Quark Matter 2017

Bottomonium measurements at forward rapidity in Pb-Pb and p-Pb collisions with ALICE

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ALICE

Outline

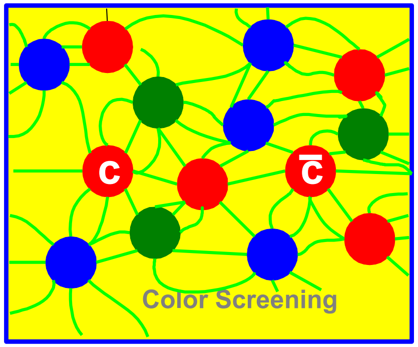
- Physics Motivation
- Experimental Setup
- Results
  - p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
  - Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV **NEW**
- Summary

Motivation

- **Quark Matter at extreme energy density and formation of Quark-Gluon Plasma (QGP)**

- **Quarkonium ($c\bar{c}$ and $b\bar{b}$) suppression due to color screening**
  [Matsui, Satz; PLB 178 (1986) 416]

  – Sequential suppression
    [Karsch, Mehr, and Satz, ZPC: Part. Fields 37 (1988) 617]



- **(Re)generation**
  – The $Q\bar{Q}$ production increases with energy : a factor of ~9 for $\mathbf{c\bar{c}}$ from RHIC to LHC

  – Dynamically during the QGP evolution or statistically at the phase boundary
    [Thews, Schroedter , Rafelski, PRC 63 (2001) 054905, Braun-Munzinger, Stachel; PLB 490 (2000) 196]

  – Less (re)generation for bottomonium [ALICE Coll., PLB 738 (2014) 361]

Various sources of medium effects

- **Nuclear modification factor R_{AA}:**

$$R_{AA} = \frac{Y_{AA}}{\langle T_{AA} \rangle \sigma_{pp}}$$

If yield scales with the number of binary collisions

→ $R_{AA} = 1$

medium effects will increase or decrease R_{AA}

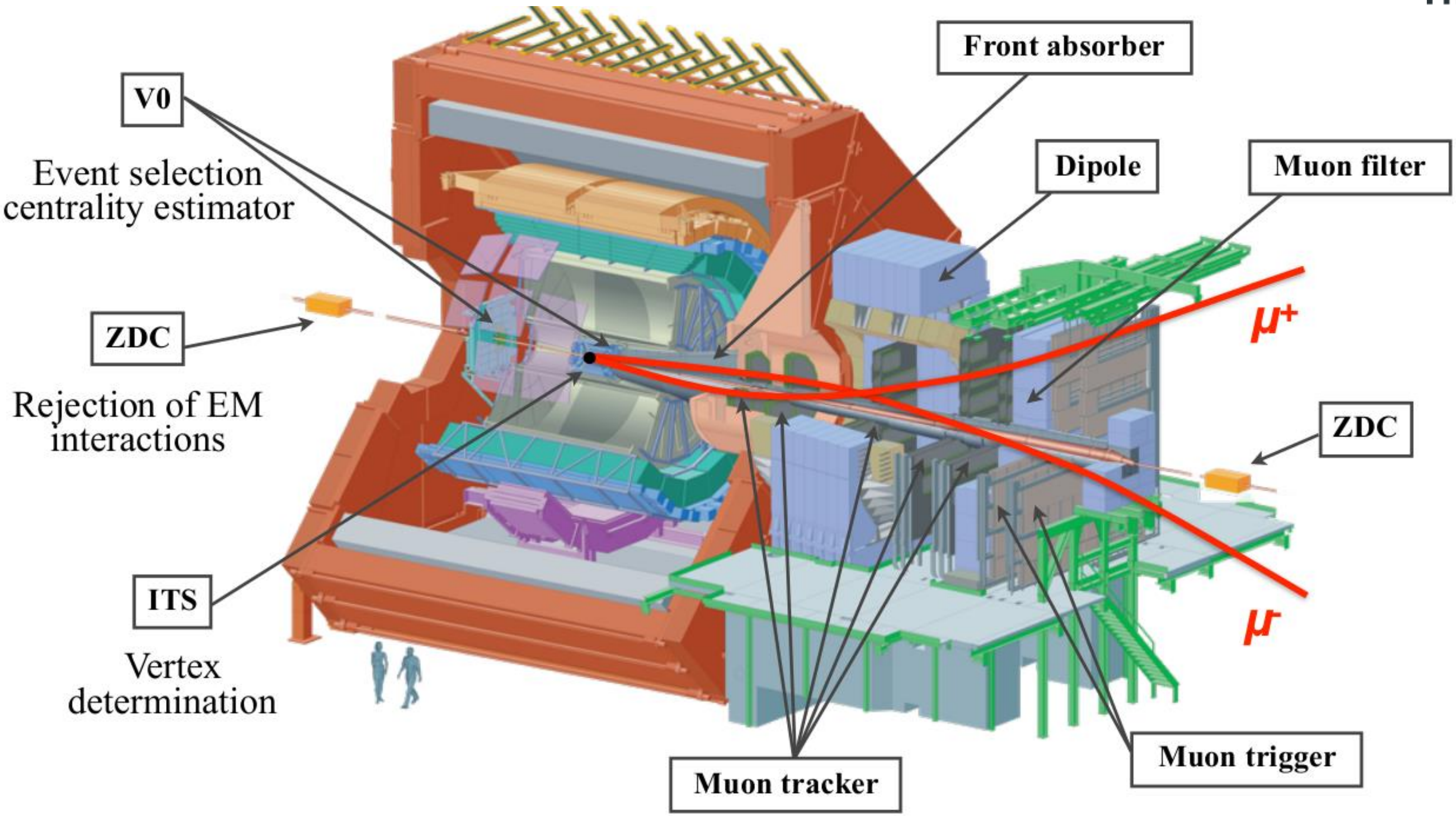
Hot Medium effects:

- Quarkonium suppression (R_{AA} ↓)
- Enhancement due to (re)generation (R_{AA} ↑)

Cold Nuclear Matter effects (CNM):

- Nuclear parton shadowing/gluon saturation
- Parton energy loss
- Nuclear break-up

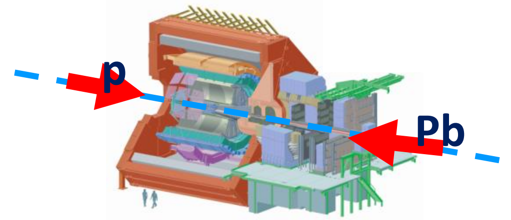
ALICE setup



Inclusive quarkonium production measured down to zero transverse momentum

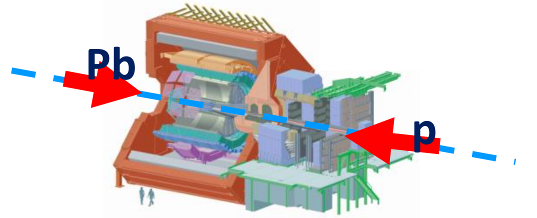
Results in p-Pb collisions

Forward rapidity



$2.03 < y_{cms} < 3.53$ L~5.03 nb^{-1}

Backward rapidity



$-4.46 < y_{cms} < -2.96$ L~5.81 nb^{-1}

$\Delta y = 0.465$ in the direction of the proton beam

Nuclear modification factor R_{pPb}:

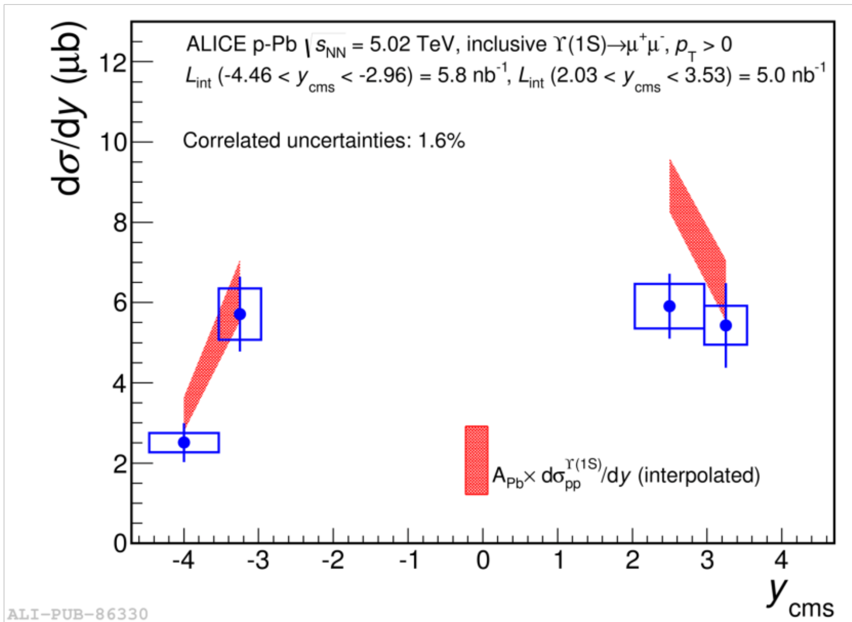
$$R_{\mathrm{pPb}} = \frac{\sigma_{\mathrm{pPb}}}{A_{\mathrm{Pb}} . \sigma_{\mathrm{pp}}}$$

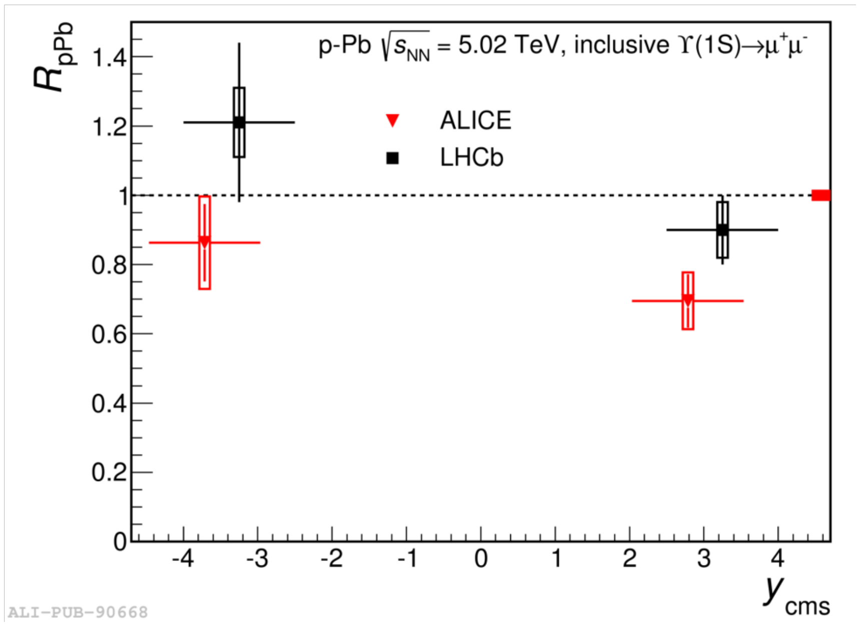
Present statistics of pp data $\sqrt{s}$ = 5.02 TeV (2015) is not sufficient to obtain reference cross section for p-Pb and Pb-Pb analyses

Reference cross section is obtained using an energy interpolation procedure [ALICE-PUBLIC-2014-002, LHCb-CONF-2014-003].

$\Upsilon(1S)$ R_{pPb} vs rapidity

ALICE Coll., PLB 740 (2015) 105



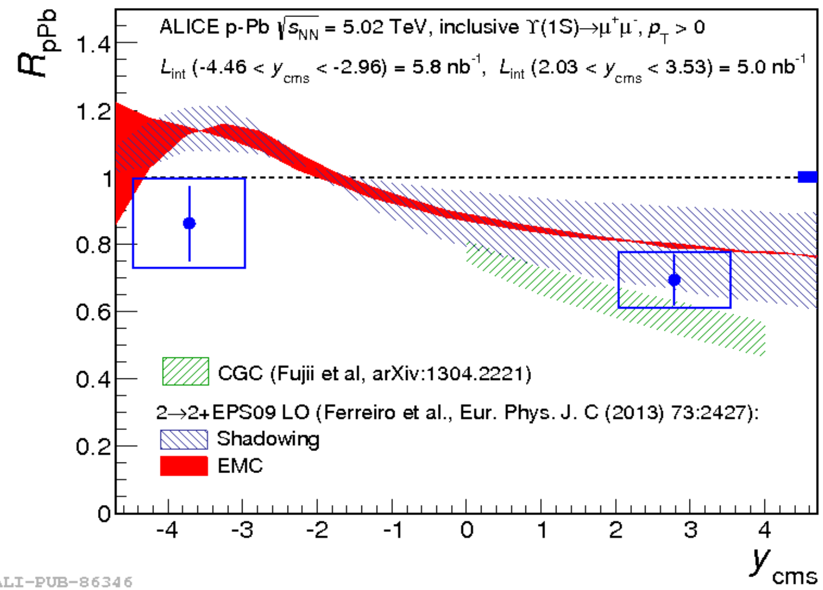


- Suppression of $\Upsilon(1S)$ at forward rapidity with respect to the binary-scaled pp reference, while the backward rapidity measurement is compatible with no suppression.
- ALICE and LHCb R_{pPb} are compatible, with LHCb results being systematically larger.

Υ(1S) R_{pPb} : model comparison

ALICE

ALICE Coll., PLB 740 (2015) 105



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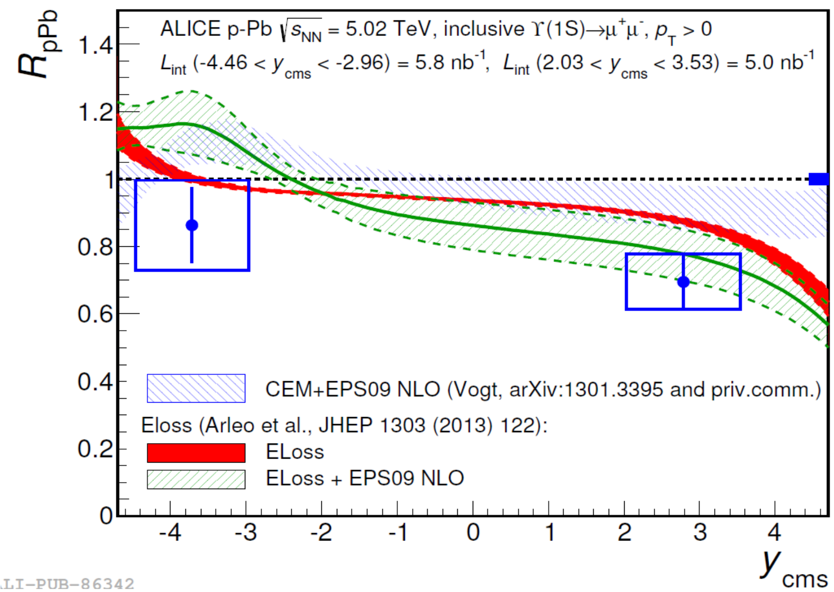
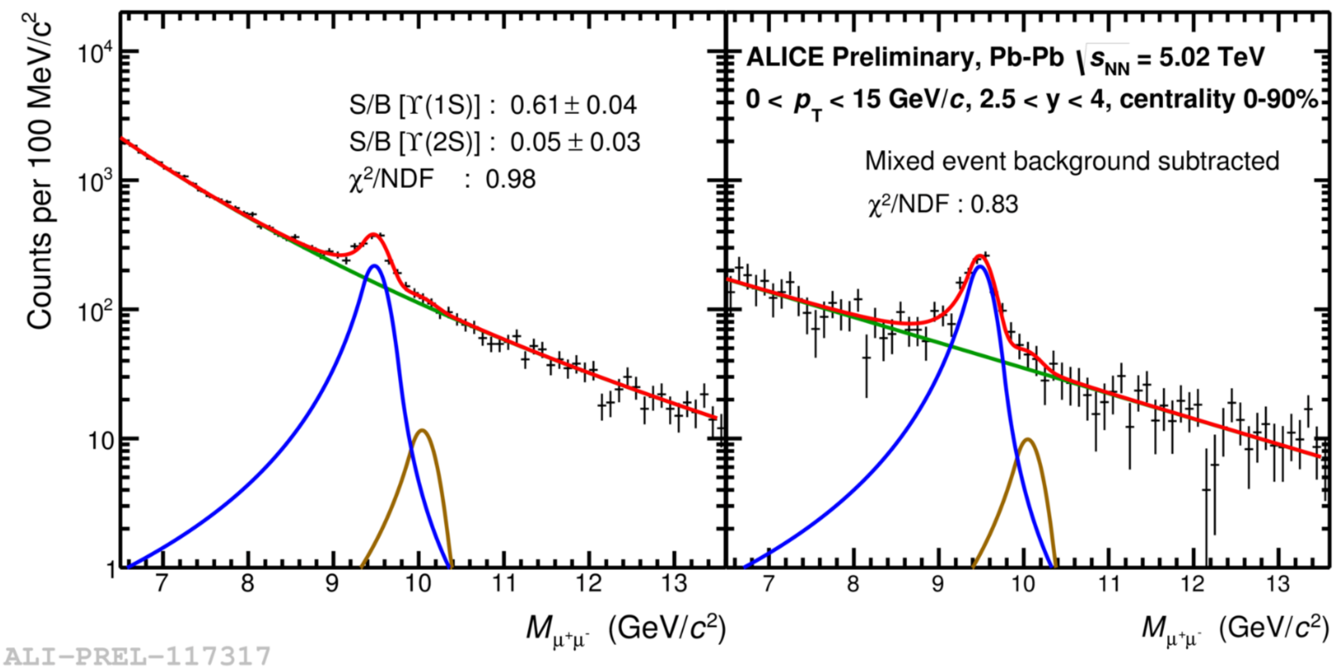


ALI-PUB-86342

- **Fuji et al. [NPA 915 (2013) 1]**
  - CGC + CEM production model
- **Ferreiro et al. [EPJC 73 (2013) 2427]**
  - 2→2 production model at LO
  - EPS09 shadowing parameterization at LO
- **Arleo et al. [JHEP 1303 (2013) 122]**
  - Model including a contribution from coherent parton energy loss
  - With or without shadowing (EPS09)
- **Vogt [Int. JMP E 22 (2013) 1330007]**
  - CEM production model at NLO
  - EPS09 shadowing parameterization at NLO

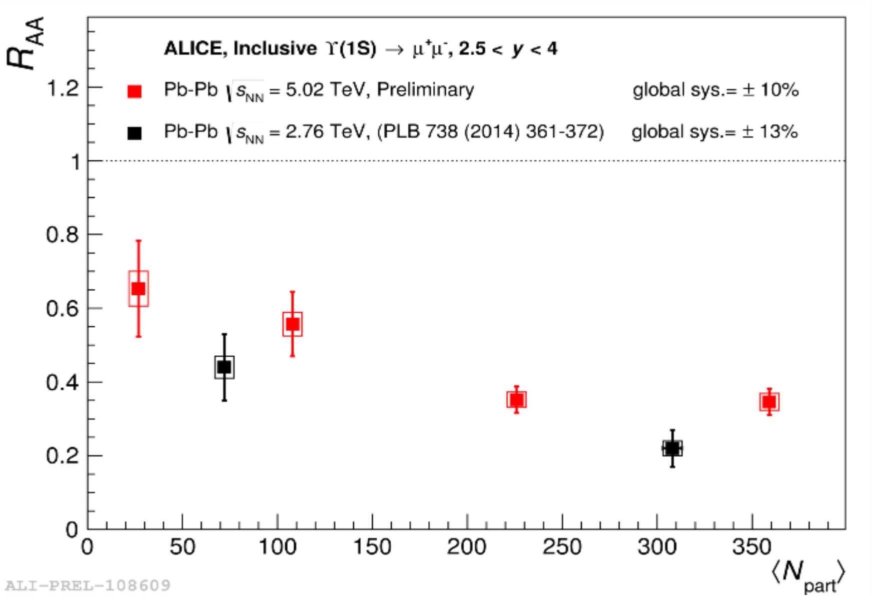
Models predictions describe the measured R_{pPb} at forward rapidity and underestimate the suppression at backward rapidity

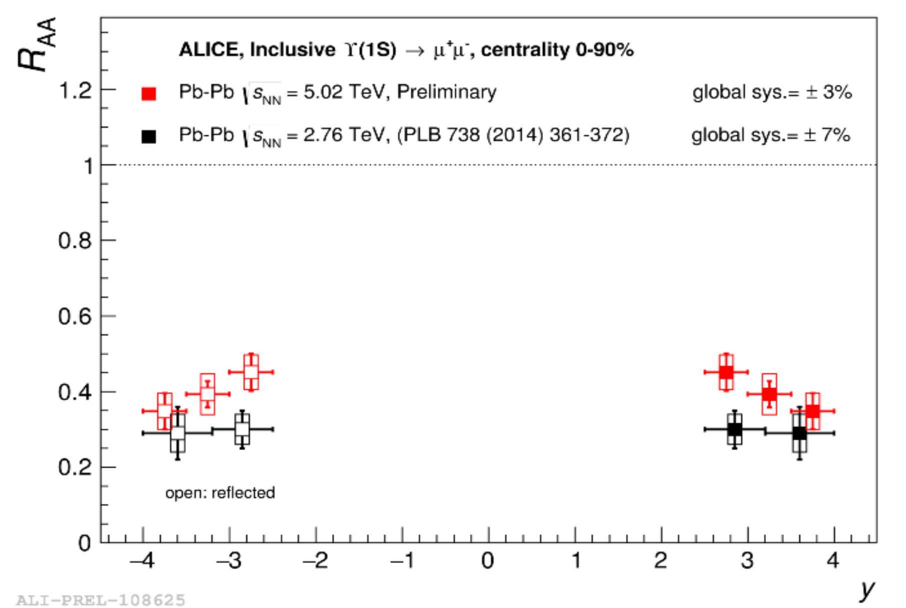
$\Upsilon(1S)$ R_{AA} in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV



- Collected statistics : $L_{int} \approx 225\ \mu b^{-1}$
  - N [$\Upsilon(1S)$] = 1107 ± 70 (stat.) ± 43 (sys.)
  - N [$\Upsilon(2S)$] = 71 ± 34 (stat.) ± 19 (sys.)
- The dominant source of systematics in R_{AA} calculation comes from signal extraction and interpolated reference cross section

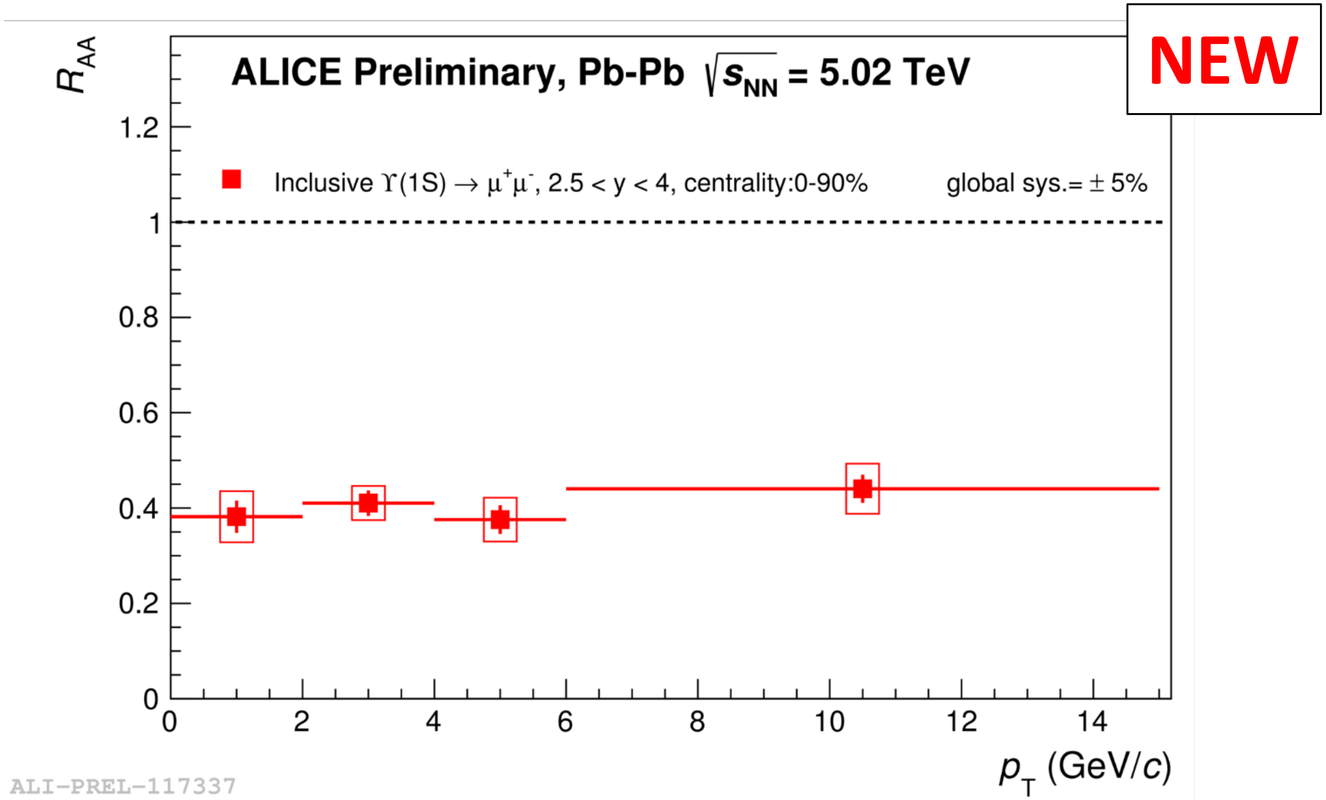
$\Upsilon(1S)$ R_{AA} in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV





- A strong suppression has been observed by ALICE
  - R_{AA} of $\Upsilon(1S)$: 0.40 ± 0.03 (stat.) ± 0.04 (sys.) (0-90%)
- The suppression is stronger in central collisions compared to peripheral events
- A hint of decreasing trend towards forward rapidity albeit within uncertainties
- The suppression of $\Upsilon(1S)$ for Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV similar, within uncertainties, to the measured R_{AA} at $\sqrt{s_{NN}}$ = 2.76 TeV

$\Upsilon(1S)$ R_{AA} in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

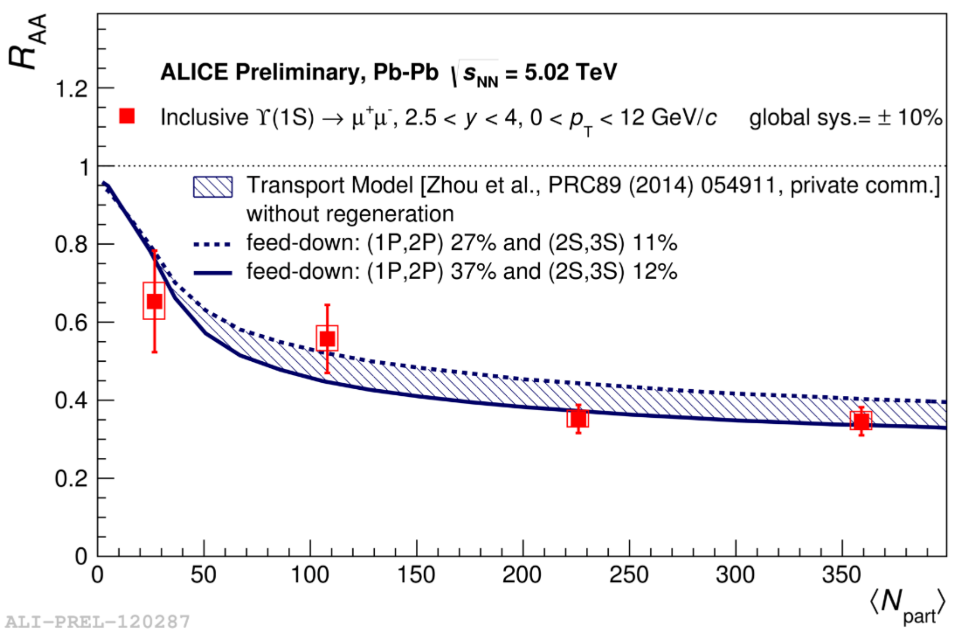


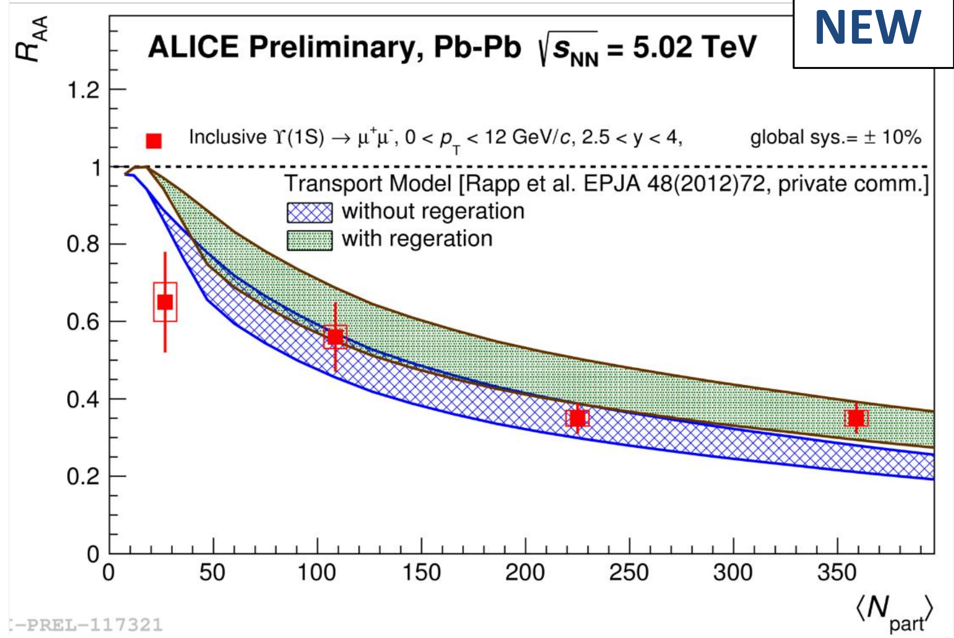
- The R_{AA} of $\Upsilon(1S)$ shows no variation as a function of transverse momentum

$\Upsilon(1S)$ R_{AA} in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

ALICE

NEW

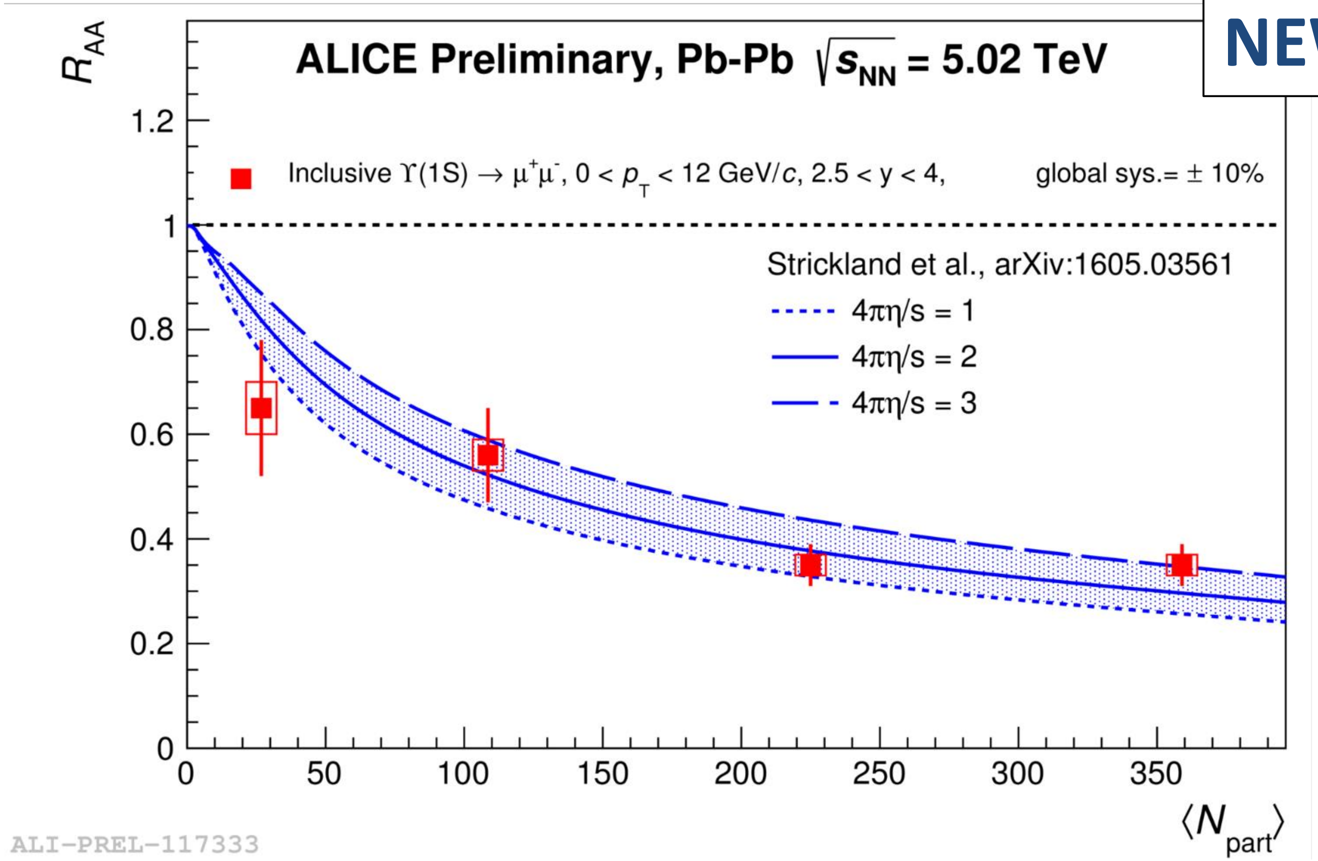




- Both transport models qualitatively reproduce the centrality dependence.
- The transport model [Zhou et al. PRC 89 (2014) 05911] can describe the data without (re)generation component
- The transport model [Rapp et al. EPJA 48 (2012) 72] with or without (re)generation component can also explain the data within uncertainties
- No strong indication of direct $\Upsilon(1S)$ suppression in most central collisions from transport model.

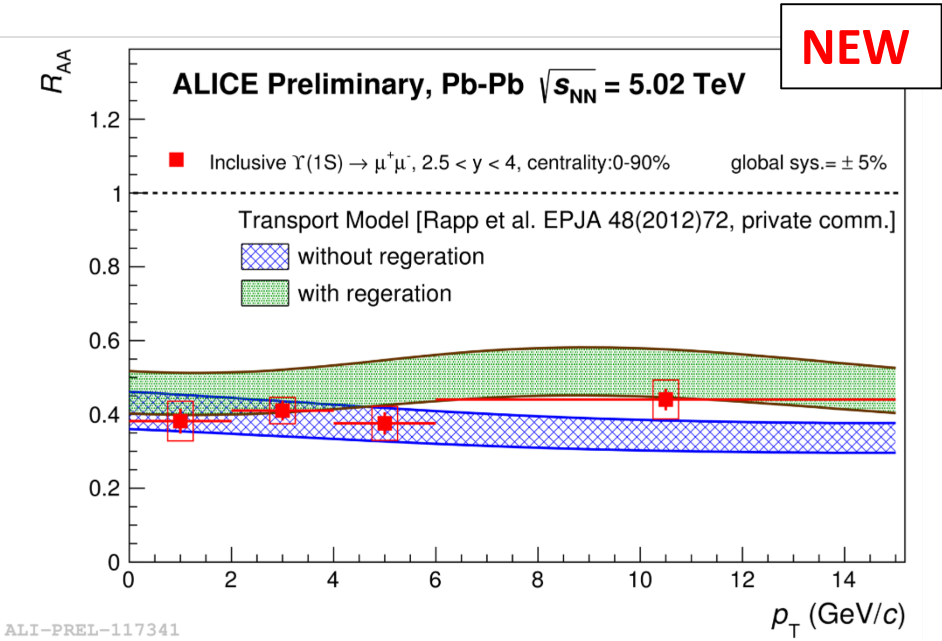
$\Upsilon(1S)$ R_{AA} in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

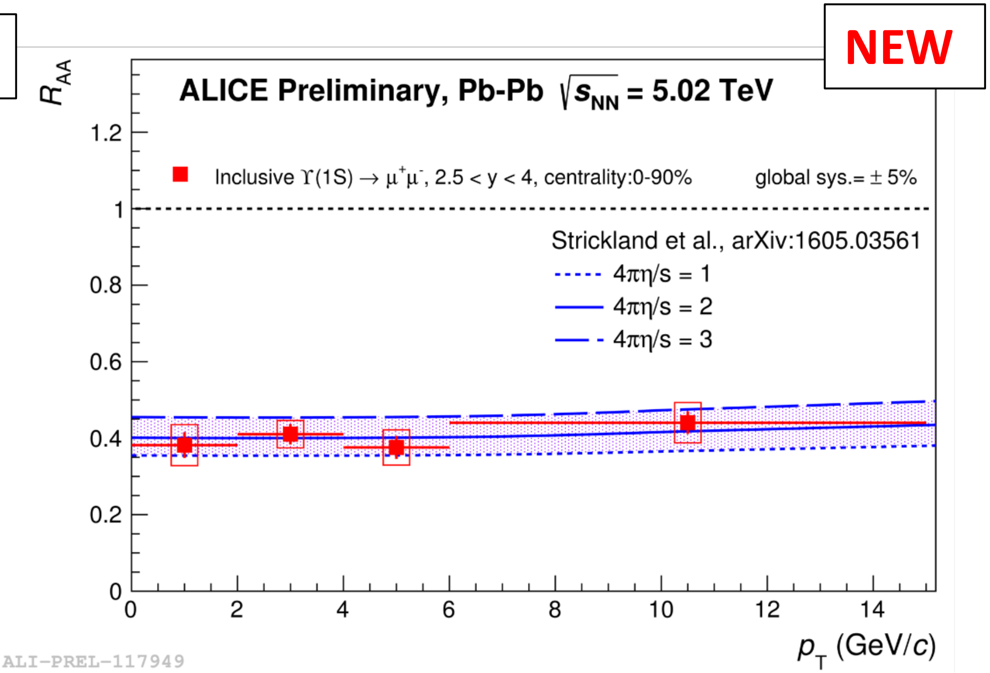
NEW



- The anisotropic hydrodynamics model which does not have the (re)generation component and CNM effect describe the data within η/s uncertainties.

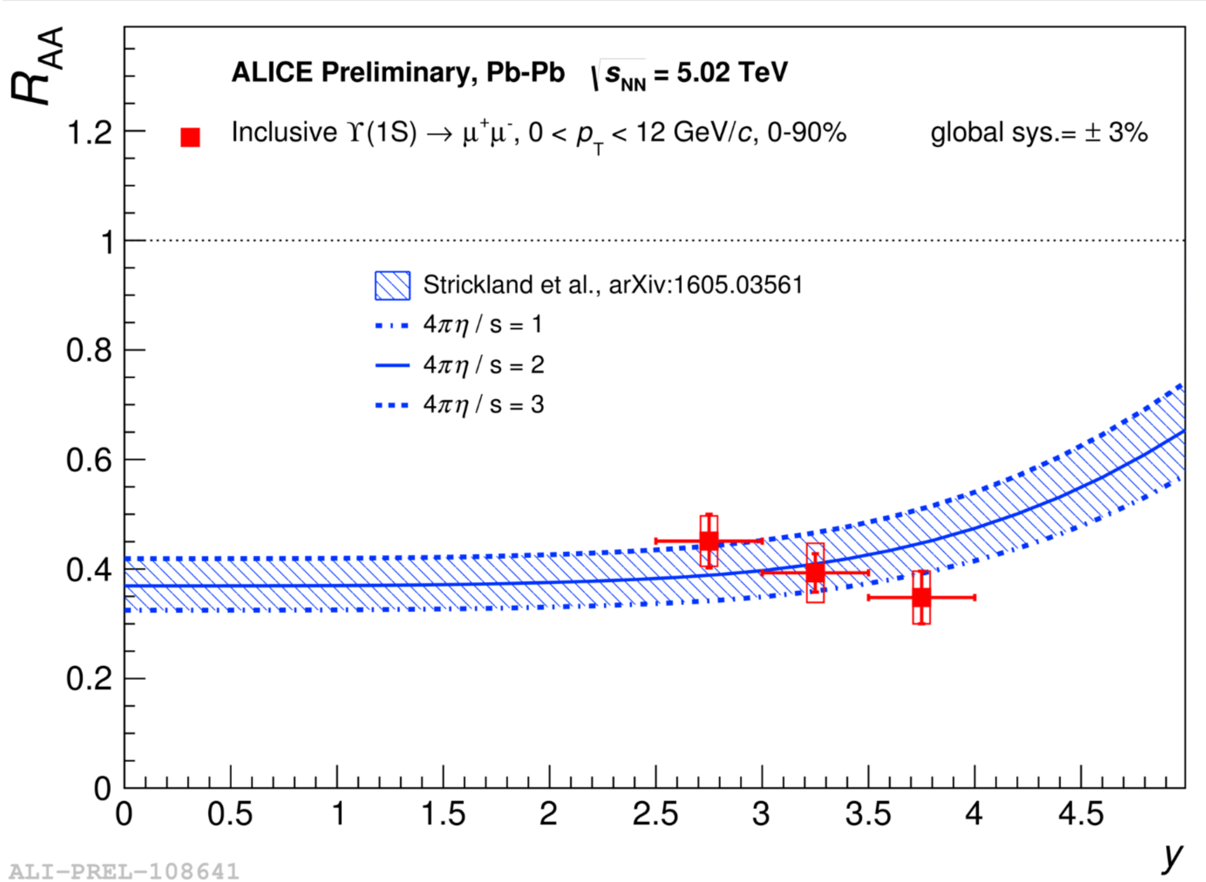
$\Upsilon(1S)$ R_{AA} in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV





- The p_T dependence of $\Upsilon(1S)$ R_{AA} in Pb-Pb collisions is described by the transport model and anisotropic hydrodynamics model
- Transport model, with or without (re)generation effect can describe the data

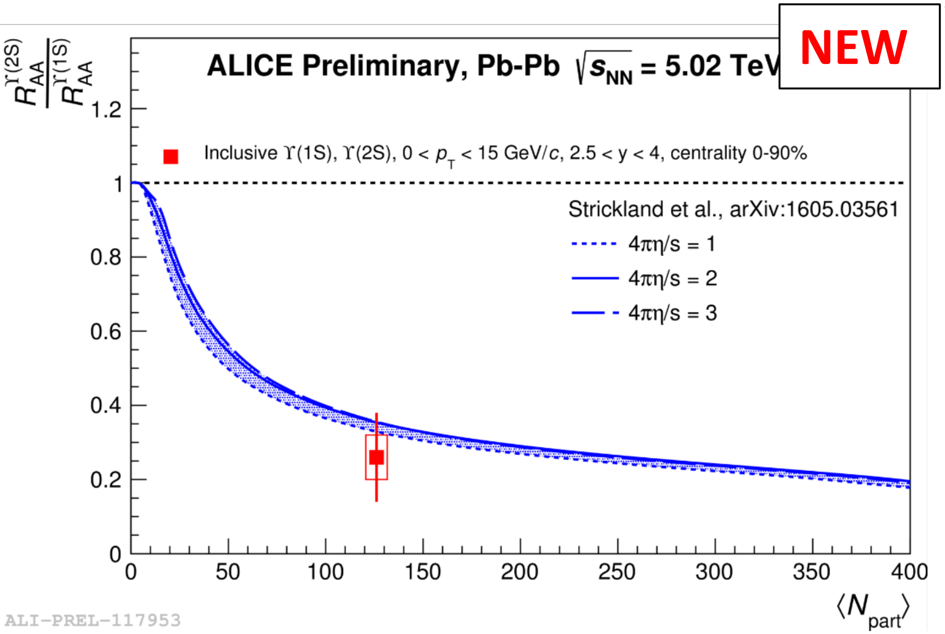
$\Upsilon(1S)$ R_{AA} in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

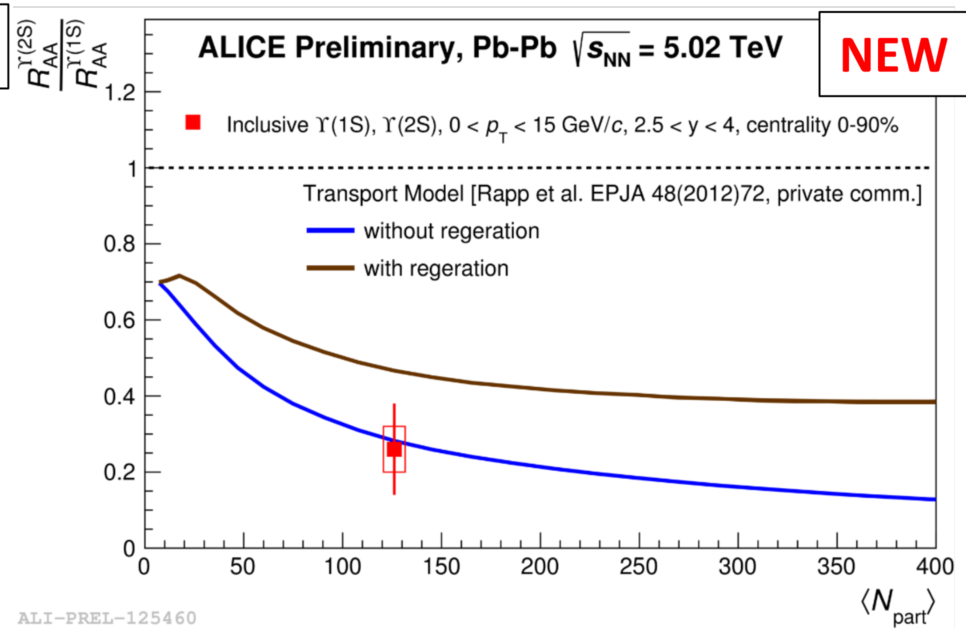


The anisotropic hydrodynamics model can describe the rapidity dependence of R_{AA} , but hint of different trend is visible

Double ratio : R_{AA} for $\Upsilon(2S)$ to R_{AA} of $\Upsilon(1S)$

ALICE





- A stronger suppression has been observed for $\Upsilon(2S)$ as compared to $\Upsilon(1S)$
  R_{AA} of $\Upsilon(2S)$: 0.09 ± 0.04 (stat.) ± 0.03 (sys.) (0-90%)
- Simple yield $\left[\frac{N_\Upsilon}{A \times \epsilon}\right]$ ratio $\Upsilon(2S)$ / $\Upsilon(1S)$ in Pb-Pb collisions
  0.06 ± 0.03 (stat.) ± 0.01 (sys.)

Yield ratio	
pp (7 TeV)	0.26 ± 0.08
P-Pb	$0.27 \pm 0.08 \pm 0.04$
Pb-p	$0.26 \pm 0.09 \pm 0.04$

[Ref : PLB 740 (2015) 105–117]

- The ratio of R_{AA} for $\Upsilon(2S)$ to $\Upsilon(1S)$ is found to be 0.26 ± 0.12 (stat.) ± 0.06 (sys.)

  Transport model without (re)generation describes the measured double ratio

Suppression factor of $\Upsilon(1S)$

NEW

$$S_{\Upsilon} = \frac{R_{\text{Pb}-Pb}}{R_{\text{p}-\text{Pb}} \times R_{\text{Pb}-\text{p}}}$$

The range of Bjorken x accessed for Pb-Pb collisions at $\sqrt{s_{\text{NN}}}$ = 2.76 TeV matches to Bjorken-x range reached in p-Pb and Pb-p collisions at $\sqrt{s_{\text{NN}}}$ = 5.02 TeV,

Bjorken-x range

Pb-Pb $\sqrt{s_{\text{NN}}}$ = 2.76 TeV	p-Pb abd Pb-p $\sqrt{s_{NN}}$ = 5.02 TeV
$6.10^{-5} \leq x_1 \leq 3.10^{-4}$	$6.10^{-5} \leq x_{\text{p}-\text{Pb}} \leq 2.10^{-4}$
$4.10^{-2} \leq x_2 \leq 2.10^{-1}$	$3.10^{-2} \leq x_{\text{Pb}-\text{p}} \leq 2.10^{-1}$

The extent of suppression with respect to the CNM effect (only due to shadowing) is,

$$S_{\Upsilon} = \frac{(R_{\text{Pb}-\text{Pb}})_{2.76\,TeV}}{(R_{\text{p}-\text{Pb}} \times R_{\text{Pb}-\text{p}})_{5.02\,TeV}} = 0.50 \pm 0.12\,(\text{uncorr.}) \pm 0.12\,(\text{corr.})$$

[ALICE Coll., PLB 738 (2014) 361, ALICE Coll., PLB 740 (2015) 105]

Summary

- ALICE p-Pb results :
  - A suppression of $\Upsilon(1S)$ production is observed at forward rapidity.
  - At backward rapidity it is consistent with unity, suggesting small gluon anti-shadowing.
  - Pure nuclear shadowing and/or (coherent) energy loss models seem to overestimate the measured nuclear modification factor.

- ALICE findings in Pb-Pb collisions:
  - Strong suppression of $\Upsilon(1S)$ at forward rapidity.
  - The R_{AA} of $\Upsilon(1S)$ shows a stronger suppression in central than peripheral collisions.
  - No transverse momentum dependence has been observed from low p_T to high p_T for $\Upsilon(1S)$.

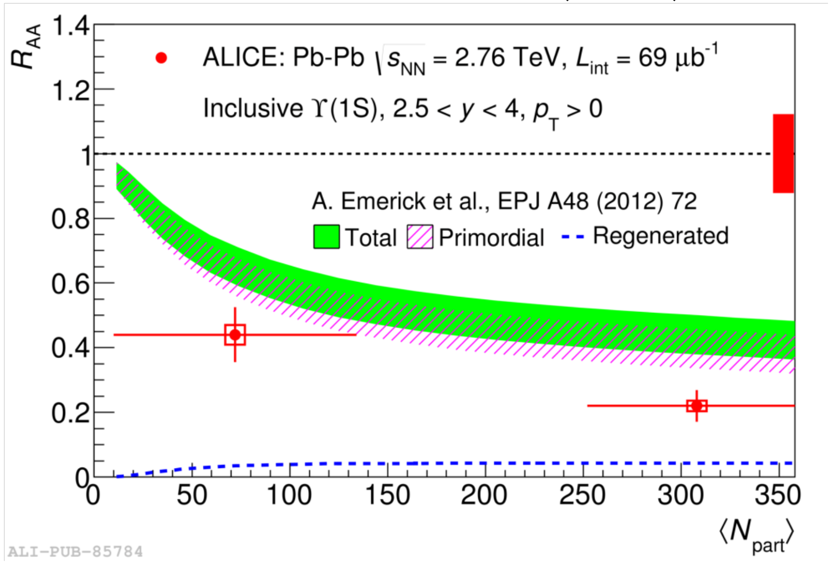
Summary

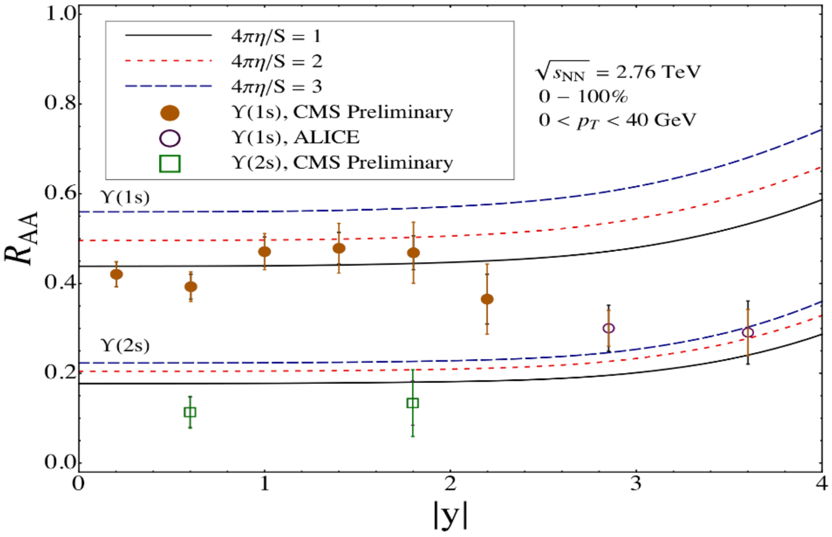
- ALICE findings in Pb-Pb collisions:
  - The suppression is stronger for $\Upsilon(2S)$ with respect to $\Upsilon(1S)$.
  - The yield ratio of 2S/1S is suppressed by ~75% in Pb-Pb collisions when compared to p-Pb or pp collisions.
  - The $\Upsilon(1S)$ suppression in Pb-Pb collisions can not be explained by shadowing effects.

Thank You

$\Upsilon(1S)$ R_{AA} in Pb-Pb collisions

ALICE Coll., PLB 738 (2014) 361



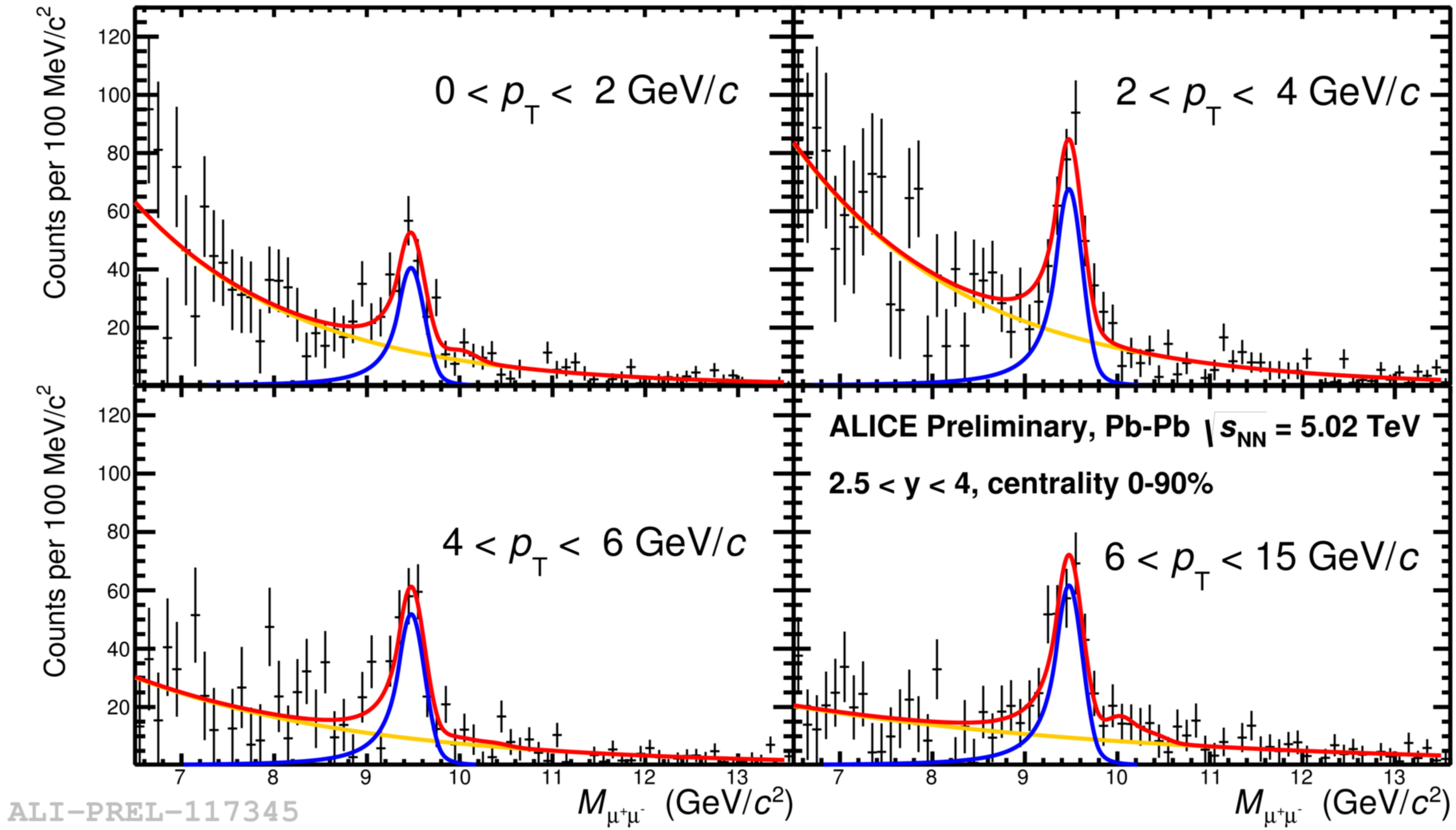


A. Emerick et al., [EPJ A48 (2012) 72]

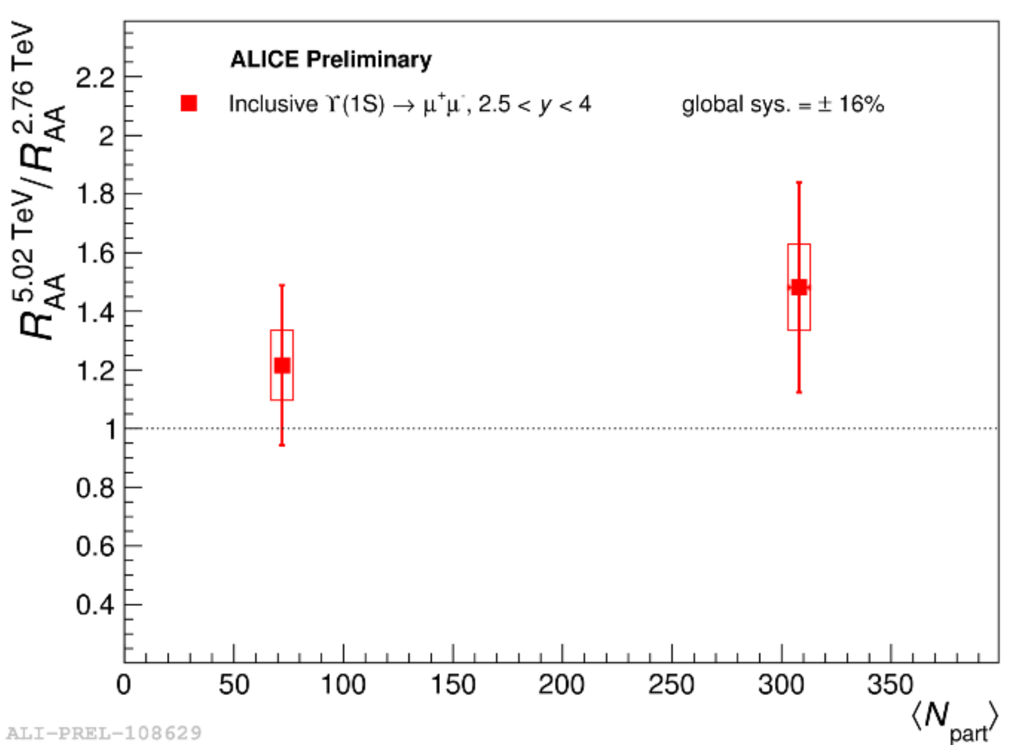
- Transport model
- Suppression of $\Upsilon(1S)$ resonances by the QGP
- Small (re)generation component included
- Feed down from higher mass states included
- CNM included via an "effective" σ_{abs} = 0–2 mb

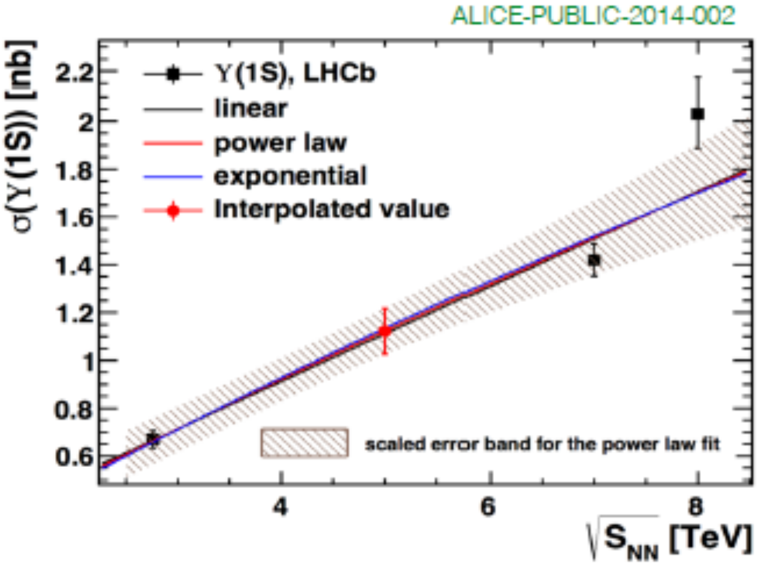
M. Strickland et al, [PRC 92, 061901 (2015)]

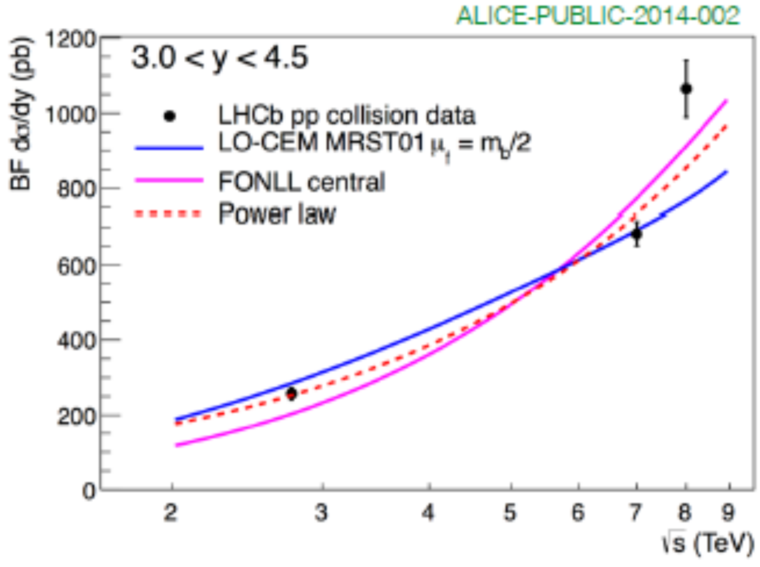
- Thermal suppression of bottomonium states
- (3+1)D Anisotropic hydrodynamic model
- Boost invariant rapidity profile with Gaussian tail
- Three shear viscosities
- Feed down from higher mass states included
- No CNM included
- No (re)generation included



Counts per 100 MeV/c^2
$0 < p_T < 2$ GeV/c
$2 < p_T < 4$ GeV/c
$4 < p_T < 6$ GeV/c
$6 < p_T < 15$ GeV/c
ALICE Preliminary, Pb-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
2.5 < y < 4, centrality 0-90%
$M_{\mu^+\mu^-}$ (GeV/c^2)
ALI-PREL-117345


ALICE Preliminary
Inclusive ϒ(1S) → μ⁺μ⁻, 2.5 < y < 4
global sys. = ± 16%
$R_{AA}^{5.02\ TeV}/R_{AA}^{2.76\ TeV}$
⟨N_{part}⟩
ALI-PREL-108629





Pb–Pb $\sqrt{s_{NN}} = 2.76$ TeV	Pb–Pb $\sqrt{s_{NN}} = 5.02$ TeV	p-Pb and Pb-p $\sqrt{s_{NN}} = 5.02$ TeV
$6 \cdot 10^{-5} \leq x_1 \leq 3 \cdot 10^{-4}$, $4 \cdot 10^{-2} \leq x_2 \leq 2 \cdot 10^{-1}$	$3 \cdot 10^{-5} \leq x_1 \leq 2 \cdot 10^{-4}$, $2 \cdot 10^{-2} \leq x_2 \leq 1 \cdot 10^{-1}$	$6 \cdot 10^{-5} \leq x_{\mathrm{p-Pb}} \leq 2 \cdot 10^{-4}$, $3 \cdot 10^{-2} \leq x_{\mathrm{Pb-p}} \leq 2 \cdot 10^{-1}$

The extent of suppression with respect to coherent energy loss effects

$$S_{\Upsilon} = \frac{(R_{Pb-Pb})_{5.02\ TeV}}{(R_{p-Pb} \times R_{Pb-p})_{5.02\ TeV}} = 0.66 \pm 0.12 \pm 0.14$$