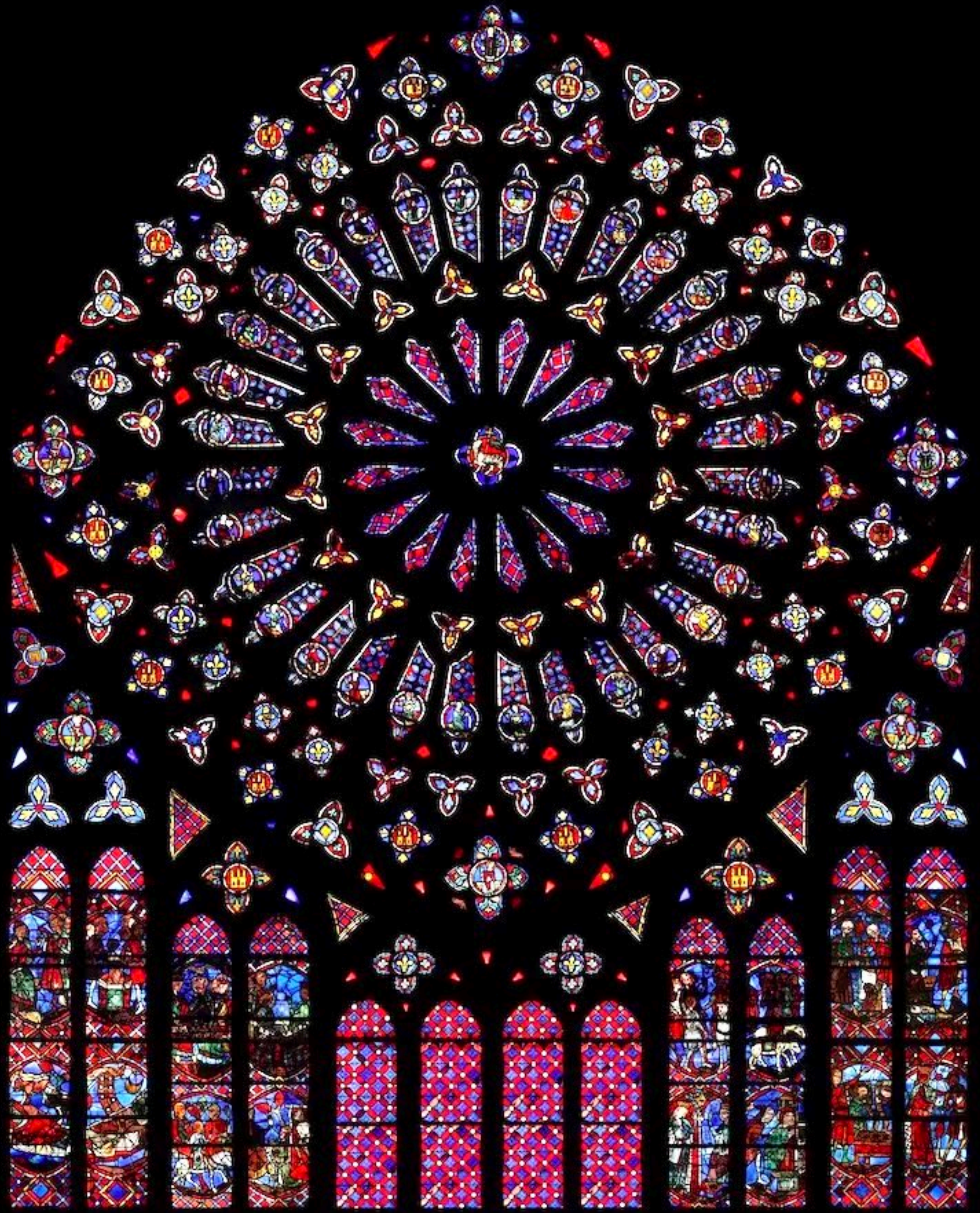
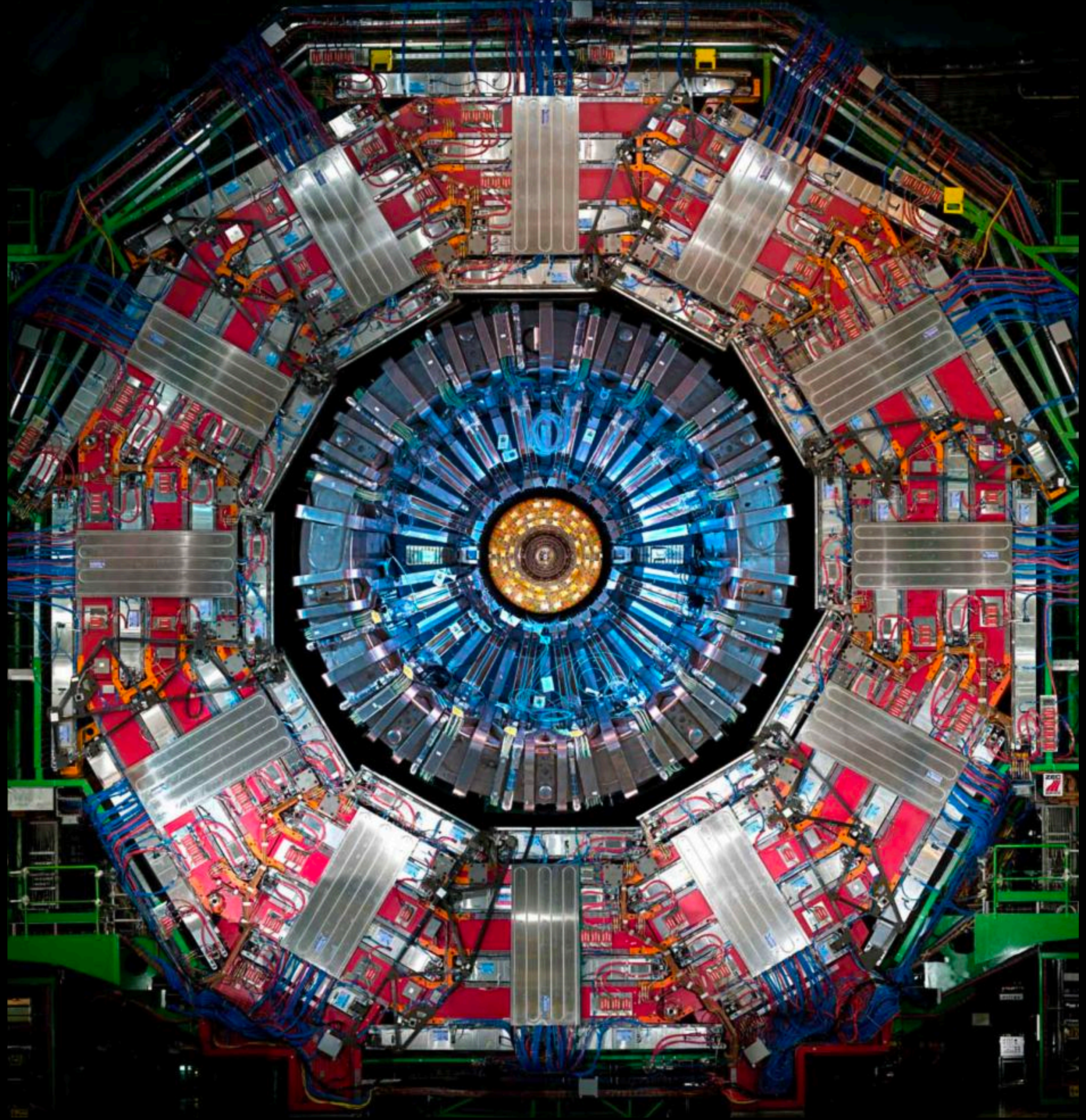
« South rose » of Saint-Gatien cathedral, Tours



Cathedral of Modern timeS



CMS overview

Selection of new results from the Quark Matter'22 campaign

Florian Damas (florian.damas@cern.ch)
Laboratoire Leprince-Ringuet, École Polytechnique

Rencontres QGP France 2022, Tours

Compact Muon Solenoid

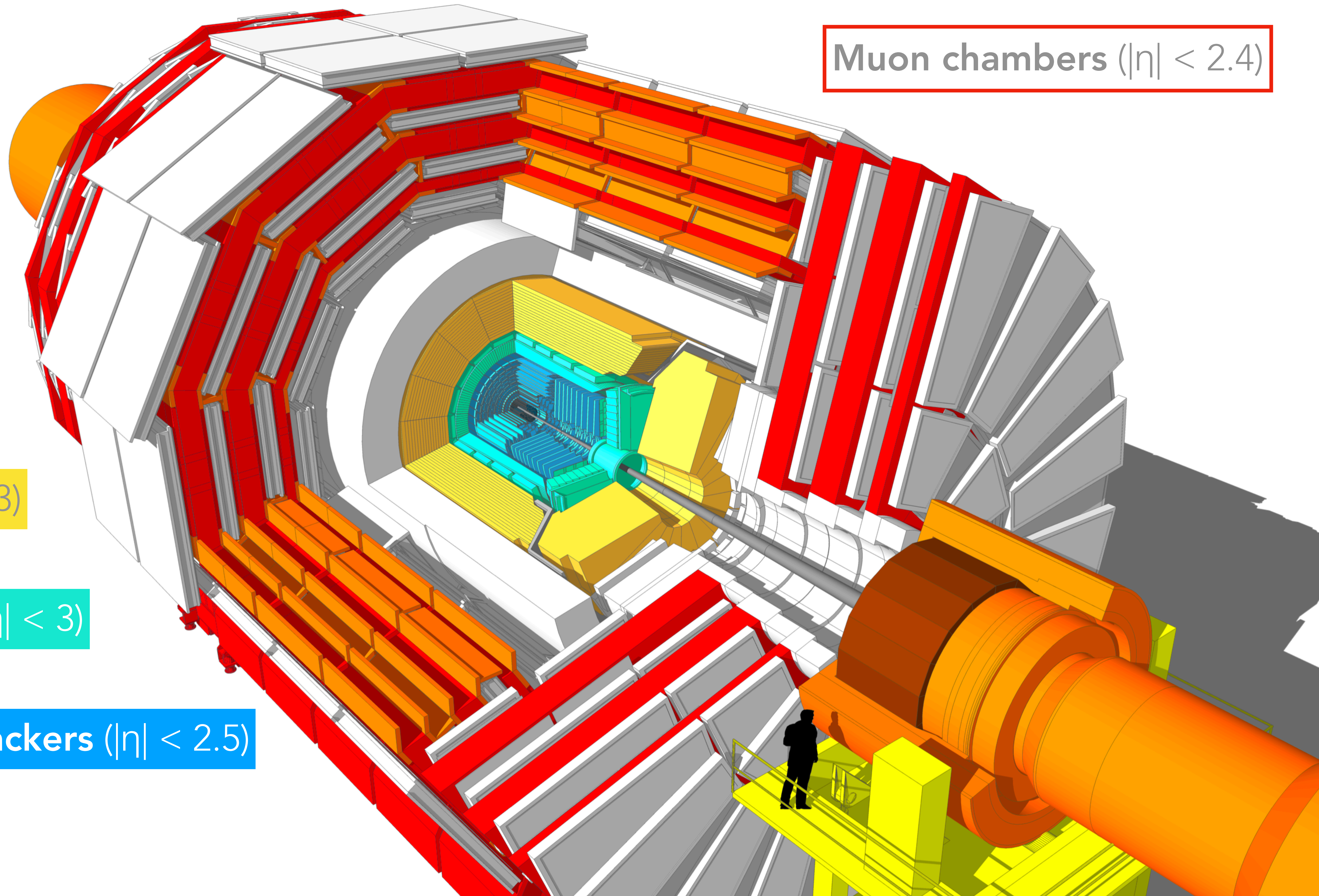
JINST 3 (2008) S08004

CMS DETECTOR

Total weight	: 14,000 tonnes
Overall diameter	: 15.0 m
Overall length	: 28.7 m
Magnetic field	: 3.8 T

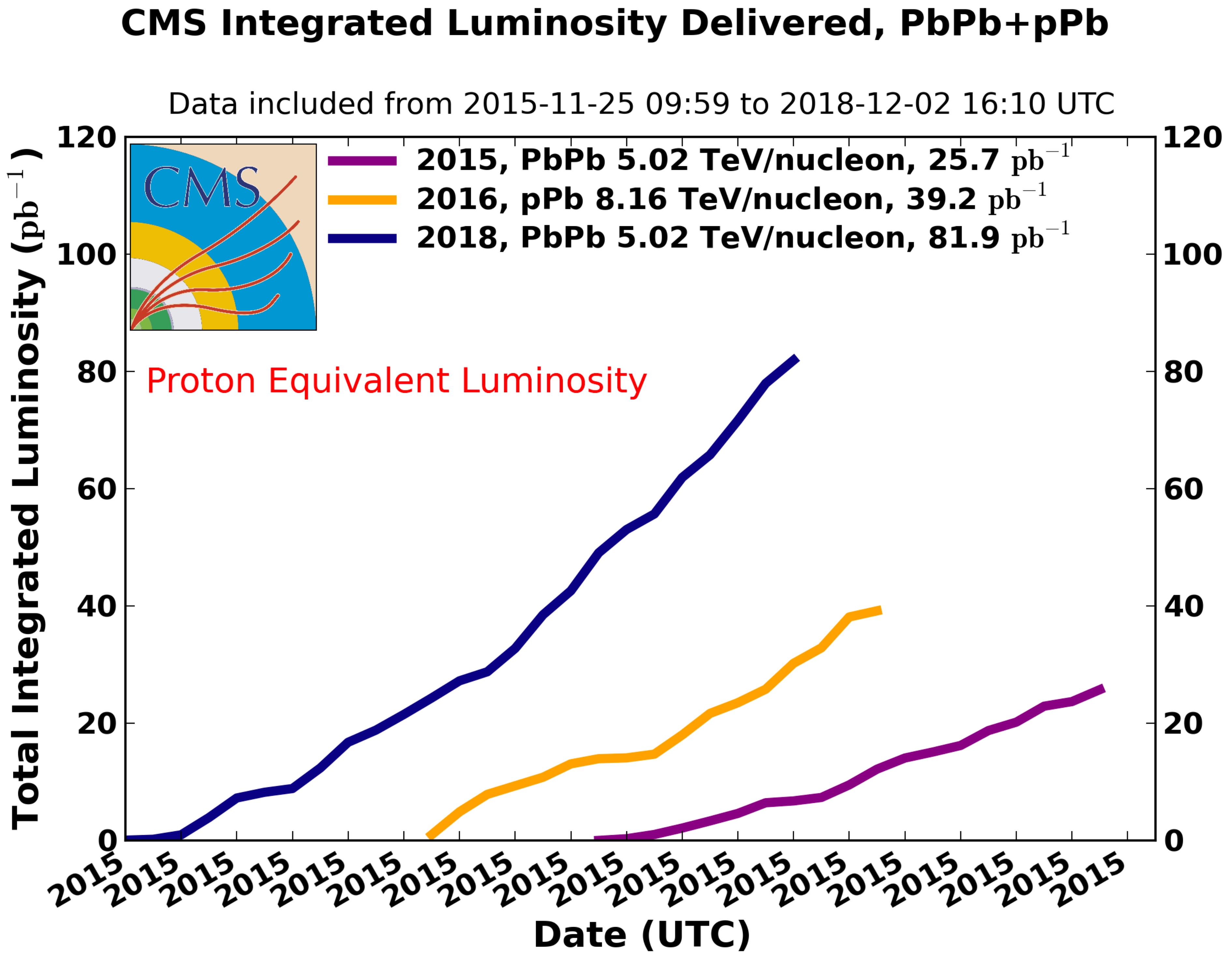
Key features

- large acceptance & hermetic apparatus
  - barrel region: $|\eta| \lesssim 1.5$
  - endcap region: $1.5 \lesssim |\eta| \lesssim 3$
- fast triggering on rare signals
- high tracking resolution



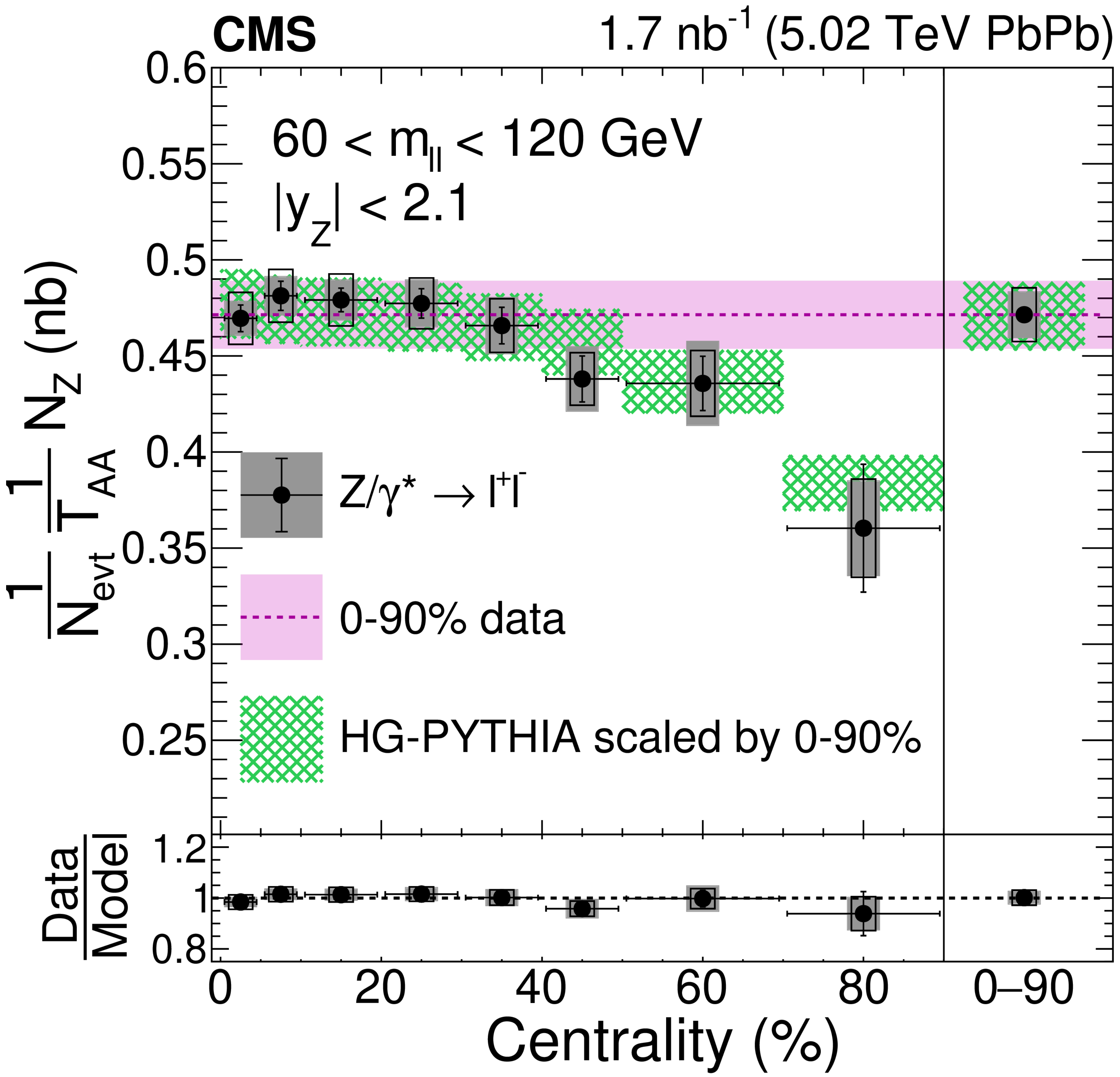
Heavy ion physics program

- Initially **focusing on hard probes** based on the trigger performance (jets, leptons, high-p_T photons)
- Extending the scope by **recording more and more minimum bias data** (~5B events in 2018)
- Compilation of results



Flagship example: constraining the initial state with the Z boson

☛ a new experimental proxy for T_{AA}?



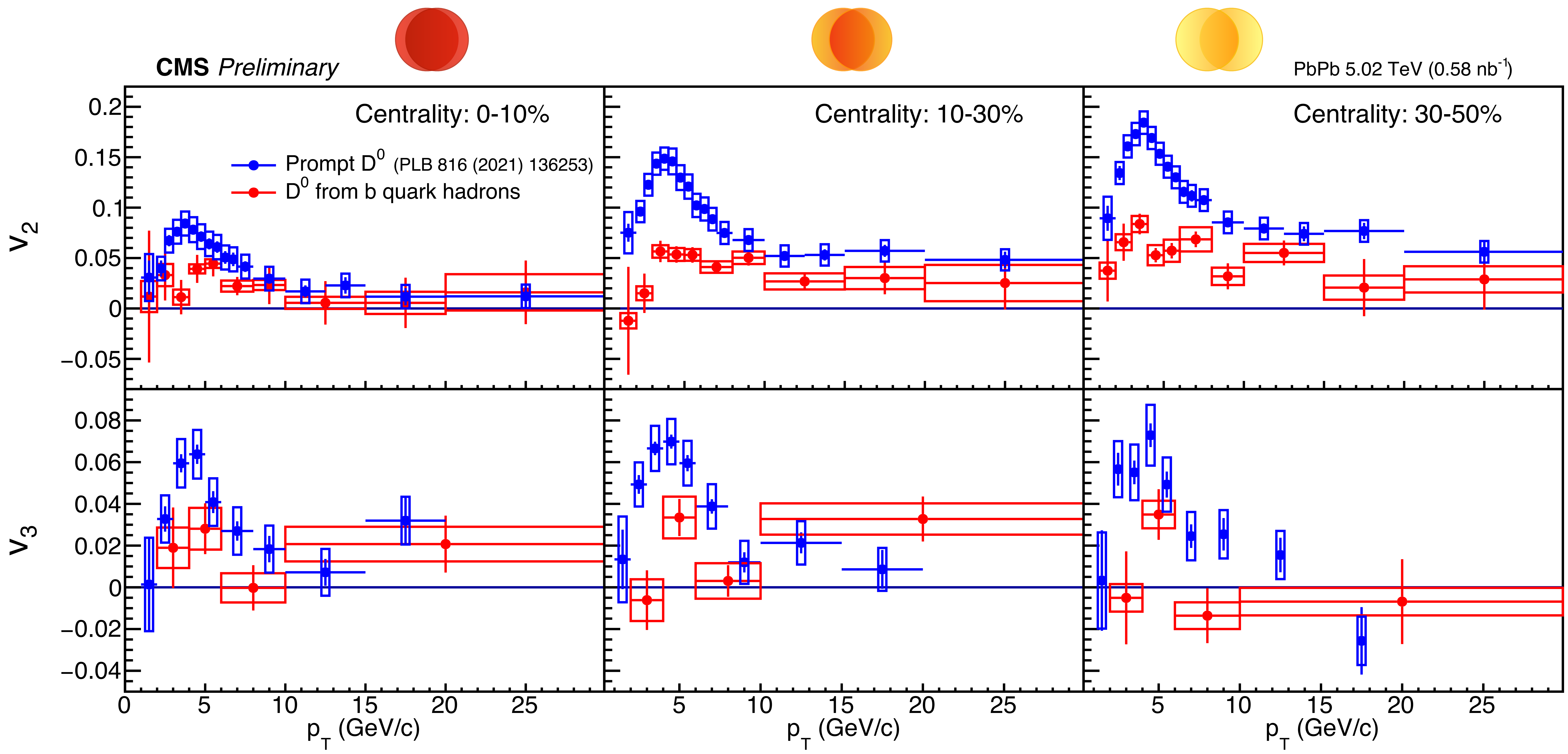
PRL 127 (2021) 102002

Investigating the dynamics of heavy quarks with flow measurements

Boats flowing towards the Chateau de Chenonceau

Azimuthal anisotropy of D^0 mesons

CMS-PAS-HIN-21-003



Elliptic flow

prompt D^0

>

b → D^0 > 0

Triangular flow

prompt D^0

≳

b → D^0 ≠ 0

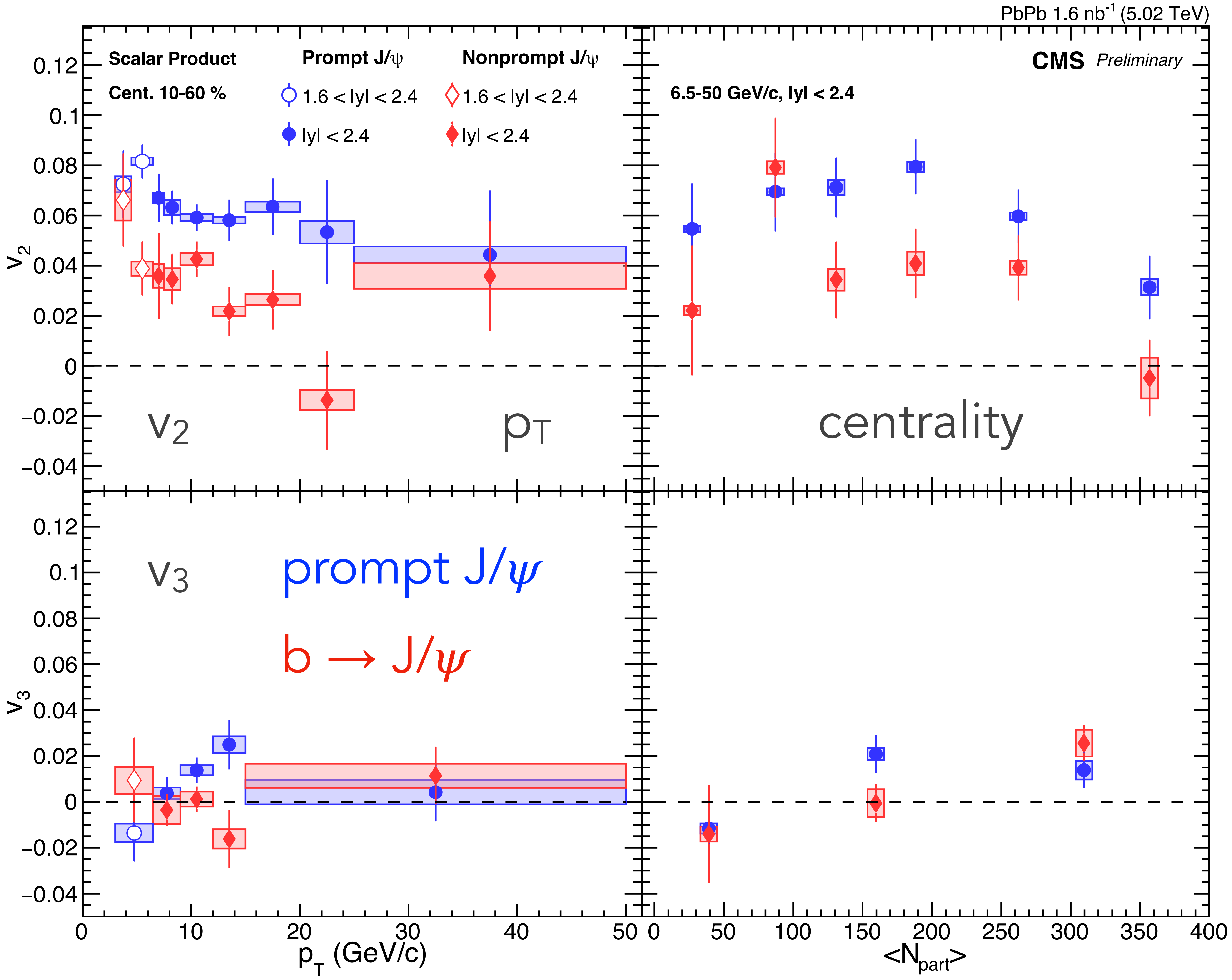
Prompt vs non-prompt D^0 flow

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

Non-zero v_3 measured in all centrality intervals for p_T ~ 5 GeV

J/Ψ flow: prompt vs non-prompt

CMS-PAS-HIN-21-008



Significant v_2 up to high p_T (~30 GeV)

- prompt J/Ψ > b → J/Ψ
  - ☛ different in-medium effects for charm and bottom quarks
- smaller for the most central collision events

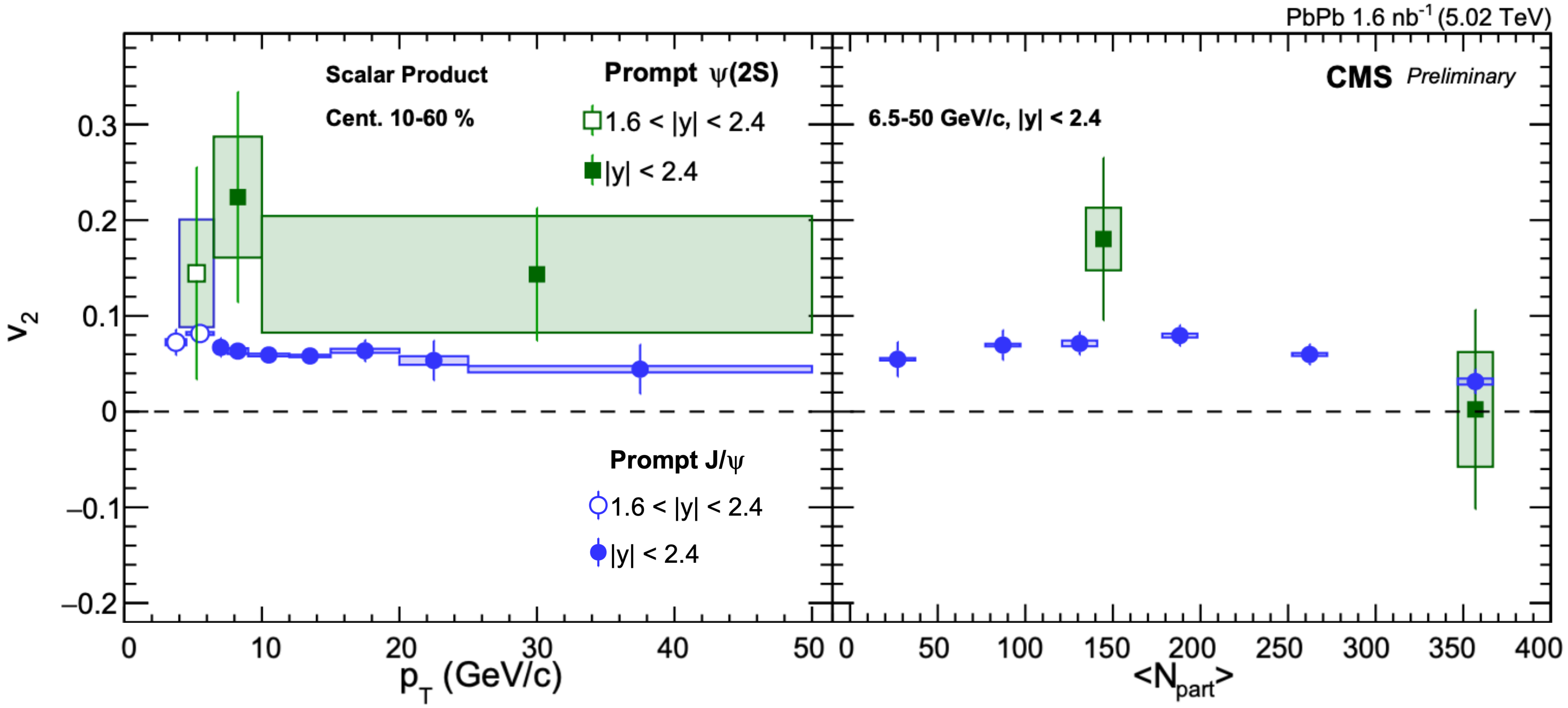
First v_3 measurement with separate components

- compatible with 0
- b → J/ψ v_3 consistent with result for b → D^0

First measurement of $\Psi(2S)$ flow!

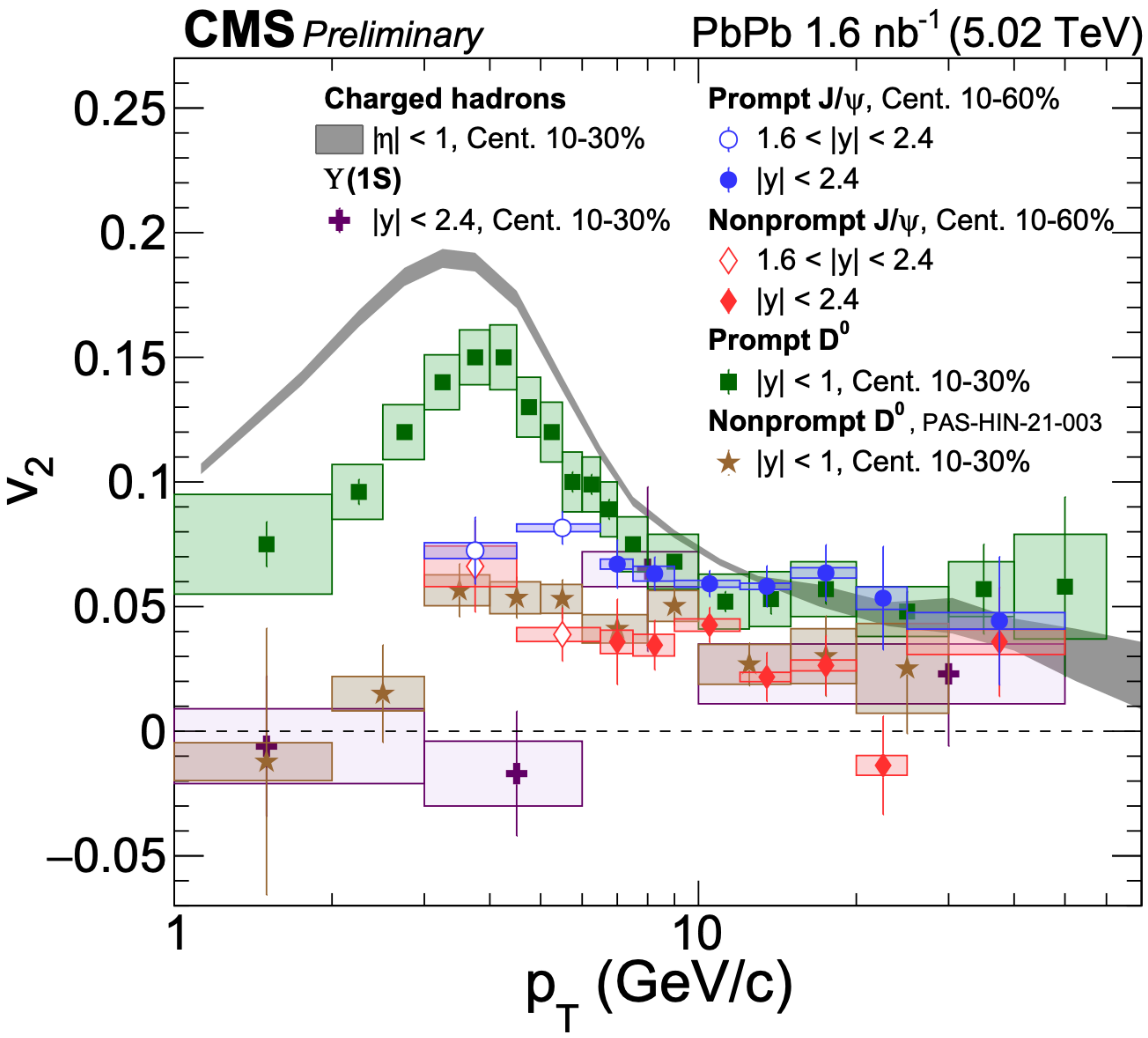
CMS-PAS-HIN-21-008

- **v_2: prompt $\Psi(2S) \gtrsim 0.1$ > prompt J/Ψ**
- v_3 signal compatible with 0 within large uncertainties (backup)



Heavy-flavour elliptic flow

figure available here



Comprehensive family picture

- steep increase at low p_T following mass hierarchy
  hydrodynamic regime: light > charm > bottom

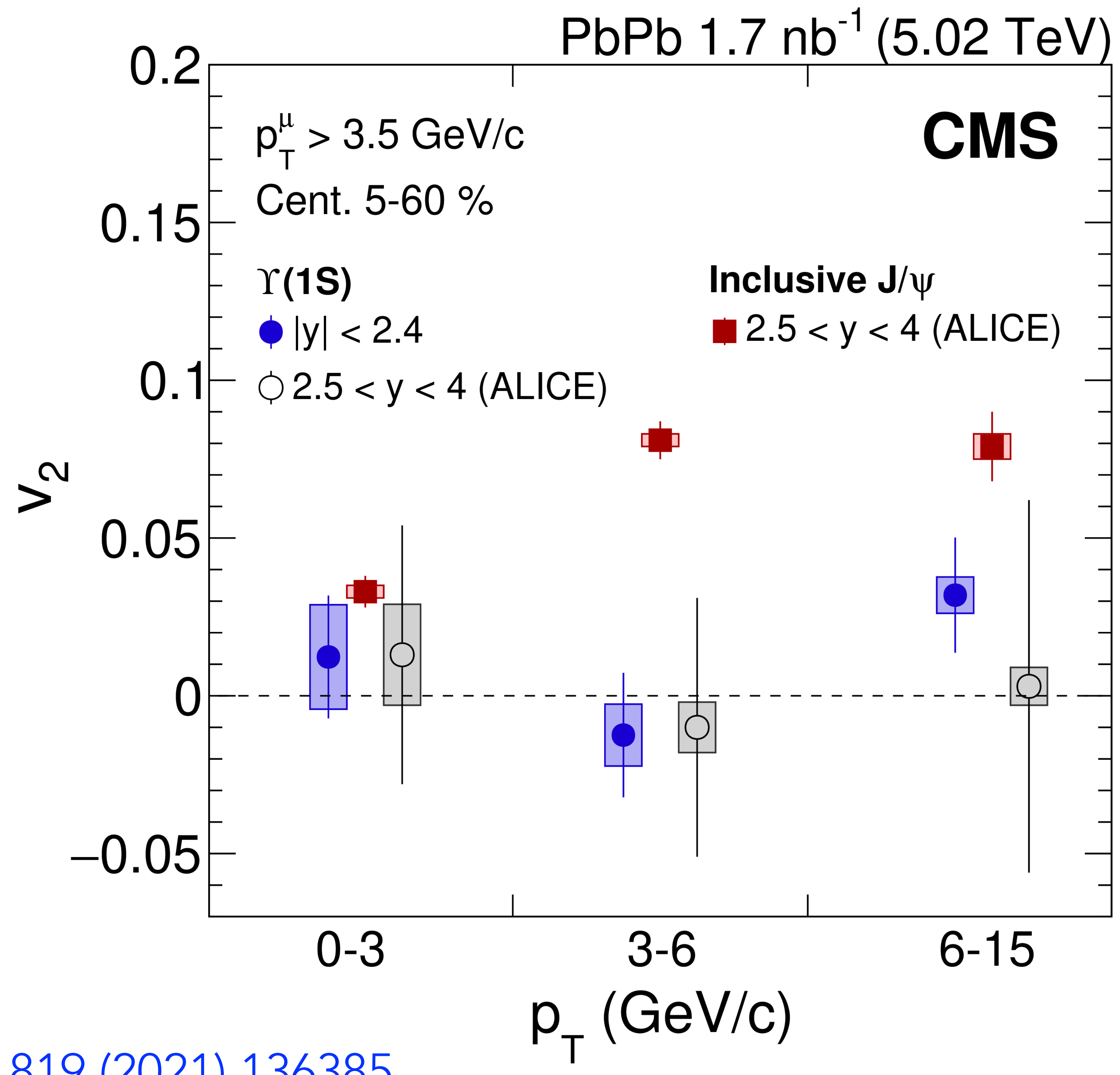
- maximum reached for $3 < p_T < 6$ GeV
  light ≳ prompt D⁰ > prompt J/Ψ > **b → hadrons**
  ☛ coalescence of heavy quarks with light ones carrying flow!

- convergence towards plateau above 8 GeV
  similar behaviour and non-zero v_2 at high p_T
  ☛ originating from universal energy loss?

No elliptic flow for Υ(1S)

CMS-PAS-HIN-21-001

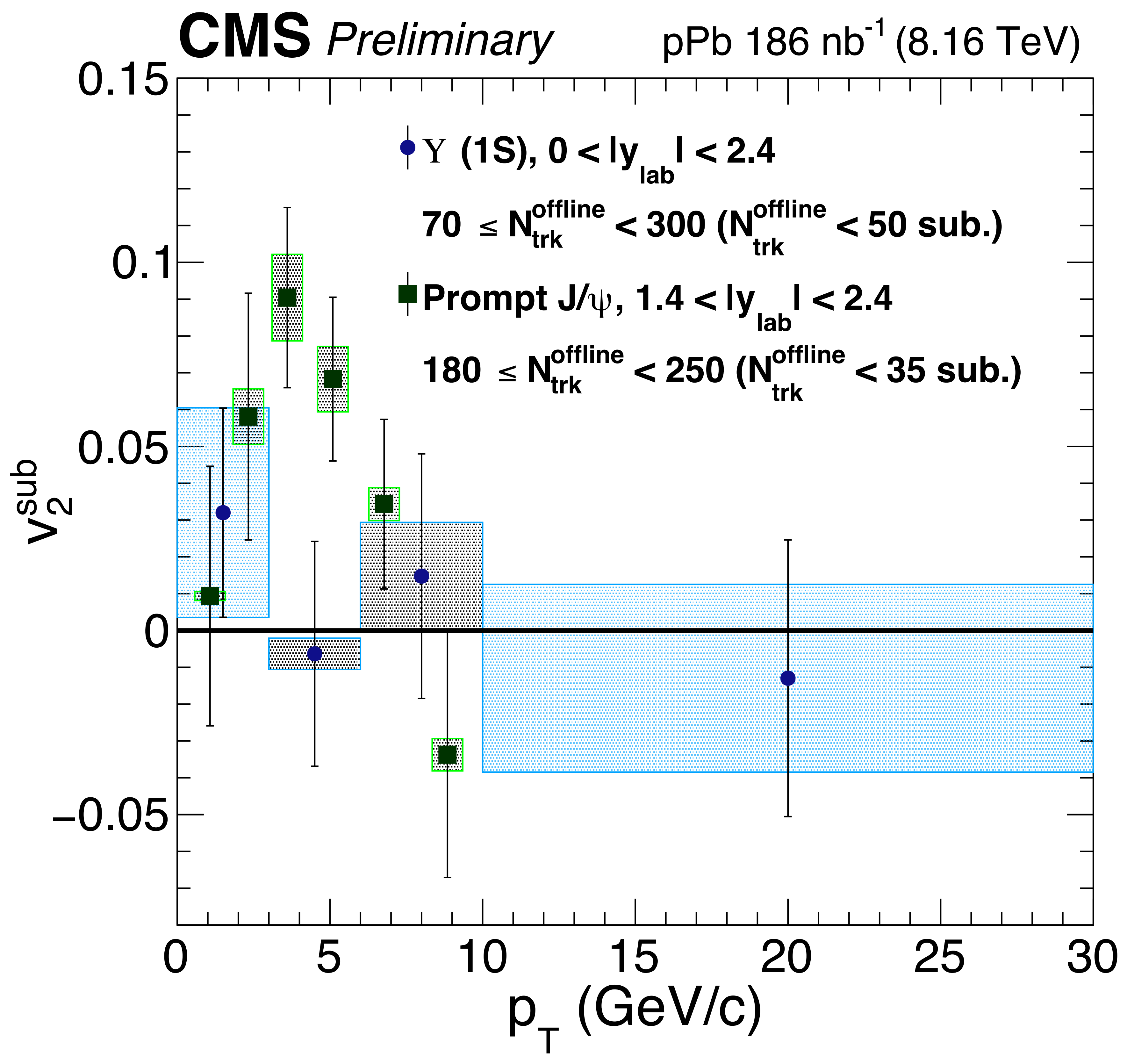
J/Ψ > Υ(1S) ~ 0 in PbPb collisions



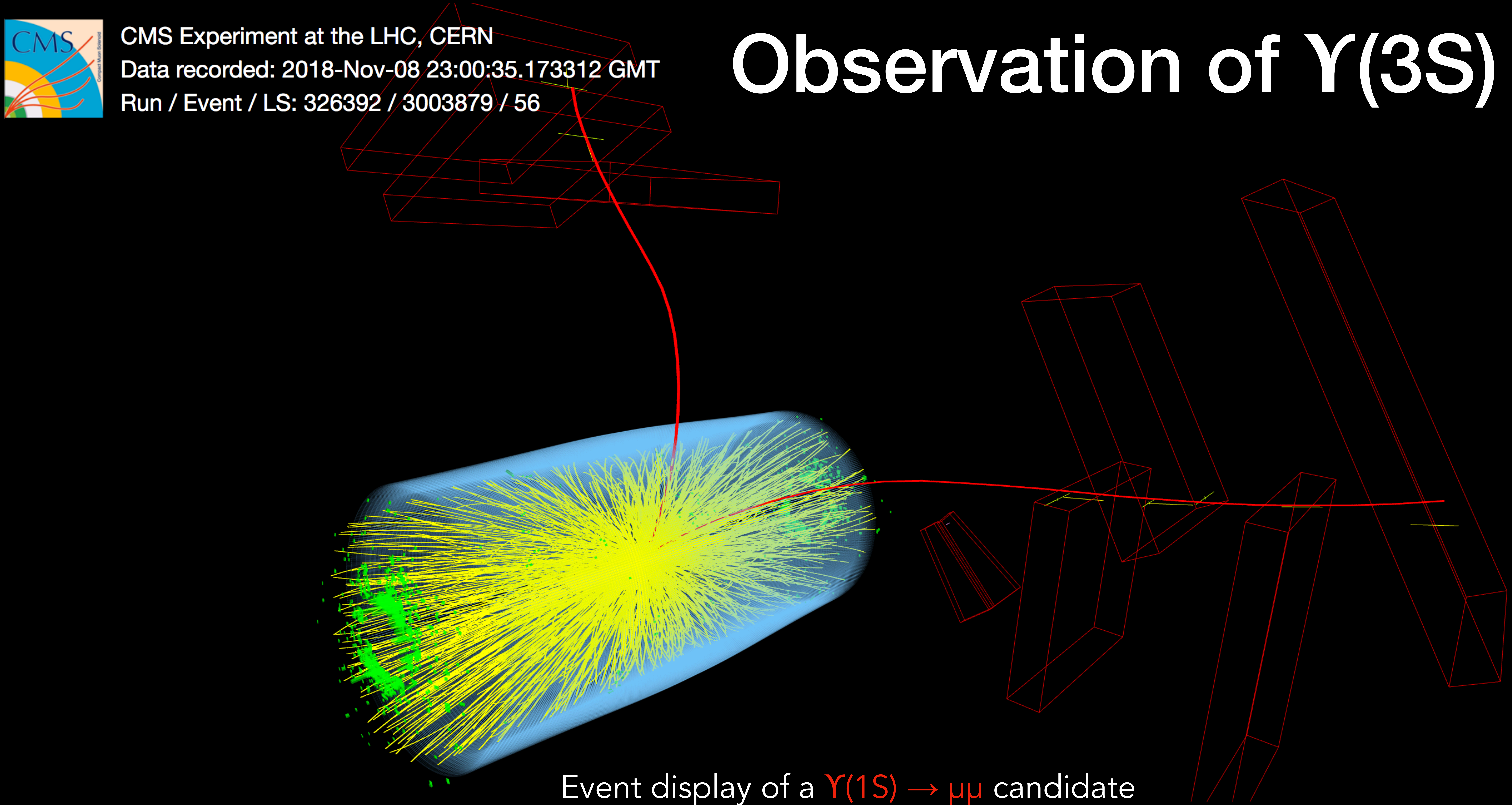
PLB 819 (2021) 136385

Same findings in high-multiplicity pPb events

- first Υ(1S) v_2 measurement consistent with 0
- J/Ψ flow magnitude similar to the PbPb case



Observation of Υ(3S)



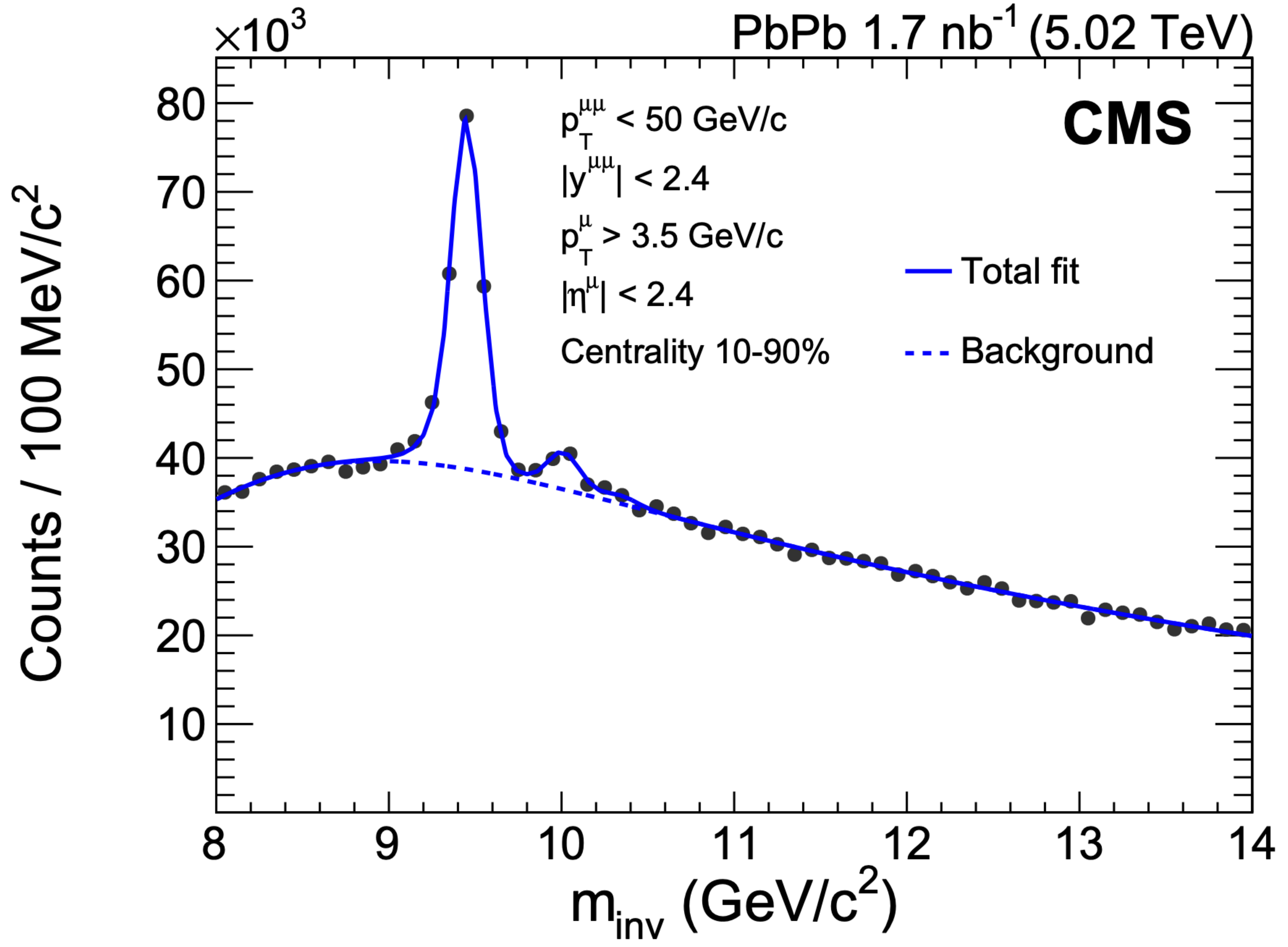
Event display of a Υ(1S) → μμ candidate

Observation of Υ(3S) in HIC!

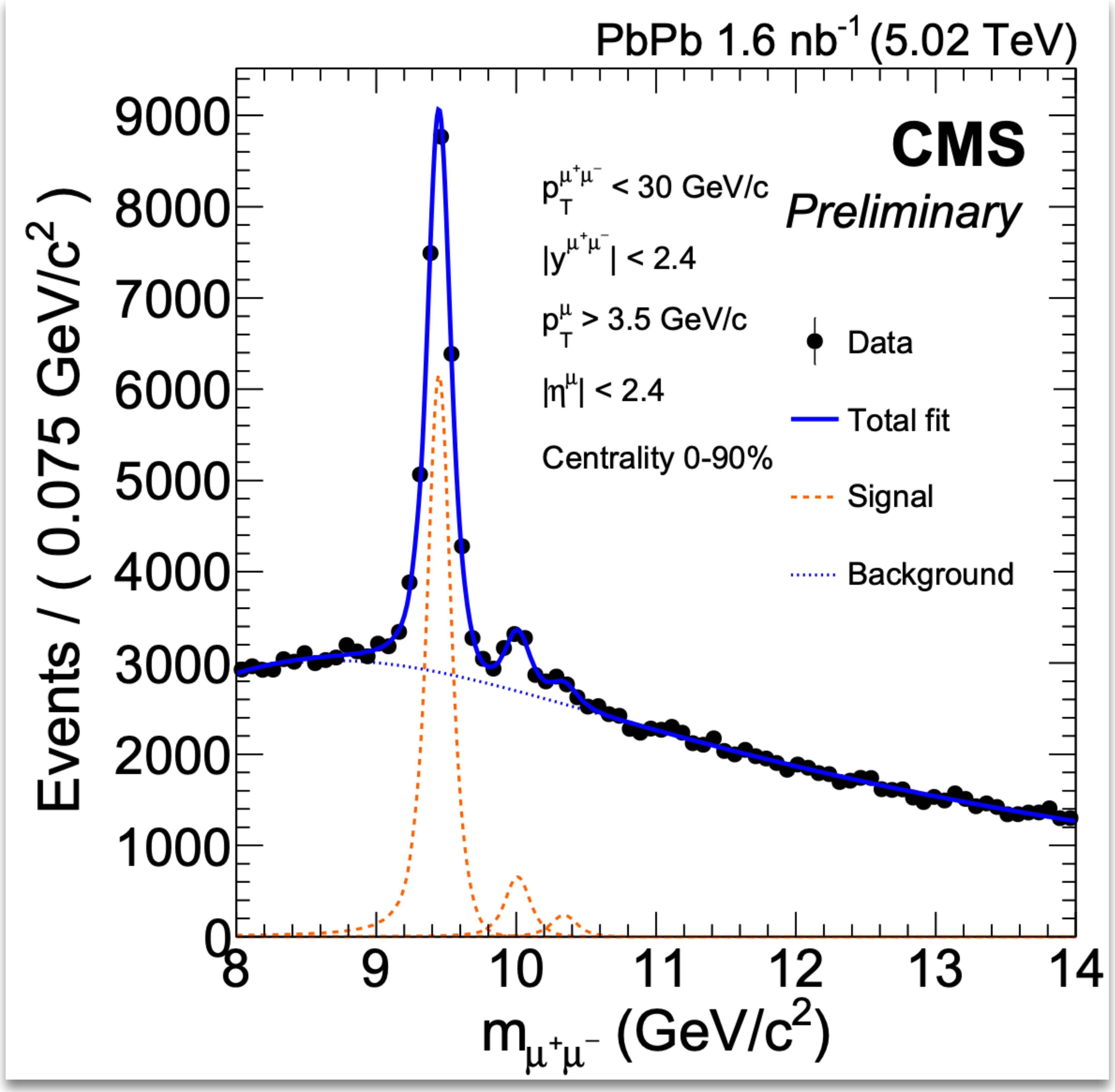
CMS-PAS-HIN-21-007

Signal barely visible despite the large dataset

☛ **enrichment with BDT** based on decay topology (vertex and dimuon variables)



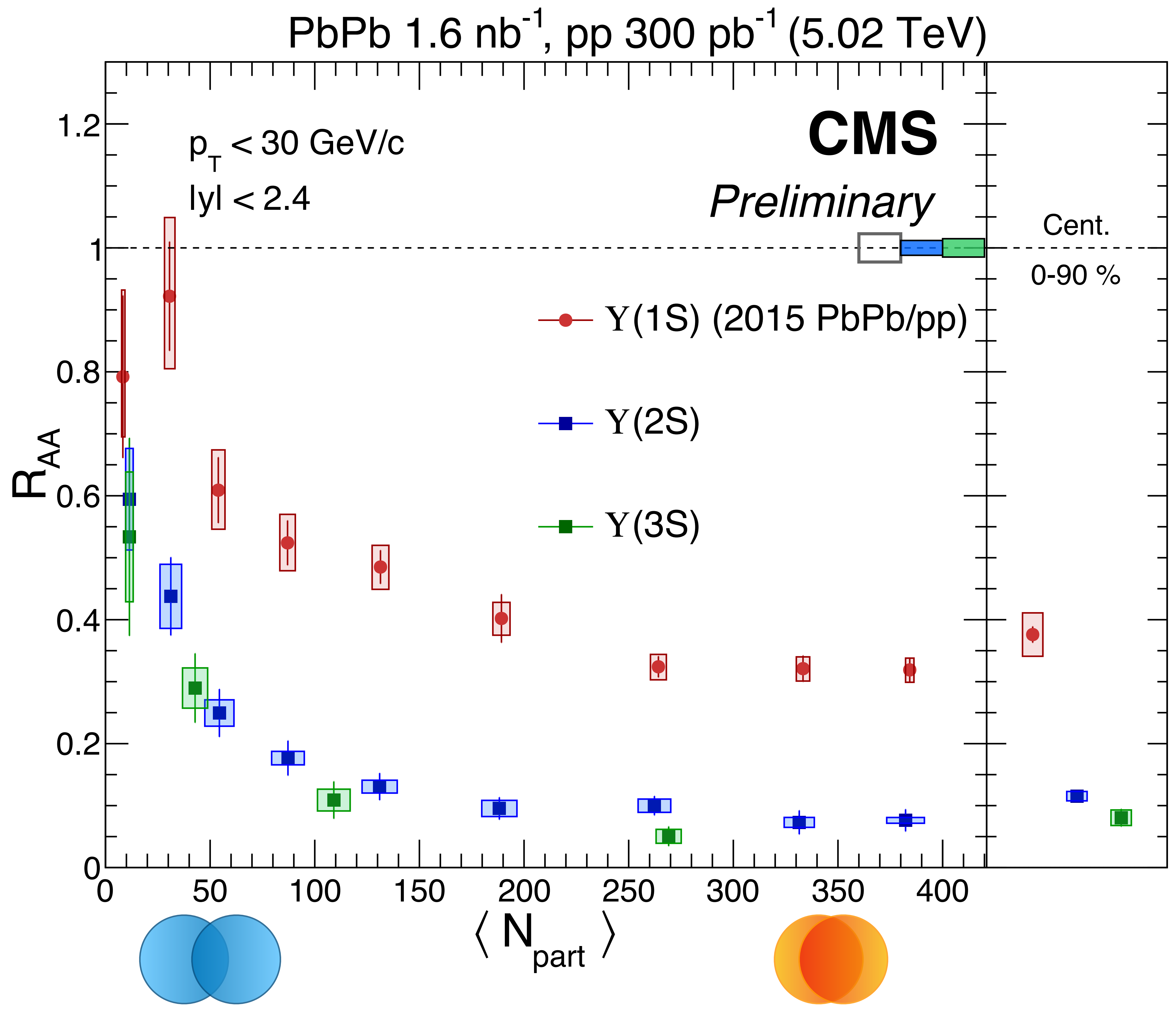
from flow measurement, PLB 819 (2021) 136385

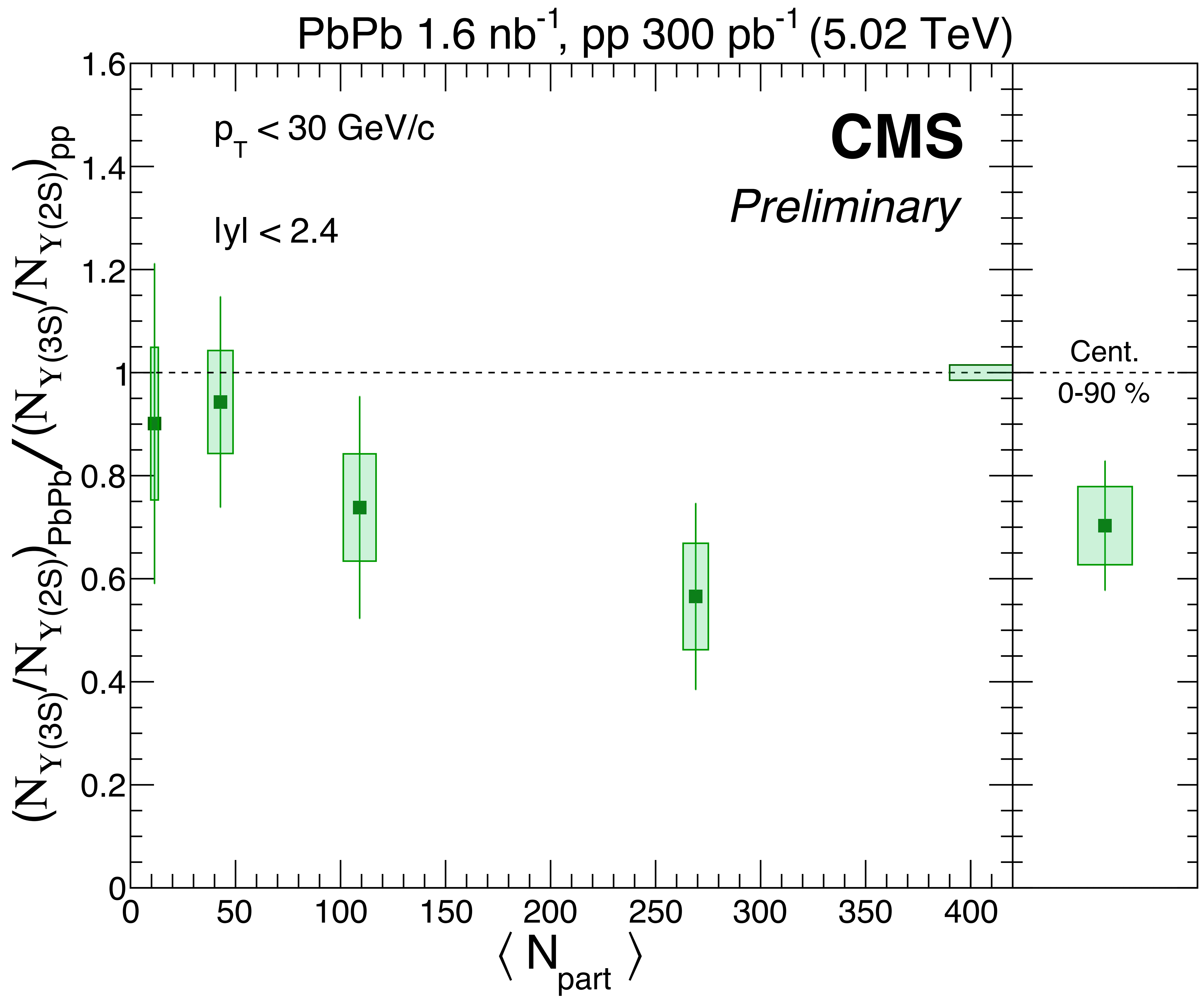


Re-discovery of the sequential suppression

CMS-PAS-HIN-21-007

- Significant Υ(3S) yield + precise Υ(2S) measurements in whole phase space
- **Excited states suppressed in all centralities, much more than Υ(1S)** [PLB 790 (2019) 270]
- Υ(3S) more suppressed than Υ(2S) for the 0–30% most central events (double yield ratio)

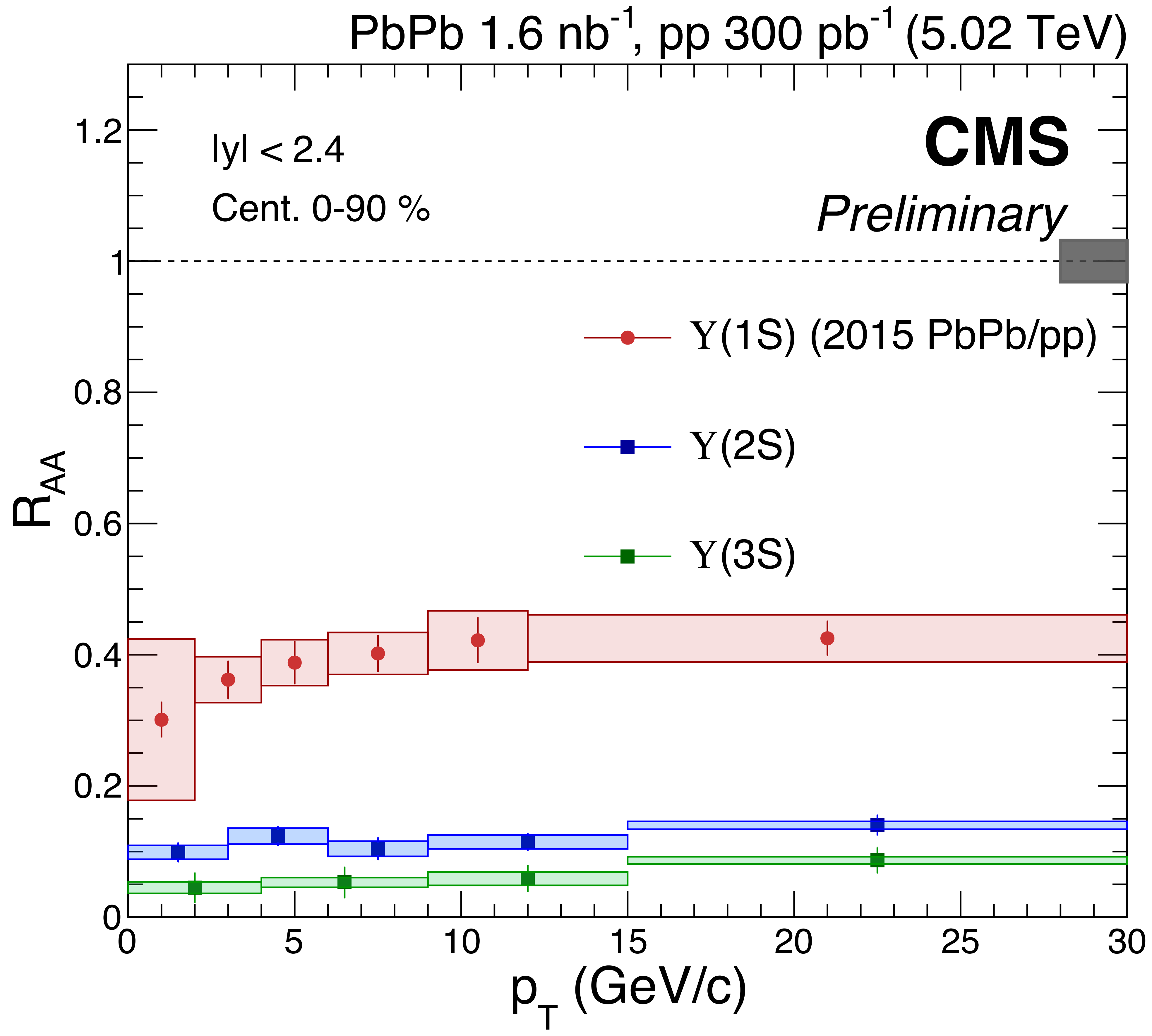


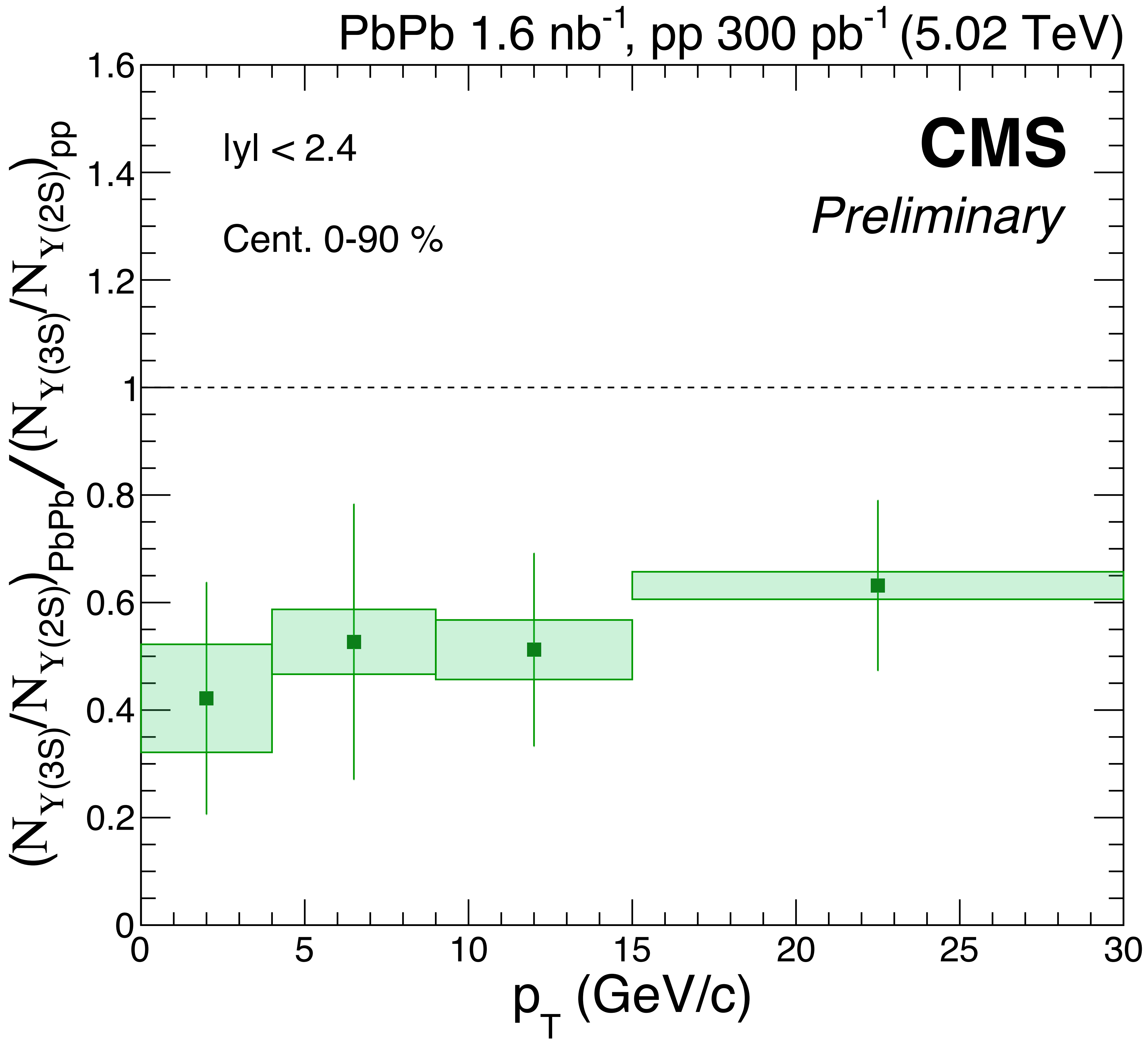


Re-discovery of the sequential suppression

CMS-PAS-HIN-21-007

- Significant Υ(3S) yield + precise Υ(2S) measurements in all p_T bins < 30 GeV
- **Clear ordering: R_{AA} Υ(1S) ≫ Υ(2S) > Υ(3S)**
- Υ(3S) more suppressed than Υ(2S) in all p_T intervals (double yield ratio)





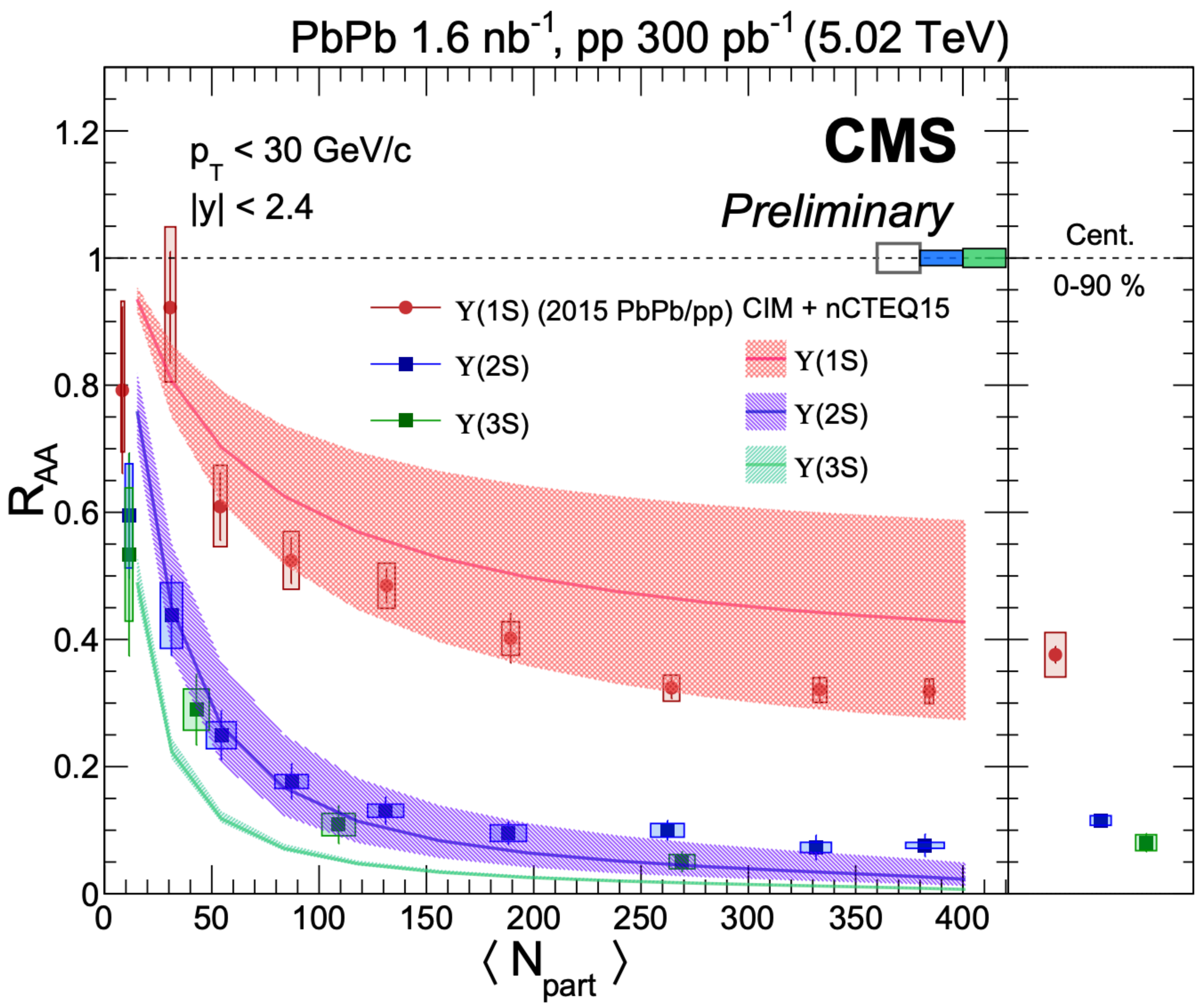
Comparison with state-of-the-art models

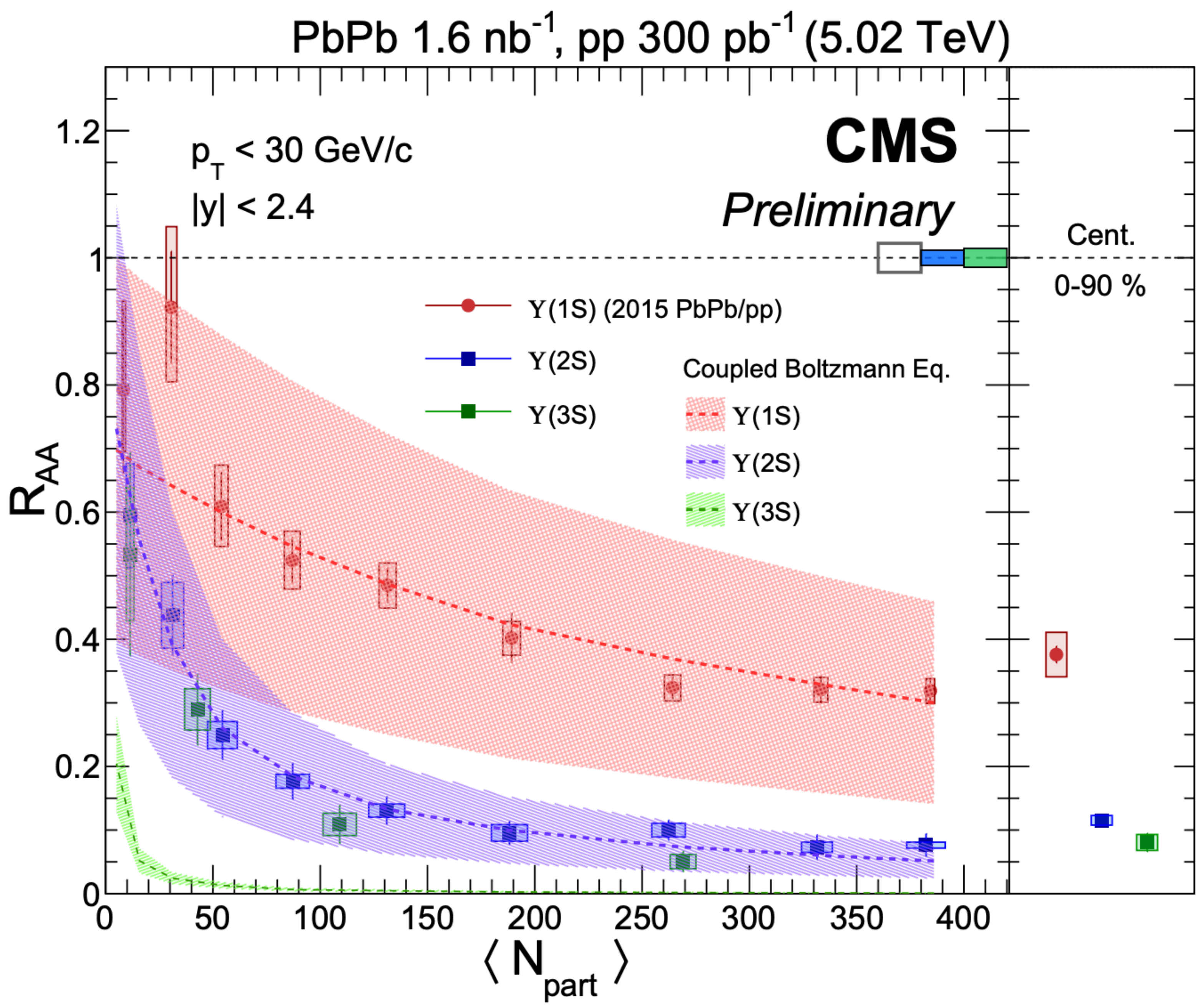
None of them can reproduce the data consistently over the 3 states! (more details in backup)

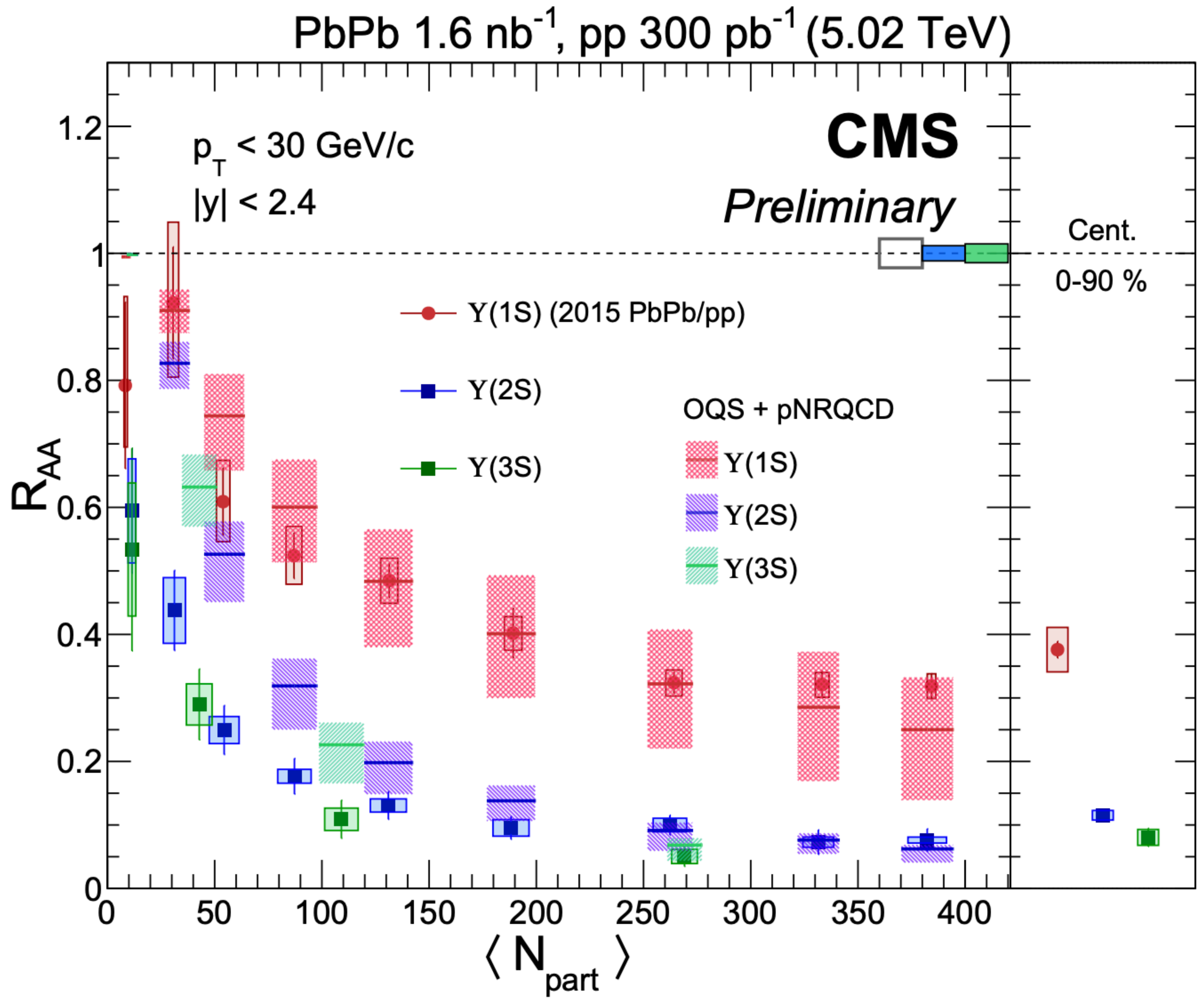
Comover interaction model
[JHEP 10 (2018) 094]
No regeneration contribution

Coupled Boltzmann equations
[JHEP 01 (2021) 046]
No regeneration for Υ(3S)

Open-quantum system
[PRD 104 (2021) 094049]
Call for CNM effects?
Limit of the EFT formalism?



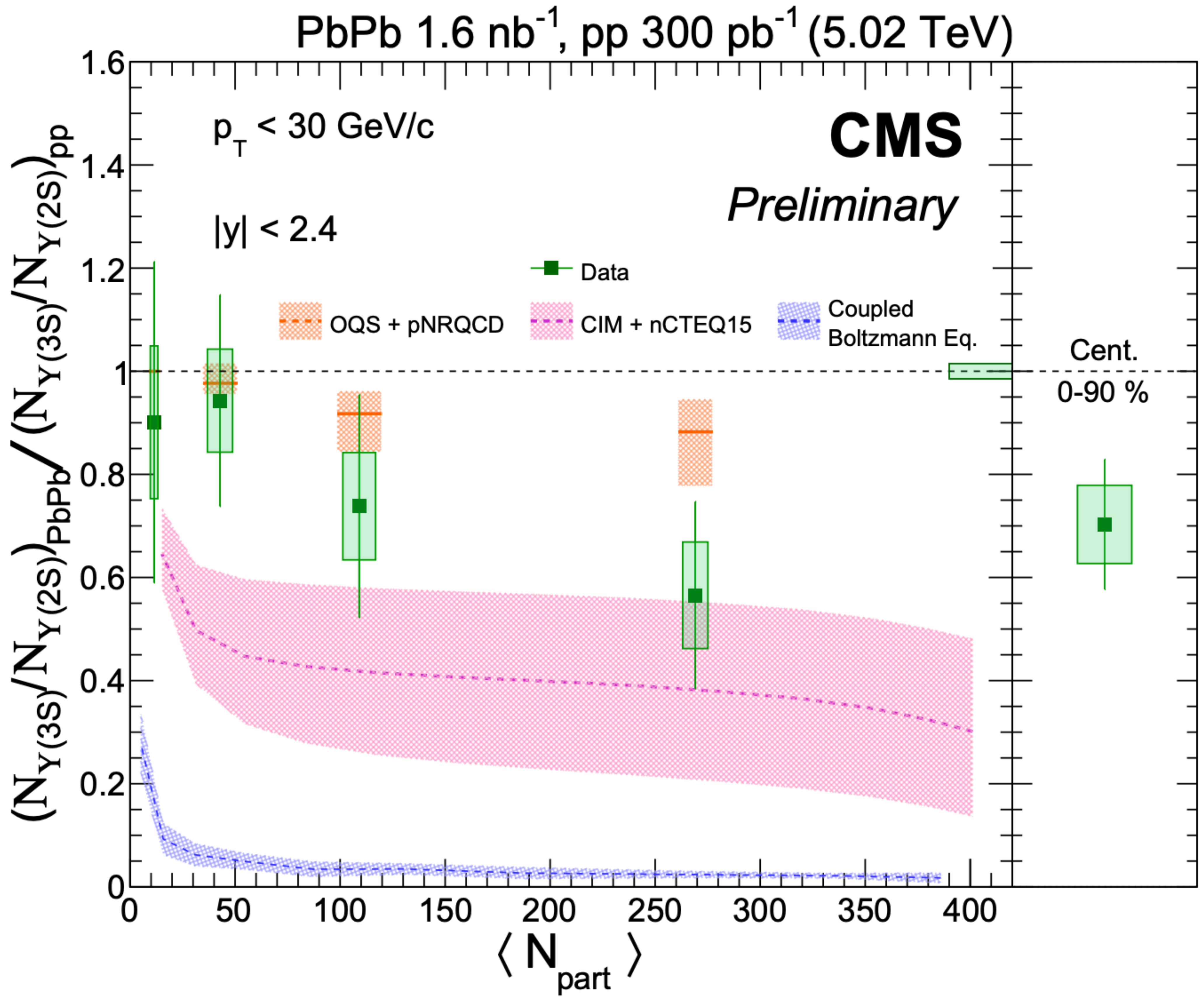


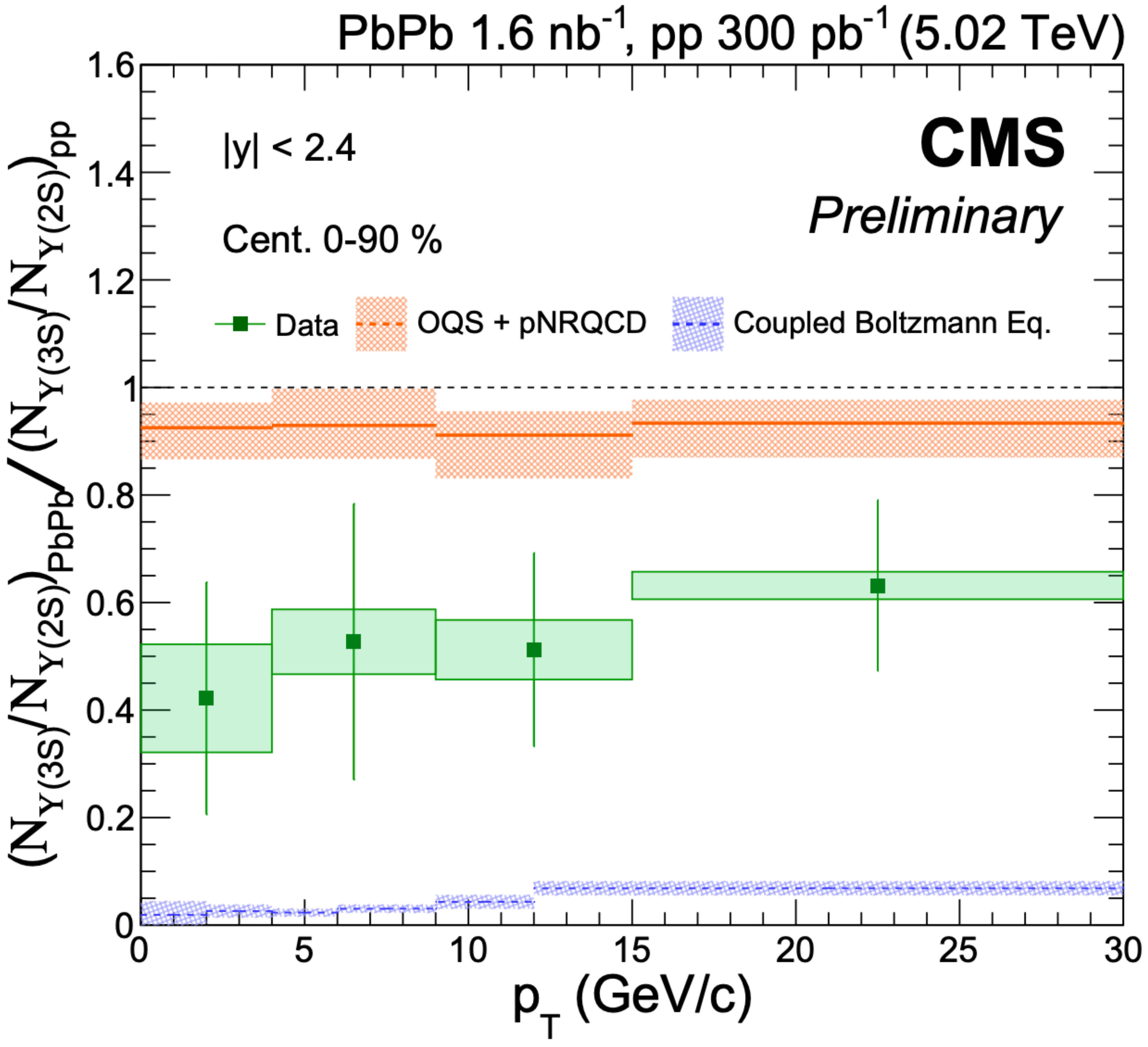


Υ(3S)-to-Υ(2S) double ratio

Cancellation of uncertainties common to both states (nPDF in calculations, correlated systematics)

- regeneration missing for Υ(3S) in Coupled Boltzmann equations [JHEP 01 (2021) 046]
- Υ(3S) ≈ Υ(2S) expected from *quantum jumps* in OQS+pNRQCD [PRD 104 (2021) 094049]





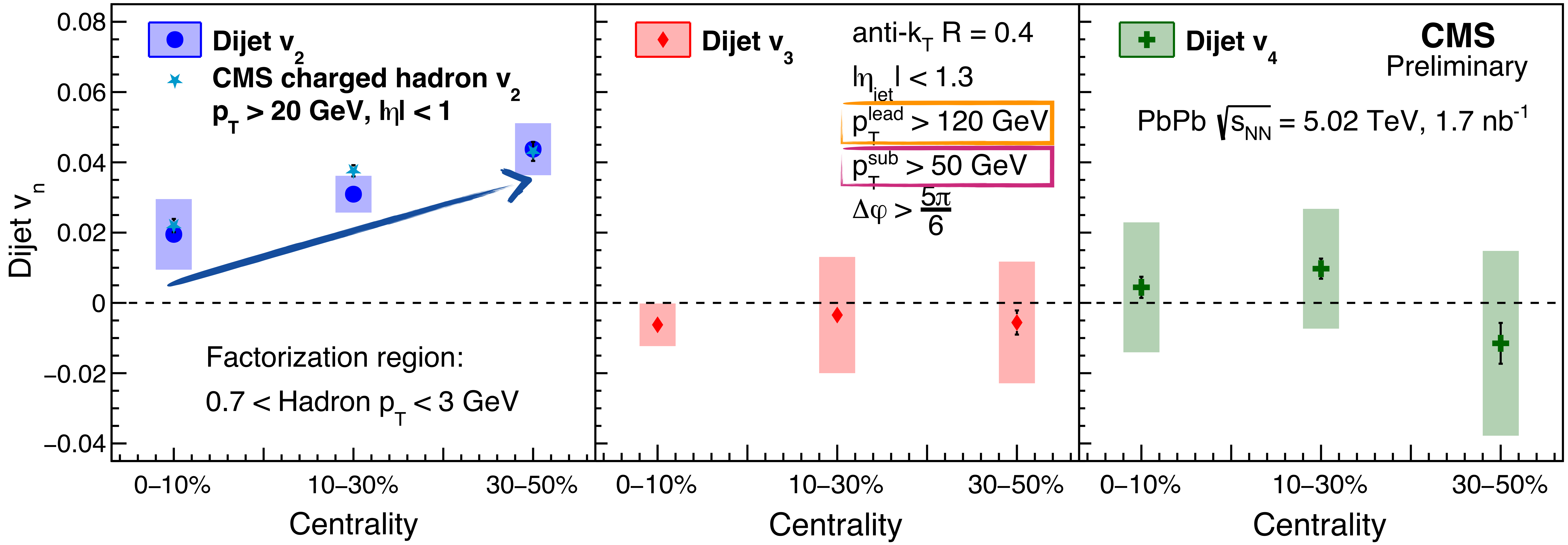
Jet quenching studies

Dijet cathedral overlooking the underlying city

Jet azimuthal anisotropies in dijet events

CMS-PAS-HIN-21-002

Selection of dijet events containing back-to-back leading and subleading jets



Positive v_2, increasing from the most central to more peripheral collisions

☛ path-length dependence of energy loss

Higher-order coefficients compatible with zero

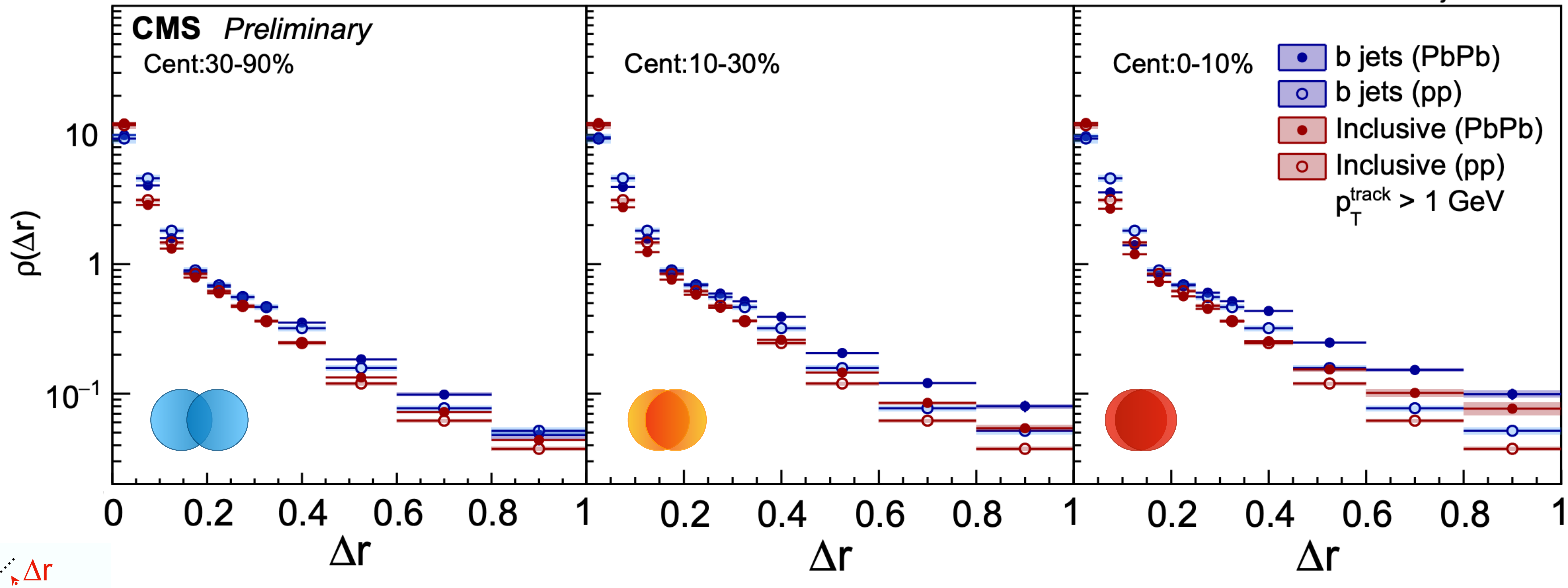
☛ dijet azimuthal distribution not impacted by medium density fluctuations

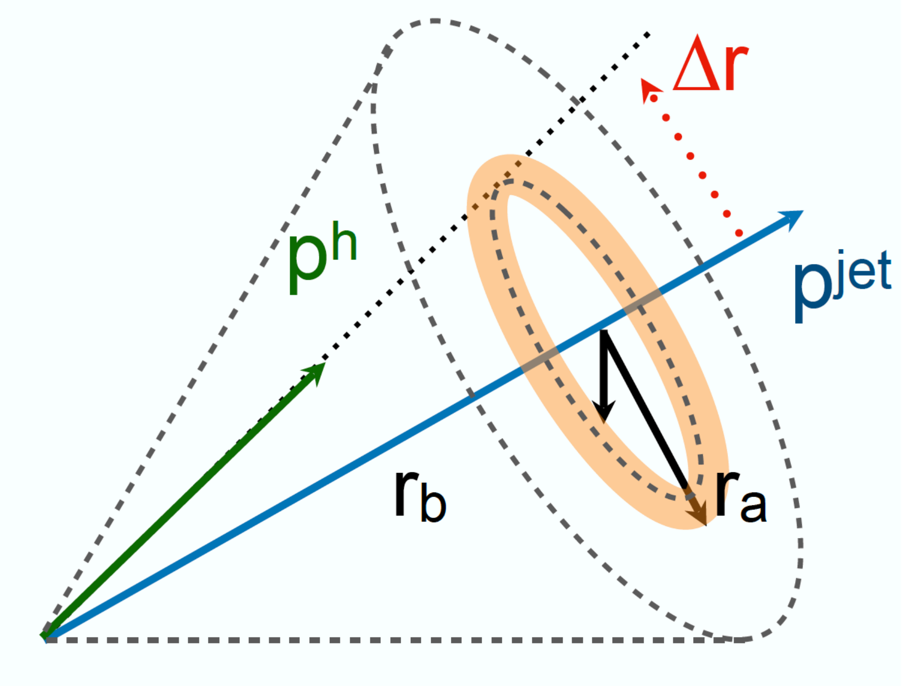
Radial profile of b-tagged jet

CMS-PAS-HIN-20-003

$$\rho(\Delta r) = \frac{1}{\delta r}\frac{\Sigma_{\mathrm{jet}}\Sigma_{\mathrm{trk}\in(\Delta r_a,\Delta r_b)}p_{\mathrm{T}}^{\mathrm{trk}}}{\Sigma_{\mathrm{jet}}\Sigma_{\mathrm{trk}}p_{\mathrm{T}}^{\mathrm{trk}}}$$

PbPb 1.7 nb^{-1}, pp 27.4 pb^{-1}, anti-k_T jet (R = 0.4): p_T^{jet} > 120 GeV, $|\eta_{jet}|$ < 1.6



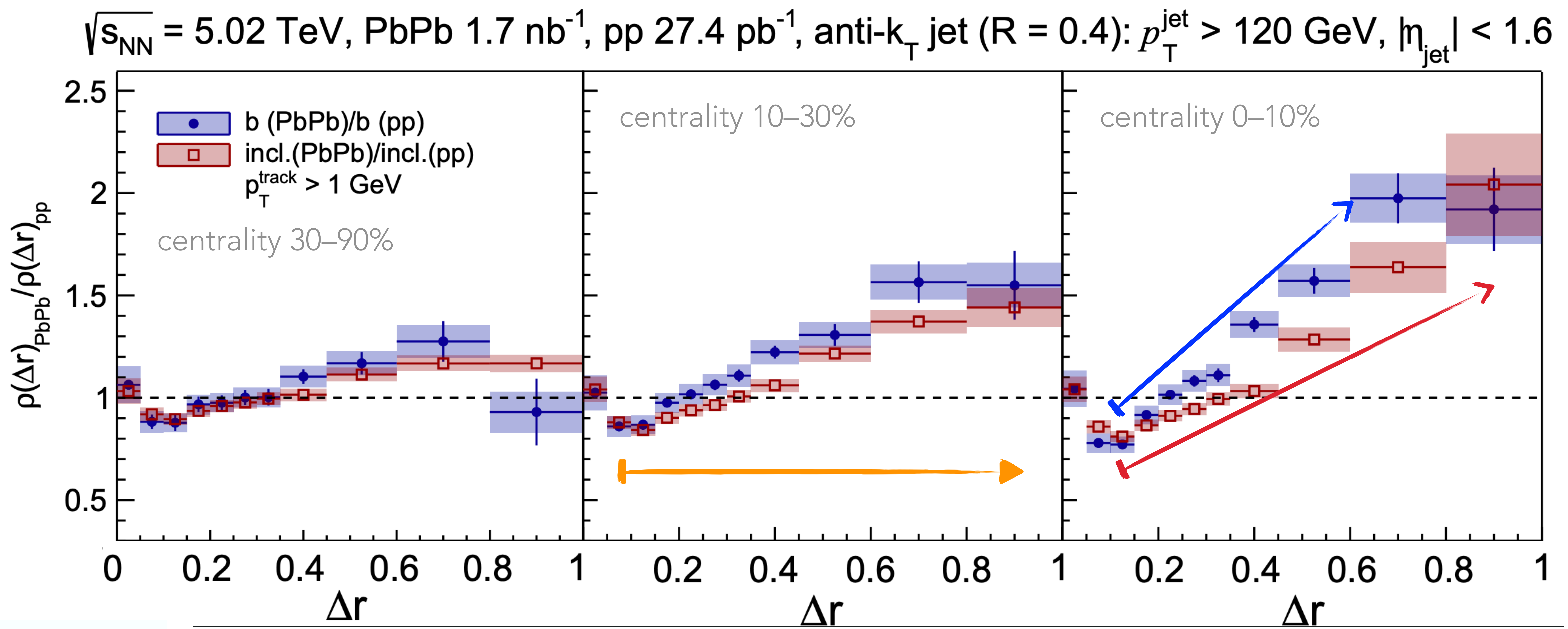


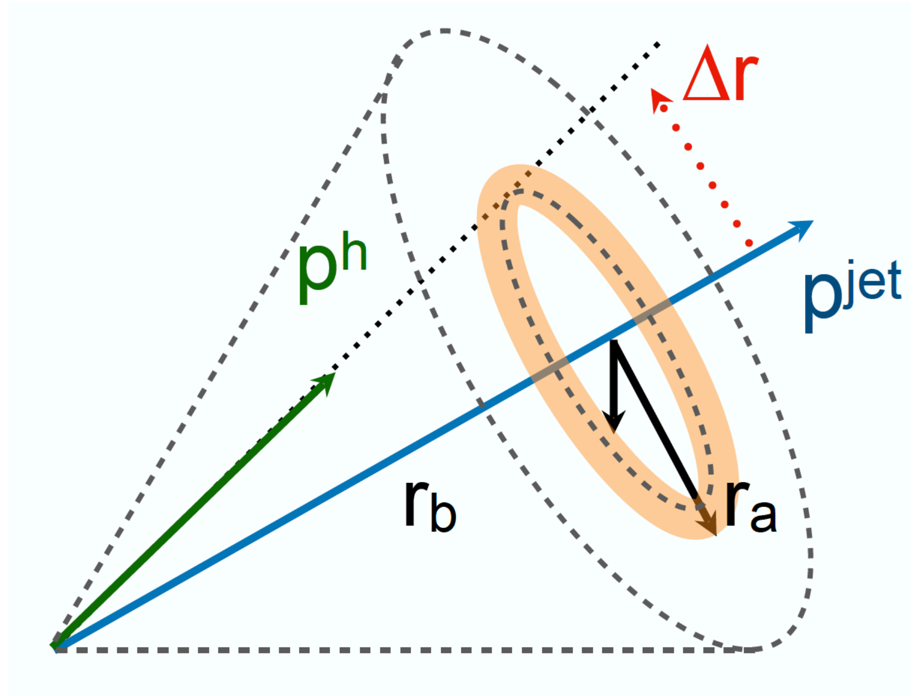
p_T distribution of the constituent charged particles around the jet axis

☛ **broadening for both inclusive and b-tagged jets** in PbPb collisions

b vs inclusive jet shape modification

CMS-PAS-HIN-20-003



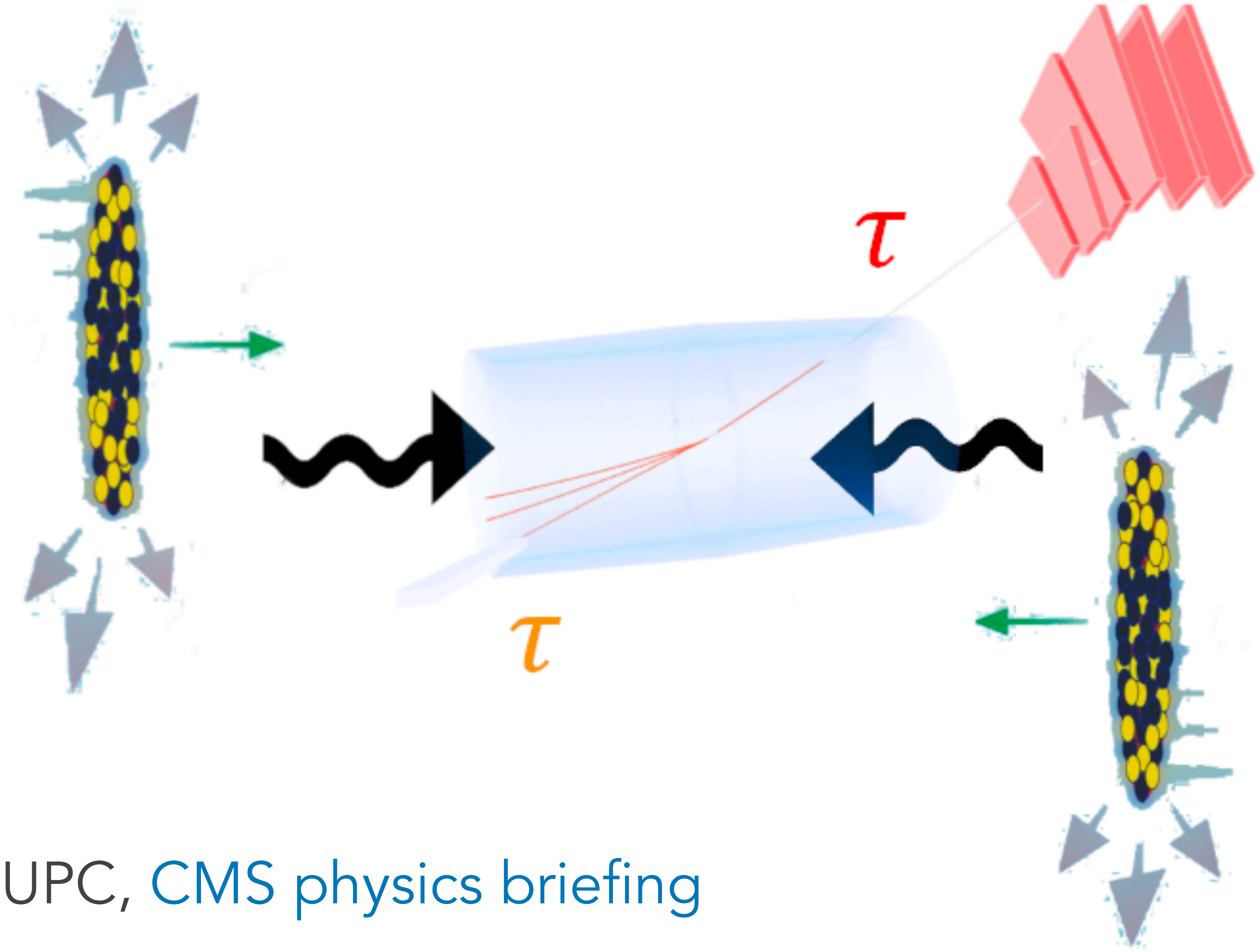


Redistribution of the transverse momentum from small to large radii

- stronger towards more central collisions (jet-medium interactions)
- excess at the verge of the cone **greater for b jets** than for inclusive jets

Two-photon interactions in ultraperipheral collisions

Enhanced rare processes for precision SM physics and for research beyond



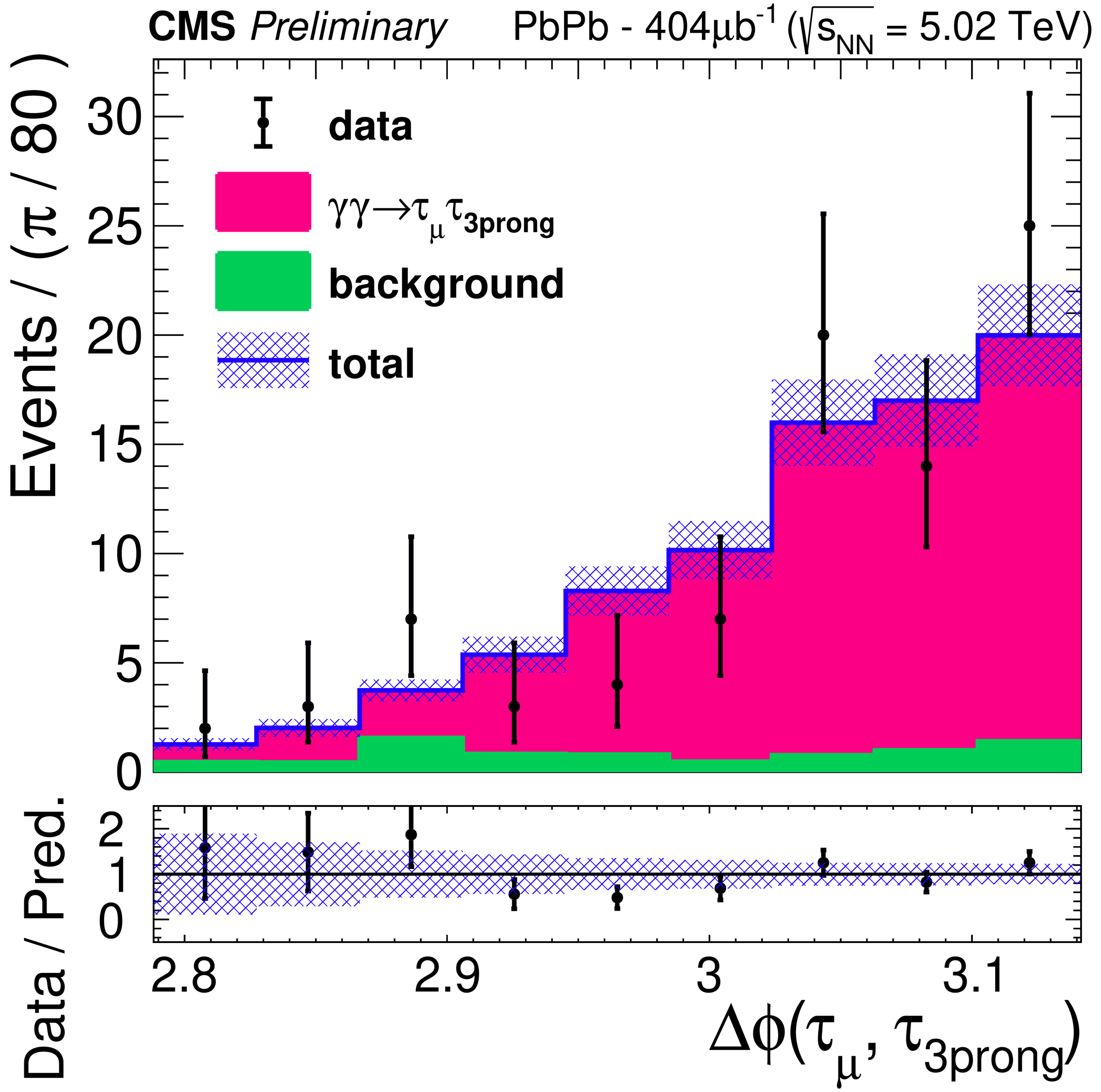
Observation of $\gamma\gamma \to \tau\tau$ in UPC, CMS physics briefing


CMS Experiment at the LHC, CERN
Data recorded: 2015-Dec-06 21:41:27.033612 GMT
Run / Event / LS: 263400 / 88515785 / 849
CMS-PAS-HIN-21-009
$\tau \to \mu \nu_\mu \nu_\tau$
$\tau \to \pi^\pm \pi^\mp \pi^\pm \nu_\tau$
Pb
Z
$\mathrm{Pb}^{(\star)}$
γ
τ^-
μ^-
ν_τ
$\bar{\nu}_\mu$
δa_τ
$\pi^\pm$
$\pi^\mp$
π^+
$\bar{\nu}_\tau$
τ^+
γ
Z
Pb
$\mathrm{Pb}^{(\star)}$

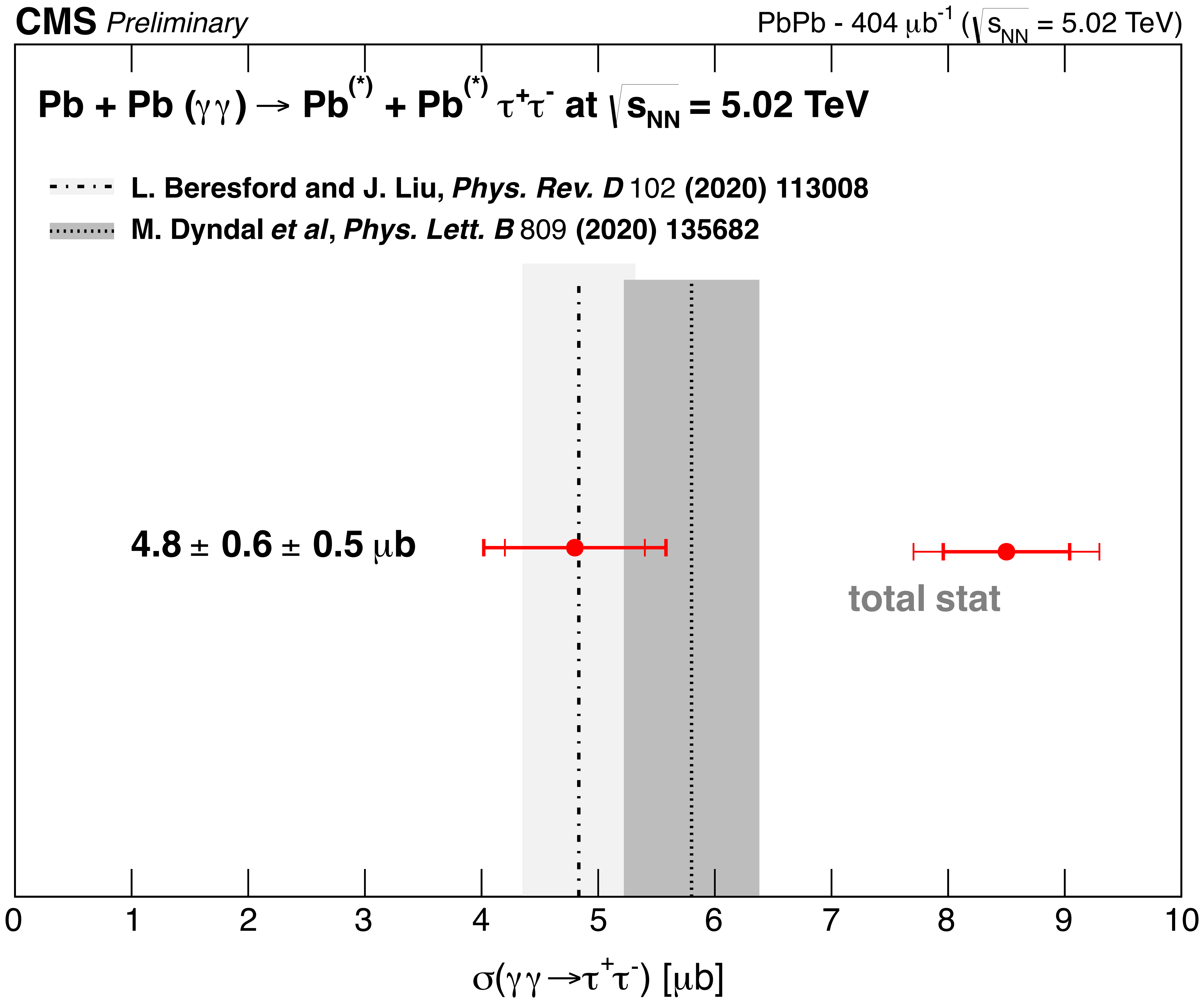
Observation of tau lepton pair photoproduction

CMS-PAS-HIN-21-009

Difference in azimuthal opening angle between τ_μ and τ_{3prong} candidates (back-to-back signature)
☛ distribution postfit: N_{signal} = 77 ± 12 events



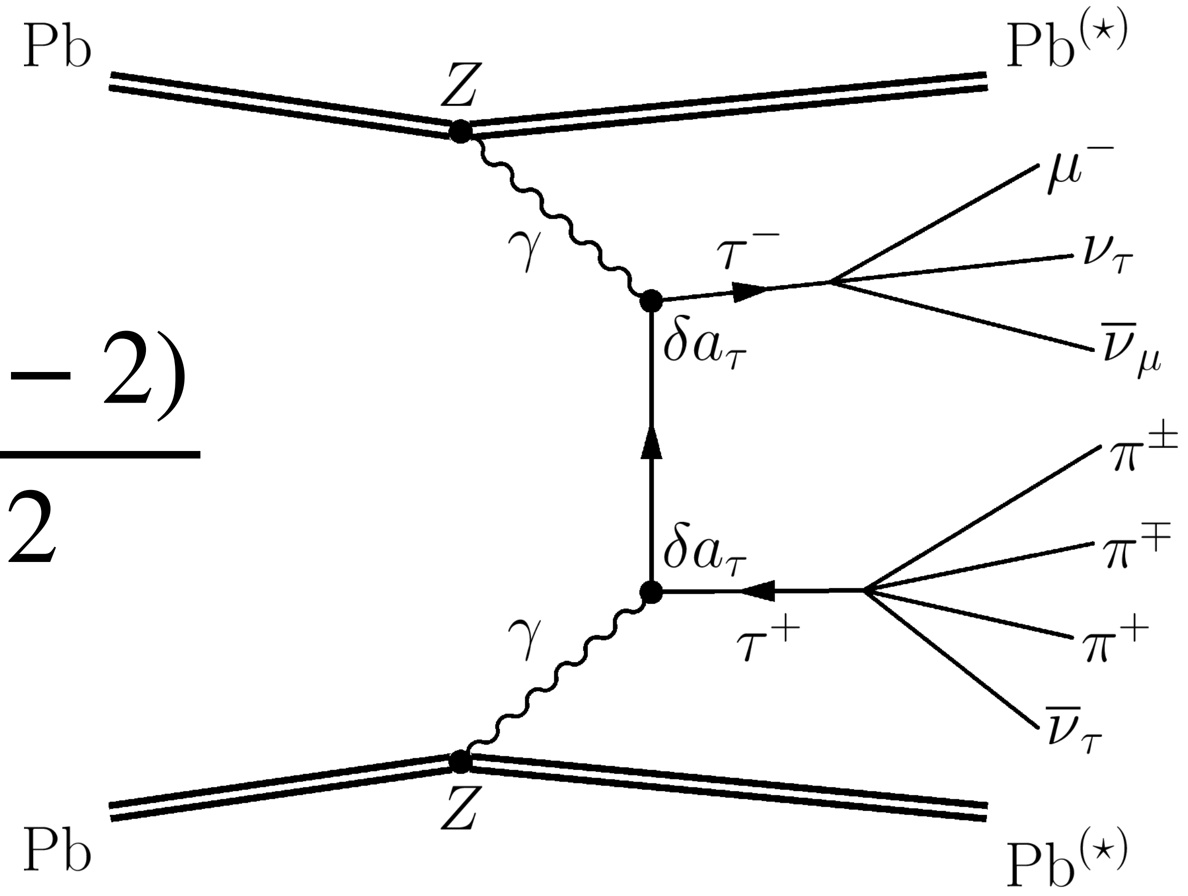
Measured fiducial cross section in agreement with SM calculations

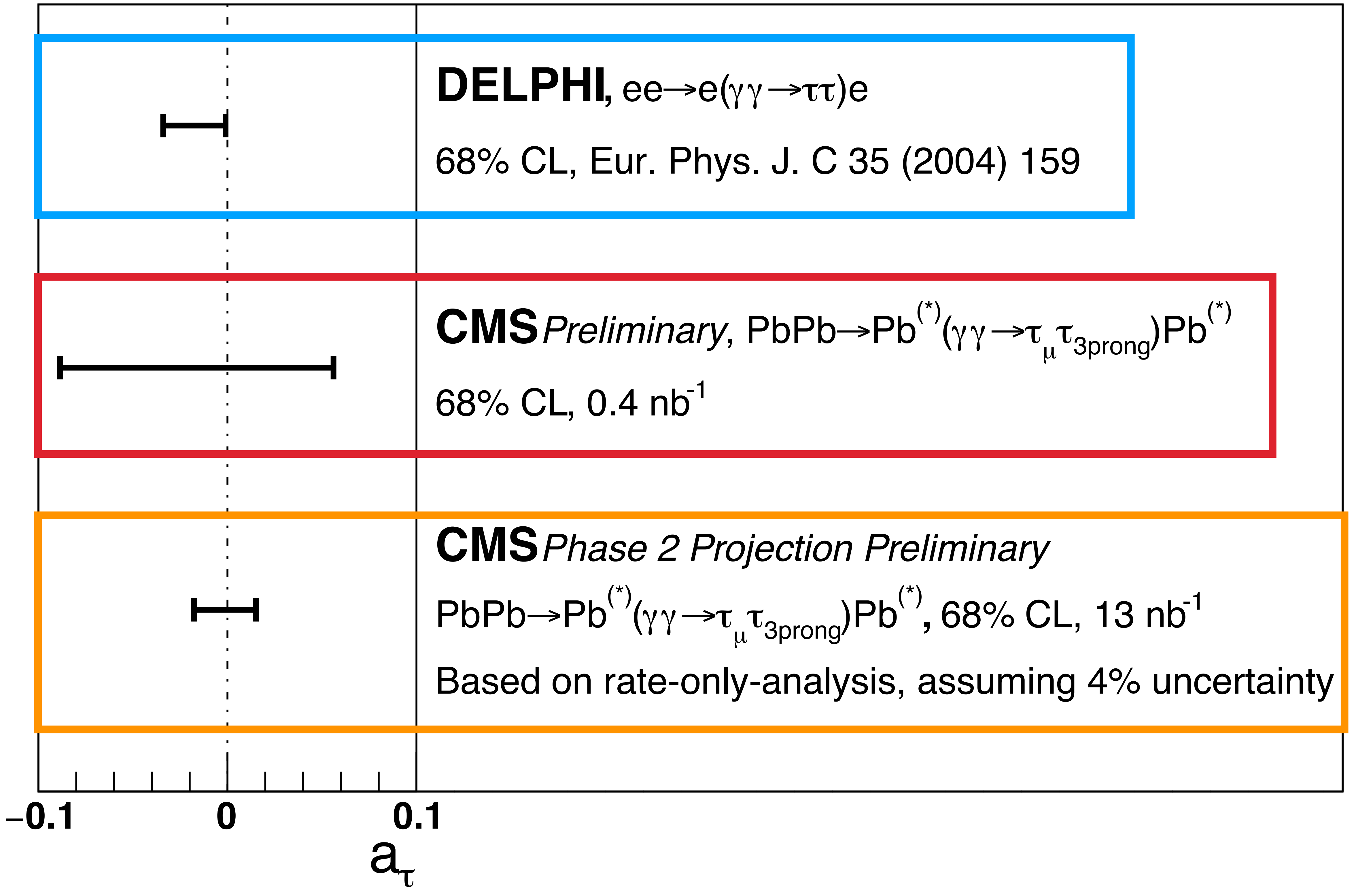


Limits on the anomalous magnetic moment

CMS-PAS-HIN-21-009

$$a_l = \frac{(g_l - 2)}{2}$$





- most-precisely measured quantity in Nature for the electron and the muon
- tau: best constraint to-date from DELPHI

☛ **a_τ derivation from $\gamma\gamma \to \tau\tau$ cross section and lepton decay kinematics**

- CMS limit: $(-8.8 < a_\tau < 5.6) \times 10^{-2}$ at 68% CL
- Projection with Run 3 & 4 luminosity competitive with LEP: $(-1.8 \pm 1.7) \times 10^{-2}$

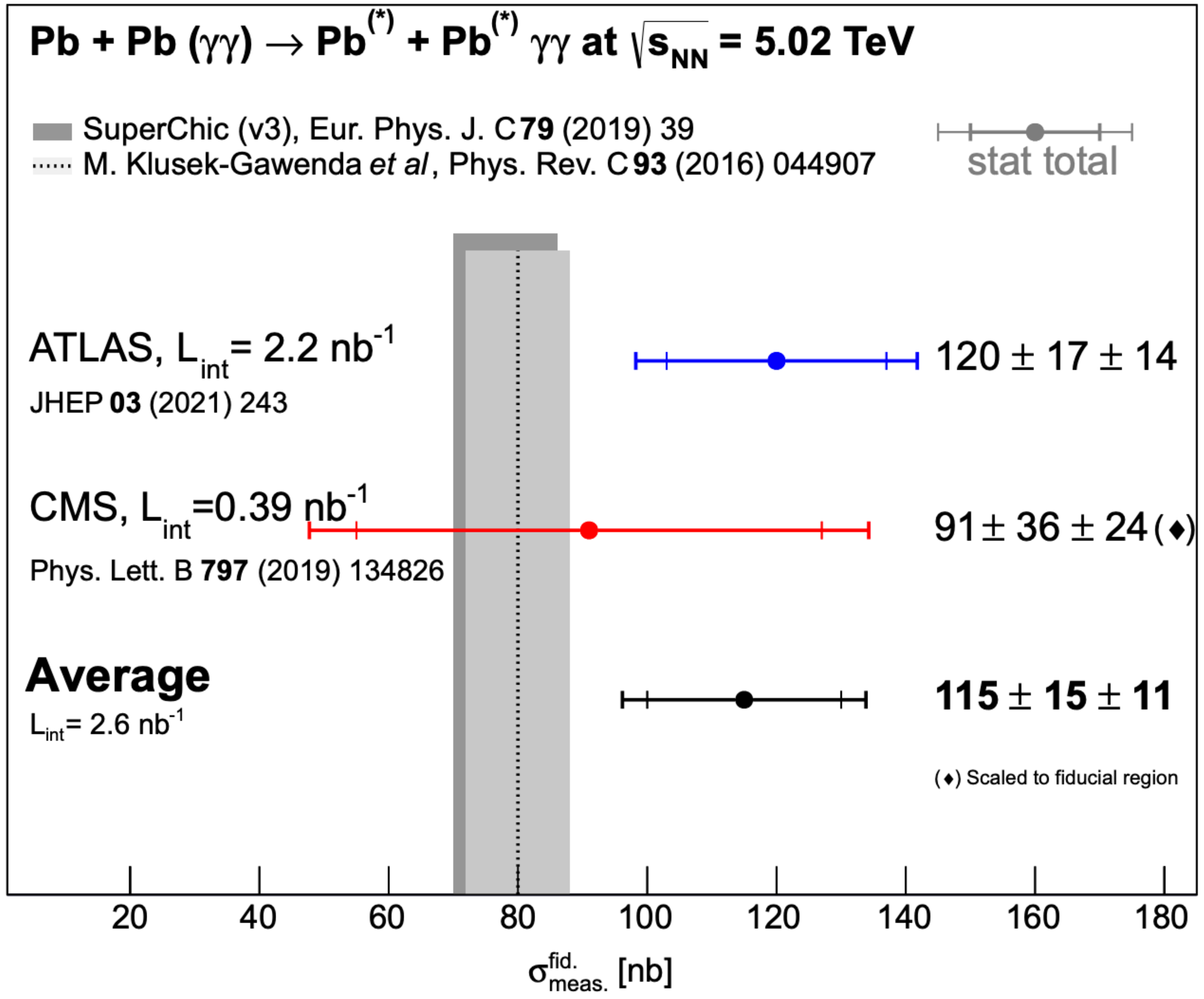
☛ 2018 data analysis with additional decay channels (+ dimuon for control)

☛ combination with ATLAS in the future?

HonexComb: one collaboration to gather them all

STRONG-2020 work package: cross-experiment combination of heavy ion measurements at the LHC

Sensitive channel to search for BSM physics!



First outcome: combination of light-by-light scattering cross section measurements [arXiv:2204.02845]

- CMS result scaled down to a fiducial region common with ATLAS (different photon E_T kinematics)
- average estimated with BLUE to account for correlations and their related assumptions

☛ **10% improvement**, but still statistically dominated

CMS update with 2018 data coming soon!

On-going projects (indico page)

- total charm cross section
- quarkonium feed-downs (driven by me 🙂)

A bright future ahead!

Now that Quark Matter is over, all our efforts are devoted to the **PbPb data taking preparation**.

Upgrades during LS2, summarised on the CERN webpage

- installation of prototype GEM chambers in the endcap region (muon detection redundancy)
- new beam pipe made of aluminium alloy (reduction of the activation by a factor of five)
- significant computing improvements (reconstruction on GPU, raw data size reduction)

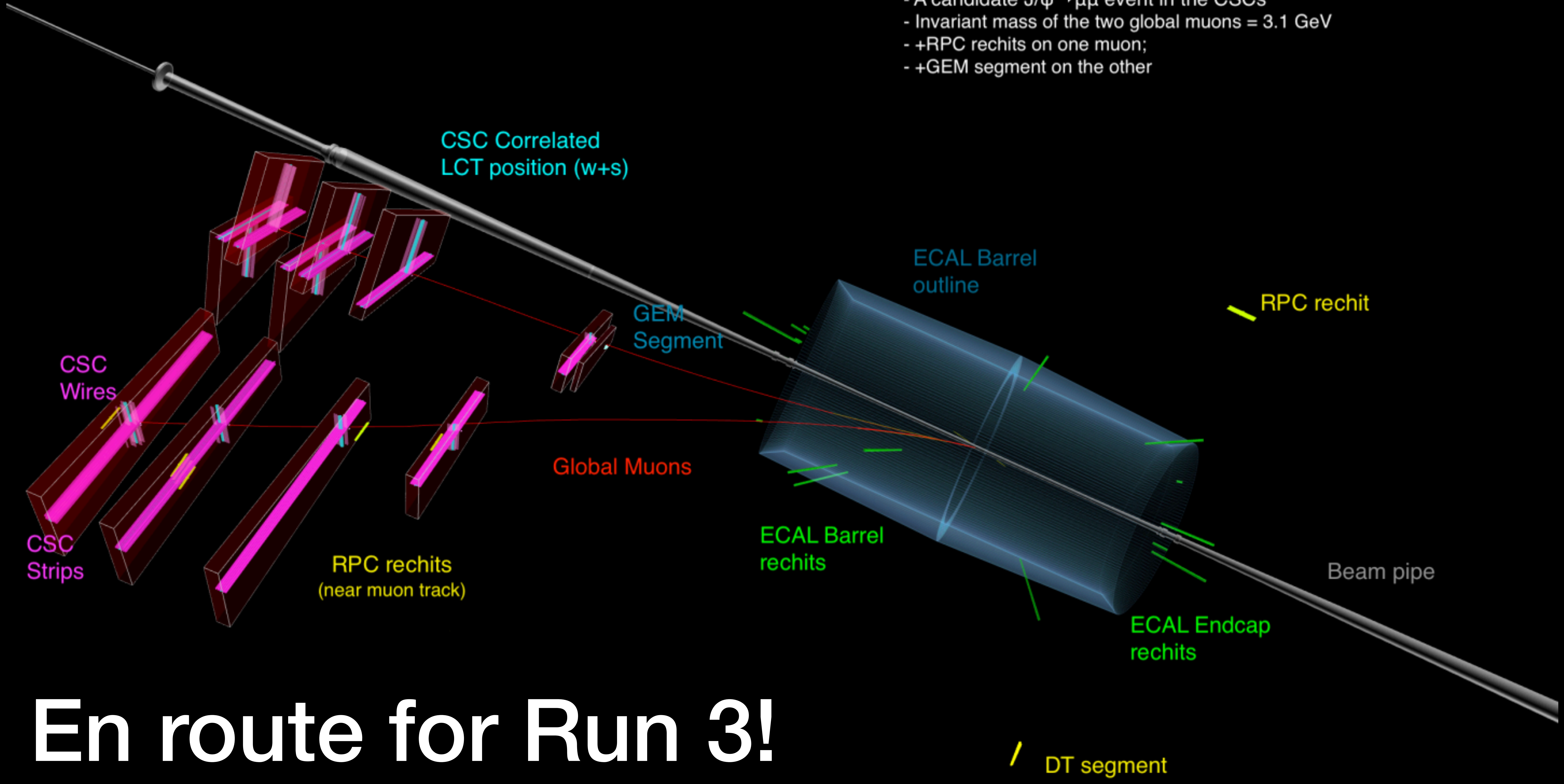
Most of these activities were carried out now to anticipate the operations for the HL-LHC era, a.k.a the **Phase-II upgrades** (cf. Matthew's talk).

Everything will come from the **luminosity increase ☛ projections for Run 3 & 4** [Yellow Report].

CMS Experiment at the LHC, CERN
Data recorded: 2021-Nov-01 00:20:45.992512 GMT
Run / Event / LS: 346509 / 28321286 / 30

First event with a track segment reconstructed in the newly-installed GEM detectors

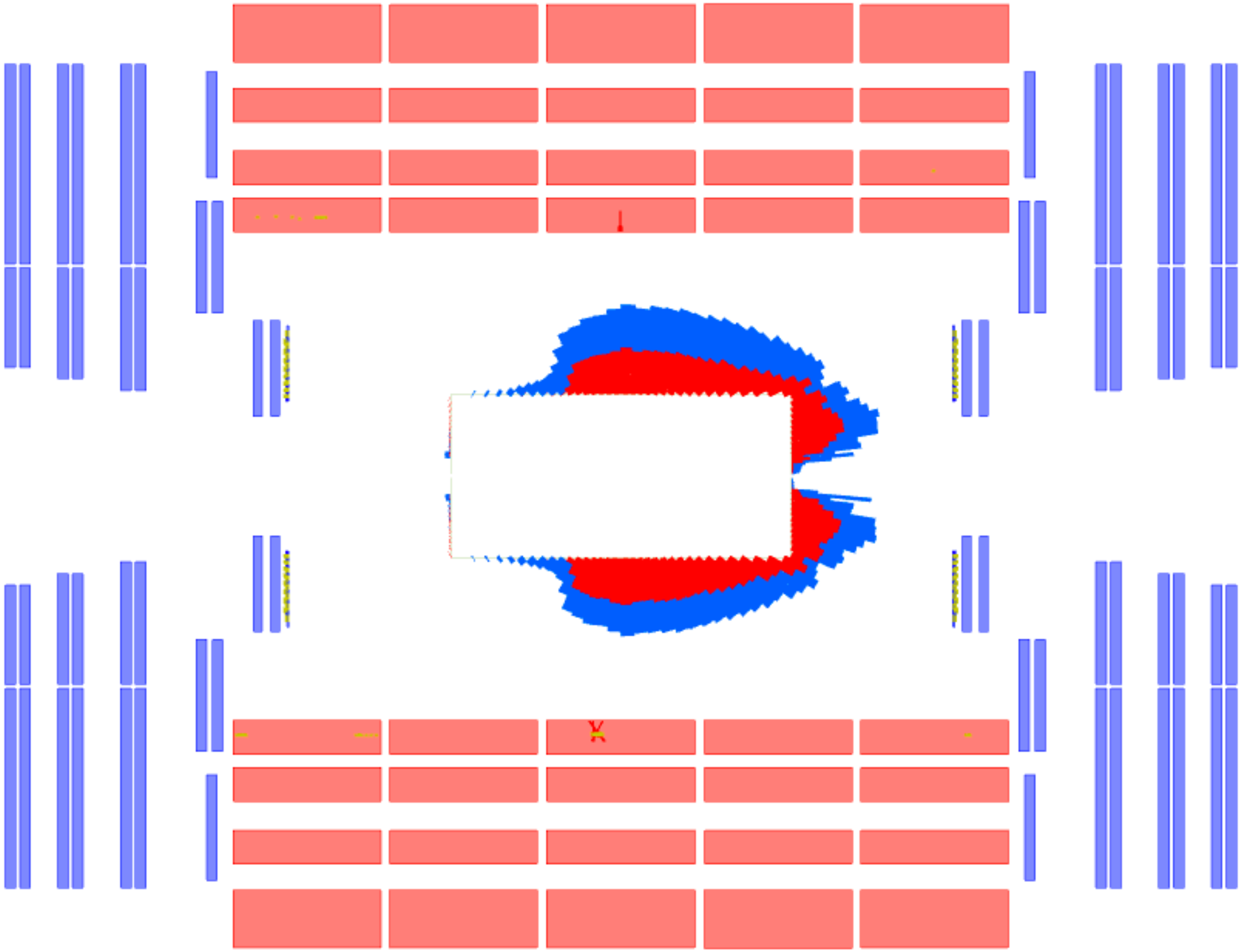
Test pp collisions at 900 GeV - Nov 2021
- A candidate $J/\psi \rightarrow \mu\mu$ event in the CSCs
- Invariant mass of the two global muons = 3.1 GeV
- +RPC rechits on one muon;
- +GEM segment on the other



En route for Run 3!

CMS Experiment at LHC, CERN
Data recorded: Thu Apr 28 13:24:34 2022 CEST
Run/Event: 350968 / 2093
Lumi section: 87

« Beam splash » event recorded last week

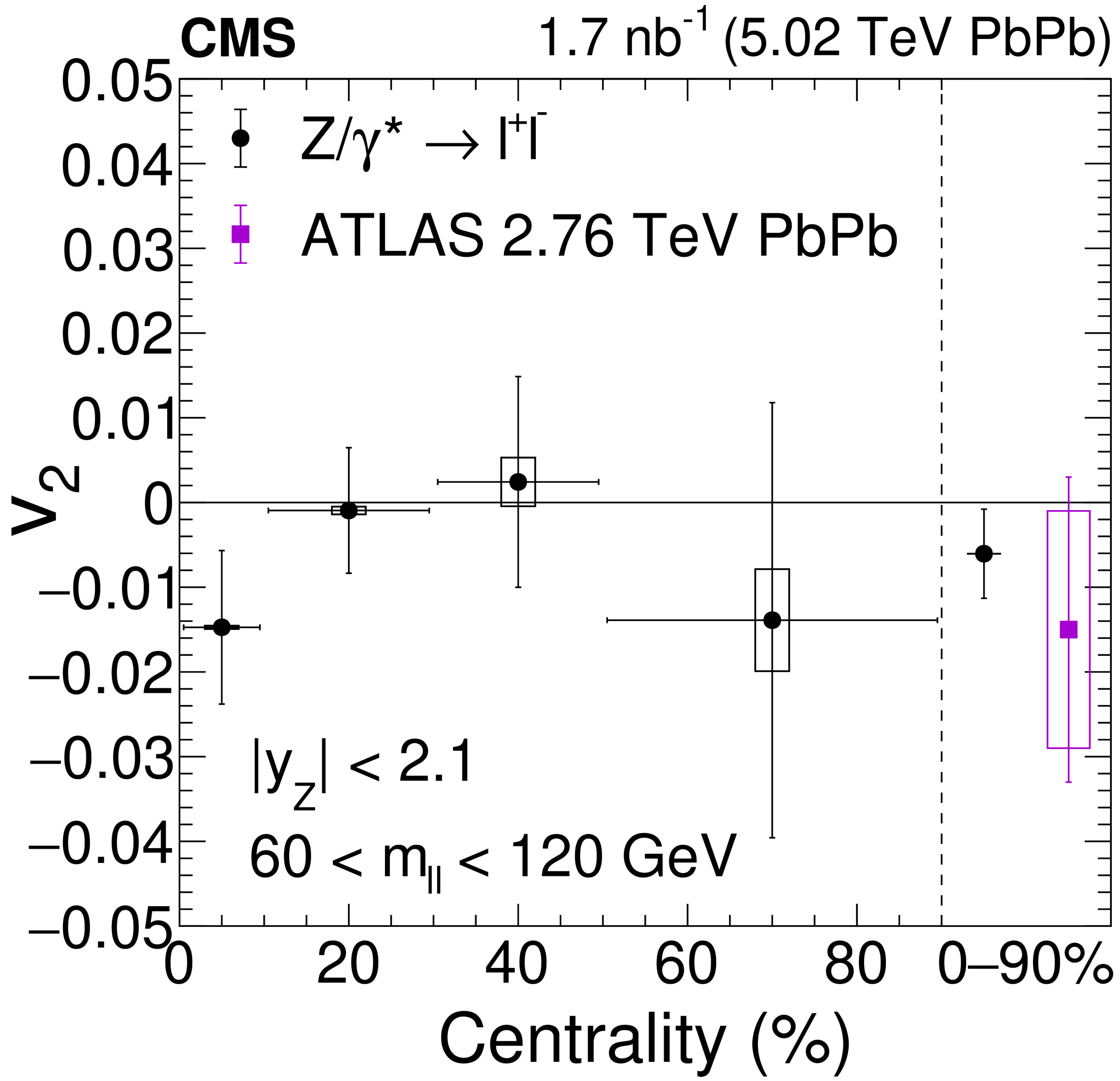


Supplementary material

Constraints on the initial state with Z boson [PRL 127 (2021) 102002]

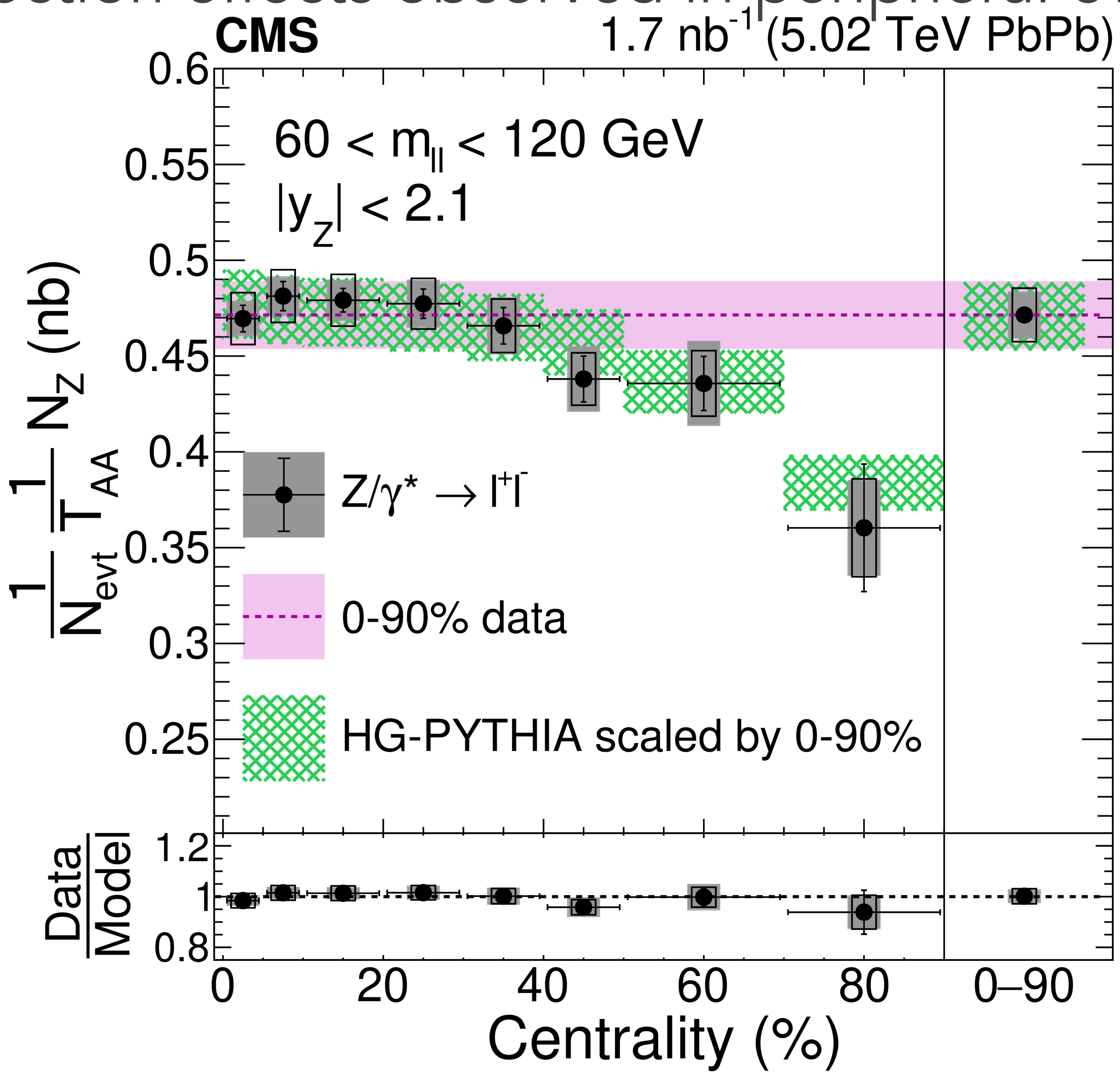
Early production, (very) fast decay

☛ unaffected by medium interactions



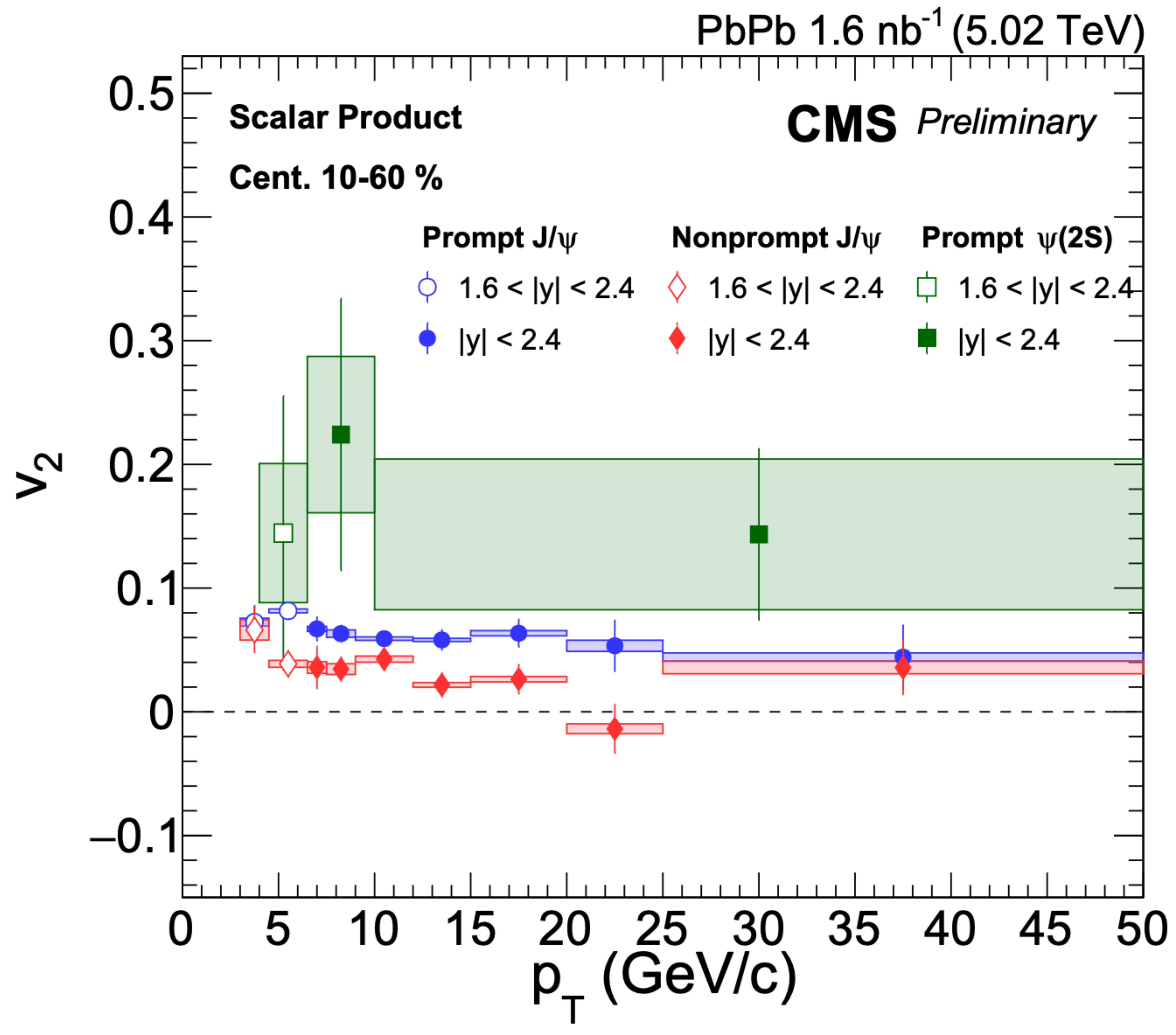
Idea: N_Z / (σ_{NN}^Z x N_{events}) as effective nucleon–nucleon luminosity proxy (instead of T_{AA})

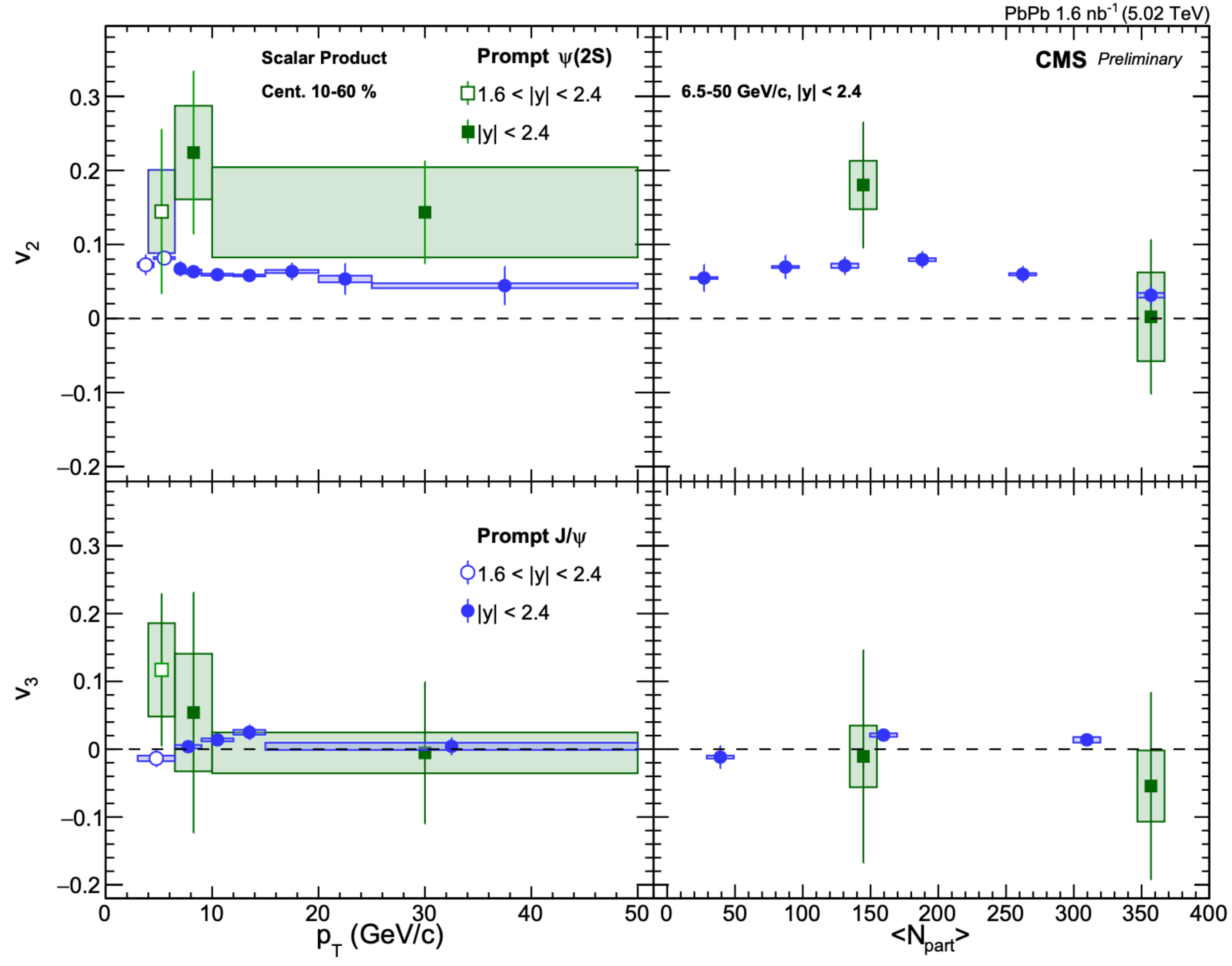
- does not rely on Glauber modeling
- incorporates the collision geometry and centrality selection effects observed in peripheral events



Flow measurements for charmonia

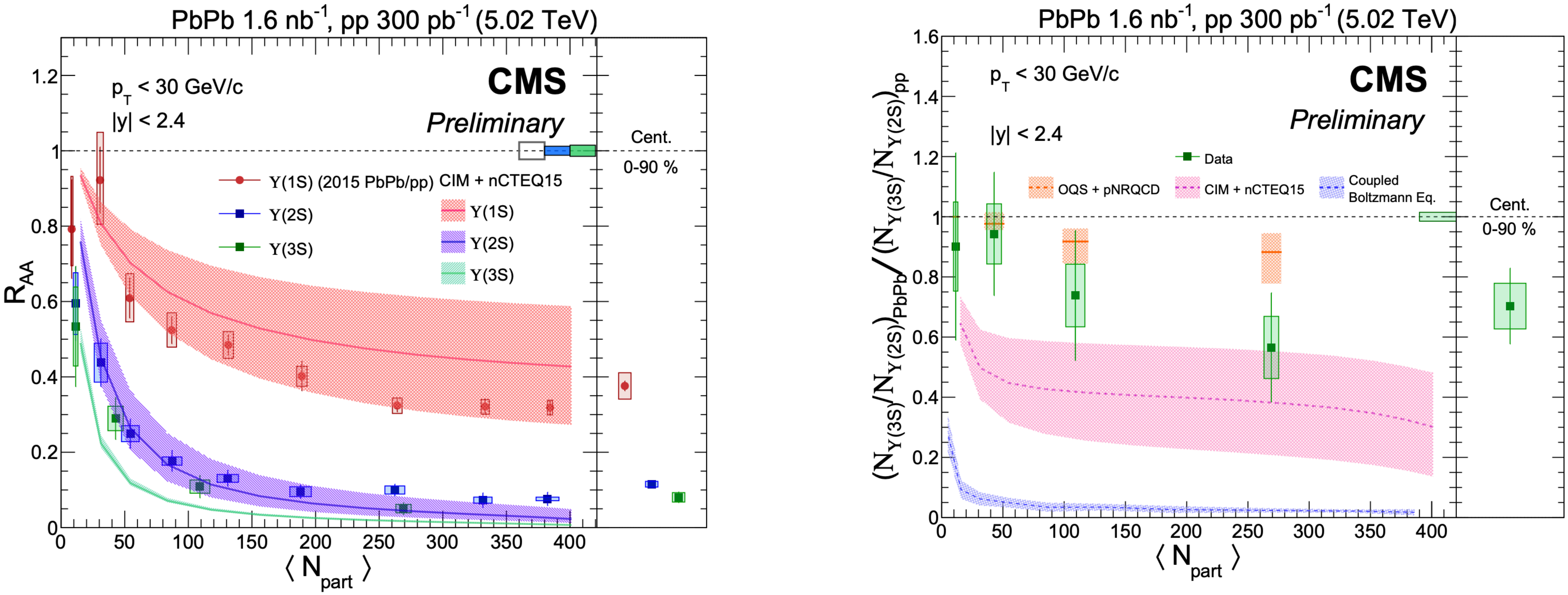
CMS-PAS-HIN-21-008





Comover interaction model [JHEP 10 (2018) 094]

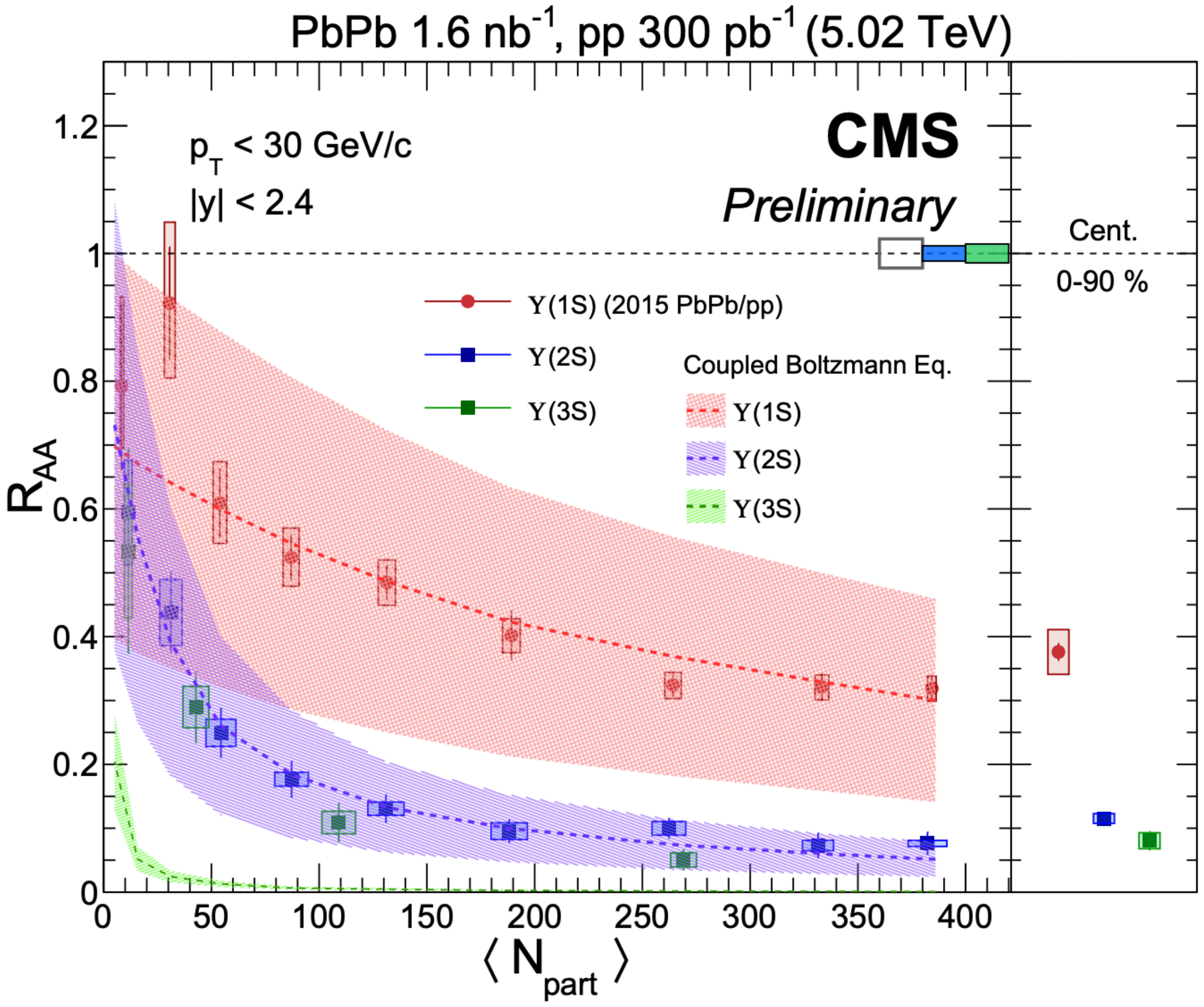
- Quarkonium suppression from scatterings with surrounding particles in the final state
- **nCTEQ15 parametrisation** for initial-state modification
- Most comprehensive picture to reproduce data in both pPb and PbPb collisions!



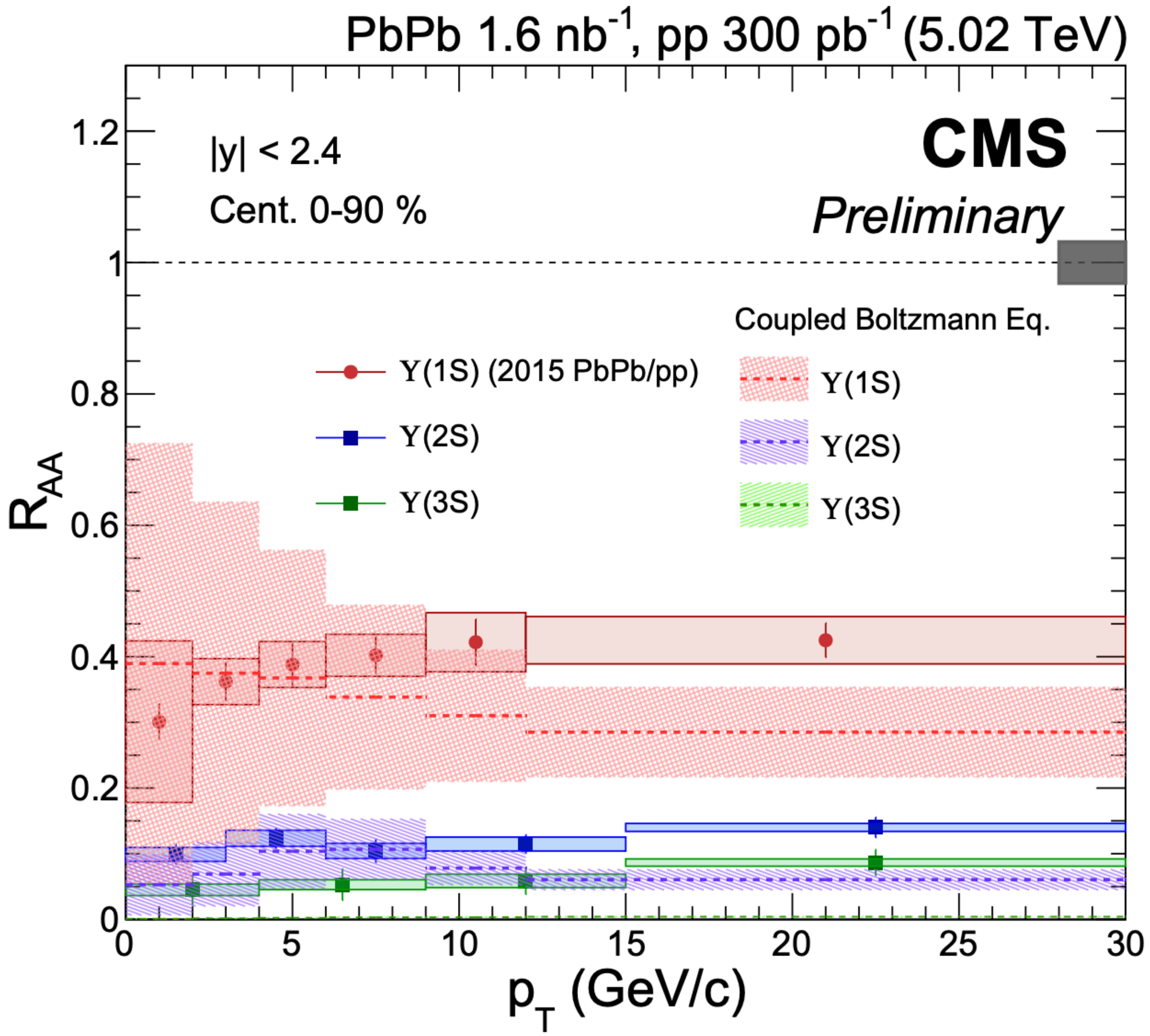
Coupled Boltzmann Equations [JHEP 01 (2021) 046]

- Continuous dissociation and recombination of heavy-quark pairs through the QGP evolution
- 2+1D viscous hydrodynamics for medium description, **EPPS16 nPDF** for initial HQ modification

No regeneration for Υ(3S)

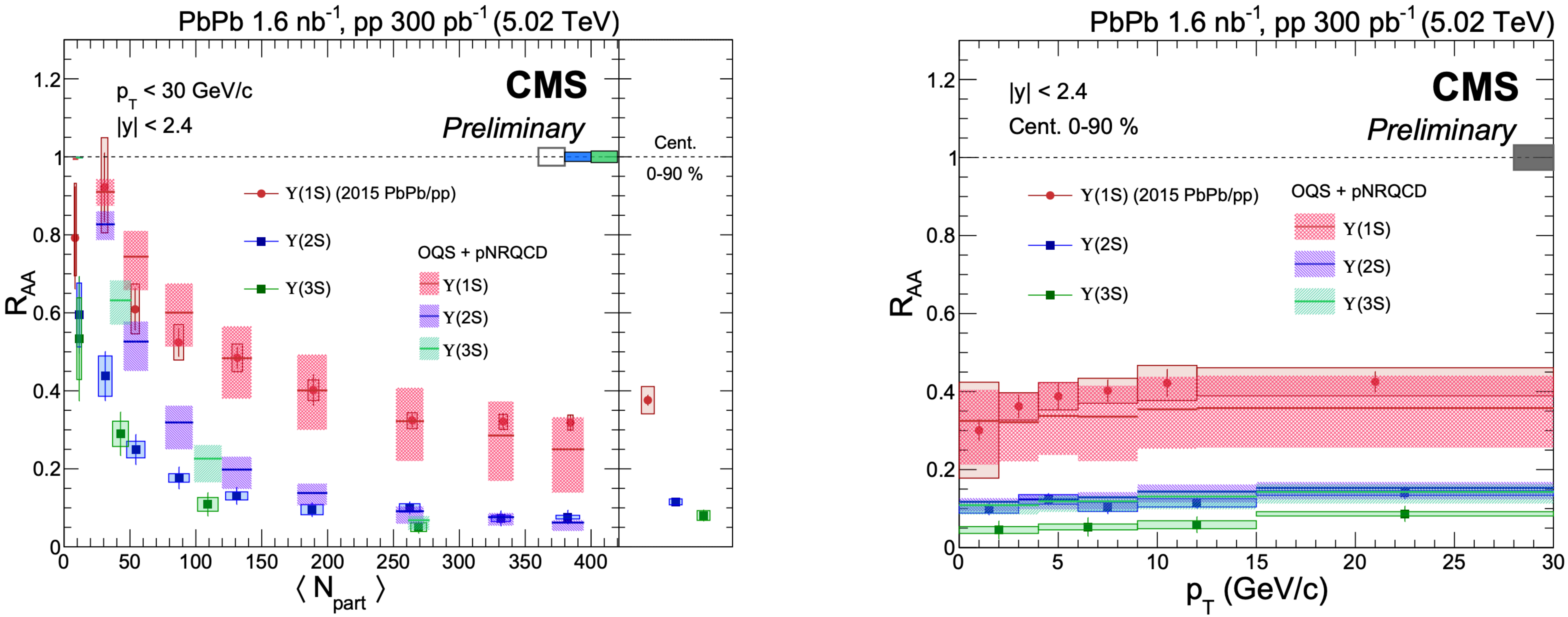


Breakdown of NRQCD calculations at high p_T?



Open-quantum system [PRD 104 (2021) 094049]

- Continuous dissociation and recombination through the QGP evolution (Linblad equation)
- 3+1D anisotropic hydrodynamics to model the bulk expansion
- Call for CNM effects? Late-stage interactions? **Vacuum-like evolution for T < 250 MeV**

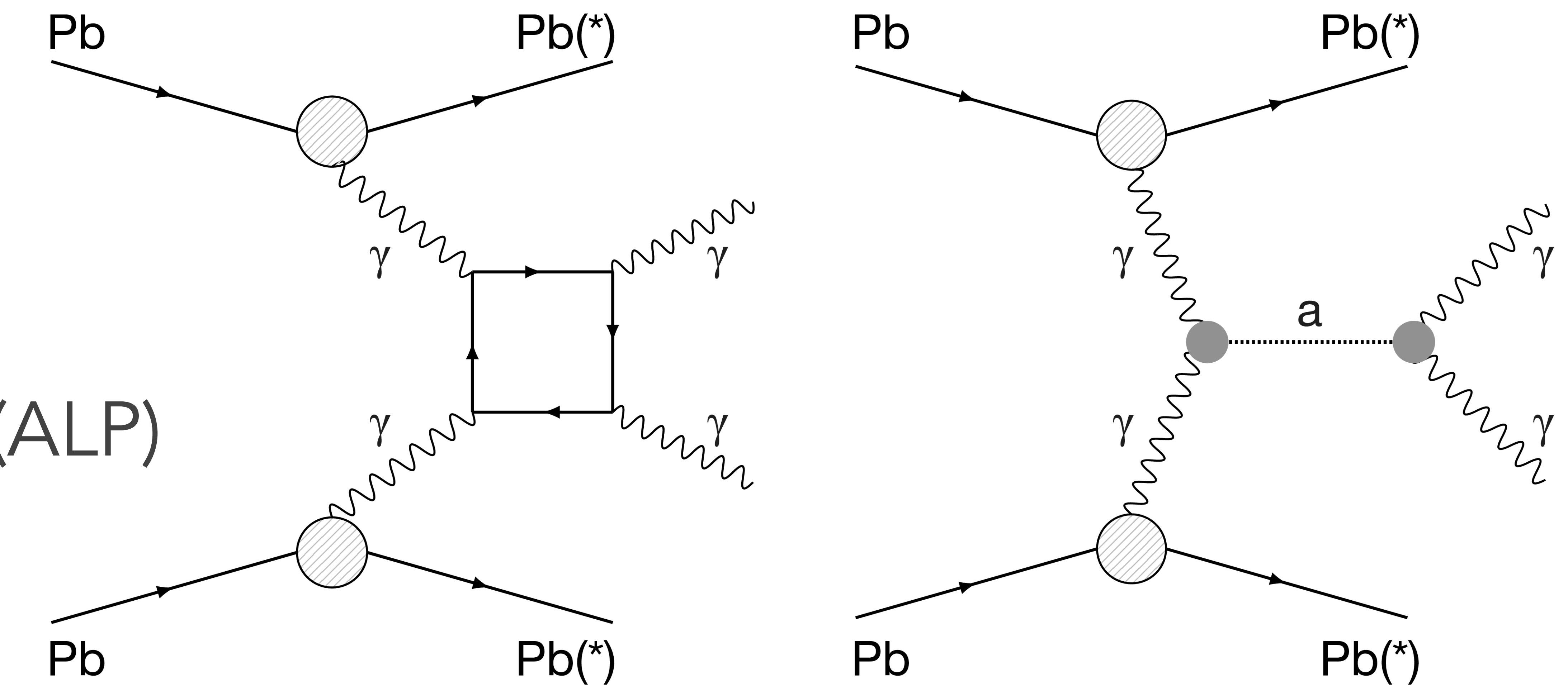


Light-by-light scattering at the LHC

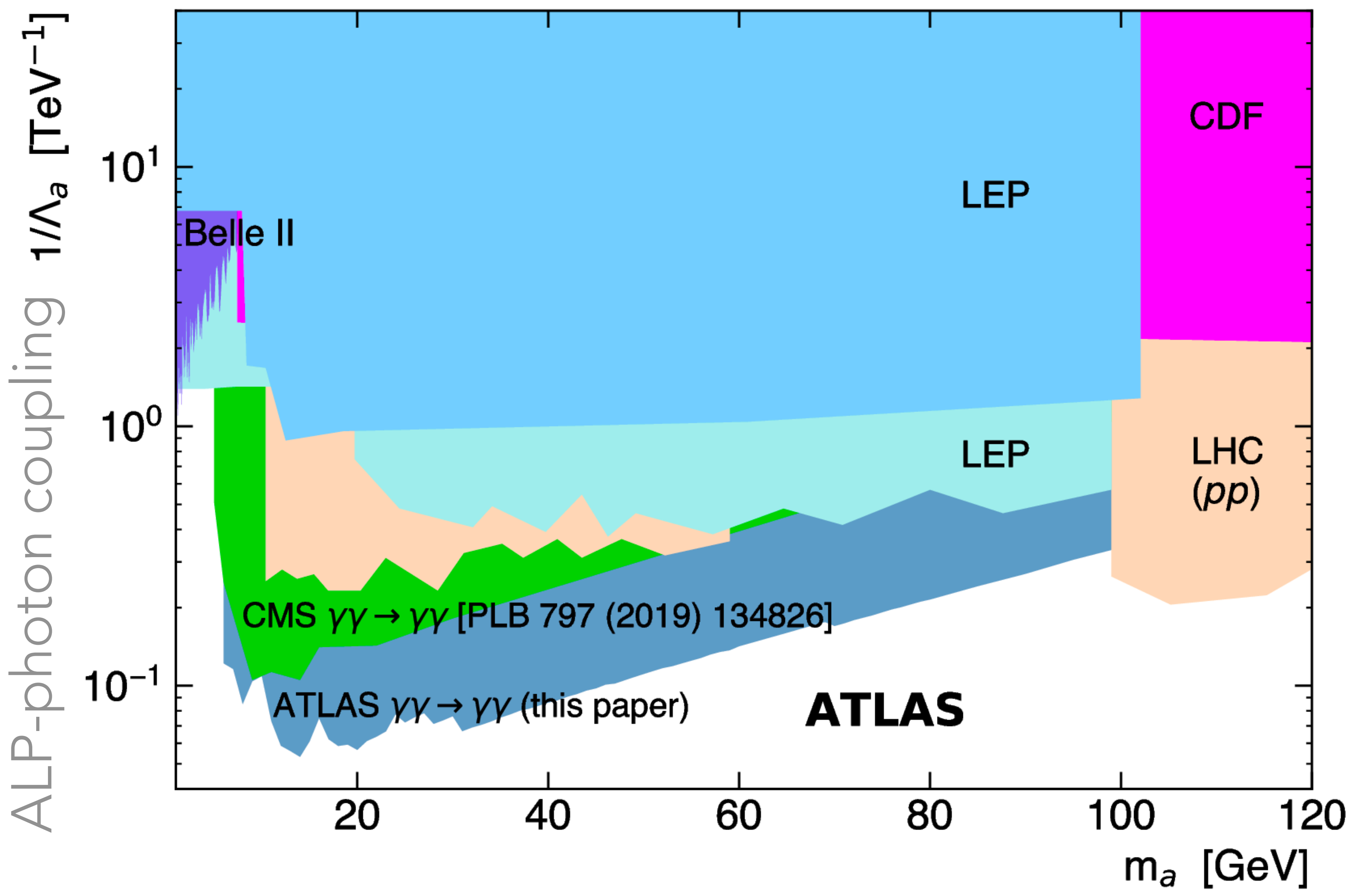
Exclusive γ γ → γ γ process occuring

- via charged-particle box diagram (LO in QED)
- from the decay of an hypothetical axion-like particle (ALP)

☛ **sensitive channel to BSM physics**



Exclusion limits on ALP production [JHEP 03 (2021) 243]



Measurements dominated by statistical uncertainties

- CMS result based on the 2015 dataset (0.39 nb^{-1})
  - ☛ update with 2018 sample coming soon!
- ATLAS analysis of full Run 2 data (2.2 nb^{-1})
  - ☛ **most stringents limits for $6 < m_a < 100$ GeV**
- experiments share the *same* phase space
  - ☛ **let's combine them!**