Inelastic cross-section in ATLAS

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First measurement of pp inelastic cross-section

ATLAS Paper: Nature Comm. 2 (2011) 463

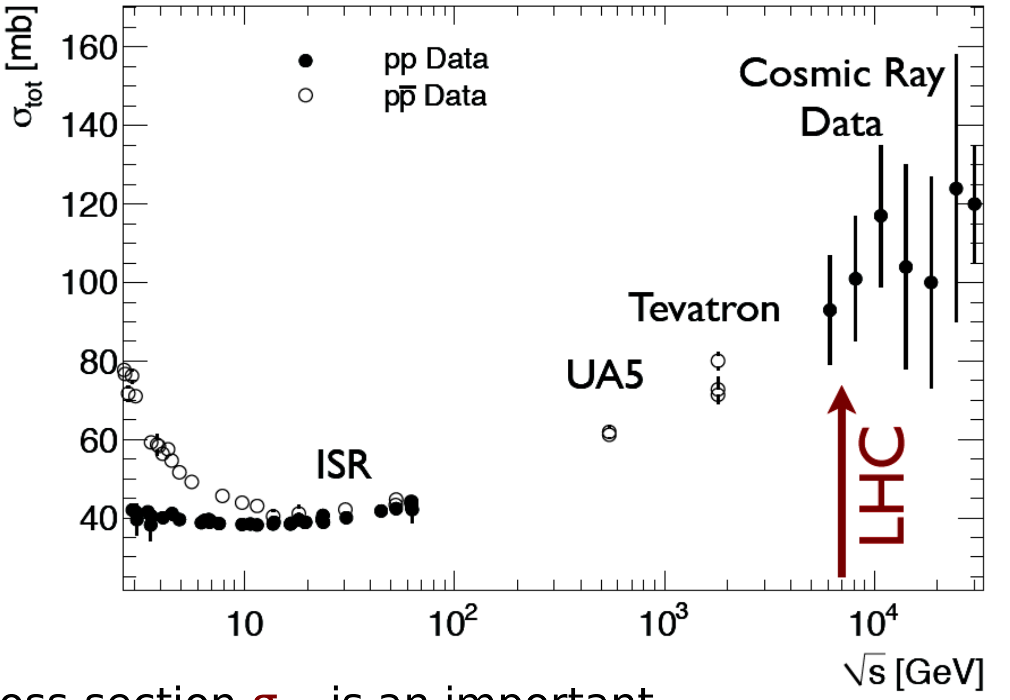
Measurement of pseudo-rapidity gaps in pp collisions at $\sqrt{s}$=7TeV

ATLAS Paper: Eur. Phys. J. C72 (2012) 1926

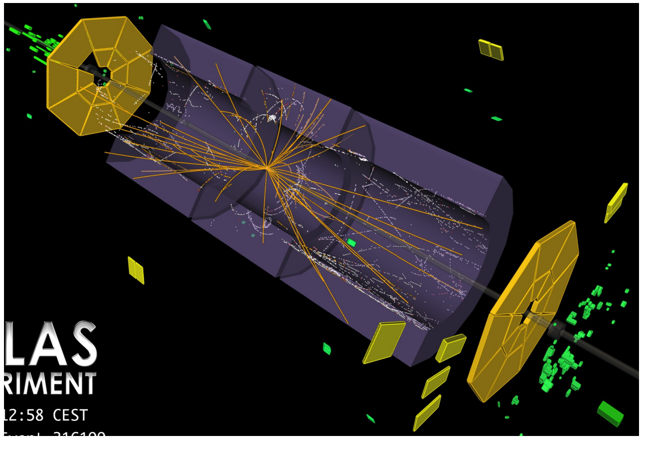
Early 7TeV data in 2010, 20 μb^{-1}, negligible multiple pp interactions

Proton-proton cross-section

- Total cross-section at 7 TeV
  - 20% elastic, 80% of inelastic
  - Diffractive fraction: σ_D/σ_{inel}~0.2-0.3
- Large extrapolation uncertainties, due to 2.7σ discrepancy between CDF and E811

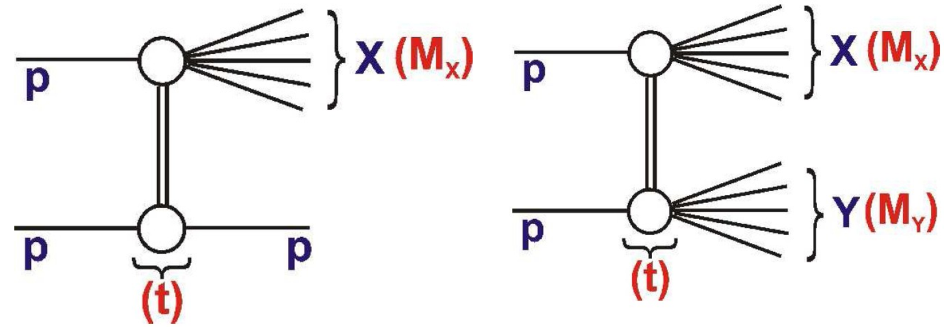


- **Well-defined** measurement of inelastic cross-section σ_{inel} is an important complement to measurements based on optical theorem and cosmic ray measurements
- Measurement using Minimum Bias Trigger Scintillator (MBTS)
  - Acceptance 2.09<|η|<3.84
  - Essentially a counting experiment



Acceptance of MBTS

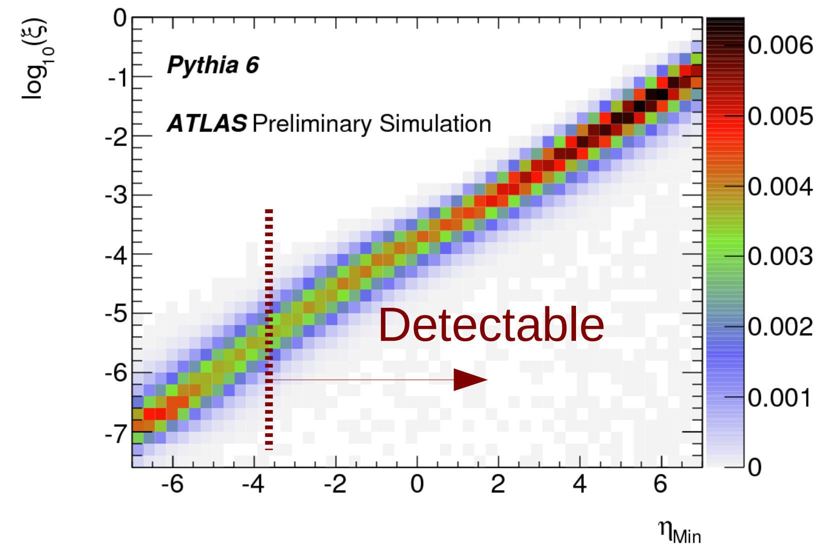
- Close to 100% detection efficiency for non-diffractive events
- Diffraction – due to color singlet exchange => **rapidity gaps**
- Detection efficiency depends on kinematics



- Mass of dissociated system: $\xi = M_X^2/s$
- Largest central gap used to separate M_X, M_Y on particle level
- ξ translates to (pseudo)rapidity gap size inside detector, therefore **detector acceptance**

$$\eta_{min} \propto \log 1/\xi$$

- Fiducial region of the measurement $\xi > 5\times10^{-6}$
  - MBTS acceptance > 50%



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

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

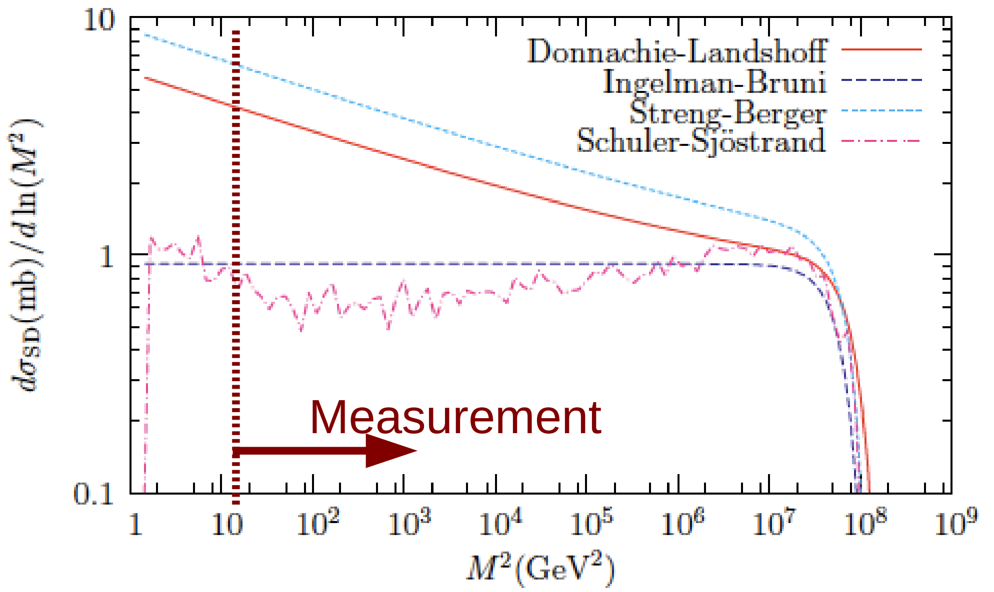
- Luminosity from Beam Scan Calibration
- Correction factors taken from MC, detector response tuned to data

- Dataset: 1.2 M Events (2nd day of 7 TeV LHC stable beams, 2010)

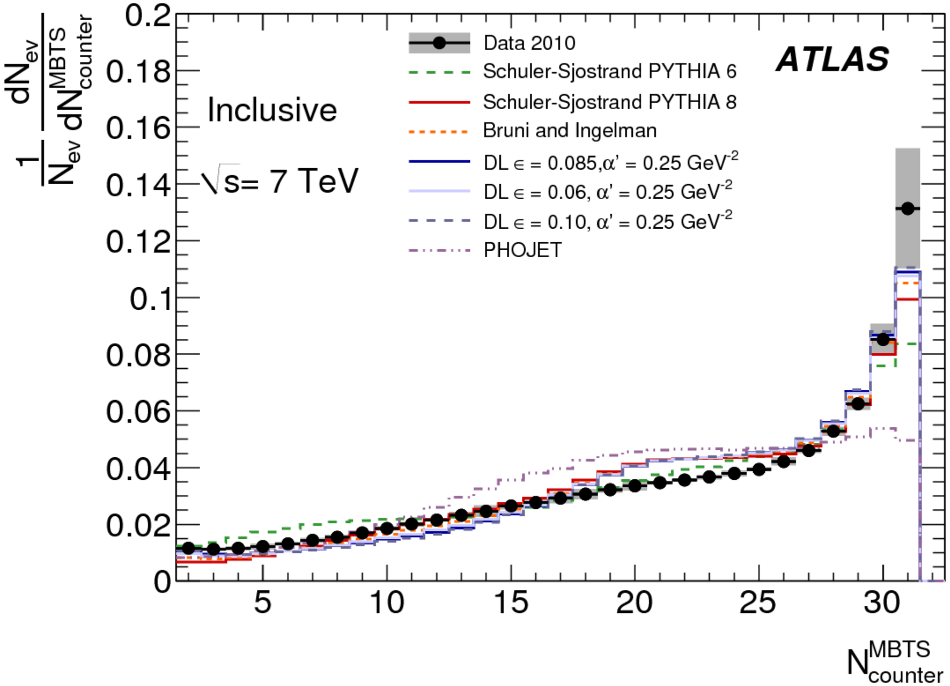
Monte Carlo models

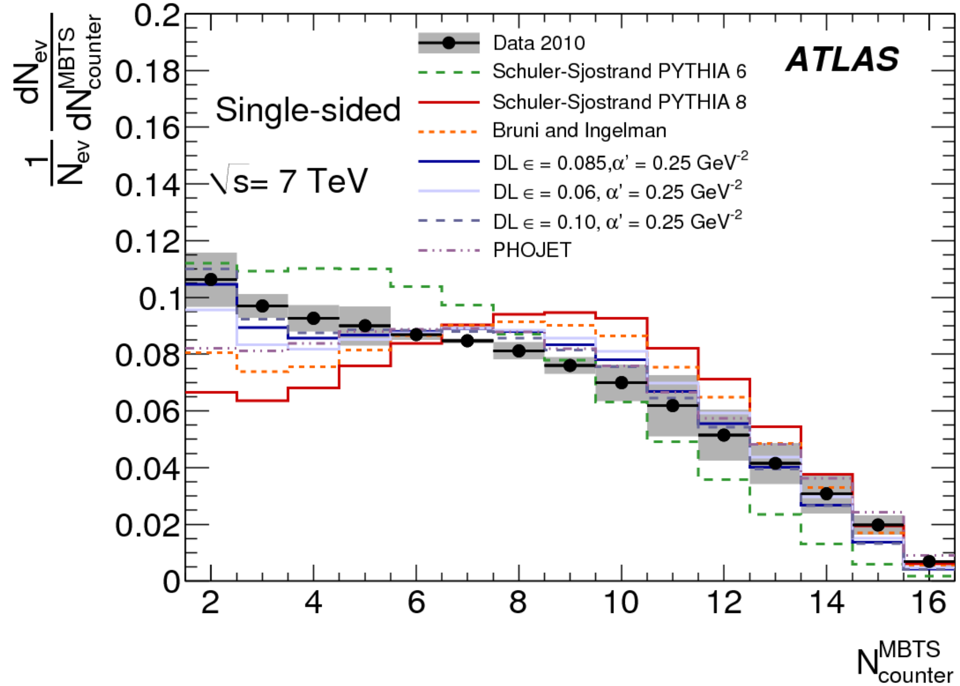
- ε_{sel} and $f(\xi<10^{-6})$ depend on M_X distribution near the acceptance cut
- Variety of models to asses the M_X distribution
  - PYTHIA6 and PYTHIA8, PHOJET
  - Flat
  - Variations of a power law
- **Donnachie and Landshoff** chosen as a default model
  - With $\varepsilon=0.085$, $\alpha'=0.25$ GeV^{-2}

$$\frac{d\sigma_{SD}}{d\xi} \propto \frac{1}{\xi^{1+\epsilon}}(1+\xi)$$



Inclusive and single-sided samples





- Inclusive sample (N_{inc}):
  used for the measurement
- For most of the distribution, models span the data

  errors = stat+response+material

- 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

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Diffractive fraction

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

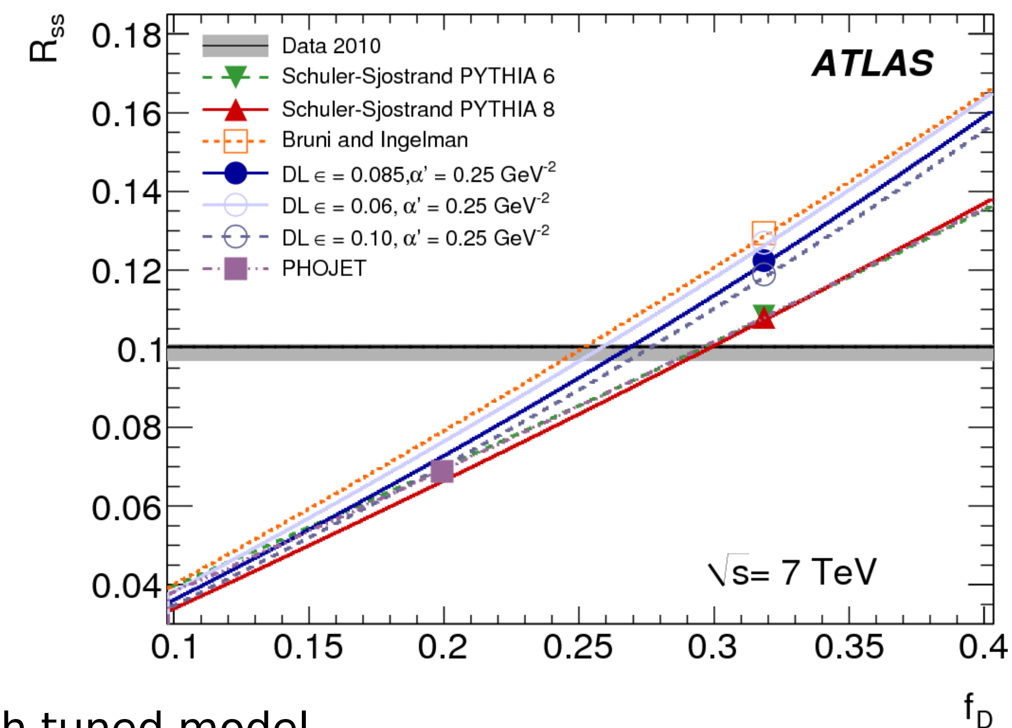
$$R_{ss}(f_D) = \frac{N_{SS}}{N_{inc}}$$
$$= \frac{A^D_{SS} f_D + A^{ND}_{SS}(1 - f_D)}{A^D_{inc} f_D + A^{ND}_{inc}(1 - f_D)}$$

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

- Default model yields:

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

$$f_D = \frac{\sigma_{SD} + \sigma_{DD} + \sigma_{CD}}{\sigma_{inel}}$$



- Calculate MC dependent corrections with tuned model

Systematic uncertainties

- Trigger efficiency: Uncertainty from two independent triggers
- MBTS Response: MC/Data agreement cross-checked by using overlapping detectors - inner tracker and EM calorimetry. MBTS response is tuned to match the data by adjusting counter thresholds.
- Background 100% uncertainty: beam interaction with residual gas, interaction with upstream material, slowly decaying background 'afterglow
  - Measured in unpaired bunches, afterglow investigated using MBTS timing asymmetry
- Relative diffractive contribution: f_D varied within uncertainties
- Material: 40% uncertainty on material in $|\eta|>2.5$
- MC Multiplicity: Difference between Pythia6 and Pythia 8
- ξ distribution: largest difference between default and alternative models

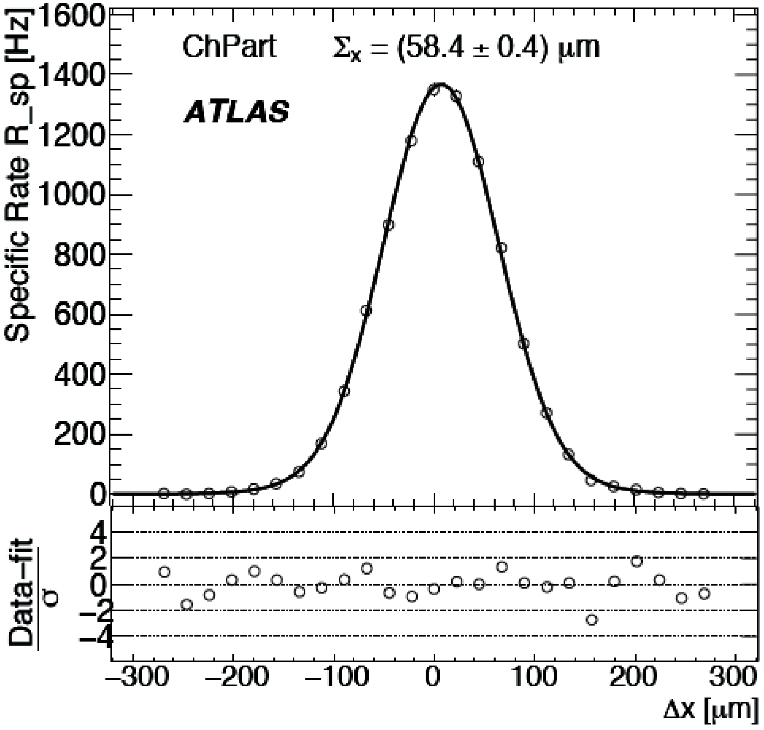
Source	Uncertainty (%)
Trigger Efficiency	0.1
MBTS Response	0.1
Beam Background	0.4
f_D	0.3
MC Multiplicity	0.4
ξ-Distribution	0.4
Material	0.2
Luminosity	3.4
Total	3.5

Luminosity

- Luminoisity calibration derived from van der Meer scans, using beam separation

- Default luminosity using LUCID event counting
  - Several other methods
  - Stability better then 0.5% over 2010

- Systematic uncertainty of 3.4%
  - Dominated by the uncertainty on the knowledge of the bunch charge (beam current) of 3.1%



Results – Cross-section in fiducial range

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

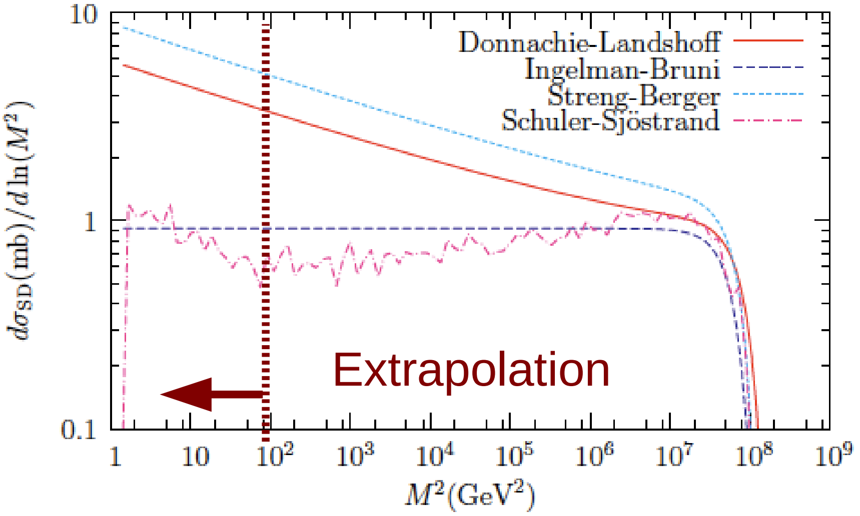
0.4 % overall correction factor small

$\sigma(\xi > 5 \times 10^{-6})$ [mb]	
ATLAS Data 2010	$60.33 \pm 2.10(\text{exp.})$
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 σ_{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

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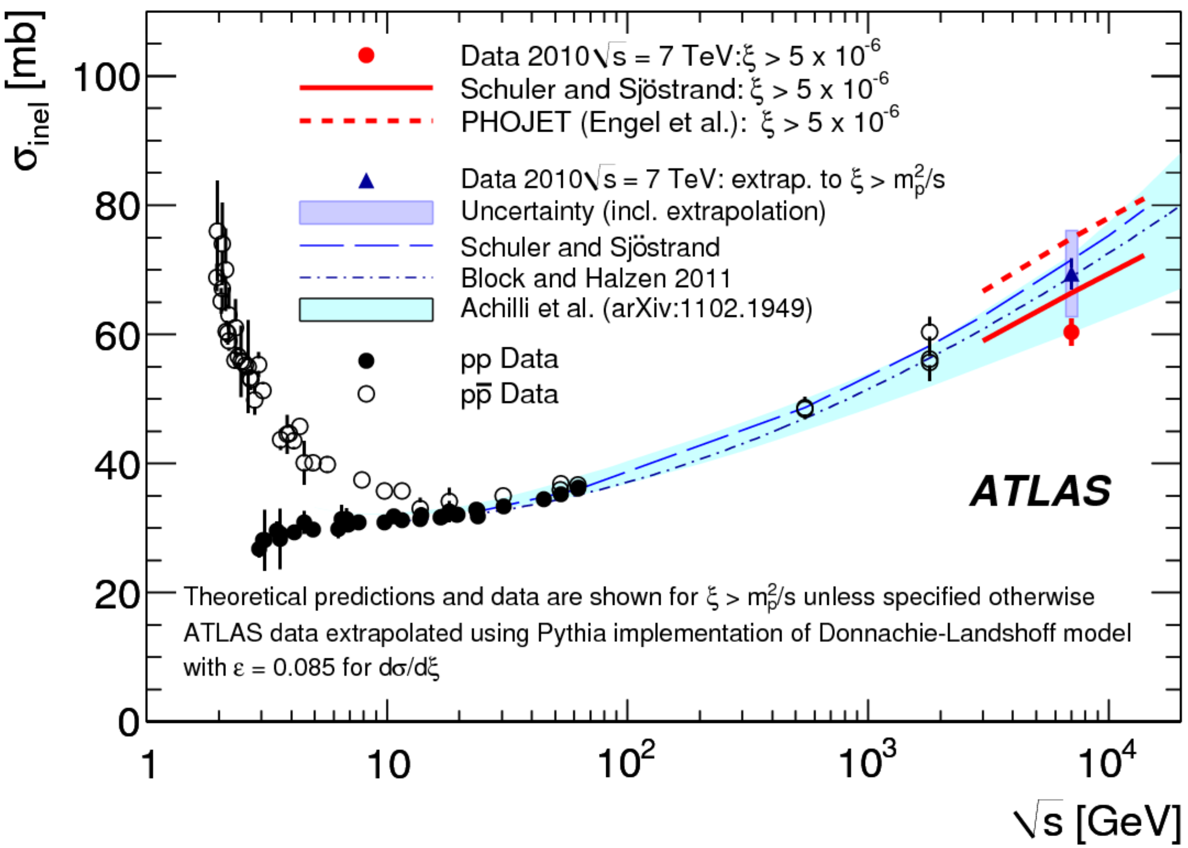
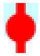
Comparison: older experiments



- Extrapolated value:

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

- Fiducial cross-section



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

  - by factor 3 more precise than extrapolated value

- Data lower than MC predictions, extrapolated value agrees with models

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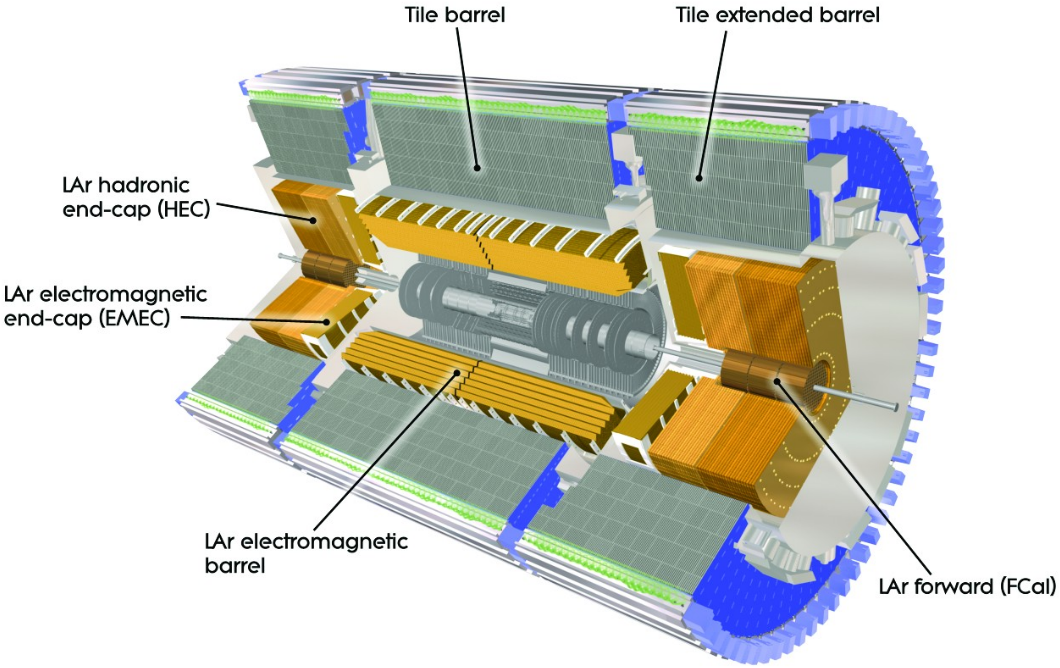
Measurement of pseudo-rapidity gaps in pp collisions at $\sqrt{s}$=7TeV

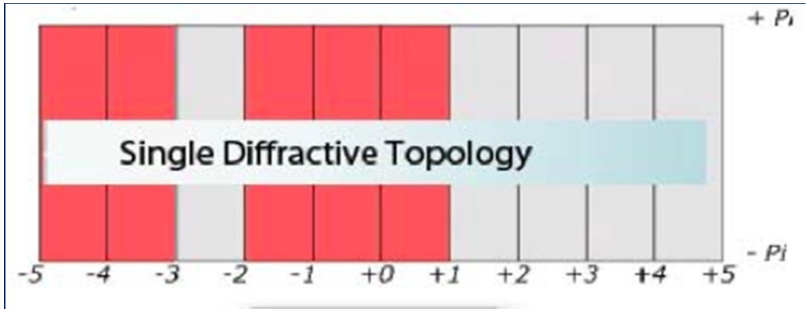
ATLAS Paper: Eur. Phys. J. C72 (2012) 1926

- Using ATLAS calorimeters and Inner detector to reconstruct rapidity gaps in forward direction

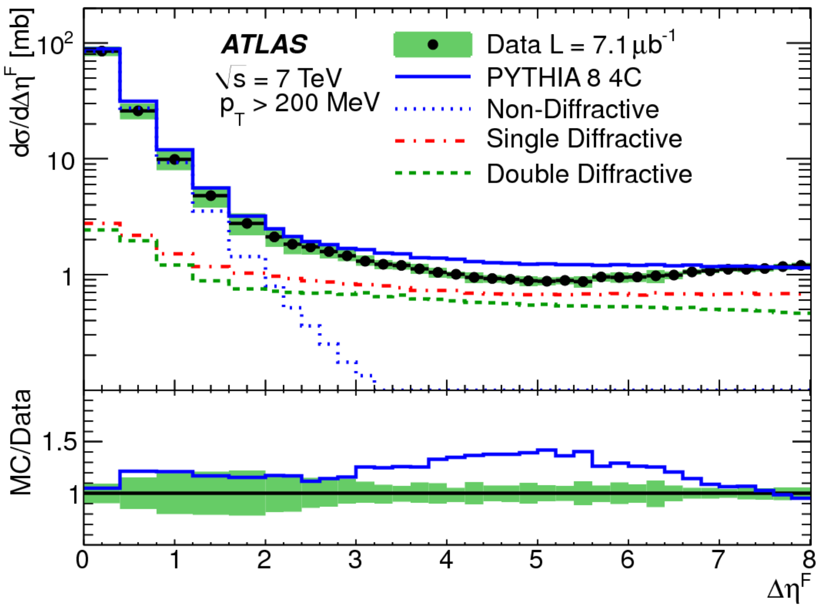


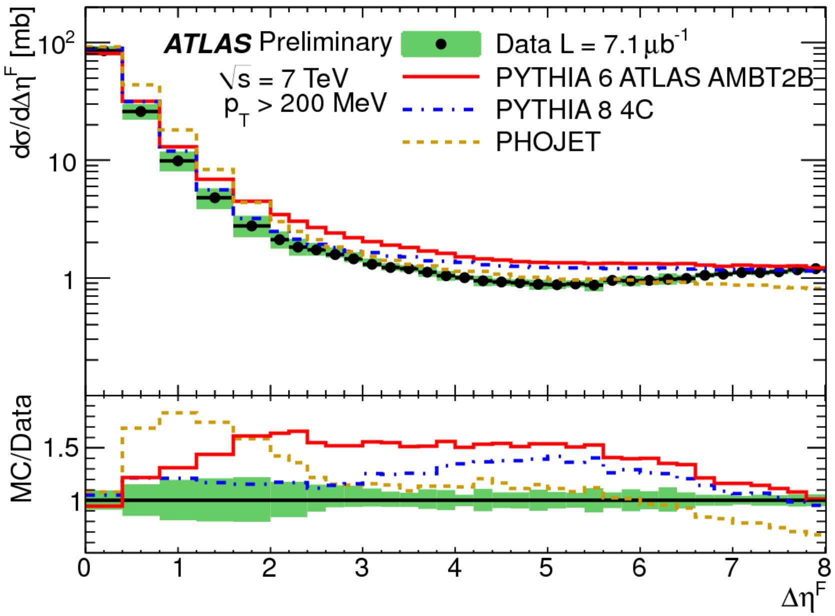
See '*ATLAS: MPI aspects of Rapidity gaps and forward Eflow*' by Peter Wijeratne on Tuesday

Total cross-section versus gap size



- $\Delta\eta_F$ defined as a largest gap extending from $\eta=\pm4.9$
  - no stable particle above p_T> 200 MeV
- Measured gaps up to size $0<\Delta\eta_F<8$
  - No track / calorimeter cluster above p_T> 200 MeV, no cell with E > noise level
- Non-diffractive events dominate at small gaps, diffractive plateau observed for large gaps
- Non-diffractive events are too soft in PHOJET, overestimated diffractive fraction on PYTHIA





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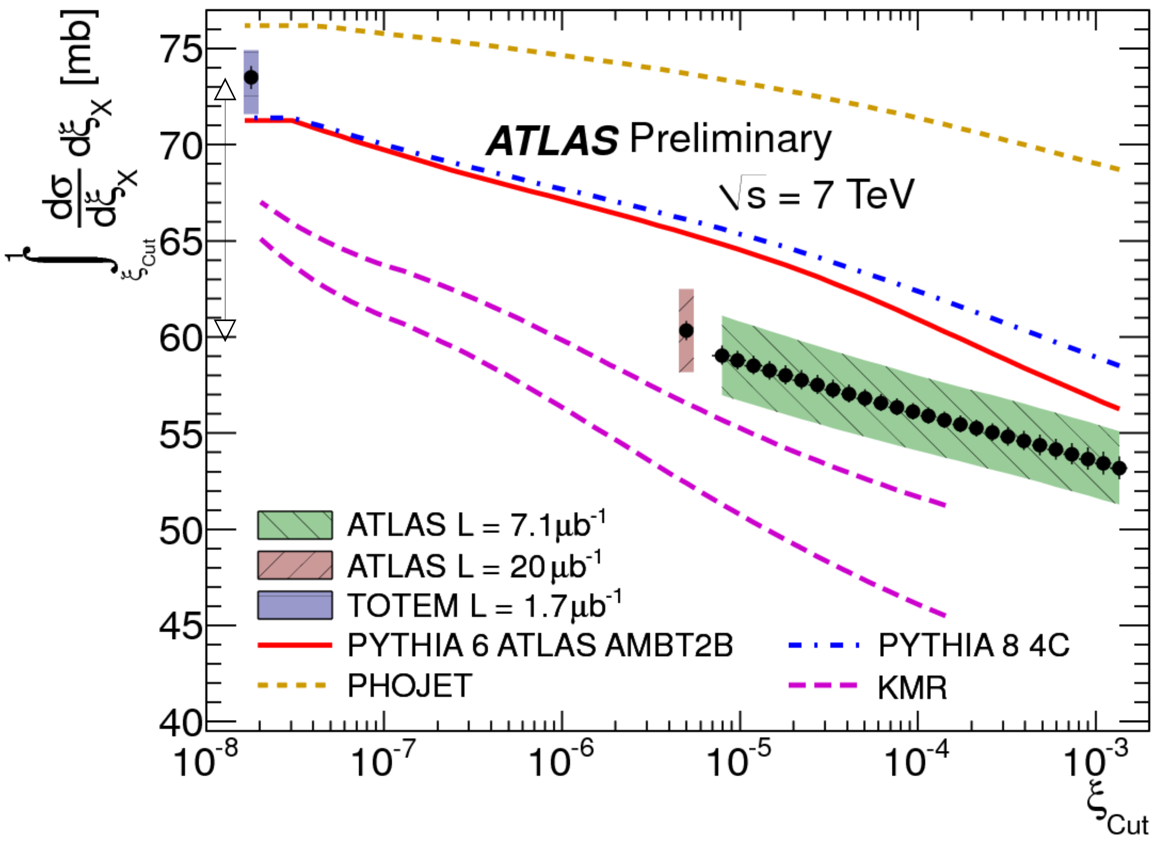
Uncertainties in low-ξ extrapolation



$\eta_{min} \propto \log 1/\xi$

From MC

- Inelastic cross section integrated up to some max $\Delta\eta_F$ (equivalently min ξ_X) and compared with TOTEM
- Indication that small ξ_X region underestimated in PHOJET and PHYTHIA:
  - 14 mb with $\xi < 10^{-5}$, compared to 6 (3) mb in PYTHIA (PHOJET)
  - KMR model gets it about right

Summary

- Inelastic pp cross-section measurement in fiducial region discriminates between various models

- PHOJET prediction too high even after extrapolation when precision of the measurement is smaller

- Rapidity gap measurement enables to tune diffractive components in generators and effectively probes the inelastic cross-section as a function of diffractive mass

Thank you for you attention!

Monte Carlo models

- PYTHIA 6
  - Schuler and Sjostrand - 48.5 mb (ND), 13.7 mb (SD) and 9.3 mb (DD)

- PYTHIA 8 – several models implemented
  - Schuler and Sjostrand – predicted cross-section similar to PYTHIA6, but difference in modelling the hadronic final state
  - Bruni and Ingelman
  - Donnachie and Landshoff

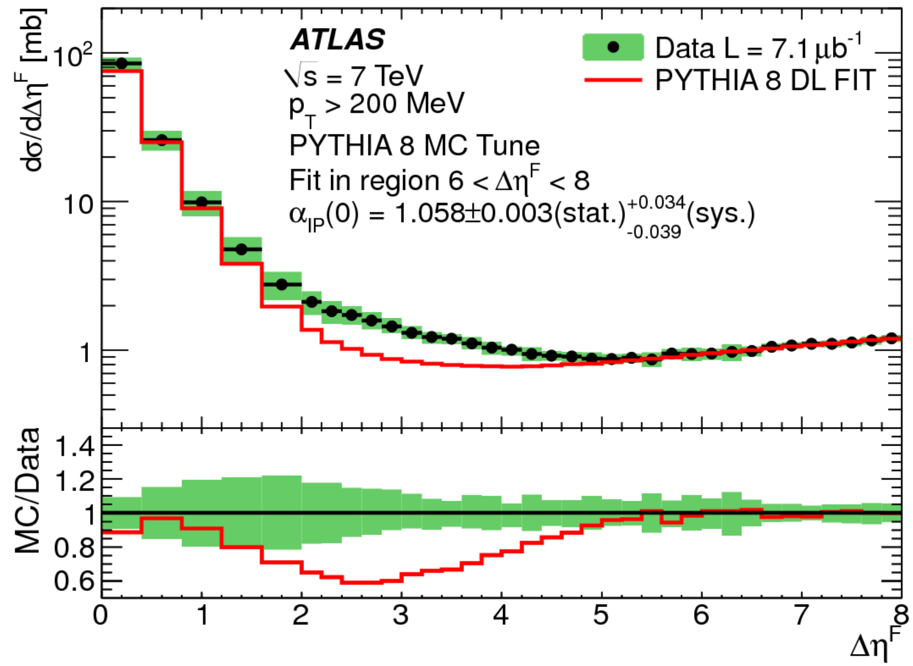
  - Diffractive cross-section dependence on ξ differs (see later)

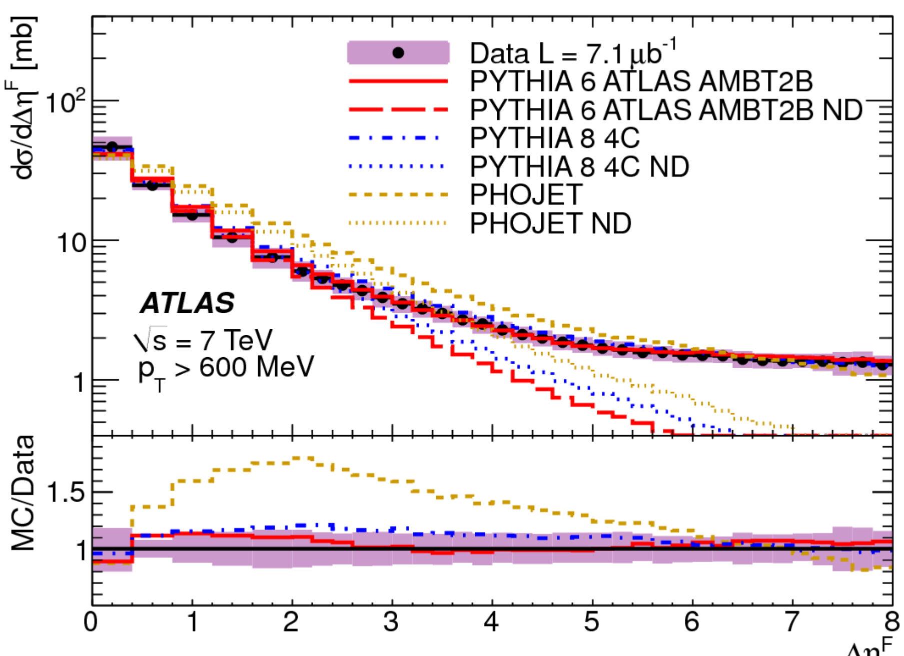
- PHOJET
  - 61.6 mb (ND), 10.7 mb (SD), 3.9 mb (DD) and 1.1 (CD)

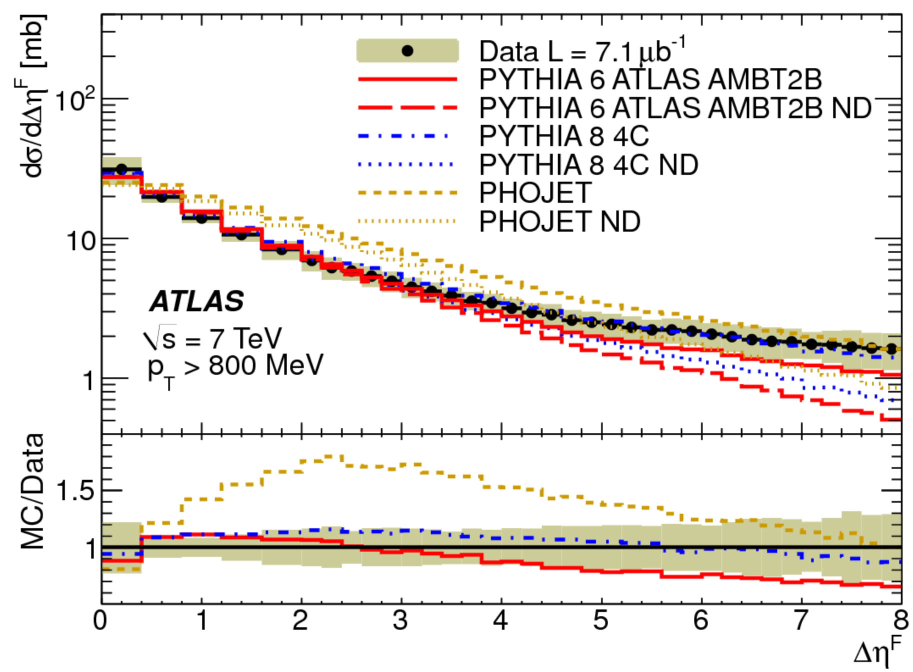
Rapidity gap cross-section

- Fits of Pomeron intercept within DL parameterization in PYTHIA8

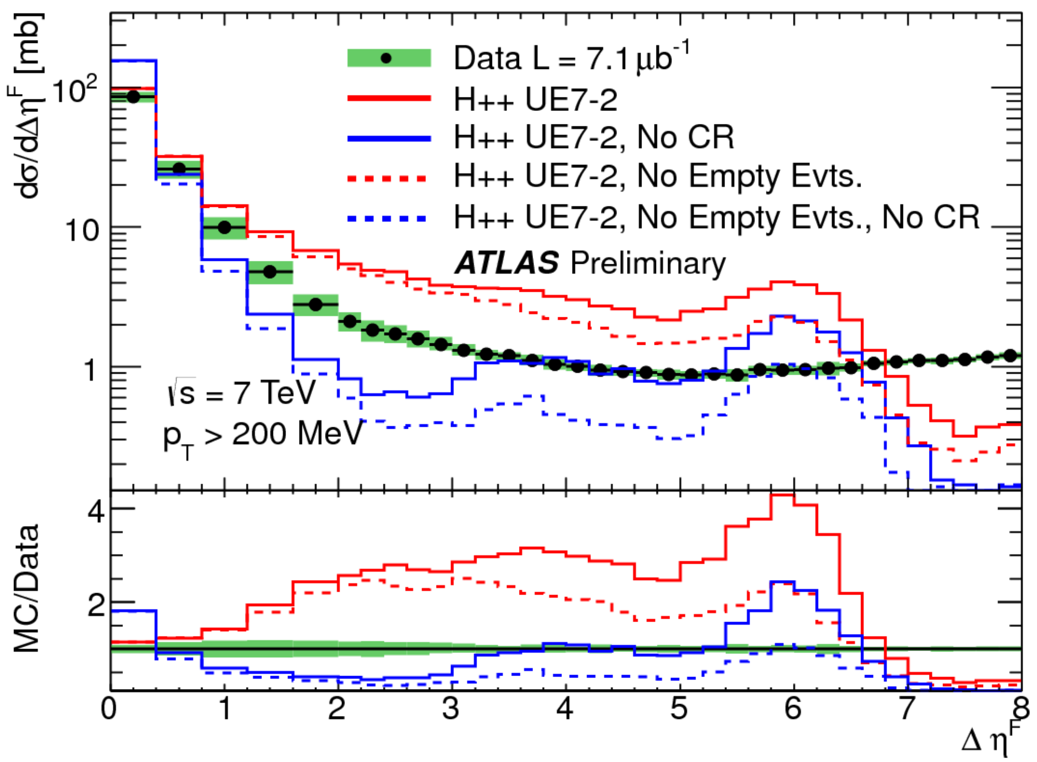
- Spectrum for higher particle thresholds: p_T^{min} =400, 600, 800 MeV – confirms results that particle production is dominated by low p particles







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

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