# Overview of results on diffraction from the ATLAS Experiment

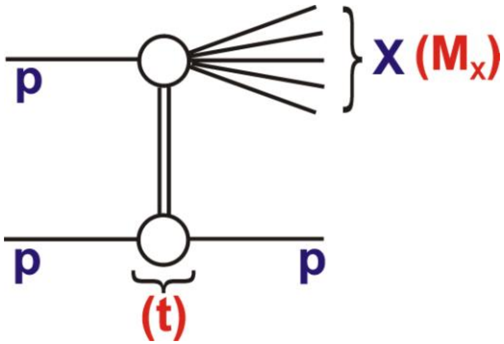
Hardeep Bansil
(University of Birmingham)

MPI@LHC 2013, Antwerp
2-6 December 2013

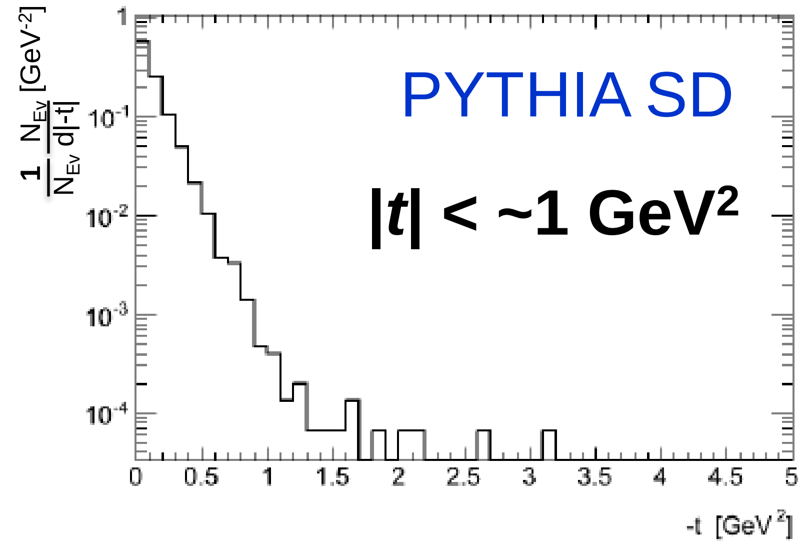
→ Total Inelastic Cross Section
[Nat. Commun. 2 (2011) 463, arXiv:1104.0326]
→ Rapidity Gap Cross Sections
[Eur. Phys. J. C72 (2012) 1926, arXiv:1201.2808]
→ Forward Transverse Energy Flow
[JHEP11(2012)033, arXiv:1208.6256]

# Diffractive Dissociation

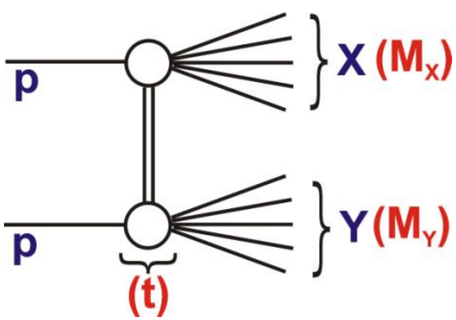
**Single dissociation (SD),** $pp \rightarrow Xp$



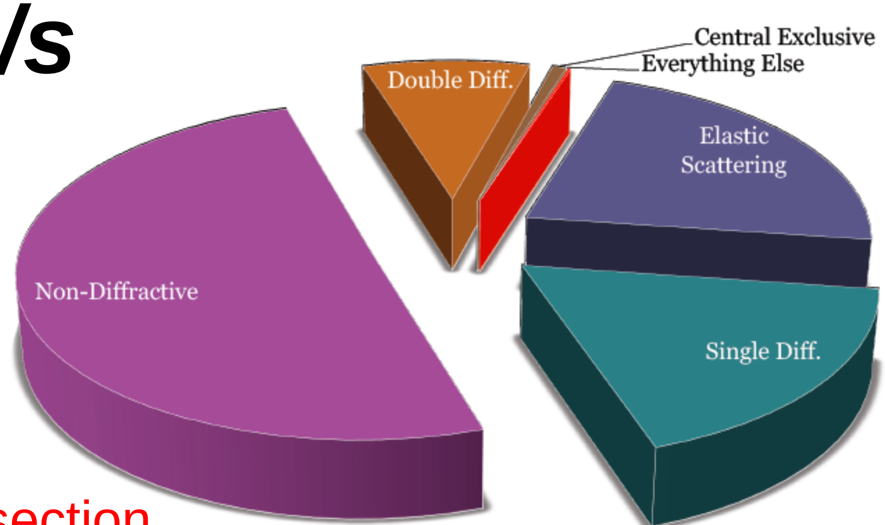

$$\xi_{(X)} = M_X^2/s$$




**Double dissociation (DD),** $pp \rightarrow XY$



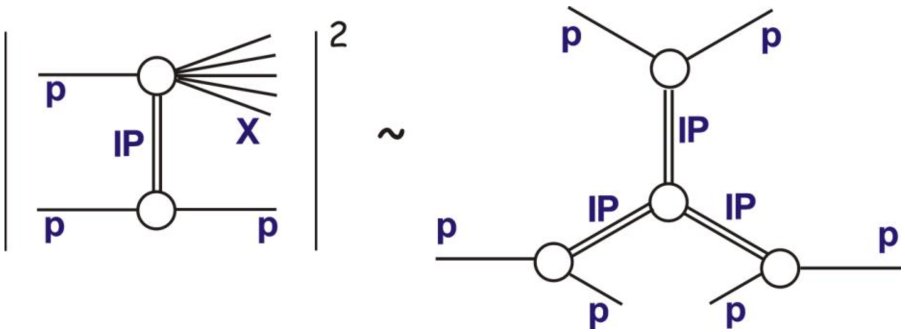

$$\xi_Y = M_Y^2/s$$




- At LHC energies, $M_X$, $M_Y$ can range from $m_p+m_\pi \rightarrow$ ~1 TeV
- Diffractive channels together account for ~ quarter of total LHC cross section

# "Standard Model" of Soft Diffraction

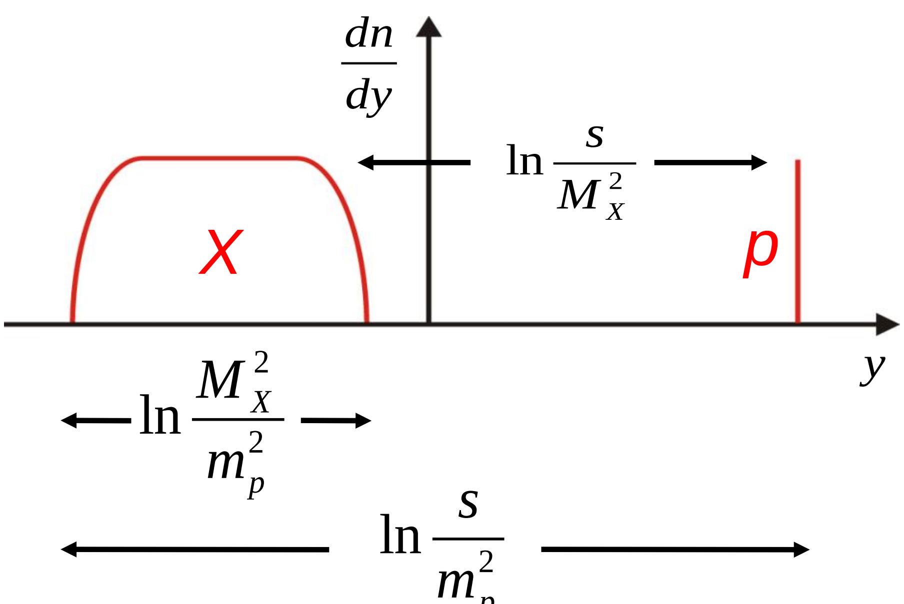
$$\left[\alpha(t) = \alpha(0) + \alpha' t\right]$$




At fixed $s$: $\dfrac{d\sigma}{d\xi\, dt} \propto \left(\dfrac{1}{\xi}\right)^{2\alpha(t)-\alpha(0)} e^{bt}$

i.e. approximately: $\dfrac{d\sigma}{d\xi} \propto \dfrac{1}{\xi}$

Deviations from this behaviour sensitive to $\alpha_{IP}(t)$ and to absorptive corrections → c.f. multi-parton interactions

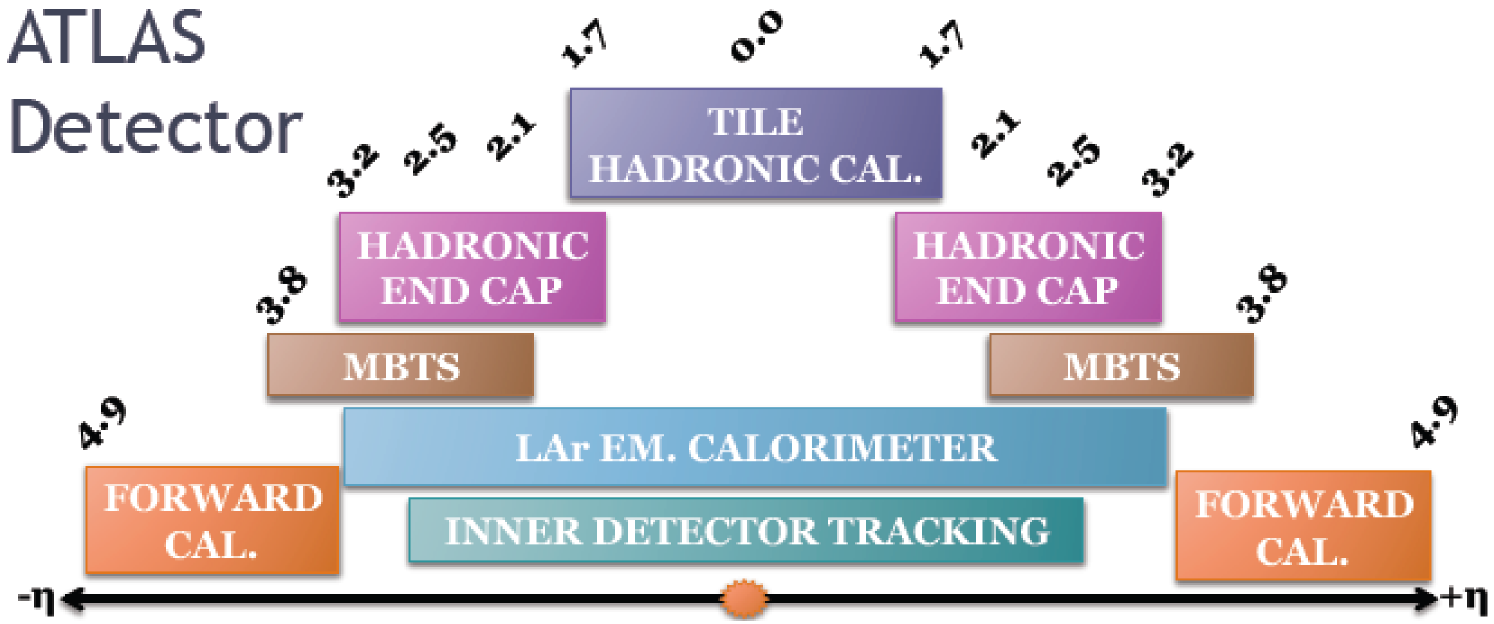



Up to event-by-event hadronisation fluctuations, $\xi$ variable predictable from empty rapidity regions

$$\Delta\eta \approx -\ln \xi$$

… ~ flat gap distributions $\dfrac{d\sigma}{d\Delta\eta} \approx \text{const.}$

# ATLAS Acceptance



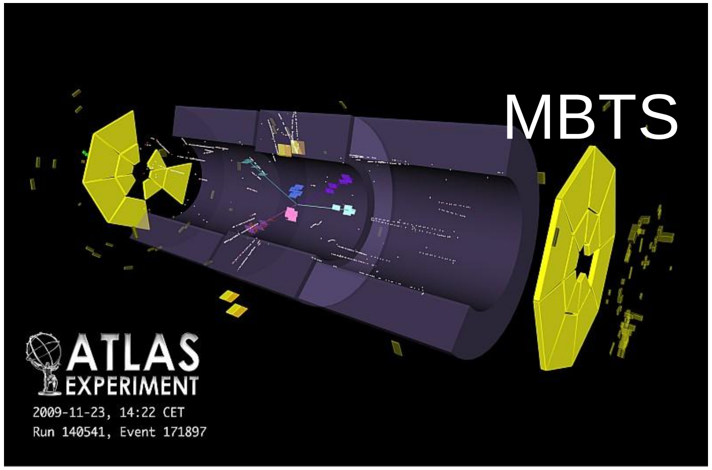

- Data obtained using full calorimeter coverage (|η| < 4.9) and inner tracking detector (|η| < 2.5)
- MBTS scintillators provide almost unbiased trigger

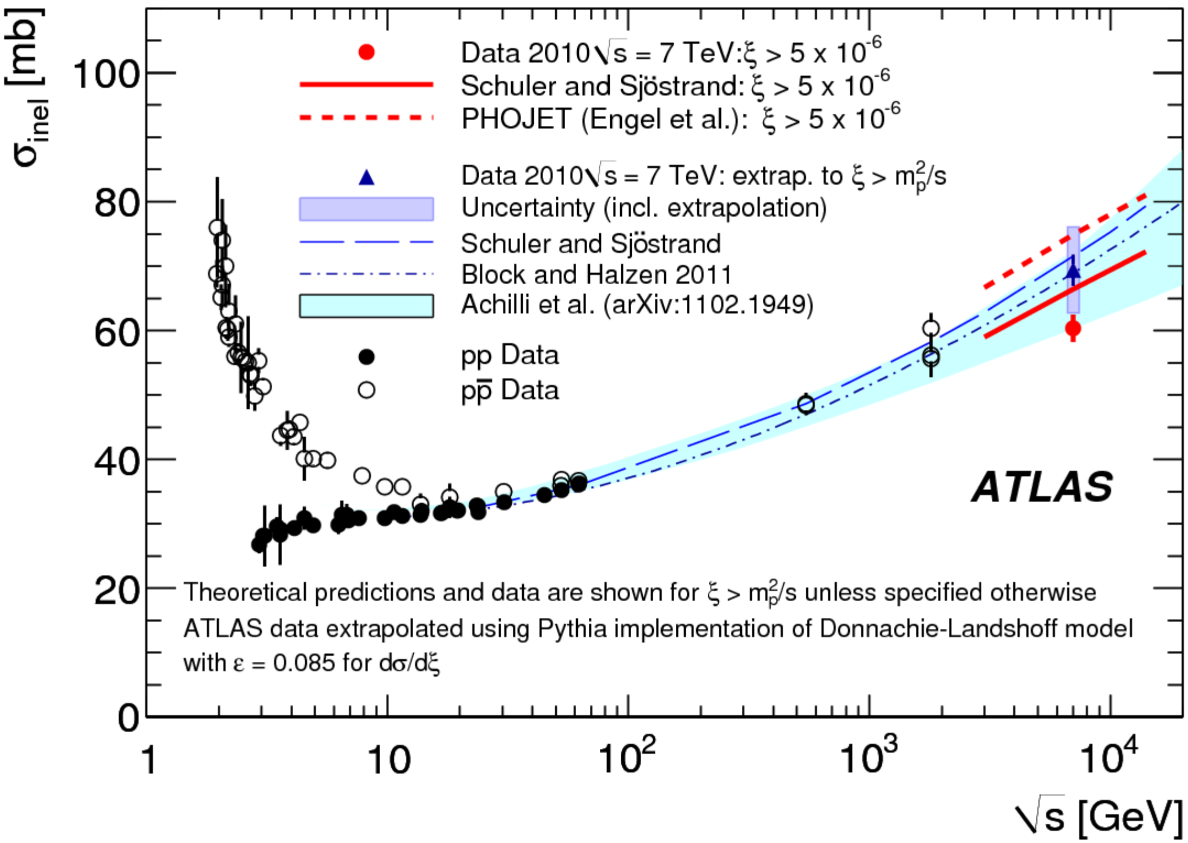
- Systems with $M_X$ ($M_Y$) < 7 GeV fall out of acceptance

- Detector is sensitive to particle production with $p_T$ > ~200 MeV

# Total Inelastic pp Cross Section (ATLAS)

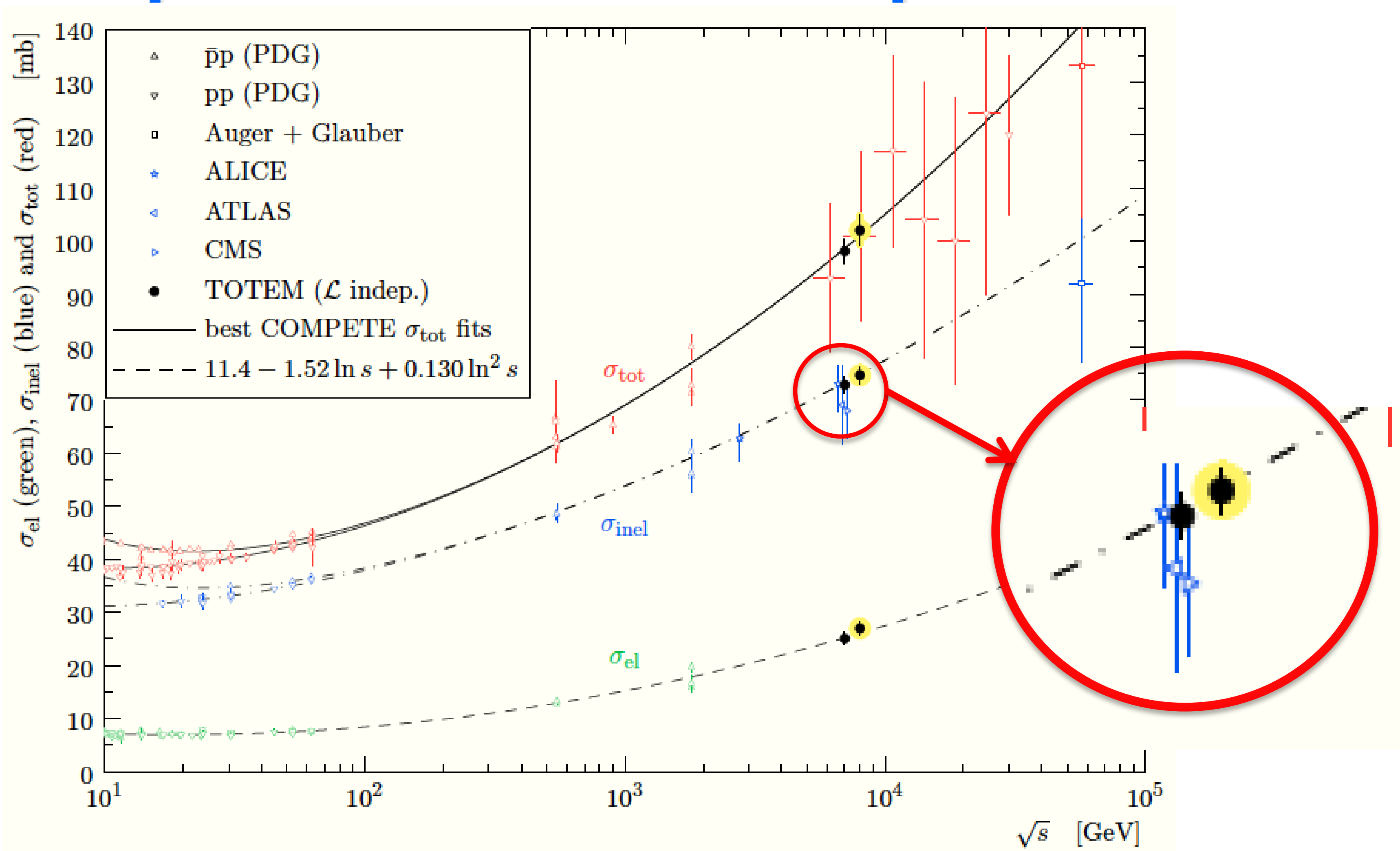
- 20 μb$^{-1}$ sample selected using MBTS trigger (2.1 < |η| < 3.8), miss only elastic (*pp→pp*) and low mass diffraction (*pp→pX* etc) using limit of ξ > 5×10$^{-6}$




- Unextrapolated result below PYTHIA and PHOJET defaults
- 5-15% extrapolation yields total inelastic cross section
- Extrapolation includes large uncertainty on low mass diffraction

# Comparison with Subsequent Data




Central Value of extrapolated ATLAS result consistent with TOTEM (due to large model dependence errors), but central value somewhat lower … need improved modelling of low mass diffraction ...

# Differential rapidity gap cross-sections

• Cross sections differential in "visible" rapidity gap size $\Delta\eta^F$

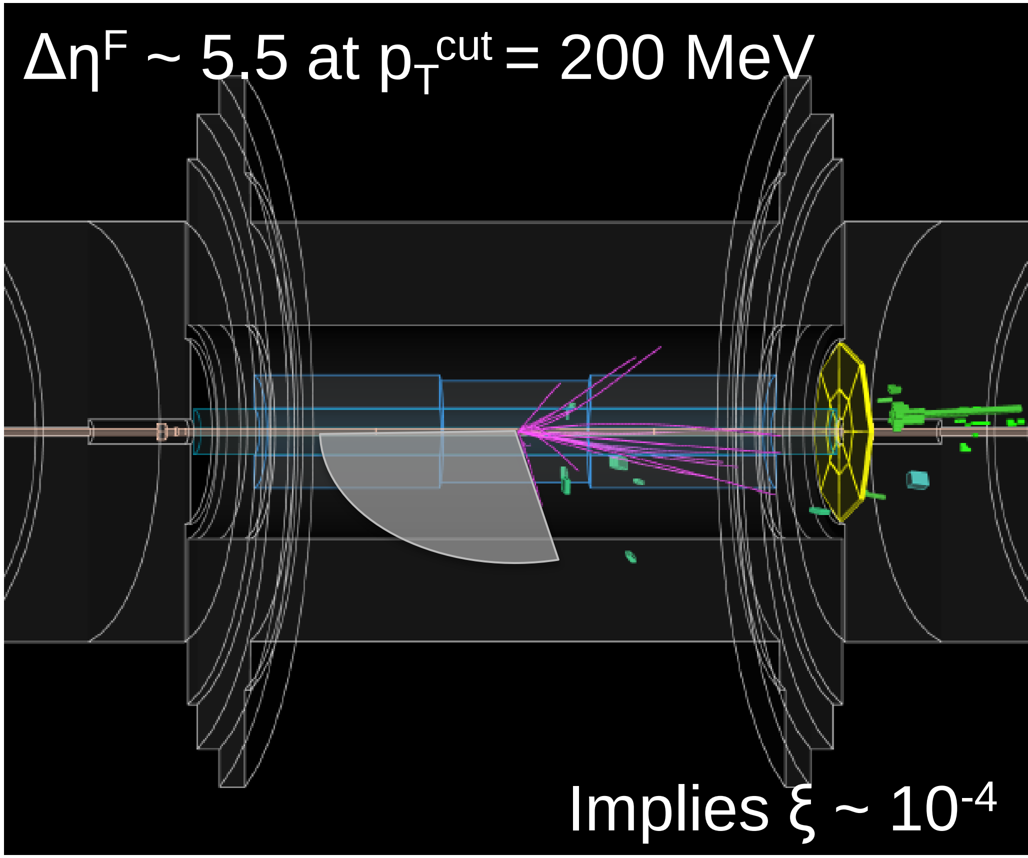
- $\Delta\eta^F$ extends from $\eta = \pm 4.9$ to first particle with $p_T > p_T^{cut}$

200 MeV < $p_T^{cut}$ < 800 MeV

$0 < \Delta\eta^F < 8$

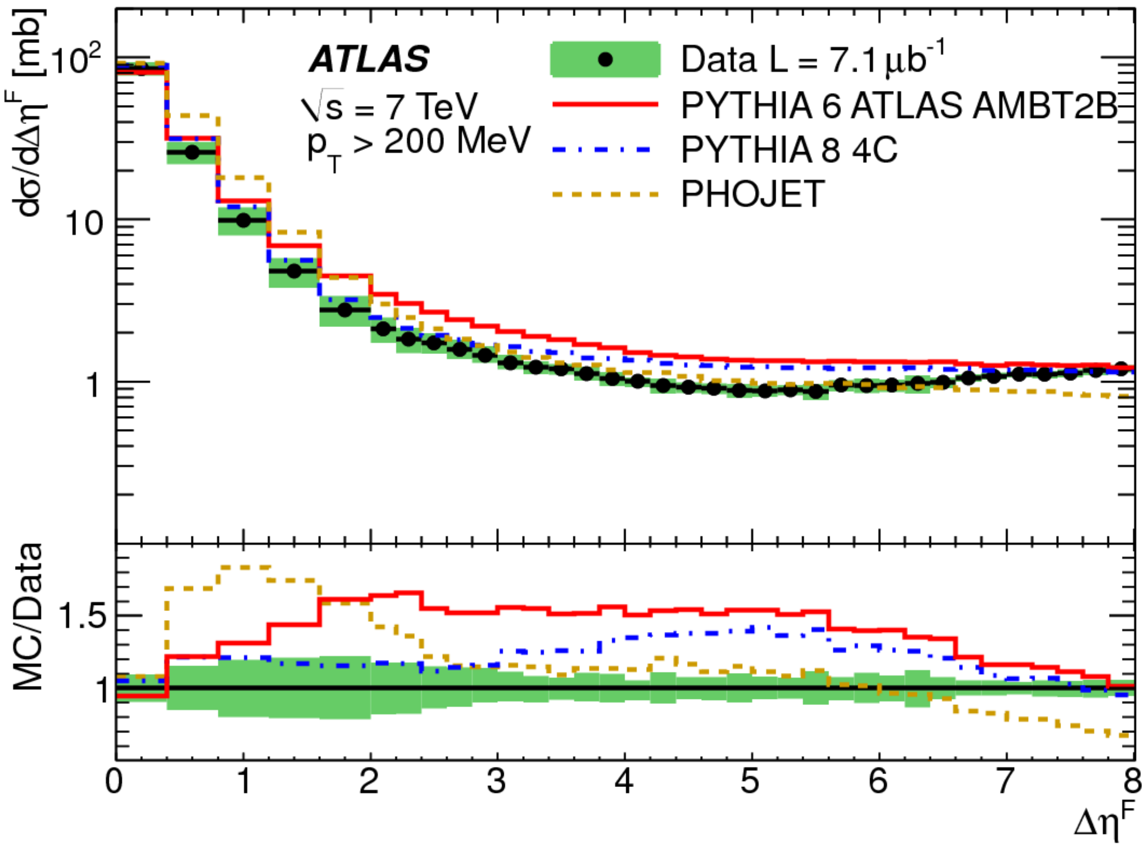
… corresponding (where diffraction dominates) to $\sim 10^{-6} < \xi < \sim 10^{-2}$ … or $\sim 7 < M_x < \sim 700$ GeV

Corrected for experimental effects to level of stable hadrons




$p_T^{cut} = 200$ MeV results follow …

# Differential Rapidity Gap Cross Section




Precision between ~8% (large gaps) and ~20% ($\Delta\eta^F$ ~ 1.5)

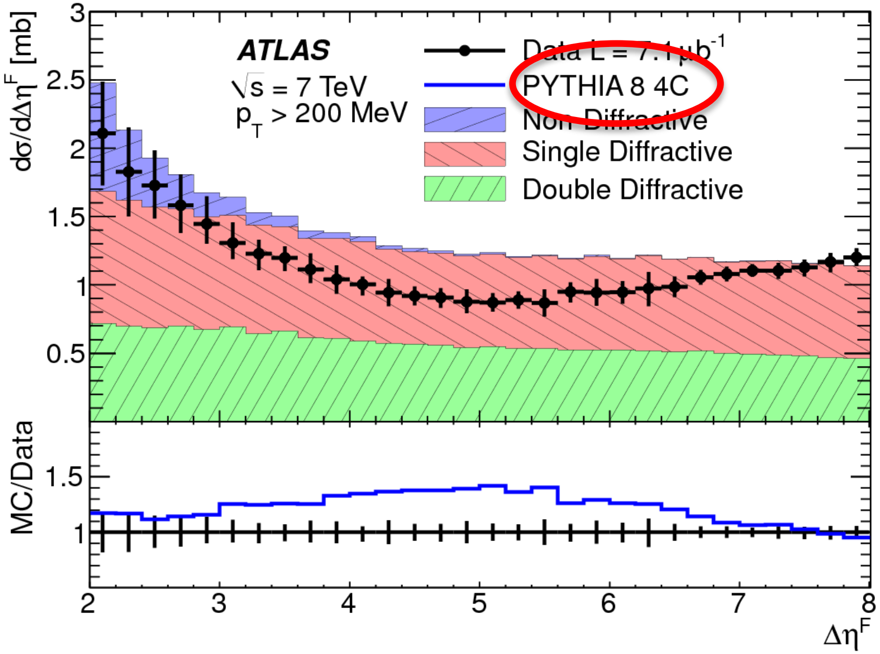
Large gaps measure x-sec for SD [+ DD with $M_Y$ < ~7 GeV]

Small gaps sensitive to hadronisation fluctuations / MPI

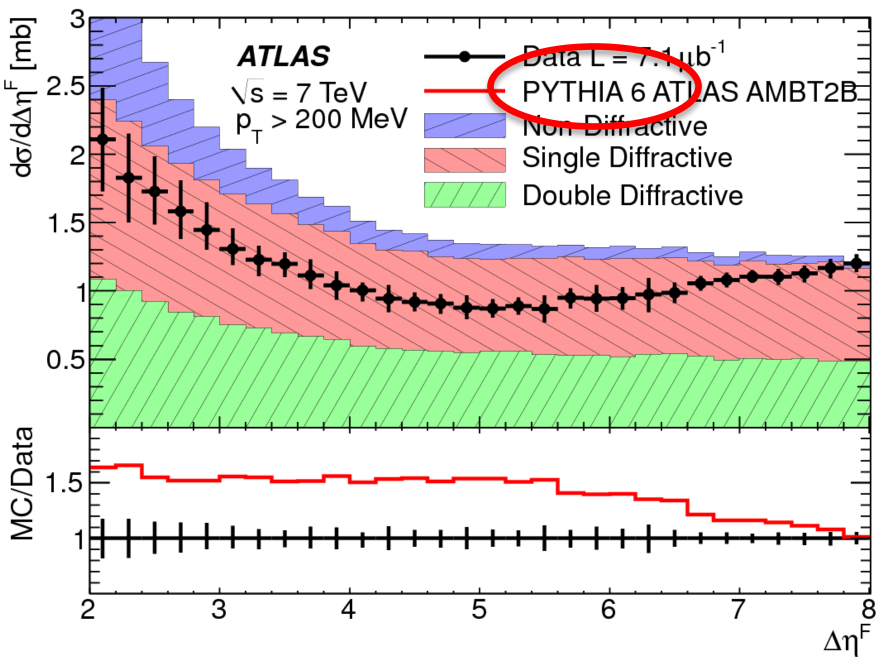
… huge uncertainties

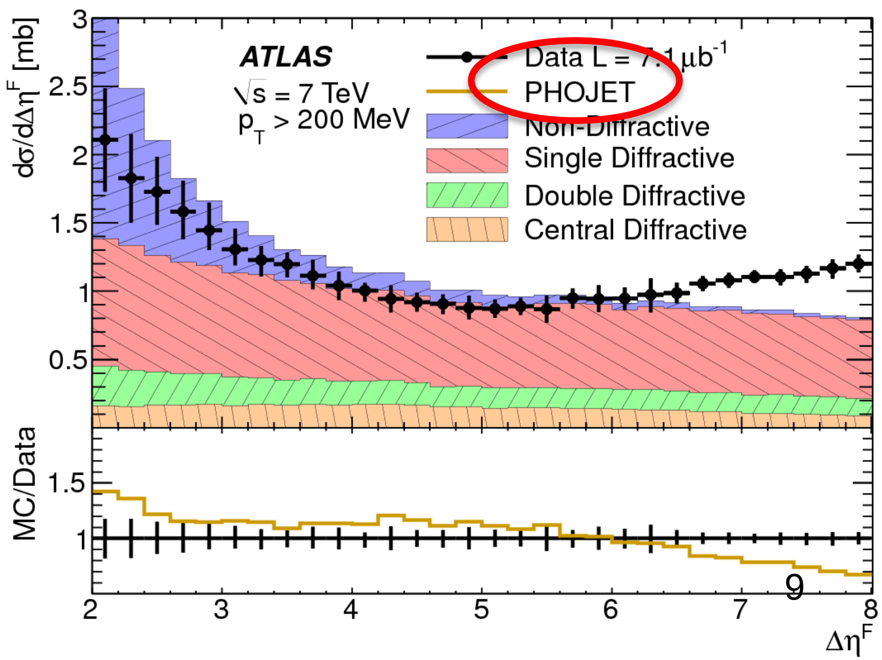
PYTHIA best at small gaps, PHOJET > 50% high at $\Delta\eta^F$ ~ 1.5

# Large Gaps and Diffractive Dynamics

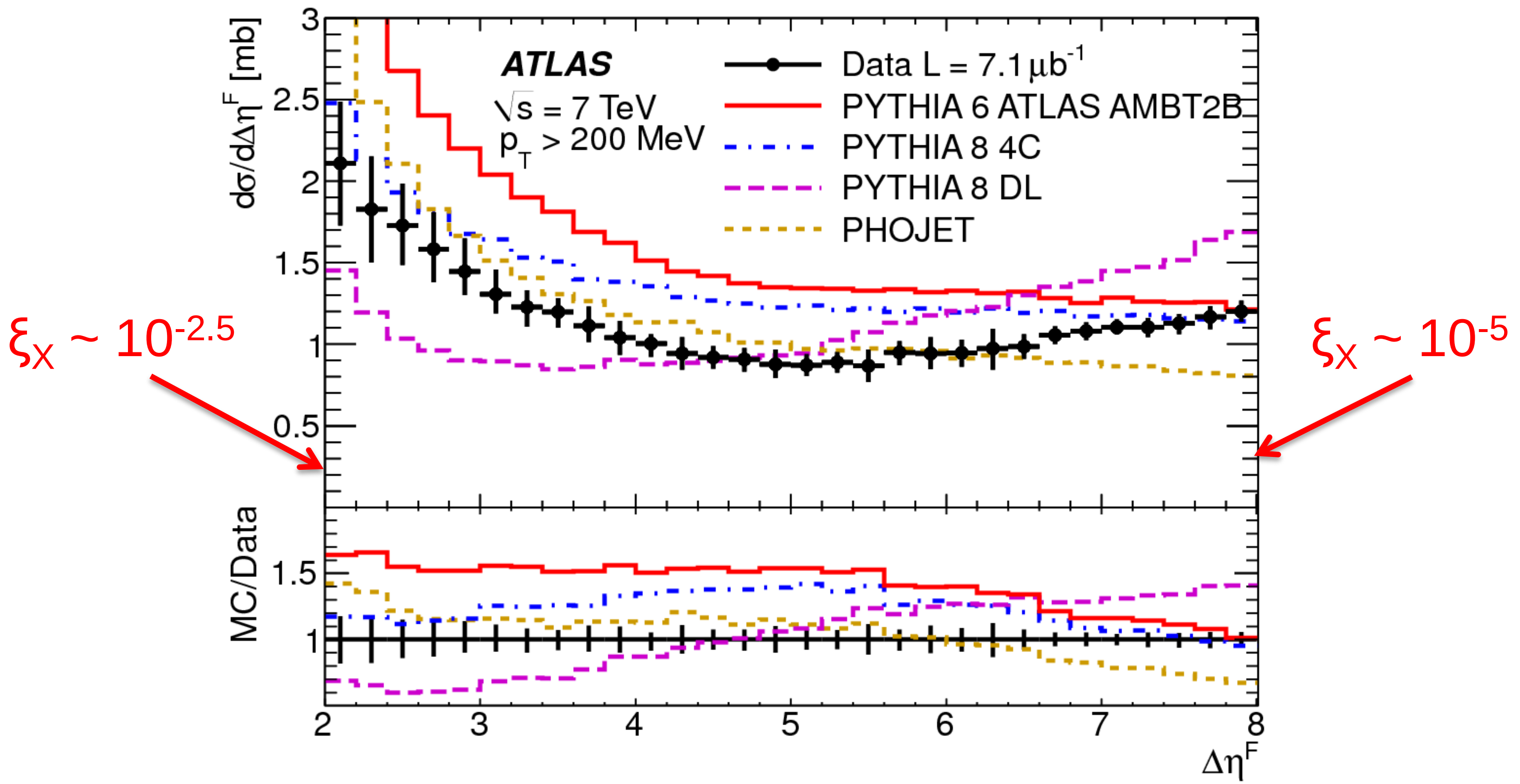



- Diffractive plateau with ~1 mb per unit of gap size for $\Delta\eta^F > 3$ broadly described by models
- PYTHIA high (DD much larger than in PHOJET)
- PHOJET low at high $\Delta\eta^F$



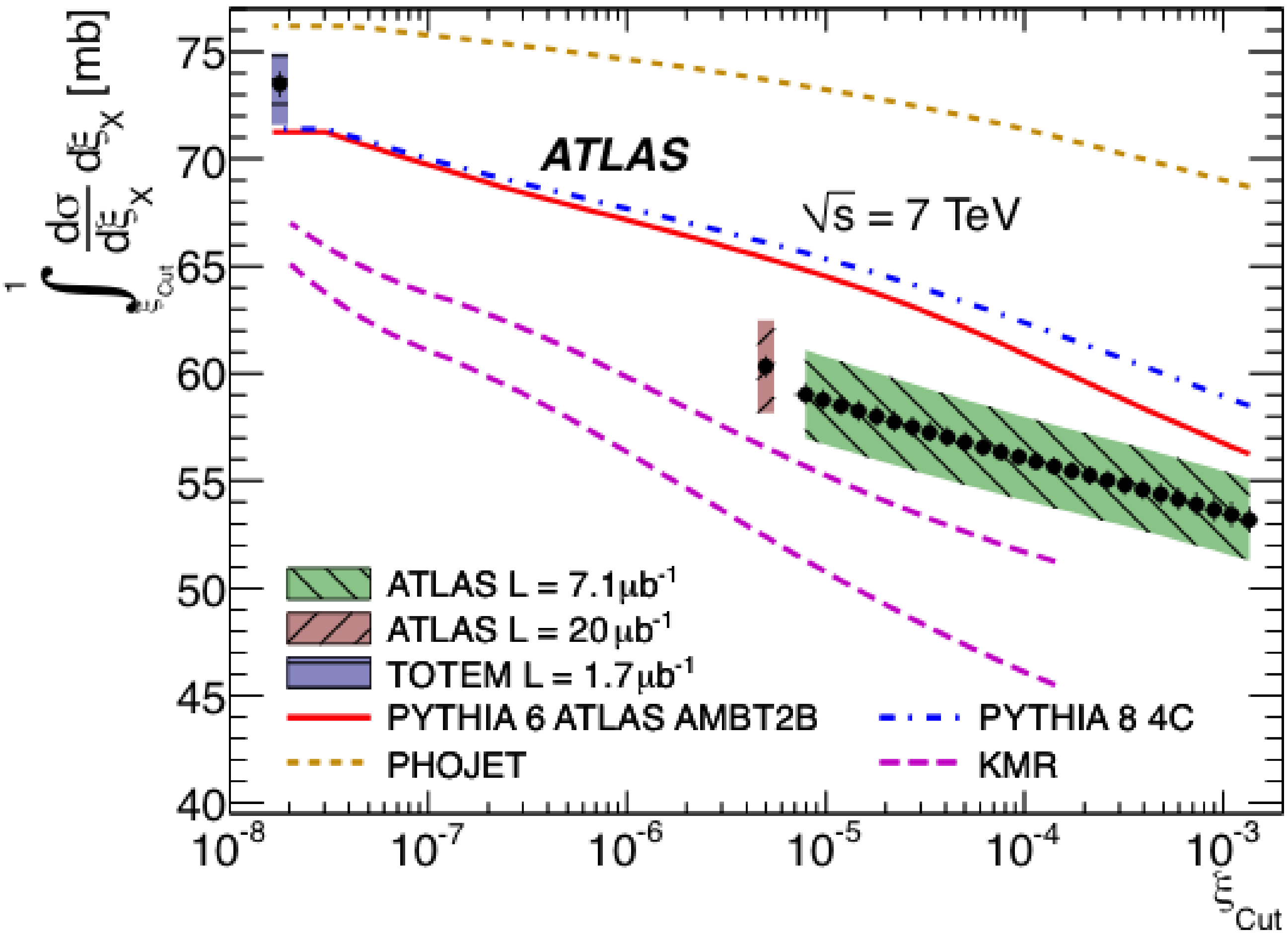



# Large Gaps and Diffractive Dynamics




Default PHOJET and PYTHIA models have $\alpha_{IP}(0) = 1$
Donnachie-Landshoff flux has $\alpha_{IP}(0) = 1.085$
Fit $6<\Delta\eta^F< 8$ region: $\alpha_{IP}(0) = 1.058 \pm 0.003$ (stat) $\pm 0.036$ (sys)
[Absorptive corrections neglected in all cases]

# Investigating Low Mass Extrapolations



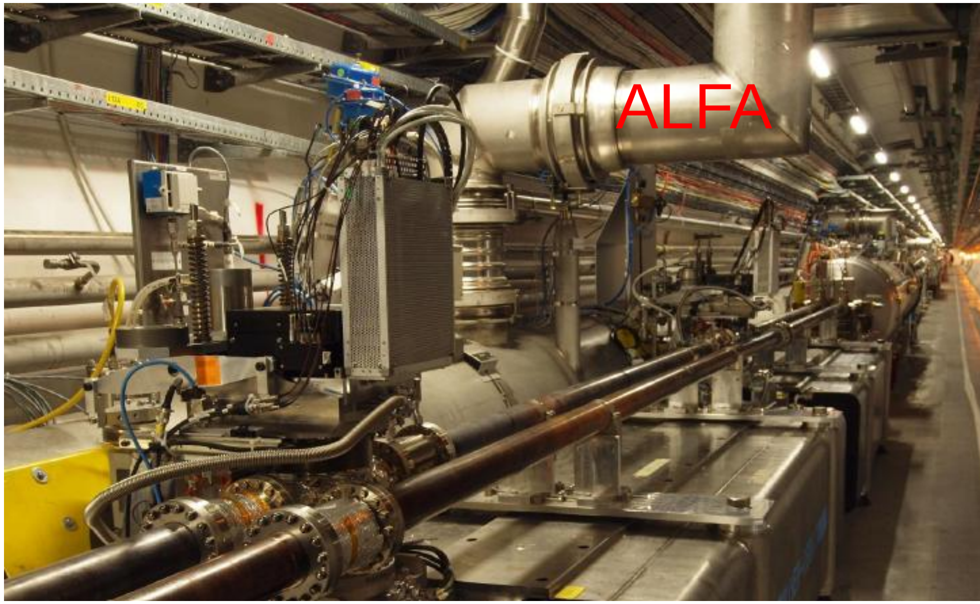

[Inelastic cross section excluding diffractive channels with $\xi < \xi_{cut}$ ]

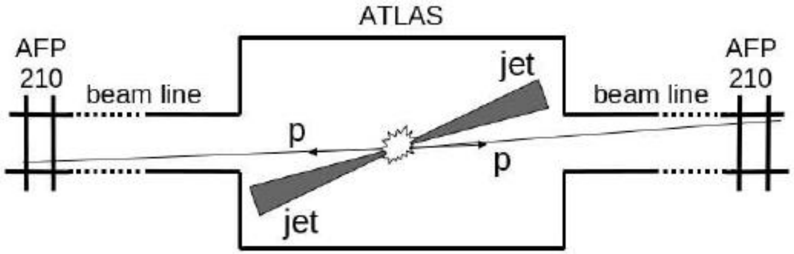
- Integrating ATLAS gap cross section up to some max $\Delta\eta^F$ (equivalently min $\xi_X$) and comparing with TOTEM indicates that small $\xi_X$ region underestimated in PHOJET and PYTHIA:
    - 14 mb with $\xi < 10^{-5}$, compared to 6 (3) mb in PYTHIA (PHOJET)

# Proton Spectrometry at ATLAS

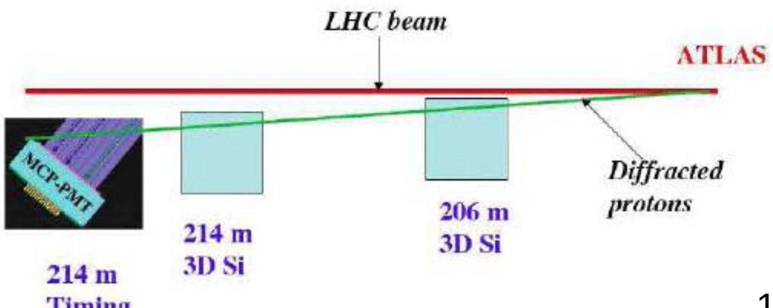
Rapidity gap measurements limited by several factors

ALFA and AFP are the medium and long-term future of diffraction in ATLAS




… will not be covered here … see talks in Friday's session (Christophe Royon)



# Forward energy flow

2010 study of energy flow in soft and hard QCD processes

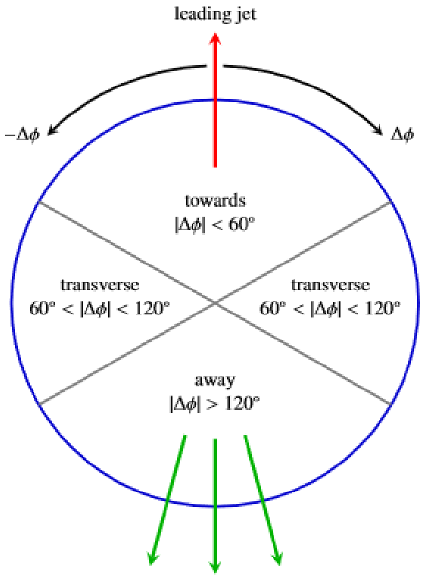
MinBias sample (7.1 μb$^{-1}$) – MBTS trigger, 1 vtx with at least 2 tracks > 250 MeV truth (> 150 MeV reco), no additional vertices

Dijet sample (590 μb$^{-1}$) - as above, study UE with back-to-back jets
$E_T > 20$ GeV, $|\eta| < 2.5$, $|\Delta\varphi_{jj}| > 2.5$, $E_T(J2)/E_T(J1) > 0.5$

Correct for experimental effects back to hadron level for particles with $|\eta| < 4.8$ ($p^{charged} > 500$ MeV, $p^{neutral} > 200$ MeV)

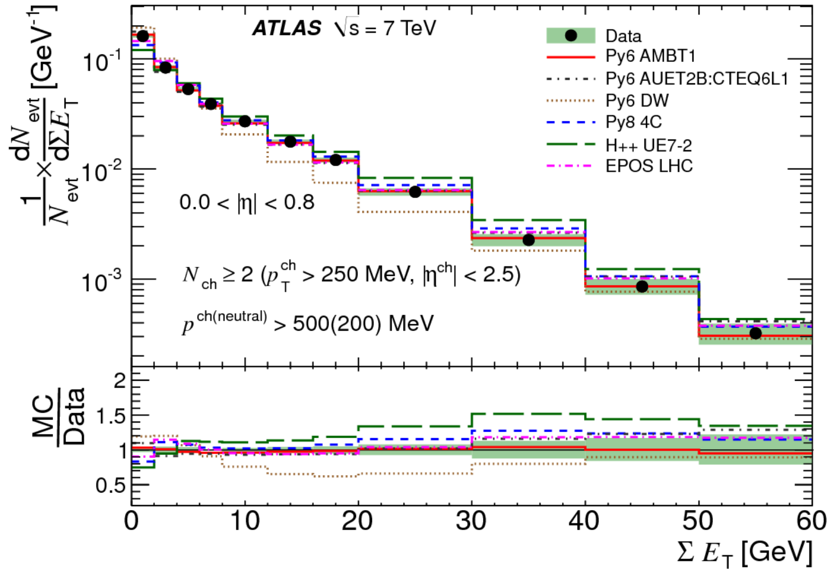
Transverse energy sum $$\frac{1}{N_{evt}}\frac{dN}{d\Sigma E_T}$$

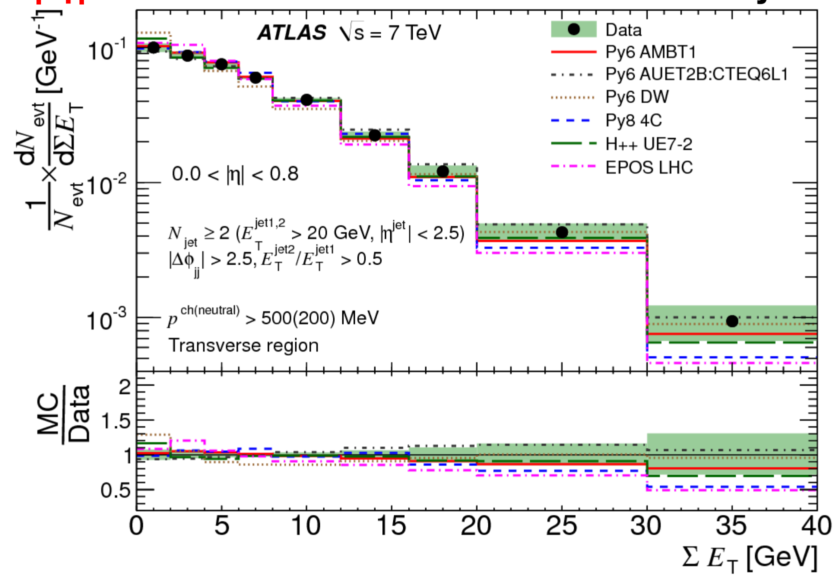
Average transverse energy density $$\left\langle \frac{d^2\Sigma E_T}{d\eta\, d\phi} \right\rangle$$



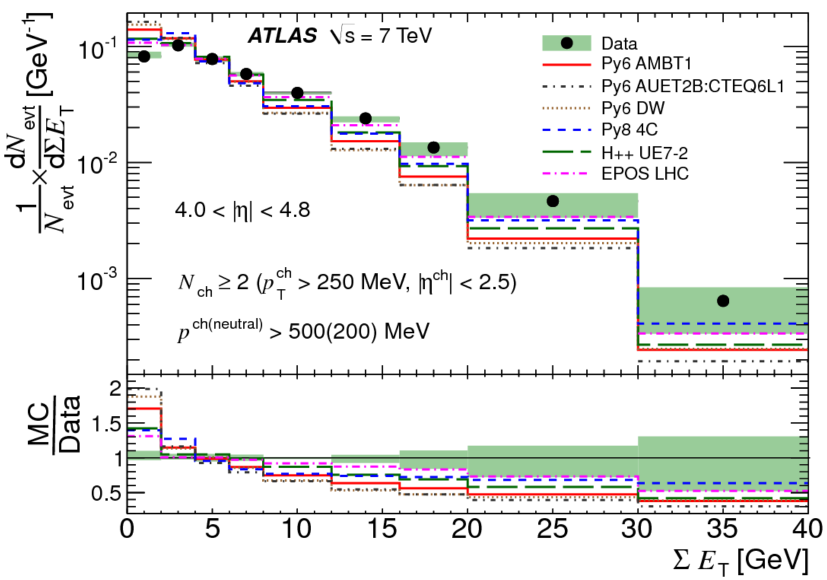
# Comparison in |η| bins

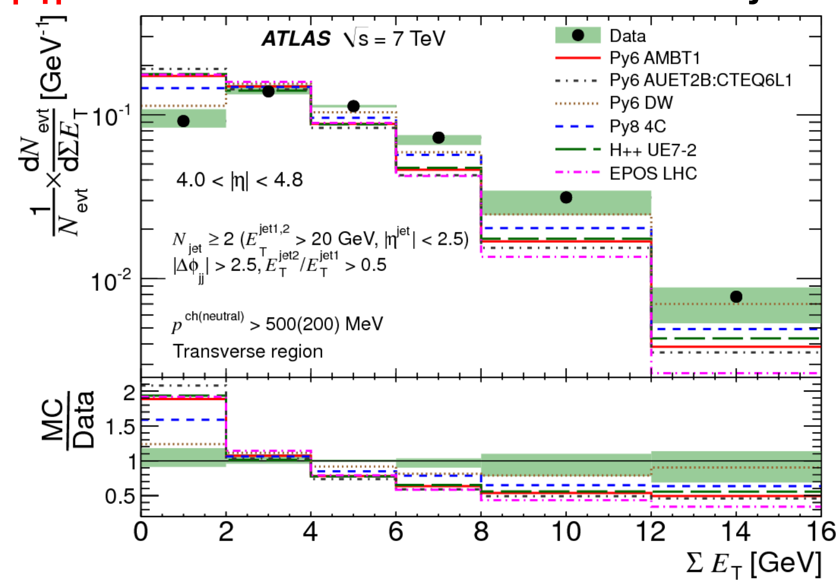
MinBias    0.0 < |η| < 0.8    UE Dijets



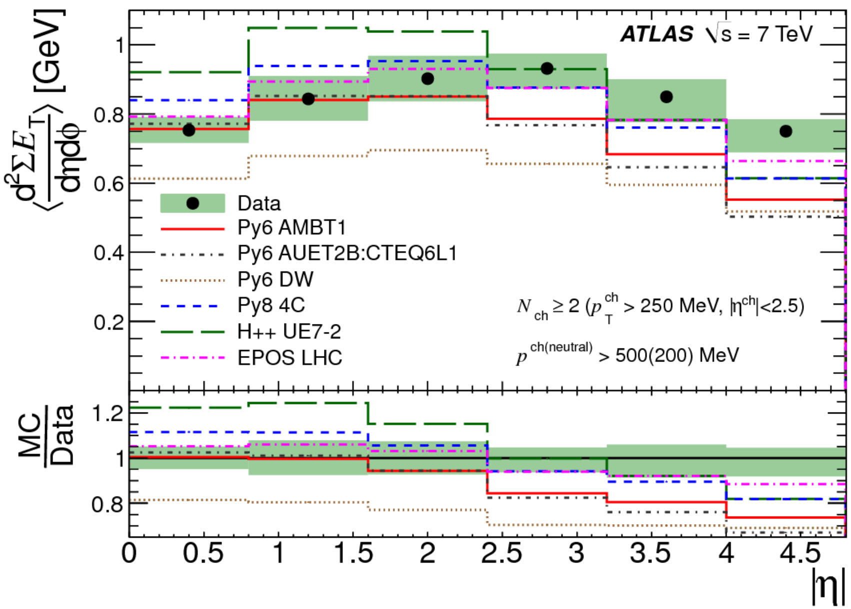

MinBias    4.0 < |η| < 4.8    UE Dijets



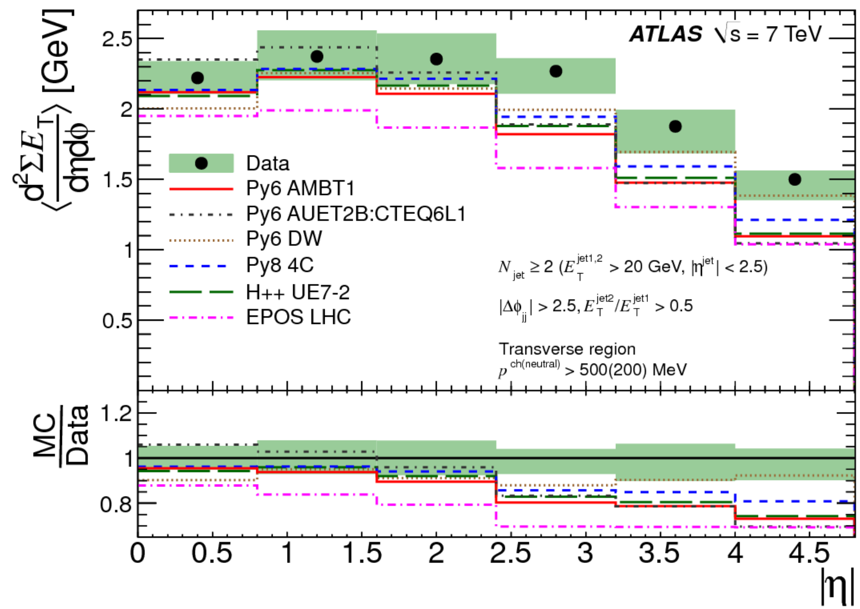



# Transverse Energy Density in |η|

MinBias




UE Dijets




- MinBias: Several models do acceptable job in central region
- All models low for forward energy flow (emerging LHC theme)
- Dedicated forward heavy ion / cosmic air shower model, EPOS, among best descriptions

- UE dijets: 3 times higher energy flow than in minimum bias events
- Similar conclusions, in particular poor forward description
- Pythia 6 DW provides best overall description
- [EPOS was never tuned on LHC UE data]

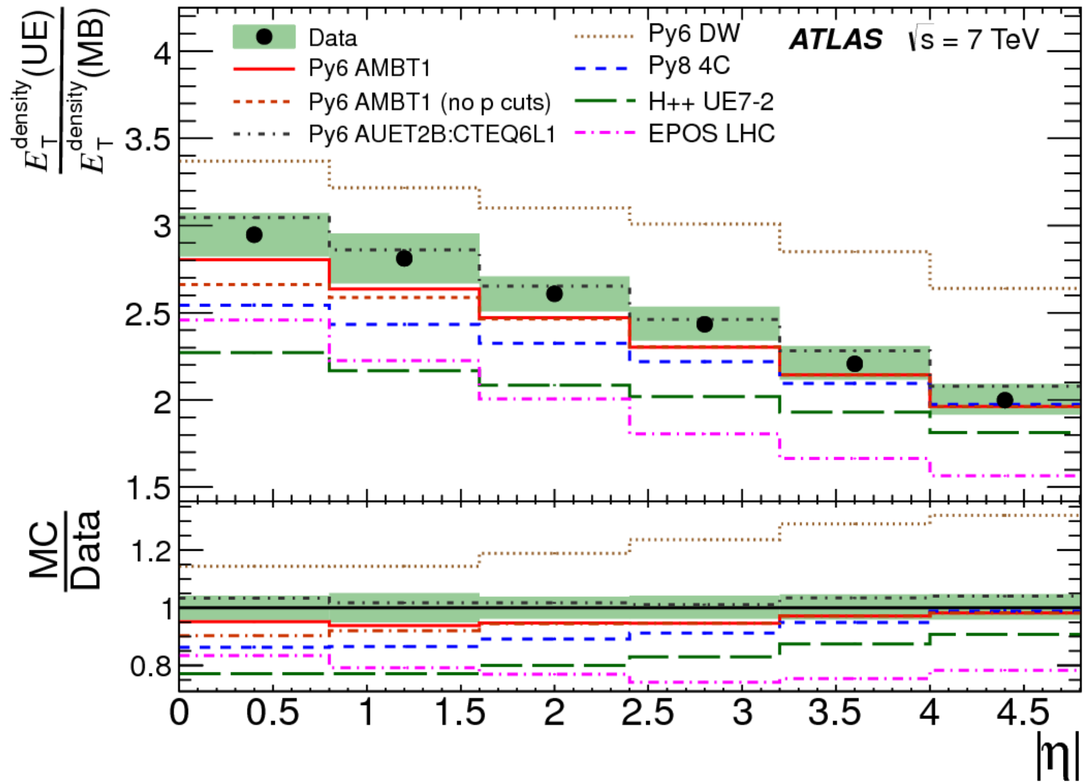
# Transverse Energy Density Ratio

- Dijet $E_T^{density}$ larger than for minbias → hard scatter biases to small impact parameter.

- Sensitive to multi parton interactions.

- Reduction with |η| partly due to *p* cuts on particles in $\Sigma E_T$ (c.f no p cuts curve).

- Further decrease associated to additional UE in the central region from hard scatter.

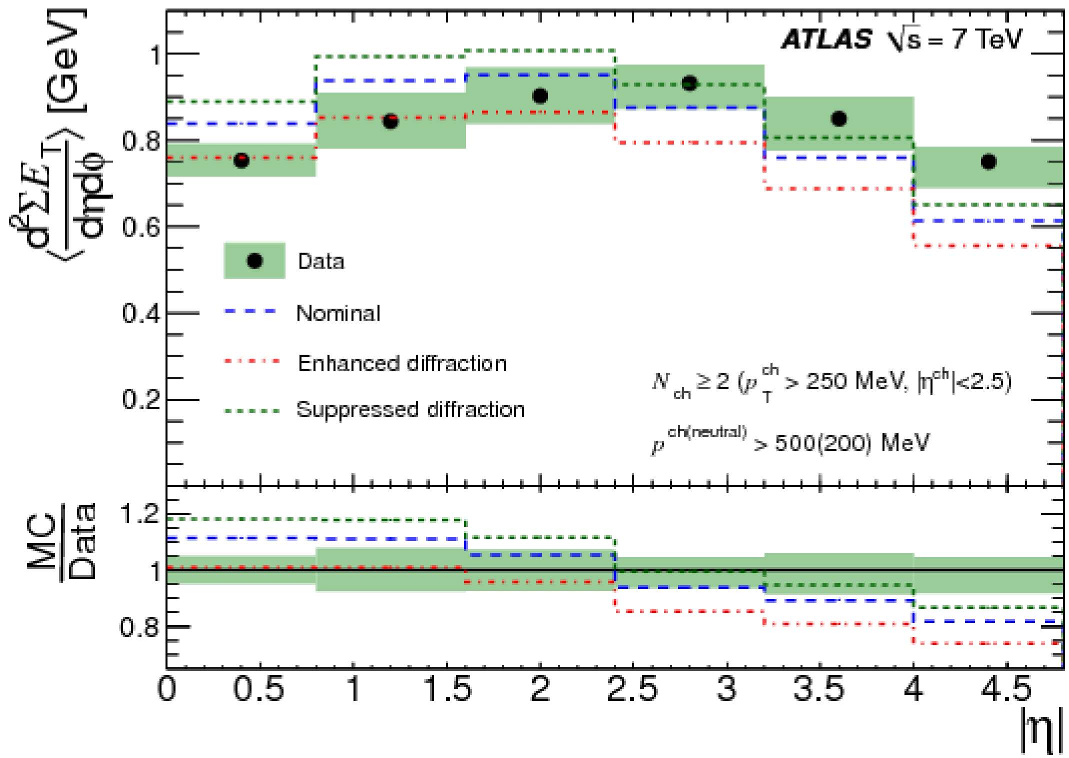


# Diffractive contribution

Compare nominal Pythia8 4C [N = 51; S = 12; D = 8] (mb) with [N; **S/2**; **D/2**] and [N; **2S**; **2D**].

Fewer particles in diffractive events: Changing contribution of diffractive components alters normalisation.

Shape of $E_T^{\text{density}}$ not significantly affected




PDF contribution discussed in ATLAS small-*x* talk by Alexei Myagkov

# Summary

Precise soft diffractive and inelastic cross section data
- Broadly described by single soft pomeron with intercept as expected
- Low mass diffractive dissociation remains unresolved

Forward energy flow generally underestimated by around 20-30%, with the exception of PYTHIA6 DW for dijet data and EPOS LHC for minbias data.
- Diffractive processes reduce ‹$E_T^{\mathrm{density}}$› but adjusting contributions leaves shapes largely unaffected

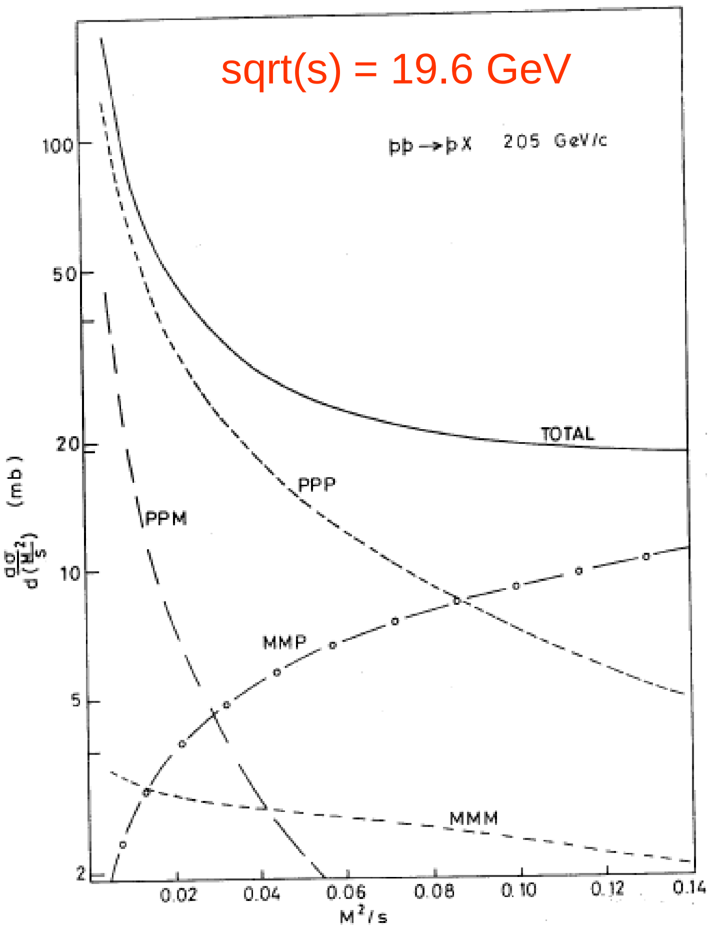
… progress in first phase of LHC, but still a long way to go to completely understand diffractive physics. In particular, simultaneous description of diffractive / non-diffractive data in framework of multiple interactions / rapidity gap survival …

# Back up slides

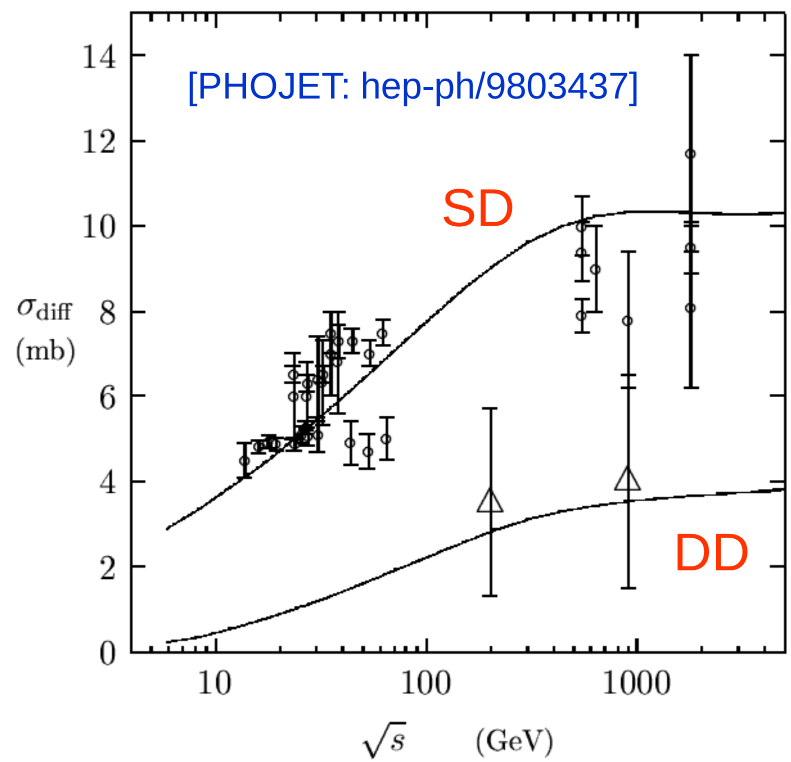
# Uncertainties in pre-LHC Predictions

**Single dissociation**
$\sigma$ = 14mb (PYTHIA8)
$\sigma$ = 10mb (PHOJET)

**Double dissociation**
$\sigma$ = 9mb (PYTHIA8)
$\sigma$ = 4mb (PHOJET)

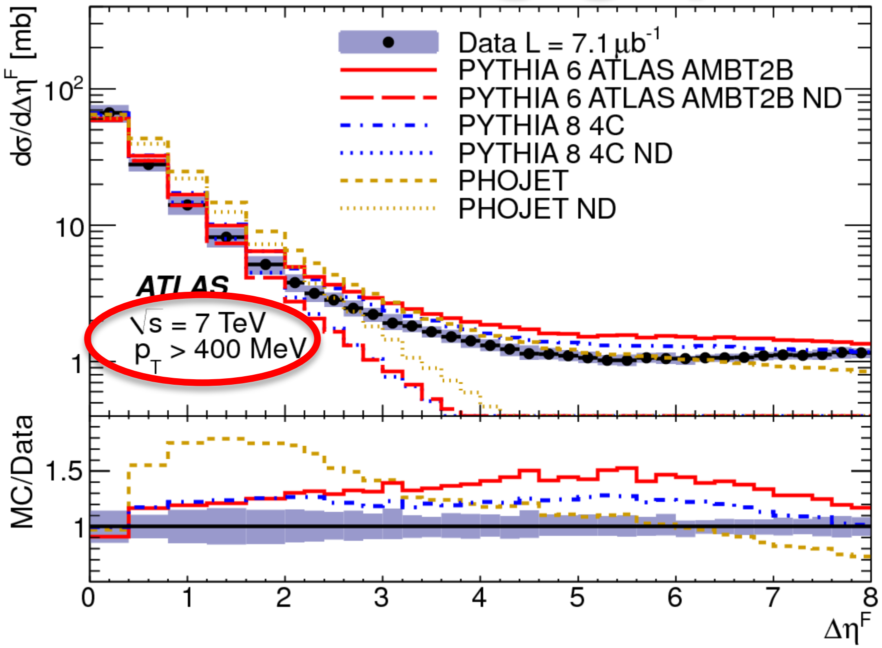


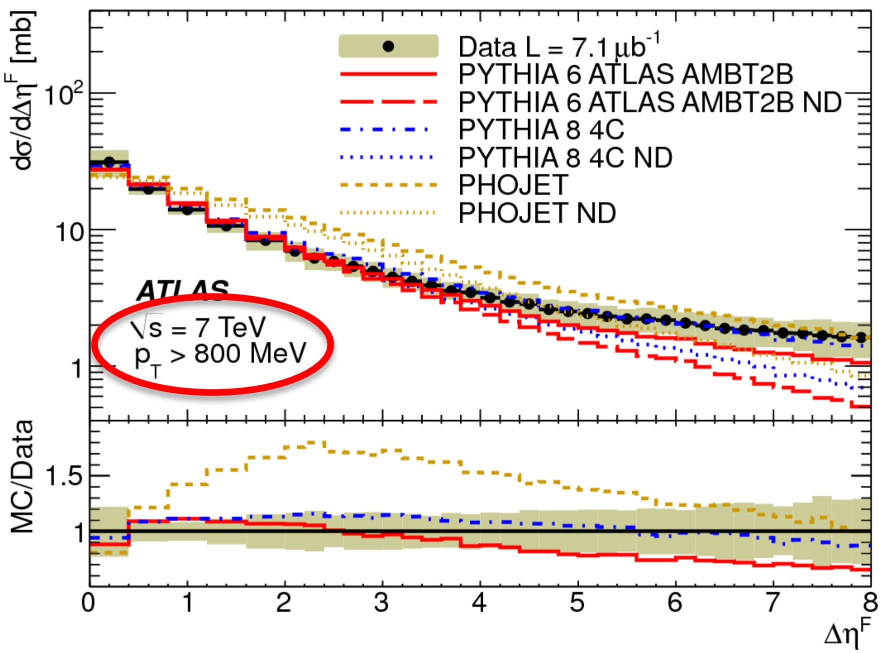

Parameterisations based on old low energy data, particularly poor for DD



# Increasing the $p_T$ cut defining gaps

As $p_T^{cut}$ increases, data shift to larger $\Delta\eta^F$ in a manner sensitive to hadronisation fluctuations and underlying event



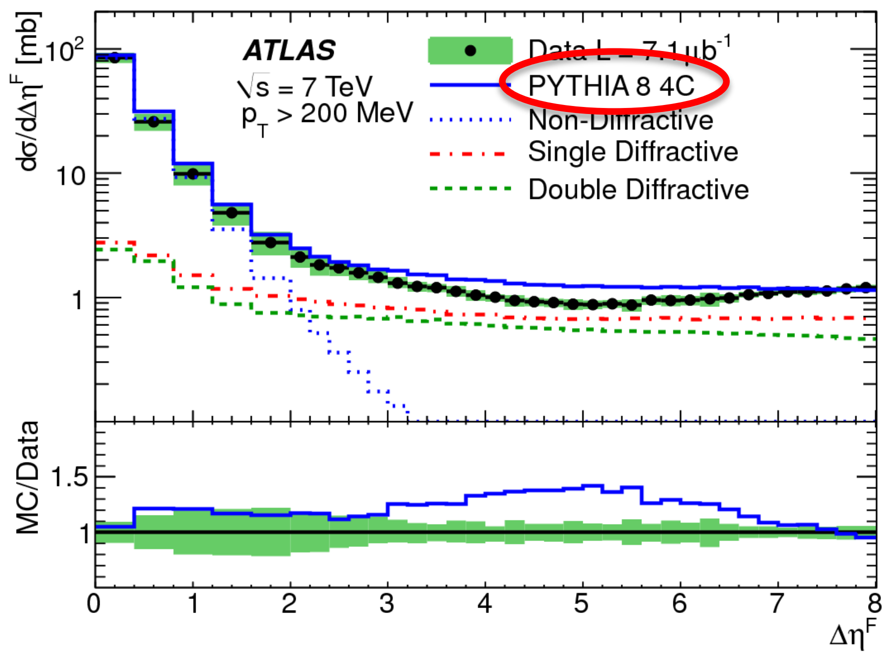



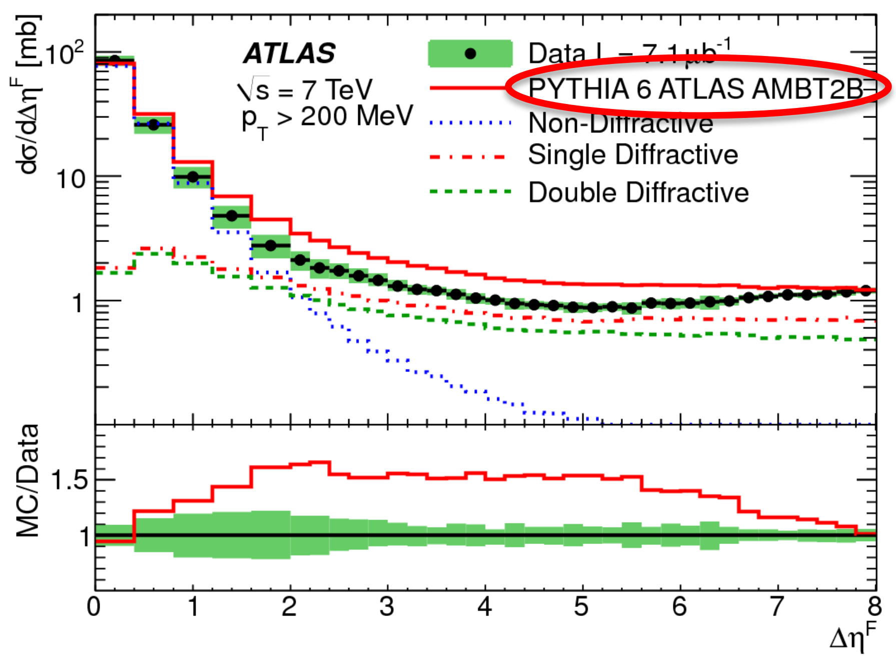

- Switching to $p_T^{cut}$ = 400 MeV doesn't change qualitative picture

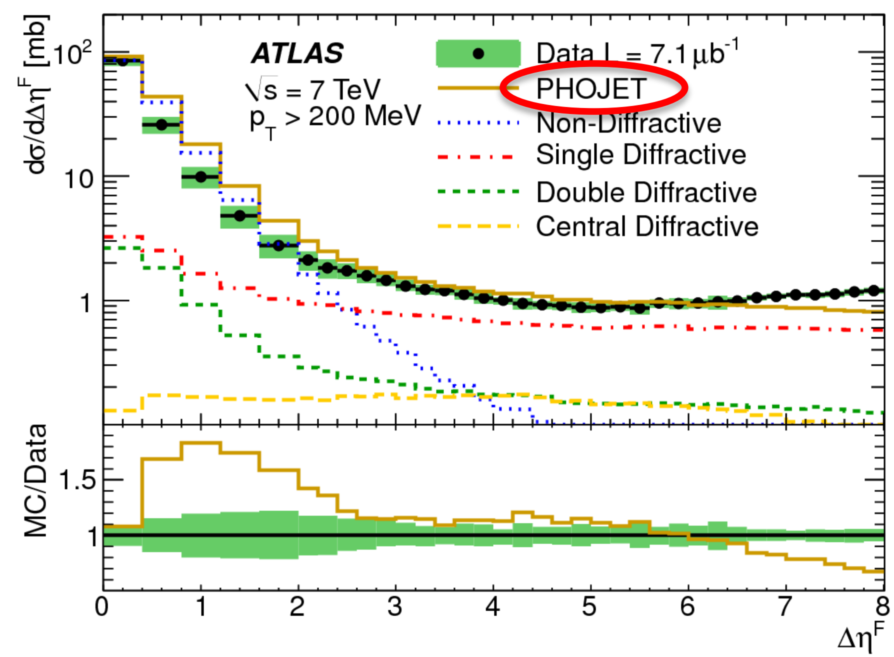
- Diffractive / non-diffractive processes barely distinguished at $p_T^{cut}$ = 800 MeV

# Small Gaps and Hadronisation

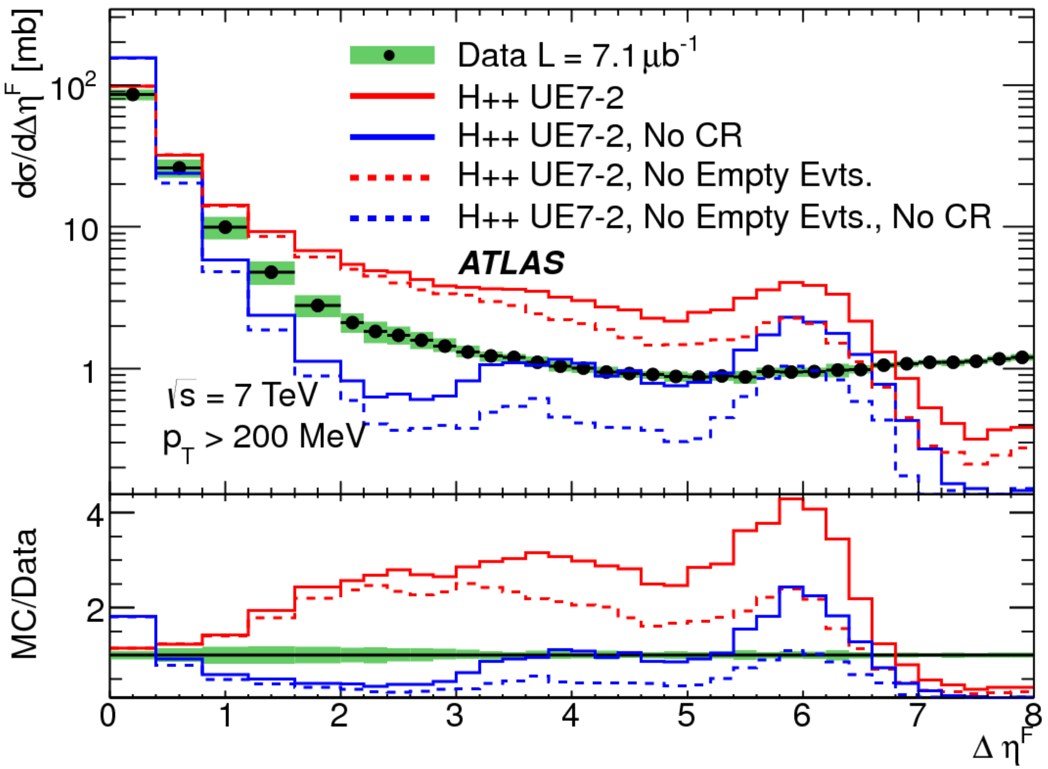
- Big variation between MCs in small non-zero gap production via ND → fluctuations / UE
- PYTHIA8 best at small gaps
- PHOJET > 50% high at $\Delta\eta^F \sim 1.5$
- See also higher $p_T$ cut data



# Cluster Fragmentation: HERWIG++



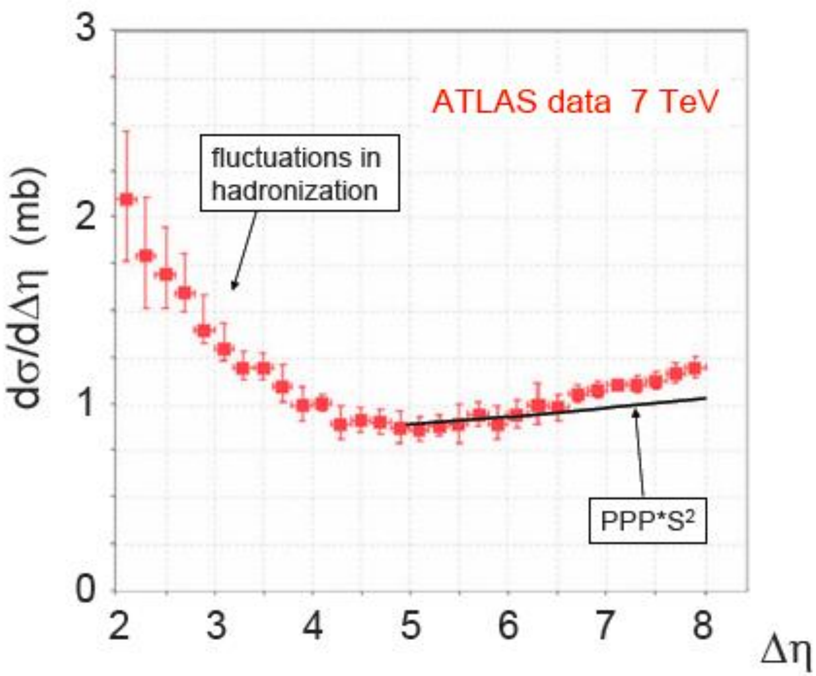

Some investigations / progress since, but still not fully solved and remains a challenge

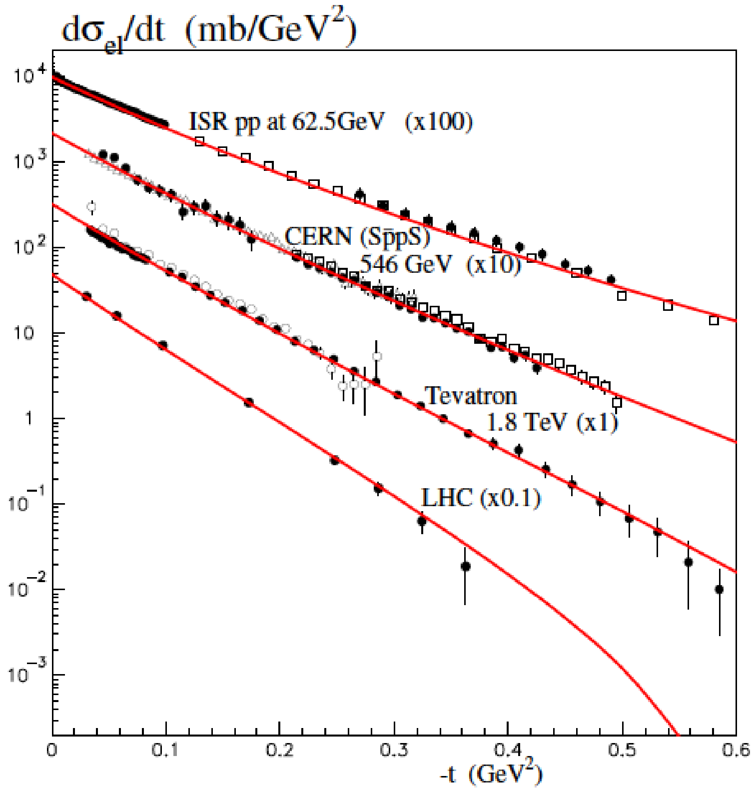
- HERWIG++ with underlying event tune UE7-2 contains no explicit model of diffraction, but produces large gaps at higher than measured rate and a "bump" near $\Delta\eta^F = 6$

- Effect not killed by removing colour reconnection or events with zero soft or semi-hard scatters in eikonal model

# Durham Model of all Soft Diffractive Processes

[arXiv:1201.6298]




… simultaneous Durham (KMR) description of ATLAS gaps data and elastic cross section data from ISR to Totem based on a single pomeron in a 3-channel eikonal model, with <u>significant absorptive corrections in gaps / dissociation case</u>

# Dijet production with veto on additional central jet activity

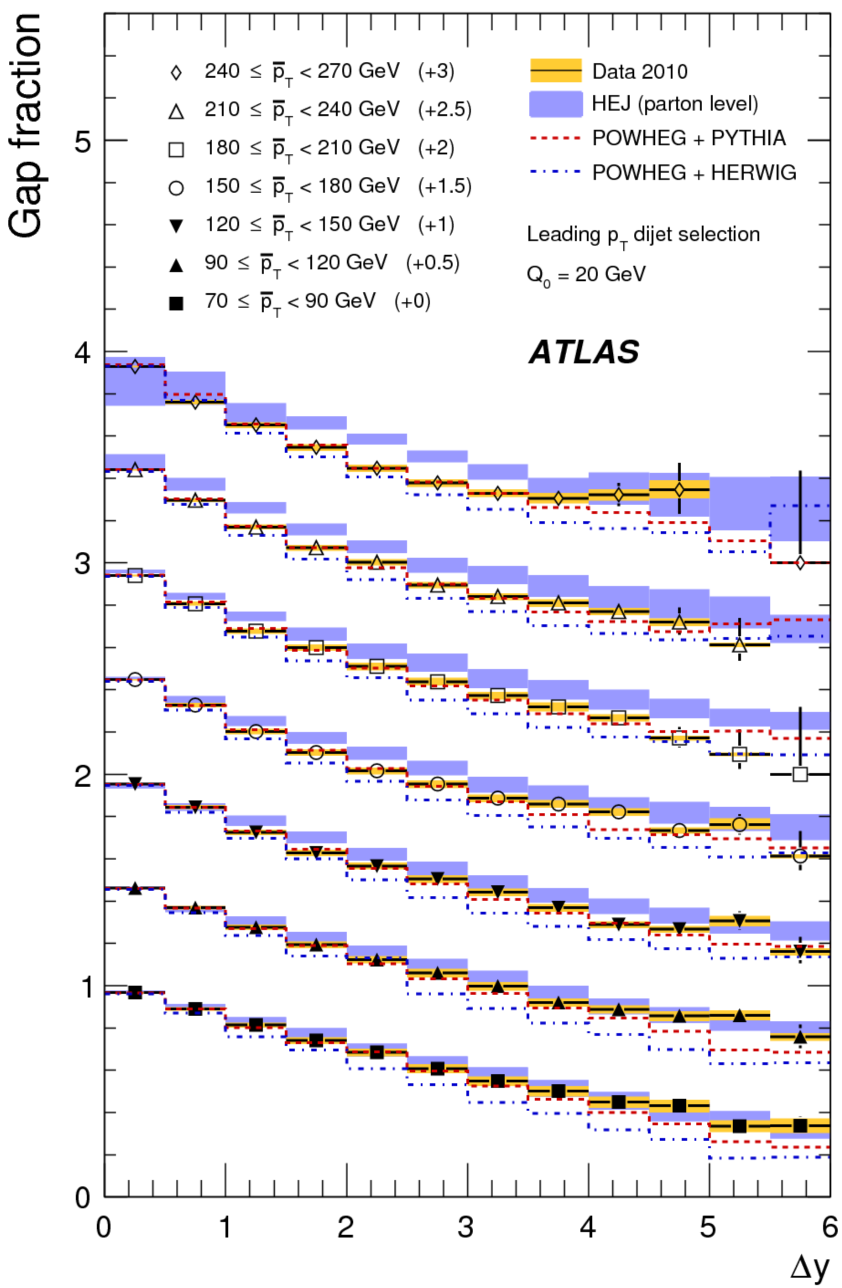
Select events with two high $p_T$ jets, separated in rapidity by $\Delta y$
Veto on additional jet activity (with kT > $Q_0$, with $Q_0 \gg \Lambda QCD$) between the two jets
$Q_0$ taken as 20 GeV (not necessarily diffractive events)

Measure "gap fraction": $\dfrac{\text{dijet events with jet veto}}{\text{total dijet events}}$

Compared to HEJ at parton level and NLO POWHEG interfaced with PYTHIA and HERWIG

# Dijet production with veto on additional central jet activity

Gap fraction



# Dijet production with veto on additional central jet activity

Gap fraction