Diffraction and rapidity gap measurements with ATLAS

P. Růžička, on behalf of the ATLAS Collaboration

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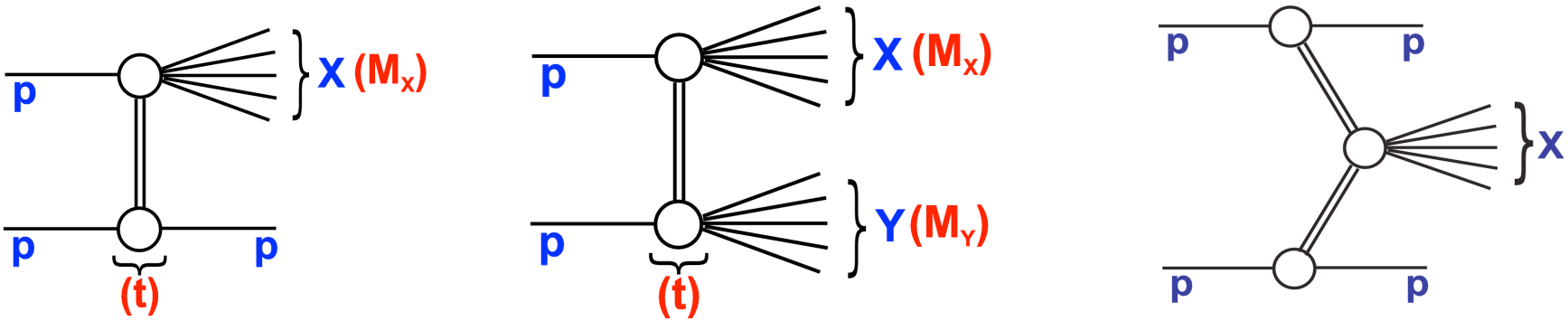
Introduction

- Diffraction = processes containing large rapidity gaps
- Dominated by soft processes => phenomenological description based on Regge theory - exchange of object with quantum numbers of vacua – Pomeron
- Described in variables $\xi = M^2/s$, t
- MC models based on triple pomeron approach parameterised as: $\frac{d\sigma^{SD}}{d\xi dt} \propto \xi^{1-2\alpha_{IP}(t)} e^{bt}$ $\quad \alpha_{IP}(t) = \alpha_{IP}(0) + \alpha_{IP}'(0)t$



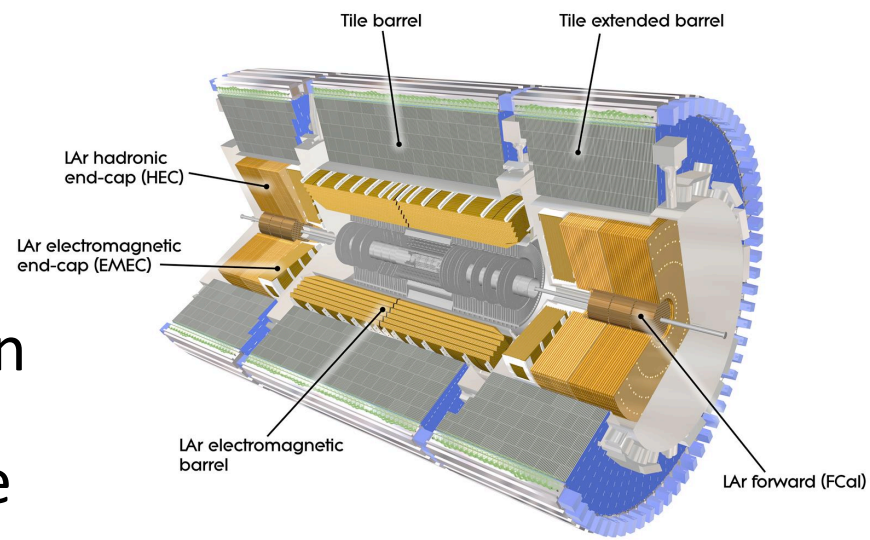
Motivation and goals

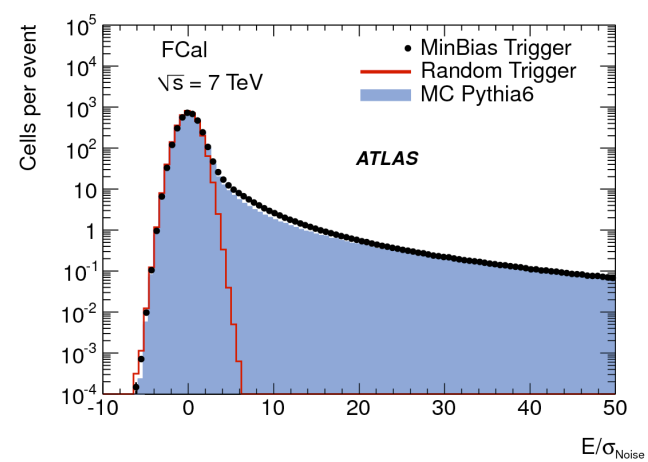
- Direct measurement of $d\sigma/d\xi$ without proton taggers is not possible due to small detector acceptance
- We measured rapidity gaps at first LHC runs with low instantaneous luminosity
- Correlation between gaps and ξ, $\Delta\eta \approx -\ln(\zeta)$, allows to constrain diffractive models
- Measurement of $d\sigma/d\Delta\eta$ corrected to level of stable particles with $p_T > 200, 400, 600, 800$ MeV tests hadronisation and UE models.

ATLAS detector I.

Calorimeter:

- Large coverage |η|<4.9
- **Using calorimeter clusters for gap definition**
- Additional conditions applied on cells to reduce noise (E/sigma >~5.5) => requires well describe noise dist. by MC.
- Using EM, HEC and FCal sub-detectors – cell noise well described by Gaussian distribution
- TileCal was not used due to different cell noise distribution.

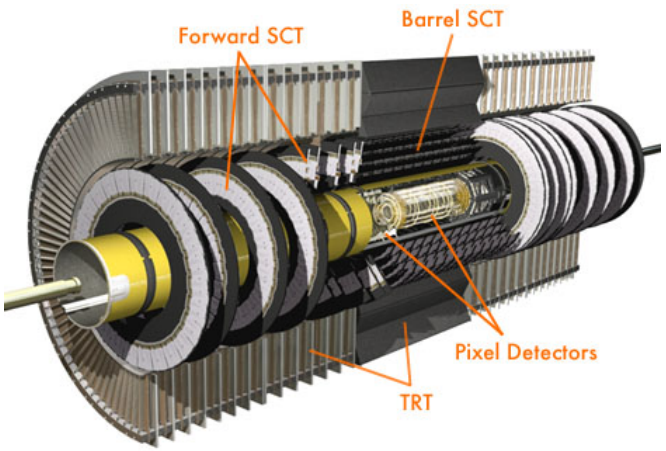




ATLAS detector II.

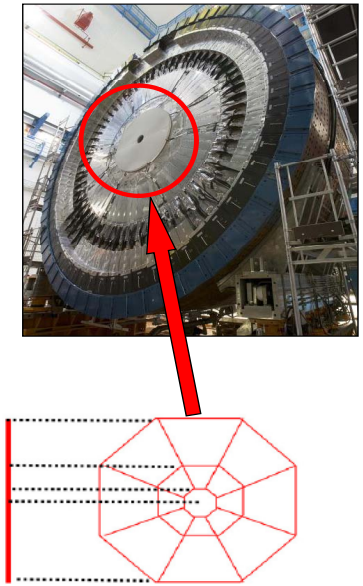
Inner Detector:

- Coverage $|\eta| < 2.5$
- Consists of Pixel Detector, Silicon Strip Tracker and Transition Radiation Tracker.
- **Using tracks for gap definition (in combination with calo. clusters)**

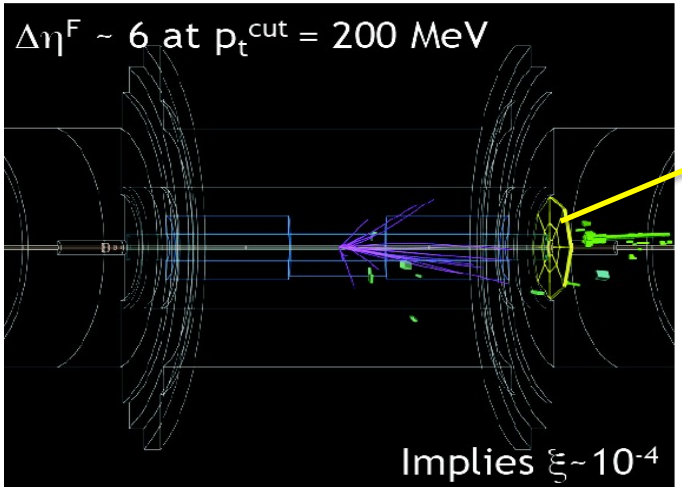


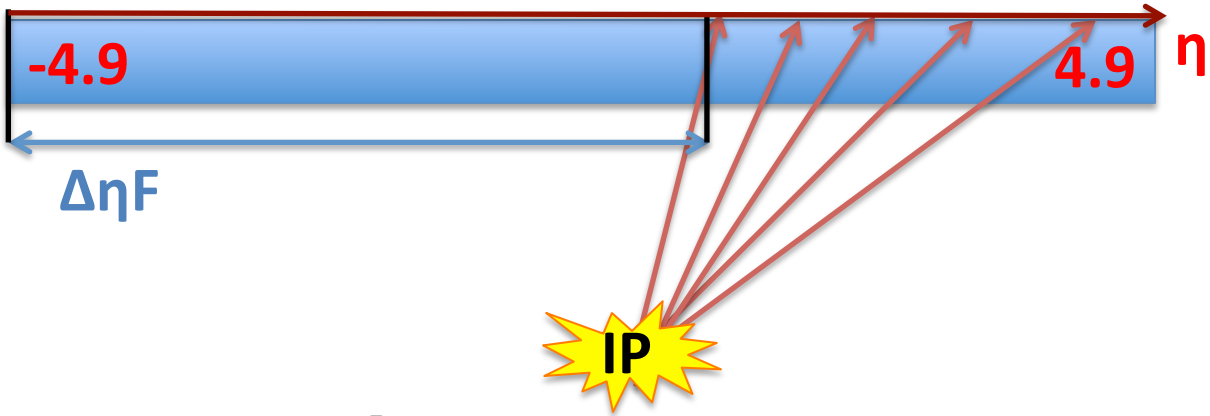
Minimum Bias Trigger Scintillator (MBTS):

- Two discs symmetrically positioned 3 m from IP.
- Coverage $2.1 < |\eta| < 3.8$.
- **Used for event selection:**
  - single online hit
  - two offline hits in order to reduce noise contribution



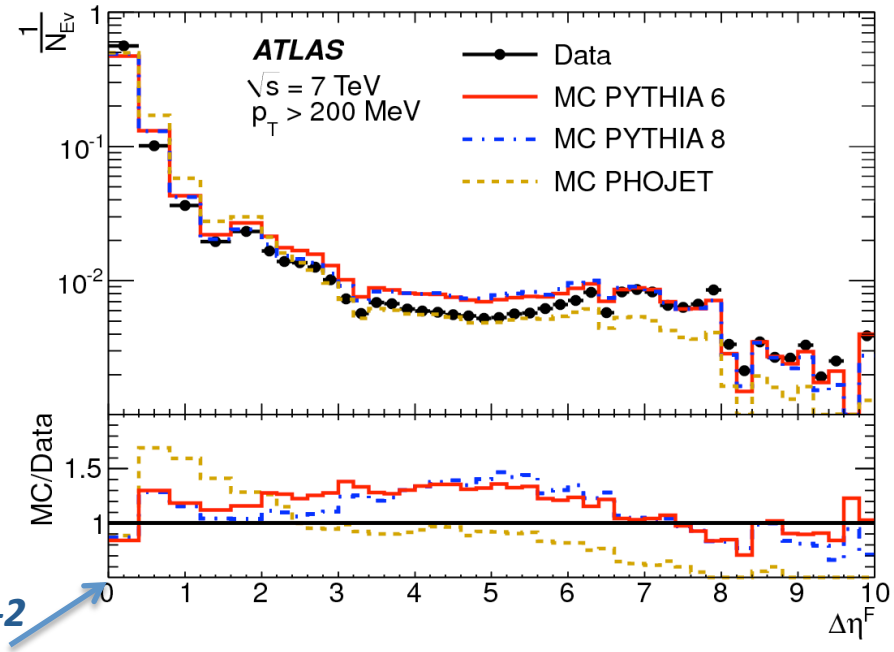
Experimental rapidity gap definition





- **Forward Rapidity Gap $\Delta\eta^F$ =** largest distance from the edge of the detector ($\eta = \pm 4.9$) to first calorimeter cluster or track with p_T > 200, 400, 600, 800 MeV

Measured (uncorrected) rapidity gap distribution

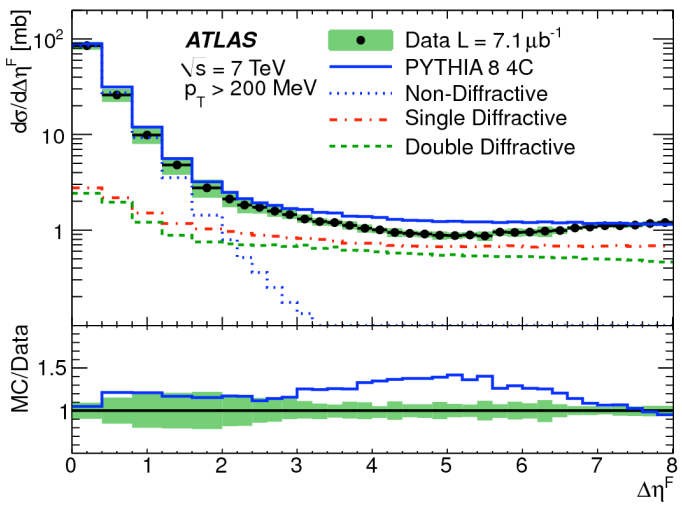


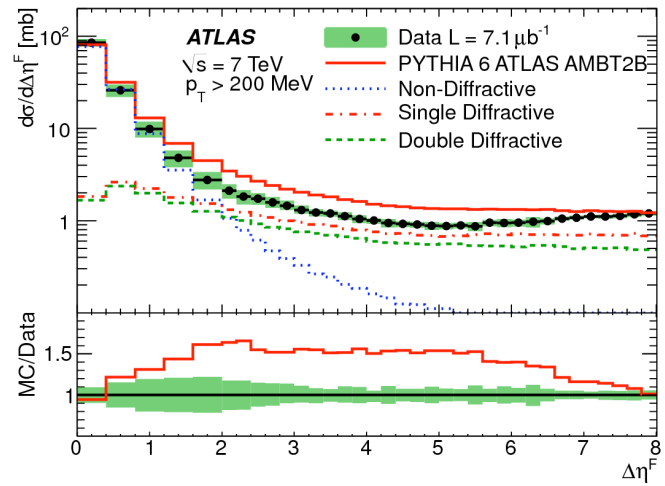
$\xi_X \sim 10^{-2}$

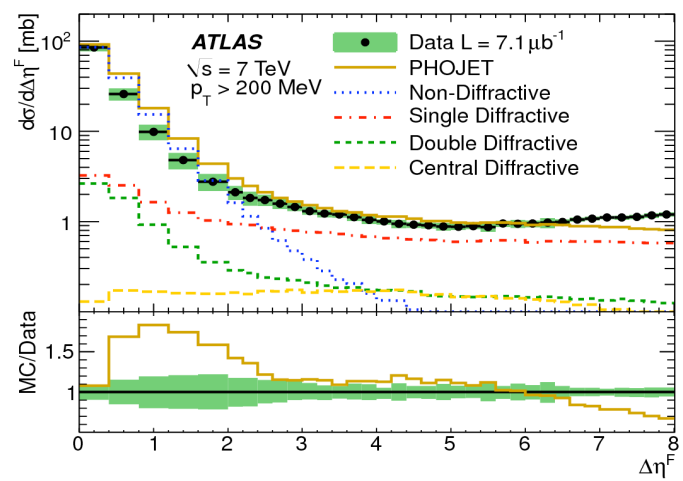
$\xi_X \sim 10^{-6}$

- Exponential fall at small $\Delta\eta^F$ typical for ND events
- Plateau for $\Delta\eta^F > 3$ suggests presence of diffractive events
- Suppression at $\Delta\eta^F > 8$ caused by low trigger efficiency (large corrections from MC) => the results presented for $\Delta\eta^F < 8$

Rapidity gap cross section for p_T>200 MeV

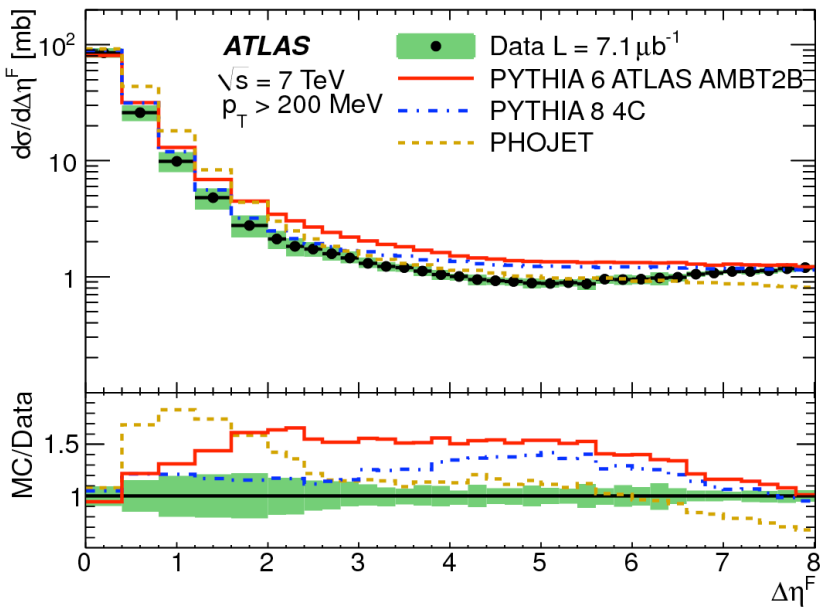


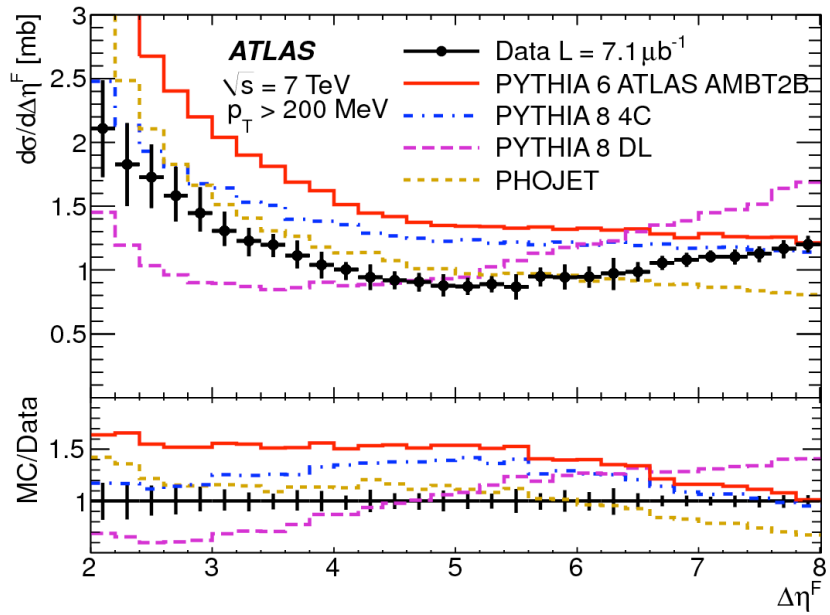




- All MCs predict dominant contribution of ND at $\Delta\eta^F < 3$, with exponential decreasing behaviour due to fluctuations in hadronisation.
- Large gaps created only by SD and DD (with M_Y < 7 GeV)

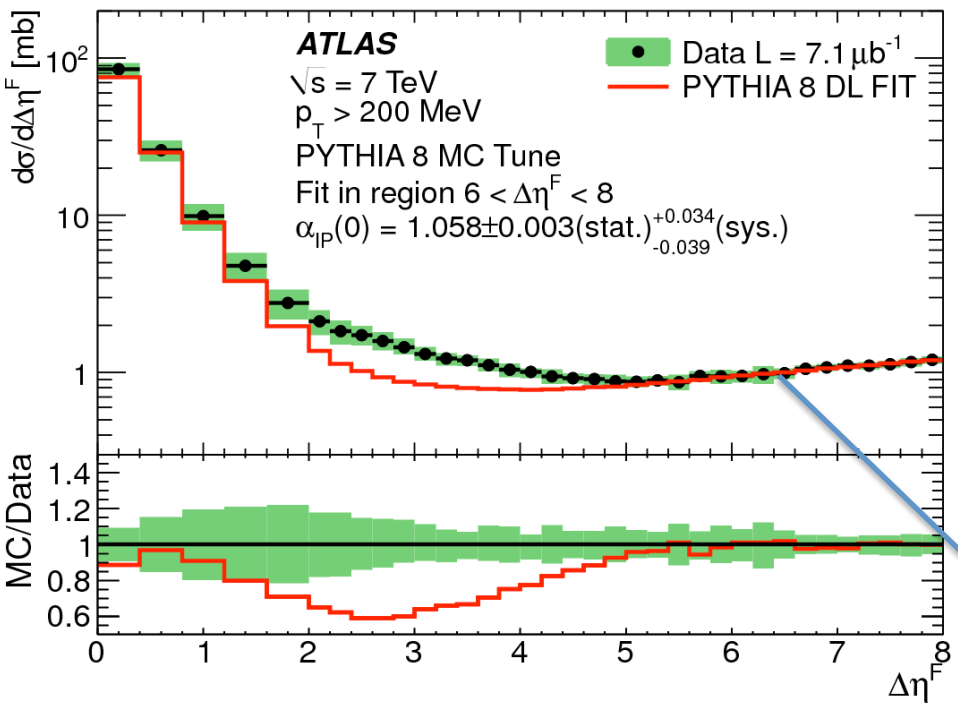
Rapidity gap cross section for p_T>200 MeV





- Overall precision between 8% (large gaps) and 20% ($\Delta\eta_F$ ~ 1.5)
- Different prediction for various MC models
- Pythia8 good description at small gaps
- Phojet overestimates gaps $\Delta\eta^F < 1.5$ but reasonable description of large gaps
- Data exhibit slope in between Pythia8 DL (higher slope) and rest of MCs (smaller slope) at $\Delta\eta_F > 5$

Estimation of pomeron intercept $\alpha_P(0)$ in Donnachie-Landshoff model



- Using DL model implementation in Pythia8 to fit $\alpha_P(0)$ in data

Default DL:

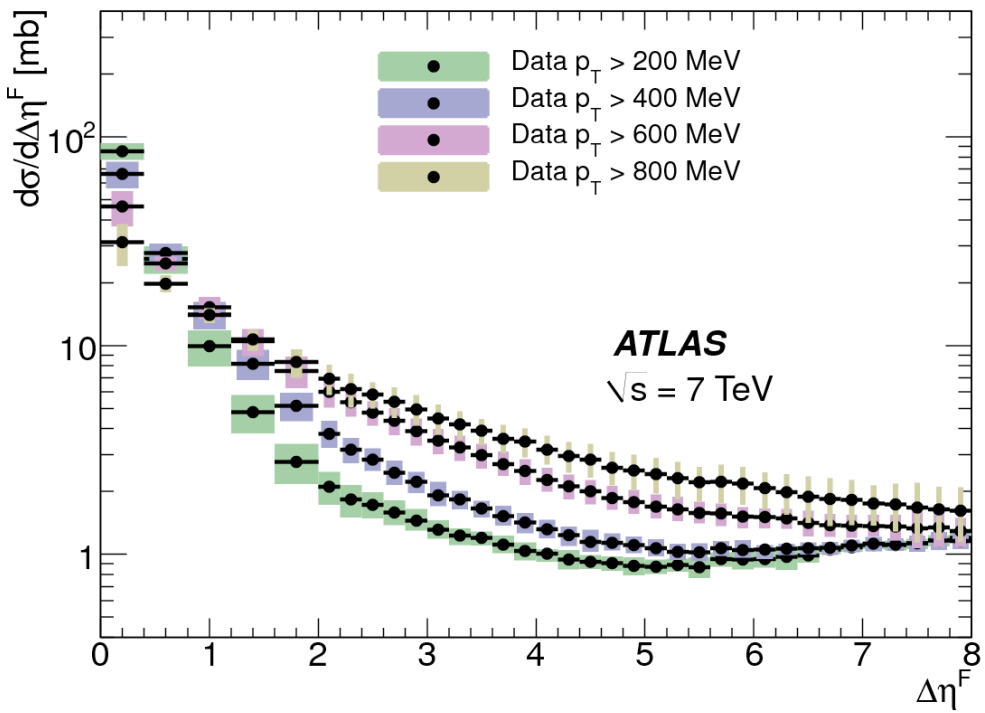
$$\frac{d\sigma^{SD}}{d\xi dt} \propto \xi^{1-2\alpha_{IP}(t)} e^{bt}$$

$$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha_{IP}' t$$
$$\alpha_{IP}(0) = 1.085$$
$$\alpha_{IP}' = 0.25$$

$\alpha_P(0)$ responsible for slope of the distribution at large $\Delta\eta^F$

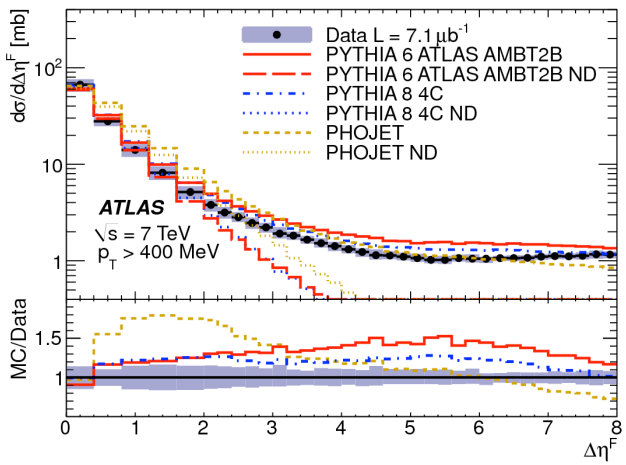
- Fit result $\boldsymbol{\alpha_P(0) = 1.058 \pm 0.003(Stat.) + (0.034 - 0.039)(Syst.)}$
- Result is consistent with the default DL value due to large model uncertainty

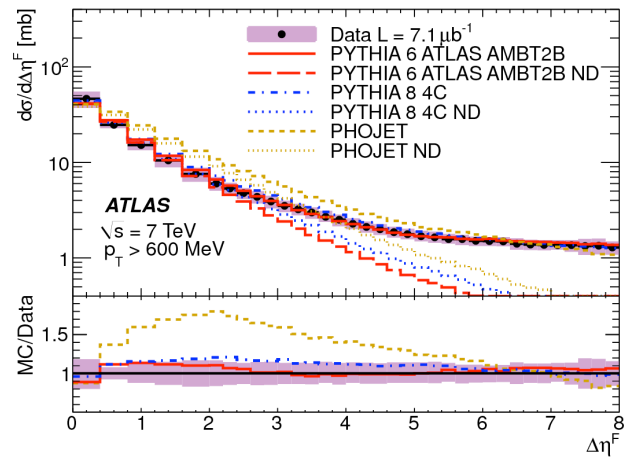
Rapidity gap cross section for p_T>400, 600, 800 MeV

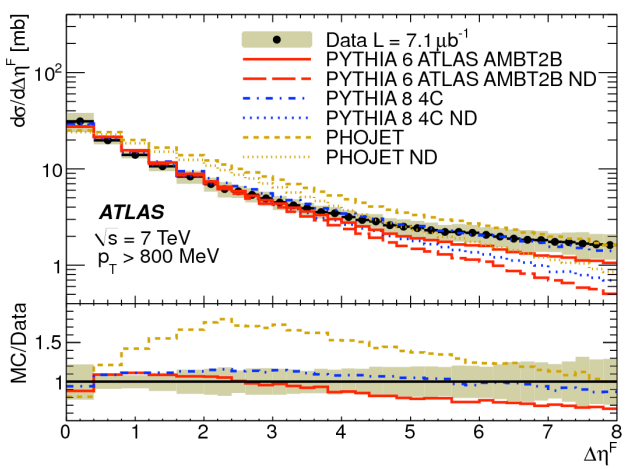


- Increasing p_T cut produces larger rapidity gaps
- Sensitivity to hadronic fluctuation at different p_T thresholds

Rapidity gap cross section for p_T> 400, 600, 800 MeV

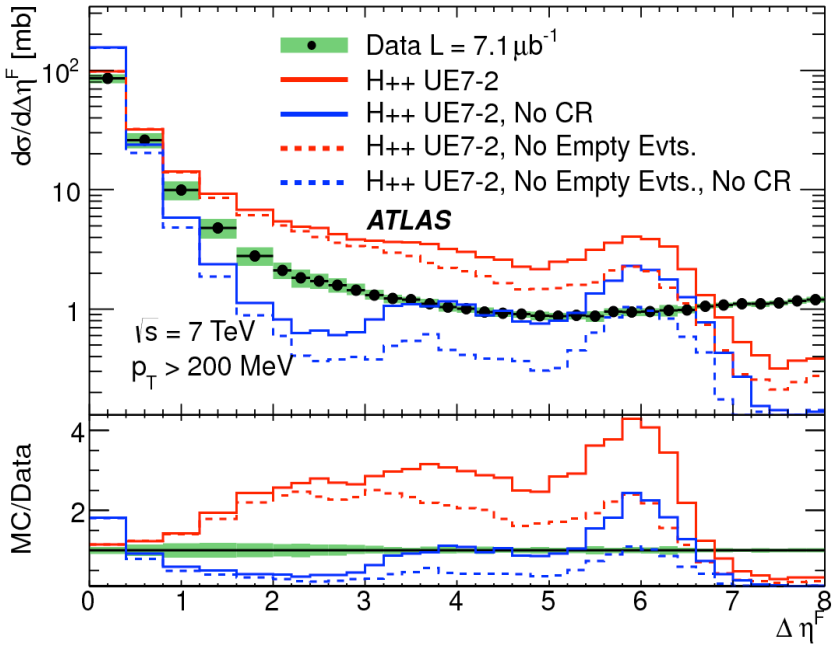


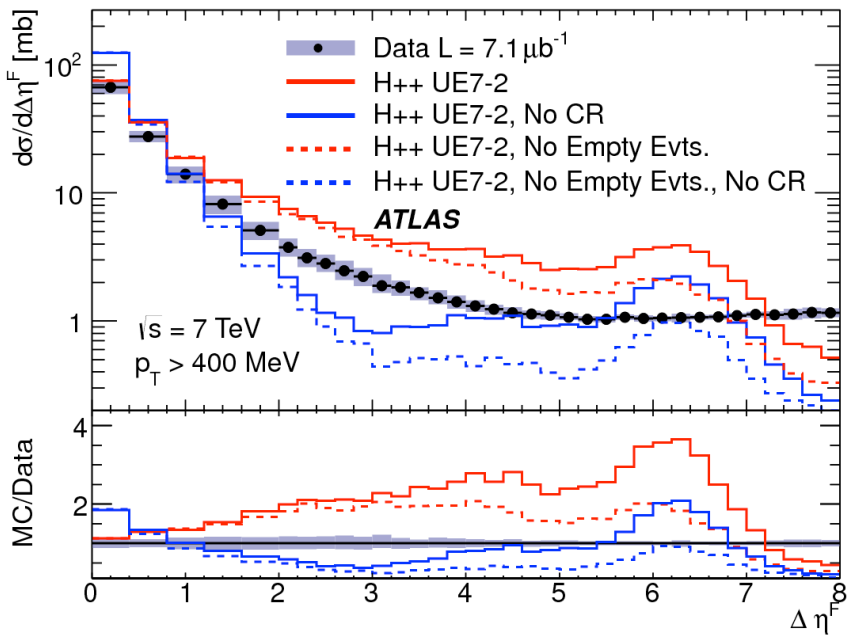




- p_T > 400 MeV keeps similar behaviour as p_T > 200 MeV. ND contribution relevant up to $\Delta\eta^F < 3$
- Particle production for p_T > 600 MeV starts to be rare => ND events produce very large gaps by fluctuations

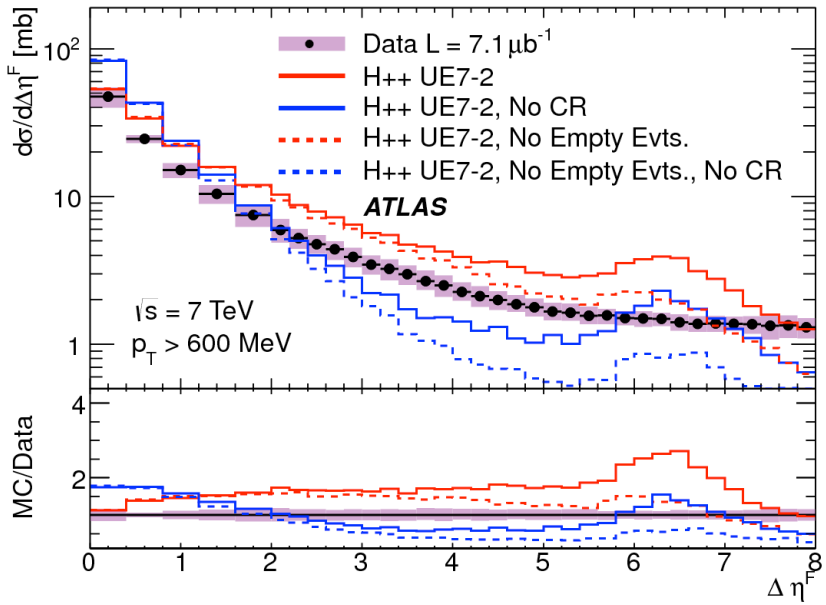
Herwig++ MinBias UE7-2 tune I.

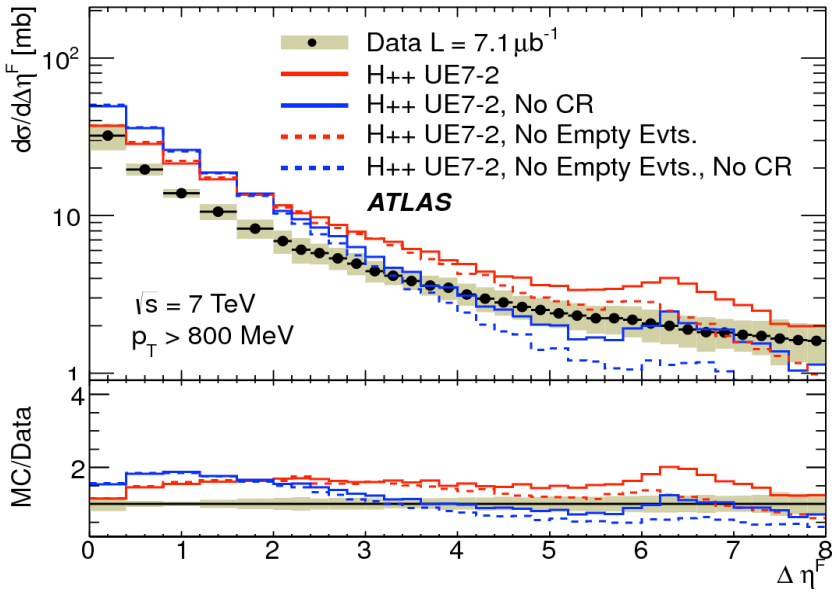




- Testing of H++ MinBias model containing different hadronisation – cluster model
- **H++ MinBias contains only ND model** – production of large rapidity gaps
- Does not follow exponential decrease at large gaps – bump at $\Delta\eta^F \sim 6$
- This feature present with colour reconnection on/off

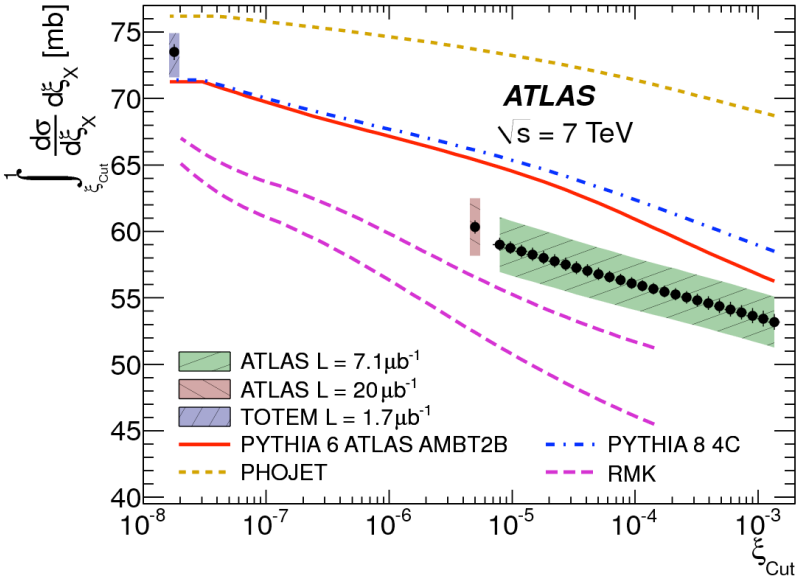
Herwig++ MinBias UE7-2 tune II.





- Similar features occur for higher p_T cuts.

Integrated inelastic cross section



- Integrated cross section $\int_{\xi_{Cut}}^{1} \frac{d\sigma}{d\xi_X} d\xi_X$ is obtained from the MC prediction due to strong correlation $\Delta\eta \approx -\ln(\xi_X)$
- Small correction is applied to include particles with $p_T < 200$ MeV and for hadronisation fluctuations
- Error is dominated by uncertainty on luminosity measurement
- Result is compared with recent TOTEM measurement and previous ATLAS measurement which was done using MBTS trigger
- Models fail to describe evolution from low ξ_X (TOTEM data) to large ξ_X (ATLAS data) – KMR model has better shape description than the others

Conclusions

- ATLAS measured rapidity gap distributions $d\sigma/d\Delta\eta_F$ for different p_T cuts p_T > 200, 400, 600, 800 MeV
- Observed plateau in gap distribution suggests presence of diffractive processes.
- Pomeron intercept in DL model was fitted at large gaps. The result is compatible with default DL value.
- Small gaps are sensitive to fluctuation in hadronisation. Different hadronisation and UE models has been compared with data. Herwig++ produces very large gaps in ND processes.
- Using MC prediction we obtained integrated inelastic cross section as a function of ξ variable. This allows direct comparison of our measurement with different experiments and various models
- For further details see ATLAS Paper: **arXiv:1201.2808**

Backup slides

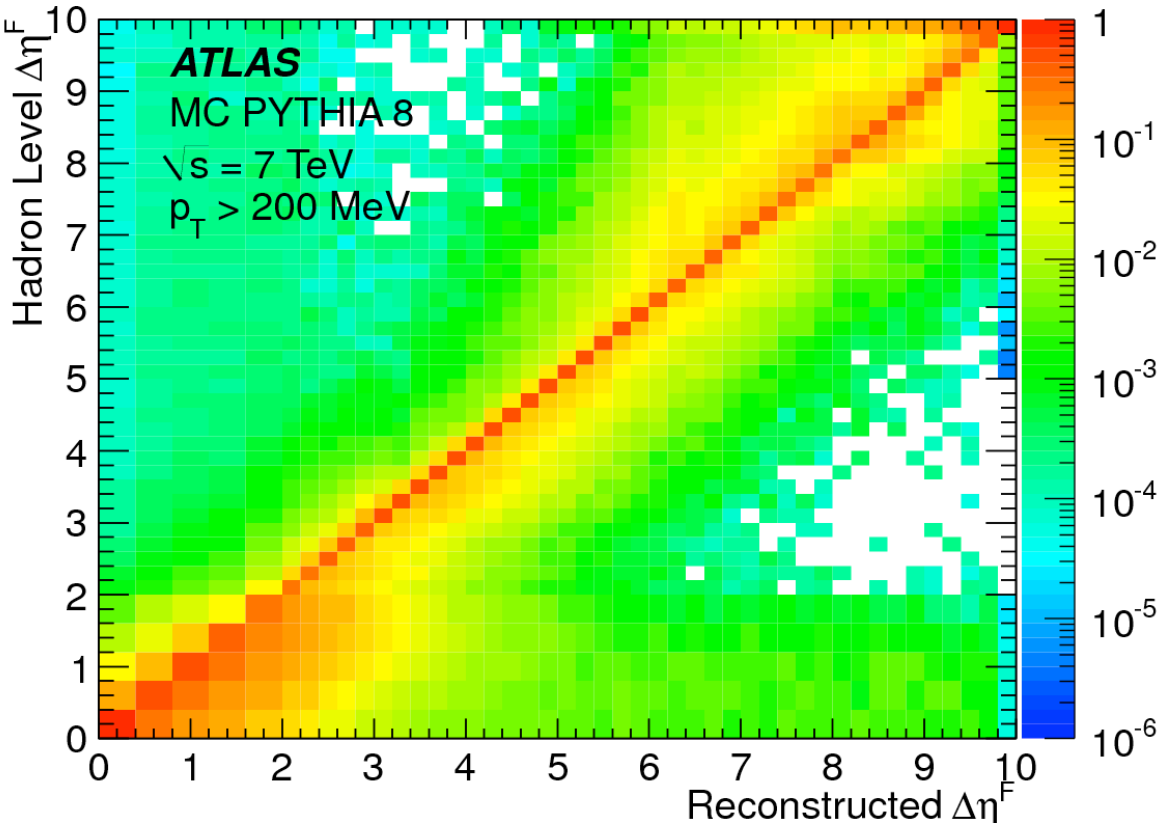
Corrections for experimental effects

- Measured rapidity gap distribution corrected for detector effects to level of stable hadrons

$$\frac{\mathrm{d}\sigma(\Delta\eta^F)}{\mathrm{d}\Delta\eta^F} = \frac{A(\Delta\eta^F)}{\Delta\eta_{\mathrm{ring}}} \; \frac{N(\Delta\eta^F) - N_{\mathrm{BG}}(\Delta\eta^F)}{\varepsilon(\Delta\eta^F) \times \mathcal{L}}$$

- $N(\Delta\eta^F)$ measured distribution
- $N_{BG}(\Delta\eta^F)$ beam induced background
- $\varepsilon(\Delta\eta^F)$ trigger efficiency, estimated from MC
- $A(\Delta\eta^F)$ corrections for detector effects – using Bayesian unfolding
- $\Delta\eta_{ring}$ bin size
- $\mathcal{L}$ luminosity = 7.1 ± 0.2 μb^{-1} (400 kevents)

Corrections for detector effects



- Matrix used in Bayesian unfolding

Systematic uncertainties

- Effect of various systematic uncertainties has been included: **cluster energy scale, MC model uncertainty**, tracking efficiency, luminosity measurement, MBTS trigger eff.
- Overall precision between 8% (large gaps) and 20% ($\Delta\eta_F \sim 1.5$)