# Rapidity Gap Distributions in ATLAS

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November 29, 2011, Workshop on QCD and Diffraction, Cracow

- ATLAS Conf Note: ATLAS-CONF-2011-059

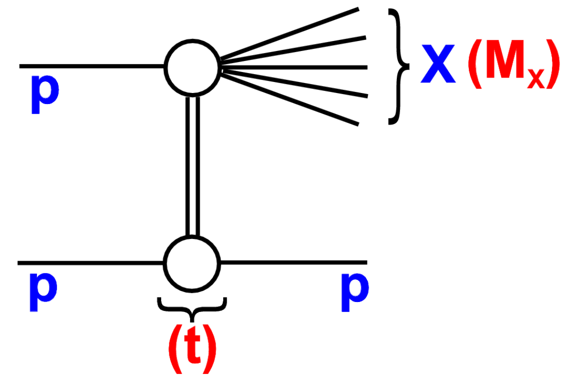
# Soft Diffraction at the LHC

- Total cross-section at 7 TeV
  - 20% elastic, 80% of inelastic

Diffractive fraction: $\sigma_D/\sigma_{inel}$~0.2-0.3

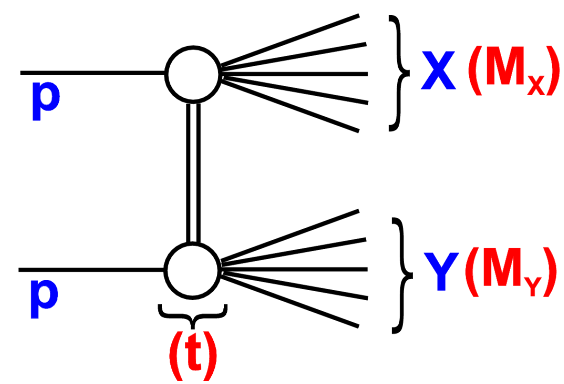
- Single Diffraction (SD) pp $\rightarrow$ pX

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




- Double Diffraction (DD) pp $\rightarrow$ XY

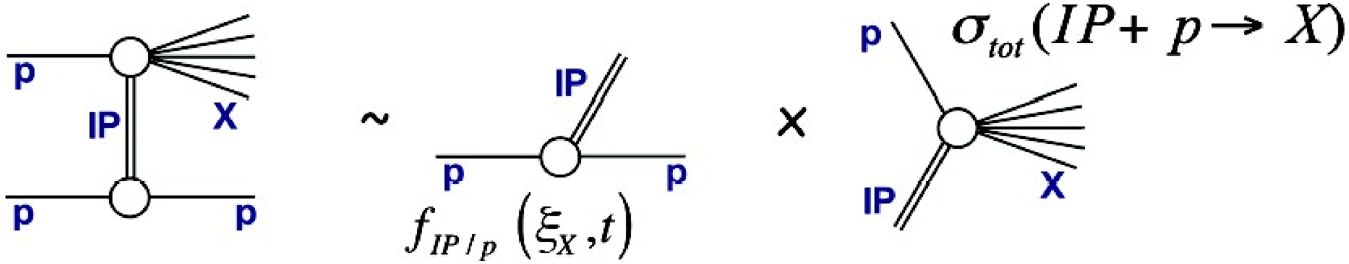
$$\xi_Y = M_Y^2/s$$



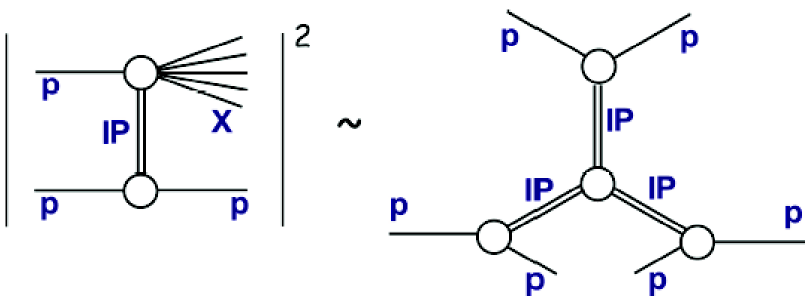

- At LHC, $M_X$, $M_Y$ range from $m_p+m_\pi \rightarrow$ ~1TeV
- Large uncertainties in cross section, especially DD

# Modeling of Soft Diffraction

- Factorize SD into a pomeron (IP) flux  and total p+IP cross section




- Calculate SD cross section from triple pomeron amplitudes




$$\frac{d\sigma}{d\xi\, dt} \propto \left(\frac{1}{\xi_X}\right)^{2\alpha(t)-\alpha(0)} e^{bt} \quad \text{(fixed s)}$$

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

i.e approx: $\frac{d\sigma}{d\xi_X} \propto \frac{1}{\xi_X}$

- Implemented in PHOJET, PYTHIA models
- In reality $\alpha(0) \neq 1$ … seen by ATLAS
- Deviation from triple-pomeron approach ?

# How to see diffraction – Forward Gaps

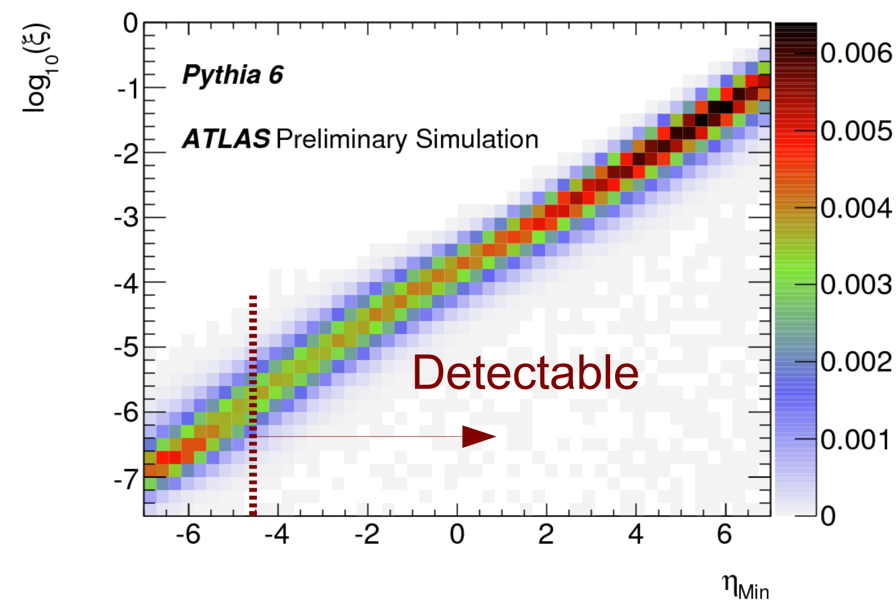
- No proton tag SD data yet available → ALFA, AFP (future upgrade)

- Cross section vs. forward gap size

$$\Delta\eta \propto \log(1/\xi) \qquad \frac{d\sigma}{d\xi} \propto \frac{1}{\xi} \Rightarrow \frac{d\sigma}{d\Delta\eta} \sim \text{flat}$$

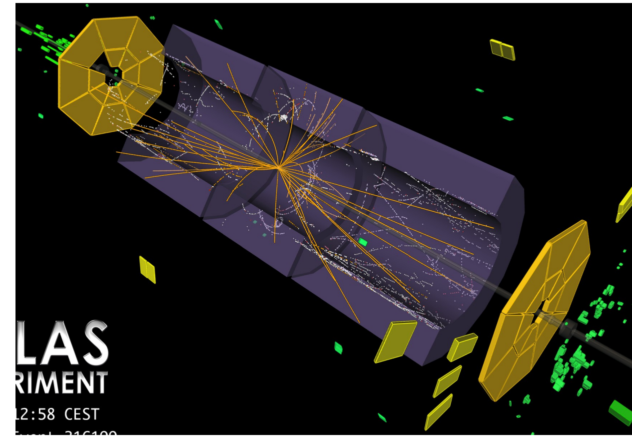
- ξ relates to rapidity gap size inside detector (|η|<4.9 calorimeter)

- Acceptance $10^{-6} < \xi < 10^{-2}$
- Equivalently in terms of diffractive mass $7 <\sim M_X <\sim 700$ GeV



# Forward Gap Detector Definition

- Measurement using Minimum Bias Trigger Scintilator (MBTS)
  - Acceptance $2.09<|\eta|<3.84$
  - Close to 100% efficiency for non-diffractive

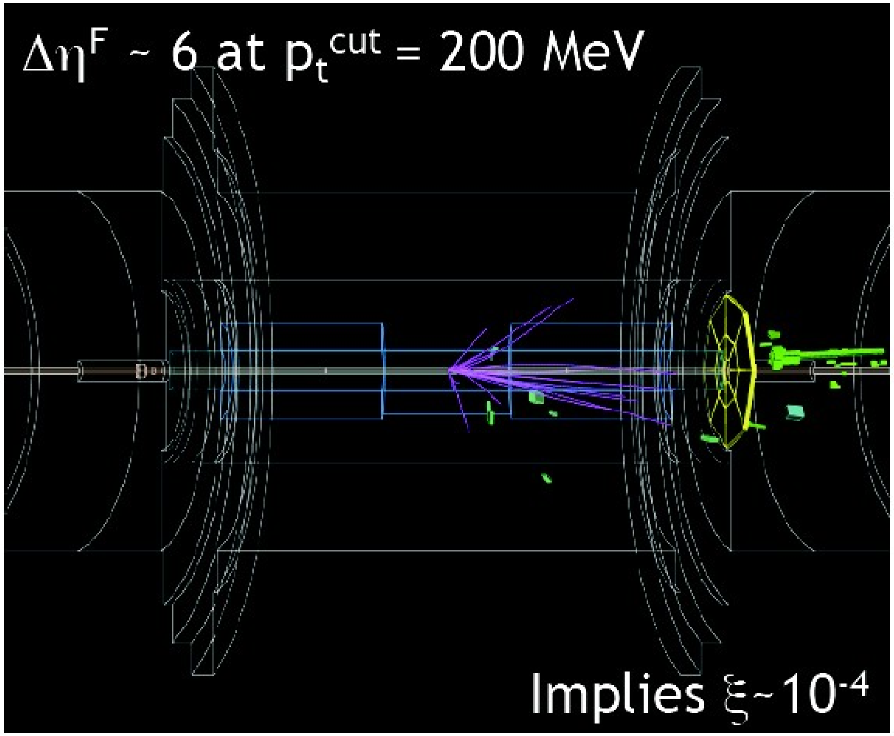


- Gap = Largest empty space on positive or negative side

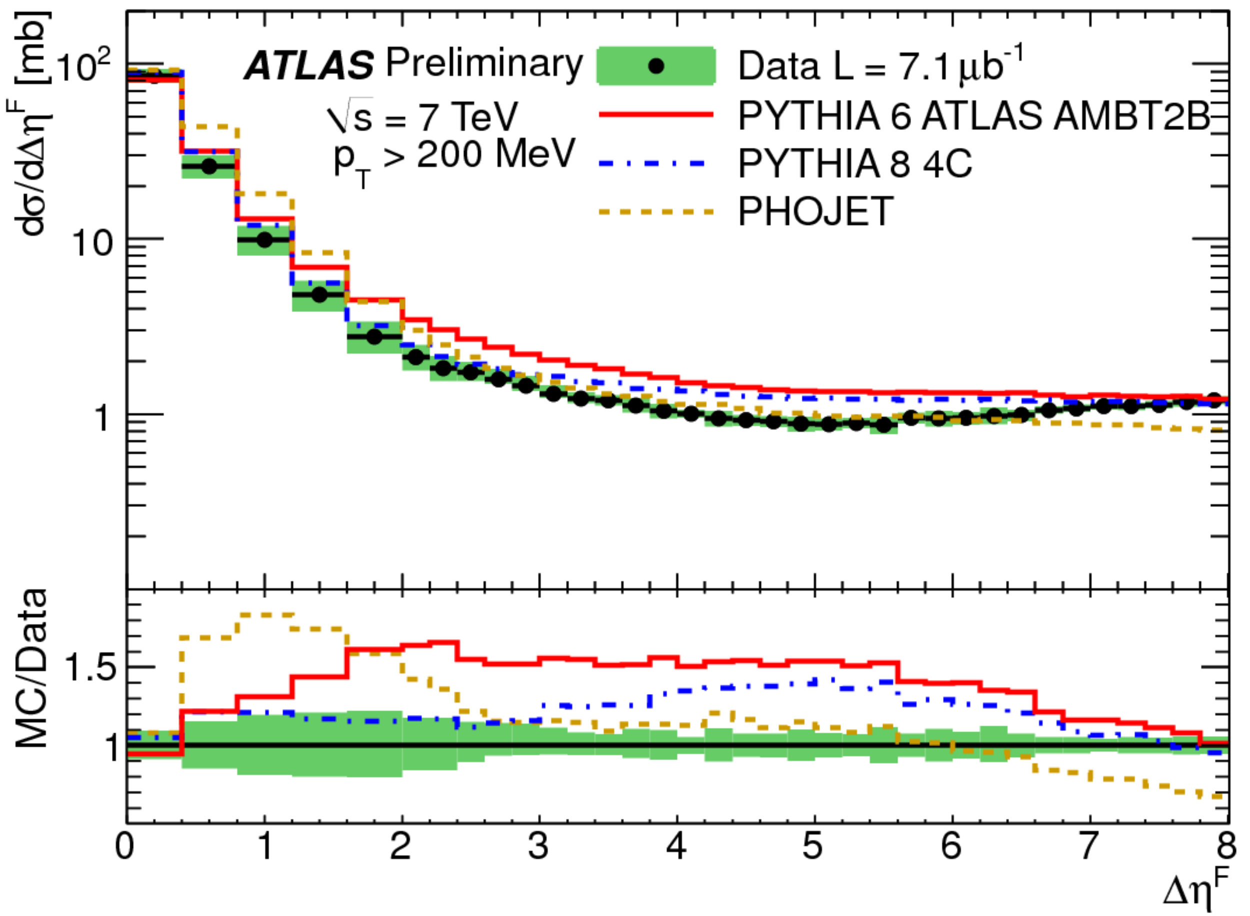
- Detector gap definition
- Calorimeter:
  - no cell above threshold $E/\sigma > S_{th}$
  - prb of noisy cell in ring smaller then $10^{-4}$
  - electronic noise only, no pile-up environment
- Tracker:
  - no good track above $p_T > 200$ MeV $|\eta| < 2.5$

# Differential Gap Cross Section

- Differential in gap size $\Delta\eta_F$
- $\Delta\eta_F$ extends from $\eta=\pm4.9$ to first particle with $p_T > p_T^{cut}$
- Measured gaps up to size $0<\Delta\eta_F<8$
- 4 different kinematic phase-spaces
  - 200 GeV < $p_T$ < 800 GeV
- Data corrected for detector effect to hadron level



# ATLAS: Forward Gap Cross Section




- Systematics uncertainties: ~8% large gaps ~20% around $\Delta\eta_F$~1.5
- Small gaps sensitive to fluctuations in hadronization
- Large gaps dominated by SD and DD ($M_Y$ <~ 7GeV)

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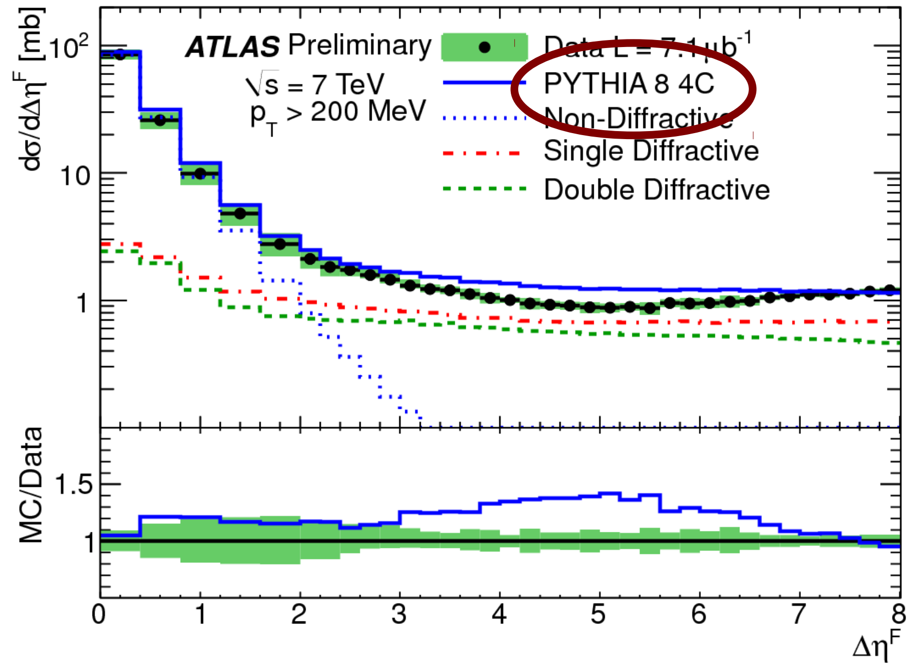
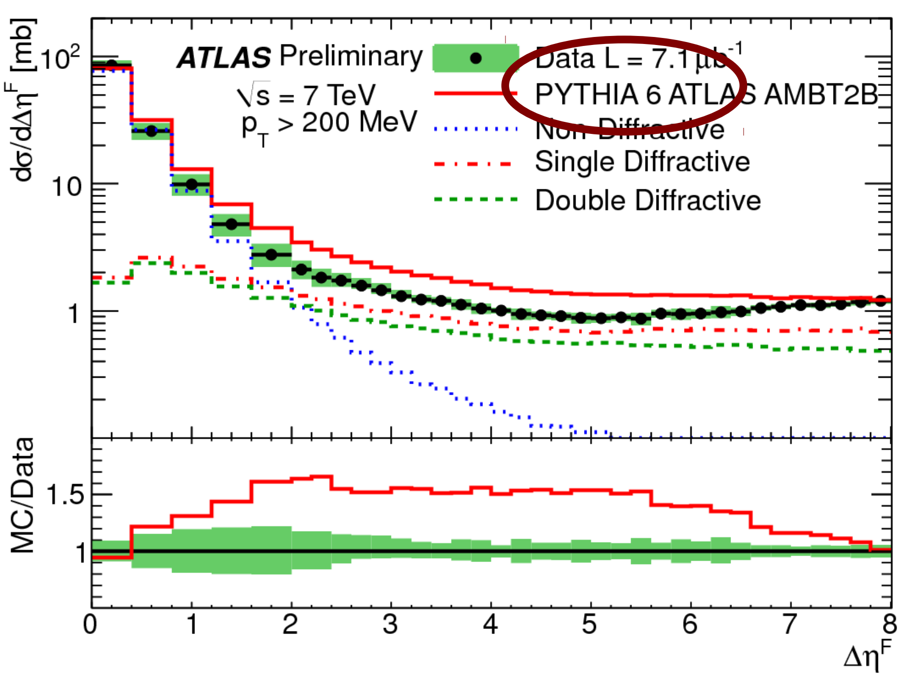
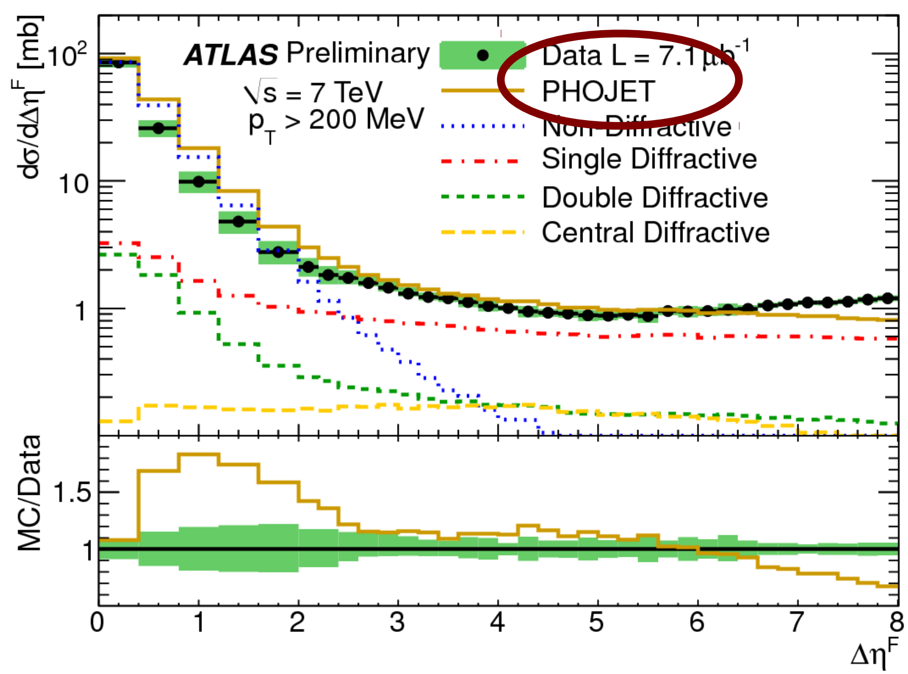
# Small Gaps

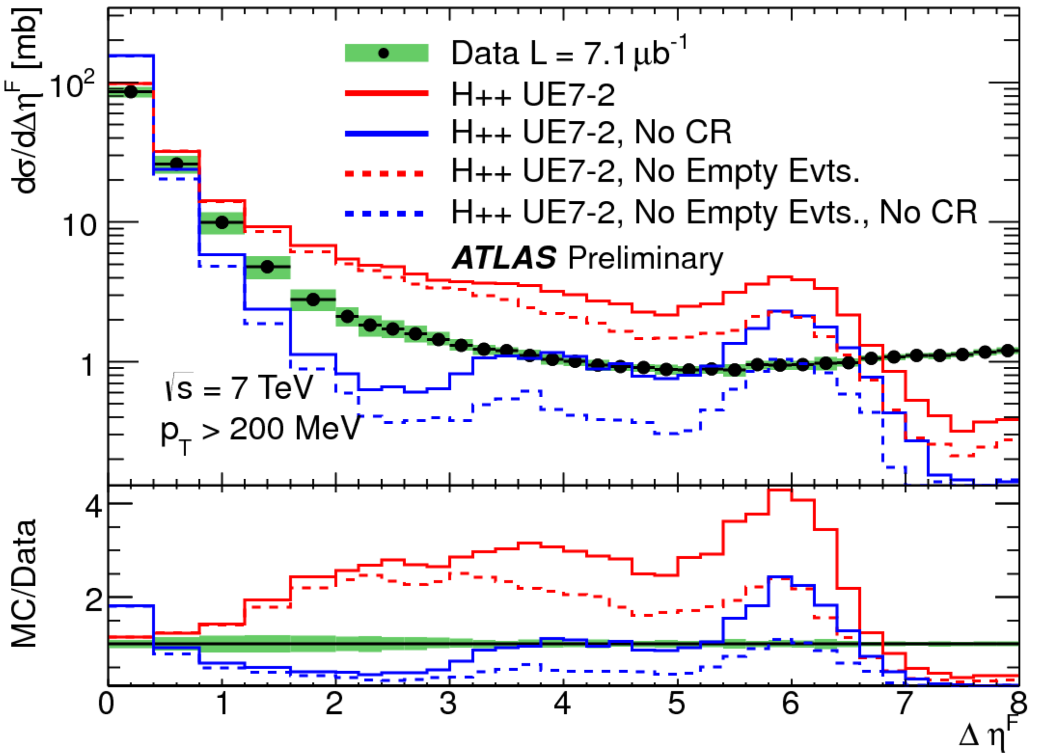
- Big differences between models in modeling ND component
- Sensitive to tunning of MC in forward region
- PYTHIA8 best describes the data at small gaps
- PHOJET best at large gaps (but fails at low end completely)



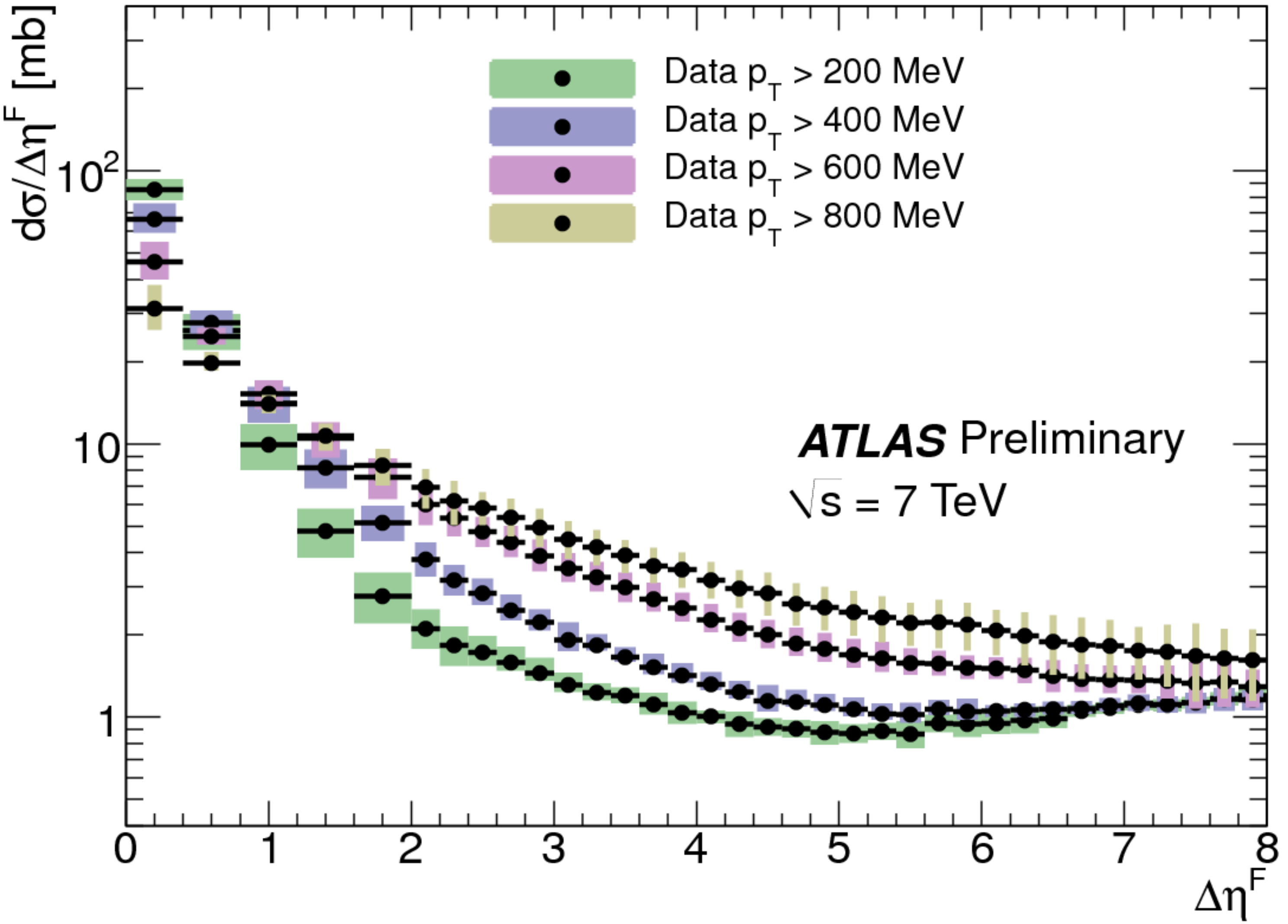
# Herwig++: Cluster Fragmentation Model




- H++ does not contain model of soft diffraction, but exhibits production of large gap above measured rate and a bump around $\Delta\eta_F=6$

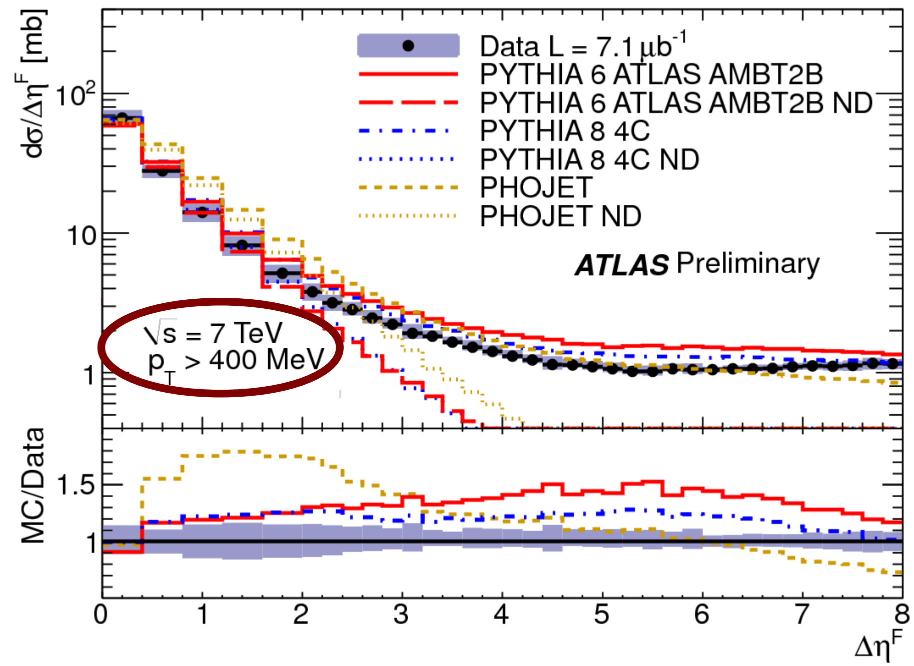
  => Gap spectrum is a very good observable to check Cluster Model
- Effect not due to Color Reconnection (CR recent add-on to H++)
- Removing events with zero soft or semi-hard scatters also did not remove large gaps

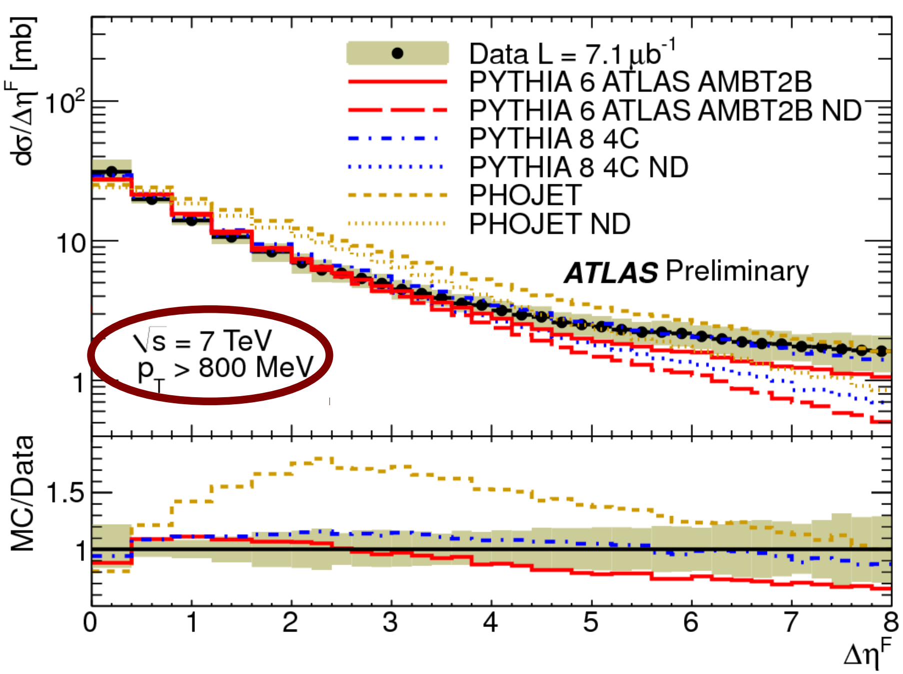
# Increasing the $p_T^{cut}$ defining gaps



# Increasing the $p_T$ $^{cut}$ defining gaps

- As the $p_T^{cut}$ increases, data show larger gaps
- Distributions probe the particle $p_T^{cut}$ spectrum in forward region
- Sensitive to hadronization fluctuation and underlying event

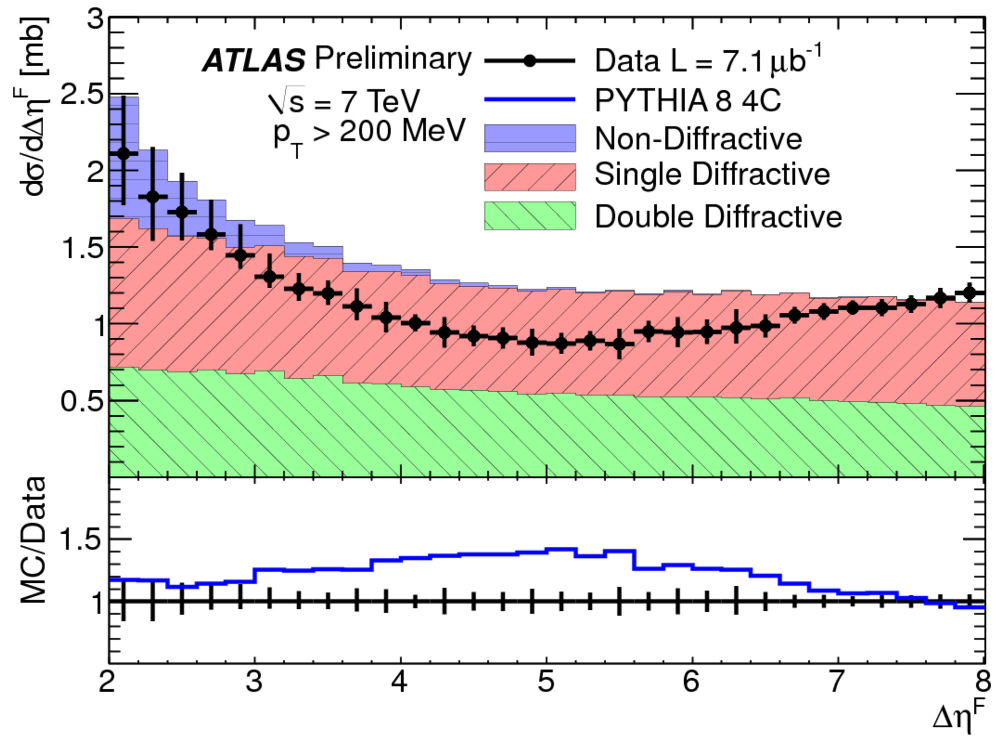


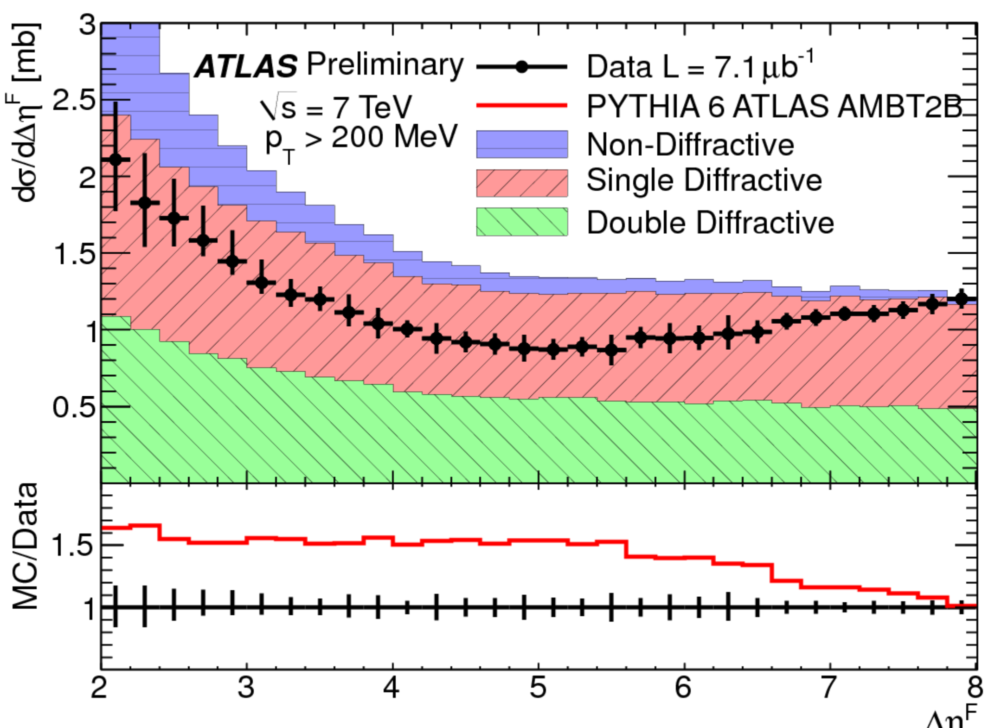



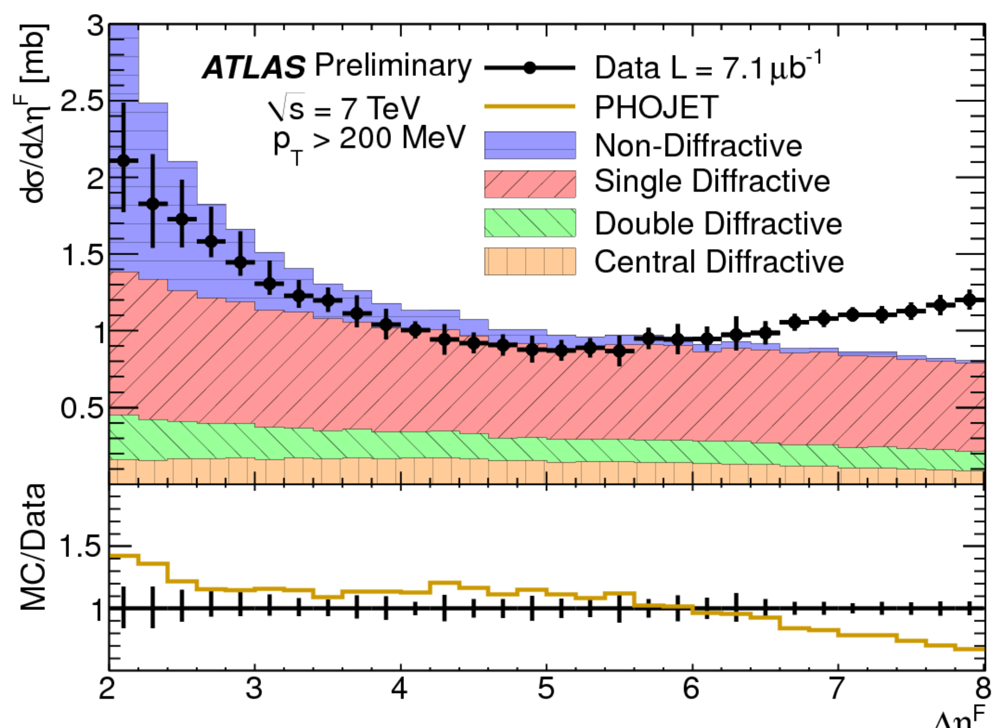

- Important to measure gaps down to low $p_T$ to see diffraction
- Diffractive/non-diffractive processes barely distinguished at $p_T^{cut}$ = 800 GeV

# Large gaps

- Diffractive plateau ~1mb per unit of gaps size for $\Delta\eta_F > 3$
- PHOJET too small in the tail
- PYTHIA too high (DD contribution larger than in PHOJET)

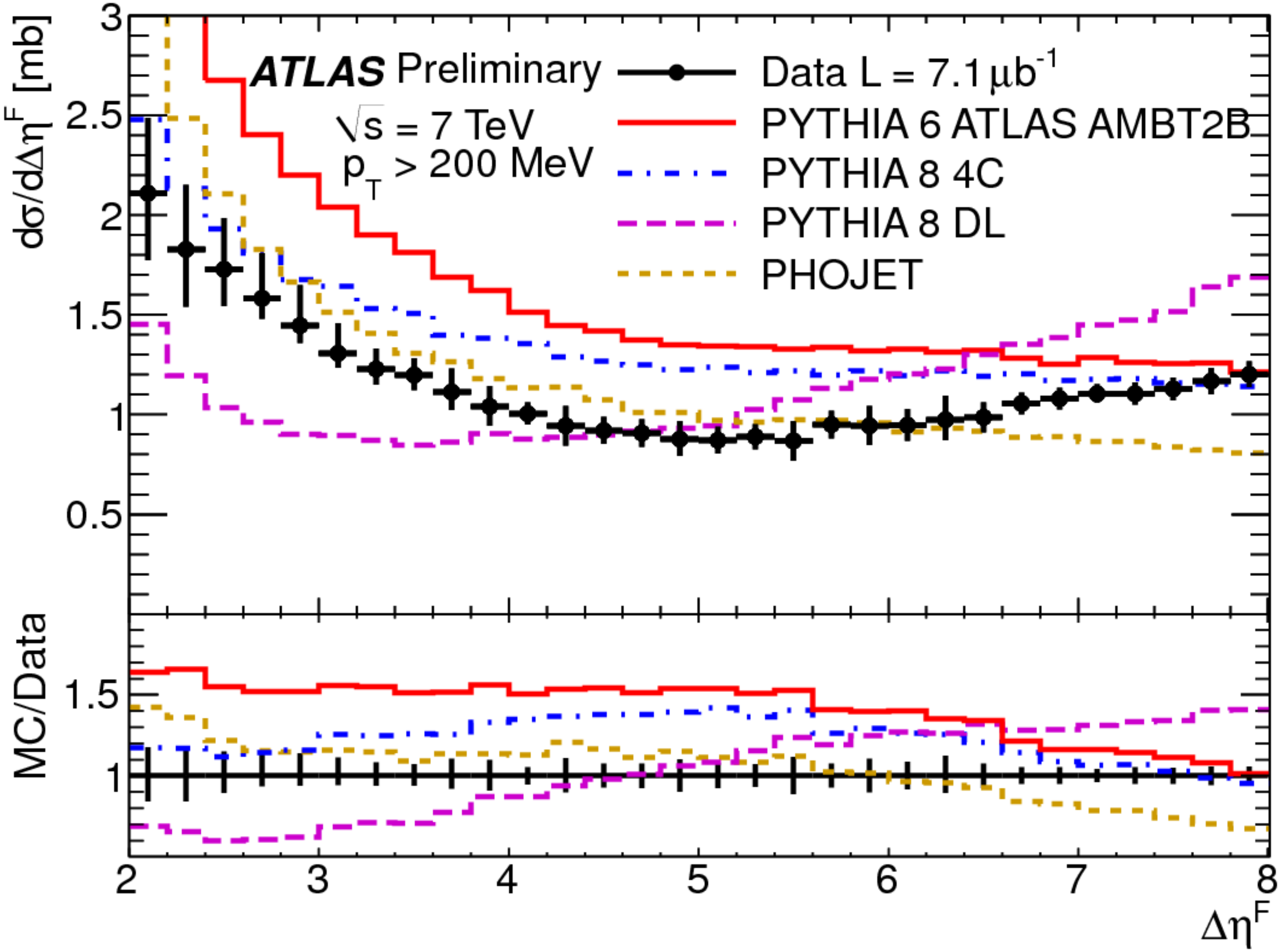


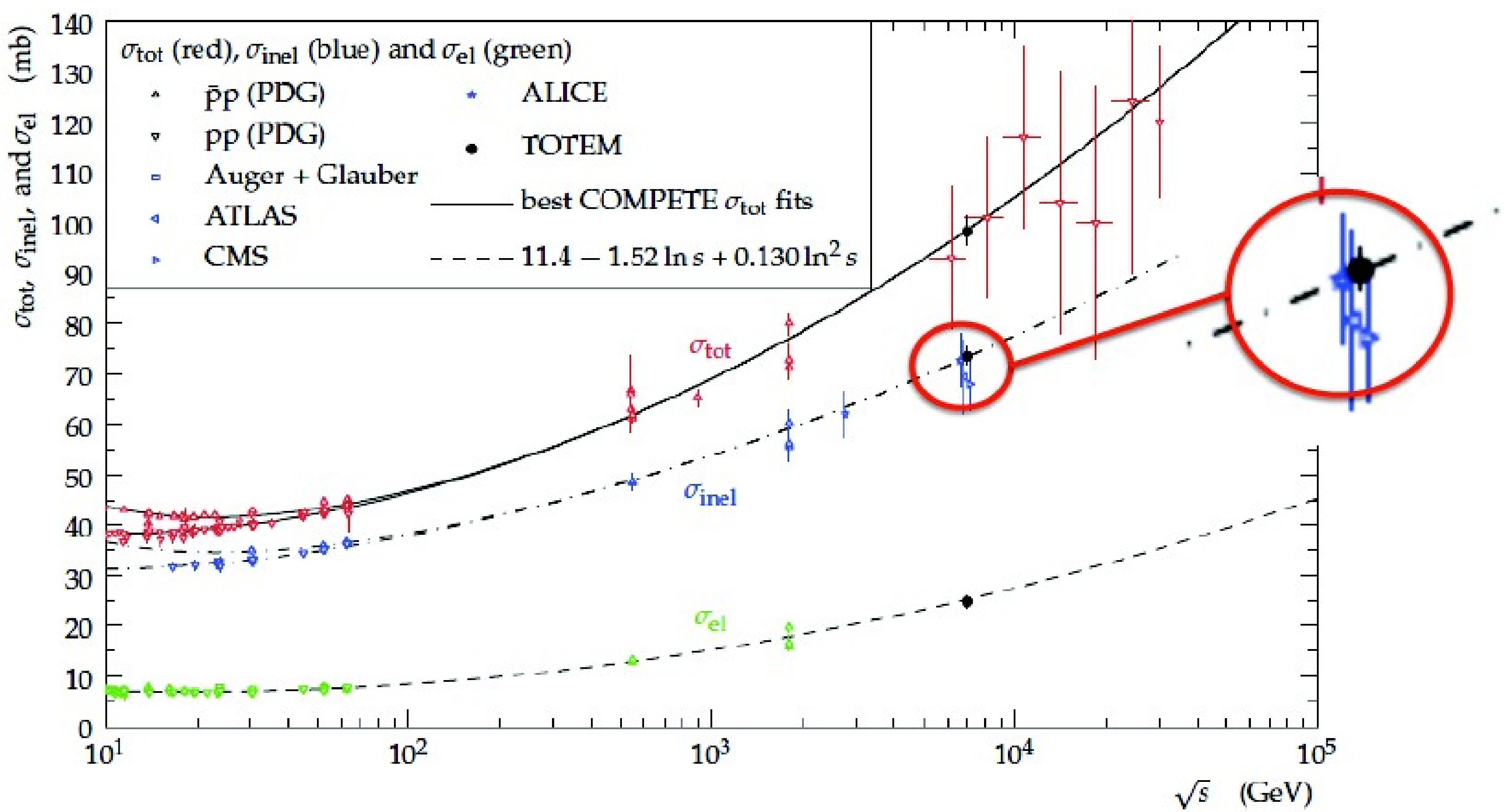
# Dynamics of large gaps

- PYTHIA has $\alpha_{IP}(0) = 1.0$
- Donnachie-Landshoff flux has $\alpha_{IP}(0)=1.085$
- Data laying somewhere in between these models …

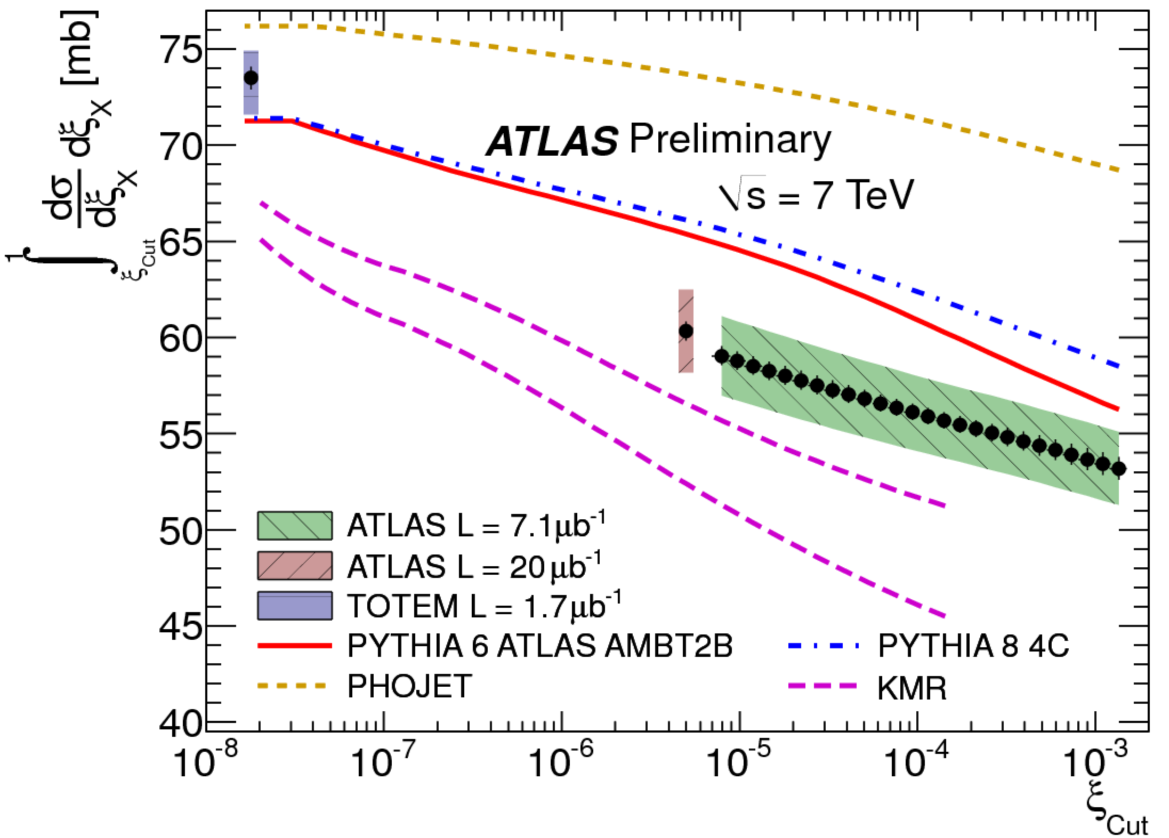


# Link to Total Inelastic Cross Section

- Current picture on the total cross section (TOTEM)
- ATLAS and CMS central values lower than TOTEM
  - after extrapolation to low ξ region below ξ=1x10$^{-6}$ (extrapolation error dominant)



# Uncertainties in Low ξ Extrapolation




- Cross section integrated up to some max $\Delta\eta_F$ (equivalently min $\xi_X$) and compared with TOTEM
- Indication that small $\xi_X$ region underestimated in PHOJET and PHYTHIA:
  - ~14 mb with $\xi < 10^{-5}$, compared to 6 (3) mb in PYTHIA (PHOJET)

# Summary

- Soft diffractive processes measured in ATLAS
  - Crucial: response to single particles in forward calorimeters under control down to 200 MeV
- Small non-zero gaps sensitive to hadronization / underlying event
- Large gaps probe the diffractive dynamics
- => Probes of soft MC models $\rightarrow$ tuning
- Compare with TOTEM $\rightarrow$ constrains of low mass diffraction

- Data to be included in HepData with all components of systematics uncertainties
  - allow theorists to fully interpret the data

# Additional Material

# Inelastic Cross-Section Measurement

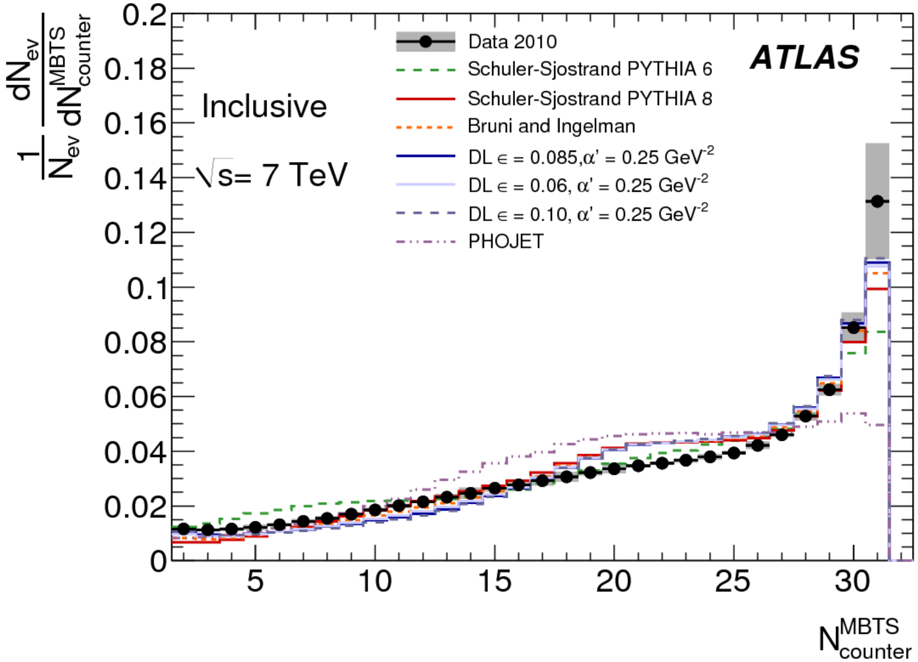
- Defined within MBTS acceptance ($M_X$>15.7 GeV)
  - At least 2 MBTS hits
- Background and trigger efficiency measured in Data

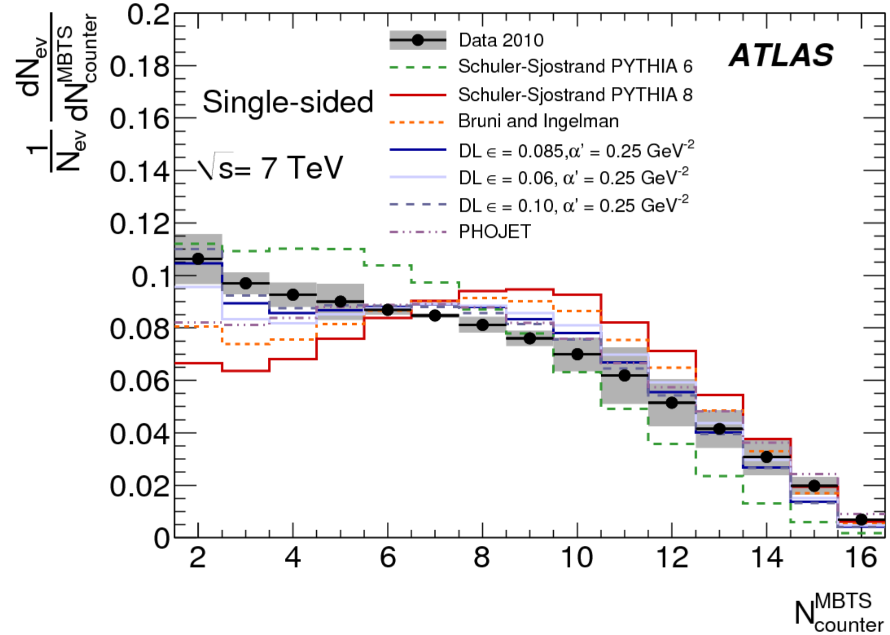
$$\sigma(\xi > 5 \times 10^{-6}) = \frac{N - N_{BG}}{\epsilon_{trig} \times \int Ldt} \frac{1 - f_{\xi < 5\times 10^{-6}}}{\epsilon_{sel}}$$

- Luminosity from Beam Scan Calibration
- Correction factors taken from MC, detector response tuned to Data

- Dataset: 1.2 M Events (2nd day of 7 TeV LHC stable beams, 2010)
- Default model used **Donnachie and Landshoff** with ε = 0.084, α' = 0.25 $GeV^{-2}$

# Inclusive and Single-Sided Samples




- Inclusive sample ($N_{inc}$):
  used for the measurement

- For most of the distribution, models span the Data

- Single-Sided sample ($N_{SS}$):
  requires hit on **one** side of MBTS only
  - Dominated by diffraction

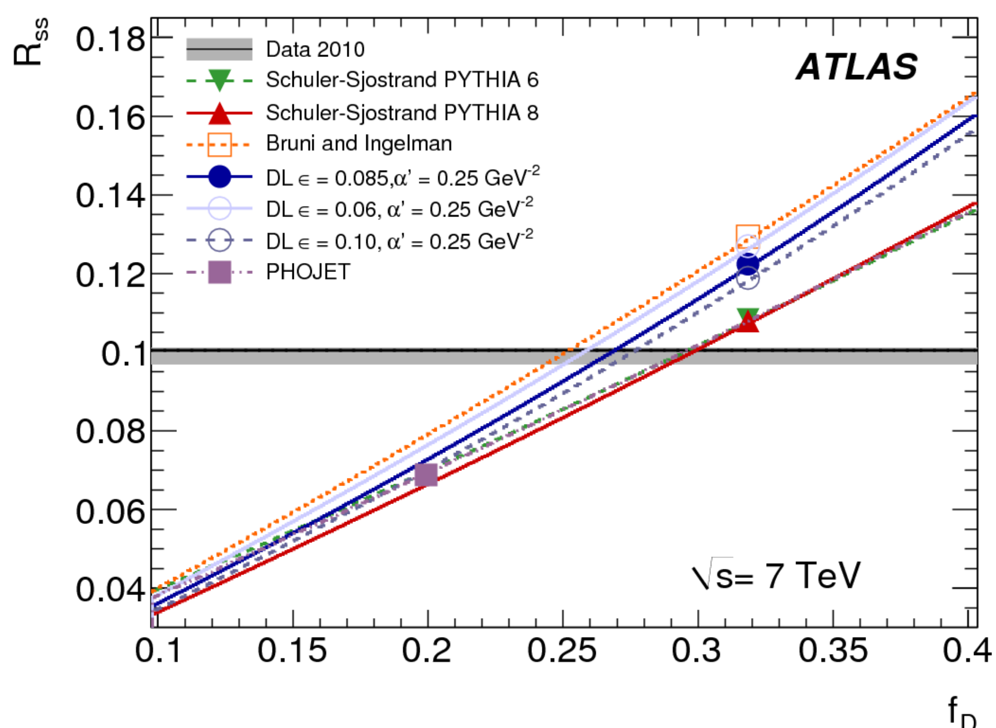
- Used to constrain contribution of diffractive events to inclusive sample

# Diffractive Fraction

- Fractional contribution of diffractive events ($f_D$) varies significantly between models

$$R_{ss}(f_D) = \frac{N_{SS}}{N_{inc}}$$
$$= \frac{A^{D}_{SS} f_D + A^{ND}_{SS}(1 - f_D)}{A^{D}_{inc} f_D + A^{ND}_{inc}(1 - f_D)}$$

- Constrain $f_D$ by finding a value which reproduces the ratio of single-sided to inclusive event sample ($R_{ss}$) seen in Data




- Default model yields:

$f_D = 26.9^{-1.0}_{+2.5}\ \%$

- Calculate MC dependent corrections with tuned model

# Results

- The cross-section is obtained using
  - $\varepsilon_{sel}$ = 98.8%
  - $\varepsilon_{trig}$ = 99.8%
  - $f_{\xi<5x10-6}$ = 1 %
  - Luminosity 20 $\mu b^{-1}$

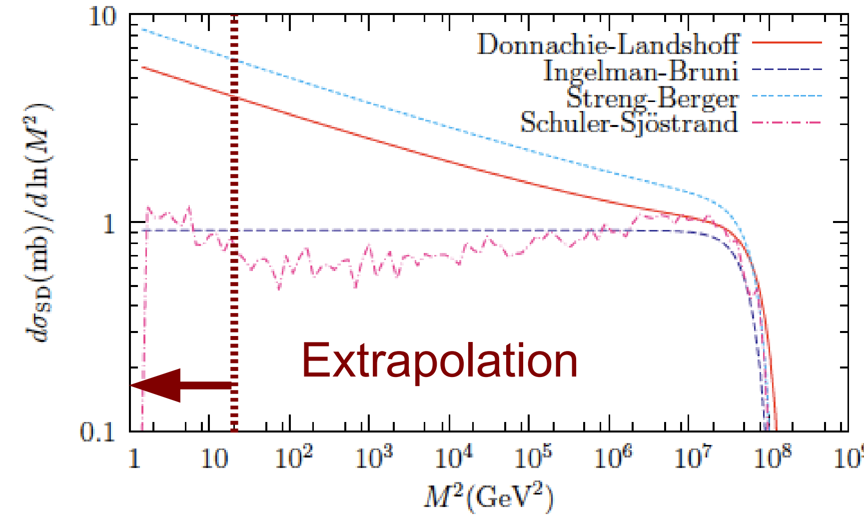
  } 0.4 % Correction factor small

| $\sigma(\xi > 5 \times 10^{-6})$ [mb] | |
|---|---|
| ATLAS Data 2010 | $60.33 \pm 2.10$(exp.) |
| Schuler and Sjöstrand | 66.4 |
| PHOJET | 74.2 |
| Ryskin *et al.* | 51.8 – 56.2 |

- Default PYTHIA/PHOJET above Data, analytic calculation of Ryskin *et al.* below Data

# Extrapolation to $\sigma_{inel}$

- To compare with previous experiments, Data are extrapolated using DL default model (+15%)
  - Other models range from 5% to 25%
  - Systematic uncertainty taken as 10%

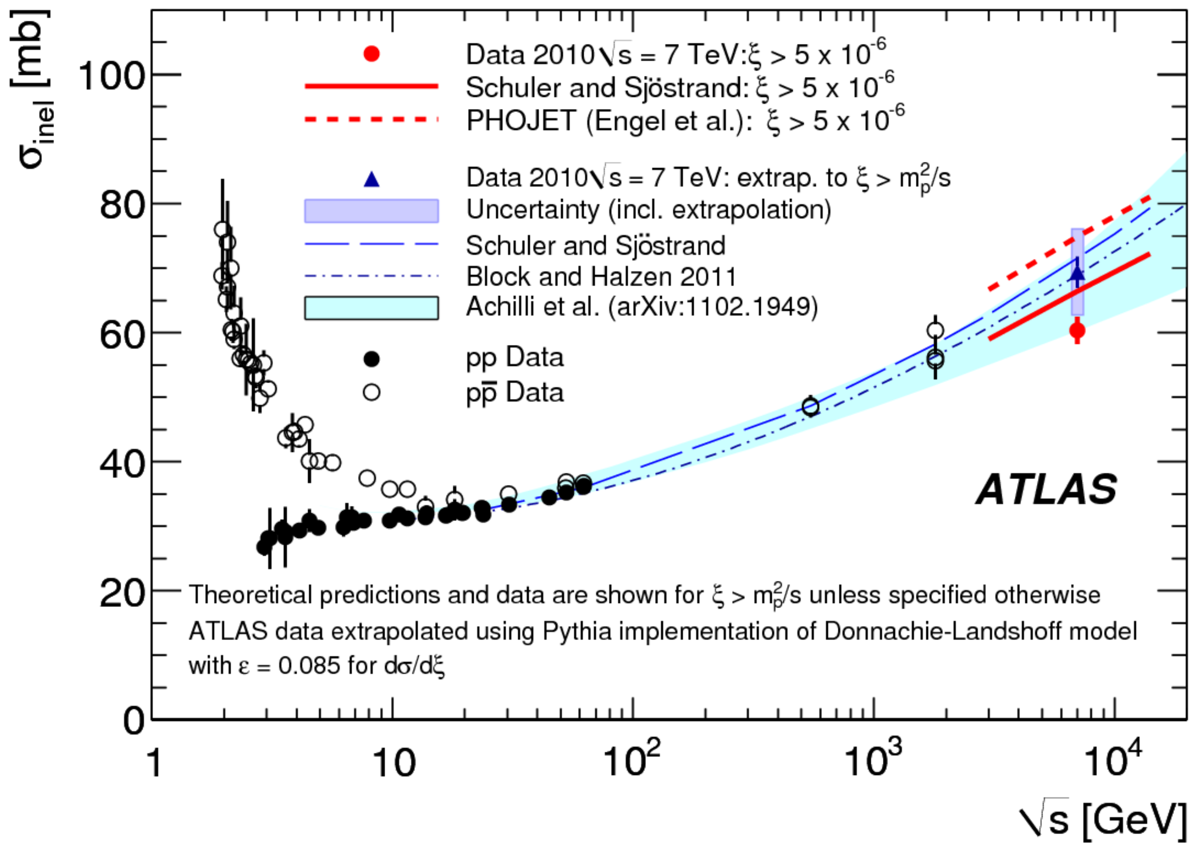



| $\sigma(\xi > m_p^2/s)$ [mb] | |
|---|---|
| ATLAS Data 2010 | $69.4 \pm 2.4(\text{exp.}) \pm 6.9(\text{extr.})$ |
| Schuler and Sjöstrand | 71.5 |
| PHOJET | 77.3 |
| Block and Halzen | 69 |
| Ryskin *et al.* | 65.2 – 67.1 |
| Gotsman *et al.* | 68 |
| Achilli *et al.* | 60 – 75 |

- Good agreement with most of the models

- Data lower than PHOJET

# Comparison: Other Experiments




- Extrapolated value:

$$69.4 \pm 2.4(\mathrm{exp.}) \pm 6.9(\mathrm{extr.})$$

- Fiducial cross-section

$$60.33 \pm 2.10(\mathrm{exp.})$$

  - by factor 3 more precise than extrapolated value

- Presented first measurement of inelastic cross-section
  - Data lower than MC predictions, extrapolated value agrees with models

# The Gap Measurement

- Truth gap definition
  - No stable particle above $p_T$>200 MeV
  - $p_T$ cut to approximate energy threshold in calorimeter that rises with |η|

$$\left[\frac{d\sigma}{d\Delta\eta^F}\right]^i = \frac{\mathcal{M}^{ij}}{\Delta\eta_{ring} \times \int Ldt} \left[\frac{N - N_{BG}}{\epsilon}\right]^j$$

- Background and trigger efficiency from Data
- MBTS selection efficiency from MC
- Account for migration of events (Bayesian unfolding)