



(some dimuons)

Measurement of (quarkonia) productions in
Pb-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$ with
ALICE

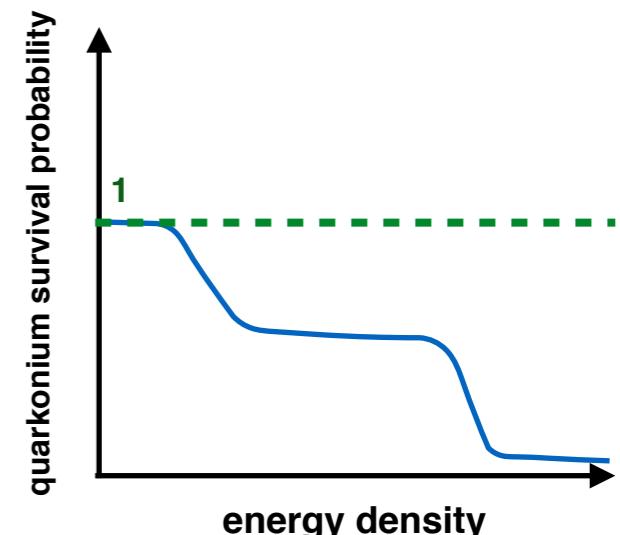
Mohamad Tarhini
QGP France 2017
Etretat, 10 September

Outline

- Physics motivations
- Experimental setup
- Results
 - $J/\psi R_{AA}$ in different kinematic ranges
 - $\psi(2s) R_{AA}$
 - Z-boson invariant yield and R_{AA}
- Summary

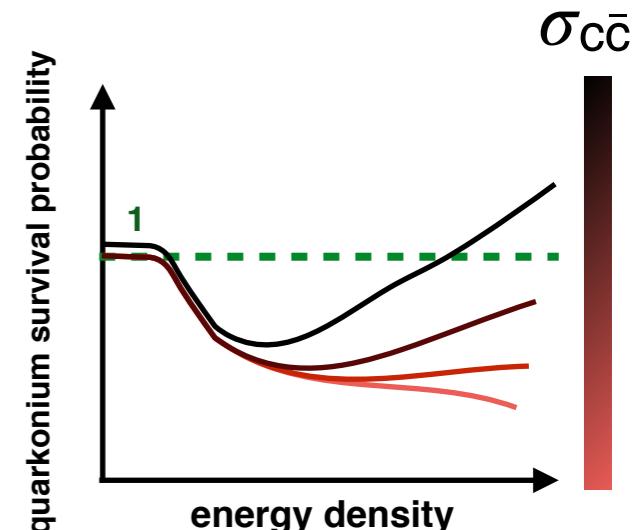
Original motivation

- Measurement of quarkonium production in heavy-ion collisions is a probe for the QGP de-confinement
 - Sequential dissociation of different quarkonium states can serve as a QGP thermometer



But:

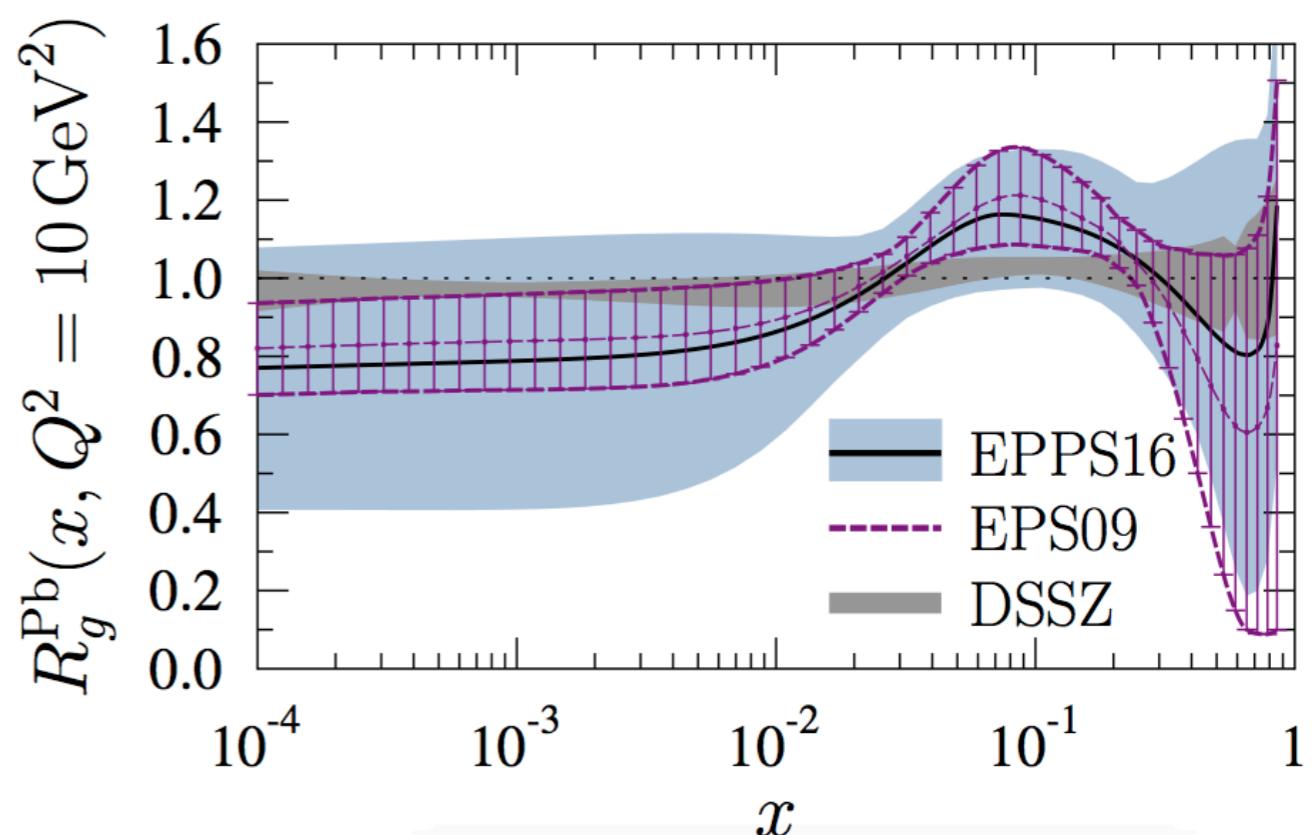
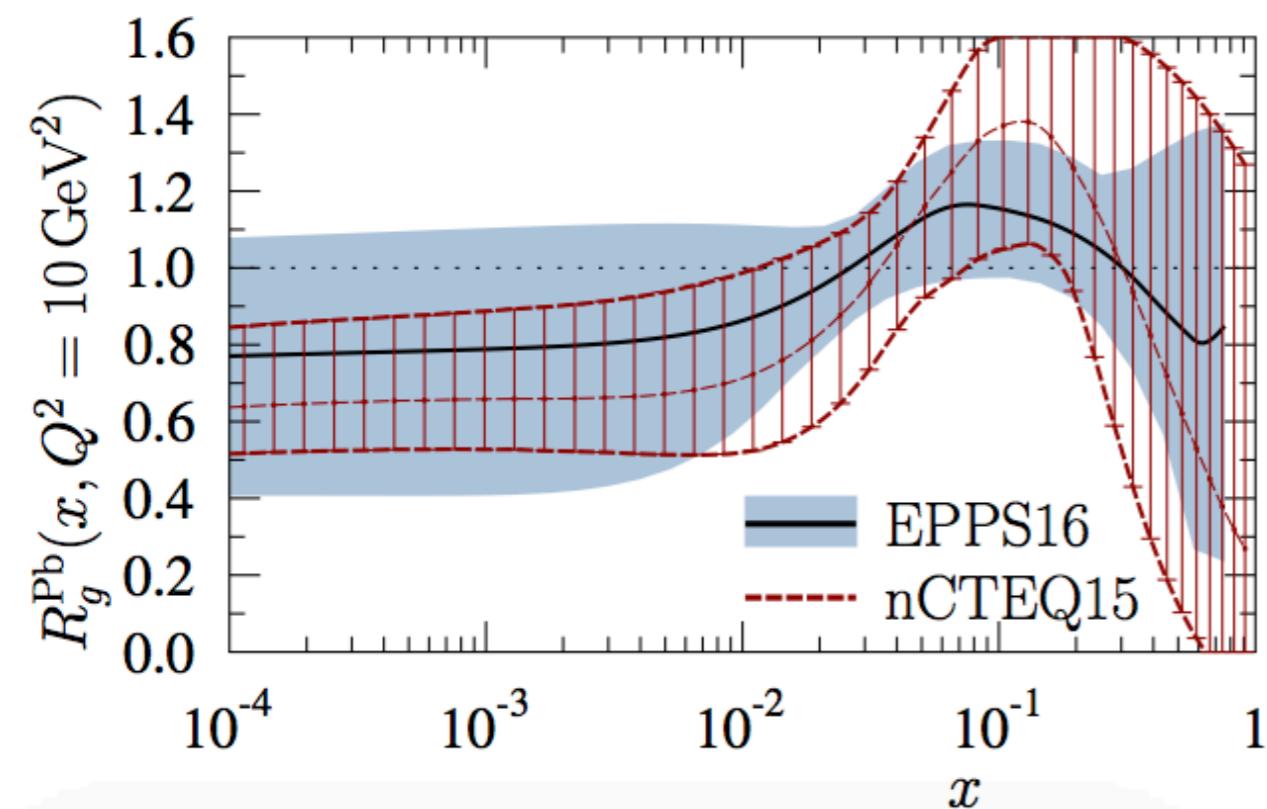
- If there are enough heavy quark pairs, quarkonium can be (re)generated
 - (re)generation is treated in different ways in different models
 - How to distinguish between models ?
 - heavy quark cross section is a key ingredient



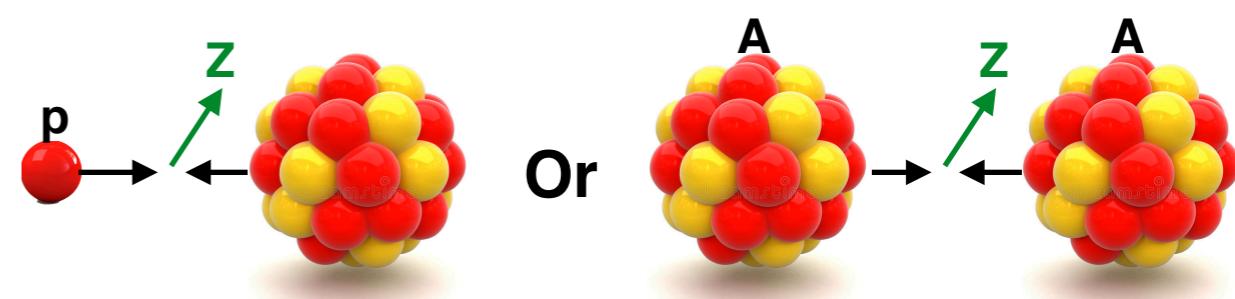
Other (But)s:

- Different sources of quarkonium production [inclusive = direct + indirect (feed down) + non-prompt (for charmonia)]
- Effects of cold nuclear matter (CNM) on the heavy quark and quarkonium production

- Lack of experimental datasets to constrain nPDFs → **large uncertainties**



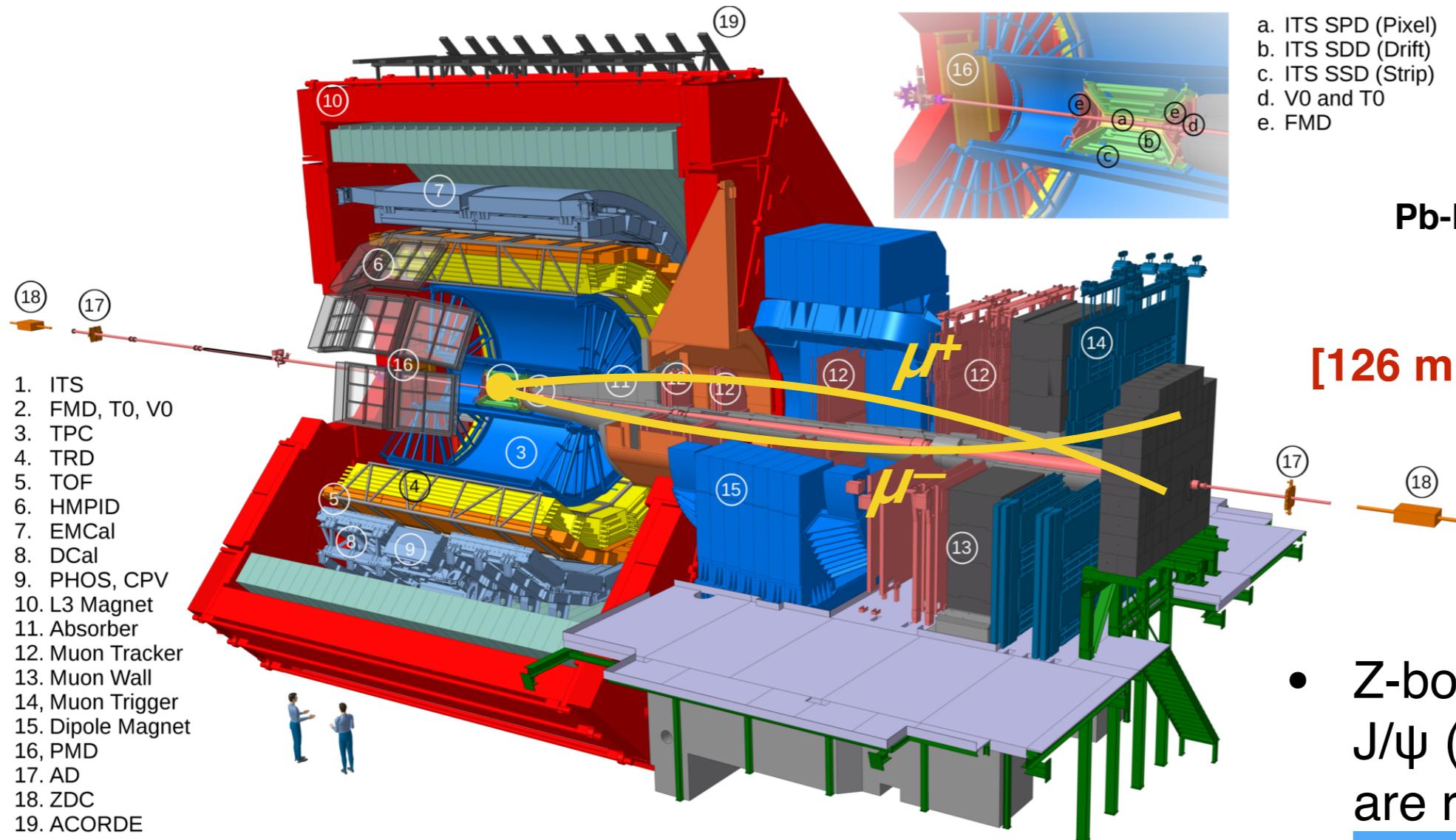
- Z-boson production in heavy-ion collisions:
- Not affected by the presence of the strongly-interacting medium in heavy-ion collisions
- The PDF modification is the major CNM effect



(Di)muon in ALICE

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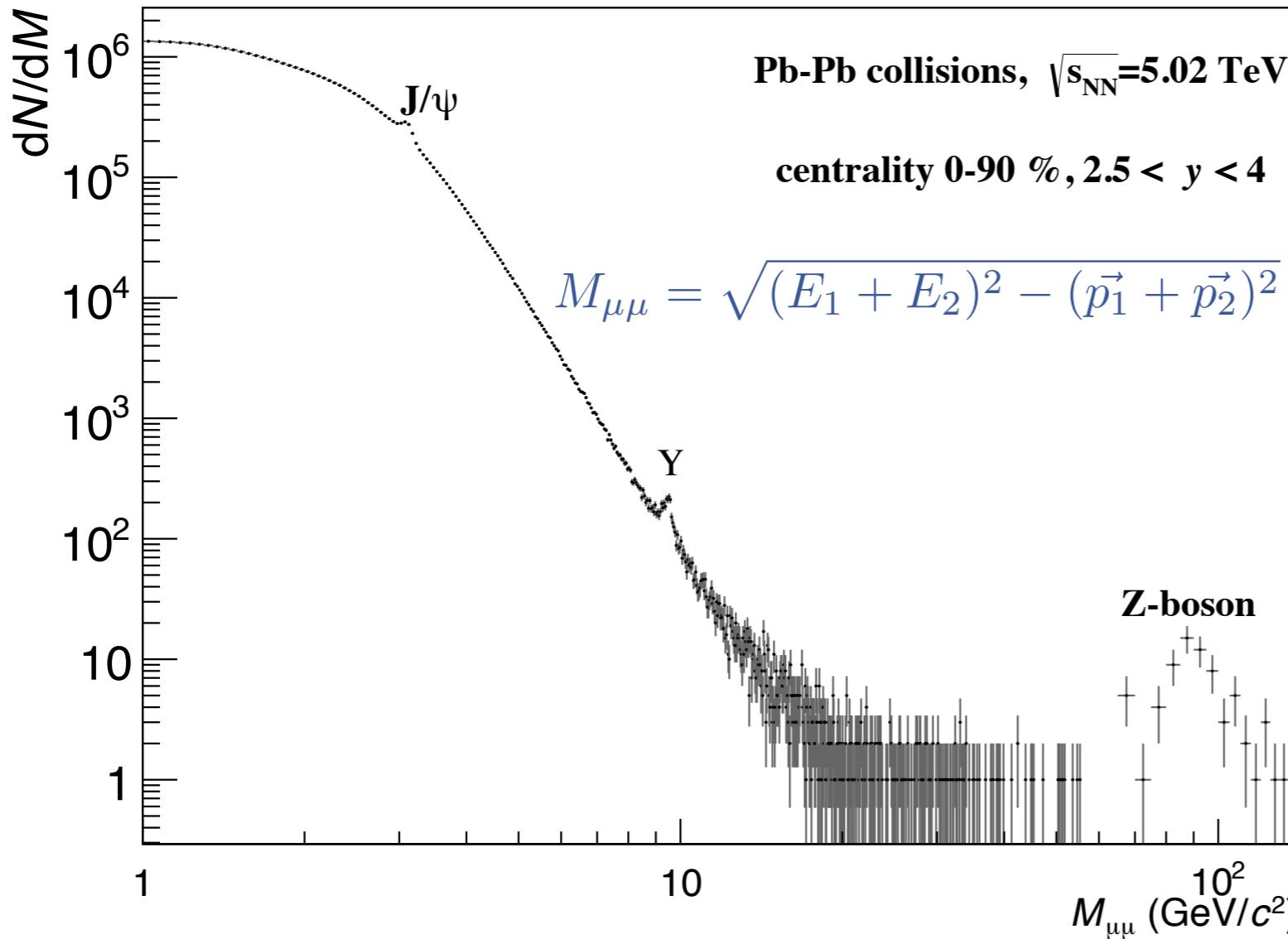
Pb-Pb at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$
 $2.5 < y_{\text{cms}} < 4$
 $L_{\text{int}} \sim 225 \mu\text{b}^{-1}$

[126 million dimuon events]

- Z-boson and **inclusive** J/ ψ (down to zero p_T) are reconstructed via the **dimuon** decay in the **muon spectrometer**

- **Dipole magnet:** 3 T.m
- **Absorber system:** Reject hadrons (pions, kaons) and beam-gas interactions
- **5 Tracking stations:** 10 planes of Cathode Pad Chambers. Reconstruct muon tracks
- **2 trigger stations:** 4 planes of Resistive Plate Chambers. Trigger on the muon p_T

- Dimuon signals are extracted using the invariant mass distribution:



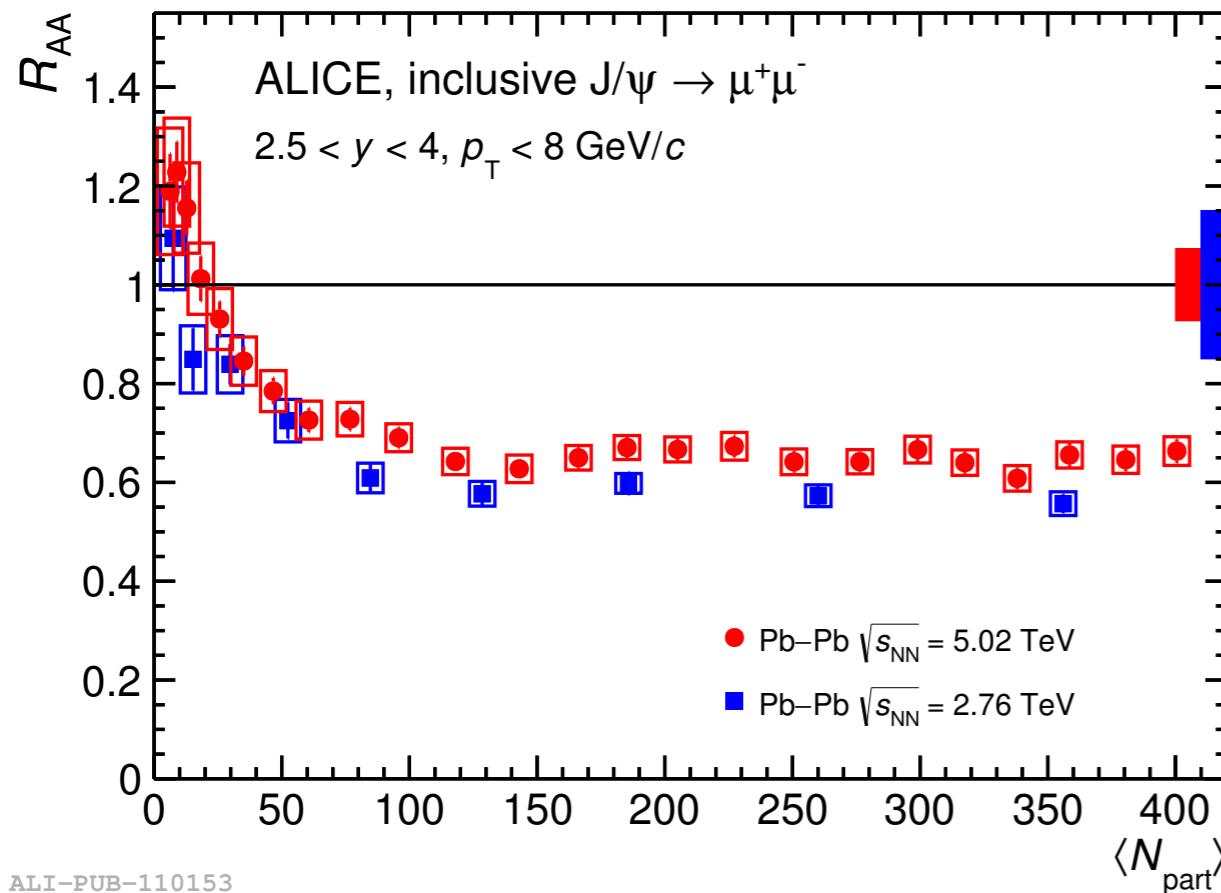
- Main single muon selections:
 - $-4 < \eta_\mu < -2.5$
 - $2^\circ < \Theta_{\text{abs}} < 9^\circ$
 - Matching between trigger and tracker
- Muon pair selections:
 - $2.5 < y < 4$
 - Opposite sign charges

- Z-boson raw yields are obtained by counting the opposite-charge dimuons after estimating the background physics sources with MC
- J/ ψ raw yields are obtained by fitting the data with signal+background functions
- Raw yields are corrected by acceptance and efficiency of the detector

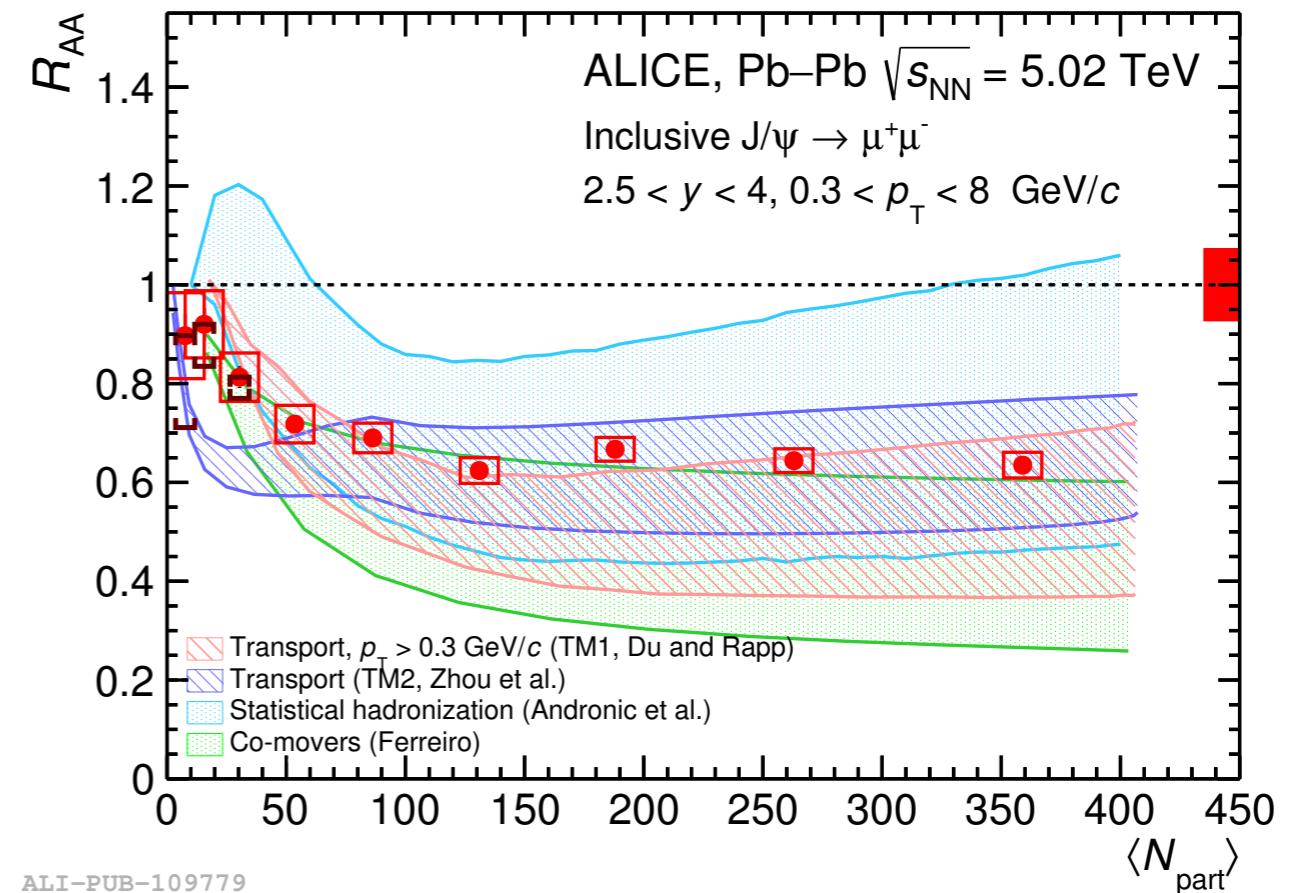
J/ ψ R_{AA} in Etretat 2016

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ALI-PUB-110153

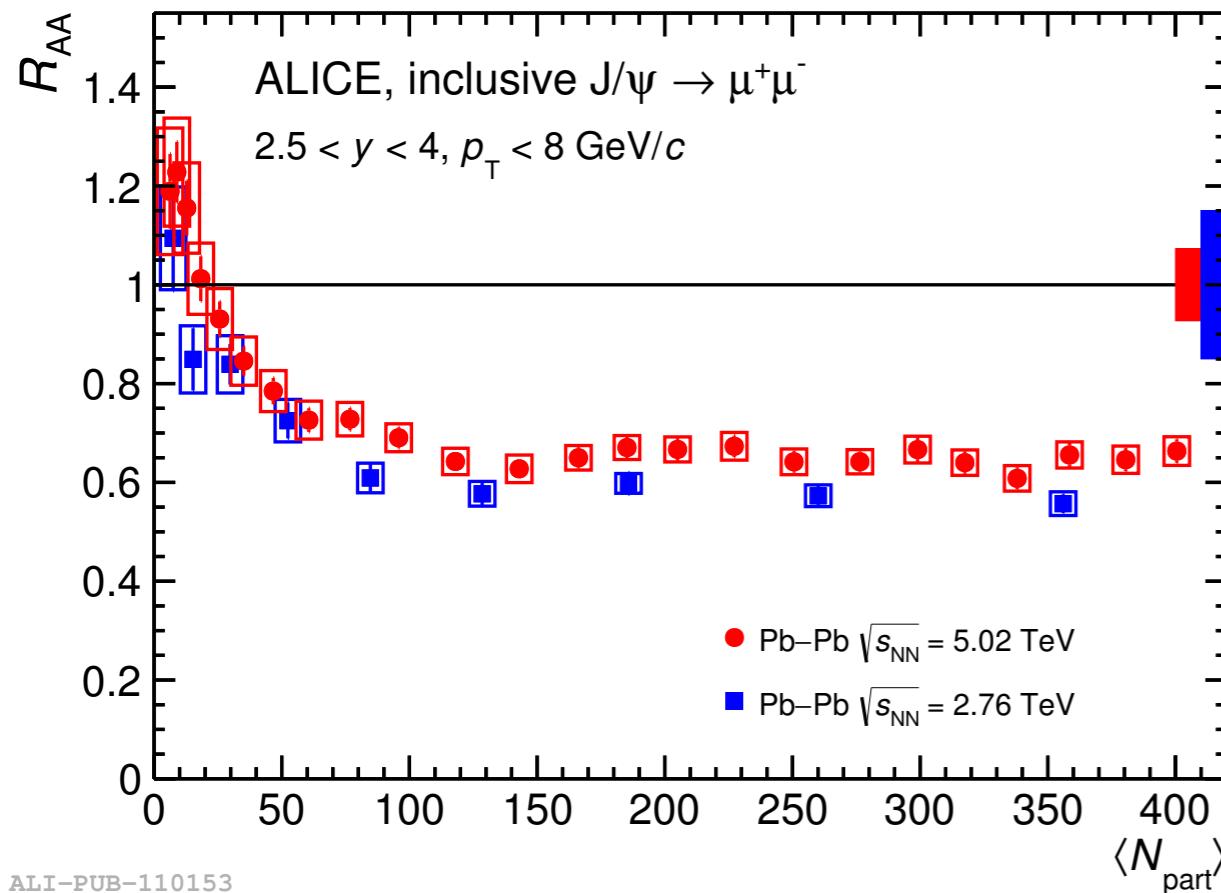


- **Clear J/ ψ suppression and almost no centrality dependence for $N_{\text{part}} > 100$ (centrality < 50 %)**
- A systematic increase of ~15% between the R_{AA} at two energies (but within uncertainties)
- Models calculations are able to describe the data within large uncertainties

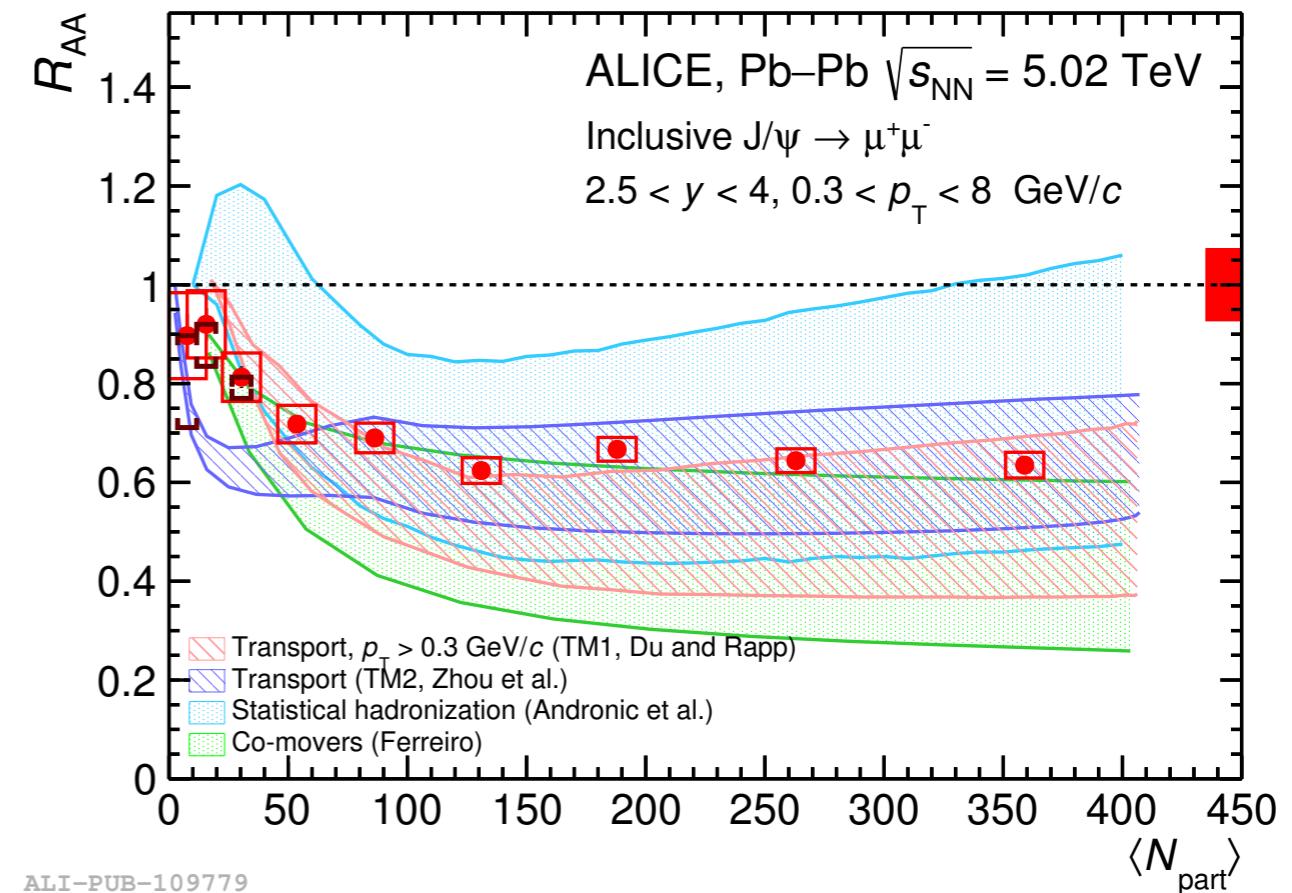
J/ ψ R_{AA} in Etretat 2016

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ALI-PUB-110153



ALI-PUB-109779

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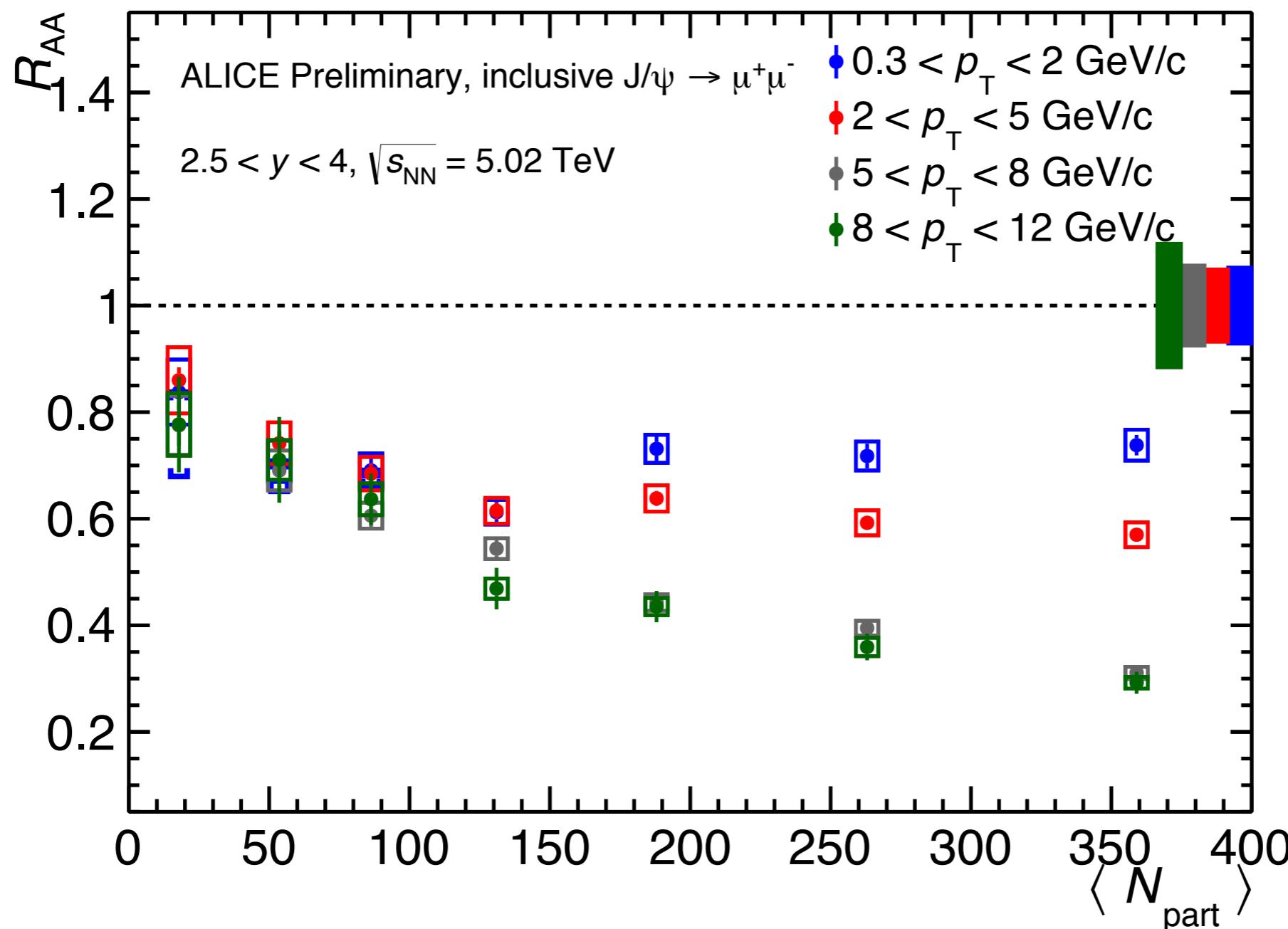
More differentially →

J/ ψ R_{AA} vs centrality (in p_T ranges)

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- For central events, the suppression is smaller at lower p_T
- R_{AA} shows a stronger centrality dependence at high p_T
- For $p_T > 5$ GeV/c, the R_{AA} is stable as a function of p_T (regeneration expected to be negligible)

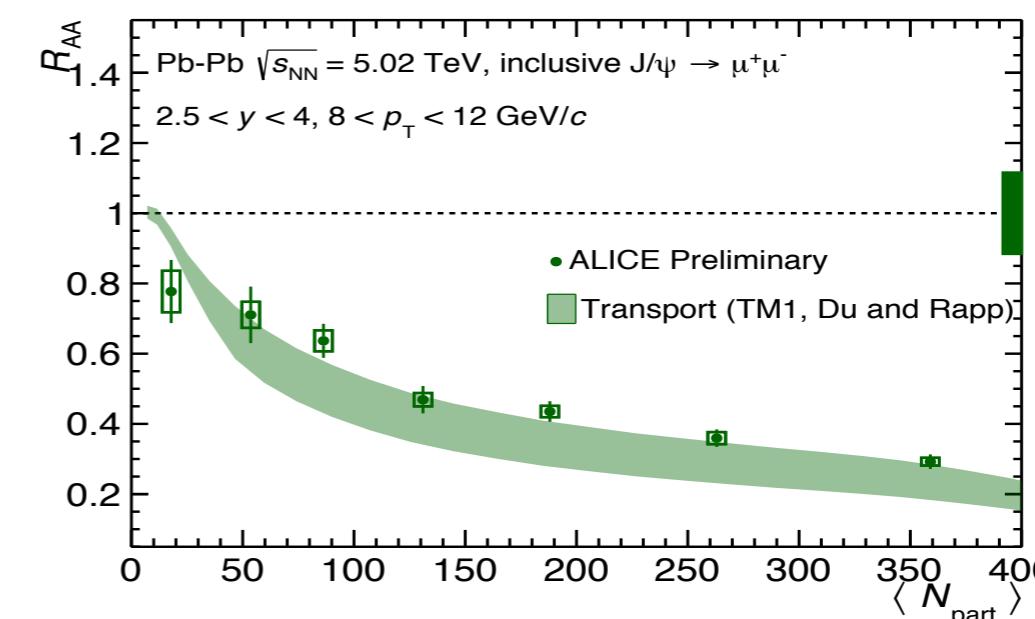
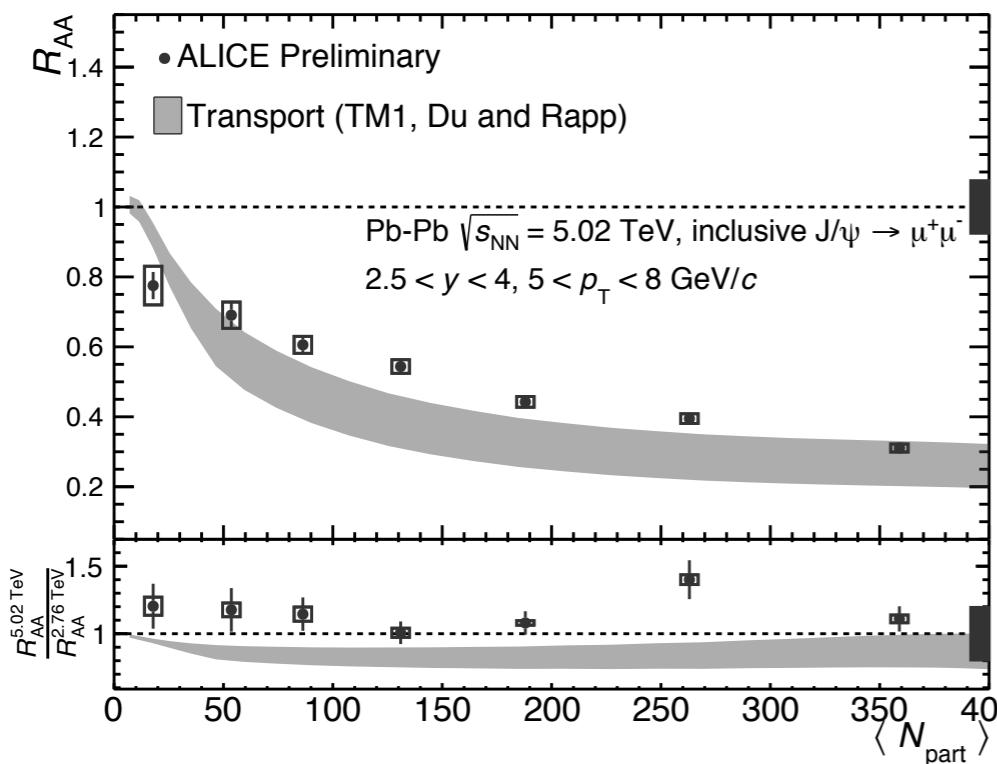
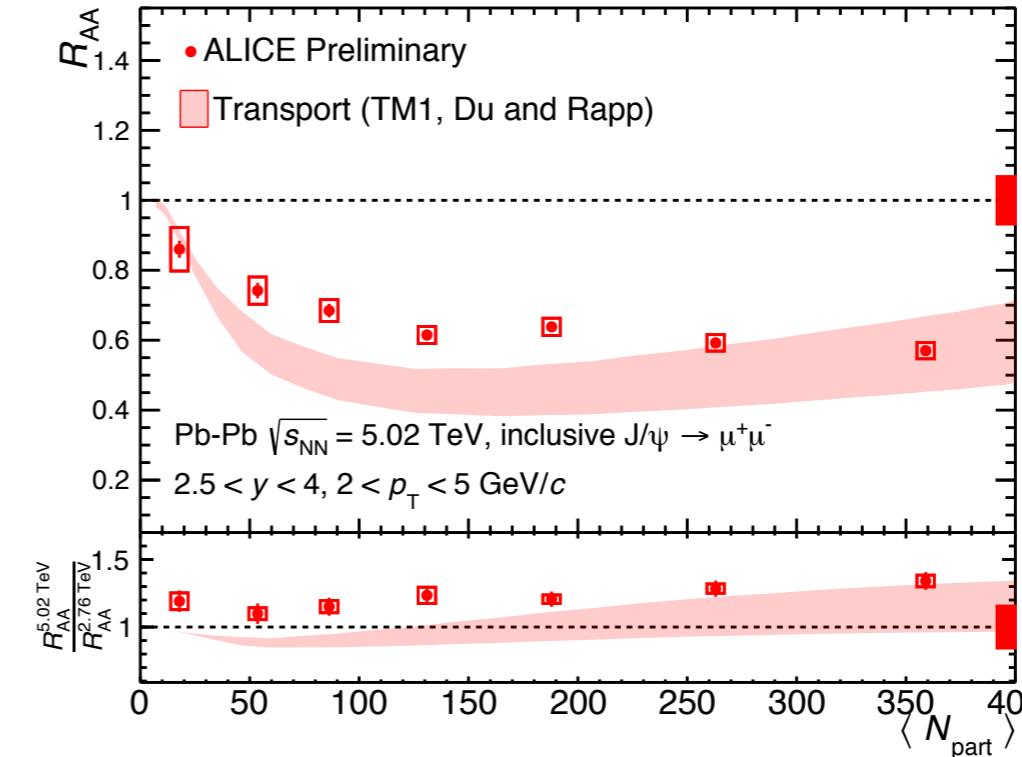
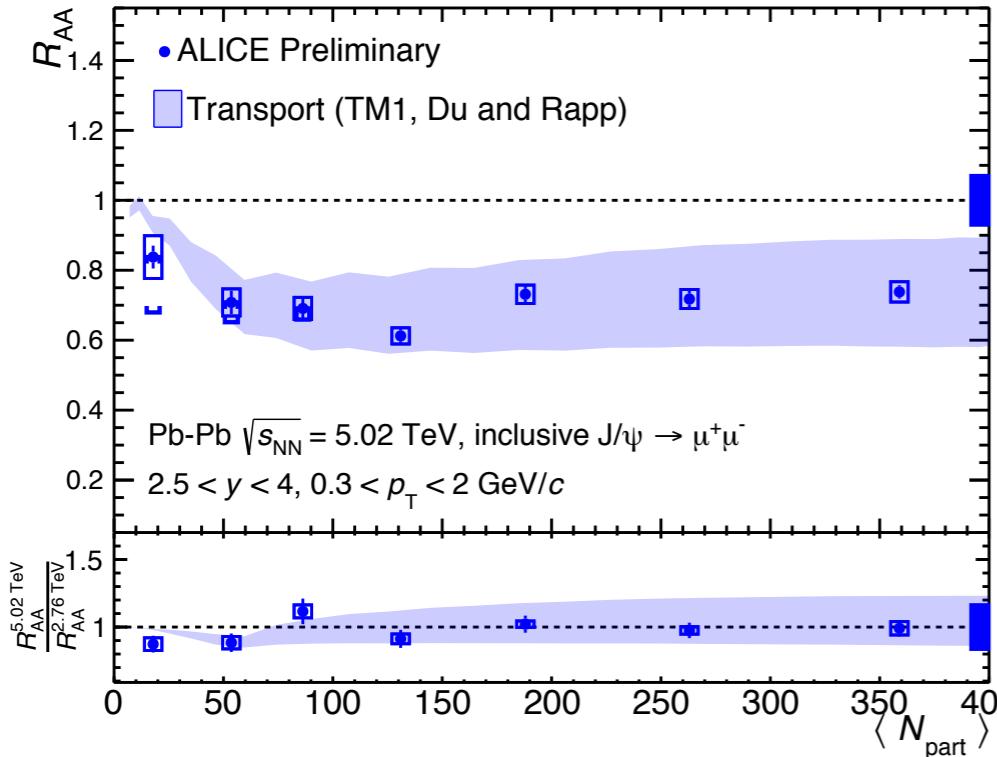


J/ ψ R_{AA} vs centrality (in p_T ranges)

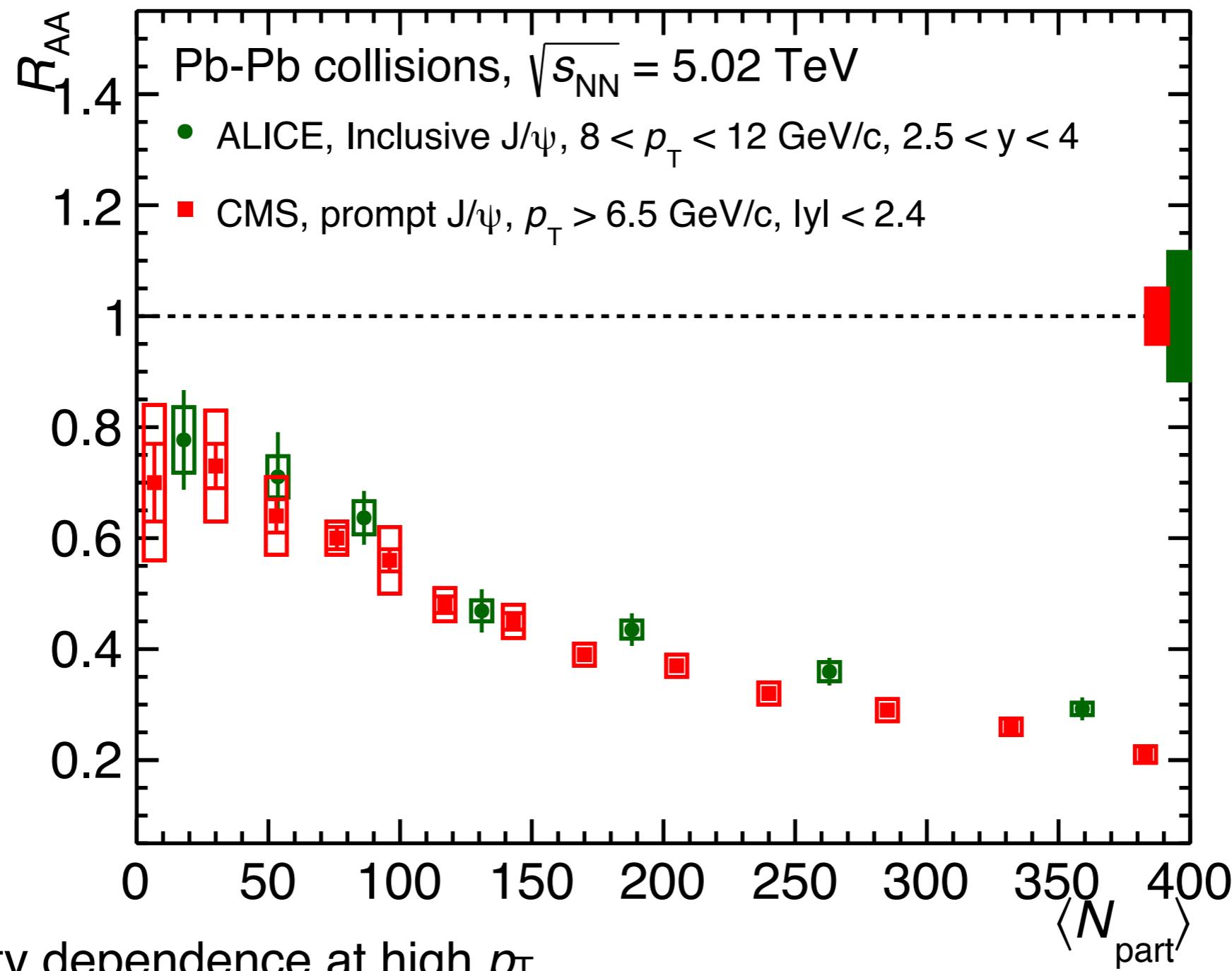
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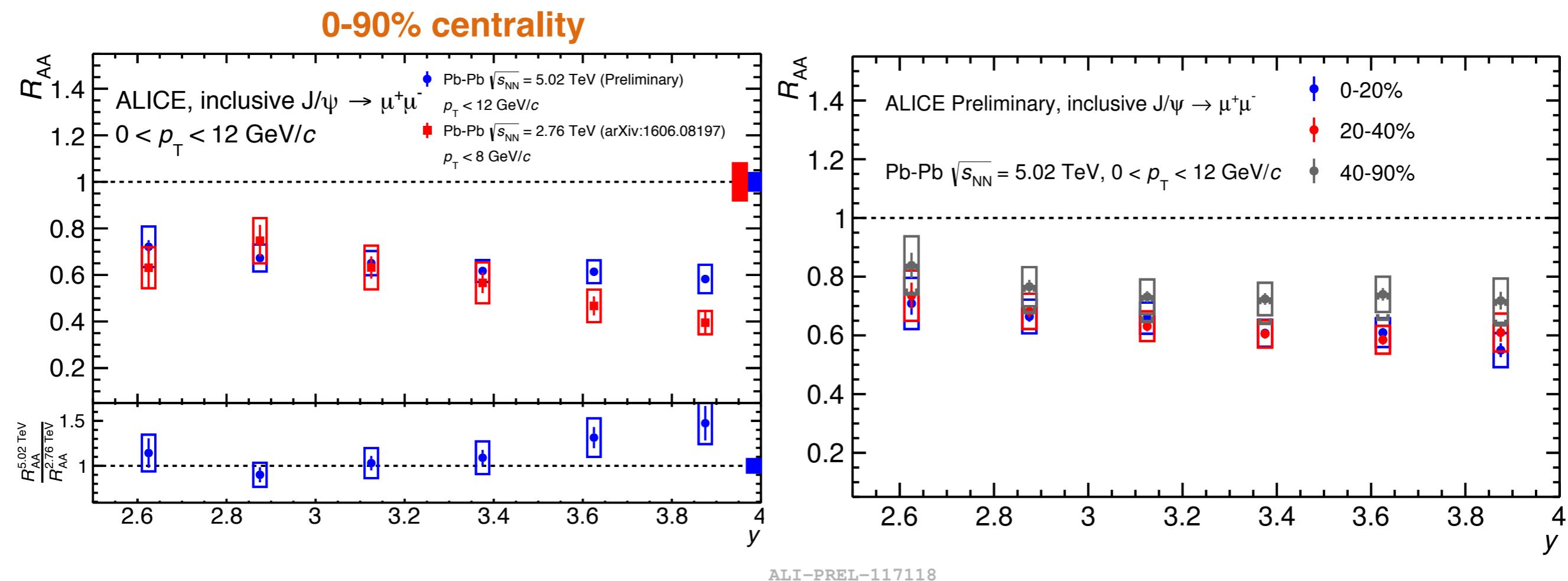
- For central events, the suppression is smaller at lower p_T
- Expected behaviour J/ ψ (re)generation scenario (for instance TM1)
- R_{AA} shows a stronger centrality dependence at high p_T



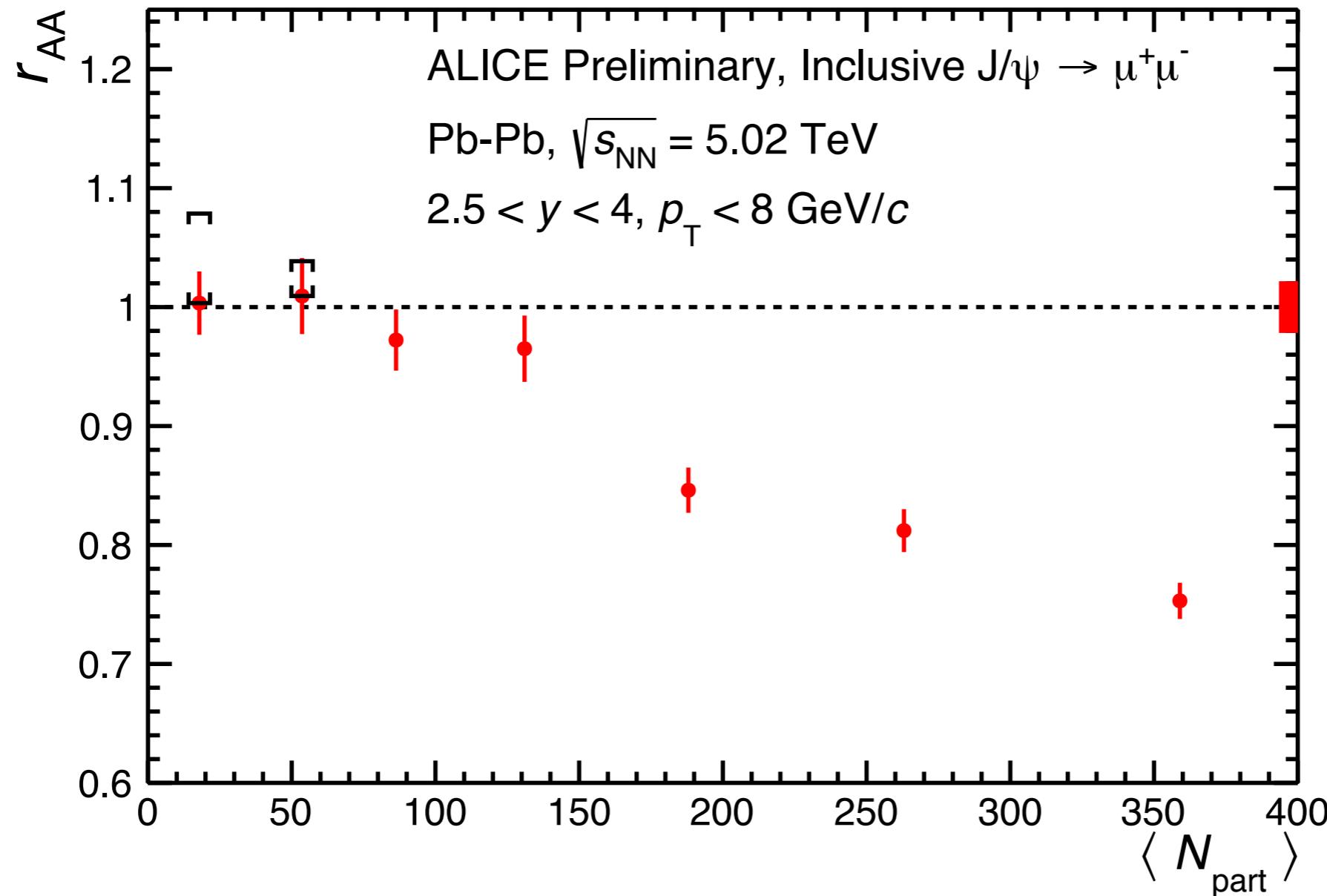
- At high p_T , ALICE and CMS [1] results are compatible [caveats: Different rapidity, prompt and inclusive]



- Motivation: In regeneration scenario, R_{AA} decreases going to more forward rapidities

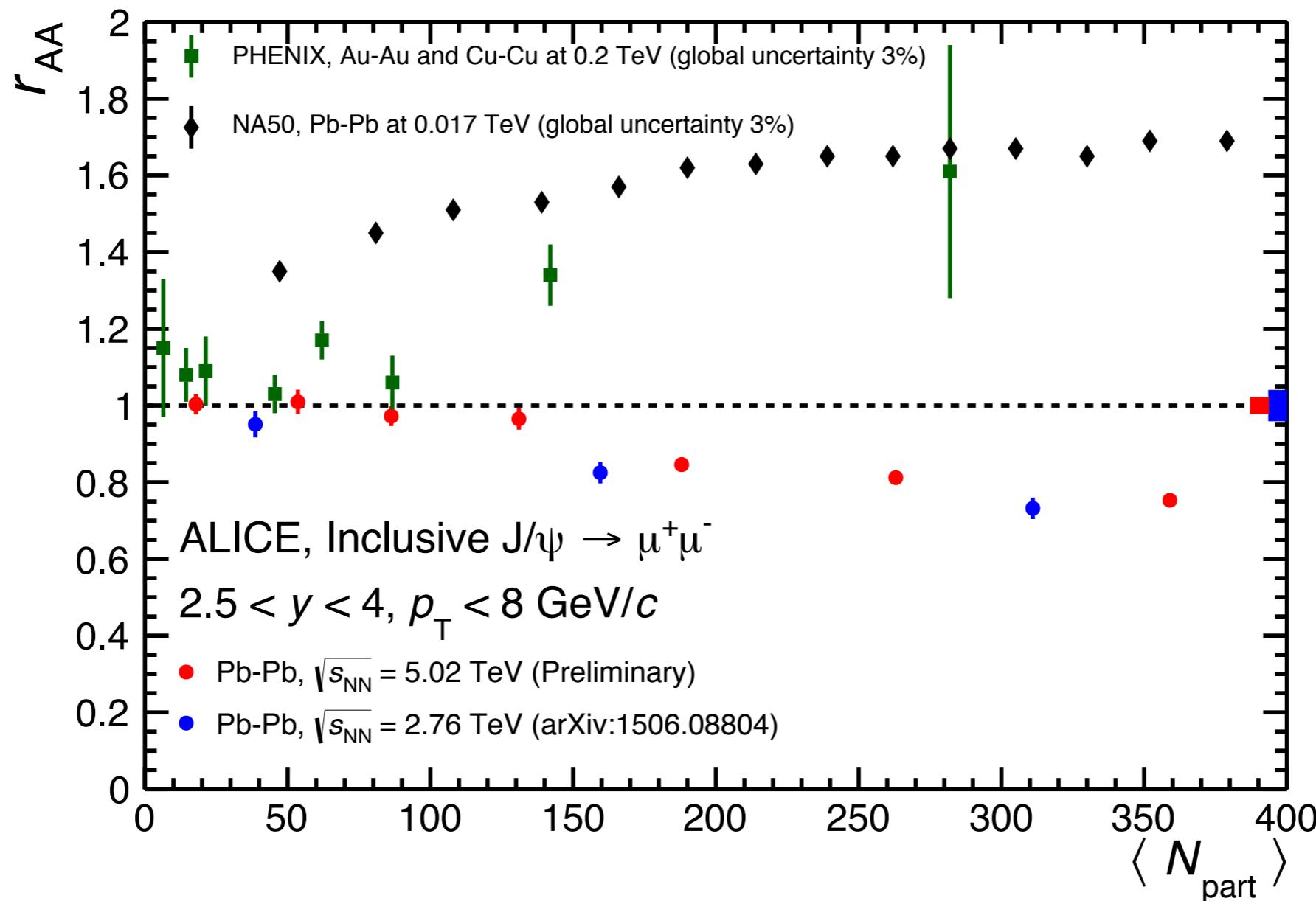


- Small rapidity dependence at low p_T in different centrality
- In agreement with 2.76 TeV results

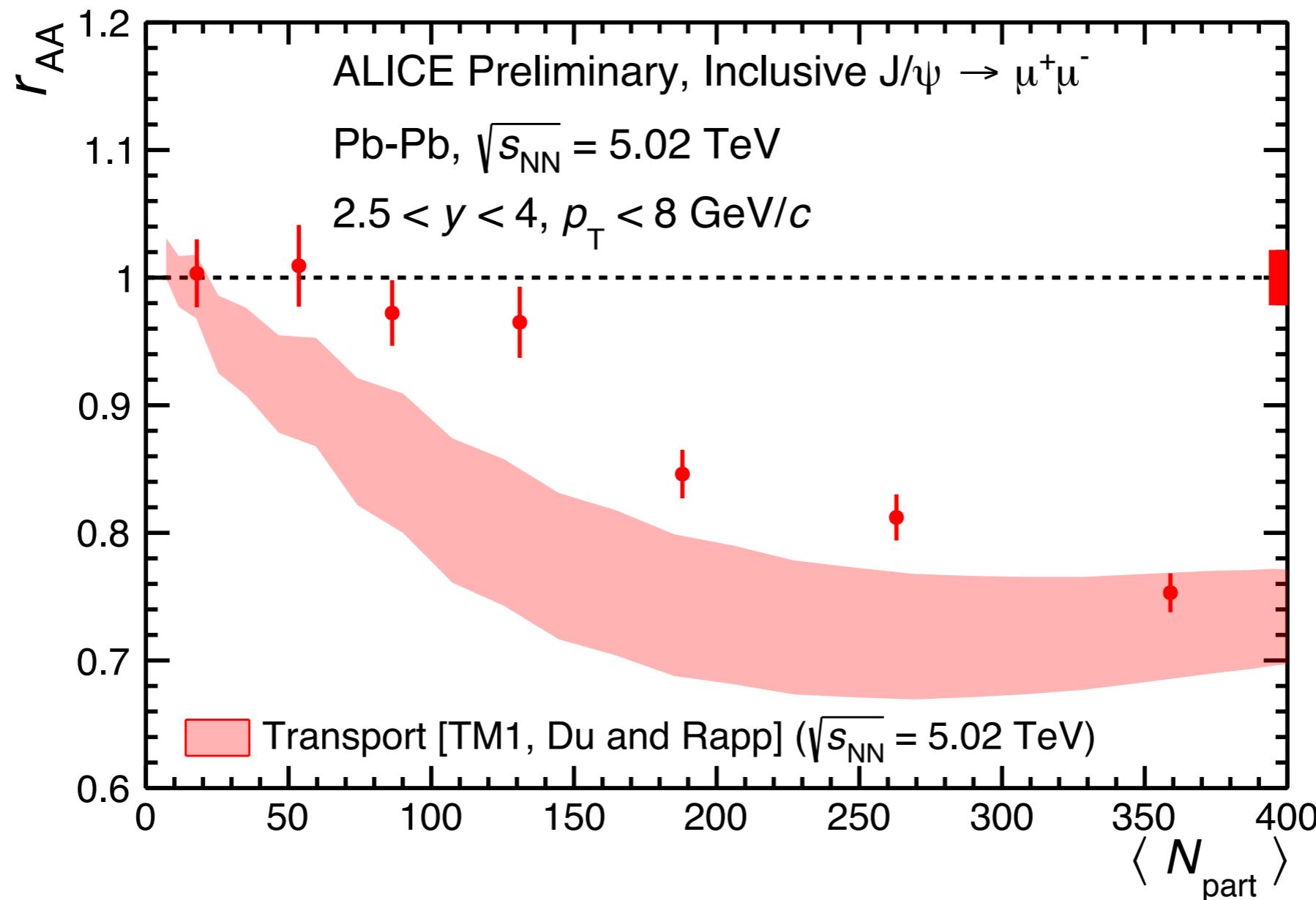


$$r_{AA} = \frac{\langle p_T^2 \rangle_{AA}}{\langle p_T^2 \rangle_{pp}}$$

- The r_{AA} quantify the p_T broadening with respect to pp collisions
- A decrease of the $\langle p_T^2 \rangle$ can be explained by regeneration (more important in central collisions and favours low pt J/ψ)
 - Expected with the increase of the R_{AA} at low p_T

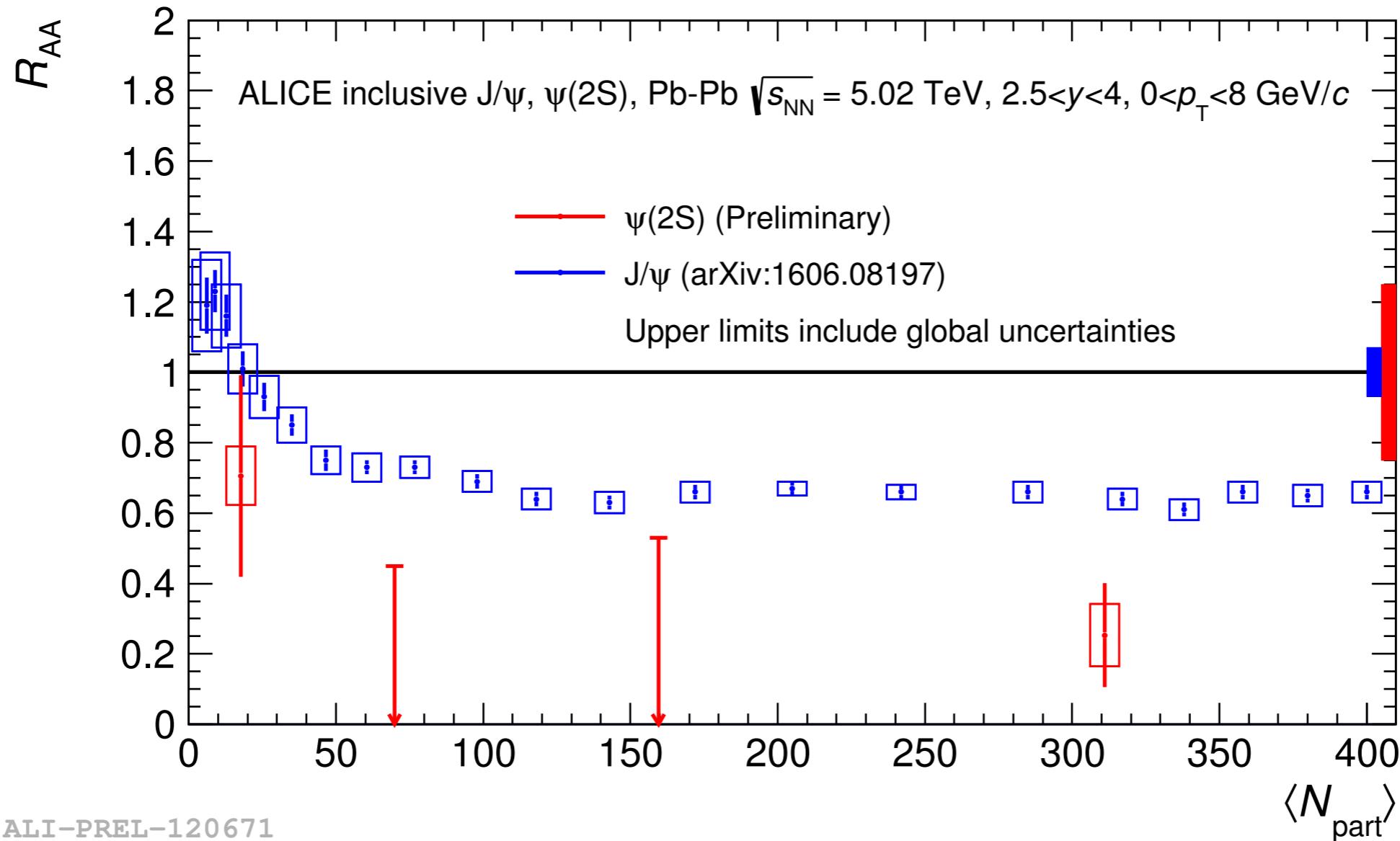


- The results of r_{AA} at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$ and $\sqrt{s_{NN}} = 2.76 \text{ TeV}$ are compatible within uncertainties
- Very different behaviour than at **SPS** and **RHIC**



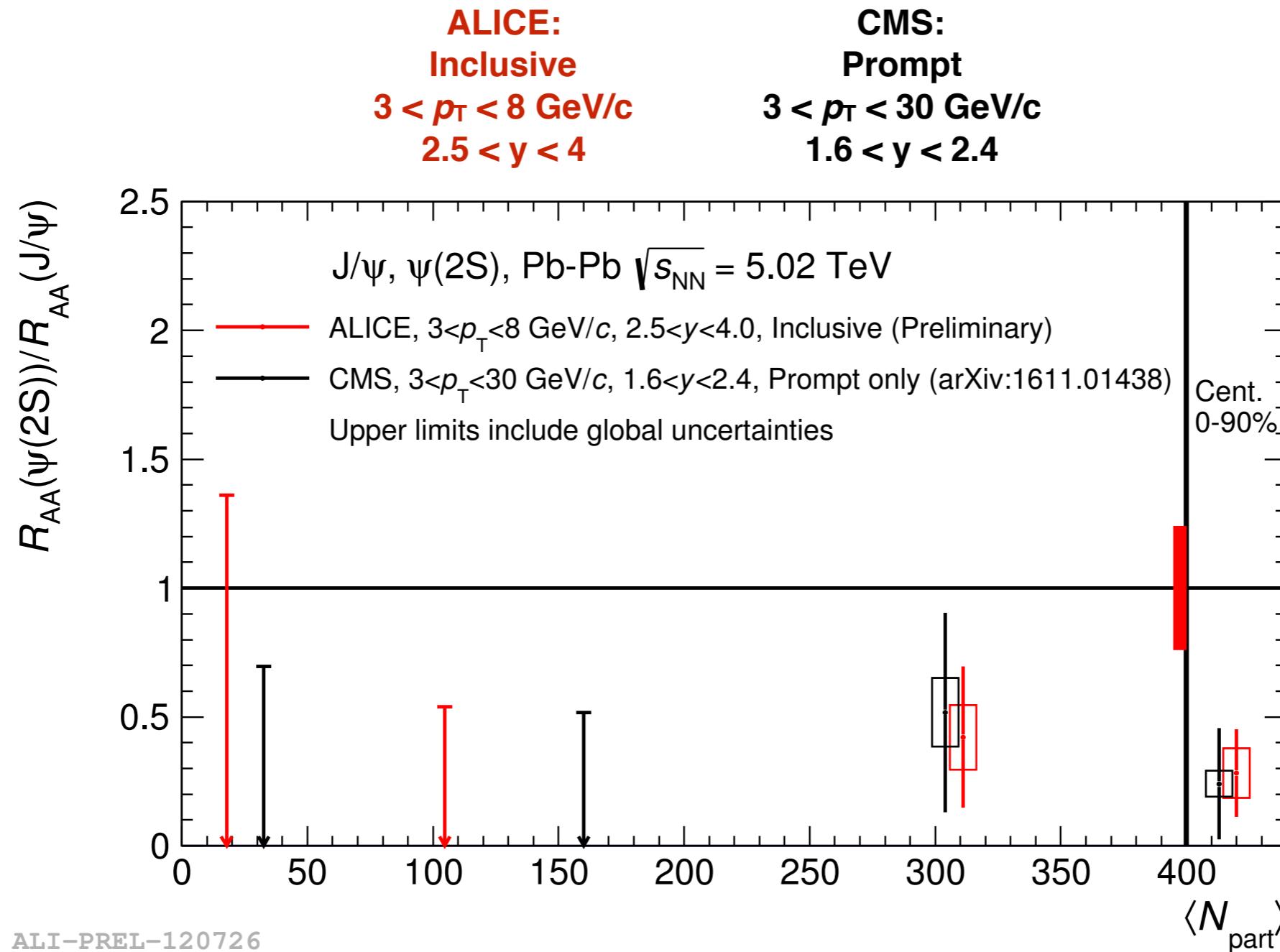
- The results of r_{AA} at $\sqrt{s_{NN}} = 5.02$ TeV and $\sqrt{s_{NN}} = 2.76$ TeV are compatible within uncertainties
- Very different behaviour than at **SPS** and **RHIC**
- Discrepancies are seen in semi-central collisions between the measurements and calculations based on transport model

- The ratios between different charmonium states are essential to discriminate between different models



- For the bins with too small $\psi(2S)$ significance, an upper limit with 95% CL is calculated
- The $\psi(2S)$ is more suppressed than the J/ψ in semi-central and central collisions**

- The ratios between different charmonium states are essential to discriminate between different models



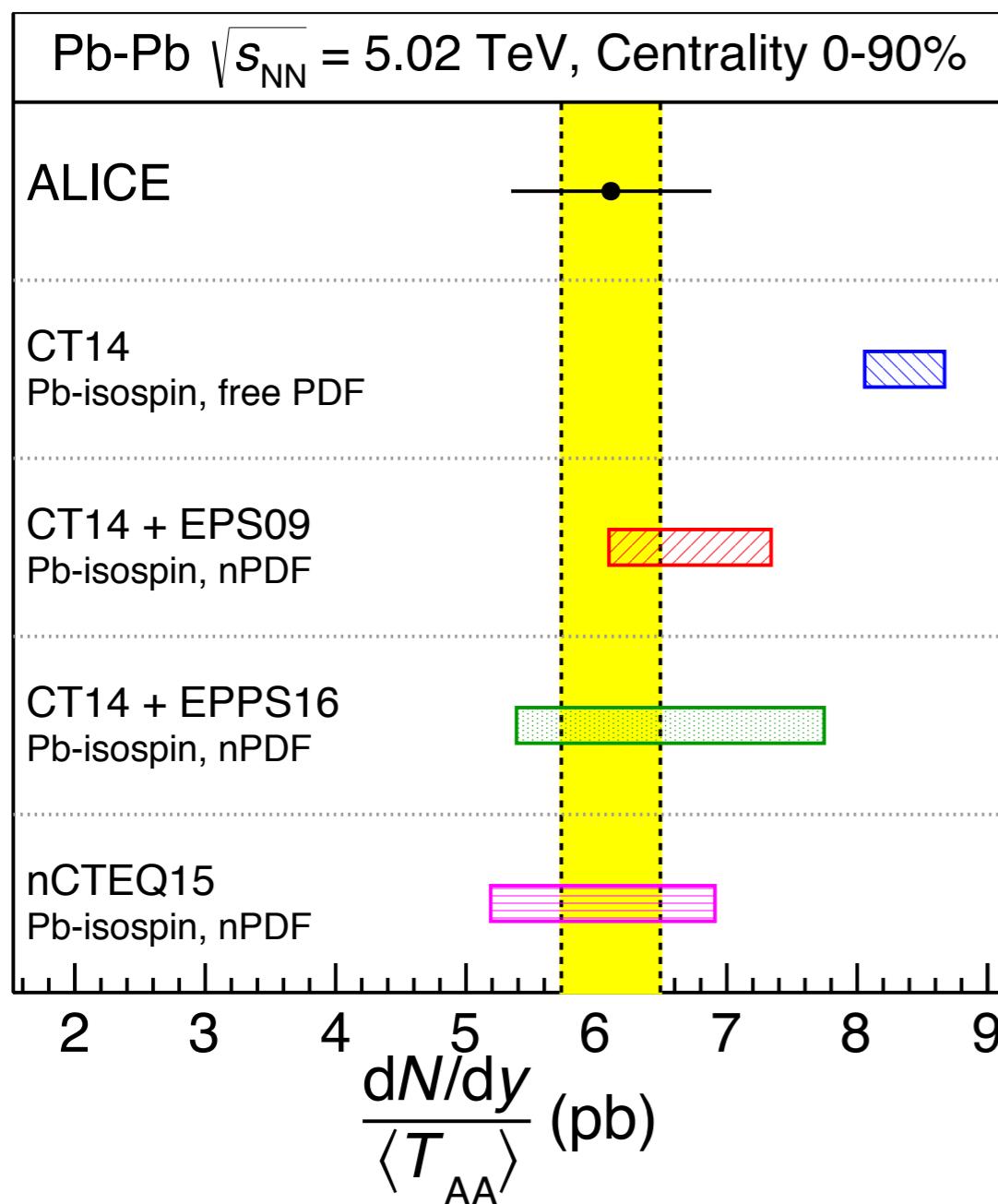
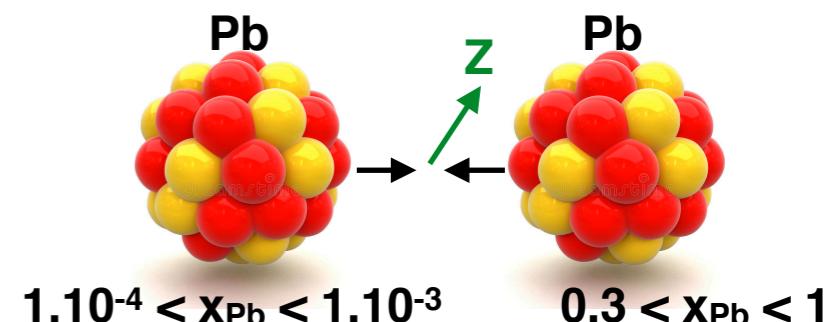
- The results of the double ratio at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$ are compatible within uncertainties with the ones from CMS

Z-boson production in Pb-Pb collisions I

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- Larger data sample than the p-Pb collisions at 5.02 TeV
- **First Z-boson measurement in Pb-Pb collisions at forward rapidity**

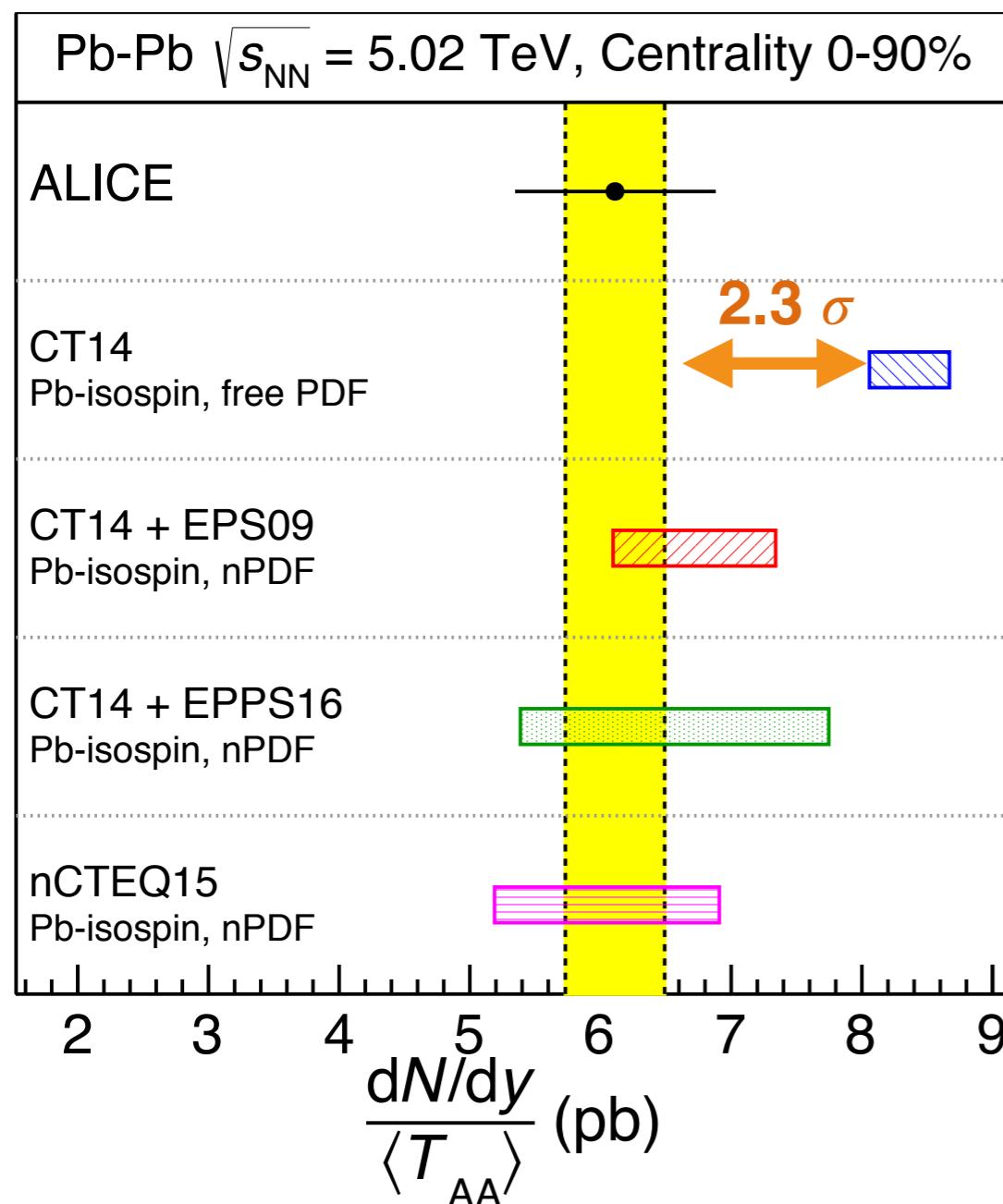
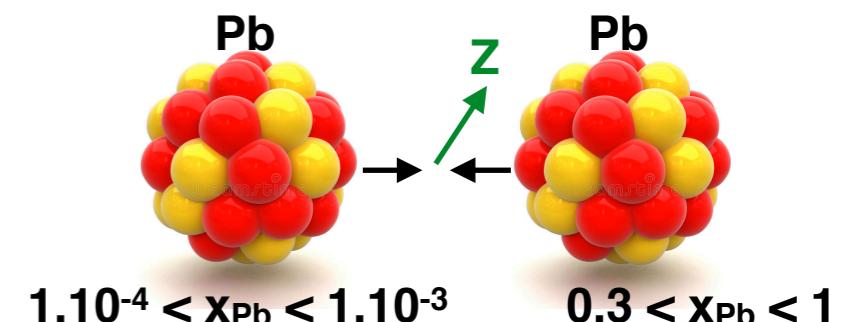


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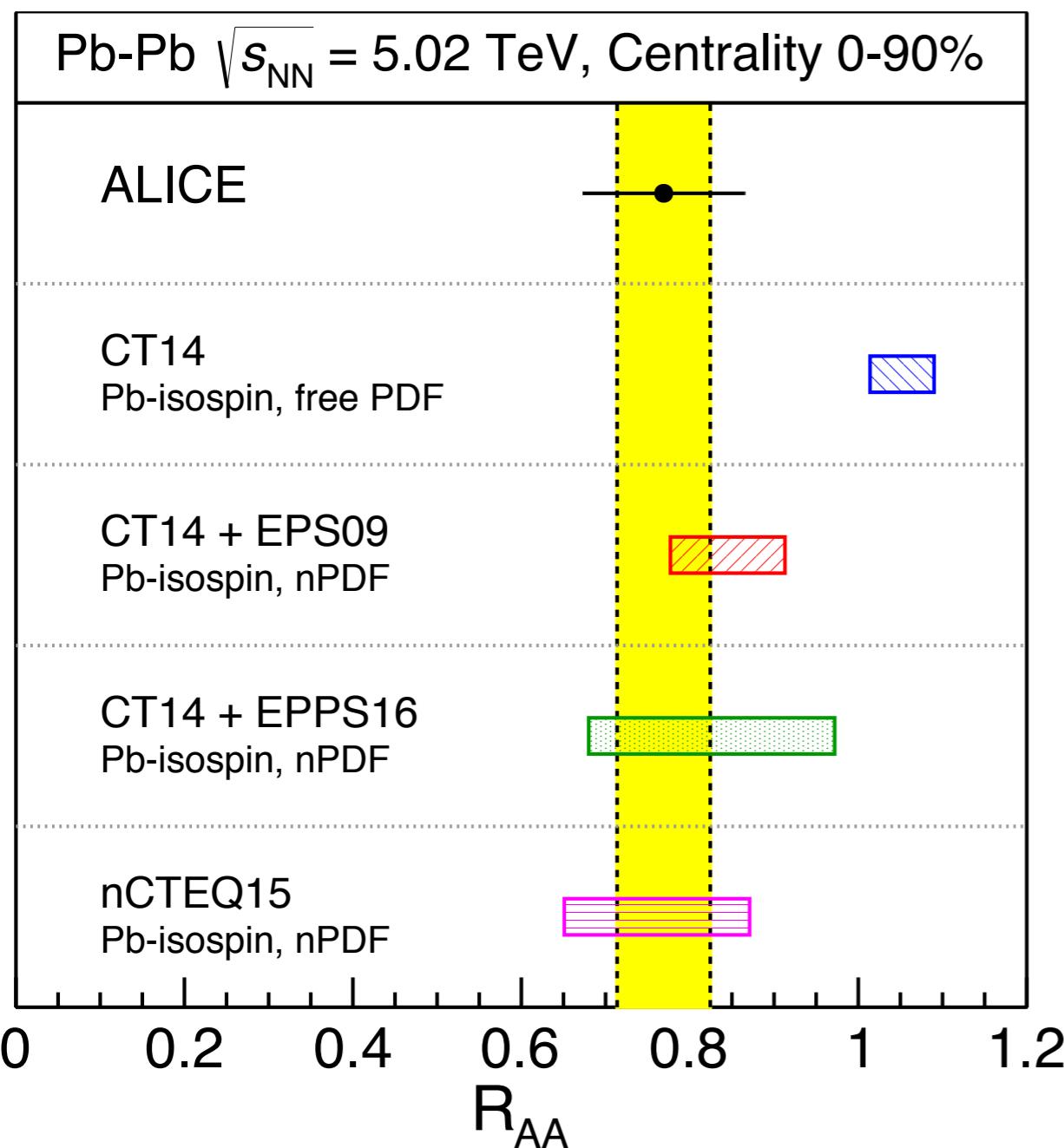
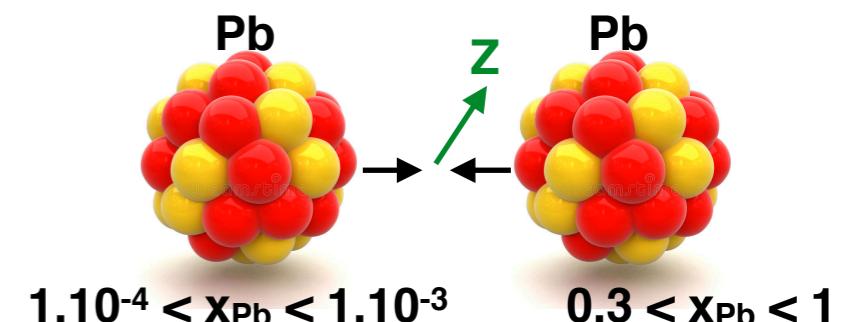
- 2.3 sigma separation between the results and the calculations without including nPDF
- Within uncertainties, the result is in agreement with the calculation using three different nPDF

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$$R_{AA} = \frac{Y^{AA}}{\langle T_{AA} \rangle \times \sigma_{pp}}$$

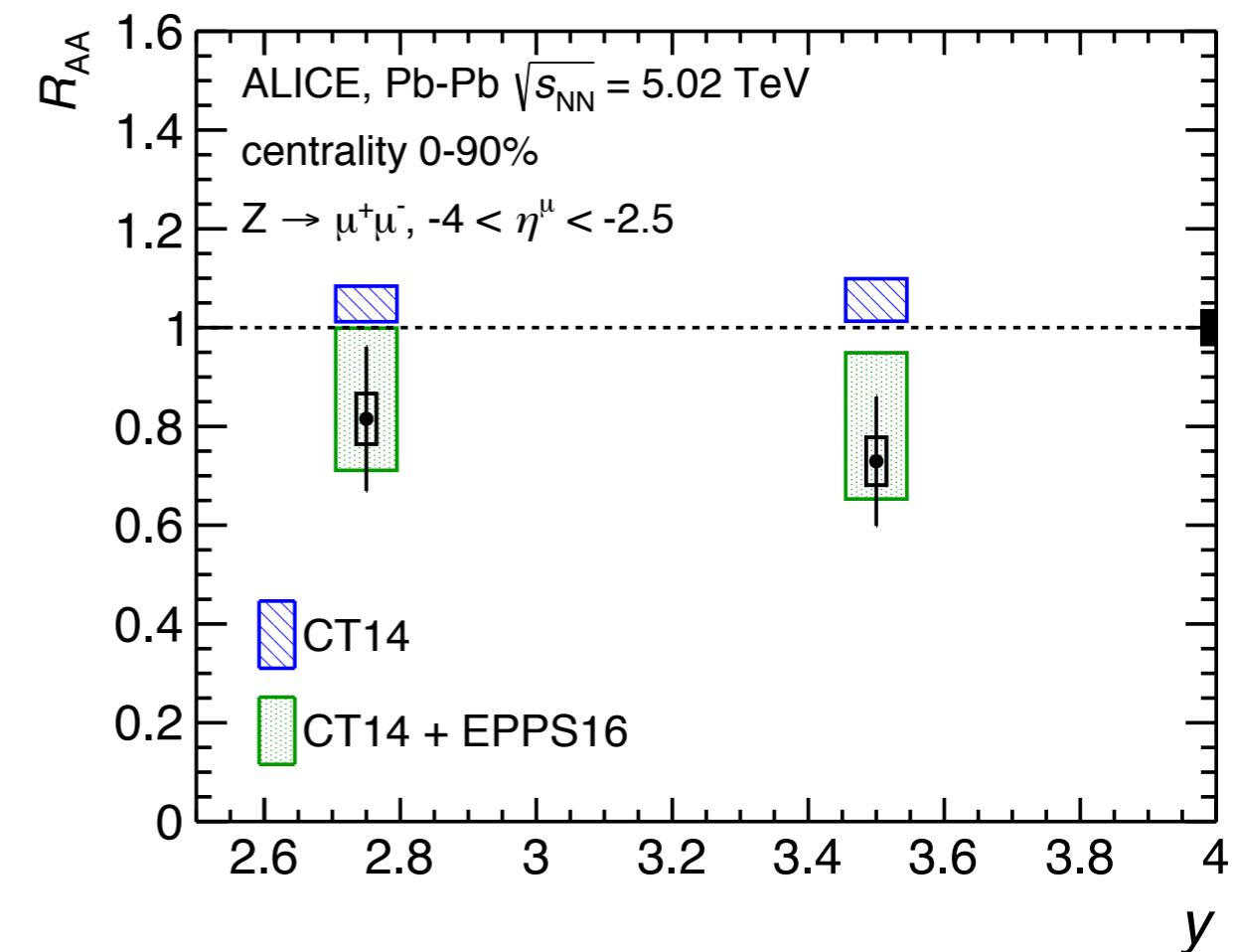
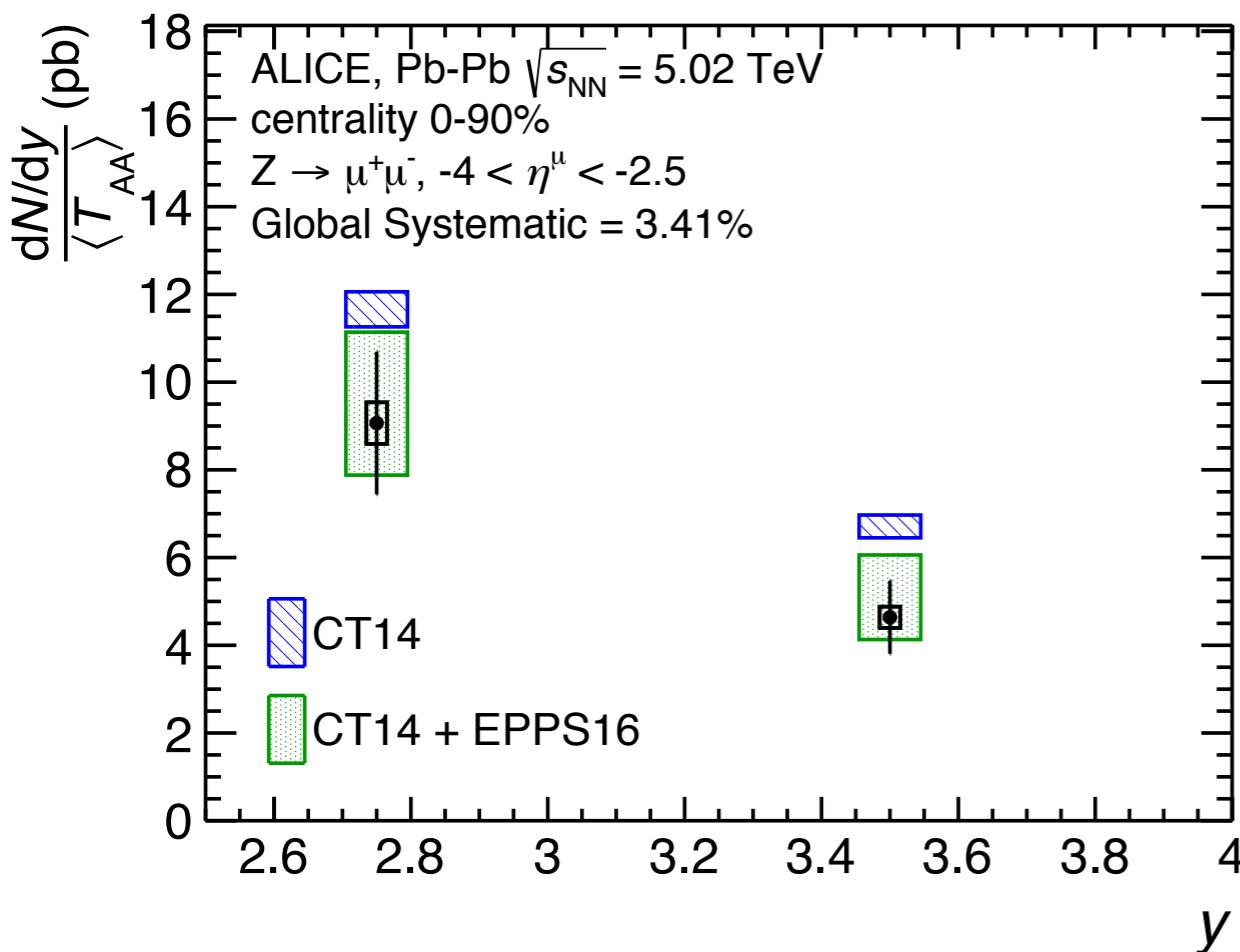
Using CT14NLO, $\sigma_{pp} = 11.92 \pm 0.43$ pb

Z-boson production in Pb-Pb collisions II

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- The nPDF modification is expected to have rapidity dependence
(At LO $x = (M_Z/\sqrt{s_{NN}})e^{\pm y}$)



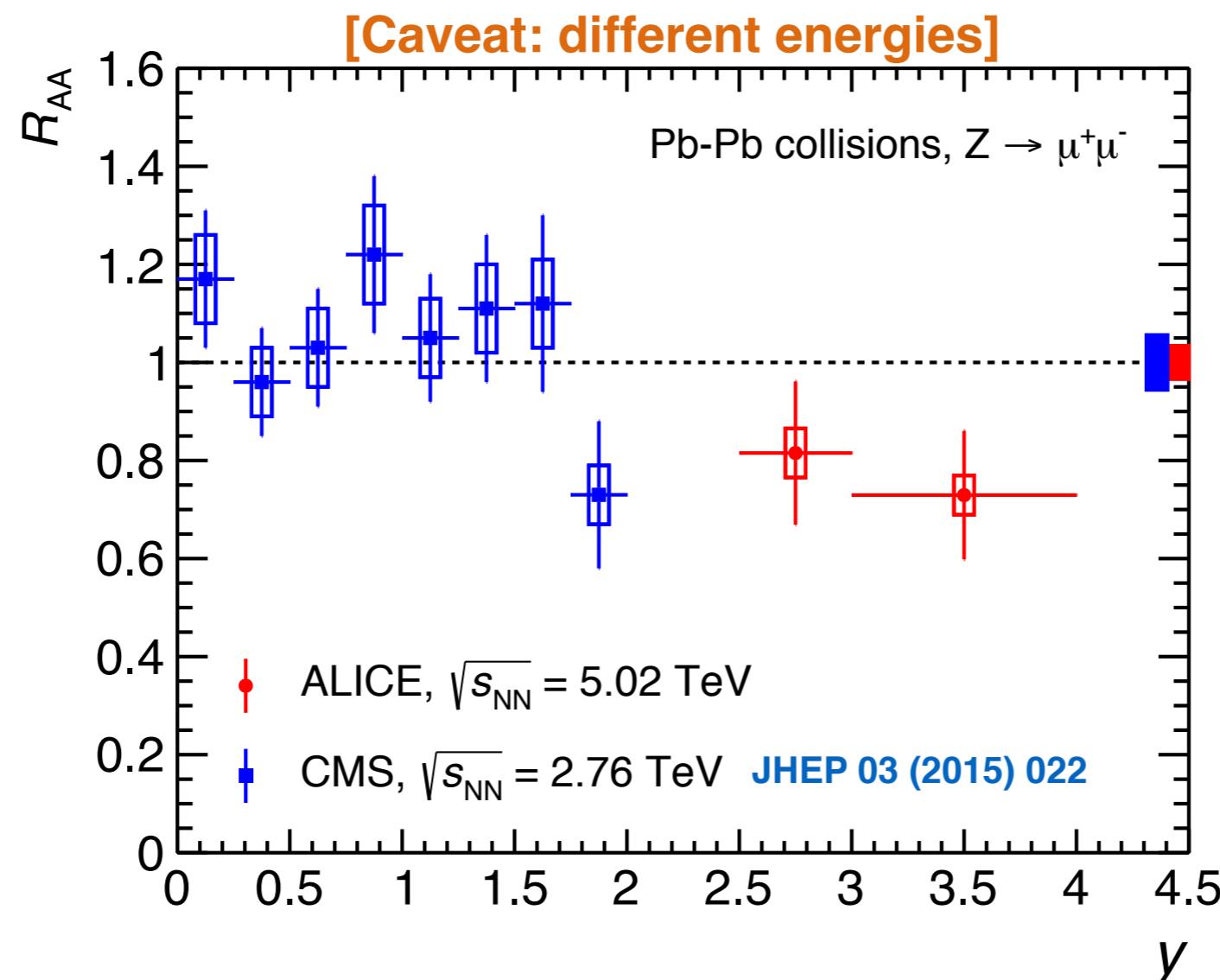
- The results are in a better agreement with the calculation that includes PDFs modification

Z-boson production in Pb-Pb collisions II

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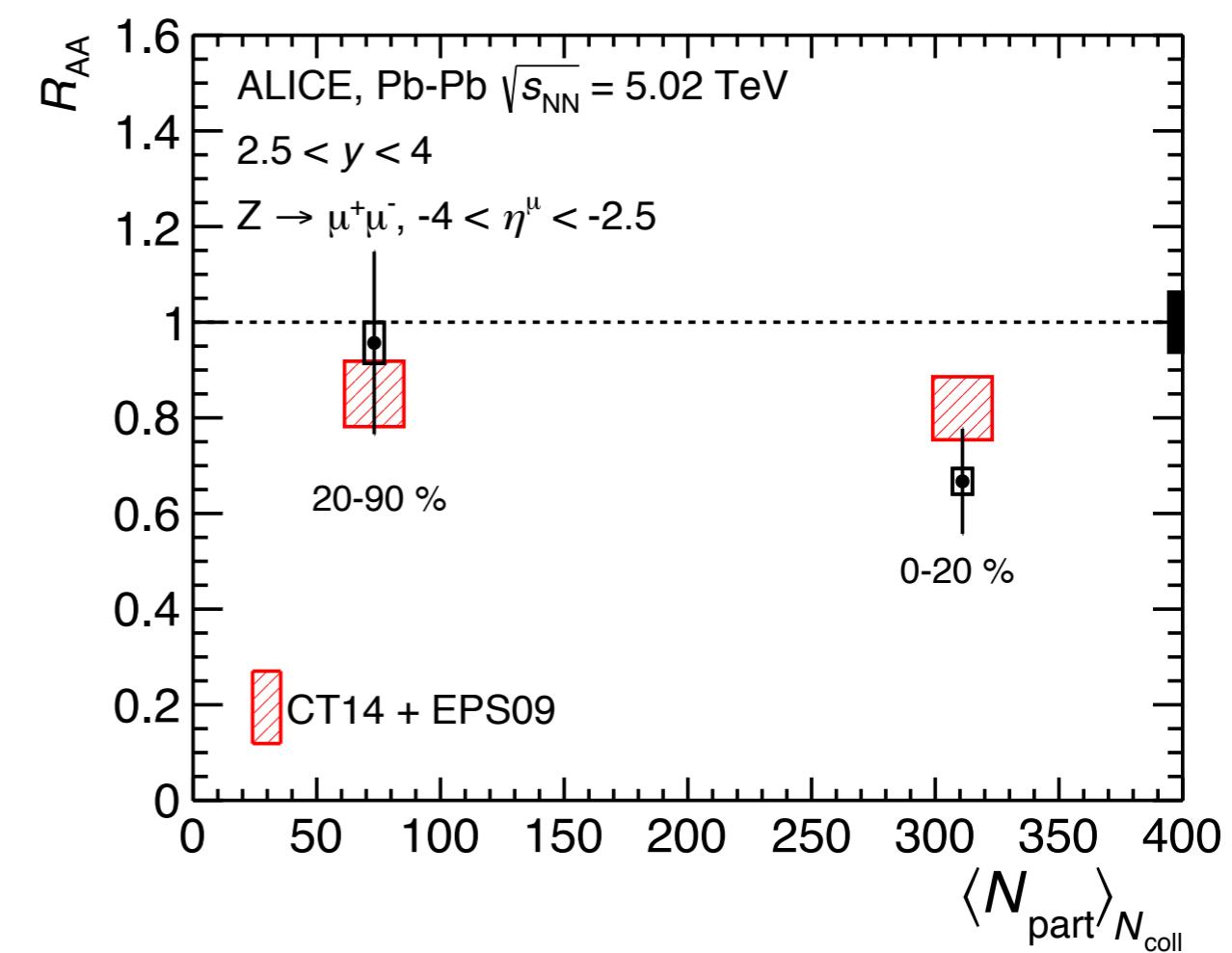
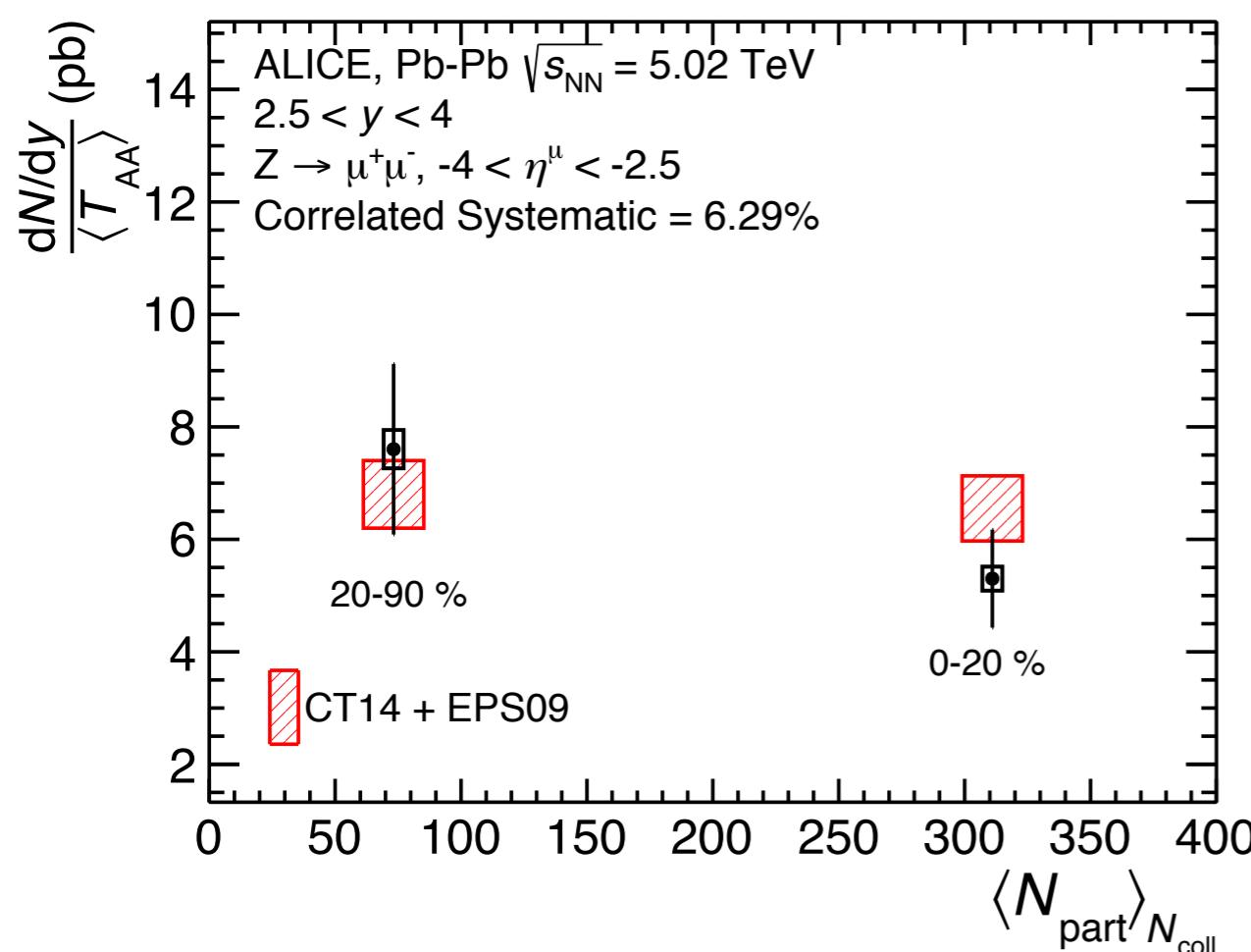
- The results are in a better agreement with the calculation that includes PDFs modification
- Complementary to the CMS and ATLAS rapidity coverage

Z-boson production in Pb-Pb collisions III

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- The centrality dependence probes the impact parameter dependence of nPDFs



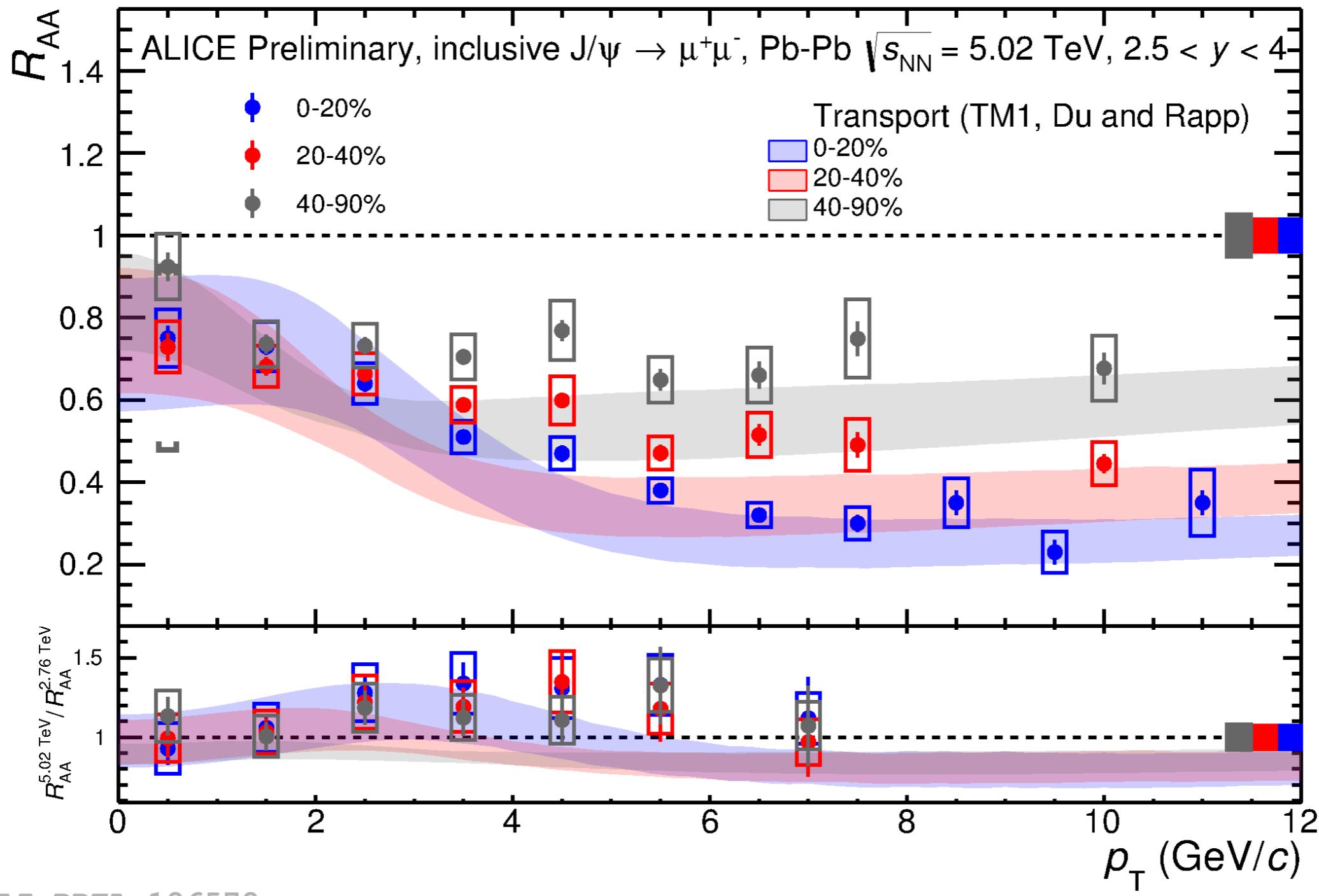
- R_{AA} smaller than one by 2.2 sigmas for 0-20% centrality
- The results are in agreement within uncertainties with calculations based on EPS09

- **Charmonia production in Pb-Pb at 5.02 TeV**
 - Clear J/ψ suppression
 - $R_{AA}(\text{low } p_T) > R_{AA}(\text{high } p_T)$
 - Small rapidity dependence
 - Different models (with large uncertainties) can describe the data
 - $\Psi(2s)$ seems to be more suppressed than J/ψ
- **Z-boson production in Pb-Pb at 5.02 TeV**
 - First measurement at forward rapidity
 - Results and predictions with free PDFs are separated by 2.2 sigmas

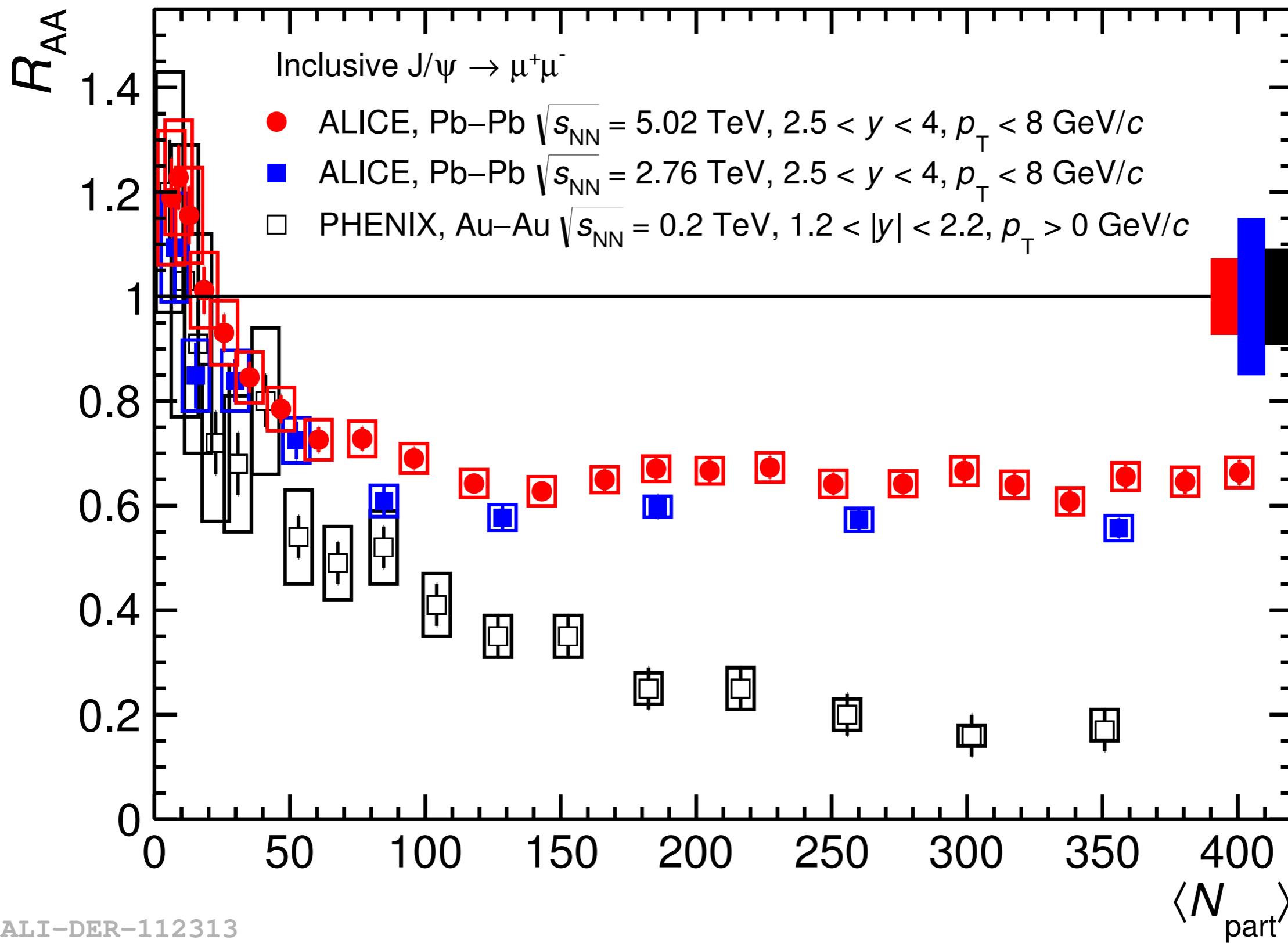
Extra slides

J/ψ Backup

J/ Ψ R_{AA} Vs p_T

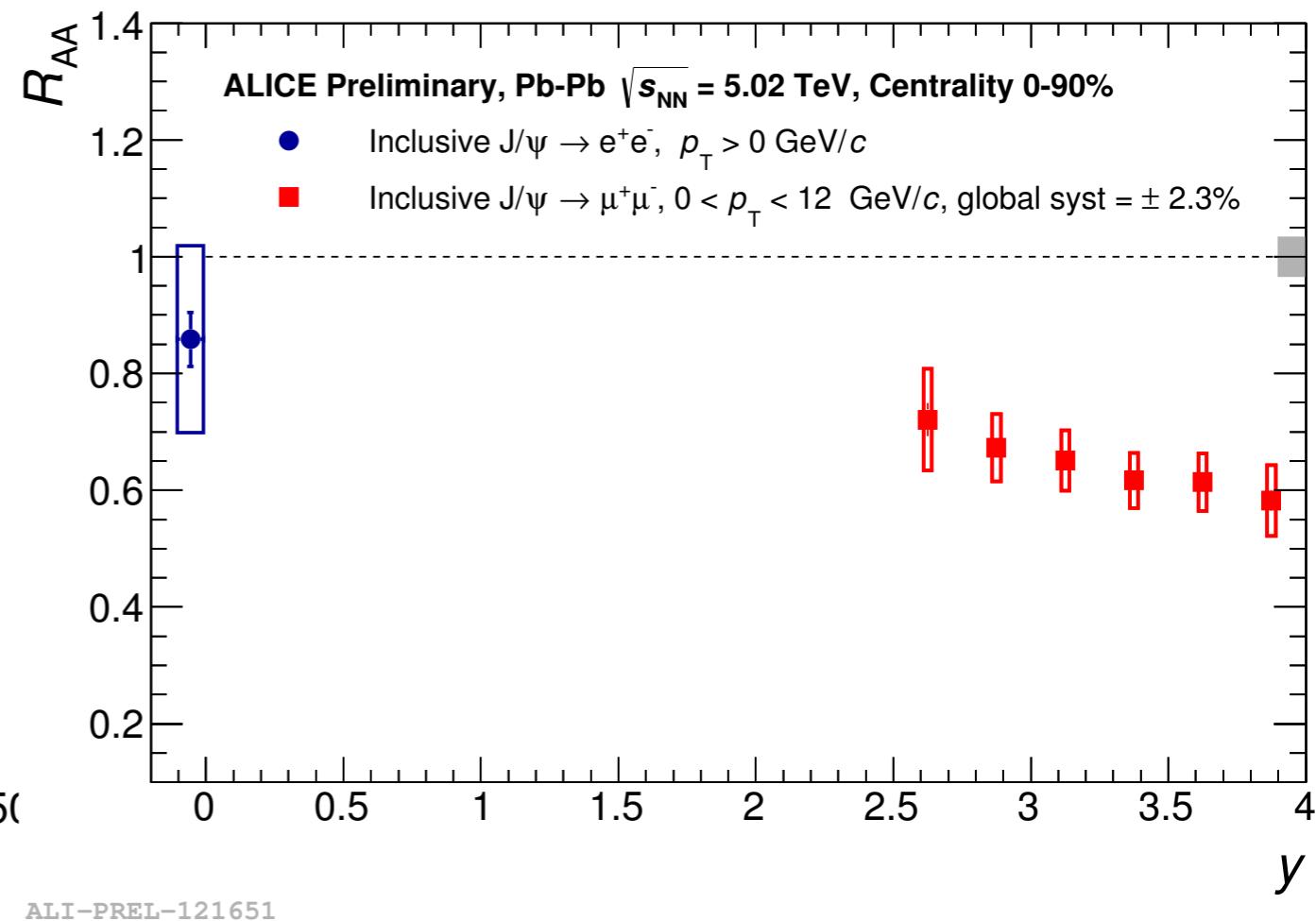
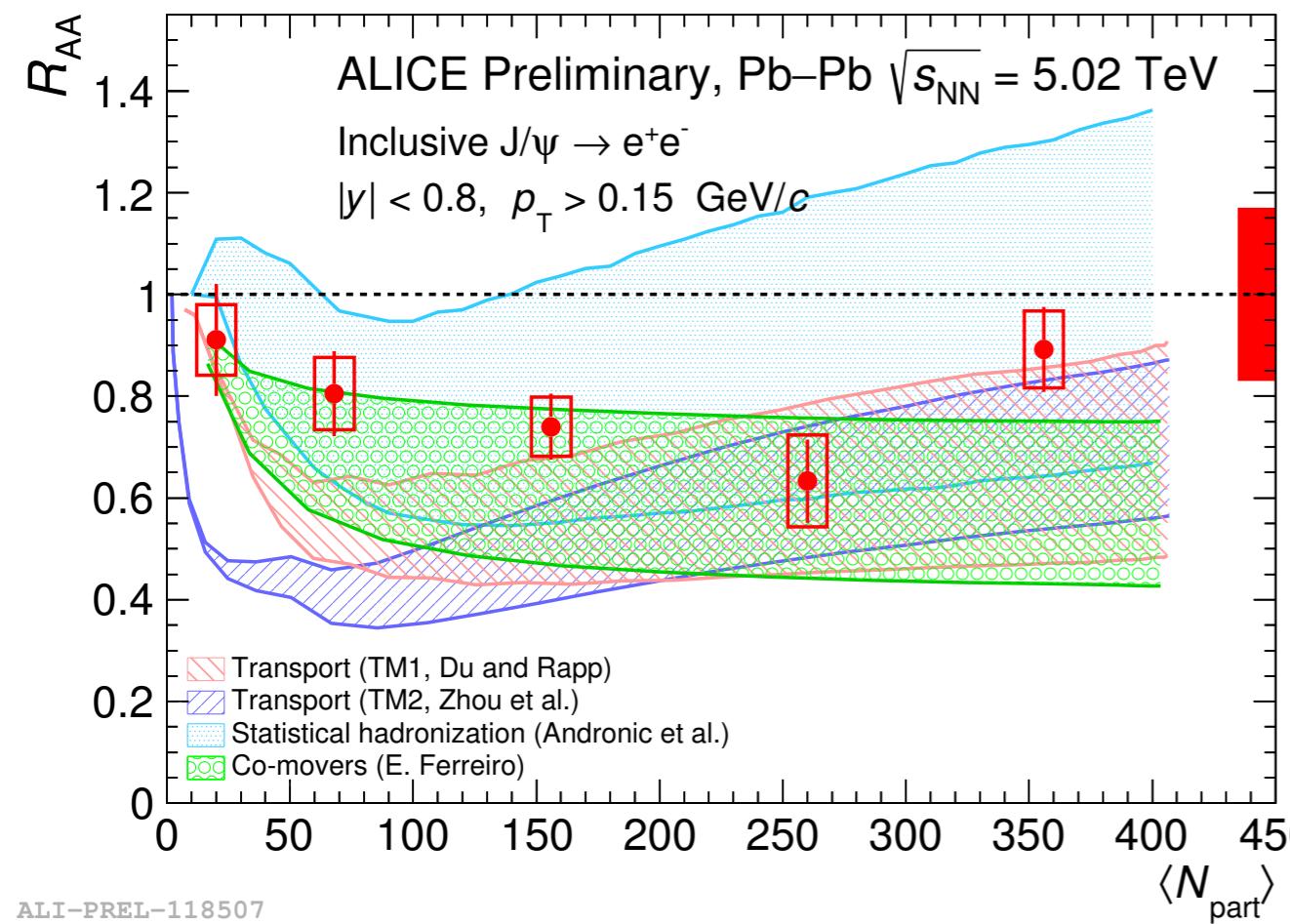


J/ Ψ R_{AA} LHC Vs RHIC



J/ ψ R_{AA} at mid-rapidity

- Reconstructed via the di-electrons decay channel using central barrel detectors



- Small centrality dependence
- Described by models (also large uncertainties!)

- Suppression is compatible at forward and mid-rapidity
- Need more precision to distinguish regeneration effect ?

Maximal variation of prompt R_{AA}

Vs
Centrality

p_T (GeV/c)	0-2	2-5	5-8	8-12
$R_{AA}(\text{non-prompt}) = 0$	+10% → +17%	+10% → +17%	+10% → +17%	+10% → +17%
$R_{AA}(\text{non-prompt}) = 1$	+10% → +17%	+10% → +17%	+10% → +17%	+10% → +17%

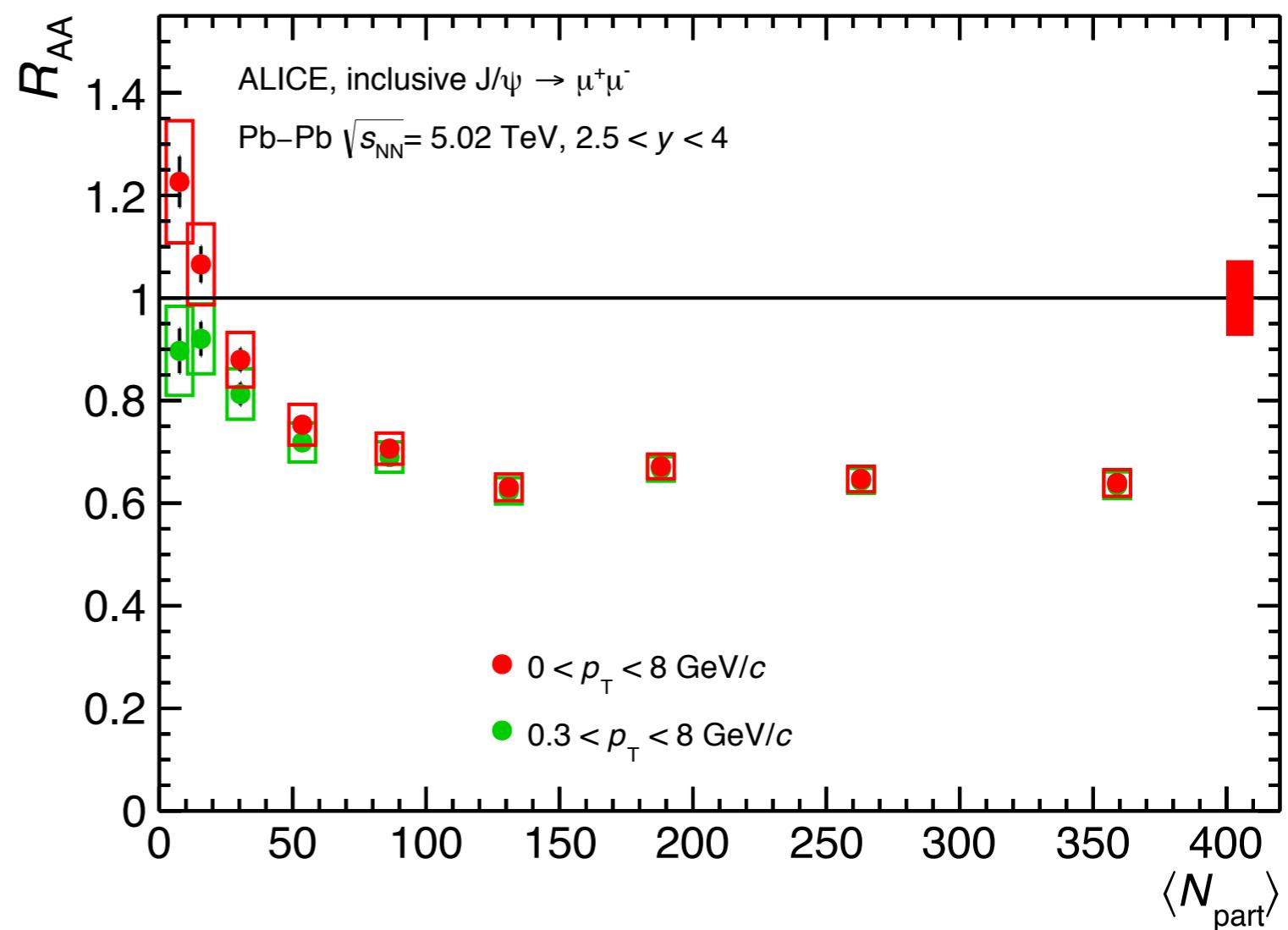
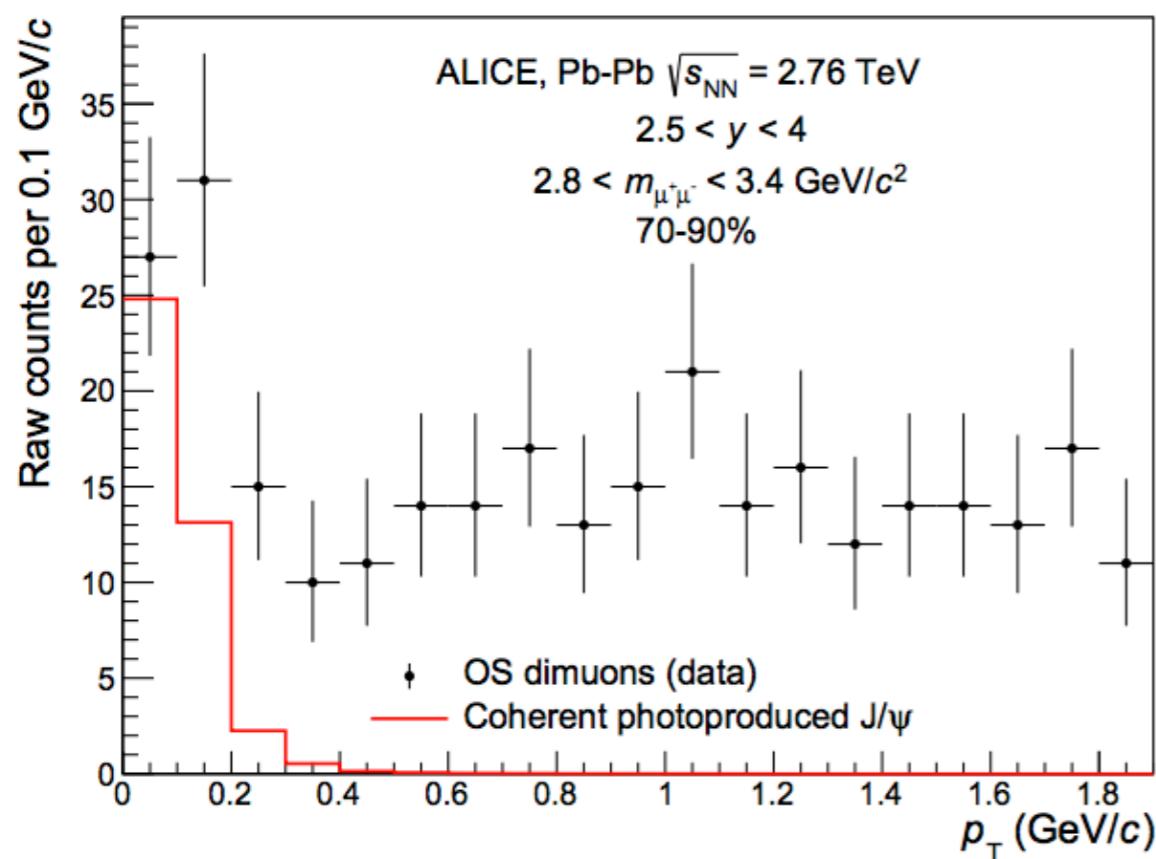
Vs Pt

<i>centrality (%)</i>	0-20	20-40	40-90
$R_{AA}(\text{non-prompt}) = 0$	+10% → +17%	+10% → +17%	+10% → +17%
$R_{AA}(\text{non-prompt}) = 1$	+10% → +17%	+10% → +17%	+10% → +17%

Vs y

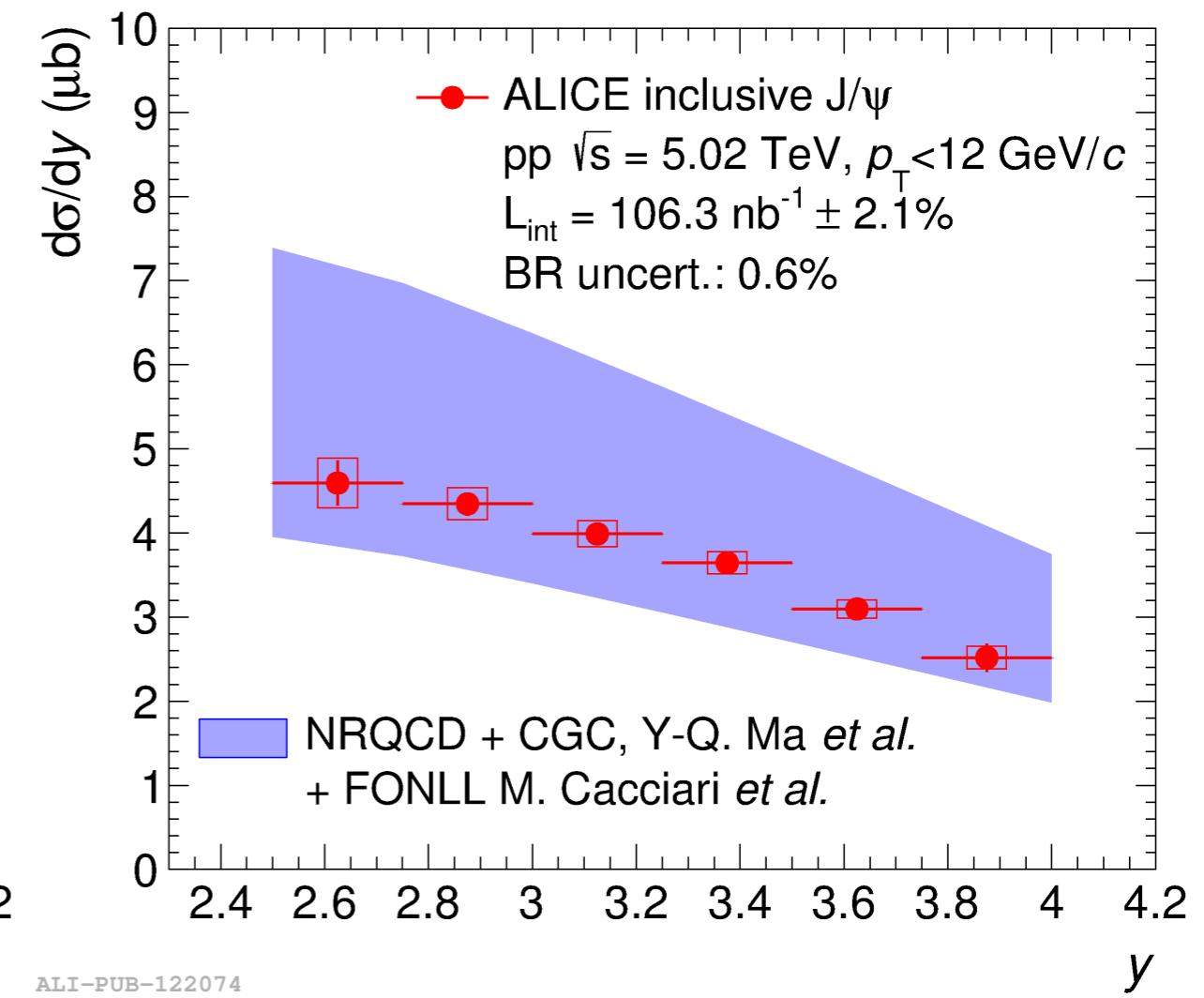
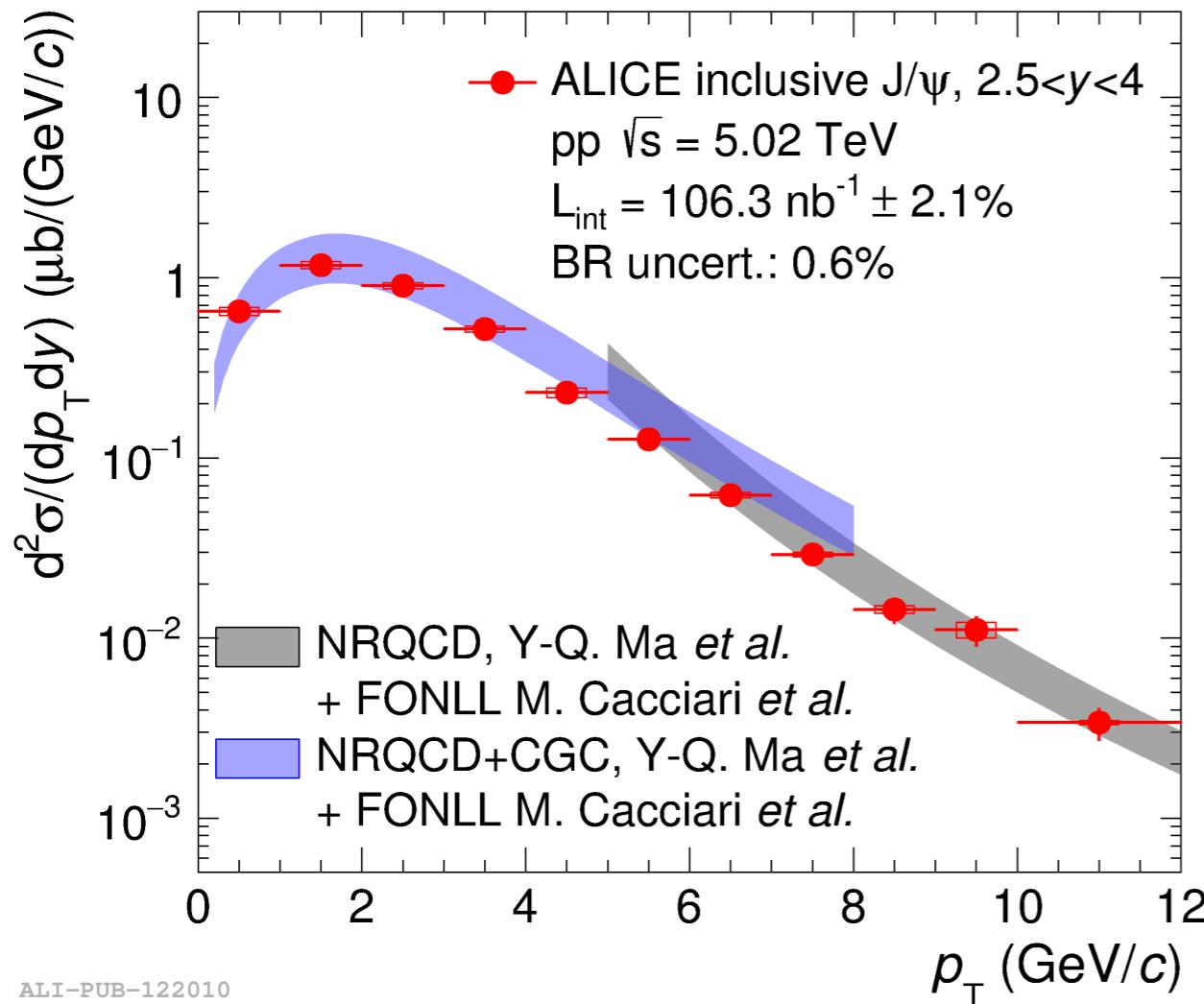
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Effect of 300 MeV pT cut



pp cross section at 5.02 TeV

- The psi pp cross section used in the denominator of R_{AA} is measured using LHC data



- Based on a sample of about 8000 J/ψ
 - Precision is improved with respect to 2.76 TeV
- Within uncertainties, the cross section can be described by a “composite” theoretical calculation

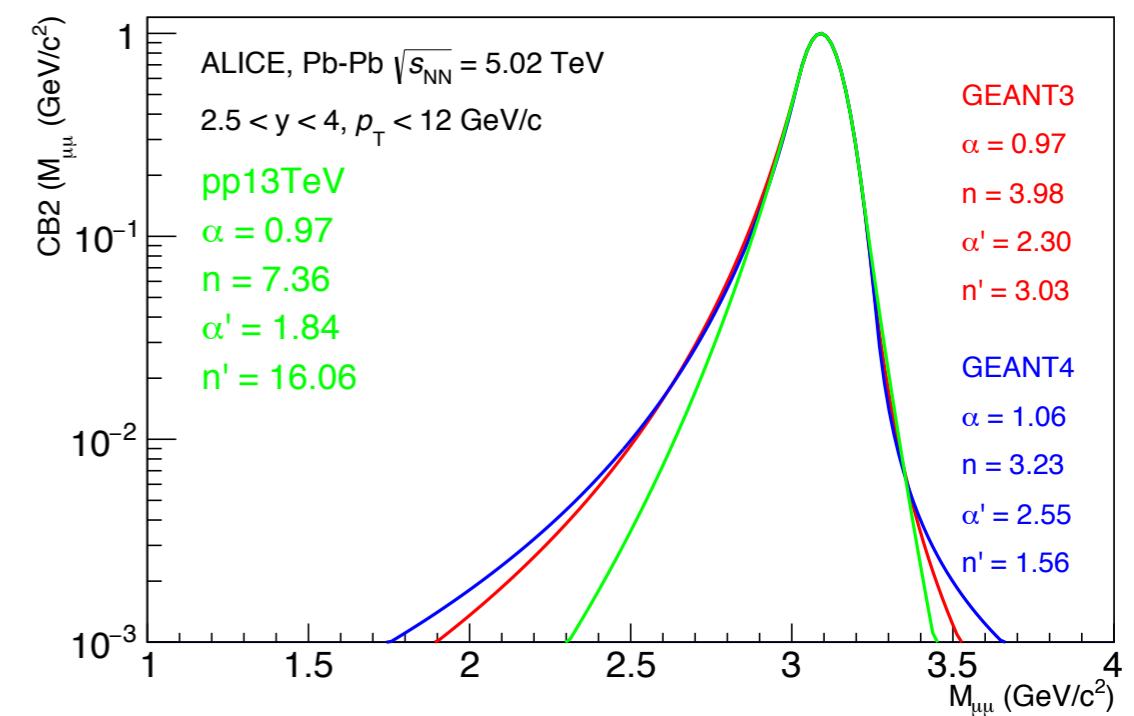
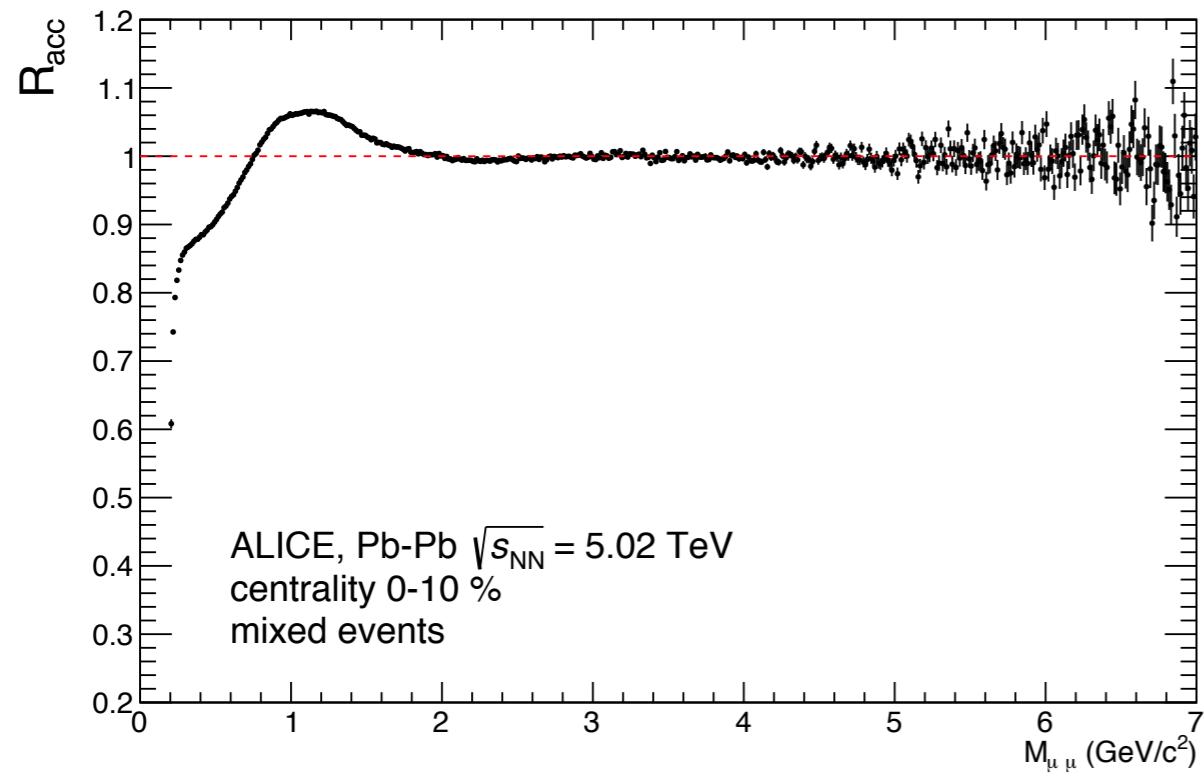
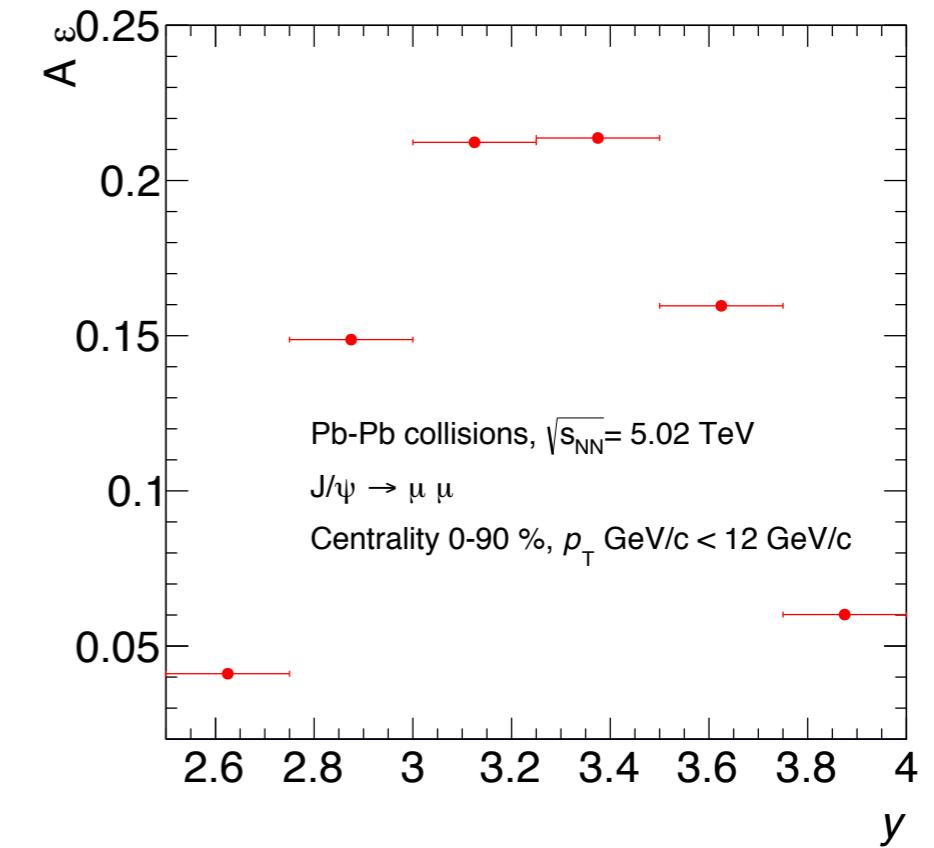
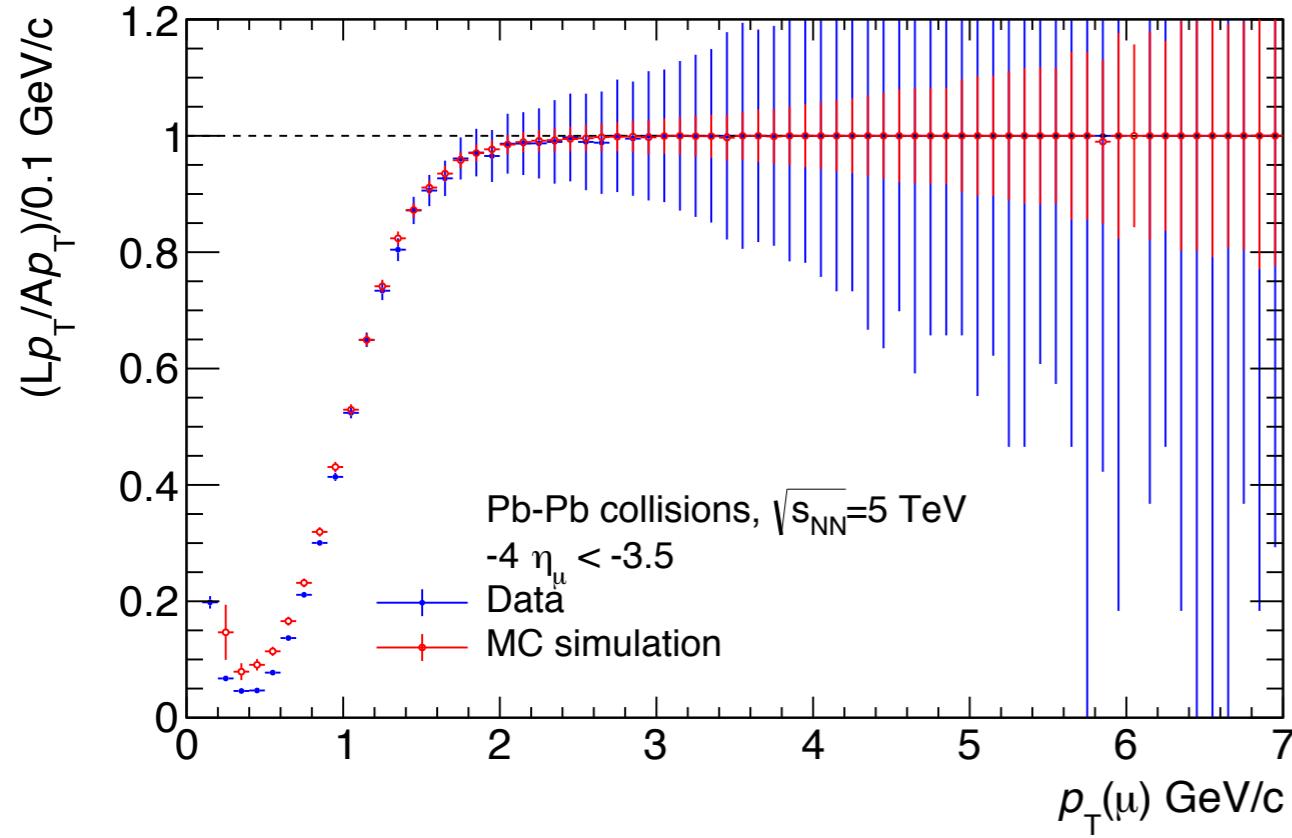
Models

model	$\sigma_{c\bar{c}}$	N-N $\sigma_{J/\Psi}$	comover $\sigma_{J/\Psi}$	non-prompt contribution
Transport(Rapp)	0.57 mb consistent with FONLL and take 5% error. shadowing is varied between 10 and 25%	3.14 μb	-	Yes
Transport(Zhou)	0.82 mb upper limits of FONLL. either 0 shadowing or central set of EPS09	3.5 μb	-	Yes
Stat. hadronization	0.45 mb LHCb at 7 TeV + extrapolation with FONLL 17% error including shadowing	-	-	No
Comovers	[0.45,0.7] mb	3.53 μb	0.65 mb	No

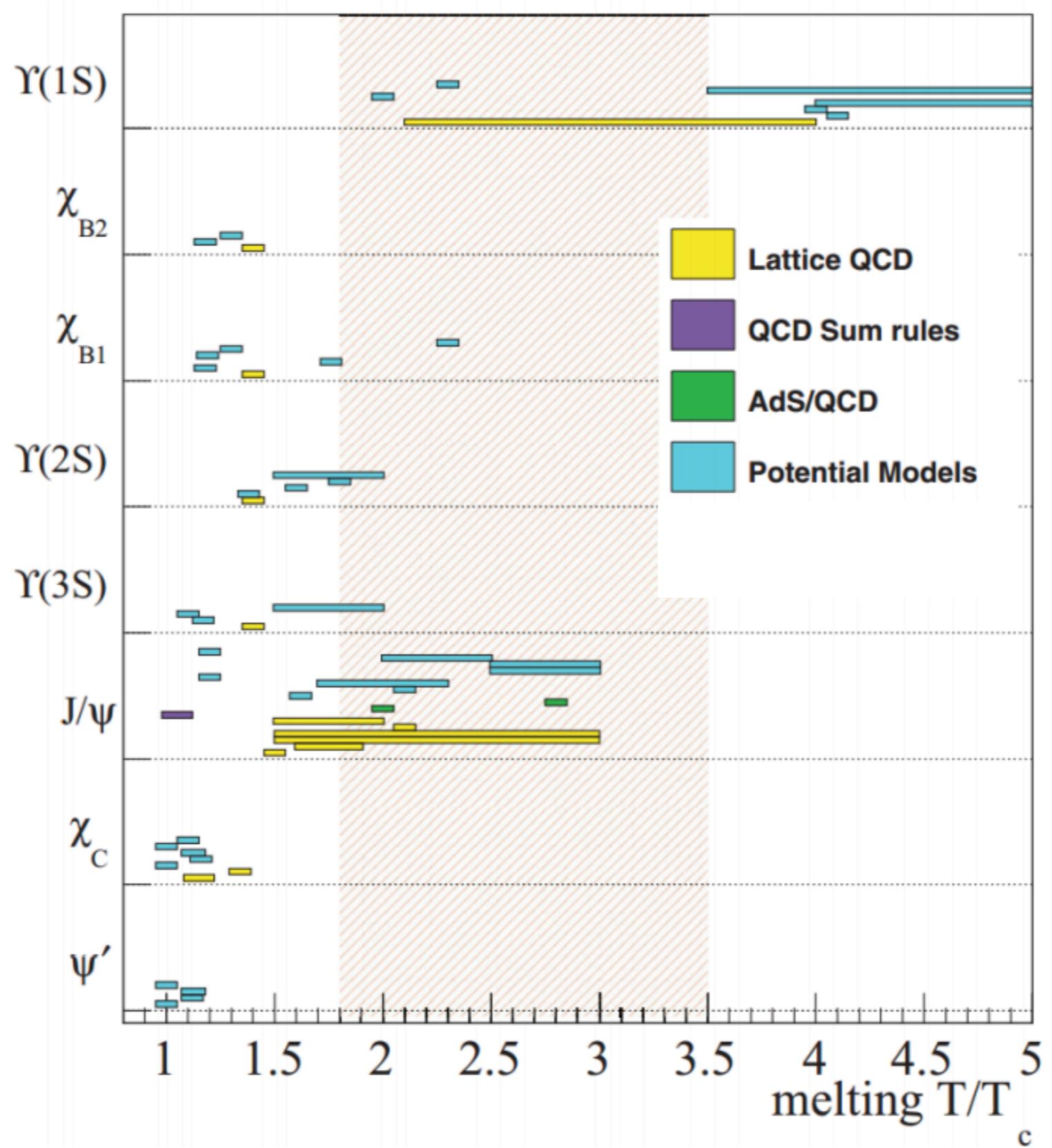
statistical weight for stat hadronization

$$\langle n_j \rangle = \frac{(2J_j + 1)V}{(2\pi)^3} \int d^3 p \left[e^{\sqrt{p^2 + m_j^2}/T + \mu \cdot q_j/T} \pm 1 \right]^{-1}$$

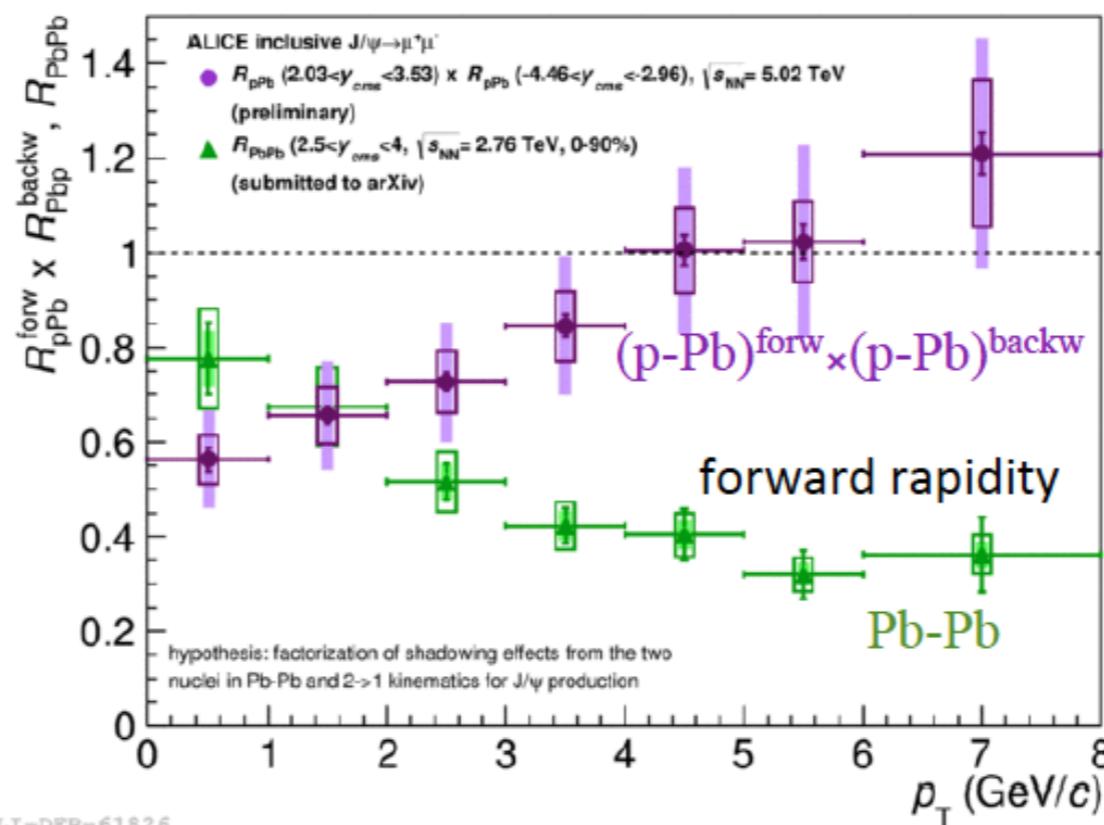
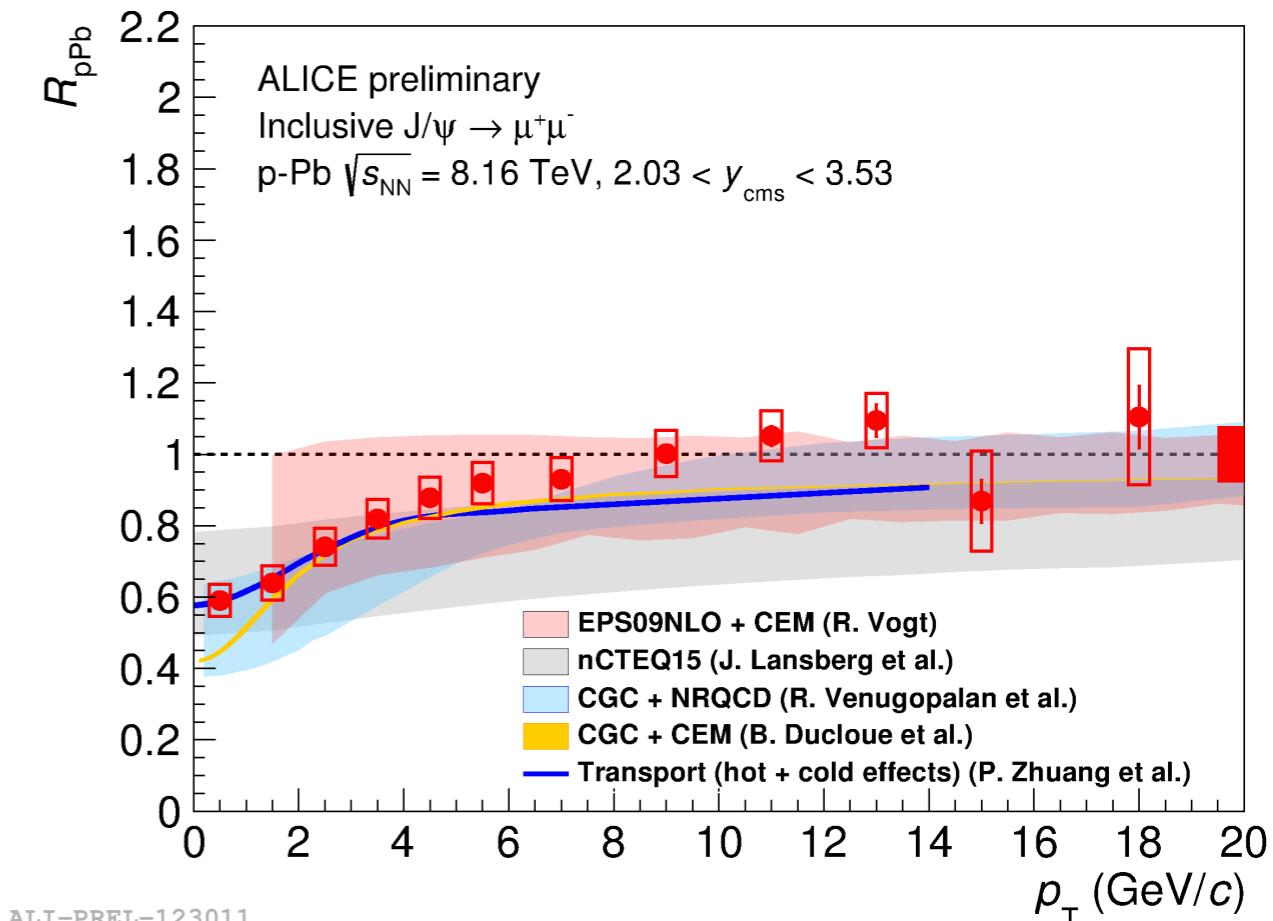
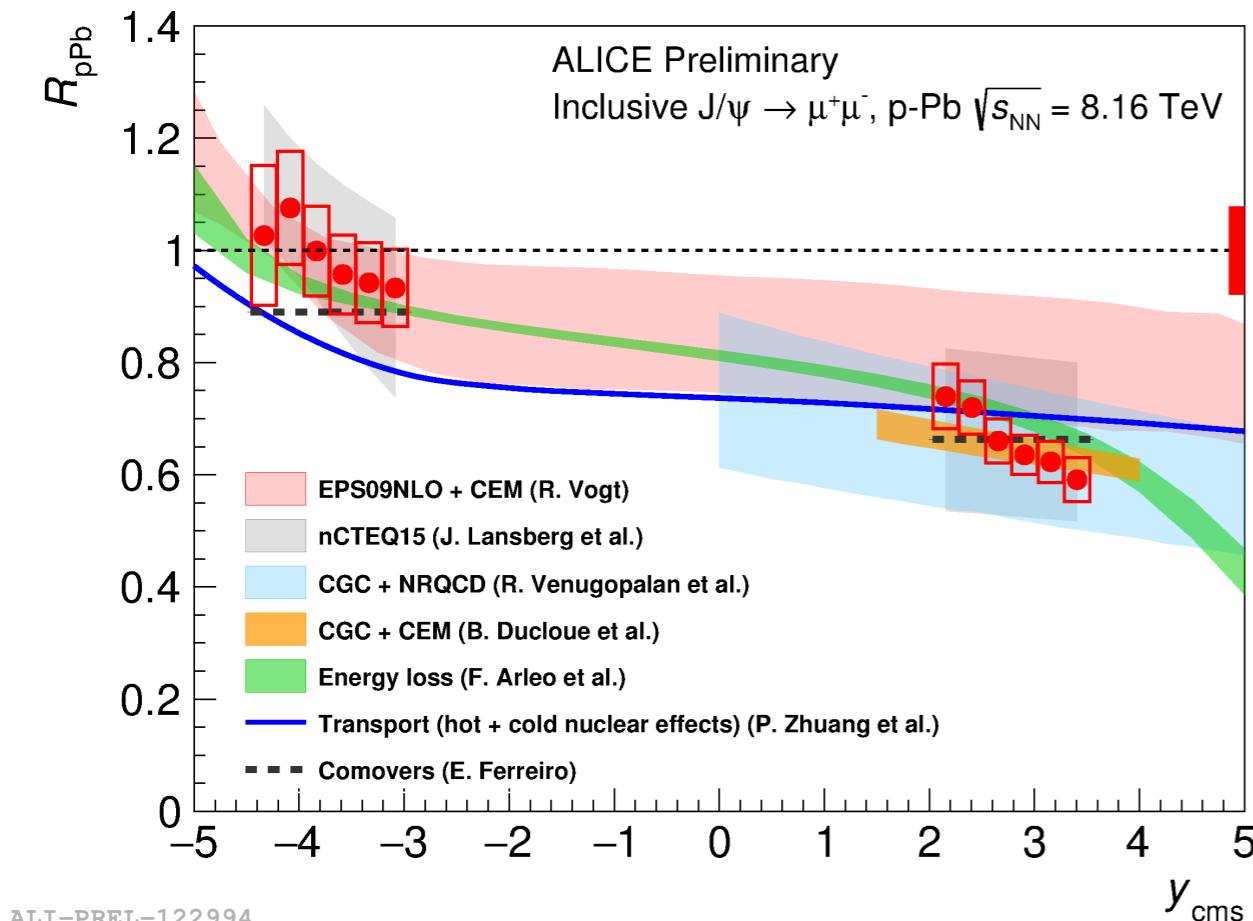
Jpsi Analysis



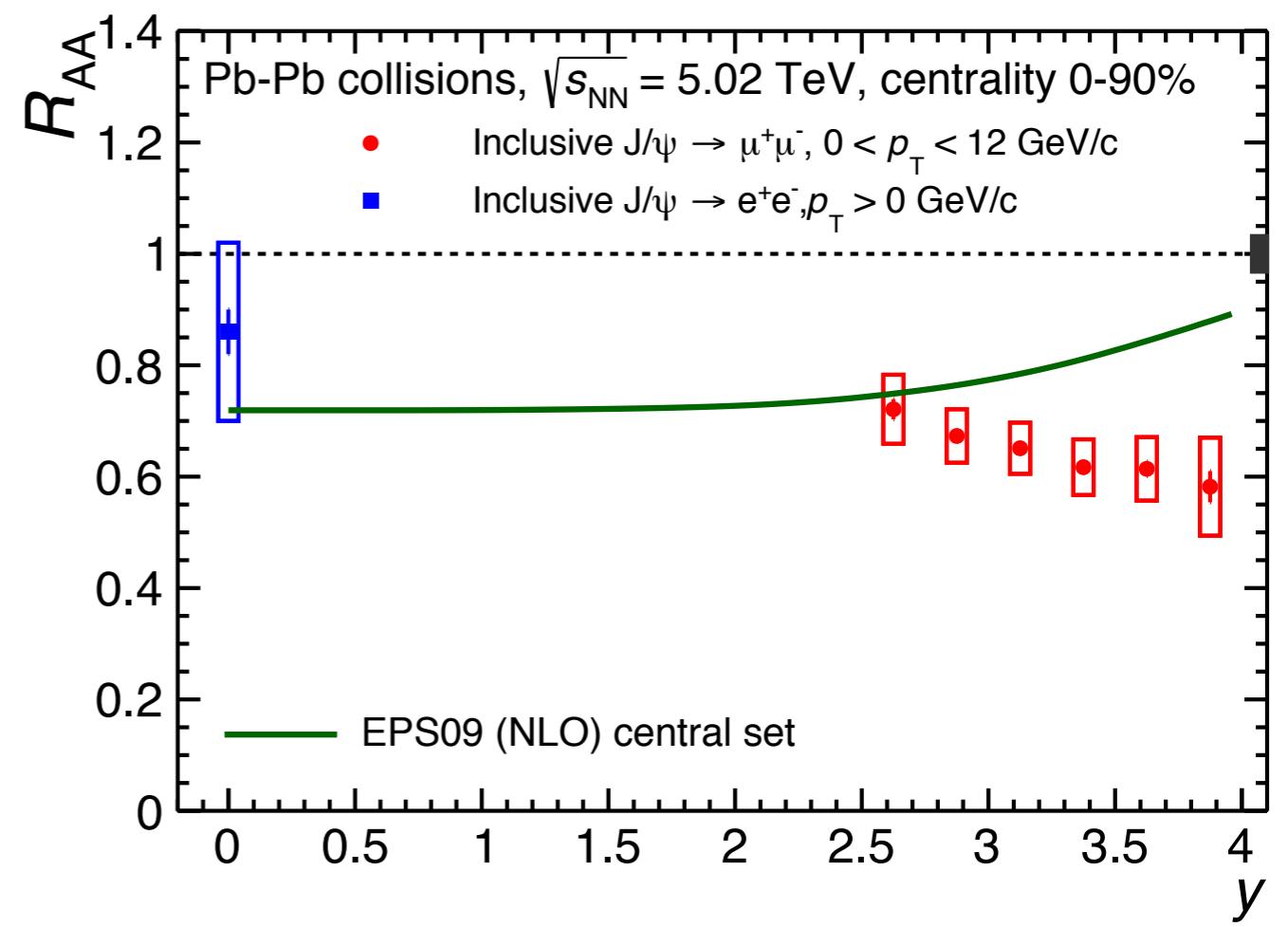
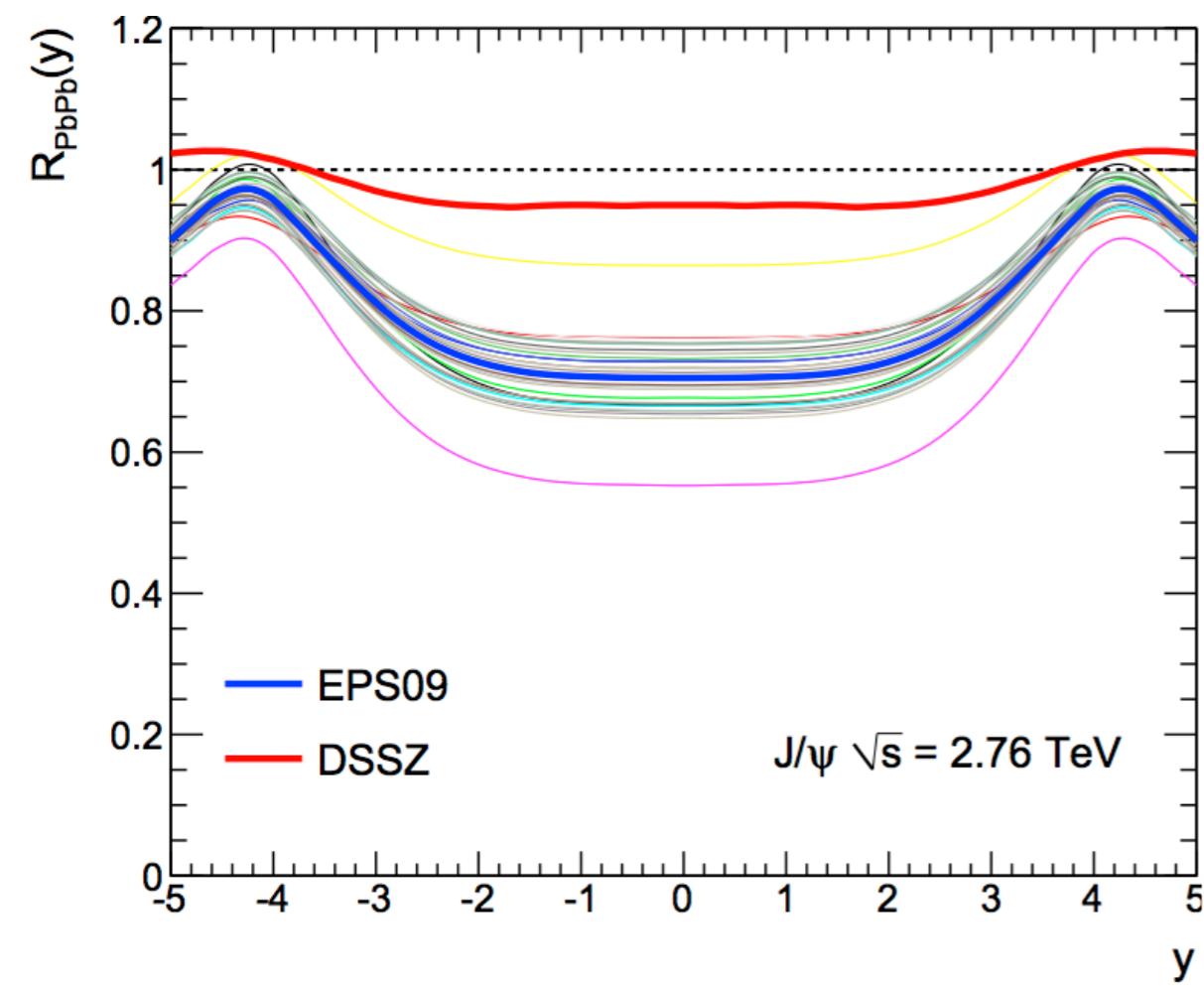
Charmonium Tc



J/ ψ in p-Pb collisions at $\sqrt{s_{NN}} = 8.16$ TeV

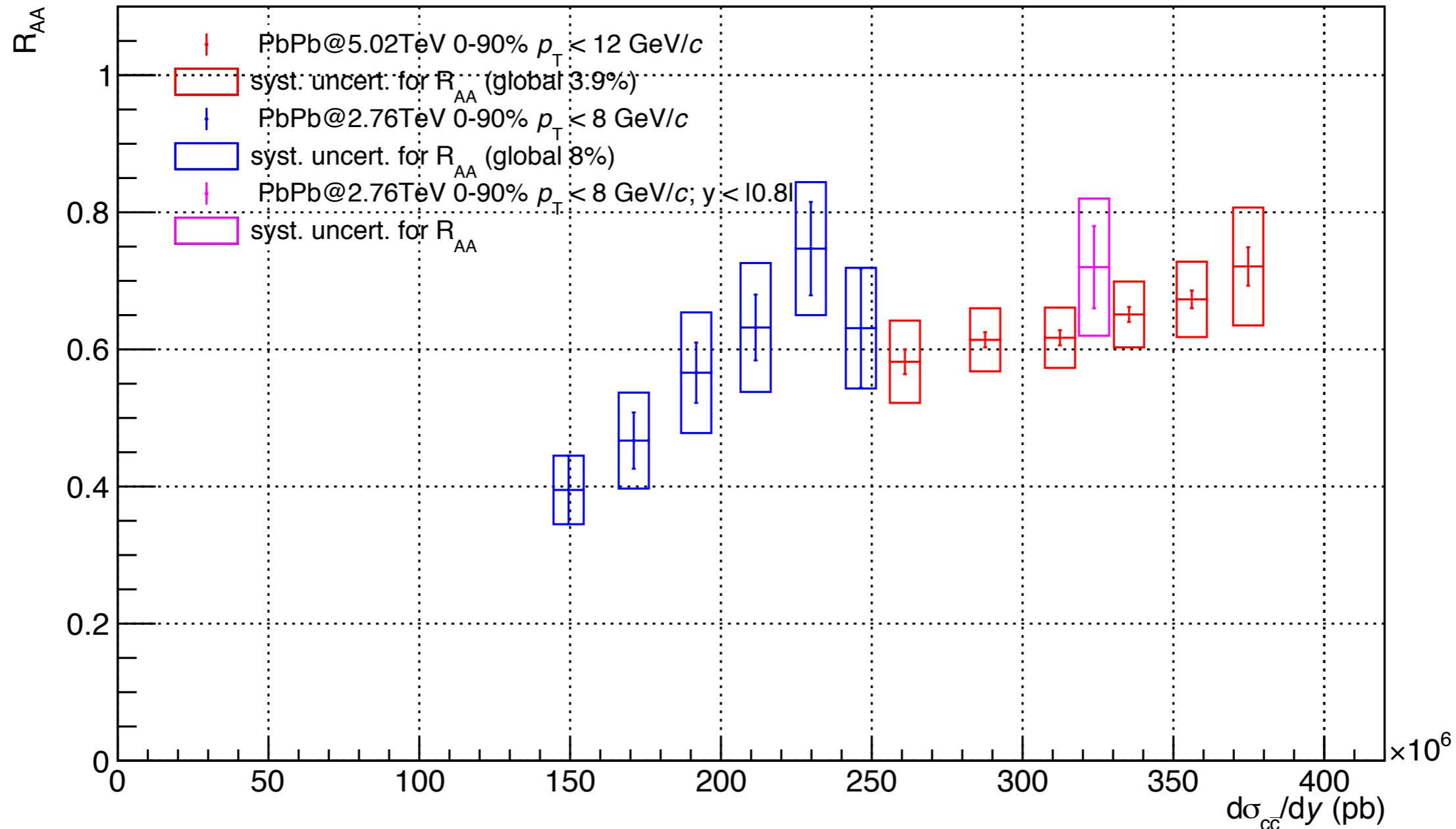


Jpsi Shadowing



J/ ψ R_{AA} vs Rapidity

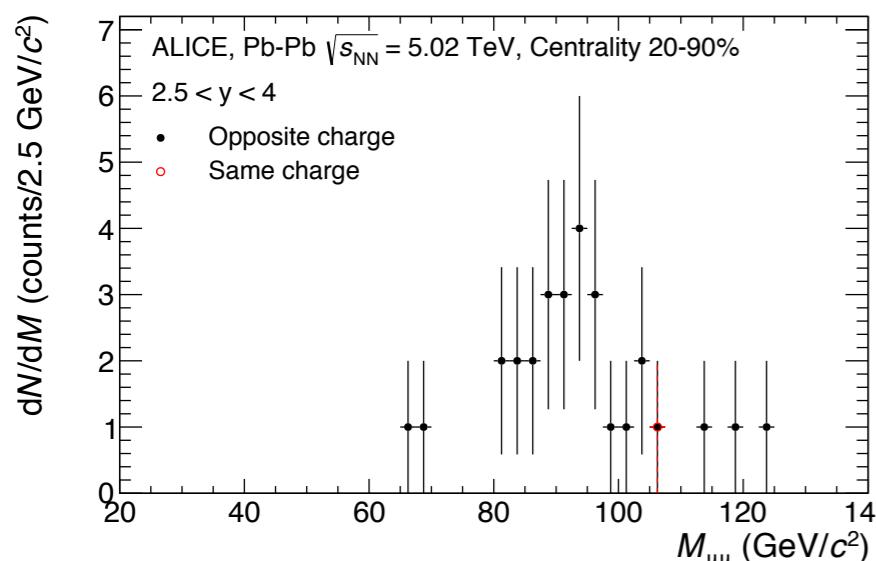
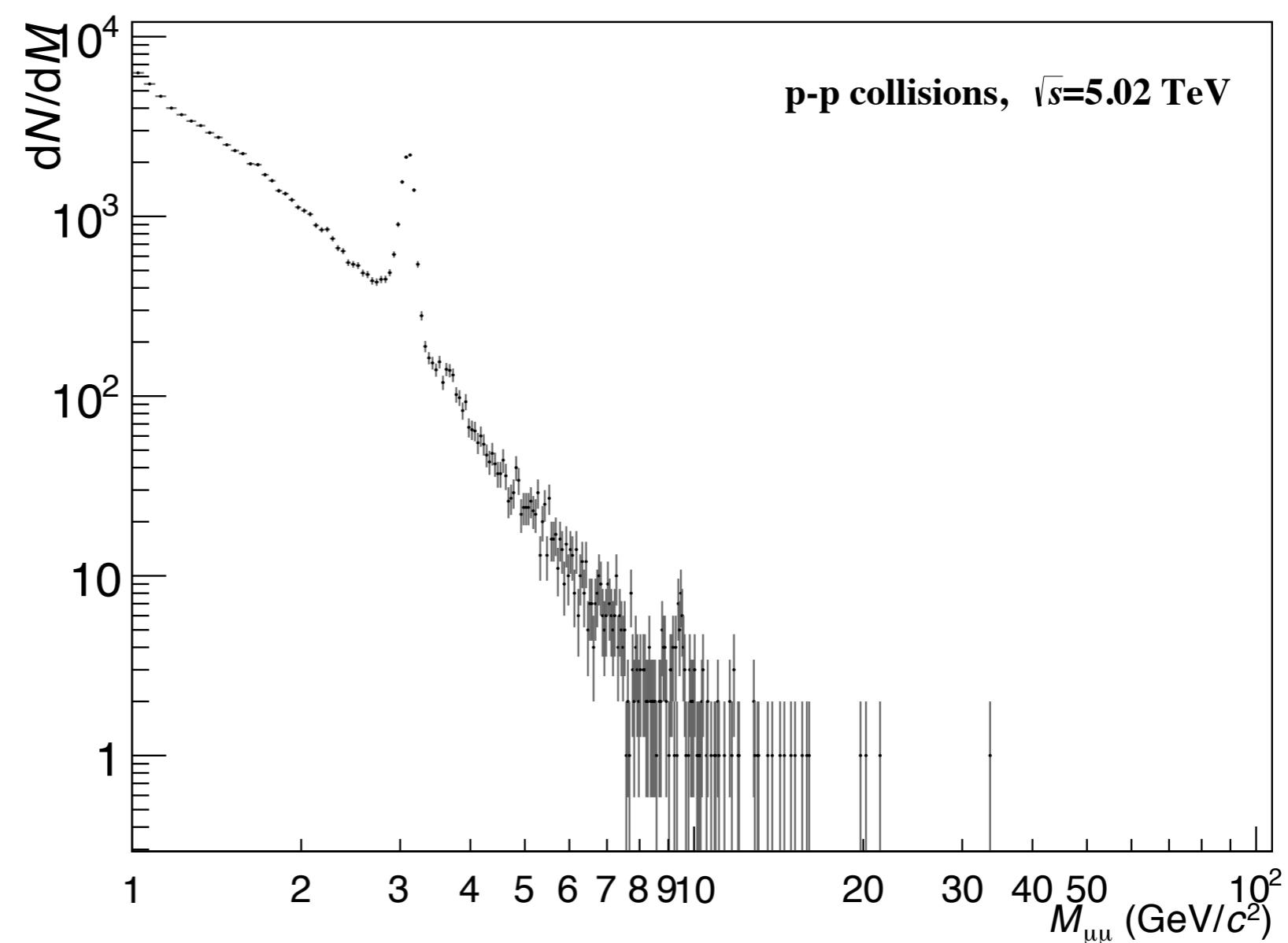
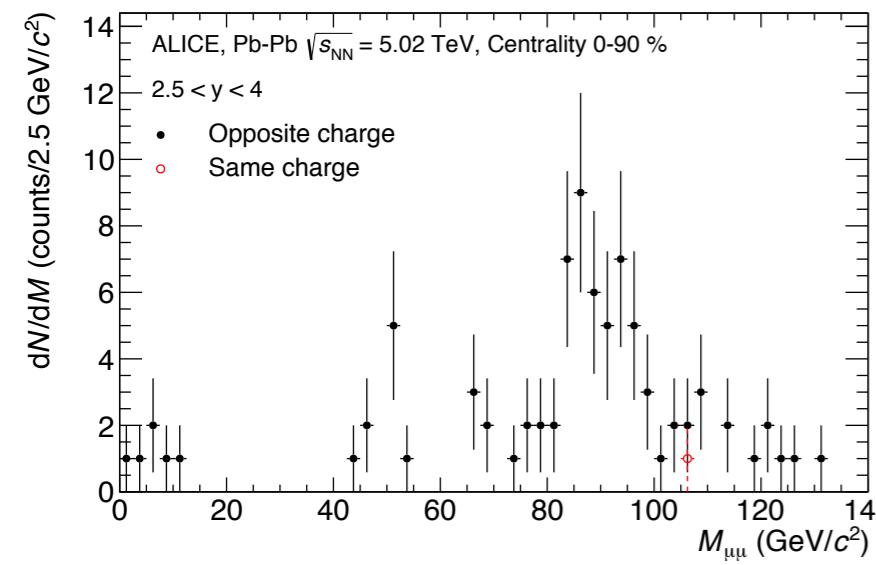
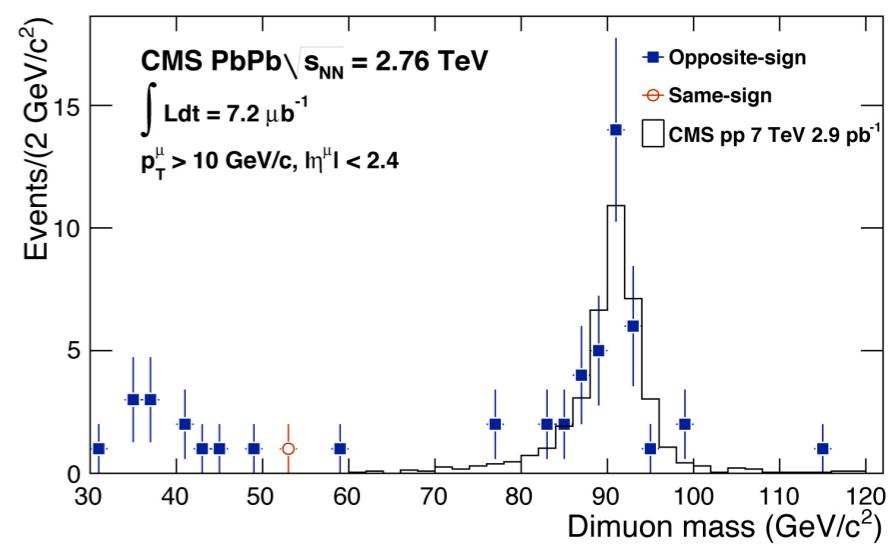
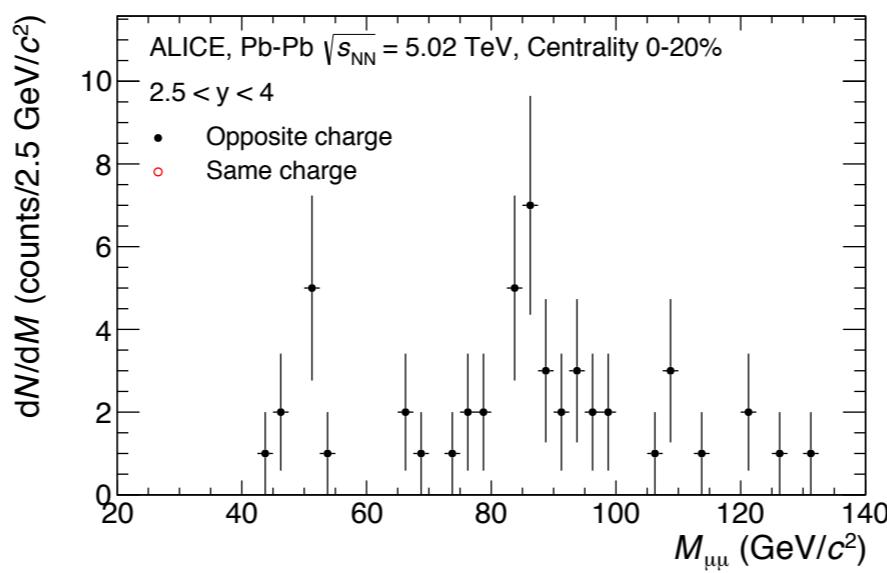
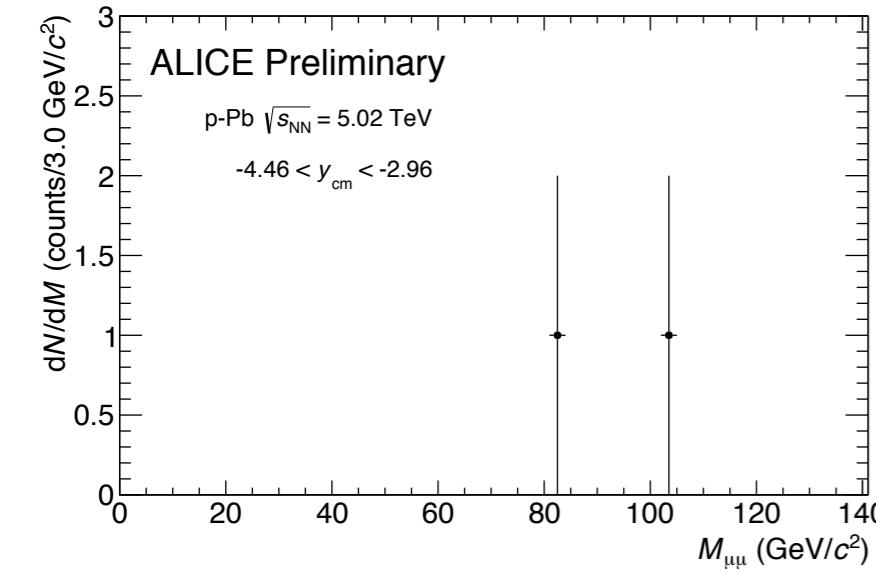
[Benjamin Audurier's Thesis defence]



- Small rapidity dependence at low p_T in different centrality
- In agreement with 2.76 TeV results

Z-boson Backup

Z-boson signals



Z-boson analyses

