Quarkonium production in pp, p-Pb and Pb-Pb collisions with ALICE at the LHC

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Overview

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3. The Nuclear Modification Factor
4. Motivation for the three systems (pp, p-Pb, Pb-Pb)
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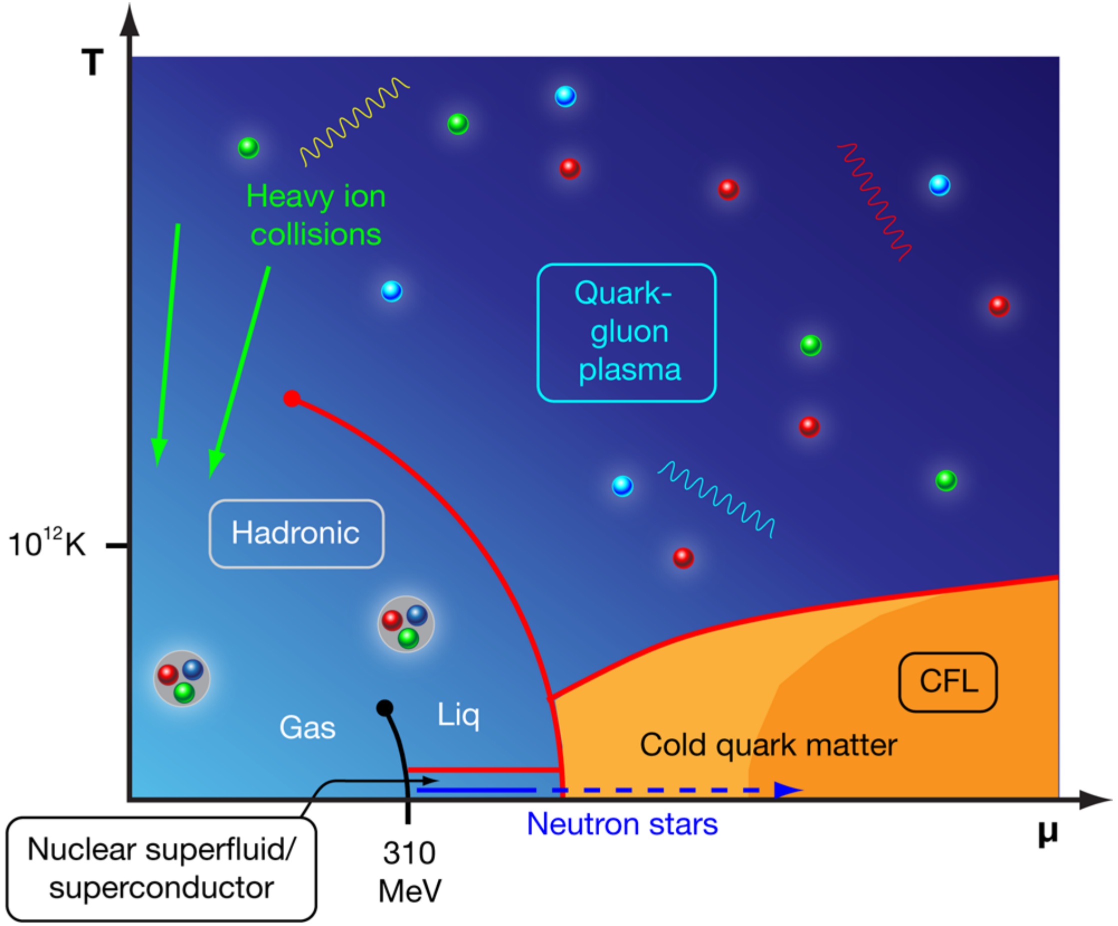
7. J/ψ and $\Upsilon(1S)$ in Pb-Pb @ $\sqrt{s_{\mathrm{NN}}}$ 5.02 TeV
8. Conclusions

Introduction

What is the QGP?

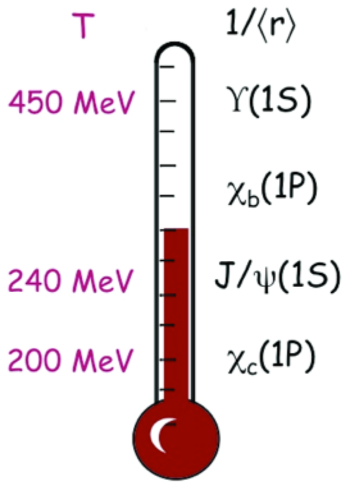
- QGP (Quark-Gluon Plasma) is a deconfined state of hadronic matter which can form at high temperatures and/or baryonic densities
- ALICE @ LHC observes QGP produced in ultra-relativistic collisions of heavy ions
- Direct observation of QGP is impossible due to the short life of the deconfined phase
- QGP is studied indirectly by means of a number of probes

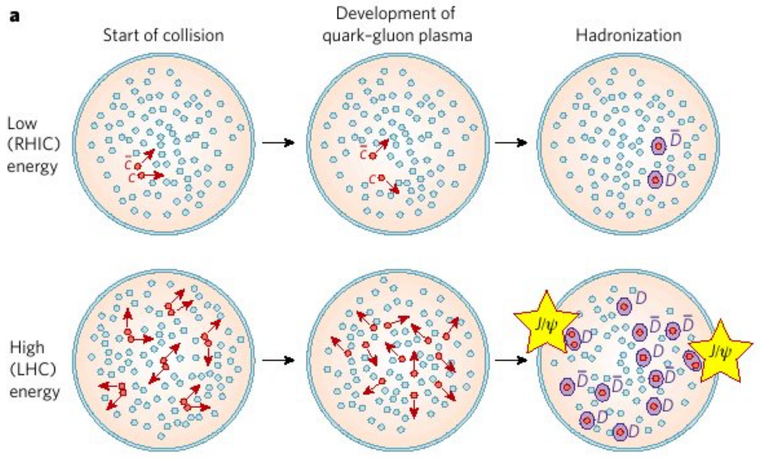


QGP study via quarkonium production measurement

$Q\bar{Q}$ is produced at early stages of the collision → Q and $\bar{Q}$ cross QGP interacting with it → Information about QGP characteristics are extracted via the modified production of resonant states

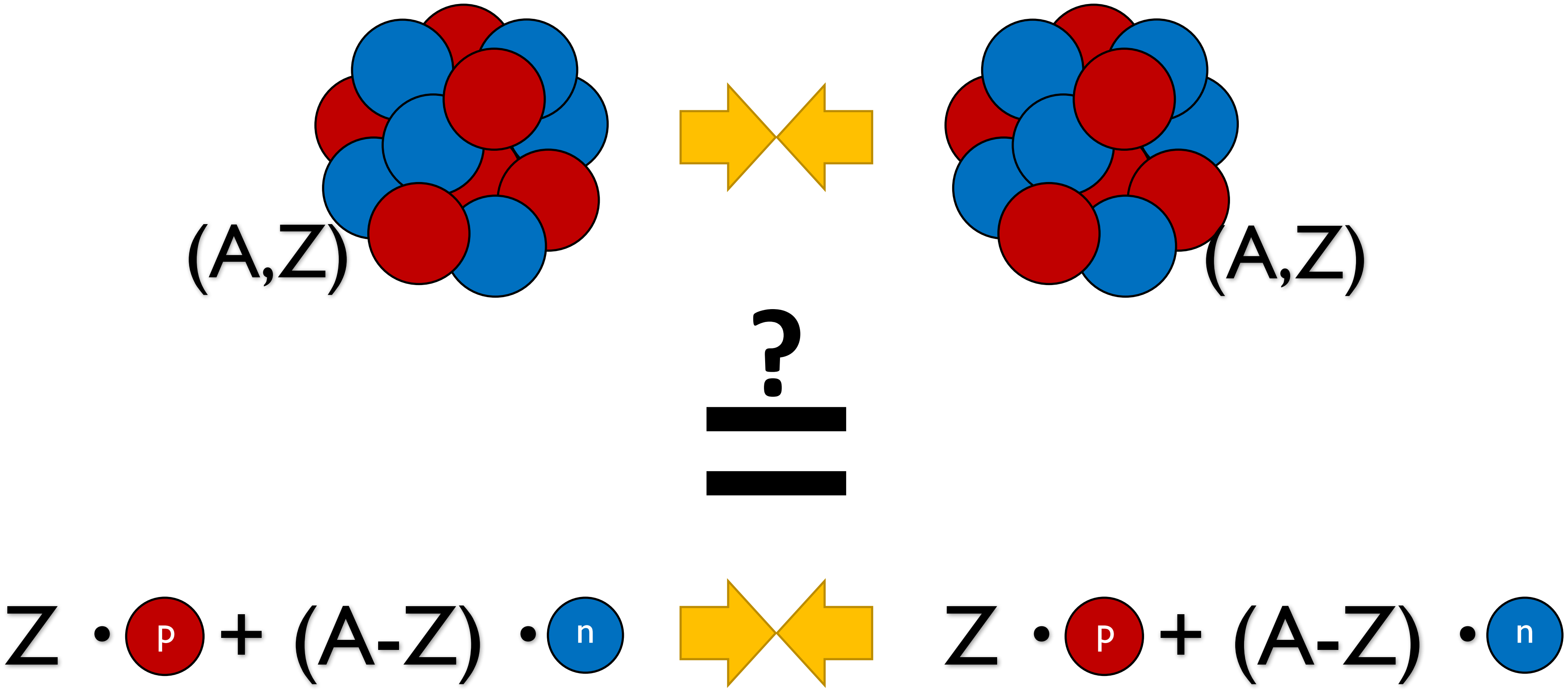
- QGP modifies quarkonium production ($R_{AA} \neq 1$):
  - Screening by free colour charges reduces $Q\bar{Q}$ potential;
  - Sequential melting of differently bound $Q\bar{Q}$ states can be seen as a thermometer of the QGP;
  - High abundance of Q and $\bar{Q}$ may cause regeneration of quarkonium states





Nuclear Modification Factor R_{AA}

The question is:



Nuclear Modification Factor R_{AA}

An observable is the nuclear modification factor:

$$R_{\mathrm{AA}}^{x} = \frac{1}{T_{\mathrm{AA}}} \cdot \frac{N_{\mathrm{AA}}^{x}}{\sigma_{pp}^{x}} \qquad T_{\mathrm{AA}} = \frac{\langle N_{Coll} \rangle}{\sigma_{pp}^{inel}}$$

Where x is the probe we want to study

An observable is the nuclear modification factor

Number of produced $Q\bar{Q}$ bound states in nuclear collisions

$$R_{\text{AA}}^{x} = \frac{1}{T_{\text{AA}}} \cdot \frac{N_{\text{AA}}^{x}}{\sigma_{pp}^{x}}$$

$$T_{\text{AA}} = \frac{\langle N_{Coll} \rangle}{\sigma_{pp}^{inel}}$$

$Q\bar{Q}$ cross section measured in proton-proton collisions

Nuclear thickness function, directly related to the number of nucleon-nucleon collisions

An observable is the nuclear modification factor

Number of produced $Q\bar{Q}$ bound states in nuclear collisions

Obtained from the invariant mass spectrum

$$R_{\mathrm{AA}}^{x} = \frac{1}{T_{\mathrm{AA}}} \cdot \frac{N_{\mathrm{AA}}^{x}}{\sigma_{pp}^{x}}$$

$$T_{\mathrm{AA}} = \frac{\langle N_{Coll} \rangle}{\sigma_{pp}^{inel}}$$

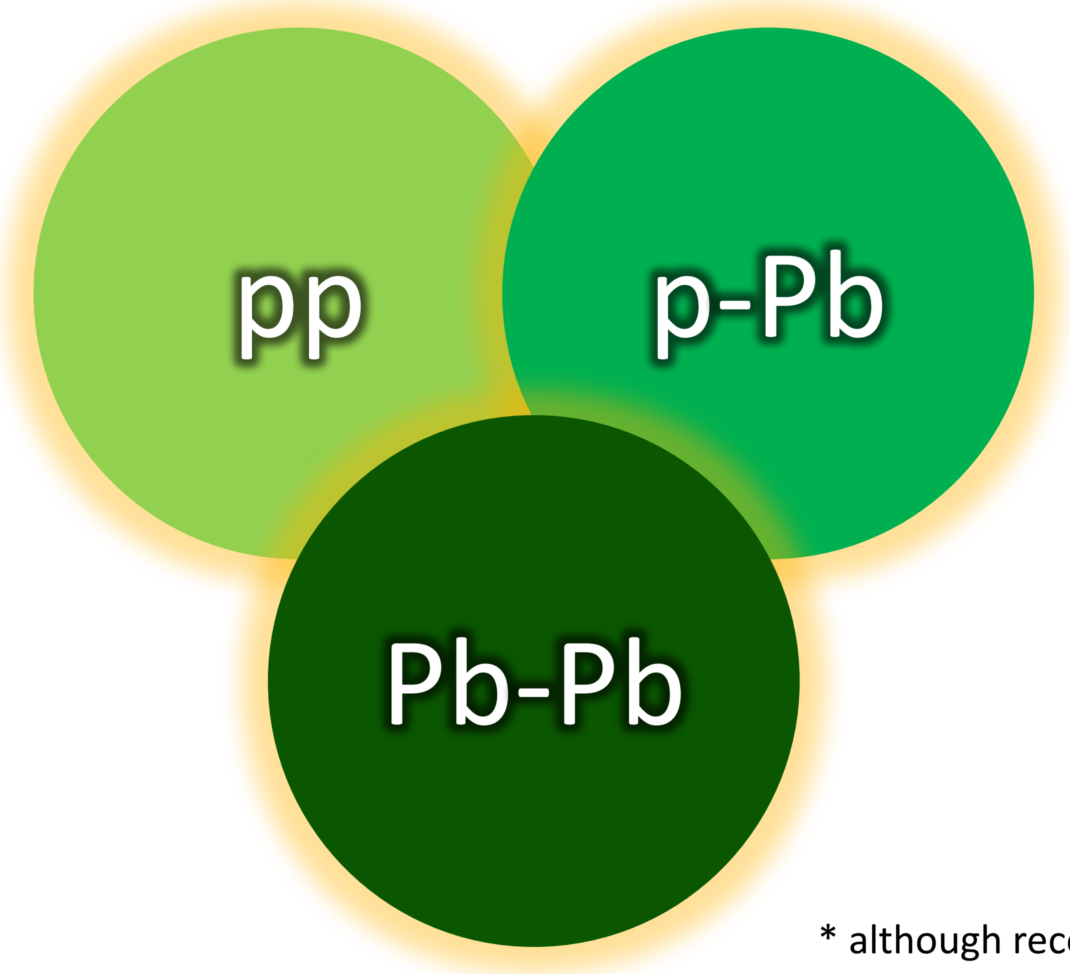
$Q\bar{Q}$ cross section measured in proton-proton collisions

Measured in collisions where $\sqrt{s} = \sqrt{s_{\mathrm{NN}}}$

Nuclear thickness function, directly related to the number of nucleon-nucleon collisions

$\langle N_{Coll} \rangle$ is the number of binary collisions

Three systems: pp, p-Pb e Pb-Pb

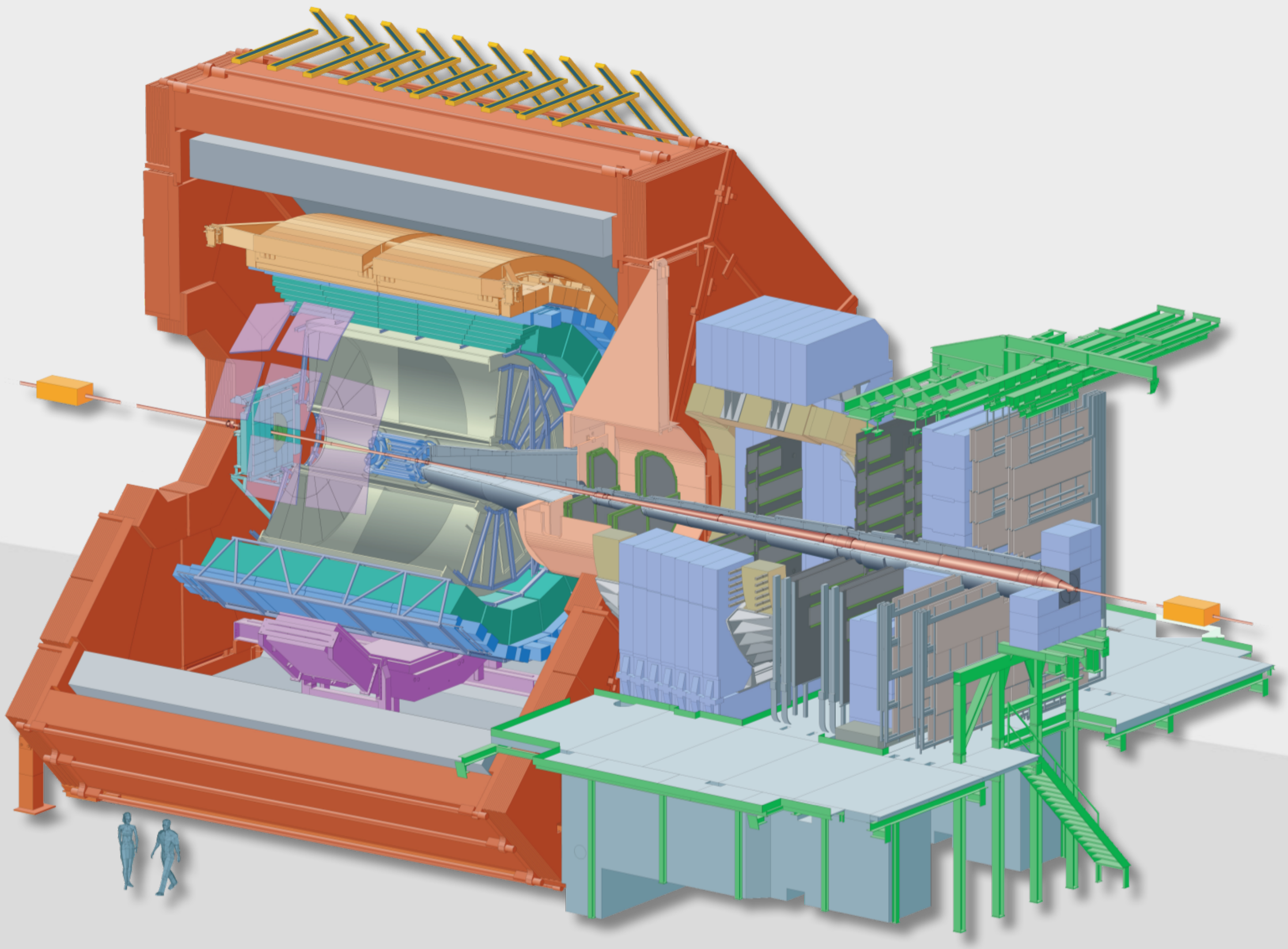


- pp → σ_{pp} for R_{AA} computation + quarkonium production not totally understood (intrinsically non-perturbative)
- p-Pb → no QGP* formed but *Cold Nuclear Matter effects* (CNM) may happen
- Pb-Pb → QGP forms and might be characterised

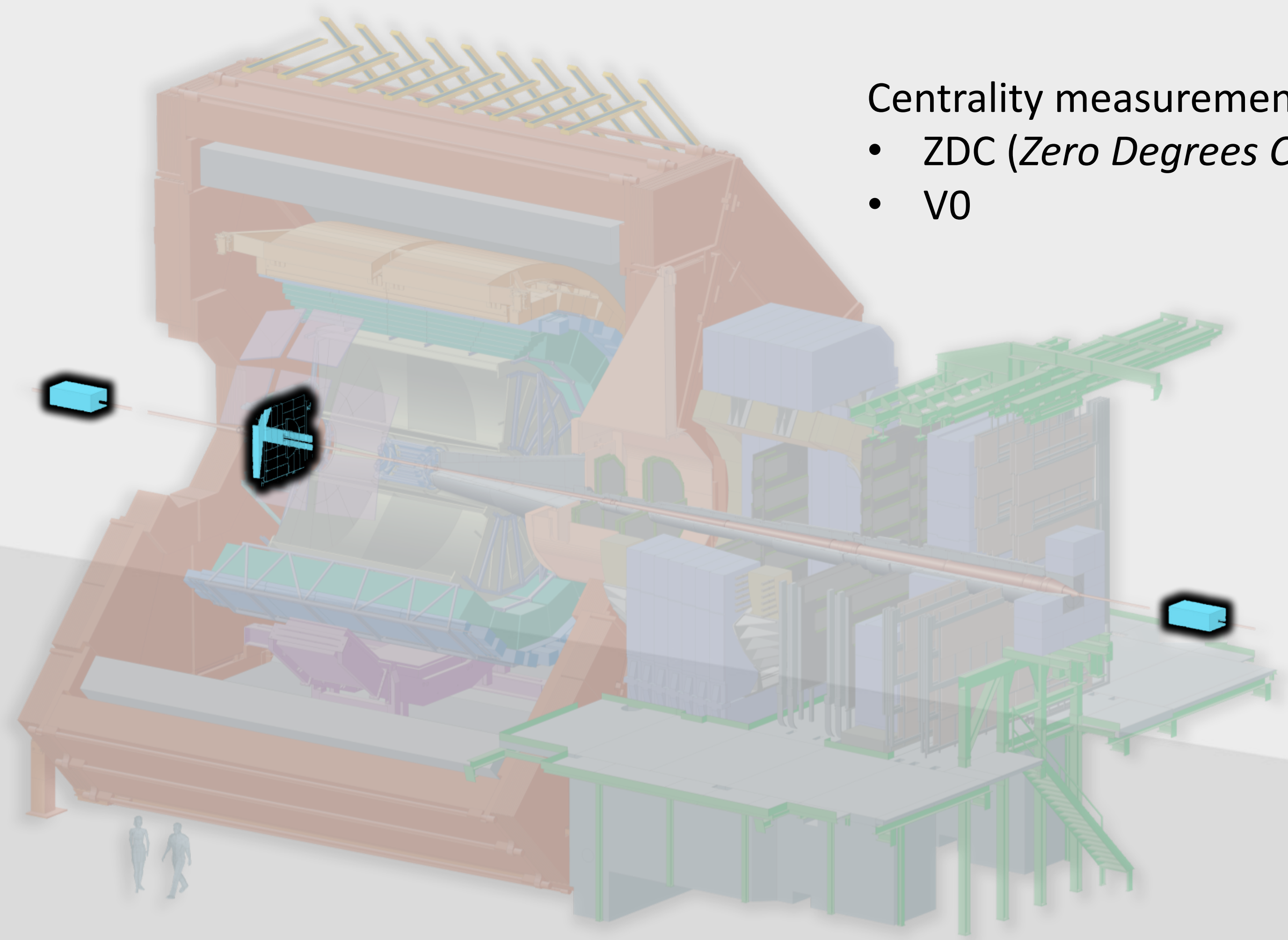
* although recent measurements in high-multiplicity pp and p-Pb collisions point to the presence of collective effects reminiscent of those observed in Pb-Pb collisions

ALICE experimental setup

ALICE experimental setup



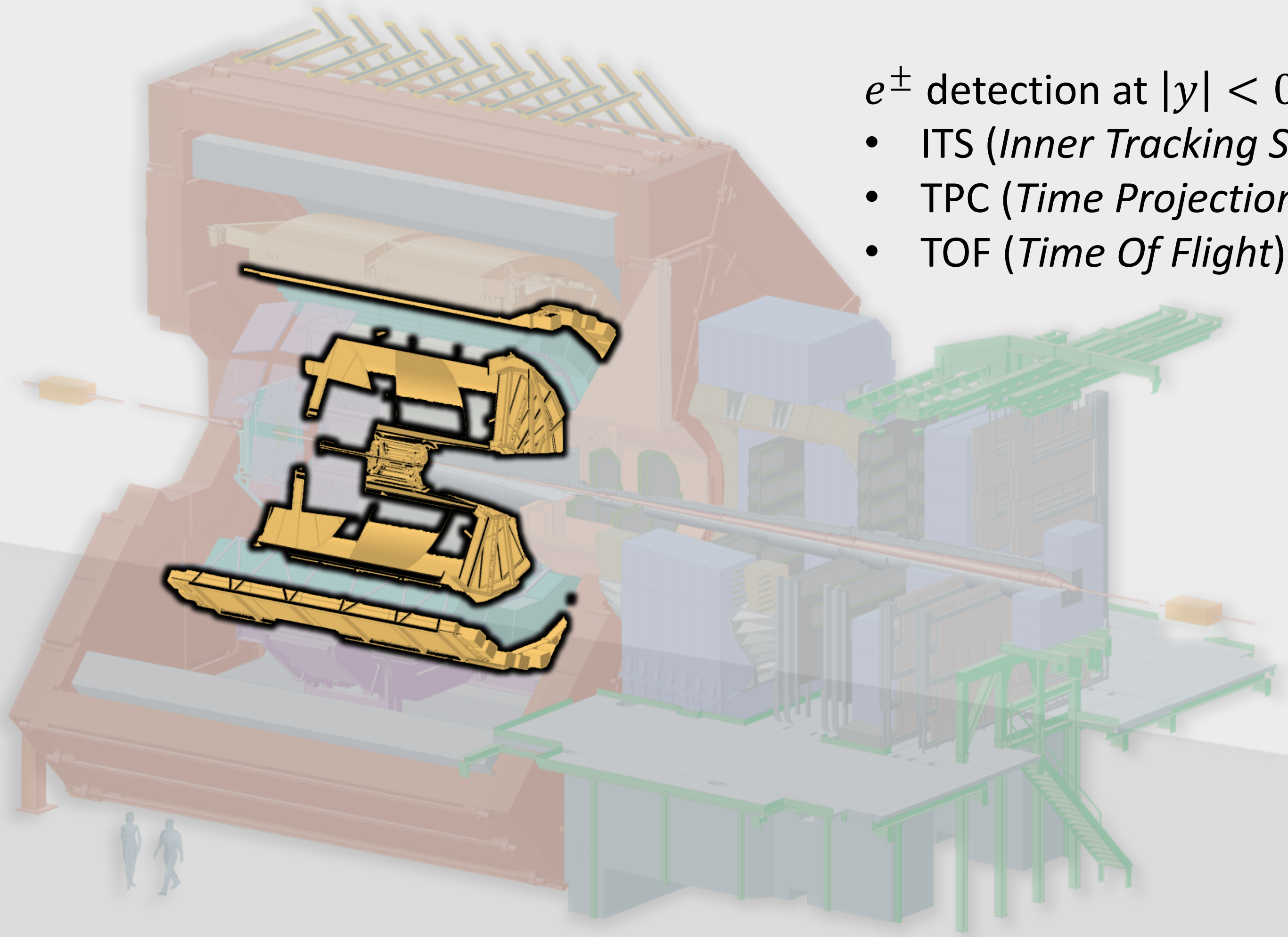
ALICE experimental setup



Centrality measurement:

- ZDC (*Zero Degrees Calorimeters*)
- V0

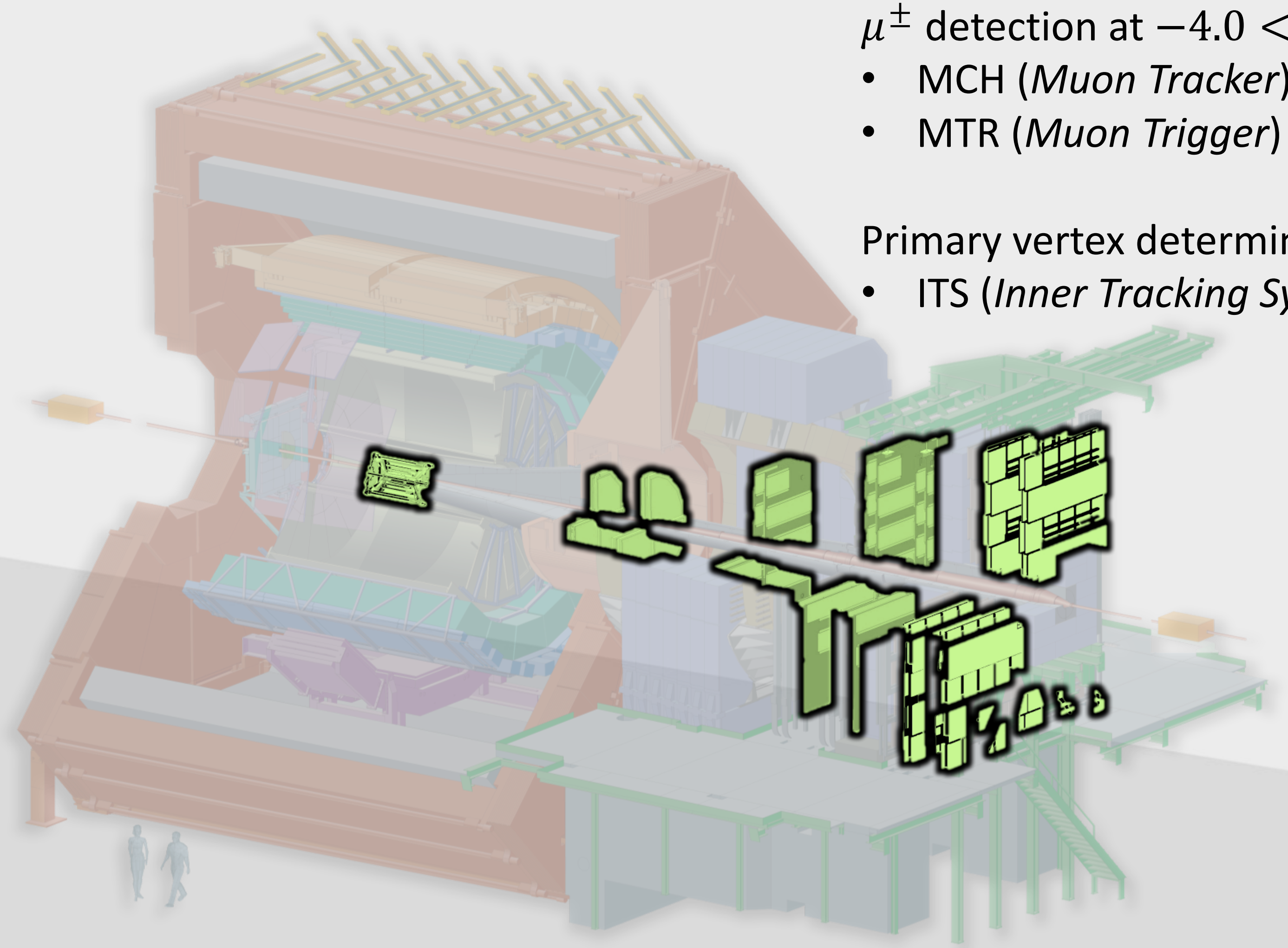
ALICE experimental setup



$e^{\pm}$ detection at $|y| < 0.9$:

- ITS (*Inner Tracking System*)
- TPC (*Time Projection Chamber*)
- TOF (*Time Of Flight*)

ALICE experimental setup



$\mu^{\pm}$ detection at $-4.0 < \eta < -2.5$:

- MCH (*Muon Tracker*)
- MTR (*Muon Trigger*)

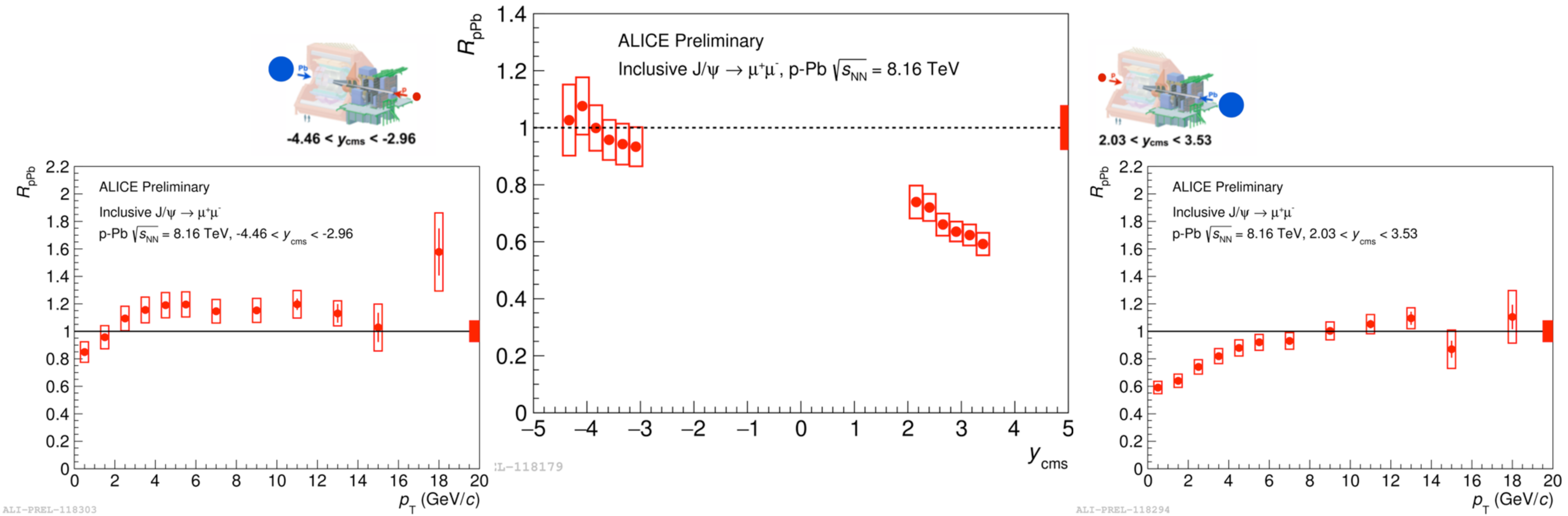
Primary vertex determination:

- ITS (*Inner Tracking System*)

p-Pb measurements

2013 and 2016 @ $\sqrt{s_{\mathrm{NN}}}$=5.02 TeV & 8.16 TeV

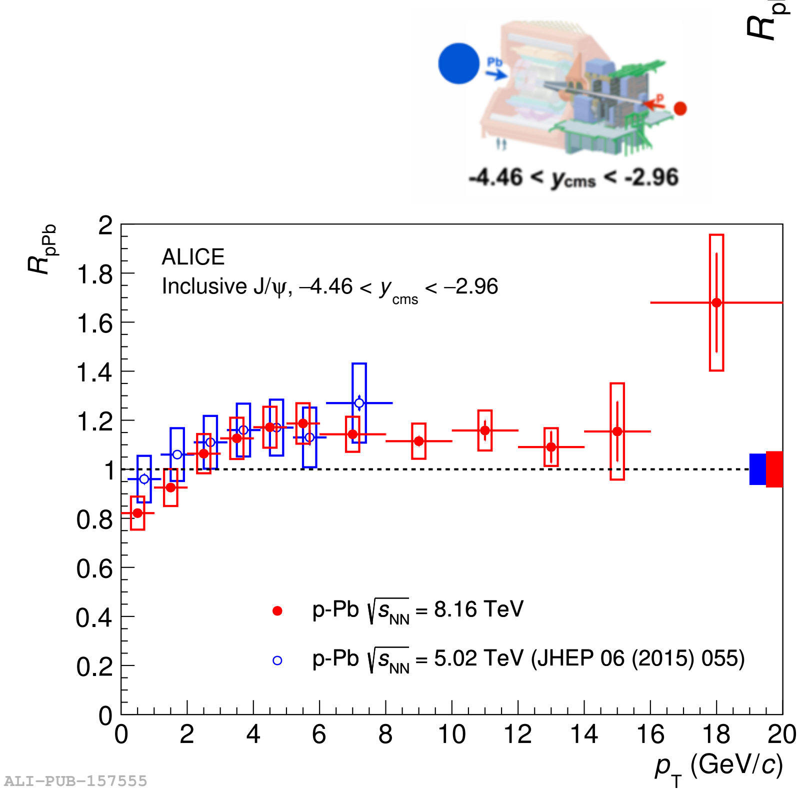
J/ψ R_{pA} @ $\sqrt{s_{\mathrm{NN}}}$=8.16 TeV

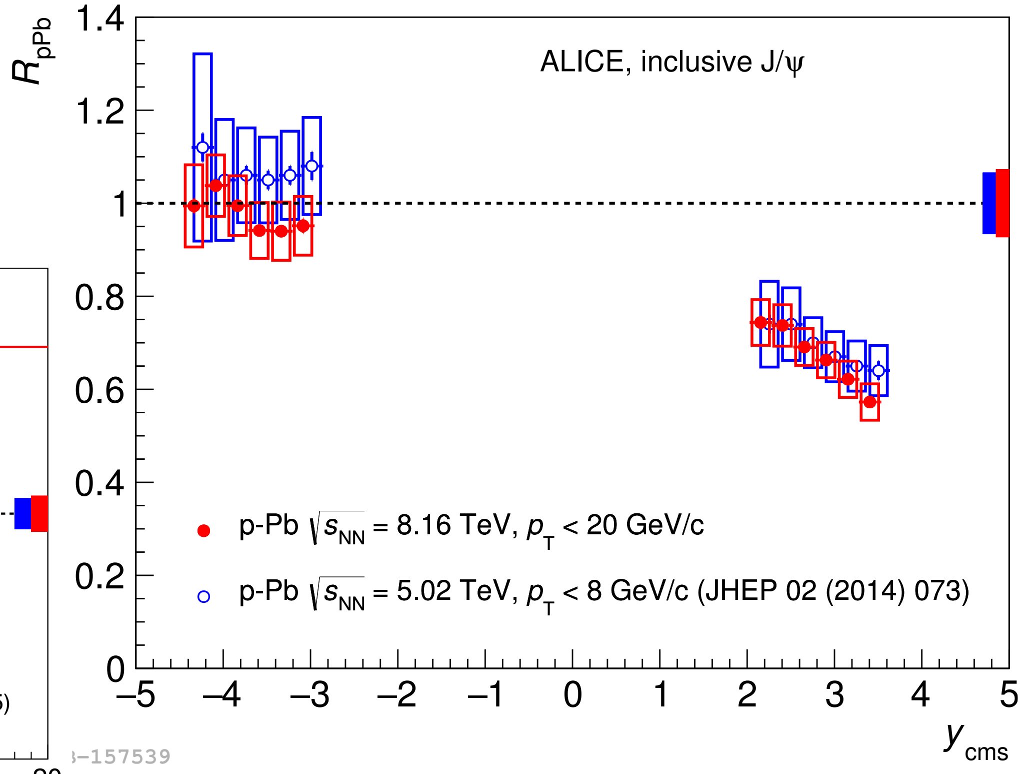


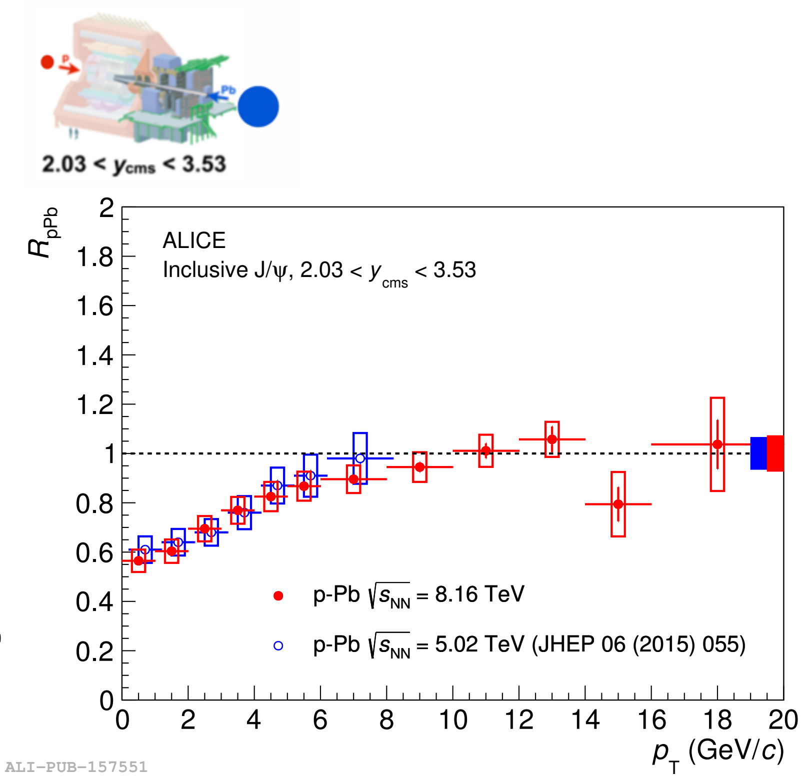
- Data compatible with no suppression at backward rapidity
- Important suppression at forward rapidity and low p_{T}

REF JHEP 07 (2018) 160

$J/\psi\ R_{pA}$ @ $\sqrt{s_{NN}}$=8.16 TeV







- No significant dependence from $\sqrt{s_{NN}}$
- Suppression is still more important at low p_T

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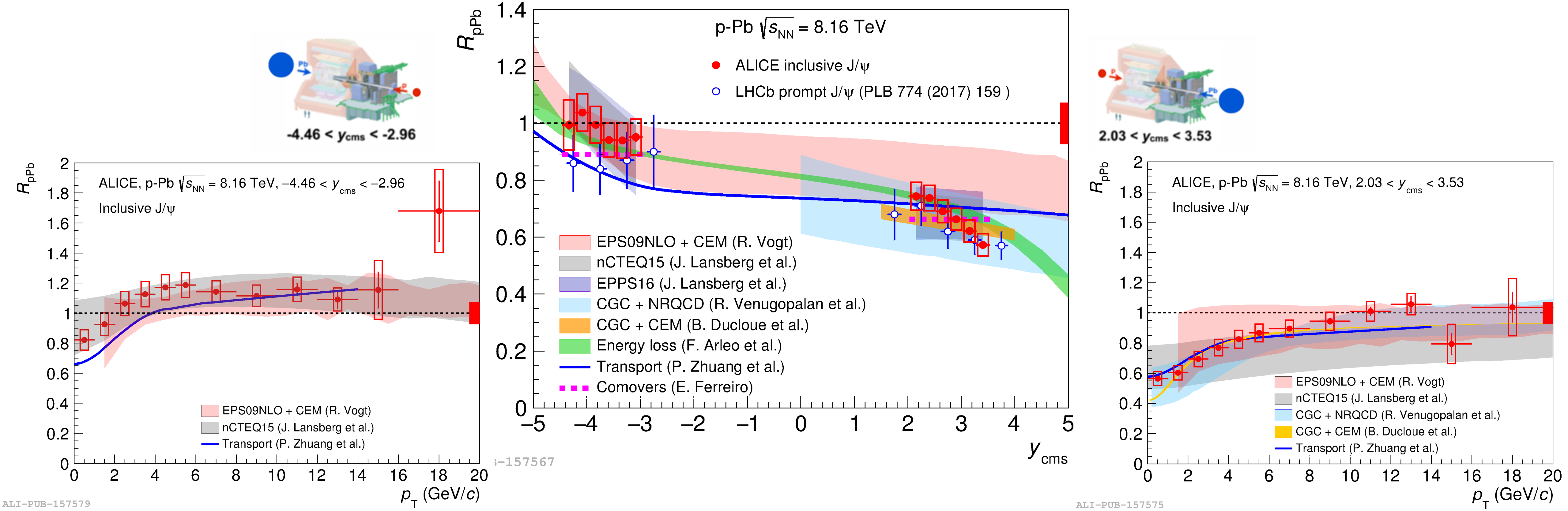
REF JHEP 07 (2018) 160

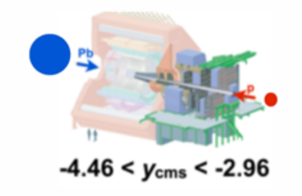
$J/\psi\ R_{pA}$ @ $\sqrt{s_{NN}}$=8.16 TeV

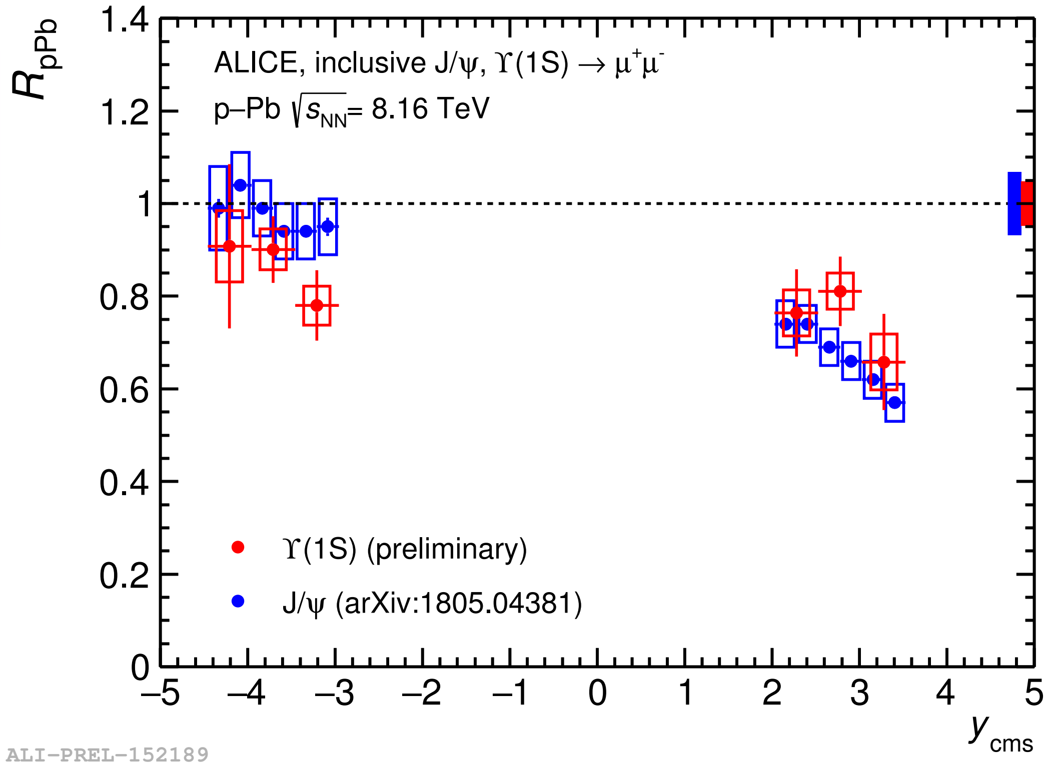


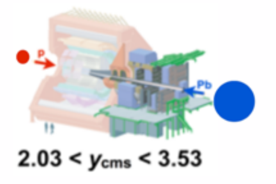
- Compatible with Energy Loss and nuclear modification of the PDFs
- Good agreement with models based on shadowing and energy loss

REF JHEP 07 (2018) 160

$\Upsilon(1S)$ R_{pA} @ $\sqrt{s_{NN}}$=8.16 TeV

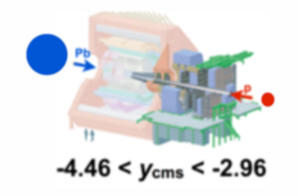


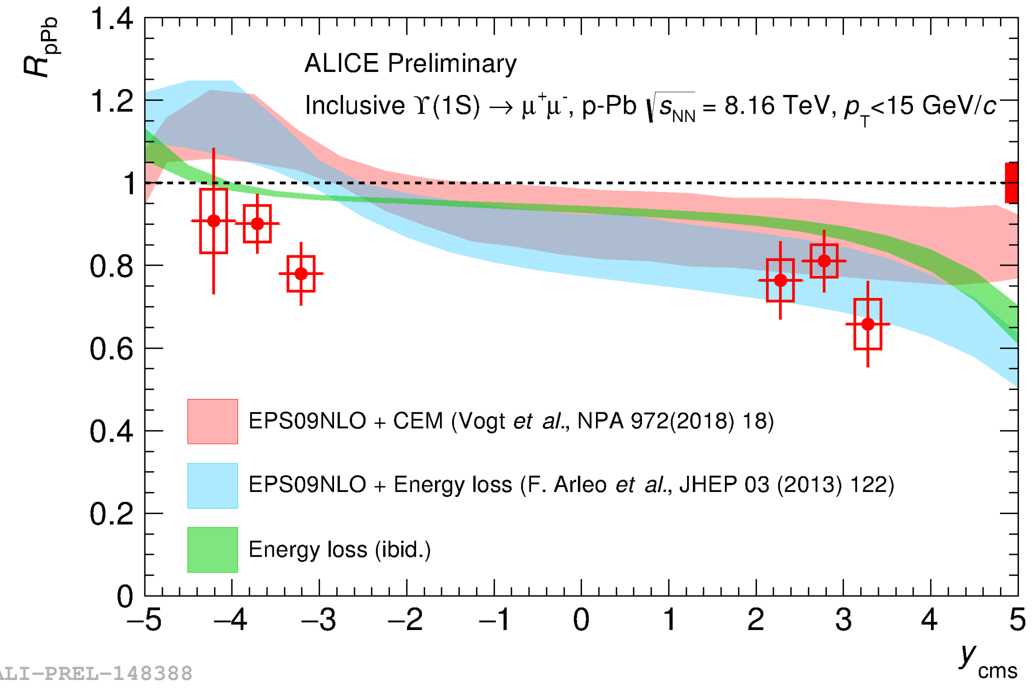


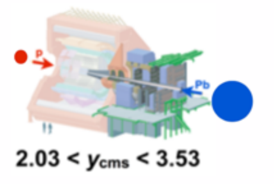


$\Upsilon(1S)$ production is similar to the J/ψ's one

$\Upsilon(1S)\ R_{pA}$ @ $\sqrt{s_{NN}}$=8.16 TeV





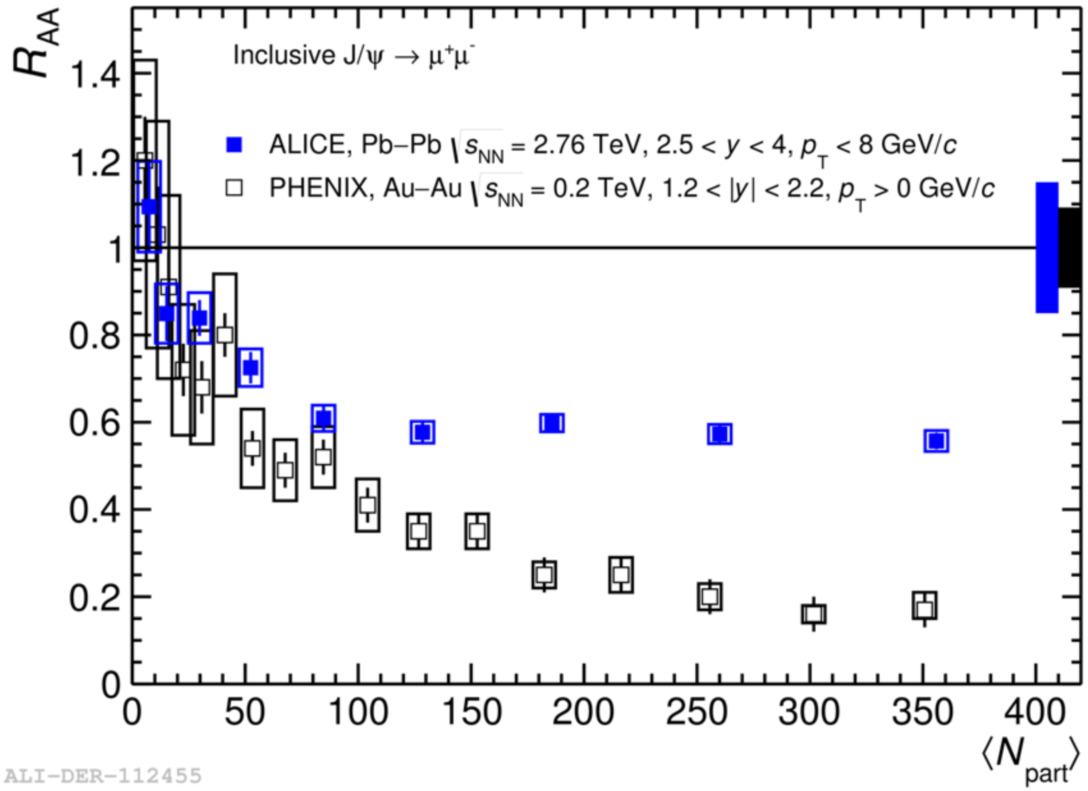


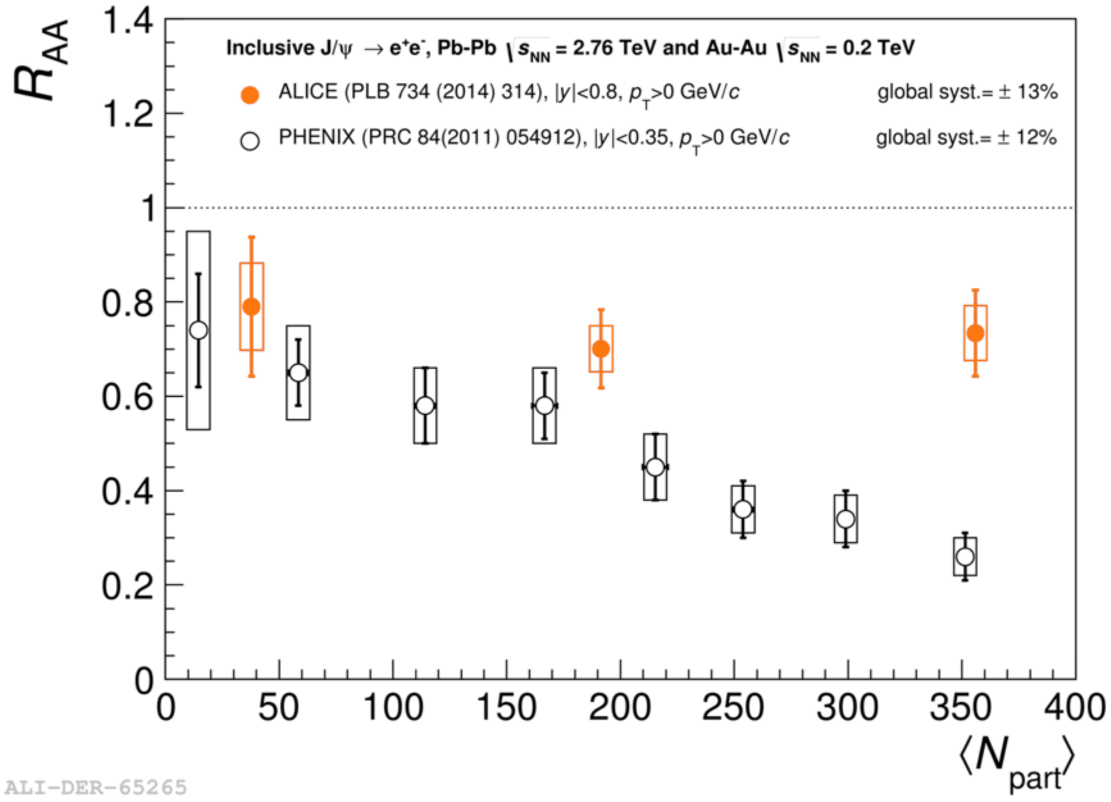
- Good agreement with models at forward rapidity
- Some tension present between data and models at backward rapidity

Pb-Pb measurements

2011 @ $\sqrt{s_{\mathrm{NN}}}$=2.76 TeV & 2015 @ $\sqrt{s_{\mathrm{NN}}}$=5.02 TeV

$J/\psi\ R_{AA}$

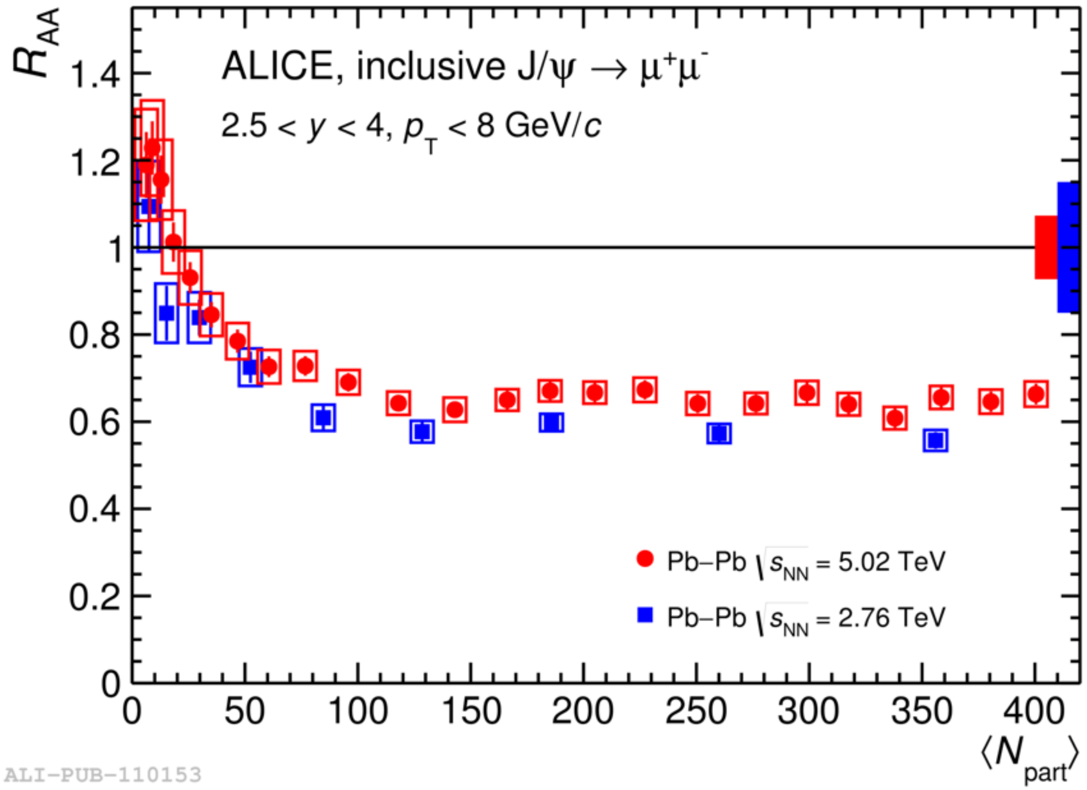


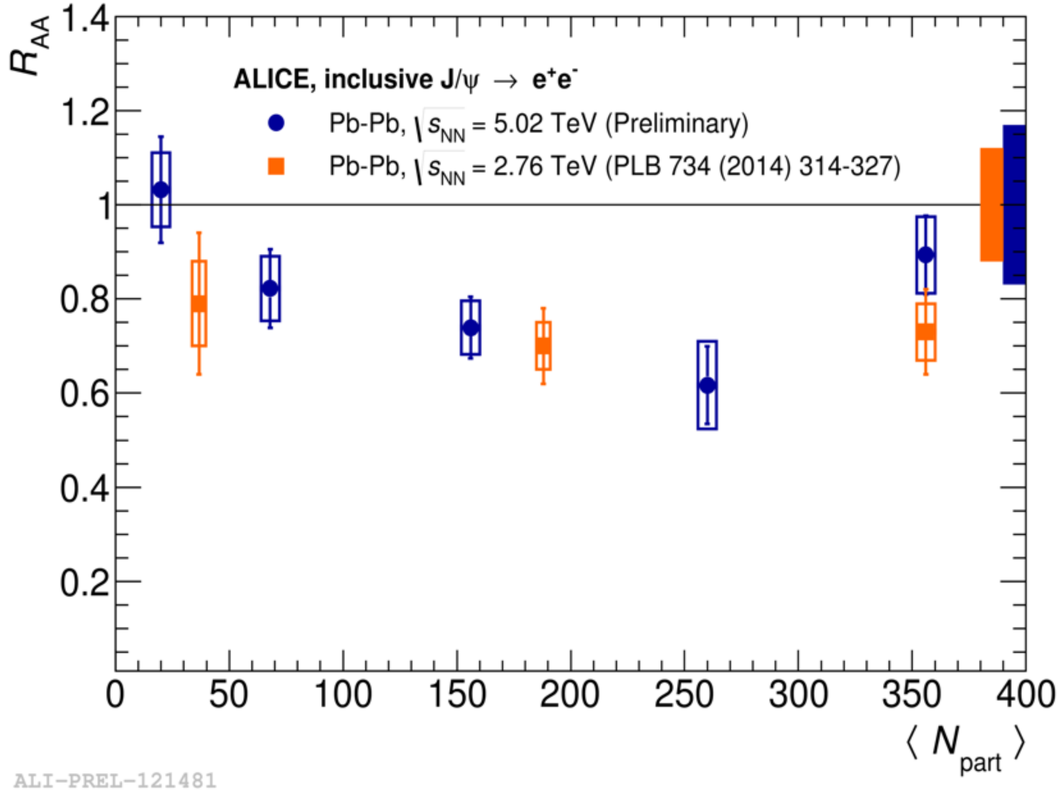


- PHENIX @ RHIC at $\sqrt{s_{NN}}$=200 GeV: monotone suppression increases going to more central collisions
- ALICE @ LHC at $\sqrt{s_{NN}}$=2.76 TeV: less suppression than at RHIC despite energy is 14x higher

REF Phys. Lett. B 734 (2014) 314-327

$\mathrm{J}/\psi \ R_{\mathrm{AA}}$

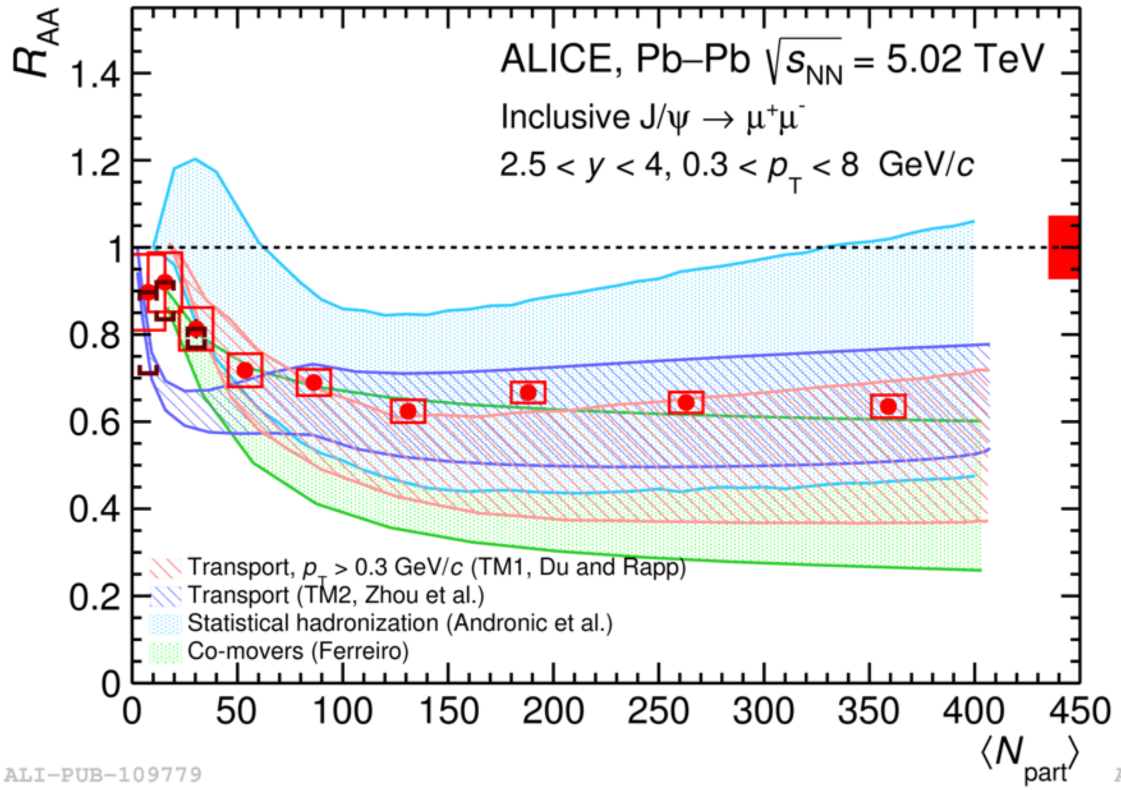


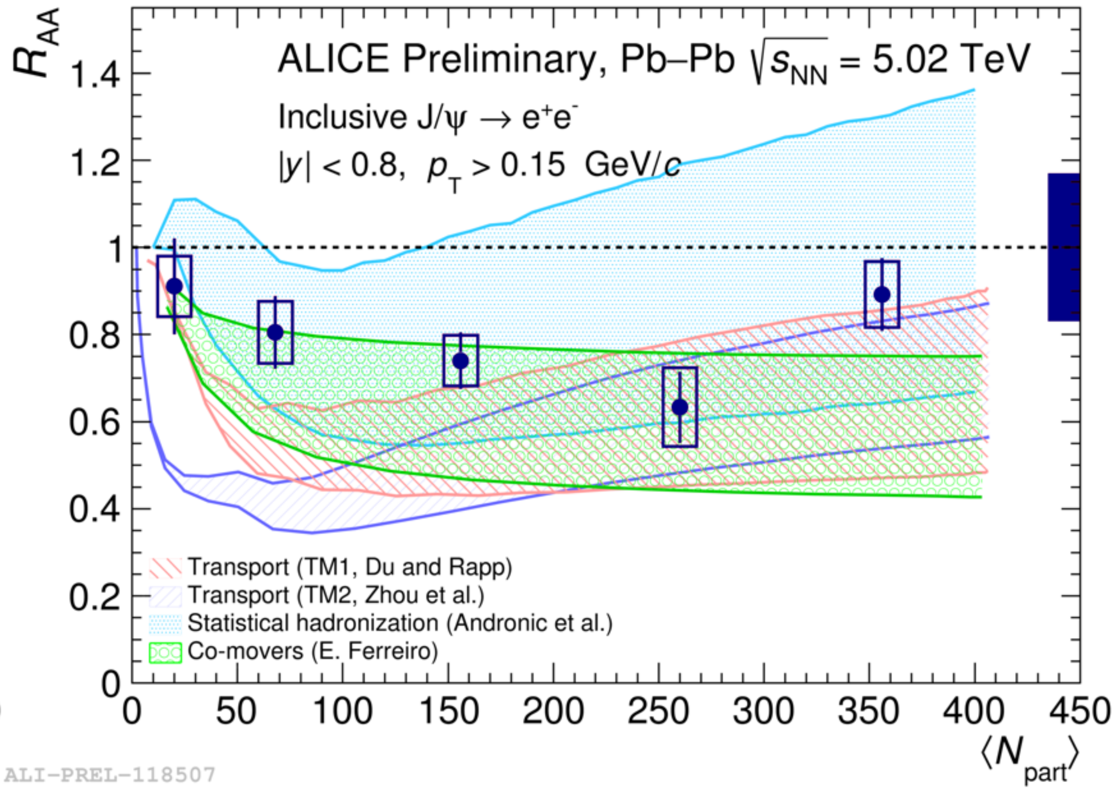


- No clear energy dependence observed
- R_{AA} at $\sqrt{s_{\mathrm{NN}}}$= 5.02 TeV systematically higher than at lower energy, , although compatible within uncertainties

REF Phys. Lett. B 766 (2017) 212-224

$J/\psi\ R_{AA}$

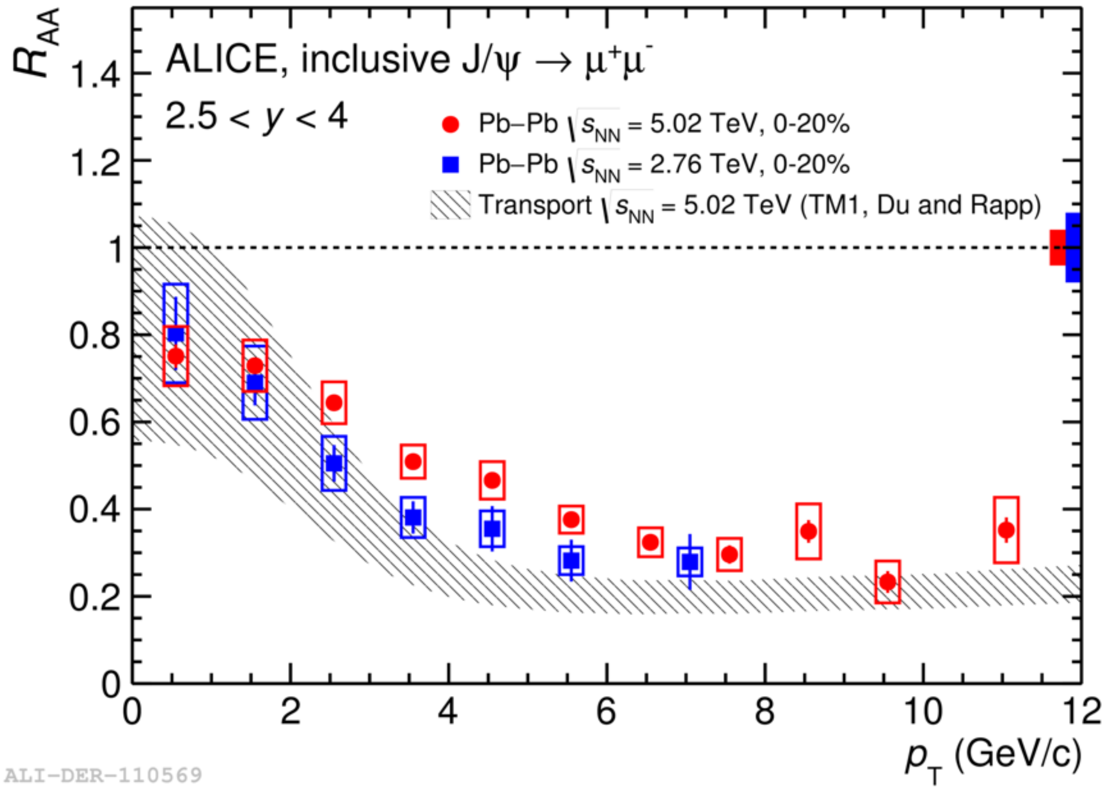




Good agreement between measurements and models which include regeneration phenomena

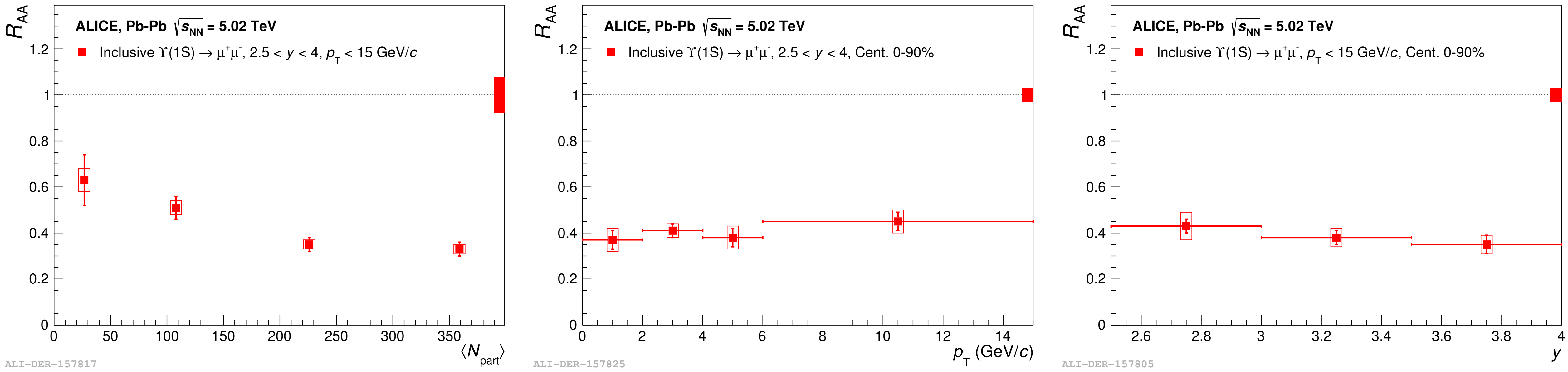
REF Phys. Lett. B 766 (2017) 212-224

$J/\psi\ R_{AA}$



- larger R_{AA} at low p_{T}, as predicted by regeneration models
- In agreement with regeneration models

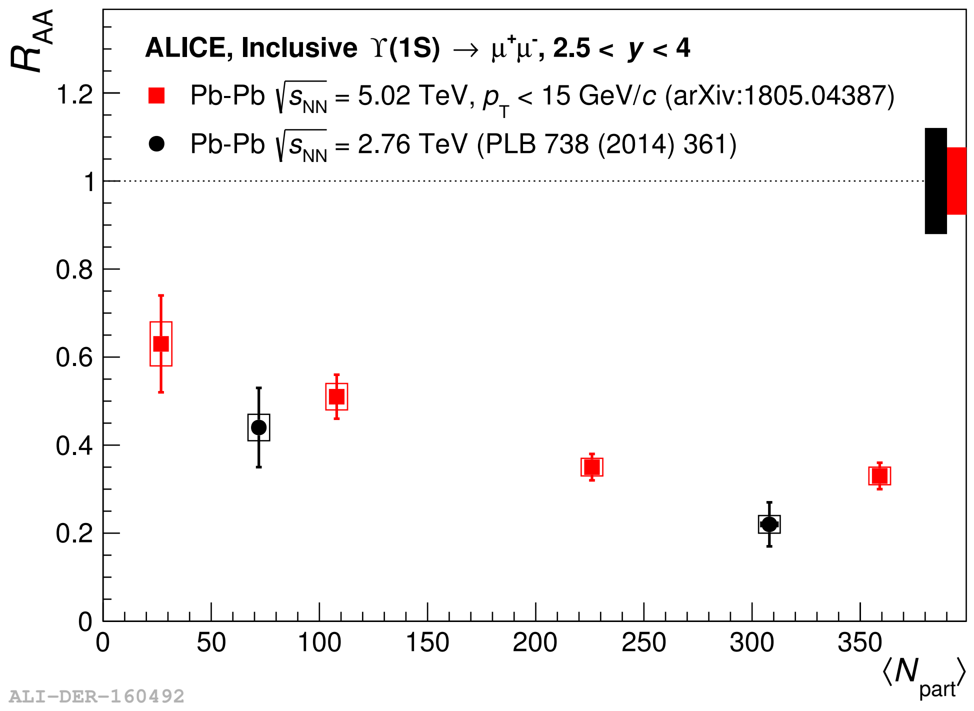
$\Upsilon(1S)$ R_{AA} @ $\sqrt{s_{NN}}$=5.02 TeV



- Bottomonium study complements and extends charmonium one (smaller regeneration expected for bottomonium)
- No evidence of p_T and y dependency

REF arXiv:1805.04387

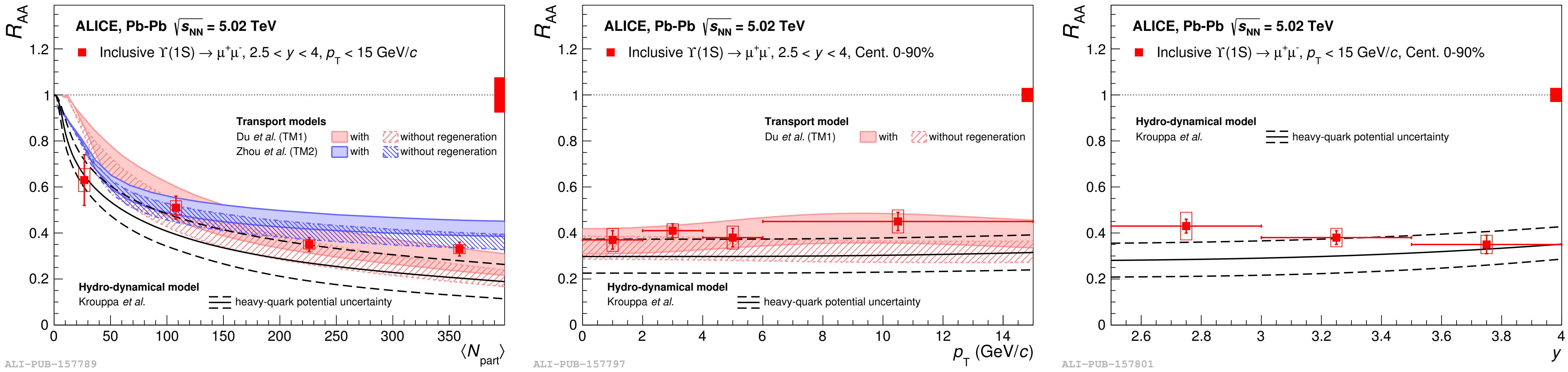
$\Upsilon(1S)$ $R_{\rm AA}$ @ $\sqrt{s_{\rm NN}}$=5.02 TeV



- R_{AA} at $\sqrt{s_{\rm NN}}$=5.02 TeV systematically higher than at $\sqrt{s_{\rm NN}}$=2.76 TeV
- Compatibility between measurements at the two energies

REF arXiv:1805.04387

$\Upsilon(1S)$ R_{AA} @ $\sqrt{s_{NN}}$=5.02 TeV



- No evidence for regeneration effects (expected to be small anyway)
- Some tension between the trend of latest hydro-dynamical predictions and measurements

REF arXiv:1805.04387

Conclusions

Conclusions

- ALICE successfully measures the production of quarkonium in p-Pb and Pb-Pb collisions:
  - The shape of nuclear modification factor in p-Pb collisions is well described by models which include CNM effects
  - Energy, rapidity and p_{T} dependences of J/ψ R_{AA} are well described by models which include regeneration
  - $\Upsilon(1S)$ allows for an independent check of models since its regeneration is foreseen to be small at the LHC
  - Further measurements will help in better constraining models and clarifying the scaling of quarkonium production with respect to the colliding energy:
    - Further Pb-Pb measurements during the last part of 2018
    - Increase of statistics → RUN3 continuous readout (50 kHz triggerless vs. 8kHz triggered at 1kHz)
    - Separation of prompt and non-prompt quarkonia → Muon Forward Trackerin RUN3

Grazie per la vostra attenzione!

Backup