Quarkonia studies in heavy-ion collisions with CMS

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HIF on Quarkonium Physics, CERN
3 June, 2013

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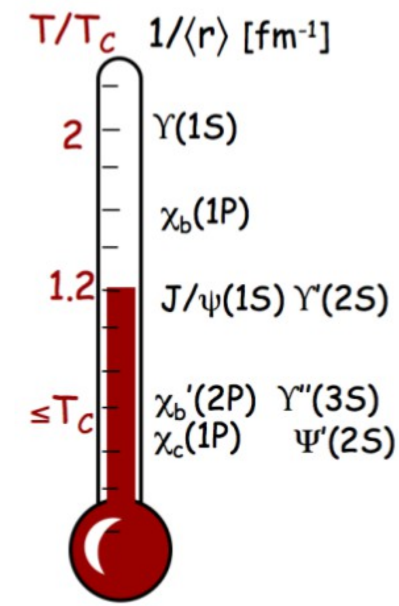
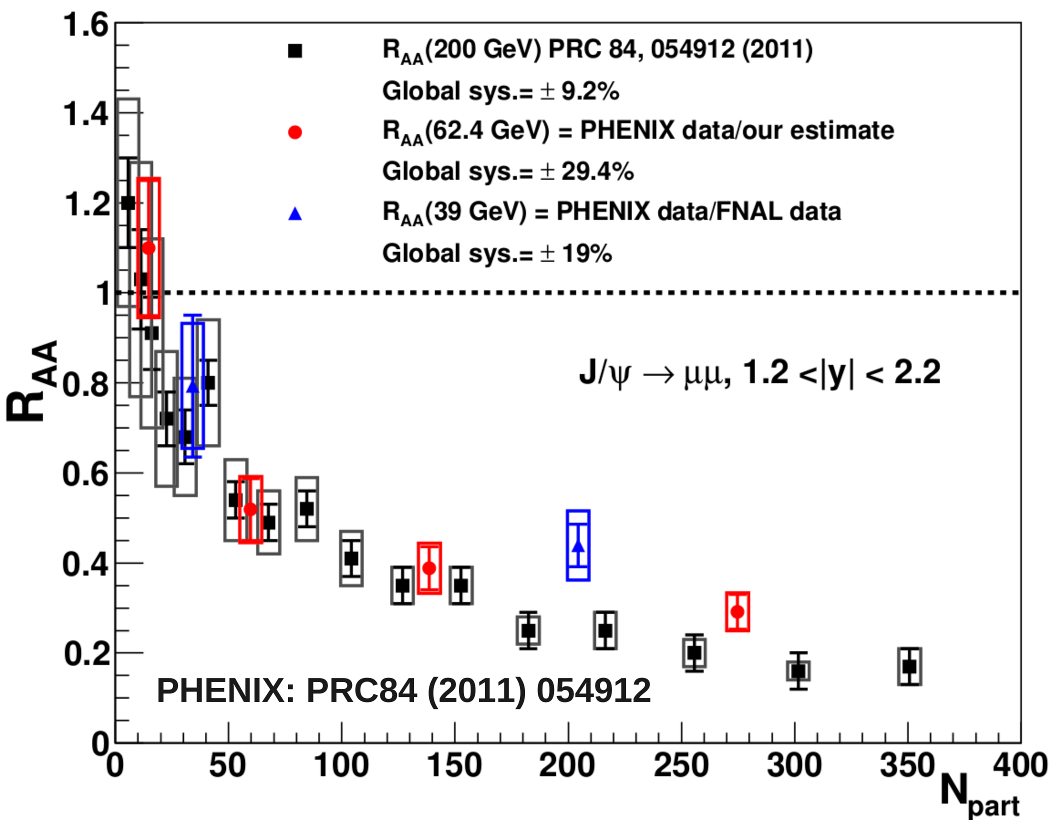
Introduction

- 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 **Matsui & Satz, PLB 178 (1986) 416**

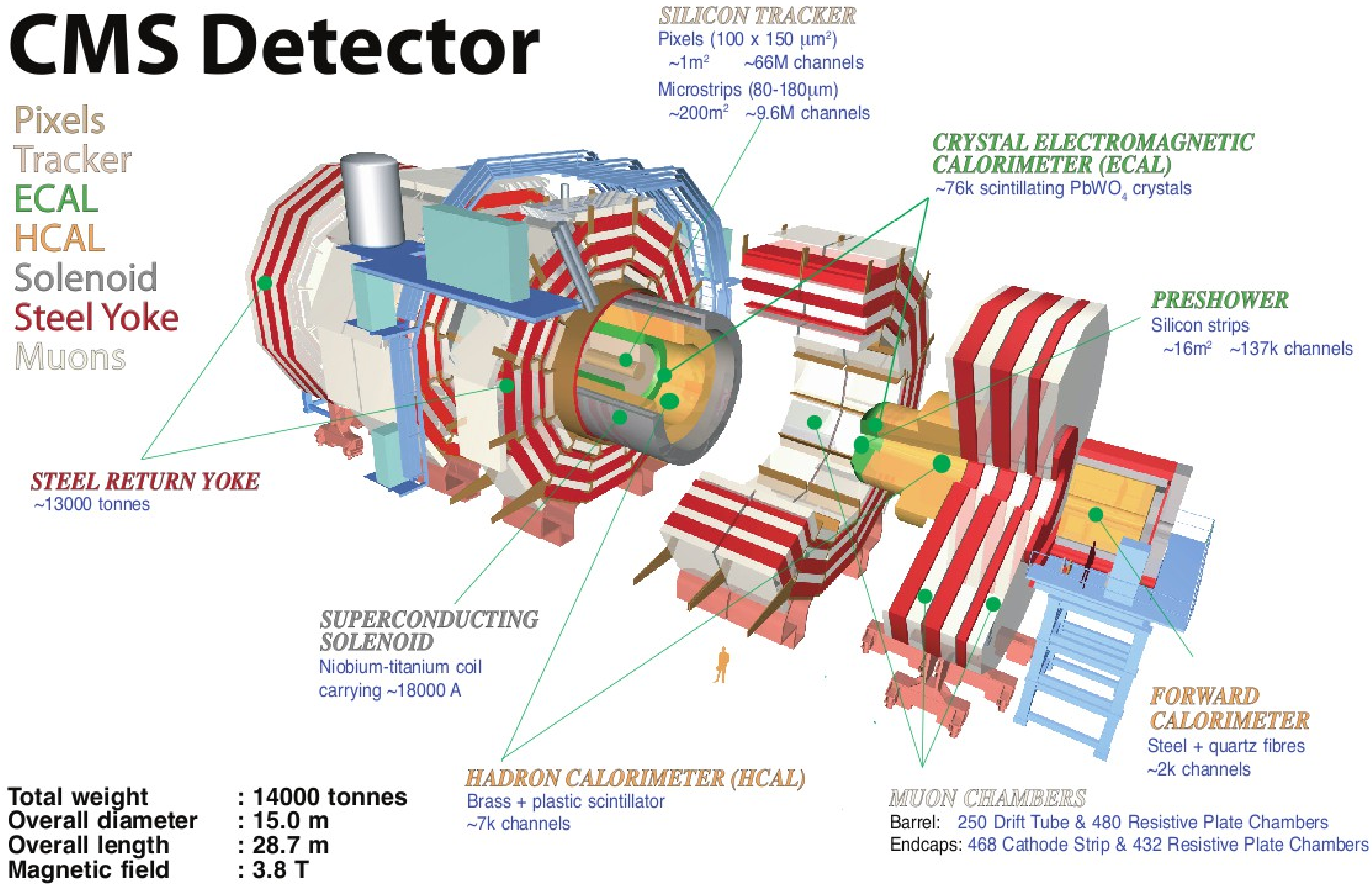
Mocsy, EPJ C 61 (2009) 705



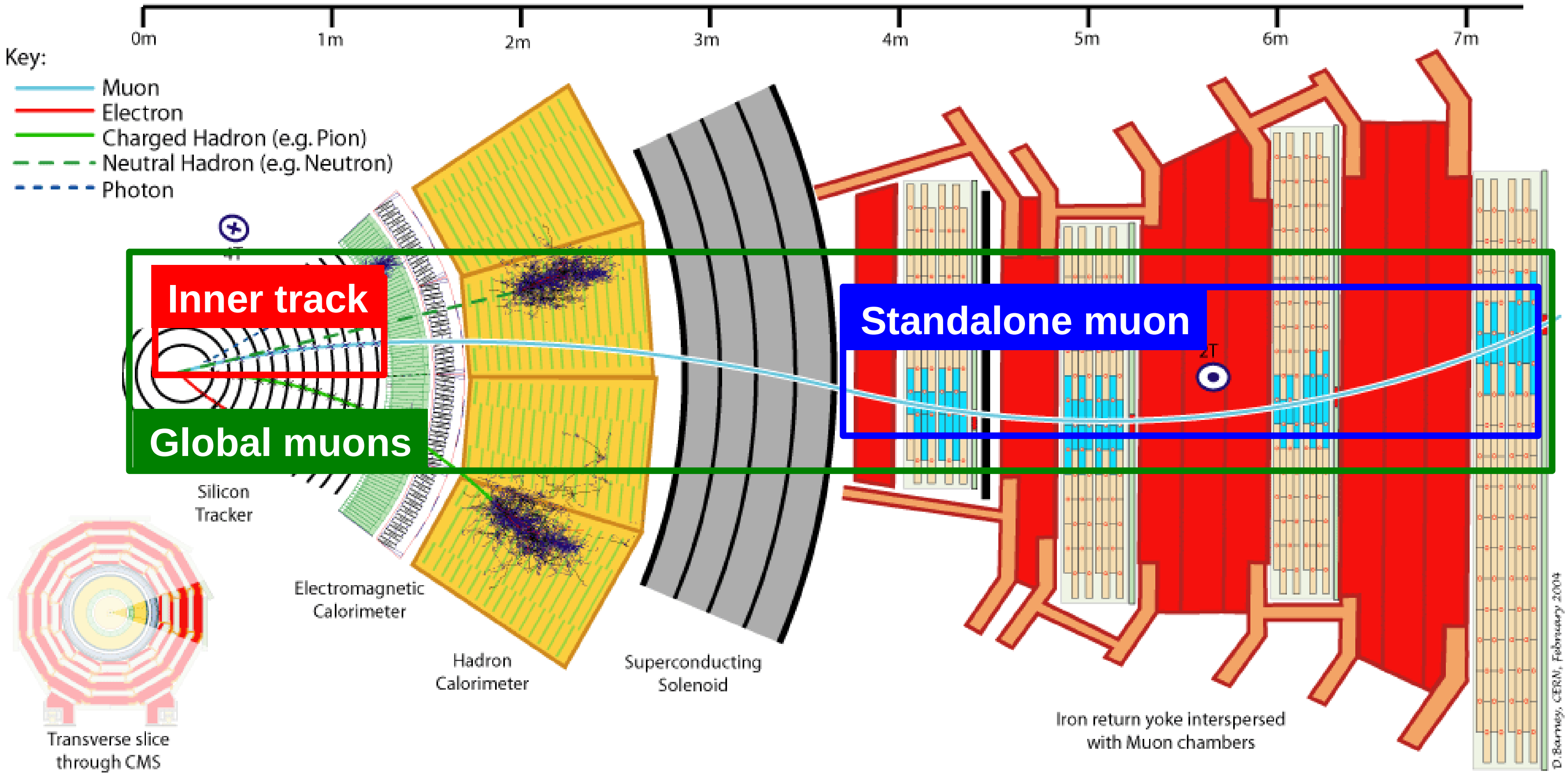


- J/ψ R_{AA} over different collision energy have similar trends at PHENIX
- What happens at the LHC with higher energy, luminosity?

CMS Detector

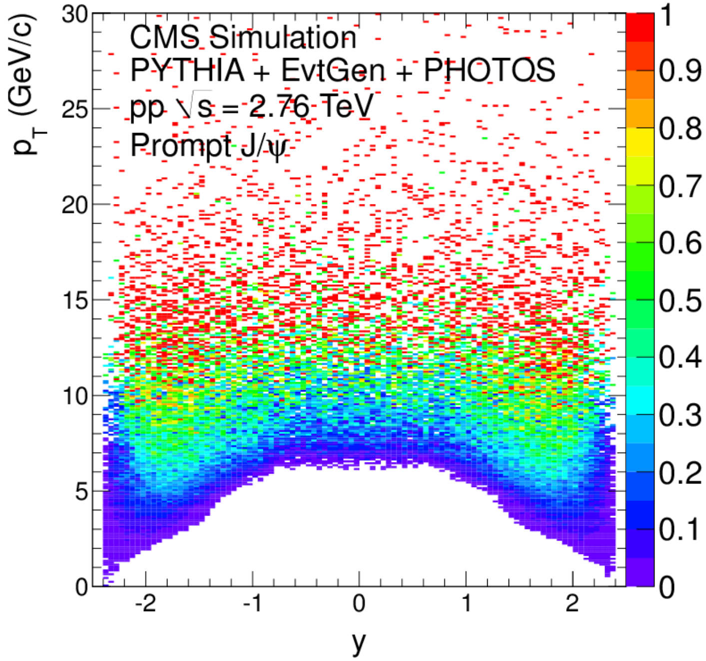


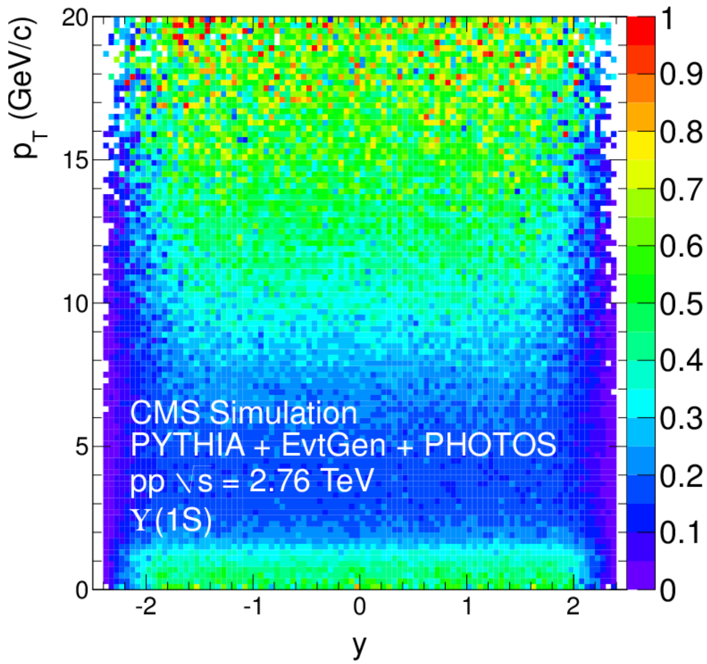
Muon reconstruction in CMS



- Excellent muon identification & triggering (Muon system)
- High mass/momentum resolution (Tracker)

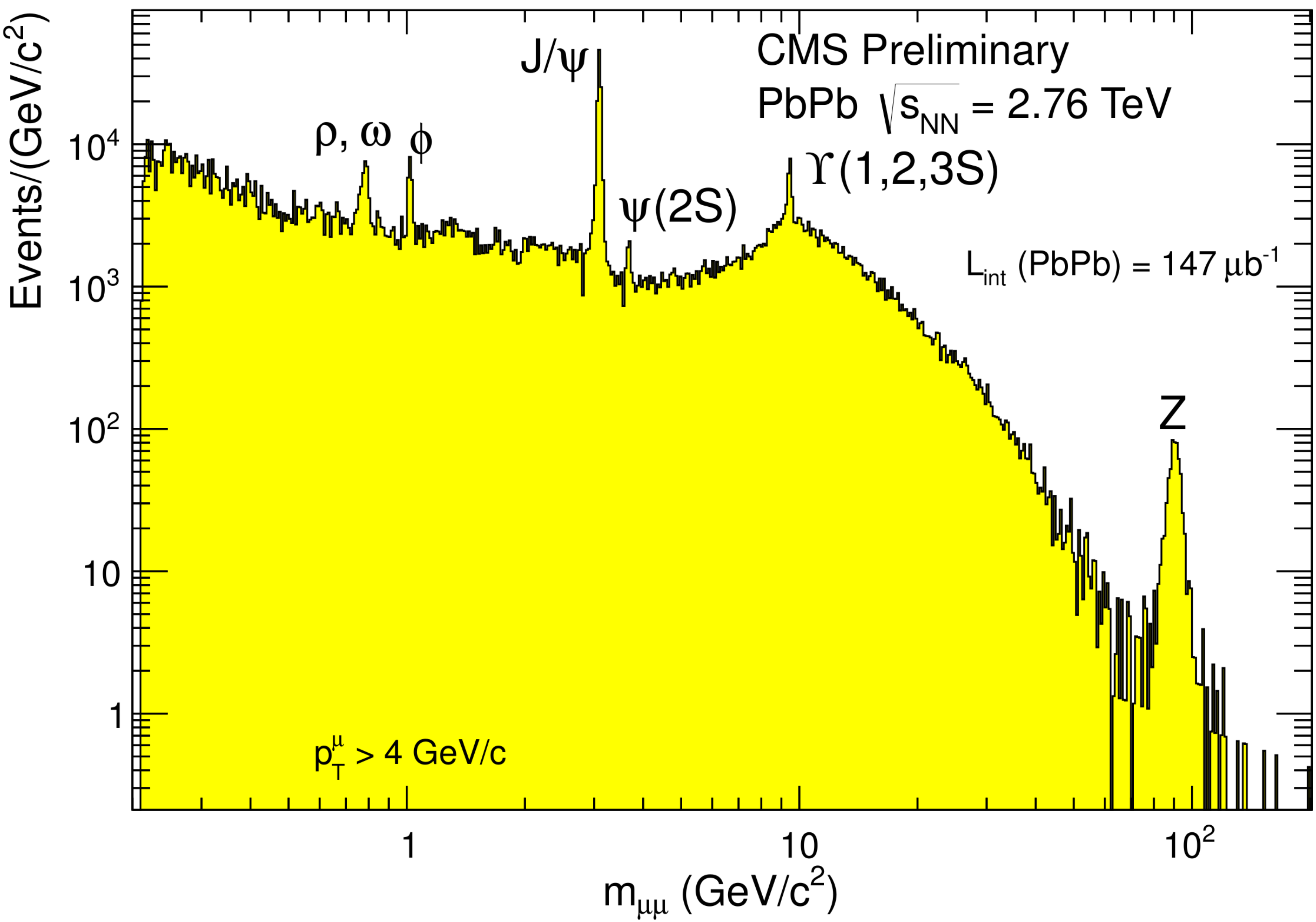
Dimuon acceptance



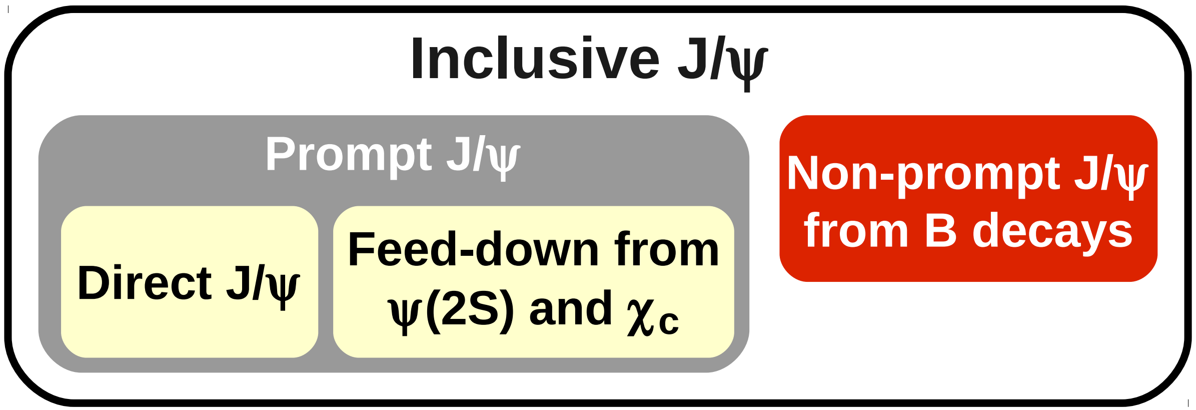


- Due to the strong magnetic field and energy loss in the absorber, minimum momentum to reach the muon stations is 3~5 GeV/c
- J/ψ acceptance
  - Mid-rapidity: J/ψ $p_T > 6.5$ GeV/c
  - Forward rapidity: J/ψ $p_T > 3$ GeV/c
- ϒ acceptance
  - All rapidity: ϒ $p_T > 0$ GeV/c

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

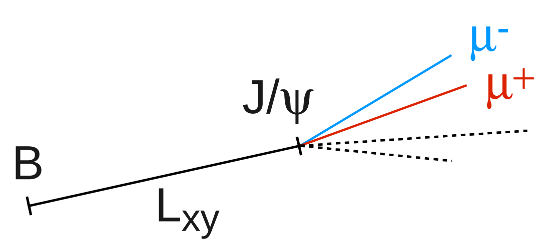


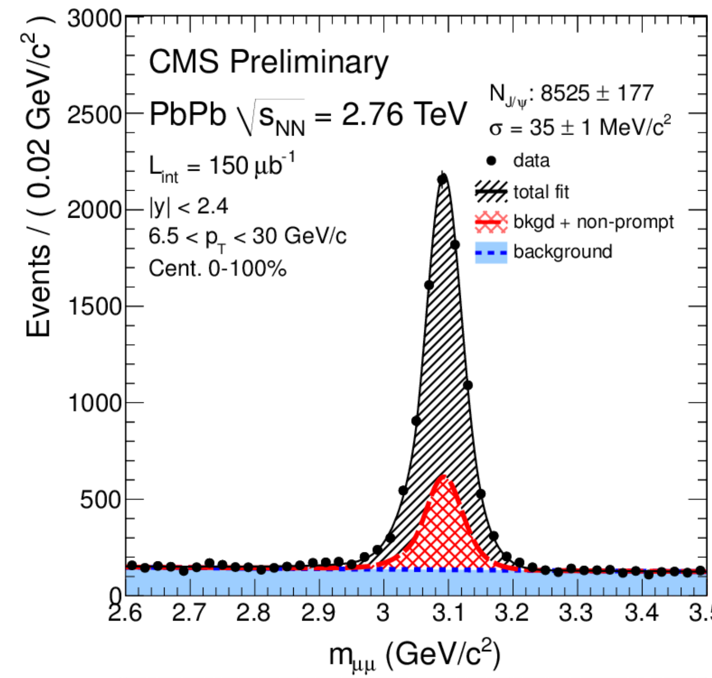
J/ψ in PbPb at $\sqrt{s_{NN}}$ =2.76 TeV

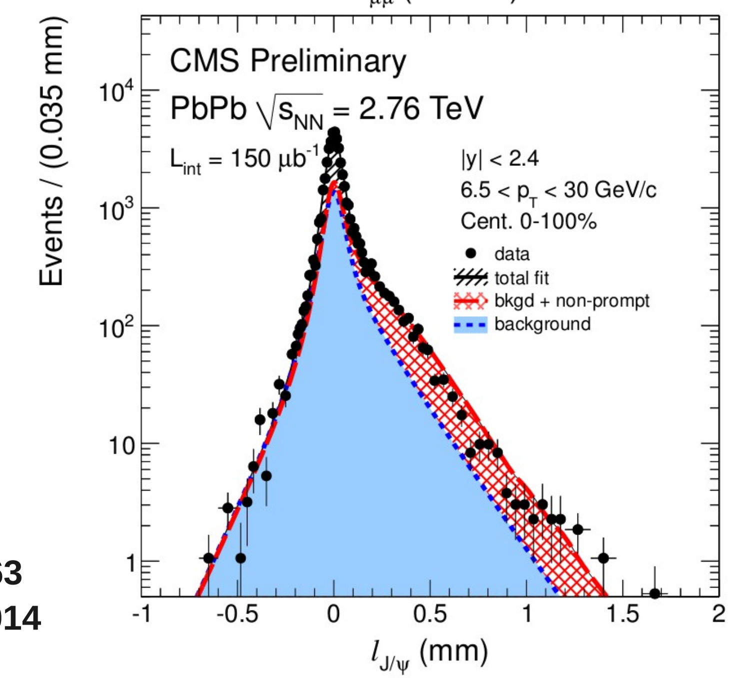


- Reconstruction of $\mu^+\mu^-$ vertex
- 2D simultaneous fit of $\mu^+\mu^-$ mass and pseudo-proper decay length $l_{J/\psi}$
- Extract the non-prompt J/ψ fraction

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

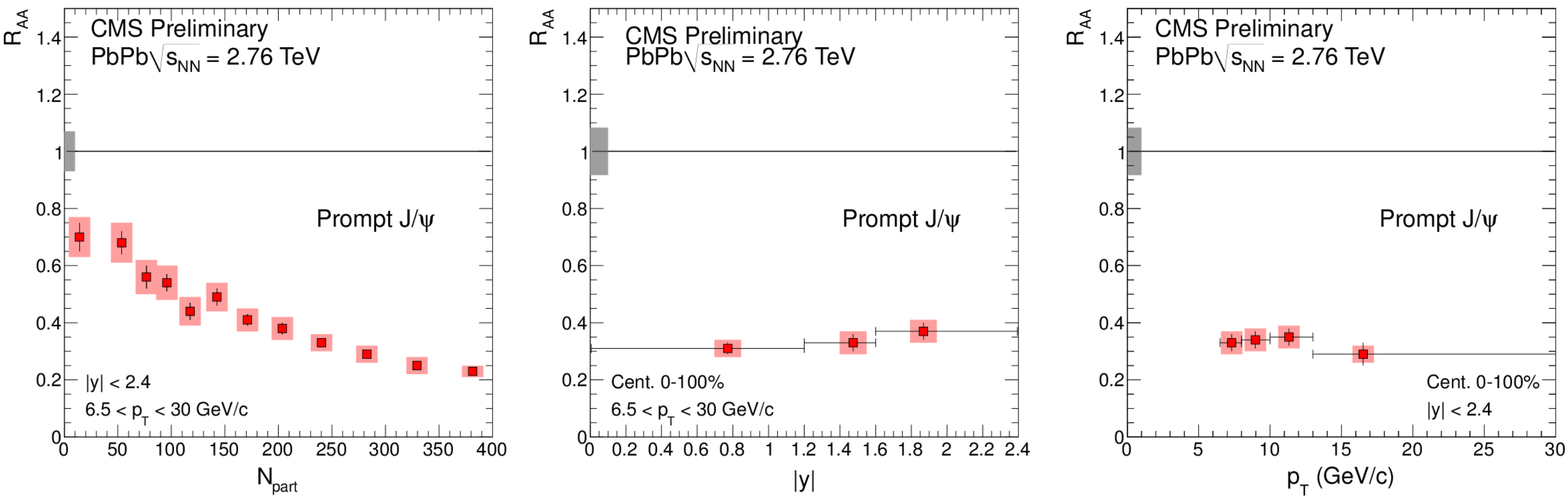






2010 PbPb data 7.28 μb^{-1}: JHEP 05 (2012) 063
2011 PbPb data 150 μb^{-1}: CMS PAS HIN-12-014

Prompt J/ψ R_{AA}



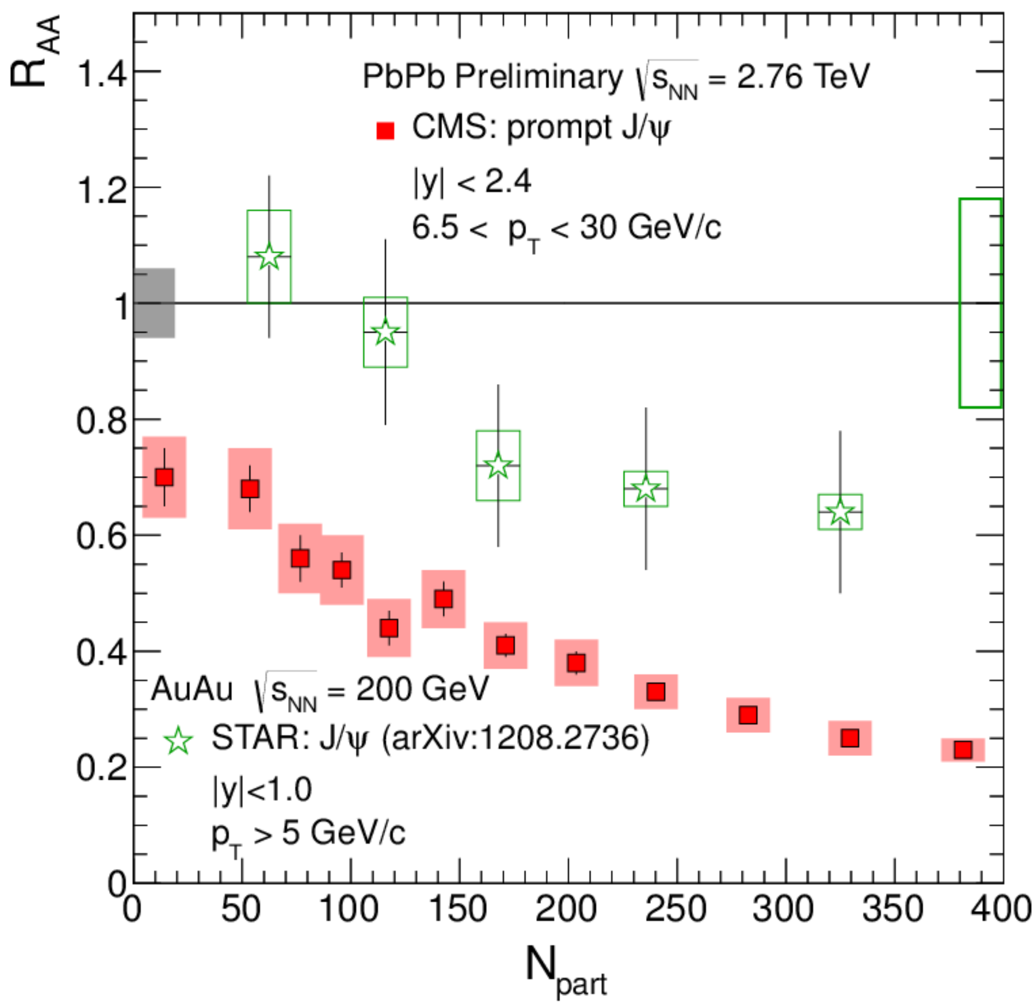
$$R_{AA} = \frac{L_{pp}}{T_{AA} N_{MB}} \frac{N_{PbPb}(J/\psi)}{N_{pp}(J/\psi)} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}(Cent.)}$$

- Prompt J/ψ R_{AA} with pp reference at 2.76 TeV, 231 nb^{-1}
- Strong centrality dependence on $6.5 < p_T < 30$ GeV/c, $|y| < 2.4$ region
  - 0-5% centrality events shows suppression by a factor 5
- No significant dependence on rapidity or p_T

CMS PAS HIN-12-014

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN12014

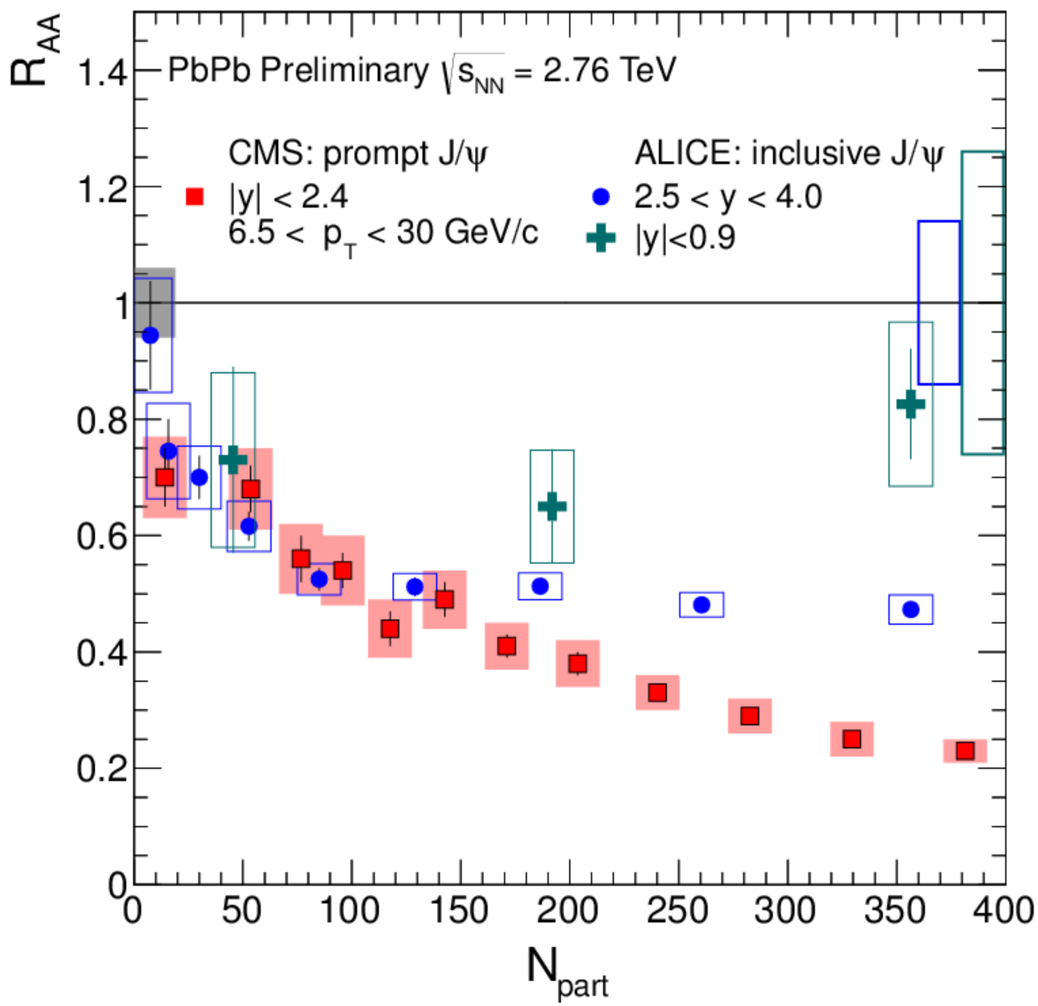
Prompt J/ψ R_{AA} : Comparison to STAR



- 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 trends but stronger suppression at CMS

CMS PAS HIN-12-014
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN12014

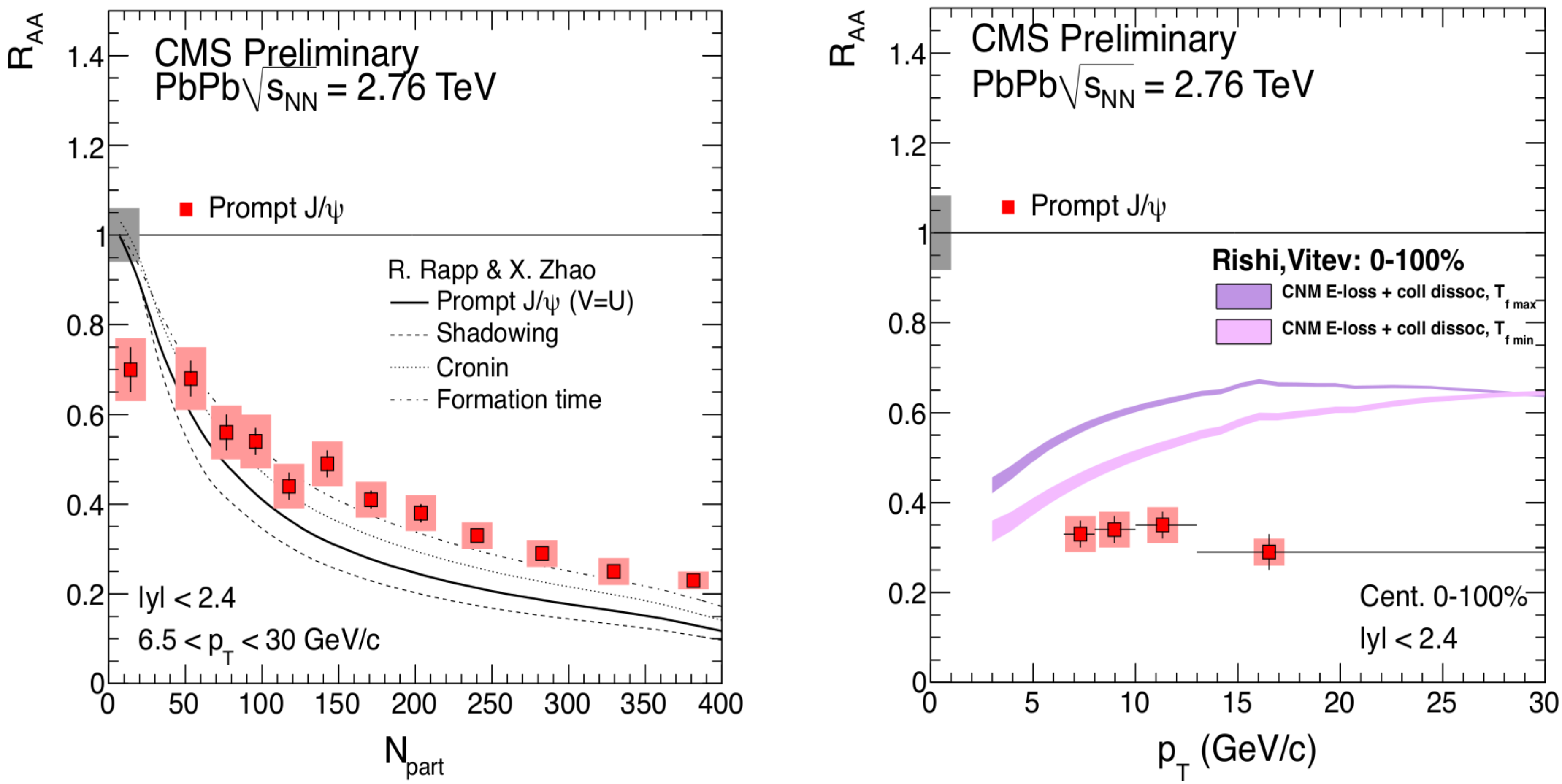
Prompt J/ψ R_{AA} : Comparison to ALICE



- 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

CMS PAS HIN-12-014
ALICE forward rapidity: Phys. Rev. Lett. 109 (2012) 072301,
ALICE mid-rapidity: preliminary results from QM2012

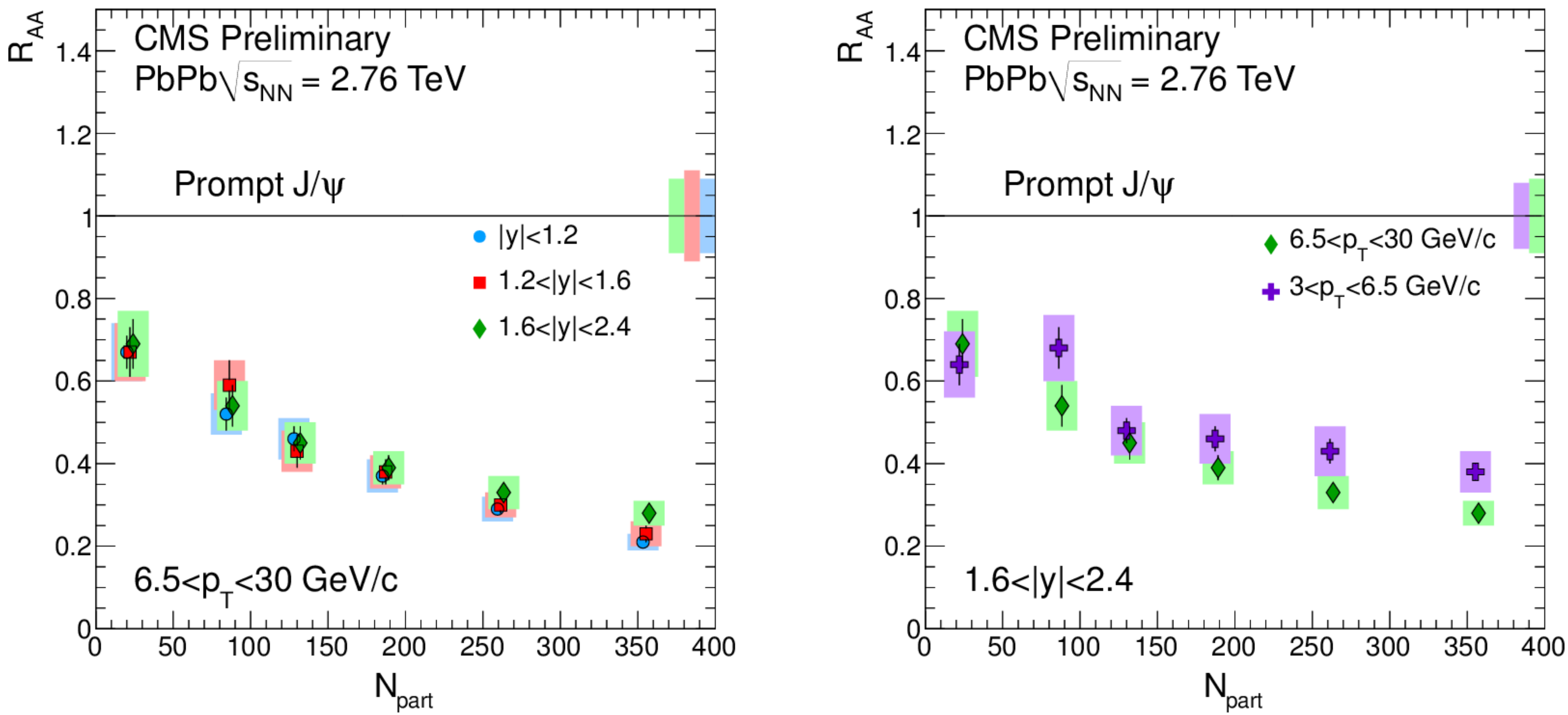
Prompt J/ψ R_{AA} : Comparison to theory



- Prompt J/ψ R_{AA} 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
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN12014

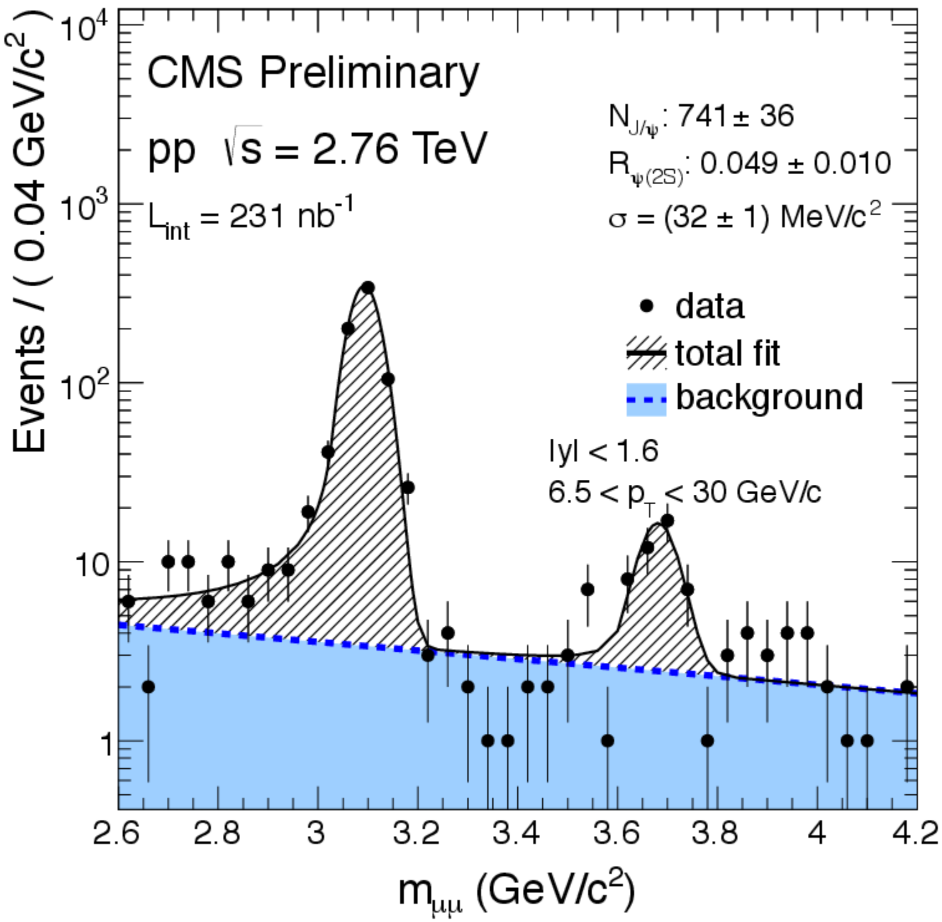
Prompt J/ψ R_{AA} : Double differential

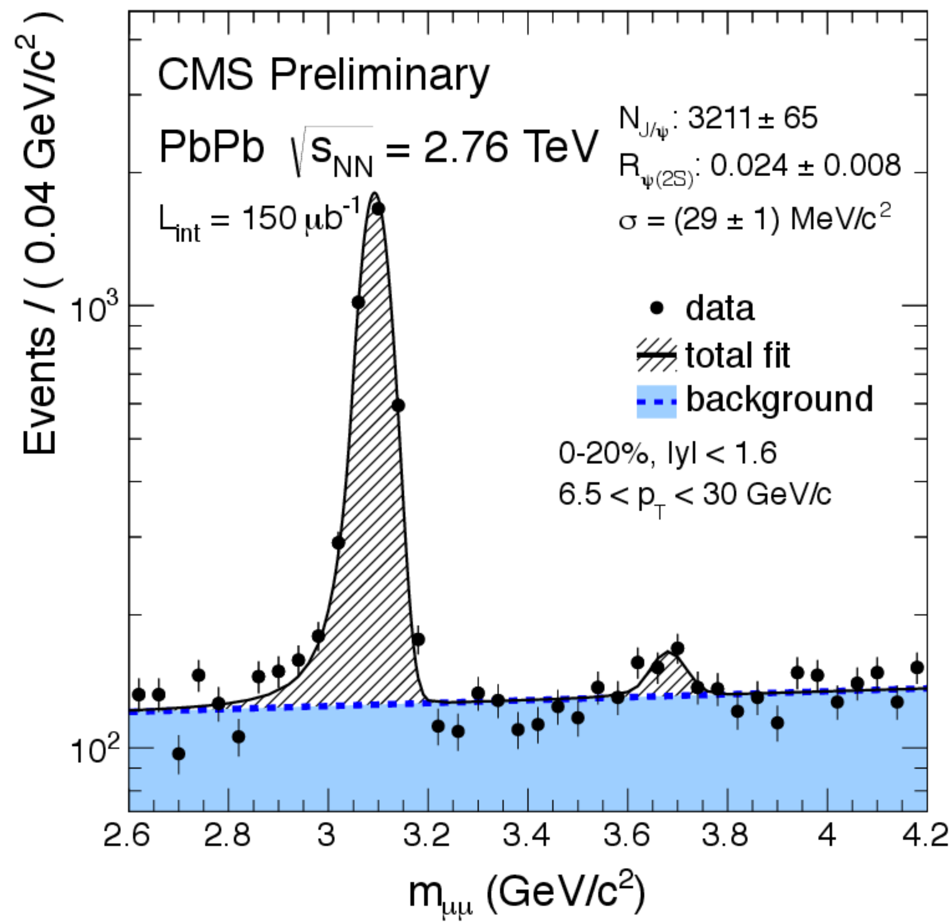


- Different rapidity regions have similar centrality dependent suppression for same amount for $6.5 < p_T < 30$ GeV/c
- At forward rapidity, lower p_T ($3 < p_T < 6.5$ GeV/c) is accessible
  - In most central case, lower p_T is slightly less suppressed

CMS PAS HIN-12-014
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN12014

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



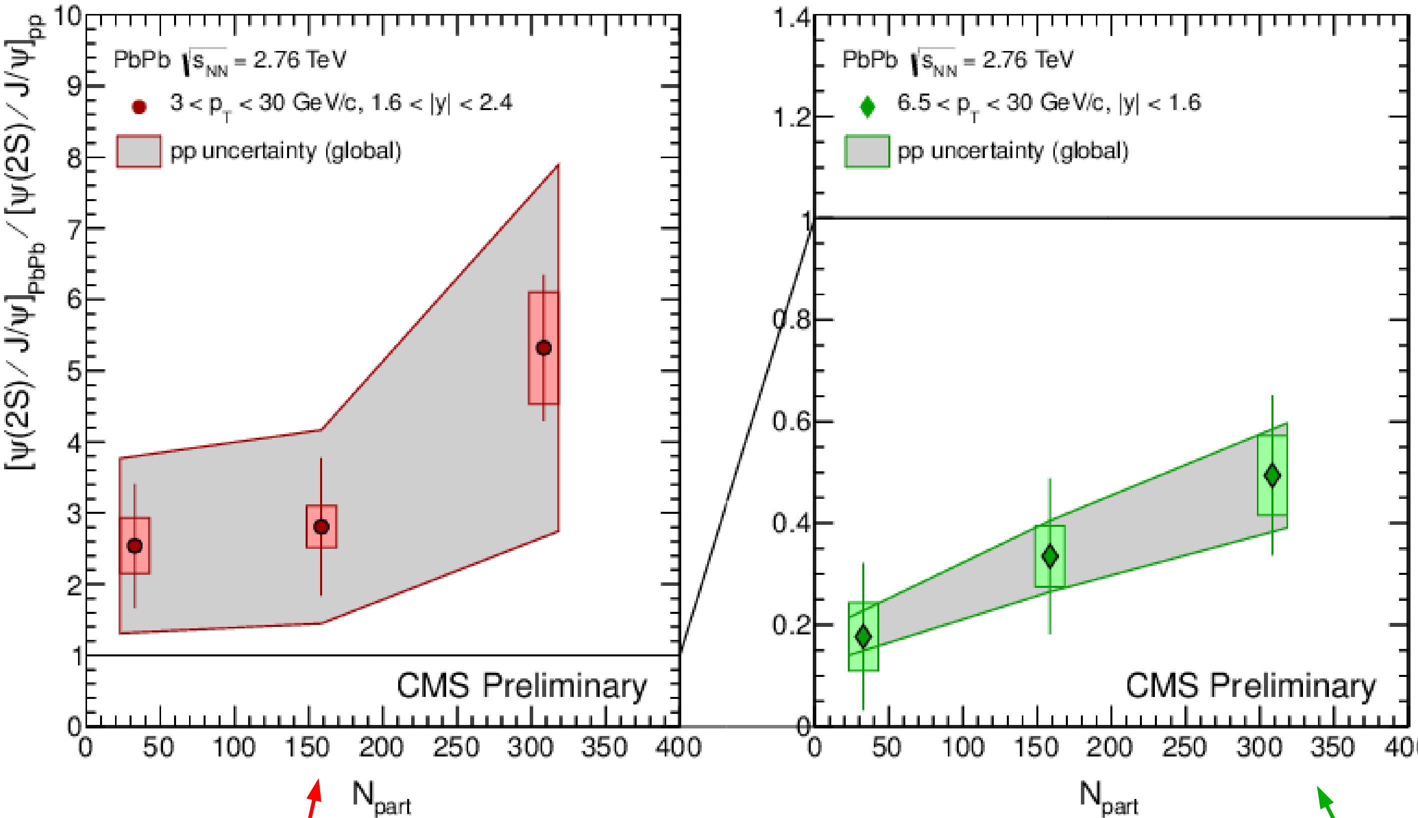


$$R_{\psi(2S)} = \frac{\psi(2S)/J/\psi \;\; (PbPb)}{\psi(2S)/J/\psi \;\; (pp)}$$

- $R_{\psi(2S)}$ in 0-20% PbPb is ~2x smaller than in pp at $p_T > 6.5$ 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

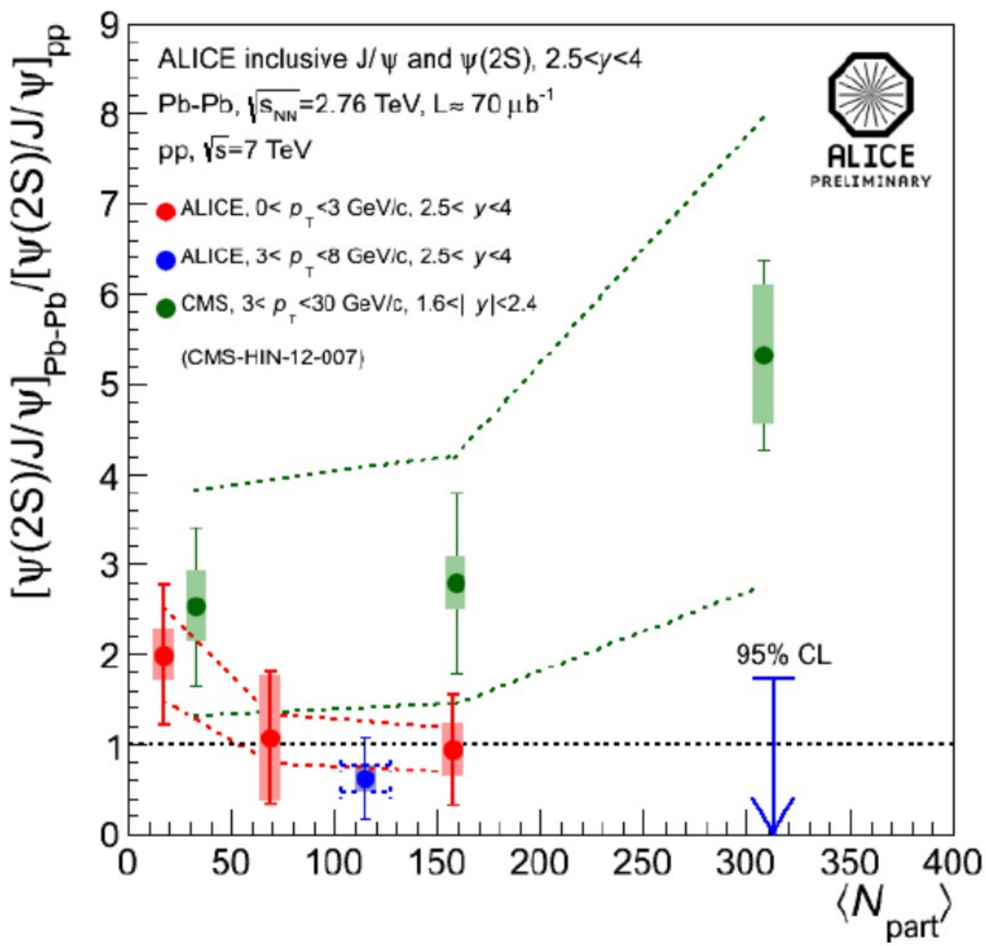
$$R_{AA}(\psi(2S)) = \frac{\psi(2S)/J/\psi\ (PbPb)}{\psi(2S)/J/\psi\ (pp)} \times R_{AA}(J/\psi)$$

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

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

- For p_T > 3 GeV/c, 1.6 < |y| < 2.4, large uncertainties on pp
  - Indication of ψ(2S) is less suppressed than J/ψ but need more statistics
- ψ(2S) is more suppressed at p_T > 6.5 GeV/c, |y| < 1.6

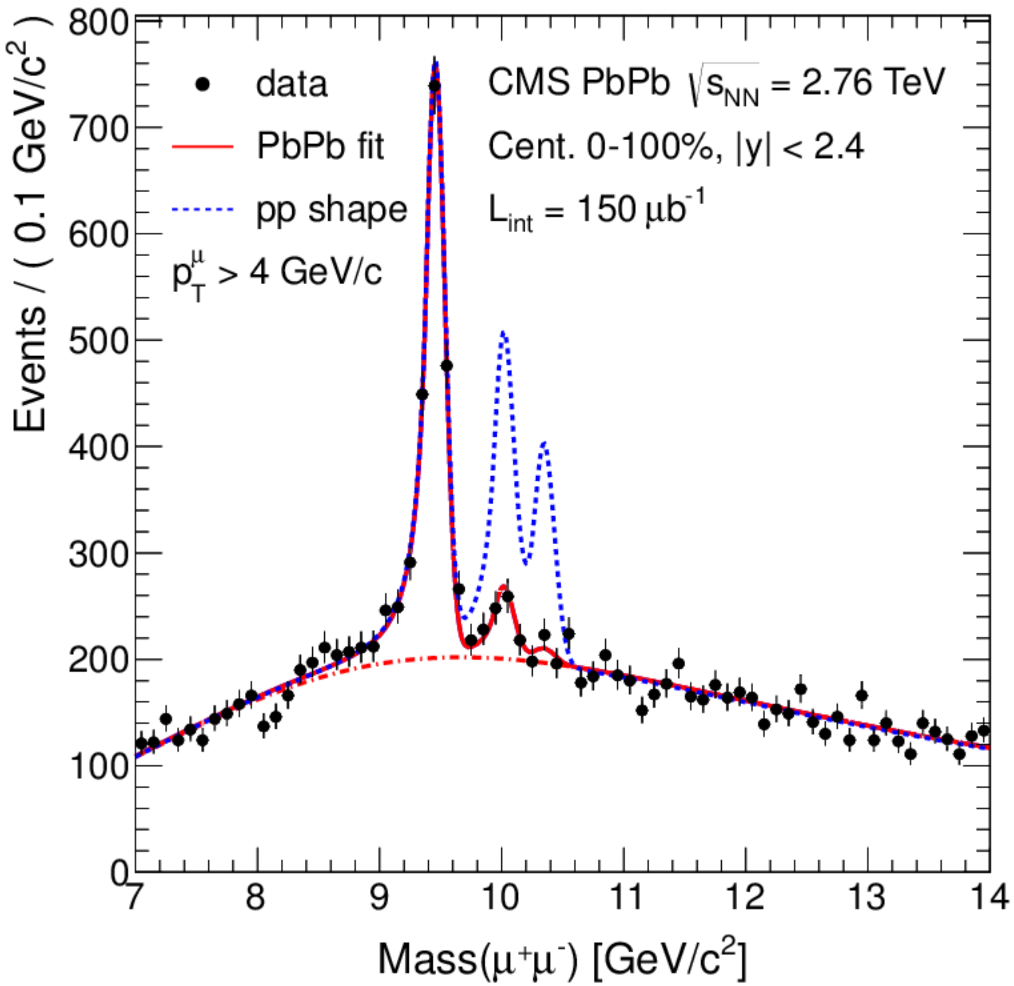
ψ(2S) / J/ψ Double ratio : CMS and ALICE



- 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

ϒ(nS)/ϒ(1S) ratios



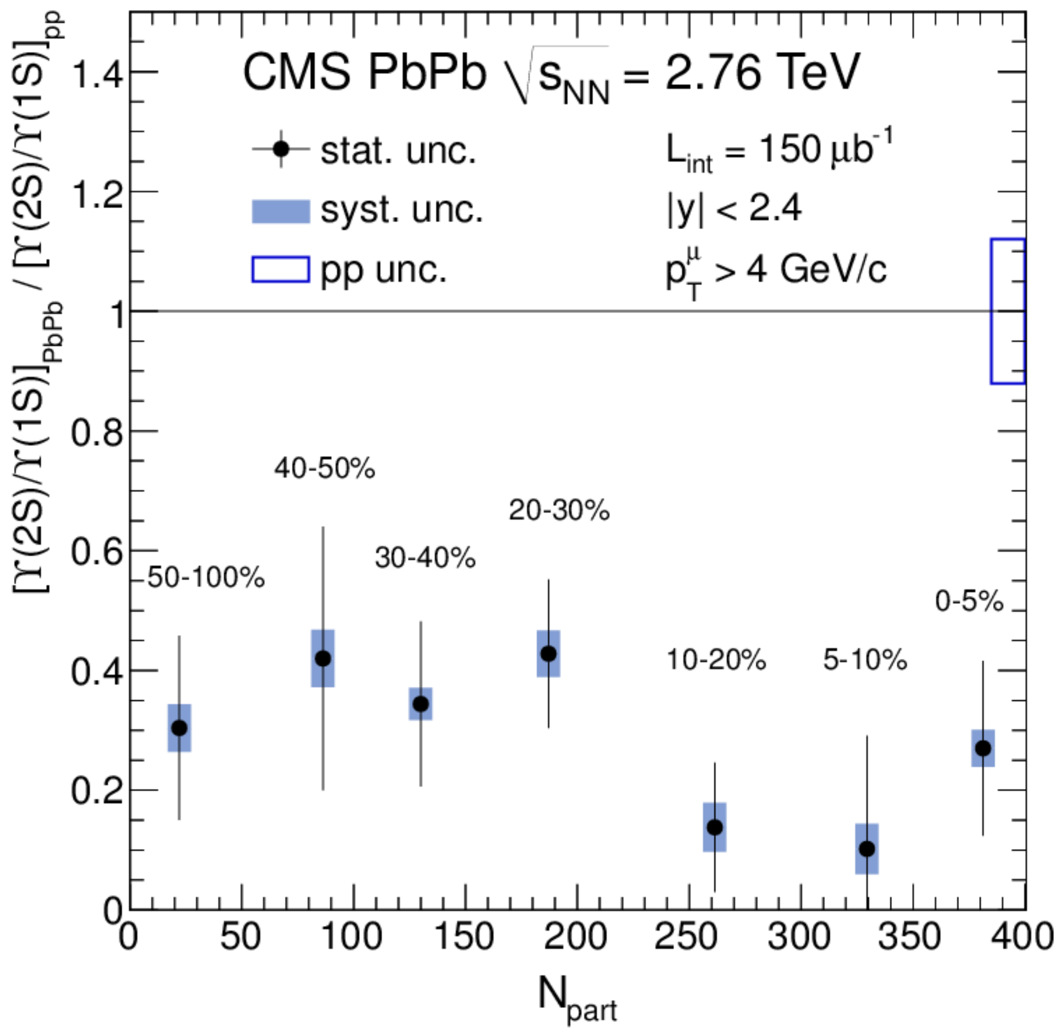
- Fit curve of pp is superimposed onto PbPb data by fixing the Y(1S) yields and background and mass peak components to PbPb
- ϒ(2S)/ϒ(1S) and ϒ(3S)/ϒ(1S) ratio come from fit curve of pp
- Double ratios on minimum-bias

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

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

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

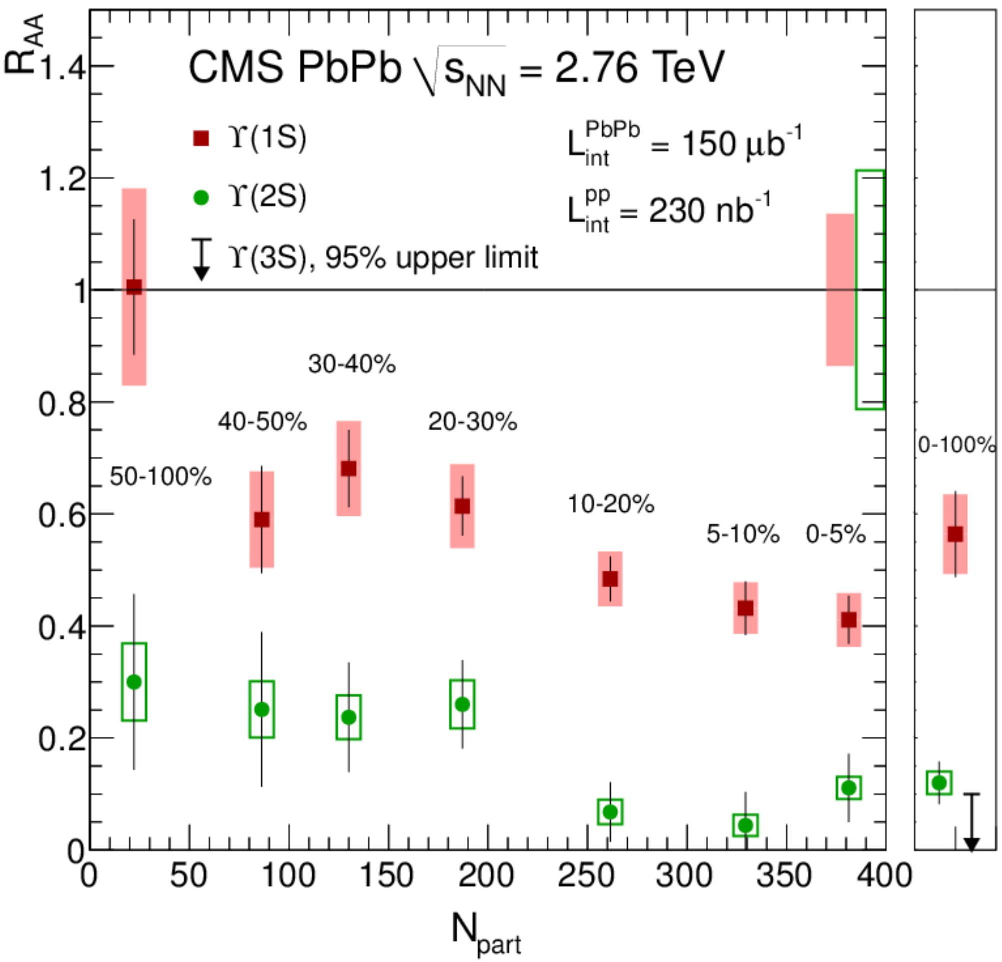
$\Upsilon(nS)/\Upsilon(1S)$ Double ratios



- $\Upsilon(2S)/\Upsilon(1S)$ 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

$\Upsilon(nS)$ R_{AA}



- $\Upsilon(2S)$ is clearly suppressed
- $\Upsilon(1S)$ 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 $\Upsilon(nS)$

$$R_{AA}(Y(1S))=0.56\pm0.08(stat.)\pm0.07(syst.)$$

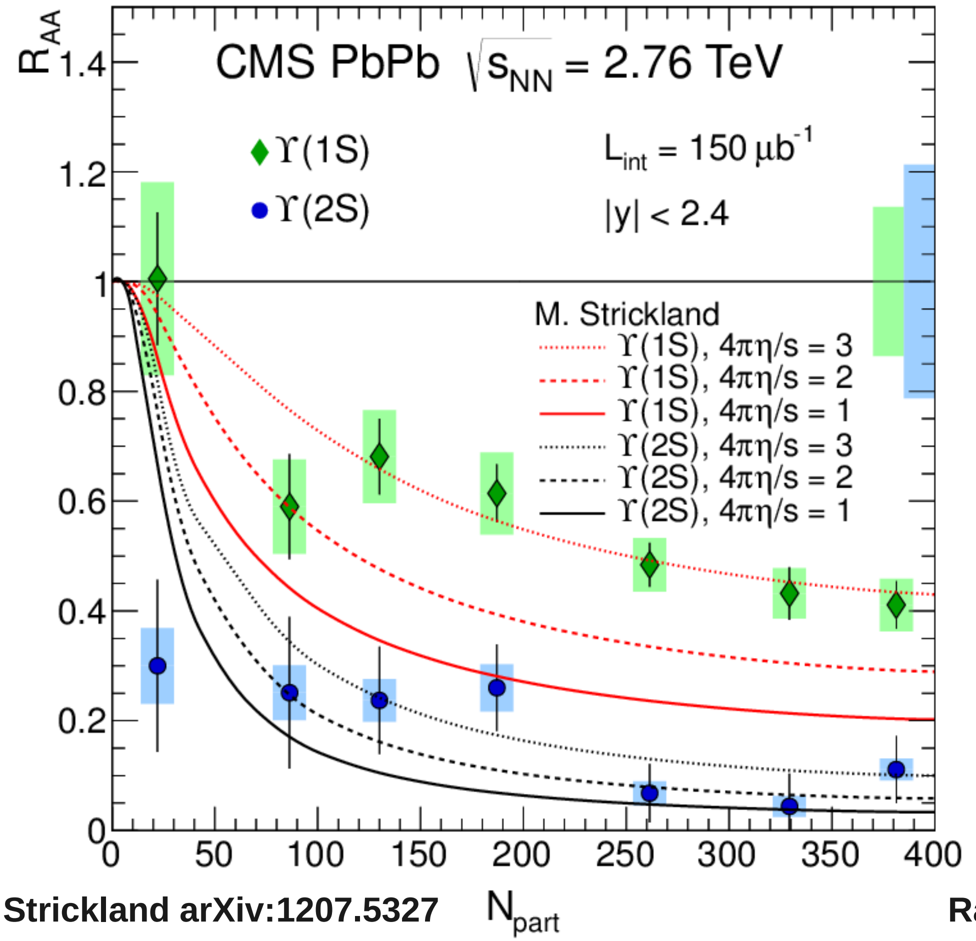
$$R_{AA}(Y(2S))=0.12\pm0.04(stat.)\pm0.02(syst.)$$

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

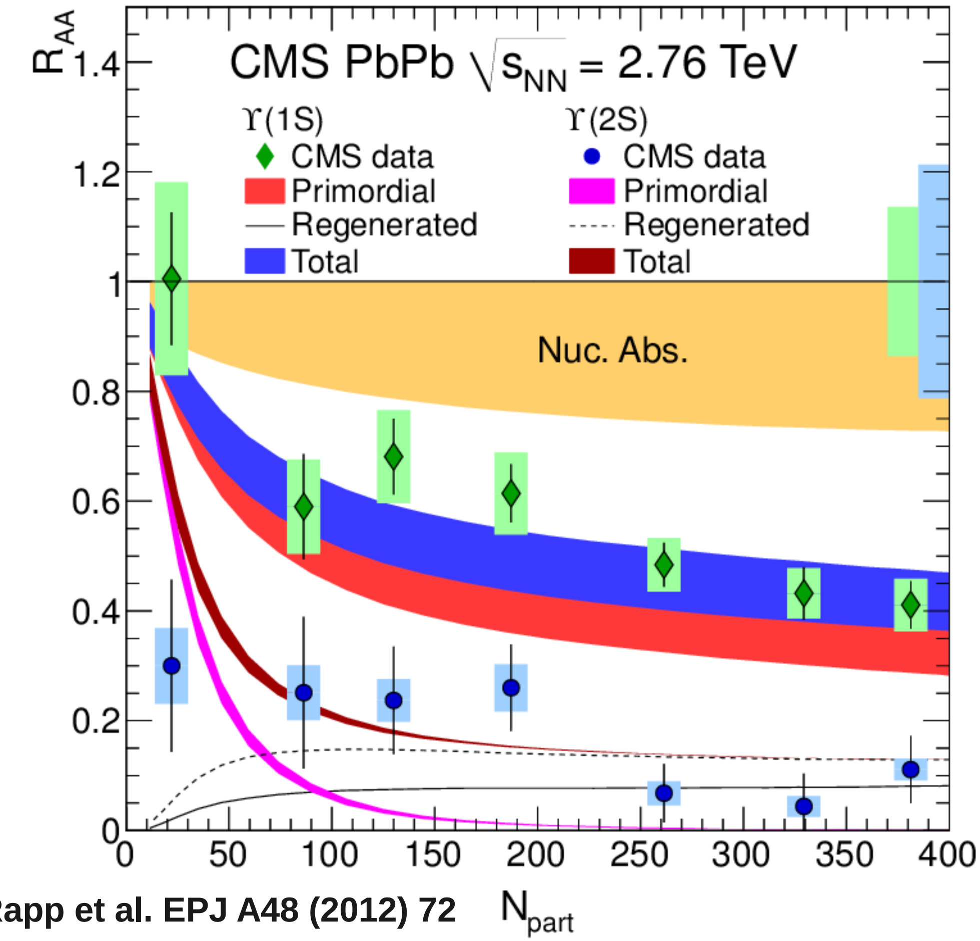
- Sequential suppression of $\Upsilon(nS)$ in order of binding energy

Phys. Rev. Lett. 109 (2012) 222301

Υ(nS) R_{AA} : Comparison to theory



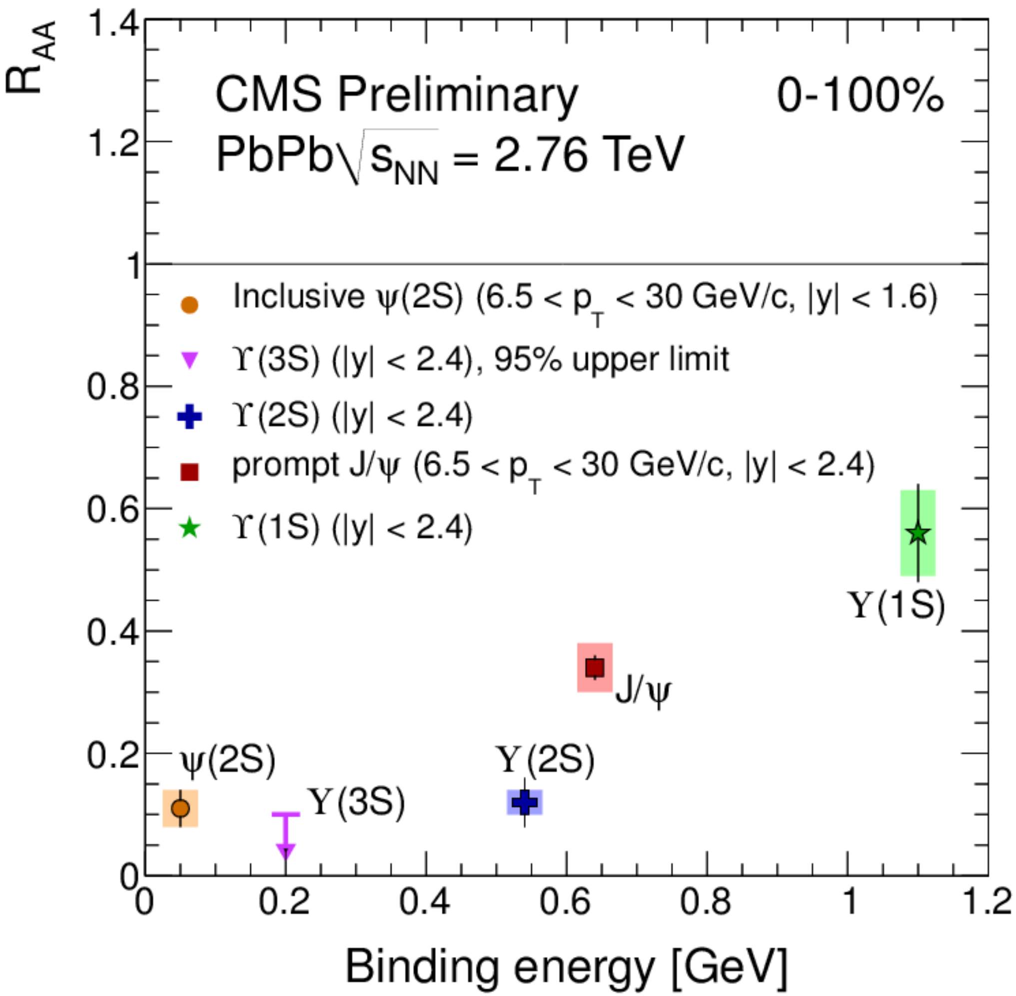
Strickland arXiv:1207.5327



Rapp et al. EPJ A48 (2012) 72

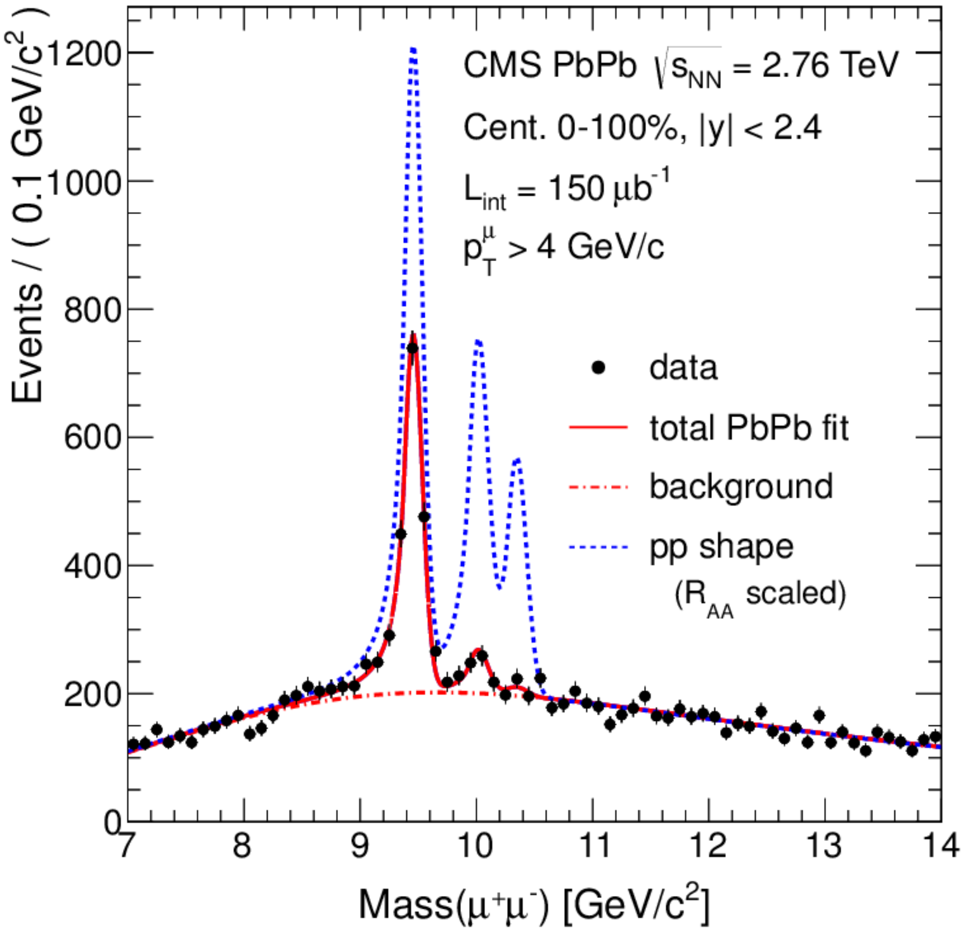
- Strickland: some tension to describe Υ(1S) and Υ(2S) simultaneously with the same η/s value
- Rapp: regeneration and nuclear absorption could be significant also for bottomonia

Summary



- Charmonia at lower p_T
  - ψ(2S) suppression have too large uncertainties to draw a conclusion
- 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

BACK UP

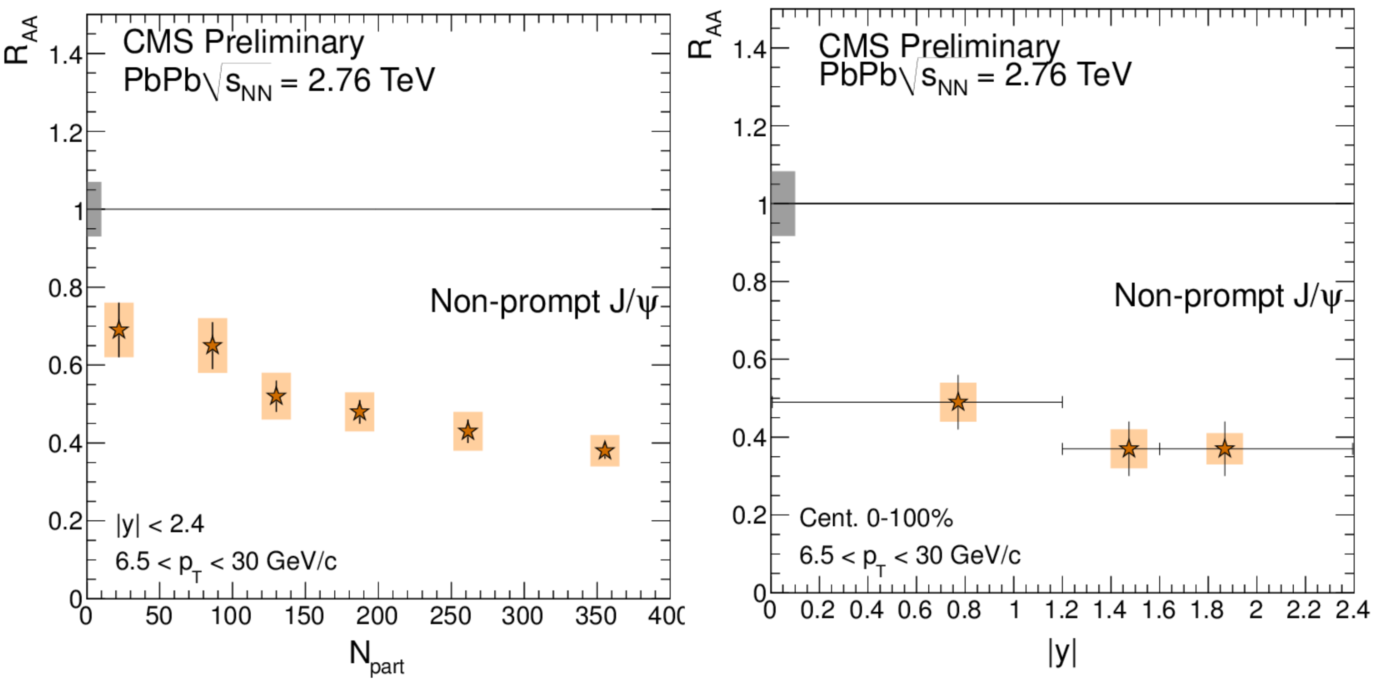

CMS PbPb $\sqrt{s_{NN}}$ = 2.76 TeV
Cent. 0-100%, |y| < 2.4
L_{int} = 150 μb^{-1}
p_T^{μ} > 4 GeV/c
data
total PbPb fit
background
pp shape
(R_{AA} scaled)
Events / (0.1 GeV/c^2)
Mass($\mu^+\mu^-$) [GeV/c^2]
0
200
400
600
800
1000
1200
7
8
9
10
11
12
13
14

Non-prompt J/ψ

- Partons in the medium lose energy by inelastic/elastic collisions
- Dead-cone effect
  - Small-angle gluon radiation for heavy quarks is reduced
- R_{AA}(light hadrons) < R_{AA}(D) < R_{AA}(B)

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

Non-prompt J/ψ R_{AA}

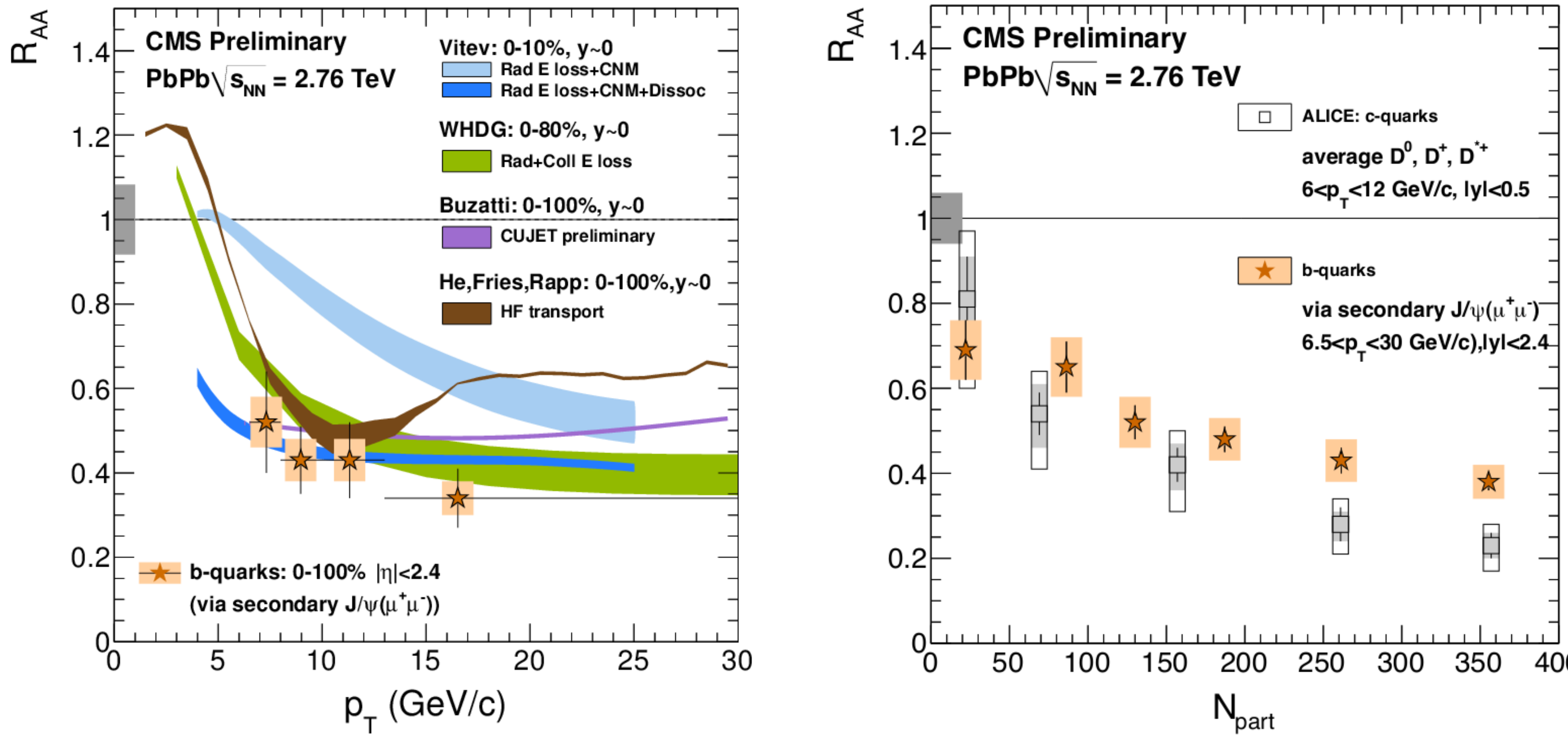


- Non-prompt J/ψ from b-hadron decays is a probe to energy loss of b quarks in the medium
- Centrality dependent suppression on $6.5 < p_T < 30$ GeV/c, $|y| < 2.4$ region
  - 0-5% centrality events shows suppression by a factor 2.5
- A hint of rapidity or p_T dependent suppression

CMS PAS HIN-12-014

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN12014

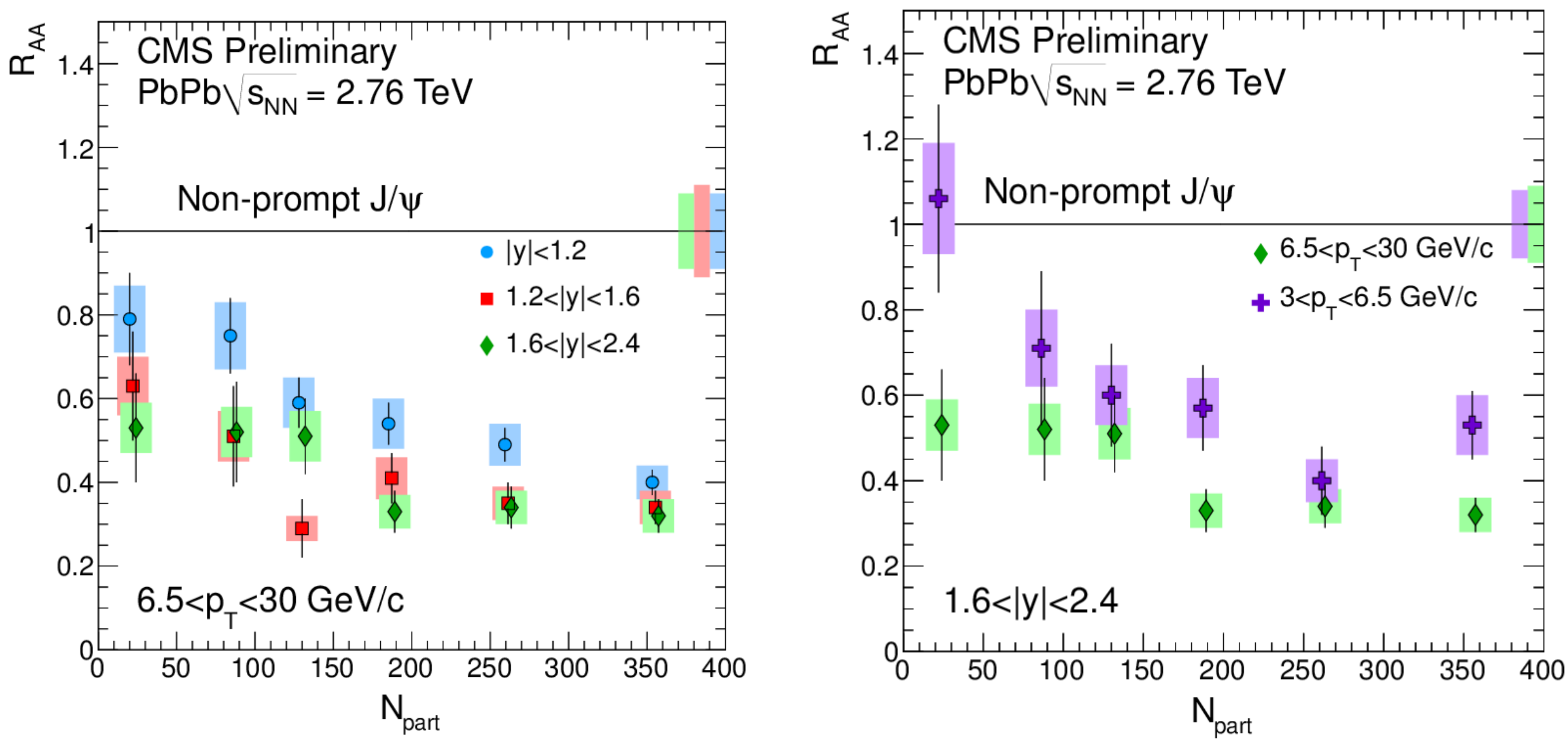
Non-prompt J/ψ R_{AA} : Comparison to theory



- 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} as a function of centrality

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.

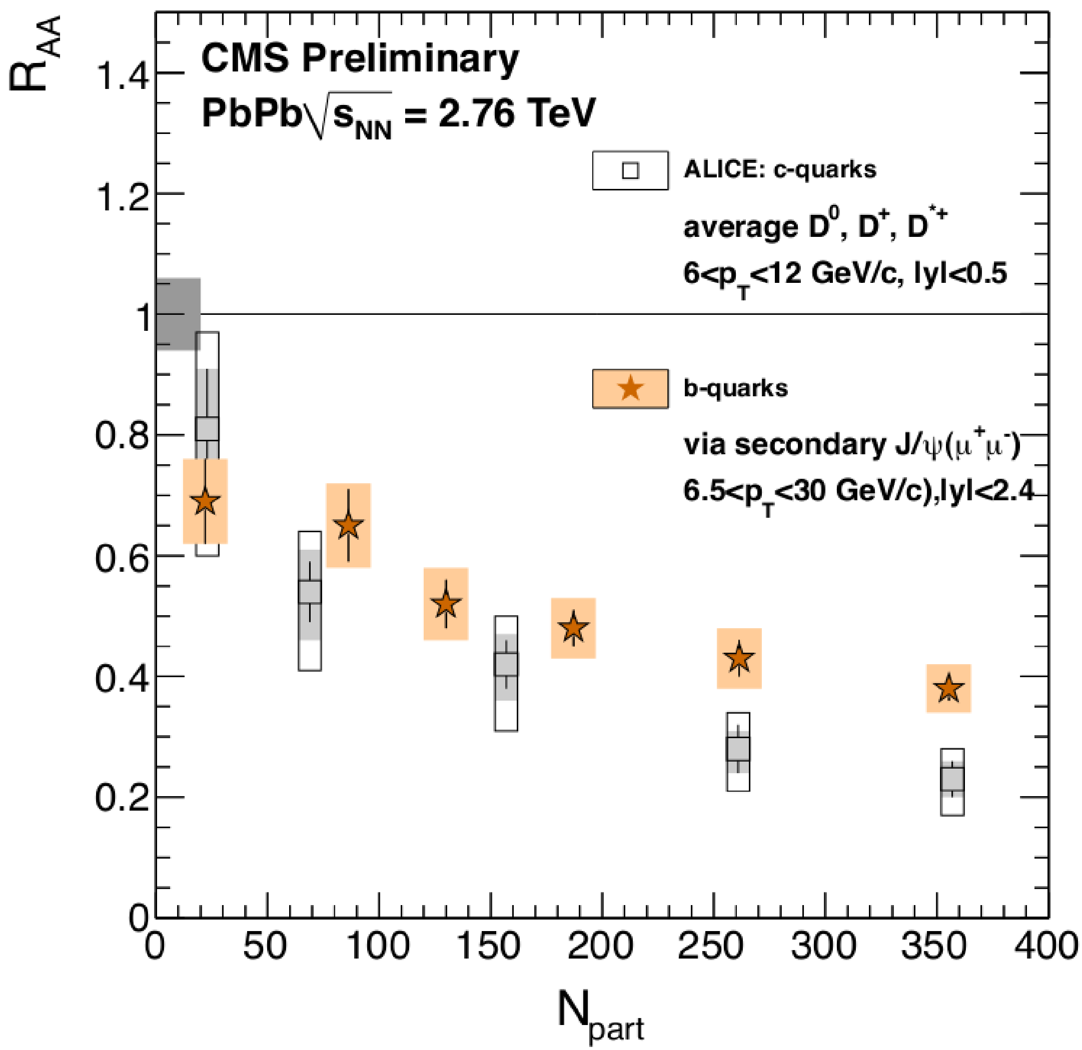
Non-prompt J/ψ R_{AA} : Double differential



- Centrality dependence is observed on all rapidity region
- At forward rapidity, 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

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN12014


CMS Preliminary
PbPb $\sqrt{s_{NN}}$ = 2.76 TeV
ALICE: c-quarks
average D^0, D^+, D^{*+}
6<p_T<12 GeV/c, |y|<0.5
b-quarks
via secondary J/ψ($\mu^+\mu^-$)
6.5<p_T<30 GeV/c),|y|<2.4
R_{AA}
N_{part}