ATLAS measurements of Underlying event in Z-boson production

LHC-EW Precision WG

May. 25th, 2018

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for the ATLAS Collaboration

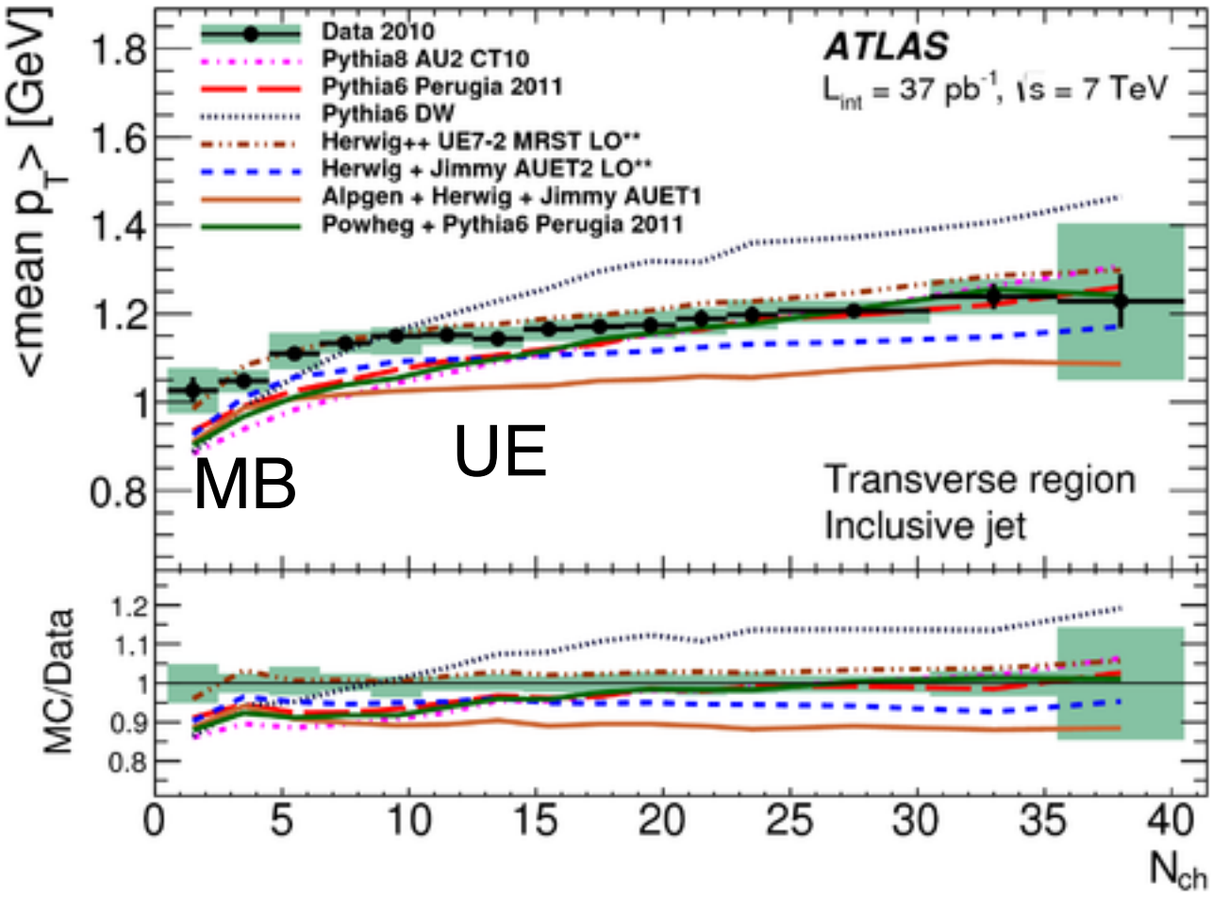
Outline

- What is underlying event
- Why should you care for EWK precision physics?
- ATLAS measurements sensitive to underlying event in Drell-Yan
  - Underlying event in Drell-Yan
  - Event shapes in Drell-Yan
- And their comparison to our PP8-AZNLO model
- Some perspectives on possible future measurements, also in view of the low-mu run

The Underlying event

- The Underlying Event is usually defined as ***the collection of particles produced in a single hadronic interaction which do not originate from the primary scattering.***

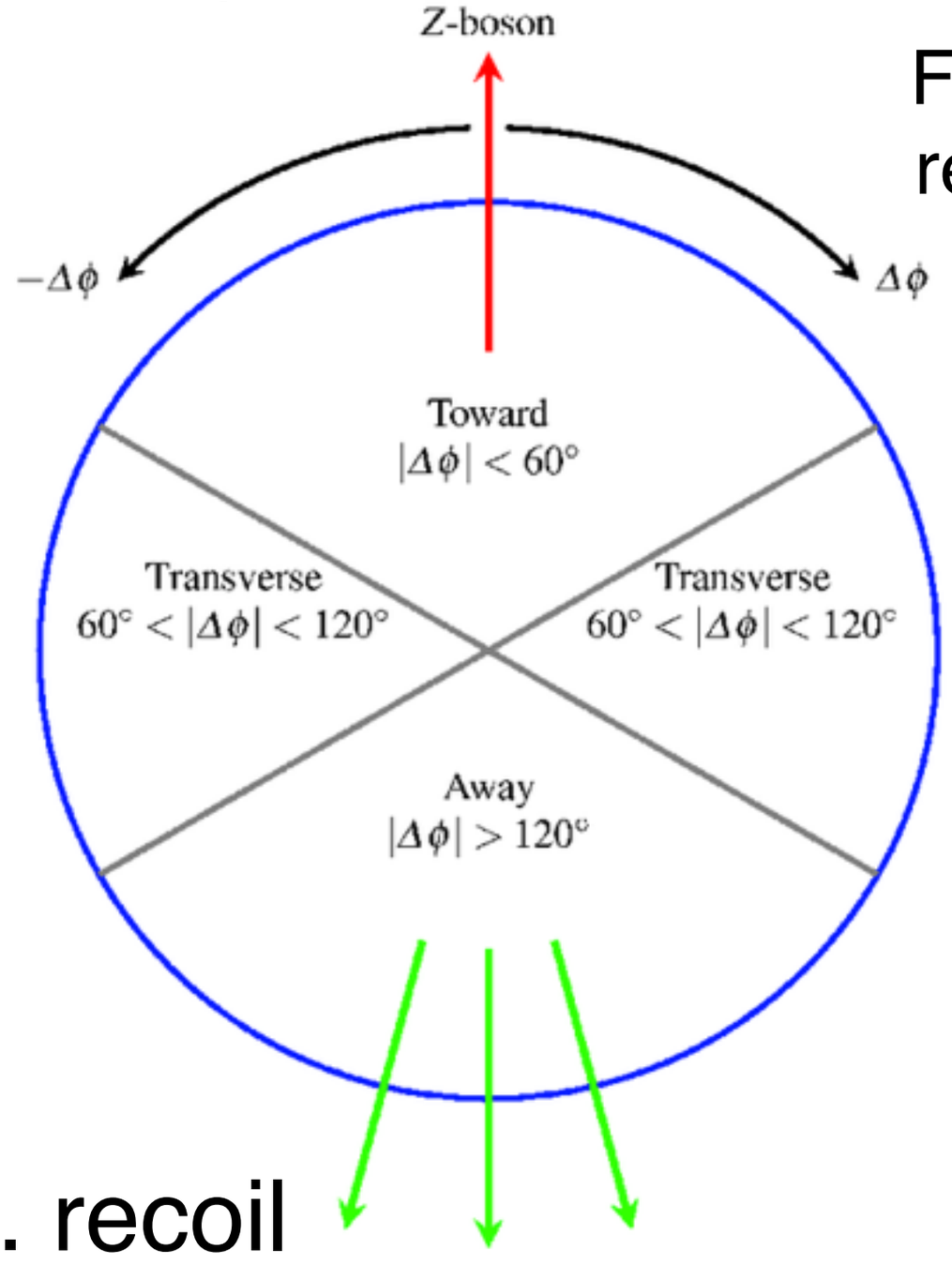
- Events with a jet trigger are accompanied by a higher amount of overall activity, also away from the core of the jet
- Interpreted as a biasing effect in the impact parameter
  - Large matter overlap, more (hard) MPIs produced



- Described in MC with Multiple Parton Interactions models
  - Phenomenological description, dependent on many parameters tuned to data (and assumed universal)

UE sensitive observables

- Regions are defined in the transverse plane with respect to a hard probe:



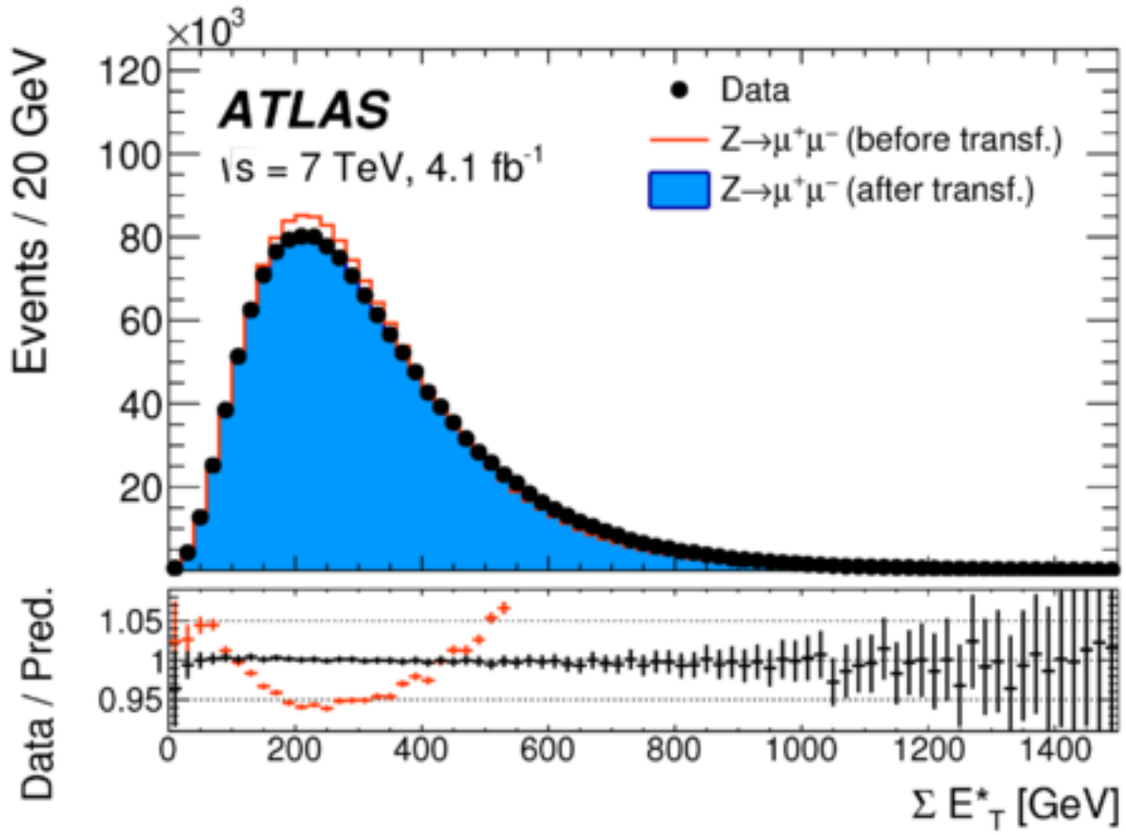
had. recoil

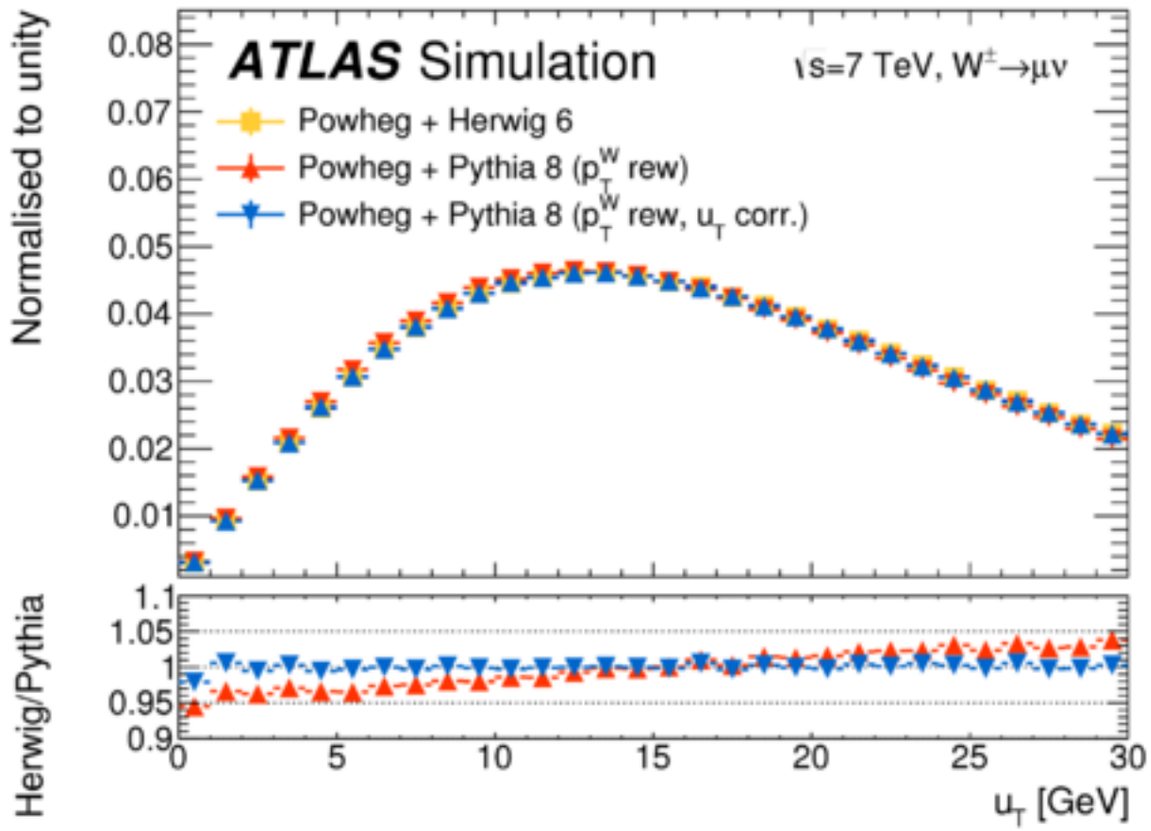
For DY production the Toward region (subtracting leptons) is also a probe of the UE

"Transverse region" is UE enhanced

Why should you care?

- Underlying Event activity will enter you lepton isolation cones
  - Scale-factors will correct this, introducing a dependency on the UE model used in the generator
- In our W-mass measurement, the recoil response is calibrated to data using Z event
  - Assuming the Underlying Event contribution is the same in the two samples (tested with Pythia8 vs Herwig6), giving a residual 5 MeV uncertainty on the W mass





Atlas measurements in DY

- ATLAS has performed two measurements of observables sensitive to the Underlying Event in Drell-Yan at 7 TeV

- [STDM-2014-07] Measurement of distributions sensitive to the underlying event in inclusive Z-boson production in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector

- [STDM-2011-42] Measurement of event-shape observables in $Z \rightarrow l^+l^-$ events in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector at the LHC

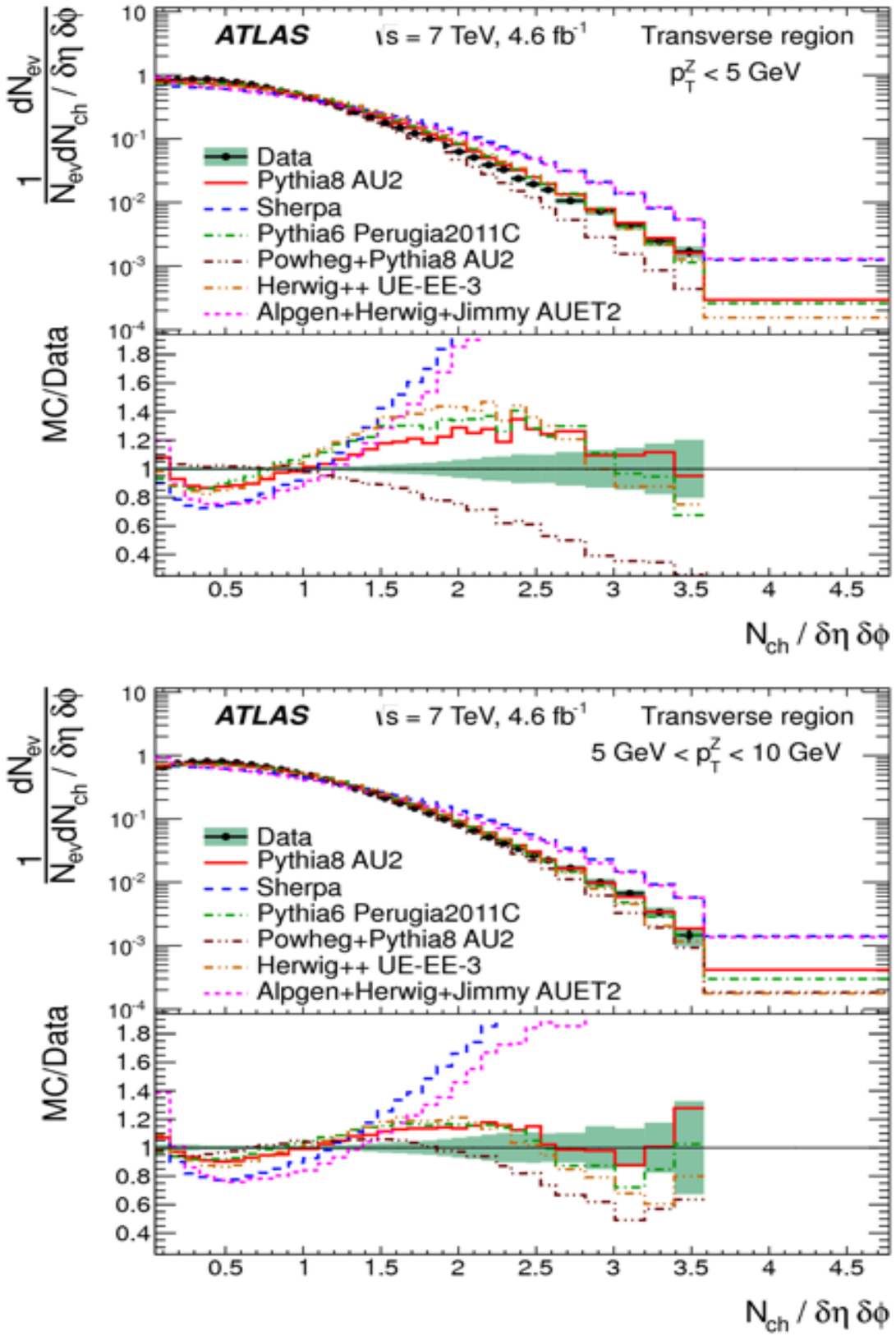
Underlying Event in DY

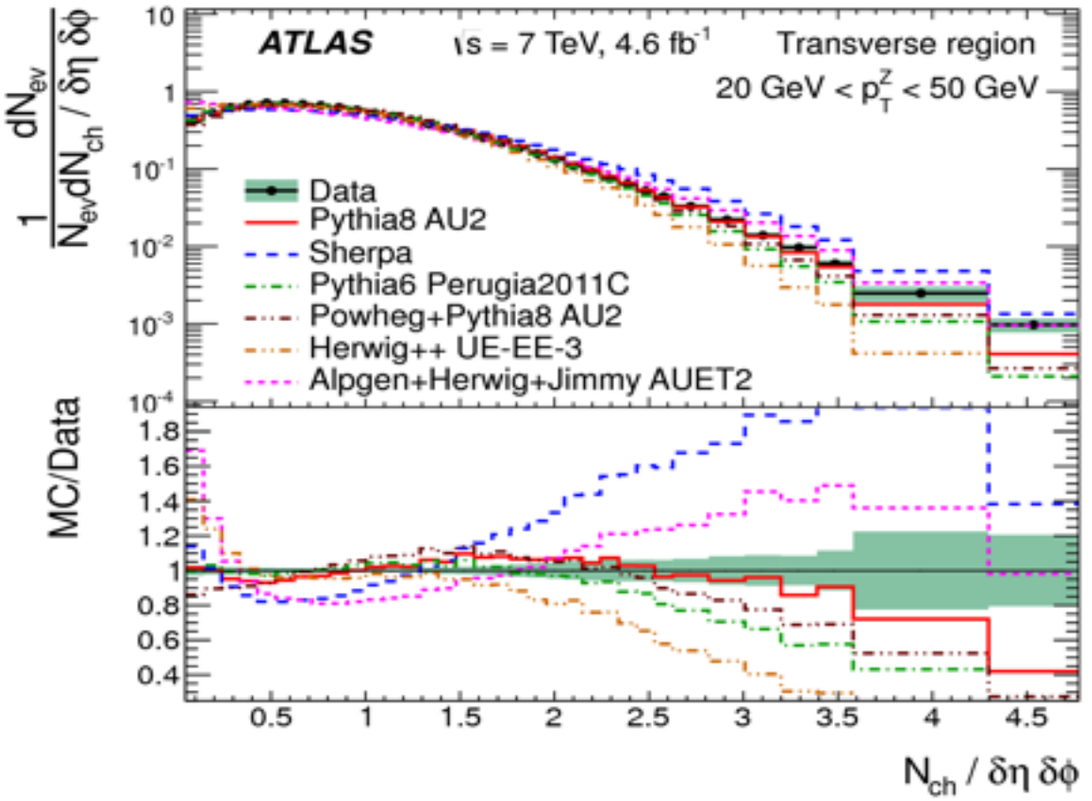
- Standard measurement of Underlying Event in Drell-Yan
- Z-candidates are built from leptons of p_T>20 GeV and eta<2.4
- The measured observables are built from the number and transverse momenta of stable charged particles GeV in the event with p_T>500

- Observables are presented both inclusively and showing their mean value as a function of Z p_T
- The mean charged particle transverse momentum is constructed on an event-by-event basis and averaged over all events

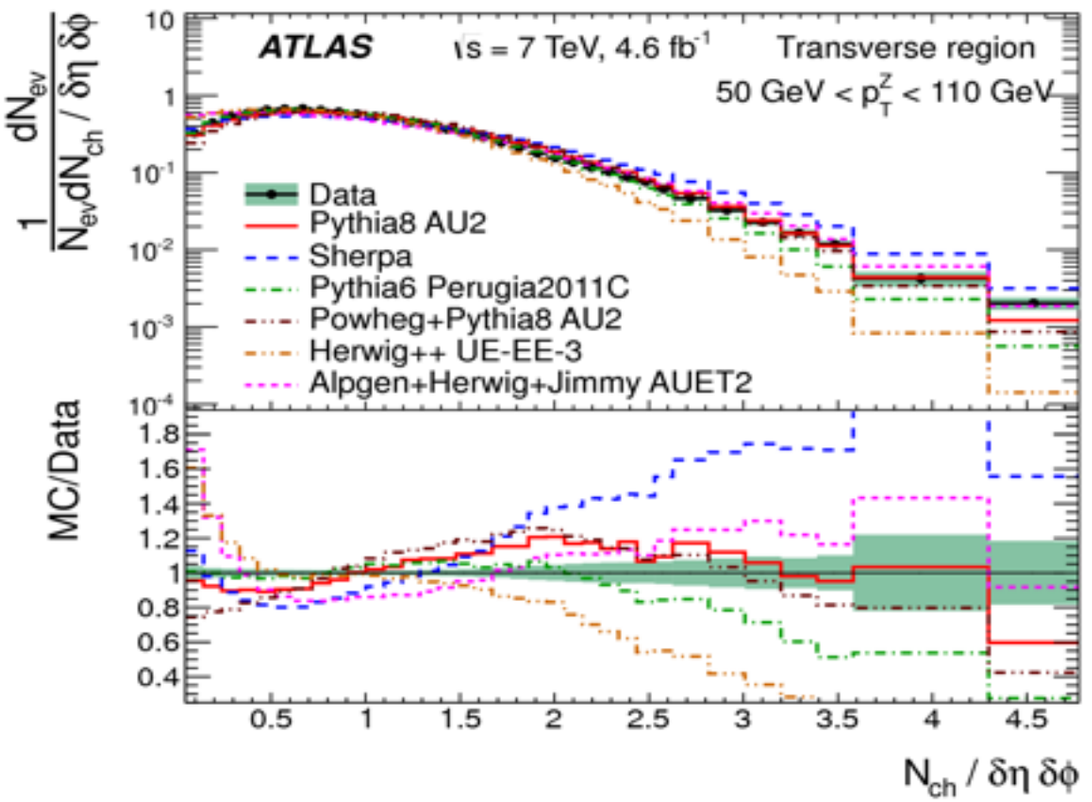
Observable	Definition
p_{T}^{Z}	Transverse momentum of the Z-boson
$N_{\mathrm{ch}}/\delta\eta\,\delta\phi$	Number of stable charged particles per unit η–ϕ
$\sum p_{\mathrm{T}}/\delta\eta\,\delta\phi$	Scalar p_{T} sum of stable charged particles per unit η–ϕ
Mean p_{T}	Average p_{T} of stable charged particles

UE in DY

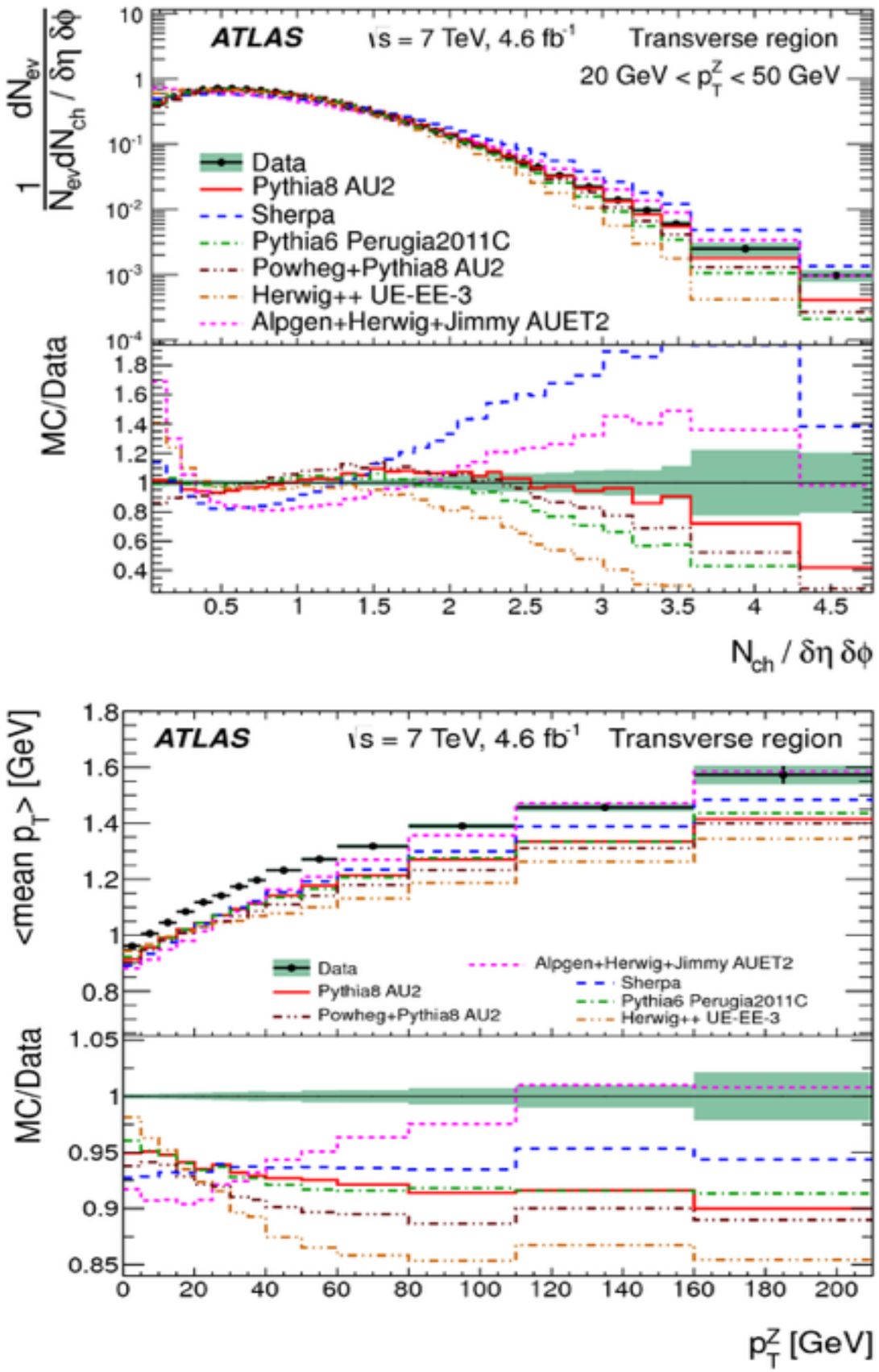

ATLAS
√s = 7 TeV, 4.6 fb-1
Transverse region
p_T^Z < 5 GeV
Data
Pythia8 AU2
Sherpa
Pythia6 Perugia2011C
Powheg+Pythia8 AU2
Herwig++ UE-EE-3
Alpgen+Herwig+Jimmy AUET2
1/(N_ev dN_ch/dη dφ) dN_ev
MC/Data
N_ch / δη δφ

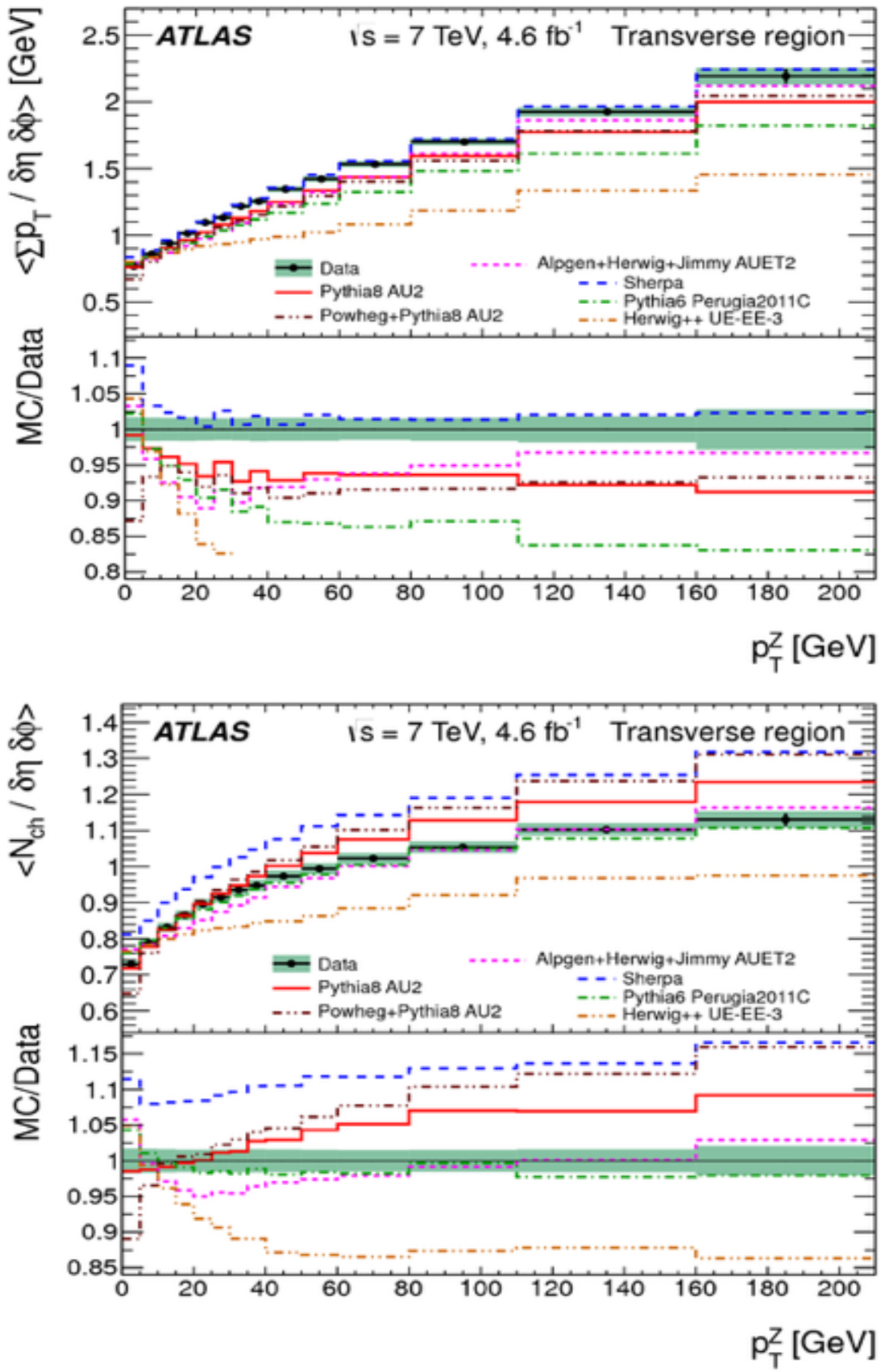

ATLAS
√s = 7 TeV, 4.6 fb-1
Transverse region
20 GeV < p_T^Z < 50 GeV
Data
Pythia8 AU2
Sherpa
Pythia6 Perugia2011C
Powheg+Pythia8 AU2
Herwig++ UE-EE-3
Alpgen+Herwig+Jimmy AUET2
1/(N_ev dN_ch/dη dφ) dN_ev
MC/Data
N_ch / δη δφ

ATLAS
√s = 7 TeV, 4.6 fb-1
Transverse region
5 GeV < p_T^Z < 10 GeV
Data
Pythia8 AU2
Sherpa
Pythia6 Perugia2011C
Powheg+Pythia8 AU2
Herwig++ UE-EE-3
Alpgen+Herwig+Jimmy AUET2
1/(N_ev dN_ch/dη dφ) dN_ev
MC/Data
N_ch / δη δφ

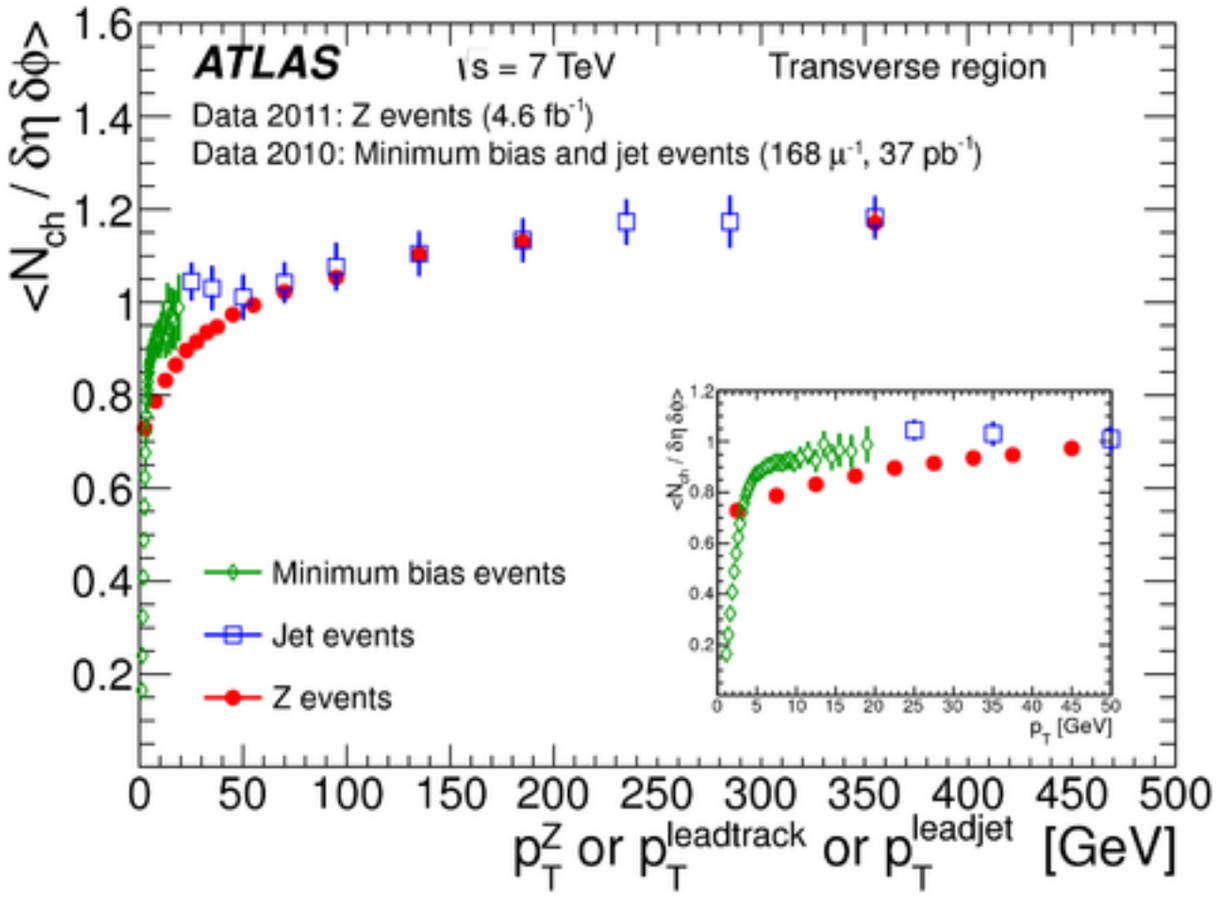

ATLAS
√s = 7 TeV, 4.6 fb-1
Transverse region
50 GeV < p_T^Z < 110 GeV
Data
Pythia8 AU2
Sherpa
Pythia6 Perugia2011C
Powheg+Pythia8 AU2
Herwig++ UE-EE-3
Alpgen+Herwig+Jimmy AUET2
1/(N_ev dN_ch/dη dφ) dN_ev
MC/Data
N_ch / δη δφ

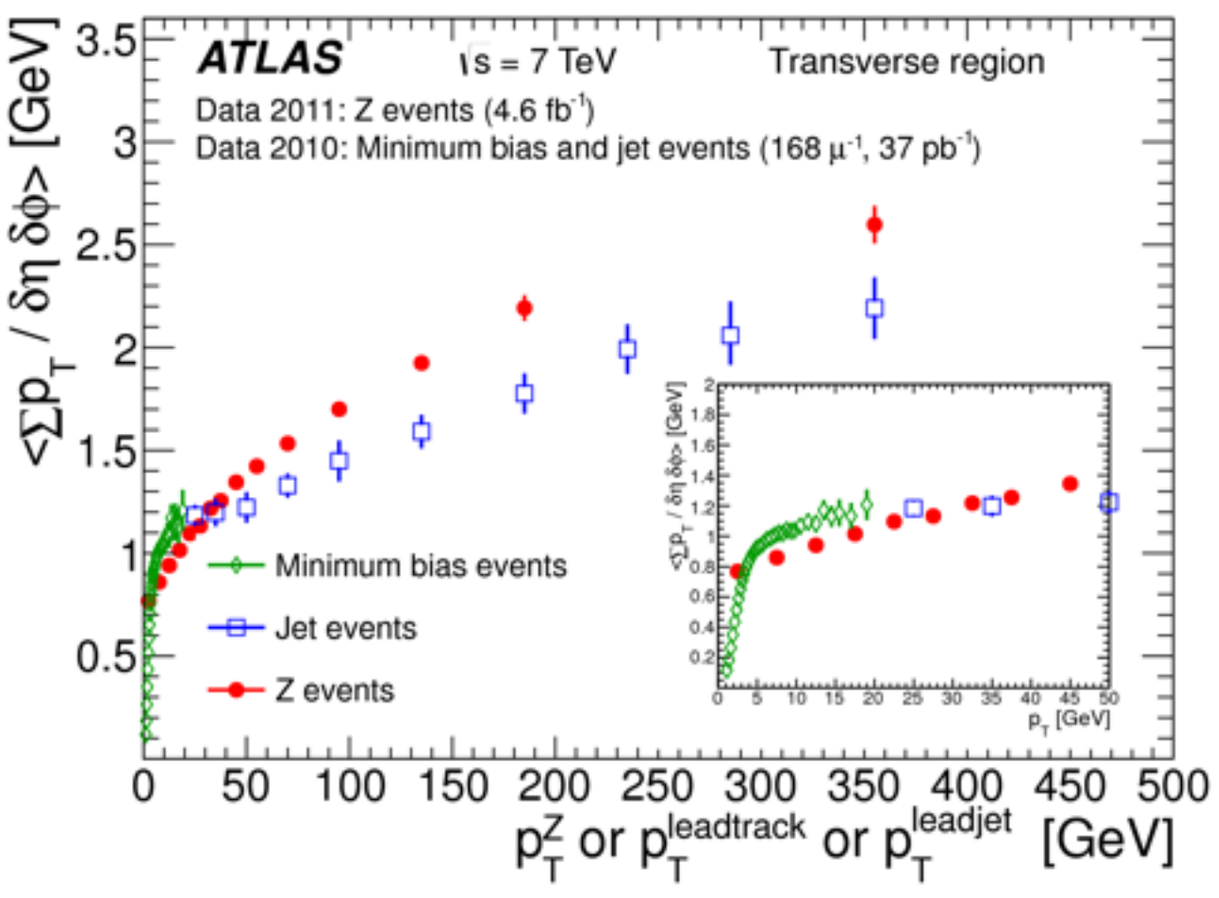
UE in DY


ATLAS
√s = 7 TeV, 4.6 fb-1
Transverse region
20 GeV < pTZ < 50 GeV
Data
Pythia8 AU2
Sherpa
Pythia6 Perugia2011C
Powheg+Pythia8 AU2
Herwig++ UE-EE-3
Alpgen+Herwig+Jimmy AUET2
1/Nev dNev/dNch/dη dφ
MC/Data
Nch / δη δφ
<mean pT> [GeV]
pTZ [GeV]


ATLAS
√s = 7 TeV, 4.6 fb-1
Transverse region
Data
Pythia8 AU2
Powheg+Pythia8 AU2
Alpgen+Herwig+Jimmy AUET2
Sherpa
Pythia6 Perugia2011C
Herwig++ UE-EE-3
<ΣpT / δη δφ> [GeV]
MC/Data
pTZ [GeV]
<Nch / δη δφ>
MC/Data
pTZ [GeV]

Testing universality





- Similar distribution of N_{ch} between jets and DY for Z p_T>50 GeV
- Residual differences in the P_T densities
- The activity in events with a Z-boson is systematically higher than that in events with jets

Event Shapes in DY

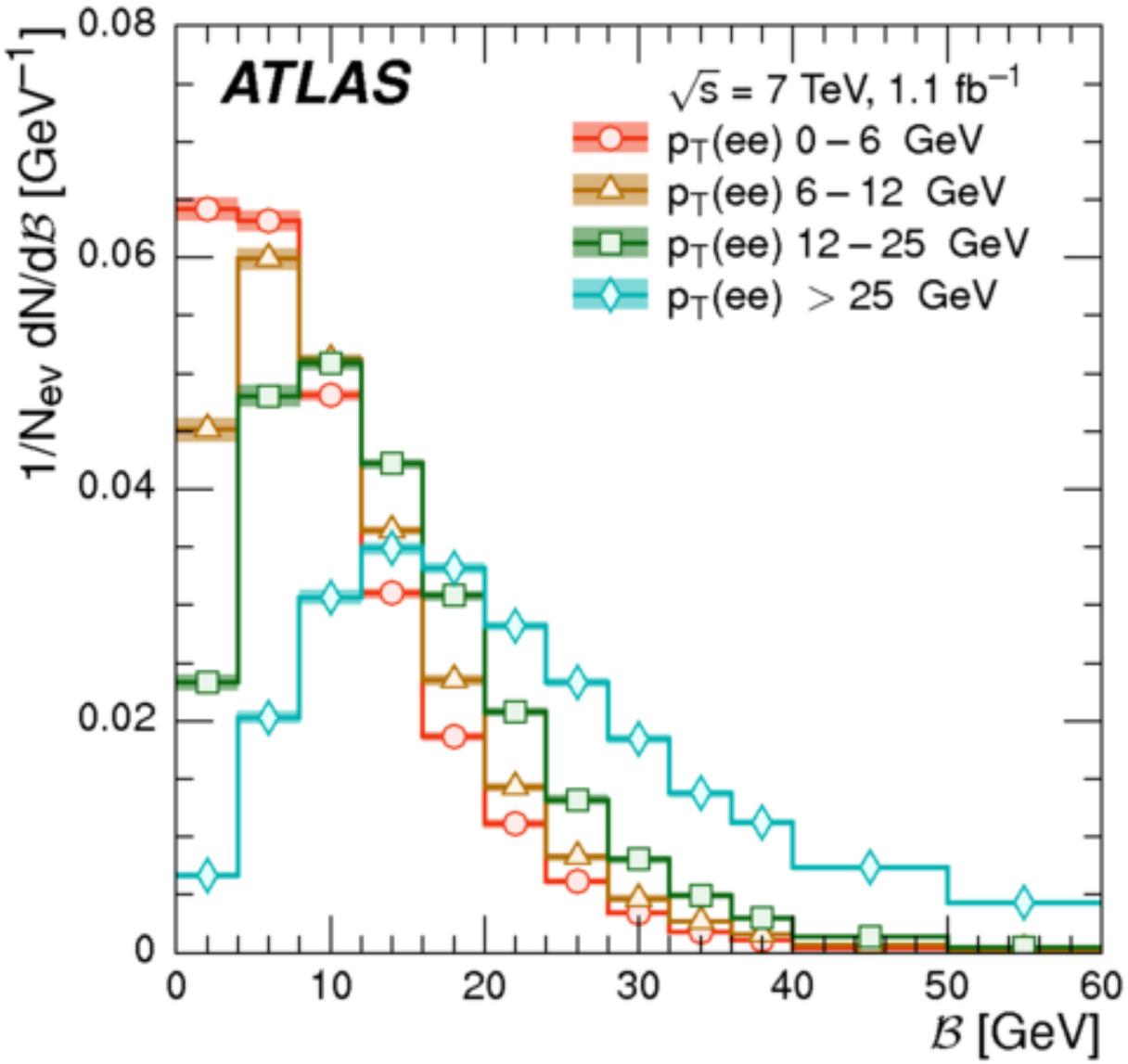
- Measurement of event shape observables using charged particles in Drell-Yan events

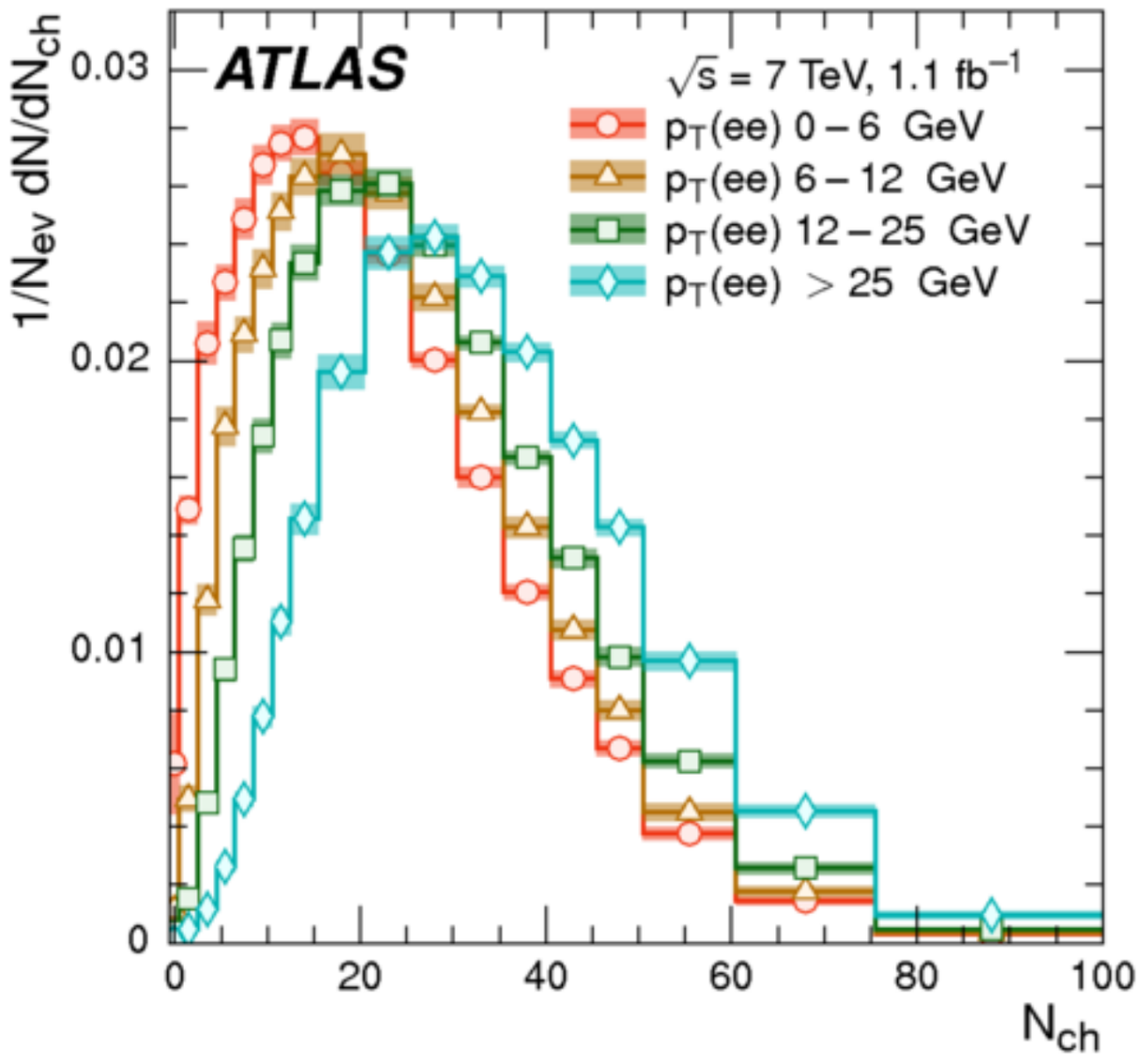
- Performed in four Z p_T bins: [0,6],[6,12],[12,25],[25,inf]
  - at low p_T enhanced contribution from UE, at higher p_T significant effects from jets

- Using charged particles with p_T>500 MeV and |eta|<2.5 after removing the boson decay products

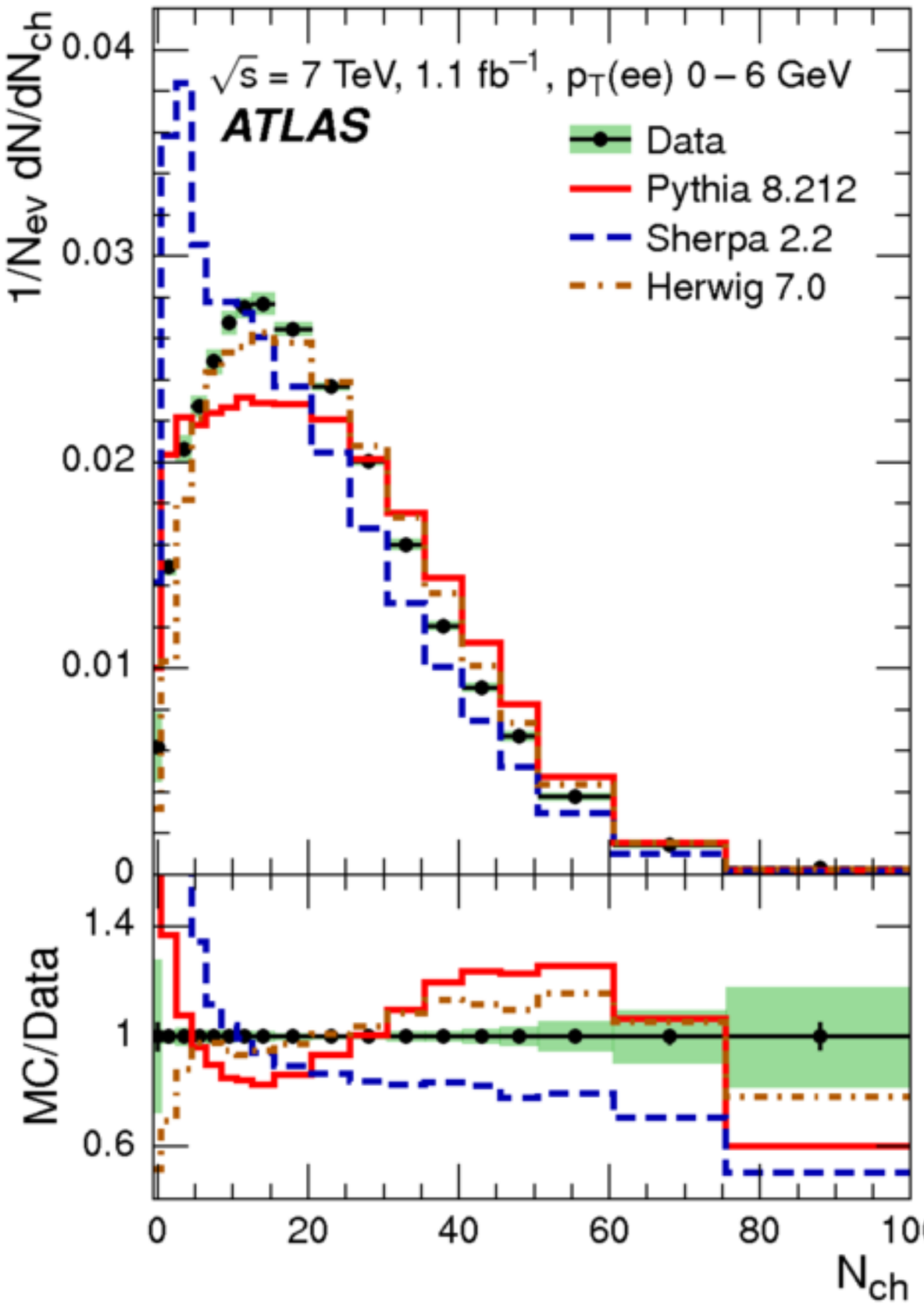
- The charged multiplicity, scalar sum of transverse momenta, beam thrust, transverse thrust, spherocity, F-parameter are measured

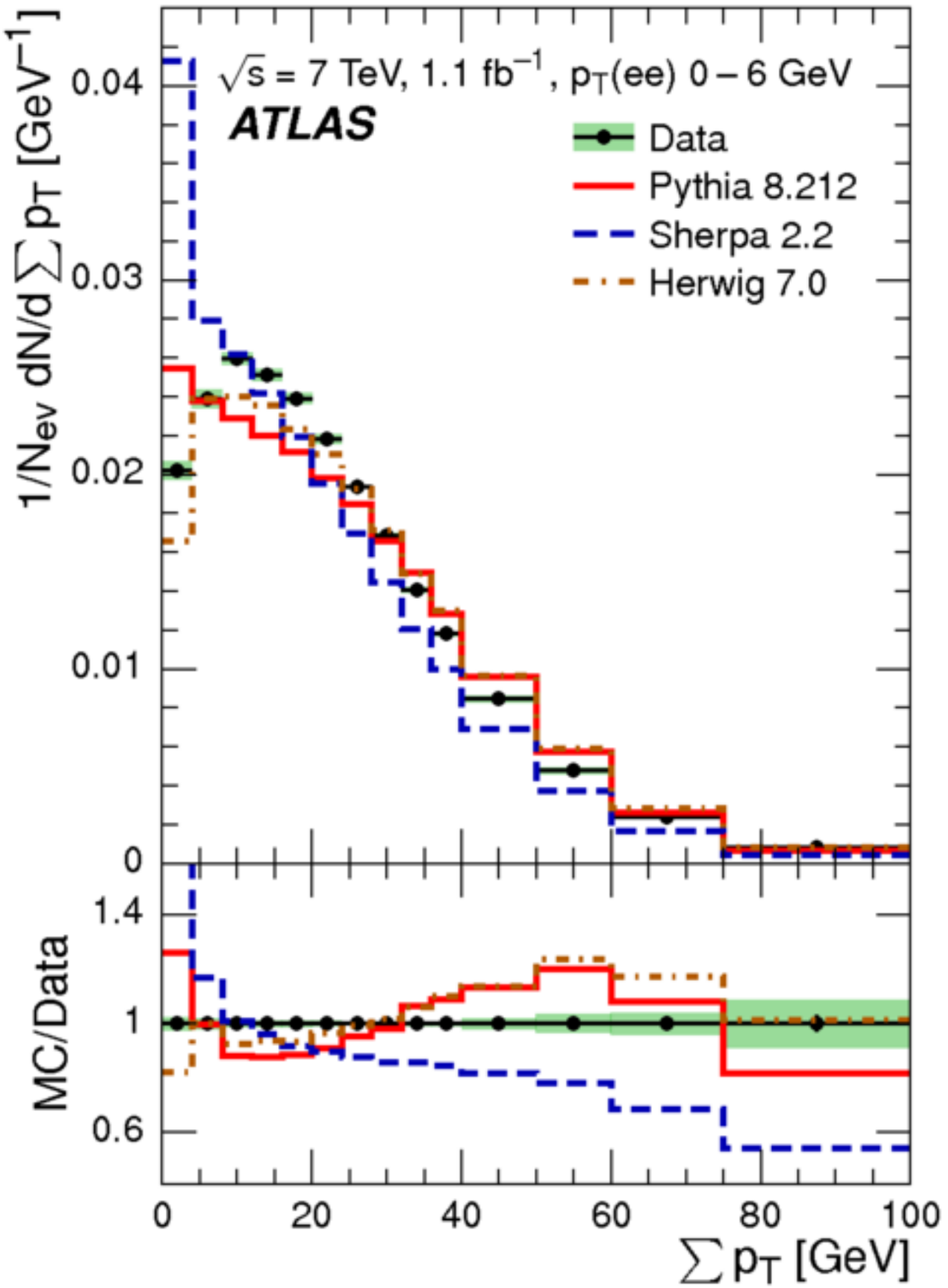
Event shapes



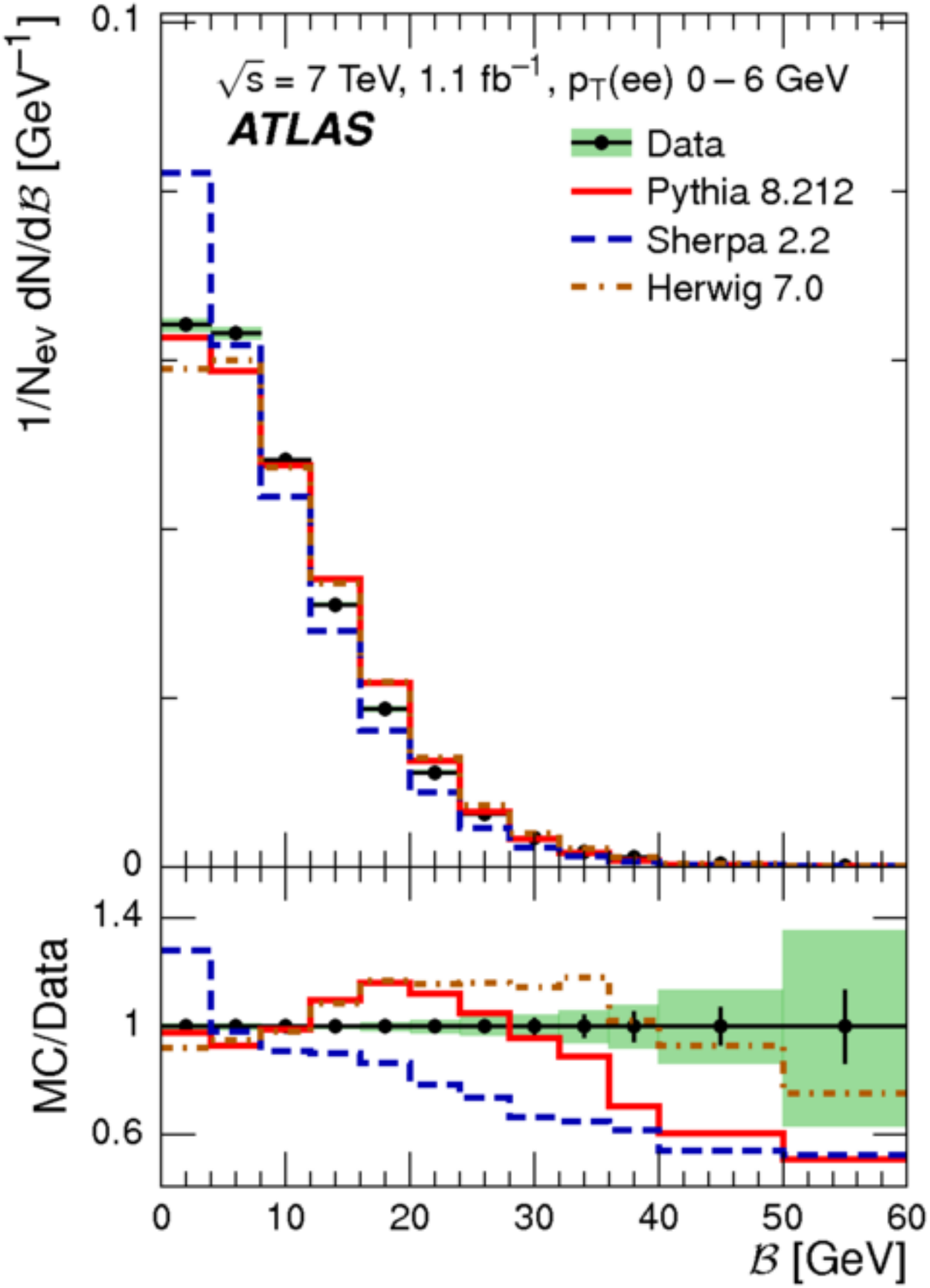


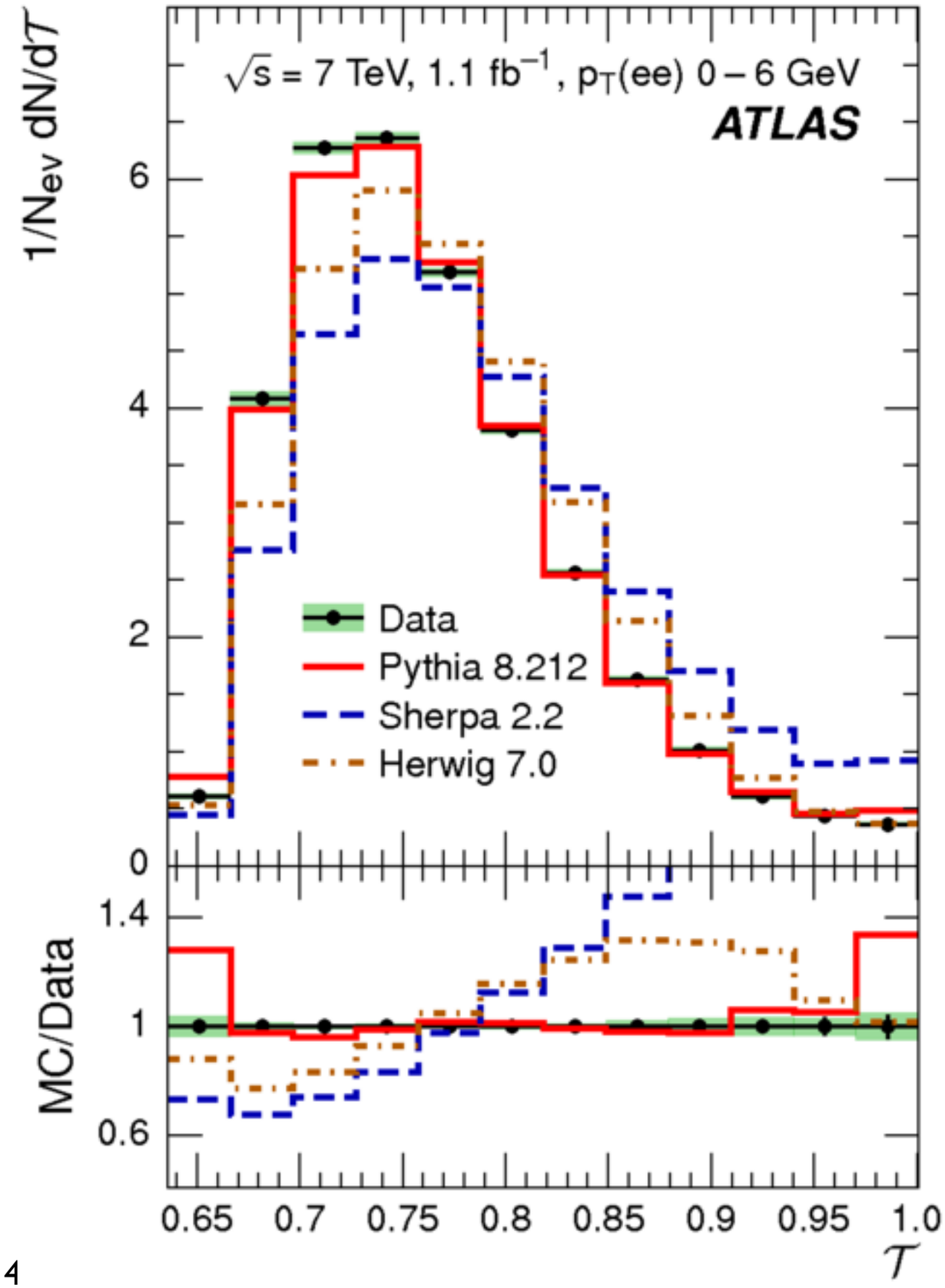
Event shapes





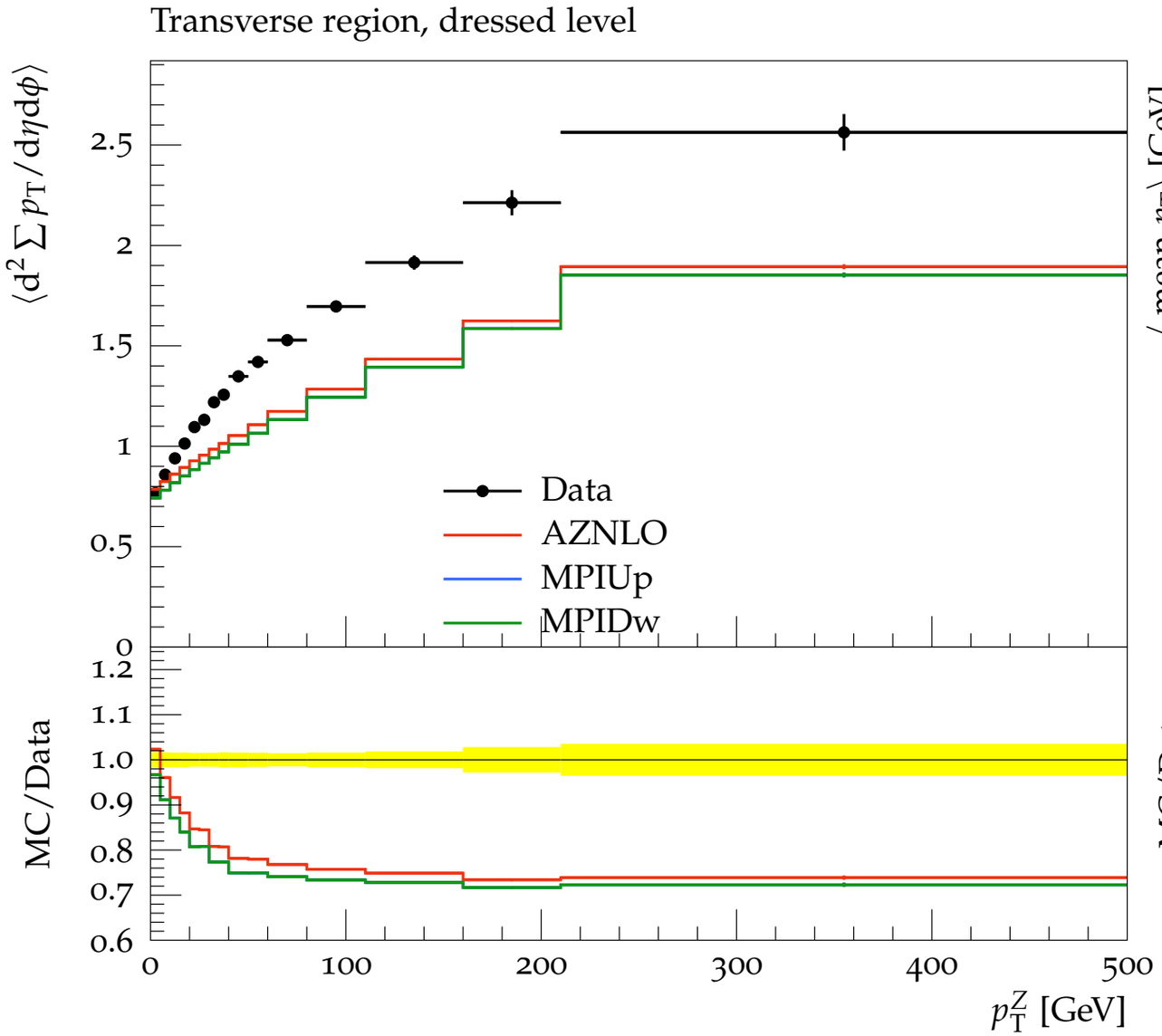
Event shapes

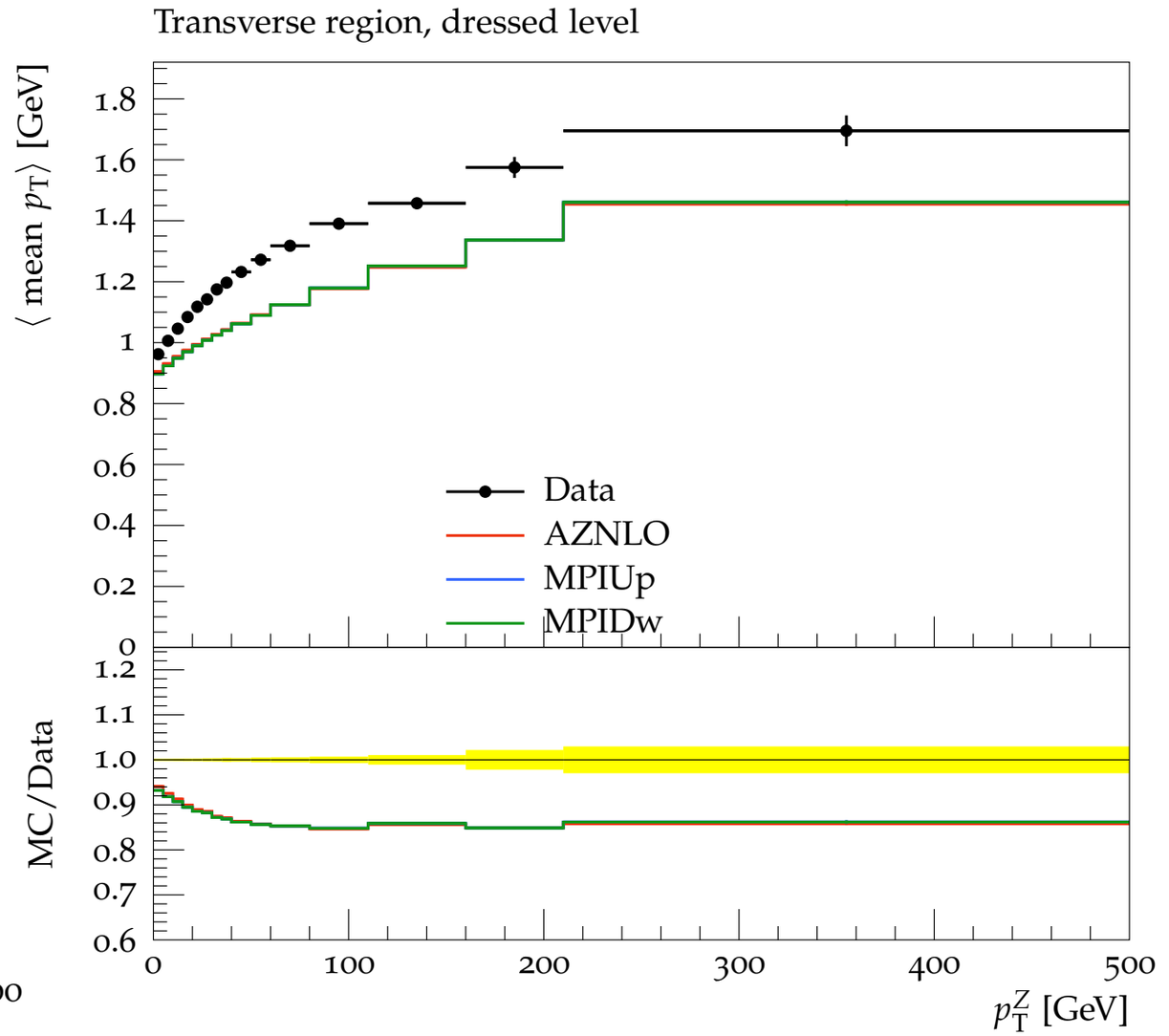




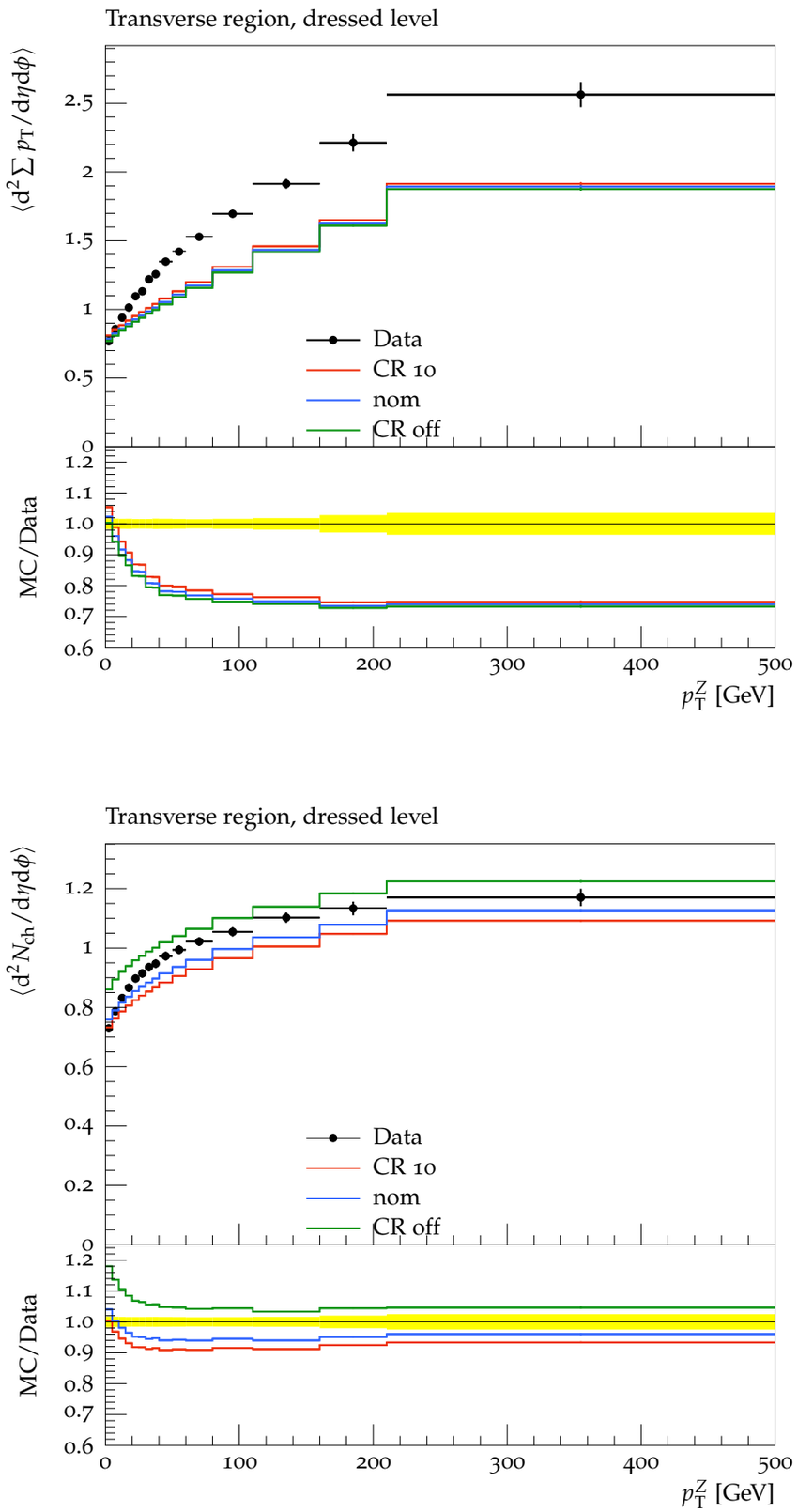
UE and PP8-AZNLO

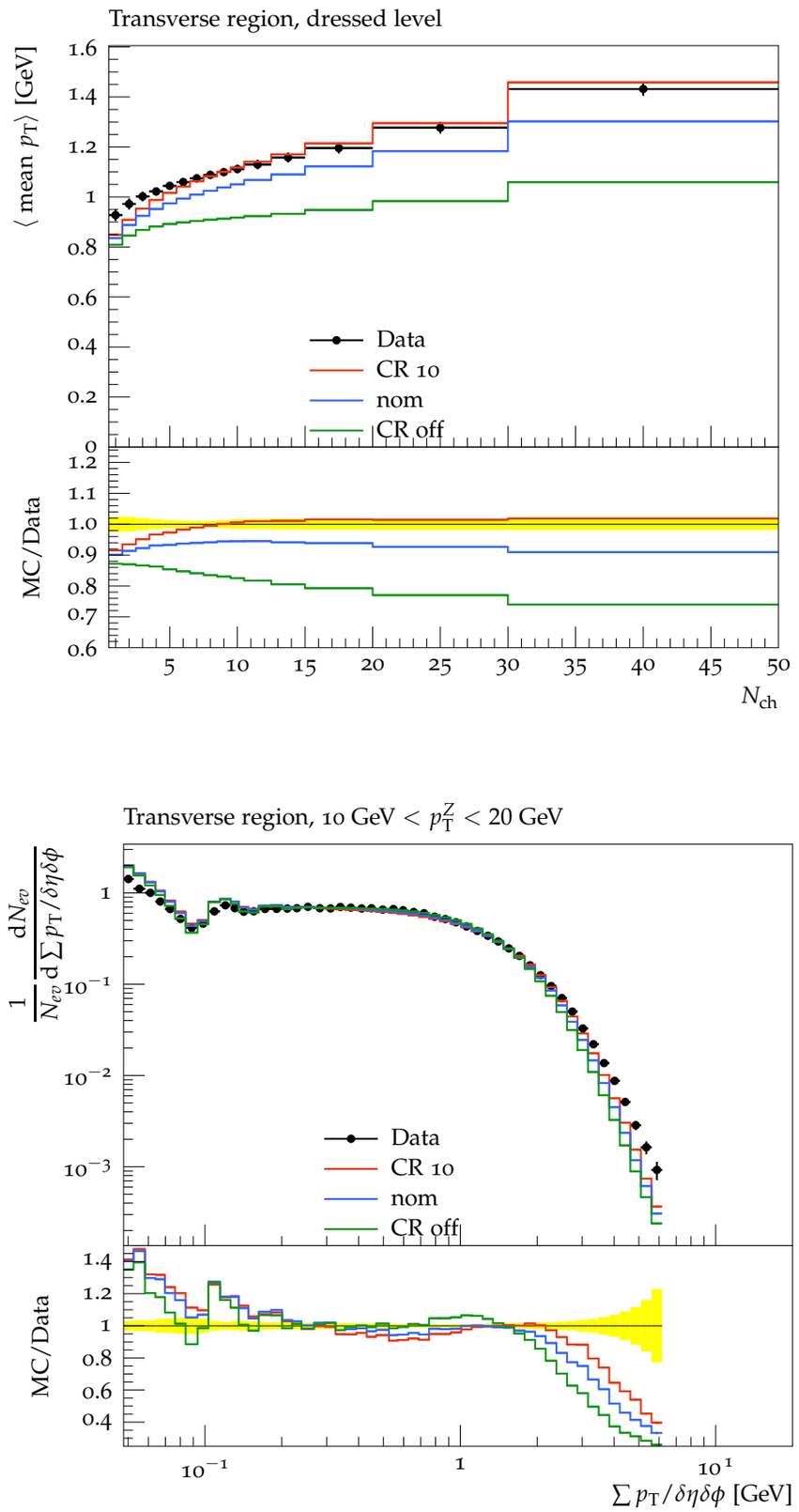
- The nominal PowhegPythia8-AZNLO W MC was not tuned to these measurements (not available at the time)
- How good do we describe UE? Ans how do our uncertainties cover data/model differences?



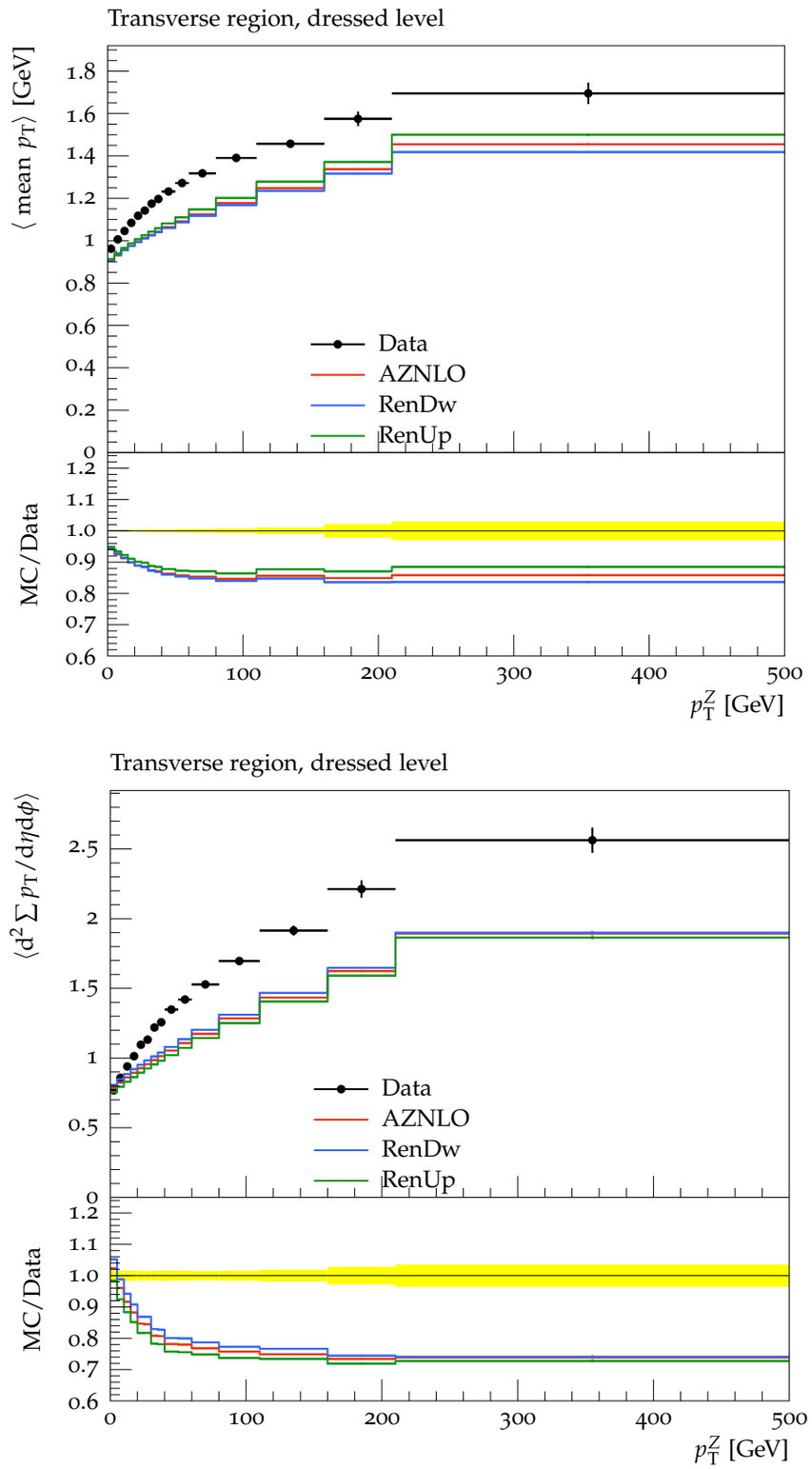


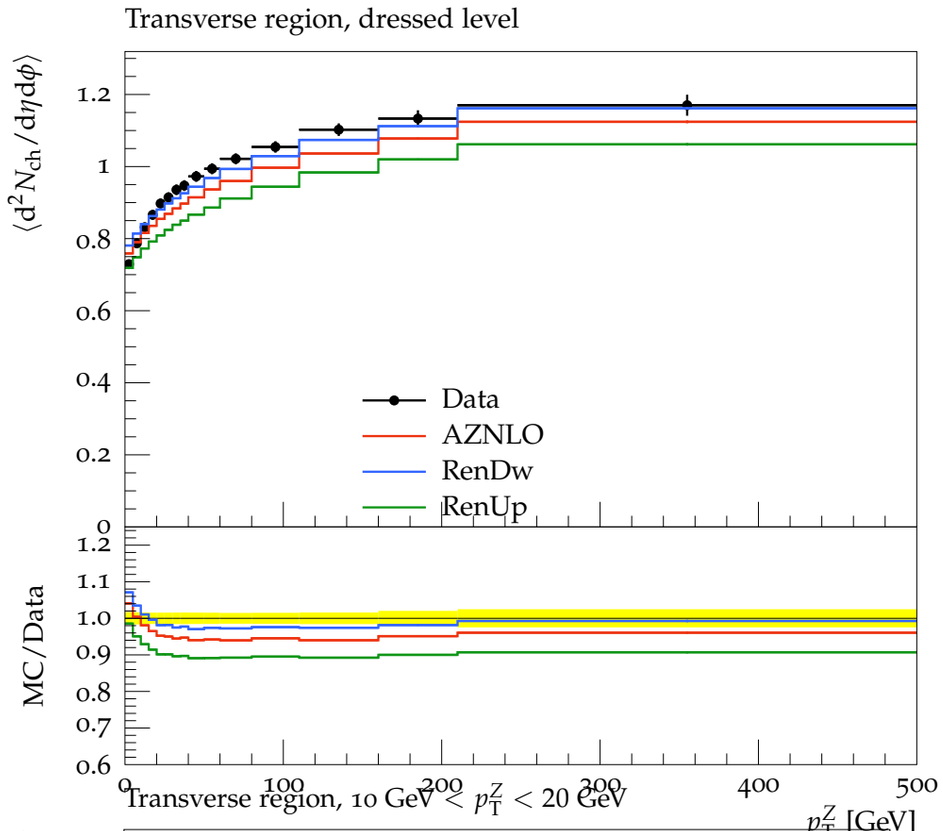
UE and PP8-AZNLO

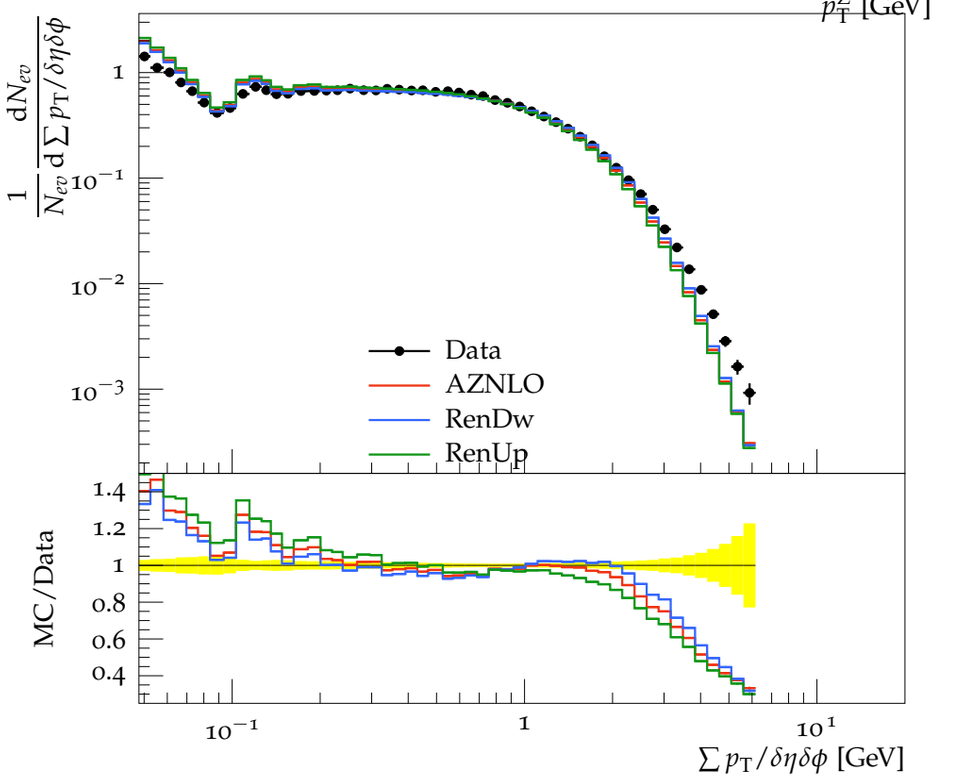




UE and PP8-AZNLO

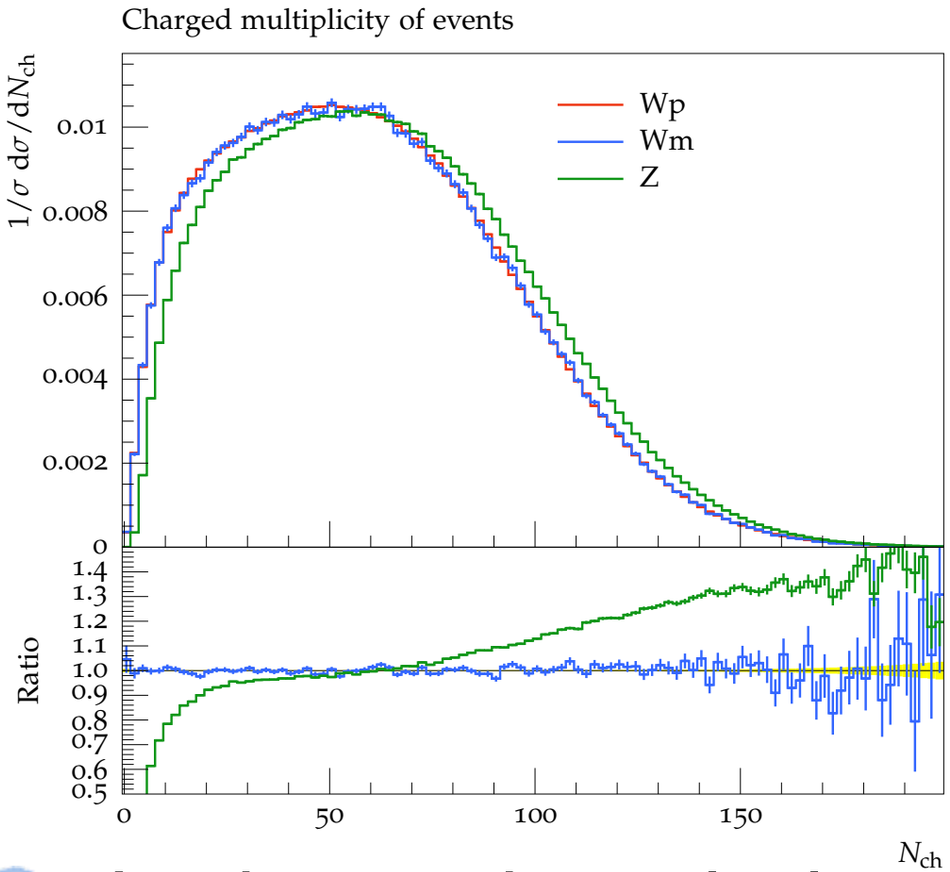


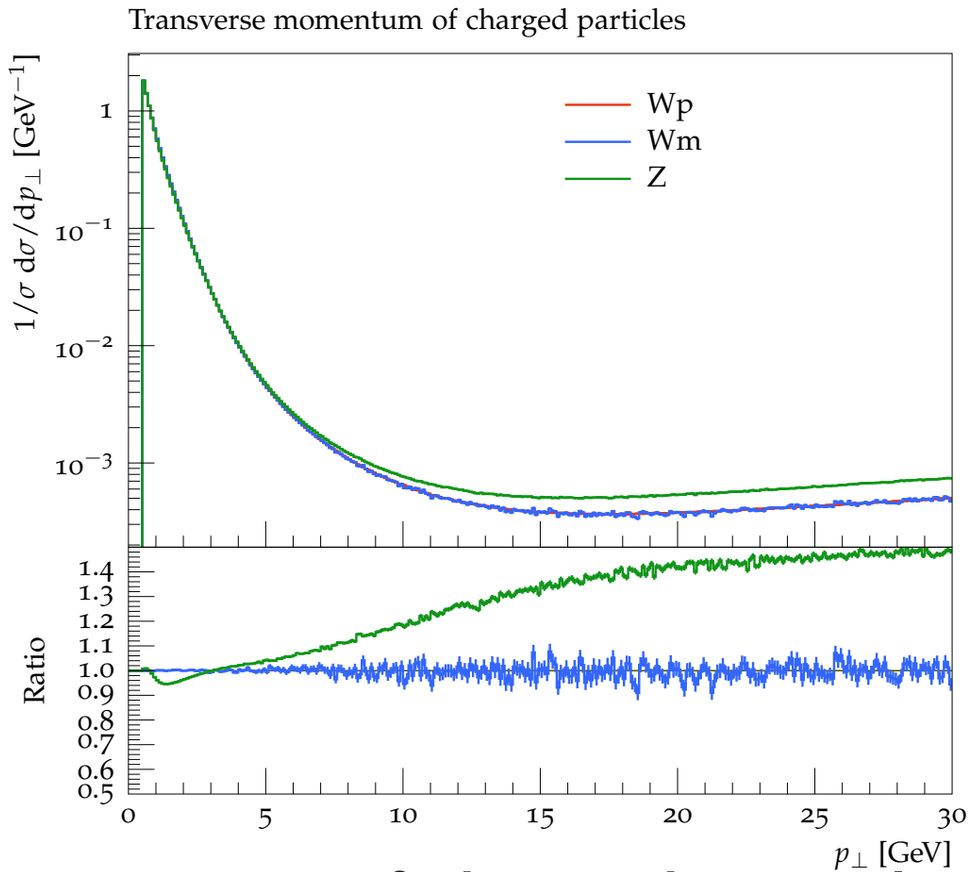




Z to W extrapolation

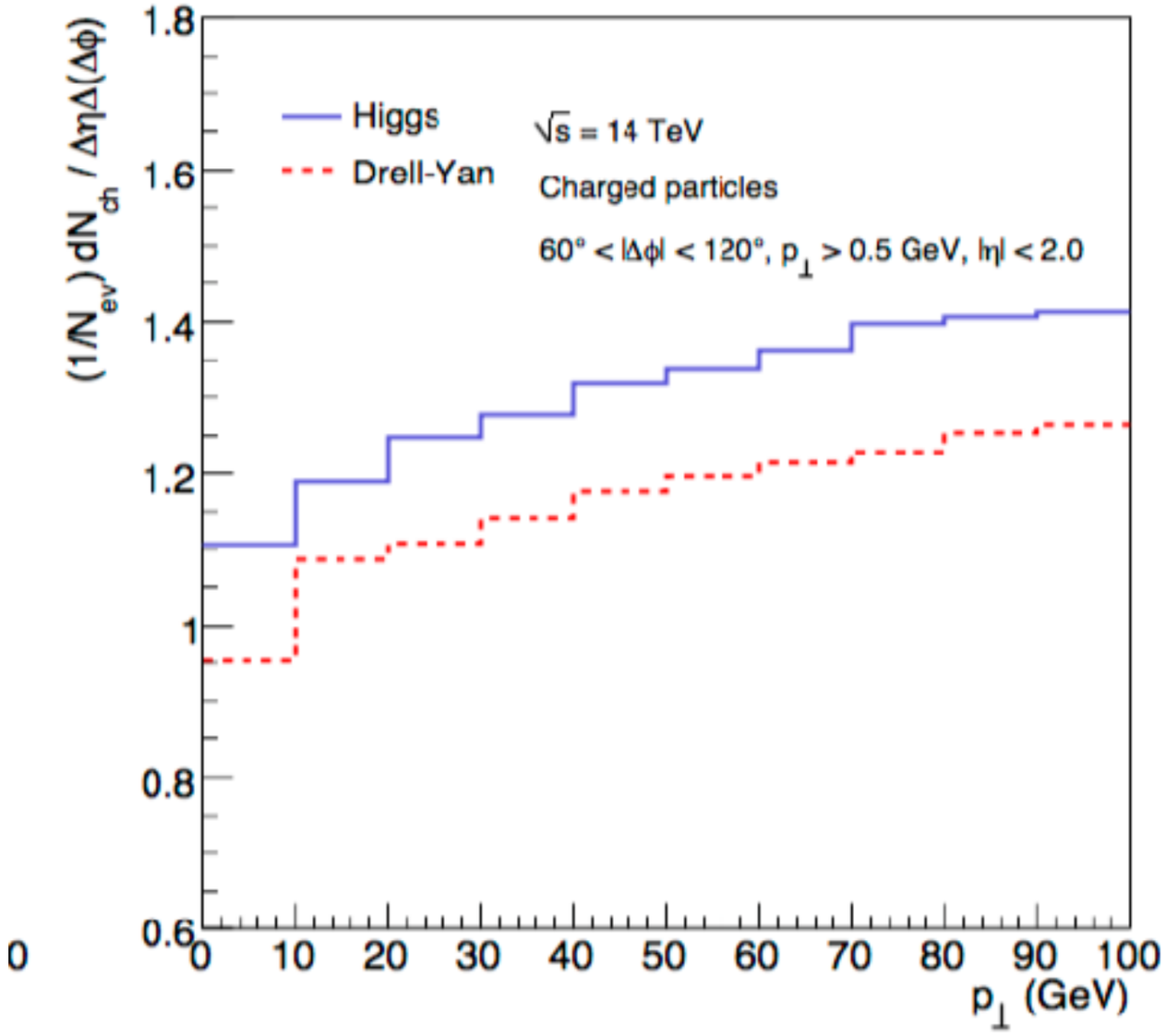
- While the existing measurements already challenge the models, plenty of possibilities with new measurements to guide theory

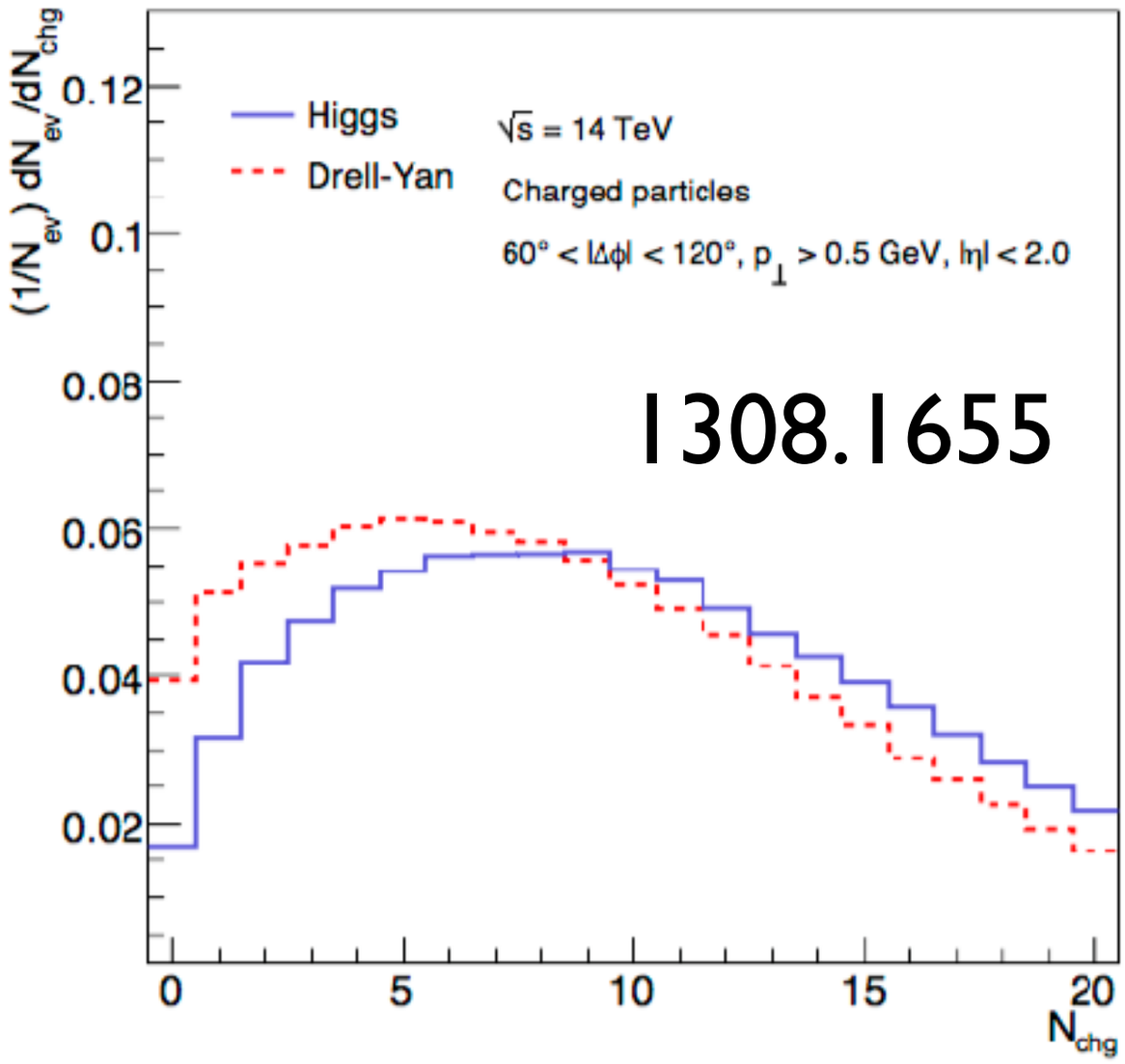




- Looking at the multiplicity and momenta of charged particles in W and Z events in Powheg+Pythia8 one would expect differences in the underlying event distributions
  - Can we measure them to test wether they are well predicted?

Extrapolating Dy and Higgs





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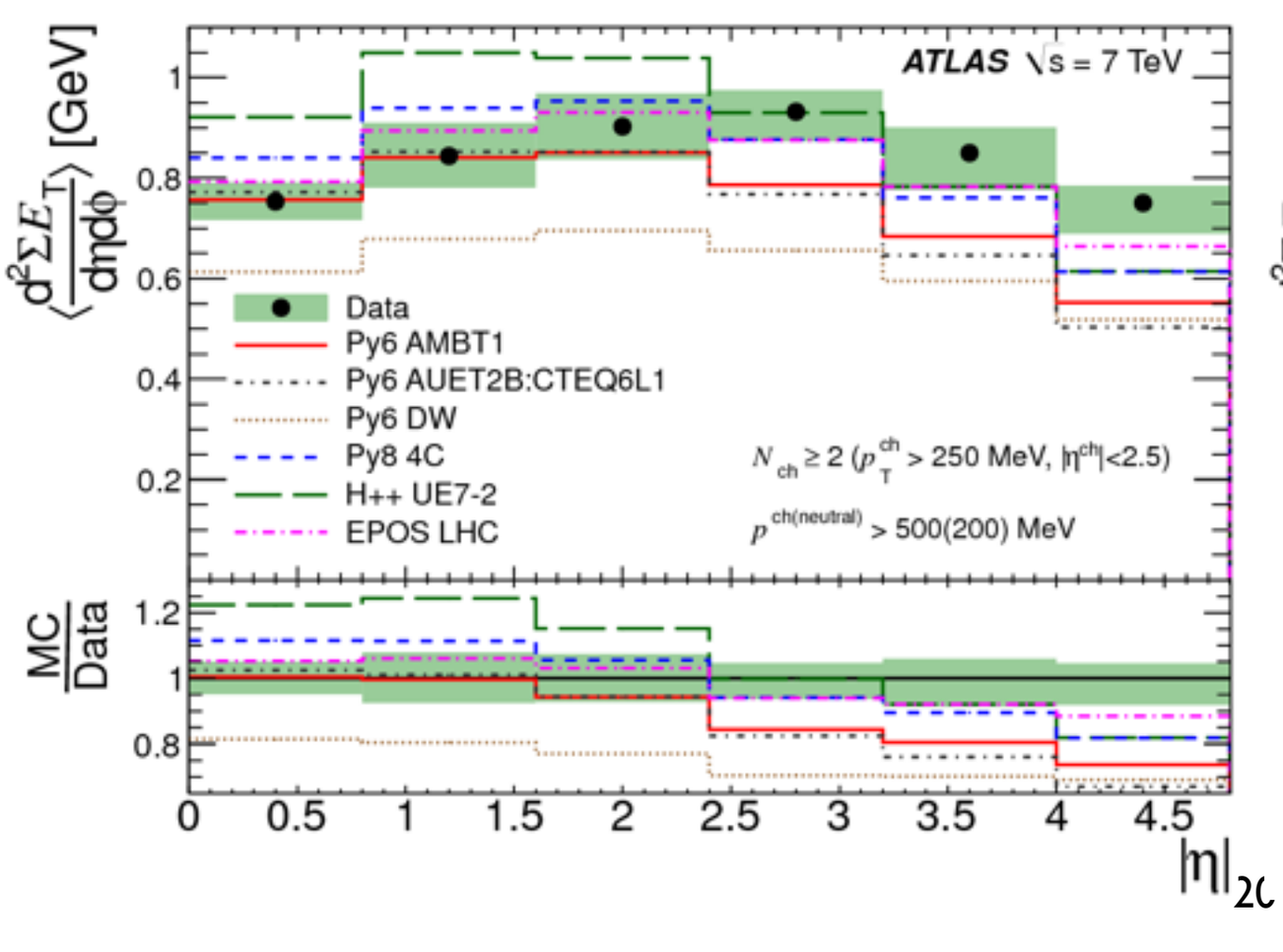
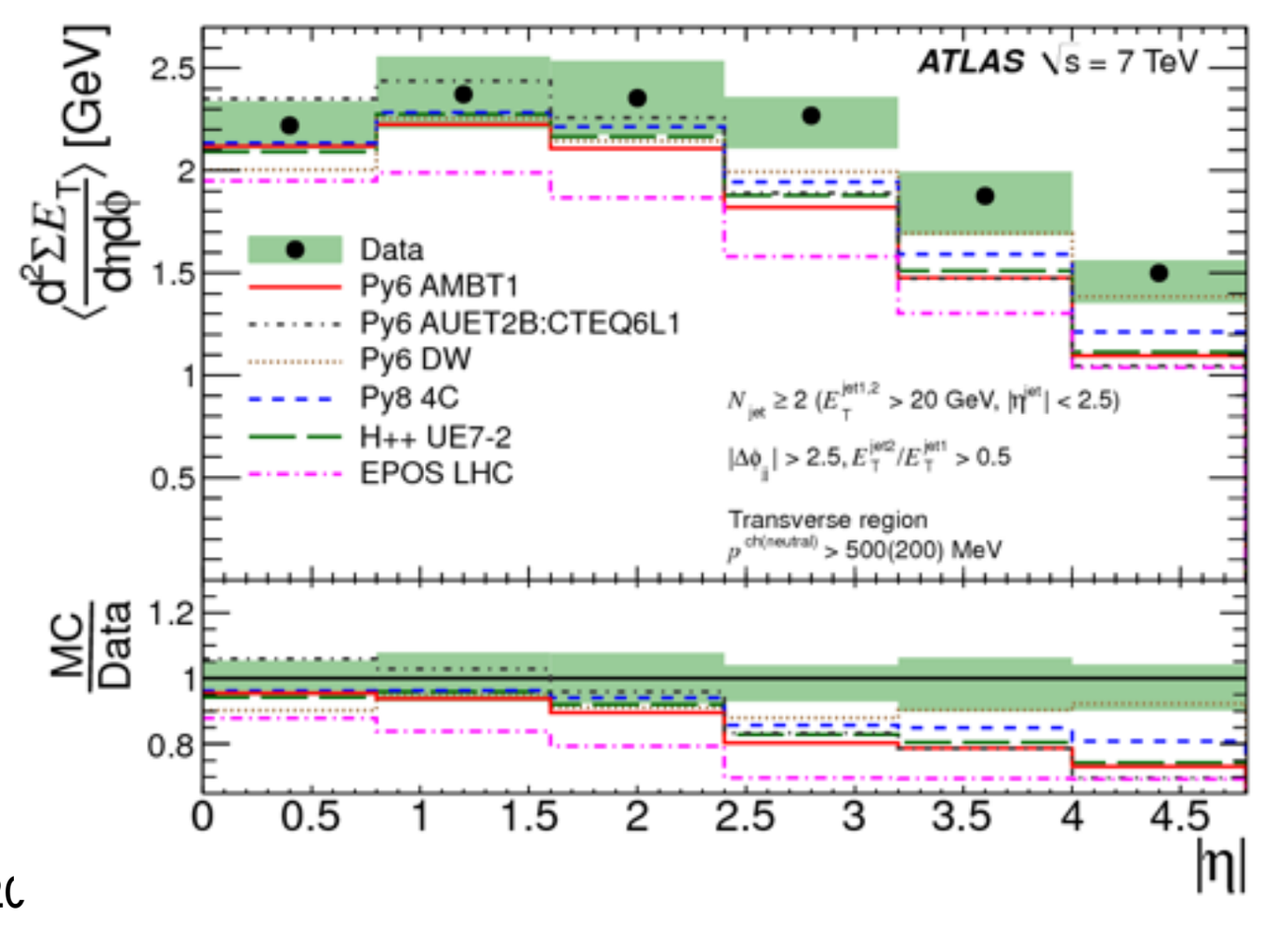
- Besides the W and Z differences, we can expect a very different UE in Higgs production due to the different initial state (gg/qq)
- Extremely interesting possibility to access to a pure gluon sample

Forward Energy Flow

- At 7 TeV we measured the energy flow in the forward region with calorimeter clusters, in a minimum bias and a dijet selection
- Significant differences between the various generators/tunes
  - EPOS the only able to describe it in minbias
  - How much of an impact for the hadronic recoil and W mass?
- Repeat this measurement with a W/Z selection at low-mu?

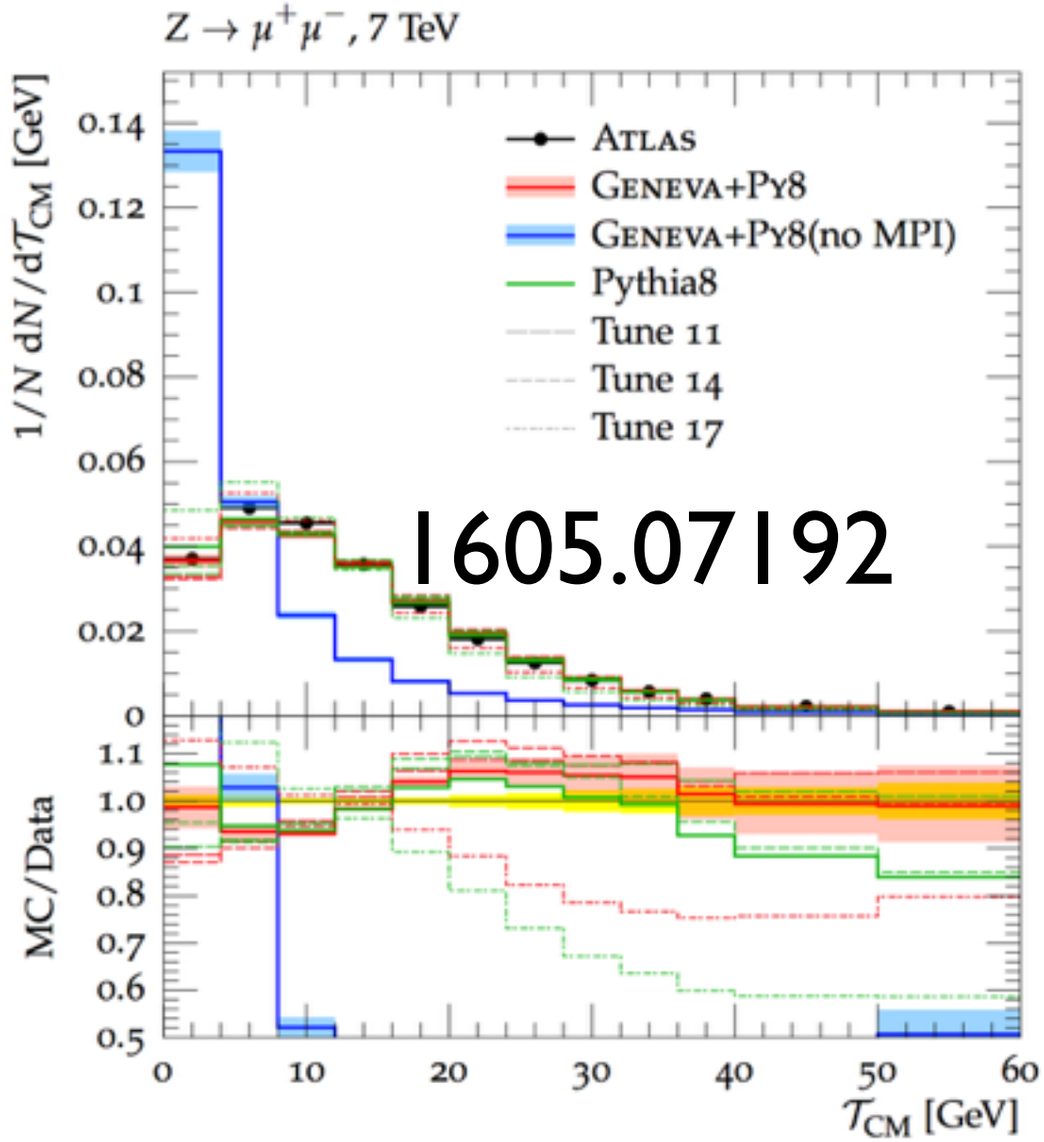




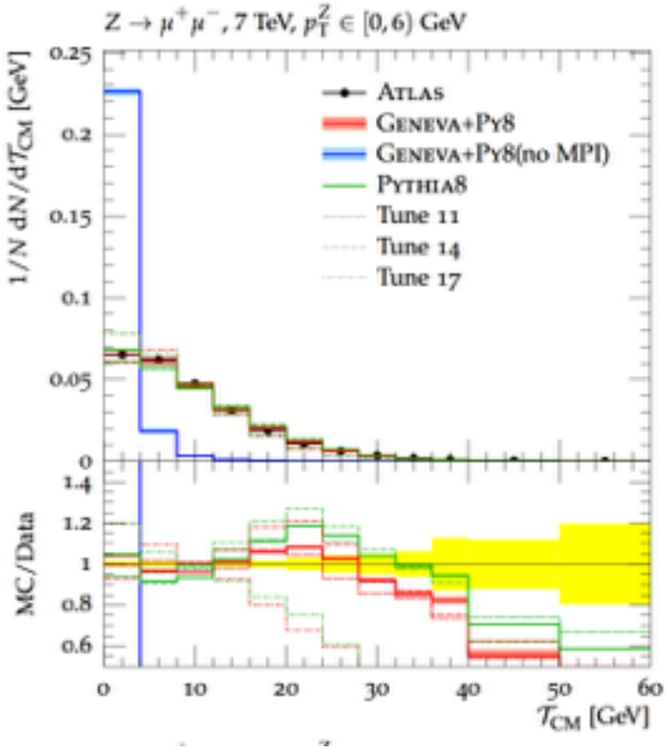
Geneva and beam thrust

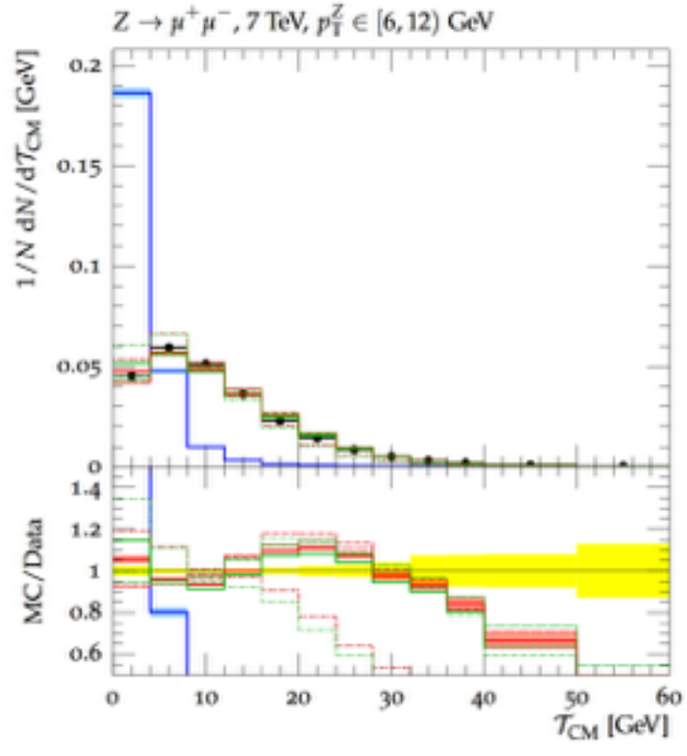
- Observables used in tuning are sensitive to the description of both perturbative and non-perturbative physics effects
  - The interplay between them is very hard to disentangle
- Interesting to look at observables for which the perturbative part is precisely known

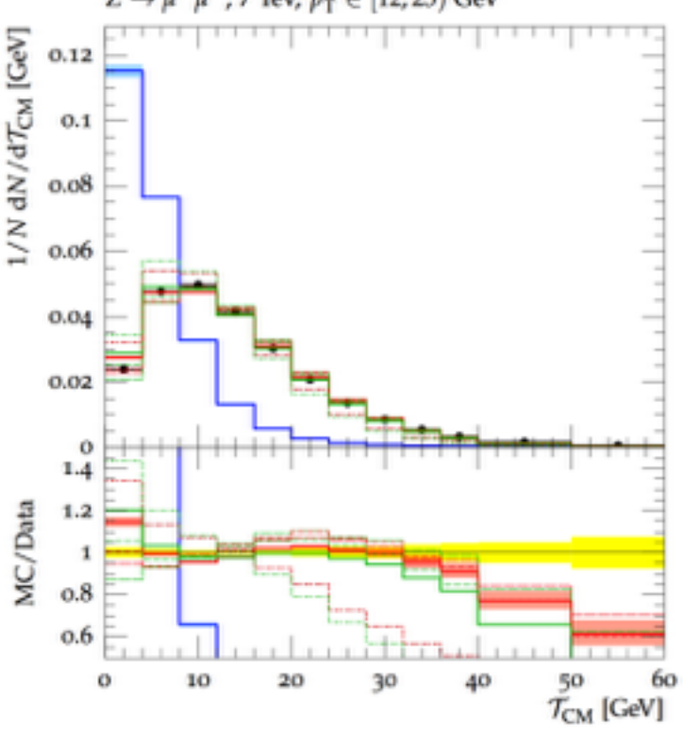
- logarithmic resummation at low T_0, NLO_1 accuracy at large T_0 and including effects from MPI and hadronization with Pythia8
- Tests the resummed prediction where we know it should work
- And can help isolate the true MPI component and get a better understanding of the models

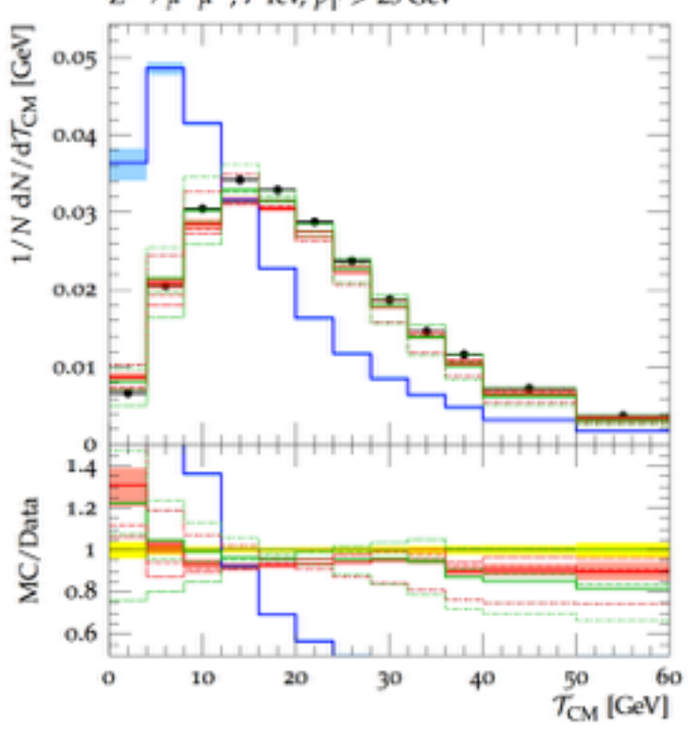


BACKUP


$Z \to \mu^+\mu^-$, 7 TeV, $p_T^Z \in [0, 6)$ GeV
ATLAS
GENEVA+PY8
GENEVA+PY8(no MPI)
PYTHIA8
Tune 11
Tune 14
Tune 17
$1/N\, dN/dT_{CM}$ [GeV]
MC/Data
T_{CM} [GeV]


$Z \to \mu^+\mu^-$, 7 TeV, $p_T^Z \in [6, 12)$ GeV
$1/N\, dN/dT_{CM}$ [GeV]
MC/Data
T_{CM} [GeV]


$Z \to \mu^+\mu^-$, 7 TeV, $p_T^Z \in [12, 25)$ GeV
$1/N\, dN/dT_{CM}$ [GeV]
MC/Data
T_{CM} [GeV]


$Z \to \mu^+\mu^-$, 7 TeV, $p_T^Z > 25$ GeV
$1/N\, dN/dT_{CM}$ [GeV]
MC/Data
T_{CM} [GeV]

W-boson charge	W^+		W^-		Combined	
Kinematic distribution	p_{T}^{ℓ}	m_{T}	p_{T}^{ℓ}	m_{T}	p_{T}^{ℓ}	m_{T}
δm_W [MeV]						
$\langle\mu\rangle$ scale factor	0.2	1.0	0.2	1.0	0.2	1.0
$\Sigma\bar{E}_{\mathrm{T}}$ correction	0.9	12.2	1.1	10.2	1.0	11.2
Residual corrections (statistics)	2.0	2.7	2.0	2.7	2.0	2.7
Residual corrections (interpolation)	1.4	3.1	1.4	3.1	1.4	3.1
Residual corrections ($Z \to W$ extrapolation)	0.2	5.8	0.2	4.3	0.2	5.1
Total	2.6	14.2	2.7	11.8	2.6	13.0

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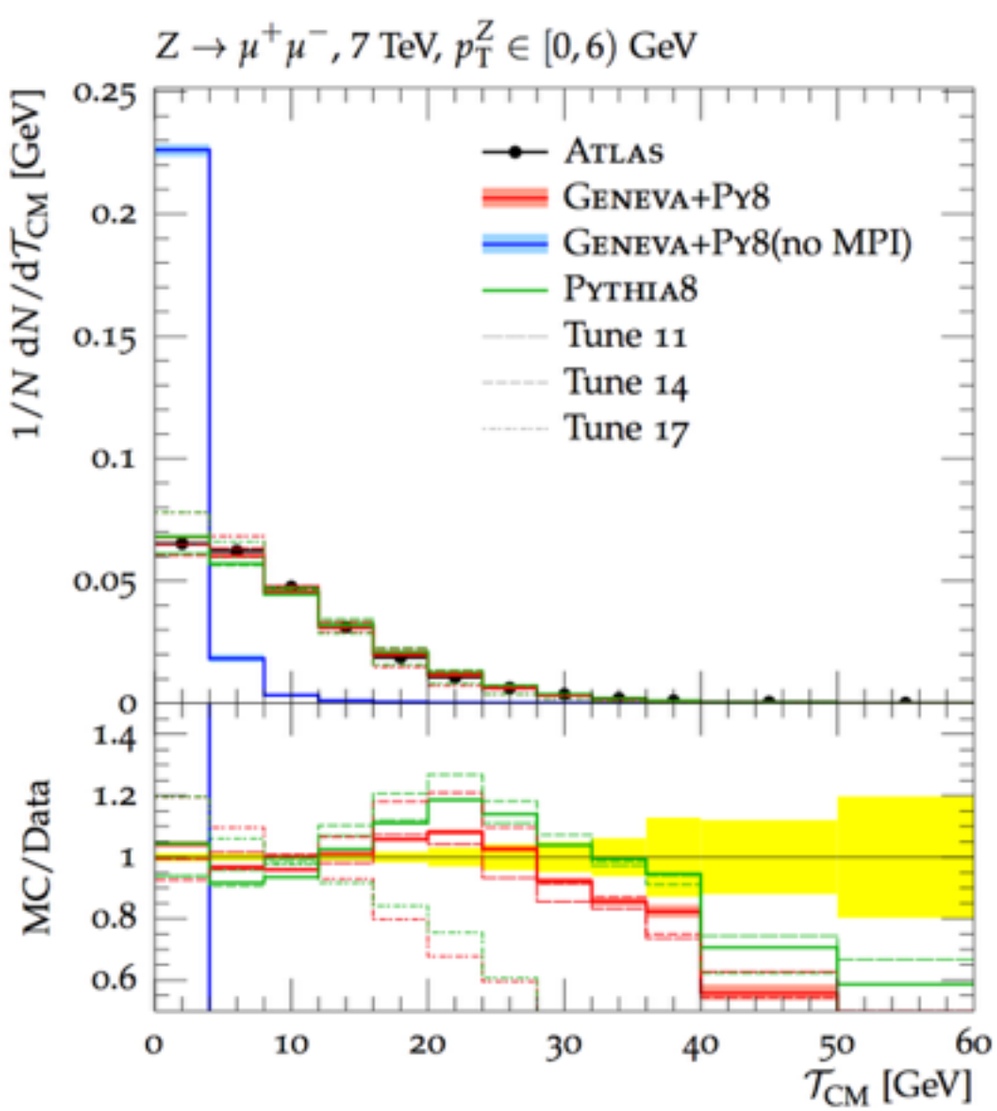
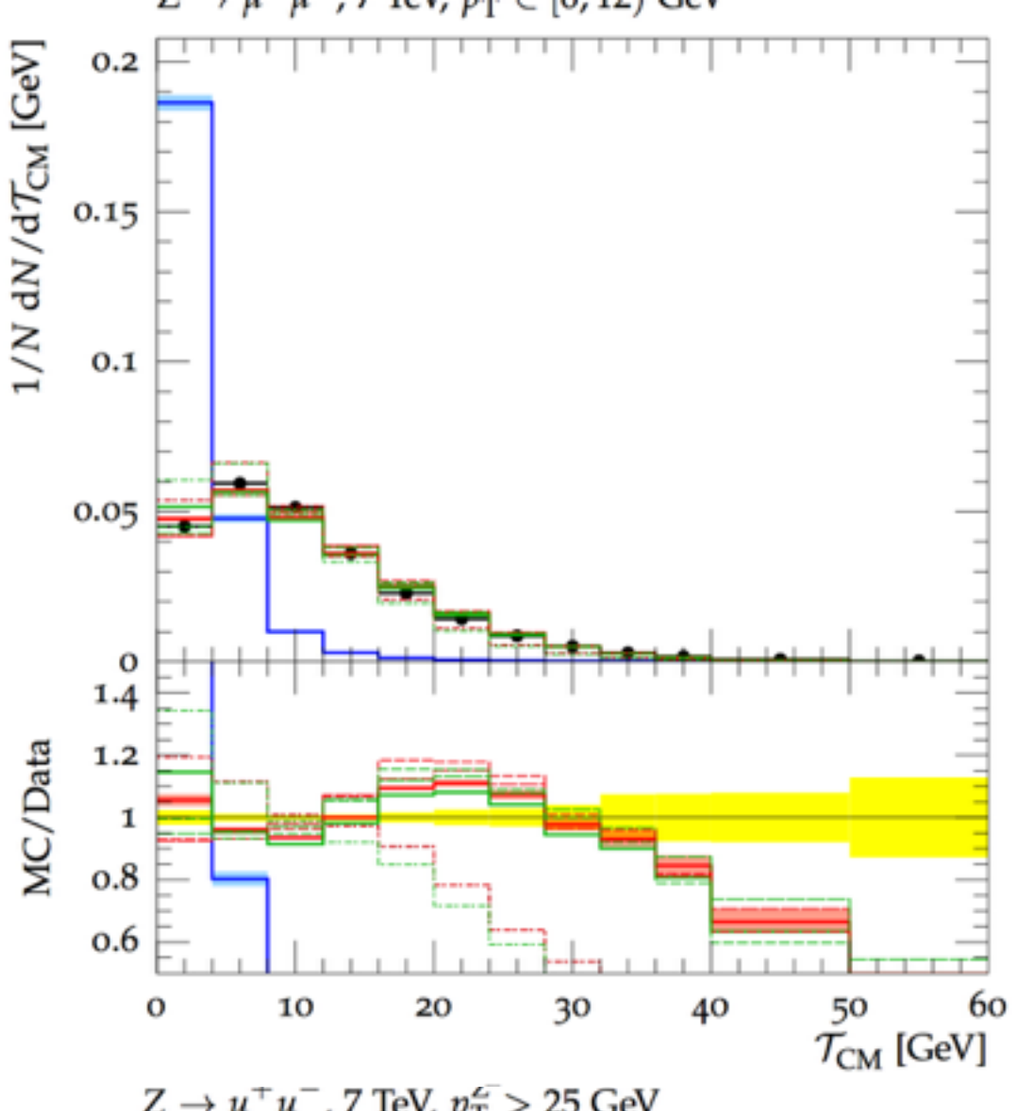

$Z \to \mu^+\mu^-$, 7 TeV, $p_T^Z \in [0,6)$ GeV
ATLAS
GENEVA+PY8
GENEVA+PY8(no MPI)
PYTHIA8
Tune 11
Tune 14
Tune 17
$1/N\ dN/d\mathcal{T}_{CM}$ [GeV]
MC/Data
$\mathcal{T}_{CM}$ [GeV]


$1/N\ dN/d\mathcal{T}_{CM}$ [GeV]
MC/Data
$\mathcal{T}_{CM}$ [GeV]

$1/N\ dN/d\mathcal{T}_{CM}$ [GeV]
MC/Data
$\mathcal{T}_{CM}$ [GeV]

$Z \to \mu^+\mu^-$, 7 TeV, $p_T^Z > 25$ GeV
$1/N\ dN/d\mathcal{T}_{CM}$ [GeV]
MC/Data
$\mathcal{T}_{CM}$ [GeV]