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

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Overview

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9. Conclusions.

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; Ref. PLB 178(4): 416-422
  - Sequential suppression (leads to a QGP thermometer); Ref. PLB 178(4)
  - Regeneration phenomena in the QGP or at the phase boundary. Ref. PLB490 (2000) 196

- 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 $N_{b\bar{b}} \ll N_{c\bar{c}}$;
  - Cold Nuclear Matter effects expected to be smaller.

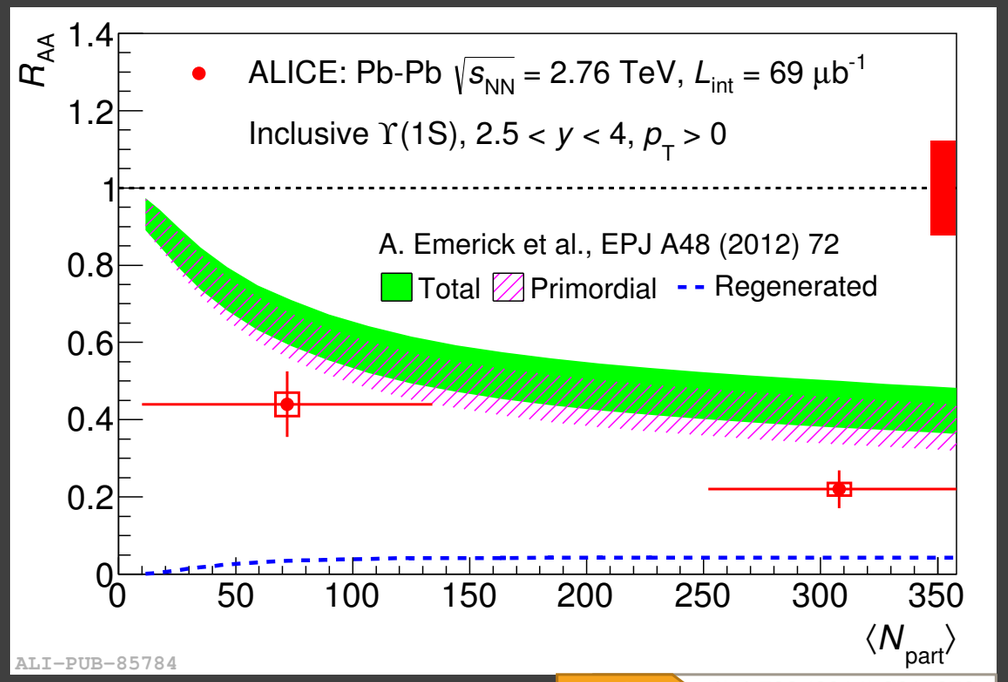
- Moreover bottomonium study allows to scan a different Bjorken-*x* range compared to charmonia.

Pb-Pb @ $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV: centrality dependence

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

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

Ref. LHCb-PAPER-2013-066



Ref. PLB 738 (2014) 361–372

ϒ(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 σ_{pp} reference measured by the LHCb collaboration in pp @ $\sqrt{s}$= 2.76 TeV.

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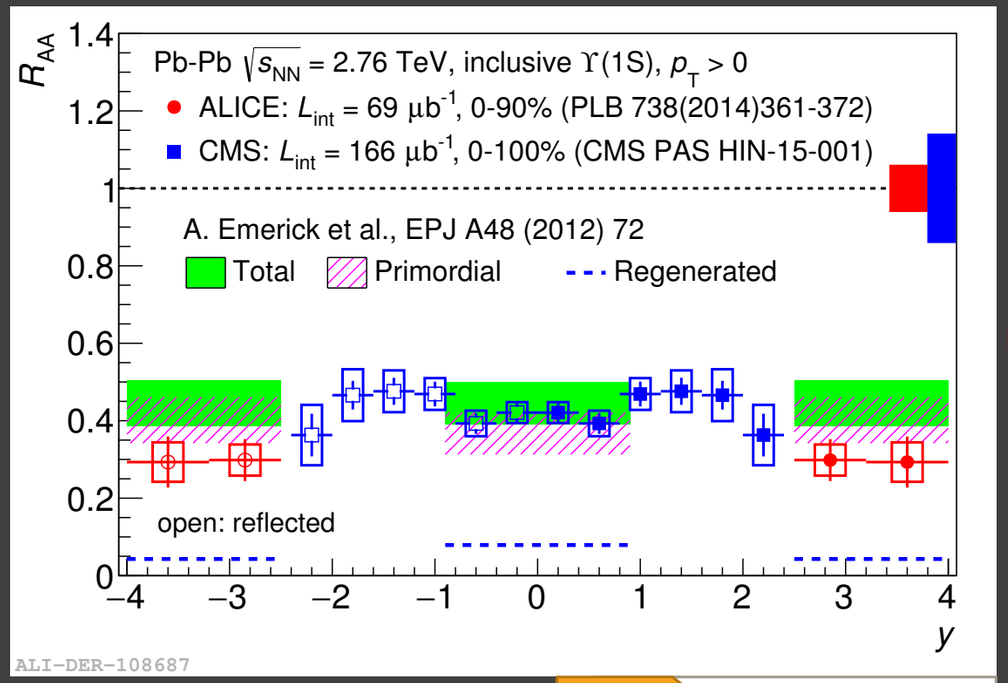

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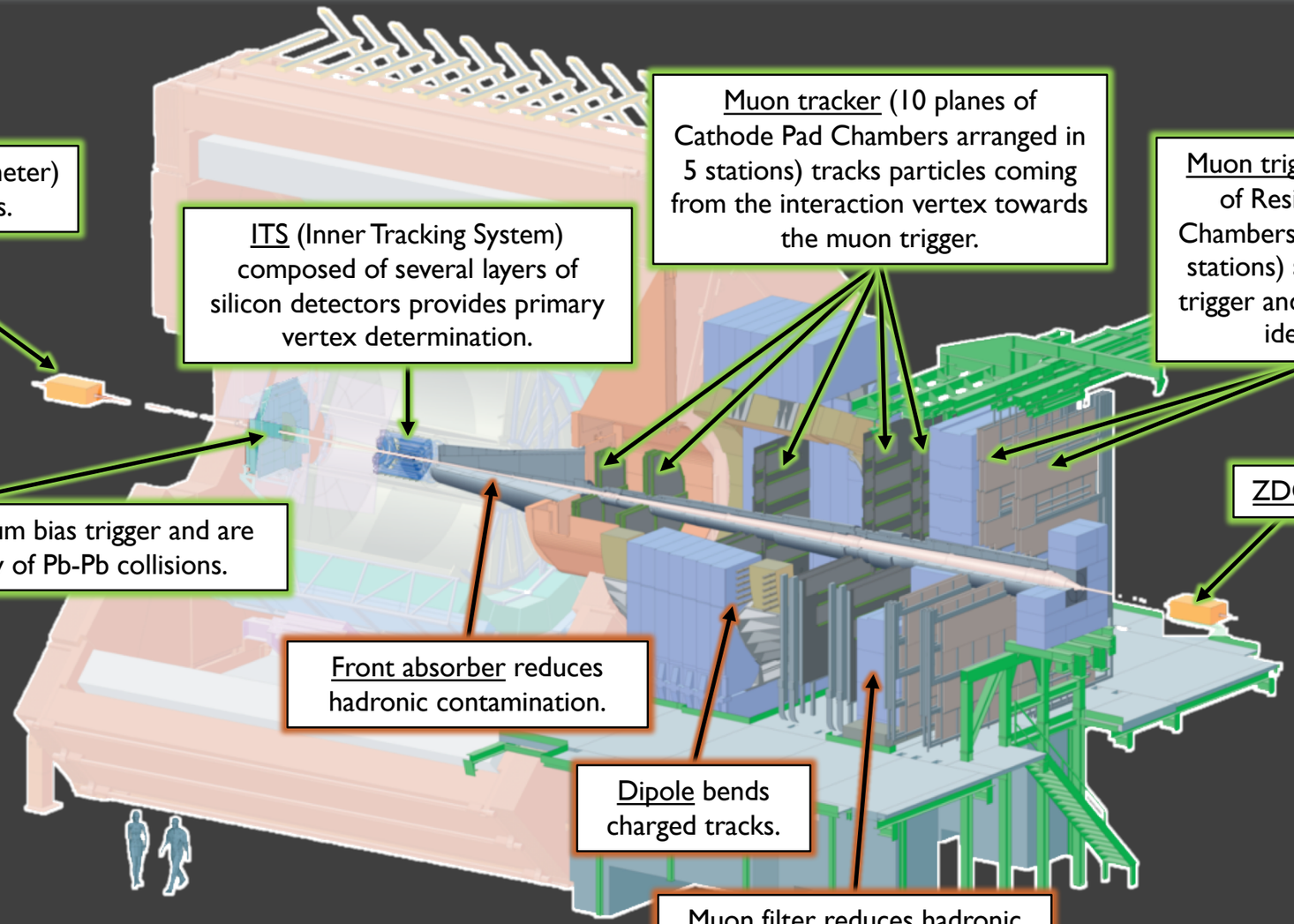
ϒ (1S) suppression observed at forward rapidity (ALICE) and at mid rapidity (CMS) are compatible with model predictions.

Data analysis

Experimental setup



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

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.

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

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

ZDC

Front absorber reduces hadronic contamination.

Dipole bends charged tracks.

Muon filter reduces hadronic contamination to less than 1%.

Detectors

Passive elements

Events and track selection - Analysis strategy

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

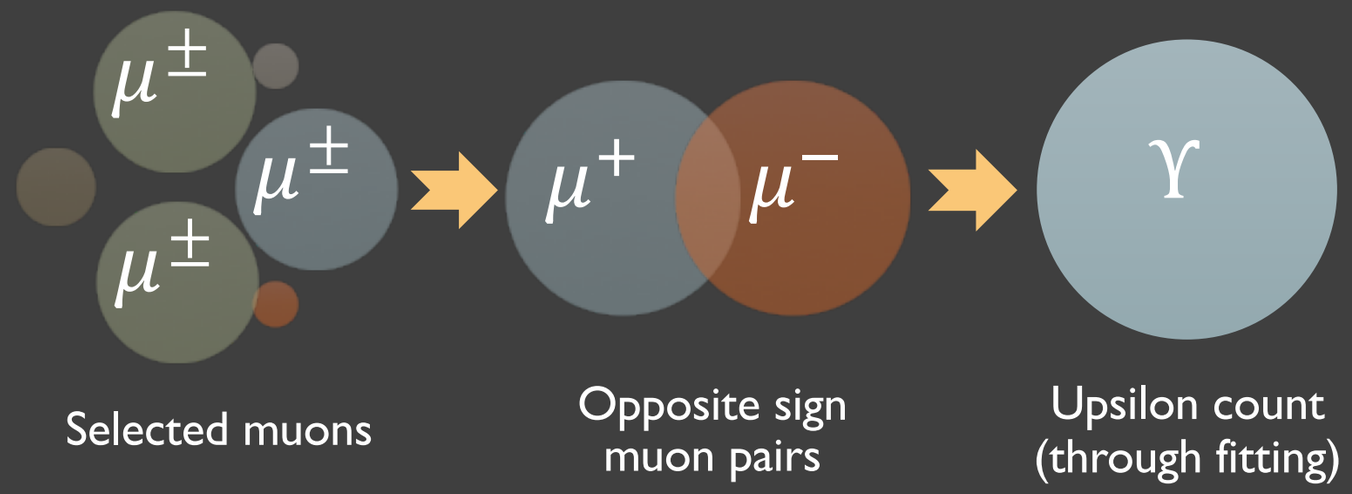
Dimuon trigger with a p_T threshold of 1GeV/c for each muon.

Single muon cuts:

- Matching between tracker and trigger tracks;
- $-4.0 < \eta_\mu < -2.5$;
- $p_{T\,\mu} \geq 2\ \mathrm{GeV}/c$;
- $17.6\ cm < R_{abs} < 89.5\ cm$.

Unlike sign muon pairs cuts:

- $-4.0 < y_{\mu\mu} < -2.5$.



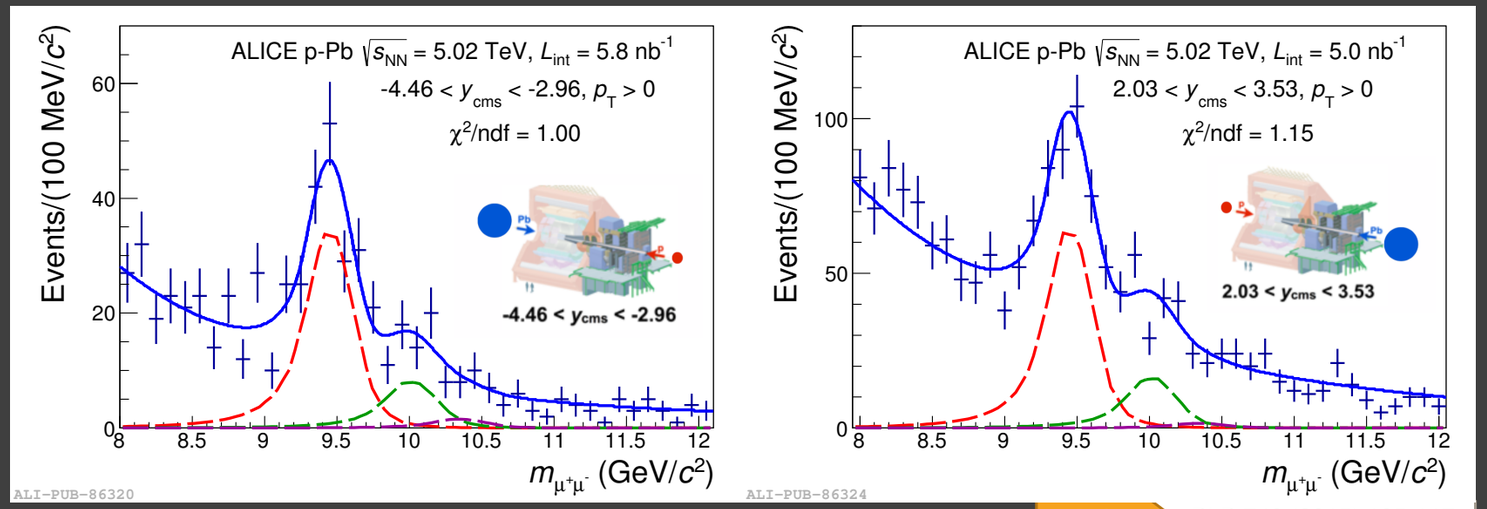
Invariant mass spectrum fitting function:

- 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

	$\mathcal{L}_{INT}$	Rapidity range
Pb-p	$5.8\ nb^{-1}$	$-4.46 < y_{CMS} < -2.96$
p-Pb	$5.0\ nb^{-1}$	$2.03 < y_{CMS} < 3.53$

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



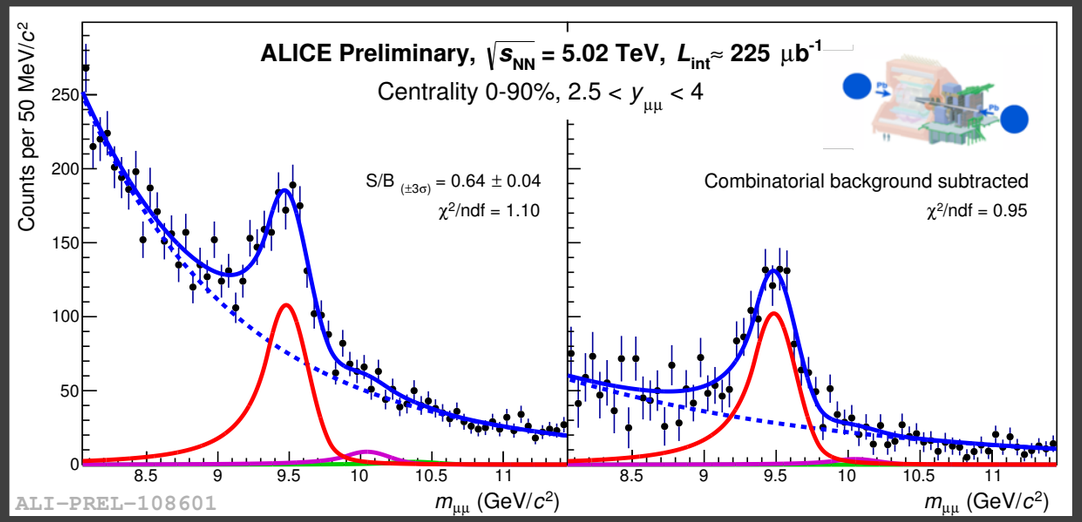
Ref. PLB 740 (2015) 105-117

σ_{pp} has to be computed with $\sqrt{s} = \sqrt{s_{NN}}$.
Not enough statistics is available @ $\sqrt{s}$=5.02 TeV.
The used σ_{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 @ $\sqrt{s_{\mathrm{NN}}}$=5.02 TeV

	$\mathcal{L}_{INT}$	Rapidity range	Centrality range
Pb-Pb	$225\ \mu b^{-1}$	$2.5 < y_{CMS} < 4.0$	0%-90%



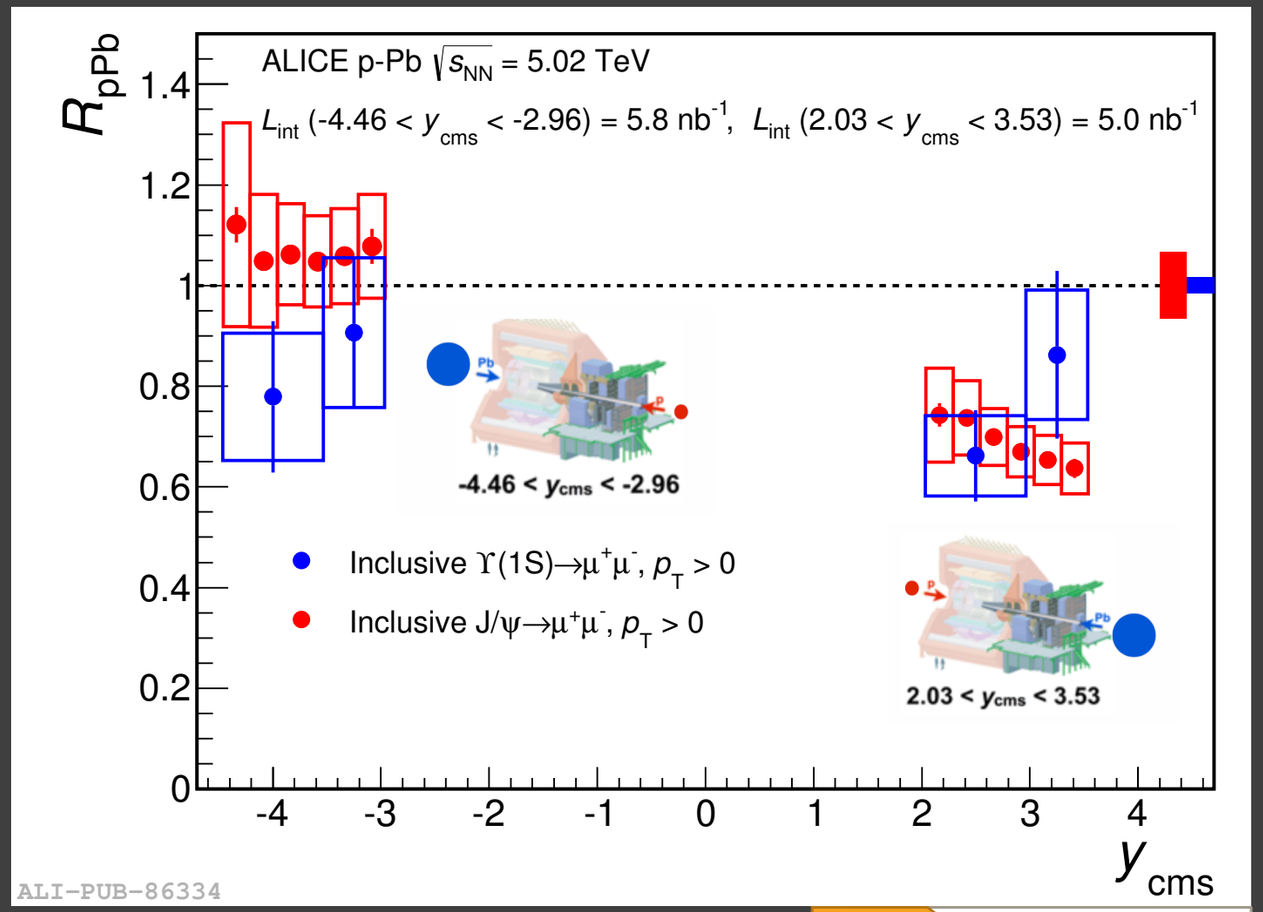
The measured number of $\Upsilon(1S)$ measured @ $\sqrt{s_{\mathrm{NN}}}$=5.02 TeV is about 10 times greater than the number measured @ $\sqrt{s_{\mathrm{NN}}}$=2.76 TeV. Ref. PLB 738 (2014) 361-372

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;



Ref. PLB 740 (2015) 105-117

Forward rapidity

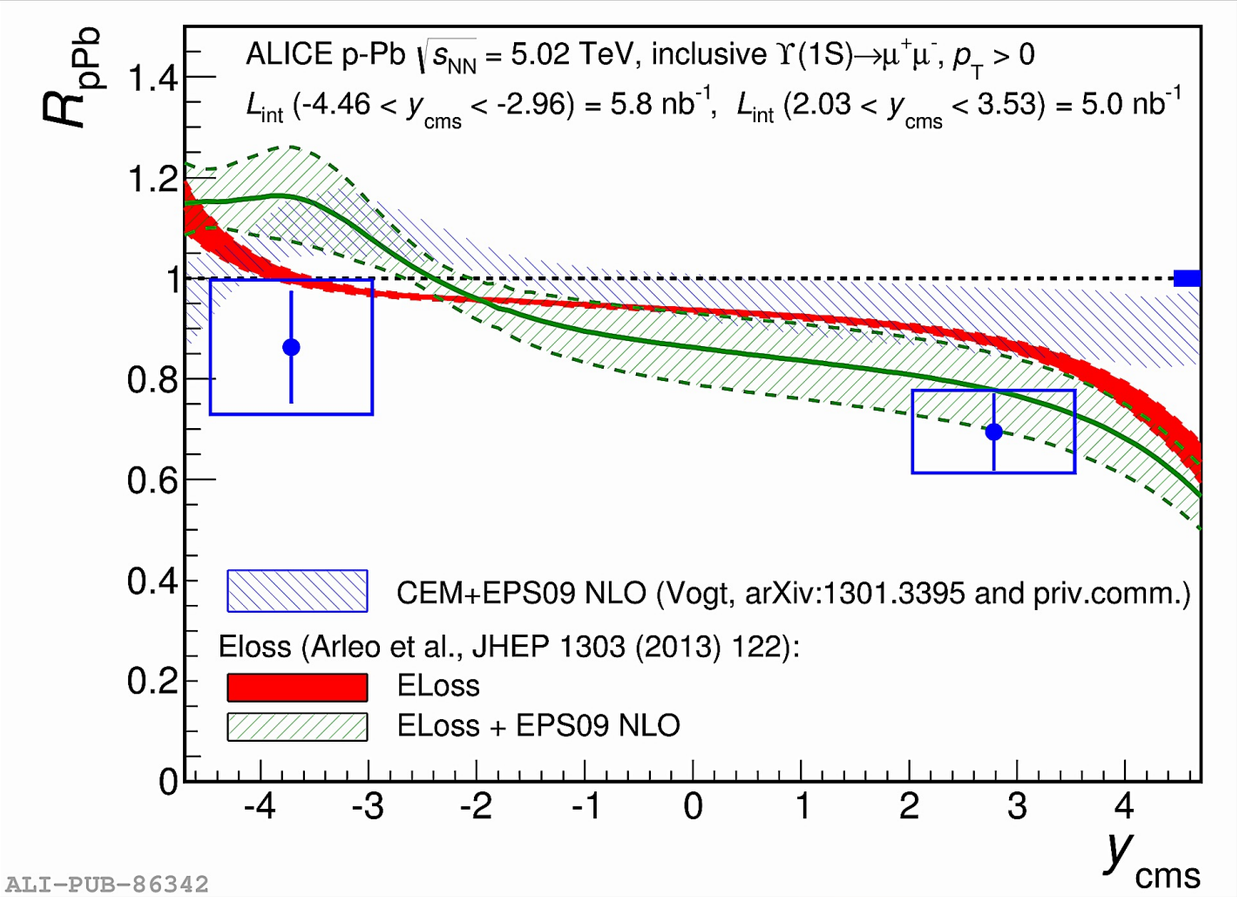
- Forward rapidity (p-going side) shows a suppression hint;

R_{pPb}: Model comparison (1)

Hint of CNM effects at forward rapidity

Backward rapidity

- Better agreement between data and Energy Loss -only model;



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Forward rapidity

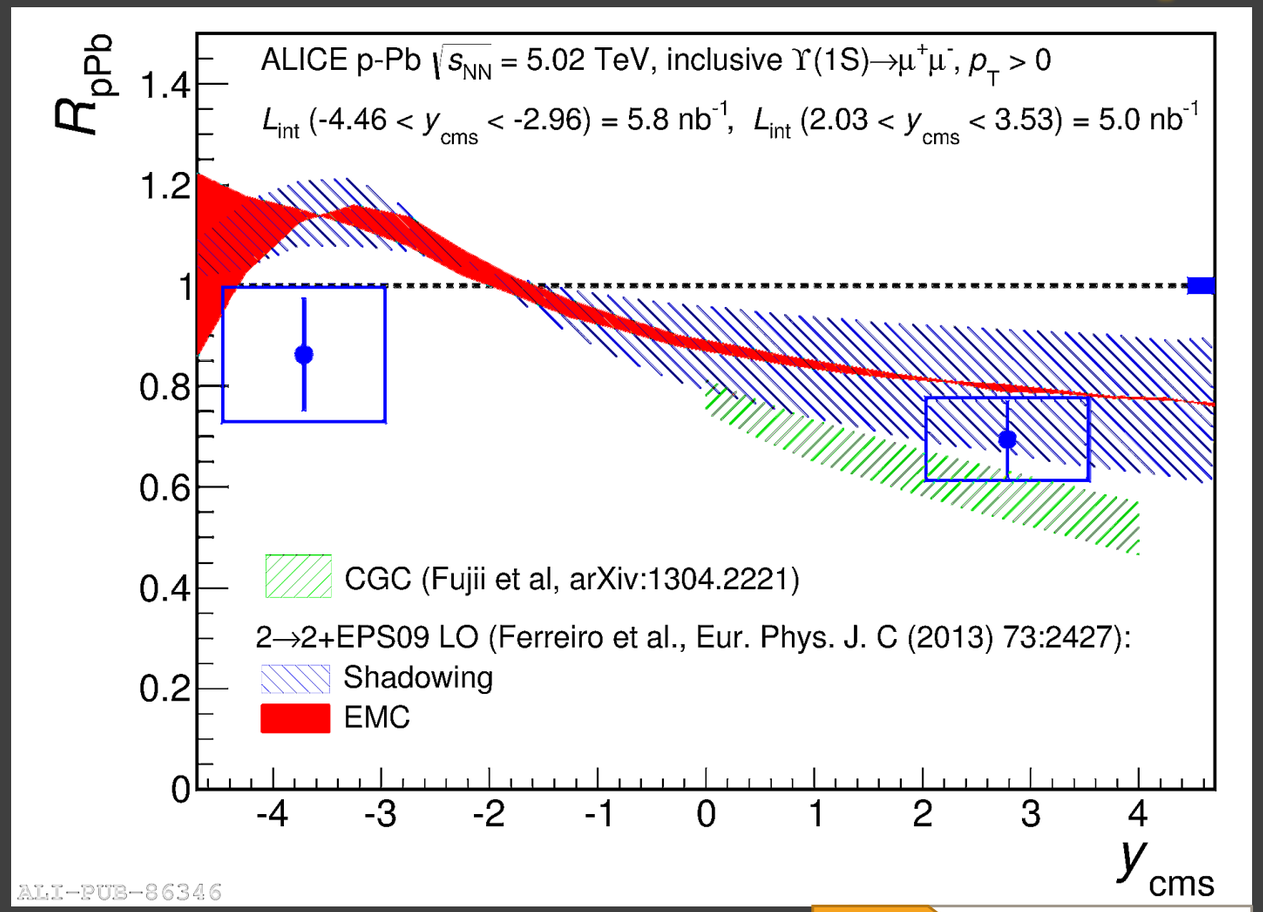
- Reasonable agreement is found between energy Loss + NLO nuclear shadowing calculation and data;

R_{pPb}: Model comparison (2)

Hint of CNM effects at forward rapidity

Backward rapidity

- Hint of an anti-shadowing lower than expected.



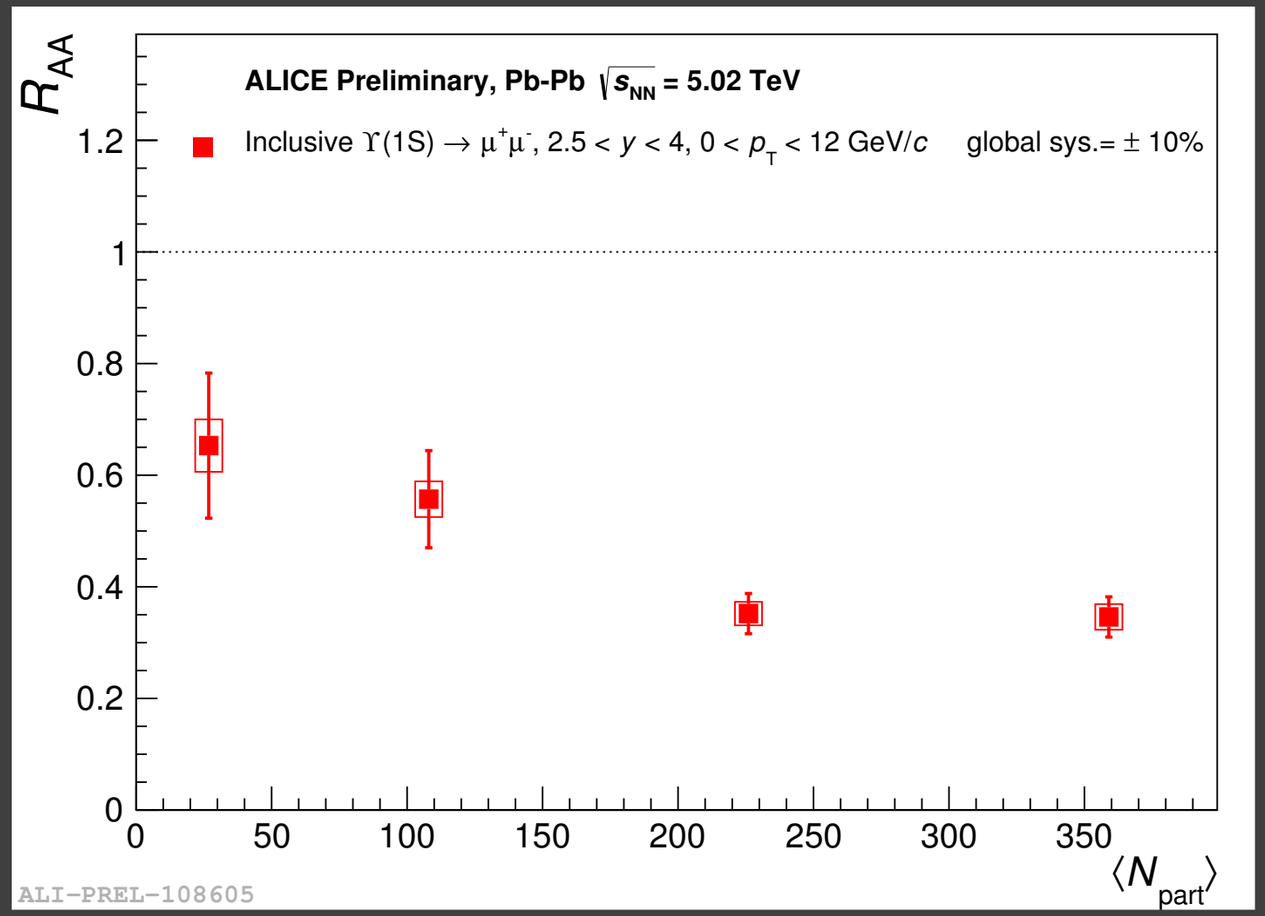
Ref. PLB 740 (2015) 105-117

Forward rapidity

- 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 TeV: centrality dependence



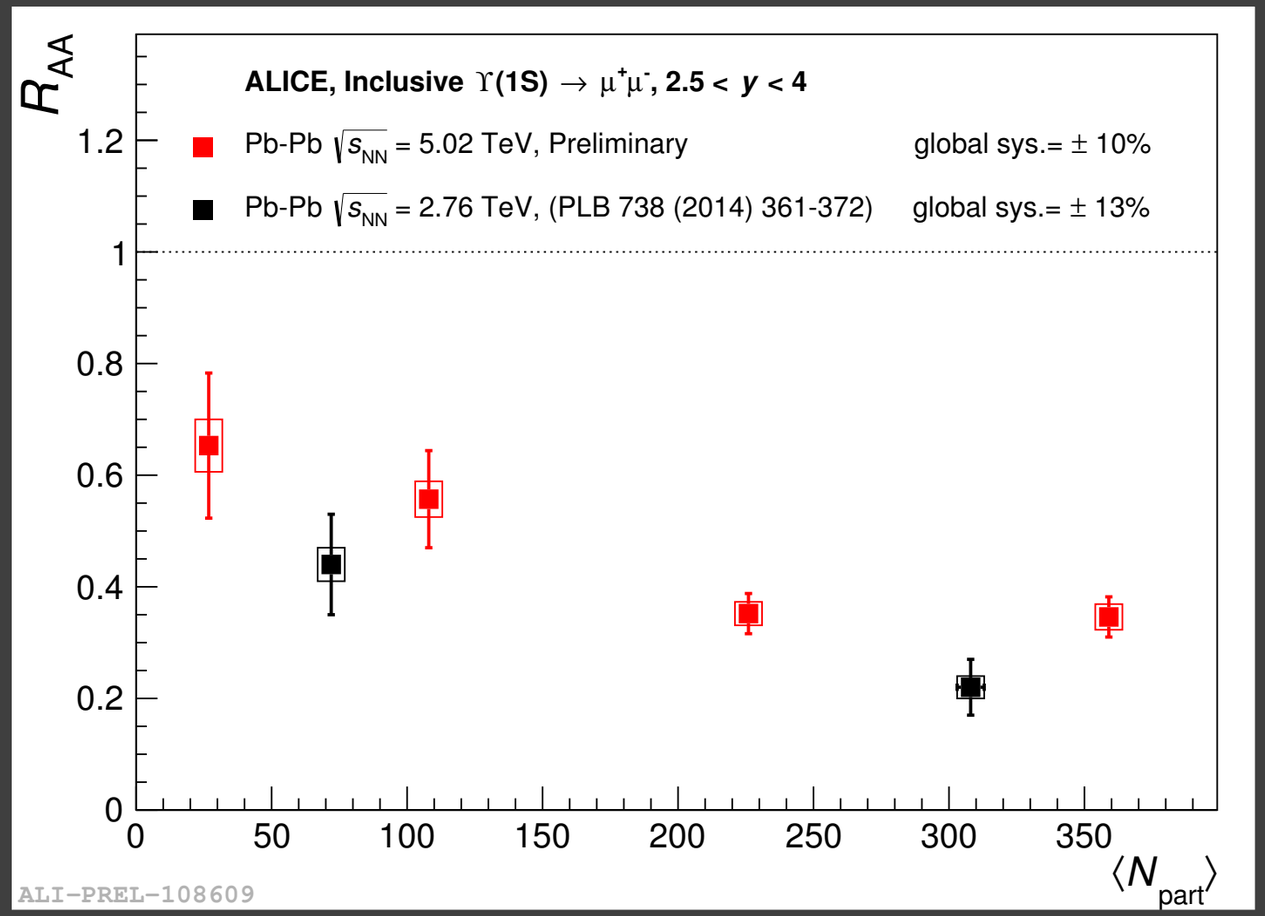
$$N_{\Upsilon(1S)} = 1107 \pm 70\ (stat.) \pm 43\ (syst.)$$

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.

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

$\Upsilon(1s)$ R_{AA} @ $\sqrt{s_{NN}}$=5.02 TeV and 2.76 TeV: centrality dependence

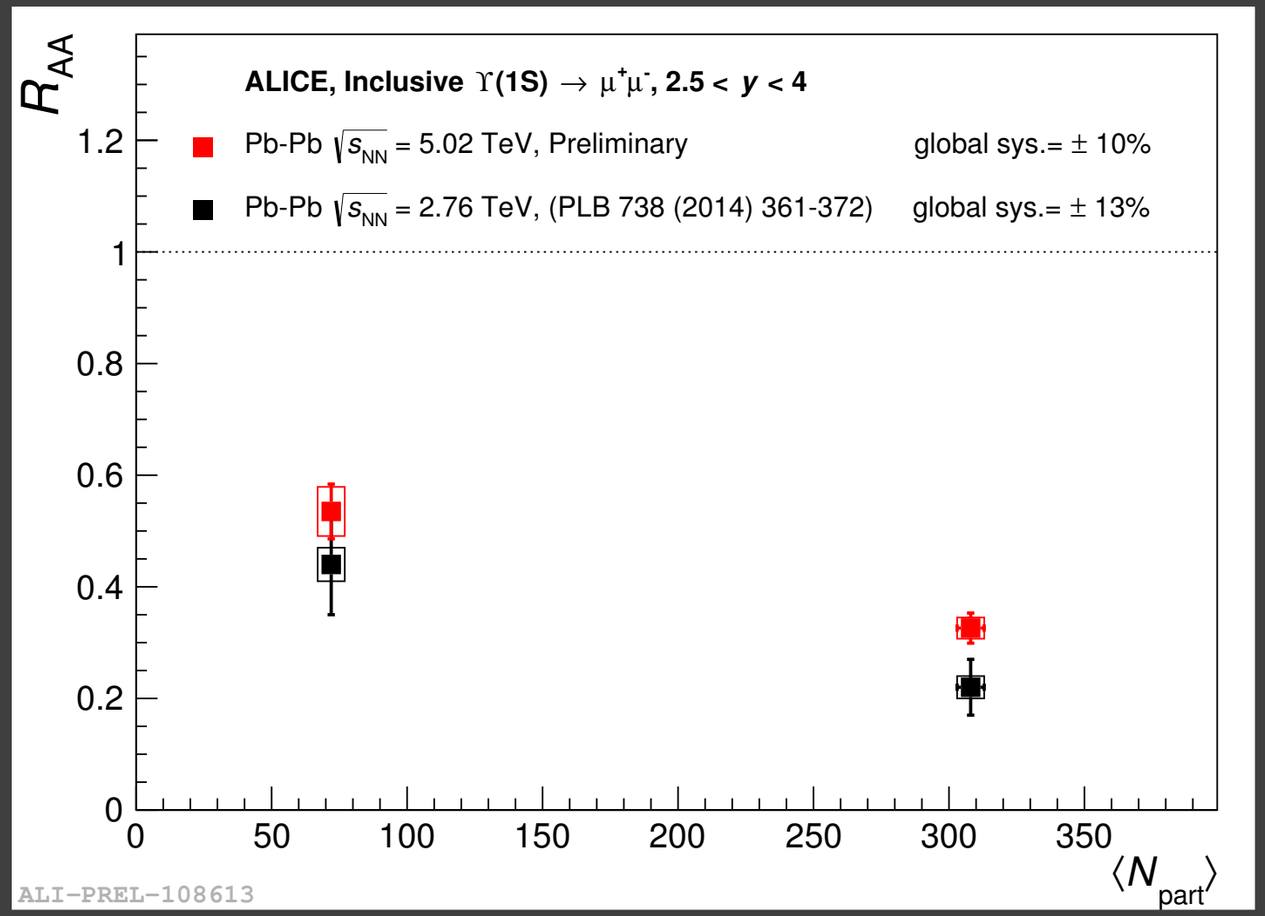


Measurements at $\sqrt{s_{NN}}$=5.02 TeV and 2.76 TeV are compatible within uncertainties.

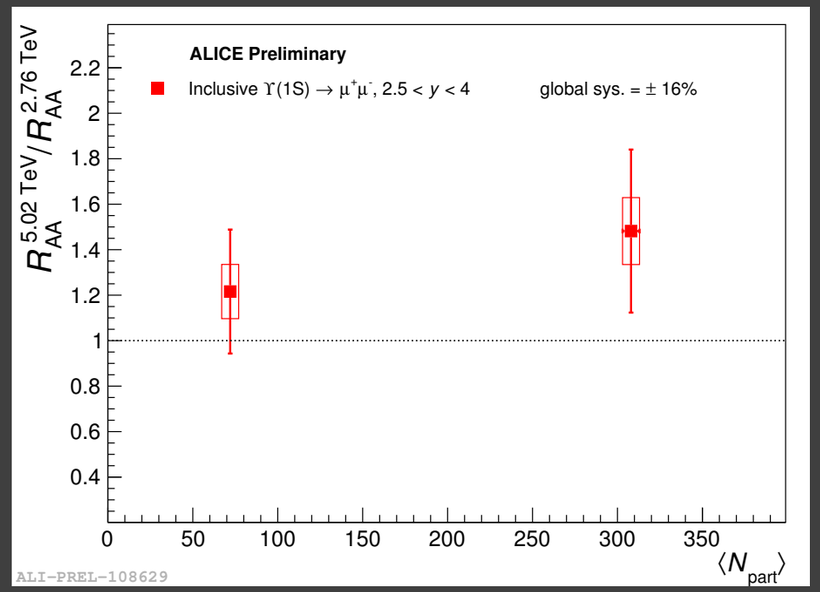
$$R_{AA}(5.02\ \text{TeV, 0-90\%}) = 0.40 \pm 0.03(stat.) \pm 0.04(syst.)$$

$$R_{AA}(2.76\ \text{TeV, 0-90\%}) = 0.30 \pm 0.05(stat.) \pm 0.04(syst.)$$

$\Upsilon(1s)$ R_{AA} @ $\sqrt{s_{NN}}$=5.02 TeV and 2.76 TeV: centrality dependence



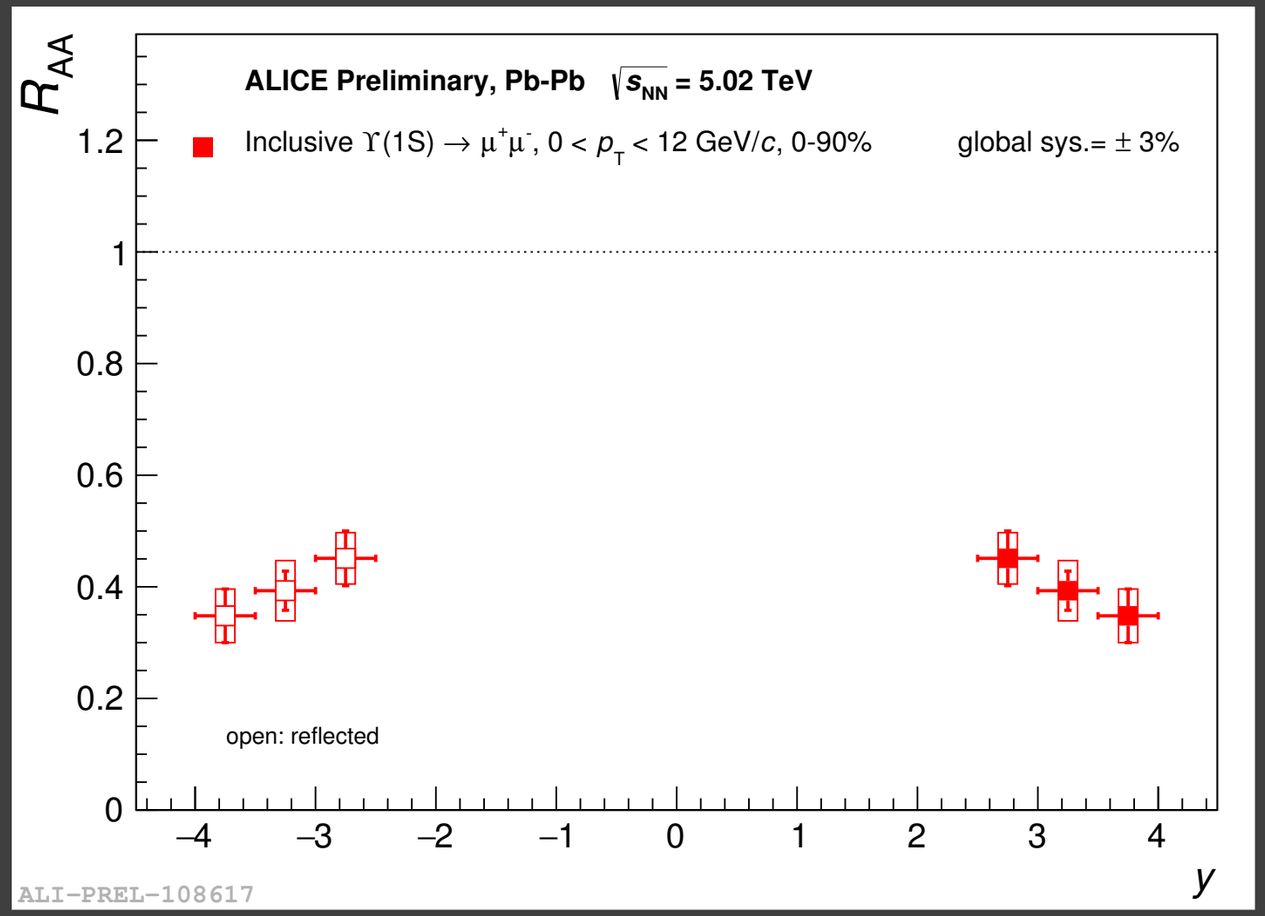
No firm conclusion on the R_{AA} energy dependence.



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

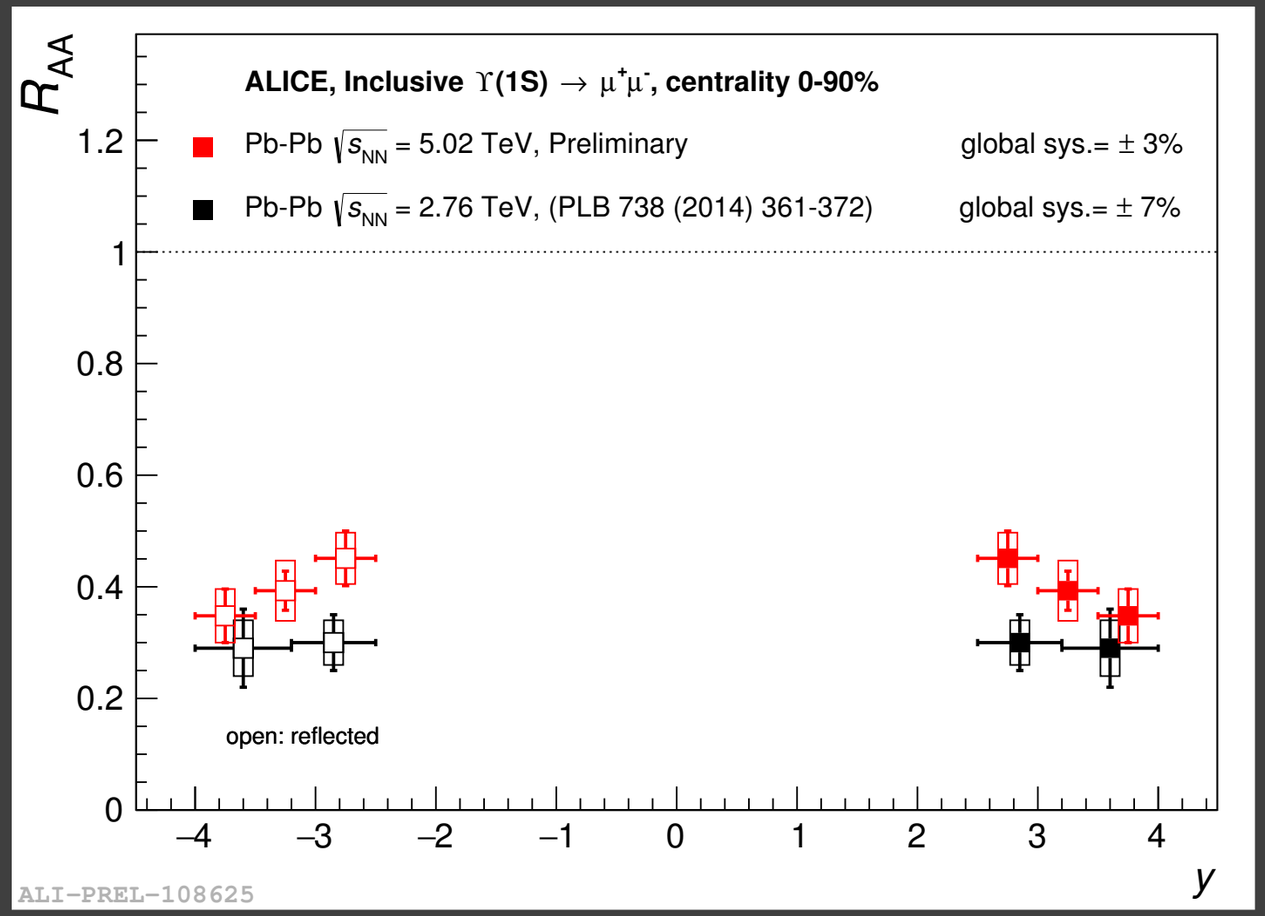
To ease the comparison between the two data sets the $\sqrt{s_{NN}}$=5.02 TeV analysis has been performed using the same centrality bins of the $\sqrt{s_{NN}}$=2.76 TeV analysis.

$\Upsilon(1s)$ R_{AA} @ $\sqrt{s_{NN}}$=5.02 TeV: rapidity dependence



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 TeV and 2.76 TeV: rapidity dependence

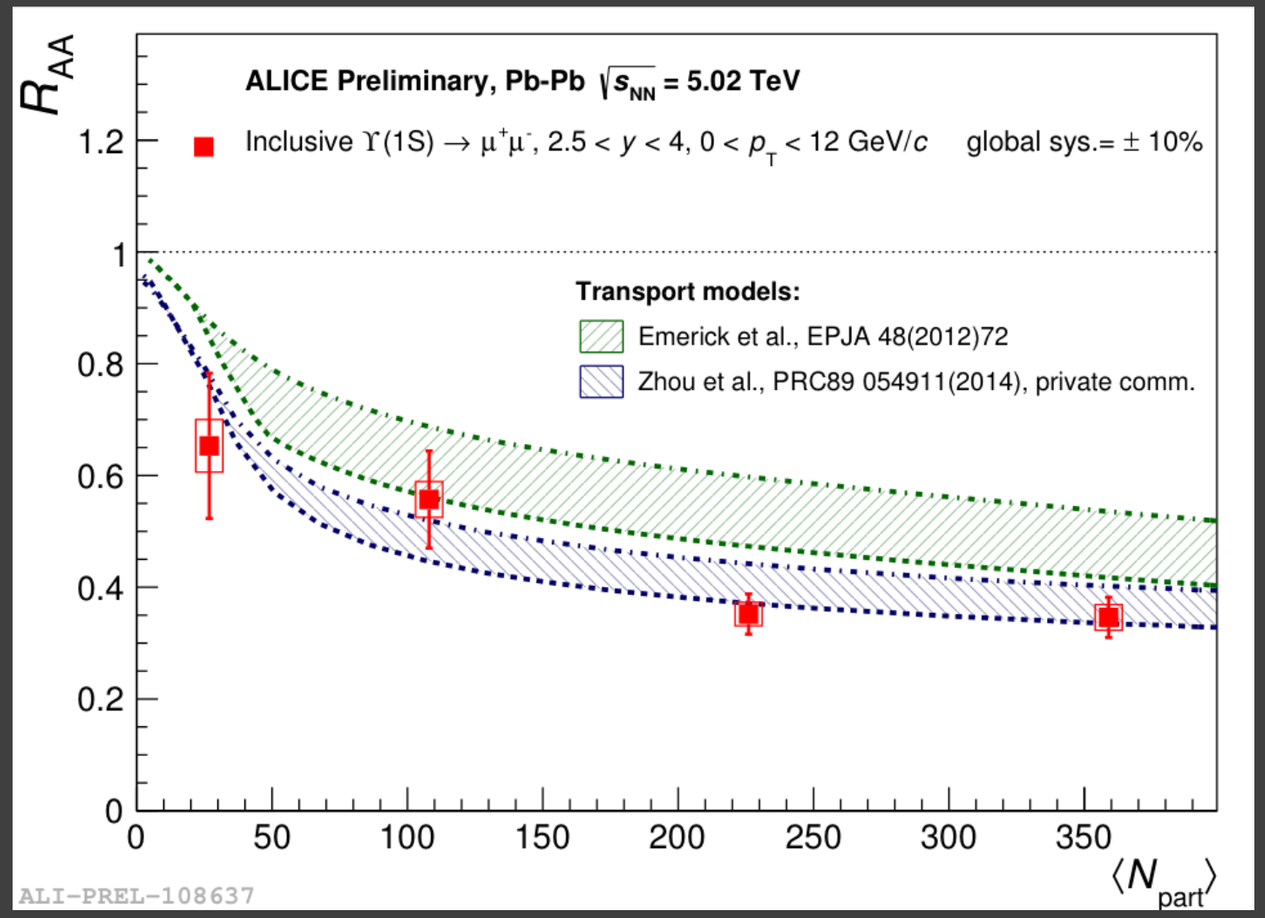


R_{AA} values are systematically smaller @ $\sqrt{s_{NN}}$=2.76 TeV however measurements at $\sqrt{s_{NN}}$ =5.02 TeV and 2.76 TeV are compatible within uncertainties.

	Rapidity (y) binning		
$\sqrt{s_{NN}}$=2.76 TeV	2.5-3.25		3.25-4.0
$\sqrt{s_{NN}}$=5.02 TeV	2.5-3.0	3.0-3.5	3.5-4.0

Model comparison

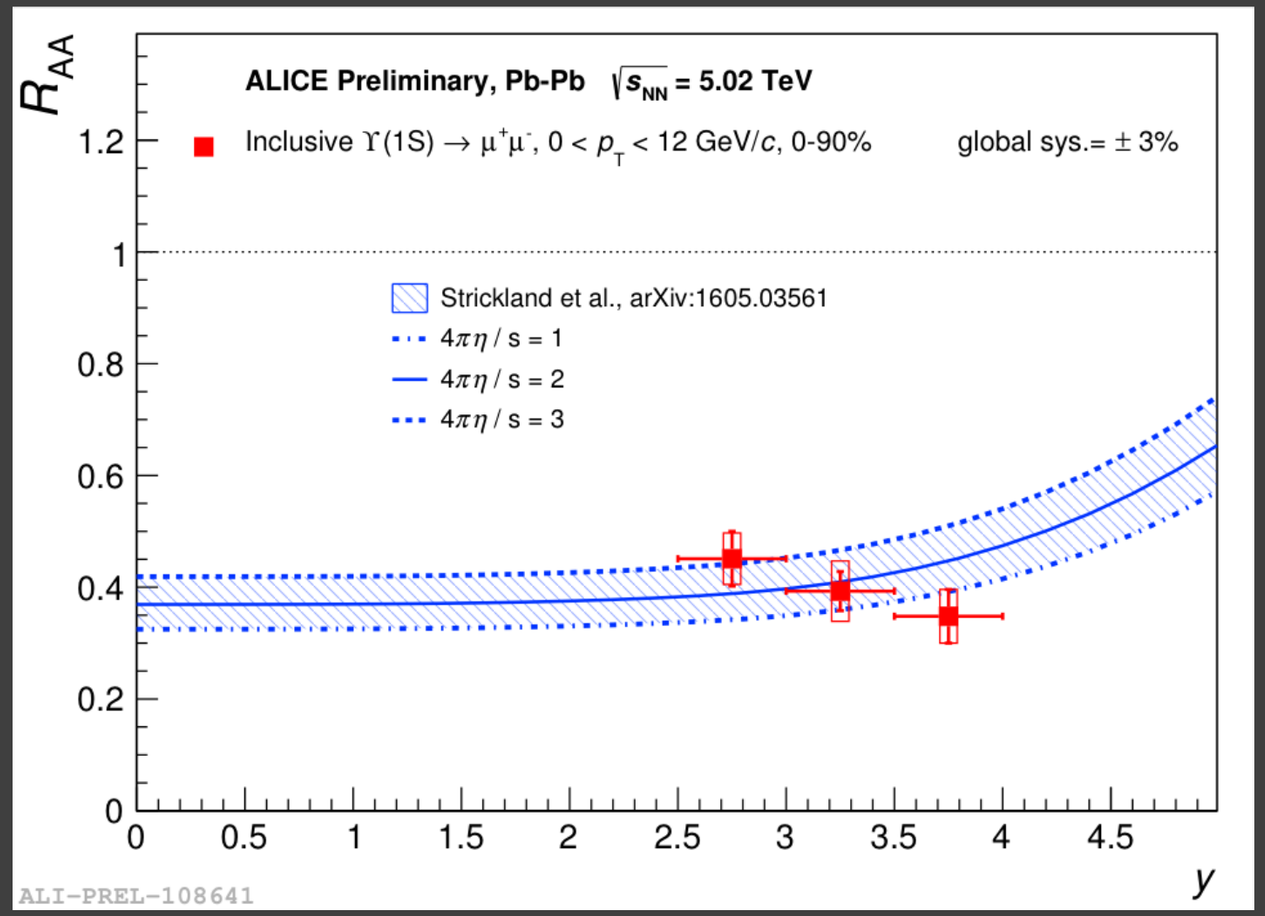
Centrality dependence: transport models



- 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 η/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 $\Upsilon(1S)$ 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 $\mathcal{L}_{INT}$.

Thanks for your attention

Backup

X coverage in Pb-Pb and pp

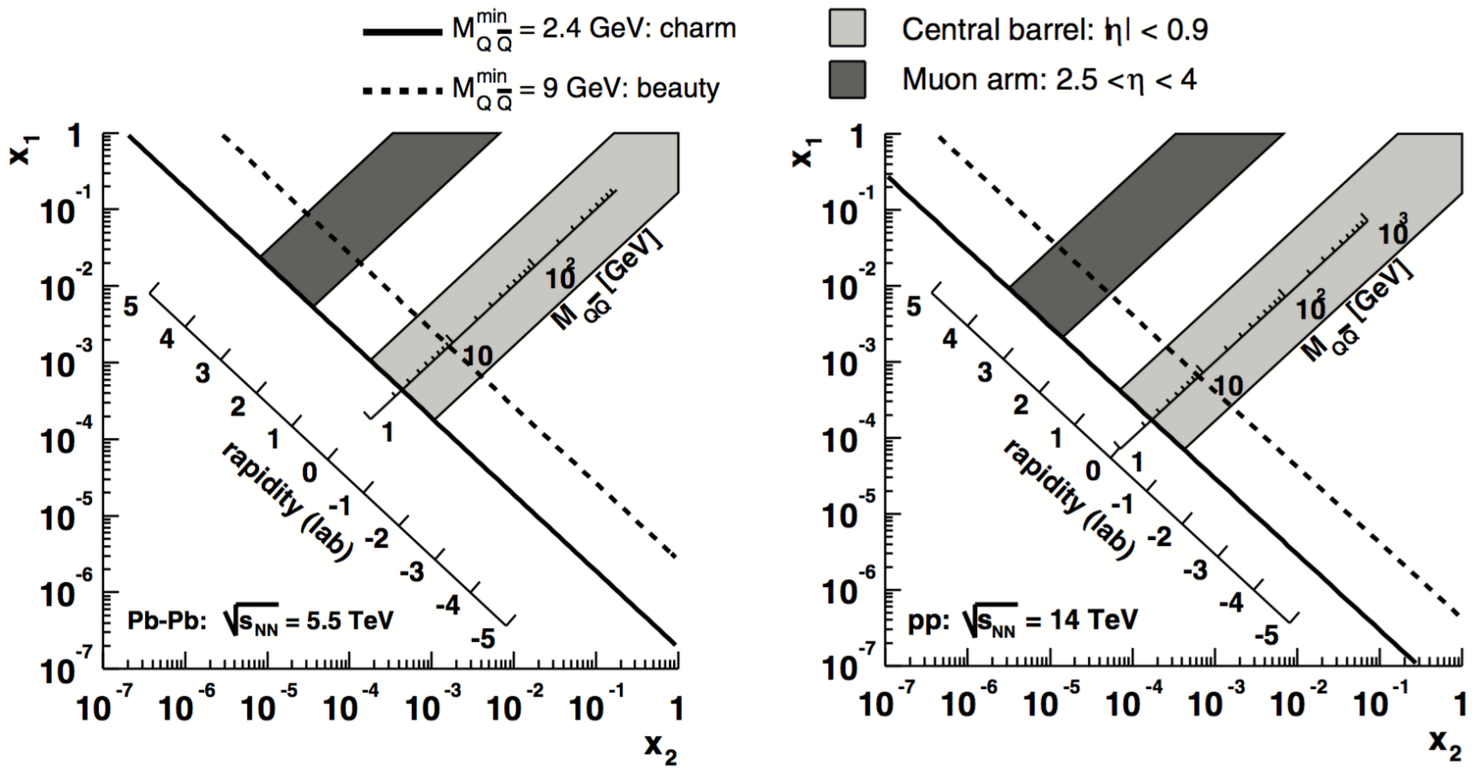


Figure 6.256. ALICE acceptance in the (x_1, x_2) plane for heavy flavours in Pb–Pb at 5.5 TeV (left) and in pp at 14 TeV (right). The figure is explained in detail in the text.

R_{pA} and R_{AA}

Quarkonia suppression studied via R_{pA} and R_{AA}, defined as follows:

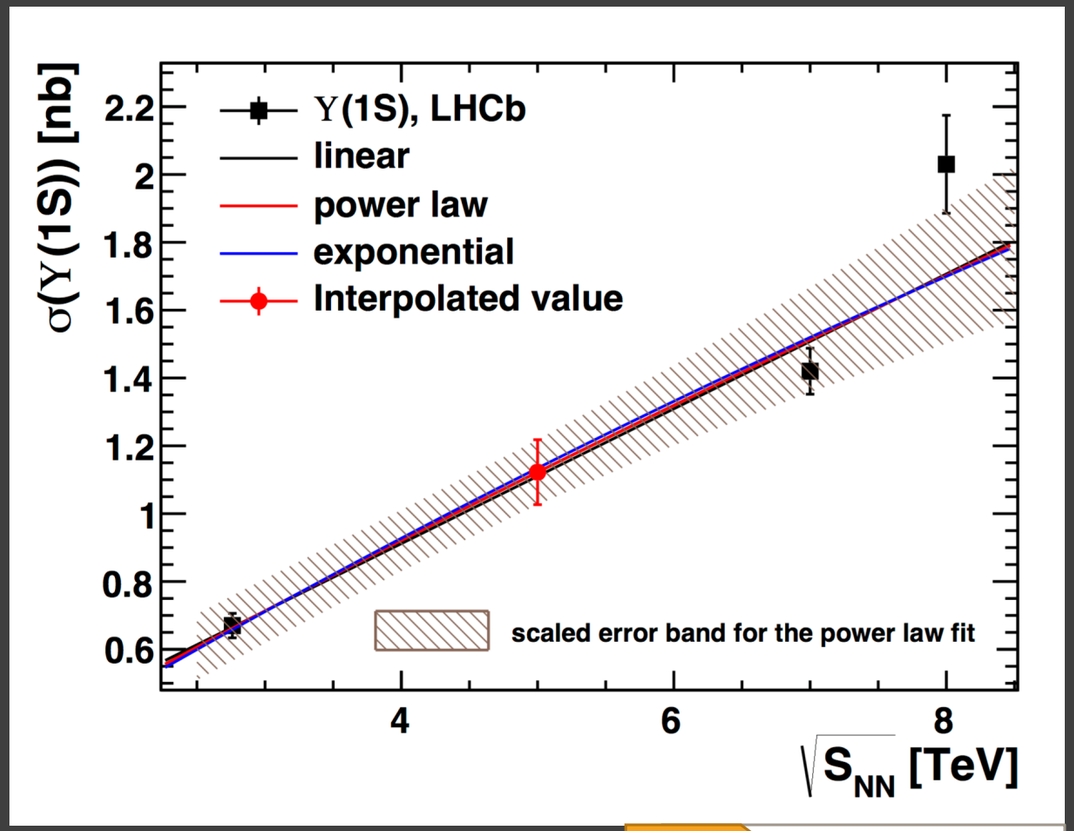
$$R_{pA}^{\Upsilon(1s)} = \frac{1}{A} \cdot \frac{\sigma_{pA}^{\Upsilon(1S)}}{\sigma_{pp}^{\Upsilon(1S)}}$$

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

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

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

Interpolated σ_{pp}



Ref. ALICE-PUBLIC-2014-002

- 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 σ_{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