Measurement of Bottomonia in pp, pPb and PbPb collisions at 5.02 TeV

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Y(nS) mesons provide evidence for color charge screening that sequentially increases w.r.t. binding energy.

This presentation reviews the recent observation of upsilon state modifications in pPb and PbPb collisions at 5.02 TeV.
Upsilon states in Heavy ion collision

- Suppression of excited $\Upsilon(nS)$ in PbPb at 2.76 TeV
  \[PRL 107 (2011) 052302\]

- Quarkonium production in PbPb collisions at 2.76 TeV
  \[JHEP 1205 (2012) 063\]

- Observation of $\Upsilon(nS)$ suppression at 2.76 TeV
  \[PRL 109 (2012) 222301\]

- Suppression of $\Upsilon(nS)$ in PbPb at 2.76 TeV
  \[PLB 770, 357(2017)\]

- Event activity of $\Upsilon(nS)$ in pPb at 5.02 TeV
  \[JHEP 04 (2014) 103\]

- Suppression of $\Upsilon(nS)$ in PbPb at 5.02 TeV
  \[PRL 120 (2018) 142301\]

- Nuclear modification of $\Upsilon(nS)$ in PbPb at 5.02 TeV
  \[PLB 790 (2019) 270\]

**New data 2017-2018**

PbPb : $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}, L \sim 1.6 \text{ nb}^{-1}$, pp : $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}, L \sim 300 \text{ pb}^{-1}$

Run 1

- 2011-2013
  PbPb : $\sqrt{s_{\text{NN}}} = 2.76 \text{ TeV}, L = 166 \text{ \mu b}^{-1}$
  pPb : $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}, L = 34.6 \text{ nb}^{-1}$
  pp : $\sqrt{s_{\text{NN}}} = 2.76 \text{ TeV}, L = 5.4 \text{ pb}^{-1}$

Run 2

- 2015
  PbPb : $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}, L = 368 \text{ \mu b}^{-1}$
  pp : $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}, L = 28 \text{ pb}^{-1}$
Upsilon states in Heavy ion collision

From the first PbPb run at LHC, we observed different ratio of $Y(nS)/Y(1S)$ between pp and PbPb. Sequential melting?

The observation led us to measure the double ratio

$$\frac{R_{AA} \text{ of } Y(nS)}{R_{AA} \text{ of } Y(1S)}$$

- **Precision measurement** for very few corrections beyond signal counting
- **Isolates** the final state effects from production mechanism
- **Used** 7.3 $\mu$b$^{-1}$
In the following year, we got 20 times more data

- First measurement of $R_{AA}$ vs centrality
- Not enough statistics for $\Upsilon(3S)$ measurement
- Used $150 \mu b^{-1}$ (x20 than 2010)
In 2013, we took pPb data at 5.02 TeV
- pPb serves as cold nuclear baseline
- Drop of double ratios observed in pPb less than PbPb but in the analogous manner
- confirmed that large suppression of excited states is primarily due to hot medium (QGP)
Lessons from Run I result

- \( Y(nS) \) is suppressed by interaction with medium, but not exactly as predicted by the classical sequential melting picture. All-or-nothing switch by temperature threshold.

- Yet, suppression is higher for more excited states.

- Suppression smoothly depends on the centrality.

- Results with more statistics and in different collision energy would be useful to comprehend the thermal property of QGP, as a function of space and time.
Upsilon results with Run II data

- Nuclear modification measured for all three states

[Graph showing nuclear modification measured for all three states]
Upsilon results with Run II data

- Nuclear modification measured for all three states

- Dedicated trigger for un-prescaled peripheral collision
  - to illuminate the moment of turn-\(R_{AA}\) of excited state

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Upsilon results with Run II data

- Nuclear modification measured for all three states
- Same ordering of suppression in 2.76 TeV
  - $R_{AA}(\Upsilon(1S)) : 0.376 \pm 0.013 \text{ (stat)} \pm 0.035 \text{ (syst)}$
  - $R_{AA}(\Upsilon(2S)) : 0.117 \pm 0.022 \text{ (stat)} \pm 0.019 \text{ (syst)}$
  - $R_{AA}(\Upsilon(3S)) < 0.096$ in 95% C.L.
- $R_{AA}$ Gradually decreases for higher centrality for 1S and 2S
  - Hints for rapid turn-on at very peripheral collision ( > 70%)
Upsilon results with Run II data

- Nuclear modification measured for all three states
- Same ordering of suppression in 2.76 TeV
  \[ R_{AA}(\Upsilon(1S)) : 0.376 \pm 0.013 \text{ (stat)} \pm 0.035 \text{ (syst)} \]
  \[ R_{AA}(\Upsilon(2S)) : 0.117 \pm 0.022 \text{ (stat)} \pm 0.019 \text{ (syst)} \]
  \[ R_{AA}(\Upsilon(3S)) < 0.096 \text{ in 95\% C.L.} \]
- \( R_{AA} \) Gradually decreases for higher centrality for 1S and 2S
- Strong suppression of 3S
[Comparison with 2.76 TeV] $R_{AA}$ vs centrality

- $\Upsilon(1S)$
  - $R_{AA}(5.02) / R_{AA}(2.76) = 1.2 \pm 0.15$
  - compatible within uncertainties

- $\Upsilon(2S)$
  - Monotonic dependence on centrality is clearer in 5.02 TeV
  - Similar suppression in both energies

[PLB 790 (2019) 270] [PLB 770, 357(2017)]
[Comparison with 2.76 TeV] $R_{AA}$ vs $p_T$

- Extended high-$p_T$ reach by 10 GeV for 5.02 TeV
- No significant $p_T$ dependence for Y(1S) and Y(2S) in both energy
- Compatible suppression for both energies
Comparison with models at 5.02 TeV

- $\Upsilon$(1S): 600 MeV
- $\Upsilon$(2S): 230 MeV
- $\Upsilon$(3S): 170 MeV

$T_0 = \{641,632,629\}$ MeV

- No regeneration

~67% direct production of $\Upsilon$(1S) for both models

$\overline{\mathrm{Phys.~Rev.~C}}$ 96, 054901
High speed upsilon can escape QGP

$\rightarrow$ Smooth increase $R_{AA}$ for $p_T$

Yet, both models are compatible with data within statistical uncertainty.

Have to check high $p_T > 20$ GeV $\rightarrow$ Need more data
Comparison with Charmonia results

• Very similar behavior between Charmonia and Bottomonia
  • $\Upsilon(1S)$ aligns with J/psi(1S)
  • $\Upsilon(2S)$ aligns with psi(2S)
• Any geometrical indication?
Remarks and plan

- $R_{AA}$ of Y(1S), Y(2S) and Y(3S) were measured as a function of $p_T$, rapidity and centrality, improving the previous results at 2.76 TeV
  - Consistent with 2.76 TeV data within uncertainty (Models predicted -16%)
  - Clearer dependence on centrality, yet we need more data for peripheral collisions to find the turn-on curve of $R_{AA}$
- The Y(3S) peak is not visible yet
- Compatible with both two different models
  - $p_T$ dependence study with higher statistics may help to resolve
- New data with ~4 times more statistics was taken in 2018. It will lead us to much more interesting physics, so stay tuned!
BACKUP
Comparison with 2.76 TeV

- No dependence on rapidity

Y(1S)

\[ p_T < 30 \text{ GeV} \]

Cent. 0-100%

Y(2S)

\[ p_T < 30 \text{ GeV} \]

Cent. 0-100%