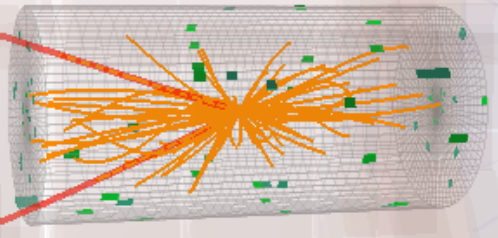
CMS Experiment at LHC, CERN
Data recorded: Sat Nov 12 16:47:55 2016 CET
Run/Event: 285216 / 269187420

Quarkonia measurements in pPb and PbPb collisions at $\sqrt{s}$=5.02 TeV with CMS



Workshop on
Heavy Flavor Production in High Energy Collisions
November 1, 2017
LBNL

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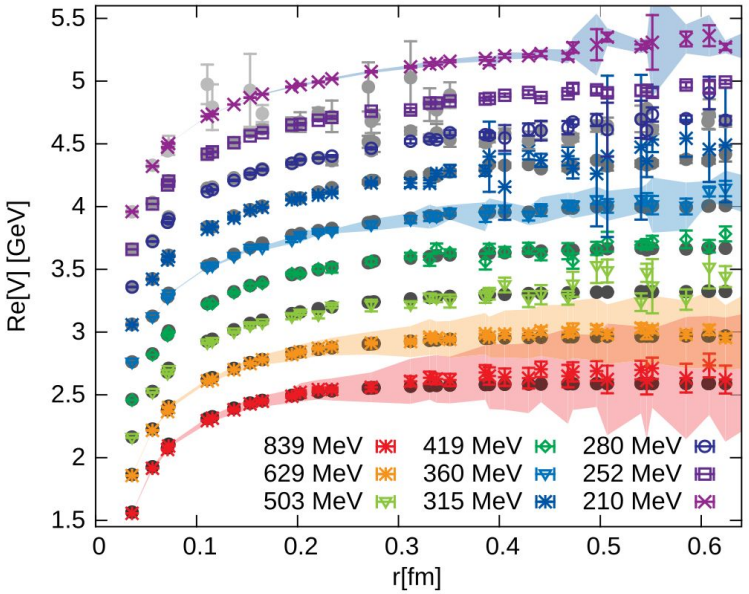
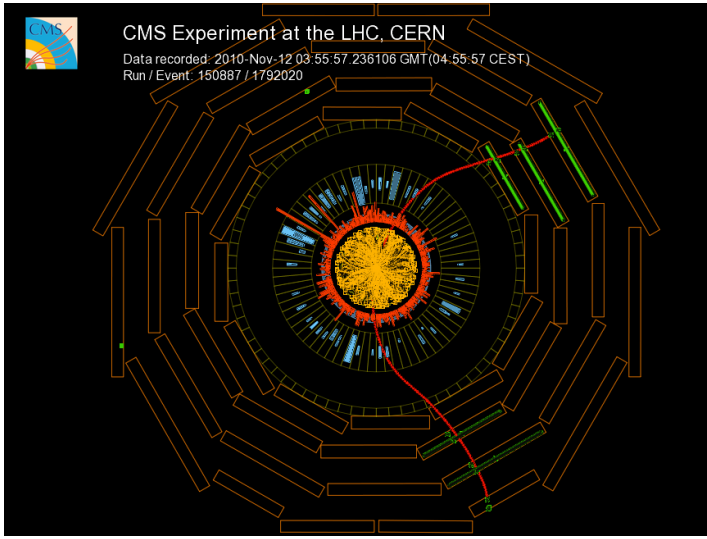
CMS Collaboraion
UCDAVIS

Quarkonium in pA and AA collisions

- Quarkonia: a probe of color deconfinement
  - Suppression of yield: states melt in a hot, color-deconfined medium
    - Color screening, gluodissociation, partonic breakup/Landau damping.
- Charmonium:
  - High-pT: less affected by regeneration
- Bottomonium advantages:
  - Different regeneration contributions for bottom compared to charm
- Charmonium + Bottomonium:
  - 2 + 3 : 5 states experimentally accessible
  - Full Spectroscopy yields more information for models
    - QGP Thermometer
    - Regeneration contribution and rates
    - Compare initial- vs. final-state effects

Y. Burnier et al. ,PRL 114, 082001

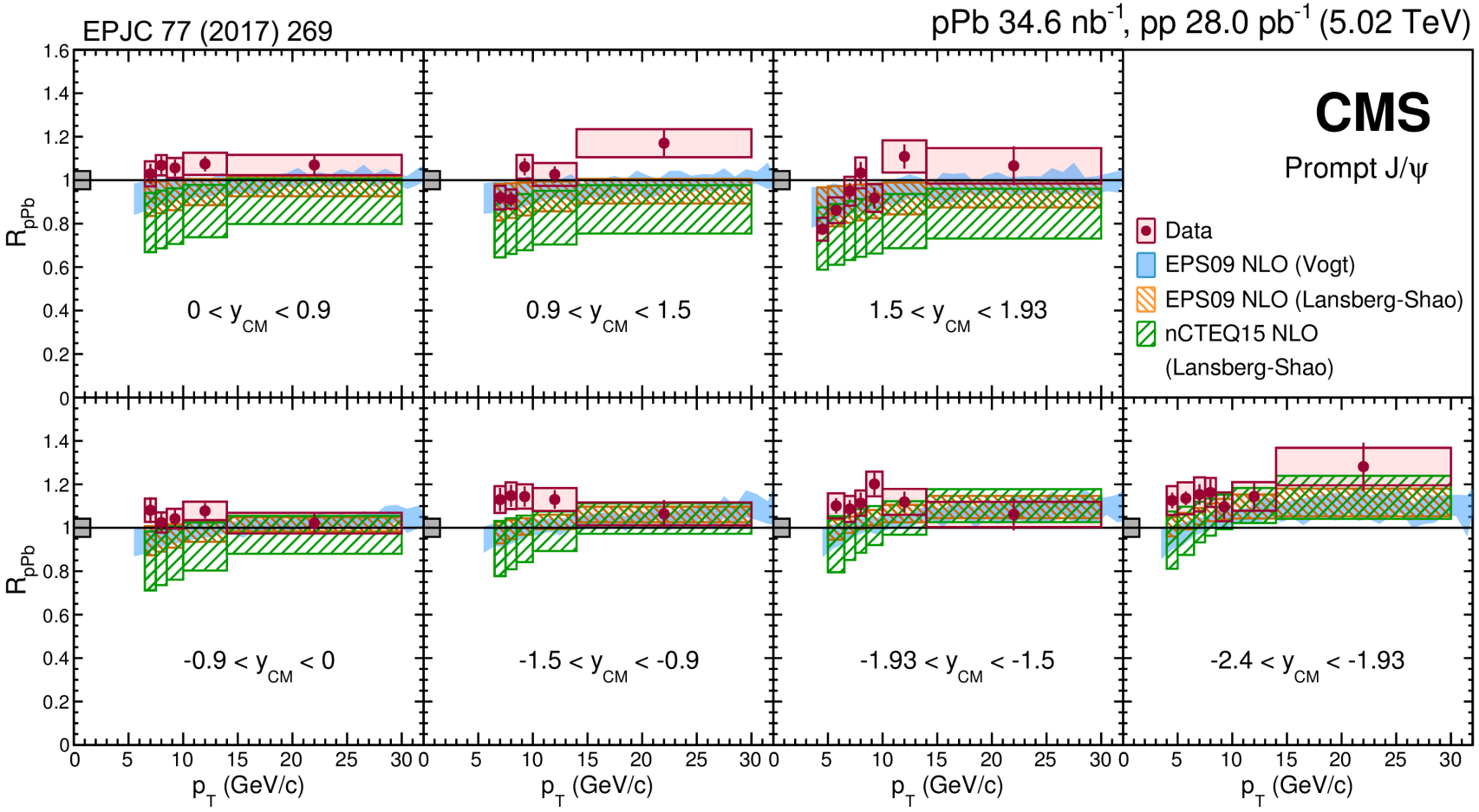




Outline: Observables

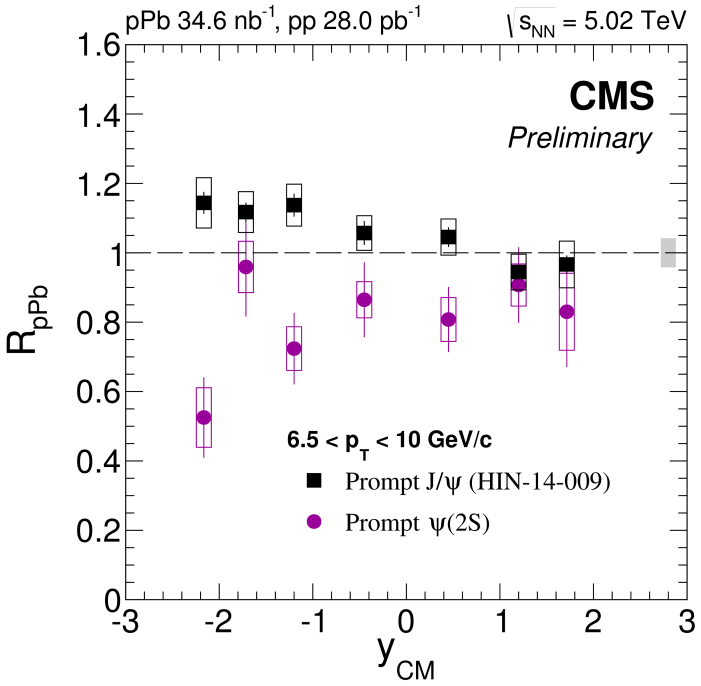
- J/ψ, ψ(2S) in pPb
  - Cold Nuclear Matter
  - Initial vs final state effects
- PbPb Results
  - Charmonium and Bottomonium Double Ratio
    - Relative modification of excited states compared to ground state
      - Cancellation of efficiency and acceptance corrections
      - Cancellation of initial state effects, e.g. shadowing
  - Bottomonium RAA
    - Absolute modification from pp to AA

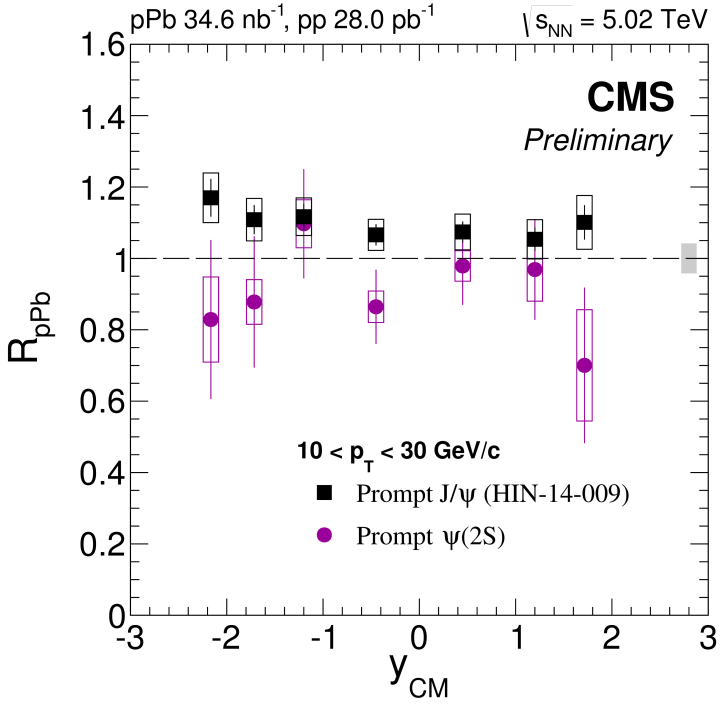
Prompt J/ψ R_{pPb} at 5.02 TeV



- Prompt J/ψ RpPb > 1 at mid-y and backward region (Pb-going, high x).
- Suppression in the forward region for $p_T < 7.5$ GeV
- Shadowing calculations (initial-state effect):
  - Slightly below data, but describe suppression in forward region

Prompt ψ(2S) R_{pPb} at 5.02 TeV

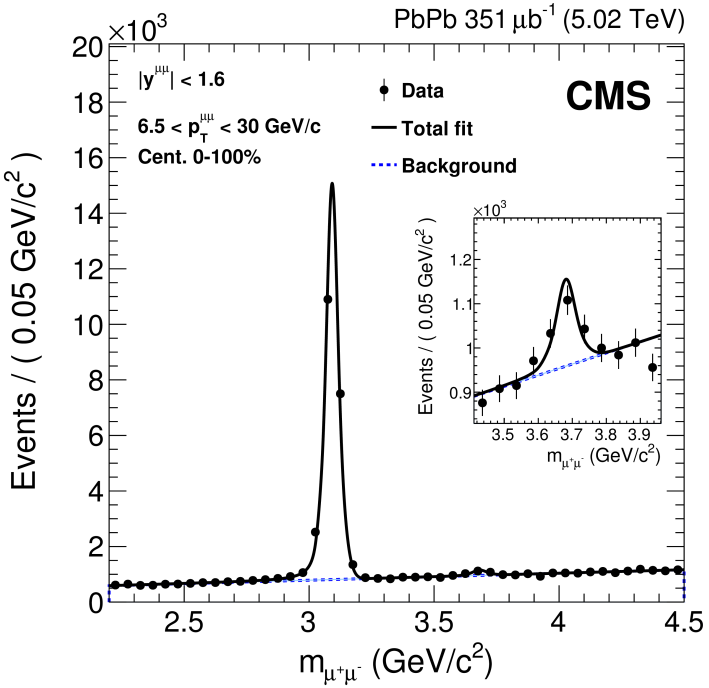


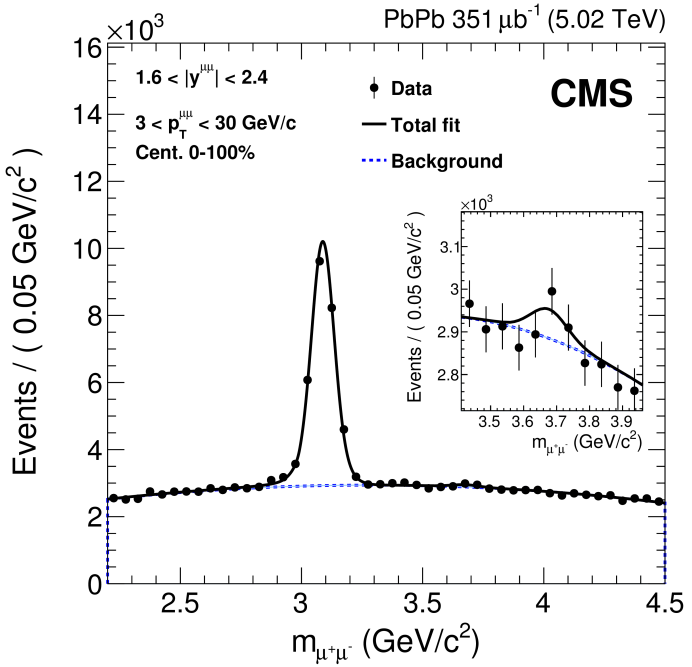


CMS-PAS-HIN-16-015

- $R_{pPb}(\psi(2S)) < R_{pPb}(J/\psi)$,
  - Effect stronger at backward rapidity (Pb-going), p_T~7 GeV/c.
  - Indication of final-state efect
    - Possible suppression by interaction with co-moving matter?
    - Caveat: multiplicity does not change much from forward to backward y

Charmonia Results PbPb: J/ψ and ψ(2S)

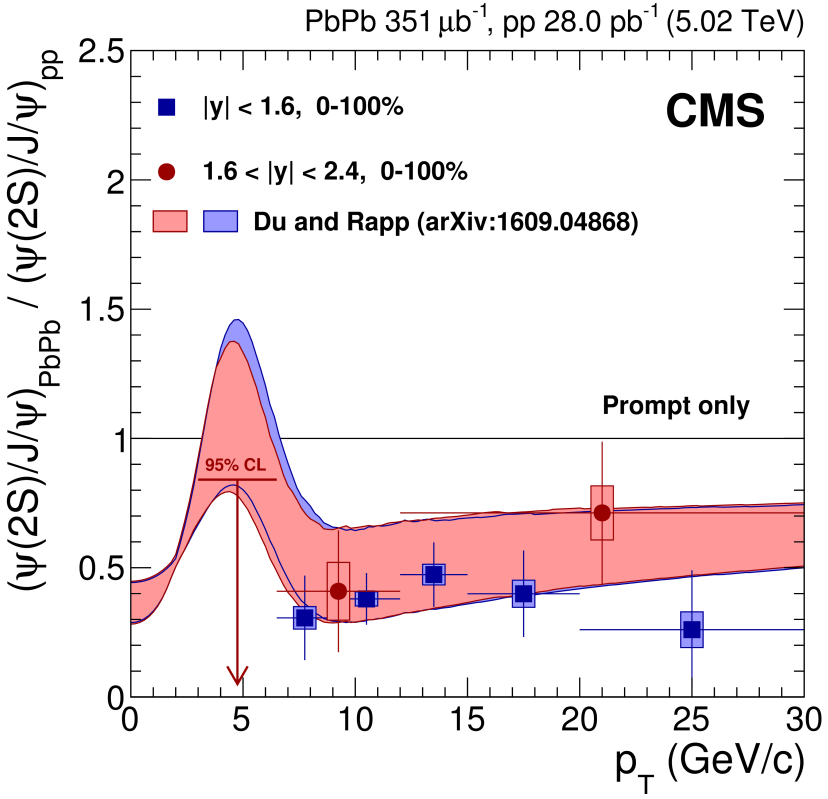




PRL 118 (2017) 162301

- Mid-rapidity:
  - $|y|<1.6$, $p_T > 6.5$ GeV/c
- Endcap region:
  - $1.6 < |y| < 2.4$, $p_T > 3$ GeV/c

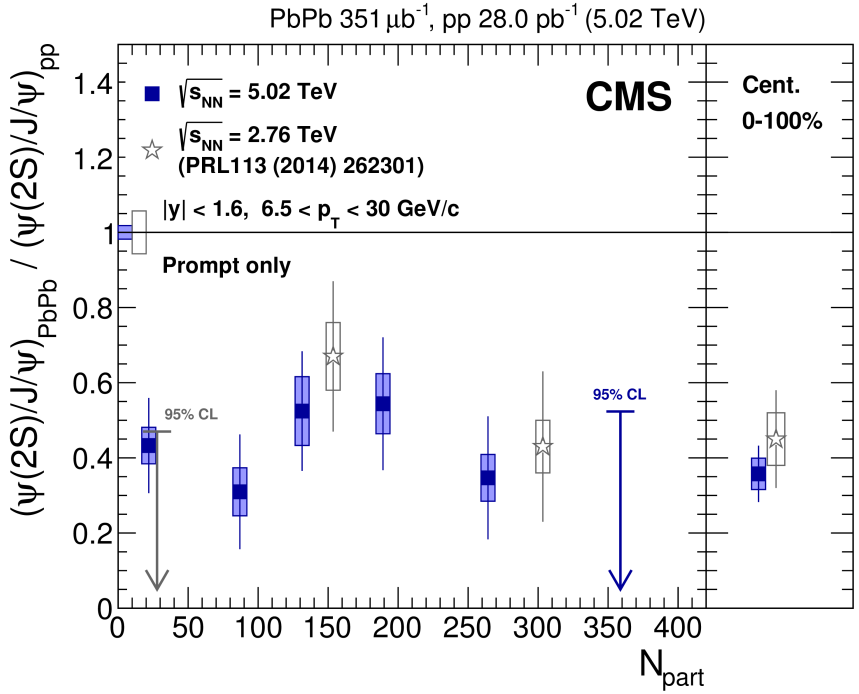
ψ(2S) Double Ratio vs p_T

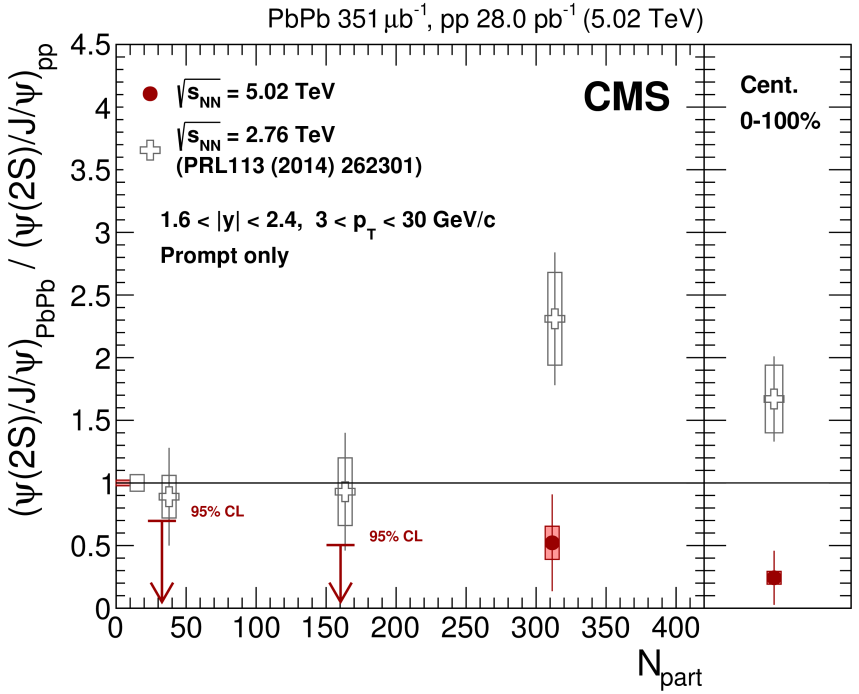


PRL 118 (2017) 162301

- Double ratio < 1 in all bins: ψ(2S) is more suppressed than J/ψ.
- Constant pT dependence, within uncertainties.
- Model comparison:
  - Rapp et al. : Transport model, T-dependent reaction rates, binding
    - Regeneration of excited state occurs later than ground state in fireball evolution
    - Regeneration effects : important for excited charmonia and bottomonia

ψ(2S) Double Ratio vs centrality

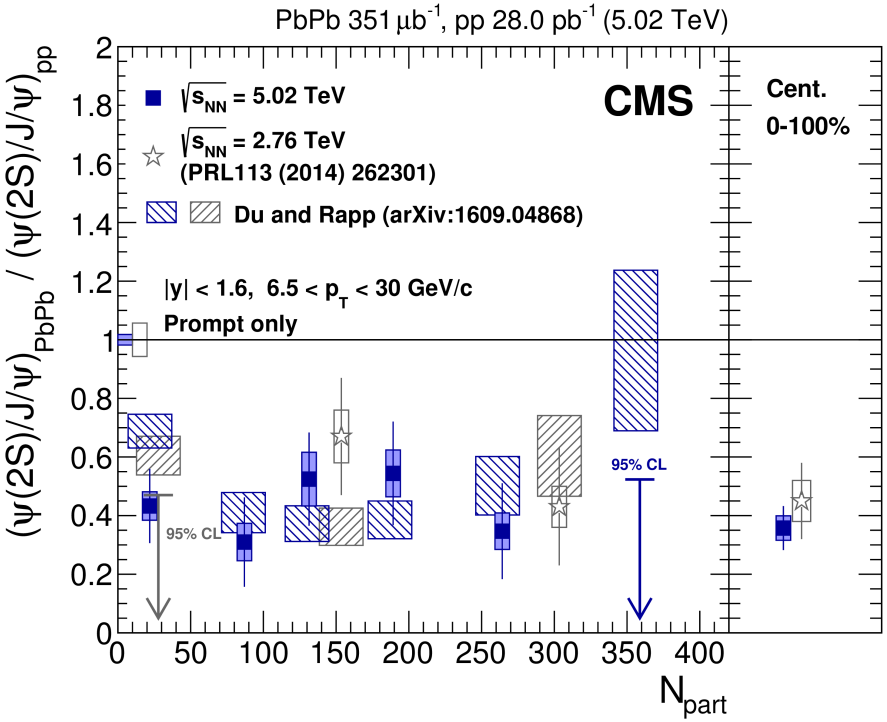


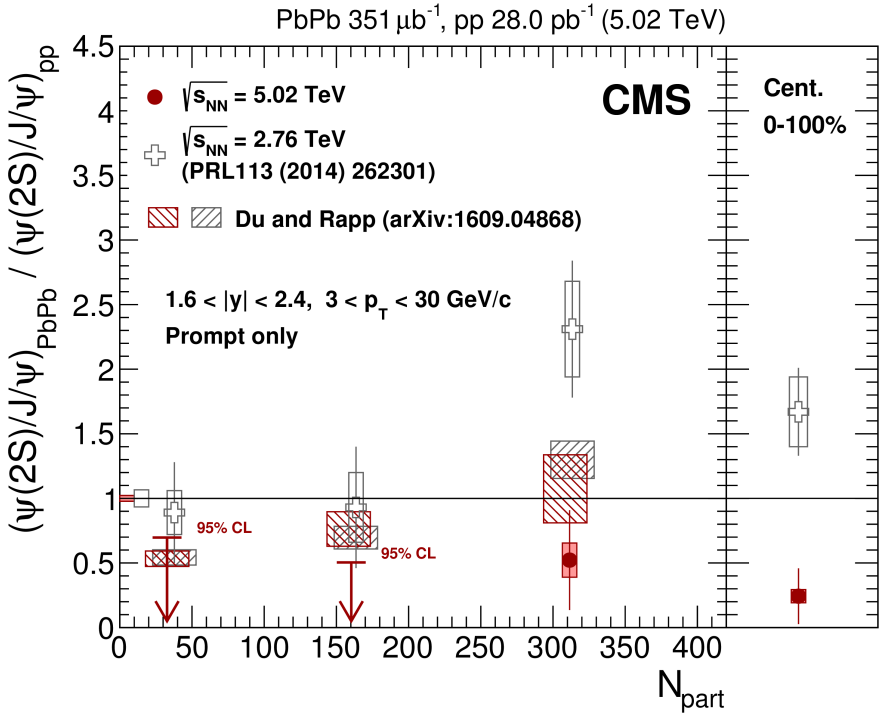


PRL 118 (2017) 162301

- ψ(2S) is more suppressed than J/ψ at all centralities
- N_{part} dependence: consistent with constant at 5.02 TeV
- Comparison to 2.76 TeV:
  - Double ratio consistently lower at 5.02 TeV
  - Suppression in most central bin, forward y, low pT.

Model Comparison: ψ(2S) Double Ratio

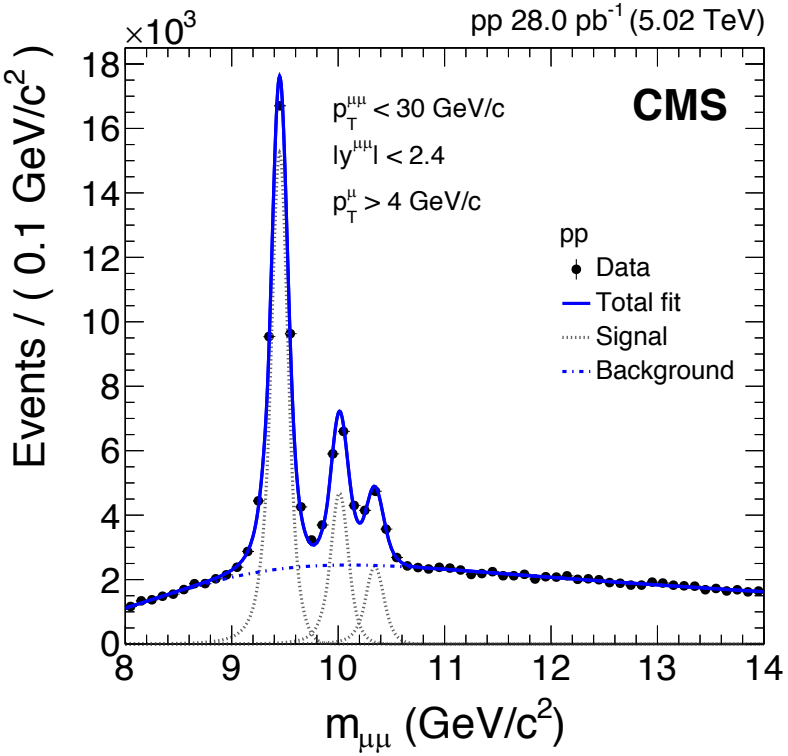


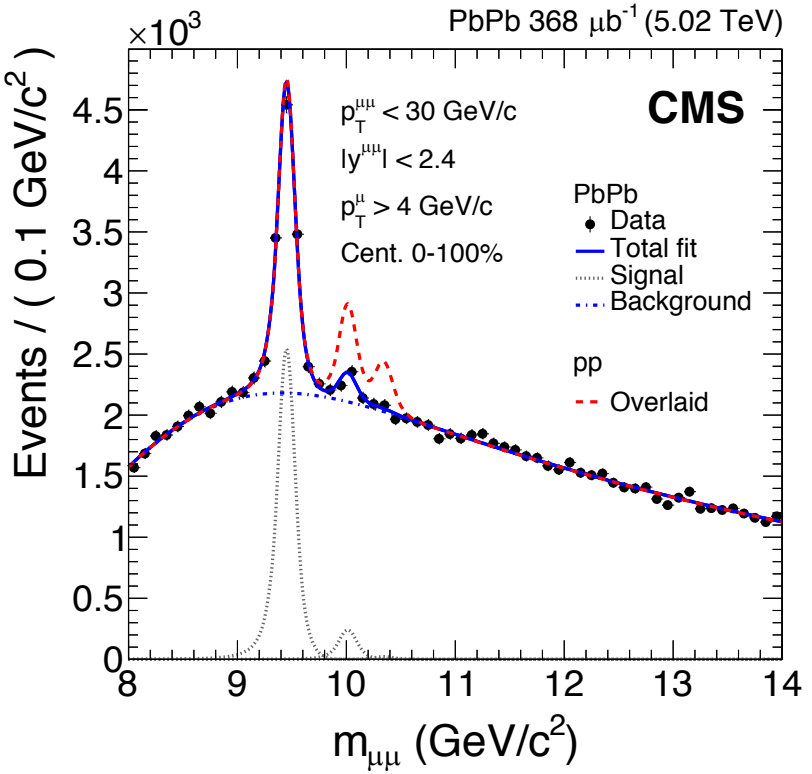


PRL 118 (2017) 162301

- Our data can help to constrain :
  - Relative contribution of primordial and regenerated charmonia
  - Dissociation and regeneration rates
  - Temperatures at which each state regenerates

ϒ Double Ratios in PbPb at 5.02 TeV



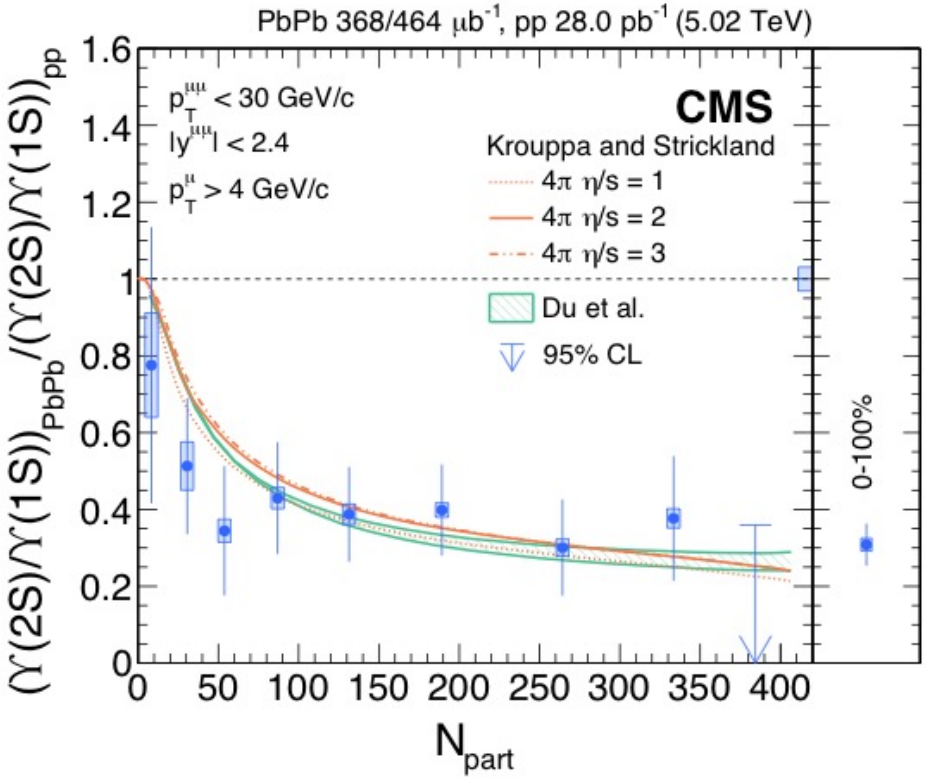


arXiv:1706.05984

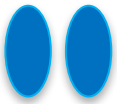
- Invariant mass distribution in ϒ region.
  - PbPb:
    - Visual representation of Double Ratio: $\frac{\frac{\Upsilon(nS)}{\Upsilon(1S)}_{PbPb}}{\frac{\Upsilon(nS)}{\Upsilon(nS)}_{pp}} = \frac{R_{AA}(\Upsilon(nS))}{R_{AA}(\Upsilon(1S))}$
    - pp fit scaled to 1S in PbPb and overlayed on PbPb data.
    - Strong suppression of 3S state!

Υ(2S) Double Ratio vs. Centrality

arXiv:1706.05984



Peripheral collisions

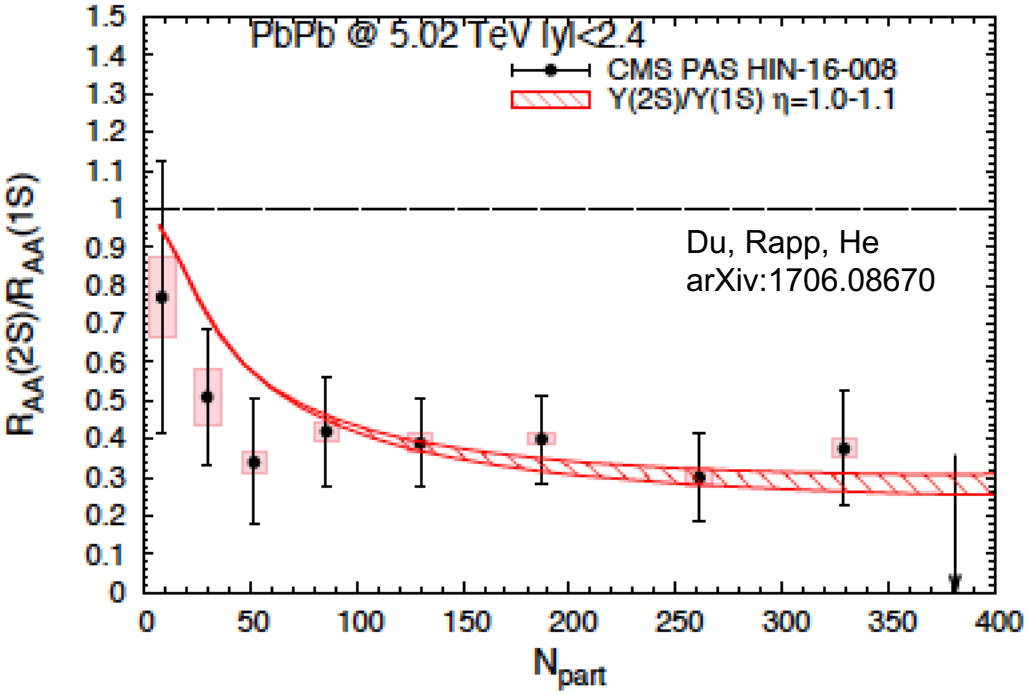


Central collisions

- Larger suppression toward more central events
- Consistent with unity in most peripheral bin
- Comparison to theory:
  - Model: Strickland et al.
  - Containing bottomonia evolved using anistropic hydrodynamics
  - Curves:
  - $\frac{4\pi\eta}{s} = \{1,2,3\}, T_0 = \{641, 632, 629\} MeV$
- Consistent with our data

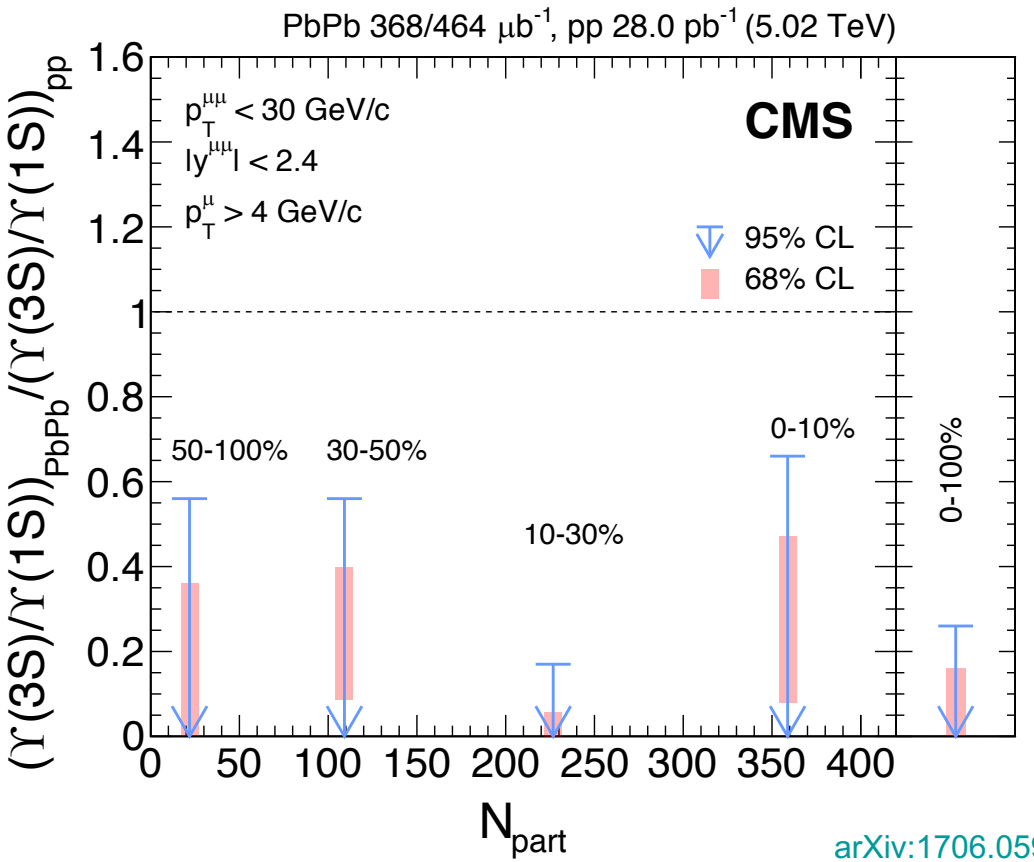
Double Ratio vs. Centrality

- CMS results compared to Transport Model,
  - T-Matrix temperature-dependent binding
  - Key ingredient: regeneration
    - Without regeneration, 2S yield would be zero!



Υ(3S) : Strong suppression!

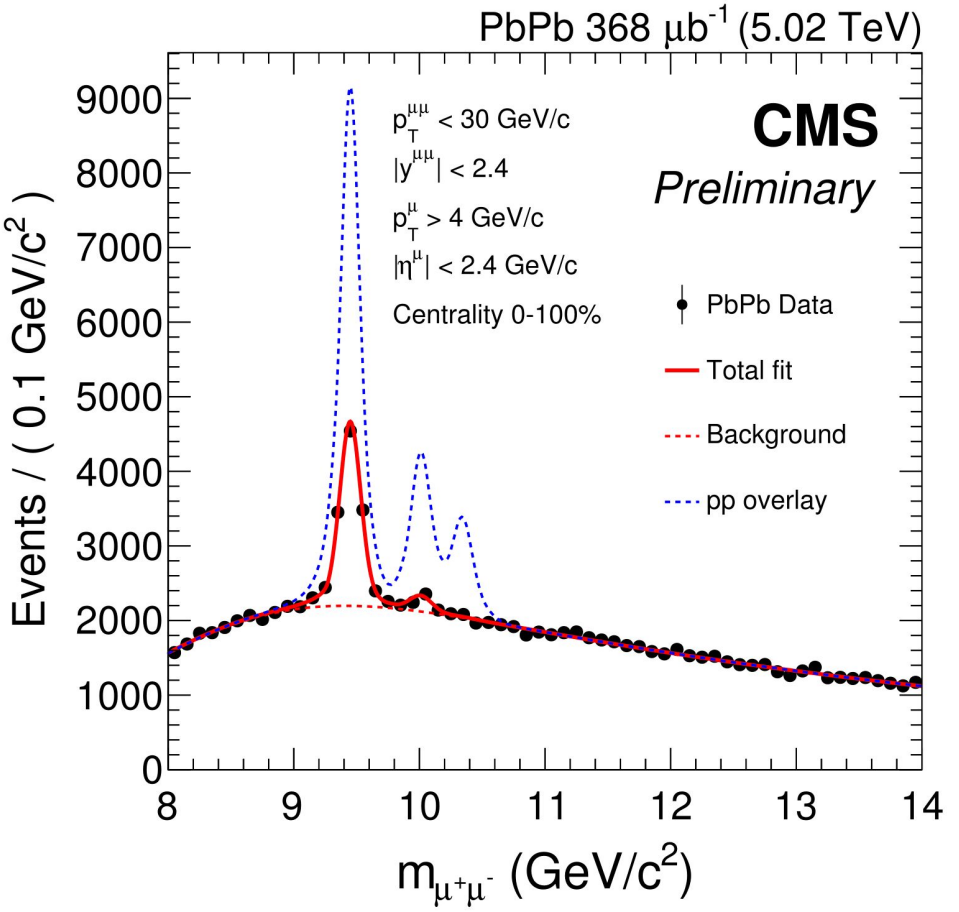
- Strong suppression of Υ(3S) relative to the 1S in all centralities
- Upper limits calculated in all cases
- Υ(3S) has smallest binding energy
  - Sequential suppression of Υ states
  - Supports picture of melting in a color-deconfined QGP



arXiv:1706.05984

ϒ Nuclear modification at 5.02 TeV

- R_{AA}:
  - Ratios of yields in AA to those in pp
    - Scaled by $T_{AA} = N_{coll}/\sigma_{pp}$
  - Absolute modification
- Visually displayed with PbPb data and T_{AA}-scaled overlay of pp fit
- Clear absolute suppression of all 3 states

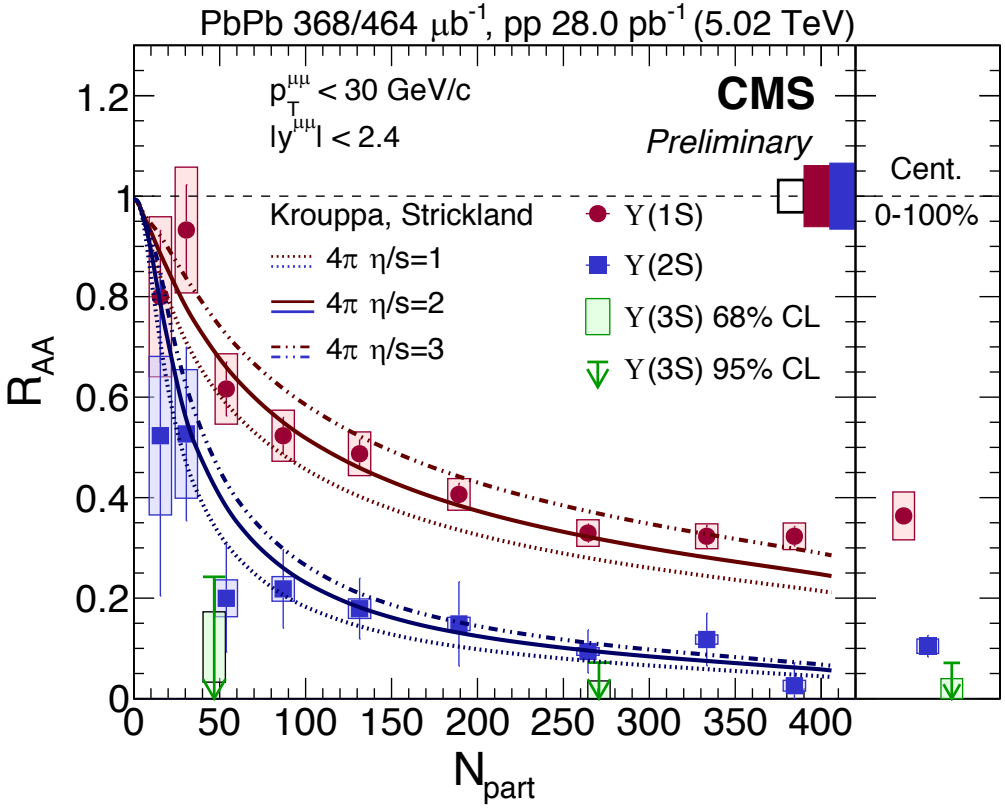


CMS-PAS-HIN-16-023

Υ(nS) R_{AA} vs. Centrality at 5.02 TeV

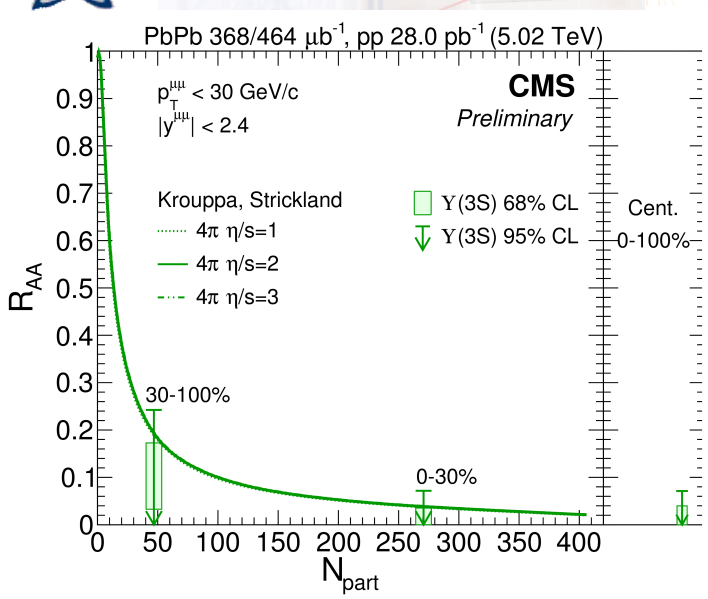
$$R_{AA} = \frac{L_{pp}}{T_{AA} N_{MB}} \frac{N_{PbPb}}{N_{pp}} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}}$$

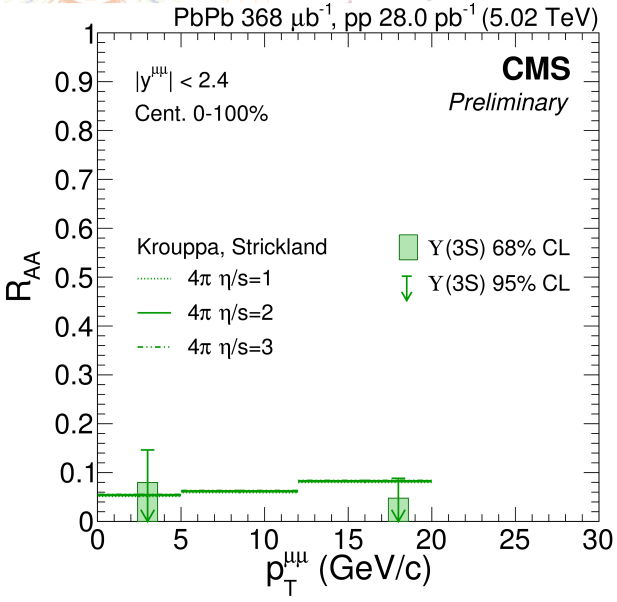
- Nuclear modification for the 3 S-states:
  - Sequential melting!
- Suppression of 1S and 2S:
  - Increasing for more central events
- R_{AA} Integrated results (0-100%)
  - 1S: 0.364 ± 0.014 ± 0.048
  - 2S: 0.104 ± 0.021 ± 0.014
  - 3S: 0.071 at 95% CL

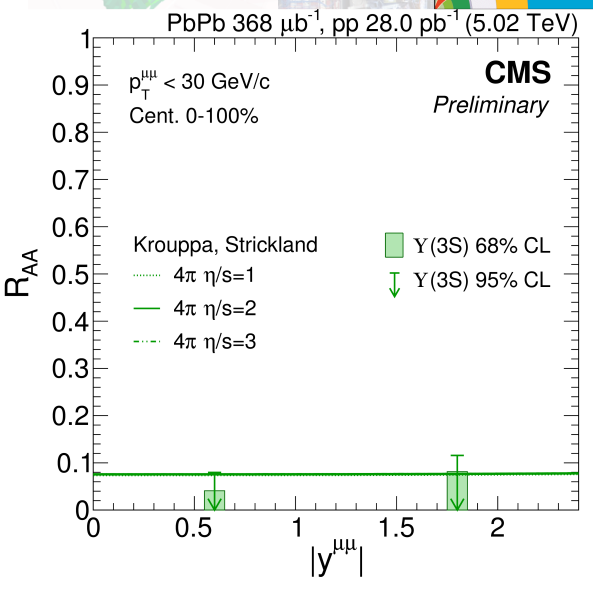


CMS PAS HIN-16-023

3S State: Strong suppression!



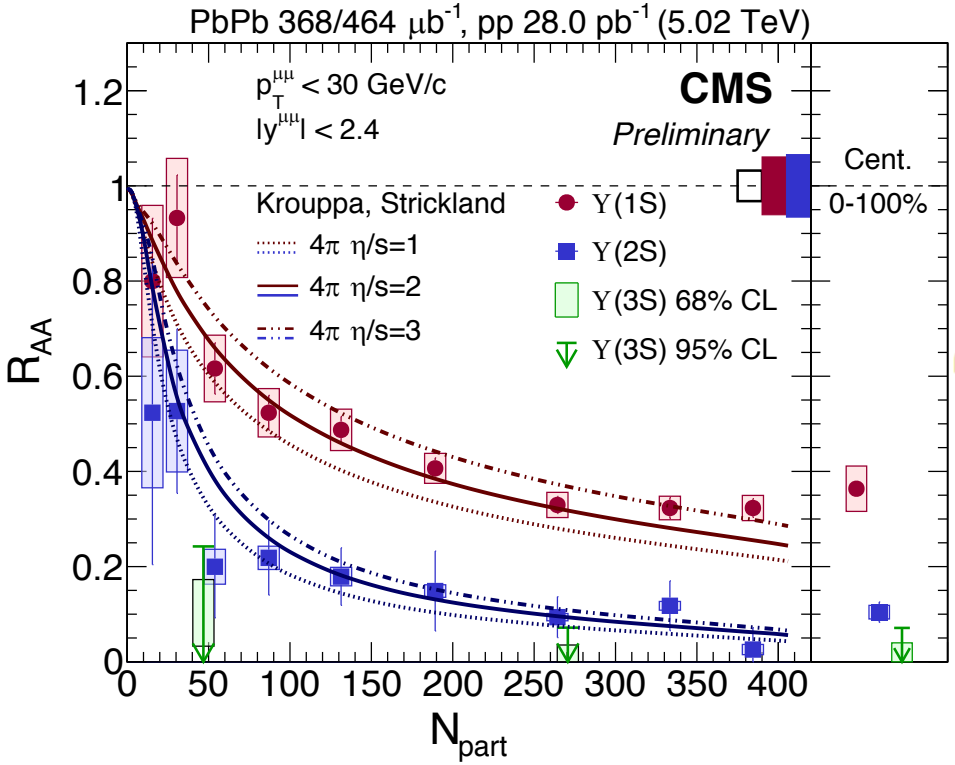


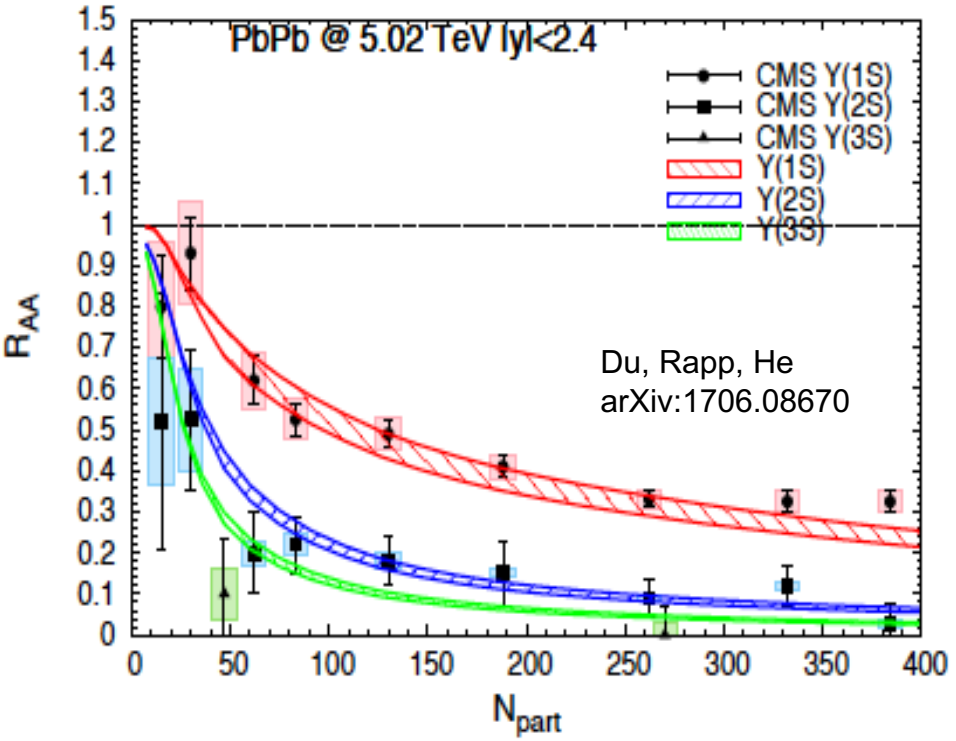


CMS-PAS-HIN-16-023

- Centrality integrated: 0.071 at 95% CL
  - Smallest R_{AA} observed for any hadron.
- Kinematic dependence:
  - Strong suppression (factor ~5-10) seen at all p_T and all y.

Υ(nS) R_{AA} vs. Centrality: Models



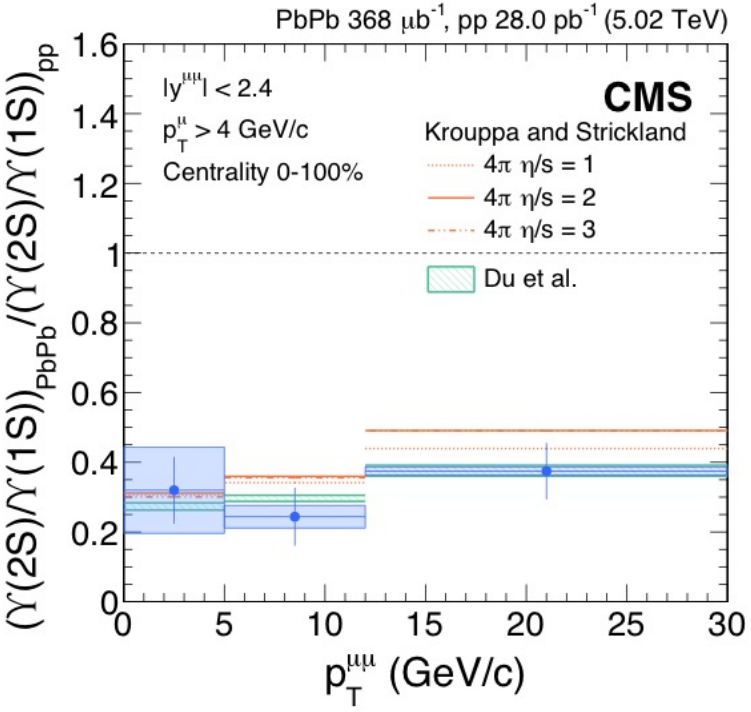


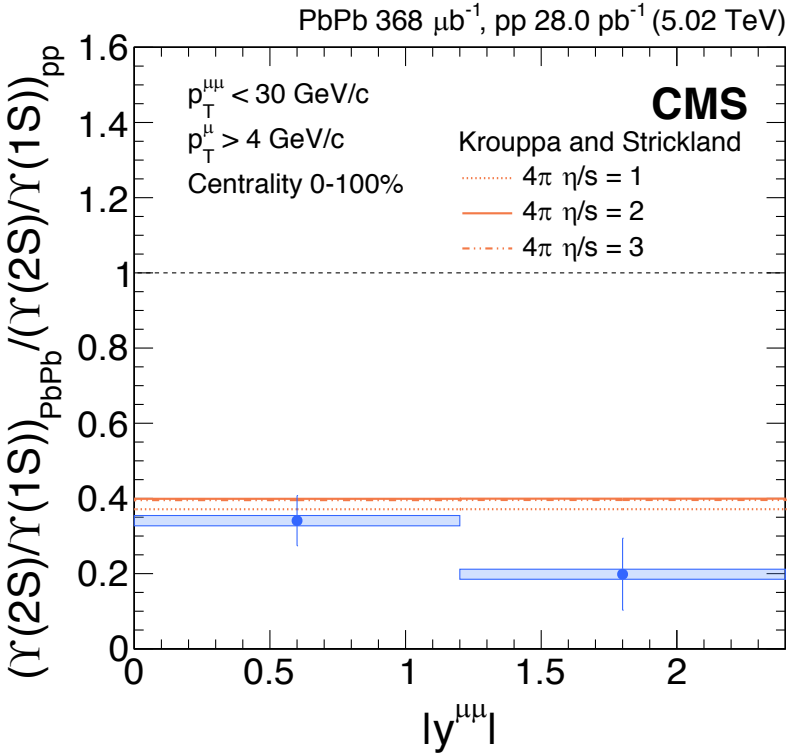
- Strickland et al.:
  - $\frac{4\pi\eta}{s} = \{1,2,3\}, T_0 = \{641, 632, 629\} MeV$
  - Increase in T compared to 2.76 TeV of ~16%.

- Rapp et al.:
- T-Matrix Binding Scenario (TBS): Binding energy depends on Temperature.
- Strong Binding Scenario (SBS): Binding energy is constant
- Comparison to data prefers TBS
- Ground state is only slightly dissociated: feed-down
  - Regeneration contribution modest for 1S
- Excited states: primordial suppression is dramatic, R_{AA}~0
  - Finite R_{AA} : due to regeneration contribution

Kinematic Dependence: Double Ratio

- Constant ratio, within statistical uncertainties.





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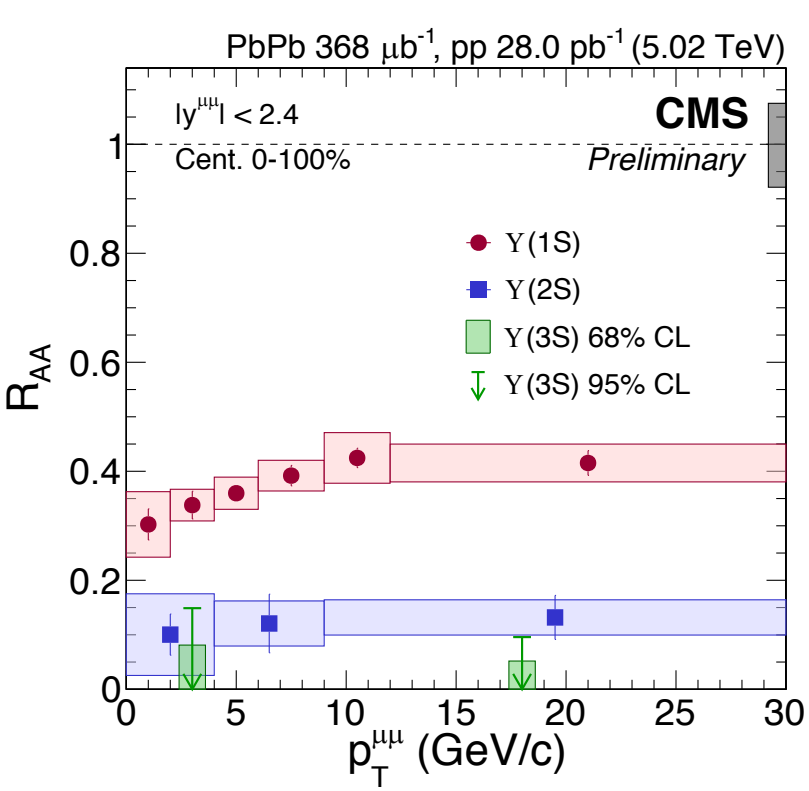
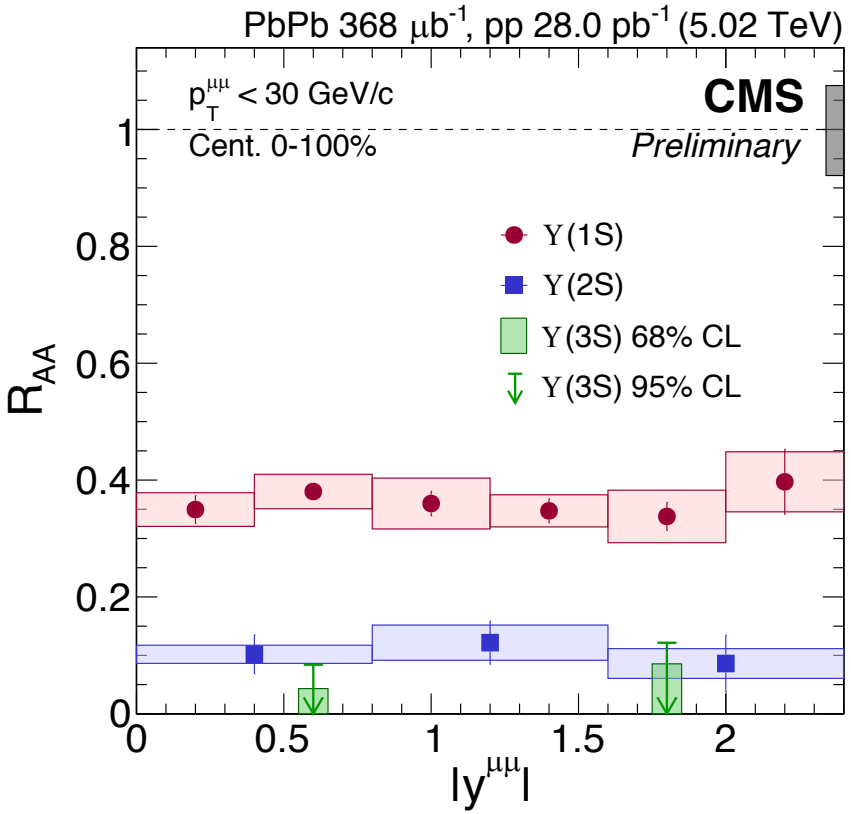
Kinematic Dependence of R_{AA}



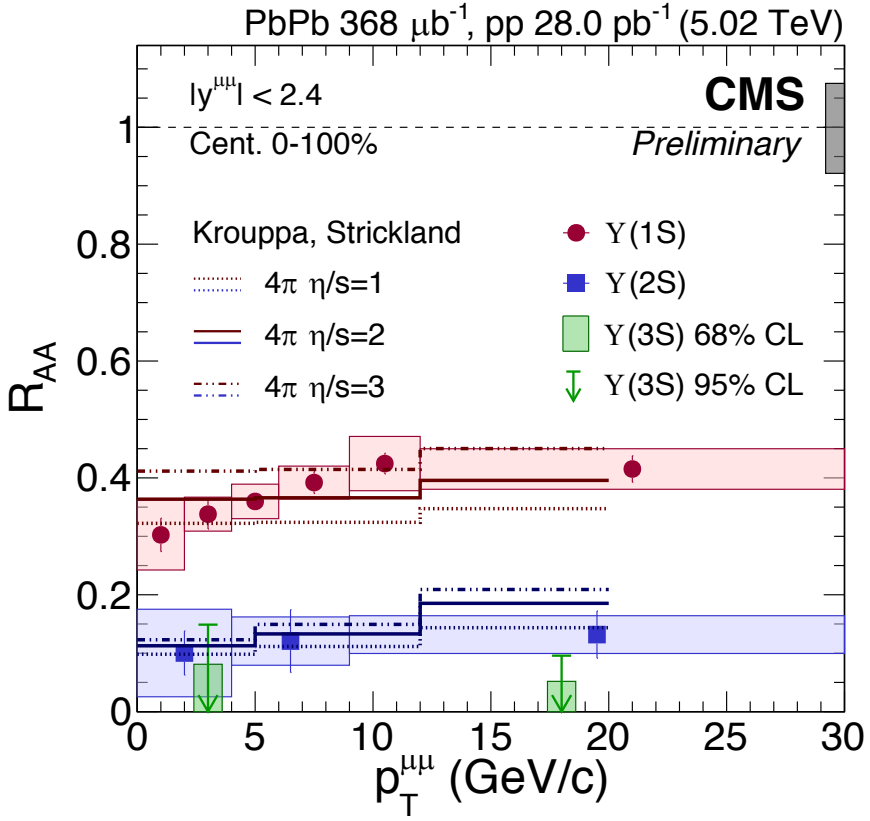


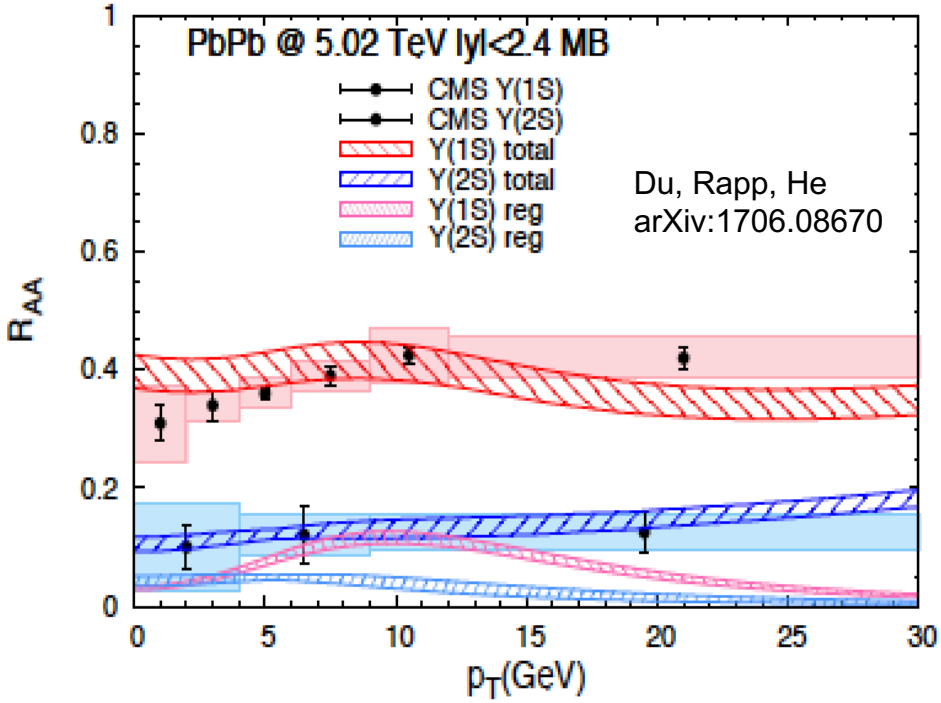
CMS-PAS-HIN-16-023

- p_T:
  - $\Upsilon(1S)$: R_{AA} increases vs p_T.
  - $\Upsilon(2S)$, $\Upsilon(3S)$: Constant R_{AA} vs p_T.
- Rapidity:
  - Constant R_{AA} vs y for all 3 States.

Model comparison: p_T dependence

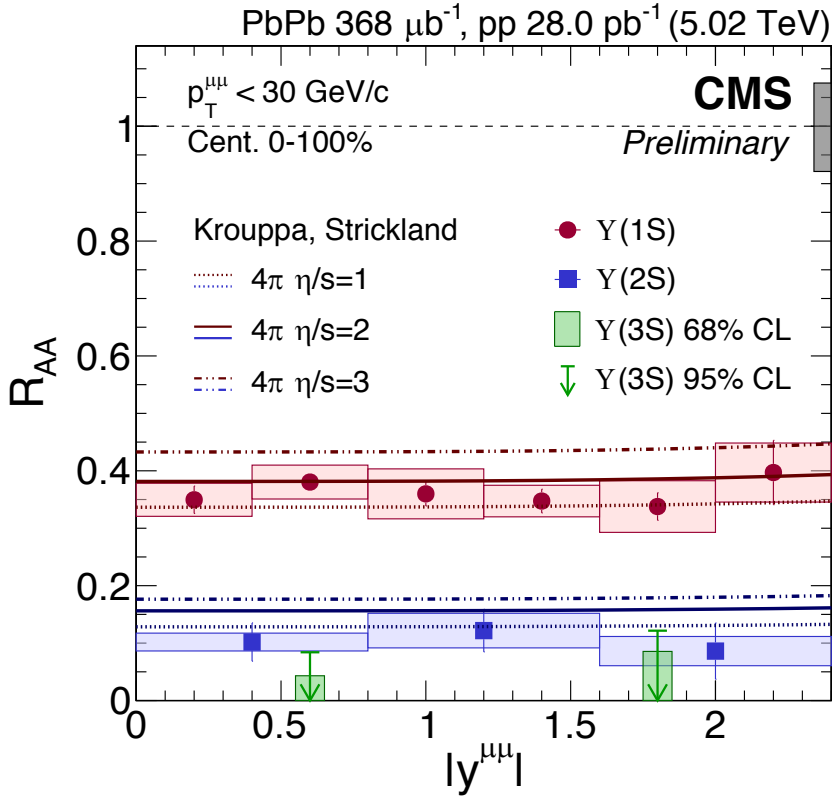
- R_{AA} vs pT:

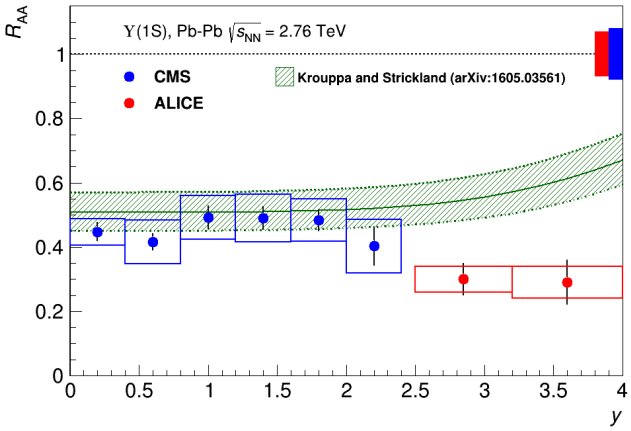


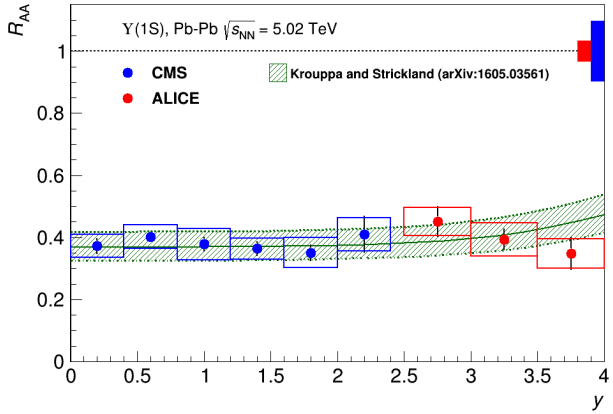


- Strickland et al.:
  - Expect small increase vs pT.
- Rapp et al.:
  - Contribution from regeneration modifies shape of 1S compared to 2S.

Comparison: y dependence



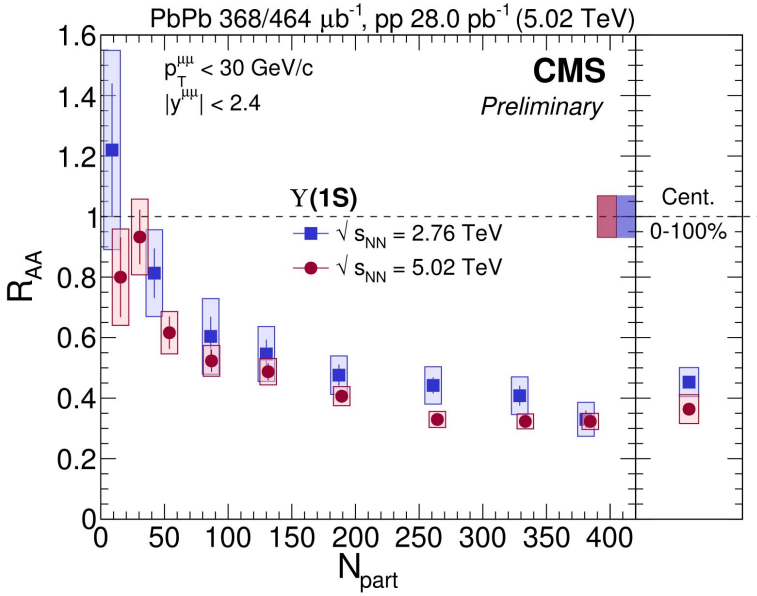


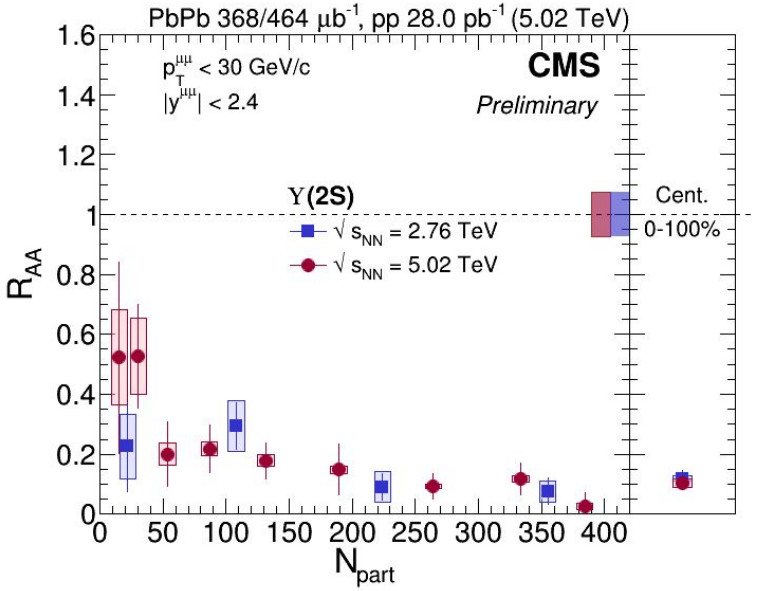


- Strickland et al.:
  - Modest increase in RAA vs y up to y=2.4
  - Consistent with our data
- CMS and ALICE, together:
  - Compiled from Preliminary results; QM17, E. Scomparin
  - 2.76 TeV: hint of decreasing R_{AA} vs y
  - 5.02 TeV: R_{AA} ~ constant vs y!

Comparison to 2.76 TeV Results

- $\Upsilon(1S)$:
  - Indication of larger suppression at higher energy
- $\Upsilon(2S)$:
  - Suppression level is consistent between the two energies
    - Rapp model: Larger role of regeneration for 2S state





CMS 5.02 TeV R_{AA}: CMS PAS HIN-16-023
CMS 2.76 TeV R_{AA}: PLB 770 (2017) 357

Summary and Conclusions

- CMS has measured charmonia and bottomonia production and suppression with 5.02 TeV pPb and PbPb collisions
- Charmonia:
  - CNM effects:
    - J/ψ R_{pPb}: no strong pT or y dependence
      - Shadowing calculations only slighly lower
    - ψ(2S) R_{pPb} : Lower than J/ψ R_{pPb}
      - Indications of Final-state effects.
- Bottomonia:
  - Sequential melting is observed, similar to 2.76 TeV
  - Strong suppression of 3S state
    - Smallest value of R_{AA} yet measured for any hadron
  - Stronger suppression of 1S state at 5.02 compared to 2.76 TeV
    - Increase in medium T
  - Similar suppression of 2S state at 5.02 compared to 2.76 TeV
    - Spectroscopy of all states can help constrain thermal suppression vs. regeneration contributions