Feed-Down contributions to charmonium production at the LHC

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GOBIERNO
DE ESPAÑA

MINISTERIO
DE CIENCIA
E INNOVACIÓN

With special thanks to Florian for his help

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IGFAE
Instituto Galego de Física de Altas Enerxías

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1. Introduction

Feed-downs correspond to transitions from a given quarkonium state to a lighter one of the same family.

Prompt = direct + feed-down

This is important because affects the productions measured experimentally. The fraction of quarkonium $\mathscr{Q}'(nl')$ originated from the $\mathscr{Q}(ml)$ feed-down ($n \geq m$) is defined as:

$$\mathscr{F}^{\mathscr{Q}'(nl')}_{\mathscr{Q}(ml)} \equiv \frac{\sigma(\mathscr{Q}'(nl'))}{\sigma(\mathscr{Q}(ml))} \times \mathscr{B}(\mathscr{Q}'(nl') \to \mathscr{Q}(ml) + X)$$

Charmonia:

- Feed-Downs to prompt J/Ψ
- X(3872) contributions to prompt $\Psi(2S)$ and J/Ψ

(Florian is working in the bottomonia case)*

Implications in quarkonium measurements:

- p_T spectrum of production cross sections.
- Key role in the "polarization puzzle"
- Essential to understand the sequential suppression pattern observed in heavy-ion collisions

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* https://indico.cern.ch/event/1129834/contributions/4741665/attachments/2395622/4096096/feeddowns_honexcomb_22-02-2022.pdf
https://indico.cern.ch/event/1088380/contributions/4575431/attachments/2334470/3978903/feeddowns_honexcomb_26-10-2021.pdf.

2. Overview of available data

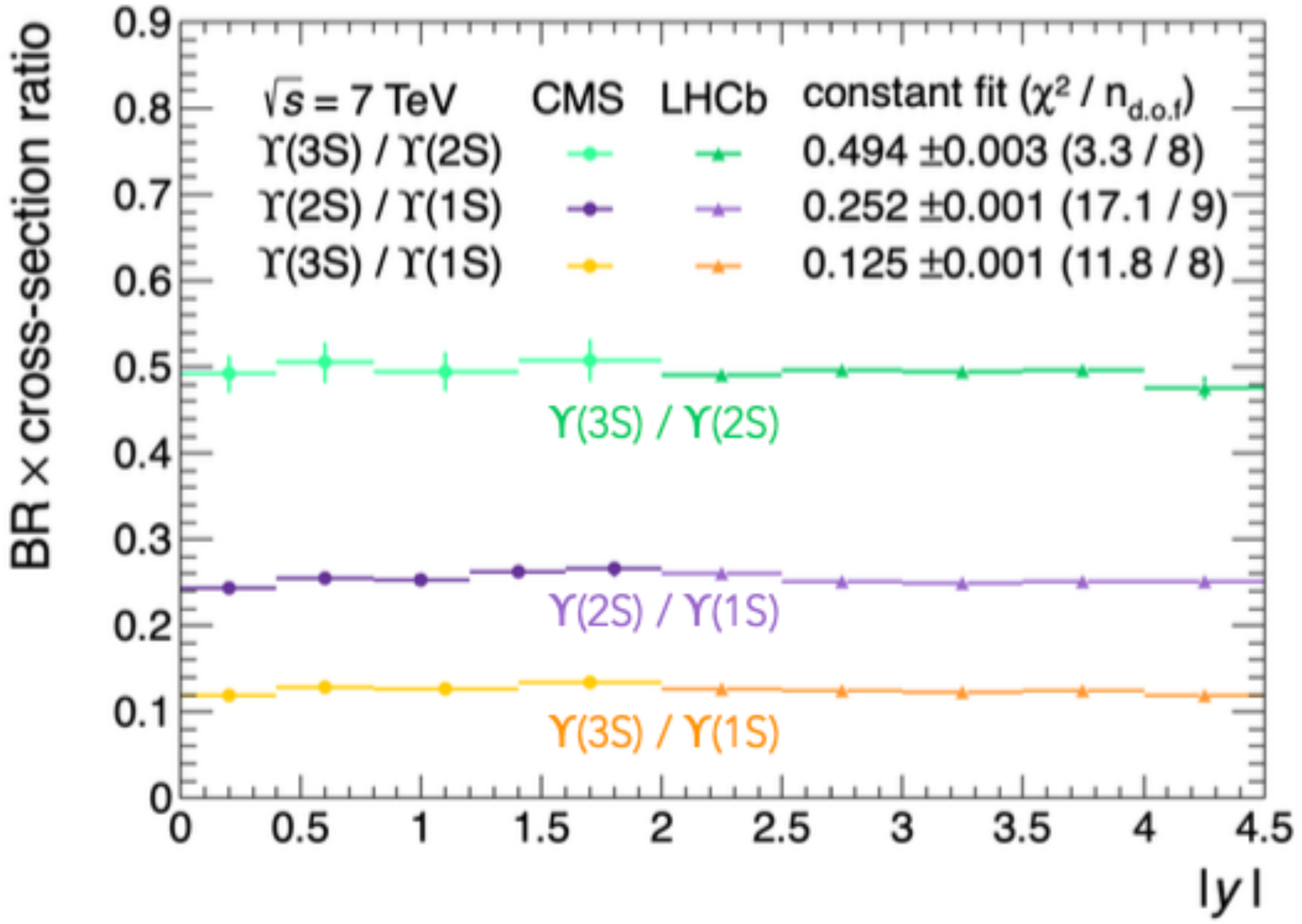
Text: Means that there is not public data available

Centre-of-mass energy	Psi(2S) measurements	Xc(1P) measurements	X(3872) measurements
7 TeV	**ATLAS** : Ratio to JPsi (in rapidity) J/Psi cross-section |y|<2.4 **CMS:** Ratio to J/Psi |y|<1.2 **LHCb:** Psi(2S) cross-section, pt > 2 GeV Psi(2S) cross-section pt < 12 GeV	**ATLAS** : Ratio Xc1,2 / JPsi pT>10 GeV **CMS:** Relative Xc2 / Xc1, pt > 7 GeV **LHCb:** Relative Xc2/Xc1 Xc0/Xc2 Ratio Xc0,1,2 / JPsi Relative Xc2/Xc1	**CMS:** Inclusive ratio X(3872)/Psi(2S) to JPsi pipi pT>10GeV |y|<1.2 **LHCb:** X(3872) cross-section integrated, 5 < pt < 20 GeV
8 TeV	**ATLAS** : Ratio to JPsi pT>8 GeV (in rapidity bins)	None	**ATLAS:** X(3872) and Psi(2S) to JPsi pipi pT>10 GeV |y| <0.75 **LHCb:** Ratio X(3872) to Psi(2S) in Jpsi pi pi, pt > 4 GeV (Ratios splitted in years of data taking and rapidity)
13 TeV	**CMS:** Ratio to JPsi pT>20 GeV **LHCb:** Ratio to JPsi y ∊ [2,4.5] pT ∊ [2,14]	None	**LHCb:** Ratio X(3872) to Psi(2S) in Jpsi pi pi, pt > 4 GeV (Ratios splitted in years of data taking and rapidity)

3. Dependences

It is important to check the dependence of the cross-section ratios with the rapidity and energy to know if it is justified merging the data measured in different conditions.

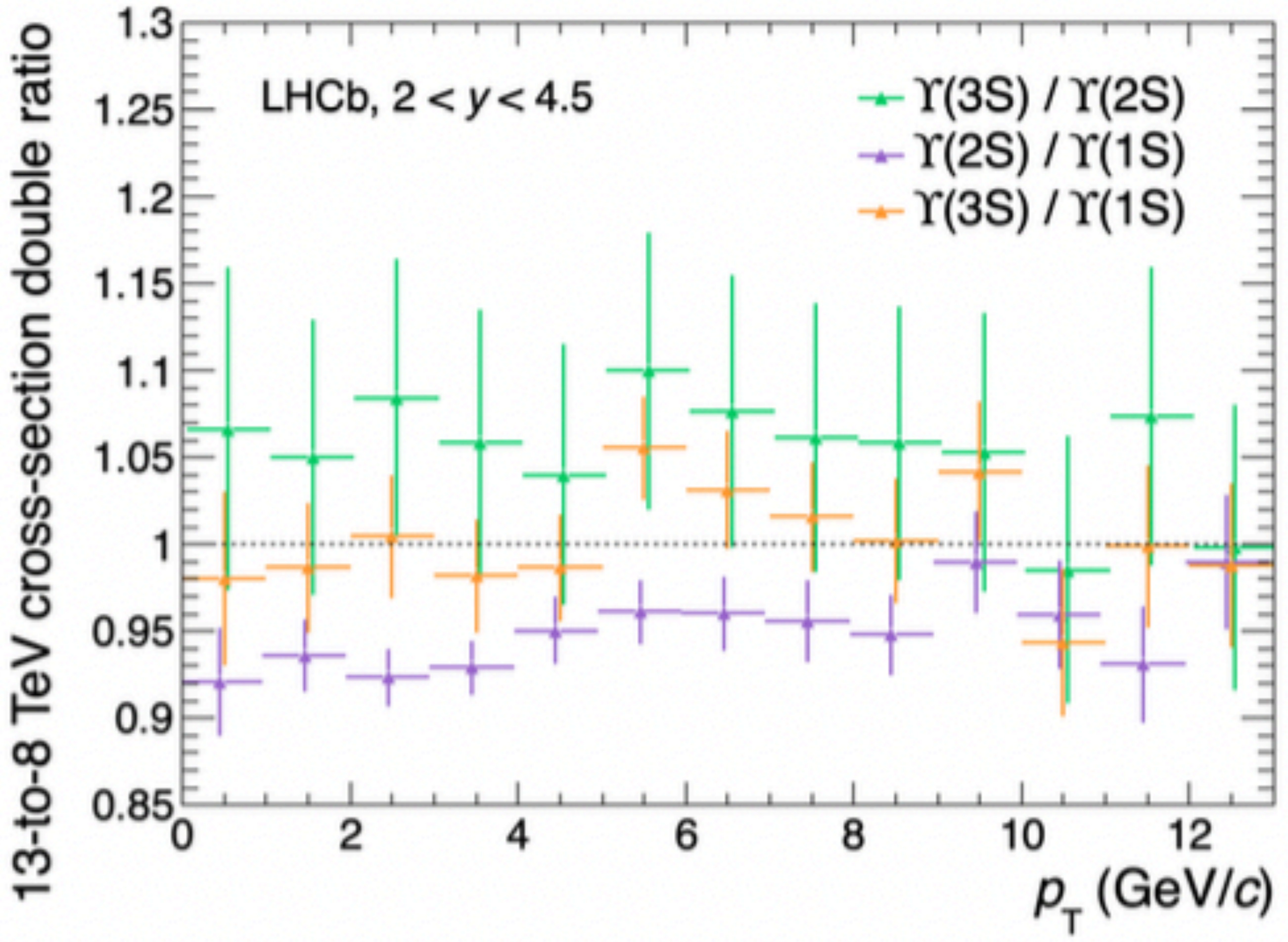
In the bottomonium case Florian demonstrated that there is no dependence with the rapidity.

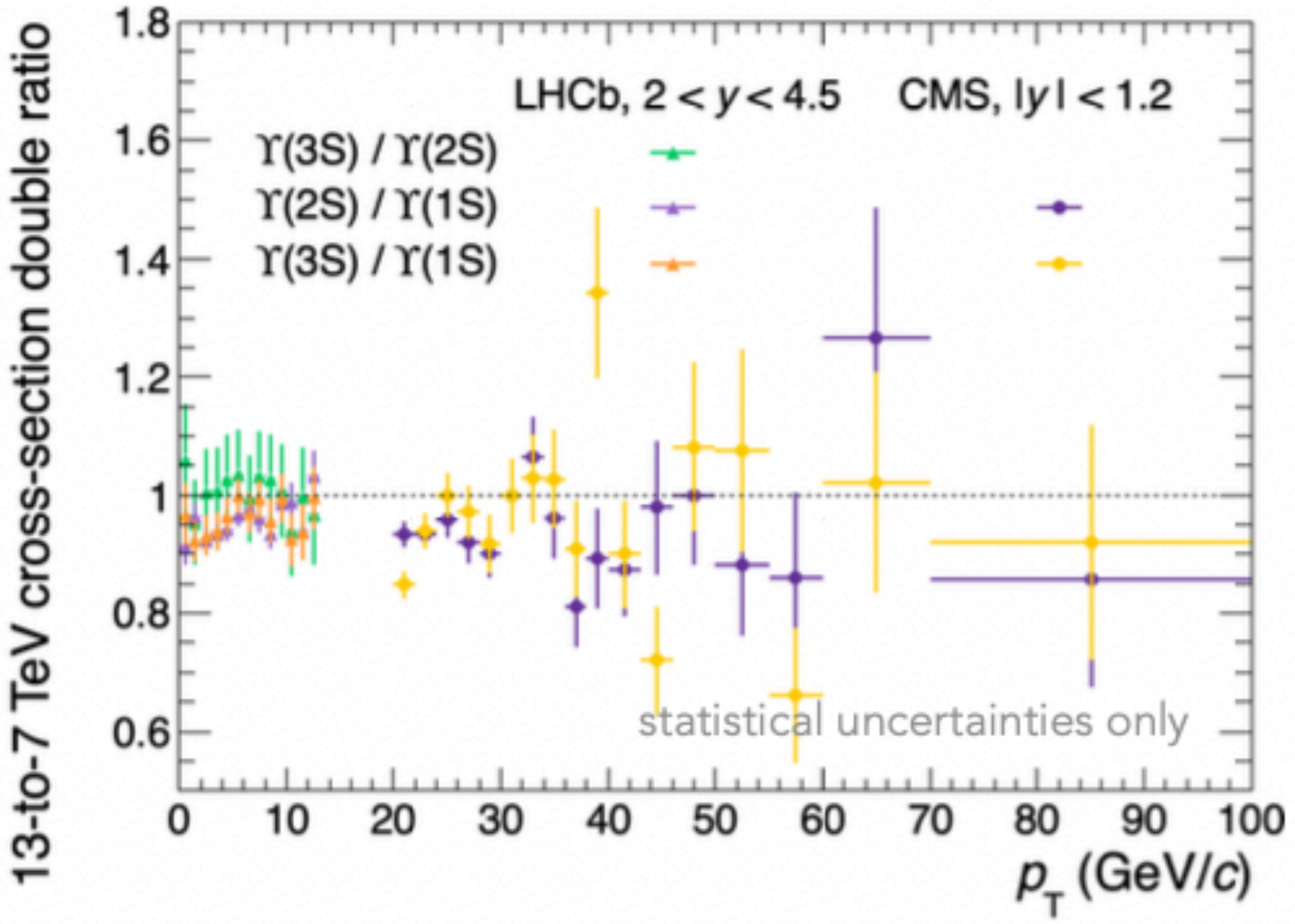


For the energy dependence, we can exploit measurements performed at different energies just by applying global scale factors:

Low p_T: No p_T dependence and small E dependence

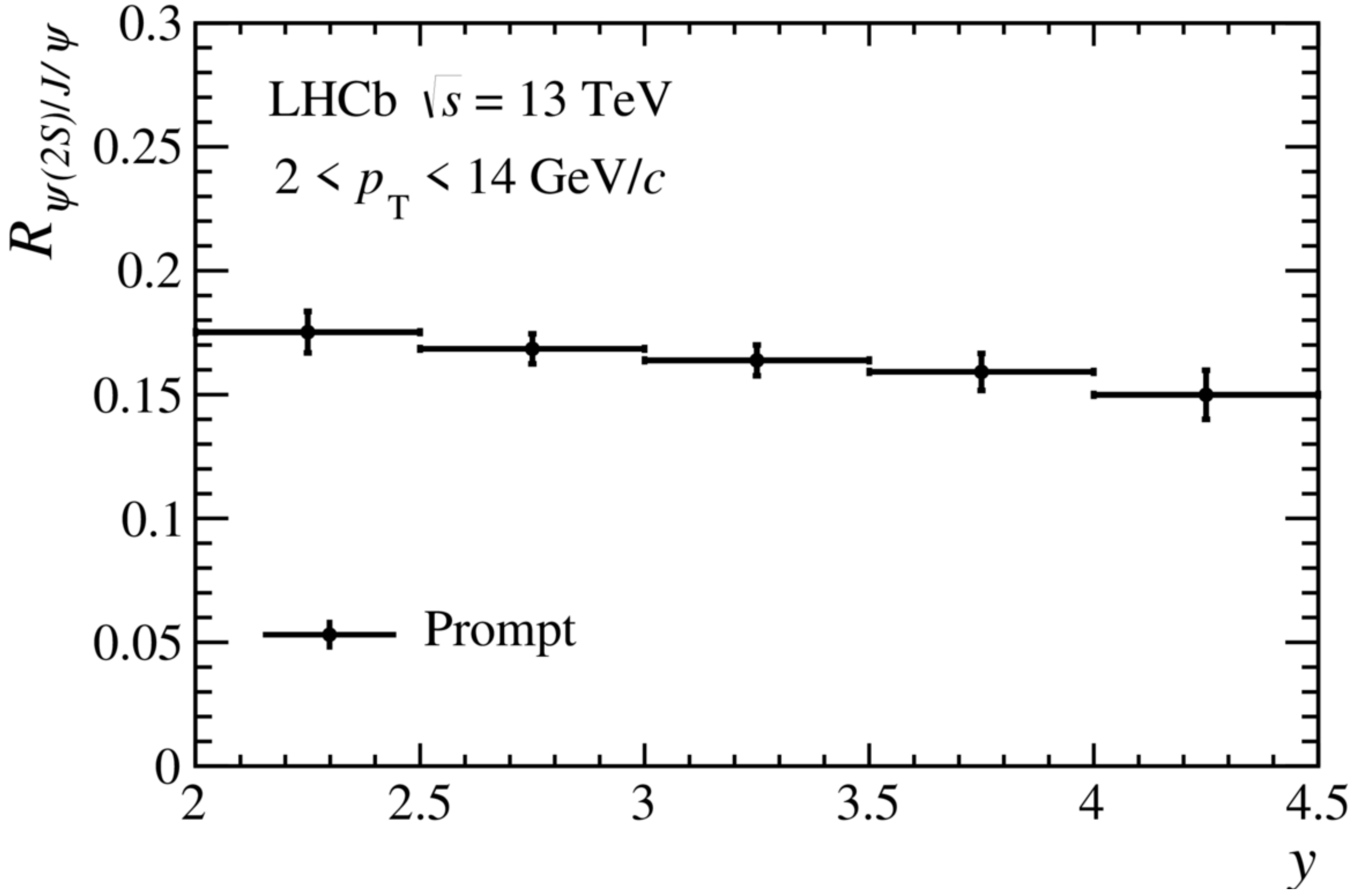
High p_T : Not clear behavior

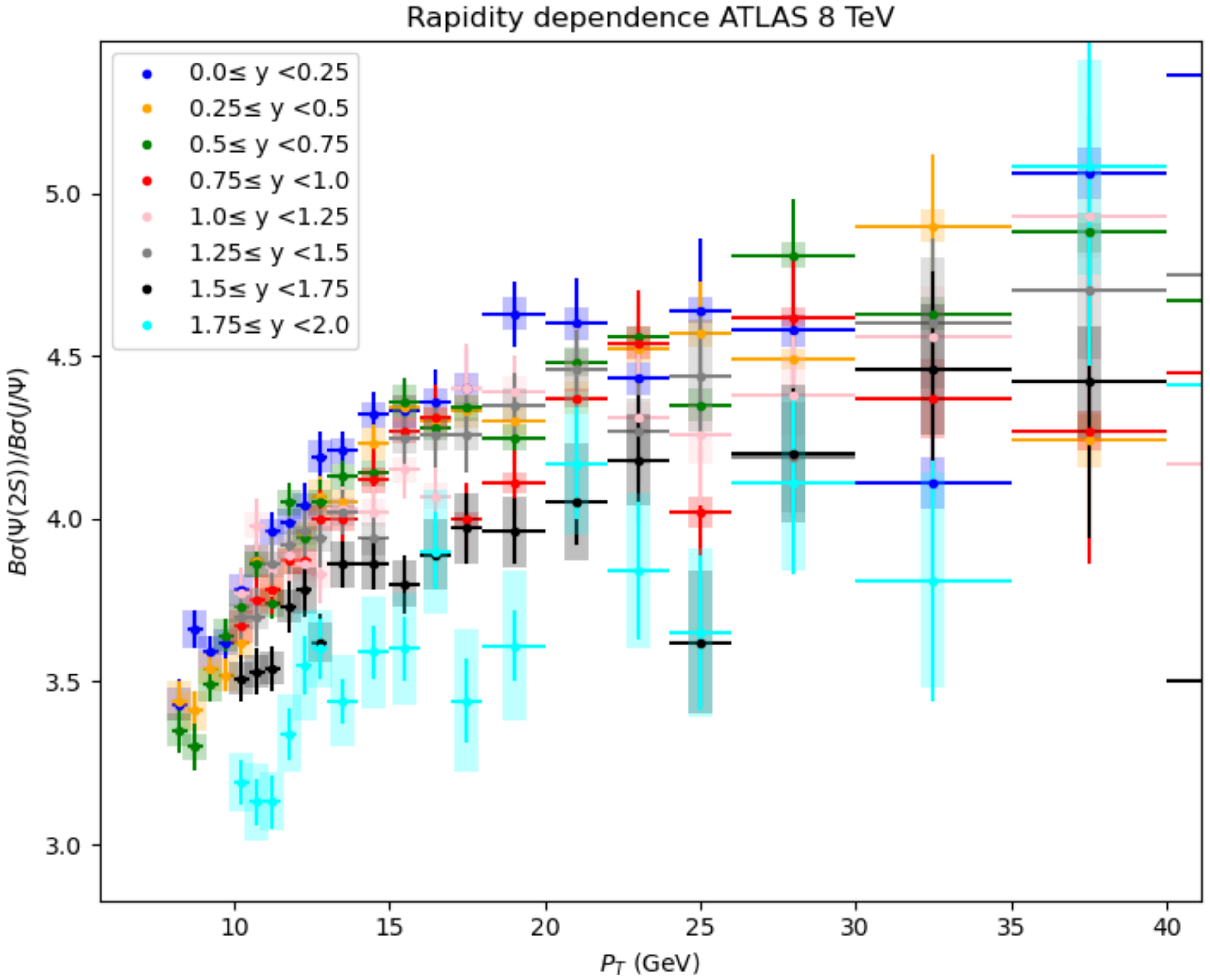


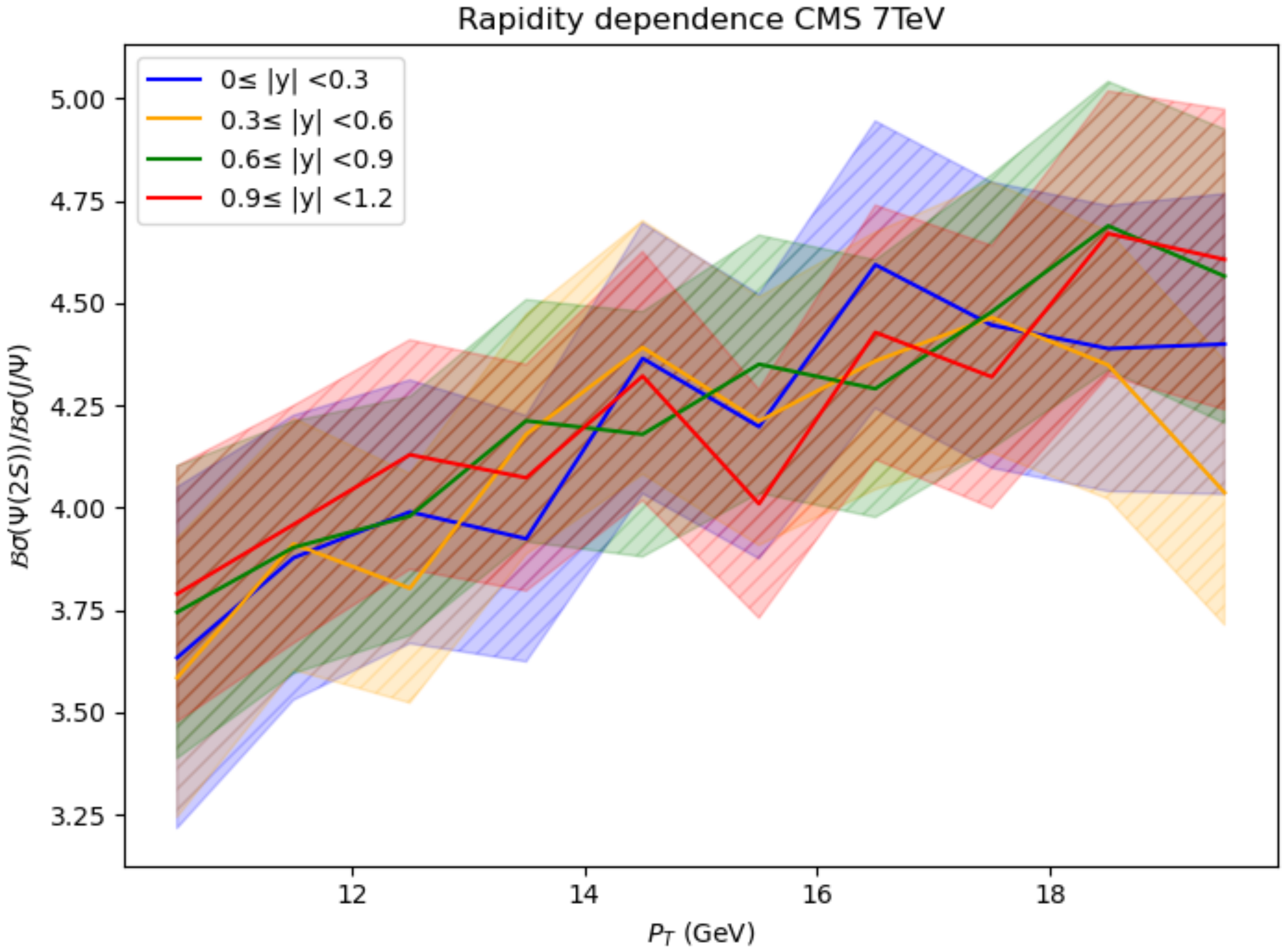


3.1. Rapidity dependence

In the charmonium case we can only check the dependence for high p_T and the results obtained by LHCb, ATLAS and CMS point to some kind of dependence.







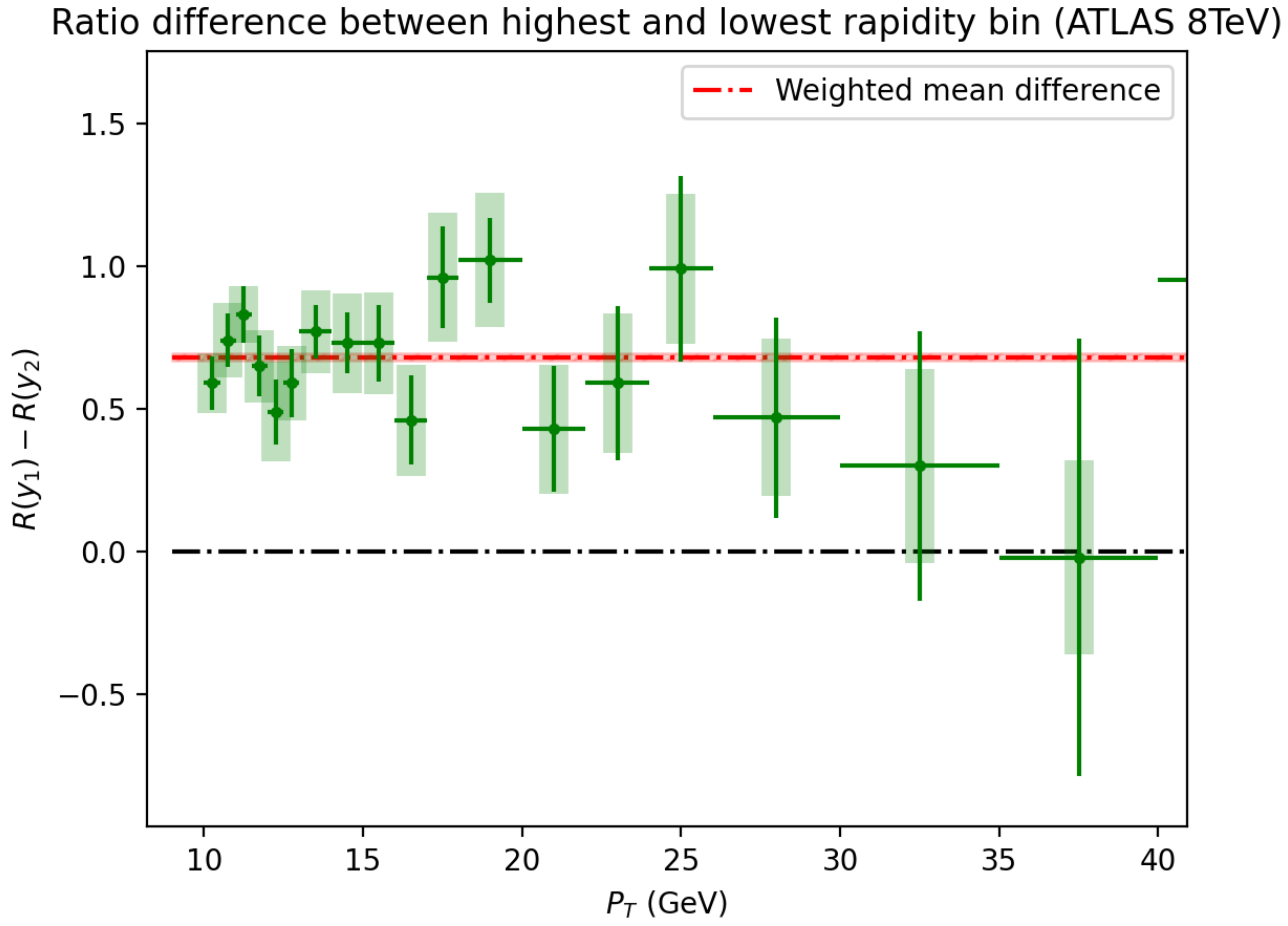
Boxes: Systematic uncertainties

Lines: Statistic uncertainties, if it is the only displayed then it its stat and sys combined

To asses the importance of the difference between the rapidity bins we can use the most extreme ones.

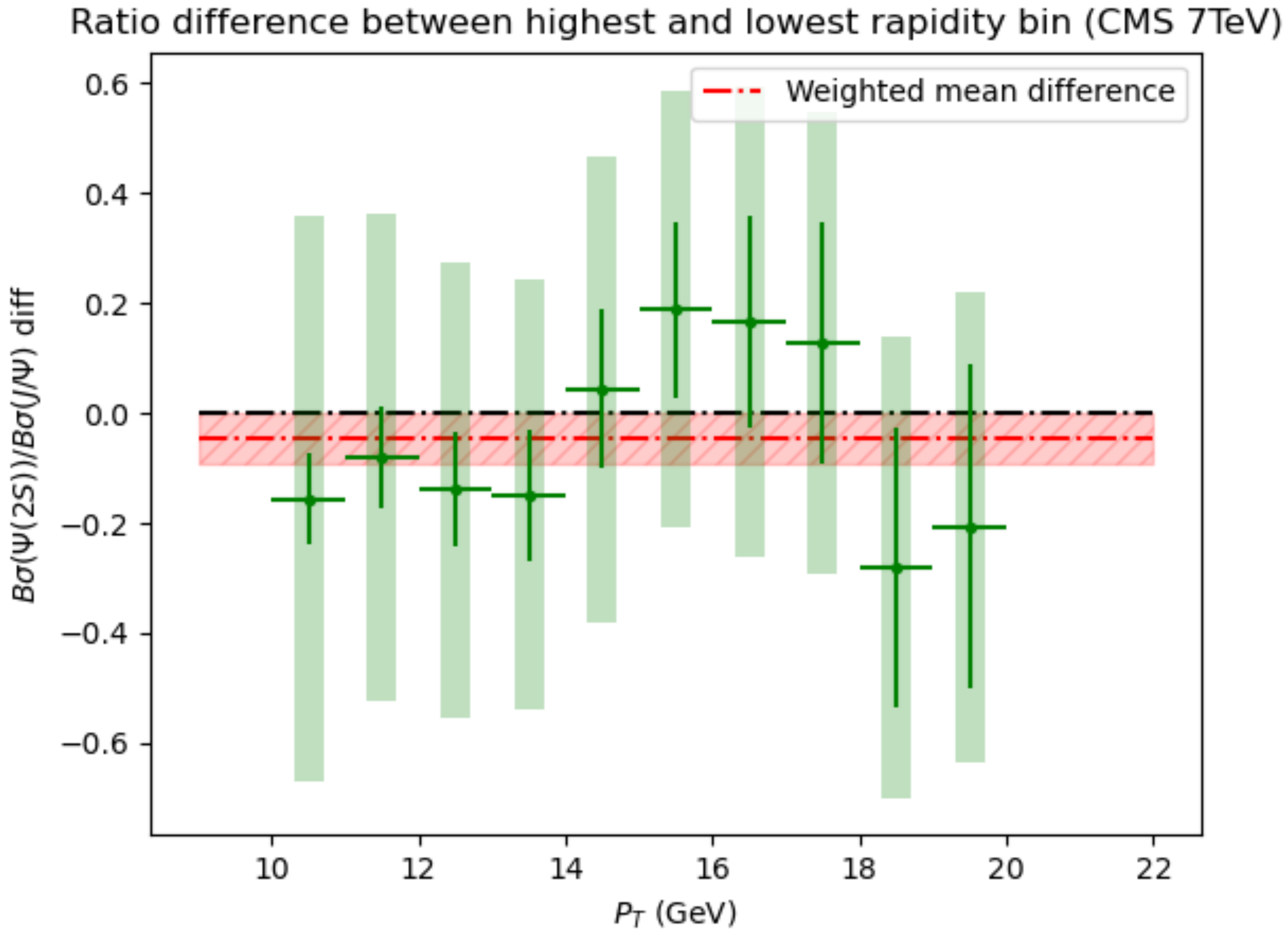
ATLAS: $0.00 \leq y < 0.25$ - $1.75 \leq y < 2.0$

The weighted mean **is not** compatible with a 0 difference between ratios. Mean diff= 0.681± 0.013



CMS: $0.00 \leq y < 0.3$ - $0.9 \leq y < 1.2$

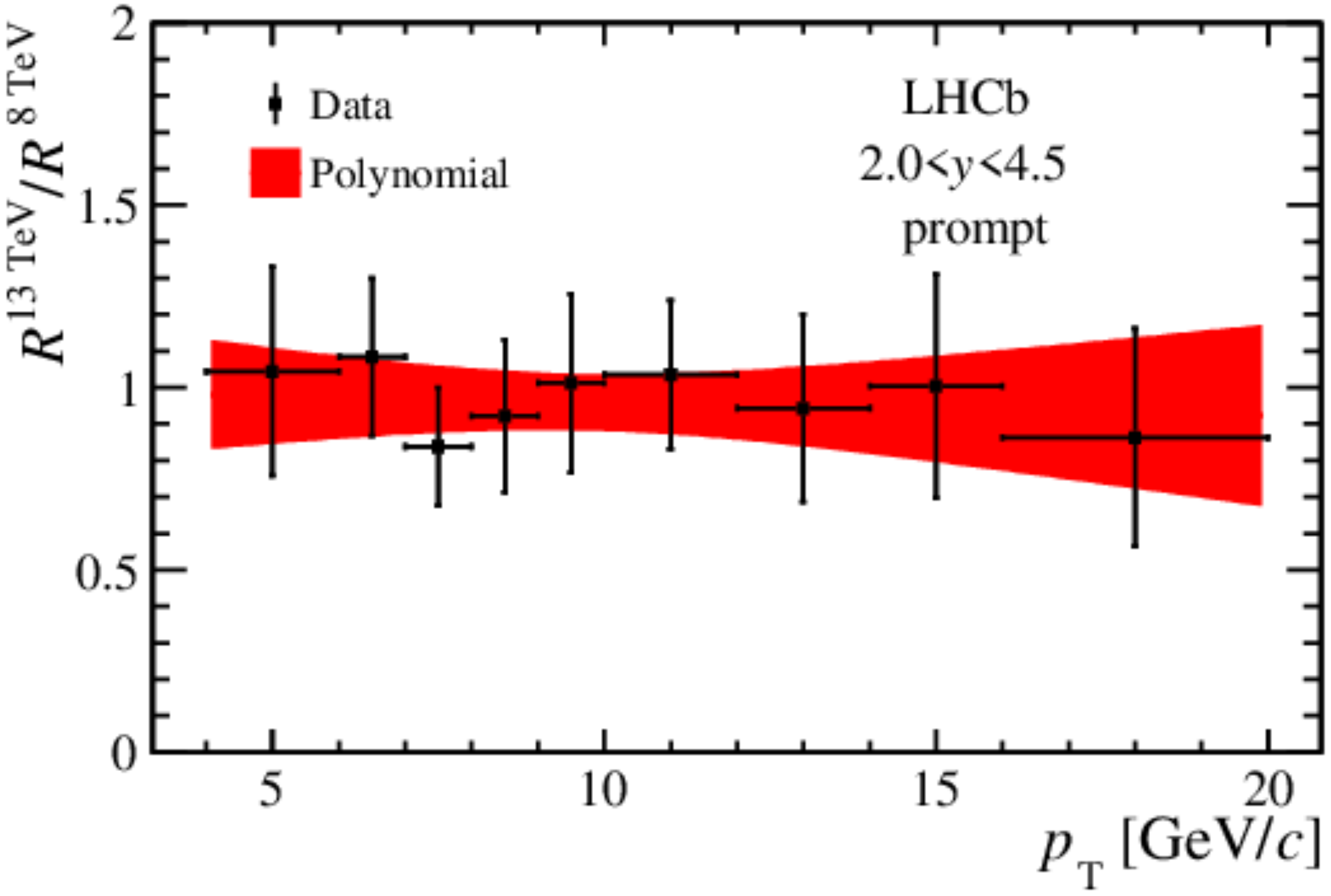
In this case the mean **is** compatible with no difference between ratios in the two rapidity bins

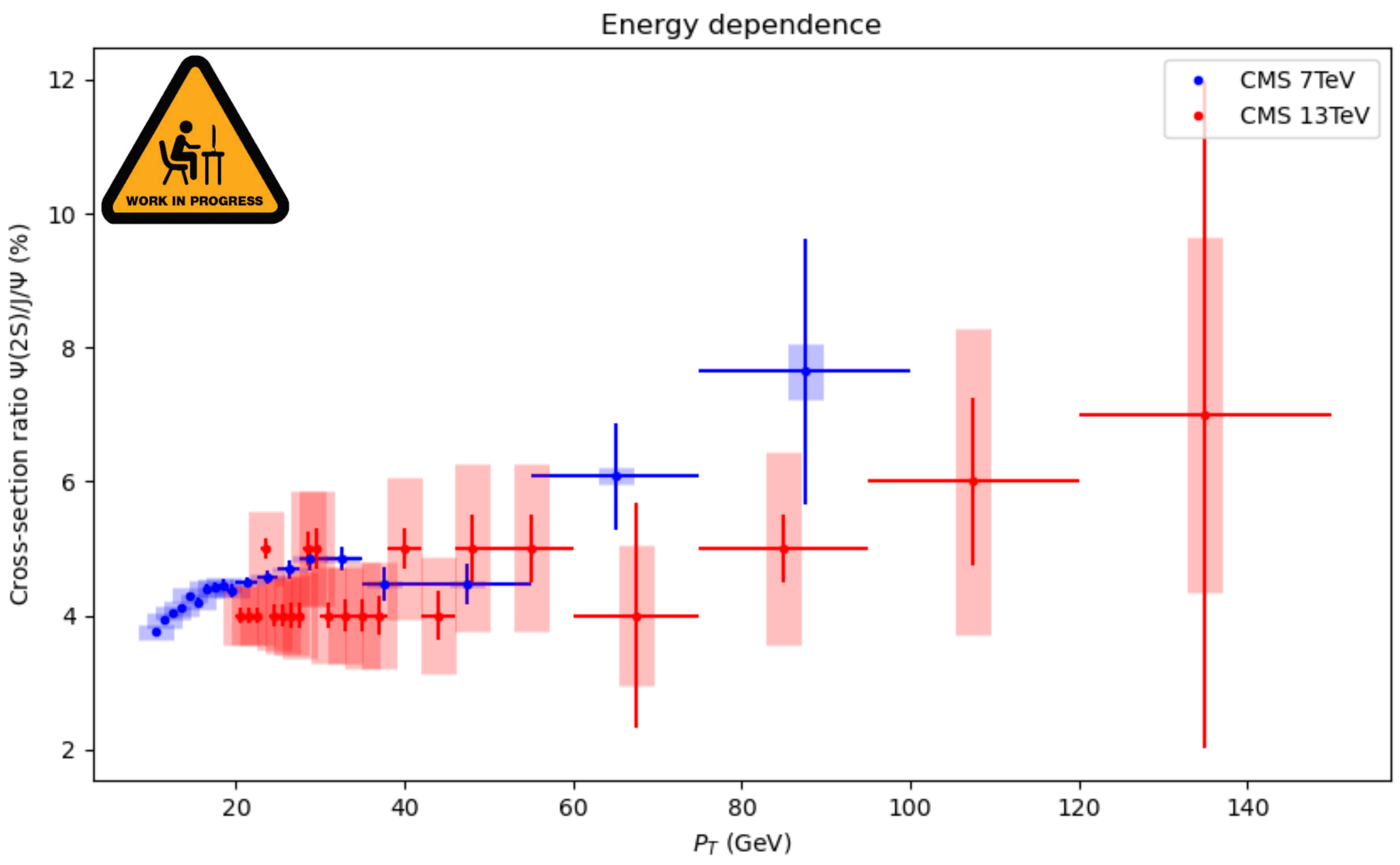


3.2. Energy dependence

This was checked by LHCb with the double ratio of the prompt X(3872) production cross-section relative to that of $\Psi(2S)$ and they got a polynomial fit with slope consisten with zero

It would be interesting to study this dependence in CMS data. But the binnings are not equal so we will have to compute the weighted average cross-section ratio for J/Ψ to match the $\Psi(2S)$ binning.





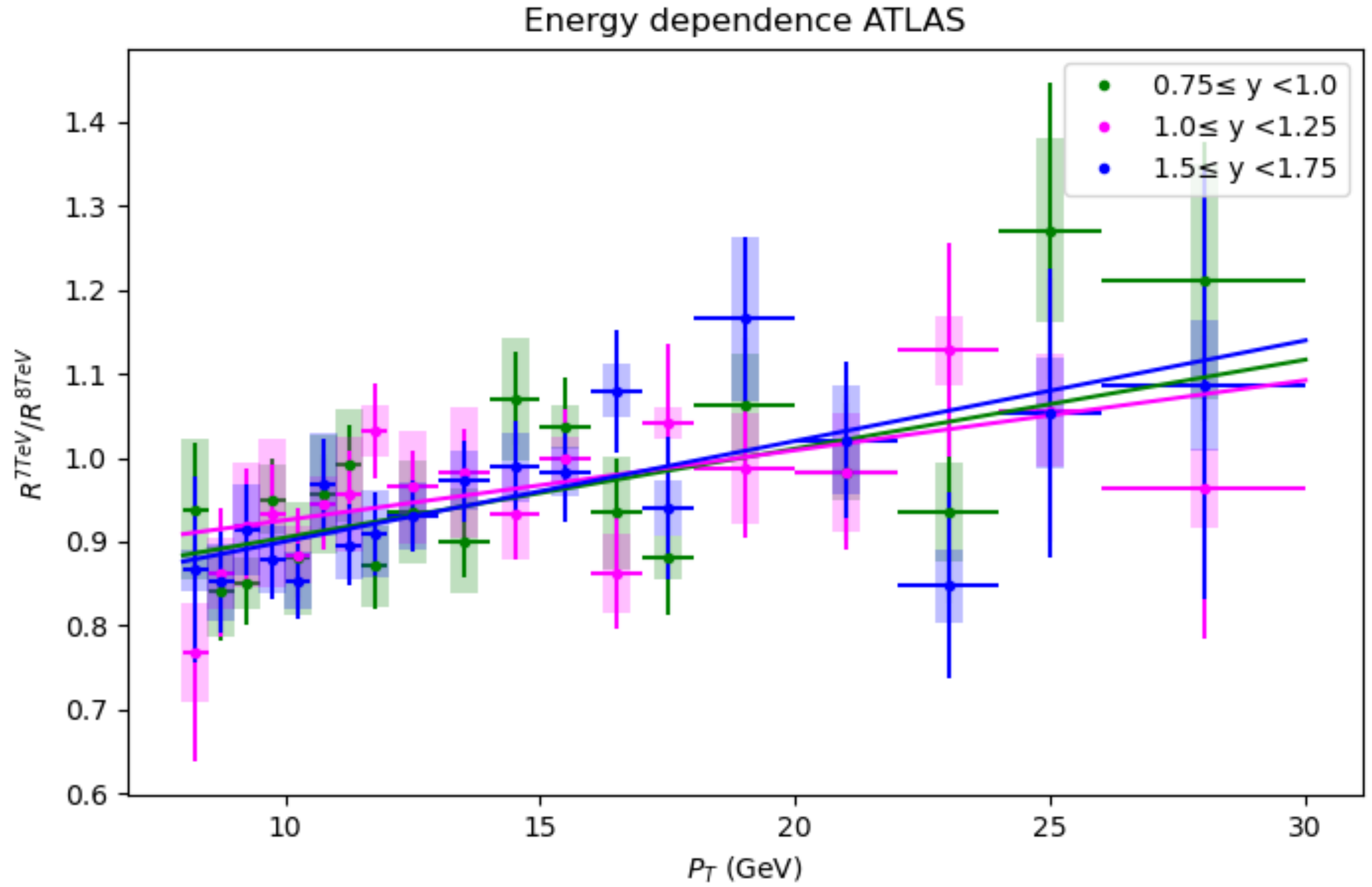
With ATLAS data at 7,8 TeV we can compute the double ratio to study the dependence with energy and tranverse momentum. Defining the ratio as:

$$R^{xTeV} = \frac{B \cdot \sigma(\Psi(2S))}{B \cdot \sigma(J/\Psi)}$$

Fitting results

y

R7/R8 = (0.0064 ± 1.3e-05) * pT + (0.92 ± 0.0026)
R7/R8 = (0.0026 ± 4e-06) * pT + (0.98 ± 0.00086)
R7/R8 = (0.0076 ± 4.8e-06) * pT + (0.92 ± 0.00094)
R7/R8 = (0.011 ± 1.4e-05) * pT + (0.8 ± 0.0028)
R7/R8 = (0.0083 ± 1.1e-05) * pT + (0.84 ± 0.0023)
R7/R8 = (0.0026 ± 2.6e-05) * pT + (0.91 ± 0.0053)
R7/R8 = (0.012 ± 1.2e-05) * pT + (0.78 ± 0.0022)
R7/R8 = (0.00059 ± 3.9e-05) * pT + (0.89 ± 0.0064)



For clarity we only show the cases with more dependence

The slopes obtained in the fits are not compatible with 0 in most of the cases, nevertheless we are using here the results of ATLAS 7TeV that are not very precise. It would be interesting to do this in just one joined rapidity bin as in the previous slide.

4. $\Psi(2S)$ to J/Ψ feed-down fraction

By definition: $\mathscr{F}(\Psi(2S) \to J/\Psi) \equiv \dfrac{\sigma(\Psi(2S))}{\sigma(J/\Psi)} \times \mathscr{B}(\Psi(2S) \to J/\Psi + \text{anything})$

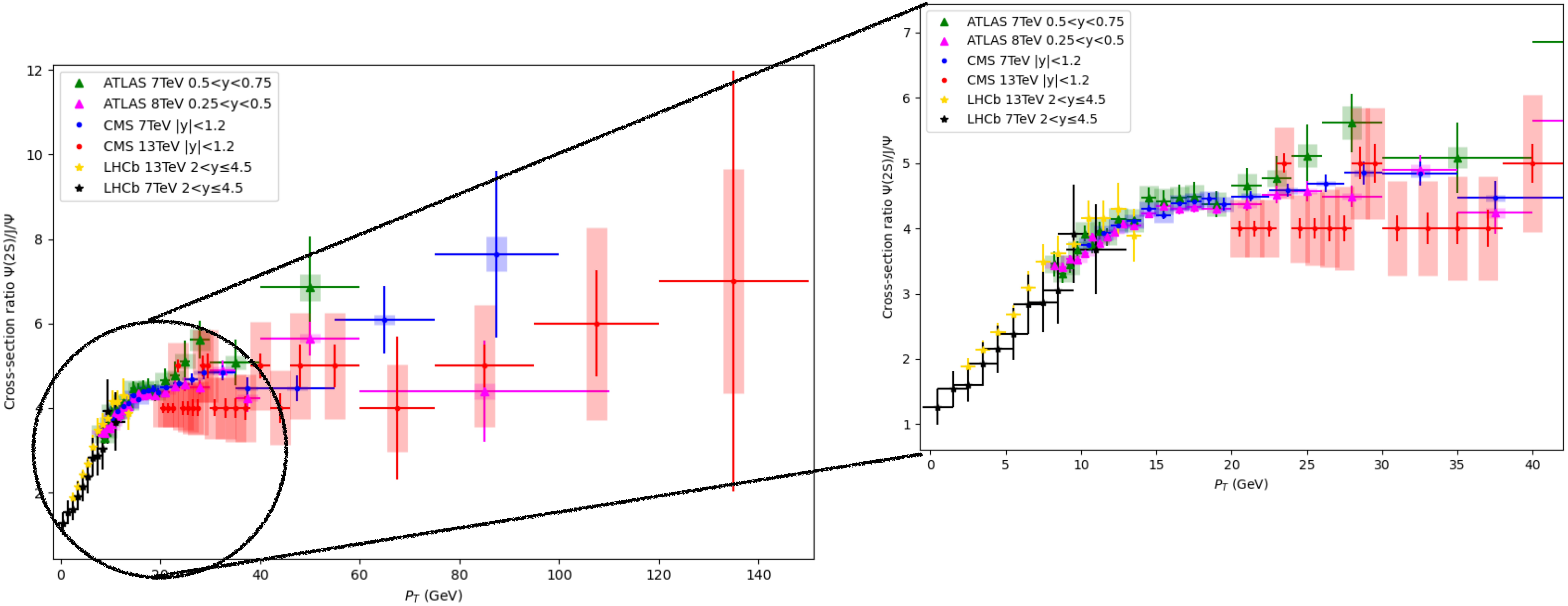
In most cases, the experiments measure only cross-section ratios, not corrected by the corresponding branching fractions, so we have to take this into account in the calculations

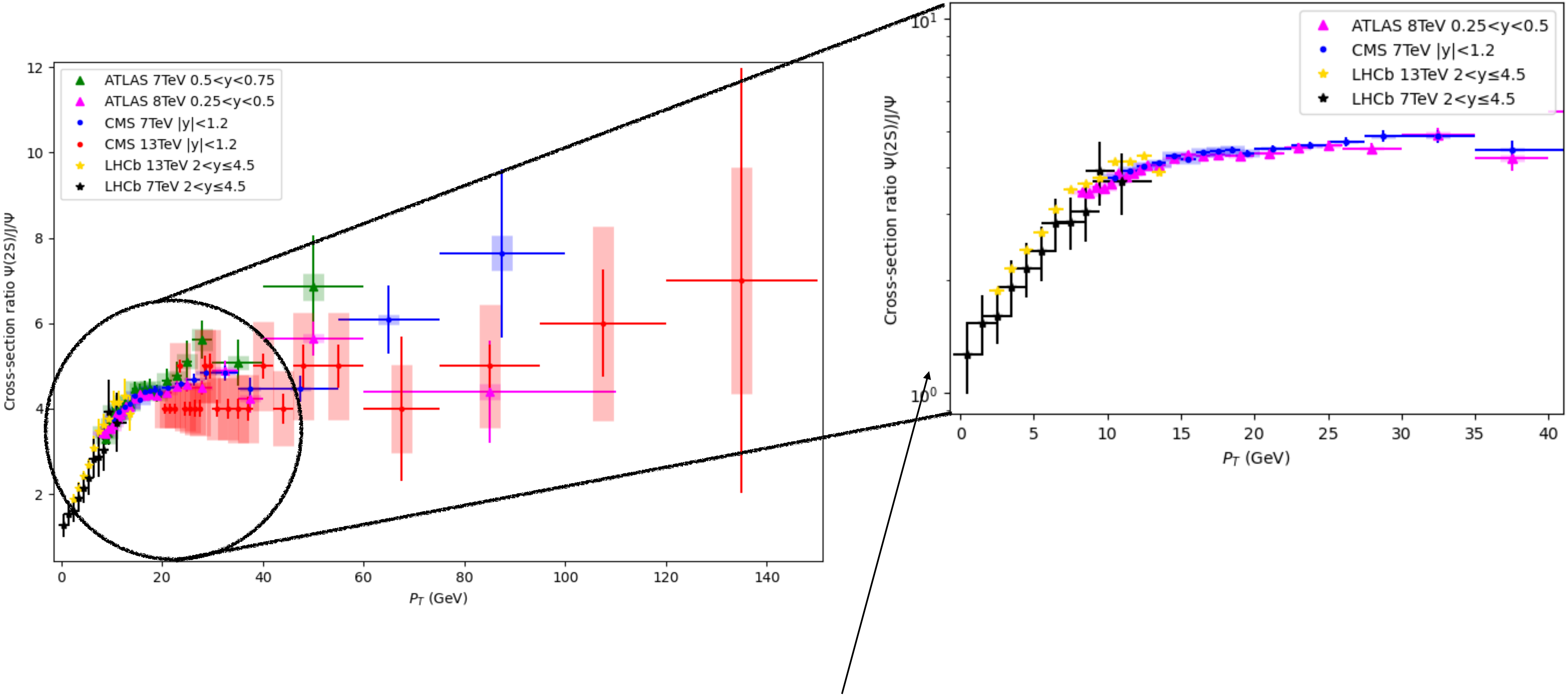
$$\mathscr{F}(\Psi(2S) \to J/\Psi) = \boxed{\frac{\mathscr{B}(\Psi(2S) \to \mu\mu) \times \sigma(\Psi(2S))}{\mathscr{B}(J/\Psi \to \mu\mu) \times \sigma(J/\Psi)}} \times \frac{\mathscr{B}(\Psi(2S) \to \mu\mu)}{\mathscr{B}(J/\Psi \to \mu\mu)} \times \mathscr{B}(\Psi(2S) \to J/\Psi + \text{anything})$$

Measurements

4.1. Cross-section ratios

- These are the $\Psi(2S)$ over J/Ψ cross section ratios measured experimentally multiplied by the branching ratios



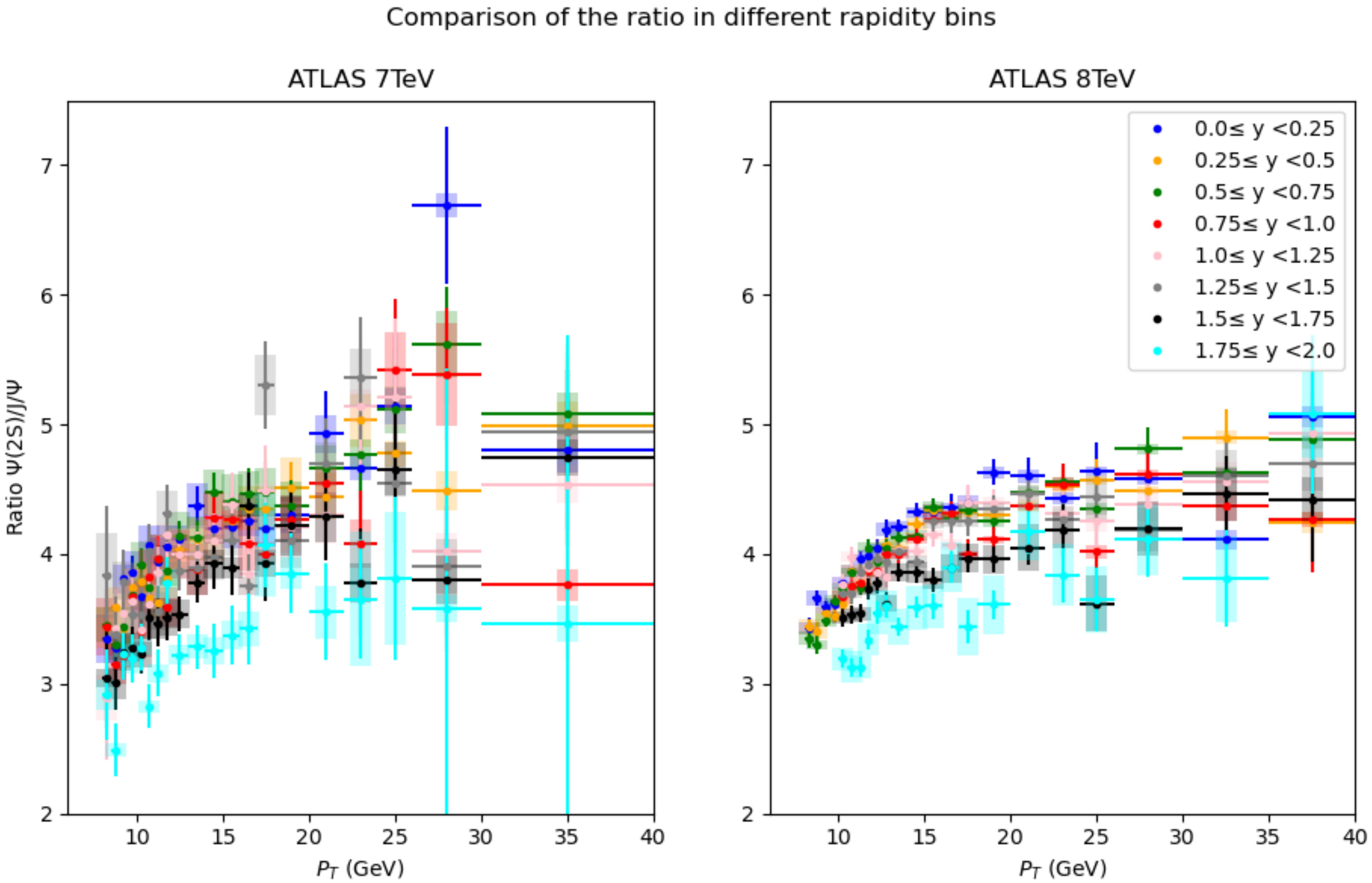

ATLAS 7TeV 0.5<y<0.75
ATLAS 8TeV 0.25<y<0.5
CMS 7TeV |y|<1.2
CMS 13TeV |y|<1.2
LHCb 13TeV 2<y≤4.5
LHCb 7TeV 2<y≤4.5
Cross-section ratio Ψ(2S)/J/Ψ
P_T (GeV)
0
20
40
60
80
100
120
140
2
4
6
8
10
12
ATLAS 8TeV 0.25<y<0.5
CMS 7TeV |y|<1.2
LHCb 13TeV 2<y≤4.5
LHCb 7TeV 2<y≤4.5
Cross-section ratio Ψ(2S)/J/Ψ
P_T (GeV)
10^1
10^0
0
5
10
15
20
25
30
35
40

Log scale!

4.2. ATLAS data

We are not going to consider the 7TeV data because it is way less precise than the 8TeV results.

To choose which rapidity interval to use we compute the mean relative uncertainty of each rapidity bin. The most precise interval is $0.25 \leq y < 0.5$ which will be used from now on.

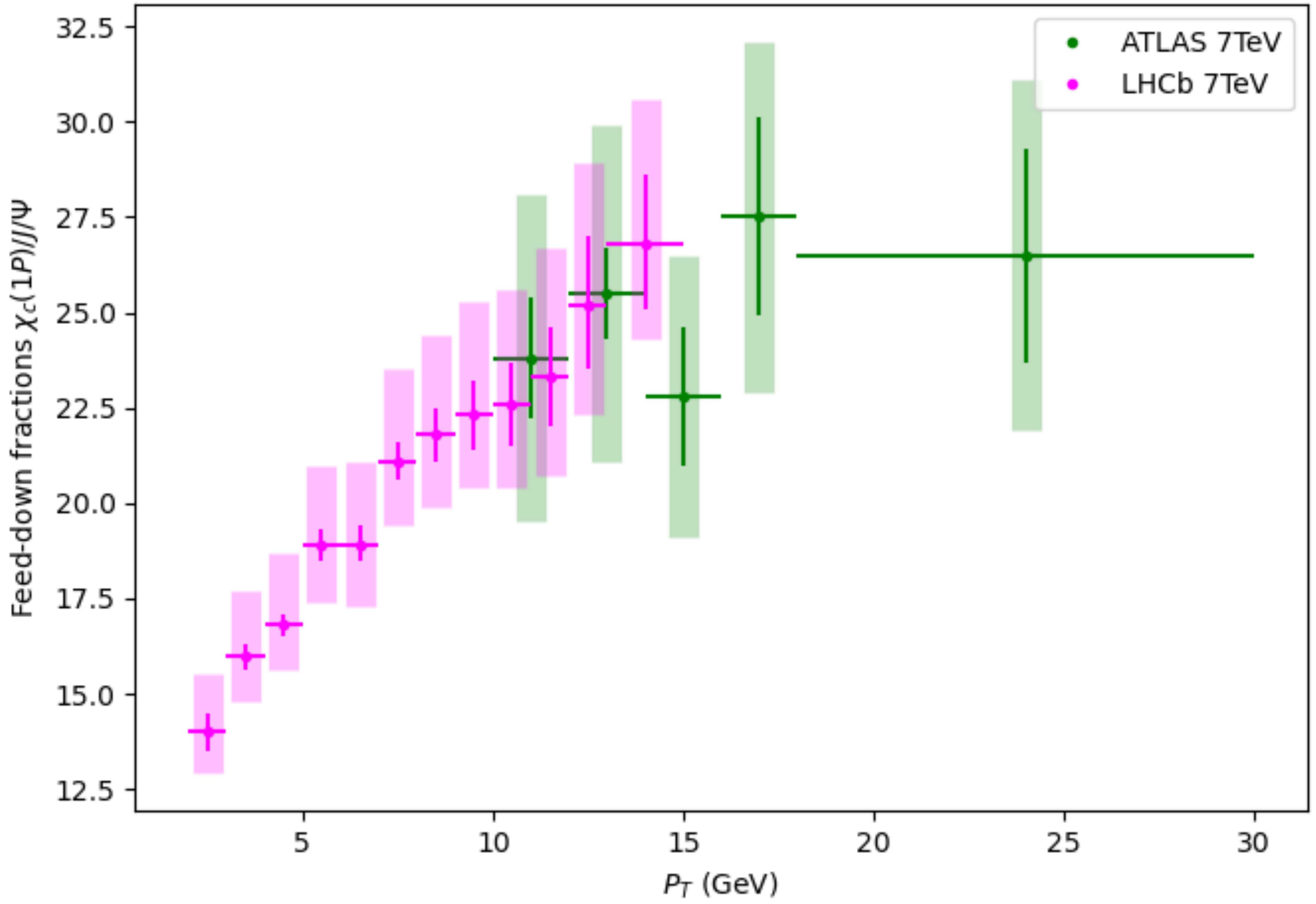


5. χ_c multiplet feed-down

$$\mathcal{F}^{\chi_c(nP)}_{j/\Psi(mS)} = \frac{\sigma(\chi_{c0}(1P))}{\sigma(J/\Psi)} \times \mathcal{B}(\chi_{c0}(1P) \to J/\Psi + \gamma) + \frac{\sigma(\chi_{c1}(1P))}{\sigma(J/\Psi)} \times \mathcal{B}(\chi_{c1}(1P) \to J/\Psi + \gamma) + \frac{\sigma(\chi_{c2}(1P))}{\sigma(J/\Psi)} \times \mathcal{B}(\chi_{c2}(1P) \to J/\Psi + \gamma)$$

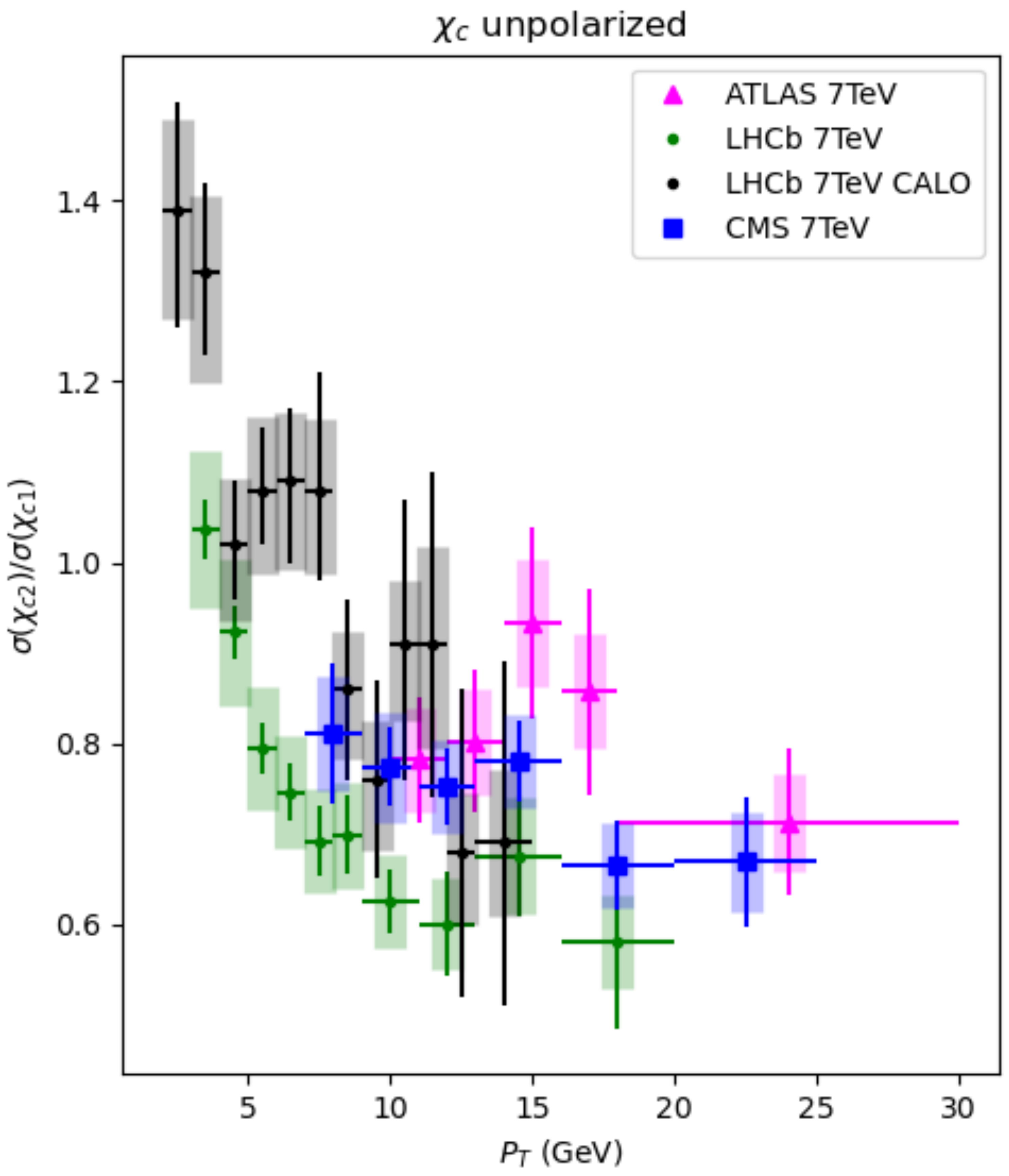
In most cases χ_{c0} is not considered in the global calculation because its $\mathcal{B}$ to J/Ψ is too small to measure $\mathcal{B}(\chi_{c0}(1P) \to J/\Psi + \gamma) = 1.27 \pm 0.06\,\%$

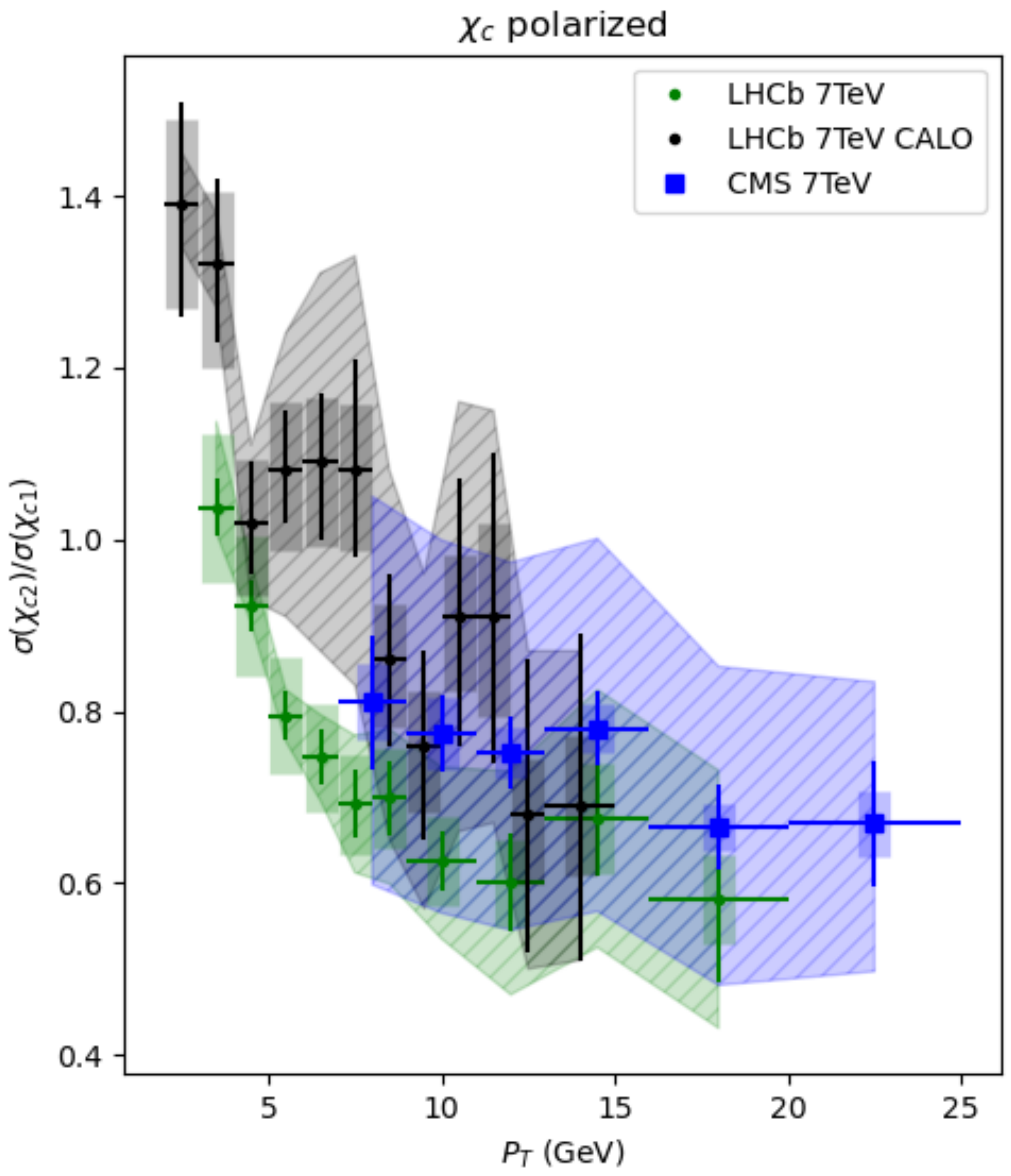
Considering the multiplet only formed by $\chi_{c1,2}$ the feed-down to J/Ψ is:



5.1. Ratio of χ_{c2} to χ_{c1} cross-sections

We can compare the results obtained by the different collaborations for the $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ ratio





Under the non-zero polarization assumption the shaded bands are due to changes in the polarization of the χ_c

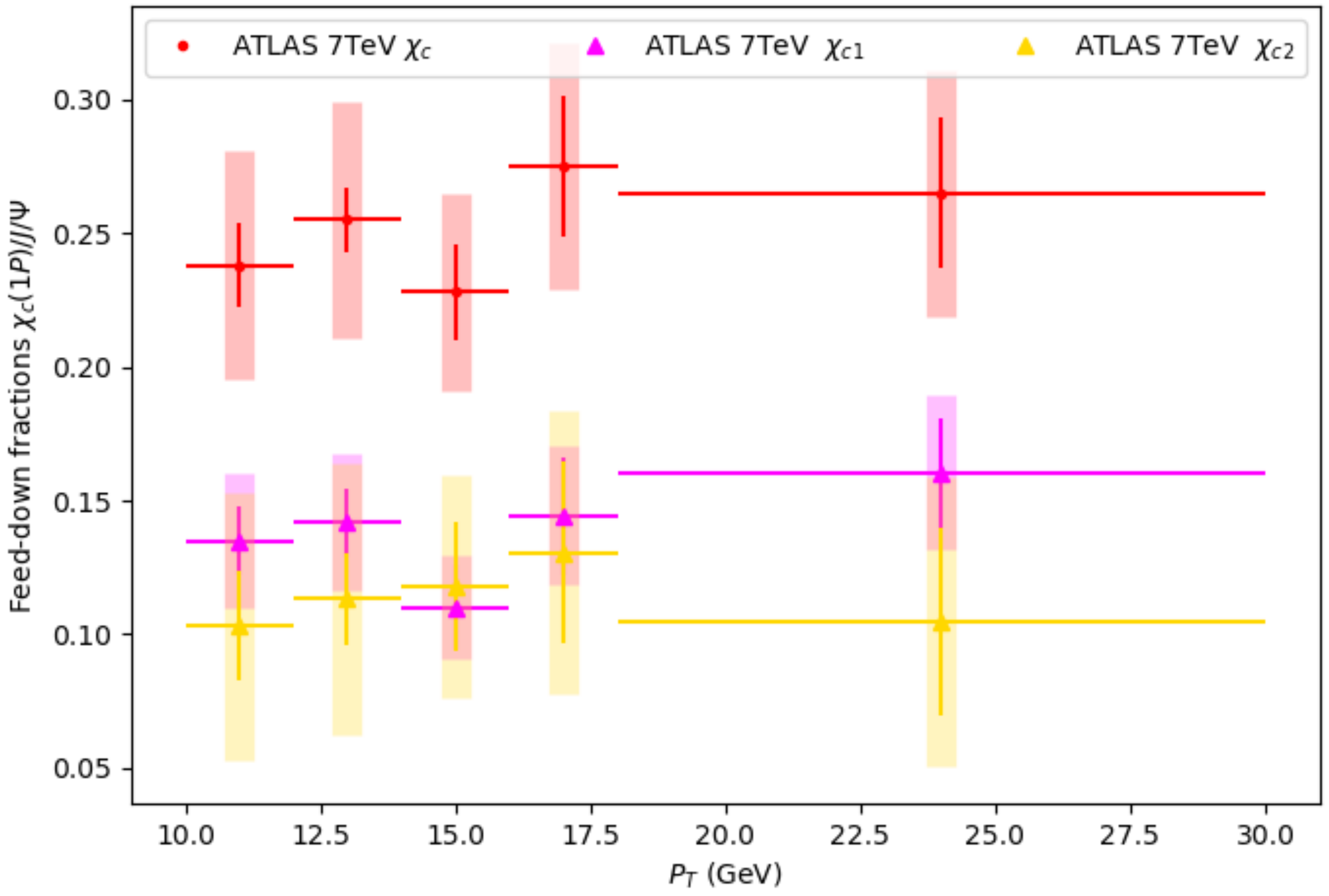
5.2. Separation of the multiplet contributions.

We can compute the individual contributions of $\chi_{c1,2}$ to the feed-down in ATLAS data using the following equation:

$$F_{J/\Psi}^{\chi_{c1}} = \boxed{F_{J/\Psi}^{\chi_c}} \times \left[1 - \boxed{\frac{\sigma(\chi_2)}{\sigma(\chi_1)} \cdot \frac{B(\chi_{c2} \to J/\Psi + \gamma)}{B(\chi_{c1} \to J/\Psi + \gamma)}} \right]$$

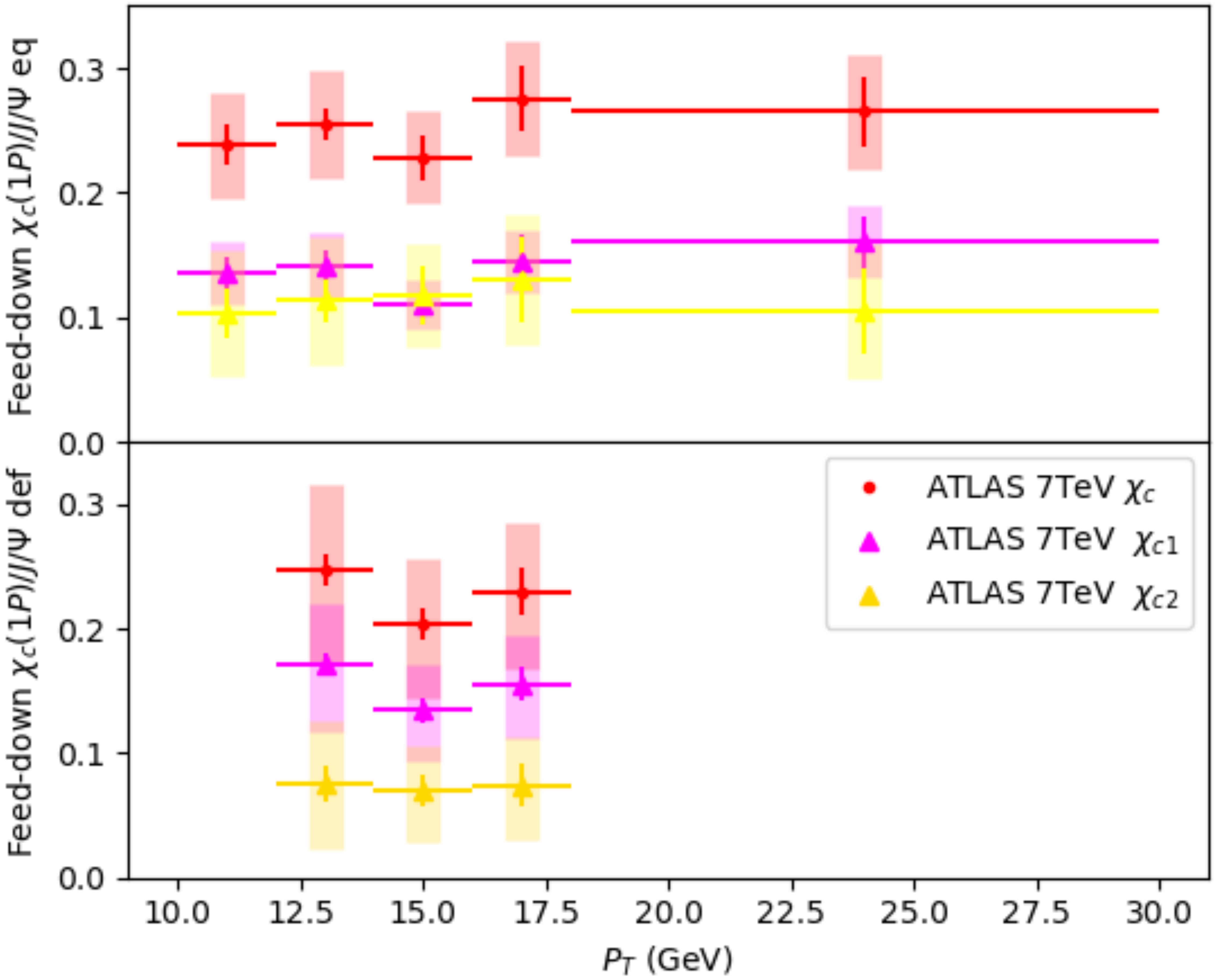
In ATLAS both observables are measured as a function of p_T

$$F_{J/\Psi}^{\chi_{c2}} = F_{J/\Psi}^{\chi_c} - F_{J/\Psi}^{\chi_{c1}}$$



To be sure that the previous equation is indeed correct, we can compute the individual feed-downs with the general definition presented before.

We can see that the results in both cases lie in the same range of values, so the equation is presumably well obtained

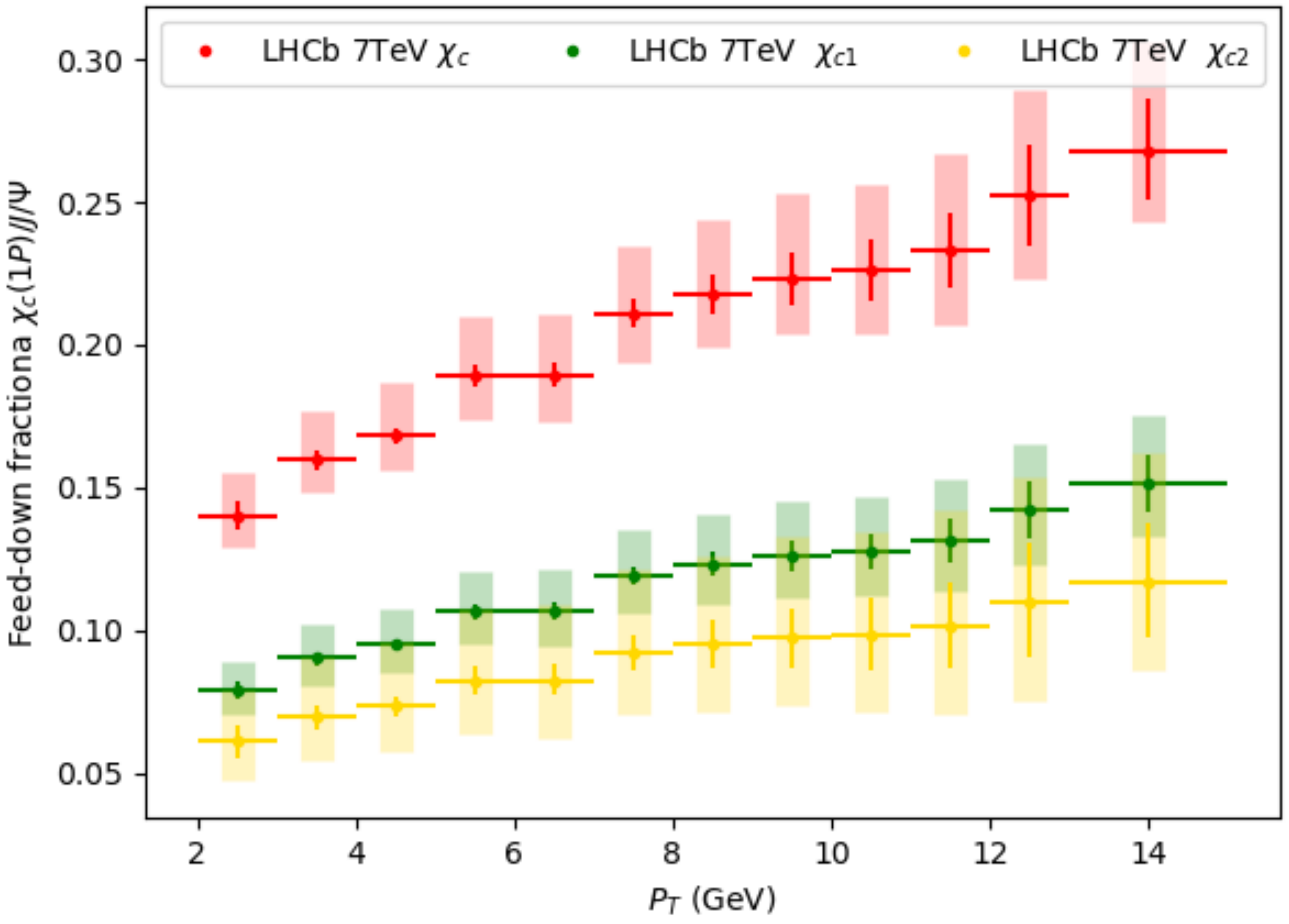


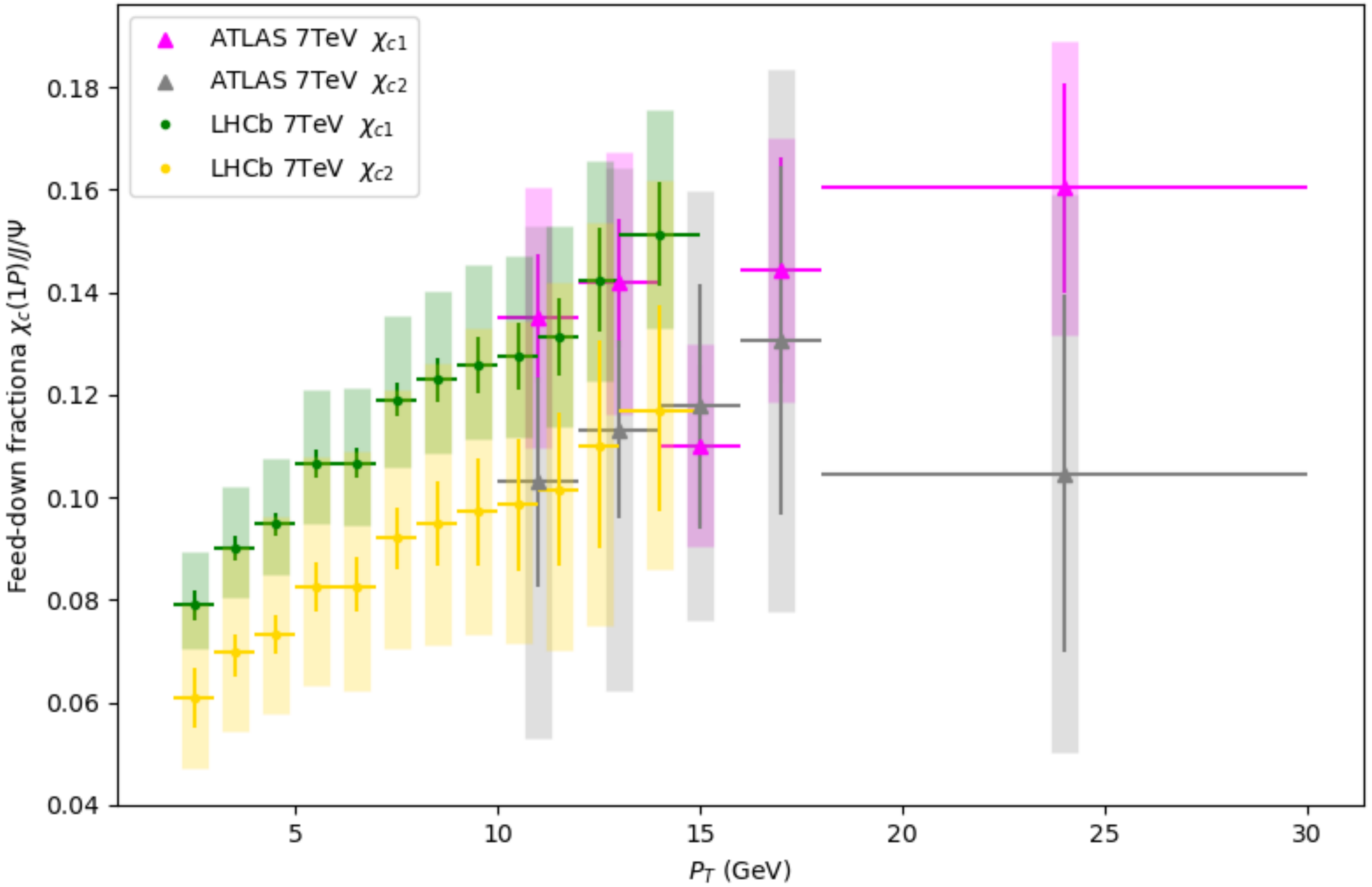
In the LHCb data we could consider the contribution of χ_{c0}, as it is reported to be detected in their analysis.
We will consider it as a second order correction given the small BR to J/Ψ, and follow the same procedure as with ATLAS data.

$$\sigma(\chi_{c0})/\sigma(\chi_{c2}) = 1.19 \pm 0.27 \text{ (stat)} \pm 0.29 \text{ (syst)} \pm 0.16 (p_T \text{ model}) \pm 0.09 (\mathscr{B})$$

$$\sigma(\chi_{c2})/\sigma(\chi_{c1}) = 0.787 \pm 0.014 \text{ (stat)} \pm 0.034 \text{ (syst)} \pm 0.051 (p_T \text{ model}) \pm 0.047 (\mathscr{B})$$

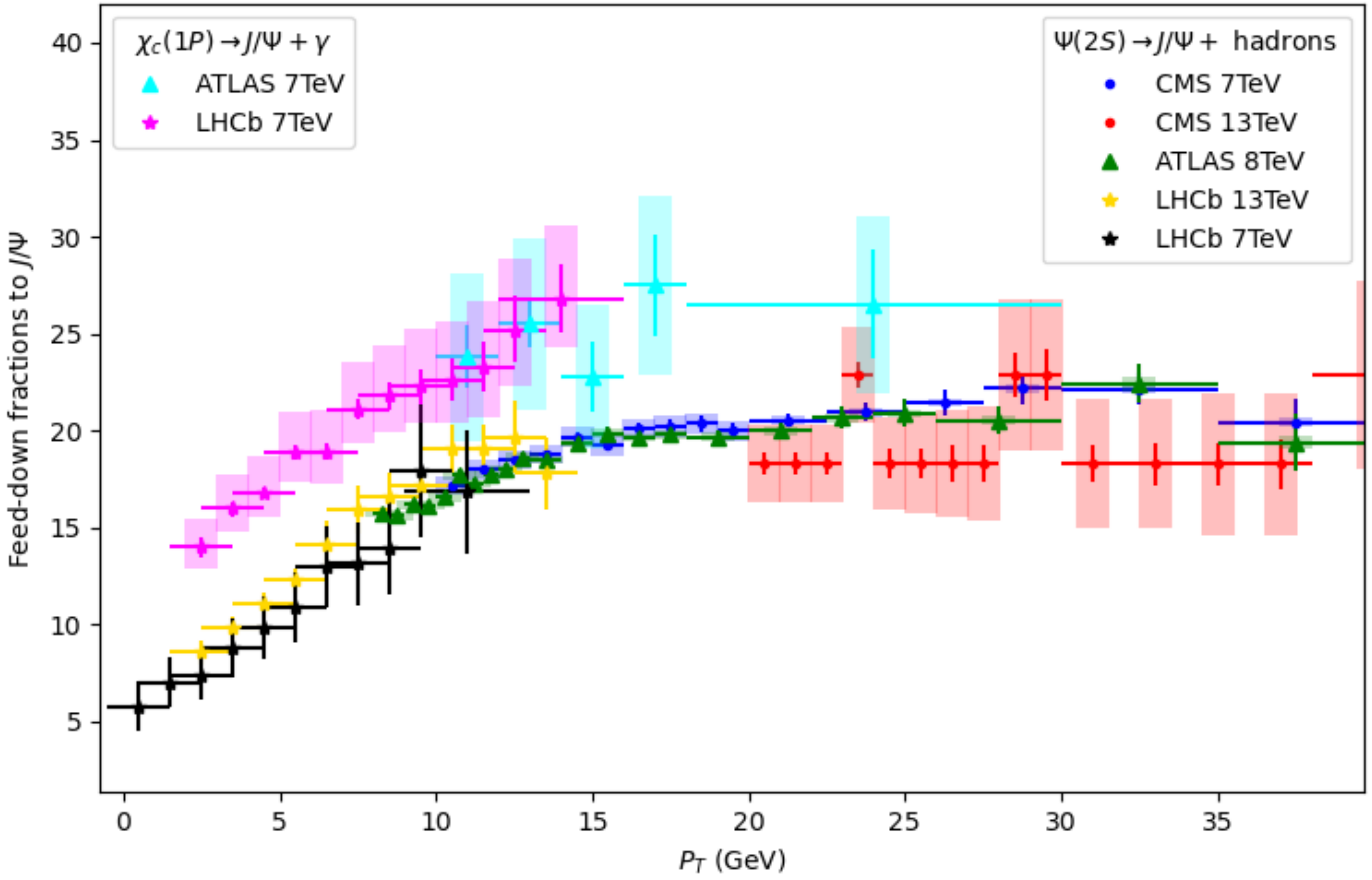
In the systematic error I am adding in quadrature all the sources not indicated as statistic

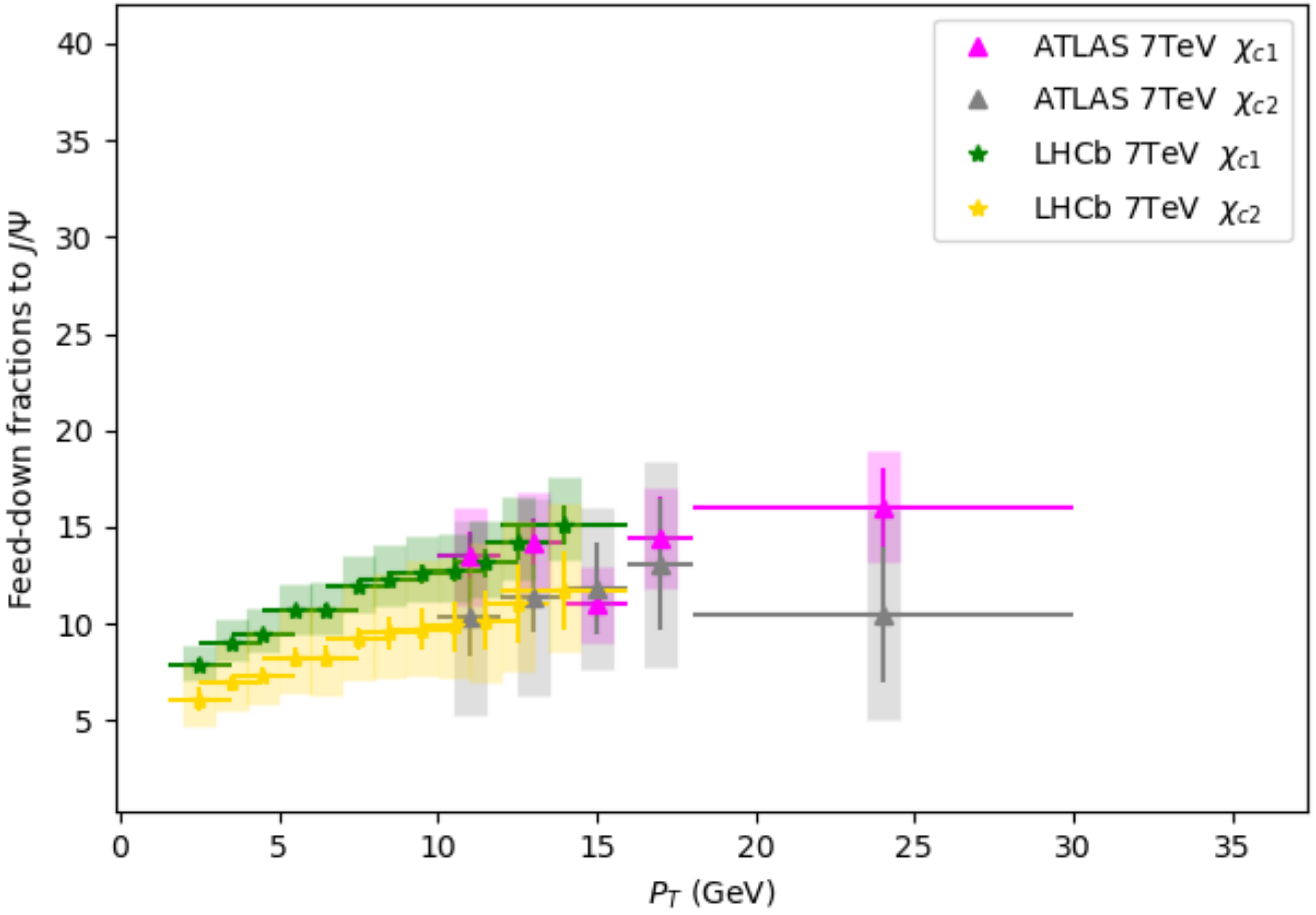




6. Feed-downs to prompt J/Ψ

Correcting the measurements to obtain the feed downs and putting everything together:



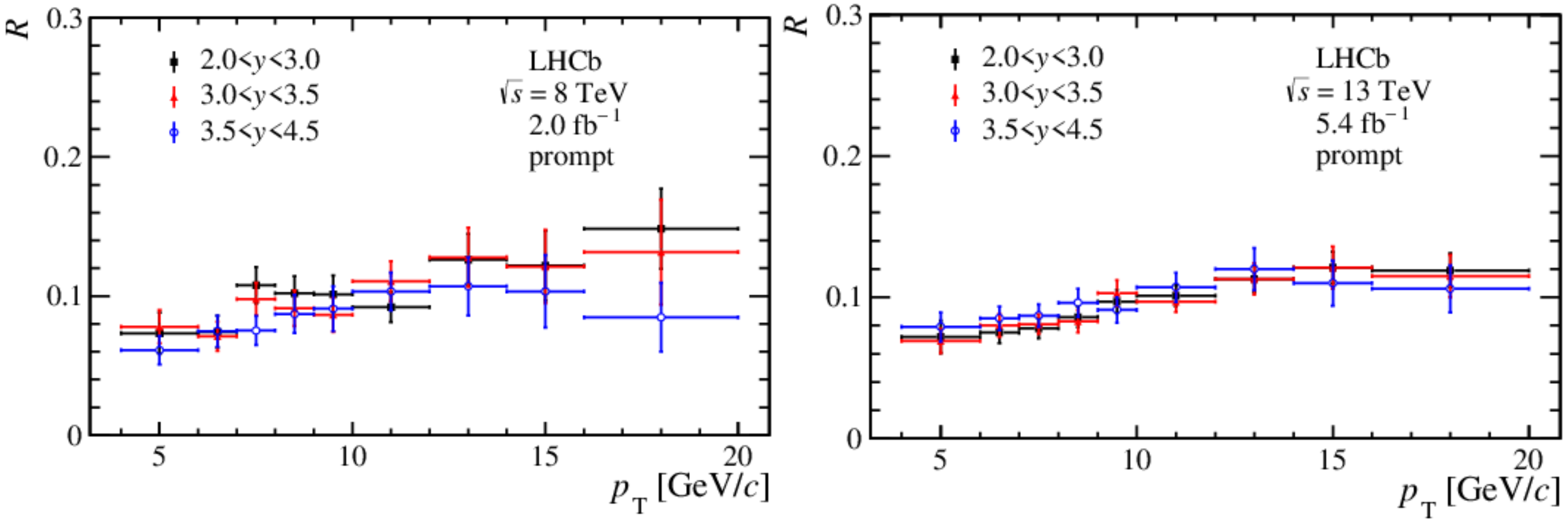


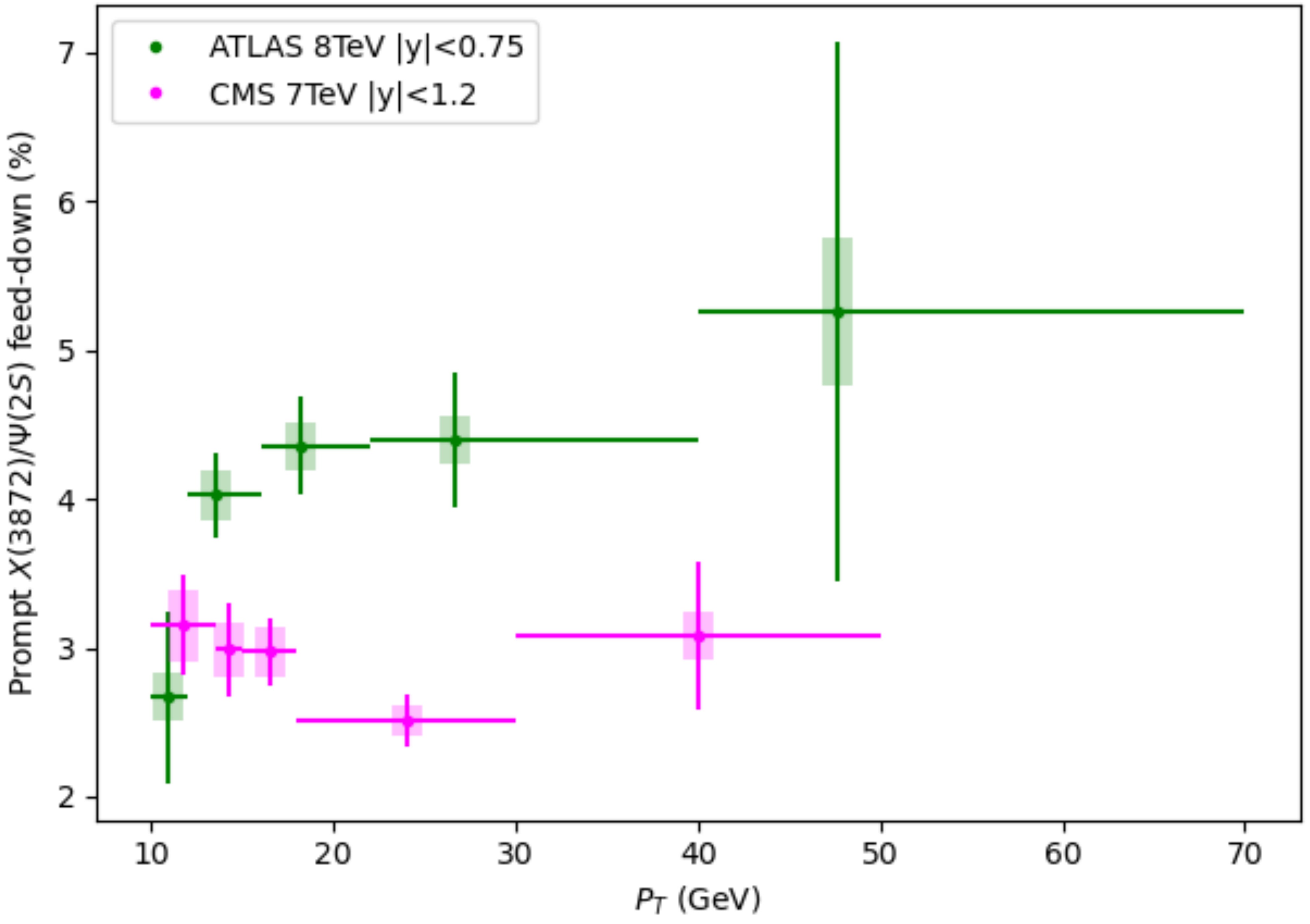
7. X(3872) to $\Psi(2S)$ feed-downs

Measurements

$$\mathcal{F}(X(3872)\to\Psi(2S)) = \boxed{\frac{\mathcal{B}(X(3872\to J/\Psi\pi^+\pi^-)\times\sigma(pp\to X(3872)+\text{anything})}{\mathcal{B}(\Psi(2S)\to J/\Psi\pi^+\pi^-)\times\sigma(pp\to\Psi(2S)+\text{anything})}}\times\frac{\mathcal{B}(\Psi(2S)\to J/\Psi\pi^+\pi^-)}{\mathcal{B}(X(3872\to J/\Psi\pi^+\pi^-)}\times\mathcal{B}(X(3872)\to\Psi(2S)+\gamma)$$

Caveat: CMS measurement is inclusive





Need LHCb results on hepData to extend the measurements at low pT

8. Conclusions

Our main objective is to derive the feed-down fractions in quarkonium production at LHC. In this preliminary study the main takeaways are:

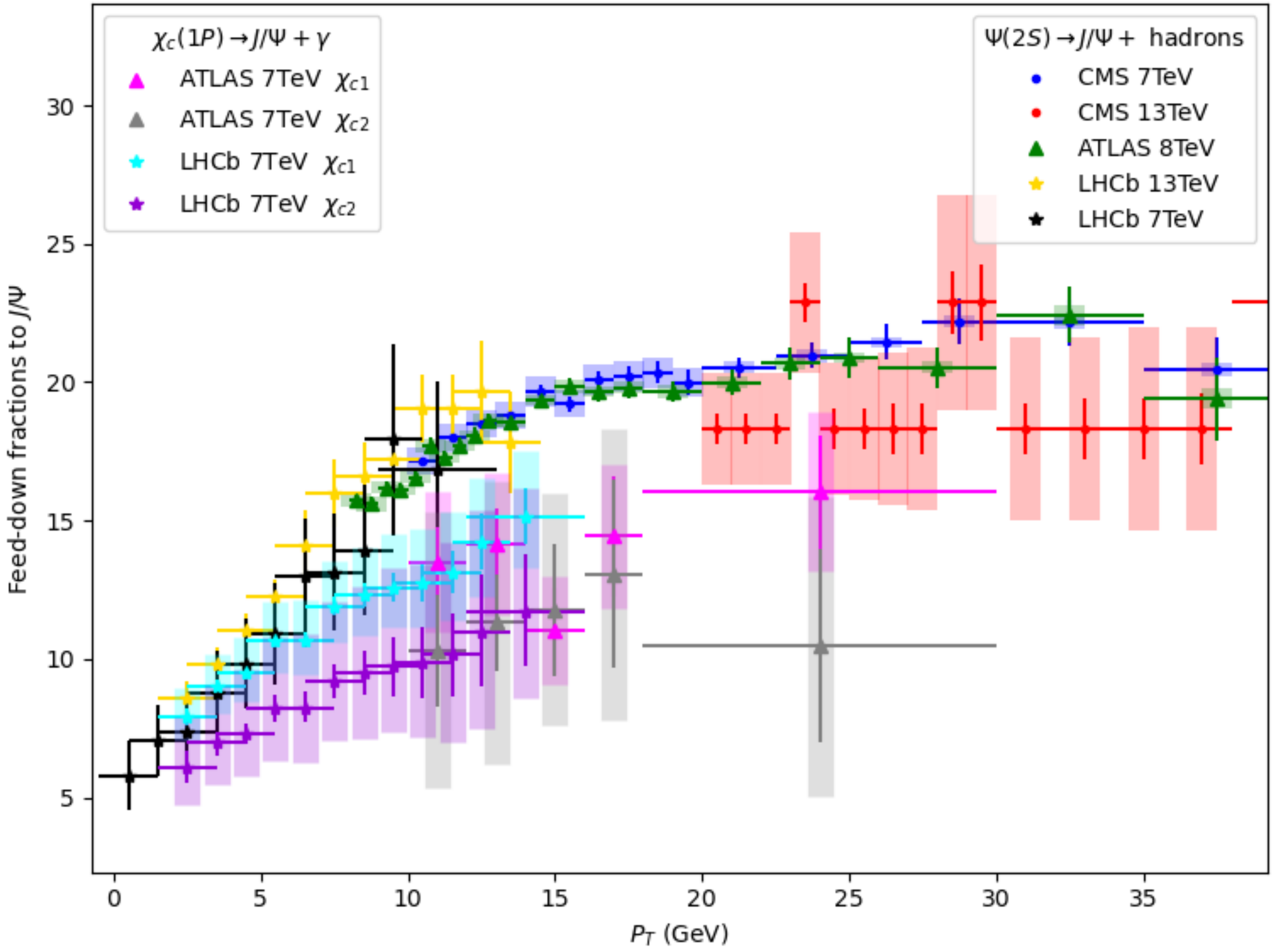
- Significant rapidity dependence for $\Psi(2S)/J/\Psi$, especially in ATLAS data.
- No significant energy dependence reported by LHCb. Not clear in ATLAS and CMS
- Good agreement in mid-pt range for the $\Psi(2S)$ to J/Ψ feed-down for the 3 experiments.
- Good agreement between LHCb and ATLAS for the χ_c feed-down with the multiplet considered as one or separated.

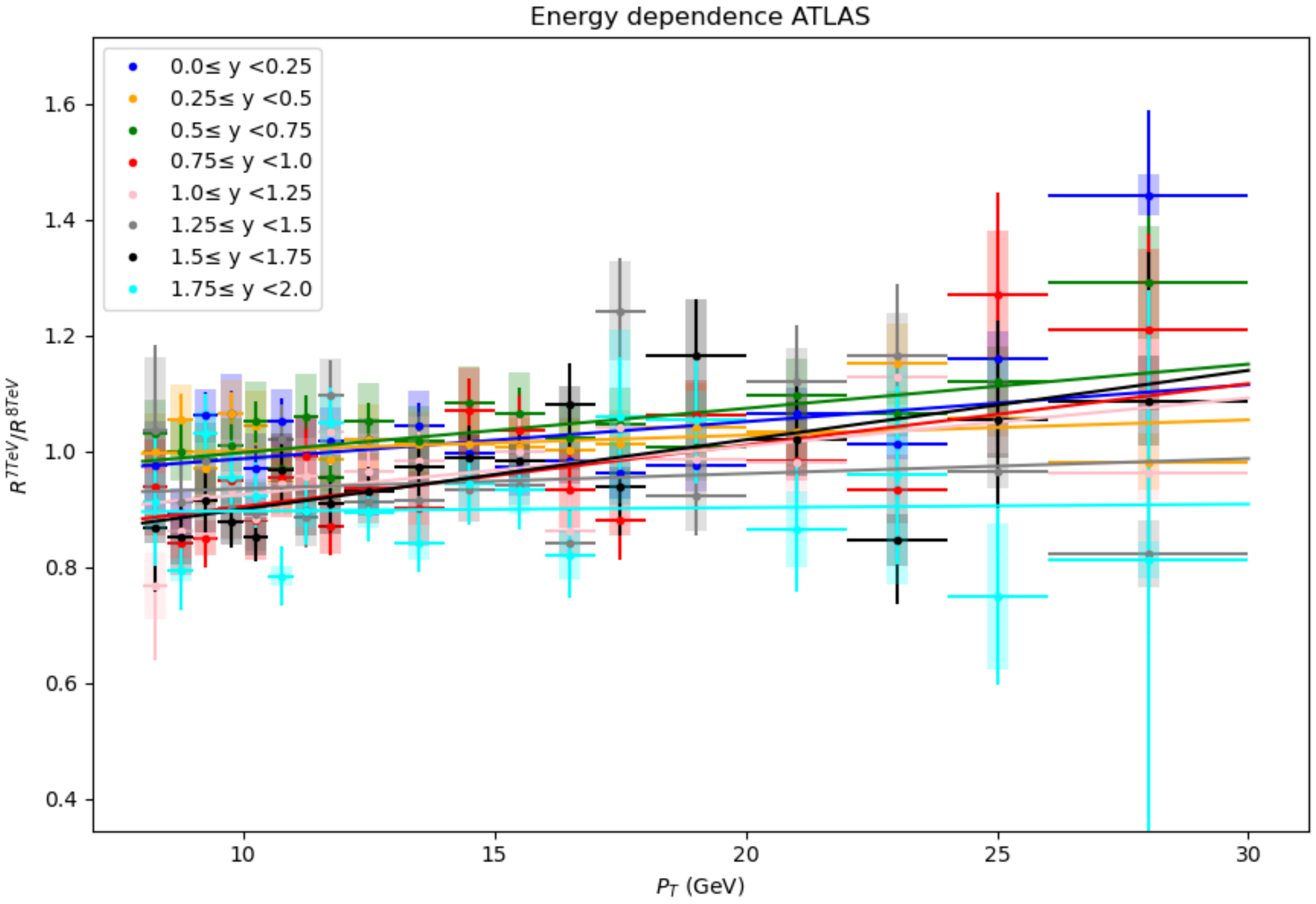
Next steps

- Obtain LHCb data to study low pt range
- Rapidity dependent study of the feed-downs (high, low and medium rapidity)
- Further study of the energy dependence in the different experiments.
- Comparison con theoretical predictions
- X(3872) to $\Psi(2S)$ feed-downs to be studied in more detail

Any suggestion is welcome 🤗

Backup


$\chi_c(1P) \to J/\Psi + \gamma$
ATLAS 7TeV χ_{c1}
ATLAS 7TeV χ_{c2}
LHCb 7TeV χ_{c1}
LHCb 7TeV χ_{c2}
$\Psi(2S) \to J/\Psi +$ hadrons
CMS 7TeV
CMS 13TeV
ATLAS 8TeV
LHCb 13TeV
LHCb 7TeV
Feed-down fractions to J/Ψ
P_T (GeV)
5
10
15
20
25
30
0
5
10
15
20
25
30
35


Energy dependence ATLAS
$0.0 \leq y < 0.25$
$0.25 \leq y < 0.5$
$0.5 \leq y < 0.75$
$0.75 \leq y < 1.0$
$1.0 \leq y < 1.25$
$1.25 \leq y < 1.5$
$1.5 \leq y < 1.75$
$1.75 \leq y < 2.0$
R^{7TeV}/R^{8TeV}
P_T (GeV)
0.4
0.6
0.8
1.0
1.2
1.4
1.6
10
15
20
25
30

Charmonium spectrum