Experimental overview on:
Quarkonium production and polarization

Andre Ståhl

T.W. Bonner Laboratory, William Marsh Rice University

19th International Conference on
Strangeness in Quark Matter

RICE

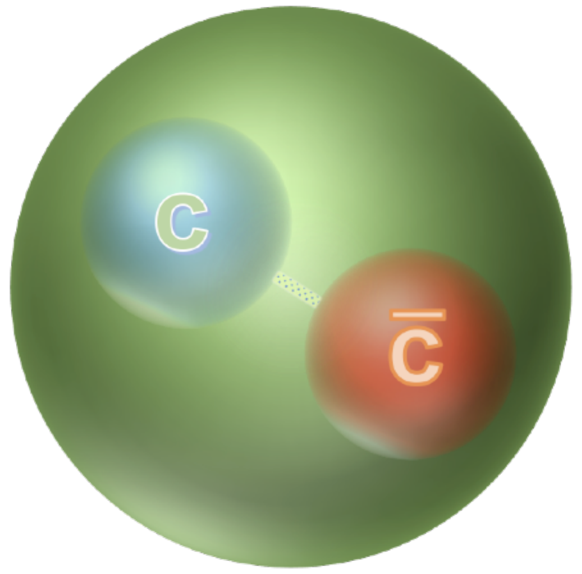
The 19th International Conference on Strangeness in Quark Matter

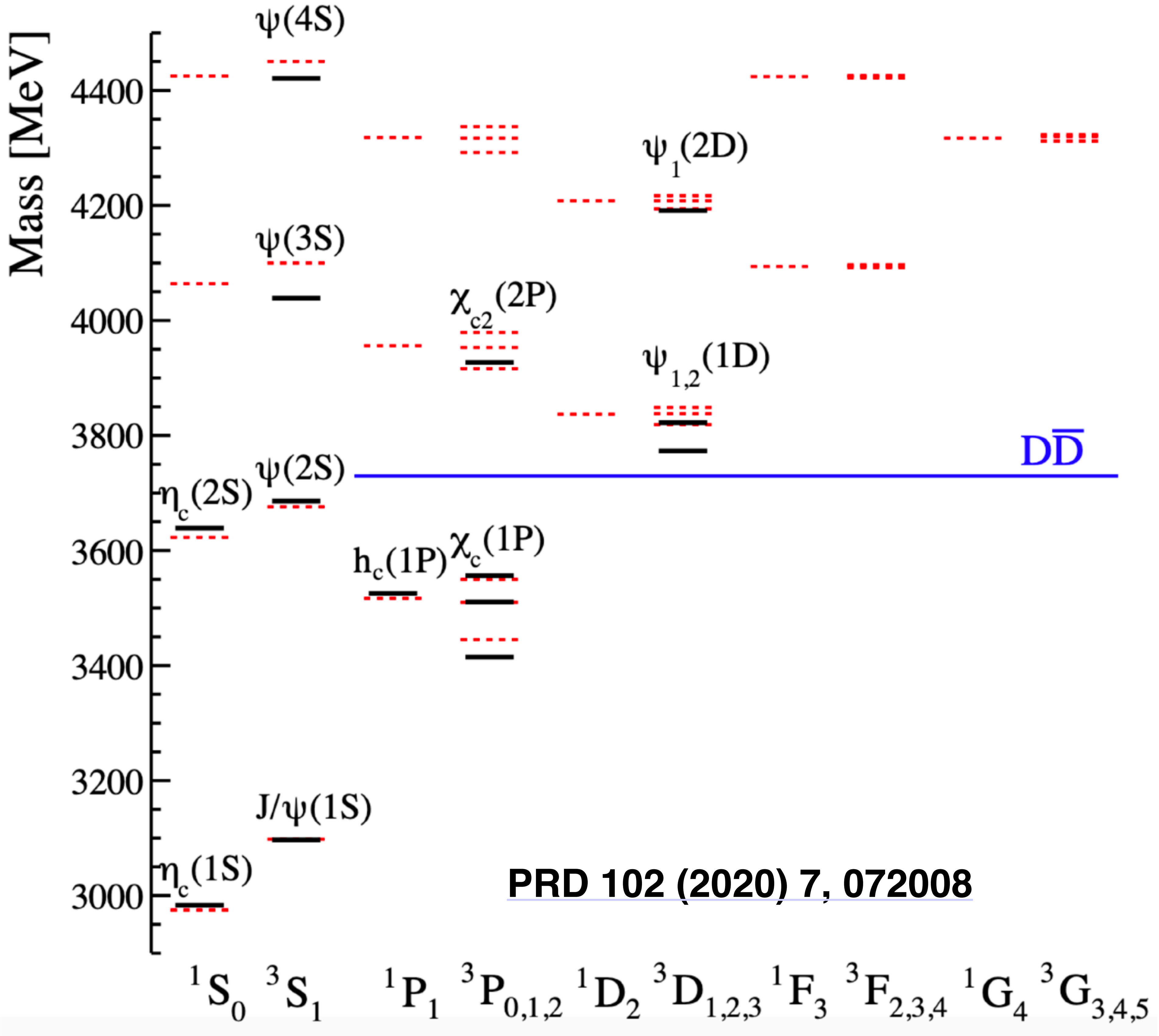
May 17-22, 2021, sponsored by Brookhaven National Laboratory, Upton, New York

SQM2021

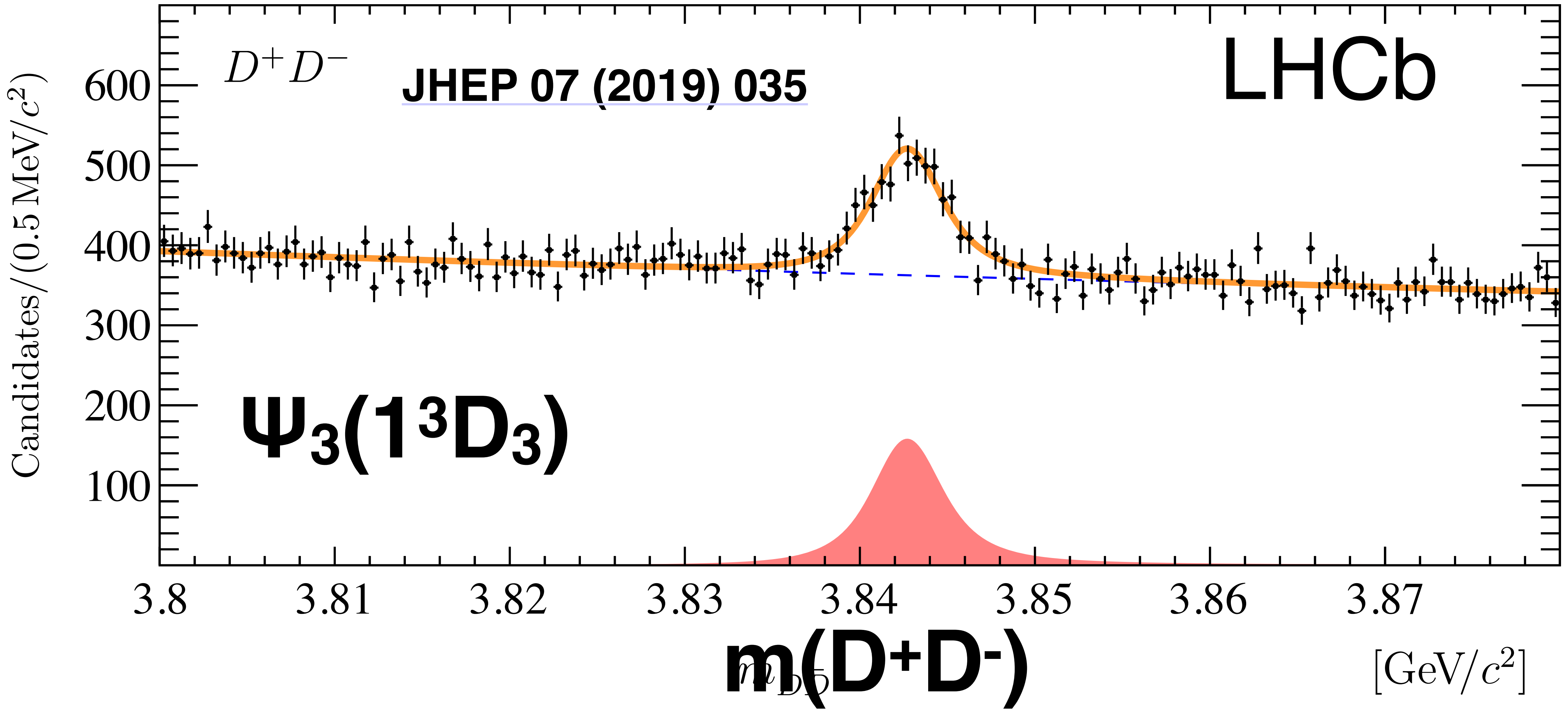
Why quarkonia are interesting?

- Quarkonia are made of charm and bottom quarks (m_c, $m_b >> \Lambda_{QCD}$):
  - Their production cross section can be calculated with pQCD.
  - Different production models available: CSM, CEM, NRQCD.



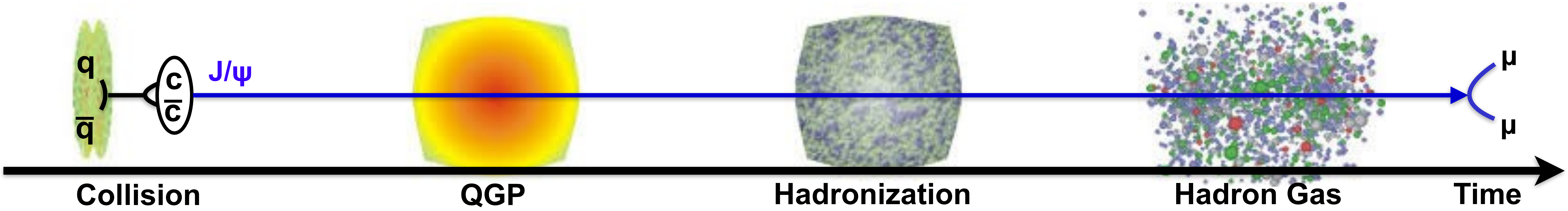


- Quarkonia appears in a variety of states:
  - J/Ψ, Ψ(2S), ϒ(1S), ϒ(2S), …
  - Characterised by different masses and binding energies.
  - And still new states been found in recent years.



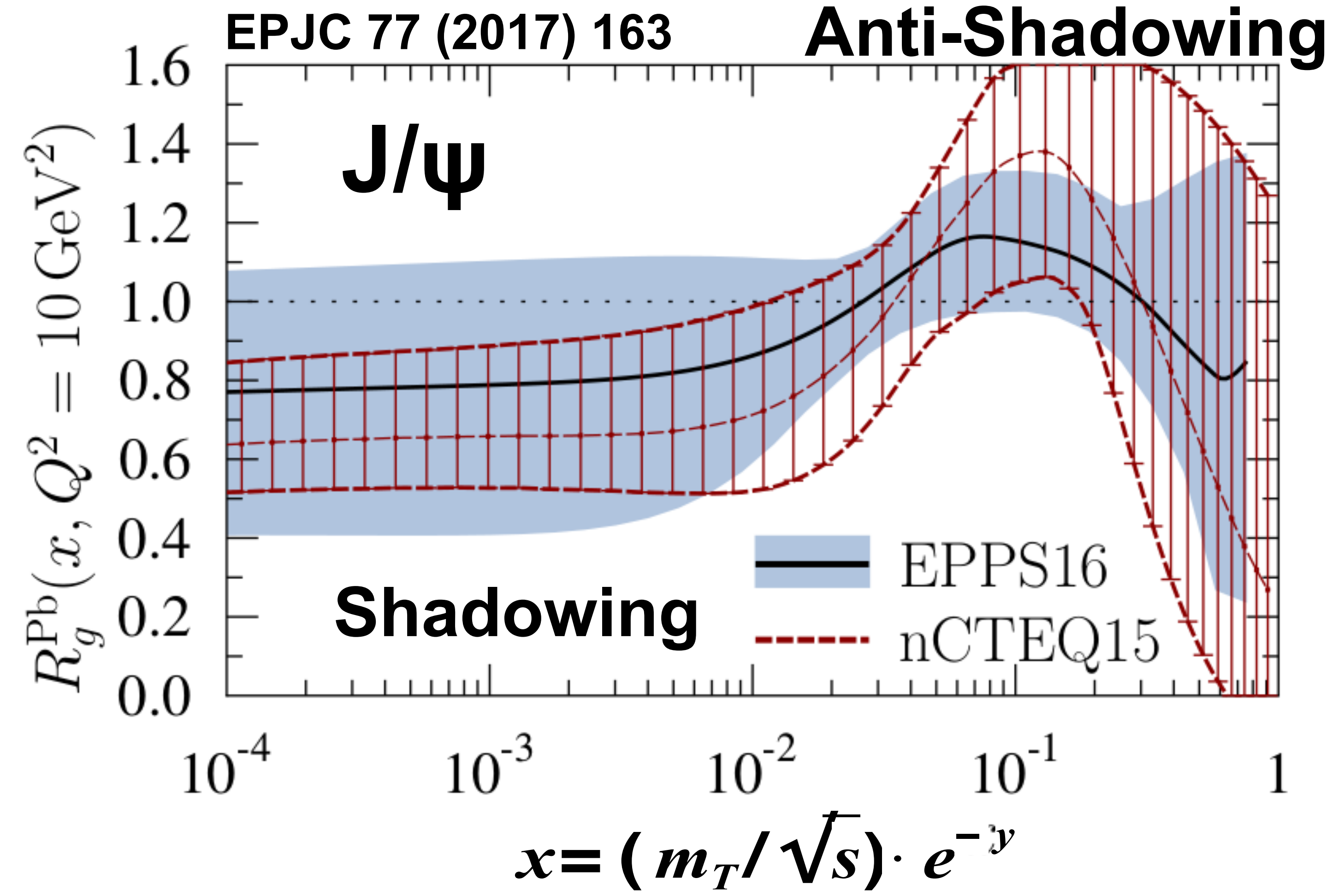
Quarkonia in URHI collisions

Quarkonia are produced in the early stages of the collision



Cold nuclear matter effects

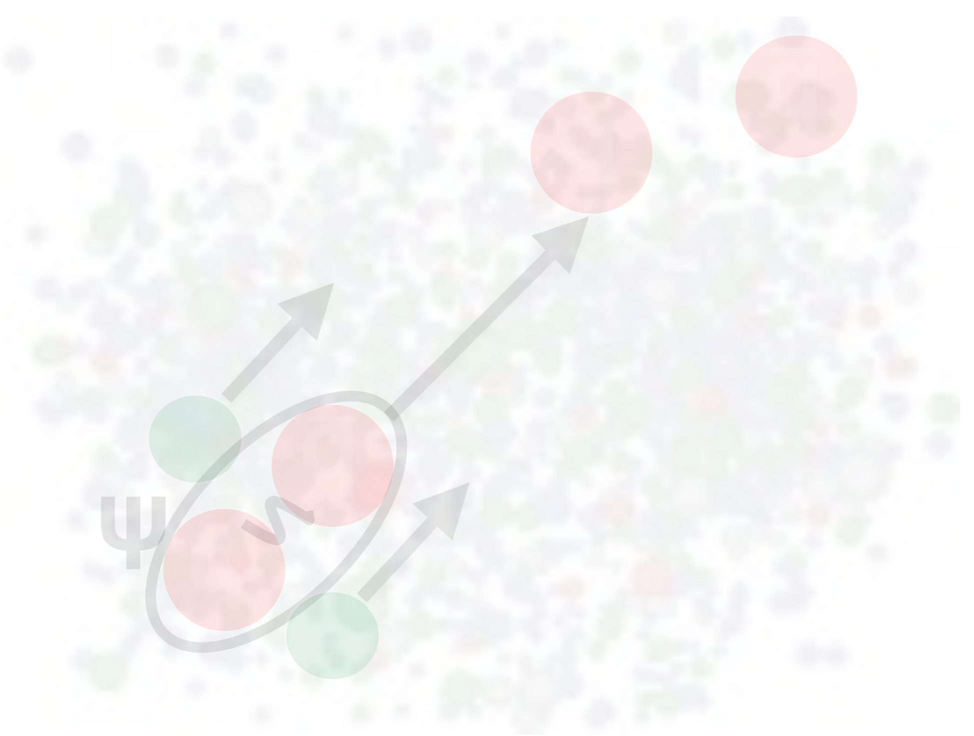
nPDF modification



Coherent energy loss

Nuclear medium

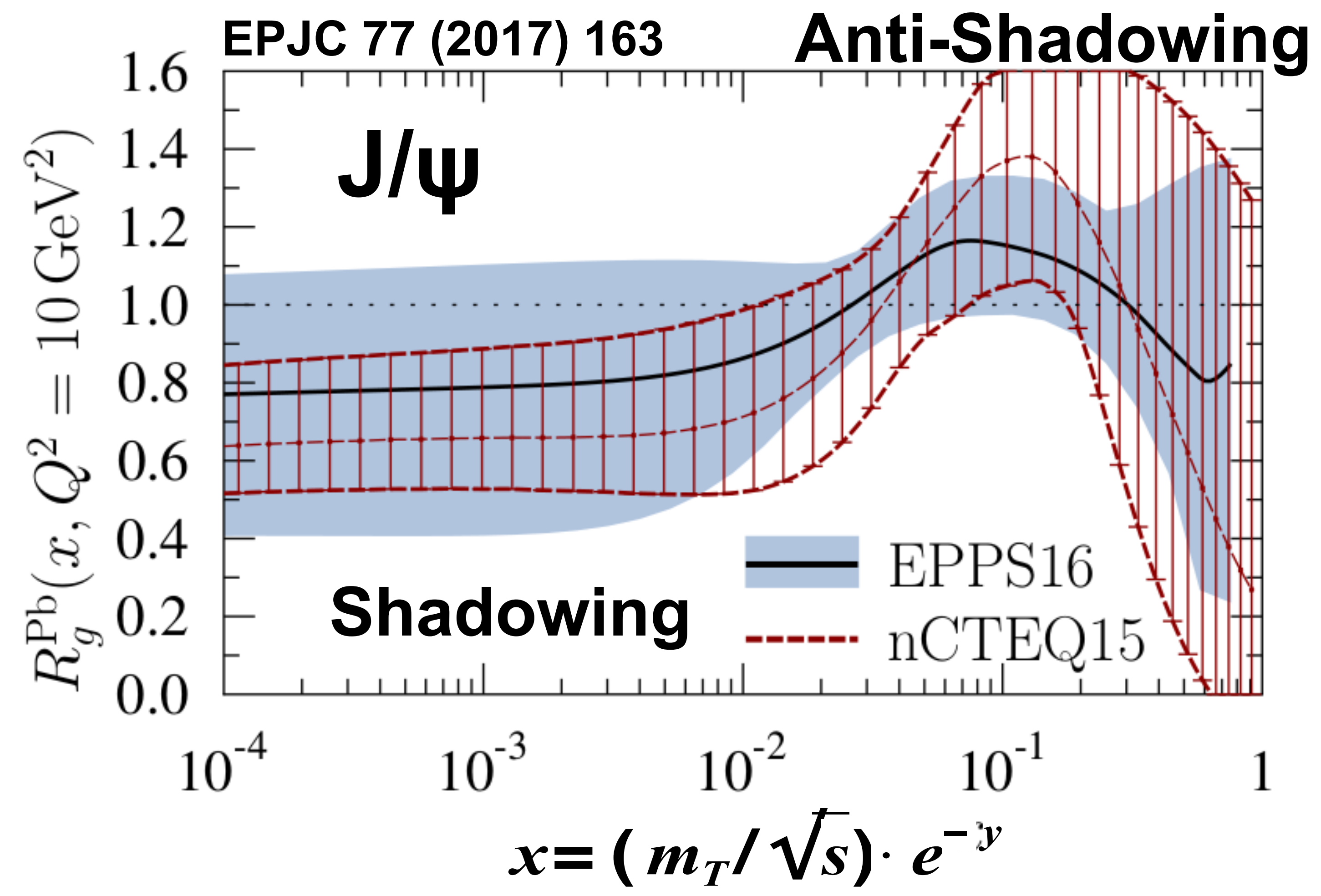
Co-mover breakup



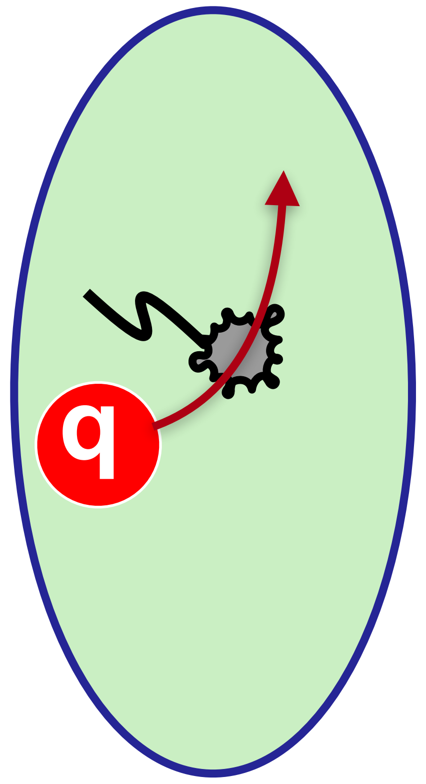
Hadronic matter

Cold nuclear matter effects

nPDF modification

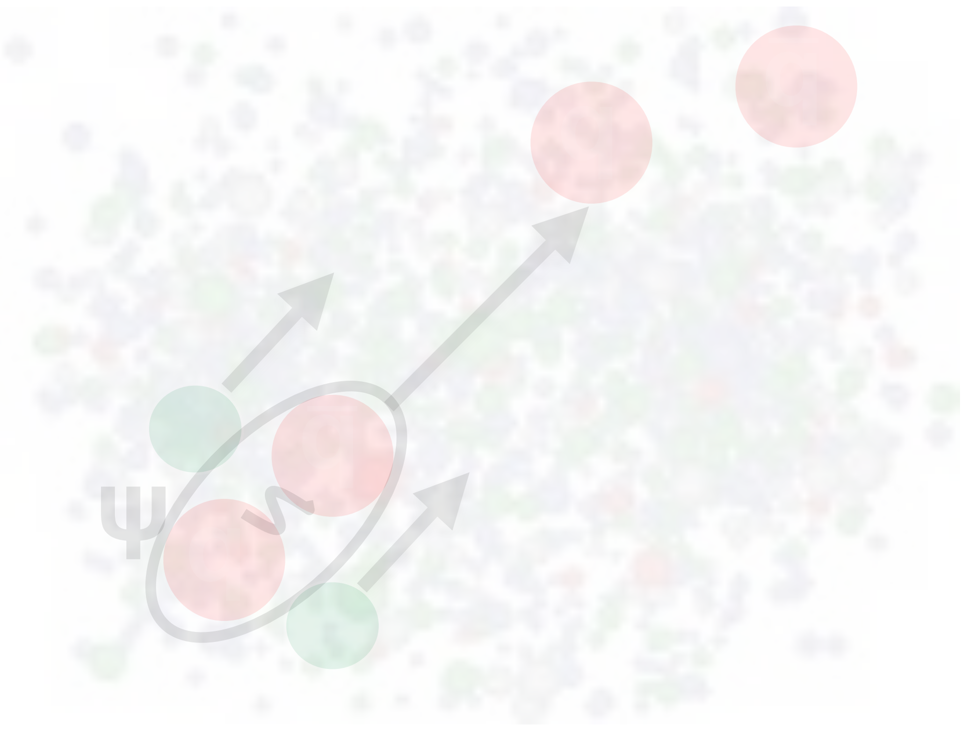


Coherent energy loss



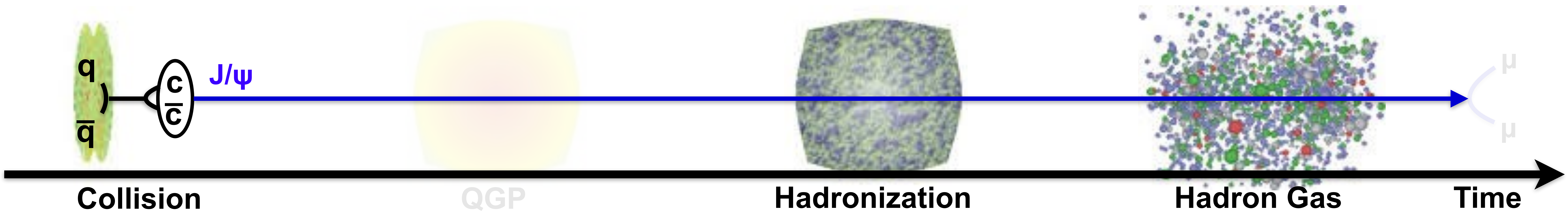
Nuclear medium

Co-mover breakup

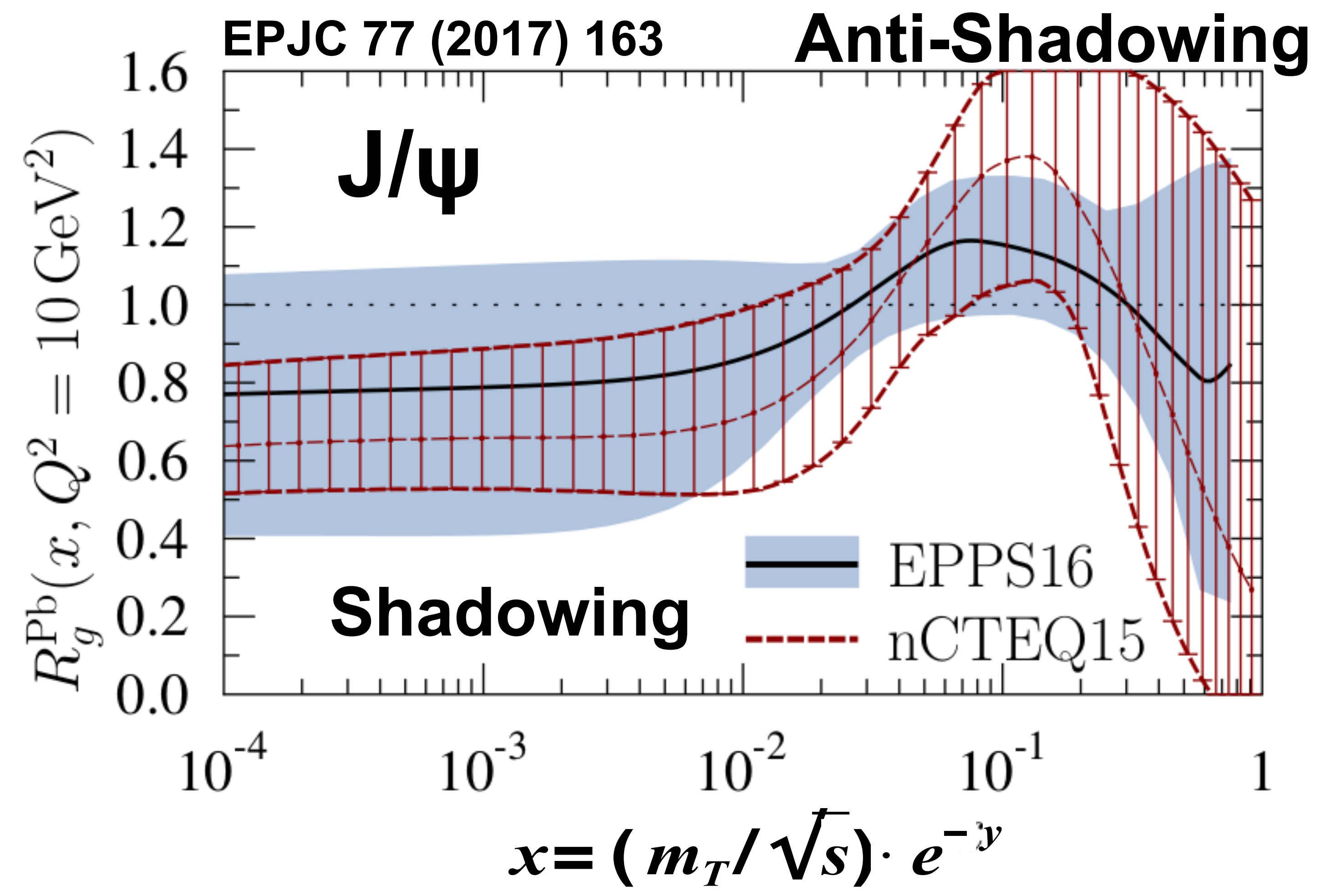


Hadronic matter

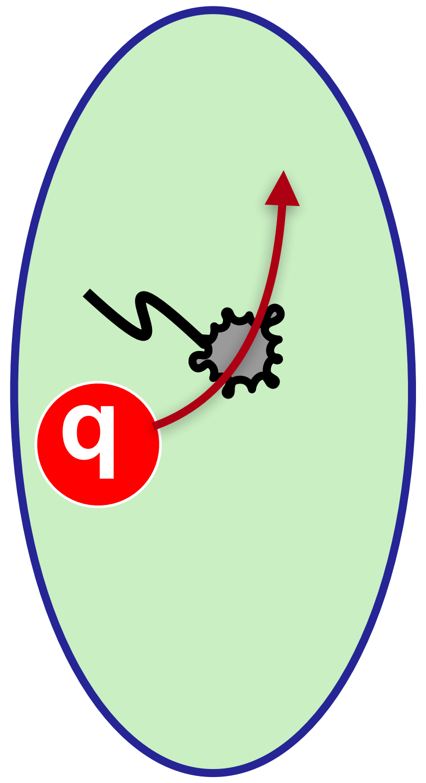
Cold nuclear matter effects



nPDF modification

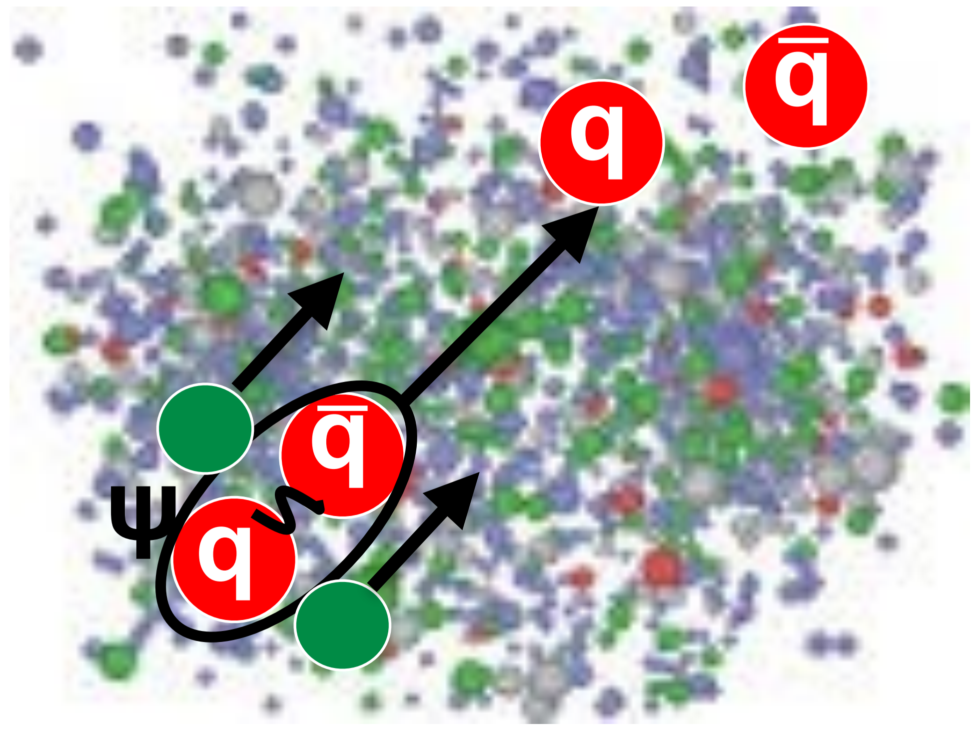


Coherent energy loss



Nuclear medium

Co-mover breakup

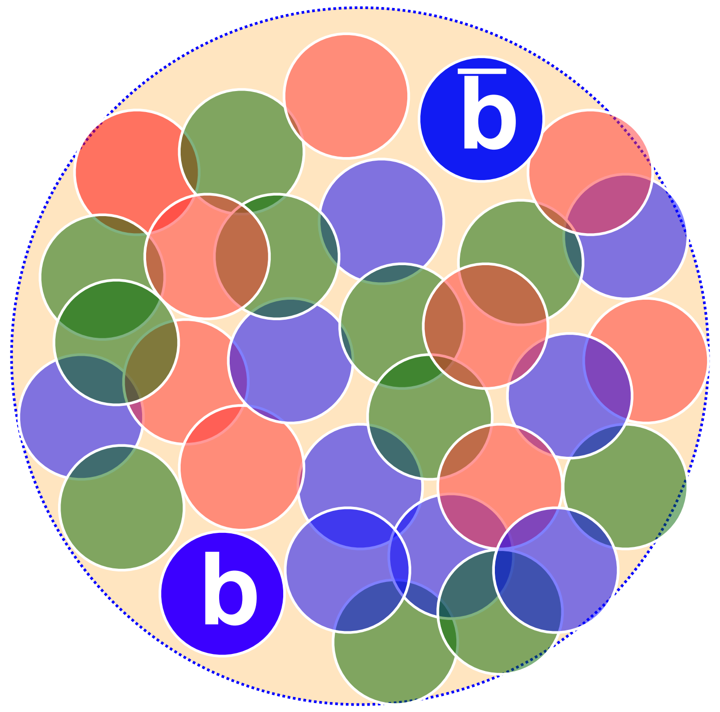


Hadronic matter

QGP medium effects

The Quark-Gluon Plasma is expected to modify the quarkonium production

QGP

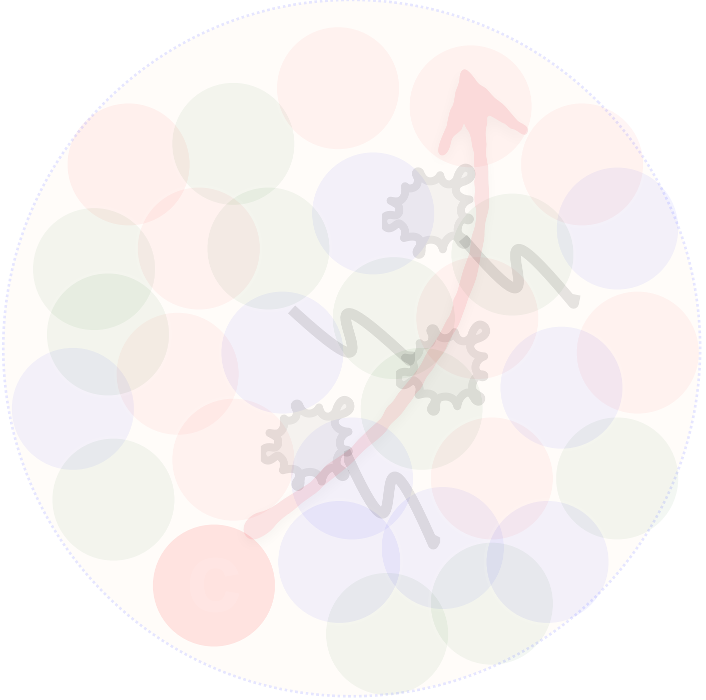


Suppression
Medium-induced dissociation

QGP
@ high energy density

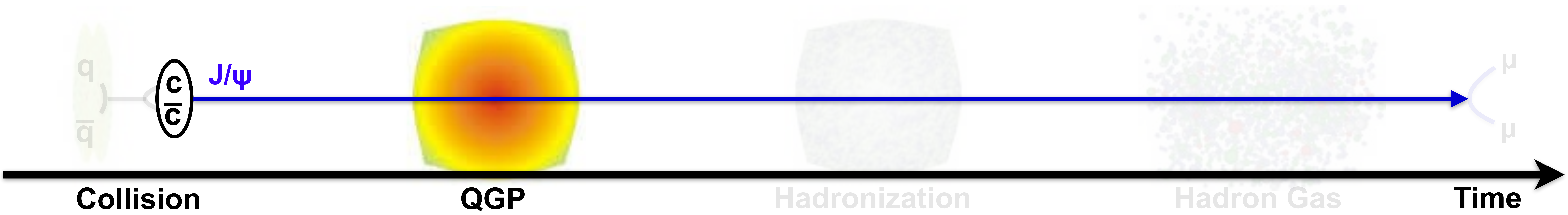
+Enhancement
Regeneration

QGP



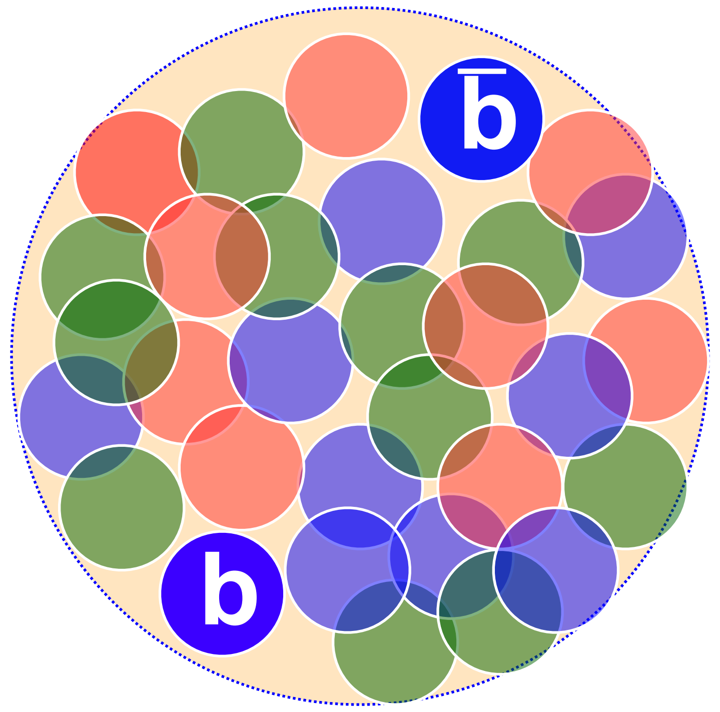
+Parton energy loss
at high p_T

QGP medium effects



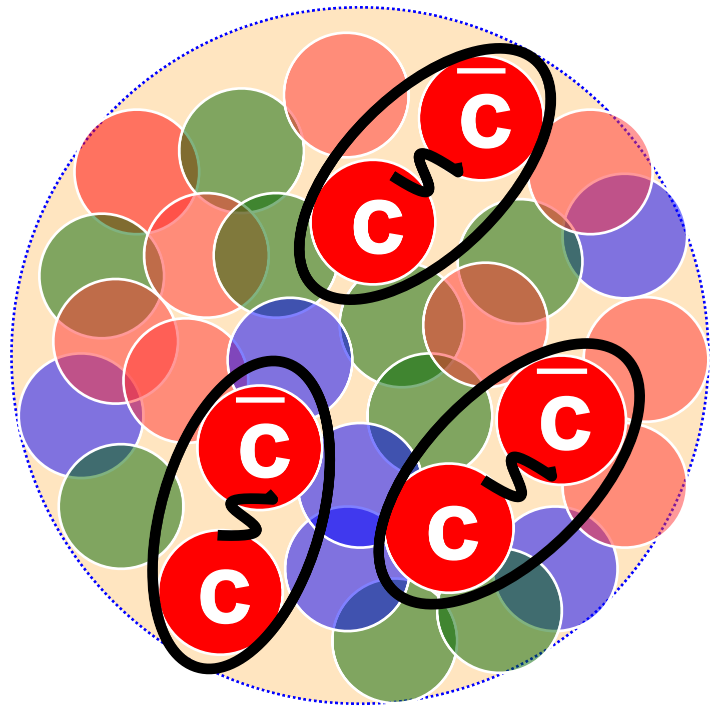
The Quark-Gluon Plasma is expected to modify the quarkonium production

QGP



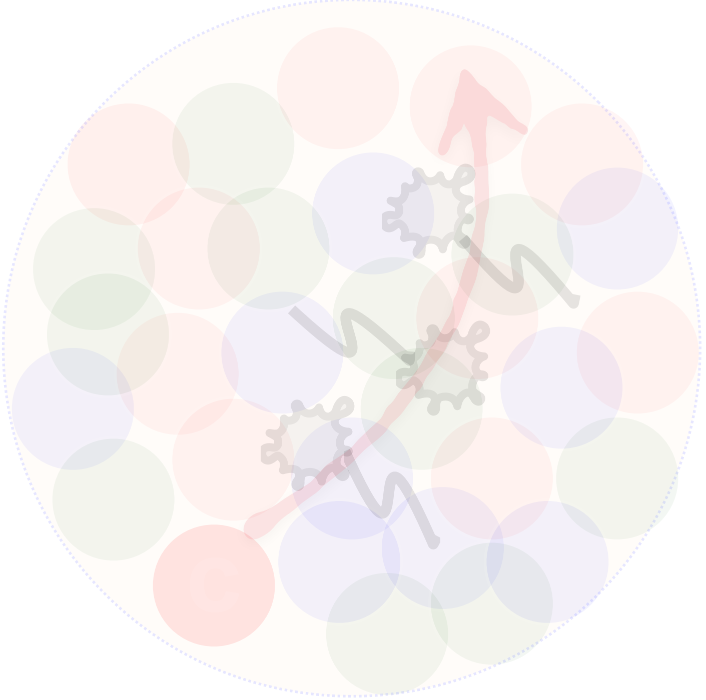
Suppression
Medium-induced dissociation

QGP
@ high energy density



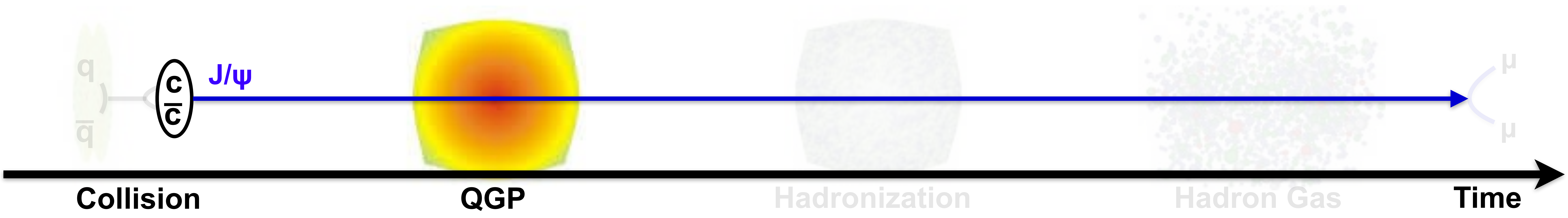
+Enhancement
Regeneration

QGP



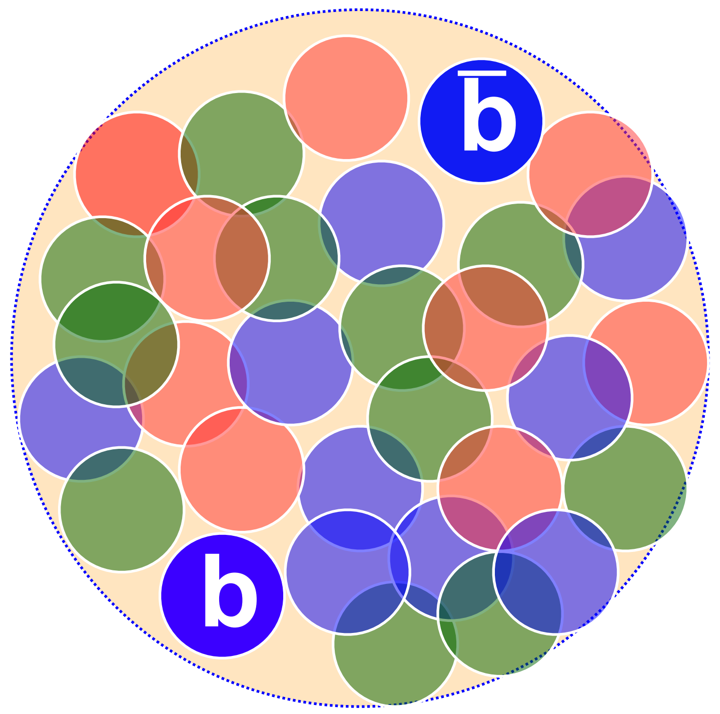
+Parton energy loss
at high p_T

QGP medium effects



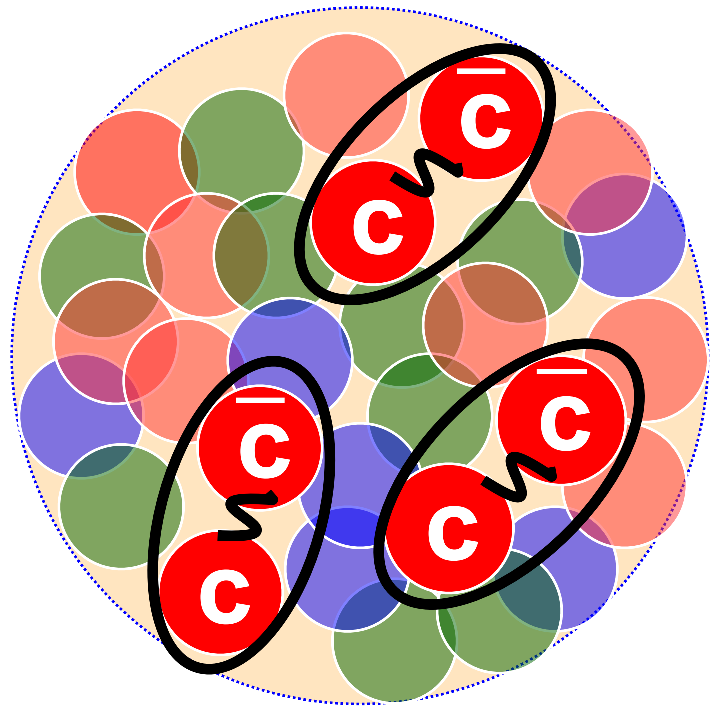
The Quark-Gluon Plasma is expected to modify the quarkonium production

QGP



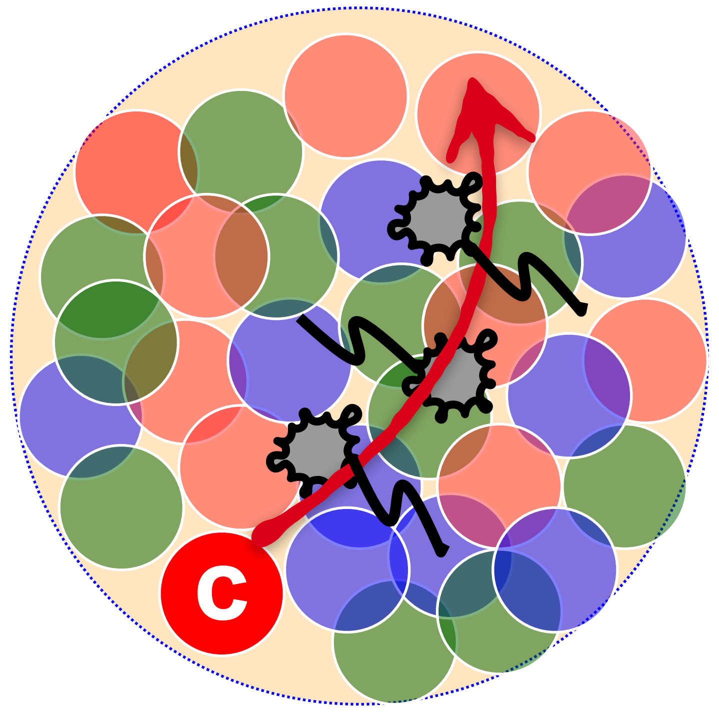
Suppression
Medium-induced dissociation

QGP @ high energy density



+Enhancement
Regeneration

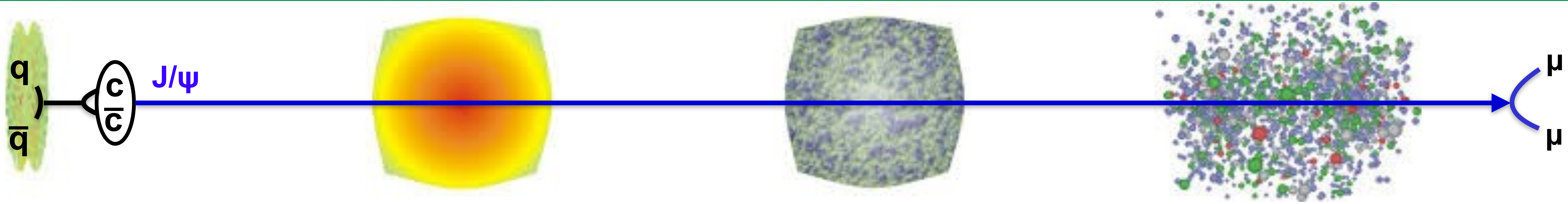
QGP

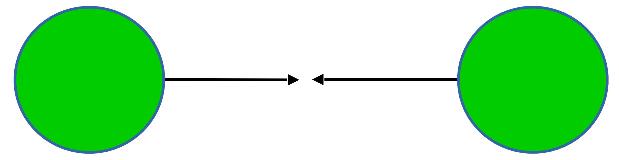


+Parton energy loss
at high p_T

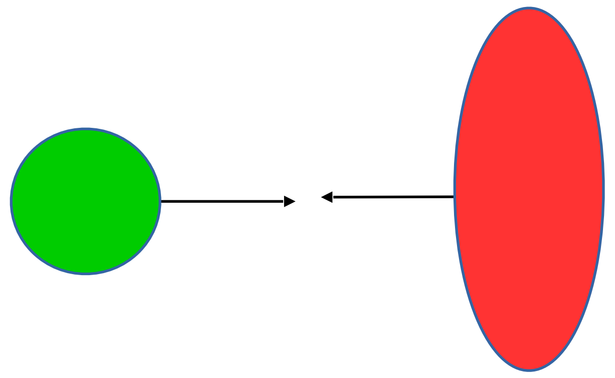
Quarkonia are good probes of the medium evolution

OUTLINE

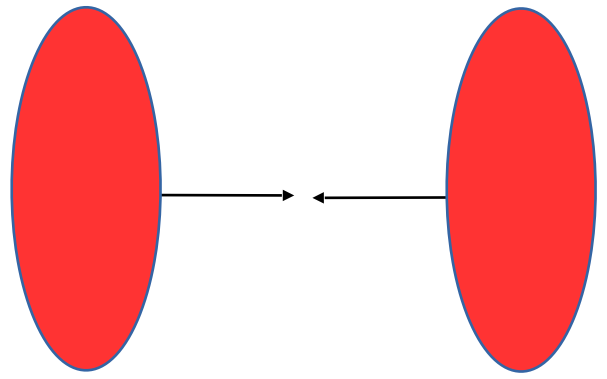




- $Q\bar{Q}$ production mechanism:
  - Polarization in pp
  - Production in pp

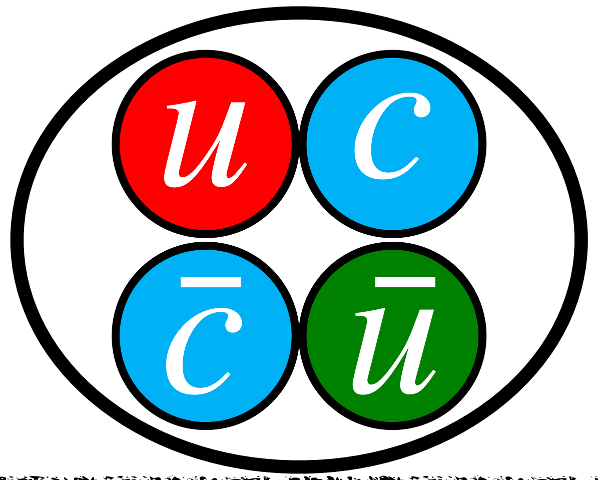


- Probing cold nuclear effects:
  - $Q\bar{Q}$ production in pA

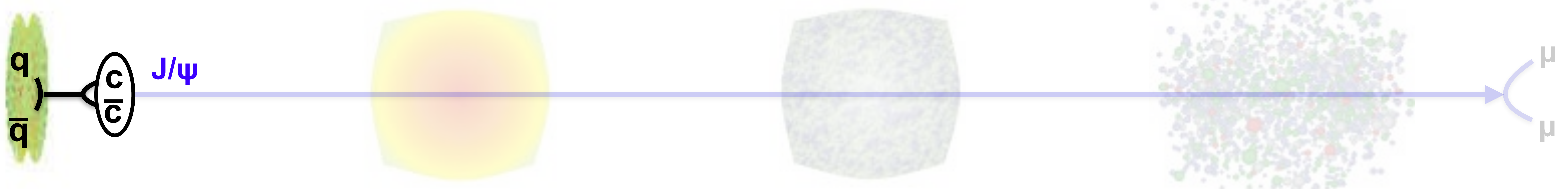


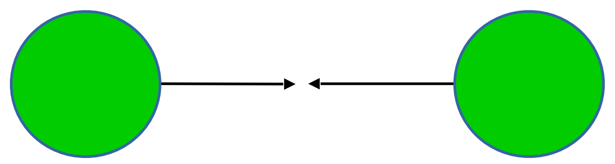
- Probing QGP effects:
  - $Q\bar{Q}$ polarization in AA
  - $Q\bar{Q}$ production in AA

- Exotic quarkonium states



OUTLINE





- $Q\bar{Q}$ production mechanism:
  - **Polarization in pp**
  - Production in pp

- Probing cold nuclear effects:
  - $Q\bar{Q}$ production in pA

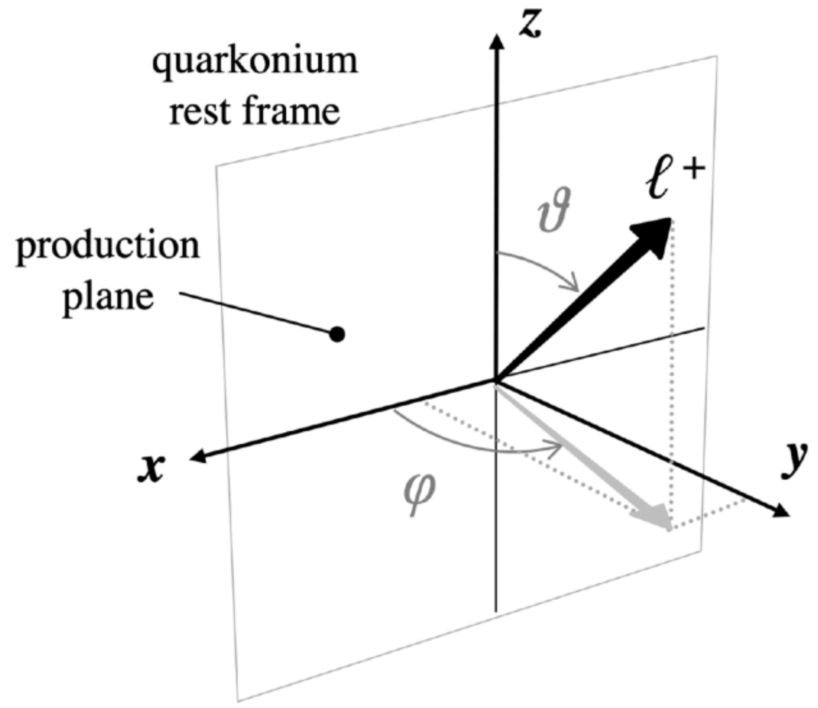
- Probing QGP effects:
  - $Q\bar{Q}$ polarization in AA
  - $Q\bar{Q}$ production in AA

- Exotic quarkonium states

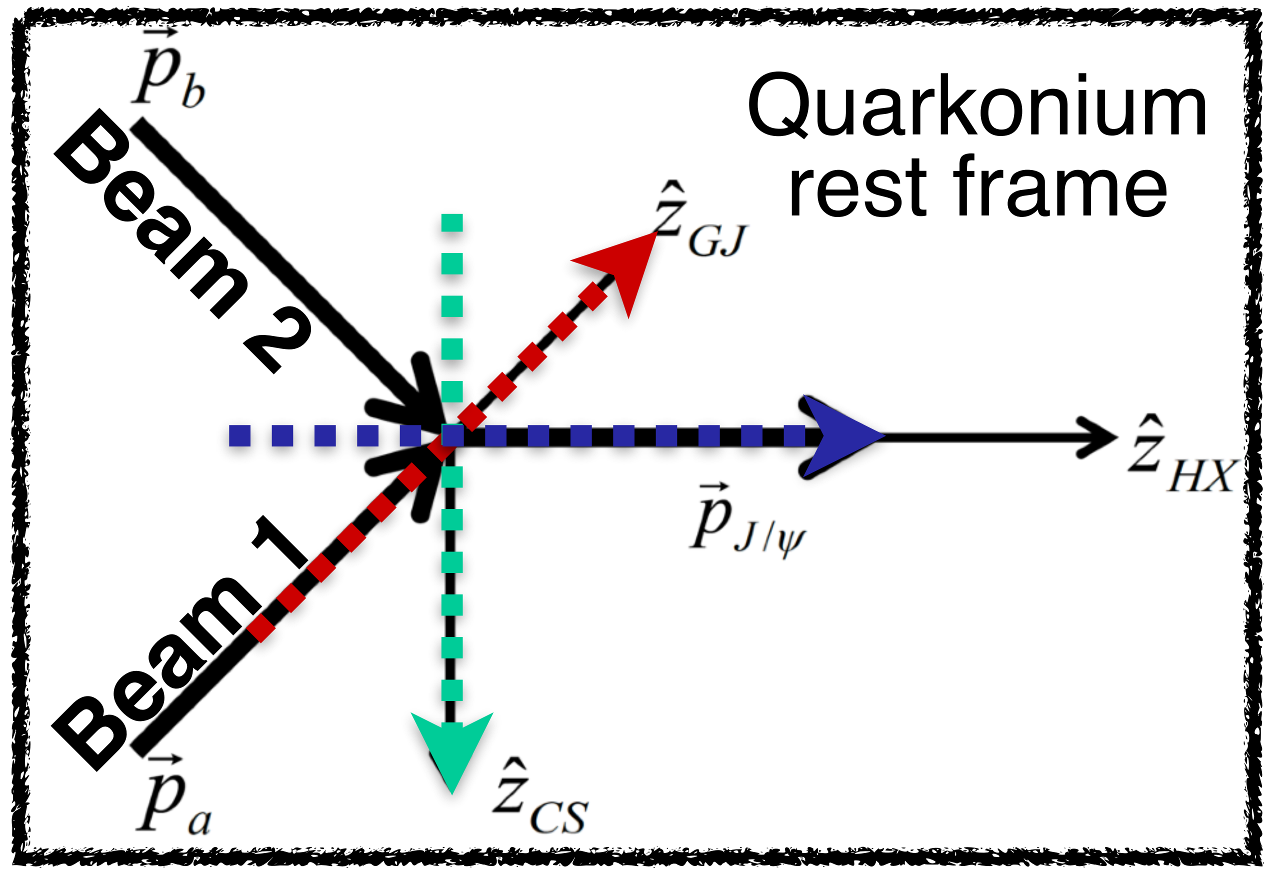
Quarkonium polarization

- Polarization is defined as the spin alignment with respect to a chosen direction.

$$W(\theta,\phi) \propto \frac{1}{3+\lambda_\theta}\left(1+\lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta\cos 2\phi + \lambda_{\theta\phi}\sin 2\theta\cos\phi\right)$$



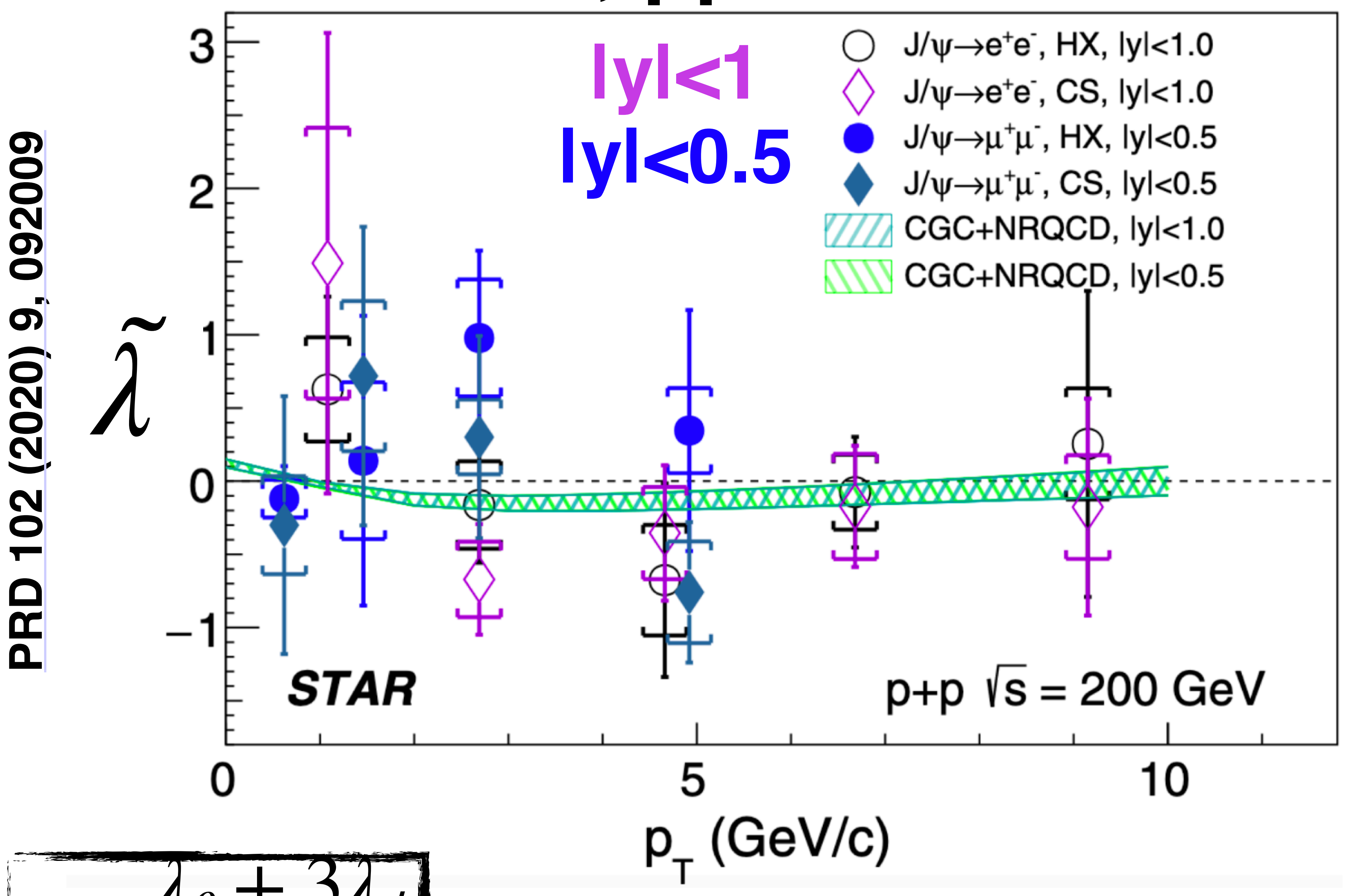
- Measured as anisotropies in the angular distributions of decay products in the QQ CM w.r.t:
  - **Helicity (HX)**: quarkonium p_T direction.
  - **Collins-Soper (CS)**: bisector of angle between beams.
  - **Gottfried-Jackson (GJ):** direction of one beam.



- Constrains J/Ψ production mechanism:
  - LO NRQCD: transverse polarization **($\lambda_\theta > 0$)** at high p_T.
  - NLO CSM: longitudinal polarization **($\lambda_\theta < 0$)**.
  - Medium effects could possible modify J/Ψ polarization.

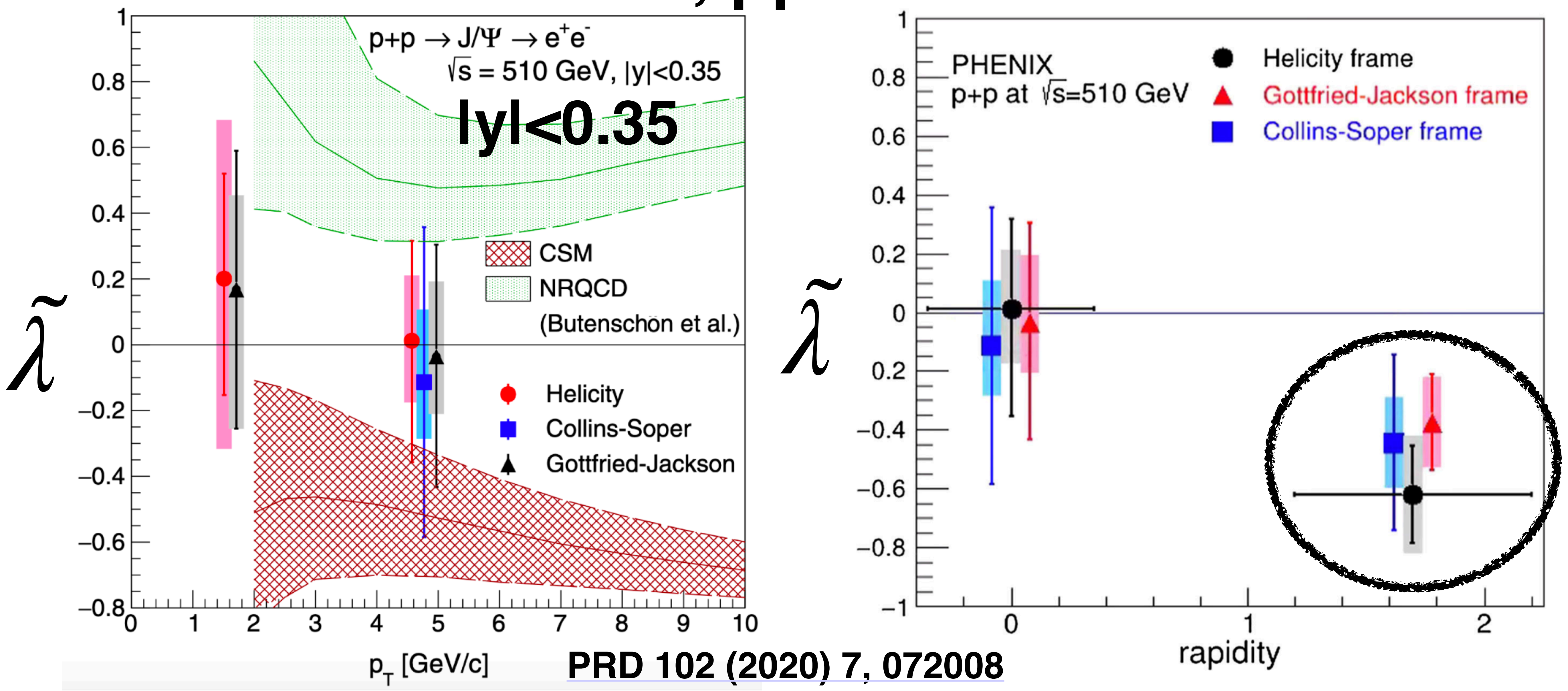
J/Ψ polarization in pp at RHIC

STAR, pp @ 200 GeV



$$\tilde{\lambda} = \frac{\lambda_\theta + 3\lambda_\phi}{1 - \lambda_\phi}$$

PHENIX, pp @ 510 GeV

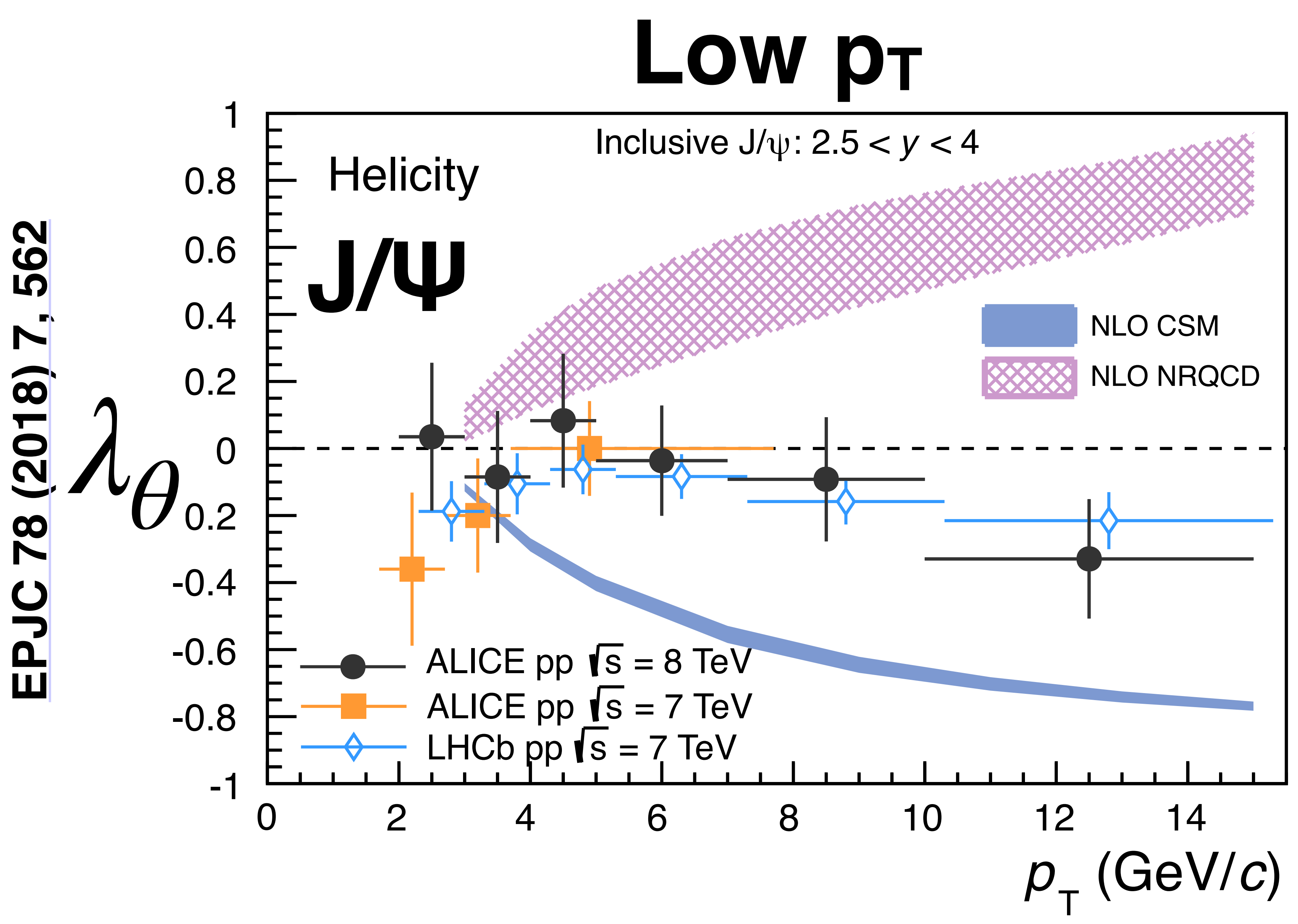


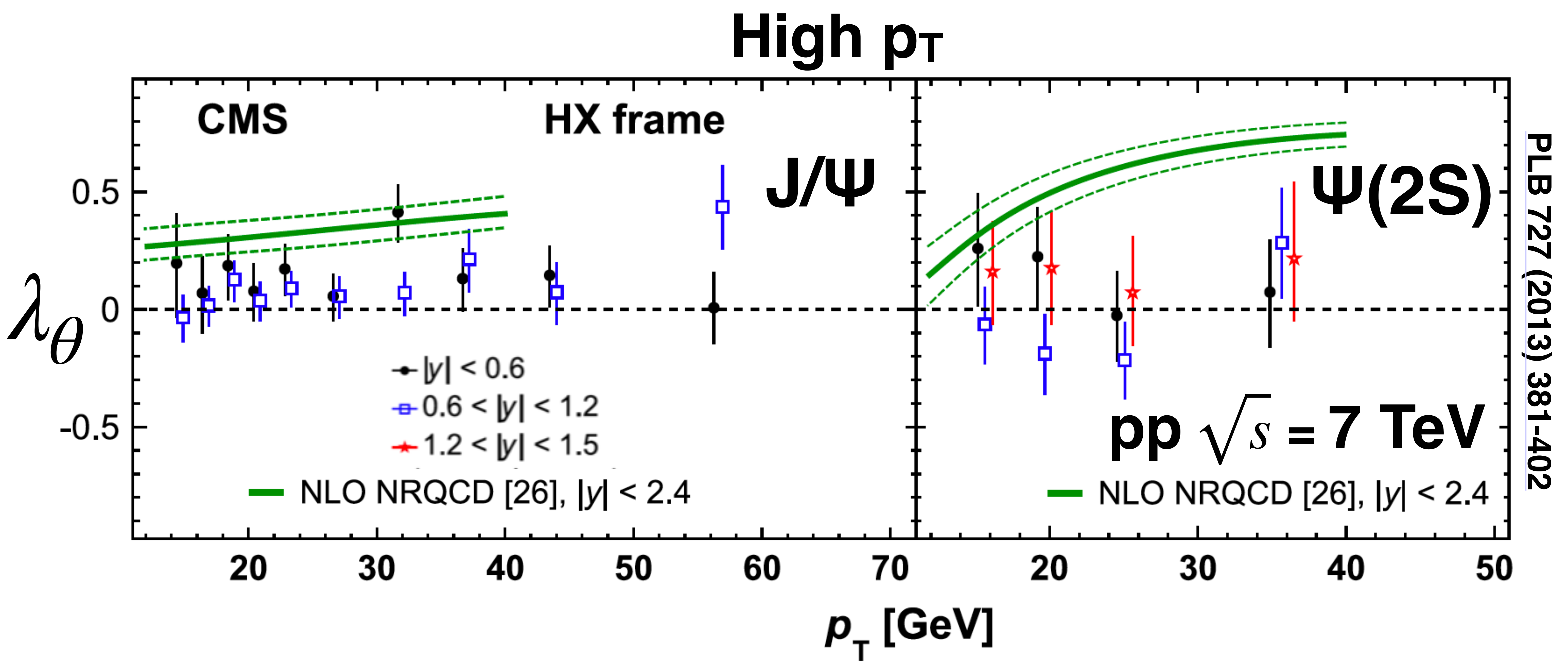
PRD 102 (2020) 7, 072008

Murad Sarsour, May 21, Room D 10:30

- J/Ψ production at mid-rapidity do not exhibit significant polarization.
  - CGC+NRQCD expects no polarization in agreement with data.
  - CSM and NRQCD predicts non-zero polarization towards high p_T.
- J/Ψ production at forward rapidity shows hint of longitudinal polarization ($\tilde{\lambda} < 0$).

Charmonium polarization in pp at LHC

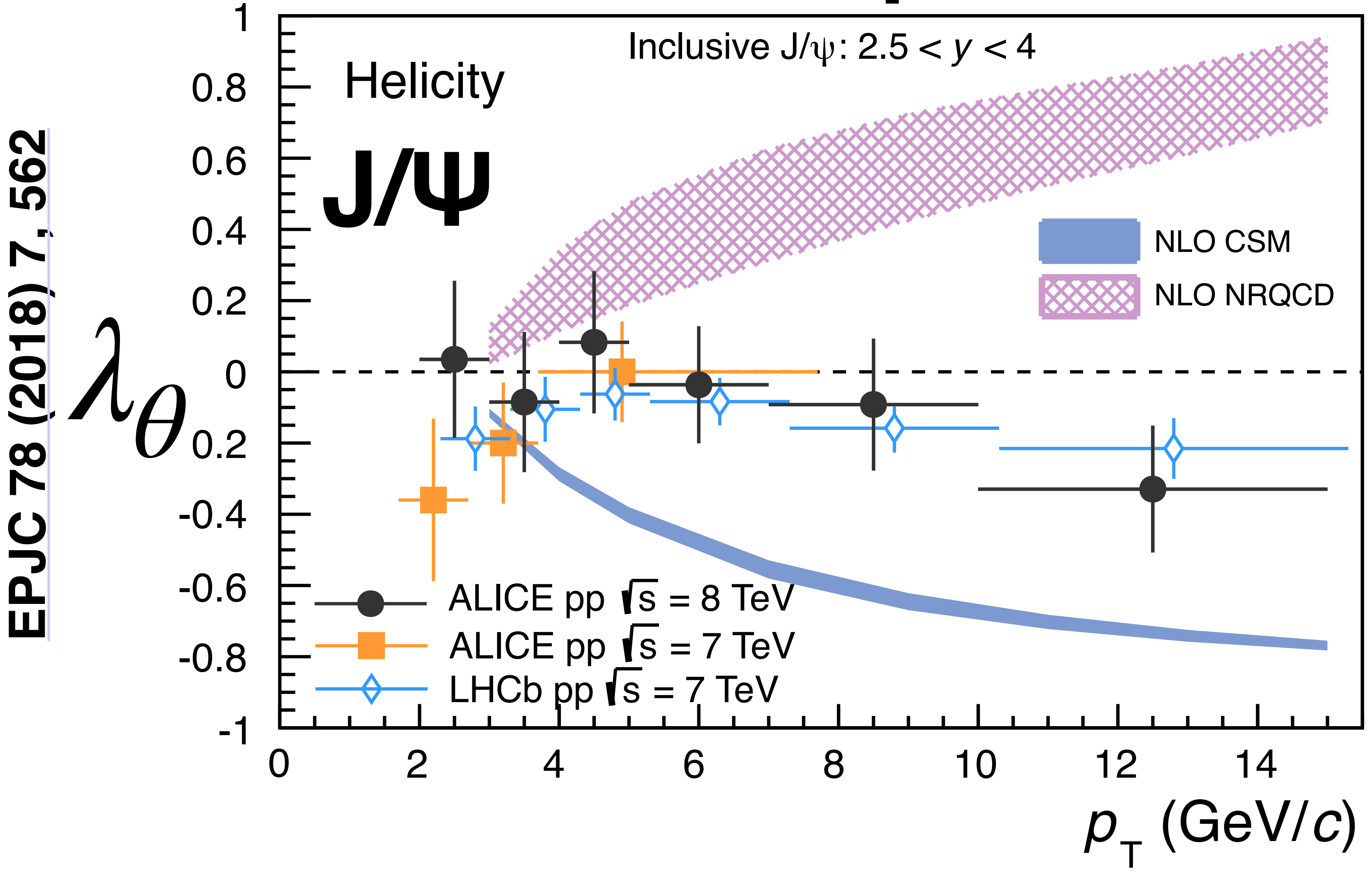




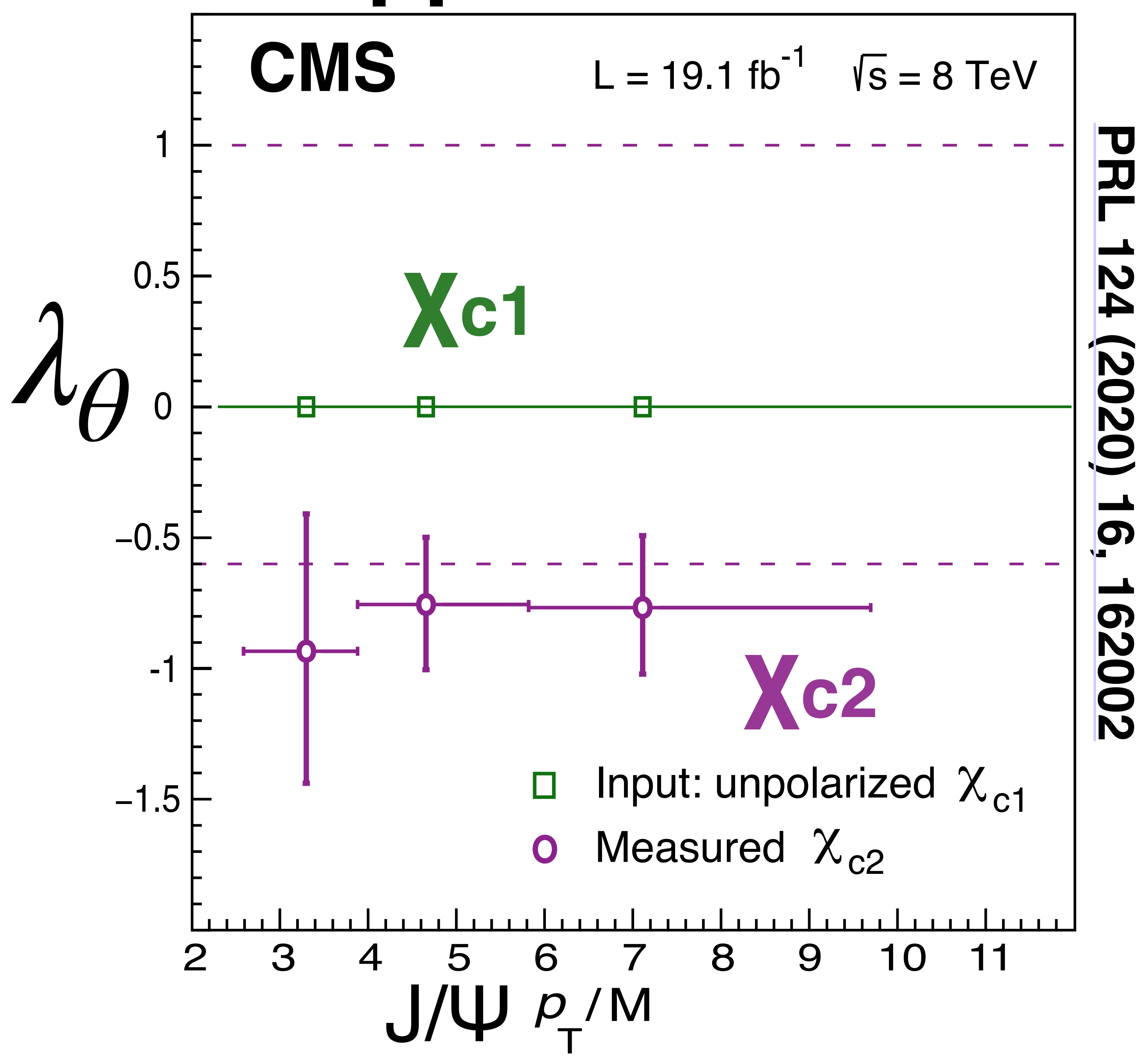
- Ψ(nS) production in pp at LHC shows no significant polarization up to $p_T \sim$ 60 GeV.
- NRQCD and CSM also fail to describe Ψ(nS) polarization @ 8 TeV.

Charmonium polarization in pp at LHC

Low p_T

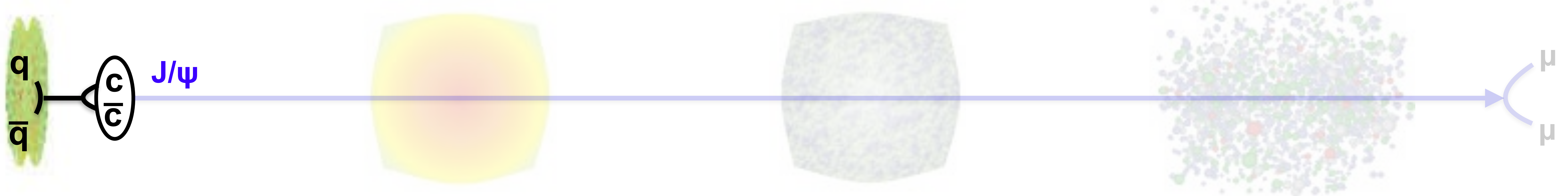


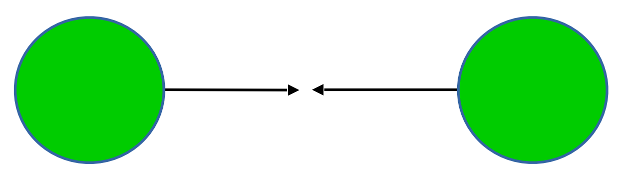
pp @ 8 TeV



- Ψ(nS) production in pp at LHC shows no polarization up to $p_T \sim 60$ GeV.
- NRQCD and CSM also fail to describe Ψ(nS) polarization @ 8 TeV.
- Prompt $X_c \rightarrow J/\Psi+\gamma$ production favours scenario where at least one X_c state is polarized.
  - Need to be careful with feed-down contribution when studying J/Ψ polarization.

OUTLINE





- $Q\bar{Q}$ production mechanism:
  - Polarization in pp
  - Production in pp

- Probing cold nuclear effects:
  - $Q\bar{Q}$ production in pA

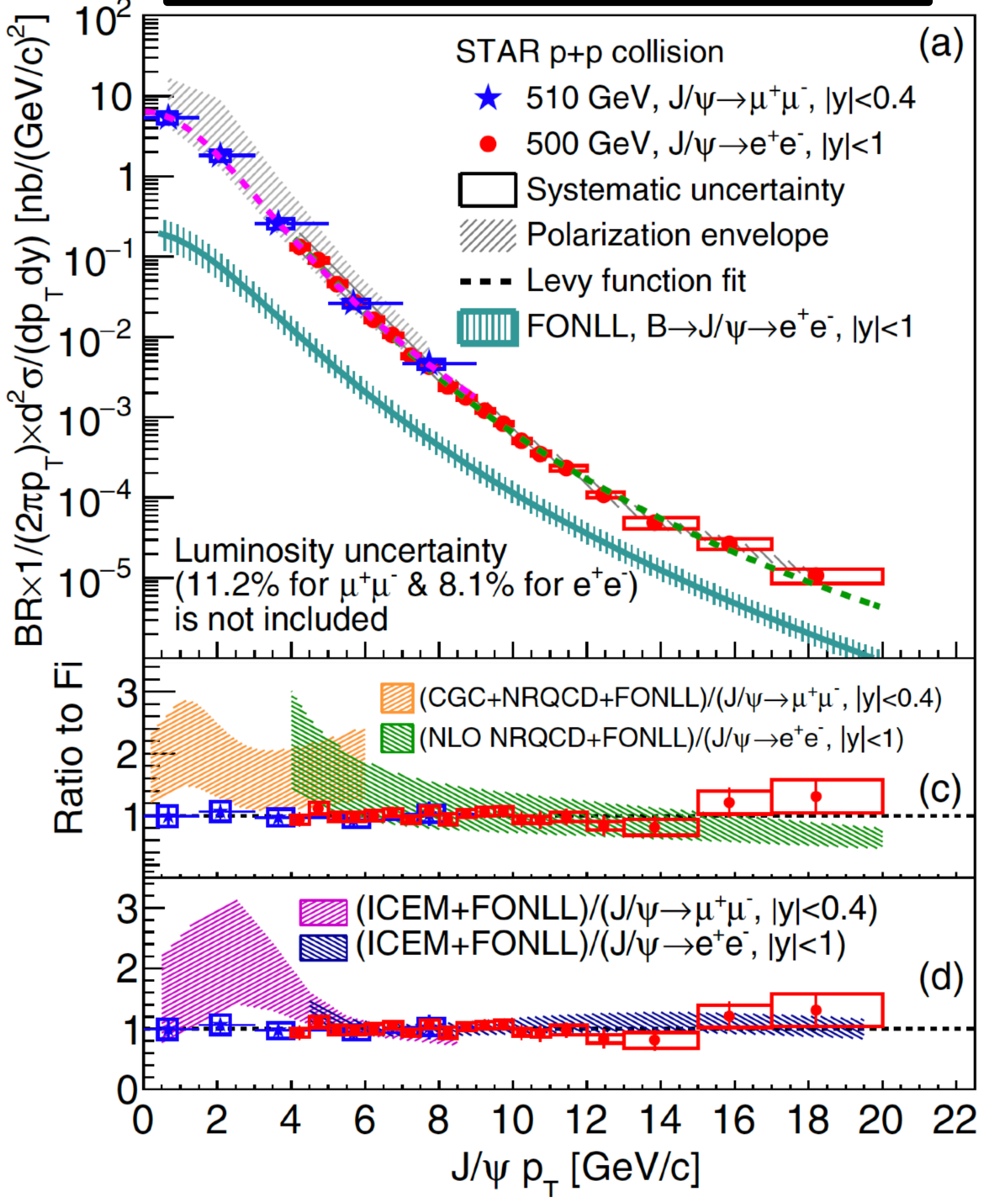
- Probing QGP effects:
  - $Q\bar{Q}$ polarization in AA
  - $Q\bar{Q}$ production in AA

- Exotic quarkonium states

J/Ψ production in pp

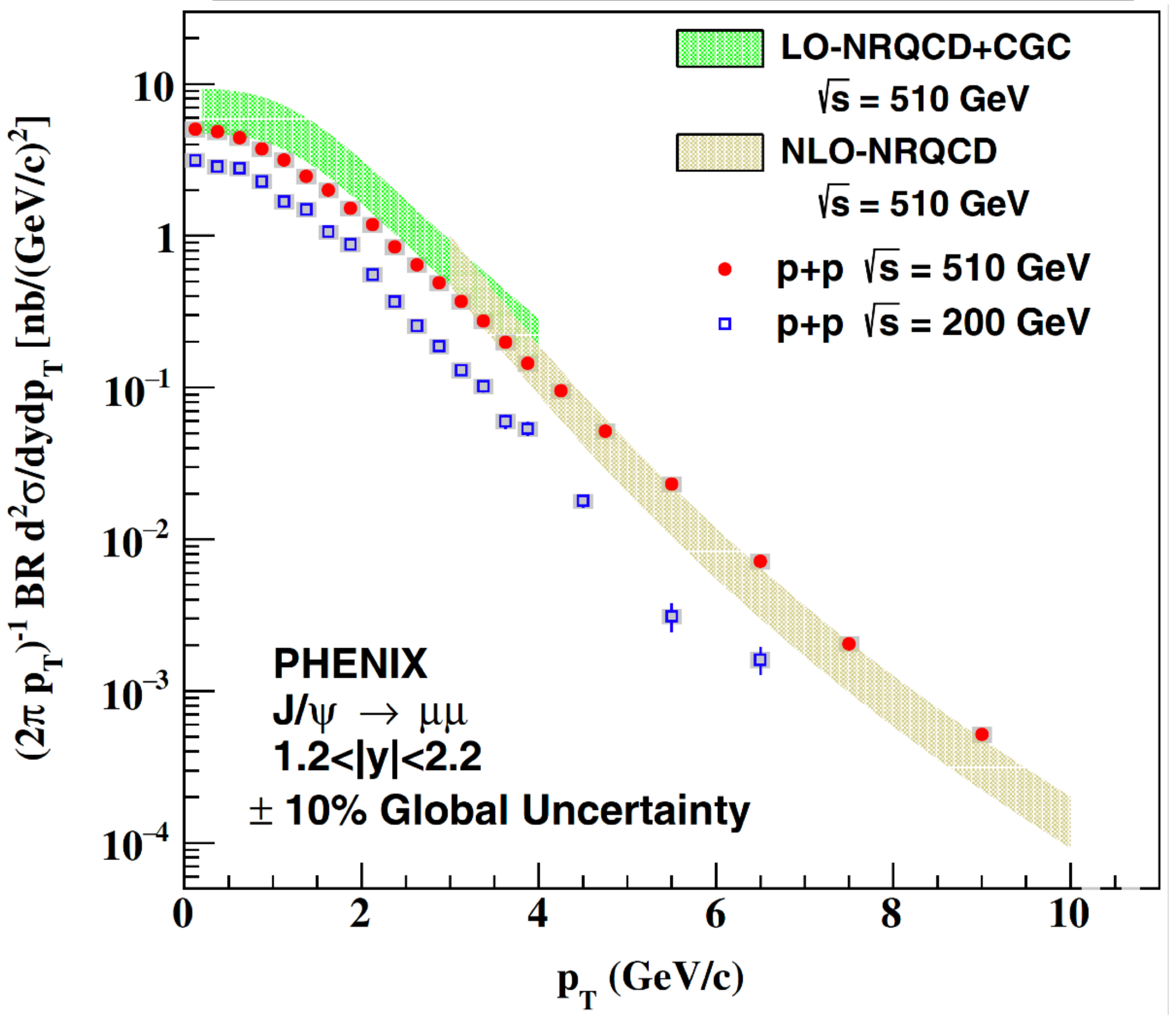
RHIC pp @ 510 GeV

Kaifeng Shen, May 21, Room D 10:10



PRD 100 (2019) 5, 052009

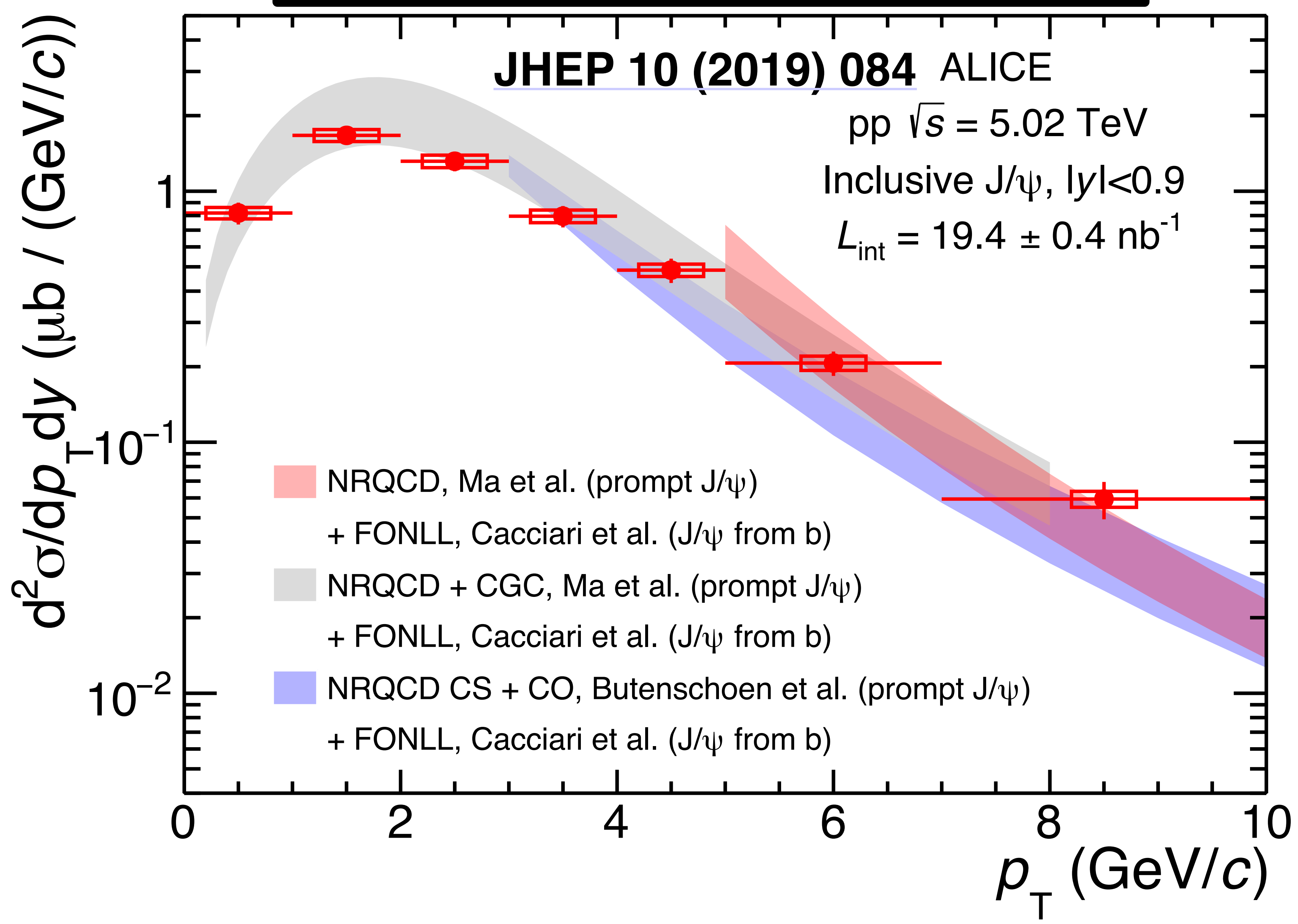
Murad Sarsour, May 21, Room D 10:30



PRD 101 (2020) 5, 052006

LHC pp @ 5 TeV

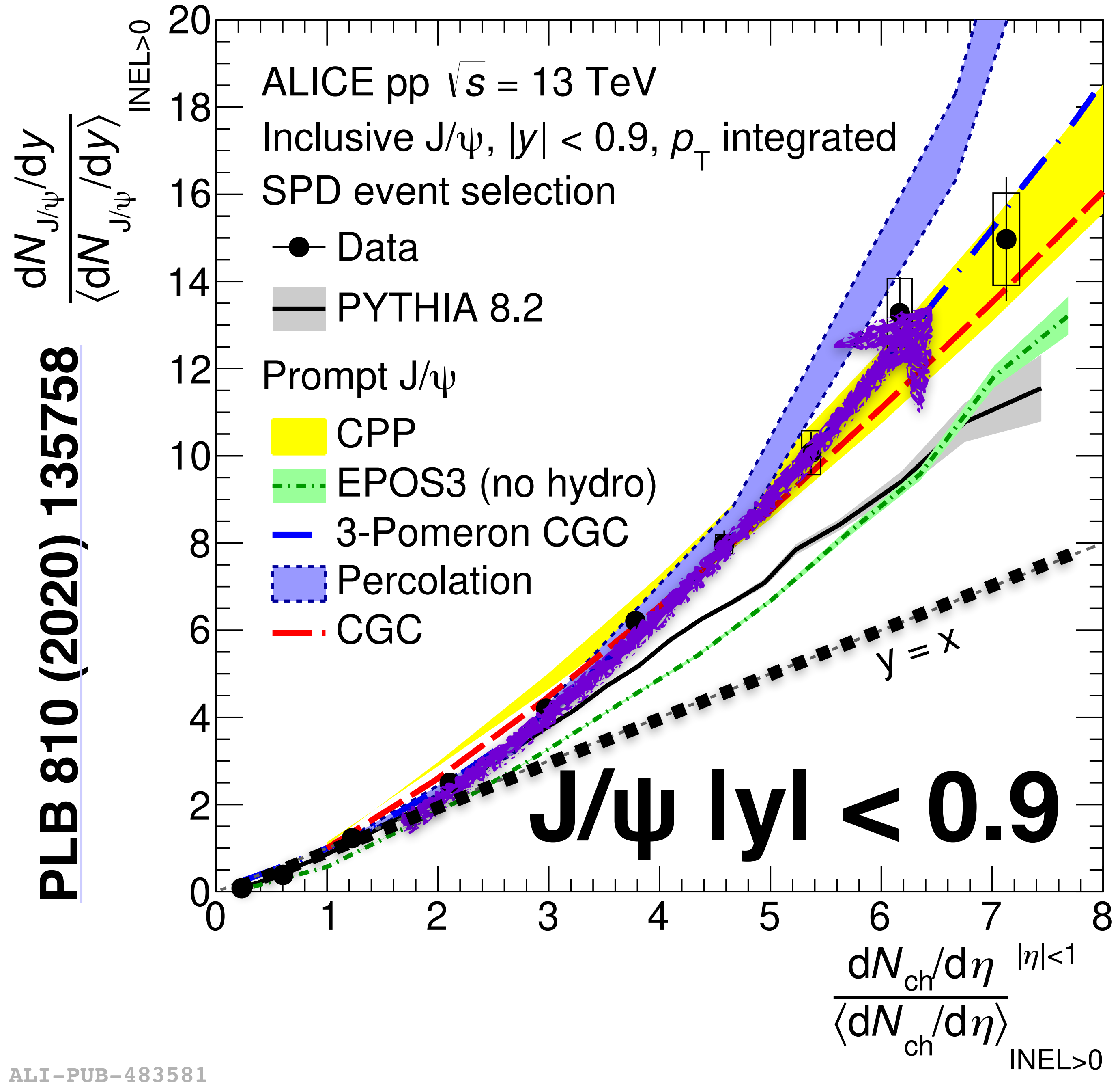
Yanchun Ding, May 18, Room D 11:30

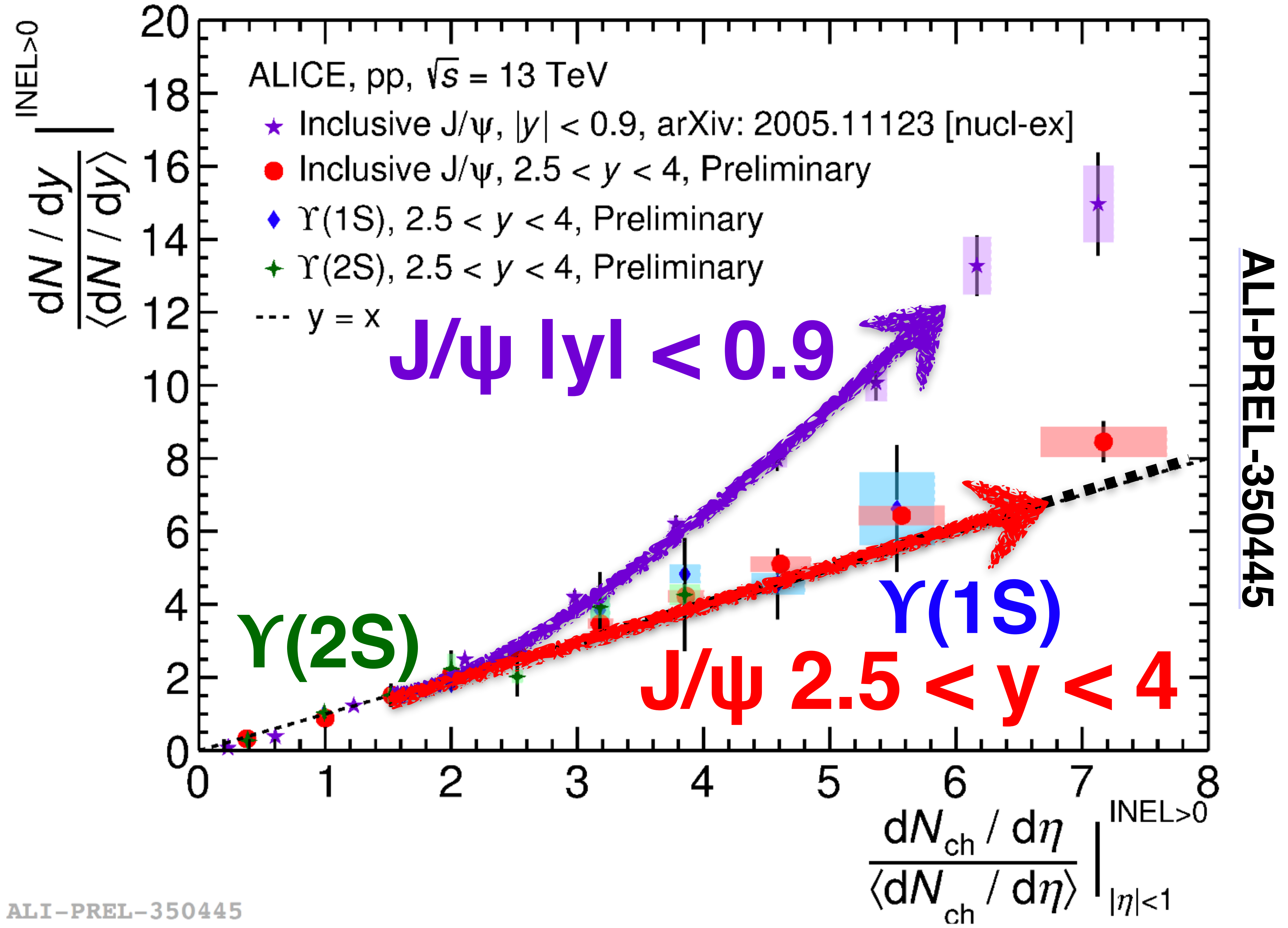


- Precise pp data measured over a wide range of beam energies.
- NRQCD + FONLL (b-hadron decays) describe pp measurements at both RHIC and LHC.

Quarkonium in high multiplicity pp

Yanchun Ding, May 18, Room D 11:30





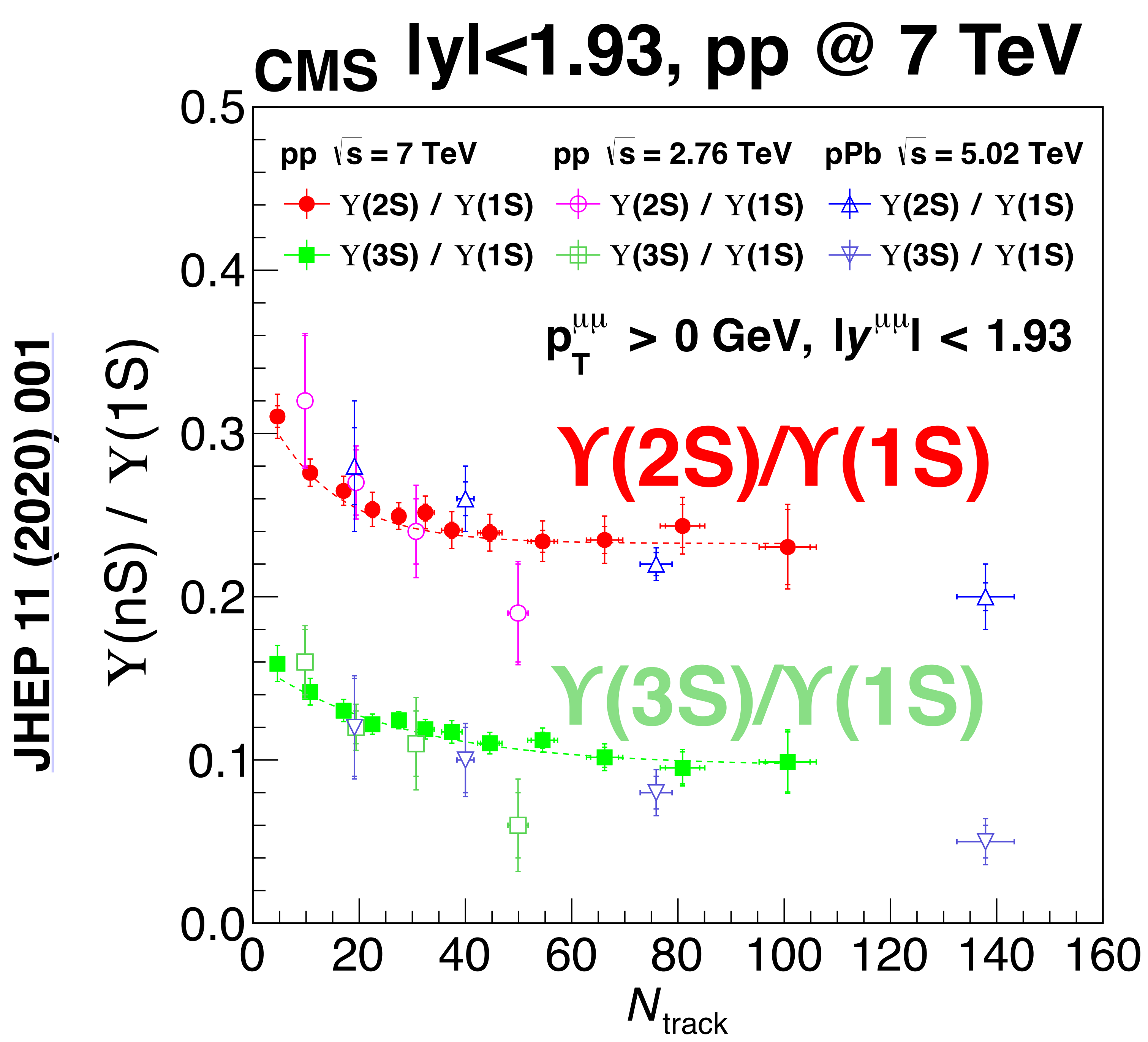
Mid rapidity

- J/Ψ yield grows faster than linear.

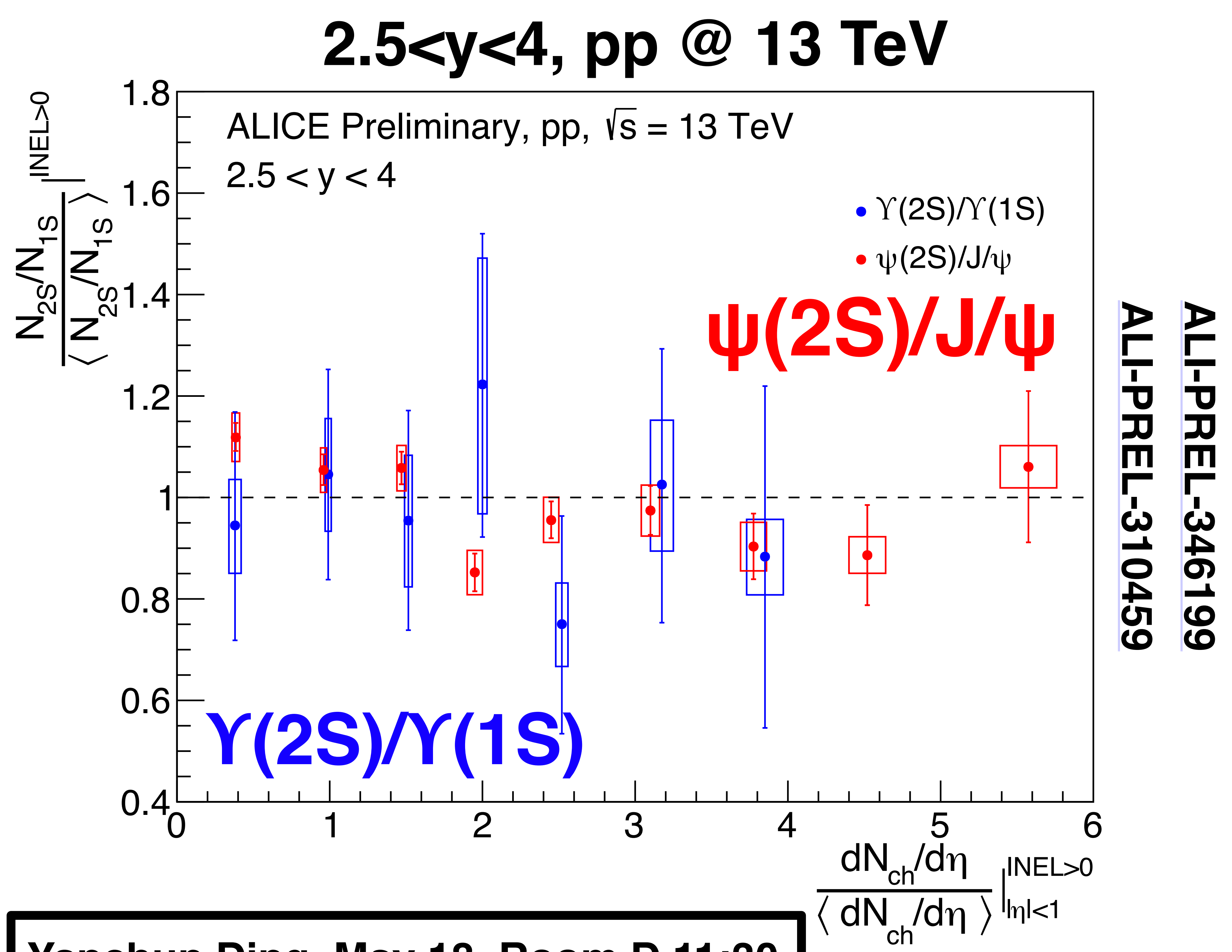
Forward rapidity

- QQ yields consistent with linear growth.

Quarkonium in high multiplicity pp



Jaebeom Park, May 20, Room D 10:50



Yanchun Ding, May 18, Room D 11:30

Mid rapidity

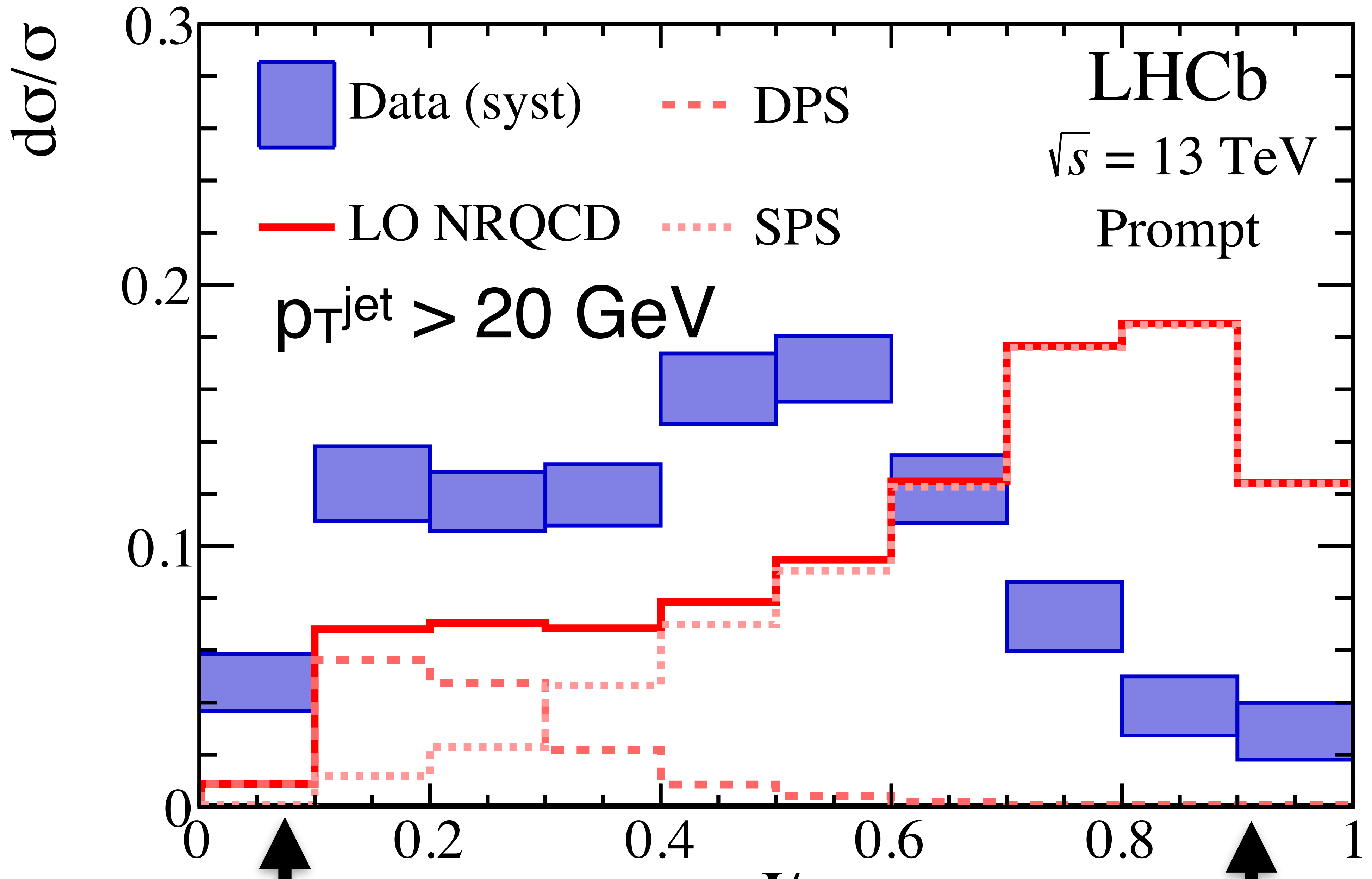
- J/Ψ yield grows faster than linear.
- Υ(nS)/Υ(1S) reduced at larger dN/dη.

Forward rapidity

- QQ yields consistent with linear growth.
- Flat 2S/1S ratios vs event activity.

J/Ψ in jets in pp

PRL 118 (2017) 19, 192001

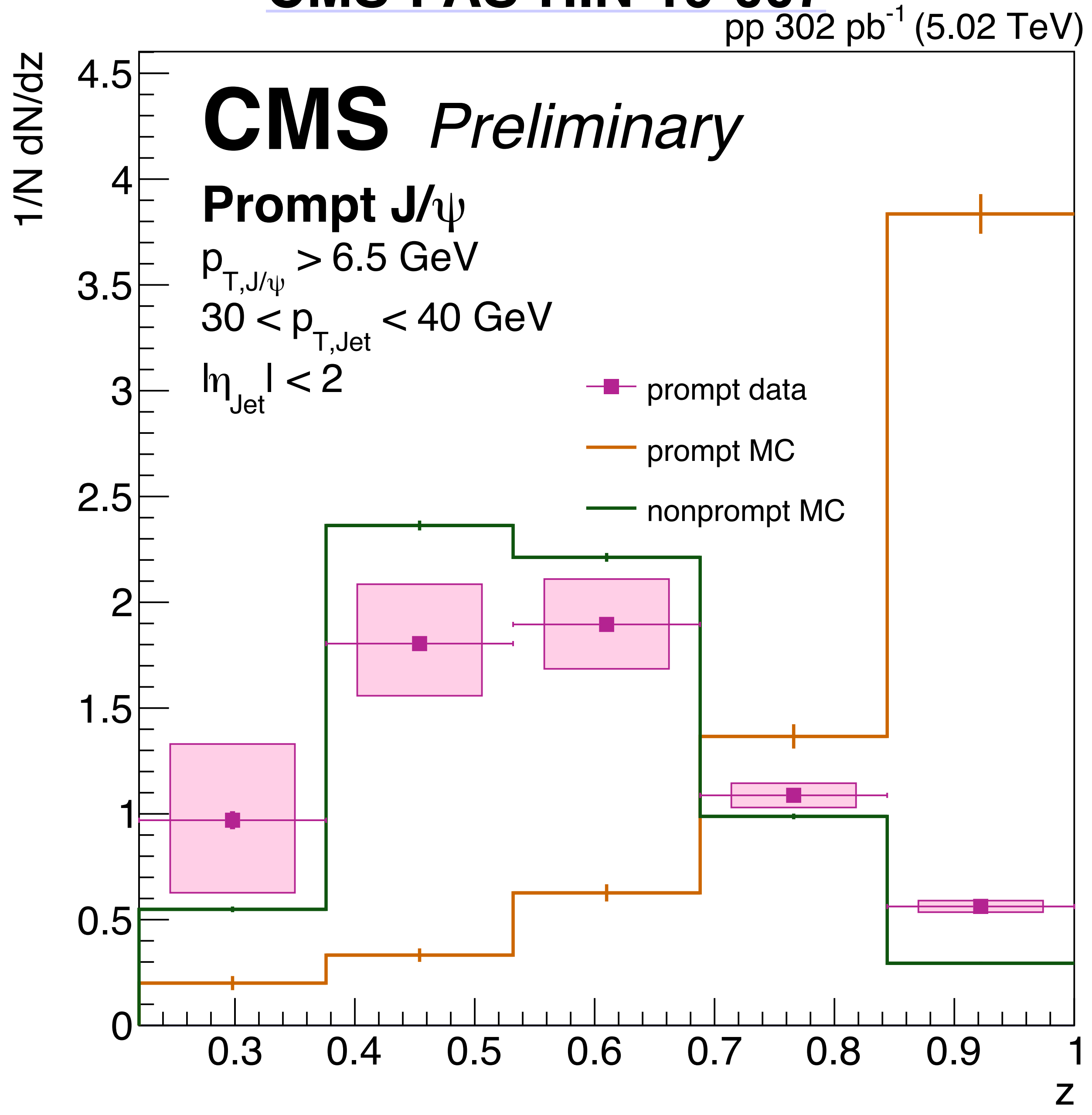


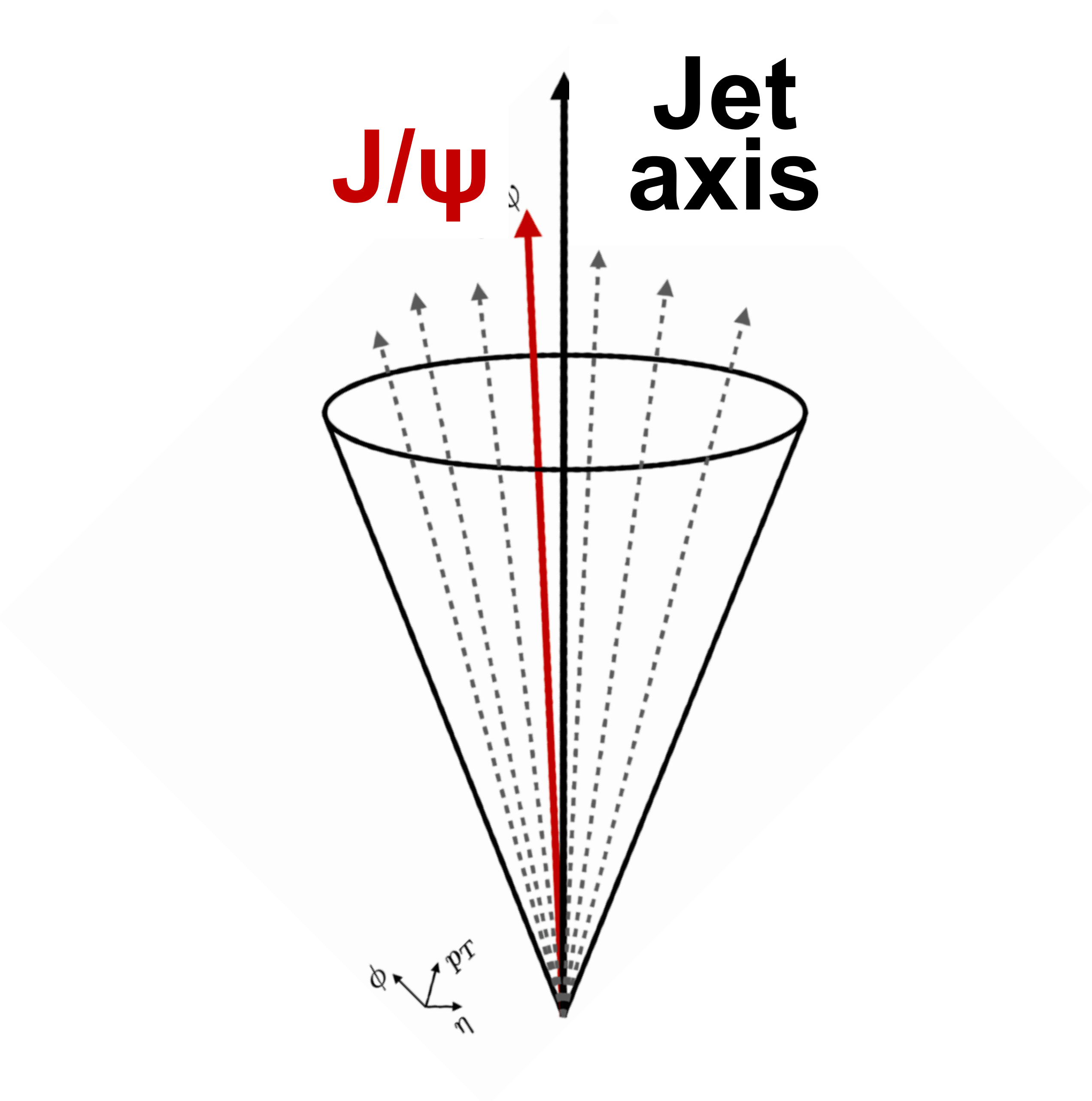
J/Ψ + large jet activity

$$z = \frac{p_T^{J/\psi}}{p_T^{jet}}$$

J/Ψ + little jet activity

CMS-PAS-HIN-19-007

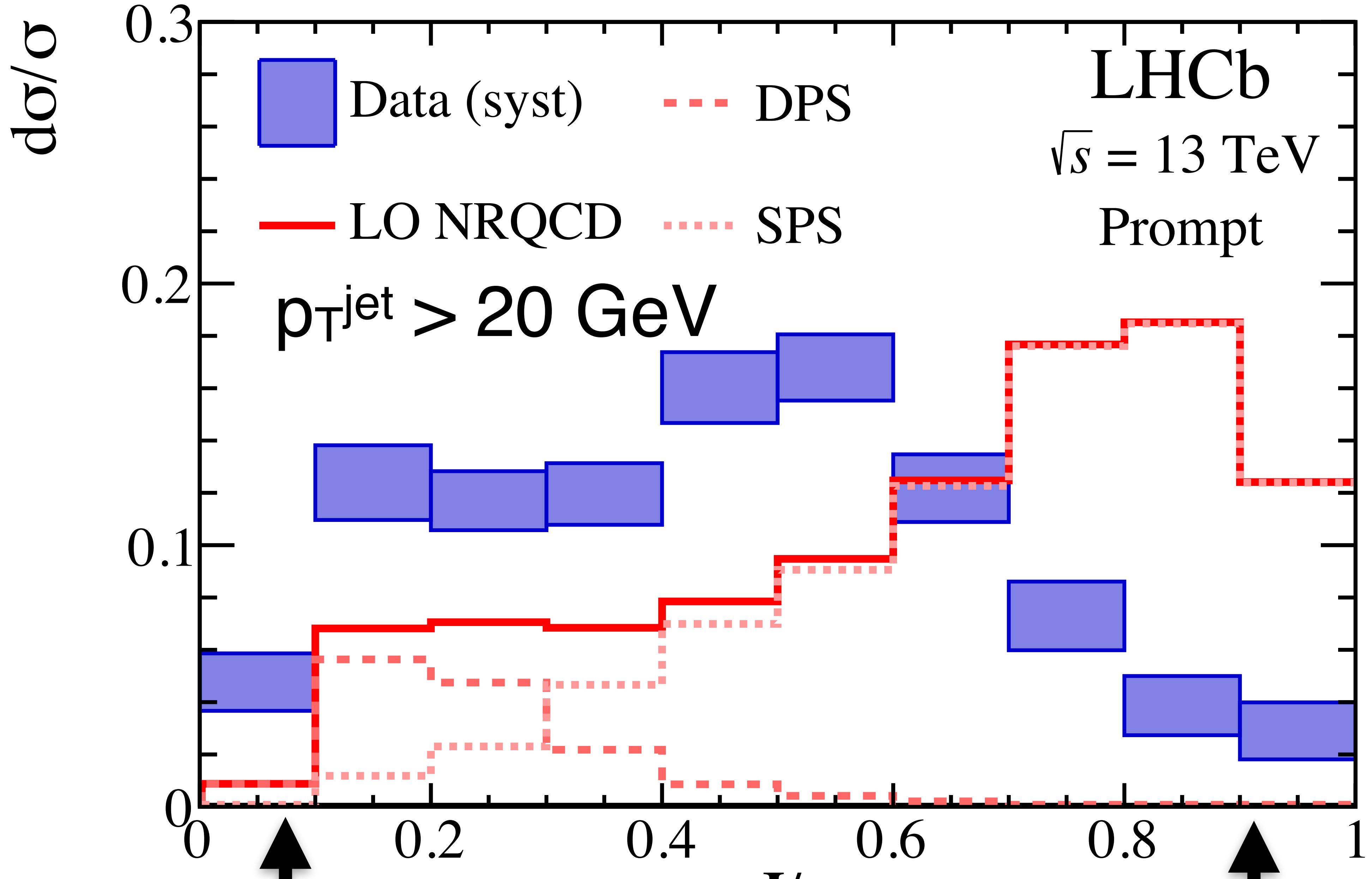




- Results at LHC show that prompt J/Ψ is less isolated than expected by LO NRQCD in PYTHIA.

J/Ψ in jets in pp

PRL 118 (2017) 19, 192001

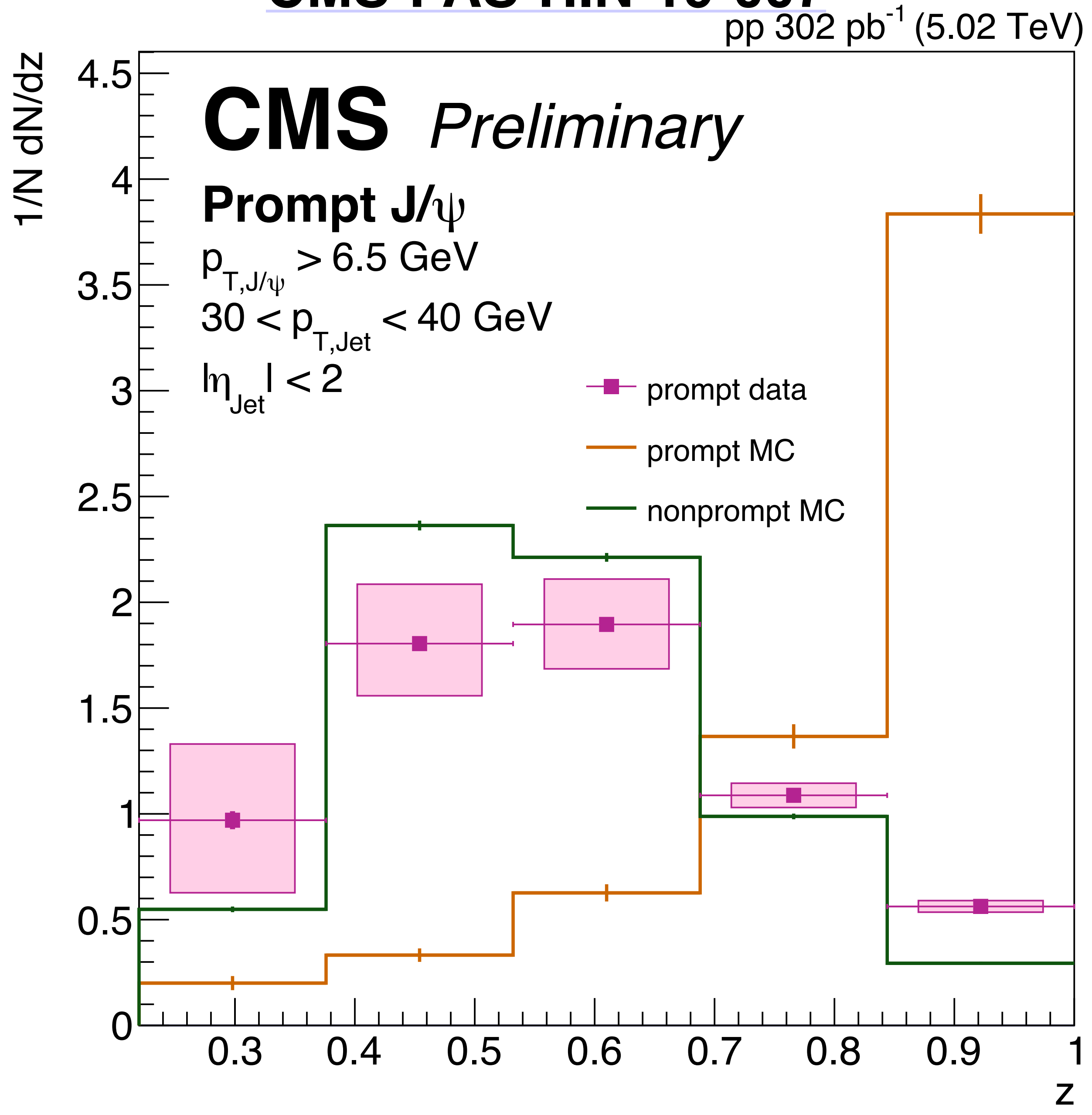


J/Ψ + large jet activity

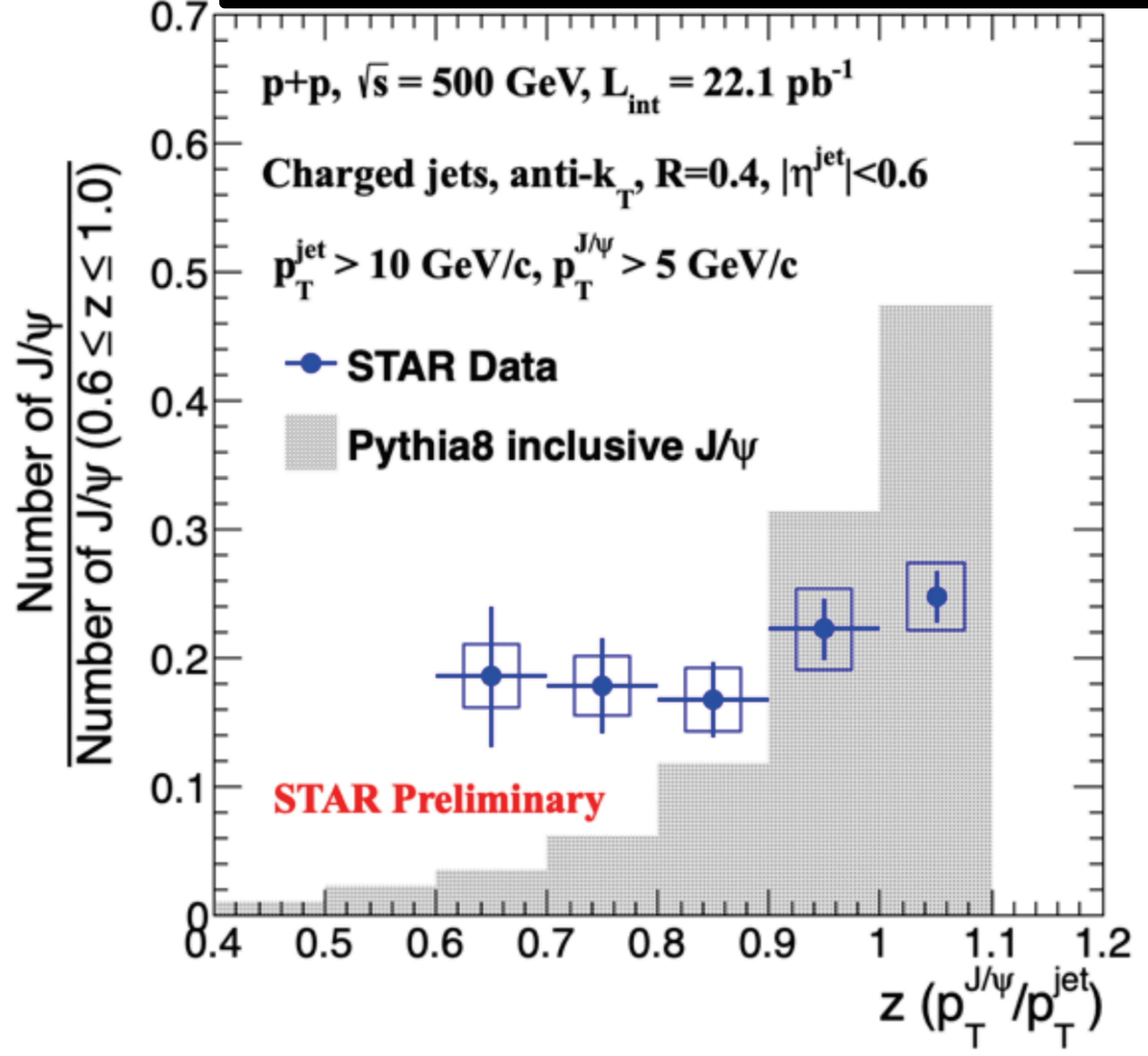
$$z = \frac{p_T^{J/\psi}}{p_T^{jet}}$$

J/Ψ + little jet activity

CMS-PAS-HIN-19-007



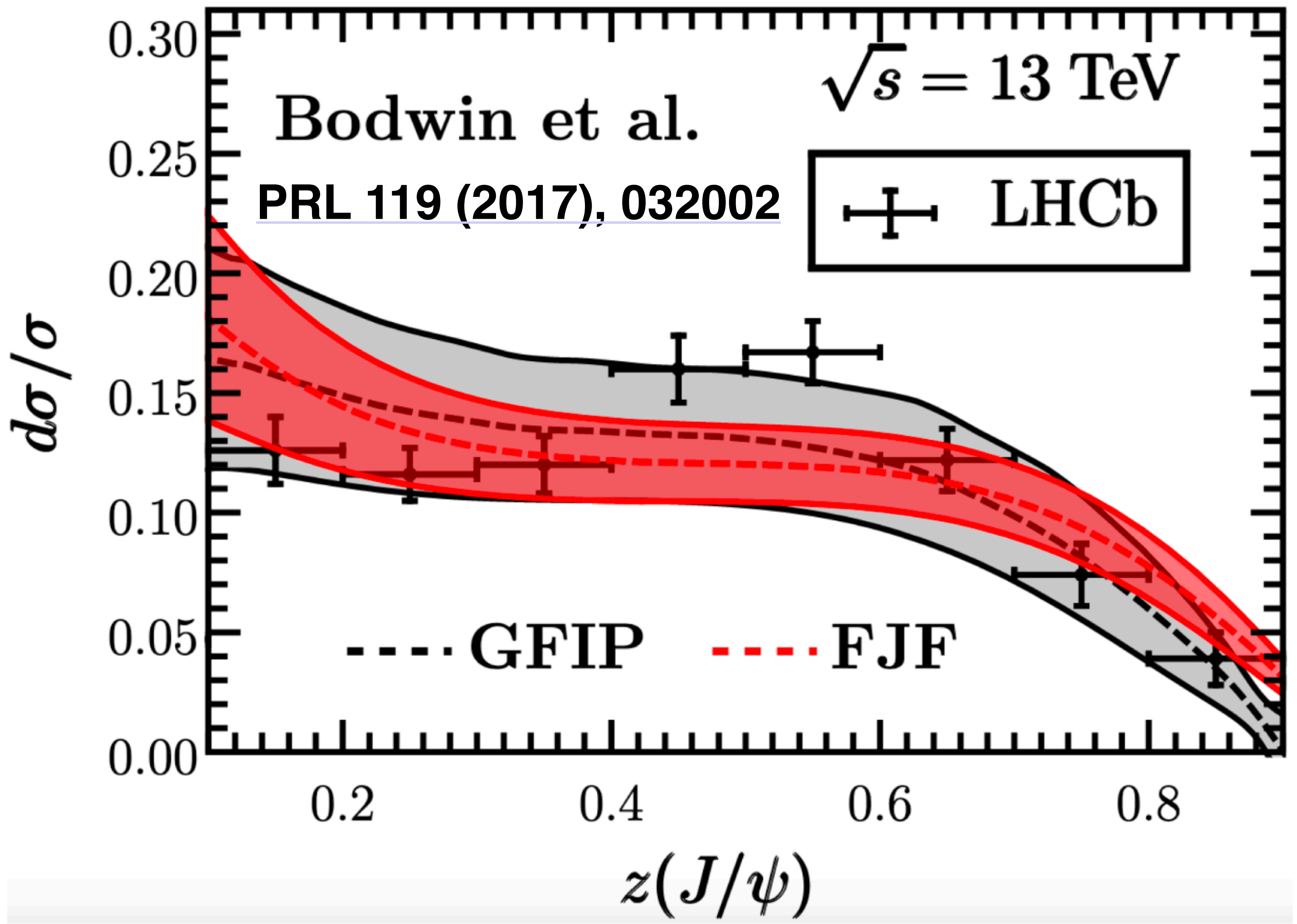
Kaifeng Shen, May 21, Room D 10:10



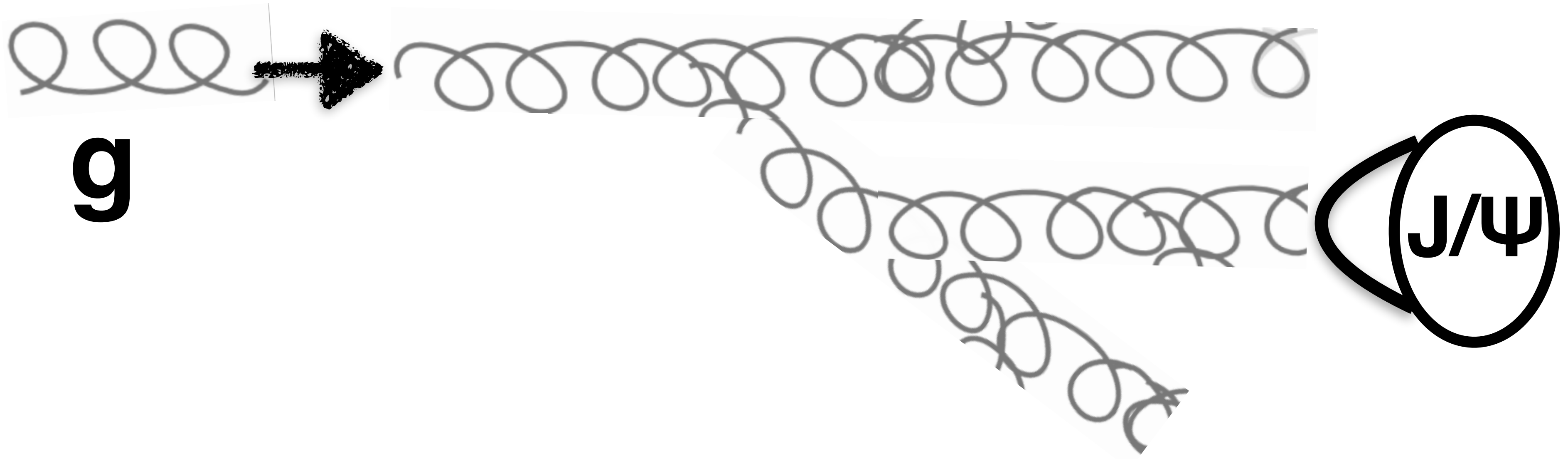
- Results at LHC show that prompt J/Ψ is less isolated than expected by LO NRQCD in PYTHIA.
- New measurements from STAR also see more jet activity with no z-dependence.

J/Ψ in jets in pp

- Parton-parton scattering not enough to describe J/Ψ production in pp.

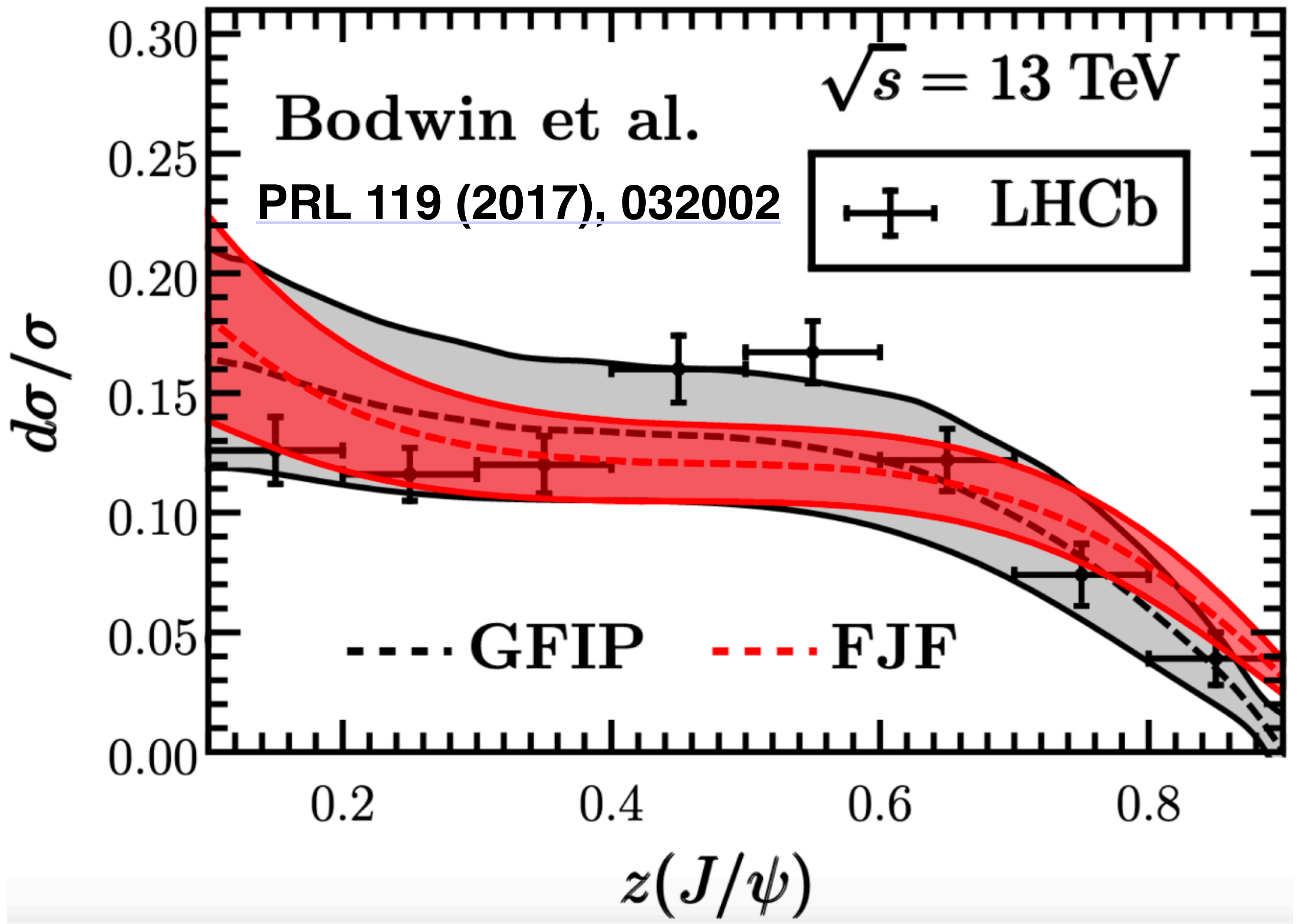


- Model including J/Ψ produced in parton showers successfully describe LHCb data.

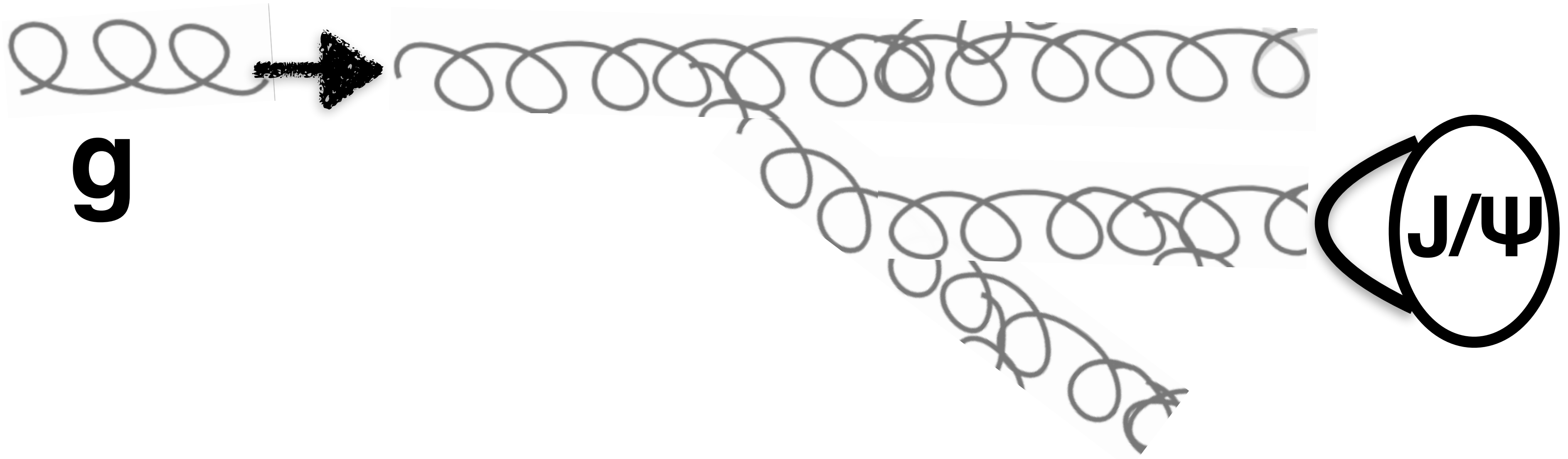


J/Ψ in jets in pp

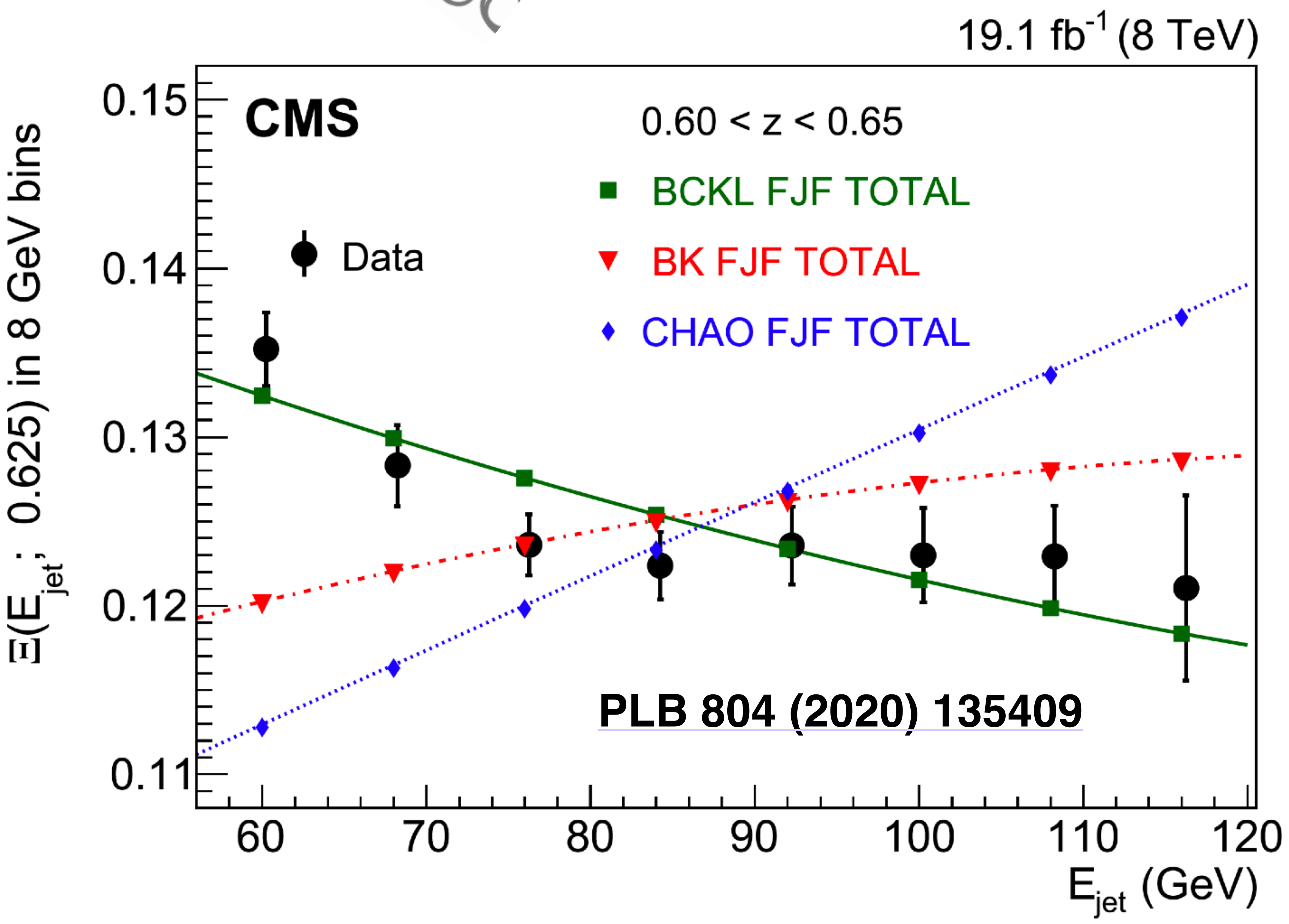
- Parton-parton scattering not enough to describe J/Ψ production in pp.



- Model including J/Ψ produced in parton showers successfully describe LHCb data.



- Recent CMS results of J/Ψ in jets vs jet energy is also described by gluon jet fragmentation model.
- CMS data sensitive to LMDE parametrisation:
  - Favours LMDE set of Bodwin et al.



Take-home note: Quarkonium production

✓J/Ψ polarization:

➡ $\lambda_\theta \sim 0$ up $p_T \sim 60$ GeV at LHC.

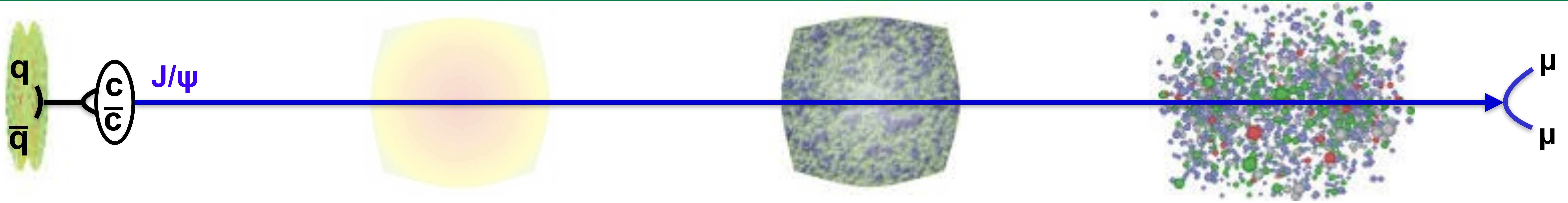
➡ Hint of $\lambda_\theta < 0$ at forward rapidity at RHIC.

✓Event activity dependence:

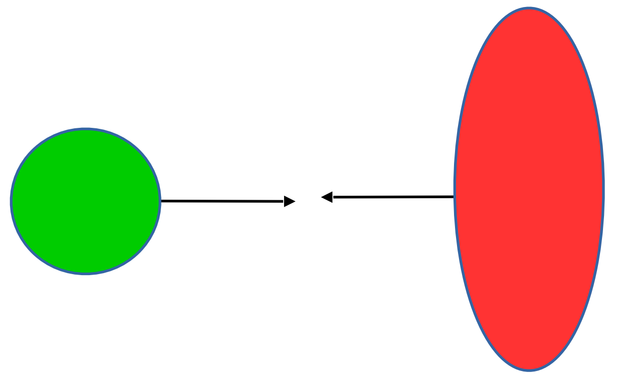
- QQ(nS)/QQ(1S) ~ flat at forward y.
- ϒ(nS)/ϒ(1S) suppressed at mid-y.

✓J/Ψ formed in parton showers crucial to describe production in jets.

OUTLINE



- $Q\bar{Q}$ production mechanism:
  - Polarization in pp
  - Production in pp



- **Probing cold nuclear effects:**
  - $Q\bar{Q}$ **production in pA**

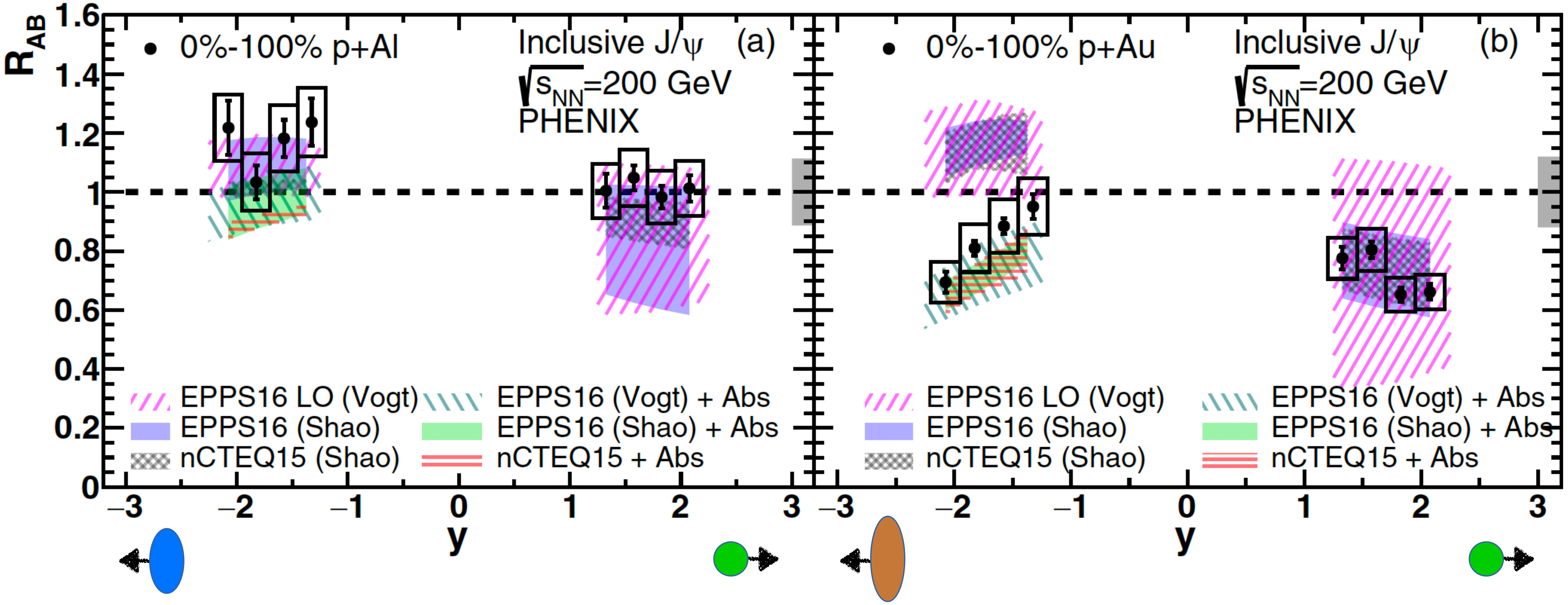
- Probing QGP effects:
  - $Q\bar{Q}$ polarization in AA
  - $Q\bar{Q}$ production in AA

- Exotic quarkonium states

J/Ψ production in pX @ 200 GeV

Murad Sarsour, May 21, Room D 10:30

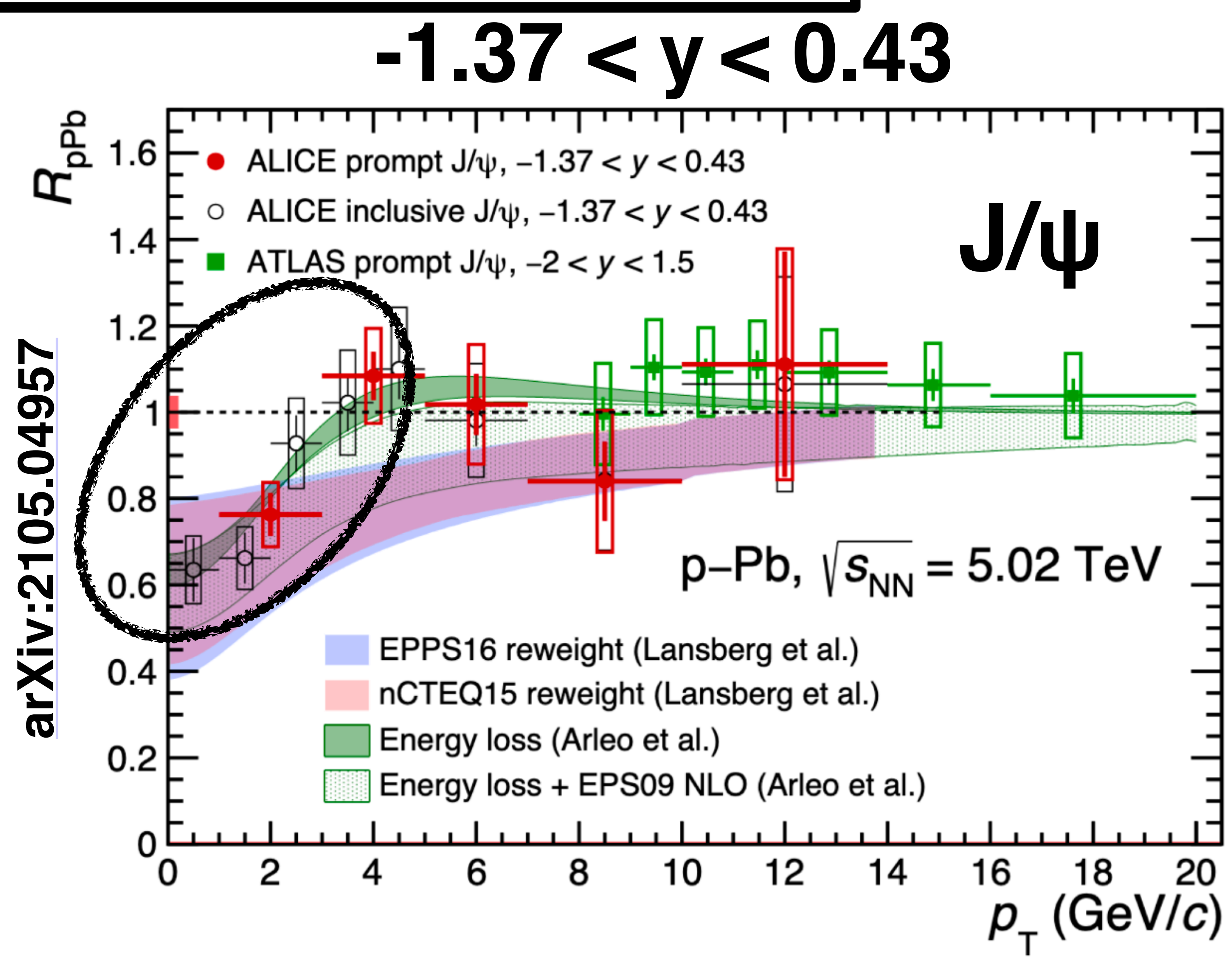
PRC 102 (2020) 1, 014902



- Significant suppression seen at forward rapidity for p+Au compared to p+Al → Al smaller target size.
- nPDF model calculations describe forward rapidity.
- Nuclear absorption effect needed to explain results at backward rapidity in p+Au.

Ψ(nS) production in pPb

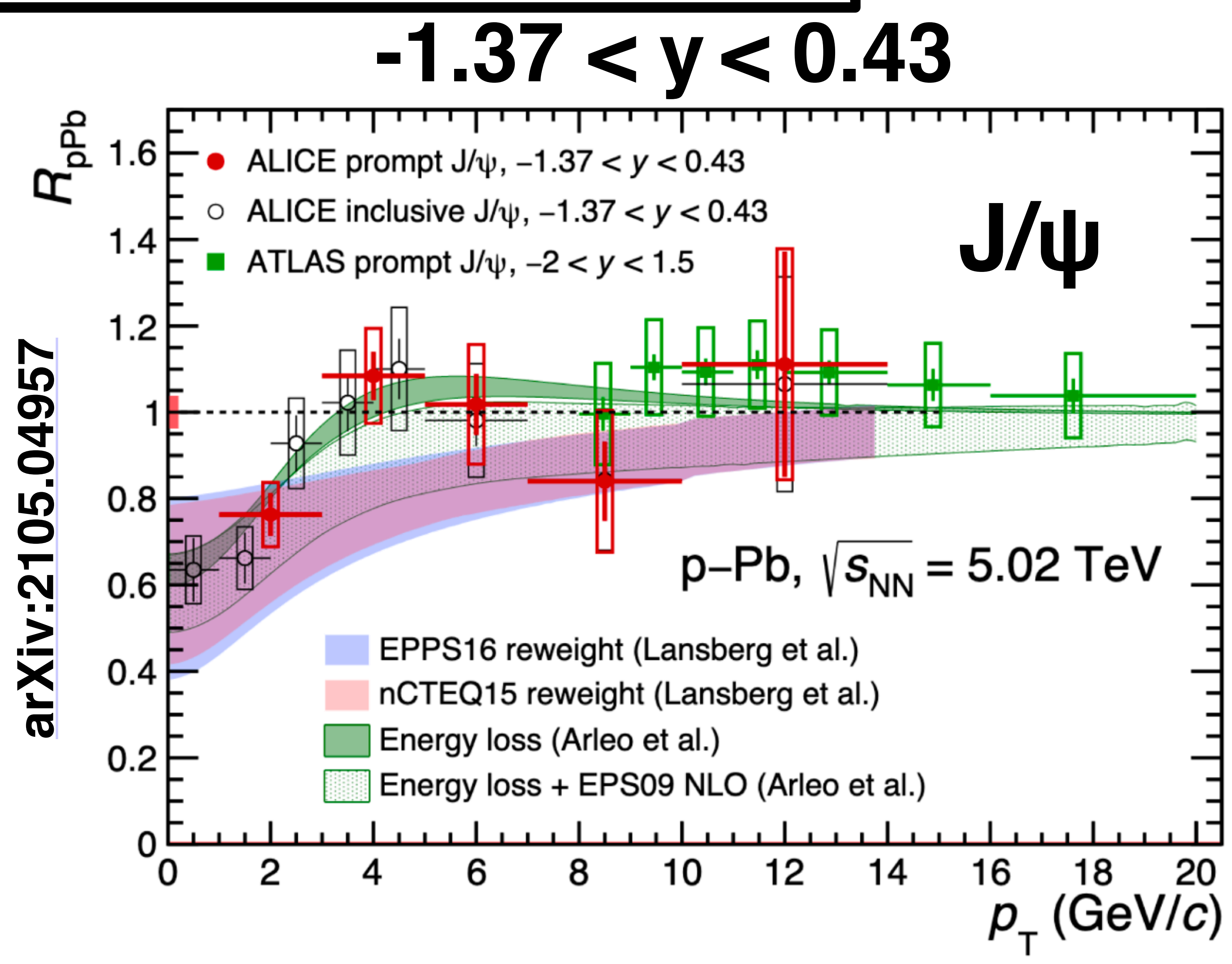
Yanchun Ding, May 18, Room D 11:30

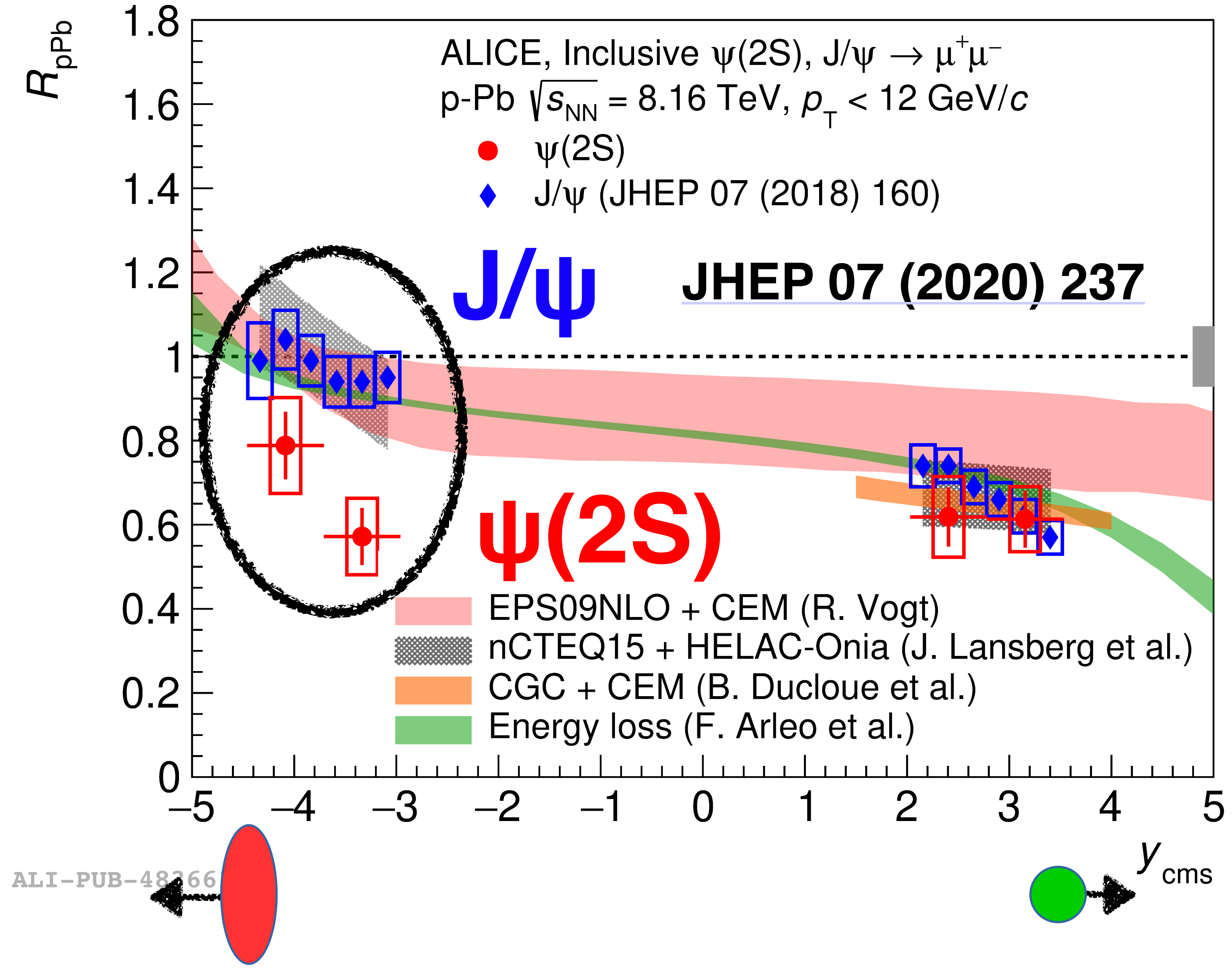


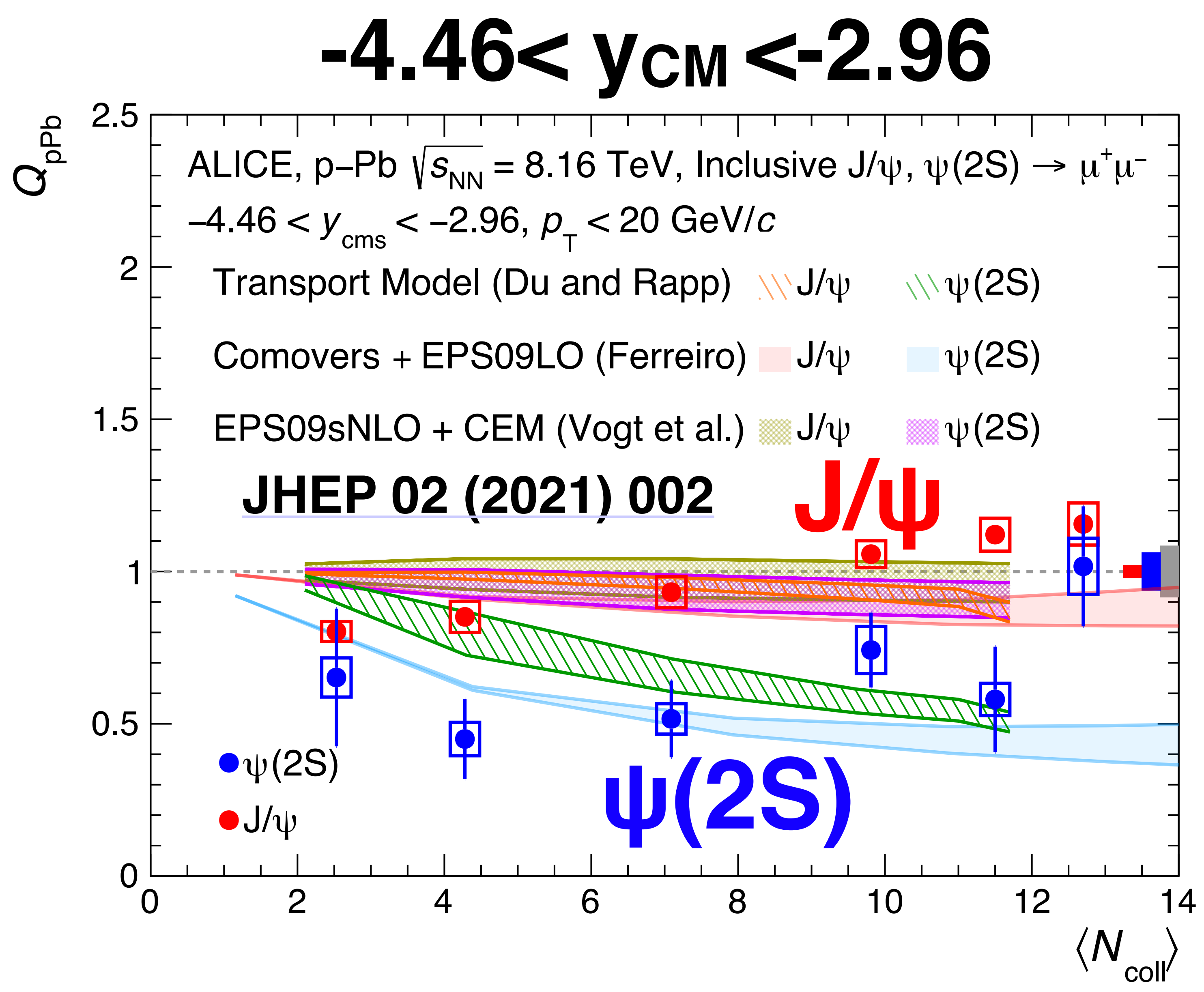
- J/Ψ production suppressed at $p_T < 3$ GeV in mid rapidity.
  - Energy loss model captures p_T dependence of J/Ψ R_{pPb}.

Ψ(nS) production in pPb

Yanchun Ding, May 18, Room D 11:30



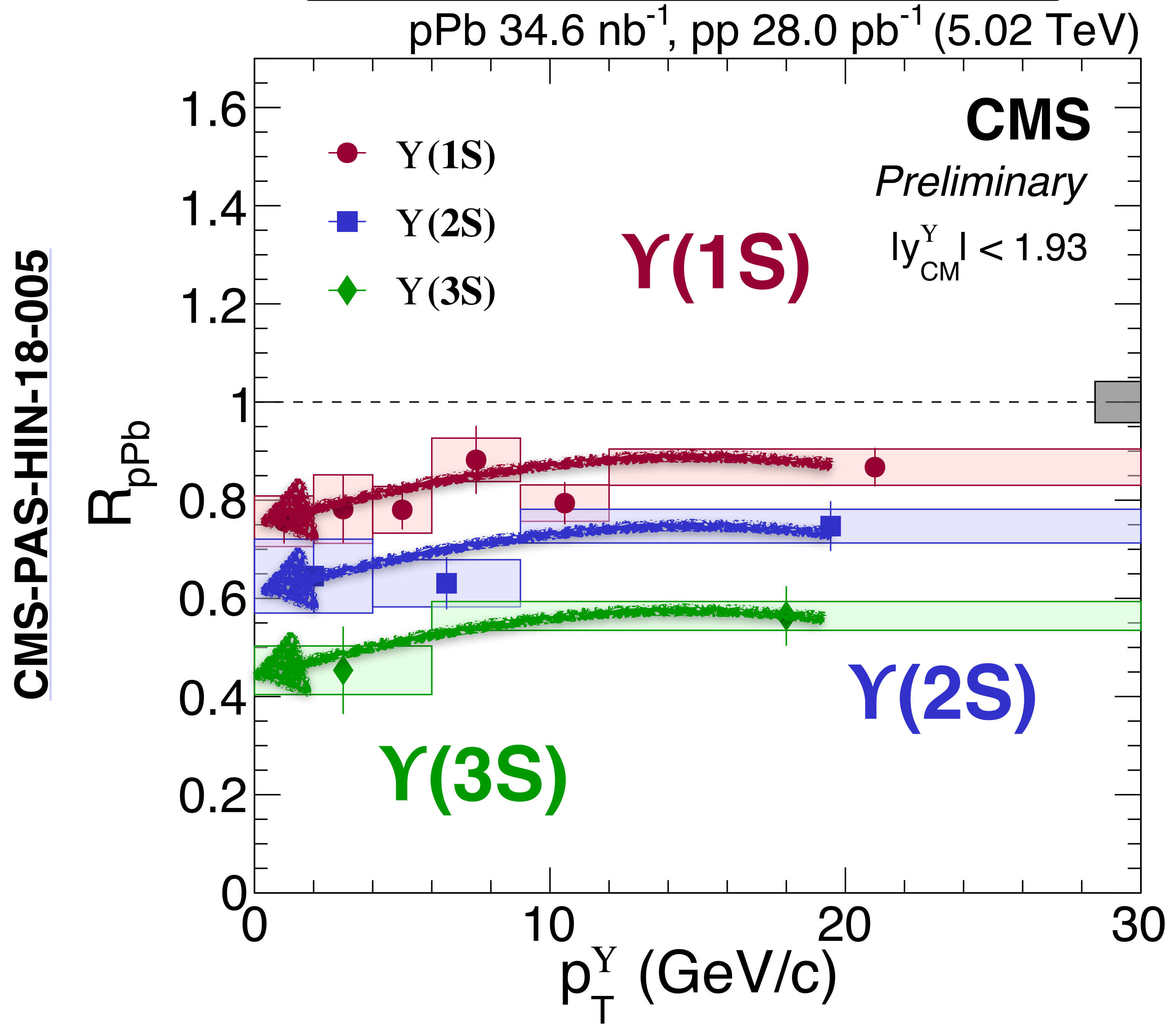




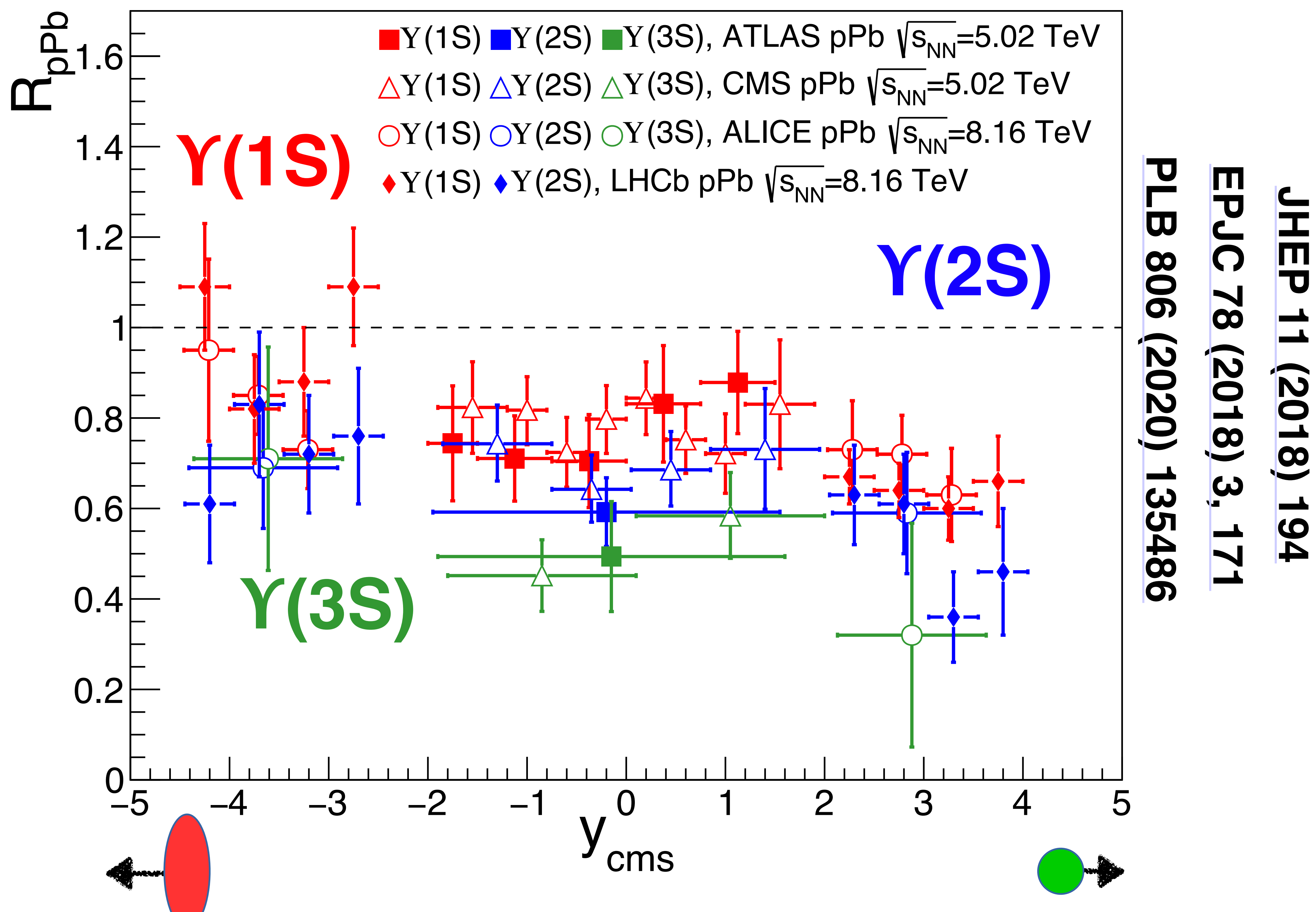
- J/Ψ production suppressed at $p_T < 3$ GeV in mid rapidity.
  - Energy loss model captures p_T dependence of J/Ψ R_{pPb}.
- Ψ(2S) R_{pPb} < J/Ψ R_{pPb} in Pb-going side (backward rapidity).
  - Final state comover model describe the trend of Ψ(nS) production in pPb.

ϒ(nS) production in pPb

Jaebeom Park, May 20, HF 10:50



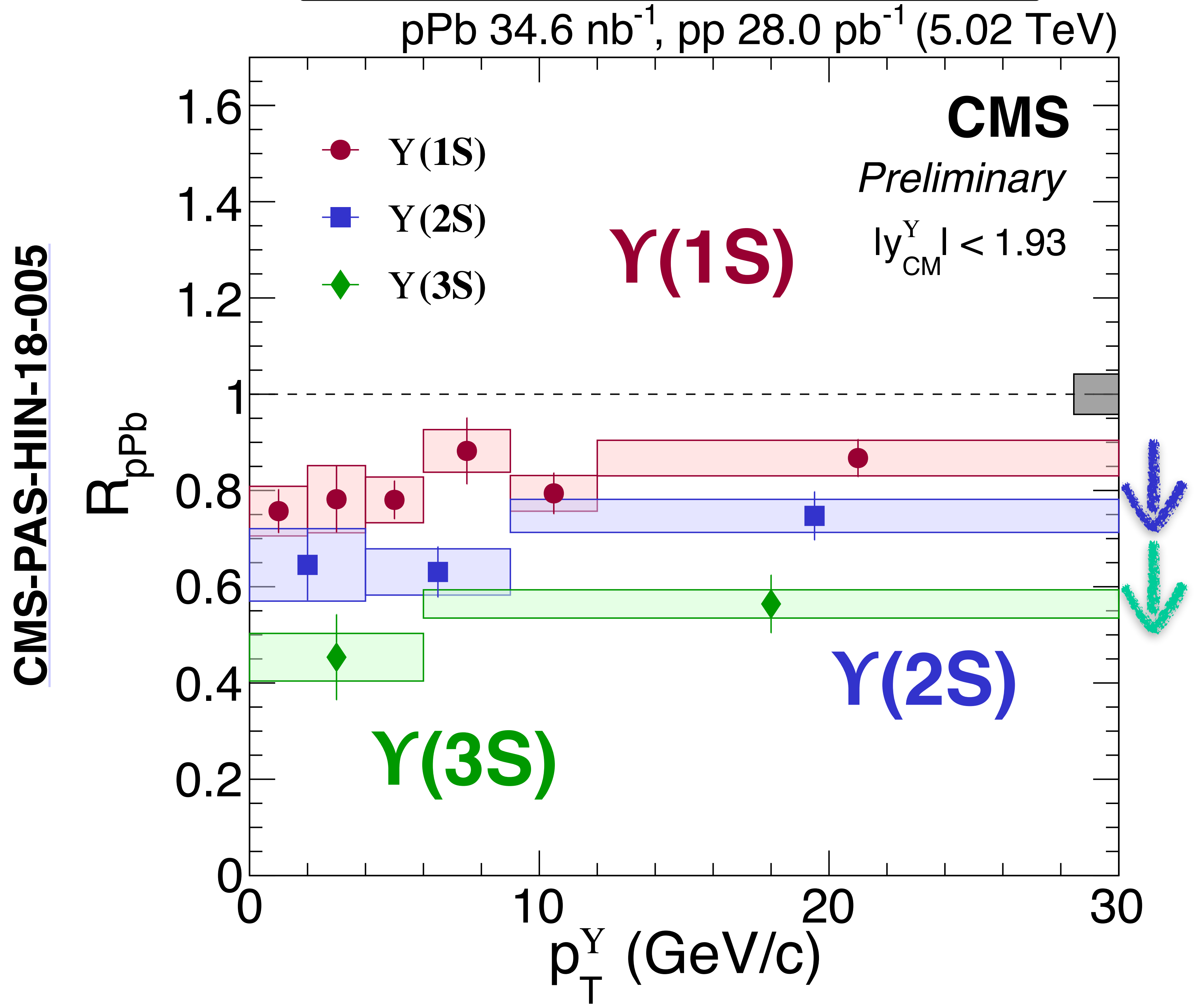
Yanchun Ding, May 18, Room D 11:30



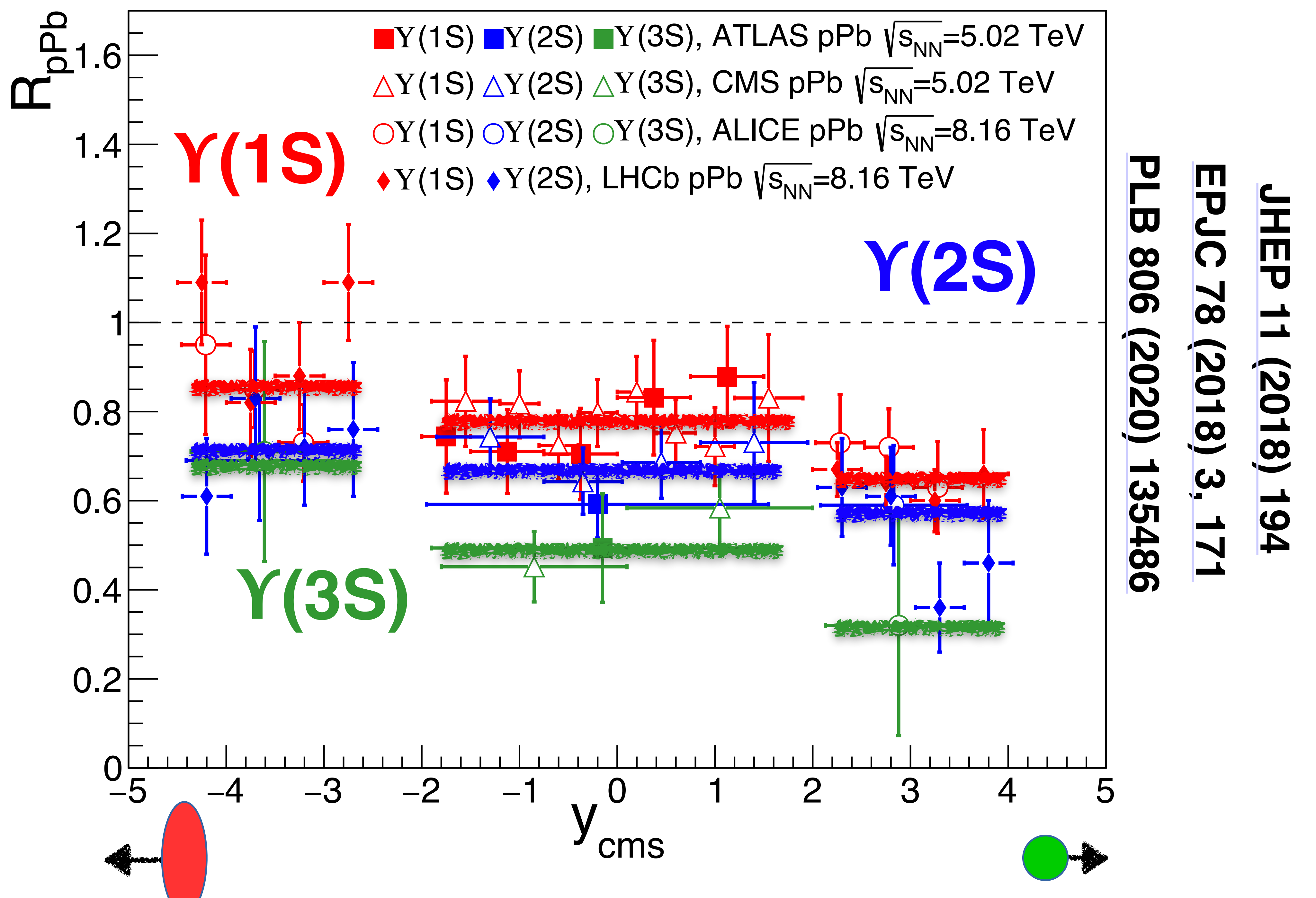
- Hint of stronger ϒ(nS) suppression towards low p_T.

ϒ(nS) production in pPb

Jaebeom Park, May 20, HF 10:50



Yanchun Ding, May 18, Room D 11:30

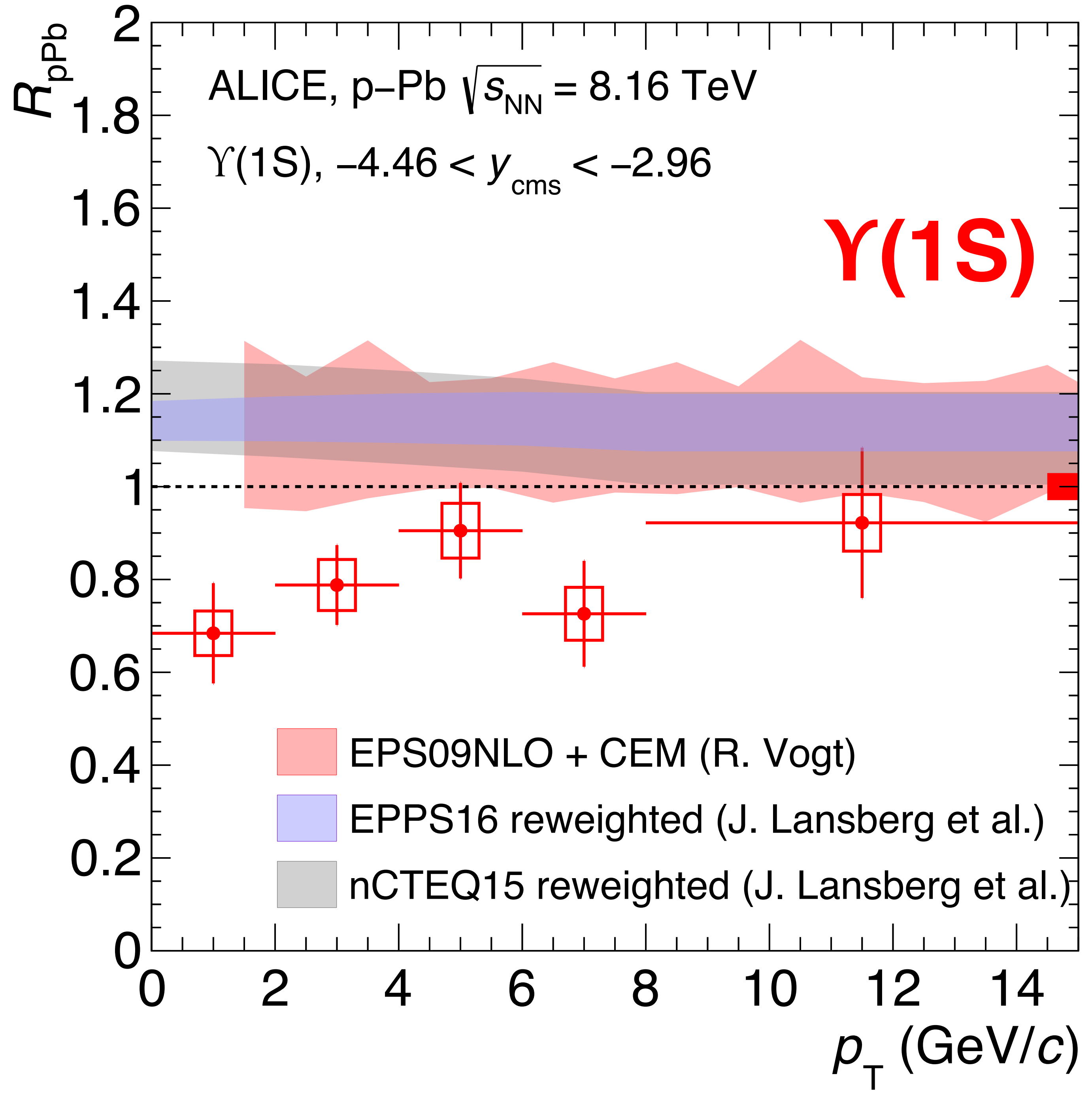


- Hint of stronger ϒ(nS) suppression towards low p_T.
- ϒ(1S) R_{pPb} > ϒ(2S) R_{pPb} > ϒ(3S) R_{pPb} → sequential suppression of bottomonium states

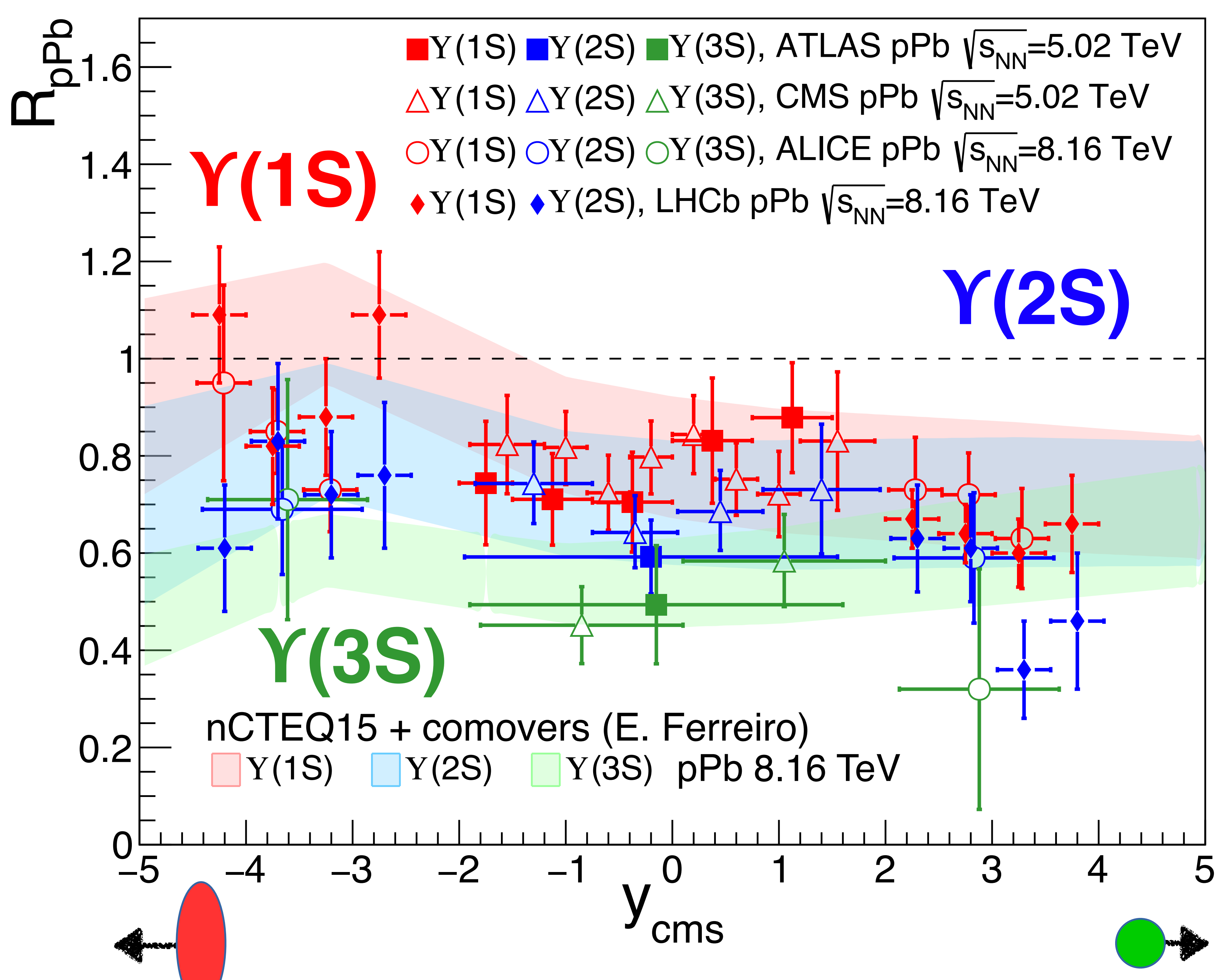
Υ(nS) production in pPb

Yanchun Ding, May 18, Room D 11:30

PLB 806 (2020) 135486



Yanchun Ding, May 18, Room D 11:30

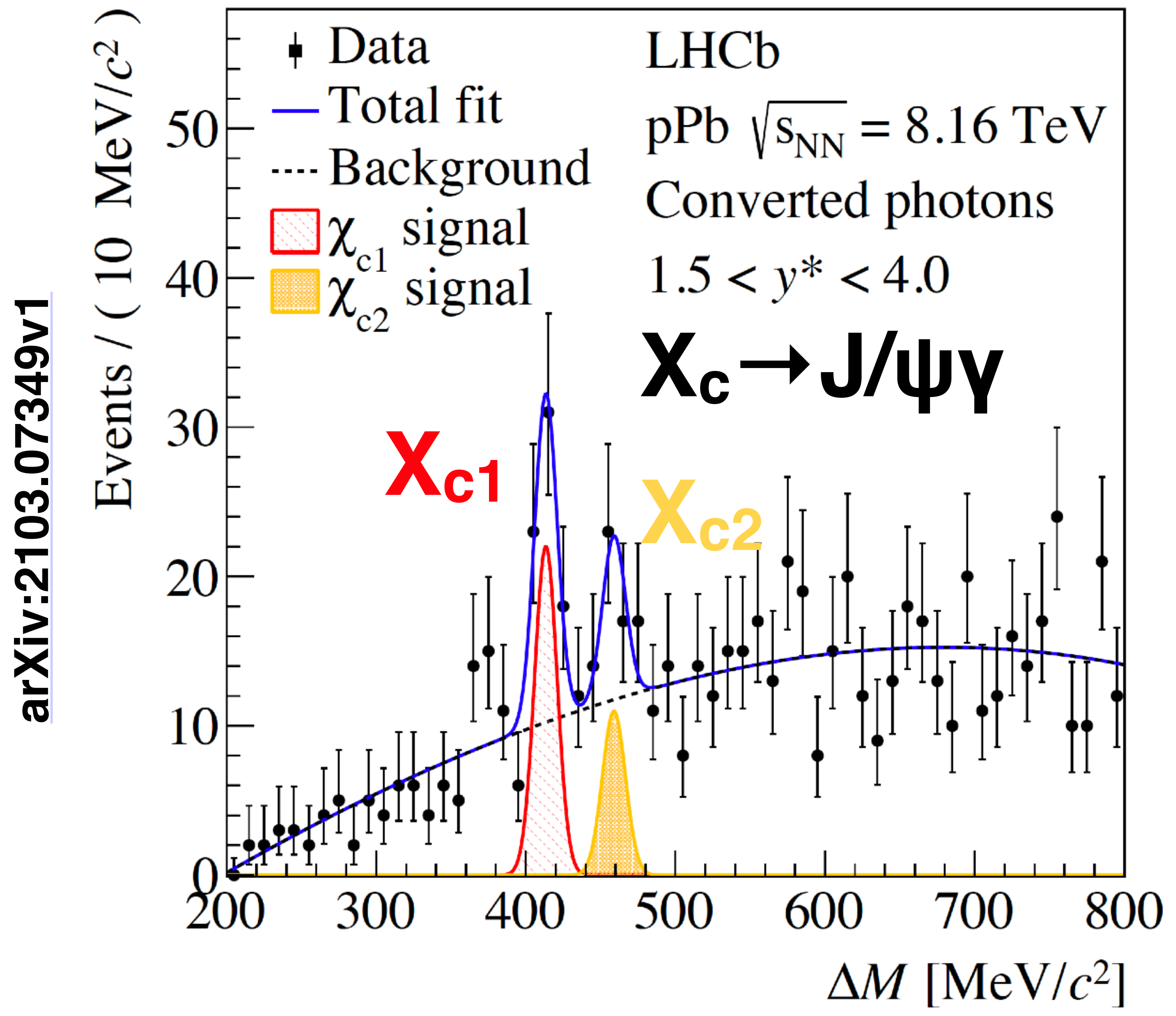


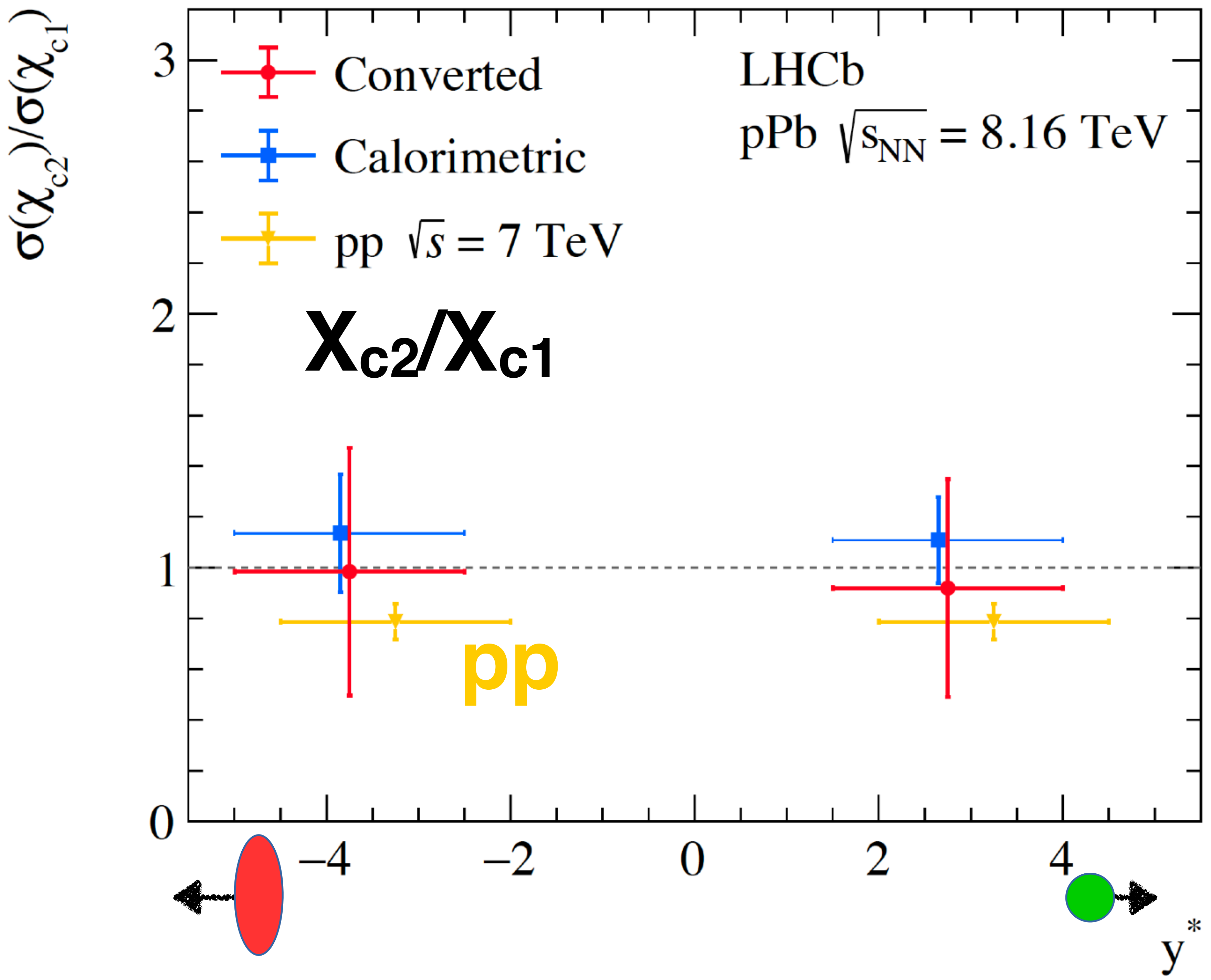
PLB 806 (2020) 135486
EPJC 78 (2018) 3, 171
JHEP 11 (2018) 194

- Hint of stronger Υ(nS) suppression towards low p_T.
- **Υ(1S) R_{pPb}** > **Υ(2S) R_{pPb}** > **Υ(3S) R_{pPb}** → sequential suppression of bottomonium states
- nPDF models overestimate Υ(1S) R_{pPb} at backward rapidities.
- Comover + nPDF model predicts the suppression trend of Υ(nS) production in pPb.

X_c production in pPb

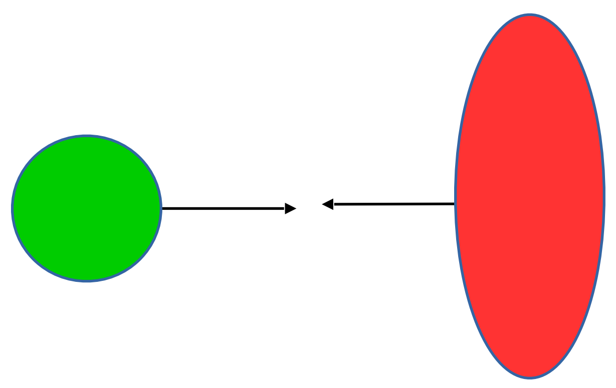
Jiayin Sun, May 17, Plenary 11:30





- First measurement of X_{c1} and X_{c2} in HI collisions at LHC.
- Prompt X_{c1}/X_{c2} ratio in pPb consistent with unity and pp within uncertainties.

Take-home note: Quarkonia in pA



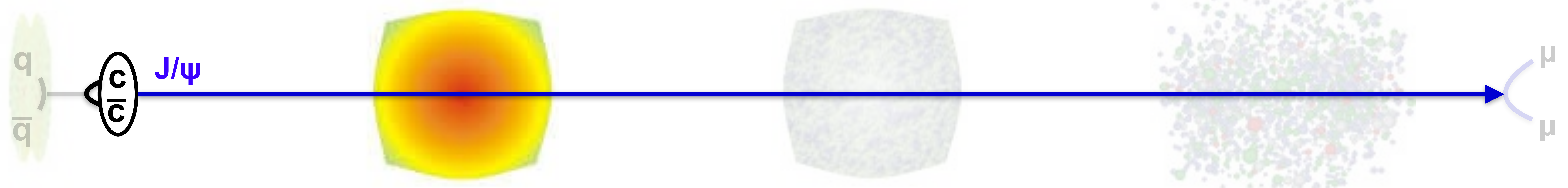
✓nPDF effects not enough to describe R_{pPb} in backward y at both RHIC and LHC.

✓Sequential suppression of $Q\bar{Q}$ states in pA.

➡ **Υ(1S) R_{pPb}** > **Υ(2S) R_{pPb}** > **Υ(3S) R_{pPb}**

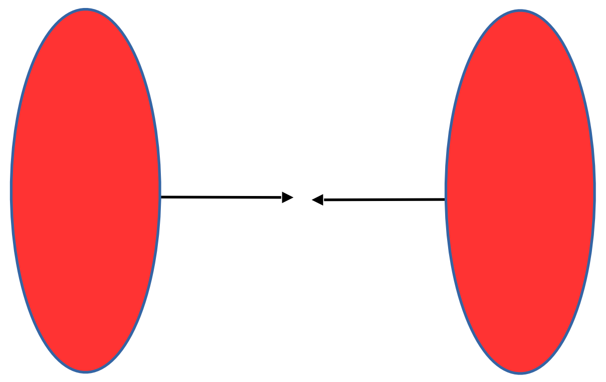
✓ New $Q\bar{Q}$ states been explored in pA: X_c.

OUTLINE



- $Q\bar{Q}$ production mechanism:
  - Polarization in pp
  - Production in pp

- Probing cold nuclear effects:
  - $Q\bar{Q}$ production in pA



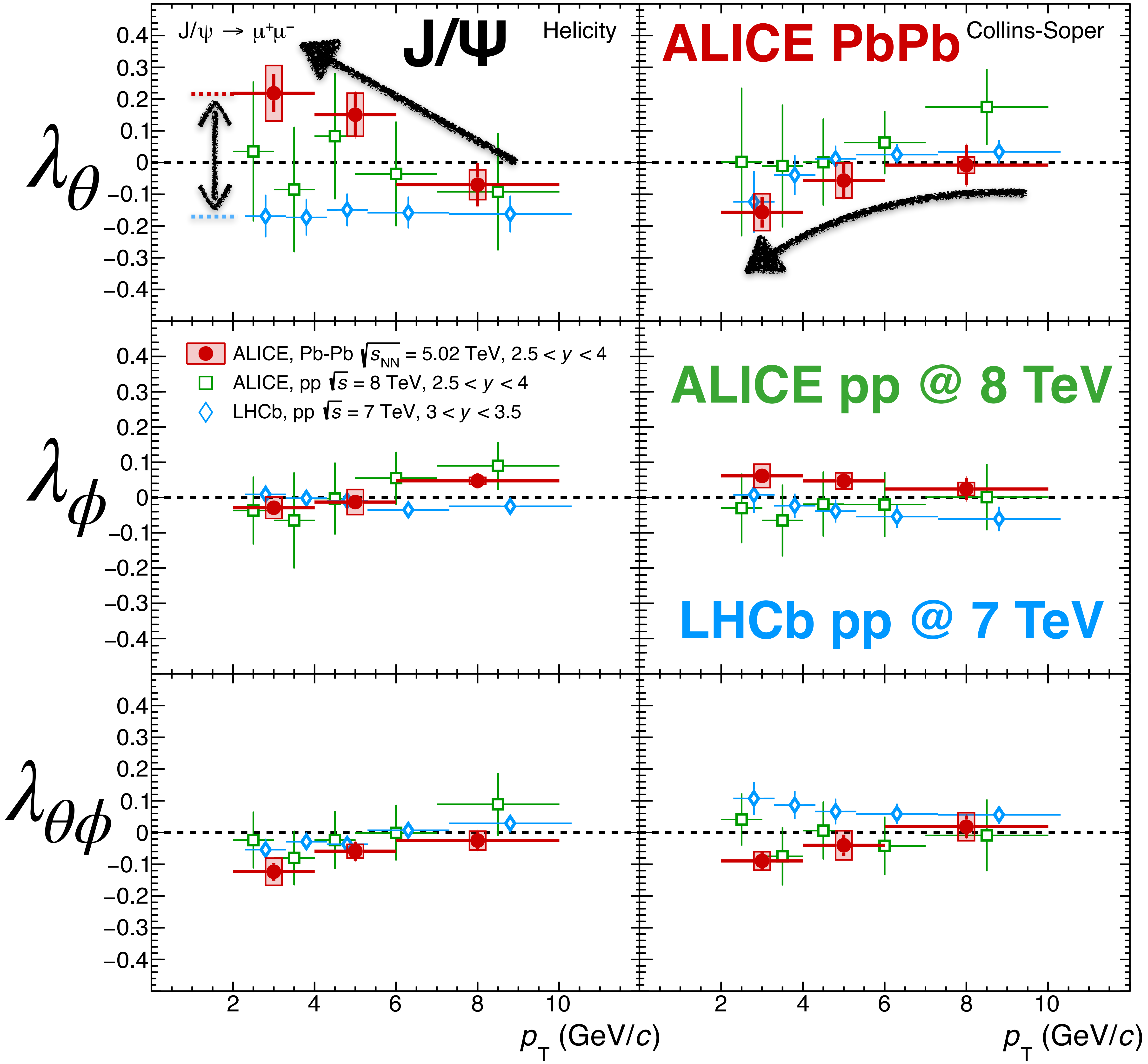
- **Probing QGP effects:**
  - **$Q\bar{Q}$ polarization in AA**
  - $Q\bar{Q}$ production in AA

- Exotic quarkonium states

Quarkonium polarization in PbPb

Ingrid Lofnes, May 21, Room D 09:50

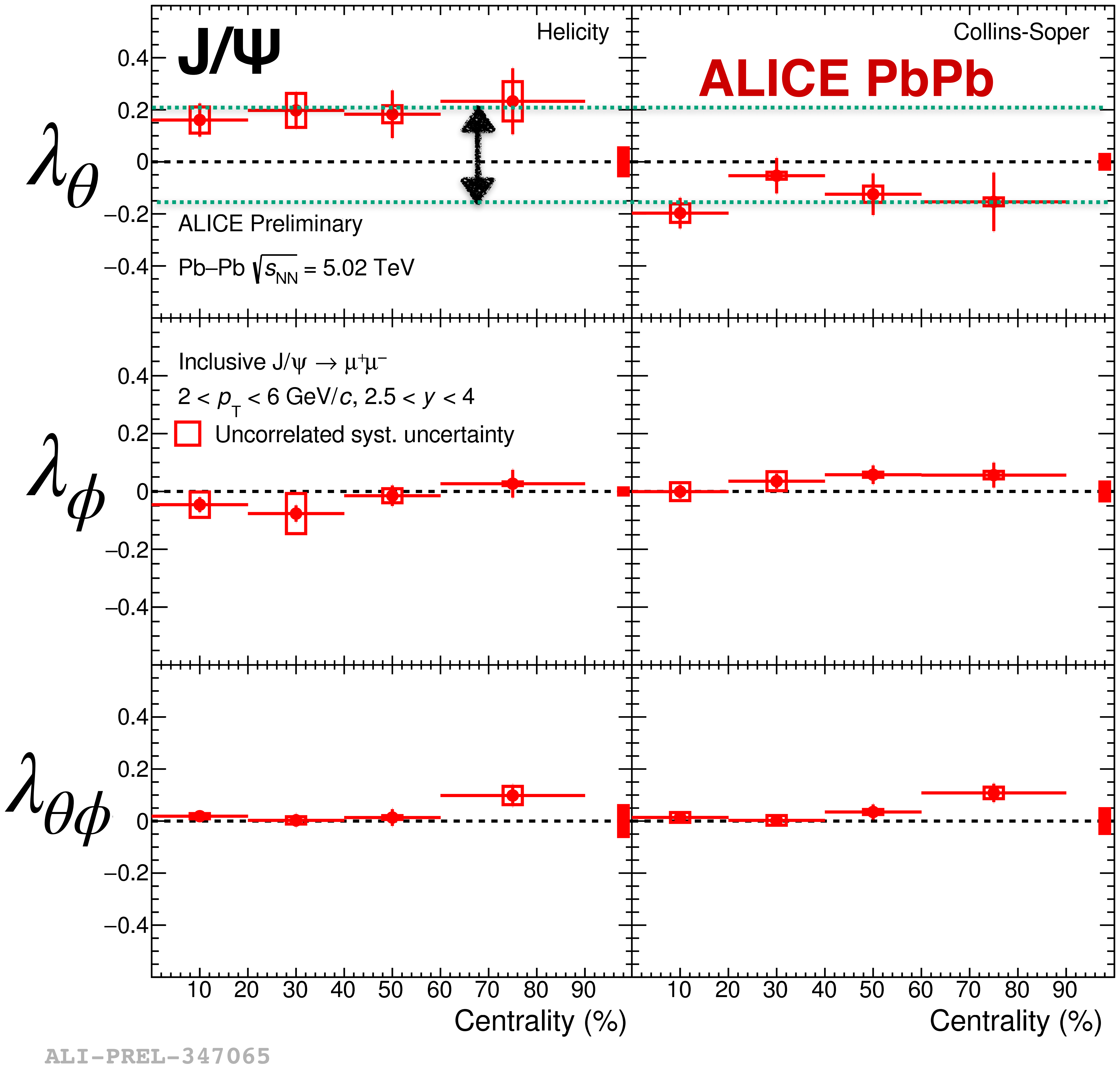
PLB 815 (2021) 136146



- J/Ψ polarization in PbPb:
  - Polarization parameters close to zero.
  - Hint of J/Ψ polarization towards low p_T.
  - Tension with pp LHCb λ_θ at low p_T in HX frame.

Quarkonium polarization in PbPb

Ingrid Lofnes, May 21, Room D 09:50

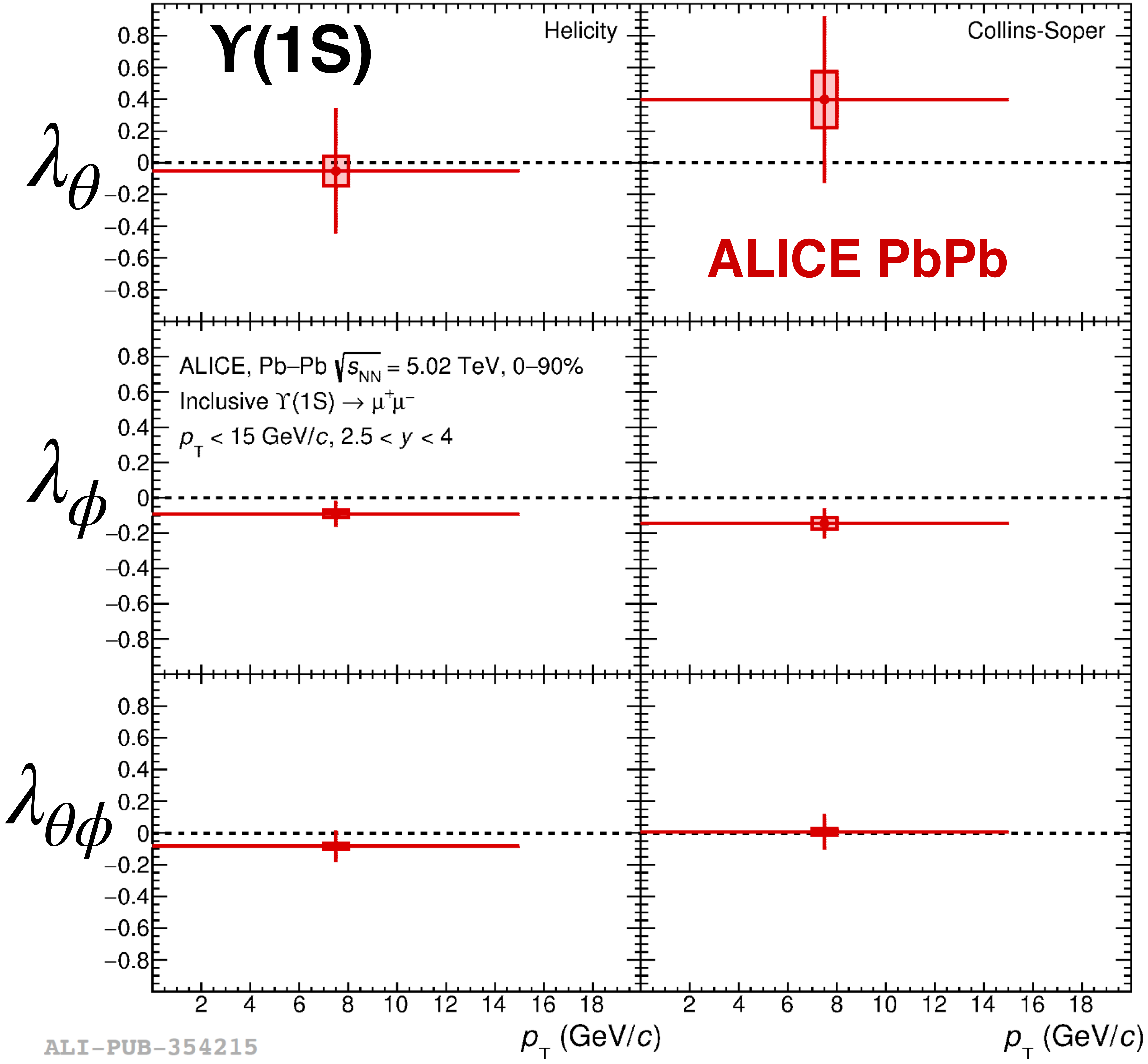


- J/Ψ polarization in PbPb:
  - Polarization parameters close to zero.
  - Hint of J/Ψ polarization towards low p_T.
  - Tension with pp LHCb λ_θ at low p_T in HX frame.
  - No significant centrality dependence.
  - Differences between reference frames.

Quarkonium polarization in PbPb

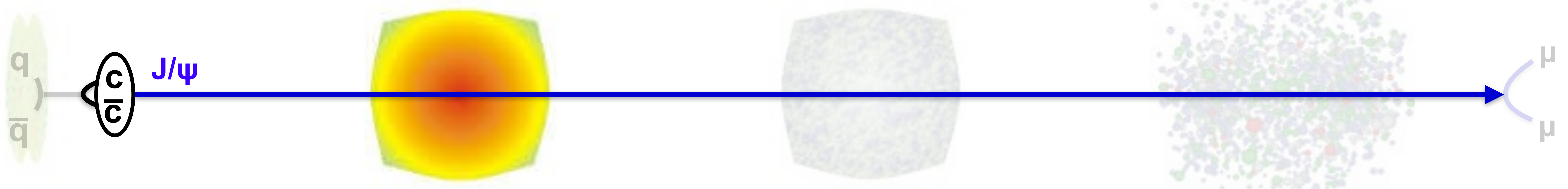
Ingrid Lofnes, May 21, Room D 09:50

PLB 815 (2021) 136146



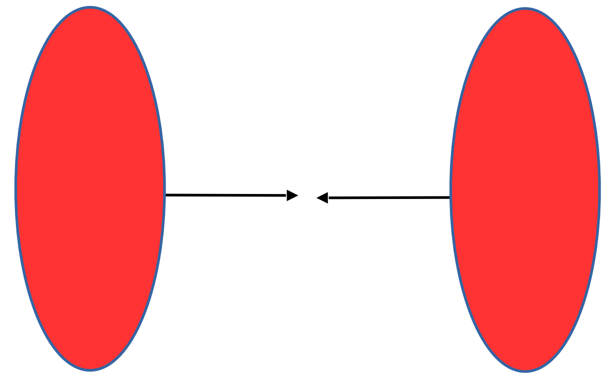
- J/Ψ polarization in PbPb:
  - Polarization parameters close to zero.
  - Hint of J/Ψ polarization towards low p_T.
  - Tension with pp LHCb λ_θ at low p_T in HX frame.
  - No significant centrality dependence.
  - Differences between reference frames.
- Υ(1S) polarization in PbPb:
  - Compatible with zero within uncertainties.

OUTLINE



- $Q\bar{Q}$ production mechanism:
  - Polarization in pp
  - Production in pp

- Probing cold nuclear effects:
  - $Q\bar{Q}$ production in pA

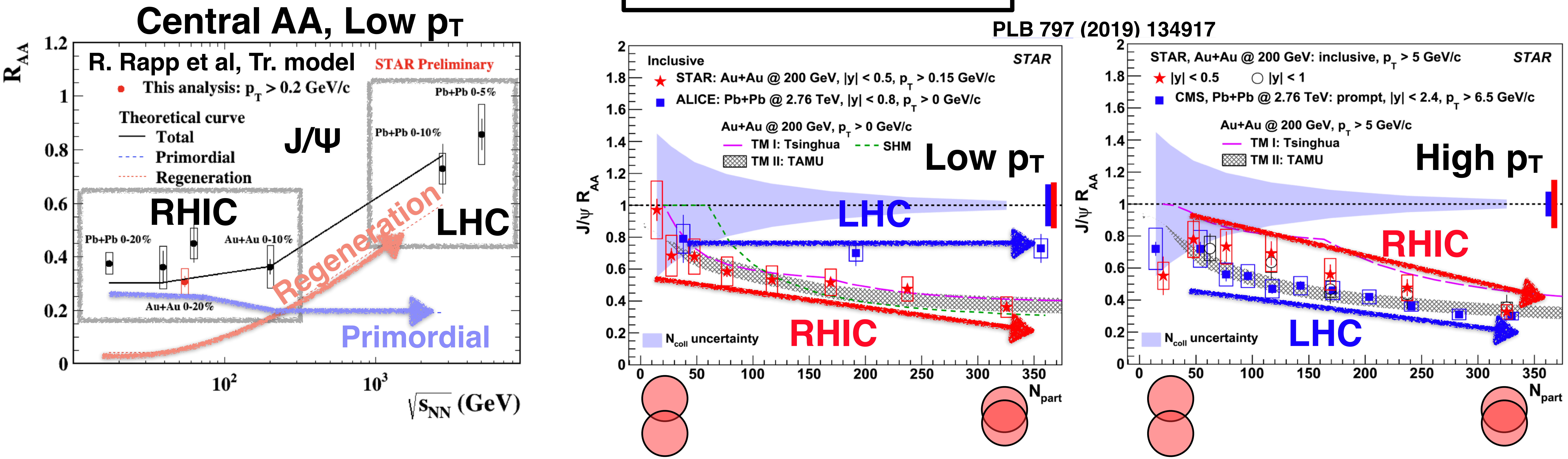


- **Probing QGP effects:**
  - $Q\bar{Q}$ polarization in AA
  - **$Q\bar{Q}$ production in AA**

- Exotic quarkonium states

J/Ψ production in AA

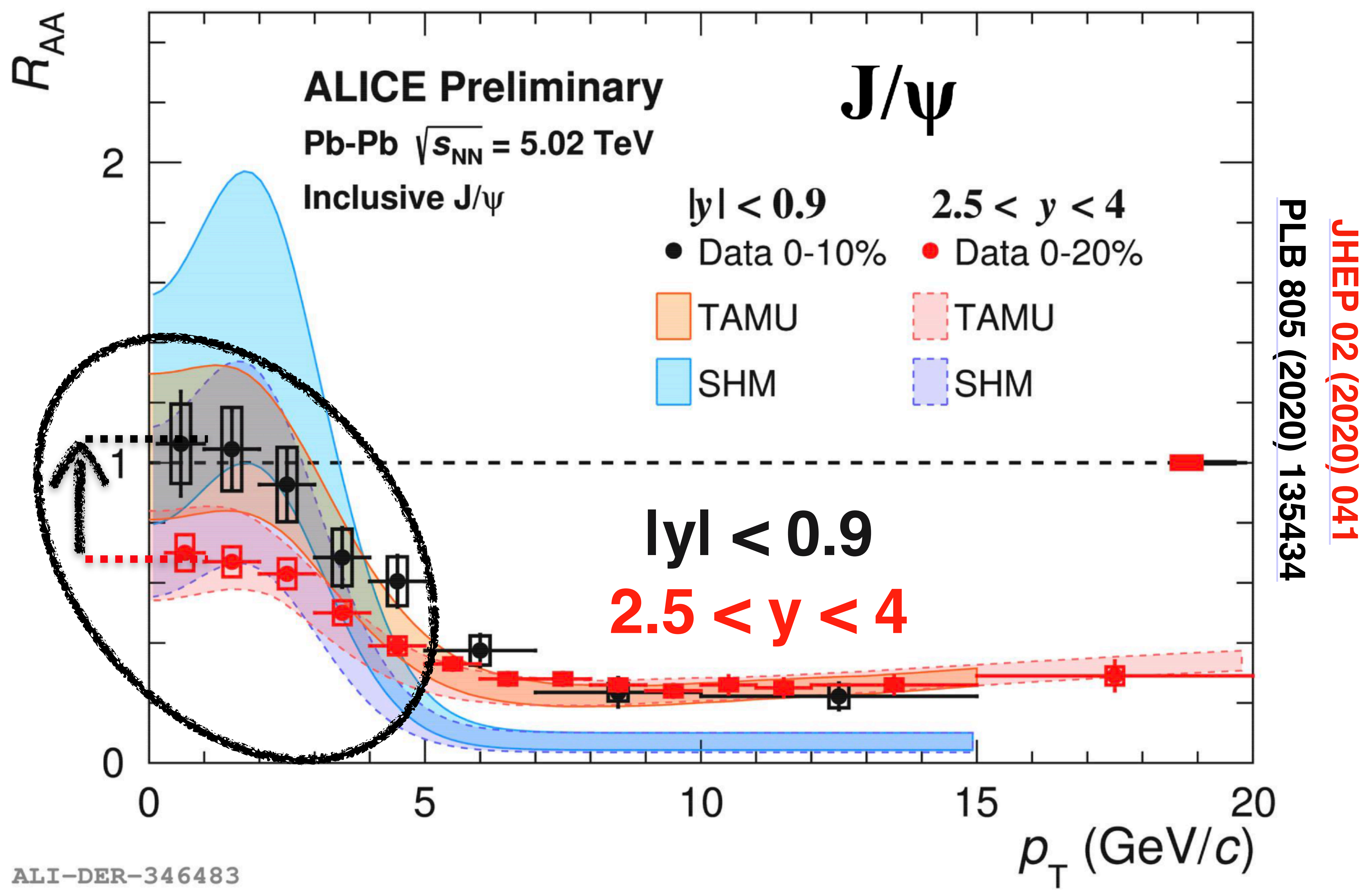
Kaifeng Shen, May 21, Room D 10:10



- J/Ψ production suppressed in all centrality bins, decreasing from peripheral to central events.
  - Interplay of J/Ψ primordial and regenerated production in central AA vs beam energy.
  - LHC > RHIC R_{AA} at low p_T: higher charm production at LHC → larger regeneration.
  - LHC < RHIC R_{AA} at high p_T: primordial production → larger suppression at LHC.

J/Ψ production in PbPb

Ingrid Lofnes, May 21, Room D 09:50

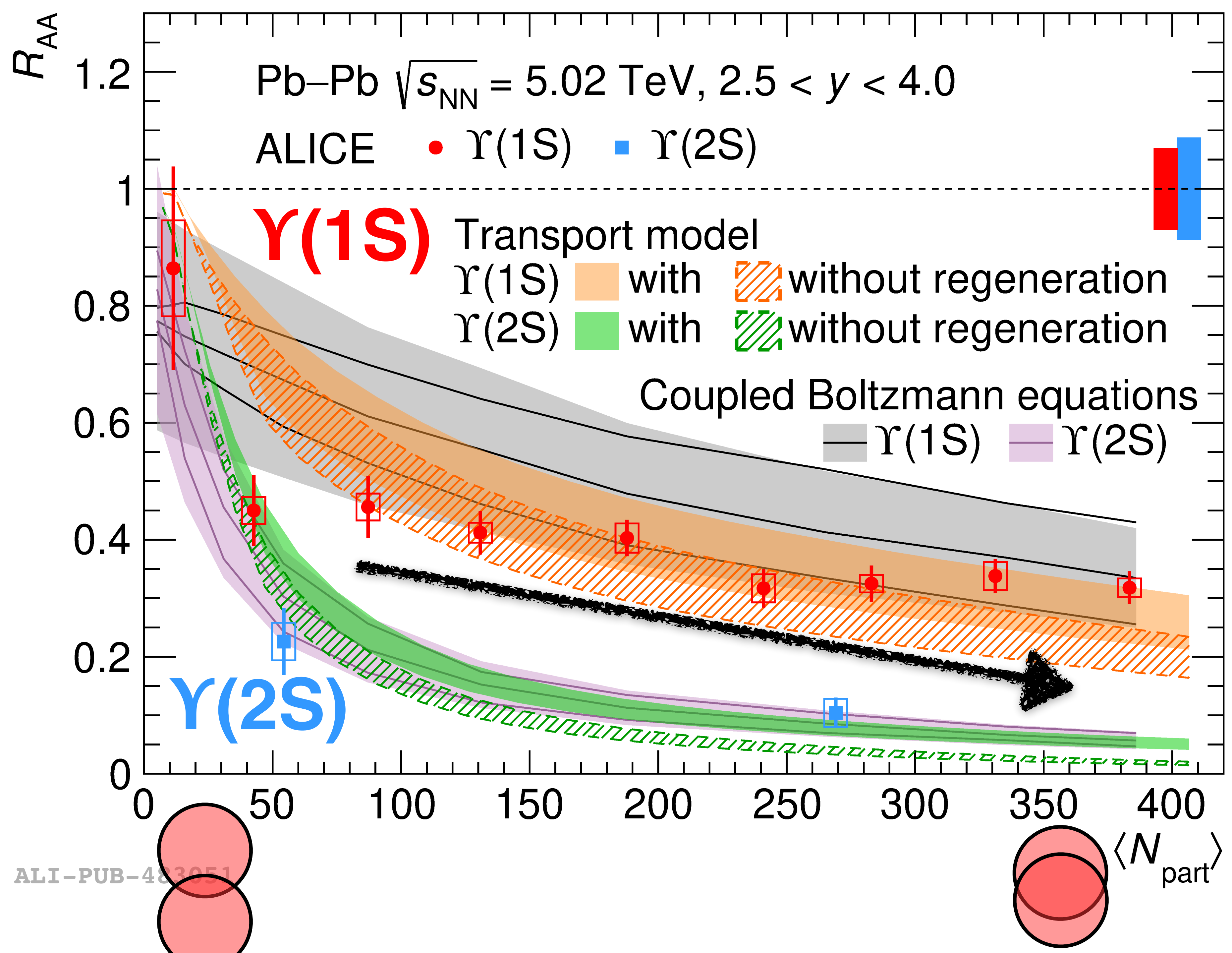


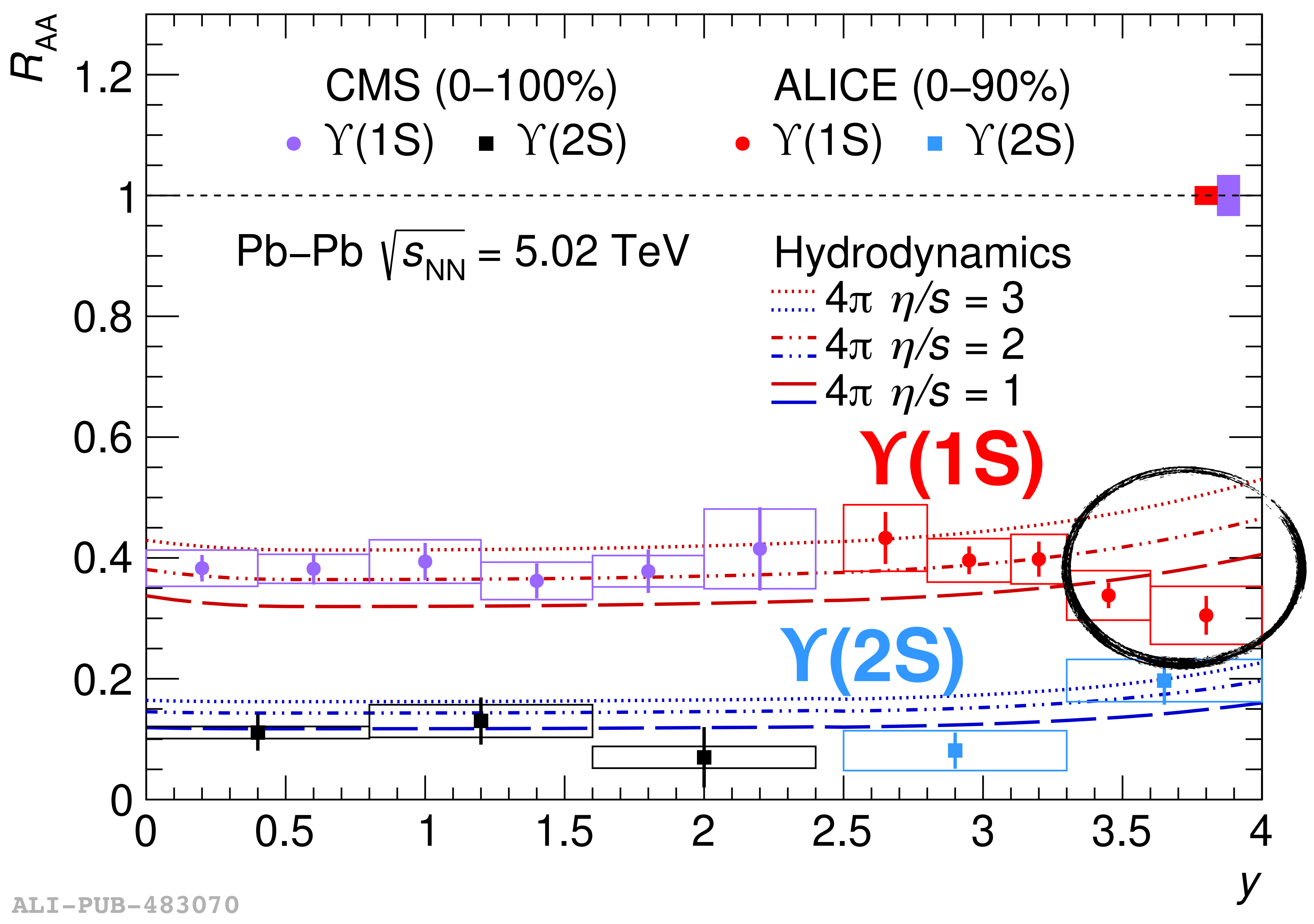
- Hint of less J/Ψ suppression at mid-rapidity compared to forward rapidity.
- Models including J/Ψ production via regeneration are able to describe data at low p_T.

Υ(nS) production in PbPb

Ingrid Lofnes, May 21, Room D 09:50

arXiv:2011.05758





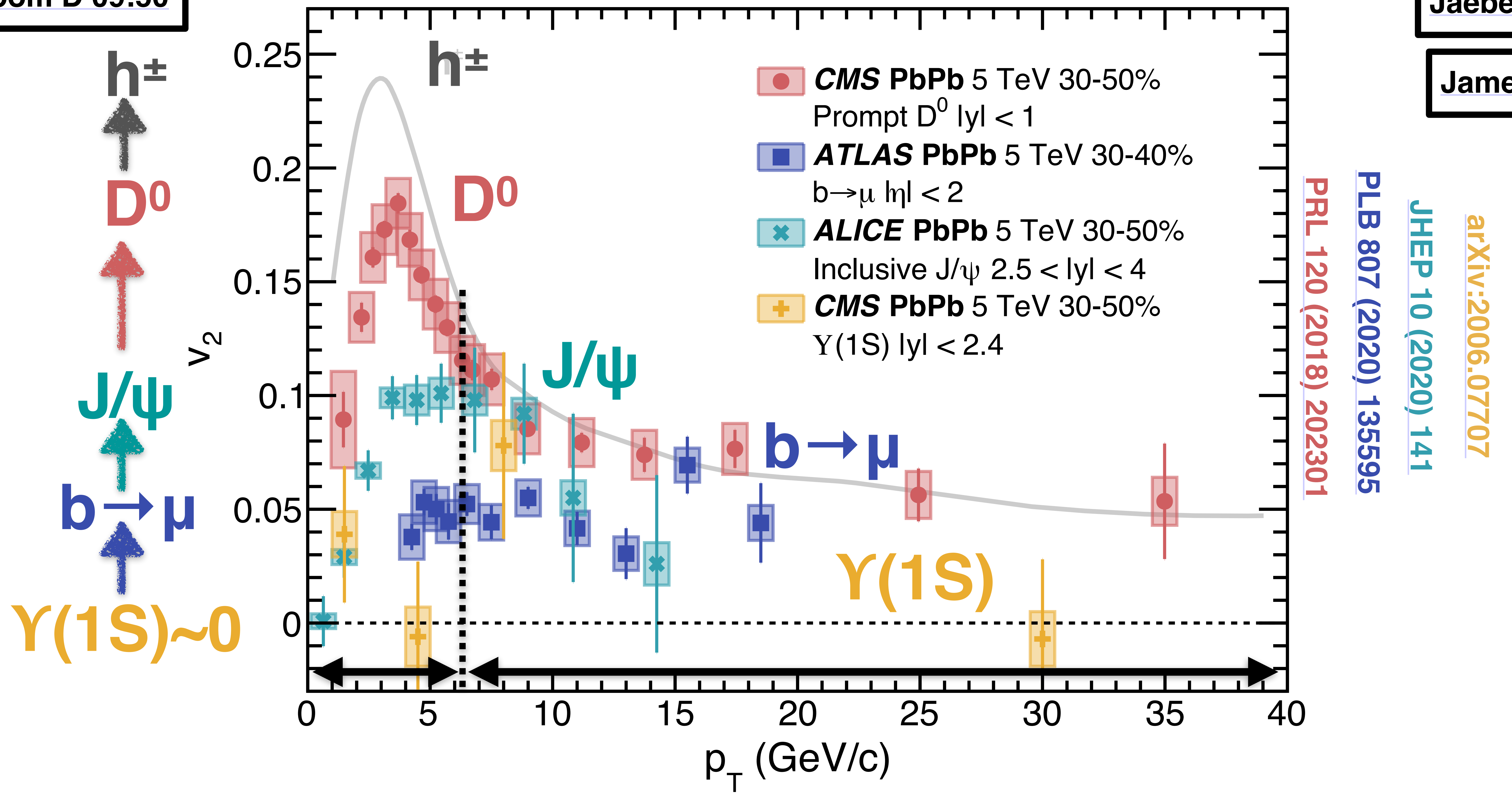
- Υ(nS) more suppressed towards central collisions.
- Υ(2S) R_{AA} < Υ(1S) R_{AA} → sequential suppression of bottomonia.
- LHC data favours model with regeneration and hydrodynamics.
- Hydrodynamic model show tension in Υ(1S) R_{AA} at forward rapidity.

Quarkonium collectivity in PbPb

Ingrid Lofnes, May 21, Room D 09:50

Jaebeom Park, May 20, Room D 10:50

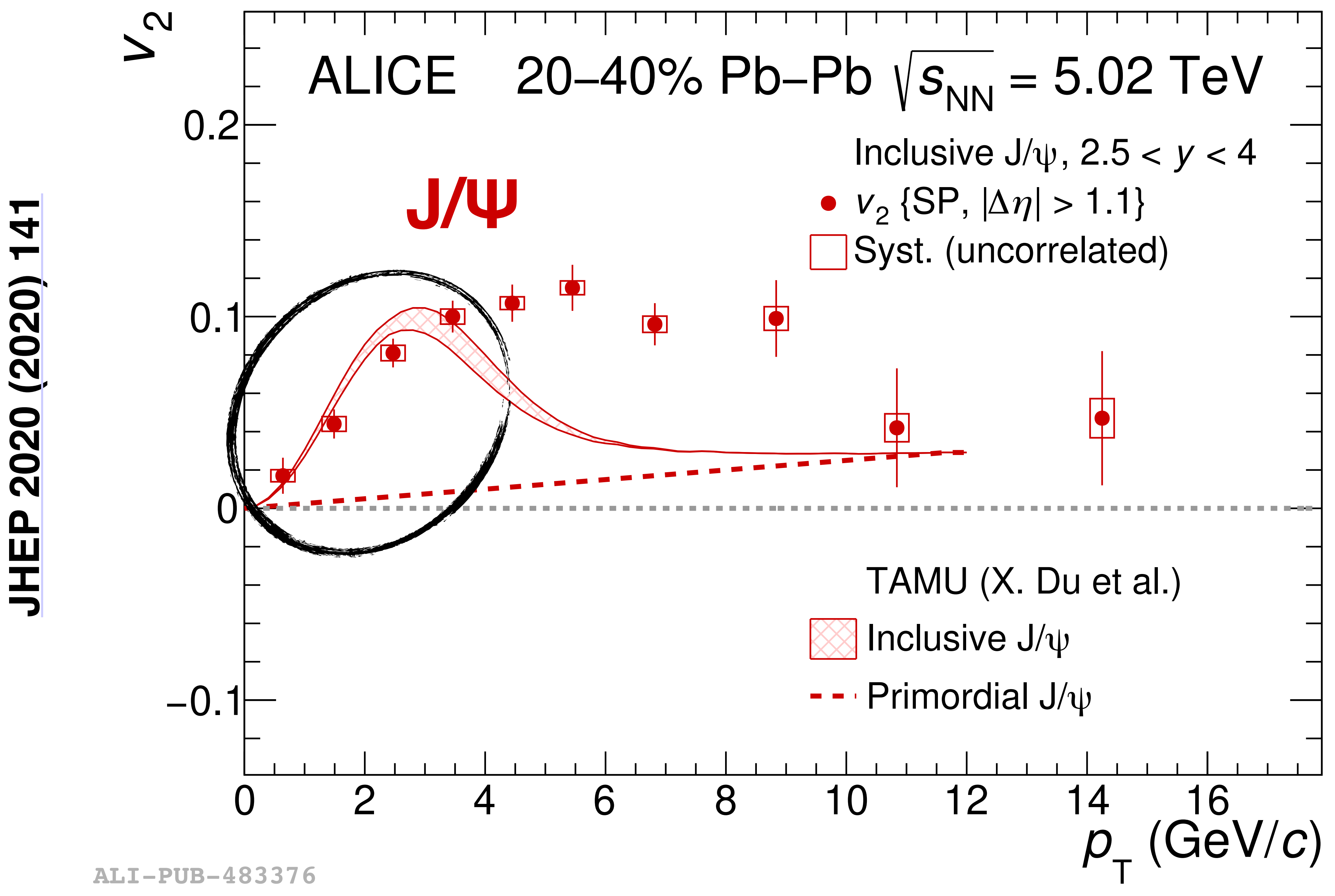
James Nagle, May 18, Room A 10:30



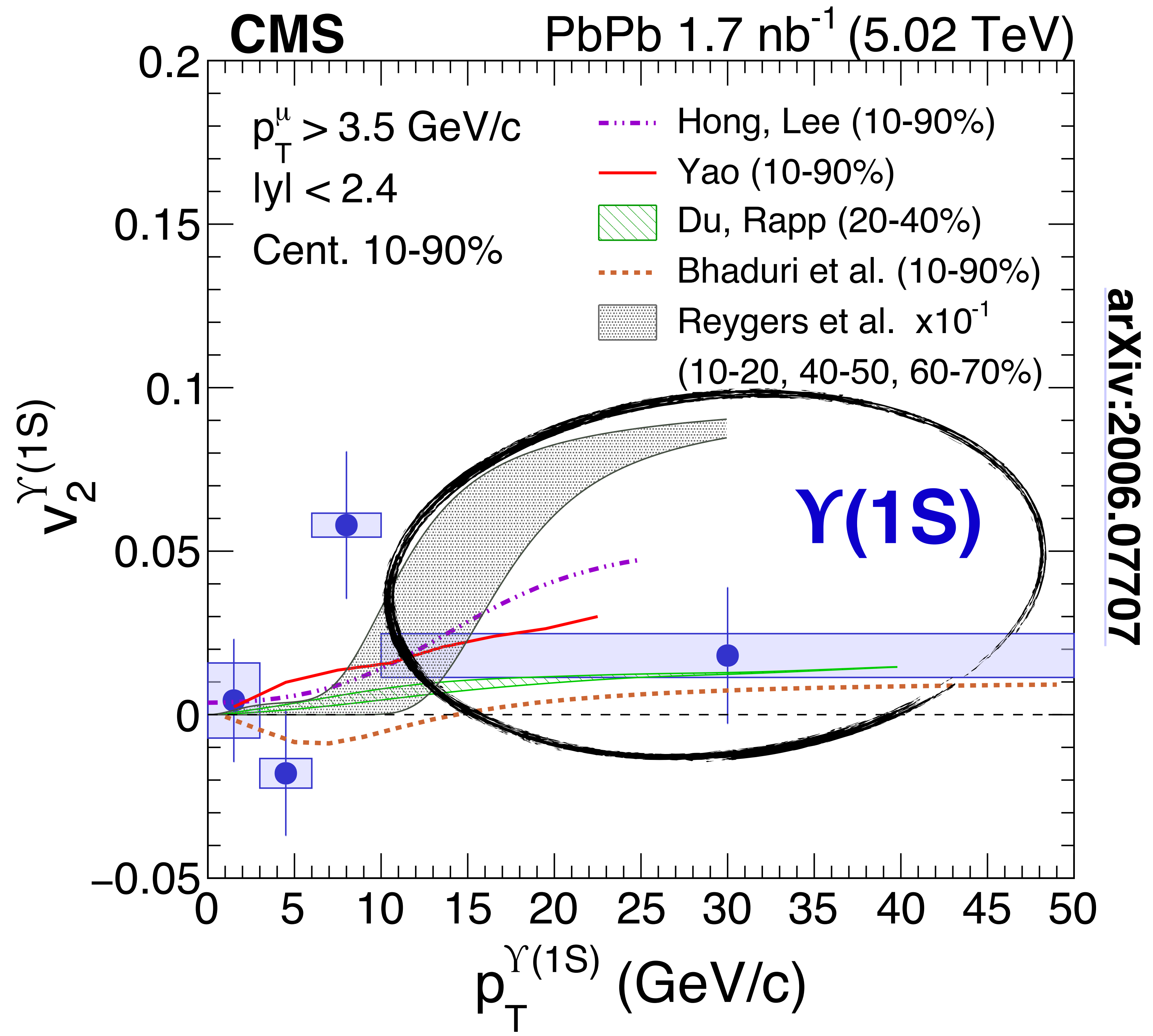
- Clear v_2 ordering:
  - Low p_T: $v_2(h) > v_2(D) > v_2(J/\Psi) > v_2(b) > v_2(\Upsilon) \sim 0$
  - High p_T: $v_2(h) \sim v_2(D) \sim v_2(J/\Psi) \sim v_2(b)$

Quarkonium collectivity in PbPb

Ingrid Lofnes, May 21, Room D 09:50



Jaebeom Park, May 20, Room D 10:50

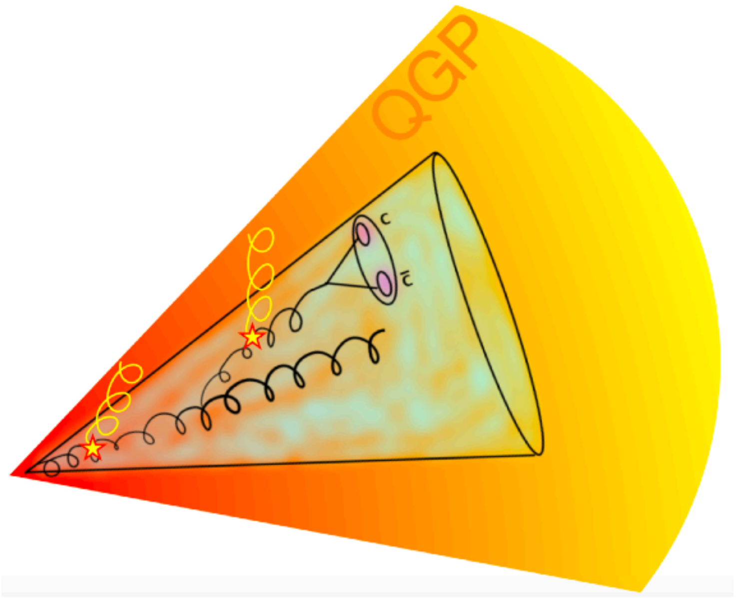


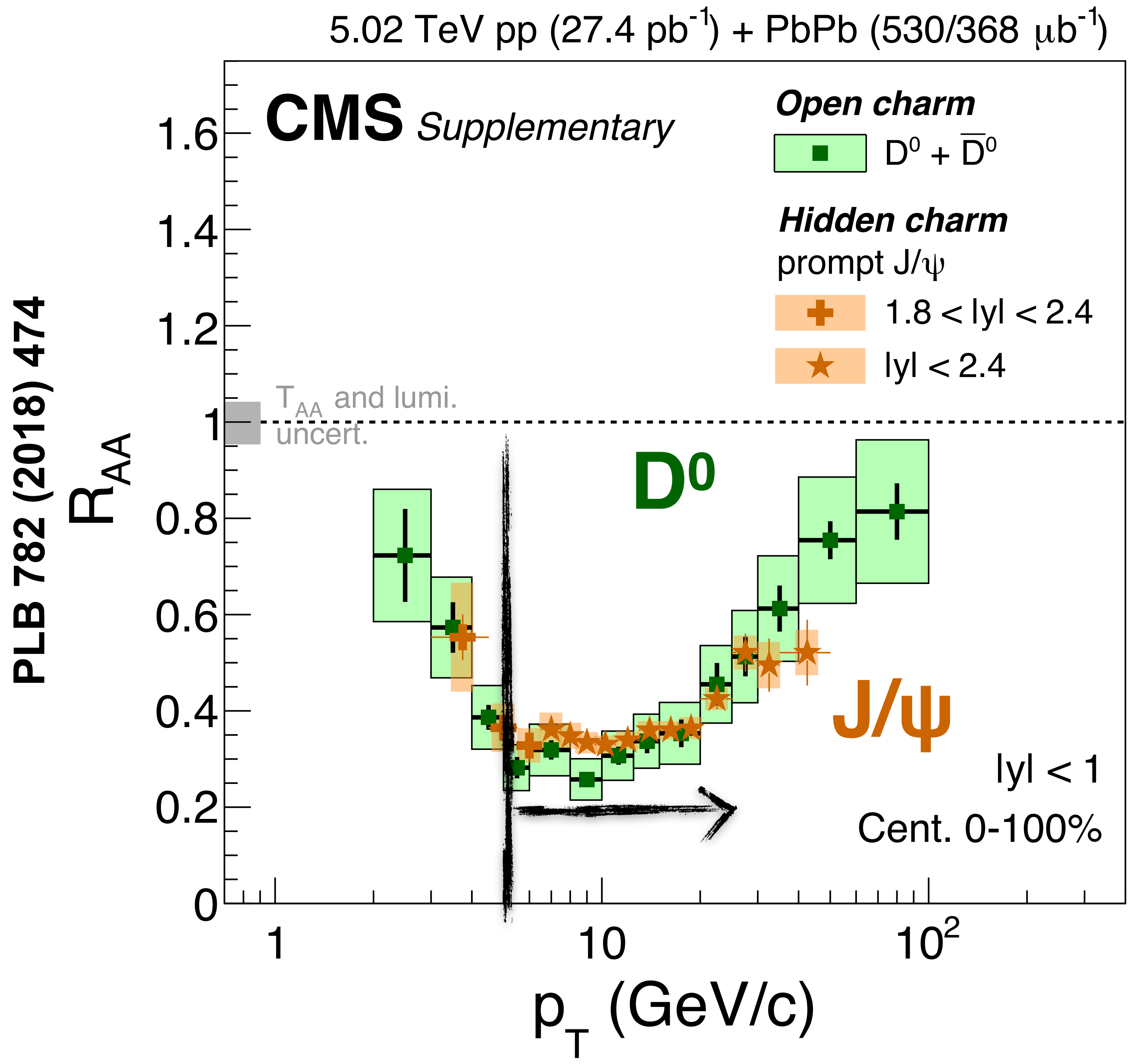
- Models with recombination describe low p_T.
- Large v_2 at high p_T not explained by TAMU.

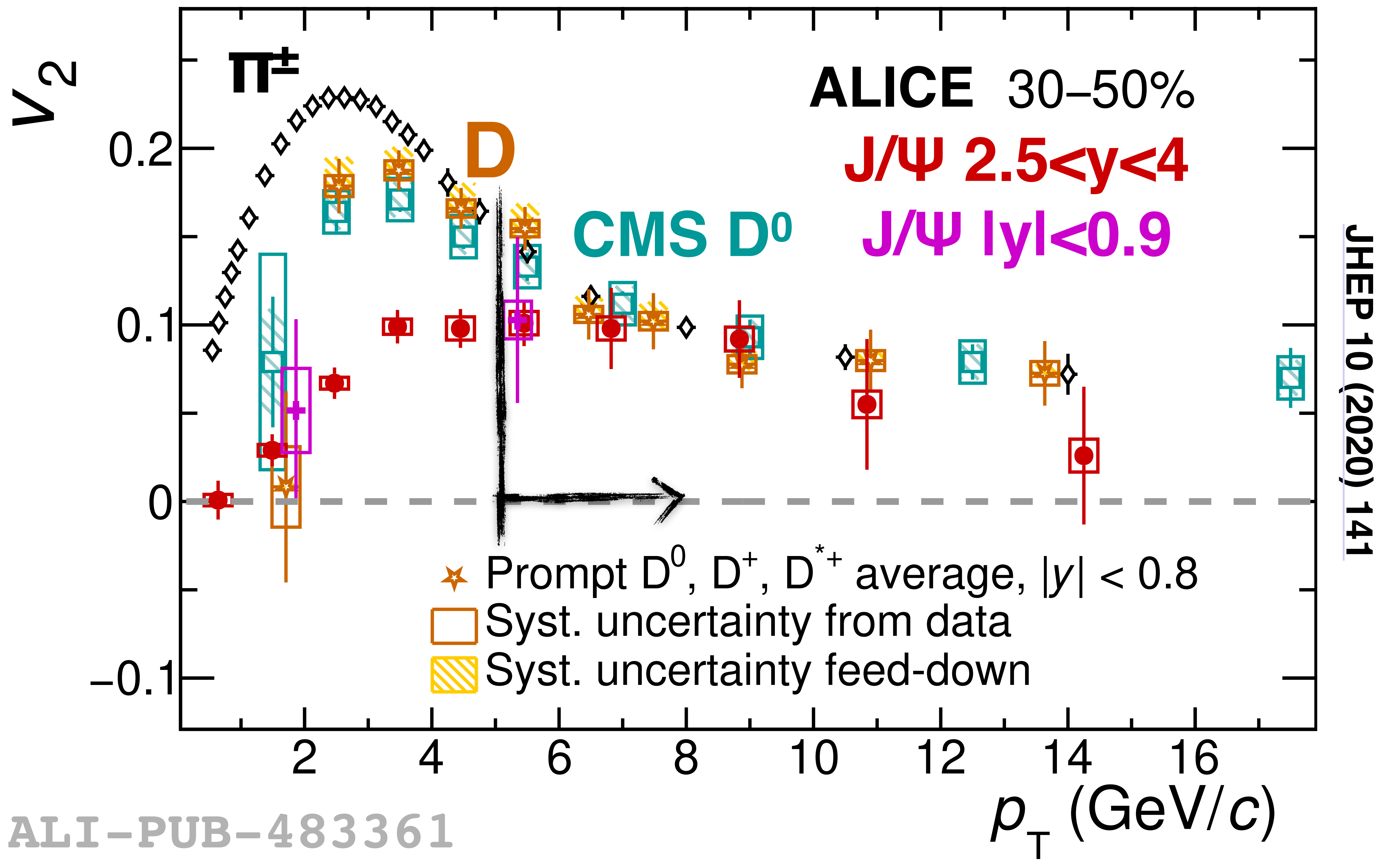
- Models predict small v_2 at low p_T as in data.
- Clear differences start to appear at high p_T.

J/Ψ in jets in PbPb

- J/Ψ produced in parton showers may play an important role at high p_T in PbPb:
  - Implies that J/Ψ at high p_T could be formed at later stages in parton showers.
  - May be affected by parton energy loss in the QGP medium.

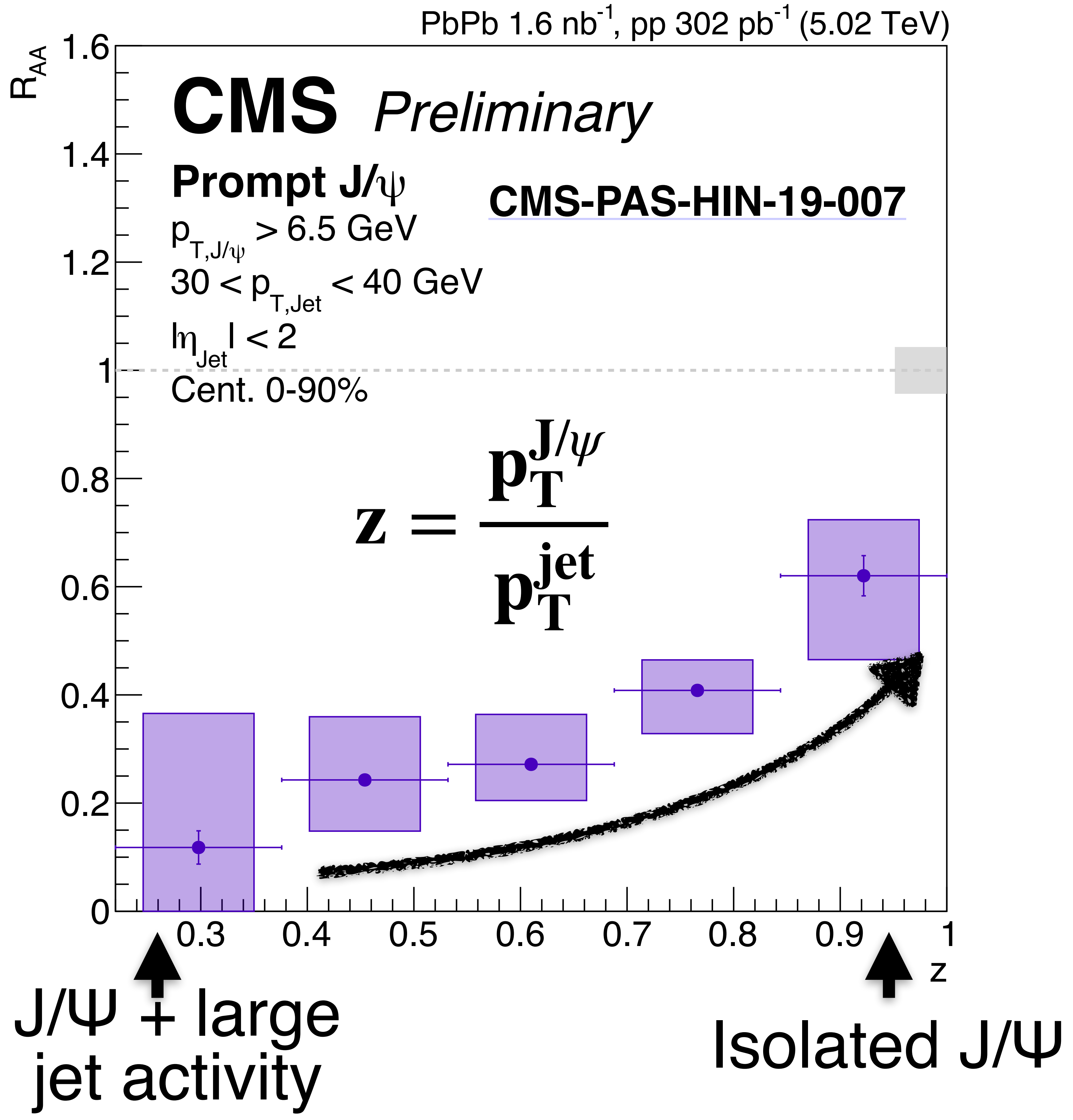






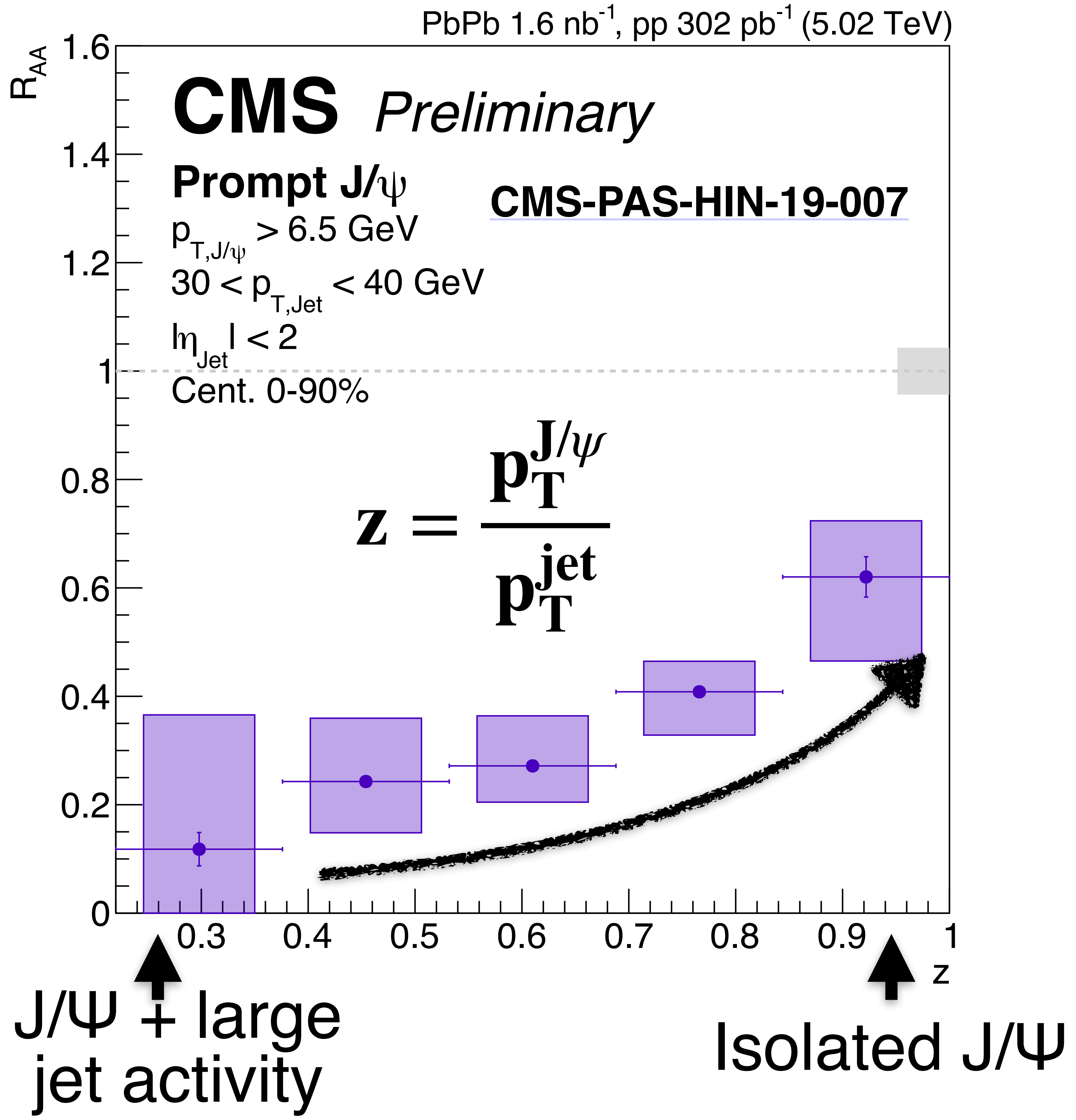
- Would show similar v_2 and suppression between open and hidden charm production.

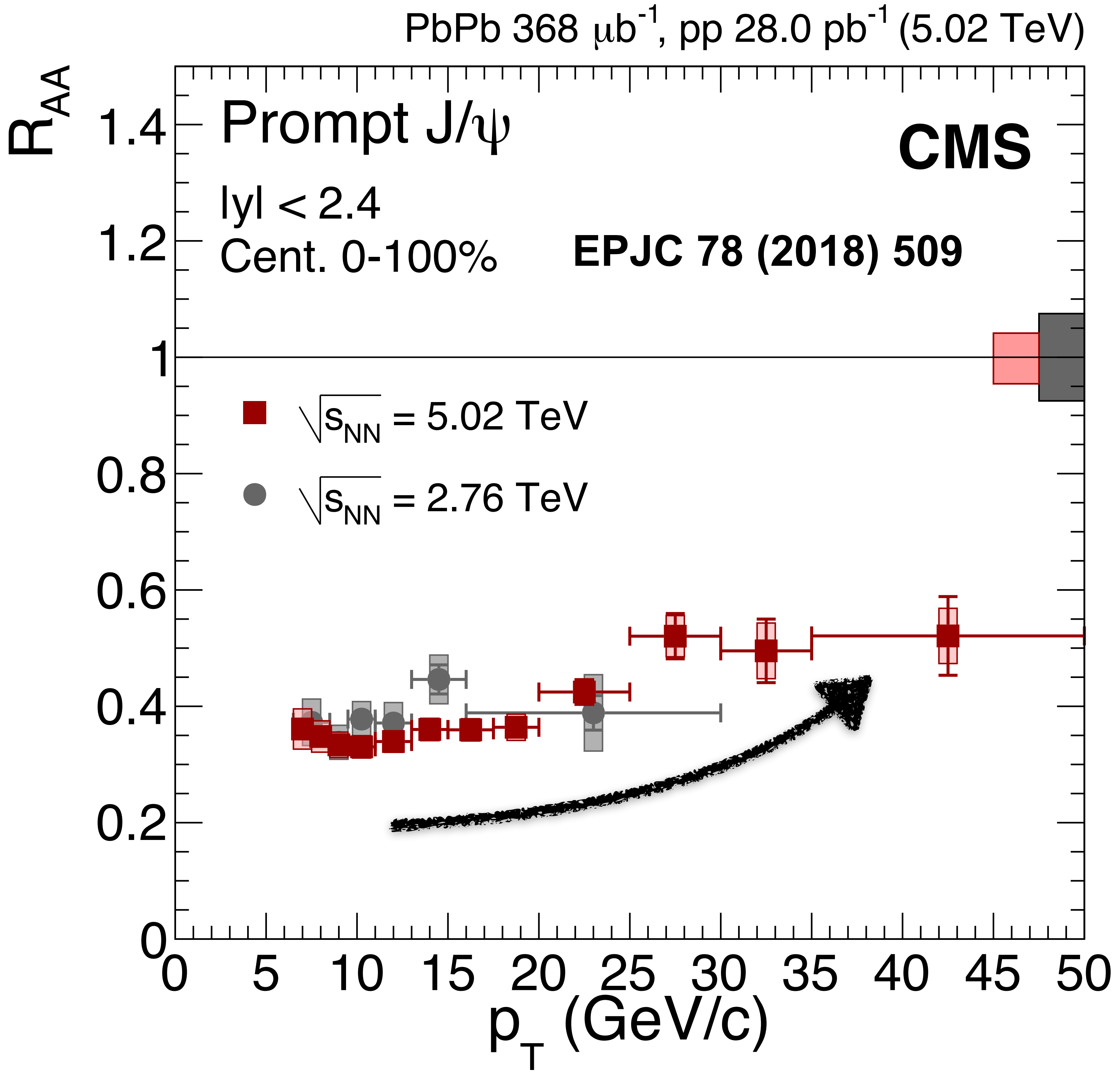
J/Ψ in jets in PbPb



- New CMS results show that isolated J/Ψ less suppressed than J/Ψ with larger jet activity in PbPb.

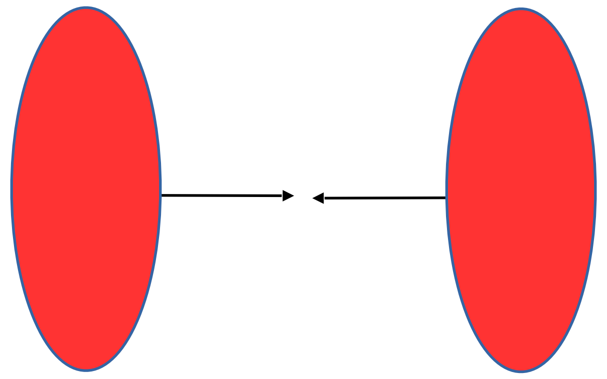
J/Ψ in jets in PbPb





- New CMS results show that isolated J/Ψ less suppressed than J/Ψ with larger jet activity in PbPb.
- Parton energy loss in QGP could explain rising trend of inclusive prompt J/Ψ R_{AA} at high p_T.

Take-home note: Quarkonia in AA



✓Hint of J/Ψ polarization towards low p_T.

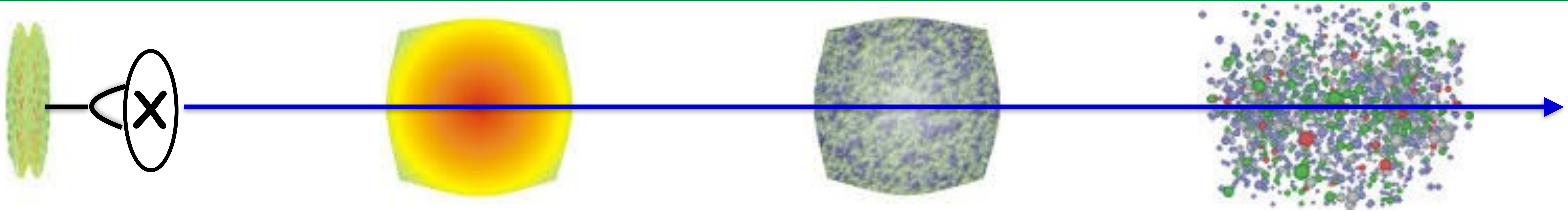
✓$Q\bar{Q}$ results are consistent with dissociation and regeneration picture.

✓High $Q\bar{Q}$ p_T:

➡ **v_2(D)** ~ **v_2(J/Ψ) > 0** and **v_2(Υ(1S)) ~ 0**.

➡ J/Ψ R_{AA} suppressed vs jet activity.

OUTLINE

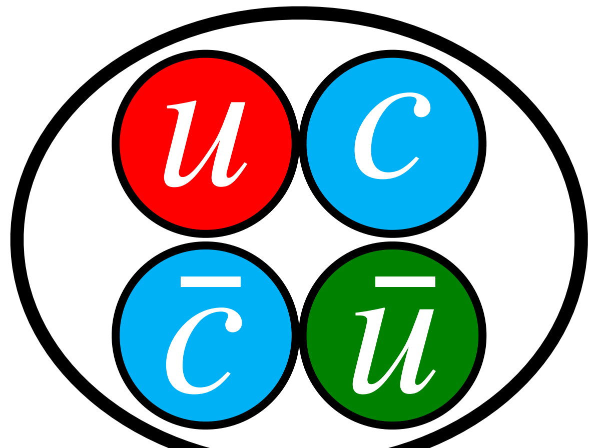


- $Q\bar{Q}$ production mechanism:
  - Polarization in pp
  - Production in pp

- Probing cold nuclear effects:
  - $Q\bar{Q}$ production in pA

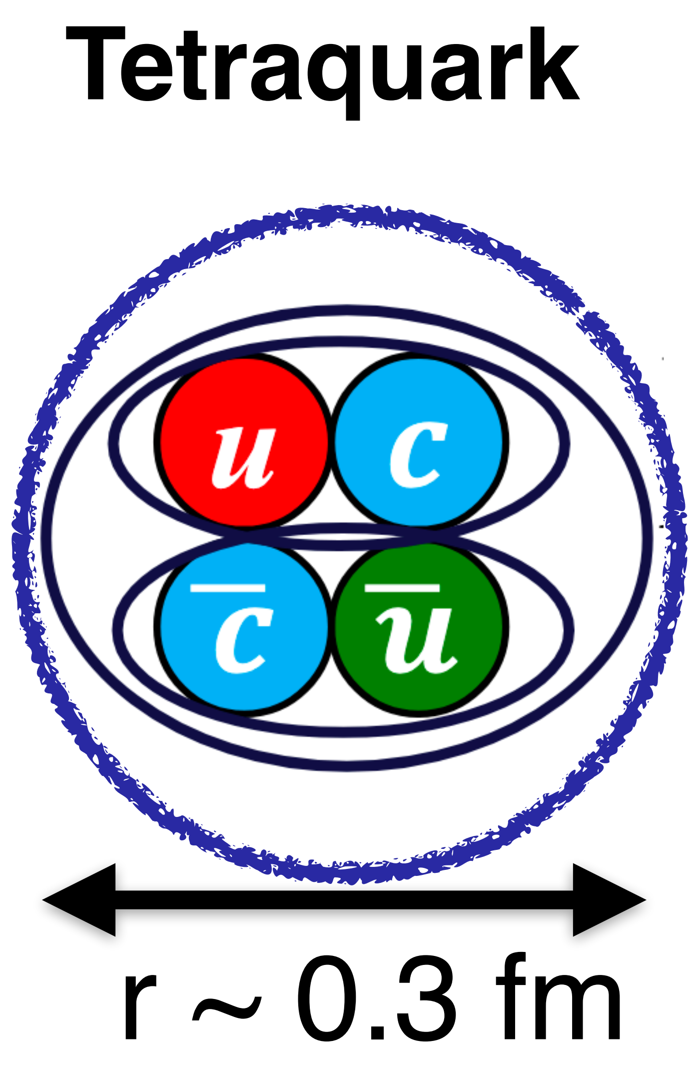
- Probing QGP effects:
  - $Q\bar{Q}$ polarization in AA
  - $Q\bar{Q}$ production in AA

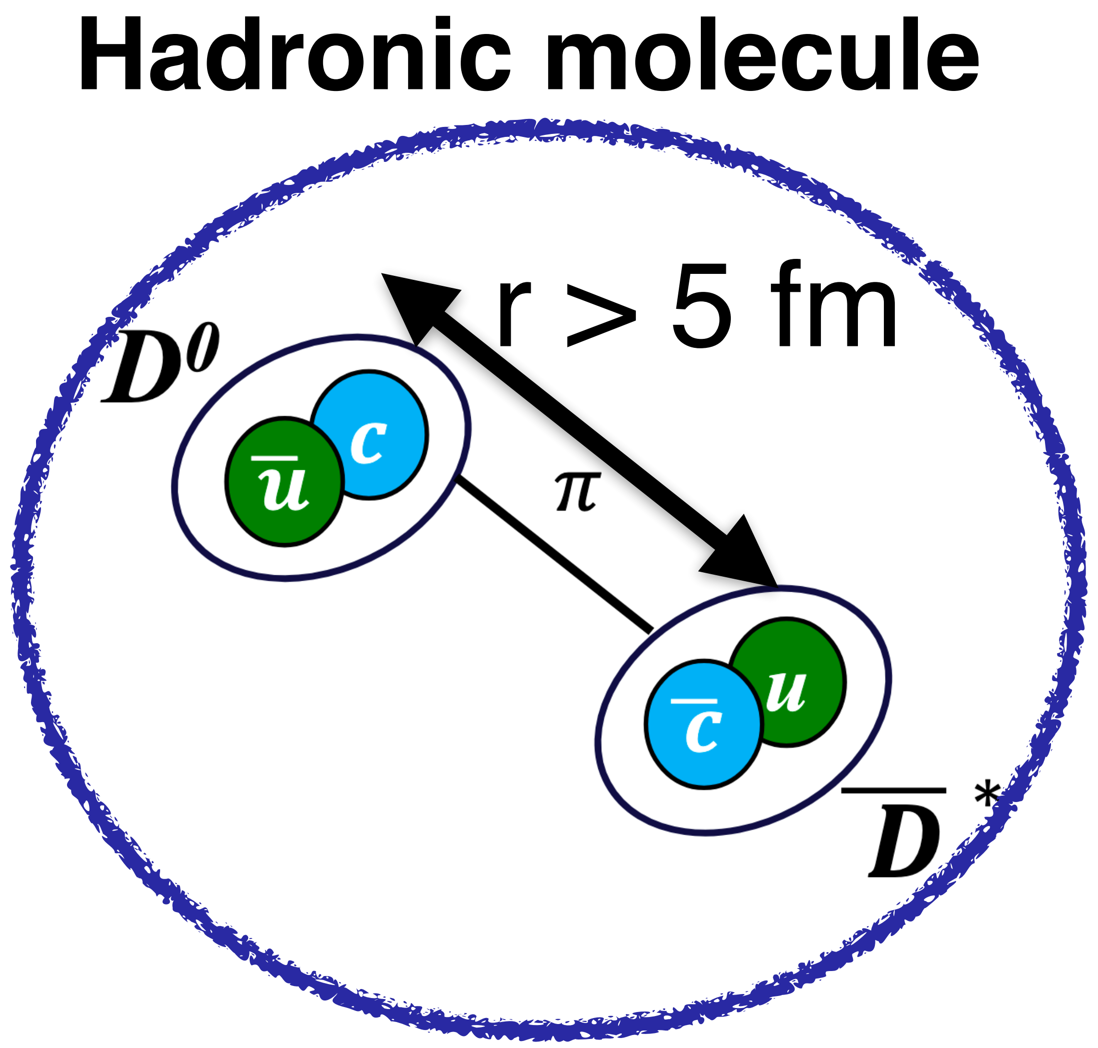
- **Exotic quarkonium states**

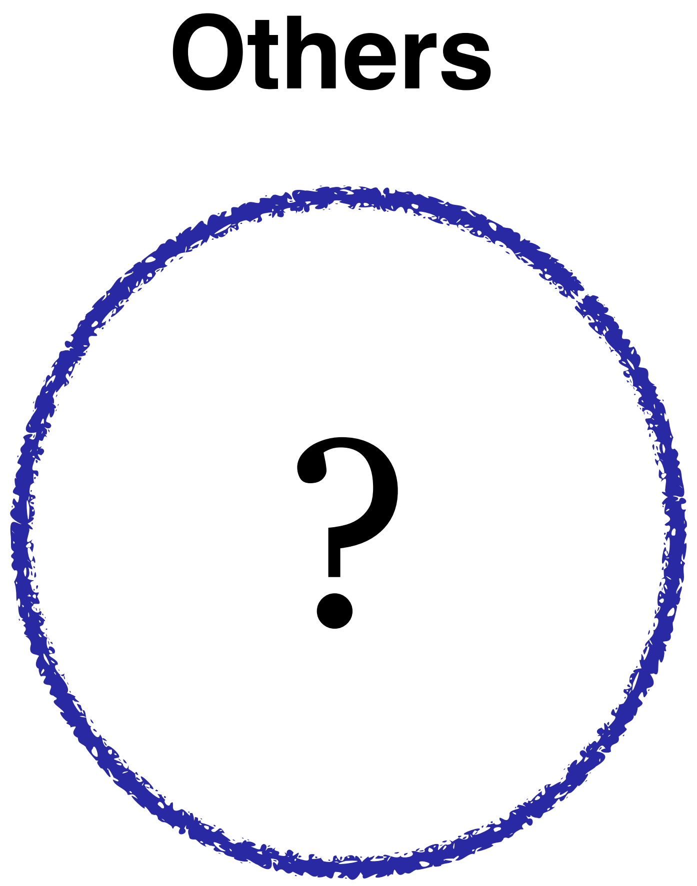


Exotic quarkonium states: X(3872)

- First observed by Belle and later confirmed by LHCb.





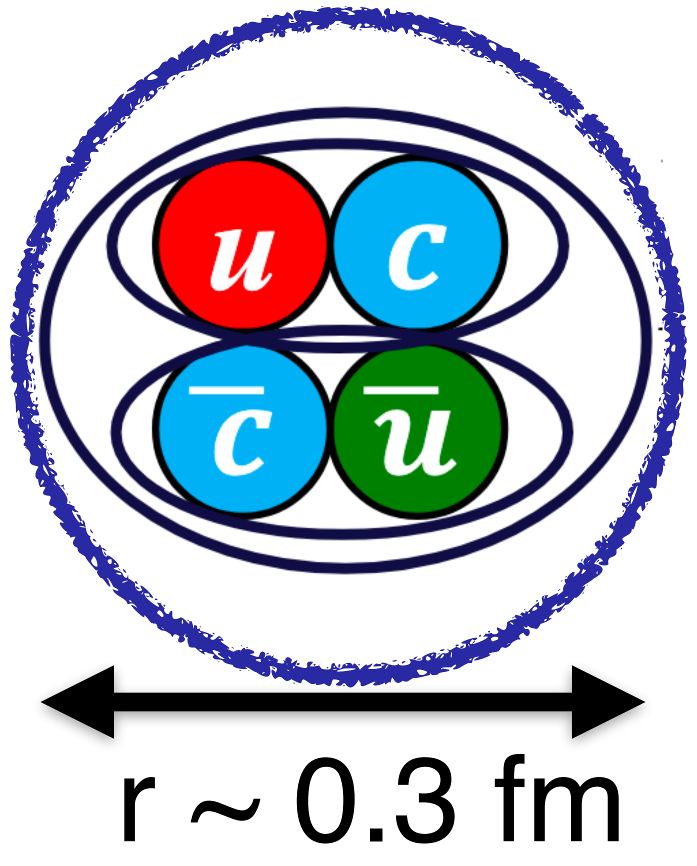


- Structure not yet understood: tetraquark or hadron molecule or …?

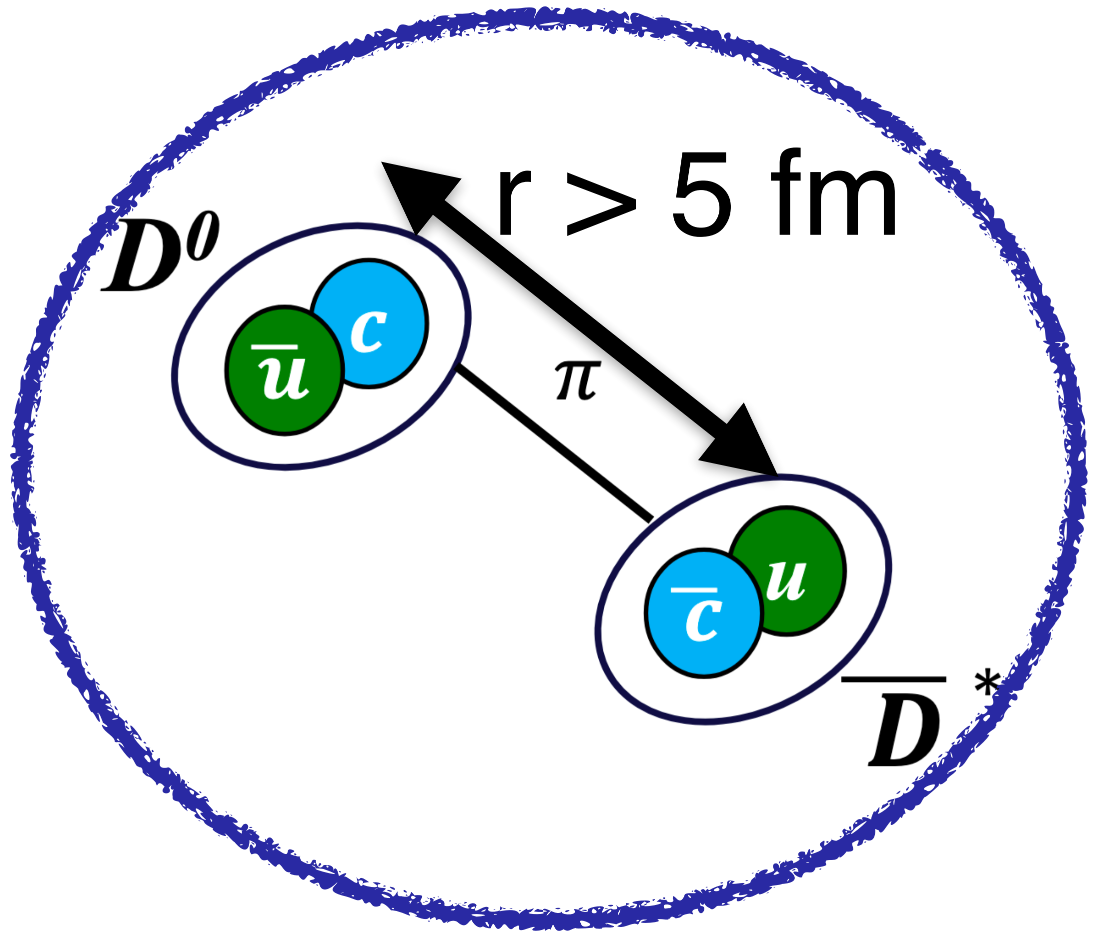
Exotic quarkonium states: X(3872)

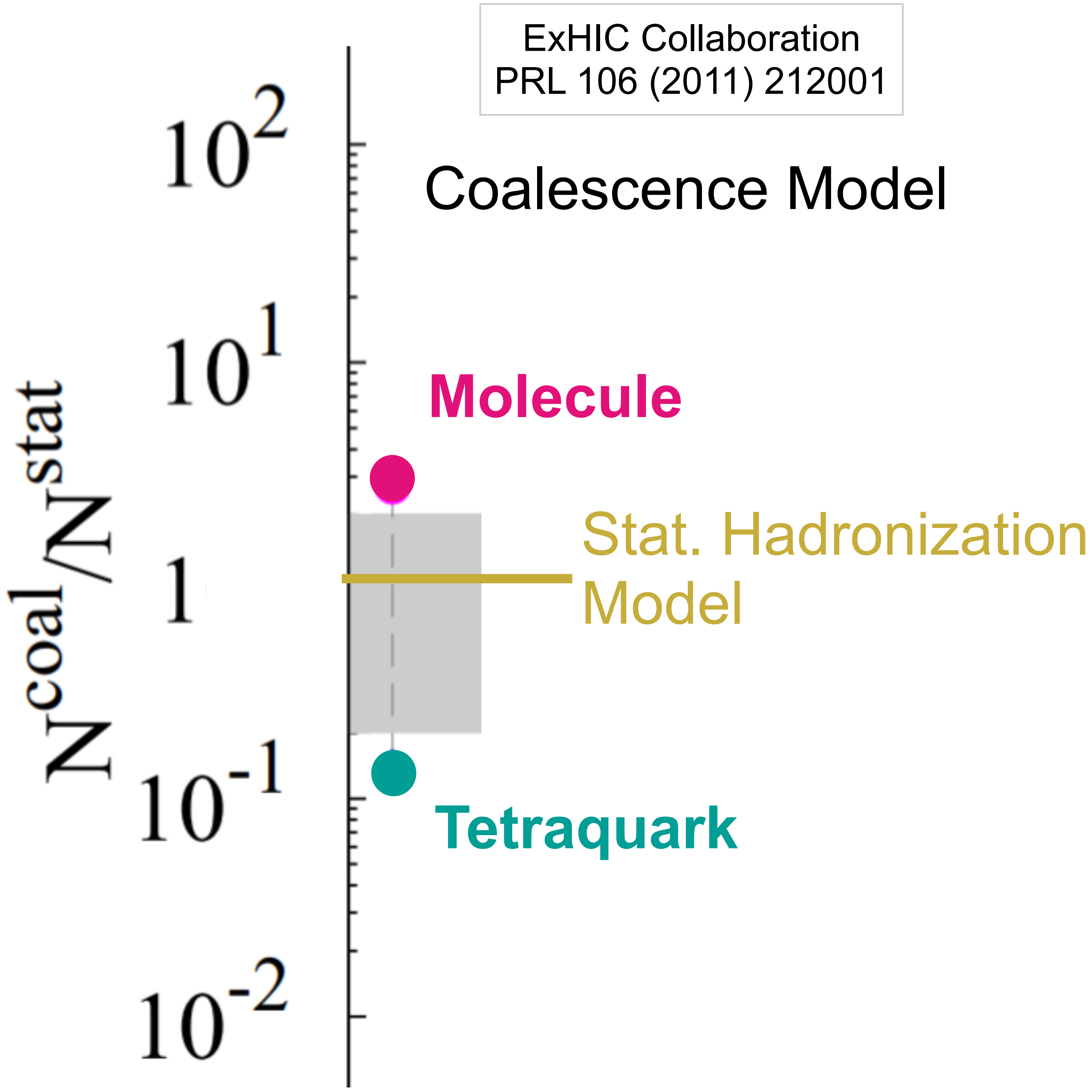
- First observed by Belle and later confirmed by LHCb.

Tetraquark



Hadronic molecule



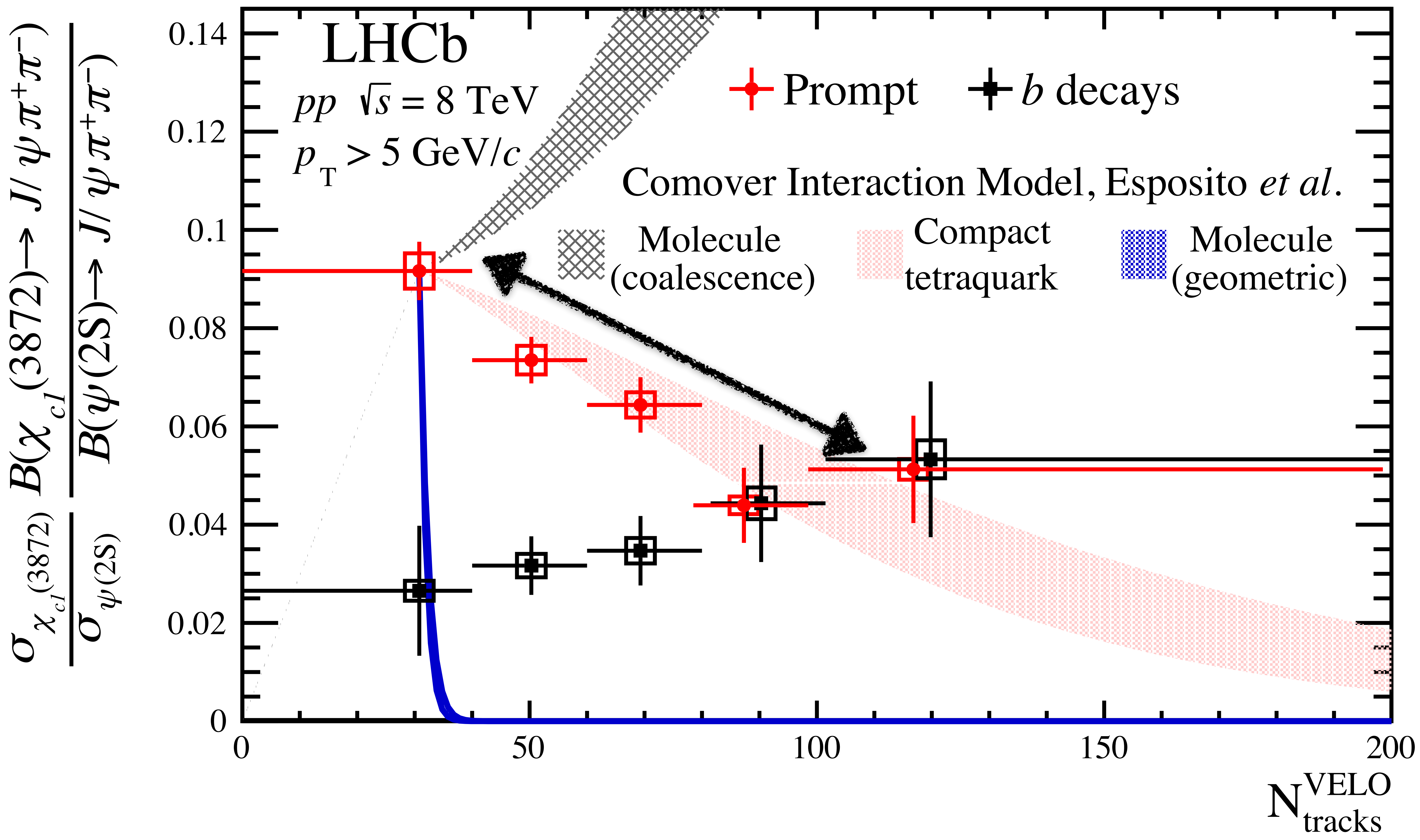


- Structure not yet understood: tetraquark or hadron molecule or …?

- Production yield in QCD medium strongly reflects internal structure.

X(3872) in pp @ 8 TeV

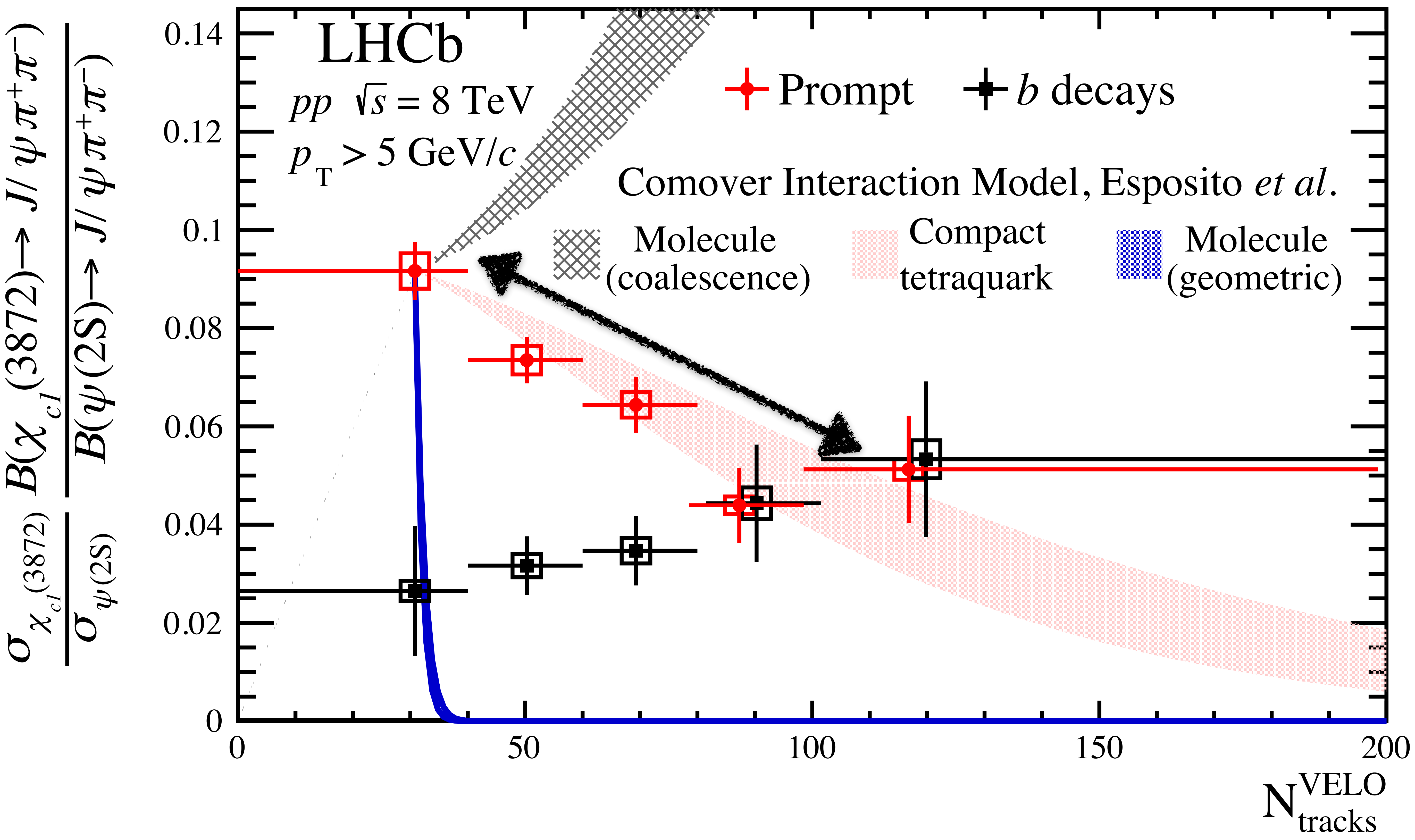
PRL 126 (2021) 092001



- Prompt X(3872) / Ψ(2S) decreases with event activity → X(3872) more suppressed than Ψ(2S)

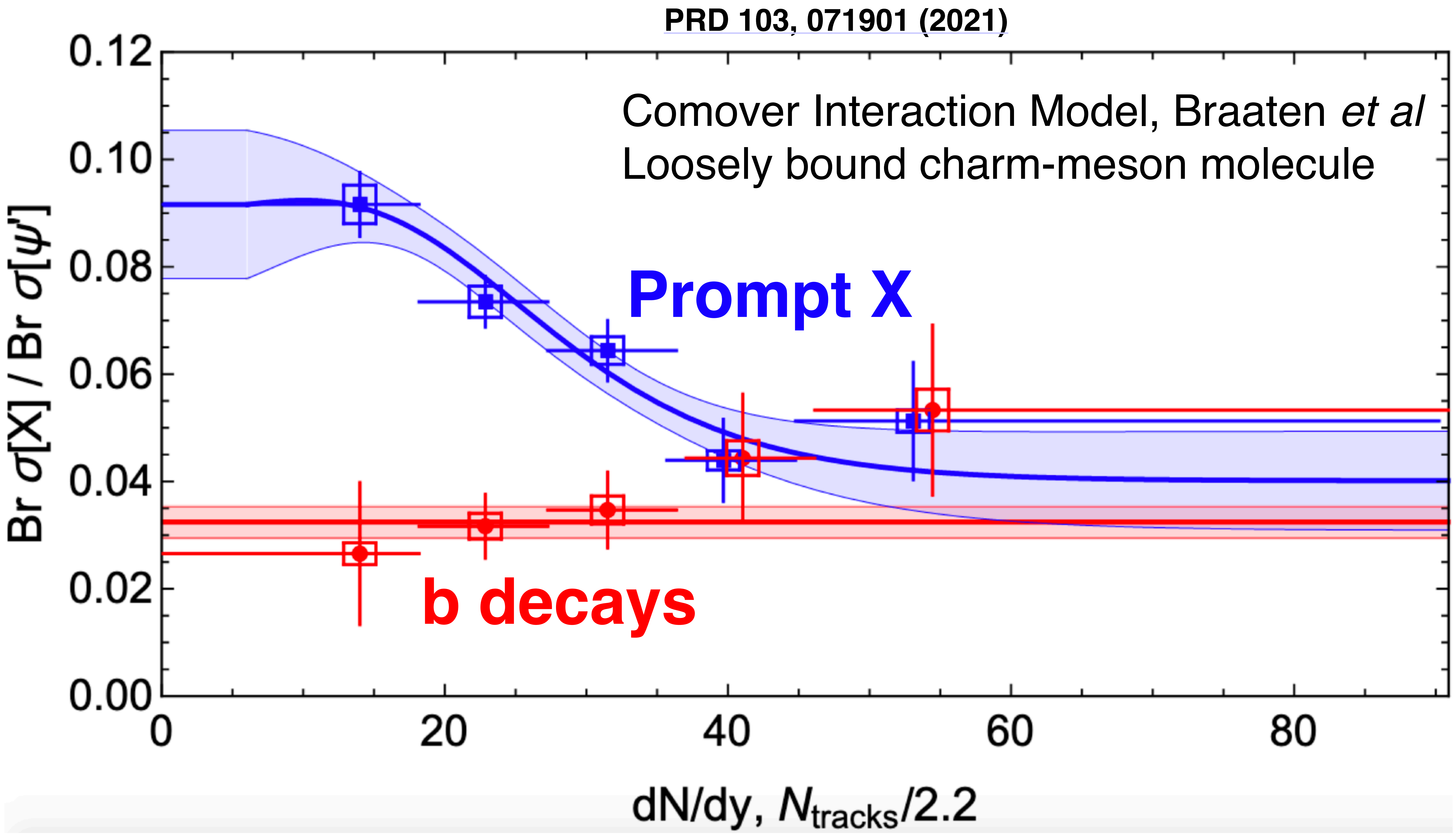
X(3872) in pp @ 8 TeV

PRL 126 (2021) 092001



- Prompt X(3872) / Ψ(2S) decreases with event activity → X(3872) more suppressed than Ψ(2S)
- Data described by comover interaction model assuming X(3872) being a tetraquark.

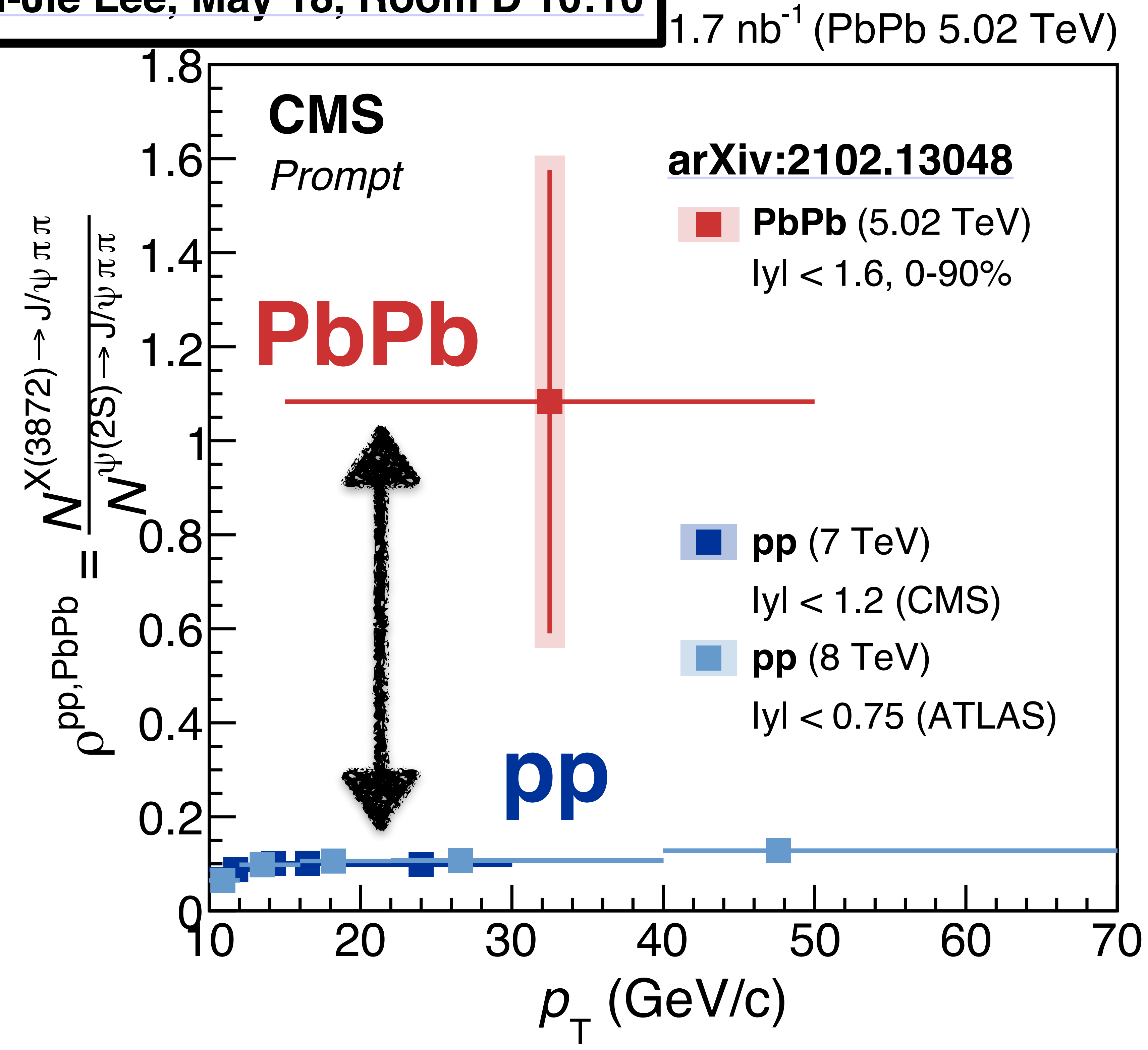
X(3872) in pp @ 8 TeV



- Prompt X(3872) / Ψ(2S) decreases with event activity → X(3872) more suppressed than Ψ(2S)
- Data described by comover interaction model assuming X(3872) being a tetraquark.
- However using a different breakup xsec. ansatz for CIM can also favour X(3872) being a molecule.

X(3872) in PbPb @ 5.02 TeV

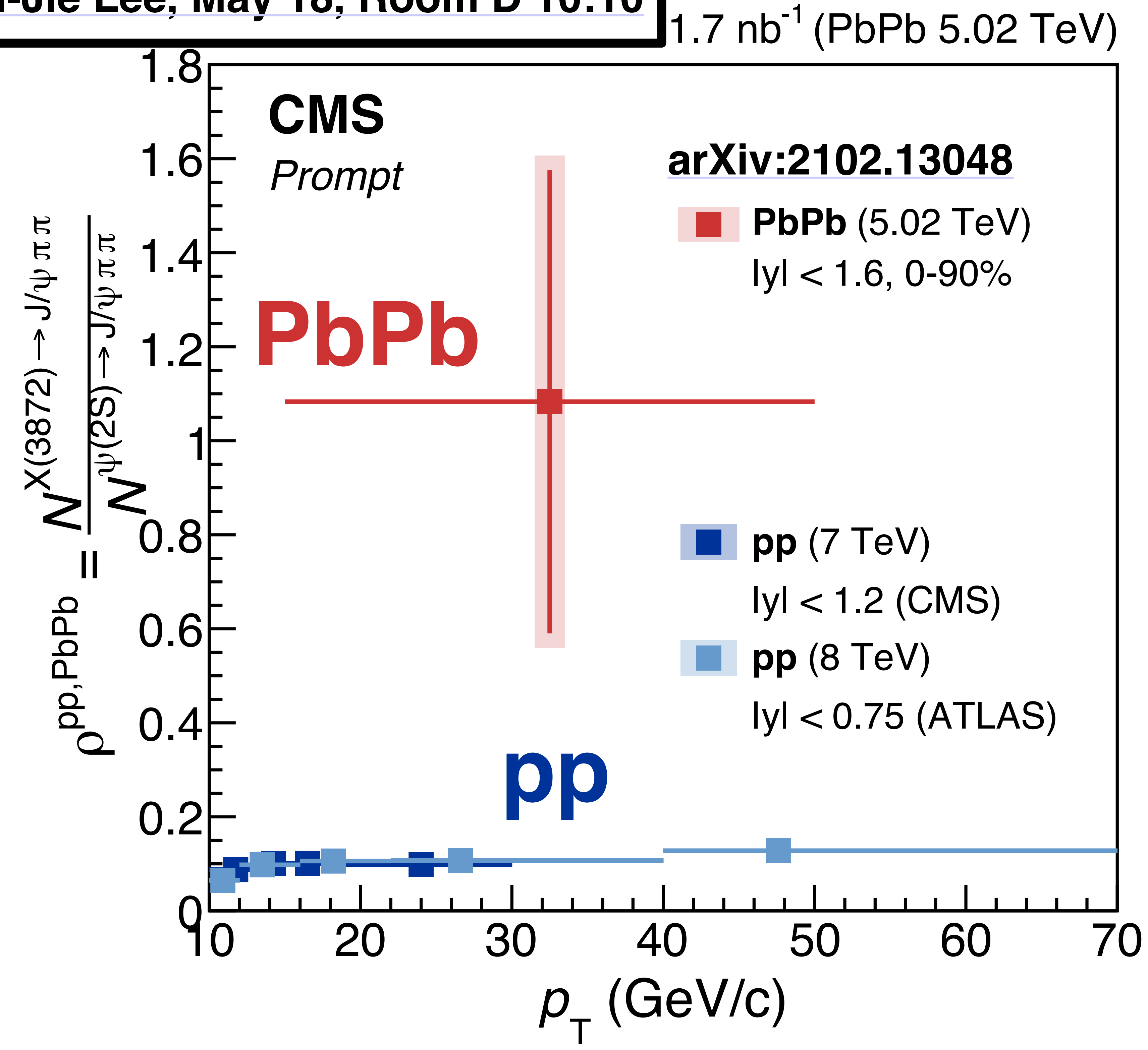
Yen-Jie Lee, May 18, Room D 10:10



- Hint of prompt X(3872) to Ψ(2S) enhancement in PbPb
  - X(3872)/Ψ(2S) in PbPb = 1.10 ± 0.51 ± 0.53
  - X(3872)/Ψ(2S) in pp ≈ 0.1

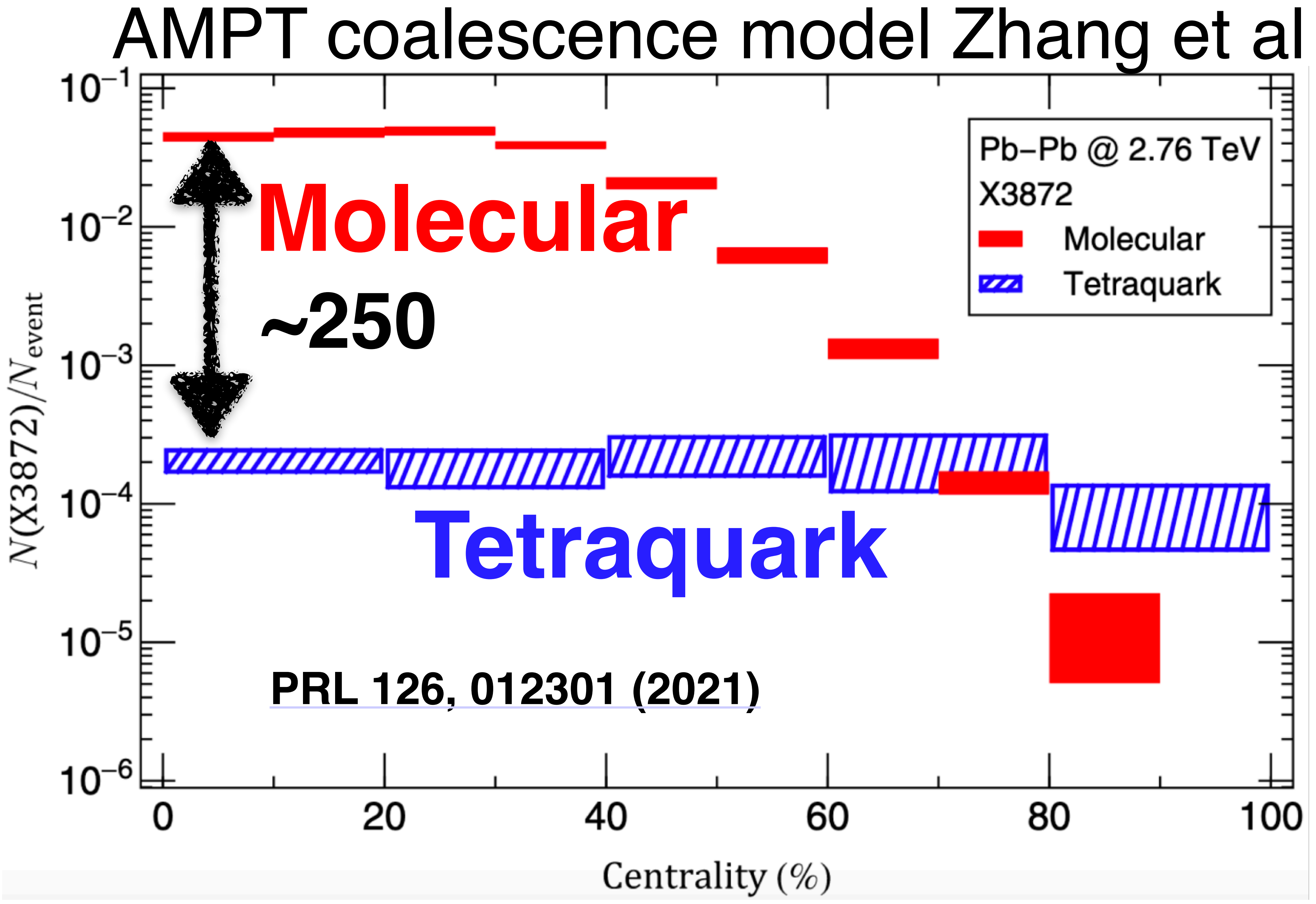
X(3872) in PbPb @ 5.02 TeV

Yen-Jie Lee, May 18, Room D 10:10



- Hint of prompt X(3872) to Ψ(2S) enhancement in PbPb
  - X(3872)/Ψ(2S) in PbPb = 1.10 ± 0.51 ± 0.53
  - X(3872)/Ψ(2S) in pp ≈ 0.1

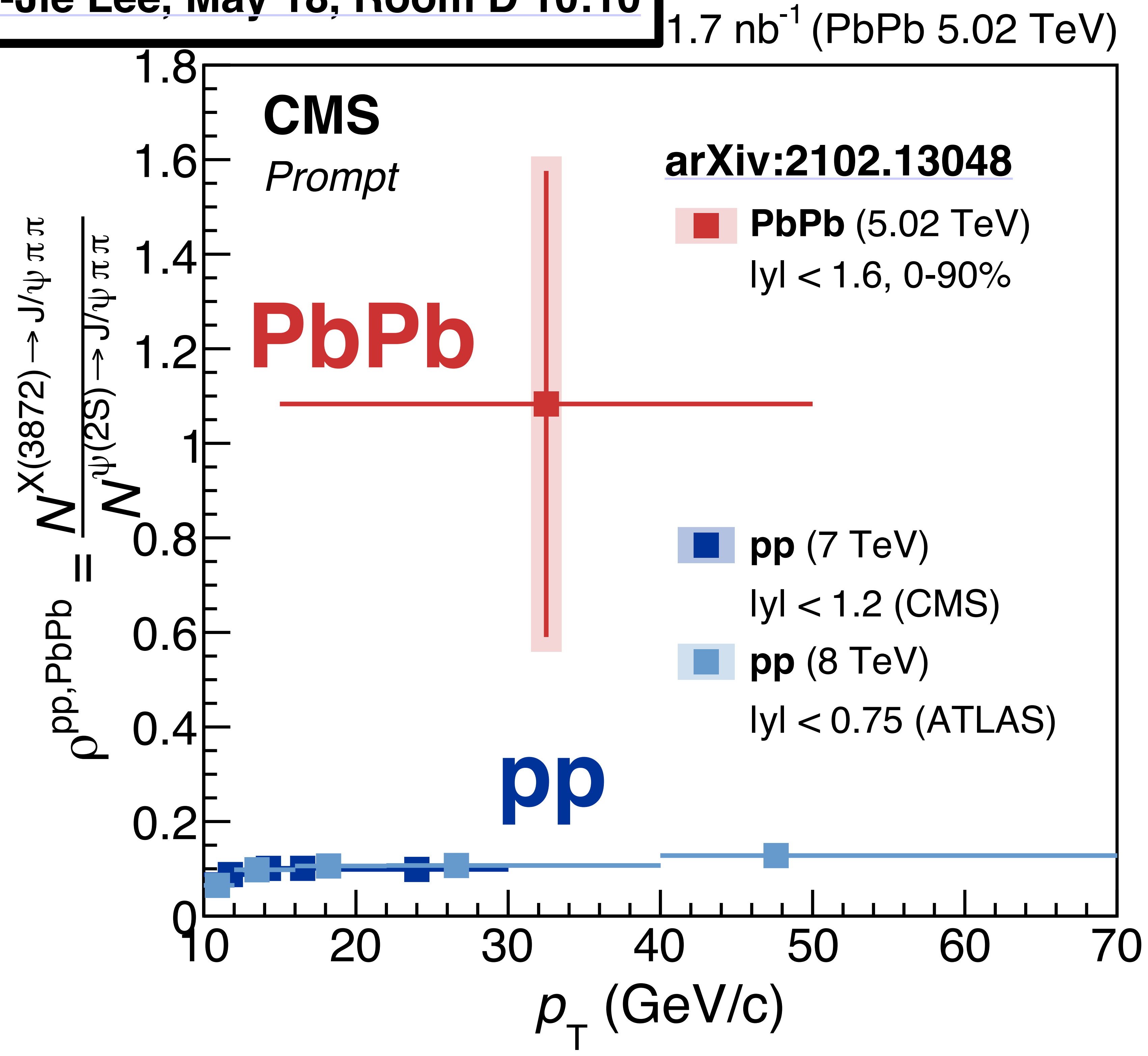
Hui Zhang, May 18, Charm 10:30



- Coalescence model expects a larger yield for molecular vs tetraquark up to a factor of ~250 in central PbPb.

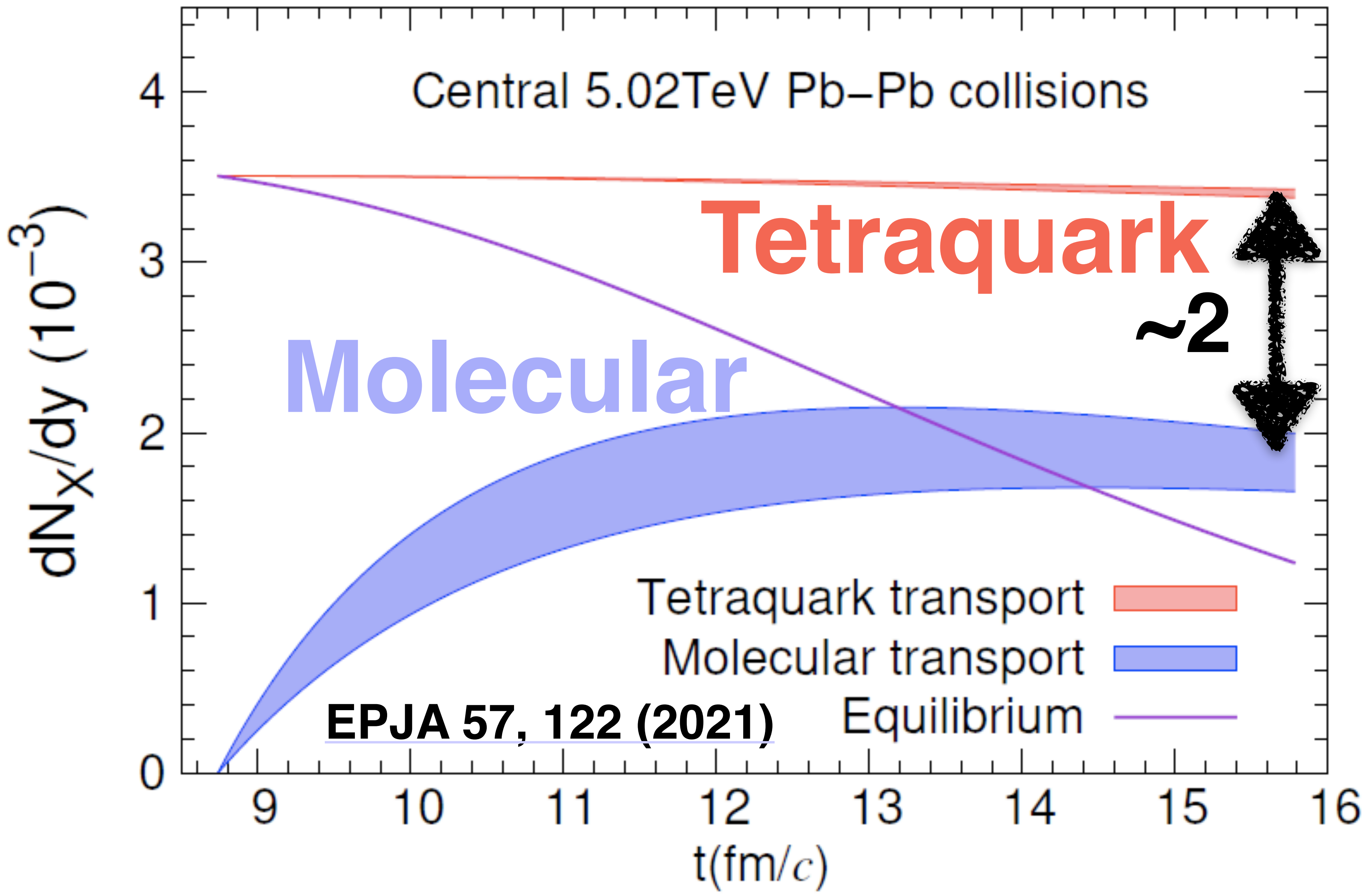
X(3872) in PbPb @ 5.02 TeV

Yen-Jie Lee, May 18, Room D 10:10



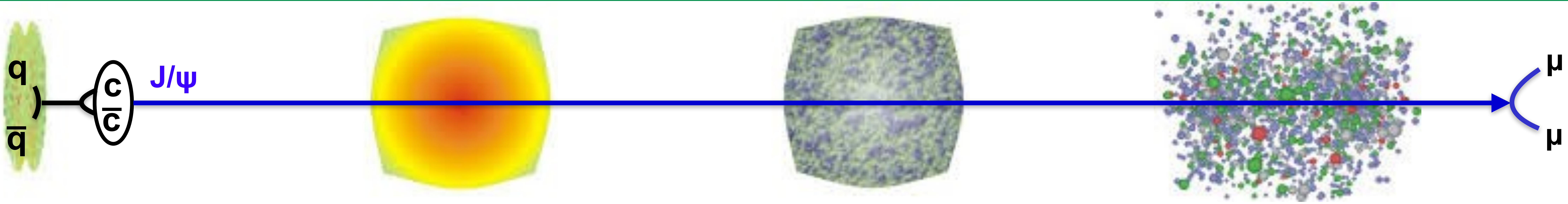
- Hint of prompt X(3872) to Ψ(2S) enhancement in PbPb
  - X(3872)/Ψ(2S) in PbPb = 1.10 ± 0.51 ± 0.53
  - X(3872)/Ψ(2S) in pp ≈ 0.1

TAMU transport model Wu et al



- Coalescence model expects a larger yield for molecular vs tetraquark up to a factor of ~250 in central PbPb.
- However large differences prevail between models.
- Future data will help elucidate the nature of X(3872).

Summary



- ✓ Hints of $Q\bar{Q}$ polarization seen in pp at forward y and PbPb at low p_T.
- ✓ Sequential suppression of $Q\bar{Q}$ states in pA.
- ✓ J/ψ flow at high p_T challenge the model description.
- ✓ J/ψ formed in jets provides new insights into production at high p_T.
- ✓ Exotic charmonium states are becoming accessible in HI.

Thank you for your attention!

Acknowledgement

U.S. DEPARTMENT OF ENERGY

Office of Science

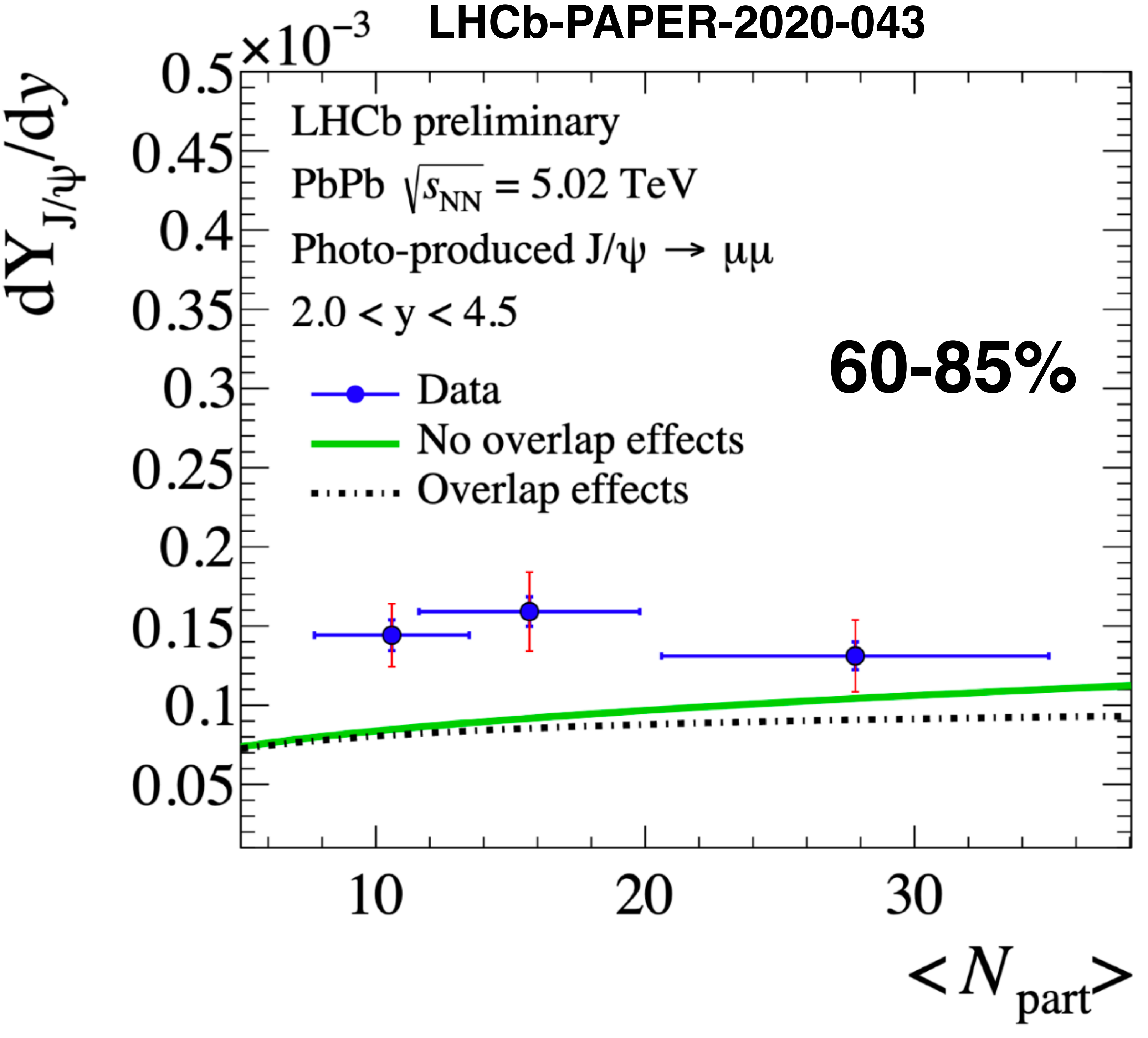
Alfred P. Sloan FOUNDATION

THE Welch FOUNDATION

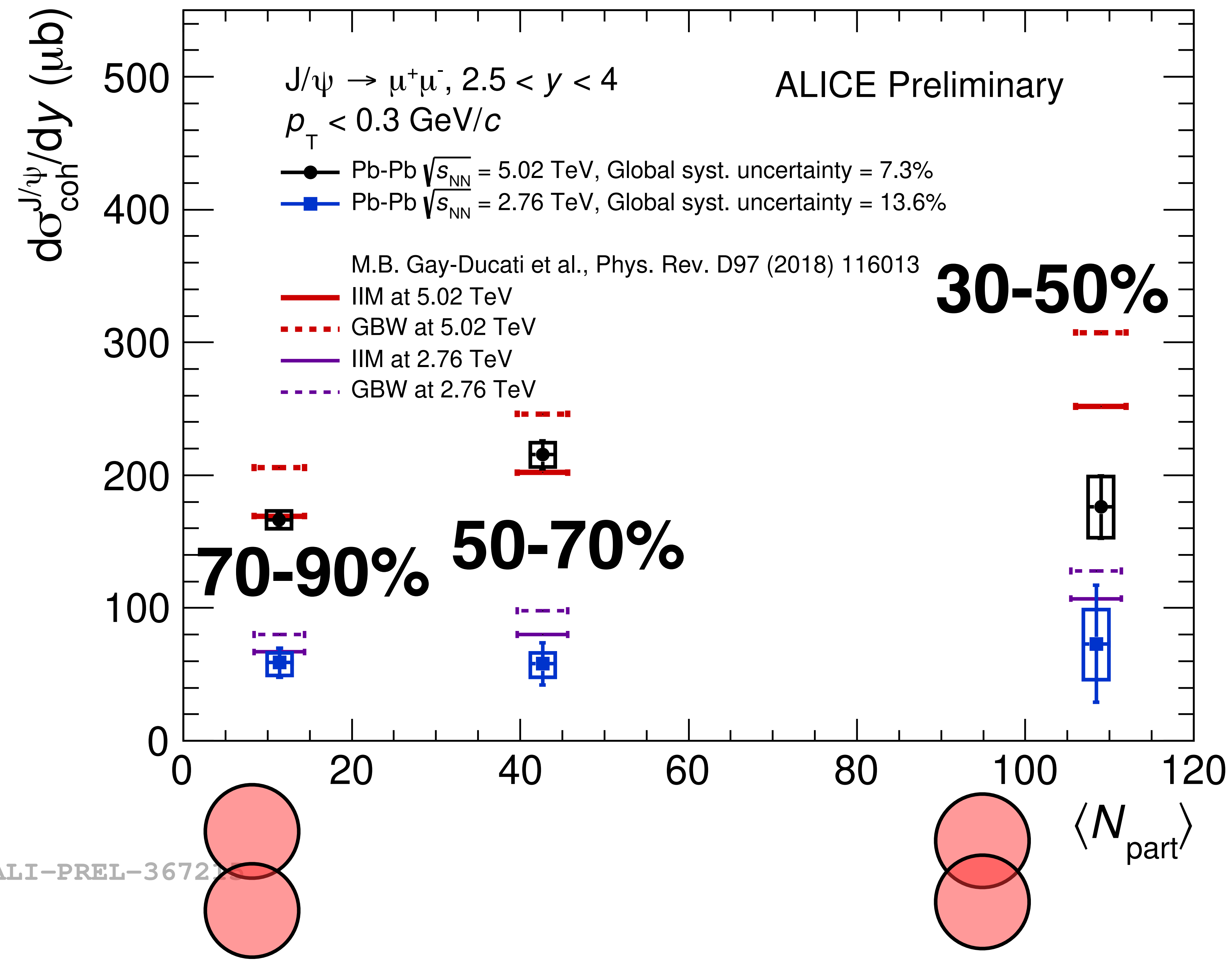
BACKUP

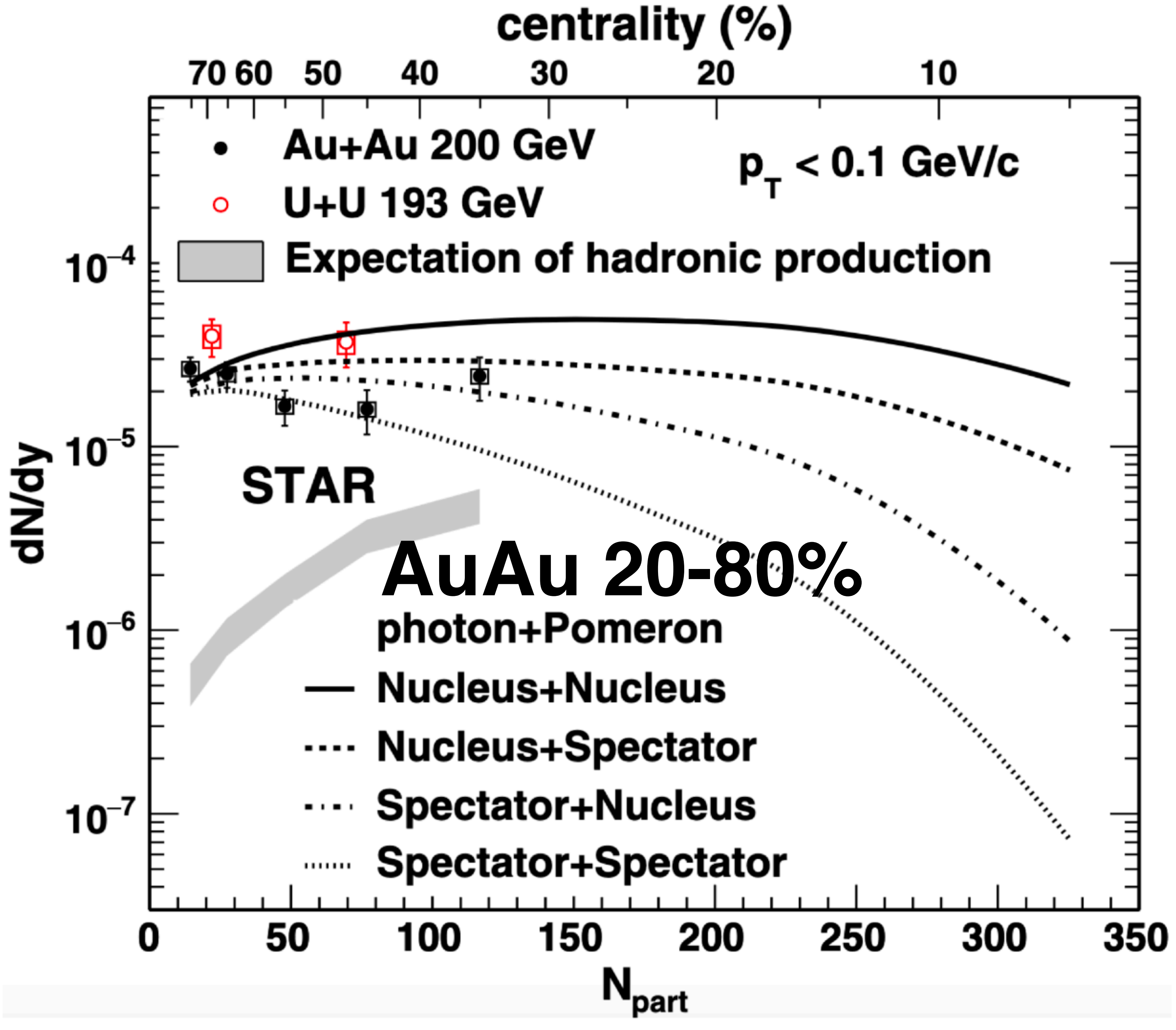
Coherent J/ψ photoproduction in semi-central AA

LHCb-PAPER-2020-043



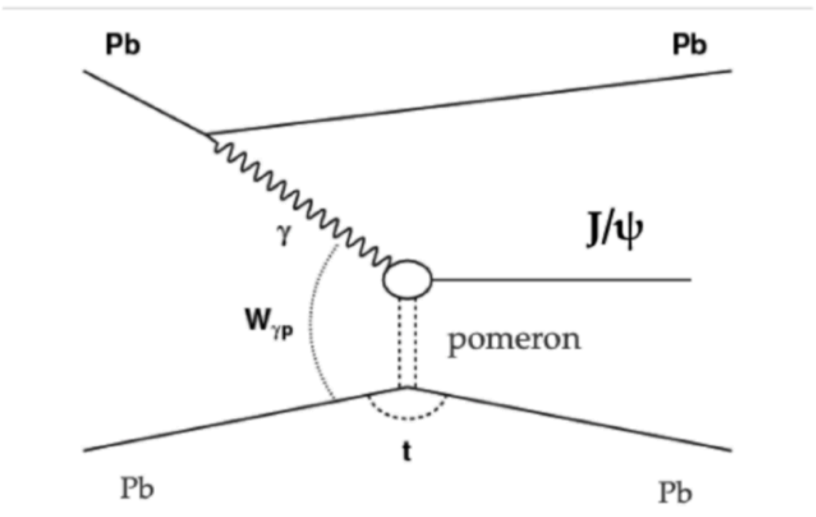
ALI-PREL-367215





PRL 123 (2019), 132302

Coherent photo-production

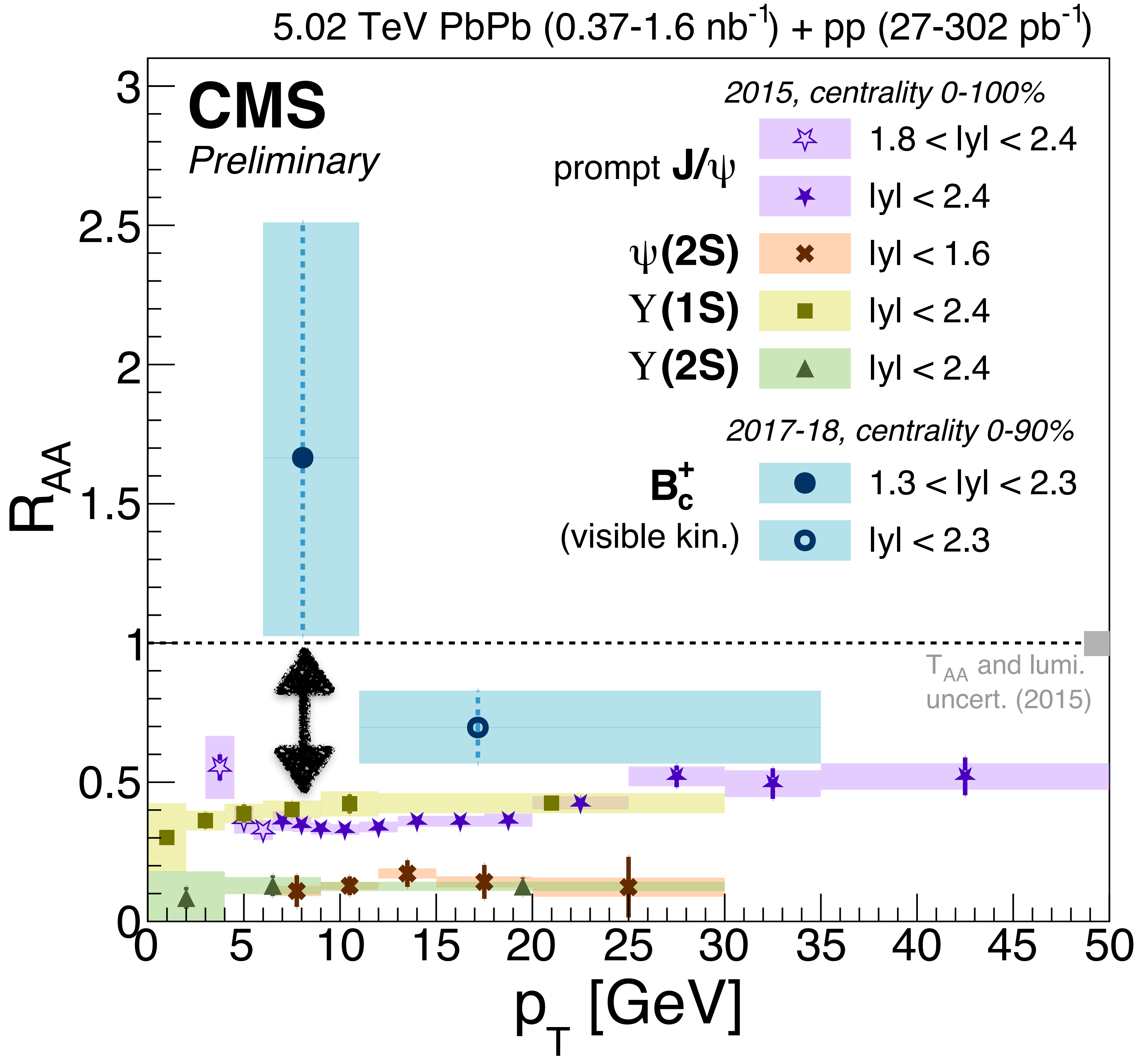


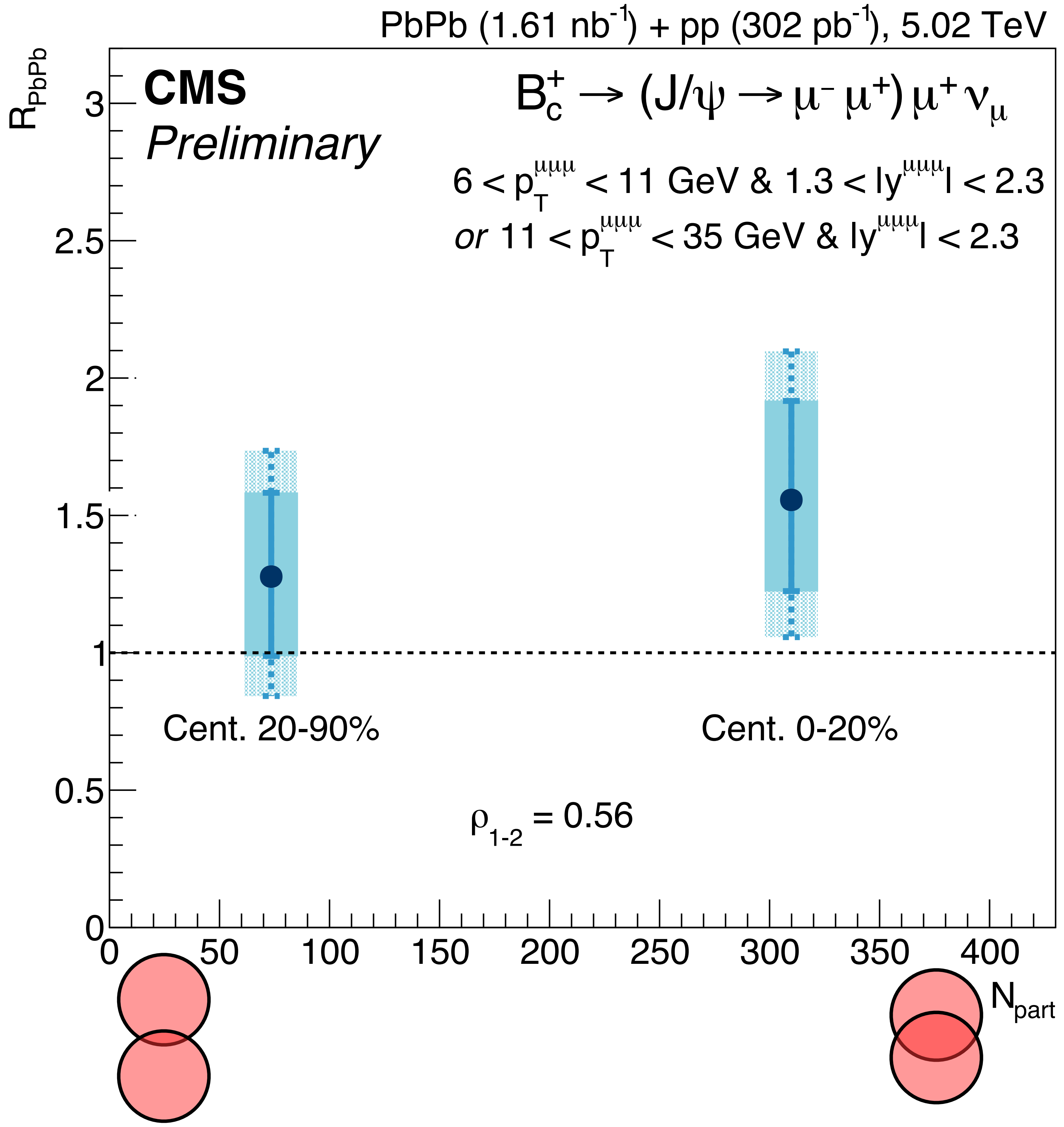
$\gamma(pomeron) \rightarrow J/\psi$

- No significant centrality dependence seen at LHCb down to 60%.
- Qualitative good model description in peripheral events using models with modified photon flux w.r.t to UPC.
- Results at RHIC disfavour production from nucleus-nucleus interactions.

B_c production in PbPb

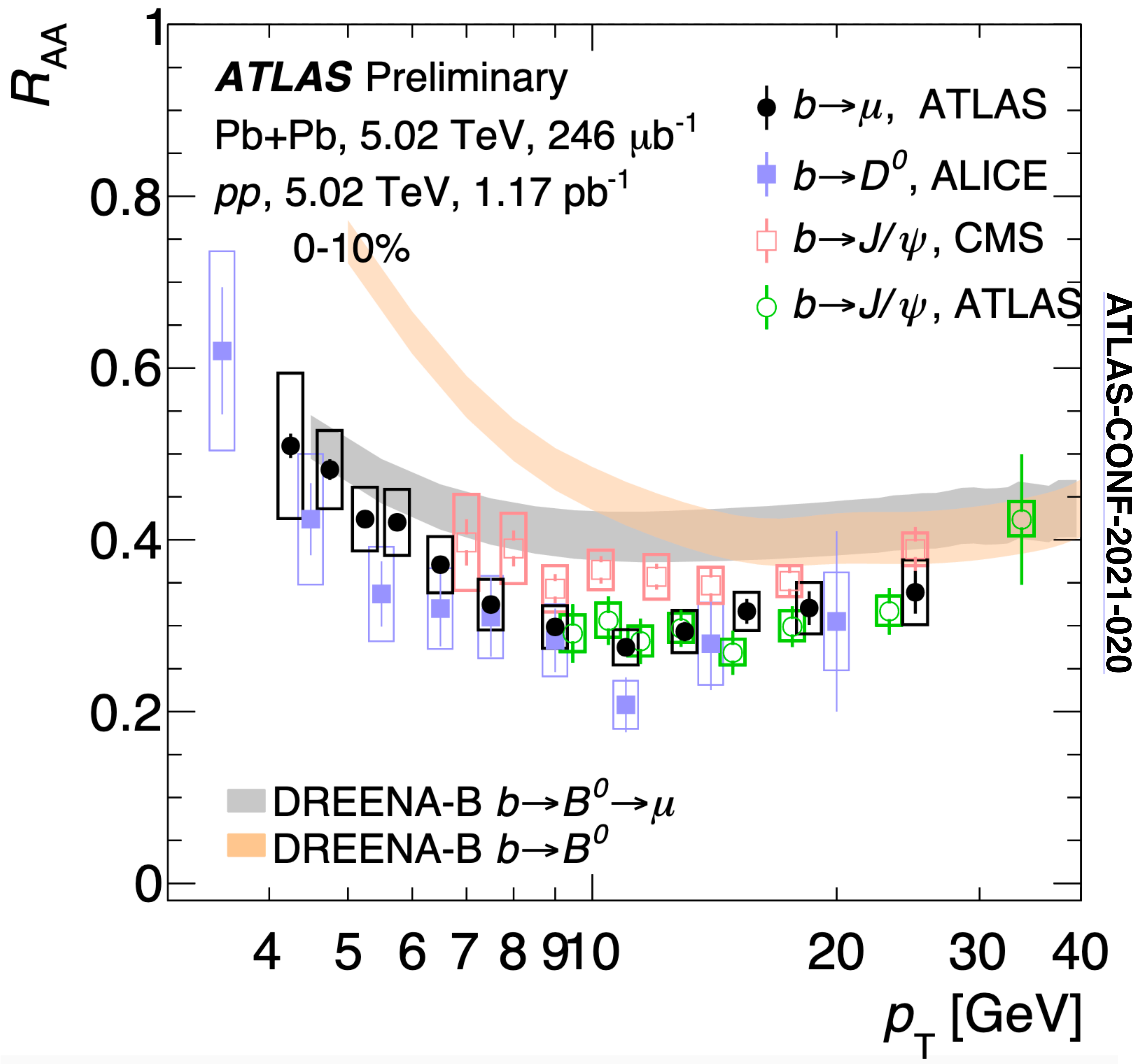
CMS-PAS-HIN-20-004





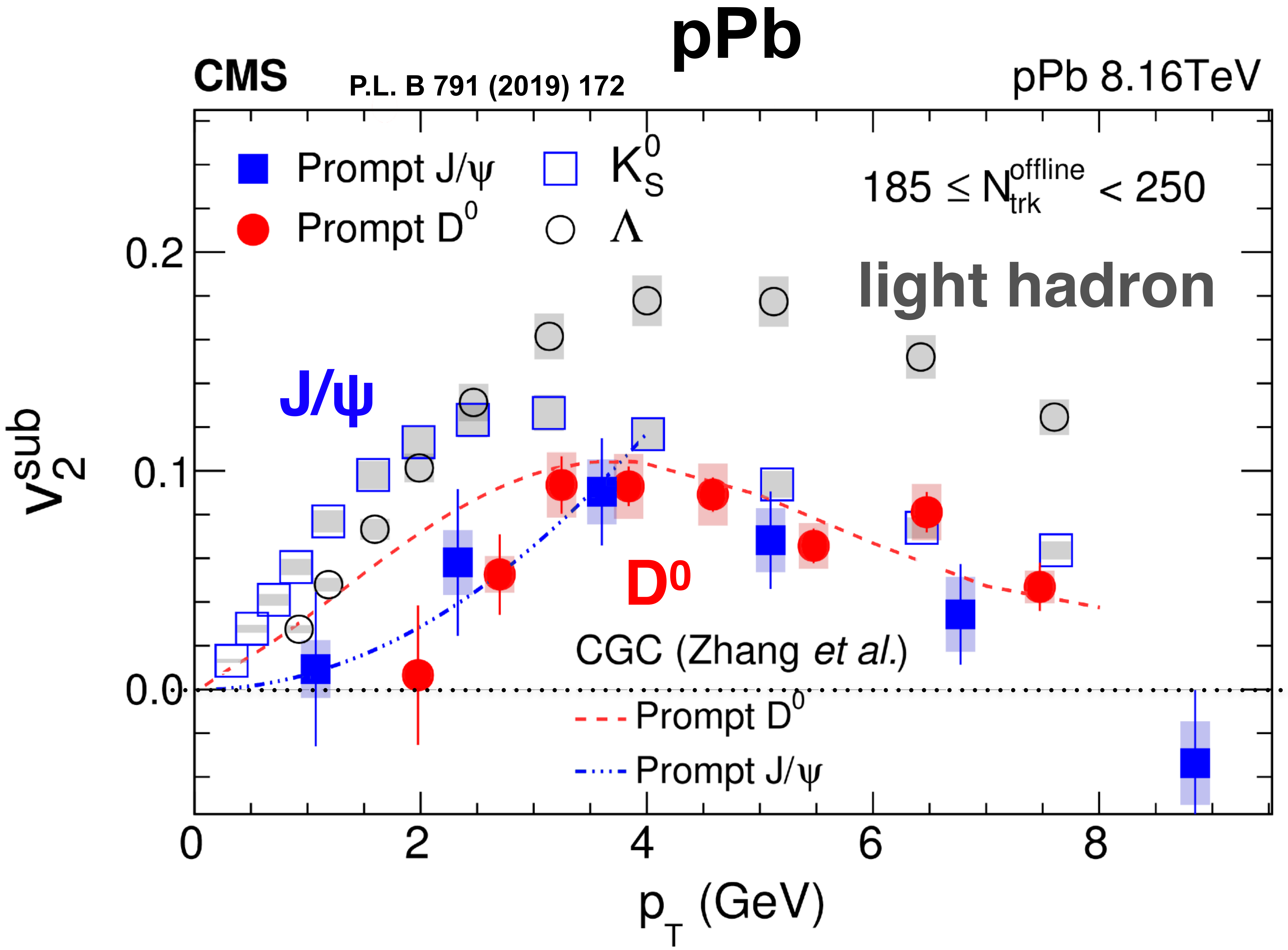
- First measurement of B_c in HI collisions.
- Hint of less suppression than quarkonia.

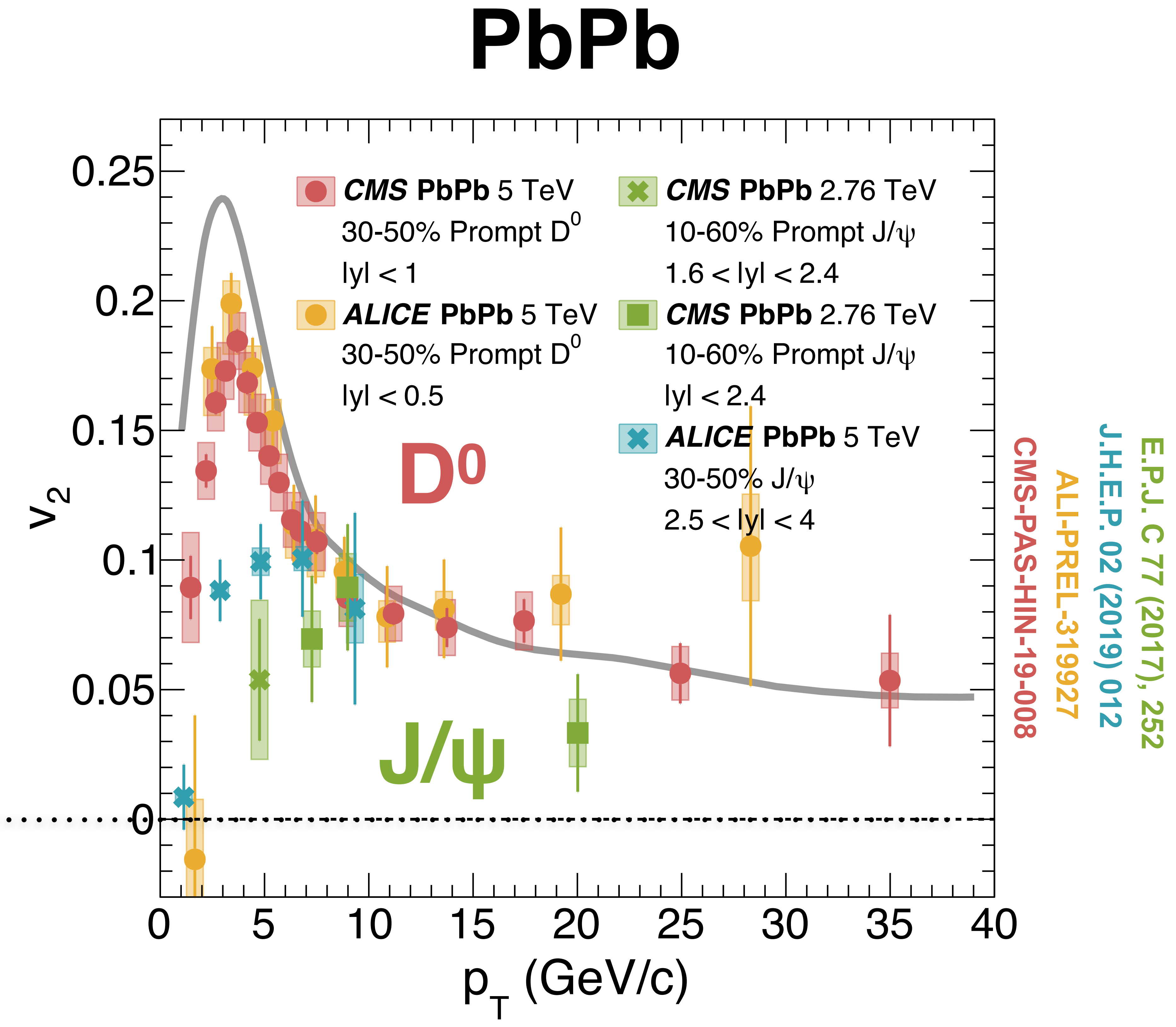
Non-prompt J/ψ production in PbPb



- Non-prompt J/ψ production consistent with other b-decay measurements.
- b-hadron suppression described qualitatively by energy loss models.

J/ψ v_2 in high-multiplicity pPb





- Observation of prompt J/ψ flow in high-multiplicity pPb → charm collectivity.
- **pPb**: $v_2(J/\psi)$ ~ $v_2(D^0)$ < v_2(light hadron) , **PbPb**: $v_2(J/\psi)$ < $v_2(D^0)$
- Final state effects don't describe charm v_2 in pPb → CGC in agreement with results.

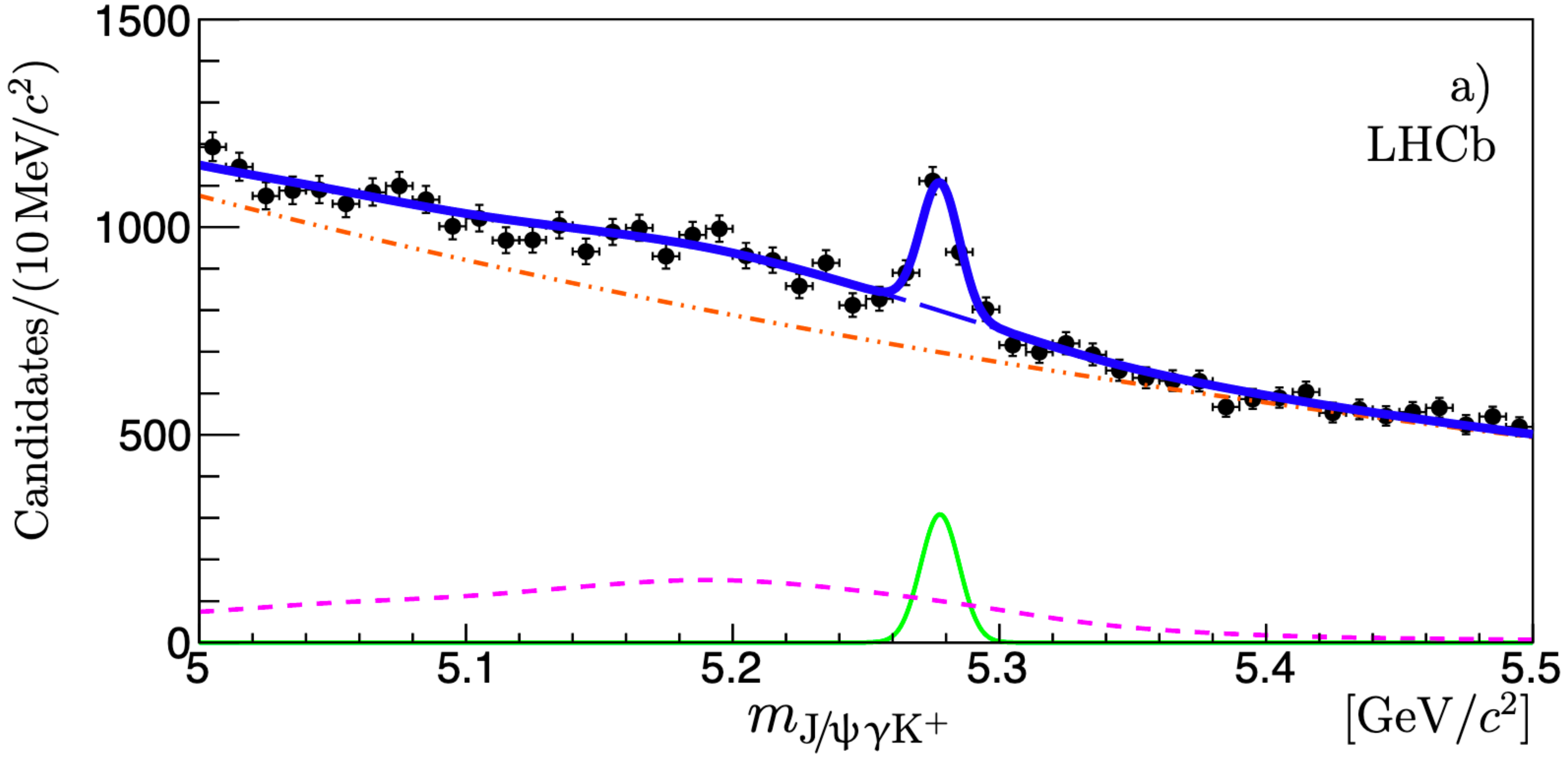
J/ψ FJF test of LMDE in pp

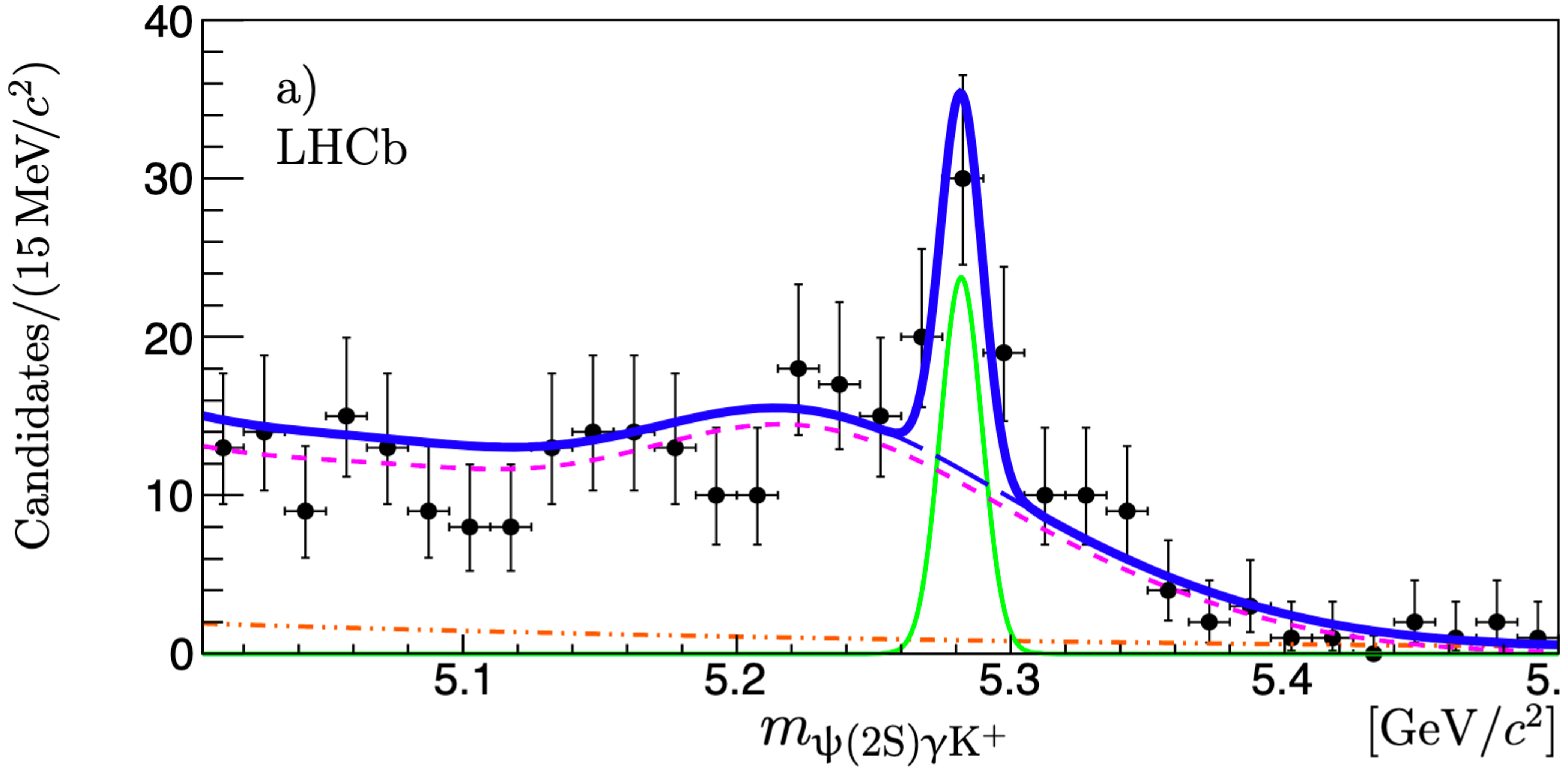
PLB 804 (2020) 135409

$$\Xi(E_c; z_1) \equiv \frac{N(E_c; z_1)}{\int_{0.3}^{0.8} N(E_c; z)\, dz}$$

- ~85% of J/ψ produced within a jet at high energies ($E_{J/\psi}$ > 15 GeV, E_{jet} > 19 GeV, |y| < 1).
- CMS results in pp at 8 TeV sensitive to LMDE sets.
- Within FJF approach, the BCKL (Bodwin et al) LMDE set is favoured.

NPB 886 (2014) 665-680

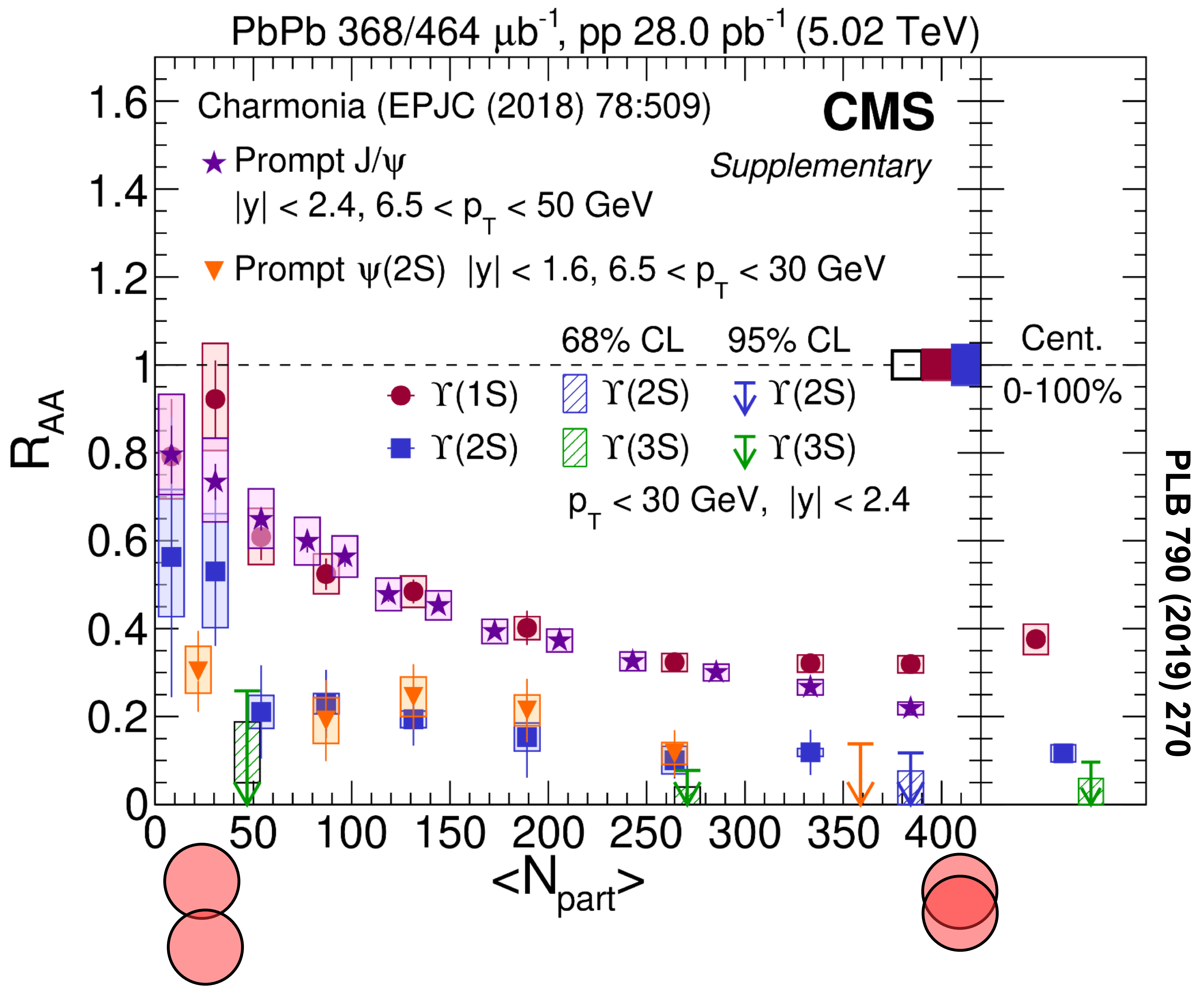


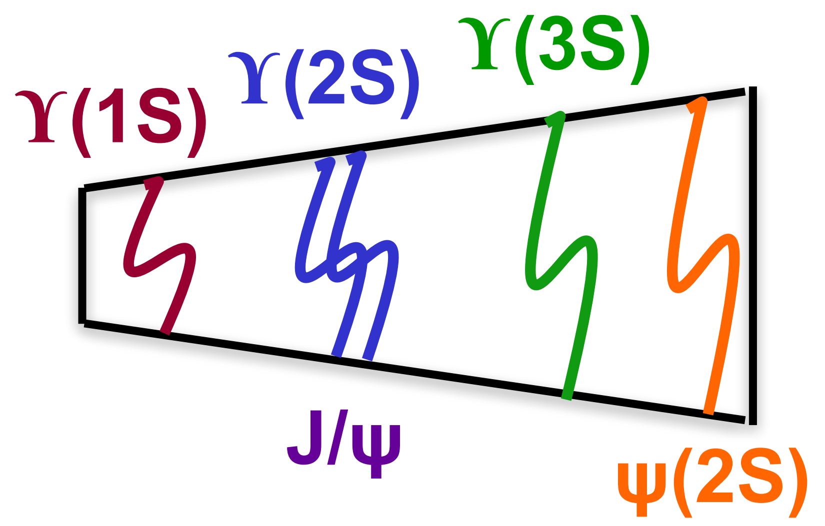


- Measured result in pp at 7 TeV and 8 TeV:
  - $$R = \frac{B(X(3872) \to \psi(2S)\gamma)}{B(X(3872) \to J/\psi\gamma)} = 2.46 \pm 0.64 \pm 0.29$$

- Does not support a pure DD molecular interpretation.

ϒ(nS) vs ψ(nS) modification in PbPb





- R_{AA}(J/ψ) ~ R_{AA}(ϒ(1S)) > R_{AA}(ψ(2S)) ~ R_{AA}(ϒ(2S)) > R_{AA}(ϒ(3S)).
- Effects beyond Debye colour-screening suppression.