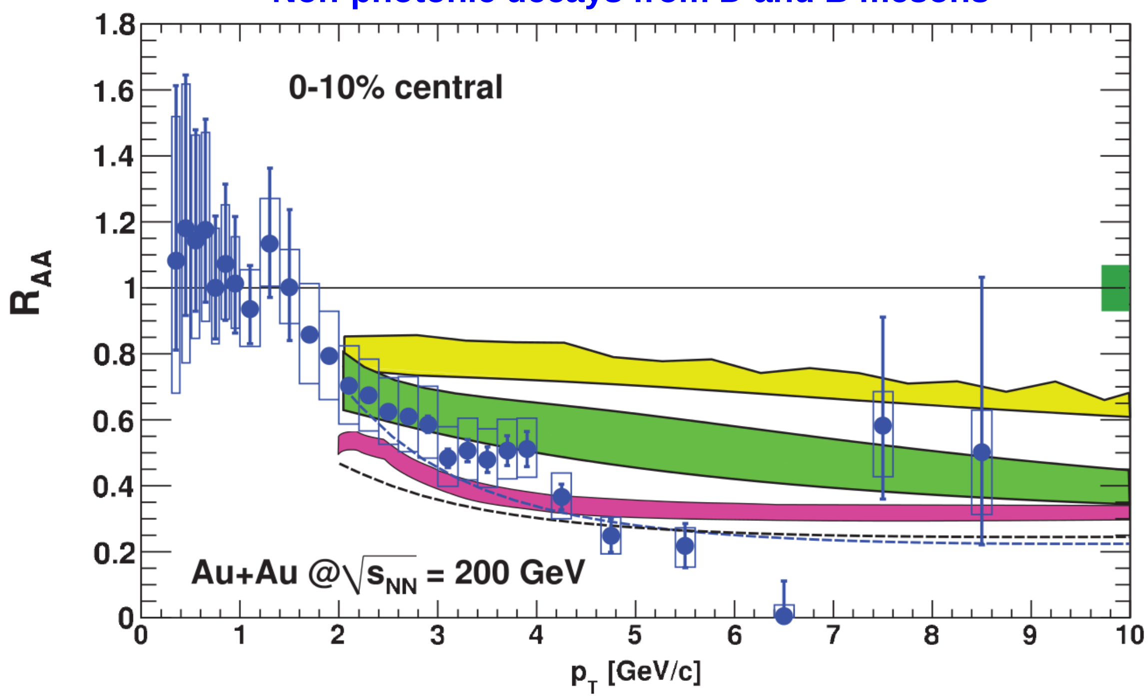
Y.L. Dokshitzer, D.E. Kharzeev, Phys. Lett. B 519 (2001) 199

- Open b mesons have not been measured separately at RHIC
- Would R_{AA} be ordered as predicted by theory?

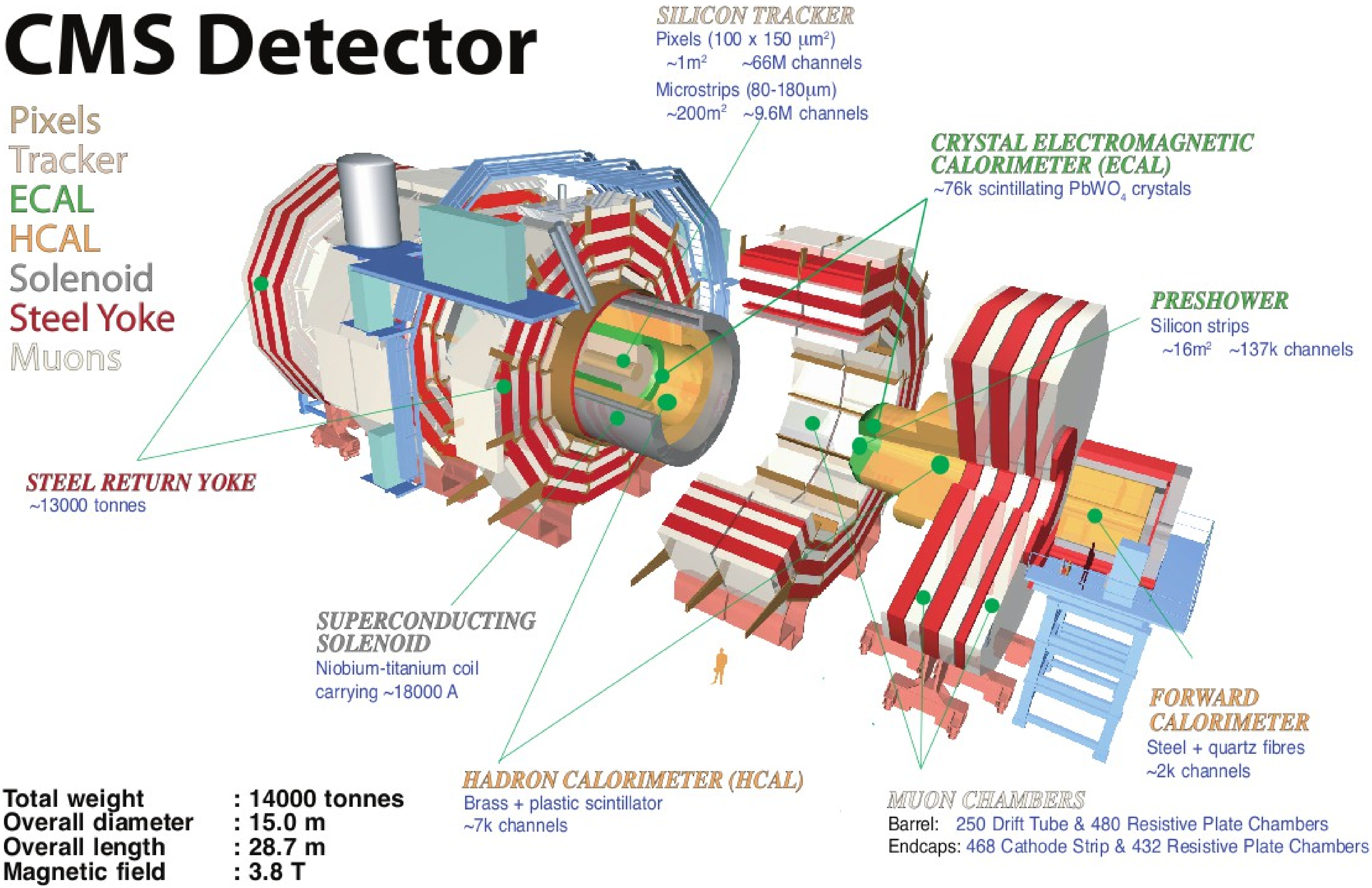
R_{AA}(light hadrons) < R_{AA}(D) < R_{AA}(B)

PHENIX Collaboration, Phys. Rev. C 84, 044905 (2011)

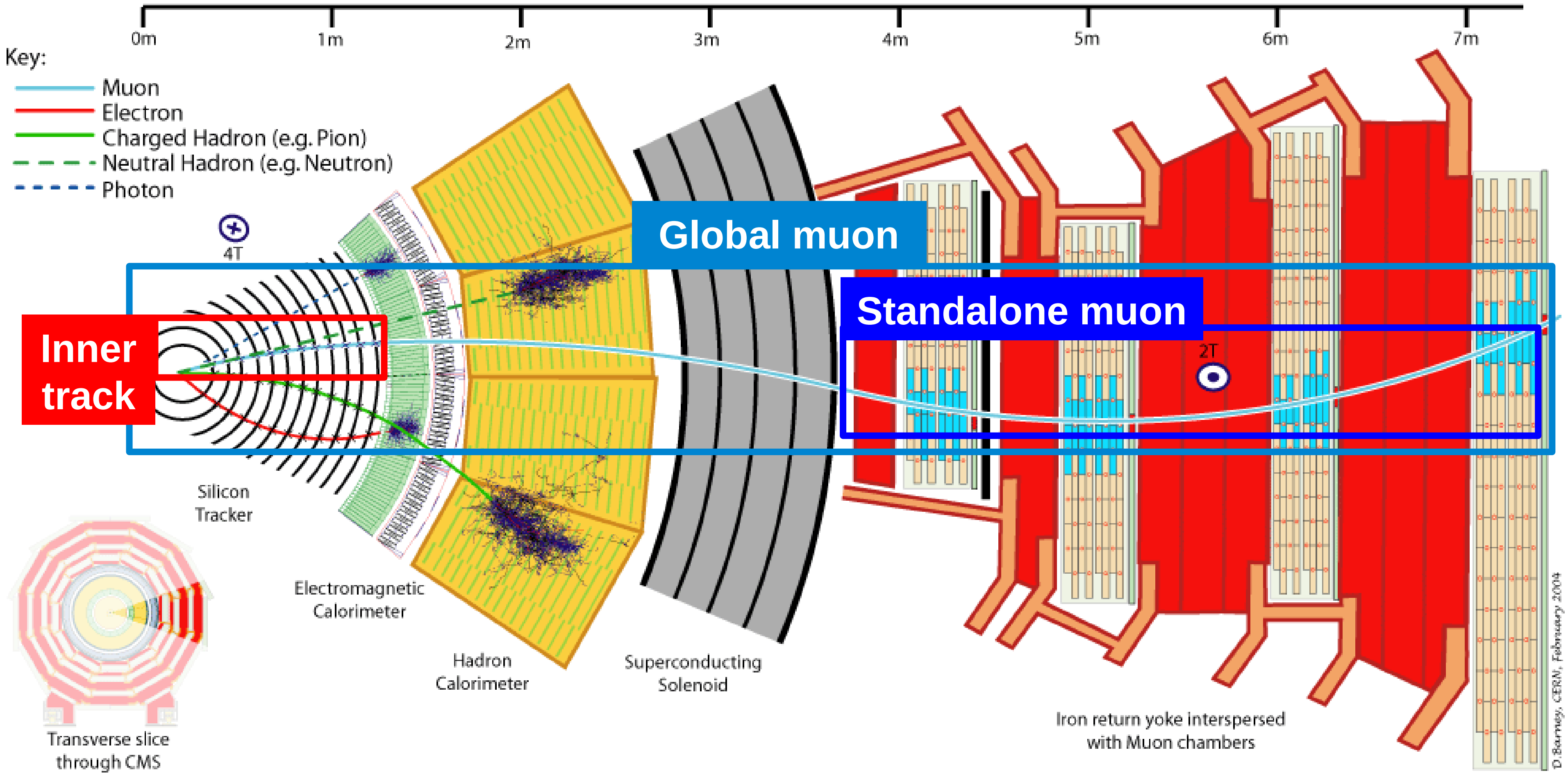
Non-photonic decays from D and B mesons



CMS Detector

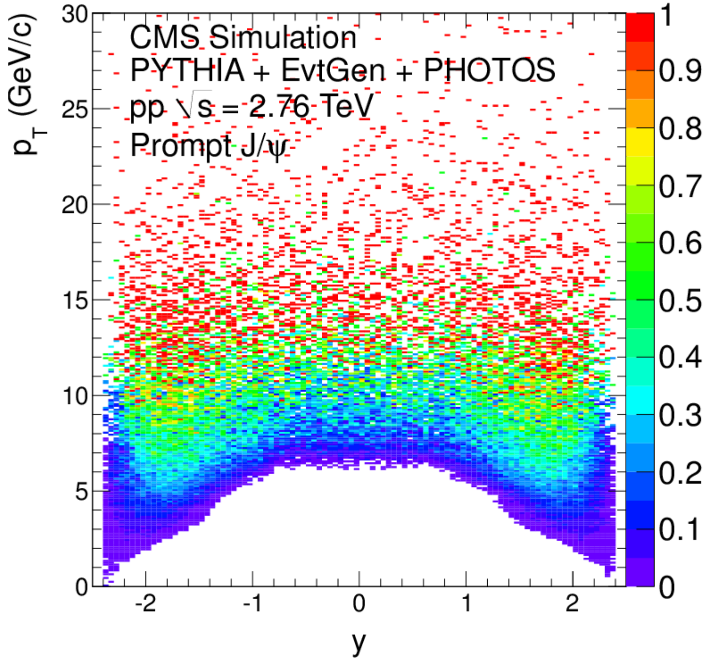


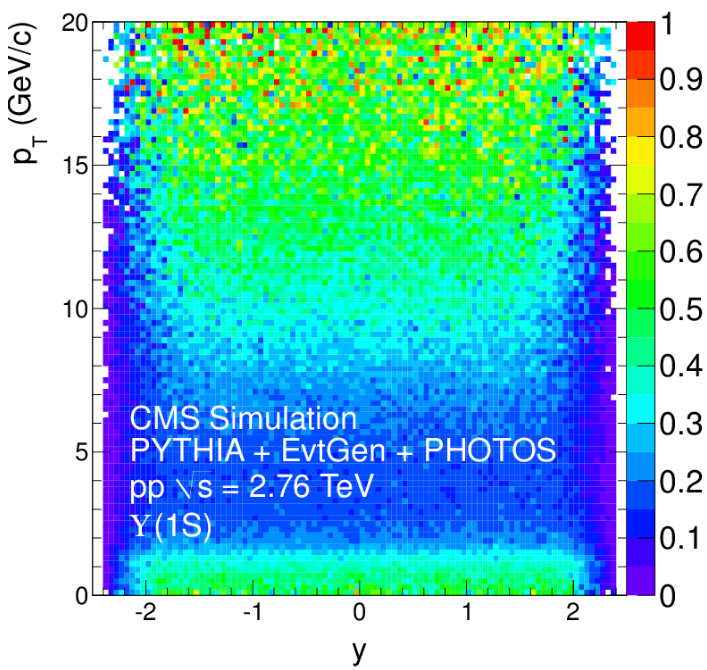
Muon reconstruction in CMS



- Excellent muon identification & triggering (DT, CSC, RPC)
- High mass/momentum resolution (Pixel & Strip silicon tracker)

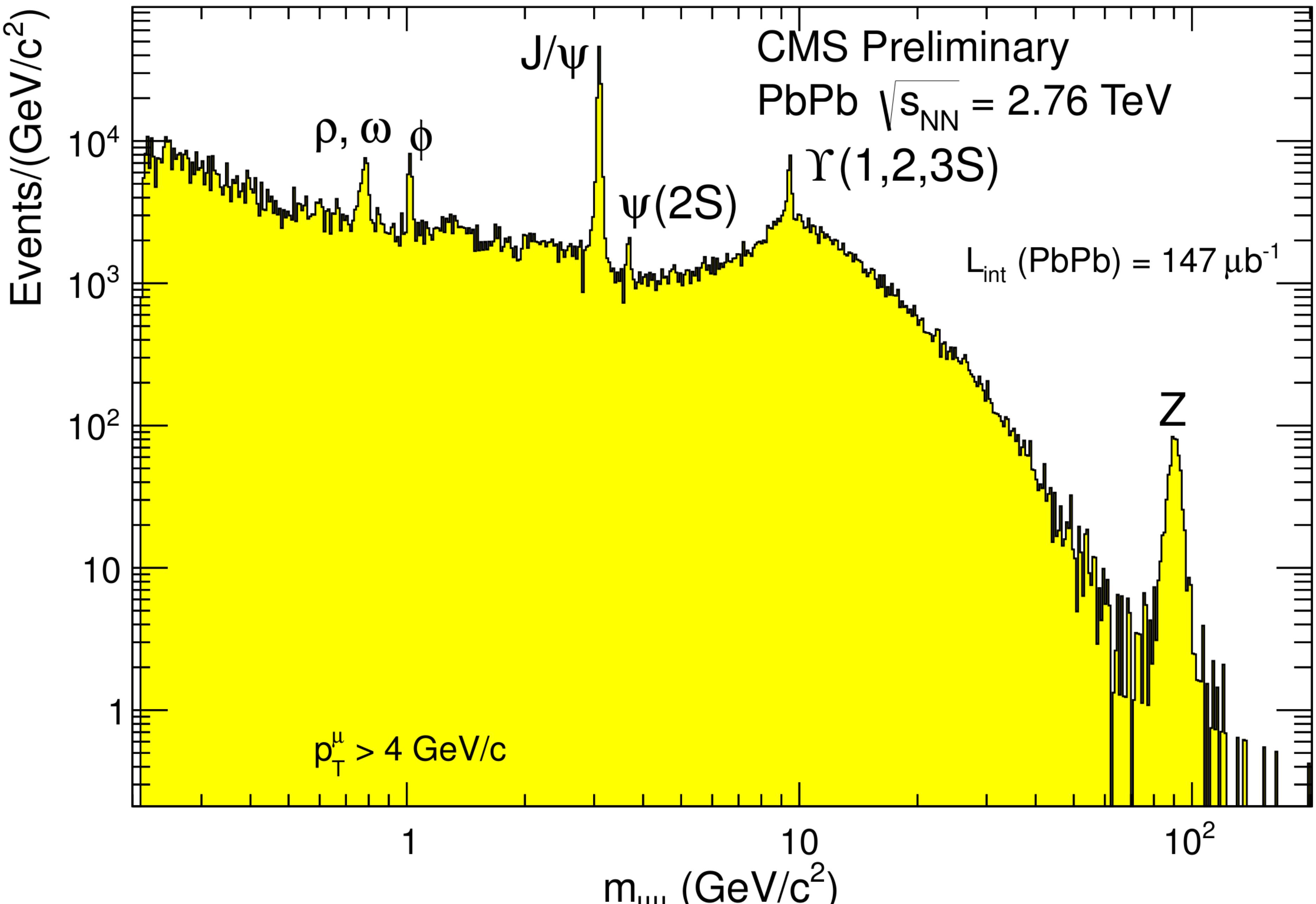
Dimuon acceptance



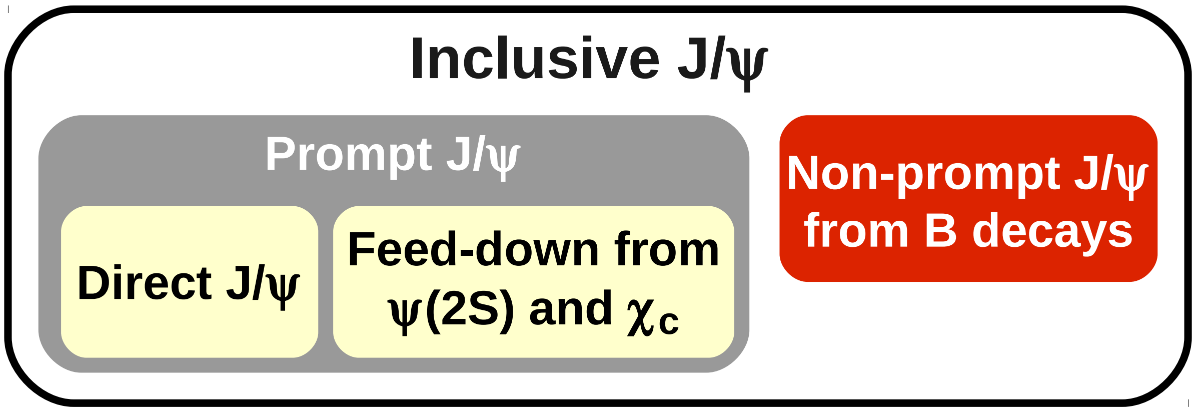


- Due to the strong magnetic field and energy loss in the absorber, minimum momentum to reach the muon stations is 3~5 GeV/c
- J/ψ acceptance
  - Mid-rapidity: J/ψ $p_T > 6.5$ GeV/c
  - Forward rapidity: J/ψ $p_T > 3$ GeV/c
- ϒ acceptance
  - All rapidity: ϒ $p_T > 0$ GeV/c

Dimuon spectrum in PbPb at $\sqrt{s_{NN}}$ =2.76 TeV

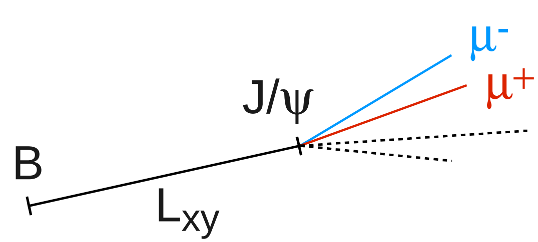


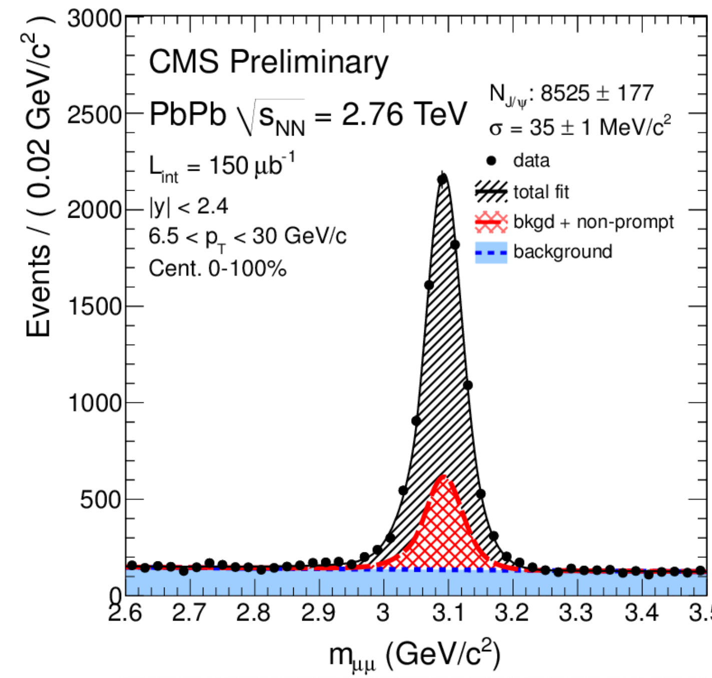
J/ψ in PbPb at $\sqrt{s_{NN}}$ =2.76 TeV

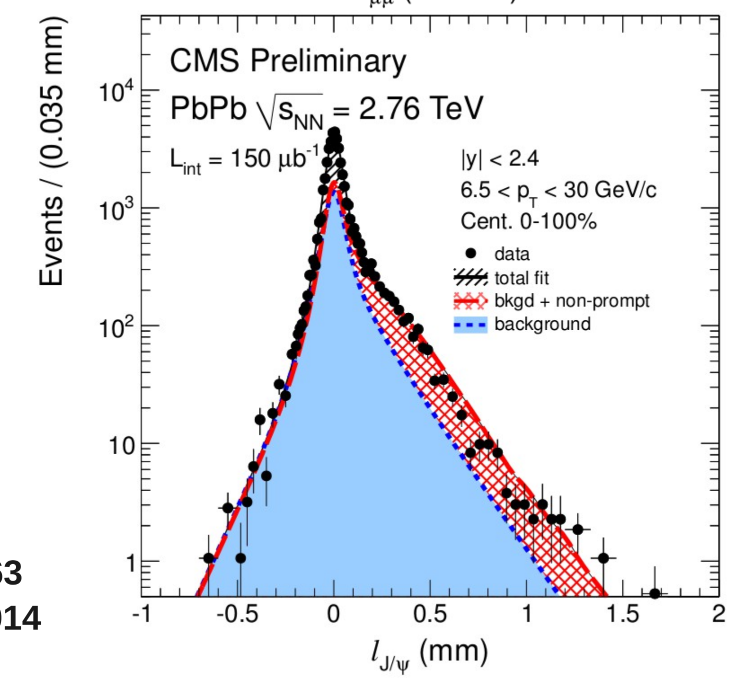


- Reconstruction of $\mu^+\mu^-$ vertex
- 2D simultaneous fit of $\mu^+\mu^-$ mass and pseudo-proper decay length $l_{J/\psi}$
- Extract the non-prompt J/ψ fraction

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

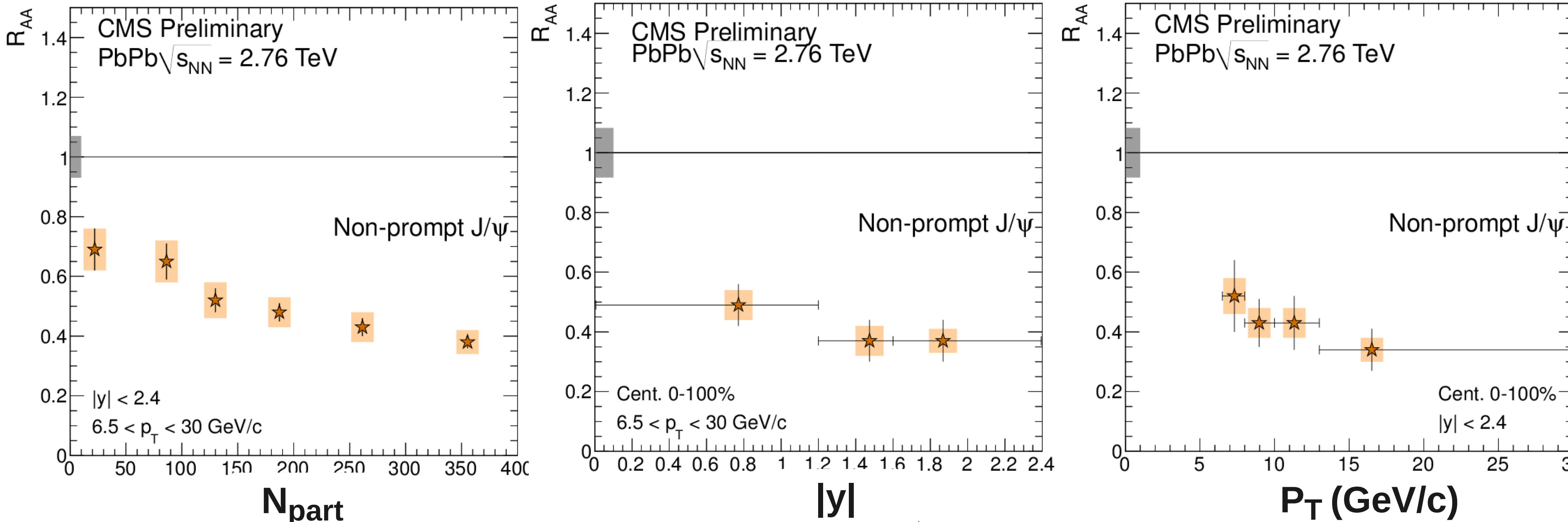






2010 PbPb data 7.28 μb^{-1}: JHEP 05 (2012) 063
2011 PbPb data 150 μb^{-1}: CMS PAS HIN-12-014

Non-prompt J/ψ R_{AA}

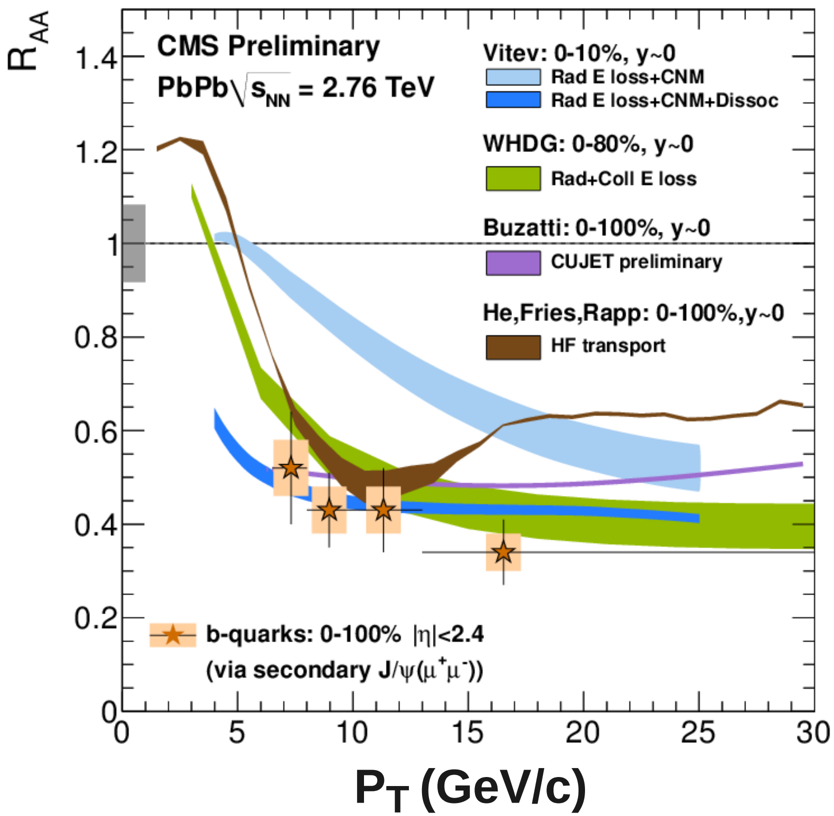


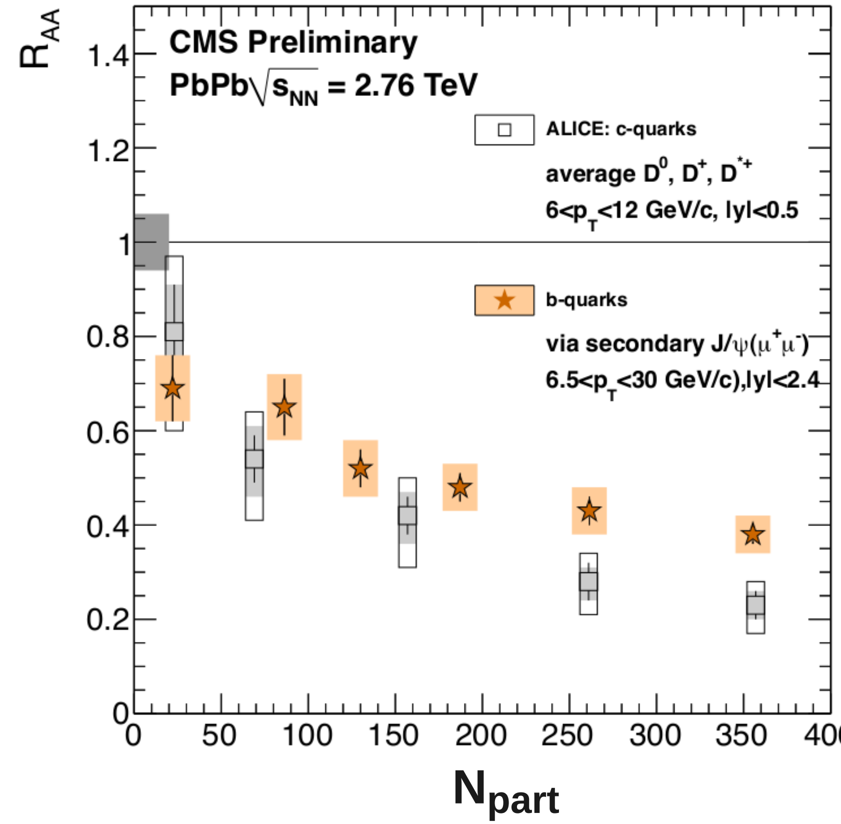
$$R_{AA} = \frac{L_{pp}}{T_{AA} N_{MB}} \frac{N_{PbPb}(J/\psi)}{N_{pp}(J/\psi)} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}(Cent.)}$$

- Non-prompt J/ψ from b-hadron decays is a probe to energy loss of b quarks in the medium
- Centrality dependent suppression on 6.5 < p_T < 30 GeV/c, |y| < 2.4 region
  - 0-5% centrality events shows suppression by a factor 2.5
- A hint of rapidity or p_T dependent suppression

CMS PAS HIN-12-014

Non-prompt J/ψ R_{AA} : Comparison to theory

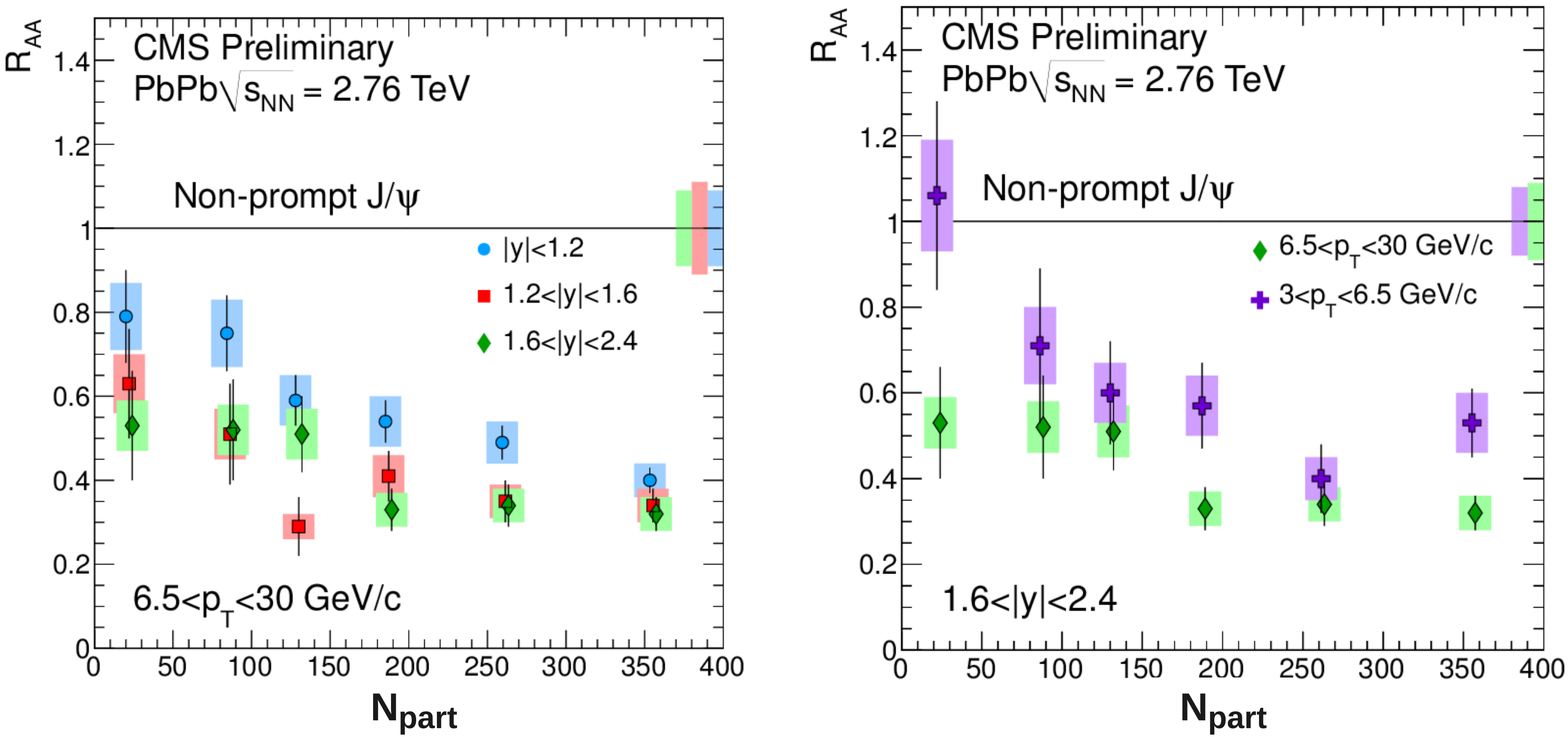




- R_{AA} of non-prompt J/ψ as a function of J/ψ p_T is compared to theoretical calculations as a function of B p_T (note: B p_T > J/ψ p_T)
- Radiative energy loss is not enough to describe b-quark energy loss
- D meson R_{AA} < Non-prompt J/ψ R_{AA} for most central collisions

CMS PAS HIN-12-014
ALICE: JHEP 09 (2012) 112
Vitev: J. Phys. G35 (2008) 104011 + priv. comm.
Horowitz: arXiv:1108.5876 + priv. comm.
Buzzatti, Gyulassy: arXiv:1207.6020 + priv. comm.
He, Fries, Rapp: PRC86 (2012) 014903 + priv. comm.

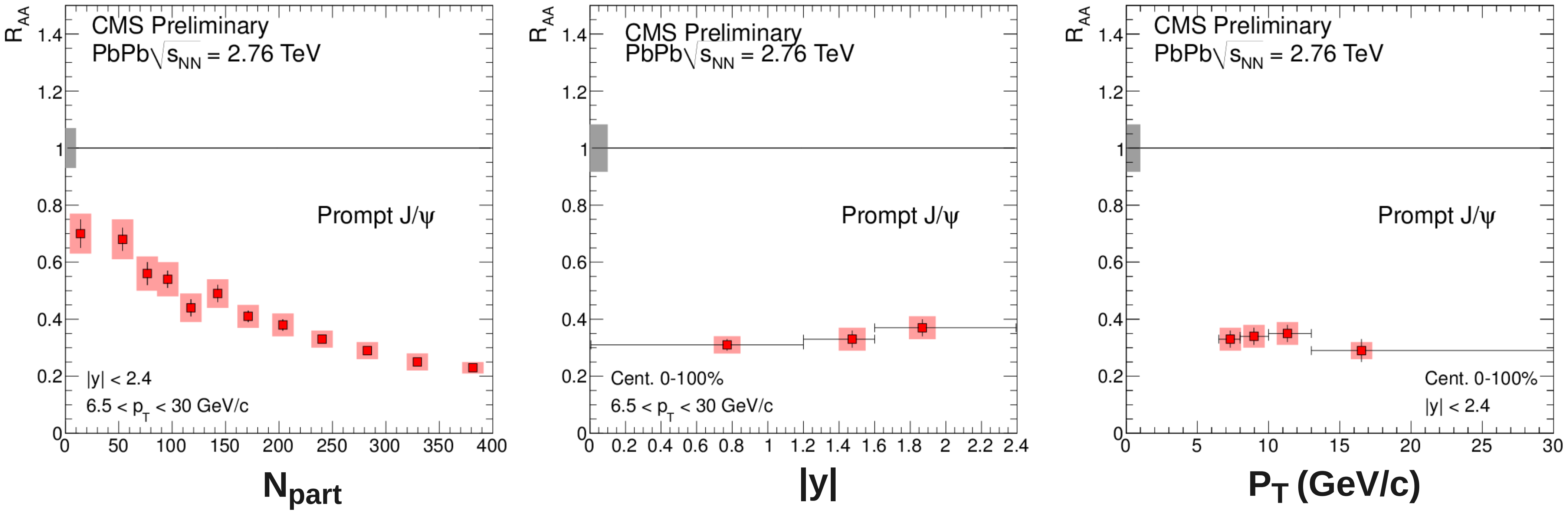
Non-prompt J/ψ R_{AA} : Double differential



- Centrality dependence is observed in all rapidity region
- At forward rapidity(1.6<|y|<2.4), lower p_T ($3 < p_T < 6.5$ GeV/c) is accessible
  - Lower p_T is less suppressed than higher p_T

CMS PAS HIN-12-014

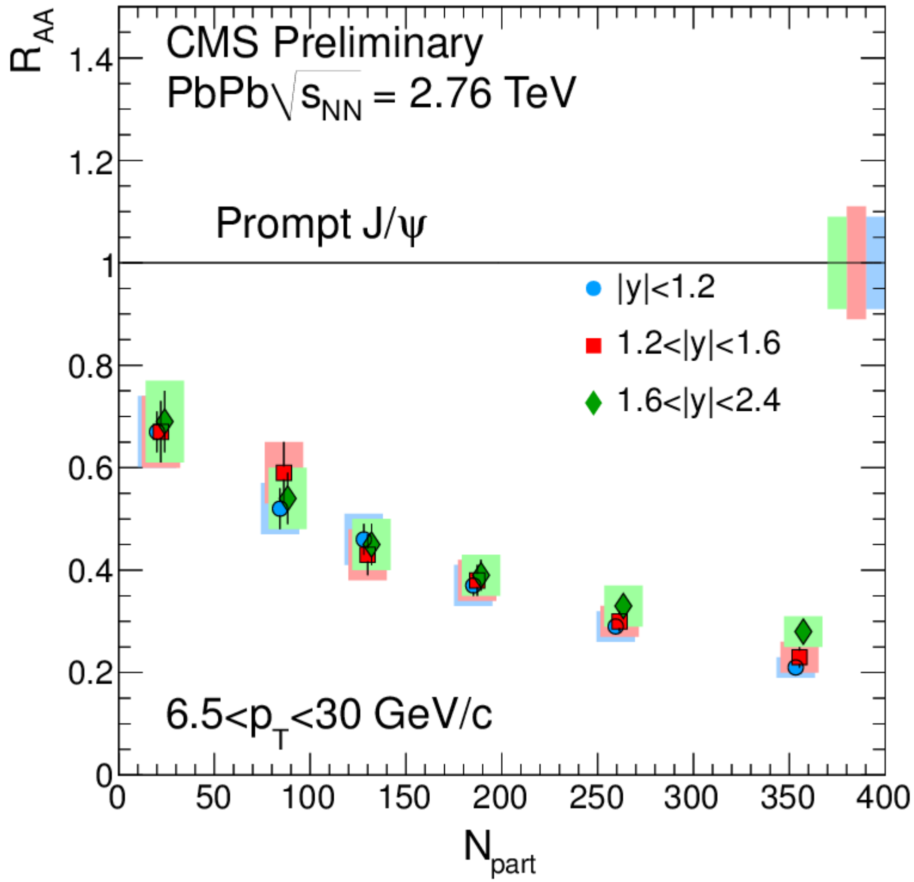
Prompt J/ψ R_{AA}

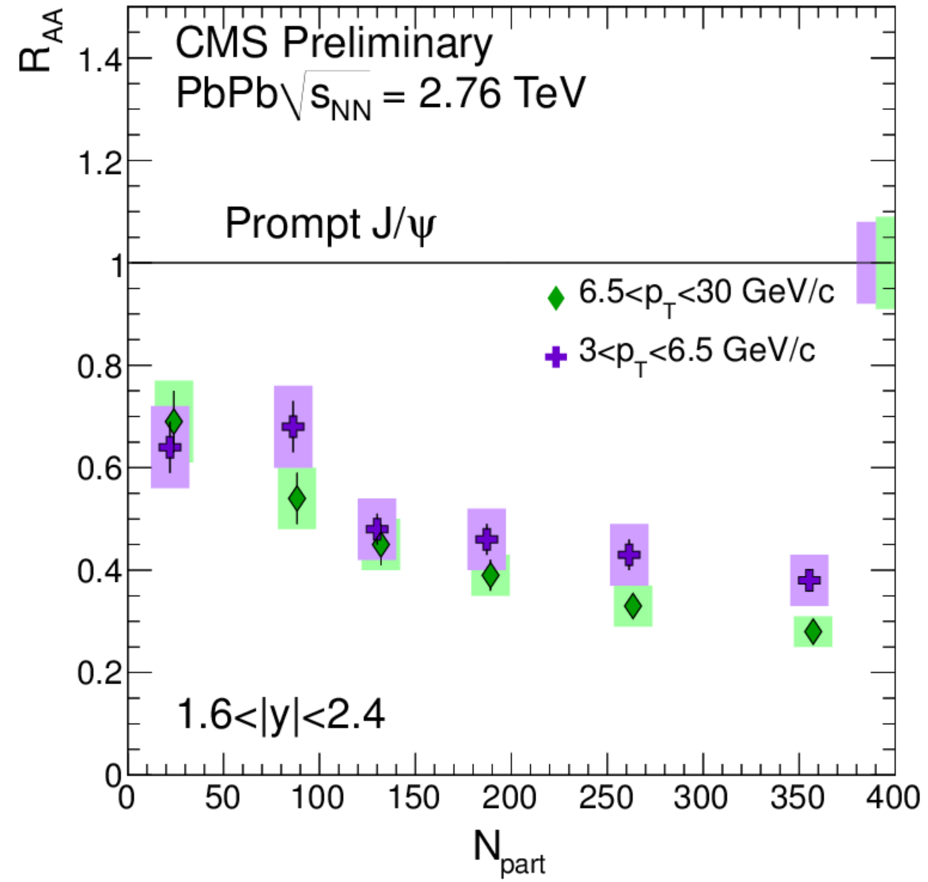


- Prompt J/ψ R_{AA} with pp reference at 2.76 TeV, 231 nb^{-1}
  - R_{AA} vs. p_T and y will be updated with more statistics. Stay tuned!
- Strong centrality dependence for 6.5 < p_T < 30 GeV/c, |y| < 2.4 region
- 0-5% centrality events shows suppression by a factor almost 5
- No significant dependence on rapidity or p_T

CMS PAS HIN-12-014

Prompt J/ψ R_{AA} : Double differential

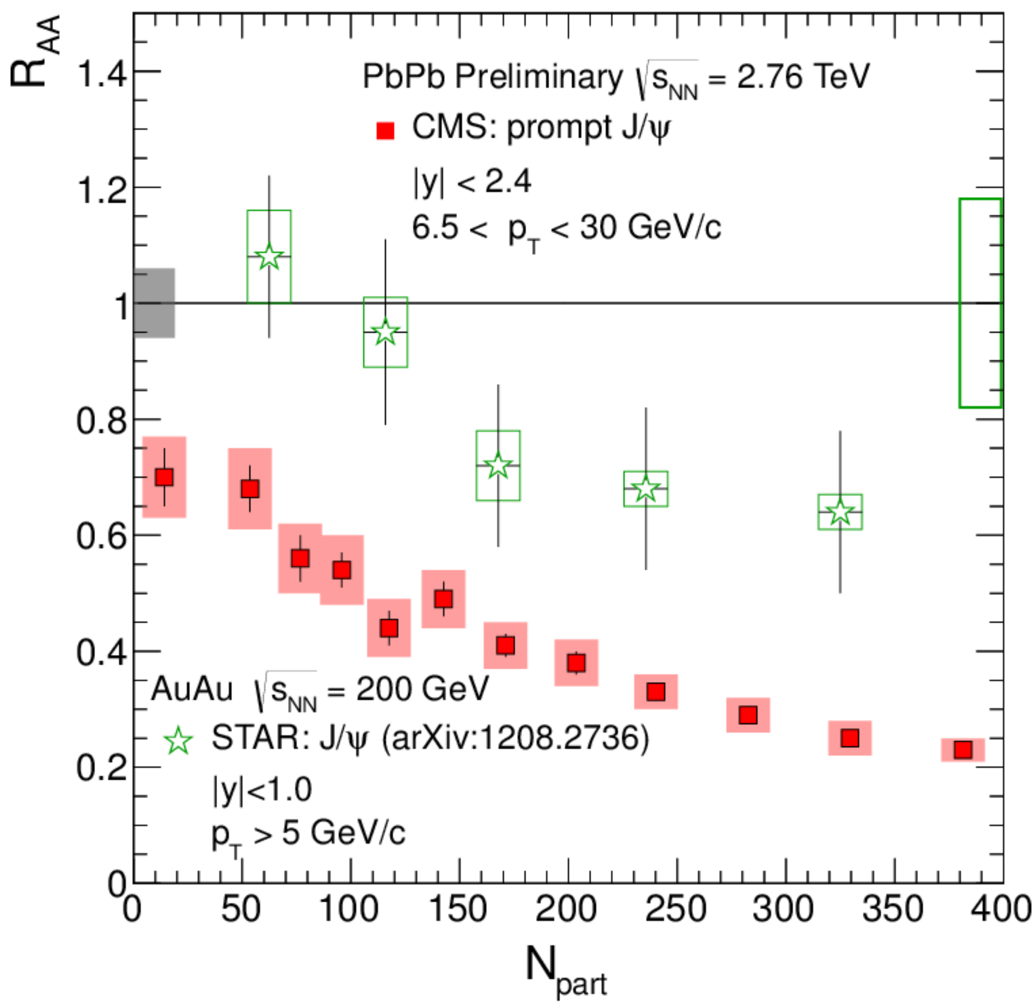




- Different rapidity regions have similar suppression magnitude and centrality dependence for 6.5 < p_T < 30 GeV/c
- At forward rapidity(1.6<|y|<2.4), lower p_T (3 < p_T < 6.5 GeV/c) is accessible
  - In most central case, lower p_T is slightly less suppressed

CMS PAS HIN-12-014

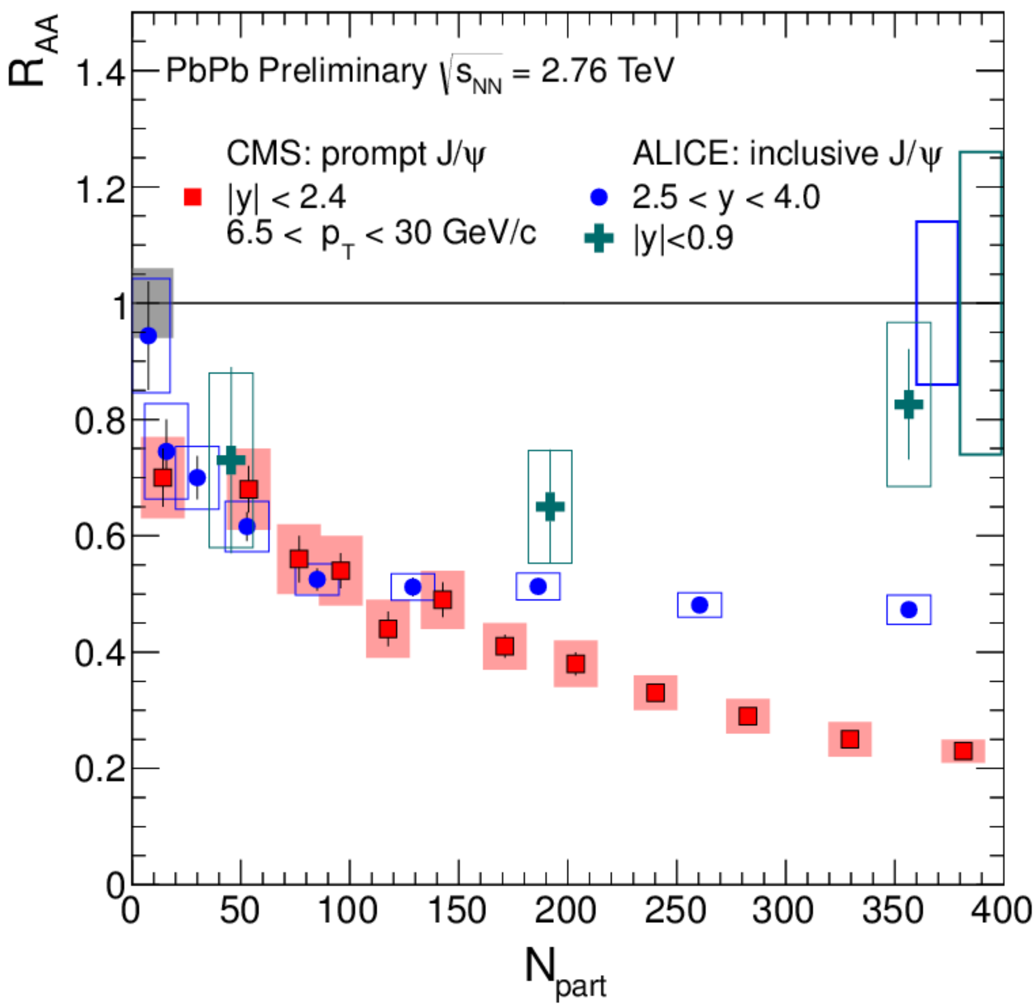
Prompt J/ψ R_{AA} : Comparison to STAR



- CMS: Prompt J/ψ
  - $\sqrt{s_{NN}}$ = 2.76 TeV
  - 6.5 < p_T < 30 GeV/c, |y| < 2.4
- STAR: Inclusive J/ψ
  - $\sqrt{s_{NN}}$ = 200 GeV
  - p_T > 5 GeV/c, |y| < 1
- Similar centrality trends but stronger suppression at CMS

CMS PAS HIN-12-014

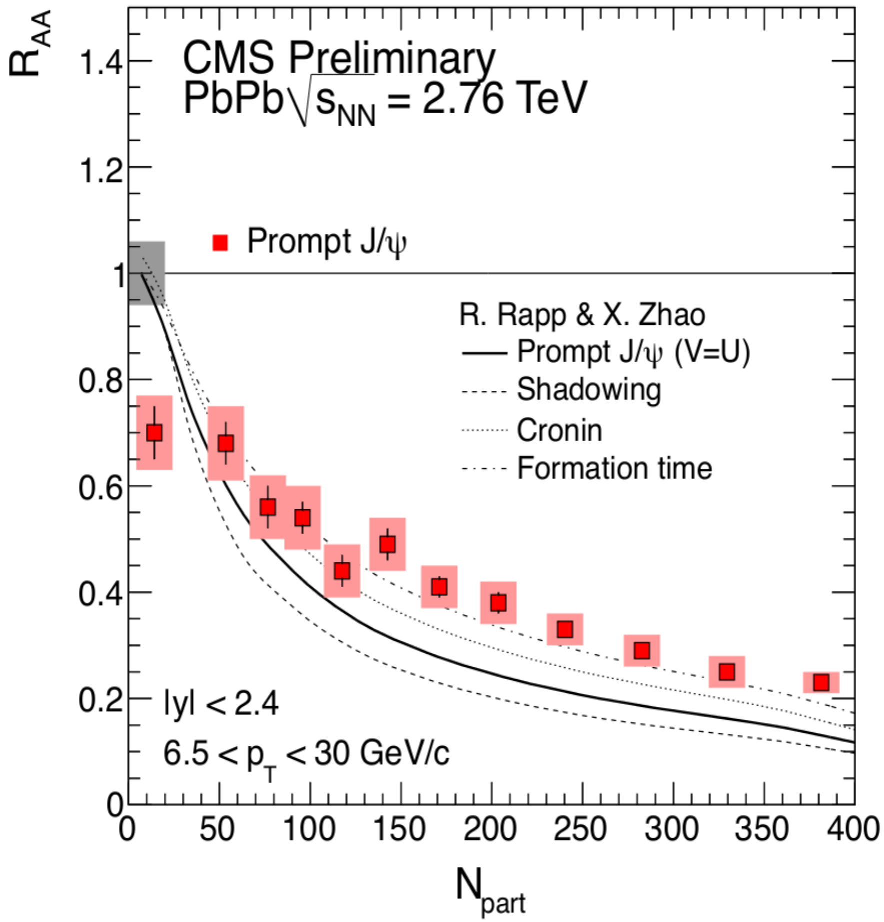
Prompt J/ψ R_{AA} : Comparison to ALICE

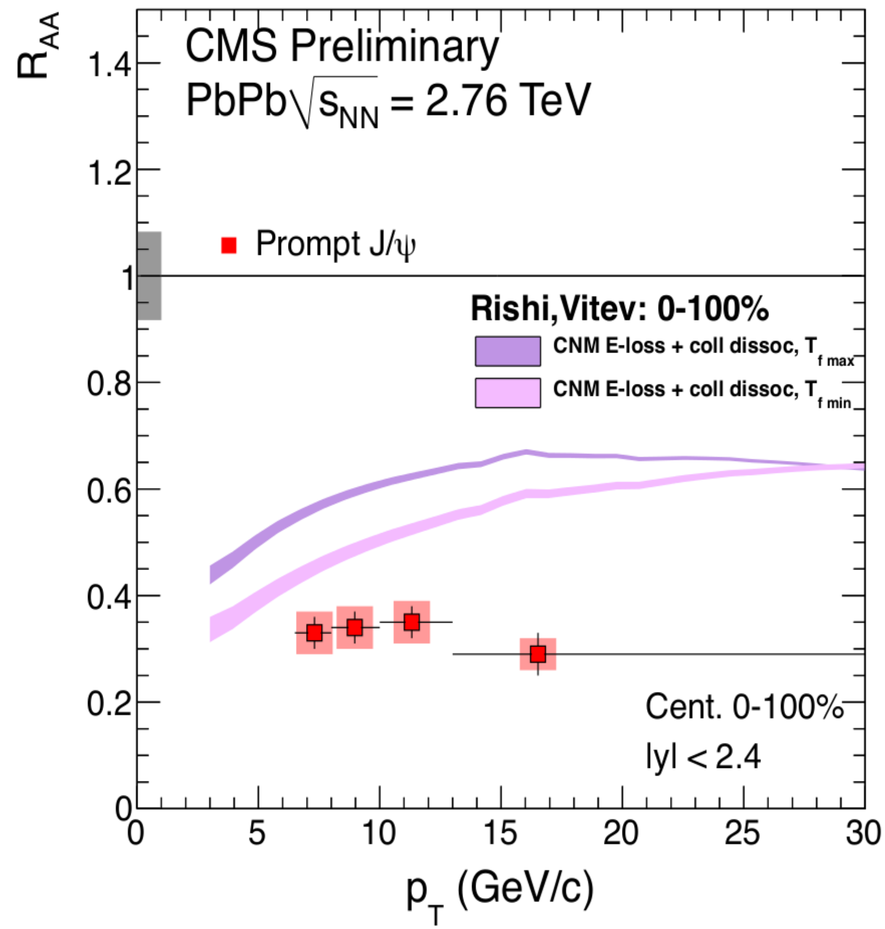


- CMS: Prompt J/ψ
  - $6.5 < p_T < 30$ GeV/c, $|y| < 2.4$
- ALICE: Inclusive J/ψ
  - $p_T > 0$ GeV/c, $|y| < 0.9$
  - $p_T > 0$ GeV/c, $2.5 < |y| < 4$
- Stronger suppression at CMS for central events
  - Less suppression at low p_T due to regeneration?

CMS PAS HIN-12-014
ALICE mid-rapidity: Nucl.Phys.A904-905 2013 (2013) 623c-626c
ALICE forward rapidity: Nucl.Phys. A904-905 (2013) 595c-598c

Prompt J/ψ R_{AA} : Comparison to theory

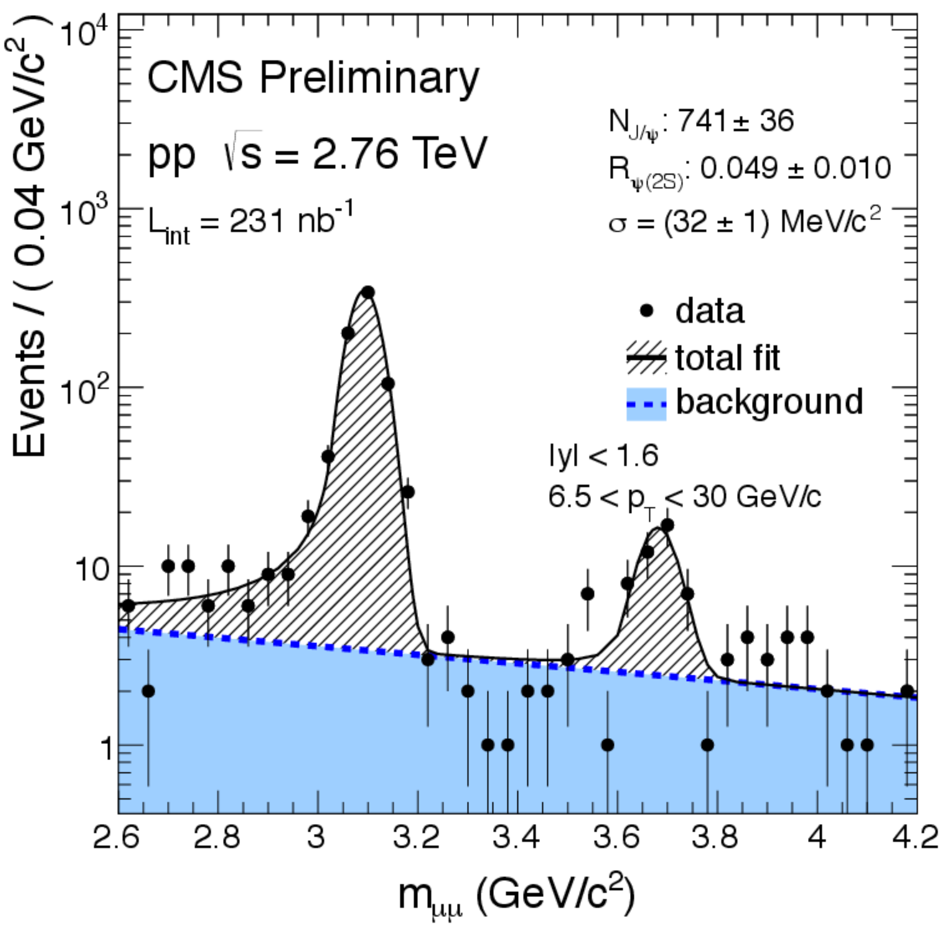


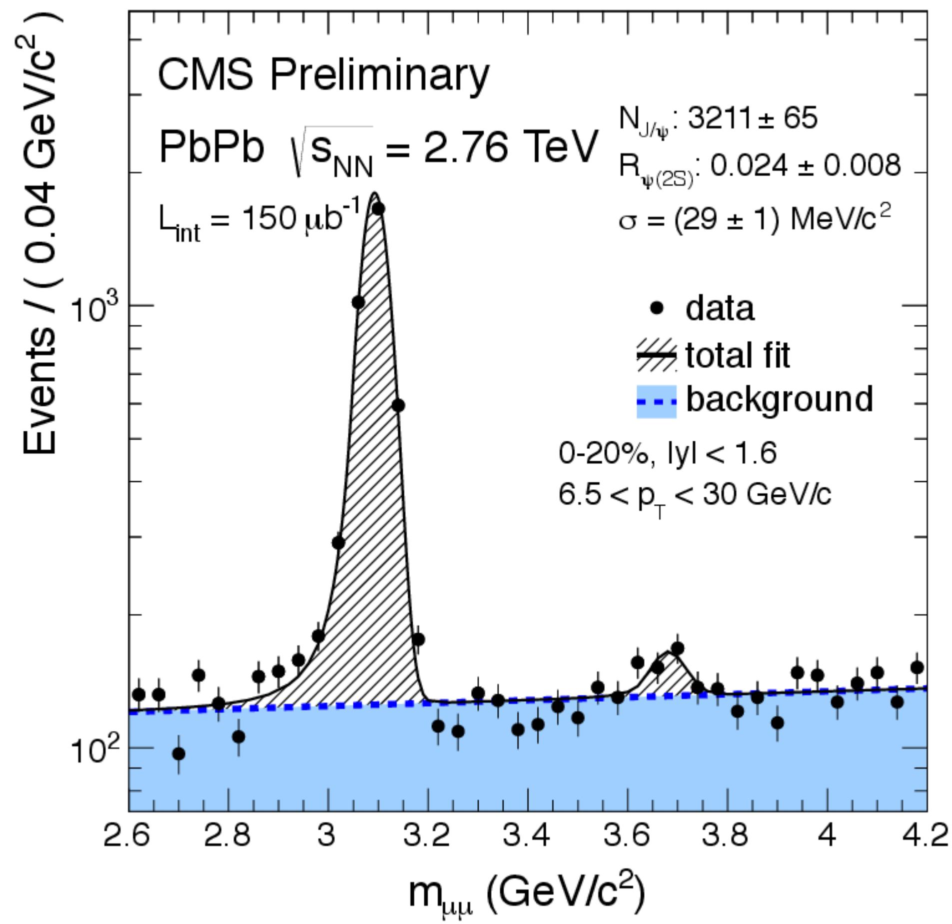


- Prompt J/ψ R_{AA} at high p_T is described well without recombination
- Collisional energy loss and CNM effects are not enough to describe prompt J/ψ suppression

CMS PAS HIN-12-014

$\psi(2S)$ in pp & PbPb at $\sqrt{s_{NN}}$ =2.76 TeV





$$R_{\psi(2S)} = \frac{\psi(2S)/J/\psi \ \ (PbPb)}{\psi(2S)/J/\psi \ \ (pp)}$$

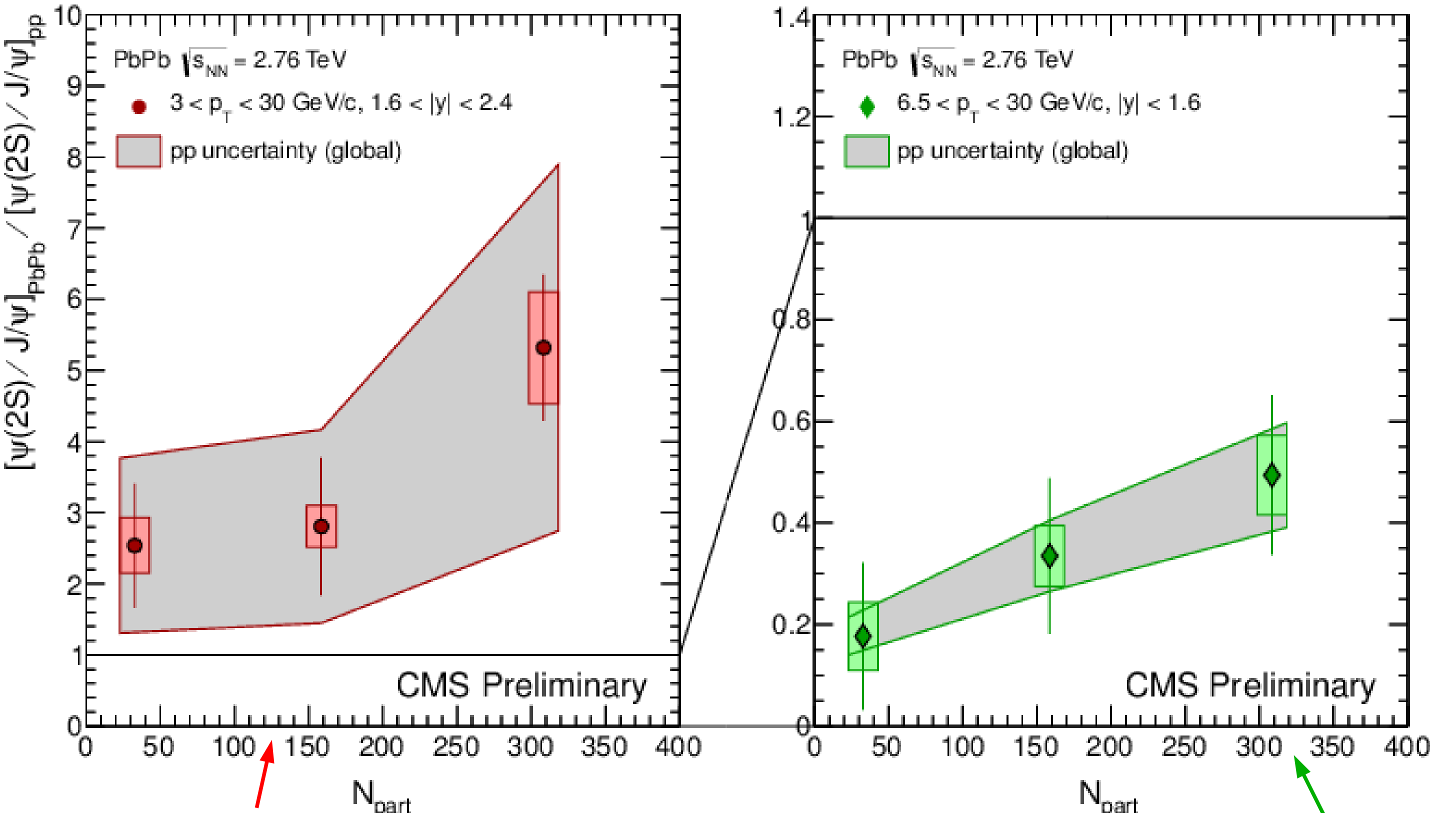
In pp: $R_{\psi(2S)}$: 0.049±0.010

In PbPb $R_{\psi(2S)}$: 0.024±0.008

- $R_{\psi(2S)}$ in 0-20% PbPb is ~2x smaller than in pp for p_T > 6.5 GeV/c, |y| < 1.6 region

CMS PAS HIN-12-007

ψ(2S) / J/ψ Double ratio



CMS PAS HIN-12-007
J/ψ R_{AA} for ψ(2S) is quoted from JHEP 05 (2012) 063

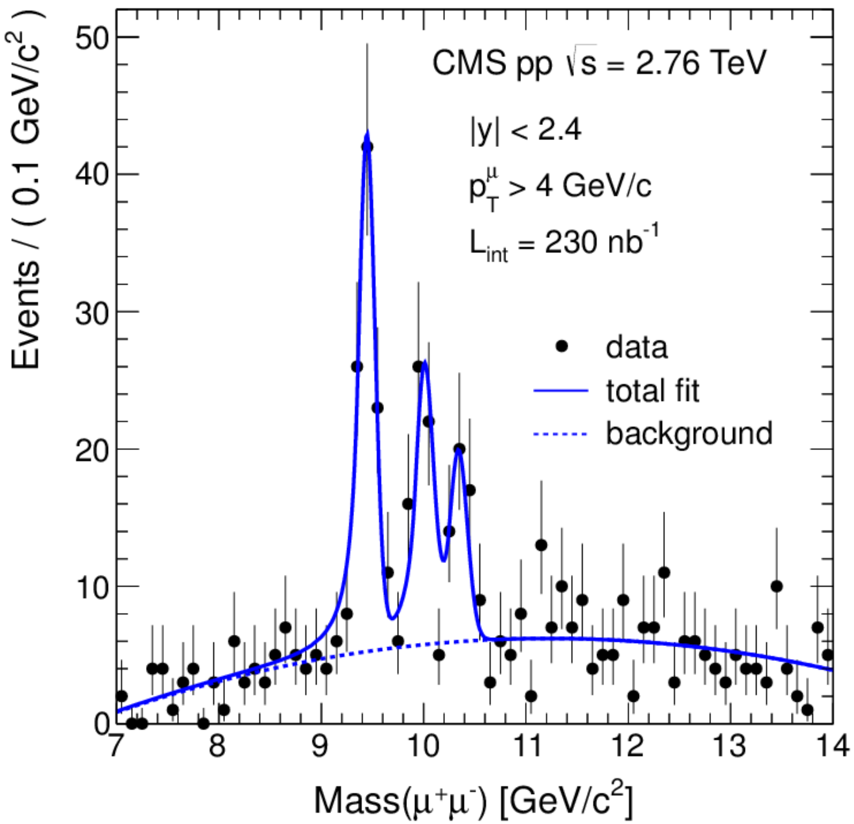
$$R_{AA}(\psi(2S)) = \frac{\psi(2S)/J/\psi\ \ (PbPb)}{\psi(2S)/J/\psi\ \ (pp)} \times R_{AA}(J/\psi)$$

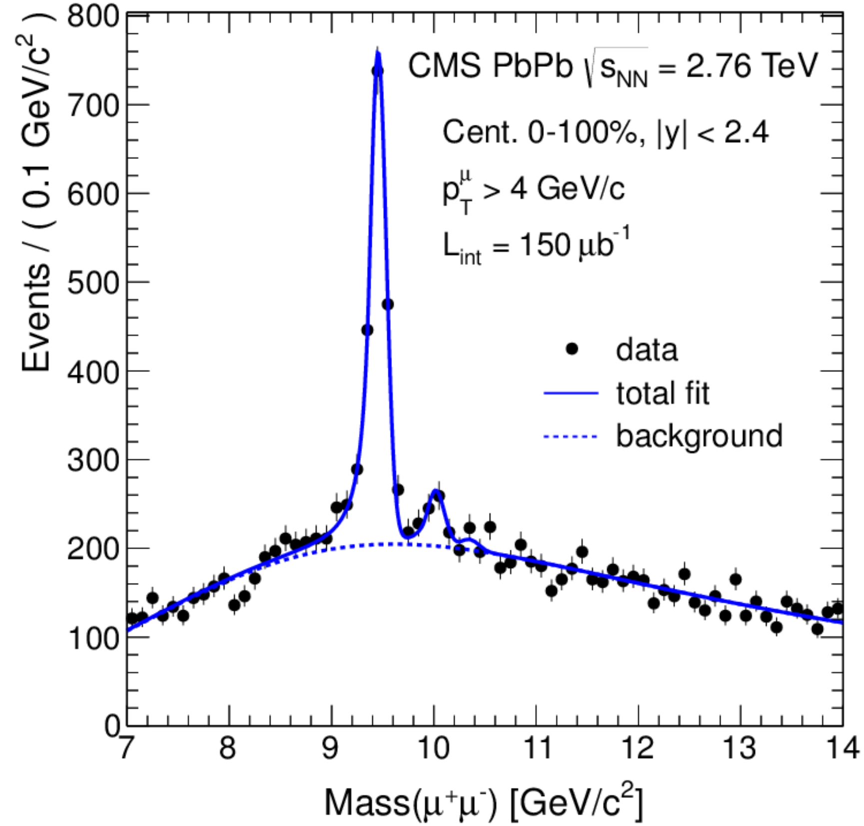
$$R_{AA}^{0-100\%}(\psi(2S)) = 1.54 \pm 0.32(stat.) \pm 0.22(syst.) \pm 0.76(pp)$$

$$R_{AA}^{0-100\%}(\psi(2S)) = 0.11 \pm 0.03(stat.) \pm 0.02(syst.) \pm 0.02(pp)$$

- For p_T > 3 GeV/c, 1.6 < |y| < 2.4, large uncertainties on pp
  - Indication that ψ(2S) is less suppressed than J/ψ but need more pp statistics
  - R_{AA} vs. p_T and y will be updated with more statistics. Stay tuned!
- ψ(2S) is more suppressed at p_T > 6.5 GeV/c, |y| < 1.6

Υ(nS)/Υ(1S) ratios



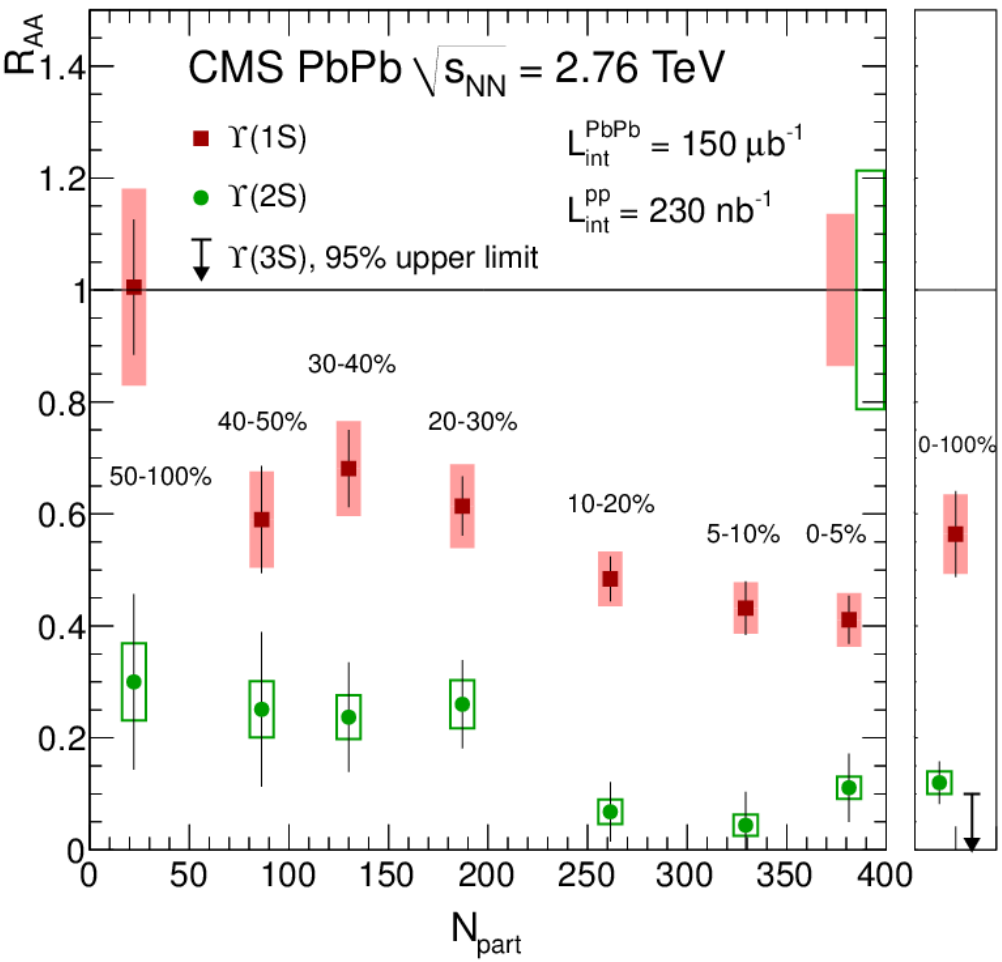


- Υ(2S)/Υ(1S) and Υ(3S)/Υ(1S) ratios on minimum-bias

$$\frac{N_{\Upsilon(2S)}/N_{\Upsilon(1S)}(PbPb)}{N_{\Upsilon(2S)}/N_{\Upsilon(1S)}(pp)} = 0.21 \pm 0.07 \pm 0.02 \qquad \frac{N_{\Upsilon(3S)}/N_{\Upsilon(1S)}(PbPb)}{N_{\Upsilon(3S)}/N_{\Upsilon(1S)}(pp)} < 0.17 \quad (95\%\, C.L.)$$

Phys. Rev. Lett. 109 (2012) 222301

$\Upsilon(nS)\ R_{AA}$



- Υ(2S) is clearly suppressed
- Υ(1S) suppression is consistent with excited state suppression (~50% feed down)

CDF: Phys. Rev. Lett. 84 (2000) 2094
LHCb: JHEP 11 (2012) 031

- Mimimun-bias R_{AA} of Υ(nS)

$$R_{AA}(Y(1S)) = 0.56 \pm 0.08(stat.) \pm 0.07(syst.)$$

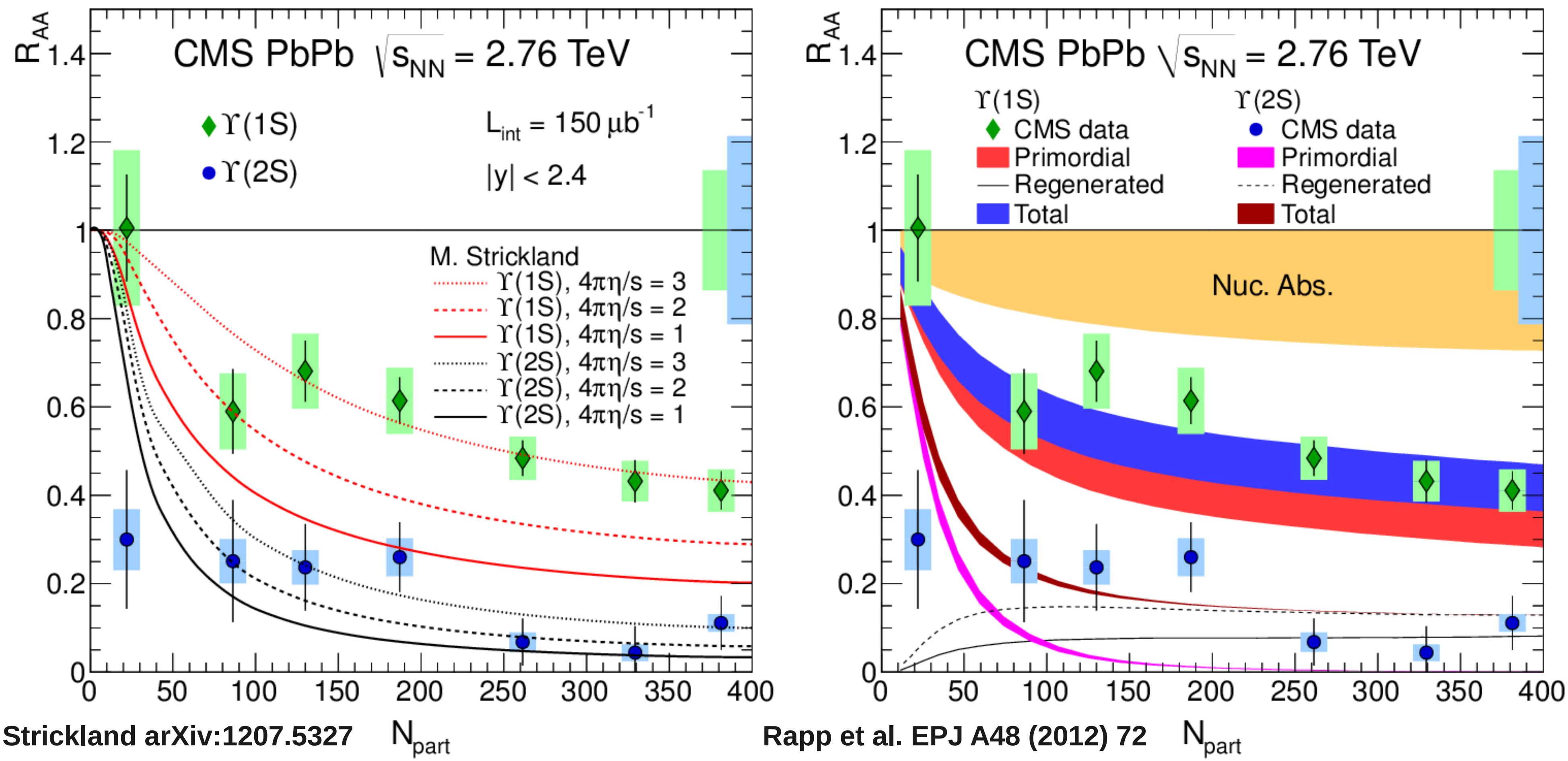
$$R_{AA}(Y(2S)) = 0.12 \pm 0.04(stat.) \pm 0.02(syst.)$$

$$R_{AA}(Y(3S)) < 0.1 \quad (95\%\,C.L.)$$

- Sequential suppression of Υ(nS) in order of binding energy

Phys. Rev. Lett. 109 (2012) 222301

ϒ(nS) R_{AA} : Comparison to theory

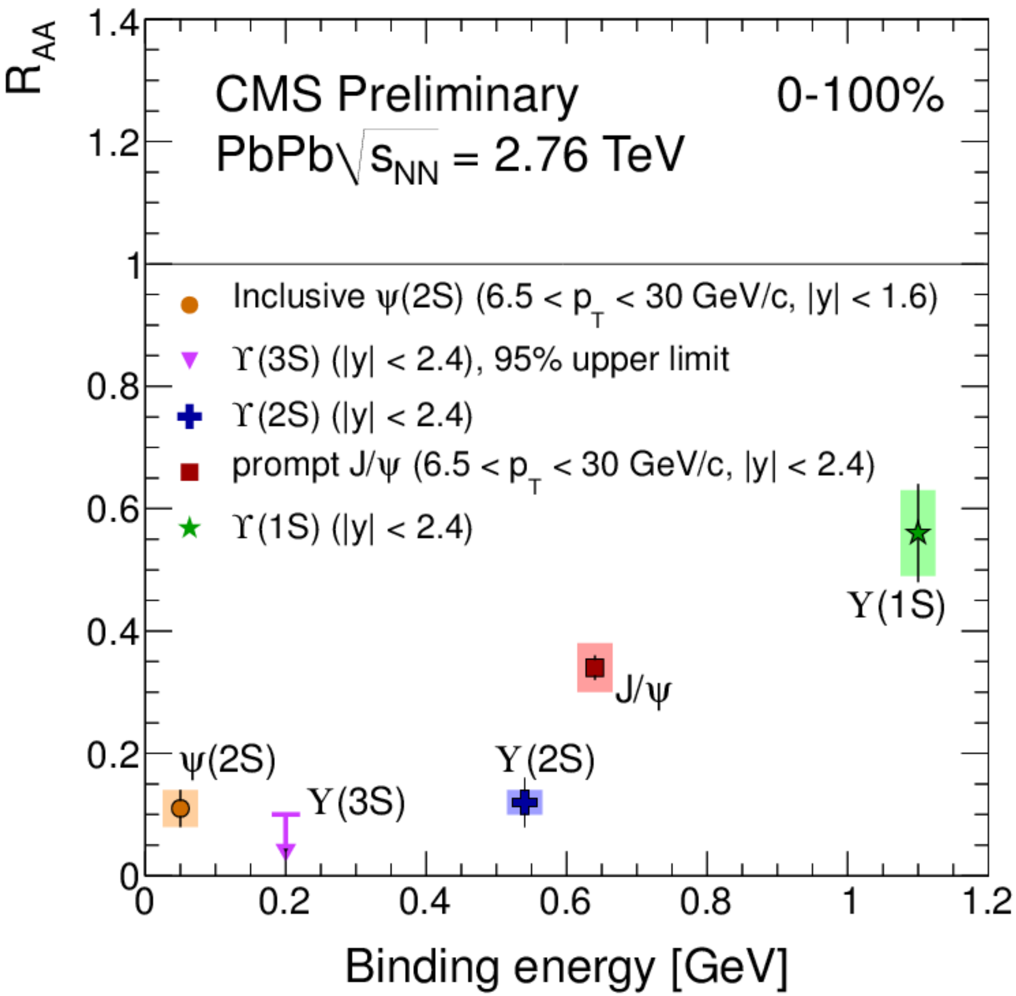


Strickland arXiv:1207.5327

Rapp et al. EPJ A48 (2012) 72

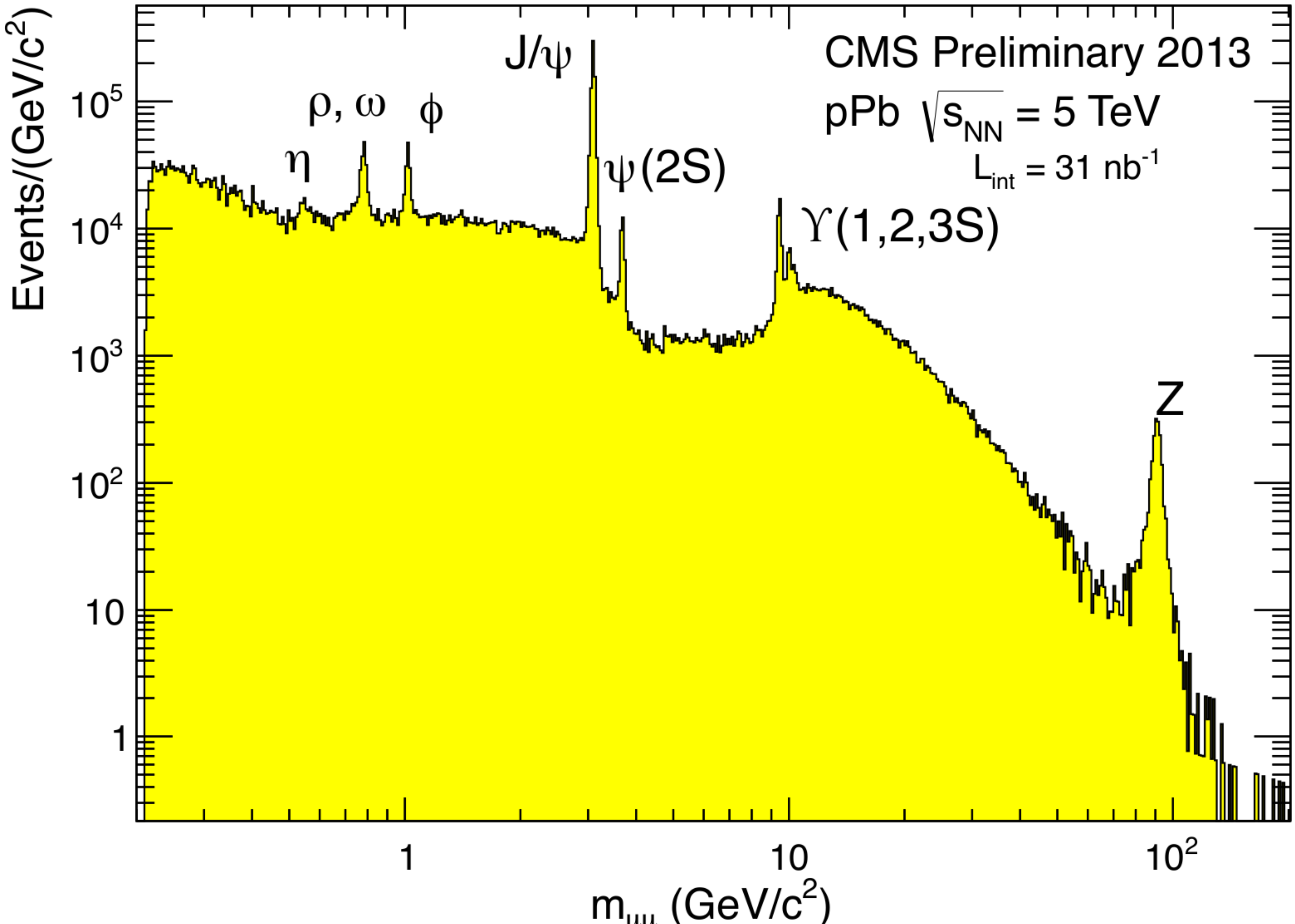
- Strickland: some tension to describe ϒ(1S) and ϒ(2S) simultaneously with the same η/s value
- Rapp: regeneration and nuclear absorption could be significant also for bottomonia

Summary



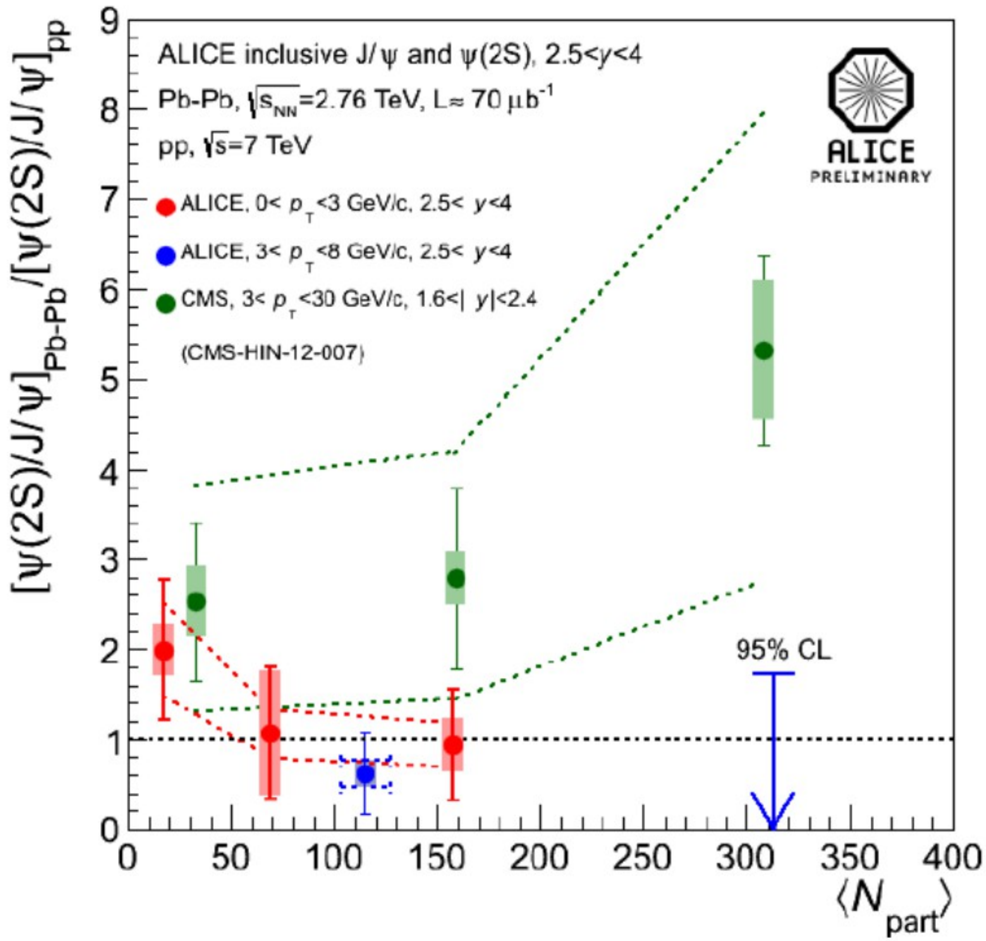
- Charmonia at lower p_T
  - ψ(2S) suppression has too large uncertainties to draw a conclusion
  - New pp data from 2013 will help to solve this question!
- Charmonia at higher p_T
  - J/ψ are more suppressed than RHIC energy
  - ψ(2S) is more suppressed than J/ψ
- Bottomonia
  - Clear ordering of the suppression of the ϒ(nS)
- Measured quarkonia family shows sequential melting as a function of binding energy

Dimuon spectrum in pPb at $\sqrt{s_{NN}}$ =5.02 TeV



BACK UP

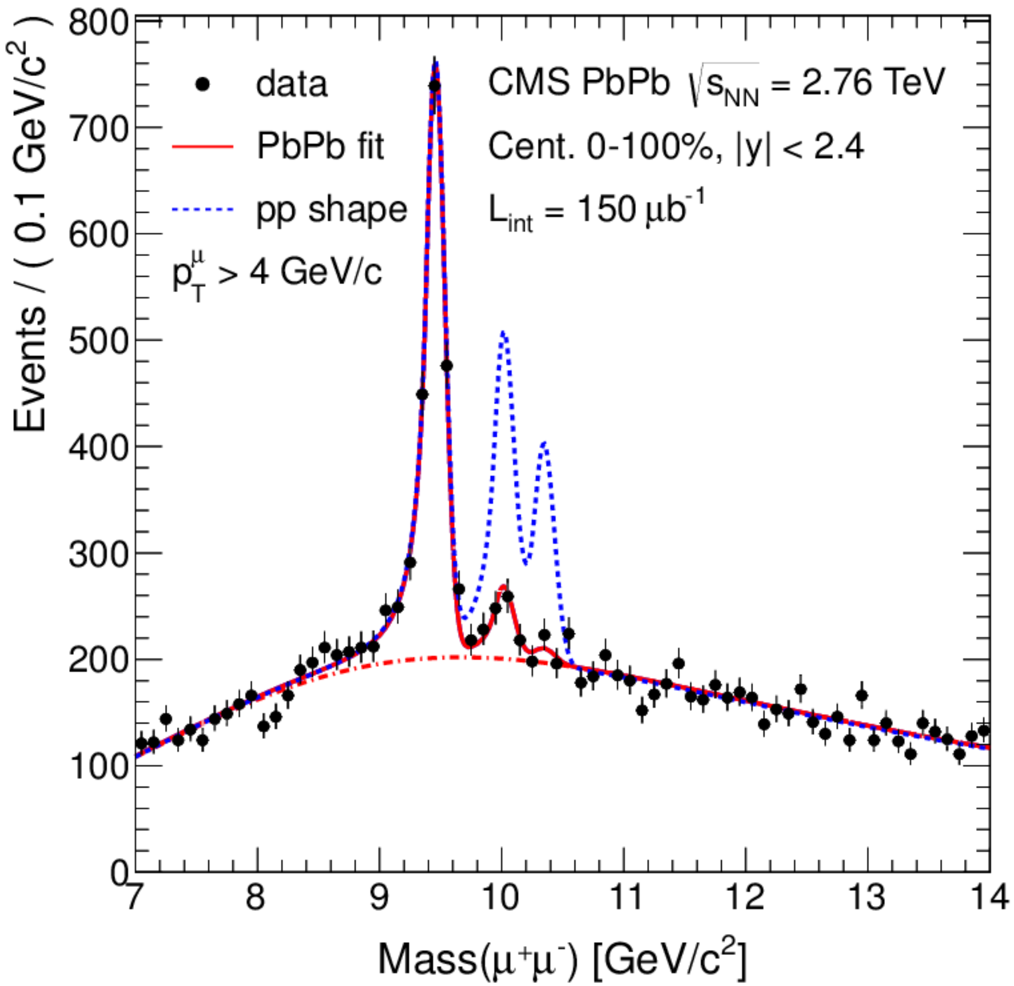
ψ(2S) / J/ψ Double ratio : CMS and ALICE



- CMS has a hint of less suppression of the ψ(2S) compare to J/ψ at lower p_T
  - pp reference at $\sqrt{s} = 2.76\,TeV$
- ALICE does not see same effect
  - pp reference at $\sqrt{s} = 7\,TeV$
- Given the large uncertainties on the results
  - No discrepancy

CMS PAS HIN-12-007
ALICE: preliminary results from QM2012 by Scomparin, Arnaldi

$\Upsilon(nS)/\Upsilon(1S)$ ratios



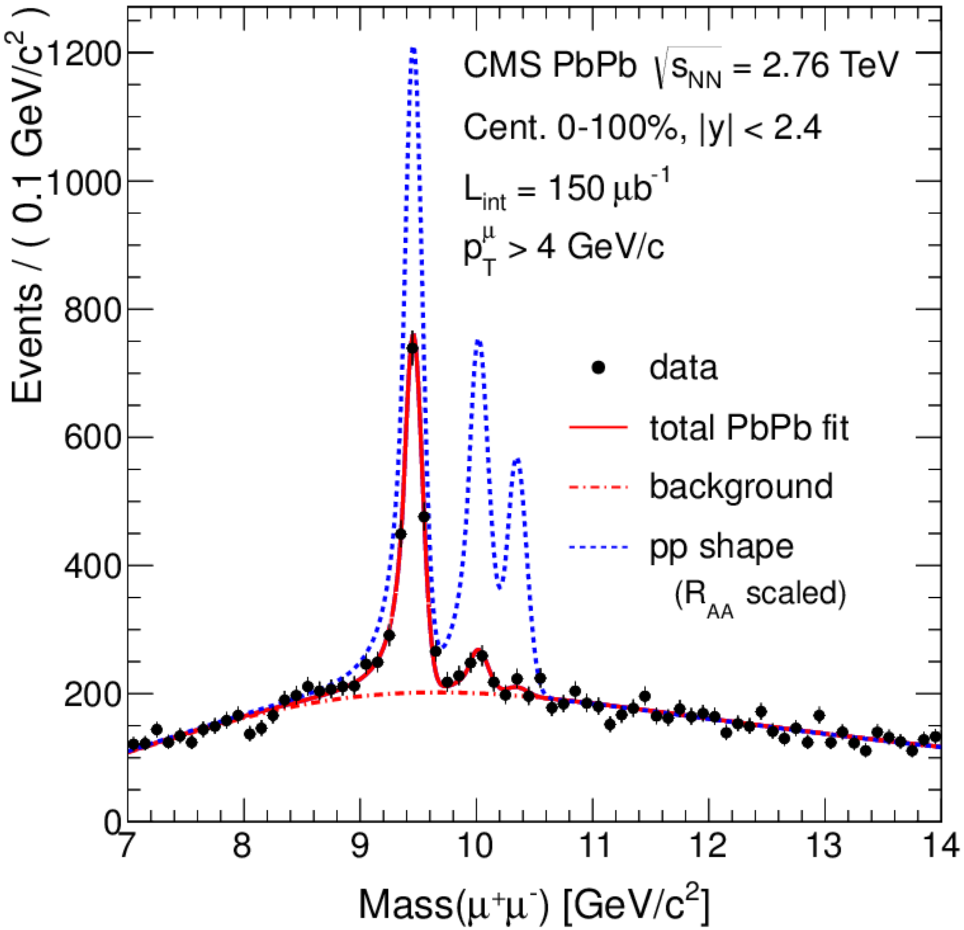
- Fit curve of pp is superimposed onto PbPb data by fixing the $\Upsilon(1S)$ yields and background and mass peak components to PbPb
- $\Upsilon(2S)/\Upsilon(1S)$ and $\Upsilon(3S)/\Upsilon(1S)$ ratio come from fit curve of pp
- Double ratios on minimum-bias

$$\frac{N_{Y(2S)}/N_{Y(1S)}(PbPb)}{N_{Y(2S)}/N_{Y(1S)}(pp)} = 0.21 \pm 0.07 \pm 0.02$$

$$\frac{N_{Y(3S)}/N_{Y(1S)}(PbPb)}{N_{Y(3S)}/N_{Y(1S)}(pp)} < 0.17 \quad (95\%\,C.L.)$$

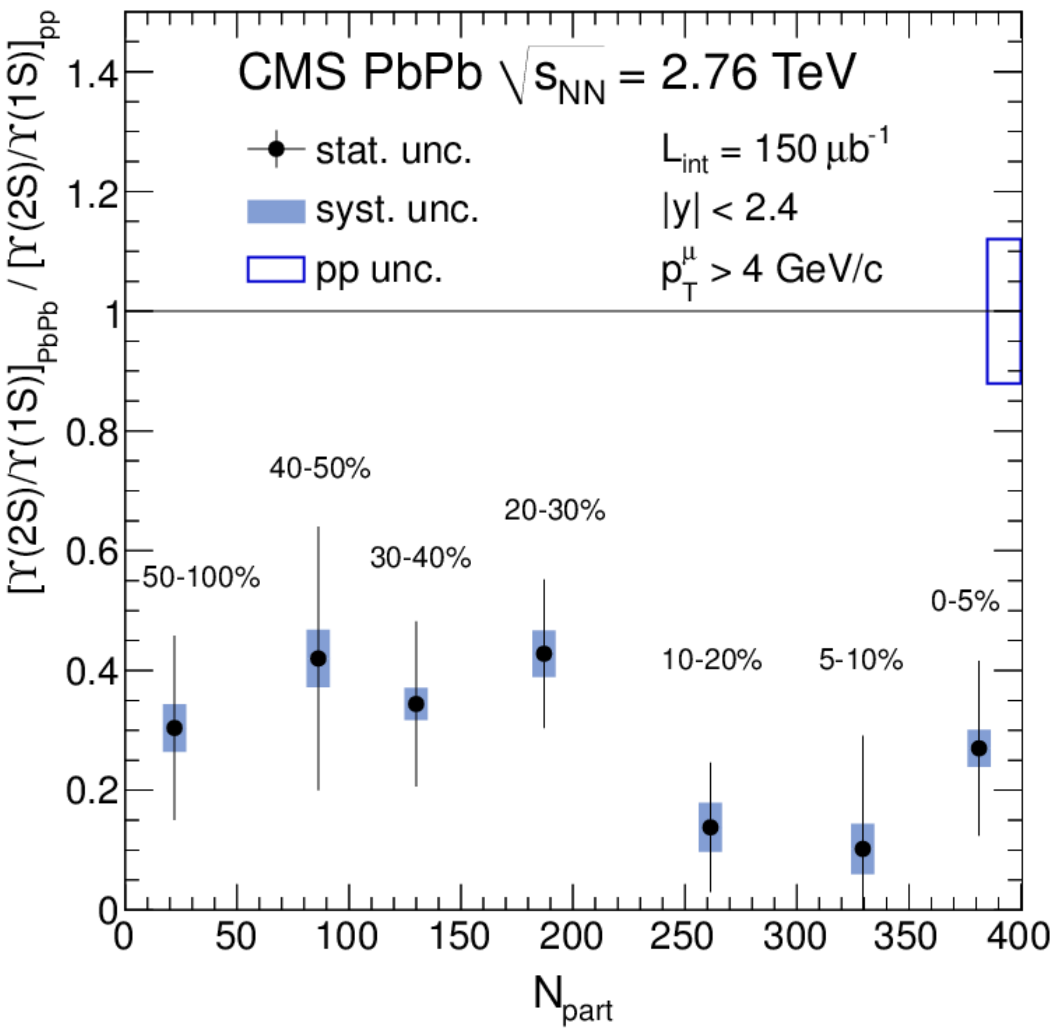
Phys. Rev. Lett. 109 (2012) 222301
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN11011

ϒ(nS) signal extraction in pp and PbPb



- Much smaller number of higher order states in PbPb compare to pp

$\Upsilon(2S)/\Upsilon(1S)$ Double ratios



- $\Upsilon(2S)/\Upsilon(1S)$ double ratio of differential centrality bin is measured
- No strong centrality dependence is observed on $\Upsilon(2S)/\Upsilon(1S)$ double ratio

Phys. Rev. Lett. 109 (2012) 222301
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN11011