Rencontres 2GP France 2016

Overview of charmonium production in p-Pb and Pb-Pb collisions

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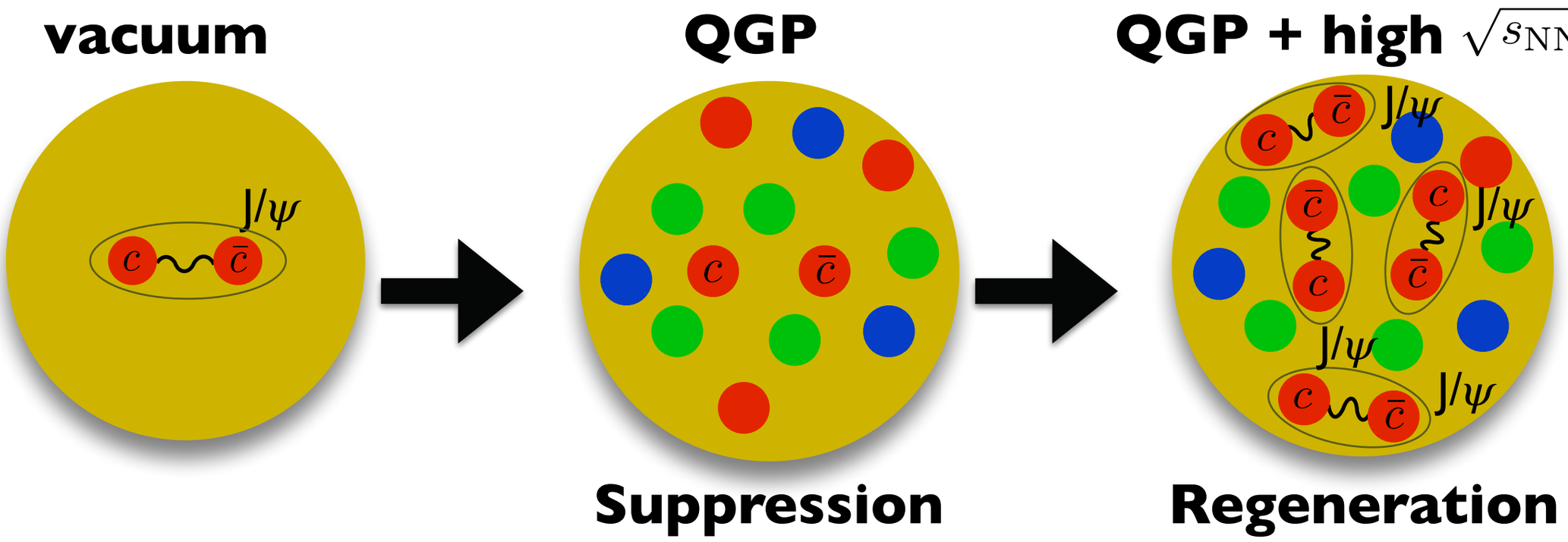
CHARMONIA IN HEAVY-ION COLLISIONS

$$\tau^{c\bar{c}}_{\text{formation}} < \tau^{QGP}_{\text{formation}} < \tau^{QGP}_{\text{life}} < \tau^{\text{quarkonium}}_{\text{decay}}$$

→ expected to **experience the whole QGP evolution**

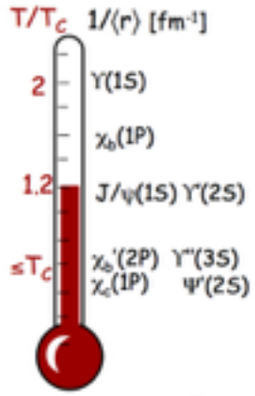
The presence of QGP affects quarkonia production (yield and kinematics)



Quarkonia are ideal probes for the QGP

HOT MATTER EFFECTS

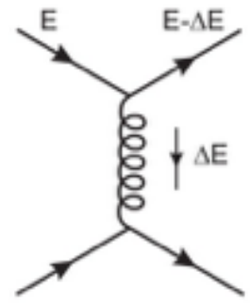
Hot matter effects:



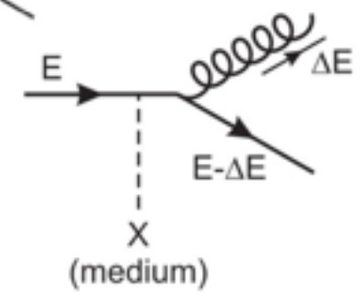
- **Sequential dissociation in QGP (color screening)**

- **Energy loss mechanisms** of partons in QGP:

  - **Collisional energy loss:** Depends on the medium thickness and initial parton energy



  - **Radiative energy loss:** Dominant effect for fast partons in medium



⟶ Open beauty is a key to understand dynamics of parton-QGP interactions

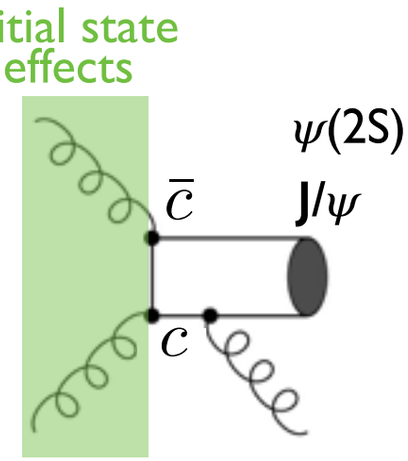
- **Quarkonium regeneration:**

  - **Statistical Hadronization models:** Deconfinement and thermalization of the bulk of the $c\bar{c}$ pairs. Statistical hadronization of charm quarks at the phase boundary.

  - **Transport models**: Dynamical competition between suppression in the QGP and regeneration mechanism.

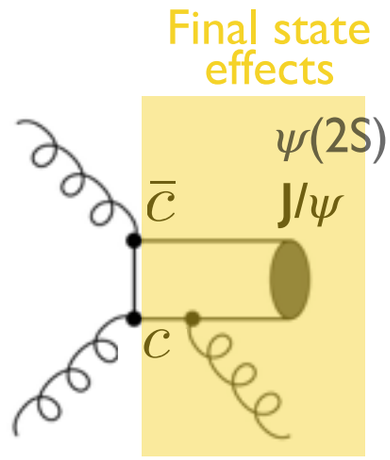
COLD NUCLEAR MATTER EFFECTS

Cold nuclear matter effects:



- Initial state effects: **Gluon shadowing** (or **saturation**)
  - Shadowing: gluon pdf in a nucleus ≠ in a nucleon (saturation: when energy is high enough, gluons start to recombine with each other)

    Expected to be significant at LHC energies



- **Coherent energy loss**
  - The medium-induced gluon radiation modifies the initial-state gluon kinematics and affects the final-state $c\bar{c}$ pair

- Final state effects: **Nuclear absorption**
  - Destruction of pre-resonant or final state ψ by collisions with nucleons

    Should be negligible at the LHC since nuclei crossing-times are smaller than $c\bar{c}$ formation times

Cold nuclear matter effects also modify the charmonia **production pattern and kinematics**

MAIN OBSERVABLES

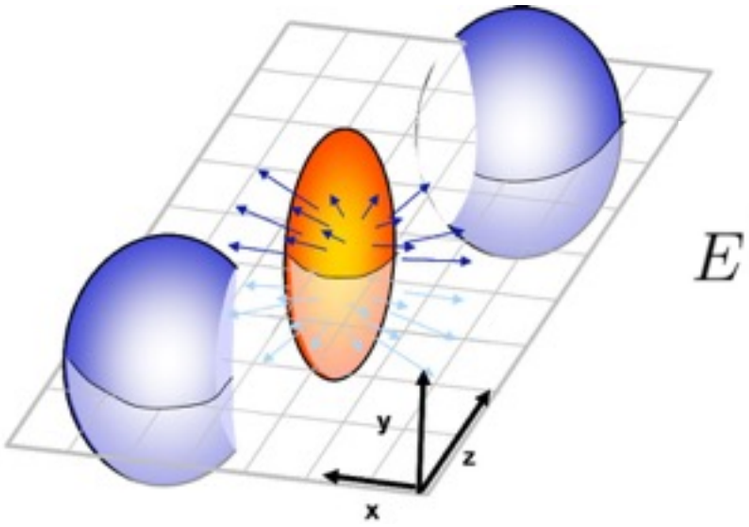
To disentangle nuclear effects (hot/cold) we study **pp**, **p-Pb** and **Pb-Pb** collisions

- Nuclear effects quantified with the **nuclear modification factor:**

$$R_{AA} = \frac{dN^{AA}_{J/\psi}/dp_T dy}{\langle N^{AA}_{coll}\rangle dN^{AA}_{J/\psi}/dp_T dy}$$

1 if no nuclear effects
> 1 if production enhancement
< 1 if production suppression

- **Elliptic flow** (v_2): Azimuthal anisotropy with respect to the reaction plane

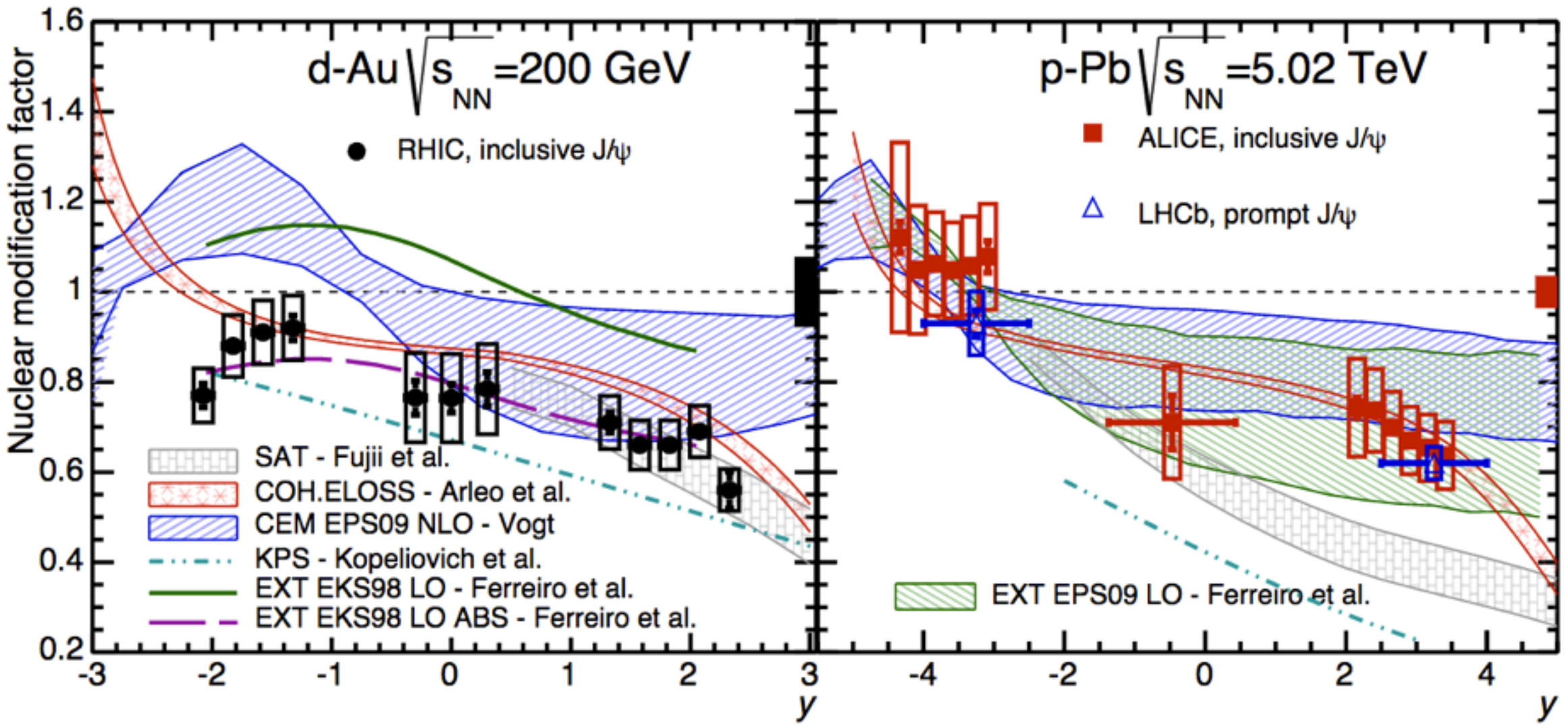


$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy} \times \left(1 + \sum_{n=1}^{\infty} 2v_n(p_T, y)\cos\left[n\left(\varphi - \Psi_R\right)\right]\right)$$

Non-zero v_2 can be interpreted as an effect of collective expansion and/or path-length dependent E. loss.

Disclaimer: This presentation shows a biased summary of charmonia results

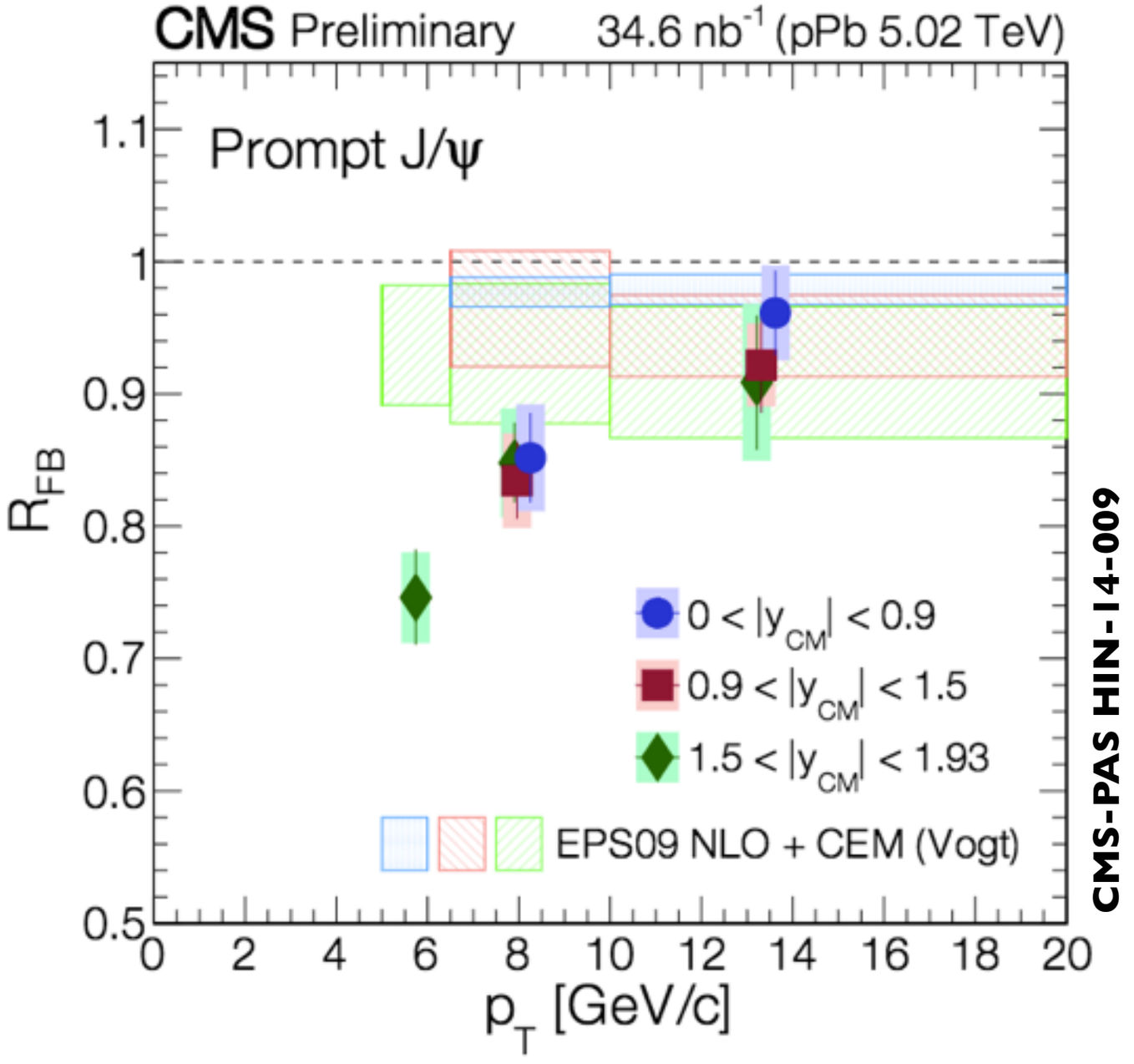
RESULTS IN p-Pb: RAPIDITY



- **Increasing suppression** from backward to forward rapidity at RHIC and LHC
- nPDF models overestimate RHIC data
- Coh. E.loss describes trend at RHIC and LHC
- Saturation model only describes RHIC and LHC data for certain rapidities

Experimental and nPDF uncertainties avoid further conclusions

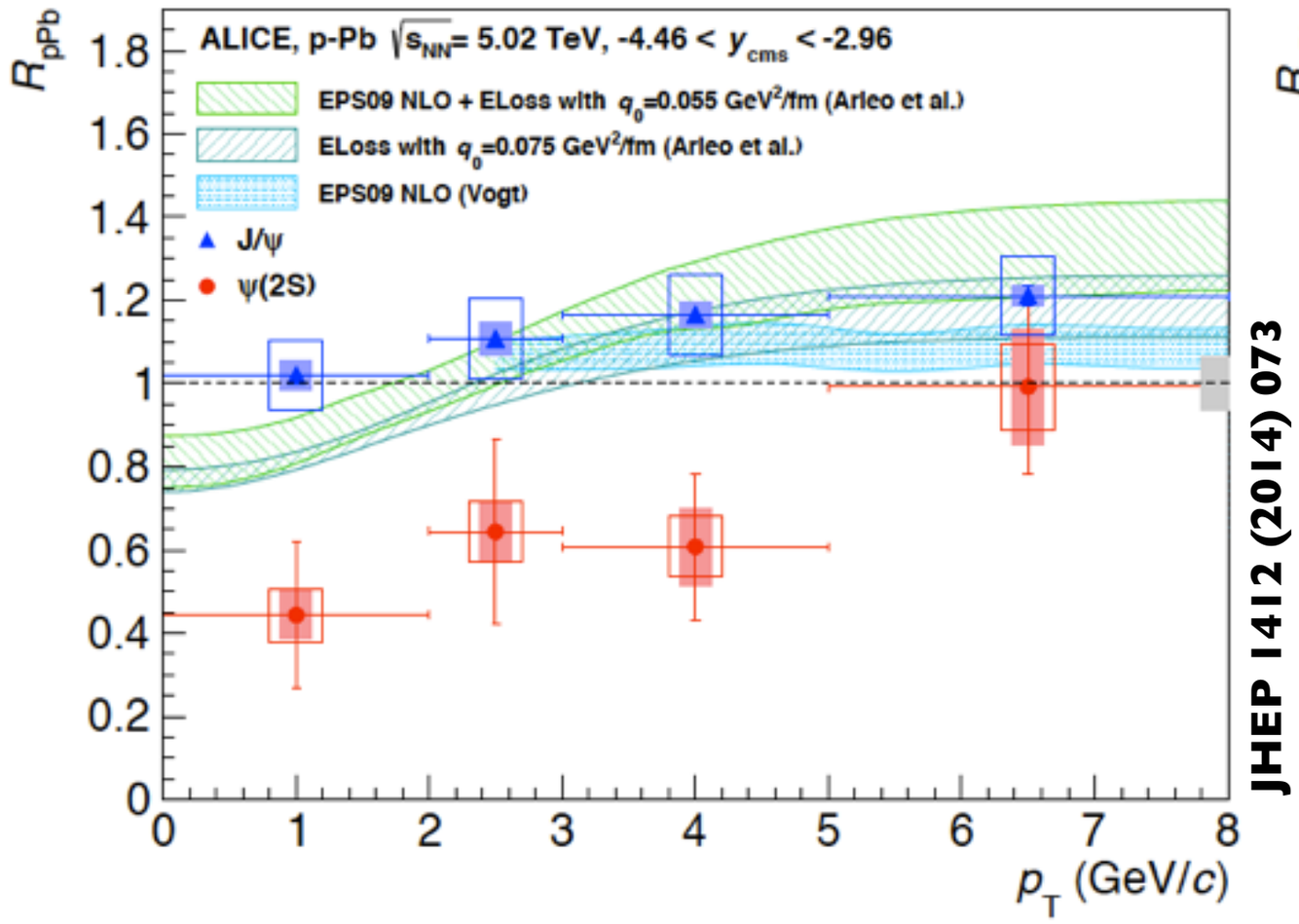
RESULTS IN p-Pb: p_T

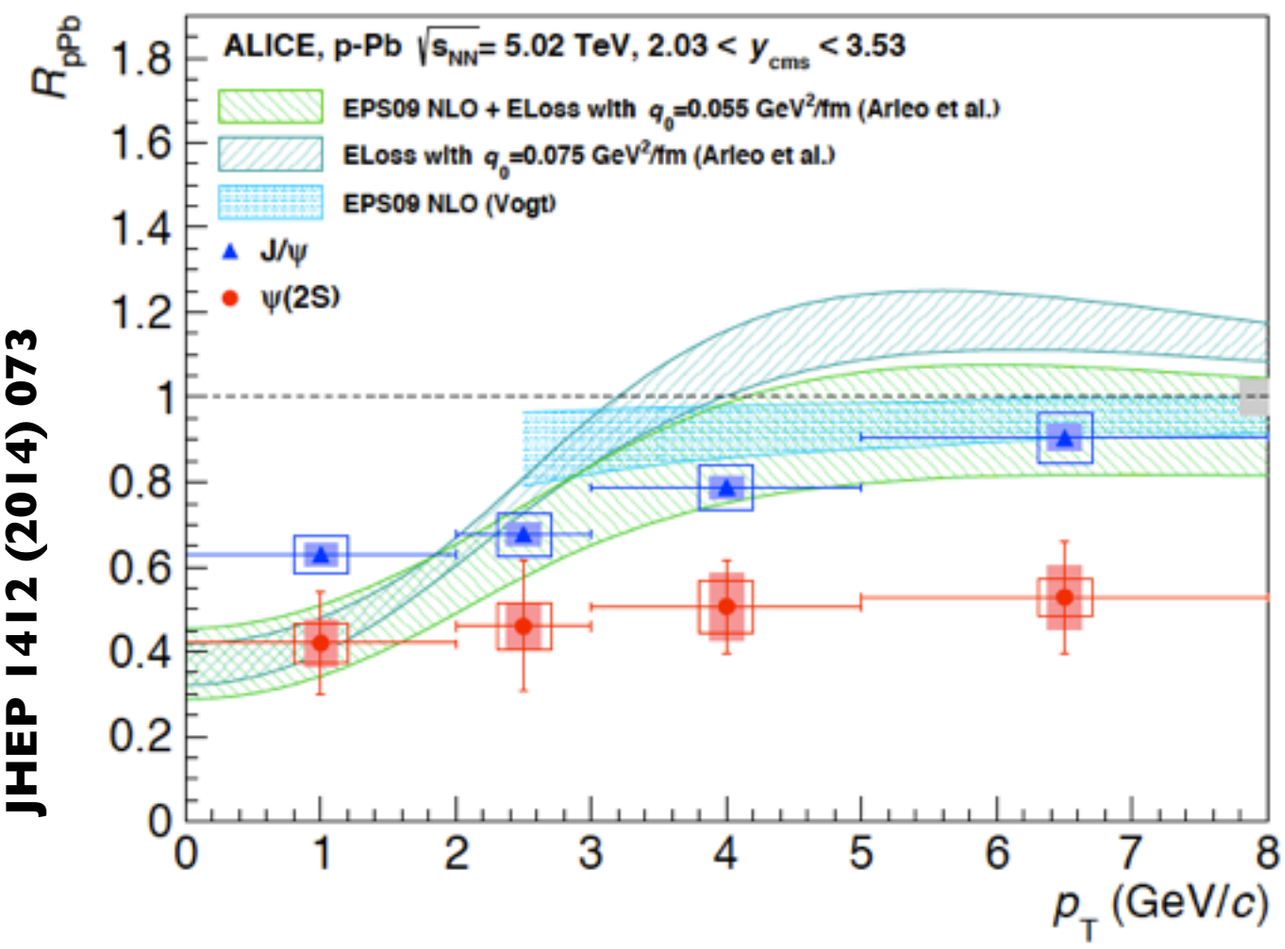


- $R_{FB} < 1$ at low p_T and increases with p_T
- nPDF model does not describe data at low p_T

Hint for other effects **beyond nPDFs?**

RESULTS IN p-Pb: p_T





JHEP 1412 (2014) 073

- J/ψ data compatible with **no nuclear effects**. No variation with p_T
- ψ(2S) is suppressed at low p_T

- J/ψ is **more suppressed** at low p_T
- ψ(2S) **suppression ~flat** with p_T

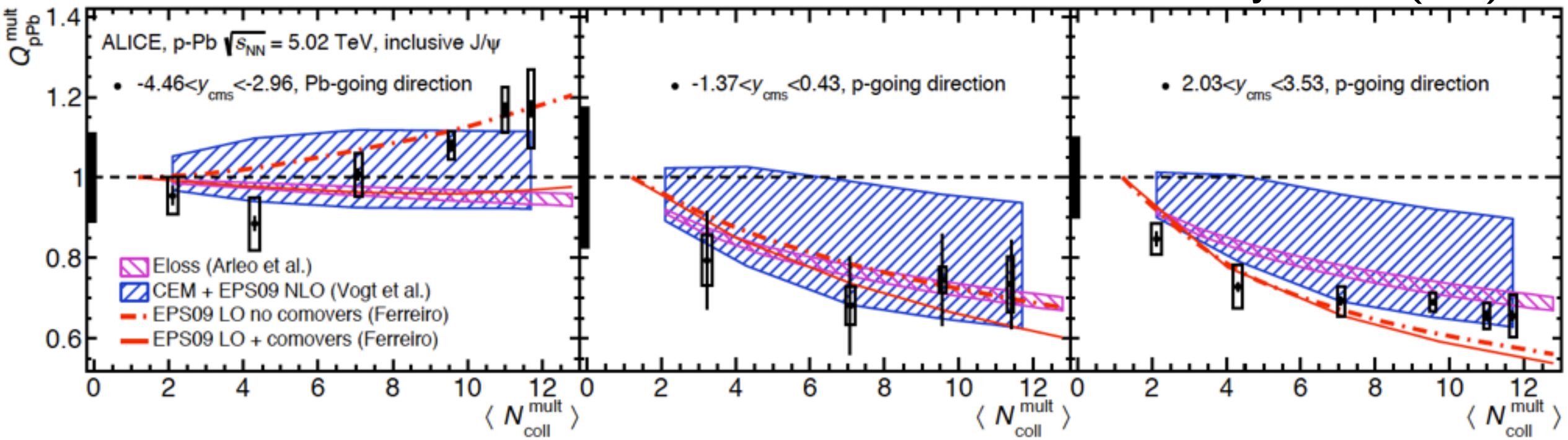
Data shows ψ(2S) more suppressed than J/ψ

nPDF and E.loss w/wo nPDF predict same suppression for J/ψ and ψ(2S).

Something else **beyond nPDFs and E.loss. ψ(2S) dissociation by comovers?**

RESULTS IN p-Pb: EVENT ACTIVITY

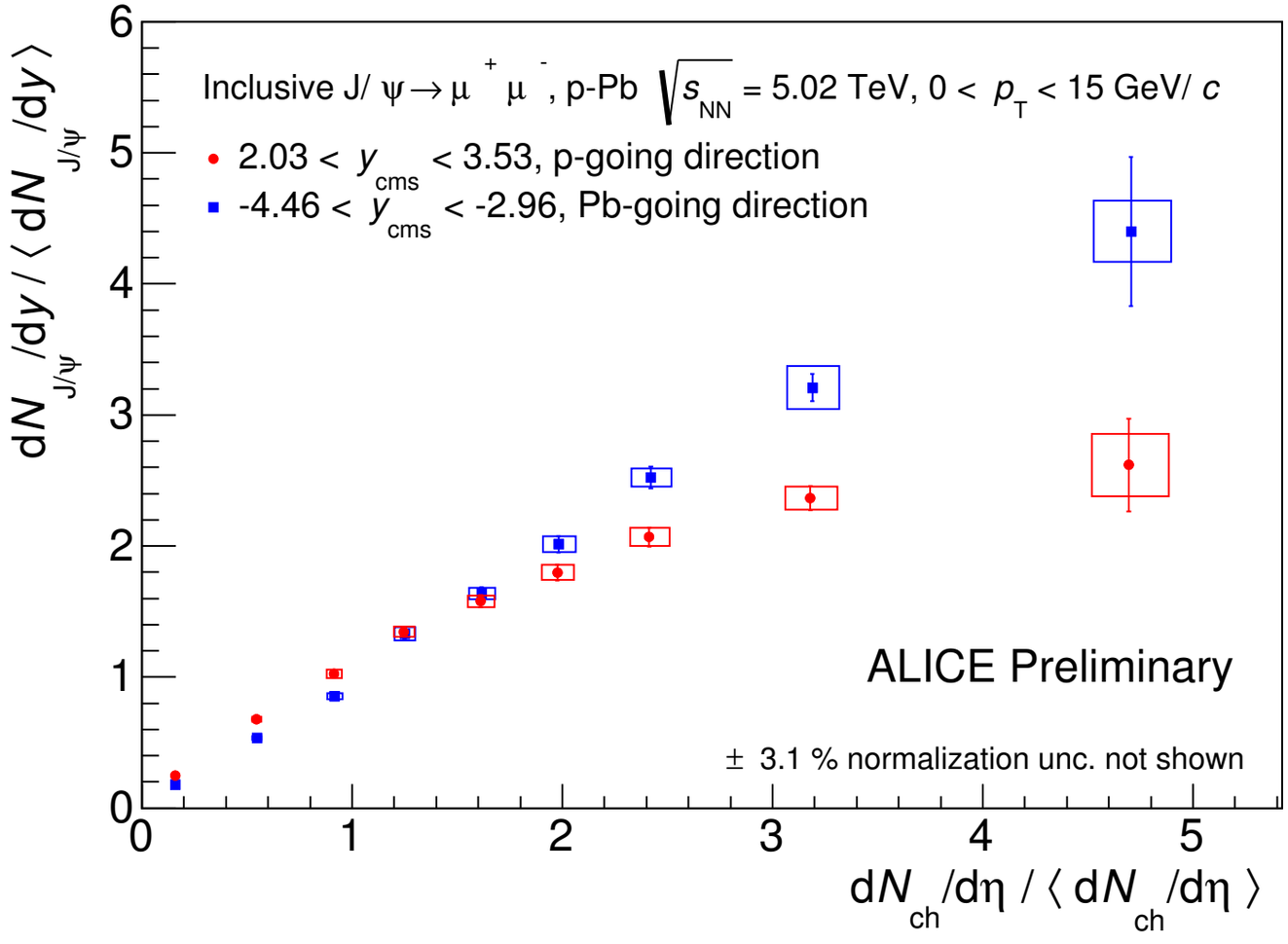
JHEP 1511 (2015) 127

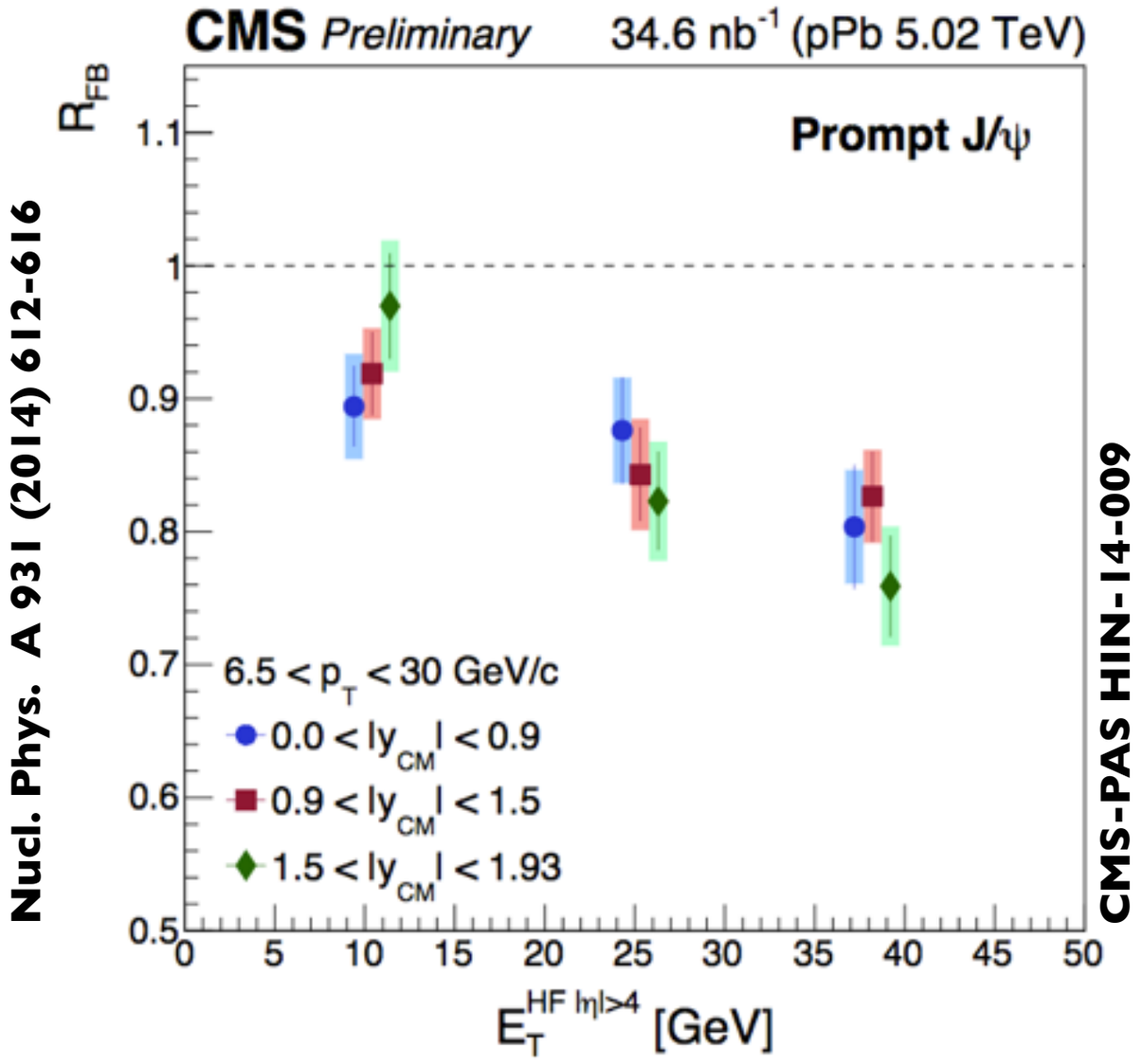


- At backward rapidity results are consistent with binary-scaled pp within uncertainties
- At mid and forward rapidities J/ψ are suppressed for all centralities
- Pure nPDF model reproduces centrality dependence (huge uncertainties)
- nPDF+comovers model: Effect of comovers small at forward. Increases towards backwards
- Coh. E.loss model describes shape and magnitude of data

No model can be ruled out with the present exp./th. uncertainties

RESULTS IN p-Pb: EVENT ACTIVITY





- **Strong increase** of J/ψ yields at fwd. and bwd. rapidity with multiplicity at low $dN_{ch}/d\eta$
- At bwd. rapidity **close to linear** behavior, **deviation** at fwd. rapidity and high $dN_{ch}/d\eta$
- R_{FB} decreases with increasing event activity. Similar behaviour at different $|y_{CMS}|$

Measurements at **high event activity** can help to constrain CNM models

RESULTS IN p-Pb: CONCLUSIONS

• CNM models fairly describe LHC and RHIC charmonia data. Current experimental uncertainties and nPDF ones avoid to discriminate among different models

• Measurements show than nPDF alone might not be sufficient to reproduce data.

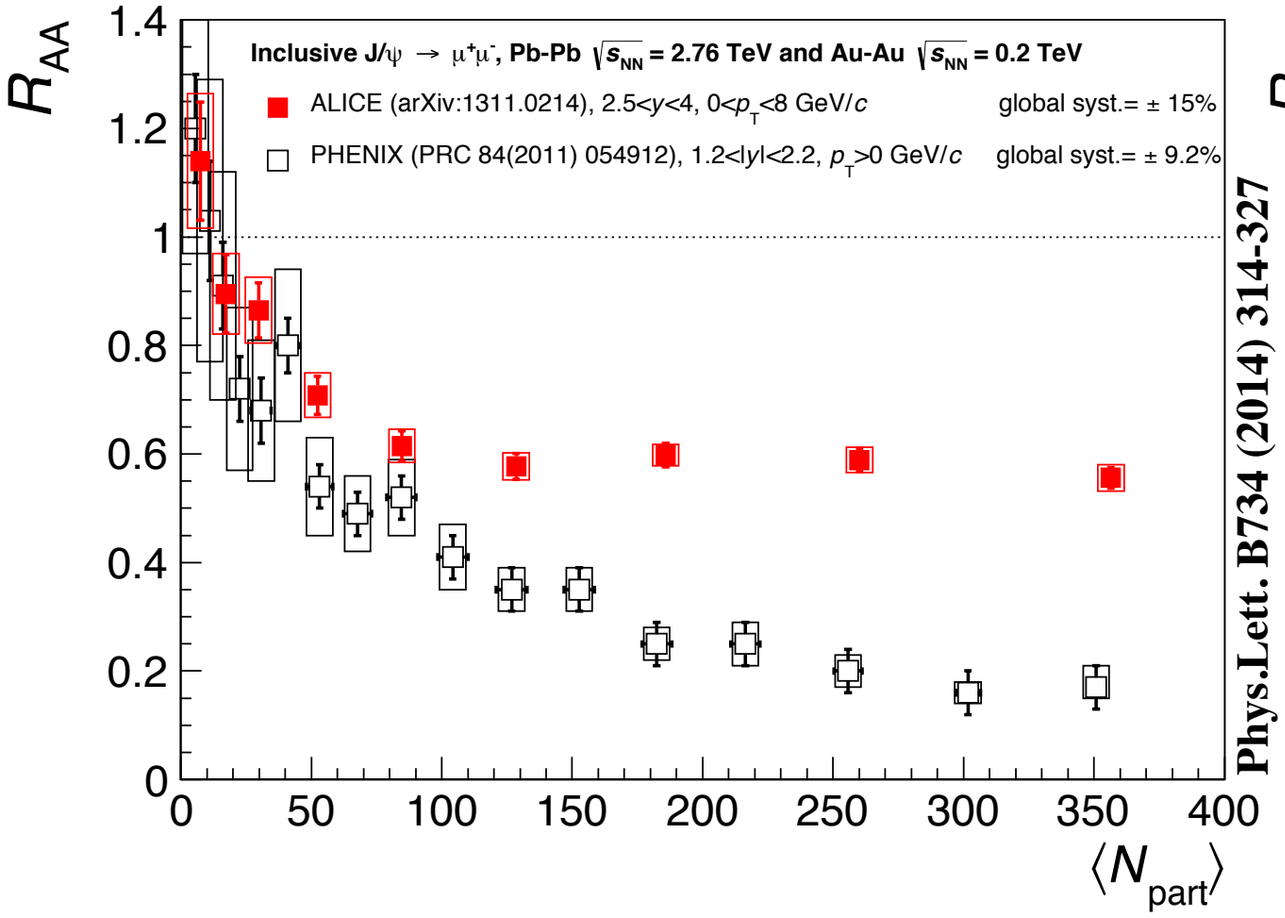
• Current implementations of CNM effects don't explain ψ(2S) data. Final state effects (dissociation by comovers) or hot medium?? (Phys. Lett. B 728 (2014) 437-442)

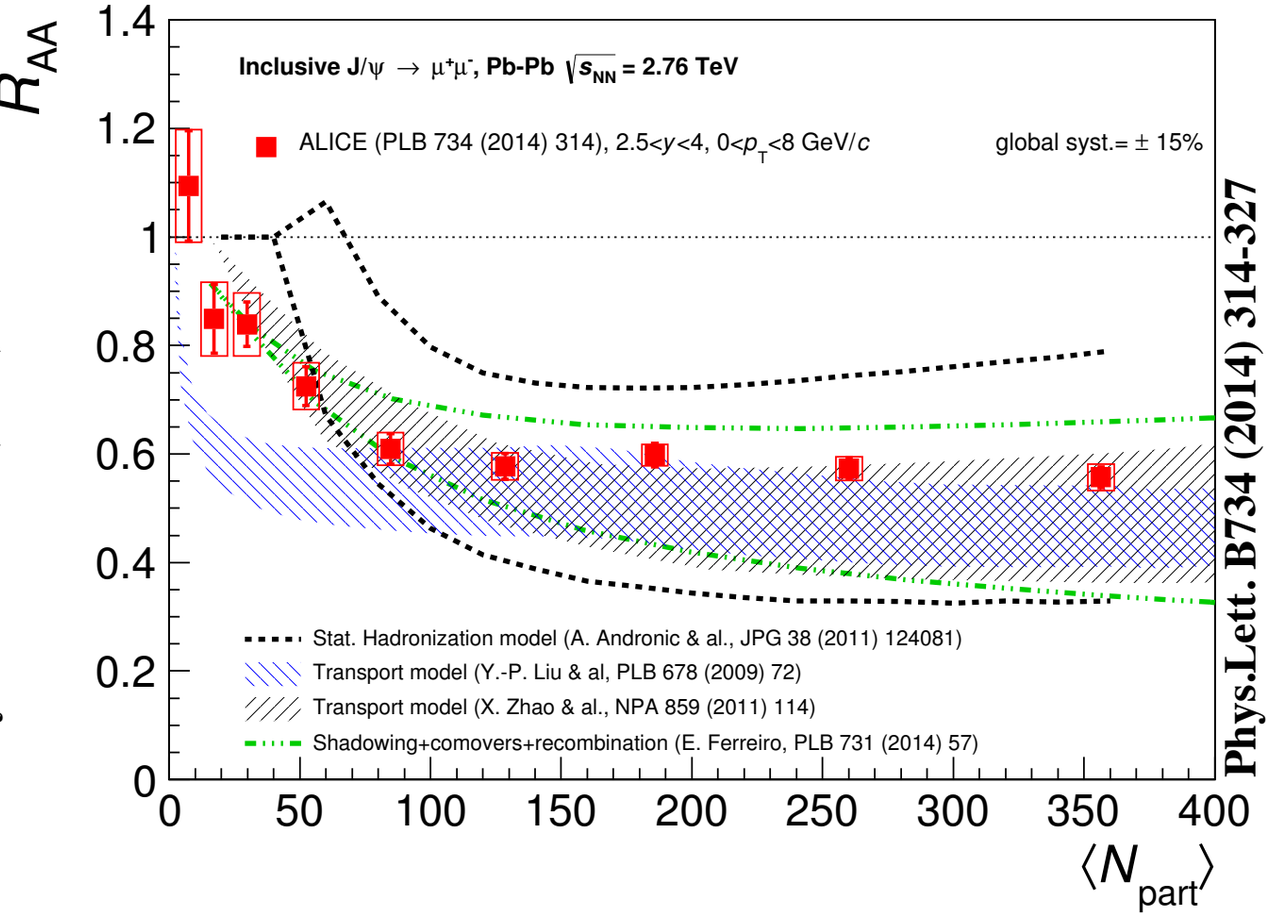
• Measurements at high event activity allows to study regimes where fluctuations on particle production are big (impact param. ~ 0), and can help to constrain models

OUTLOOK:

- Big systematics: update experimental results with pp@5TeV reference (Run2)
- Limited ψ(2S) statistics: more coming in Run2
- Run2 p-Pb results @ 8 TeV will help to constrain models
- v_2 measurements in p-Pb can give insight to whether a collective medium is formed or not

RESULTS IN Pb-Pb: LOW p_T

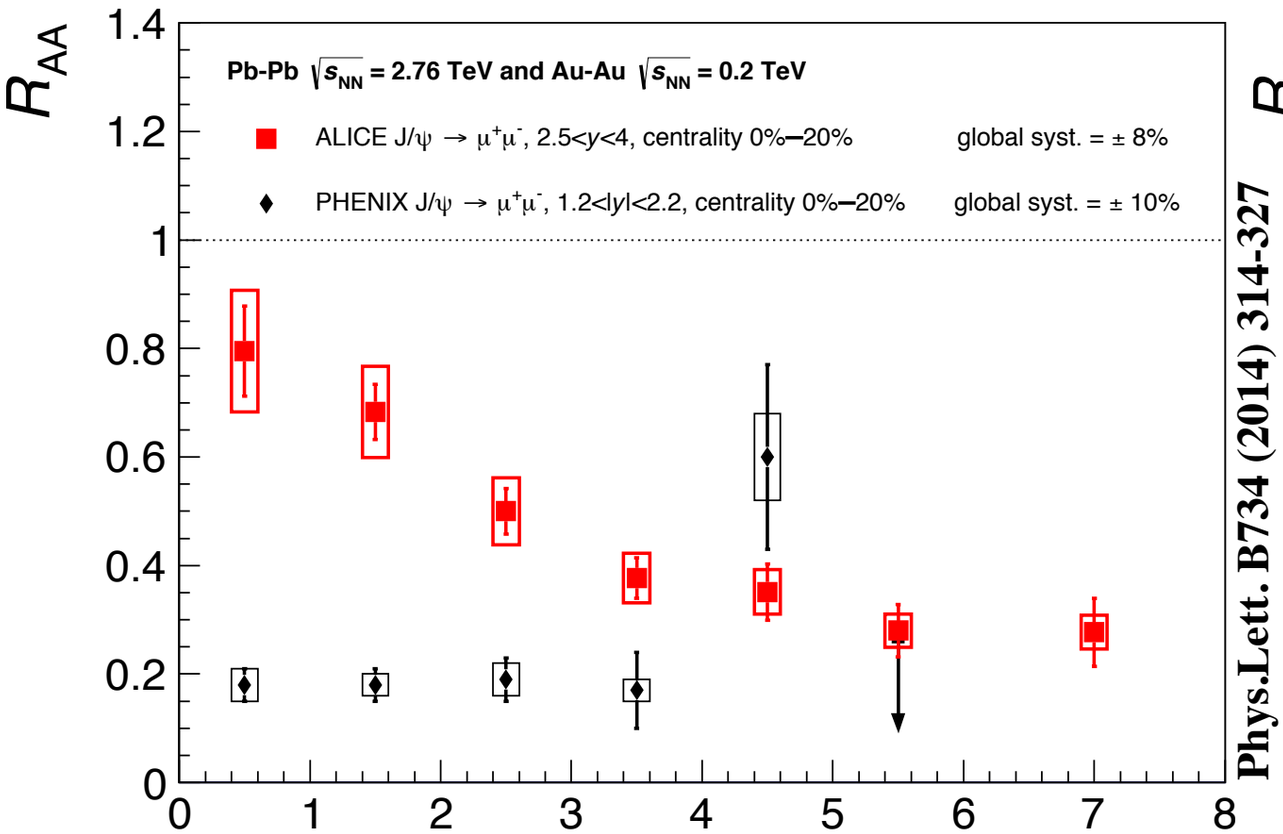


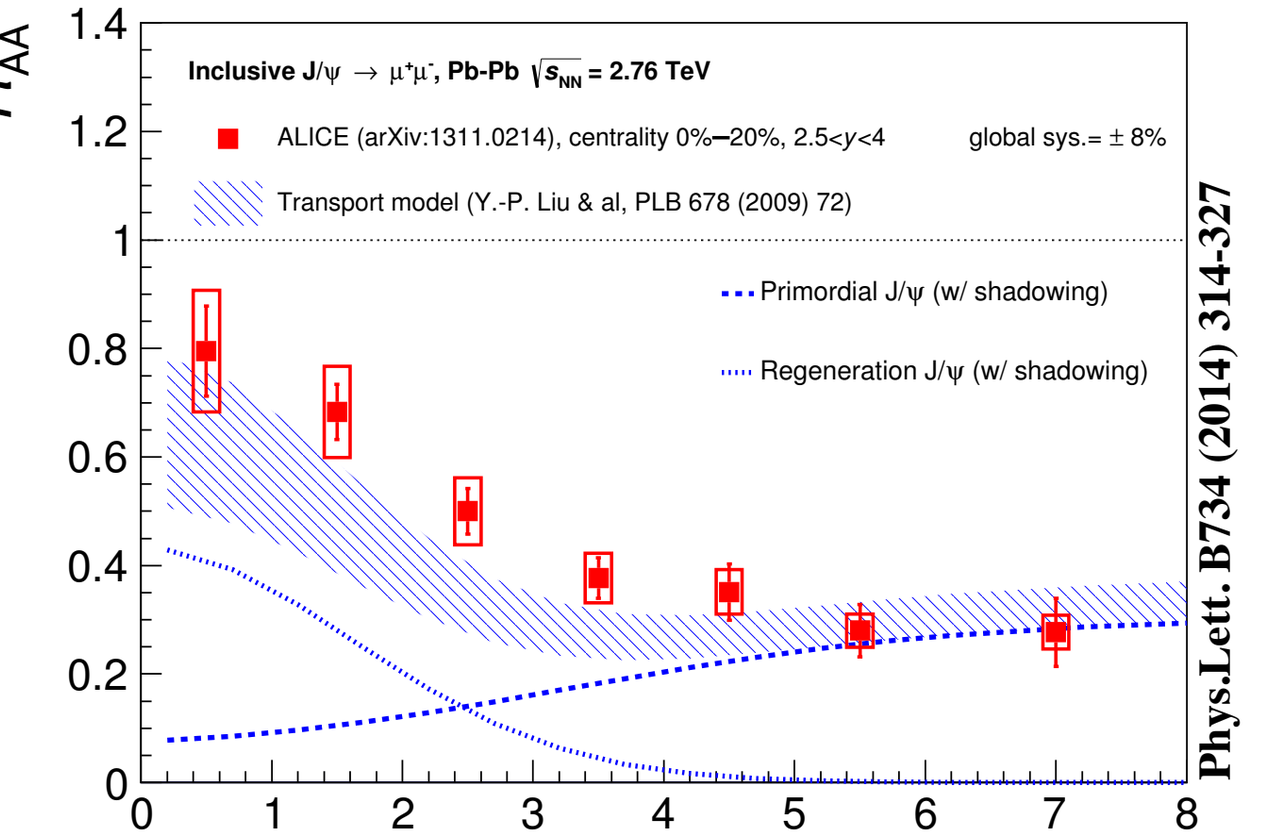


- Significantly **less suppression than at lower energy**
- No strong centrality dependence for $N_{part} > 70$
- Statistical hadronization and transport models describe the data ((re)combination)
- Shadowing-comovers-recombination model also describes data
- Need a precise measurement of σ_{cc} and CNM effects in p-Pb to sharpen the conclusions

First hint of recombination

RESULTS IN Pb-Pb: LOW p_T

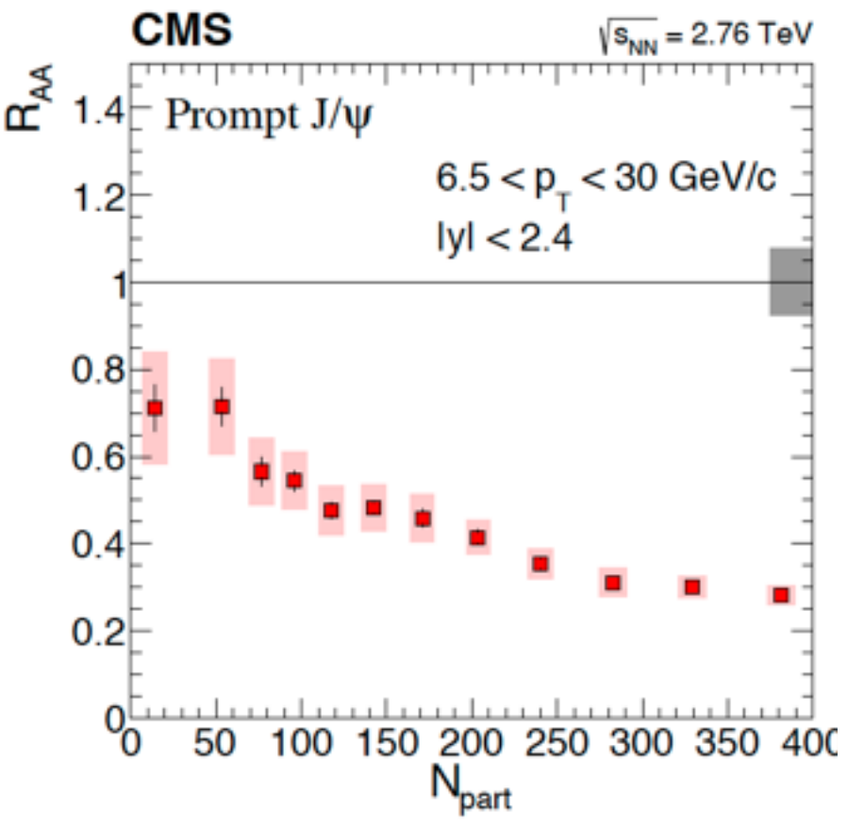




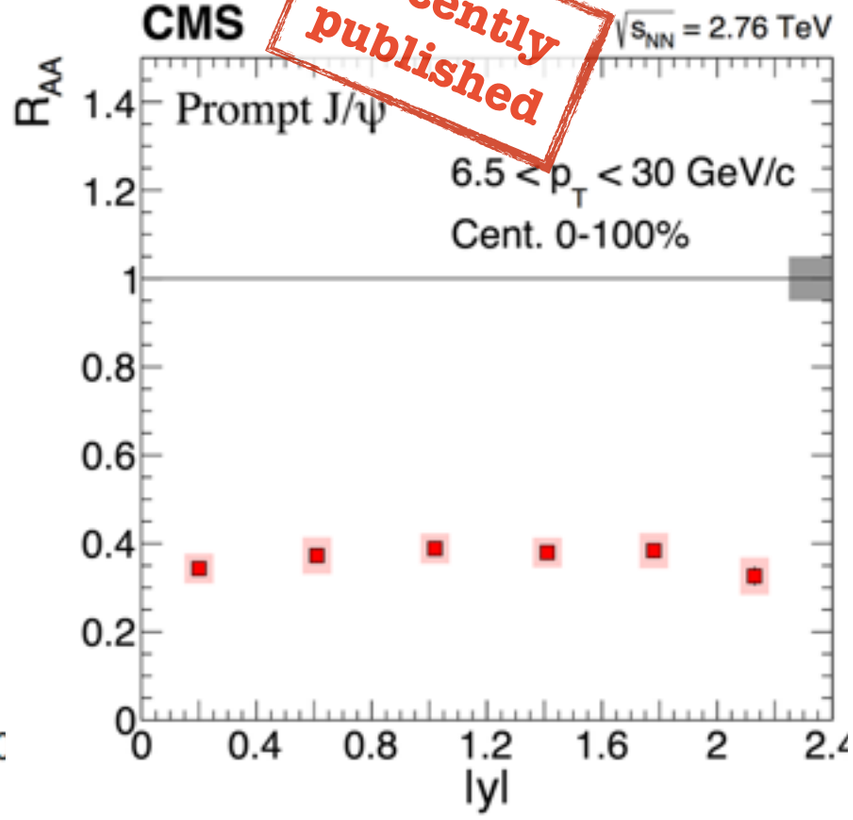
- **Less suppression at low p_T** than at lower energies
- Transport model describes the data

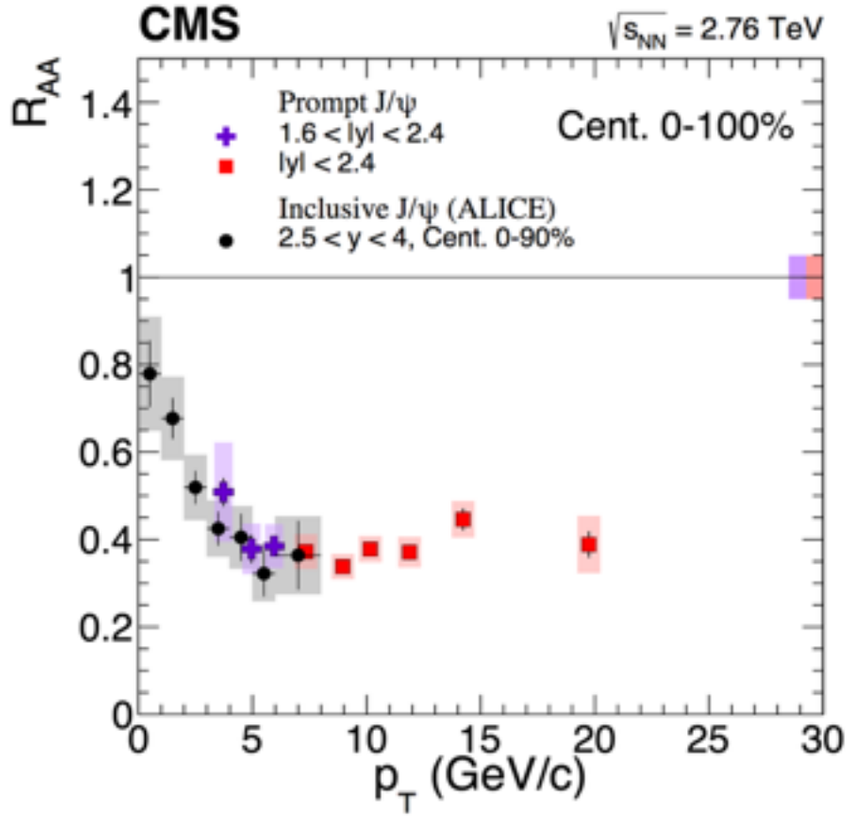
Recombination contribution important al low p_T

RESULTS IN Pb-Pb: HIGH p_T



Recently published

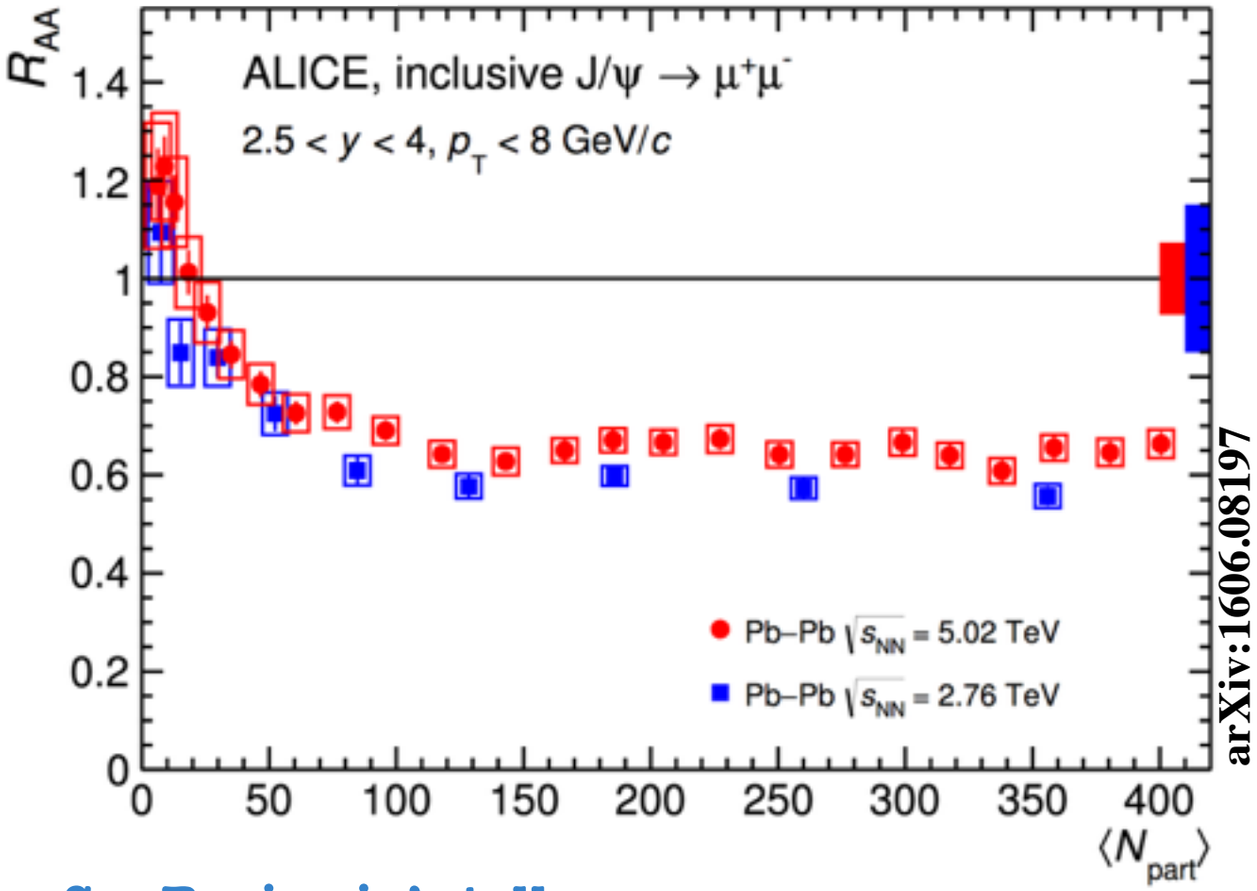


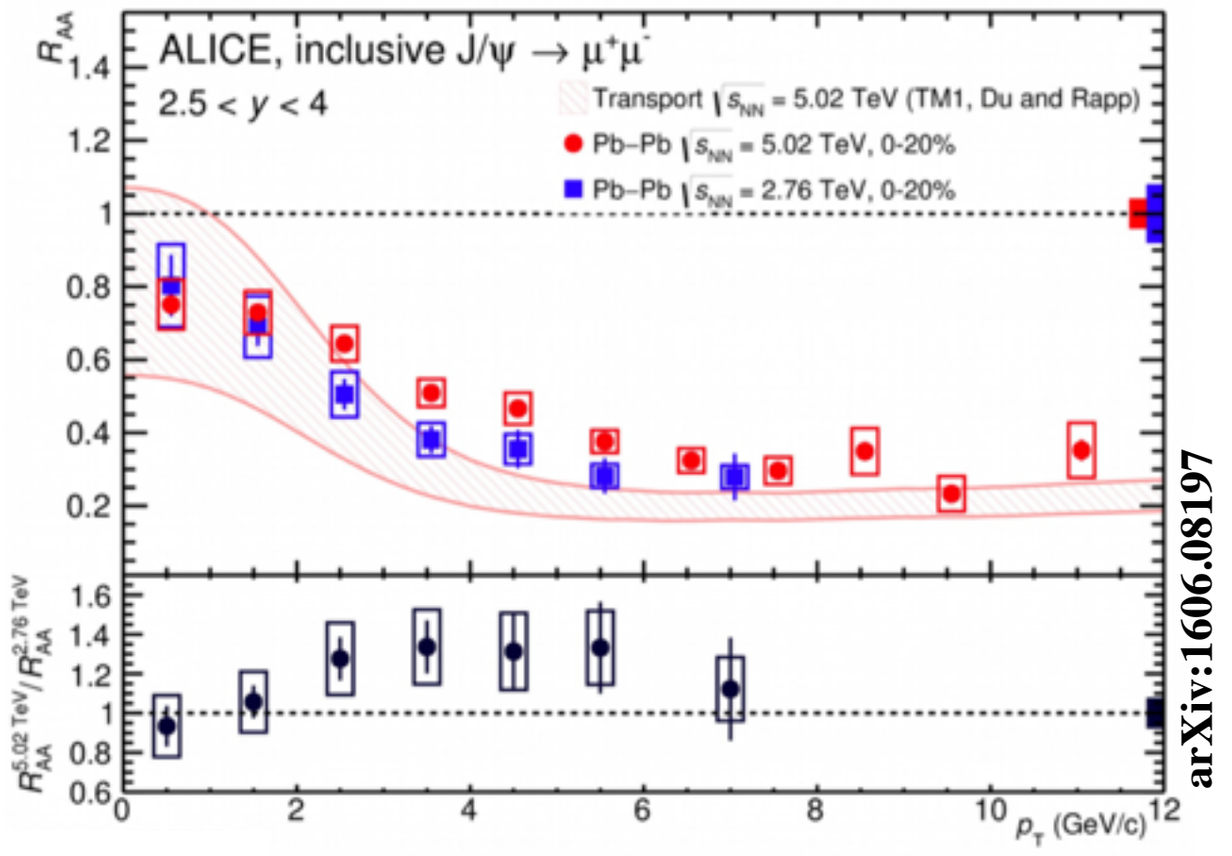


arXiv:1610.00613

- Increasing suppression from peripheral to central events
- No significant rapidity or p_T dependence
- Complements ALICE (low-p_T) results

RESULTS IN Pb-Pb: 2.76 vs. 5.02 TeV





See Benjamin's talk

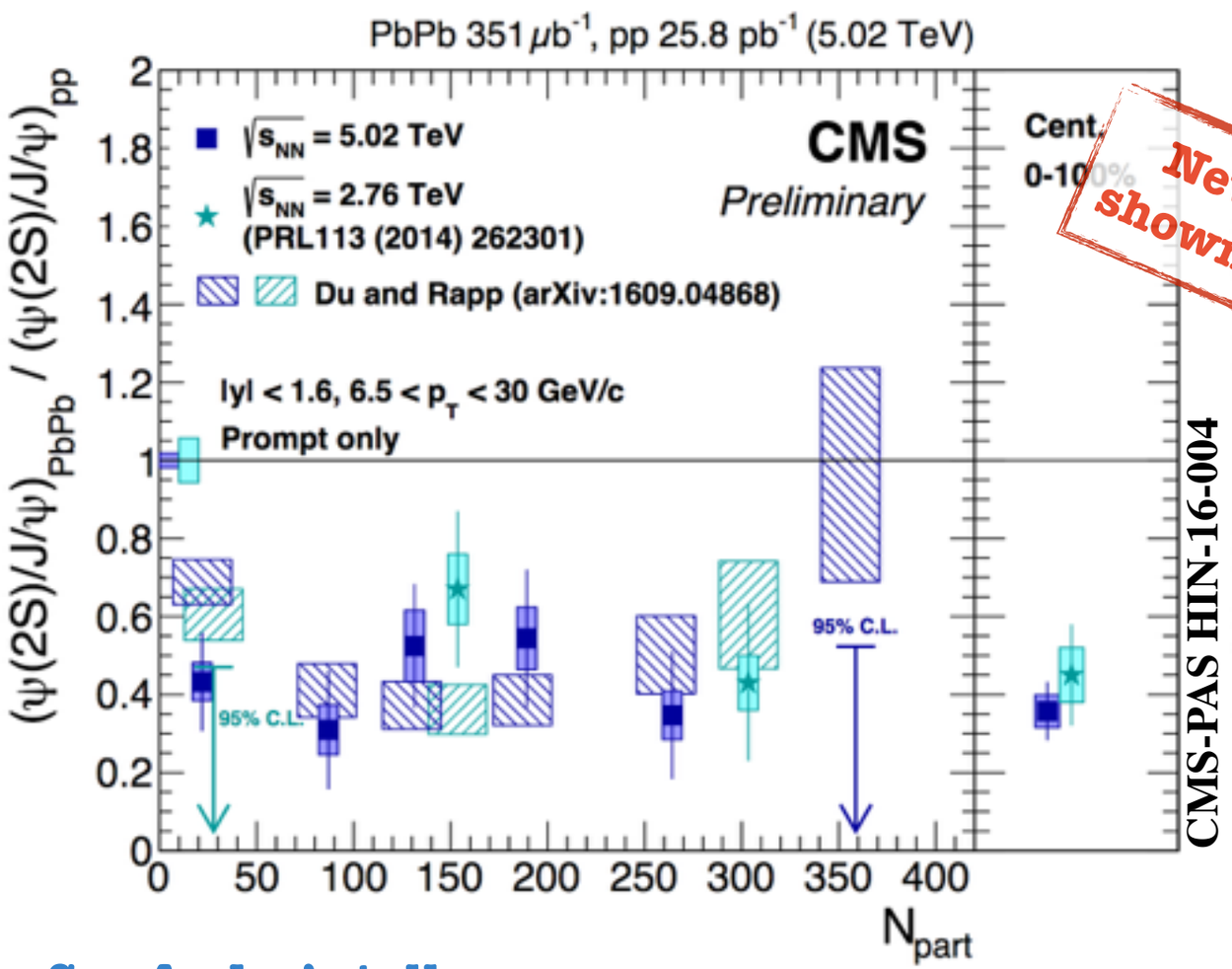
- Results consistent within uncertainties
- $R_{AA} > 1$ for peripheral events. Excess concentrated at low p_T: J/ψ from photoproduction

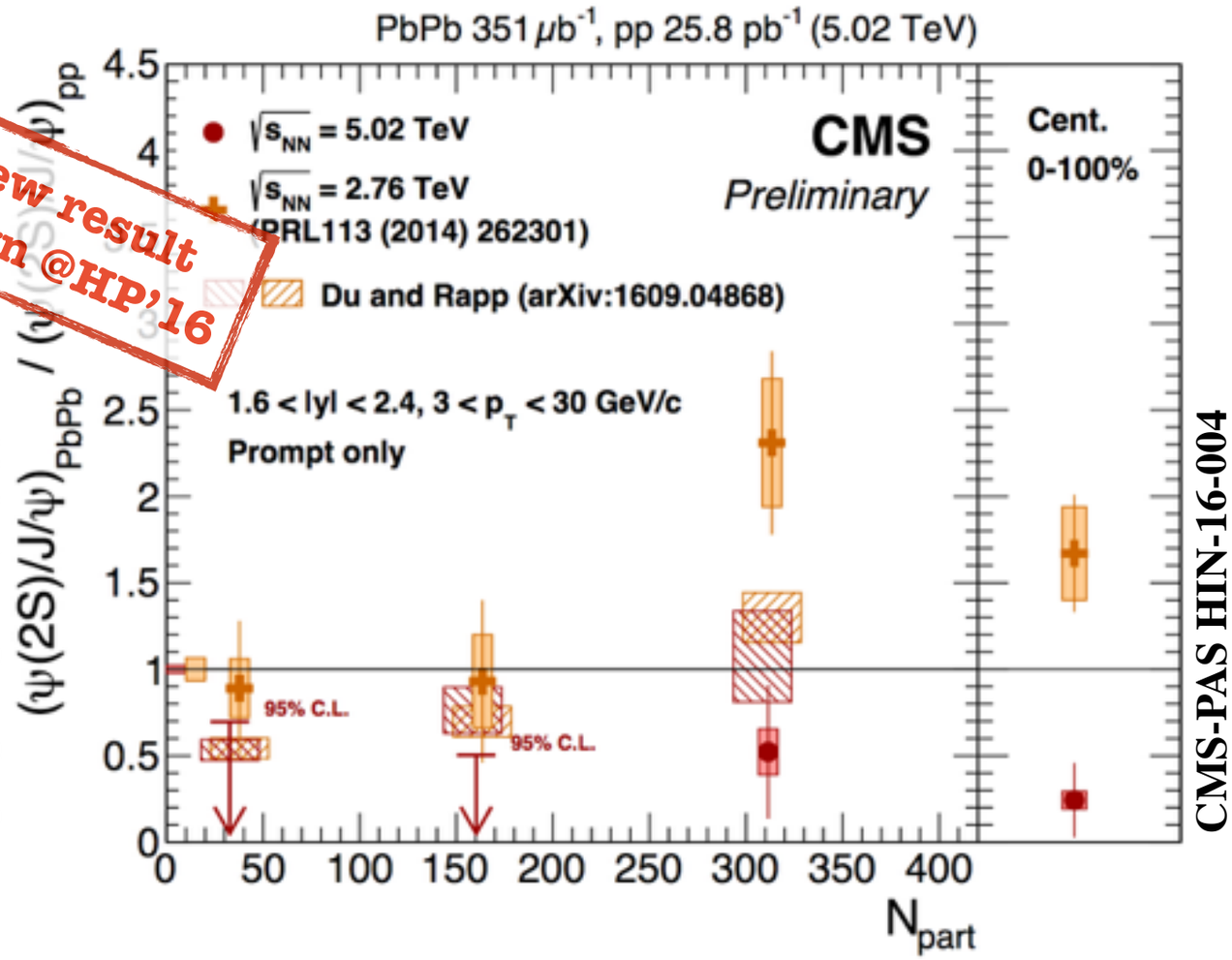
not discussed here

- Similar p_T dependence: Recombination stronger at low p_T
- Hint of an increase on R_{AA} at 5 TeV with respect to 2.76 TeV in $2 < p_T < 6$ GeV/c

CMS J/ψ R_{AA} results @5TeV coming early 2017!

RESULTS IN Pb-Pb: ψ(2S) VS J/ψ





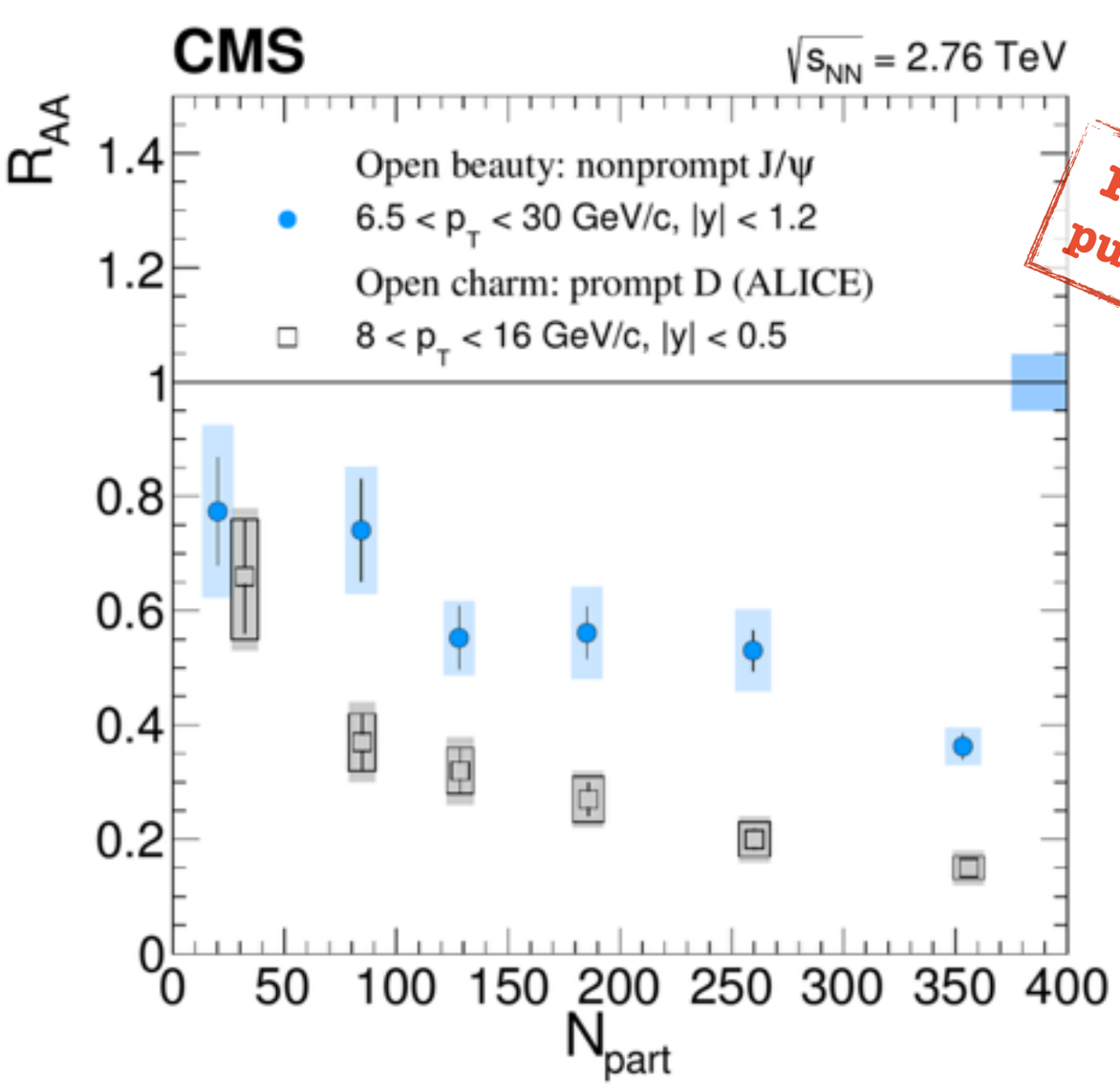
New result shown @HP'16

See Andre's talk

- **ψ(2S) is more suppressed than J/ψ** for most of the centrality bins
- No strong N_{part} dependence at 5.02 TeV
- Good agreement between 2.76 and 5.02 TeV results for most of the bins. Difference

(~3 s.d.) only for peripheral events in $1.6 < |y| < 2.4$

RESULTS IN Pb-Pb: NON-PROMPT J/ψ



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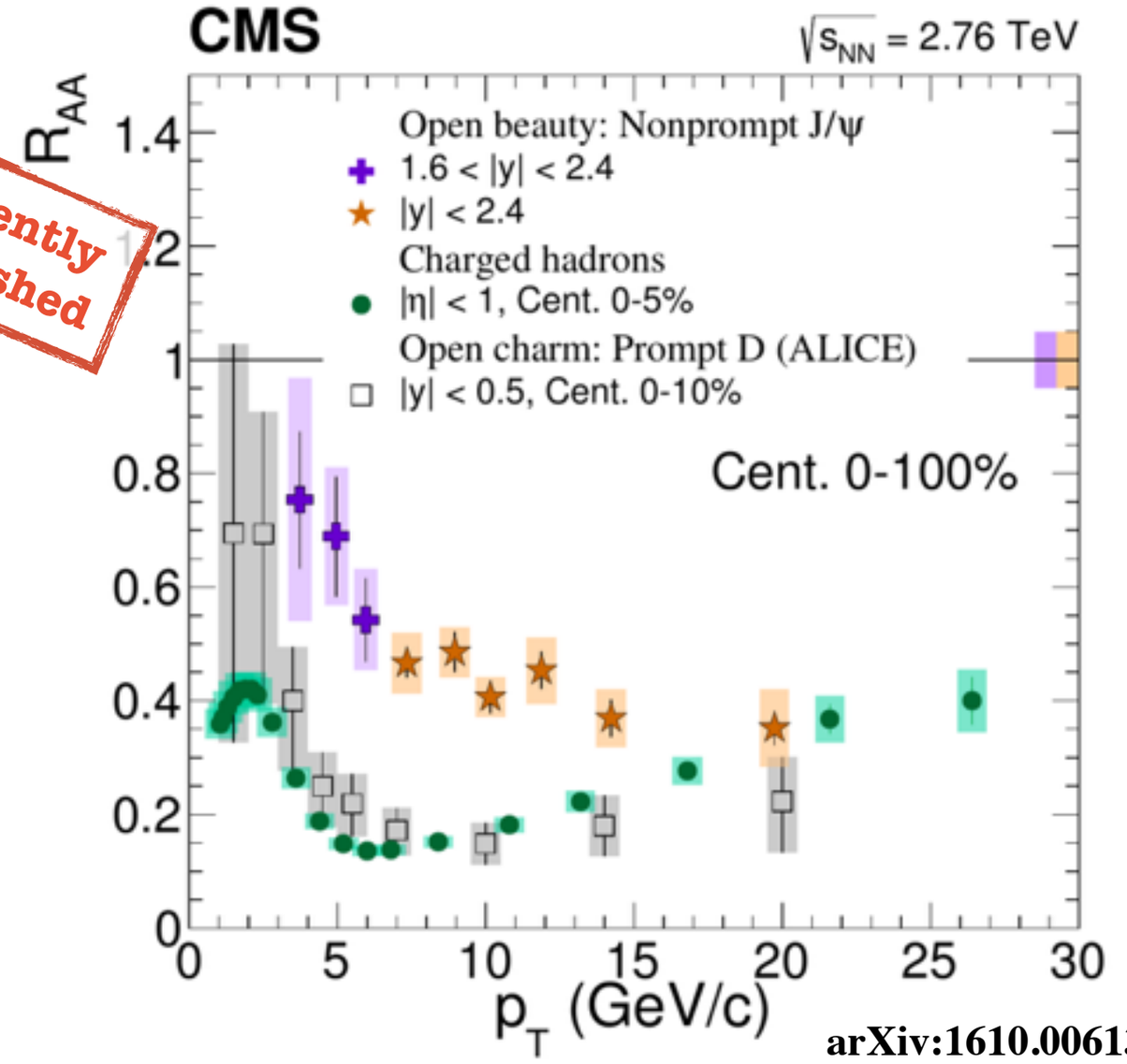
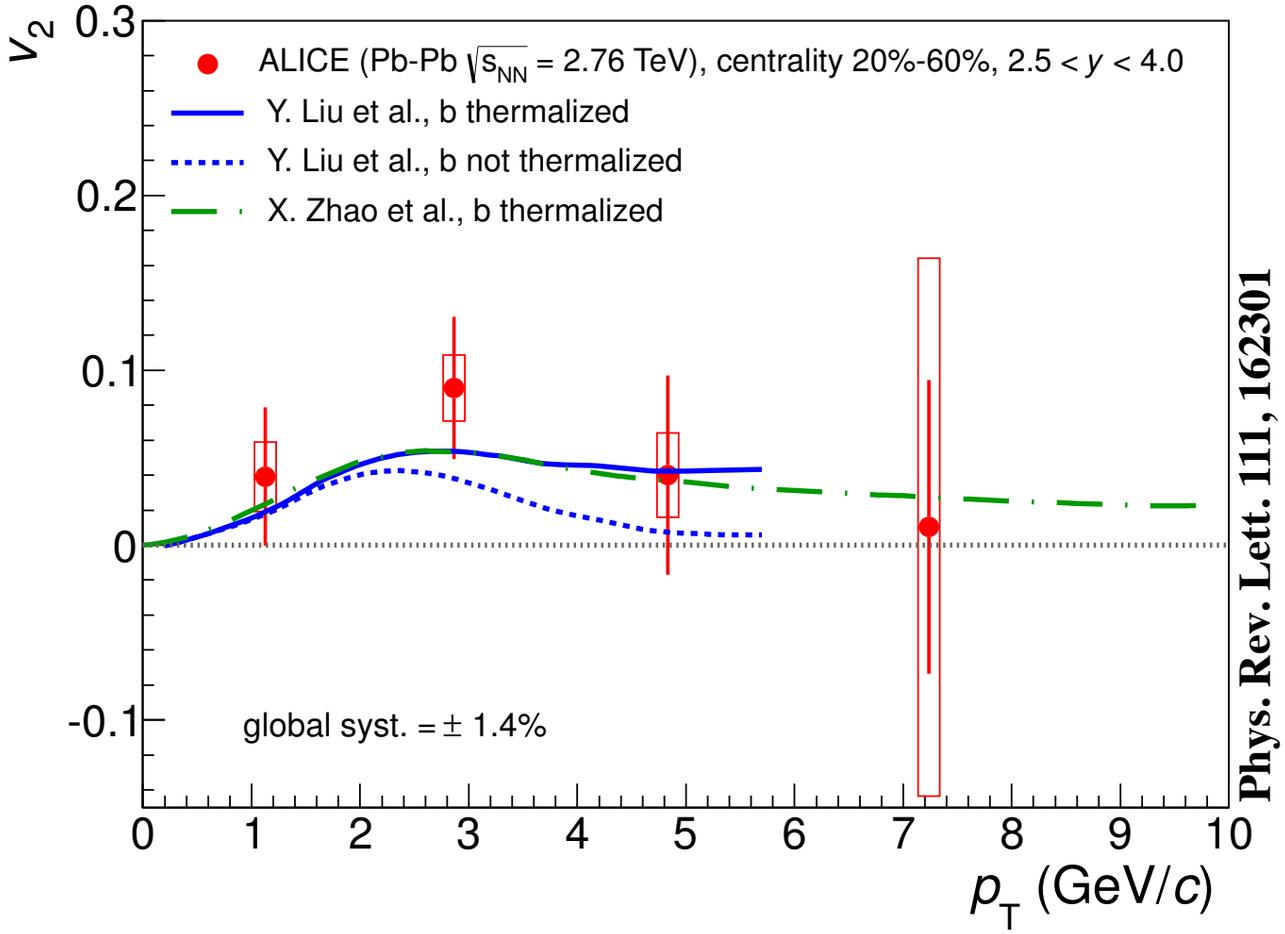


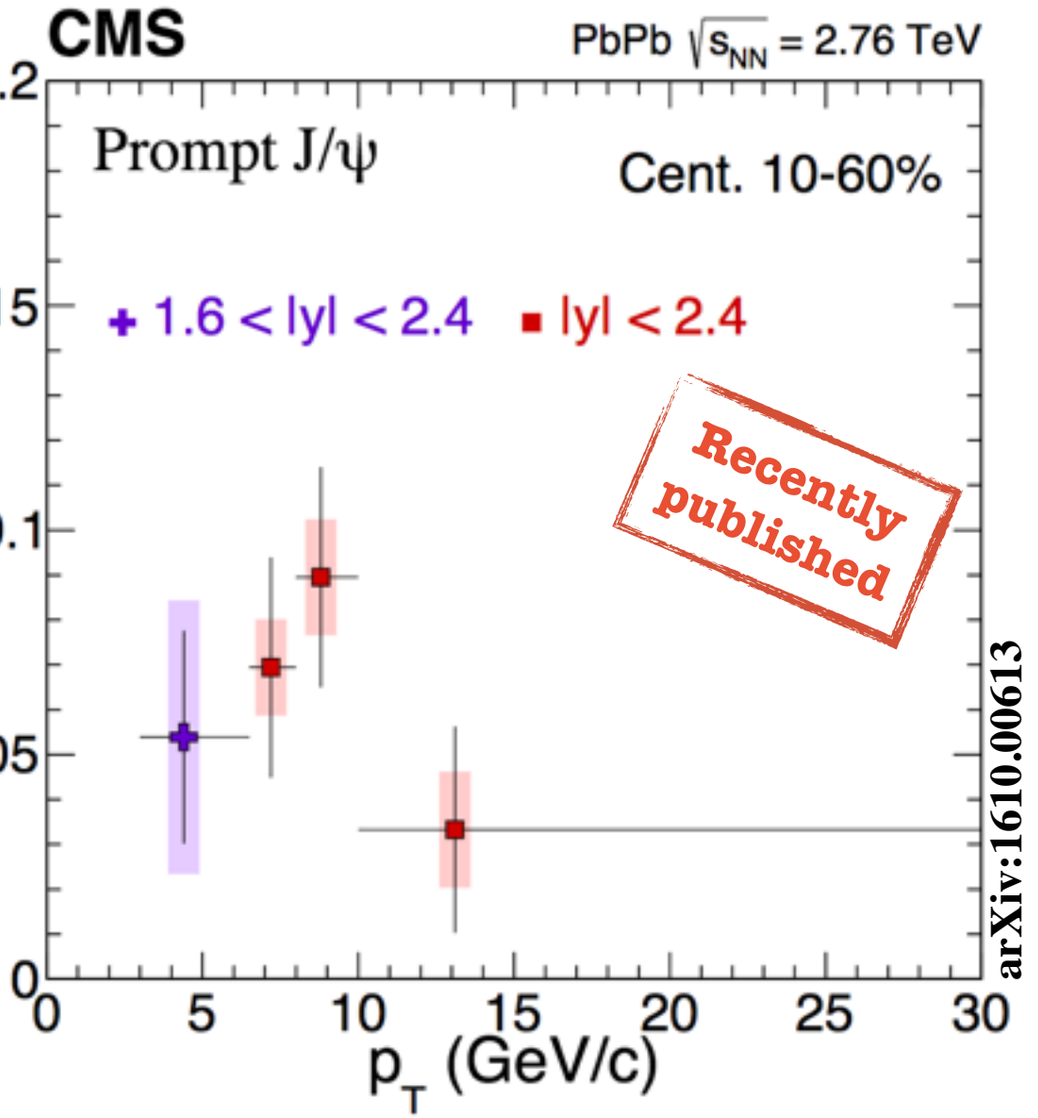
arXiv:1610.00613
Eur. Phys. J. C (2012) 72:194
Phys. Rev. C 90 (2014) 034904
JEP 11 (2015) 205

- Strong non-prompt J/ψ suppression increasing with centrality and p_T
- R_{AA}(non-prompt J/ψ) > R_{AA}(prompt D) ≈ R_{AA}(light partons)
  - Indication of smaller energy loss of b quarks at p_T < 20 GeV/c

    Note: shape of quark p_T distr. and fragmentation fnc. are different for c and b. Models predict R_{AA}(non-prompt J/ψ) > R_{AA}(prompt D)

RESULTS IN Pb-Pb: v_2





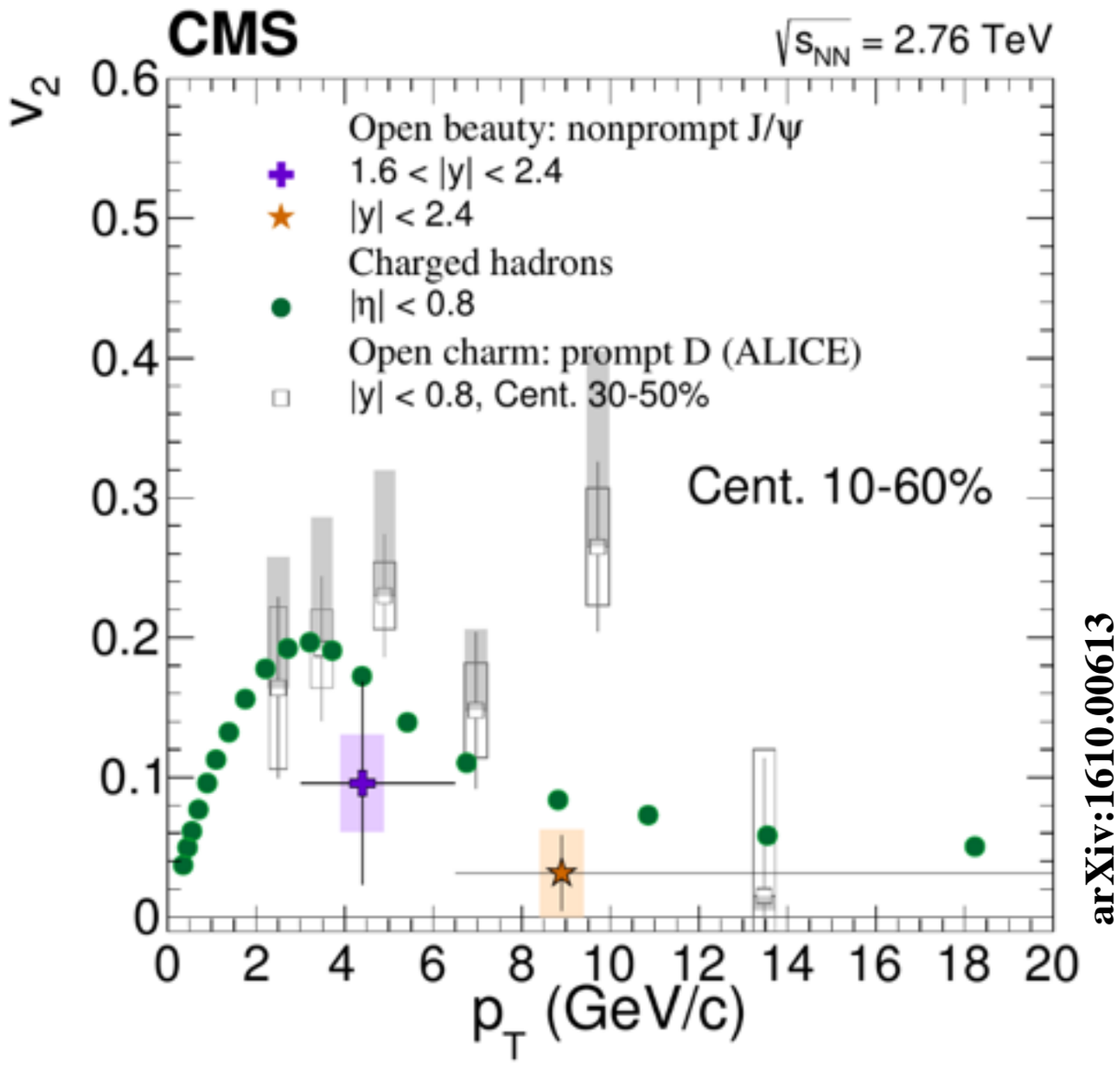
ALICE:

- 2σ significance of nonzero v_2 in $2 < p_T < 4$ GeV/c
- Transport models assuming thermalization of b quarks qualitatively describes the data
- Further hint of recombination at low p_T

CMS:

- 3.3σ significance of nonzero v_2 in $6.5 < p_T < 30$ GeV/c

RESULTS IN Pb-Pb: v_2



Recently published

- **First measurement of non-prompt J/ψ v_2** . $v_2 \approx 0$ within unc.
- Large uncertainties:
  - Low p_T: *b* quarks also participate in the collective expansion of the medium?
  - High p_T: quark-flavor path-length dependance of E.loss?

RESULTS IN Pb-Pb: CONCLUSIONS

• R_{AA} (@2.76 TeV) shows less suppression at LHC energies than at lower energies. **Suggest recombination component** on J/ψ production

• R_{AA} (@2.76 TeV) shows less suppression at low p_T at LHC energies than at lower energies. Important contribution of **recombination at low p_T**

• **ψ(2S) is more suppressed than J/ψ** (@5.02 TeV) for all centralities

• R_{AA}(non-prompt J/ψ) > R_{AA}(prompt D) ≈ R_{AA}(light partons). Indication of **smaller energy loss of b quarks** at p_T < 20 GeV/c

• Non negligible J/ψ v_2 (@2.76 TeV) at intermediate p_T. Further hint of recombination

• **First measurement of non-prompt J/ψ v_2** (@2.76 TeV) is consistent with zero with big uncertainties. No conclusions can be drawn

OUTLOOK:

- Need precise measurement of $\sigma_{c\bar{c}}$
- Improve understanding of CNM effects needed to refine conclusions
- Need more differential ψ(2S) measurements
- Improve significance of v_2 measurements

More run2 charmonia measurements coming soon: Stay tuned!!

THANK YOU FOR YOUR ATTENTION