MPI aspects of rapidity gaps and forward ET flow

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on behalf of the ATLAS collaboration

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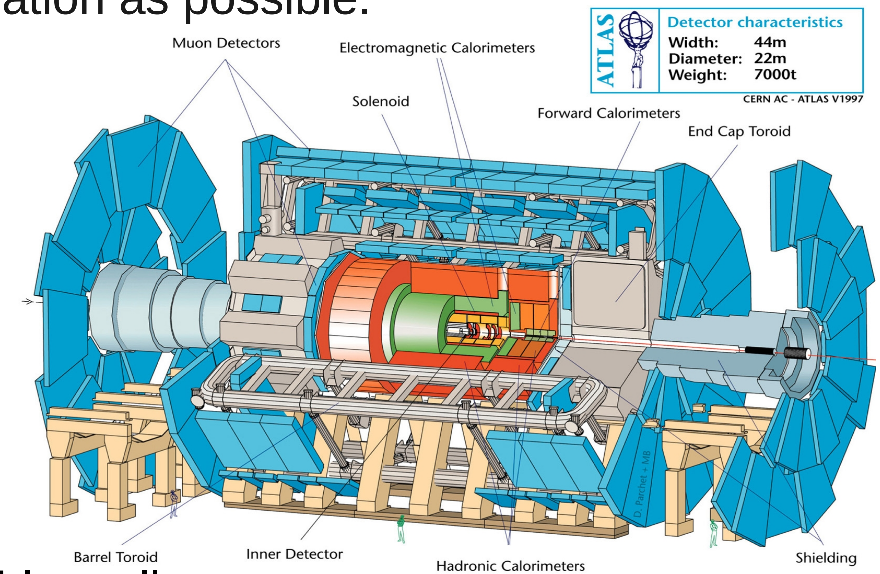
MPI@LHC

Measurement aims

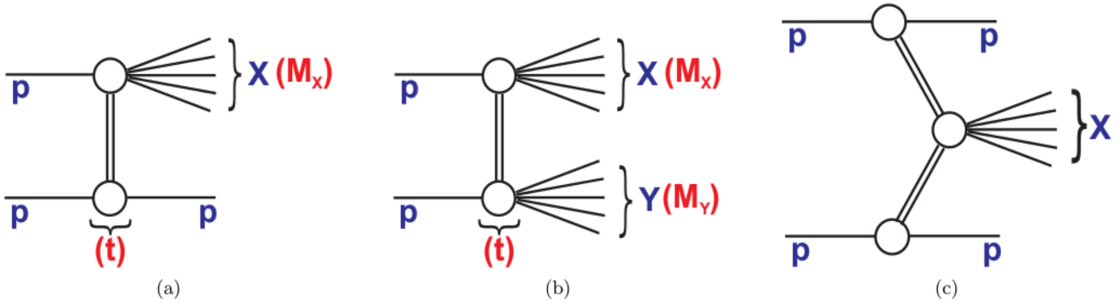
To best simulate soft processes, need as much information as possible.



- Utilise full coverage of ATLAS detector (|η| < 4.9)
  - Tricky, since for |η| > 2.5 we have no tracking information
- Use event topologies that are ideal for probing soft activity
  - Inclusive pp: select as much physics as possible – allows us to understand the huge level of 'pile-up' at the LHC
  - Di-jets: select events with a hard process, then measure the “soft” activity

Further information yielded by making diffractive measurements.

- Again utilise full coverage of ATLAS detector
  - Probe gap sizes due to t-channel colour exchange



single diffractive double diffractive central diffractive

Analysis variables: ET flow

Paper can be found here: http://arxiv.org/abs/1208.6256
"Measurements of the pseudorapidity dependence of the total transverse energy in proton-proton collisions at sqrt(s)=7 TeV with ATLAS"

Here we use 2 variables to measure soft activity:

1. The mean ΣE_T per unit η-Φ as a function of |η|

$$\frac{1}{N_{\mathrm{evt}}} \frac{d\Sigma E_{\mathrm{T}}}{d\eta d\phi}$$

2. The ΣE_T distribution in each bin of |η|

$$\frac{1}{N_{\mathrm{evt}}} \frac{dN_{\mathrm{evt}}}{d\Sigma E_{\mathrm{T}}}$$

This is also called the 'E_T density'.

These variables are constructed from calorimeter clusters in the region |η| < 4.8

- This allows us to probe the full detector coverage

Selection criteria: ET flow

Inclusive pp selection summary:

- ensure a collision has occurred
- pile-up is under control
- select all calorimeter clusters
- compare to truth particles that make it to the detector

NB. pile-up

- For our MB results, peak <μ> = 0.007
- Compare pile-up veto versus no veto
  - Difference ~0.1%
- Residual pile-up ~0.005%

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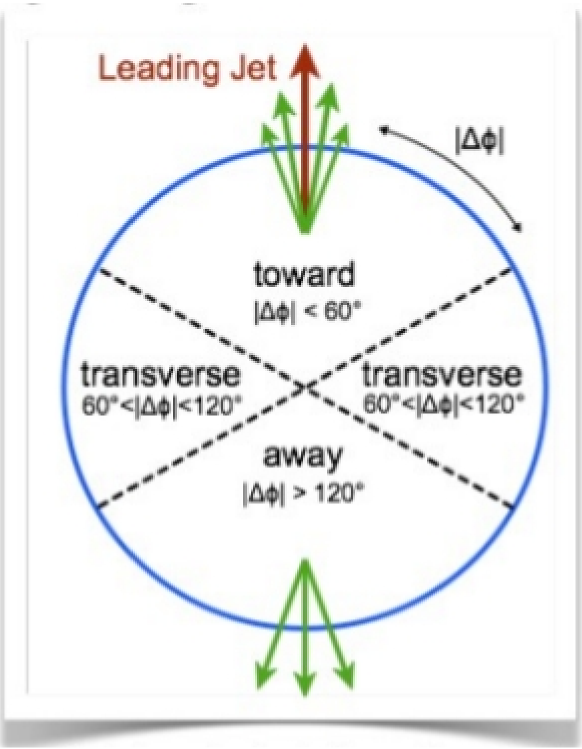
Di-jet selection summary:

- Same as inclusive pp
- Also ensure we have 2 balanced back-to-back anti-k_T4 jets



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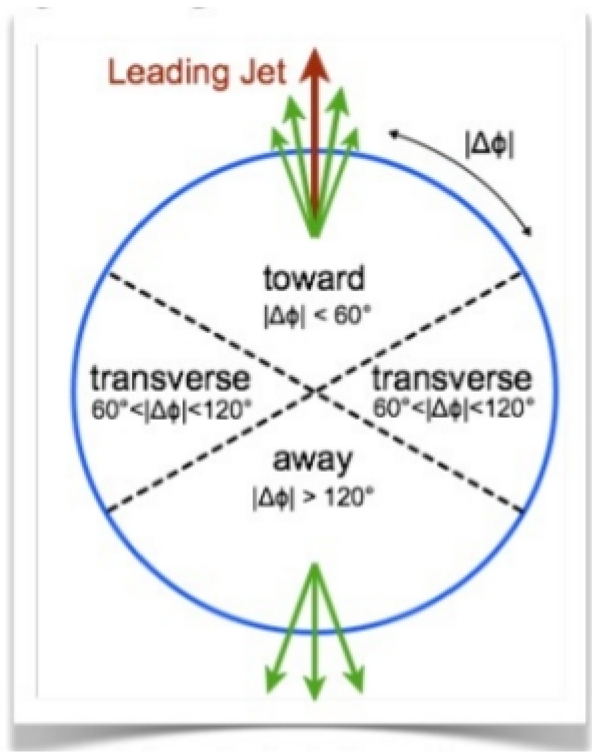
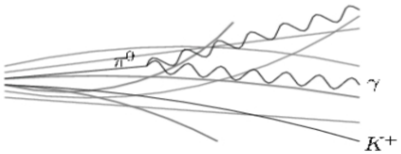


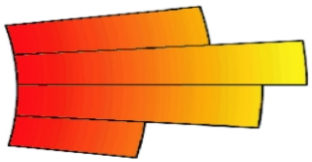
- The di-jet selection gives us a central di-jet topology
- To best analyse the effects of the underlying event (UE) in such a hard-scatter system, use Rick Field's phase space approach
  - Transverse region ($60^o < |\Delta\Phi| < 120^o$) most sensitive to the UE

Systematic uncertainties: ET flow

The 3 primary systematic effects in both data sets are:

- Difference between MC and data energy response
  - ➔ Probe using $\pi^0 \rightarrow \gamma\gamma$ candidates for the EM particles; E/p and test-beam results for the hadronic scale
- Model dependence when unfolding



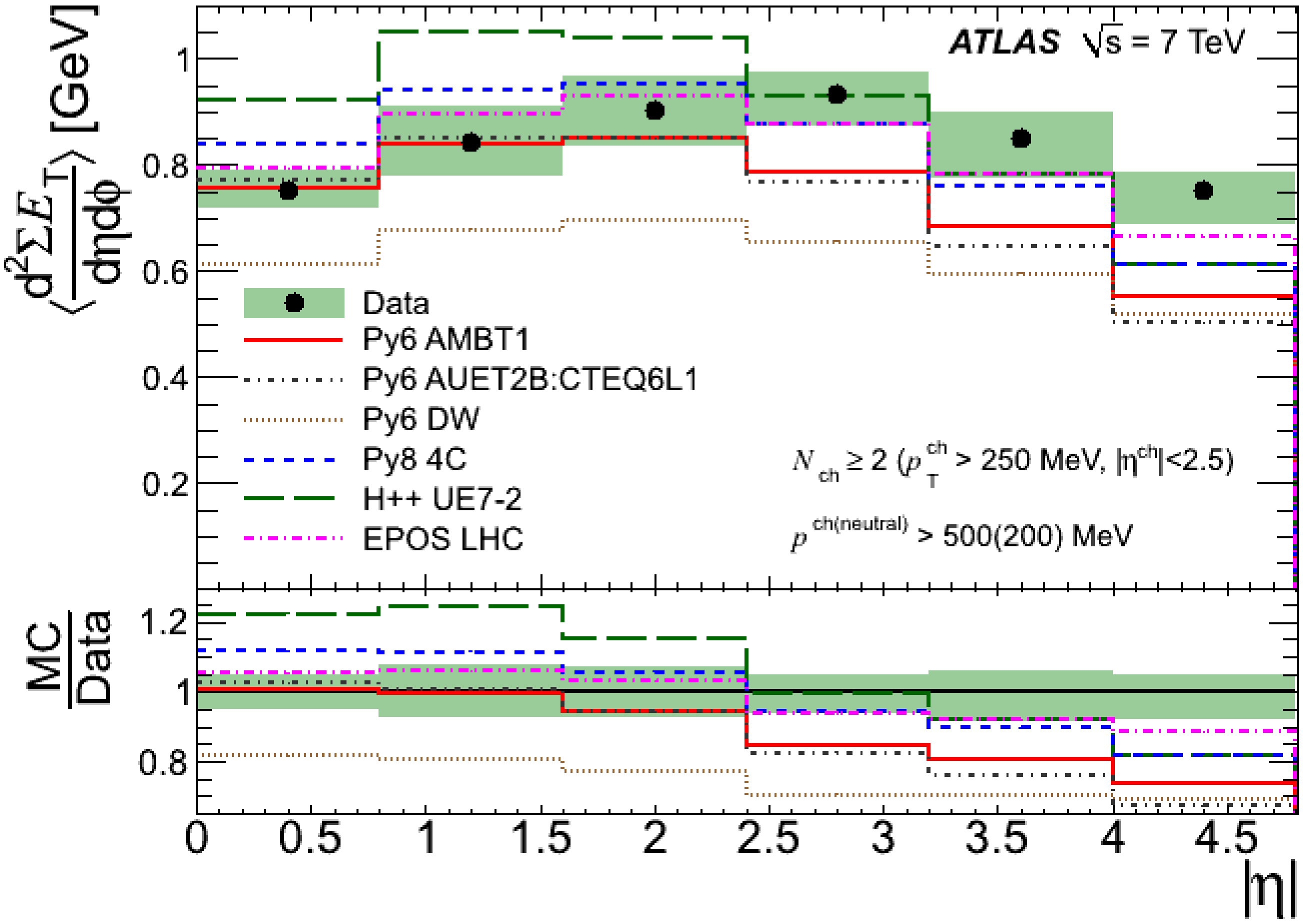


  - ➔ Compare data unfolded using various MC models and tunes
- Possible discrepancies in detector material simulation
  - ➔ Compare reconstructed MC between standard and extra-material ATLAS geometries

The di-jet analysis also counts the jet energy scale as an additional systematic error.

UCL

Inclusive pp

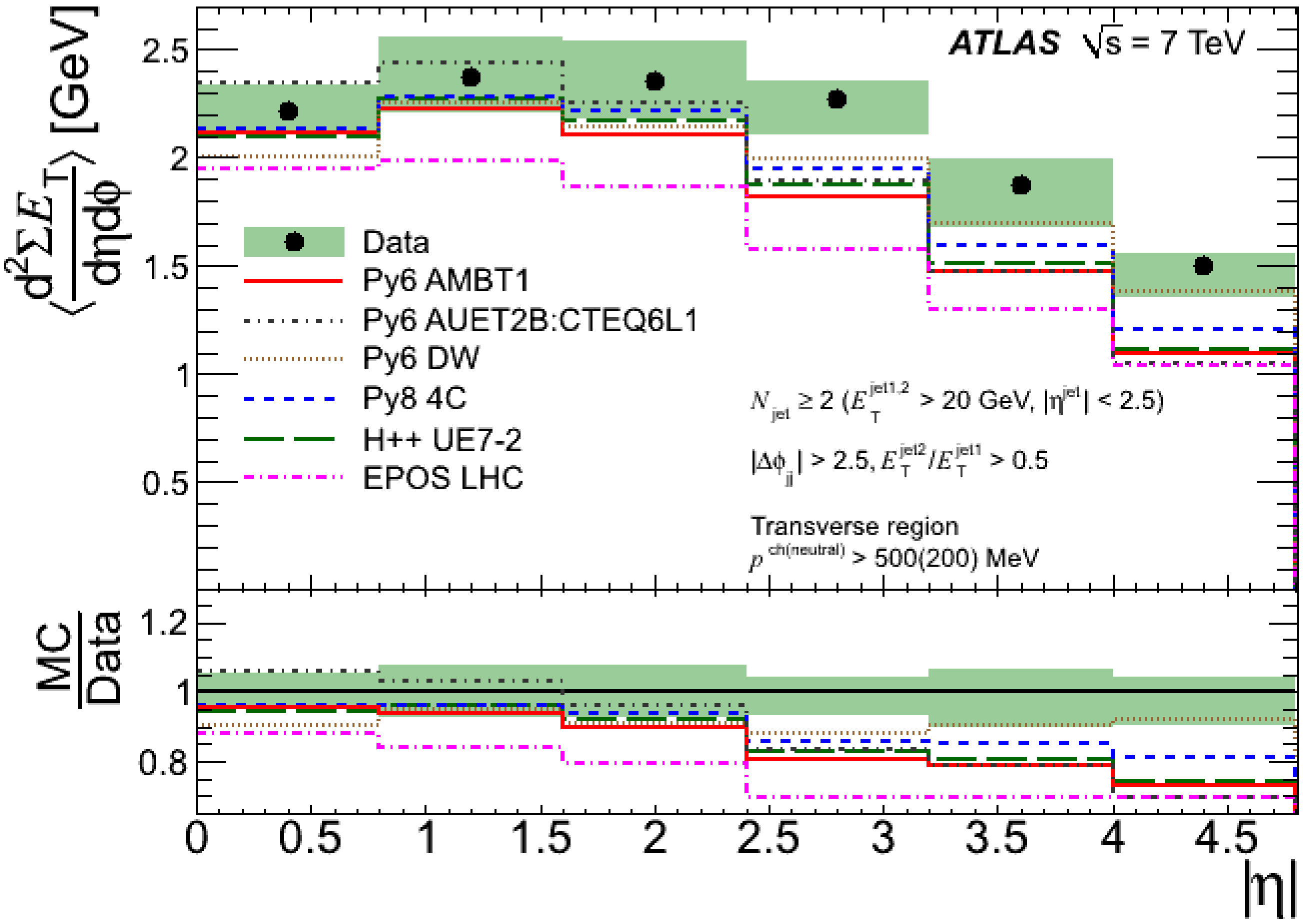


- Pythia6 AMBT1 does best in the central region
- All MCs under-predict the degree of activity in the forward region, with H++ 2.5.1 UE7-2 and Py8 4C performing best here
- Pythia6 DW gets the shape (η-dependence) best, but generally under-predicts in all bins

- EPOS LHC agrees best overall!

Results: ET density

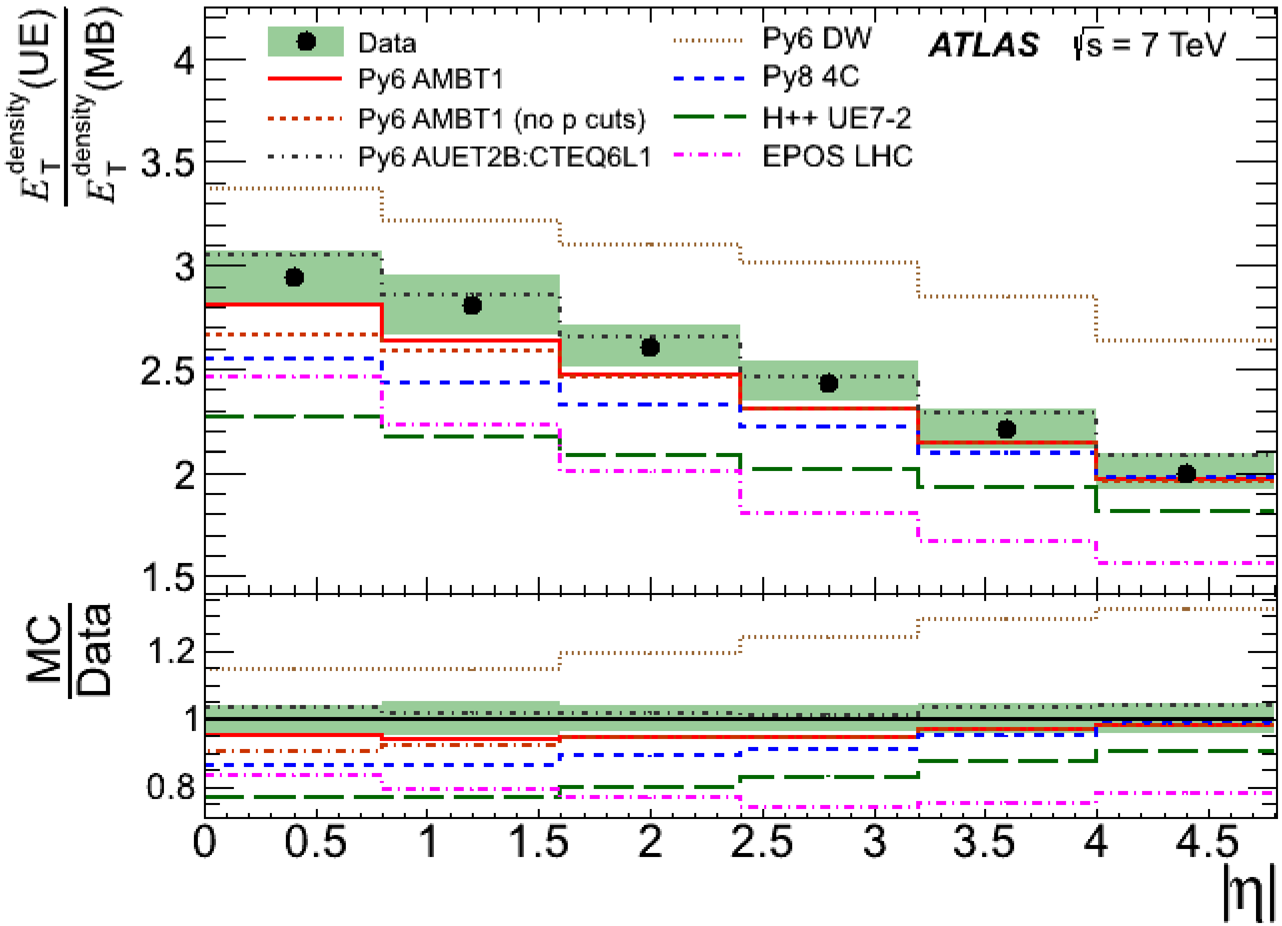
Di-jets



- Transverse region shows approximately 3 times more energy than the inclusive pp
  - Hard scatter biases to head-on collisions – more parton-parton interactions
- Similar relation between data and MC
  - All models and tunes tend to under-predict the activity
  - Here EPOS LHC fairs less well; perhaps because it's never seen LHC UE data

Results: ET density (di-jet) / ET density (inc. pp)

Ratio

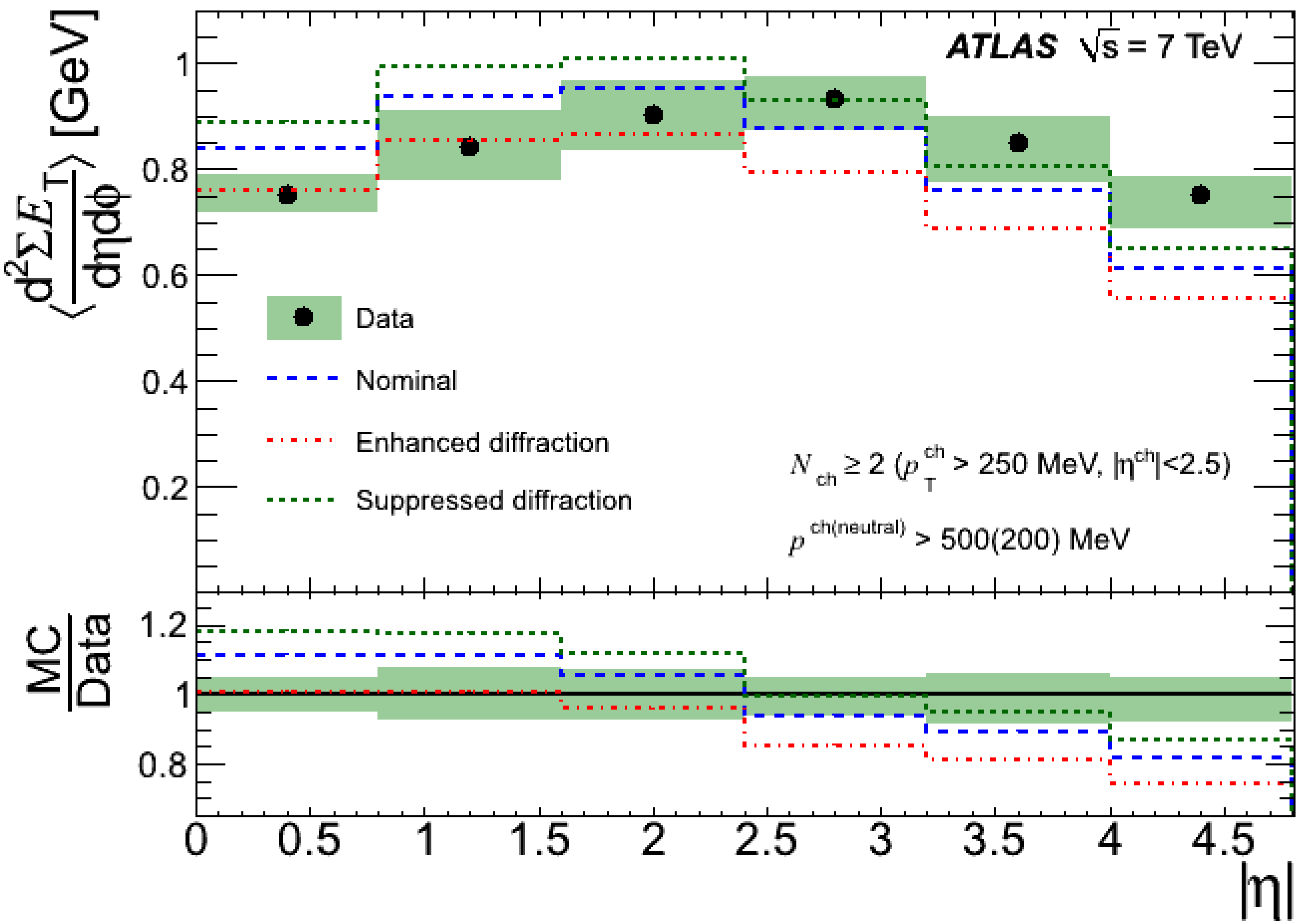


- Fall-off with |η| well reproduced, especially by Pythia 6 AMBT1 and Pythia6 AUET2B:CTEQ6L1

- Pythia 6 AMBT1 (no p cuts)
  - Fall-off partly due to momentum cuts applied to particles included in ΣE_T calculation. In the di-jet sample particles tend to have higher momenta, hence fewer particles are removed.

Results: Variations in diffractive contributions

Inclusive pp



- Probe sensitity to relative fraction of diffractive events
  - Diffractive scatters tend to have less activity than non-diffractive scatters (especially in central region)
- Enhance/suppress relative diffractive contribution by 50% in Pythia8 4C, whilst keeping non-diffractive contribution constant
- Enhanced diffraction gives lower average activity, but shape is roughly similar

Results: Variations in PDFs

• Parton Distribution Functions will affect both overall activity and shape

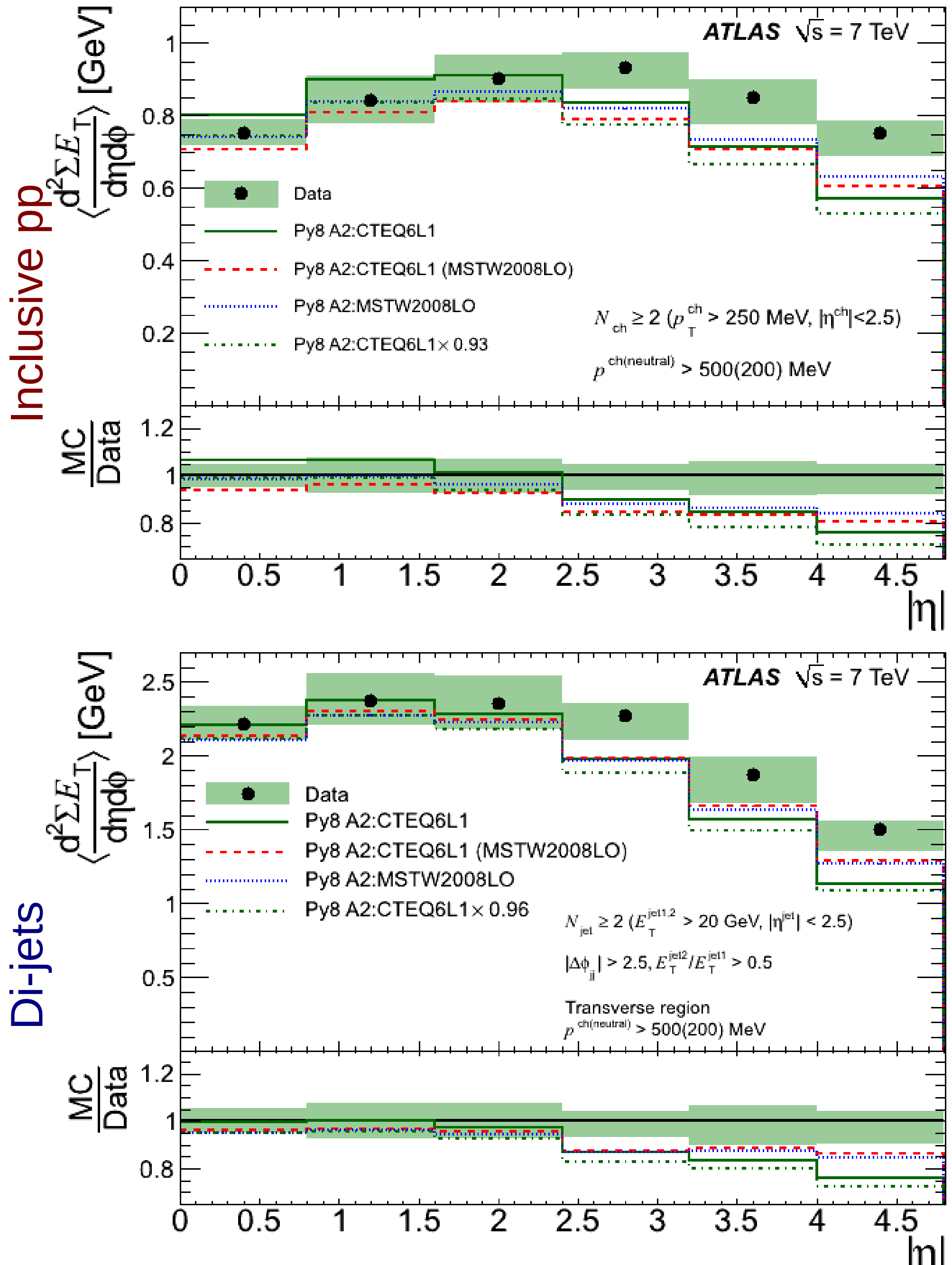
• Compare data to Pythia 8 A2 group of tunes:

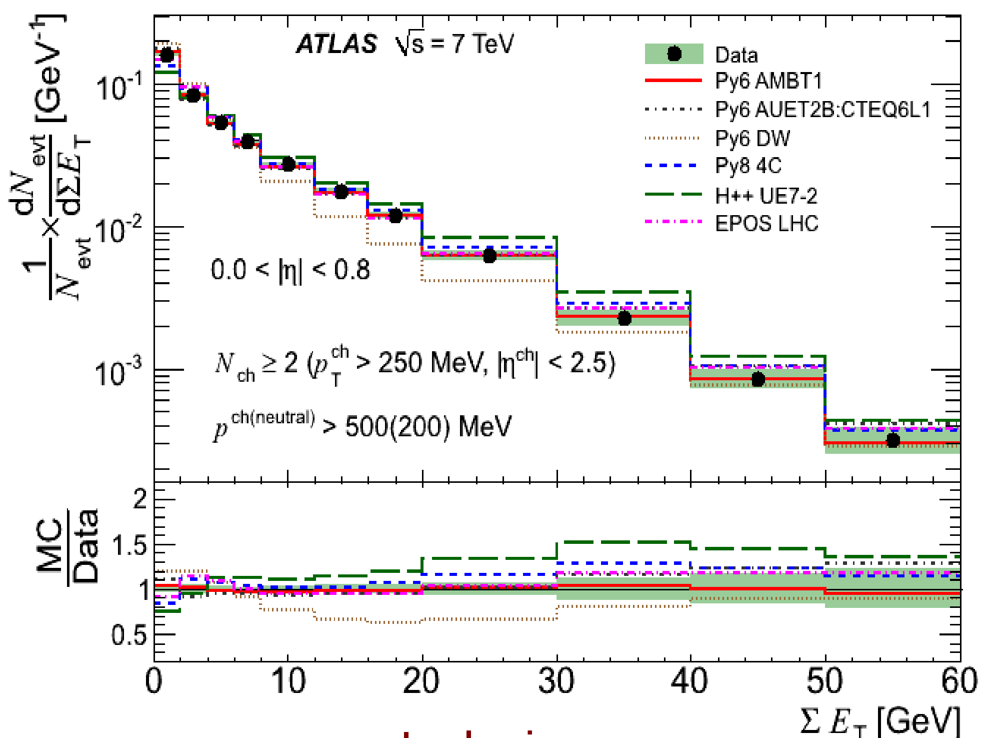
a) Compare tunes
→tuning parameters to MSTW2008LO increases overall activity

b) Probe PDF dependence
→keep tune parameters constant and replace CTEQ6L1→MSTW2008LO

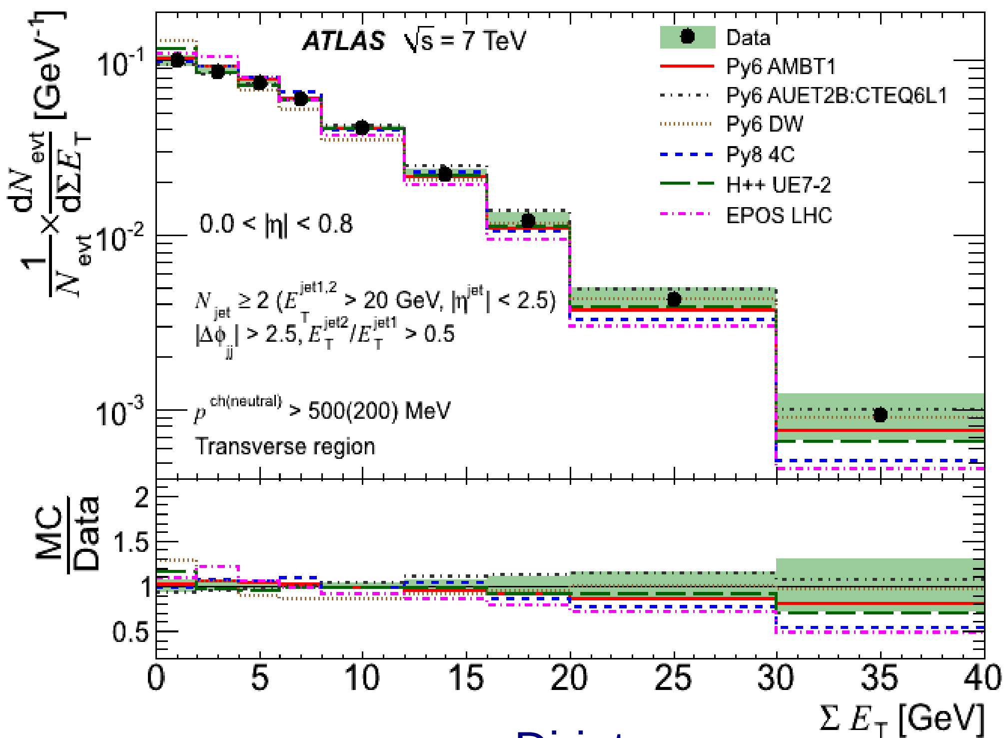
→decreases amount of energy in central region; increases amount in forward region (increase in both high and low-x gluon PDF wrt. to mid-x region)

c) Relative forward/central activity
→ scale A2:CTEQ6L1 so that it agrees with A2:MSTW2008LO in most central |η| bin
• A2:MSTW2008LO provides better description in forward region





Inclusive pp



Di-jets

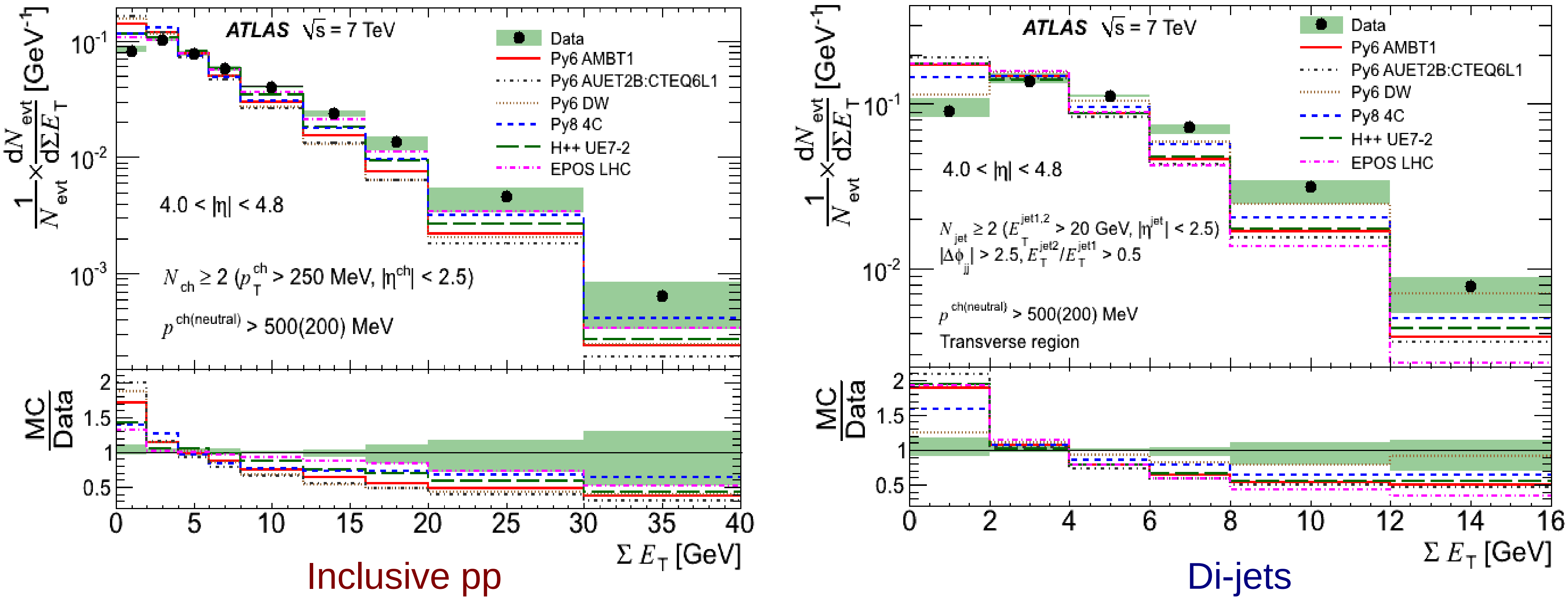
- Distributions are broader in the region |η| < 3.2 with more events populating the tails, i.e. more variation in ΣET from event to event in central part of detector

– Features reproduced by MC:

- Inclusive pp: again, Pythia 6 AMBT1 provides best description of ΣE_T shape in the central region

- Di-jets: all tunes do a reasonable job, Pythia 8 4C underestimates high ΣE_T tails

Results: ΣET distributions (4.0 < |η| < 4.8)



- Data distributions peak at higher values in forward region
  - Not reproduced by MC
- ΣE_T in forward region largely underestimated

Conclusions: ET flow

The ΣE_T distributions in different $|\eta|$ bins as well as the E_T density, up to $|\eta| < 4.8$, have been measured in inclusive pp and di-jet events.

- Data used were corrected for detector effects, back to the level of stable truth particles
- In general, all MC predictions underestimate the amount of activity in the forward region $|\eta| > 2.4$, for both inclusive pp and di-jet
- Diffractive contribution does not significantly alter the central/forward ratio
- We have also investigated the effect of PDF choice, which changes the relative forward to central energy
  - Pythia 8 A2:MSTW2008LO provides a comparatively better description of the activity in the forward region, and is now used for pileup simulation
  - EPOS LHC describes the inclusive pp minimum bias data very well (but still underestimates the activity in the forward region)

Analysis variables and selection: rap gaps

Paper can be found here: http://arxiv.org/abs/1201.2808
"Rapidity Gap Cross Sections in pp Interactions at sqrt(s) = 7 TeV measured with the ATLAS detector"

Main analysis variable is the gap size:

$$\Delta \eta^F$$

Largest continuous interval in η, per event, which starts from the edge of the detector at η = +/- 4.9 and continues to the first particle with p_T > 200 MeV.

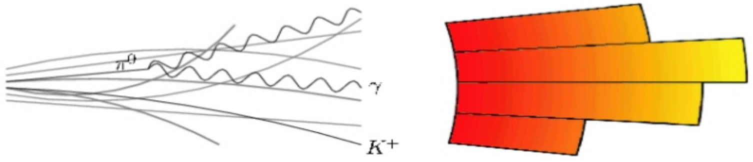
This variable is constructed from both tracks and calorimeter clusters in the region |η| < 4.8.

Selection summary:

- MBTS trigger to ensure collision
- subtract beam-induced background
- particle p_T > 200 MeV

The 3 primary systematic effects are:

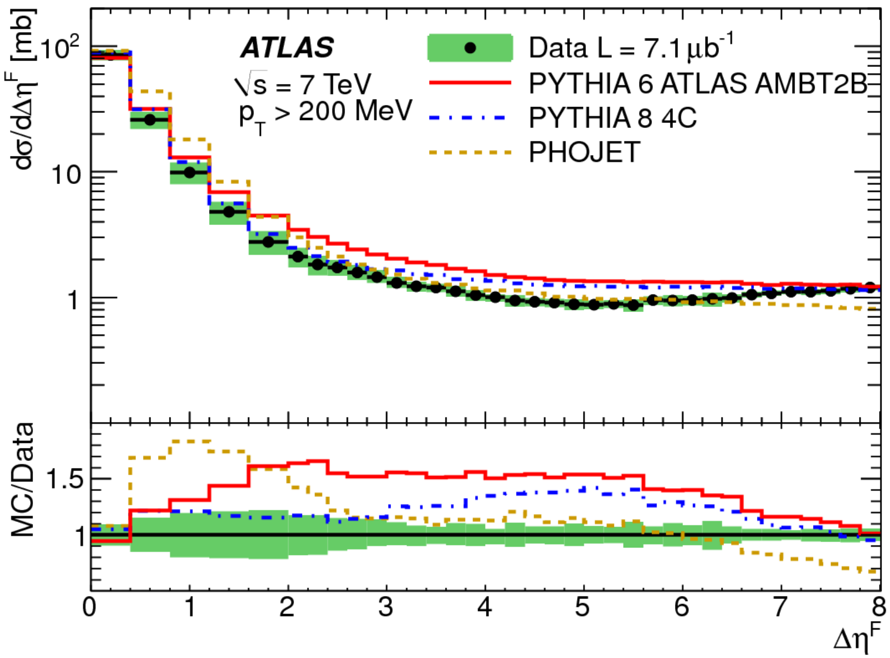
- Difference between MC and data energy response
  - ➔ Same techniques as E_T flow analysis

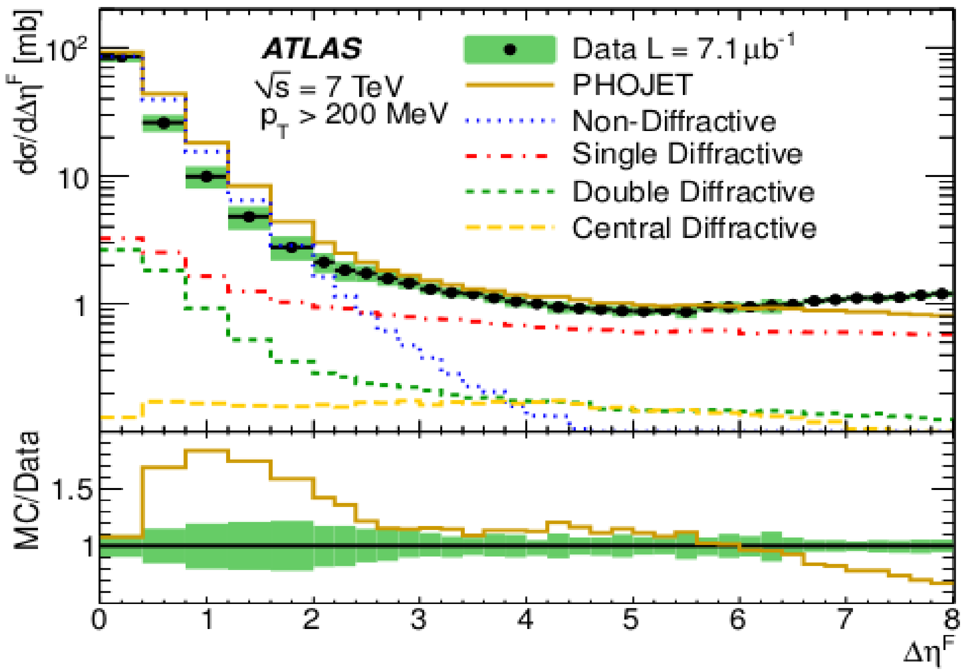


- Model dependence when unfolding
  - ➔ Again, same techniques as E_T flow analysis
- Modelling of diffractive contributions
  - ➔ Alter single and double diffractive contributions, then unfold

Also count trigger, tracking and luminosity as additional systematic errors.

Results: rap gaps

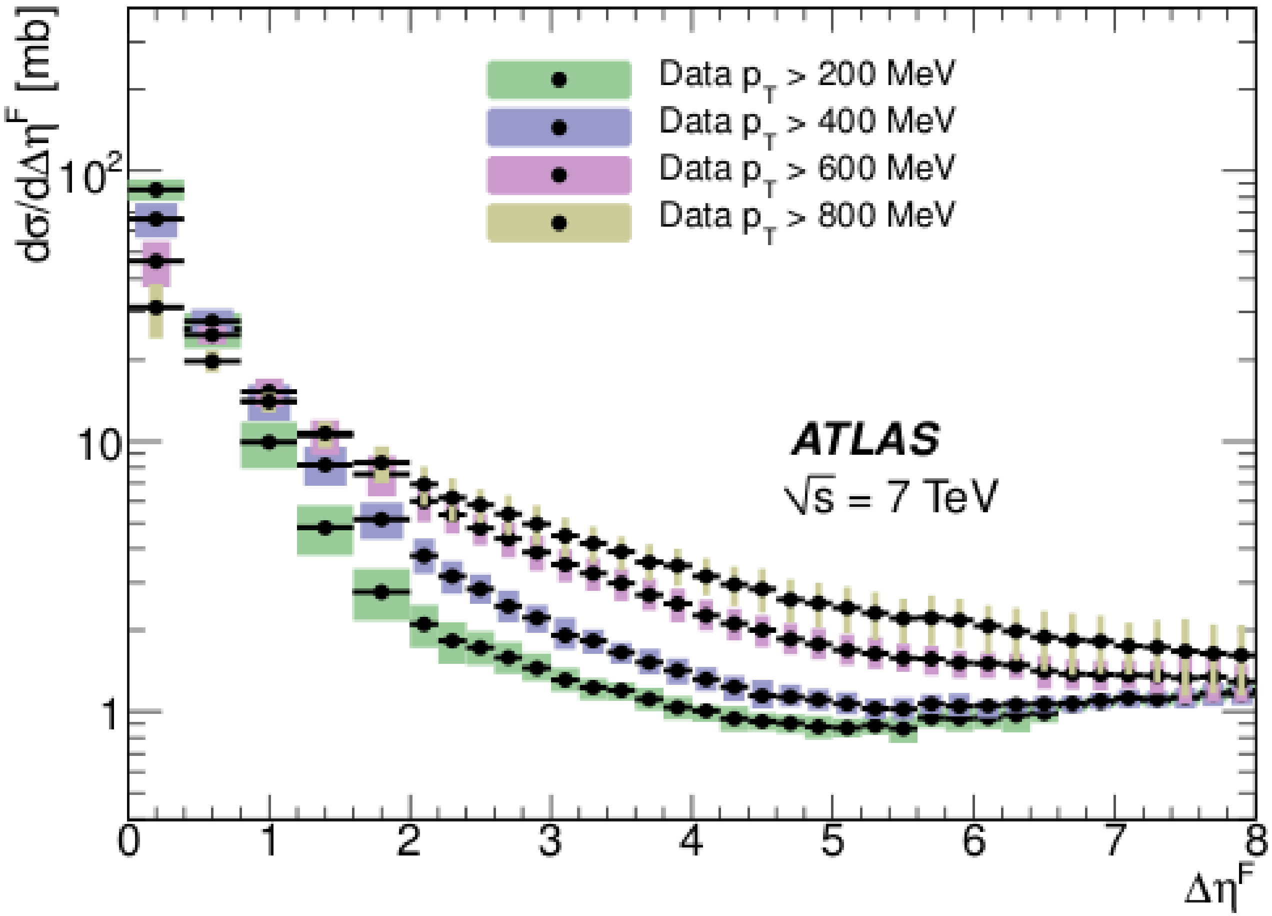




- Exponential fall in cross section at small gap size
  - Due to exponential suppression of gap size in hadronisation
- Plateau region is dominated by events with t << M_X (mass of diffractive system) << s and therefore dominated by the Triple Regge amplitude ($1/M_X^2$ dependence)

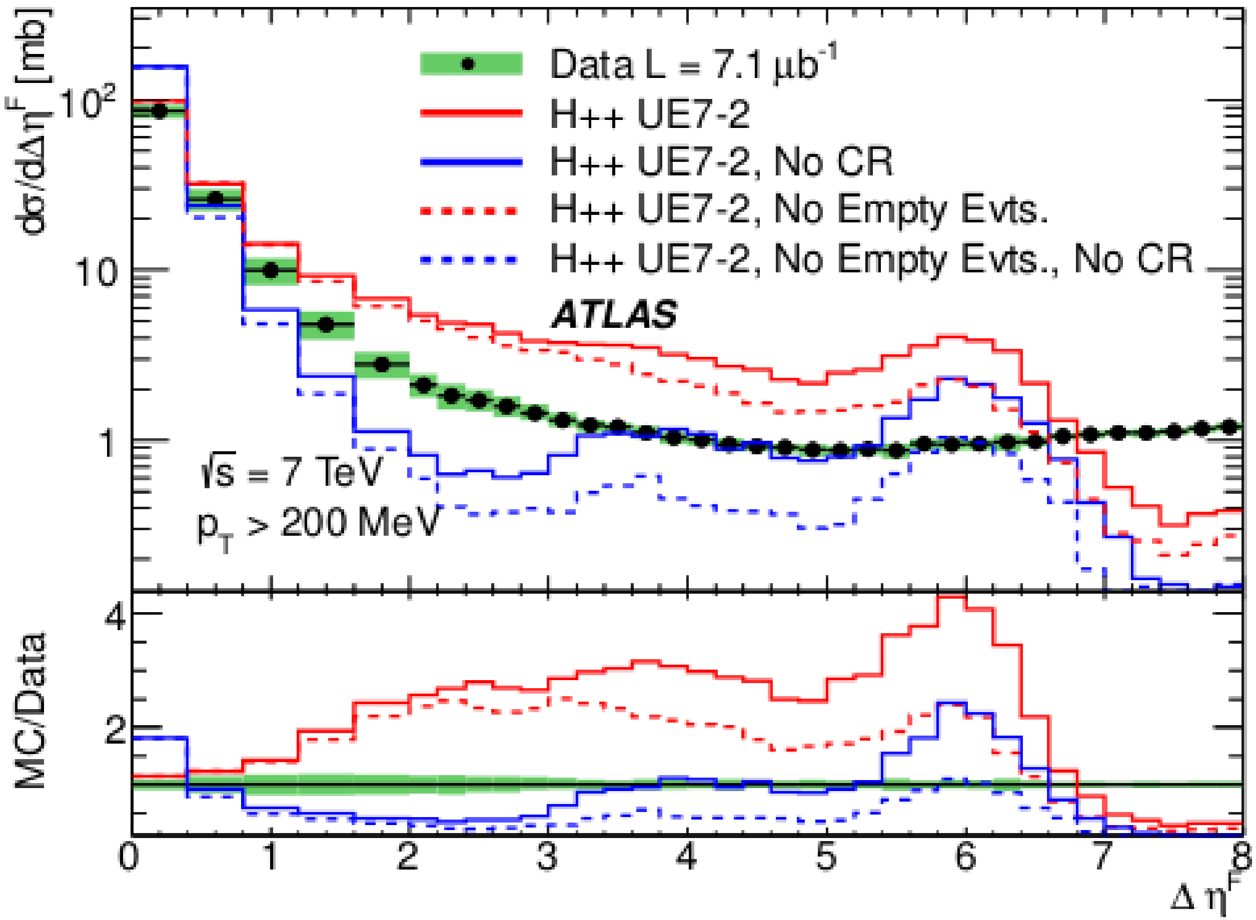
- Pythia 8 4C performs best in general, but plateau is best described by PHOJET, which also contains central diffraction

Results: rap gaps



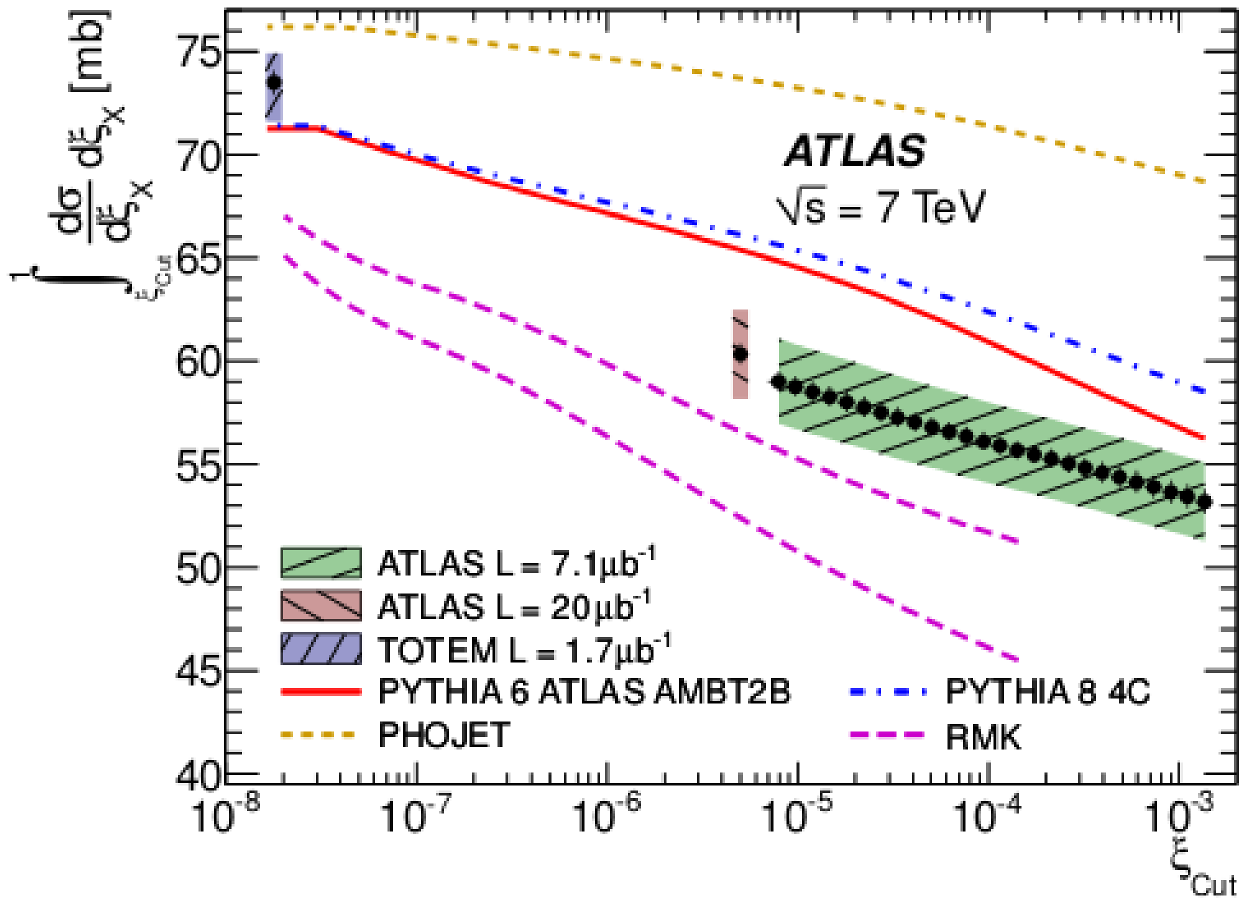
- Same plot, but with different p_T cuts
  - Allows us to probe the degree of MPI and colour reconnection
- Flattens out non-diffractive contribution as p_T cuts increase

Results: rap gaps



- Herwig++ has no explicit diffractive model – get some weird results!
- Turning off colour reconnection and empty events does not completely fix the issue
  - All combinations display a non-exponential tail and large gap size enhancement
  - ➔ Alternative cluster based hadronisation model in H++ is incompatible with data

Results: rap gaps



- Green band shows shift in integral over cross-section, for gap size increasing from right to left
- Shows running of total inelastic cross-section as more low-mass diffraction is included
  - Degree of low-mass diffraction is different between data and MC: $\xi_X < 10^{-5}$ region contributes much more in data than MC

Conclusions: rap gaps

Rapidity gaps in the final state in minimum bias events in ATLAS have been successfully identified down to a particle p_T of 200 MeV, and the differential cross-section plotted as a function of a given event's gap size.

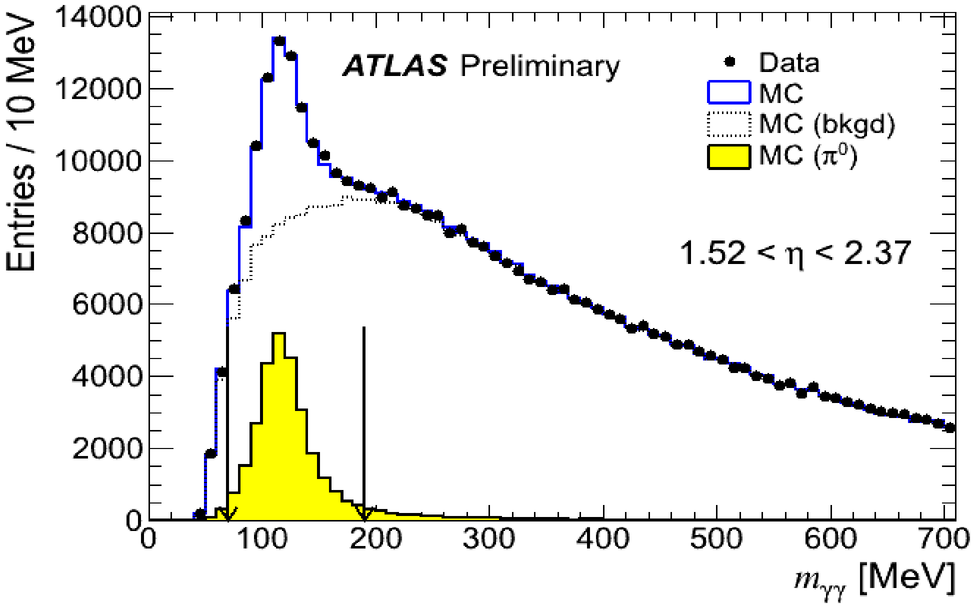
- Data used were corrected for detector effects, back to the level of stable truth particles
- An exponentially falling non-diffractive contribution is seen at small gap sizes
  - Described reasonably well by Pythia, Phojet and H++
- At larger gap sizes, a mixed diffractive state is observed, amounting to ~ 1mb per unit of gap size
  - Described roughly by Pythia and Phojet
- None of the models describe the rise of the differential cross-section at highest gap size
  - Interpreted within the triple Pomeron-based approach of Pythia 8
- The contribution to the total inelastic cross section from the region $\xi_X < 10^{-5}$ is determined to be around 20%
  - This is considerably larger than is predicted by most models.

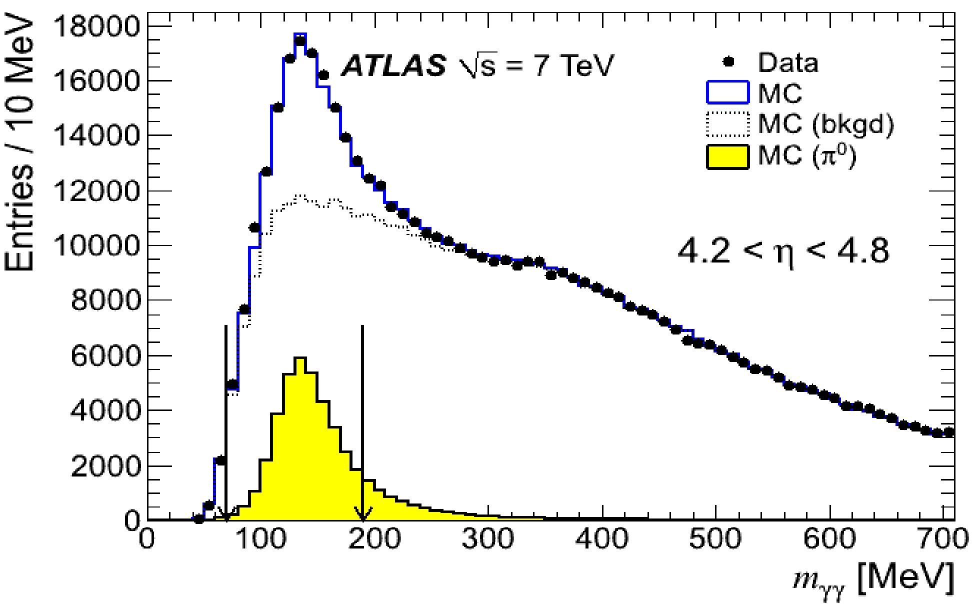
Conclusion

Both sets of results are being used to improve our models' descriptions of LHC physics.

Thanks for listening!

Backup: calorimeter resolutions





Figures showing $\pi^0 \rightarrow \gamma\gamma$ resolution in both the central and forward regions.

$\|\eta\|$	$\langle \frac{d^2\Sigma E_T}{d\eta d\phi} \rangle$ [GeV]	Stat. [%]	E_1^* [%]	E_2 [%]	M_1 [%]	M_2 [%]	M_3^* [%]	P_1 [%]	Total [%]
0.0 – 0.8	0.753	±0.19	$^{+3.2}_{-2.9}$	—	±2.9	—	±0.51	±2.6	$^{+5.1}_{-4.9}$
0.8 – 1.6	0.844	±0.17	$^{+5.4}_{-4.9}$	—	±3.2	±0.49	±1.2	±4.6	$^{+7.9}_{-7.5}$
1.6 – 2.4	0.902	±0.16	$^{+4.0}_{-3.8}$	—	—	±0.89	±5.0	±3.4	$^{+7.4}_{-7.2}$
2.4 – 3.2	0.932	±0.16	$^{+2.4}_{-5.0}$	—	—	—	±3.0	±2.5	$^{+4.6}_{-6.4}$
3.2 – 4.0	0.850	±0.15	$^{+4.3}_{-4.4}$	−6.2	—	—	±2.7	±3.2	$^{+6.0}_{-8.7}$
4.0 – 4.8	0.750	±0.14	$^{+2.7}_{-2.7}$	−6.8	—	—	±0.8	±3.6	$^{+4.6}_{-8.2}$

Table 3. Measured E_T^{density} and systematic uncertainty breakdown for the minimum bias data. The systematic uncertainties marked with a $*$ are uncorrelated between $|\eta|$ bins.