Upsilon production in hadronic collisions

Bottomonia(Υs) in ALICE Run-I (PAG summary)

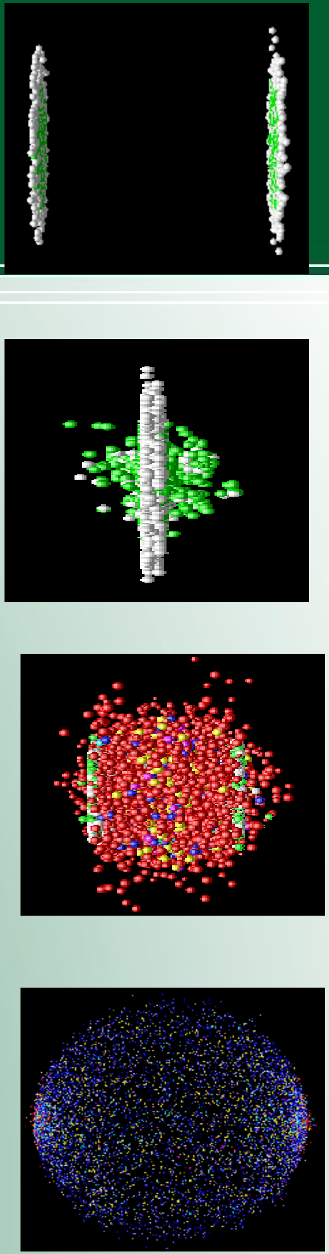
Proton-Proton(pp) results (**EPJC 74 (2014), 2974**)

Heavy-ion(Pb-Pb) results (**PLB 738 (2014), 361**)

Proton-Lead(p-Pb) results (**PLB 740 (2015), 105**)

The **first PAG summary at ALICE PHYSICS WEEK** (April, **2012**) Frascati :
https://agenda.infn.it/contributionDisplay.py?contribId=65&sessionId=1&confId=4447

Heavy Quarks



Heavy quarks carry information of early stage of collisions:

- Charm(c) and bottom(b) quarks are massive.
- Formation takes place only early in the collision.
- Sensitivity to initial gluon density and gluon distribution
- Suppression or enhancement pattern of heavy quarkonium production reveal important and critical features of the medium
- **Cold Nuclear Matter effect (CNM):**
  Different scaling properties in central and **forward rapidity** region
  CGC; Gluon shadowing, etc

Proposed Signature of De-confinement :

Color screening of static potential between heavy quarks:
J/ψ suppression: Matsui and Satz, *Phys. Lett. B* **178** (1986) 416
Suppression determined by T_C and binding energy

De-confinement → Color screening → heavy quarkonia states "dissolved"

Quarkonia

Charmonia: J/ψ, Ψ’, χ_c **Bottomonia**: ϒ(1S), ϒ’ (2S), ϒ”(3S)

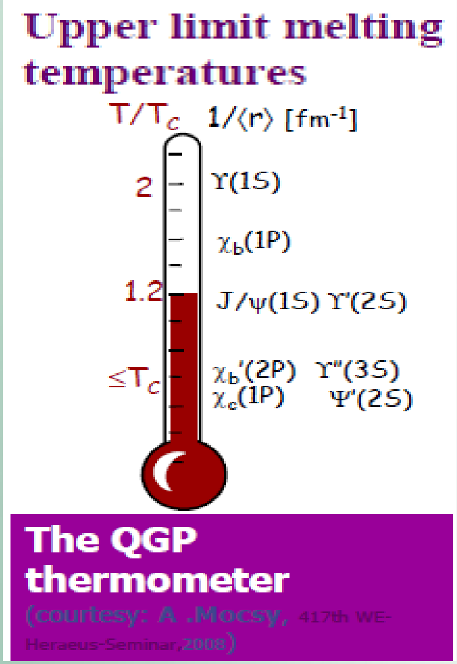
Lattice QCD: Evaluation of spectral functions ⇒ $T_{melting}$

Models based on potential with largest possible binding ⇒ most bound states melt by $1.3T_c$

Upsilon (1S) survives until $2T_c$

Lattice results : Consistent with quarkonium melting

Suppression pattern ⇒ thermometer of QCD matter



(courtesy: A .Mocsy, 417th WE-Heraeus-Seminar,2008)

$$\Gamma(T) \geq 2E_{bin}(T)$$

State	χ_c	ψ'	J/ψ	Υ'	χ_b	Υ
$T_{\rm dis}$	$\le T_c$	$\le T_c$	$1.2T_c$	$1.2T_c$	$1.3T_c$	$2T_c$

Increasing binding energy

PRL 99, 211602

Quantifying suppression requires: **Baseline p+p measurement**

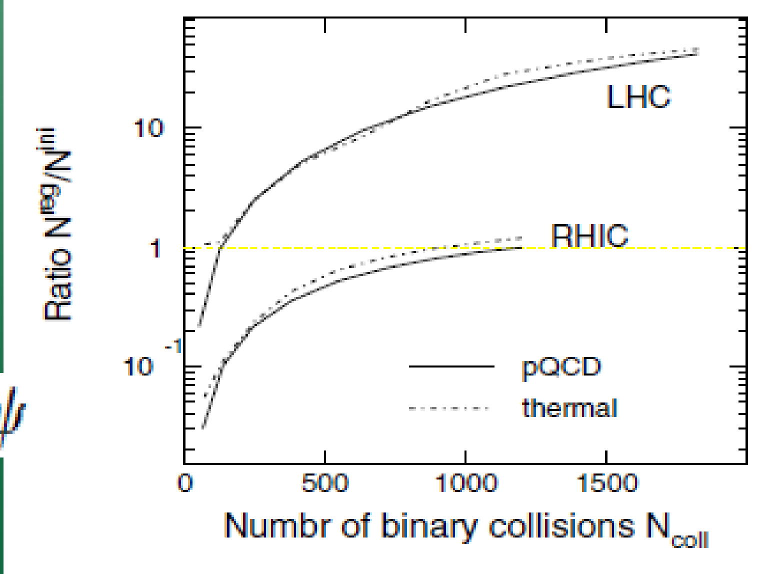
Measurement of Cold Nuclear Matter effects: **p+A collisions**

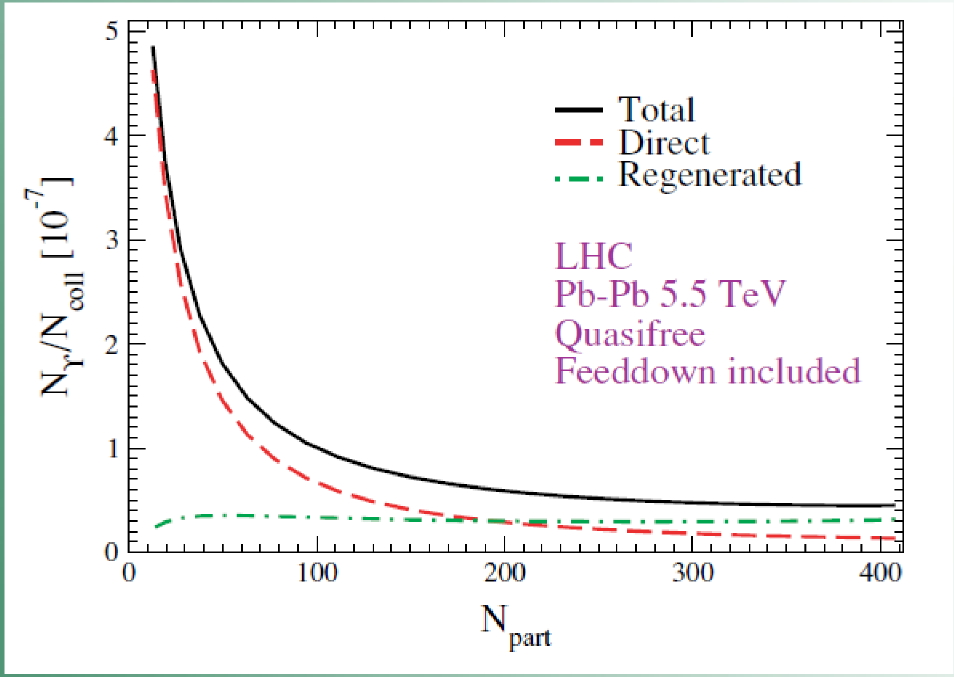
Bottomonia vs Charmonia

Bottomonia :

- Regeneration effects are much weaker.
- No feed-down from open heavy-flavors but only from higher-mass bottomonia.
- Suppression effects **should be more evident.**

J/ψ





Regeneration @ LHC: **Dominant** mechanism
More charmonia created

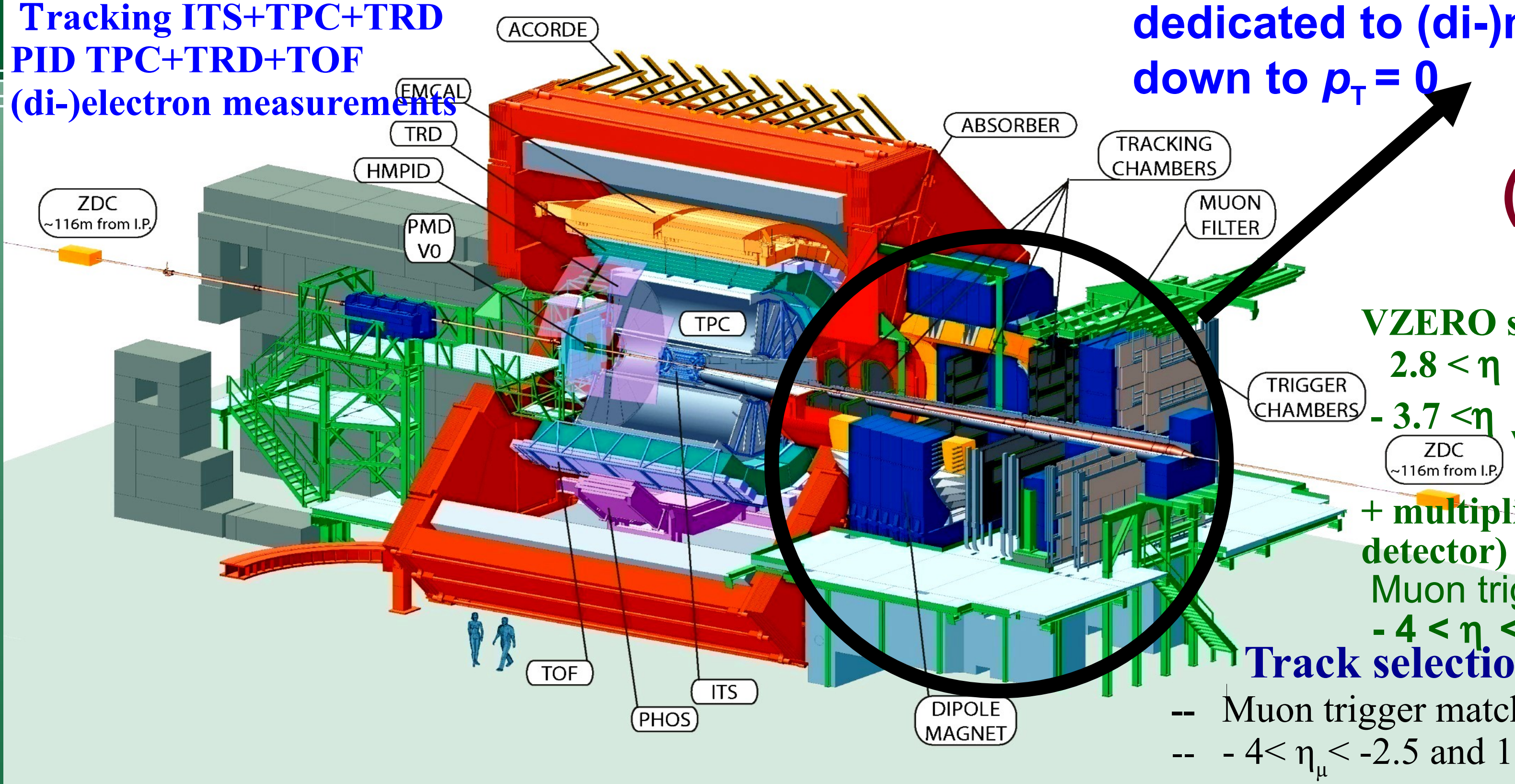
Suppression picture : complicated
PRL 97, 232301 for charmonia !

Suppression picture : holds for Υ
PRC 73, 064906 → Despite regeneration @ LHC

Bottomonia powerful probe for QGP

The ALICE experiment (LHC-CERN)

A Large Ion Collider Experiment



Central barrel ($|\eta|<0.9$)

Tracking ITS+TPC+TRD
PID TPC+TRD+TOF
(di-)electron measurements

Forward Muon Spectrometer is dedicated to (di-)muons measurement down to $p_T = 0$

($-4 < \eta < -2.5$)

Trigger detectors
VZERO scintillator Hodoscopes
$2.8 < \eta_{v0\text{-}A} < 5.1$
$-3.7 < \eta_{v0\text{-}C} < -1.7$

+ multiplicity in Pb-Pb ITS (pixel detector) → primary Vertex ($\eta < 1.4$)

Muon trigger chambers
$-4 < \eta < -2.5$

Track selection:

-- Muon trigger matching

-- $-4 < \eta_\mu < -2.5$ and $17.6 < R_{abs} < 89$ cm

(R_{abs} = track position at the absorber end)

-- $-4 < y_{\mu\mu} < -2.5$ and track momentum > 2 GeV/c

Data sample (ALICE Υ analysis in Pb-Pb 2.76 TeV):

- Minimum bias trigger (V0A && V0C && SPD)
- Rejecting for beam-gas or electromagnetic interactions using tracks to point to interaction vertex
- Run selection dependent on the stability of the muon spectrometer tracking and triggering performance

Centrality selection:

- Based on a geometrical-Glauber model fit of V0 amplitude
- Centrality bins used in this analysis: [0% - 20%], [20% - 90%] & [0% - 90%] with rapidity bins [$y_{\mu\mu}$] (2.5 to 3.2) and (3.2 to 4.0)

◊ **Integrated luminosity after data selection: 69 μb^{-1}**

ϒ(1S) analysis in Pb-Pb 2.76 TeV

PLB 738 (2014) 361
ALICE-PUBLIC-2014-001
Pb-Pb @ 2.76 TeV

--The ϒ signal is extracted by means of a fit to the opposite-sign dimuon invariant mass spectrum

--The ϒ line-shapes are described by extended crystal ball with the tail parameters fixed with Monte Carlo results

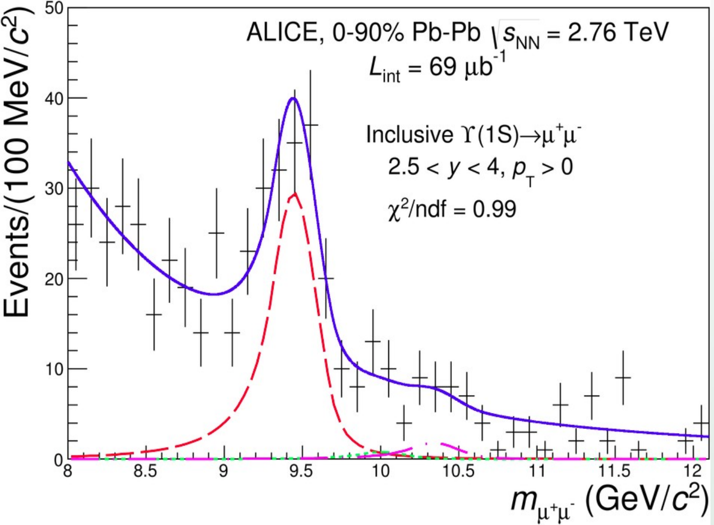
--The underlying background is fitted using a sum of two exponentials or a sum of two power-law functions

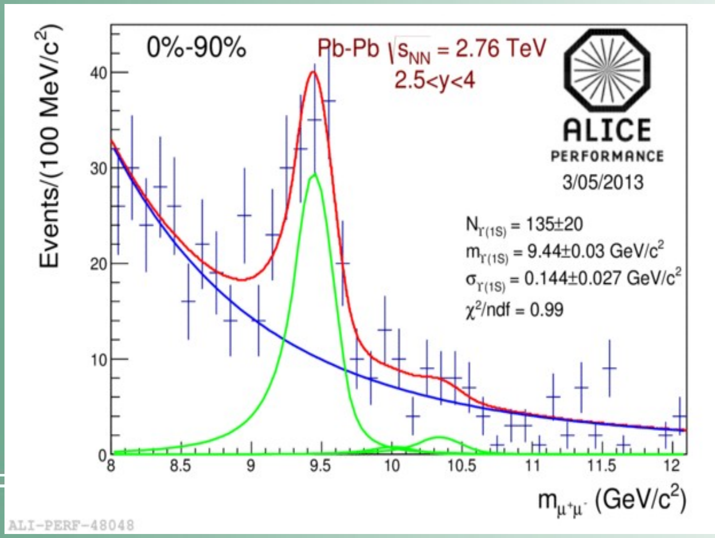
--The amplitude, position and width of ϒ(1S) are kept as free parameters

--Parameters of the double exponential and amplitude of ϒ (2S) and ϒ(3S)kept free

--Width of 2S and 3S constrained to those of 1S as per PDG ratio

--The mass differences between states were fixed from PDG values





https://aliceinfo.cern.ch/ArtSubmission/node/193

Υ(1S) : Acceptance x Efficiency

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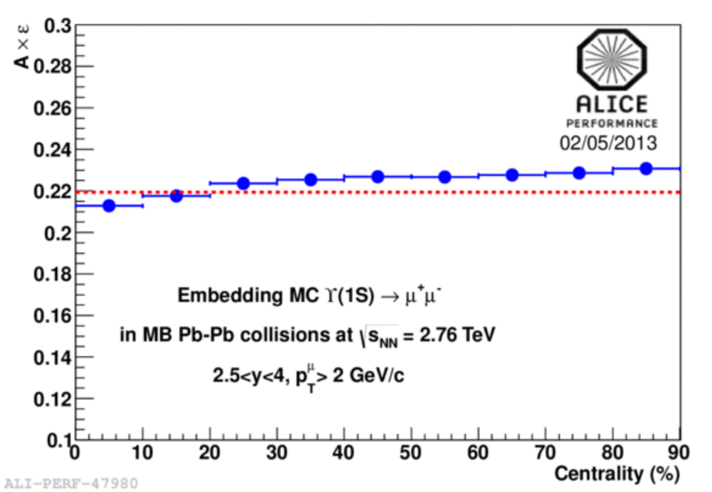
ALICE-PUBLIC-2014-001
Pb-Pb @ 2.76 TeV

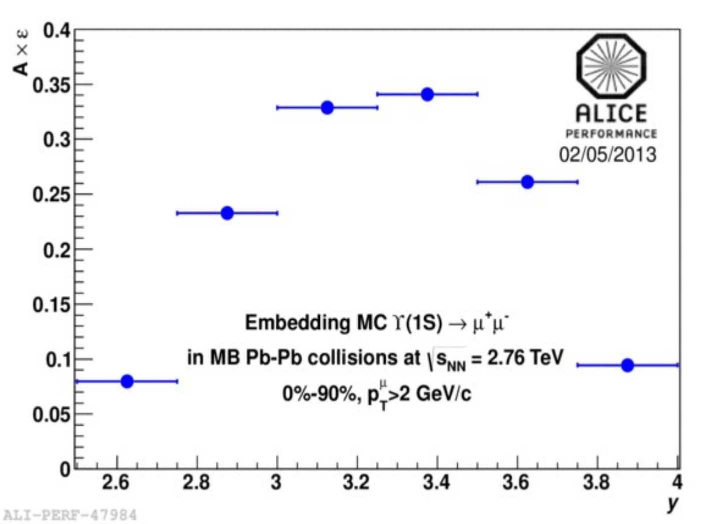
-- Acc × Eff correction plotted as a function of **centrality** and **rapidity**

-- Small decreasing of the reconstruction efficiency with increasing centrality ~7% due to increasing detector occupancy

-- Acc x eff peaked at mid-rapidity and decreasing towards the edge of the acceptance

--Systematic uncertainty on Υ(1S) cross section includes conributions from tracking (~10%) and trigger (~2%) efficiencies, matching between tracking and trigger detectors (1%), signal extraction (~5-10 %) and Monte Carlo inputs to acceptance calculation (~4-7%)





Inclusive Υ(1S) : Nuclear Modification factor

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ALICE-PUBLIC-2014-001
Pb-Pb @ 2.76 TeV

Υ(1S) yield per unit rapidity

$$\frac{dY_{\Upsilon(1S)}}{dy} = \frac{N_{\Upsilon(1S)}}{BR \cdot N_{MB} \cdot A \times \varepsilon \cdot \Delta y}$$

0% - 90%
$2.5 < y < 4.0$ $p_T > 0$
($R_{AA}^{\Upsilon(1S)}$ ± stat. ± syst.)
0.30 ± 0.05 ± 0.04

Υ(1S) Nuclear Modification factor

$$R_{AA} = \frac{\frac{dY_{\Upsilon(1S)}}{dy}}{\langle T_{AA} \rangle \cdot \frac{d\sigma^{pp}}{dy}}$$

$\langle T_{AA} \rangle$ = the average nuclear overlap function

$\frac{d\sigma_{pp}}{dy}$ = the pp reference y-differential cross-section

The inclusive Υ(1S) cross-section per unit of rapidity in pp collisions at 2.76 TeV is obtained from the rapidity interpolation of LHCb data [R Aaij et. al. , LHCb Collab. , arXiv:1402.2359 ,EPJC 74, 2835(2014)]

Comparisons of $\Upsilon(1S)$ R_{AA}: ALICE and CMS

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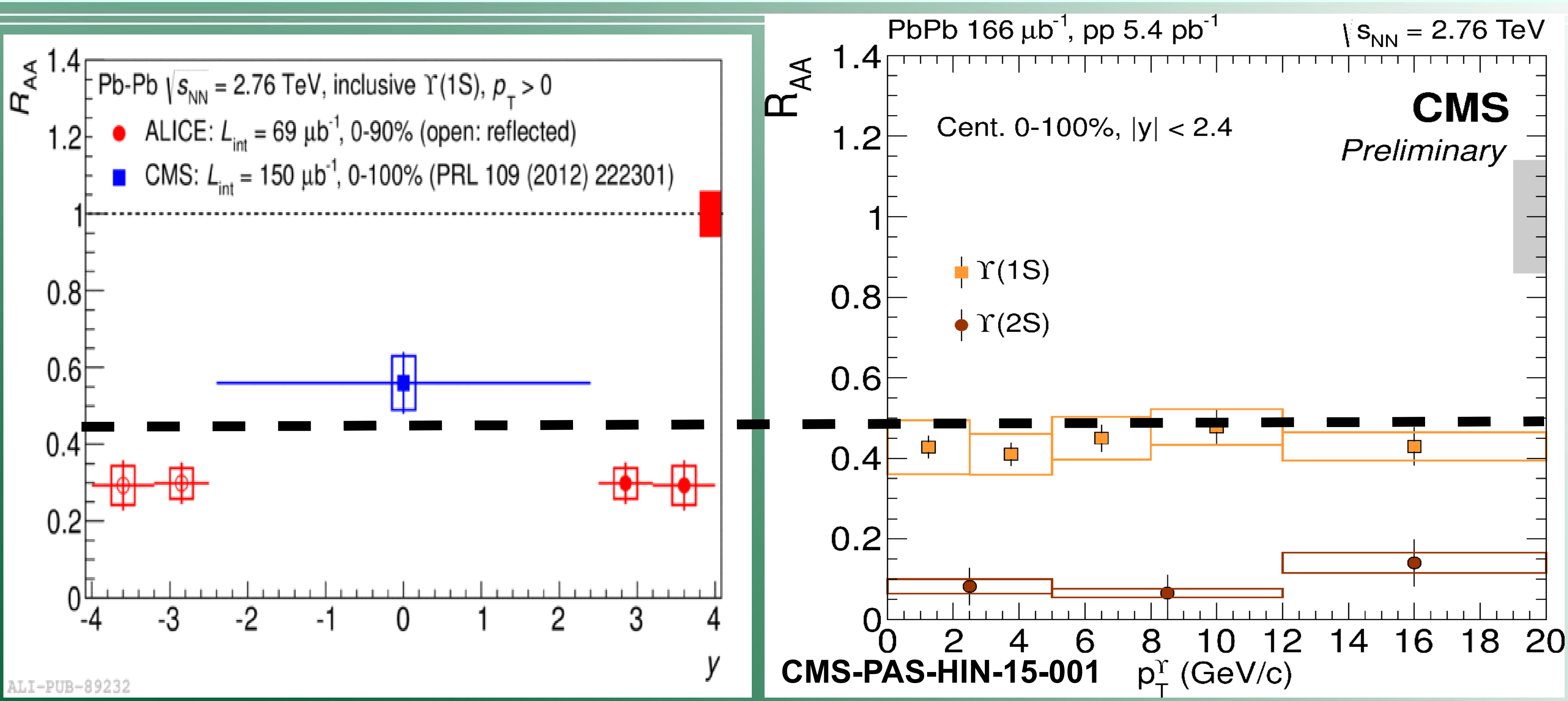
ALICE-PUBLIC-2014-001
Pb-Pb @ 2.76 TeV



- $\Upsilon(1S)$ more suppressed in recent measurements than what was before in
- (CMS :PRL 109 (2012) 222301) old: R_{AA} (Y(1S)) = 0.56 ± 0.08 ± 0.07

  new: R_{AA} (Y(1S)) = 0.425 ± 0.029 ± 0.070
- The results now compare better with ALICE measurements

Comparisons of $\Upsilon(1S)$ and J/ψ R_{AA}

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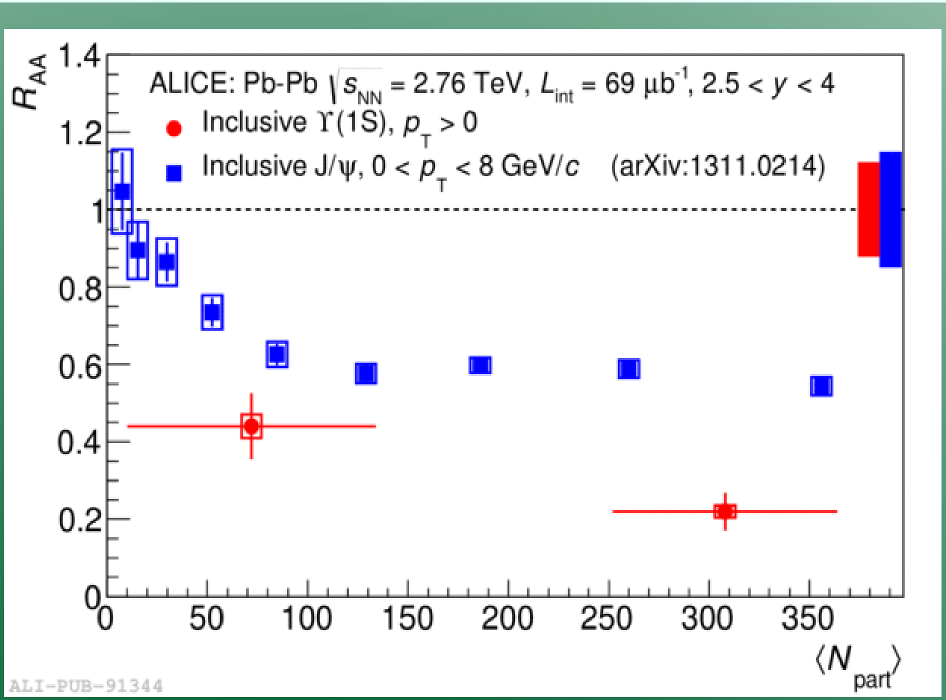
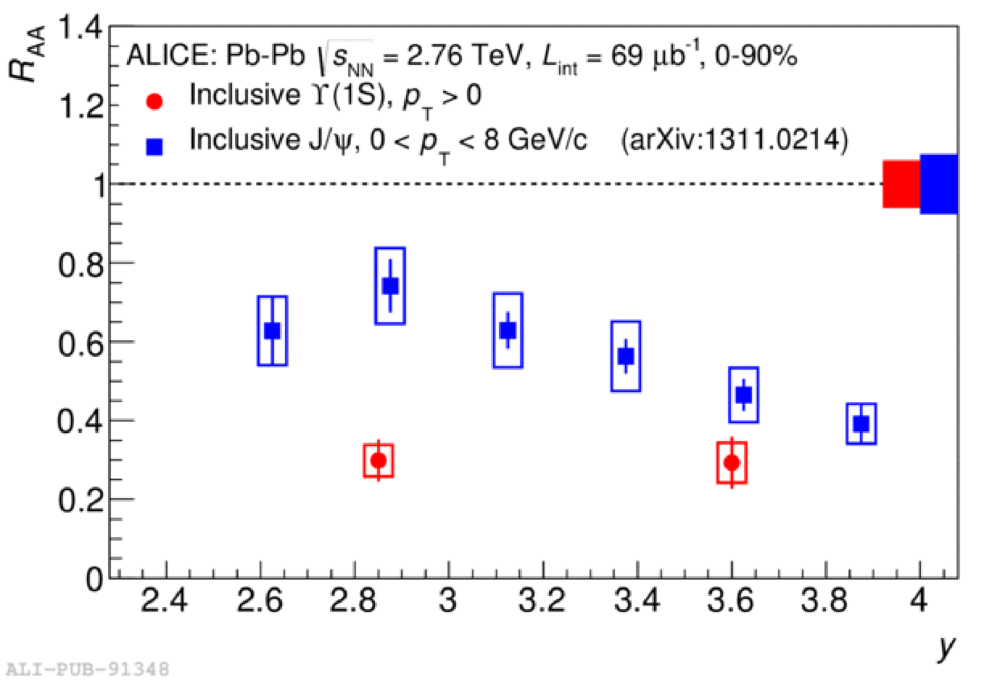
ALICE-PUBLIC-2014-001
Pb-Pb @ 2.76 TeV





- Inclusive ϒ(1S) showing more suppression in rapidity and centrality than J/ψ
- Not a straight forward interpretation due to important contributions of regeneration of J/ψ and feed-down from higher mass states for ϒ

Comparisons of $\Upsilon(1S)$ R_{AA} with Dynamical model

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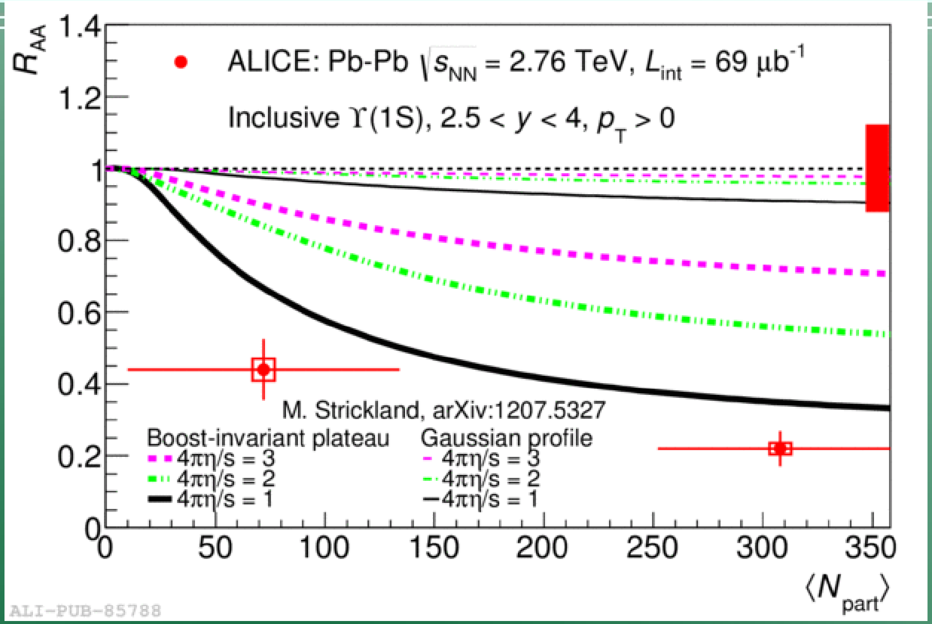
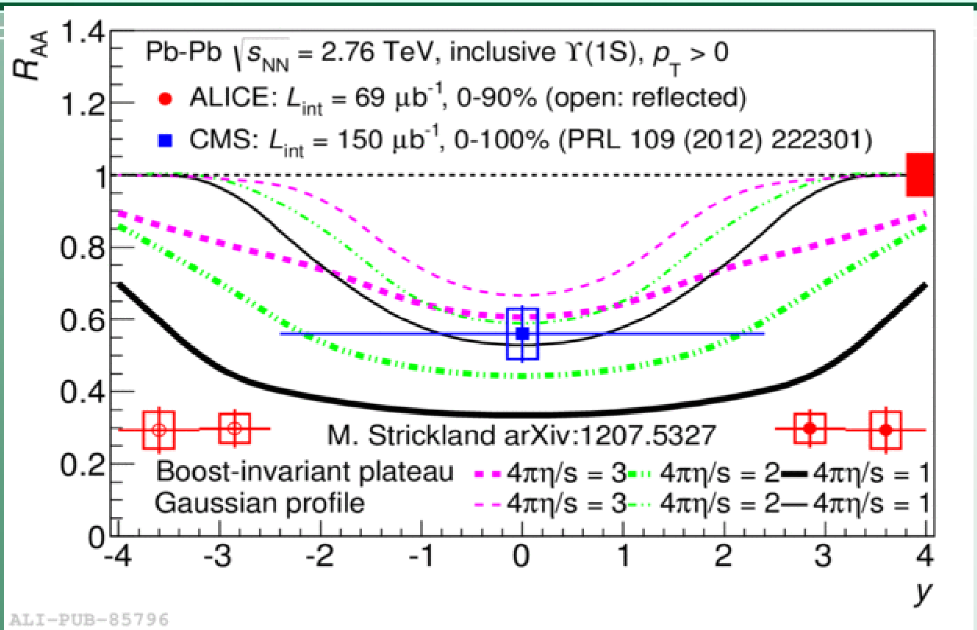
ALICE-PUBLIC-2014-001
Pb-Pb @ 2.76 TeV





Thermal suppression of bottomonium states :

- Utilizes a potential model to determine the impact of QGP phase on Υ suppression
- States and decay widths utilizing this potential is integrated over
- the space-time evolution of QGP using anisotropic hydro formalism
- Two temperature rapidity profiles: Boost invariant or Gaussian
- Three tested shear viscosities
- Feed down from higher mass states included
- No Cold Nuclear Matter(CNM) effects included
- Does not also include recombination effects

ALICE $\Upsilon(1S)$ R_{AA} is underestimated by the dynamical model

M. Strickland, arXiv:1207.5327v3

Comparisons of $\Upsilon(1S)$ R_{AA} with Dynamical model

B. Krouppa, R. Ryblewski & M. Strickland
ArXiv:1507.03951, Phys. Rev. C 92, 061901(R)

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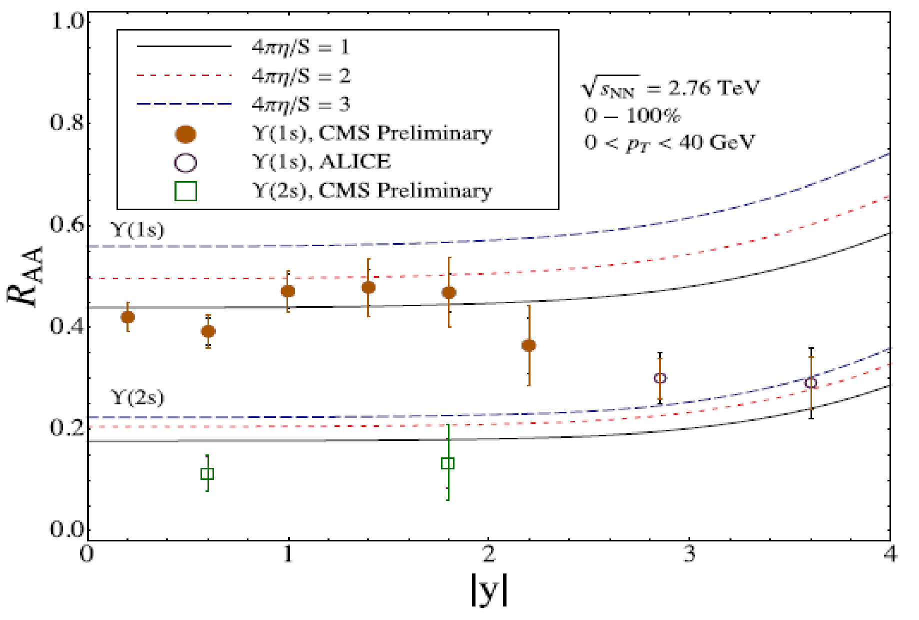
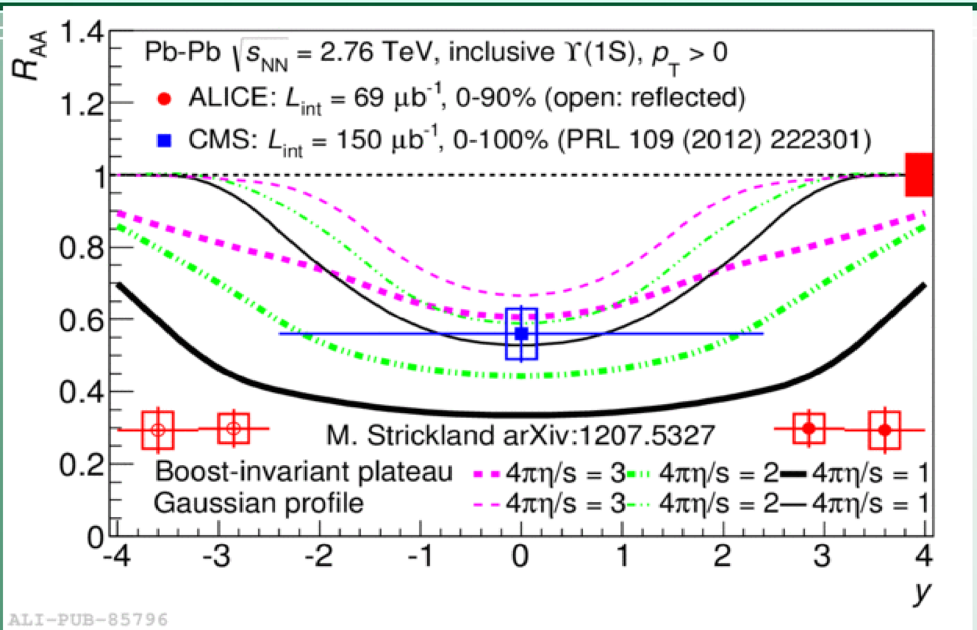
ALICE-PUBLIC-2014-001
Pb-Pb @ 2.76 TeV





Thermal suppression of bottomonium states (new calculations):

- Compared to earlier predictions the model shows milder trend and closer to ALICE Υ **data**
- Change in centrality averaging where previously a flat probability distribution was used
- Three tested shear viscosities
- Feed down from higher mass states included
- No Cold Nuclear Matter(CNM) effects included
- Does not also include recombination effects

Comparisons of $\Upsilon(1S)$ R_{AA} with Transport model (I)

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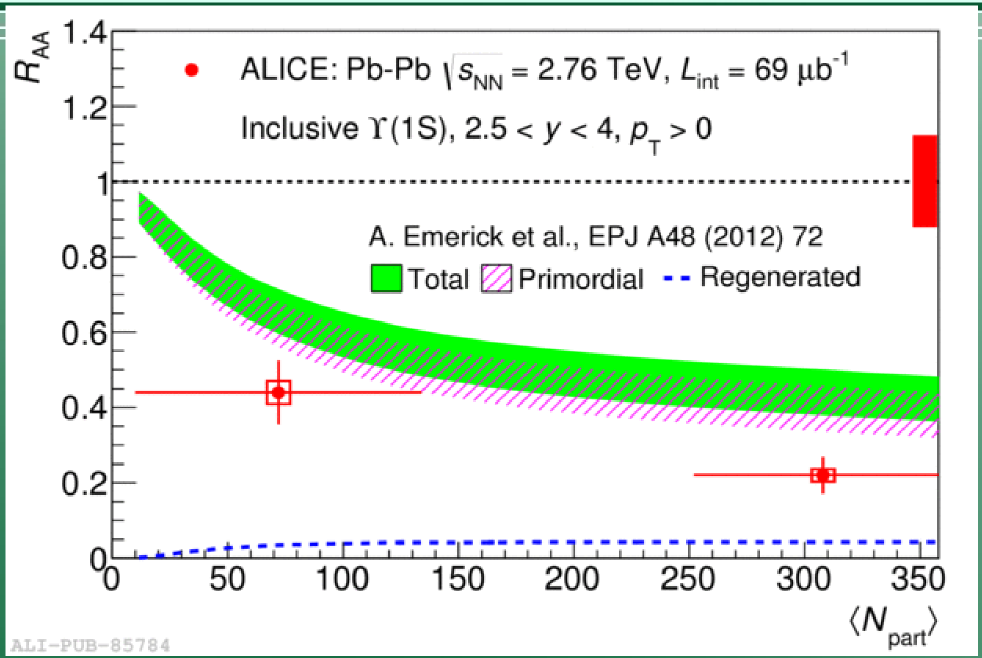
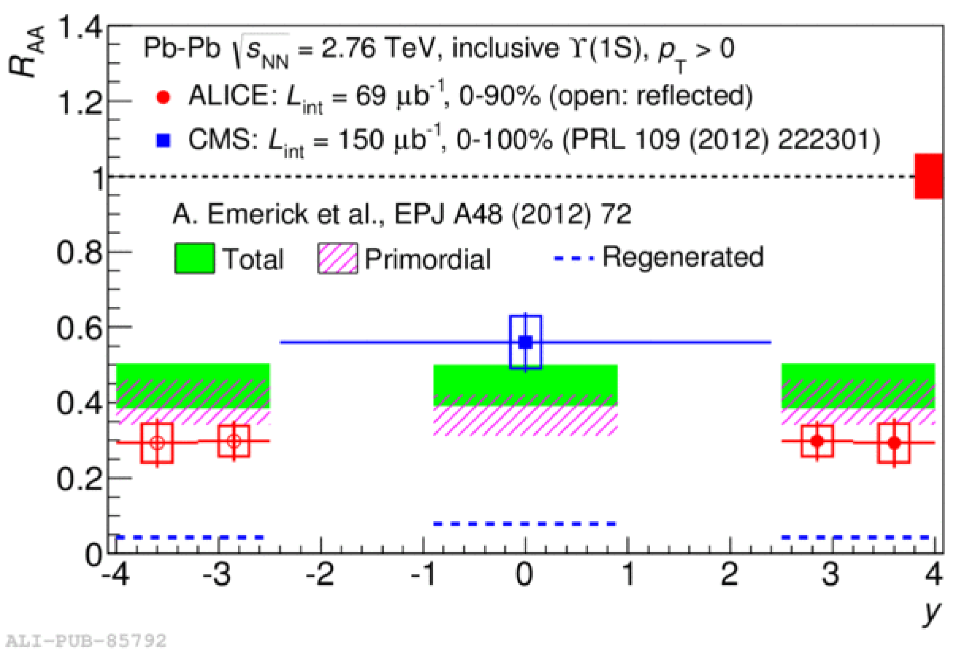
ALICE-PUBLIC-2014-001
Pb-Pb @ 2.76 TeV





Transport model [A. Emerick et al., EPJ A 48 (2012) 72]

- Suppression of primordial resonances by the QGP
- Suppression and regeneration mechanism implemented using a rate equation
- Spatio temporal evolution tuned according to recent LHC results
- Small regeneration component included
- Feed down from higher mass states included
- CNM included via an "effective" σ_{abs} with values at 0 and 2 mb

ALICE $\Upsilon(1S)$ R_{AA} is underestimated by this transport model

Comparisons of $\Upsilon(1S)$ R_{AA} with Transport model (II)

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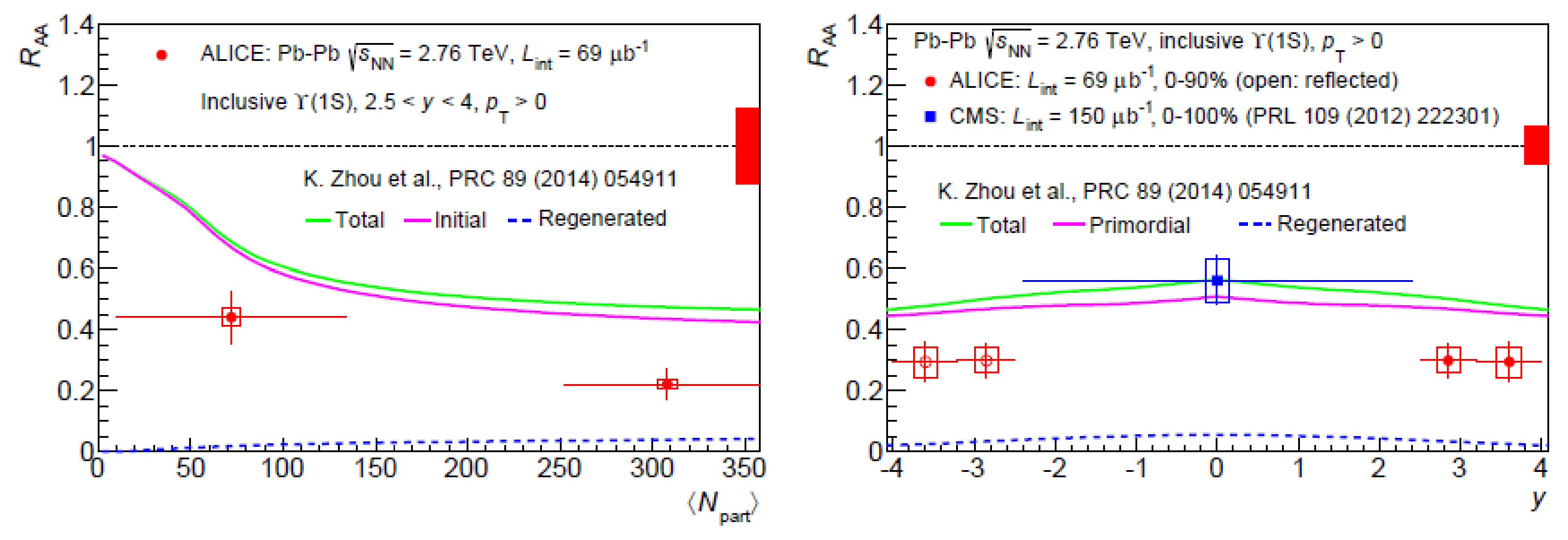
ALICE-PUBLIC-2014-001
Pb-Pb @ 2.76 TeV



Transport model [K.Zhou et. al. ArXiv : 1401.5845 , PRC89 (2014) 054911 and private communication]

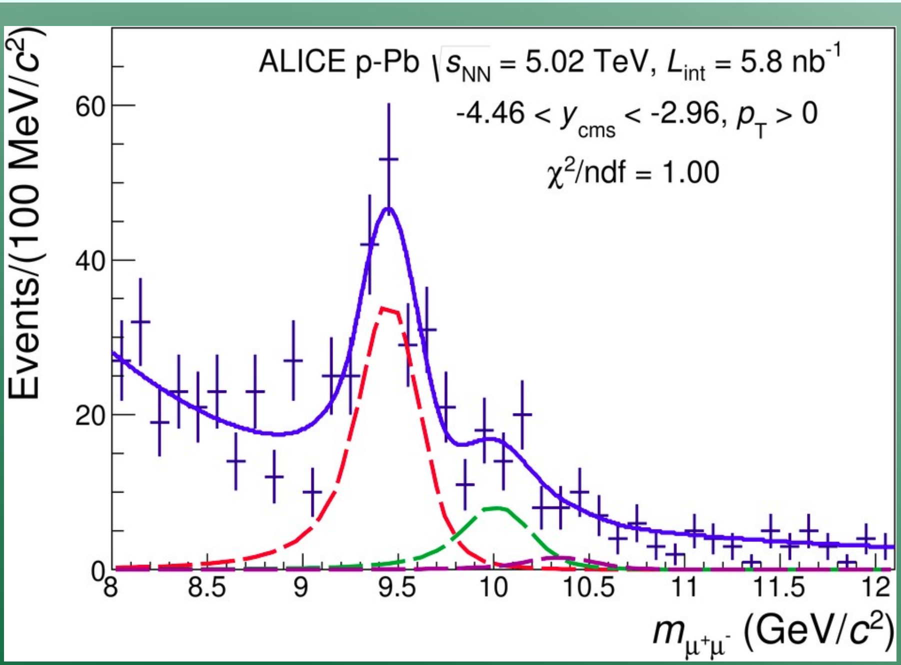
- Similar approach as before but also using potential model results quantitatively
- Small regeneration component included
- Feed down from higher mass states included
- CNM included using the EKS98 shadowing parameterization

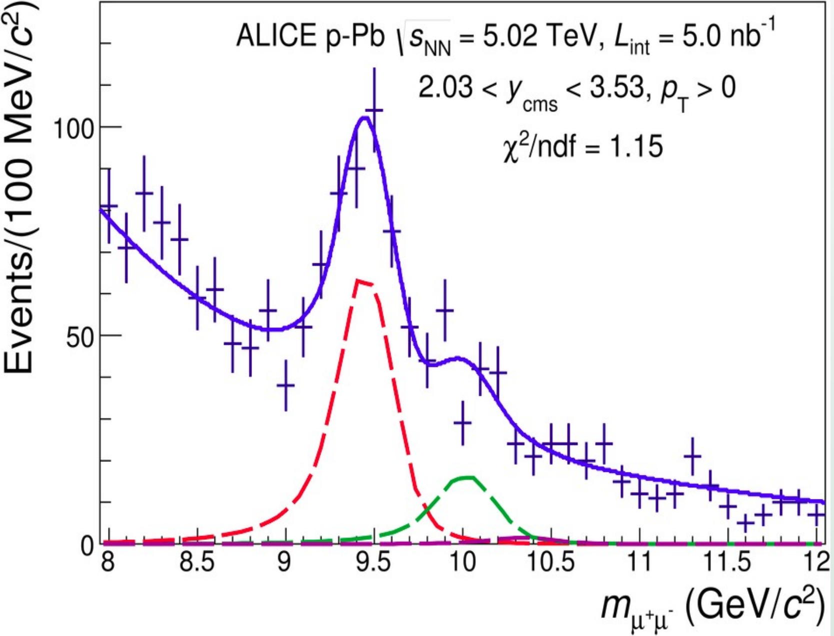
Model reproduces CMS mid-rapidity point but underestimates ALICE results at forward rapidity

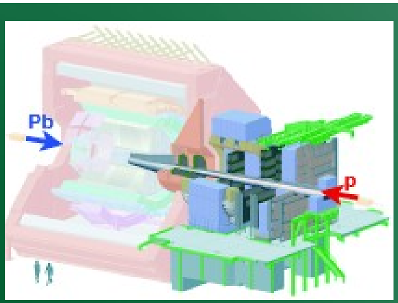
Different rapidity behaviour --- What role do CNM effects play?

$\Upsilon(1S)$, $\Upsilon(2S)$ in p-Pb & Pb-p collisions @ 5.02 TeV

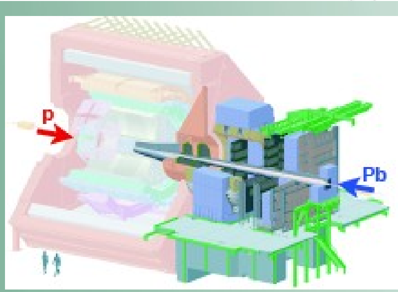
PLB 740 (2015) 105
p-Pb @ 5.02 TeV







Two configurations



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

($2.03 < y_{cms} < 3.53$)

https://aliceinfo.cern.ch/ArtSubmission/node/211

Production cross-sections and ratios

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p-Pb @ 5.02 TeV

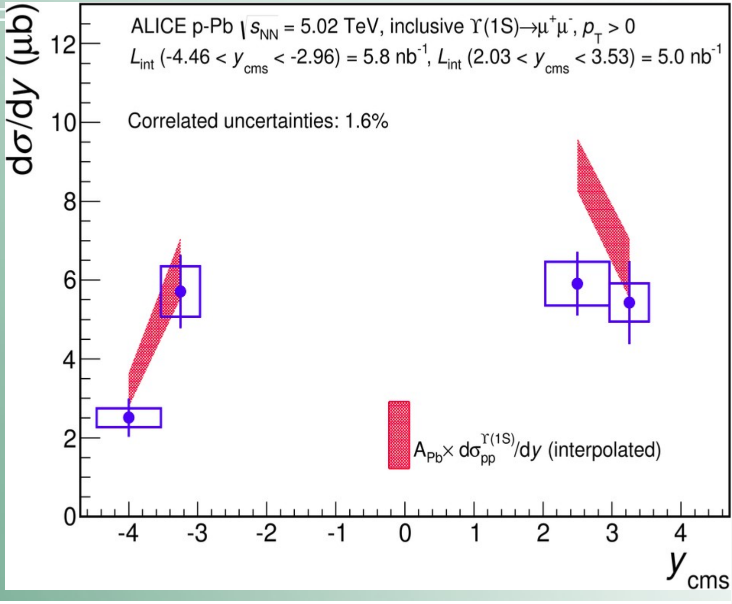
Rapidity integrated cross-sections:

$\sigma^{\Upsilon(1S)}$ (-4.46 <y_{cms}<-2.96) = 5.57 ± 0.72 (stat) ± 0.60(syst) μb

$\sigma^{\Upsilon(1S)}$ (2.03 <y_{cms}< 3.53) = 8.45 ± 0.94 (stat) ± 0.77(syst) μb

$\sigma^{\Upsilon(2S)}$ (-4.46 <y_{cms}<-2.96) = 1.85 ± 0.61 (stat) ± 0.32(syst) μb

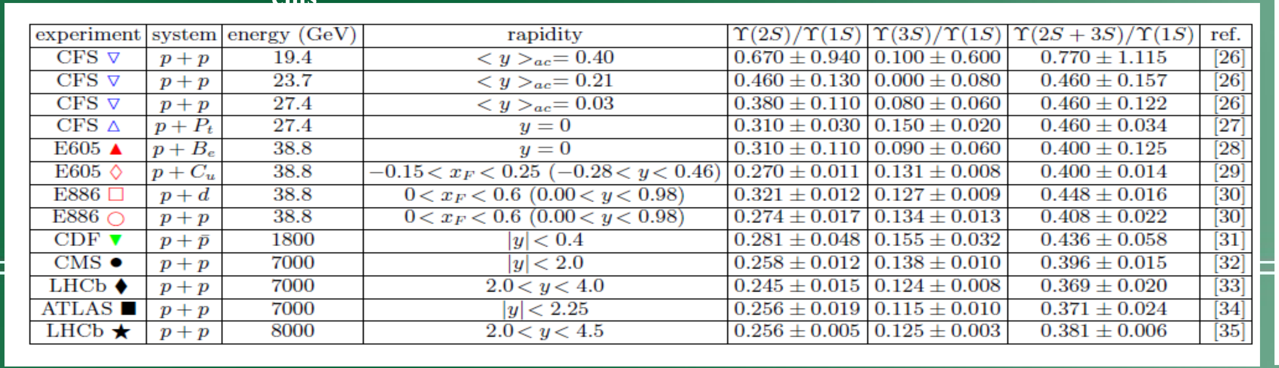
$\sigma^{\Upsilon(2S)}$ (2.03 <y_{cms}< 3.53) = 2.97 ± 0.82 (stat) ± 0.50(syst) μb



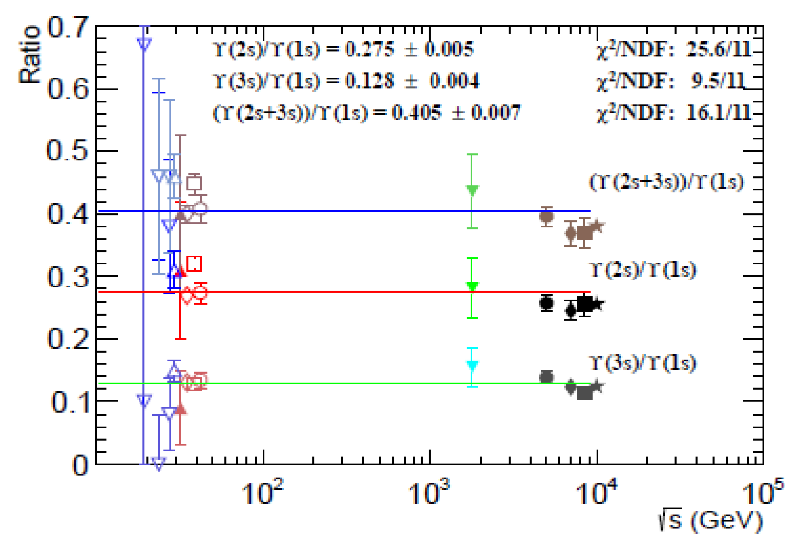
Rapidity integrated cross-section ratios of Υ(2S)/ Υ(1S):

(-4.46 <y_{cms}<-2.96) : 0.26 ± 0.09(stat) ± 0.04(syst)

(2.03 <y_{cms}< 3.53) : 0.27 ± 0.08(stat) ± 0.04(syst)



experiment	system	energy (GeV)	rapidity	$\Upsilon(2S)/\Upsilon(1S)$	$\Upsilon(3S)/\Upsilon(1S)$	$\Upsilon(2S+3S)/\Upsilon(1S)$	ref.
CFS ▽	$p+p$	19.4	$< y >_{ac}= 0.40$	0.670 ± 0.940	0.100 ± 0.600	0.770 ± 1.115	[26]
CFS ▽	$p+p$	23.7	$< y >_{ac}= 0.21$	0.460 ± 0.130	0.000 ± 0.080	0.460 ± 0.157	[26]
CFS ▽	$p+p$	27.4	$< y >_{ac}= 0.03$	0.380 ± 0.110	0.080 ± 0.060	0.460 ± 0.122	[26]
CFS △	$p+P_t$	27.4	$y = 0$	0.310 ± 0.030	0.150 ± 0.020	0.460 ± 0.034	[27]
E605 ▲	$p+B_e$	38.8	$y = 0$	0.310 ± 0.110	0.090 ± 0.060	0.400 ± 0.125	[28]
E605 ◇	$p+C_u$	38.8	$-0.15< x_F < 0.25$ $(-0.28< y< 0.46)$	0.270 ± 0.011	0.131 ± 0.008	0.400 ± 0.014	[29]
E886 □	$p+d$	38.8	$0< x_F < 0.6$ $(0.00< y< 0.98)$	0.321 ± 0.012	0.127 ± 0.009	0.448 ± 0.016	[30]
E886 ○	$p+p$	38.8	$0< x_F < 0.6$ $(0.00< y< 0.98)$	0.274 ± 0.017	0.134 ± 0.013	0.408 ± 0.022	[30]
CDF ▼	$p+\bar{p}$	1800	$\|y\| < 0.4$	0.281 ± 0.048	0.155 ± 0.032	0.436 ± 0.058	[31]
CMS ●	$p+p$	7000	$\|y\| < 2.0$	0.258 ± 0.012	0.138 ± 0.010	0.396 ± 0.015	[32]
LHCb ◆	$p+p$	7000	$2.0< y< 4.0$	0.245 ± 0.015	0.124 ± 0.008	0.369 ± 0.020	[33]
ATLAS ■	$p+p$	7000	$\|y\| < 2.25$	0.256 ± 0.019	0.115 ± 0.010	0.371 ± 0.024	[34]
LHCb ★	$p+p$	8000	$2.0< y< 4.5$	0.256 ± 0.005	0.125 ± 0.003	0.381 ± 0.006	[35]



W.Zha et. al.,ArXiv:1308.4720

W.Zha et. al.,ArXiv:1308.4720

p-p cross-sections @ 5.02 TeV

ALICE-PUBLIC-2014-002
p-Pb @ 5.02 TeV

- No experimental data exist for pp at 5.02 TeV
- Using energy interpolation at forward rapidity

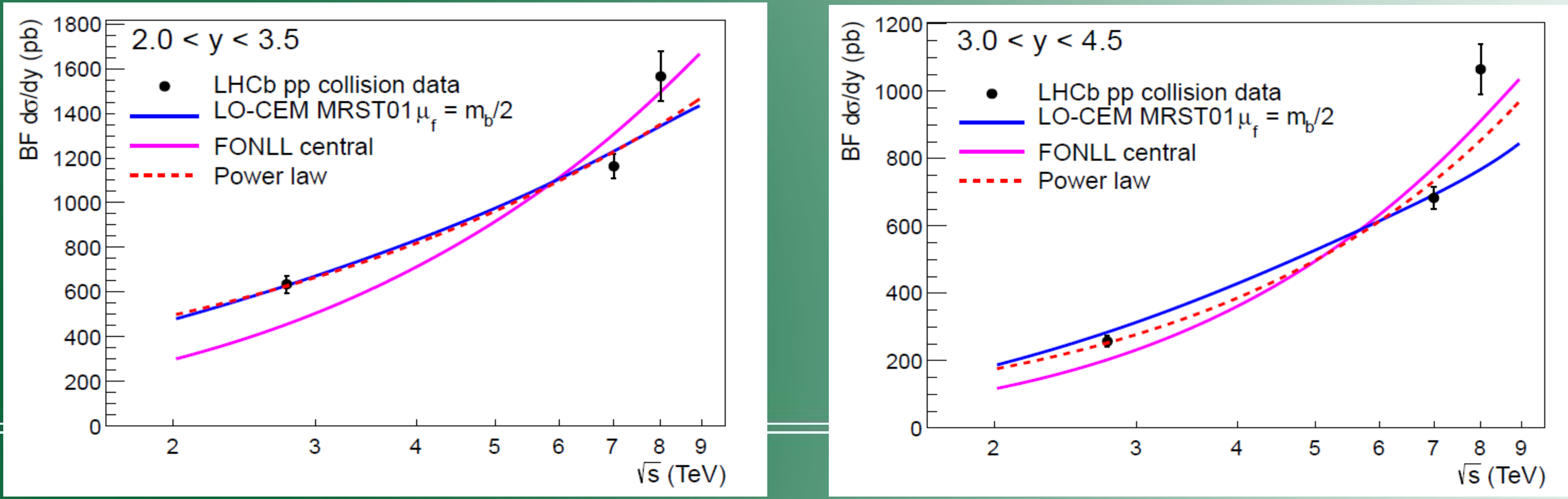
  --LHCb measurements of $\Upsilon(1S)$ at 2.76, 7 and 8 TeV

  --Several functional forms used

  --Of which some are also based on pQCD FONLL calculations
- Thus interpolated cross-sections used are :

  $d\sigma^{\Upsilon(1S)}/dy$ (2.0 <y <3.5 , 5.02 TeV) x BF($\mu^+\mu^-$) = 967 ± 76 pb

  $d\sigma^{\Upsilon(1S)}/dy$ (3.0 <y <4.5 , 5.02 TeV) x BF($\mu^+\mu^-$) = 513 ± 58 pb



Forward to Backward ratio (R_{FB})

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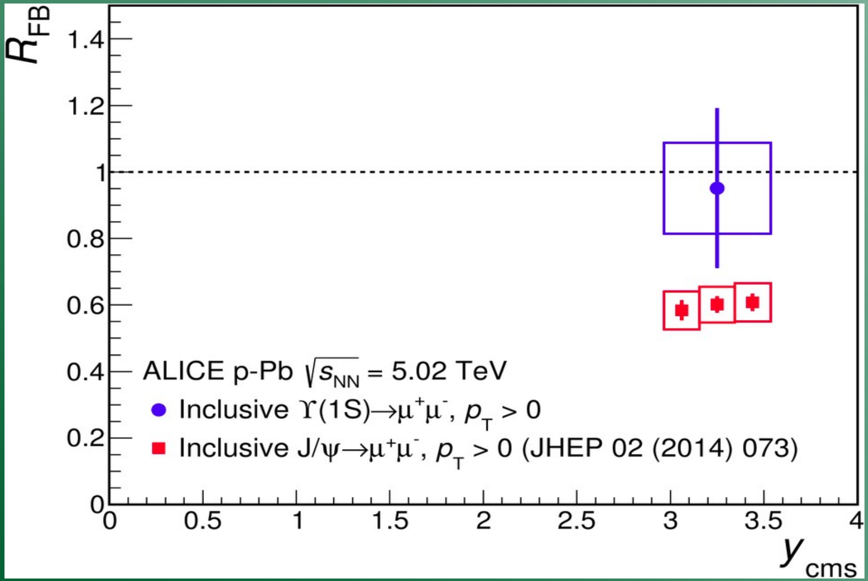
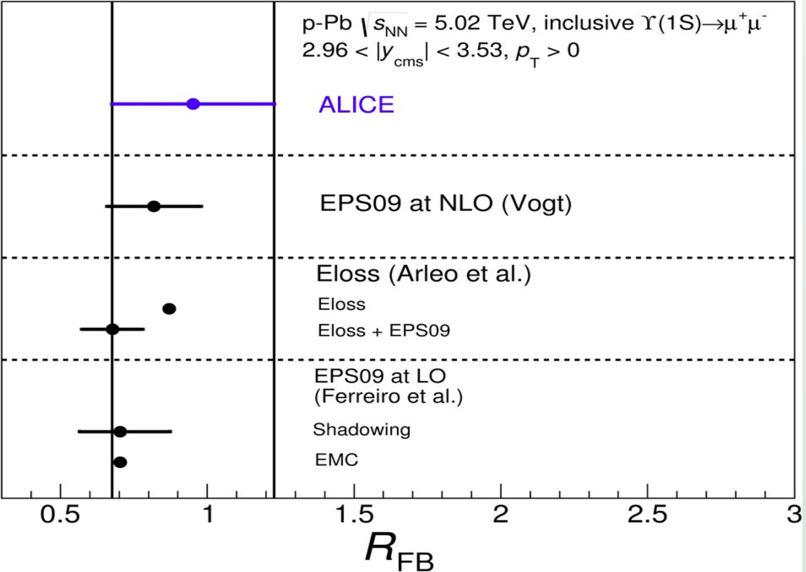
p-Pb @ 5.02 TeV

R_{FB} calculated from production cross-section ratio of forward and backward rapidities

-- Hence it does not depend on $\sigma_{pp}^{\Upsilon(1S)}$

– But needs to be restricted in the common rapidity region of 2.96 <$|y_{cms}|$< 3.53





All models describe the data within the present uncertainties of the measurement.

ϒ(1S) nuclear modification factor in p-Pb

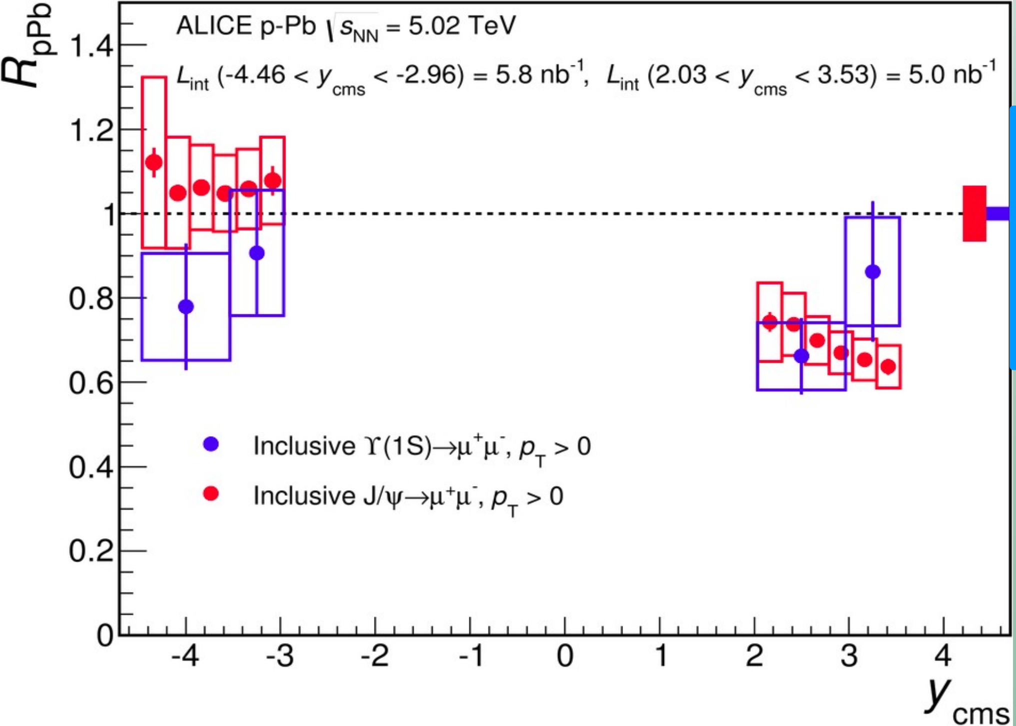
PLB 740 (2015) 105
p-Pb @ 5.02 TeV

Inclusive ϒ(1S) R_{pPb}

R_{pPb} of ϒ(1S) show **no suppression** (0.8σ) at backward rapidity

Uncertainties as :

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



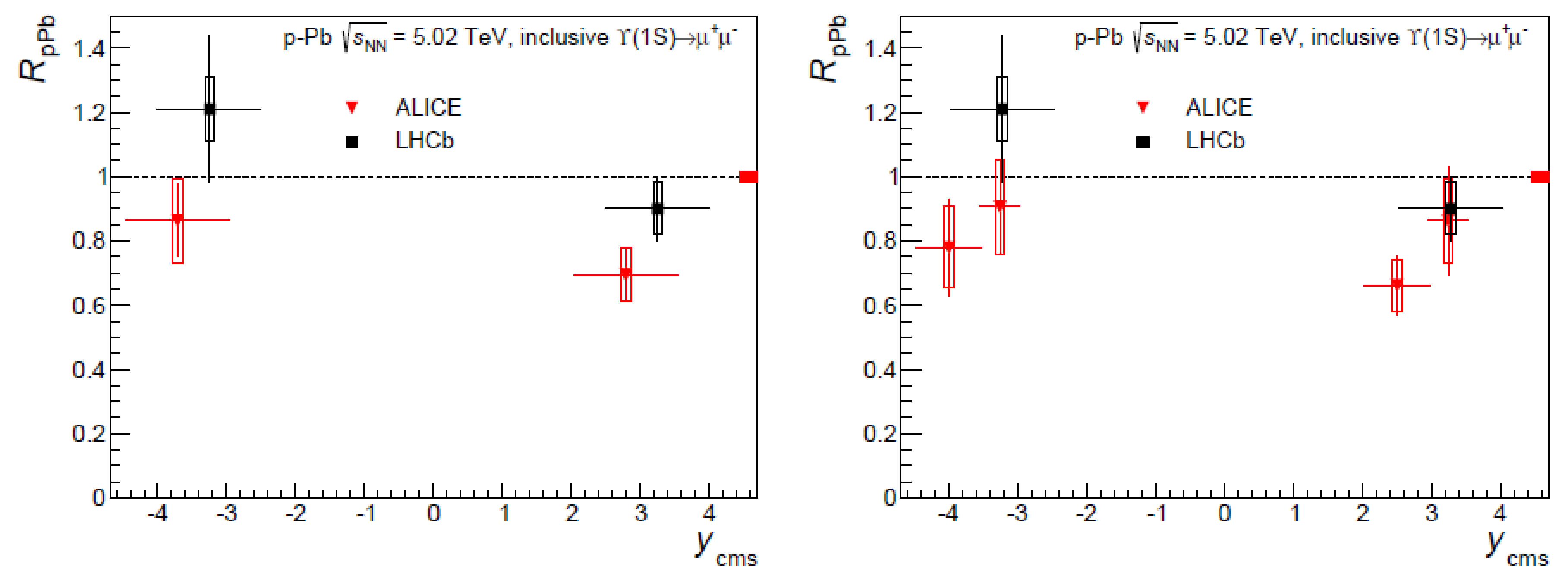
R_{pPb} of ϒ(1S) **show suppression** (2.7σ) at forward rapidity

- R_{pPb} of ϒ(1S) and J/ψ are similar at forward rapidity.
- At backward rapidity R_{pPb} of ϒ(1S) is slightly smaller than J/ψ but consistent within uncertainties.

Under the assumption of a 2→1 production process the sampled Bjorken-x ranges are
– Backward(anti-shadowing region): $3.6\cdot10^{-2} < x < 1.6\cdot10^{-1}$ (ϒ) and $1.2\cdot10^{-2} < x < 5.3\cdot10^{-2}$ (J/ψ)
– Forward(shadowing region): $5.5\cdot10^{-5} < x < 2.5\cdot10^{-4}$ (ϒ) and $1.8\cdot10^{-5} < x < 8.1\cdot10^{-5}$ (J/ψ)

R_{pPb} comparisons : LHCb and ALICE

ALICE-PUBLIC-2014-002
LHCb-CONF-2014-003
p-Pb @ 5.02 TeV



Comparison with LHCb R_{pPb} of $\Upsilon(1S)$:

– Both experiments show compatible measurements

– R_{pPb} systematically higher for LHCb than ALICE

Model comparisons with R_{pPb} of $\Upsilon(1S)$ [I]

PLB 740 (2015) 105
p-Pb @ 5.02 TeV

Arleo et al. [JHEP 1303 (2013) 122]

– Model has a contribution from coherent parton energy loss

– With or Without shadowing (EPS09) calcuations

– **Forward:** Better agreement with ELoss and shadowing

– **Backward:** Better agreement with ELoss only

==

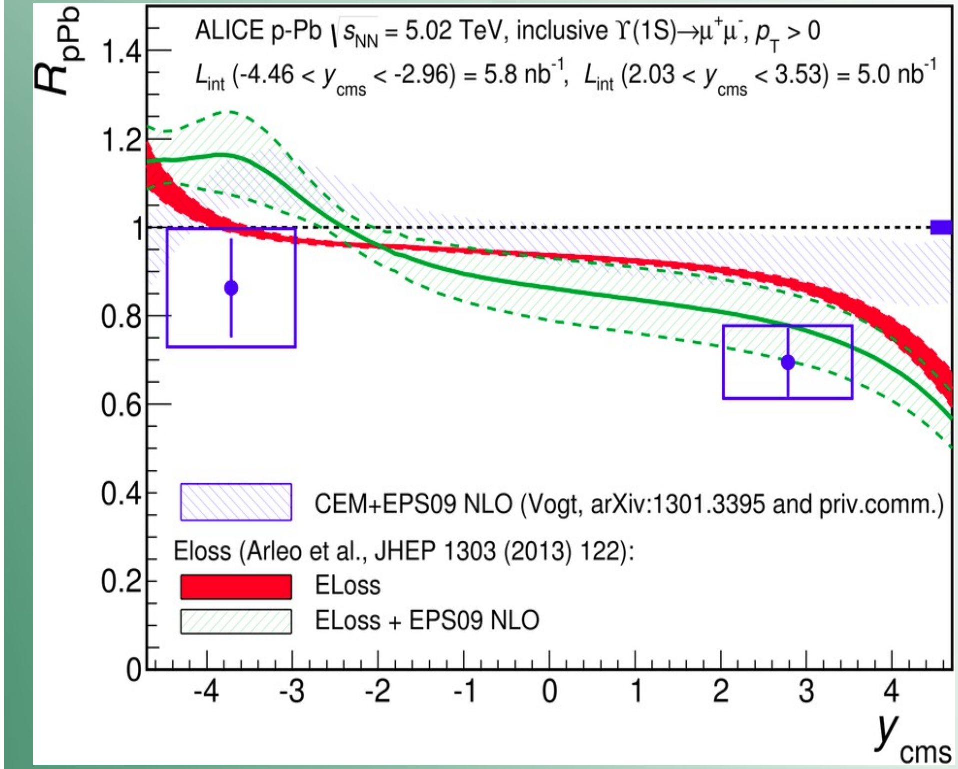
Vogt [arXiv:1301.3395]

– NLO CEM calculation

– EPS09 shadowing parameterization at NLO used

– Fair agreement with measured R_{pPb} within uncertainties dominated by EPS09 parameterizations

– But slight overestimation



Model comparisons with R_{pPb} of $\Upsilon(1S)$ [II]

PLB 740 (2015) 105
p-Pb @ 5.02 TeV

Ferreiro et al. [EPJC 73 (2013) 2427]

- A 2→2 production model at LO
- EPS09 shadowing parameterization used at LO
- Reasonable agreement with the measured R_{pPb}
- The red band shows the uncertainity in the EMC region i.e at high Bjorken-x
- Although slightly overestimates it in the anti-shadowing region

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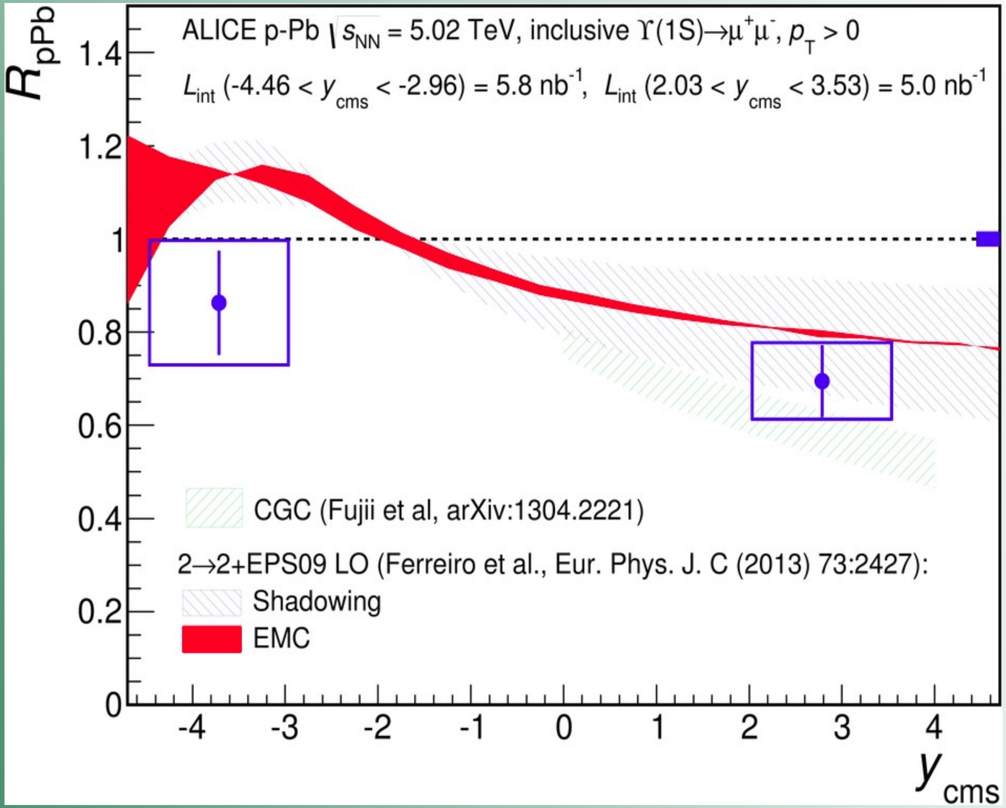
CGC(Fuji et. al. ArXiv:1304.2221)

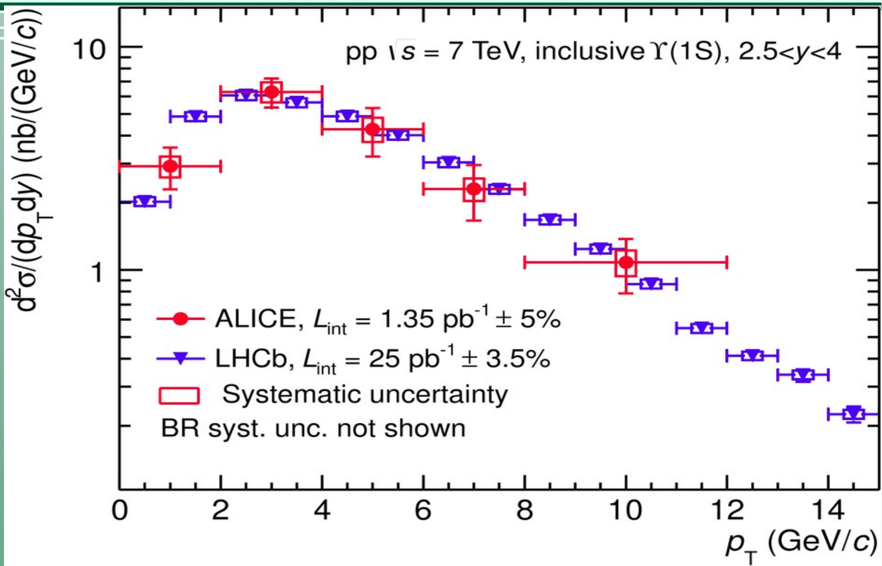
- CGC framework coupled with CEM
- Slightly underestimating in forward rapidity

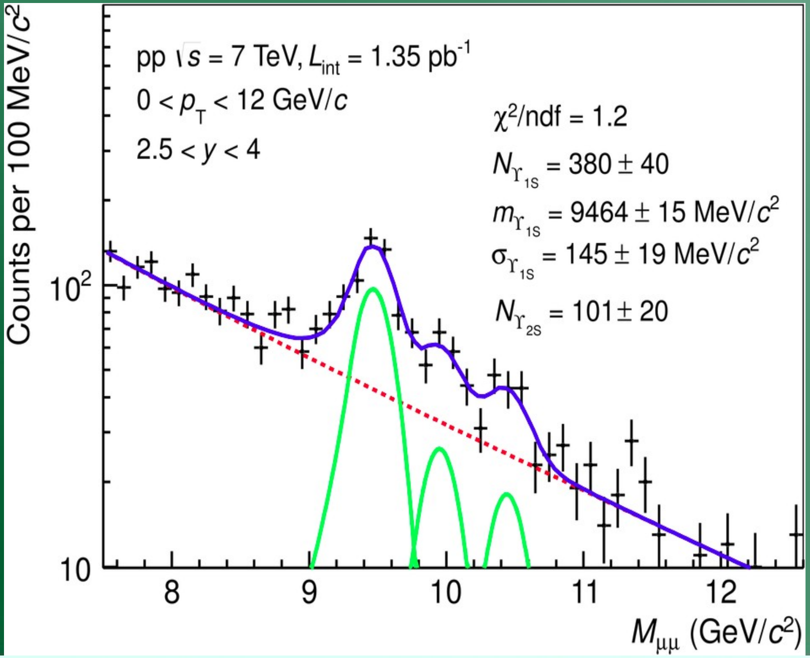


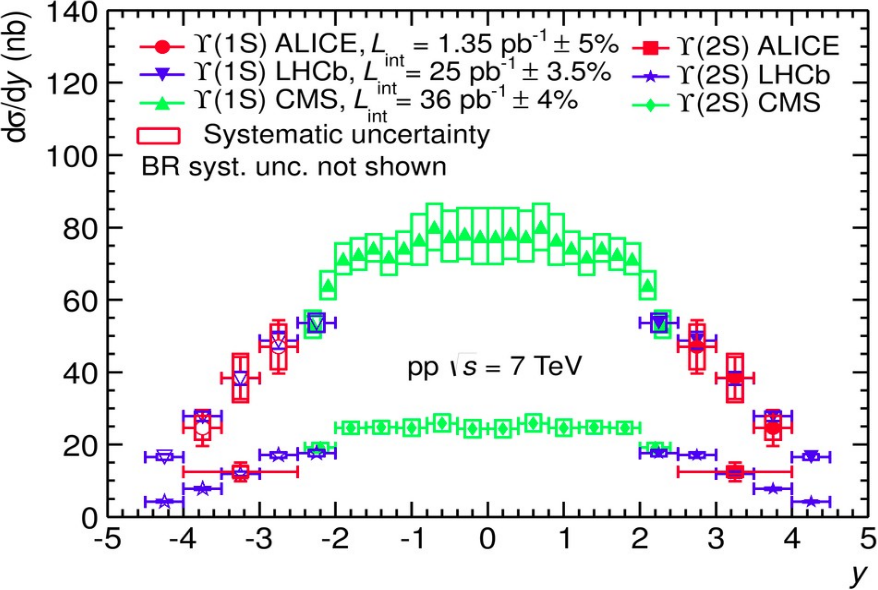
Results @ p-p 7 TeV

EPJC 74 (2014) 2974
p-p @ 7 TeV

- Υ(1S) and Υ(2S) yields measured in pp @ 7 TeV
- Υ cross-section vs p_T and rapidity
- Results in good agreement for Υ(1S) and Υ(2S) with LHCb results [EPJ C 72 (2012) 2025]
- Fraction of inclusive Υ(1S) coming from Υ(2S) decays : $f^{\Upsilon(2S)} = 0.90 \pm 0.027(stat) \pm 0.005(syst)$



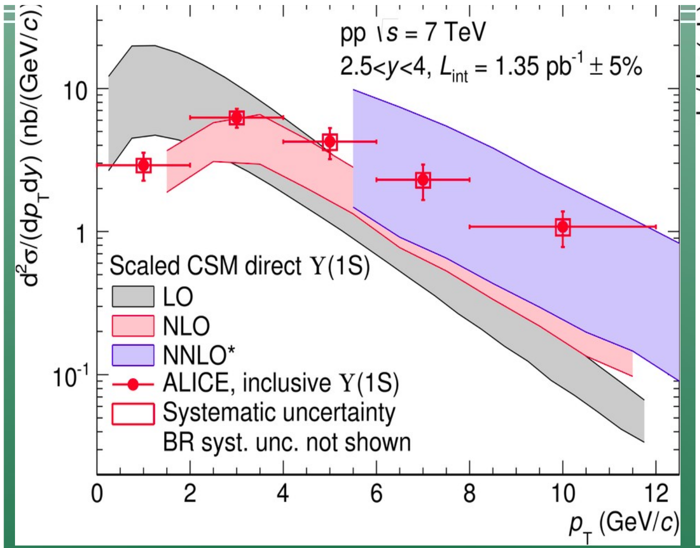


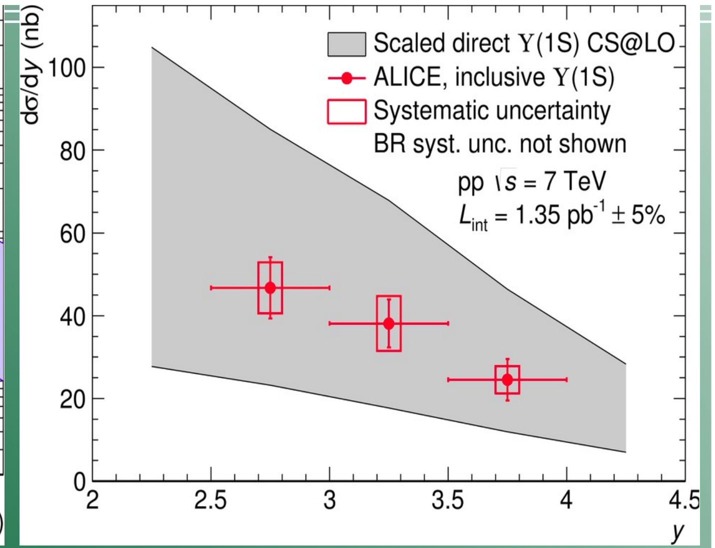


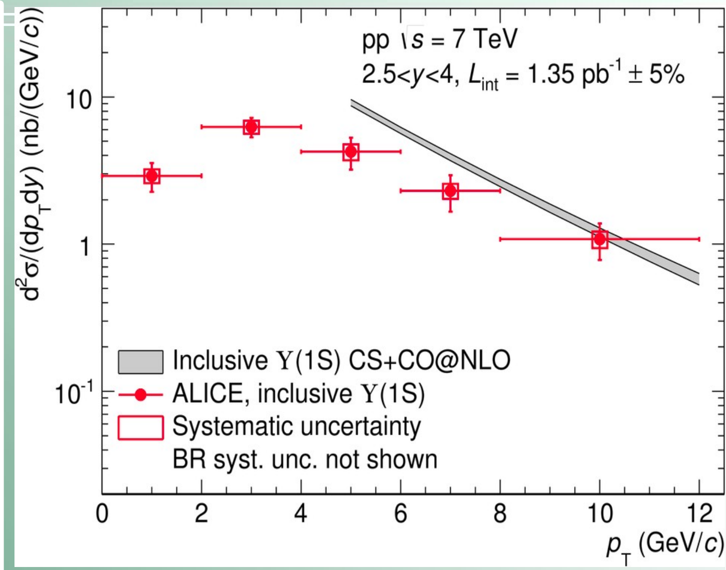
https://aliceinfo.cern.ch/ArtSubmission/node/189

Comparisons with Models : p-p 7 TeV

EPJC 74 (2014) 2974
p-p @ 7 TeV







Color Singlet Model [NPA470 (2013) 910]

– Calculations for LO and NLO

- Qualitative features like data for low p_T and rapidity dependence
- Underestimates the data at high p_T

– Also the leading-p_T NNLO contributions

- Better agreement at high p_T, but with large uncertainties

Non-Relativistic QCD (NRQCD) [PRD84 (2011) 114001, PRD85 (2012) 114003]

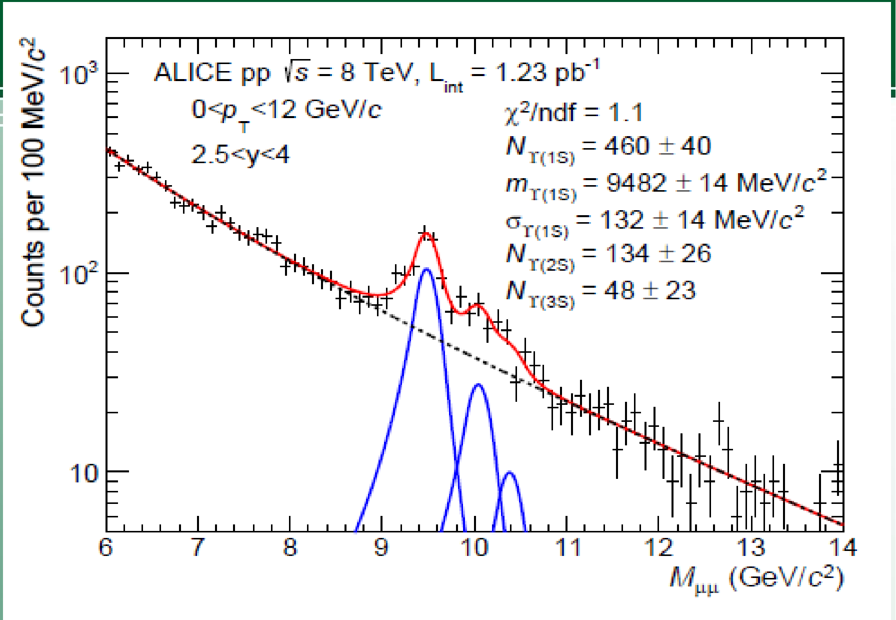
-- Theory overestimates the data

-- Smaller disagreement at high p_T

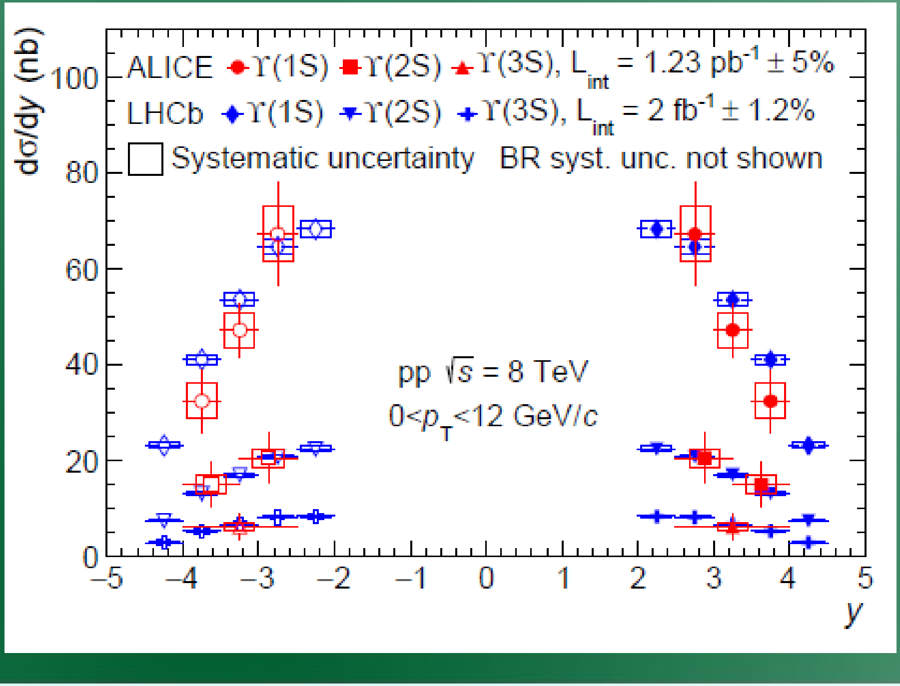
Υ(2S) -to-Υ(1S) ratio in good agreement with CSM and NRQCD approach[Mod. Phys. Lett. A 28, 1350120 (2013)]

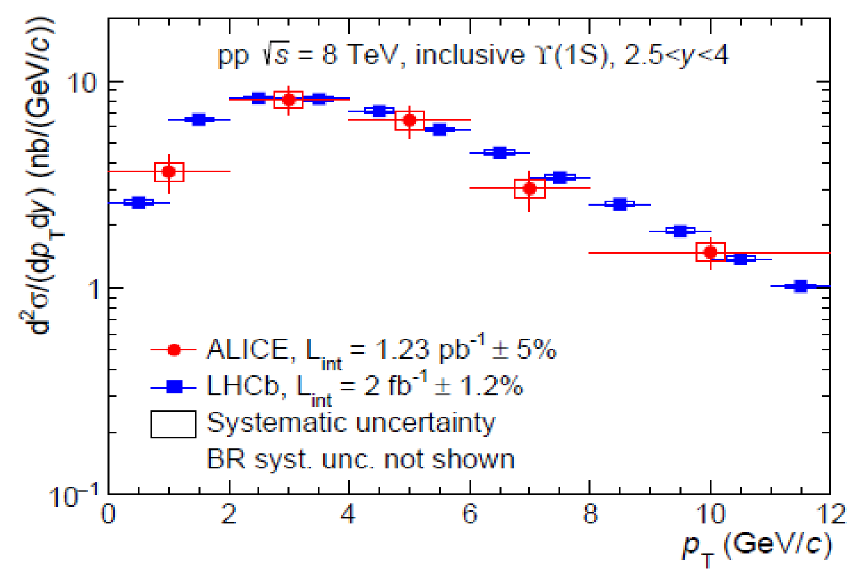
Results @ p-p 8 TeV

submitted to EPJC
p-p @ 8 TeV



- – ϒ(1S) , ϒ(2S), ϒ(3S) yields measured in pp @ 8 TeV
- – ϒ cross-section vs p_T and rapidity
- – Results compared with LHCb results [JHEP 1511 (2015) 103]





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Summary and Outlook

The production of inclusive Υ(1S) and Υ(2S) at forward rapidity has been measured in pp collisions at $\sqrt{s}$ = 7 TeV and 8 TeV [also Υ(3S)] (submitted)

- 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 than at central rapidity. However new CMS data show more compatibility with ALICE in rapidity

  -- Available models do not reproduce the strong rapidity dependence of the R_{AA} and underestimate the measured suppression at forward rapidity
- **What role do CNM effects play?**

The production of inclusive Υ(1S) and Υ(2S) in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV which shows

– A suppression of Υ(1S) at the forward rapidity (small-x region); Similar R_{pPb} as for J/ψ

– No indication, within uncertainties, of different CNM effects on Υ(2S) with respect to Υ(1S)

Data taking and analysis goals for 2015

pp@13 TeV
(very preliminary statistics)

RUN II : ~1500 Υ(1S) [for two major periods]

Pb-Pb in RUN II

– 5.02 TeV Energy
-- with respect to 2011

Initial results show

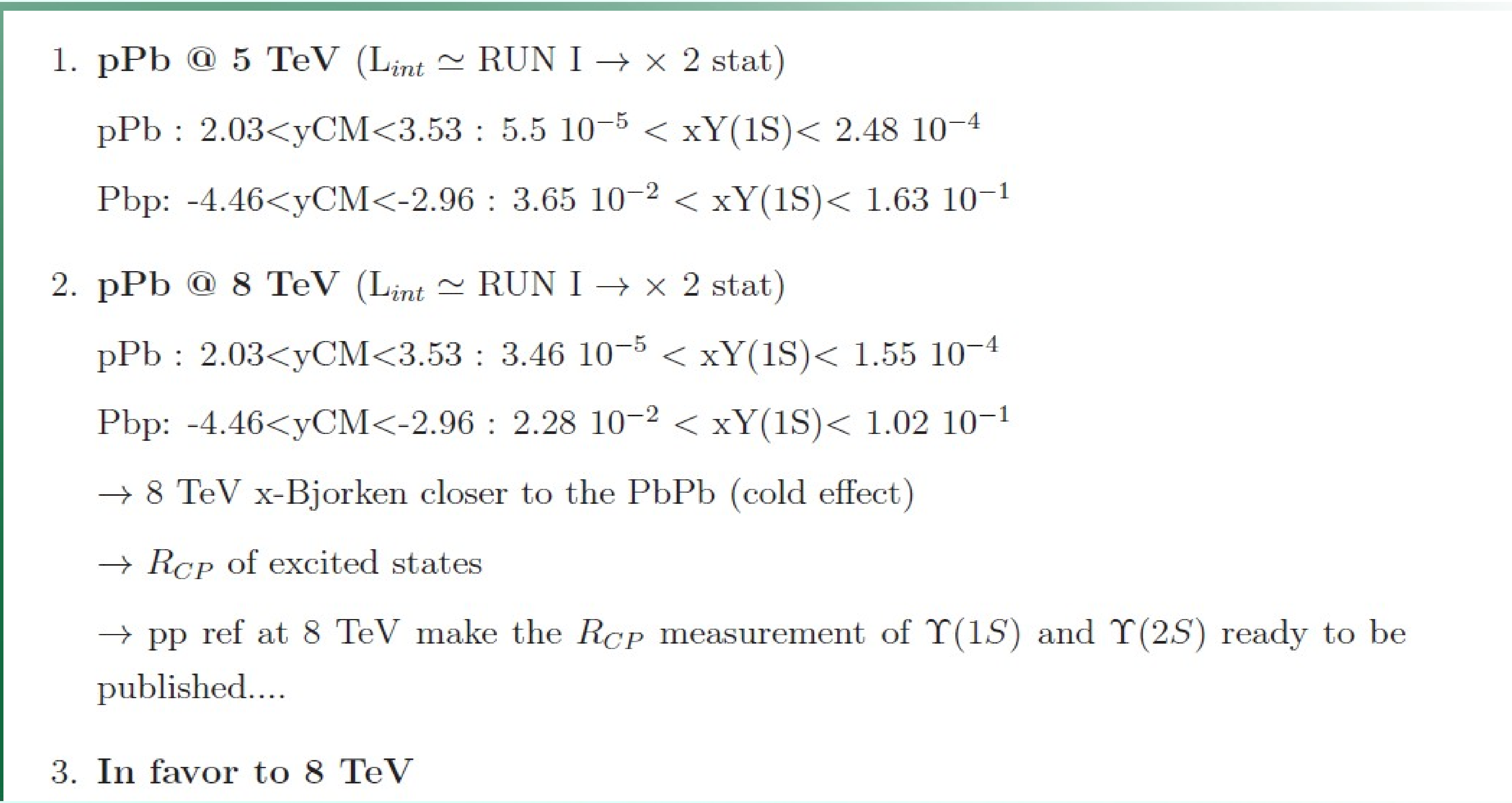
– ~ 1100 Υ(1S)

– Reachable goals
• 3-4 centrality bins with smaller stat uncertainty
• Will be exciting if an betterment in Υ(2S) signal

https://indico.cern.ch/event//353424
[Run-II prospects discussed in DQ meeting and QM poster]

Quark Matter-2014 [ALICE]: https://indico.cern.ch/event/219436/session/2/contribution/133[D.Das]

Perspectives of Run-II : p-Pb



1. **pPb @ 5 TeV** ($L_{int} \simeq$ RUN I $\rightarrow \times$ 2 stat)

   pPb : 2.03<yCM<3.53 : $5.5\ 10^{-5}$ < xY(1S)< $2.48\ 10^{-4}$

   Pbp: -4.46<yCM<-2.96 : $3.65\ 10^{-2}$ < xY(1S)< $1.63\ 10^{-1}$

2. **pPb @ 8 TeV** ($L_{int} \simeq$ RUN I $\rightarrow \times$ 2 stat)

   pPb : 2.03<yCM<3.53 : $3.46\ 10^{-5}$ < xY(1S)< $1.55\ 10^{-4}$

   Pbp: -4.46<yCM<-2.96 : $2.28\ 10^{-2}$ < xY(1S)< $1.02\ 10^{-1}$

   → 8 TeV x-Bjorken closer to the PbPb (cold effect)

   → R_{CP} of excited states

   → pp ref at 8 TeV make the R_{CP} measurement of $\Upsilon(1S)$ and $\Upsilon(2S)$ ready to be published....

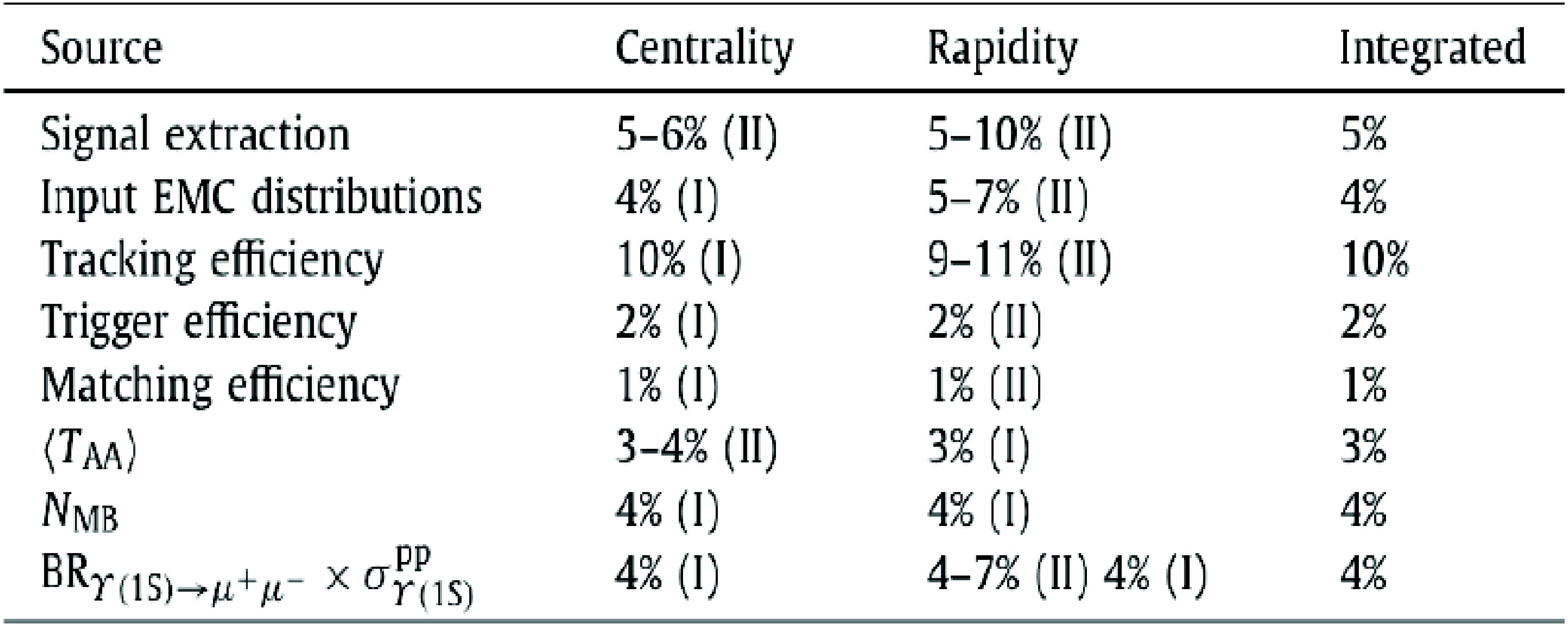
3. **In favor to 8 TeV**

https://indico.cern.ch/event//353424
[Run-II prospects discussed in DQ meeting]

Other slides

Systematics in pp @ 7 TeV

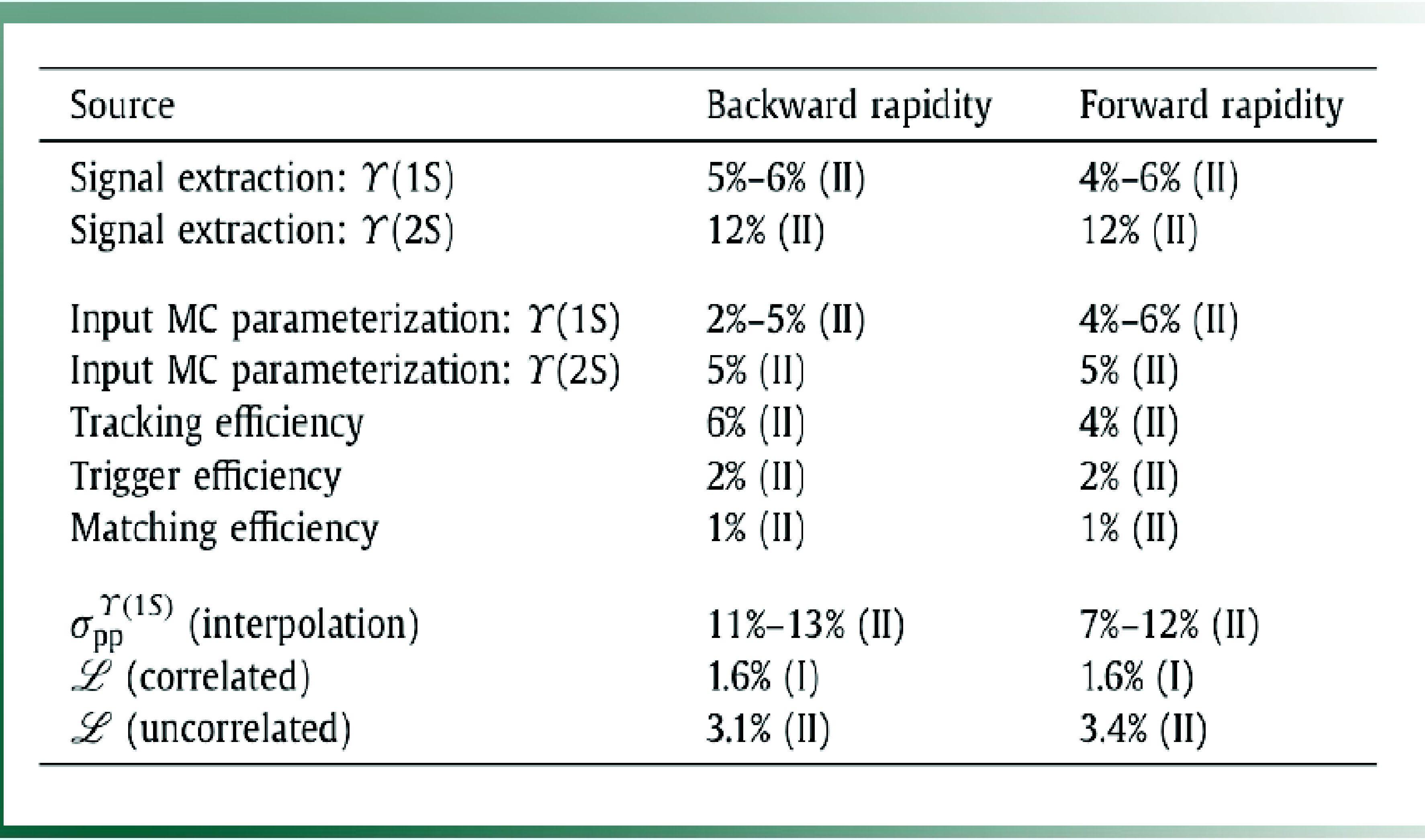
EPJC 74 (2014) 2974
p-p @ 7 TeV



Source	Centrality	Rapidity	Integrated
Signal extraction	5–6% (II)	5–10% (II)	5%
Input EMC distributions	4% (I)	5–7% (II)	4%
Tracking efficiency	10% (I)	9–11% (II)	10%
Trigger efficiency	2% (I)	2% (II)	2%
Matching efficiency	1% (I)	1% (II)	1%
$\langle T_{AA} \rangle$	3–4% (II)	3% (I)	3%
N_{MB}	4% (I)	4% (I)	4%
$\mathrm{BR}_{\Upsilon(1S)\to\mu^+\mu^-} \times \sigma^{pp}_{\Upsilon(1S)}$	4% (I)	4–7% (II) 4% (I)	4%

Systematics in p-Pb @ 5.02 TeV

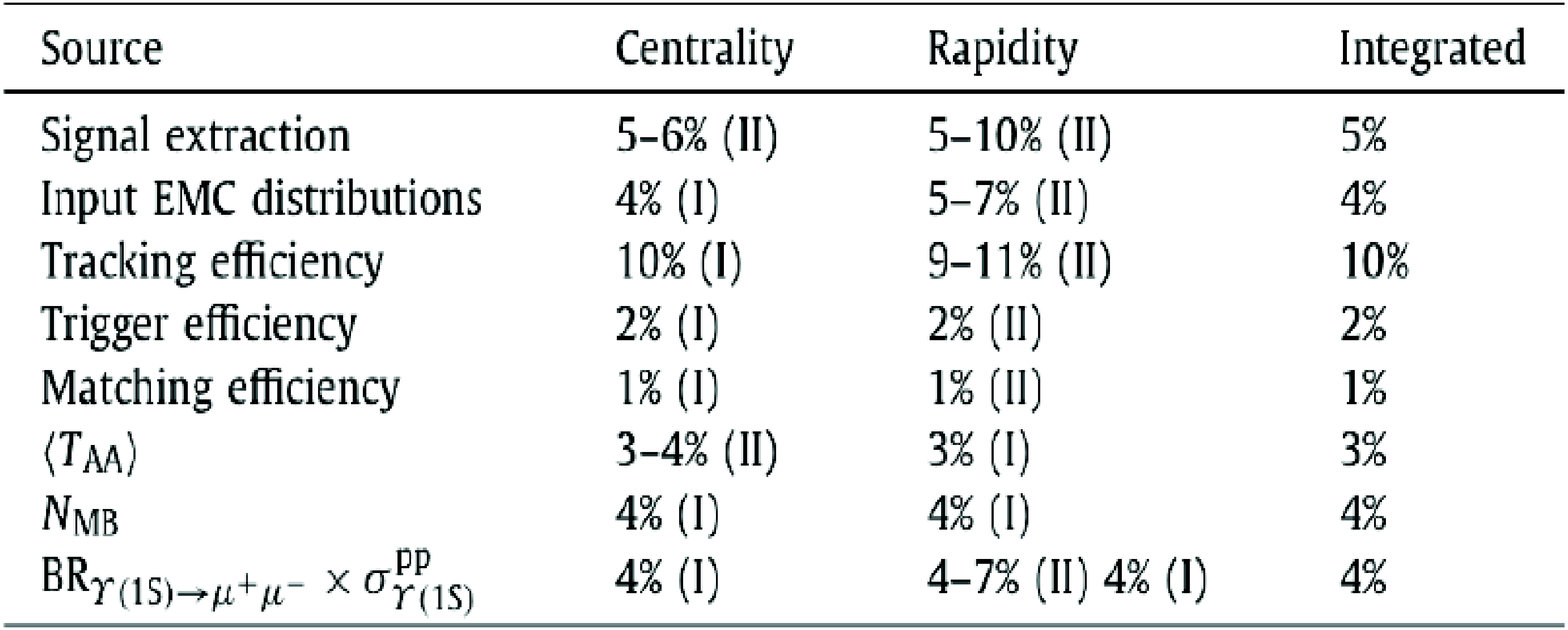
PLB 740 (2015) 105
p-Pb @ 5.02 TeV



Source	Backward rapidity	Forward rapidity
Signal extraction: $\Upsilon(1S)$	5%–6% (II)	4%–6% (II)
Signal extraction: $\Upsilon(2S)$	12% (II)	12% (II)
Input MC parameterization: $\Upsilon(1S)$	2%–5% (II)	4%–6% (II)
Input MC parameterization: $\Upsilon(2S)$	5% (II)	5% (II)
Tracking efficiency	6% (II)	4% (II)
Trigger efficiency	2% (II)	2% (II)
Matching efficiency	1% (II)	1% (II)
$\sigma_{\mathrm{pp}}^{\Upsilon(1S)}$ (interpolation)	11%–13% (II)	7%–12% (II)
$\mathscr{L}$ (correlated)	1.6% (I)	1.6% (I)
$\mathscr{L}$ (uncorrelated)	3.1% (II)	3.4% (II)

Systematics in Pb-Pb @ 2.76 TeV

PLB 738 (2014) 361
ALICE-PUBLIC-2014-001
Pb-Pb @ 2.76 TeV



Source	Centrality	Rapidity	Integrated
Signal extraction	5–6% (II)	5–10% (II)	5%
Input EMC distributions	4% (I)	5–7% (II)	4%
Tracking efficiency	10% (I)	9–11% (II)	10%
Trigger efficiency	2% (I)	2% (II)	2%
Matching efficiency	1% (I)	1% (II)	1%
$\langle T_{AA} \rangle$	3–4% (II)	3% (I)	3%
N_{MB}	4% (I)	4% (I)	4%
$\mathrm{BR}_{\Upsilon(1S)\to\mu^+\mu^-} \times \sigma^{pp}_{\Upsilon(1S)}$	4% (I)	4–7% (II) 4% (I)	4%