Underlying Event Tuning for VINCIA

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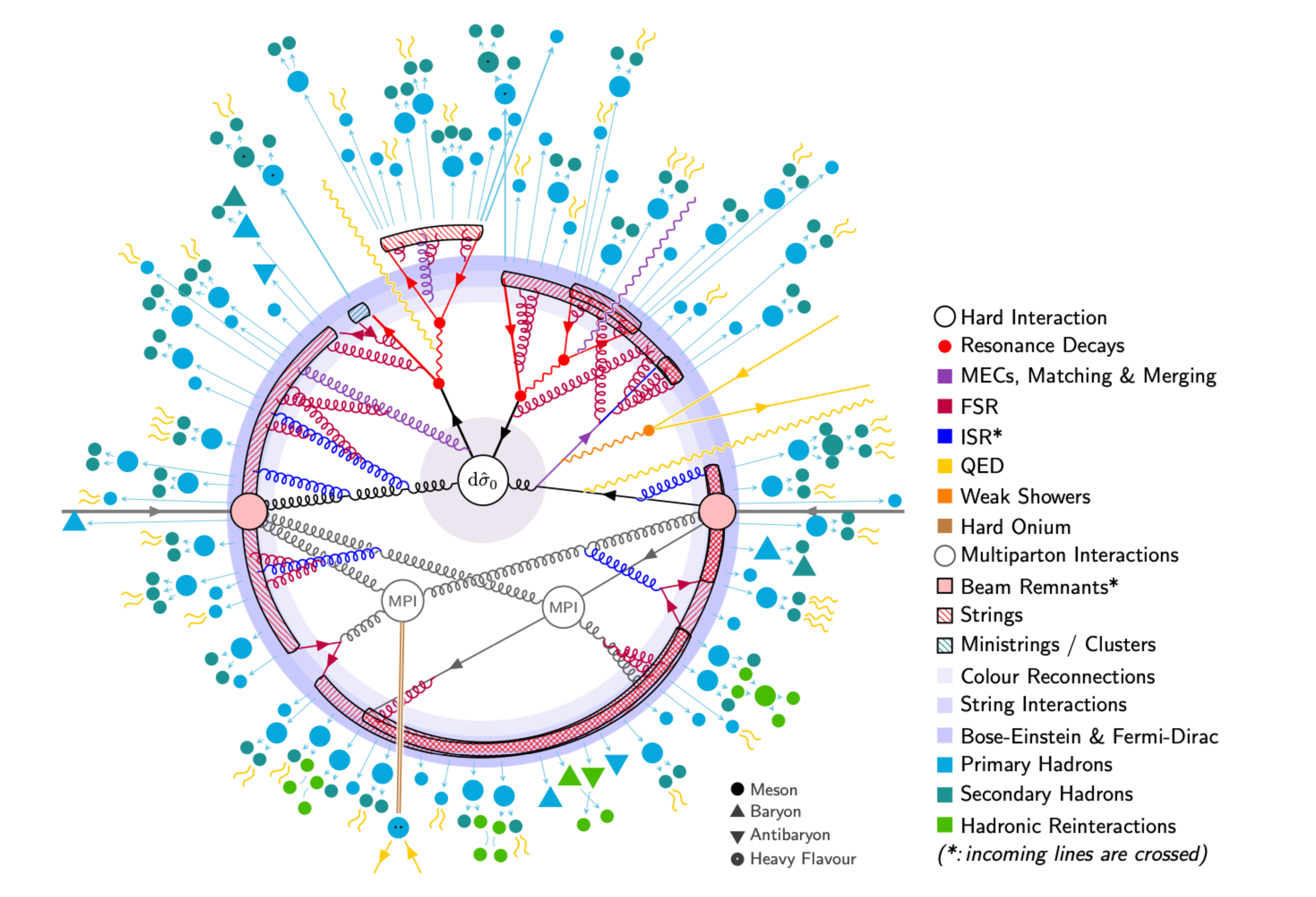
PYTHIA



Bierlich, C., Chakrabort, S., Desai, N. et al.,
"A comprehensive guide to the physics and usage of PYTHIA 8.3" (2022),
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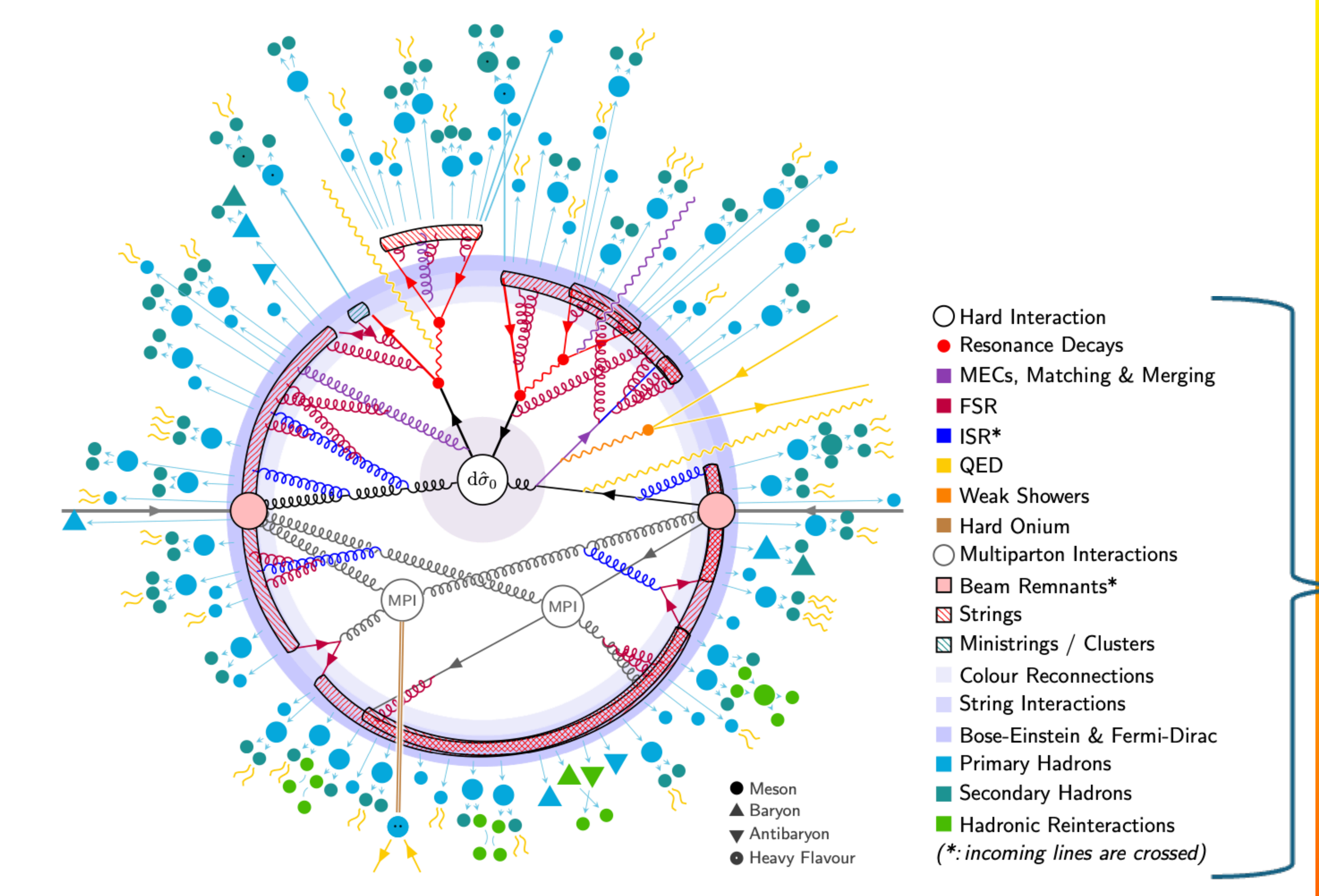

- Monte Carlo generators start the chain of simulation of SM physics

Physical predictions of QCD at different energy scales

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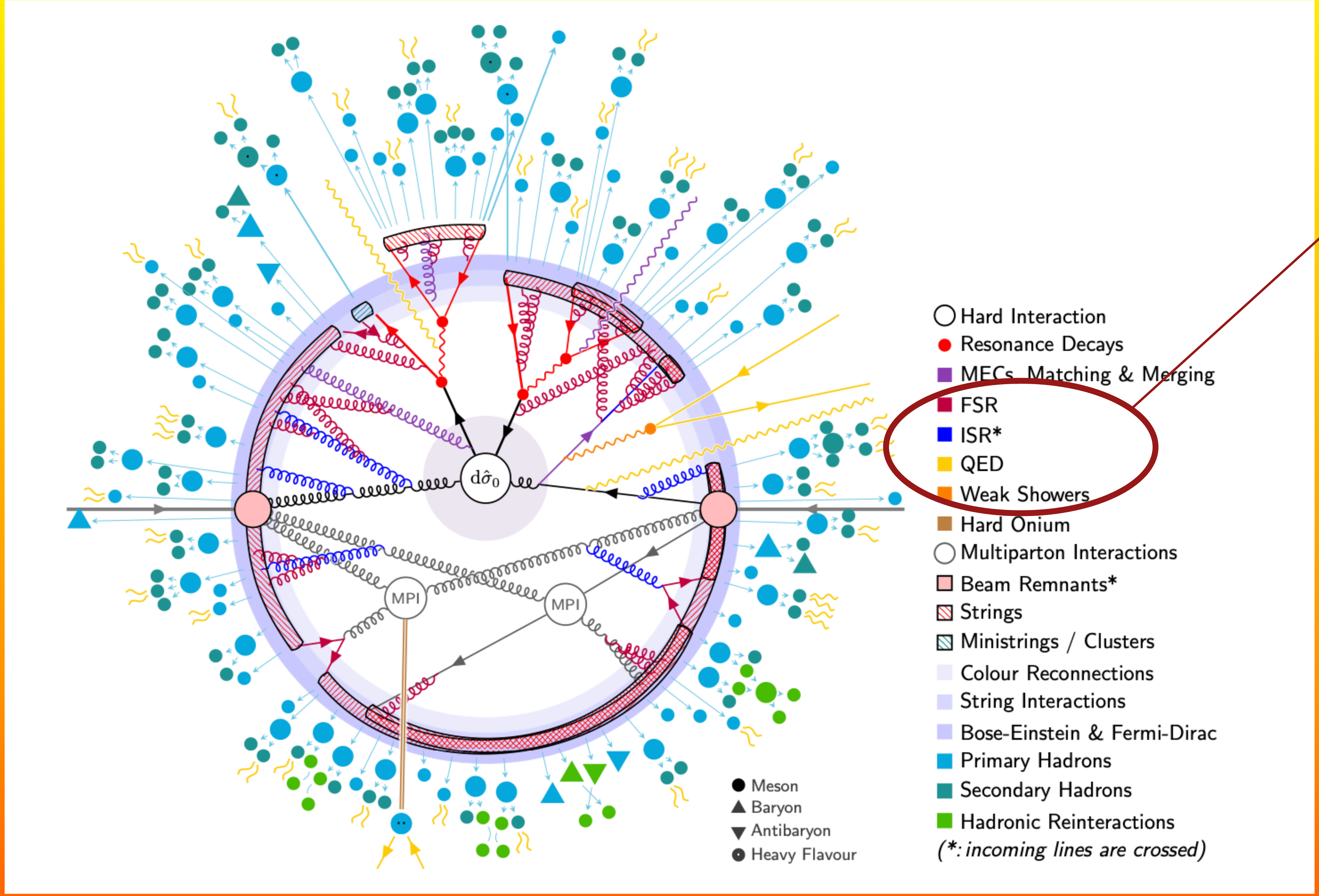

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- Parton shower:
  - Perturbative emission of additional partons until $\Lambda_{QCD} \approx 1$ GeV
- Physics processes are dependent on multiple parameters: *Tuning*
- Accurate modelling **vital** for precision SM measurements: m_W
  - Predicted to high precision
  - LEP, Tevatron, and LHC

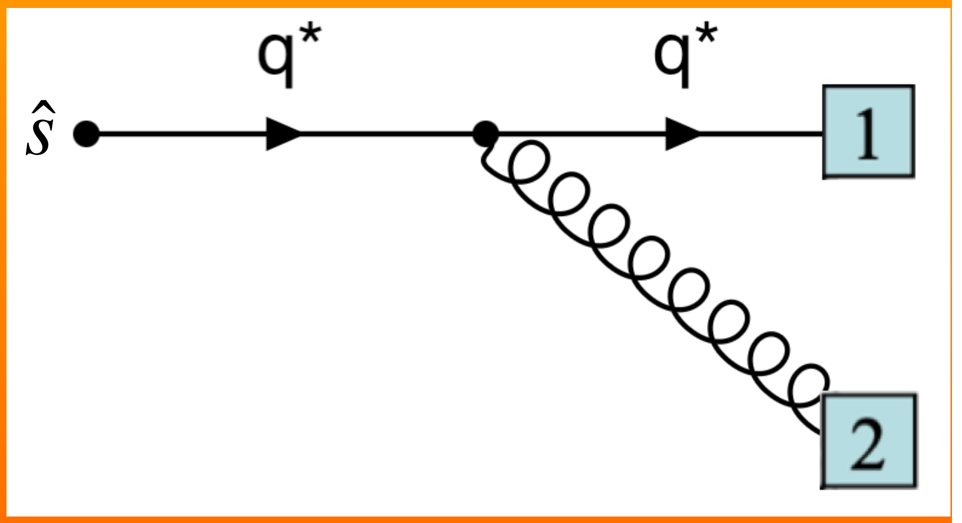
CDF (2022): $m_W = 80433.5 \pm 9.4\,\mathrm{MeV}$

Why?

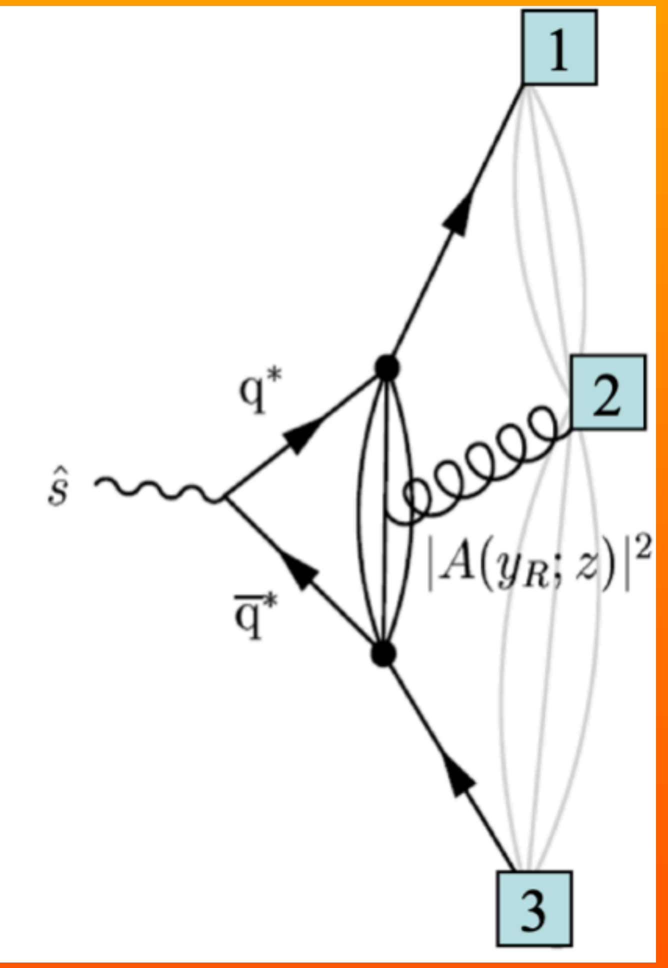
Why VINCIA*?

- 2 → 3 branching
- Antenna-based
  - Soft + Collinear Limits in the antenna function
  - PYTHIA's default shower: DGLAP
- Improved colour coherence
- No ATLAS dedicated tune

VINCIA Shower



Default PYTHIA Shower



Skands, LoopFest V (2006) "Pythia and Vincia"

* VIrtual Numerical Collider with Interleaved Antenna

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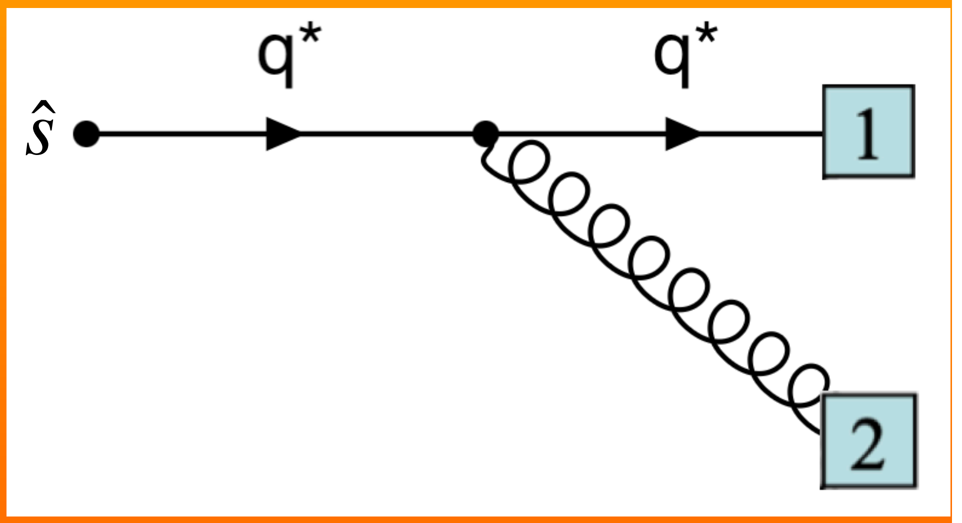

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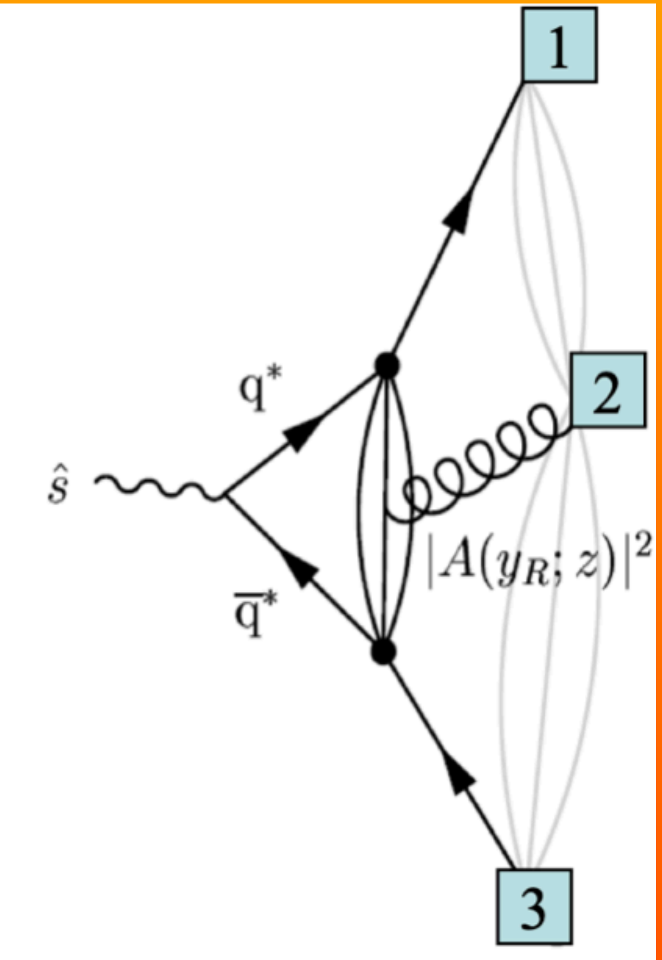

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Why Underlying Event (UE)?

- Beam remnants + Multiple Parton Interactions (MPI)
- Mismodelling → high uncertainties for precision measurements
  - Novel low-pileup m_W measurement by ATLAS
- Recoil calibration:
  - Correction for UE+pileup: $\sum E_T$
  - Probe UE with such observables

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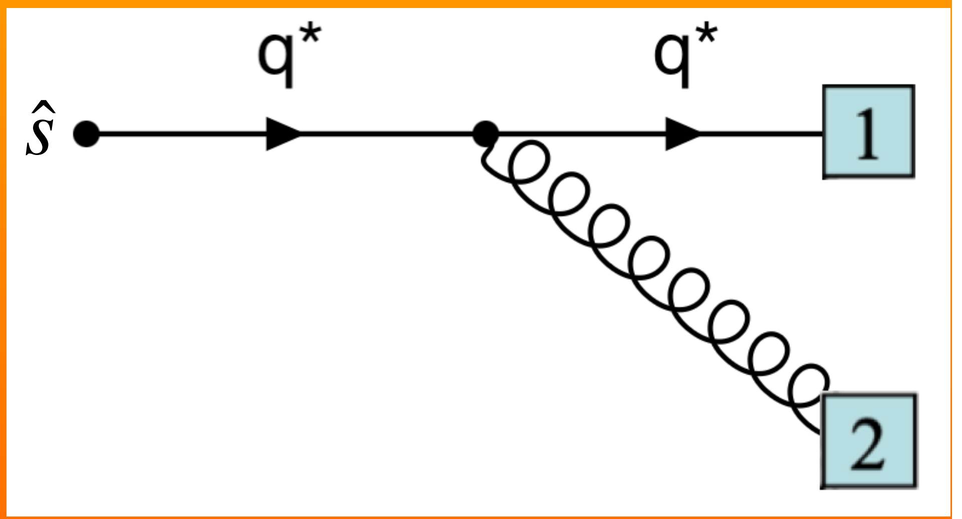

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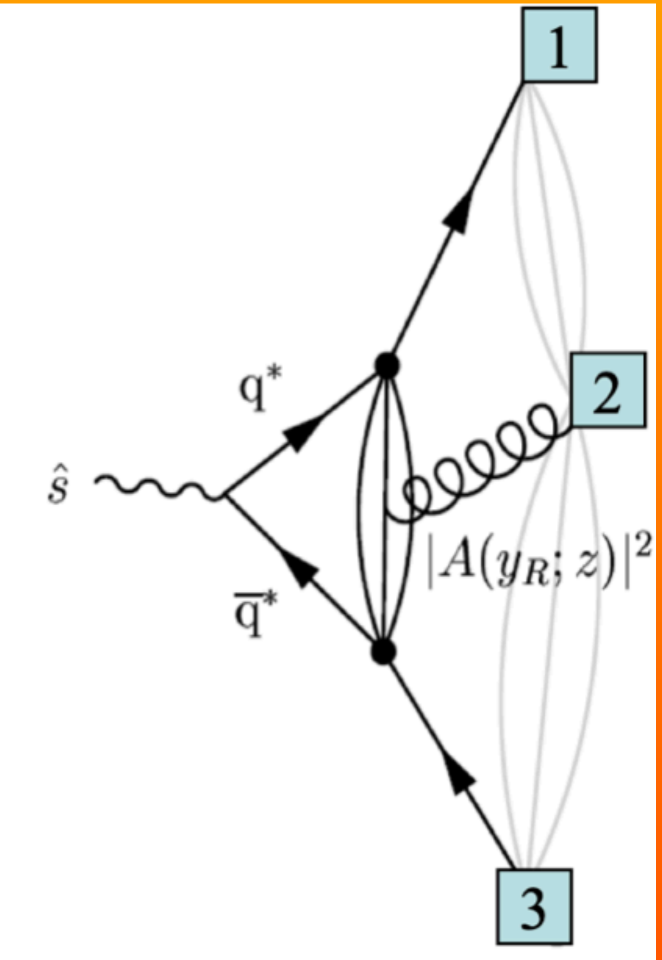
VINCIA Shower



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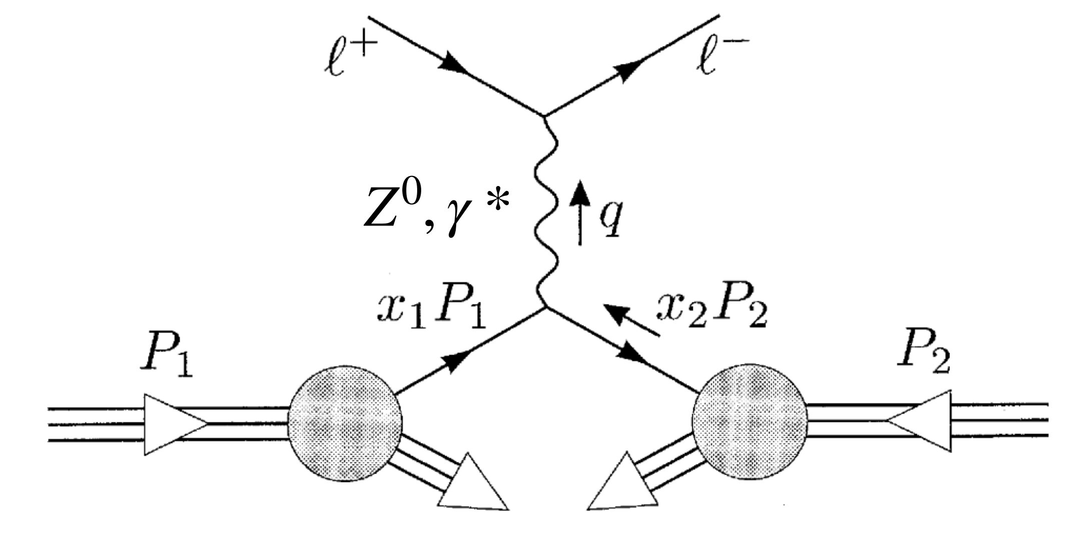
Why Drell-Yan?

- Role in recoil calibration for m_W measurement
- Z boson is colour neutral and fully reconstructed



Peskin, M. E. and Schroeder D.V. (1995) "An Introduction To Quantum Field Theory" (p. 595). CRC Press.

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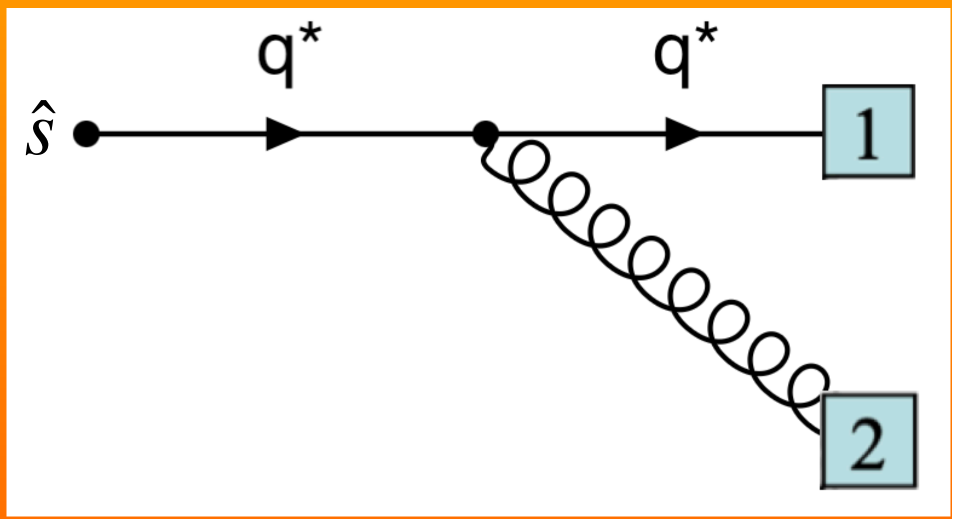
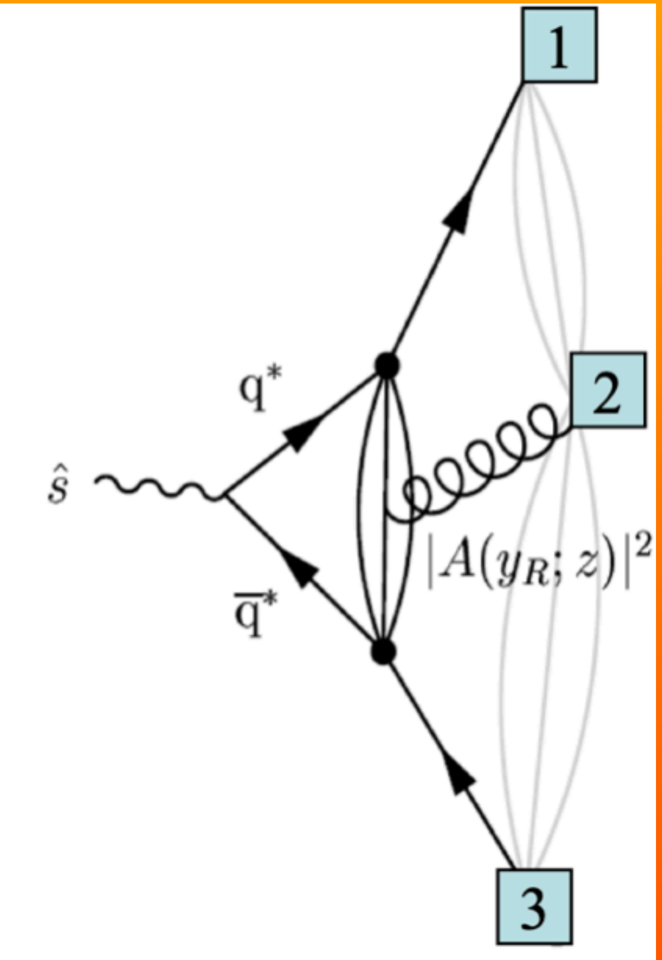


Default PYTHIA Shower

VINCIA Shower



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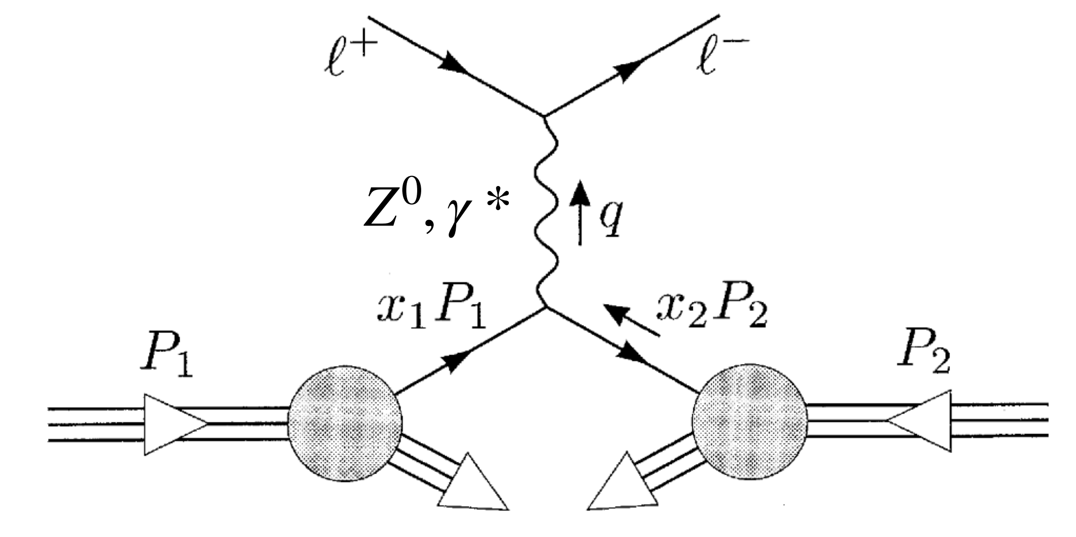

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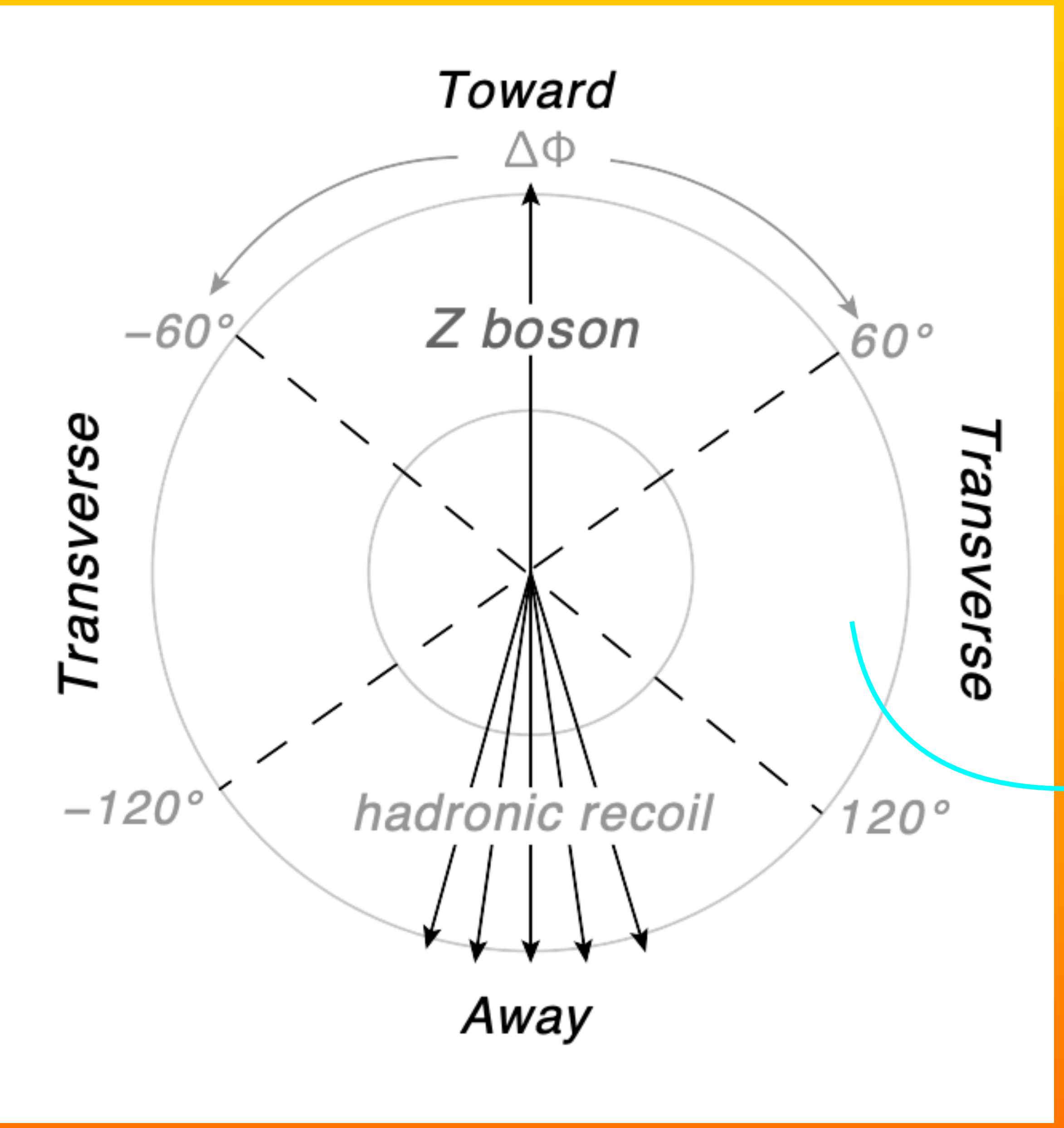
PowhegBox matched to:

1. Default PYTHIA 8 Shower
   - Monash tune
2. VINCIA
   - Own hadronisation parameters
   - Sensitivity: Monash

✦ ATLAS Measurement of UE-Sensitive Observables for Drell-Yan Events

- Events with a muon-antimuon pair with an invariant mass near that of the *Z* boson, in *pp* collisions at $\sqrt{s} = 13$ TeV
- Plane transverse to the beam:



ATLAS Collaboration, Eur. Phys. J. C 79 (2019) 666,
DOI: 10.1140/epjc/s10052-019-7162-0

Divided according to $\sum p_T$

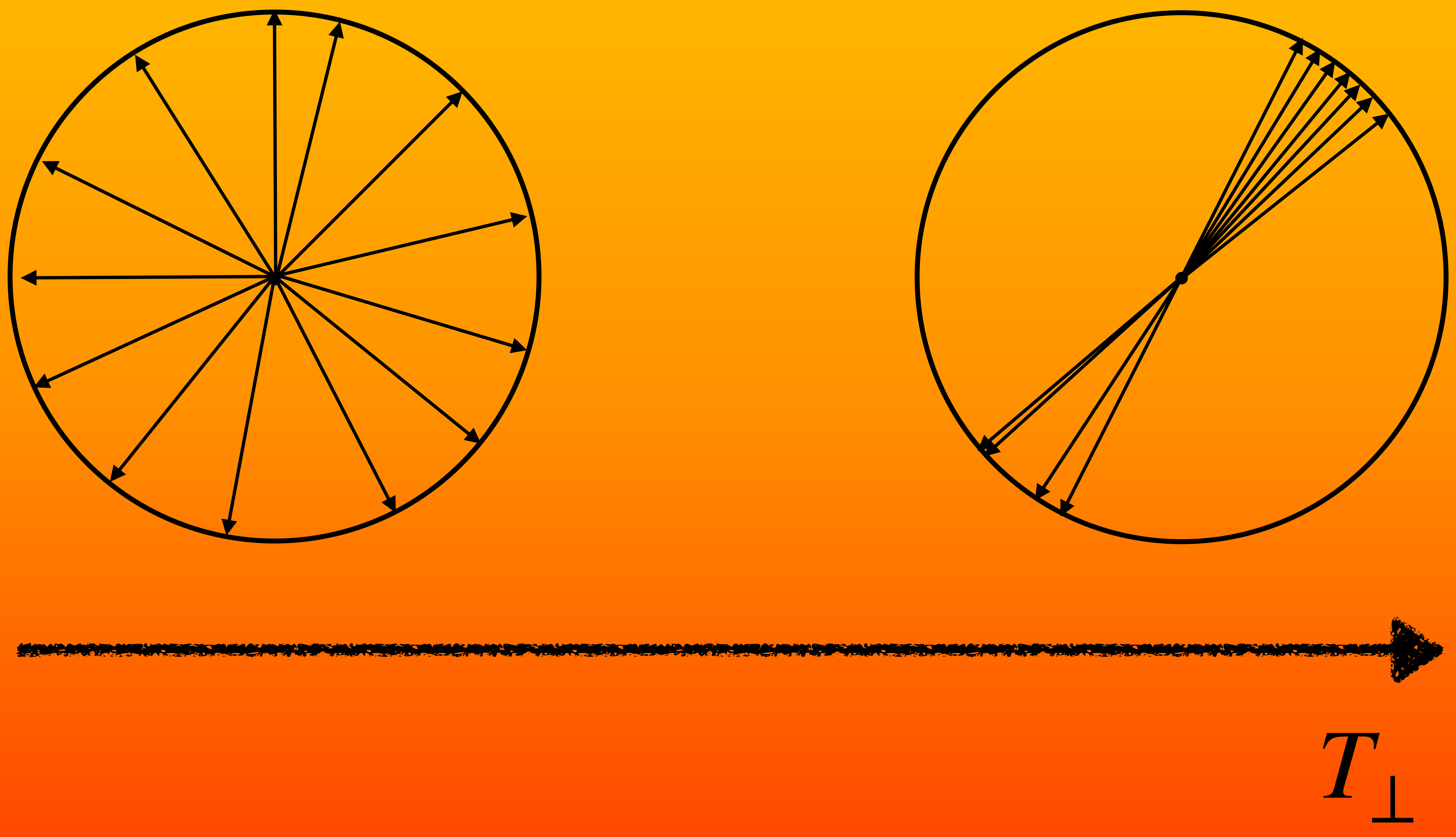
- Away: Dominated by recoil, low sensitivity to UE
- Transverse: Less contamination from the hard process
  - (+) *Transmax:* more radiation from the recoiling jets, less UE-sensitive than
  - (−) *Transmin:* high sensitivity to UE
- Toward: high sensitivity to UE

✦ ATLAS Measurement of UE-Sensitive Observables for Drell-Yan Events

- Another divide based on transverse thrust $T_\perp$:

$$T_\perp = \frac{\sum_j |\overrightarrow{p_{\mathrm{T},j}} \cdot \hat{n}|}{\sum_j |\overrightarrow{p_{\mathrm{T},j}}|}$$

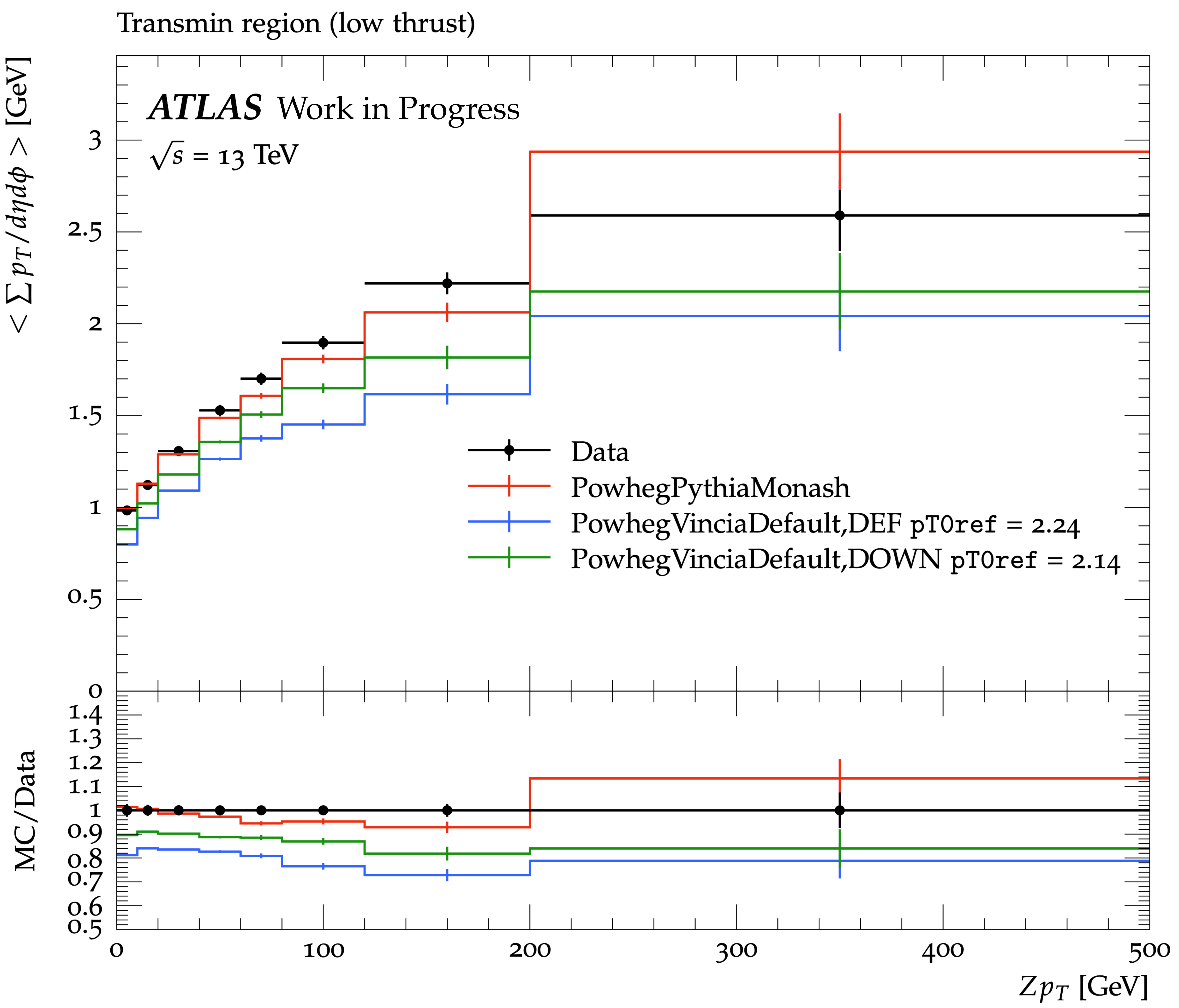
- Low-thrust: $T_\perp < 0.75$
- High-thrust: $T_\perp > 0.75$

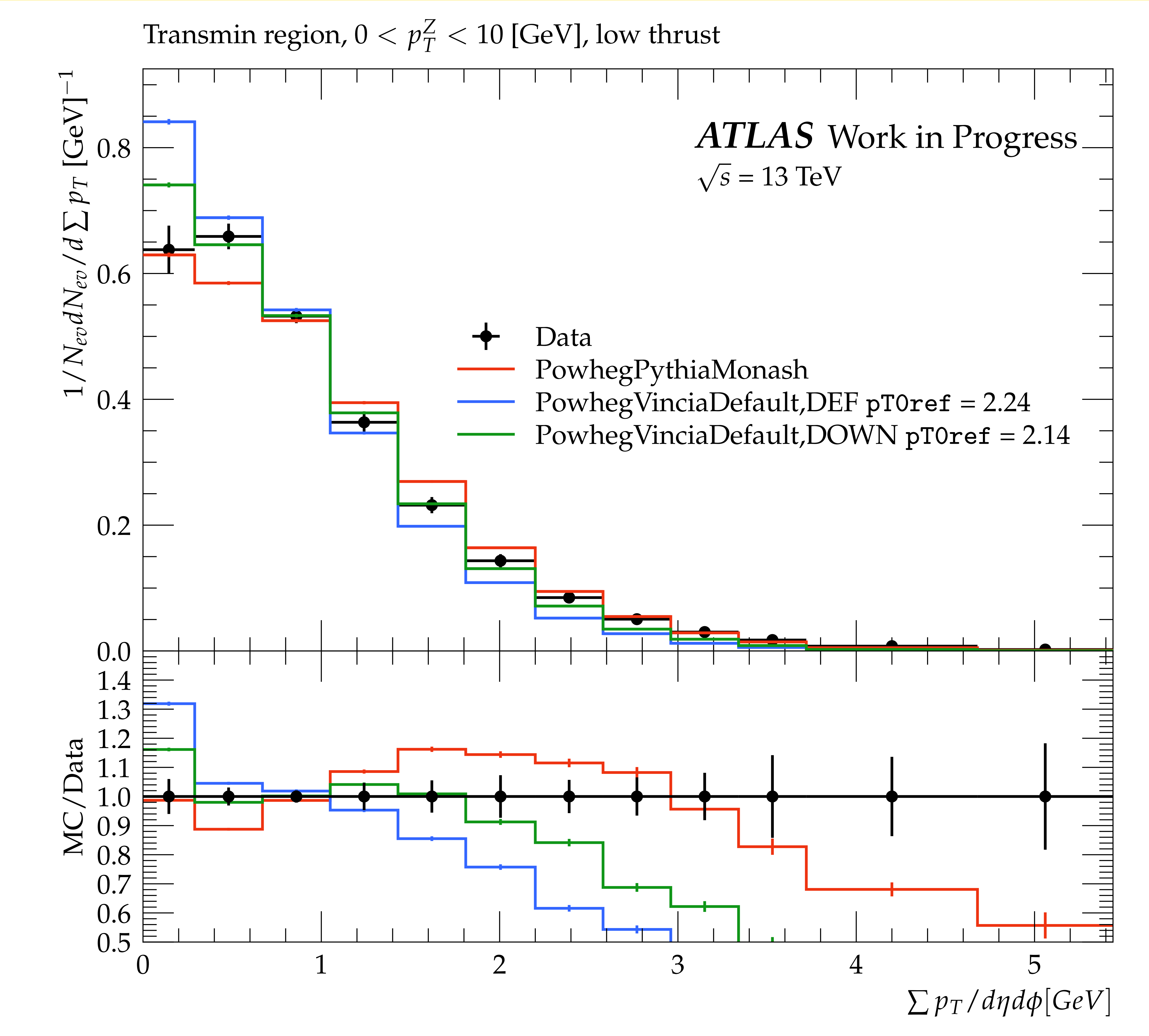


- Events with low thrust: largest relative contribution from UE
- MPI: most spherical energy distributions

✦ Sensitivity I-MultipartonInteractions:pT0ref

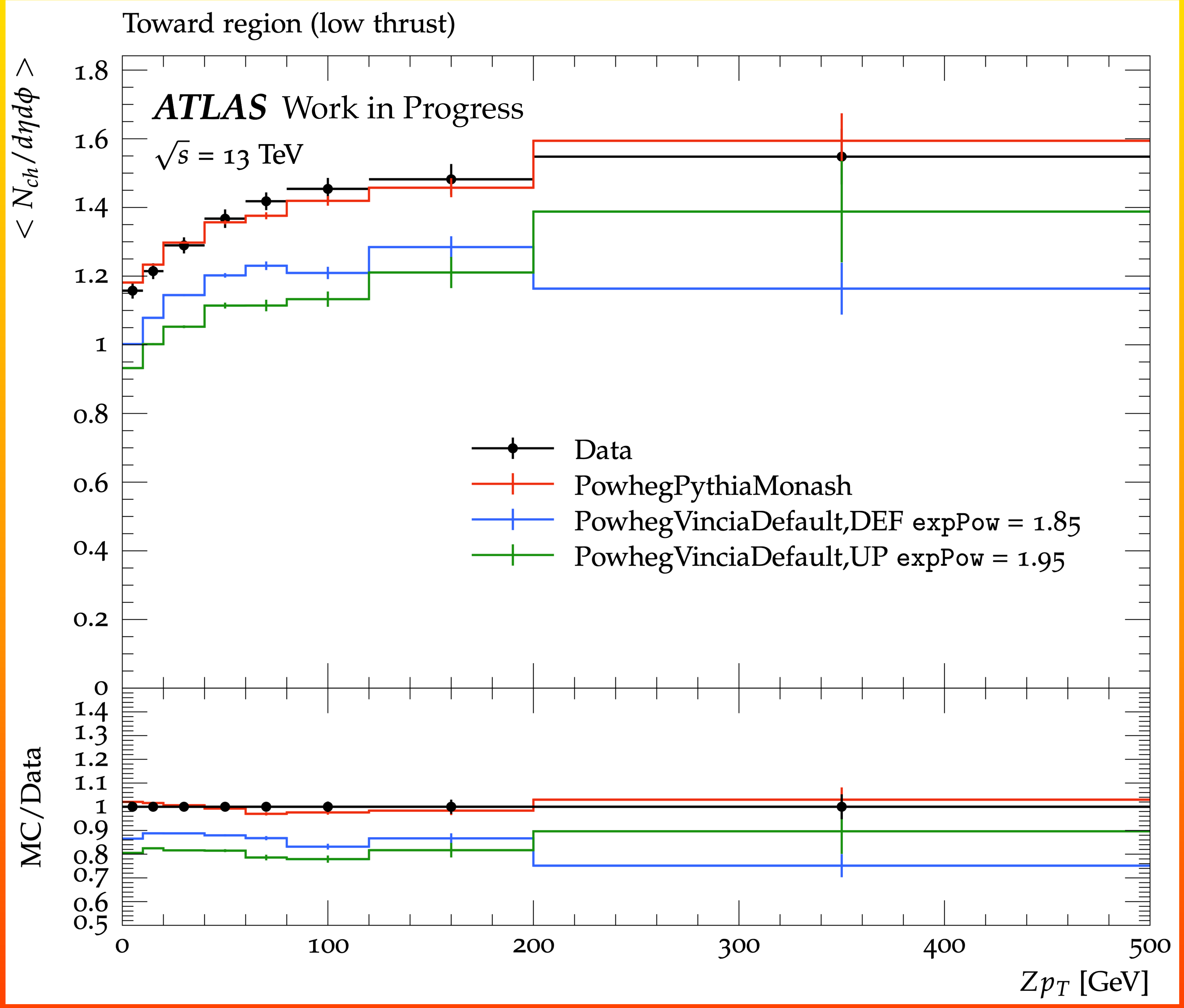
- pT0ref ↓ MPI ↑
- High sensitivity observed: in terms of total energy, little differential dependence

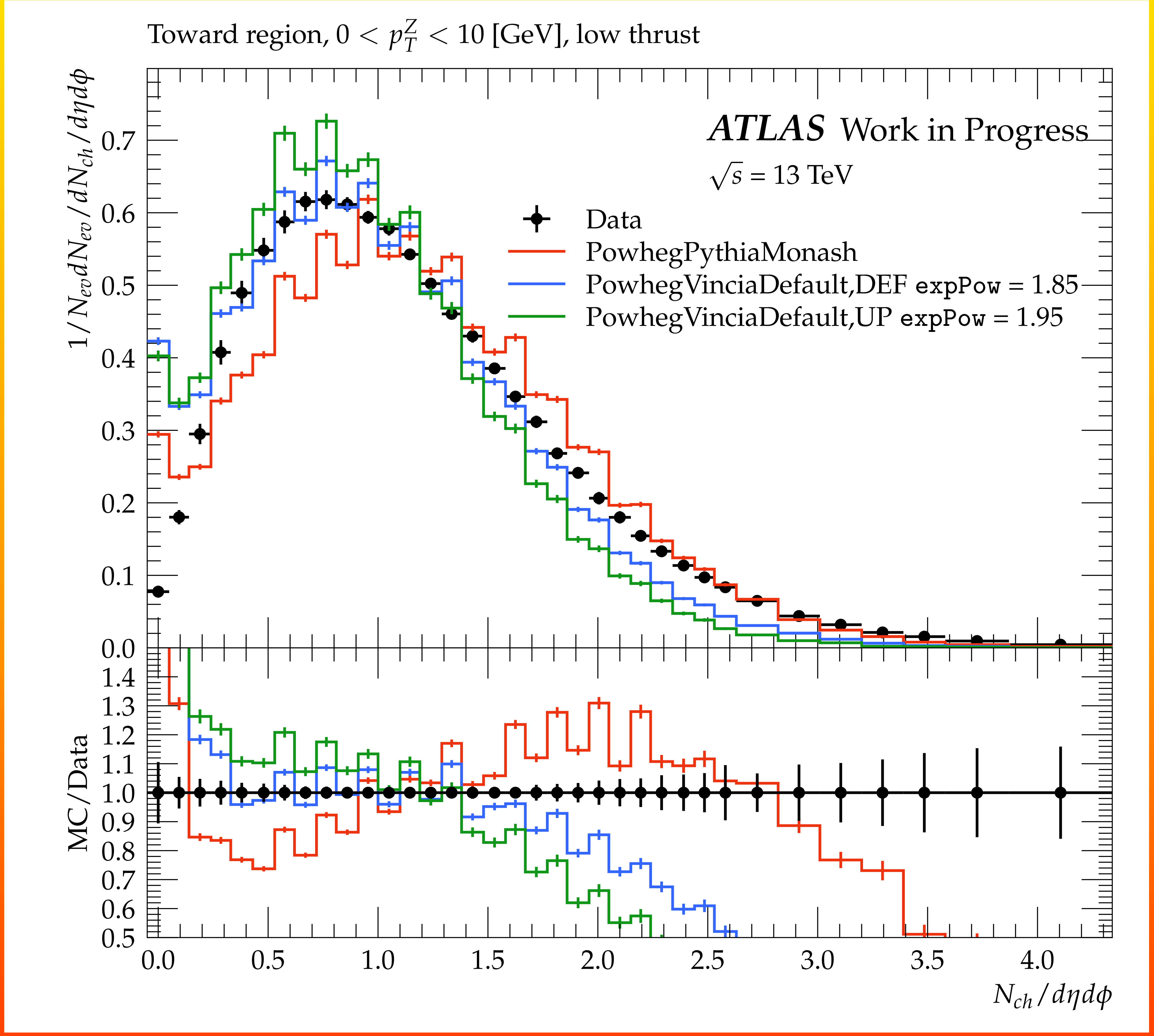




✦ Sensitivity II-MultipartonInteractions:expPow

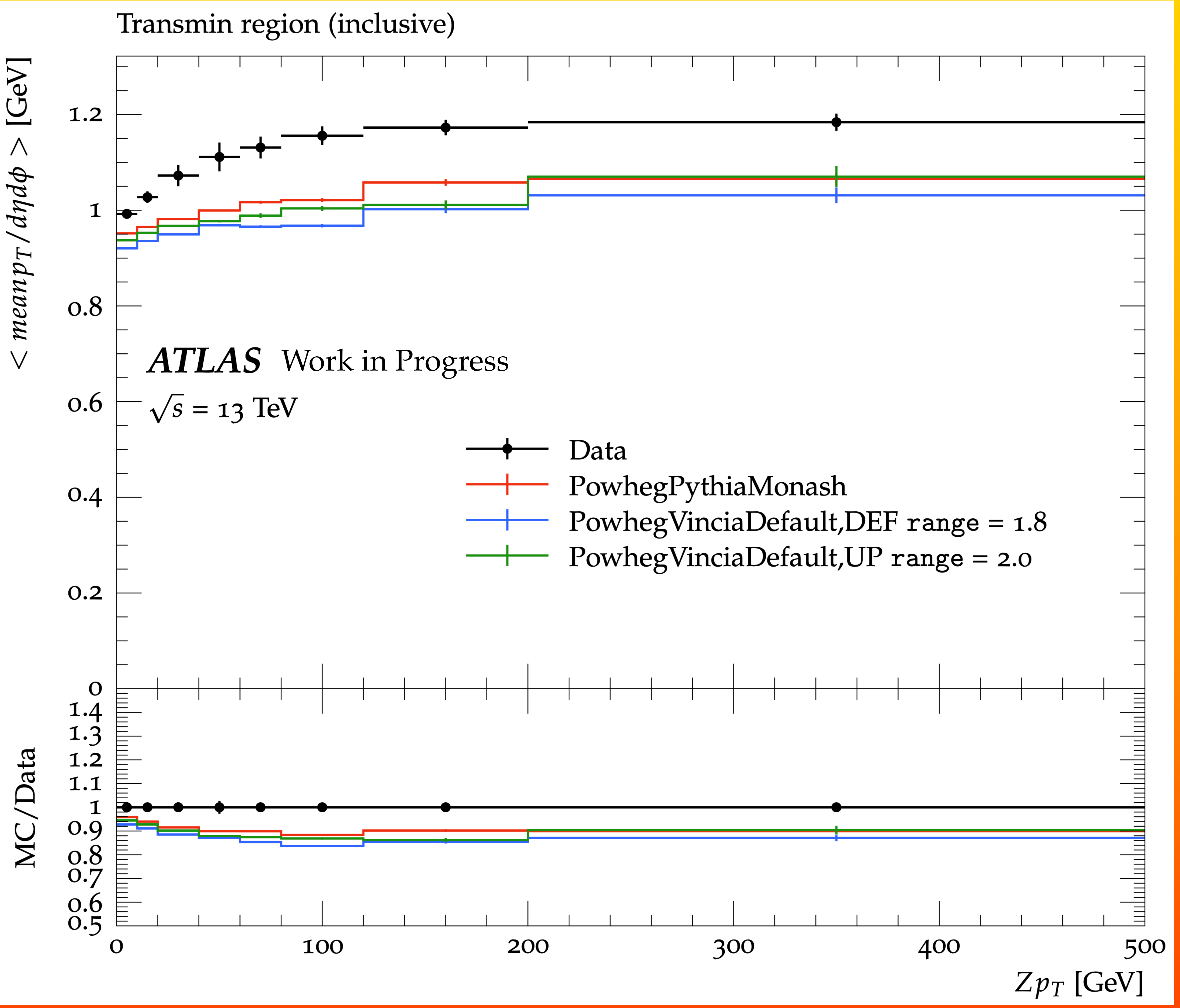
- MultipartonInteractions:bProfile → impact parameter profile of the incoming protons
  - Default: convolution of the form $exp(-b$^expPow)

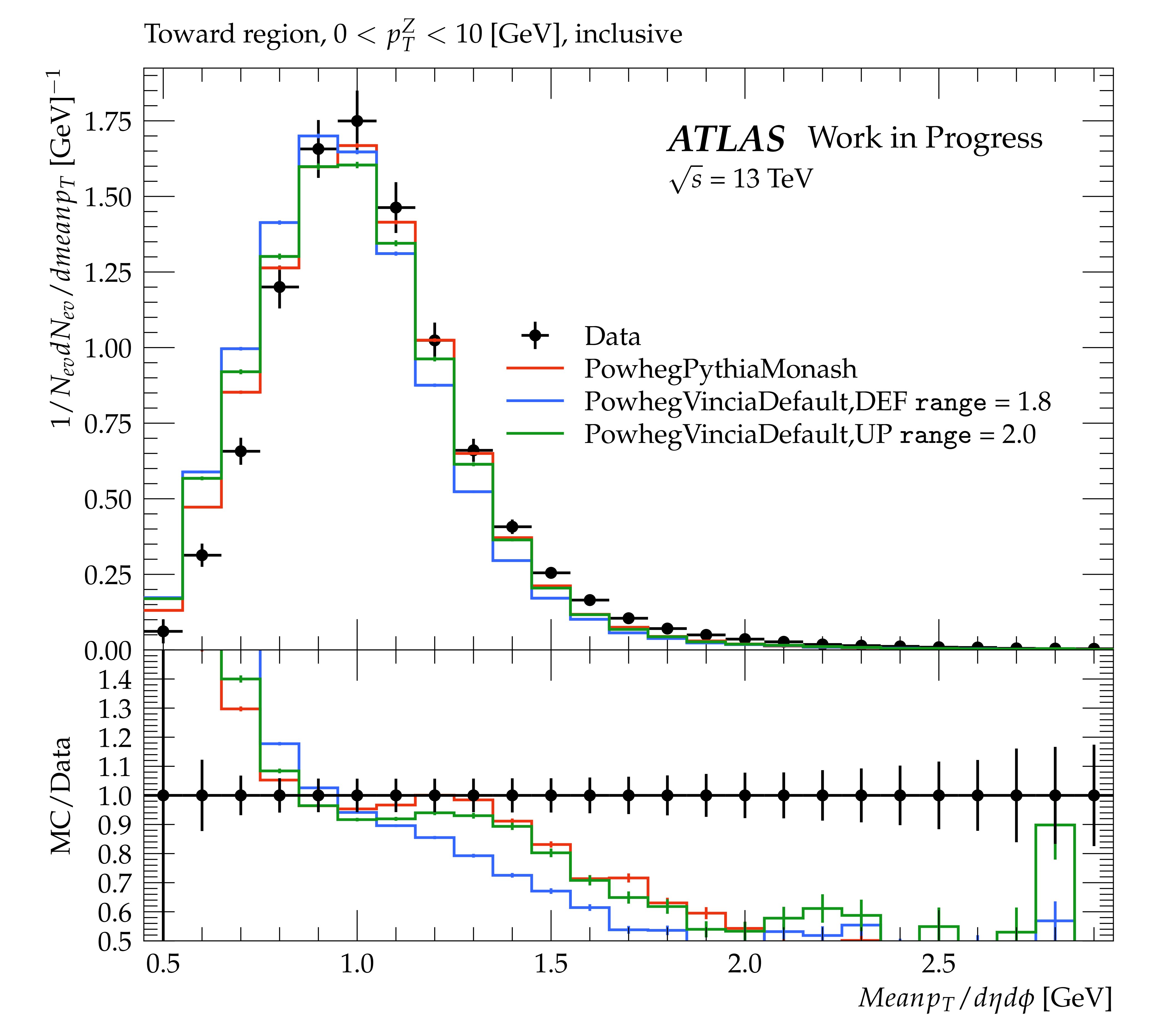




✦ Sensitivity III-ColourReconnection:range

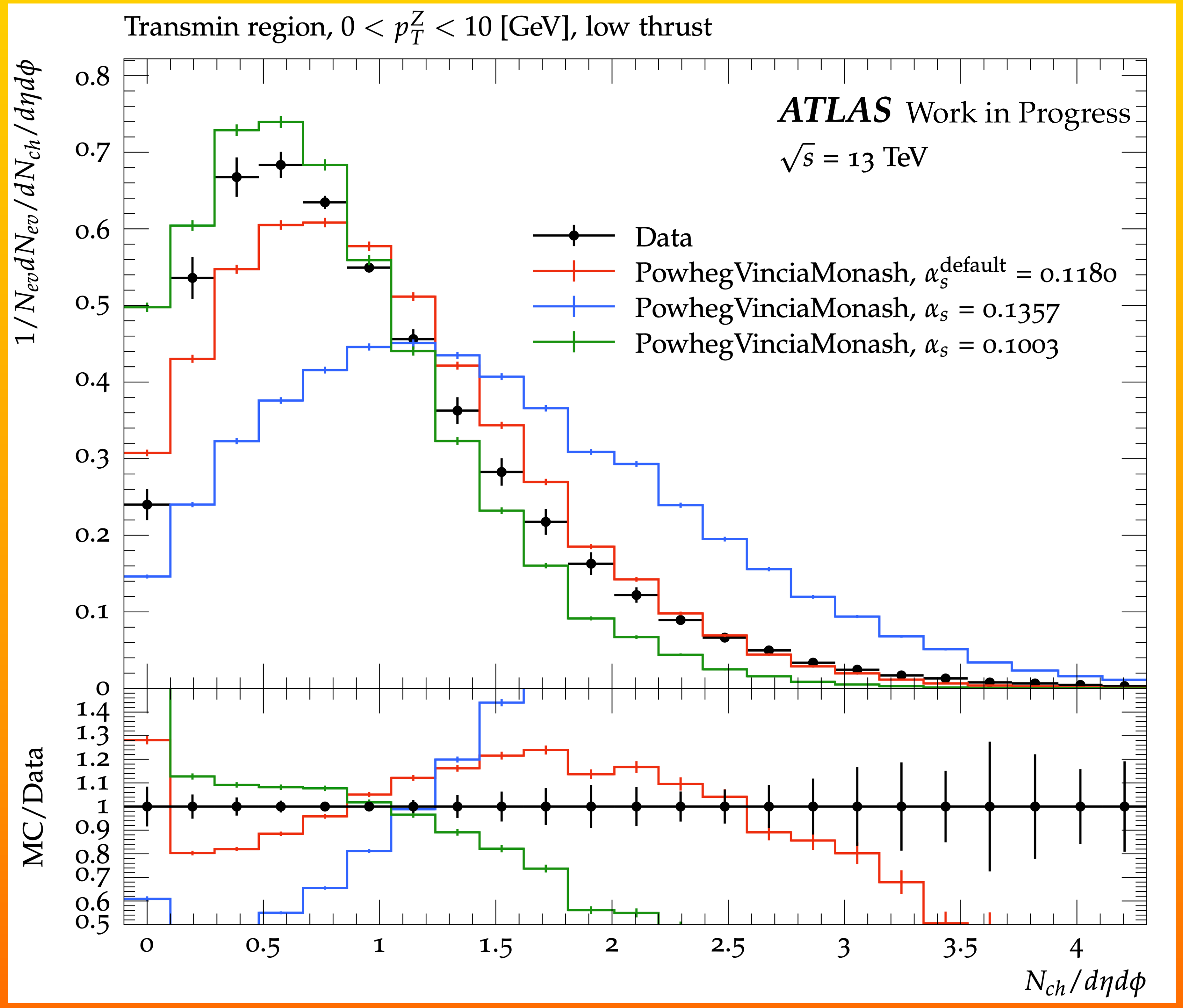
- Probability of an MPI system to be merged with a harder one: pT0ref and range
- range ↑: more colour reconnections
- A slope change needed for modelled profiles to match data

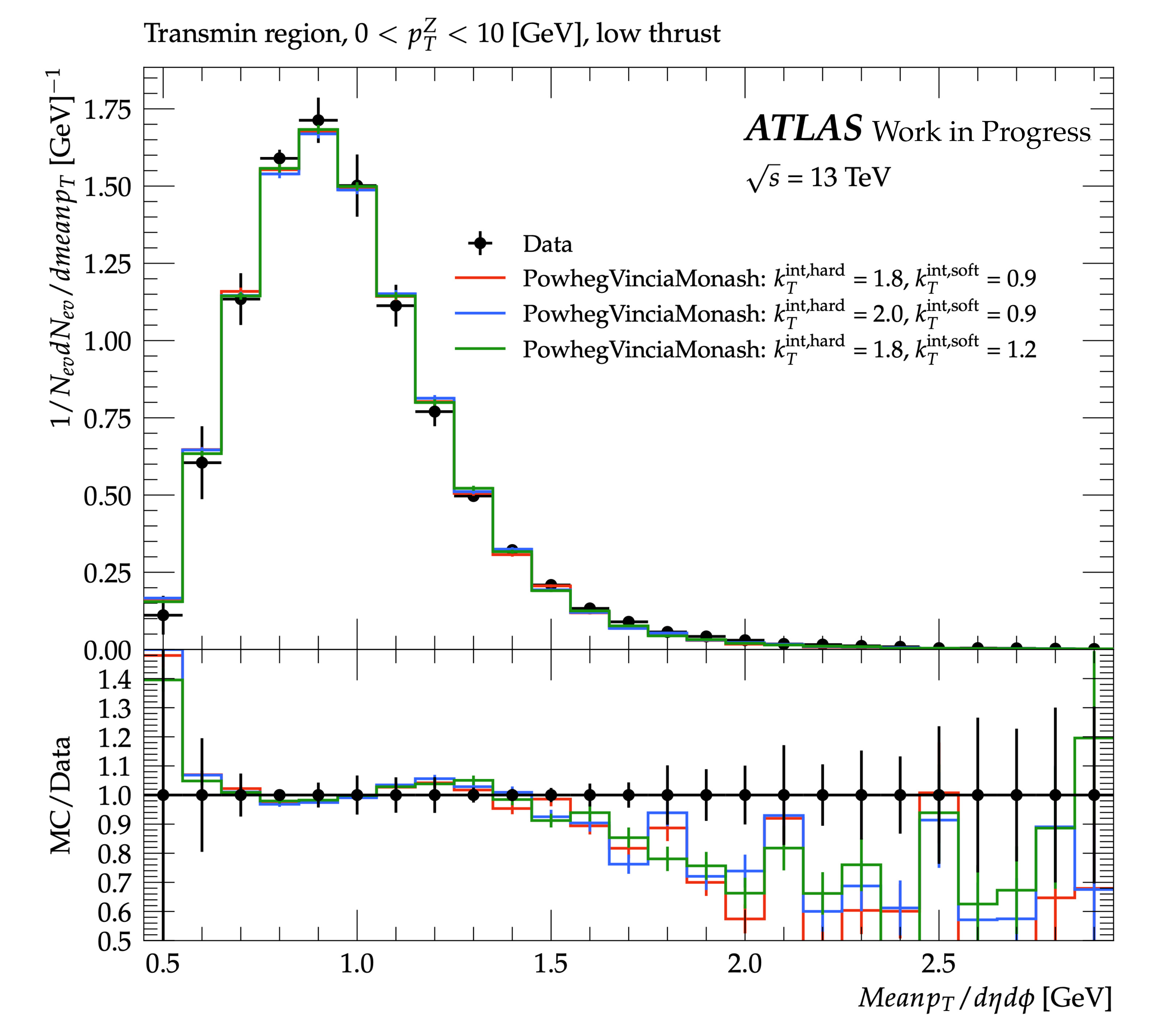


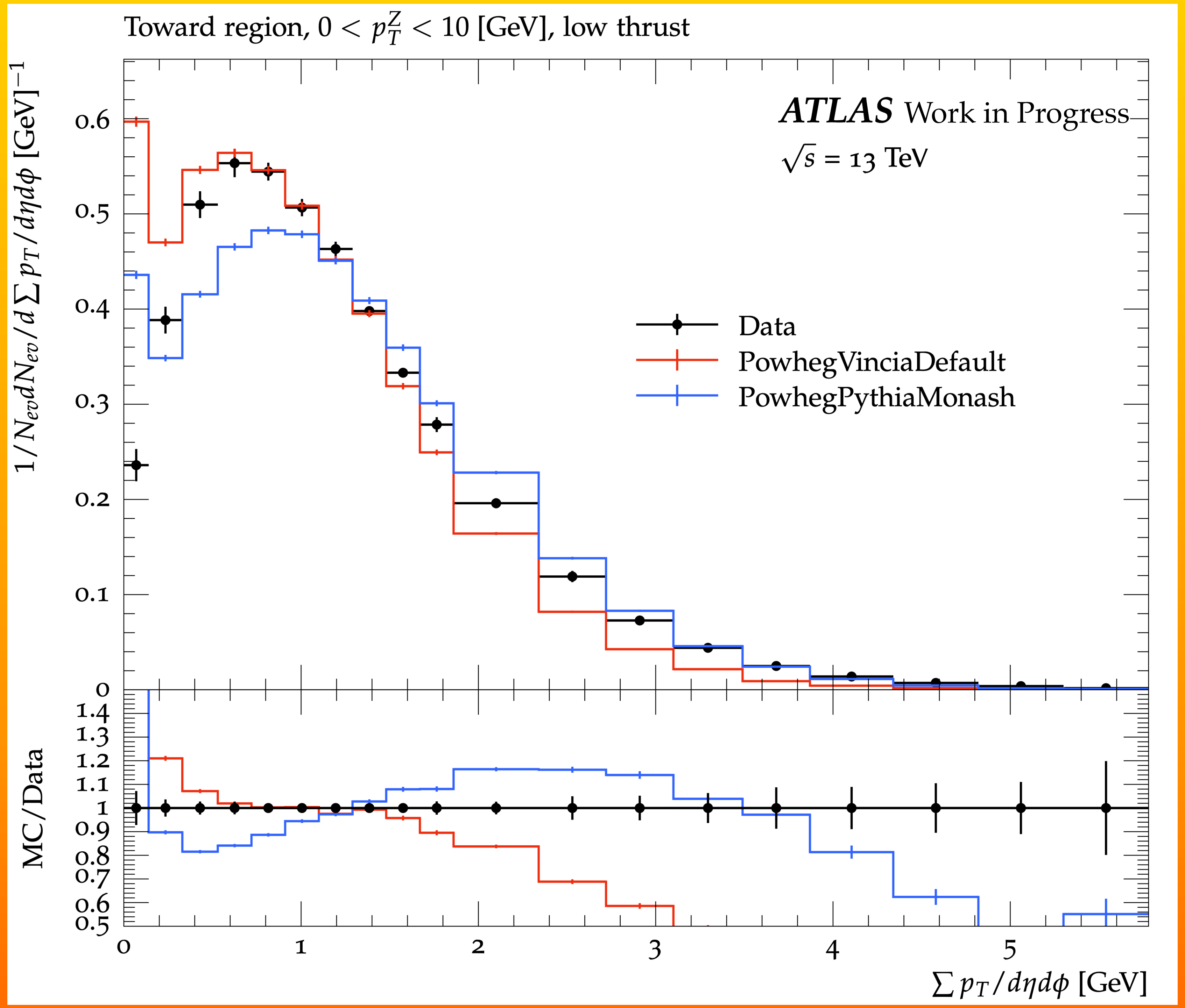


✦ Sensitivity IV: Shower α_s, Hard and Soft Intrinsic k_T

- Considerable sensitivity to shower α_s → similar to `pT0ref`
- Little sensitivity to hard and soft intrinsic k_T







The binnings of the differential distributions in N_{ch}, mean p_T, and $\sum p_T$ that are being fit during tuning

Remains the same for all the p_T^Z bins

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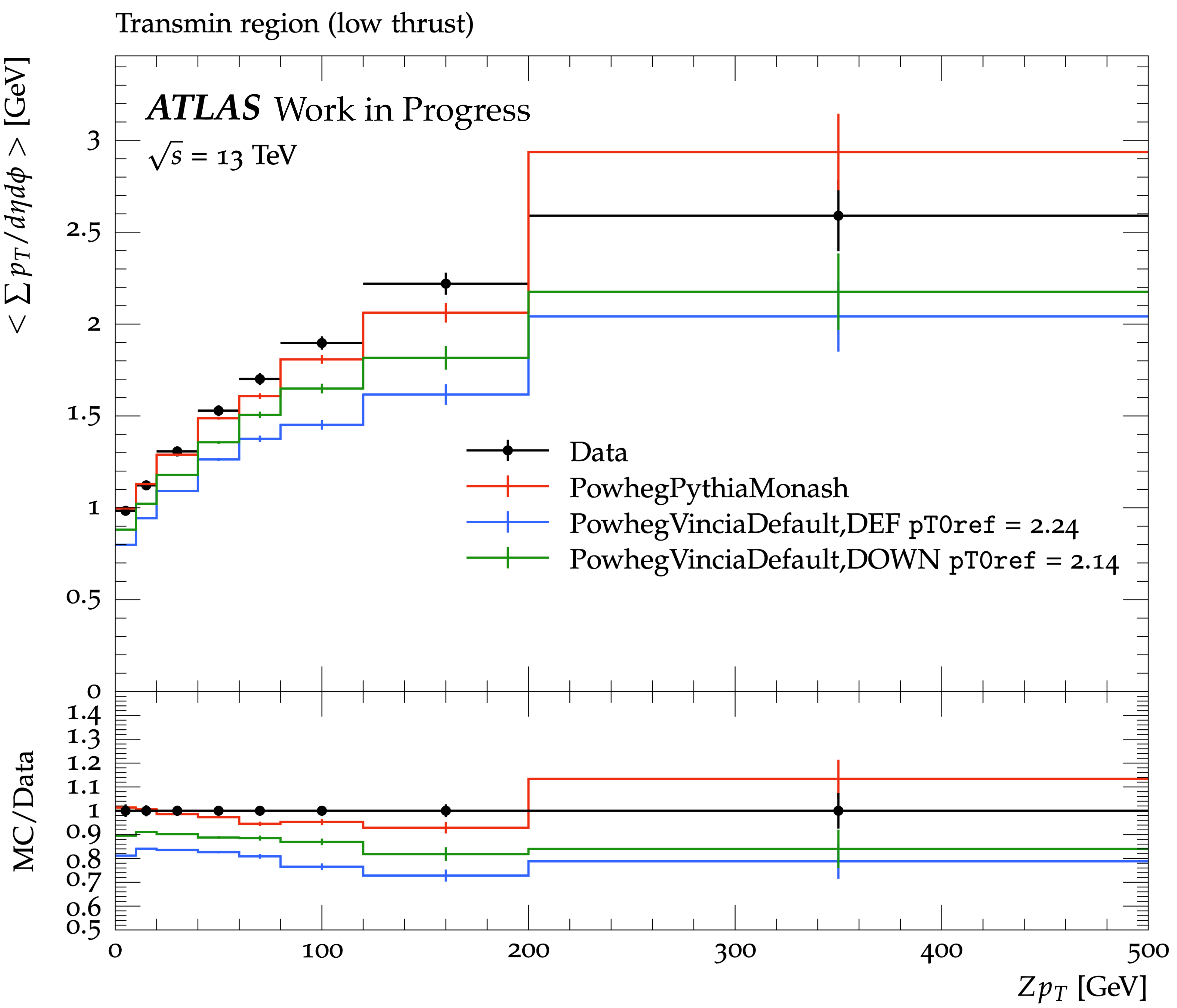
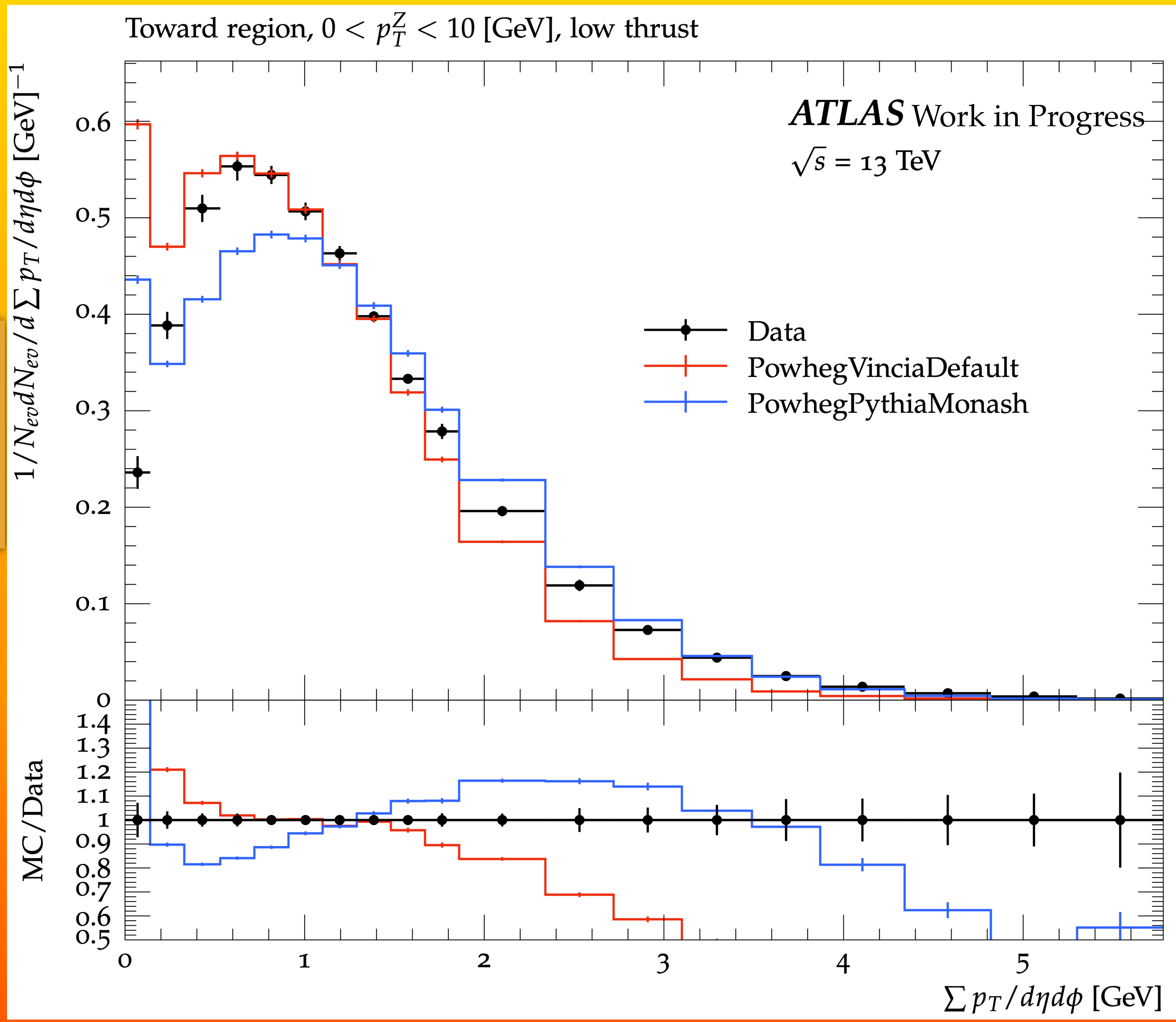


Monash: okay for profile distributions but fails for differential distributions.



The binnings of the differential distributions in N_{ch}, mean p_T, and $\sum p_T$ that are being fit during tuning

Remains the same for all the p_T^Z bins

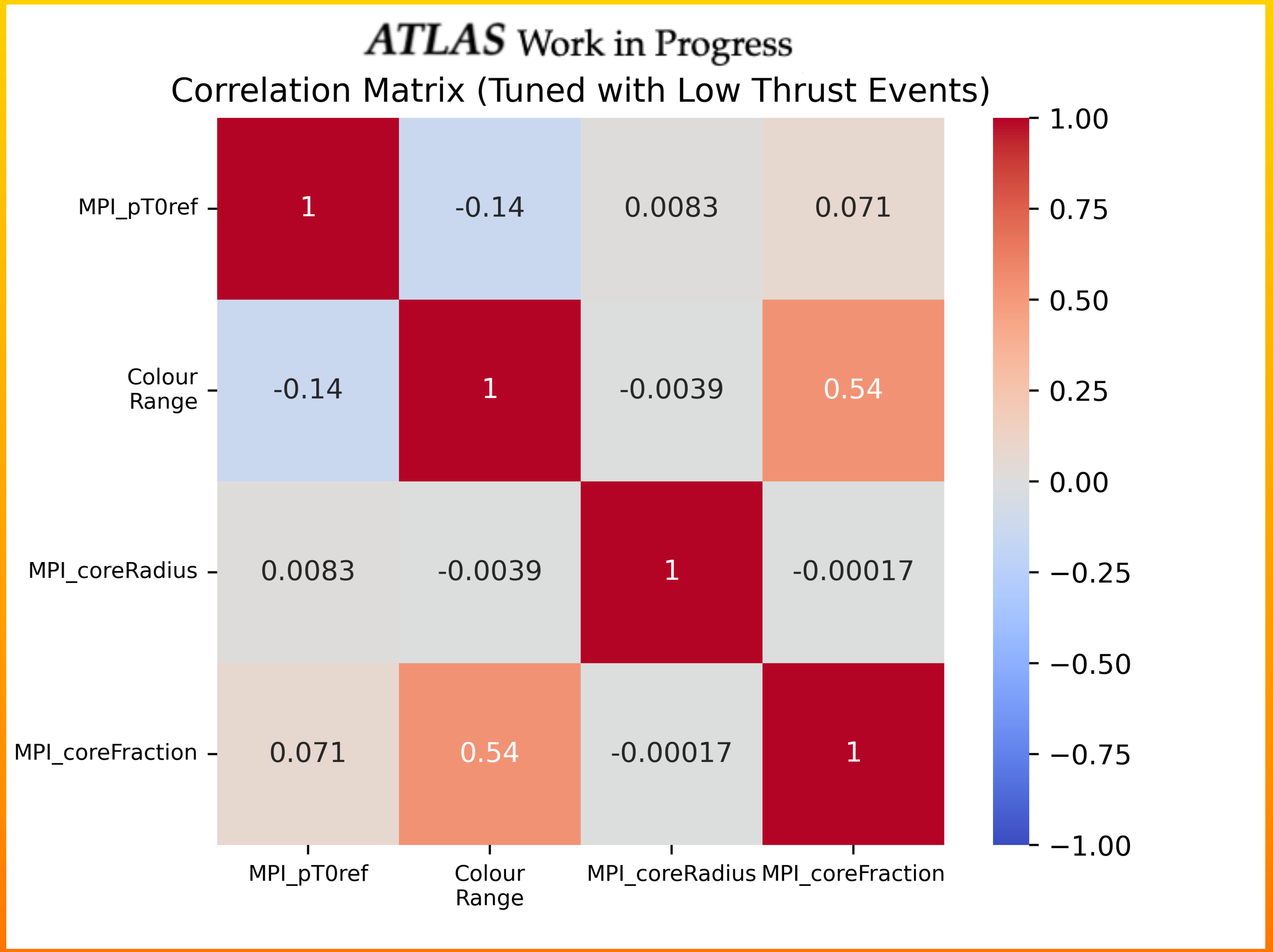
✦ Initial Tuning Results with Professor

- Inputs: Differential distributions in $\sum p_T$, N_{ch}, mean p_T for low-thrust events in trasmin and toward + χ^2 goodness-of-fit function used
- Double Gaussian bProfile
- Parameters: pT0ref, coreRadius, coreFraction, and range

!! 5% theory uncertainty included

Pythia 8 Parameter	Value
MPI:pT0ref	2.07
MPI:coreRadius	0.60
MPI:coreFraction	0.63
ColourReconnection:Range	2.12

- $\chi^2 \approx 3597, N_{\text{dof}} = 1083$



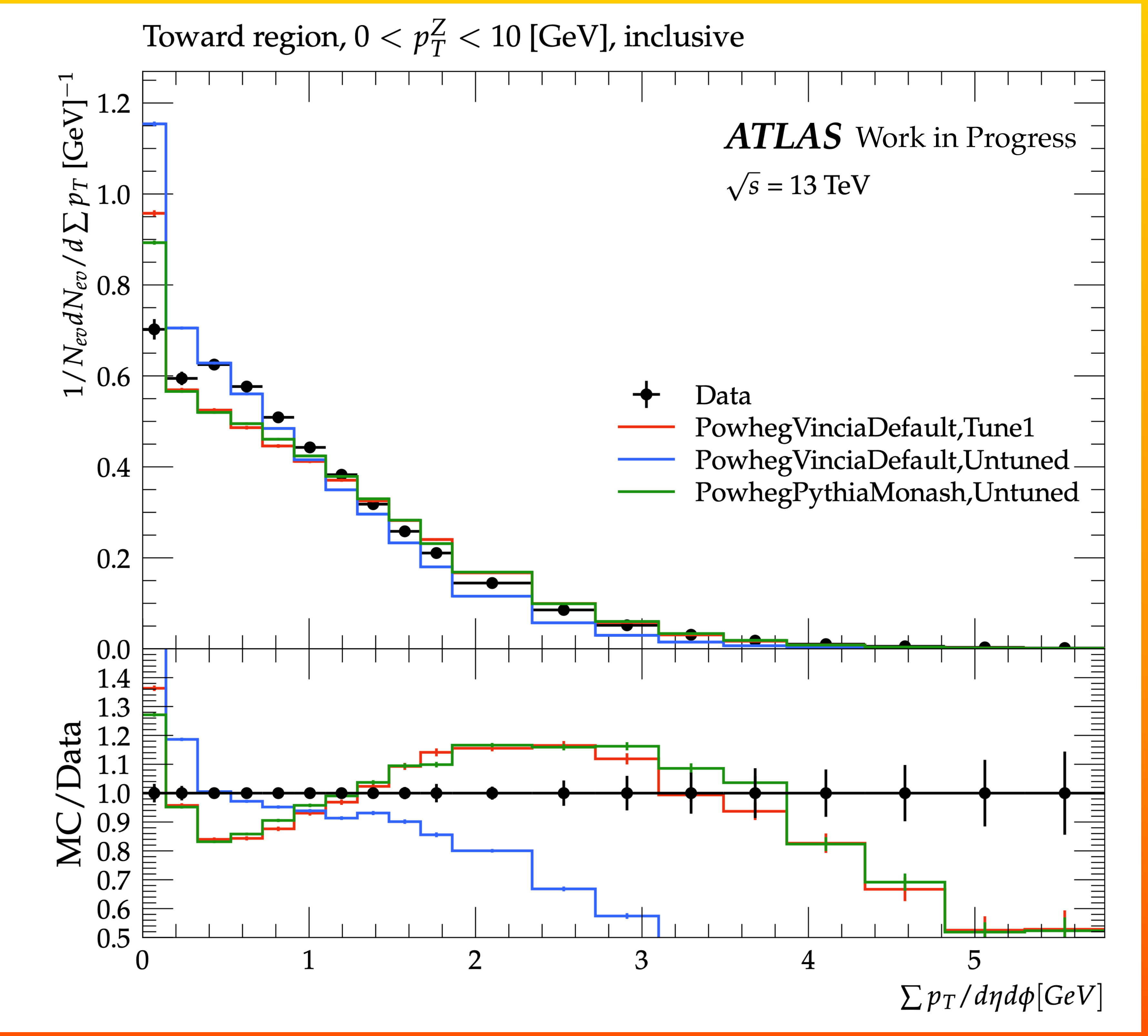
- High χ^2: systematic variations for uncertainty estimation
  - Will be done for the closest tune

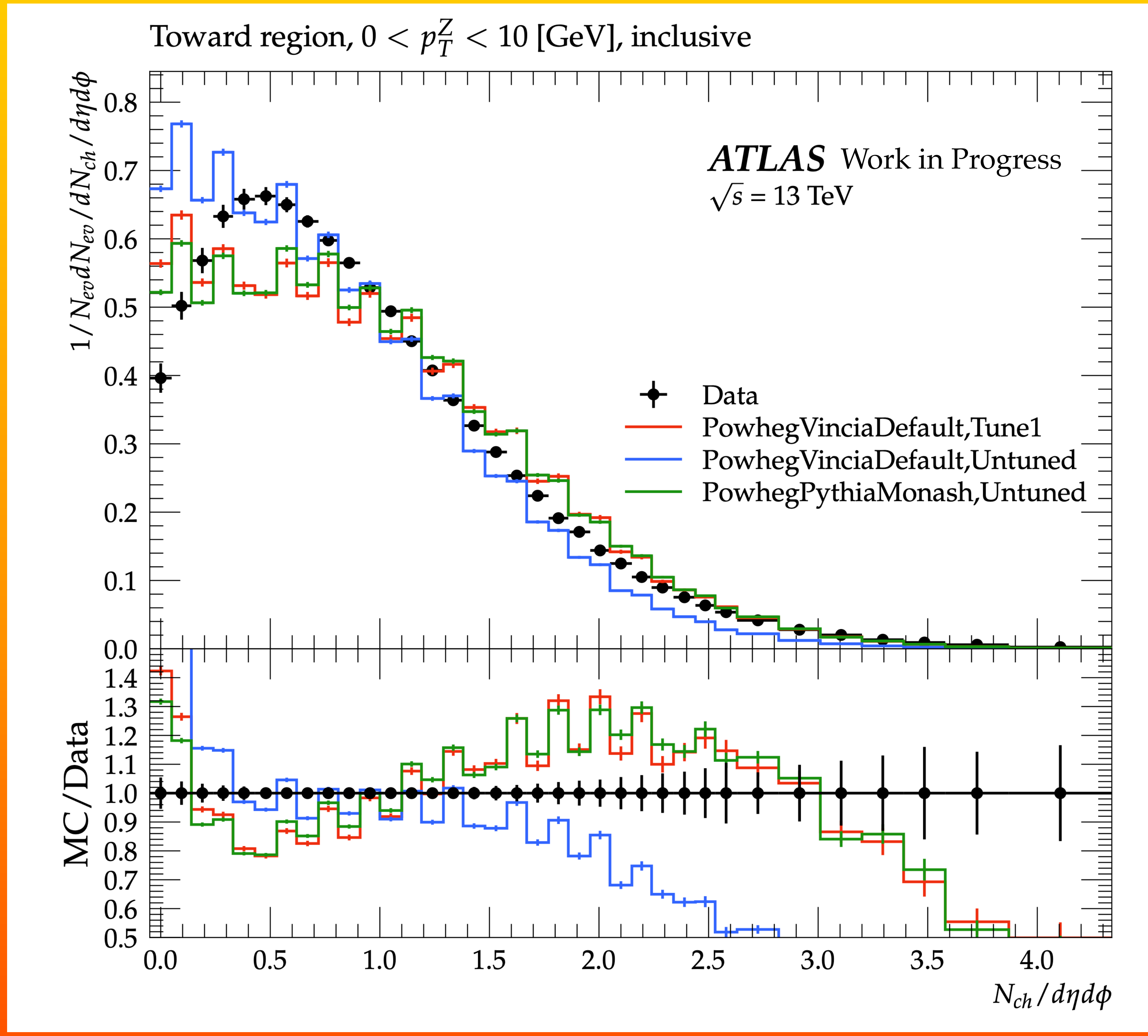
- High correlation between:
  - coreFraction and range
  - pT0ref and range

Baris Tuncay, 18.07.2024

✦ Initial Tuning Results with Professor

- Improvement in the modelling obtained compared to the starting point POWHEG+VINCIA with default parameters
- Models overestimate the fraction of events with low $\sum p_T$





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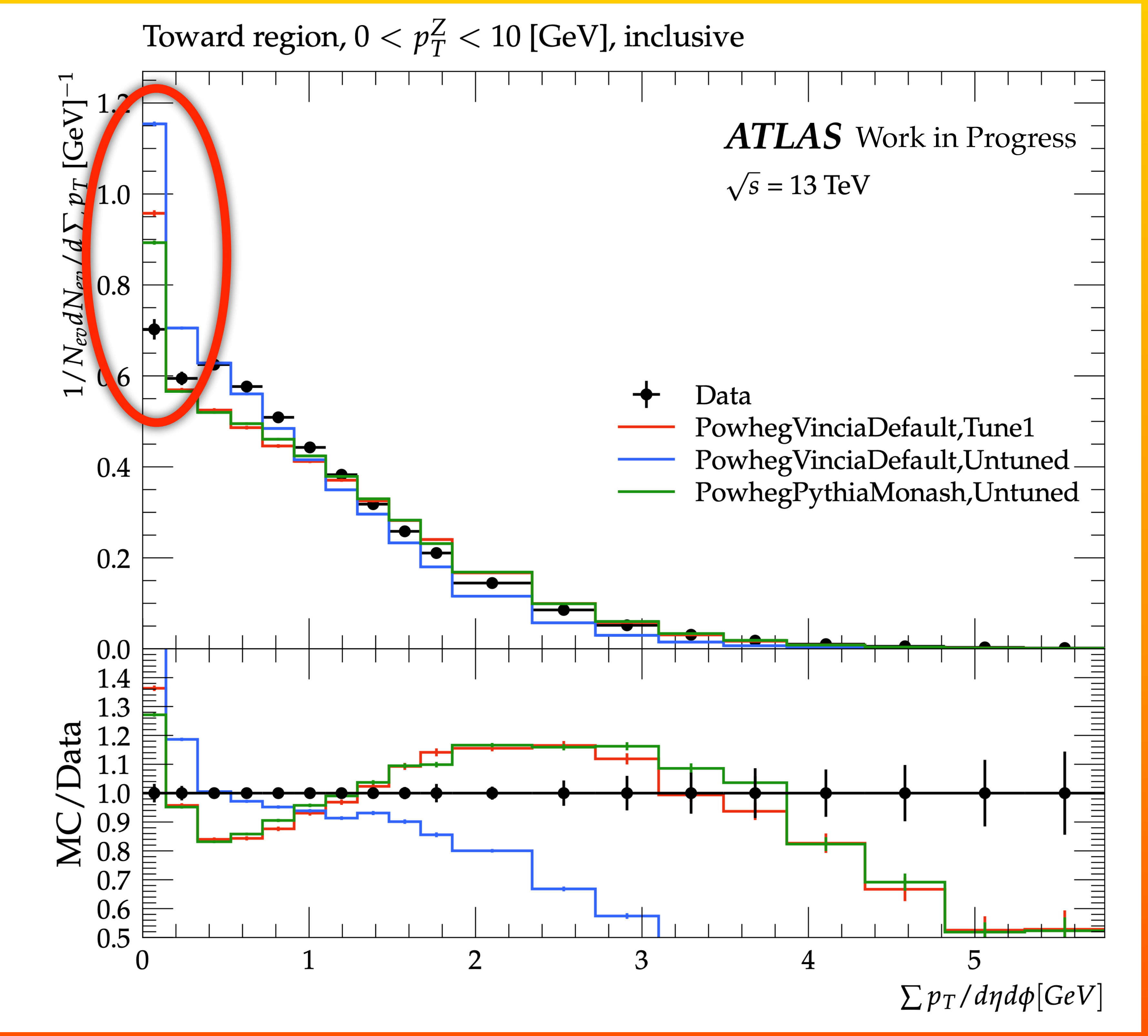
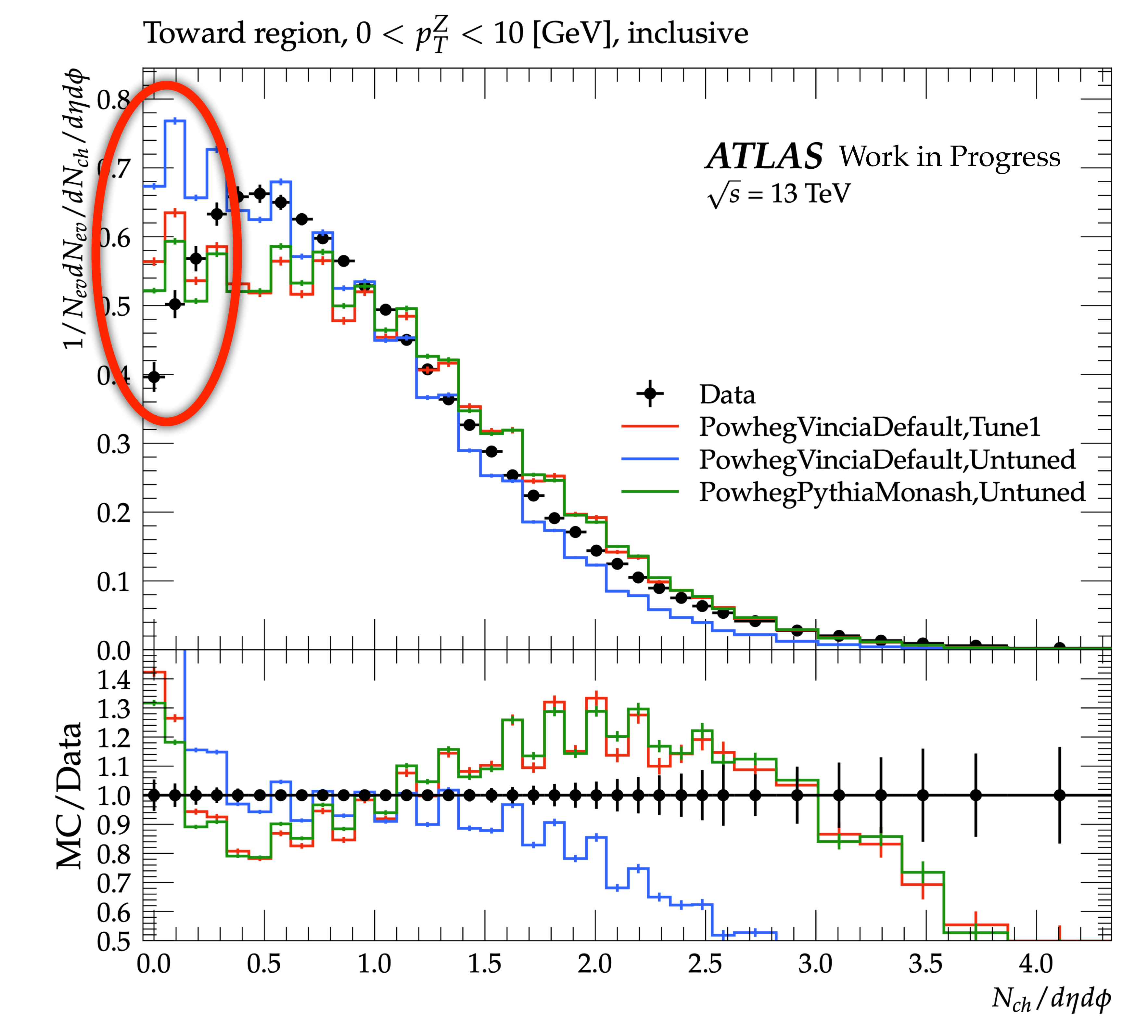




✦ Subsequent Tunes

- Parameters: pT0ref, coreRadius, coreFraction, range, and mpi_alphaS

Low Thrust in Transmin+Toward

Pythia 8 Parameter	Value
MPI:pT0ref	2.025
MPI:coreRadius	0.638
MPI:coreFraction	0.419
ColourReconnection:Range	2.134
MPI:alphaS	0.119

$\chi^2/N_{\mathrm{dof}} \approx 2.97$

Low Thrust in Transmin+Toward and Low ZpT (0-60 GeV)

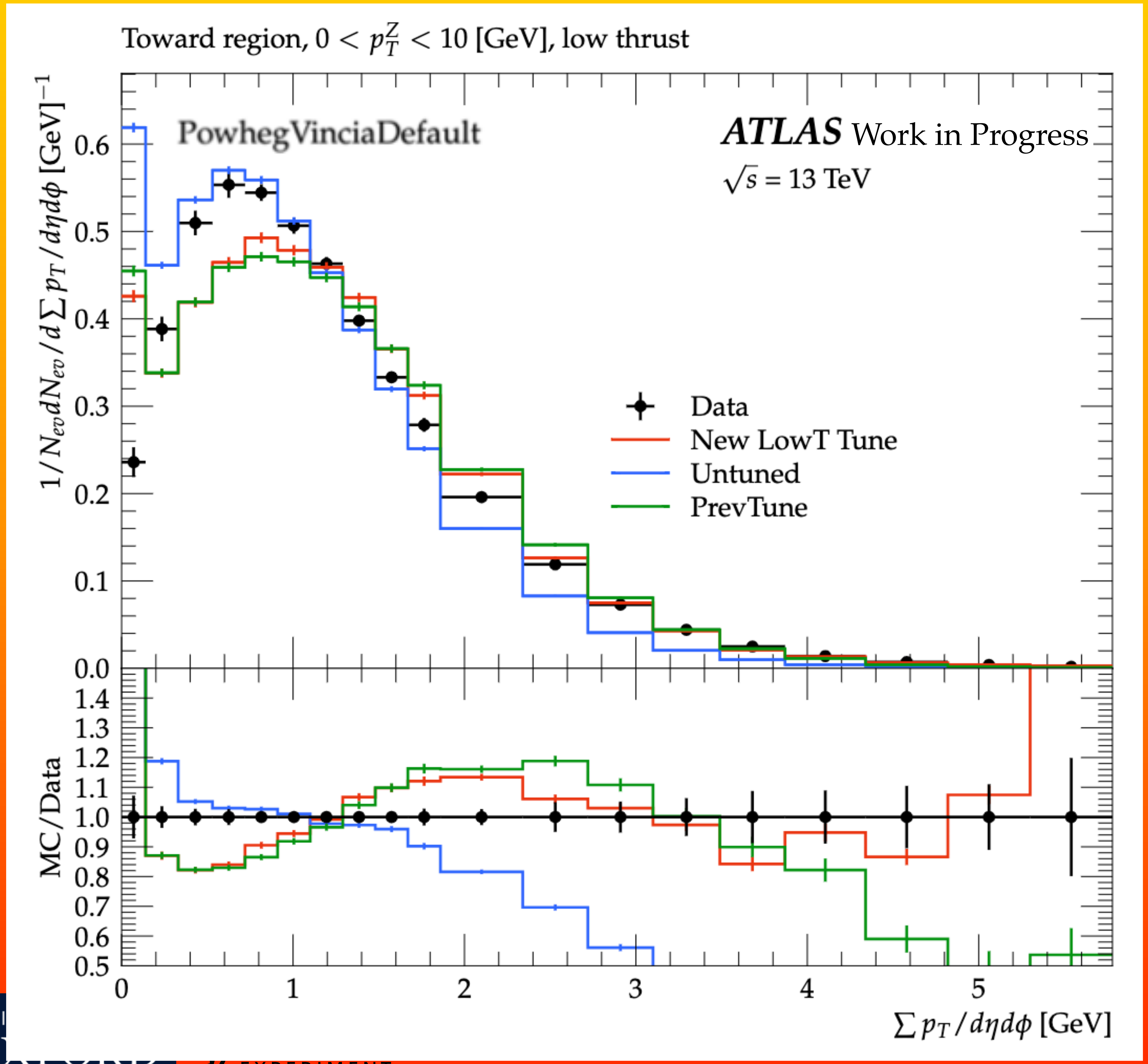
Pythia 8 Parameter	Value
MPI:pT0ref	2.003
MPI:coreRadius	0.677
MPI:coreFraction	0.400
ColourReconnection:Range	2.164
MPI:alphaS	0.119

$\chi^2/N_{\mathrm{dof}} \approx 4.23$

✦ Subsequent Tunes

- Parameters: pT0ref, coreRadius, coreFraction, range, and mpi_alphaS

Low Thrust in Transmin+Toward



Low Thrust in Transmin+Toward
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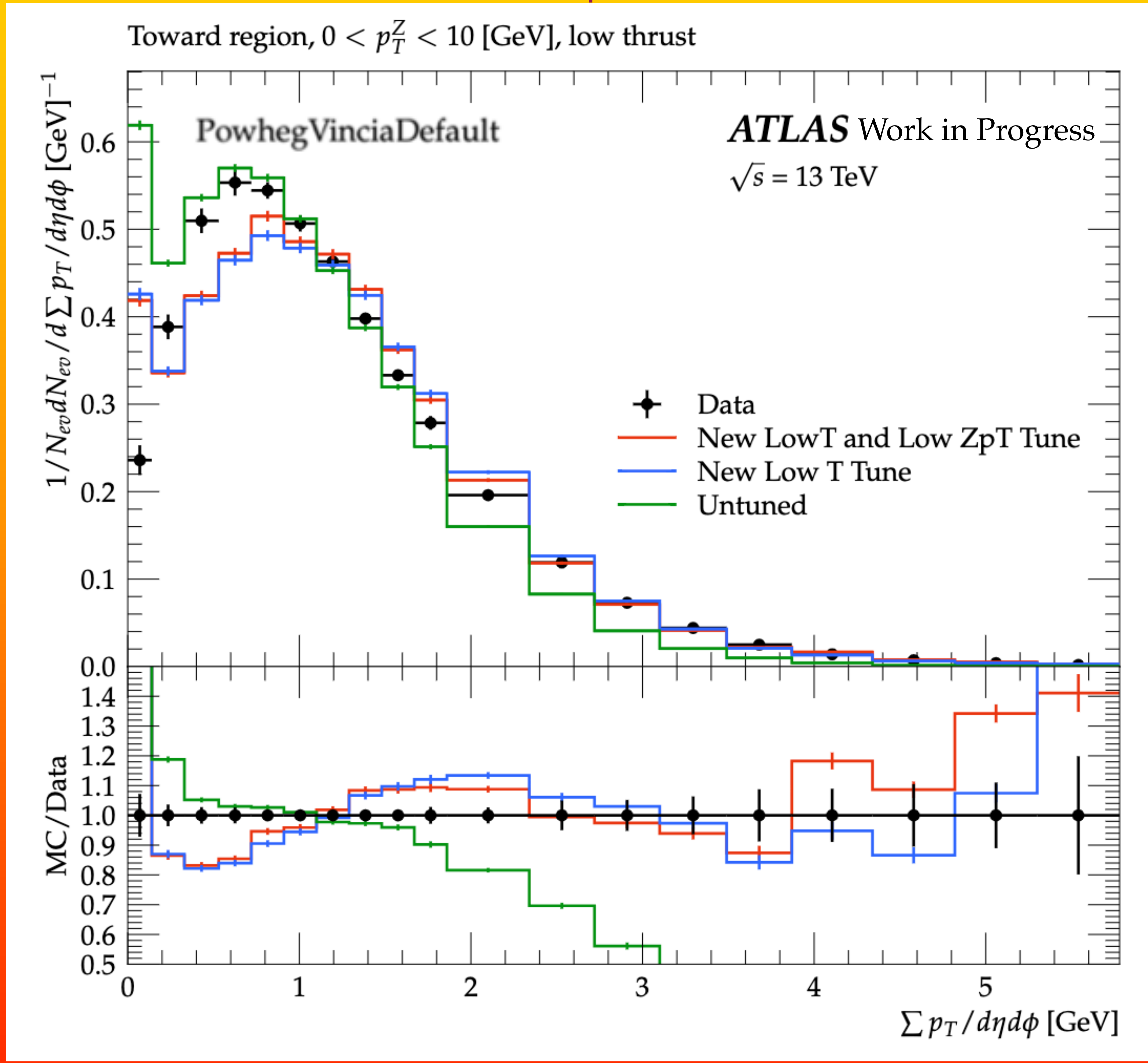

✦ Subsequent Tunes 2: Polynomial Order Change

- Parameters: pT0ref, coreRadius, coreFraction, range, and mpi_alphaS
- Order 2 polynomials used during interpolation

Low Thrust in Transmin+Toward

PYTHIA 8 Parameter	Value
MPI:pT0ref	2.164
MPI:coreRadius	0.336
MPI:coreFraction	0.301
ColourReconnection:Range	2.297
MPI:alphaS	0.120

$\chi^2/N_{\mathrm{dof}} \approx 2.79$

Low Thrust in Transmin+Toward and Low ZpT (0-60 GeV)

PYTHIA 8 Parameter	Value
MPI:pT0ref	2.040
MPI:coreRadius	0.692
MPI:coreFraction	0.433
ColourReconnection:Range	2.222
MPI:alphaS	0.119

$\chi^2/N_{\mathrm{dof}} \approx 3.84$

✦ Subsequent Tunes 2: Polynomial Order Change

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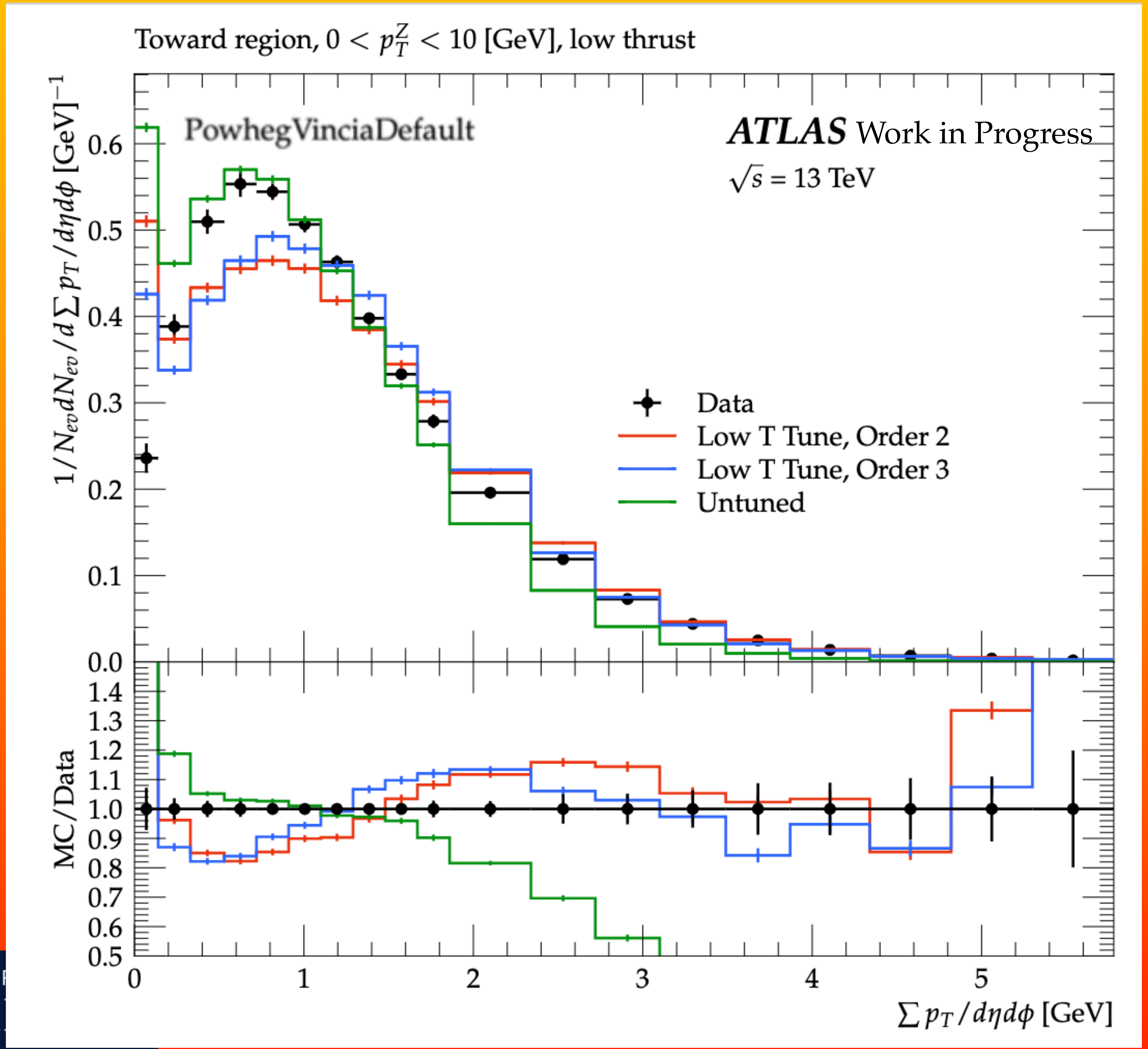
- Order 2 polynomials used during interpolation

Low Thrust in Transmin+Toward



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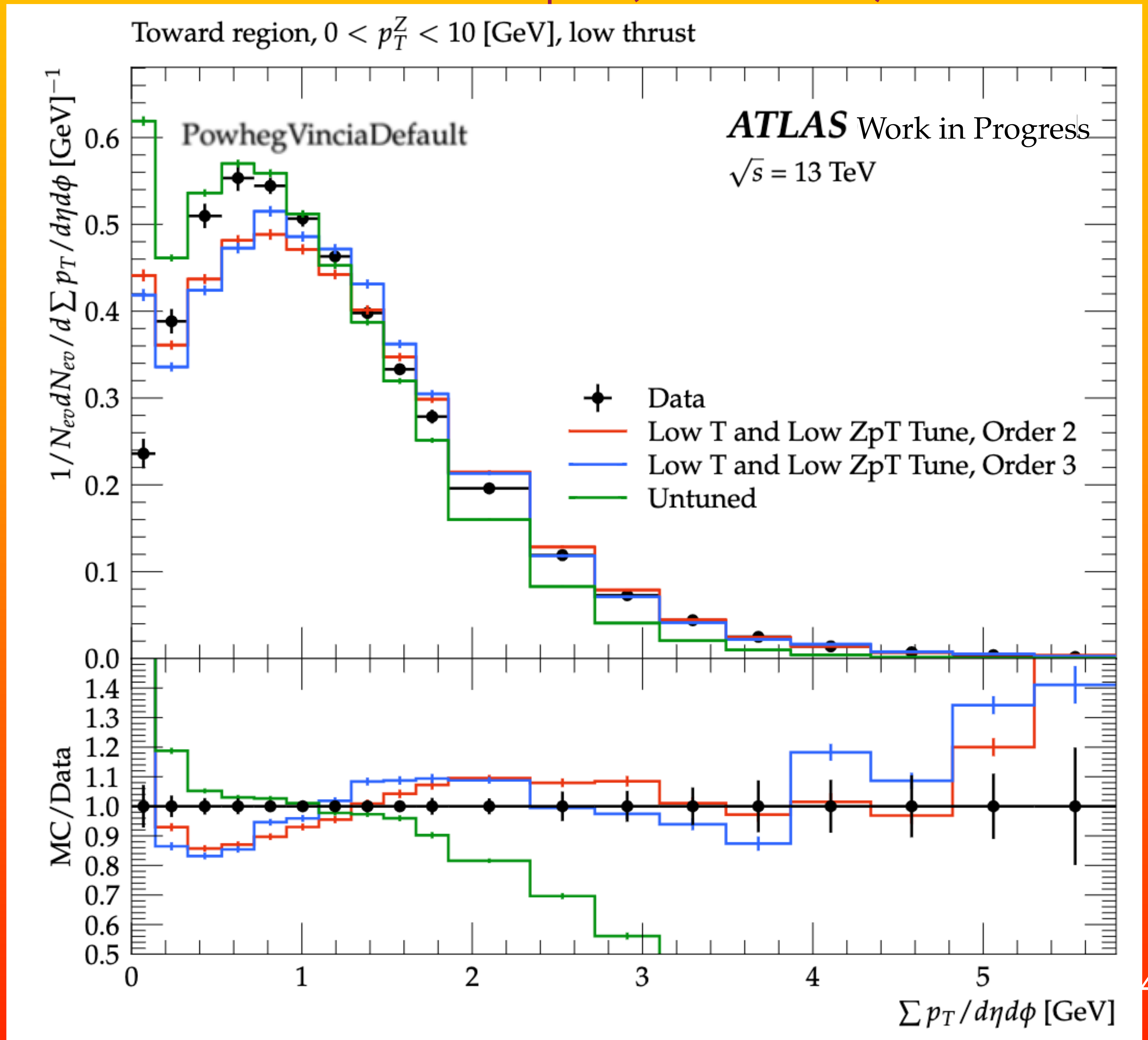


✦ Conclusion and Plans

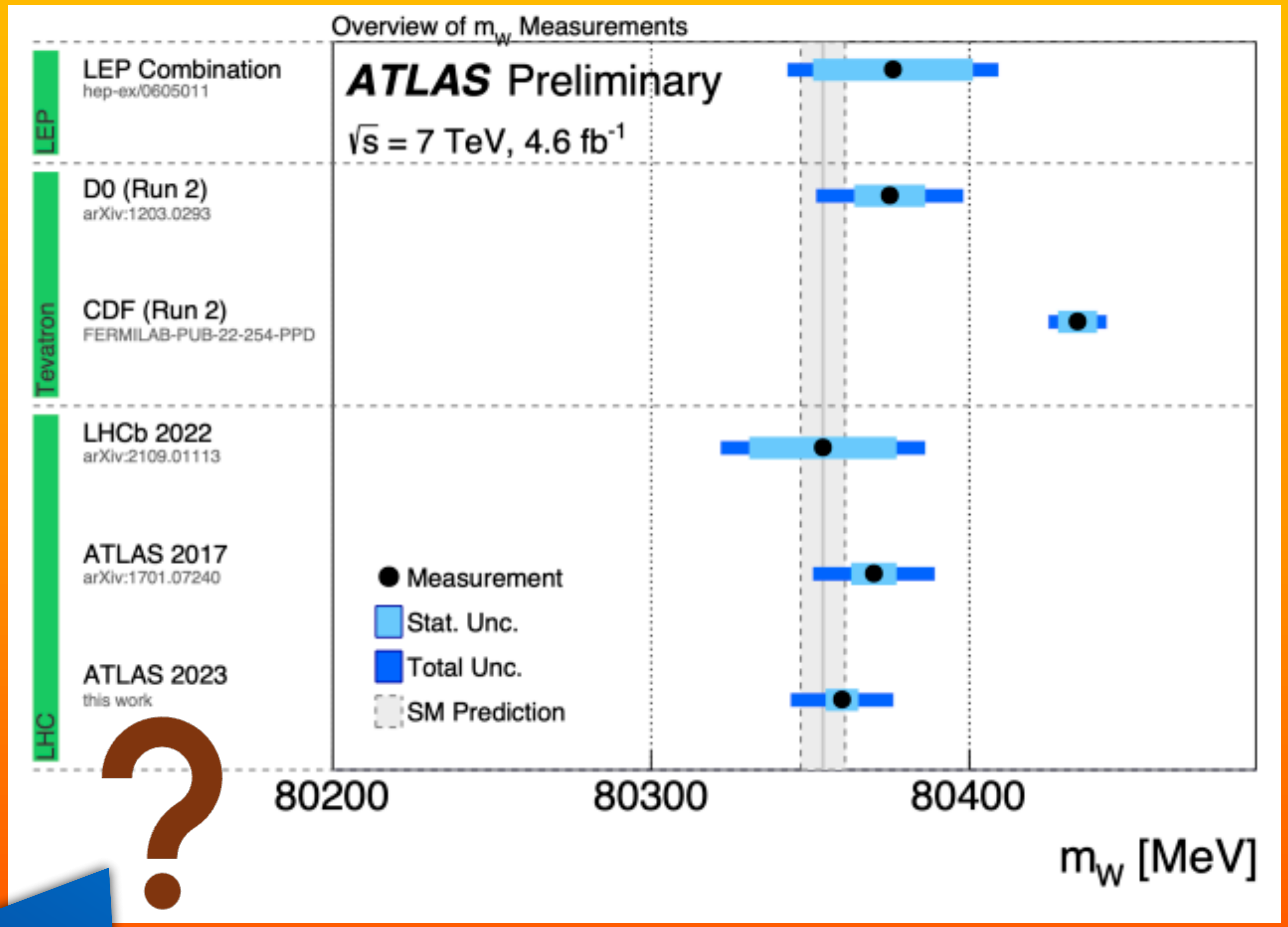
- The first ATLAS dedicated tune for VINCIA
- An initial tune with MPI and colour reconnection parameters, to low-thrust distributions:

$$\chi^2/N_{\text{dof}} \approx 3.3$$

- Best: Order 2, low T in transmin+toward, $\chi^2/N_{\text{dof}} \approx 2.79$
- Tuned, untuned VINCIA; and PYTHIA samples overpredict the number of events with low $\sum p_T$ and N_{ch} $\longrightarrow$ will be investigated.

◉ <u>Next Steps:</u>

- Obtain a tune with better χ^2 → for NLO samples, focus on a smaller p_T^Z range with correct parameters
- Extend to include more distributions → higher order calculations:
  - MiNNLO+VINCIA and MiNNLO+PYTHIA samples will be studied

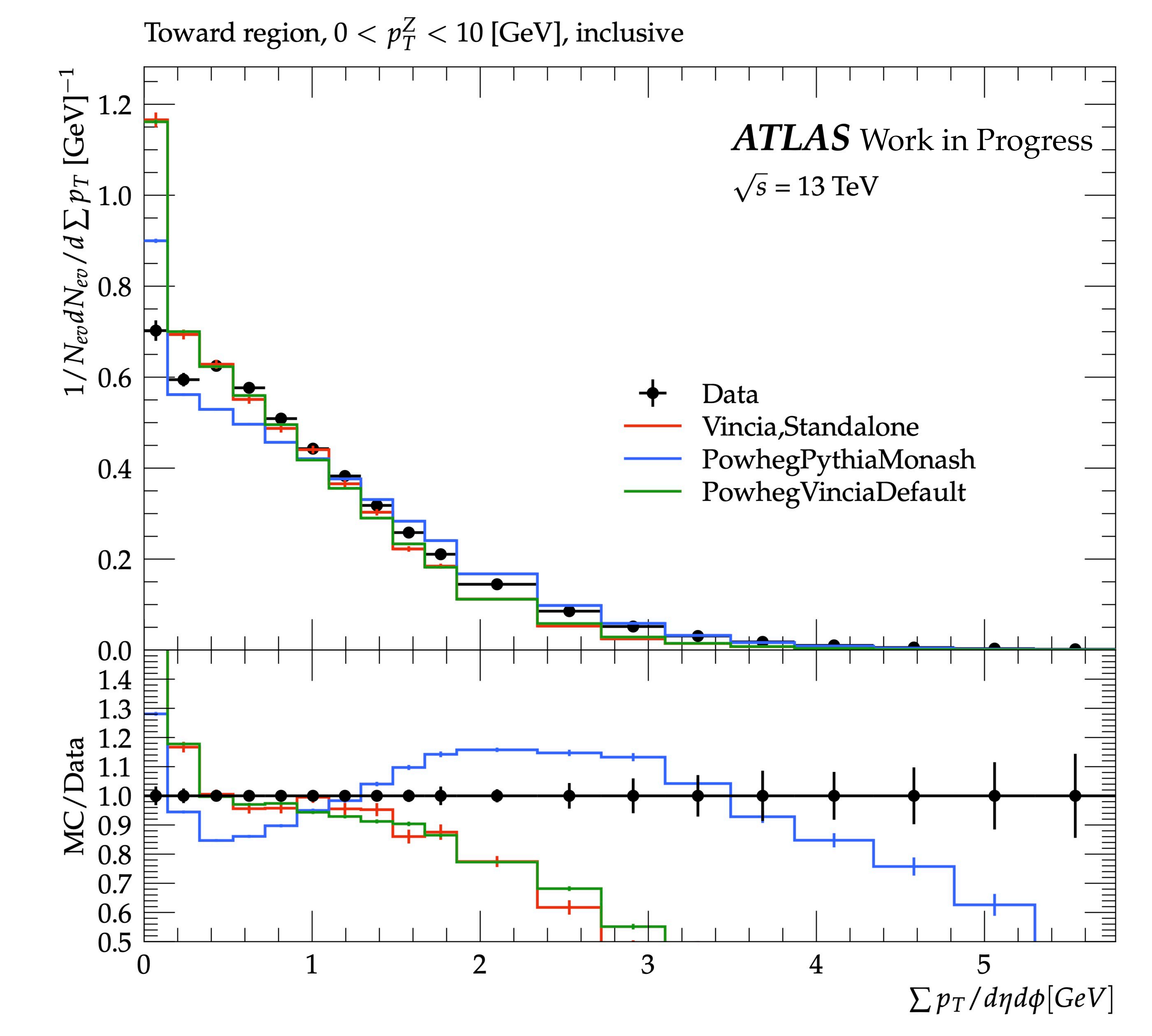


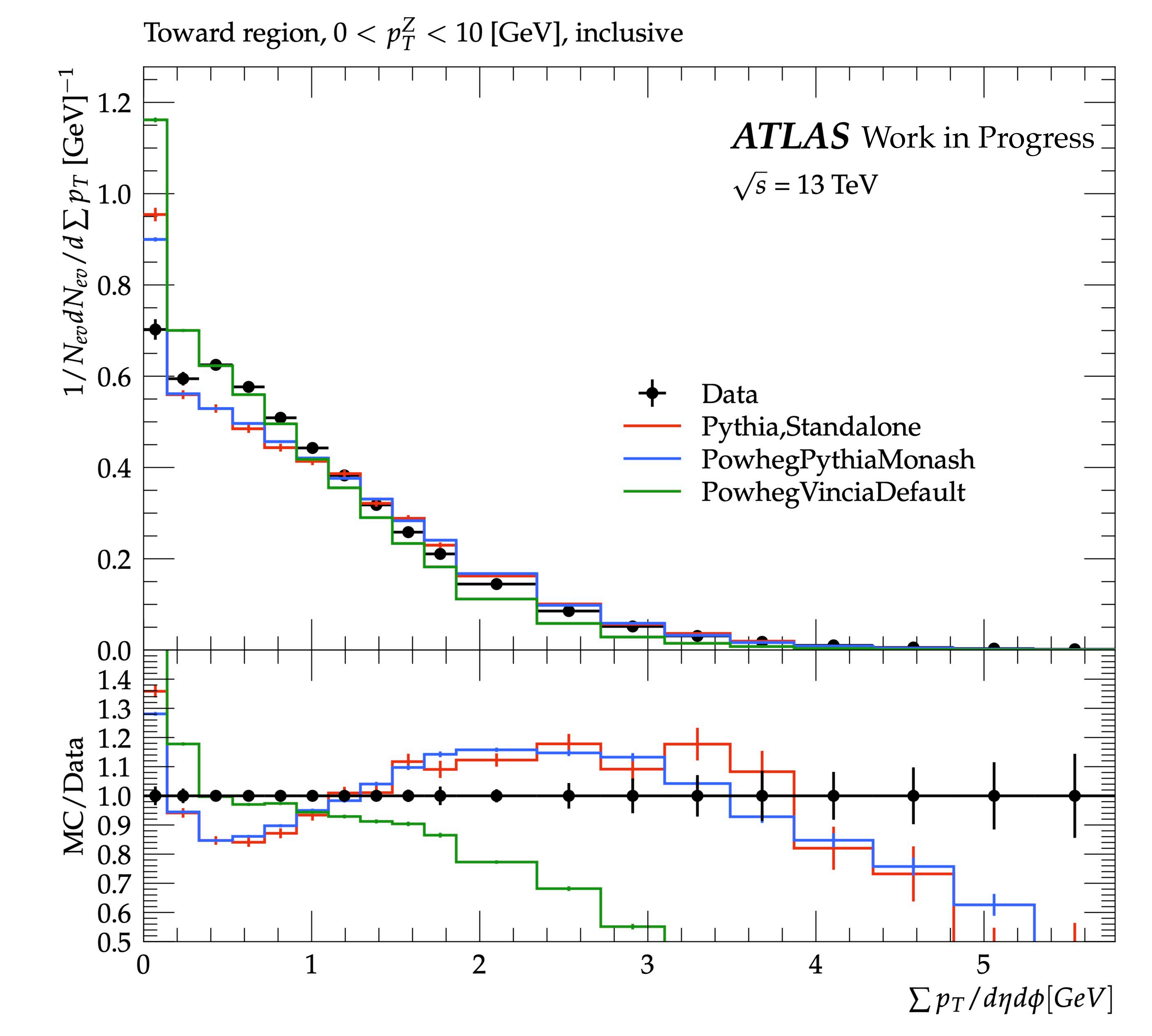
ATLAS Collaboration, "ATLAS Experiment: Measurements of the W boson mass"(2023), URL: https://cds.cern.ch/record/2853216

BACKUP

✦ Investigation: Standalone PYTHIA and VINCIA

◉ ME from Pythia 8





✦ Employed PYTHIA Parameters

- MultipartonInteractions:pT0Ref → transition between hard and soft interactions, pT0ref ↓ MPI ↑
- MultipartonInteractions:bProfile → impact parameter profile of the incoming protons
  - Default: Convolution of the form $exp(-b$^expPow) → MultipartonInteractions:expPow
  - Alternative: Double Gaussian impact parameter profiles

MultipartonInteractions:coreFraction	MultipartonInteractions:coreRadius
Fraction of proton content in the inner core	Inner core radius

- ColourReconnection:range → enters the probability of an MPI system to be merged with a harder one
  range ↑ more colour reconnections

- BeamRemnants:primordialKTsoft and BeamRemnants:primordialKThard → intrinsic k_T in the soft and high interaction limits
- Vincia:alphaSvalue → shower α_s for initial and final state

✦ Trial Tune with Professor

- Parameters: pT0ref, expPow, range
- Inputs: Differential distributions in $\sum p_T$, N_{ch}, mean $\mathrm{p_T}$ for low-thrust events
- χ^2 goodness-of-fit function used

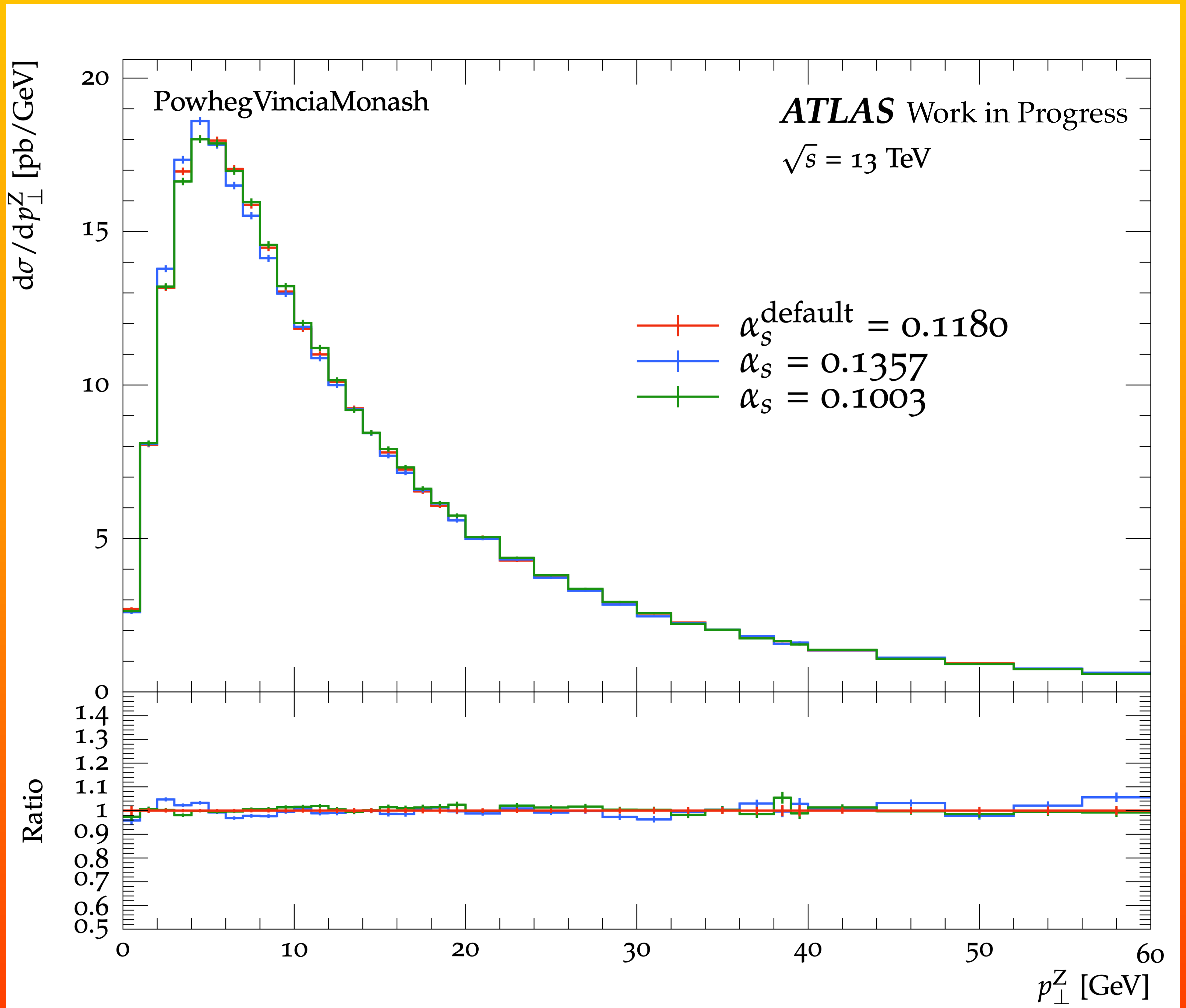
$\mathrm{expPow} \approx 1.96$

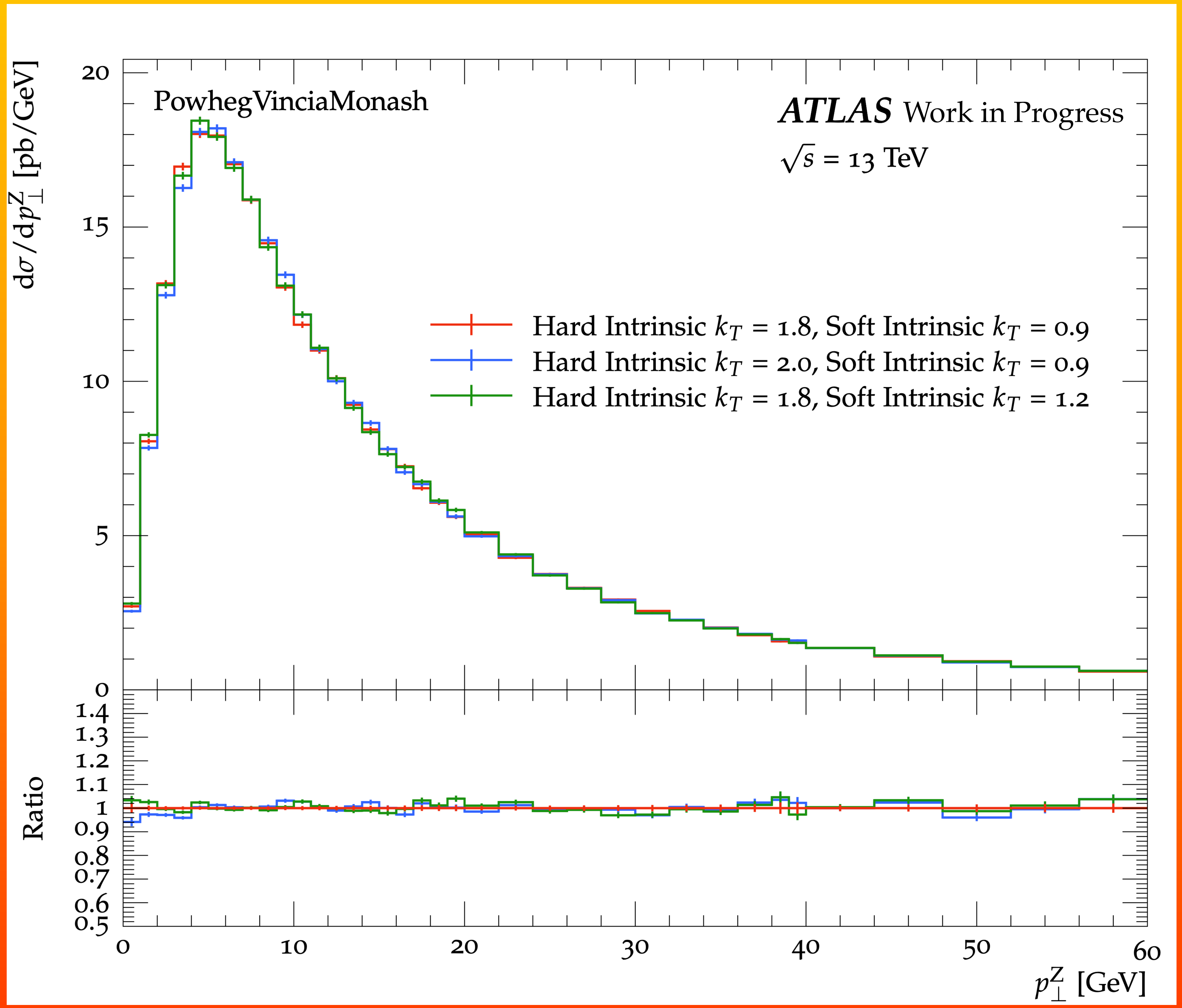
$\mathrm{expPow} = 2$ corresponds to Gaussian impact parameter profiles for the incoming protons

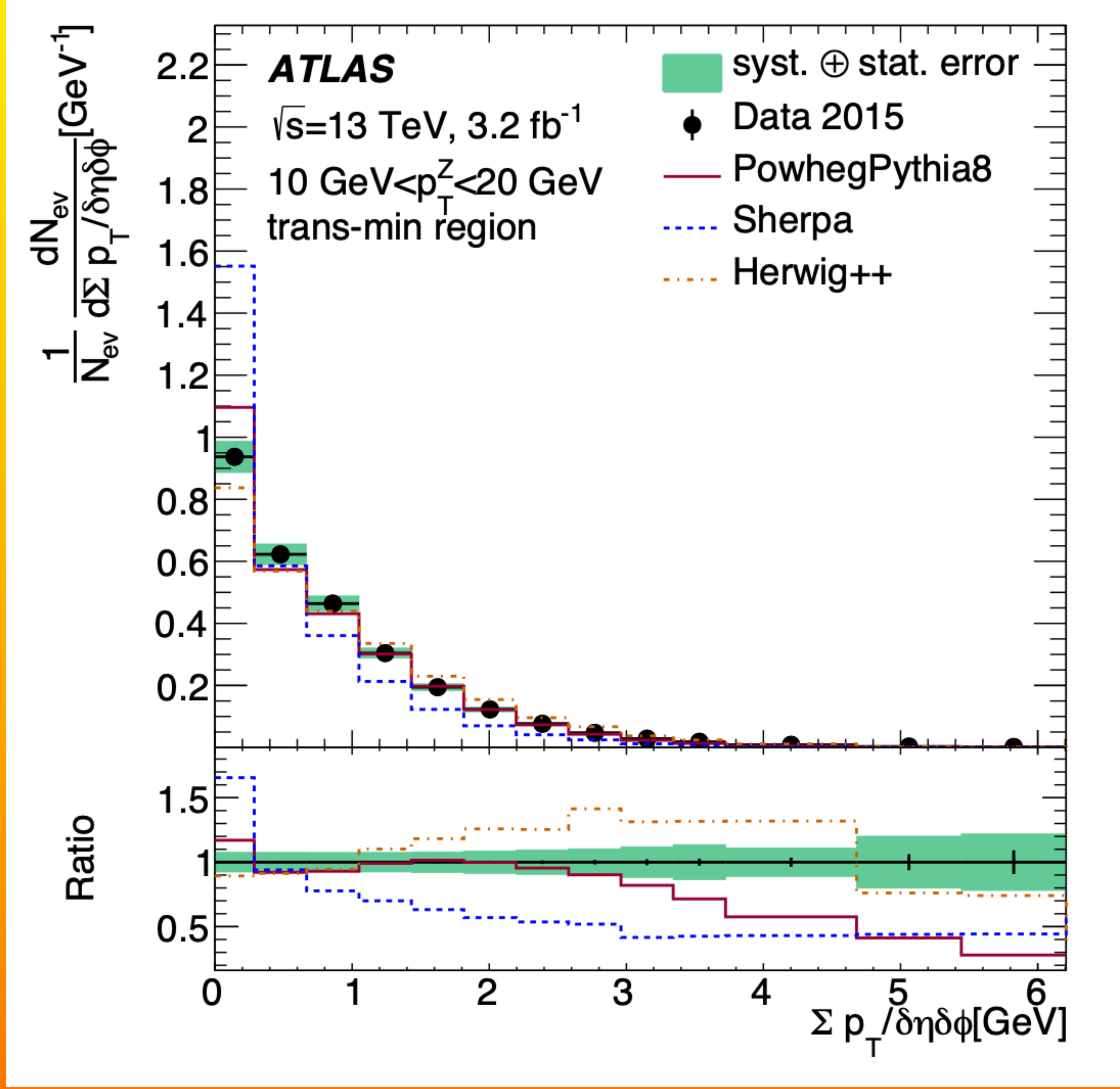
✦ Modelling of p_T^Z

- Matrix element at NLO accuracy → reweighting p_T^Z distribution to that used in m_W analysis
- Test of robustness of the tune → shower α_s + hard and soft intrinsic k_T → Control the radiation spectrum

Sensitivities:







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