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

Javier Castillo
for the
ALICE Collaboration

Outline

- Introduction
- Υ suppression in Pb-Pb collisions
  - Probing the QGP
- Υ production in p-Pb collisions
  - Addressing cold nuclear matter effects
- Summary

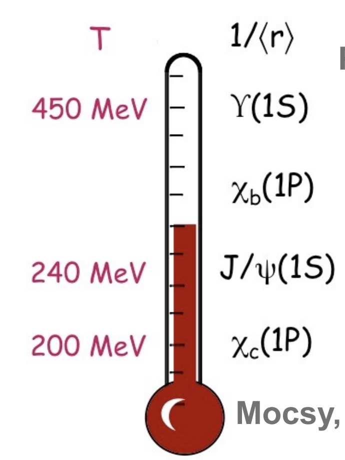
See also:

- Charmonia in Pb-Pb and p-Pb
  - I. Lakomov, Thursday AM
  - M. Leoncino, Thursday AM
- Quarkonia in pp
  - H. Pereira Da Costa, Friday AM

Motivations

- Quarkonia are important probes of QCD matter
  - Heavy-quark pair production is a perturbative process
  - Their binding is inherently non-perturbative
  - Produced early in the collision
    - Sensitive to the properties of the surrounding medium

- ϒ in pp collisions
  - Test of production models
  - Reference for Pb-Pb studies
- ϒ in Pb-Pb collisions
  - Quarkonia could be suppressed in the QGP by colour screening
    - Different binding energies mean that sequential suppression of different quarkonium states is expected
  - Compared to charmonia
    - Regeneration is expected to be smaller
    - No feed-down from open heavy flavours
    - Smaller cold nuclear matter effects are expected
- ϒ in p-Pb collisions
  - Study Cold Nuclear Matter effects
  - Compared to charmonia
    - Different kinematics range (Bjorken-*x*) probed

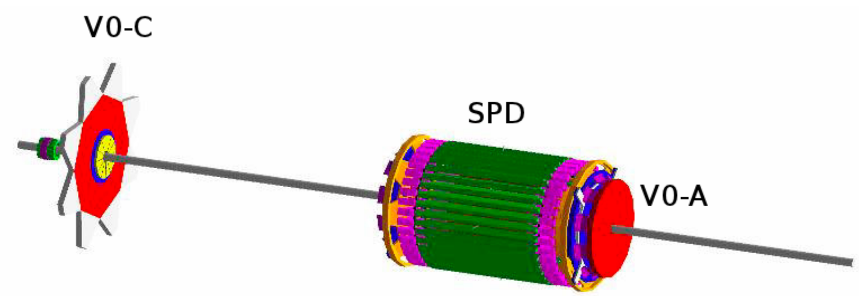


Matsui & Satz, PLB168 (1986) 415

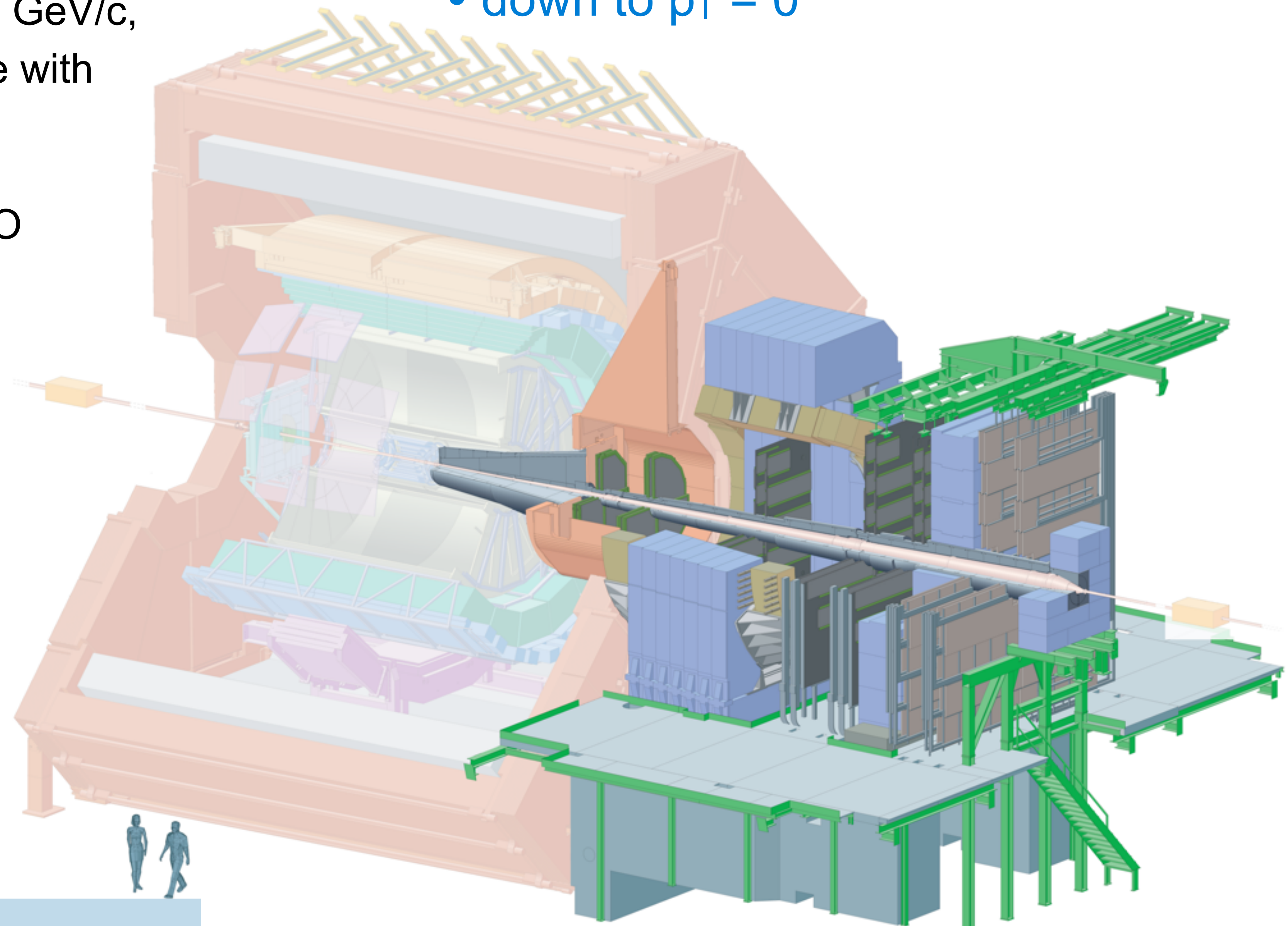
Mocsy, EPJC61 (2009) 705

Υ reconstruction in ALICE

- Minimum Bias trigger: VZERO and SPD
- Di-muon trigger: opposite-sign muon pair candidate (single muon track $p_T \gtrsim 0.5$ or 1 GeV/c, depending on data sample) in coincidence with MB trigger
- Vertex determination: SPD
- Centrality in Pb-Pb: Glauber fit to VZERO signal amplitude



Muon spectrometer ($-4.0 < \eta_{lab} < -2.5$)
- Quarkonia
  - $\rightarrow \mu^+\mu^-$
  - down to $p_T = 0$



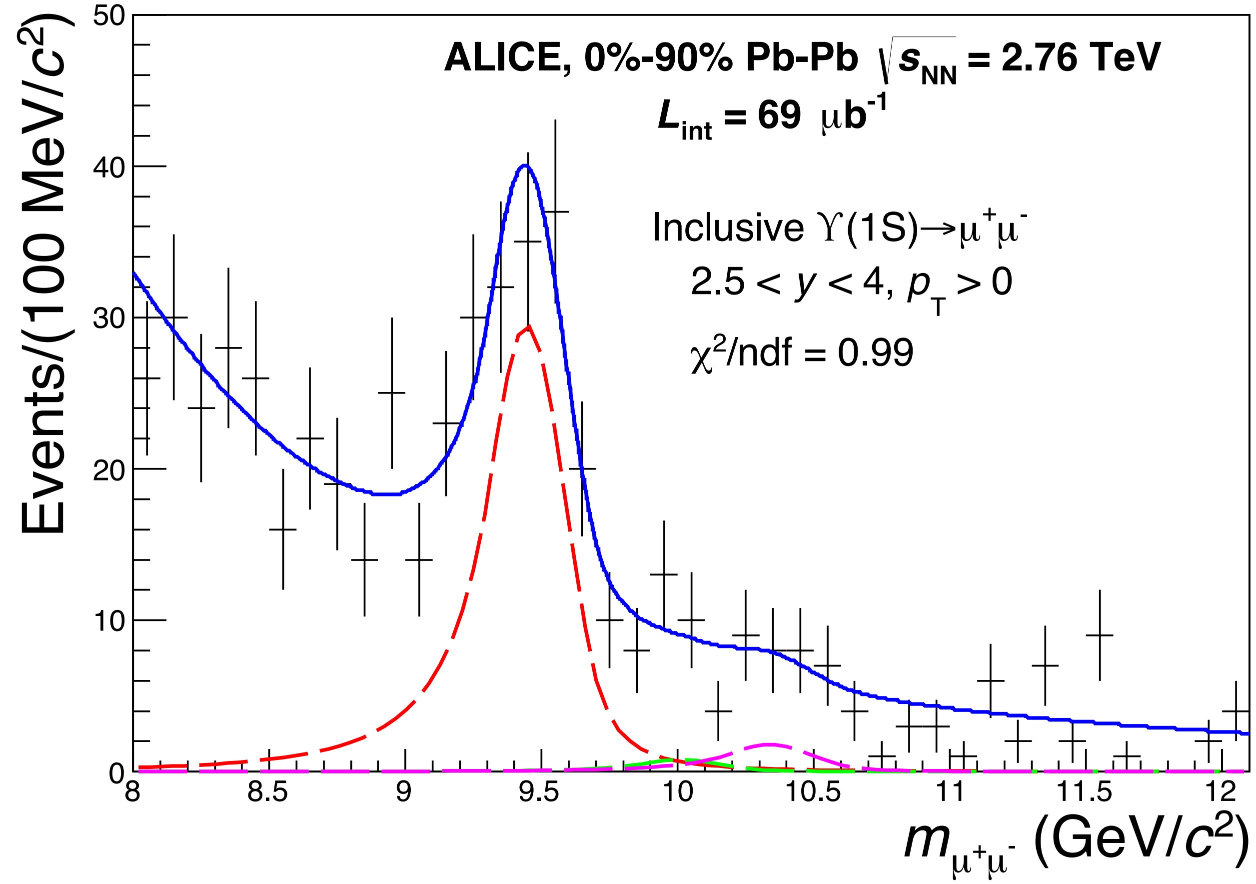
Data sets

System	Pb-Pb	Pb-p	p-Pb
$\sqrt{s_{NN}}$	2.76 TeV	5.02 TeV	5.02 TeV
Int. Luminosity	69 μb^{-1}	5.8 nb^{-1}	5.0 nb^{-1}

Pb-Pb collisions

PLB 738 (2014) 361

- Υ(1S) production in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV



- Suppression of Υ(1S) production in Pb-Pb collisions can be measured by the nuclear modification factor

$$R_{AA} = \frac{Y^{\Upsilon}}{\langle T_{\mathrm{AA}} \rangle \times \sigma^{\Upsilon}_{\mathrm{pp}}}$$

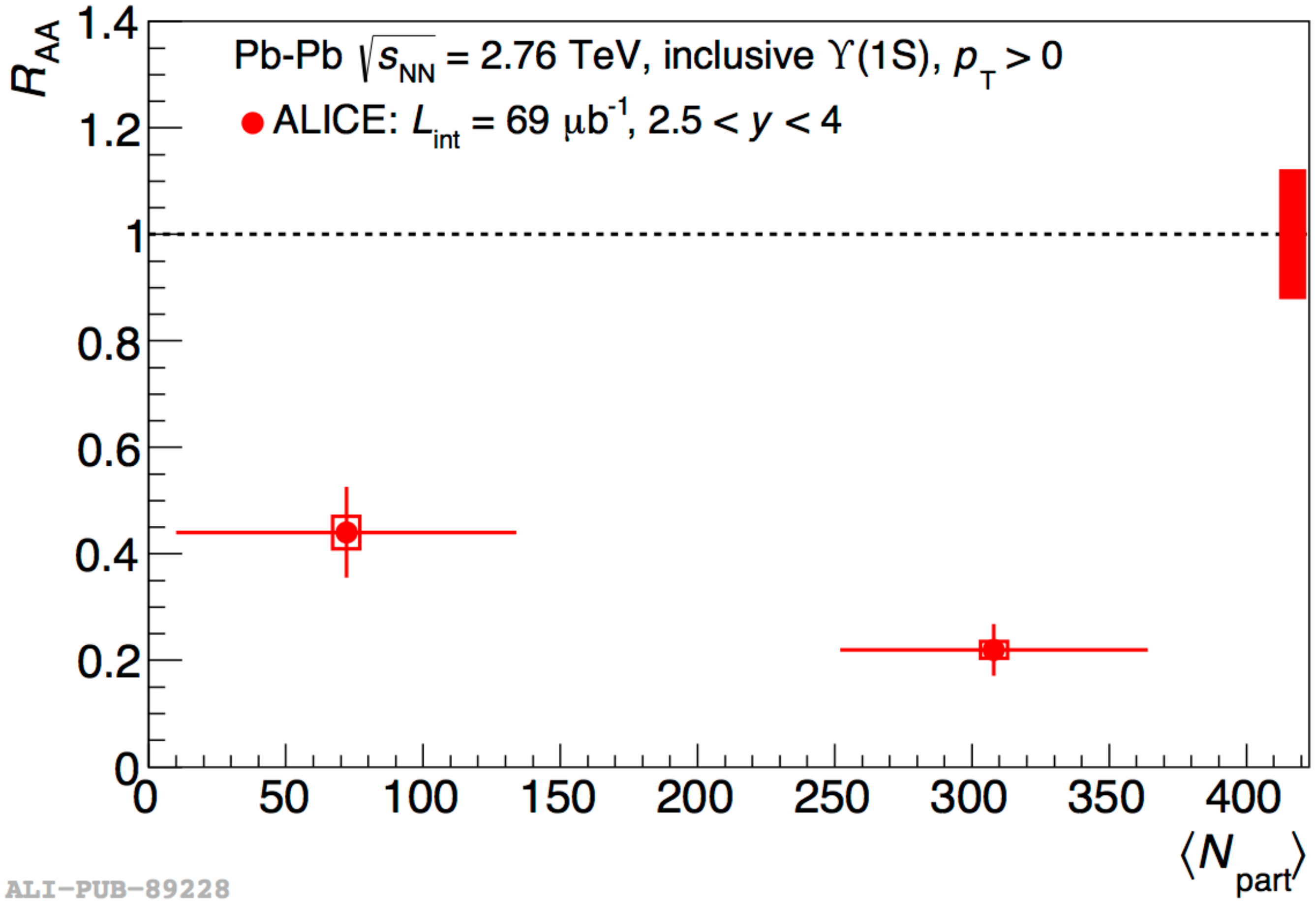
- To calculate the nuclear modification factor we now use the Υ(1S) cross section measured by LHCb in pp collisions at 2.76 TeV [EPJC74 2835 (2014)]

Inclusive ϒ(1S) nuclear modification factor

PbPb @ 2.76 TeV

PLB 738 (2014) 361

- R_{AA} of inclusive ϒ(1S) in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV



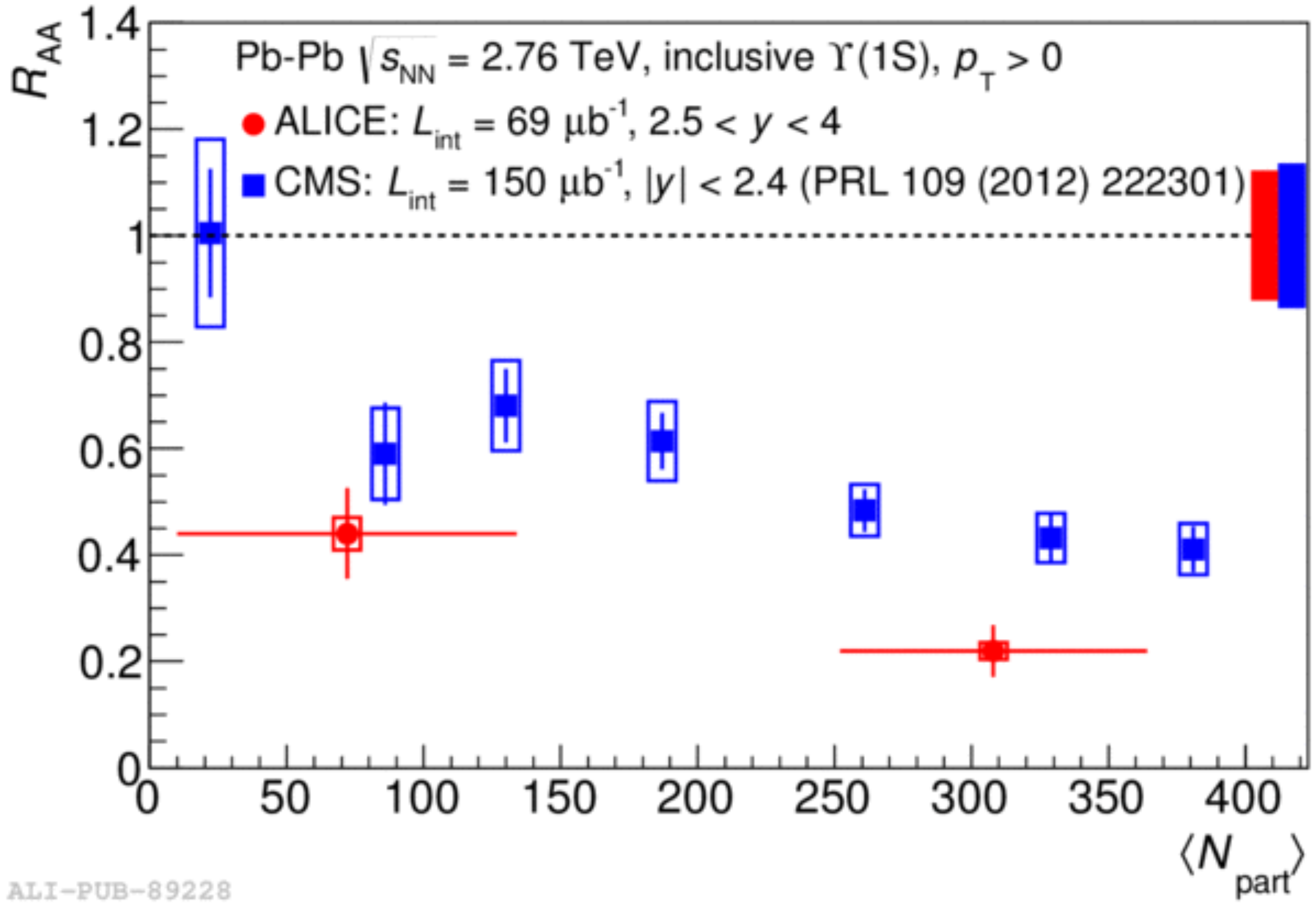
Uncertainties:
- Bars: Statistical
- Open boxes: Uncorrelated systematic
- Full box: Correlated systematic

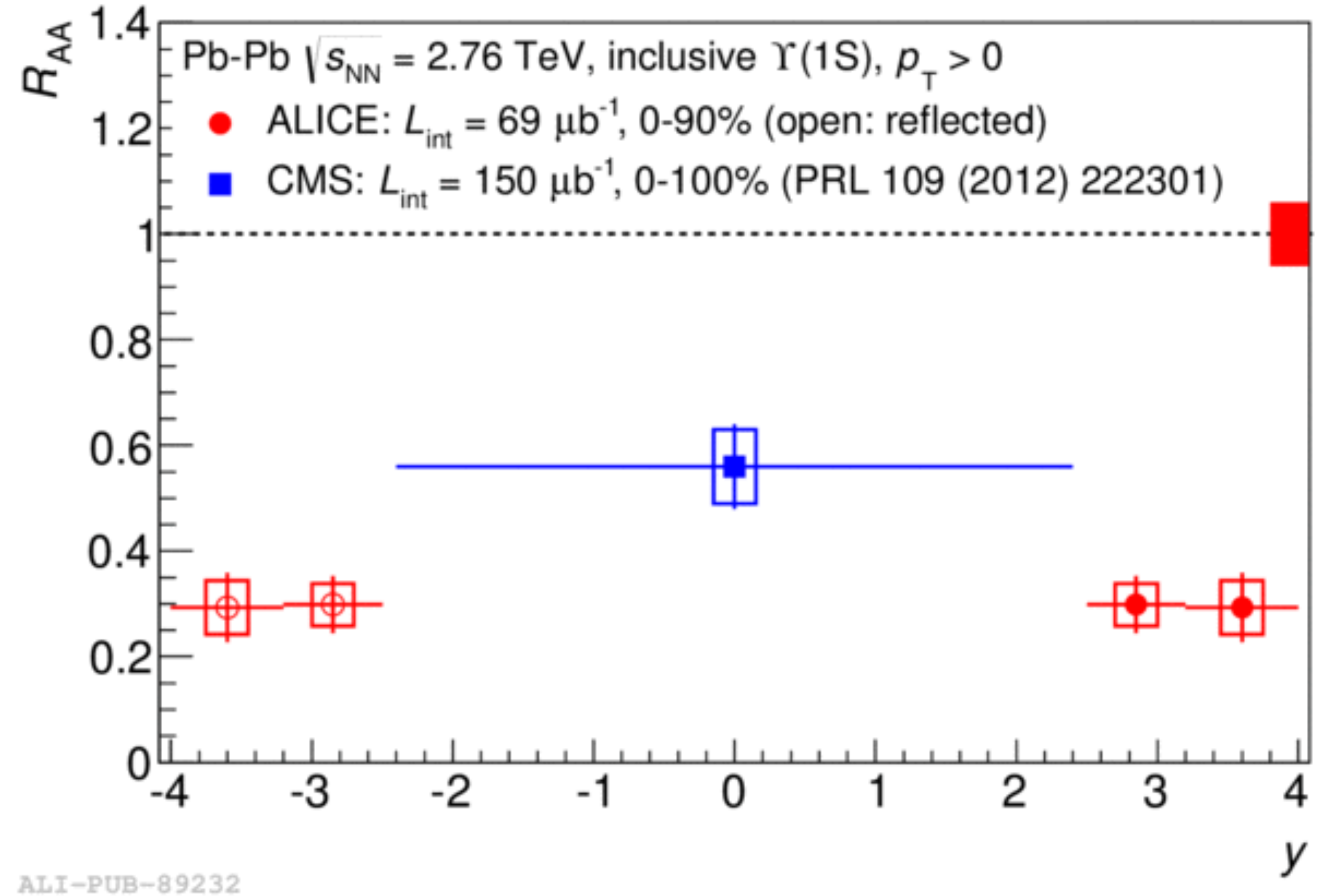
- Strong suppression of inclusive ϒ(1S)
  - Centrality 0% – 90%; $p_T > 0$; $2.5 < y < 4.0$:
    - R_{AA} = 0.304 ± 0.047(stat) ± 0.042(syst)
  - Stronger suppression in more central collisions

Comparison with mid-rapidity measurement

PLB 738 (2014) 361

- Mid-rapidity measurement from CMS Collaboration [PRL 109 (2012) 222301]





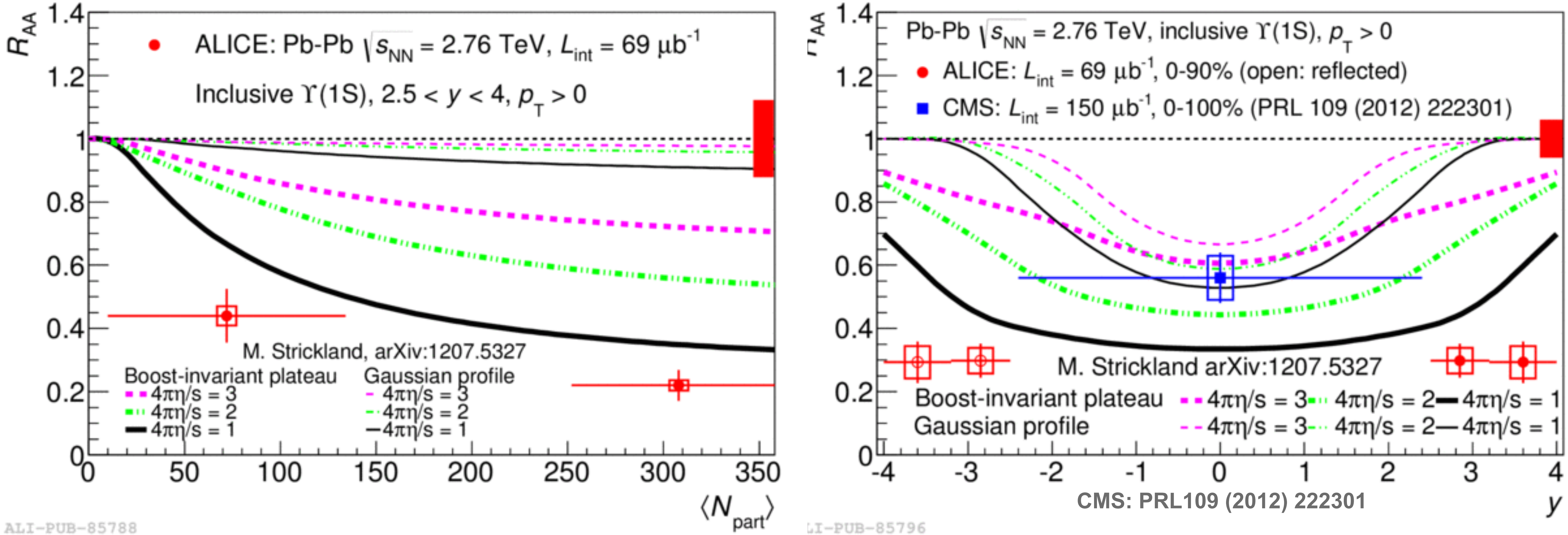
- Stronger suppression at forward rapidity than at mid rapidity
  - Although smaller or similar energy density expected at forward than at mid rapidity
  - Role of regeneration?
  - Role of CNM?

Comparison with models – Dynamical

PbPb @ 2.76 TeV

PLB 738 (2014) 361

- R_{AA} of inclusive Υ(1S) in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV



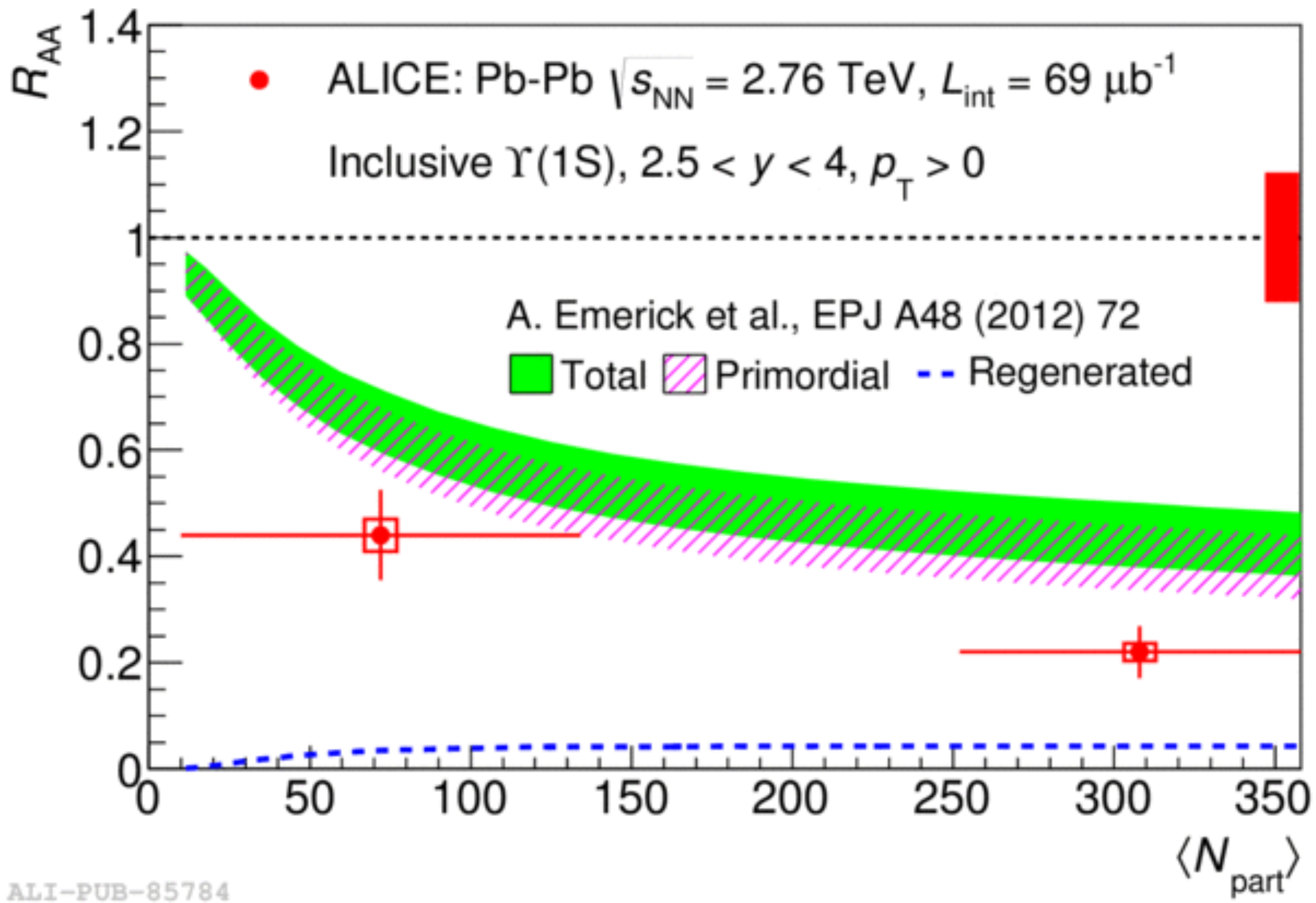
- M. Strickland, [arXiv:1207.5327]
  - Thermal suppression of bottomonium states
  - Anisotropic hydro model
  - Two temperature rapidity profiles: Boost invariant or Gaussian
  - Three tested shear viscosities
  - Feed down from higher mass states included
  - No CNM included
  - No regeneration included

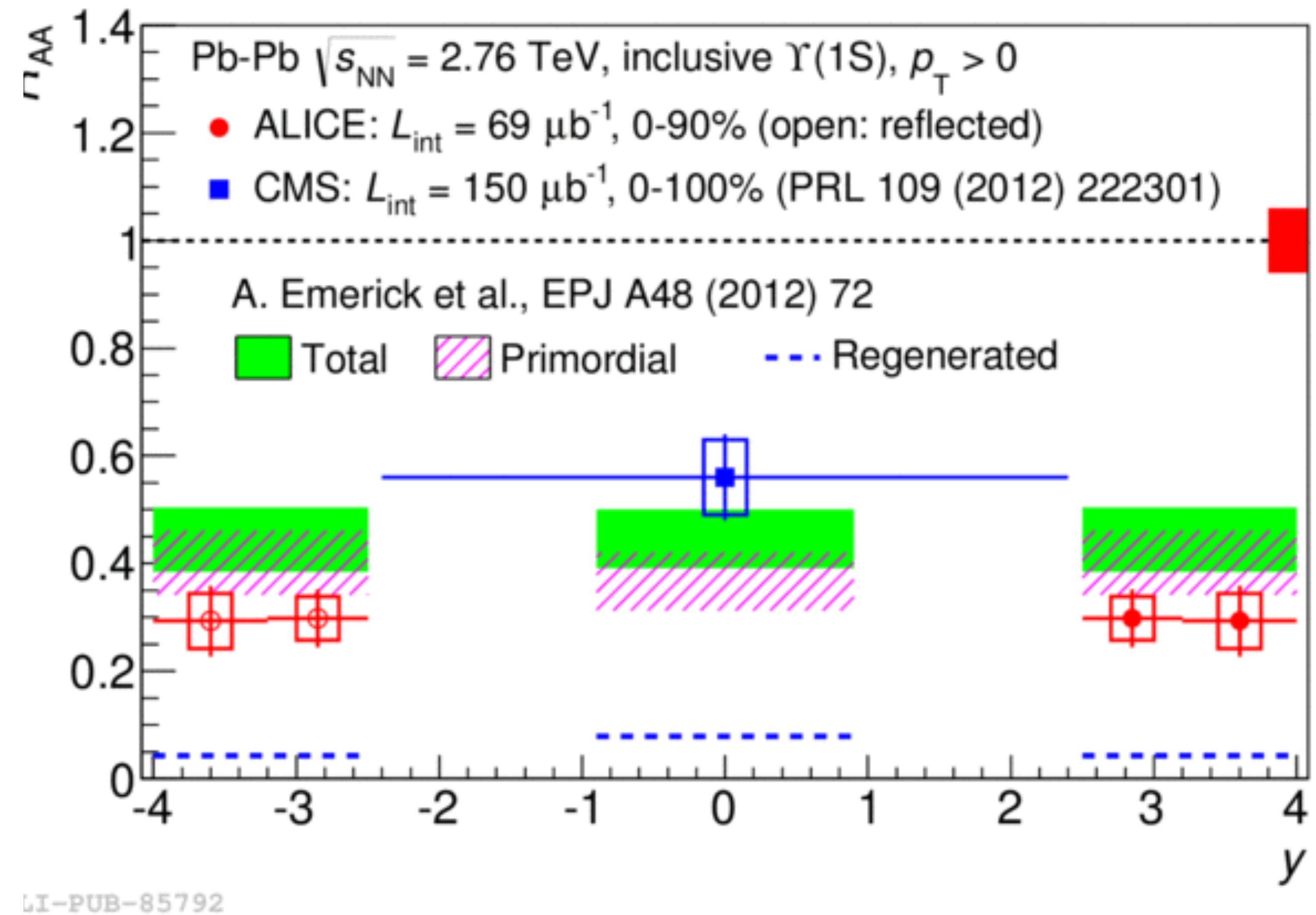
In all cases the model underestimates the measured Υ(1S) suppression at forward rapidity

Comparison with models – Transport

PLB 738 (2014) 361

- R_{AA} of inclusive ϒ(1S) in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV





- A. Emerick et al., [EPJ A48 (2012) 72]
  - Transport model
  - Suppression of ϒ resonances by the QGP
    - Mainly of the higher mass states
  - Small regeneration component included
  - Feed down from higher mass states included
  - CNM included via an "effective" σ_{ABS} = 0–2 mb

Model does not reproduce the strong rapidity dependence of the R_{AA} and underestimates the ϒ(1S) suppression at forward rapidity

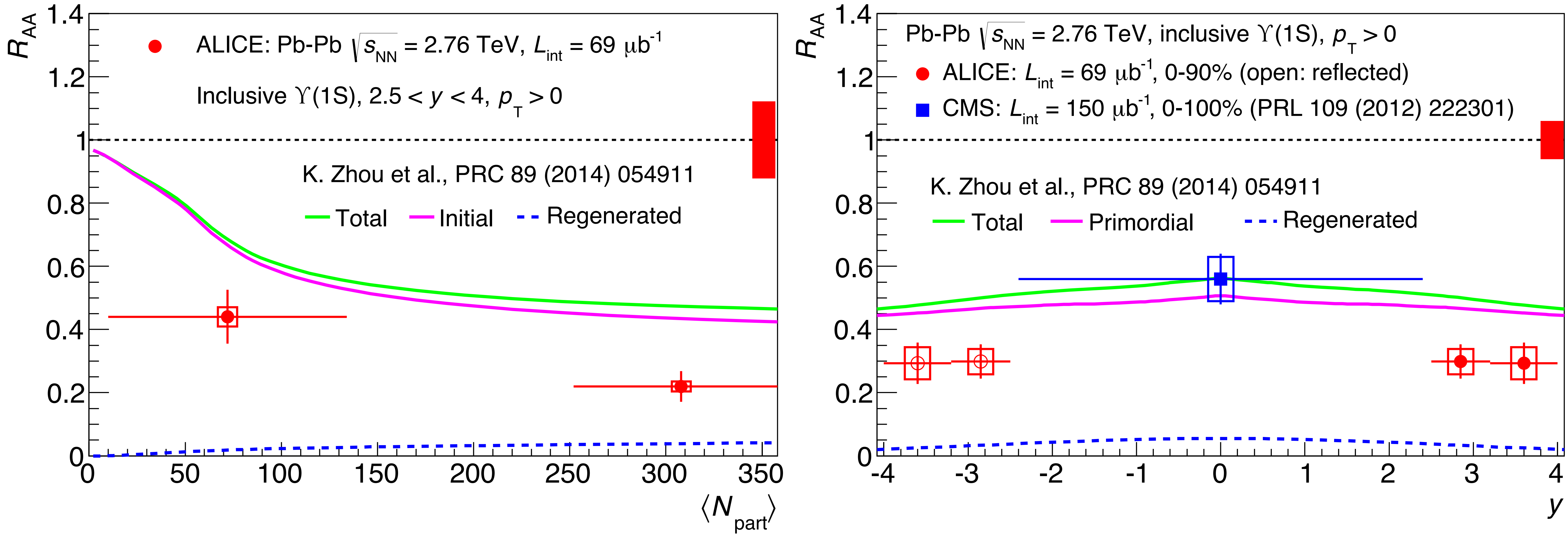
- Stronger suppression of direct ϒ(1S)?
- Role of regeneration?
- Role of CNM?

Comparison with models – Transport II

PbPb @ 2.76 TeV

ALICE-PUBLIC-2014-001

- R_{AA} of inclusive ϒ(1S) in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV



- K. Zhou et al., [PRC89 (2014) 054911 and private communication]
  - Transport model
  - Suppression of resonances by the QGP
    - Mainly the higher mass states
  - Small regeneration component included
  - Feed down from higher mass states included
  - CNM included: EKS98

Model does not reproduce the strong rapidity dependence of the R_{AA} and underestimates the ϒ(1S) suppression at forward rapidity

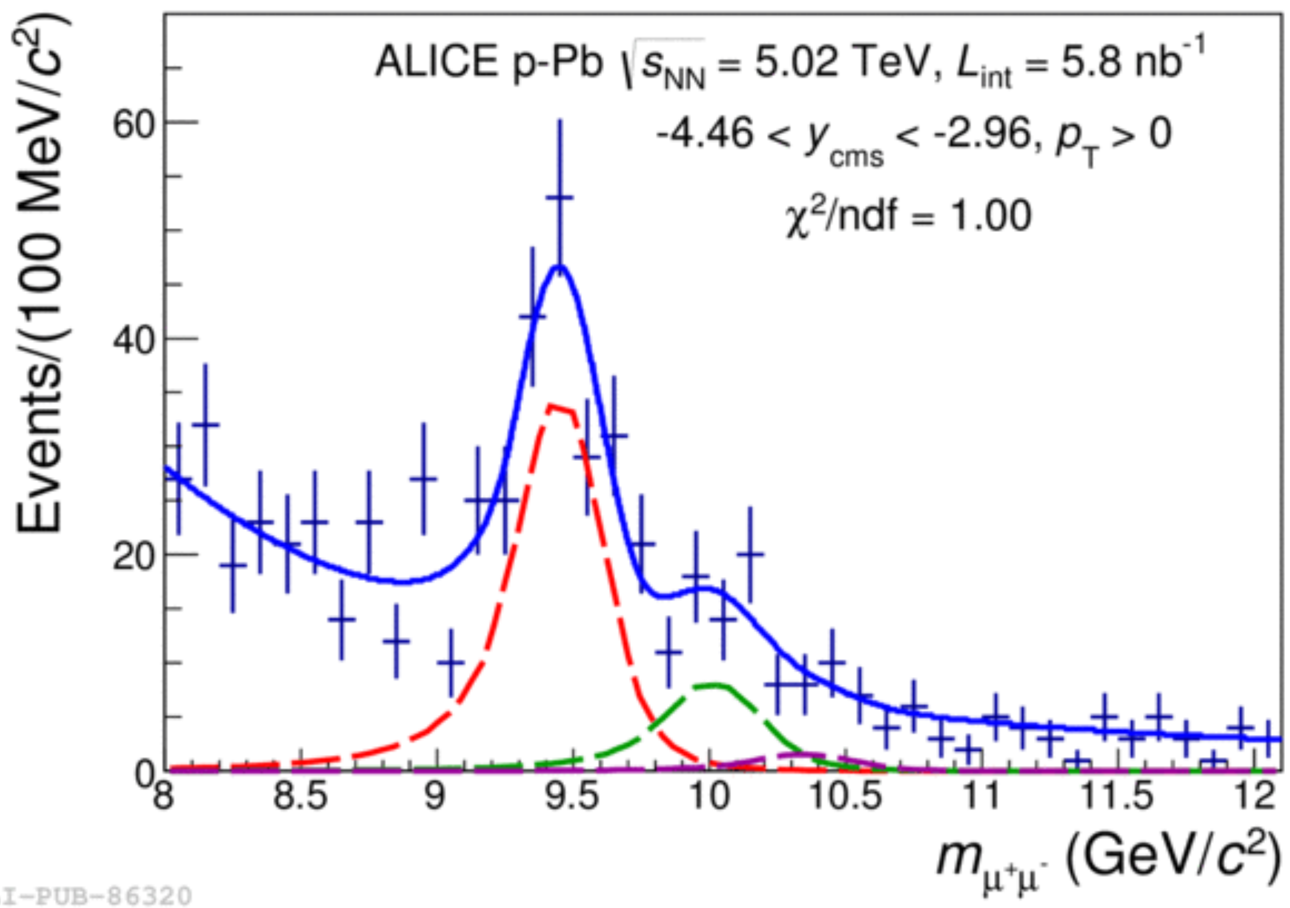
- Suppression of direct ϒ(1S)?
- Role of regeneration?
- Role of CNM?

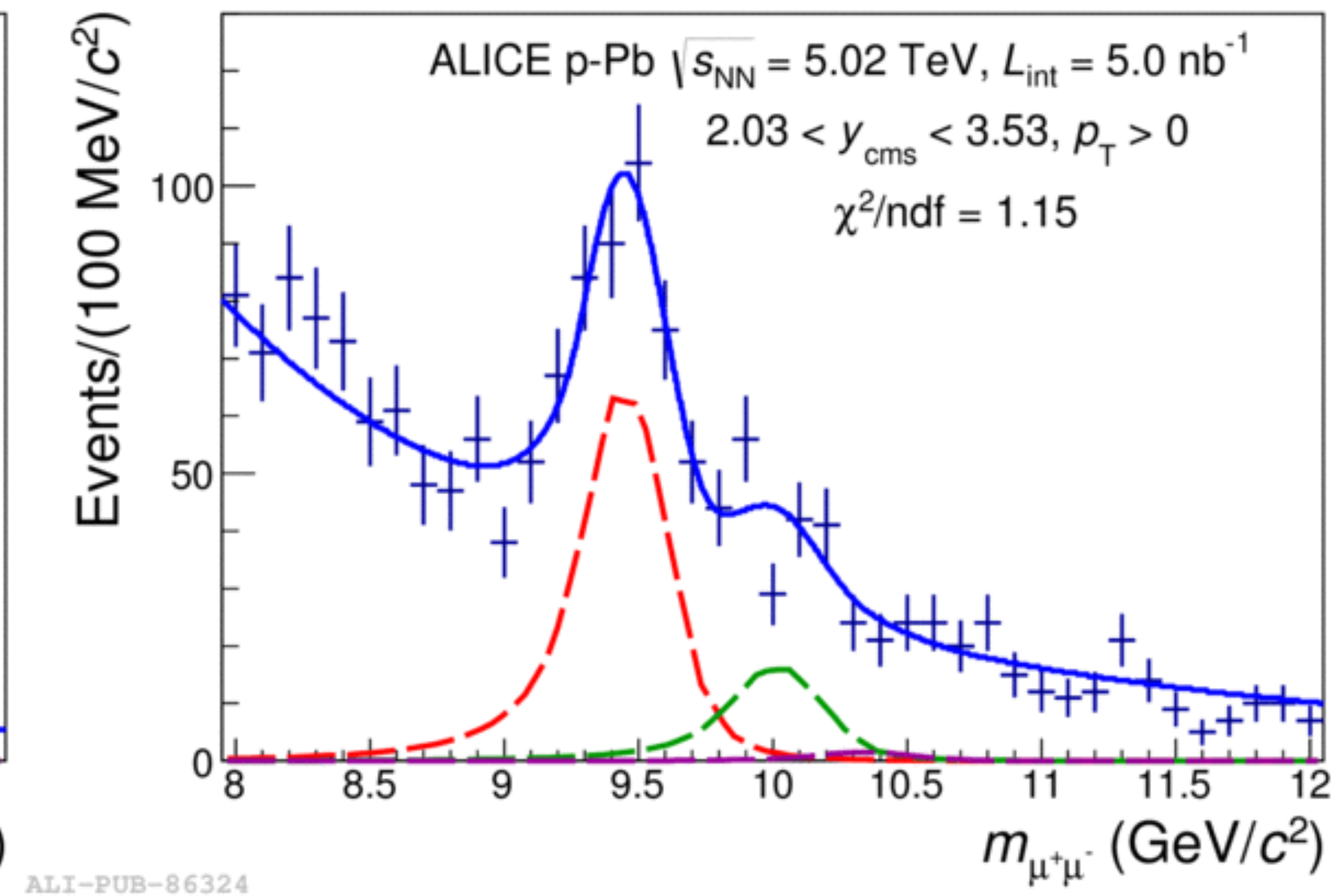
p-Pb and Pb-p collisions

pPb @ 5.02 TeV

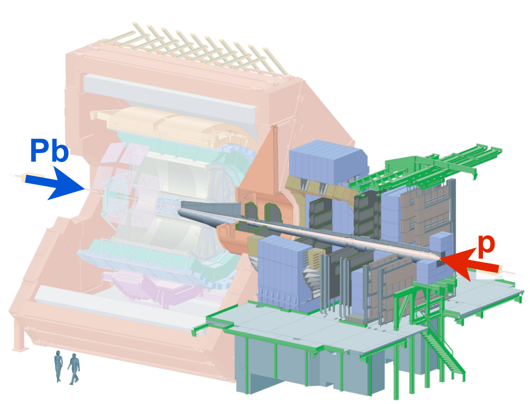
arXiv:1410.2234

- Inclusive ϒ(1S) production in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

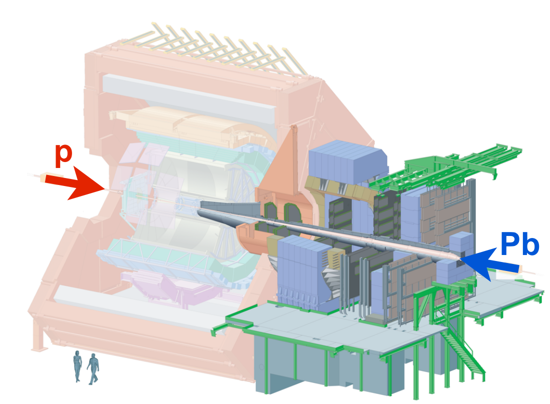




- Two configurations



$-4.46 < y_{cms} < -2.96$

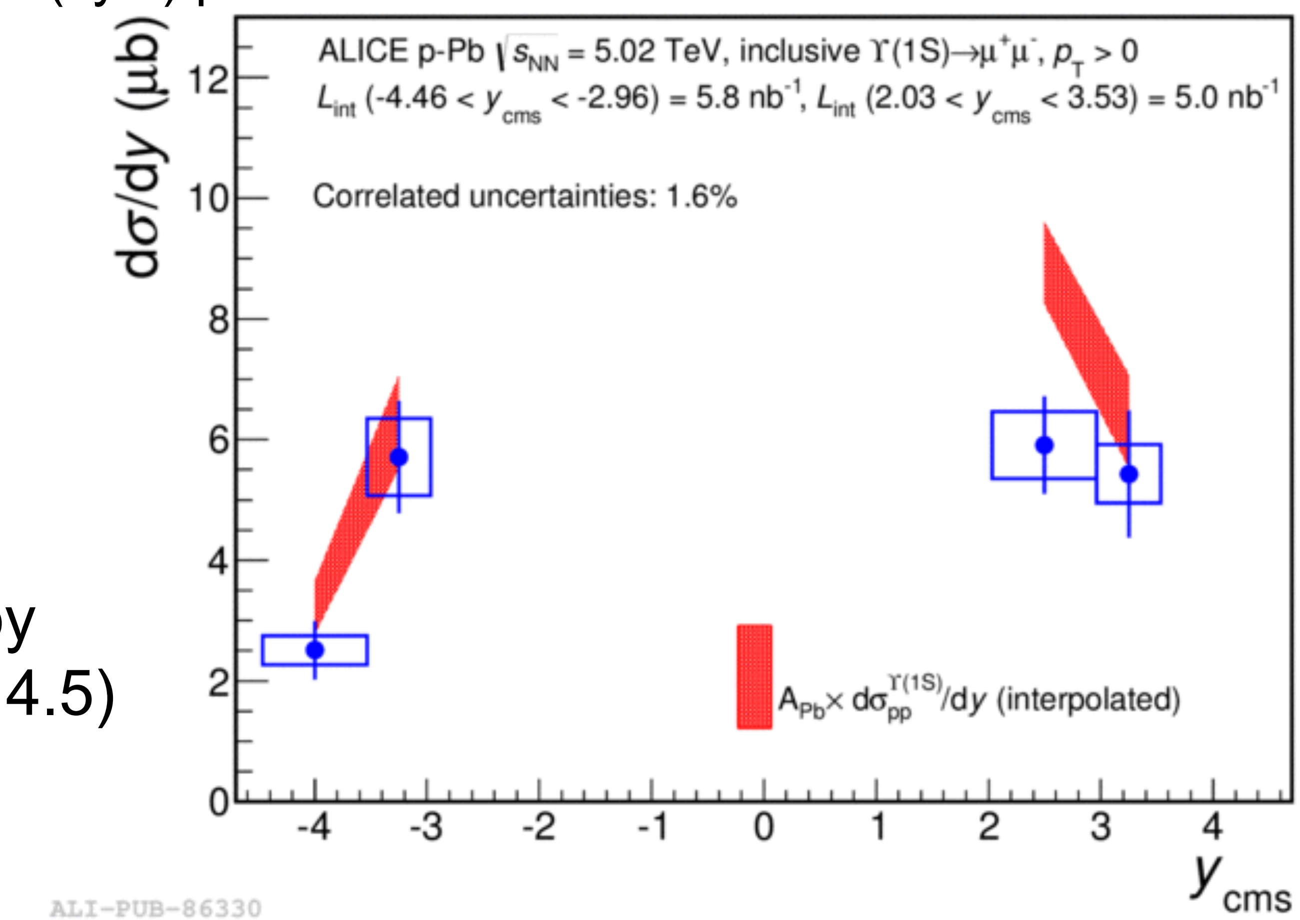


$2.03 < y_{cms} < 3.53$

Production cross section

arXiv:1410.2234

- Rapidity integrated cross sections
  - $\sigma_{\Upsilon(1S)}(-4.46 < y_{cms} < -2.96) = 5.57\pm0.72(stat)\pm0.60(syst)$ μb;
  - $\sigma_{\Upsilon(1S)}(2.03 < y_{cms} < 3.53) = 8.45\pm0.94(stat)\pm0.77(syst)$ μb.
  - $\sigma_{\Upsilon(2S)}(-4.46 < y_{cms} < -2.96) = 1.85\pm0.61(stat)\pm0.32(syst)$ μb,
  - $\sigma_{\Upsilon(2S)}(2.03 < y_{cms} < 3.53) = 2.97\pm0.82(stat)\pm0.50(syst)$ μb.



- Y(2S)-to-Y(1S) cross section ratio
  - $-4.46 < y_{cms} < -2.96$: 0.26 ± 0.09 ± 0.04
  - $2.03 < y_{cms} < 3.53$: 0.27 ± 0.08 ± 0.04

- Similar values measured in pp collisions by ALICE (2.5 < y < 4.0) and LHCb (2.0 < y < 4.5)
  - ALICE 7 TeV: 0.28 ± 0.08
  - LHCb 2.76 TeV: 0.24 ± 0.03
  - LHCb 7 TeV: 0.25 ± 0.02
  - LHCb 8 TeV: 0.23 ± 0.01

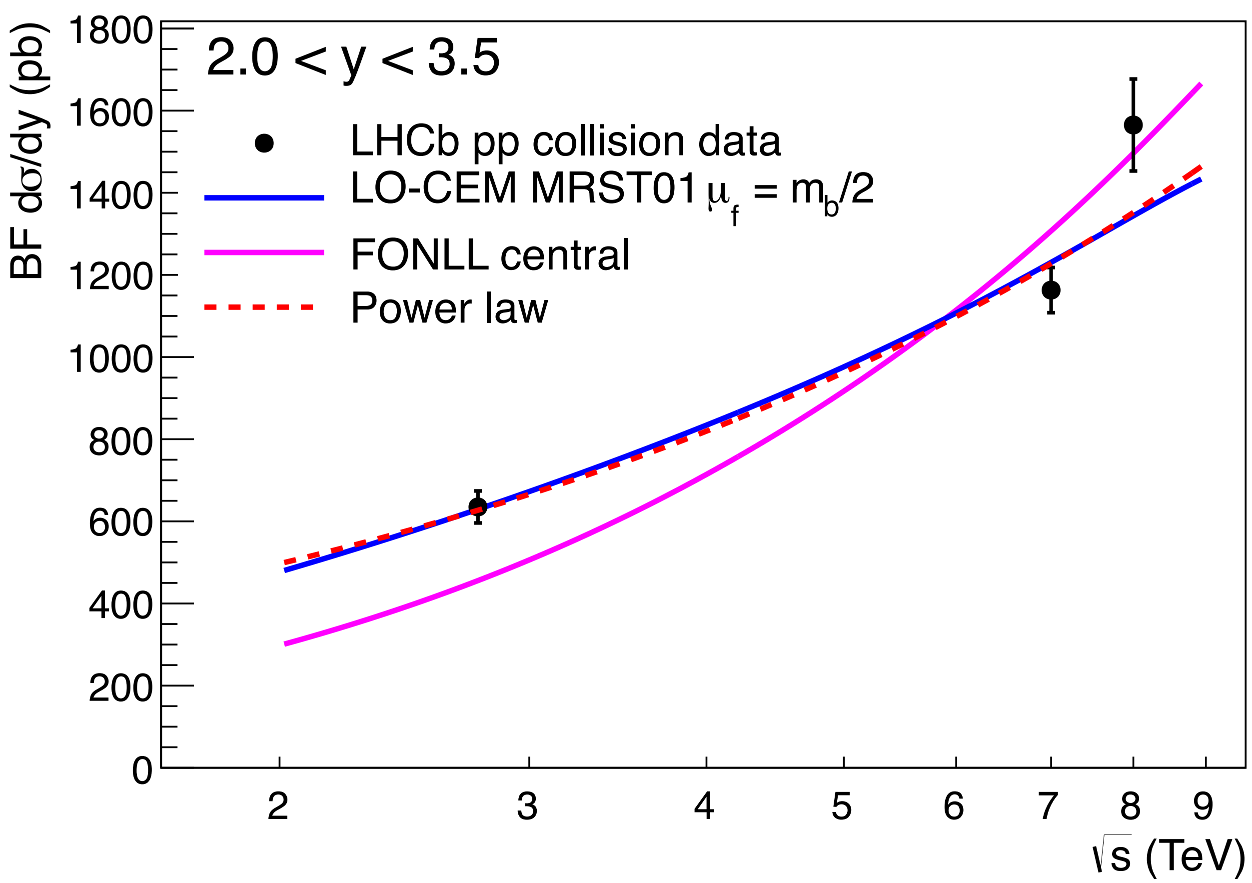
No evidence of different CNM effects on Y(2S) than on Y(1S)

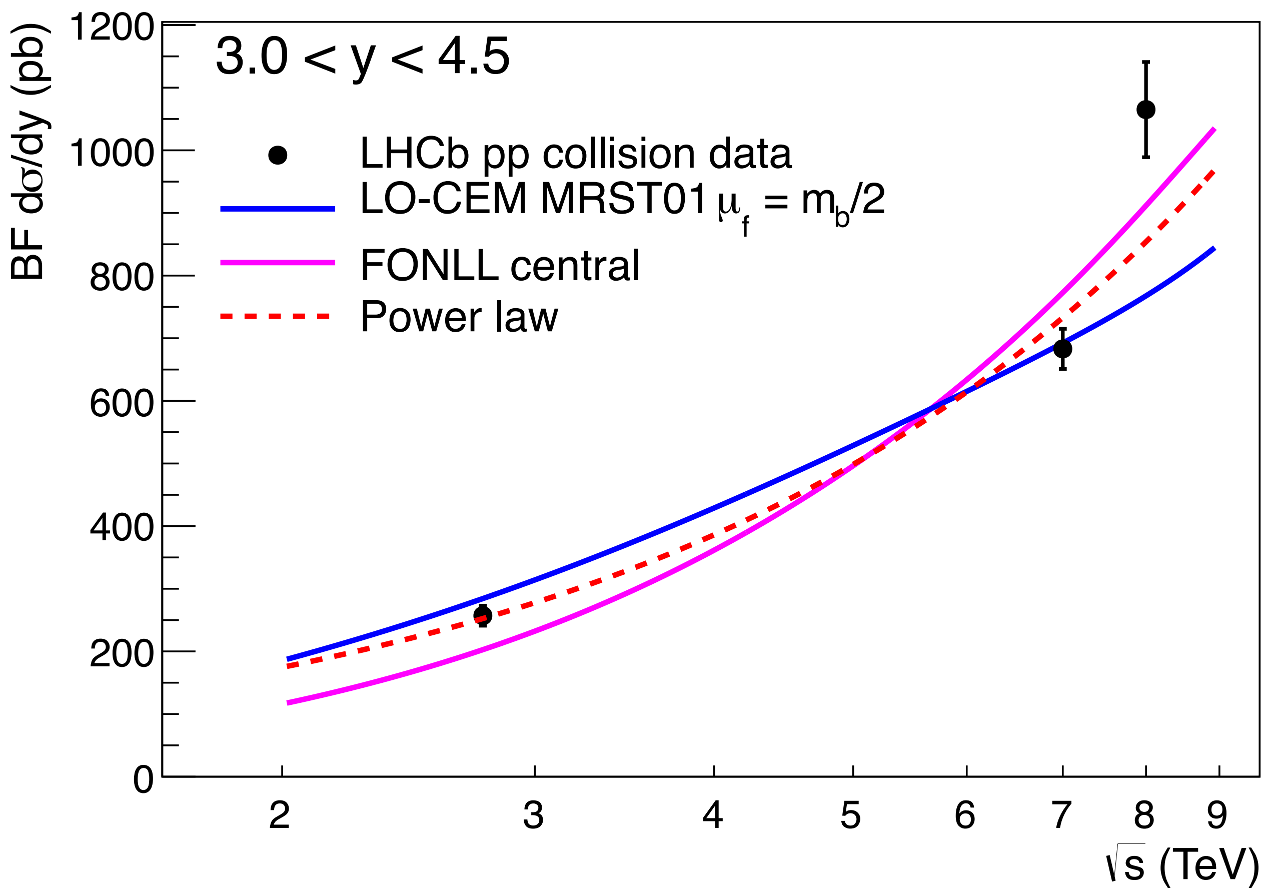
pp reference @ 5.02 TeV

pPb @ 5.02 TeV

ALICE-PUBLIC-2014-002

- Energy interpolation at forward rapidity
  - using LHCb data at 2.76, 7 and 8 TeV
  - and several "reasonable" functional forms
  - but also pQCD FONLL calculation
- Obtained cross-sections
  - $d\sigma/dy(5.02\text{ TeV}, \Upsilon(1S), 2.0 < y < 3.5)\times BF(\mu^+\mu^-) = 967\pm76$ pb,
  - $d\sigma/dy(5.02\text{ TeV}, \Upsilon(1S), 3.0 < y < 4.5)\times BF(\mu^+\mu^-) = 513\pm58$ pb.



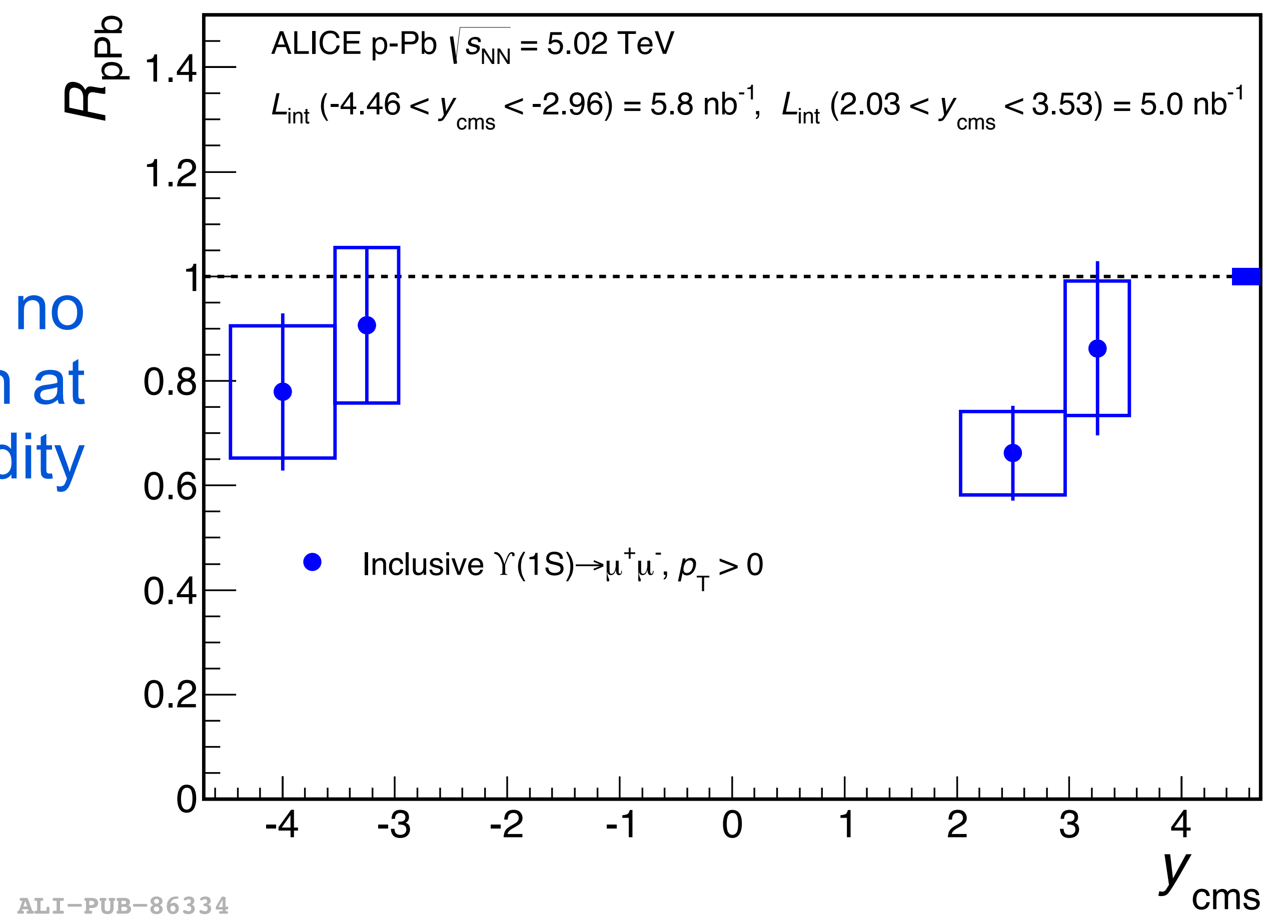


Υ nuclear modification factor in p-Pb

- Inclusive Υ(1S) R_{pPb}

Uncertainties:
- Bars: Statistical
- Open boxes: Systematic
- Full box: Correlated systematic

Consistent with no suppression at backward rapidity



Indication of suppression at forward rapidity

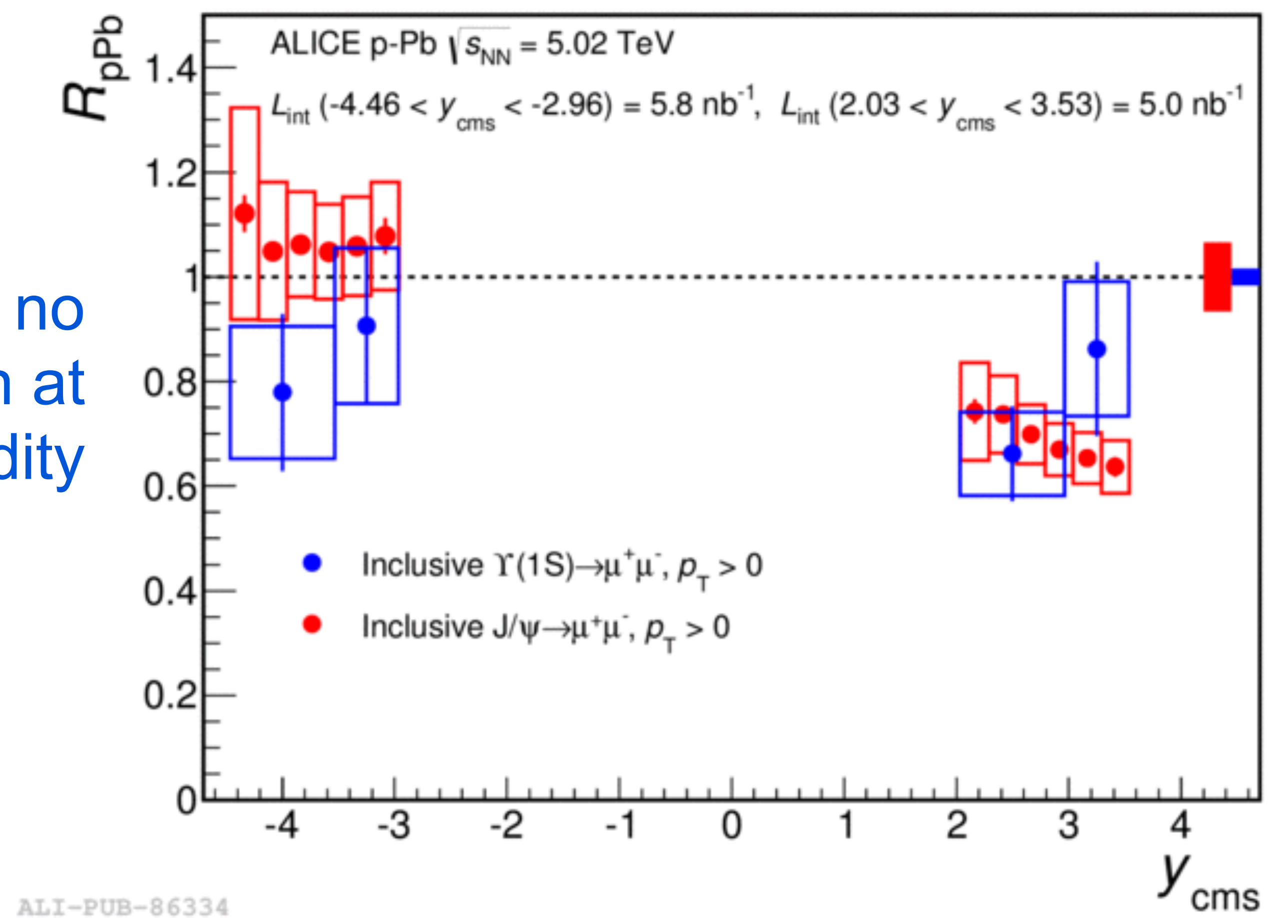
- Assuming a 2→1 production process the tested Bjorken-*x* ranges are
  - Backward: $3.6 \cdot 10^{-2} < x < 1.6 \cdot 10^{-1}$ (antishadowing region)
  - Forward: $5.5 \cdot 10^{-5} < x < 2.5 \cdot 10^{-4}$ (shadowing region)

Comparison with J/ψ

arXiv:1410.2234
JHEP 02 (2014) 073

- Comparison with ALICE J/ψ R_{pPb}
  - Forward: similar suppression
  - Backward: slightly lower ϒ R_{pPb}, but compatible within uncertainties

Consistent with no suppression at backward rapidity



Indication of suppression at forward rapidity

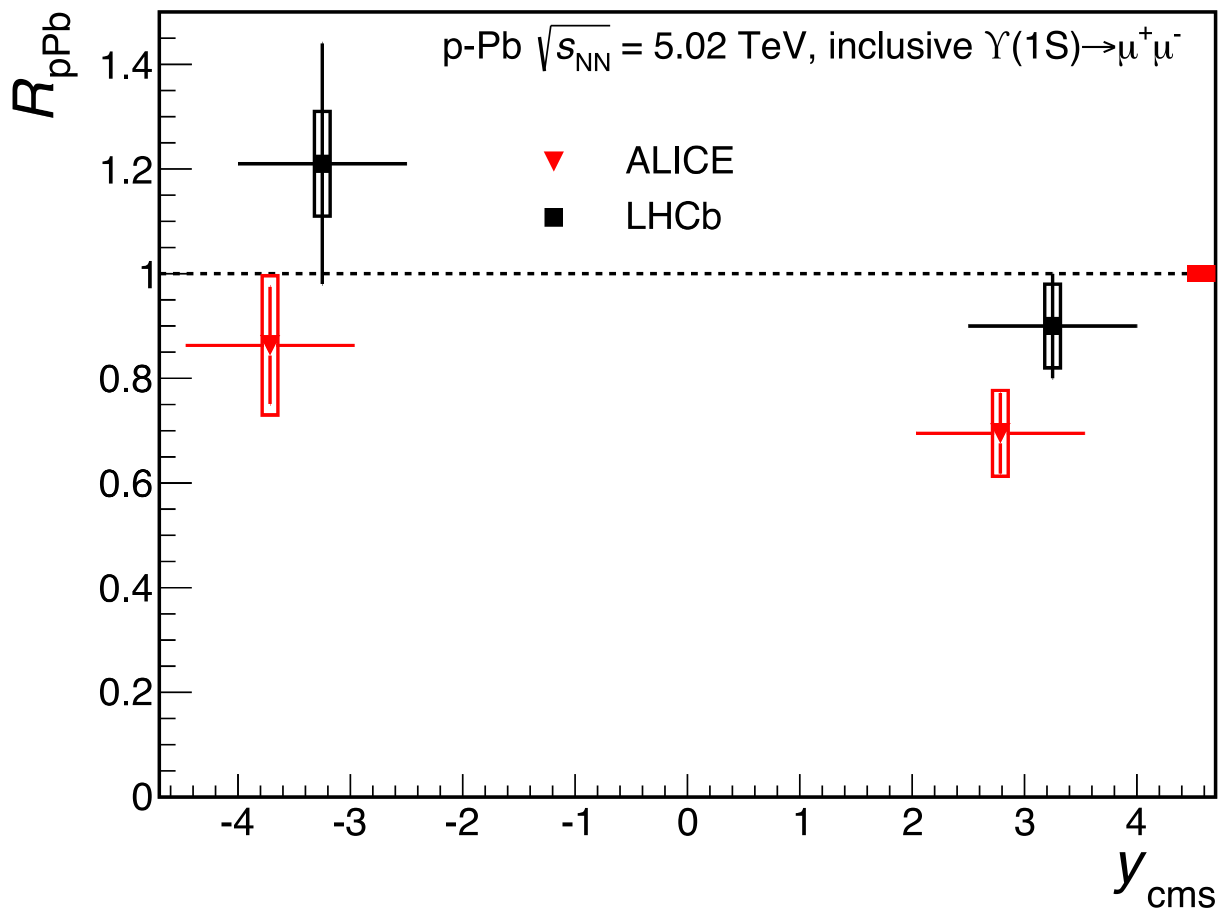
- Assuming a 2→1 production process the tested Bjorken-x ranges are
  - Backward: $3.6 \cdot 10^{-2} < x < 1.6 \cdot 10^{-1}$ (ϒ) and $1.2 \cdot 10^{-2} < x < 5.3 \cdot 10^{-2}$ (J/ψ)
  - Forward: $5.5 \cdot 10^{-5} < x < 2.5 \cdot 10^{-4}$ (ϒ) and $1.8 \cdot 10^{-5} < x < 8.1 \cdot 10^{-5}$ (J/ψ)

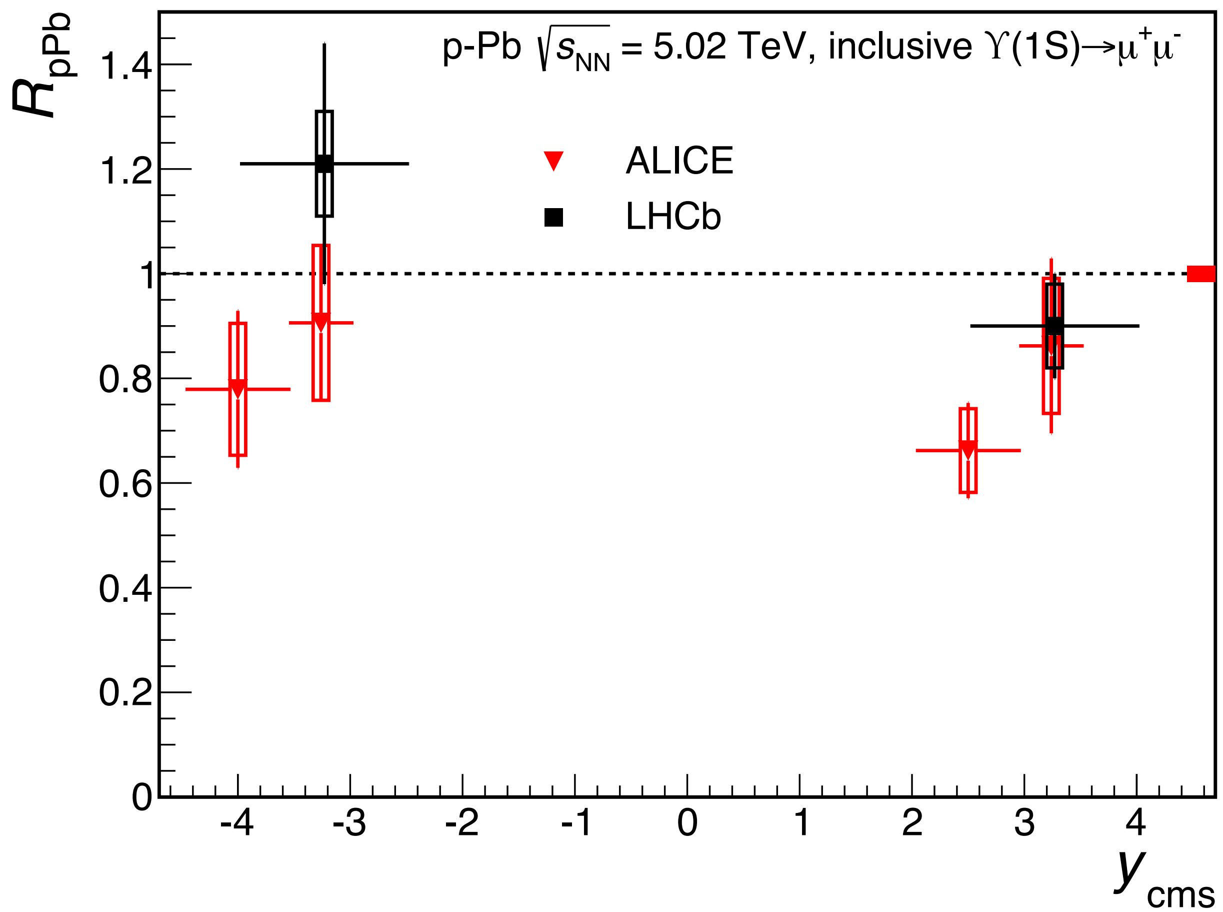
Comparison with LHCb

pPb @ 5.02 TeV

ALICE-PUBLIC-2014-002
LHCb-CONF-2014-003

- Comparison with LHCb Υ R_{pPb}
  - Both measurements are compatible
  - Systematically higher for LHCb than ALICE

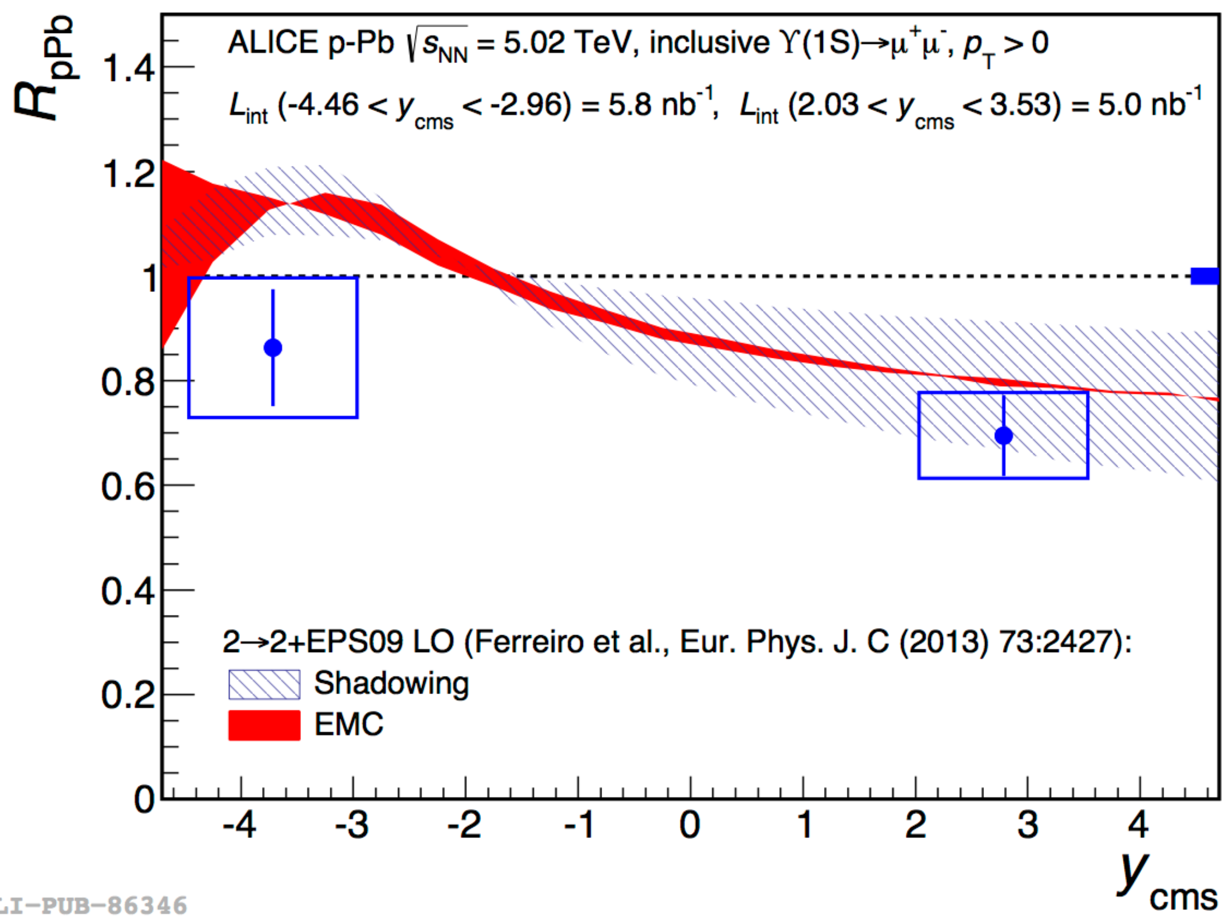


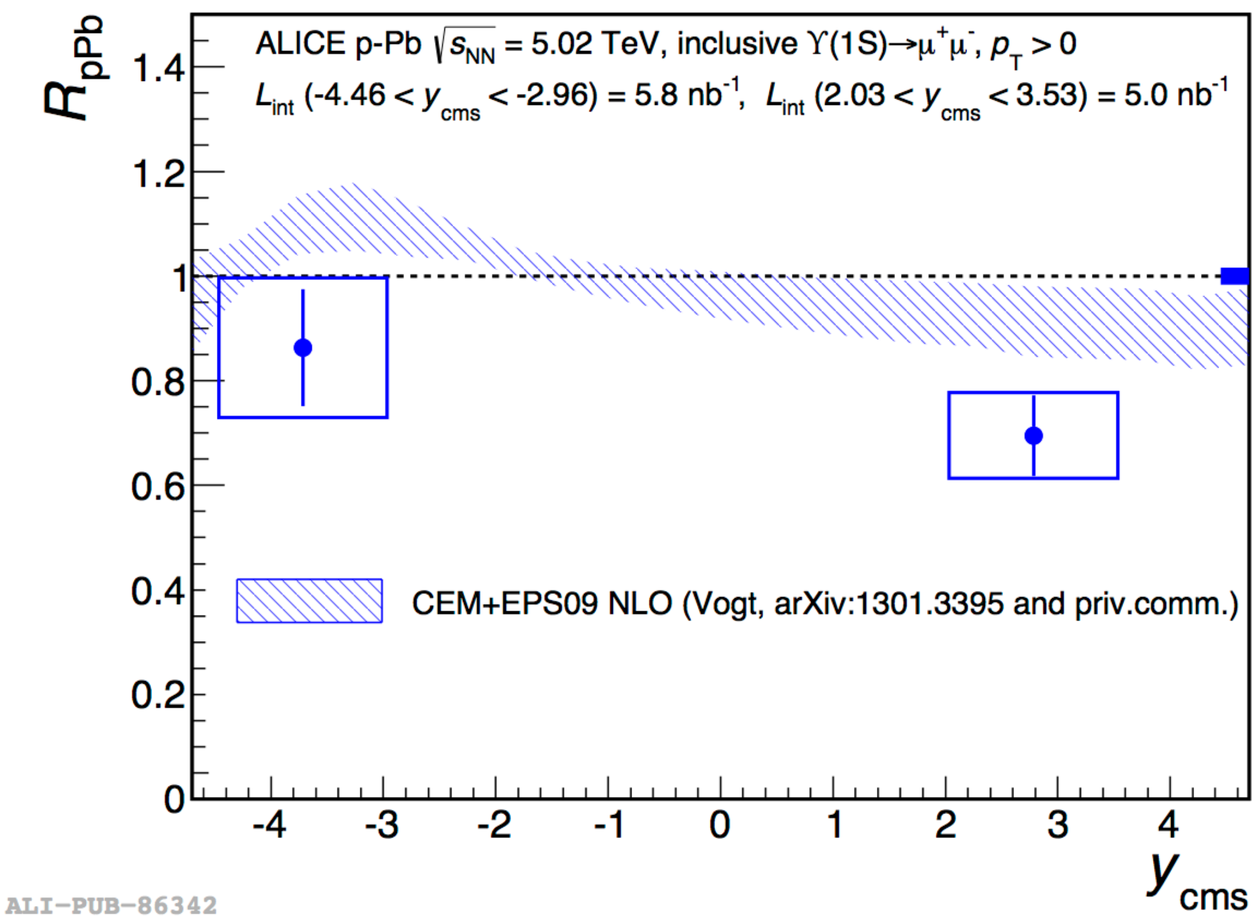


R_{pPb} – Model comparisons

ALICE pPb @ 5.02 TeV

arXiv:1410.2234



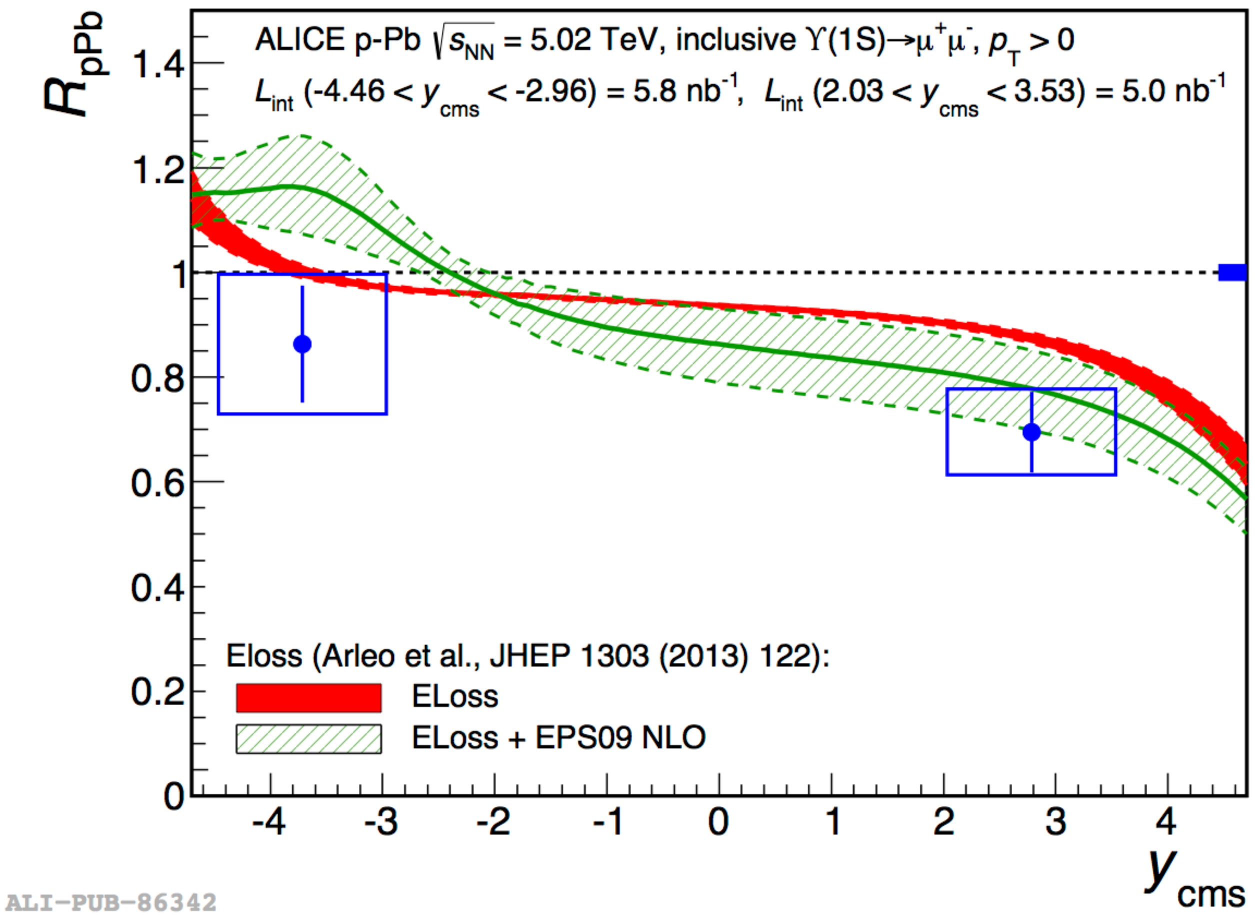


- Ferreiro et al. [EPJC 73 (2013) 2427]
  - Generic 2→2 production model at LO
  - EPS09 shadowing parameterization at LO
  - Fair agreement with measured R_{pPb}
    - Although slightly overestimates it in the antishadowing region

- Vogt [arXiv:1301.3395]
  - CEM production model at NLO
  - EPS09 shadowing parameterization at NLO
  - Fair agreement with measured R_{pPb} within uncertainties
    - Although slightly overestimates it

R_{pPb} – Model comparisons

arXiv:1410.2234



- Arleo et al. [JHEP 1303 (2013) 122]
  - Model including a contribution from coherent parton energy loss
  - With or without shadowing (EPS09)
  - Forward: Better agreement with ELoss and shadowing
  - Backward: Better agreement with ELoss only

Summary

- The production of inclusive Υ(1S) and Υ(2S) at forward rapidity has been measured in pp collisions at $\sqrt{s}$ = 7 TeV

- The production of inclusive Υ(1S) in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV shows
  - Strong suppression of Υ(1S) at forward rapidity
    - Suppression increases with increasing centrality of the collision
    - Suppression is larger at forward rapidity than at central rapidity
  - Available models do not reproduce the strong rapidity dependence of the R_{AA} and underestimate the measured suppression at forward rapidity
    - Stronger suppression of direct Υ(1S)?
    - Role of regeneration?
    - Role of CNM?

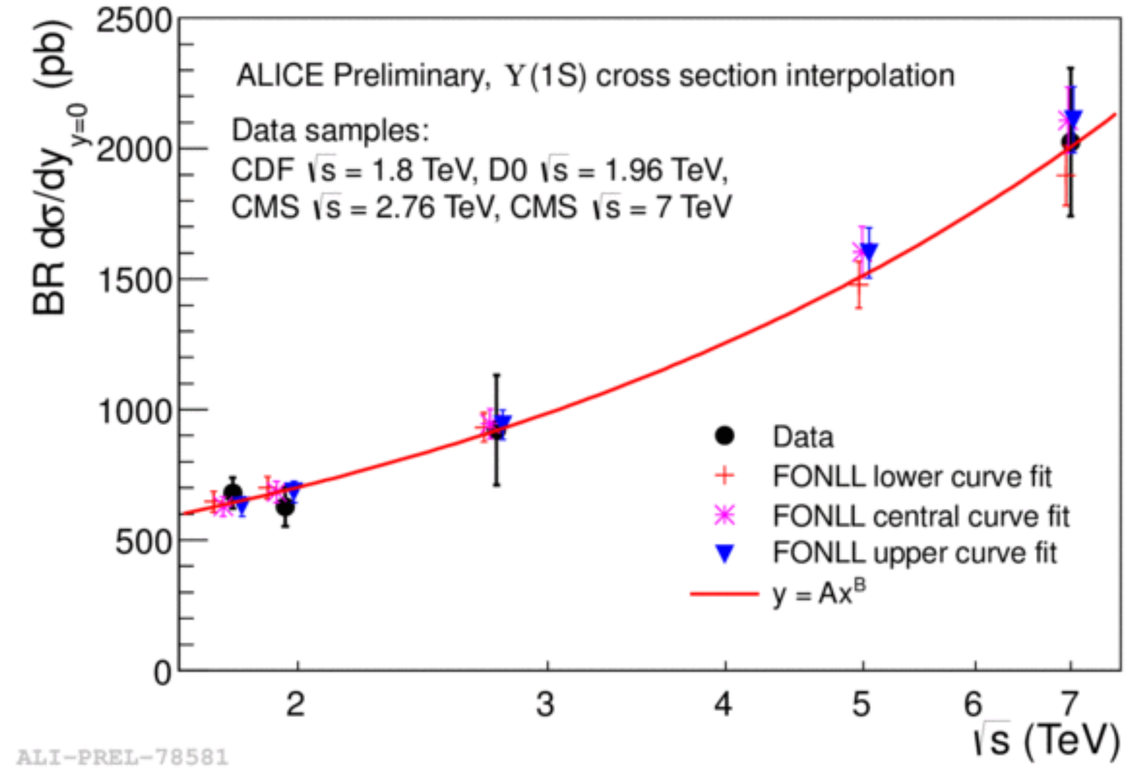
- The production of inclusive Υ(1S) and Υ(2S) in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV shows
  - A suppression of Υ(1S) at forward rapidity (small-*x* region)
    - Similar R_{pPb} as for J/ψ
  - A R_{pPb} consistent with unity at backward rapidity (large-*x* region)
    - Model comparisons suggest smaller anti-shadowing than assumed
  - No indication, within uncertainties, of different CNM effects on Υ(2S) with respect to Υ(1S)

Back-up

pp reference @ 2.76 TeV

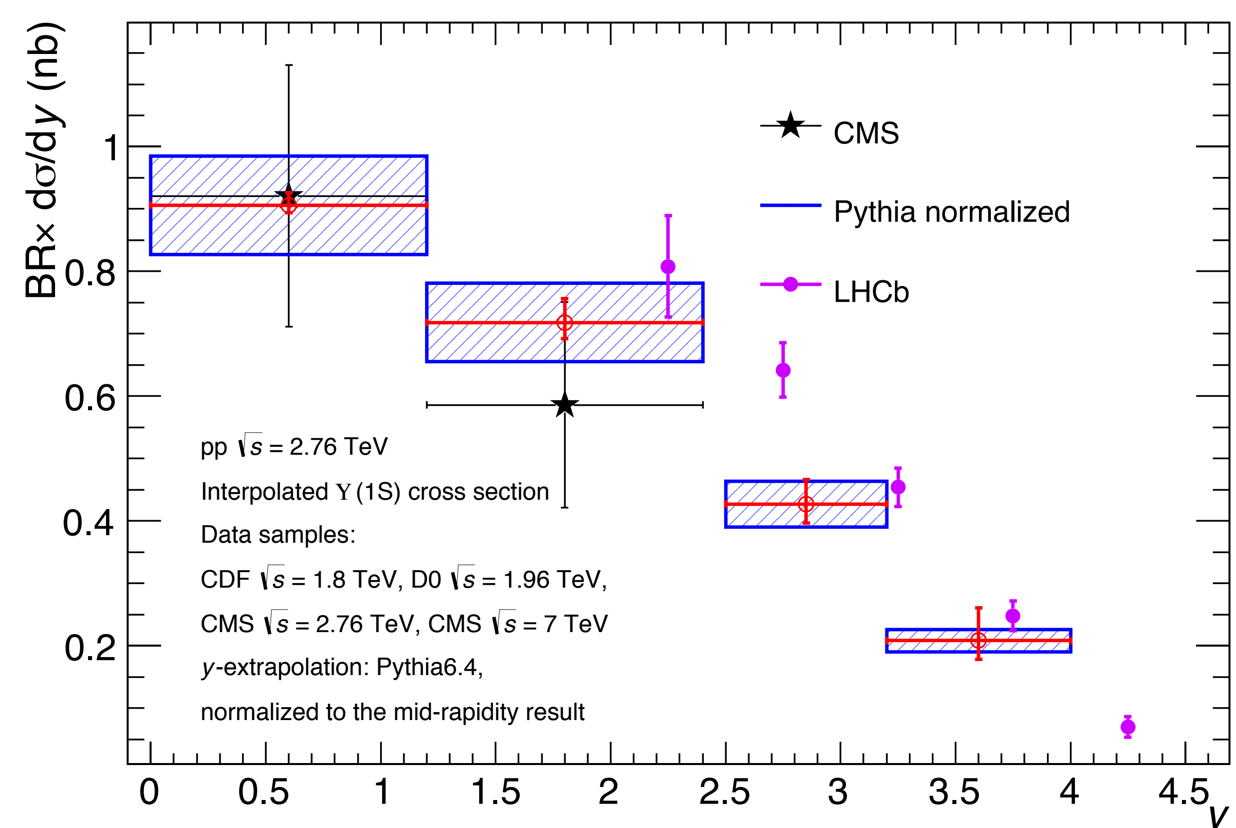
Approach used for preliminary results

- Energy interpolation at mid-rapidity
  - using CDF@1.8 TeV, D0@1.96 TeV, CMS@2.76 TeV, CMS@7 TeV data
  - and several "reasonable" functional forms
  - but also pQCD FONLL calculation
- Rapidity extrapolation
  - Test and select many Pythia tunes using CMS and LHCb data at 7 TeV
  - With selected tunes extrapolate the mid-rapidity point above to forward rapidity



Approach used for the publication

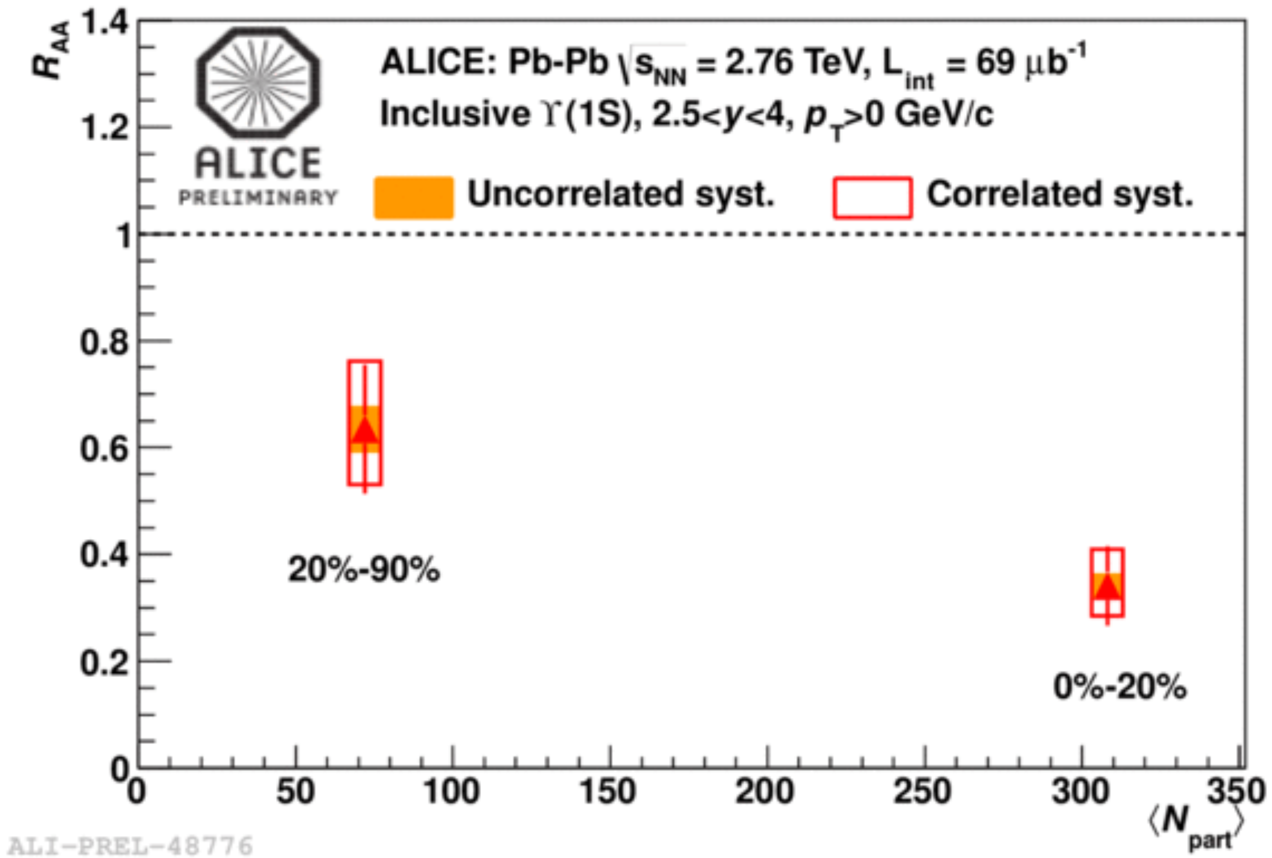
- Use data from LHCb [EPJC74 2835 (2014)]
- pp cross section at 2.76 TeV (2.5<y<4)
  - LHCb measurement: $\sigma[\Upsilon(1S)\rightarrow\mu\mu]=0.670\pm0.025$ (stat.)±0.026 (syst.) nb
  - ALICE extrapolation: $\sigma[\Upsilon(1S)\rightarrow\mu\mu]=0.465^{+0.071}_{-0.045}$ (extrap.) ±0.041(norm.) nb

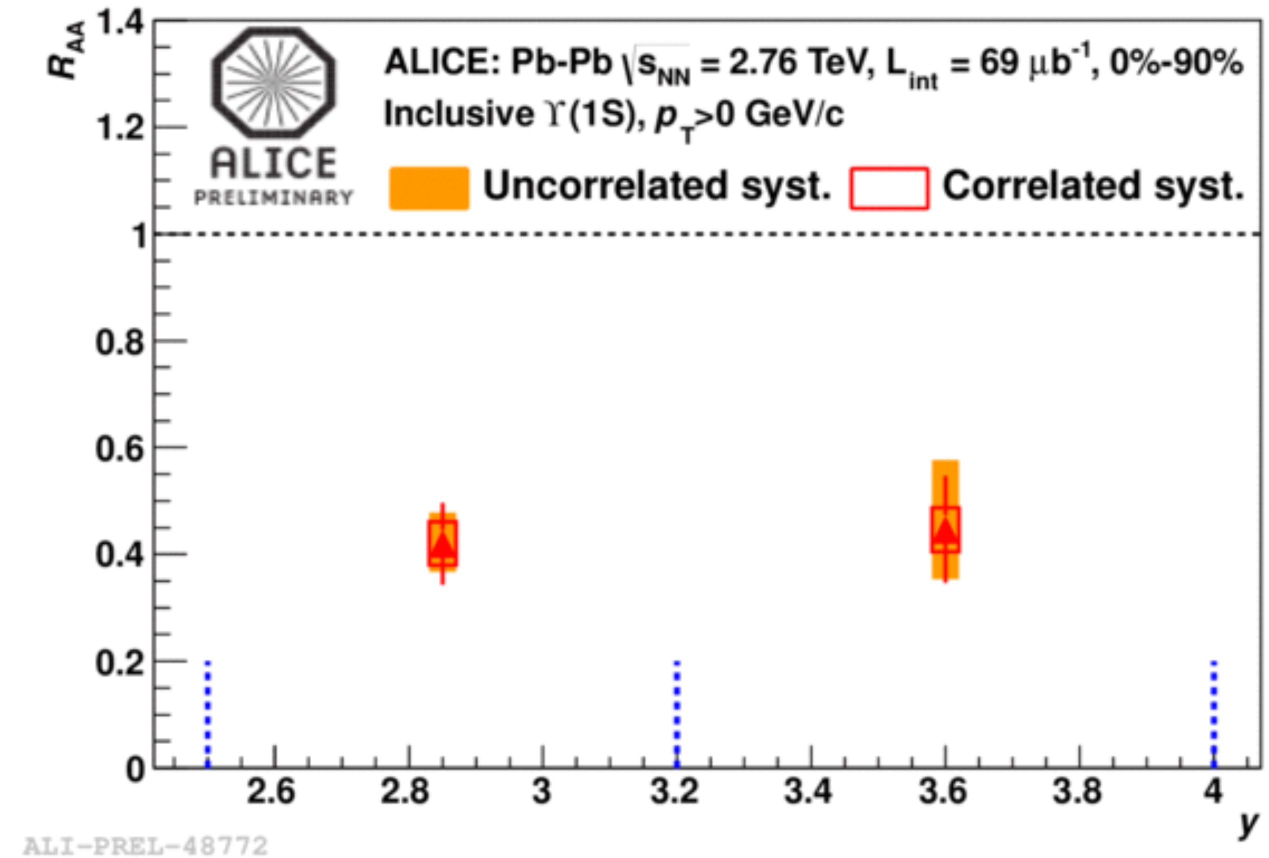


Preliminary inclusive Υ(1S) R_{AA}

ALICE PbPb @ 2.76 TeV

- R_{AA} of inclusive Υ(1S) in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV



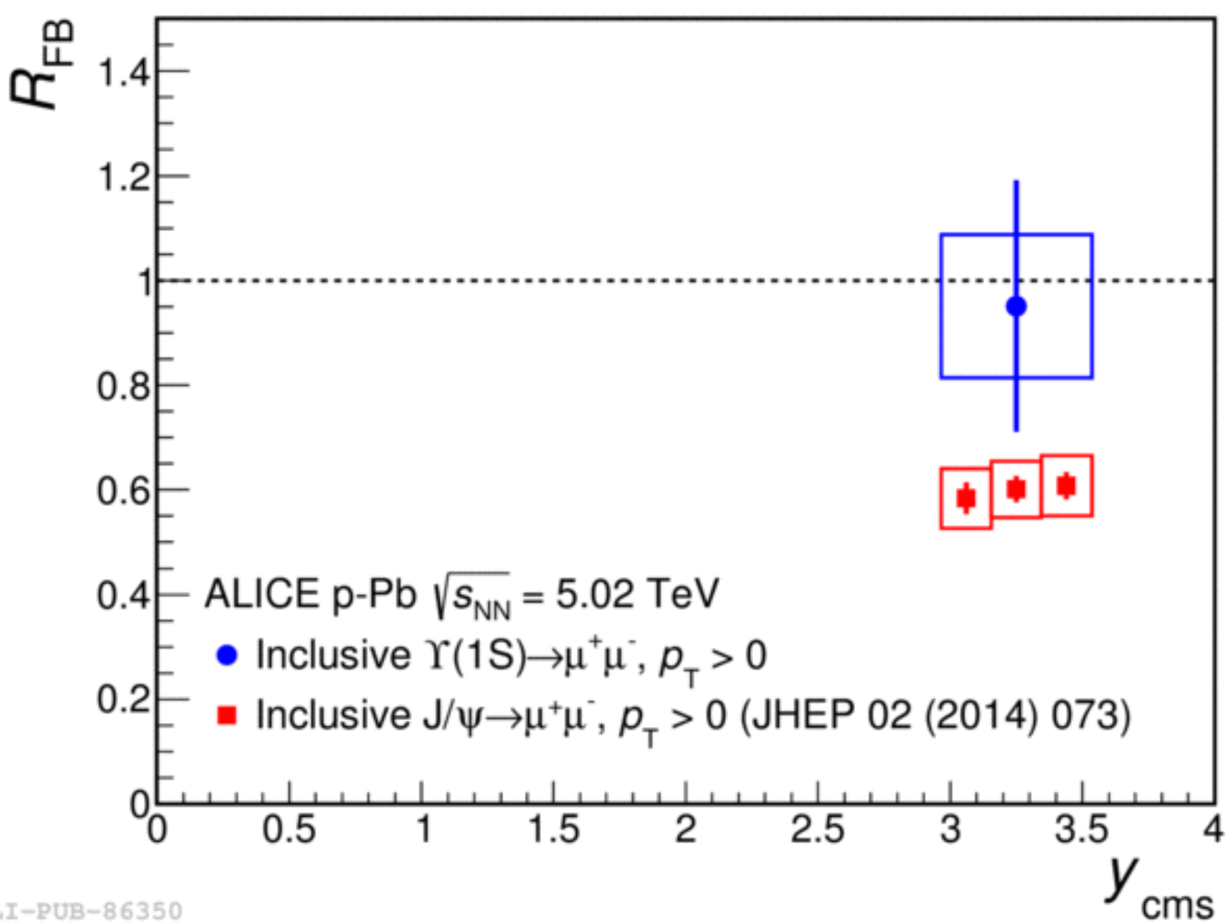


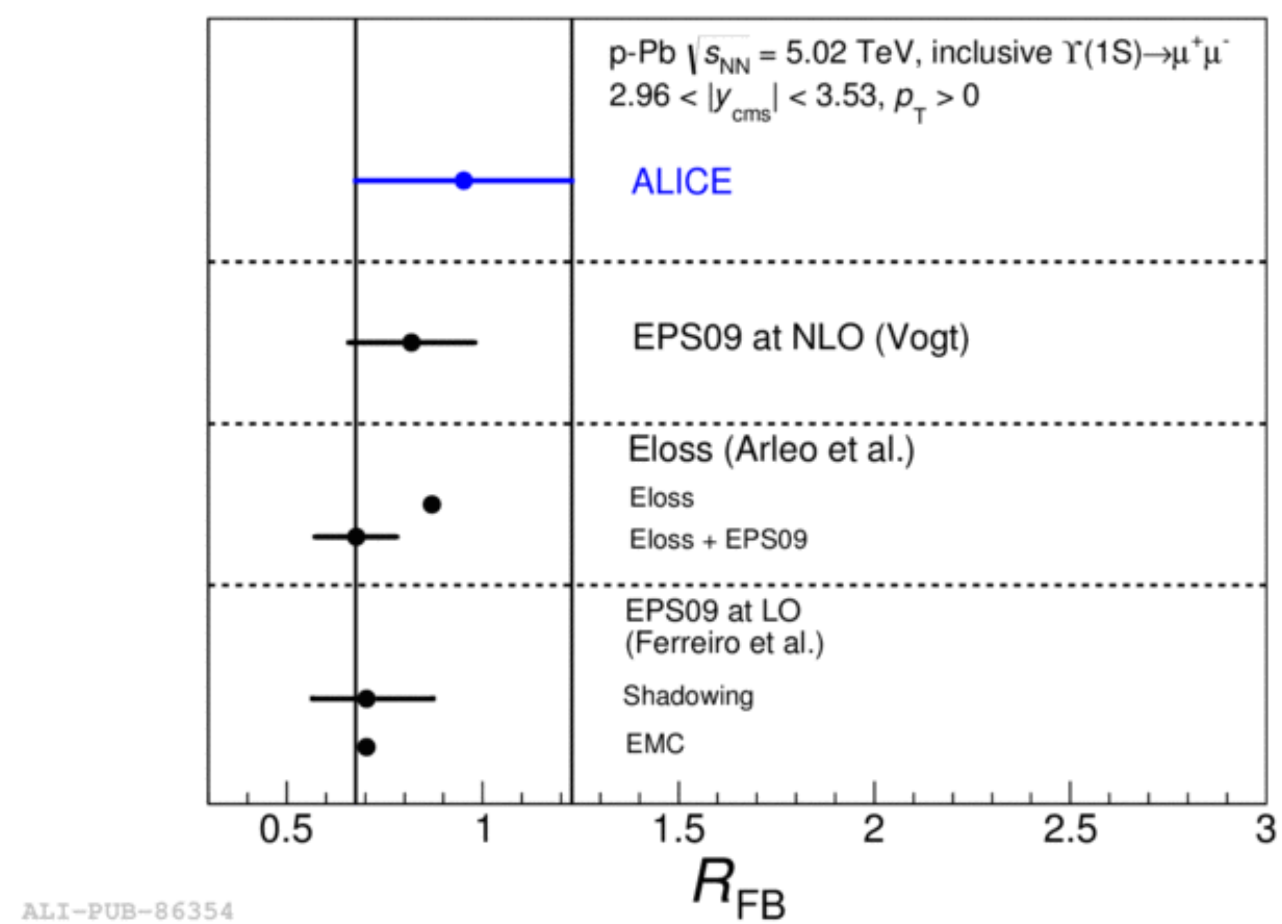
- Depending on the rapidity interval, the pp reference obtained with the interpolation and extrapolation procedure and the LHCb data [EPJC74 (2014) 2835] differ by 30-35%, which implies a change on the modification factor by 1.3 to 2.2σ.

Forward to Backward ratio

PLB 738 (2014) 361

- Ratio of the Forward to Backward yields
  - Pros: No need of pp reference
  - Cons: Rapidity acceptance restricted to common region $2.96 < |y_{cms}| < 3.53$





- All models are in agreement with our measurement within uncertainties