Charmonium production in Pb-Pb collisions with ALICE at the LHC

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for the ALICE Collaboration

Quark Matter 2015 – Tuesday, September 29 2015

Introduction

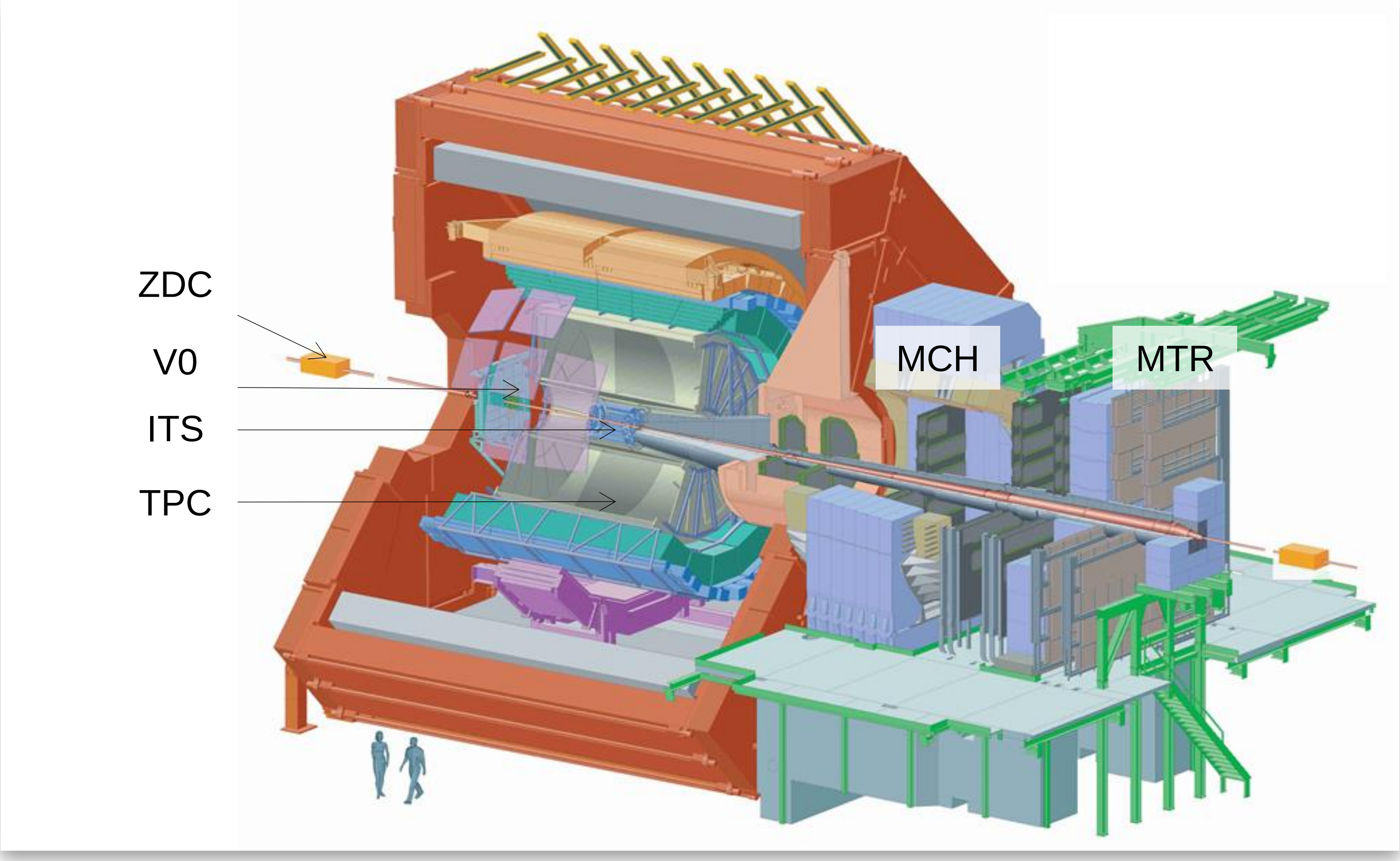
Charmonia (J/ψ, ψ(2S)) as a probe of deconfinement in Heavy Ion (HI) collisions:

- suppression via color screening Matsui, Satz, PLB 178 (1986) 416
- statistical recombination at phase boundary Braun-Munzinger, Stachel, PLB 490 (2000) 196
- dissociation and recombination in the QGP Thews et. al., PRC 63 (2001) 054905

Complications:

- cold nuclear matter effects also alter charmonium production in HI, even without a QGP (shadowing, energy loss) M. Leoncino, Monday, Quarkonia I
- inclusive production of J/ψ has contributions from higher mass resonances decay (~25%) and *b*-hadrons decay (~10%)

Charmonium measurements in ALICE



Charmonia are measured down to zero p_T

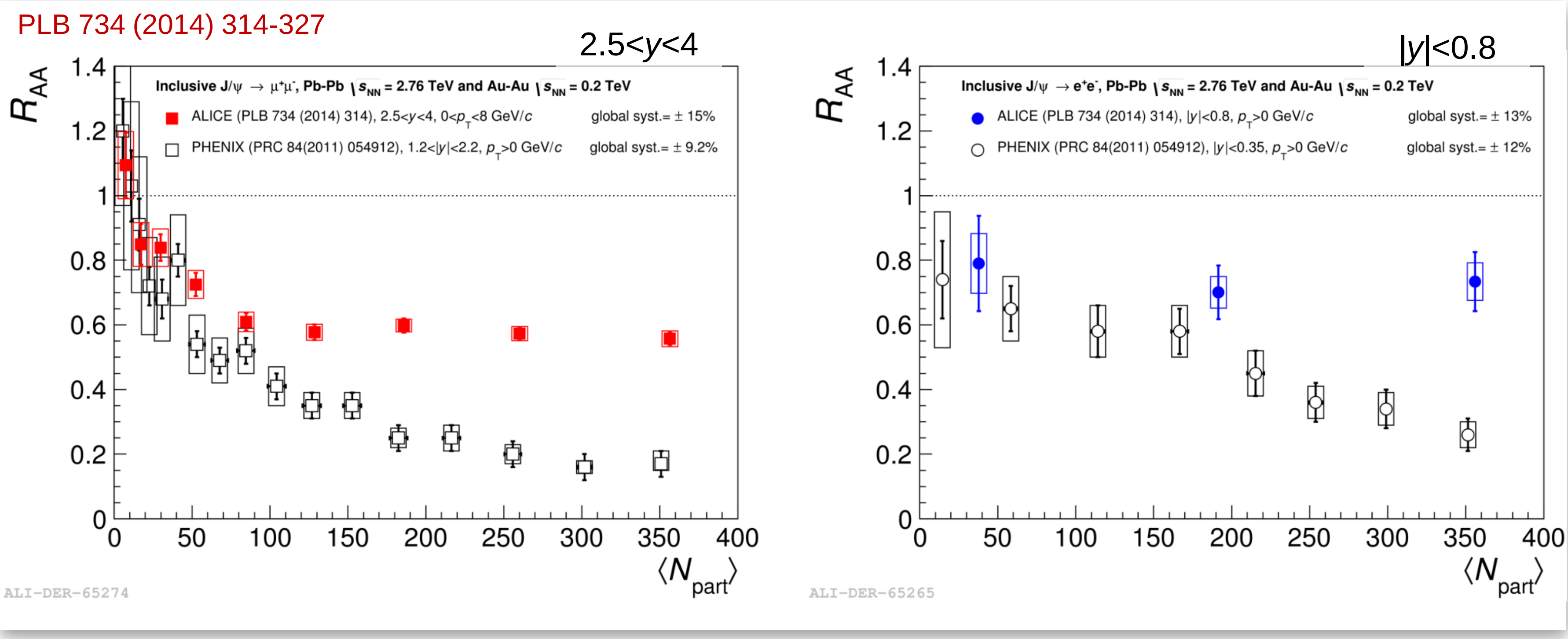
- at forward rapidity ($2.5<y_{lab}<4$) in the $\mu^+\mu^-$ channel, using MTR, MCH and ITS
- at mid rapidity ($|y_{lab}|<0.9$) in the e^+e^- channel, using TPC and ITS

Trigger system uses V0, ITS and MTR

Centrality uses V0, ZDC

Status at last Quark Matter

J/ψ nuclear modification factor R_{AA} at forward and mid-rapidity vs centrality, in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV, compared to RHIC ($\sqrt{s_{NN}}$ = 0.2 TeV)



A suppression is observed for central collisions

It is less pronounced at LHC than at RHIC, and shows no dependence on centrality for N_{part} > 70

A few words about models

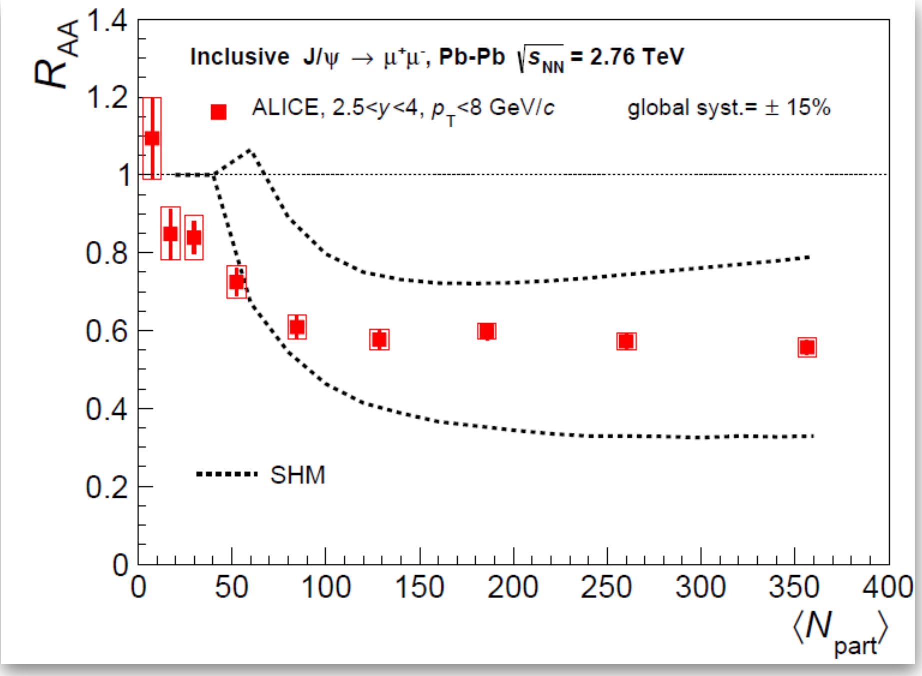
Statistical Hadronization Model (SHM)

Andronic et. al., JPG 38 (2011) 124081

Primordial charmonia are completely suppressed in the QGP

Charmonium production occurs at phase boundary by the statistical hadronization of charm quarks

arXiv:1506.08804 [nucl-ex]



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Transport Models (TM)

TM1: Zhao et. al., NPA 859 (2011) 114–125,
TM2: Zhou et. al., PRC 89 (2014) 054911

Continuous charmonium dissociation and regeneration in the QGP, described by a rate equation

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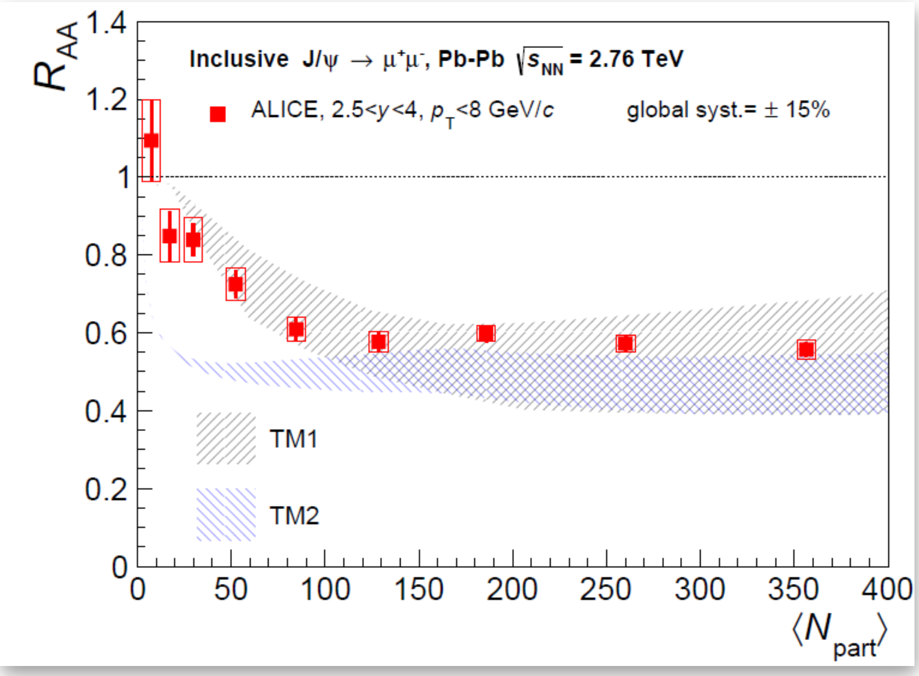

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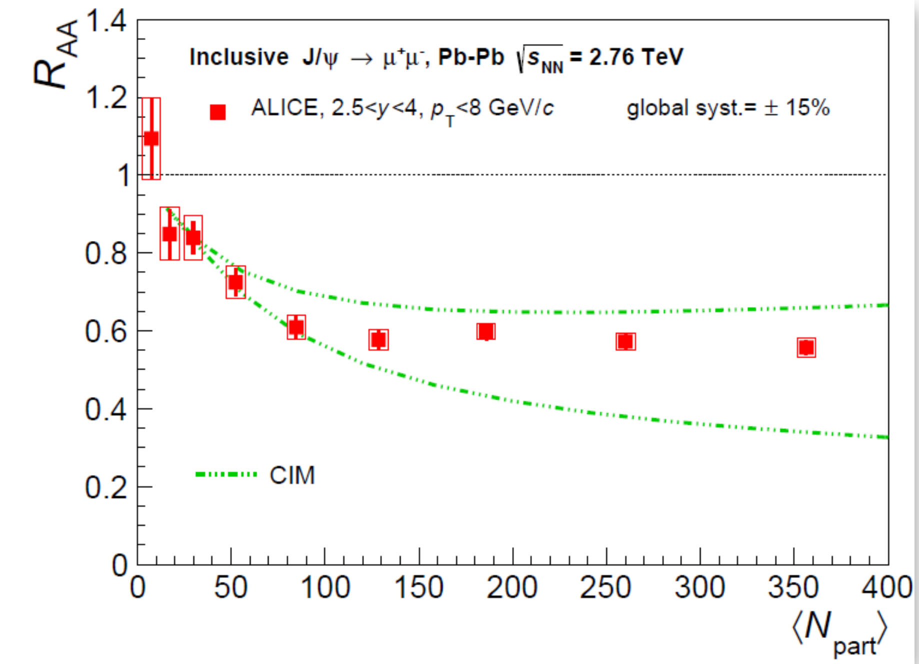

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Comover Interaction Model (CIM) Ferreiro, PLB 731 (2014) 57

Dissociation occurs by interaction with a dense co-moving partonic medium

Regeneration is added as a gain term to the comover dissociation

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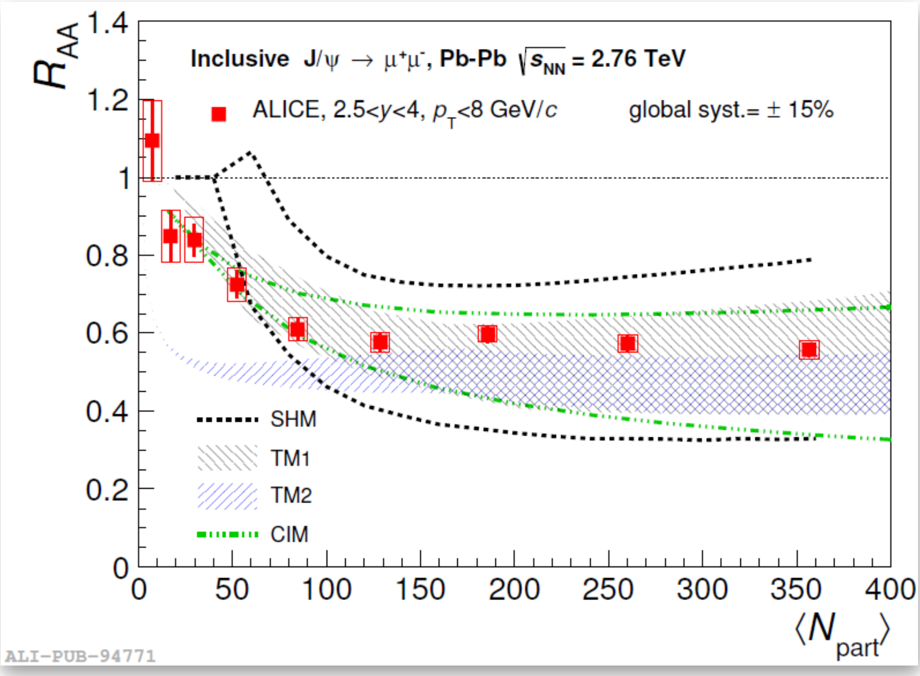

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Dissociation occurs by interaction with a dense co-moving partonic medium
Regeneration is added as a gain term to the comover dissociation

All models require a (re)combination component to describe the data
All models also include cold nuclear matter effects (shadowing)

New published results

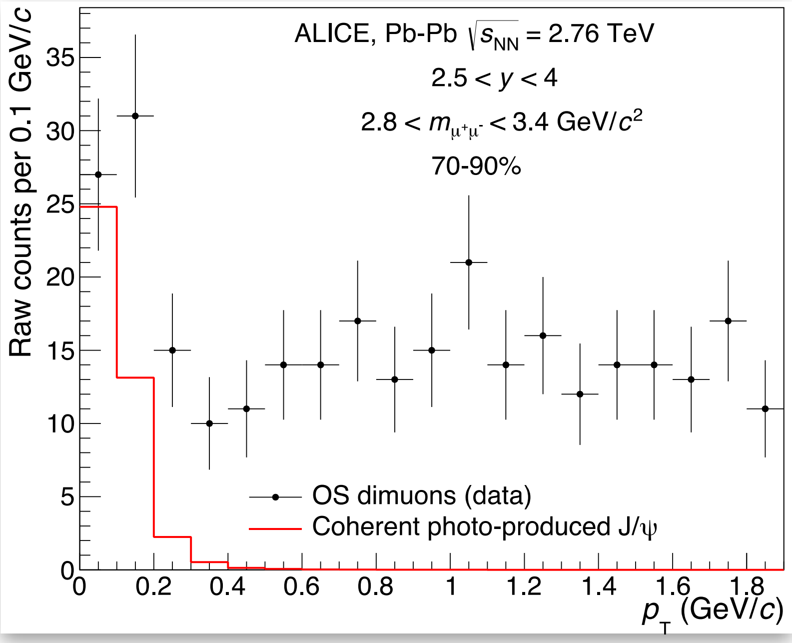
- Double differential studies of J/ψ R_{AA} vs centrality and p_T
- Mean transverse momentum (square) measurements
- Prompt and non-prompt J/ψ separation
- ψ(2S) R_{AA} at forward rapidity

arXiv:1506.08804 [nucl-ex]
JHEP 07 (2015) 051

A word on J/ψ photo-production

An excess of the J/ψ production has been observed at forward rapidity, low-p_T (p_T < 300 MeV/c) and in peripheral collisions

CERN-PH-EP-2015-268



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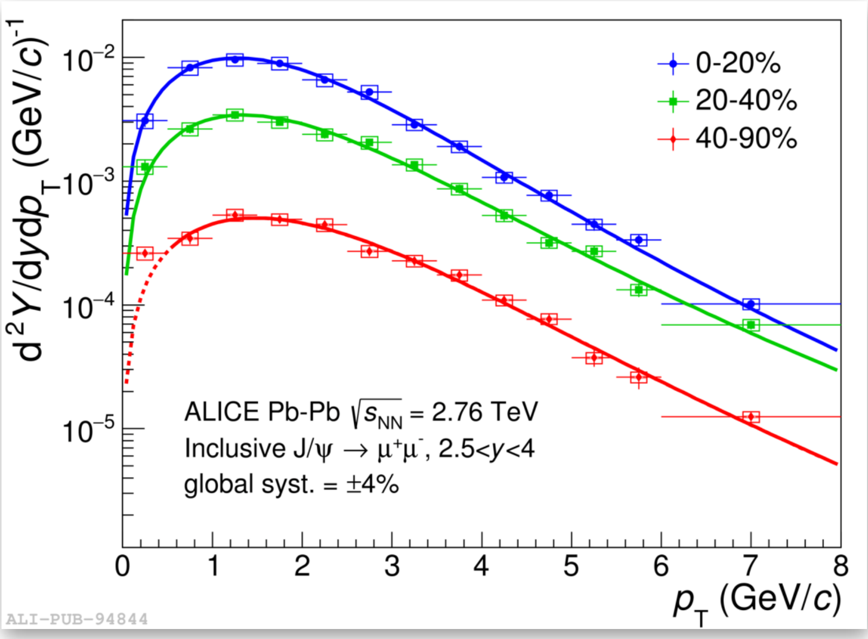


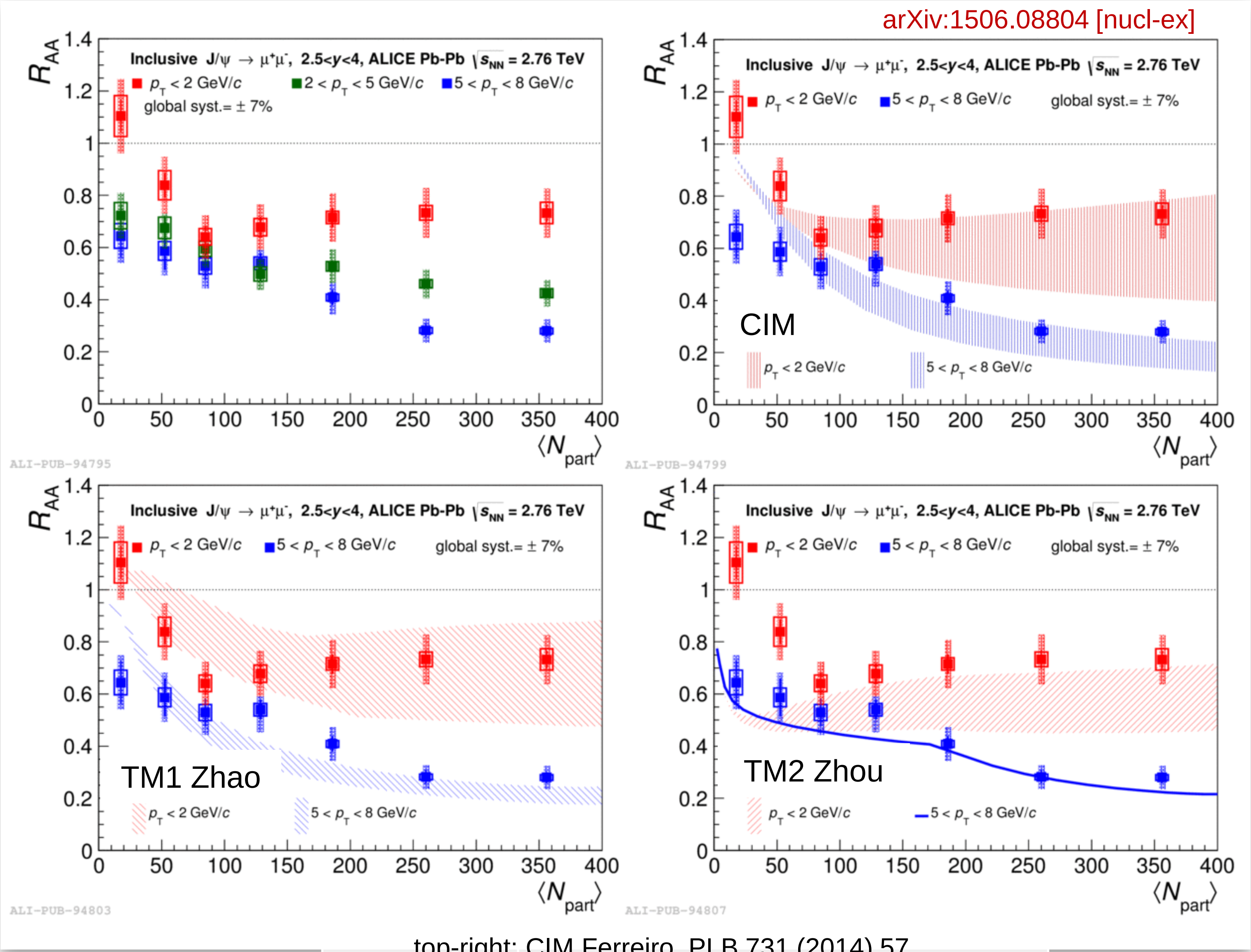
It is discussed in detail in the talk from G. Martinez, Wednesday, Quarkonia IV

It could originate from coherent J/ψ photo-production, as also measured in ultra-peripheral collisions (b>2r) PLB 718 (2013) 1273, EPJC 73 (2013) 11

It must be properly accounted for (or removed) when interpreting the results on R_{AA} or $\langle p_T \rangle$

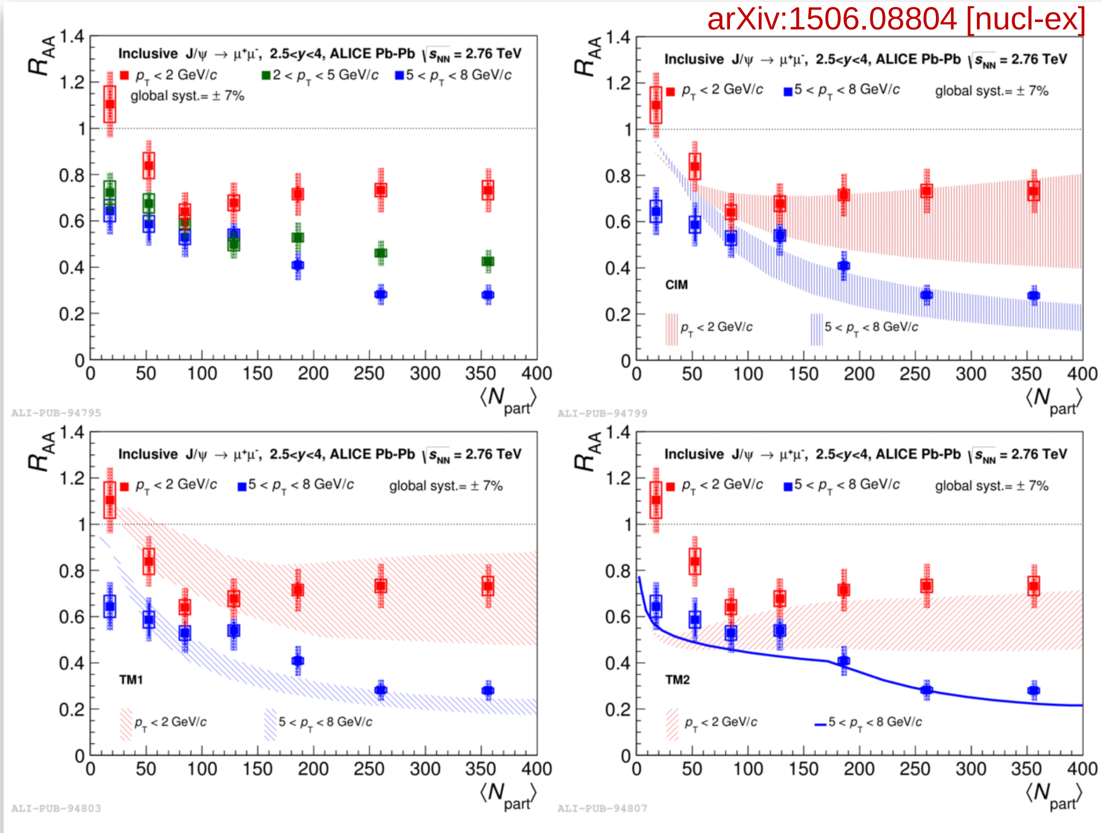
J/ψ R_{AA} vs N_{part} in bins of p_T

arXiv:1506.08804 [nucl-ex]



top-right: CIM Ferreiro, PLB 731 (2014) 57
bottom-left: TM1, Zhao et. al., NPA 859 (2011) 114–125
bottom-right: TM2, Zhou et. al., PRC 89 (2014) 054911

J/ψ R_{AA} vs N_{part} in bins of p_T



CIM

TM1 Zhao

TM2 Zhou

For N_{part}> 150, the suppression is larger at high-p_T than at low-p_T

Suppression pattern is compared to the Comover Interaction Model (top-right) and to two Transport Models (bottom-left and bottom-right)

All models reproduce the data reasonably well

They all require a contribution of J/ψ from recombination, at low-p_T

J/ψ R_{AA} vs p_T in bins of centrality

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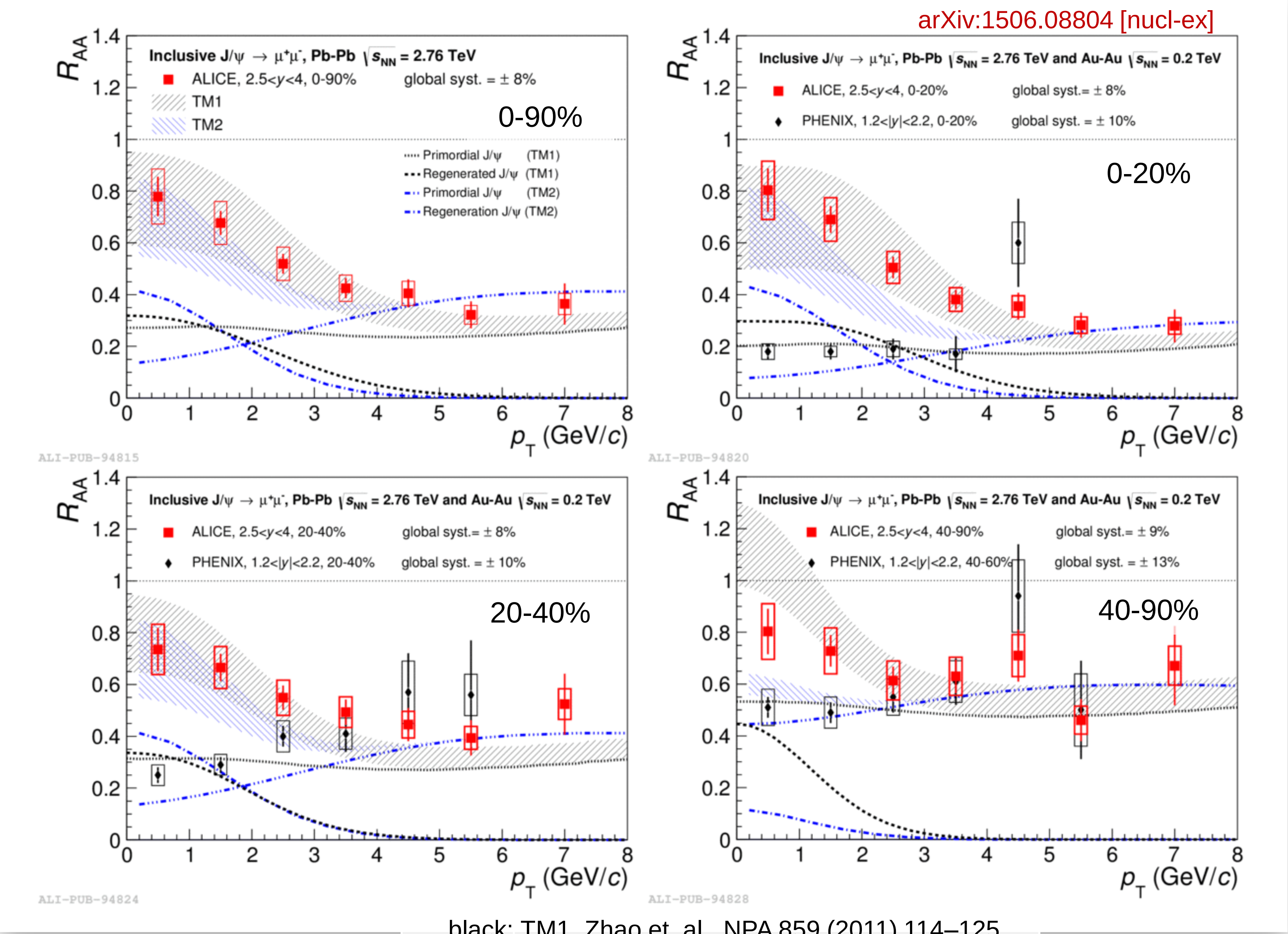

black: TM1, Zhao et. al., NPA 859 (2011) 114–125
blue: TM2, Zhou et. al., PRC 89 (2014) 054911

J/ψ R_{AA} vs p_T in bins of centrality

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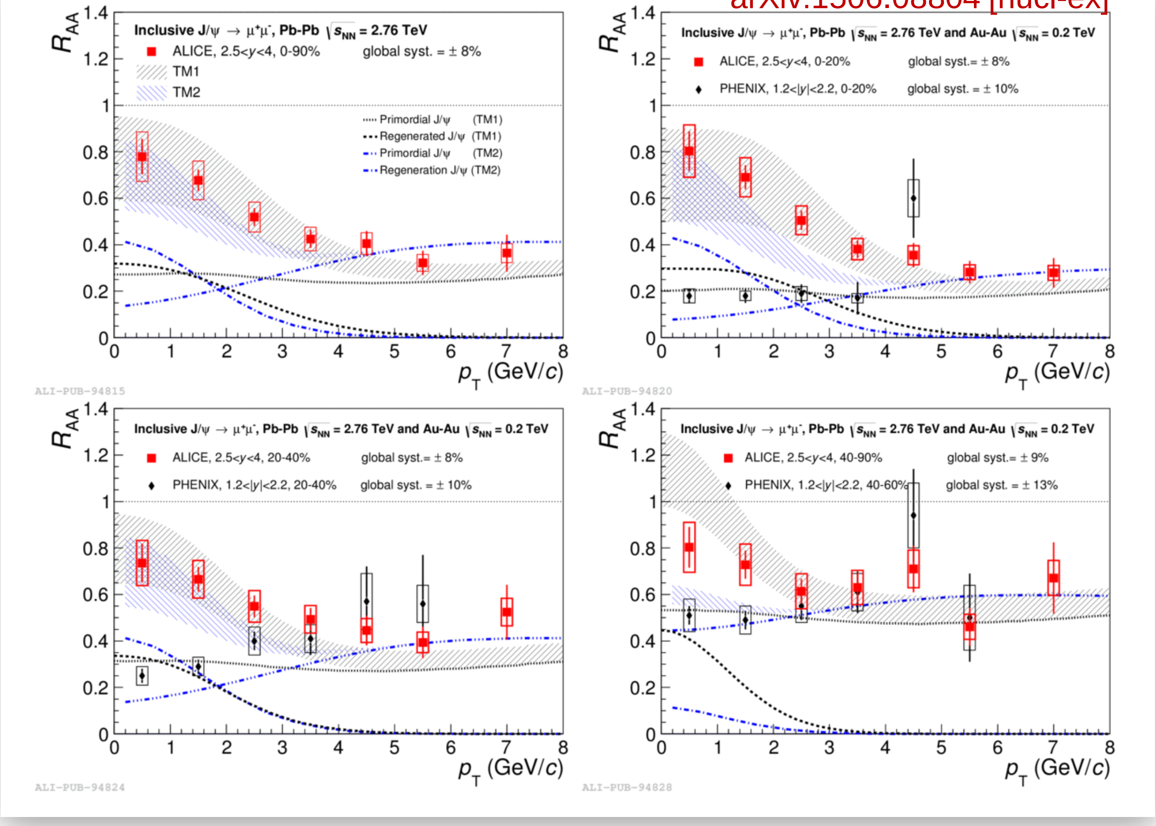
0-90%

0-20%

20-40%

40-90%



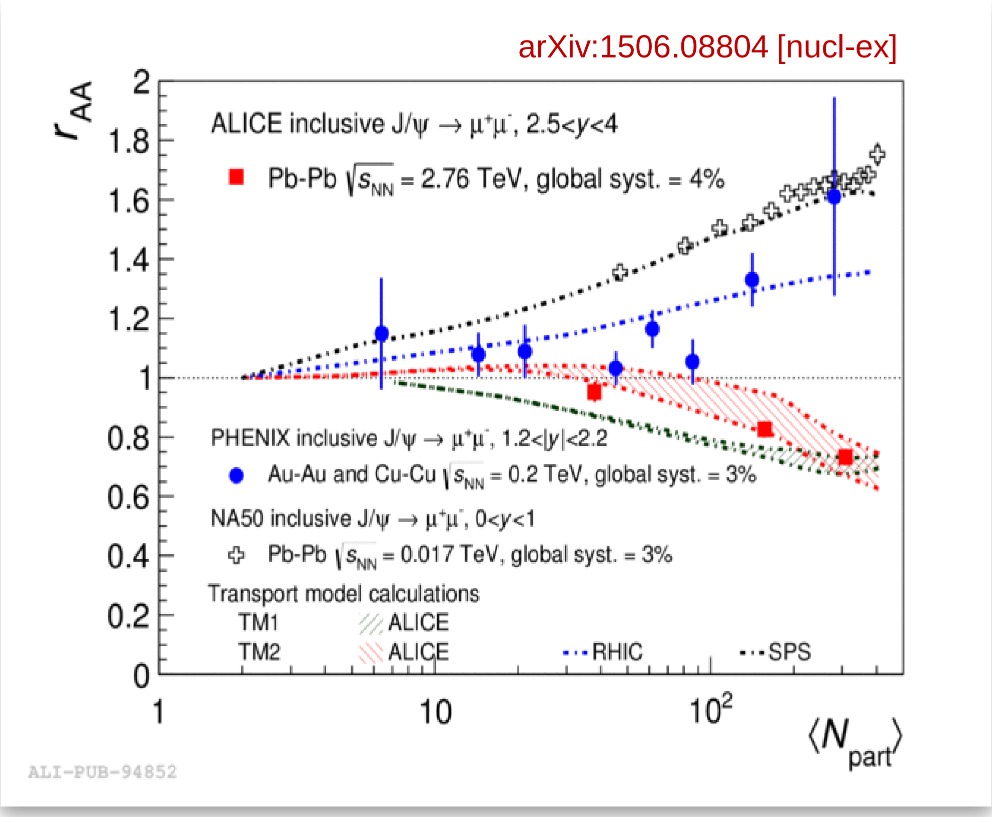
Although both transport models reproduce the data reasonably well, they have a different balance between suppression and recombination

In peripheral collisions, our data could discriminate between the two models (but beware of the low-p_T excess)

$\langle p_T^2 \rangle$ at forward rapidity

$\langle p_T^2 \rangle$ estimated using fits to the p_T-differential yields

$$r_{AA} = \langle p_T^2 \rangle_{AA} / \langle p_T^2 \rangle_{pp}$$



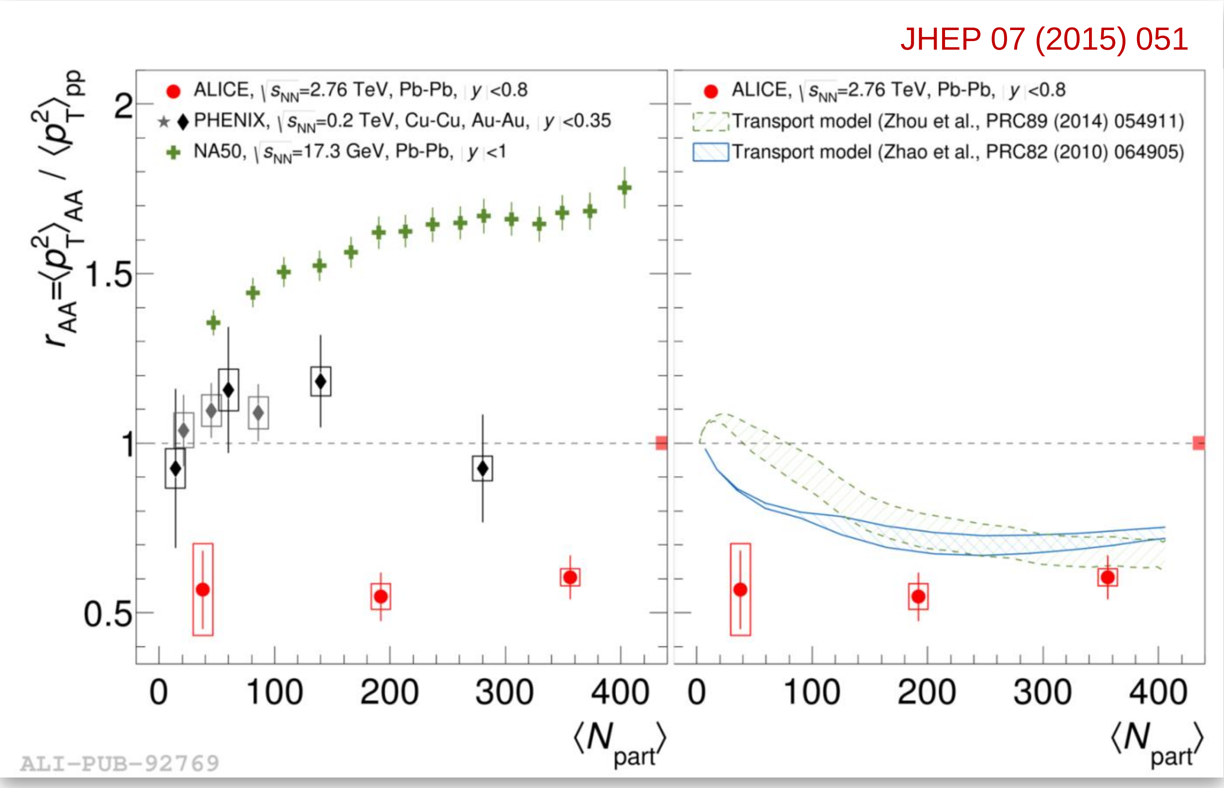
Strong energy dependence of r_{AA} vs N_{part}

Well reproduced by (some) transport models, and attributed to the onset of recombination

$\langle p_T^2 \rangle$ at mid-rapidity

$\langle p_T^2 \rangle_{J/\psi}$ is estimated using a fit to the distribution of $\langle p_T^2 \rangle_{ee}$ vs M_{ee}

$$r_{AA} = \langle p_T^2 \rangle_{AA} / \langle p_T^2 \rangle_{pp}$$



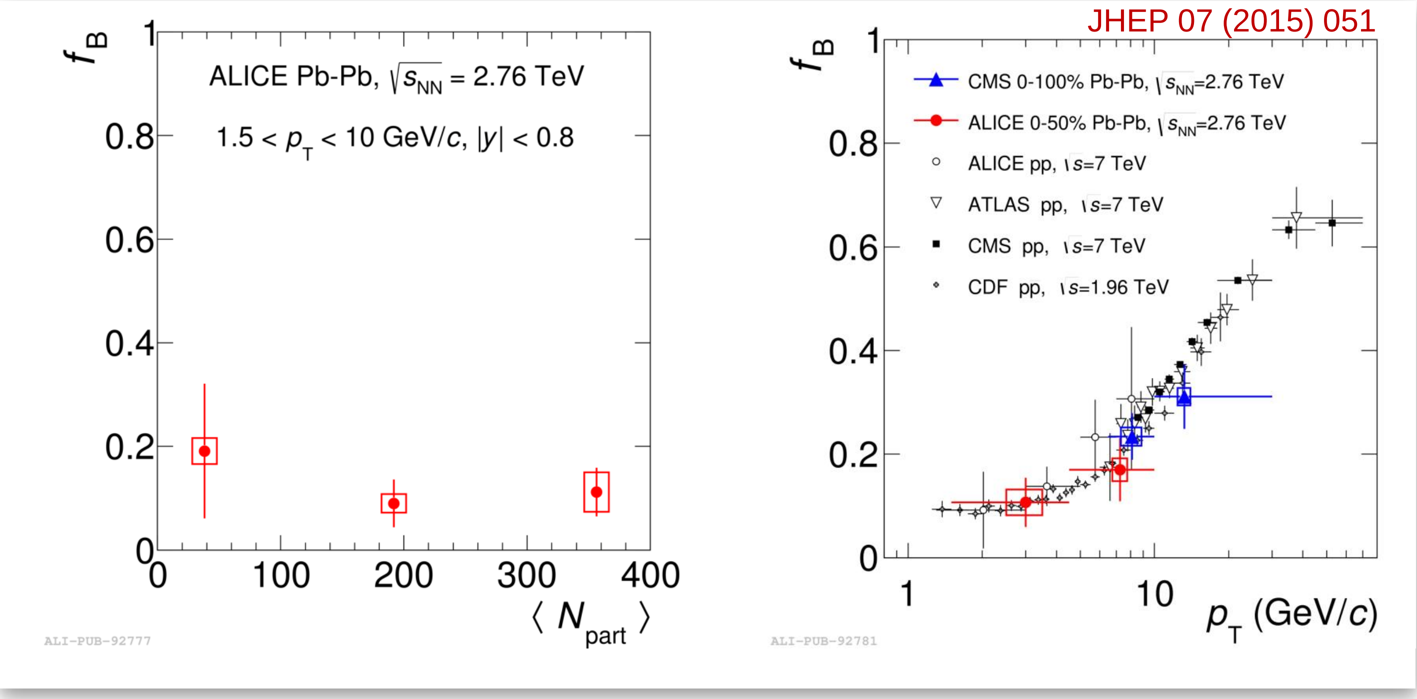
Strong energy dependence is observed as at forward rapidity

However, the centrality dependence is less pronounced, and not reproduced by models

Prompt and non-prompt separation at mid-rapidity

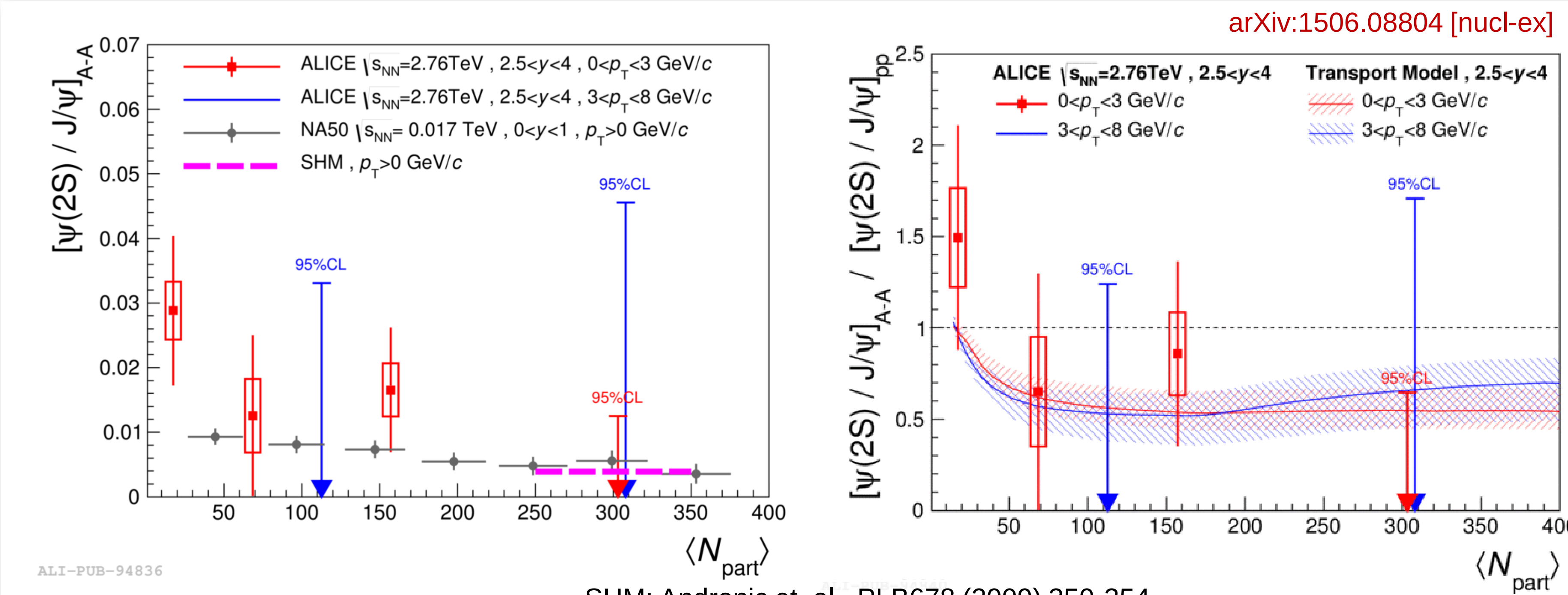
Allows one to disentangle QGP effects on charmonia and on *b* quarks
Separation performed by simultaneous fit to inv. mass and pseudo-proper decay length

f_B = non-prompt / inclusive



p_T(GeV/c)	f_B(%)	R_{AA}(inclusive J/ψ)	R_{AA}(prompt J/ψ)	R_{AA}(non-prompt J/ψ)
0.0 – 1.5	–	0.89±0.20±0.21	–	–
1.5 – 4.5	10.7±4.8±2.5	0.76±0.09±0.08	0.76±0.10±0.08	0.73±0.34±0.20
4.5 – 10.0	17.0±6.1±2.2	0.38±0.07±0.06	0.38±0.07±0.06	0.37±0.15±0.09

ψ(2S) production



SHM: Andronic et. al., PLB678 (2009) 350-354

Transport Model: Chen et. al., PLB726 (2013) 725-728

Left: ψ(2S)-to-J/ψ ratio in Pb-Pb, vs centrality in two bins of p_T

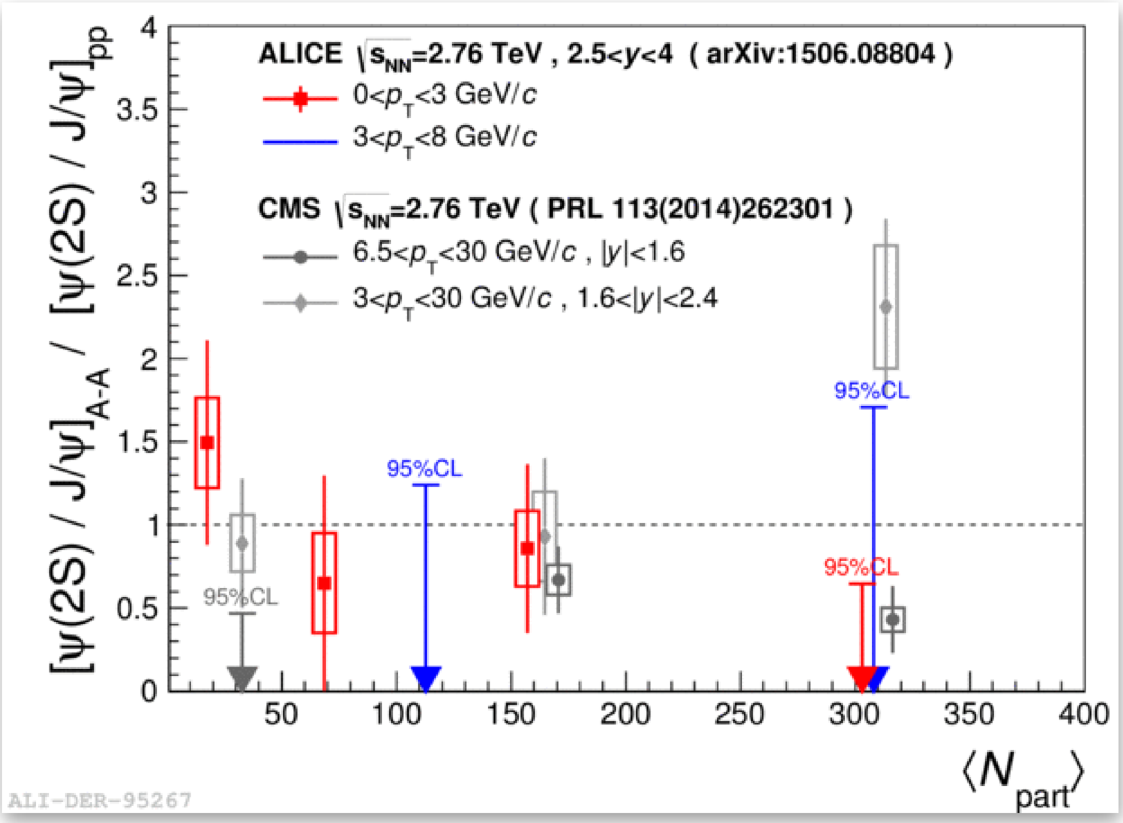
Right: ψ(2S)-to-J/ψ double-ratio, Pb-Pb/pp, vs centrality in two bins of p_T

These ratios could be used to discriminate between Statistical and Transport models

Statistics being limited, only 95% C.L. are available for central collisions

Statistical and transport models are not inconsistent with these C.L.

ψ(2S) production - comparison to CMS



Situation gets more complicated when also considering CMS measurements of the same quantity

Some tension between the enhancement observed by CMS for p_T > 3 GeV/c and the 95% C.L. observed by ALICE at N_{part} ~ 300, but on the other hand rapidity ranges are slightly different

Summary

Double differential measurements of inclusive J/ψ R_{AA} are consistent with a regeneration component at low-p_T that increases with increasing centrality

$\langle p_T^2 \rangle$ measurements are also consistent with this hypothesis, at least at forward rapidity

Contribution from non-prompt J/ψ (from *b*-hadron) does not impact the inclusive nuclear modification factor significantly, at mid-rapidity

Situation for ψ(2S) is unclear, due to some tension between ALICE and CMS. ALICE results at least, are not inconsistent with calculations from the same models that describe the J/ψ