Upsilon Production in Pb-Pb and p-Pb Collisions at Forward Rapidity with ALICE at the LHC

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Outline

- Motivation
- ALICE Detector
- Results from 2011 Pb-Pb run at $\sqrt{s_{NN}}$ = 2.76 TeV :
  - → Υ(1S) R_{AA} versus centrality
  - → Υ(1S) R_{AA} versus rapidity
  - → Comparison to model predictions
- Results from 2013 p-Pb and Pb-p run at $\sqrt{s_{NN}}$ = 5.02 TeV :
  - → Υ(1S) R_{pPb} at forward and backward rapidity
  - → Forward Backward Ratio (R_{FB}) for Υ(1S)
  - → Comparison to model predictions
- Summary and Outlook

Motivation: Bottomonium in Heavy-Ion Collisions

- Quarkonium (J/ψ and ϒ) suppression is one of the most striking signatures for QGP formation in AA collisions
- Charm (1.2 - 1.4 GeV) and Bottom (4.6 - 4.9 GeV) quarks are massive

  → Production takes place at very early stage of the collision

- Sequential suppression pattern acts as a QGP thermometer

Resonance	J/ψ	Ψ'	ϒ(1S)	ϒ(2S)	ϒ(3S)
Mass [GeV]	3.10	3.68	9.46	10.02	10.36
ΔE [GeV]	0.64	0.05	1.10	0.54	0.20
Radius [fm]	0.25	0.45	0.14	0.28	0.39

- Quarkonium (re)generation effects may take place if the initial heavy quark multiplicity is large
- ϒ expected to be cleaner than J/ψ
  → Absence of b-hadron feed-down
  → Less recombination is expected than for charm

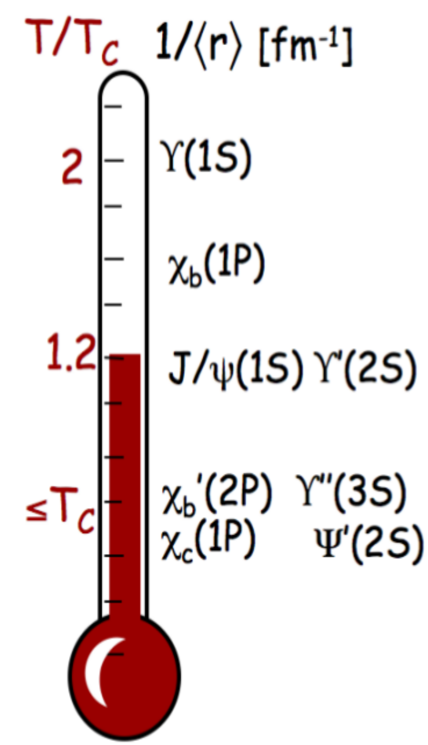
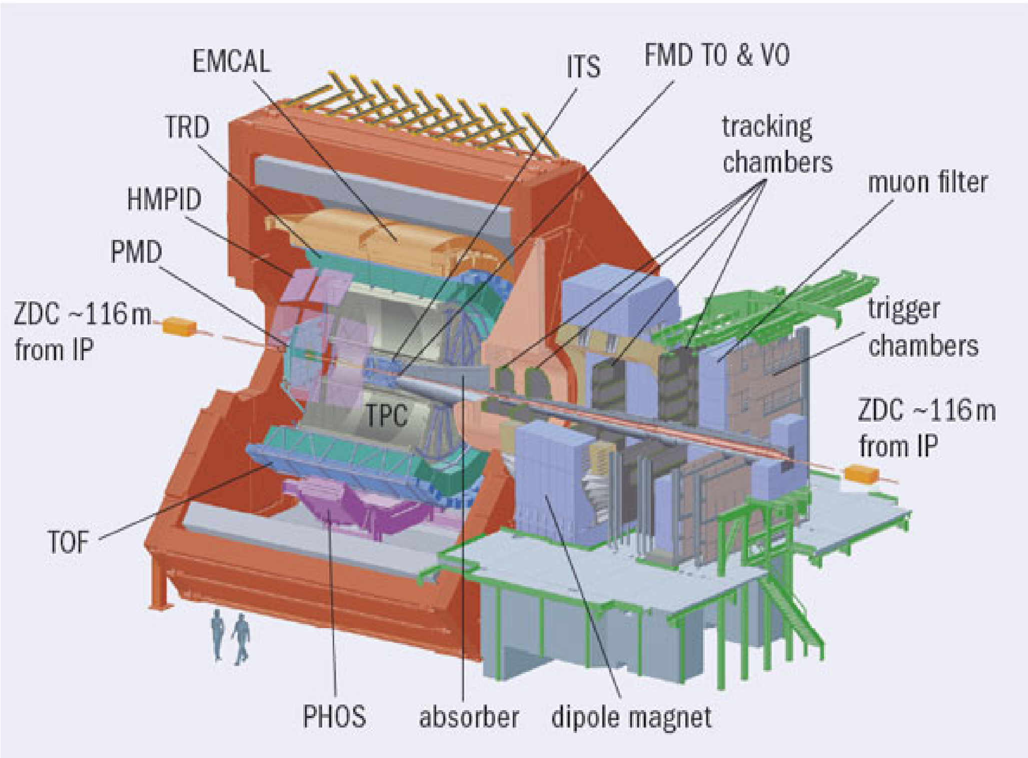
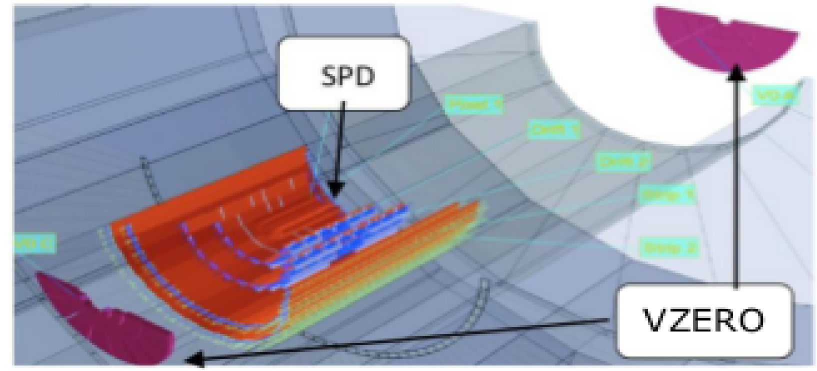


Fig. 5. The QGP thermometer.
Agnes Mocsy, Eur.Phys.J.C61, 2009

ALICE Detector





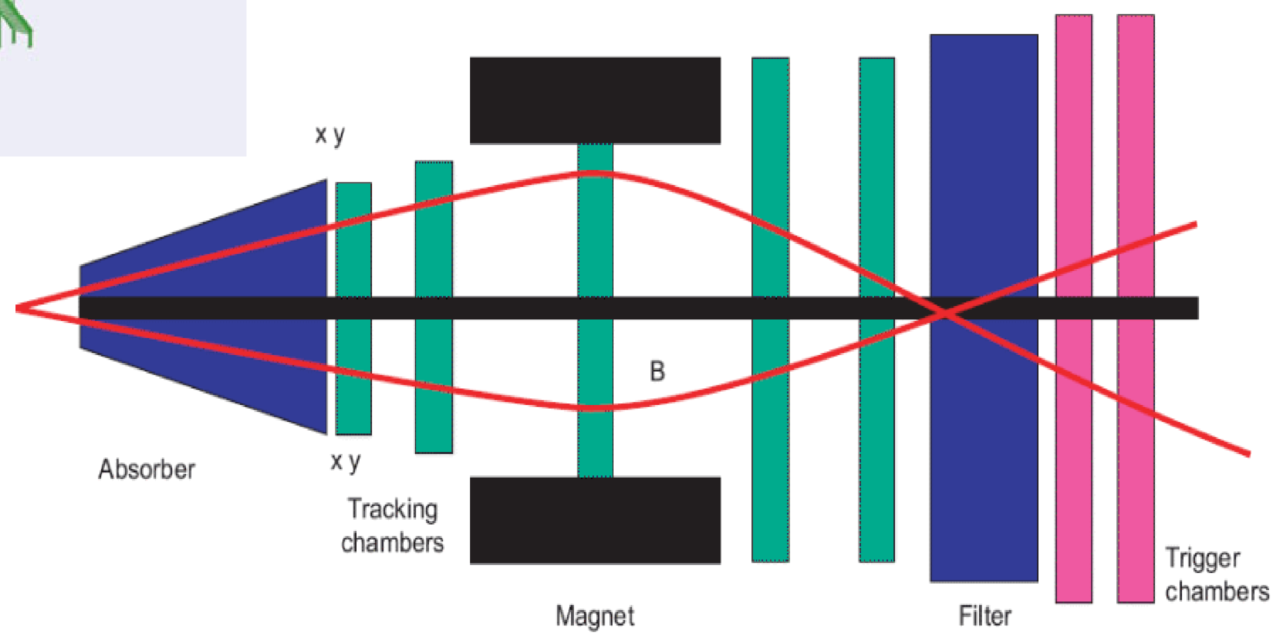
→ SPD used for vertex determination

→ Centrality in Pb-Pb estimated by fitting VZERO amplitude with Glauber model

→ Forward Rapidity: $2.5 < y < 4.0$

→ Acceptance down to zero p_T

→ $\Upsilon(1S) \rightarrow \mu^+\mu^-$ (2.48 %)

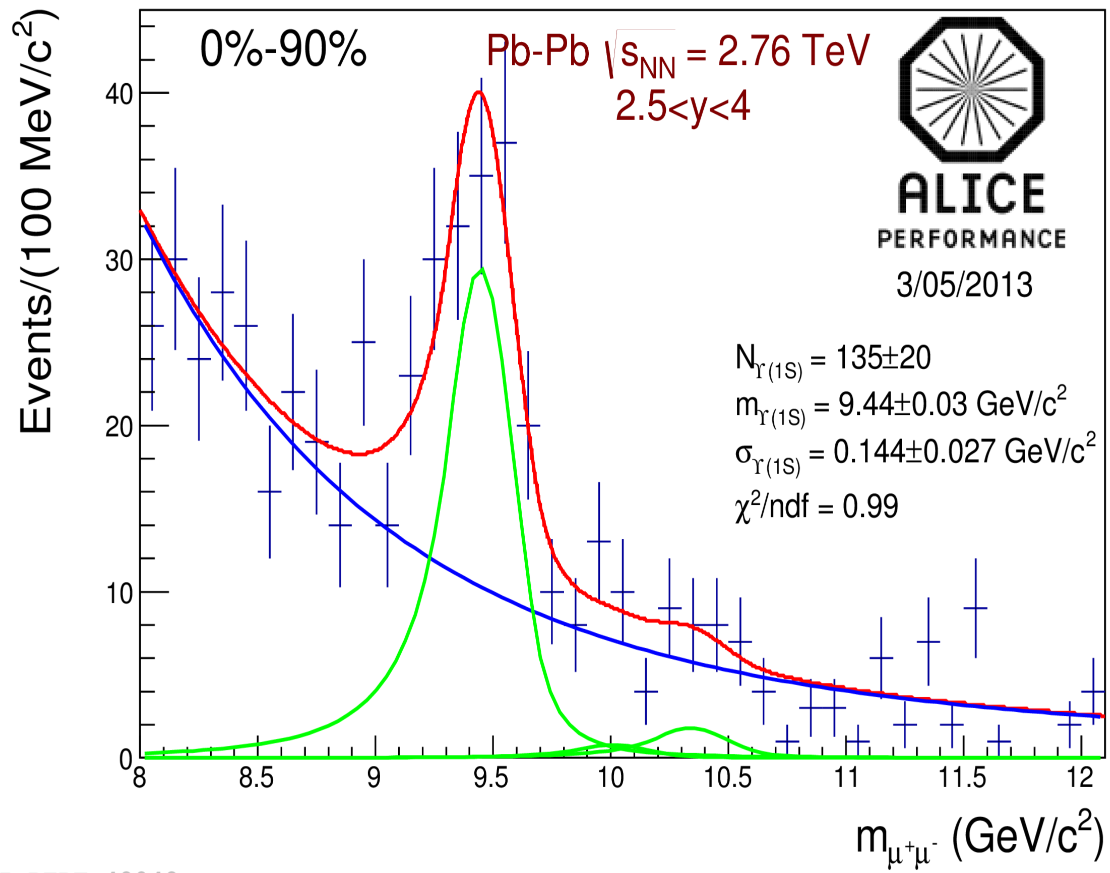


Rapidity Coverage of CMS: |y| < 2.4

Nuclear Modification Factor

The suppression of quarkonia can be quantified by measuring the Nuclear Modification Factor $R_{AA(pPb)}$, which is the ratio of the production in AA(pPb) collisions to the production in pp scaled by the number of binary collisions.

$$R_{AA(pPb)} = \frac{N^{\Upsilon(1S)}_{AA(pPb)}}{\langle N_{coll} \rangle_{AA(pPb)} \times N^{\Upsilon(1S)}_{pp}}$$



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$N_{\Upsilon(1S)}$ → measured number of $\Upsilon(1S) \rightarrow \mu^+\mu^-$

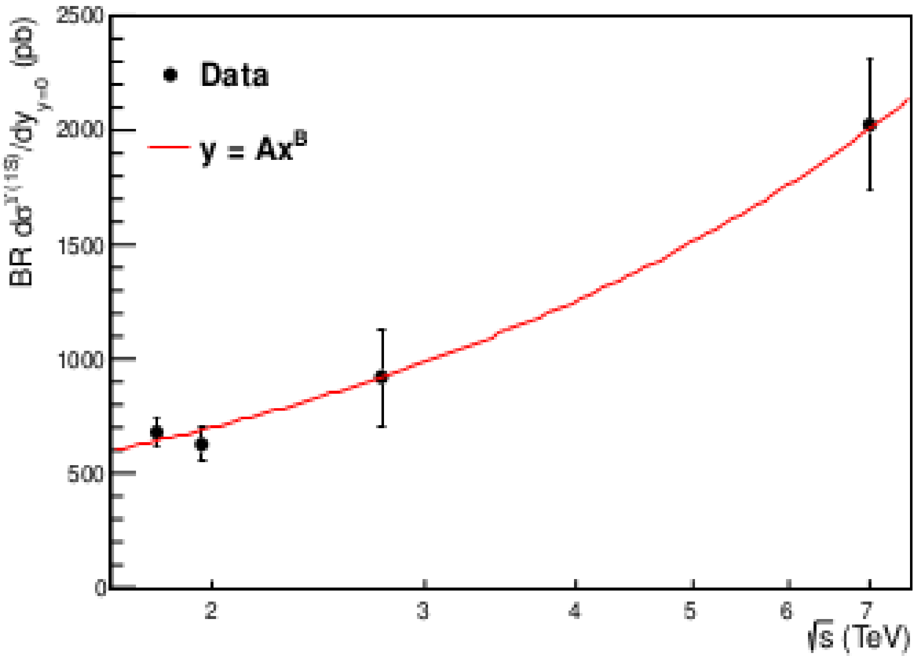
N_{coll} → number of binary collisions

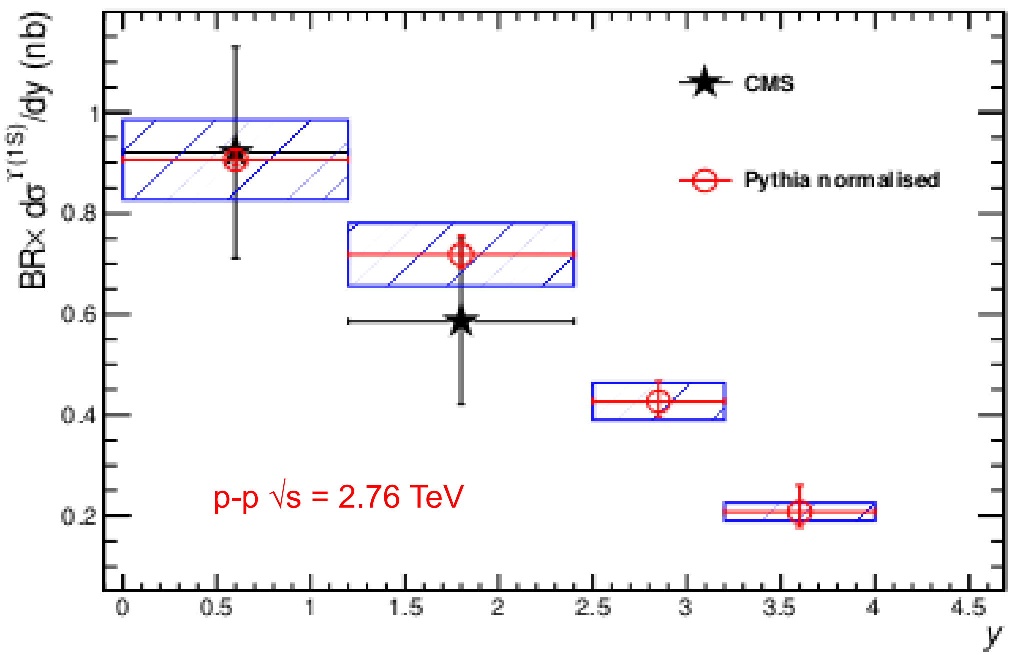
Estimation of pp Reference Cross-Section

- The pp reference dσ/dy for ϒ(1S) in the forward rapidity regions of interest for $\sqrt{s_{NN}}$ = 2.76(5.02) TeV is evaluated in two steps:

1. Interpolation of dσ/dy at y=0 using available mid-rapidity data (Tevatron + LHC) to get ϒ(1S) cross-section at 2.76(5.02) TeV

2. Extrapolation of dσ/dy from mid to forward rapidity using the rapidity shape given by Pythia 6.4





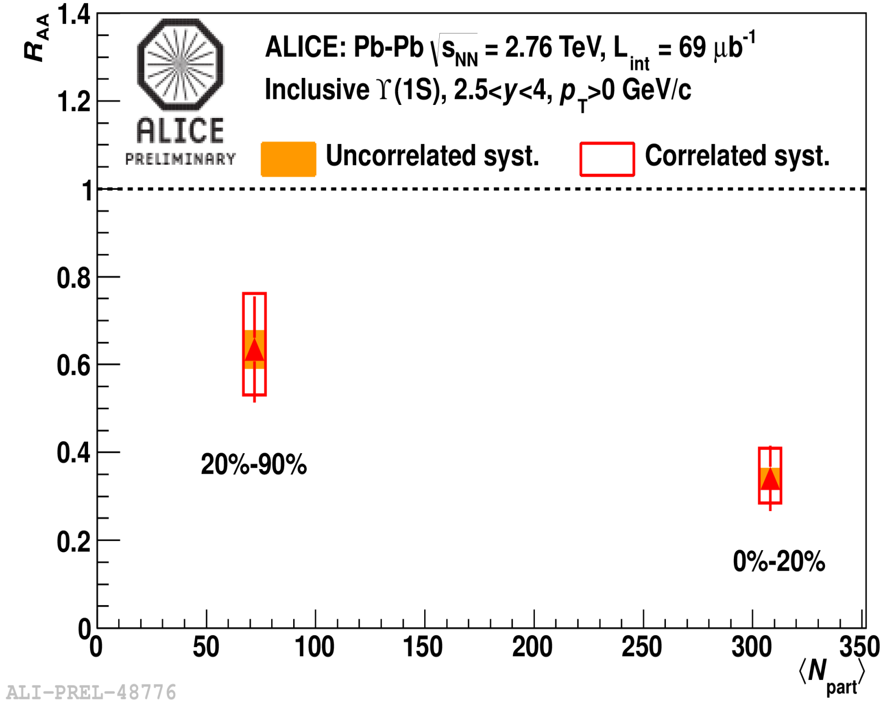
References for Experimental Data Points:

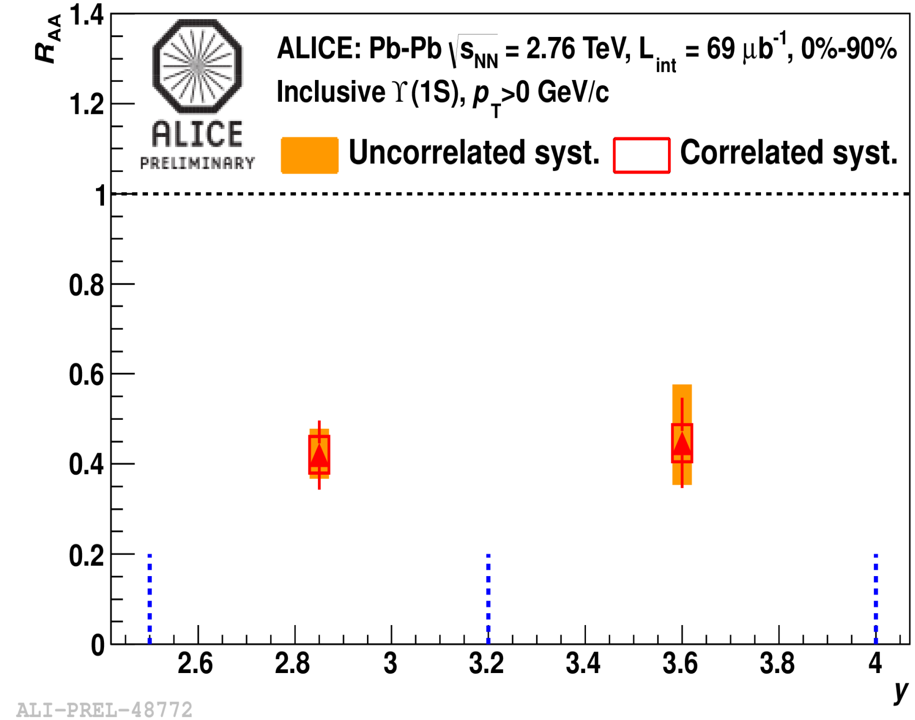
CDF(1.8 TeV) → D. Acosta et al. [CDF Collaboration], Phys. Rev. Lett. 88 (2002) 161802.
D0 (1.96 TeV) → V. M. Abazov et al. [D0 Collaboration], Phys. Rev. Lett. 94 (2005) 232001 [Erratum-ibid. 100 (2008) 049902] [hep-ex/0502030].
CMS(2.76 TeV) → S. Chatrchyan et al. [CMS Collaboration], JHEP 1205, 063 (2012) [arXiv:1201.5069 [nucl-ex]].
CMS(7 TeV) → V. Khachatryan et al. [CMS Collaboration], Phys. Rev. D 83, 112004 (2011) [arXiv:1012.5545 [hep-ex]].
LHCb(7 TeV) → R. Aaij et al. [LHCb Collaboration], Eur. Phys. J. C 72, 2025 (2012) [arXiv:1202.6579 [hep-ex]].

Pb-Pb Results at $\sqrt{s_{NN}}$ = 2.76 TeV

(Integrated Luminosity 69 μb^{-1})

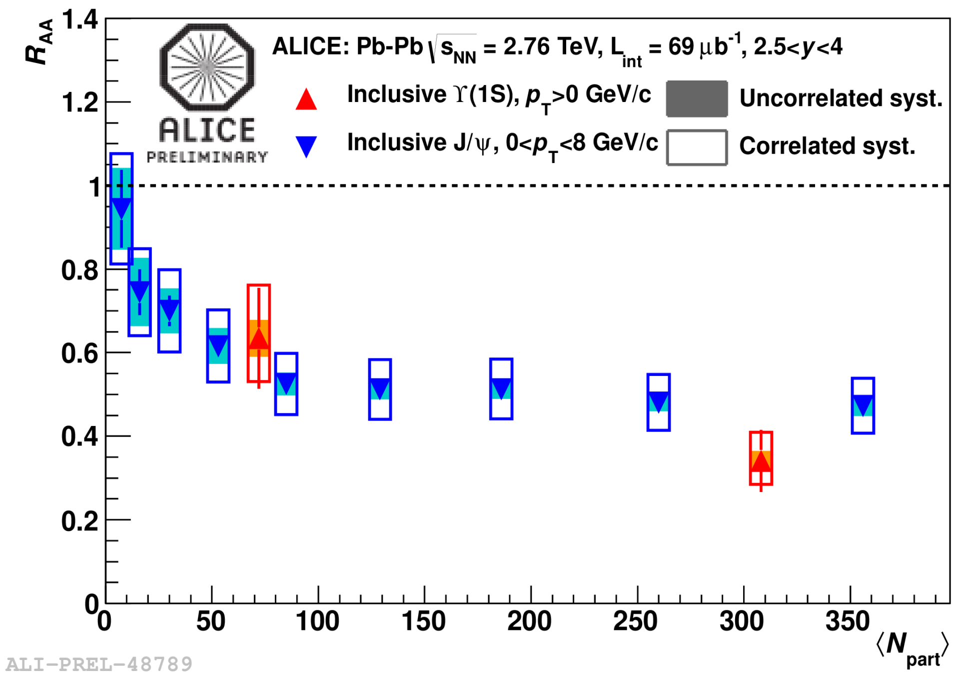
Nuclear Modification Factor of Inclusive ϒ(1S) in Pb-Pb

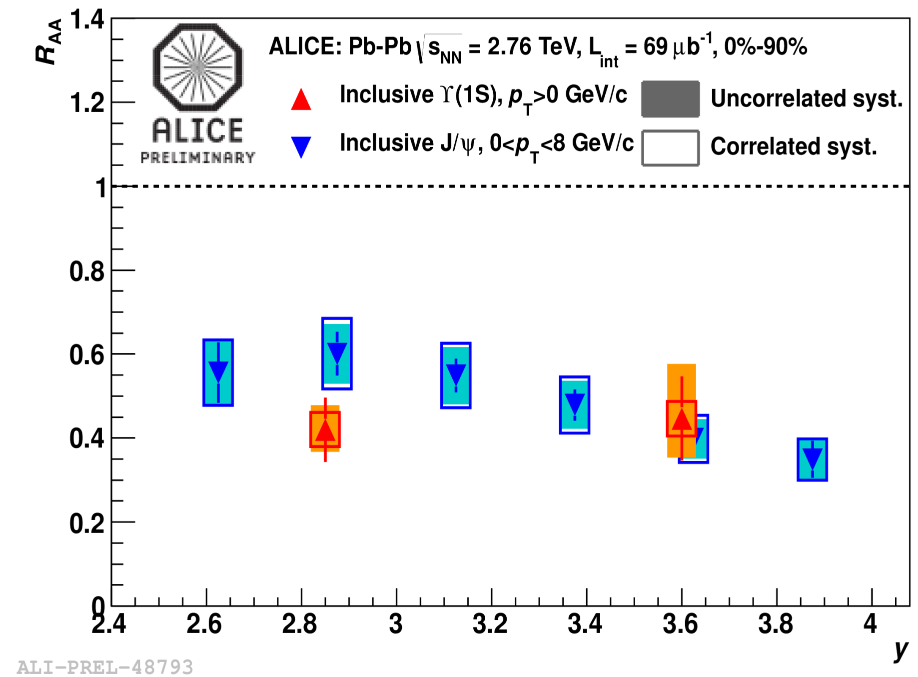




- We observe suppression of inclusive ϒ(1S)
- Suppression stronger in central collisions
- No rapidity dependence within uncertainties

Comparison of J/ψ and ϒ(1S)





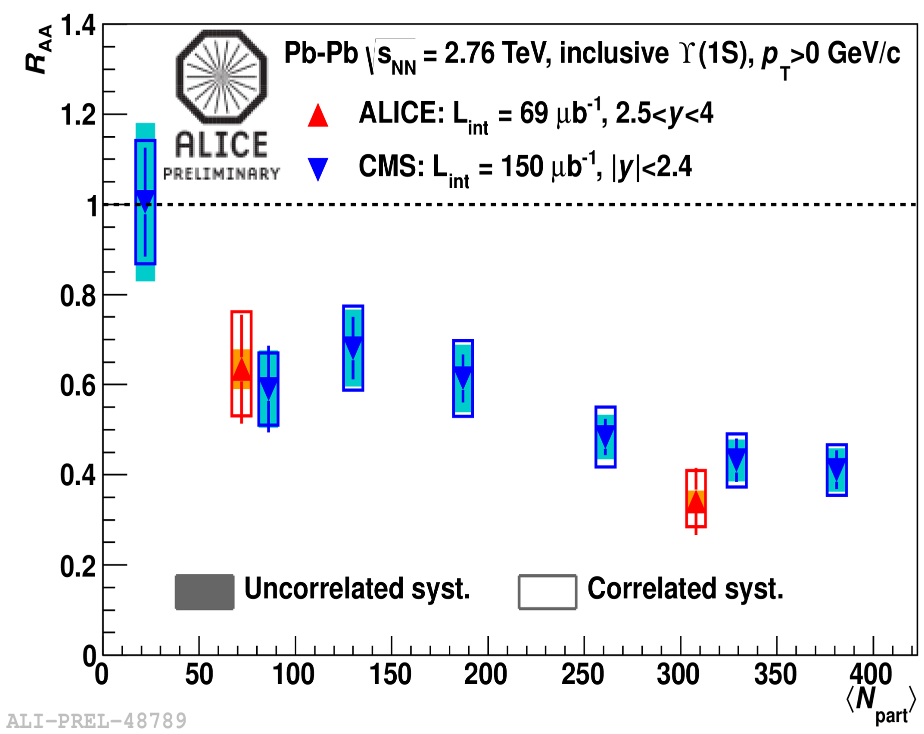
→ Suppression of ϒ and J/ψ is comparable within the present uncertainties

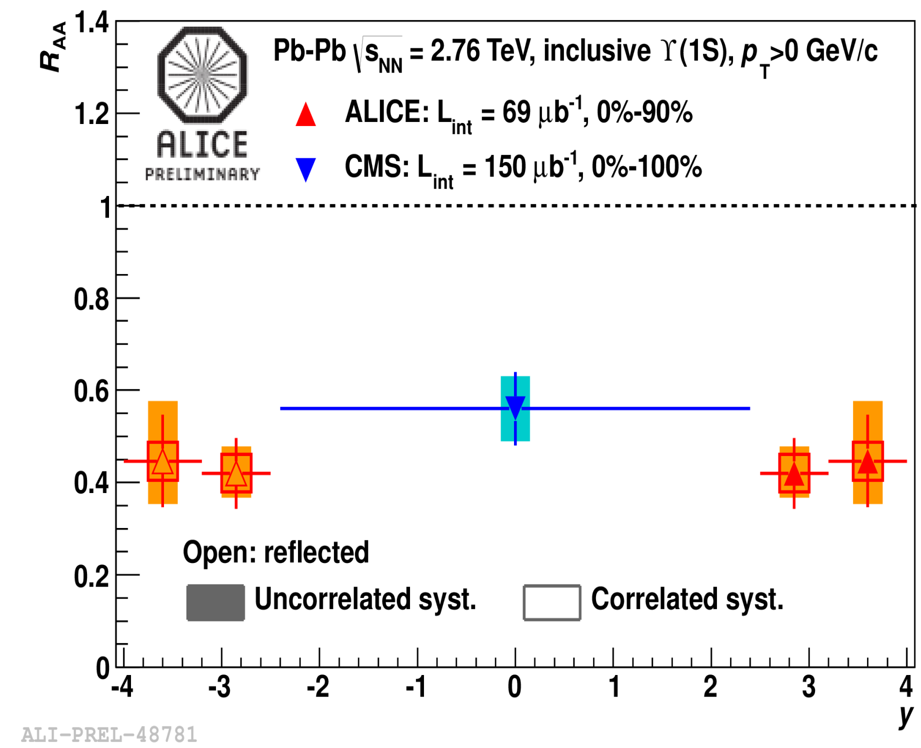
→ ϒ is expected to be less sensitive to regeneration than J/ψ

→ Feed down from higher excited states ϒ(2S), ϒ(3S), χ_b, χ_b' ~ 50 %

→ Weak rapidity dependence of R_{AA} for both J/ψ and ϒ(1S)

Comparison of ALICE forward-rapidity results with CMS mid-rapidity



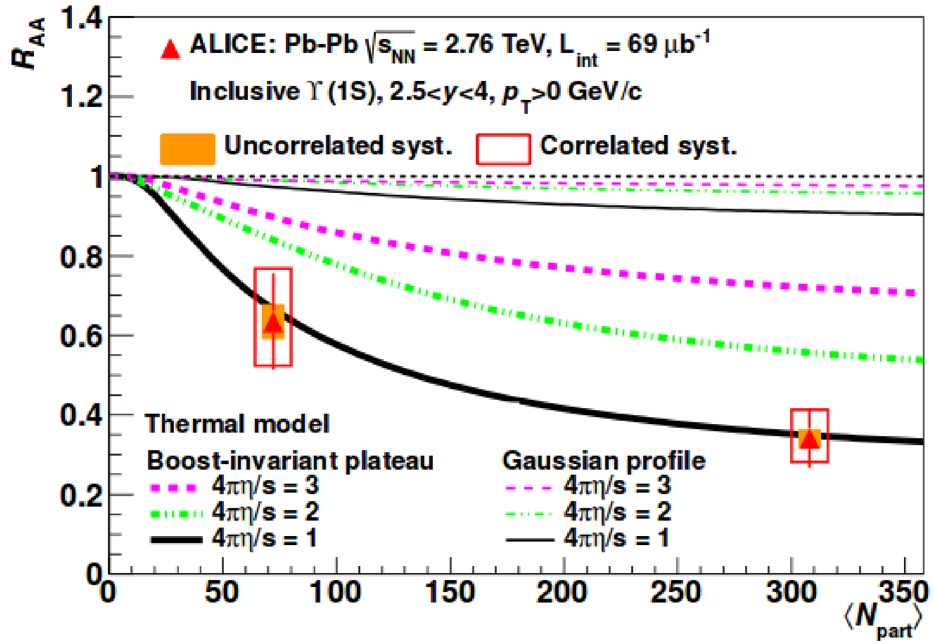


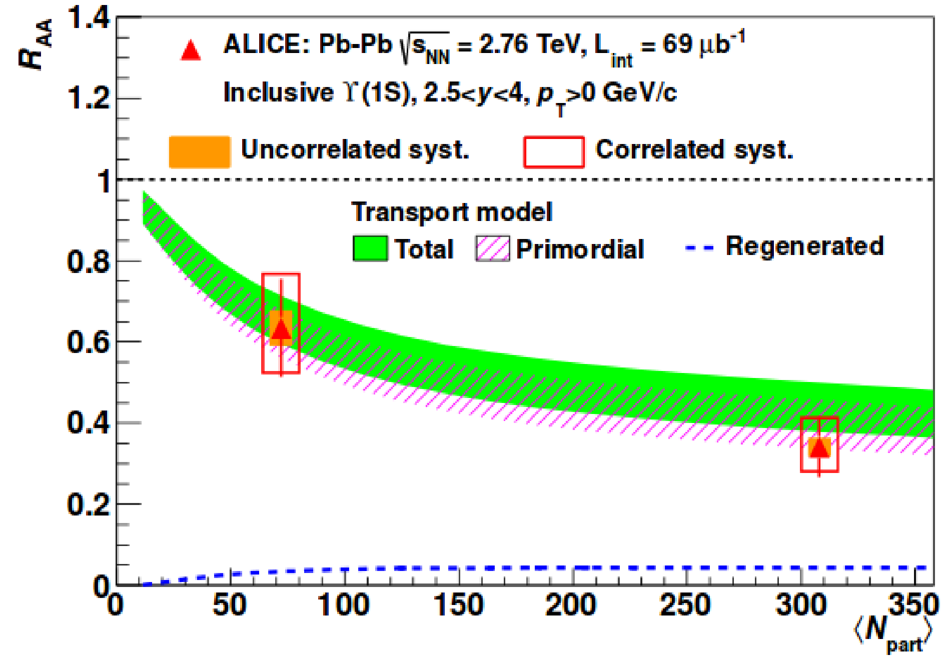
→ The suppression at forward rapidity in ALICE is similar to that at mid-rapidity measured by CMS for both central and semi-peripheral collisions

→ No strong rapidity dependence of R_{AA} within the large range probed by ALICE and CMS

Reference for CMS Data points: PRL 109, 222301, (2012)

Comparison With Model Predictions





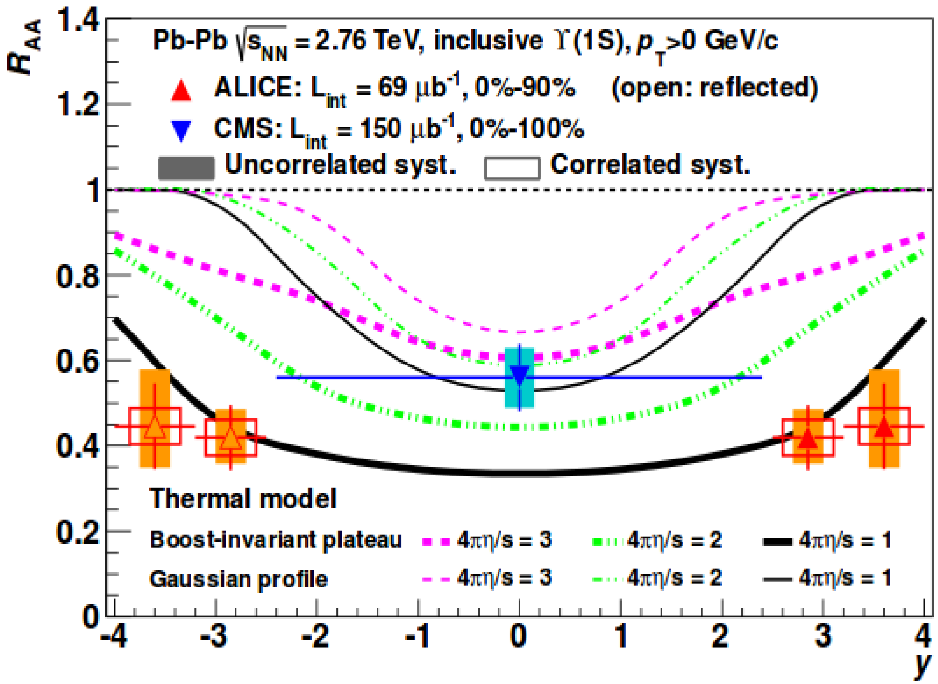
→ Strickland anisotropic hydro model includes feed-down of Υ(1S) by higher mass states, but does not include recombination effects and cold nuclear matter effects

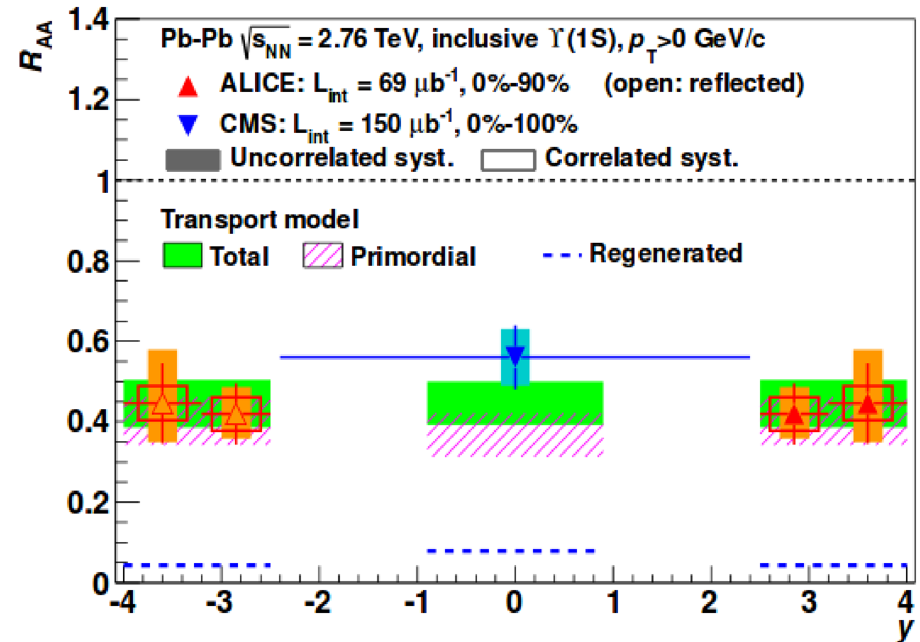
→ Data is described with the hypothesis of a boost invariant plateau temperature profile with minimum shear viscosity at forward-rapidity

→ Emerick et al. rate equation model includes small $b\bar{b}$ regeneration, feed-down from higher mass (~ 50 %) and CNM effects by an overall absorption cross-section of 0-2 mb

→ The model is in fair agreement with data within uncertainties

Comparison With Model Predictions





→ Both temperature profile can describe the mid-rapidity data, however Gaussian temperature profile is disfavored at forward rapidity

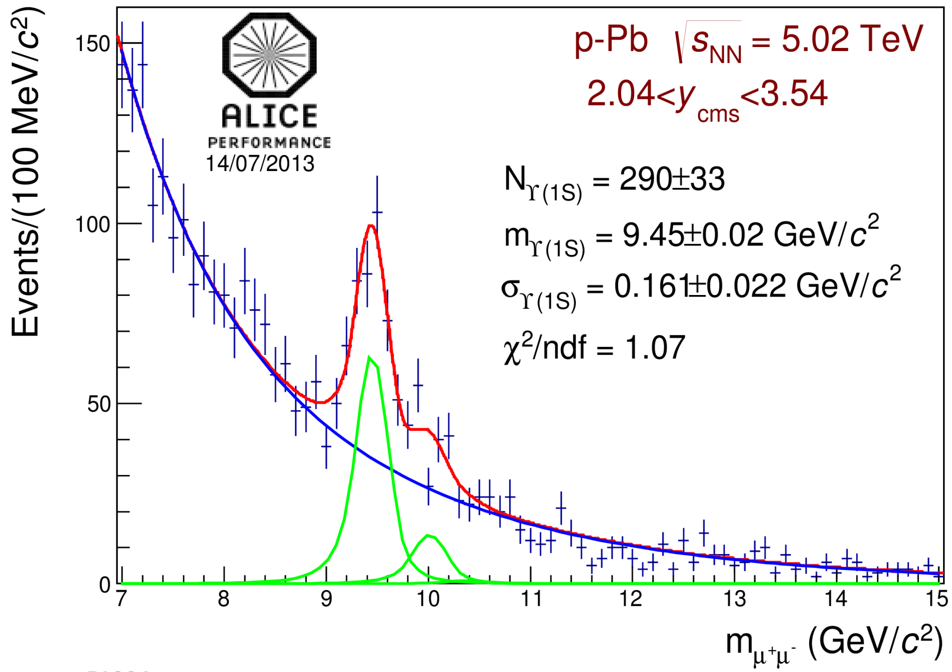
→ Although at forward-rapidity data is described with lowest 4πη/s, the predicted R_{AA} should be considered as an upper limit, as CNM is not taken into account

→ The Transport can describe the data both at mid- and forward-rapidity region

p-Pb and Pb-p Results at $\sqrt{s_{NN}} = 5.02$ TeV

[Integrated Luminosity 5.0 nb^{-1} (p-Pb) and 5.8 nb^{-1}(Pb-p)]

Nuclear Modification Factor of Inclusive Υ(1S) in p-Pb



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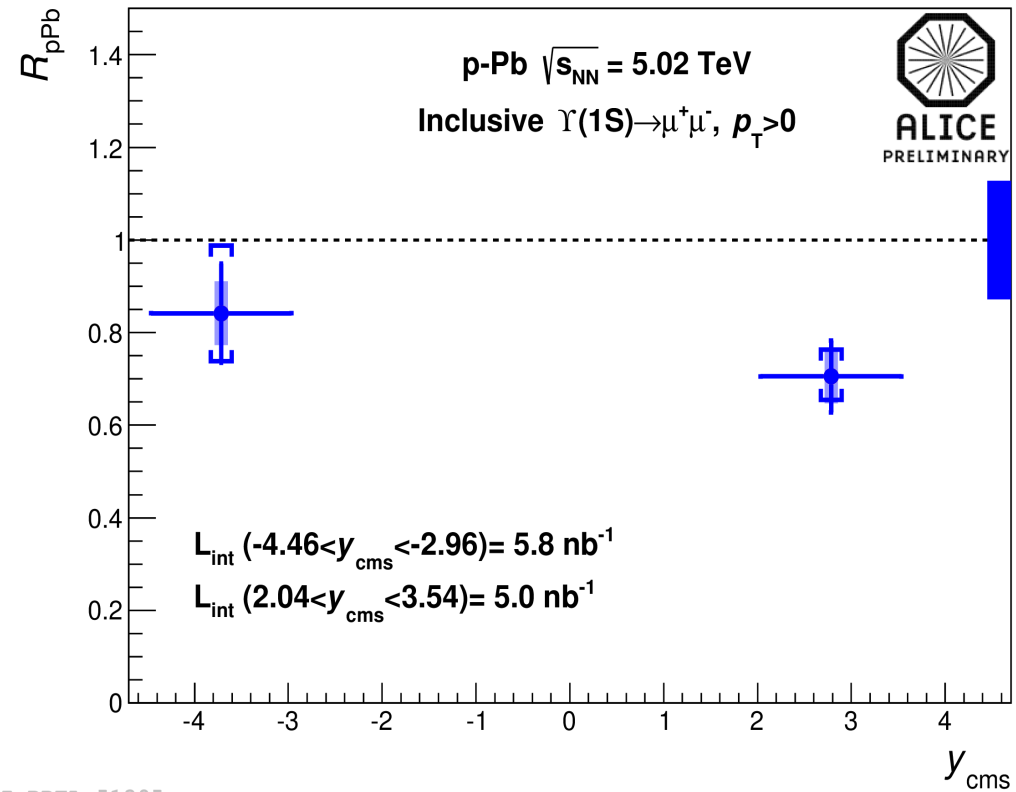

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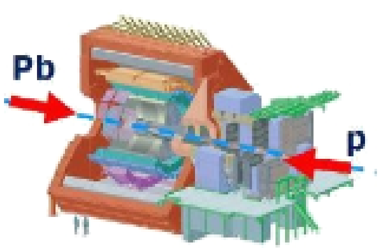
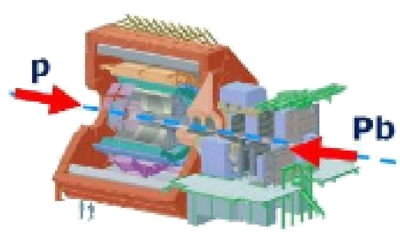


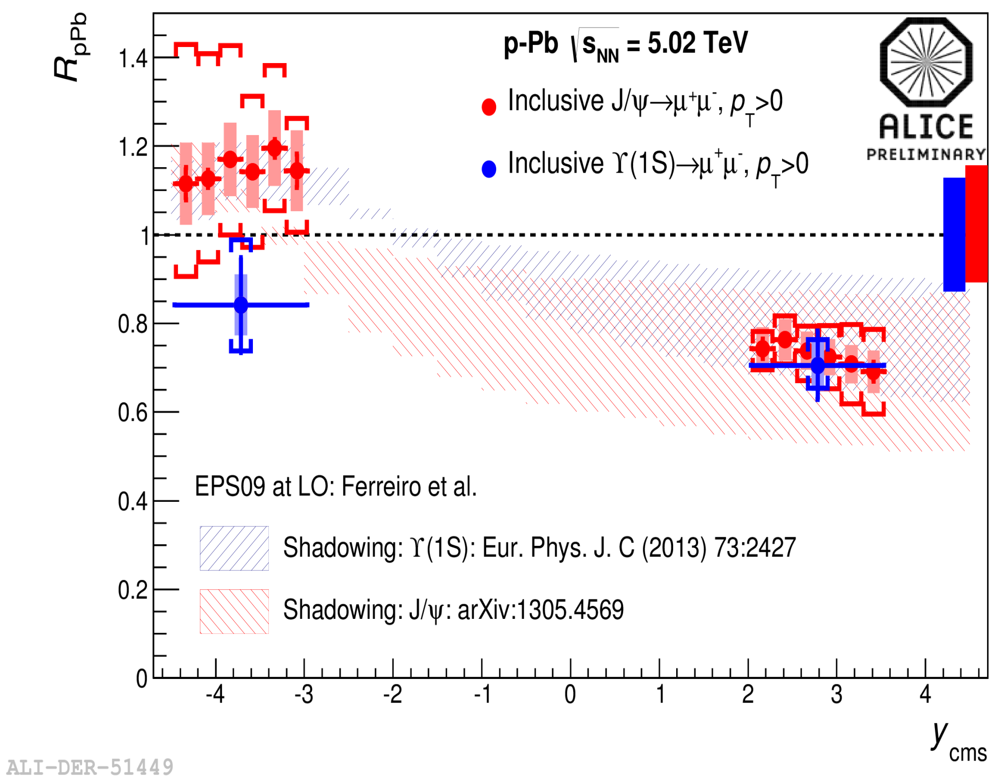
-4.46<y_{CMS}<-2.96

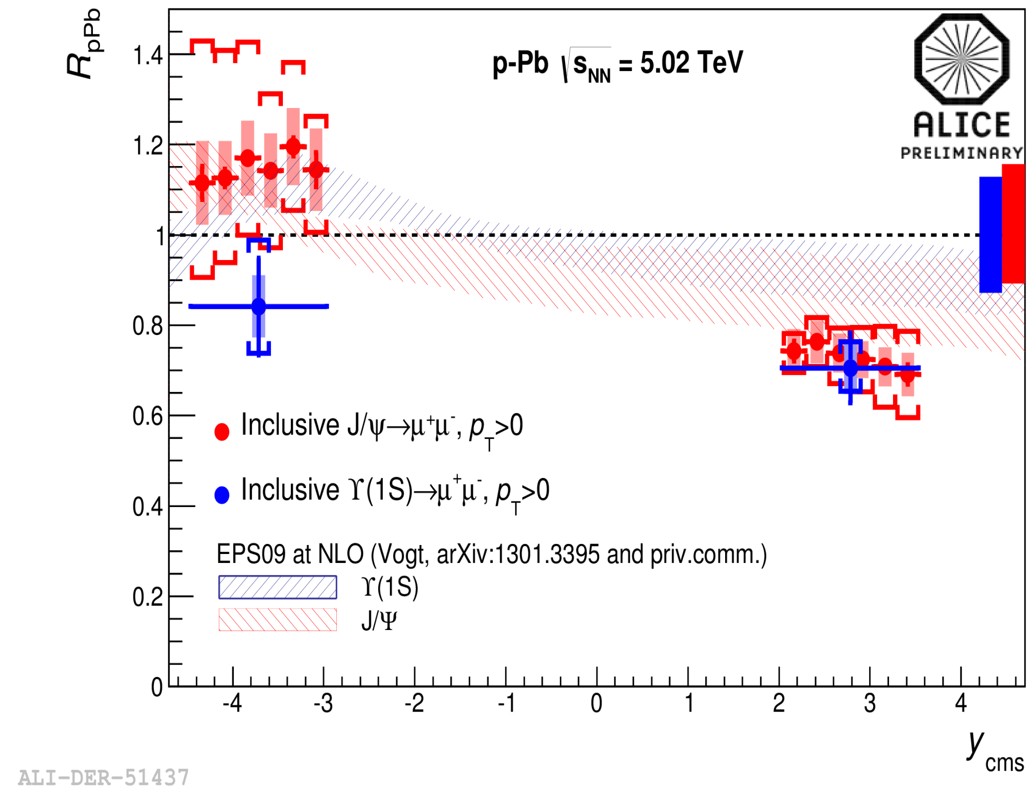


2.03<y_{CMS}<3.53

→ A suppression is observed for inclusive Υ(1S), stronger at forward rapidity

Comparison With Model Predictions



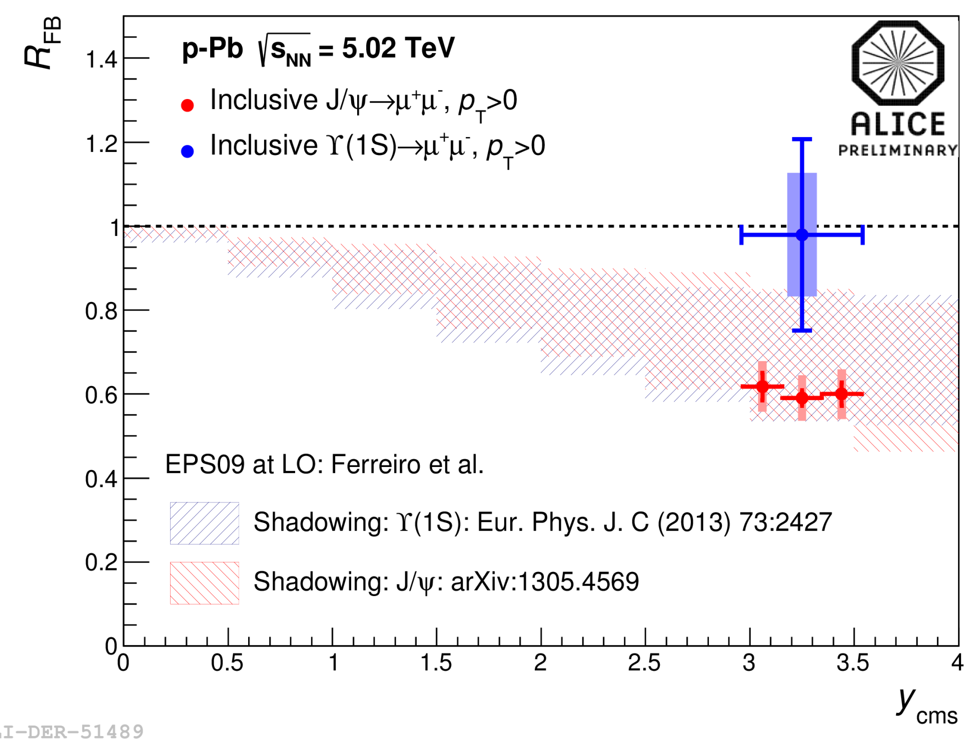


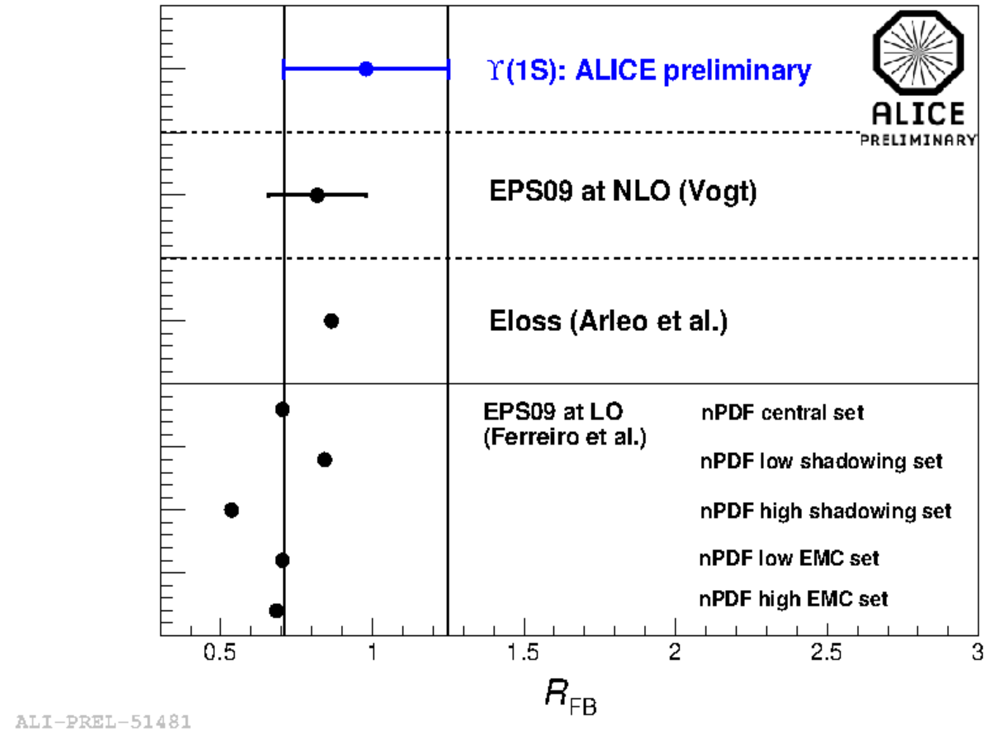
→ EPS09 calculation at LO from Ferreiro et al. model describes the data within uncertainties.

→ The agreement is better for J/ψ

→ EPS09 calculation at NLO from Vogt model describes quite well the J/ψ data and reproduces, with slightly larger values, the observed trend for ϒ(1S)

Comparison With Models R_{FB}





$$R_{FB}^{\Upsilon(1S)} = \frac{R_{pA}^{\Upsilon(1S)}}{R_{Ap}^{\Upsilon(1S)}} = \left[\frac{N_{pA}^{\Upsilon(1S)}}{N_{Ap}^{\Upsilon(1S)}}\right] X \left[\frac{\langle AccxEff \rangle_{Ap}^{\Upsilon(1S)}}{\langle AccxEff \rangle_{pA}^{\Upsilon(1S)}}\right] X \left[\frac{N_{Ap}^{MB}}{N_{pA}^{MB}}\right]$$

→ The J/ ψ R_{FB} is significantly lower than ϒ(1S)

→ Within the uncertainties Ferreiro Model explains quite well the R_{FB} both for J/ψ and ϒ(1S)

→ All the models reproduce the forward to backward ratio within uncertainties

→ The ϒ(1S) result is at the upper edge of shadowing calculations, while for J/ψ the agreement is at the lower edge

Summary and Outlook

Results on Υ(1S) from Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV:

→ The nuclear modification factor for inclusive Υ(1S) has been measured at forward rapidity 2.5 < y < 4.0 down to zero p_T

→ Suppression stronger in central collisions

→ No rapidity dependence within uncertainties

→ Suppression pattern is comparable with forward-rapidity J/ψ result from ALICE within uncertainties

→ No strong rapidity dependence of R_{AA} within the large range probed by ALICE and CMS

Results on Υ(1S) from p-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV :

→ We observe small suppression of Υ(1S) in p-Pb data, which tends to increase from backward to forward rapidity

→ J/ψ suppression is comparable with Υ(1S) within uncertainties

→ J/ψ R_{FB} is significantly lower than Υ(1S)

THANK YOU

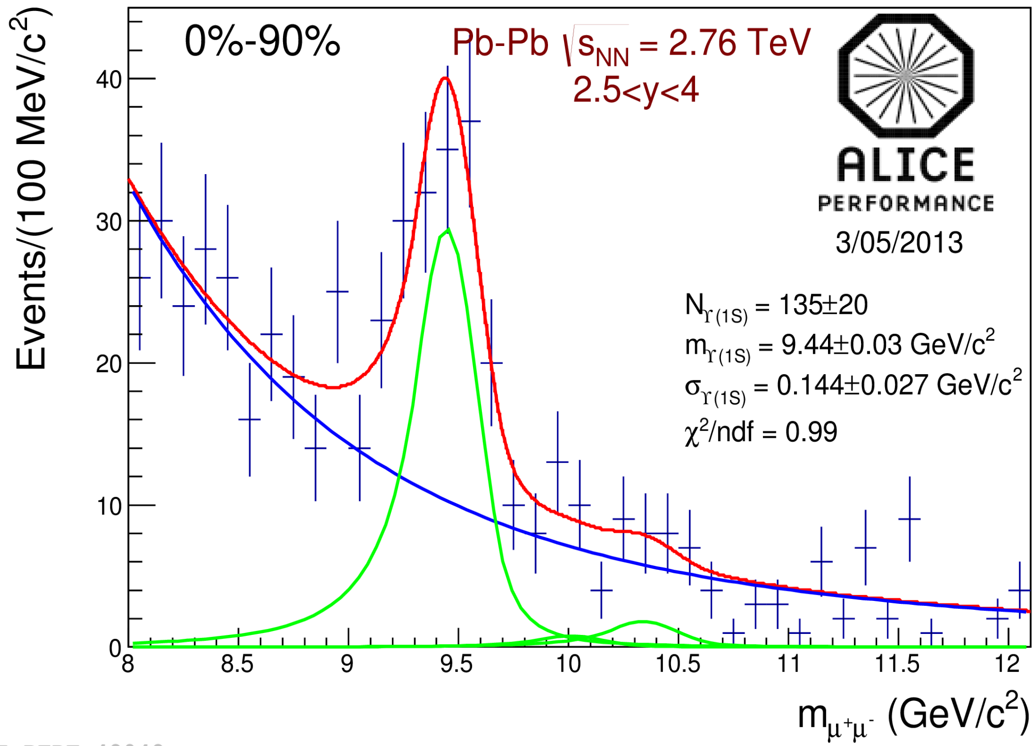
BACKUP

Signal Extraction - PbPb

Event Cuts:
Physics Selection
Unlike Sign Trigger
Centrality (0-90) %

Muon Cuts:
Trigger Matched Track (Lpt,Lpt)
$-4.0 < \eta < -2.5$
$17.6\ \text{cm} < R_{abs} < 89.5\ \text{cm}$
pDCA Selection
pT >= 2 GeV

Dimuon Cuts:
$-4.0 < y < -2.5$



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$$M_{Y(2S)} = M^{PDG}_{Y(2S)} + \left(M^{FIT}_{Y(1S)} - M^{PDG}_{Y(1S)} \right) \frac{M^{PDG}_{Y(2S)}}{M^{PDG}_{Y(1S)}}$$

$$M_{Y(3S)} = M^{PDG}_{Y(3S)} + \left(M^{FIT}_{Y(1S)} - M^{PDG}_{Y(1S)} \right) \frac{M^{PDG}_{Y(3S)}}{M^{PDG}_{Y(1S)}}$$

$$\sigma_{Y(2S)} = \sigma_{Y(1S)} \frac{M^{PDG}_{Y(2S)}}{M^{PDG}_{Y(1S)}} \qquad \sigma_{Y(3S)} = \sigma_{Y(1S)} \frac{M^{PDG}_{Y(3S)}}{M^{PDG}_{Y(1S)}}$$

→ Signal fitted with Double Crystal Ball

→ Tail parameters fixed from embedding

→ Mass, Sigma and Amplitude free for ϒ(1S)

→ Amplitude of ϒ(2S) and ϒ(3S) kept free

Systematic From Signal Extraction

Following sources of systematics have been considered:

1. Background Fit Function
   (Double Exponential and Double Power Law)

2. Mass Scaling of Υ(2S) and Υ(3S) → varied ± 0.5 %

3. Sigma Scaling of Υ(2S) and Υ(3S) → varied ± 25 %

4. Scaling of CB tail parameter alpha of Υ(2S) and Υ(3S) → varied ± 25 %

5. Scaling of CB tail parameter n of Υ(2S) and Υ(3S) → varied ± 25 %

→ Central value is the arithmetic average between results of reliable fits

→ Statistical error is the average value of statistical uncertainties

→ Systematic error is the RMS value between results of reliable fits for a given source of systematic

$$N_{\Upsilon(1S)} = N^{cent}_{\Upsilon(1S)} \pm N^{stat}_{\Upsilon(1S)} \pm N^{syst}_{\Upsilon(1S)}$$

$$N^{cent}_{\Upsilon(1S)} = \frac{\sum N^{i}_{\Upsilon(1S)}}{n}$$

$$N^{stat}_{\Upsilon(1S)} = \frac{\sum Error\ N^{i}_{\Upsilon(1S)}}{n}$$

$$N^{syst}_{\Upsilon(1S)} = \sqrt{\frac{\sum (N^{i}_{\Upsilon(1S)} - N^{cent}_{\Upsilon(1S)})^2}{n}}$$

RMS of two background functions and tail parameters (common source of systematics) are merged by this formula:

$$RMS = \sqrt{\frac{1}{N1+N2}\{N1*RMS1^2 + N2*RMS2^2\}}$$

Systematic From Signal Extraction - LHC13de

Sources of Systematics	Central Value ± Stat Error ± Syst Error	Central Value ± Stat Error ± Syst Error
Background Fit Function : Double Exponential Double Power Law	288 ± 28 (9.72 %) ± 12 (4.17 %) 304 ± 24 (7.89 %) ± 10 (3.29 %)	296 ± 26 (8.78 %) ± 11 (3.72 %)
Mass Scaling Factor :	294 ± 31 (10.54 %) ± 4 (1.36 %)	294 ± 31 (10.54 %) ± 4 (1.36 %)
Sigma Scaling Factor :	297 ± 32 (10.77 %) ± 9 (3.03 %)	297 ± 32 (10.77 %) ± 9 (3.03 %)
Crystal Ball Tail Parameters : Crystal Ball α Crystal Ball n	301 ± 30 (9.97 %) ± 9 (2.99 %) 295 ± 31 (10.51 %) ± 5 (1.69 %)	298 ± 31 (10.40 %) ± 7 (2.35 %)
TOTAL	… … ...	296 ± 30 (10.14 %) ± 16 (5.41 %)

Central Value : Arithmetic Average

Stat Error: Arithmetic Average

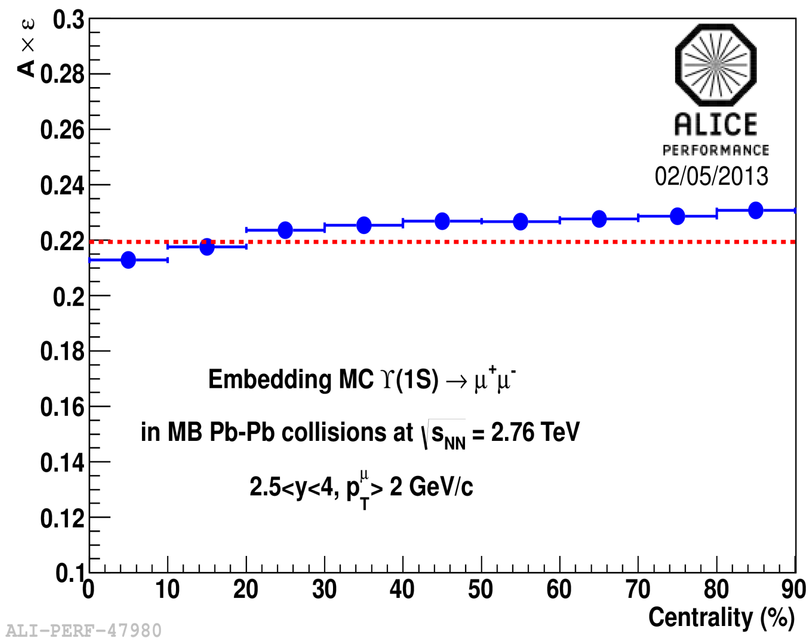
Syst Error: Quadratic Sum

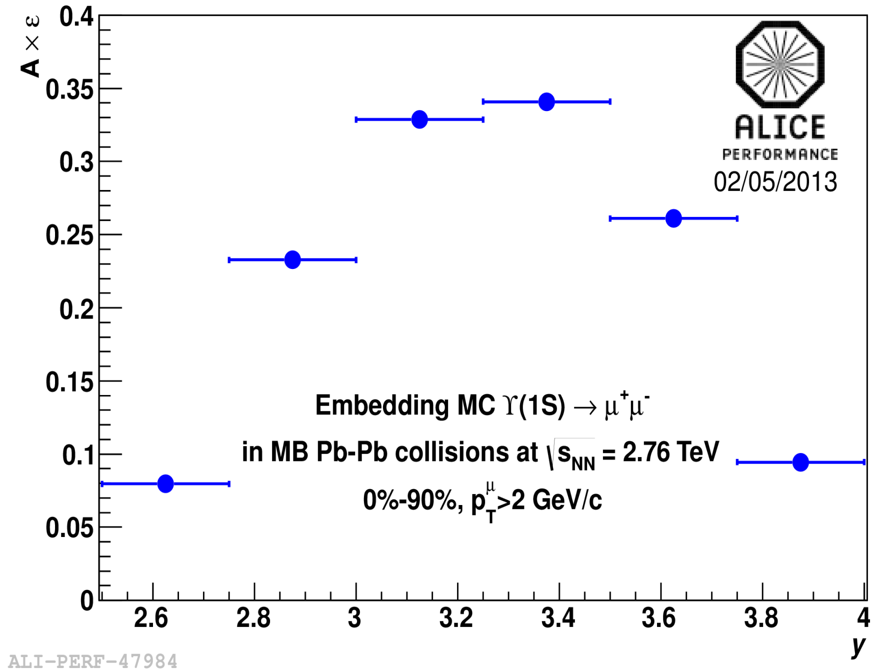
→ Statistical Error ~ 10 %

→ Systematic Error ~ 5 %

→ Dominant Source of Systematic is the BKG Fitting Function (~ 4%)

Acceptance Efficiency





→ Particle multiplicity high in Pb-Pb collisions, which affects tracl reconstruction efficiency

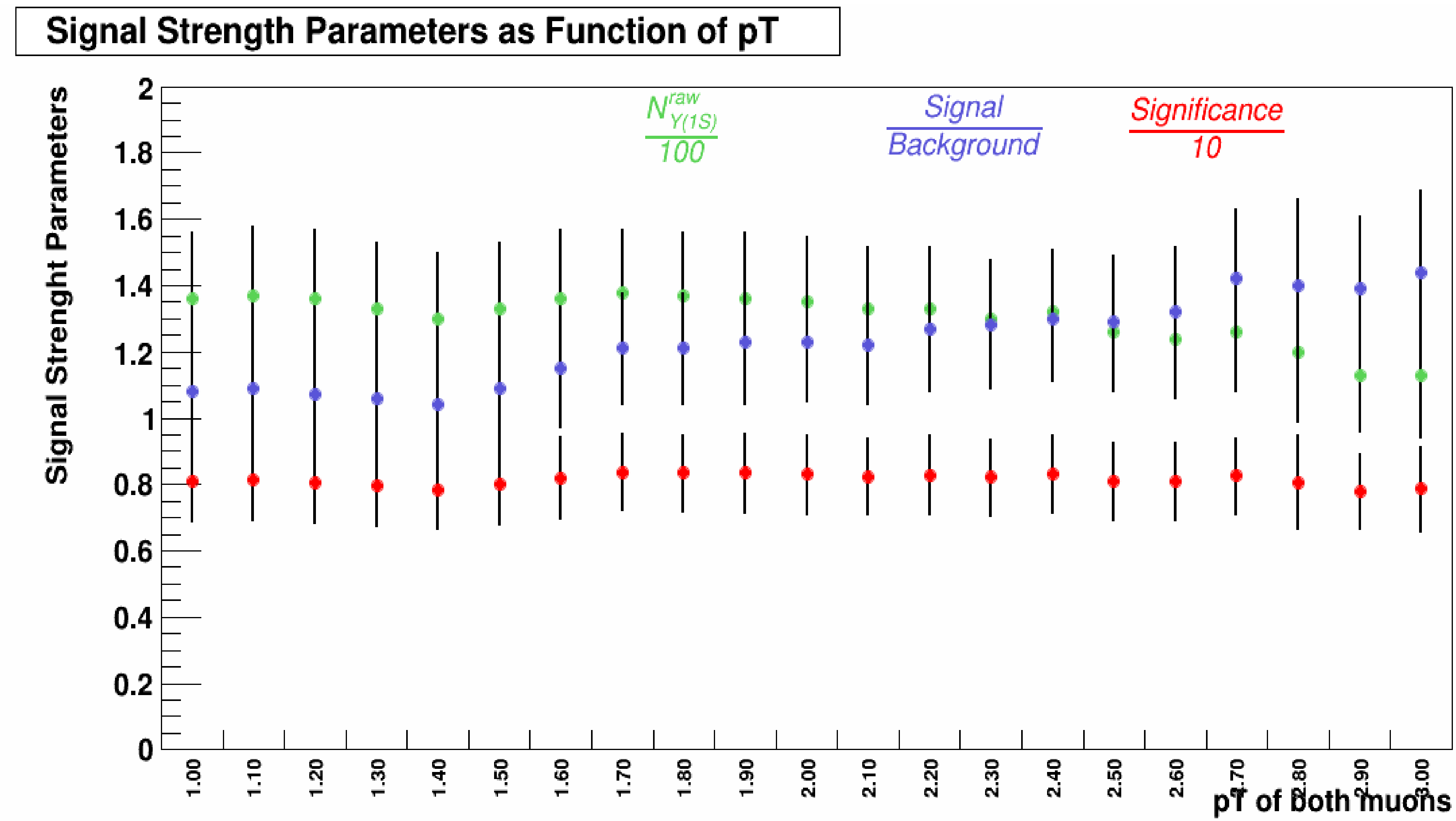
→ Embedding technique provides the most realistic background condition

→ ϒ(1S) generated using fast generator and forced to decay in dimuons

→ Particle transport and detector response provided by GEANT3

→ Run by run simulation done to incorporate time dependence of detector set up

Signal Strength Parameters

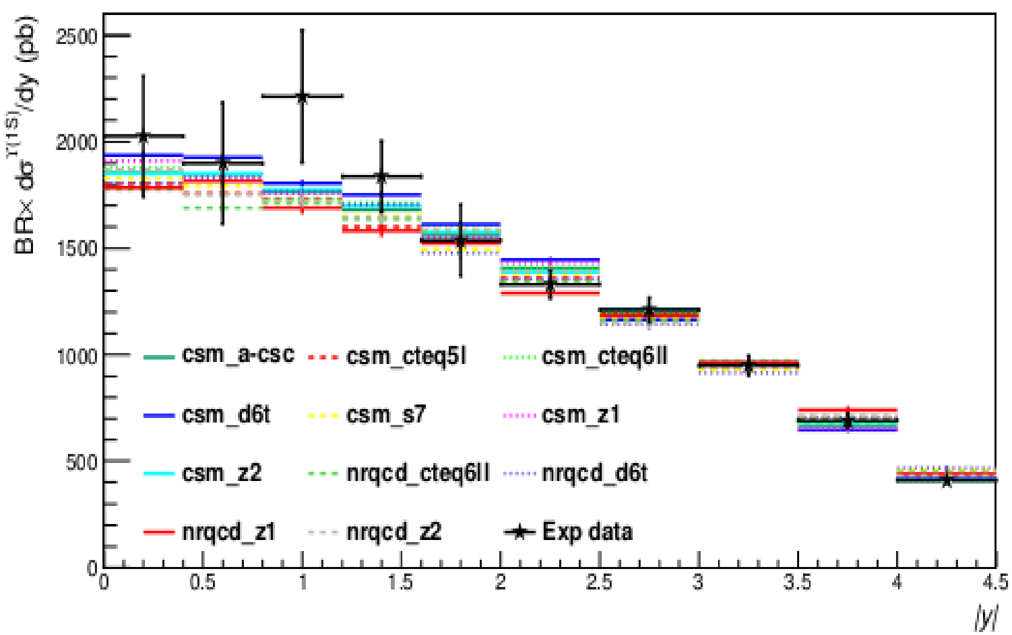


R_{pA} and R_{FB}

Nuclear Modification Factor R_{pA} :

$$R_{pA} = \frac{N_{pA}^{\Upsilon(1S)}}{\langle AccxEff\rangle_{pA}^{\Upsilon(1S)} \times \langle T_{pA}\rangle \times N_{pA}^{MB} \times \Delta y \times BR^{\Upsilon(1S)} \times \sigma_{pp}^{\Upsilon(1S)}}$$

- T_{pPb} = 0.0983 ± 0.0035 mb^{-1} (arXiv: 1210.4520)
- BR*dσ/dy → 945 +62-76 (norm) + 27-56 (extrap) pb for 2.03 < y < 3.53 in p-p
  → 510 +34-41 (norm) +35-95 (extrap) pb for 2.96 < y < 4.46 in p-p



dσ/dy for ϒ(1S) obtained with Pythia6.4 productions (several tunings), validated with 7 TeV pp data from CMS and LHCb

Event Cuts and Muon cuts

Event Cuts:

Physics Selection

Unlike Sign Trigger

Muon Cuts:

Trigger Matched Track (Lpt,Lpt)

$-4.0 < \eta < -2.5$

17.6 cm < R_{abs} < 89.5 cm

pDCA Cut

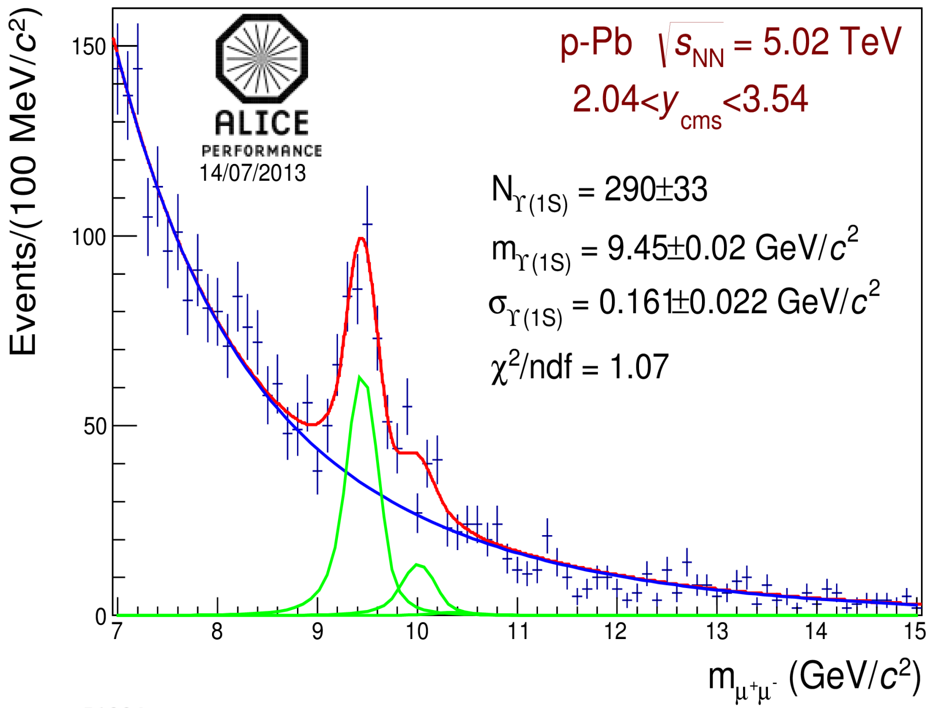
Dimuon Cuts:

$-4.0 < y < -2.5$

Beam Type	Analized CMUL Events (after physics selection)
p-Pb (LHC13de)	9.274e+06
Pb-p (LHC13f)	20.913e+06

Quantity	p-Pb	Pb-p
Rapidity Coverage	$2.035 < y_{cms} < 3.535$ $2.50 < y_{lab} < 4.00$	$2.965 < y_{cms} < 4.465$ $2.50 < y_{lab} < 4.00$
Common Rapidity Coverage	$2.965 < y_{cms} < 3.535$ $3.43 < y_{lab} < 4.00$	$2.965 < y_{cms} < 3.535$ $2.50 < y_{lab} < 3.07$

Signal Extraction: p-Pb and Pb-p



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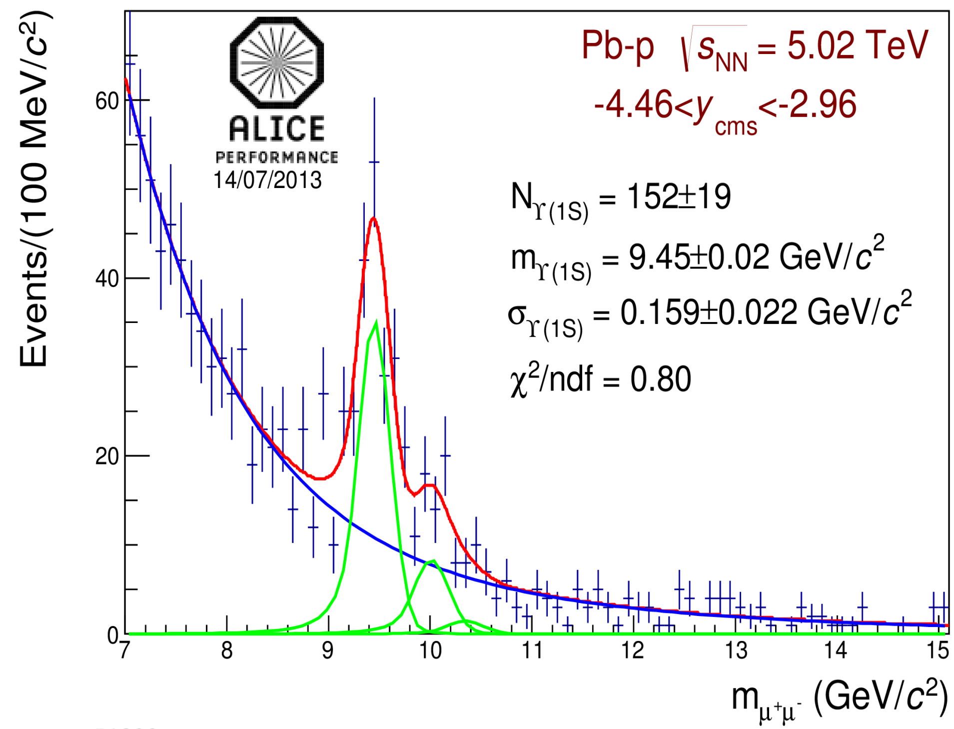

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→ Tail parameters taken from pure simulation

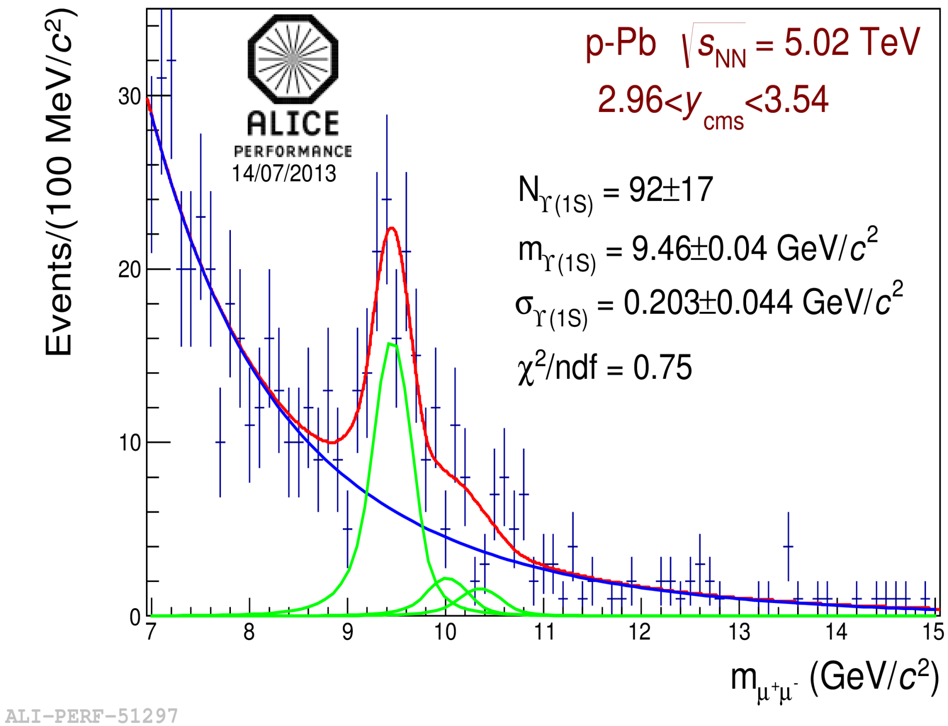
→ Mass, Sigma and Amplitude free for ϒ(1S)

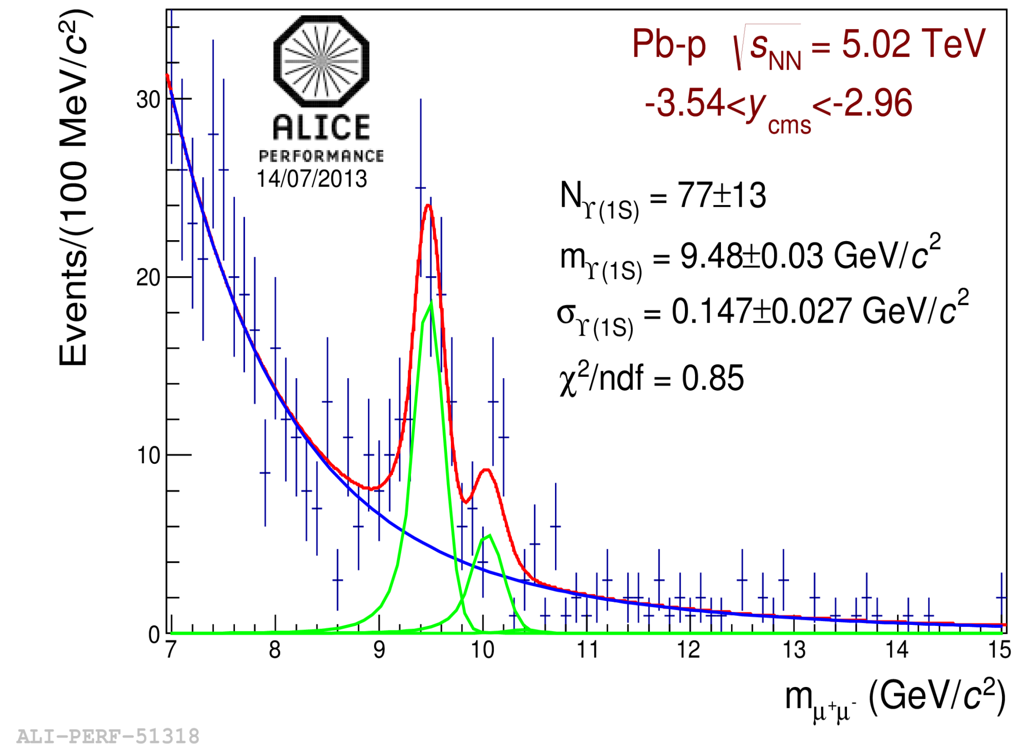
→ Amplitude of ϒ(2S) and ϒ(3S) kept free

→ Mass and Sigma of ϒ(2S) and ϒ(3S) fixed from ϒ(1S) mass and sigma values

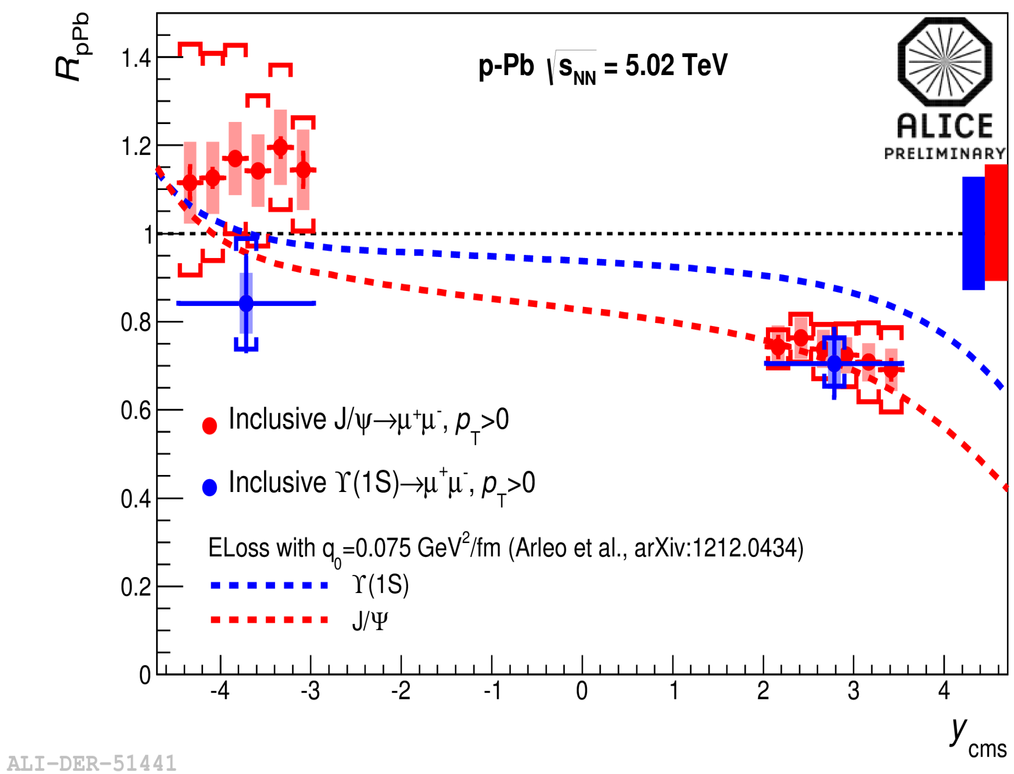
→ Tail Parameters of ϒ(2S) and ϒ(3S) are assumed to be the as that of ϒ(1S)

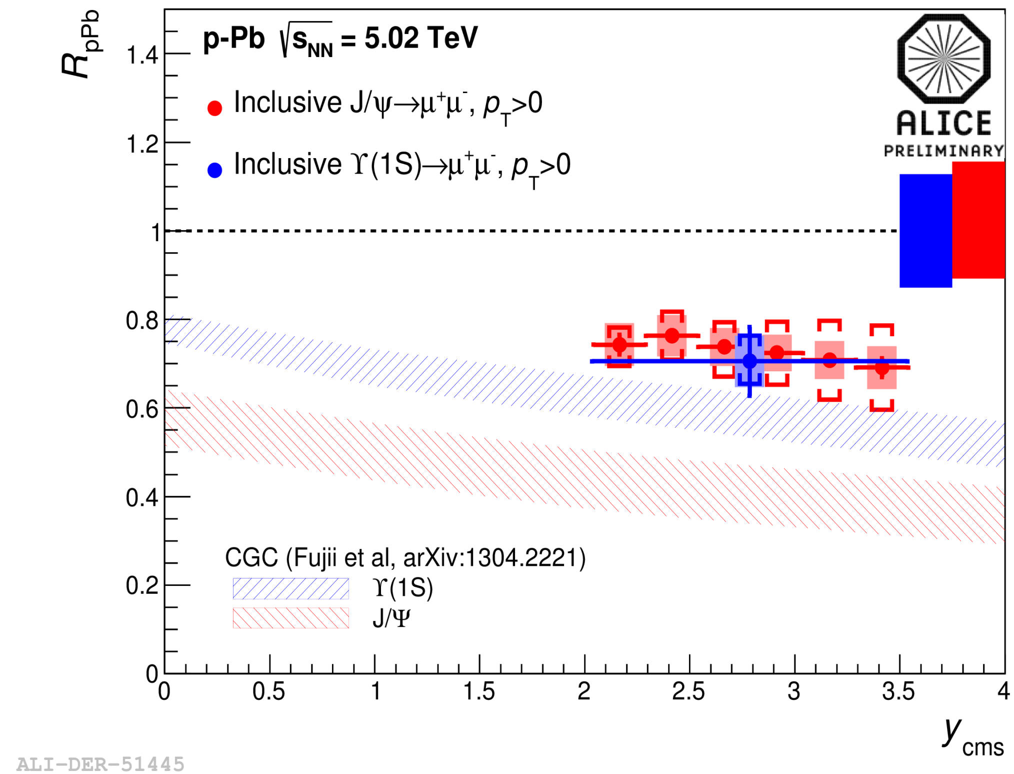
Invariant Mass Spectrum In Common Rapidity Region for p-Pb and Pb-p





Comparison With Models





→ Arleo et al. Model is based on parton energy loss mechanism. Although this model reproduces the suppression in backward within the uncertainties it over estimates the suppression in forward

→ Fujii et al. Model includes low-x gluon saturation and agrees with the ALICE data

Inclusive Υ(1S) R_{pA} and R_{FB} from ALICE