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γ production in p-Pb and Pb-Pb collisions with ALICE at the LHC
Overview

1. Motivation for quarkonium study;
2. RUN1 results;
3. Experimental setup;
4. Analysis strategy;
5. Data samples;
6. Results in p-Pb collisions @ $\sqrt{s_{NN}} = 5.02$ TeV;
7. Results in Pb-Pb collisions @ $\sqrt{s_{NN}} = 5.02$ TeV;
8. Interpretation of Pb-Pb results within theoretical models;
Introduction
Physics motivation for quarkonium study

• Early $Q\bar{Q}$ production ➤ sensitive to QGP evolution;

• Quarkonium can probe the hot medium effects by:
  • Color screening by free color charges;
  • Sequential suppression (leads to a QGP thermometer);
  • Regeneration phenomena in the QGP or at the phase boundary.

• Bottomonium is a good candidate for QGP study and, with respect to charmonia:
  • The perturbative approach is reliable, since the bottom quark has an higher mass;
  • No feed-down from open bottom flavoured states;
  • Statistical recombination is less relevant since $N_{bb} \ll N_{cc}$;
  • Cold Nuclear Matter effects expected to be smaller.

• Moreover bottomonium study allows to scan a different Bjorken-x range compared to charmonia.

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ALICE has already published results in Pb-Pb \( @ \sqrt{s_{NN}} = 2.76 \) TeV.

\( R_{AA} \) was computed using the \( \sigma_{pp} \) reference measured by the LHCb collaboration in \( pp @ \sqrt{s} = 2.76 \) TeV.

\( \Upsilon(1S) \) \( R_{AA} \) compatible with suppression which increases from peripheral to central collisions.

Results are in agreement, within uncertainties, with theoretical predictions.
Pb-Pb @ $\sqrt{s_{NN}} = 2.76$ TeV: rapidity dependence

ALICE at the LHC already produced results in Pb-Pb @ $\sqrt{s_{NN}} = 2.76$ TeV.

$R_{AA}$ was computed using the $\sigma_{pp}$ reference measured by the LHCb collaboration in pp @ $\sqrt{s} = 2.76$ TeV.

$\Upsilon (1S)$ suppression observed at forward rapidity (ALICE) and at mid rapidity (CMS) are compatible with model predictions.
Data analysis
Experimental setup

**ZDC (Zero Degree Calorimeter)** used to reject EM events.

**V0** scintillators provide a minimum bias trigger and are used to measure the centrality of Pb-Pb collisions.

**ITS** (Inner Tracking System) composed of several layers of silicon detectors provides primary vertex determination.

**Muon tracker** (10 planes of Cathode Pad Chambers arranged in 5 stations) tracks particles coming from the interaction vertex towards the muon trigger.

**Front absorber** reduces hadronic contamination.

**Dipole** bends charged tracks.

**Muon filter** reduces hadronic contamination to less than 1%.

**Muon trigger** (4 planes of Resistive Plate Chambers arranged in 2 stations) acts as online trigger and offline muon identifier.

**ZDC**

**Detectors**

**Passive elements**
Events and track selection - Analysis strategy

\( N_{Y(1s)} \) obtained by fitting the \( \mu^+ \mu^- \) invariant mass spectrum.

Dimuon trigger with a \( p_T \) threshold of 1GeV/c for each muon.

**Single muon cuts:**
- Matching between tracker and trigger tracks;
- \(-4.0 < \eta_\mu < -2.5\);
- \( p_T \mu \geq 2 \) GeV/c;
- \( 17.6 \) cm < \( R_{abs} \) < 89.5 cm.

**Unlike sign muon pairs cuts:**
- \(-4.0 < \gamma_{\mu\mu} < -2.5\).

**Invariant mass spectrum fitting function:**
- One extended Crystal Ball function for each resonance;
- A background shape: e.g. double or single exponentials and power laws.
Data sample for p-Pb @ $\sqrt{s_{NN}}=5.02$ TeV

<table>
<thead>
<tr>
<th>$L_{INT}$</th>
<th>Rapidity range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb-p</td>
<td>5.8 $nb^{-1}$</td>
</tr>
<tr>
<td>p-Pb</td>
<td>5.0 $nb^{-1}$</td>
</tr>
</tbody>
</table>

$\Delta y = 0.465$ in the direction of p beam.

$\sigma_{pp}$ has to be computed with $\sqrt{s} = \sqrt{s_{NN}}$. Not enough statistics is available @ $\sqrt{s}$=5.02 TeV. The used $\sigma_{pp}$ has been computed interpolating LHCb data @ $\sqrt{s}$=2.76, 7 and 8 TeV and ALICE data @ $\sqrt{s}$=7 and 8 TeV. Ref. ALICE-PUBLIC-2014-002

In the Pb-p configuration the spectrometer allows to study the backward rapidity range, while in p-Pb it allows to probe the forward rapidity range.
Data sample for Pb-Pb @ $\sqrt{s_{NN}}=5.02$ TeV

<table>
<thead>
<tr>
<th>$L_{INV}$</th>
<th>Rapidity range</th>
<th>Centrality range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb-Pb 225 $\mu$b$^{-1}$</td>
<td>$2.5 &lt; y_{CMS} &lt; 4.0$</td>
<td>0%-90%</td>
</tr>
</tbody>
</table>

The measured number of $\Upsilon(1S)$ measured @ $\sqrt{s_{NN}}=5.02$ TeV is about 10 times greater than the number measured @ $\sqrt{s_{NN}}=2.76$ TeV.

Ref. PLB 738 (2014) 361-372
p-Pb results
Cold Nuclear Matter reference: p-Pb collisions @ $\sqrt{s_{NN}} = 5.02$ TeV

Backward rapidity

- Both backward (Pb-going side) data points are compatible with no suppression;

Forward rapidity

- Forward rapidity (p-going side) shows a suppression hint.

Ref. PLB 740 (2015) 105-117
**Hint of CNM effects at forward rapidity**

- Better agreement between data and Energy Loss -only model;
- Reasonable agreement is found between energy Loss + NLO nuclear shadowing calculation and data;

**$R_{pPb}$: Model comparison (1)**

![Graph showing model comparison](ALICE-pPb_sNN=5.02TeV_inclusive_Y(1S)-to-mu-mu-pT>0_L_{int}(-4.46<y_{cms}<-2.96)=5.8 nb^{-1}, L_{int}(2.03<y_{cms}<3.53)=5.0 nb^{-1})

**Backward rapidity**

**Forward rapidity**

Ref. PLB 740 (2015) 105-117
Hint of CNM effects at forward rapidity

• Hint of an anti-shadowing lower than expected.

• Measured data present good agreement with models which contain suppression effects;
Pb-Pb results in LHC RUN2
$\Upsilon(1S) \; R_{AA} \; @ \; \sqrt{s_{NN}}=5.02 \; \text{TeV}$: centrality dependence

$N_{\Upsilon(1S)} = 1107 \pm 70 \; (\text{stat.}) \pm 43 \; (\text{syst.})$

Dominant sources of $R_{AA}$ systematic uncertainties are the signal extraction (4-7%) and the pp cross section (8-12%).

The $\Upsilon(1S)$ suppression is clear and increases moving from peripheral Pb-Pb collisions to the most central ones.

$R_{AA}(0-90\%) = 0.40 \pm 0.03 (\text{stat.}) \pm 0.04 (\text{syst.})$
$\Upsilon(1s) R_{AA} @ \sqrt{s_{NN}}=5.02 \text{ TeV and 2.76 TeV: centrality dependence}$

Measurements at $\sqrt{s_{NN}}=5.02 \text{ TeV}$ and $2.76 \text{ TeV}$ are compatible within uncertainties.

$R_{AA}(5.02 \text{ TeV, 0-90%}) = 0.40 \pm 0.03 \text{(stat.)} \pm 0.04 \text{(syst.)}$

$R_{AA}(2.76 \text{ TeV, 0-90%}) = 0.30 \pm 0.05 \text{(stat.)} \pm 0.04 \text{(syst.)}$
**$\Upsilon(1s)\ R_{AA}$ @ $\sqrt{s_{NN}}=5.02$ TeV and 2.76 TeV: centrality dependence**

No firm conclusion on the $R_{AA}$ energy dependence.

**Ratio** (0-90%) = $1.3 \pm 0.2$ (stat.) $\pm 0.2$ (syst.)

To ease the comparison between the two data sets the $\sqrt{s_{NN}}=5.02$ TeV analysis has been performed using the same centrality bins of the $\sqrt{s_{NN}}=2.76$ TeV analysis.
The $\Upsilon(1S)$ suppression seems to increase moving towards larger $|y|$, however the three measured points are compatible within uncertainties.
\( \Upsilon(1s) R_{AA} @ \sqrt{s_{NN}}=5.02 \, \text{TeV} \) and \( 2.76 \, \text{TeV} \): rapidity dependence

\[ R_{AA} \text{ values are systematically smaller} @ \sqrt{s_{NN}}=2.76 \, \text{TeV} \text{ however measurements at } \sqrt{s_{NN}}=5.02 \, \text{TeV} \text{ and } 2.76 \, \text{TeV} \text{ are compatible within uncertainties.} \]
Model comparison
• A. Emerick, X. Zhao and R. Rapp:
  • Regeneration is included;
  • Feed-down fraction tuned on LHCb and ALICE;
  • Band obtained varying shadowing from 0% to 25%.

• K. Zhou, N. Xu, Z. Xu and P. Zhuang:
  • Regeneration NOT included;
  • Band obtained varying feed down fractions;
  • CNM effects modelled as EKS98.

Centrality dependence is qualitatively reproduced. Emerick et al. model slightly underestimates the measured suppression.
Rapidity dependence: hydrodynamic models

- **M. Strickland et al.:**
  - Regeneration NOT included;
  - CNM effects not included;
  - Hydrodynamic thermal suppression and anisotropic screening included;
  - Initial momentum-space anisotropy $\xi_0 = 0$;
  - Band obtained varying $\eta/s$ ratio;
  - CNM effects modelled as EKS98.

Data are compatible with the model predictions, even if the model suggests the opposite slope with respect to the measured points.
Conclusions
Conclusions

• Results of p-Pb analysis:
  - No significant suppression has been observed in the backward rapidity side;
  - Forward rapidity region presents a hint of suppression;
  - All the tested models reproduce data within uncertainties.

• Results of Pb-Pb analysis:
  - Centrality dependent $Y(1S) R_{AA}$ suppression observed also at $\sqrt{s_{NN}}=5.02$ TeV;
  - No firm conclusion on the $R_{AA}$ energy dependence within the current uncertainties;
  - Theory models describe within uncertainties, the $R_{AA}$ pattern.

• Short- and medium-term perspectives:
  - p-Pb data at $\sqrt{s_{NN}}=8$ TeV will be taken at the end of this year;
  - More Pb-Pb data at $\sqrt{s_{NN}}=5.02$ TeV will be taken at the end of LHC RUN2 to achieve larger $L_{INT}$. 
Thanks for your attention
Backup
Figure 6.256. ALICE acceptance in the \((x_1, x_2)\) plane for heavy flavours in Pb–Pb at 5.5 TeV (left) and in pp at 14 TeV (right). The figure is explained in detail in the text.
Quarkonia suppression studied via $R_{pA}$ and $R_{AA}$, defined as follows:

$$R_{pA}^{Y(1S)} = \frac{1}{A} \cdot \frac{\sigma_{pA}^{Y(1S)}}{\sigma_{pp}^{Y(1S)}}$$

$$R_{AA}^{Y(1S)} = \frac{1}{T_{AA}} \cdot \frac{N_{AA}^{Y(1S)}}{\sigma_{pp}^{Y(1S)}} \quad \text{where} \quad T_{AA} = \frac{\langle N_{coll} \rangle}{\sigma_{pp}^{inel}}$$

Where $\sigma_{pp}^{Y(1S)}$ has to be obtained by studying proton proton collisions in which $\sqrt{s} = \sqrt{s_{(p,N)}N}$.

The used $\sigma_{pp}^{Y(1S)}$ reference was obtained via interpolation of $\sigma_{pp}^{Y(1S)}$ measured in pp collisions at $\sqrt{s} = 2.76$, 7 and 8 TeV. As described in Ref. ALICE-PUBLIC-2014-002.
Interpolated $\sigma_{pp}$

- Not enough pp collisions @ $\sqrt{s} = 5.02$ TeV have been performed yet at the LHC;
- The pp reference obtained via interpolation of different $\sqrt{s}$ references previously measured by LHCb collaboration.

LHCb obtained $\sigma_{pp} @ \sqrt{s}=2.76, 7$ and 8 TeV. This results have been interpolated with a total of 20 shapes:
- Two parameters functions (line, power law, exponential);
- Leading Order Color Evaporation Model (LO-CEM) calculation;
Analysis ingredients: systematic sources

- **Signal extraction**
  - CB2 tails parametrization
  - $m_Y$ and $\sigma_Y$ scaling with PDG values
  - Background function
  - Fitting range

- **MC systematics**
  - $p_t$ and $y$ input distributions

- **Detectors**

- **Centrality determination**

- **$R_{AA}$ computation**

- **Tracker systematics**

- **Trigger systematics**

- **$\sigma_{pp}$ interpolation**

- **Nuclear overlap function**

- **MC Trigger model**

- **Trigger efficiency**

- **$A \times \epsilon$ determination**

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