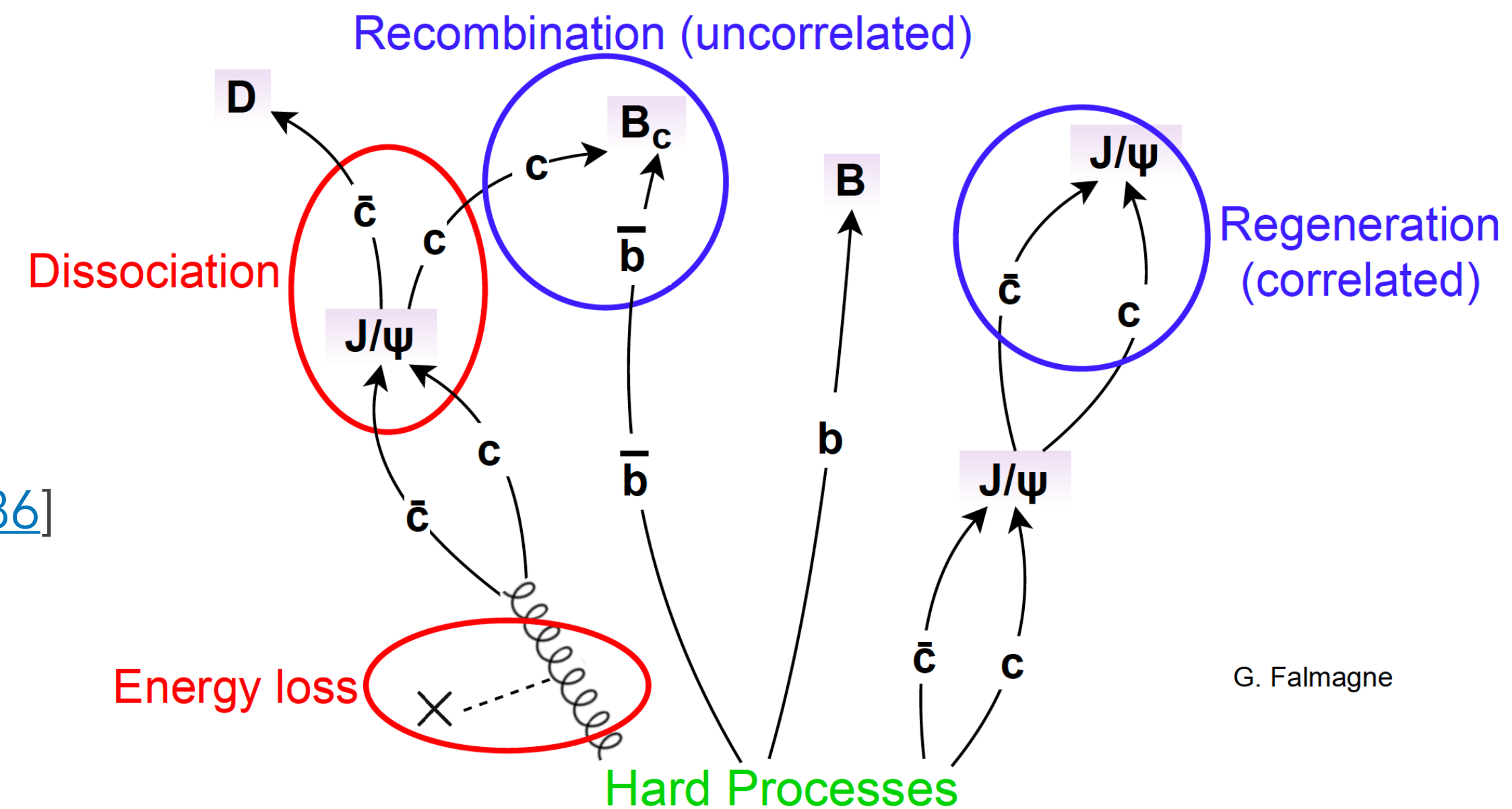


New results on heavy flavors and quarkonia in heavy ion collisions with CMS

Florian Damas (florian.damas@cern.ch) for the CMS collaboration
Laboratoire Leprince-Ringuet (École Polytechnique, CNRS-IN2P3)

Golden probes to characterize the QGP phase

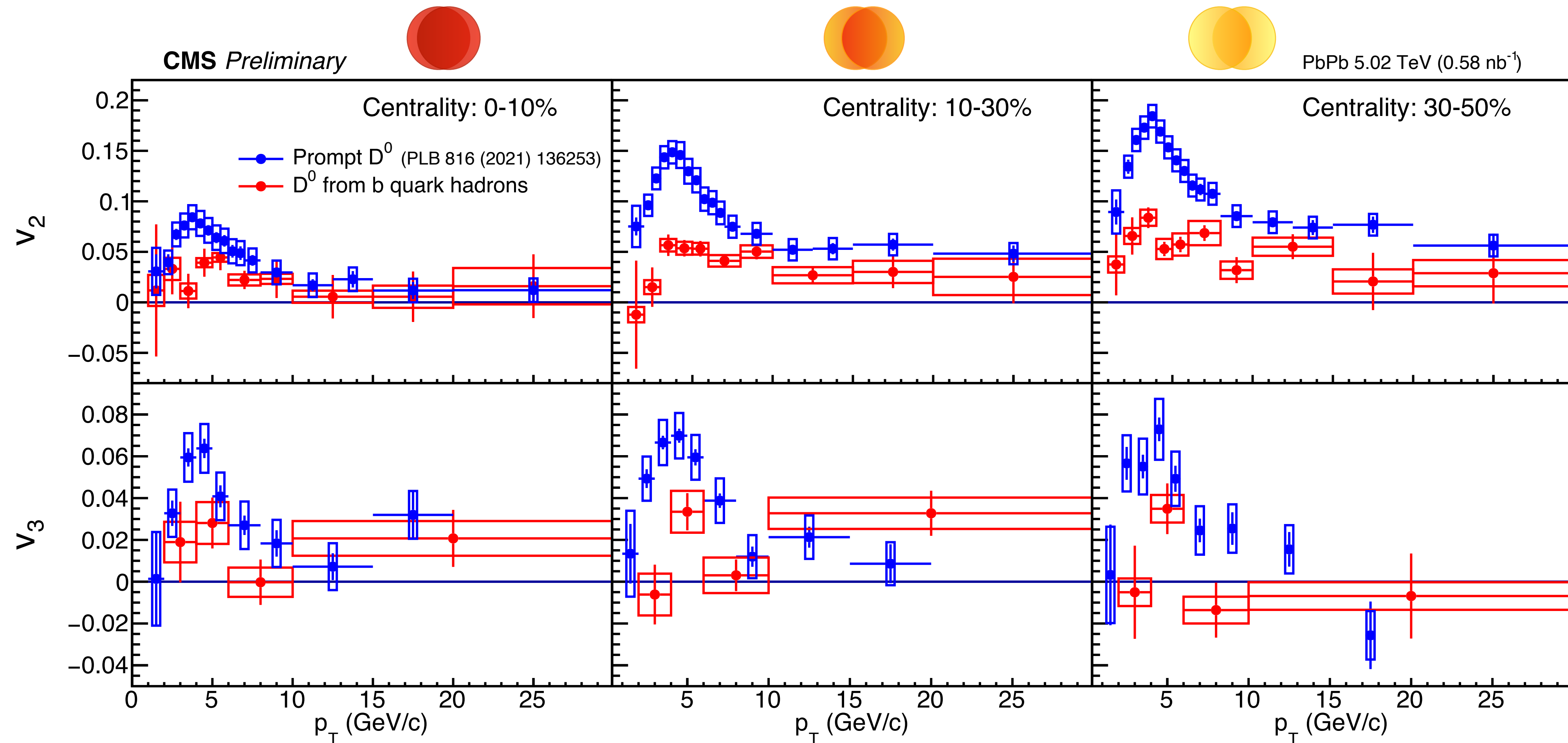
- ▶ witness the time evolution of the collision system
 - ☞ participate to the collective motion?
- ▶ **interact with medium constituents**
(energy loss mechanisms, quarkonium dissociation)
 - ☞ extraction of **transport properties** [[NPA 979 \(2018\) 21-86](#)]
- ▶ **modified hadronization** inside the medium
 - (re)combination of heavy quarks
 - suppression / enhancement of rare observables



G. Falmagne

Azimuthal anisotropy of D^0 mesons

CMS-PAS-HIN-21-003



Elliptic flow

prompt D^0

>

$b \rightarrow D^0 > 0$

Triangular flow

prompt D^0

$\approx$

$b \rightarrow D^0 \neq 0?$

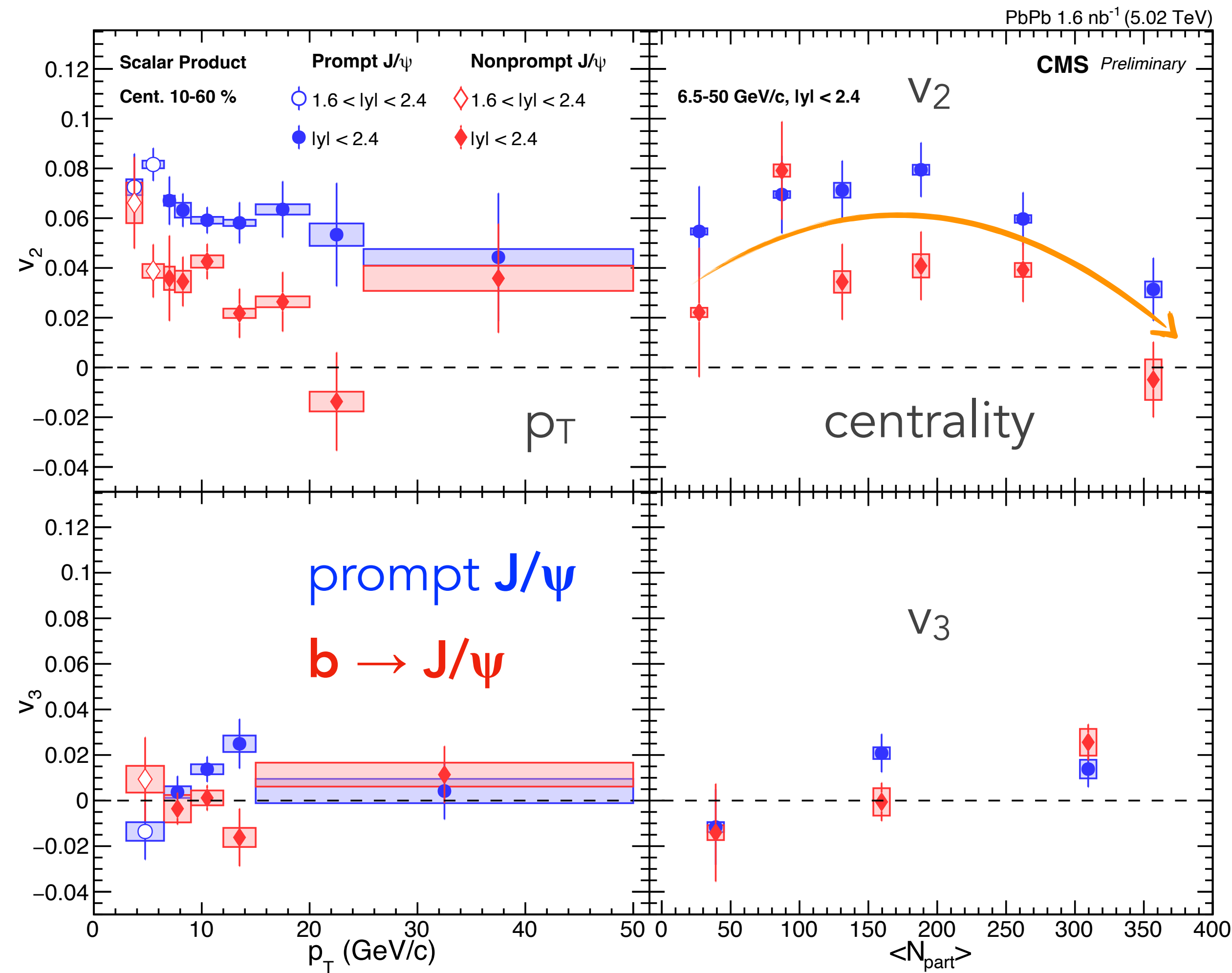
Prompt vs non-prompt D^0 flow

- ▶ mass ordering (*the lighter the hadron, the greater its flow*)
- ▶ weaker centrality and p_T dependence for $b \rightarrow D^0$

More details in Milan's talk!

[Thursday 15:00](#)

CMS-PAS-HIN-21-008

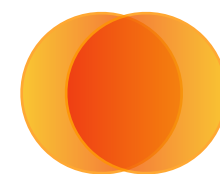
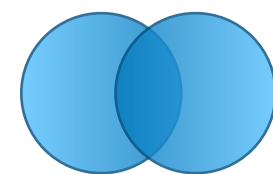


Significant and positive v_2 up to high p_T

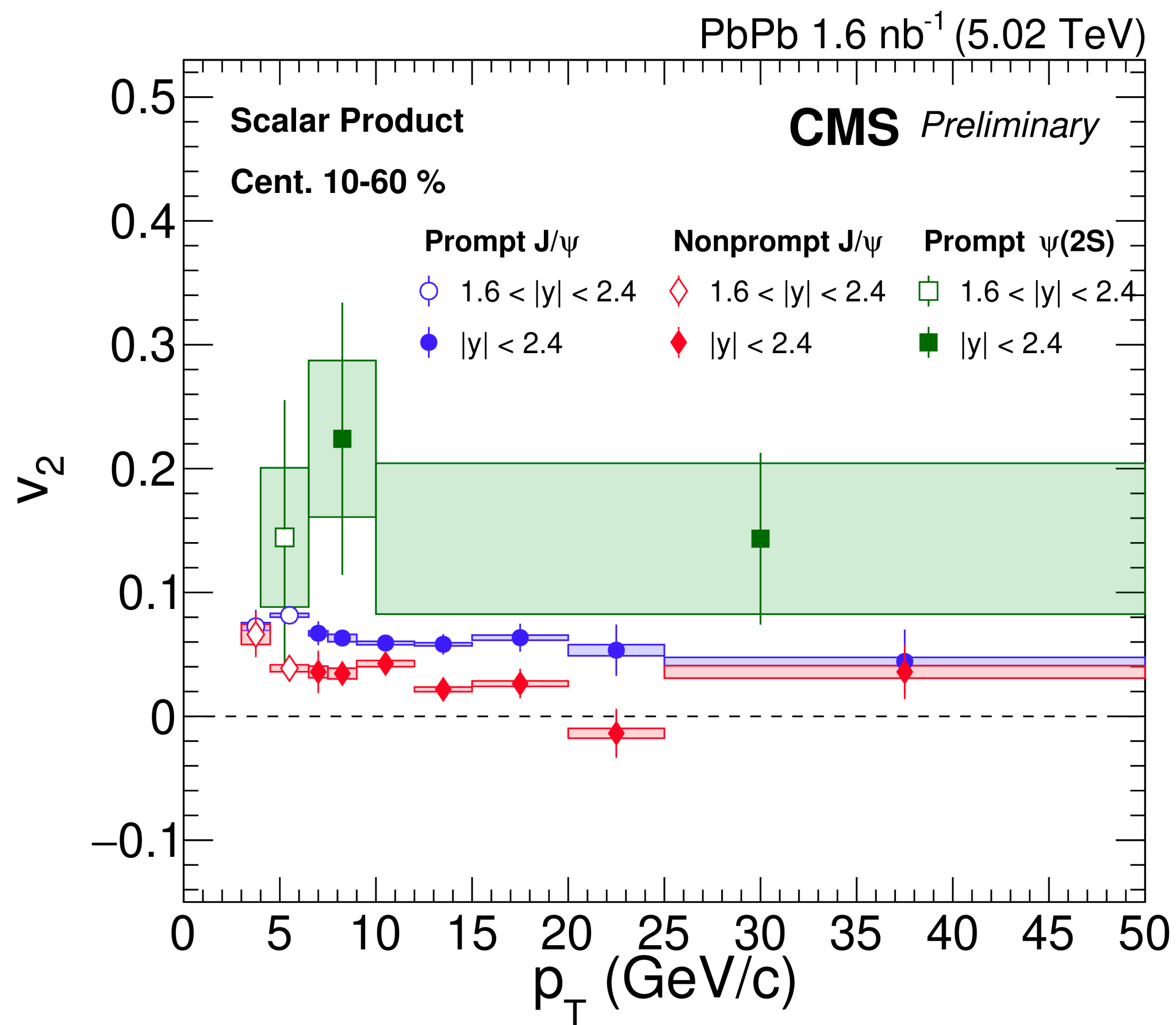
- ▶ **prompt J/ψ** > **b → J/ψ**
 - ➔ different collective motion for charm and beauty quarks
- ▶ **smaller elliptic flow in the most central collisions**
 - ➔ hydrodynamical behavior

First v_3 measurement with separate components

- ▶ compatible with 0
- ▶ **b → J/ψ** v_3 consistent with result for **b → D⁰**
 - ➔ is beauty sensitive to initial-state fluctuations?



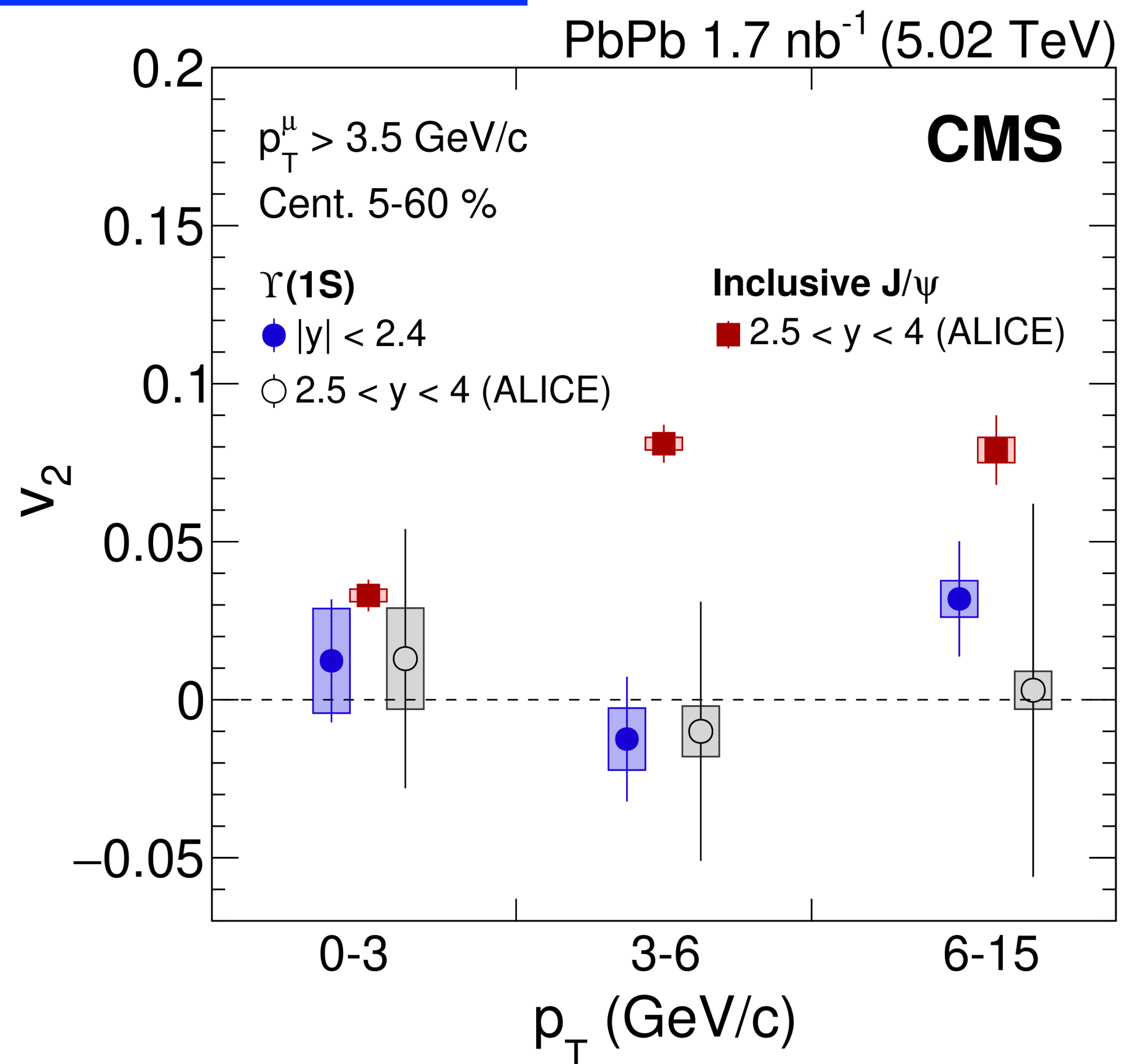
CMS-PAS-HIN-21-008



First measurement of $\psi(2S)$ azimuthal anisotropy

- ▶ v_2 : hint of **prompt $\psi(2S)$** > **prompt J/ψ**
 - ➡ different amount of recombination?
 - larger relative contribution from thermalized charm quarks!
 - ➡ what about $p_T > 10$ GeV then?
 - path-length dependent dissociation mechanism?
- ▶ v_3 signal compatible with 0 (see backup slides)

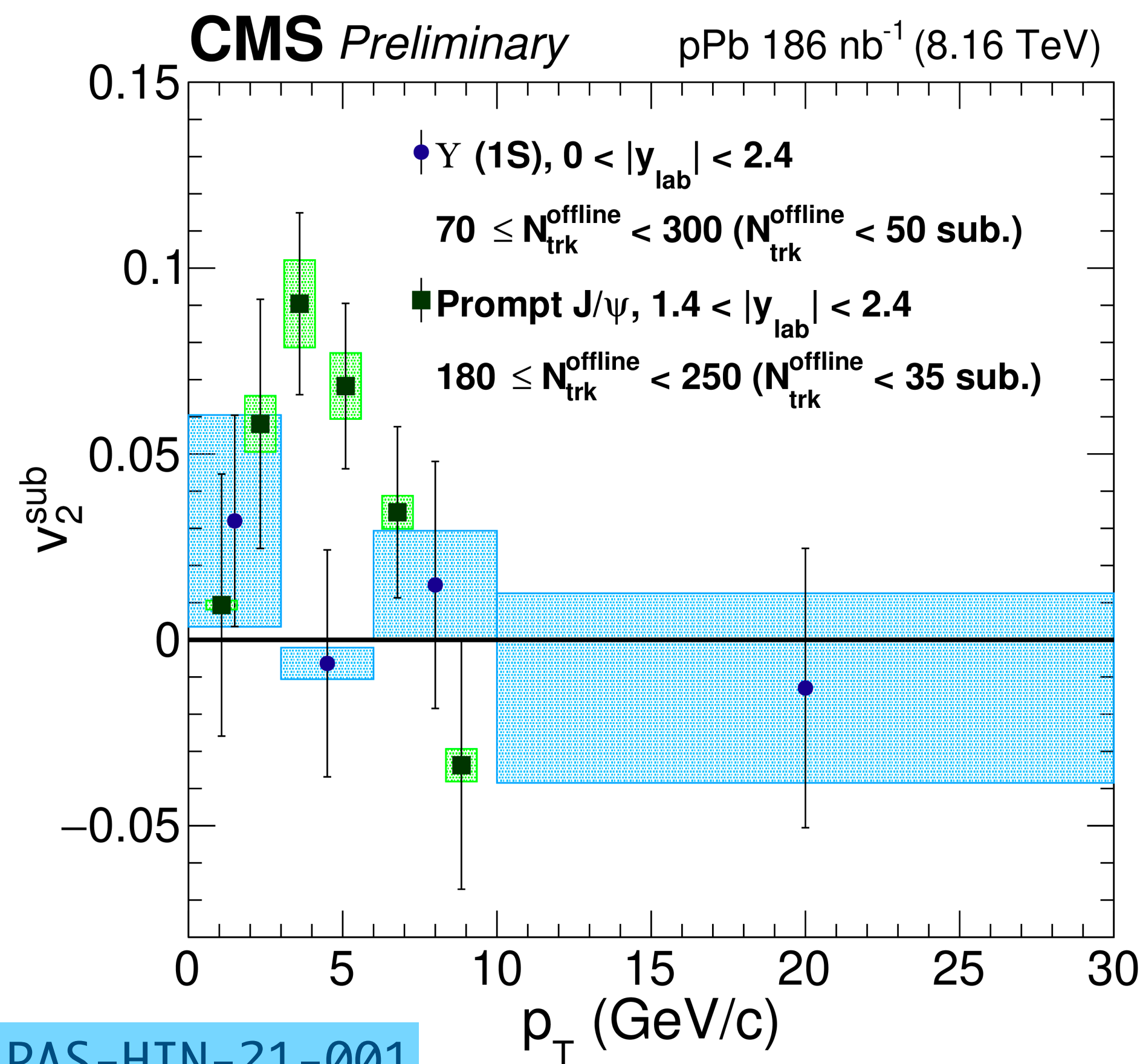
PLB 819 (2021) 136385



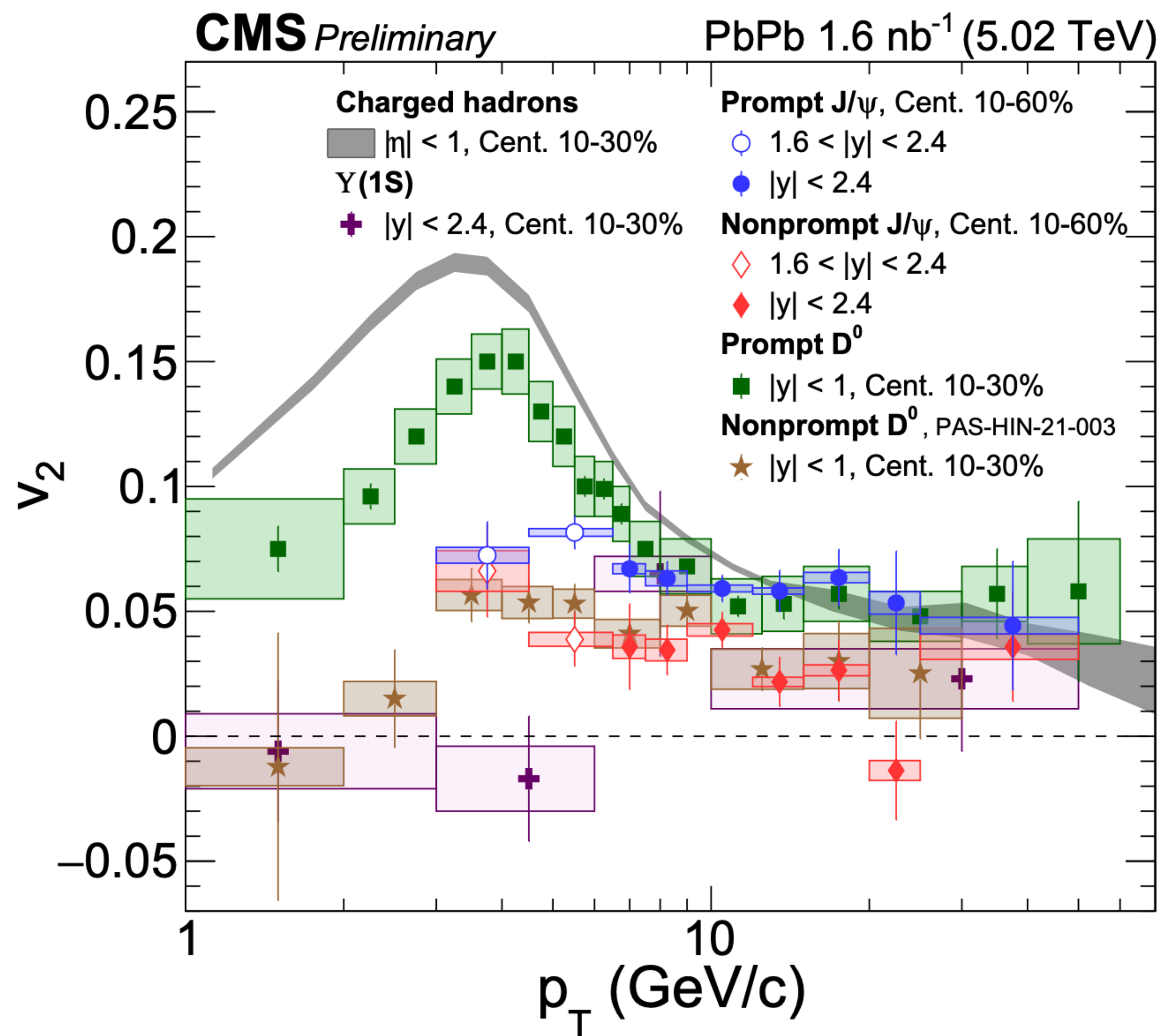
- ▶ v_2 consistent with 0 in all measured intervals
- ▶ unlike J/ψ → different sensitivity to path-length dependent effects

Same findings in high-multiplicity pPb events!

- ▶ first $\Upsilon(1S)$ v_2 measurement consistent with 0
- ▶ J/ψ flow magnitude similar to the PbPb case



CMS-PAS-HIN-21-001



Comprehensive family picture in PbPb collisions

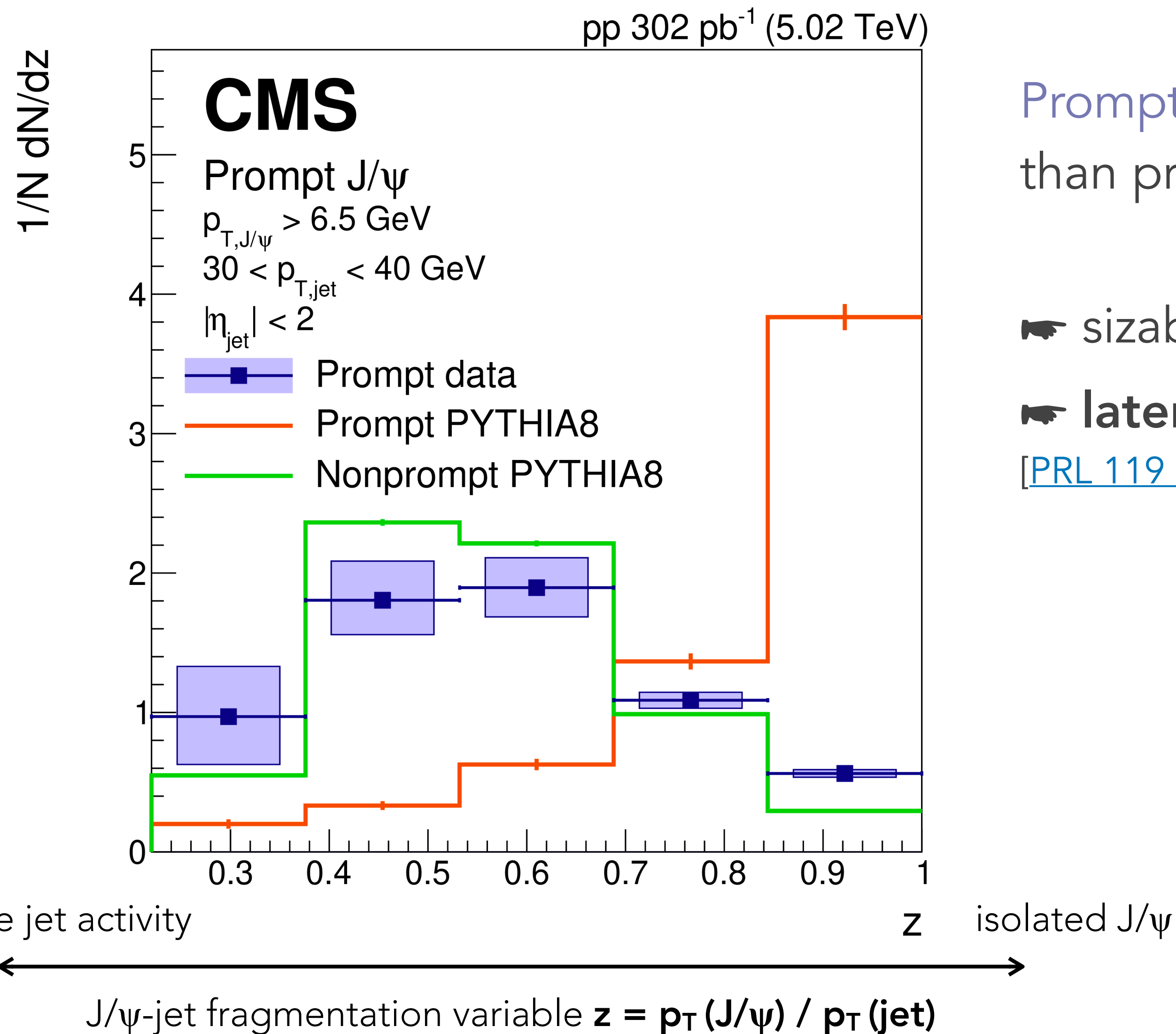
- steep increase at low p_T following mass hierarchy
hydrodynamic regime: light > charm > beauty
- maximum reached for $3 < p_T < 6$ GeV
light $\gtrsim$ prompt D^0 > prompt J/ψ > $b \rightarrow$ hadrons
 ➡ coalescence of heavy quarks with light ones carrying flow!
- convergence towards a **non-zero v_2 at high p_T**
 ➡ originating from universal parton energy loss?

figure available [here](#)

J/ψ production inside jets – in pp collisions

Normalized z distribution in pp collisions

PLB 825 (2021) 136842

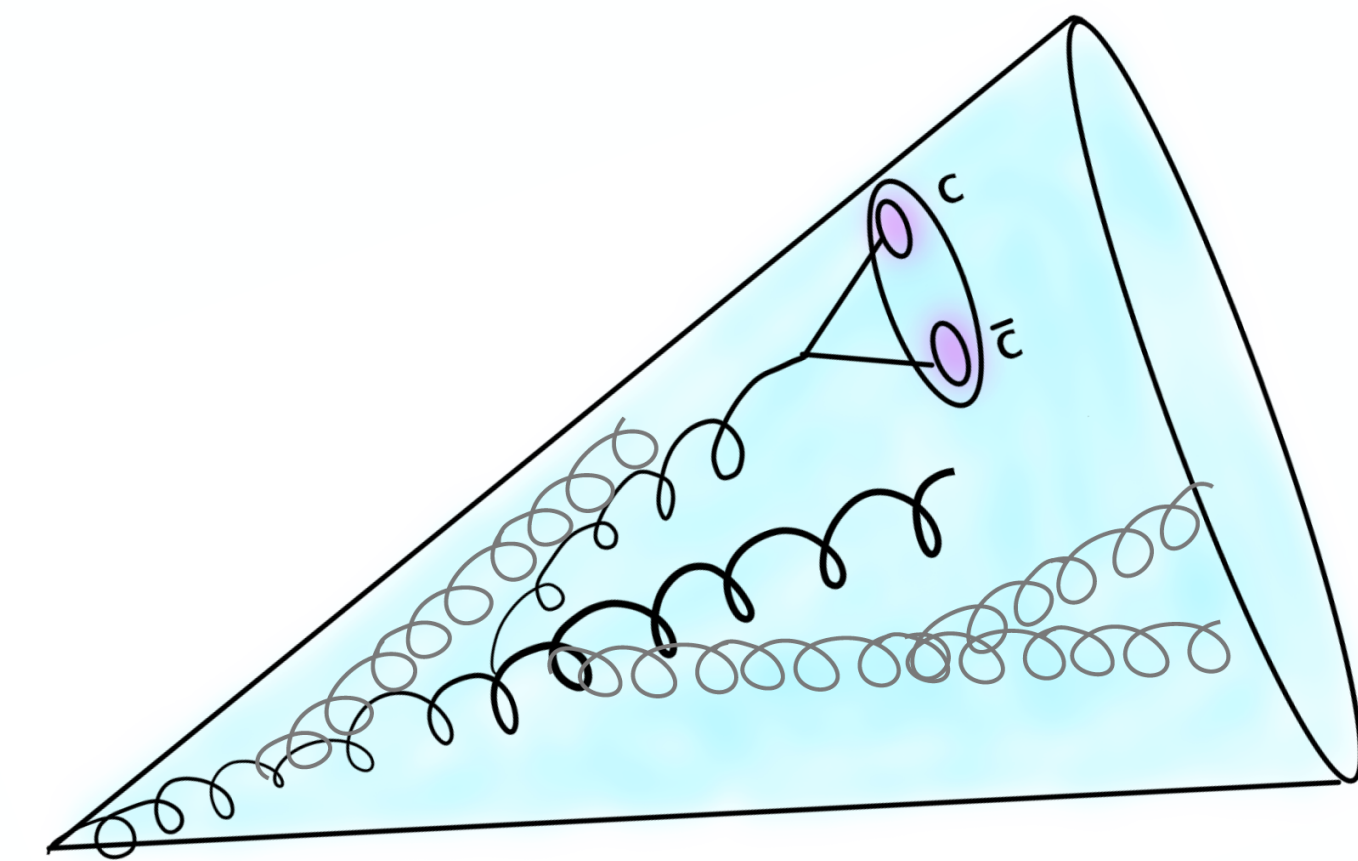


Prompt J/ψ is produced with more jet activity (low z) than predicted by models (LO calculations)

➡ sizable **contribution from parton shower**

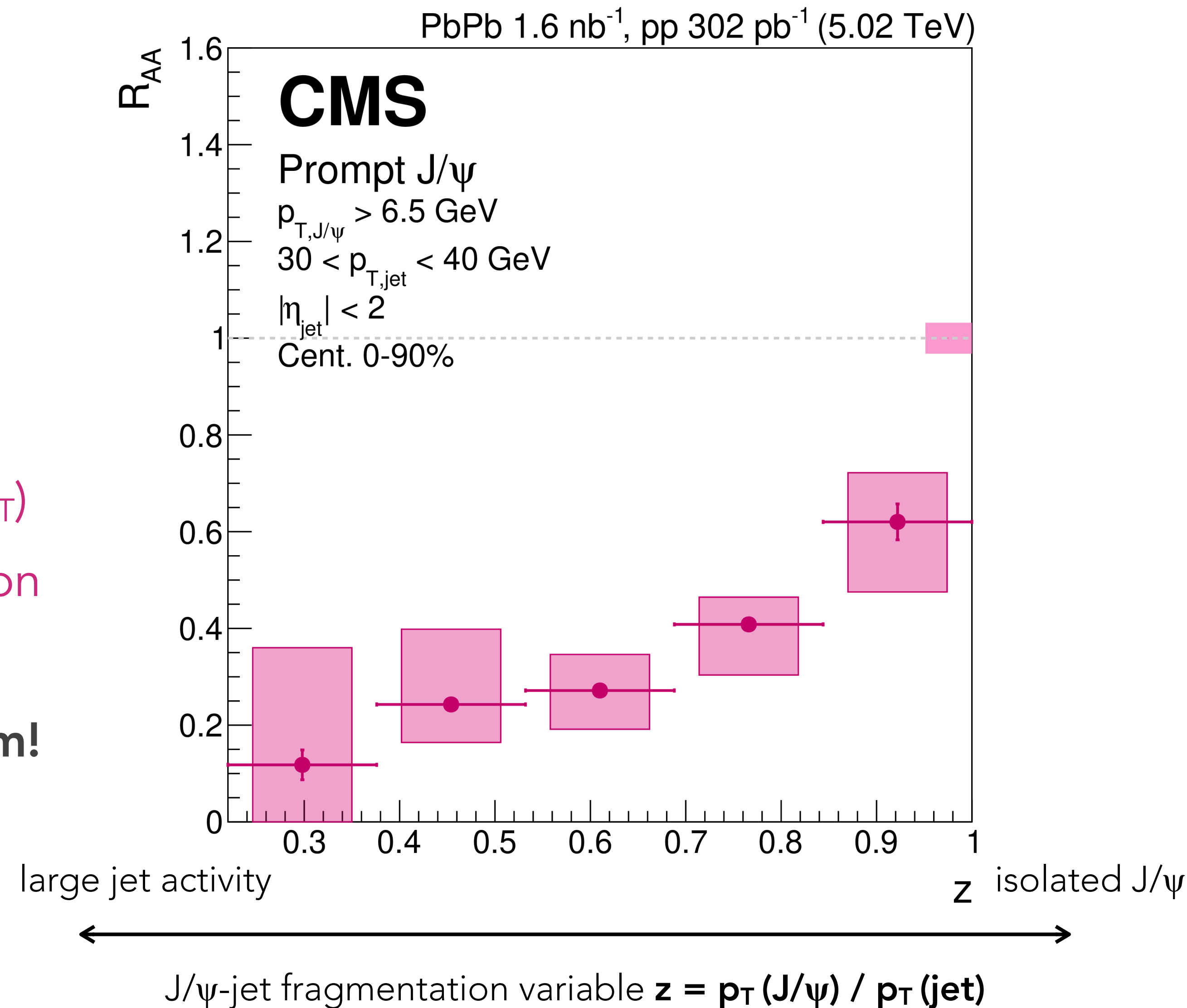
➡ **later formation** than generally assumed!

[[PRL 119 \(2017\) 032002](#)]



© Batoul Diab

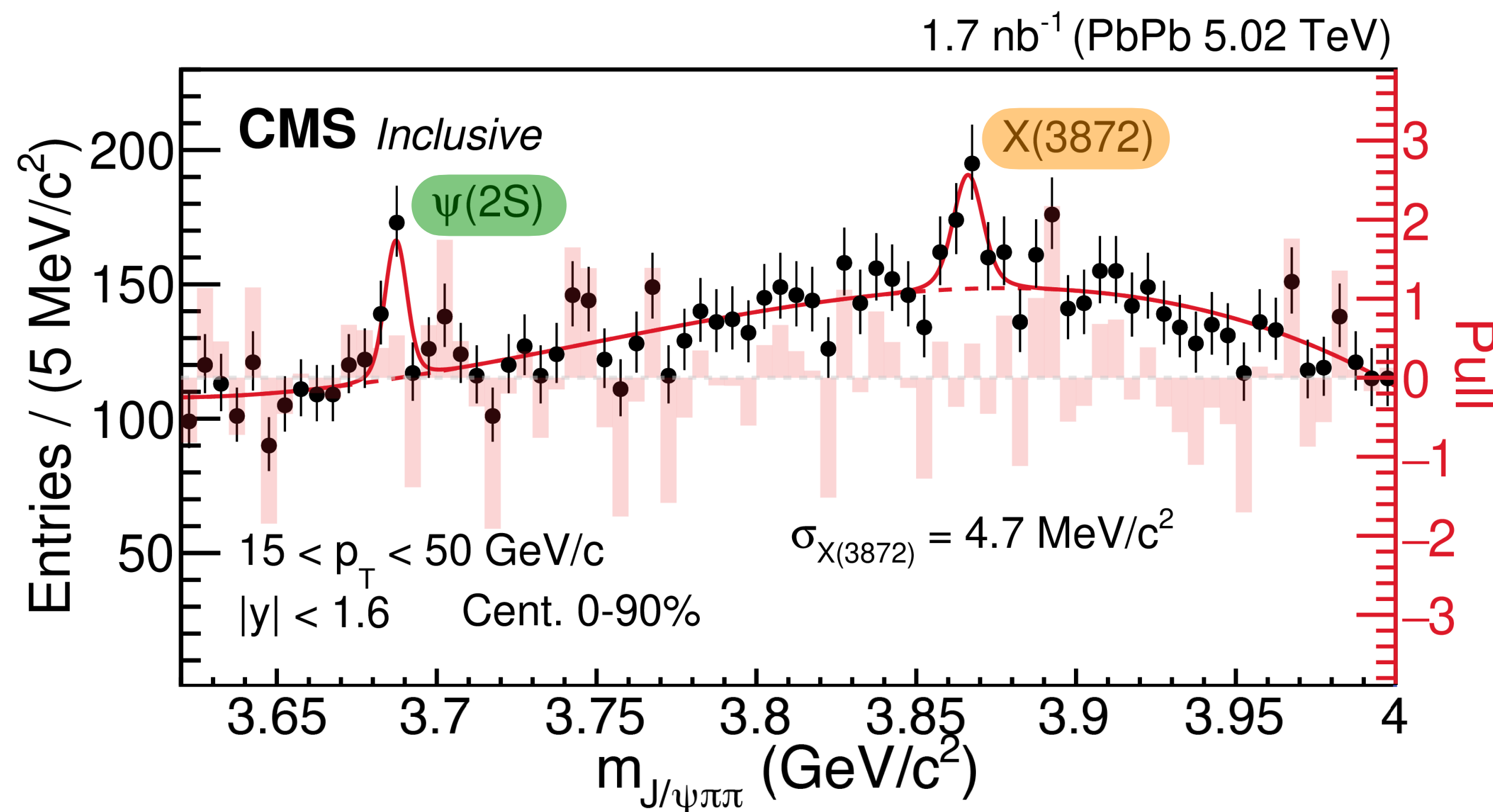
- ▶ Implication for heavy-ion data interpretation:
parton energy loss inside the QGP prior to J/ψ formation
- ▶ Measurement in PbPb collisions
 - less suppression for isolated J/ψ (i.e. high p_T)
 - more medium interactions in the low- z region
- ➡ jet quenching as J/ψ suppression mechanism!



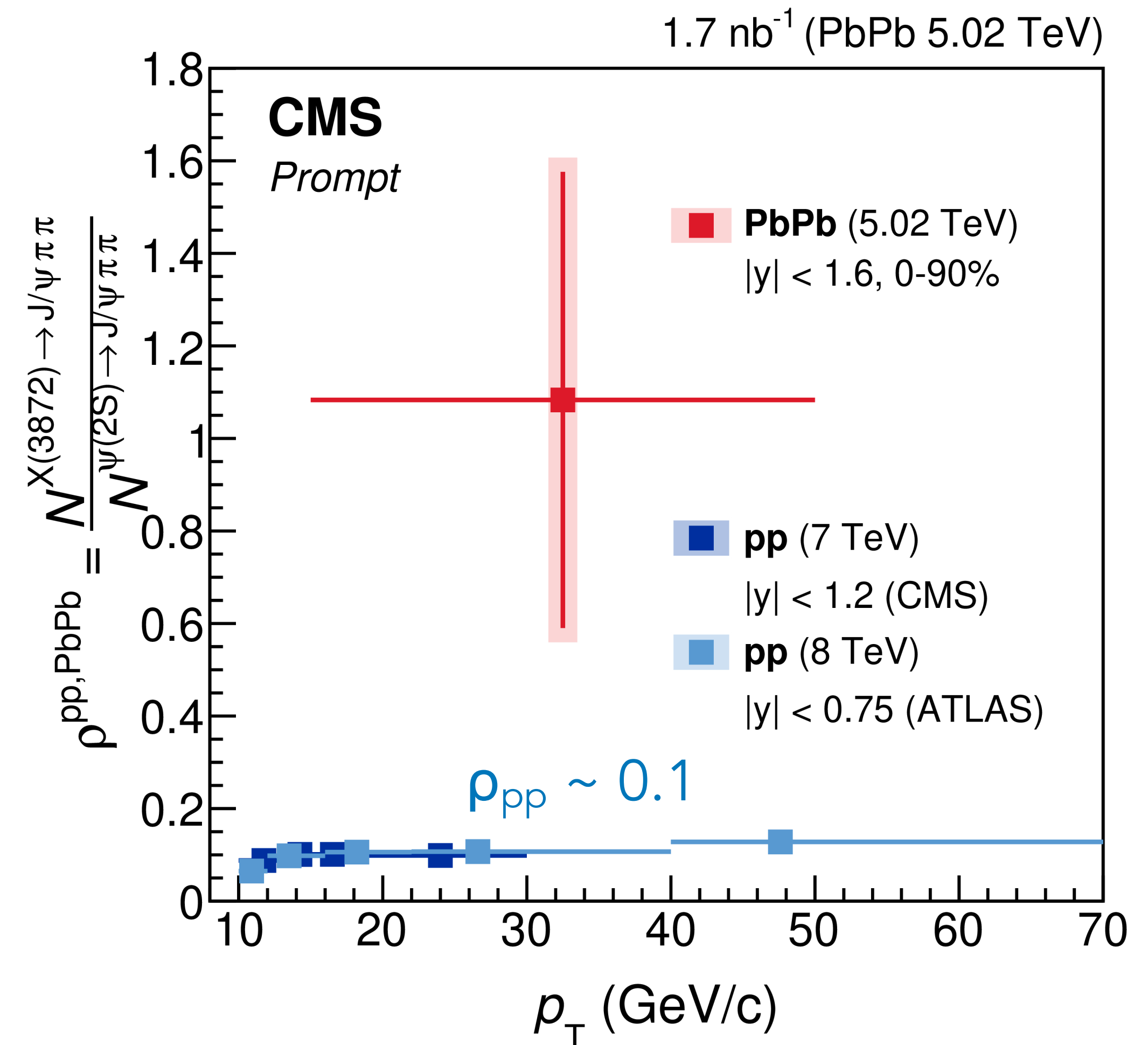
PRL 128 (2022) 032001

First evidence of **X(3872)** production! (4.2σ significance)

- ▶ potentially less suppressed than **$\psi(2S)$**
- ▶ **novel probe of the in-medium hadronization**
 - coalescence vs dissociation mechanisms
 - molecular or tetraquark bound state?

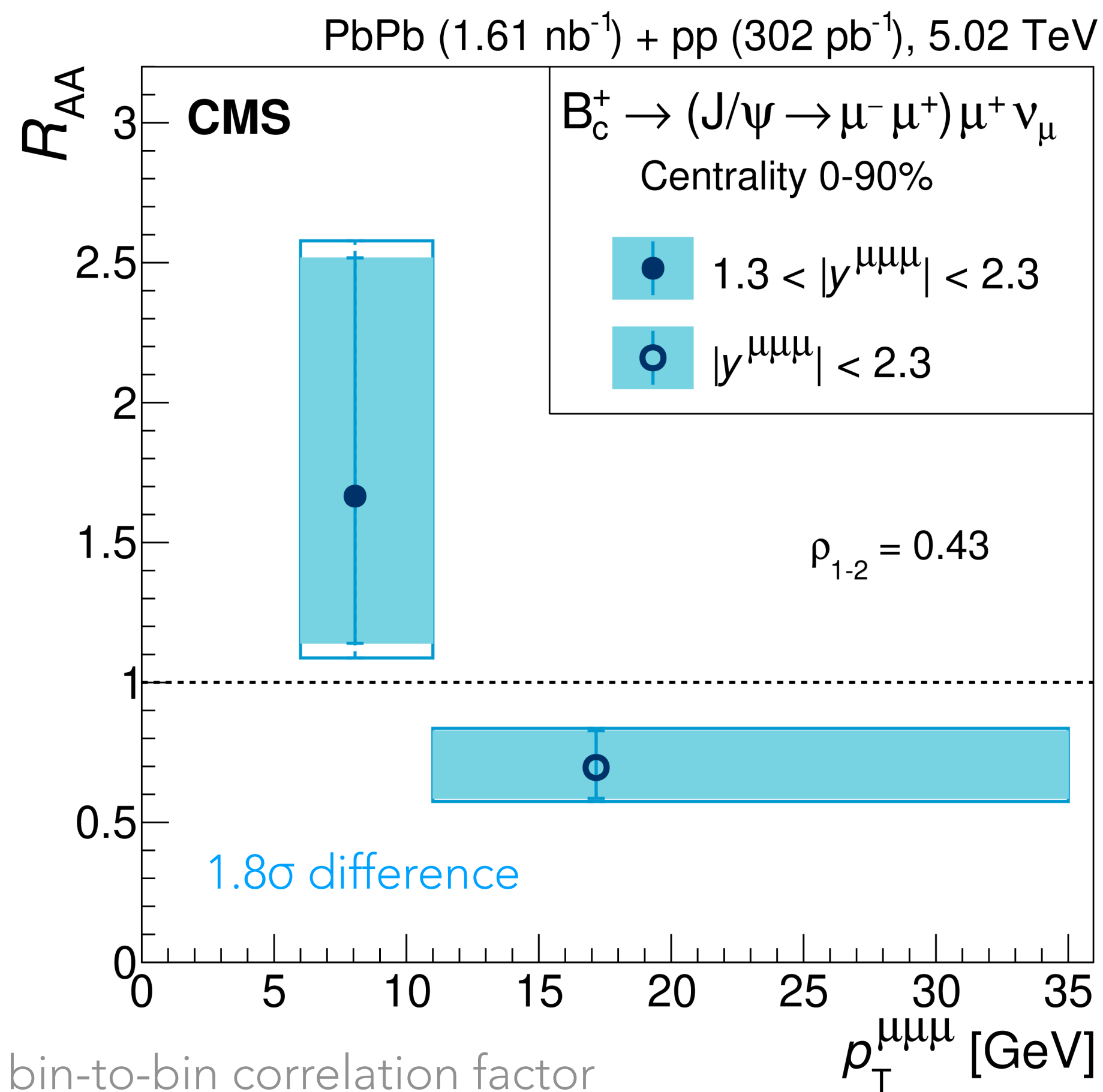


$$\rho_{\text{PbPb}} = 1.08 \pm 0.49 \text{ (stat.)} \pm 0.52 \text{ (syst.)}$$



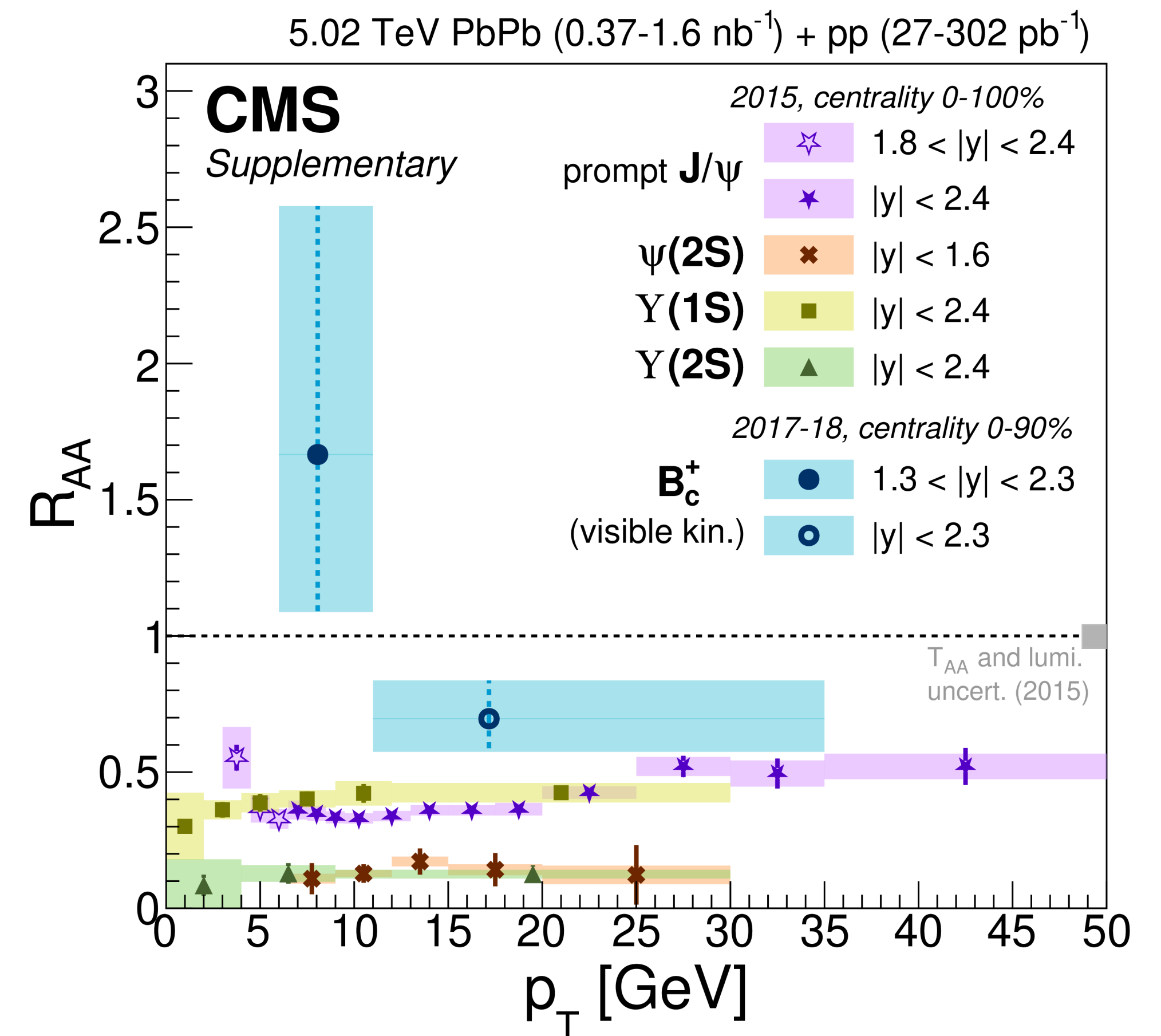
PRL 128 (2022) 252301

Hint for a **softer p_T spectrum** in PbPb with respect to pp collisions



B_c^+ less suppressed than quarkonia despite a binding energy between J/ψ and $\Upsilon(1S)$

➡ importance of heavy-quark recombination?



New insights on heavy flavor and quarkonium dynamics with Run 2 data

- ▶ detailed studies on heavy quark interactions within the QGP
 - prompt and non-prompt D^0 azimuthal anisotropy ([Milan Stojanovic, Thursday 15:00](#))
- ▶ measurements of rare probes to constrain further in-medium hadronization mechanisms
 - beauty recombination via B_s / B^+ yield ratio ([Tsu-An Sheng, Thursday 15:55](#))
 - observation of the $\Upsilon(3S)$ state in PbPb collisions ([Soohwan Lee, Saturday 11:30](#))
- ▶ connexions with jet-related observables
 - charm quark diffusion with jet- D^0 angular correlation ([Jing Wang, Thursday 14:45](#))
 - energy loss studies with b-jet shape measurements ([Matthew Nguyen, Thursday 15:35](#))

Precision era during the high-luminosity LHC phase

- ▶ projections for Run 3 based on the expected luminosity [[CERN Yellow Report](#)]
- ▶ new opportunities with the Phase-2 upgrade ([Yousen Zhang, Thursday 10:28](#))
 - ☞ hadron PID capabilities for Run 4!

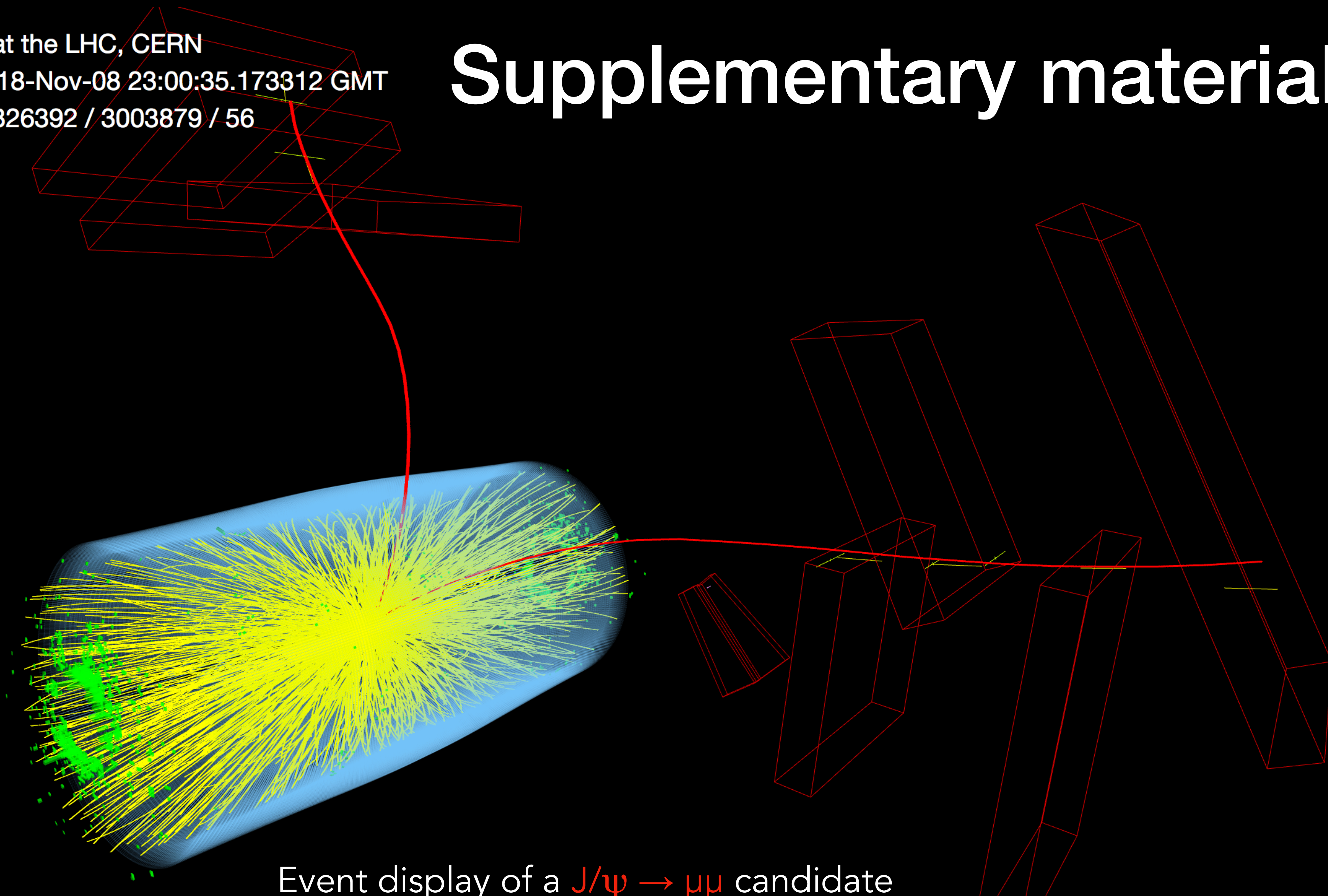


CMS Experiment at the LHC, CERN

Data recorded: 2018-Nov-08 23:00:35.173312 GMT

Run / Event / LS: 326392 / 3003879 / 56

Supplementary material



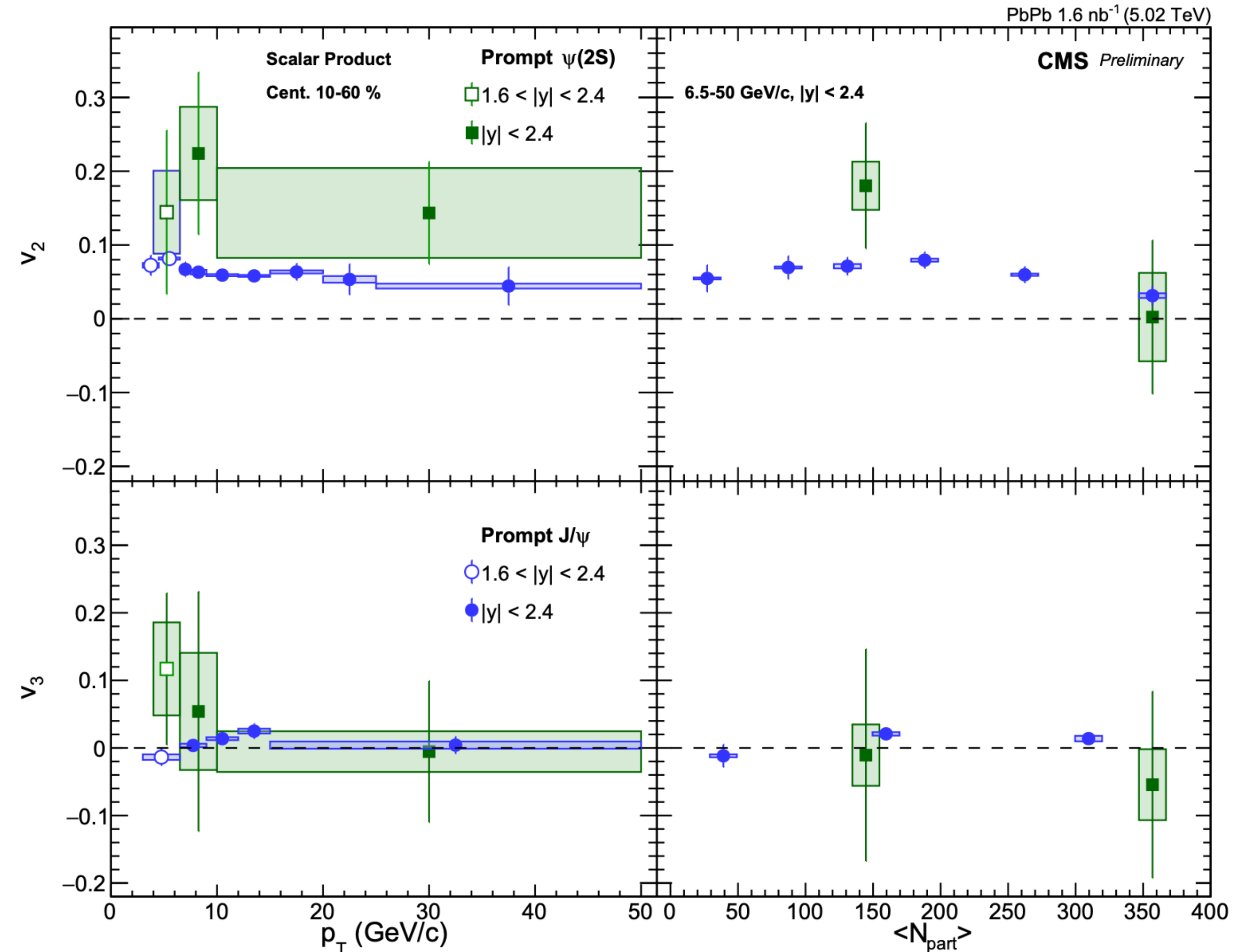
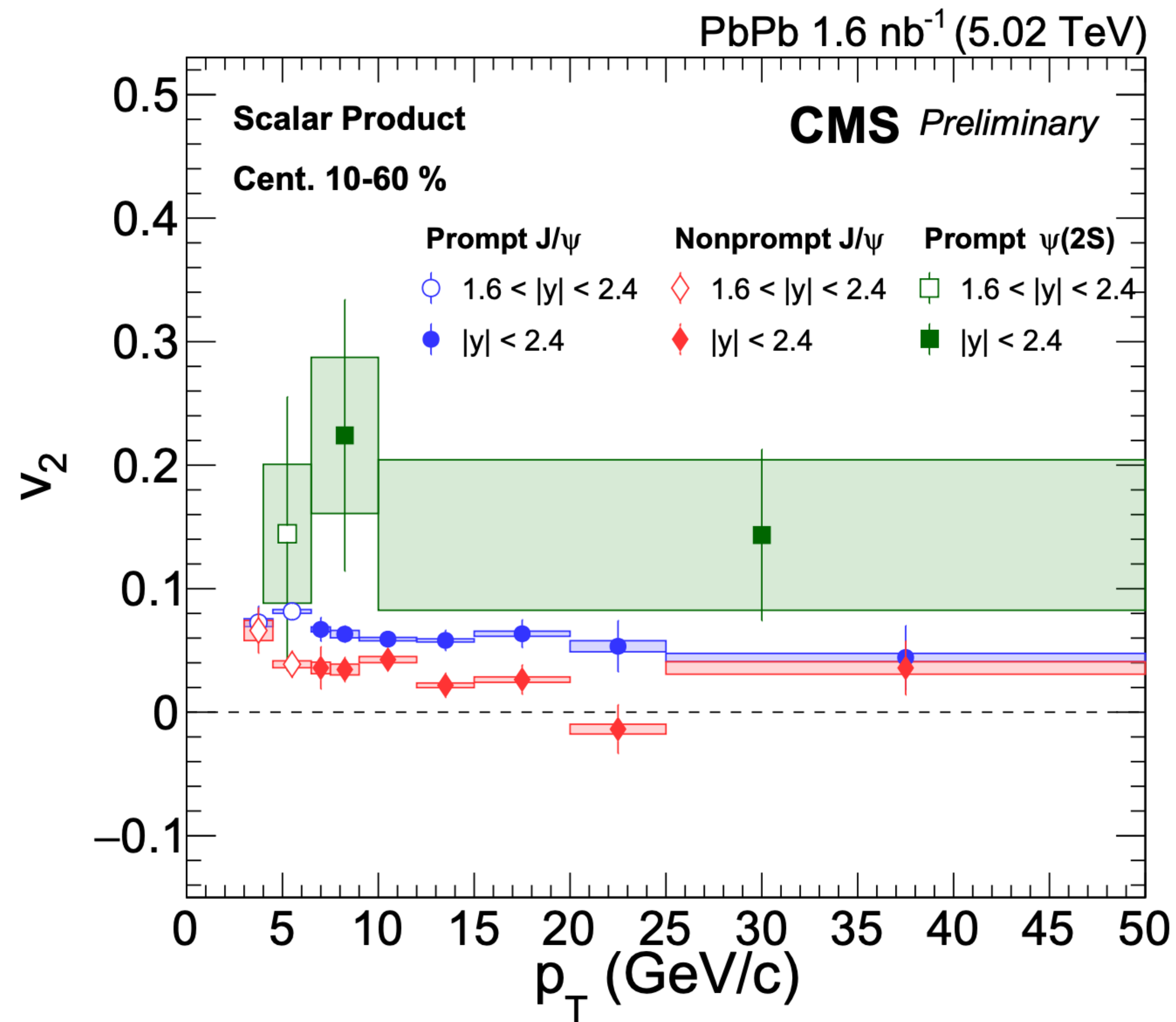
Event display of a $J/\psi \rightarrow \mu\mu$ candidate

CMS-PAS-HIN-21-008

prompt J/ψ

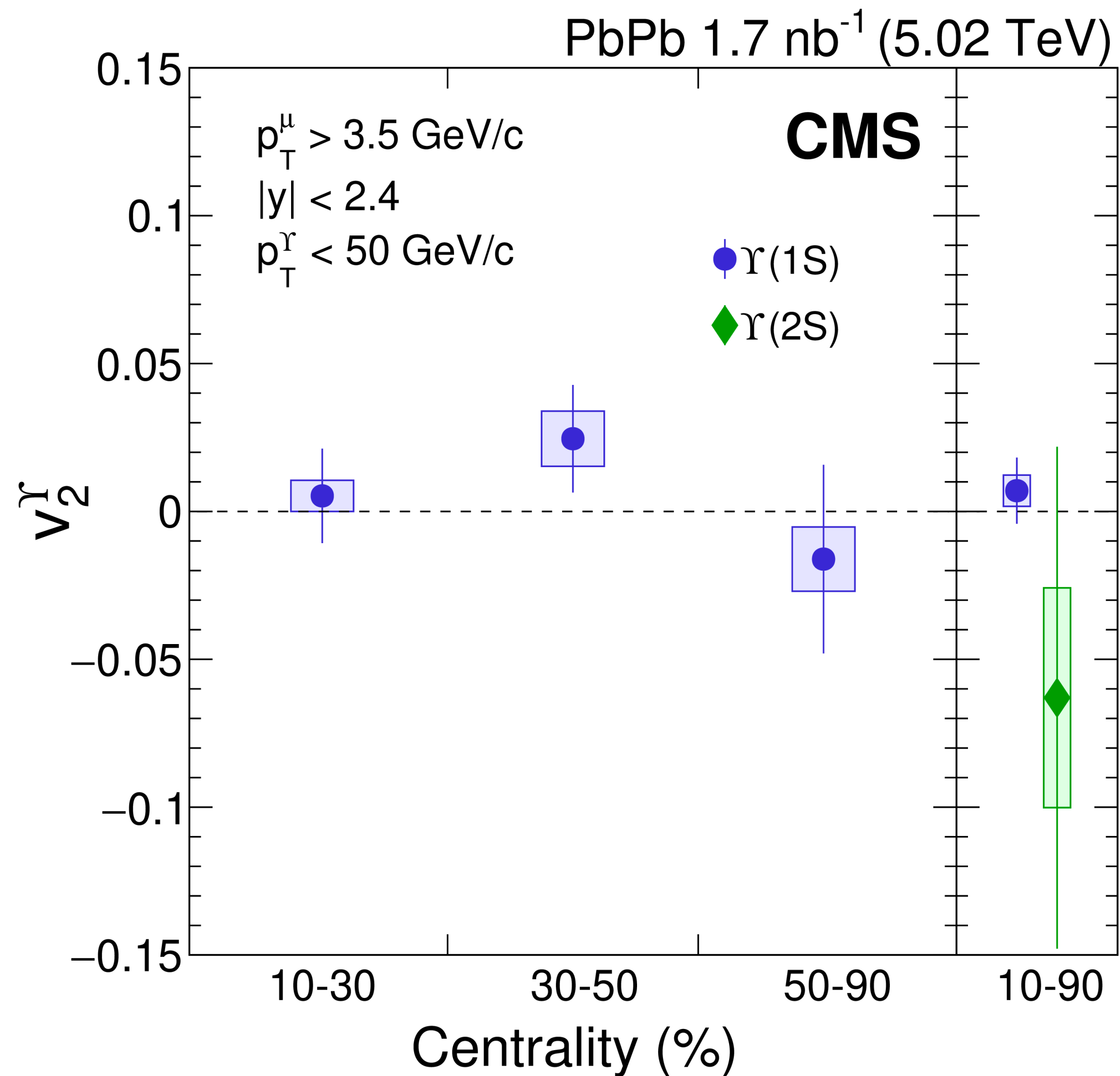
$b \rightarrow J/\psi$

prompt $\psi(2S)$



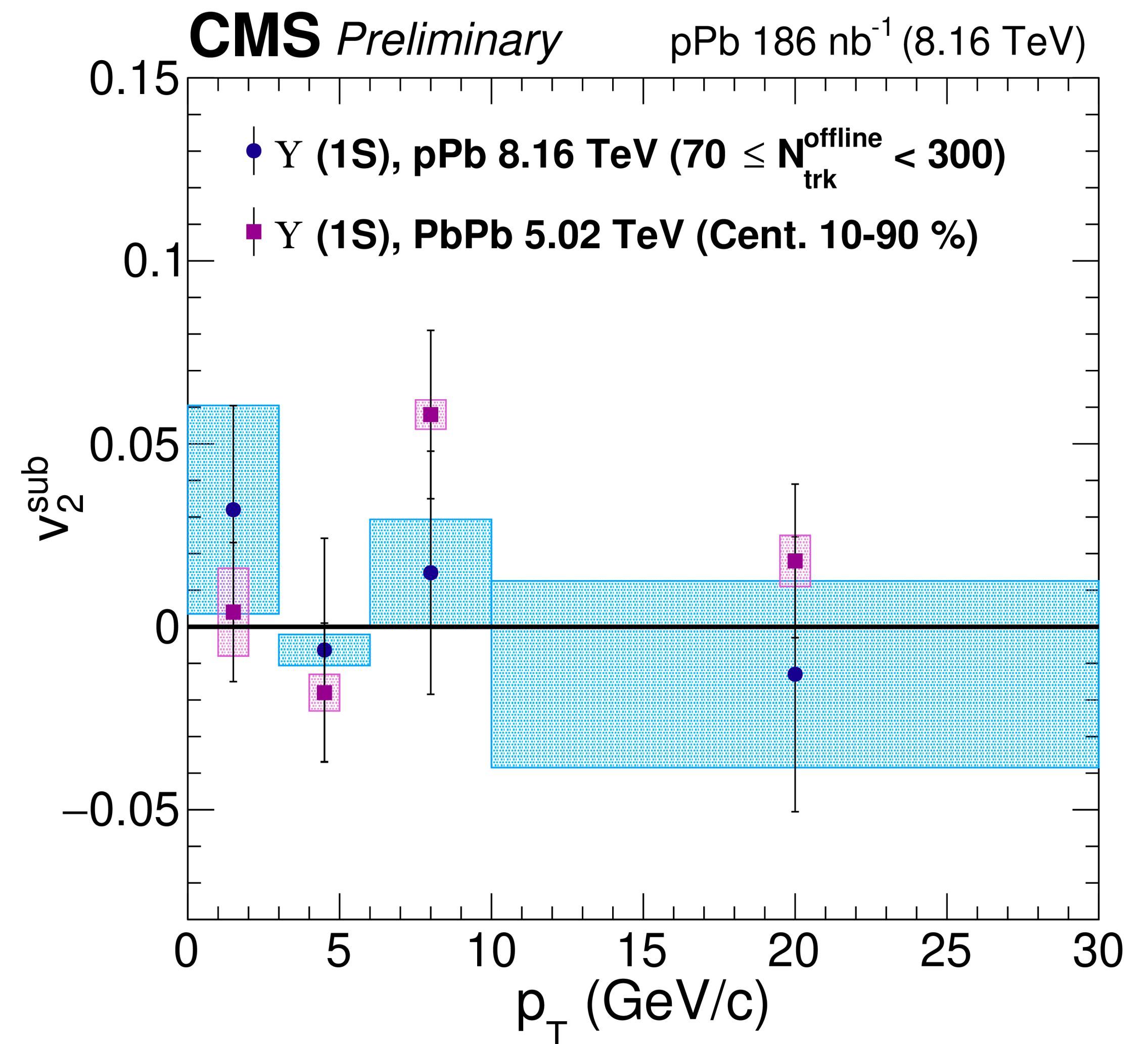
Azimuthal anisotropy of Υ mesons

in PbPb collisions [[PLB 819 \(2021\) 136385](#)]



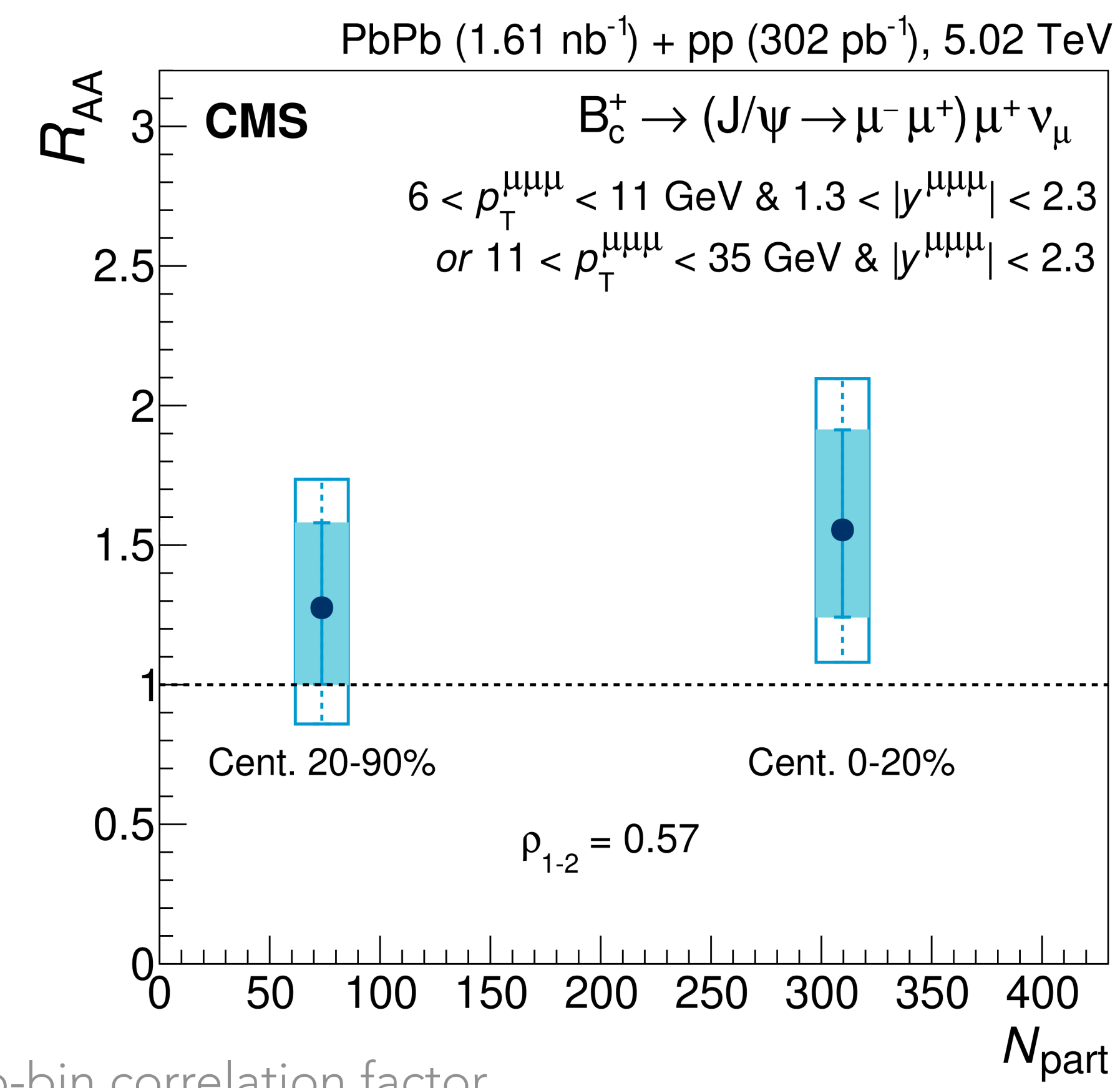
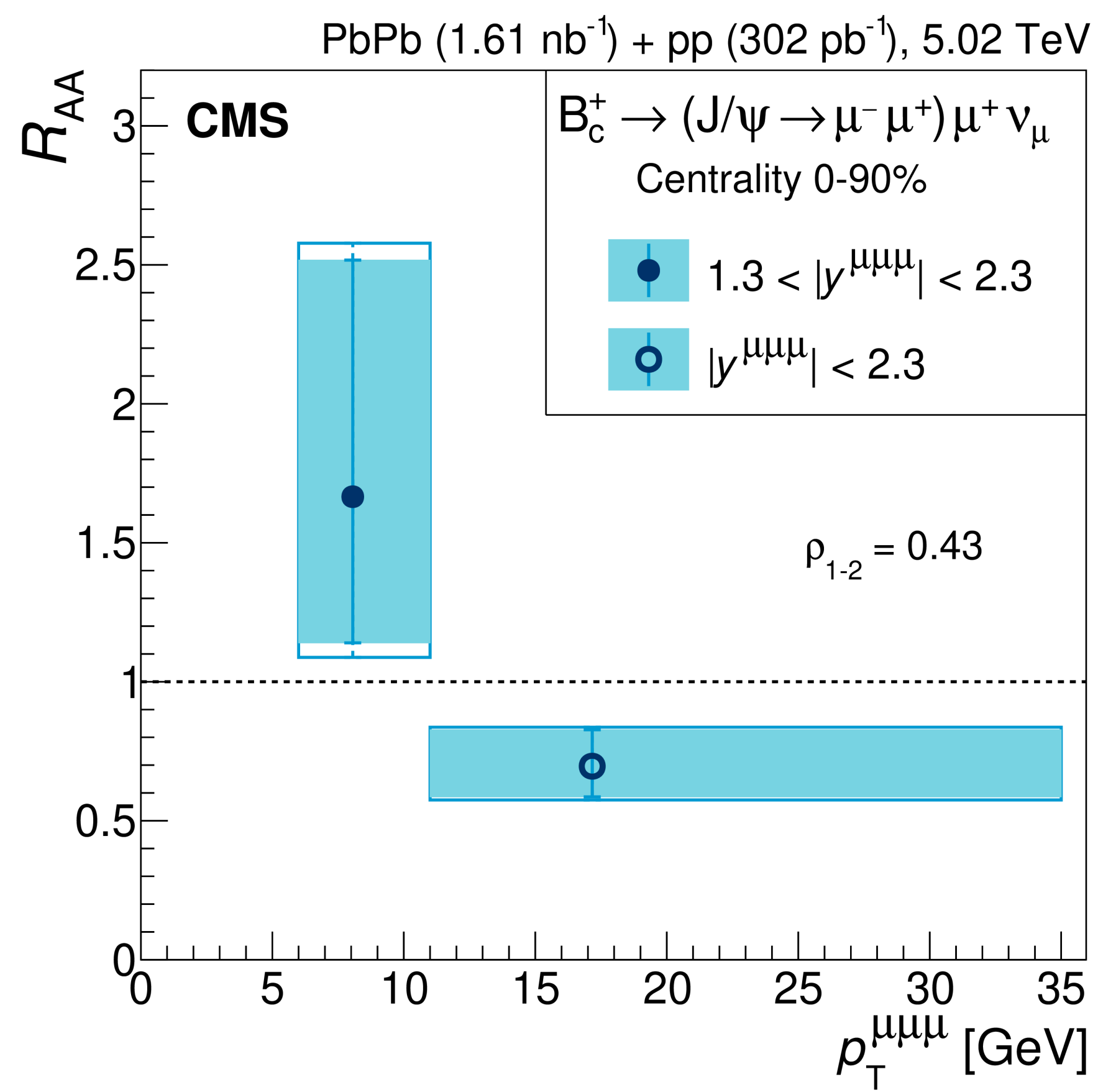
in high-multiplicity pPb collisions

[[CMS-PAS-HIN-21-001](#)]

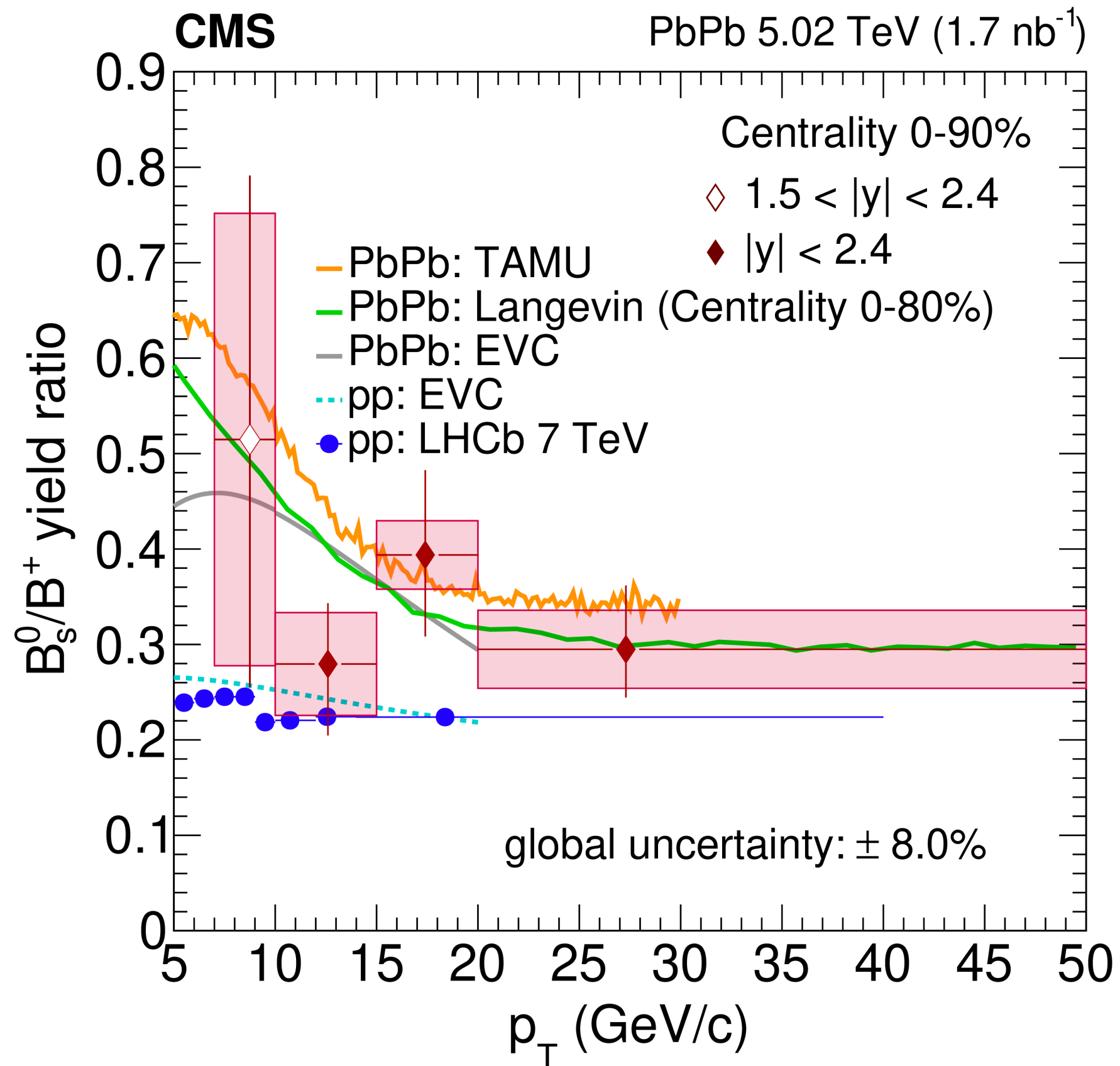


- ▶ significant suppression in the high- p_T region
- ▶ low- p_T bin standing above by 1.8σ
- 👉 hint for a **softer p_T spectrum** in PbPb collisions

No significant variation as
a function of centrality



ρ_{1-2} : bin-to-bin correlation factor



PLB 829 (2022) 137062

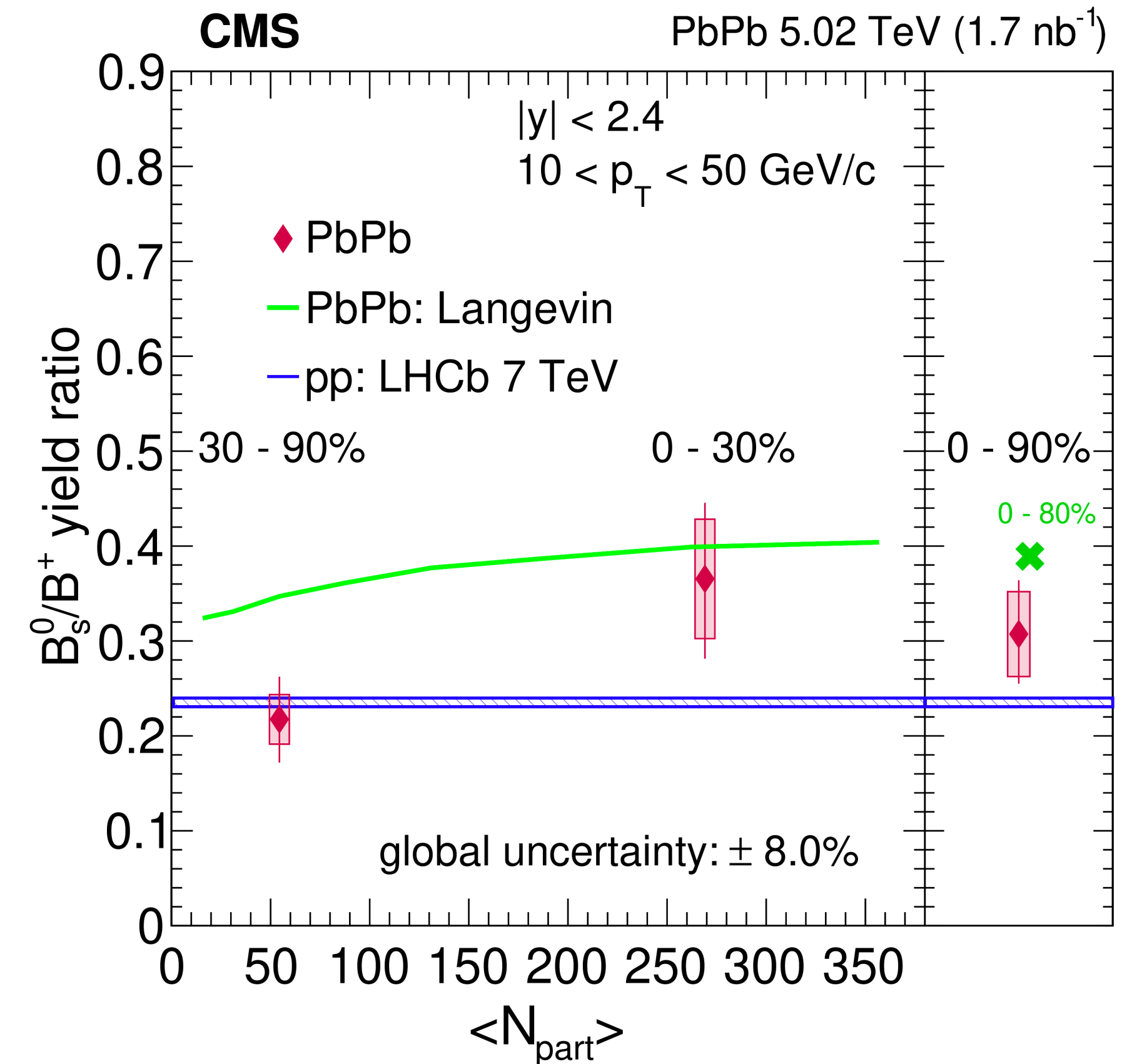
Model references

He et al., PLB 735 (2014) 445

Cao et al., PLB 807 (2020) 135561

Song et al., EPJC 78 (2018) 344

LHCb measurement in pp collisions, PRL 124 (2020) 122002



Measured yield ratios compatible with predictions from heavy-quark (re)combination models as well as with pp reference data

➡ no significant evidence for enhancement of B_s/B^+ in PbPb collisions (expected at low p_T)