Diffraction and rapidity gap measurements with ATLAS

Vlastimil Kůs[*]
On behalf of the ATLAS Collaboration

[*]Institute of Physics
Academy of Sciences of the Czech Republic

Photon-2013, Paris
21st May 2013

Introduction to diffraction

- The total cross section in hadronic scattering experiments at 7TeV

  Total = Elastic + Diffractive + Non-diffractive (ND)

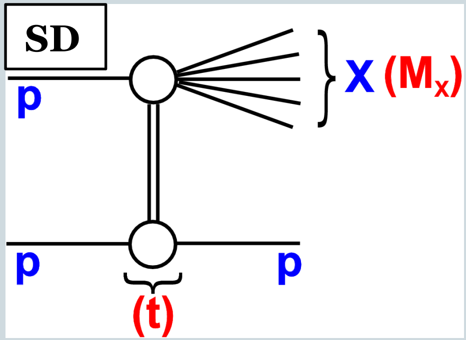
  20% elastic, 80% inelastic (diffractive + ND)

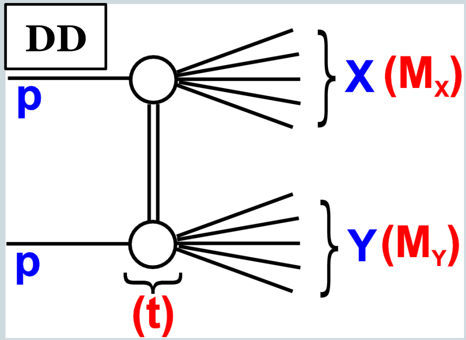
- Diffractive channels together – 25-30% of the σ_{inel}
  - Single-diffraction (SD, pp ->pX)
  - Double-diffraction (DD, pp -> XY)
- Kinematic variables
  - invariant mass of the dissociated system M_X (M_Y)
    - at the LHC energy spans m_p+m_π to ~1TeV
  - fractional momentum loss ξ of the scattered proton

  $$\xi_X = M_X^2 / s \qquad \xi_Y = M_Y^2 / s$$

- Diffraction in the realm of soft QCD

  -> description by phenomenological models (such as Regge theory)





Introduction to diffraction

- **<u>Rapidity gap</u>** = region in η devoid of hadronic activity due to the exchange of colorless object (Pomeron)
- **<u>Forward</u> rapidity gap $\Delta\eta^F$** = gap between scattered proton and closest hadron / detector object
- Non-pileup environment necessary (could fill the gap)
  - events from early runs of 2010
- <u>Regge theory</u> – description of diffractive dissociation
  - Pomeron exchange - dominant at small ξ_X
  - SD cross-section can be expressed as a triple Pomeron amplitude

    $d\sigma/dt d\xi \sim \xi^{\alpha(0)-2\alpha(t)}$ $\alpha_{IP}(t) = \alpha_{IP}(0)+\alpha_{IP}' t$ ... Pomeron trajectory

  - if Pomeron intercept $\alpha_{IP}(0)$ close to 1 and $|t|$ small => $d\sigma/d\ln\xi \approx$ const.

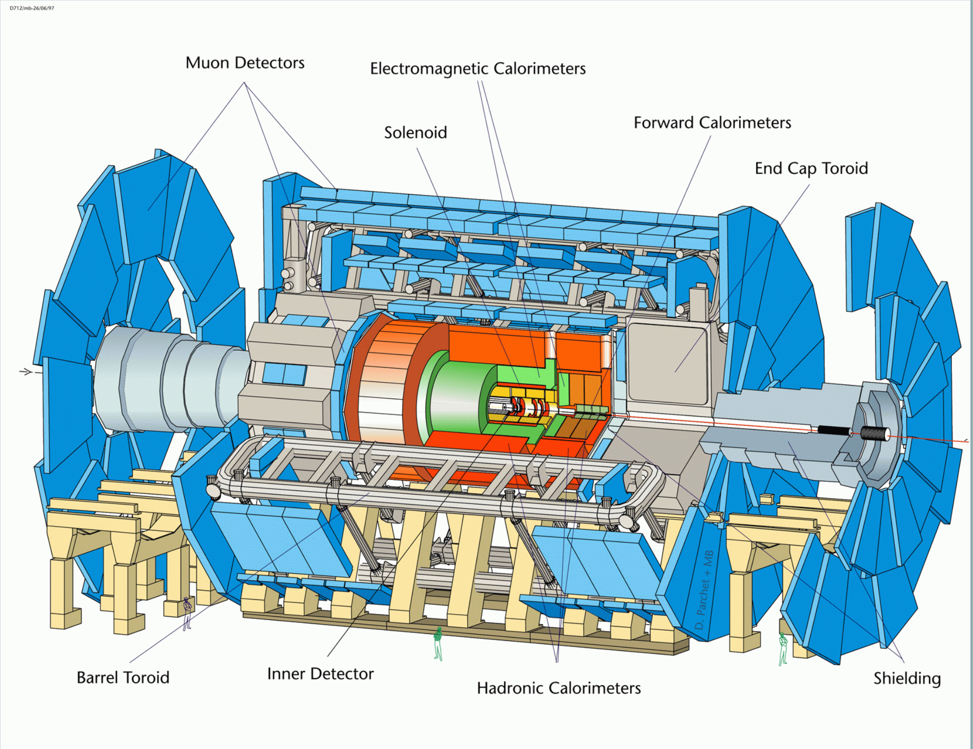
    -> <u>diffractive plateau</u>

ATLAS detector

Inner detector (ID) tracking: $|\eta|<2.5$

Calorimeters (EM+HAD): $|\eta|<4.9$

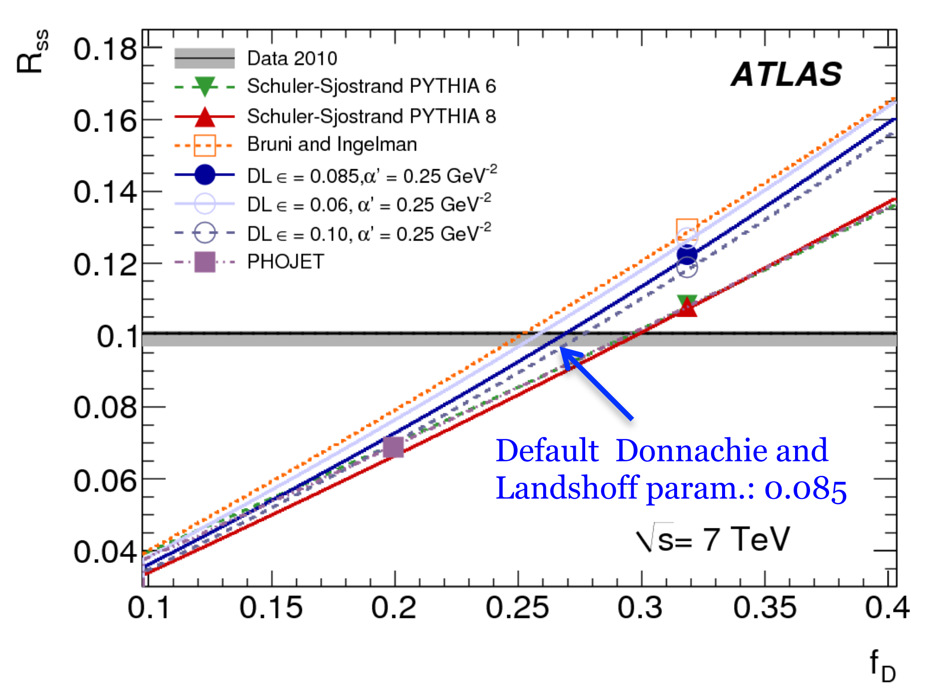
Minimum bias scintillators (MBTS):
$2.09<|\eta|<3.84$



Forward detectors:
- LUCID (Luminosity measurement): $5.6<|\eta|<6$
- ZDC (Zero Degree Calorimeter): $|\eta|>8.3$
- ALFA (Roman pots): $10.6<|\eta|<13.5$

- AFP (ATLAS Forward Proton)
  - in the approval process
  - designed for detection of diffractive protons scattered at small angles

Fraction of diffractive events in σ_{inel}



<u>Diffractive contribution to total σ:</u>

Events with hits in MBTS on <u>one side only</u> (85-98% of which is diffraction - depending on model) vs. <u>inclusive events</u>.

Ratio of single-sided events to inclusive event sample:

$$R_{SS} = N_{SS}/N_{any}$$

Fractional diffractive contribution to σ_{inel}:

$$f_D = (\sigma_{DD}+\sigma_{SD}) / (\sigma_{DD}+\sigma_{SD}+\sigma_{ND})$$

$R_{SS} = 10.02 \pm 0.03(\text{stat.})^{+0.1}_{-0.4}(\text{syst.})\%$ => $f_D = 26.9^{+2.5}_{-1.0}\%$ using default DL model

"Measurement of the Inelastic Proton-Proton Cross Section at √s = 7 TeV with the ATLAS Detector", **Nature Commun. 2 (2011) 463**

Rapidity gap cross sections measured with the ATLAS detector in *pp* collisions at $\sqrt{s}$ = 7 TeV

January 2012

Eur.Phys.J. C72 (2012) 1926

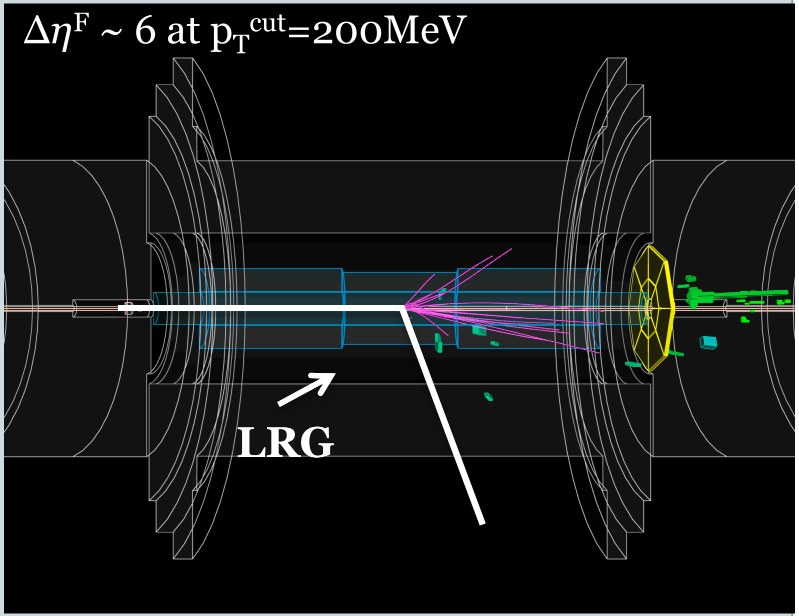
CERN-PH-EP-2011-220

e-Print: arXiv:1201.2808

Rapidity gaps in ATLAS detector

- No SD proton tagging -> ALFA, AFP (future upgrade)
- **Large Rapidity Gaps (LRG)** … $\Delta\eta^F \sim -\log_{10}\xi_X$

  Biggest region in η from edge of the detector ($\eta=\pm4.9$) absent of clusters and tracks complying selection:
  - no tracks with $p_T > p_T^{cut}$ ($200 < p_T^{cut} < 800$ MeV)
  - no clusters of cells with $E_T^{cluster} > E_T^{cut}$
  - most significant cell in the cluster: $E_{cell}/\sigma_{noise} > S_{threshold}$



- ATLAS detector acceptance

  $10^{-6} < \xi_X < 10^{-2}$ ⇔ $7 < M_X < 700$ GeV

  Limited possibility of M_X measurement ($|\eta_{calorimeters}|<4.9$)

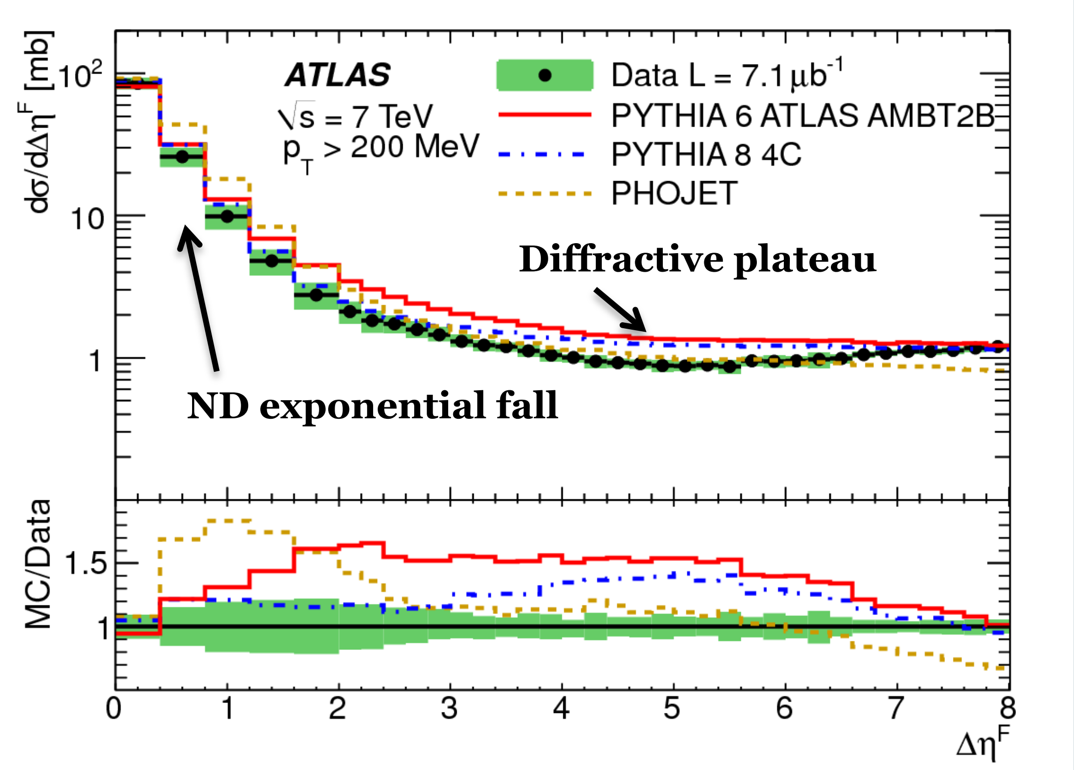
  -> measuring σ_{inel} vs. LRG size
- Using Minimum Bias Trigger Scintilator (MBTS)

  Measurement limited to the region where MBTS is at least 80% efficient.

  Data corrected for the inefficiency.
- Data fully corrected for detector effects to hadron level

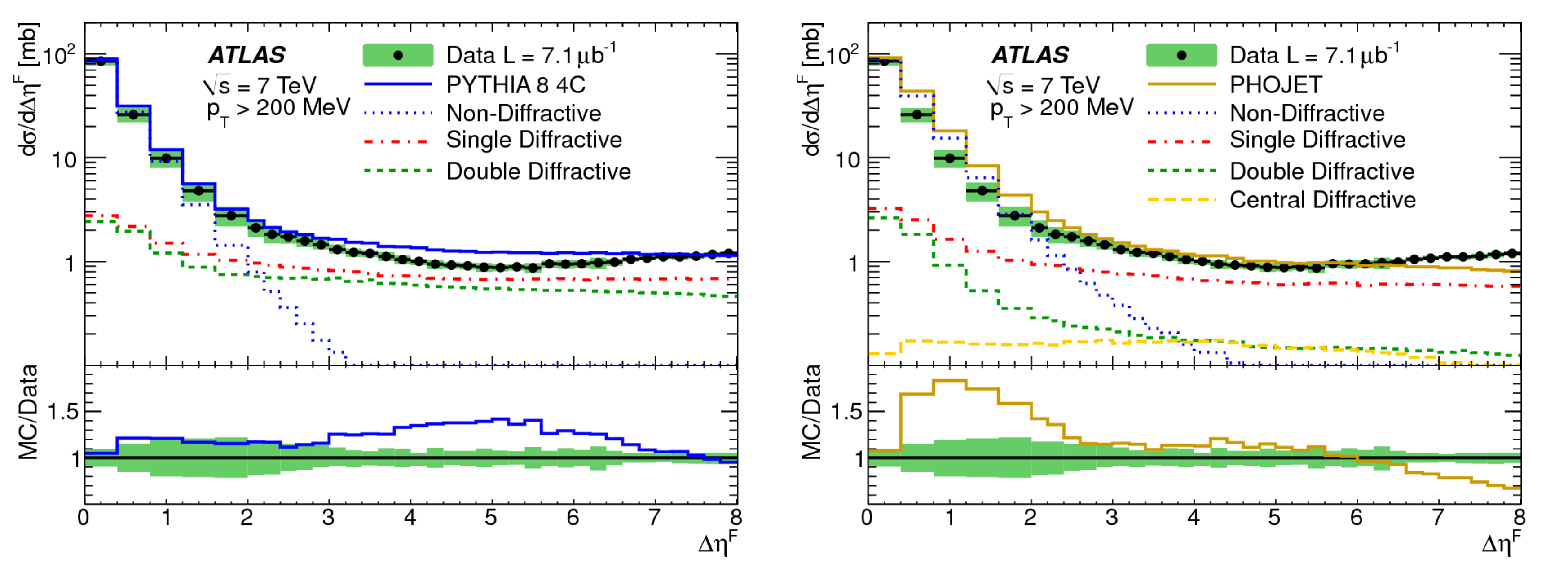
  Bayesian unfolding technique

Inelastic cross section vs. $\Delta\eta^F$



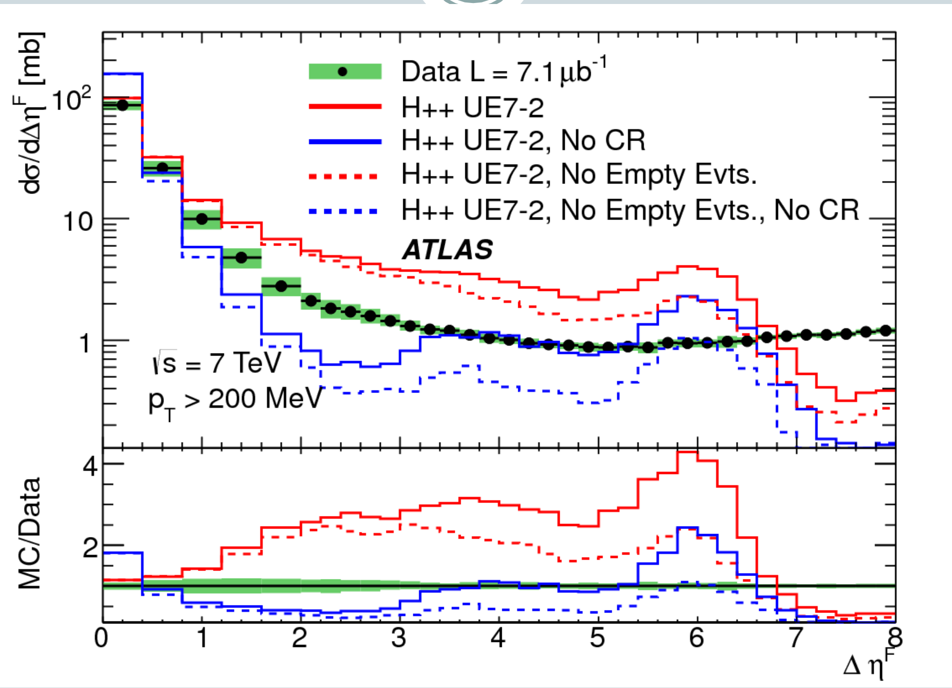
- Systematic uncertainties: ~8% at large gaps, ~20% at $\Delta\eta^F$~1.5
- Small gaps dominated by hadronization fluctuations of ND events
- Large gaps defined by SD+DD

Monte Carlo description differences



- Significant differences in models (both ND and diffractive components)
- PYTHIA 8 describes the data best at small gaps
- PHOJET better at large gaps but fails at low end of the spectrum
- Differences in MC => considerable uncertainties in obtaining large hadronization fluctuations

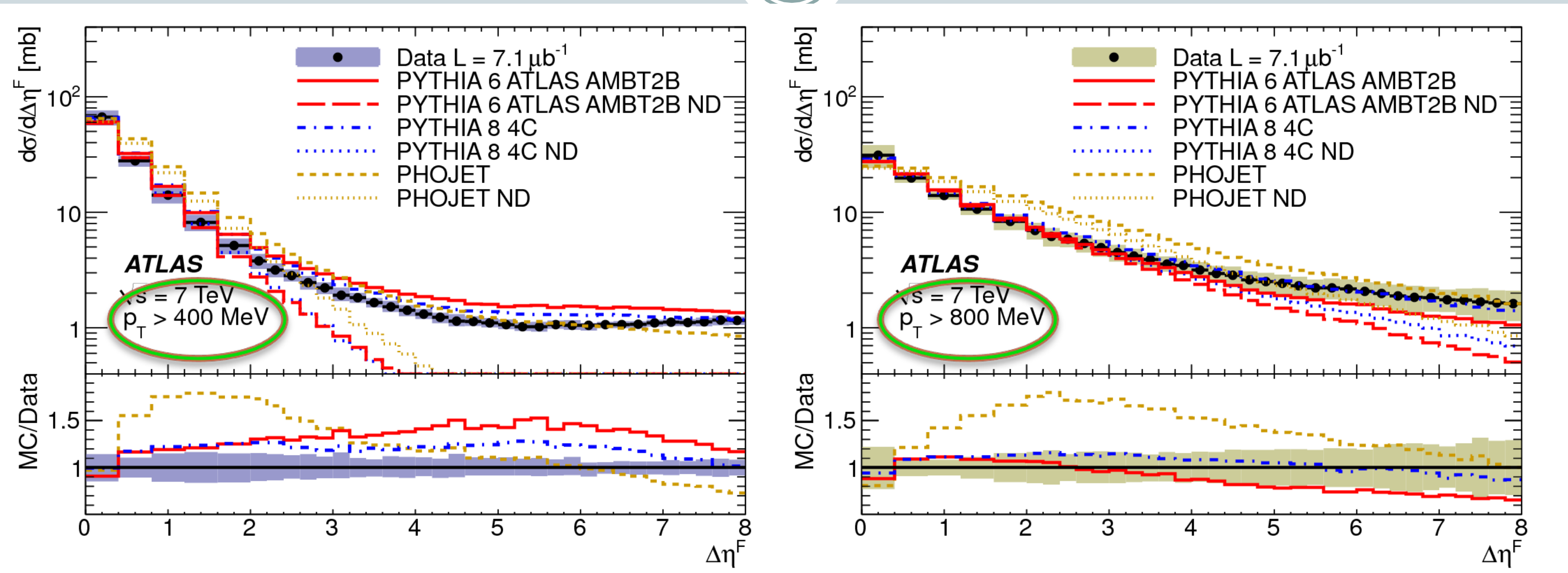
ND Herwig++ model



Herwig++ fails in gap distribution description!

- Herwig++ **doesn't** contain diffractive model, yet very large gaps exceeding those in data
- At $\Delta\eta^F$~6 unexplained bump in cross section
- These effects - neither by Color Reconnection (CR) nor by presence of soft scatters (UE generation in Herwig++), although distributions <u>sensitive</u> to these effects
- Gap spectra - a good way to test cluster-based approach to hadronization

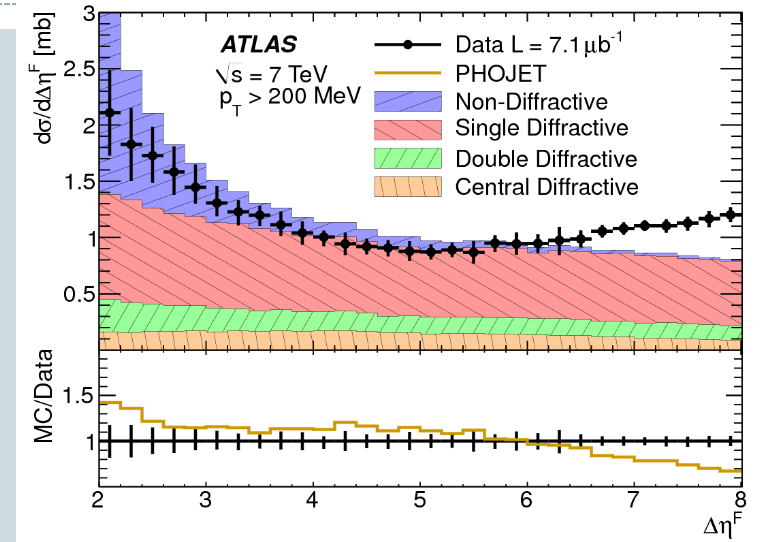
Gap definition change by p_T^{cut}

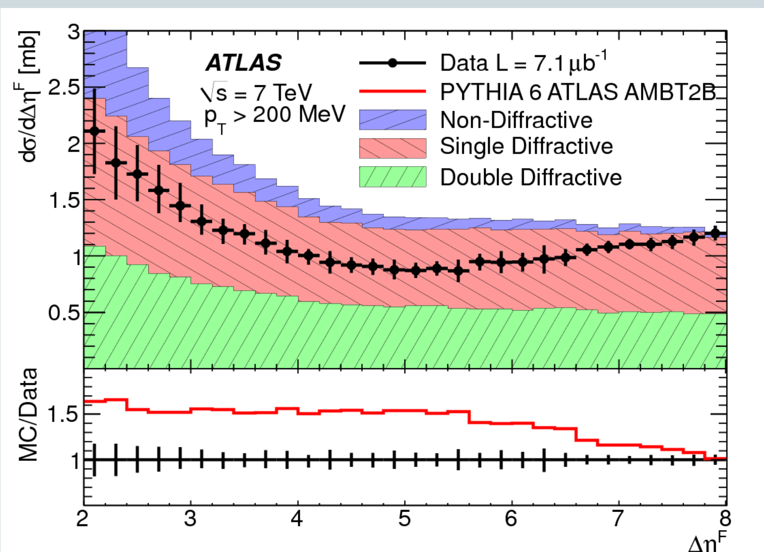


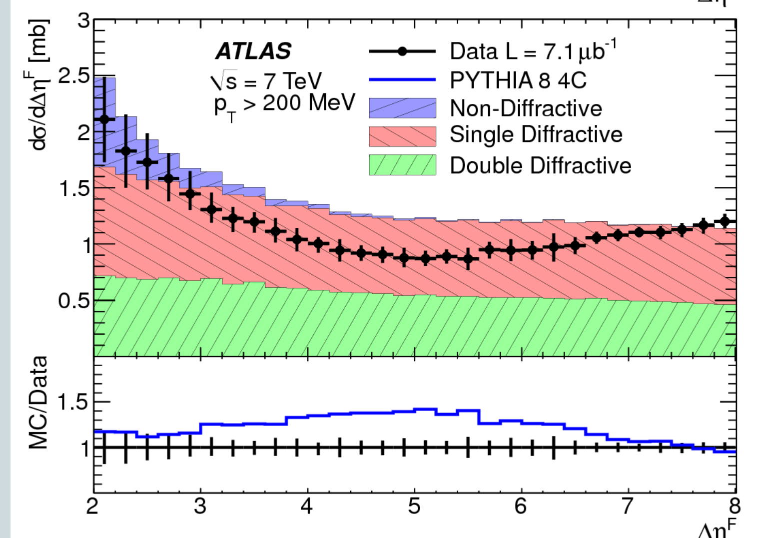
- p_T^{cut} = minimal p_T of detector objects / particles considered by gap algorithm
- Larger gaps in data as p_T^{cut} increases
- σ_{inel} dependence on p_T^{cut} provides a detailed probe of fluctuations in hadronization process
- Diffractive / non-diffractive processes barely distinguished at 800MeV
- Measurement inspired by *arXiv: 1005.4839v2 [hep-ph] 2 Aug 2010*

Inelastic cross section at large gaps
($\Delta\eta_F$>2)

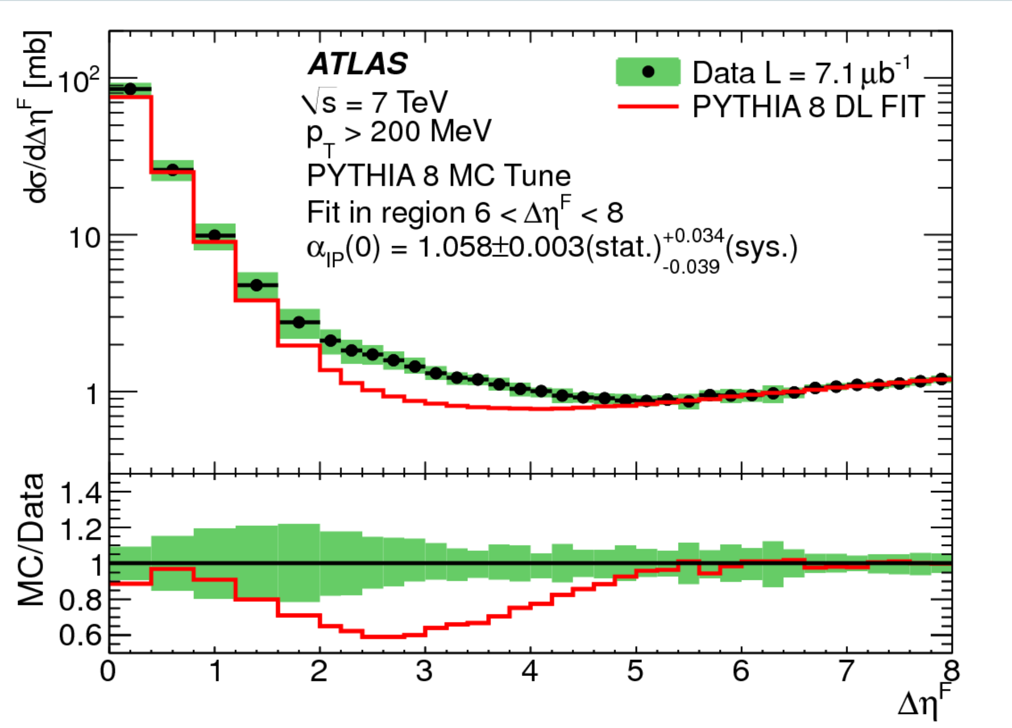
- Data: diffractive plateau ~ 1 mb per unit of gap size for $\Delta\eta_F$>3
- PHOJET describes data the best on plateau except very large gaps
- PYTHIA generally too high (DD considerably higher than in PHOJET)







Diffractive dynamics of large gaps



Regge theory – SD cross section from triple Pomeron amplitude:

$$d\sigma/dtd\xi \sim \xi^{\alpha(0)-2\alpha(t)}$$

where $\alpha_{IP}(t) = \alpha_{IP}(0)+\alpha_{IP}'t$ is the Pomeron trajectory

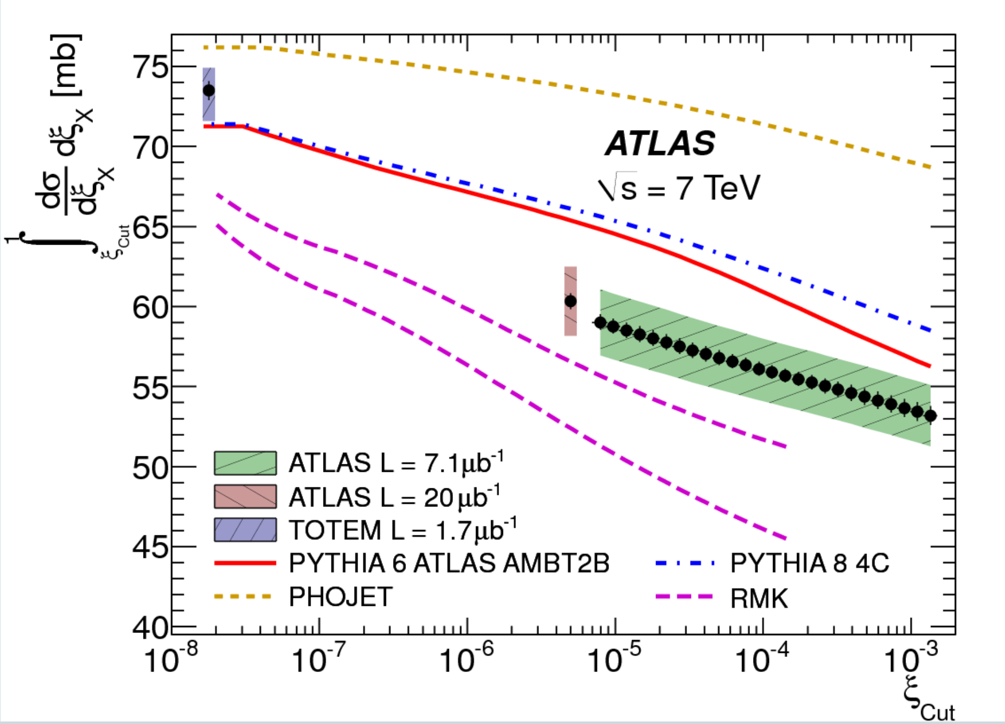
- default PYTHIA 8 has Pomeron intercept $\alpha_{IP}(0) = 1.0$
- PYTHIA 8 with Donnachie-Landshoff Pomeron flux (DL)

$\alpha_{IP}(0) = 1.058 \pm 0.003(\text{stat.})^{+0.034}_{-0.039}(\text{syst.})$ (from fits to data in $6<\Delta\eta^F<8$)

-> describes the rise of σ_{inel} at very large gaps

Integrated cross section for $\xi>\xi_{cut}$

- Inelastic cross section integrated from ξ_{cut} to 1 as a function of ξ_{cut}
  ⇔ integral from 0 to $\Delta\eta_F^{max}$
- ATLAS and TOTEM data compared to MC models
- RMK model (Ryskin, Martin, Khoze)
  - Additional model, two versions differing in radii attributed to the elastically scattered eigenstates



- Indication that small $\xi_X=M_X^2/s$ region underestimated in PYTHIA and PHOJET
  - 14.5 mb for $\xi_X< 8\text{x}10^{-6}$ compared to 6mb (3mb) predicted by PYTHIA (PHOJET)
  - RMK model gets it about right
- RMK model lies below the data in general, however the low ξ_X enhancement compatible with the one observed

Summary

- Diffractive fraction to σ_{inel} using default DL model is $f_D = 26.9^{+2.5}_{-1.0}$ %
- Soft diffractive events measured at the ATLAS experiment via rapidity gaps identification

  $d\sigma/d\Delta\eta^F$ in the range of size $0<\Delta\eta^F<8$ ($\Leftrightarrow \xi_X>5\text{x}10^{-5}$)
- Small non-zero gaps sensitive to hadronization / underlying event
  - none of the Monte Carlos describes $\Delta\eta^F$ or p_T^{cut} dependence in detail
- Large gaps probe the diffractive dynamics
- Diffractive plateau ($\Delta\eta^F>3$) amounts to ~1 mb per unit of gap size
  - roughly described by PYTHIA and PHOJET models
  - the rise of $d\sigma/d\Delta\eta^F$ at largest gaps interpreted within the triple Pomeron-based approach of PYTHIA8 with DL Pomeron flux
- Comparison with TOTEM puts a constraint on low mass diffraction
  - contribution to σ_{inel} from region $\xi_X<10^{-5}$ is ~20% -> considerably larger than most models predict
- Further investigation into the dynamics of diffractive interactions at the LHC is under way