J/ψ production in pp and Pb-Pb collisions measured by ALICE at LHC

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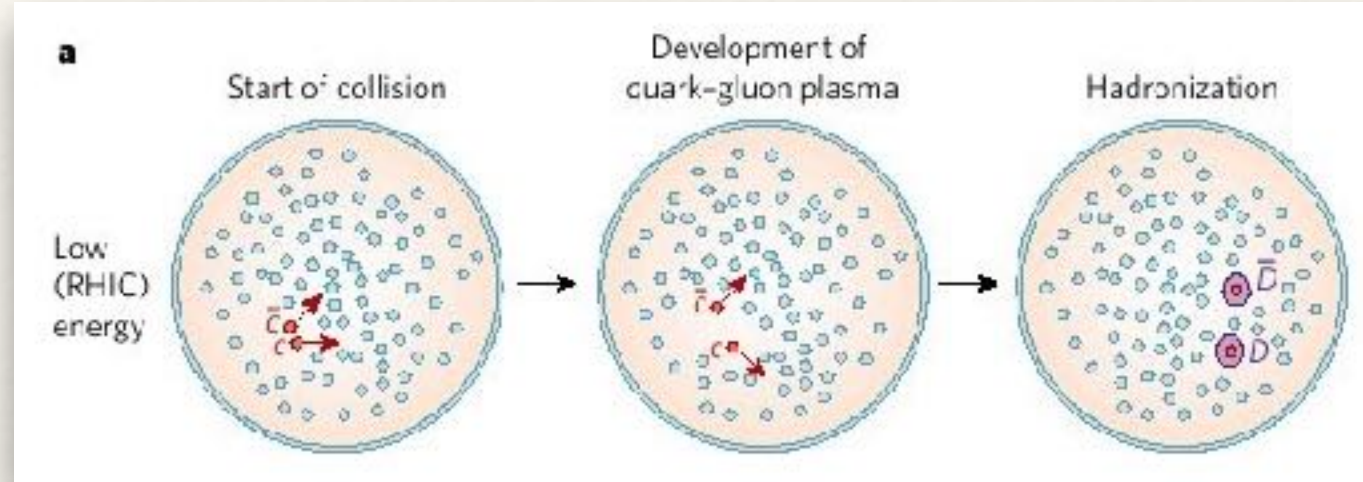
Outline

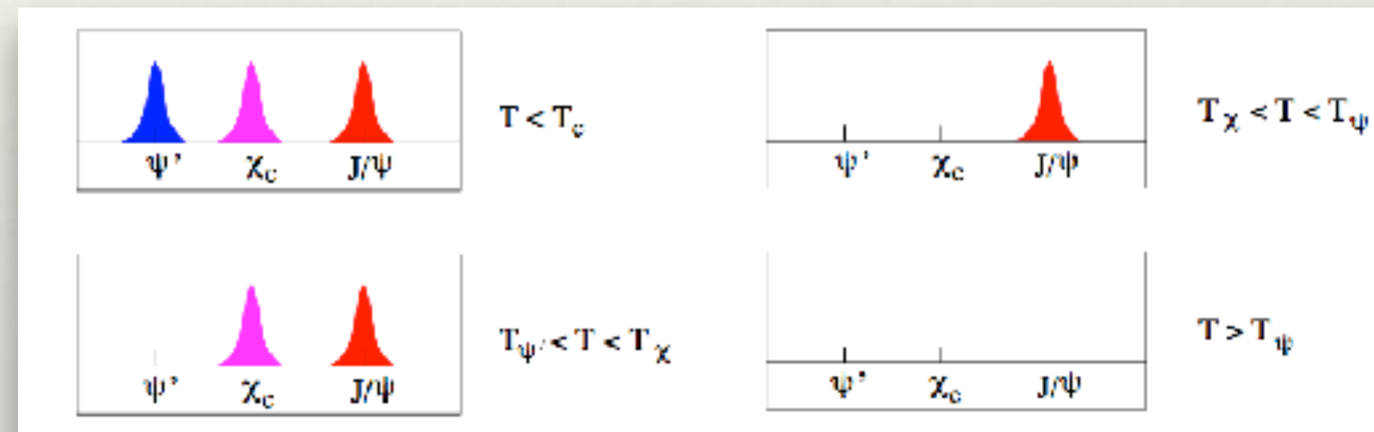
I. Physics Motivations
II. The ALICE Detector
III. J/ψ production in pp collisions
IV. J/ψ production in Pb-Pb collisions

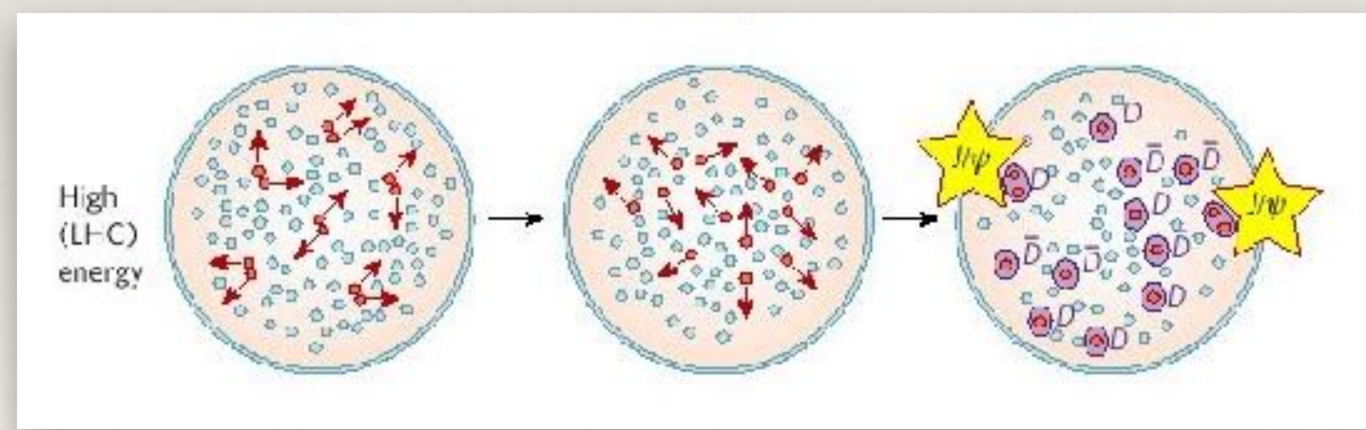
Physics Motivations

A Good Probe

- Charmonium is produced *__at the earliest stage__* of the collision.
- J/ψ suppression by the QGP through *__Debye like color screening mechanism__*[1].
- 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)

- 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.
  - Decay from from higher mass charmonium states (~ 24%).
  - Decay from B-hadrons (~ 10%).

Inclusive

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

Observables

- Assumption : ◎Pb→←◎Pb = <N_{coll}> ●p→←●p

The Nuclear Modification Factor

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

Centrality

Differential Yield in PbPb

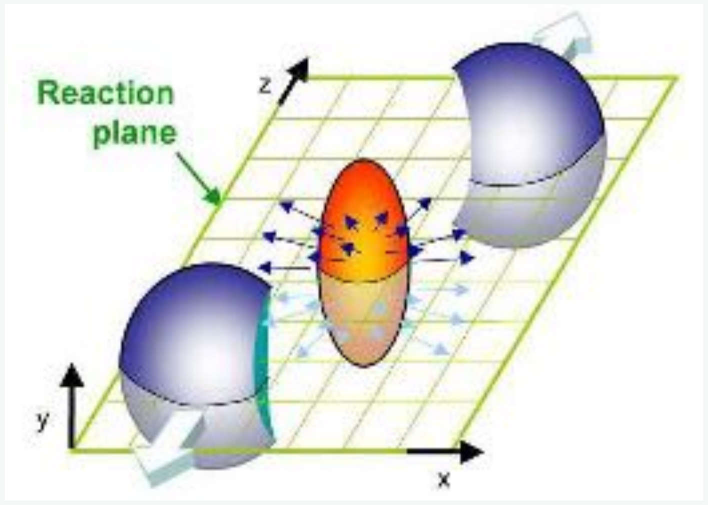
Mean number of binary collisions

Differential Yield in pp

- If $R_{AA} > 1$ → *More* charmonium produced than expected from pp results.
- If $R_{AA} = 1$ → Hard to conclude…
- 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.

See Audrey's Talk

The ALICE Detector

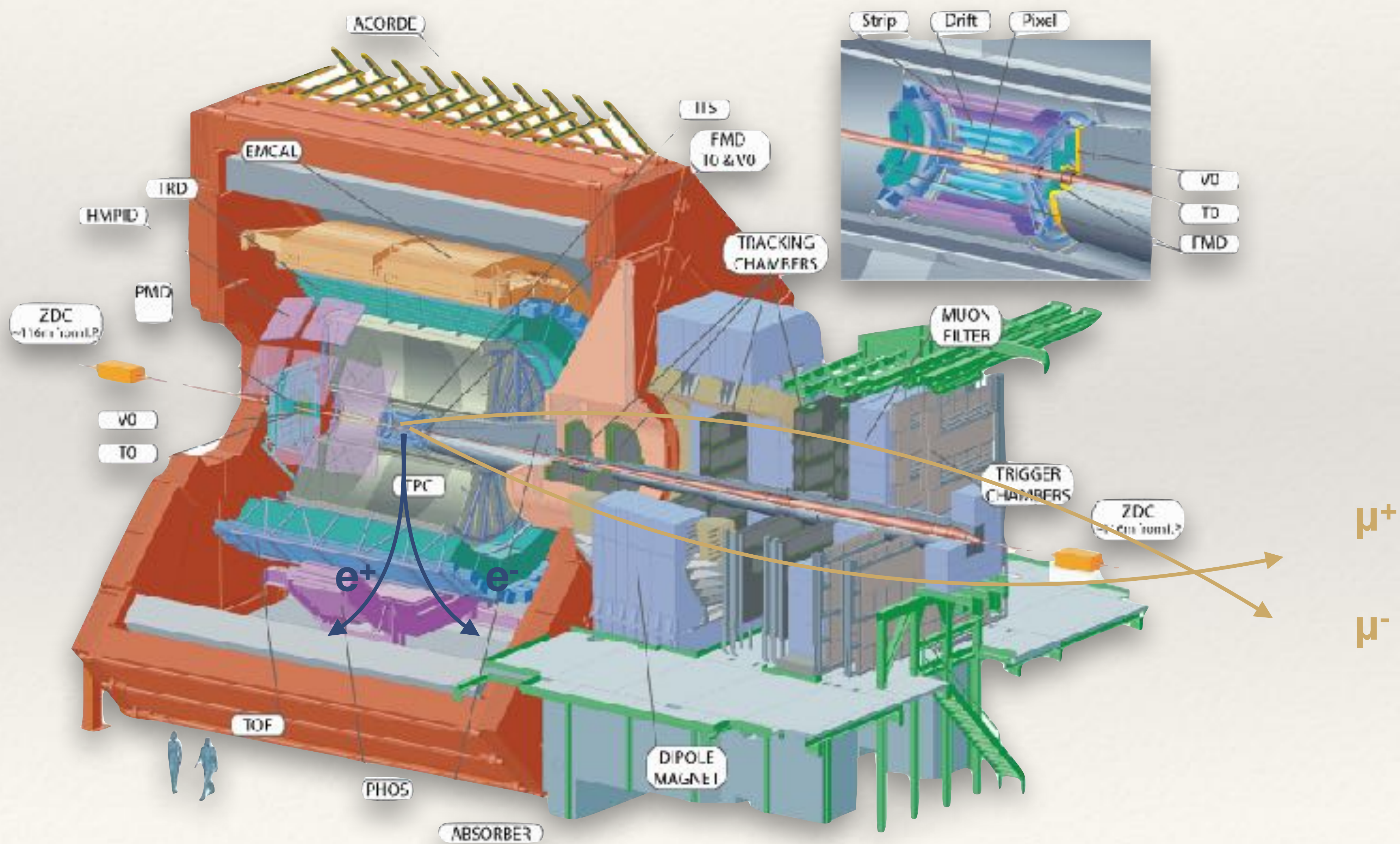
Two decay channels studied in ALICE :

J/ψ -> e^+e^- :

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

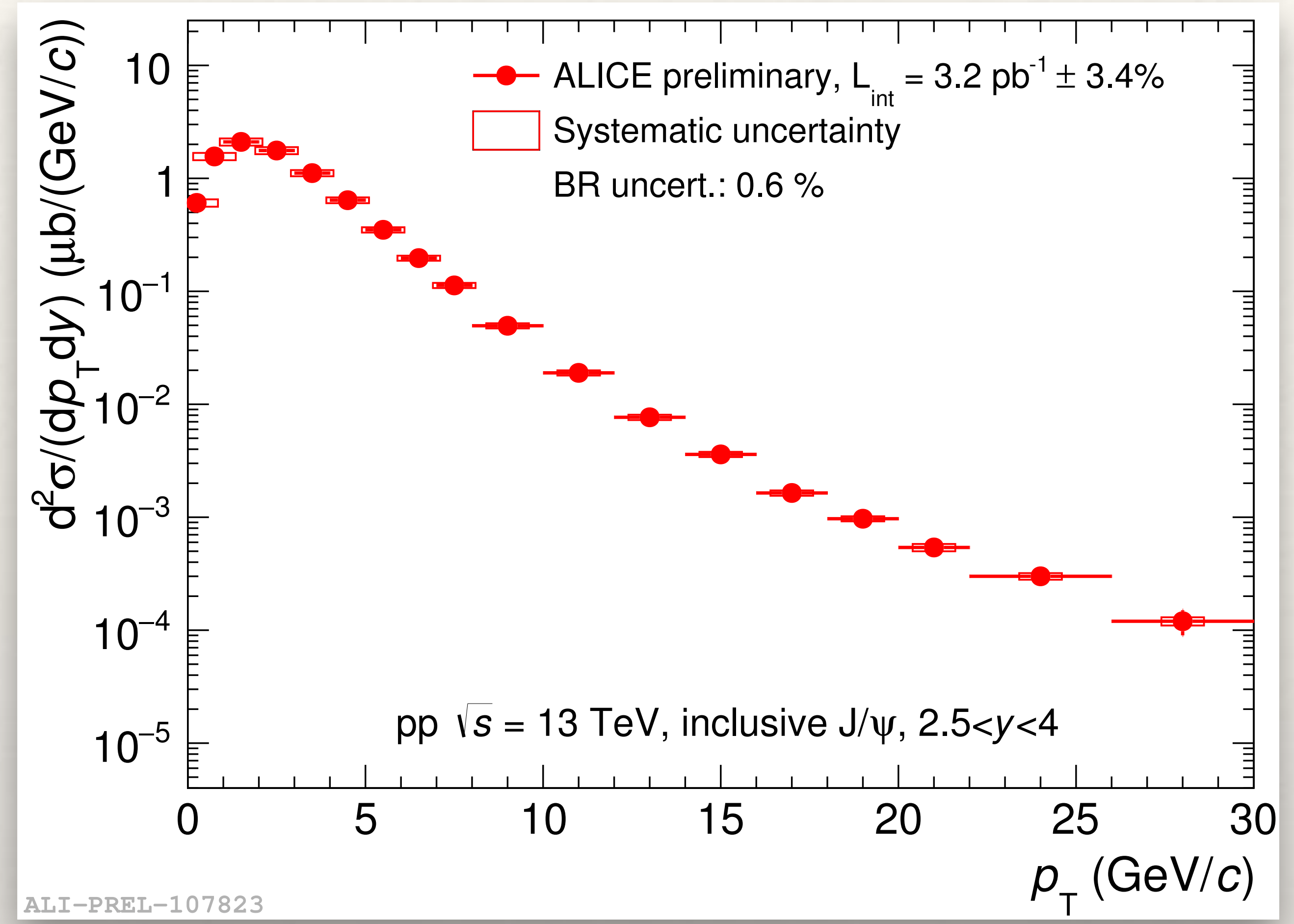
J/ψ -> $\mu^+\mu^-$:

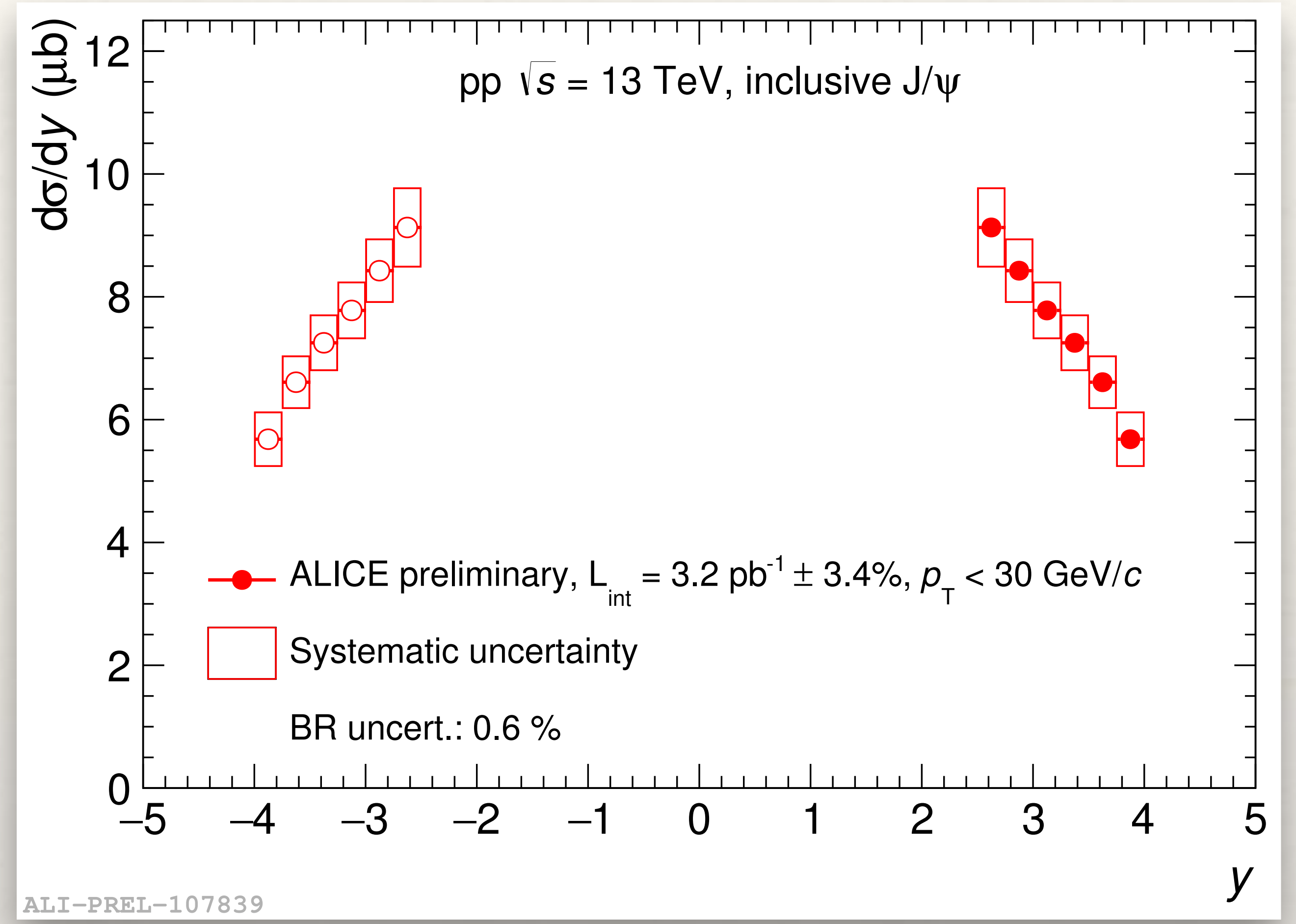
- 2.5 < y < 4
- down to $p_T = 0$
- detectors involved : muon arm



J/ψ production in pp collisions measured by ALICE

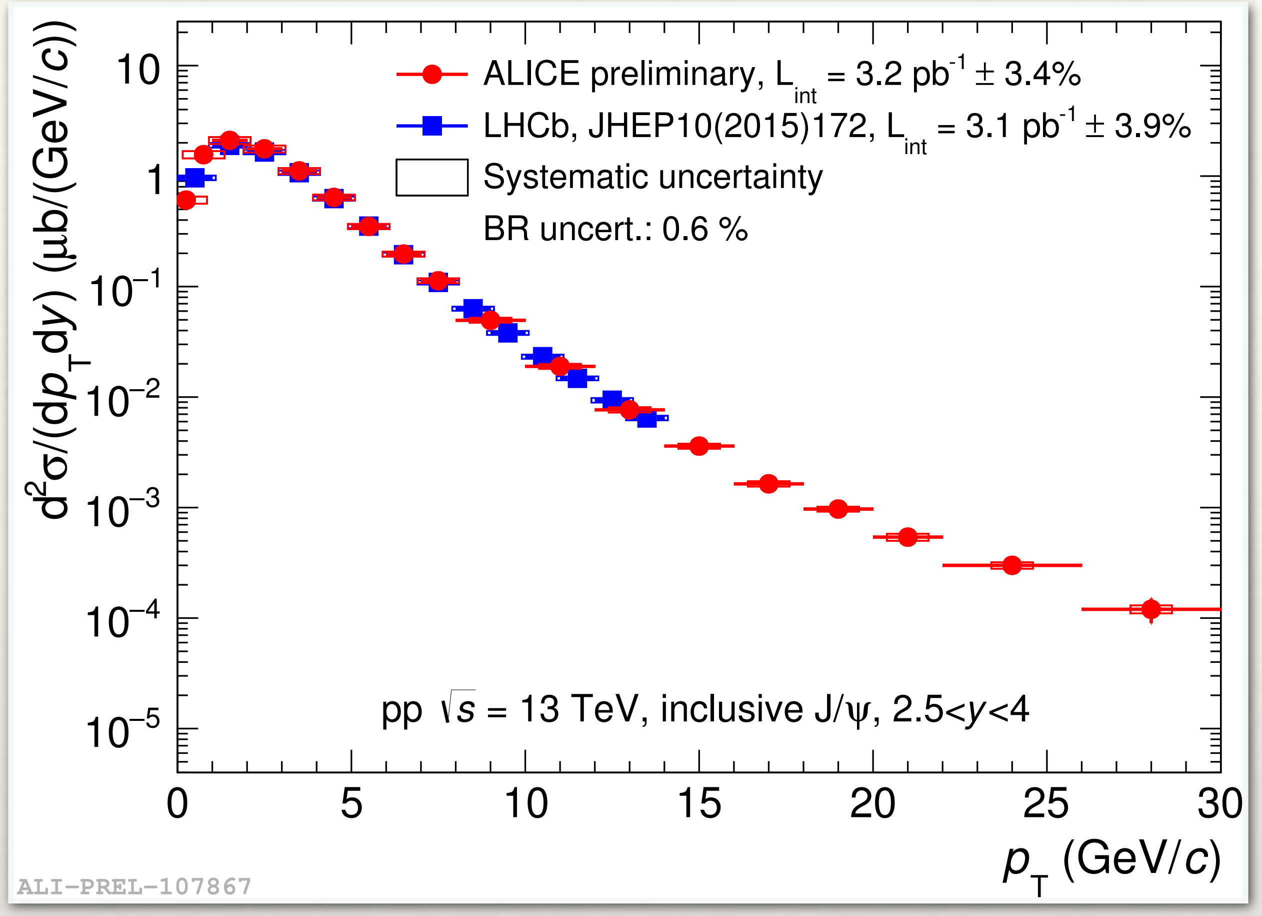
ALICE Measurement for pp@13 TeV at forward rapidity

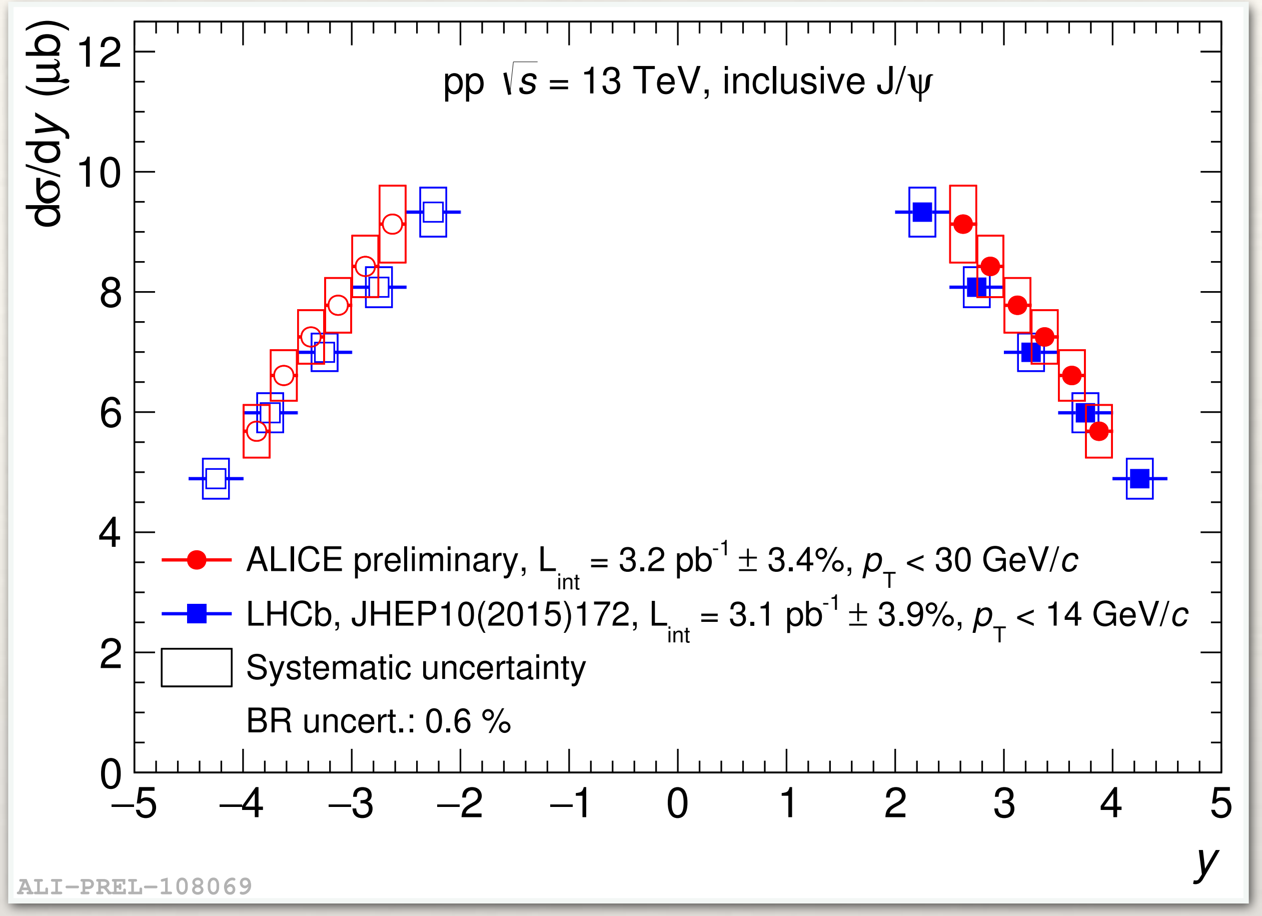




- Range extended to p_T= 30 GeV/*c* for the J/ψ
- 6 bins in *y* for 2,5 < *y* < 4

ALICE & LHCb Comparison at Forward Rapidity

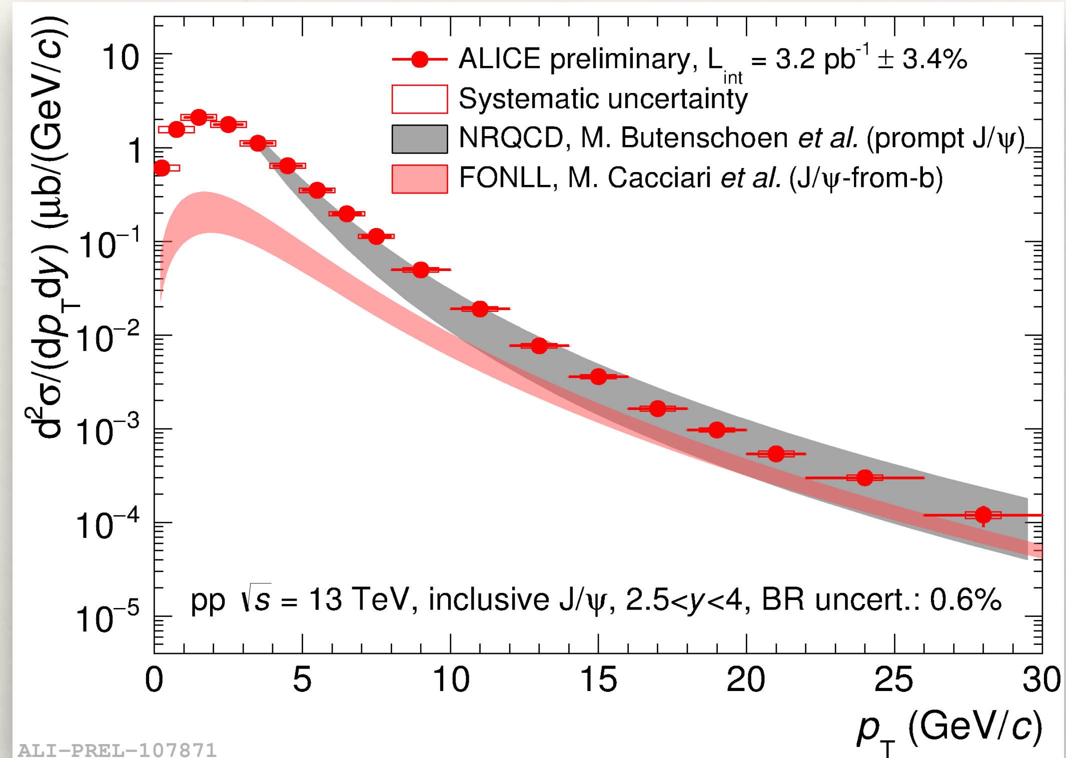


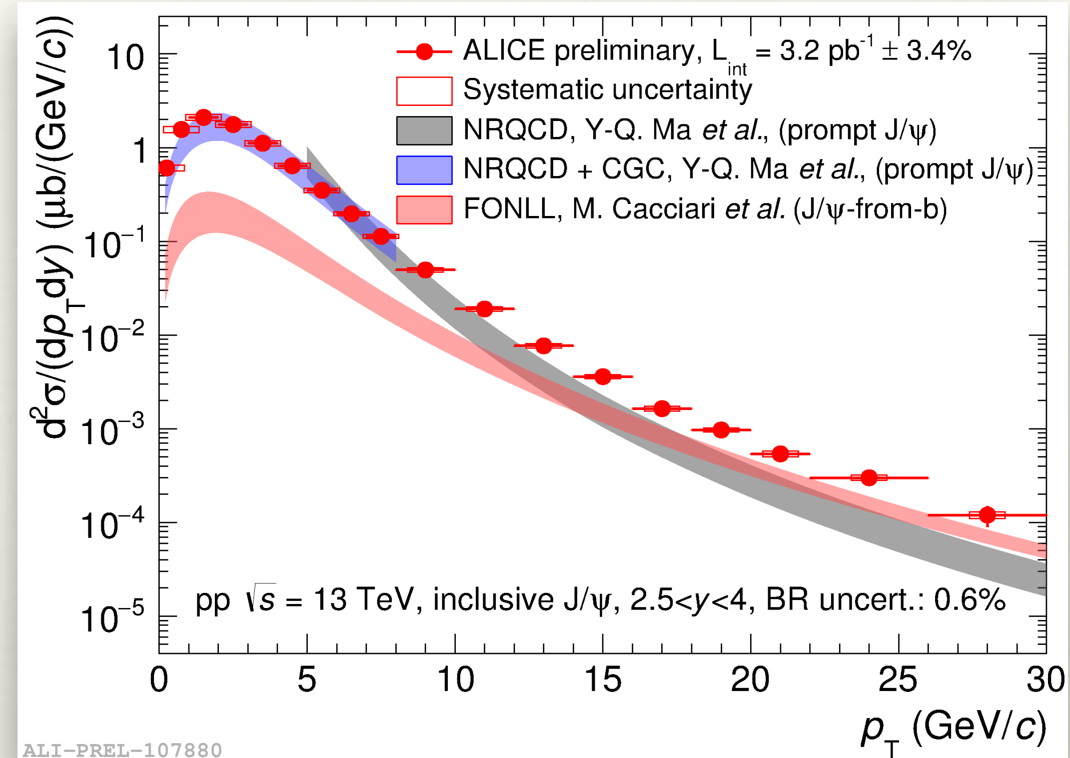


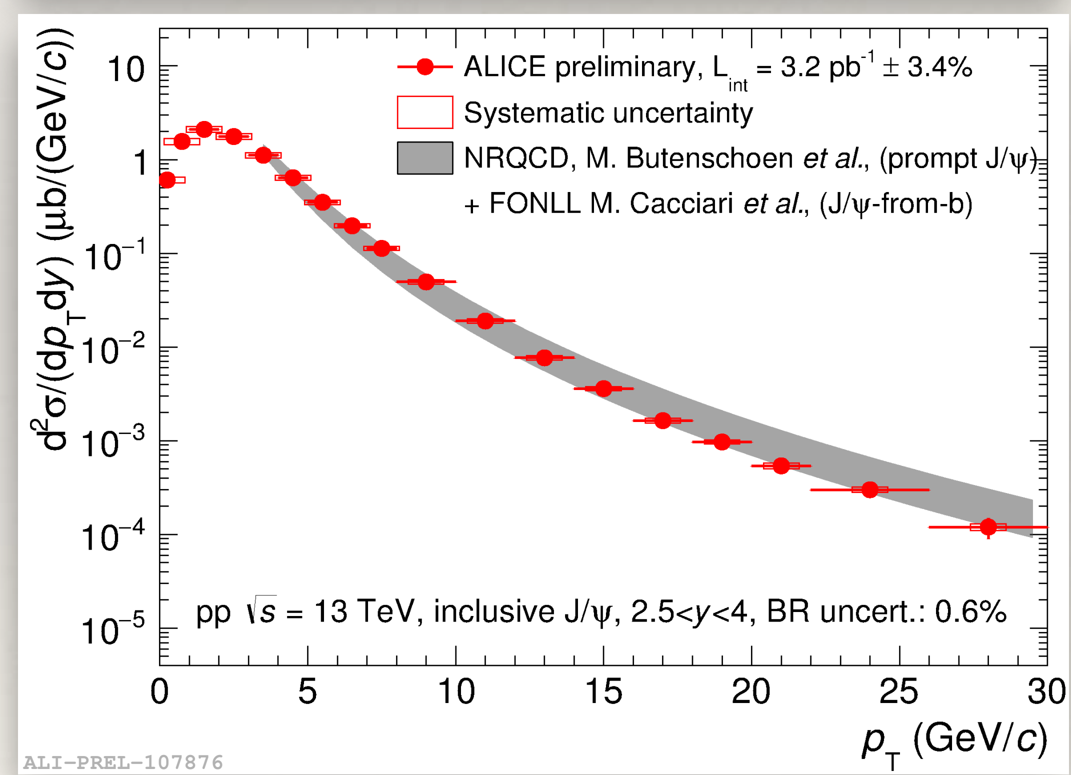
- Excellent agreement between the two experiments
- All points lie within 1 sigma (stat+syst) of each other

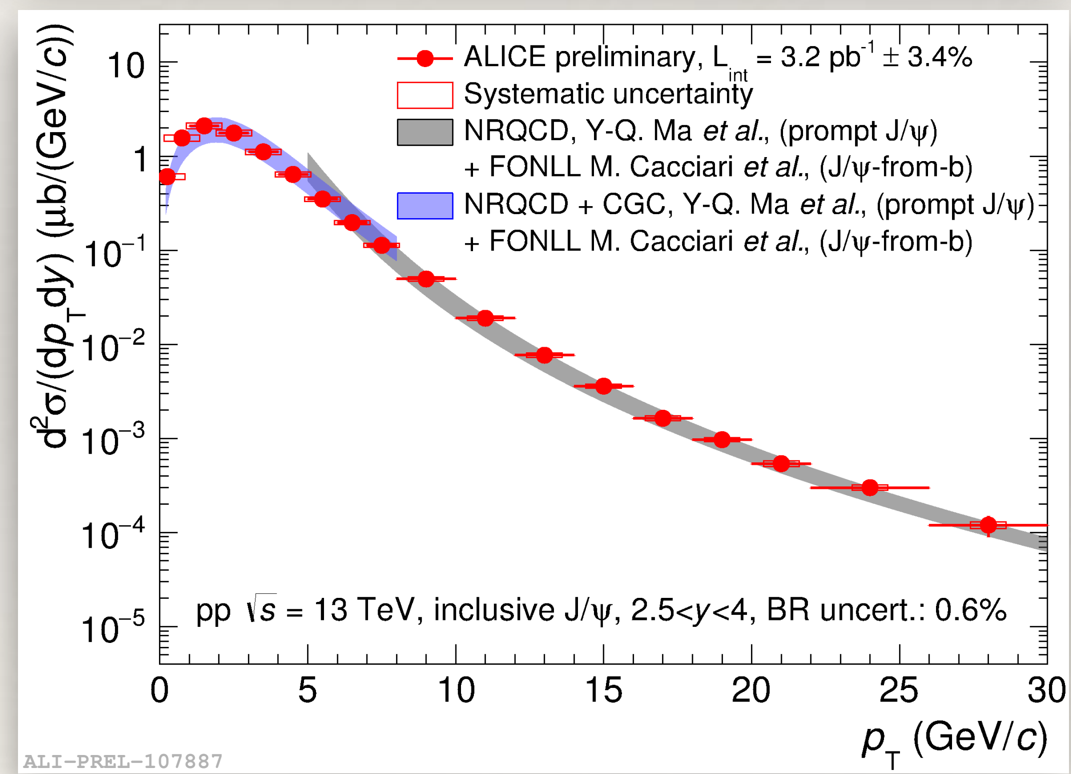
1) JHEP10 (2015) 172

ALICE's Inclusive Results Compared to Models



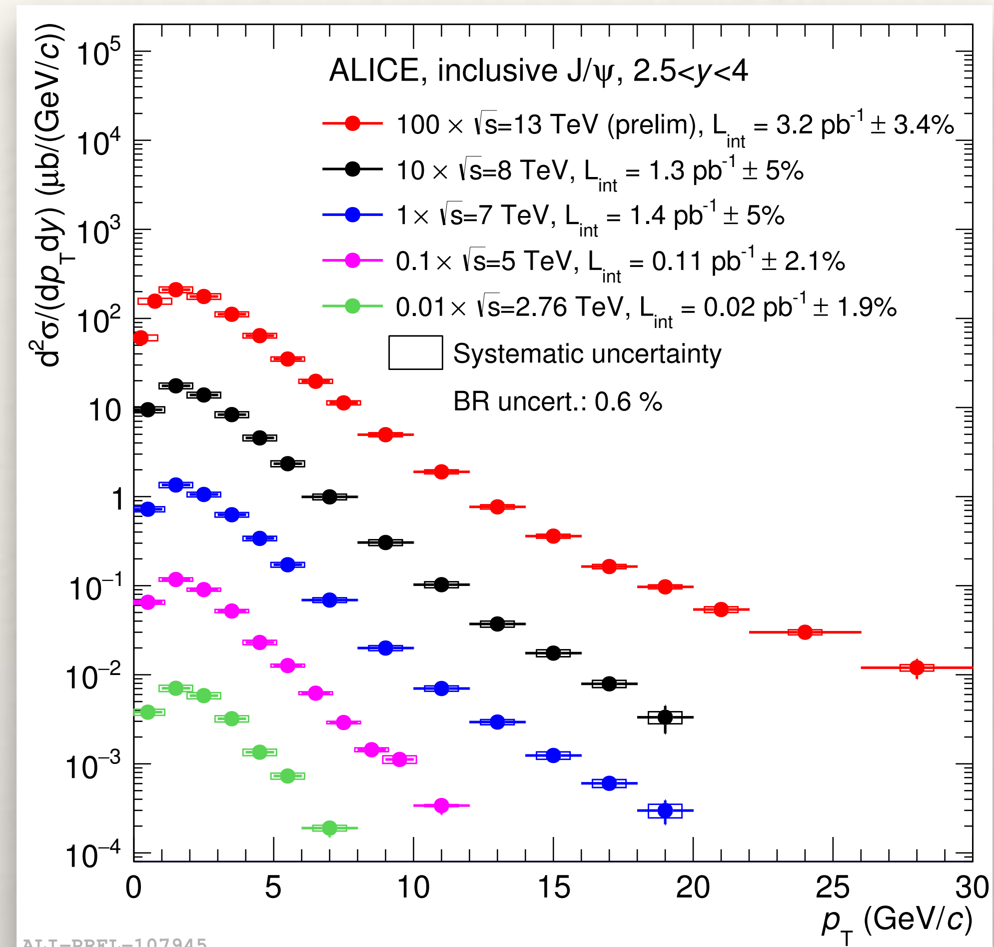


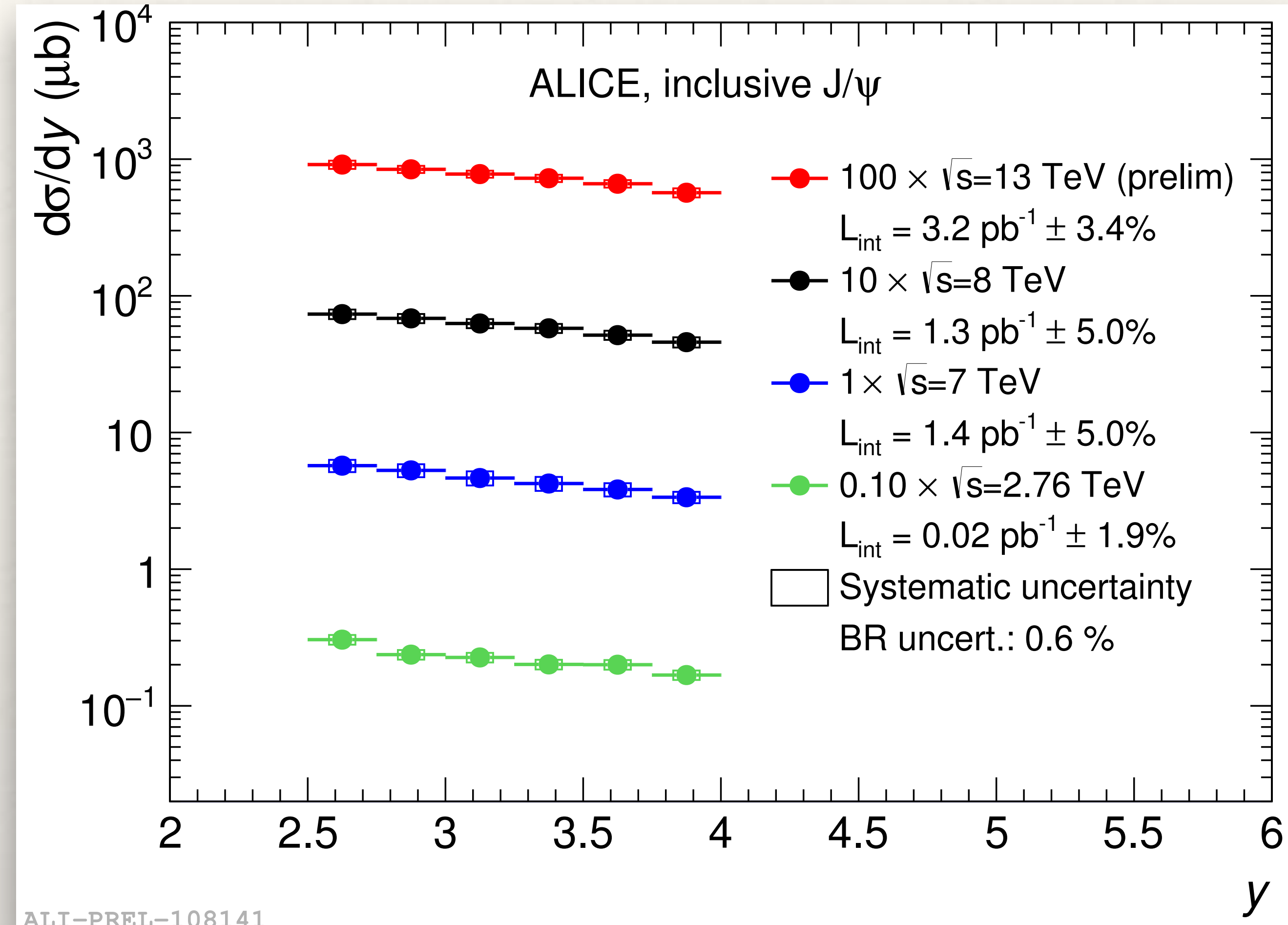




NRQCD (left) Butenschon and Kniel, PRL 106 (2011) 022003
NRQCD (right) Ma, Wang and Chao, PRL 106 (2011) 042002
NRQCD+CGC Ma and Venugopalan, PRL 113 (2014) 192301
FONLL Cacciari et al., JHEP 1210 (2012) 137

Comparison Between Energies





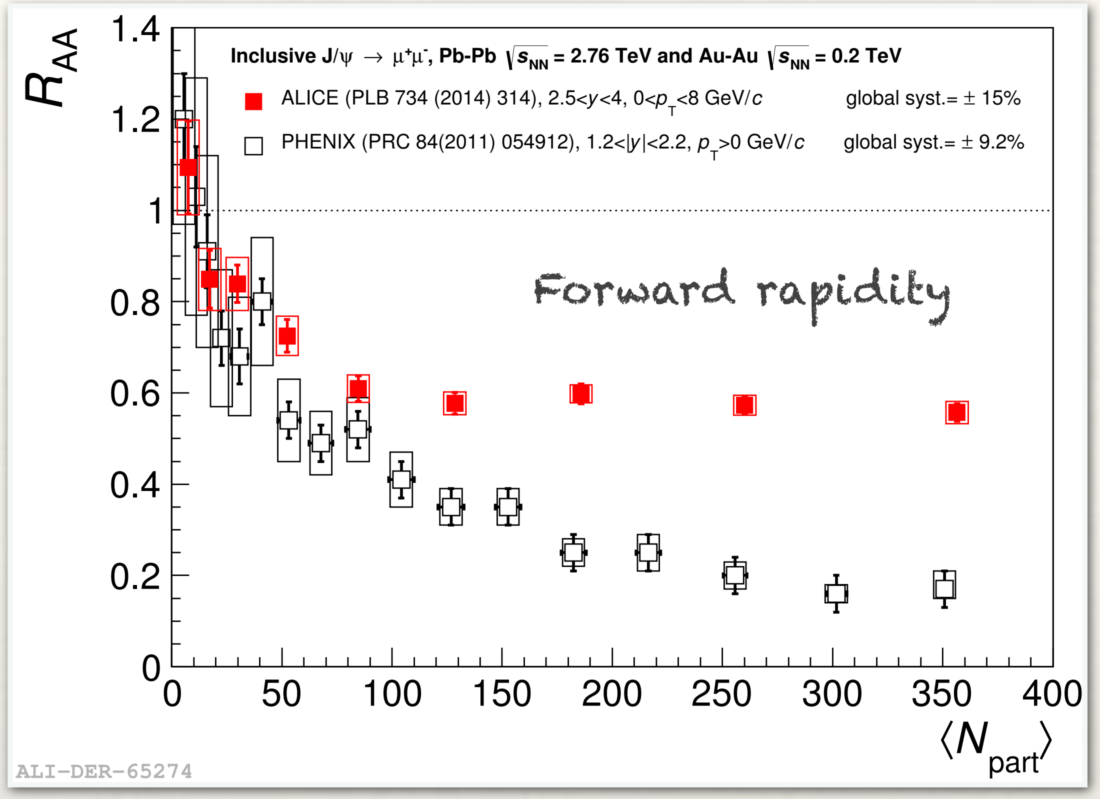
- Steady increase of the luminosity and p_T reach with increasing energy
- Change of slop at high p_T and $\sqrt{s}$ = 13 TeV -> onset of the non-prompt J/ψ contribution

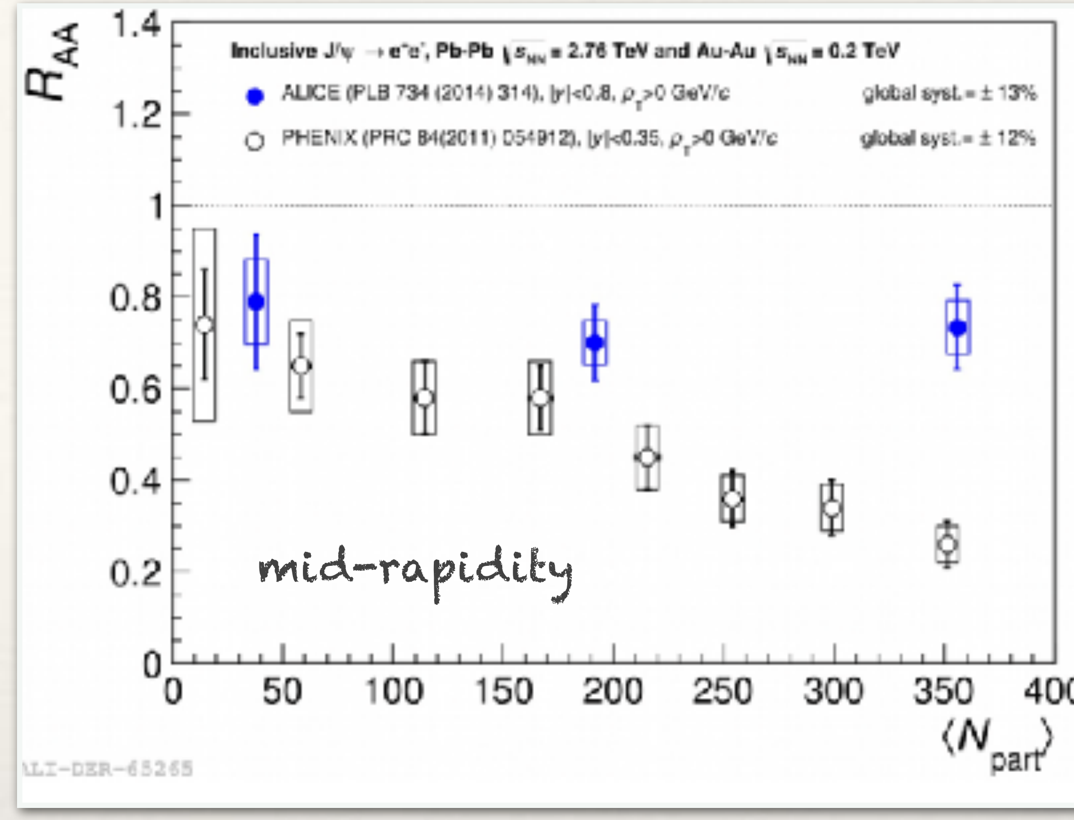
- No visible change in the *y* distribution.

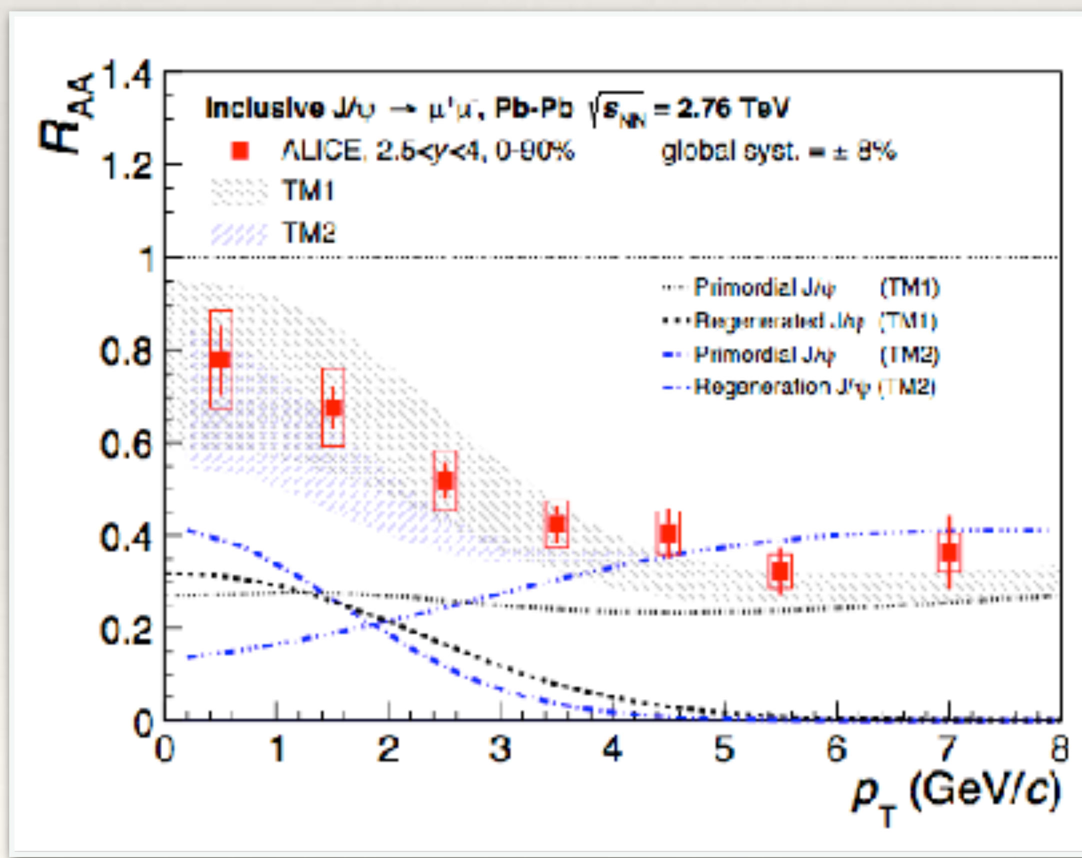
$\sqrt{s}$ = 2.76 TeV PLB 718 (2012) 295
$\sqrt{s}$ = 5 TeV ArXiv:1606.08197
$\sqrt{s}$ = 7 TeV EPJC 74 (2014) 2974
$\sqrt{s}$ = 8 TeV EPJC 76 (2016) 184

J/ψ production in PbPb collisions measured by ALICE

ALICE Results in Pb-Pb@2.76 TeV



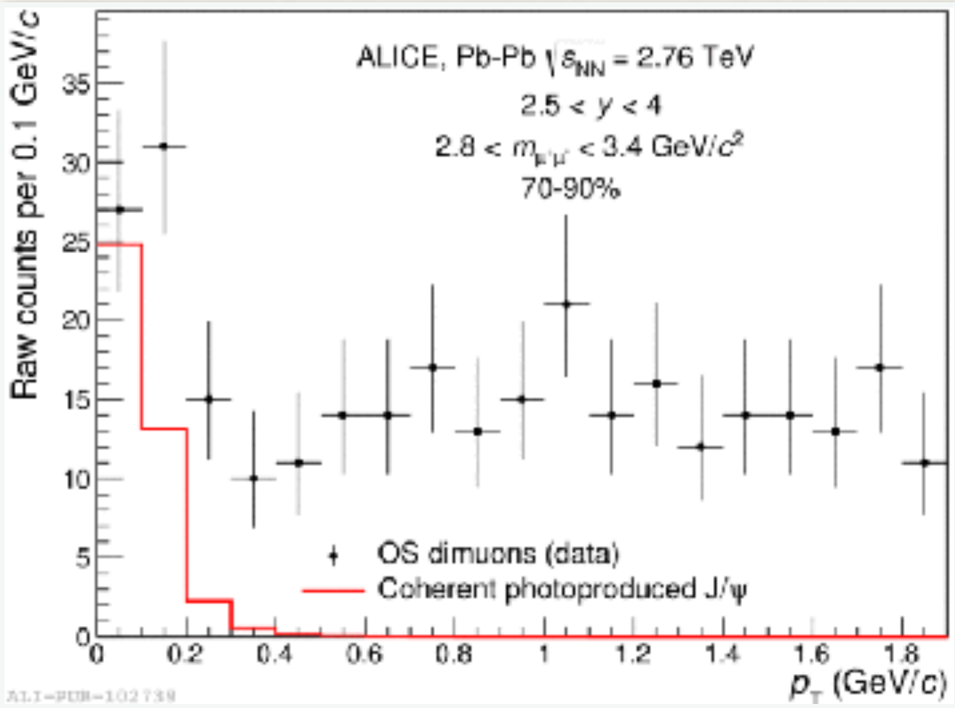




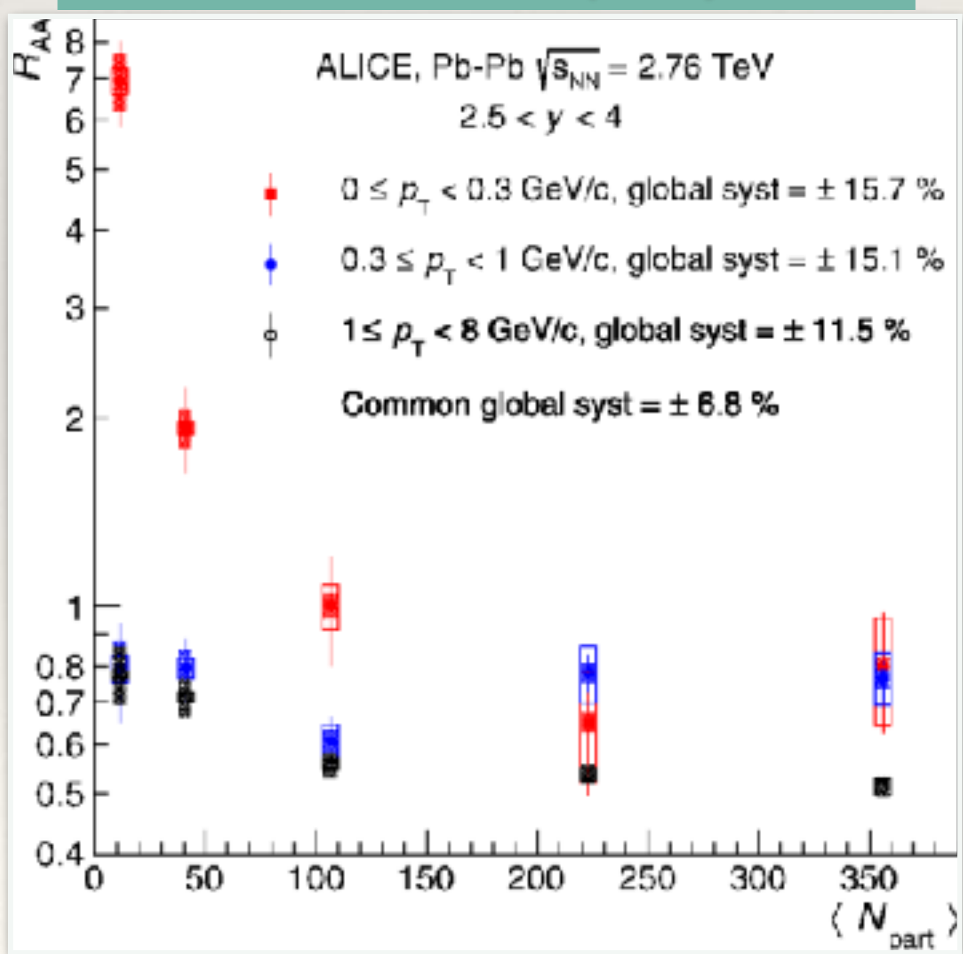
- **Clear J/ψ suppression** both at ALICE and PHENIX (Au-Au at $\sqrt{s_{NN}}$= 200 GeV).
- **Weaker centrality dependence** and **smaller suppression for central events** in ALICE compared to PHENIX.
- **Less suppression at low** w.r.t high p_T for ALICE and less suppression compared to PHENIX.
- **Previous observations expected in regeneration scenario.**

ALICE Coll. PLB 734 (2014) 314

Very Low p_T excess



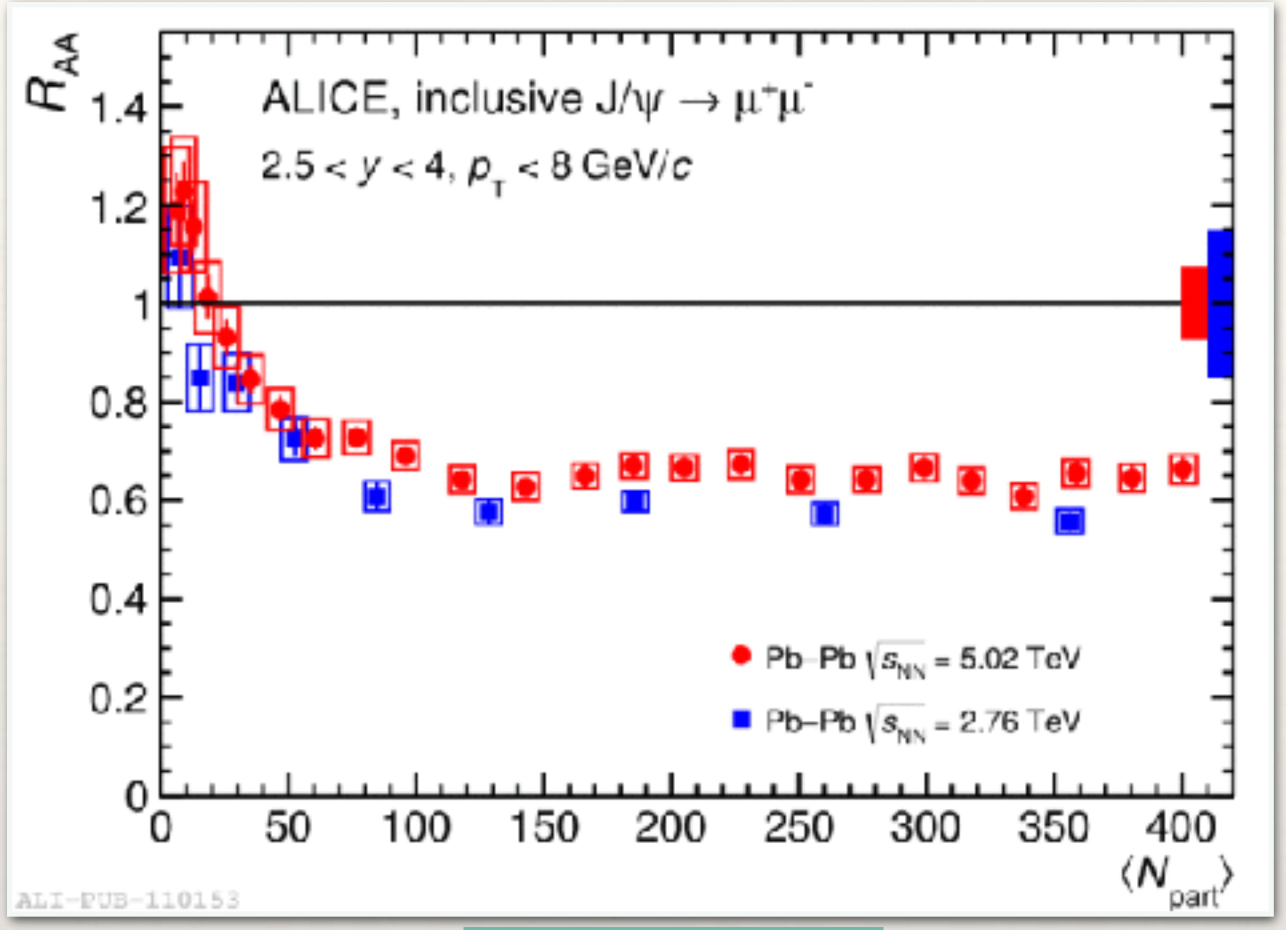
ALICE Coll. PRL116 (2016) 222301



- 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].

Inclusive J/ψ R_{AA} versus centrality in Pb-Pb@5.02 TeV



arXiv:1606.08197

- **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.)

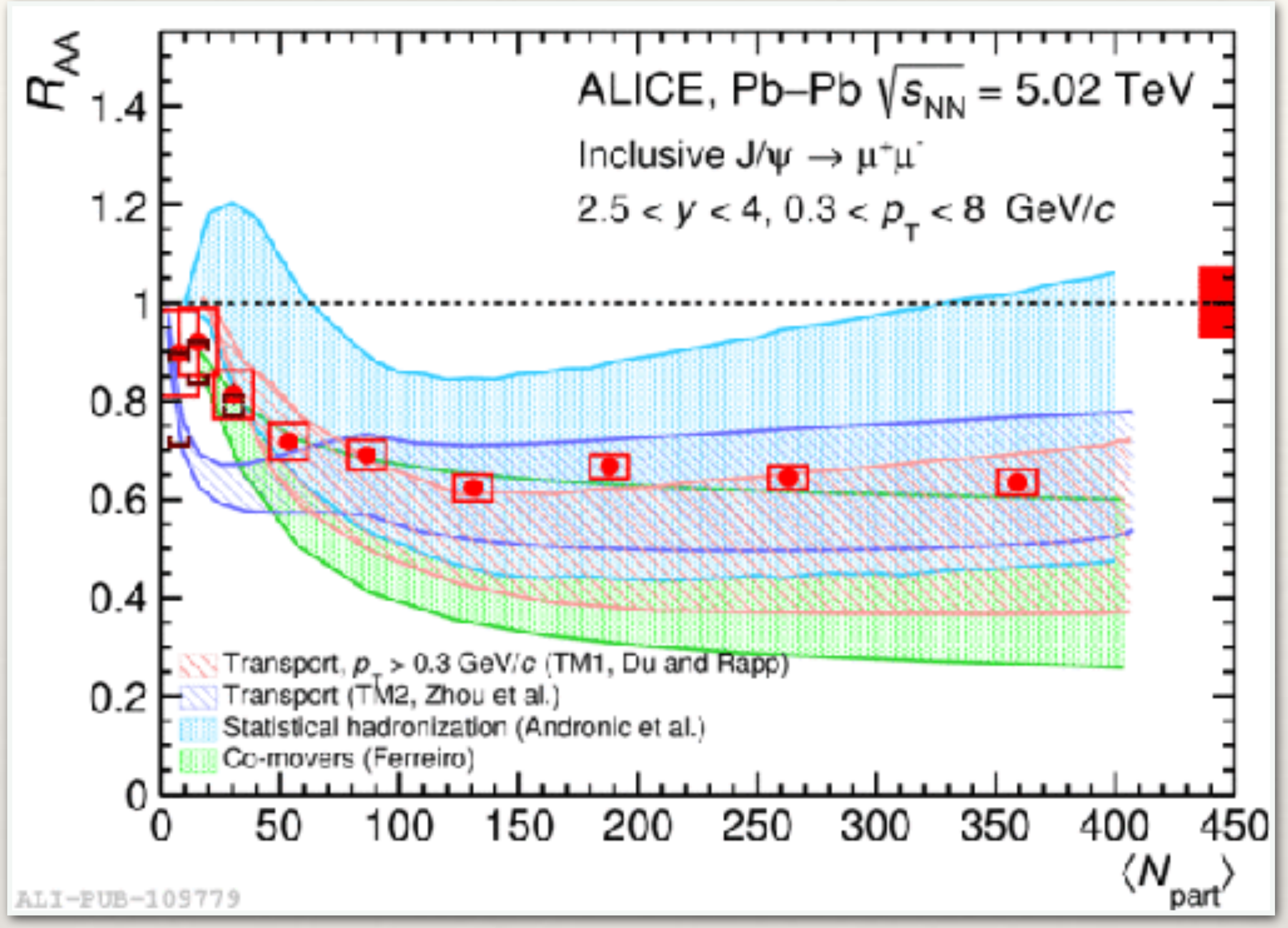
$R_{AA(non\text{-}prompt)}$ = 0
- All non-prompt J/ψ are suppressed
- $R_{AA(prompt)}$ 10% higher

↔

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

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

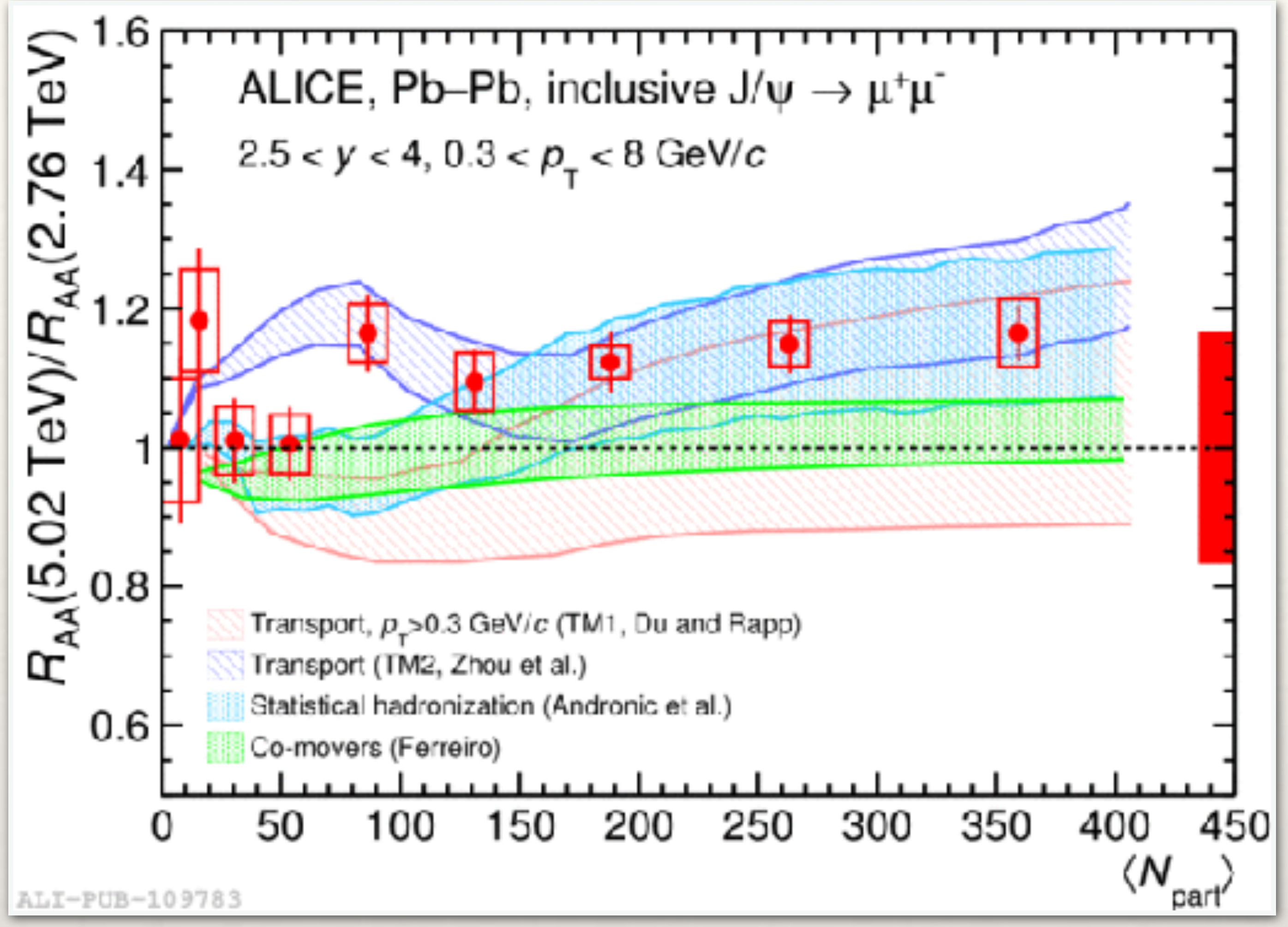
Inclusive J/ψ R_{AA} versus centrality ($0.3 < p_T < 8$ GeV/c)



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



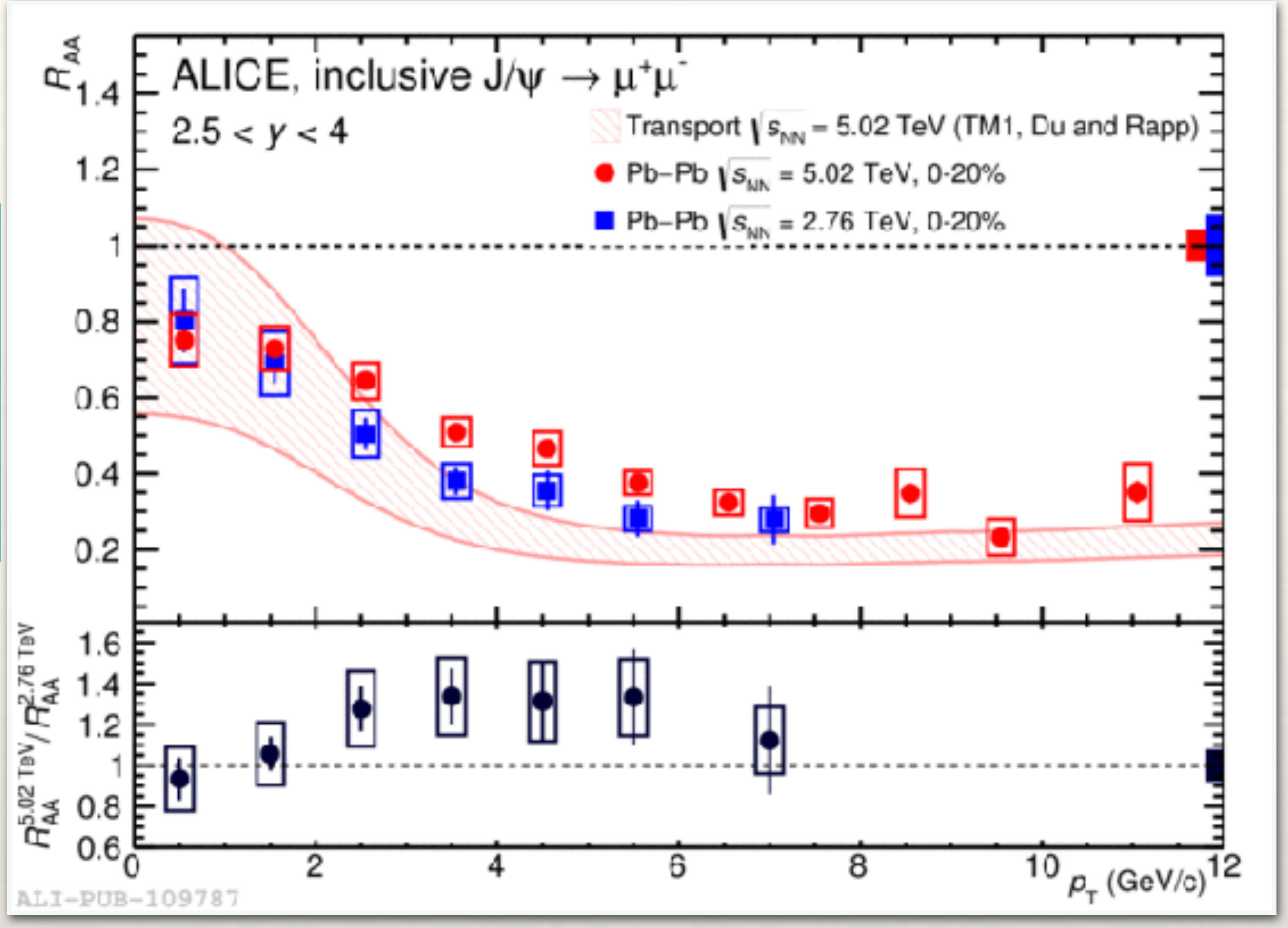
- R_{AA} ratio allows some uncertainties on the models to cancel out
- T_{AA} uncert. also cancels out for the experimental results
- Error bands on models correspond to a 5% variation of $\sigma_{c\bar{c}}$

- 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 in Pb-Pb@5.02 TeV

arXiv:1606.08197



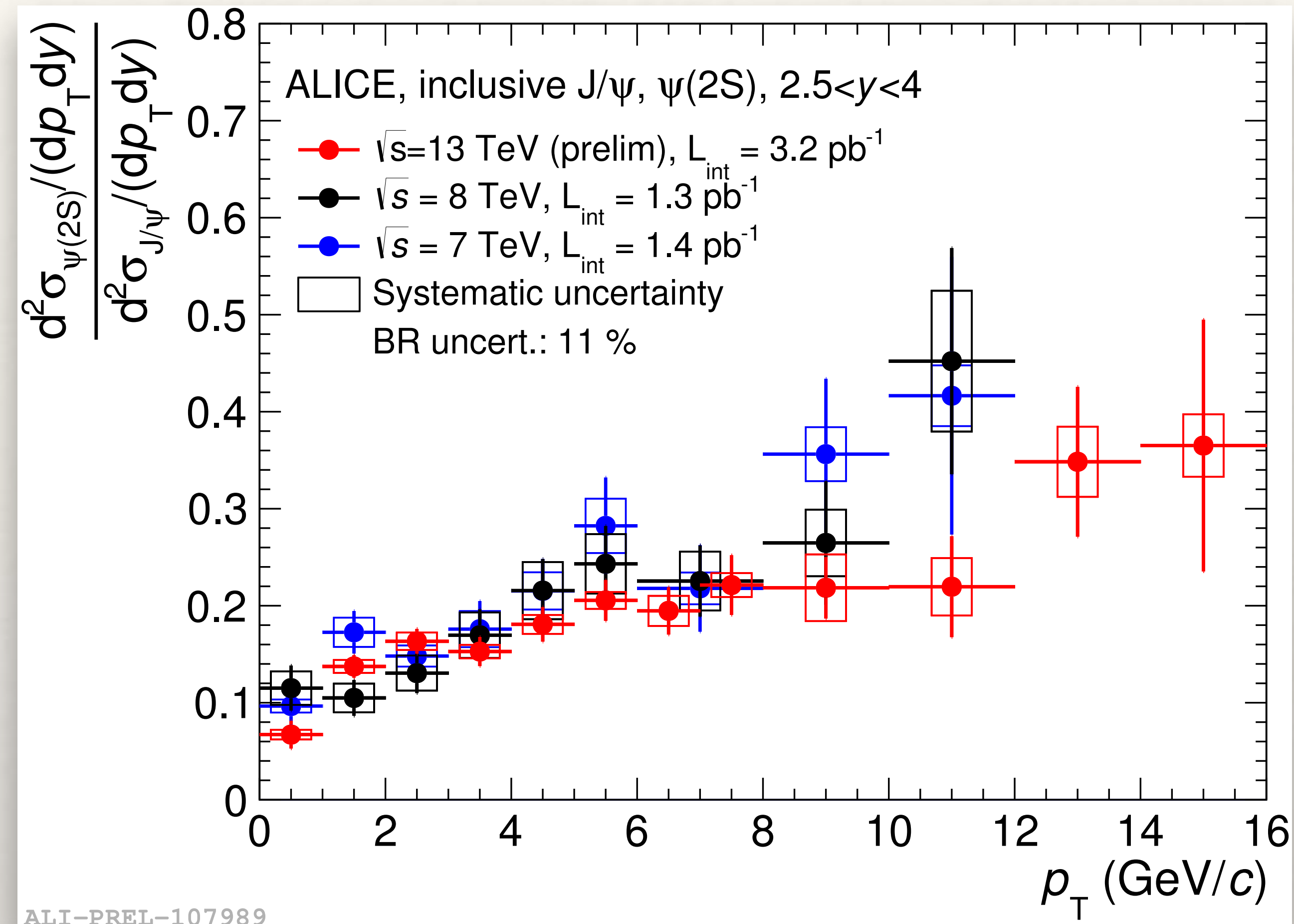
- Less suppression at low p_T w.r.t high p_T.
- Assuming **beauty fully suppressed** :
  - $R_{AA(prompt)}$ expected to be **7% larger** for $p_T < 1$ GeV/*c*.
  - $R_{AA(prompt)}$ expected to be **30% larger** for $10 < p_T < 12$ GeV/*c*.
- Assuming **beauty binary scaling** :
  - $R_{AA(prompt)}$ expected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

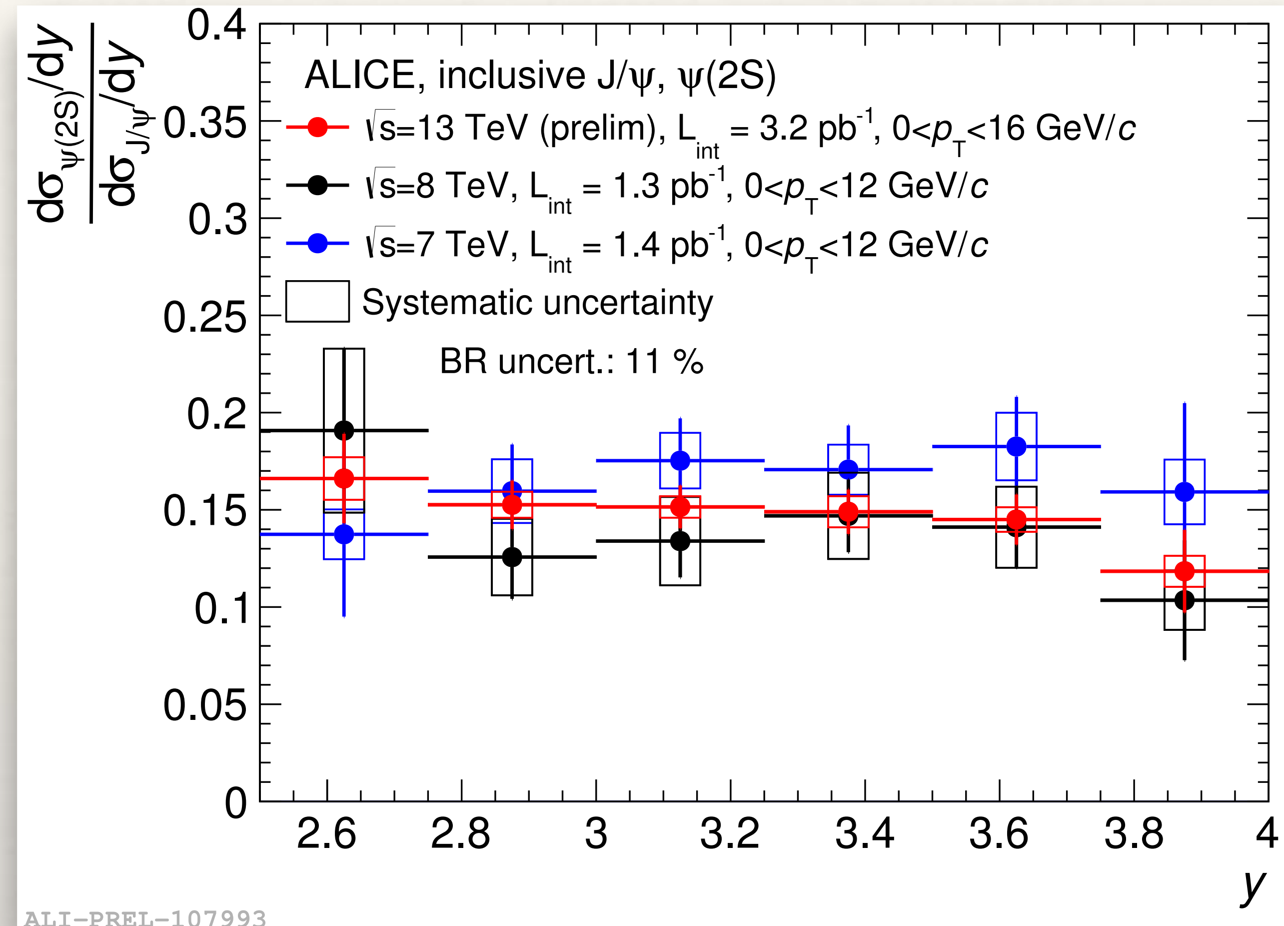
Conclusions and Outlooks

- **The J/ψ cross section in pp collisions** :
  - New measurements at $\sqrt{s}$ = 5.02 and 13 TeV.
  - Good agreement between ALICE and LHCb data.
  - Change of slop at high p_T and $\sqrt{s}$ = 13 TeV.
- **Inclusive J/ψ nuclear modification factor in PbPb collisions :**
  - New measurements at $\sqrt{s_{NN}}$ = 5.02 TeV at forward rapidity down to p_T = 0 GeV/c.
  - 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.
  - 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.
  - **Data and theoretical models are compatible within uncertainties and support a picture of competing J/ψ suppression and regeneration in the QGP.**
- **Outlooks :**
  - Multi-differential study ongoing for inclusive J/ψ nuclear modification factor in PbPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
  - Study of the mid-rapidity R_{AA} ongoing

Back-up

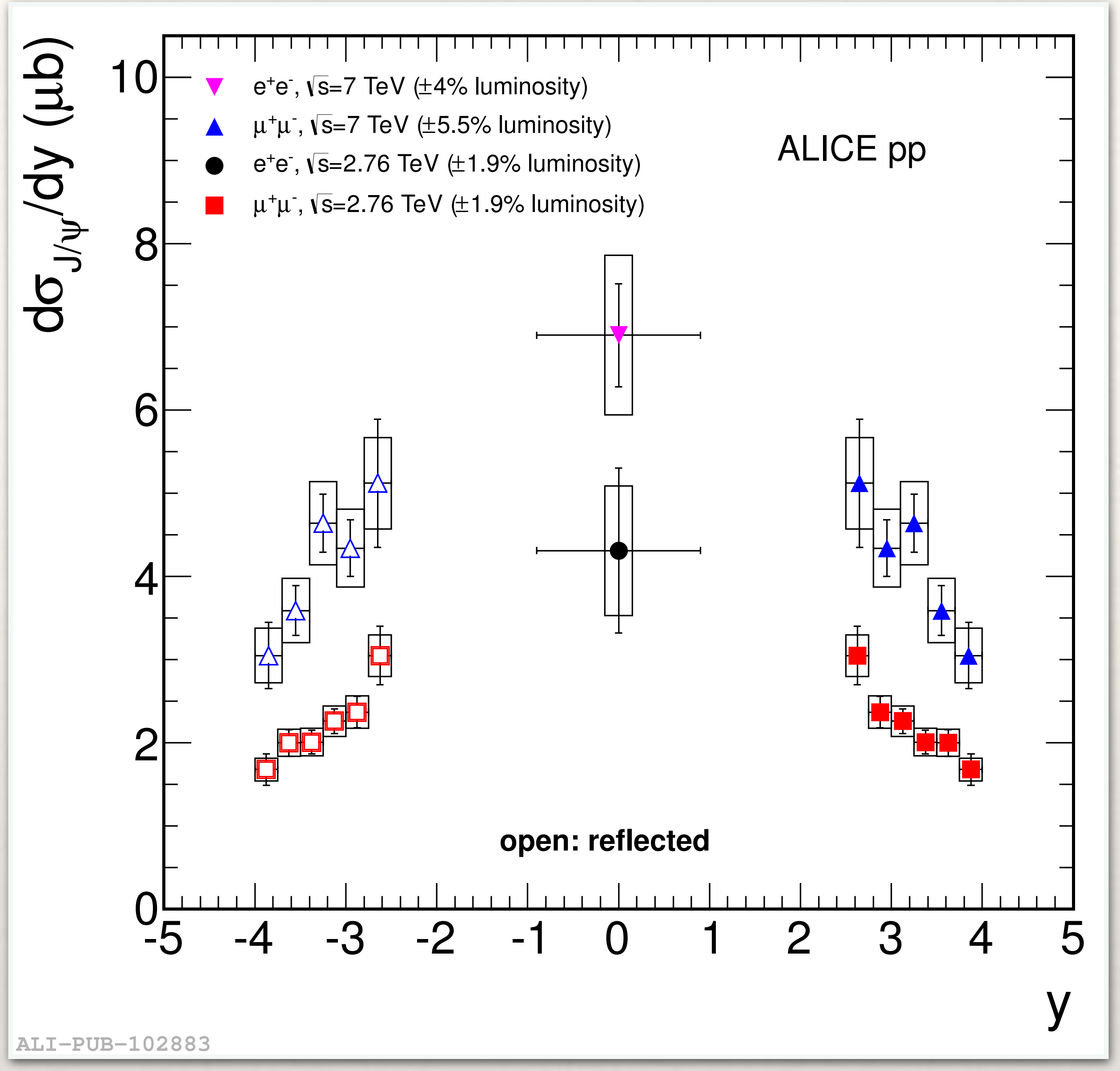
ψ(2s) to J/ψ ratios with energy





- No visible $\sqrt{s}$ dependance of the p_T differential ψ(2s)-to-J/ψ ratio
- No clear trend either vs rapidity

Results in pp@2.76 TeV and pp@7 TeV



- Good agreement between the results.

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%

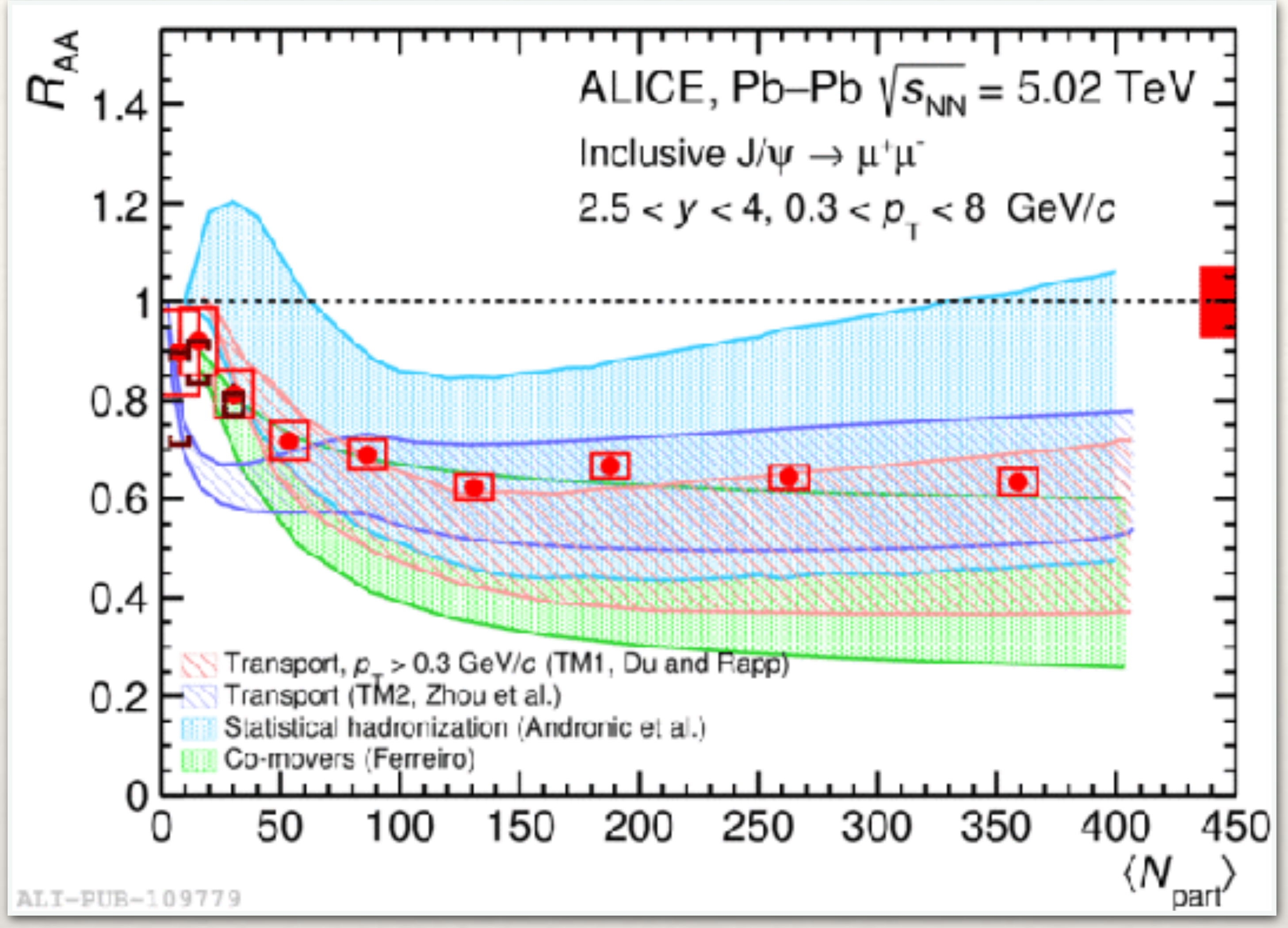
Uncorrelated uncertainties
Correlated uncertainties

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%

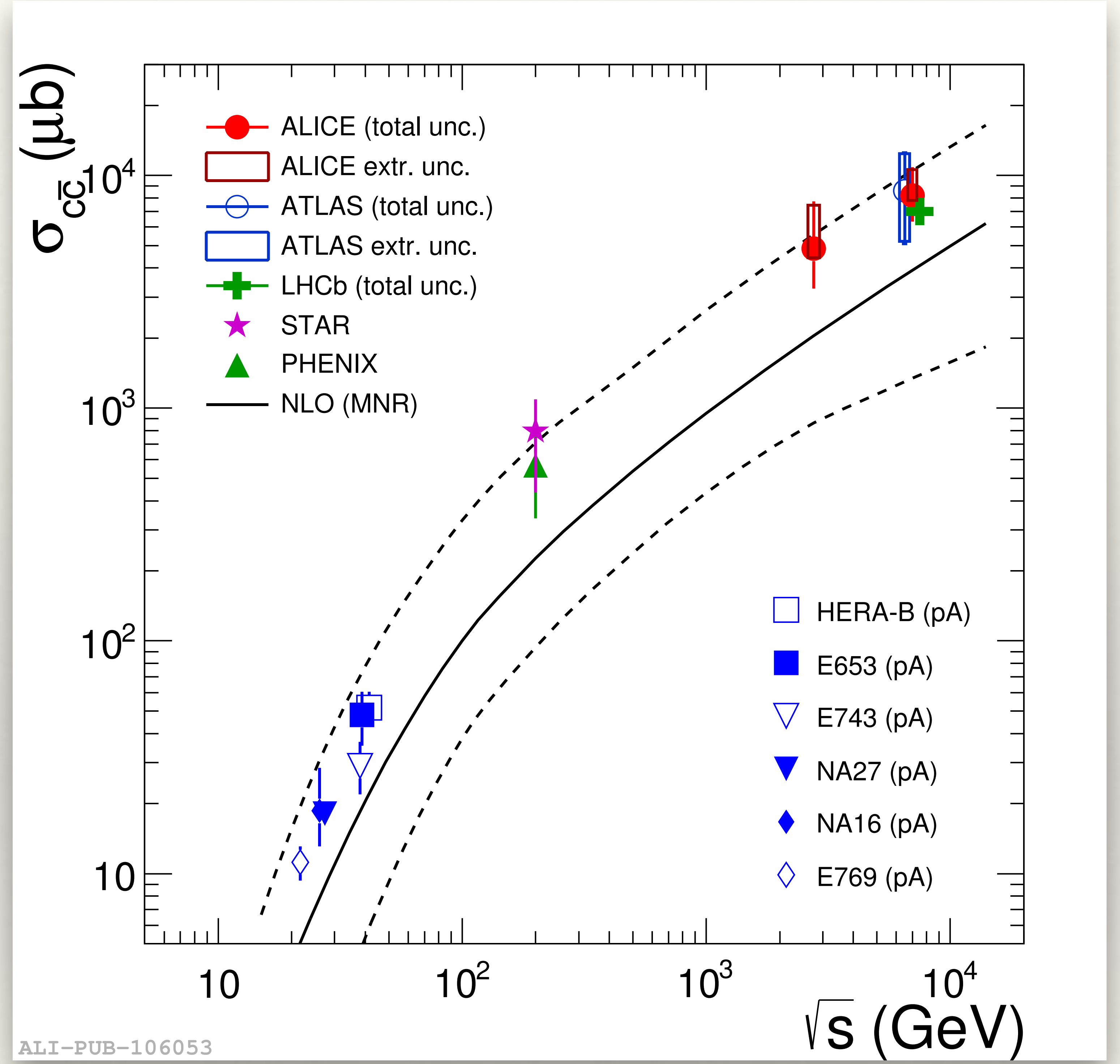
Uncorrelated uncertainties
Correlated uncertainties

Models parameters



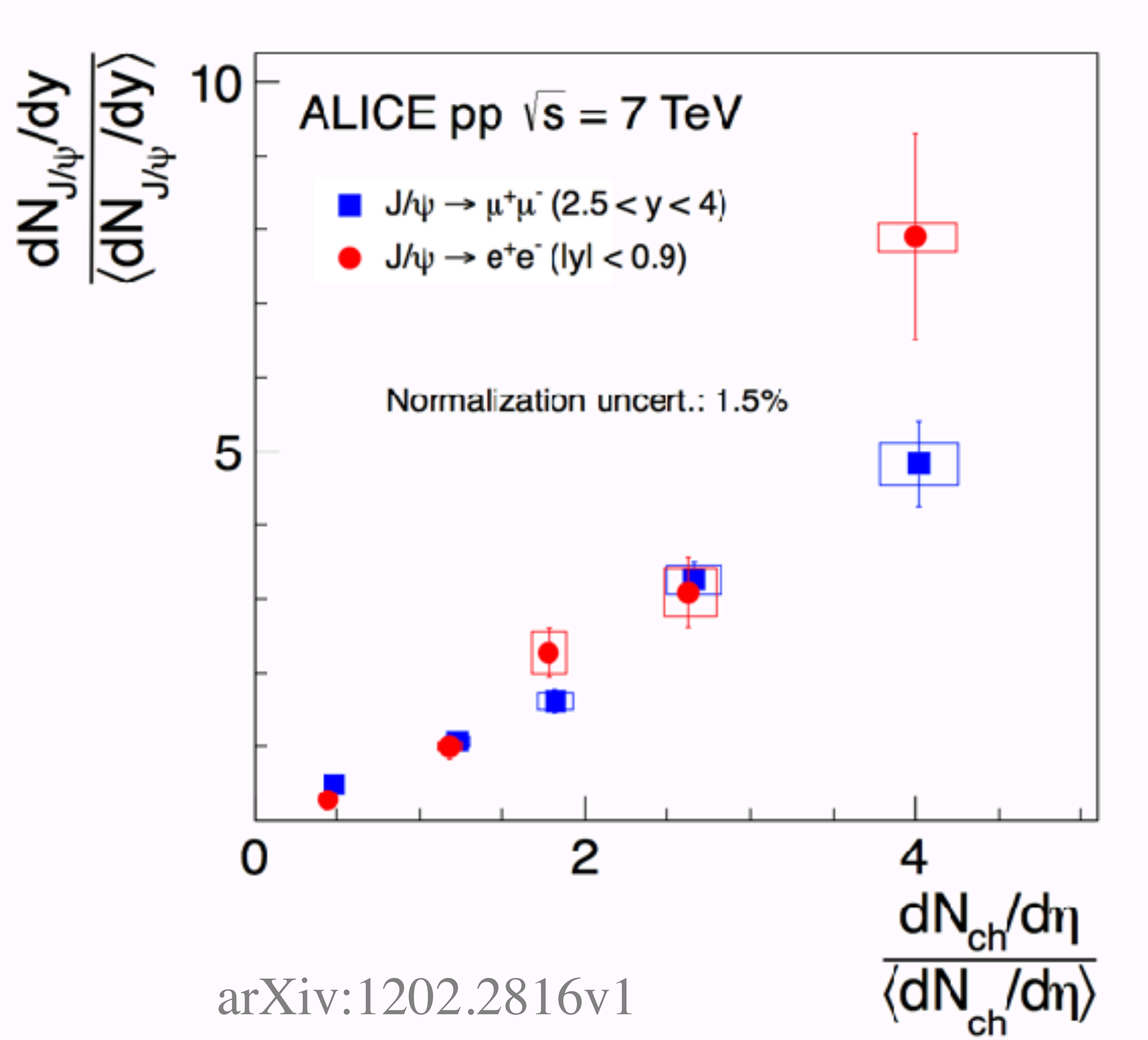
model	$\sigma_{c\bar{c}}$ (mb)	N-N $\sigma_{c\bar{c}}$ (μb)	comover $\sigma_{J/\psi}$	Shadowing
Transport	0.57	3.14	-	EPS09
Transport	0.82	3.5	-	EPS09
Stat.	0.45	-	-	EPS09
Comovers	[0.45,0.7]	3.53	0.65	Glauber-Gribov theory

The $c\bar{c}$ Cross-Section



arXiv:1605.07569 [nucl-ex]

J/ψ Production versus Multiplicity



arXiv:1202.2816v1