Bottomonia and open beauty in CMS

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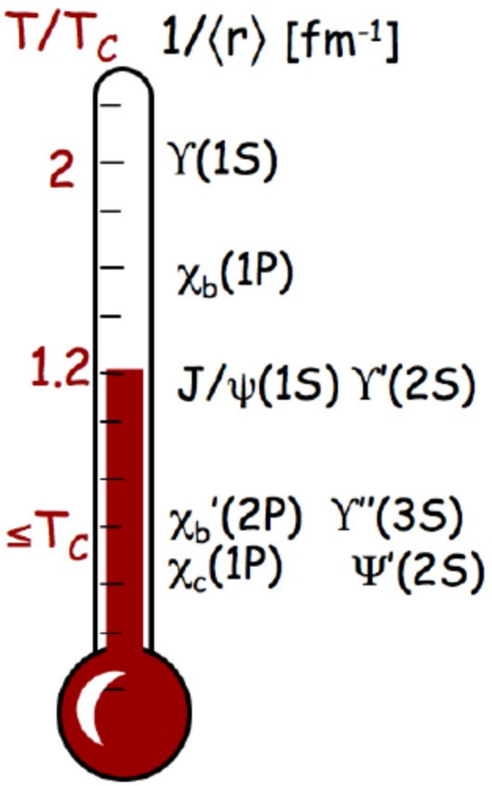
Quarkonia as a thermometer

- Different binding energies of quarkonium states
  → Sequential melting of the states with increasing medium temperature

- Advantages of bottomonium over charmonium
  - Don't need to separate prompt from non-prompt
  - Different T_d for 3 states with similar BRxσ
  - Υ(1S) melts at the highest medium temperature
  - Smaller contribution for Cold-Nuclear-Matter effect is expected
  - Less regeneration is expected
    → Clearer interpretation of suppression



EPJC 61 (2009) 705

Open beauty in the medium

- Closed and open heavy-flavor interact with the QGP differently
  - For closed heavy-flavor: color screening, recombination(QQ) and/or energy loss
  - For open heavy-flavor: energy loss and/or recombination(Qq)

- Energy loss mechanisms of partons in the QGP:
  - Radiative energy loss
  - Collisional energy loss

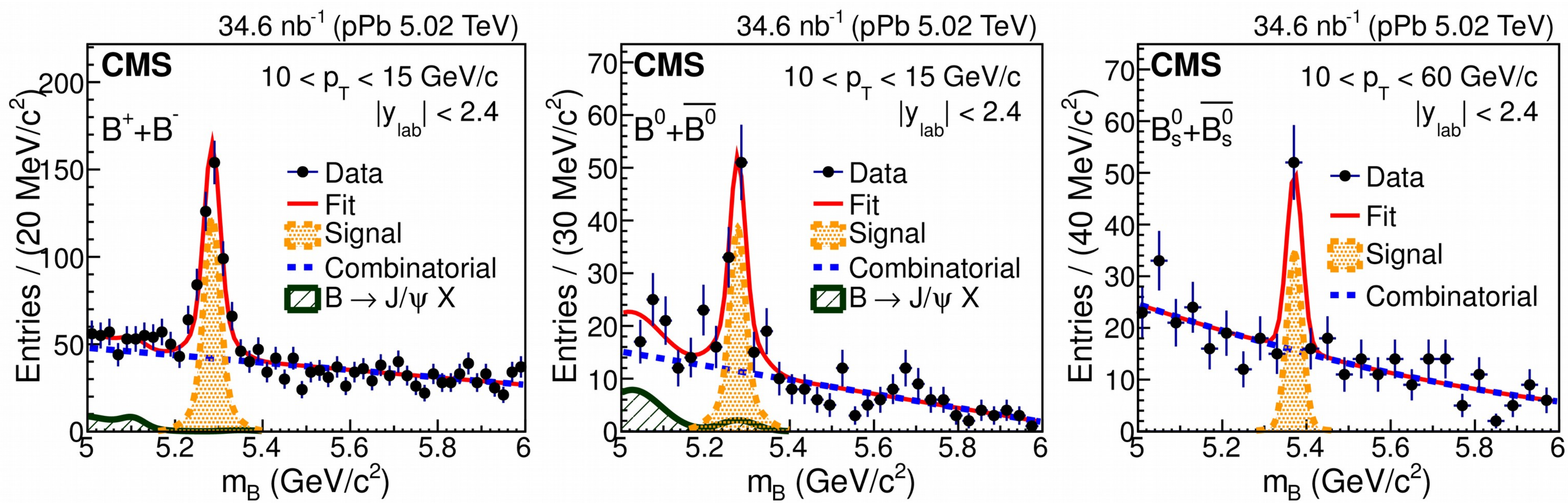
- R_{AA}(gluon) < R_{AA}(u,d,s hadrons) < R_{AA}(D) < R_{AA}(B) is expected
  - Dead-cone effect
    - Small-angle gluon radiation for heavy quarks is expected to be reduced

Exclusive B mesons in pPb collisions

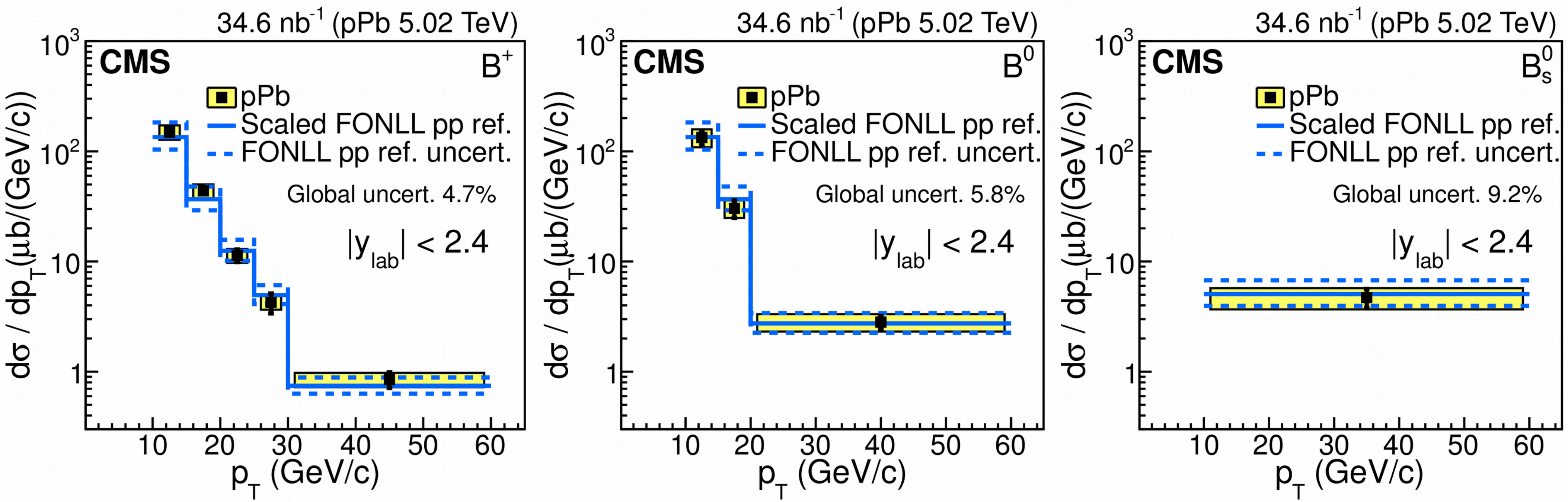
- Charged B mesons are measured by J/ψ decay channels in pPb collisions
  - $B^{+/-} \rightarrow J/\psi + K+ \rightarrow \mu^+\mu^- + K^{+/-}$
  - $B^0 \rightarrow J/\psi + K^* \rightarrow \mu^+\mu^- + K^+ + \pi^-$
  - $B_S \rightarrow J/\psi + \varphi \rightarrow \mu^+\mu^- + K^+ + K^-$

arXiv:1508.06678
(submitted to PRL)

- B meson candidates are obtained from J/ψ combined with a track (B^+) or two tracks (B^0, B_S)



pPb Differential cross sections at 5.02 TeV

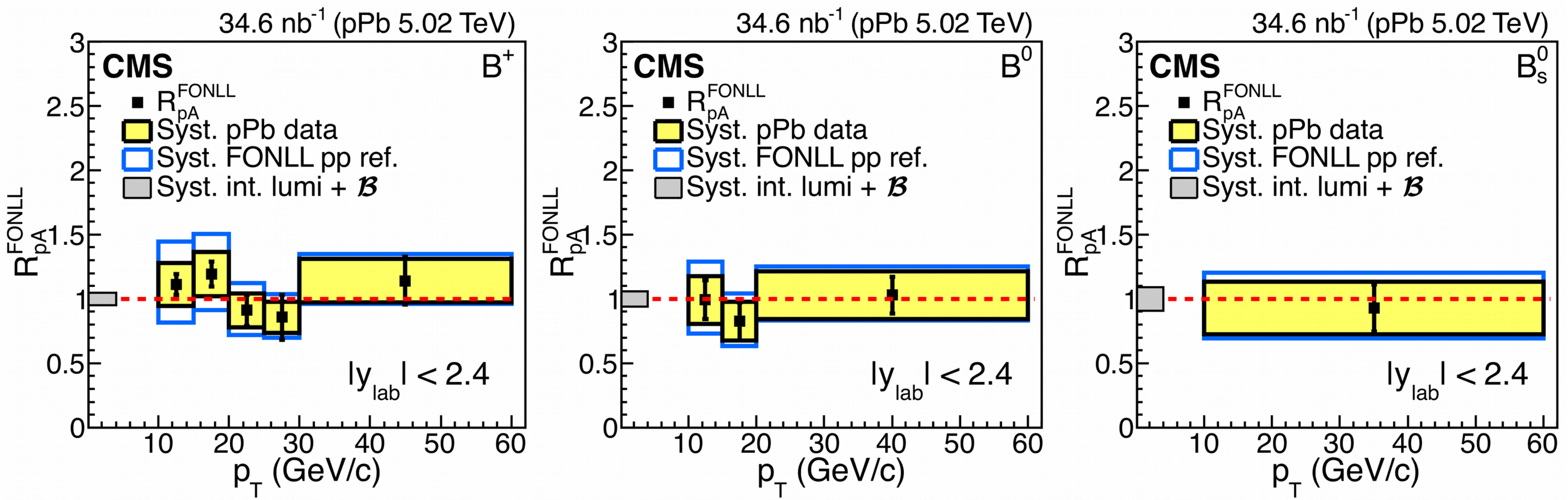


$$\left.\frac{d\sigma^{B}}{dp_{T}}\right|_{|y_{CM}|<1.93} = \frac{1}{2}\frac{1}{\Delta p_{T}}\frac{\left.N^{B}\right|_{|y_{CM}|<1.93}}{(\mathrm{Acc}\times\epsilon)\cdot \mathrm{BR}\cdot\mathcal{L}}$$

- FONLL calculation is used as pp reference and it is taken from
  http://www.lpthe.jussieu.fr/~cacciari/fonll/fonllform.html
- Good agreement with CDF and CMS results

arXiv:1508.06678
(submitted to PRL)

R_{pPb} of B mesons at 5.02 TeV



$$R_{pA}^{\mathrm{FONLL}}(p_{\mathrm{T}}) = \frac{\left(\frac{d\sigma}{dp_{\mathrm{T}}}\right)_{pPb}}{A \times \left(\frac{d\sigma}{dp_{\mathrm{T}}}\right)_{pp}}$$

- R_{pPb}^{FONLL} is compatible with unity within given uncertainties for three B mesons

arXiv:1508.06678
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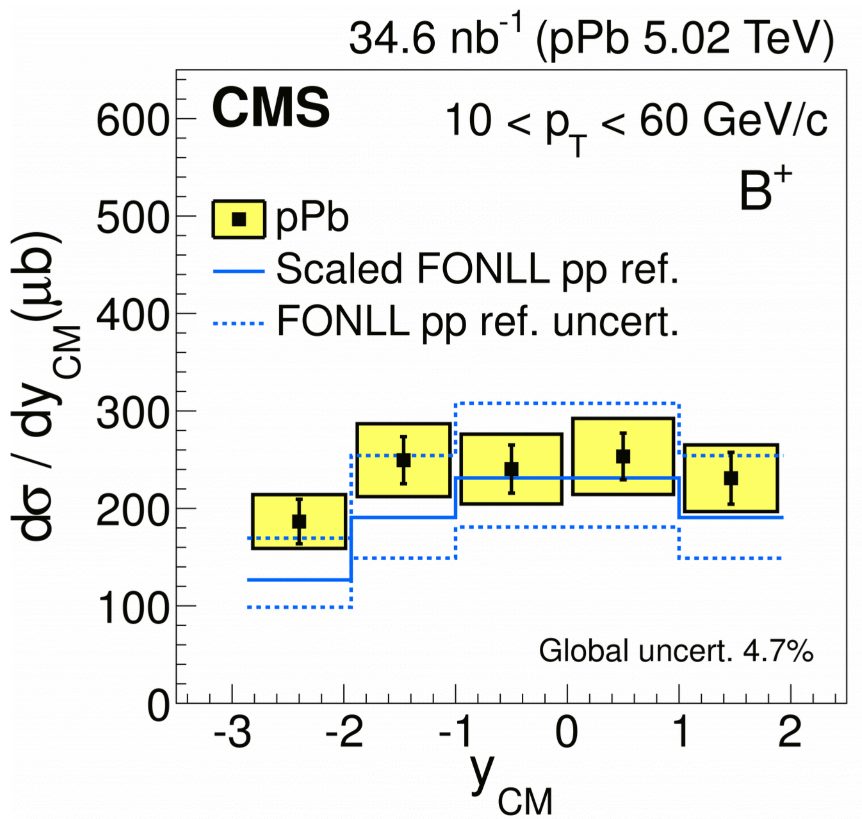
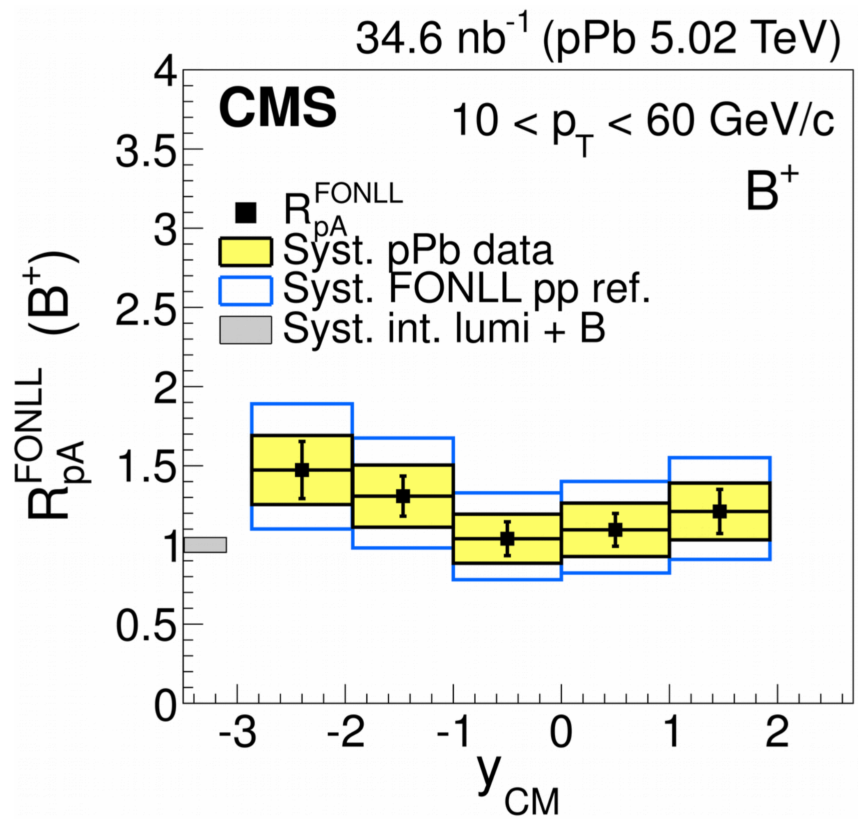
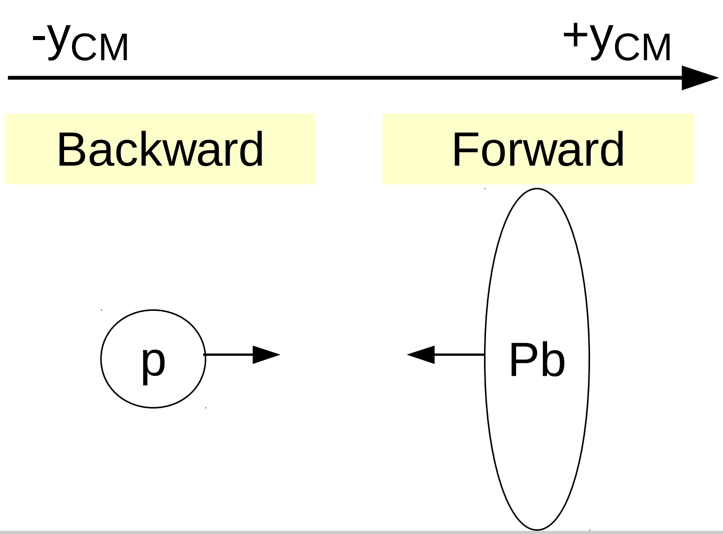
R_{FB} of B mesons in pPb







- Forward and backward ratio, R_{FB}, is unity within uncertainty

arXiv:1508.06678
(submitted to PRL)

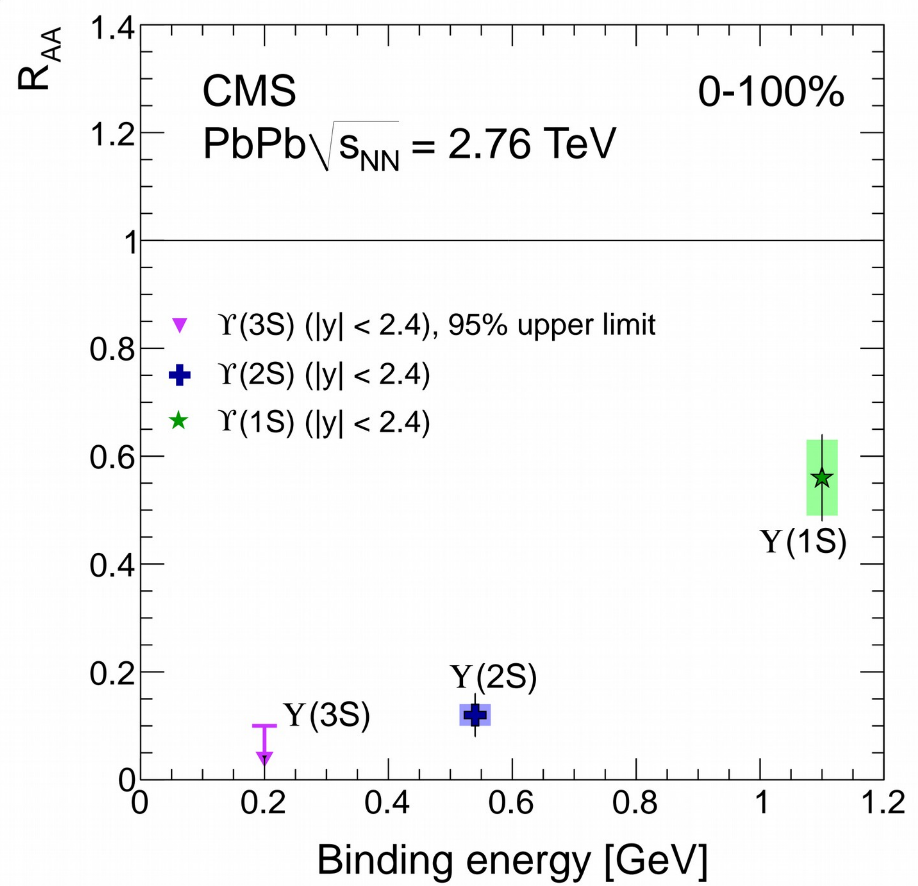
R_{AA} of Υ(nS) in PbPb

- Υ(nS) are suppressed in PbPb collisions
- Stronger suppression for excited states are observed
- Ordered with assumed binding energies

- NEW: Larger reference at the same energy

  → More precise mapping of the kinematics of the suppression in Υ is now possible!

- Let's look at pPb first!



PRL 109 (2012) 222301

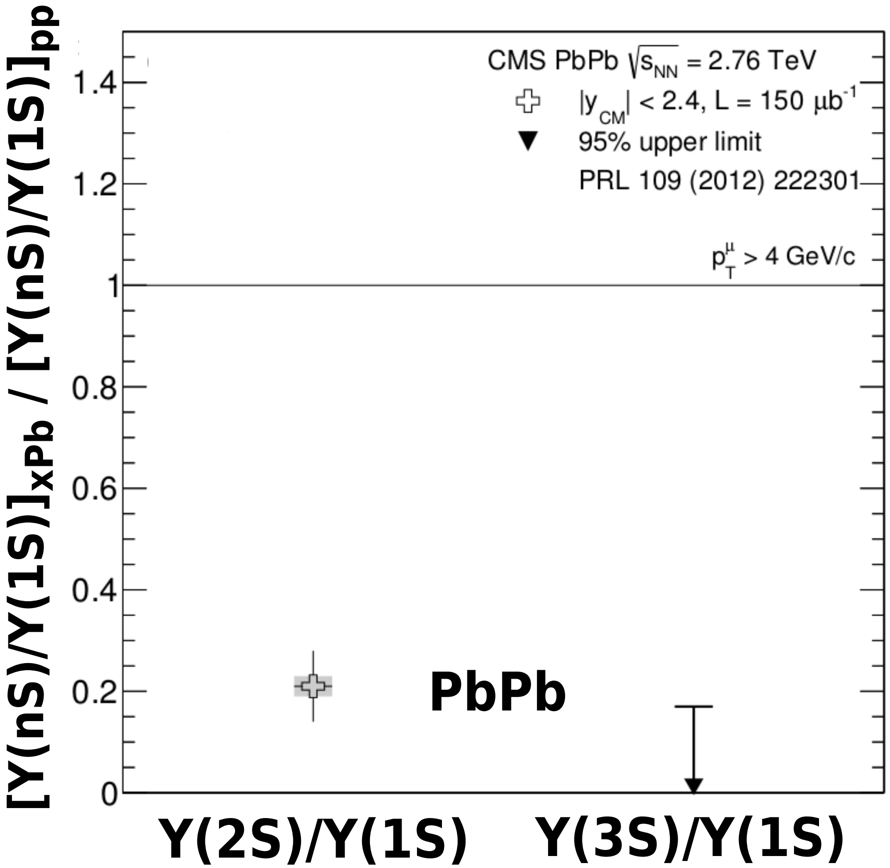
JHEP 1205 (2012) 063

Double ratio of Y(nS)/Y(1S) in pPb and PbPb

- Double ratio cancels initial state effects for excited and ground states
  - Separating final state effects from initial state effects

$$\frac{\left[\frac{\Upsilon(nS)}{\Upsilon(1S)}\right]_{PbPb}}{\left[\frac{\Upsilon(nS)}{\Upsilon(1S)}\right]_{pp}} = \frac{R_{PbPb}(Y(nS))}{R_{PbPb}(Y(1S))}$$

- Excited states are suppressed by a factor of 5 than Y(1S)

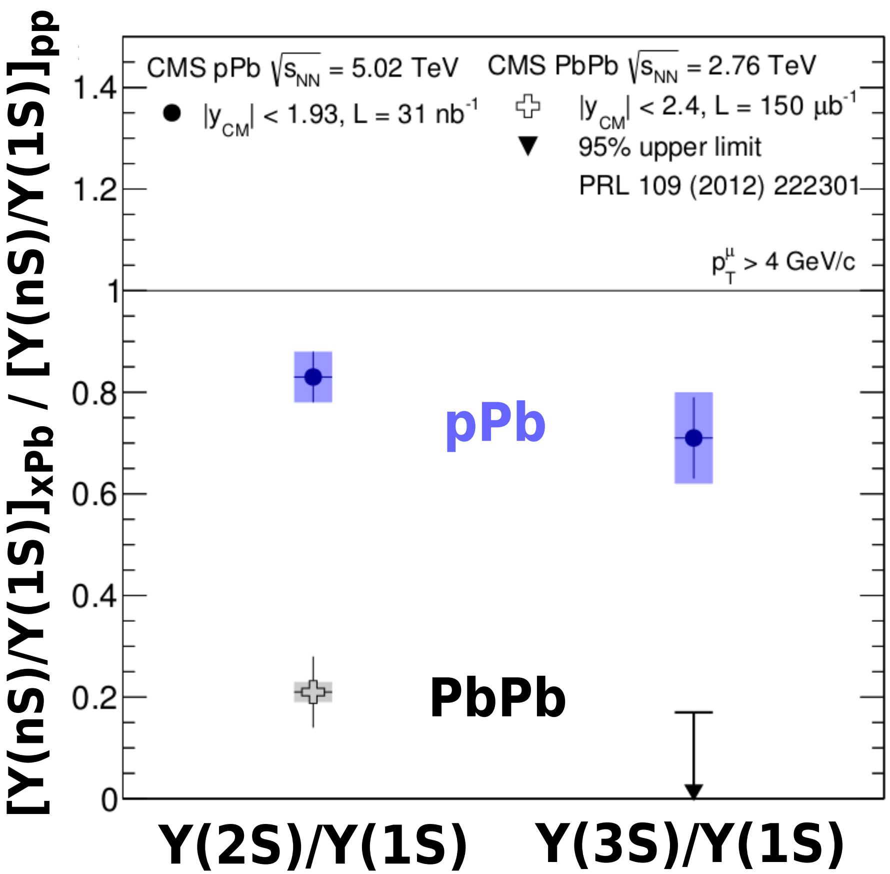


PRL 109 (2012) 222301

Double ratio of Y(nS)/Y(1S) in pPb and PbPb

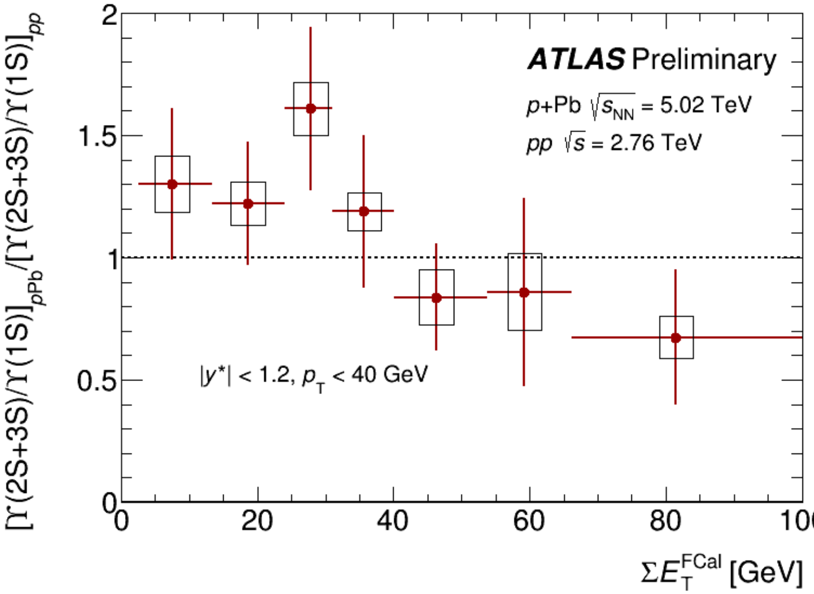
- Double ratio cancels initial state effects for excited and ground states
  - Separating final state effects from initial state effects
- Binding energy ordering is observed
  - Excited states are more suppressed with respect to ground state
- Much lower dependence on Y(nS) states in pPb
  - Excited states also suffer more from CNM effects than ground state

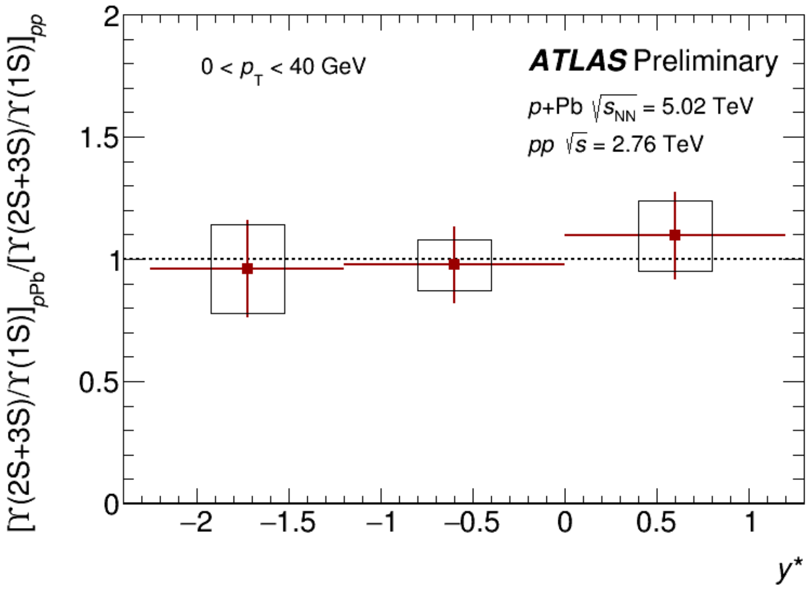
$$\frac{\left[\frac{\Upsilon(nS)}{\Upsilon(1S)}\right]_{pPb}}{\left[\frac{\Upsilon(nS)}{\Upsilon(1S)}\right]_{pp}} = \frac{R_{pPb}(\Upsilon(nS))}{R_{pPb}(\Upsilon(1S))}$$

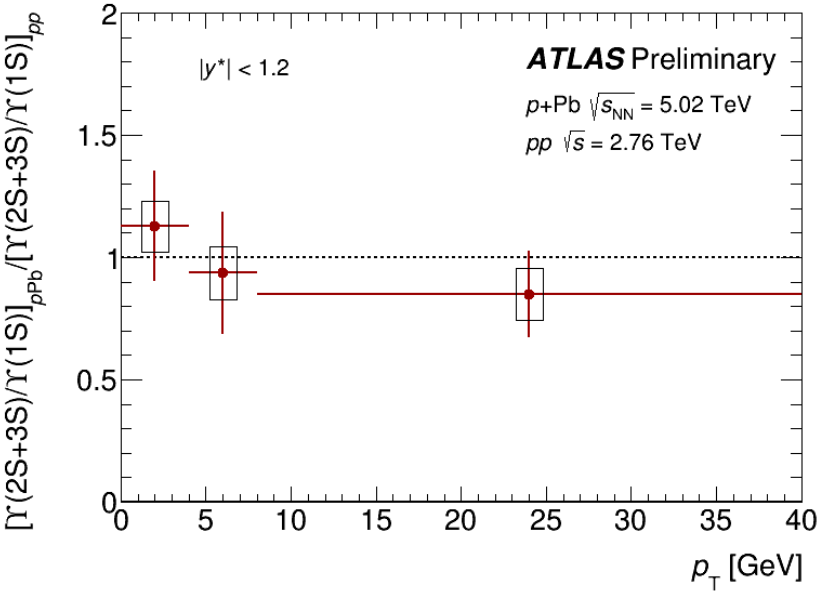


JHEP 04 (2014) 103

Double ratio of Υ(nS)/Υ(1S) in pPb from ATLAS





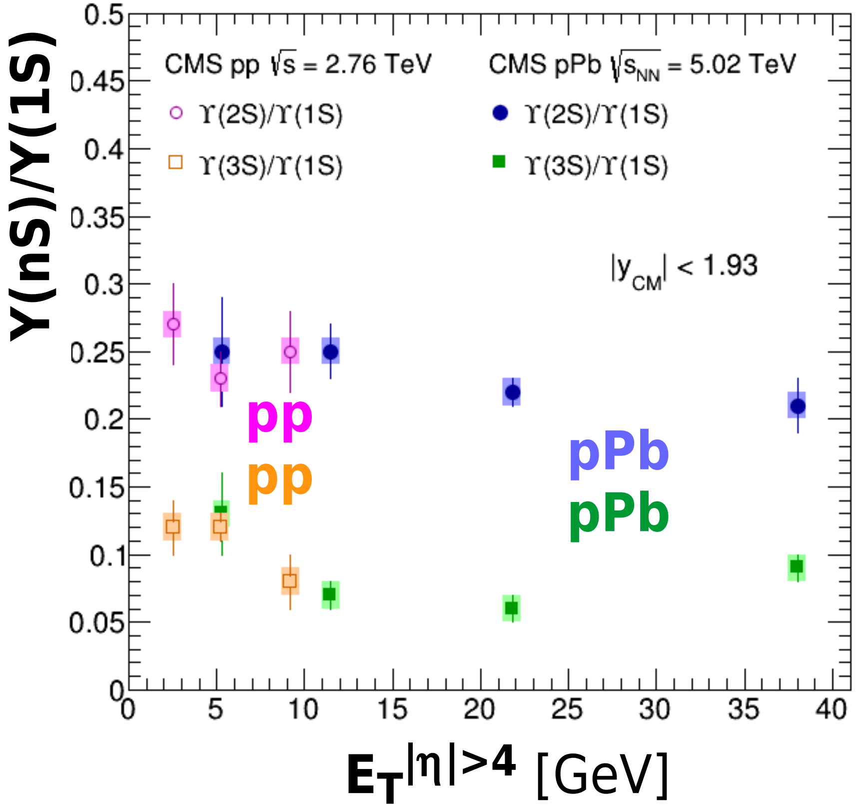


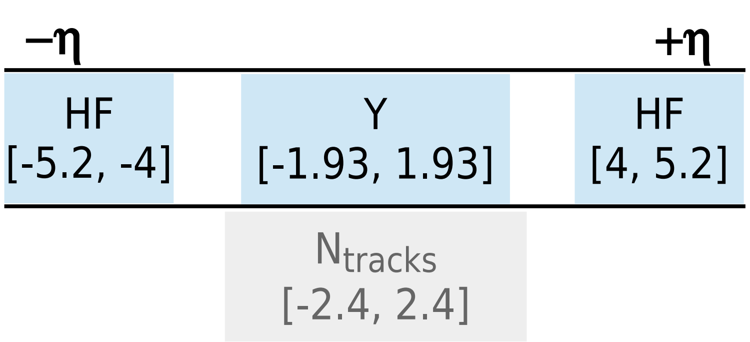
- No separation of Υ(2S) and Υ(3S)
- Agreement between CMS and ATLAS with large uncertainties on ATLAS results

Single ratio of Y(nS)/Y(1S) in pp and pPb

- Event-activity is determined with transverse energy deposited at forward hadronic calorimeter
- Y(nS)/Y(1S) ratios fall with event-activity
  - Is the multiplicity affecting the Y(nS)?
  - Are the Y(nS) produced differently with multiplicity?

JHEP 04 (2014) 103



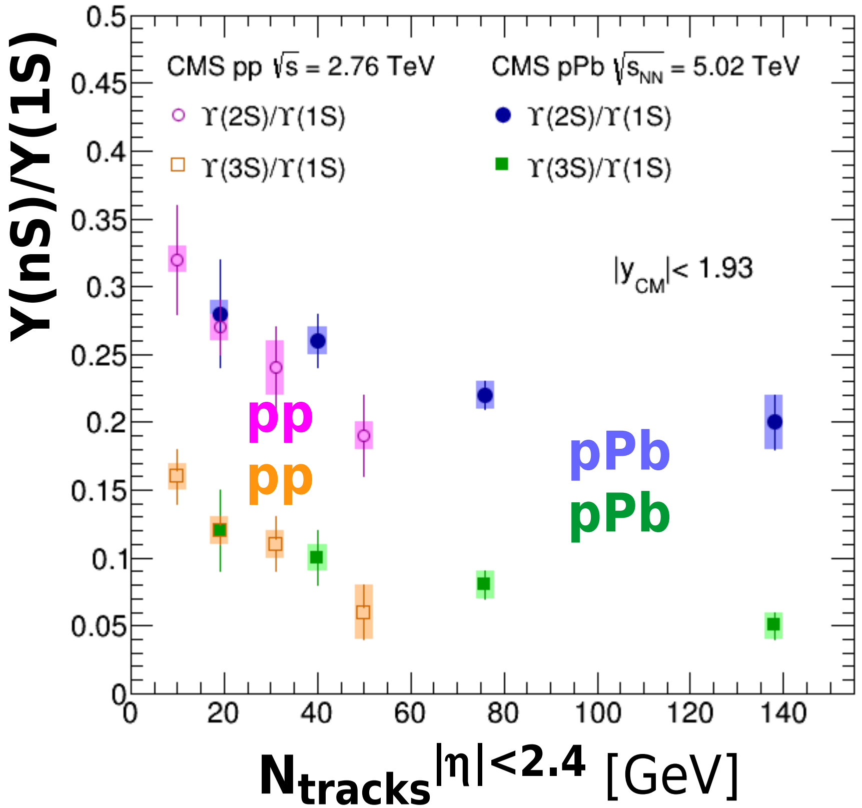


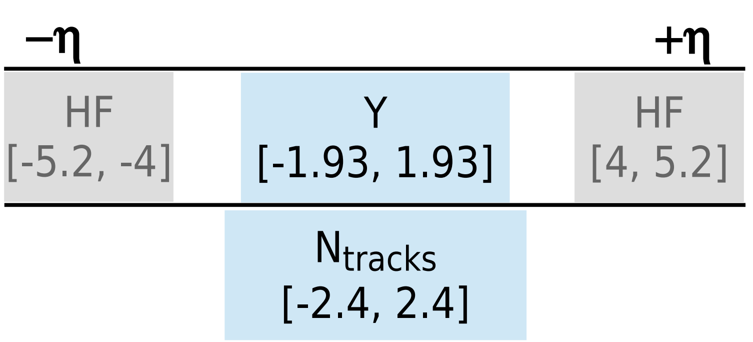
Single ratio of Υ(nS)/Υ(1S) in pp and pPb

JHEP 04 (2014) 103

- Event-activity is determined with number of charged tracks

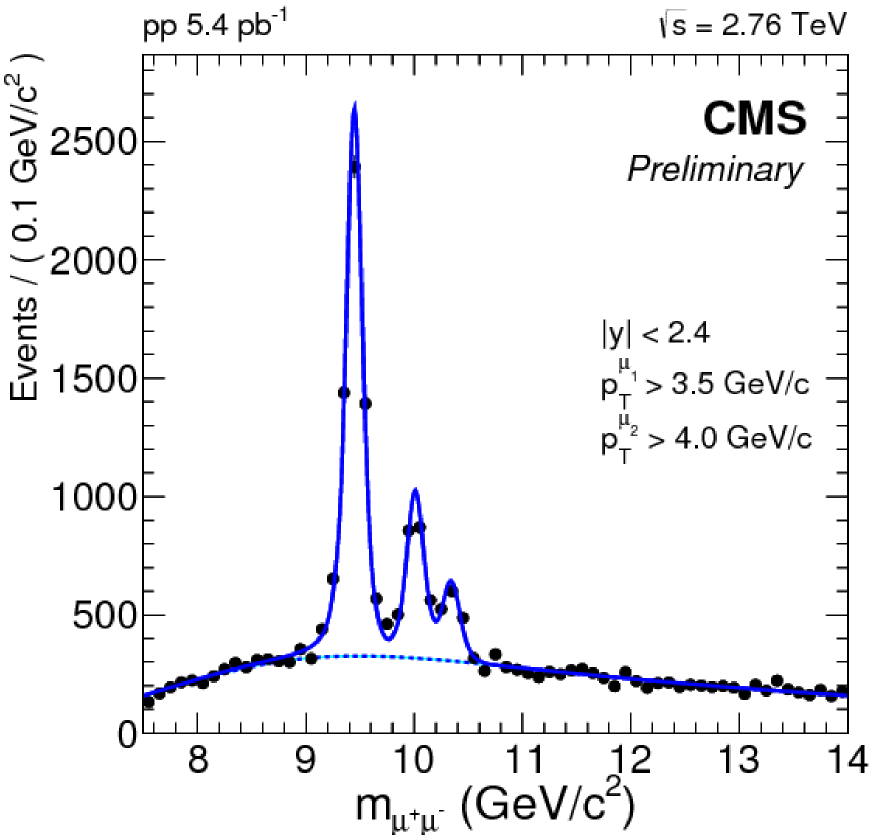
- Υ(nS)/Υ(1S) ratios fall with event-activity
  - Is the multiplicity affecting the Υ(nS)?
  - Are the Υ(nS) produced differently with multiplicity?
  - Effects become stronger with tracks nearby



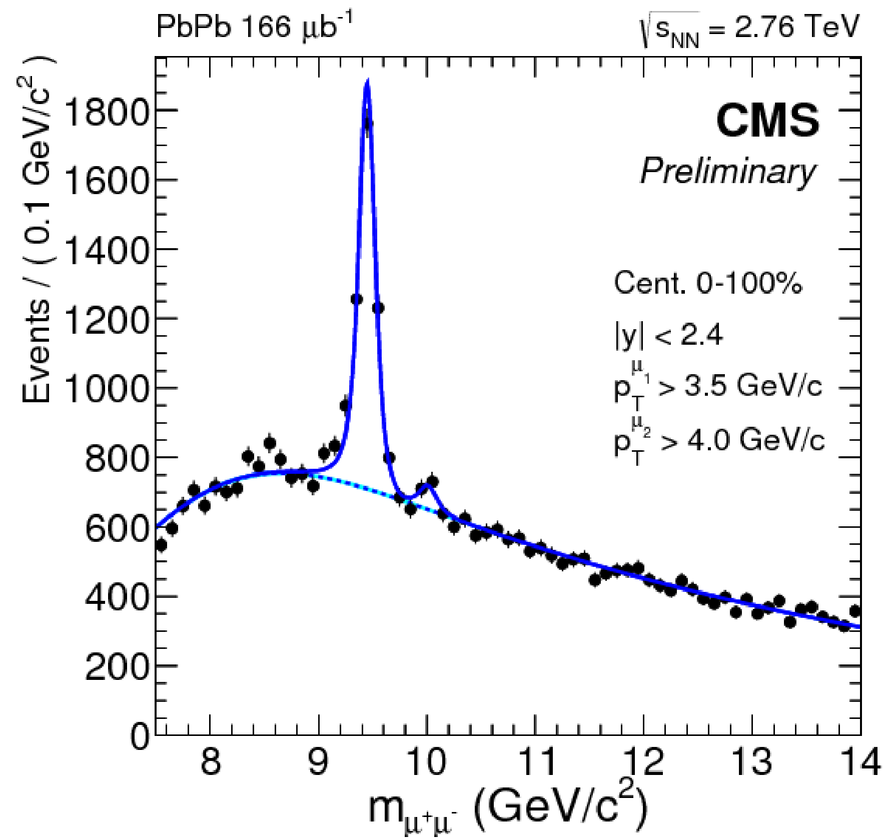


Signal extraction

- Analysis is optimized separately for Υ(1S) and excited states to minimize uncertainties



pp at 2.76 TeV data of 2013
5.4 ± 0.2 pb^{-1}

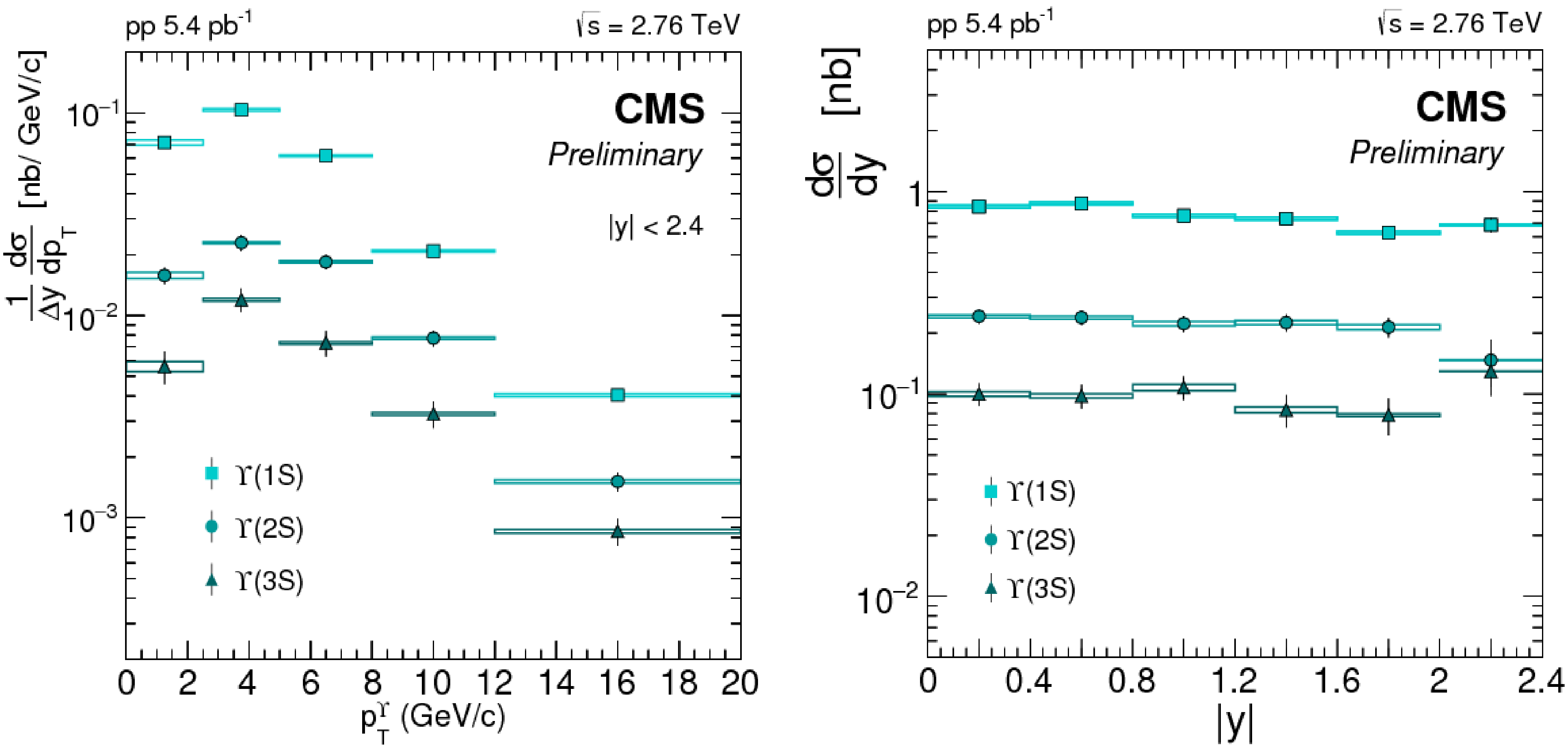


PbPb at 2.76 TeV data of 2011
166 μb^{-1} with updated reconstruction

CMS-PAS-HIN-15-001

pp cross sections at 2.76 TeV

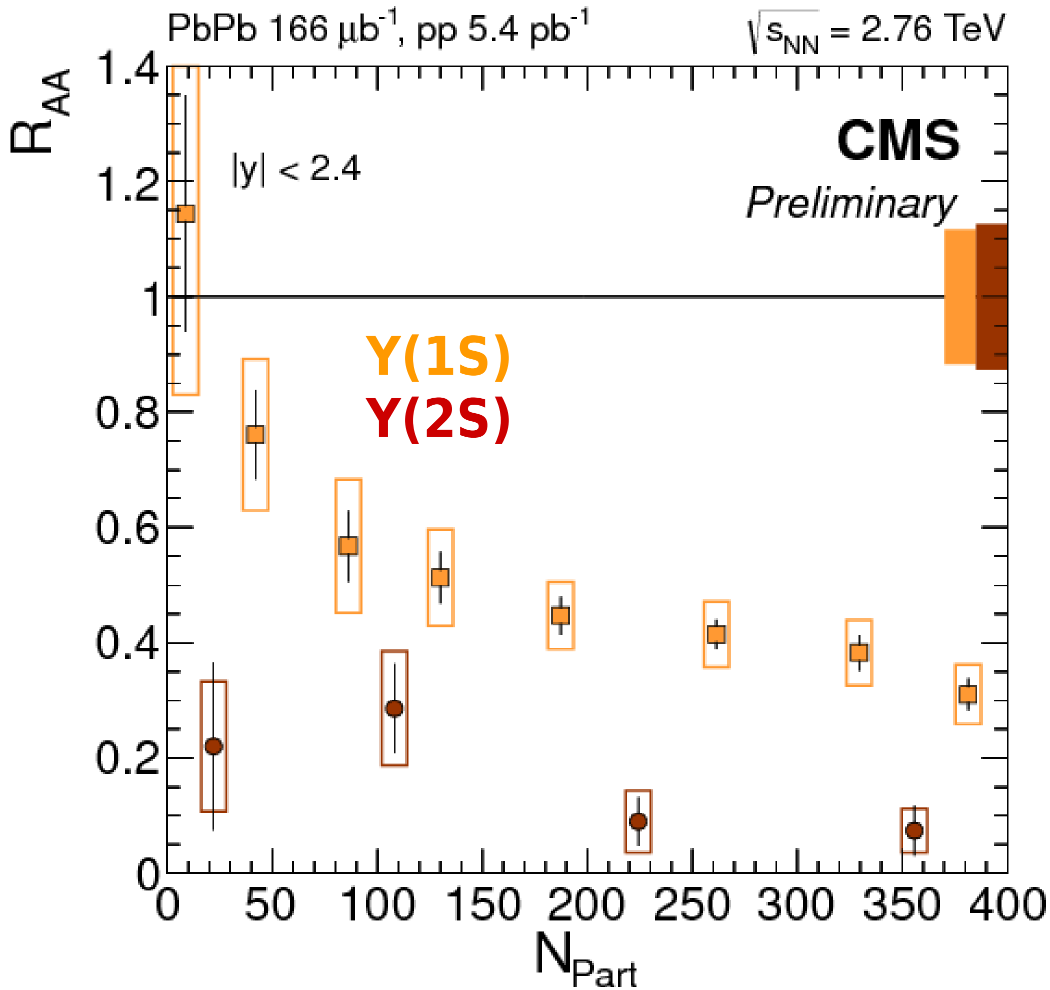
- Cross sections are extracted for the three Y states in pp
  - Y(1S), Y(2S), Y(3S) up to 20 GeV/c
- Provides an important input to production models



CMS-PAS-HIN-15-001

Υ R_{AA} vs. centrality

- Nuclear modification factor, R_{AA}, as a function of N_{part}
- Improvements: Reduced statistical uncertainties
  + finer bins for Υ(1S)



$$R_{AA} = \frac{L_{pp}}{T_{AA} N_{MB}} \frac{N_{PbPb}}{N_{pp}} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}}$$

- R_{AA} of minimum bias (0-100%)
  - R_{AA}(Υ(1S)) = 0.43 ± 0.03 ± 0.07
  - R_{AA}(Υ(2S)) = 0.12 ± 0.03 ± 0.02
  - R_{AA}(Υ(3S)) < 0.14 at 95% C.L.

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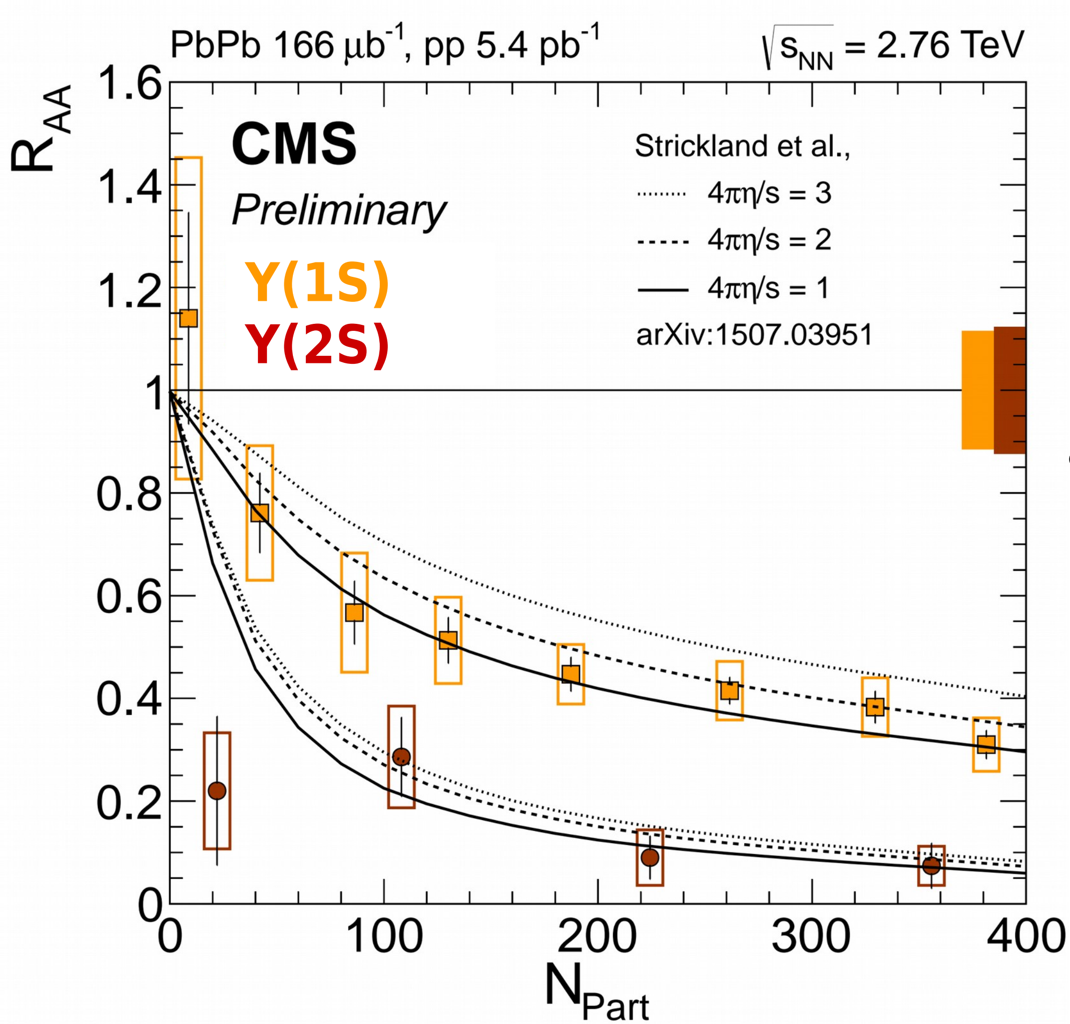
Υ R_{AA} vs. centrality with theoretical models

- Theoretical model agrees for both Υ(1S) and Υ(2S)
  - Strickland : Thermal suppression in QGP



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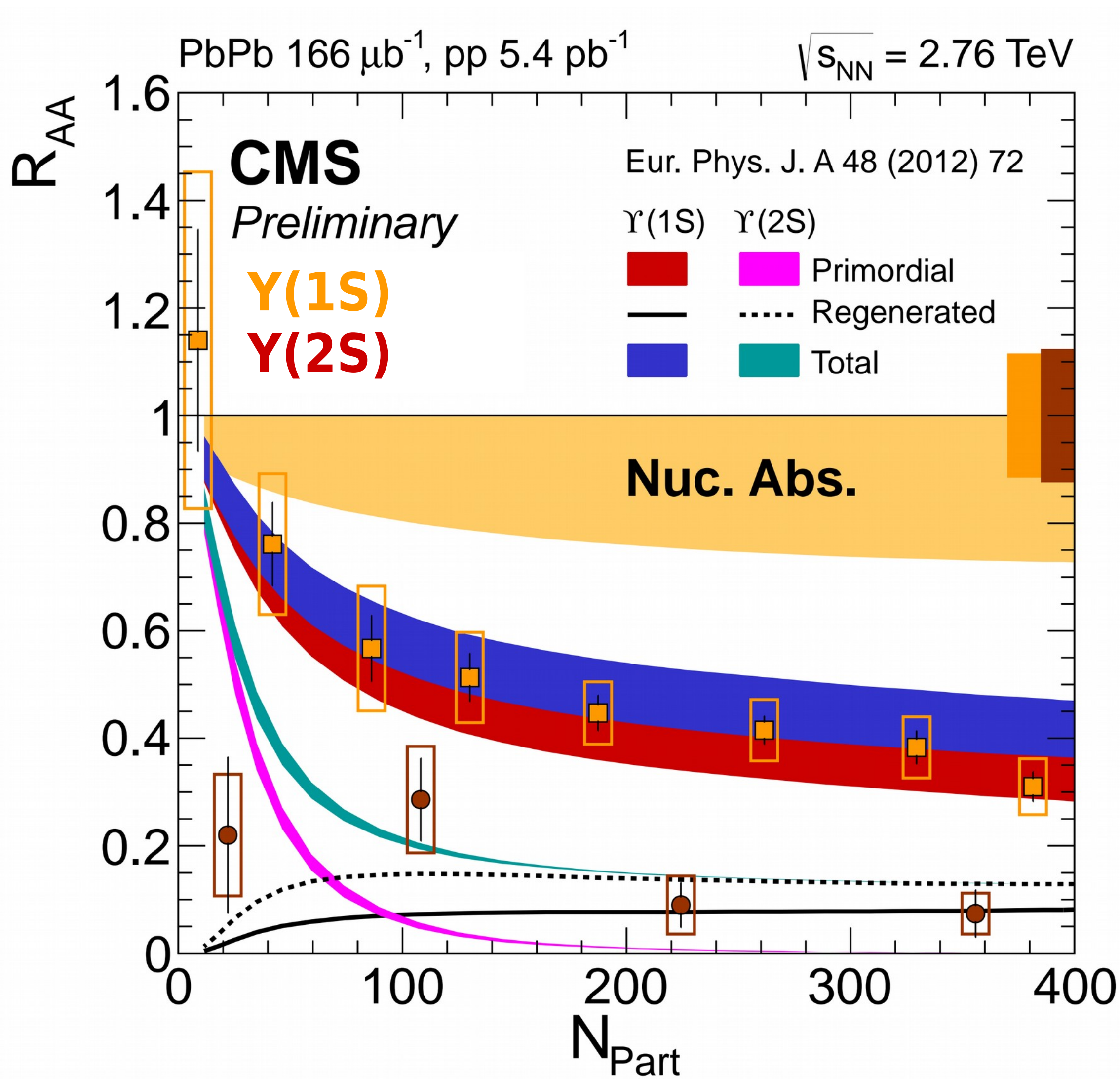
CMS-PAS-HIN-15-001
arXiv: 1507.03951

Υ R_{AA} vs. centrality with theoretical models

- Theoretical model agrees for both Υ(1S) and Υ(2S)
  - Rapp: CNM and regeneration effects are also considered



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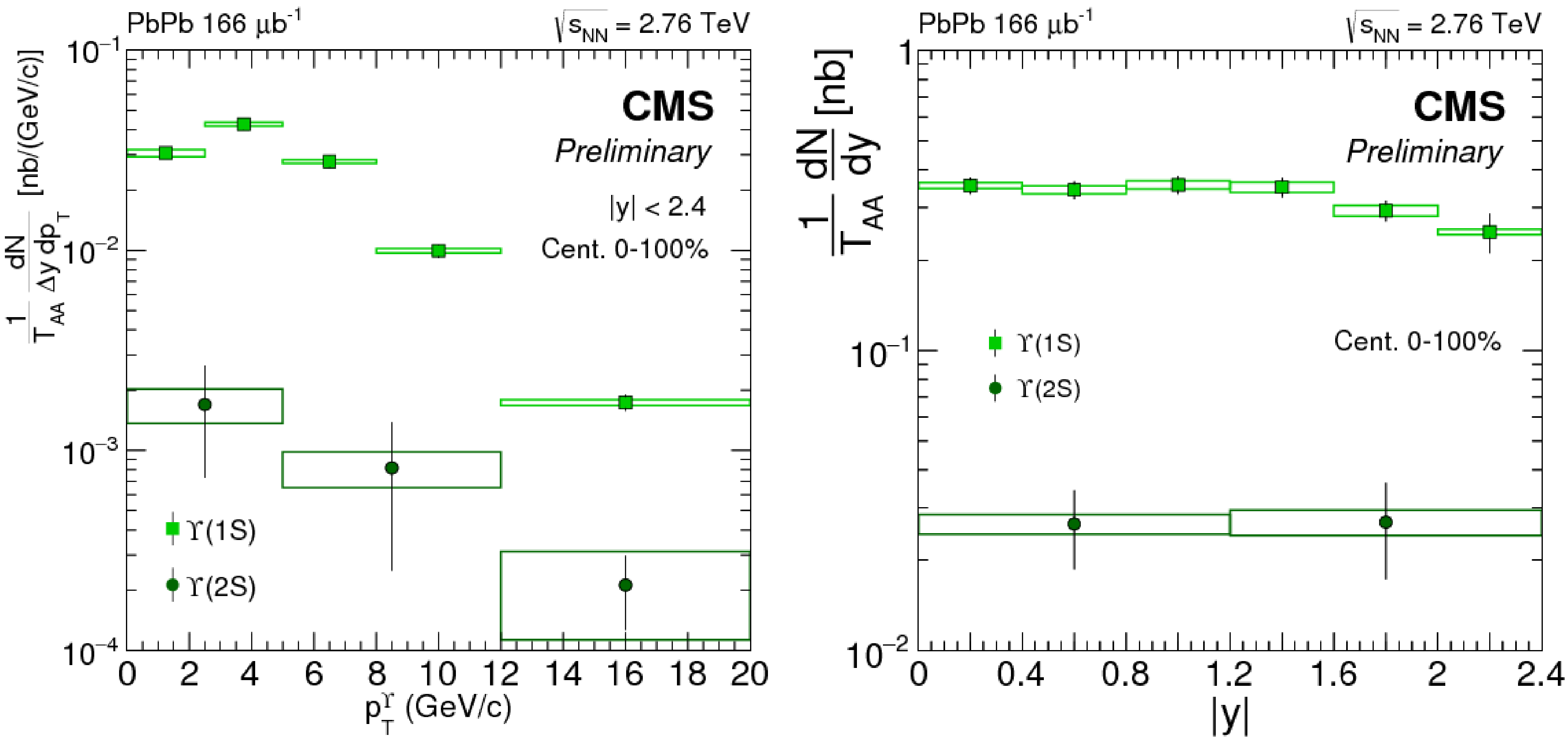
Eur. Phys. J. A48 (2012) 72

PbPb corrected yields

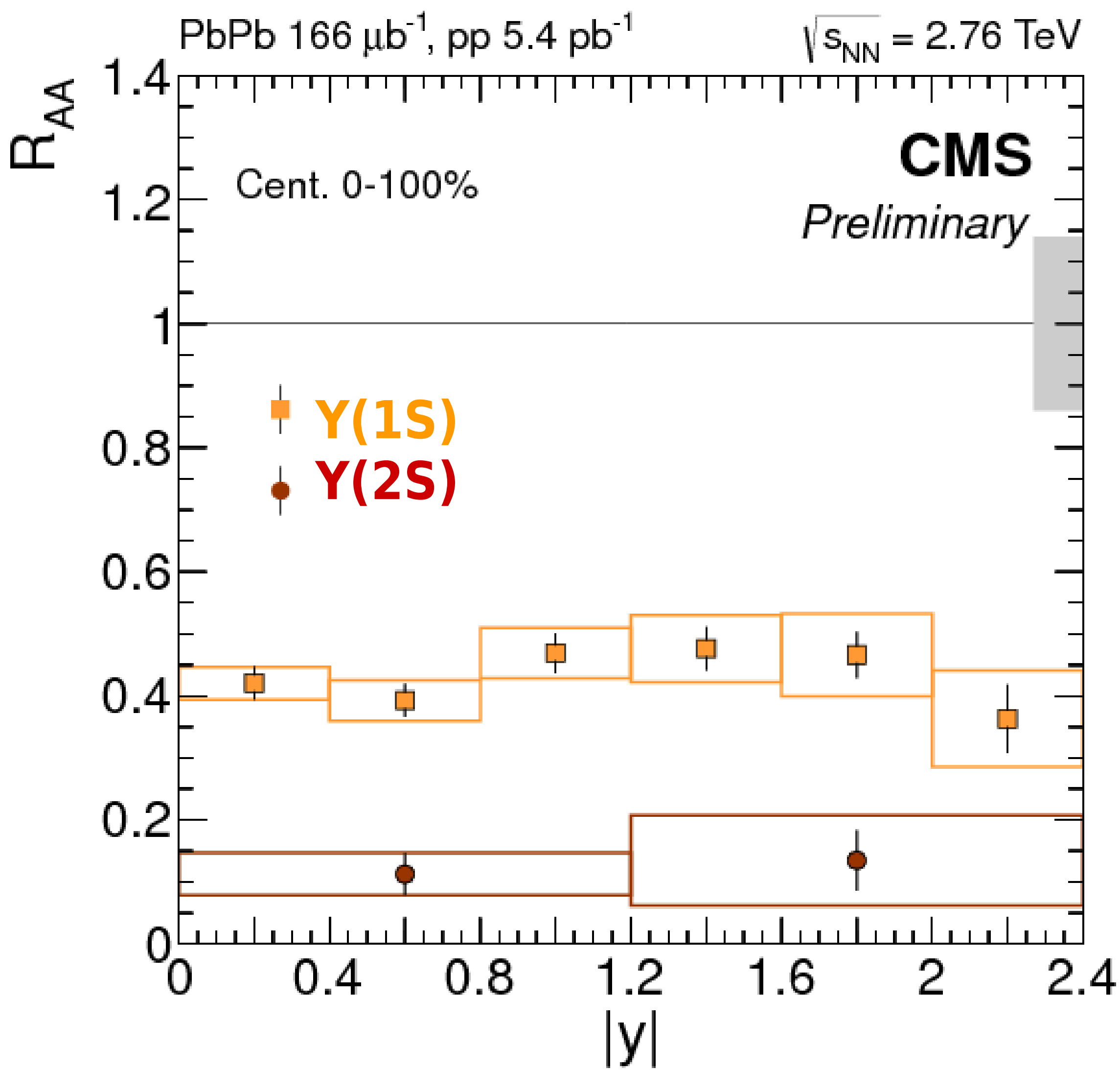
- First time measurement of Υ(2S) spectrum in PbPb
  - Υ(1S), Υ(2S) up to 20 GeV/c
- Next: compute the nuclear modification factors, R_{AA}



CMS-PAS-HIN-15-001

Υ R_{AA} vs. rapidity

- The most precise measurement on Υ(nS) R_{AA} vs. rapidity at LHC
- The suppression is constant over the measured region

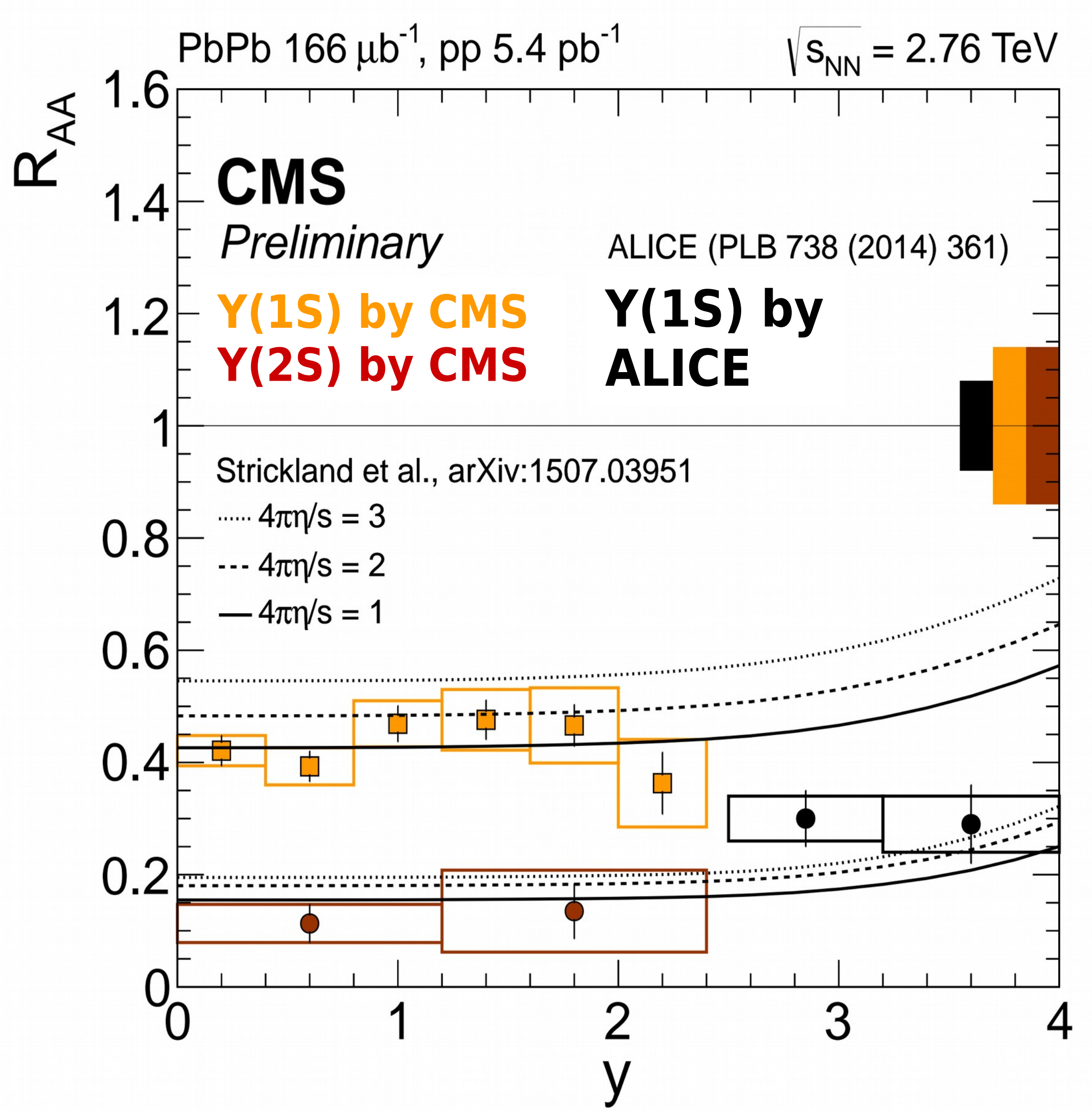


$$R_{AA} = \frac{L_{pp}}{T_{AA} N_{MB}} \frac{N_{PbPb}}{N_{pp}} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}}$$

CMS-PAS-HIN-15-001

Υ R_{AA} vs. rapidity with theoretical models

- Theoretical model agrees for both Υ(1S) and Υ(2S) at mid-rapidity only



$$R_{AA} = \frac{L_{pp}}{T_{AA} N_{MB}} \frac{N_{PbPb}}{N_{pp}} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}}$$

- Υ(1S) R_{AA} are relatively flat over CMS and ALICE
  - ALICE used LHCb pp reference

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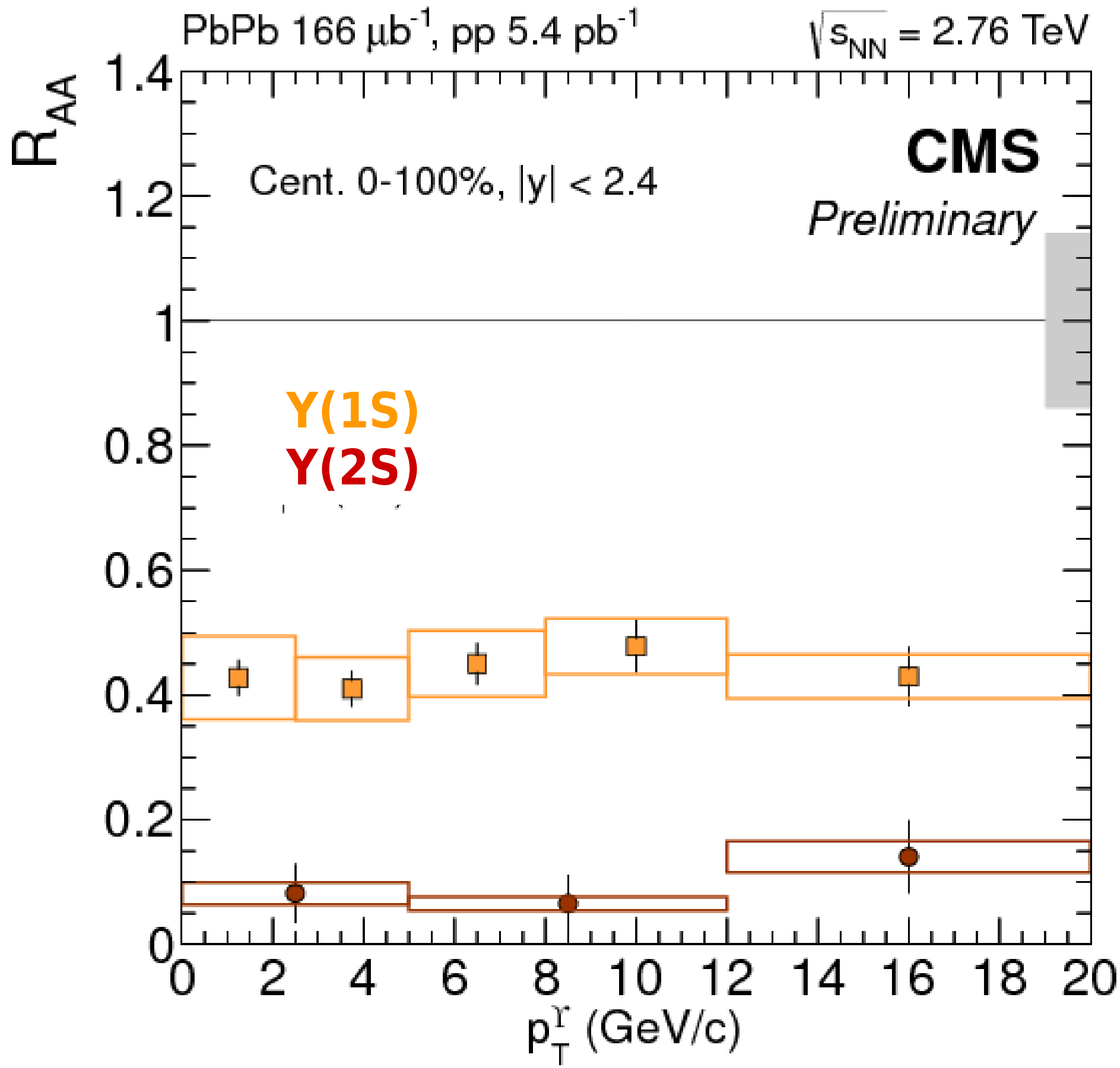
PLB 738 (2014) 361
arXiv: 1507.03951

Υ R_{AA} vs. p_T

- The suppression is constant over the measured region



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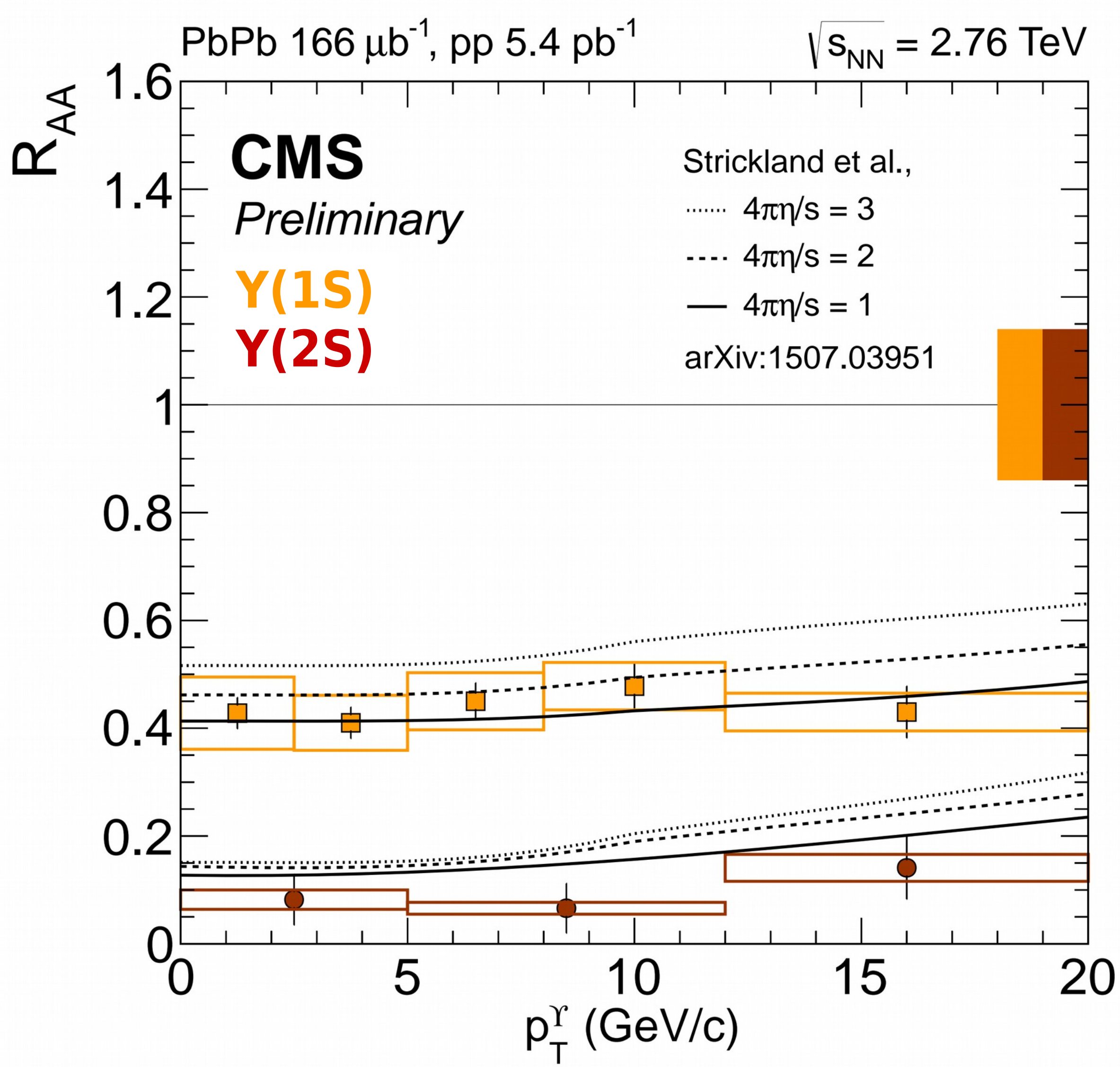
Υ R_{AA} vs. p_T

- Theoretical models describe for Υ(1S) and Υ(2S)
  - Υ(1S) is described well, there is some tension with Υ(2S)



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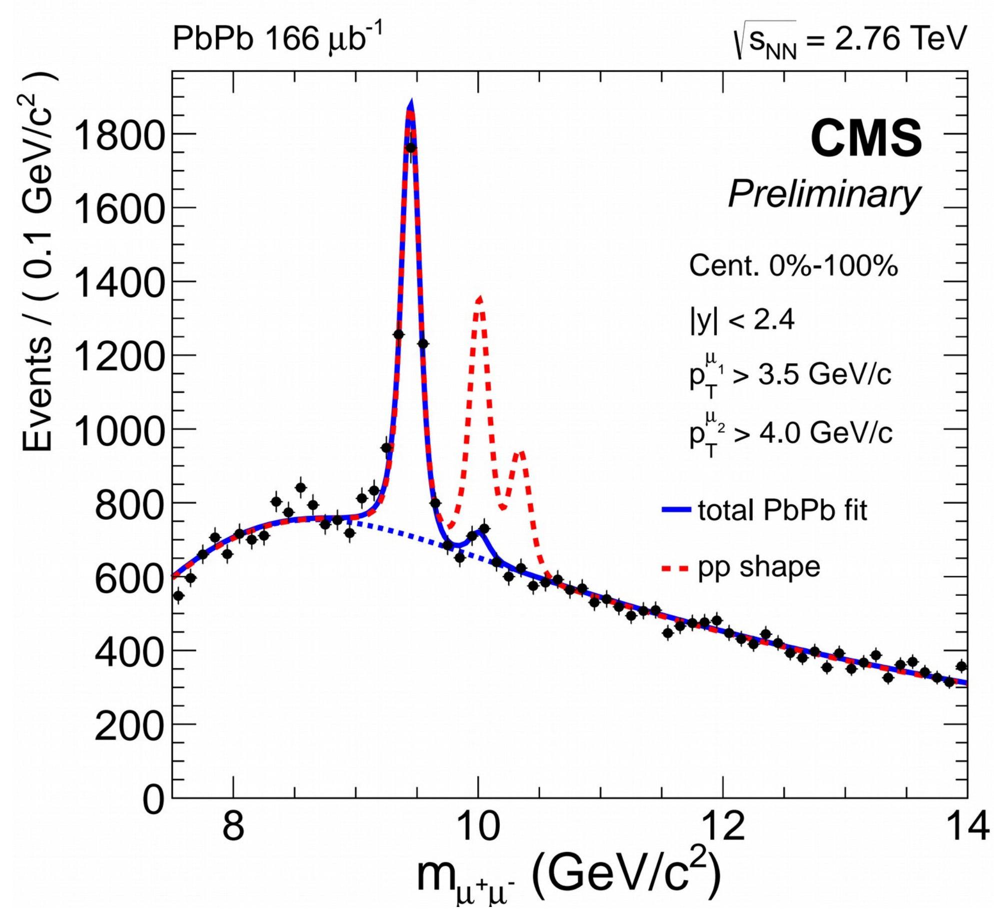
Summary

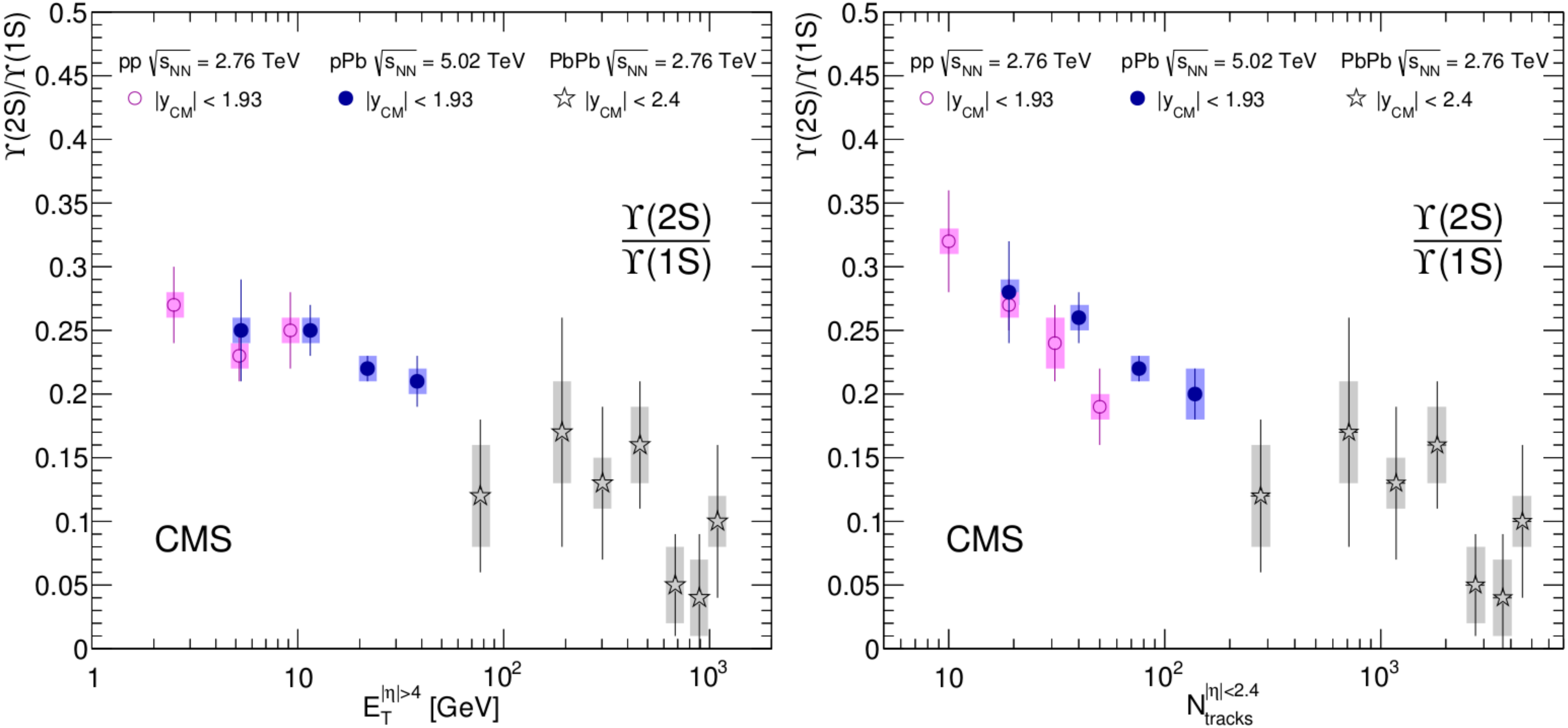
- Υ(nS) and B meson productions have been measured in CMS in pPb at 5.02 TeV, in pp and PbPb at 2.76 TeV
- In PbPb, the Υ suppression is centrality-dependent,
  - Equally suppressed up to relatively high-p_T (20 GeV/c)
  - No strong rapidity dependence as a function of rapidity
  - Suppression is larger for excited states Υ(2S), Υ(3S)



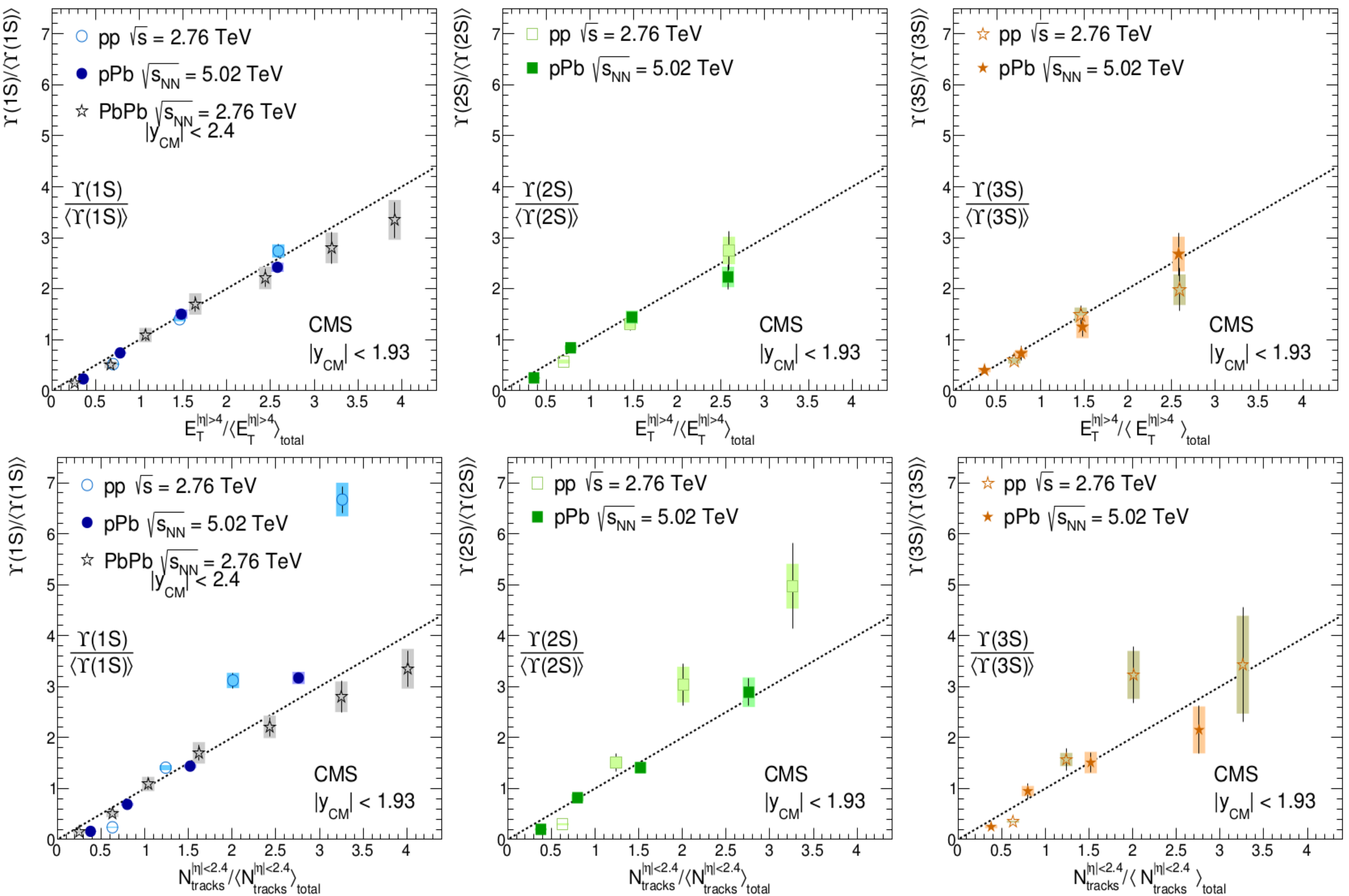
- In pPb and pp, the Υ(nS) / Υ(1S) depends on event-activity
- In pPb, B mesons show no significant modification

Back up

Single ratio of Y(nS)/Y(1S) in pp and pPb

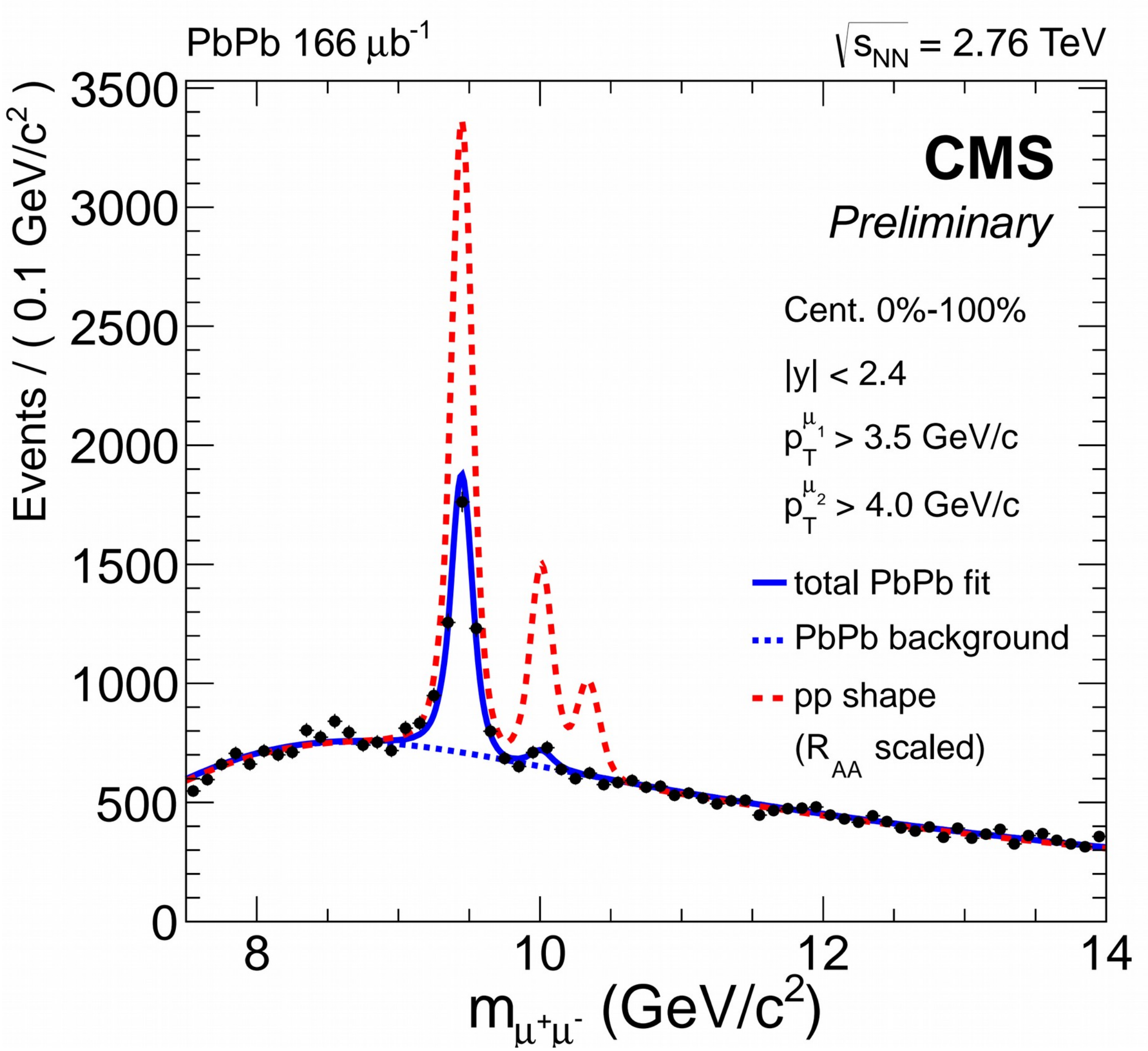


Single ratio of Υ(nS)/Υ(1S) in pp and pPb



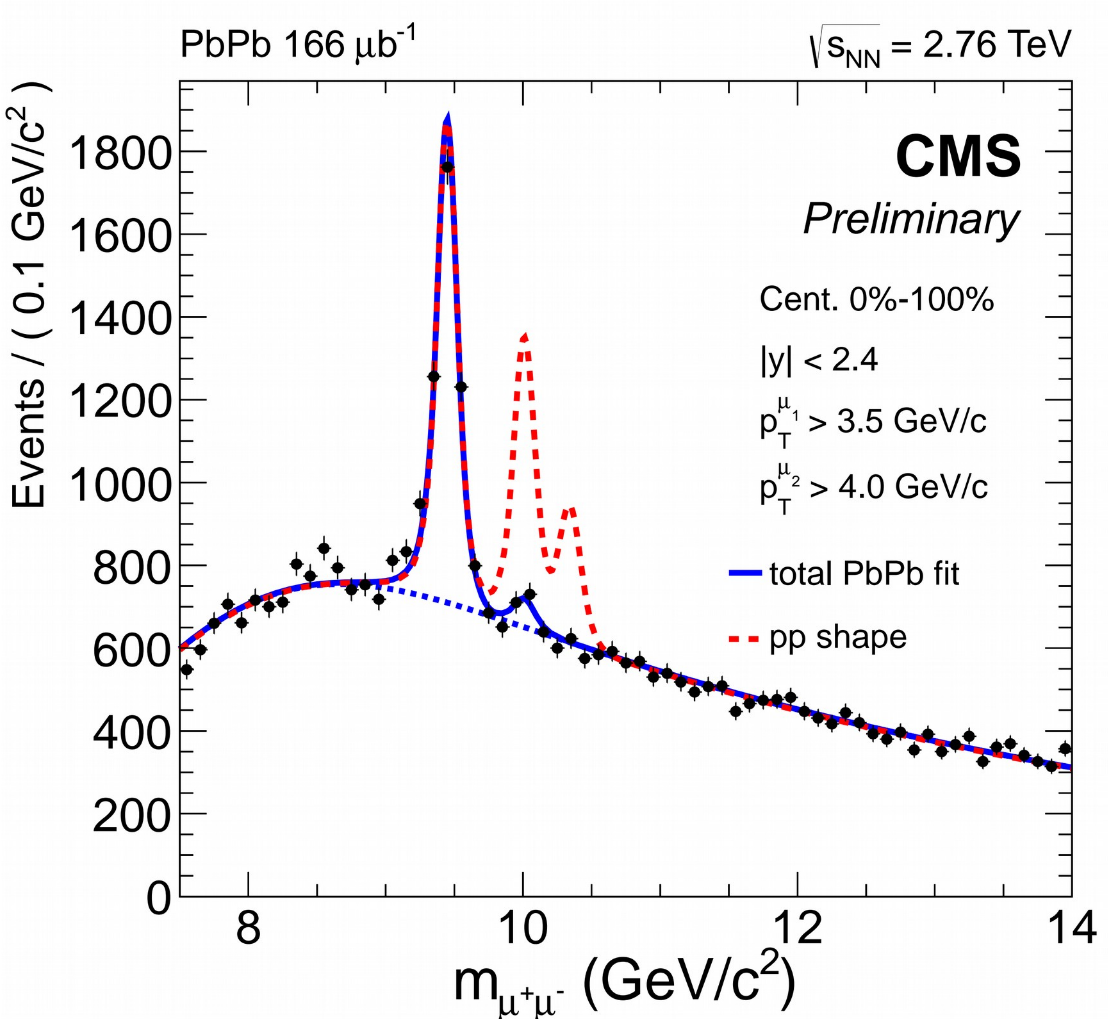
Signal extraction: Shape comparison

- PbPb and pp shapes are normalized to R_{AA}
  - PbPb shape x $1/R_{AA}$ = pp shape



Signal extraction: Shape comparison

- Analysis is upgraded with larger statistics on pp collisions
  - Kinematics of Y(nS) are now available
- pp shape is normalized to Y(1S) peak position in PbPb



pp at 2.76 TeV data of 2013
5.4 ± 0.2 pb^{-1}

PbPb at 2.76 TeV data of 2011
166 μb^{-1} with
updated reconstruction

CMS-PAS-HIN-15-001

Feed down of Υ(nS)

- Feed down contributions of Υ(1S)?
- Suppression of Υ(1S) can be explained by ~complete melting of feed down contributions?