Quarkonia and heavy-flavour production in CMS

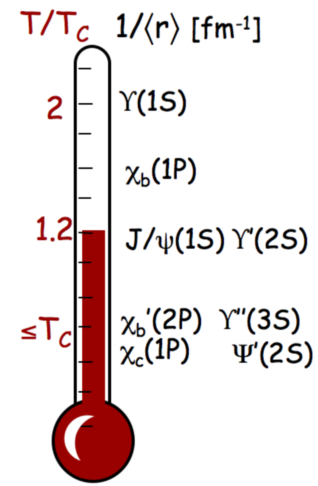
– Torsten Dahms –
LLR – École Polytechnique
(on behalf of CMS)

Quarkonia and the QGP

- Heavy quarks
  - produced in the initial hard-scattering process
- Debye screening in QGP leads to melting of quarkonia
- Different binding energy of bound states lead to sequential melting of the states with increasing temperature
  - also observable in the rates of the ground state due to suppression of feed down contribution

State	J/ψ (1S)	χ_c (1P)	ψ' (2S)
m (GeV/c^2)	3.10	3.53	3.68
r_0 (fm)	0.50	0.72	0.90

Υ (1S)	χ_b (1P)	Υ' (2S)	χ'_b (2P)	Υ'' (3S)
9.46	9.99	10.02	10.26	10.36
0.28	0.44	0.56	0.68	0.78



Mocsy,
EPJ C 61 (2009) 705

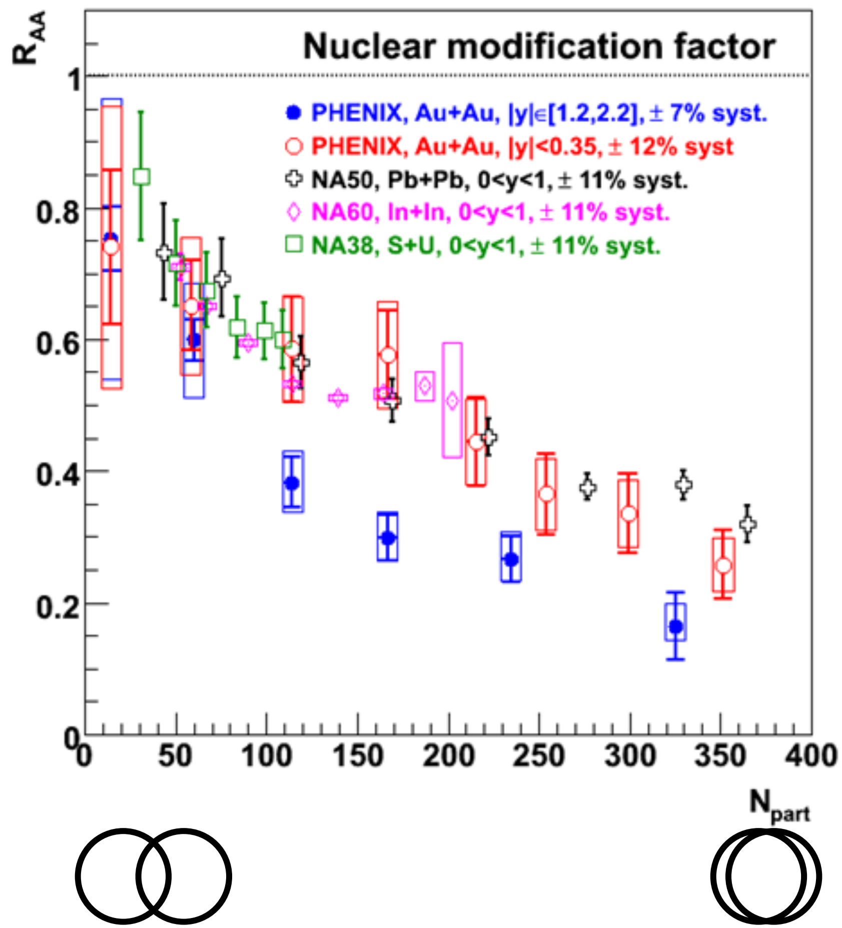
Quarkonia in pp with CMS:
Carlos Lourenco
(Tuesday, 14h15)

The beginning:
Matsui & Satz
PLB 178 (1986) 416

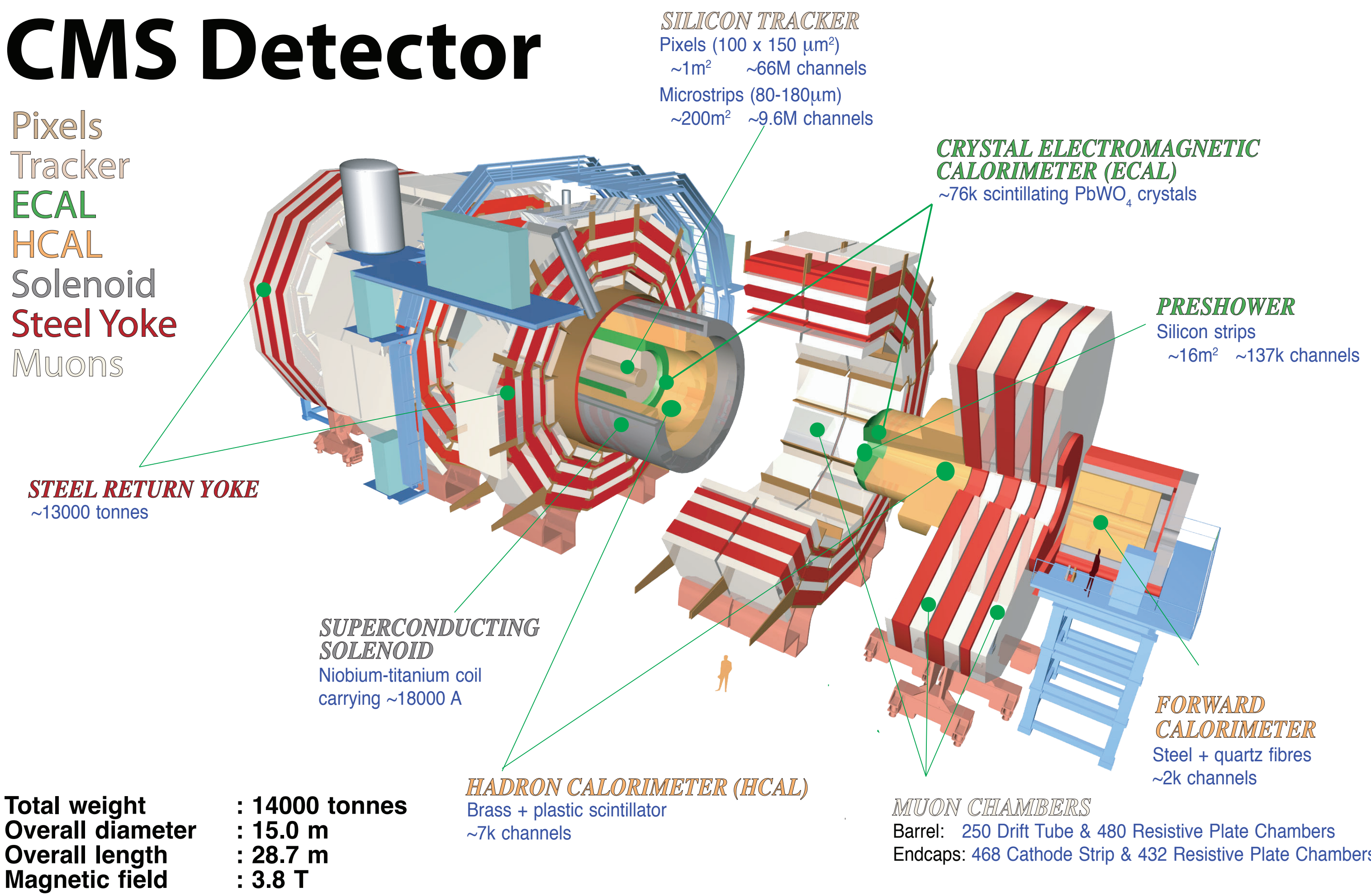
Puzzles from SPS and RHIC

- Similar J/ψ suppression at the SPS and RHIC!
  - despite 10× higher $\sqrt{s_{NN}}$
- Suppression does not increase with local energy density
  - R_{AA}(forward)<R_{AA}(mid)
- Possible ingredients
  - cold nuclear matter effects
  - sequential melting
  - regeneration
- What happens at the LHC?
  - higher energy + higher luminosity
  - more charm (more regeneration?)
  - more bottom → a new probe: Υ

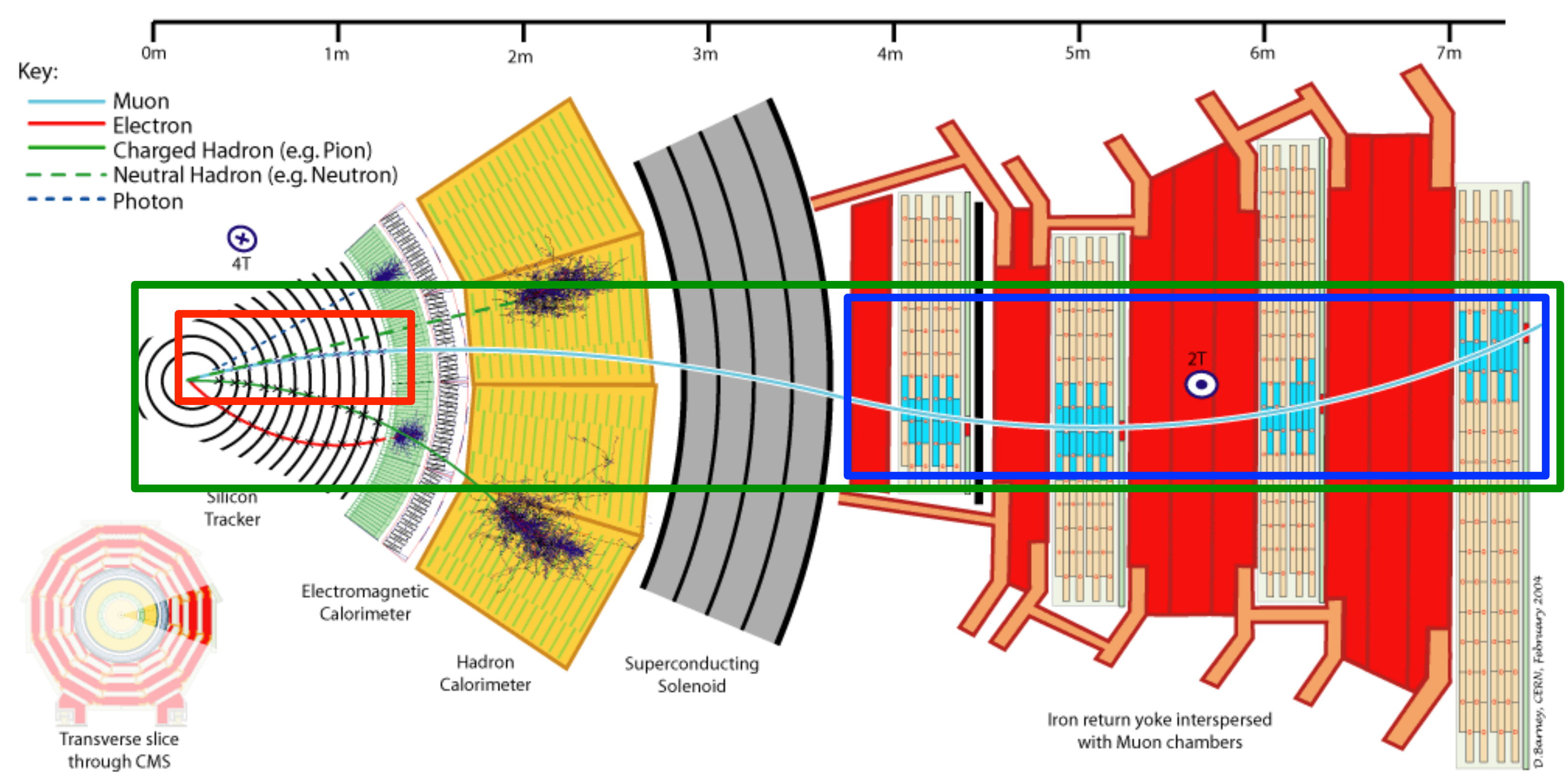
PHENIX, PRL 98 (2007) 232301
also PRC 84 (2011) 054912
SPS from Scomparin @ QM06



The Compact Muon Solenoid

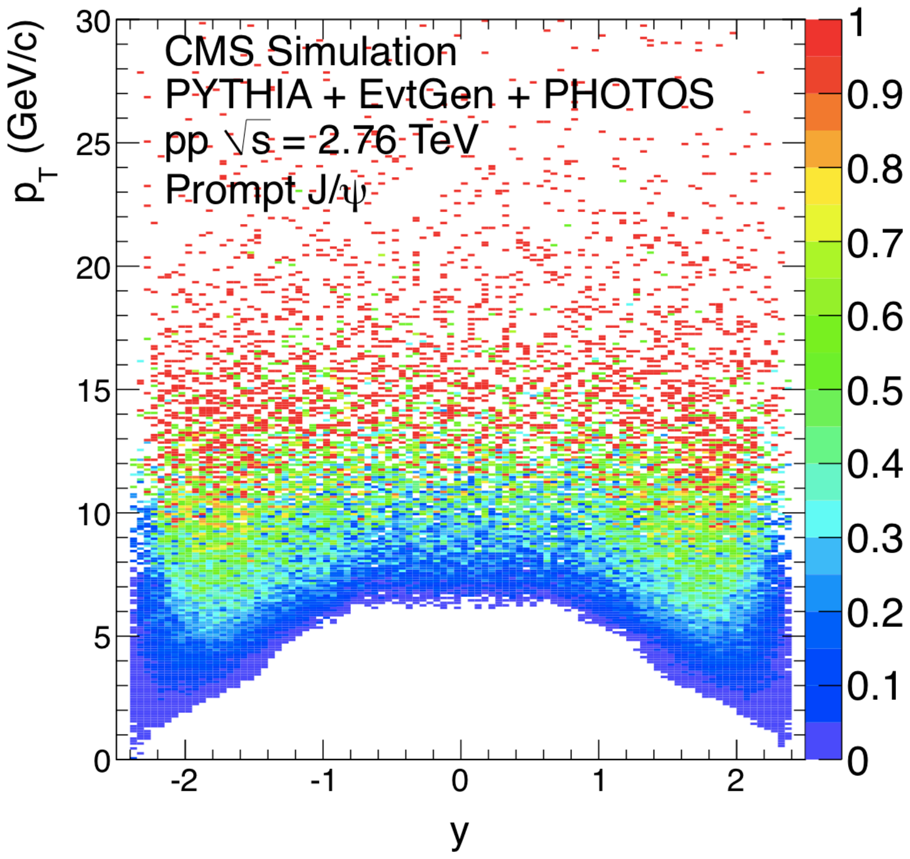


Muon Reconstruction in CMS



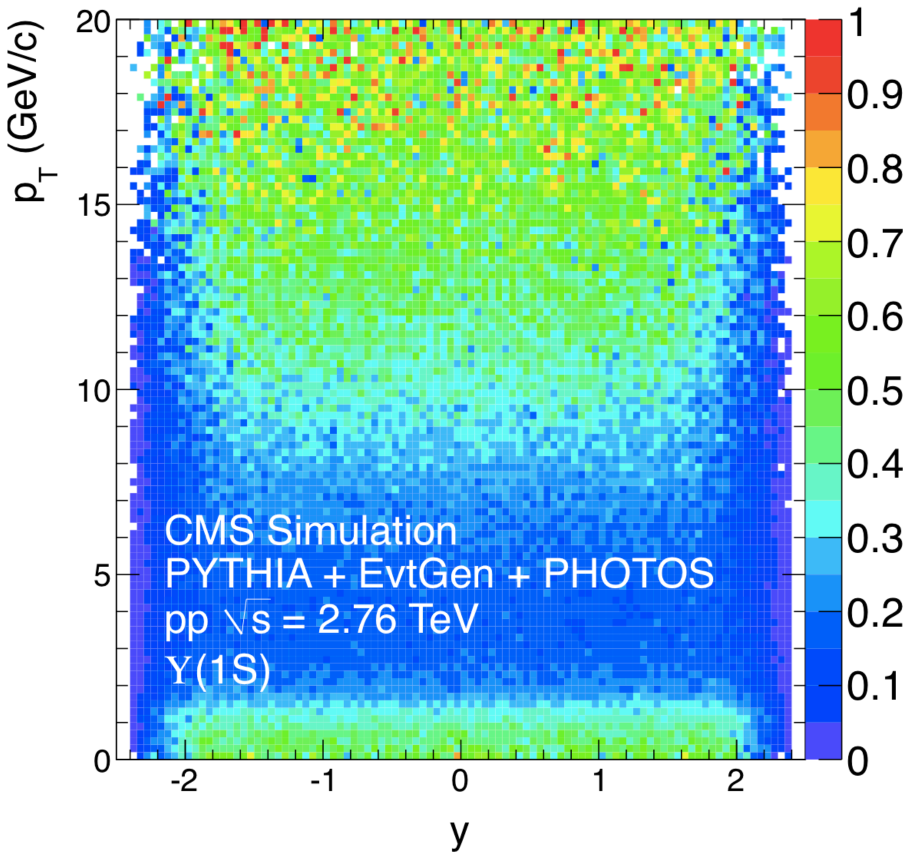
- Global muons reconstructed with information from inner tracker and muon stations
- Further muon ID based on track quality (χ^2, # hits…)

Dimuon Acceptance: J/ψ



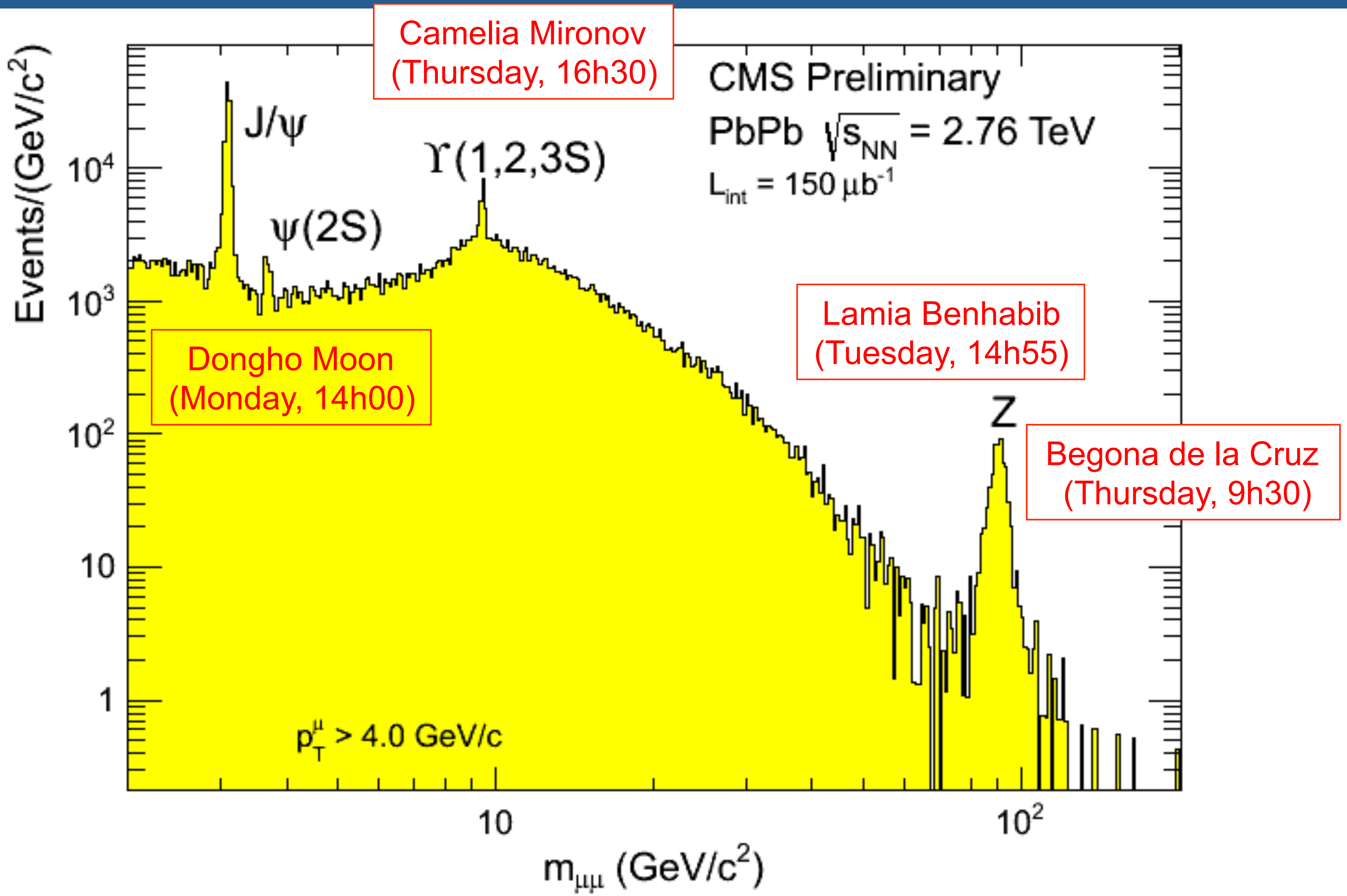
- Muons need to overcome magnetic field and energy loss in absorber
  - minimum total momentum p~3–5 GeV/c to reach muon station
- Limits J/ψ acceptance:
  - mid-rapidity: p_T>6.5 GeV/c
  - forward: p_T>3 GeV/c

Dimuon Acceptance: Υ(1S)

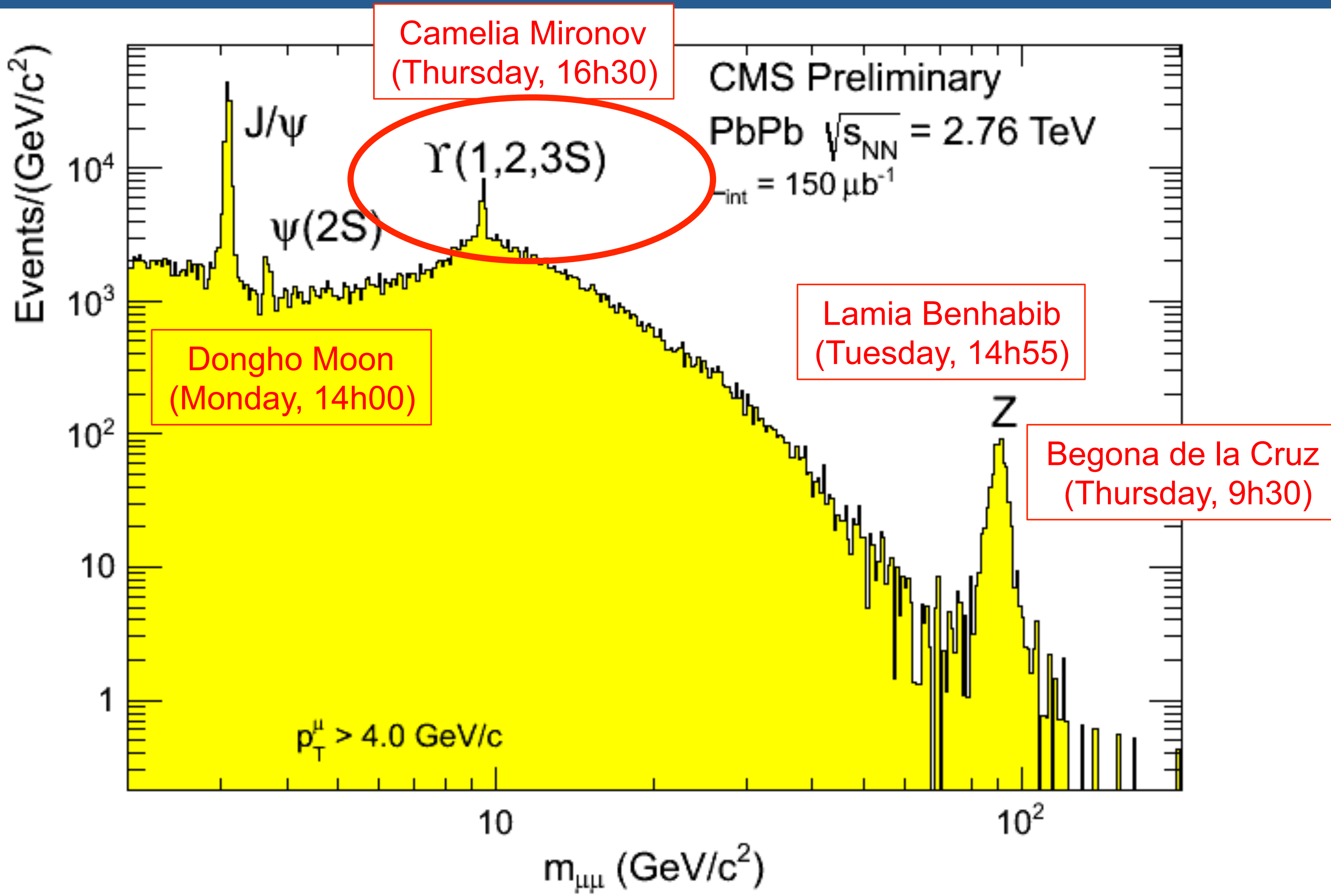


- Muons need to overcome magnetic field and energy loss in absorber
  - minimum total momentum p~3–5 GeV/c to reach muon station
- Limits J/ψ acceptance:
  - mid-rapidity: p_T>6.5 GeV/c
  - forward: p_T>3 GeV/c
- Υ acceptance:
  - p_T>0 GeV/c for all rapidity

Muon Pairs in PbPb at $\sqrt{s_{NN}}$ = 2.76 TeV



Muon Pairs in PbPb at $\sqrt{s_{NN}}$ = 2.76 TeV

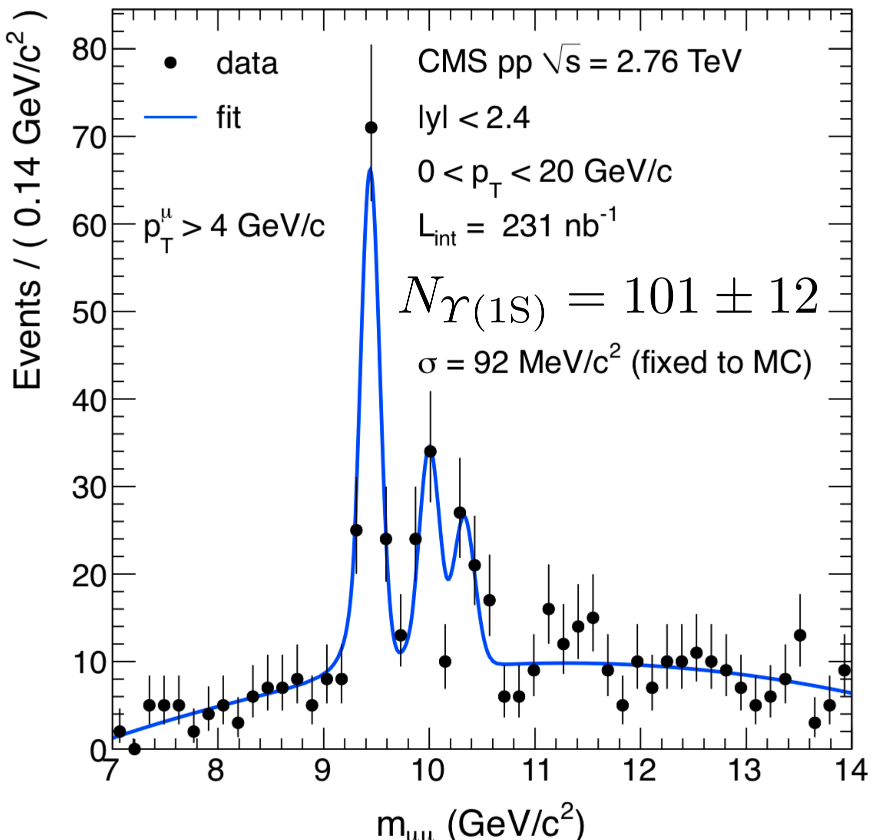


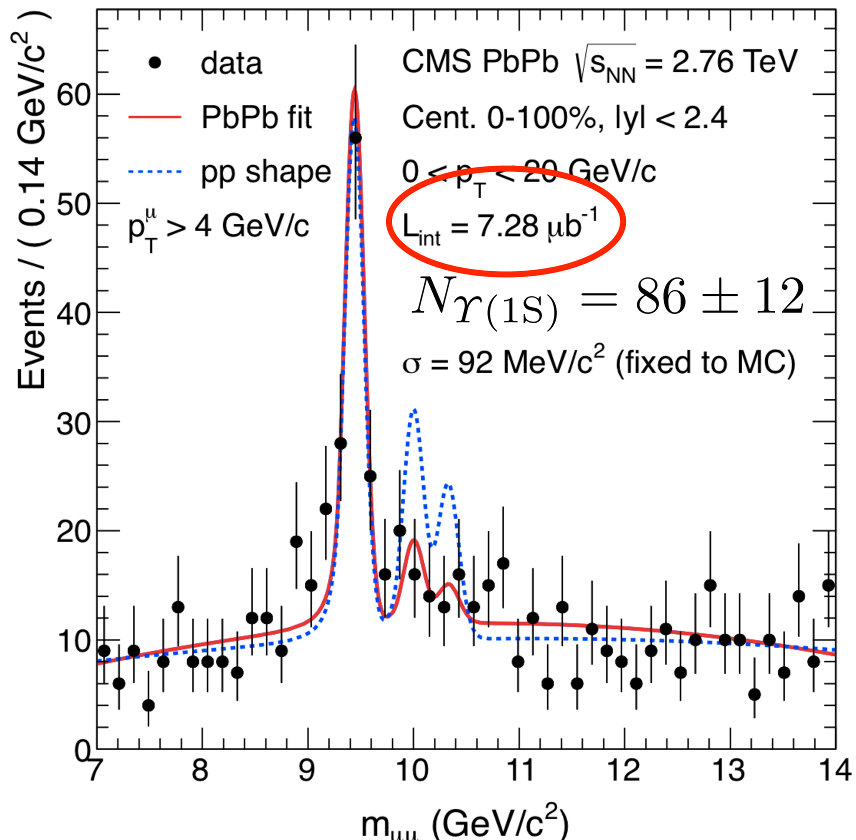
Bottomonia: with 2010 data

pp

PRL 107 (2011) 052302

PbPb





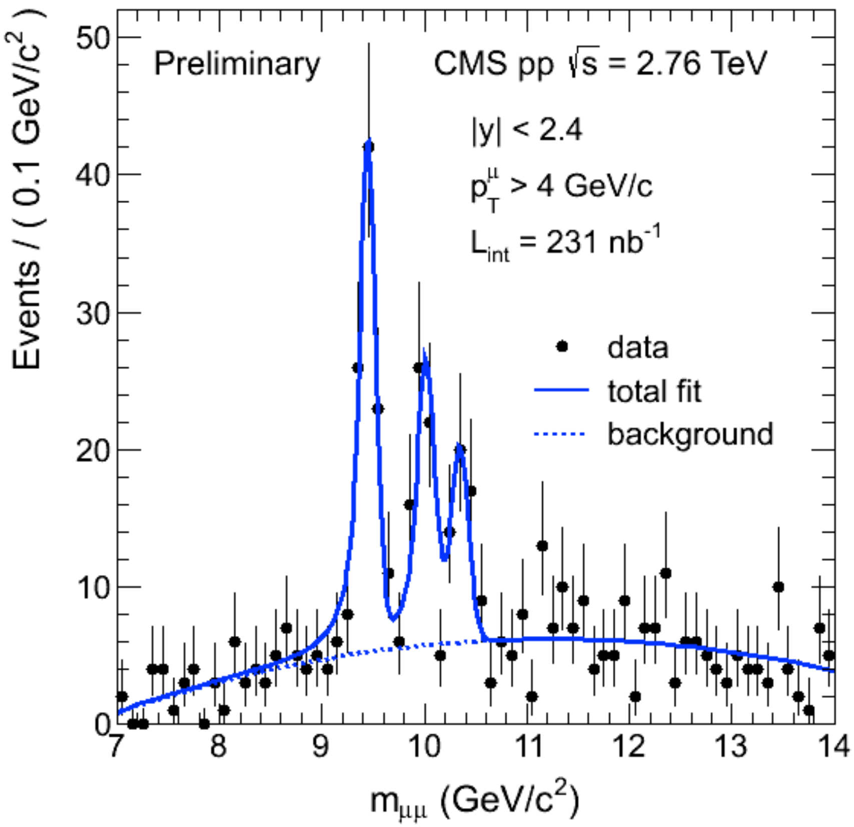
$$N_{\Upsilon(2S+3S)}/N_{\Upsilon(1S)}|_{pp} = 0.78^{+0.16}_{-0.14} \pm 0.02$$

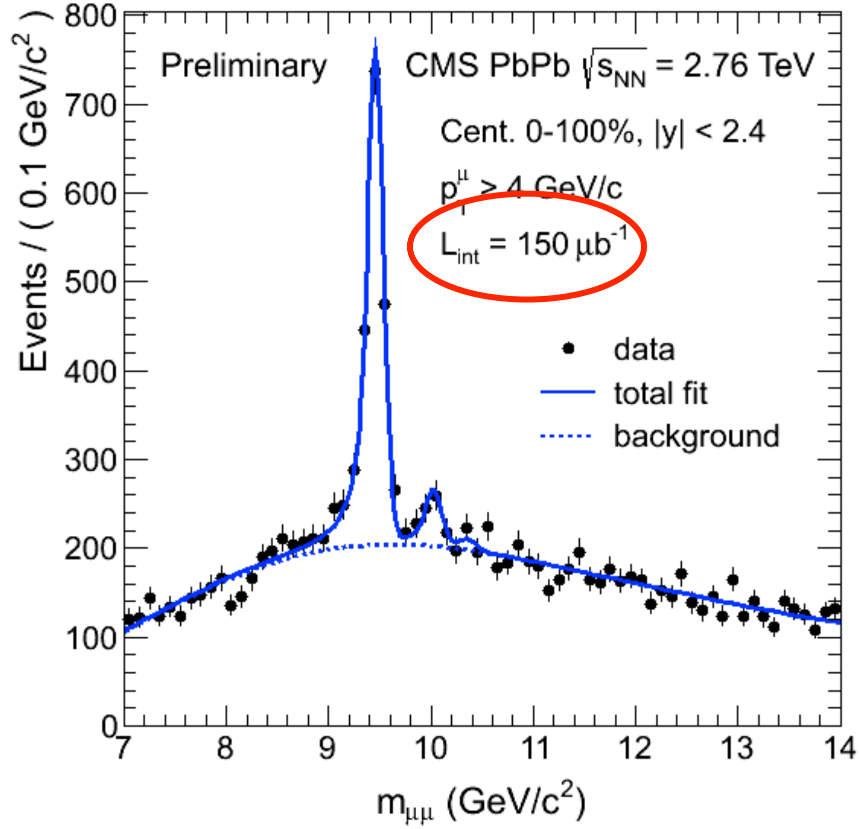
$$N_{\Upsilon(2S+3S)}/N_{\Upsilon(1S)}|_{PbPb} = 0.24^{+0.13}_{-0.12} \pm 0.02$$

$$\frac{N_{\Upsilon(2S+3S)}/N_{\Upsilon(1S)}|_{PbPb}}{N_{\Upsilon(2S+3S)}/N_{\Upsilon(1S)}|_{pp}} = 0.31^{+0.19}_{-0.15} \pm 0.03$$

Bottomonia: with 2011 data

pp CMS-HIN-11-011 PbPb



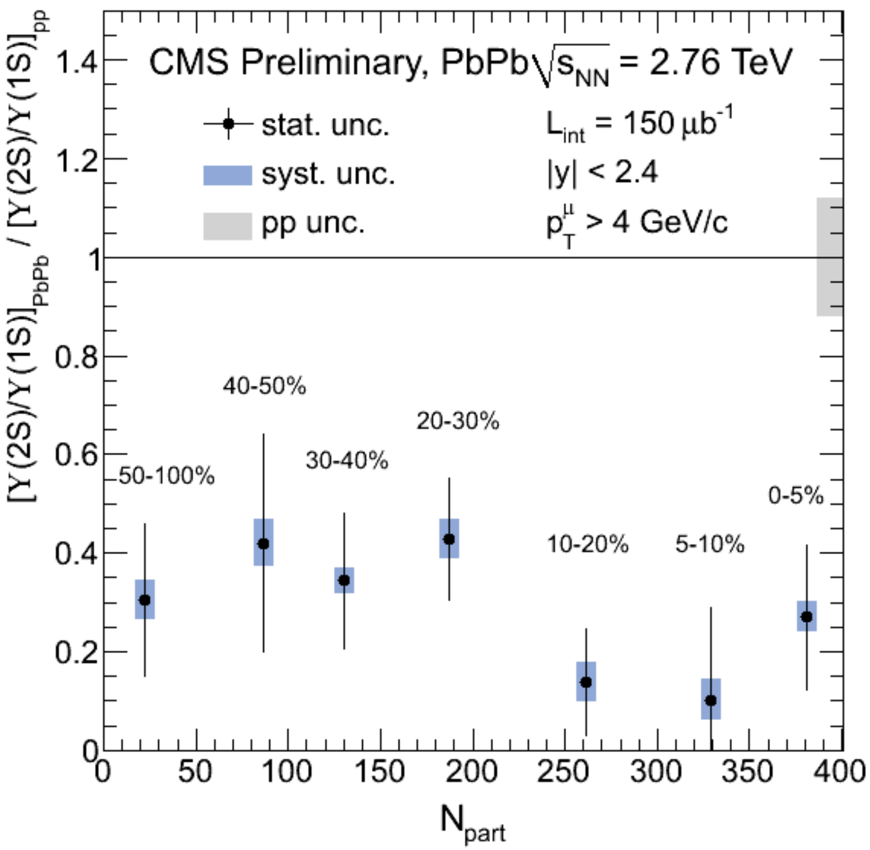


$$N_{\Upsilon(2S)}/N_{\Upsilon(1S)}|_{pp} = 0.56 \pm 0.13 \pm 0.01$$
$$N_{\Upsilon(3S)}/N_{\Upsilon(1S)}|_{pp} = 0.21 \pm 0.11 \pm 0.02$$

$$N_{\Upsilon(2S)}/N_{\Upsilon(1S)}|_{PbPb} = 0.12 \pm 0.03 \pm 0.01$$
$$N_{\Upsilon(3S)}/N_{\Upsilon(1S)}|_{PbPb} < 0.07$$

Ratios not corrected for acceptance and efficiency

Υ(nS) / Υ(1S) Double Ratio



CMS-HIN-11-011

- Separated Υ(2S) and Υ(3S)
- Measured Υ(2S) double ratio vs. centrality
  - centrality integrated:

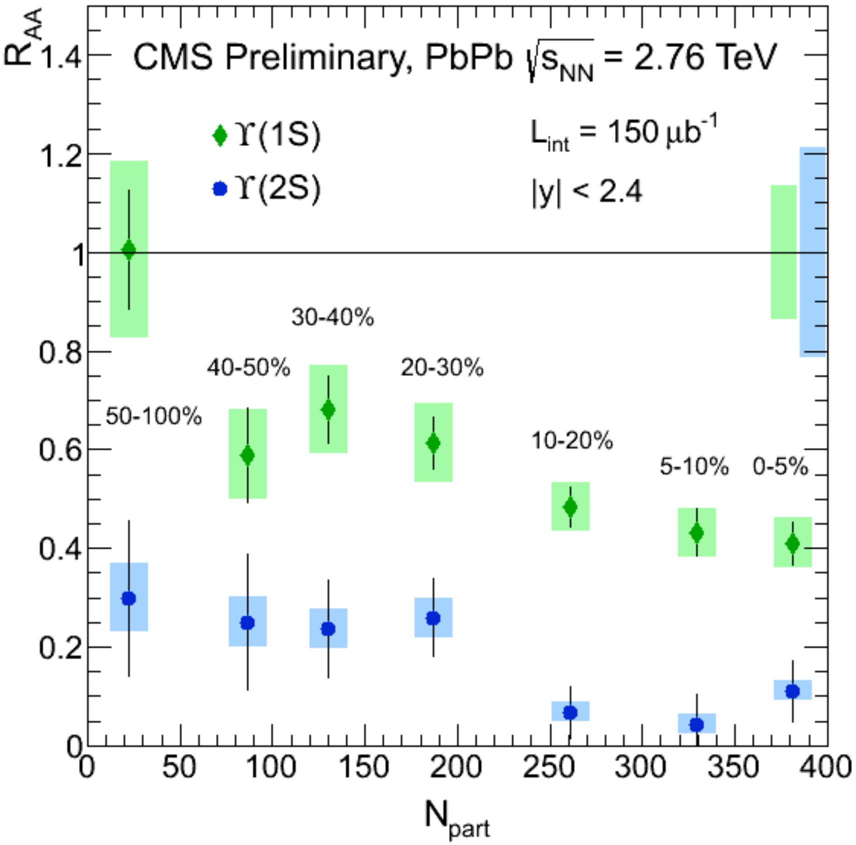
$$\frac{N_{\Upsilon(2S)}/N_{\Upsilon(1S)}|_{PbPb}}{N_{\Upsilon(2S)}/N_{\Upsilon(1S)}|_{pp}} = 0.21 \pm 0.07 \pm 0.02$$

  - no strong centrality dependence
- Upper limit on Υ(3S)
  - centrality integrated:

$$\frac{N_{\Upsilon(3S)}/N_{\Upsilon(1S)}|_{PbPb}}{N_{\Upsilon(3S)}/N_{\Upsilon(1S)}|_{pp}} < 0.1 \text{ (95\% C.L.)}$$

Υ(1S) and Υ (2S) R_{AA}

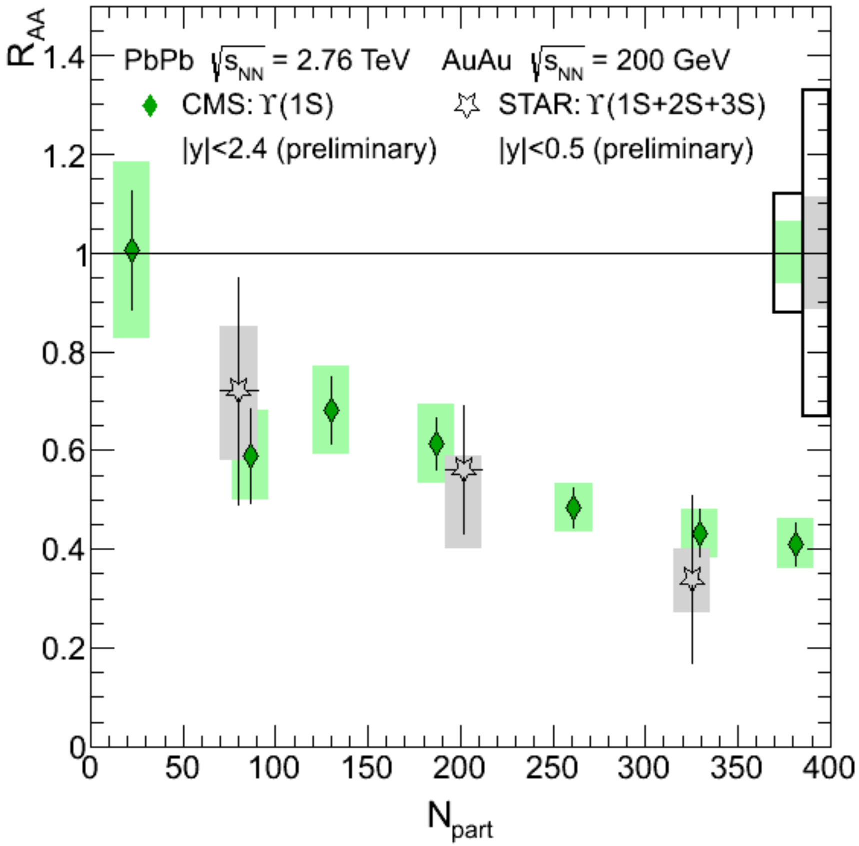
$$R_{AA} = \frac{\mathcal{L}_{pp}}{T_{AA} N_{\mathrm{MB}}} \frac{N_{\mathrm{PbPb}}(\Upsilon(\mathrm{nS}))}{N_{pp}(\Upsilon(\mathrm{nS}))} \frac{\varepsilon_{pp}}{\varepsilon_{\mathrm{PbPb}}}$$



CMS-HIN-11-011

- In 2010 ($7.28\mu b^{-1}$):
  - only Υ(1S) R_{AA} in 3 centrality bins
  - JHEP 1205 (2012) 063
- In 2011 ($150\mu b^{-1}$):
  - Υ(1S) R_{AA} in 7 centrality bins
  - first results on Υ(2S) R_{AA}
  - clear suppression of Υ(2S)
  - Υ(1S) suppression consistent with excited state suppression (~50% feed down)

Comparison to RHIC



- STAR measured R_{AA} of ϒ(1S+2S+3S) combined
  - arXiv:1109.3891
  - min. bias value:

$$R_{AA}(\Upsilon(1\mathrm{S}+2\mathrm{S}+3\mathrm{S})) = 0.56 \pm 0.21^{+0.08}_{-0.16}$$

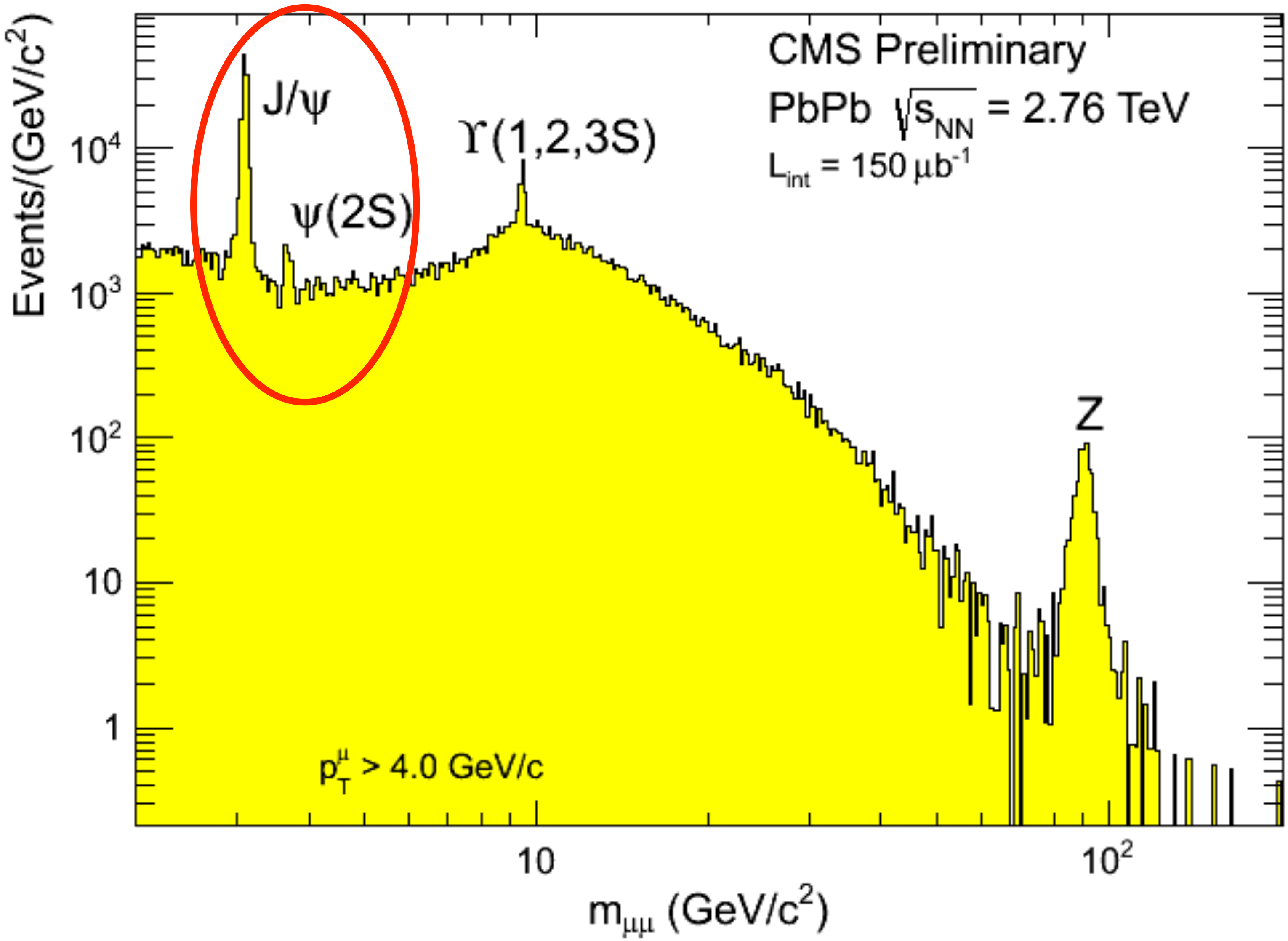
- CMS: separate R_{AA} for ϒ(1S) and ϒ(2S)
  - can calculate min. bias R_{AA} of ϒ(1S+2S+3S):

$$R_{AA}(\Upsilon(1\mathrm{S}+2\mathrm{S}+3\mathrm{S})) = R_{AA}(\Upsilon(1\mathrm{S})) \times \frac{1+\Upsilon(2\mathrm{S}+3\mathrm{S})/\Upsilon(1\mathrm{S})|_{\mathrm{PbPb}}}{1+\Upsilon(2\mathrm{S}+3\mathrm{S})/\Upsilon(1\mathrm{S})|_{\mathrm{pp}}}$$

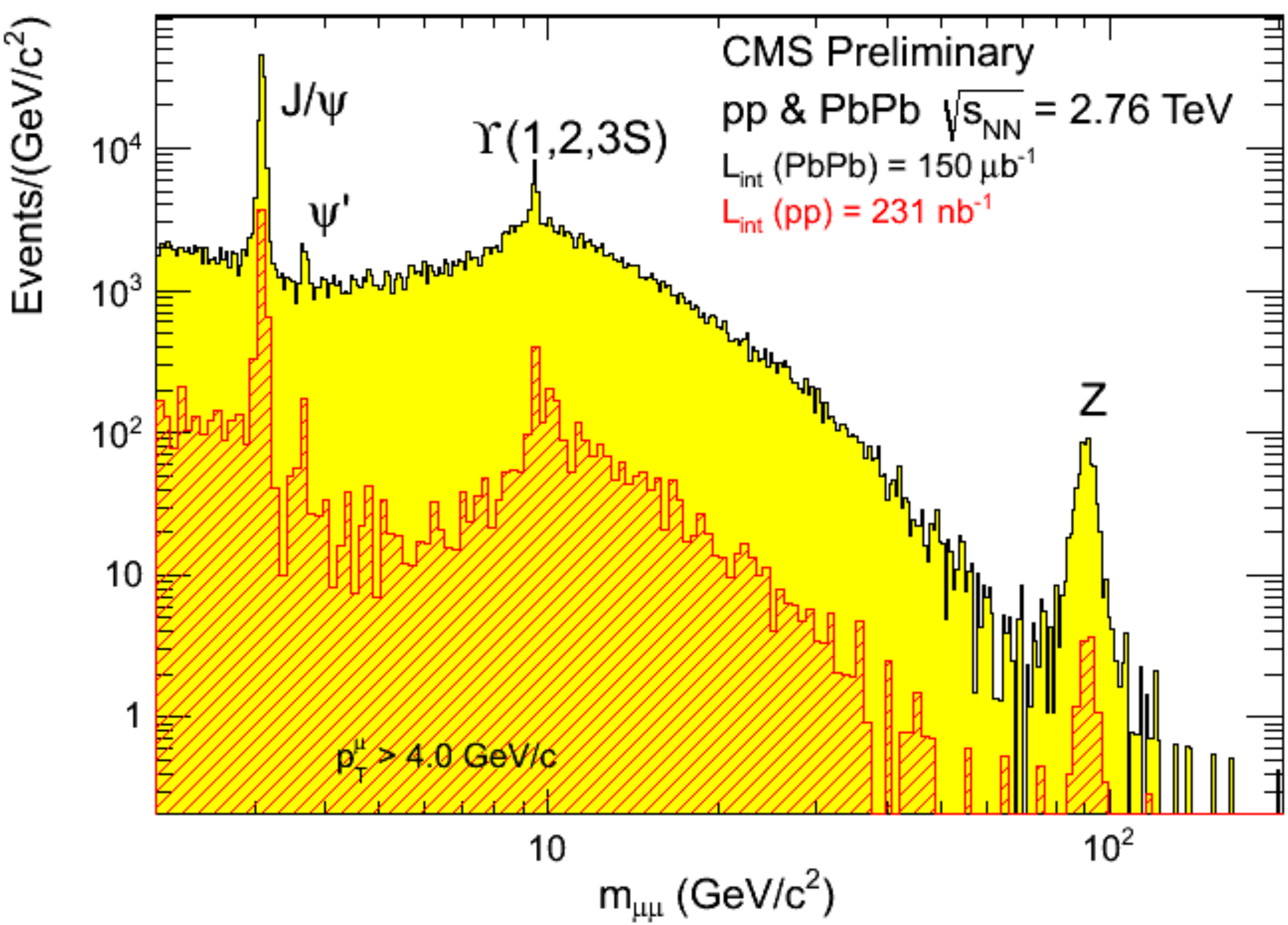
$$= 0.53 \times \frac{1+0.19}{1+0.97} \approx 0.32$$

CMS-HIN-11-011

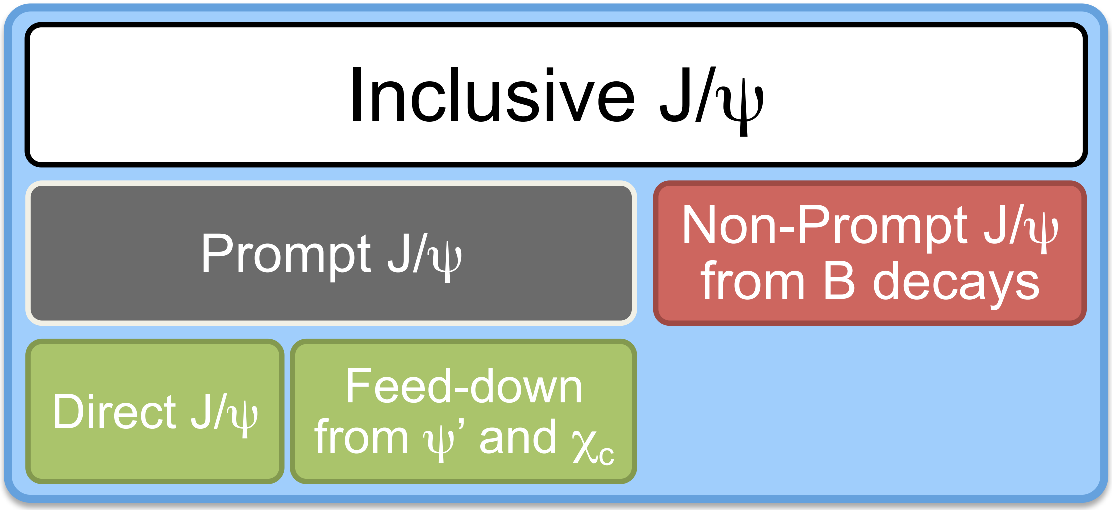
Muon Pairs in PbPb at $\sqrt{s_{NN}}$ = 2.76 TeV



PbPb vs. pp at $\sqrt{s_{NN}}$ = 2.76 TeV

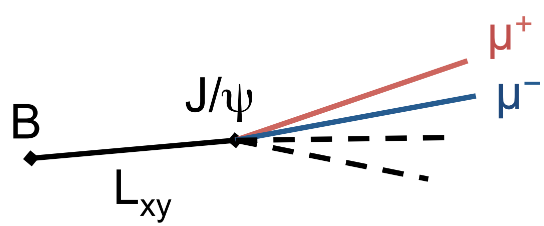


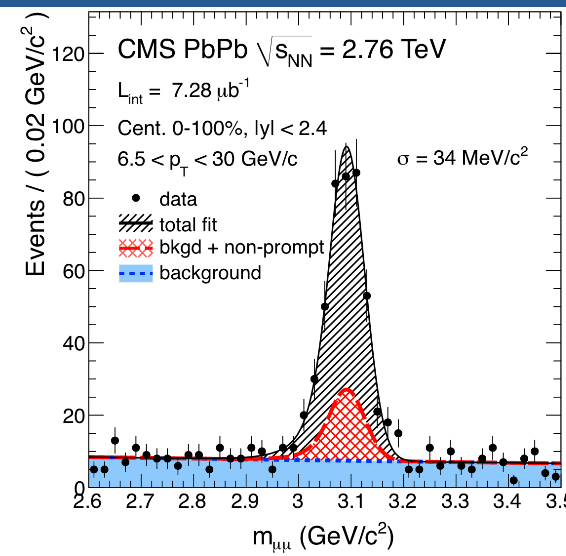
J/ψ in PbPb at $\sqrt{s_{NN}}$ = 2.76 TeV

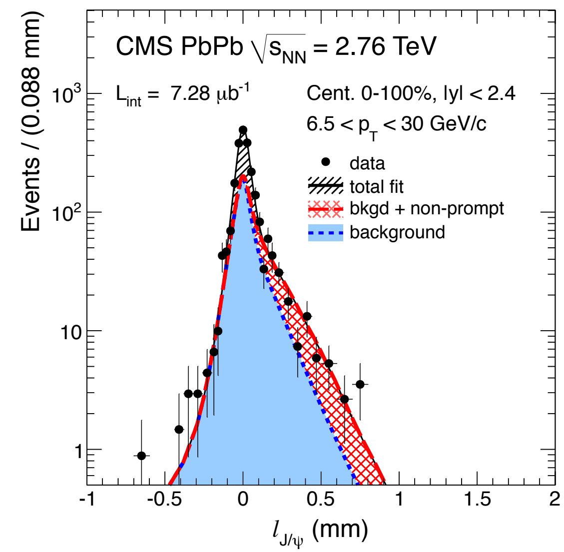


- Reconstruct $\mu^+\mu^-$ vertex
- Simultaneous fit of $\mu^+\mu^-$ mass and pseudo-proper decay length

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



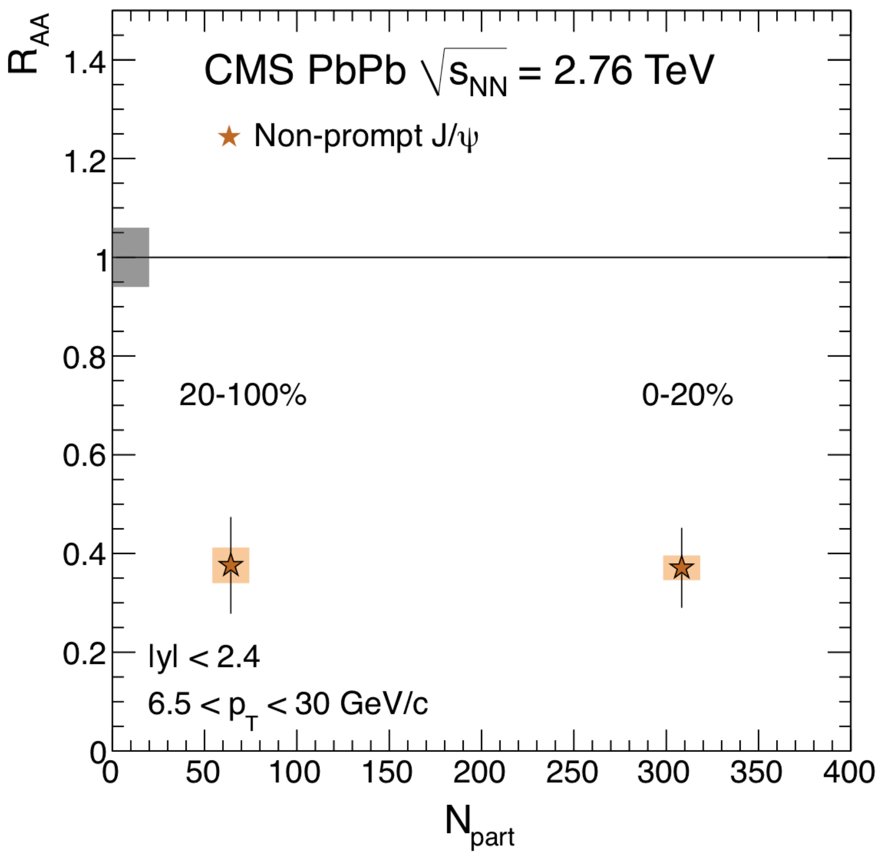


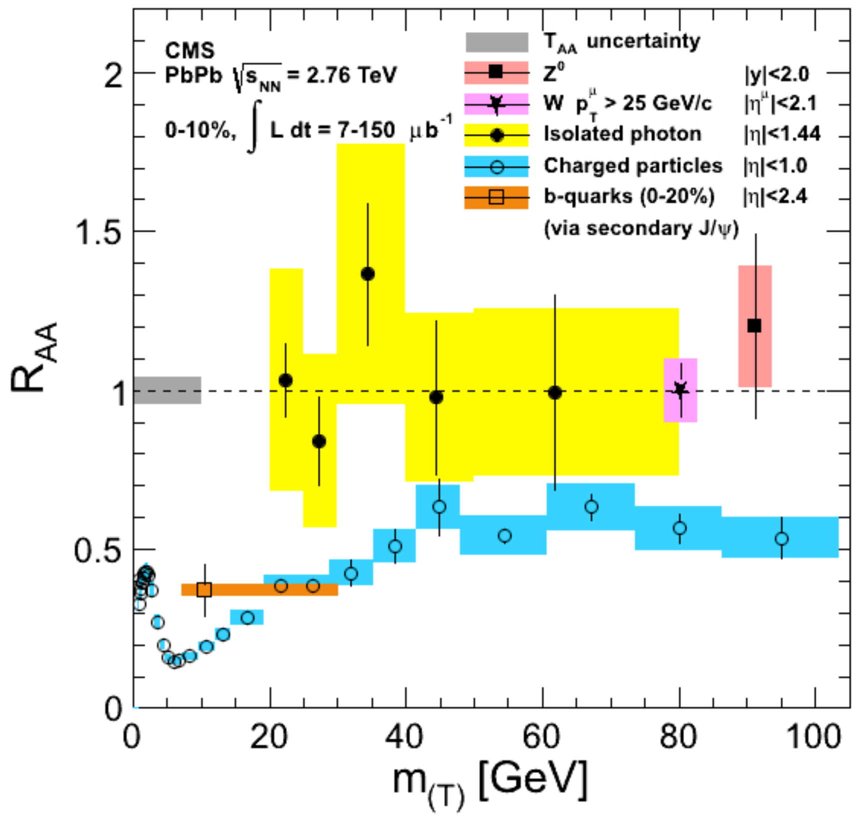


JHEP 1205 (2012) 063

Open heavy-flavour: B → J/ψ

JHEP 1205 (2012) 063

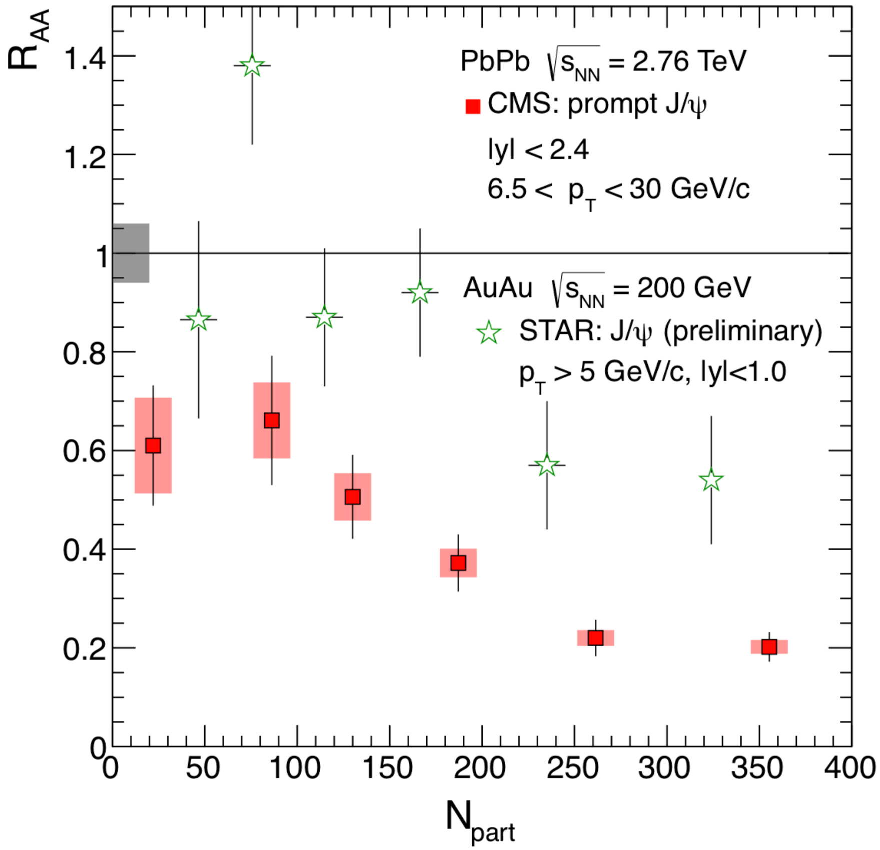




- Suppression of non-prompt J/ψ observed in PbPb
  - indication of high-p_T b-quark quenching
  - with 2011 data: will study centrality dependence

PRL 106 (2011) 212301
arXiv:1205.6334
PLB 710 (2012) 256
EPJ C 72 (2012) 1945
JHEP 1205 (2012) 063

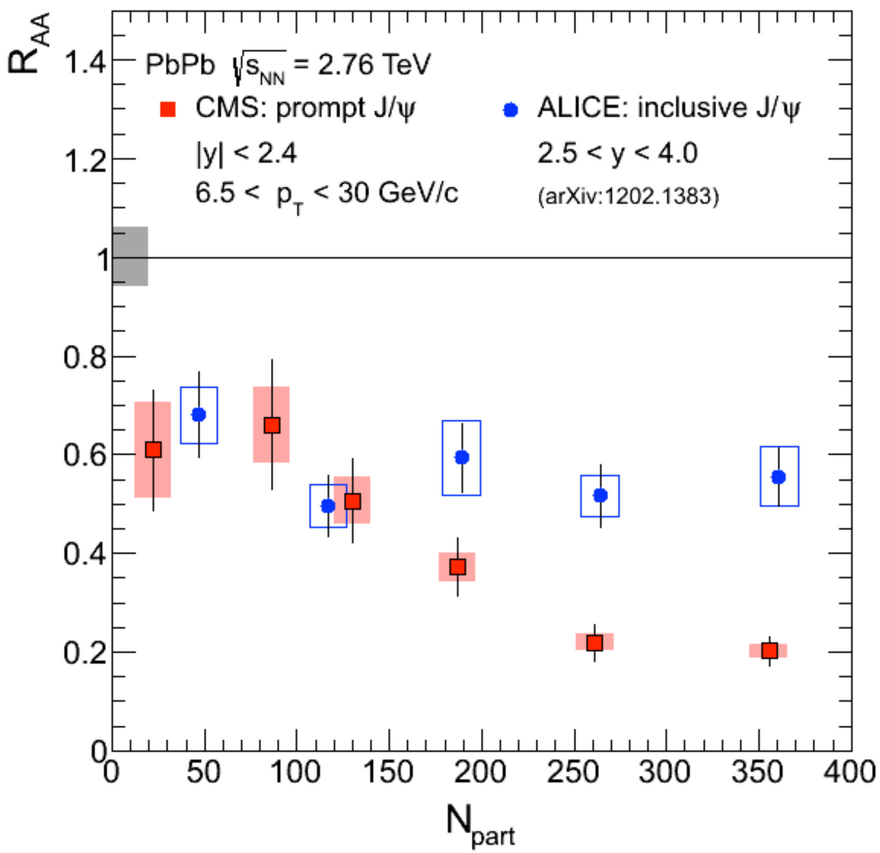
Prompt J/ψ at high p_T: RHIC - LHC



JHEP 1205 (2012) 063

- Prompt J/ψ
  - p_T > 6.5 GeV/c & |y|<2.4
  - in 0–10% centrality: suppressed by factor 5
  - in 50–100%: suppressed by factor ~1.6
- STAR
  - p_T > 5 GeV/c & |y|<1
  - less suppression at RHIC

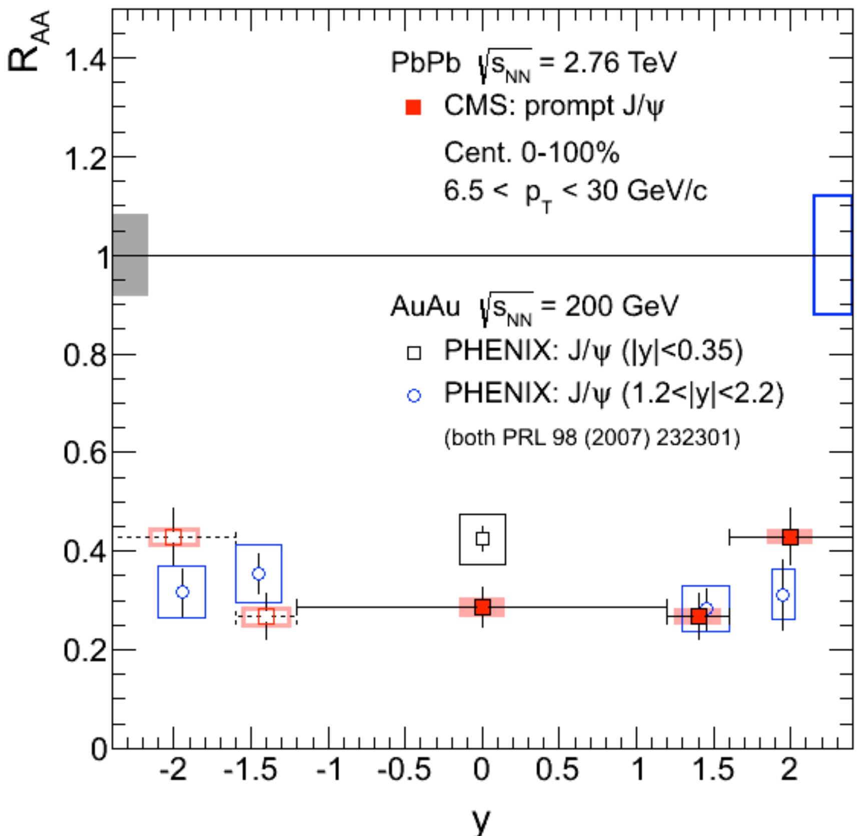
Prompt J/ψ at the LHC: ALICE - CMS

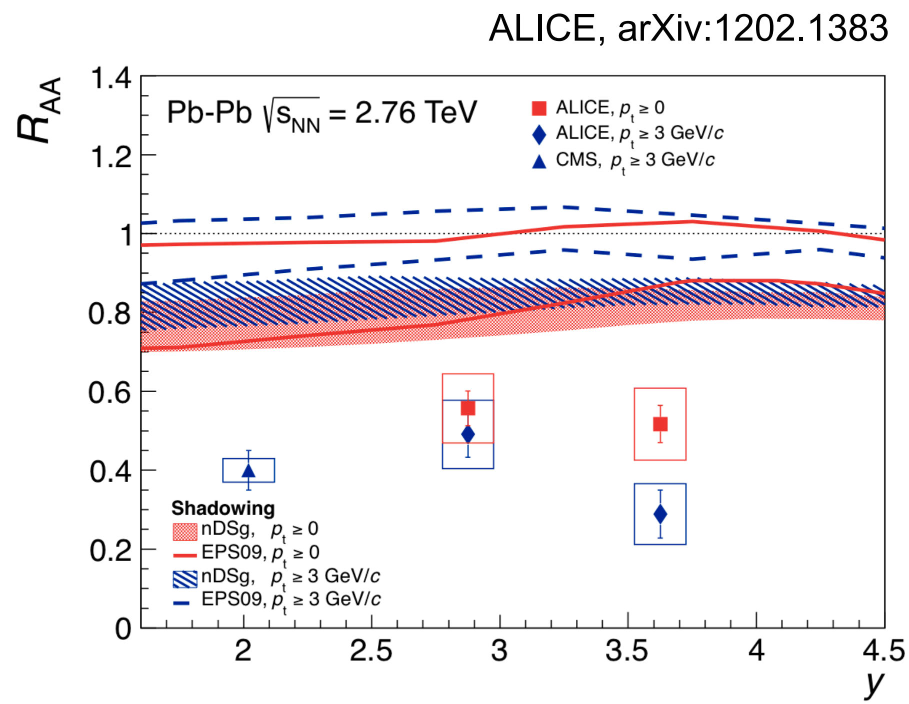


JHEP 1205 (2012) 063

- Prompt J/ψ
  - p_T > 6.5 GeV/c & |y|<2.4
  - in 0–10% centrality: suppressed by factor 5
  - in 50–100%: suppressed by factor ~1.6
- ALICE (inclusive J/ψ)
  - p_T > 0 GeV/c & 2.5<y<4
  - less suppression at forward rapidity, low p_T
  - includes ~10% b-fraction: prompt R_{AA} could drop 11%

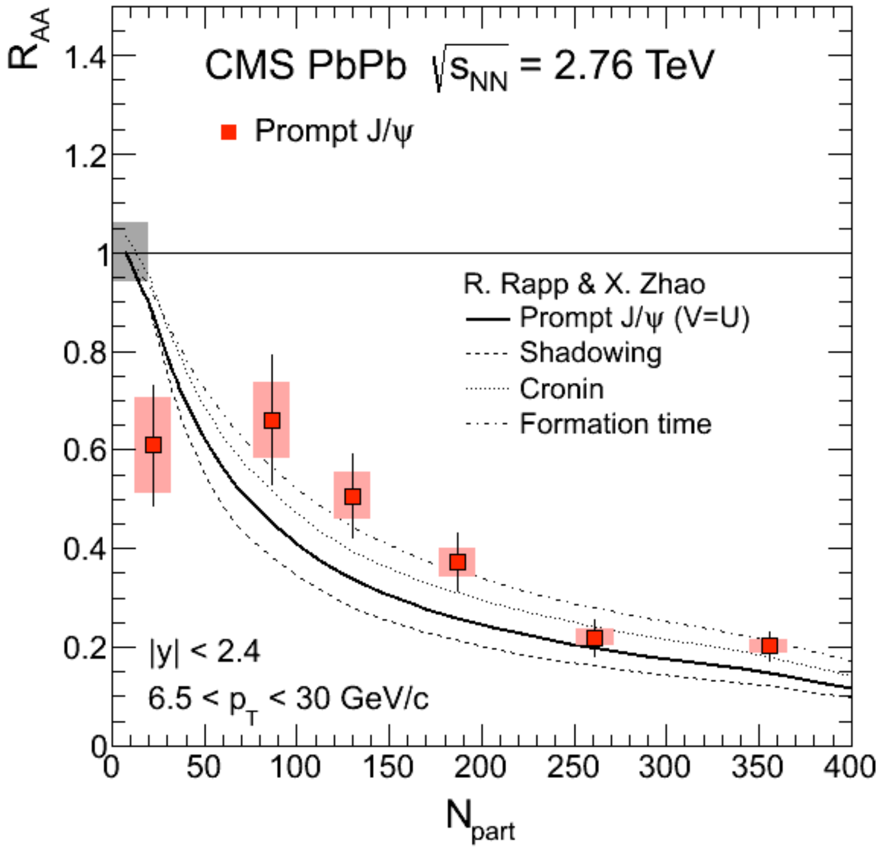
J/ψ vs. rapidity





- CMS: rapidity dependence opposite to PHENIX
  - but PHENIX is low p_T
- CMS measured at 1.6<|y|<2.4 also to lower p_T (p_T>3 GeV/c)
  - consistent with ALICE forward low p_T results

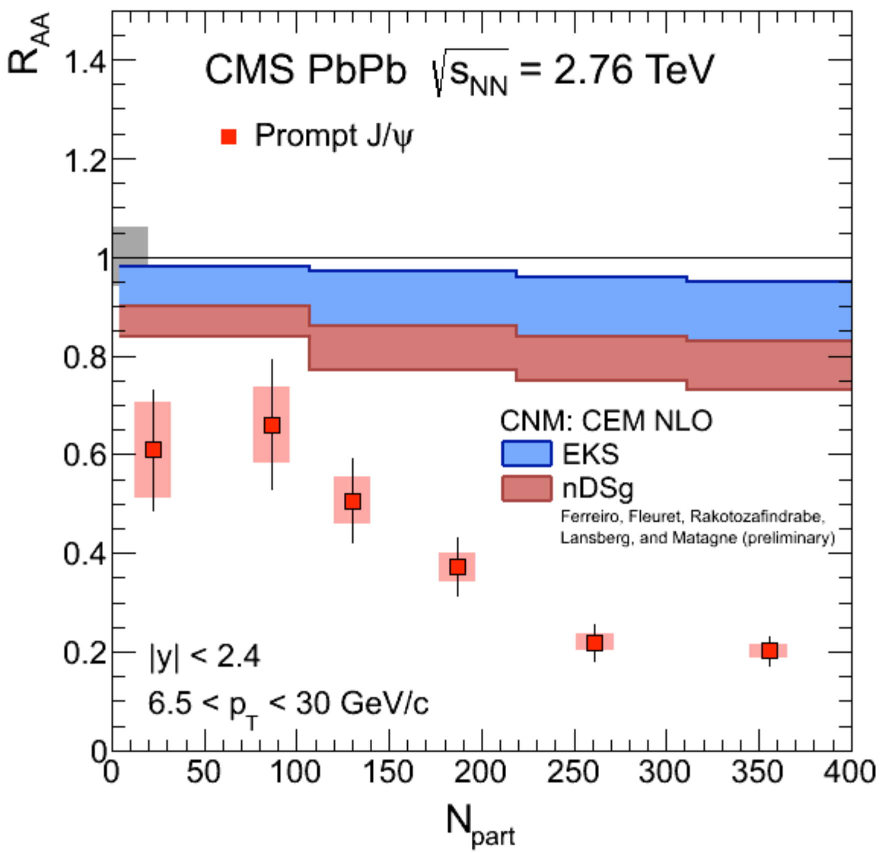
Prompt J/ψ: Model Comparison



Zhao & Rapp, NPA 859 (2011) 114
+ private communication

- Prompt J/ψ
  - p_T > 6.5 GeV/c & |y|<2.4
  - in 0–10% centrality: suppressed by factor 5
  - in 50–100%: suppressed by factor ~1.6
- Recombination effects:
  - expected to be small at high p_T

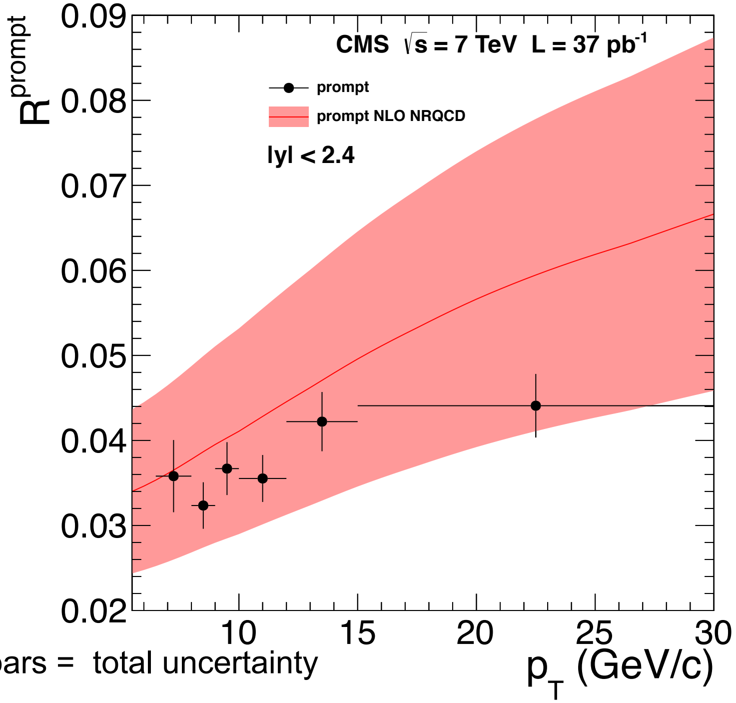
Prompt J/ψ: CNM Effects



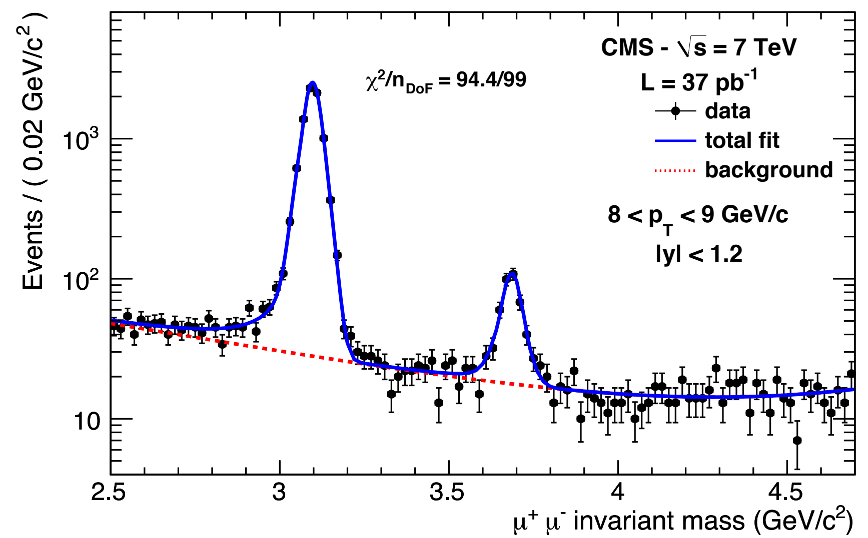
Ferreiro et al.
(preliminary)

- Prompt J/ψ
  - p_T > 6.5 GeV/c:
  - in 0–10% centrality: suppressed by factor 5
  - in 50–100%: suppressed by factor ~1.6
- Cold nuclear matter effects
  - work in progress to estimate (anti)shadowing contributions
  - relatively small at high p_T

ψ(2S) in pp at √s = 7 TeV



JHEP 1202 (2012) 011

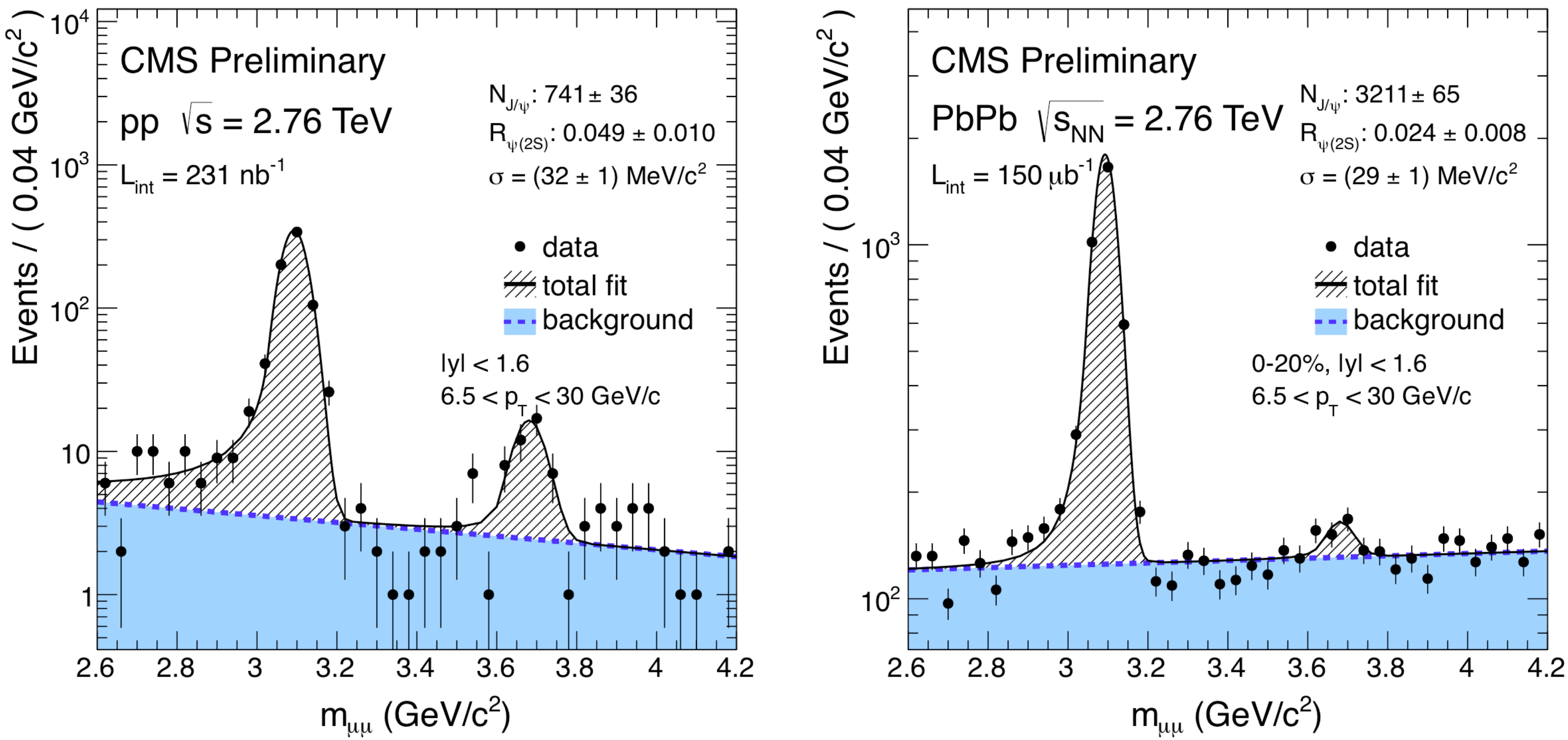


error bars = total uncertainty

- CMS measured ψ(2S) cross section in pp at √s = 7 TeV
- ψ(2S) / J/ψ cross-section ratio ~0.035 at p_T > 6.5 GeV/c
- Uncertainties on theory larger than experimental uncertainties

Carlos Lourenco
(Tuesday, 14h15)

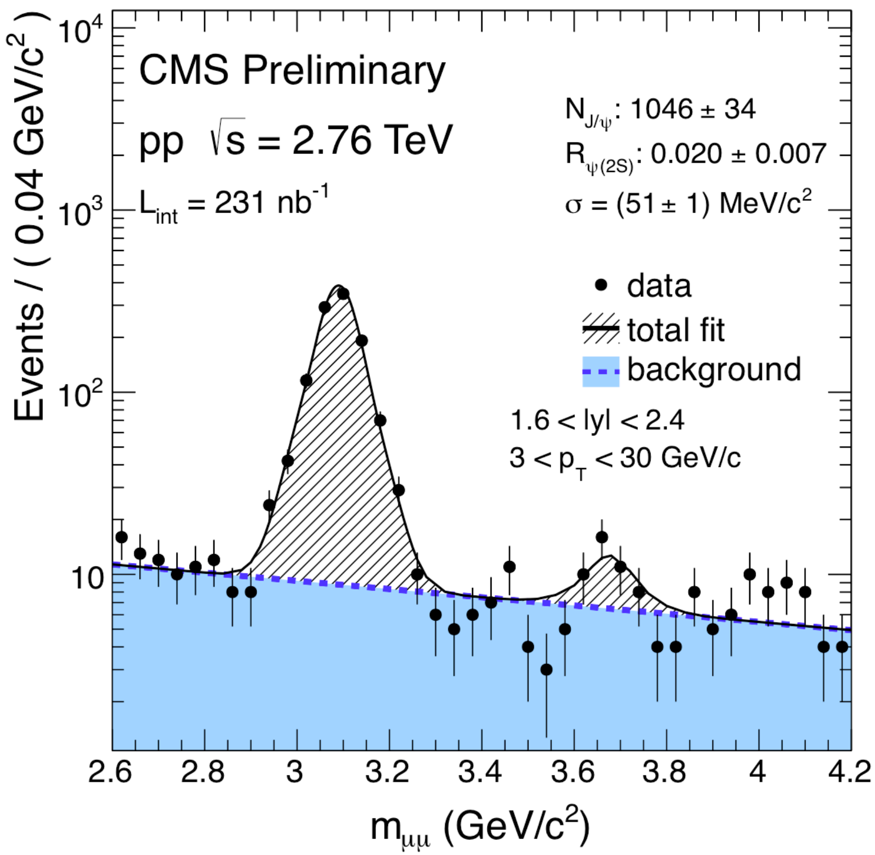
$\psi(2S)$ in pp & PbPb at $\sqrt{s_{NN}}$ = 2.76 TeV

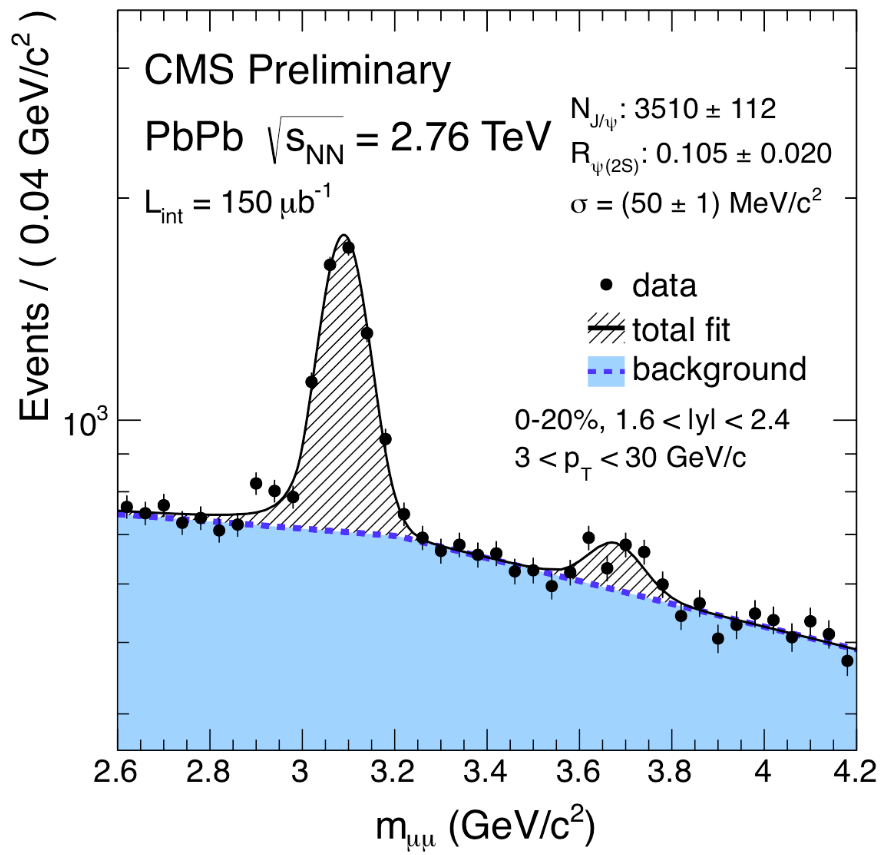


- Raw yield ratio of $\psi(2S)$ / J/ψ: $R_{\psi(2S)}$
- For p_T>6.5 GeV/c and |y|<1.6:
  $R_{\psi(2S)}$ in 0–20% PbPb ~2× smaller than in pp

CMS-HIN-12-007

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





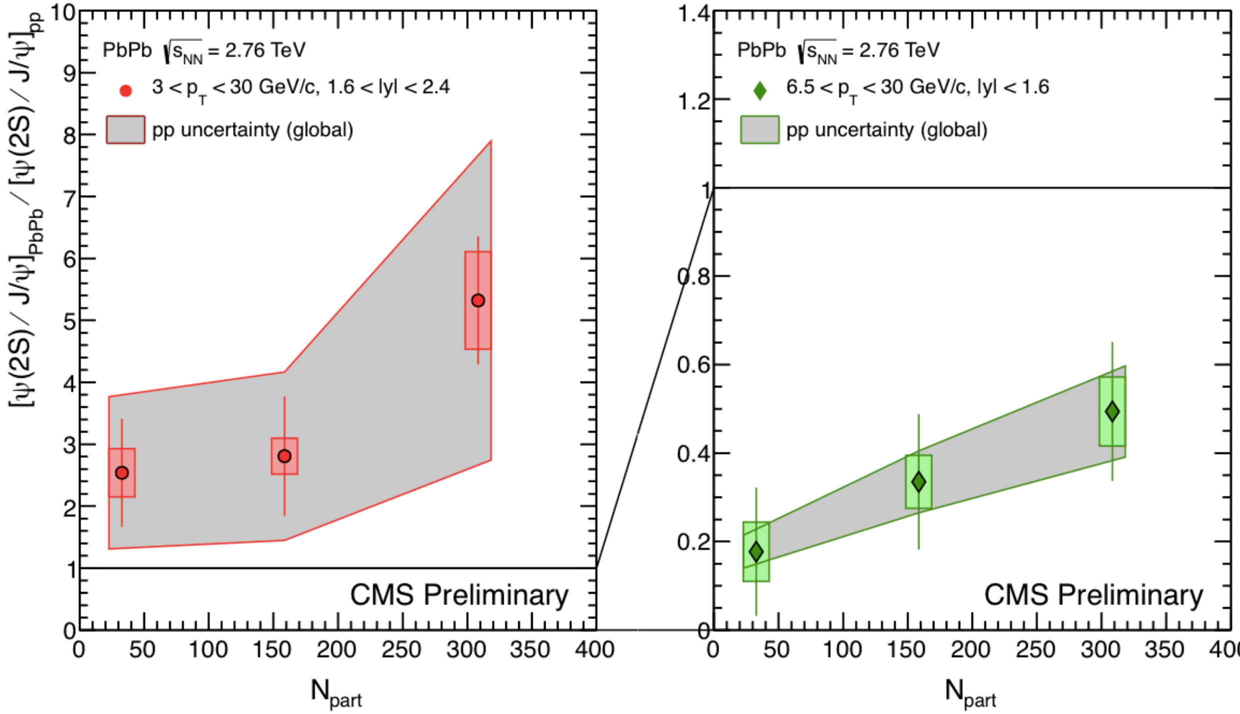
- Raw yield ratio of $\psi(2S)$ / J/ψ: $R_{\psi(2S)}$
- For p_T>3 GeV/c and 1.6<|y|<2.4:
  $R_{\psi(2S)}$ in 0–20% PbPb ~5× larger than in pp

CMS-HIN-12-007

$\psi(2S)$ / J/ψ Double Ratio

- Double ratio of $[\psi(2S) / J/\psi]_{PbPb}$ / $[\psi(2S) / J/\psi]_{pp}$

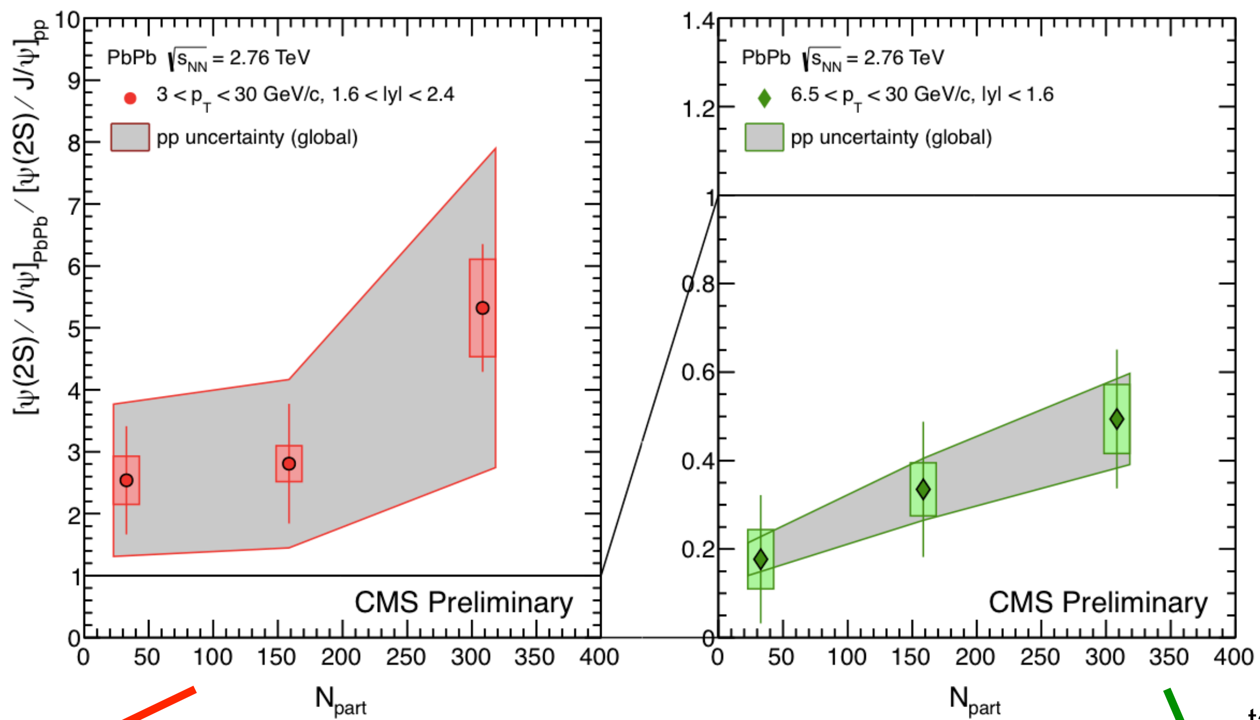
CMS-HIN-12-007



- For p_T>3 GeV/c and 1.6<|y|<2.4: large uncertainties on pp
  Indication of $\psi(2S)$ being less suppressed than J/ψ, but need more statistics (in particular pp)!
- For p_T>6.5 GeV/c and |y|<1.6: $\psi(2S)$ are more suppressed than J/ψ

ψ(2S) / J/ψ Double Ratio

CMS-HIN-12-007



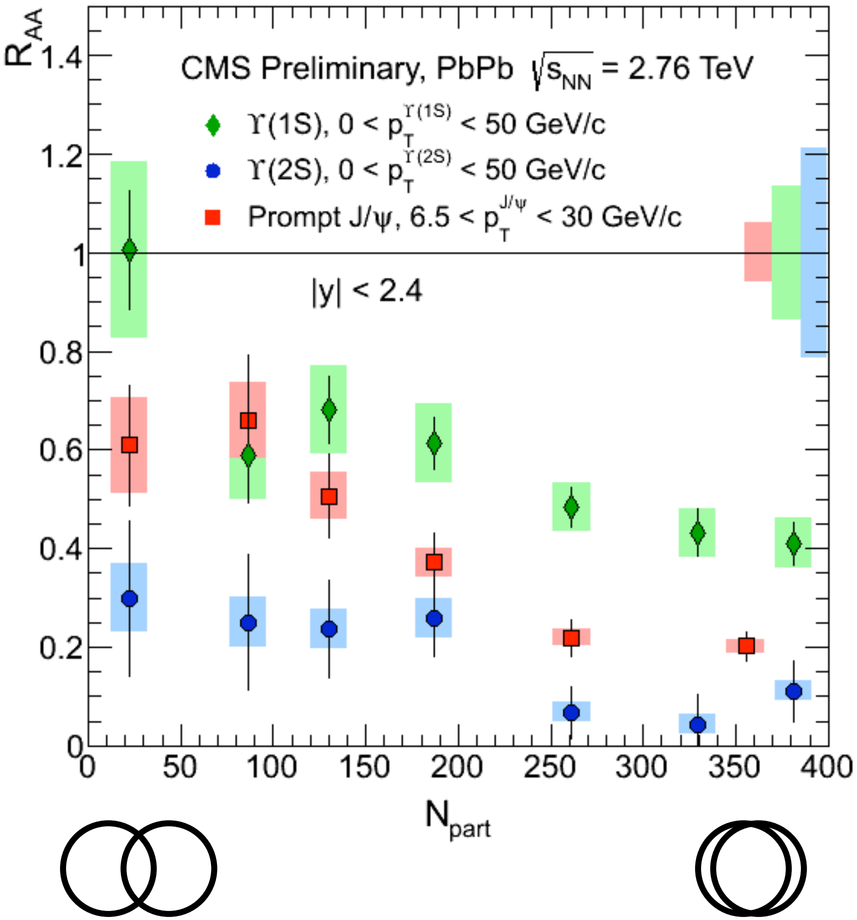
take $R_{AA}(J/\psi)$ from JHEP 1205 (2012) 063

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

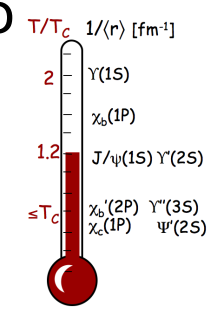
$$R_{AA}^{0-100\%}(\psi(2\mathrm{S})) = 1.54 \pm 0.32\,(\mathrm{stat}) \pm 0.22\,(\mathrm{syst}) \pm 0.76\,(\mathrm{pp})$$

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

Summary



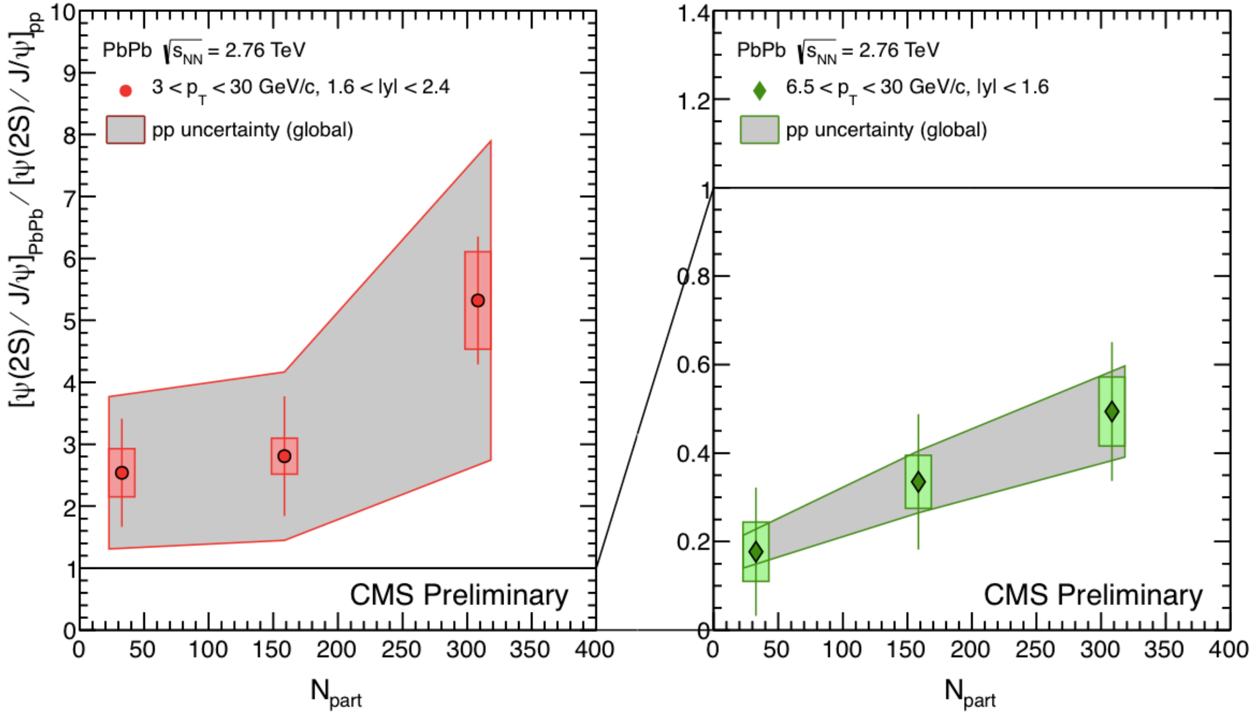
- First measurement of $\Upsilon(2S)$ suppression
  - upper limit on $\Upsilon(3S)$ double ratio
- $\Upsilon(1S)$ R_{AA} consistent with suppression of feed down from excited states (~50%)
- High-p_T $\psi(2S)$ are more suppressed than high-p_T J/ψ
  - Need more pp statistics to pin down lower-p_T double ratio
- Filling the thermometer
  - one peak at a time…



Backup

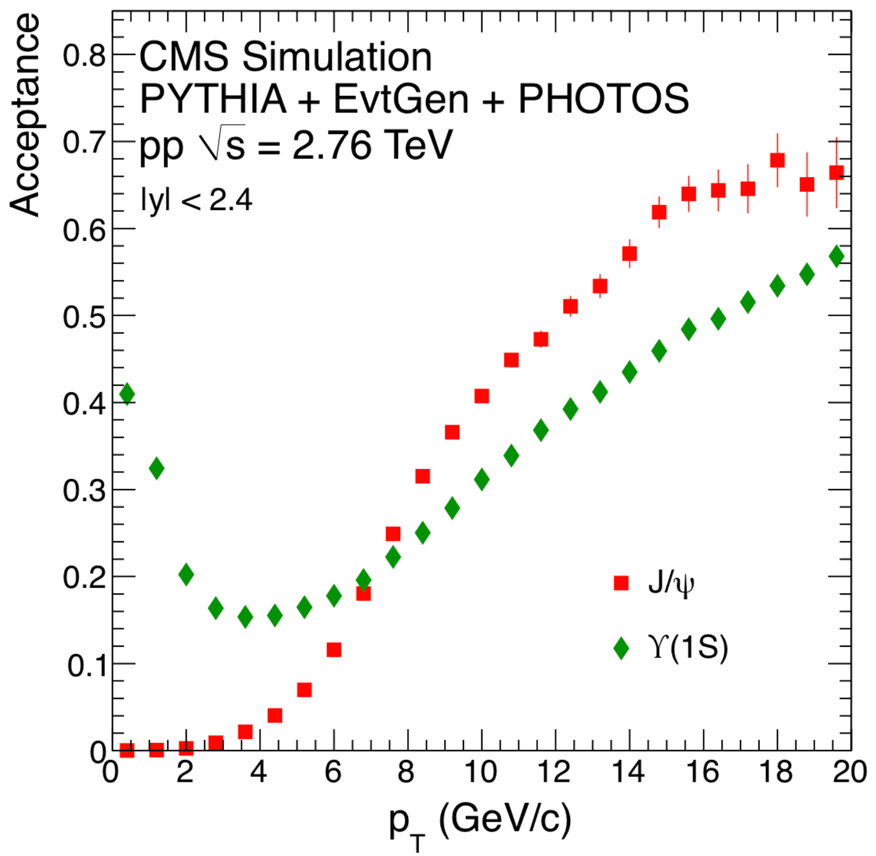
ψ(2S) / J/ψ Double Ratio

- Double ratio of $[\psi(2S) / J/\psi]_{PbPb} / [\psi(2S) / J/\psi]_{pp}$



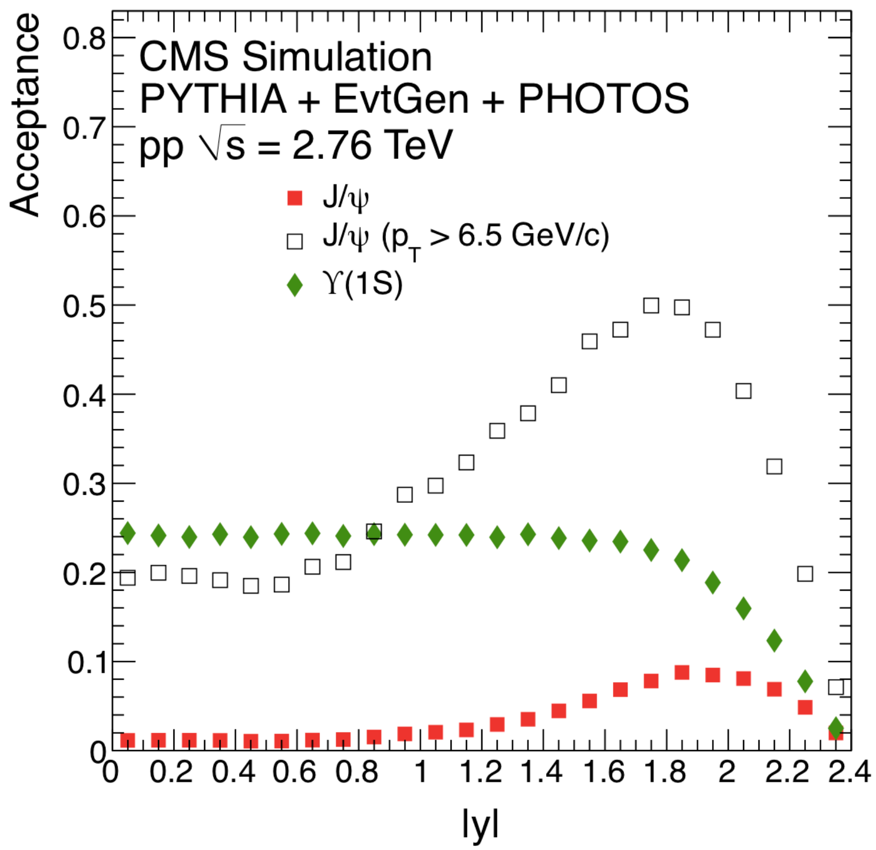
- For p_T>3 GeV/c and 1.6<|y|<2.4: large uncertainties on pp
  Indication of ψ(2S) being less suppressed than J/ψ
  - Significance: not more than 2σ, work is ongoing, but we need more pp!
- For p_T>6.5 GeV/c and |y|<1.6:
  ψ(2S) are more suppressed than J/ψ

Dimuon Acceptance



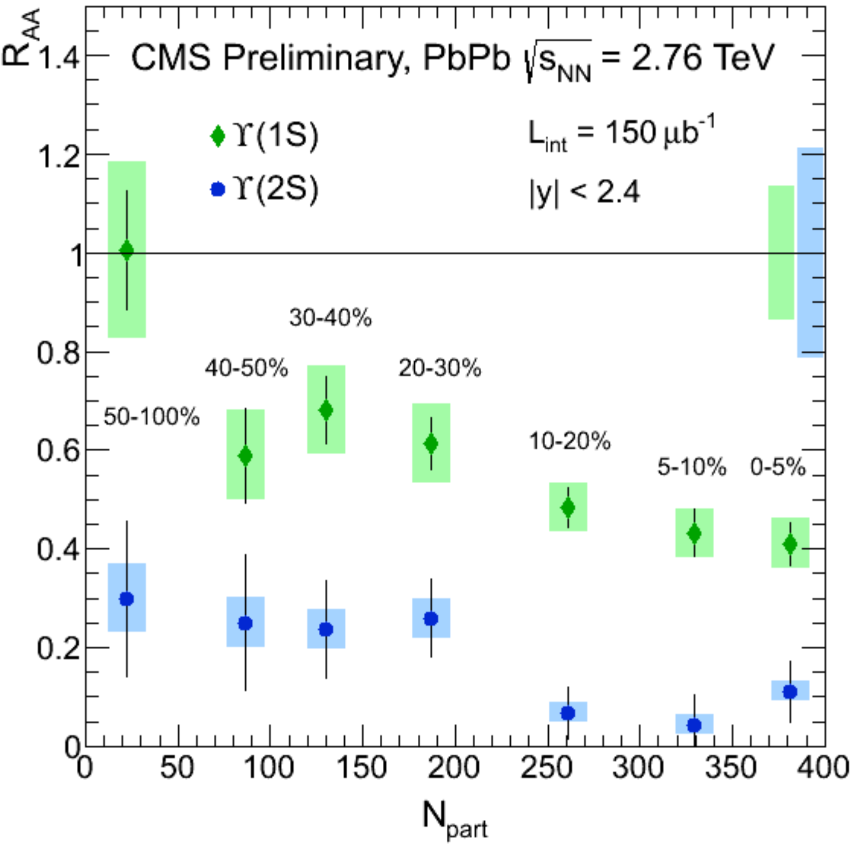
- Muons need to overcome magnetic field and energy loss in absorber
  - minimum total momentum p~3–5 GeV/c to reach muon station
- Limits J/ψ acceptance:
  - mid-rapidity: p_T>6.5 GeV/c
  - forward: p_T>3 GeV/c
- ϒ acceptance:
  - p_T>0 GeV/c for all rapidity

Dimuon Acceptance



- Muons need to overcome magnetic field and energy loss in absorber
  - minimum total momentum p~3–5 GeV/c to reach muon station
- Limits J/ψ acceptance:
  - mid-rapidity: p_T>6.5 GeV/c
  - forward: p_T>3 GeV/c
- ϒ acceptance:
  - p_T>0 GeV/c for all rapidity

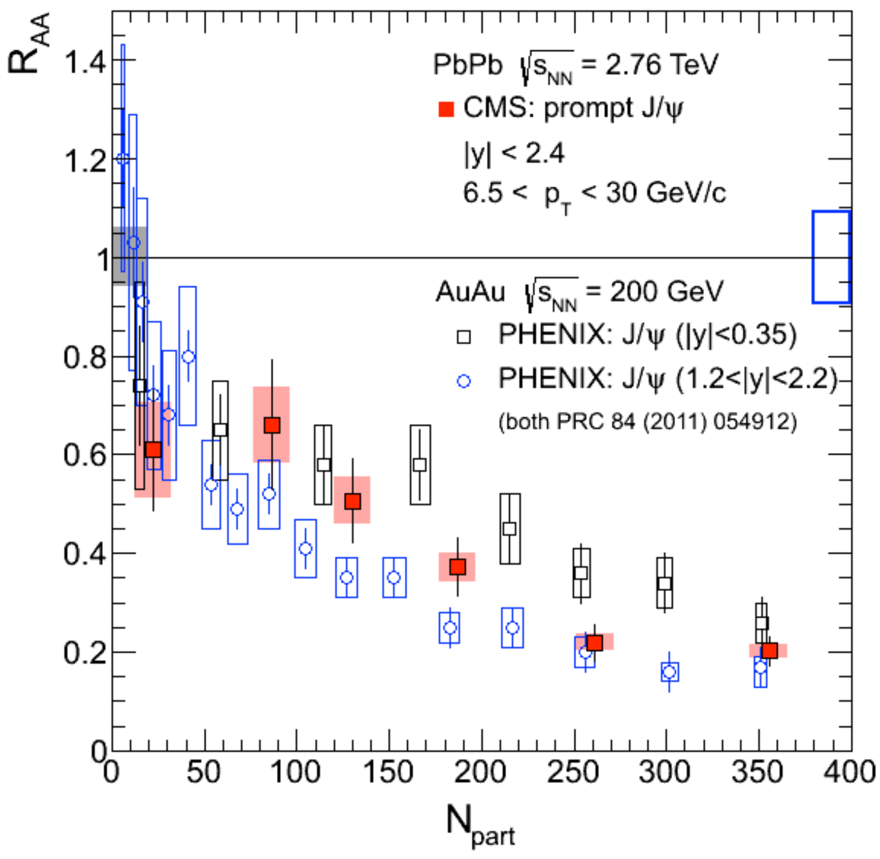
Υ(1S) feed down



- CDF measured direct fraction of Υ(1S) with p_T > 8 GeV/c (PRL 84 (2000) 2094):
  - (50.9 ± 8.2 (stat.) ± 9.0 (syst.))%
- S. Digal et al., PRD 64 (2001) 094015:
  - extrapolate to p_T = 0

state	$f_i(\bar{p}p)$ [%]
$\Upsilon(1S)$	52 ± 9
$\chi_b(1P)$	26 ± 7
$\Upsilon(2S)$	10 ± 3
$\chi_b(2P)$	10 ± 7
$\Upsilon(3S)$	2 ± 0.5
Υ	100

Prompt J/ψ at high p_T: RHIC - LHC



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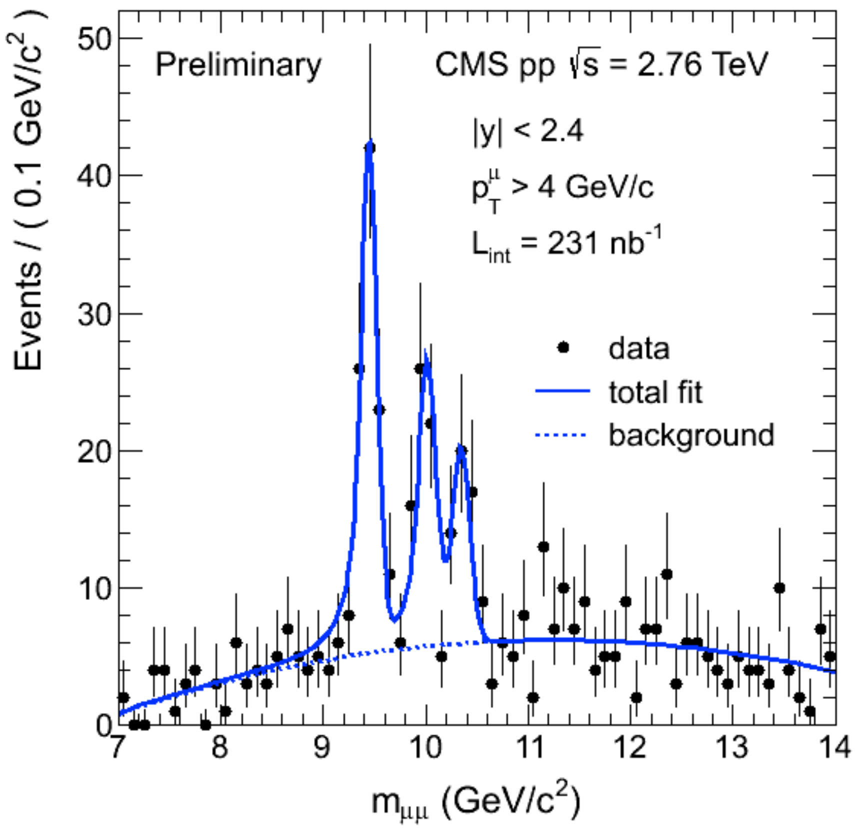
- Prompt J/ψ
  - p_T > 6.5 GeV/c:
  - in 0–10% centrality: suppressed by factor 5
  - in 50–100%: suppressed by factor ~1.6
- PHENIX
  - p_T > 0 GeV/c
  - similar suppression, though lower p_T

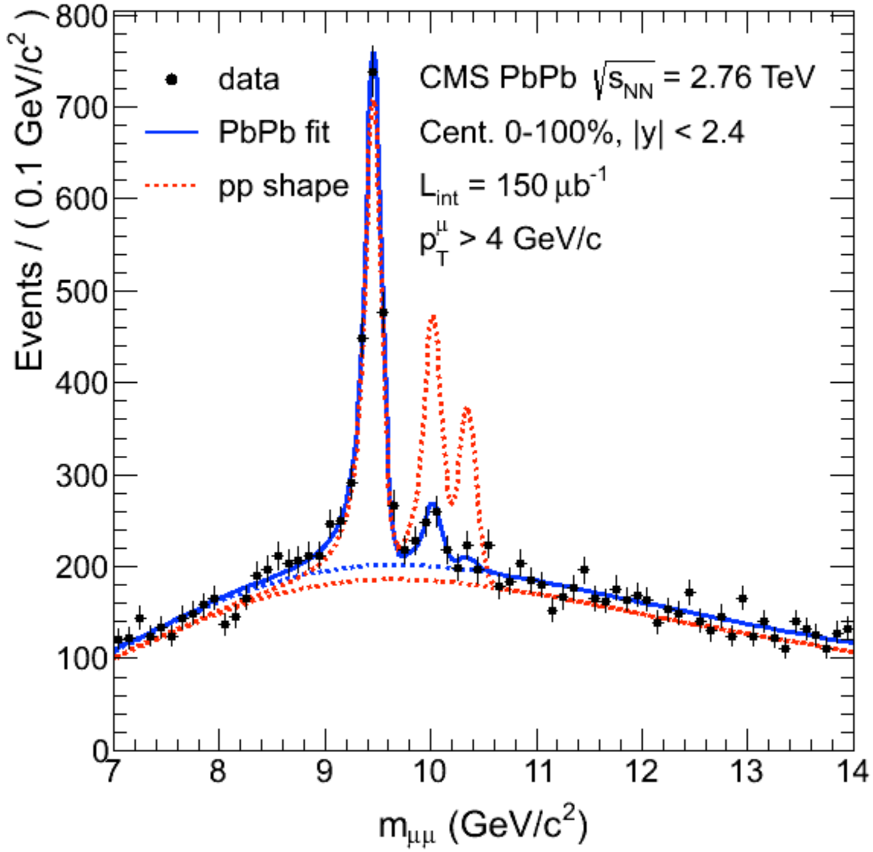
Bottomonia: with 2011 data

pp

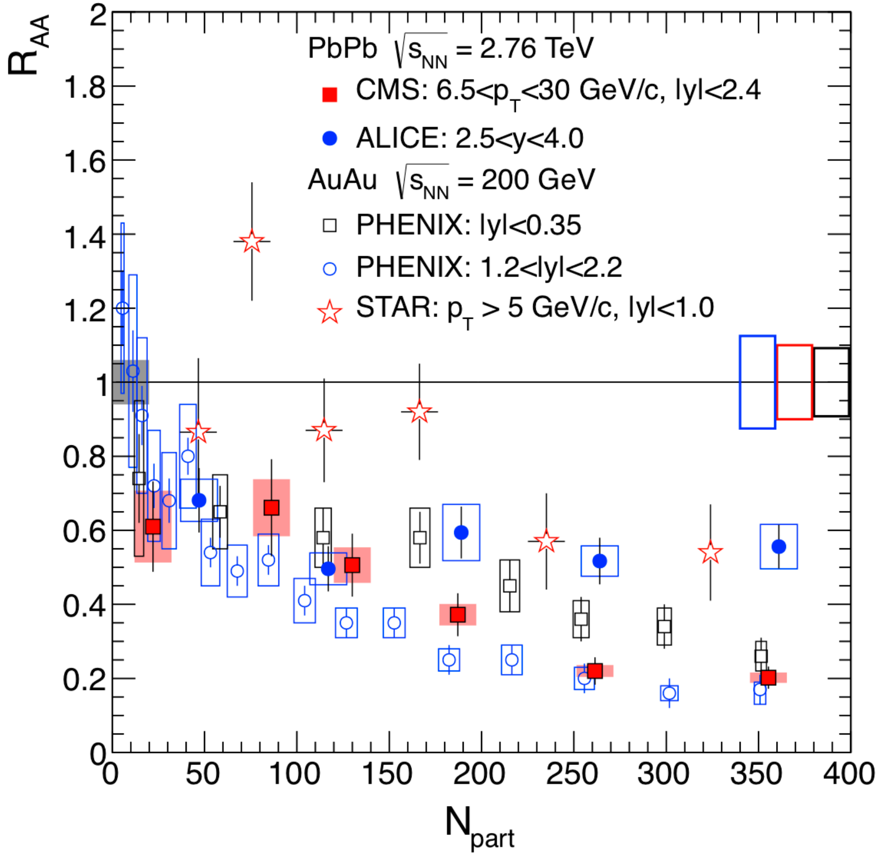
CMS-HIN-11-011

PbPb

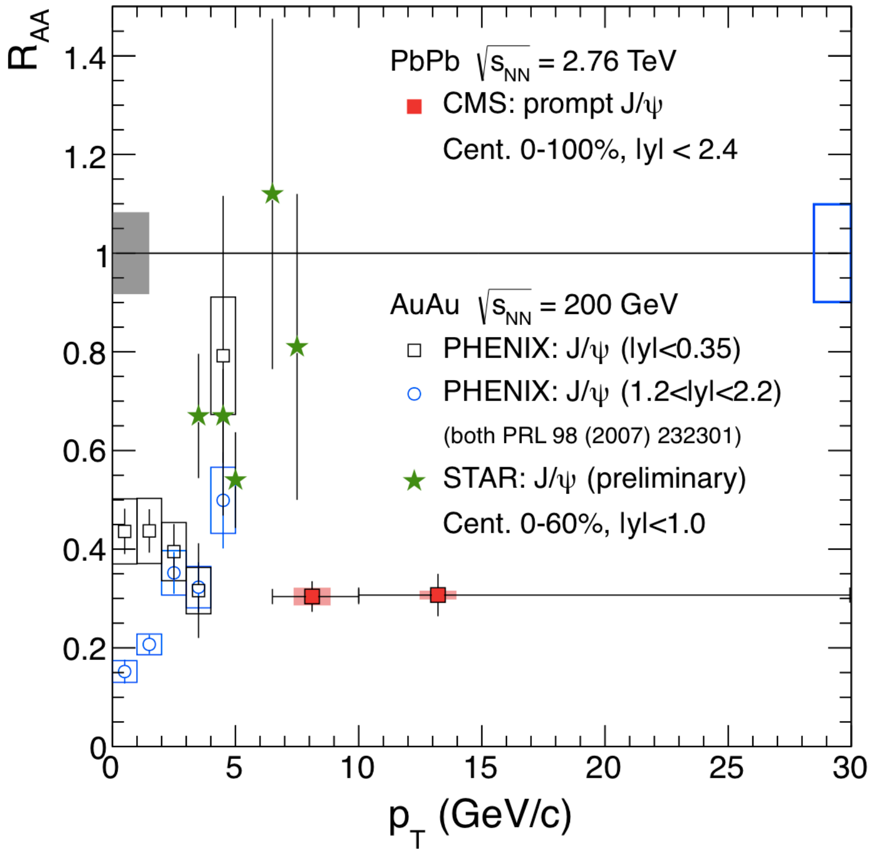




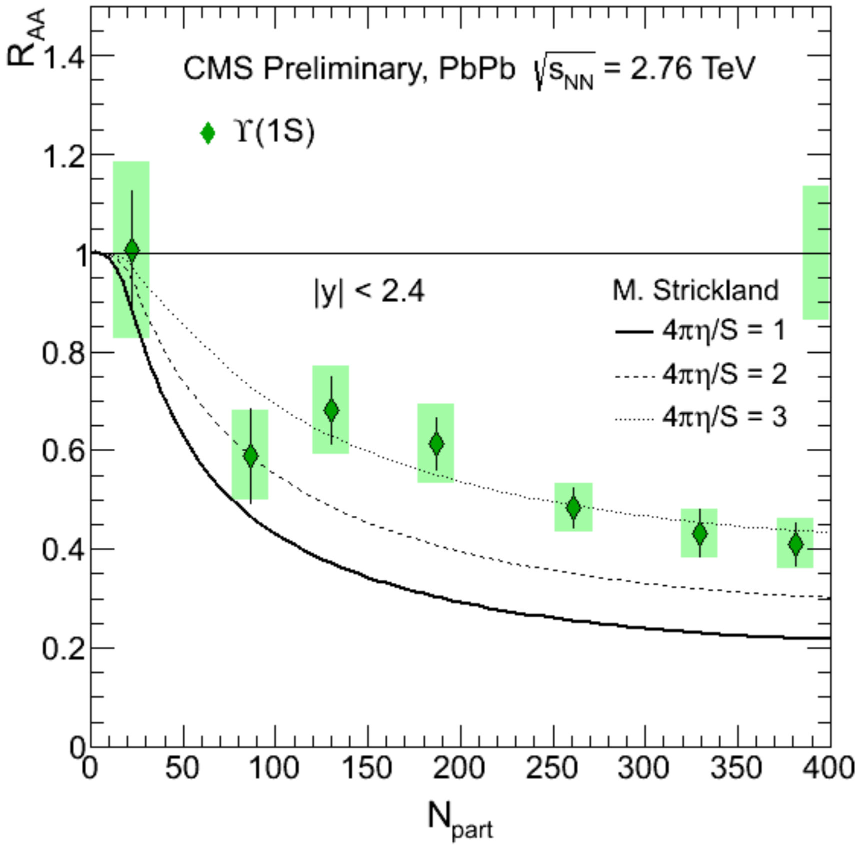
J/ψ comparison: RHIC + LHC



J/ψ p_T dependence



$\Upsilon(1S)$ R_{AA}



- Model:
  - Strickland (PRL 107 (2011) 132301)
- Other comparisons
  - Rapp et al. (arXiv:1111.6537)
  - Song et al. (PRC 85 (2012) 014902
  - Brezinski et al. PLB 707 (2012) 534