Excited bottomonia in pp collisions

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Part 1

Feed-downs among bottomonia

Project within the HonexComb work package (JRA1 of STRONG-2020)
Honexcomb goal: to foster cross-collaboration work at the LHC

Feed-down force: FD and RGdC (CMS), B. Audurier and G. Manca (LHCb)

STRONG-2020

Introduction

Feed-downs are **production modes of a given quarkonium state from the decay of heavier resonances** of the same family

☛ components of the inclusive production measured experimentally

Fraction of $\mathcal{Q}$(nL) originating from the decay of $\mathcal{Q}'$(mL′):

$$\mathcal{F}^{\mathcal{Q}'(\mathrm{mL}')}_{\mathcal{Q}(\mathrm{nL})} \equiv \frac{\sigma(\mathrm{pp} \to \mathcal{Q}'(\mathrm{mL}') + \mathrm{X})}{\sigma(\mathrm{pp} \to \mathcal{Q}(\mathrm{nL}) + \mathrm{X})} \times \mathcal{B}(\mathcal{Q}'(\mathrm{mL}') \to \mathcal{Q}(\mathrm{nL}) + \ldots)$$

Strong implications in quarkonium measurements

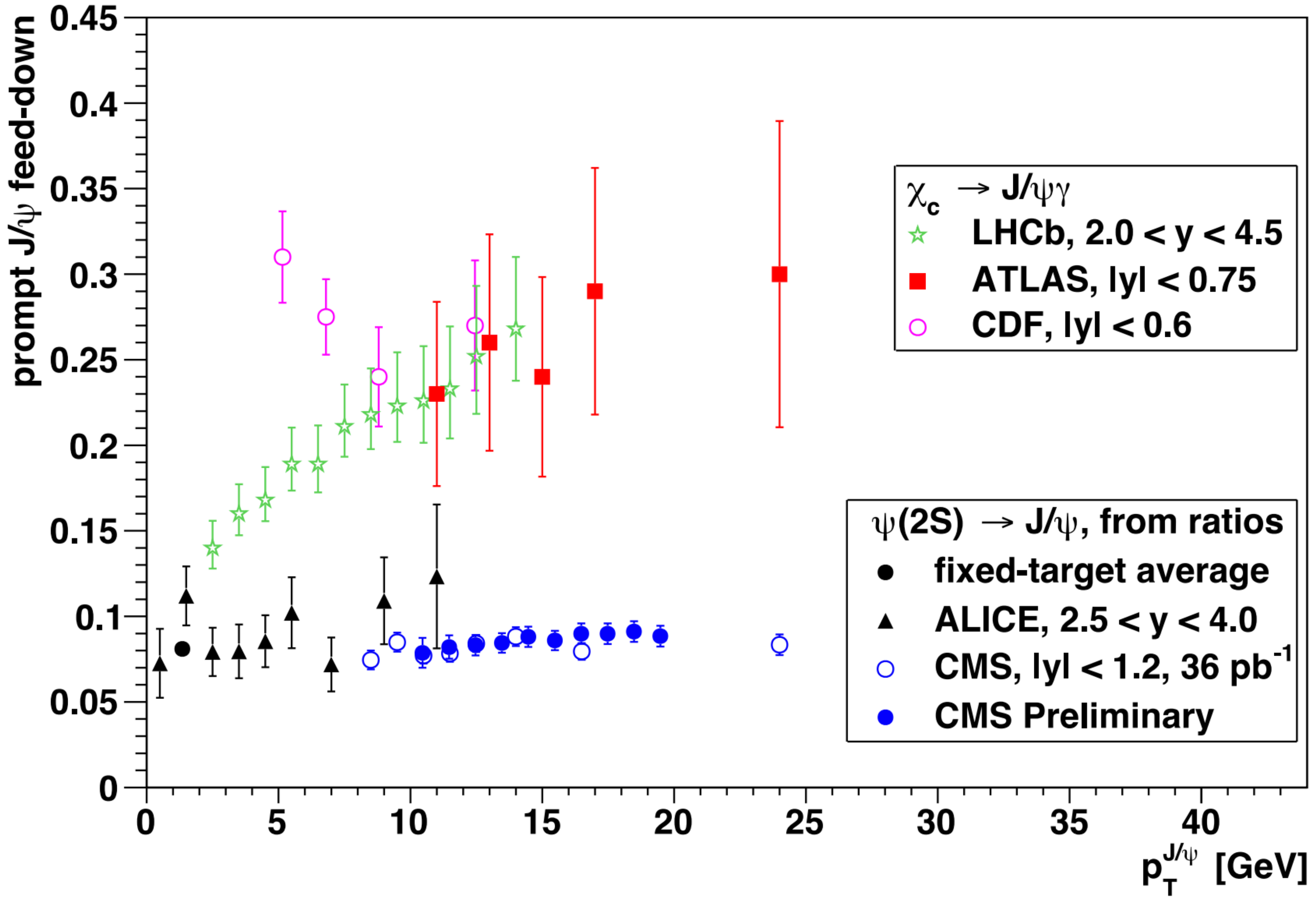
- p_T spectrum of production cross sections
- key role in the ``polarisation puzzle'' (cf PRD 94 (2016) 014028)
- essential to understand the sequential suppression pattern in heavy-ion collisions (and in proton–nucleus too!!!)

Motivations

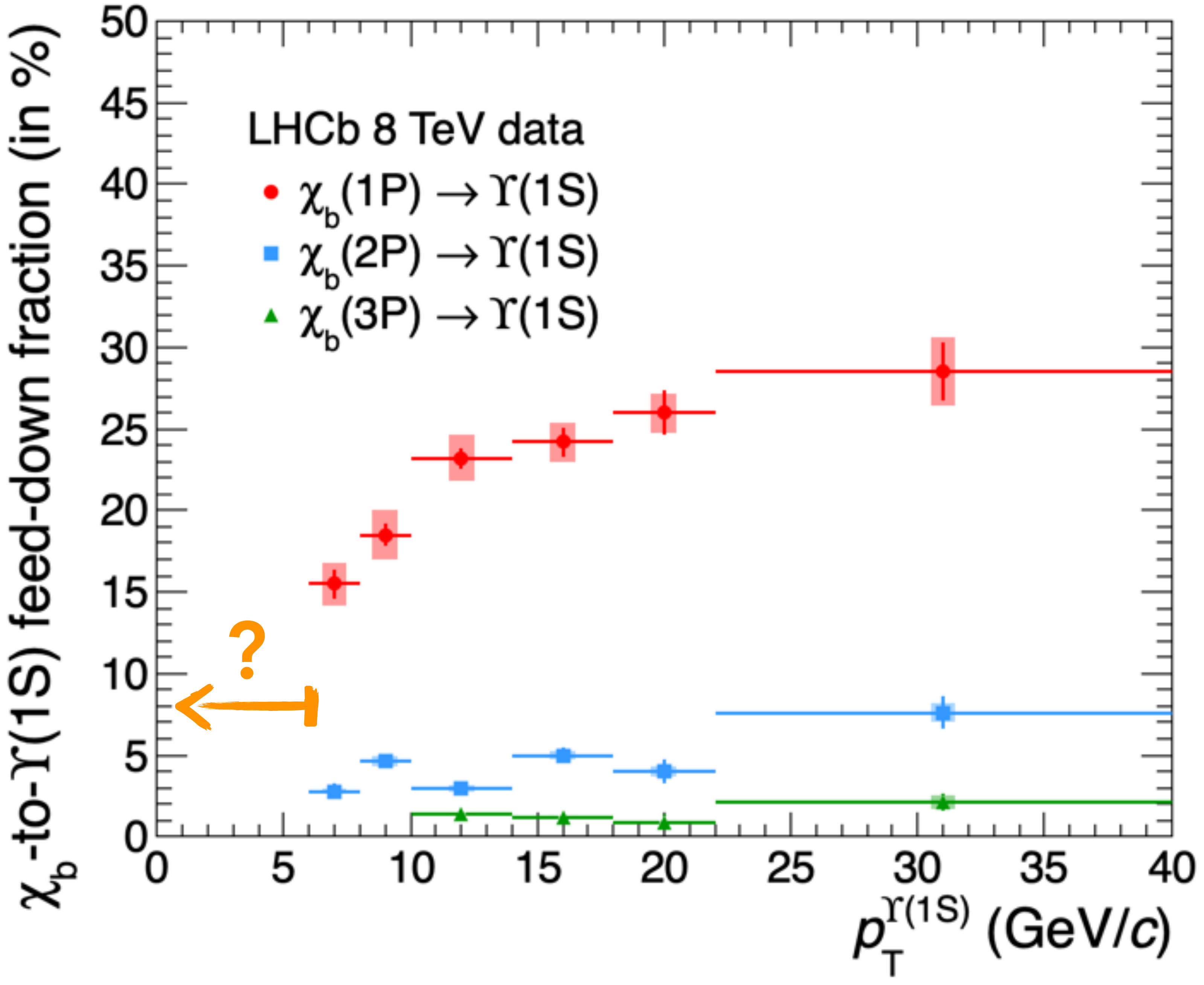
Derivation of feed-down fractions **based on early Run 1 measurements** (Hermine Wöhri at QWG 2014)

- reference for many models but results not published!
- charmonium family *under control* ☛
- **bottomonium case much more complex** (next slide)

$\chi_b \to \Upsilon(nS)\,\gamma$ cannot be reconstructed for $p_T < 6$ GeV



EPJC 74 (2014) 3092



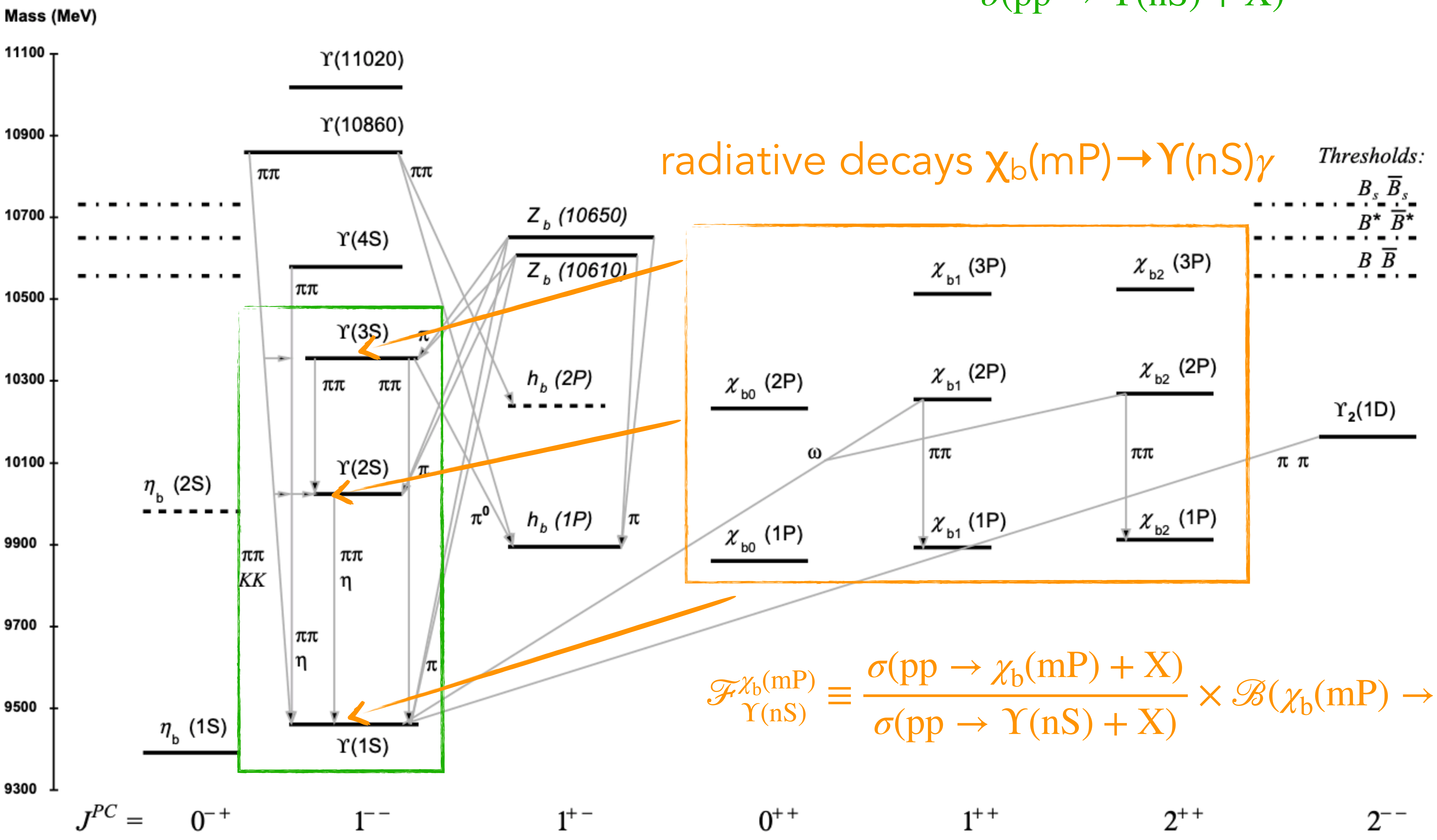
- derivation and publication of feed-down fractions exploiting all the available Run 1 and 2 measurements
- starting with bottomonia
- bonus achievement: assess long-standing questions
  ☛ *is the direct Υ(1S) production suppressed at the LHC?*

Bottomonia *accessible* at the LHC

hadronic transitions $\Upsilon(\mathrm{mS}) \to \Upsilon(\mathrm{nS})\pi\pi$

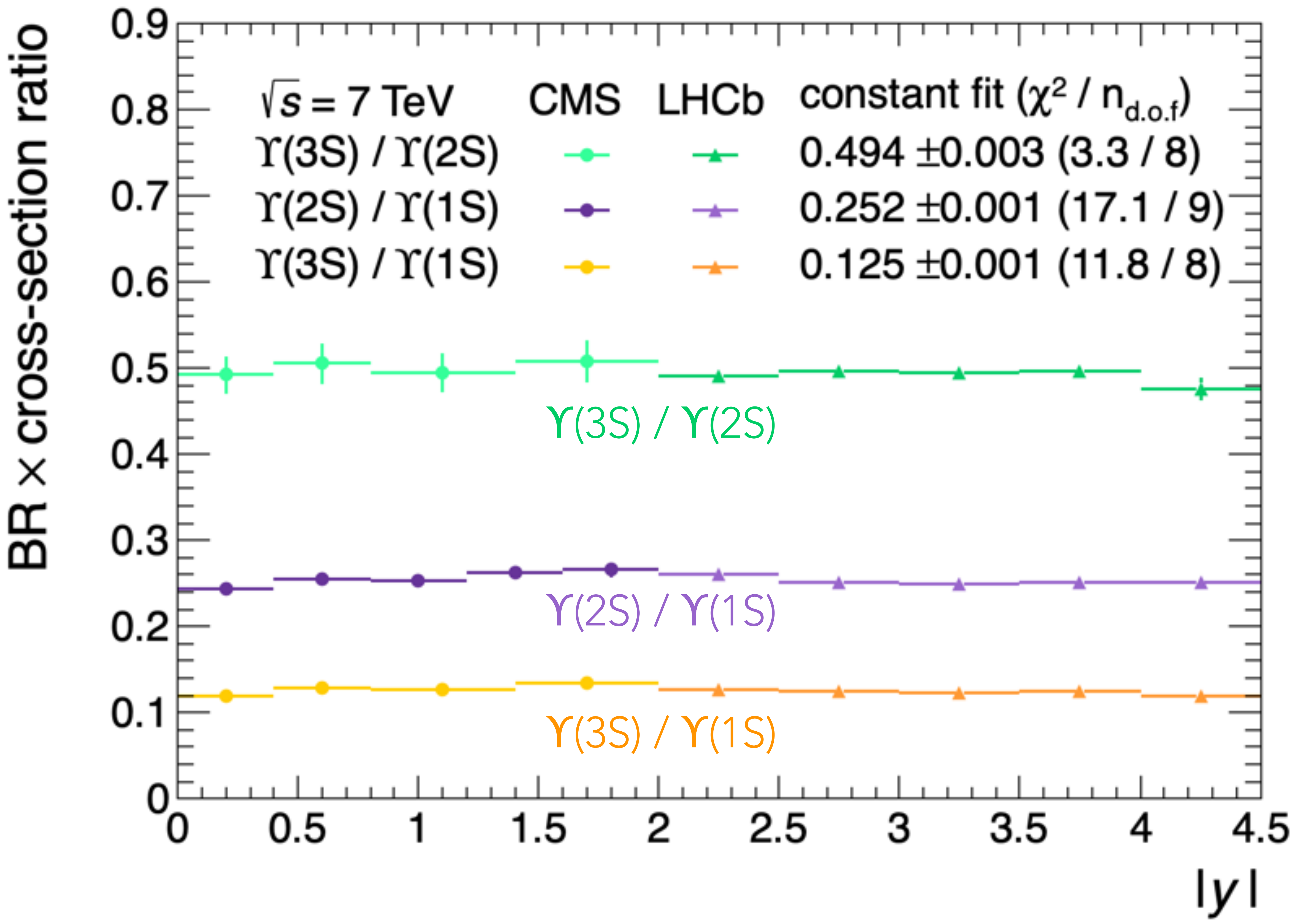
$$\mathcal{F}^{\Upsilon(\mathrm{mS})}_{\Upsilon(\mathrm{nS})} \equiv \frac{\sigma(\mathrm{pp} \to \Upsilon(\mathrm{mS}) + \mathrm{X})}{\sigma(\mathrm{pp} \to \Upsilon(\mathrm{nS}) + \mathrm{X})} \times \mathcal{B}(\Upsilon(\mathrm{mS}) \to \Upsilon(\mathrm{nS}))$$

radiative decays $\chi_b(\mathrm{mP}) \to \Upsilon(\mathrm{nS})\gamma$



$$\mathcal{F}^{\chi_b(\mathrm{mP})}_{\Upsilon(\mathrm{nS})} \equiv \frac{\sigma(\mathrm{pp} \to \chi_b(\mathrm{mP}) + \mathrm{X})}{\sigma(\mathrm{pp} \to \Upsilon(\mathrm{nS}) + \mathrm{X})} \times \mathcal{B}(\chi_b(\mathrm{mP}) \to \Upsilon(\mathrm{nS})\gamma)$$

Step 1) check the rapidity dependence



Verification of the non-dependence with rapidity (always assumed but never demonstrated)

- with ϒ(nS) cross-section ratios at 7 TeV measured by CMS (statistical uncertainties only, p_T < 50 GeV) and LHCb (p_T < 30 GeV)
- **best chi-square obtained with a constant fit**

☛ can mix data measured for different rapidities **without any correction**

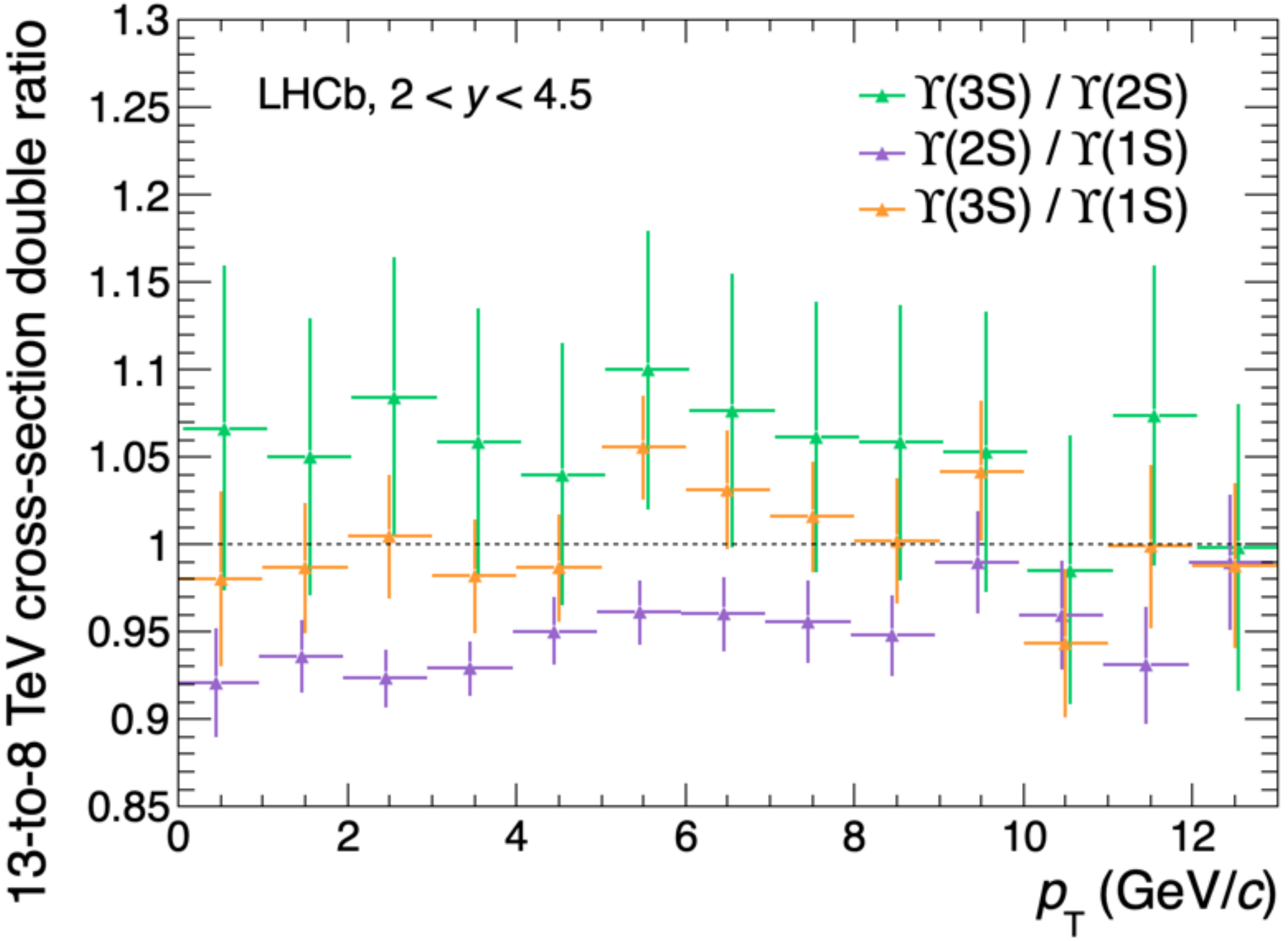
☛ what about χ_b-to-ϒ ratios? is the dependence expected to be similar?
would need guidance from theory

Step 2) study of the energy dependence

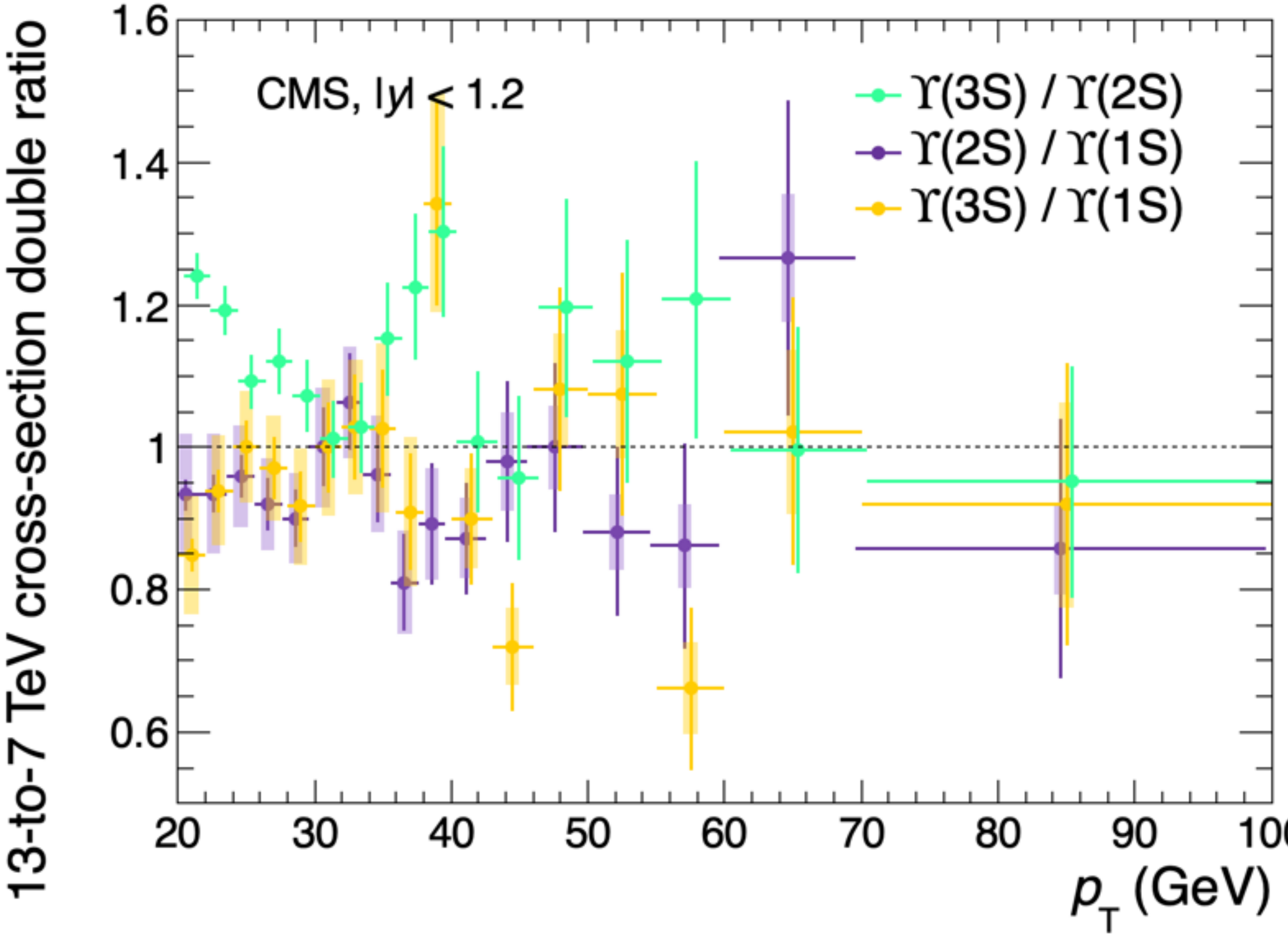
Investigation of the dependence of the cross-section ratios with the centre-of-mass energy

☛ can exploit measurements performed at different energies just by applying global scale factors

no p_T dependence + small energy dependence at low p_T



not clear for high p_T

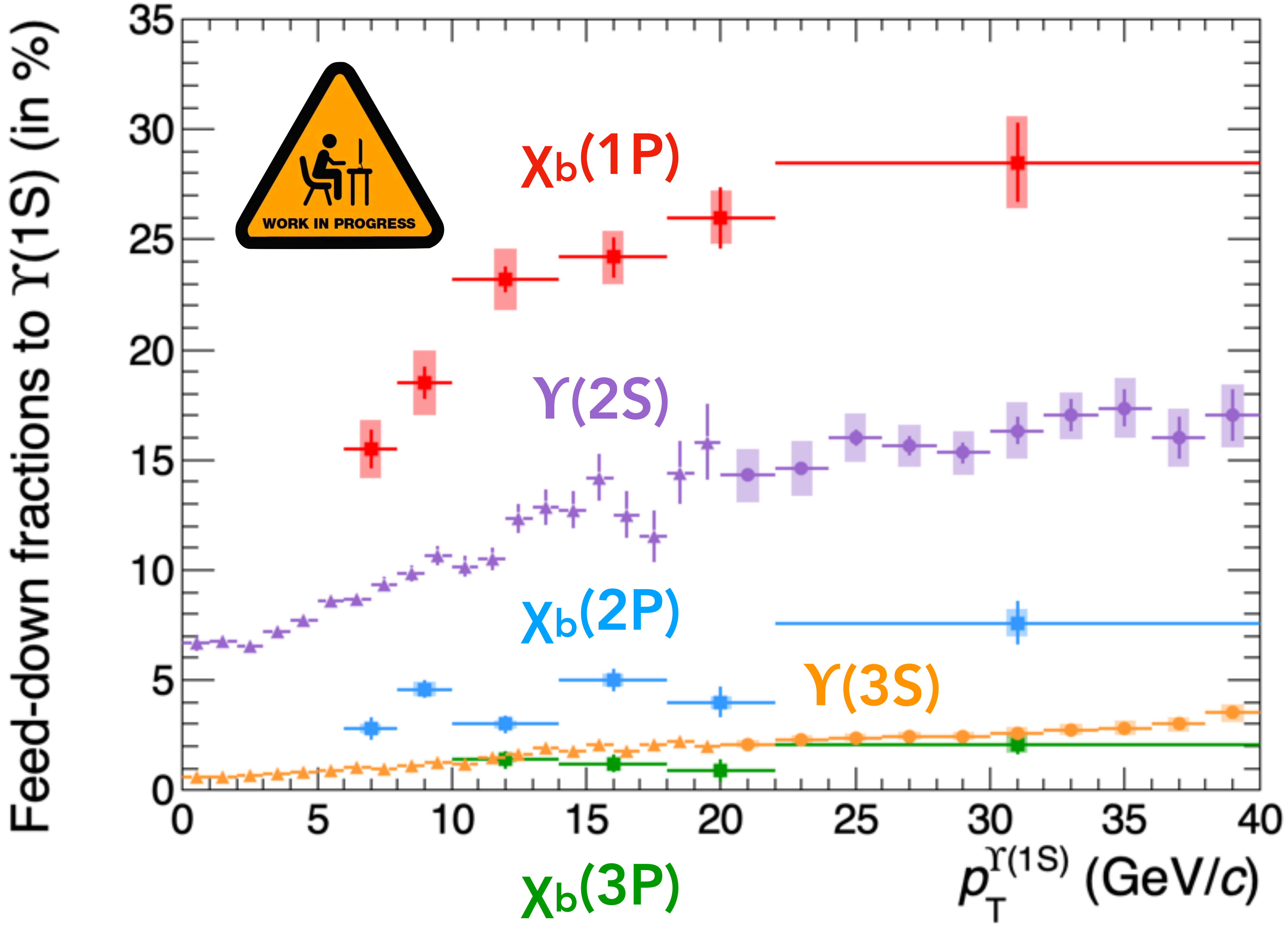


Snapshot – feed-down fractions to ϒ(1S)

Preliminary results for ϒ(1S)

- ϒ(nS) cross-section ratios from LHCb (triangles) and CMS (circles) measurements at 13 TeV
- feed-down fractions from χ_b directly taken from LHCb measurements at 8 TeV
- **branching-ratio uncertainties not represented** (probably the dominant source of final systematics)

Feed-down fractions to ϒ(1S), **no global uncertainties**



Conclusion

We aim to derive **feed-down fractions in bottomonium production** at the LHC, exploiting all available Run 1 and 2 measurements.

First study shows **no dependence with rapidity and small dependence with energy** (if any).

Next steps

- investigation of **low-p_T extrapolation for χ_b contributions**
- evaluation of global uncertainties from branching fractions (partially correlated)

Open questions

- how to extrapolate? CEM / NRQCD predictions? empirical functions?
- could we estimate contributions to χ_b aswell? in view of future measurements

Any suggestion is more than welcome!!!

Part 2

Υ(nS) versus pp multiplicity

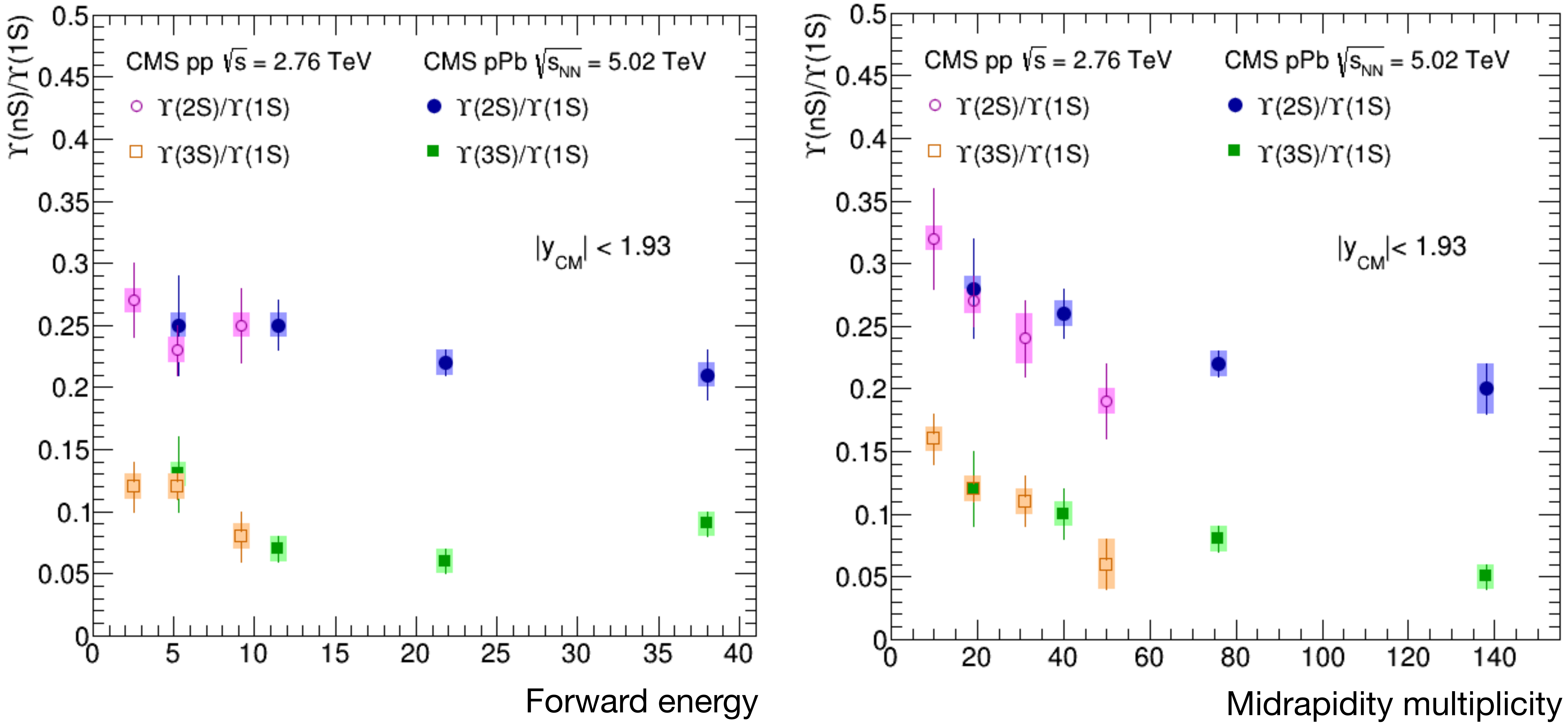
Versus pp multiplicity

CMS, JHEP04 (2014) 103

First look at pp collisions versus multiplicity, brought **a big surprise**

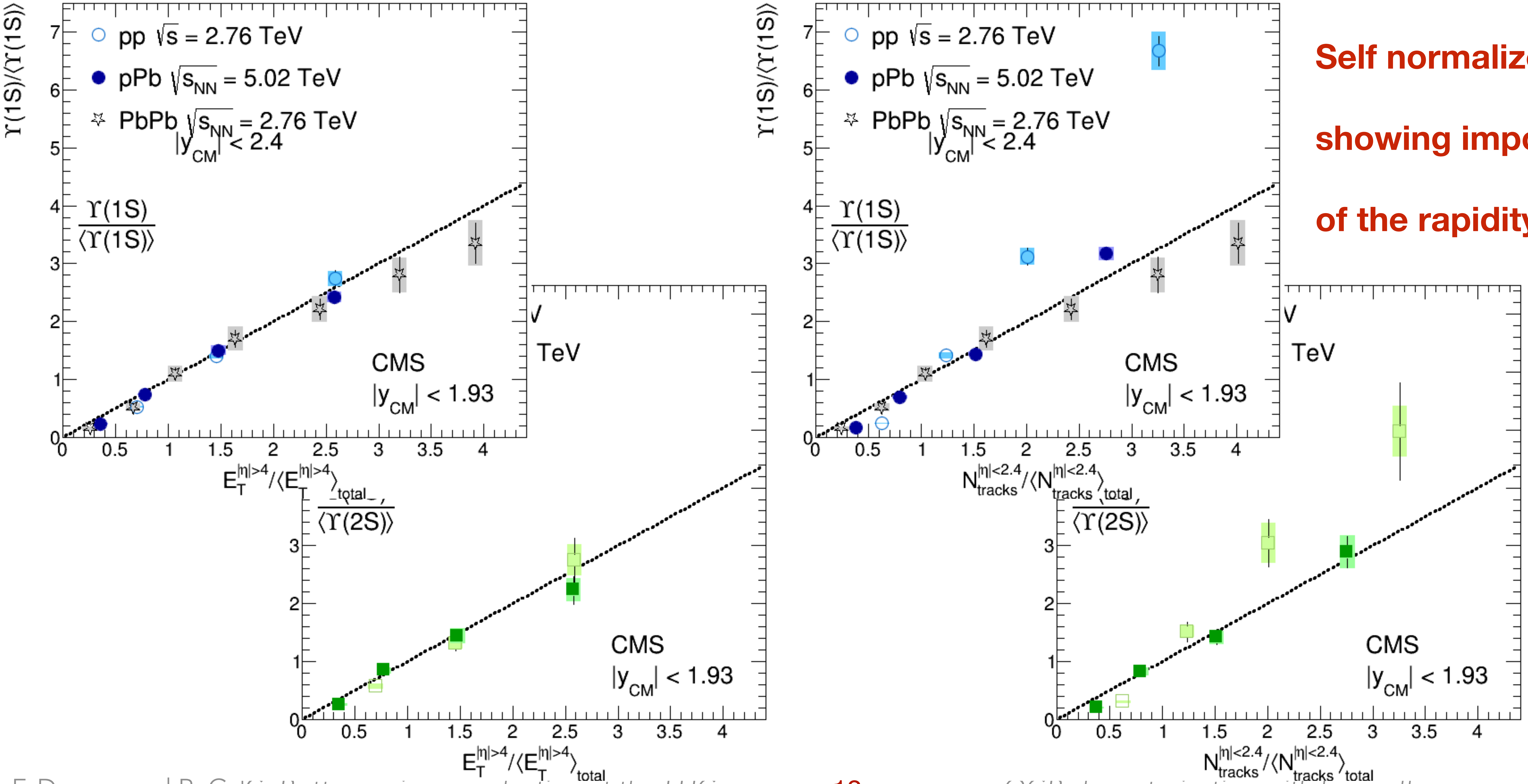
A variation of Υ(nS)/Υ(1S), larger than for pPb, larger when multiplicity is measured at same y

Is the multiplicity killing the state? or are the states modifying the multiplicity?



Versus pp multiplicity

CMS, JHEP04 (2014) 103



Self normalized yields showing importance of the rapidity gap

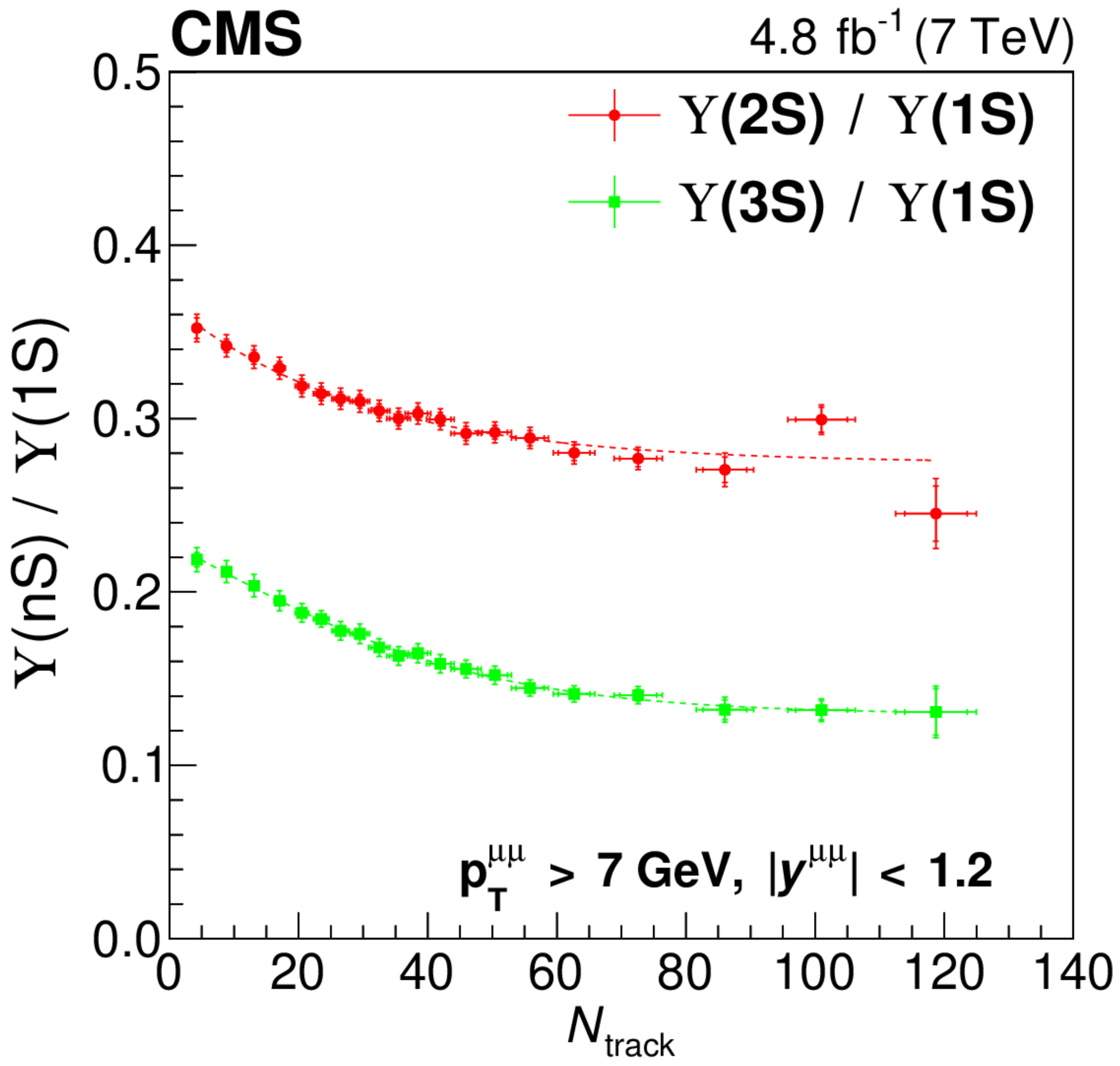
Versus pp multiplicity

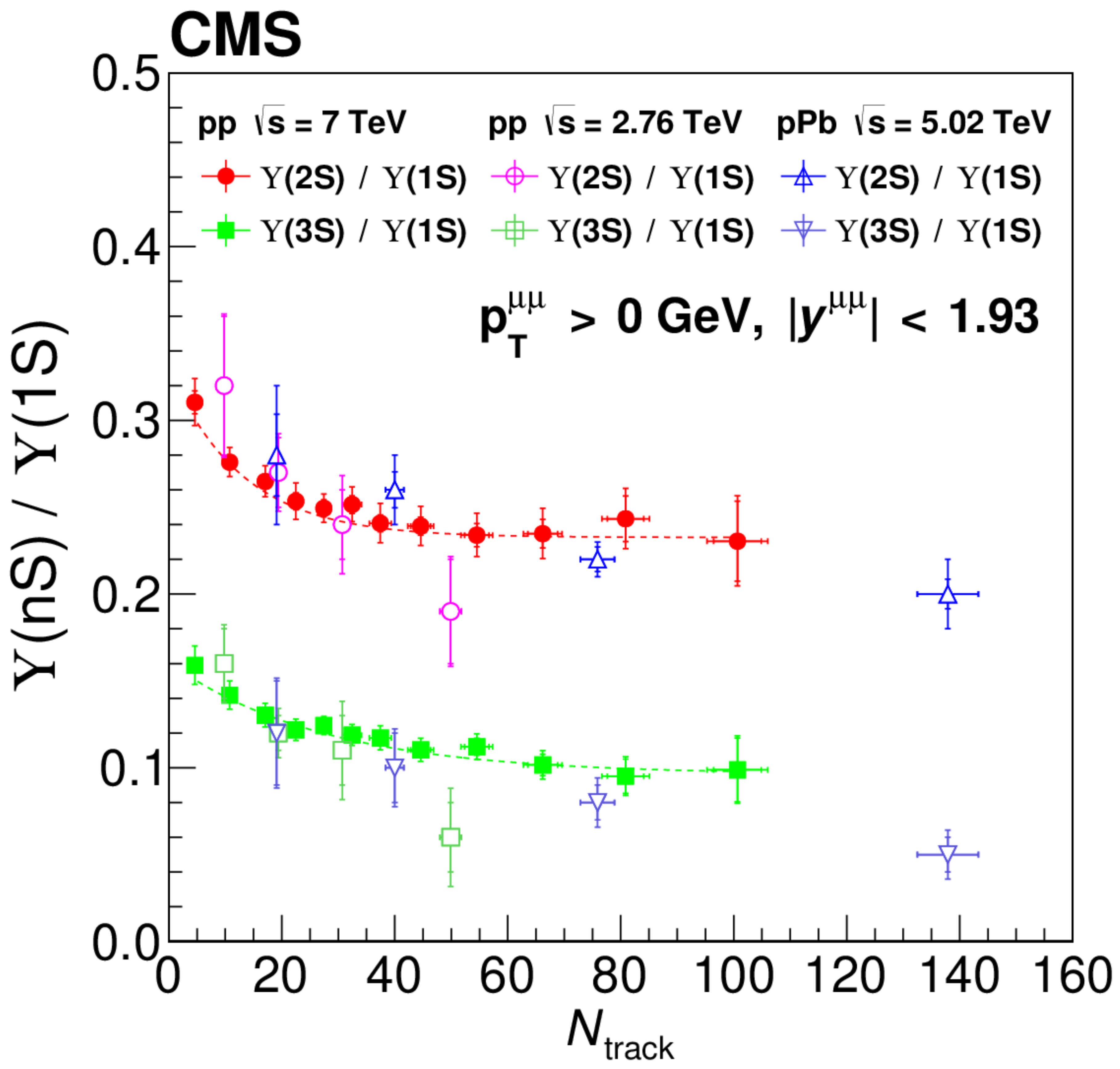
CMS, JHEP04 (2014) 103
CMS, JHEP11 (2020) 001

This triggered **a high-statistics analysis** in pp collisions @ 7 TeV

No results vs forward energy, because of pile-up 😢, but a very large sample @ high p_T

☛ A rapid plateau, **effect concentrated at very small multiplicity**



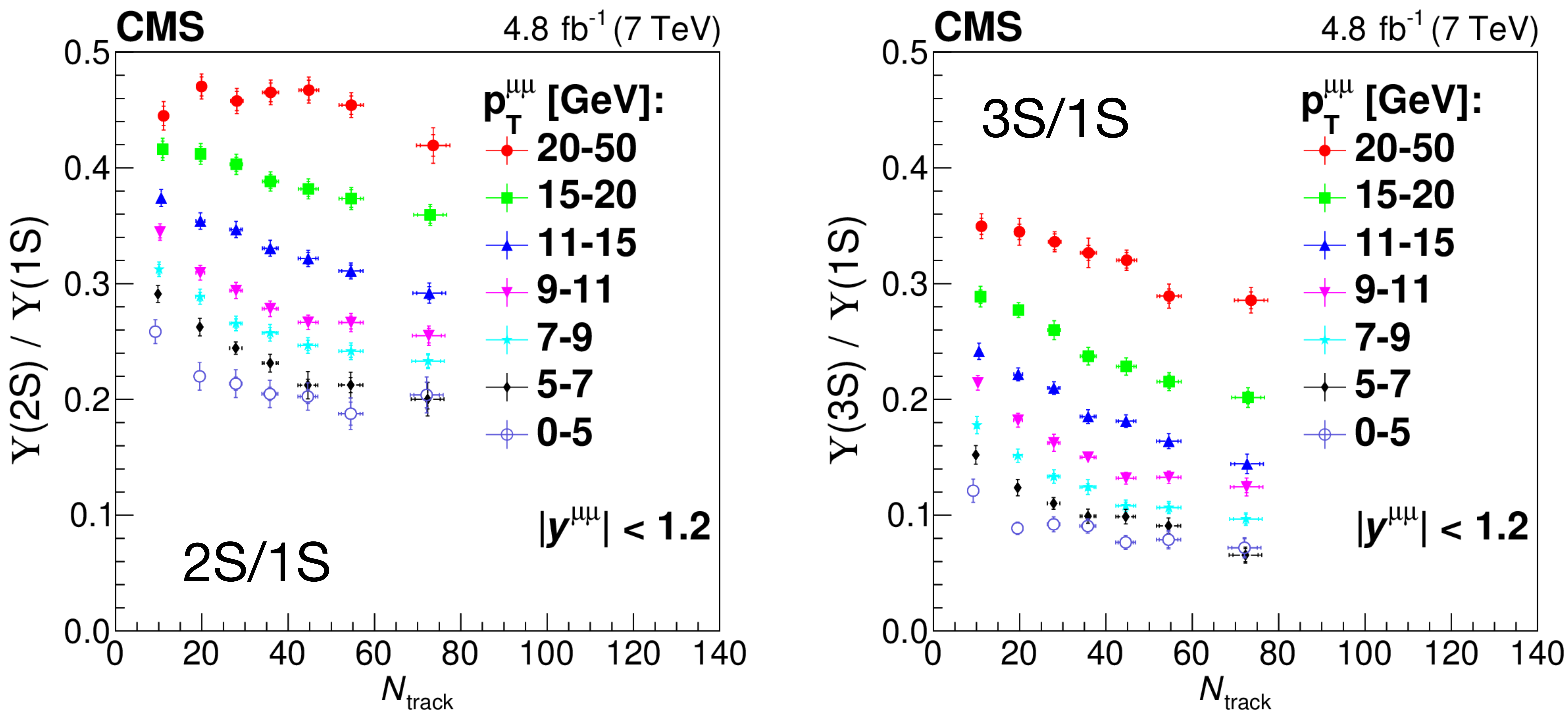


Advertised in Zaida's yesterday

Vs multiplicity, and p_T

CMS, JHEP11 (2020) 001

The effect is visible for all p_T (maximal in the 5-7 GeV bin)



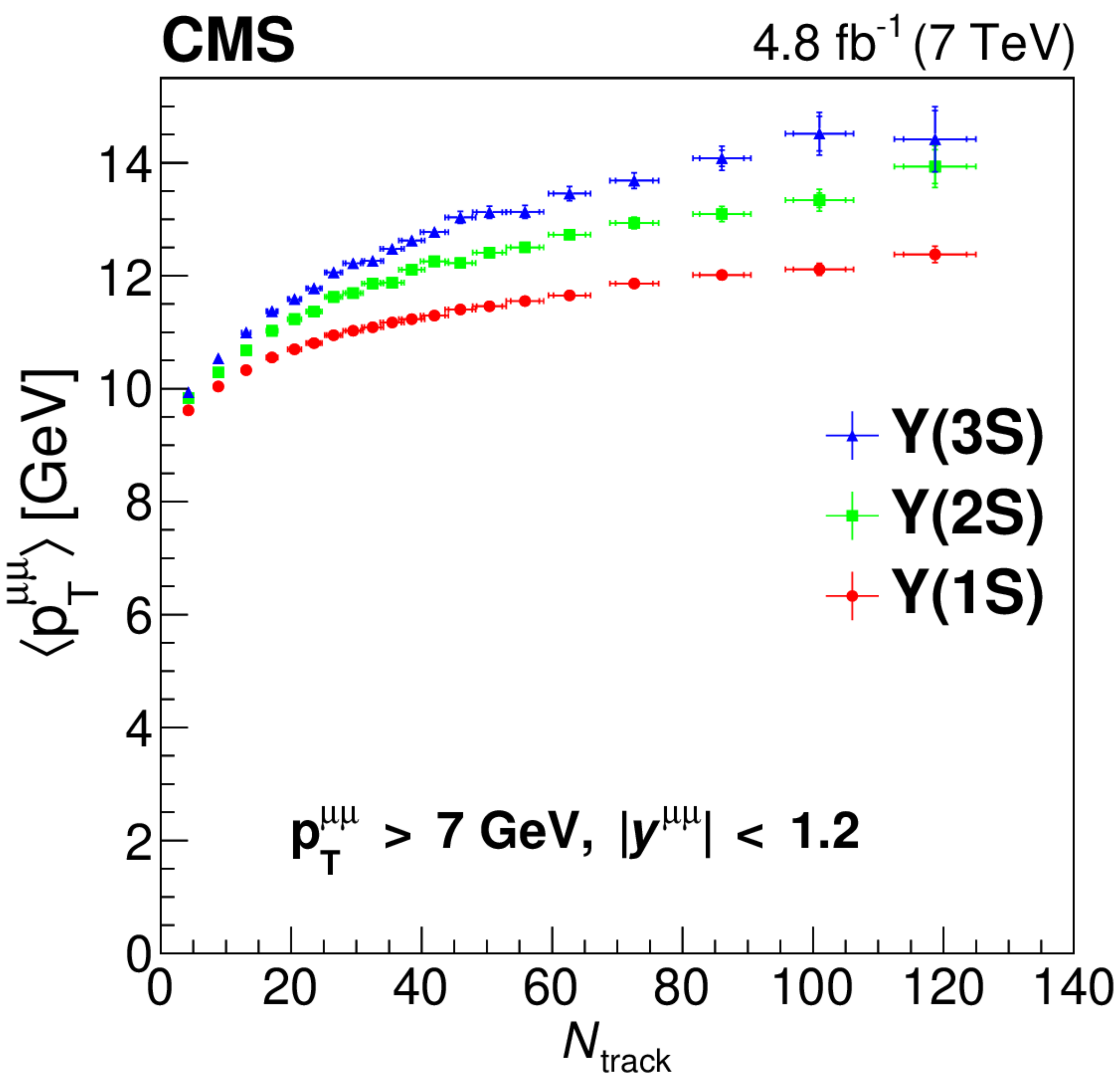
Vs pp multiplicity, and p_T

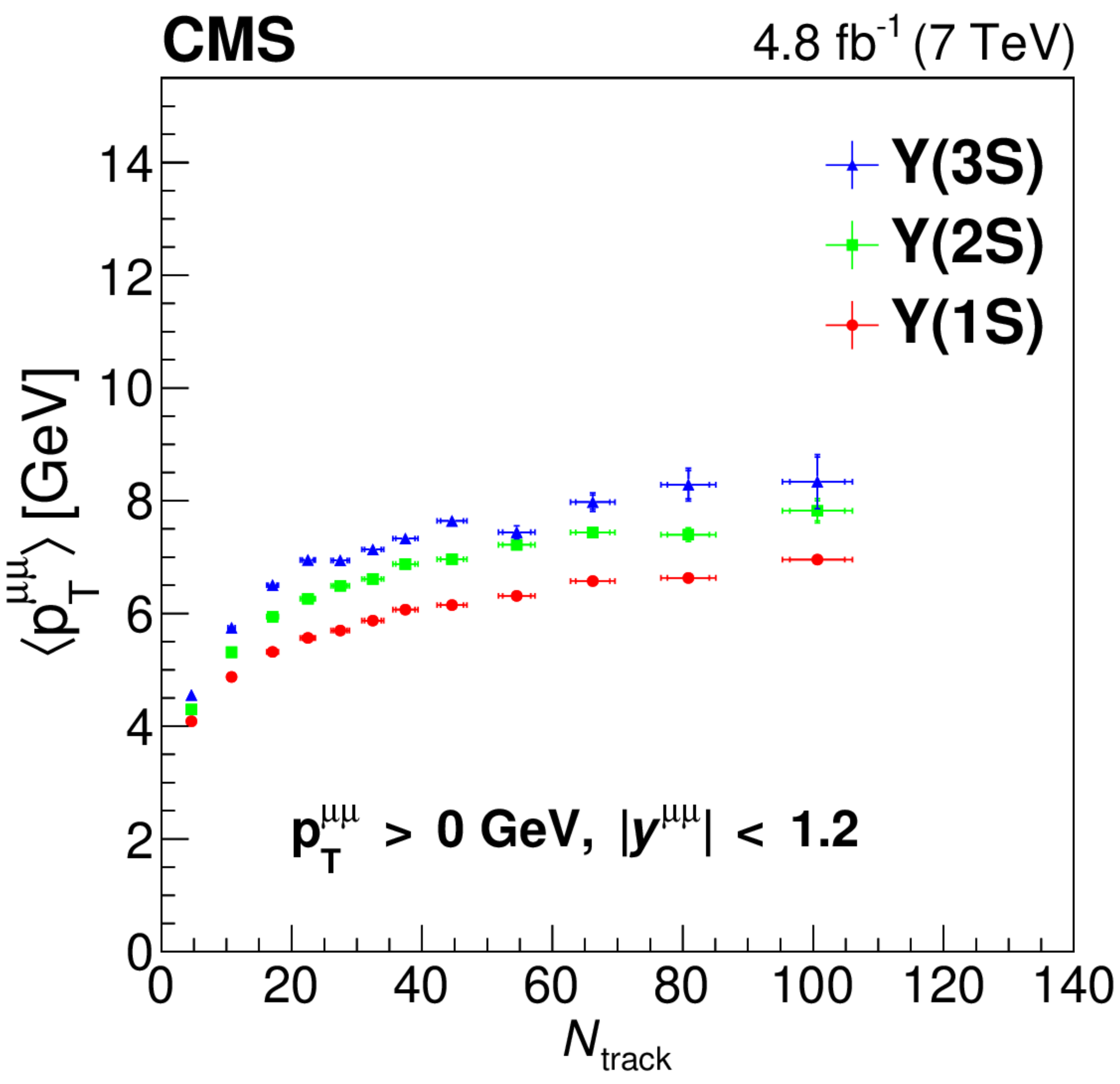
CMS, JHEP11 (2020) 001

As multiplicity grows, the states have more and more momentum

\+ Heavier states have higher momentum

☛ **Positive correlation between mass, momentum and multiplicity**





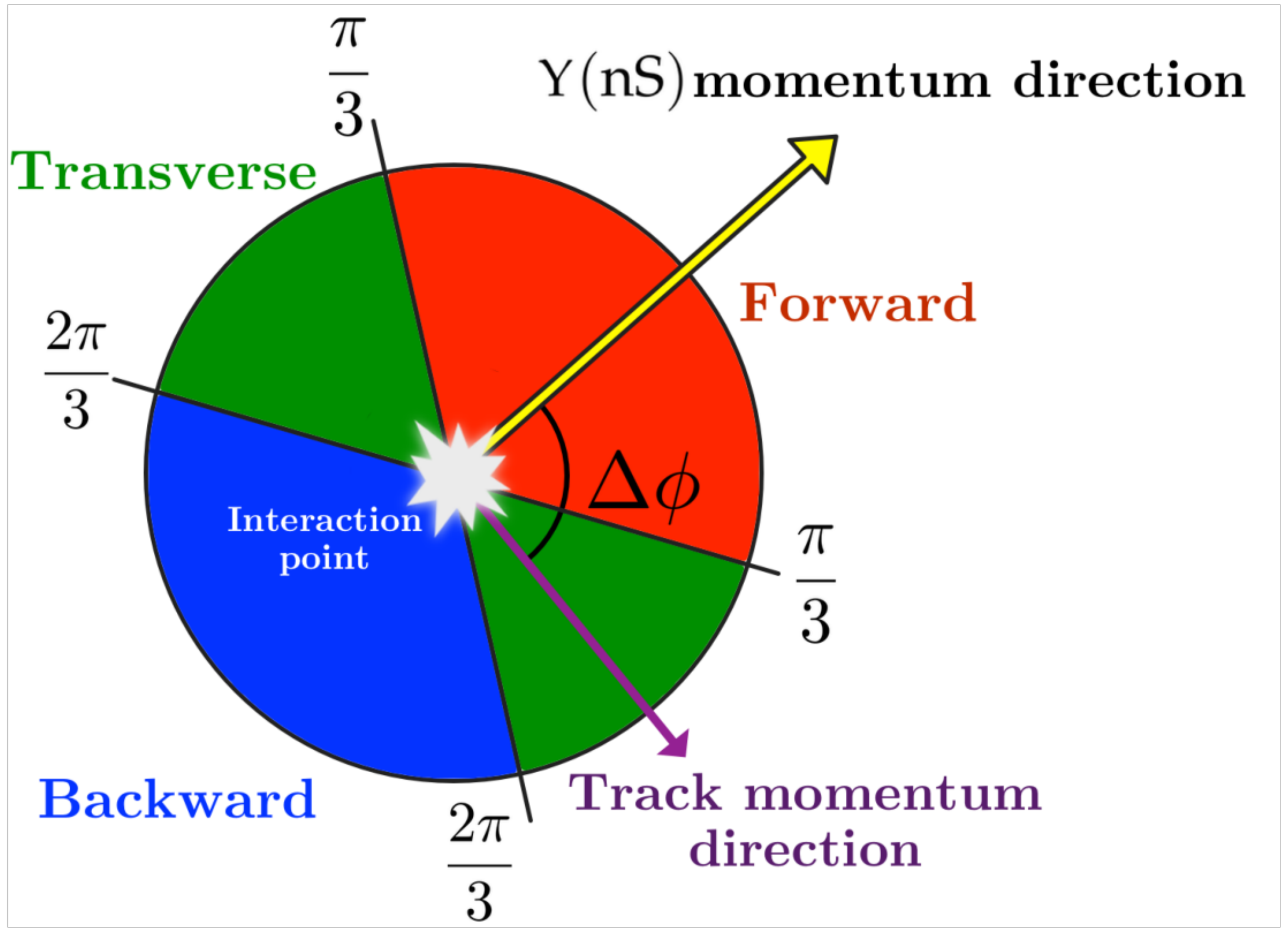
Vs pp regional multiplicity

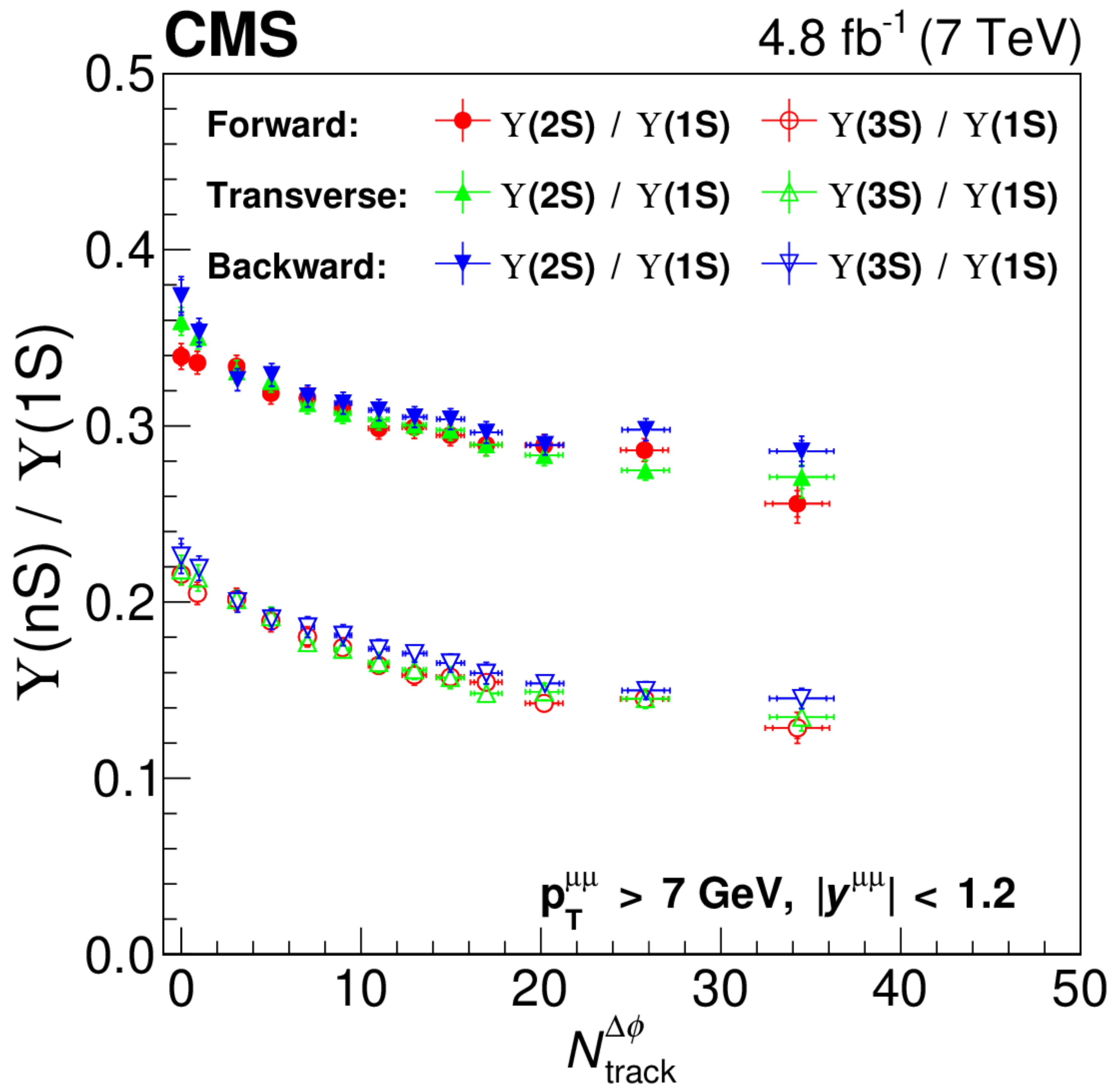
CMS, JHEP11 (2020) 001

No strong dependence with the regional multiplicity

Small dependence at super-low multiplicity: more effect in the backward region

In particular, still present **in the transverse region* -> Underlying event**





* Three less tracks in the transverse region than in the other two

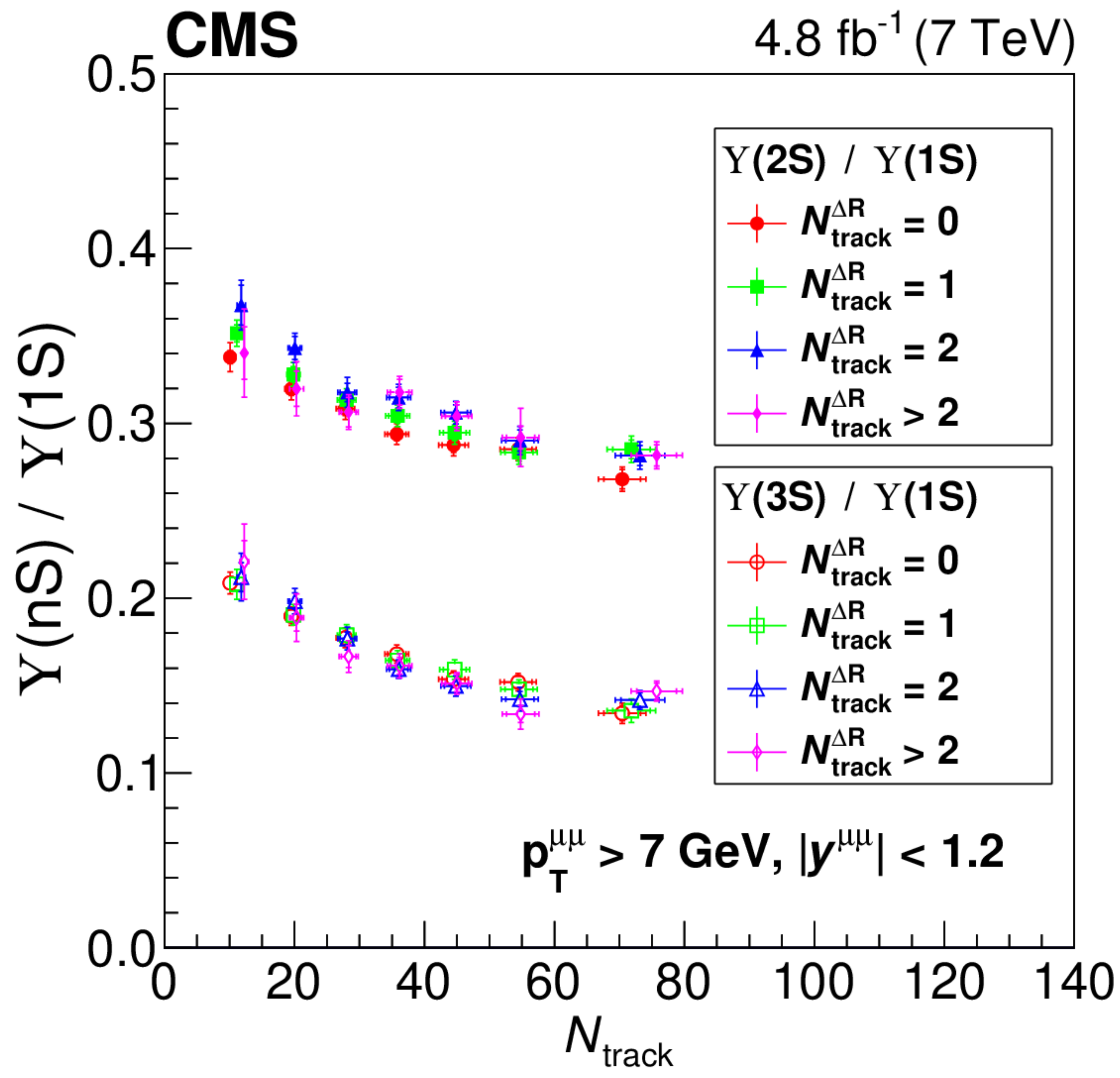
Vs pp multiplicity

CMS, JHEP11 (2020) 001

No dependence with isolation

N co-moving particles in ΔR = 0.5

(excluding ϒ(nS) → ϒ(1S) π⁺ π⁻)



Vs pp multiplicity & sphericity

CMS, JHEP11 (2020) 001

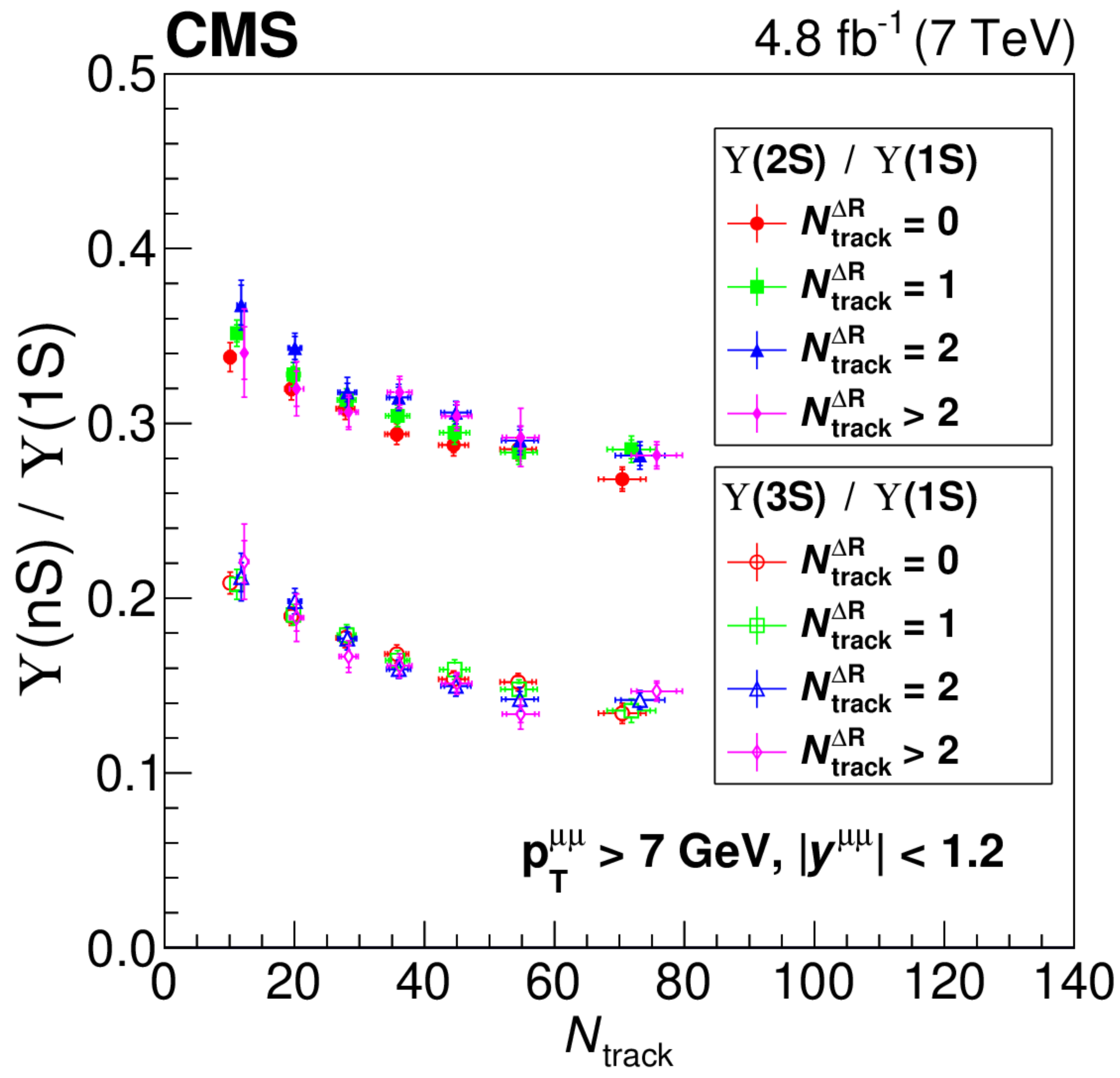
No dependence with isolation

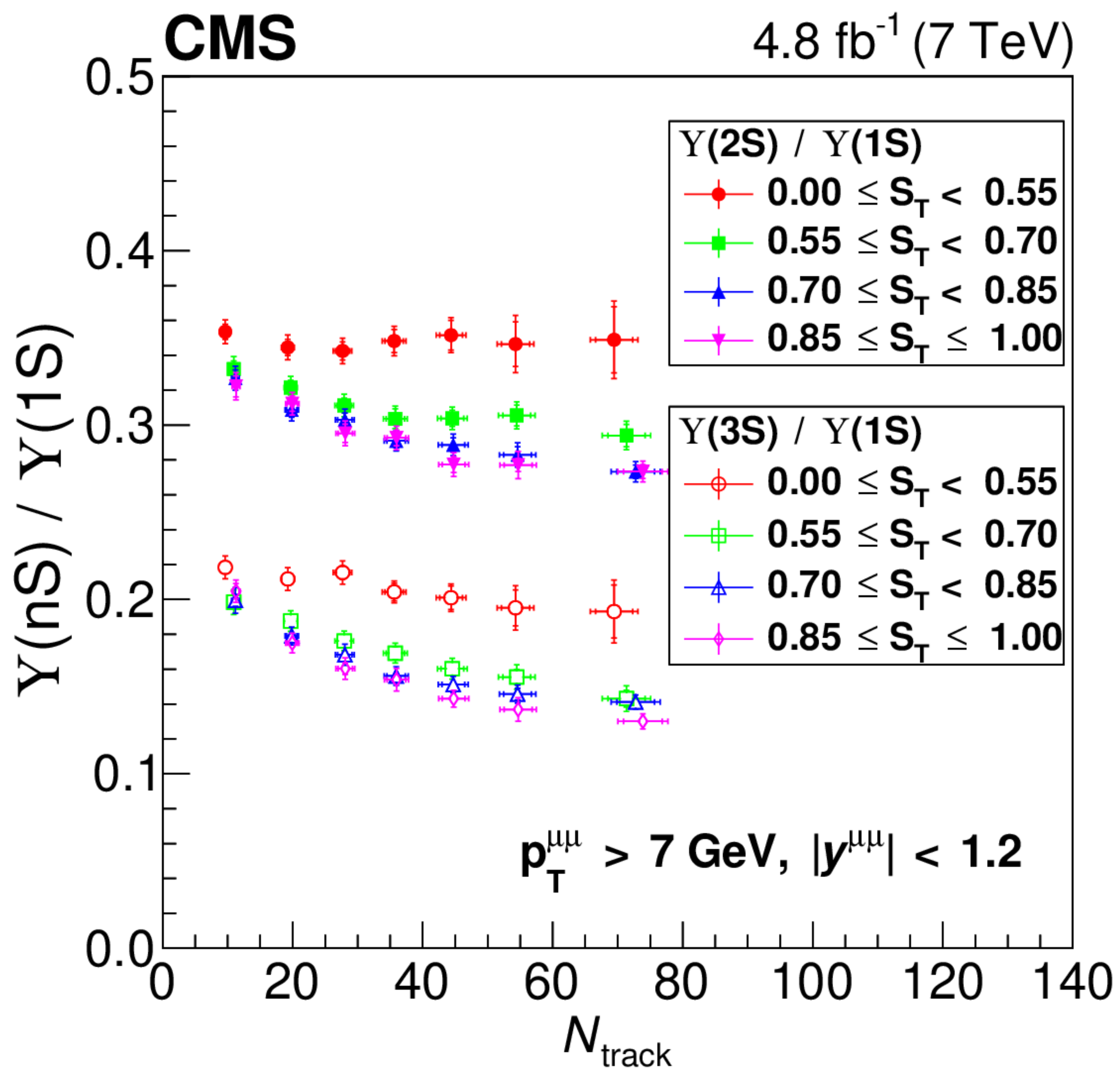
N co-moving particles in ΔR = 0.5

(excluding ϒ(nS) → ϒ(1S) $\pi^+ \pi^-$)

Sphericity S=0 jetty vs S=1 isotropic events

Lesser dependence for **jetty events**





Versus pp multiplicity

When you see an effect versus pp multiplicity, **don't panic**

Rather do a high-statistic super-differential correlation study, here :

- Lower dependence with **a rapidity gap** between probe and multiplicity
- The dependence is **located at (very) low multiplicity** and plateaus rapidly
- Positive correlation between **mass, momentum and multiplicity**
  - (overall, the $\Upsilon(1S)$ comes with 2 more tracks)
- **Does not depend regional multiplicity** (UE driven in the transverse region)
- **Does not depend on isolation** (with or without co-moving particles)
- **No effect for jetty events** (multiplicity not driven by the UE)

Conclusion

☛ Wouldn't $\Upsilon(nS)$ just come with different multiplicity, biasing the ratio measurements?

☛ Shouldn't all probe-multiplicity analyses be done with a rapidity gap?

Supplementary material

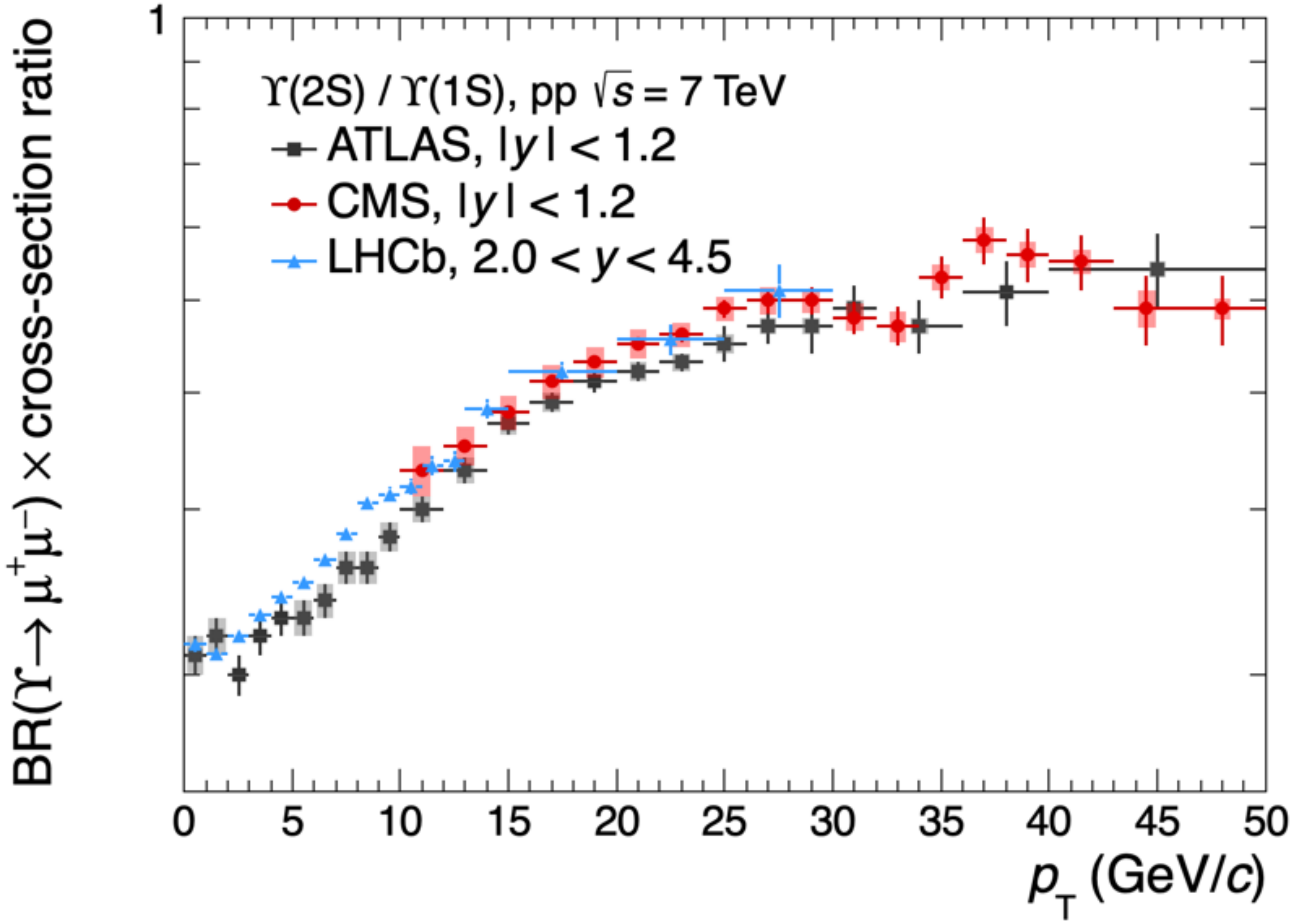
Overview of available data (for feed-down)

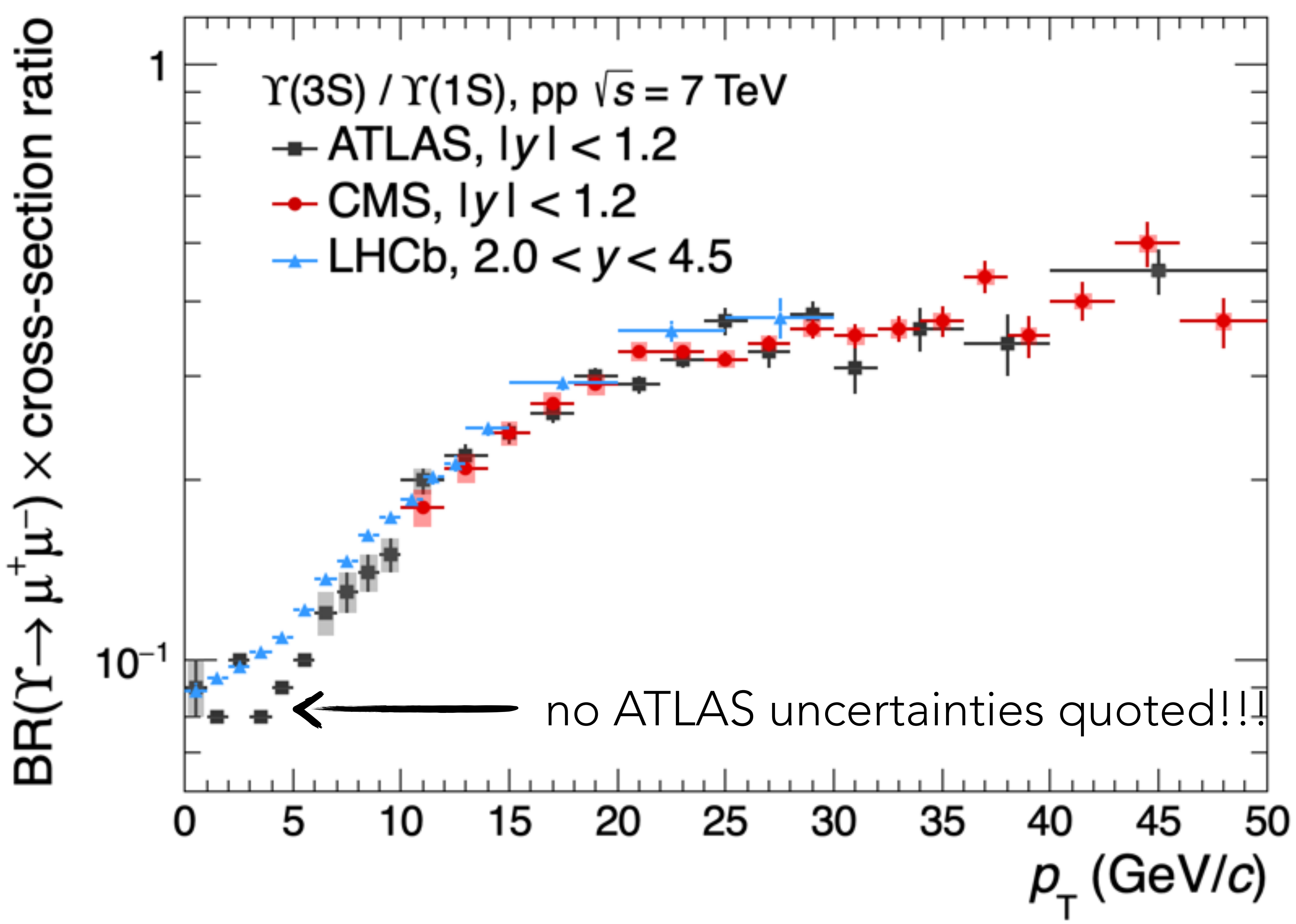
Centre-of-mass energy	Mid-rapidity		Forward rapidity	
	Υ(nS) cross-section ratio	χ_b measurement	Υ(nS) cross-section ratio	χ_b measurement
5 TeV	Only single-state cross sections are reported + binning matching pPb / PbPb measurements + no χ_b measurement		NONE!	
7 TeV	ATLAS: y-diff. and p_T-diff. up to 70 GeV CMS: p_T-diff. up to 40 GeV + **Υ(3S) / Υ(2S)** CMS: p_T-diff. from 10 to 100 GeV	ATLAS: first obervation of χ_b(3P)	LHCb: y-diff, p_T-diff, and double-diff up to 30 GeV + **Υ(3S) / Υ(2S)**	**LHCb: derivation of χ_b-to-Υ feed-down fractions** LHCb: χ_{b2}(1P) / χ_{b1}(1P)
8 TeV	None?	CMS: χ_{b2}(1P) / χ_{b1}(1P)		
13 TeV	CMS: p_T-diff. from 20 to 100 GeV + ratio to 7 TeV	CMS: observation of χ_{b1}(3P) and χ_{b2}(3P)	LHCb: y-diff, p_T-diff, and double-diff up to 30 GeV + ratio to 8 TeV	None

Which datasets to use?

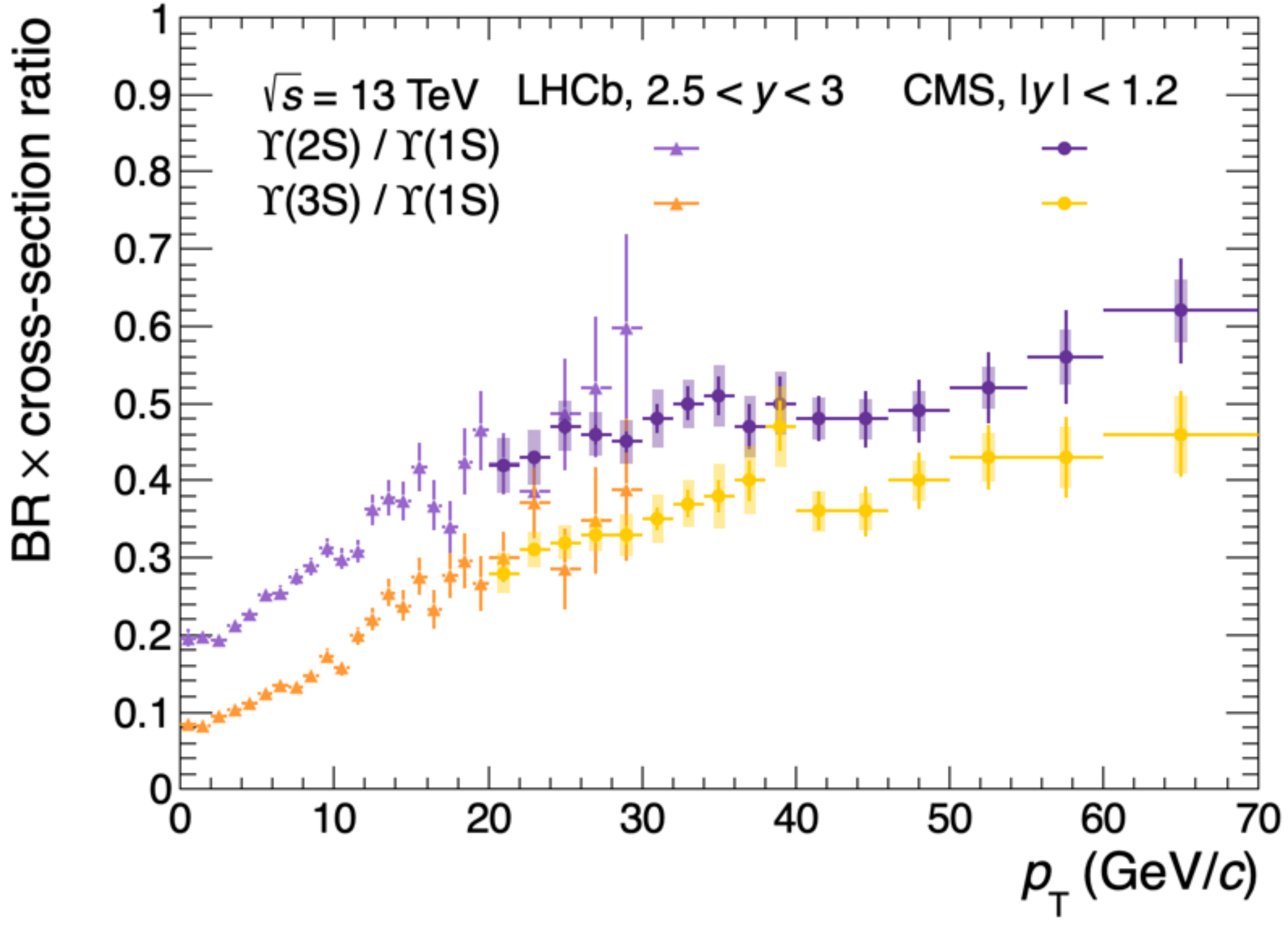
ATLAS, CMS and LHCb p_T-differential cross-section ratio measurements at 7 TeV (⚠ **log scale**)

- LHCb data more precise for $p_T \lesssim 15$ GeV
- CMS data better suited for higher p_T (up to 100 GeV)
- in agreement in the overlapping region! ($10 < p_T < 30$ GeV)





Which dataset(s) to use? – 13 TeV



p_T-differential measurements of Υ(2S)-to-Υ(1S) and Υ(3S)-to-Υ(1S) cross-section ratios

- LHCb data up to 30 GeV (⚠️ double-differential, only up to 13 GeV for 2.0 < y < 4.5)
- CMS data from 20 to 100 GeV

☛ complementarity / overlap between measurement points

However…

- Υ(3S)-to-Υ(2S) ratio to be made by hand
- **relative systematic uncertainties** (much) **larger than 8/7 TeV data** 🤷