

Bottomonium production studies in nuclear collisions at ALICE

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On behalf of the ALICE Collaboration

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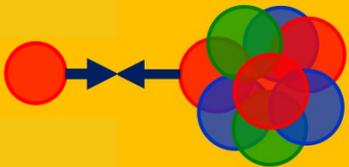
UC Davis (online)

15th – 19th March 2021

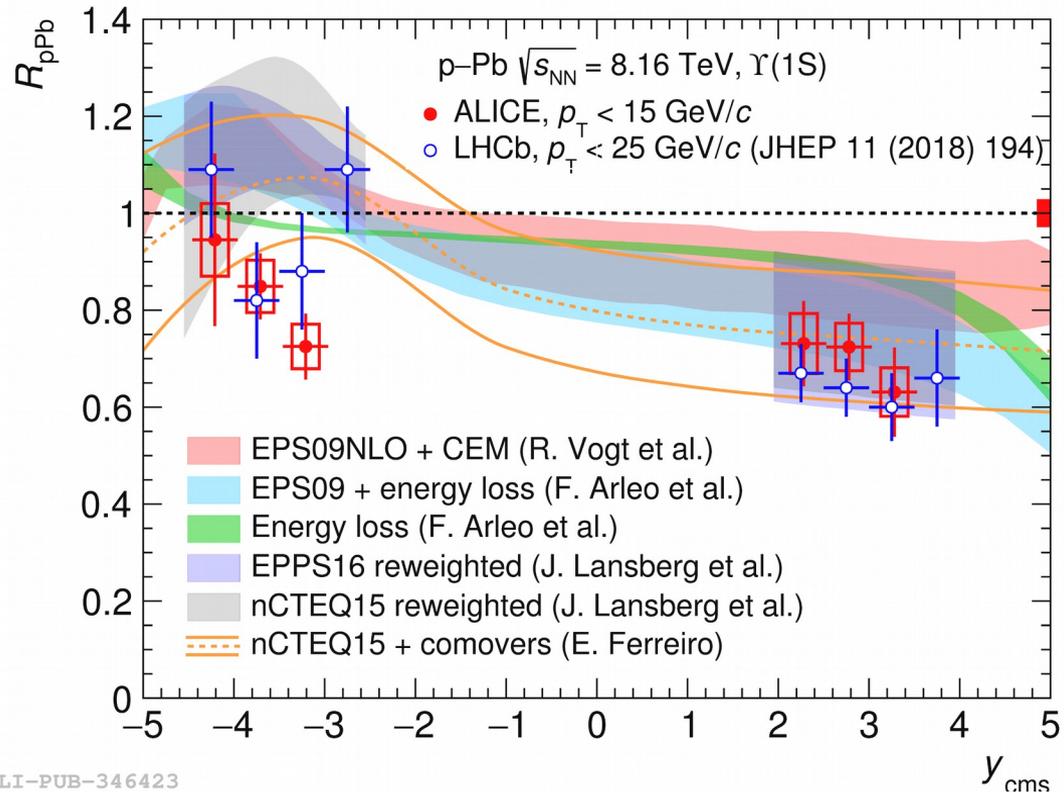


- ALICE detector
- p-Pb results at $\sqrt{s_{\text{NN}}} = 8.16 \text{ TeV}$
 - Rapidity, p_{T} and centrality dependence of $\Upsilon(1\text{S})$ production
 - Rapidity dependence of $\Upsilon(2\text{S})$ and $\Upsilon(3\text{S})$ production
 - $\Upsilon(n\text{S})/\Upsilon(1\text{S})$ ratios
- Pb-Pb results at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$
 - Centrality, p_{T} and rapidity dependence of $\Upsilon(1\text{S})$ production
 - Centrality and rapidity dependence of $\Upsilon(2\text{S})$ production
 - $\Upsilon(2\text{S})/\Upsilon(1\text{S})$ ratio
 - Elliptic flow of $\Upsilon(1\text{S})$

p-Pb



cold nuclear matter effects:
shadowing, energy loss...



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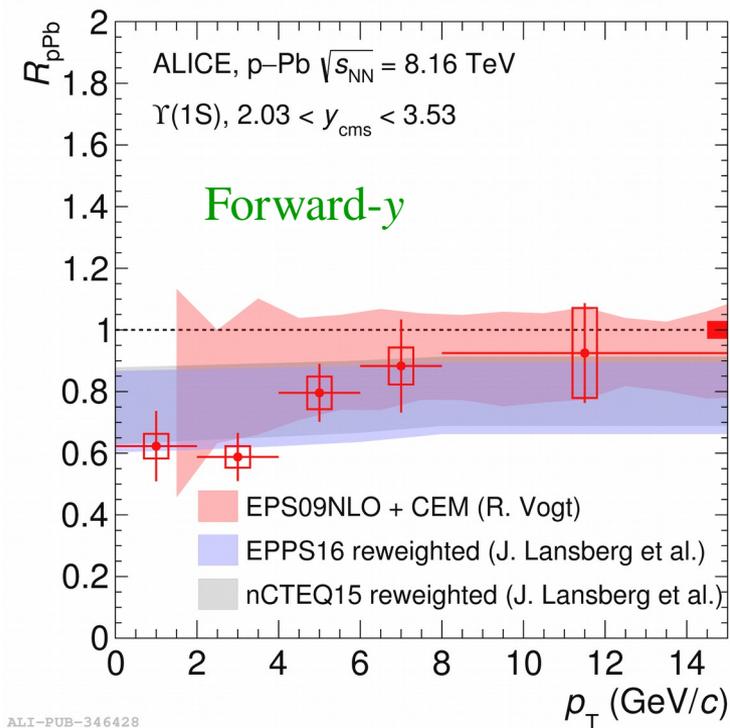
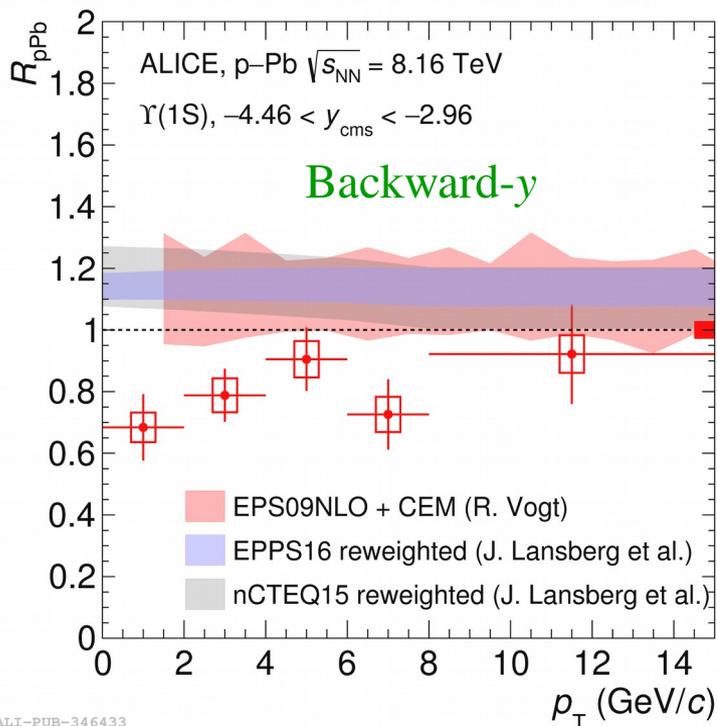
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- Nuclear modification factor:

$$R_{pPb}^{\Upsilon(nS)} = \frac{Y_{pPb}^{\Upsilon(nS)}}{\langle T_{pPb} \rangle \sigma_{pp}^{\Upsilon(nS)}}$$

- Similar $\Upsilon(1S)$ suppression at forward and backward rapidity
- Theoretical predictions based on nuclear shadowing, coherent parton energy loss or interactions with comoving particles fairly describe the data at forward rapidity while slightly overestimate them at the backward rapidity

$\Upsilon(1S) R_{pPb}$ vs p_T at $\sqrt{s_{NN}} = 8.16$ TeV

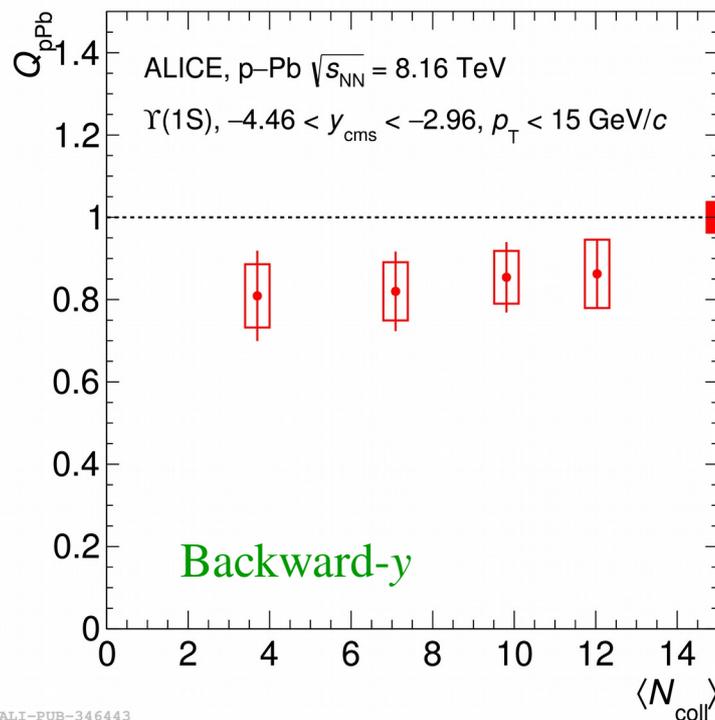


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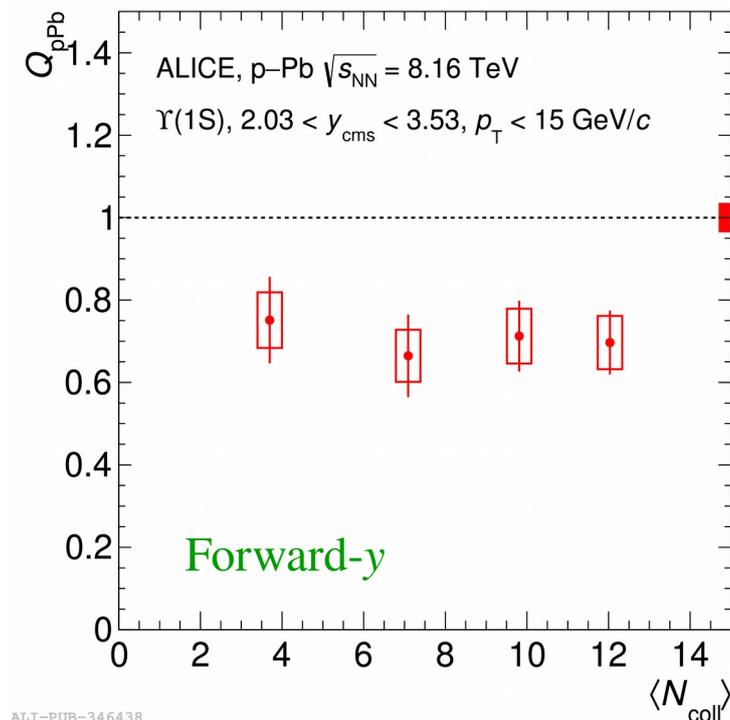
- Similar behaviour at both forward and backward rapidity with a hint of a stronger suppression at low p_T
- Theoretical predictions describe the forward rapidity results but slightly overestimate the backward rapidity results

$\Upsilon(1S) Q_{pPb}$ vs multiplicity at $\sqrt{s_{NN}} = 8.16$ TeV

$$Q_{pPb}^{\Upsilon(nS)} = \frac{Y_{pPb}^{\Upsilon(nS)}}{\langle T_{pPb} \rangle \sigma_{pp}^{\Upsilon(nS)}}$$



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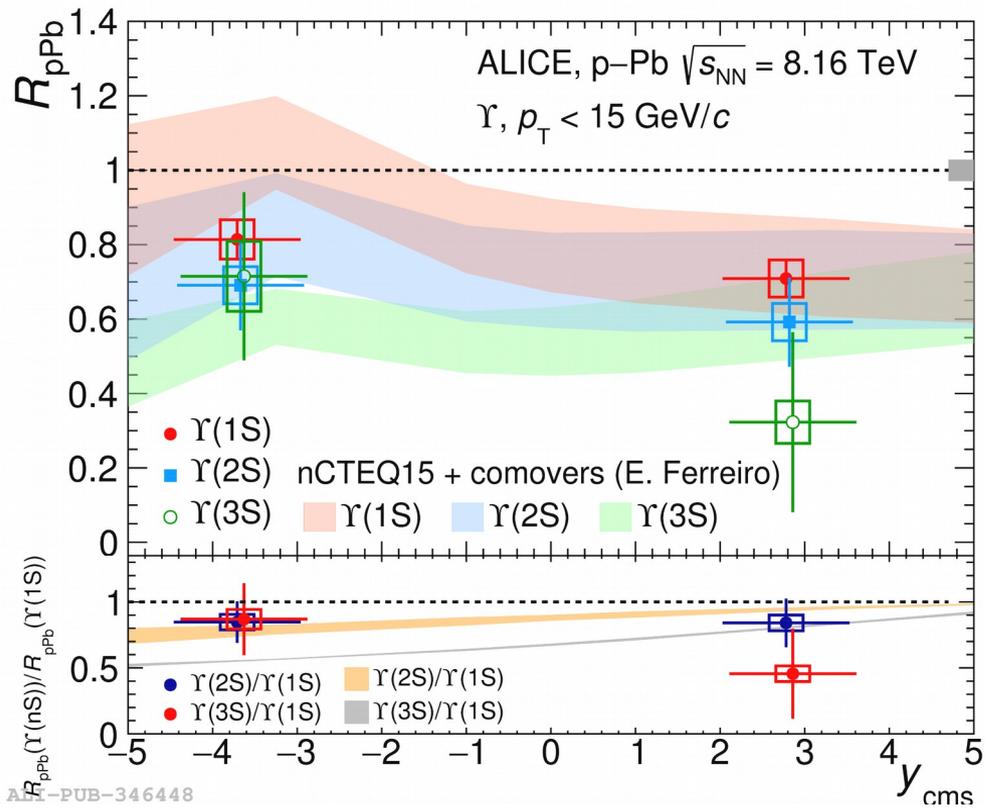


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- Two sets of Zero Degree Calorimeters (ZDC) have been used for the multiplicity estimation
- Almost no multiplicity dependence of Q_{pPb} at both the rapidities

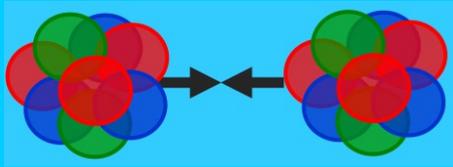
$\Upsilon(2S)$ and $\Upsilon(3S)$ R_{pPb} vs y_{cms} at $\sqrt{s_{NN}} = 8.16$ TeV



- Similar $\Upsilon(1S)$ and $\Upsilon(2S)$ suppression at forward and backward rapidity
- A first measurement of $\Upsilon(3S)$ has also been performed, the large uncertainties prevent a detailed comparison
- Comovers based model predicts at backward rapidity, an ordering in the suppression of $\Upsilon(nS)$ [JHEP 10 (2018) 094]
- ATLAS and LHCb hint for stronger suppression for excited states [EPJC 78 (2018) 171],[JHEP 11 (2018) 194]
- $\Upsilon(2S)$ ($\Upsilon(3S)$) suppression is compatible with unity within $3.1(2.7)\sigma$ at forward-y and $2.3(1.2)\sigma$ at backward-y

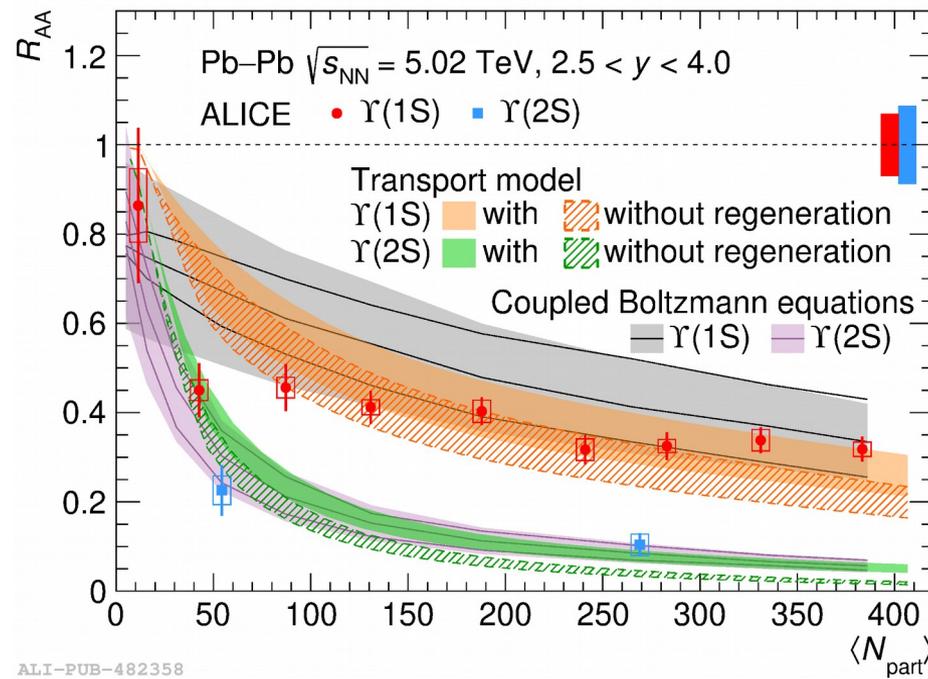
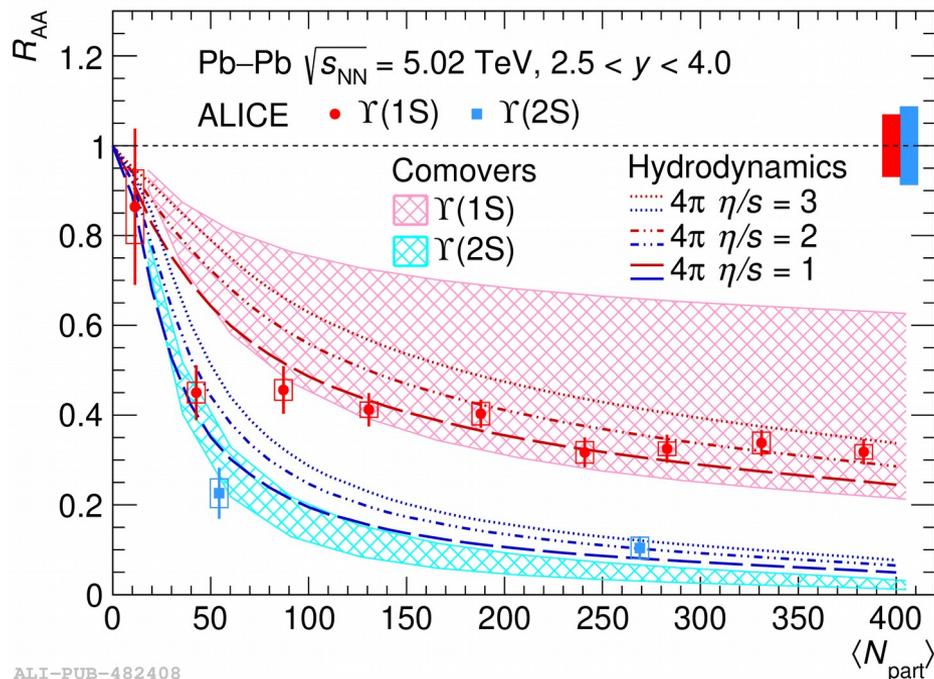
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Pb-Pb



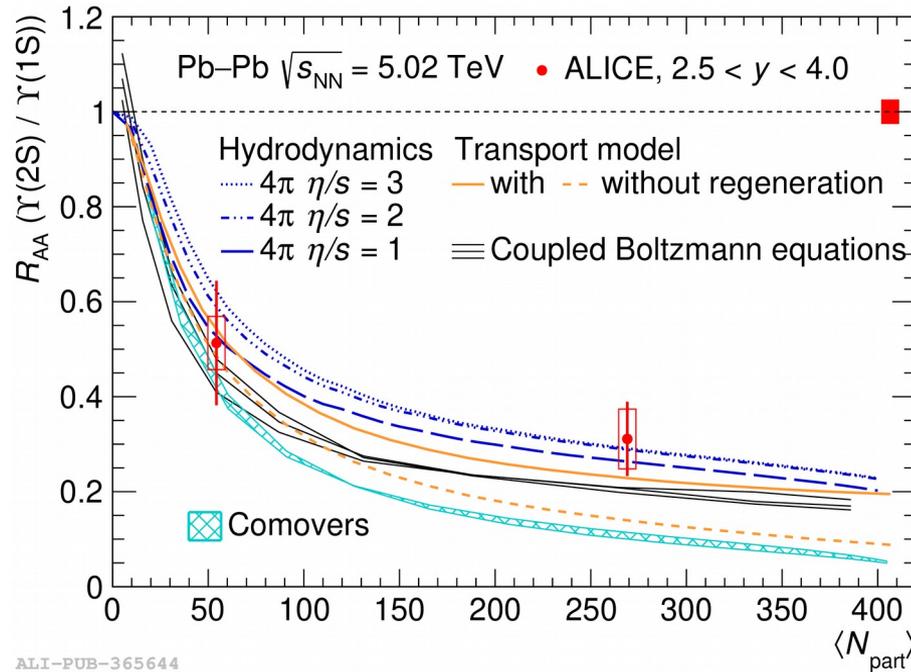
hot matter effects:
suppression, regeneration...

R_{AA} vs centrality in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV



arXiv:2011.05758

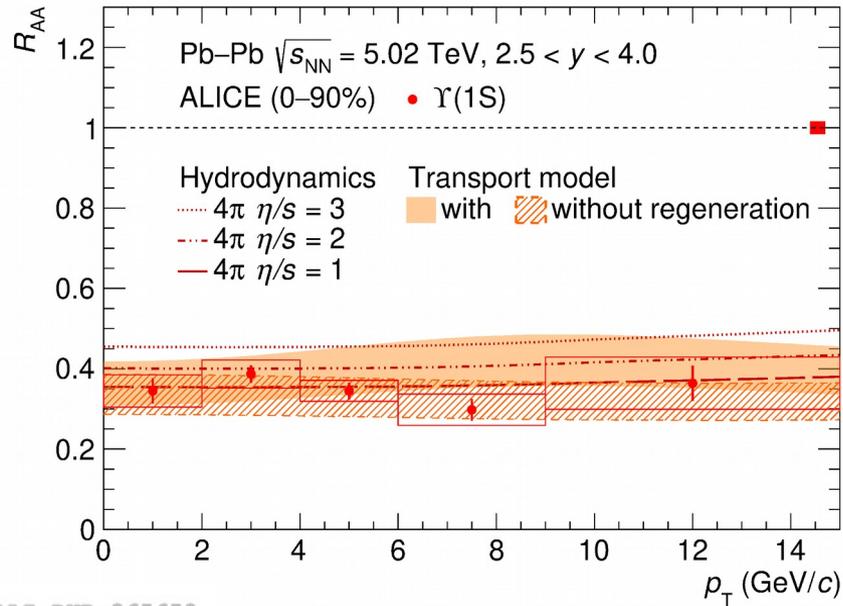
- Strong suppression of $\Upsilon(1S)$ in the most central collisions
- R_{AA} of $\Upsilon(2S)$ is smaller than $\Upsilon(1S)$ by a factor of 3
- Comovers, Transport, Hydro models describe the data



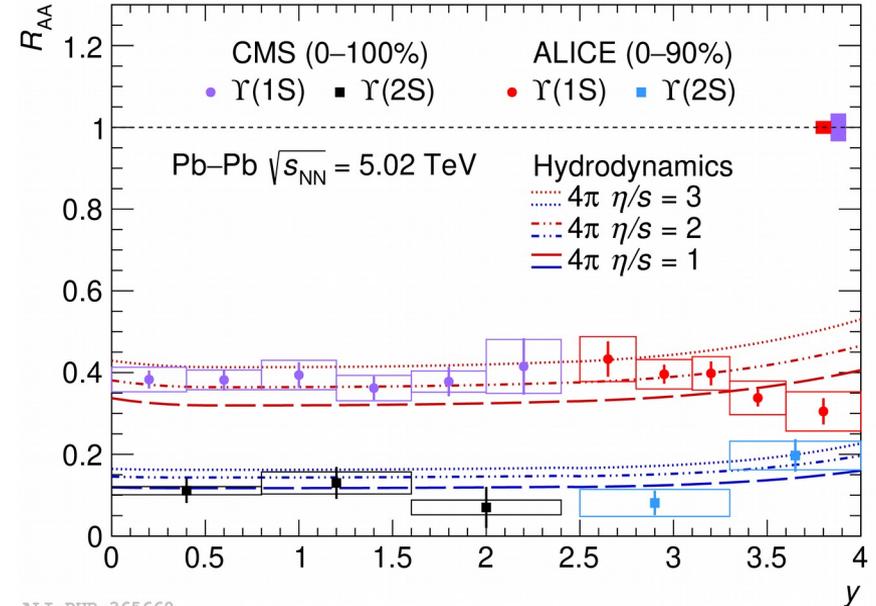
arXiv:2011.05758

- Excited-to-ground state R_{AA} ratios are in agreement with Hydro calculations, Transport model and coupled Boltzmann equations while they have tension with the comover model for most central collisions

R_{AA} vs p_T and y in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV



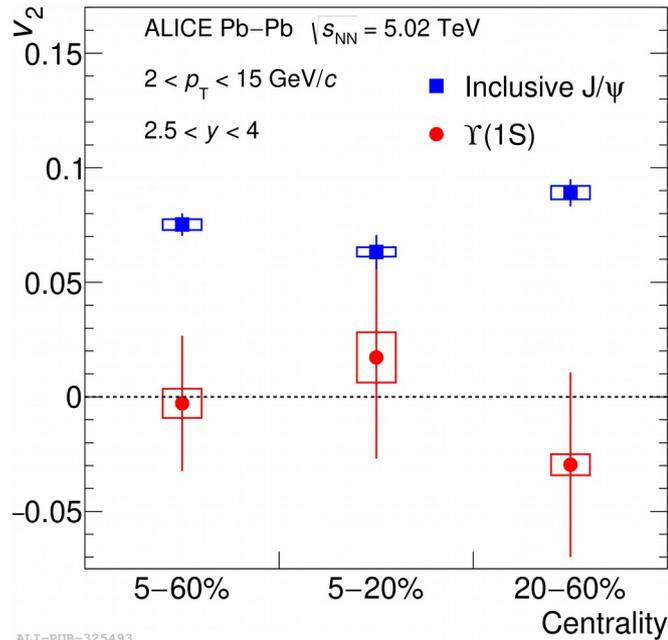
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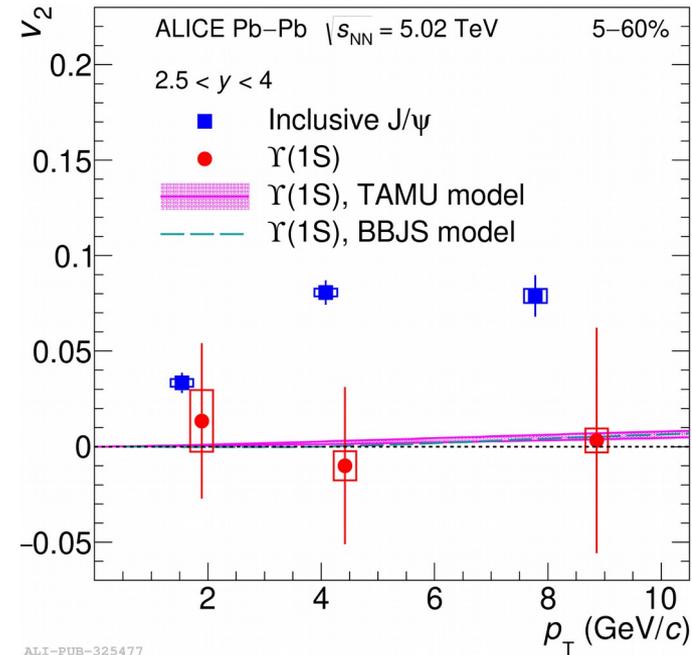
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arXiv:2011.05758

- R_{AA} of $\Upsilon(1S)$ does not show a significant dependence on p_T
- The R_{AA} of $\Upsilon(1S)$ at mid-rapidity is almost flat however its decreases if one goes towards the more forward regions
- For $\Upsilon(2S)$, the rapidity dependence is flat within the uncertainties
- The slight rapidity dependence opposite to hydrodynamical model predictions for $\Upsilon(1S)$ state



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ALI-PUB-325477

PRL 123 (2019) 192301

- $\Upsilon(1S)$ v_2 is compatible with zero and with the small values predicted by the theoretical models within uncertainties
- CMS collaboration also found $\Upsilon(1S)$ v_2 consistent with zero [CMS-PAS-HIN-19-002]
- $\Upsilon(1S)$ v_2 is 2.6σ lower with respect to that of inclusive J/ ψ in $2 < p_T < 15$ GeV/c

p-Pb:

- Similar $\Upsilon(1S)$ and $\Upsilon(2S)$ suppression at backward and forward- y
- The available models describe $\Upsilon(1S)$ behaviour at forward- y while they overestimate backward- y results
- Indication of stronger CNM effects at low p_T
- No significant multiplicity dependence

Pb-Pb:

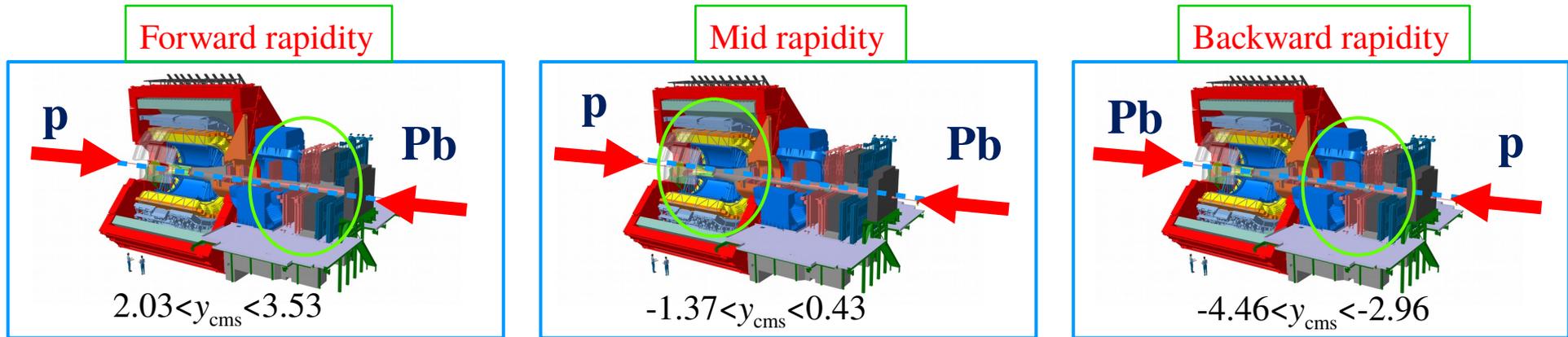
- Clear suppression of $\Upsilon(1S)$ with no indication of a significant regeneration component
- Together with the CMS data, these measurements constrain the rapidity dependence of Υ suppression
- $\Upsilon(1S) v_2$ is compatible with zero and with the current model predictions within uncertainties

Thank you

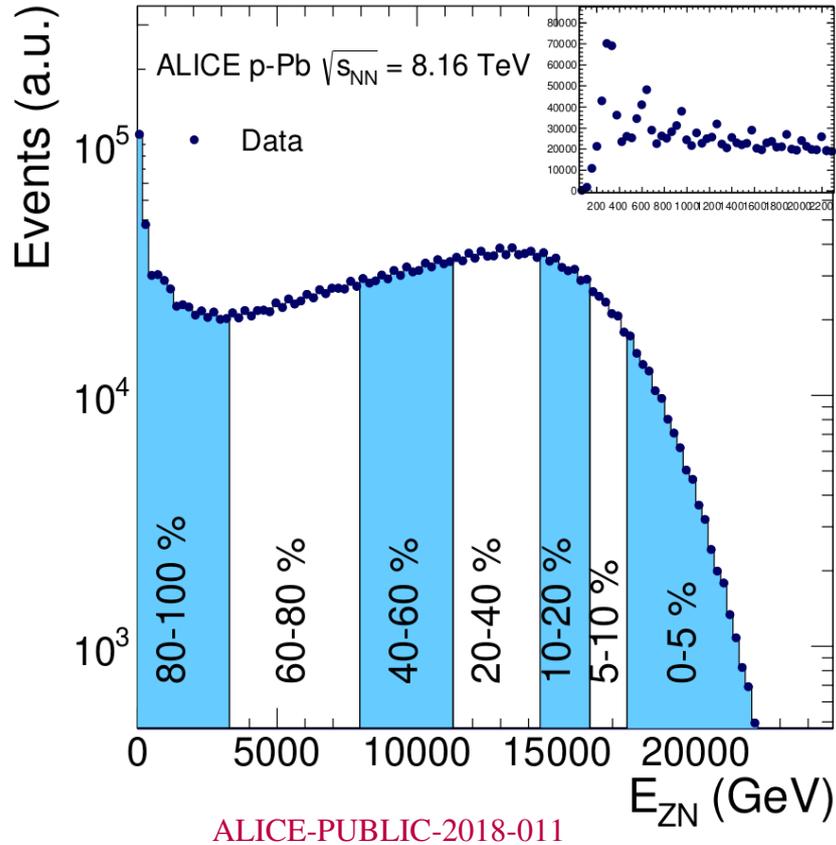
Thank you

p-Pb collisions in ALICE

- To understand Cold Nuclear Matter (CNM) effects such as nuclear parton shadowing/color glass condensate, energy loss and comovers absorption
- No Quark-Gluon Plasma (QGP) is expected in pA collisions
- The measurement of CNM effects in pA collisions is important to quantify the QGP effects in AA collisions
- ALICE has collected p-Pb data at $\sqrt{s_{NN}} = 5.02$ and 8.16 TeV
- ALICE data are collected with two beam configurations: p-Pb and Pb-p, with $\Delta y = \pm 0.465$



Multiplicity determination in p-Pb at $\sqrt{s_{NN}} = 8.16$ TeV



- Two sets of Zero Degree Calorimeters (ZDC) have been used for the multiplicity estimation
- The hybrid method aims to provide an unbiased centrality estimator.
- It is based on two assumptions:
 - The first is that the event selection based on the energy deposited in the ZDC is free from the biases due to a multiplicity selection.
 - The second assumption is that some observables scale linearly with N_{coll} and N_{part} , allowing one to establish a relationship to the collision geometry.

- The distribution of the energy deposited in the Pb-going side (ZNA) calorimeter

- **Comover model:** [JHEP 10 (2018) 094, JHEP 03 (2019) 063]

Quarkonia are dissociated via the interaction with surrounding particles in the final state. The revisited version of this model aims to explain the suppression of bottomonium production in both p-Pb and Pb-Pb collisions with the same assumptions. It takes into account the nuclear modification of parton distribution functions (nPDFs). Uncertainties from the nCTEQ15 shadowing.

- **Hydro model:** [arXiv:1605.03561]

The model is derived from the thermal modification of a complex heavy-quark potential inside an anisotropic plasma. The survival probability of bottomonia is evaluated based on the local energy density, integrating the rate equation over the proper time of each state. The background medium is described with viscous hydrodynamics for three values of the shear viscosity-to-entropy density ratio η/s . These calculations do not include any modification of nuclear PDFs or any regeneration phenomenon.

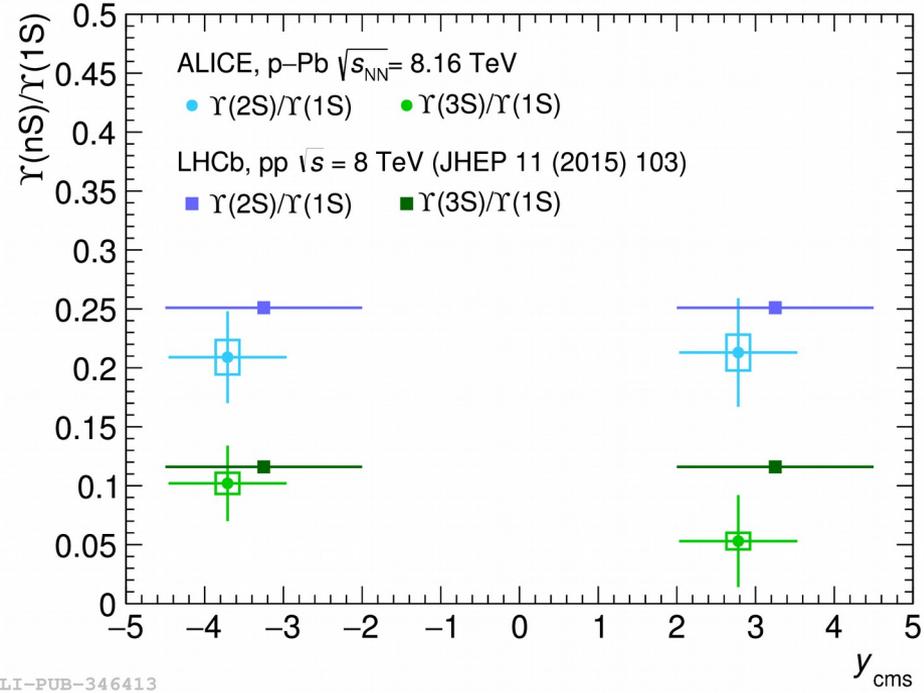
- **Transport model:** [Phys. Rev. C 96 no. 5, (2017) 054901]

Model includes an interplay of dissociation and regeneration mechanisms regulating the production of bottomonia at the QGP stage. The medium evolves as an expanding isotropic fireball. The width of the bands represents the modification of the PDF modelled by an effective scale factor on the initial number of $b\bar{b}$ pairs.

- **Coupled Boltzmann equations:** [arXiv:2004.06746]

The regeneration is dominated by real-time recombinations of correlated heavy-quark pairs. The simulation of the collision system includes the EPPS16 nPDF parametrisation. Theoretical bands are due to the nPDF uncertainty and with three curves from the variation of the coupling constants.

$\Upsilon(nS)$ vs y_{cms} at $\sqrt{s_{\text{NN}}} = 8.16$ TeV



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