EUROPEAN PHYSICAL SOCIETY
CONFERENCE ON HIGH ENERGY PHYSICS
EUROPEAN PHYSICAL SOCIETY HEP2017
5-12 July 2017 – Lido di Venezia, Italy

ALICE

Quarkonium production in nucleus-nucleus collisions with ALICE at the LHC

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Motivation

- Quark matter at extreme energy density form Quark-Gluon Plasma
- Heavy quarks are produced at the early stage of collisions
- Interact with the hot and dense QCD medium
- Quarkonium
  - Suppression due to colour screening
  - (Re)generation during the QGP evolution or at the phase boundary
  - Elliptic flow
- Cold Nuclear Matter effects
  - Nuclear parton shadowing/gluon saturation
  - Parton energy loss
  - Nuclear break-up

EPJ C 76 (2016) 107

PLB 178 (1986) 416

PRC 63 (2001) 054905, PLB 490 (2000) 196

PRC 58 (1998) 1671

See : pPb collisions with ALICE by Biswarup Paul

A Large Ion Collider Experiment

ZDC Identification of EM interactions

Dipole Magnet

Charge particle in mid-rapidity

TPC

Trigger on muon tracks

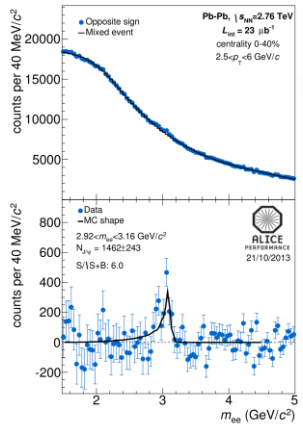
Muon Trigger

ITS

Vertex determination

V0

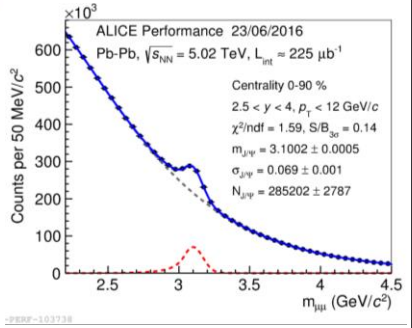
Minbias trigger, Centrality estimator



e^+ e^-

μ^-

μ^+

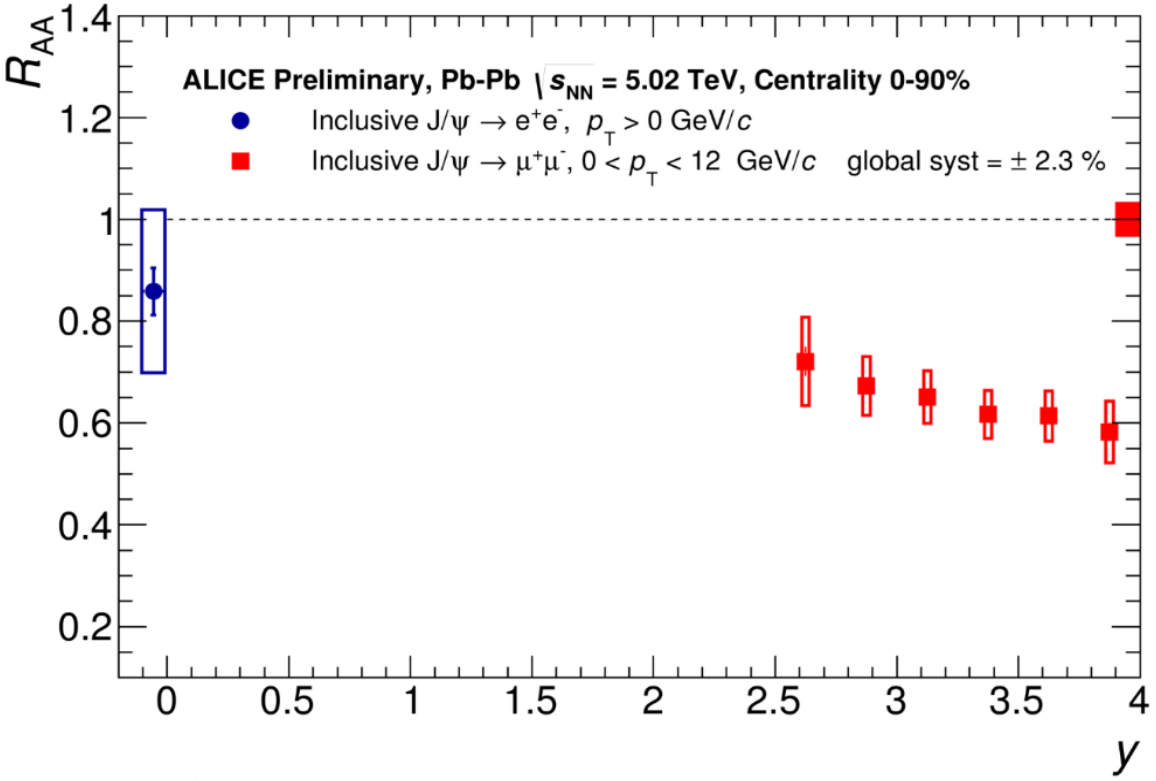


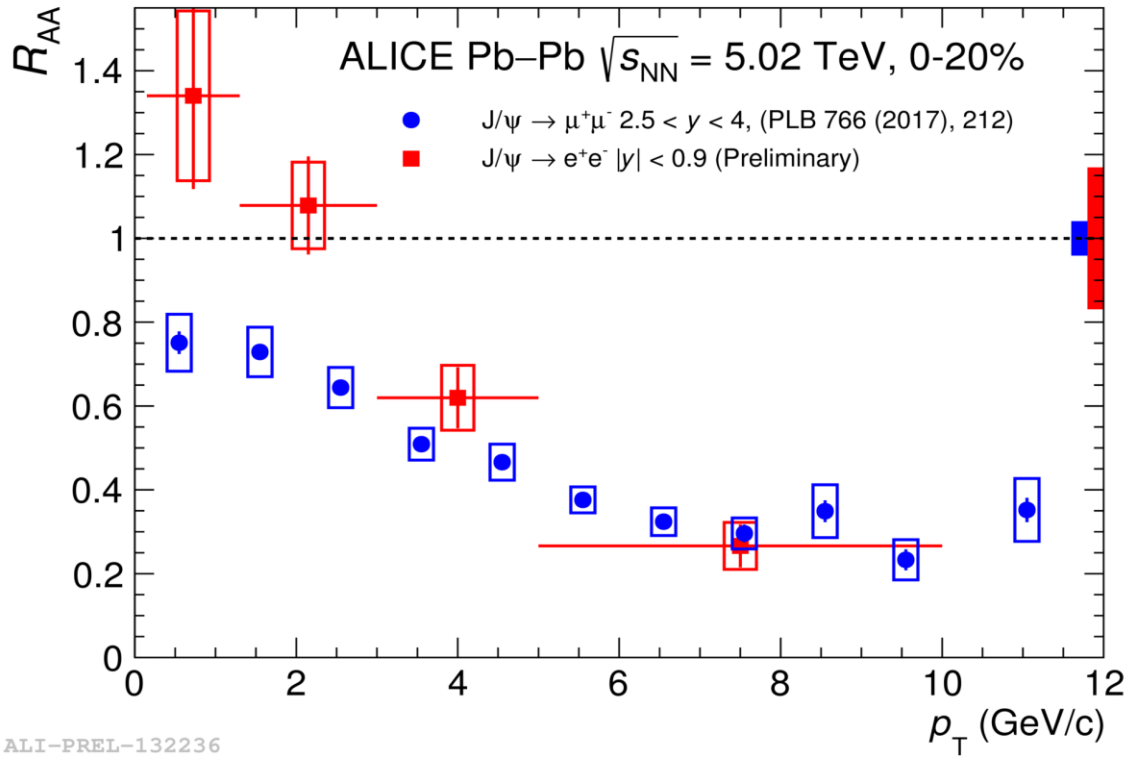
Muon Tracker

Muons at forward rapidity

J/ψ R_{AA} in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

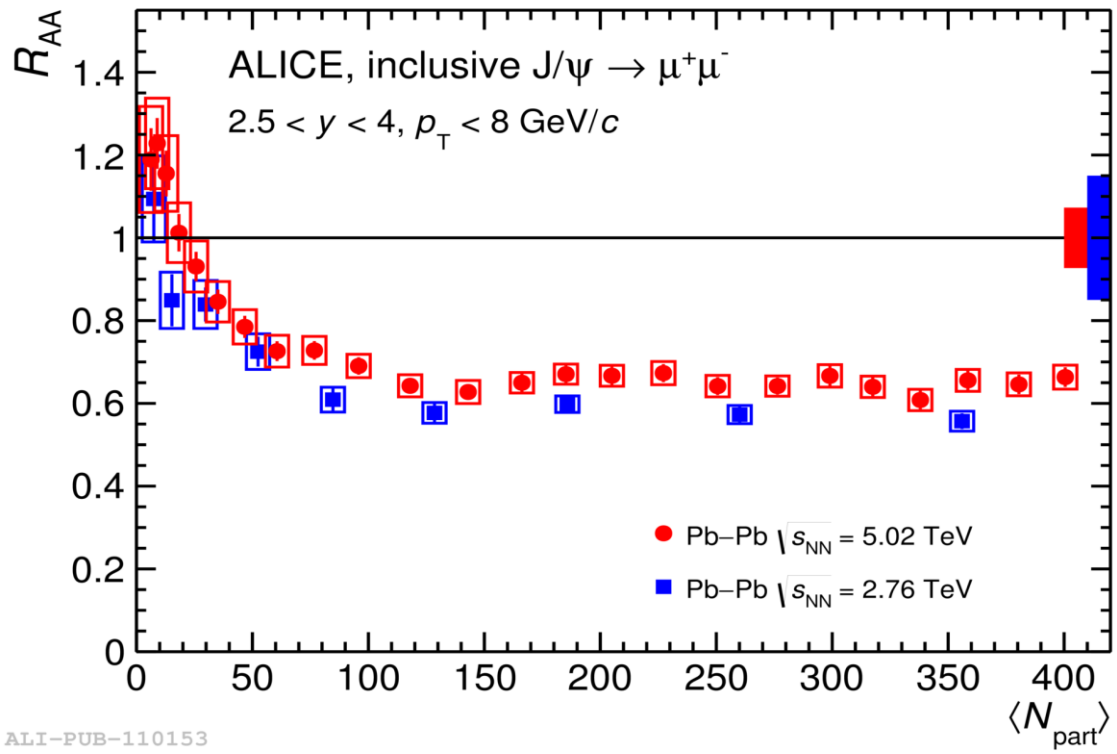
$$R_{AA} = \frac{Y_{AA}}{\langle T_{AA} \rangle \sigma_{pp}}$$

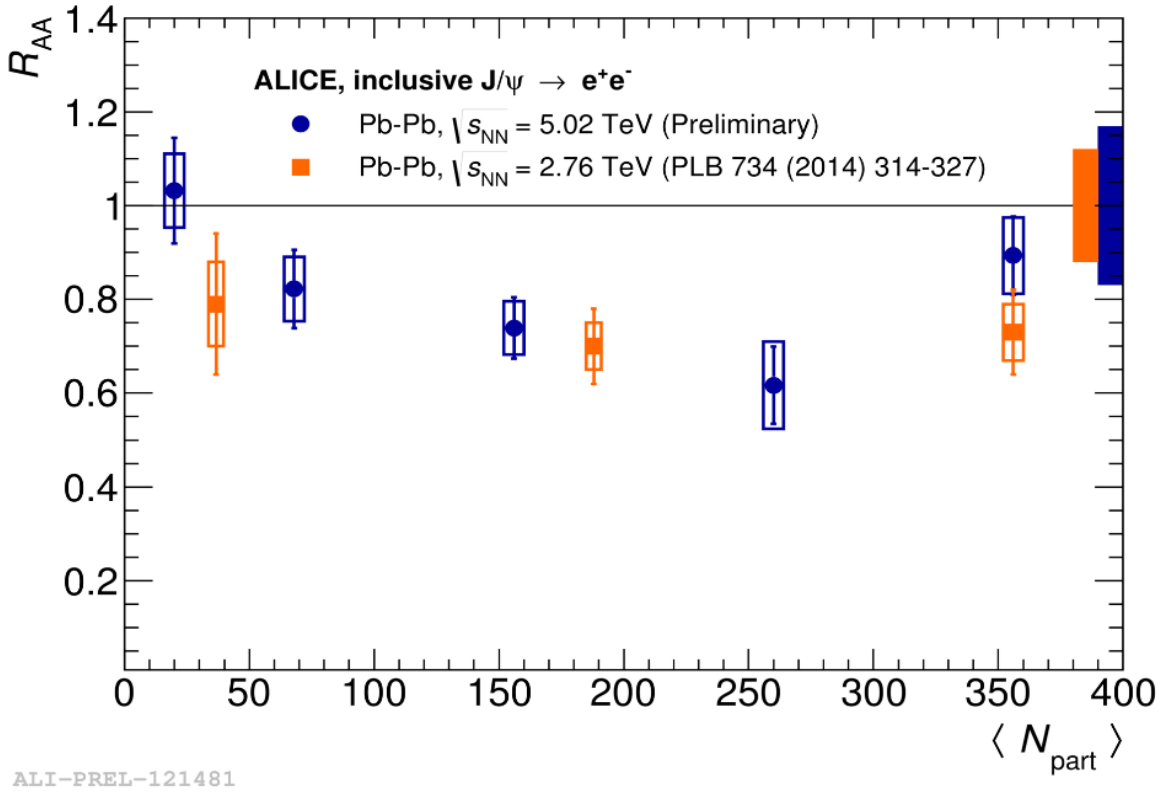




- R_{AA} changes as a function of rapidity
- Hint of weaker suppression at mid-rapidity as compared to forward rapidity
- The J/ψ is more suppressed in high-p_T than low-p_T region

J/ψ R_{AA} in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

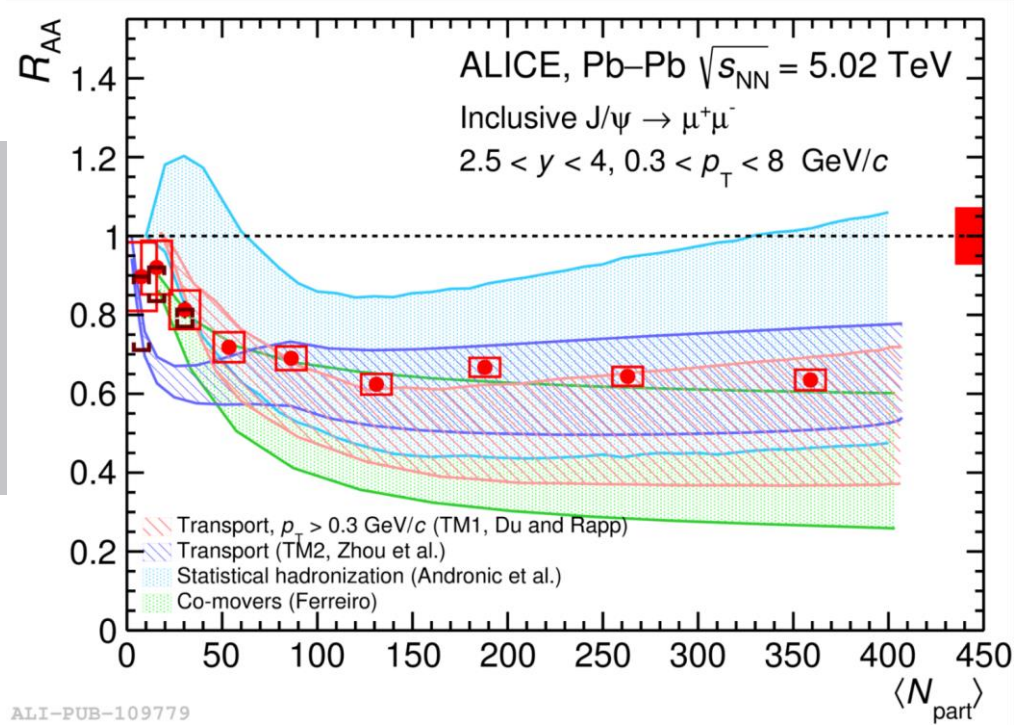


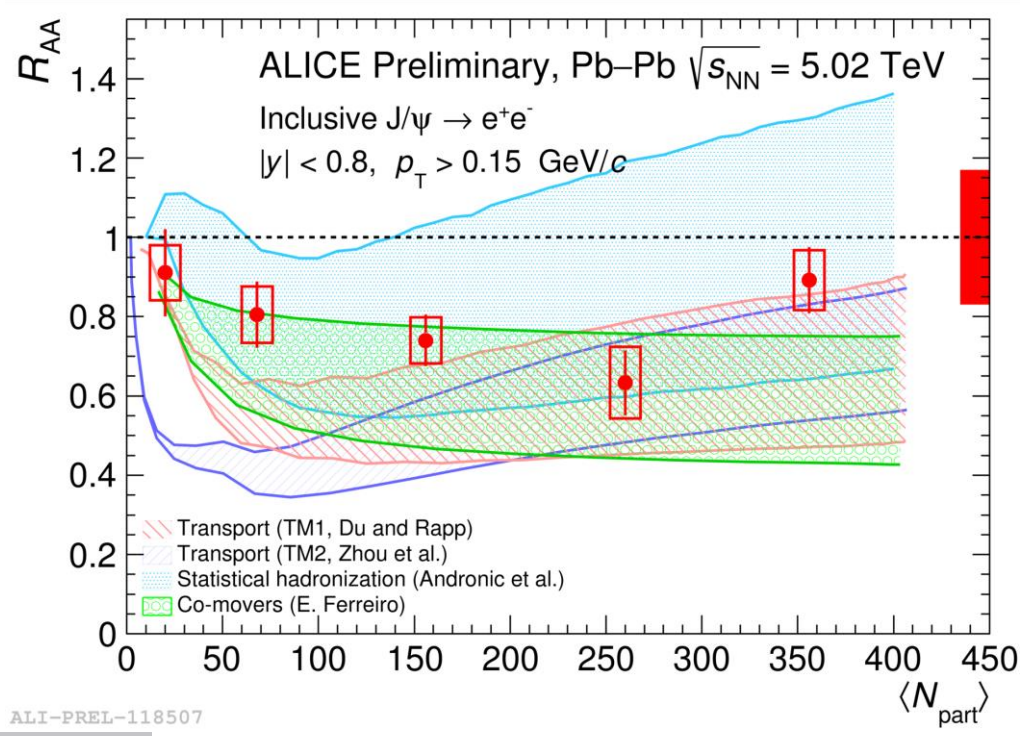


PLB 734 (2014) 314, PLB 766 (2017) 212

- A suppression from peripheral to central collisions is observed, with a flat pattern for $N_{part} > 100$
- The new results of Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV show similar trend with higher precision
- New measurements are compatible with Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV, no significant deviation at forward rapidity (left) and mid-rapidity (right).

J/ψ R_{AA} in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV





PLB 766 (2017) 212

[The brackets represent the contribution for p_T > 0.3 GeV/c]

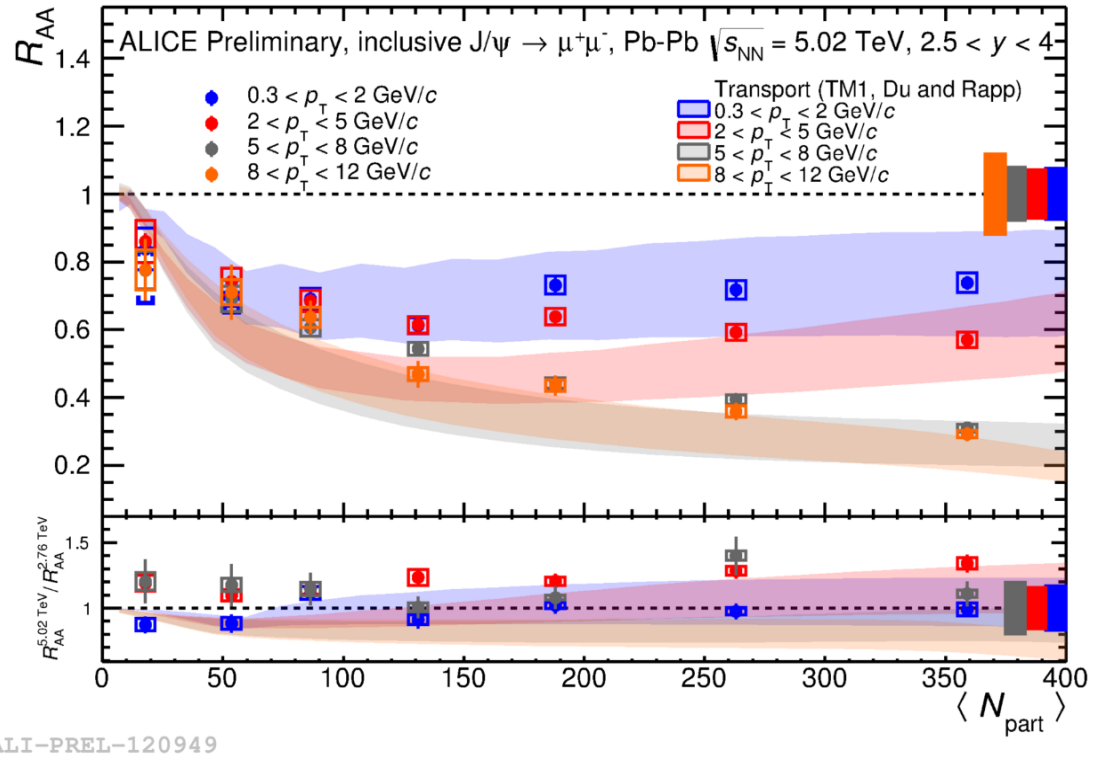
PRL 116 (2016) 222301

Statistical Hadronization : [primodial suppressed + $\bar{c}c$ phase boundary]
Co-movers interaction model : [dissociation co-moving parton + gain term]
Transport model (TM1) : [continuous $\bar{c}c$ dissociation and (re)generation]
Transport model (TM2) : [continuous $\bar{c}c$ dissociation and (re)generation]

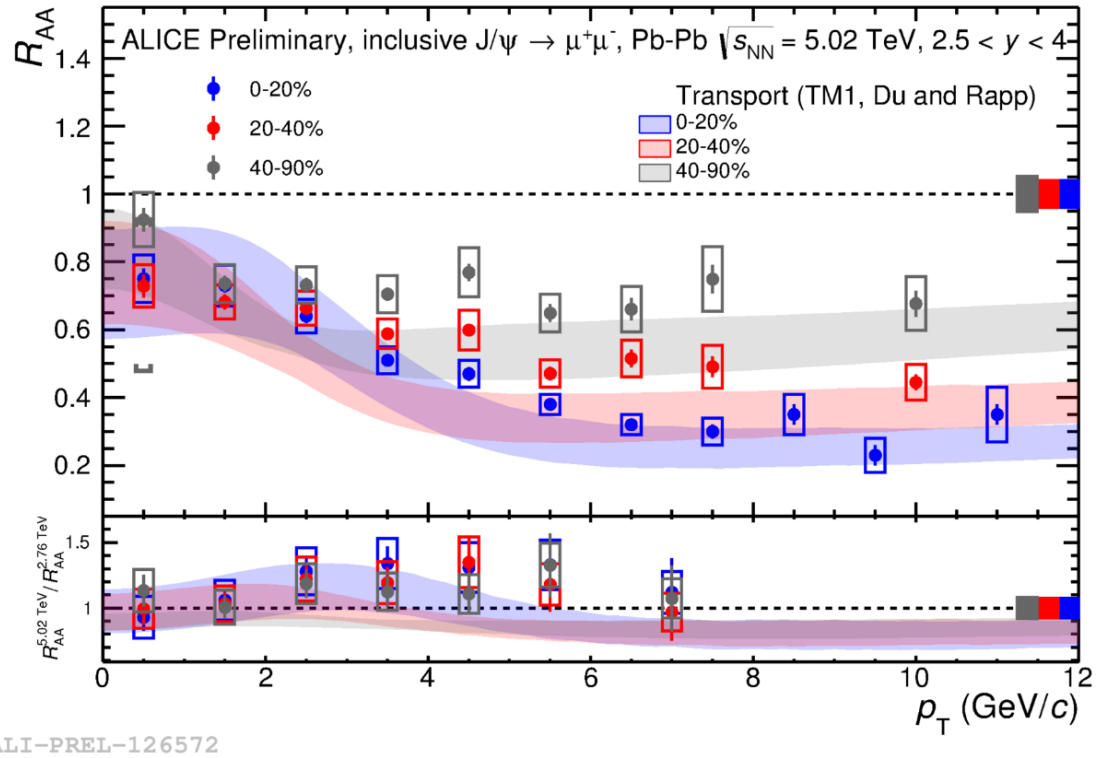
NPA 904-5 (2013) 535c
PLB 731 (2014) 57
NPA 859 (2011) 114
PRC 89 no.5, 459 (2014) 054911

Data are more precise than the model predictions

Differential measurement of J/ψ R_{AA} vs $\langle N_{part} \rangle$, p_T



ALI-PREL-120949



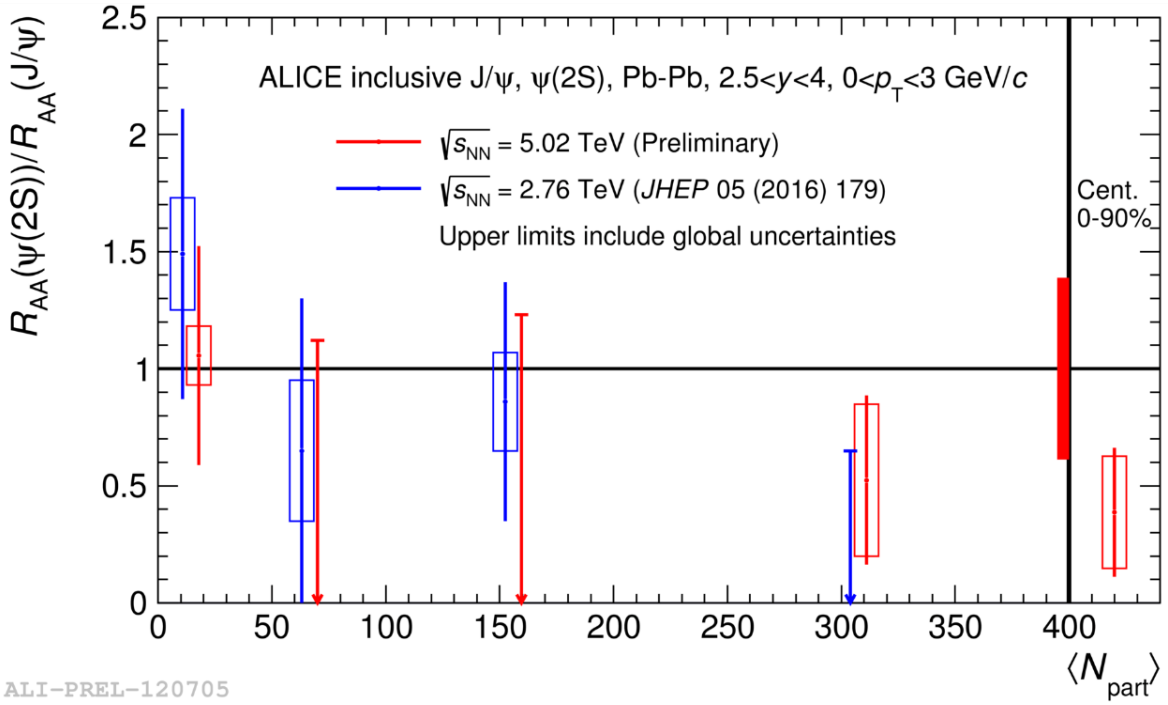
ALI-PREL-126572

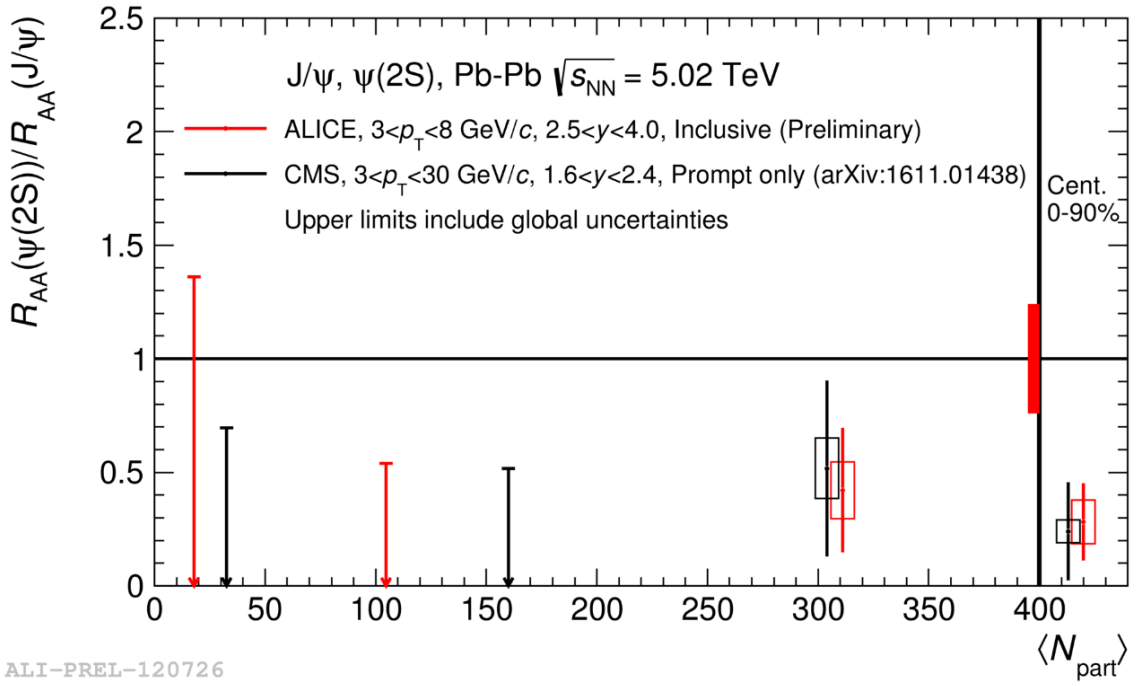
- The suppression is smaller at low-p_T for most central collision

- No centrality dependence for the lowest p_T bin
- R_{AA} decreases by 60-80% at large p_T and for most central collision

- TM1 prediction agrees with data within uncertainties for most data points
- The observed features are expected in a regeneration scenario

Ratio of R_{AA} of ψ(2S) to J/ψ in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV





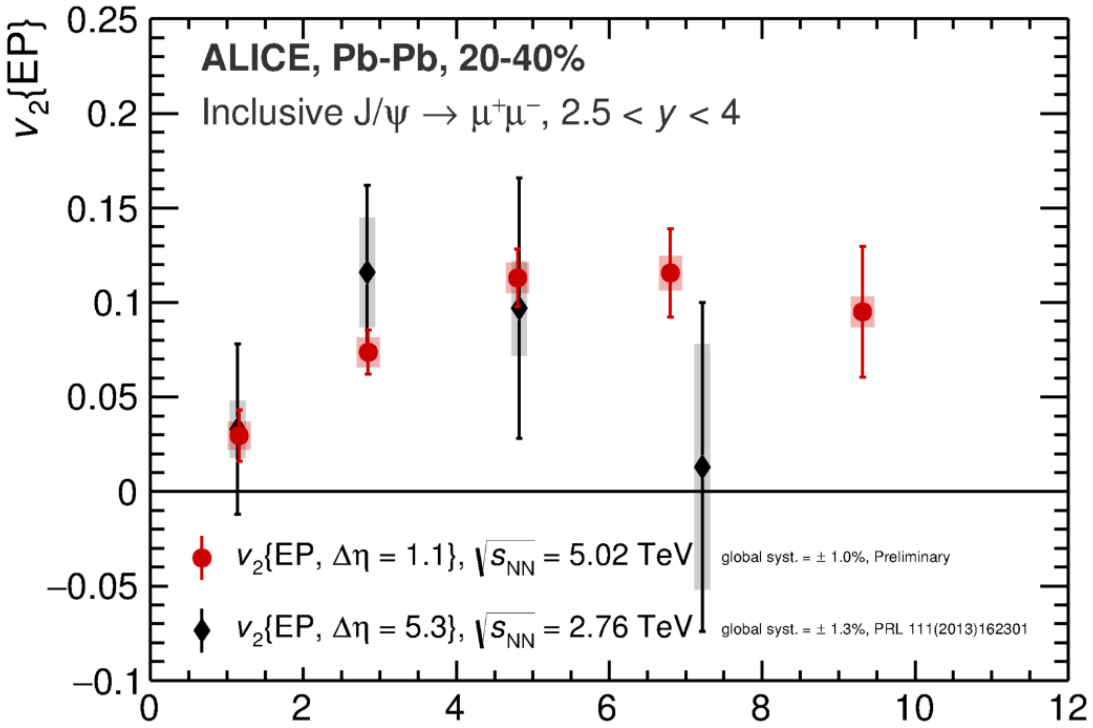
- The signal extraction of ψ(2S) is challenging and ALICE will profit from the upgrade

  See : ALICE forward rapidity upgrades talk by Maciej Slupeski

- The ratio of R_{AA} of ψ(2S) to J/ψ in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV is consistent with the 2.76 TeV results

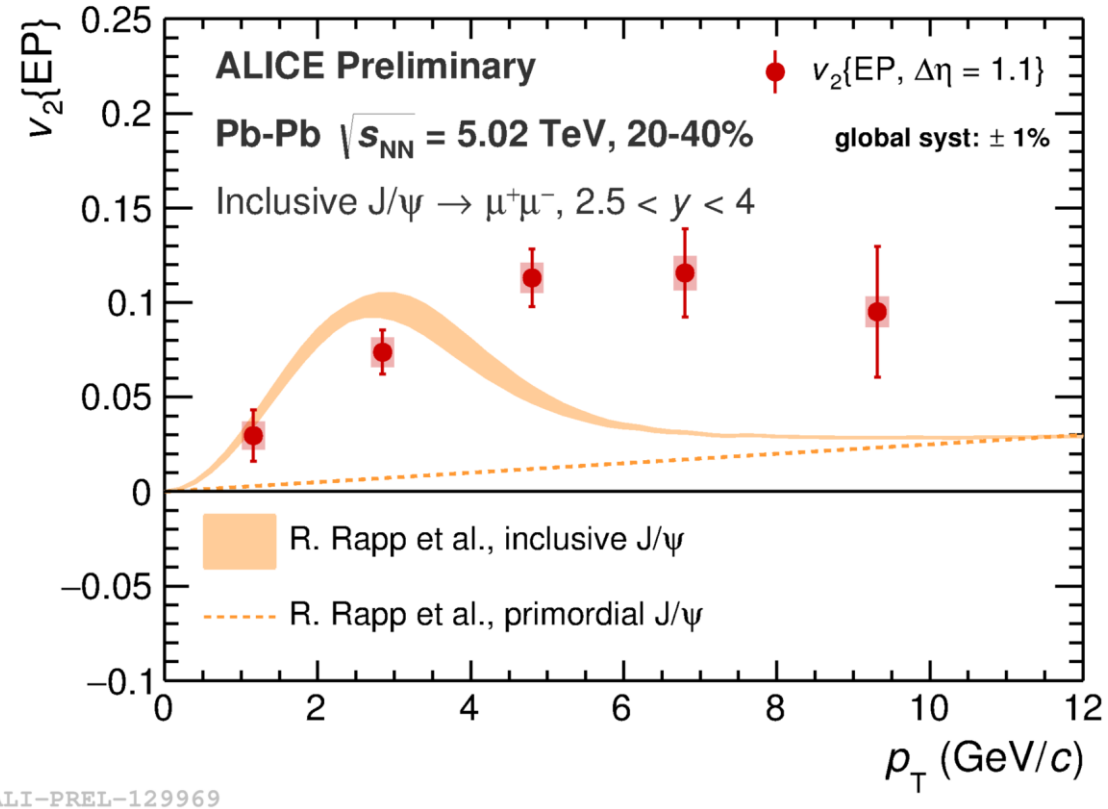
- ALICE and CMS measurements are in agreement within uncertainties

J/ψ v_2 in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV



ALI-PREL-118883

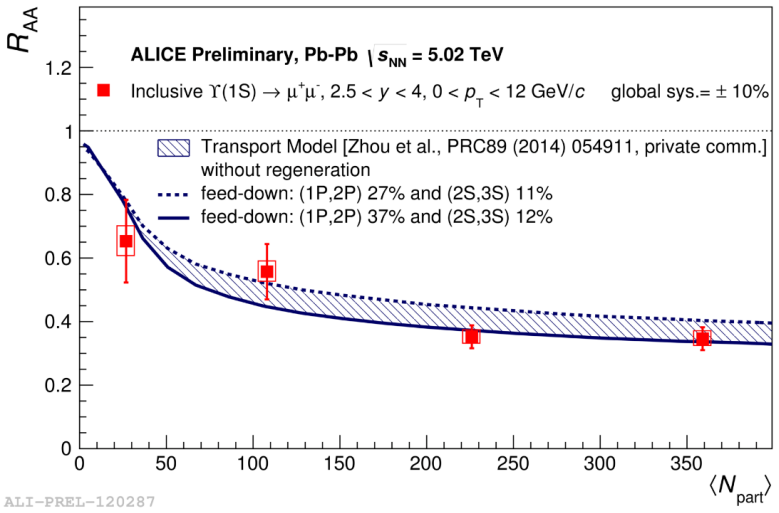
PRL 111 (2013) 162301

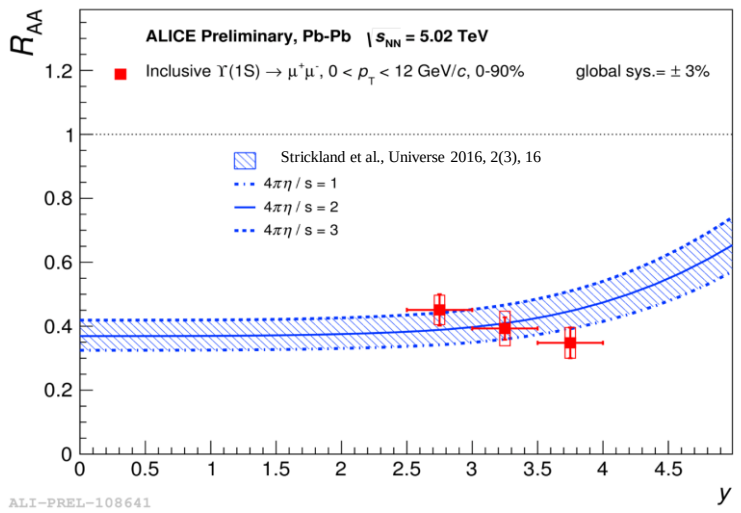


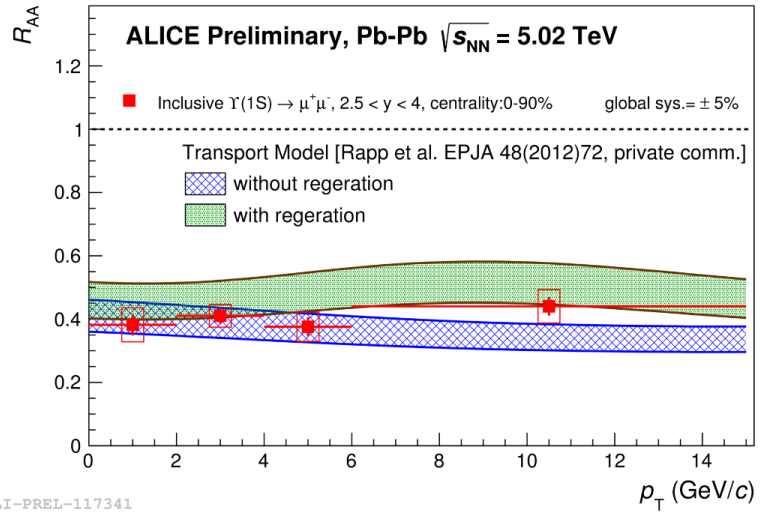
ALI-PREL-129969

- The observed v_2 suggests that J/ψ are formed by flowing charm quarks
- The hint of non-zero v_2 in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.72 TeV is now confirmed at $\sqrt{s_{NN}}$ = 5.02 TeV [7.4σ for p_T= 4-6 GeV/c]
- The transport model predictions are not able to describe the data in the high-p_T region

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







- Transport models by Zhou et al. PRC 89 (2014) 05911 (TM2) and Rapp et al. EPJA 48 (2012) 72 (TM1) qualitatively reproduce the centrality dependence.
- The anisotropic hydrodynamic model by Strickland et al. Universe 2016, 2(3), 16 can describe the rapidity dependence of R_{AA} , but hint of different trend is observed
- The p_T dependence of $\Upsilon(1S)$ R_{AA} in Pb-Pb collisions is described by the transport model and anisotropic hydrodynamics model

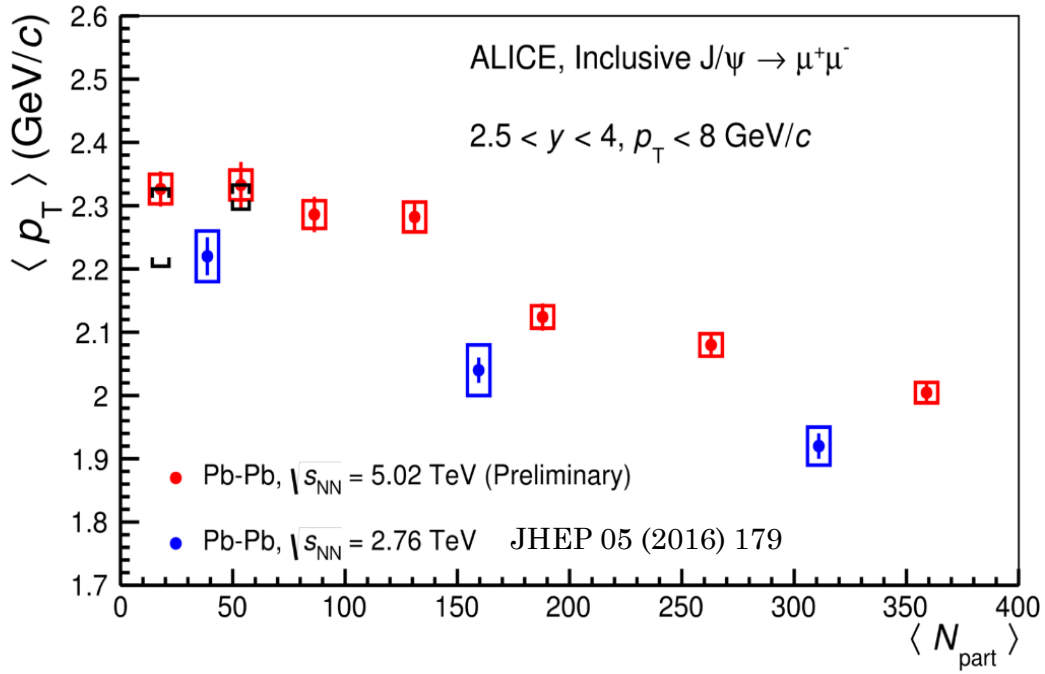
- Transport model, with or without (re)generation effect can describe the data
- The ratio of R_{AA} for $\Upsilon(2S)$ to $\Upsilon(1S)$ is 0.26 ± 0.12 (stat.) ± 0.06 (sys.) → hint of sequential suppression
- Suppression of direct $\Upsilon(1S)$?
  - R_{AA} of $\Upsilon(1S)$ = 0.40 ± 0.03 (stat.) ± 0.04 (sys.) → Also observed in CMS data [CMS PAS HIN-16-023]

Summary

- Charmonium
  - Interplay of two main mechanisms : suppression and (re)generation
  - Higher states ψ(2S) are more strongly suppressed than ground state J/ψ
  - Observation of non-zero v_2 with higher precision
- Bottomonium
  - Suppression plays dominant role with negligible (re)generation
  - Suppression is stronger for states, $\Upsilon(2S)$, with lower binding energy

More ALICE quarkonium results : Biswarup Paul and Jana Crkovska
Upgrade talk on MFT as forward rapidity detector: Maciej Slupecki

J/ψ $\langle p_T \rangle$ and r_{AA} as a function of centrality



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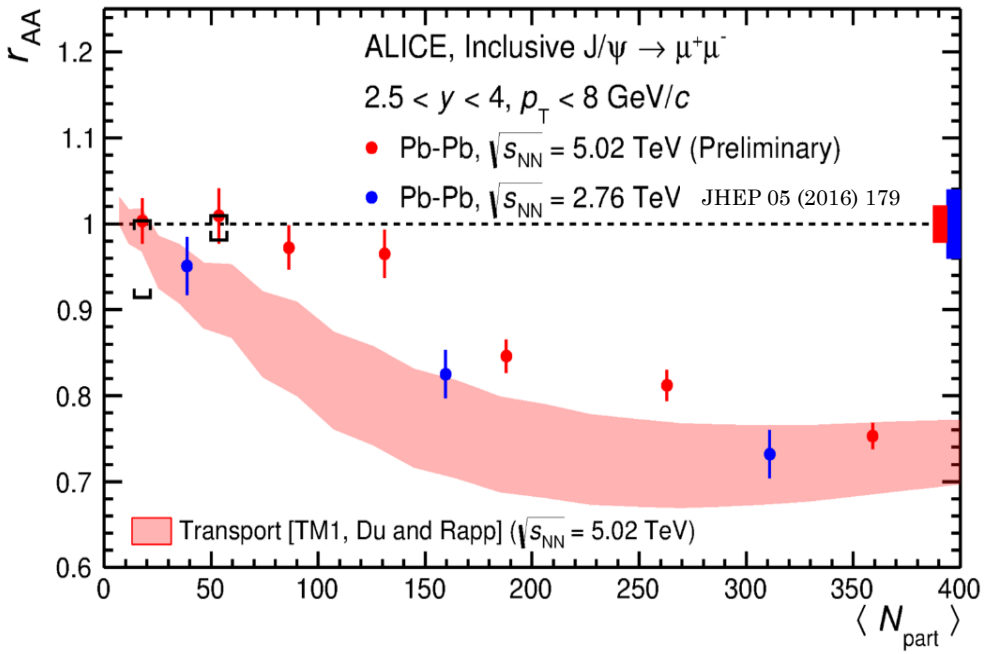


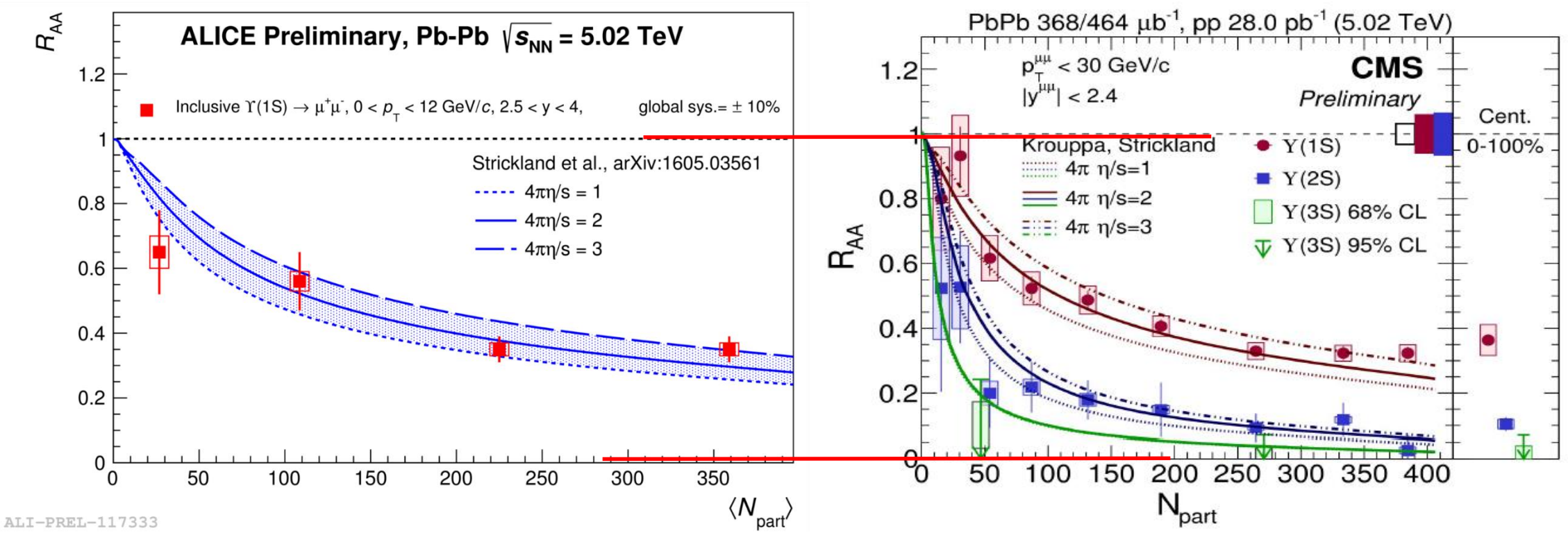
ALI-PREL-120574

- <p_T> decreases with increasing centrality → supports (re)generation scenario

$$r_{\mathrm{AA}} = \frac{\langle p_{\mathrm{T}}^2 \rangle_{\mathrm{AA}}}{\langle p_{\mathrm{T}}^2 \rangle_{\mathrm{pp}}}$$

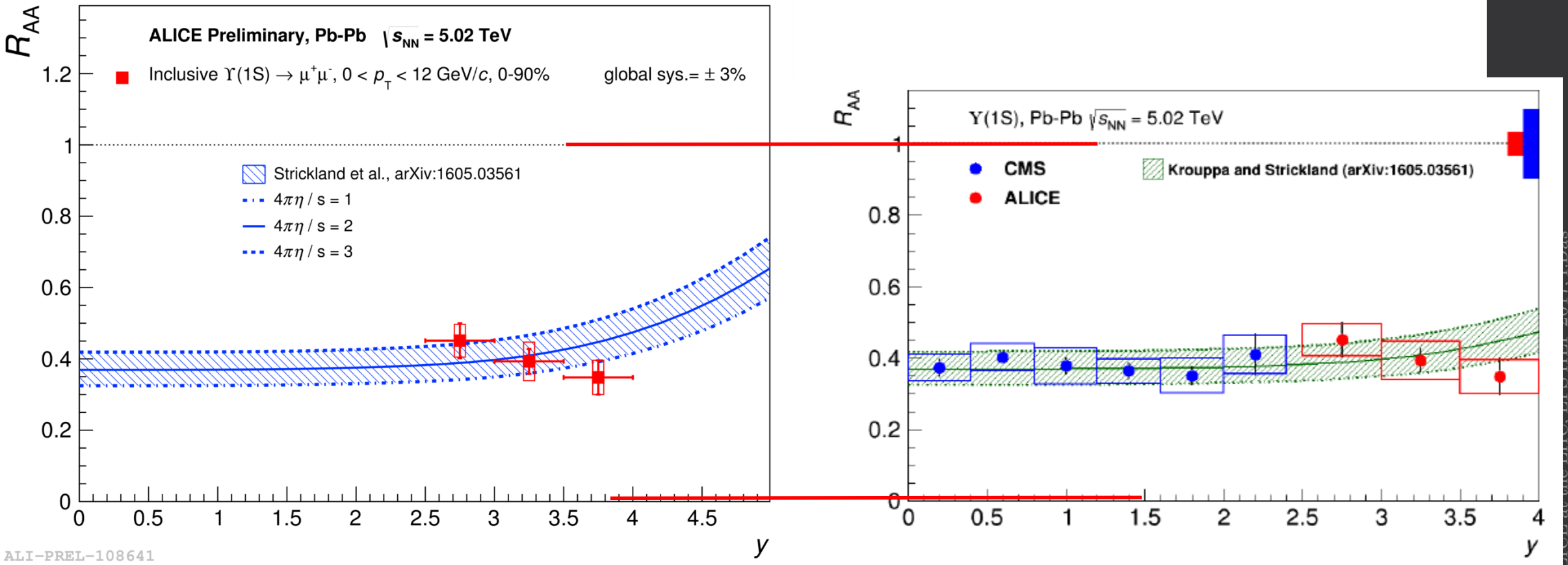
- TM1 prediction can not reproduce the r_{AA} result in semi-central collisions

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



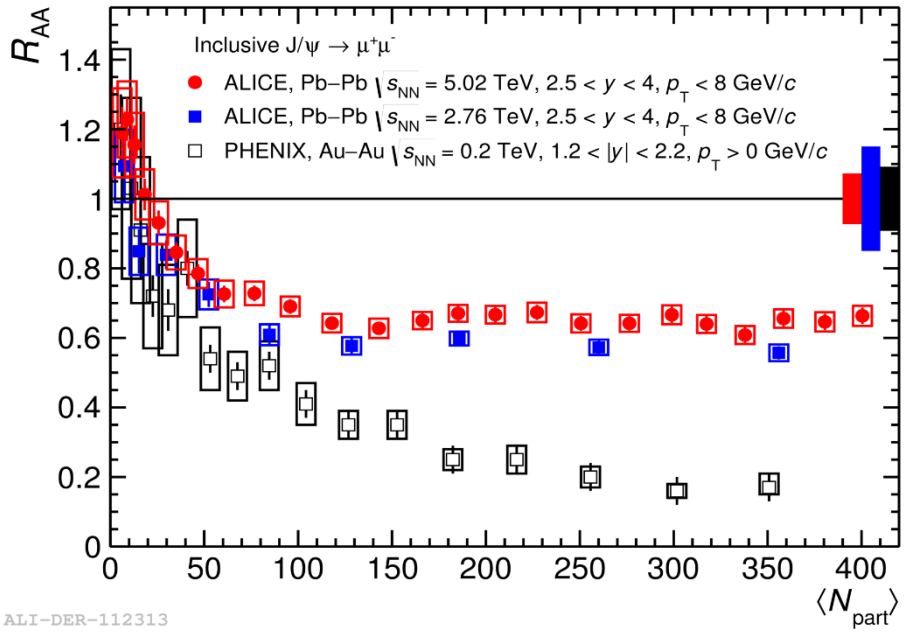
- The anisotropic hydrodynamics model which does not have the (re)generation component and CNM effect describe the data within η/s uncertainties.

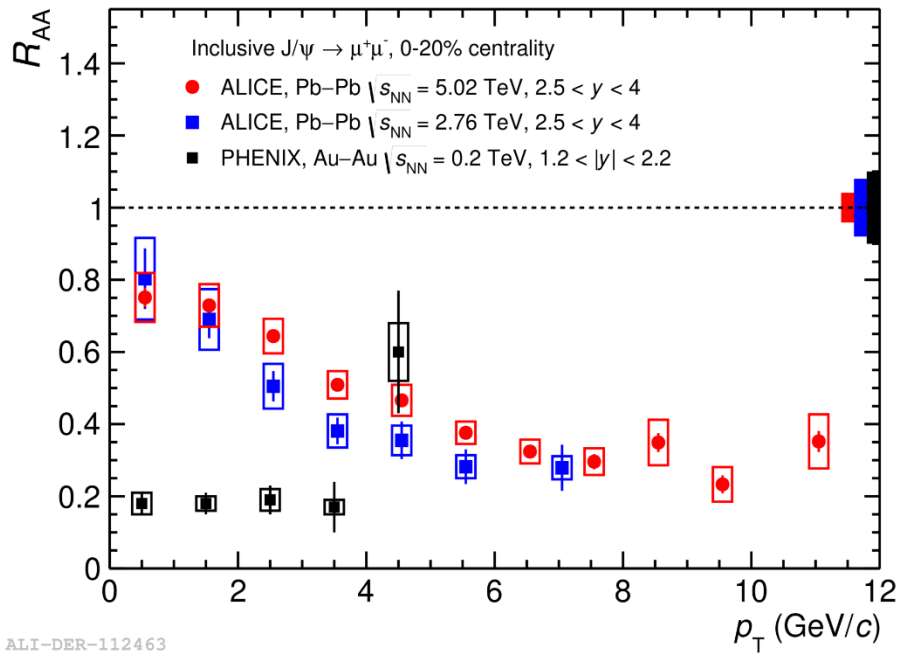
$\Upsilon(1S)$ R_{AA} in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV



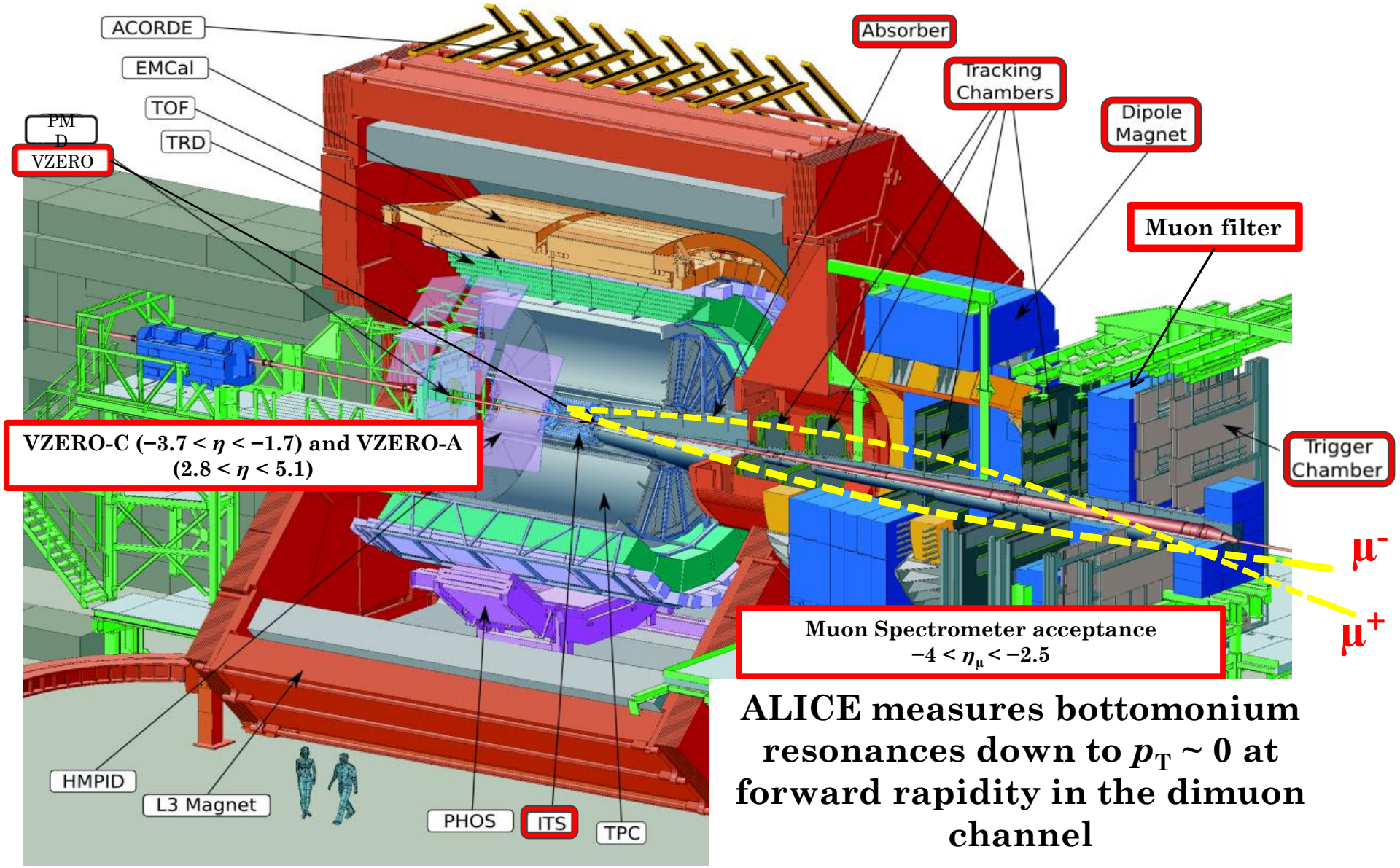
The anisotropic hydrodynamics model can describe the rapidity dependence of R_{AA} , but hint of different trend is visible

J/ψ R_{AA} in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV





- Most precise result in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV at forward rapidity
- New results are compatible with Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
- Larger R_{AA} in central collisions and it increase at low-p_T
- Suppression effect are visible at RHIC where as LHC shows the interplay of suppression and (re)generation

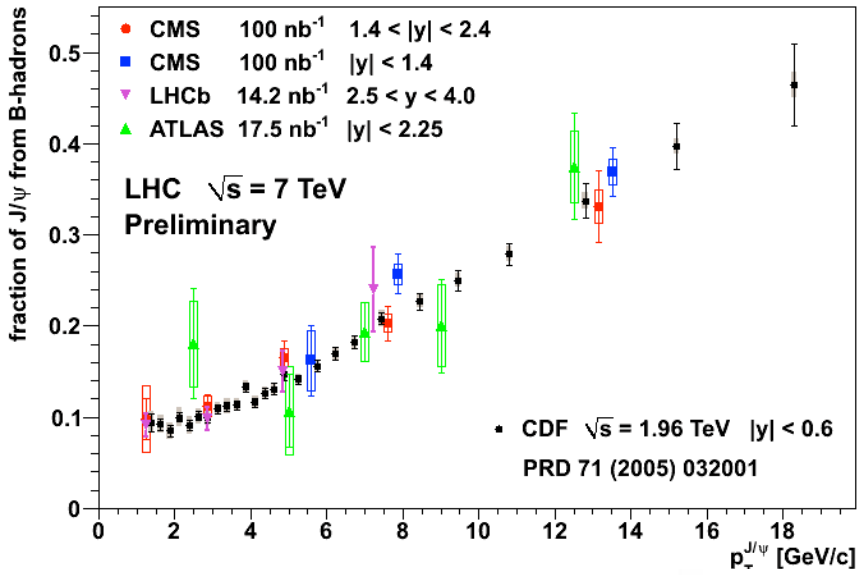


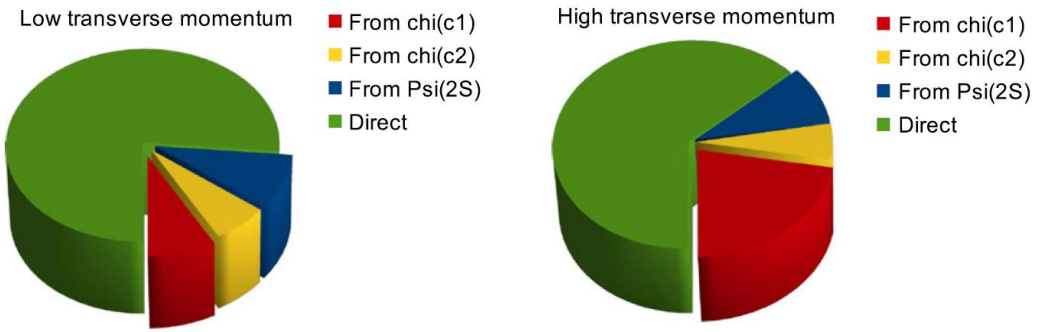
ALICE measures bottomonium resonances down to $p_T \sim 0$ at forward rapidity in the dimuon channel

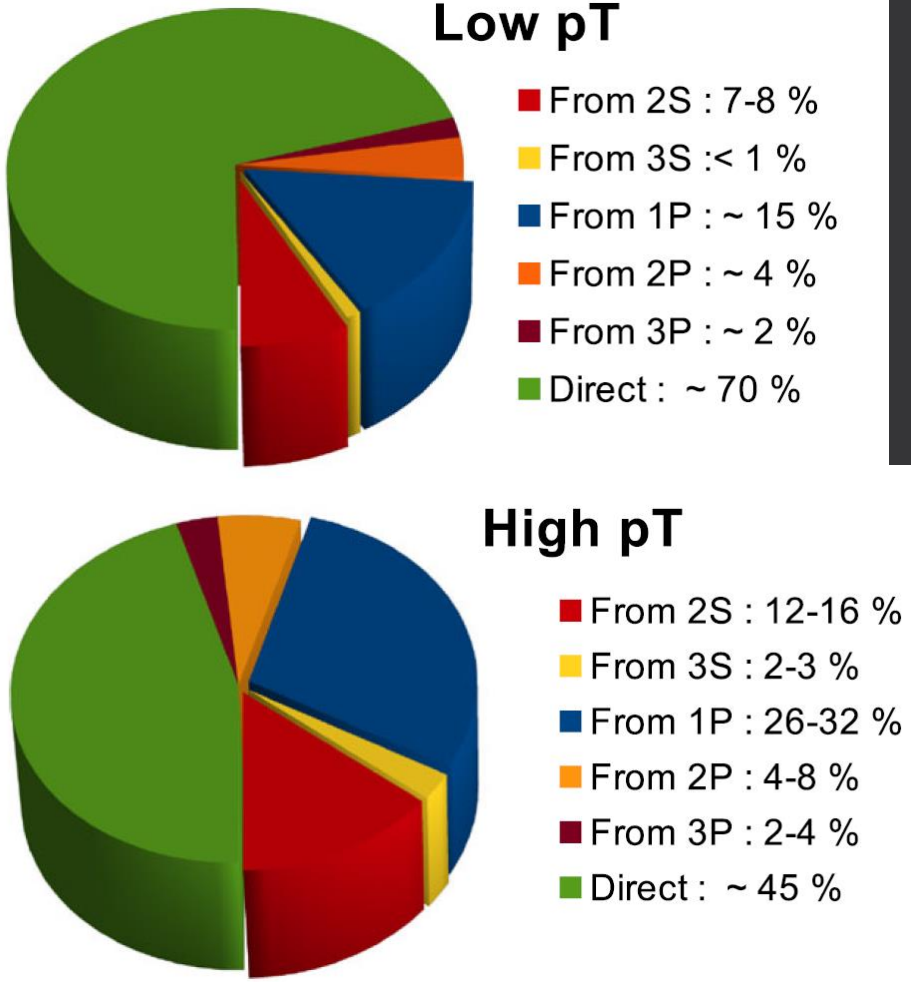
Prompt, non-prompt and feed-down

Charmonium [A. Andronic et al, EPJC 76 (2016) 107] **Bottomonium**

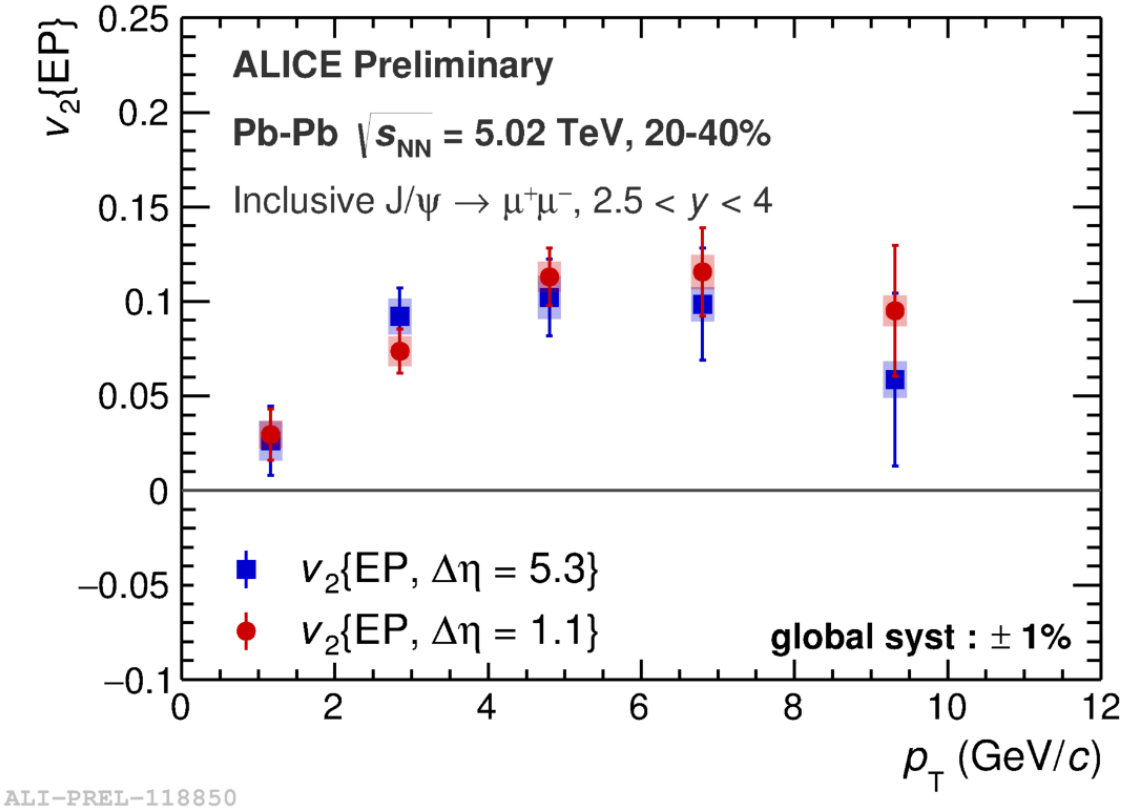
In addition to (10-30)% B-decay production







J/ψ v_2 in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV



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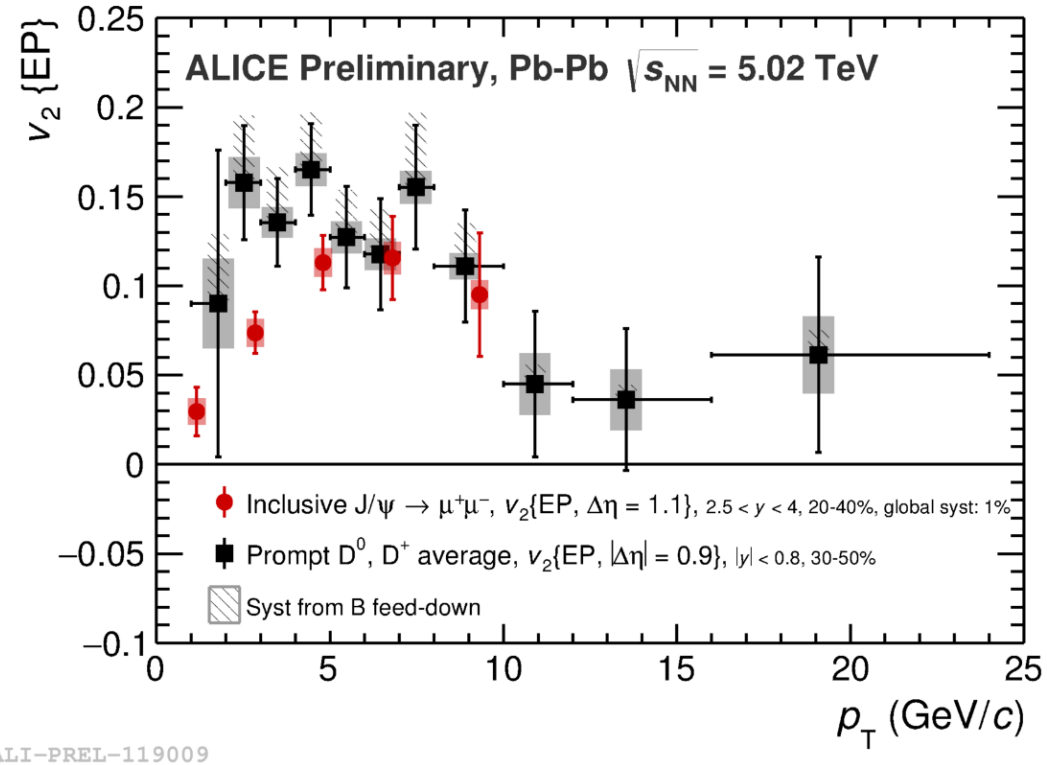

ALI-PREL-119009

- Most precise measurement of elliptic flow of charmonium
- The prompt open-charm mesons also shows non-zero elliptic flow