בס"ד

Upsilon-Underlying Event Correlations in pp Collisions at ATLAS

Zvi Citron for ATLAS

QNP2022

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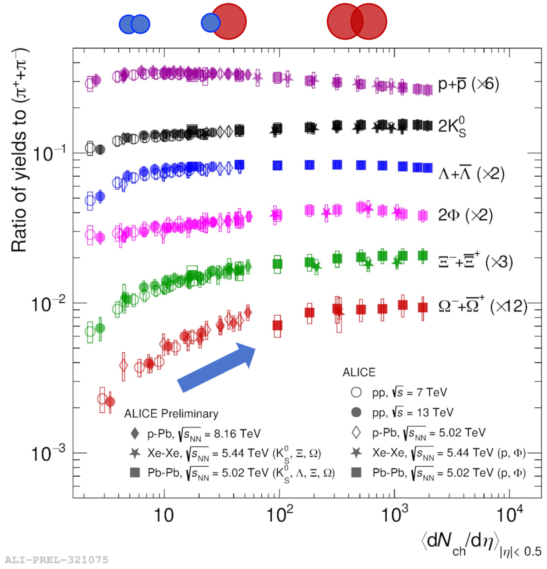
Big Picture: Why are we looking at ***Υ***-UE correlations

- Soft sector observables that were once (uniquely) associated with a QGP have been measured in pp collisions
  - Most prominently "flow" which persists to low multiplicity pp & even photo-nuclear interactions
  - Strangeness enhancement
- It's more difficult to tell this story with hard sector observables
- Here we look at **Upsilon meson correlations with inclusive charged particles** to try to bridge the soft-hard gap



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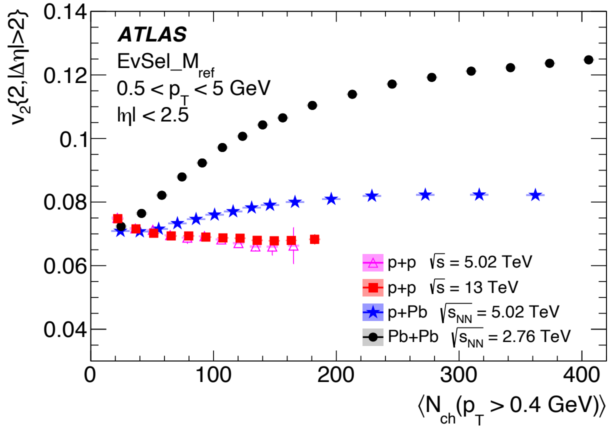
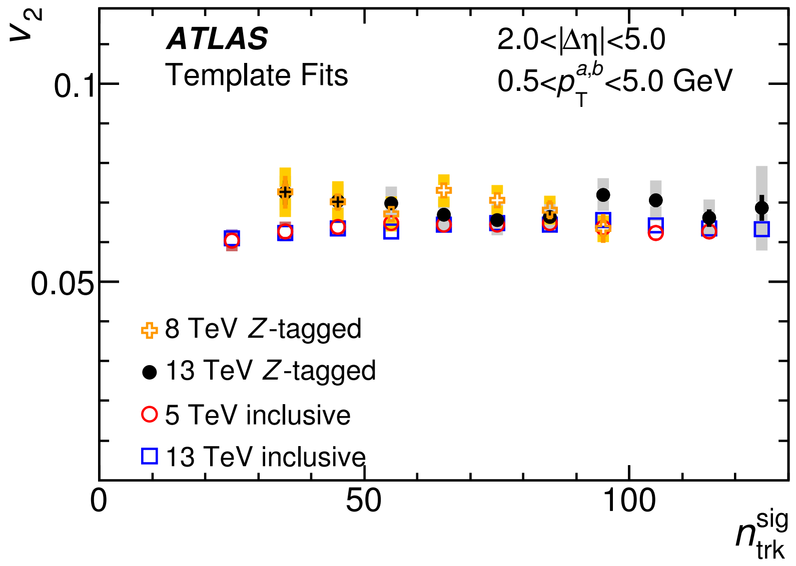


Eur. Phys. J. C 77 (2017) 428

A Previous Hard-Soft Study: Two-particle correlations in Z Boson Tagged pp Collisions

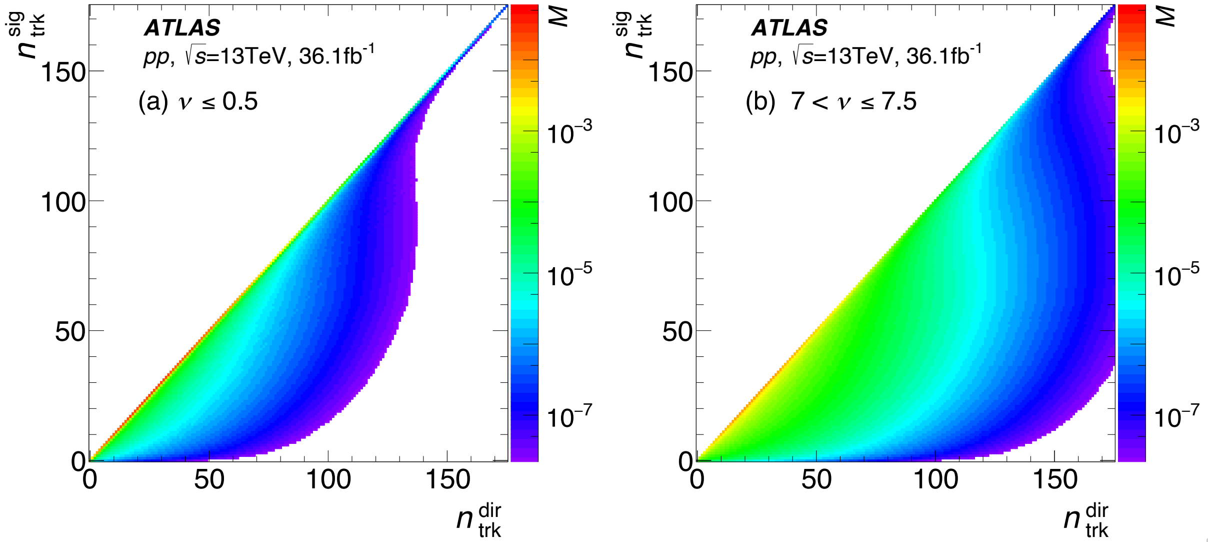
- In a previous study we asked: Does the presence of a hard scattering in the collision change "*something-like-geometry*" and consequently the observed "*flow*"?
- To answer we studied v_2 via 2-particle correlations in pp collisions 'tagged' by a Z boson
- The answer to above question is not really

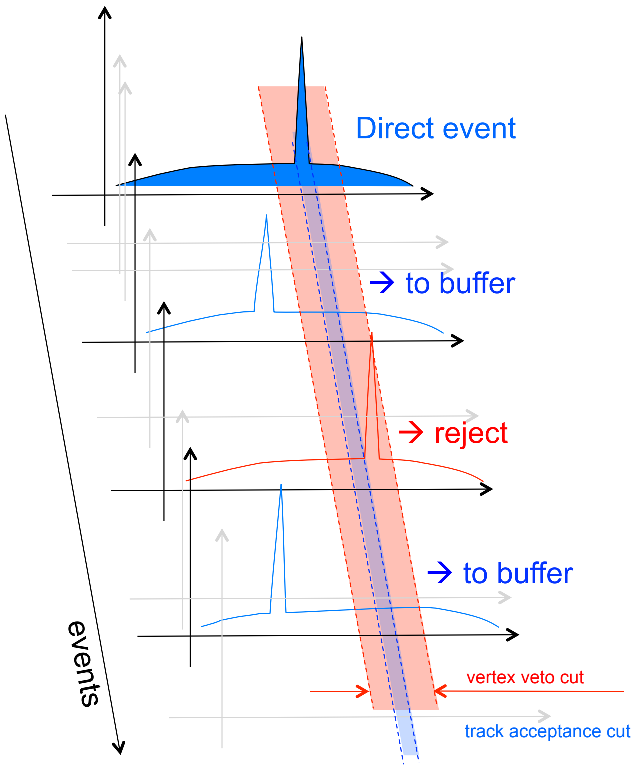
Eur. Phys. J. C **80,** 64 (2020)



A Previous Hard-Soft Study: Two-particle correlations in Z Boson Tagged pp Collisions

- Developed techniques for HI-style analysis in high-luminosity pp collisions
  - We learned how to look at all tracks in the event even with high pile-up conditions
  - Starting thinking about where else this could be used … **Upsilon mesons**!



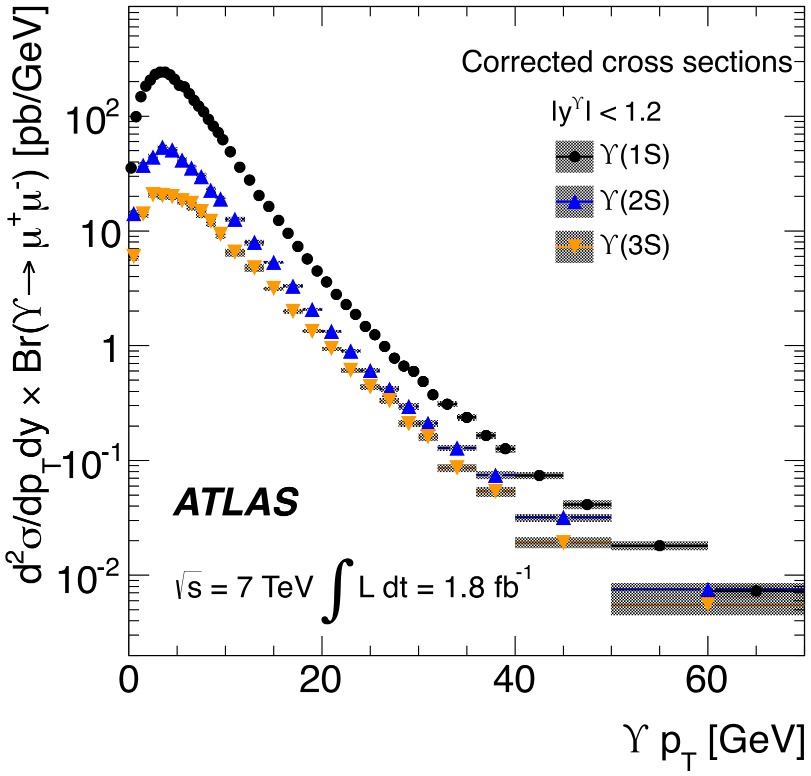


Eur. Phys. J. C **80,** 64 (2020)

What Do We Know about Upsilon Production at the LHC?

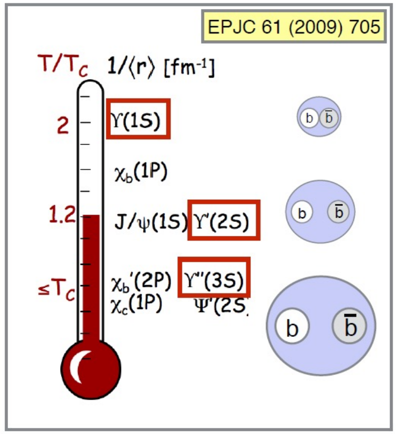
- Production cross-section seems well measured in pp collisions
- Some questions remain regarding polarization, importance of χ_b feed-down etc

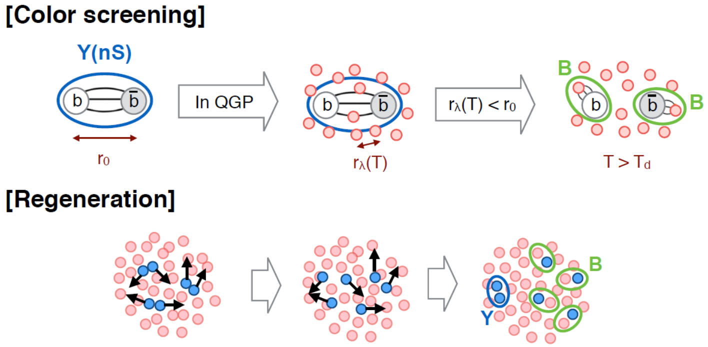
Phys.Rev.D 87 (2013) 5, 052004



What Do We Know about Upsilon Production *and collectivity* at the LHC?

- From a heavy-ion perspective Υ(nS) states could be a thermometer for a QGP





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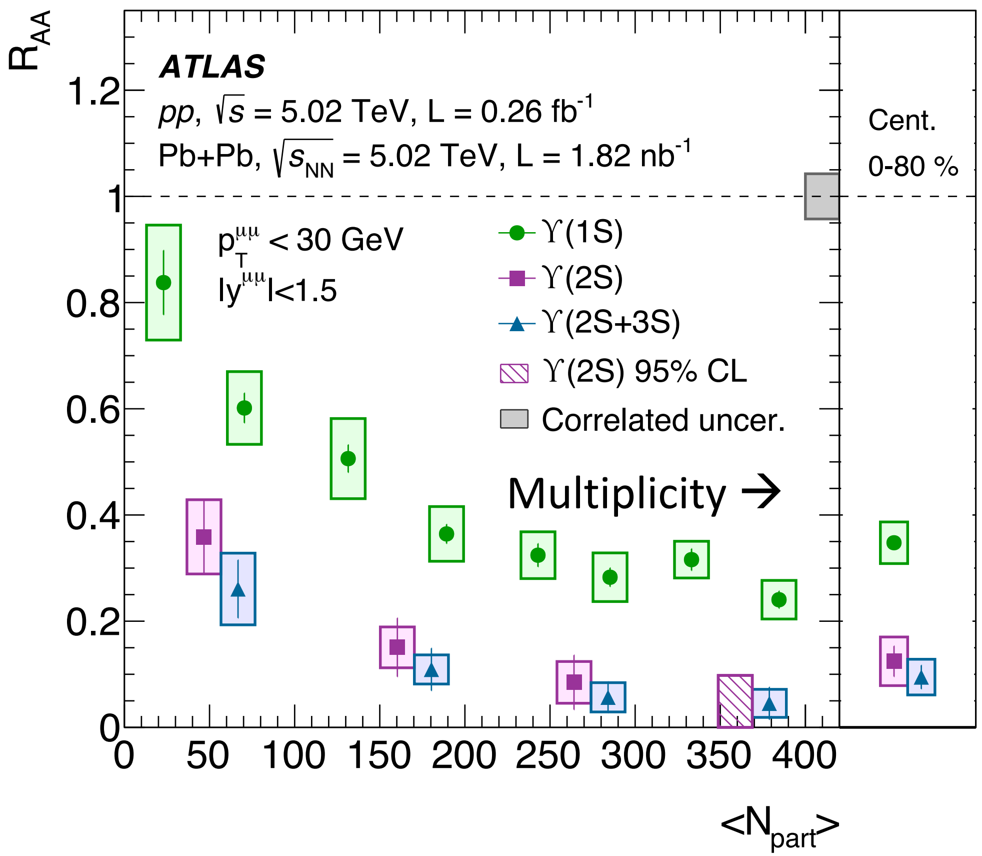
What Do We Know about Upsilon Production *and collectivity* at the LHC?

arXiv:2205.03042

- From a heavy-ion perspective Υ(nS) states could be a thermometer for a QGP
- We can measure the nuclear modification factor in heavy-ion collisions to compare AA to pp production



$$R_{AA} = \frac{N_{\Upsilon;AA}}{\langle T_{AA}\rangle \times \sigma^{pp\to\Upsilon}}$$

T_{AA} is the nuclear overlap function

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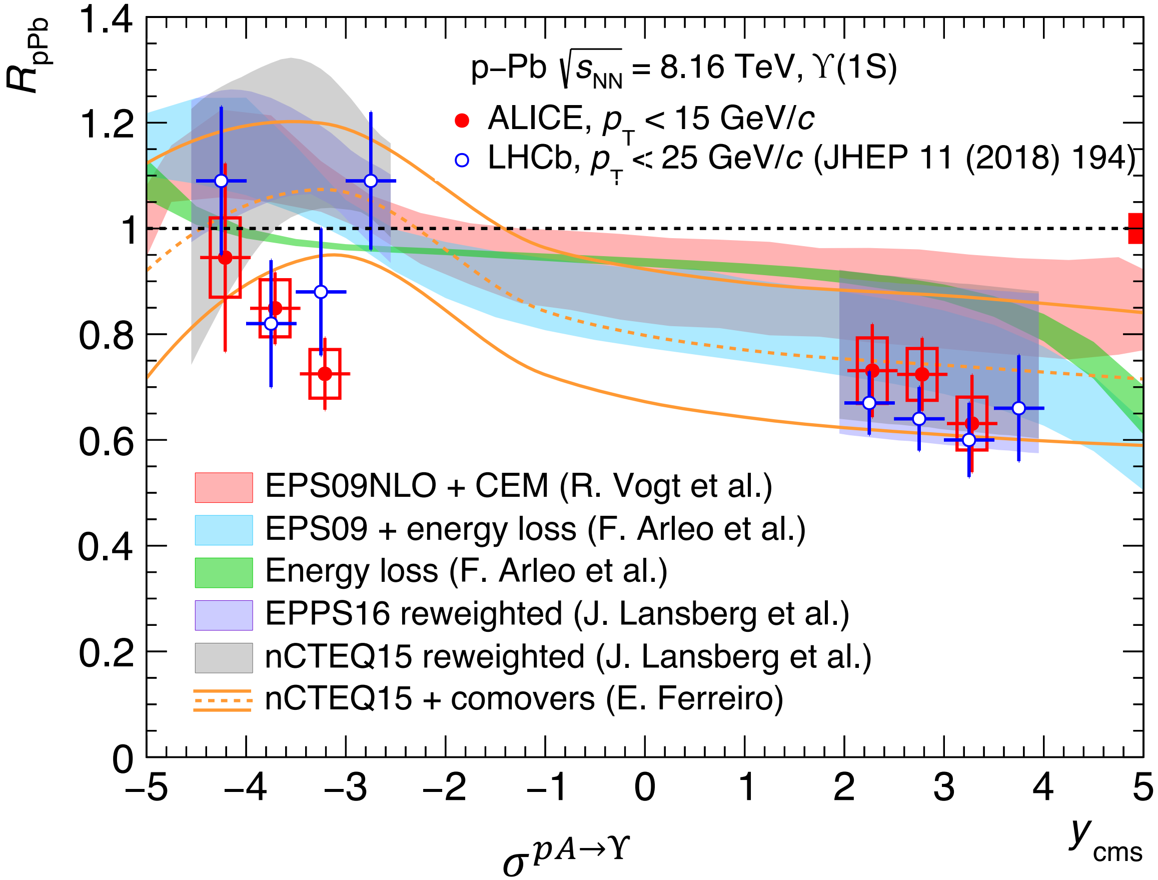
What Do We Know about Upsilon Production *and collectivity* at the LHC?

PLB 806 (2020) 135486

- From a heavy-ion perspective Υ(nS) states could be a thermometer for a QGP
- We can measure the nuclear modification factor in heavy-ion collisions to compare AA to pp production
  - pA could give us some sense of the influence of “cold nuclear effects”



$$R_{pA} = \frac{\sigma^{pA\to\Upsilon}}{A\times\sigma^{pp\to\Upsilon}}$$

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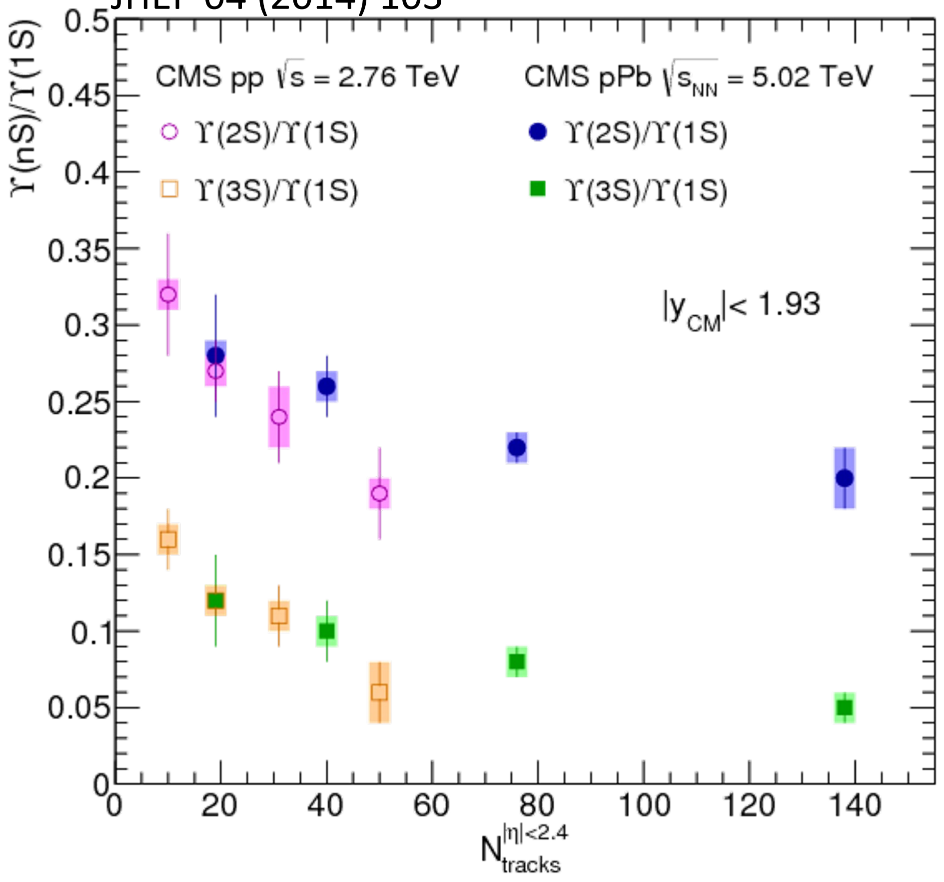
CMS Measurement of Y(nS) and pp Multiplicity

- CMS results all the way back in 2014 challenge this picture by showing a decrease in excited Y states compared to the ground state vs pp multiplicity

JHEP 04 (2014) 103



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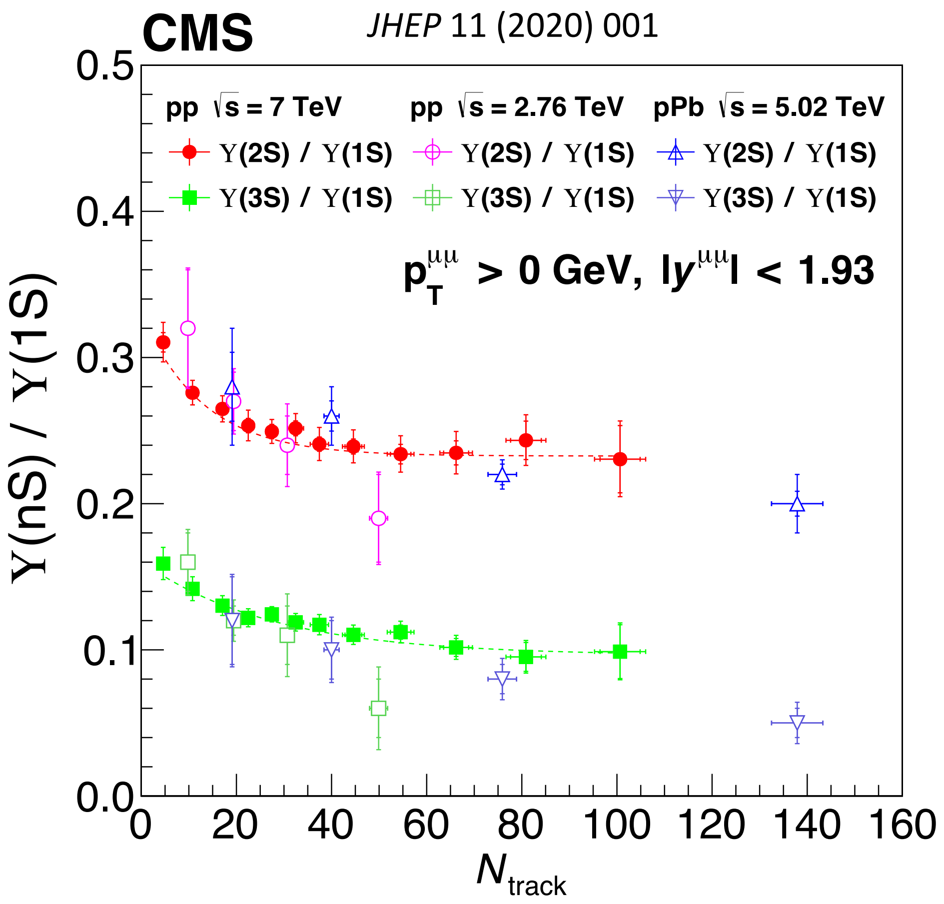
- More detailed measurements in 2020



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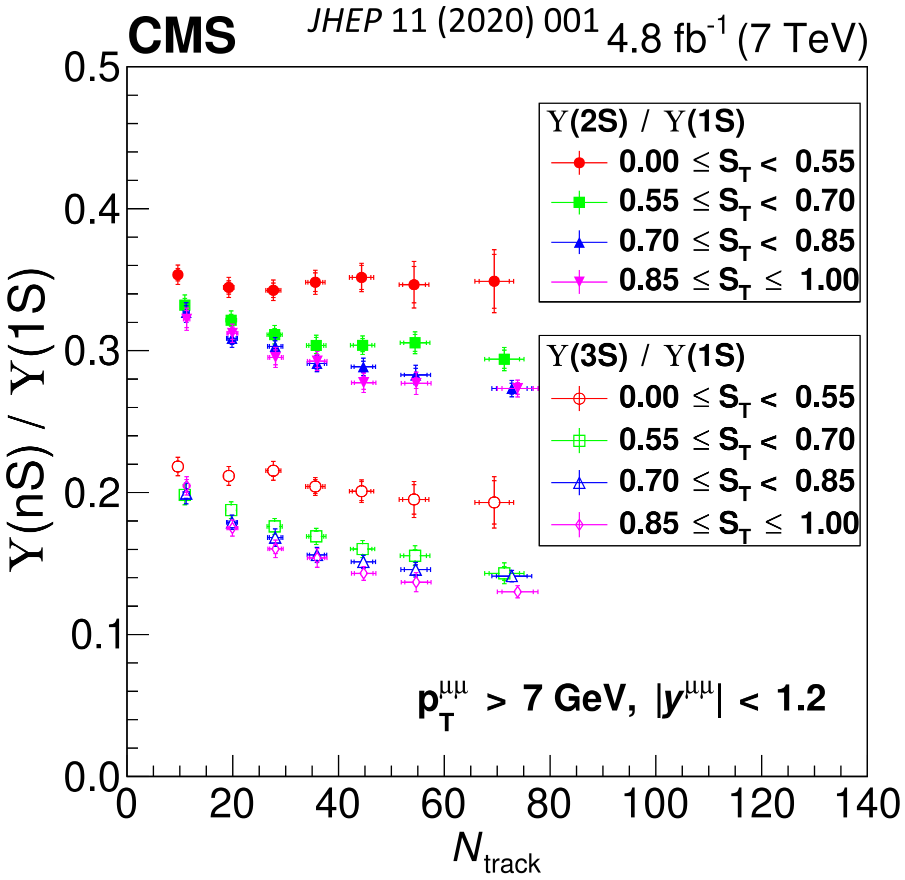
CMS Measurement of Υ(nS) and pp Multiplicity

$$S^{T}_{xy} = \frac{1}{\sum_i p_{\mathrm{T}i}} \sum_i \frac{1}{p_{\mathrm{T}i}} \begin{pmatrix} p_{xi}^2 & p_{xi}p_{yi} \\ p_{xi}p_{yi} & p_{yi}^2 \end{pmatrix}$$

- CMS results all the way back in 2014 challenge this picture by showing a decrease in excited Υ states compared to the ground state vs pp multiplicity
- More detailed measurements in 2020
  - Including analysis of event geometry via spherocity, which suggests effect **is connected with UE not jets**

$S_T = 0$ → jet-like

$S_T = 1$ → not jet-like



ATLAS Measurement of Υ(nS) and UE

ATLAS-CONF-2022-023

- Measure the total multiplicity in the event (and particle kinematics) for each Upsilon state
- Precise control of background and pile-up
- Use differential particle kinematics to reach for the UE
- Compare excited to ground states

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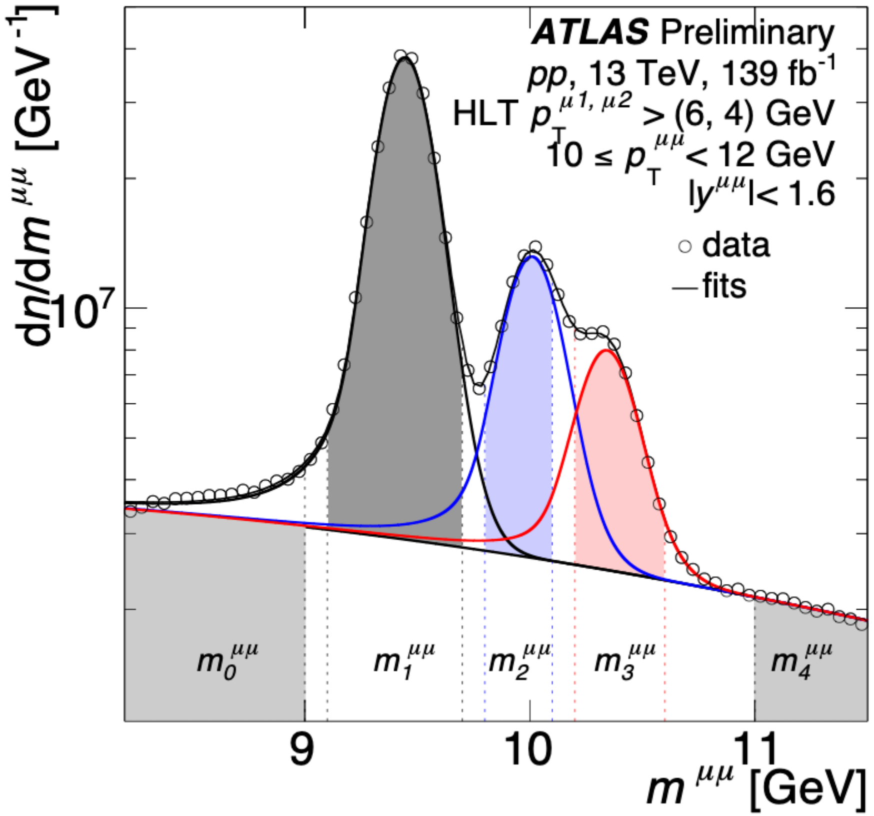

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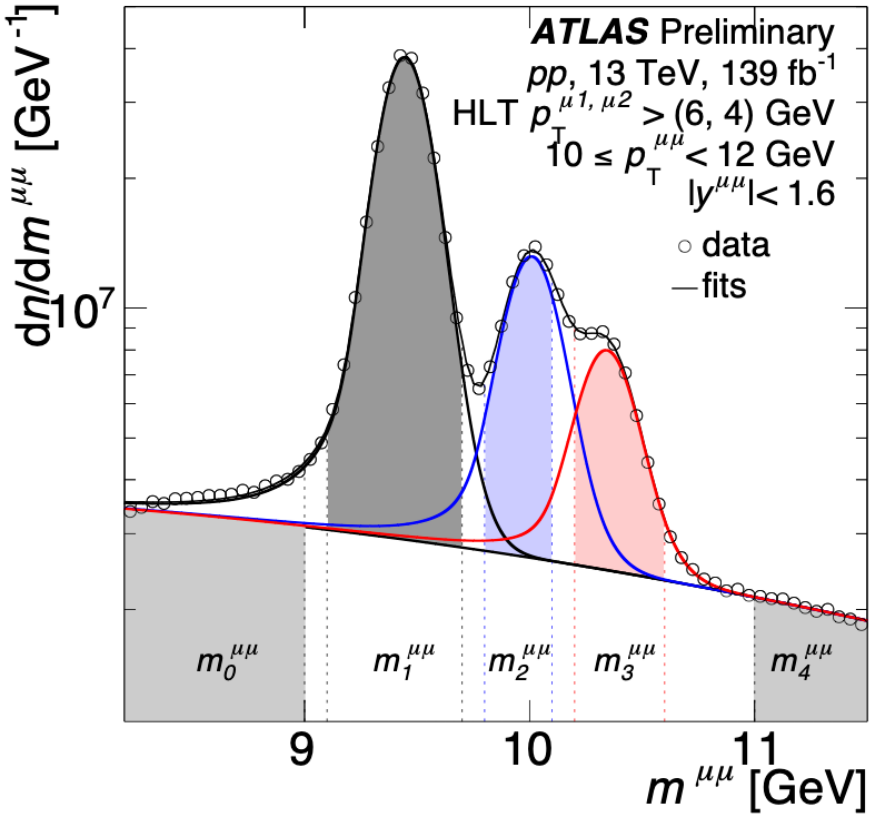

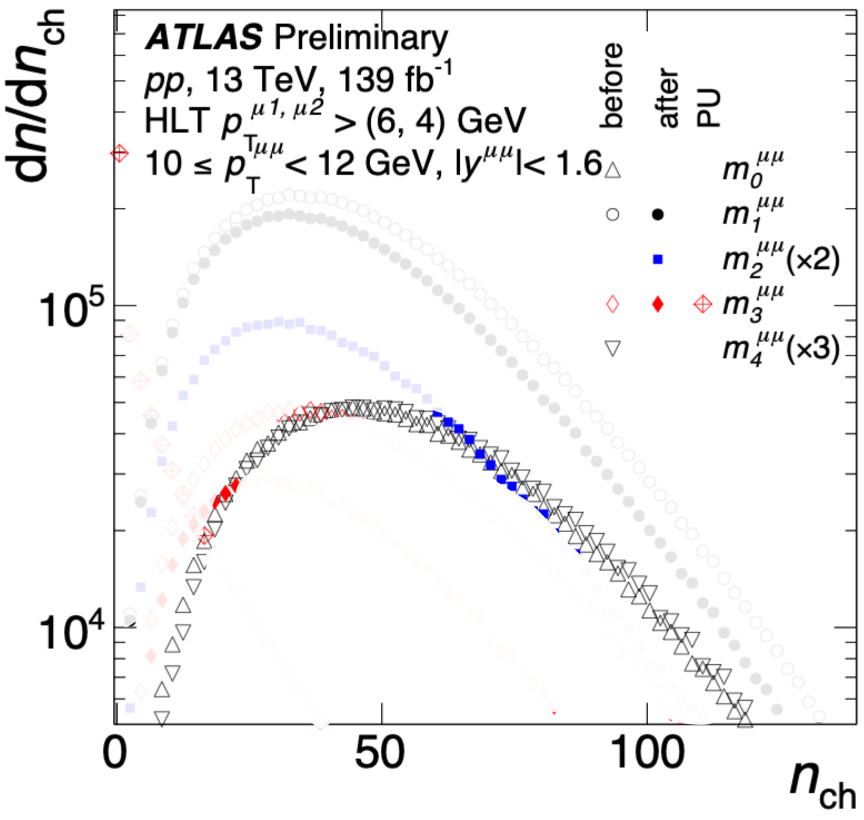

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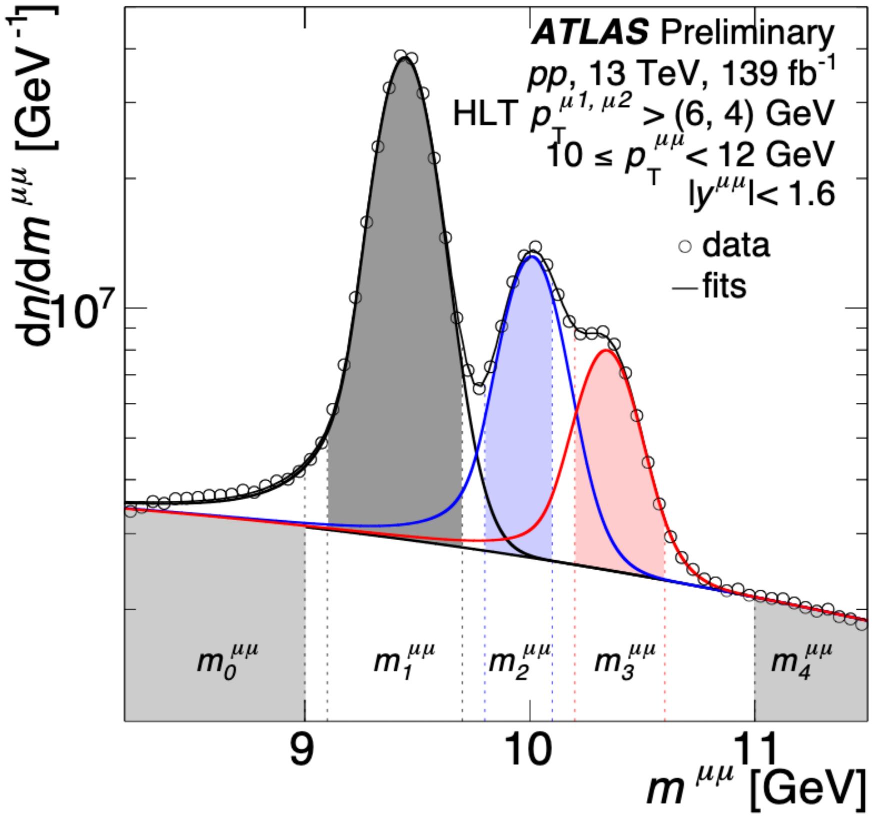

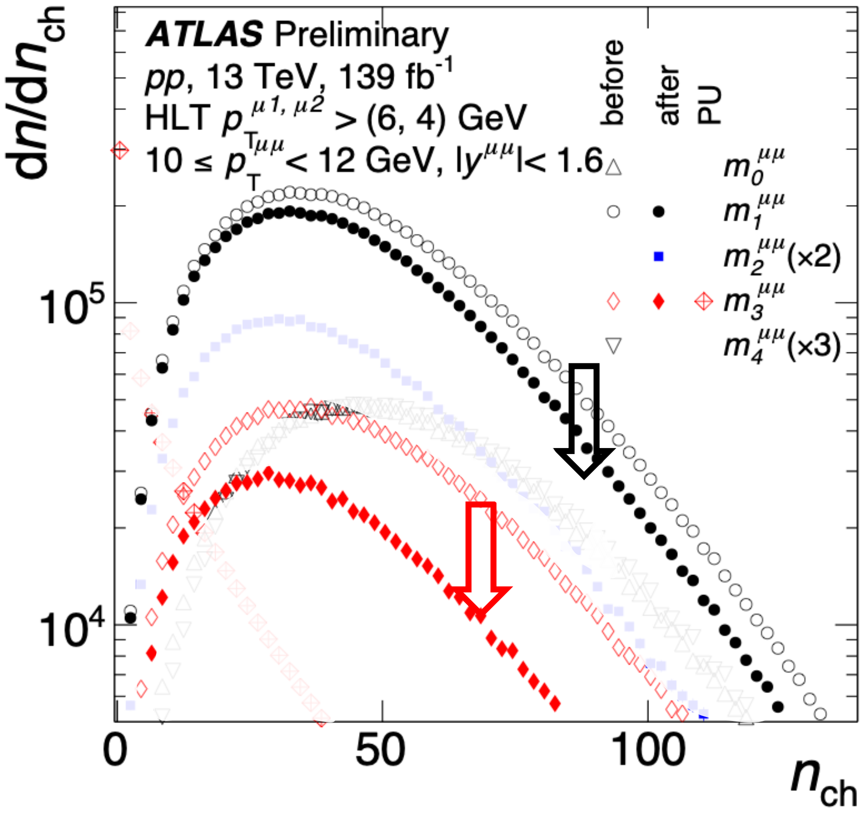

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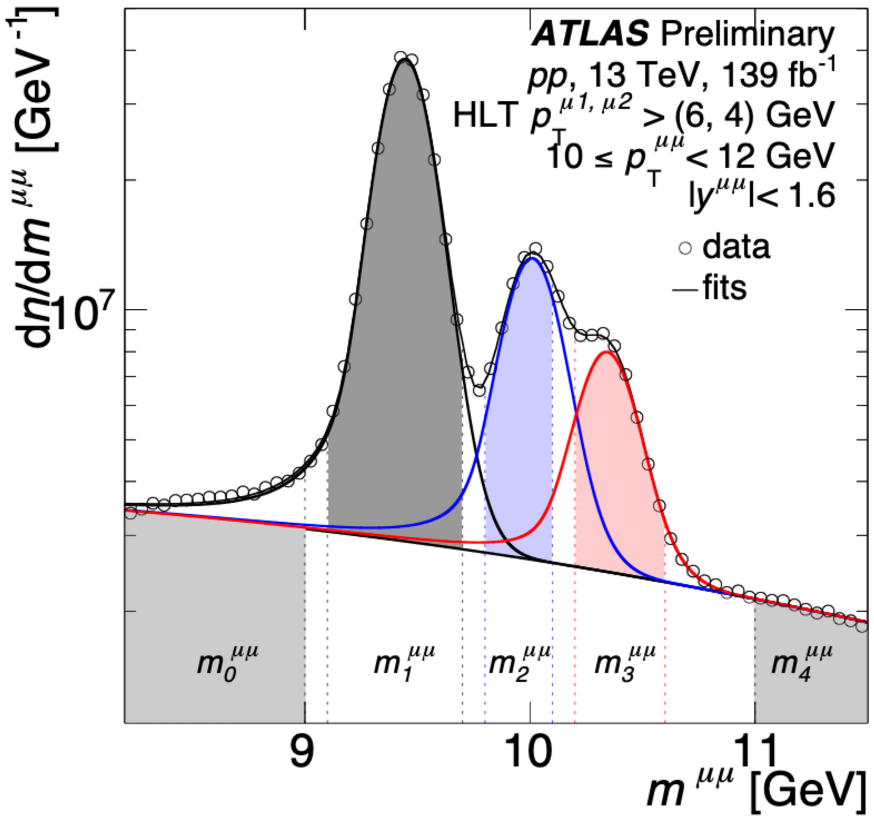

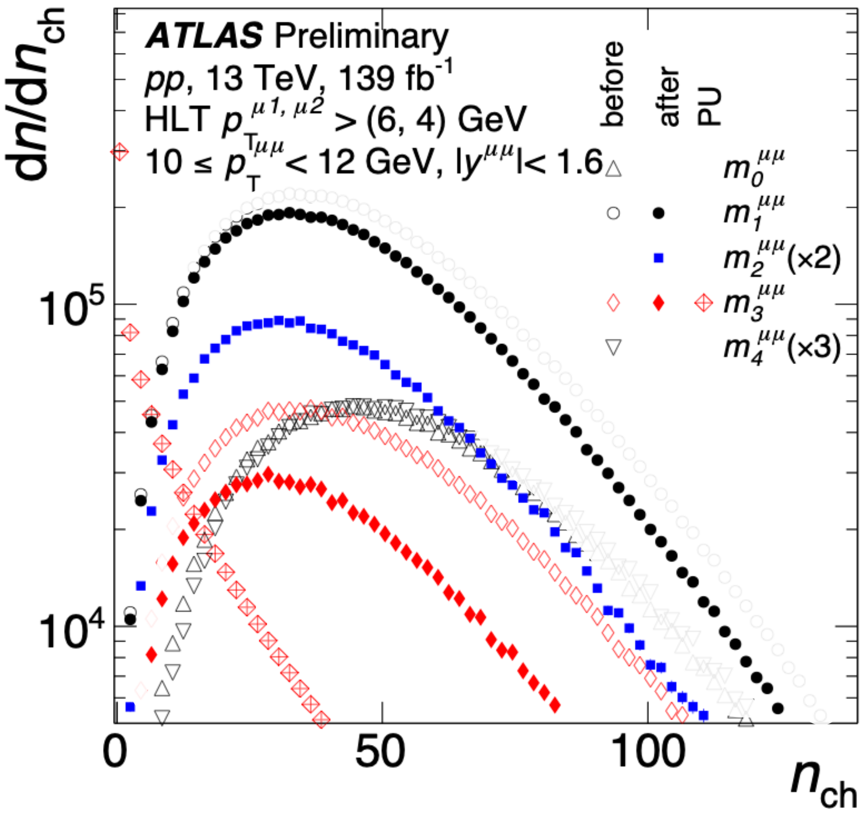

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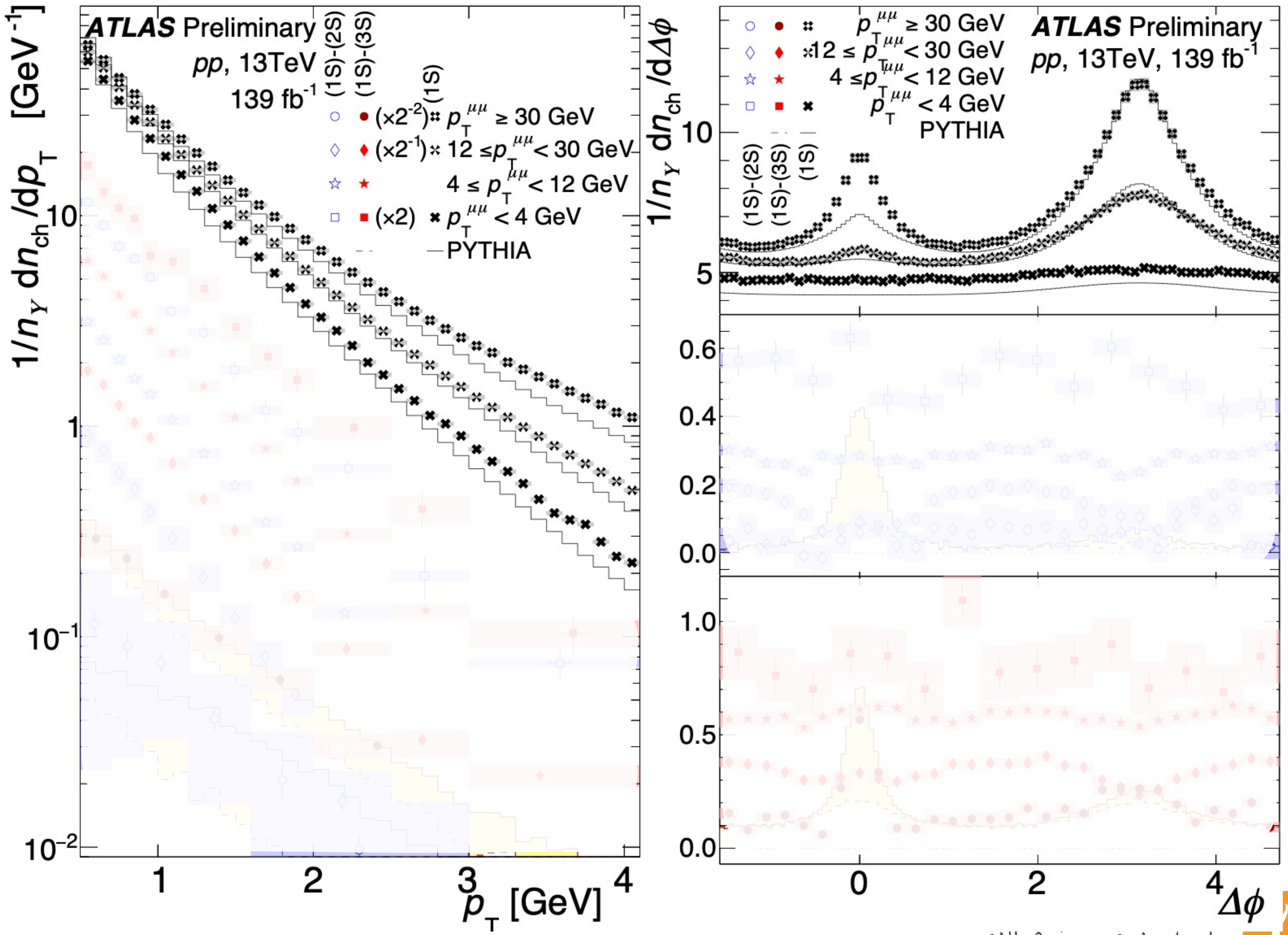

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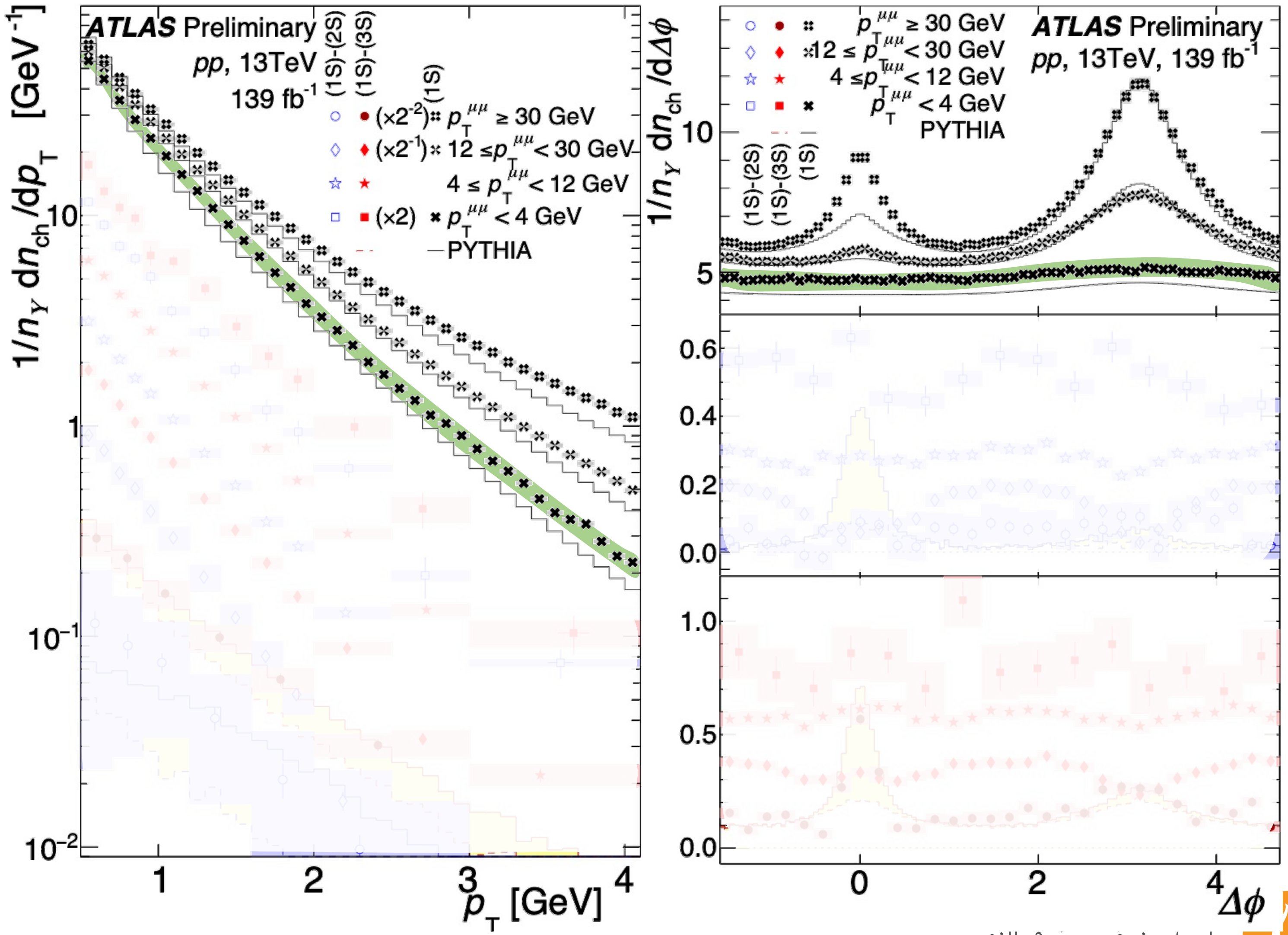

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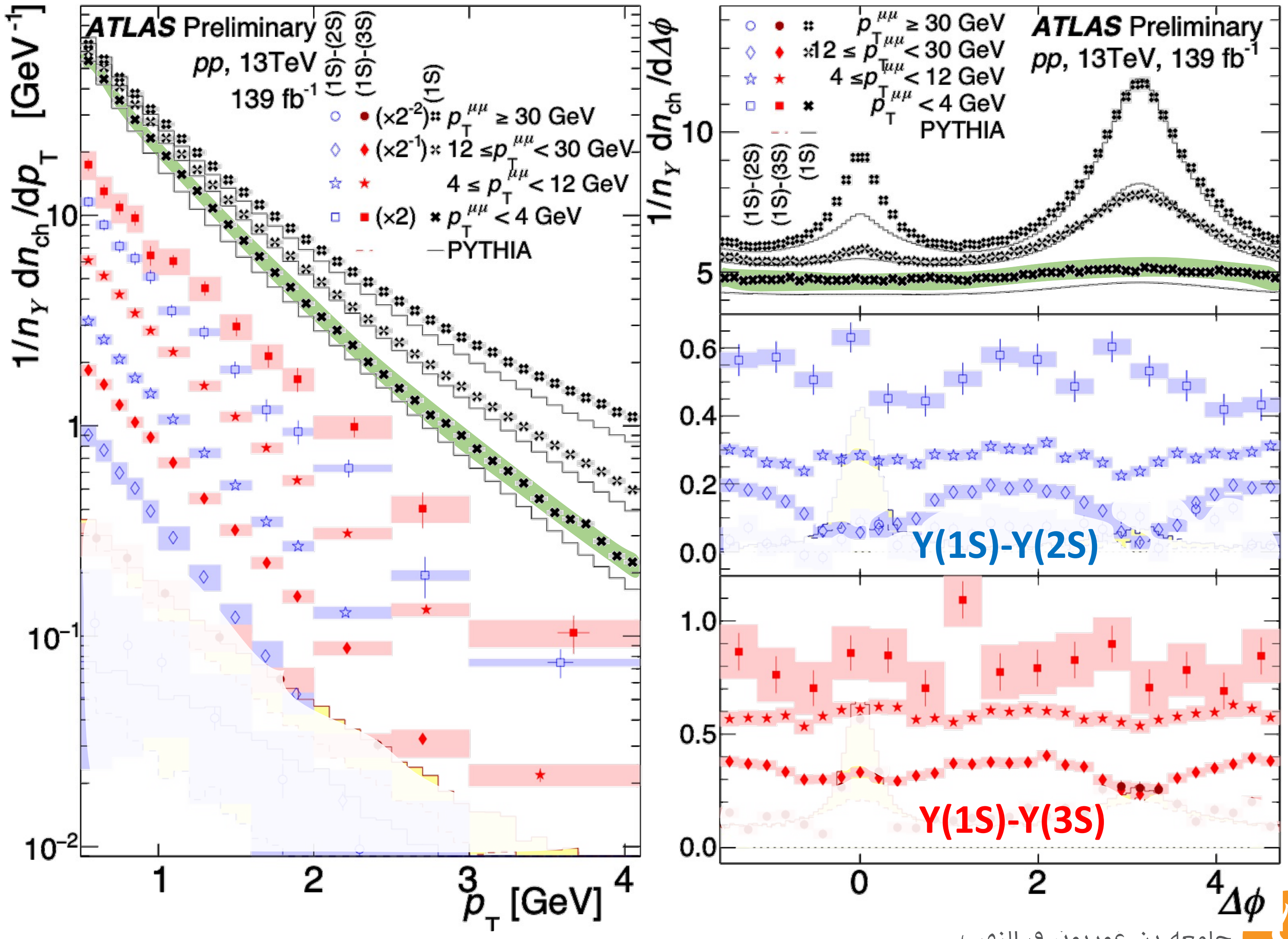

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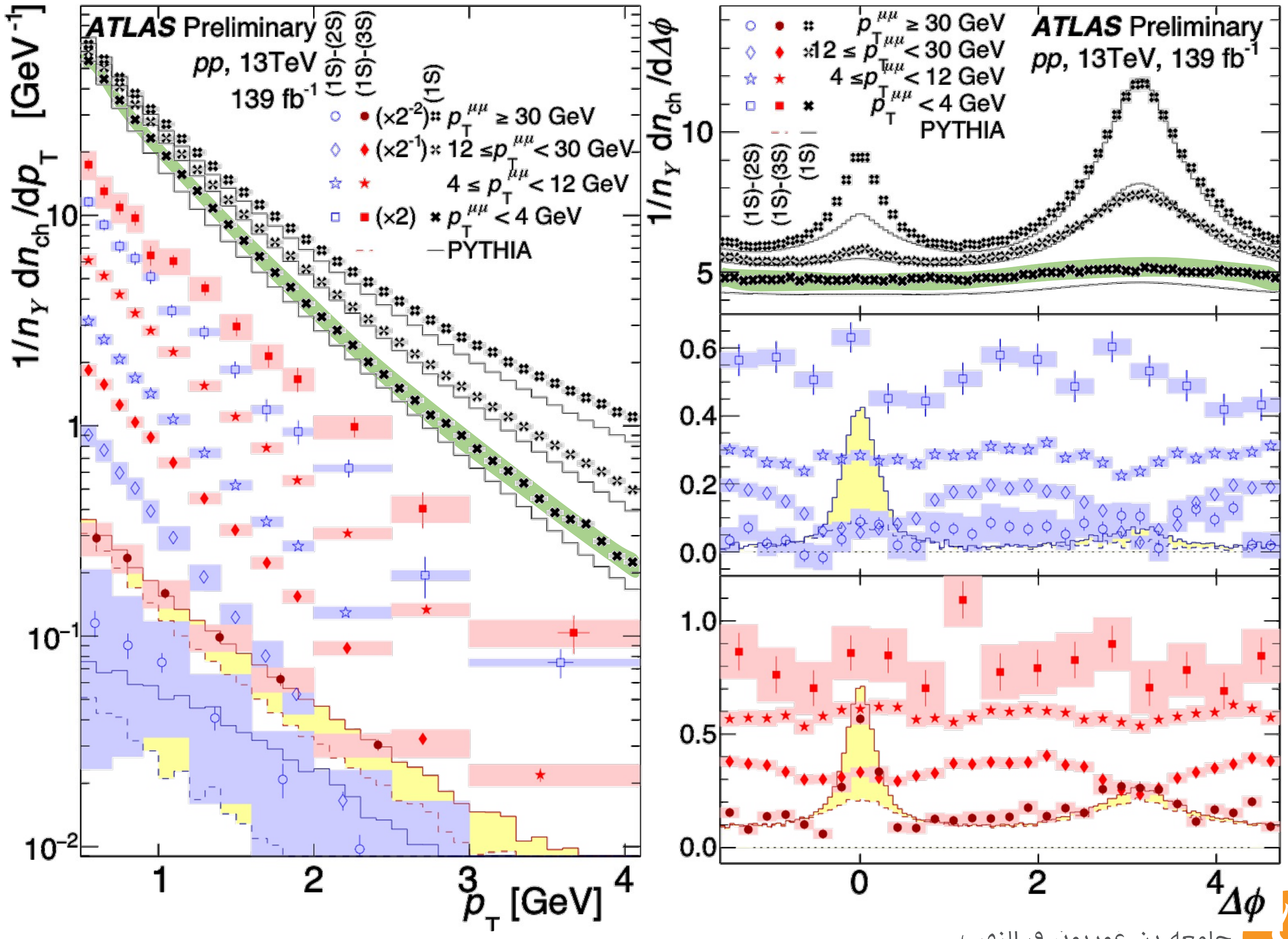

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ATLAS Measurement of Y(nS) and UE

[ATLAS-CONF-2022-023]

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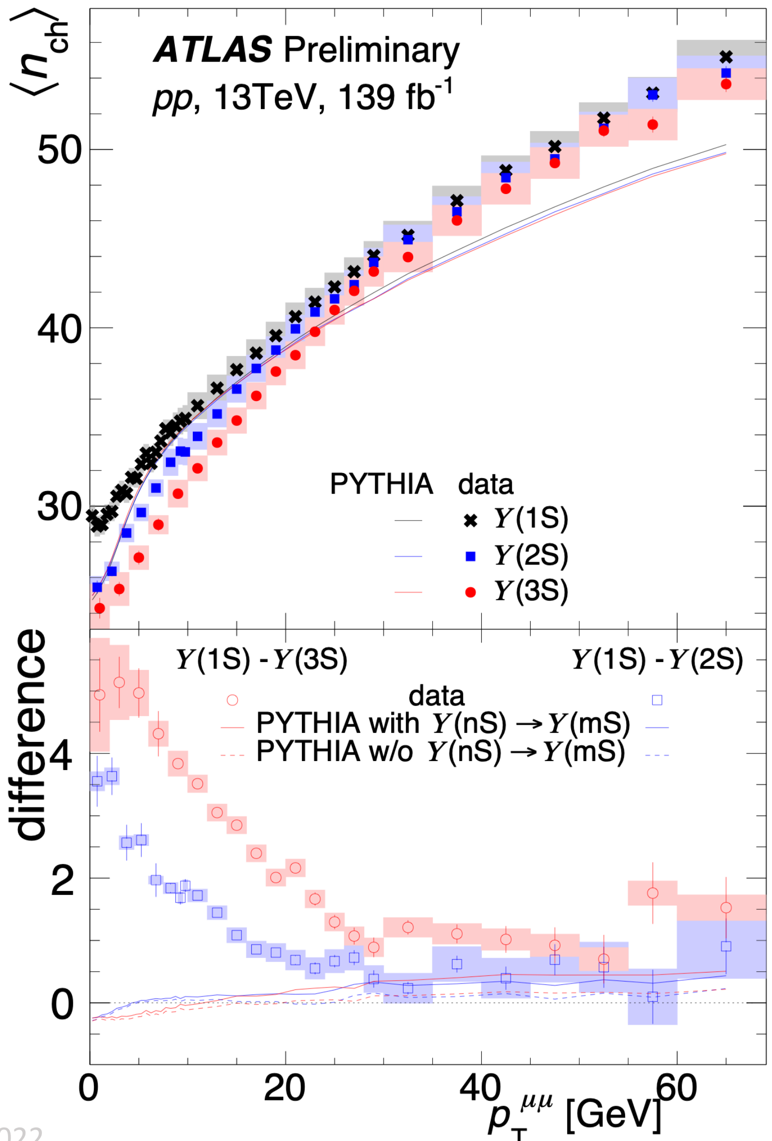

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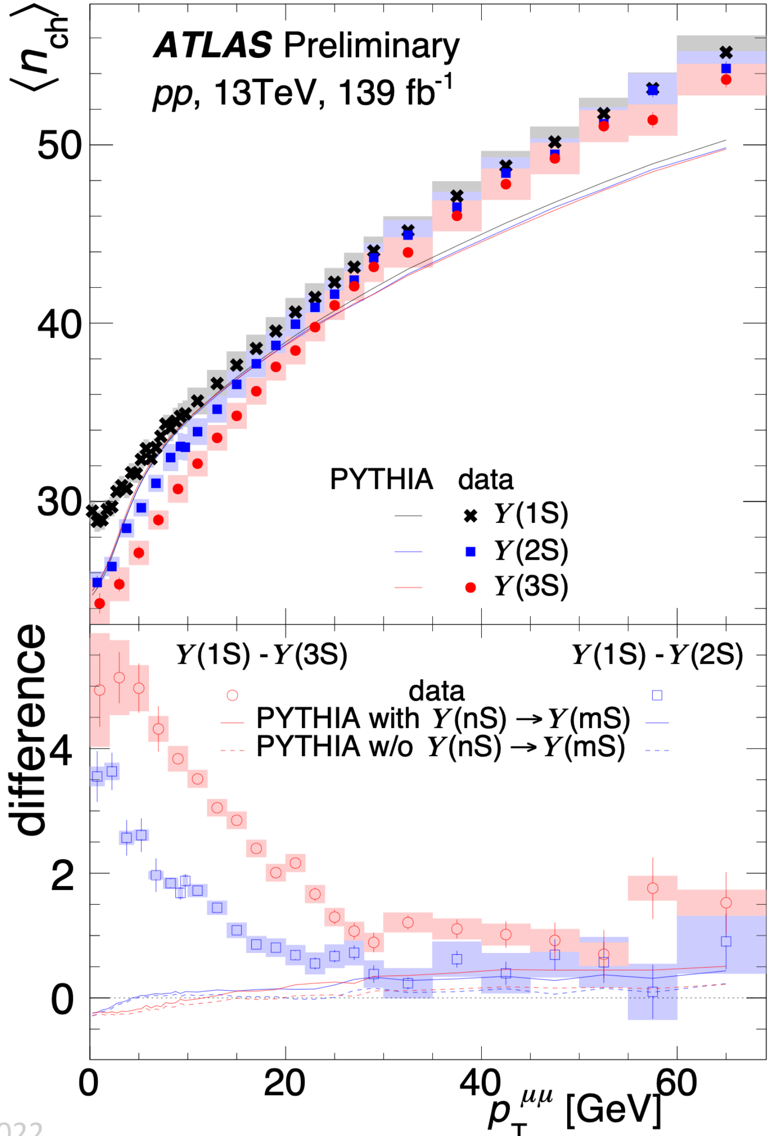
- Shift in UE multiplicity across different excitation states can be understood as suppression of excited states at higher multiplicity



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Is there Υ(nS) Suppression in pp Collisions?

- As event multiplicity (should be UE) grows larger, excited Υ states are, compared to the ground state, relatively less likely to be found
- Do the CMS and ATLAS results show some "QGP-like" quarkonium "melting"?
- Is it even a suppression? Maybe it's a lower state enhancement?
  →**In any case seems to be a hard – UE correlated phenomenon**

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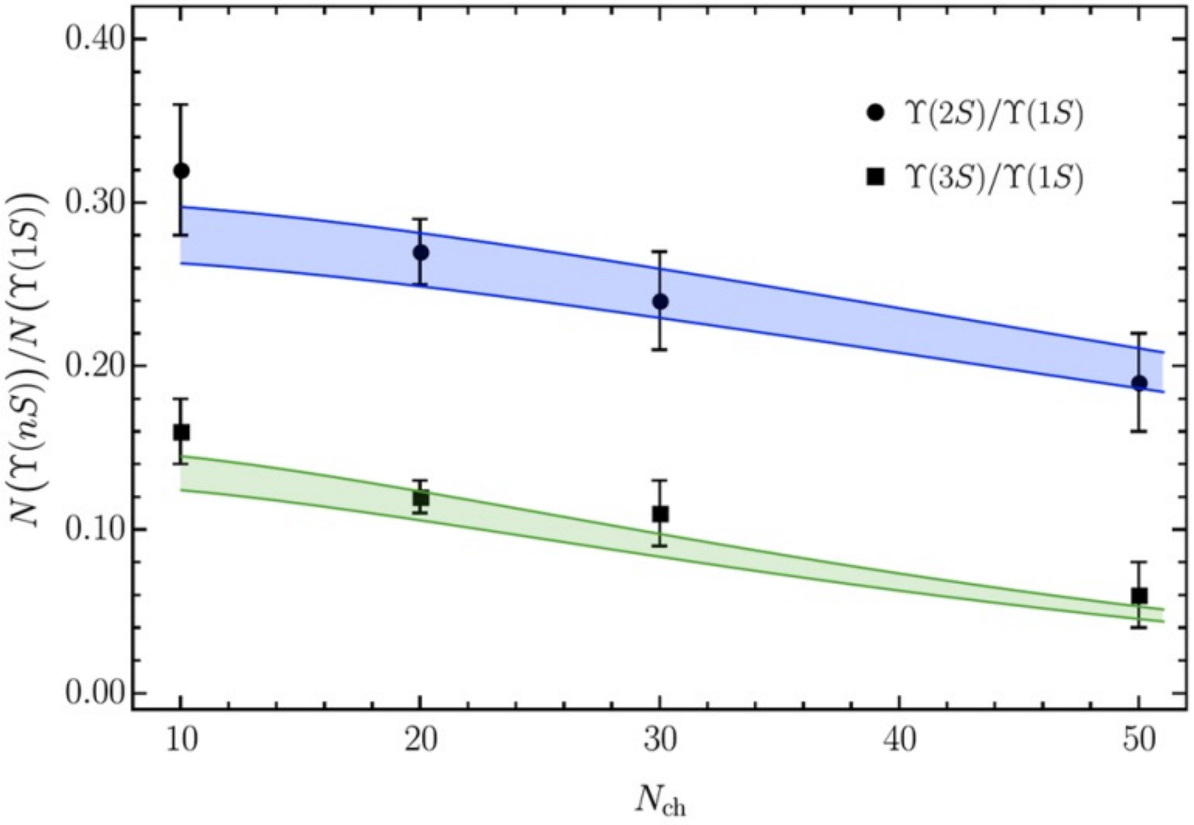
Co-mover Interaction Model (CIM)

EPJC 81, 669 (2021)

- Within CIM, quarkonia are broken by collisions with comovers – i.e. final state particles with similar rapidities.

- CIM is typically used to explain *p*+A and A+A systems, matches CMS Upsilon pp data.

- With the new data, CIM can be tested on *pp* to reproduce $\Upsilon(nS) - \Upsilon(1S)$ differences
  - in cross section
  - in n_{ch}
  - in hadron kinematic distributions: p_T, $\Delta\varphi$ $\Delta\eta$



Quarkonia Ratios Expected From m_T Scaling

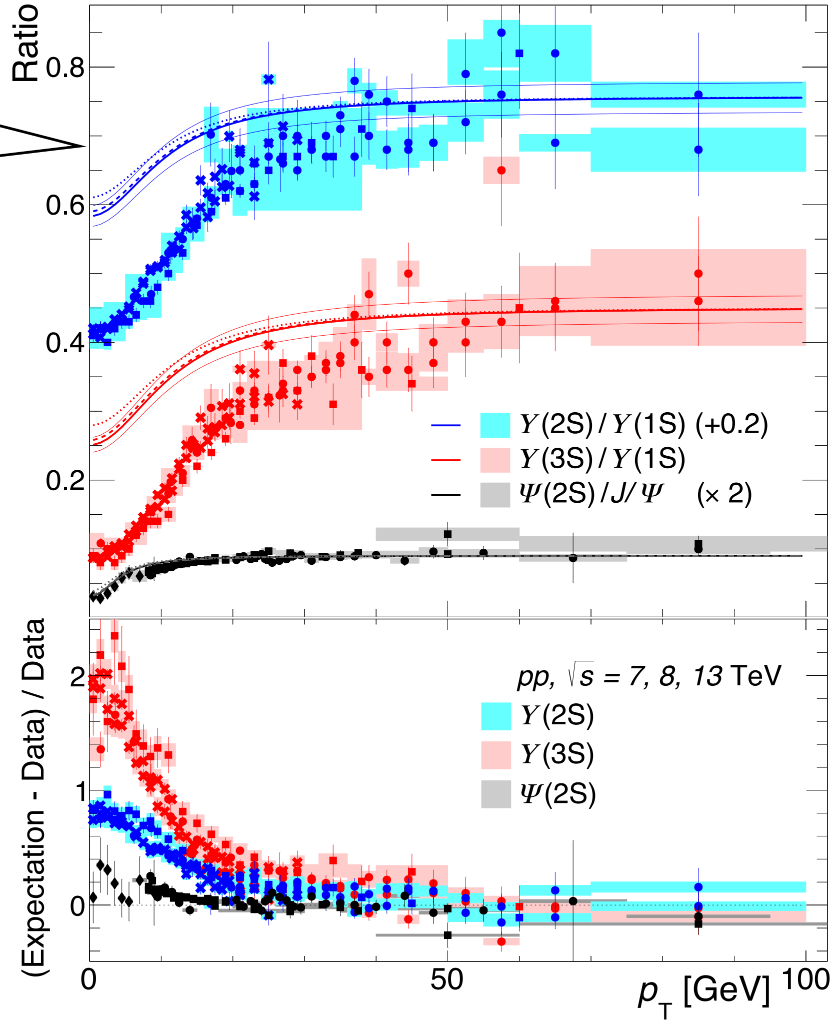
arXiv:2203.11831

- Transverse mass scaling lets one define an expectation for the excited states relative to the ground states

- Works well ~universally for light mesons at LHC energies

- Looking at Upsilon meson cross-sections shows missing excited states at low p_T
  for $\Upsilon(2S)$ factor of 1.6 are missing
  for $\Upsilon(3S)$ factor of 2.4!

$$1 - \frac{n\Delta m}{nT + m_{q\bar{q}}}$$



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Summary

- Strong evidence from Upsilon mesons that there is some non-trivial interaction between the “UE” and a hard scattering
- ATLAS & CMS have independent approaches that both point to UE driven modification of relative abundance of ground state vs excited state Upsilon mesons
  - Modification appearst to be a suppression of excited states
- ***Seems we don’t understand Upsilon hadronization as it depends on the UE***
- More investigations can be made in the data
  - Check rapidity dependence
  - Check other species etc
- Effect is large and significant
  - Can existing models see this effect?
  - New ideas?