ATLAS Results on Forward Physics

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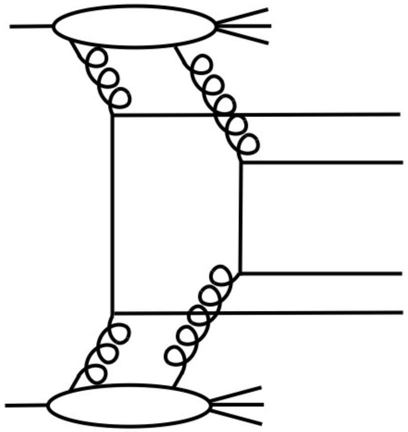
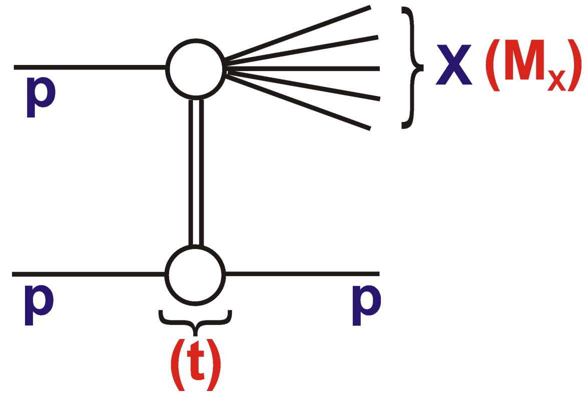


LPCC Workshop on
Forward Physics @ LHC
11 February 2013



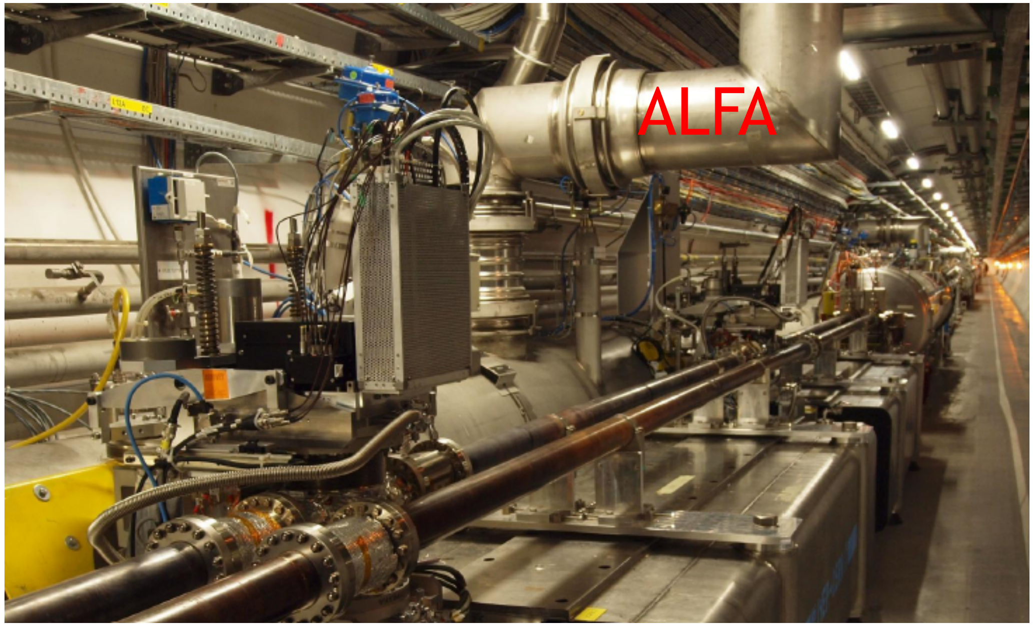
→ Total Inelastic Cross Section [arXiv:1104.0326]
→ (Large) Rapidity Gaps [arXiv:1201.2808]
→ Double Parton Int's in W+dijet events [arXiv:1301.6872]
→ (Forward) Energy Flow [arXiv:1208.6256]
→ {Azimuthal Decorrelations between jets [arXiv:1102.2696]}
→ {Energy Vetoes between jets [arXiv:1107.1641, 1203:5015]}

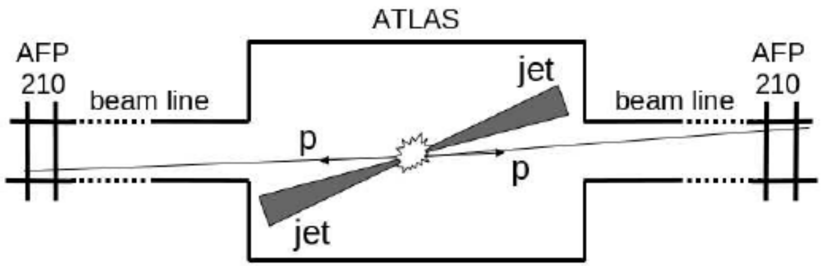
Proton Spectrometry at ATLAS

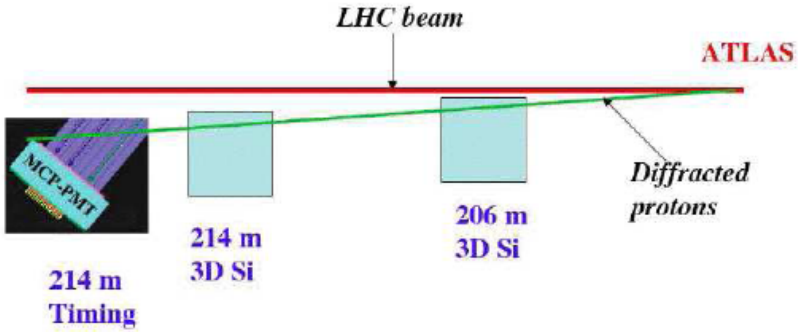
ALFA and AFP are the medium and long-term future of diffraction in ATLAS

… will not be covered here … see talks in tomorrow's session

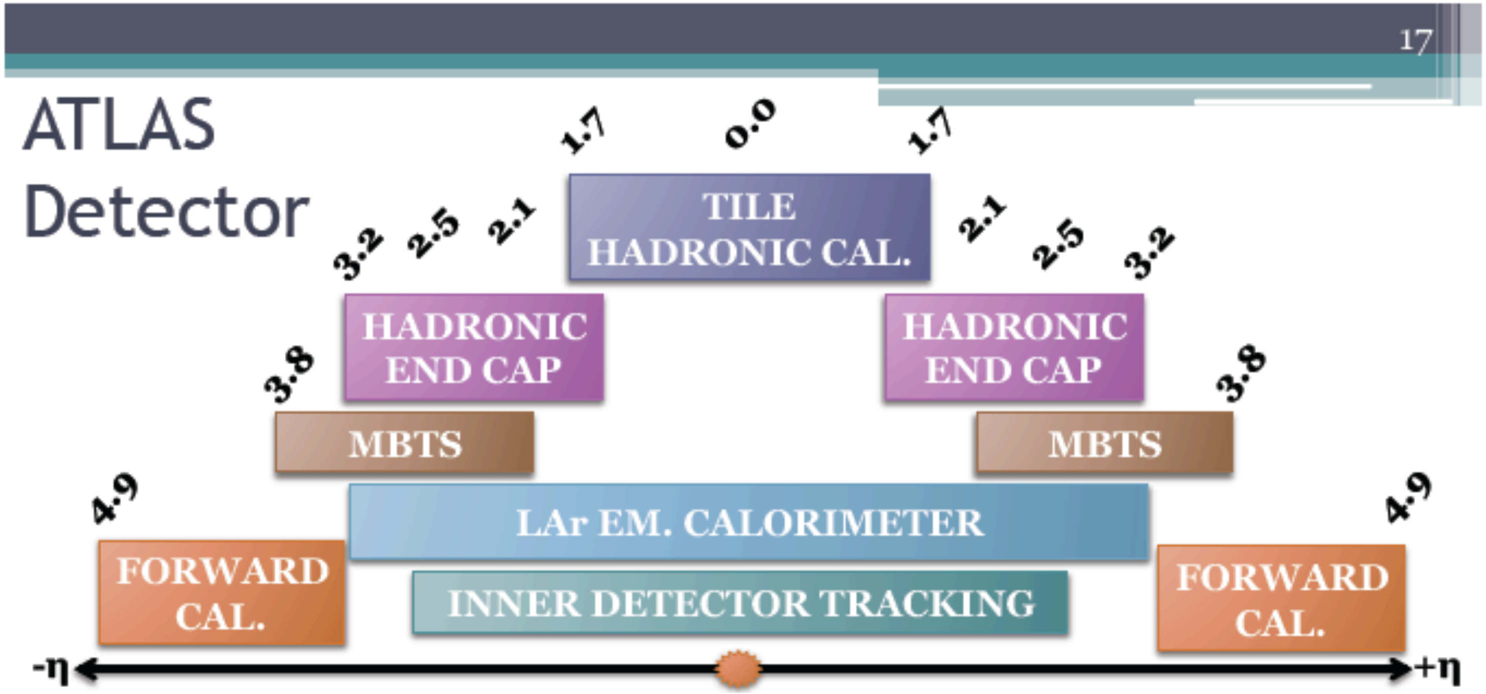
This talk deals with studies using central detector components in 2010 data (before pile-up became a significant complication)







ATLAS Acceptance



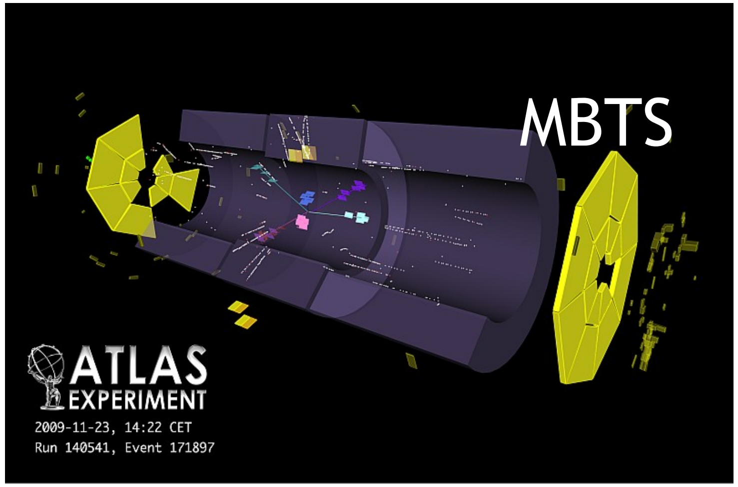
Data obtained using full calorimeter coverge ($|\eta| < 4.9$) and inner tracking detector ($|\eta| < 2.5$)

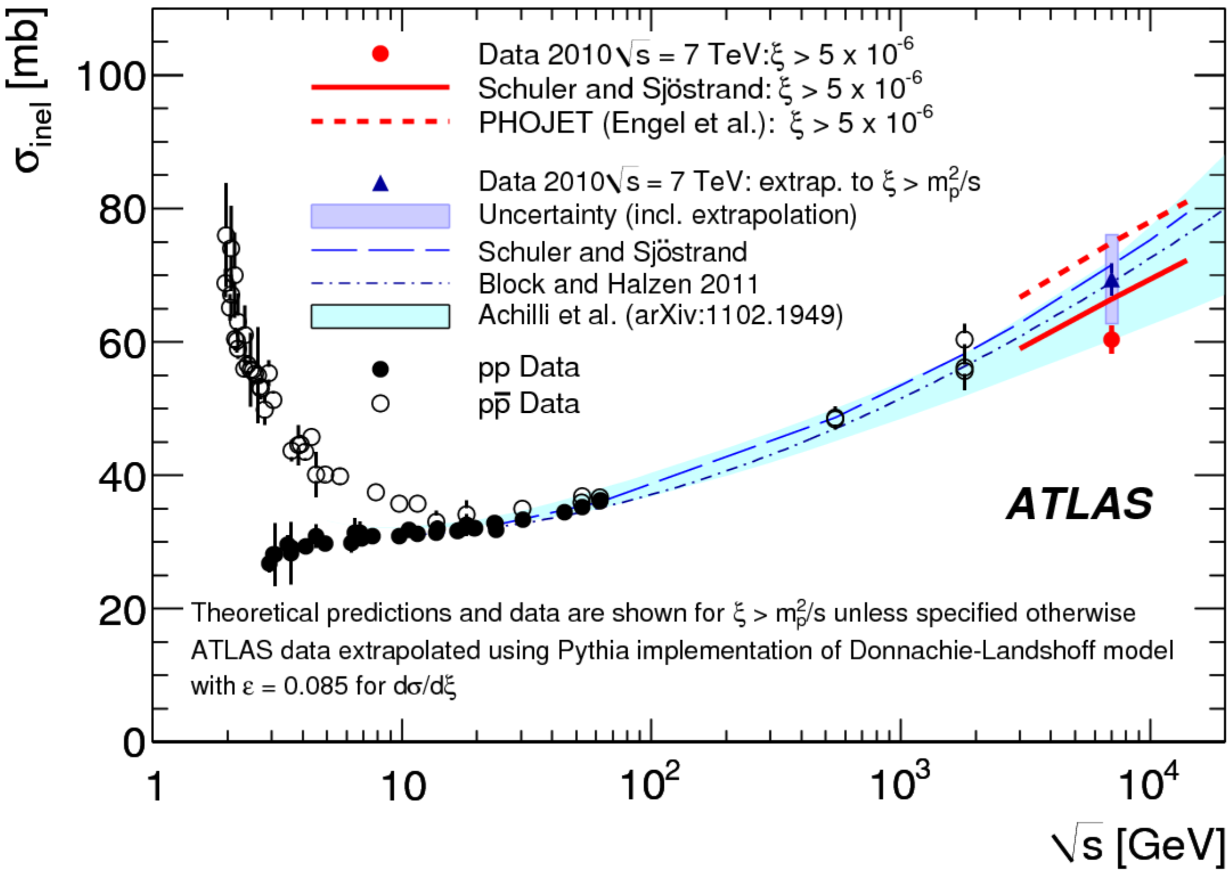
MBTS scintillators provide almost unbiased trigger

Detector is sensitive to particle production with $p_T >\sim 200$ MeV

Total Inelastic pp Cross Section (ATLAS)

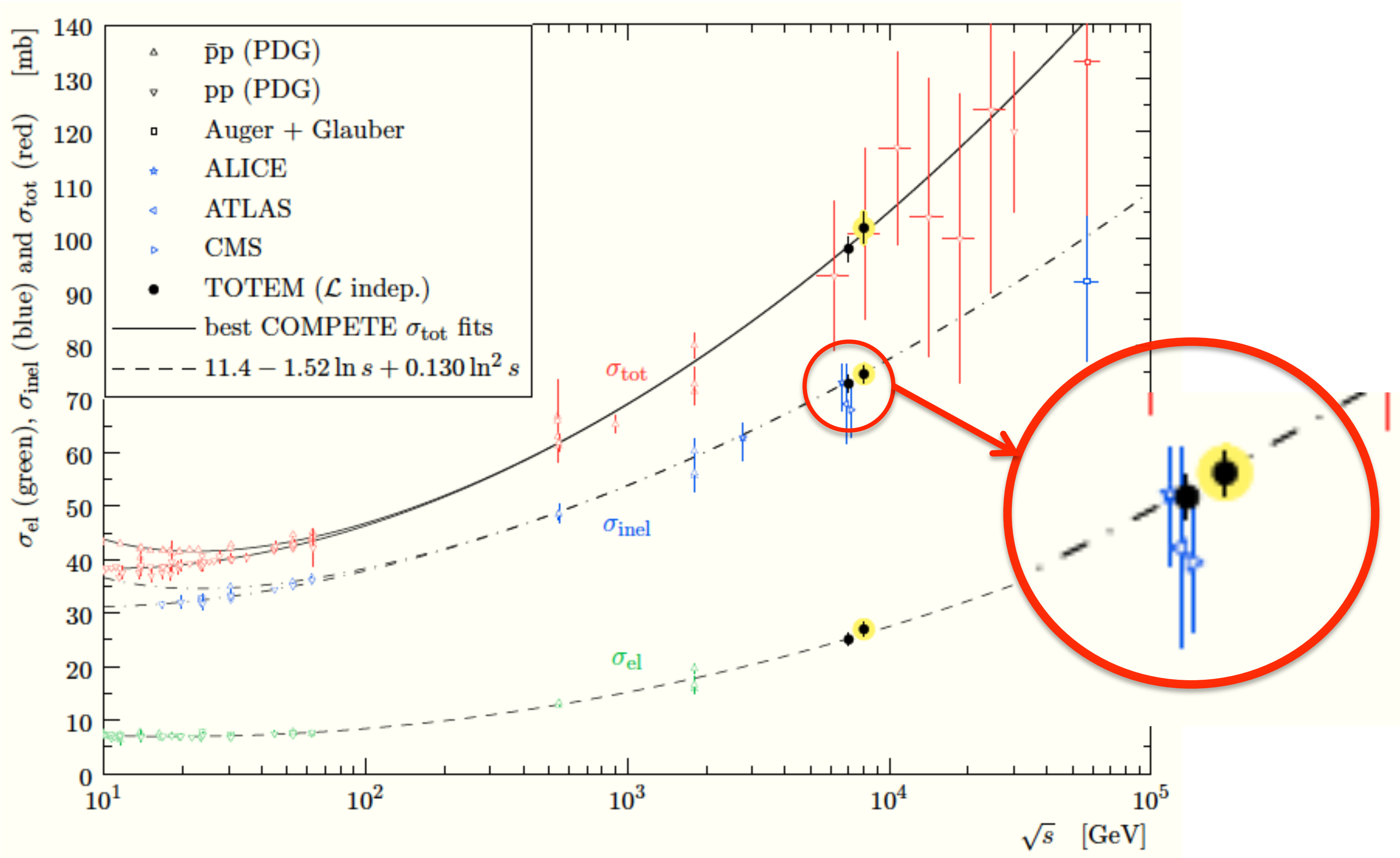
- Using MBTS trigger ($2.1 < |\eta| < 3.8$), miss only elastic (pp → pp) and low mass diffraction (pp → pX etc)





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

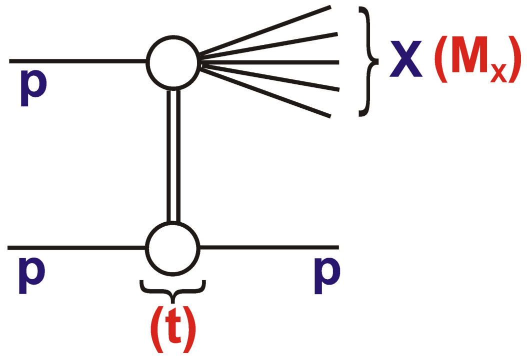
Comparison with Subsequent Data



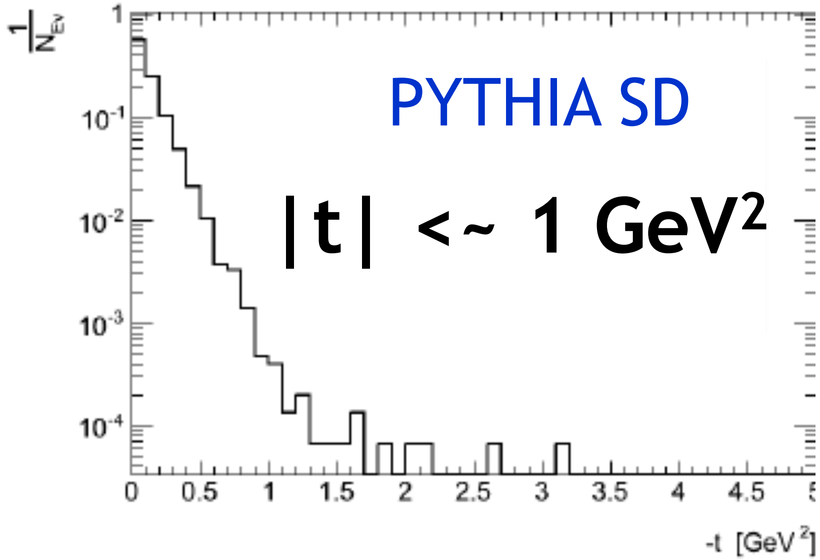
Central Value of extrapolated ATLAS result within large (model dependence) errors of TOTEM, but central value somewhat lower … need improved modelling of low mass diffraction ...

Diffractive Dissociation

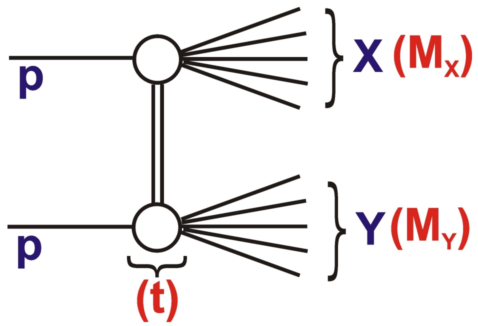
Single dissociation (SD), pp → Xp



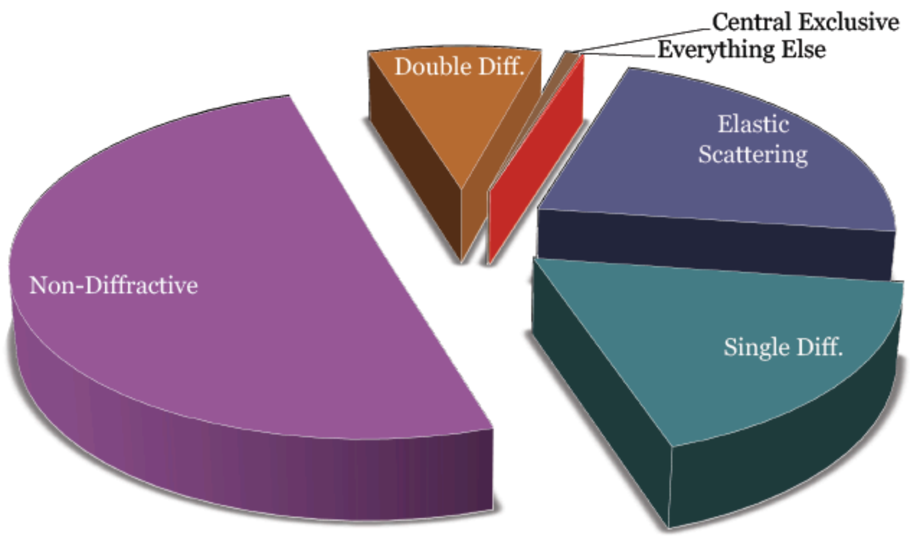
$$\xi = M_X^2/s$$



Double dissociation (DD), pp → XY



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

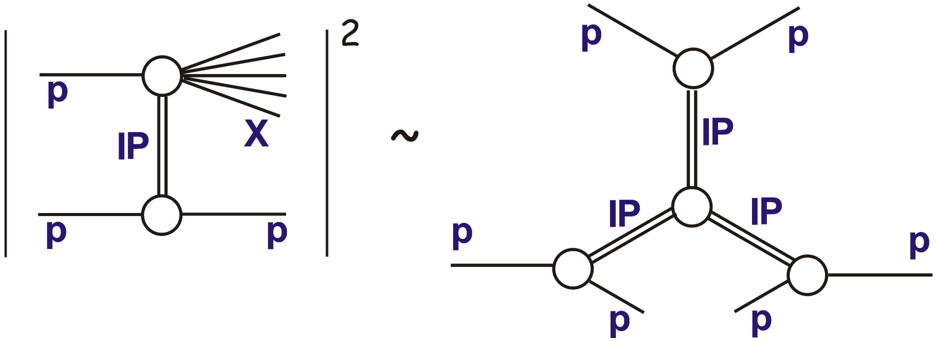


-At LHC energies, M_X, M_Y can range from m_p+m_π → ~1 TeV

- Diffractive channels together account for ~ half of total LHC cross section

"Standard Model" of Soft Diffraction

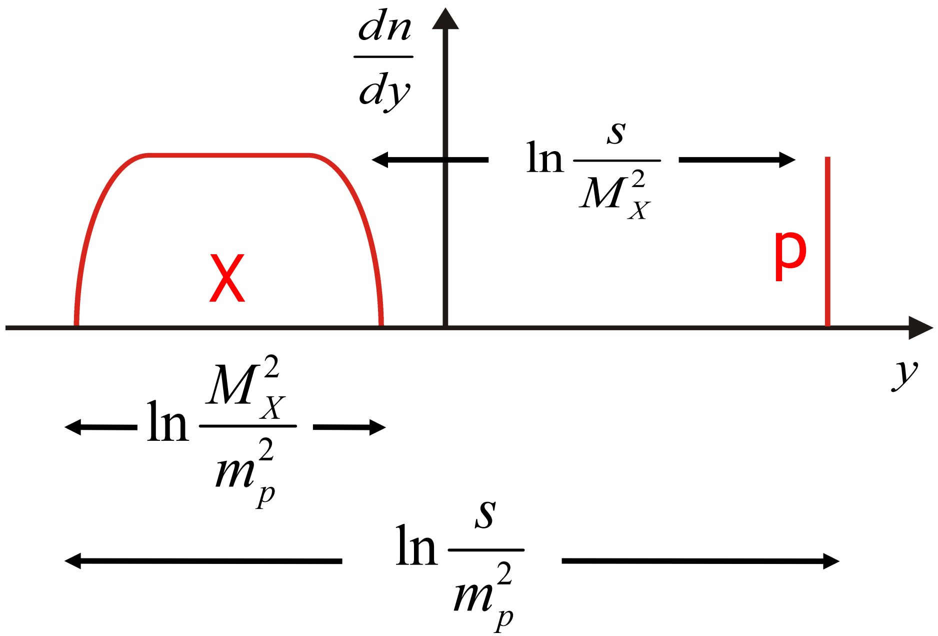
$$\left[\alpha(t) = \alpha(0) + \alpha' t\right]$$



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, ξ variable predictable from empty rapidity regions

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

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

Uncertainties in pre-LHC Predictions

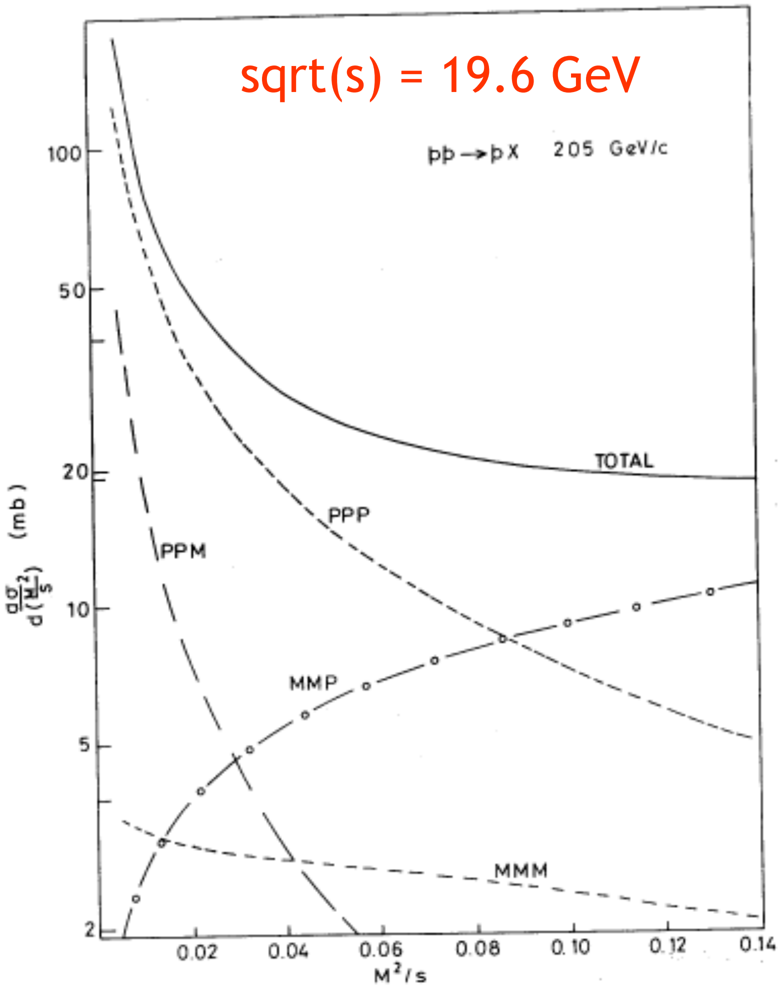
Single dissociation

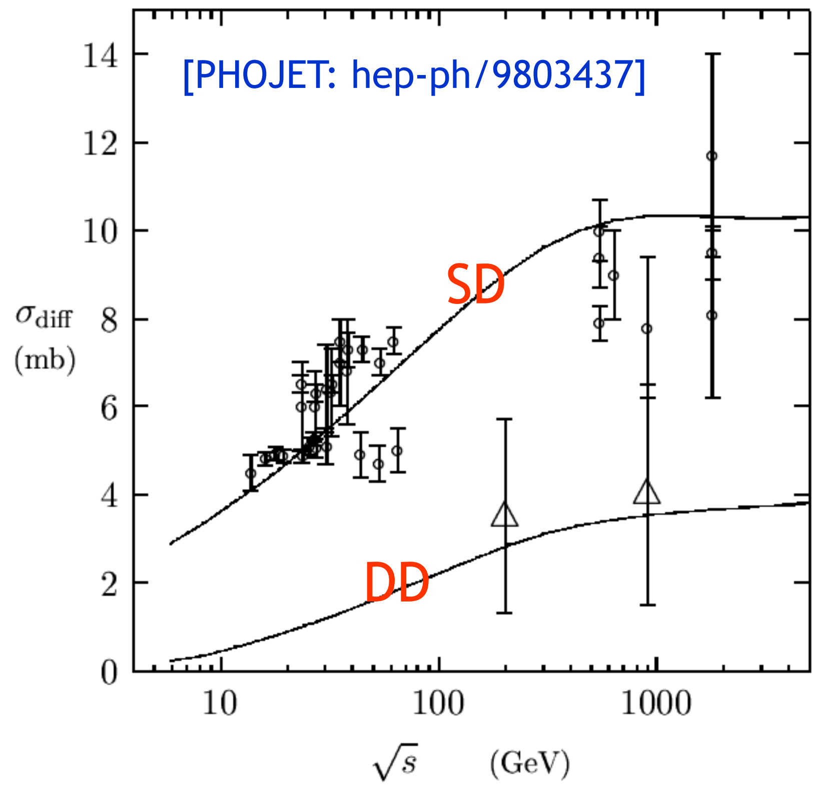
σ = 14mb (PYTHIA8)
σ = 10mb (PHOJET)

Double dissociation

σ = 9mb (PYTHIA8)
σ = 4mb (PHOJET)

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





Differential rapidity gap cross-sections

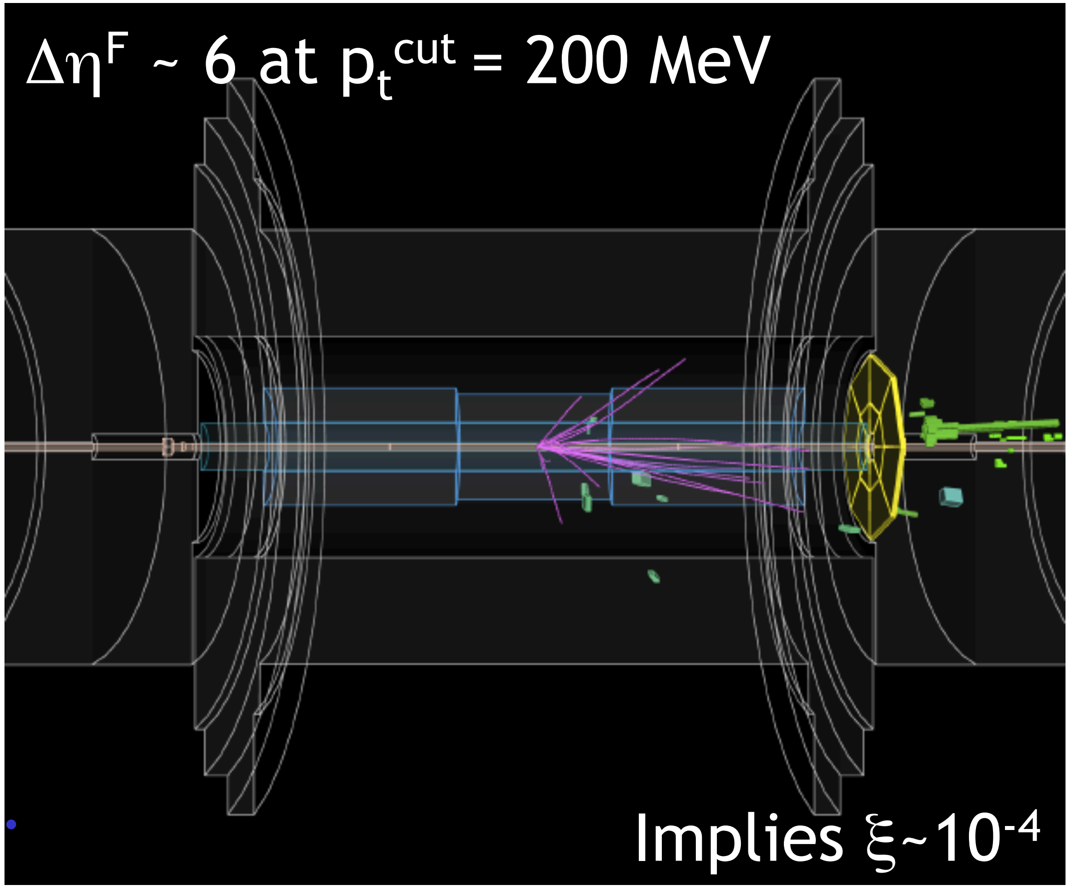
- Cross sections differential in `visible' rapidity gap size $\Delta\eta^F$
- $\Delta\eta^F$ extends from $\eta = \pm 4.9$ to first particle with $p_t > p_t^{cut}$

200 MeV < p_t^{cut} < 800 MeV
0 < $\Delta\eta^F$ < 8

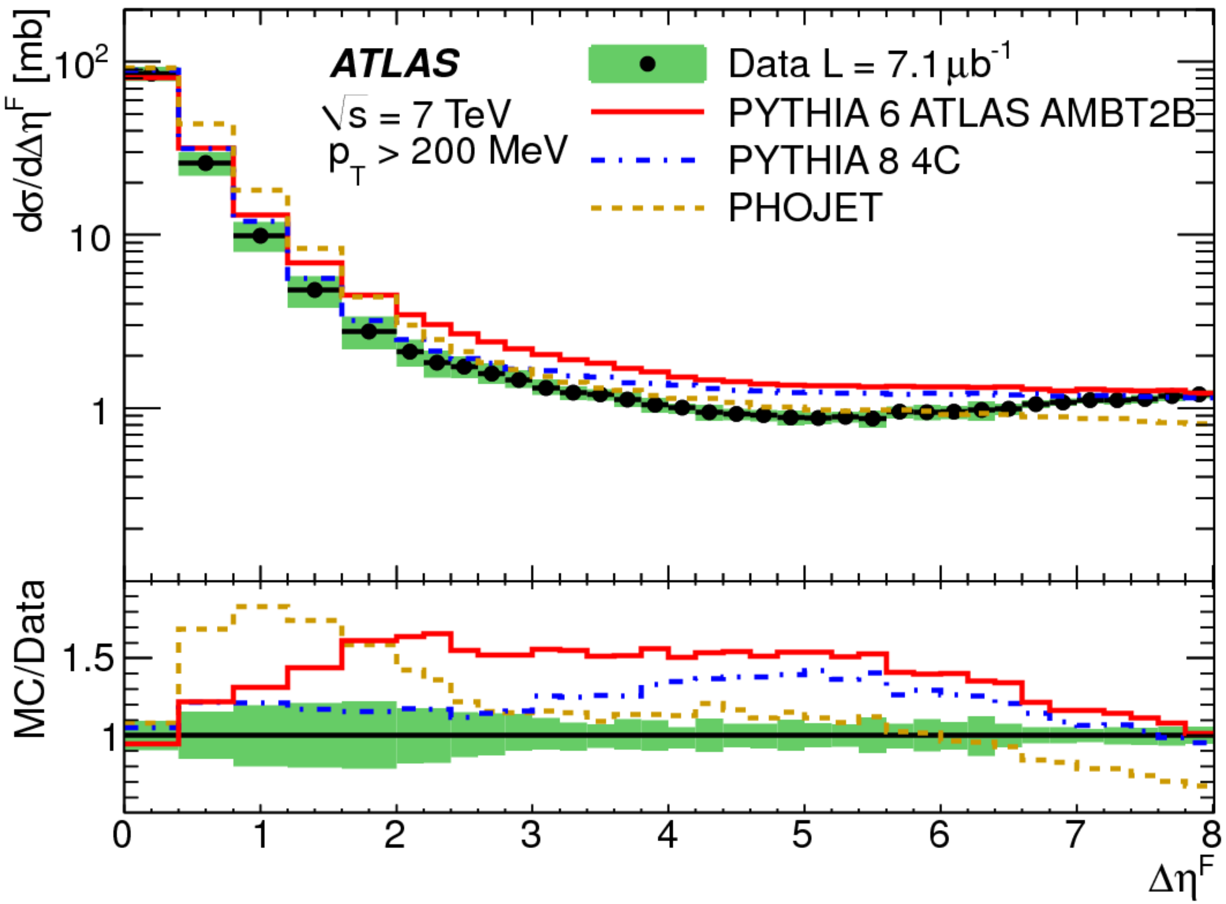
… corresponding (where diffraction dominates) to
$10^{-6} <\sim \xi <\sim 10^{-2}$ … or
$7 <\sim M_x <\sim 700$ GeV

Corrected for experimental effects to level of stable hadrons

p_t^{cut} = 200 MeV results follow …



Differential Rapidity Gap Cross Section



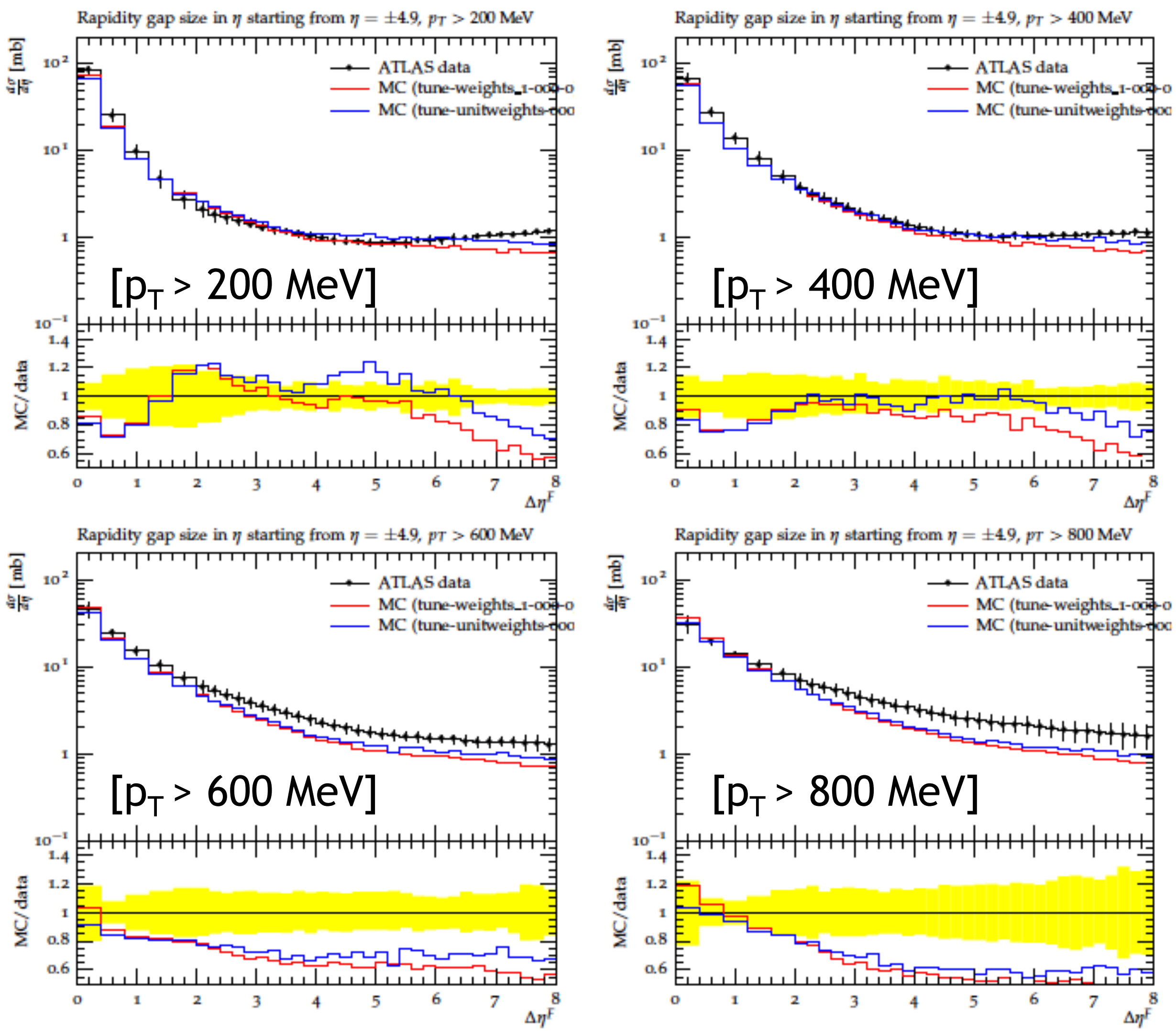
- Precision between ~8% (large gaps) and ~20% ($\Delta\eta^F$ ~ 1.5)
- Large gaps measure x-sec for SD [+ DD with M_Y <~ 7 GeV]
- Small gaps sensitive to hadronisation fluctuations / MPI

… huge uncertainties

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

SHRiMPS (MB in SHERPA) Preliminary

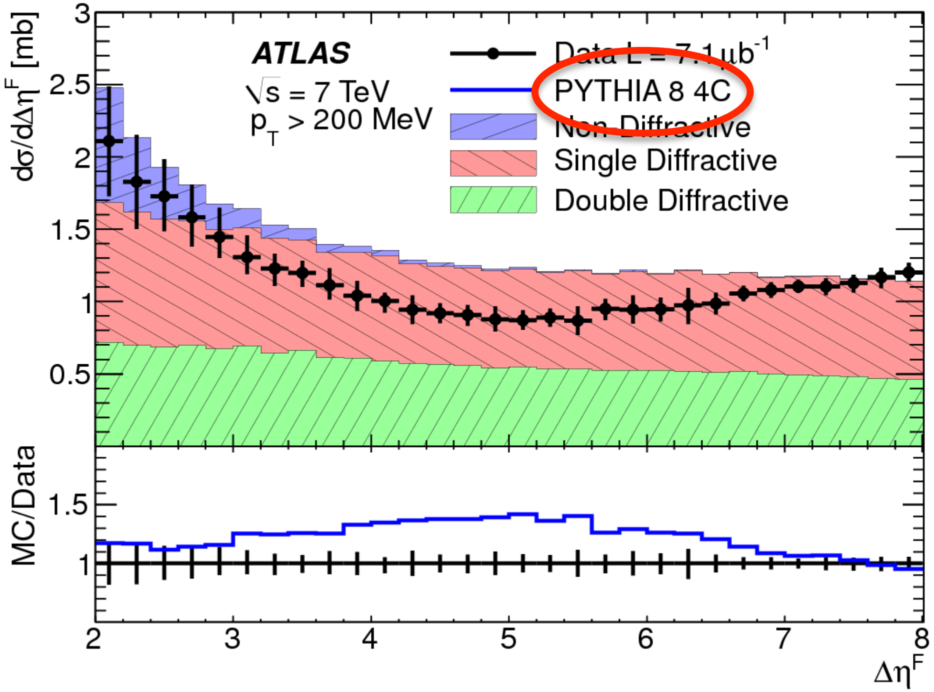
Rapidity Gap Cross Section @7 TeV



These distributions are complementary to particle spectra / correlations and dedicated underlying event measurements and should be described by any model that aims to provide a `complete' minimum bias description

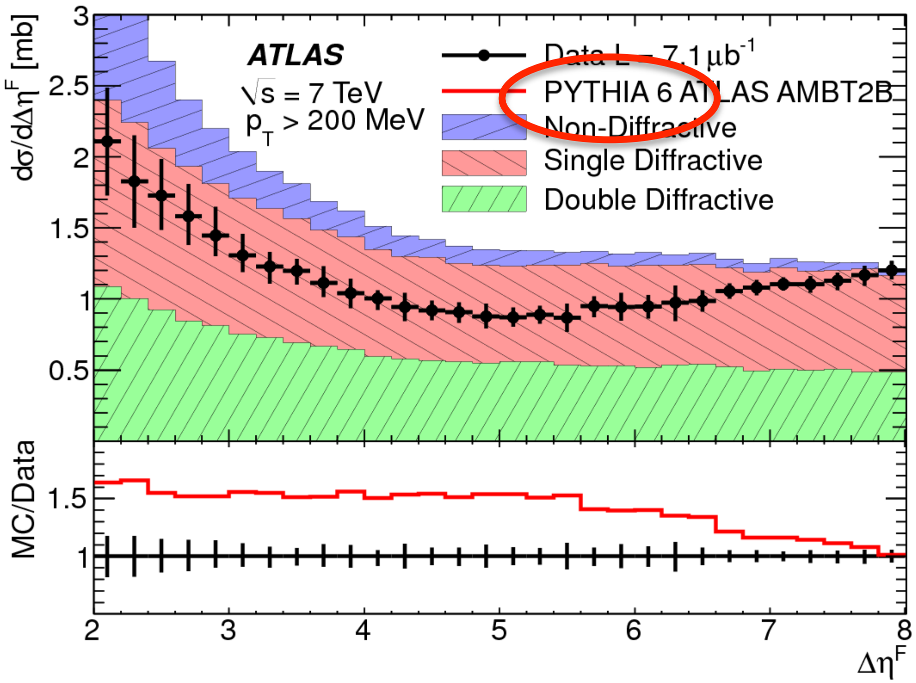
Impressive (but still not perfect) description …

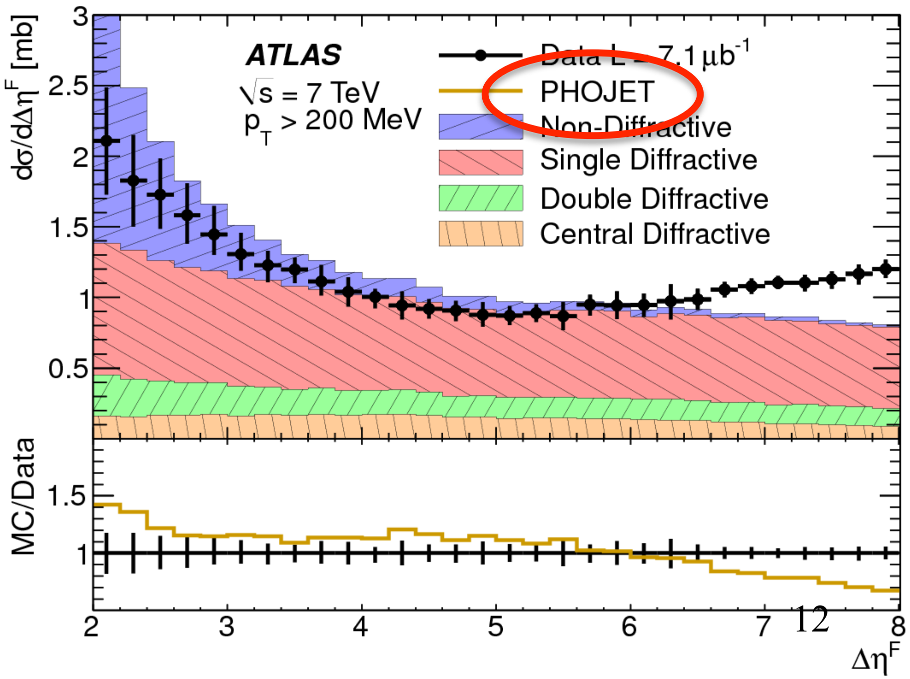
Large Gaps and Diffractive Dynamics



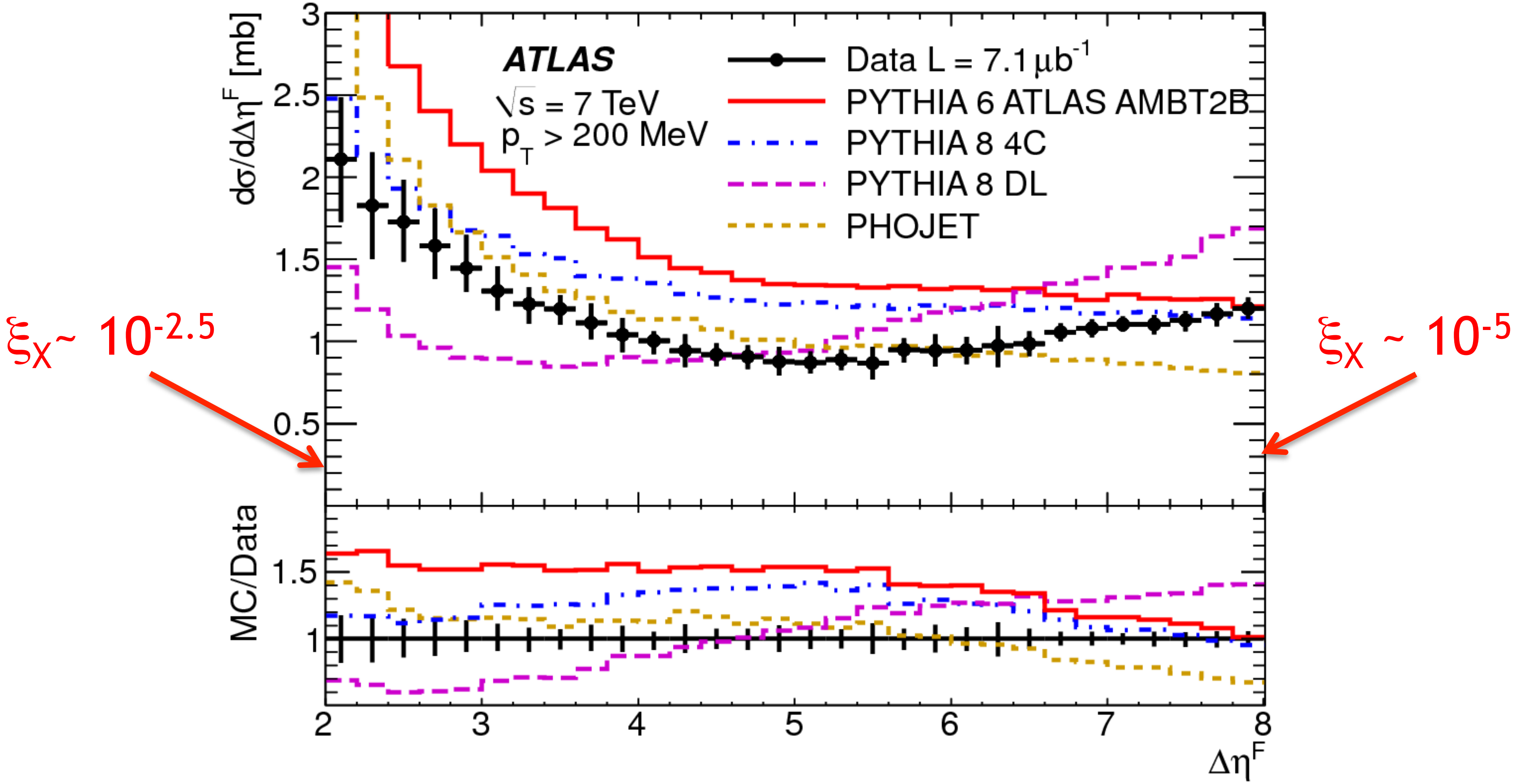
-Diffractive plateau with ~ 1 mb per unit of gap size for $\Delta\eta^F > 3$ broadly described by models

- 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 $\alpha_{IP}(0) = 1$

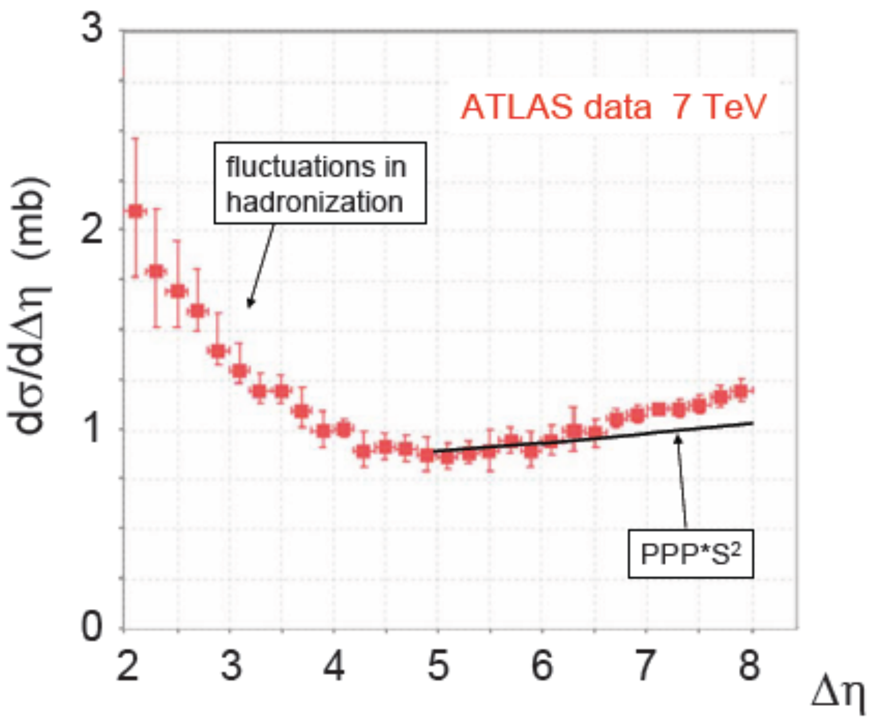
Donnachie-Landshoff flux has $\alpha_{IP}(0) = 1.085$

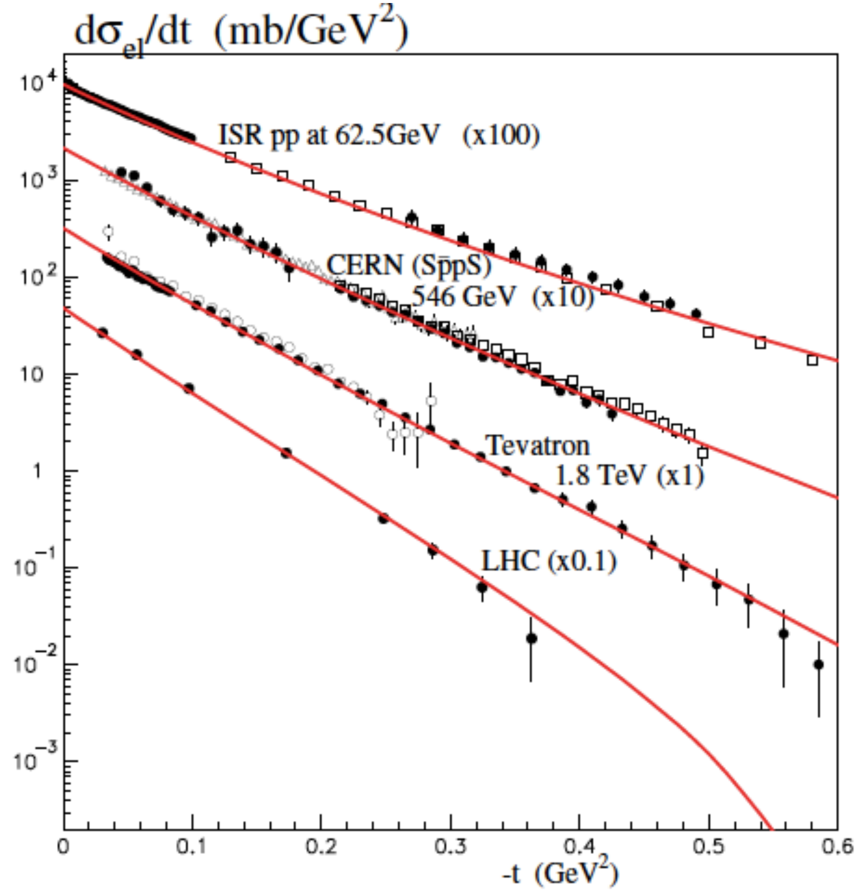
Fit to large $\Delta\eta^F$ region: $\alpha_{IP}(0) = 1.058 \pm 0.003$ (stat) ± 0.036 (syst)

[Absorptive corrections neglected in all cases]

Durham Model of all Soft Diffractive Processes

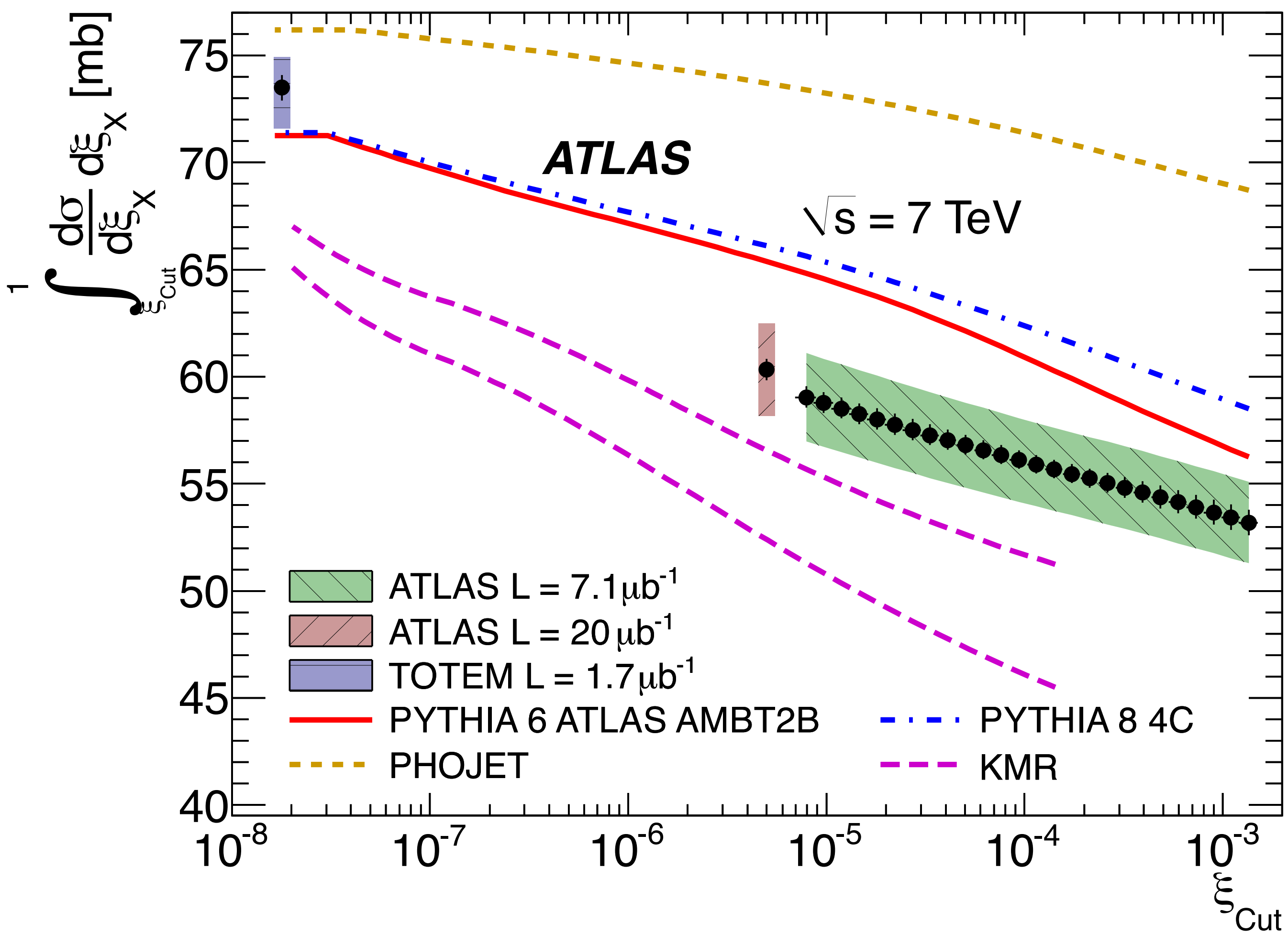
[arXiv:1201.6298]





… 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 significant absorptive corrections in gaps / dissociation case

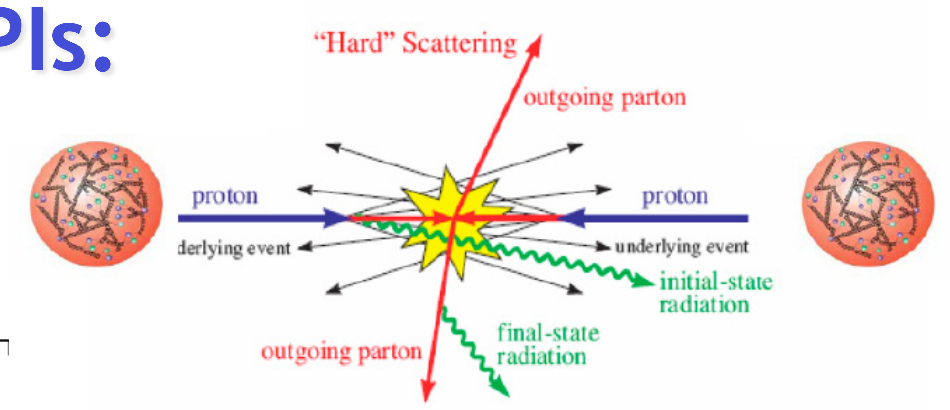
Investigating Low Mass Extrapolations

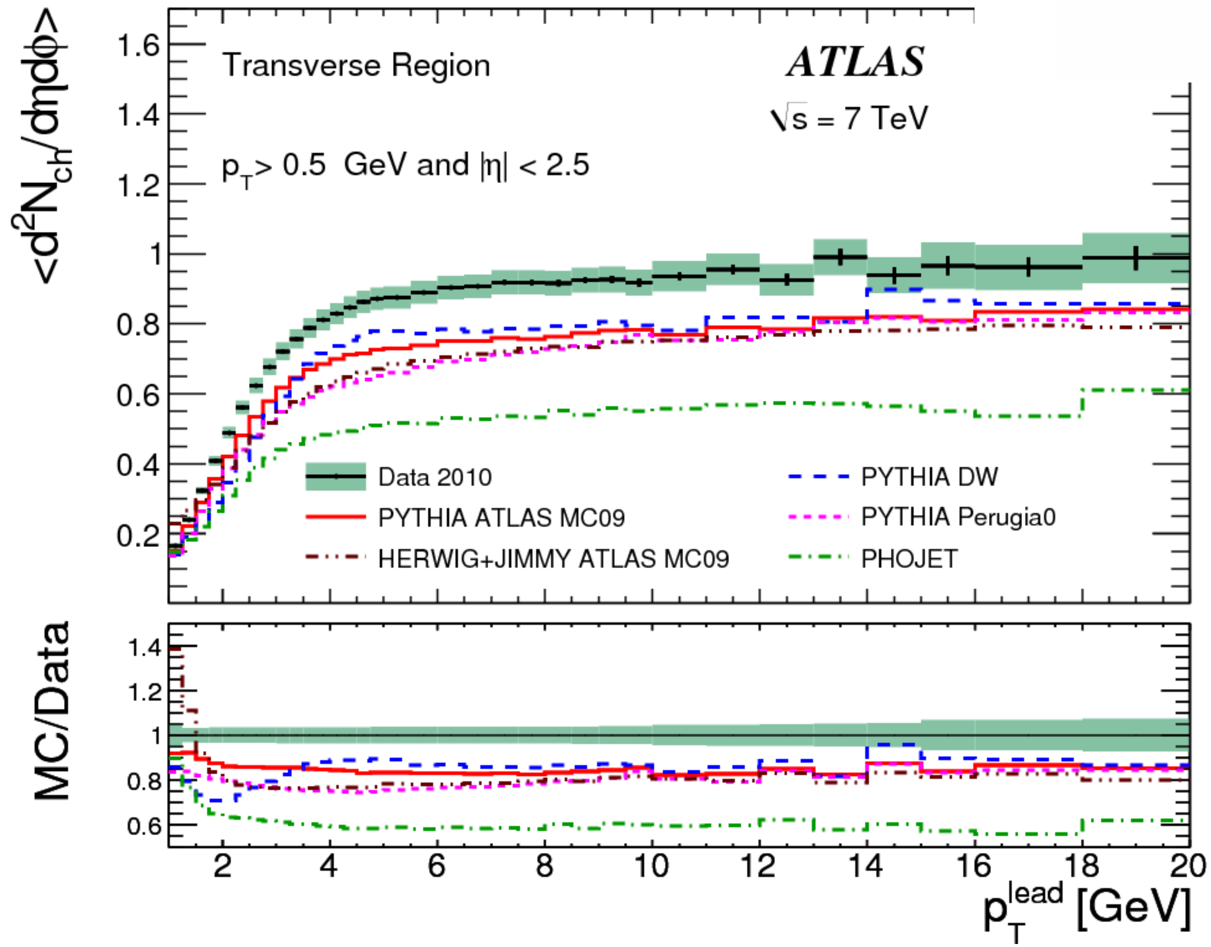


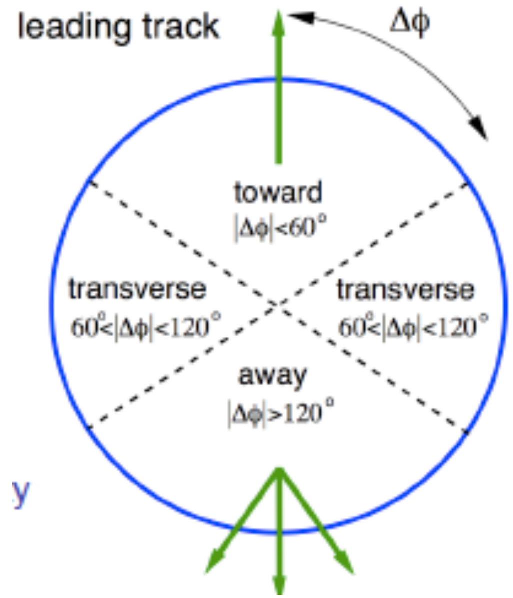
[Inelastic cross section excluding diffractive channels with $\xi < \xi_{cut}$]

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

Underlying Event and MPIs: The Bad Old Days … (2010)

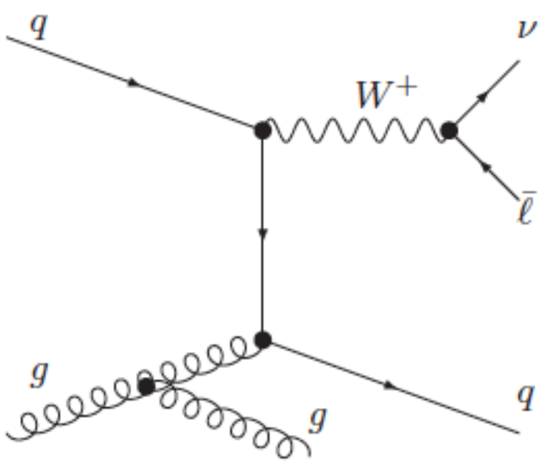




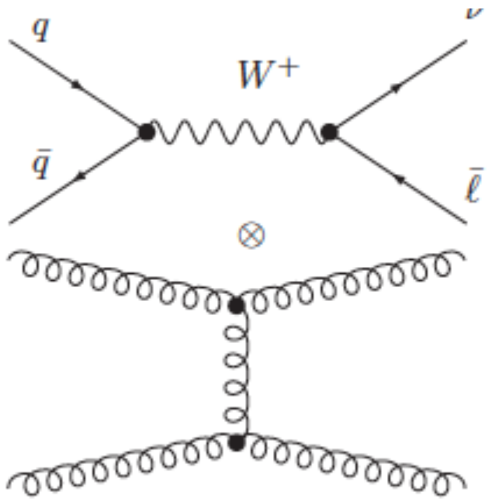


The earliest LHC data quickly showed up our lack of understanding of multi-parton scattering & underlying event

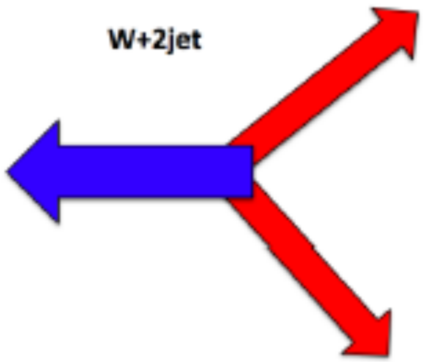
Double Parton Interactions in W + dijet Events



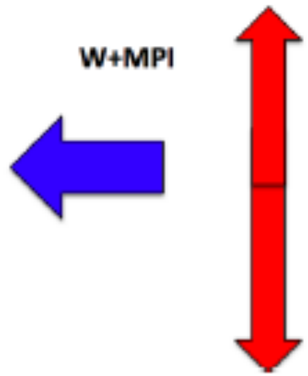
Single Hard Process



Double Parton Interaction

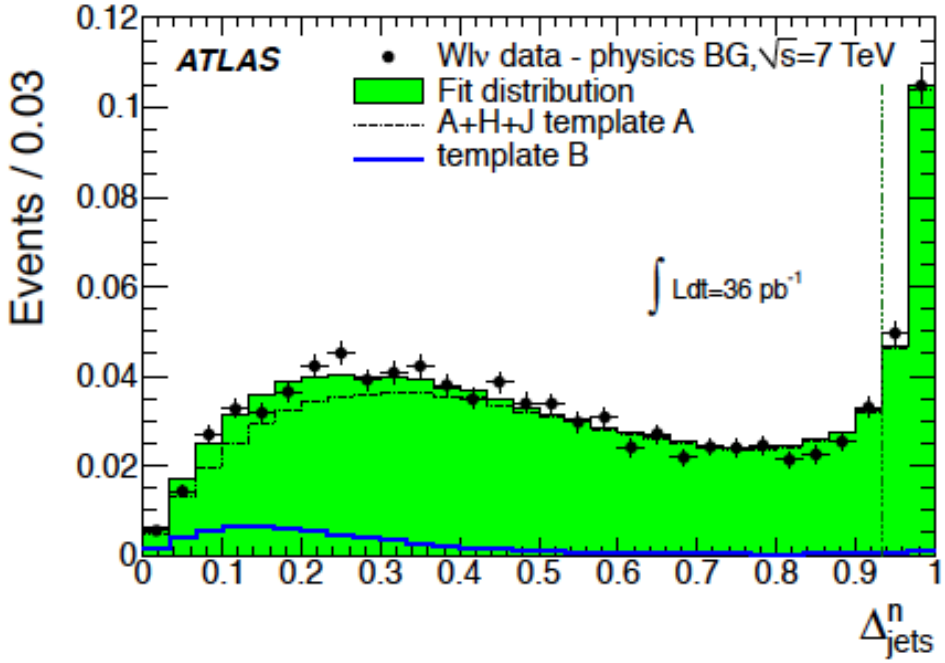


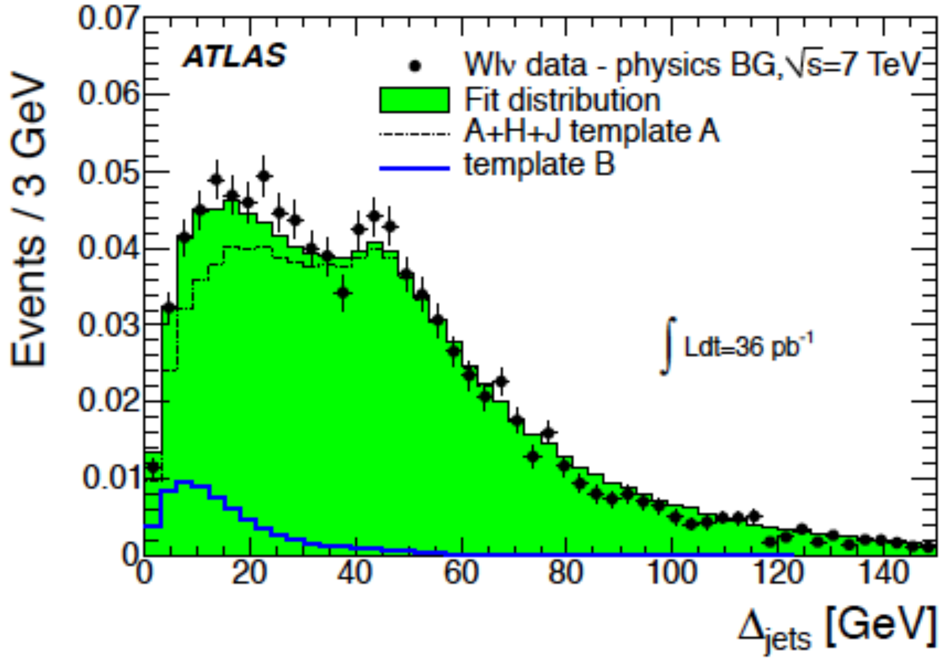
Distinguish using topology in transverse plane.



Double Parton Interactions in Wjj Events

$$\Delta^{n}_{jets} = \frac{|\vec{p}_T^{\,J_1} + \vec{p}_T^{\,J_2}|}{|\vec{p}_T^{\,J_1}| + |\vec{p}_T^{\,J_2}|} \qquad \Delta_{jets} = |\vec{p}_T^{\,J_1} + \vec{p}_T^{\,J_2}|$$





Fit normalised (or unnormalised) transverse momentum balance between jets after background subtraction to linear combination of two templates:

A (single hard process, ALPGEN+HERWIG+JIMMY with MPI off)

B (double parton interactions, standard dijet data)

Double Parton Interactions in Wjj Events

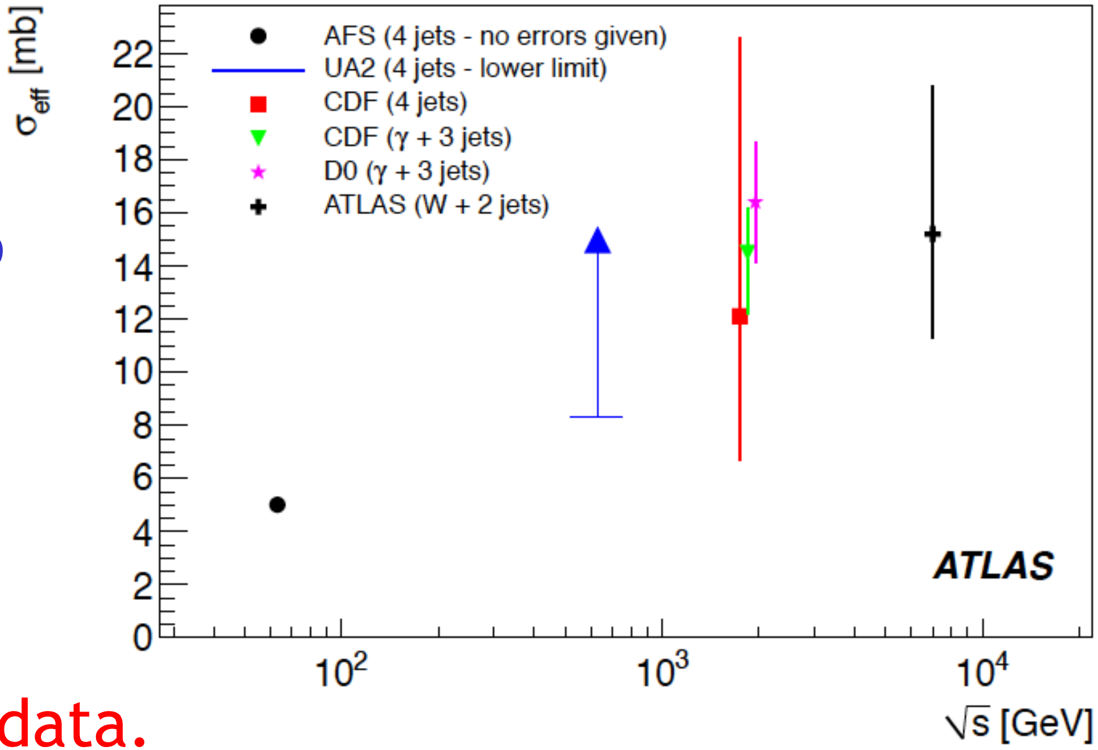
Fraction of Double Parton Interaction events in this sample: $f_{DP} = 0.076 \pm 0.013 \text{ (stat)} \pm 0.018 \text{ (sys)}$

Interpret in terms of effective area for double parton interactions σ_{eff} ...

$$\sigma_{\text{eff}} = \frac{1}{f_{\text{DP}}^{(\text{D})}} \cdot \frac{N_{W_{0\text{j}}}}{N_{W+2\text{j}}} \cdot \frac{N_{2\text{j}}}{\mathcal{L}_{2\text{j}}}$$

$= 15 \pm 3\text{(stat)} +5/-3\text{(sys) mb}$

… Significantly smaller than inelastic cross section or black disk geometry



… Consistent with previous data.

(Forward) Transverse Energy Flow

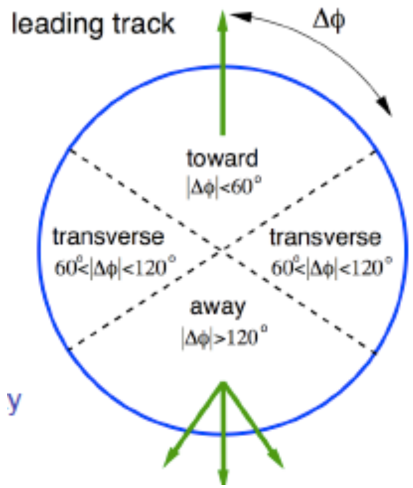
Mean E_T in $|\eta|$ ranges: $$\frac{1}{N_{evt}} \frac{dN_{evt}}{d\,\Sigma E_T}$$

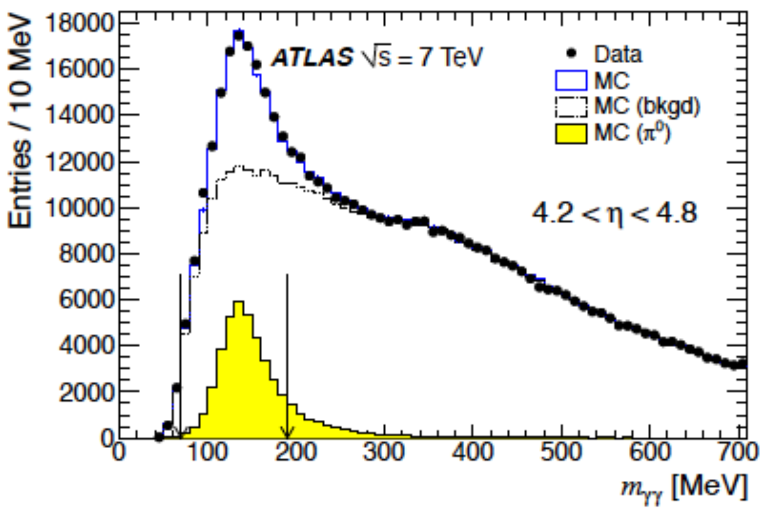
Mean E_T Density: $$\frac{1}{N_{evt}} \frac{d\,\Sigma E_T}{d\eta\, d\phi}$$

$|\eta| < 4.8$, pT > 500 MeV (charged), pT > 200 MeV (neutrals)

1) For all ϕ in minbias events and

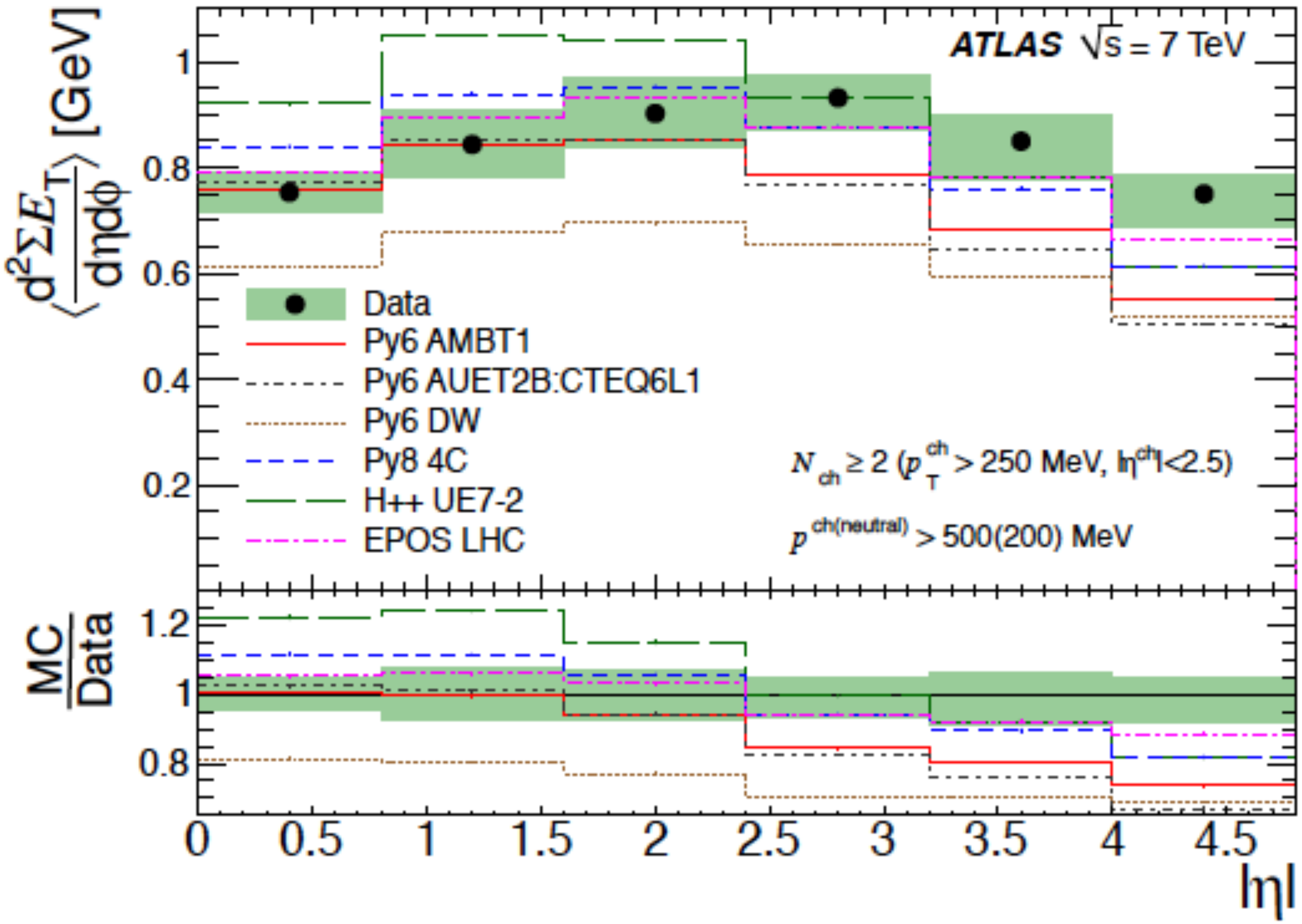
2) For transverse region in events with central dijets (E_T^{jet} > 20 GeV) → underlying event in hard process)





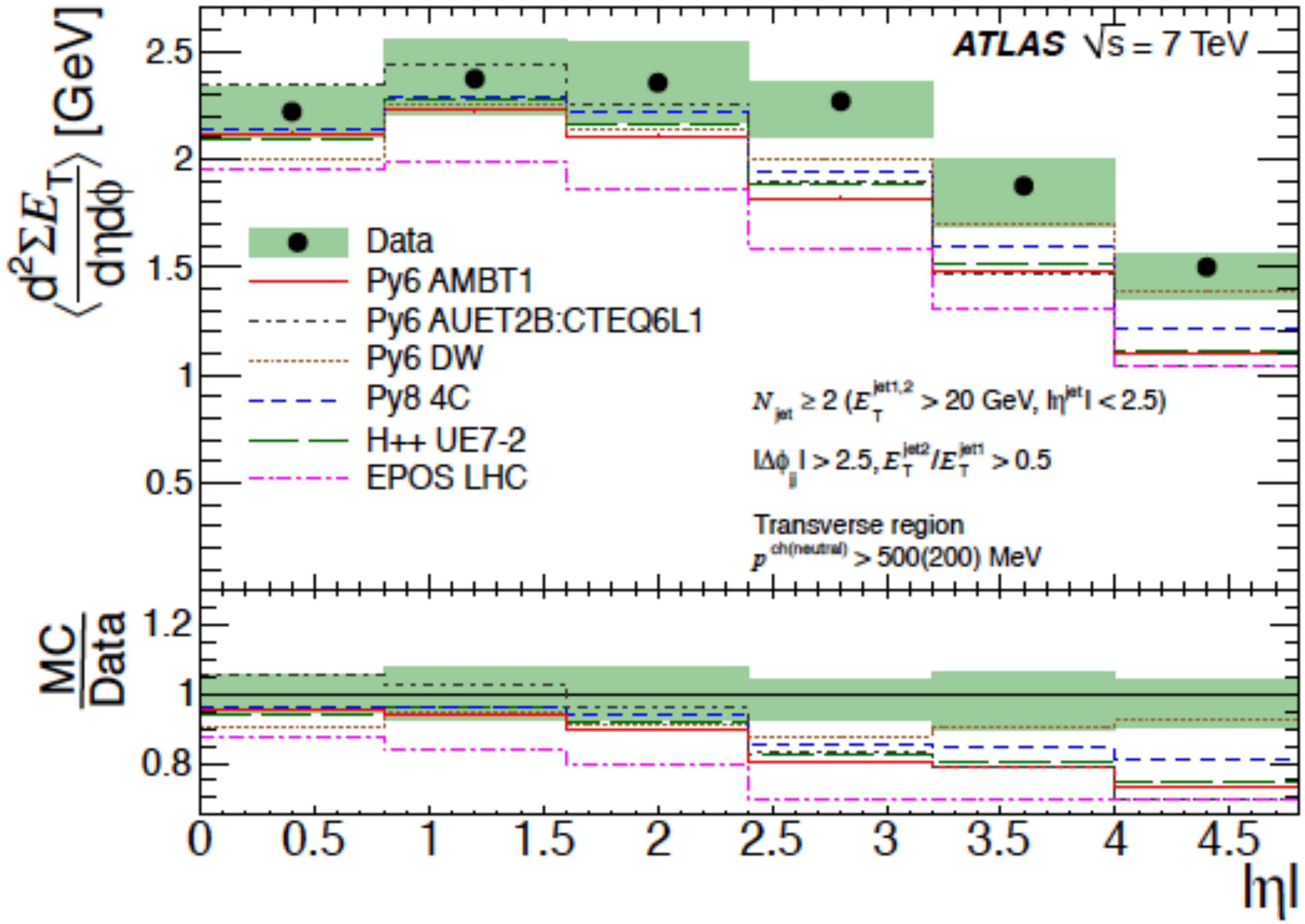
Forward calorimeter calibration based on $\pi^0 \to \gamma\gamma$ studies

Transverse Energy Density (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

Transverse Energy Density (UE in dijets)



- 3 times higher energy flow than in minimum bias events
- Similar conclusions, in particular poor forward description
- [EPOS was never tuned on LHC UE data]

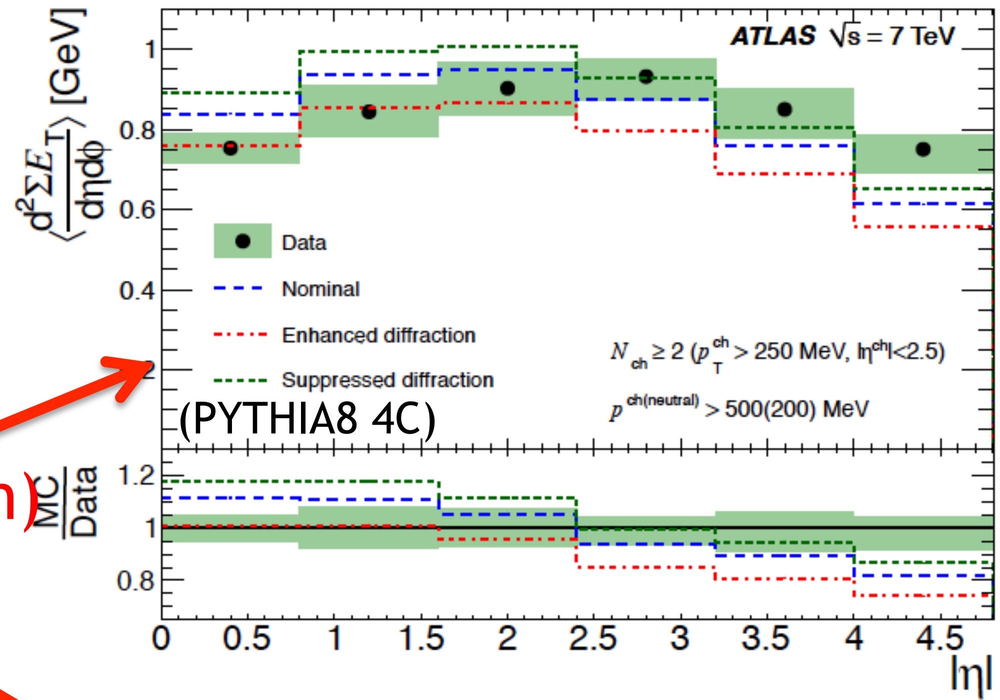
Transverse Energy Density (minbias)

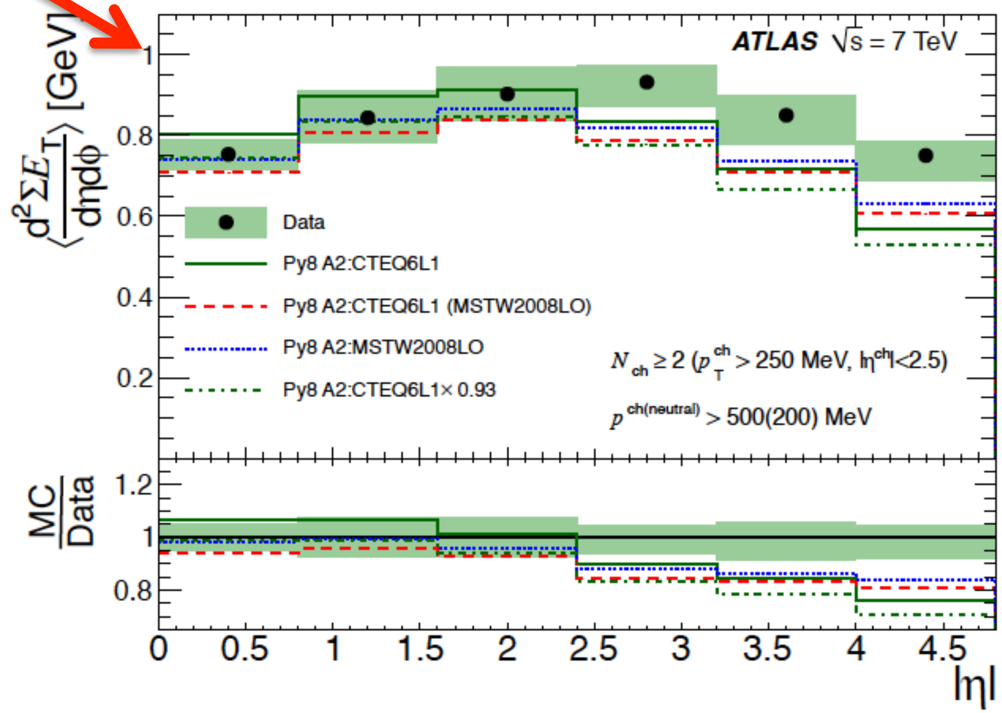
Sensitive to role of diffraction (±50% variation in normalisation)

and to PDFs (especially low x gluon)

… as well as parton cascade dynamics and the underlying event.

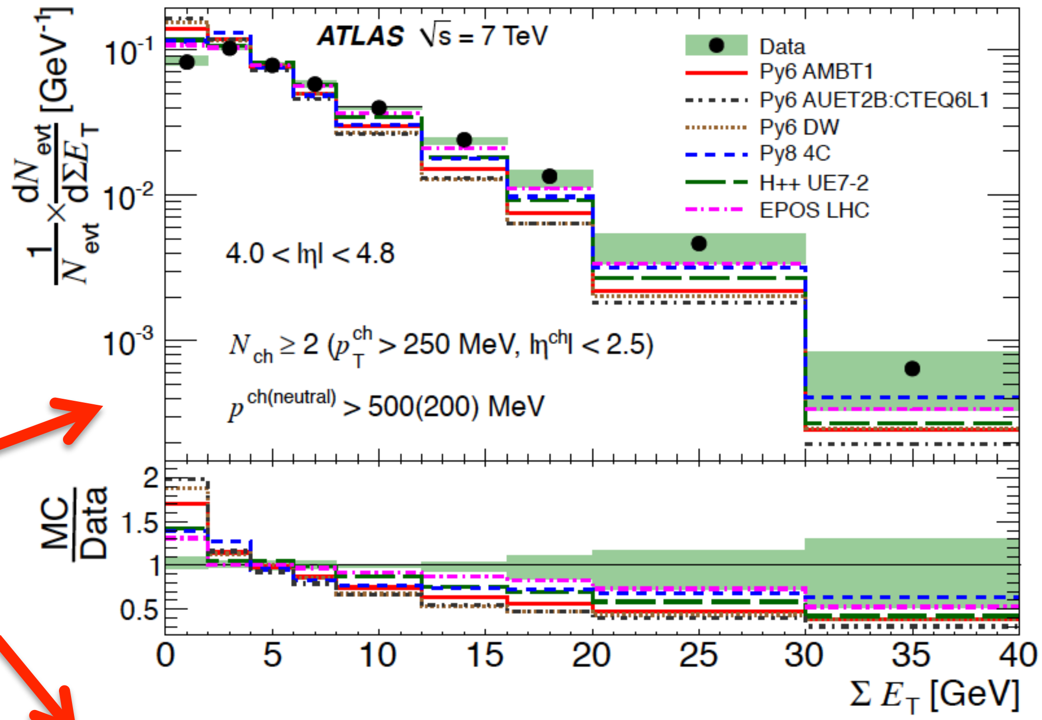
Description not completely solved by variations in any of these.



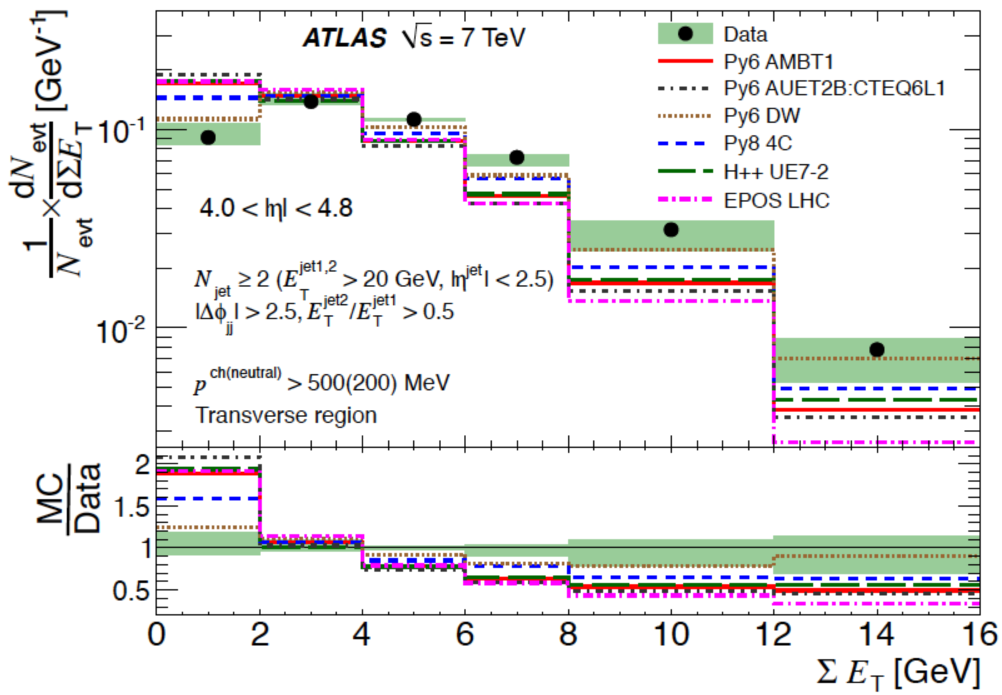


Total Forward $(4.0 < |\eta| < 4.8)$ Transverse Energy

Min Bias



UE in Dijets

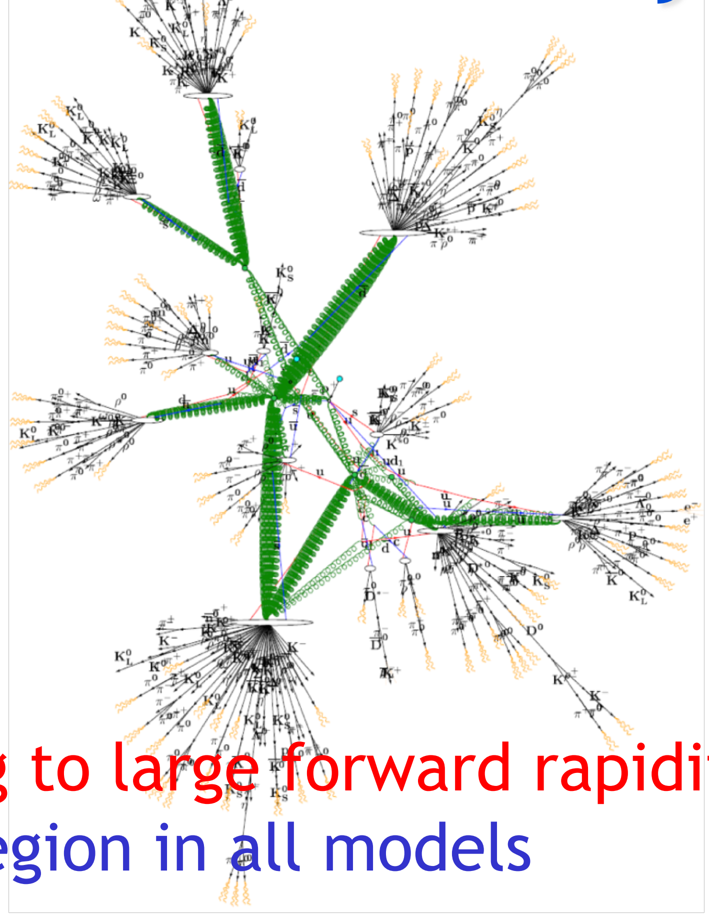


Models all tend to overestimate the low E_T contribution and underestimate the high E_T contribution in most forward region.

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



Increasingly complex MPI Data

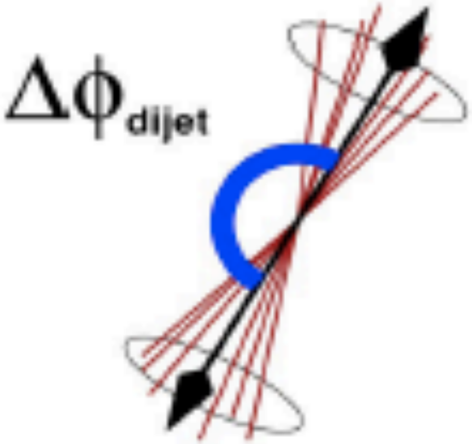
- Interpretation / universality of σ_{eff}?

Energy Flow measurements extending to large forward rapidities

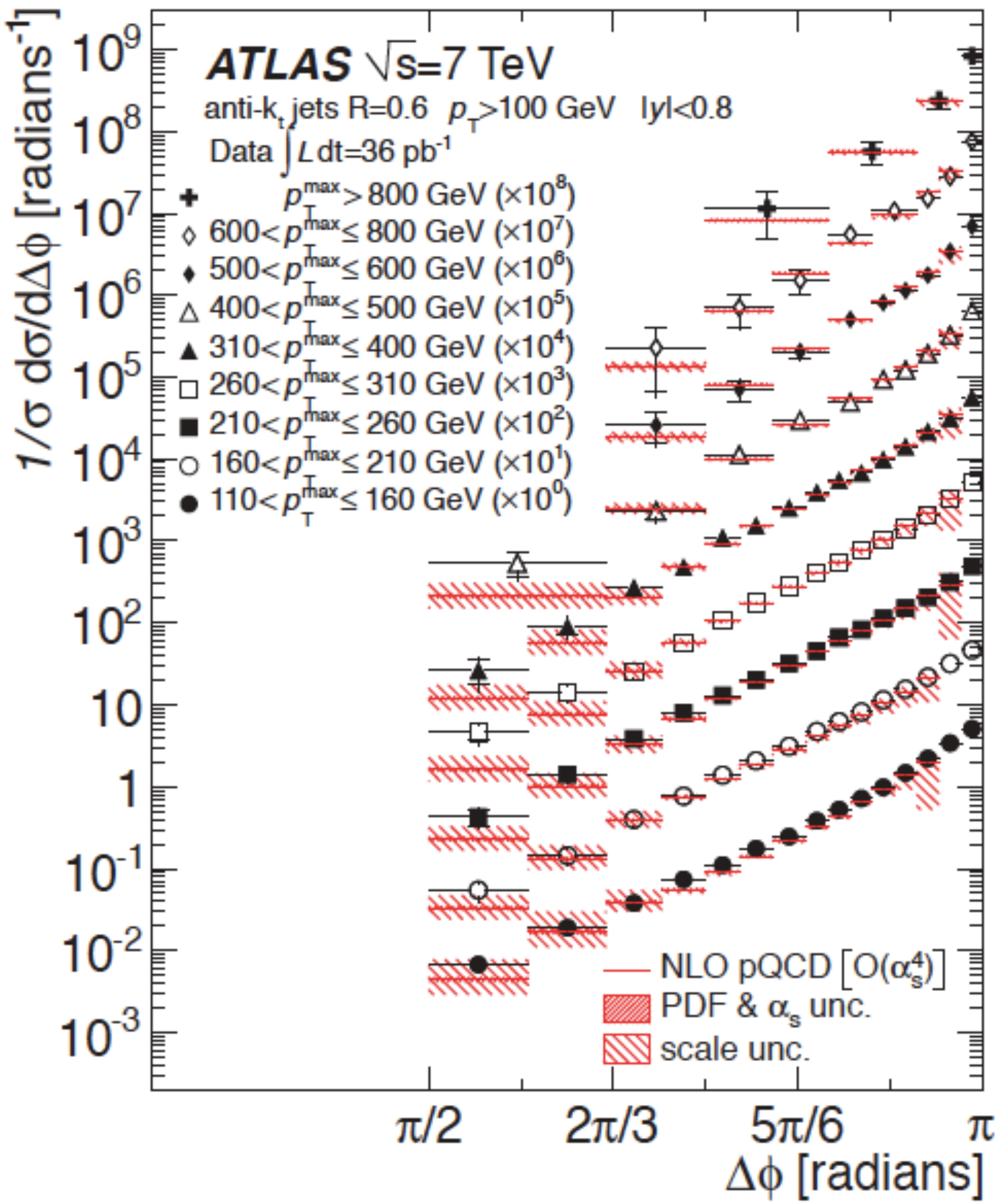
- Deficiencies in modelling forward region in all models

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

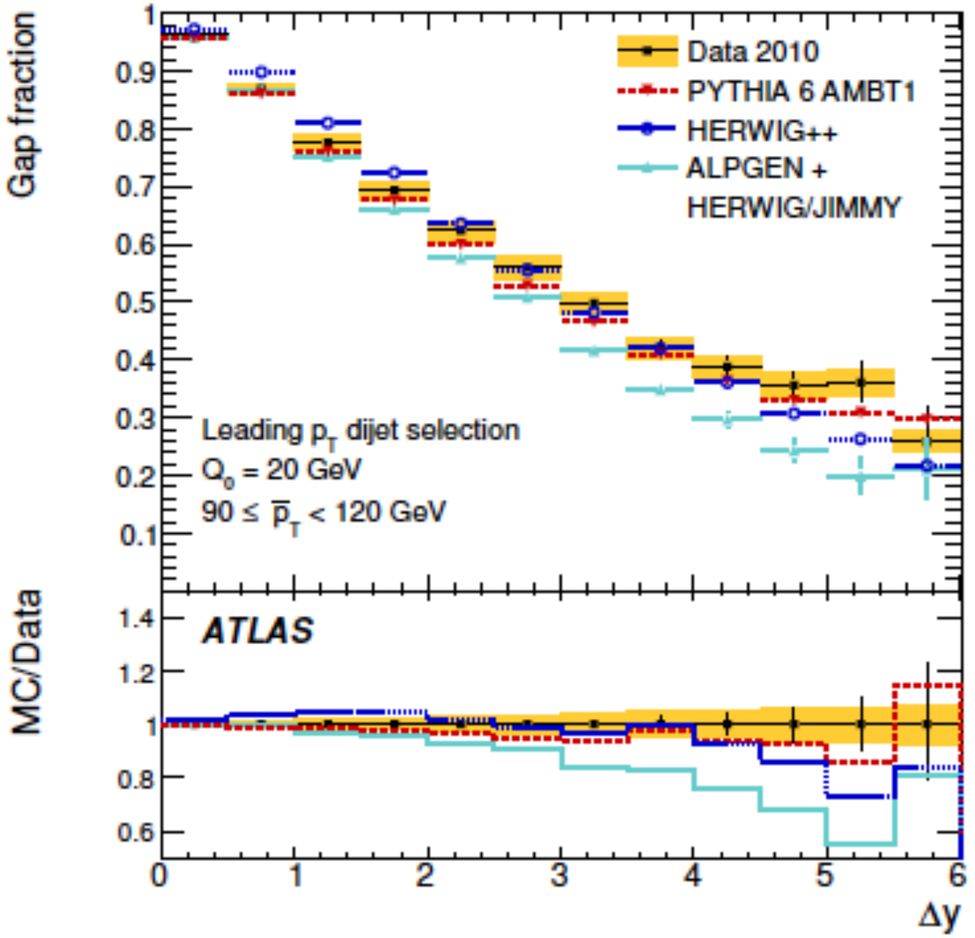
Azimuthal Decorrelations between Jets

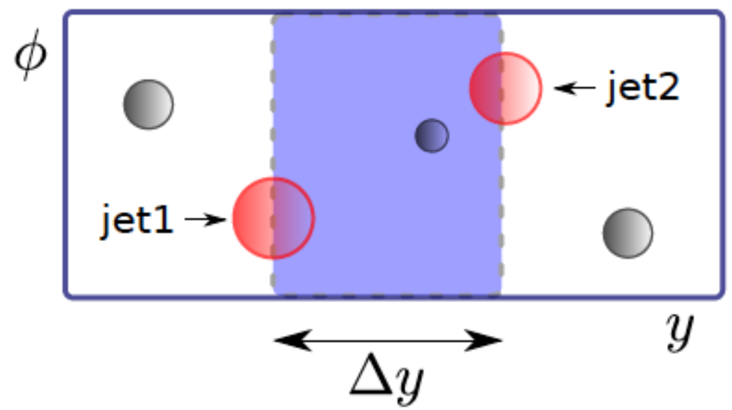


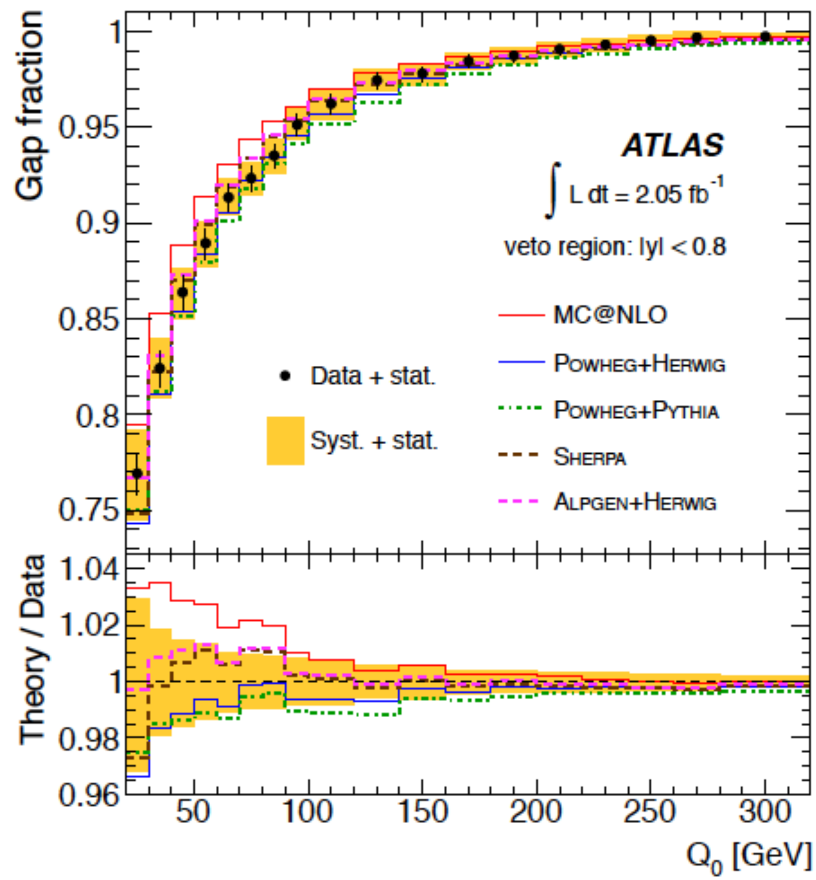
… well described by NLO QCD except near $\Delta\phi = \pi$ (region most sensitive to softest radiation)



Energy Flow Between Jets



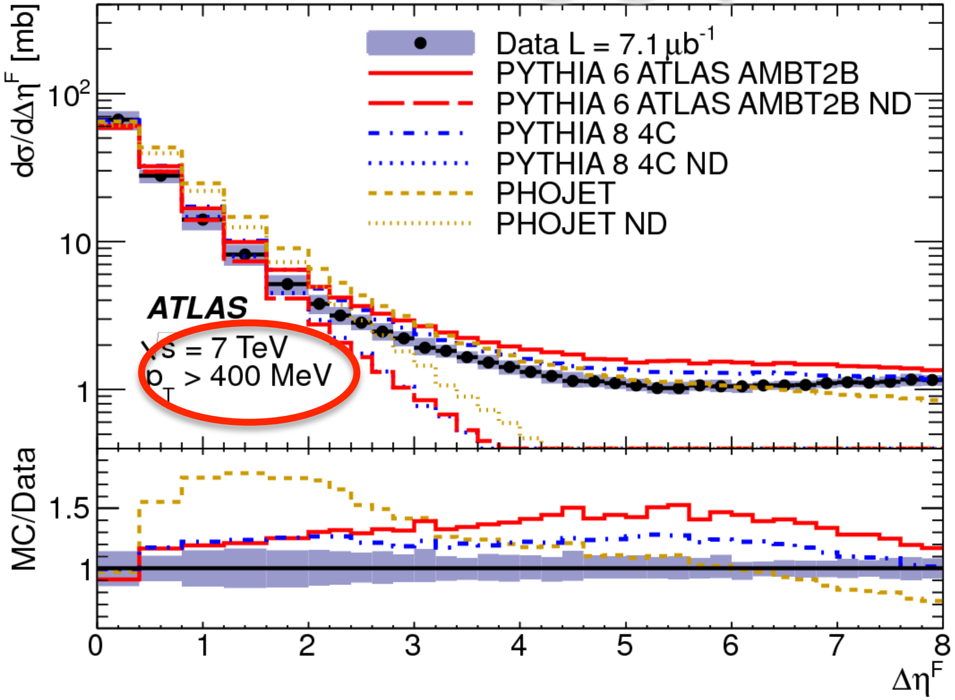


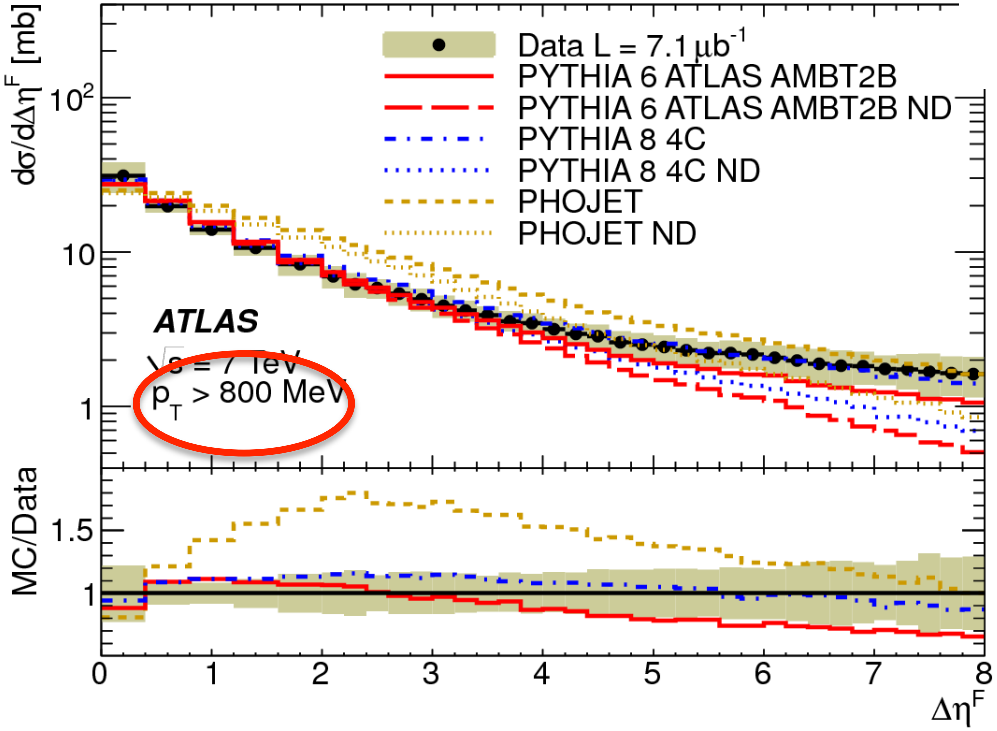


Also now in dedicated samples such as t-tbar events …
exacting test of pQCD at higher orders / colour singlet exchange

Increasing the pt 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

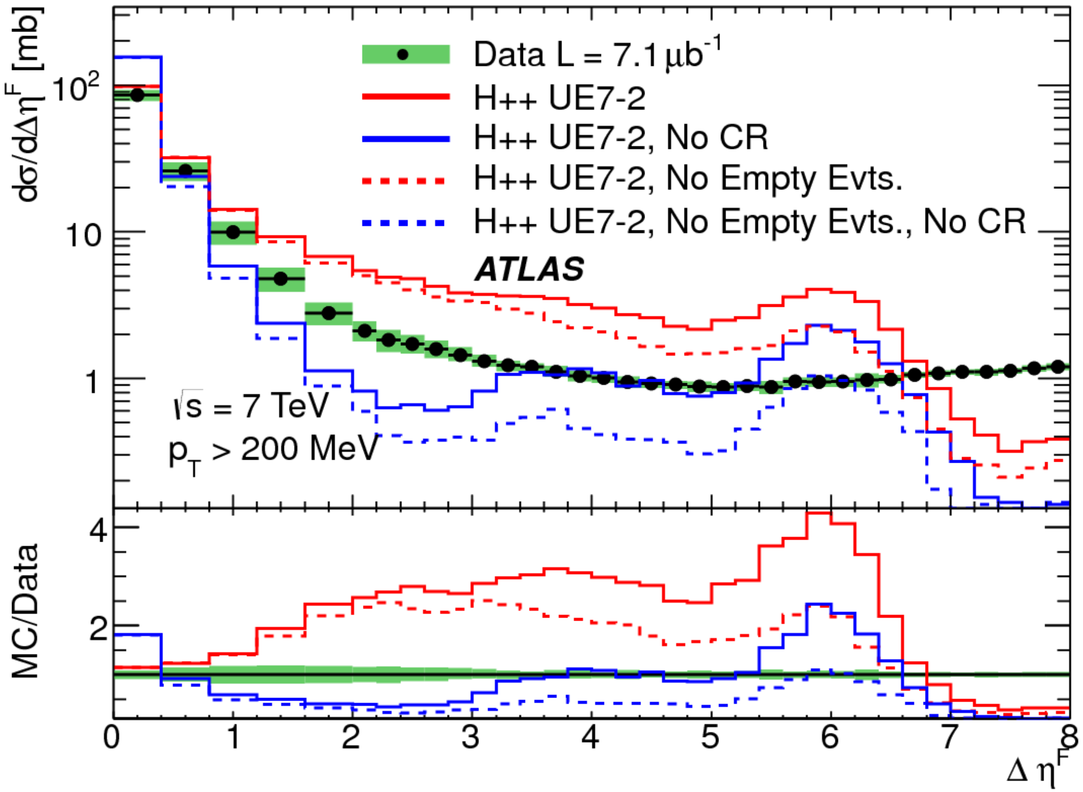




- Switching to p_t^{cut} = 400 MeV doesn’t change qualitative picture

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

Cluster Fragmentation: HERWIG++

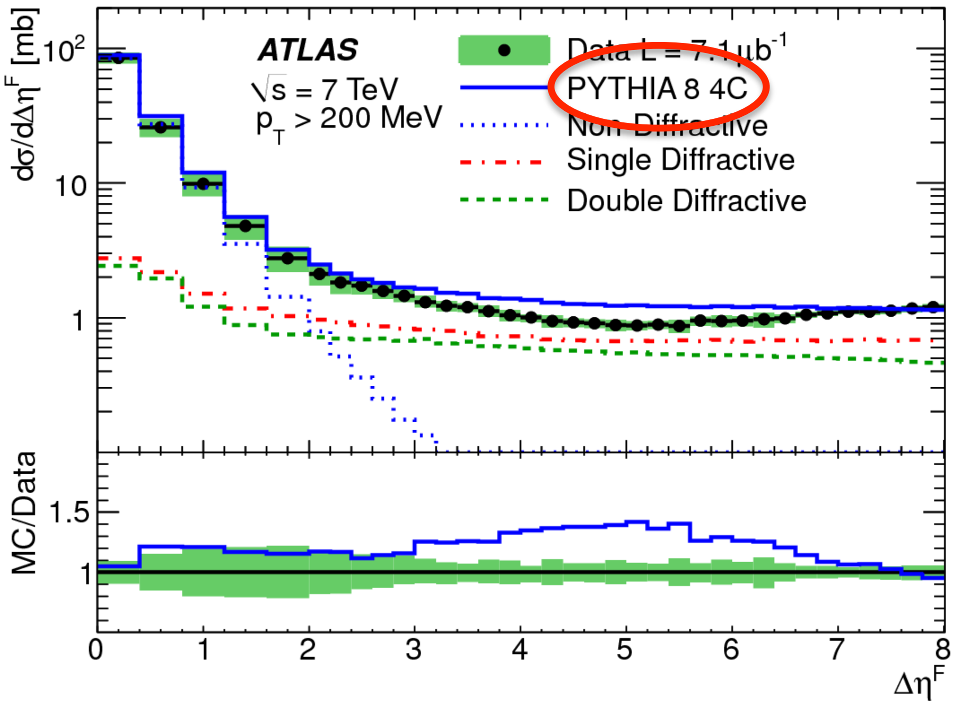


Some investigations / progress since, but still not fully solved and remains a challenge

- 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

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