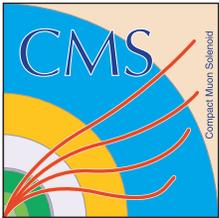# Bottomonium production in pp and PbPb collisions at 5.02 TeV

Geonhee Oh

On Behalf of the CMS Collaboration

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HARD PROBES 2018

Bottomonium production in pp and PbPb collisions at 5.02 TeV

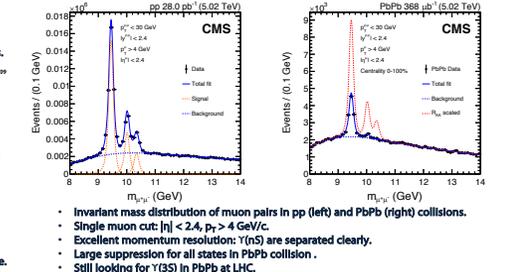Geonhee Oh, Chonnam National University
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Abstract

Bottomonia are important probes of the quark-gluon plasma since they are produced at early times and propagate through the medium. The production cross sections of the three Υ states (1S, 2S, 3S) were measured by CMS in pp and PbPb collisions at 5.02 TeV. A strong suppression is observed in PbPb collisions but the Υ(3S) was not observed clearly in PbPb collisions. This suppression was seen to depend on centrality, but not significantly on transverse momentum or rapidity.
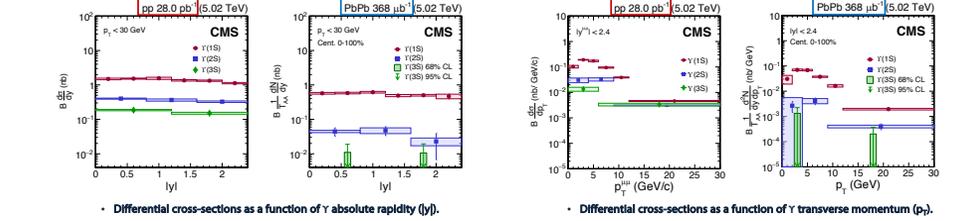
Introduction

Quarkonia in heavy-ion collisions

- One of the most powerful tools to understand the quark-gluon plasma (QGP).
- Heavy quarks created at the early stage and with a large momentum transfer.
- Effects such as Debye screening can cause sequential melting of the quarkonium states.
  - Quarkonia can be used as thermometer of the medium.

state	J/ψ (1S)	χ$_c$ (1P)	ψ (2S)	Υ (1S)	χ$_b$ (1P)	Υ (2S)	χ$_b$ (2P)	Υ (3S)
m(GeV/c²)	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
r$_0$(fm)	0.50	0.72	0.90	0.28	0.44	0.56	0.68	0.78

- A recent calculation - the melting temperatures from JHEP 1512(2015)101.
  - Υ(1S) : ~ 460 MeV (T$_{melt}$/T$_c$=2.66).
  - Υ(2S) : ~ 215 MeV (T$_{melt}$/T$_c$=1.25).
  - Υ(3S) : ~ 172.5 MeV (T$_{melt}$/T$_c$=1.01).
- Bottomonium family.
  - Smaller contribution from recombination than charmonium states.
  - Smaller modifications due to nPDF effects than charmonium states.
  - No feed-down from open heavy flavor than charmonium states.
  - A cleaner probe to study the modification of heavy-quark potential at high temperature.
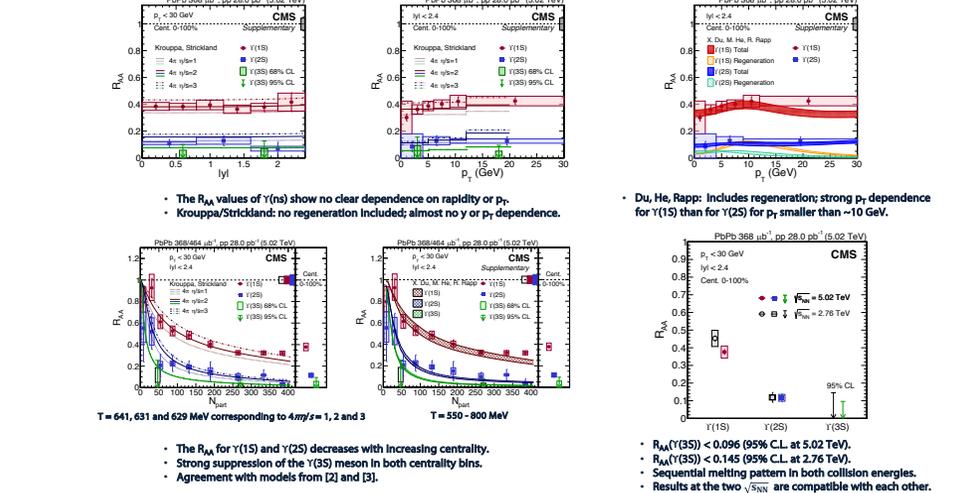
Signal extraction

- Invariant mass distribution of muon pairs in pp (left) and PbPb (right) collisions.
- Single muon cut: |η| < 2.4, p$_T$ > 4 GeV/c.
- Excellent momentum resolution: Υ(nS) are separated clearly.
- Large suppression for all states in PbPb collision.
- Still looking for Υ(3S) in PbPb at LHC.

Production cross-section

- Differential cross-sections as a function of Υ absolute rapidity (|y|).
- Differential cross-sections as a function of Υ transverse momentum (p$_T$).

Results

- The R$_{AA}$ values of Υ(ns) show no clear dependence on rapidity or p$_T$.
- Krouppa/Strickland: no regeneration included; almost no y or p$_T$ dependence.
- Du, He, Rapp: includes regeneration; strong p$_T$ dependence for Υ(1S) than for Υ(2S) for p$_T$ smaller than ~10 GeV.

T = 641, 631 and 629 MeV corresponding to 4πη/s = 1, 2 and 3

T = 550 - 800 MeV

- The R$_{AA}$ for Υ(1S) and Υ(2S) decreases with increasing centrality.
- Strong suppression of the Υ(3S) meson in both centrality bins.
- Agreement with models from [2] and [3].

- R$_{AA}$(Υ(3S)) < 0.096 (95% C.L. at 5.02 TeV).
- R$_{AA}$(Υ(3S)) < 0.145 (95% C.L. at 2.76 TeV).
- Sequential melting pattern in both collision energies.
- Results at the two $\sqrt{s_{NN}}$ are compatible with each other.

Reference

[1] Measurements of nuclear modification factors of Υ(1S), Υ(2S) and Υ(3S) mesons in PbPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. (arXiv:1805.092)

[2] B. Krouppa and M. Strickland, Predictions for bottomonia suppression in 5.023 TeV PbPb- collisions. (arXiv:1605.03561)

[3] X. Du, R. Rapp, and M. He, Color screening and regeneration of bottomonia in high-energy heavy-ion collisions. (arXiv:1706.08670)
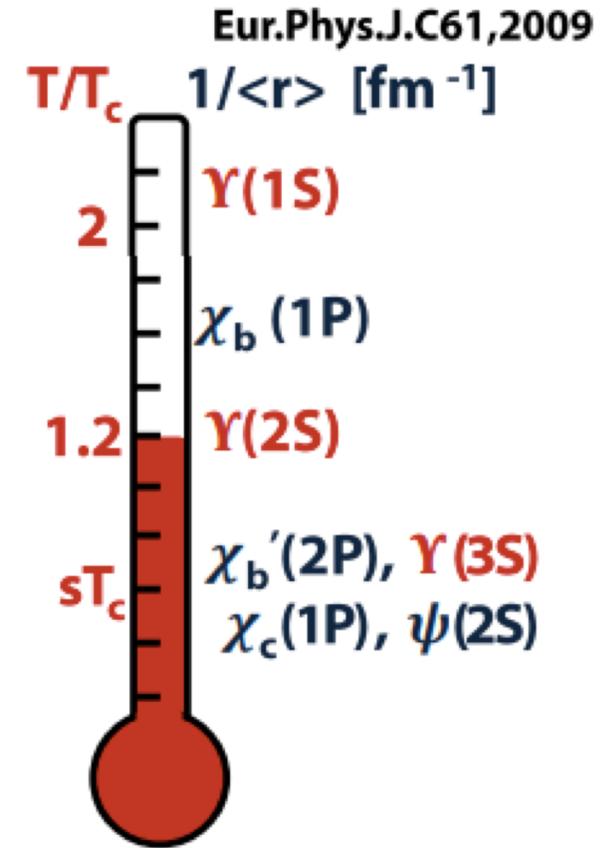
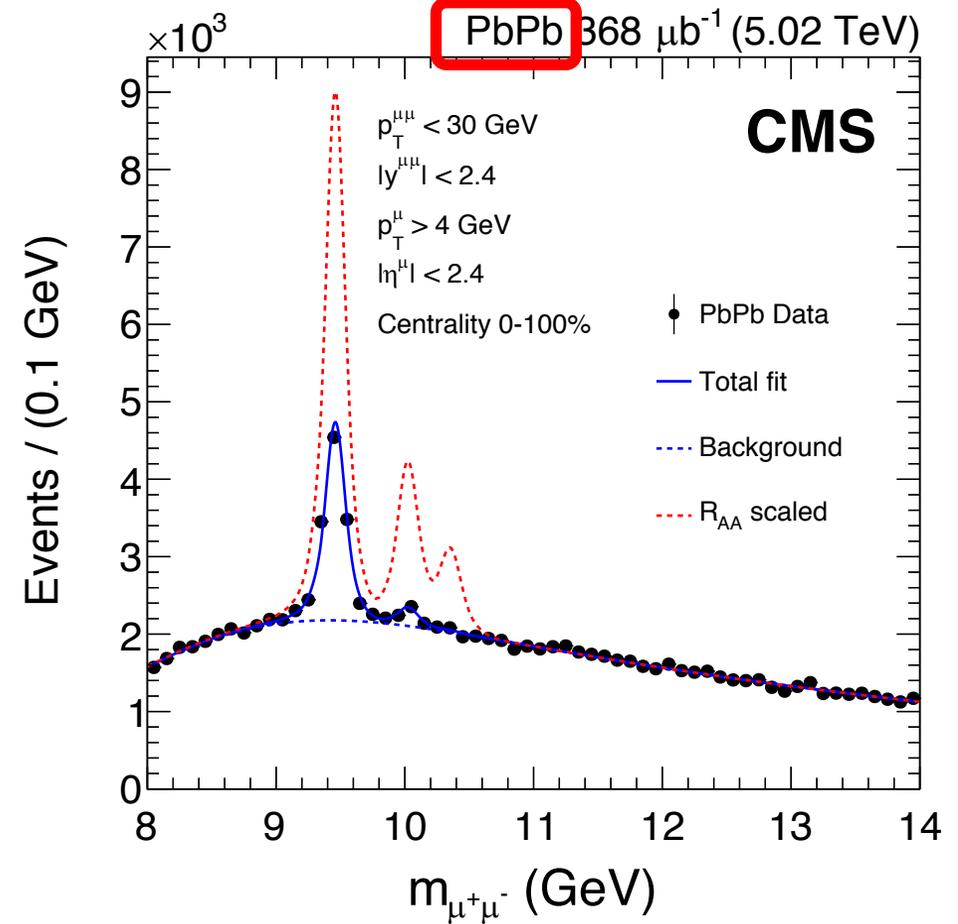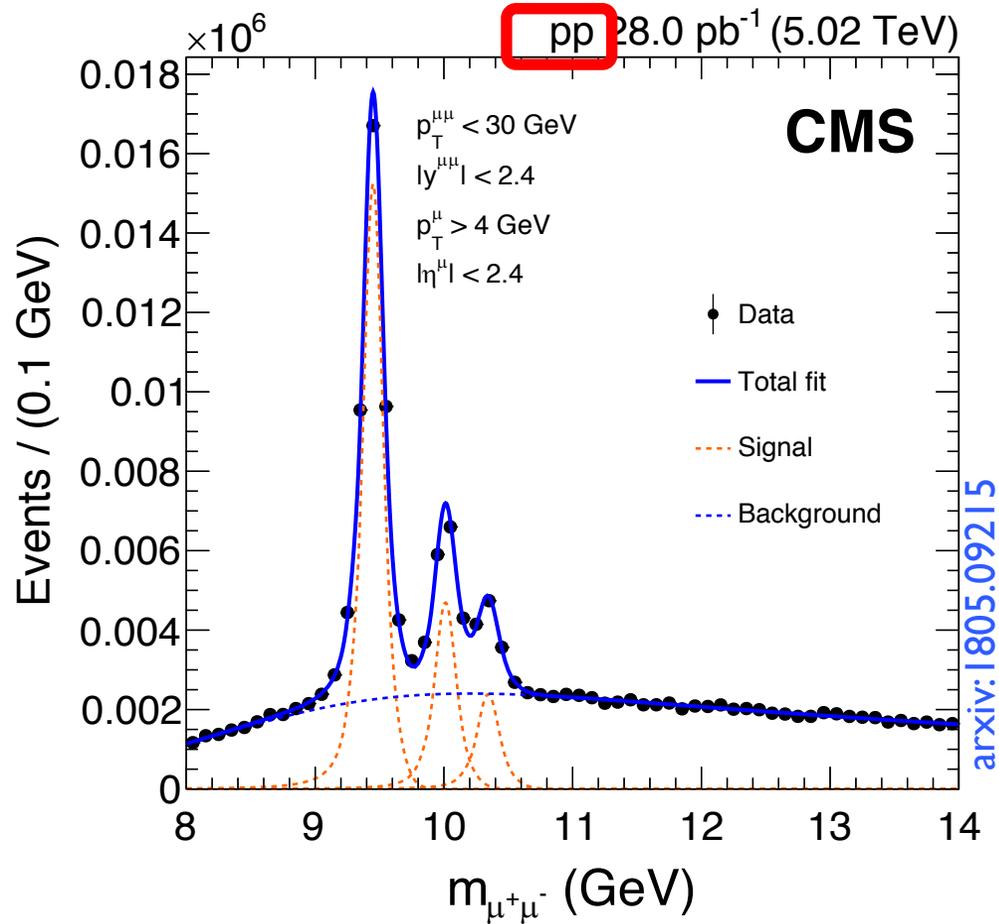- **Quarkonium production in heavy-ion collisions**
  - **Color screening:** dissociation in medium,
    at different temperatures for different states
  - **Regeneration** (at low/intermediate p_T)
  - **Parton energy loss** (at high-p_T)
  - **Initial state and CNM effect**

- **Bottomonia**
  - Cleaner probe than charmonia to study the modification of the heavy-quark potential at high temperature:
    - Much smaller regeneration contribution
      (~10bbar pairs per event at LHC energies)
    - Only feed down from excited states

Eur.Phys.J.C61,2009

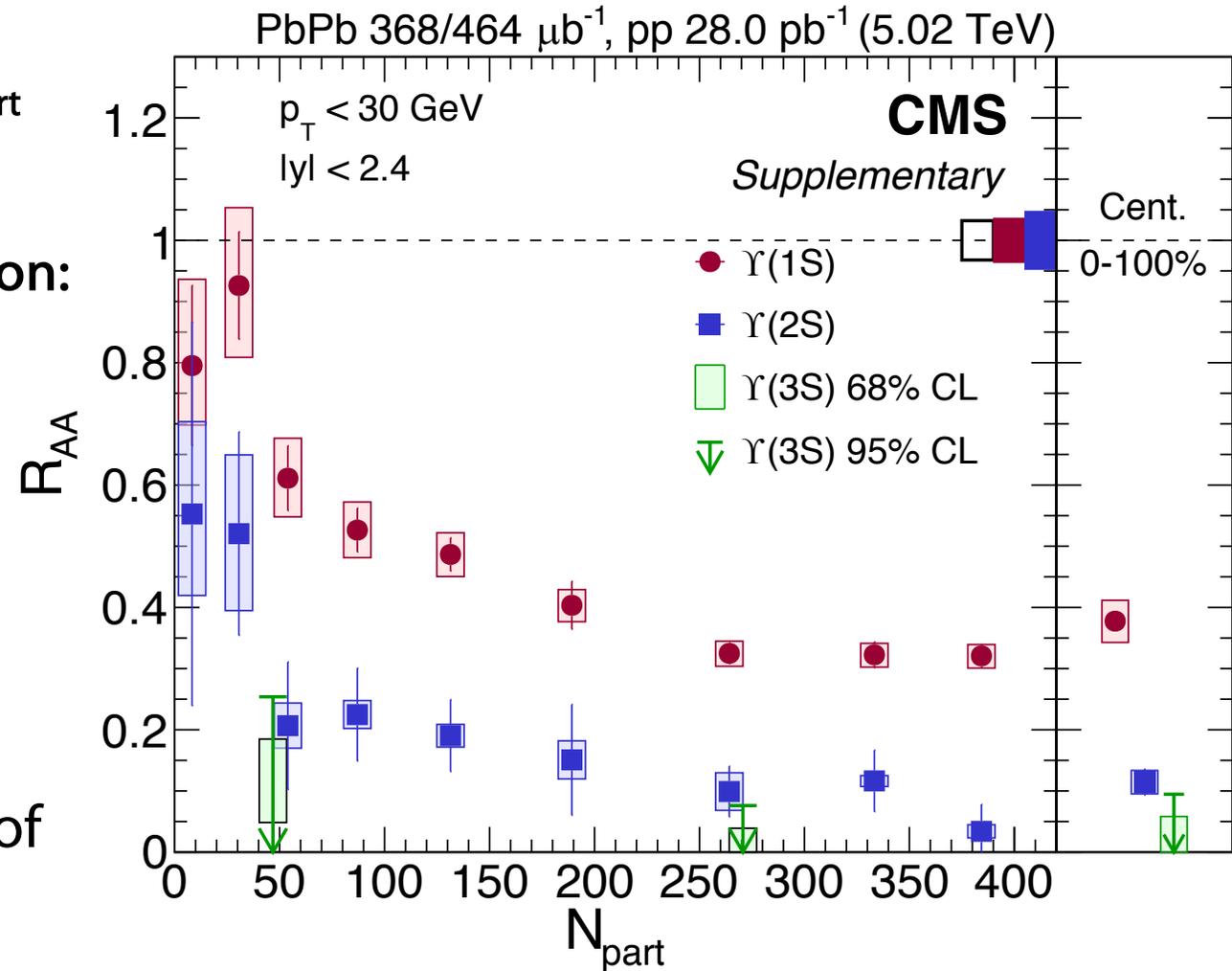T/T_c $1/<r>$ [fm^{-1}]

2   $\Upsilon(1S)$

χ_b (1P)

1.2 $\Upsilon(2S)$

sT_c χ_b'(2P), Υ(3S)

χ_c(1P), ψ(2S)

- All three ϒ states are clearly separated

- Still looking for ϒ(3S) in PbPb collisions though

arxiv:1805.09215

- **Suppression of all states, increasing with N$_{part}$**

- **Pattern consistent with sequential suppression: e.g., for Cent. 0-100%**
  - R$_{AA}$(ϒ(1S)) = 0.378 ± 0.013 (stat) ± 0.035 (syst)
  - R$_{AA}$(ϒ(2S)) = 0.114 ± 0.021 (stat) ± 0.019 (syst)
  - R$_{AA}$(ϒ(3S)) < 0.094 at 95% C.L.

- **Fun fact:**
  - R$_{AA}$(ϒ(3S)) is the smallest measured R$_{AA}$ of any hadron

PbPb 368/464 μb^{-1}, pp 28.0 pb^{-1} (5.02 TeV)

$p_T < 30$ GeV

|y| < 2.4

CMS

Supplementary

Cent.

0-100%

- ϒ(1S)
- ϒ(2S)
- ϒ(3S) 68% CL
- ϒ(3S) 95% CL

R$_{AA}$

N$_{part}$

PbPb 368/464 μb^{-1}, pp 28.0 pb^{-1} (5.02 TeV)

PbPb 368/464 μb^{-1}, pp 28.0 pb^{-1} (5.02 TeV)

CMS

$p_T < 30$ GeV

|y| < 2.4

Kroupa, Strickland
- 4π $\eta/s=1$
- 4π $\eta/s=2$
- 4π $\eta/s=3$

- $\Upsilon(1S)$
- $\Upsilon(2S)$
- $\Upsilon(3S)$ 68% CL
- $\Upsilon(3S)$ 95% CL

Cent.
0-100%

R_{AA}

N_{part}

arxiv:1805.09215

CMS

Supplementary

$p_T < 30$ GeV

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X. Du, M. He, R. Rapp
- $\Upsilon(1S)$
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- $\Upsilon(3S)$

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Cent.
0-100%

R_{AA}

N_{part}
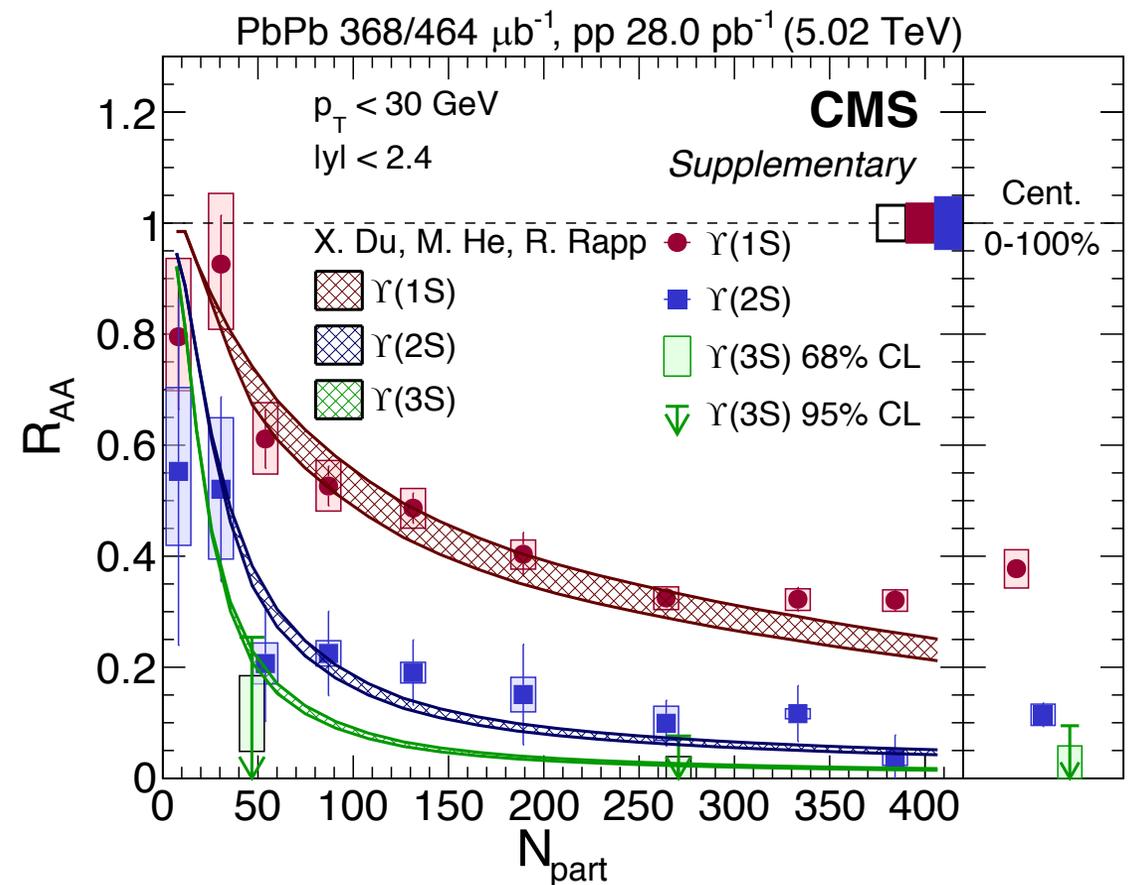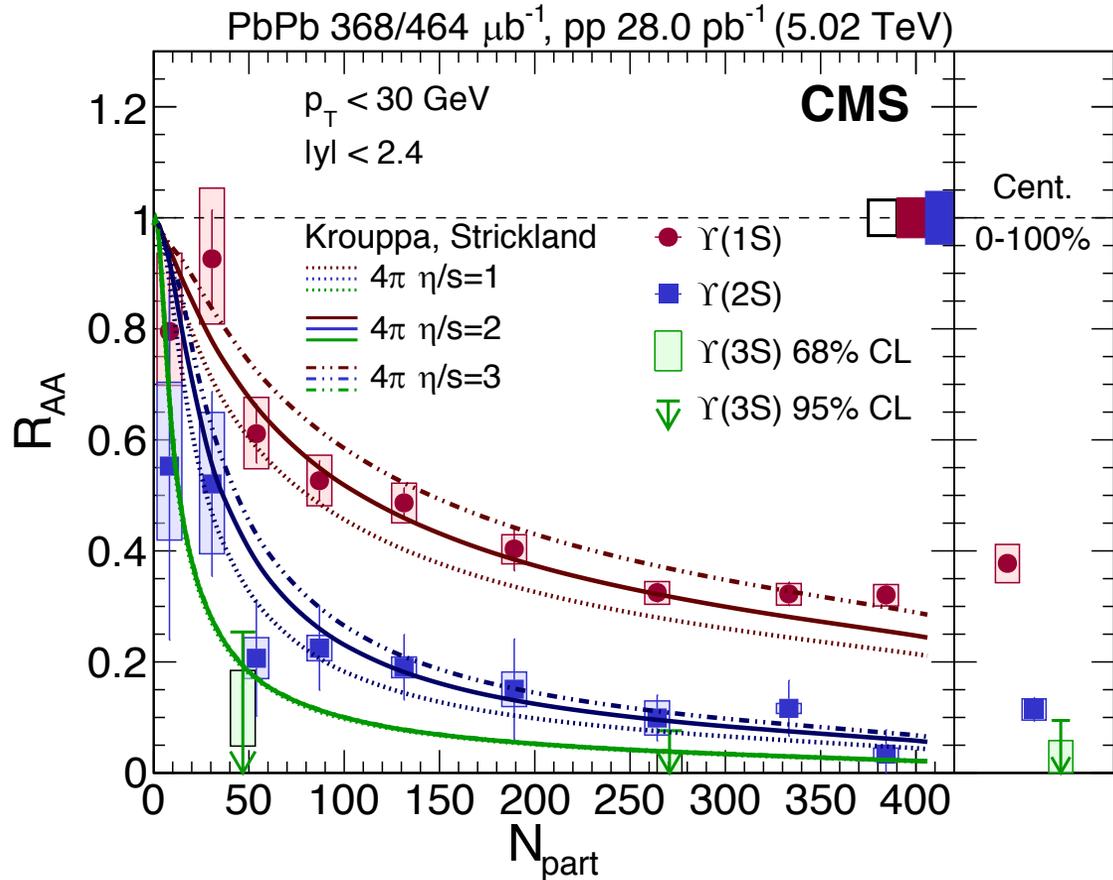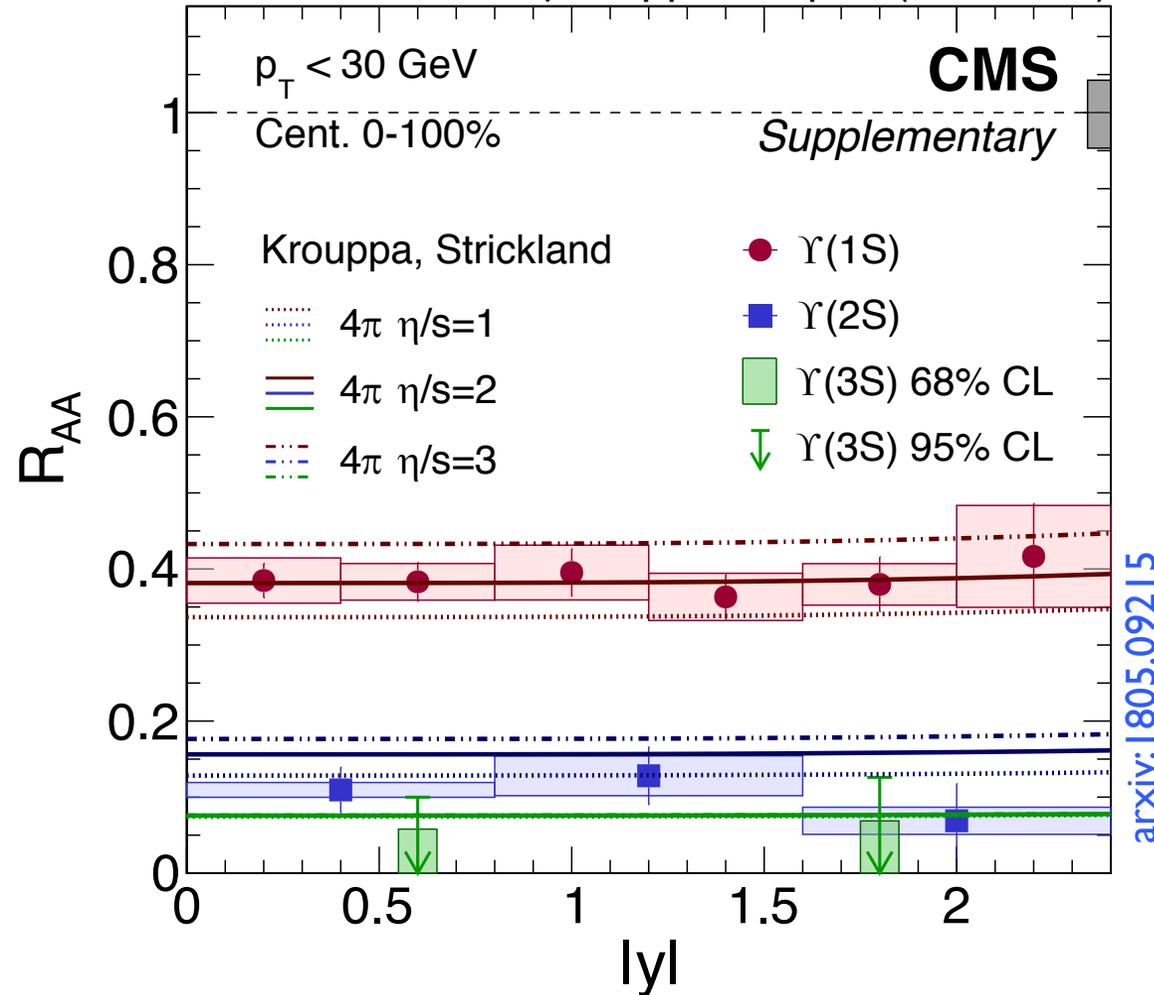
- Melting temperatures :
  - Υ(1S, 2S, 3S) : {600, 230, 170} MeV
- $4\pi\eta/s$ = {1,2,3} , T0 = {641,632,629} MeV
- No regeneration included

- Melting temperatures :
  - Υ(1S, 2S, 3S) = {500, 240, 190} MeV
- Initial temperature: 550 - 800 MeV
- Includes regeneration

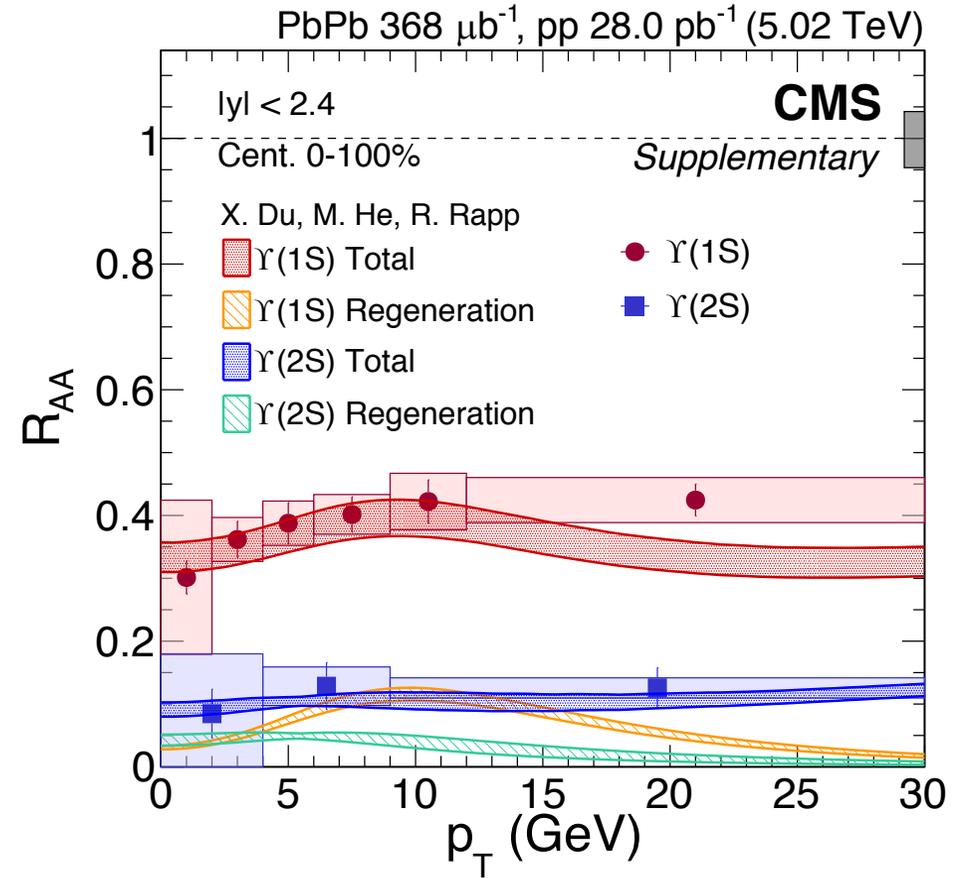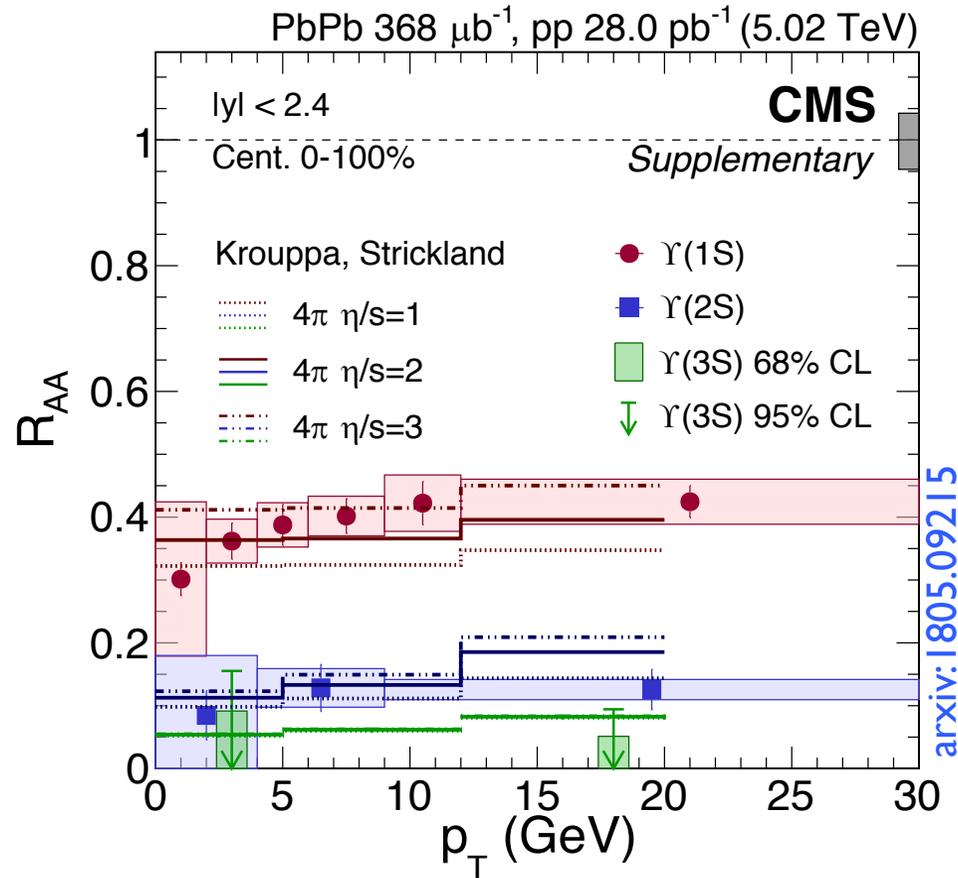■ **Agreement with models (with or without Υ regeneration)**

R$_{AA}$ vs rapidity

PbPb 368 μb^{-1}, pp 28.0 pb^{-1} (5.02 TeV)

p$_T$ < 30 GeV

CMS

Cent. 0-100%

Supplementary

Kroupppa, Strickland

⋯⋯ 4π η/s=1

—— 4π η/s=2

·−·− 4π η/s=3

● Υ(1S)

■ Υ(2S)

Υ(3S) 68% CL

Υ(3S) 95% CL

R$_{AA}$

|y|

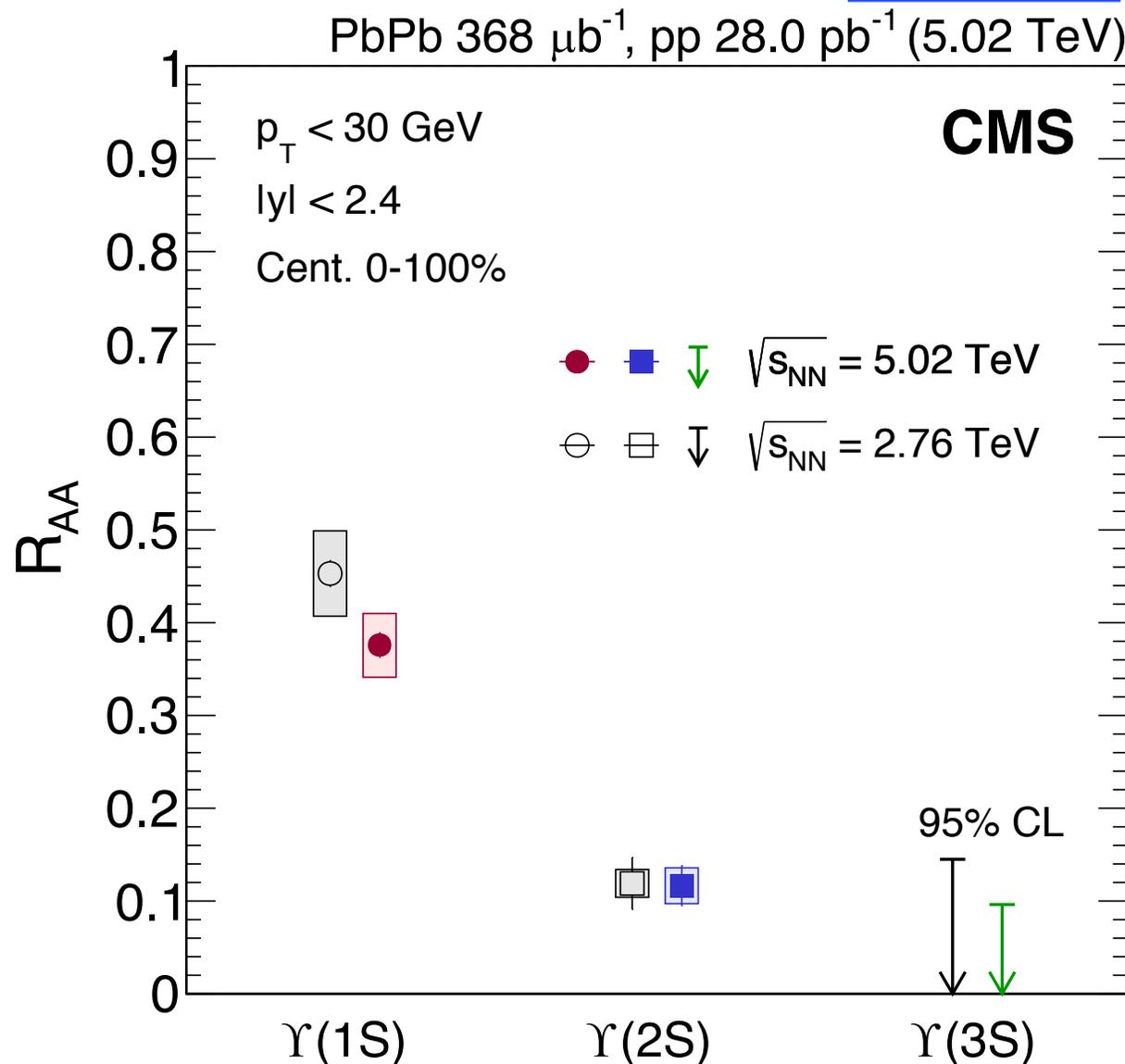arxiv:1805.09215

- **No clear dependence on rapidity**

- **Data: no significant dependence of R$_{AA}$ on p$_T$**

- **Krouppa, Strickland: no regeneration**
  - High Beta ϒ escapes the QGP

- **Du, He, Rapp: includes regeneration**
  - p$_T$ dependence, stronger for ϒ(1S) than for ϒ(2S) for p$_T$ smaller than ~10 GeV.

arxiv:1805.09215

PbPb 368 μb^{-1}, pp 28.0 pb^{-1} (5.02 TeV)

- **Bottomonium production in PbPb at 5.02 (and 2.76) TeV**

- **Sequential suppression pattern observed**
  at both collision energies

- $R_{AA}(\Upsilon(1S)) = 0.378 \pm 0.013 \text{ (stat)} \pm 0.035 \text{ (syst)}$
  - Direct production of $\Upsilon(1S)$ 60~70%
  - Is really $\Upsilon(1S)$ suppressed by QGP?
    - Need extra studies:
  e.g modification of 1P states, R_{pPb} etc

CMS

$p_T < 30$ GeV

$|y| < 2.4$

Cent. 0-100%

$\sqrt{s_{NN}} = 5.02$ TeV

$\sqrt{s_{NN}} = 2.76$ TeV

R_{AA}

95% CL

$\Upsilon(1S)$ $\Upsilon(2S)$ $\Upsilon(3S)$

Thank you