Upsilon production with ALICE at the LHC: from pp to Pb-Pb collisions

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Outline

- Physics motivation
- Experimental setup
- pp at $\sqrt{s}$ = 7 TeV
- Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV
- p-Pb and Pb-p at $\sqrt{s_{NN}}$ = 5.02 TeV

Physics motivation in heavy-ion

✧ Quarkonia are produced in first stage of heavy-ion collision

➔ sensitive to medium effects: Quark-Gluon Plasma (QGP)

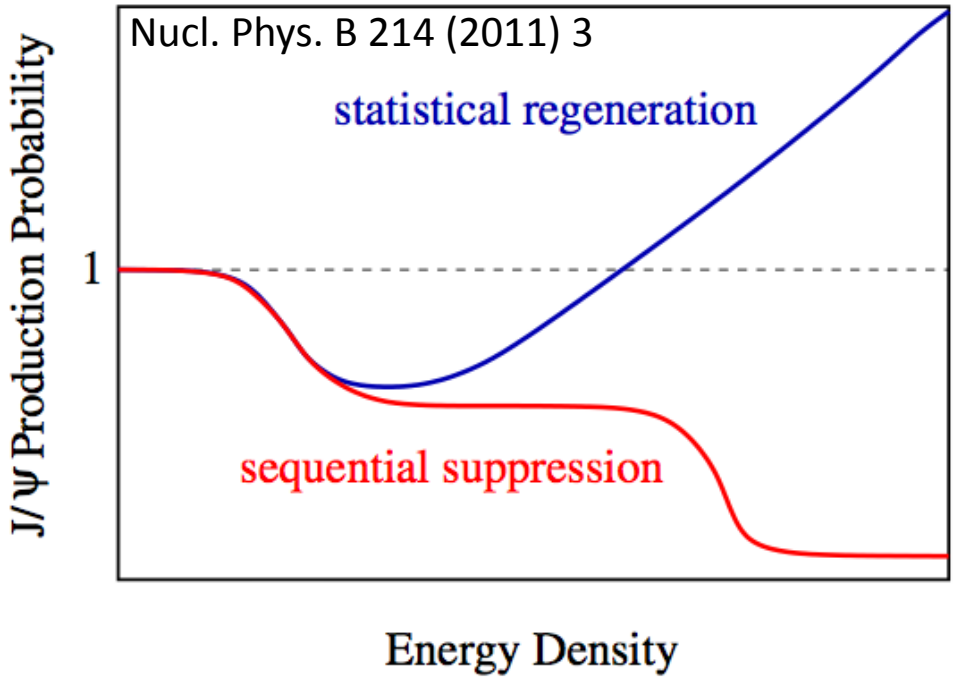
✧ Quarkonium sequential suppression via color screening [Matsui & Satz, PLB178 (1986) 178]

➔ QGP-thermometer

✧ Quarkonium statistical regeneration if large heavy quark multiplicity [Braun-Munzinger & Stachel, PLB490 (2000) 196 ; Thews, Schroedter & Rafelski, PRC65 (2001) 054905]

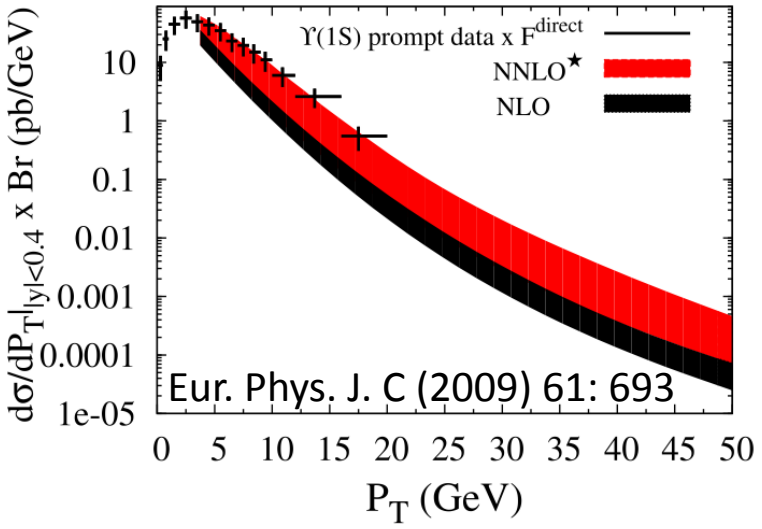
✧ **Advantages of Υ versus J/ψ**

- absence of open heavy flavour hadron feed-down
- less regeneration expected



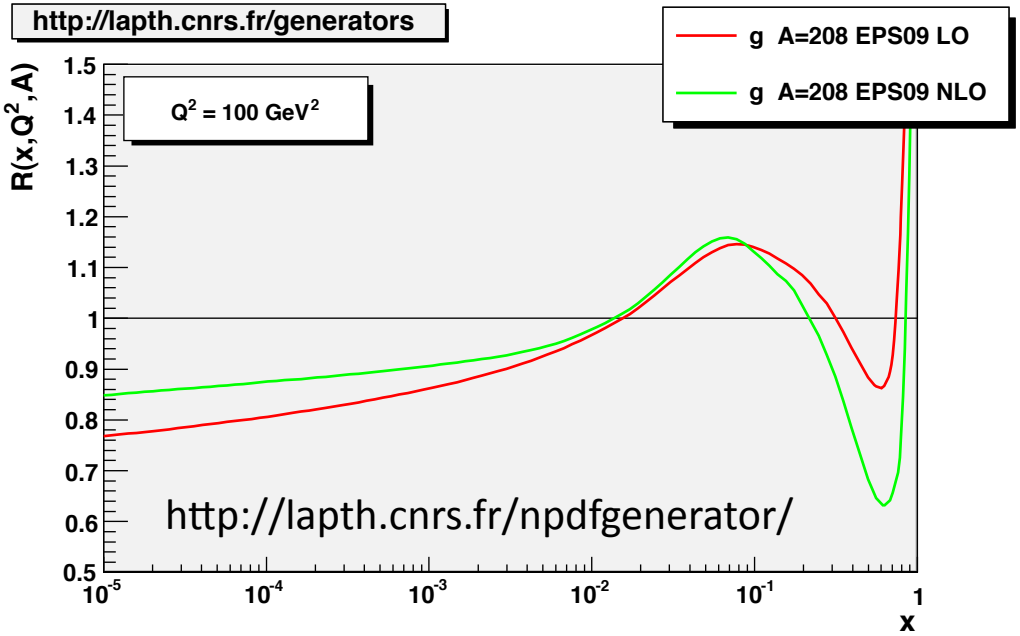
Physics motivation in proton-proton

- Used as reference for the quantification of in-medium effects
- To test QCD-based model for quarkonium production

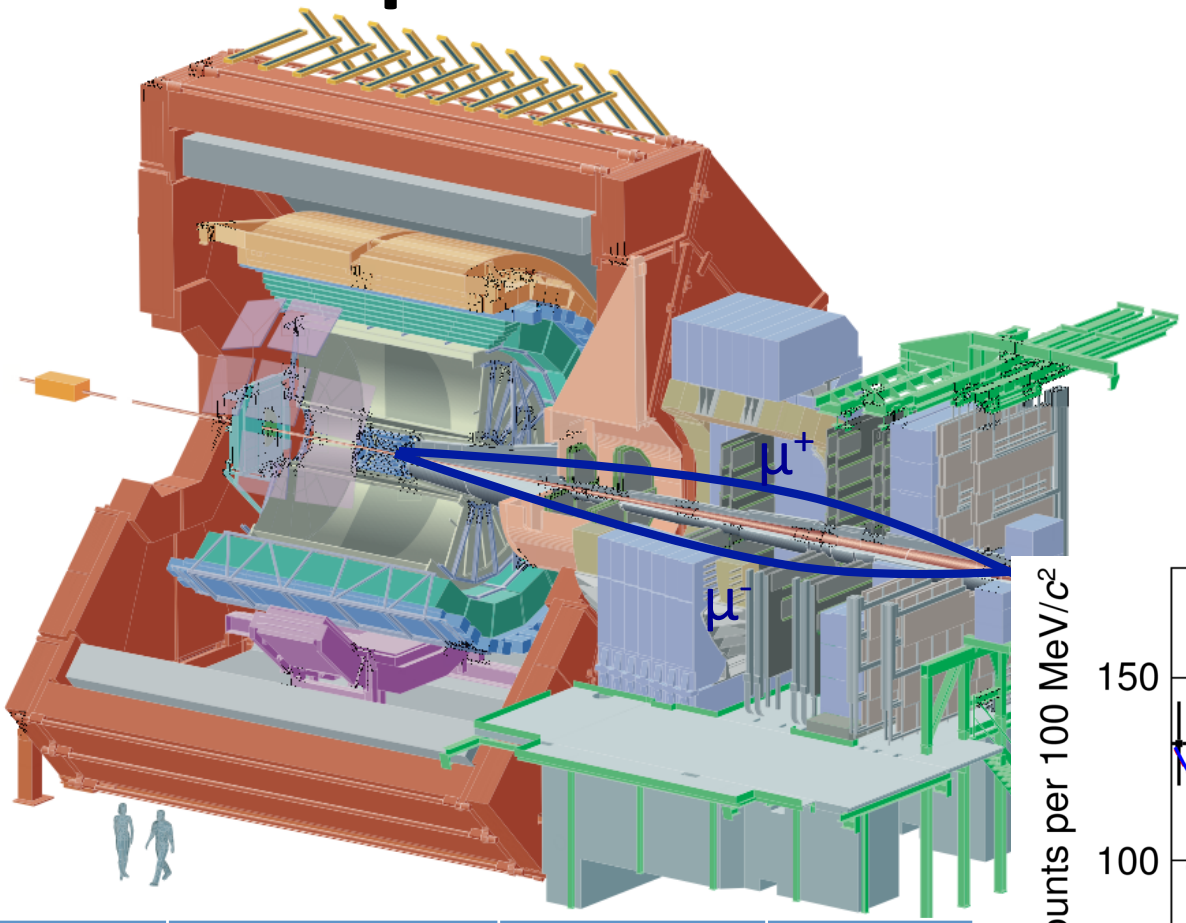


Physics motivation in proton-nucleus

- To study cold nuclear matter (CNM) effects
  - shadowing, anti-shadowing, EMC effect
  - nuclear dissociation,
  - …

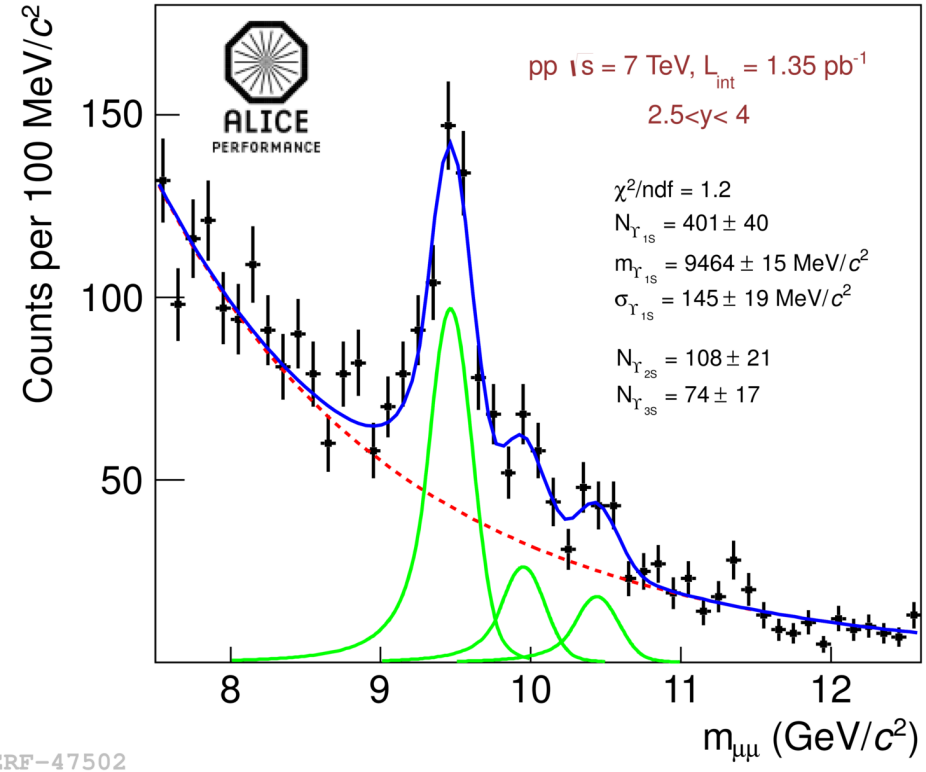


Upsilon reconstruction in ALICE



- MB trigger with SPD & V0
- Centrality with ZDC & V0
- $\mu^{\pm}$ in forward spectrometer $2.5 < y < 4$ with muon trigger
- Quarkonium reconstruction down to zero p_T

Beams	Energy	Luminosity	Year
pp	$\sqrt{s}$=7 TeV	1.35 pb^{-1}	2011
Pb-Pb	$\sqrt{s_{NN}}$=2.76 TeV	69 pb^{-1}	2011
p-Pb	$\sqrt{s_{NN}}$=5.02 TeV	5.0 nb^{-1}	2013
Pb-p	$\sqrt{s_{NN}}$=5.02 TeV	5.8 nb^{-1}	2013



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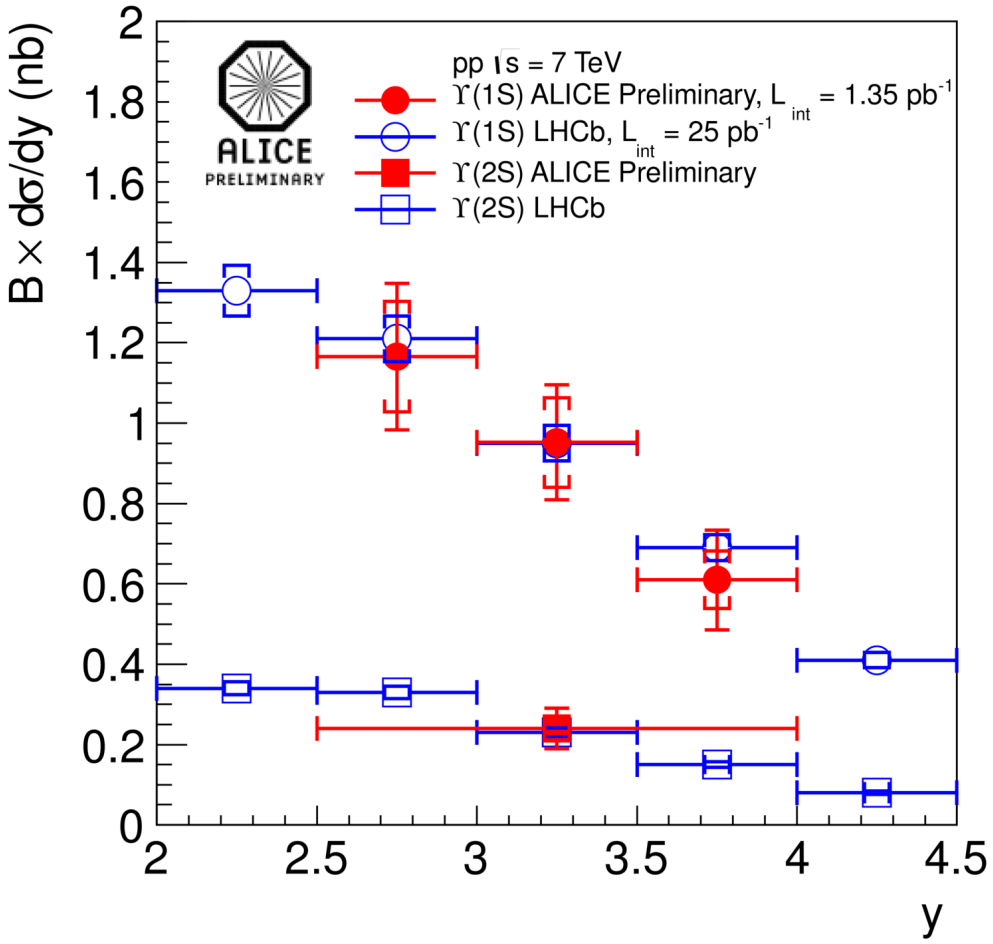
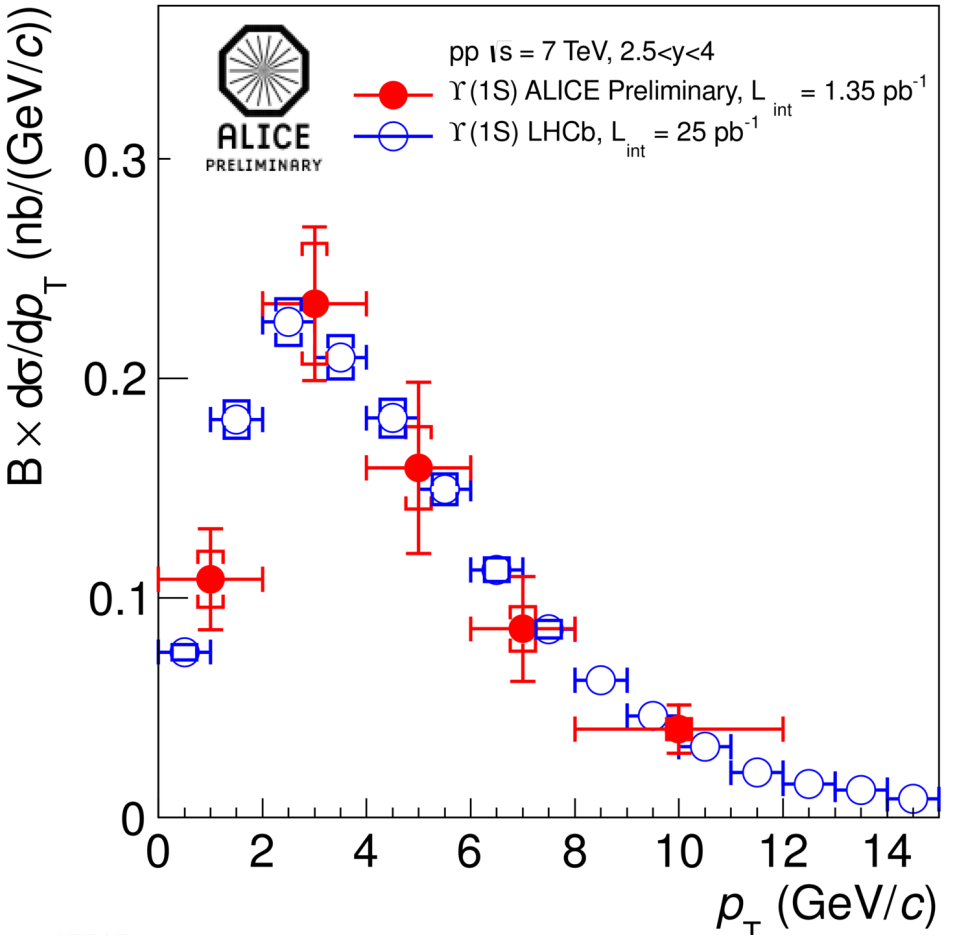
ϒ production in pp collision at 7 TeV





- pp results show the ability of ALICE for ϒ analysis
- Measured differential cross section in agreement with LHCb

[EPJ C 72 (2012) 2025]

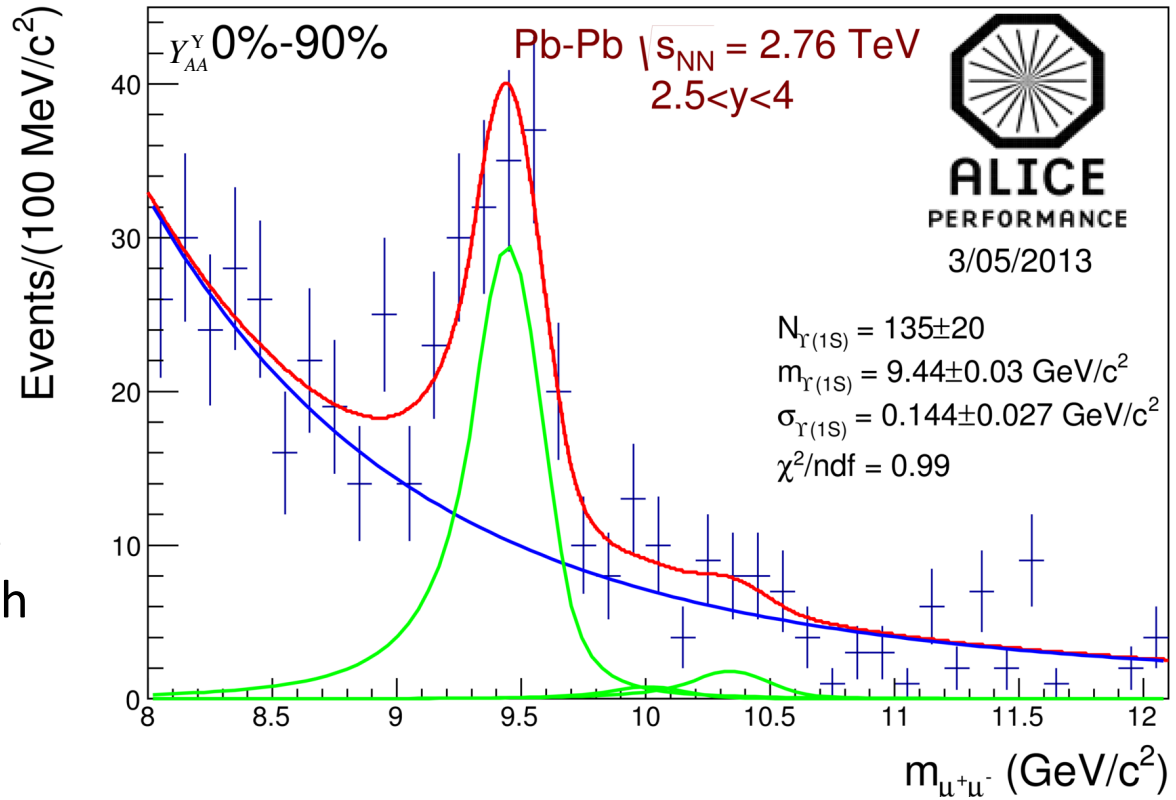
ϒ production in heavy-ion collisions

Hot and dense in-medium (or CNM) effects quantified by the nuclear modification factor: R_{AA} (or R_{pA}) in A-A (or p-A) collisions

$$R_{AA}(N_{part}, y) = \frac{Y_{AA}(N_{part}, y)}{N_{coll}(N_{part})\, Y_{pp}(y)}$$

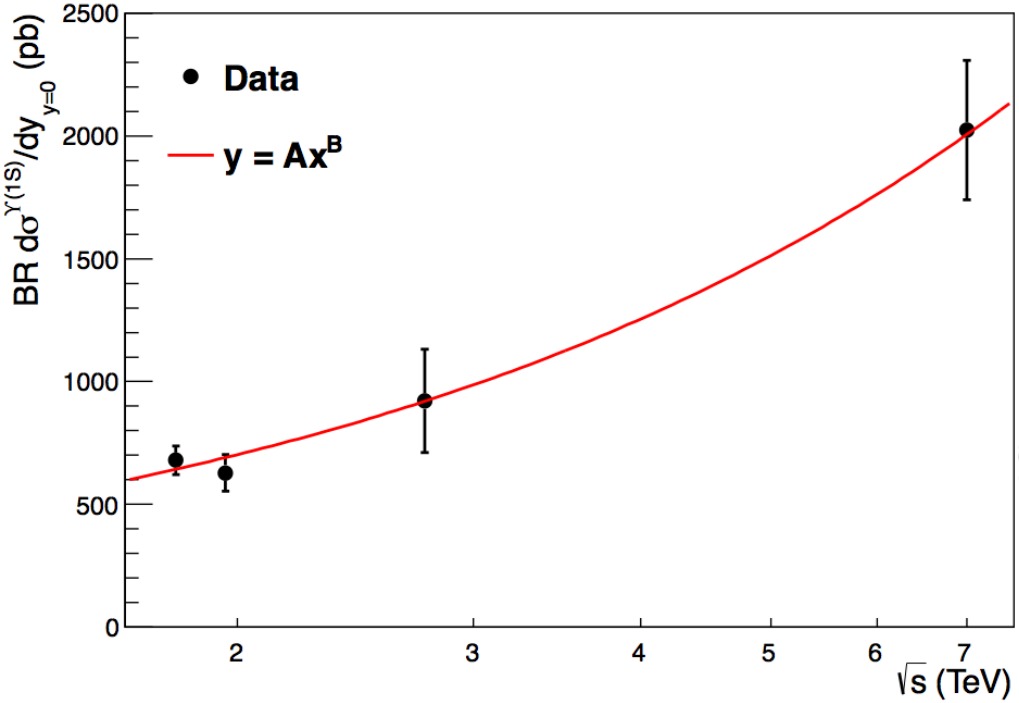
with

- Y_{AA} the yield of ϒ in AA
- Y_{pp} the yield of ϒ in pp
- N_{coll} and N_{part} the average number of binary collisions and of participating nucleons in A-A collision estimated with a Glauber model



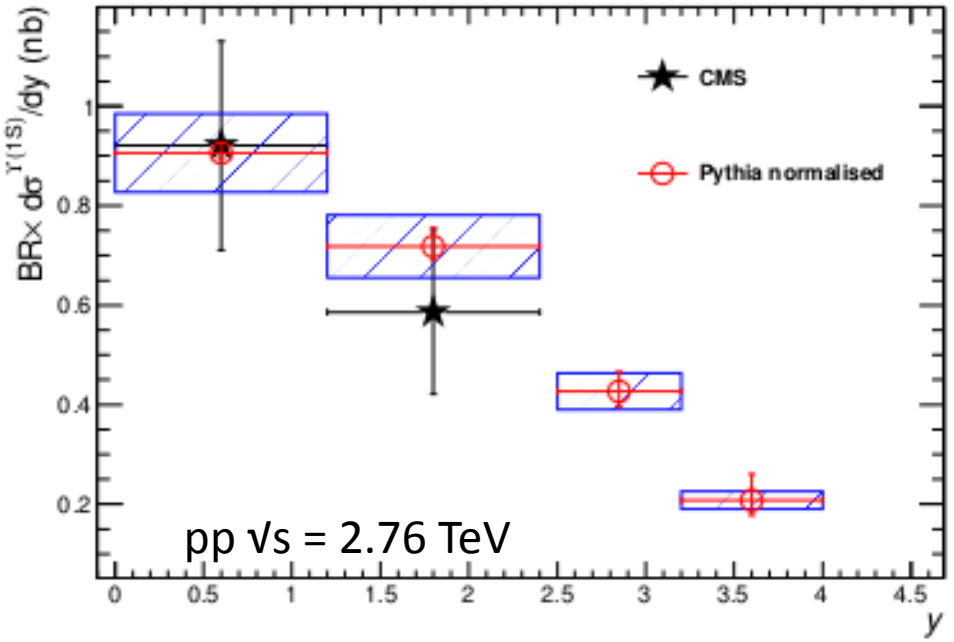
pp reference cross section

1- Interpolation of $(d\sigma/dy)_{y=0}$ at intermediate energies using available data from Tevatron and LHC: systematic by excluding CDF or D0 point and by using different fit function



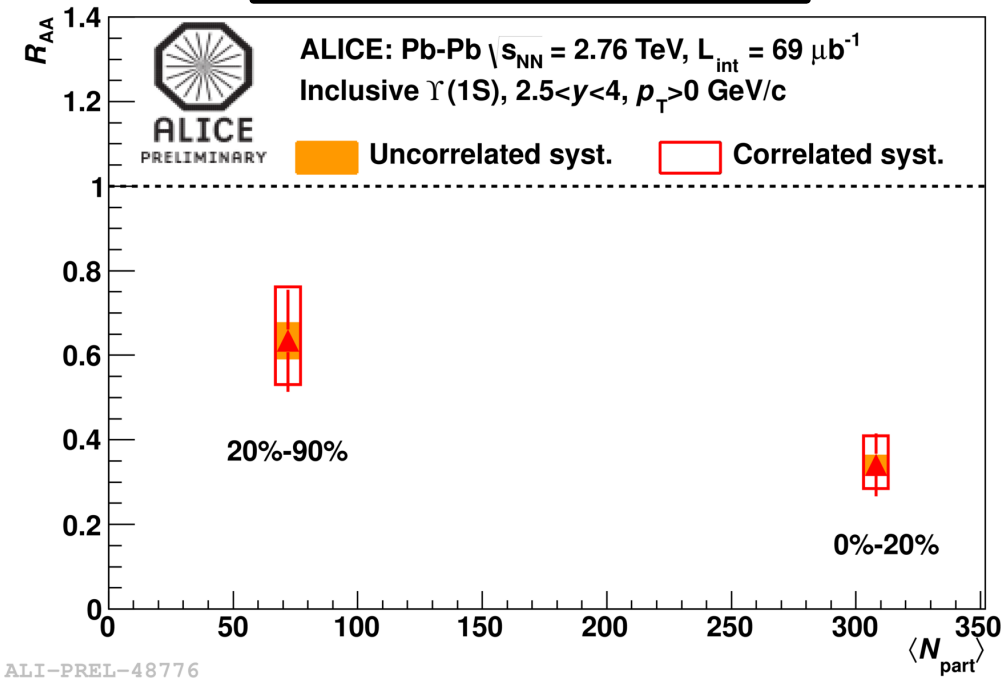
CDF (1.8 TeV): PRL 88 (2002) 161802
D0 (1.96 TeV): PRL 94 (2005) 232001
CMS (2.76 TeV): JHEP 1205, 063 (2012)
CMS (7 TeV): PR D 83, 112004 (2011)

2- Extrapolation of dσ/dy from mid to forward rapidity using Pythia 6.4 shape

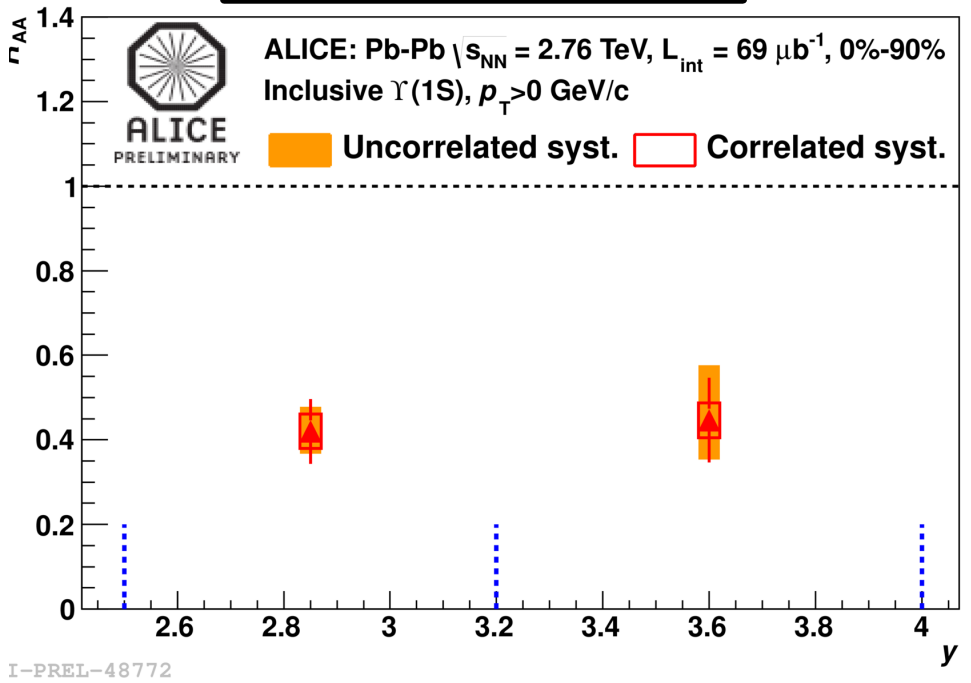


Pb–Pb collisions at 2.76 TeV: nuclear modification factor

Centrality dependence



Rapidity dependence

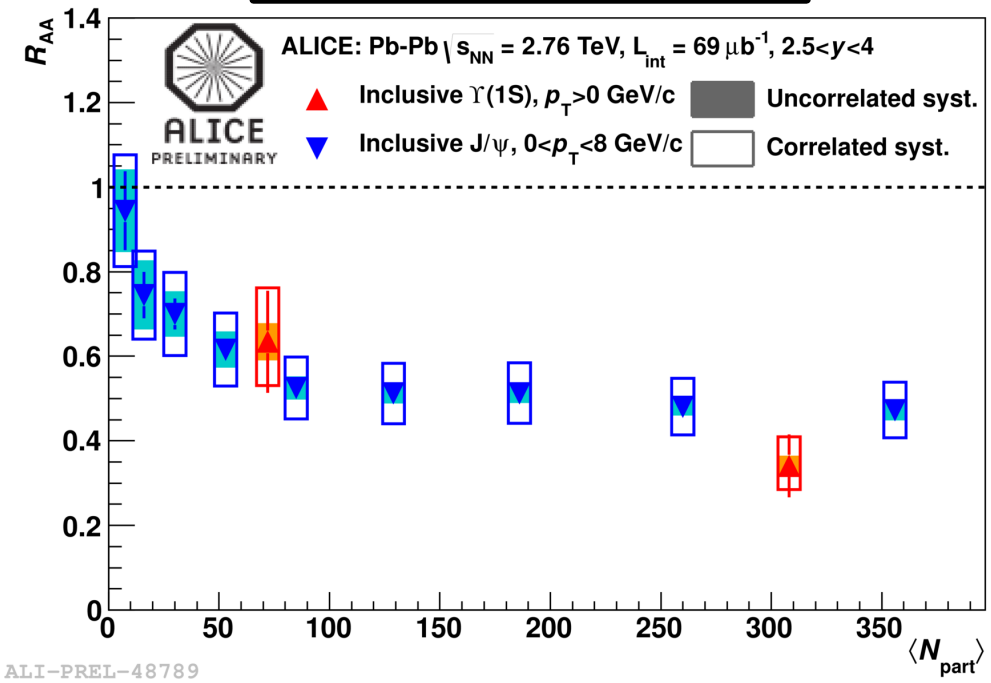


Experimental observations:

- Suppression of inclusive Υ(1S) at forward rapidity
- Suppression stronger in most central collisions
- No rapidity dependence within uncertainties

Comparison with ALICE J/ψ

Centrality dependence



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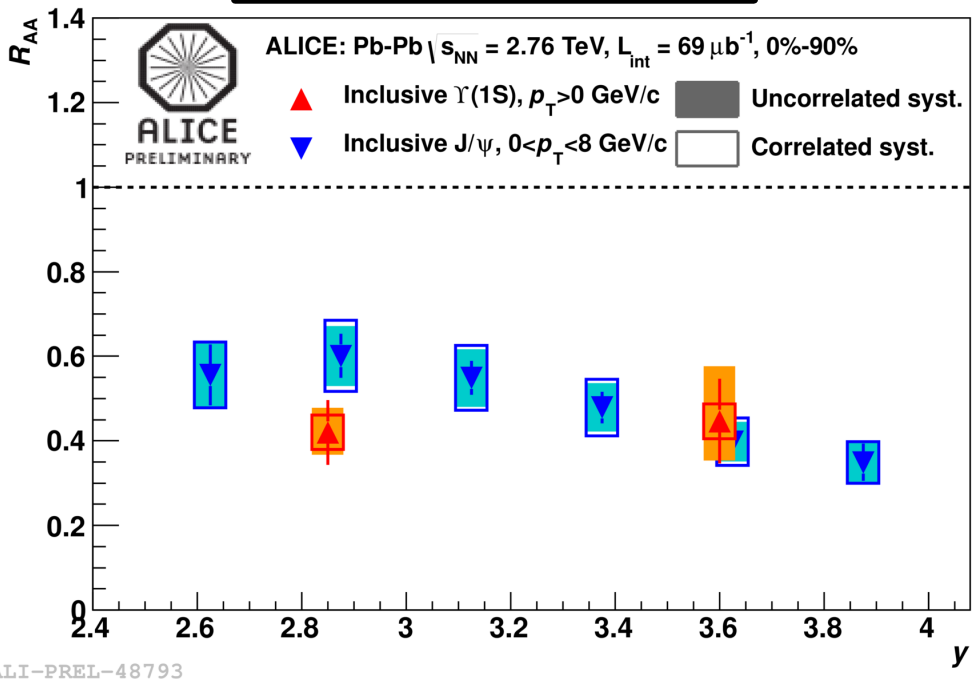
Rapidity dependence



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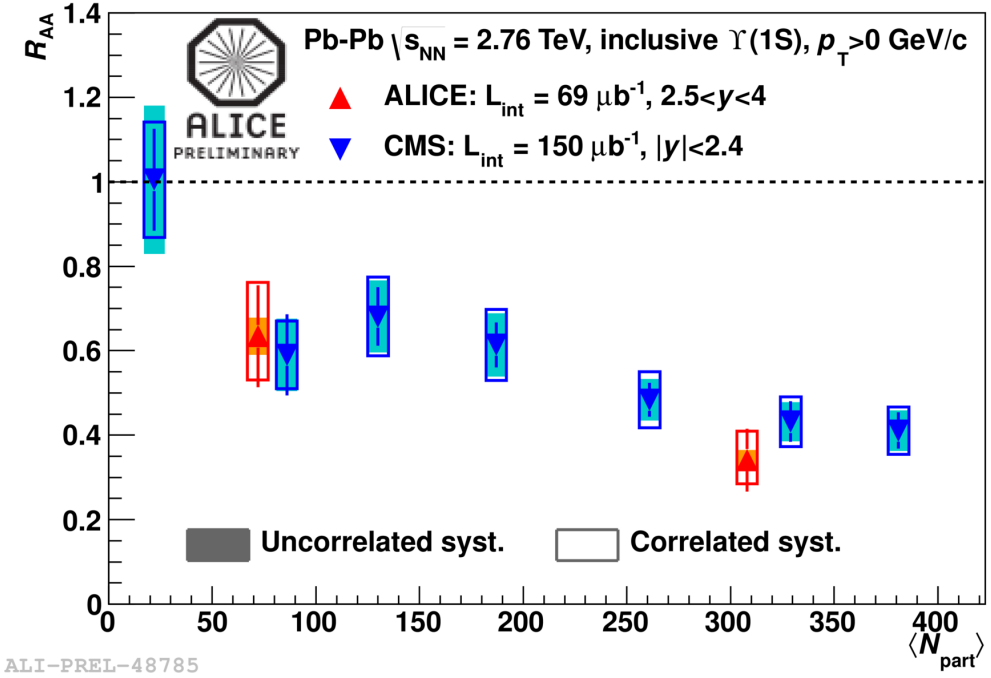
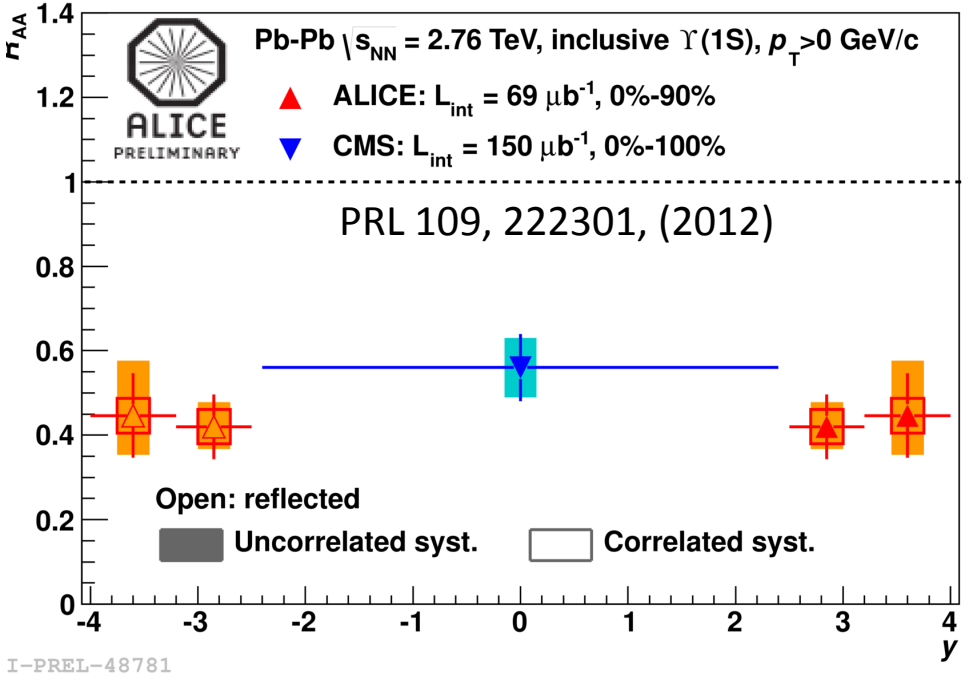
- Suppression of ϒ(1S) similar to J/ψ one within uncertainties, but ϒ expected to be less affected by regeneration
- Recall: feed-down from higher states (Υ_{2S}, Υ_{3S}, χ_b, χ_b') ~ 50%

Comparison with CMS Υ(1S)

Centrality dependence



Rapidity dependence

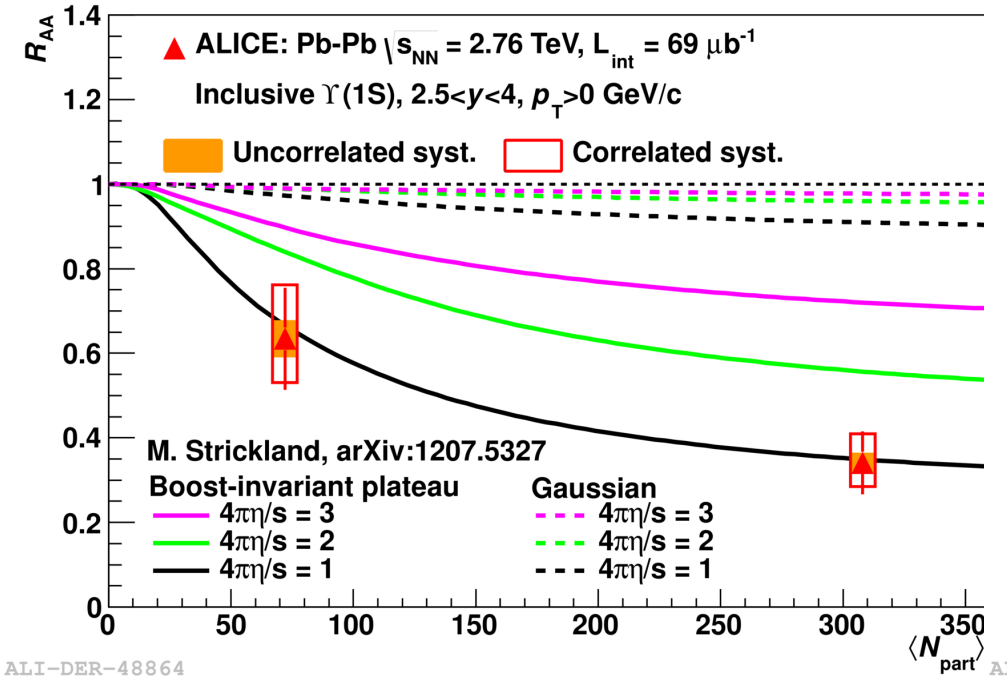


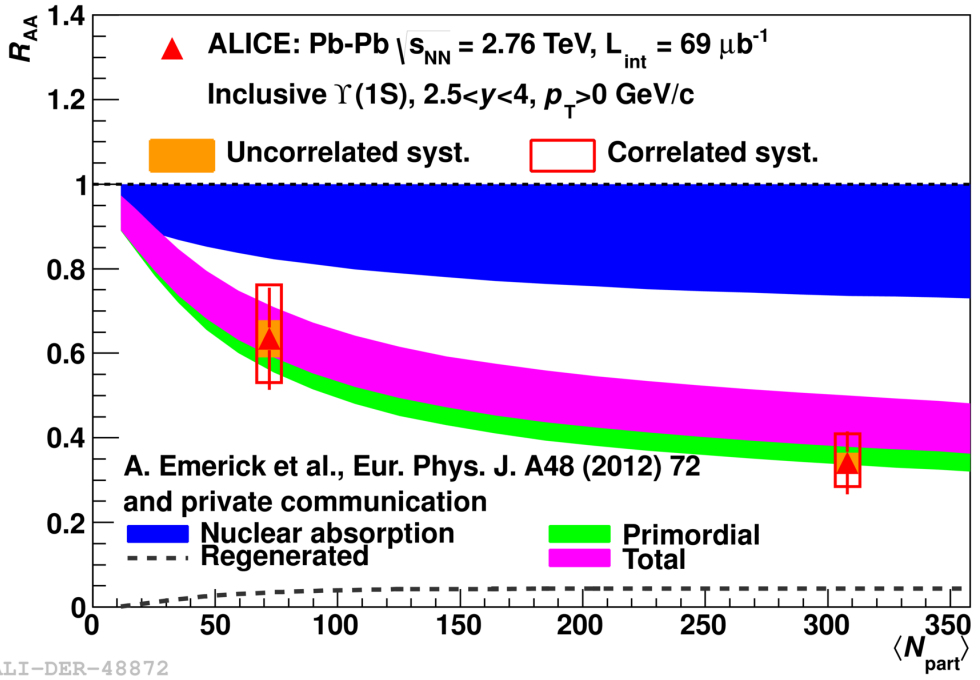
- Similar suppression of inclusive Υ(1S) at mid (CMS) and forward (ALICE) rapidities
- No evidence of rapidity dependence within the large range probed by ALICE and CMS

Comparison with models

Strickland model: complex-valued potential in anisotropic hydro evolution, including feed-down from higher mass states, but without bb regeneration nor CNM effects

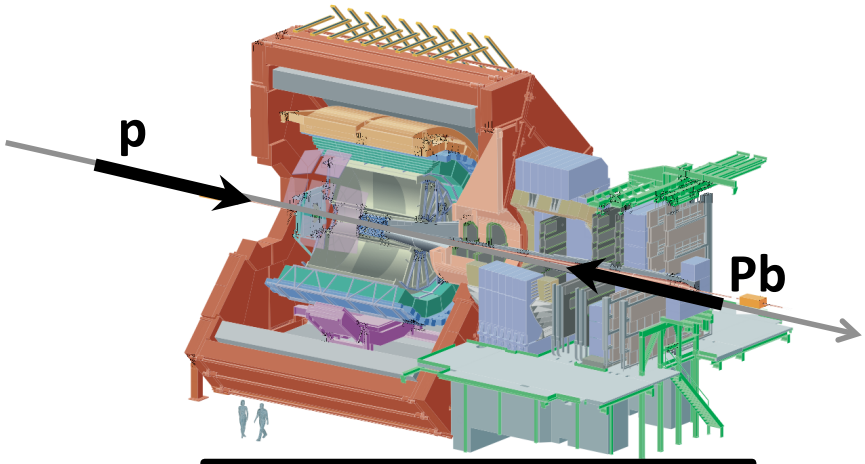
Emerick et al. model: kinetic rate equation approach in isotropic expanding fireball, including feed-down from higher mass states, bb regeneration and CNM effects



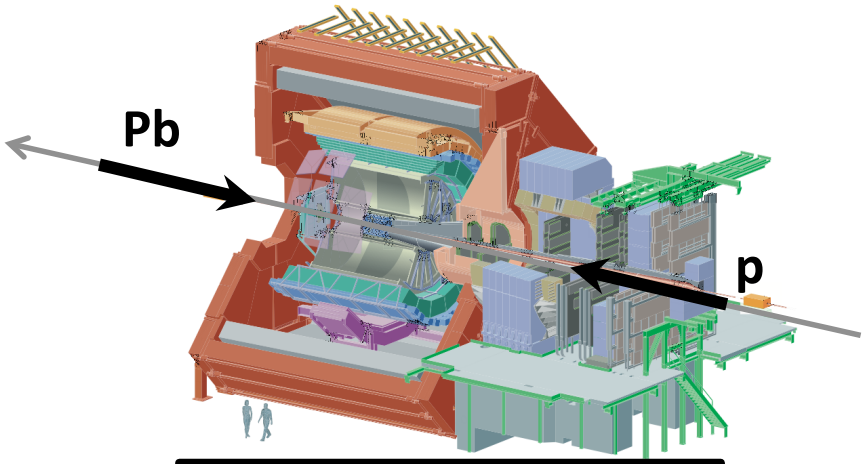


- Strickland model: described data with the hypothesis of a boost invariant plateau temperature profile with minimum shear viscosity
- Emerick et al. model: fair agreement with data within uncertainties

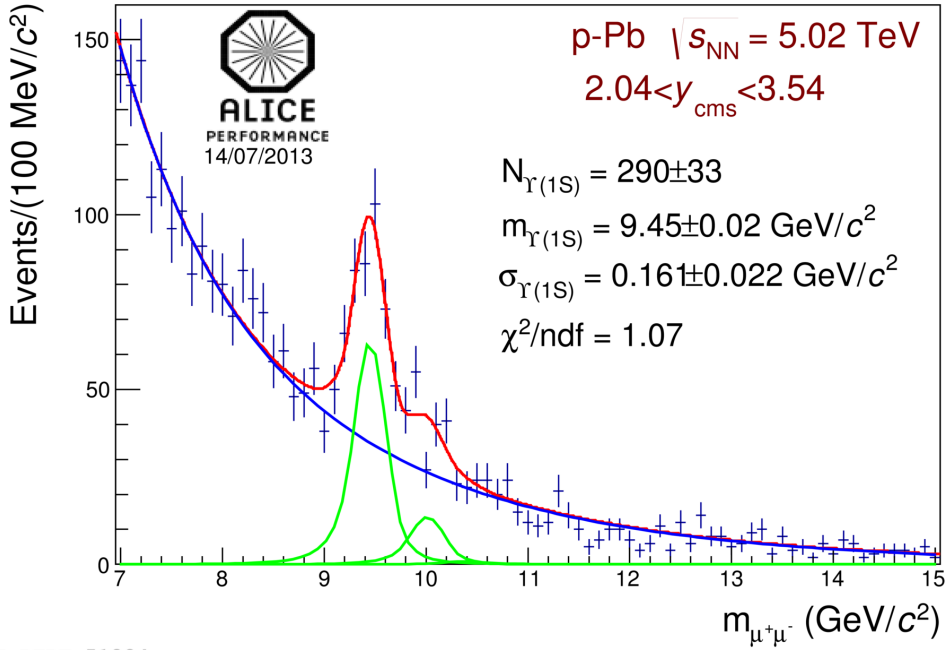
p-Pb and Pb-p collisions at 5.02 TeV

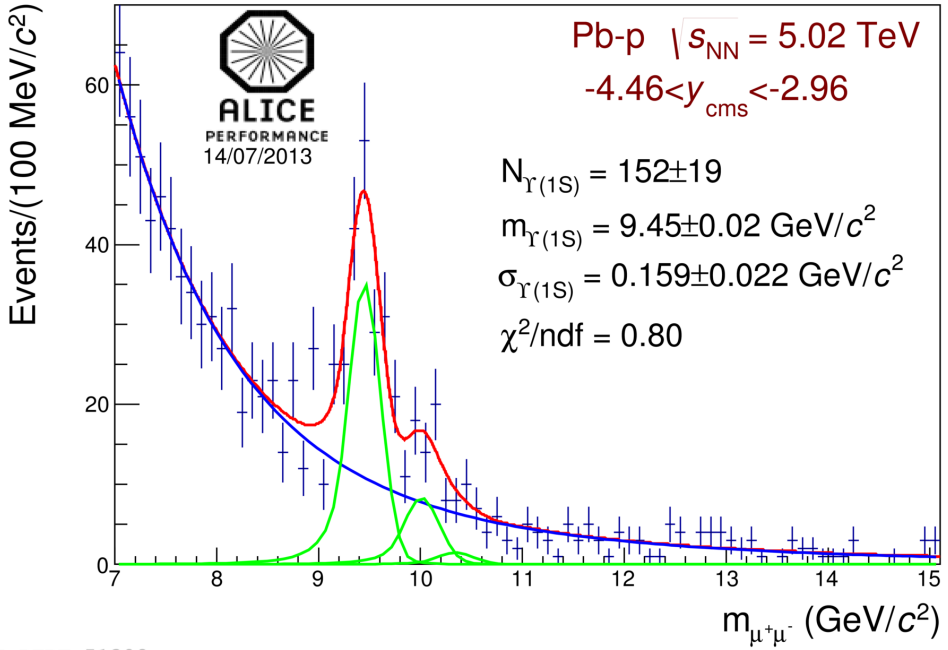


$2.04 < y_{CMS}^{p\text{-}Pb} < 3.54$
$5\times10^{-5} < x^{p\text{-}Pb} < 3\times10^{-4}$

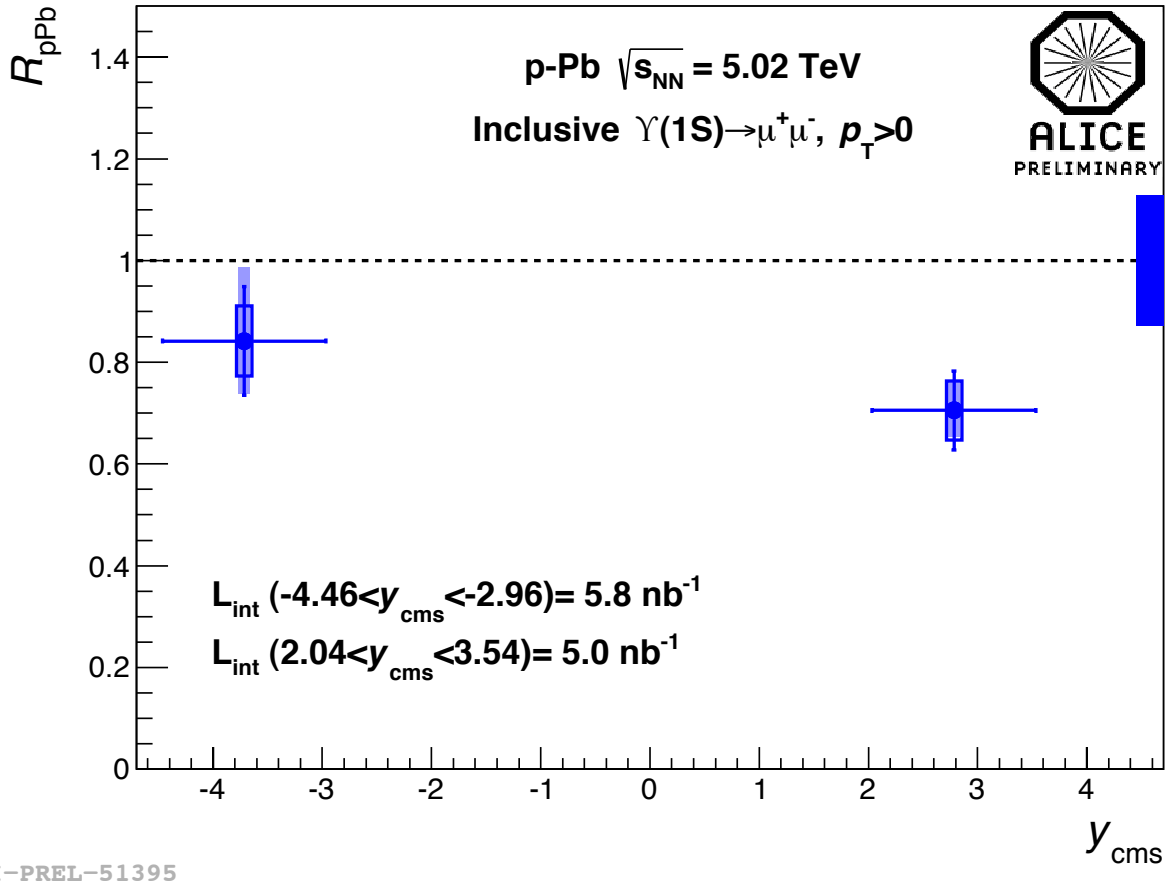


$-4.46 < y_{CMS}^{Pb\text{-}p} < -2.96$
$3.6\times10^{-2} < x^{Pb\text{-}p} < 0.16$





R_{pPb} versus y_{CMS} at 5.02 TeV



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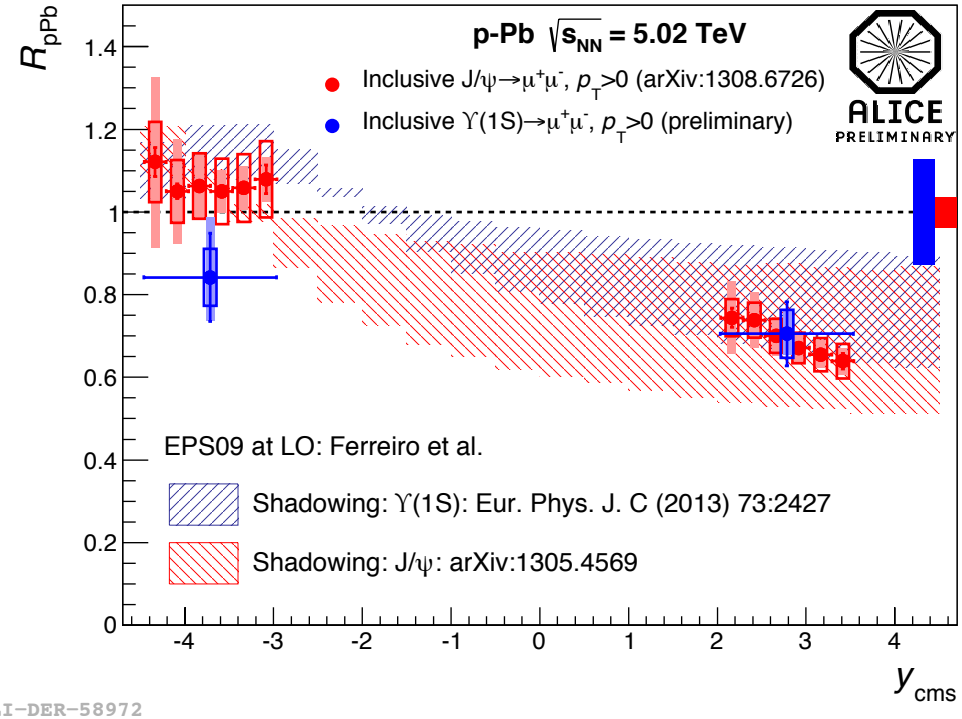
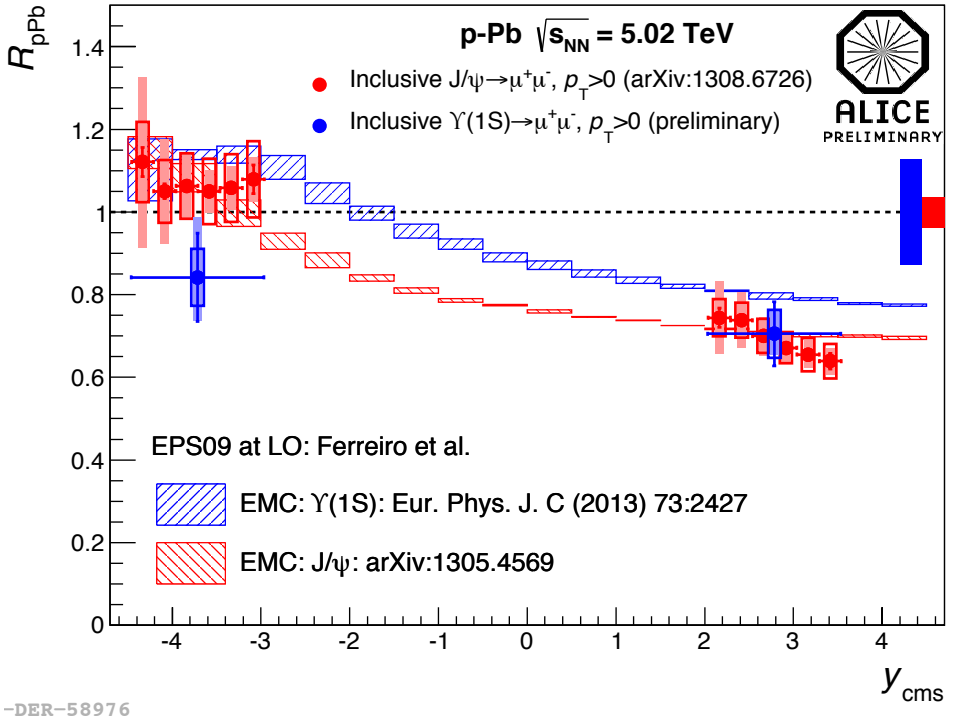
Experimental observations:

- Suppression stronger at forward than at backward rapidity
- Backward rapidity compatible with no suppression

Comparison with J/ψ and models (1)

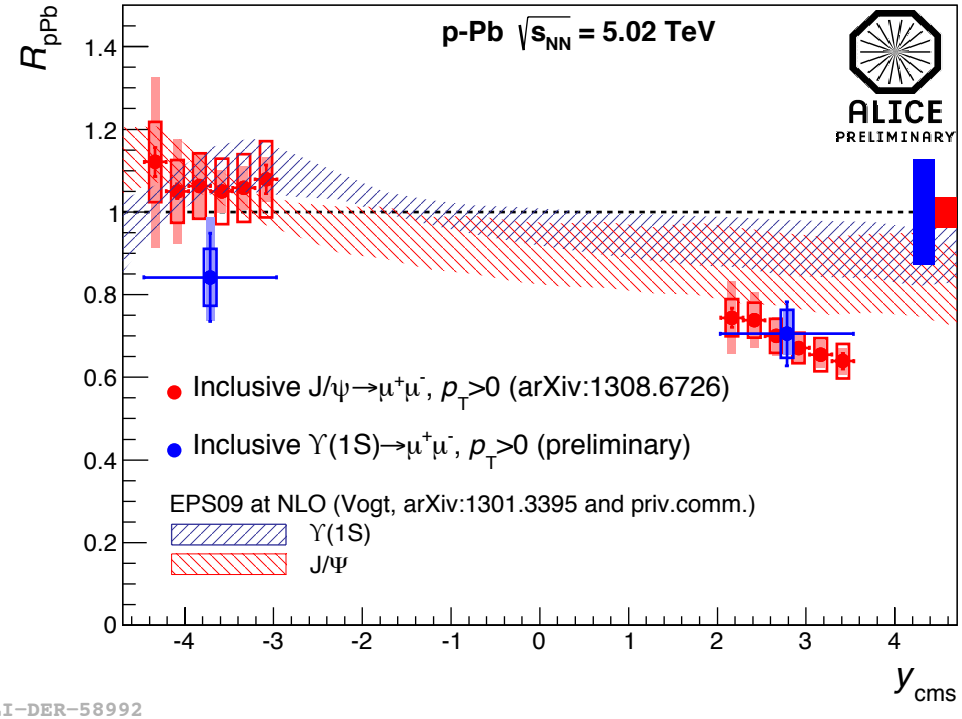


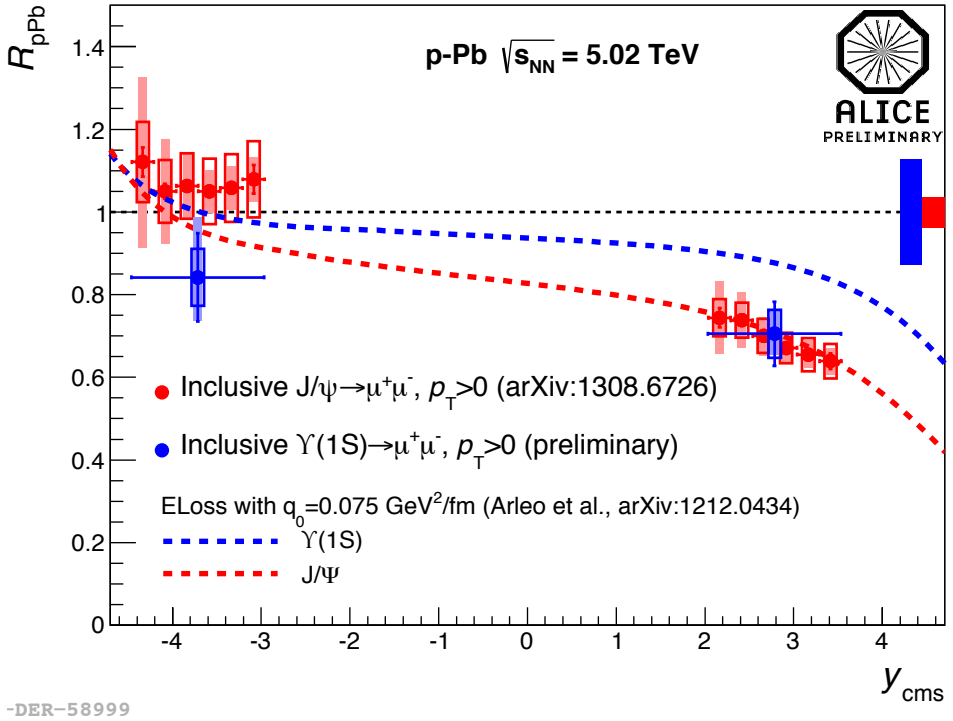


EPS09 at LO from Ferreiro et al.:

- Good description of data within shadowing uncertainties
- Better agreement with J/ψ, especially at backward rapidity

Comparison with J/ψ and models (2)





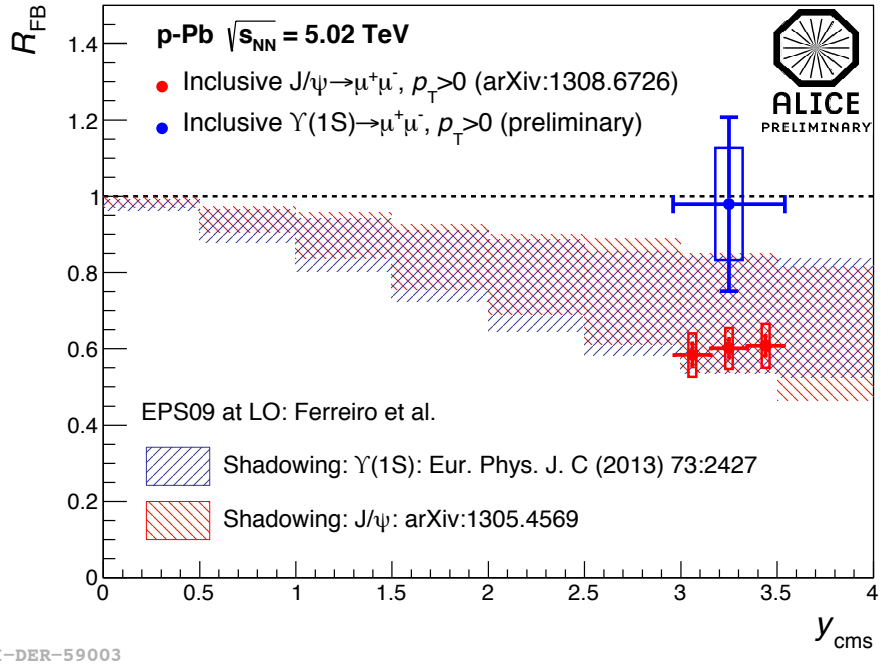
EPS09 at NLO from Vogt & Eloss from Arleo et al.

- Underestimation of ϒ(1S) suppression
- Better agreement with J/ψ data

Forward-Backward ratio

Forward-Backward ratio cancels the pp reference cross section and <N_{coll}>

$$R_{FB}^{\Upsilon}(2.96 < |y_{CMS}| < 3.54) = \frac{Y_{pA}(3.47 < |y_{LAB}| < 4)}{Y_{Ap}(2.5 < |y_{LAB}| < 3.07)}$$



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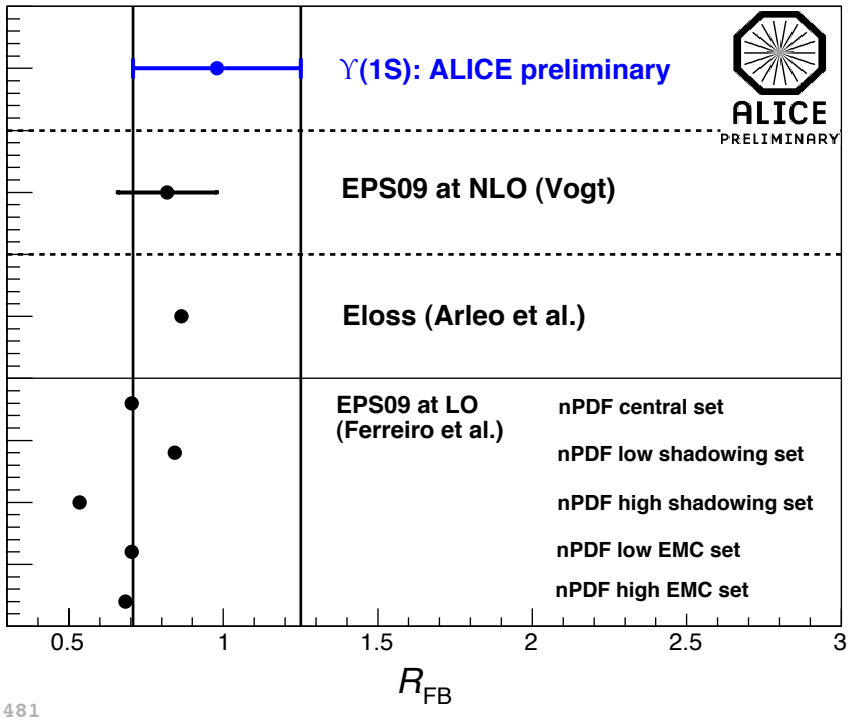

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- ϒ Forward-Backward ratio significantly higher than J/ψ one
- All models reproduce ϒ R_{FB} within uncertainties, but low shadowing effect is favoured

Summary

- **pp at √s = 7 TeV**
  - show the ability of ALICE to measure ϒ at forward rapidity
  - results in agreement with LHCb ones

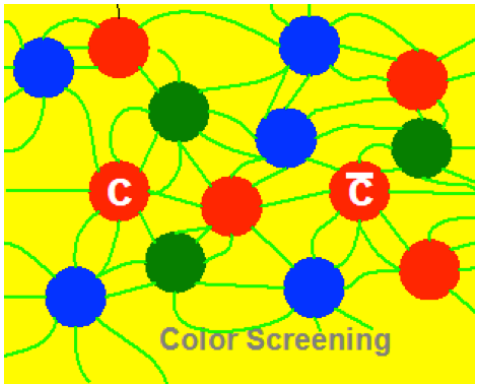
- **Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV**
  - measurement of the nuclear modification factor (R_{AA}) of inclusive ϒ(1S)
  - suppression stronger for most central collisions
  - suppression pattern comparable to ALICE J/ψ in same rapidity range
  - no evidence of rapidity dependence within uncertainties (including CMS result)

- **p-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV**
  - observation of small suppression of inclusive ϒ(1S) increasing from backward to forward rapidity
  - ϒ(1S) Forward-Backward ratio significantly higher than J/ψ

ΕΥΧΑΡΙΣΤΩ ΓΙΑ ΤΗΝ ΠΡΟΣΟΧΗ ΣΑΣ

Quarkonia = QGP thermometer

Resonance	J/ψ	Ψ(2S)	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
$T_{dissociation}$	1.2 T_c	< T_c	2 T_c	1.2 T_c	< T_c



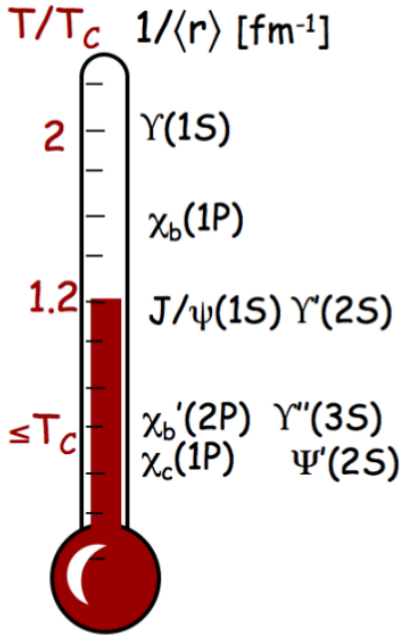
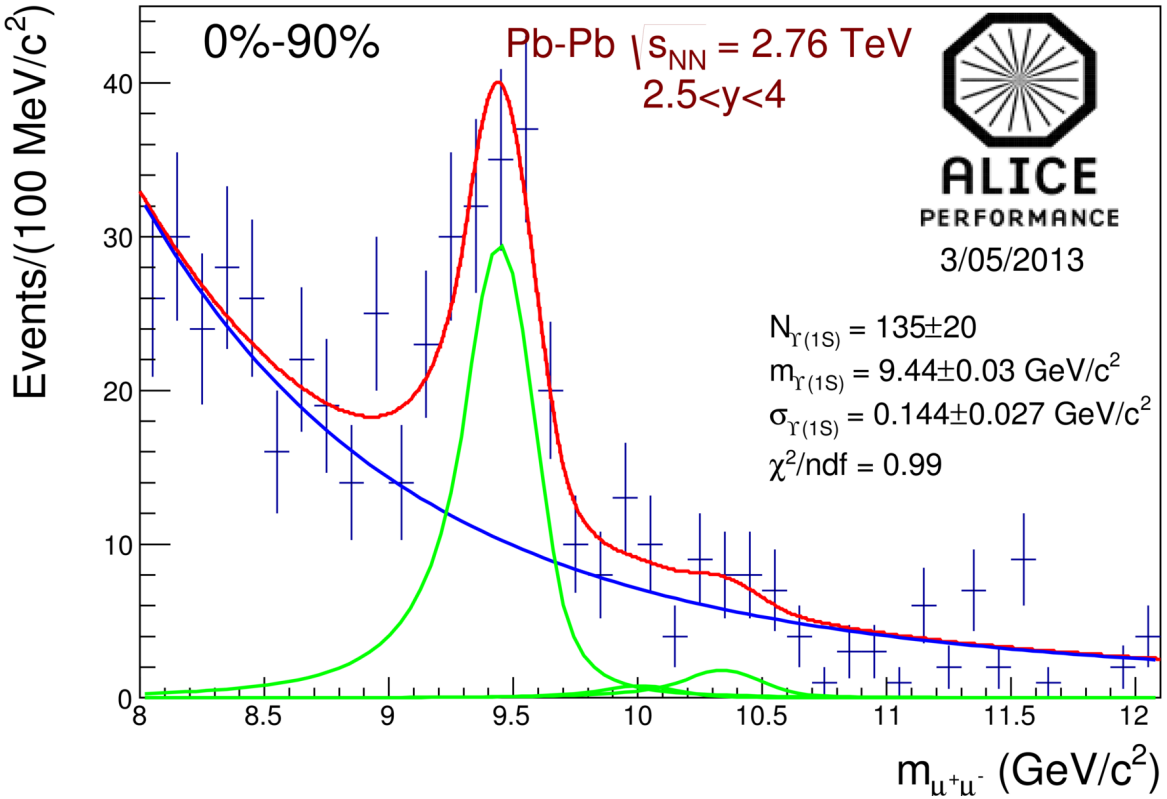


Fig. 5. The QGP thermometer.
Agnes Mocsy, Eur.Phys.J.C61, 2009

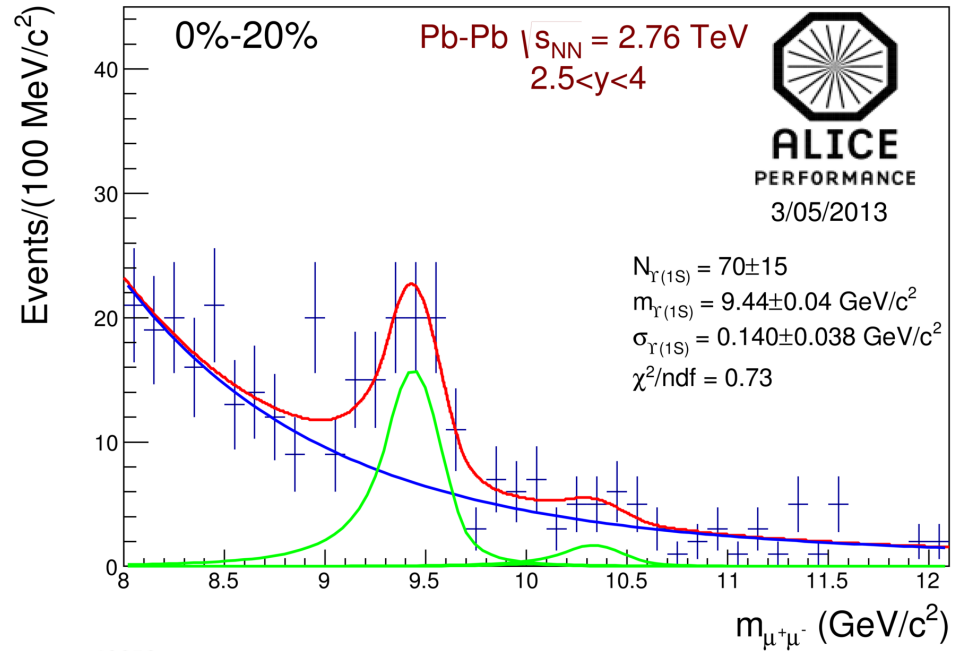
Signal extraction in Pb-Pb

- Event Cuts:
  - Physics Selection
  - Unlike Sign Trigger
  - Centrality (0-90) %
- Muon Cuts:
  - Low p_T trigger-tracking matching
  - $-4.0 < \eta < -2.5$
  - $17.6\ \text{cm} < R_{abs} < 89.5\ \text{cm}$
  - pDCA Selection
  - $p_T > 2$ GeV
- Dimuon Cuts:
  - $-4.0 < y < -2.5$



- Signal fitted with Double Crystal Ball
- Tail parameters fixed from embedding
- Free parameters:
  - mass, sigma and amplitude for Υ(1S)
  - amplitude of Υ(2S) and Υ(3S)

Signal significance in Pb-Pb



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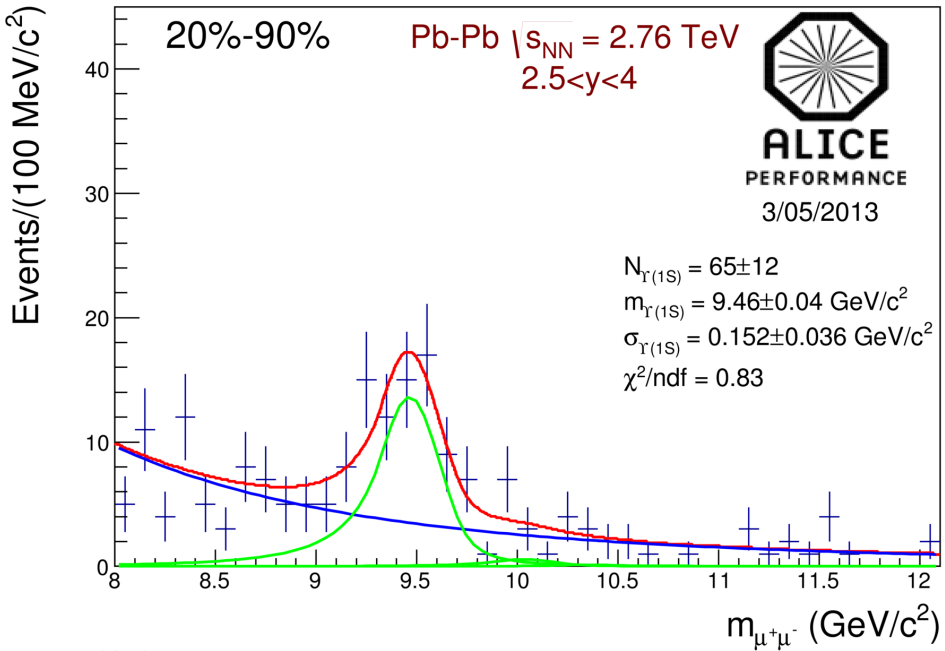

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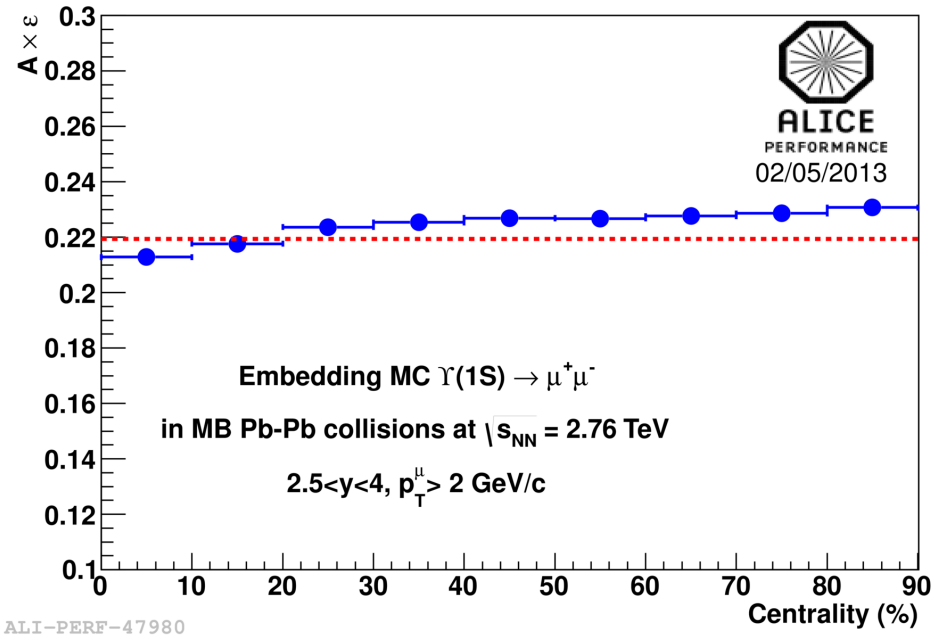
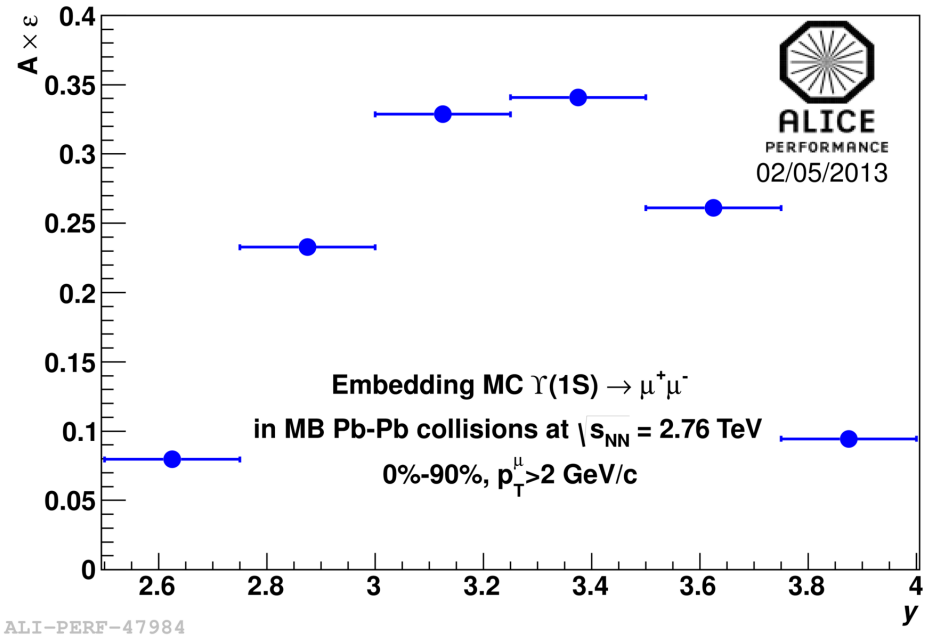
Centrality	S/B	Significance
0%-90%	1.3 ± 0.2	8.1 ± 1.3
0%-20%	1.1 ± 0.2	5.6 ± 1.2
20%-90%	1.8 ± 0.4	6.0 ± 1.4

Acceptance×efficiency in Pb-Pb





- Particle multiplicity high in Pb-Pb collision affects track 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 take into account time dependence of detector set-up