Υ production in hadron collisions at forward rapidity with ALICE at the LHC

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Outline

Bottomonium in hadron collisions

Why to study quarkonium production?

The study of quarkonium ($c\bar{c}$ and $b\bar{b}$ mesons) production in hadron collisions plays an important role for different reasons:

- the $Q\bar{Q}$ binding into quarkonium states is a non-perturbative process still not well understood: new data in pp collisions help to validate theoretical models;
- colour-screening model predicts the quarkonium suppression in AA collisions and less tightly bound states melt at a lower temperature: quarkonia give important information about the properties of the deconfined medium;
- cold nuclear matter effects are competing mechanisms: pA collisions allow to disentangle these effects from the hot ones.

...and why to choose bottomonium?

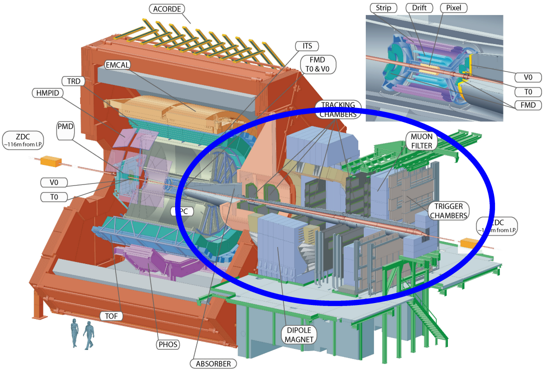
- Theoretical calculations for bottomonium production are more robust due to the higher mass of the b quark.
- The probability of Υ regeneration by $b\bar{b}$ recombination is much smaller than that for the the J/ψ.
- The measurement of the Υ in pA collisions allows a study of CNM effects in a different kinematic regime, complementing the J/ψ studies.

For these reasons this talk is focused only on Υ production: results on charmonia will be shown by Javier Martin Blanco (J/ψ) and Marco Leoncino ($\psi(2S)$).

ALICE

A Large Ion Collider Experiment

- ALICE is the LHC experiment dedicated to the study of ultrarelativistic heavy-ion collisions.
- It participates also to the LHC pp and p–Pb program.
- At forward rapidity ($2.5 < y < 4$) quarkonium states are reconstructed via the dimuon decay down to transverse momentum (p_T) equal to 0 with the **Muon Spectrometer**.

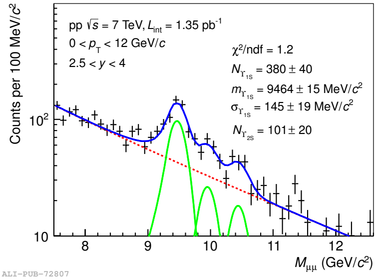


- V0 and T0 detectors are also used in the analyses for triggering purposes, while the SPD is used for primary vertex reconstruction.

Results in pp collisions at $\sqrt{s} = 7$ TeV

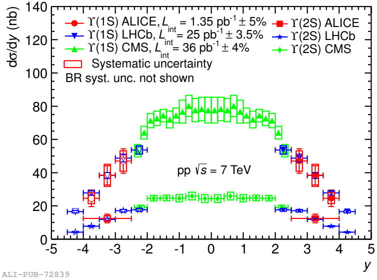
Υ production in pp collisions at $\sqrt{s} = 7$ TeV

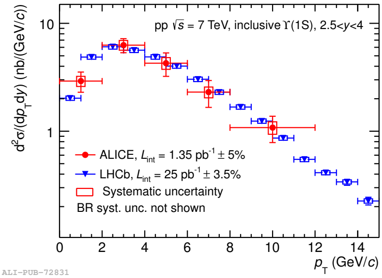
- The analysis is based on a data sample corresponding to an integrated luminosity of 1.35 pb^{-1}.
- The inclusive production cross sections of $\Upsilon(1S)$ and $\Upsilon(2S)$ are measured as a function of p_T and rapidity y.



- Results are published on EPJC 74 (2014) 2974.
- Data at 8 TeV are being analysed.

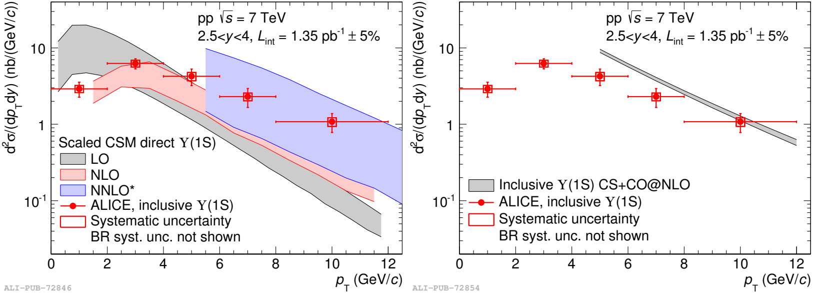
Total and differential production cross sections





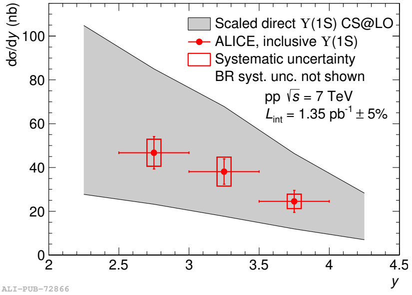
- The integrated values measured by ALICE in $2.5 < y < 4$ and $0 < p_T < 12$ GeV/c are:
  $\sigma_{\Upsilon(1S)} = 54.2 \pm 5.0 \pm 6.7$ nb $\quad \sigma_{\Upsilon(2S)} = 18.4 \pm 3.7 \pm 2.9$ nb
- The p_T and y-differential cross sections compared to the values reported by LHCb (EPJC 72 (2012) 2025) show a good agreement for both resonances. They complement the measurements performed by CMS at midrapidity.

Model comparison: p_T dependence



- CSM predictions are scaled by a factor 1/0.6 to account for the feed-down from $\Upsilon(2S)$, $\Upsilon(3S)$ and χ_b:
  - LO calculation underestimates the data for $p_T > 4$ GeV/c;
  - NLO calculation reproduces the data at low p_T, but it still underestimates the cross section over the full range;
  - a good agreement is achieved at NNLO*, over a limited p_T range and with large uncertainties.
- NRQCD (with feed-down) overestimates the data, but the disagreement becomes smaller at higher p_T.

Model comparison: y dependence



- LO CSM calculations integrated over p_{T} down to 0 are evaluated as a function of the rapidity with a large theoretical uncertainty.
- These calculations are scaled by the factor 1/0.6 and have no free parameters.
- The magnitude of the calculations is in agreement with the measurements.

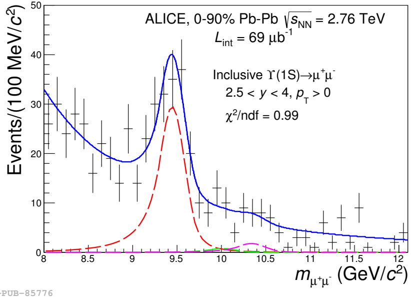
Results in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

Υ production in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV

- The analysed data sample corresponds to an integrated luminosity of 69 μb^{-1}.
- The in-medium modification is evaluated through the nuclear modification factor:

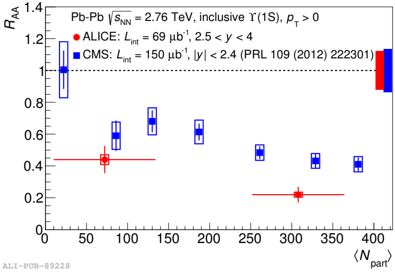
$$R_{\rm AA} = \frac{Y_{\rm AA}}{\langle T_{\rm AA} \rangle \cdot \sigma_{\rm pp}}$$

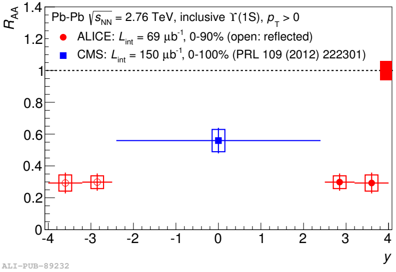
($Y_{\rm AA}$ is the yield, $T_{\rm AA}$ is the nuclear overlap function, $\sigma_{\rm pp}$ is the pp reference cross section).



- Results are available on arXiv:1405.4493 (submitted to PLB).

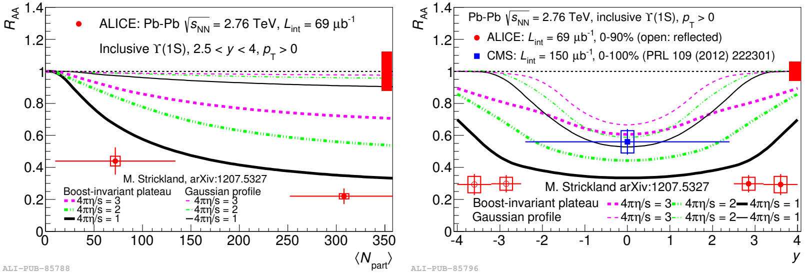
Comparison with CMS results





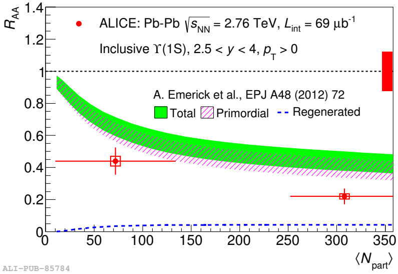
- ALICE and CMS (PRL, 109 (2012) 222301) measure inclusively the $\Upsilon(1S)$ state down to $p_T = 0$ in two complementary rapidity regions.
- In central collisions the suppression is stronger at forward rapidity than at midrapidity.
- The value of the $\Upsilon(1S)$ R_{AA} in $2.5 < y < 4$ is significantly lower than in $|y| < 2.4$.

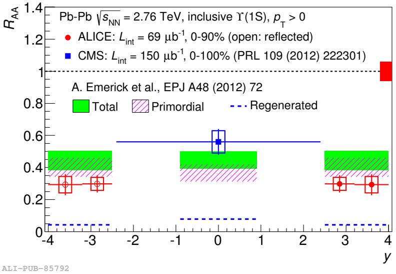
Comparison with a dynamical model



- The evolving QGP is described by means of a dynamical model which includes the suppression of the different bottomonium states, but not CNM effects nor recombination.
- Two different initial temperature rapidity profiles: boost-invariant plateau and Gaussian. For each of them 3 values of $4\pi\eta/s = \{1, 2, 3\}$.
- None of the calculations reproduce the ALICE data. The rapidity trend measured by ALICE and CMS is opposite to what foreseen by the model.

Comparison with a transport model



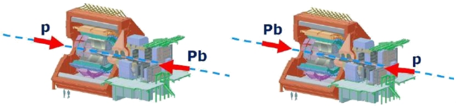


- The model accounts for both suppression and regeneration mechanisms.
- Cold nuclear matter effects are considered by means of an effective absorption cross section from 0 and 2 mb, including shadowing, nuclear absorption and Cronin effect.
- The measured R_{AA} is overestimated by the calculation which, however, reproduces the decreasing trend. The model predicts a R_{AA} almost constant as a function of rapidity, not supported by the data.

Results in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

Υ production in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

- The data set corresponds to an integrated luminosity of 5.0 nb^{-1} in p–Pb and 5.8 nb^{-1} in Pb–p collisions.

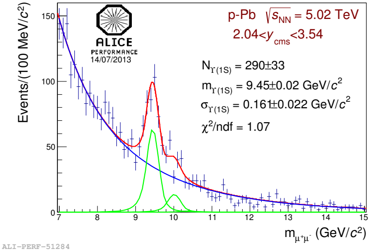


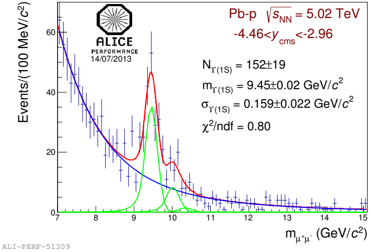
$2.03<y_{CMS}<3.53$ $-4.46<y_{CMS}<-2.96$

- The cold nuclear matter effects are quantified by the R_{pPb}:

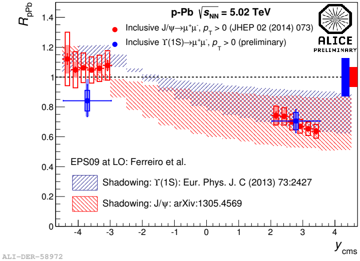
$$R_{pPb} = \frac{\sigma_{pPb}}{A_{Pb} \cdot \sigma_{pp}}$$

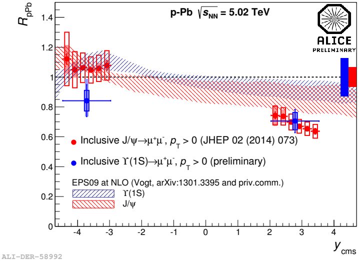
(σ_{pPb} and σ_{pp} are the Υ cross sections, A_{Pb} is the Pb mass number).





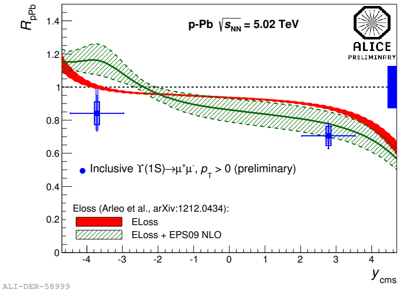
$\Upsilon(1S)$ R_{pPb} measurements

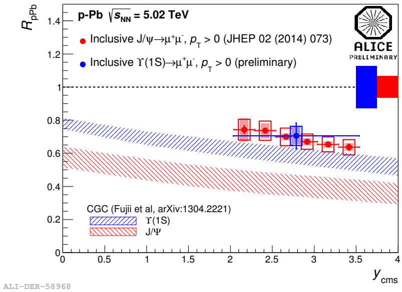




- The $\Upsilon(1S)$ is suppressed at forward rapidity, while at backward rapidity the R_{pPb} is compatible with unity within uncertainties, disfavouring a strong gluon anti-shadowing.
- At positive y_{cms} the $\Upsilon(1S)$ and J/ψ R_{pPb} are rather similar. At negative rapidity, the J/ψ R_{pPb} is systematically above that of $\Upsilon(1S)$, even if they are consistent within uncertainties.
- EPS09 shadowing at LO predicts within uncertainties the measured R_{pPb} at forward rapidity, while the NLO calculation underestimate the suppression of the $\Upsilon(1S)$.

$\Upsilon(1S)$ R_{pPb} compared to theoretical models





- The parton energy loss with EPS09 calculation reproduces well the data at forward rapidity, while data at backward rapidity are in a better agreement with parton energy loss only calculation.
- The calculation based on the CGC slightly underestimates the R_{pPb}, but it is not able to reproduce the J/ψ measurements in the same rapidity range.

Conclusions

Conclusions

pp collisions:

- the p_{T} and y-differential production cross sections are in good agreement with measurements by LHCb and complement the results at midrapidity from CMS;
- CSM calculations underestimate the data at large p_{T}. The leading-p_{T} NNLO helps to reduce the disagreement but with larger uncertainties.

Pb–Pb collisions:

- the observed $\Upsilon(1S)$ suppression is stronger in central than in semiperipheral collisions and shows a pronounced rapidity dependence over the large domain covered by ALICE and CMS;
- all models underestimate the suppression at forward rapidity.

p–Pb collisions:

- the $\Upsilon(1S)$ R_{pPb} is consistent with unity at backward rapidity suggesting a small gluon anti-shadowing;
- models tend to overestimate the measurements and cannot describe the full rapidity dependence;