Bottomonium production in heavy-ion collisions with CMS

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On behalf of the CMS Collaboration

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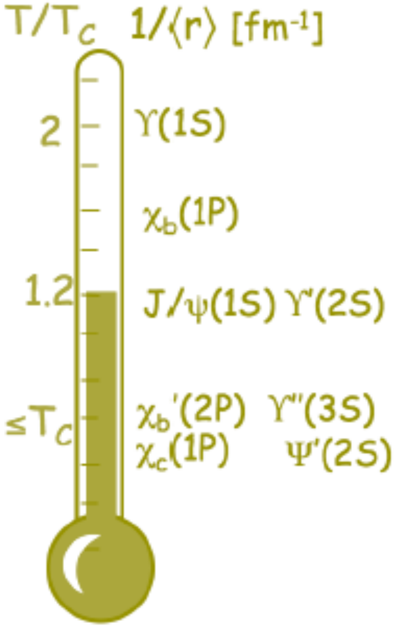
Introduction

- Quarkonia as a probe of deconfinement via colour screening
  → screening
  → melting of the bound state
  → yields suppressed
- Sequential suppression of the quarkonium states
  - Screening at different T for different states → sequential melting
- Enhancement via (re)generation of quarkonia, due to the large heavy-quark multiplicity
- Cold Nuclear Matter effects (CNM effects), such as nuclear absorption and gluon shadowing

Matsui and Satz, PLB 178 (1986) 416. Digal, Petreczky, Satz, PRD 64 (2001) 0940150. Andronic, Braun-Munzinger, Redlich, Stachel, PLB 571(2003) 36. R. L. Thews, M. Schroedter, and J. Rafelski, Phys. Rev. C63, 054905 (2001)

Advantages of bottomonium

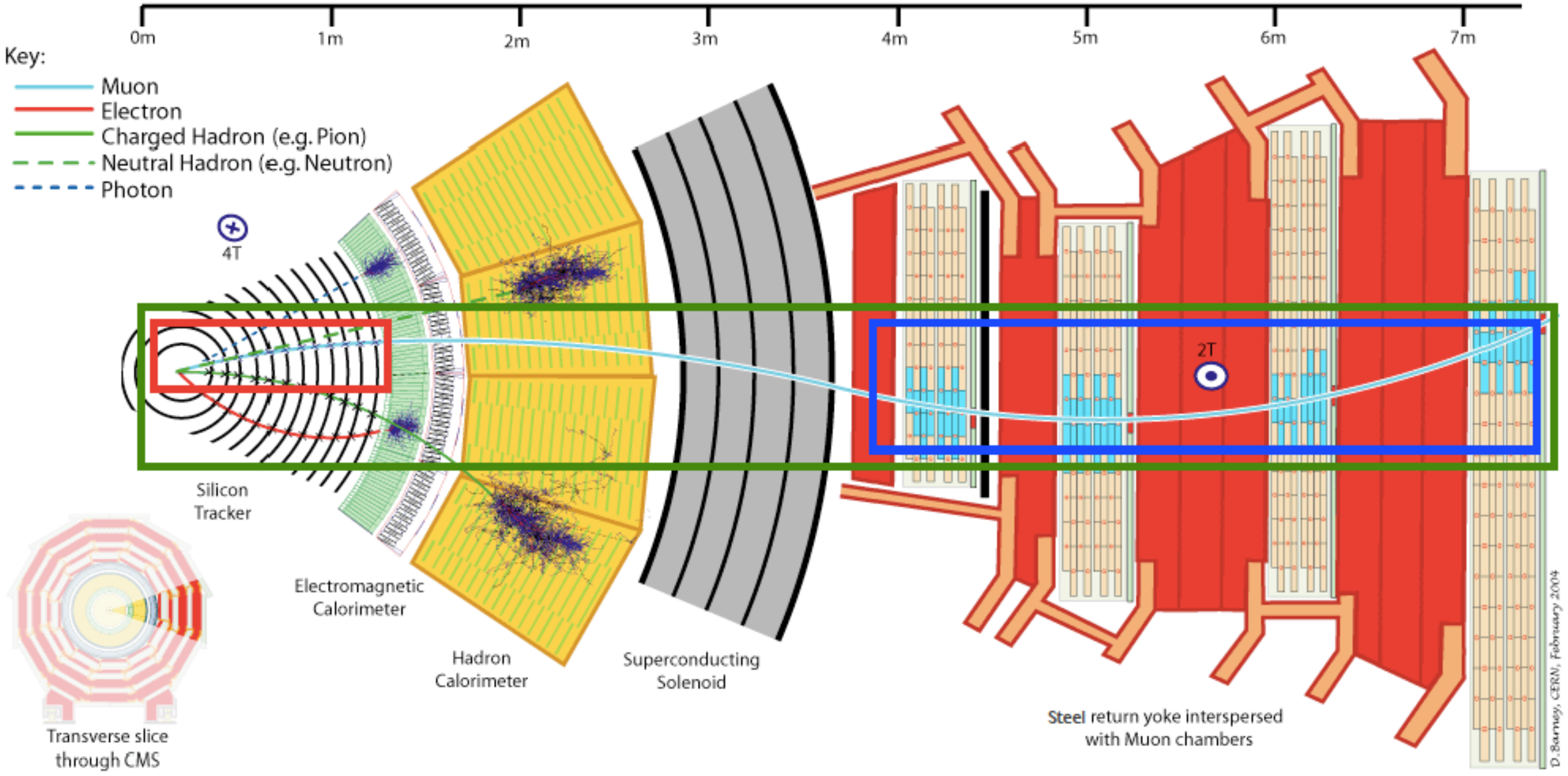
- No B-hadron feed down
- Larger feed down fraction from excited states to Υ(1S)
- Sensitive to larger temperature range above T_c
- Expect much less regeneration: cleaner interpretation of suppression



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

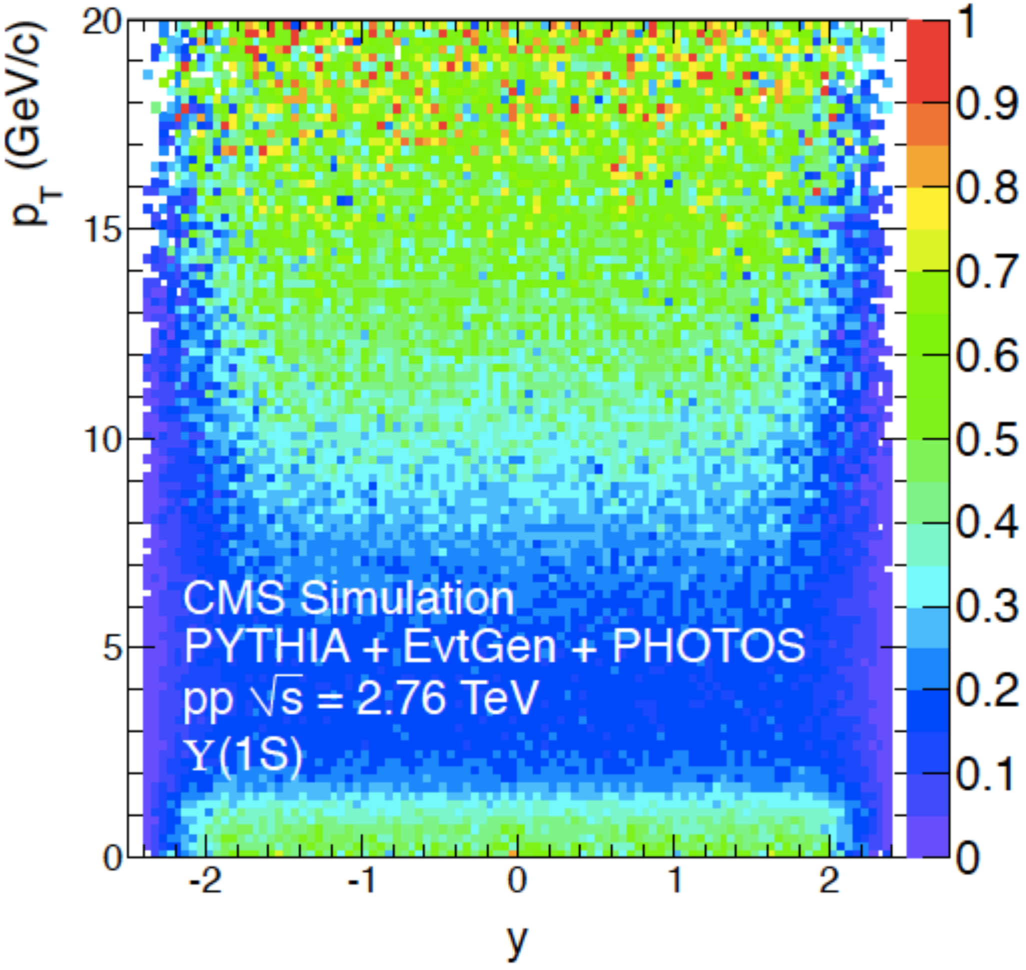
State	Υ(1S)	**χ_b(1P)**	Υ(2S)	**χ_b (2P)**	Υ(3S)
m (GeV/c^2)	9.46	9.99	10.02	10.26	10.36
r_0 (fm)	0.28	0.44	0.56	0.68	0.78

CMS Muon reconstruction



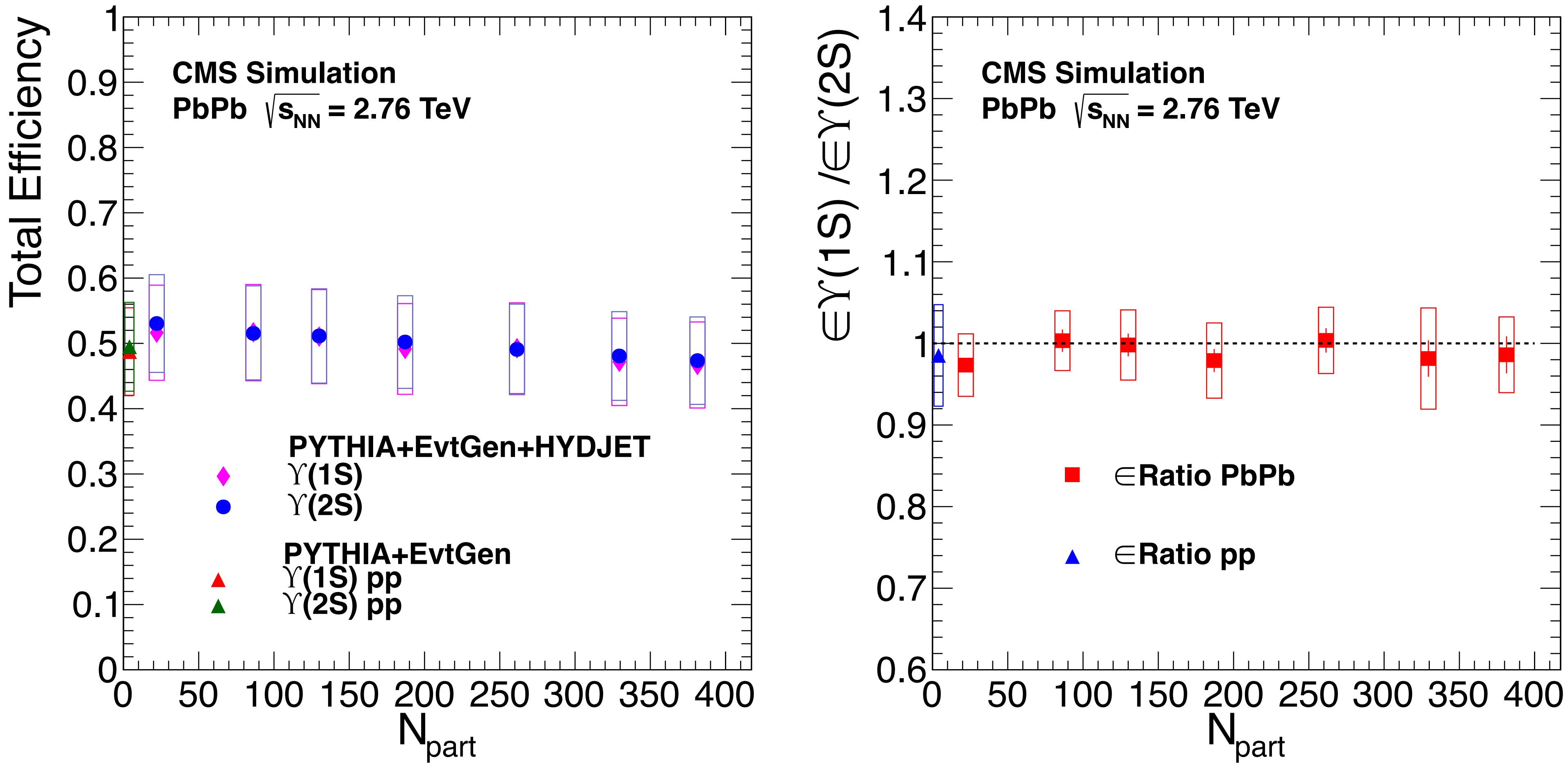
- Global muons reconstructed with information from inner tracker and muon stations
- Further muon ID based on track quality
- Global muons need $p \gtrsim 3$ GeV/c to reach the muon station, but lose 2–3 GeV energy in the absorber → a minimum of ~ 5 GeV/c total momentum required

Υ(1S) acceptance



- For the Υ(1S) we can go down to p_T = 0 GeV/c

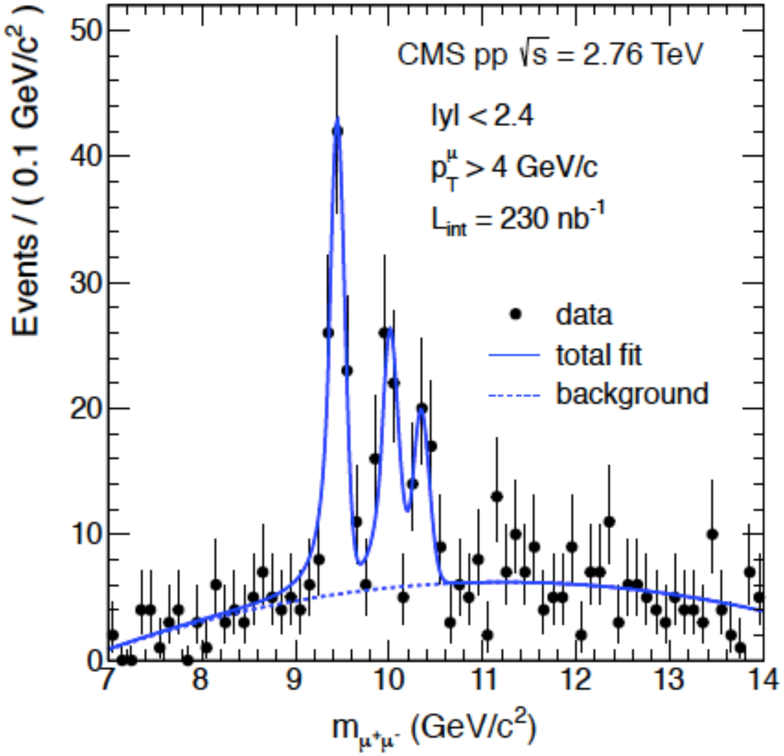
Υ(1S), Υ(2S) efficiencies

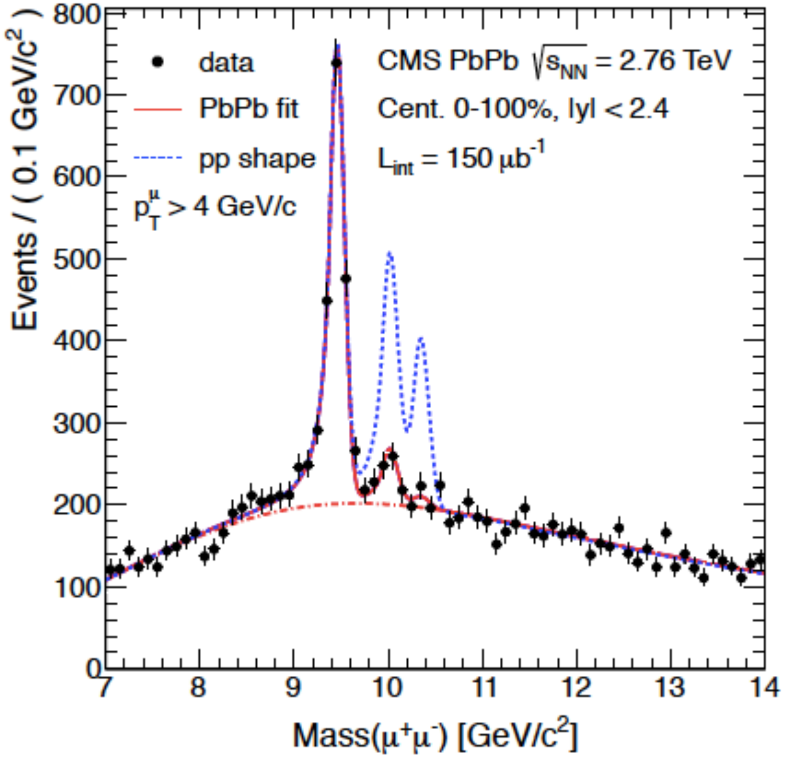


- Efficiencies from Monte Carlo validated with a data driven method (Tag&Probe)

Suppression of excited Υ states in PbPb collisions

PRL 109 (2012) 222301



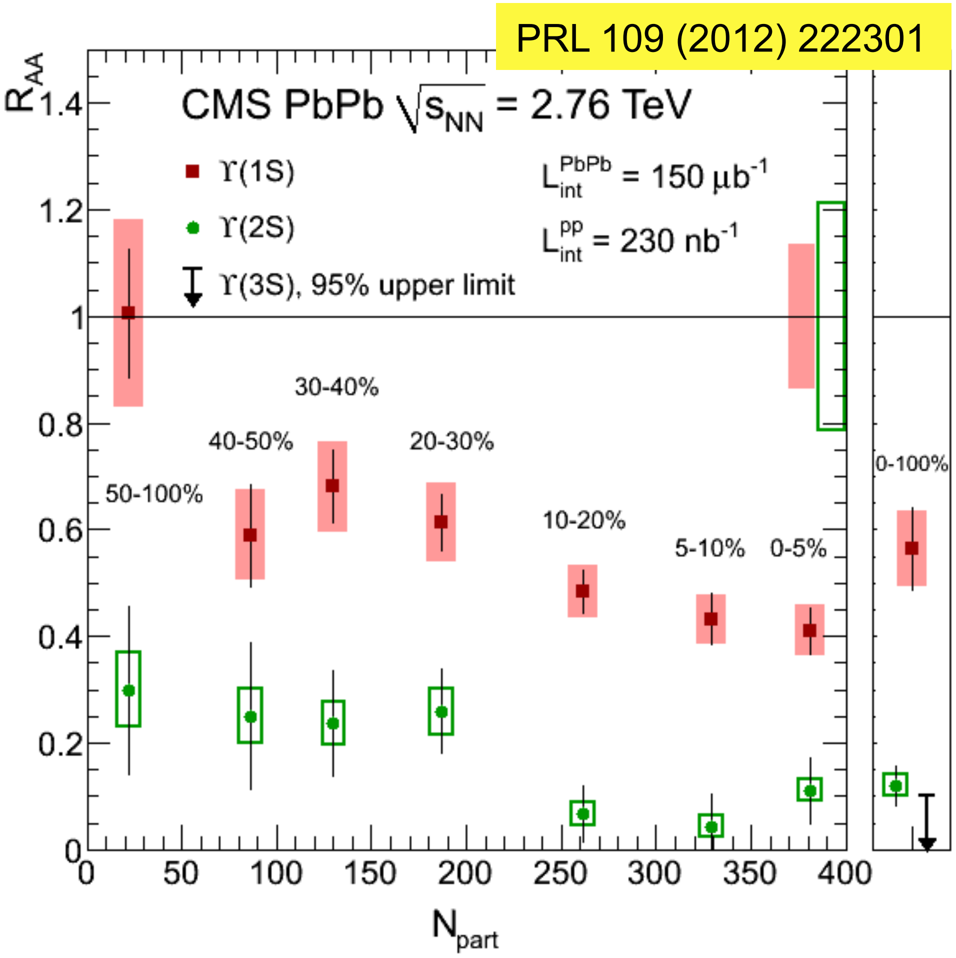


$N_{\Upsilon(2S)} / N_{\Upsilon(1S)}|pp = 0.56 \pm 0.13 \pm 0.02$
$N_{\Upsilon(2S)} / N_{\Upsilon(1S)}|PbPb = 0.12 \pm 0.03 \pm 0.02$

$N_{\Upsilon(3S)} / N_{\Upsilon(1S)}|pp = 0.41 \pm 0.11 \pm 0.04$
$N_{\Upsilon(3S)} / N_{\Upsilon(1S)}|PbPb < 0.07$

$$\frac{[\, N_{\Upsilon(2S)} + N_{\Upsilon(3S)} \,/\, N_{\Upsilon(1S)} \,]_{PbPb}}{[\, N_{\Upsilon(2S)} + N_{\Upsilon(3S)} \,/\, N_{\Upsilon(1S)} \,]_{pp}} = 0.31\,^{+0.19}_{-0.15}\,(\text{stat.}) \pm 0.03\,(\text{syst.})$$

Υ(nS) R_{AA} vs. Centrality


PRL 109 (2012) 222301

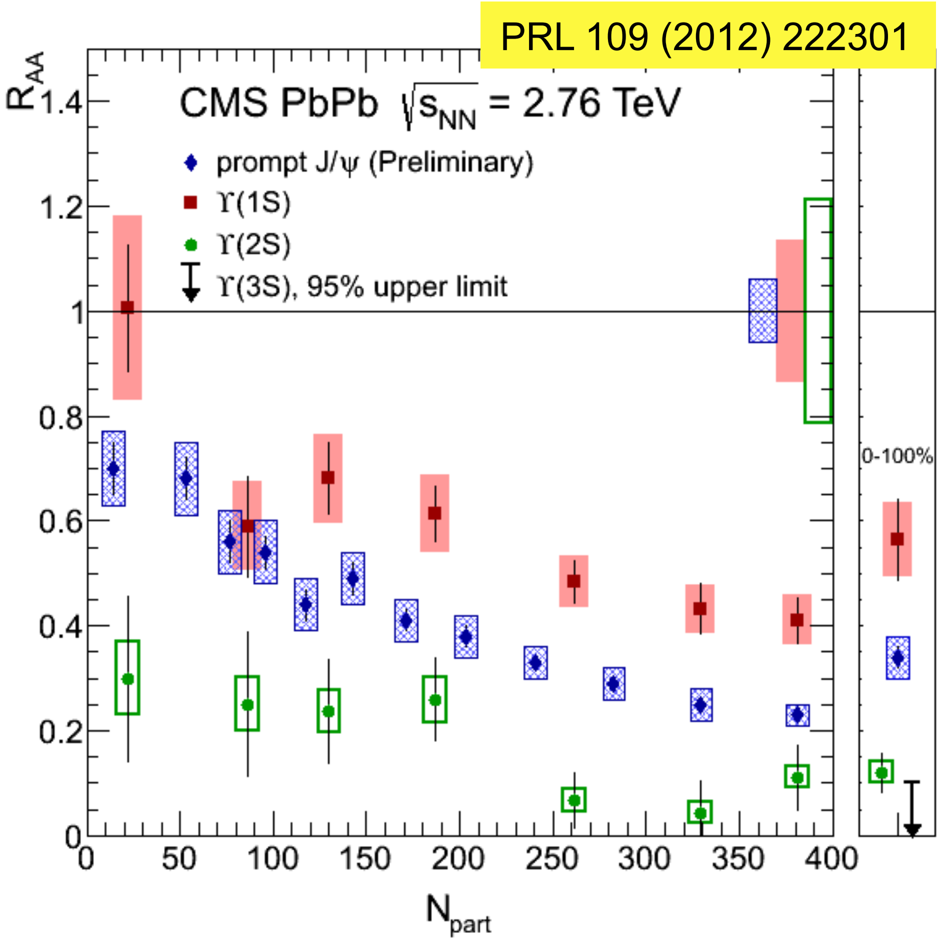
- Υ(1S) R_{AA} in 7 centrality bins
- Clear suppression of Υ(2S)
- Υ(1S) suppression consistent with excited state suppression (~50% feed down)
- Sequential suppression of the three Υ(nS) states in order of their binding energy

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

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

$R_{AA}(\Upsilon(3S)) < 0.1$ (at 95% C.L.)

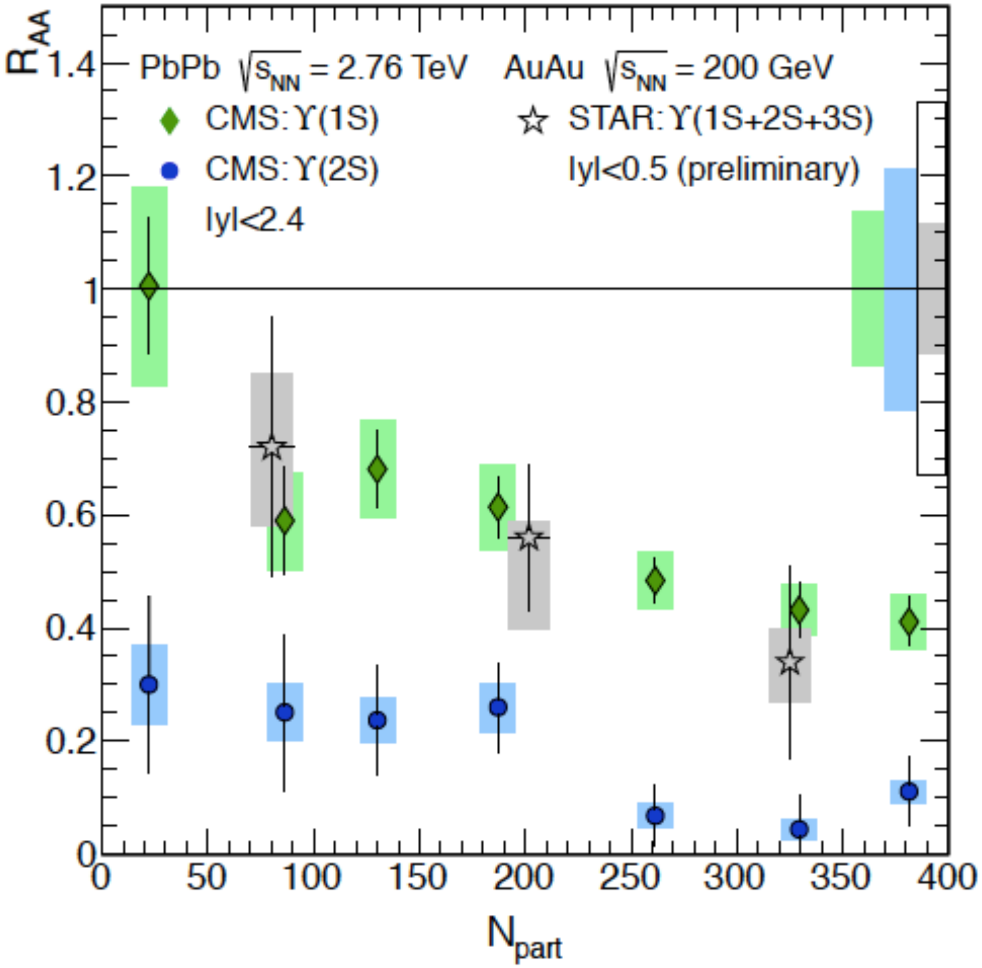
Υ(nS) and prompt-J/ψ R_{AA}



- When comparing the Υ(nS) R_{AA} to the prompt J/ψ R_{AA}
  - Sequential suppression of the quarkonium states in order of their binding energy is confirmed

$R_{AA}(\Upsilon(1S))$ = 0.56 ± 0.08 (stat.) ± 0.07 (syst.)
$R_{AA}(J/\psi)$ = 0.34 ± 0.02 (stat.) ± 0.04 (syst.)
$R_{AA}(\Upsilon(2S))$ = 0.12 ± 0.04 (stat.) ± 0.02 (syst.)
$R_{AA}(\Upsilon(3S)) < 0.1$ (at 95% C.L.)

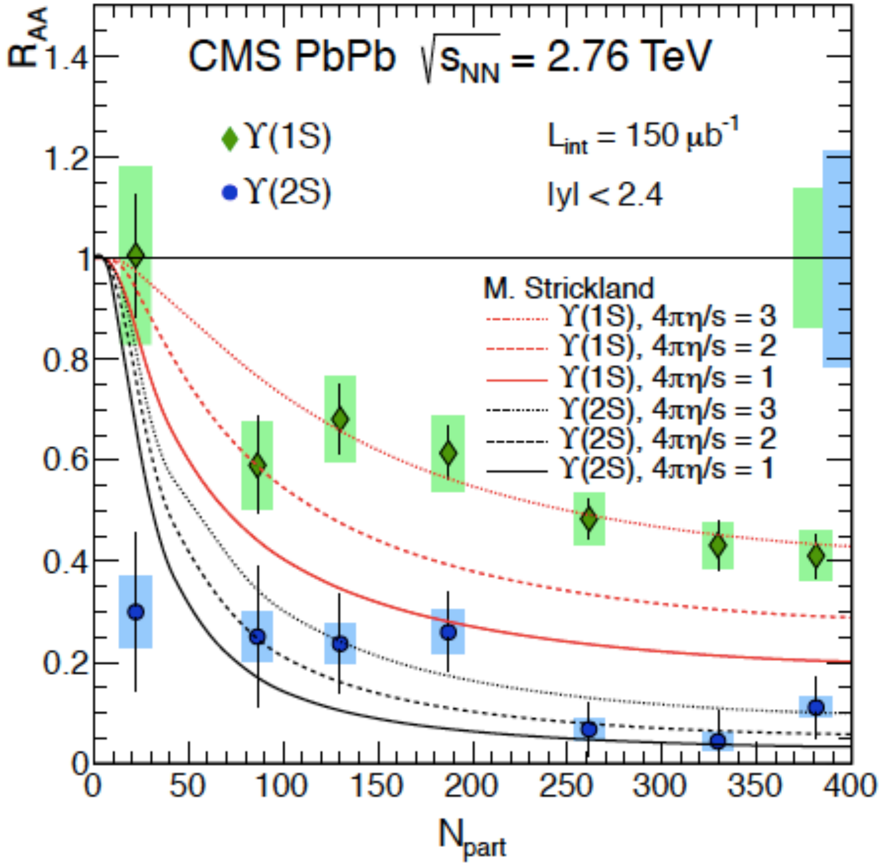
Compare to RHIC



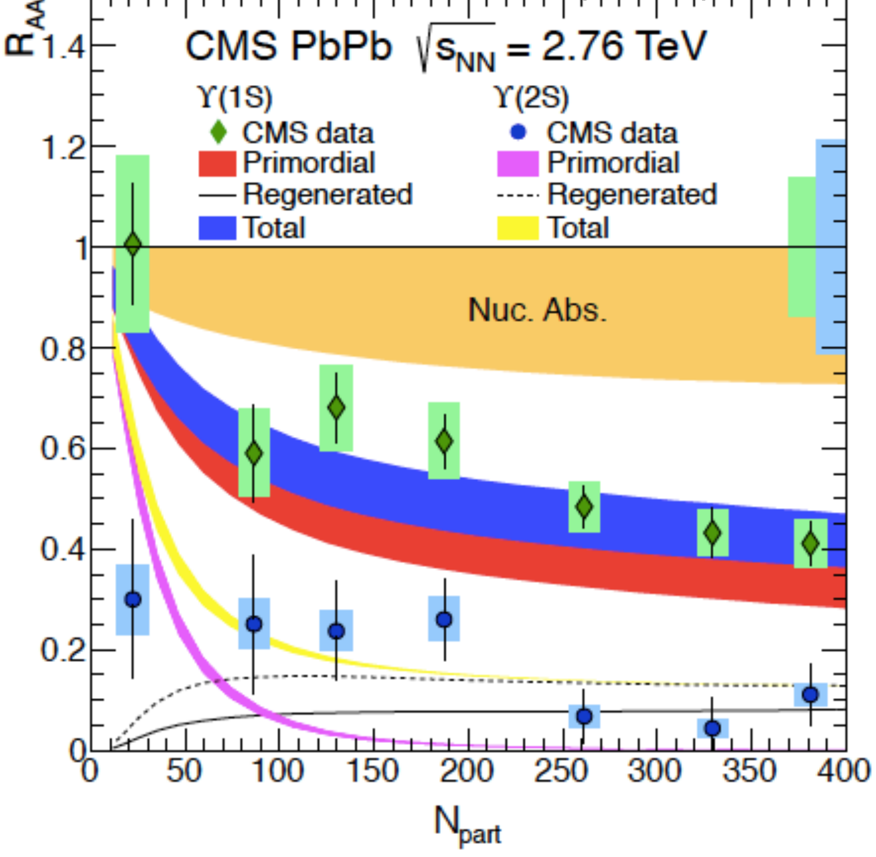
- Caveat: STAR measured R_{AA} of Υ(1S+2S+3S)

Comparison to theory

Strickland arXiv:1207.5327

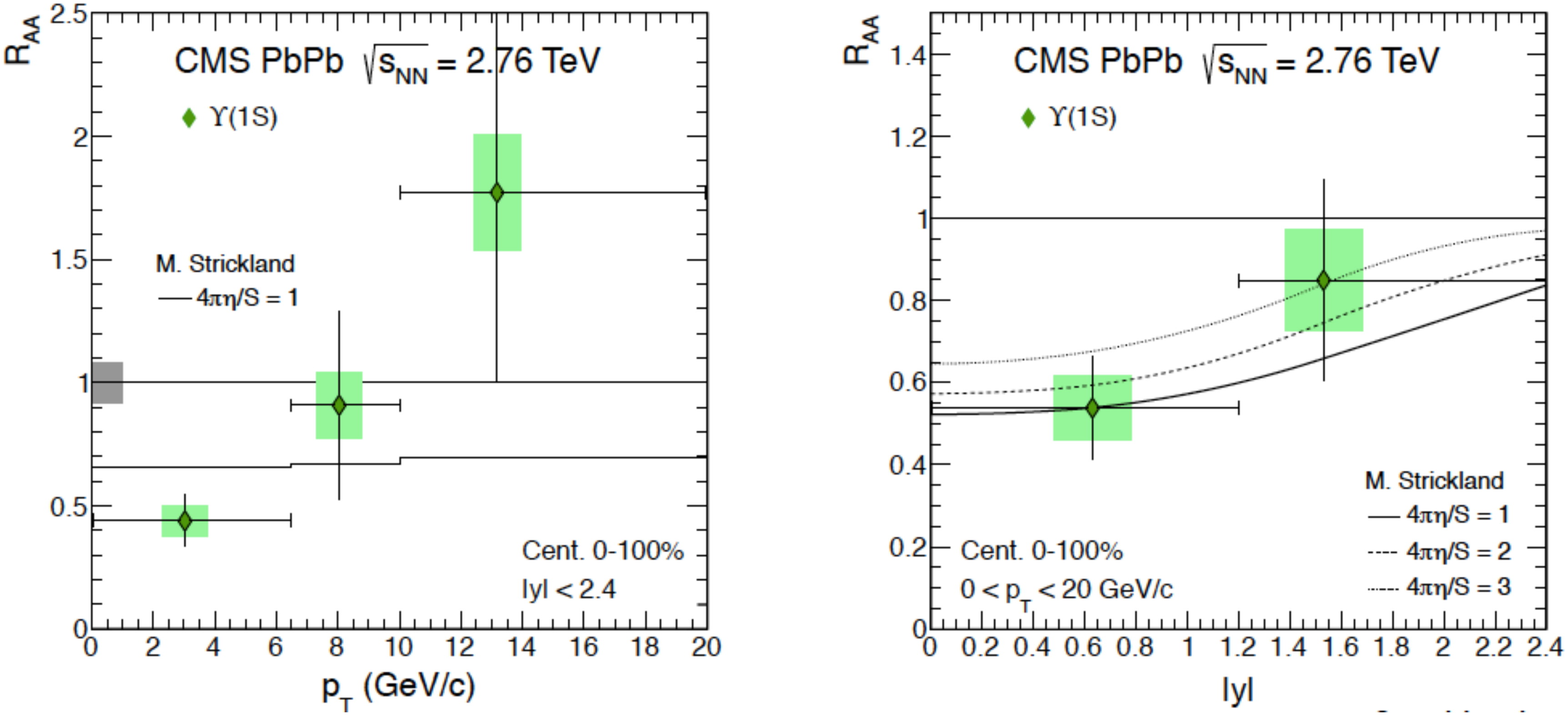


Rapp et al. EPJ A48 (2012) 72



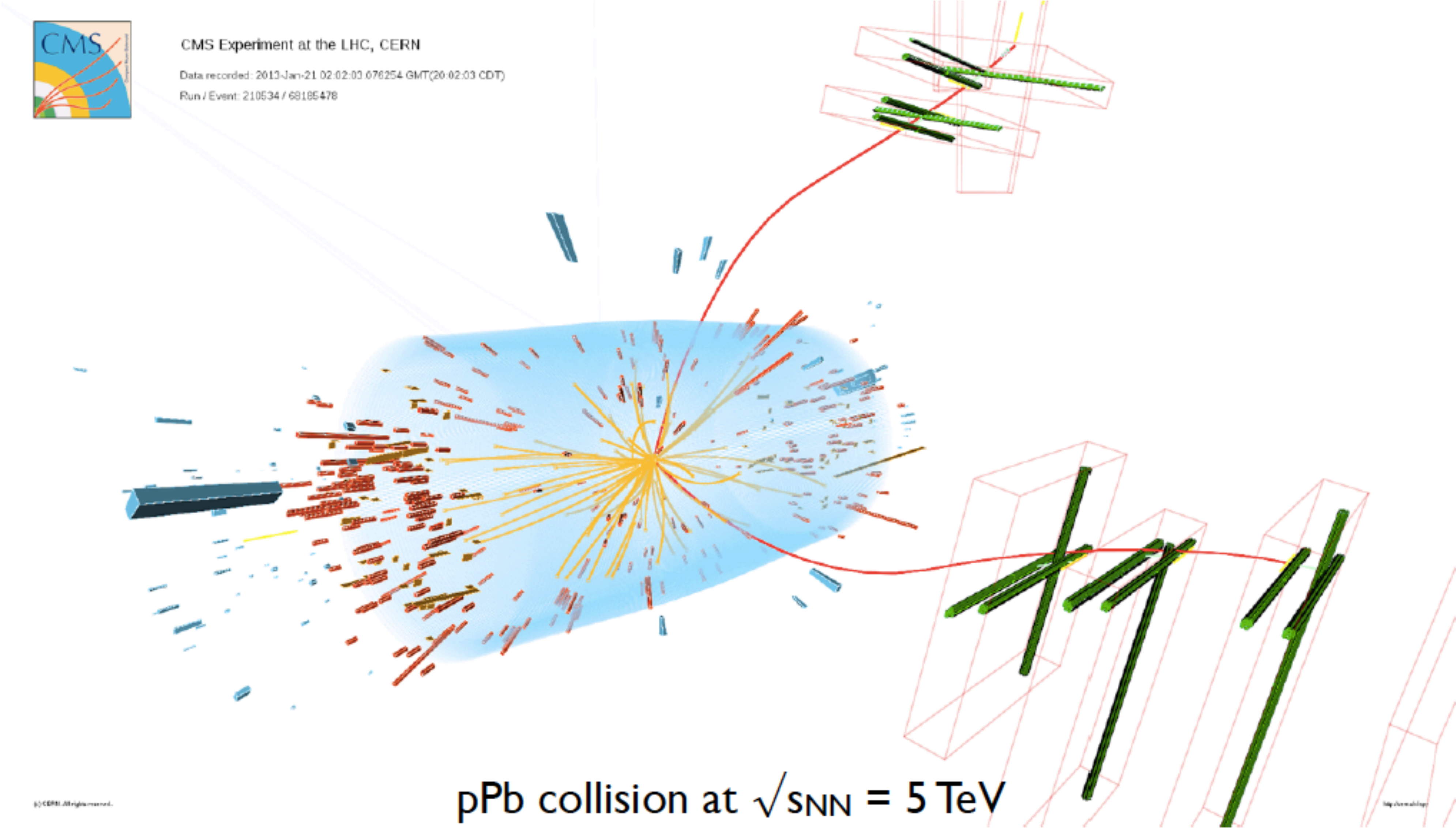
- Strickland: some tension to describe Υ(1S) and Υ(2S) simultaneously with the same η/S value
- Rapp: regeneration and nuclear absorption could be significant also for bottomonia

$\Upsilon(1S)$ R_{AA}: rapidity and p_T dependence



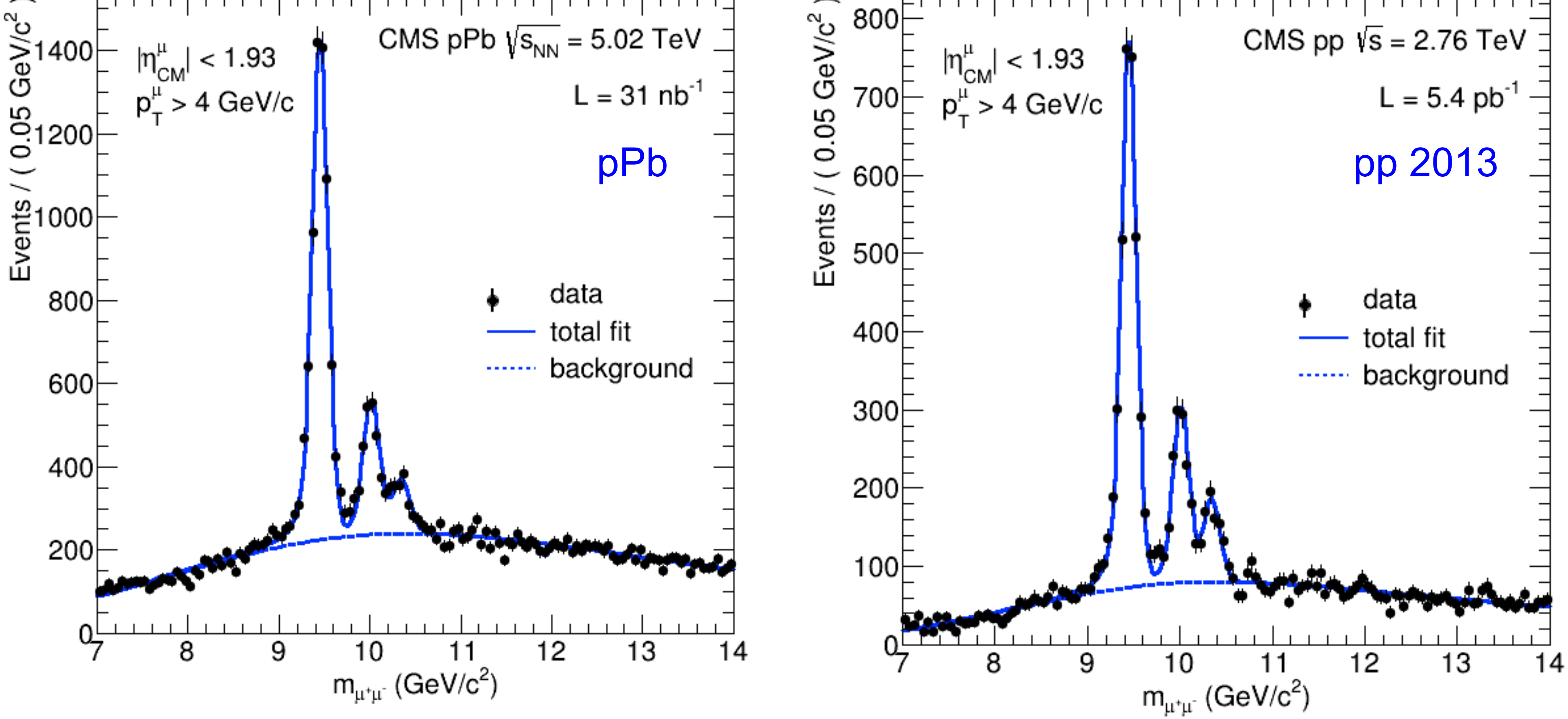
- $\Upsilon(1S)$ suppressed at low p_T, no clear rapidity dependence
  - Based on 2010 PbPb data (7.28 μb−1) and 2011 pp data (230 nb−1)
- With 2011 PbPb sample (~150 μb^{-1}) and 2013 pp sample (~5.4 pb^{-1})
  - The measurement of R_{AA} vs. p_T and y can be improved

Υ(1S) candidate in pPb



pPb collision at $\sqrt{s_{NN}}$ = 5 TeV

Bottomonia: ϒ(1S), ϒ(2S), ϒ(3S) in pPb



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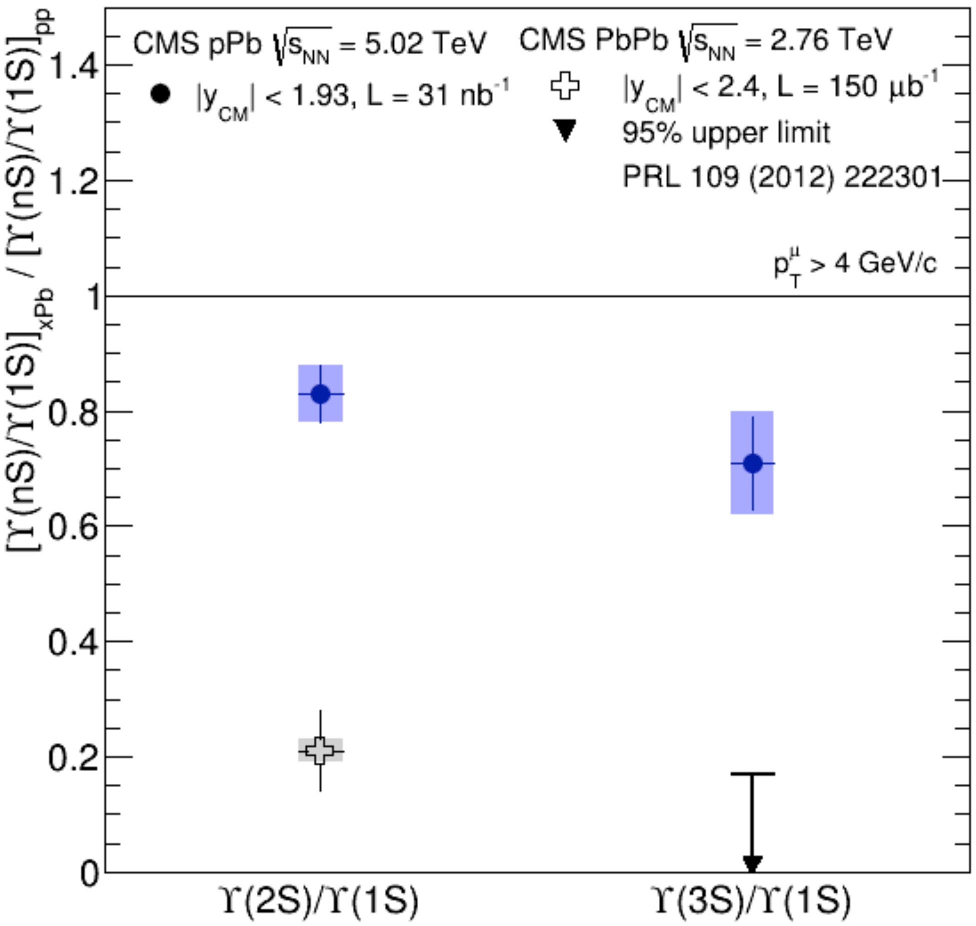
- Signal extraction same procedure in pp, pPb and PbPb:
- Unbinned maximum log likelihood with 1S, 2S/1S, 3S/1S variables in the fit.
  - signal: 3 Crystal-Ball functions
  - background: error function x exponential (all background parameters free)

Integrated measurement: Double ratio



$[\Upsilon(nS) / \Upsilon(1S)]_{xPb} / [\Upsilon(nS) / \Upsilon(1S)]_{pp}$

- pPb vs PbPb: larger double ratios in pPb suggest additional (and/or stronger) final effects in PbPb that affect more the excited states than the ground state
- pPb vs pp: excited states suppressed more than the ground state in pPb compared to pp collisions (significance <3σ)

$\Upsilon(nS)/\Upsilon(1S)$ vs. $E_T^{|\eta|>4}$

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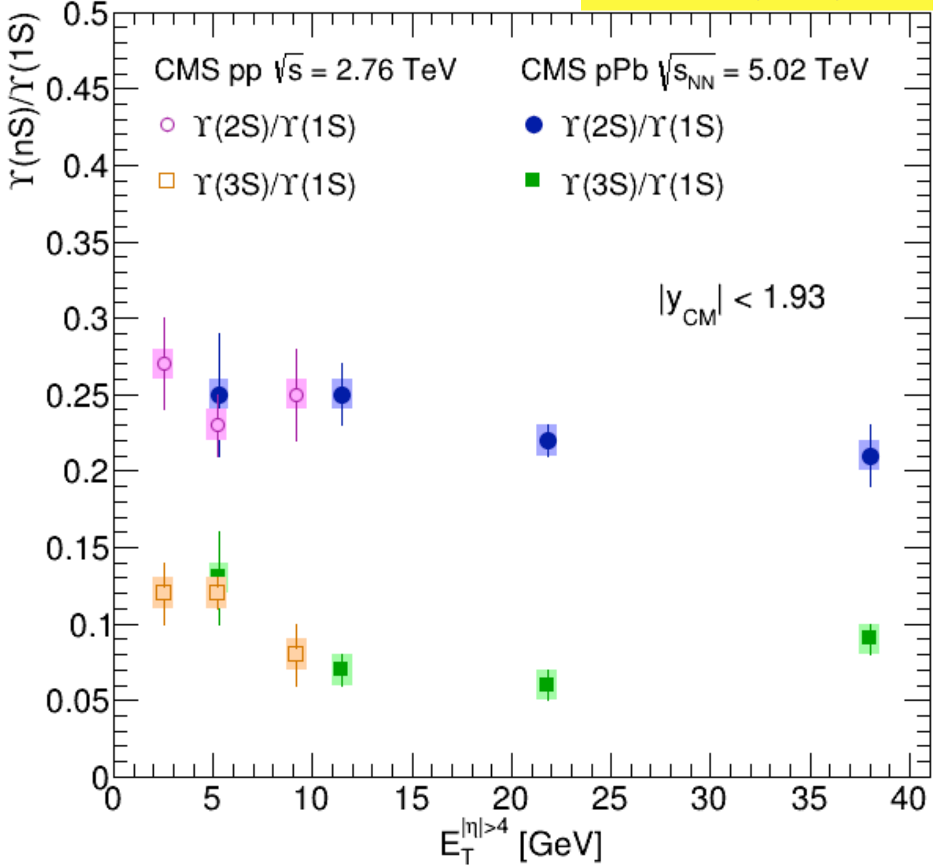
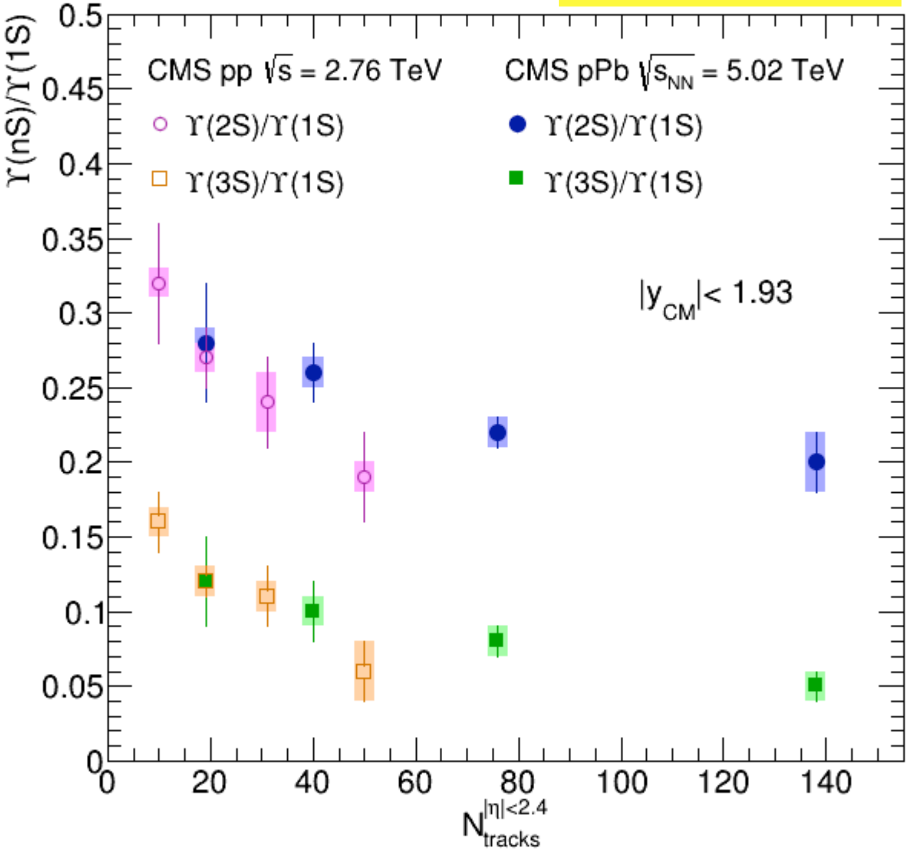


- Yields corrected for acceptance and efficiency
- Ratios $\Upsilon(nS)/\Upsilon(1S)$ are calculated in pp and in pPb
- $\Upsilon(nS)/\Upsilon(1S)$ decrease with increase of the forward transverse energy $E_T^{|\eta|>4}$ in both pp and pPb

$\Upsilon(nS)/\Upsilon(1S)$ vs. $N_{track}^{|\eta|>2.4}$



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- Yields corrected for acceptance and efficiency
- Ratios $\Upsilon(nS)/\Upsilon(1S)$ are calculated in pp and in pPb
- $\Upsilon(nS)/\Upsilon(1S)$ decrease significantly with increase of charged-particle multiplicity $N_{track}^{|\eta|>2.4}$ in both pp and pPb

- Possible explanations:
  - Υ effects the multiplicity in both pp and pPb ~2 extra tracks in a $\Upsilon(1S)$ event compared to $\Upsilon(2S)$ and $\Upsilon(3S)$ events
  - The multiplicity affects the Υ, the activity around the Υ breaks the states

$\Upsilon(nS)/\Upsilon(1S)$ event activity dependence

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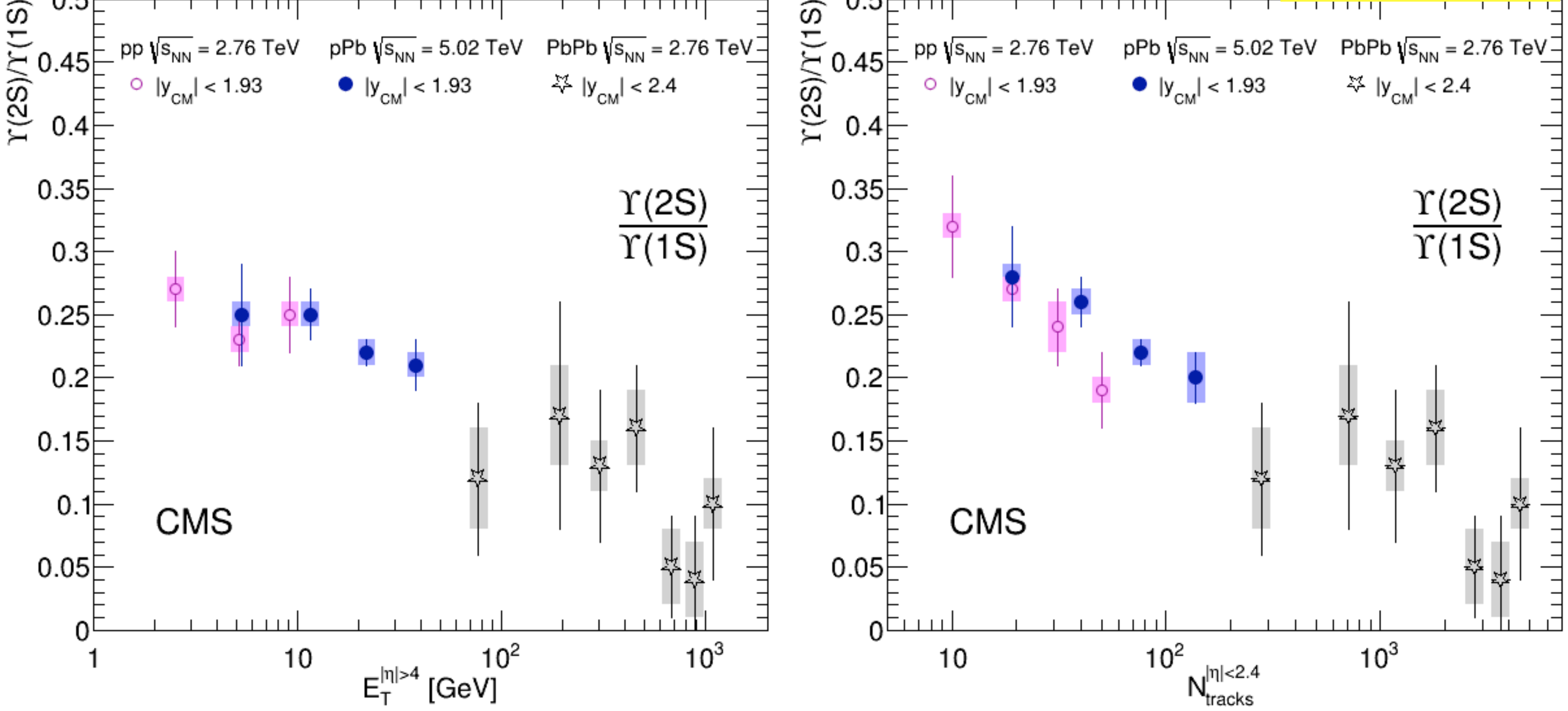

- No significant dependence for PbPb results as function of N_{tracks} and $E_T|\eta>4$, but we have large uncertainties (more PbPb data needed)

Self-normalized ratios

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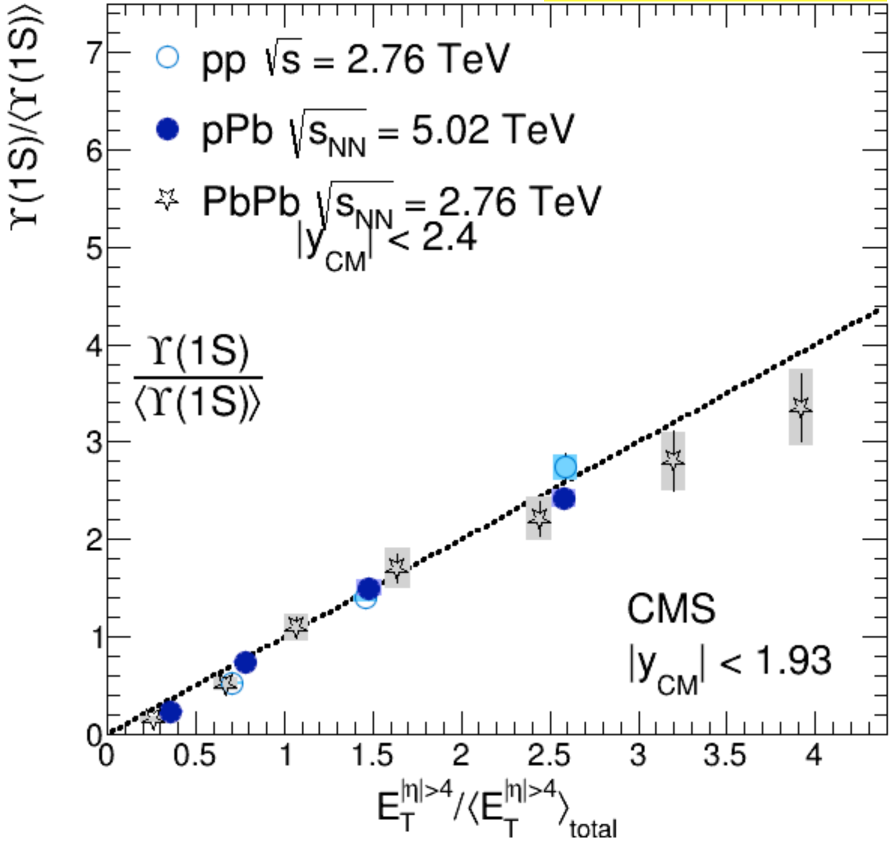

- Yields normalized to their average vs. event activity
  - Access to individual-state variations
- Different $<E_T>$:
  - In pp: 3.5 GeV
  - In pPb: 14.7 GeV
  - In PbPb: 760 GeV
- More Υ in events with higher transverse energy (E_T)
- Slopes for the 3 systems are consistent with 1

Self-normalized ratios

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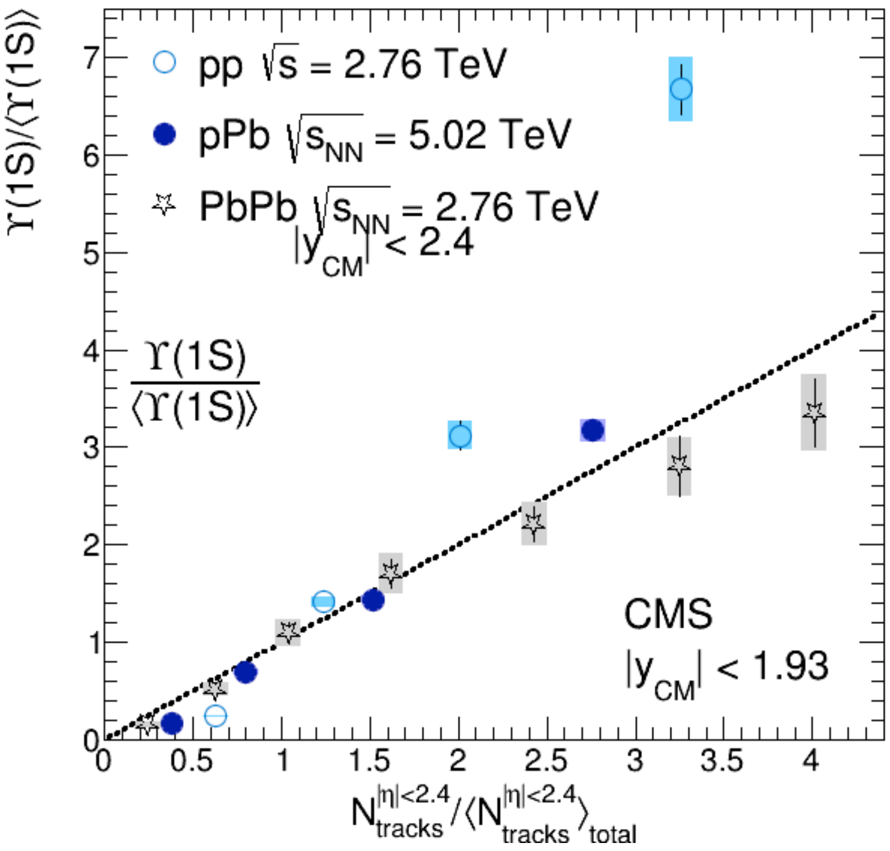

- Yields normalized to their average vs. event activity
  - Access to individual-state variations

- More Υ in events with higher multiplicity

- Less coherent behaviour when compared to the transverse energy multiplicity
  - pp : multi-parton interaction ?

Comparison to ALICE

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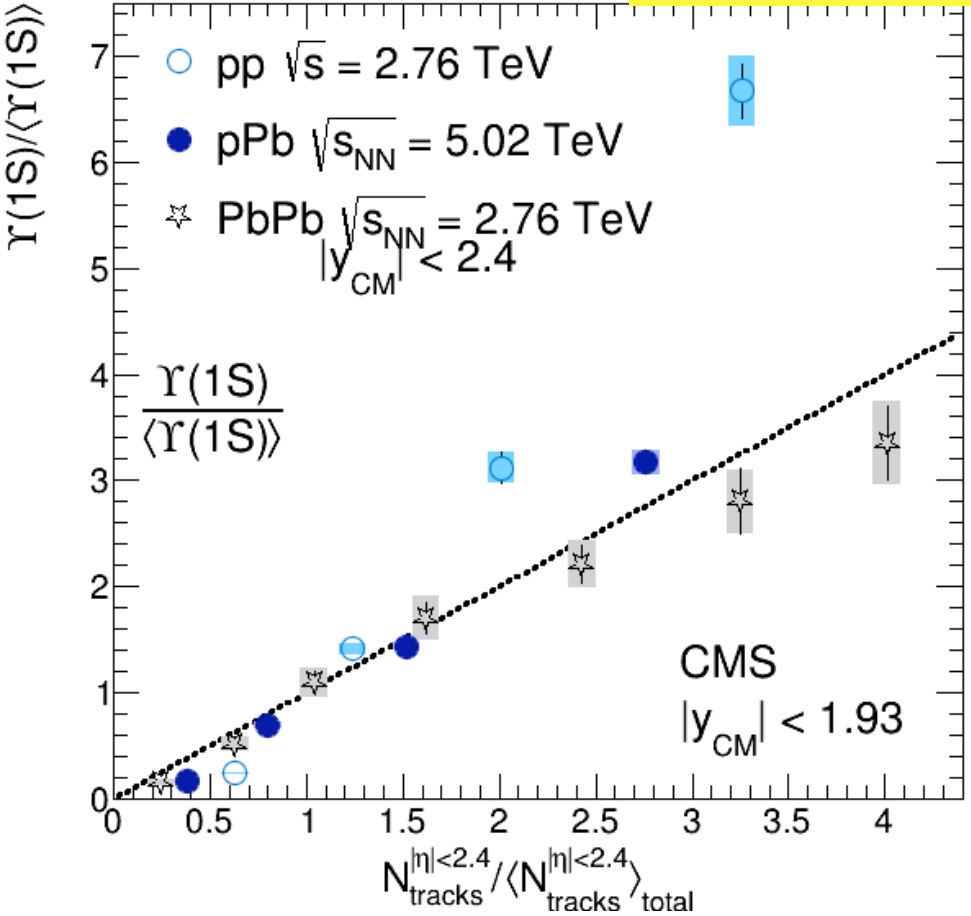
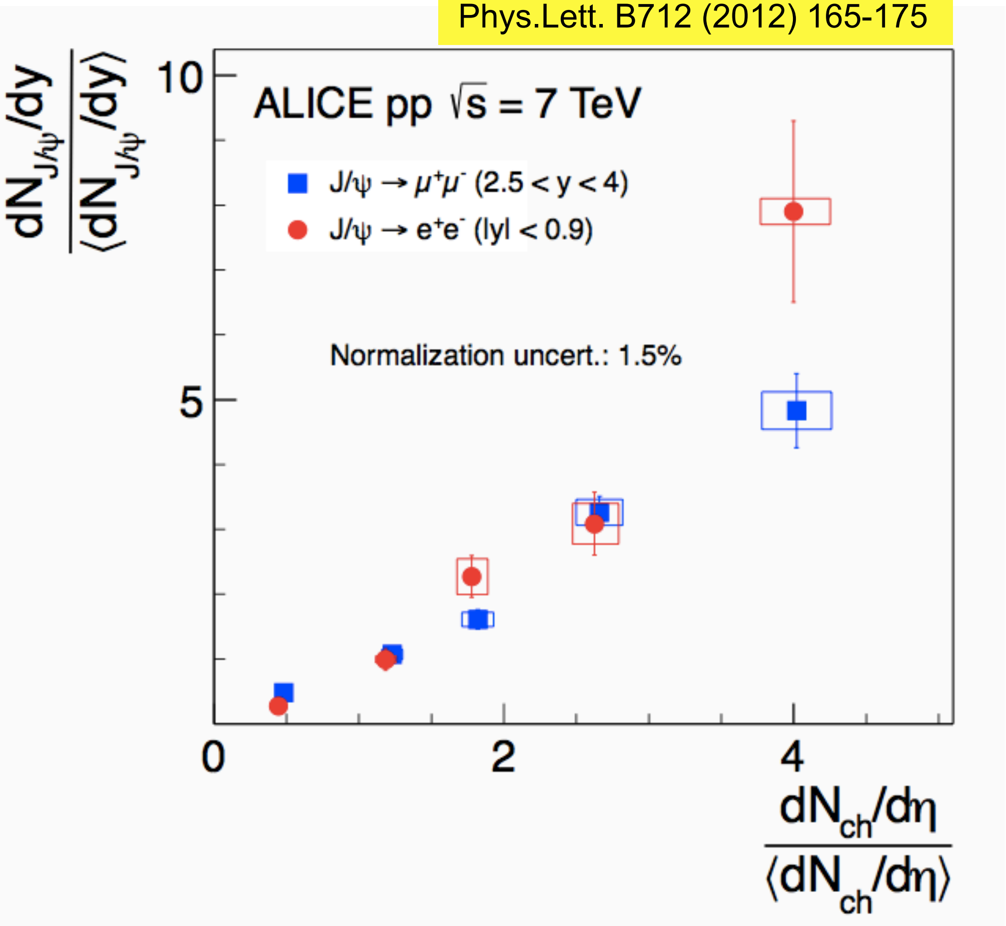


Phys.Lett. B712 (2012) 165-175



- Similar trend measured by ALICE for J/ψ in pp at 7TeV
- Activity-dependent analysis of the copious pp data at 7TeV may give a better understanding of the ϒ states

Summary

- In PbPb:
  - sequential suppression in order of binding energy of the bottomonium states
  - measurement of R_{AA} vs. p_T and y can be improved with the latest pp run (ongoing)

- In pPb:
  - double ratios $[\Upsilon(nS) / \Upsilon(1S)]_{xPb} / [\Upsilon(nS) / \Upsilon(1S)]_{pp}$ hinting the presence of additional effects in PbPb compared to pPb and more effects in pPb compared to pp, for 1S and (2S, 3S)
  - $\Upsilon(nS) / \Upsilon(1S)$: decrease with increase of charged-particle multiplicity in both pp and pPb (less pronounced when measured versus energy deposited at large pseudorapidity)
  - $\Upsilon(nS)/\langle\Upsilon(nS)\rangle$ increase with increasing event activity in pp, pPb and PbPb