Charmonium Production in Pb-Pb Collisions at $\sqrt{s_{NN}}$=2.76 and 5.02 TeV measured with ALICE at the LHC

ALICE

Hot Quarks 2016, Brownsville, September 12-17

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Outline

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1. Inclusive J/ψ R_{AA}
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3. Low-p_T excess

IV. Results at $\sqrt{s_{NN}}$ = 5.02 TeV

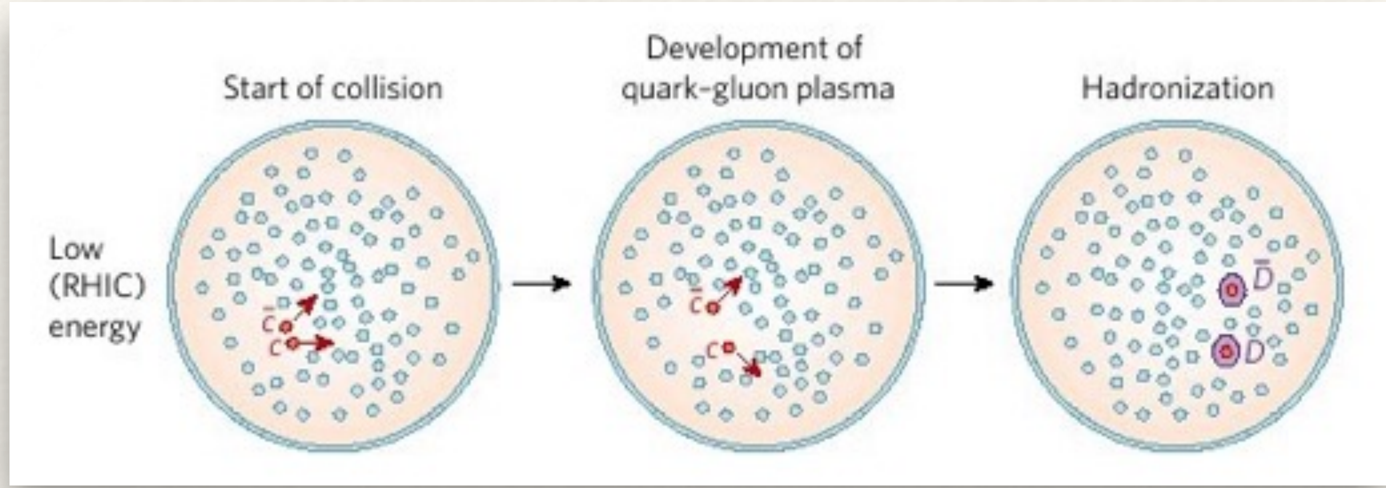
new !

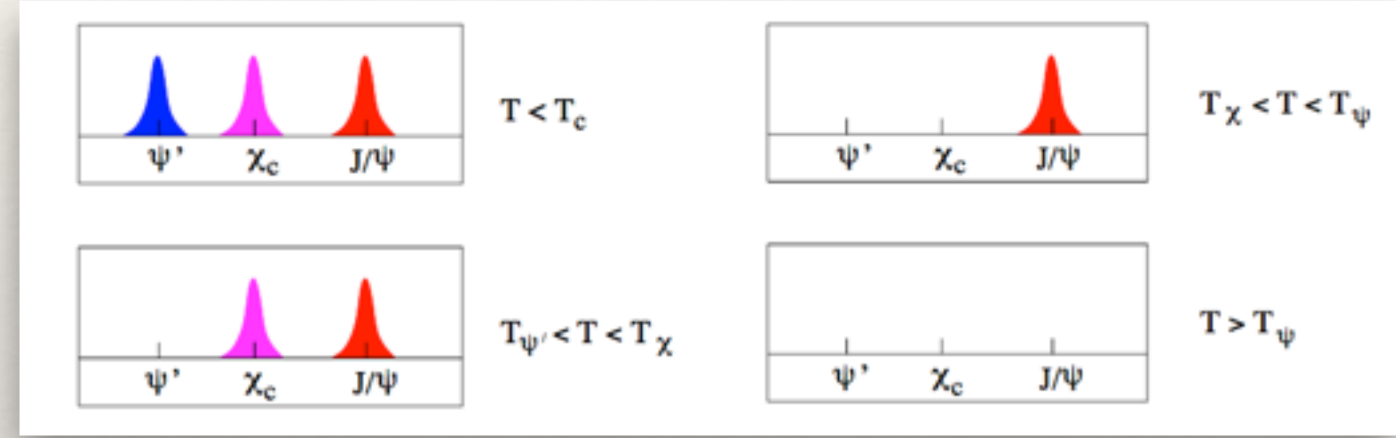
1. Inclusive J/ψ R_{AA}
2. Comparison with $\sqrt{s_{NN}}$ = 2.76 results
3. Comparison with theoretical models

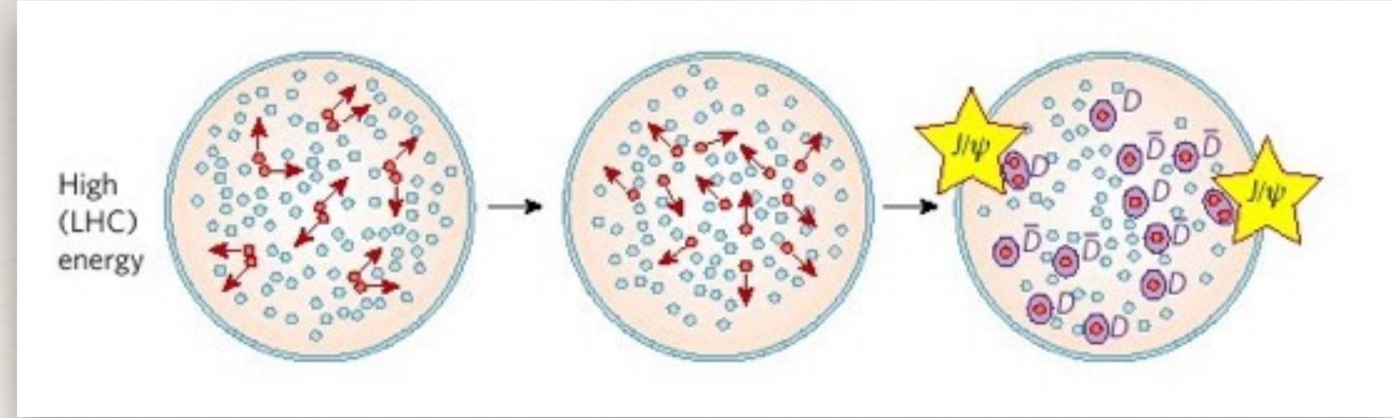
Physics Motivations

A Good Probe

- Charmonium is produced at the earliest stage of the collision.
- In 1986 Matsui & Satz[1] predicted J/ψ suppression by the QGP through Debye like color screening mechanism.
- Color screening suppression depends on charmonium binding energy and medium temperature → *Sequential suppression*
- $c\bar{c}$ cross-section increases at LHC energies → *regeneration*[2,3)].
- charmonium states = *good probes of deconfined state of QCD phase diagram.*







1) Matsui & Satz, *J/psi suppression by quark-gluon plasma formation*, Physics Letters B vol.178 n.4
2) P. Braun-Munzinger et al. PLB 490 (2000) 196
3) R. Thews et al: Phys. Rev. C63 054905 (2001)

Non-QGP effects

- Charmonium also sensitive to cold nuclear matter effects (energy loss, shadowing …) → **Studied in p-Pb collisions.**
- A reference is needed to disentangle cold/hot nuclear matter effects from standard production → **Studied in p-p collisions.**
- Different sources of charmonium production :
    - Direct production. ← Prompt
    - Decay from from higher mass charmonium states (~ 24%). ← Prompt
    - Decay from B-hadrons (~ 10%). ← Non-Prompt

Inclusive

The results presented here refer to the inclusive J/ψ production.

1) The LHCb Coll., *Measurement of the ratio of prompt x_c to J/ψ production in pp collisions at $\sqrt{s} = 7$ TeV*, arXiv:1204.1462v2
2) The LHCb Coll., *Measurement of $\psi(2S)$ meson production in pp collisions at $\sqrt{s} = 7$ TeV*, arXiv:1204.1258
3) The LHCb Coll., *Measurement of J/ψ production in pp collisions at $\sqrt{s} = 7$ TeV*, arXiv:1103.0423v2

Observables

- Assumption : ◎$_{Pb}$→←◎$_{Pb}$ = <N_{coll}> ●$_p$→←●$_p$

The Nuclear Modification Factor

Centrality

Differential Yield in PbPb

$$R^{i}_{AA} = \frac{Y^{PbPb,i}_{J/\psi} / dp_T\, dy}{<Ncoll>\; Y^{pp,i}_{J/\psi} / dp_T\, dy}$$

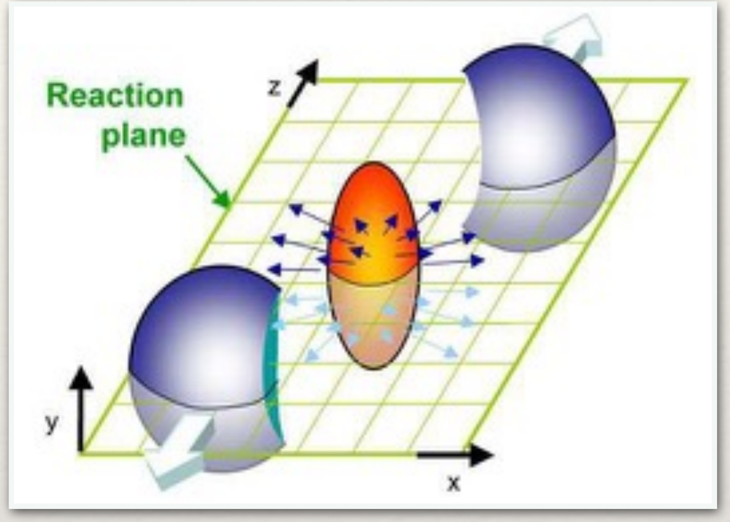
Mean number of binary collisions

Differential Yield in pp

- If $R_{AA} > 1$ → *More* charmonium produced than expected from pp results.
- If $R_{AA} = 1$ → *Same* as compared to a superposition of pp.
- If $R_{AA} < 1$ → *Less* charmonium than expected from pp results.

The Elliptic Flow v_2

$$v^i_n(p_t, y) = \langle cos[n(\varphi - \Psi_{RP}]\rangle^i$$



- J/ψ produced through the regeneration mechanism should inherit the elliptic flow of the charm quarks in the QGP → Positive v_2.

The ALICE Detector

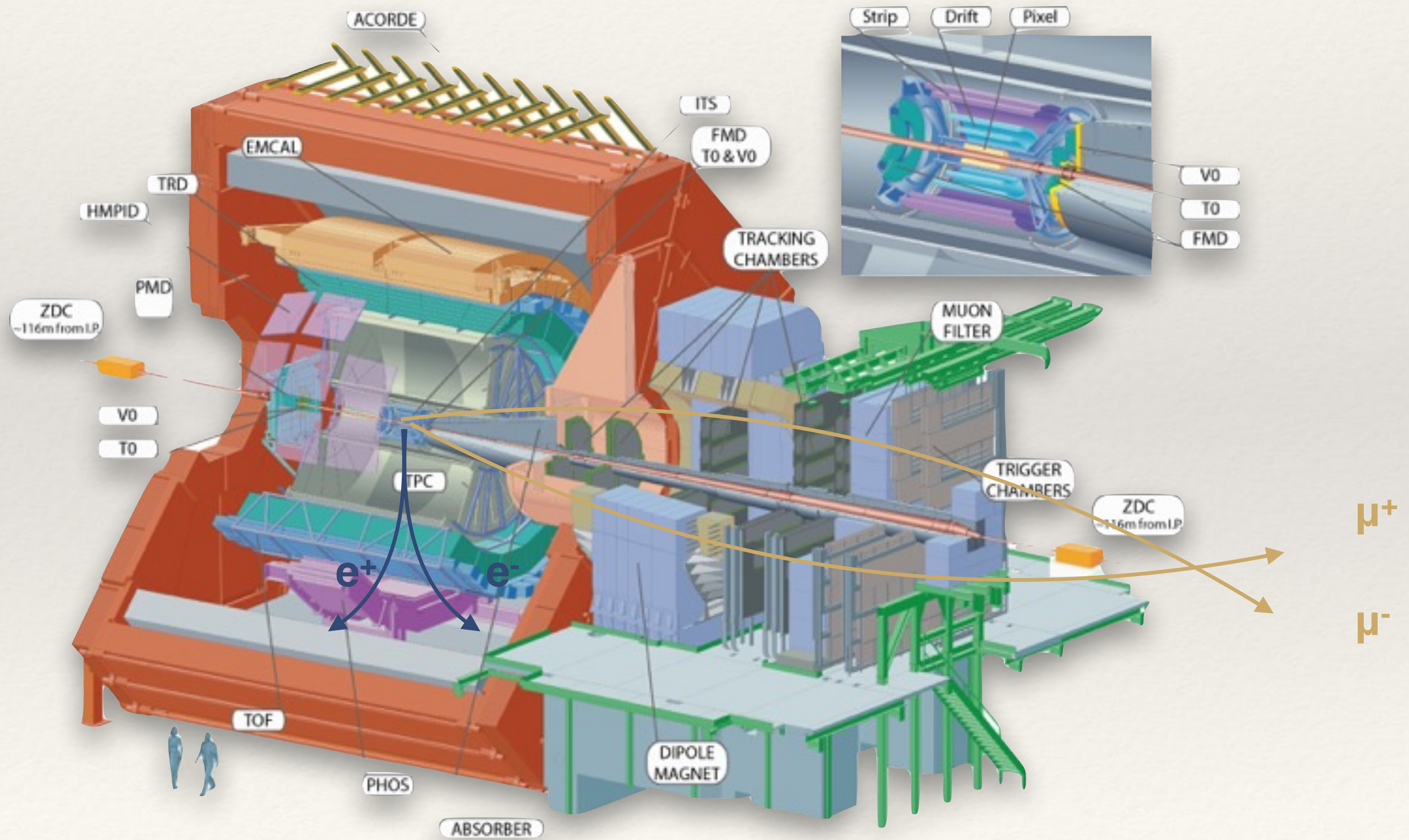
Two decay channels studied in ALICE :

$J/\psi \to e^+e^-$:

- |y|<0.9
- down to $p_T = 0$
- detectors involved : ITS,TPC,TOF

$J/\psi \to \mu^+\mu^-$:

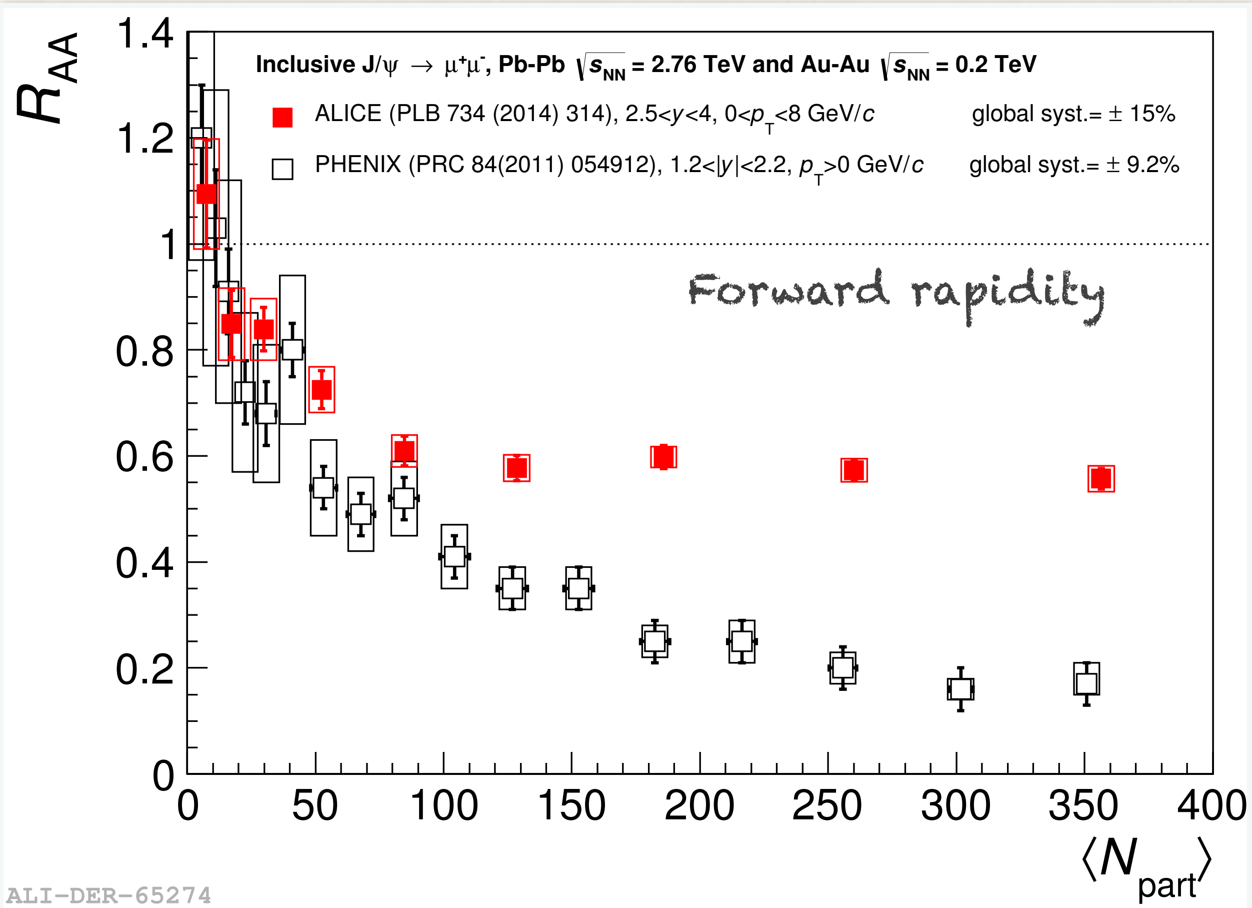
- $2.5 < y < 4$
- down to $p_T = 0$
- detectors involved : muon arm

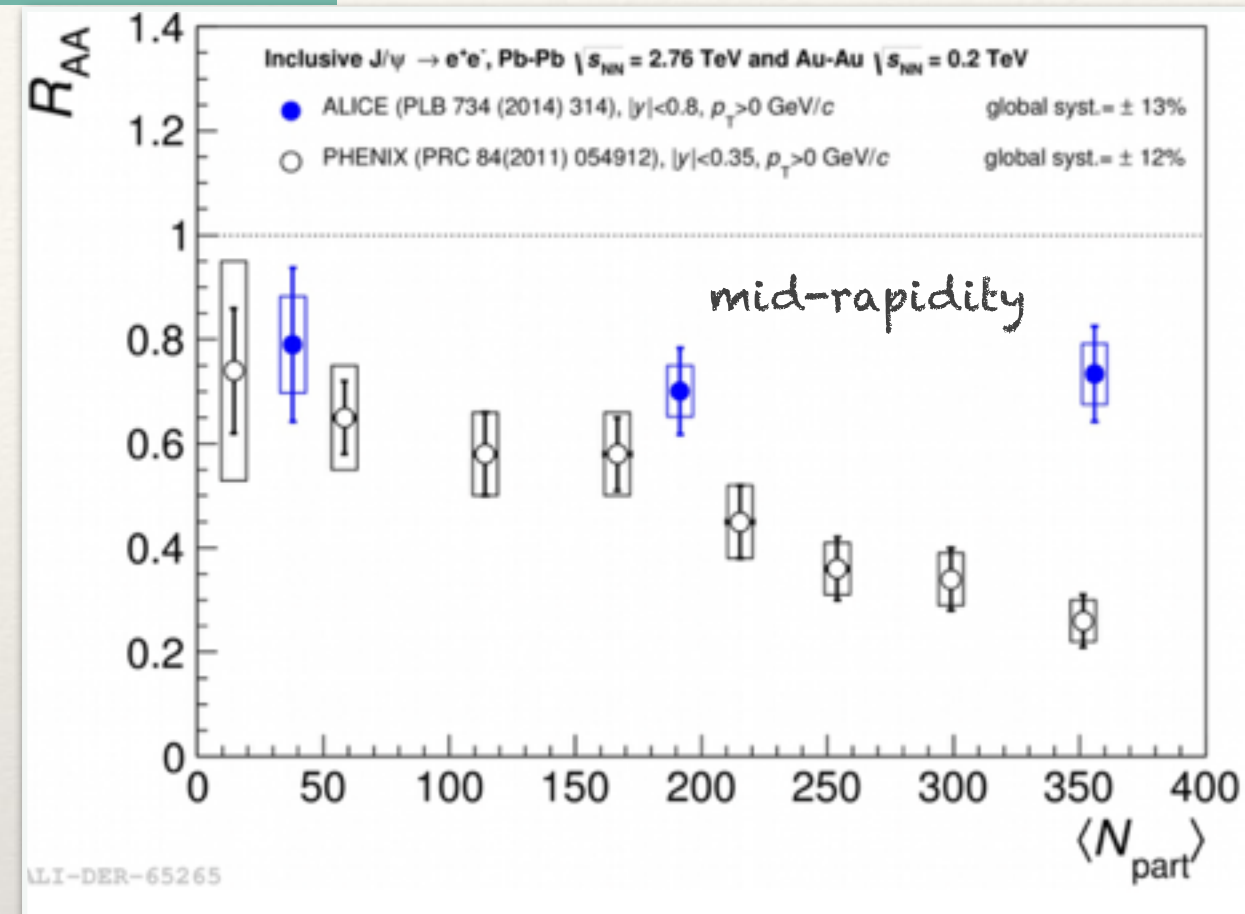


Results in Pb-Pb@2.76 TeV

J/ψ 's R_{AA} versus centrality

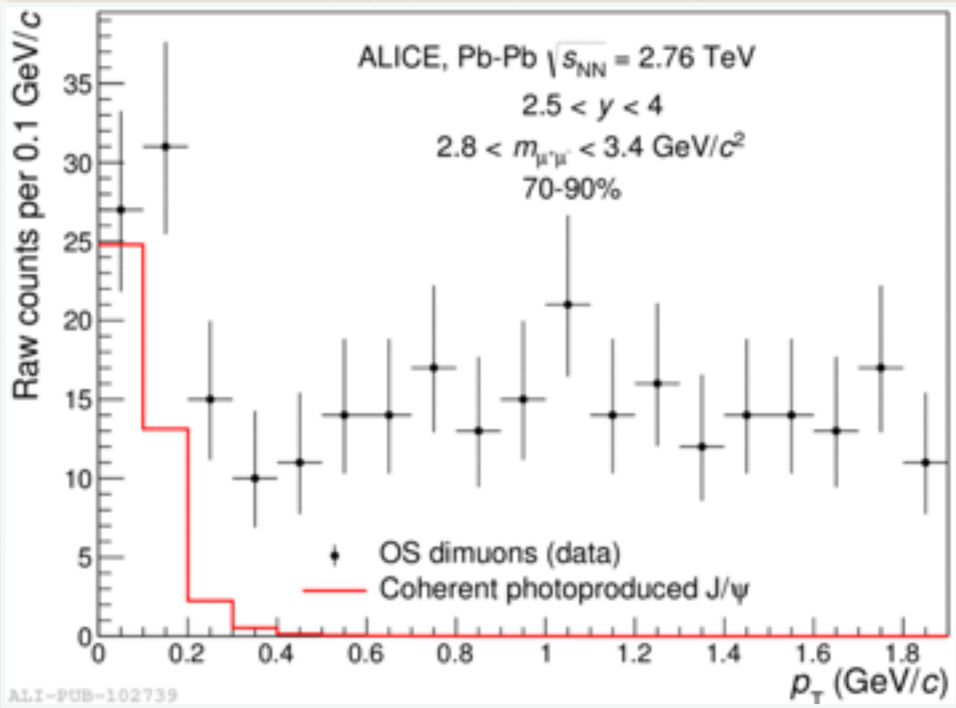
ALICE Coll. PLB 734 (2014) 314



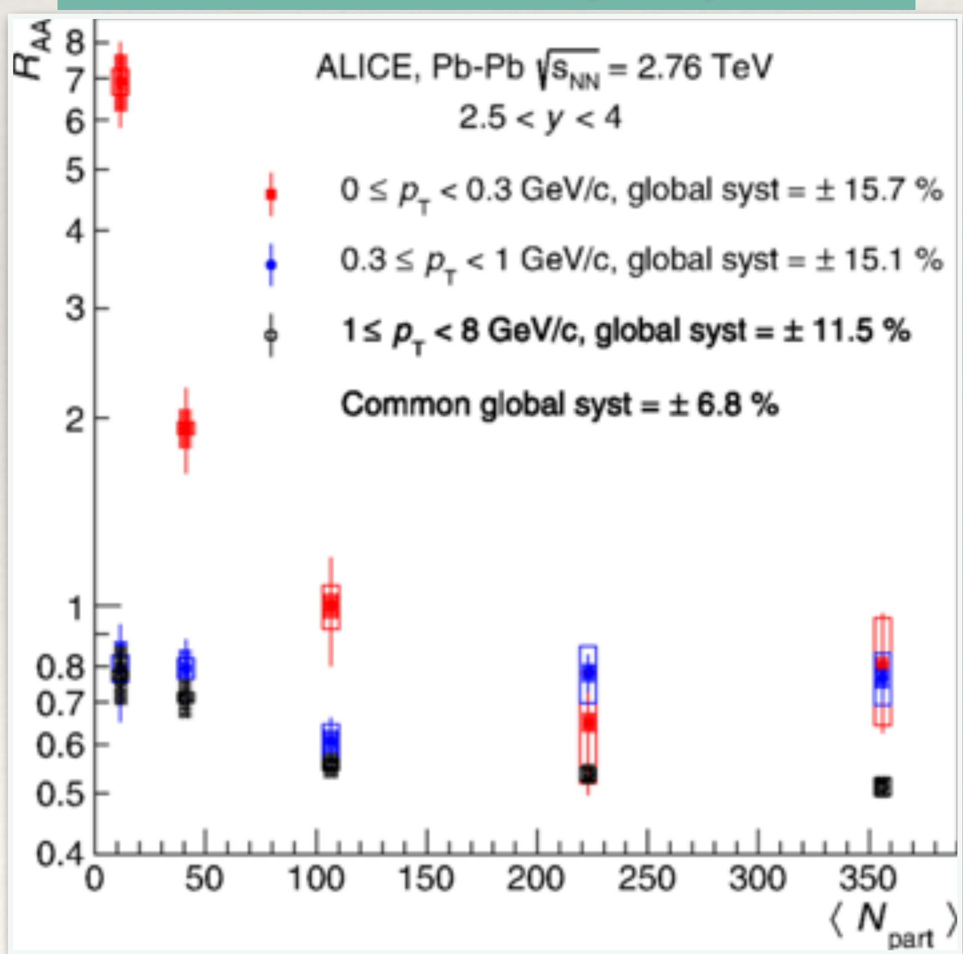


- Clear J/ψ suppression both at ALICE and PHENIX (Au-Au at $\sqrt{s_{NN}}$= 200 GeV).
- Weaker centrality dependence and smaller suppression for central events in ALICE compared to PHENIX → **expected in a regeneration scenario.**

Very Low p_T excess



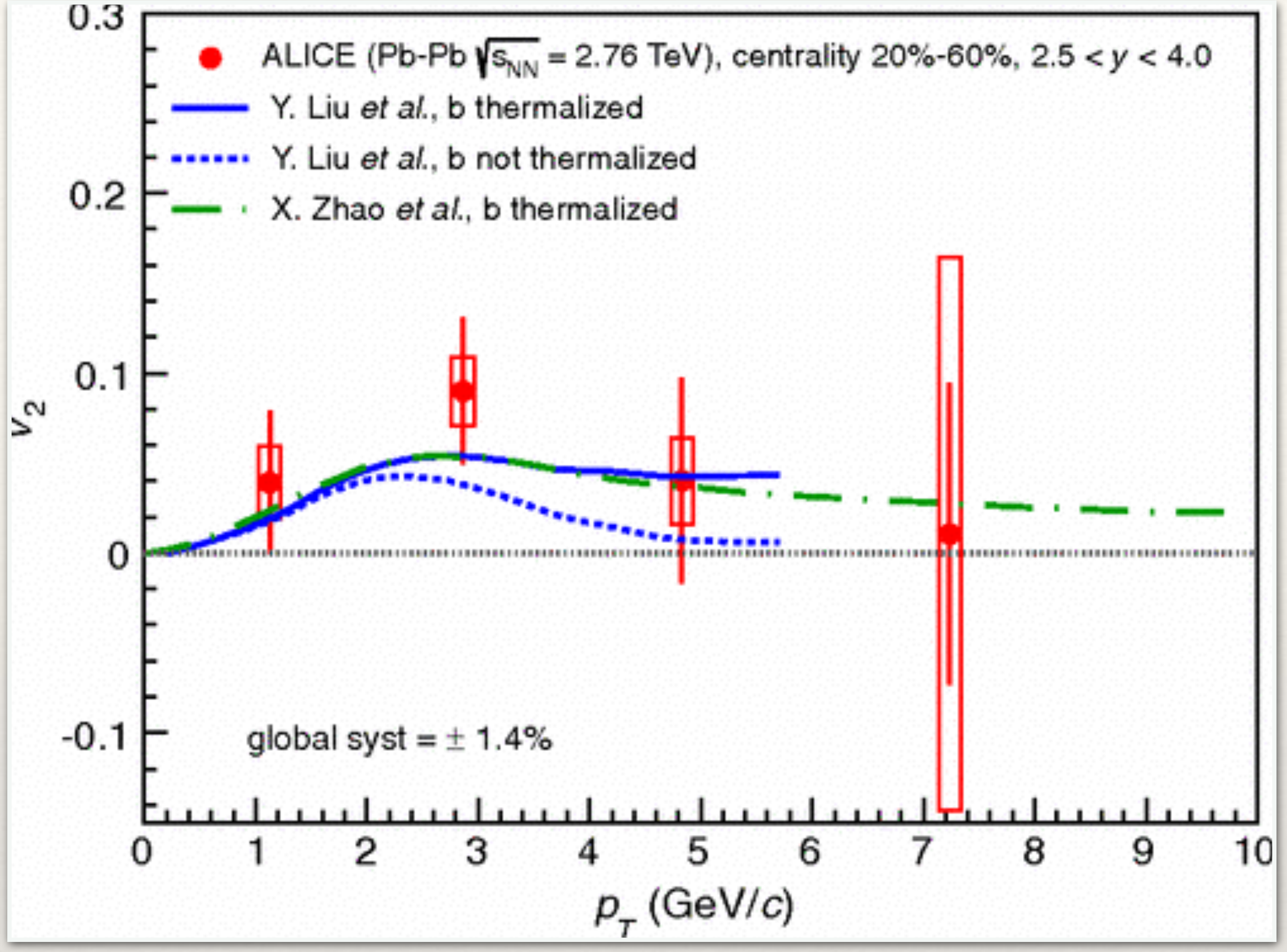
ALICE Coll. PRL116 (2016) 222301



- An excess of J/ψ was observed at very low p_T in the most peripheral collisions.
- Photoproduction mechanism for Pb-Pb collisions with b < 2R was proposed to explain this excess of J/ψ[1,2].
- The cut at p_T > 0.3 GeV/c is applied to remove ~75% of this non-hadronic contribution.
- R_{AA} smaller by 30% at maximum in peripheral bins when applying the previous cut.

1) STARLIGHT website (2013) . http://starlight.hepforge.org/.
2)M. Kusek-Gawenda and A. Szczurek, "Photoproduction of *J*/ψ mesons in peripheral and semi-central heavy ion collisions," arXiv:1509.03173 [nucl-th].

J/ψ flow



ALICE Coll. PRL111 (2013) 162301

- Hint of a J/ψ flow measured by ALICE while v_2 compatible with zero at RHIC[1].
- Agreement within uncertainties between data and transport model with regeneration.

1) PRL. 111, 052301 (2013)

In the following, we will present the J/ψ -> $\mu^+\mu^-$ analysis results for the 2015 data campaign.

Results in Pb-Pb@5.02 TeV

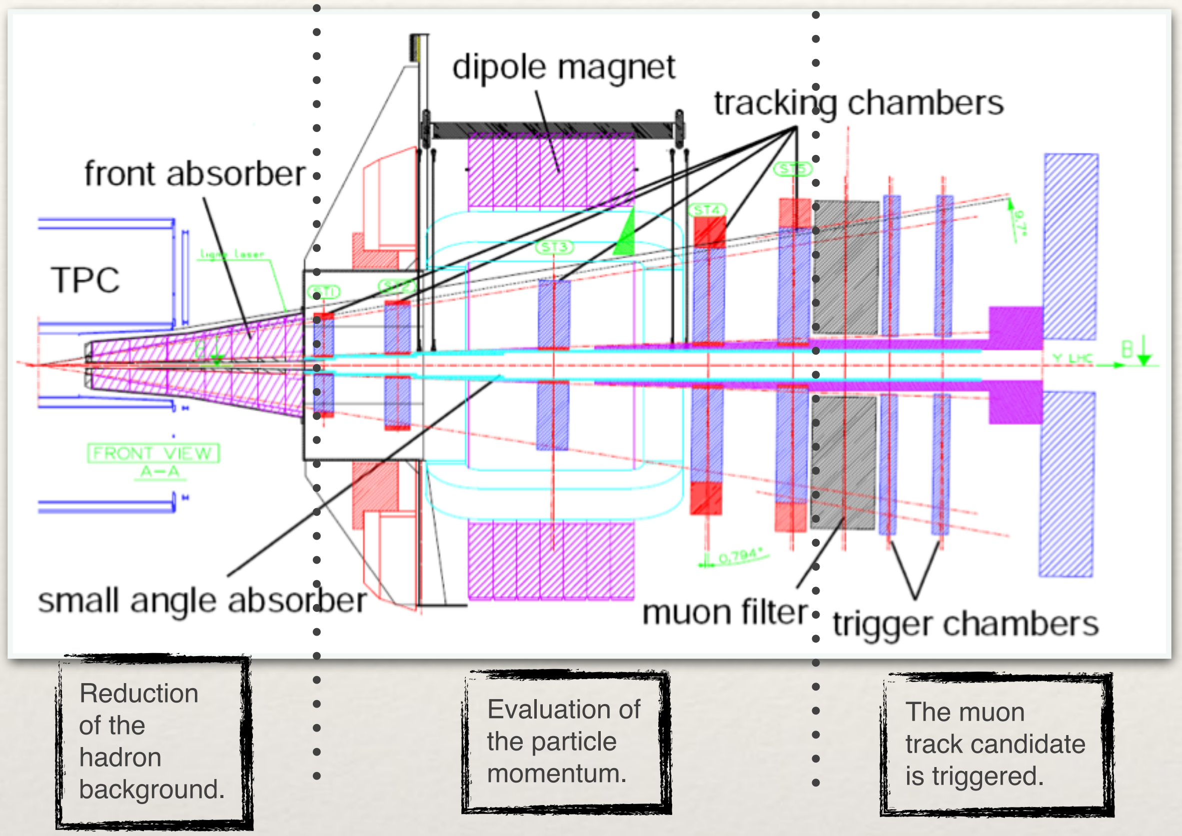
J/ψ signal extraction

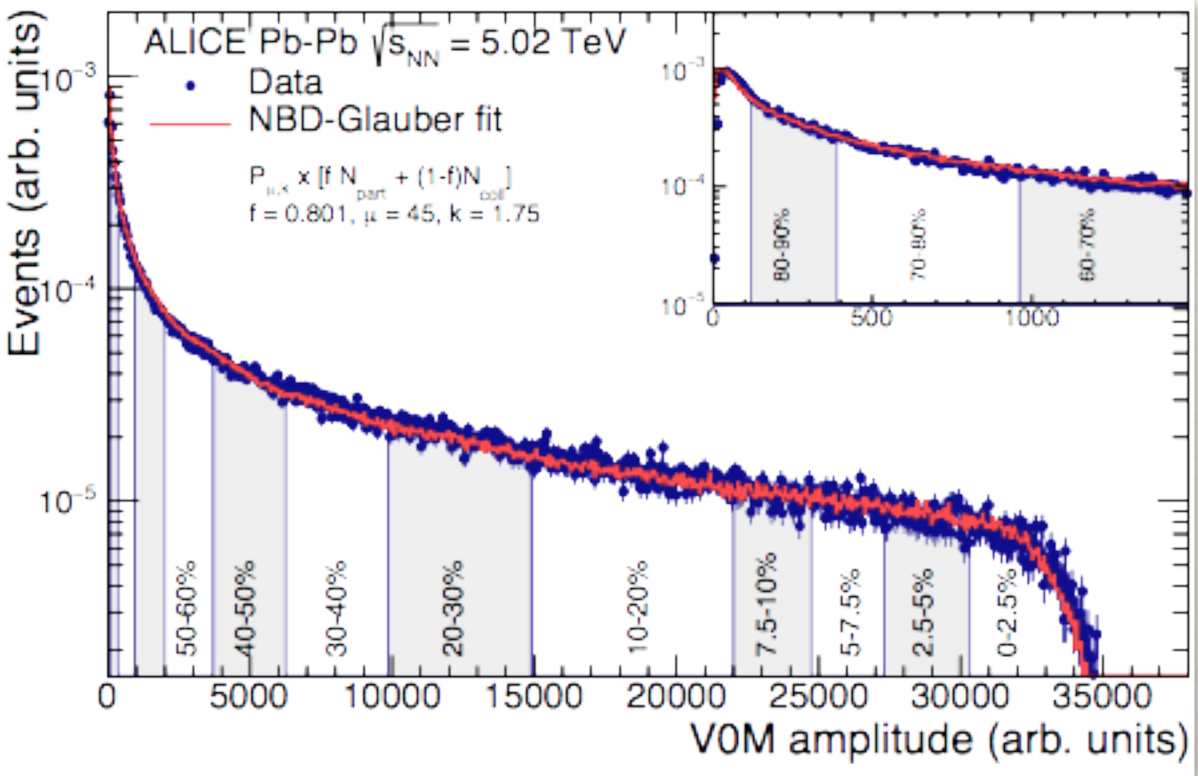
$$R^{i}_{AA} = \frac{d^2 N^{det,i}_{J/\psi} / dp_T\, dy}{<T^{i}_{AA}> BR_{J/\psi \rightarrow dimuon}\, A\epsilon^{i}\, N^{MB,i}_{evt}\, d^2\sigma^{pp,i}_{J/\psi} / dp_T\, dy}$$

J/ψ cross-section in pp

Event and Track Selection

PRL. 116, 222302 (2016)





Muon Track selection :

- $-4 < \eta_{\mu} < -2.5$
- $17.6 < R_{abs} < 89.5$ cm

Reconstructed pairs cut :

- $2.5 < y_{\mu\mu} < 4$

Event selection :

- Collision + muons of opposite sign matching the trigger.
- Beam-gas interaction rejected with V0 and ZDC.
- Vertex determination with SPD.
- Centrality estimation based on a Glauber model fit of the V0 amplitude.

Total Luminosity ~225μb^{-1}

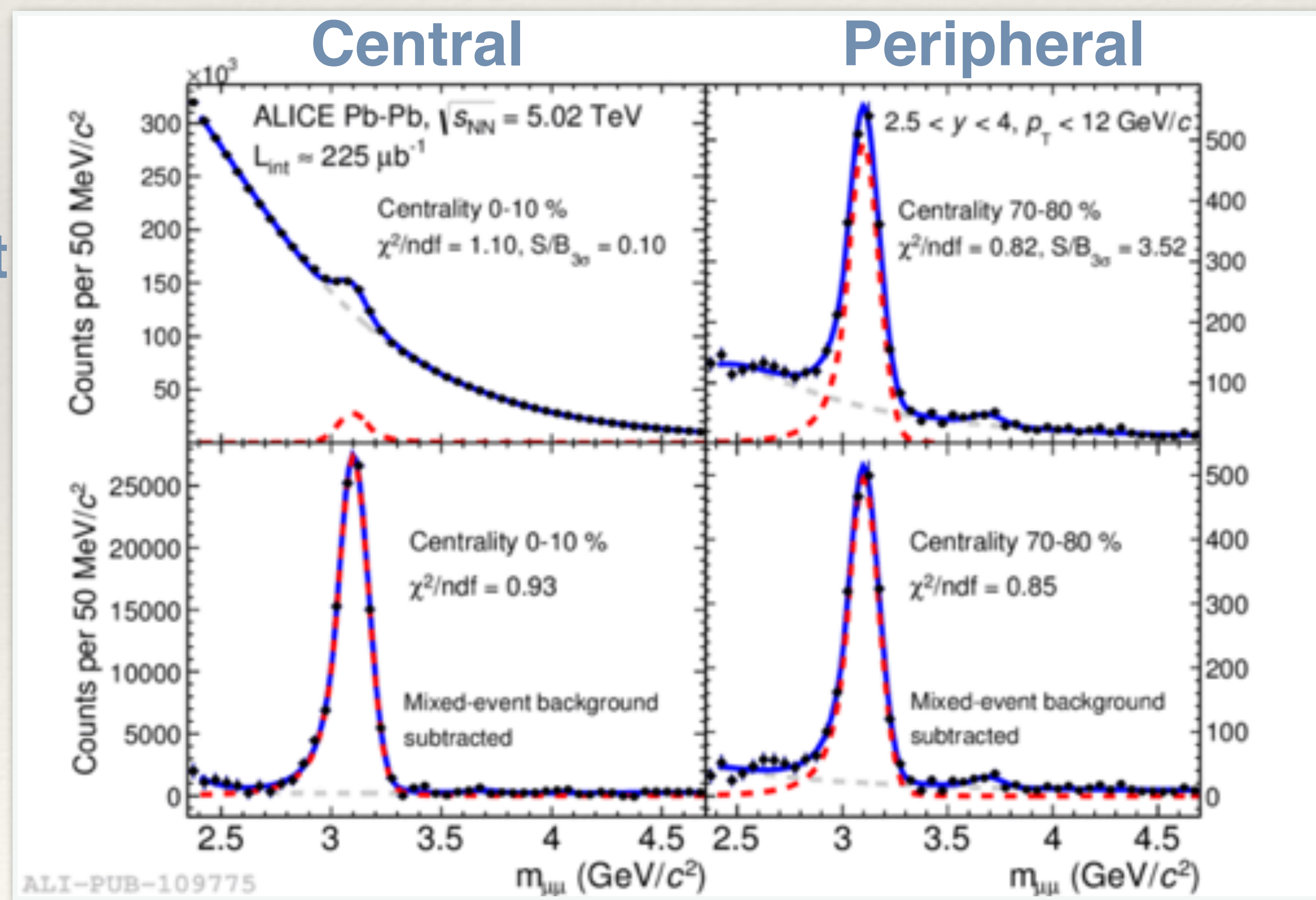
Signal Extraction

$$R^i_{AA} = \frac{d^2 N^{det,i}_{J/\psi} / dp_T\, dy}{<T^i_{AA}> BR_{J/\psi \to dimuon}\, A\epsilon^i\, N^{MB,i}_{evt}\, d^2\sigma^{pp,i}_{J/\psi} / dp_T\, dy}$$

- ~7 times more statistics compared to Run-1.
- J/ψ yield extracted by fitting the opposite sign dimuon invariant mass spectrum.
- <J/ψ> and the syst. uncertainties are evaluated from the combination of :
  - Two fit functions for the signal peak.
  - Two methods to remove the background (empirical fit or mixed-event background subtraction).
  - Two fit ranges.

empirical Fit

Mixed-event

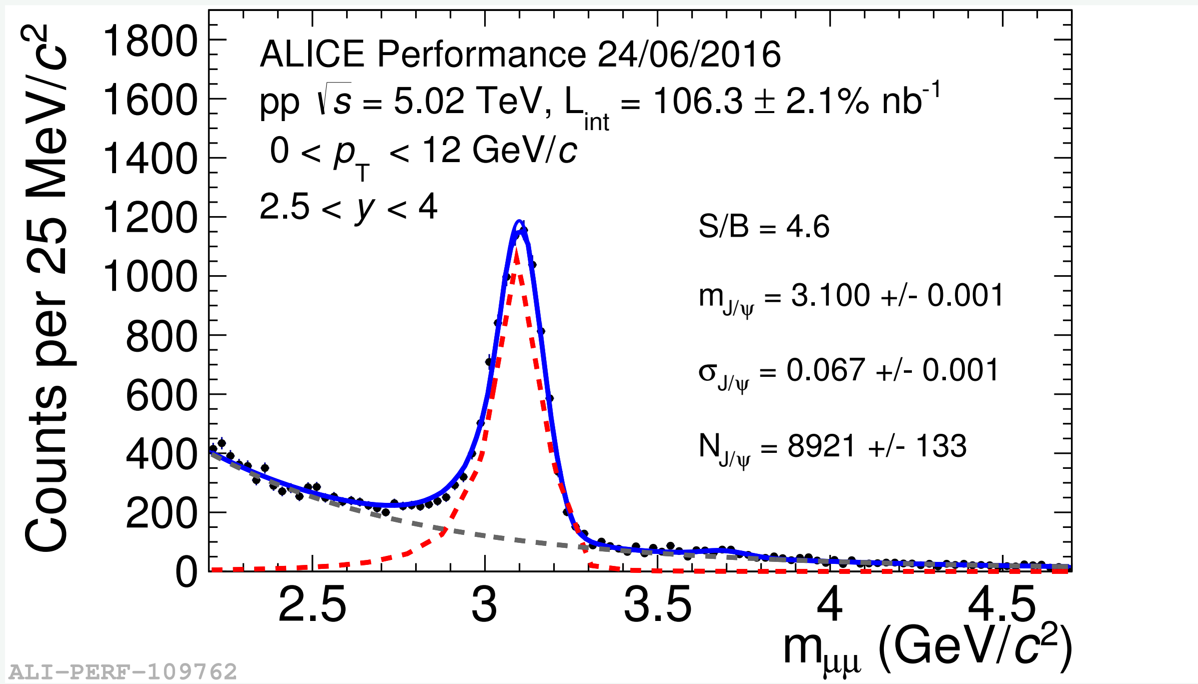


arXiv:1606.08197

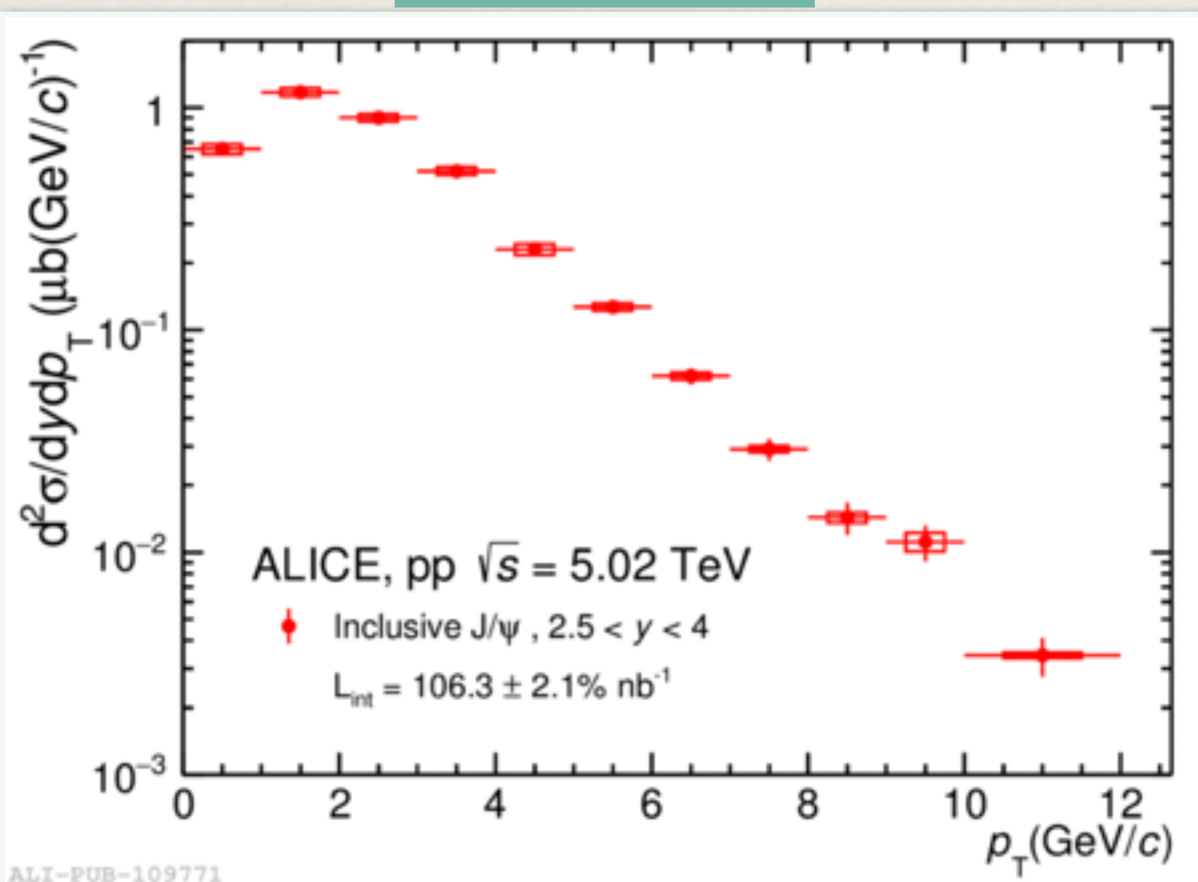
ALICE

pp cross section at $\sqrt{s}$ = 5.02 TeV

$$R^{i}_{AA} = \frac{d^2 N^{det,i}_{J/\psi}/dp_T\,dy}{<T^{i}_{AA}>\, BR_{J/\psi \to dimuon}\, A\epsilon^{i}\, N^{MB,i}_{evt}\, d^2\sigma^{pp,i}_{J/\psi}/dp_T\,dy}$$



arXiv:1606.08197



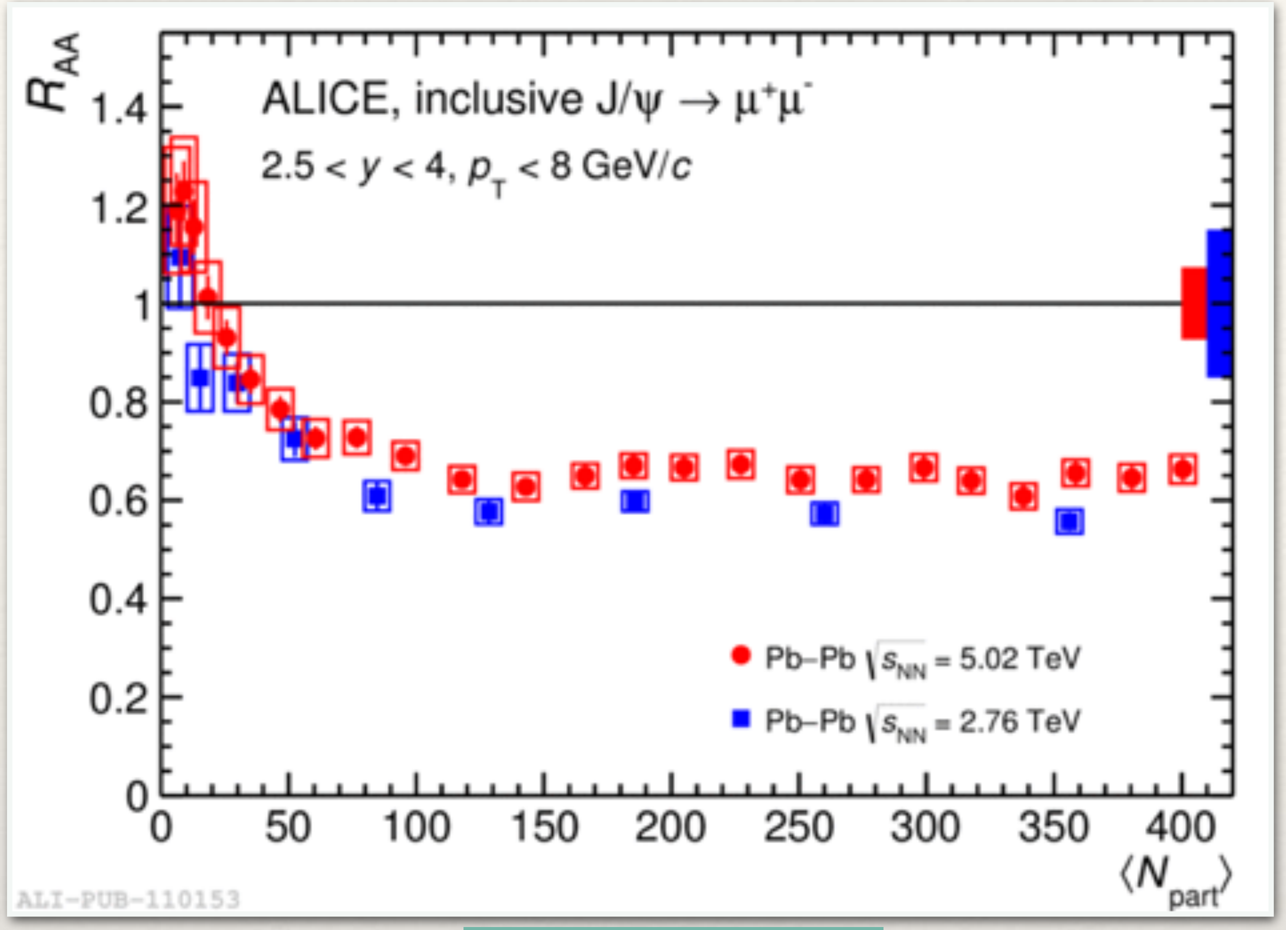
Similar ingredients as for Pb-Pb analysis

$$\frac{d^2\sigma^{pp}_{J/\psi}}{dp_T dy} = \frac{d^2 N^{det,pp}_{J/\psi}/dp_T dy}{BR_{J/\psi\to\mu^+\mu^-}\ A\epsilon} \times \frac{\sigma^{pp}_{MB}}{N^{MB}_{evt}}$$

- Data collected during 4 days at $\sqrt{s}$ = 5.02 TeV for a total of **106.3 ± 0.1(*stat.*) ± 2.1 (syst.) nb^{-1} integrated luminosity.**
- Good agreement between data and interpolated cross section values previously used for the p-Pb analysis at $\sqrt{s_{NN}}$ = 5.02 TeV.
- Extended range up to p_T =12 GeV/c compared to the interpolated cross section

Integrated cross section (p_T <12 GeV/c) :
5.61 ± 0.08 (stat.) ± 0.28 (syst.) μb

Inclusive J/ψ R_{AA} versus centrality



arXiv:1606.08197

- Higher statistics lead to **finer bins in centrality.**
- Better control of the syst. uncert.
- **Clear J/ψ suppression** with no centrality dependence in the most central collisions.
- Effect of the non-prompt component on the inclusive R_{AA}:

$R_{AA}^{0\text{-}90\%}(0 < p_T < 8$ GeV/c) :	0.66 ± 0.01 (stat.) ± 0.05 (syst.)
2011 $R_{AA}^{0\text{-}90\%}$ $(0 < p_T < 8$ GeV/c):	0.58 ± 0.01 (stat) ± 0.09 (syst.)

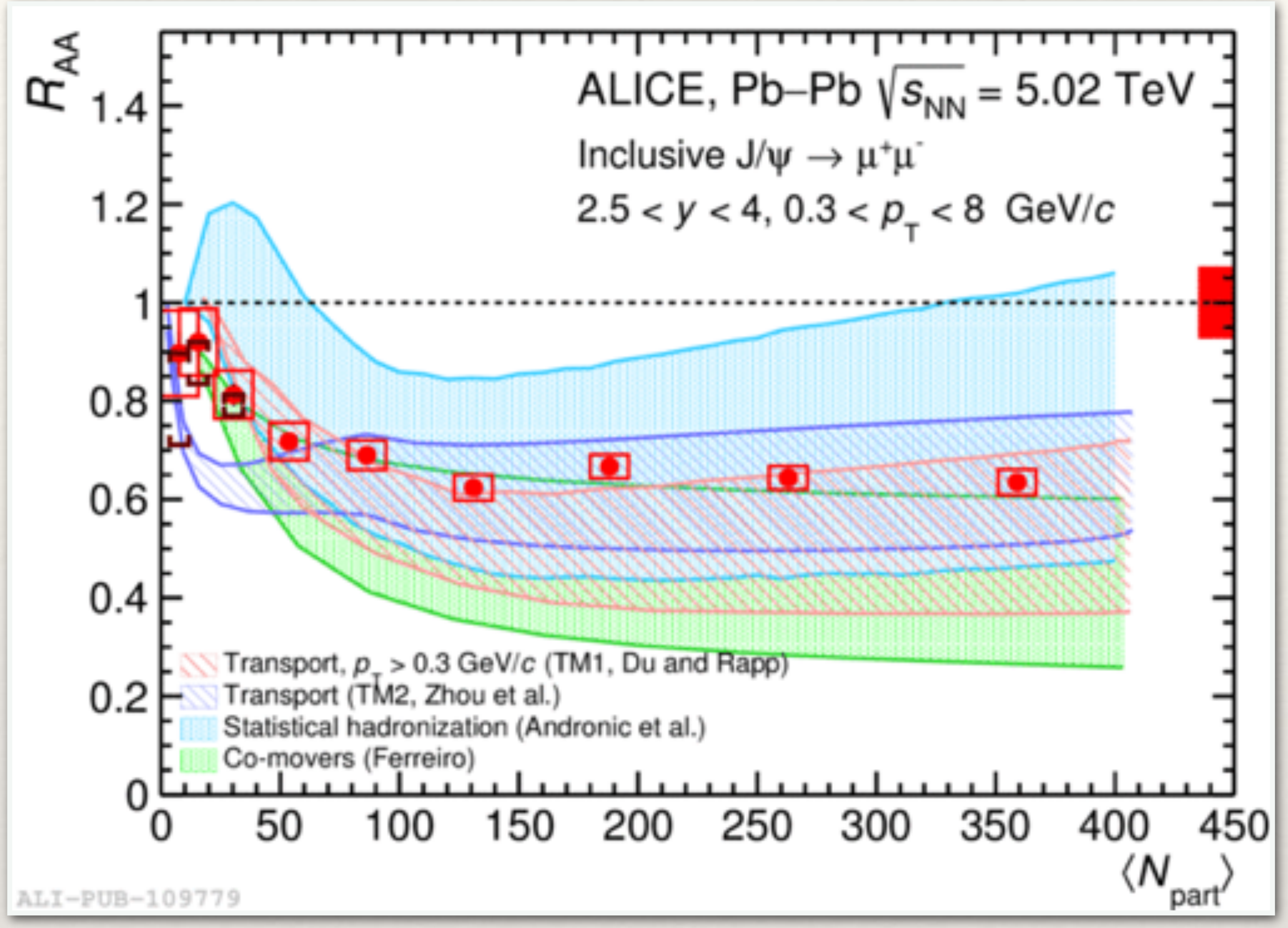
$R_{AA(non\text{-}prompt)}$ = 0
- All non-prompt J/ψ are suppressed
- $R_{AA(prompt)}$ 10% higher

$R_{AA(non\text{-}prompt)}$ = 1
- All non-prompt J/ψ survive
- $R_{AA(prompt)}$ 5% to 1% lower

Results between $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV data are compatible within uncertainties

Inclusive J/ψ R_{AA} versus centrality ($0.3 < p_T < 8$ GeV/c)

arXiv:1606.08197

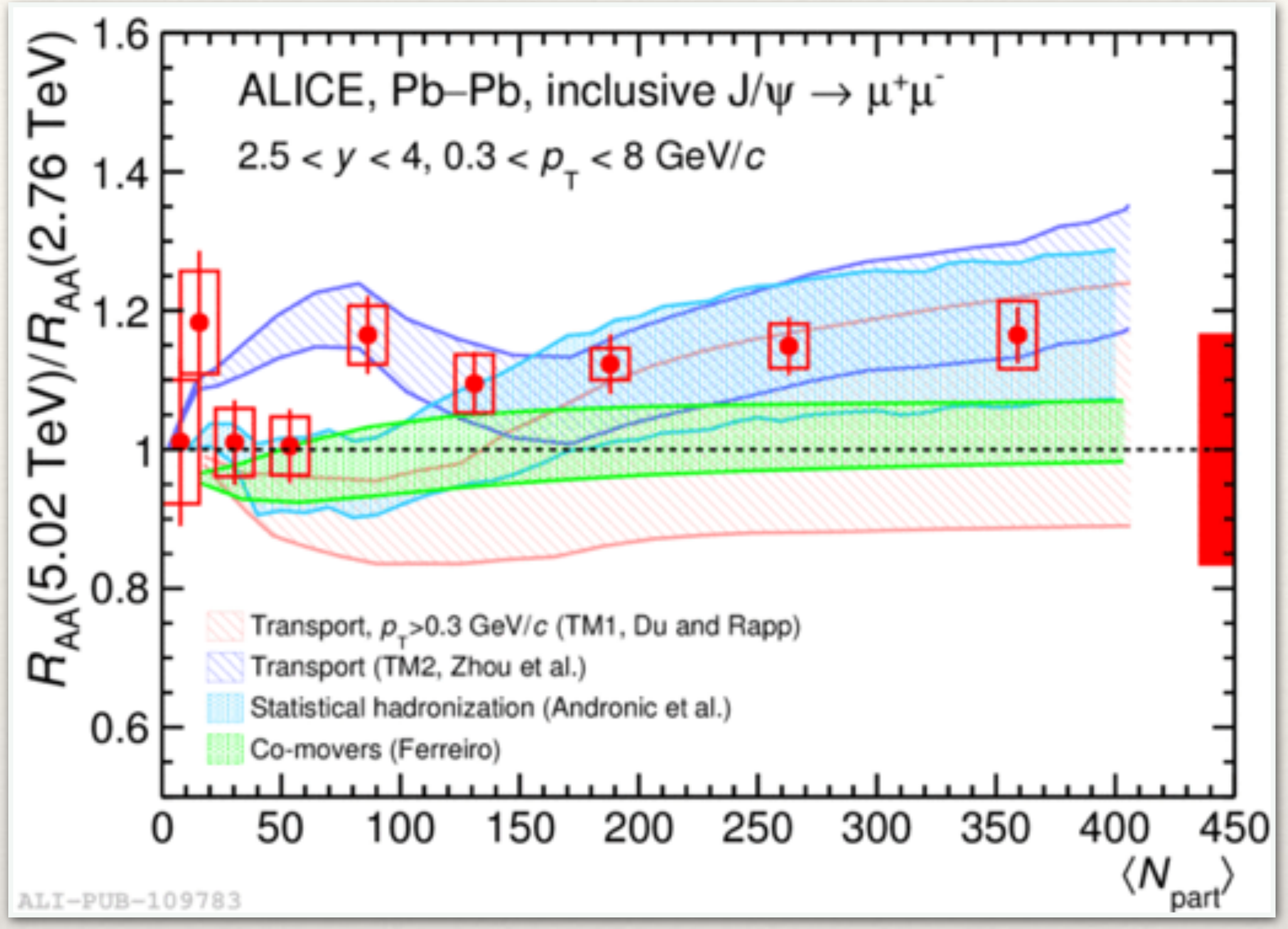


TM1: Nucl. Phys. A859 (2011) 114–125
TM2: Phys. Rev. C89 no. 5, 459 (2014) 054911
Stat. hadronization: NPA 904-905 (2013) 535c
Co-movers: Phys. Lett. B731 (2014) 57–63

- The p_T>0.3 GeV/c cut removes ~80% of the photoproduced J/ψ.
- Large uncertainties on the theoretical calculations due mainly to the choice of $\sigma_{c\bar{c}}$.
- **All models include** a large amount of **regeneration**
- A better agreement is found for some transport (Du and Rapp) and co-movers (Ferreiro) models when we consider their upper limit.
- In transport models this corresponds to **the absence of nuclear shadowing** -> **extreme assumption.**

Ratio between R_{AA} for $\sqrt{s_{NN}}$ = 5.02 and 2.76 TeV

arXiv:1606.08197

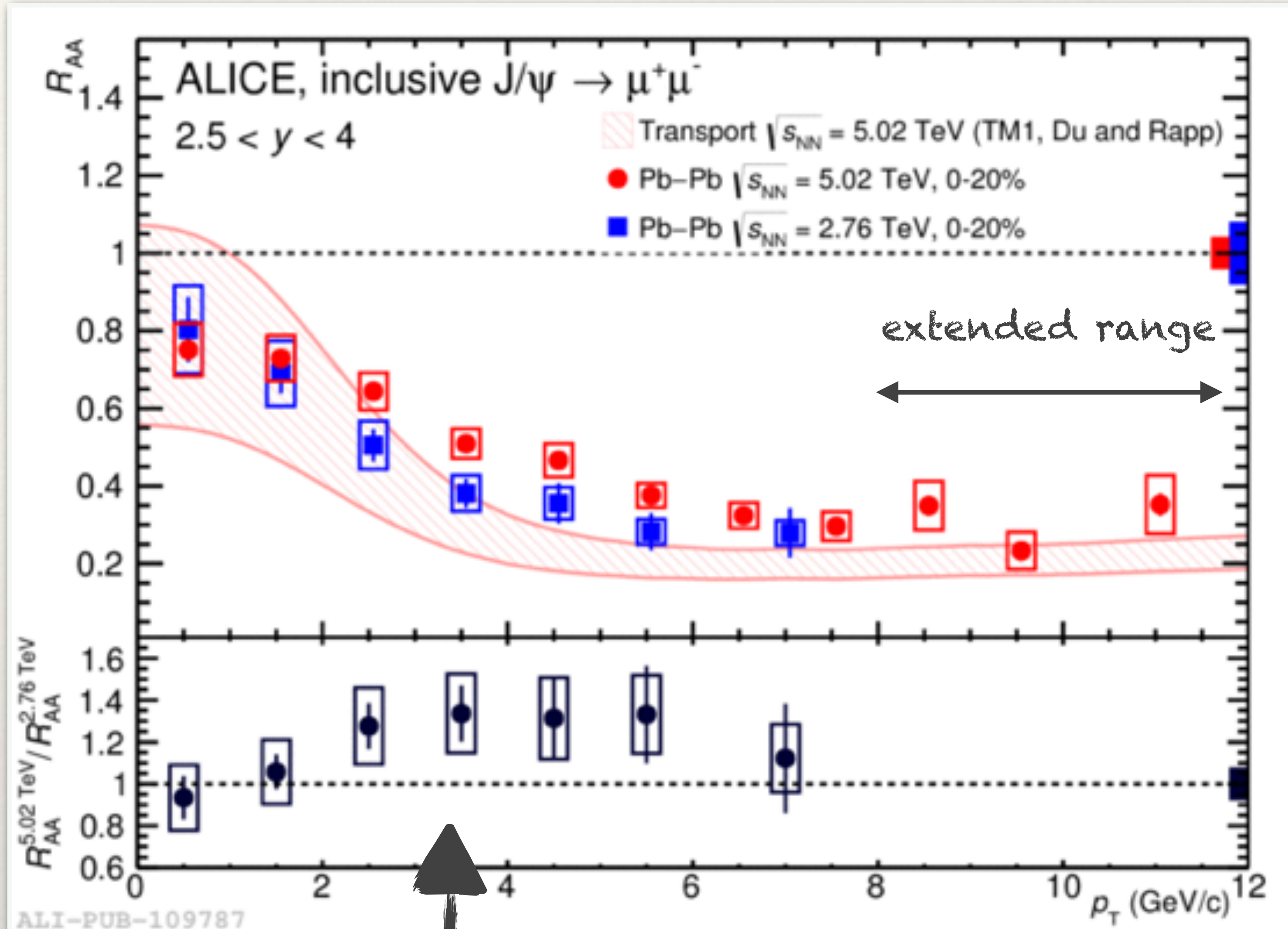


- R_{AA} ratio allows some uncertainties on the models to cancel out
- T_{AA} uncert. also cancels out for the experimental results
- Error bands on models correspond to a 5% variation of $\sigma_{c\bar{c}}$
- 2% variation of the ratio when considering the non-prompt contribution
- Ratio value for the most central events : 1.17 ± 0.04 (stat.) ± 0.20 (syst.)

Models are compatible with data within uncertainties showing no clear centrality dependance of the ratio.

Inclusive J/ψ R_{AA} versus p_T

arXiv:1606.08197



Hint of an increase of R_{AA} with colliding energy is visible between $2<p_T<6$ GeV / c

- Less suppression at low p_T w.r.t high p_T.
- Assuming **beauty fully suppressed** :
  - $R_{AA(prompt)}$ expected to be **7% larger** for p_T < 1 GeV/c.
  - $R_{AA(prompt)}$ expected to be **30% larger** for 10 < p_T < 12 GeV/c.
- Assuming **beauty binary scaling** :
  - $R_{AA(prompt)}$ expected to be **2% smaller** for p_T < 1 GeV/c.
  - $R_{AA(prompt)}$ expected to be **55% smaller** for 10 < p_T < 12 GeV/c.

Conclusions

- The J/ψ cross section in pp collisions at $\sqrt{s}$ = 5.02 TeV has been measured both versus p_T and fully integrated. This result is used as a reference for the R_{AA}
- The inclusive J/ψ nuclear modification factor in PbPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV at forward rapidity has been measured down to p_T = 0 GeV/c.
- The p_T range of the R_{AA} has been extended up to 12 GeV/c .
- The study of the centrality and p_T dependence of R_{AA} shows :
  - an increase of the J/ψ suppression with centrality up to N_{part} ~100 followed by a saturation as for previous results in PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV.
  - less suppression at low p_T with respect to high p_T.
- The comparison between $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV results through R_{AA} ratio shows :
  - Results are compatible within uncertainties in the full centrality range.
  - a hint of an increase with colliding energy for R_{AA} versus p_T for $2<p_T<6$ GeV/c.
- **Data and theoretical models are compatible within uncertainties and support a picture of competing J/ψ suppression and regeneration in the QGP.**

Thank you !

Back-up

J/ψ 's R_{AA} versus centrality

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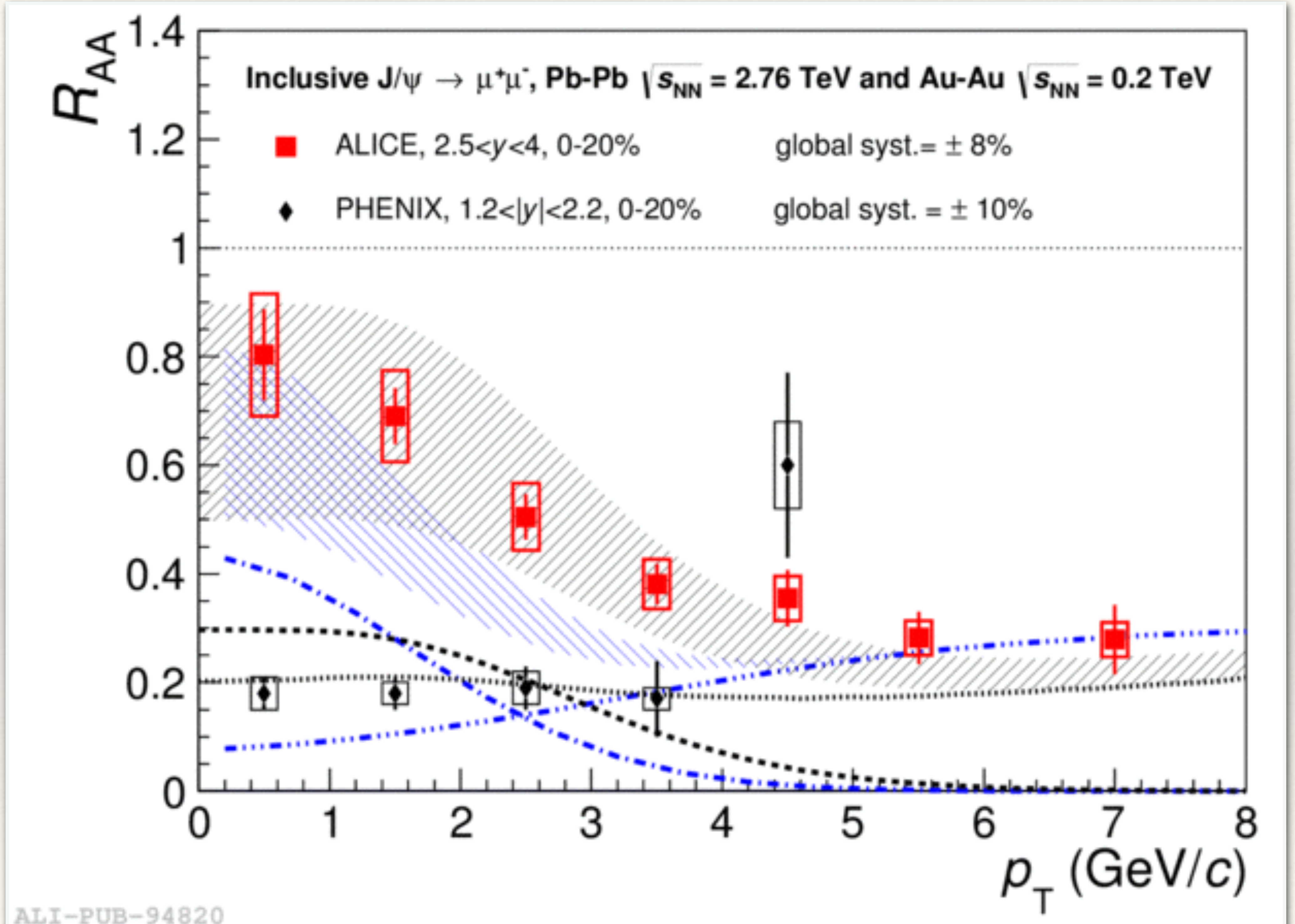


Summary of the Systematic uncertainties for PbPb@5TeV

Source	0-90% p_T<12 GeV/c	p_T (0-20%)	centrality
Signal Extraction	1,8 %	1.2-3.1 %	1.6-2.8 %
MC input	2,0 %	2,0 %	2 %
Tracking eff.	3,0 %	3,0 %	3 %
Trigger eff.	3,6 %	1.5-4.8	3,6 %
Matching Eff.	1 %	1 %	1 %
F_{Norm}	0,5 %	0,5 %	0,5 %
$<T_{AA}>$	3,2 %	3,2 %	3,1-7,6 %
Centrality limits	0 %	0,1 %	0-6,6 %
$\sigma^{pp}_{J/\psi}$ (data)	5,0 %	3-10% + 2.1%	4,9 %

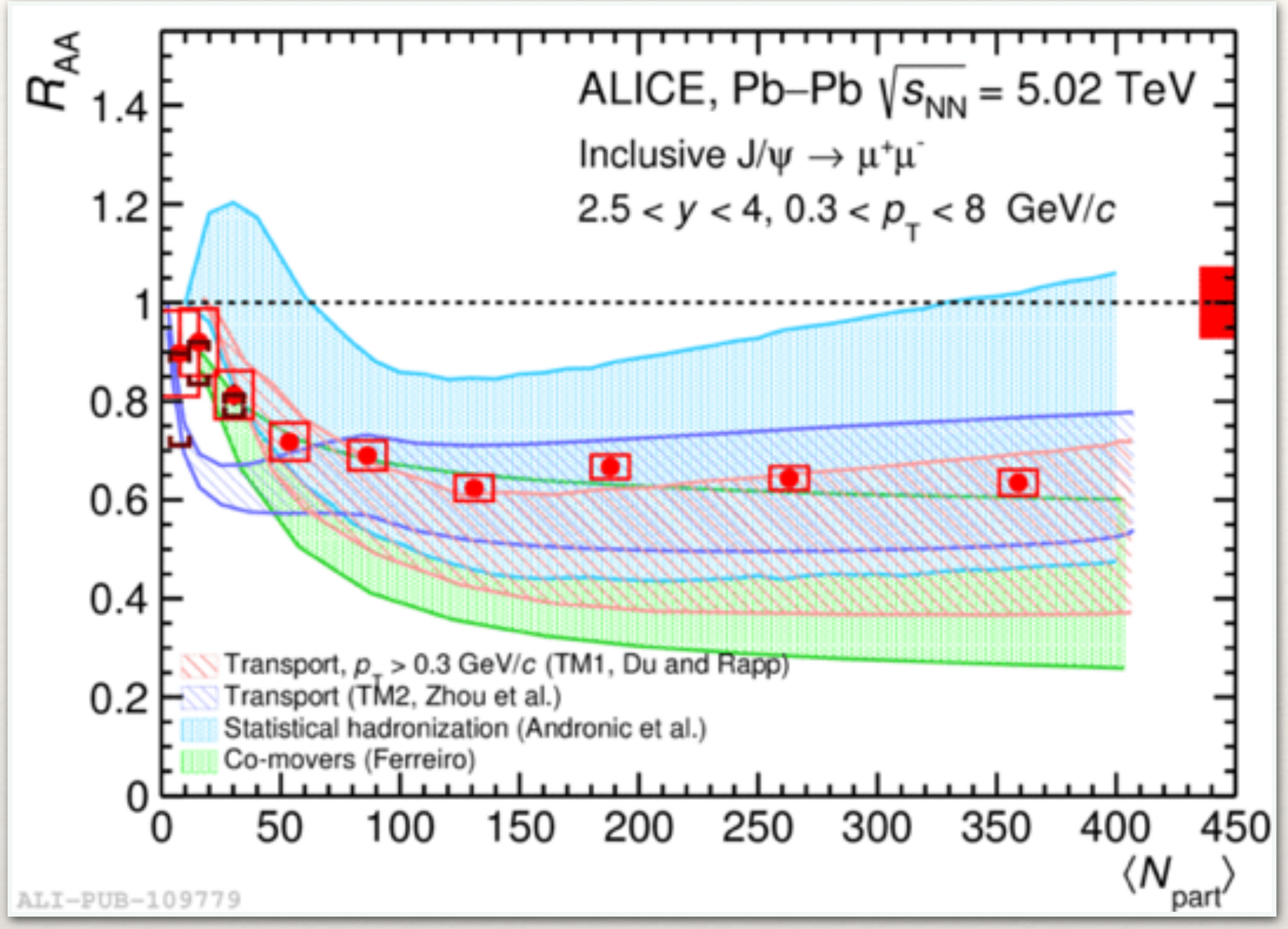
Uncorrelated uncertainties
Correlated uncertainties

Summary of the Systematic uncertainties for pp@5TeV

Source	$0 < p_T < 12$ GeV/c	p_T
Signal Extraction	3 %	1,5-9,3 %
MC input	2,0 %	0,7-1,5 %
Tracking eff.	1,0 %	1,0 %
Trigger eff.	1,8 %	1,5-1,8 %
Matching Eff.	1 %	**1 %**
Luminosity	2,1 %	**2,1 %**

Uncorrelated uncertainties
Correlated uncertainties

Models parameters

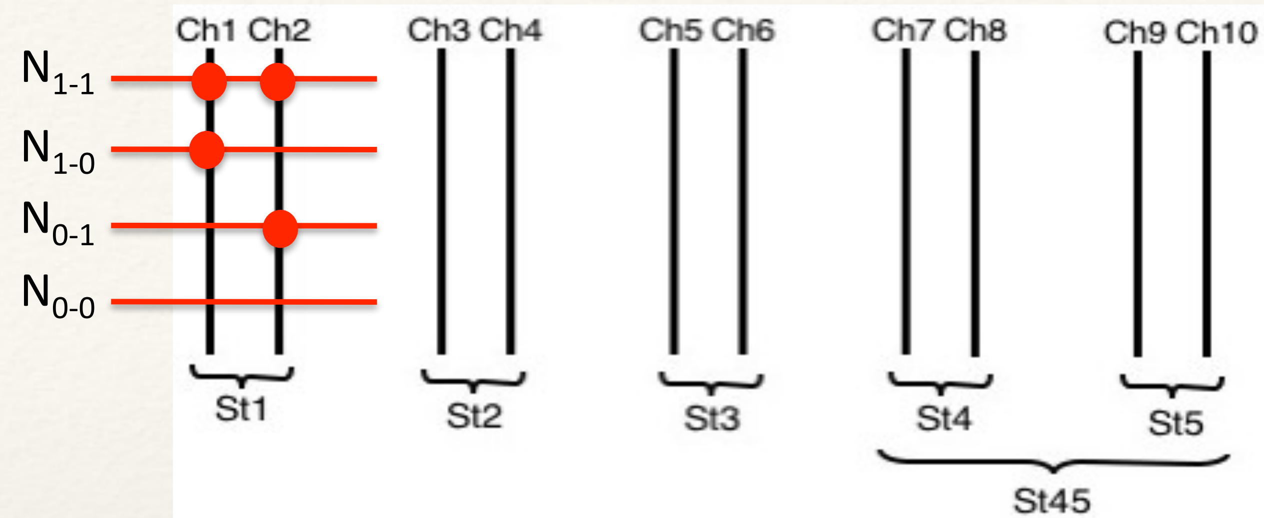


model	$\sigma_{c\bar{c}}$ (mb)	N-N $\sigma_{c\bar{c}}$ (μb)	comover $\sigma_{J/\psi}$	Shadowing
Transport	0.57	3.14	-	EPS09
Transport	0.82	3.5	-	EPS09
Stat.	0.45	-	-	EPS09
Comovers	[0.45,0.7]	3.53	0.65	Glauber-Gribov theory

Tracking Efficiency

- To evaluated the Tracking Efficiency, we use the reconstructed tracks and the redundancy of the tracking chamber.
- Syst. uncert. evaluated from the comparison of data and MC.

POSSIBLE STATION RESPONSES



$$\varepsilon_{Global} = \varepsilon_{St1}\varepsilon_{St2}\varepsilon_{St3}\varepsilon_{St45}$$