Measurement of the forward rapidity gap cross-section

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(on behalf of the ATLAS Collaboration)

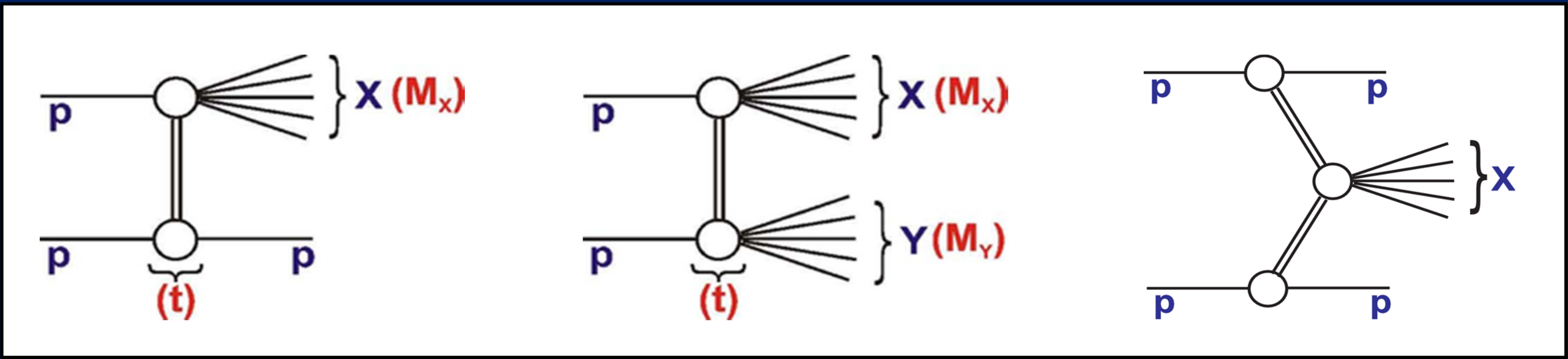
Outline:

- Diffraction at the LHC
- The ATLAS Detector
- Recent Results
  - Inelastic Cross Section
  - Forward Rapidity Gaps
- Summary and Outlook

Diffraction: introduction (i)

Diffractive Events:

1. Interactions where the beam particles emerge intact or dissociated into low-mass states
2. Interactions mediated by t-channel exchange of object with the quantum numbers of the vacuum, color singlet exchange or Pomeron



Single Diffraction (SD) **Double Diffraction (DD)** **Central Diffraction (CD) ~1/10 of the SD**

Kinematic variables:

- t : the 4-momentum exchanged at the proton vertex
- the mass of diffractive systems: M_X , M_Y , or $\xi \equiv M_X^2/s$

Diffraction: introduction (ii)

In general such processes lead to final state particles separated by large rapidity gaps

Diffraction: Events with large rapidity gap not exponentially suppressed

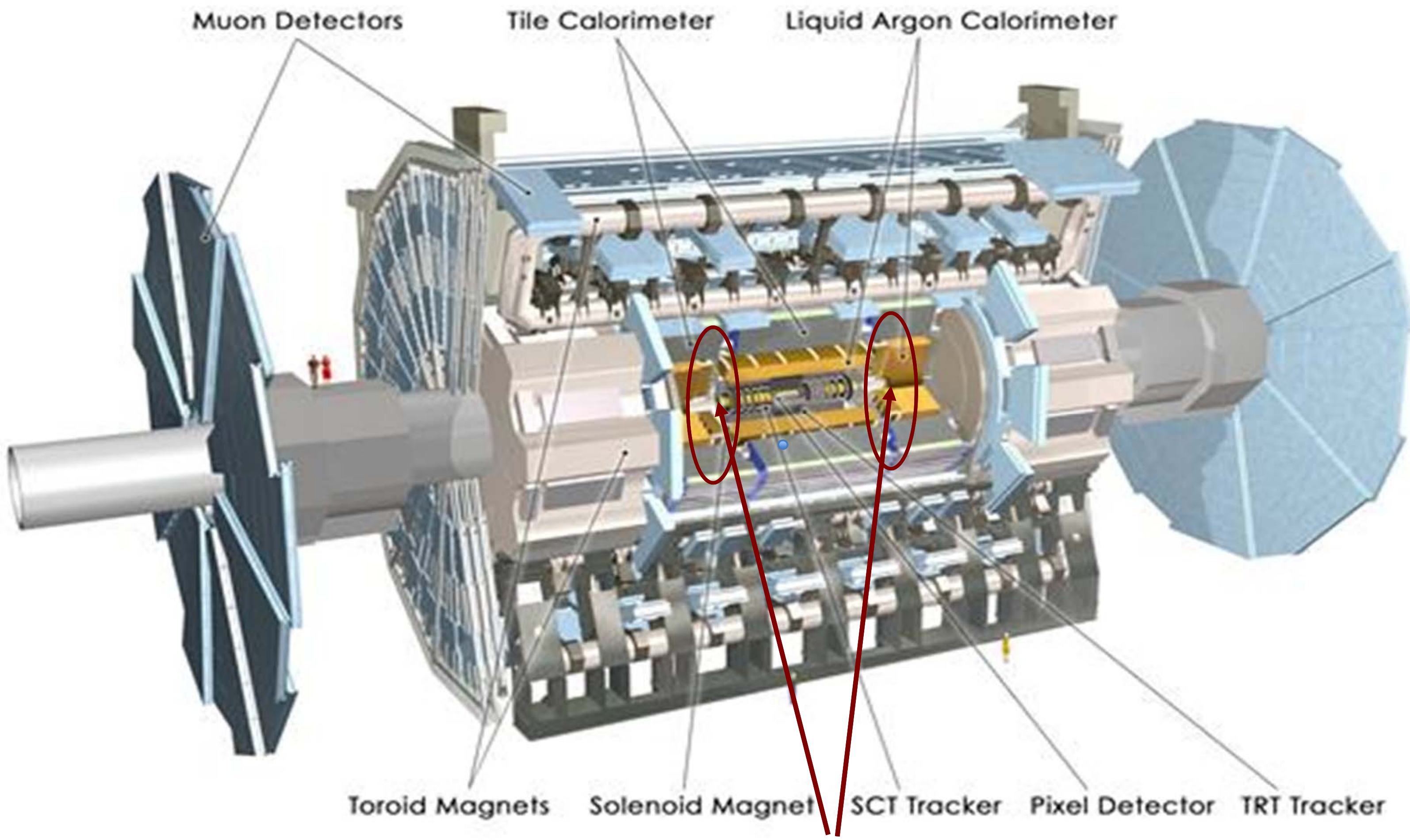
$$\Delta\eta = \ln s/M_X^2 = -\ln\xi \qquad\qquad \xi = M_X^2/s$$

Experimentally:

- Substantial fraction (~30%) of total cross section of pp interactions is due to diffractive dissociation processes
- The ATLAS central detector sensitive to high mass diffraction; low-mass diffractive dissociation not immediately observable

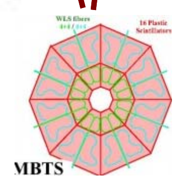
ATLAS: $|\eta| < 4.9 \Rightarrow \xi_X > 10^{-5}$; $M_X > 7$ GeV

The ATLAS detector



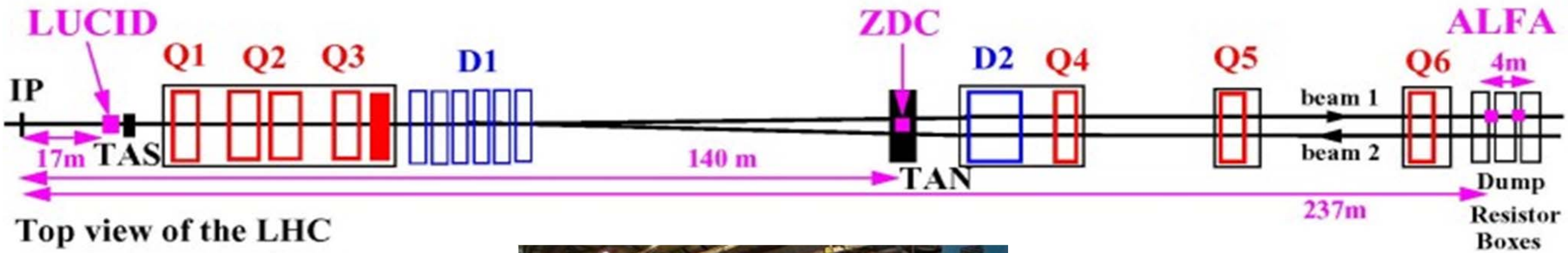
Trackers: |η|<2.5

Calorimeters: |η|<4.9

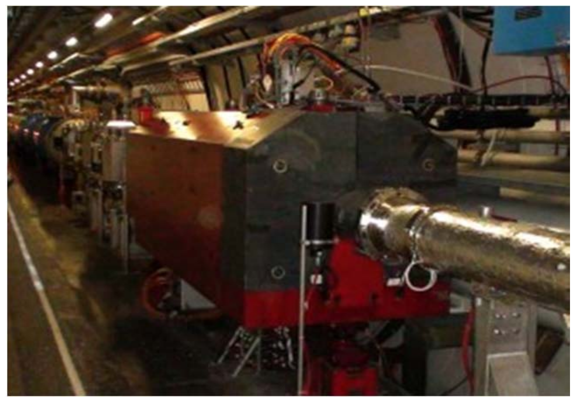


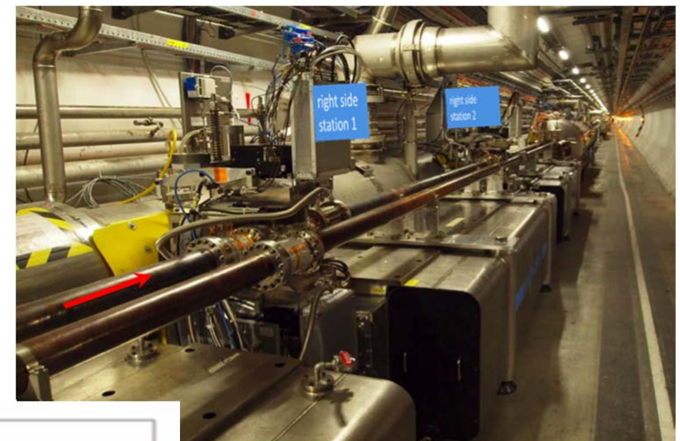
Minimum **B**ias
Trigger **S**cintillator
2.1< |η|<3.8

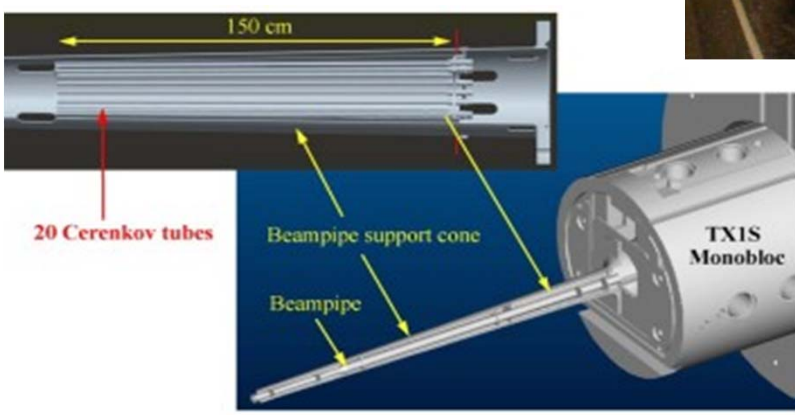
ATLAS Forward Detectors



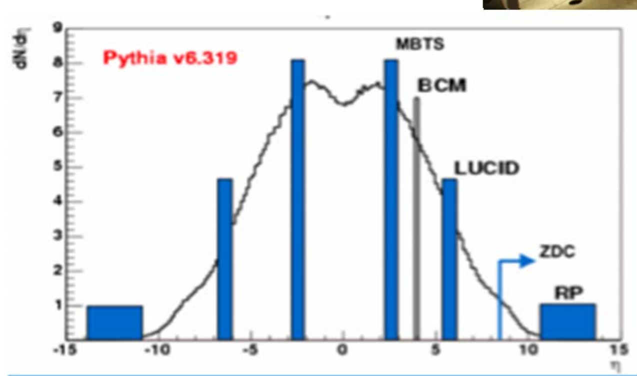
Zero Degree
Calorimeter
$|\eta|>8.3$





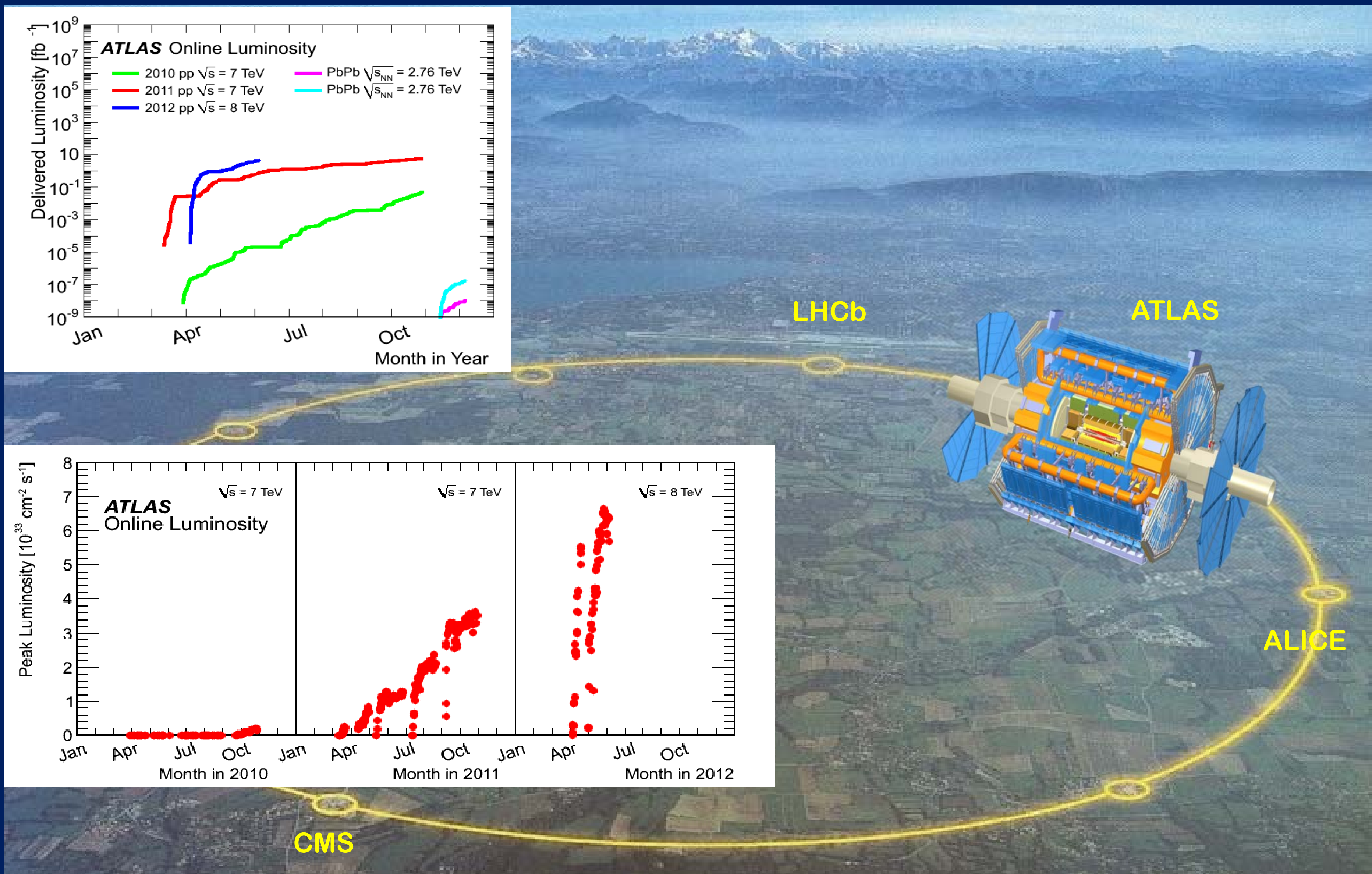


LUCID Cherenkov tubes $5.6<|\eta|<6$

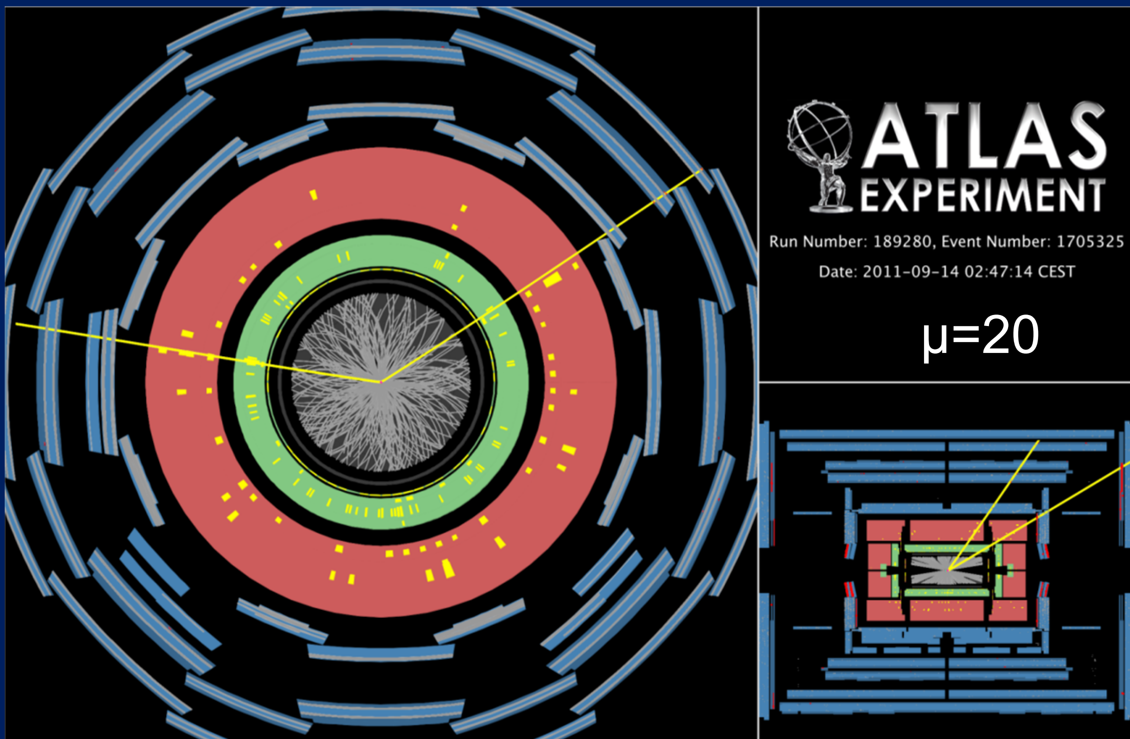


ALFA roman pots
$10.6<|\eta|<13.5$

ATLAS and the LHC



Luminosity and PileUp (μ)

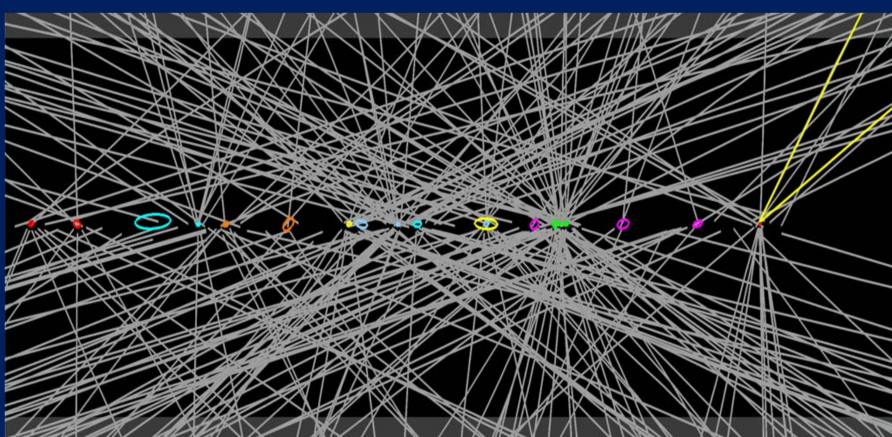


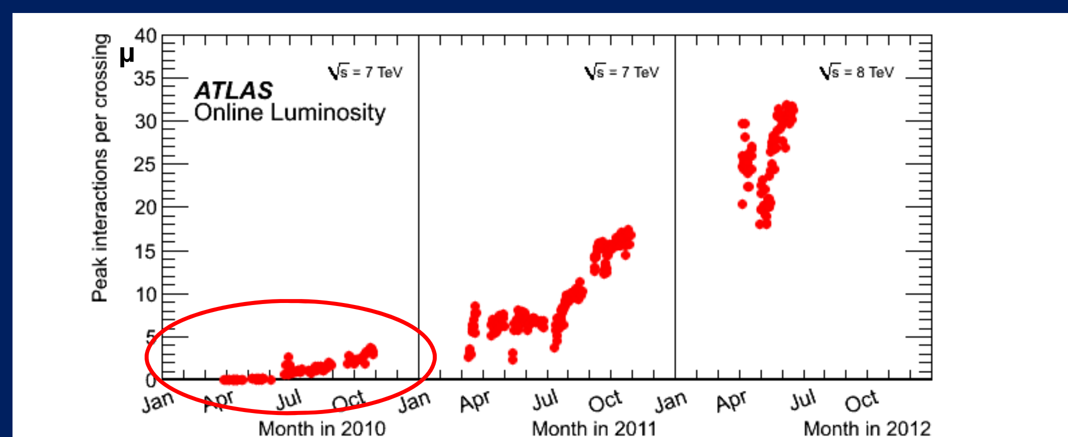
ATLAS nominal/design run conditions:

- Bunch intensity ~ 10^{11} protons
- ~ 2080 colliding bunches , 25 ns Luminosity at 10^{34} cm^{-2} s^{-1}
- 20 pileup events

Pileup interactions appear as noise in the Primary Vertex reconstruction, and add (mainly low p_T) energy deposits in the detector

In 2012: μ~30, 50ns interactions, 1.7x 10^{11} p, 1380 bunches





Measurement of the inelastic pp cross-section at $\sqrt{s}$=7 Tev with the ATLAS Detector

Nature Comm. 2 (2011), April 2011

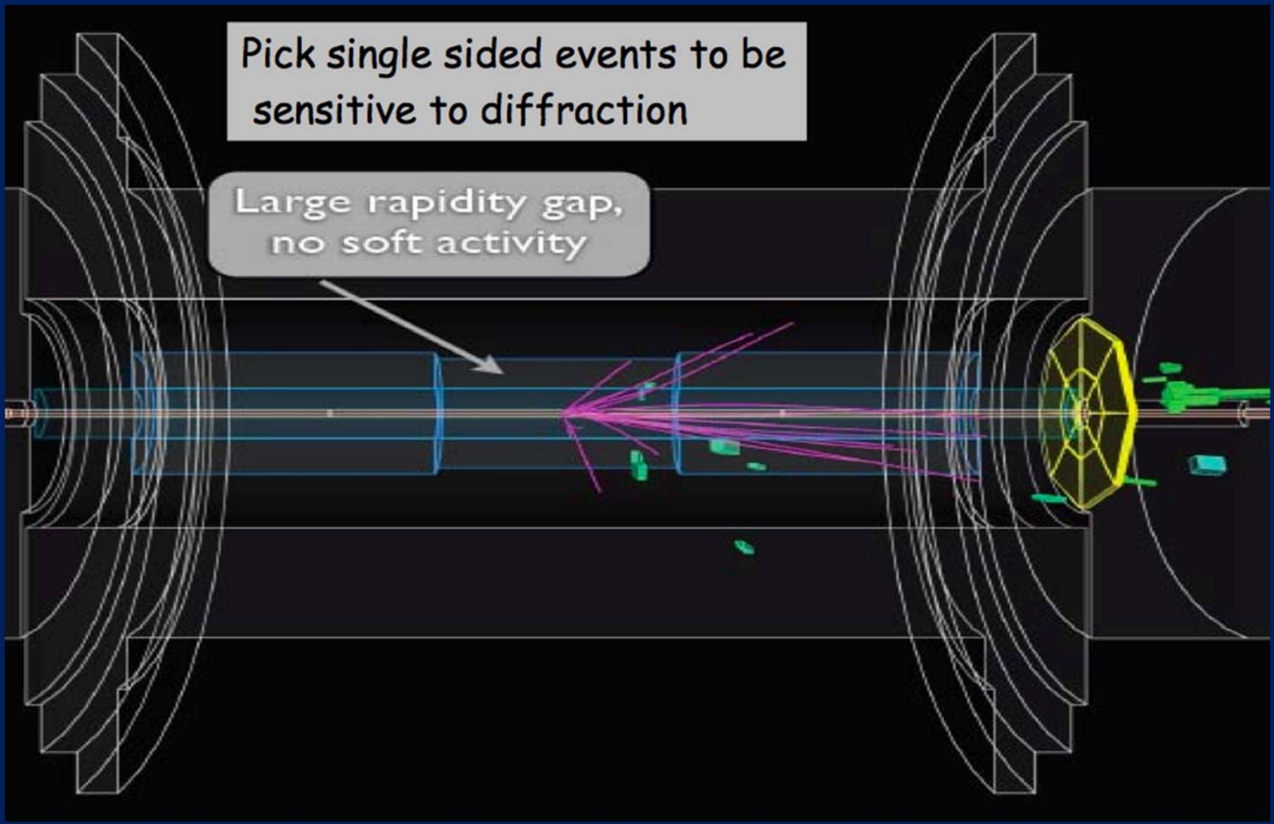
20 μb^{-1}, single fill in March 2010 (μ=0.01)

trigger by minimum bias trigger scintillator detectors,

with acceptance for $\xi \sim 10^{-6}$, M_X>15.7 GeV.

Analysis extrapolated also at M_X>M_p

Fraction of diffractive events constrained by the ratio of single sided to inclusive events



Asymmetric events:

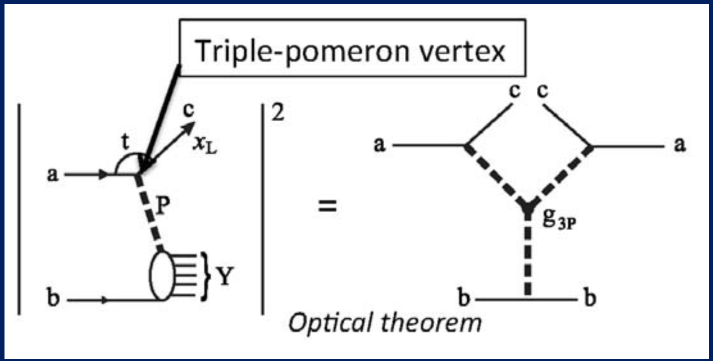
- → Measure $R_{ss} = \frac{N_{ss}}{N_{incl}}$ ratio of **single sided** MBTS events divided by **the number inelastic events**

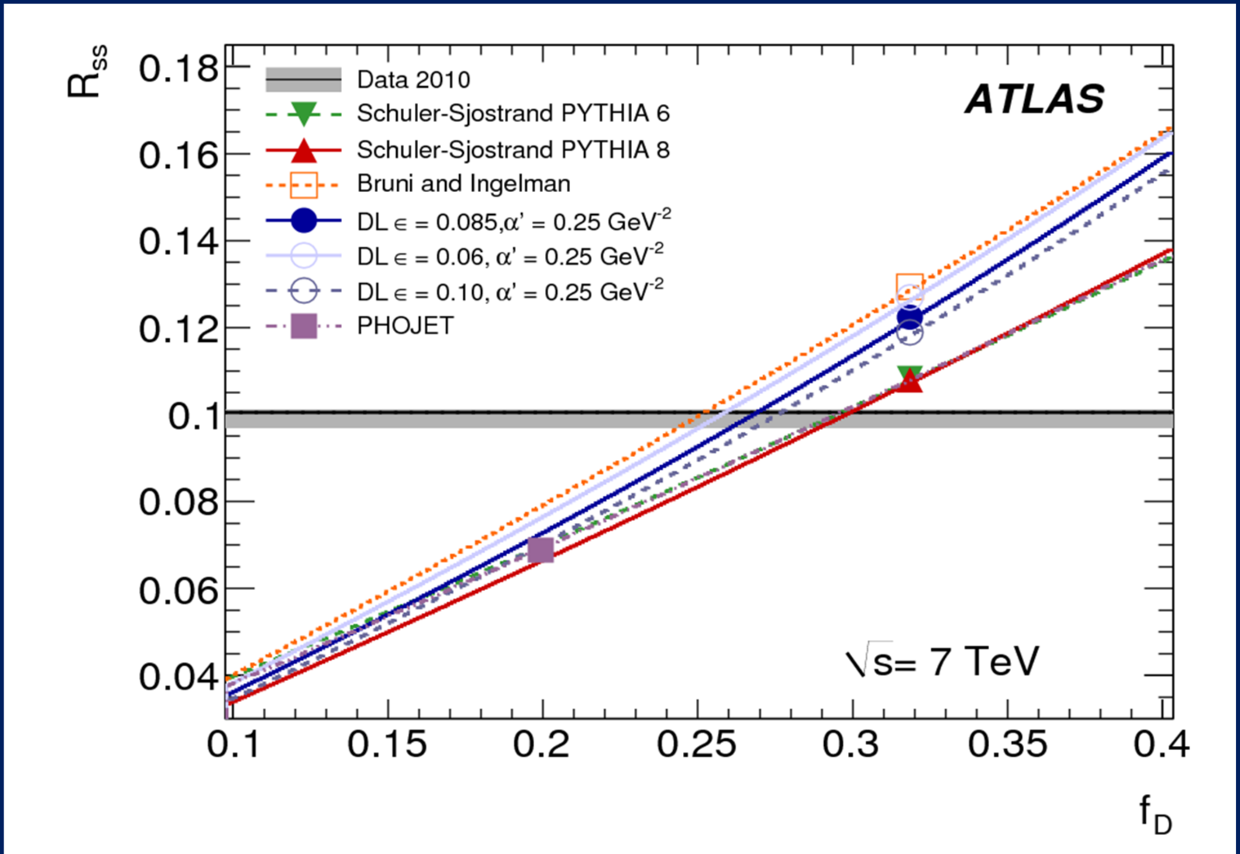
Single sided Events fraction in ATLAS (from MC):

- Single Diffractive + Double Diffractive (from 27% to 41%); less than 1% of ND

Fraction of diffractive events in inclusive cross section

The ratio of the single-sided to inclusive event sample R_{ss} as a function of the fractional contribution of diffractive events to the inelastic cross-section f_D. MC models based on triple Pomeron exchange





$d\sigma/d\xi \sim 1/\xi^{1+\varepsilon}$, $\varepsilon = \alpha_{IP} - 1$

R_{SS} =10.0±0.4% ➔ f_D~25-30% depending on the models

Inelastic cross section vs √s

Measured cross section is for $\xi > 5\times10^{-6}$

$$\xi = \frac{M_X^2}{s} > 5\times10^{-6} \quad M_X > 15.7\,\mathrm{GeV}$$

$$\sigma_{inel}(\xi > 5\times10^{-6}) = \sigma_{inel} \times (1 - f_{\xi<5\times10^{-6}})$$

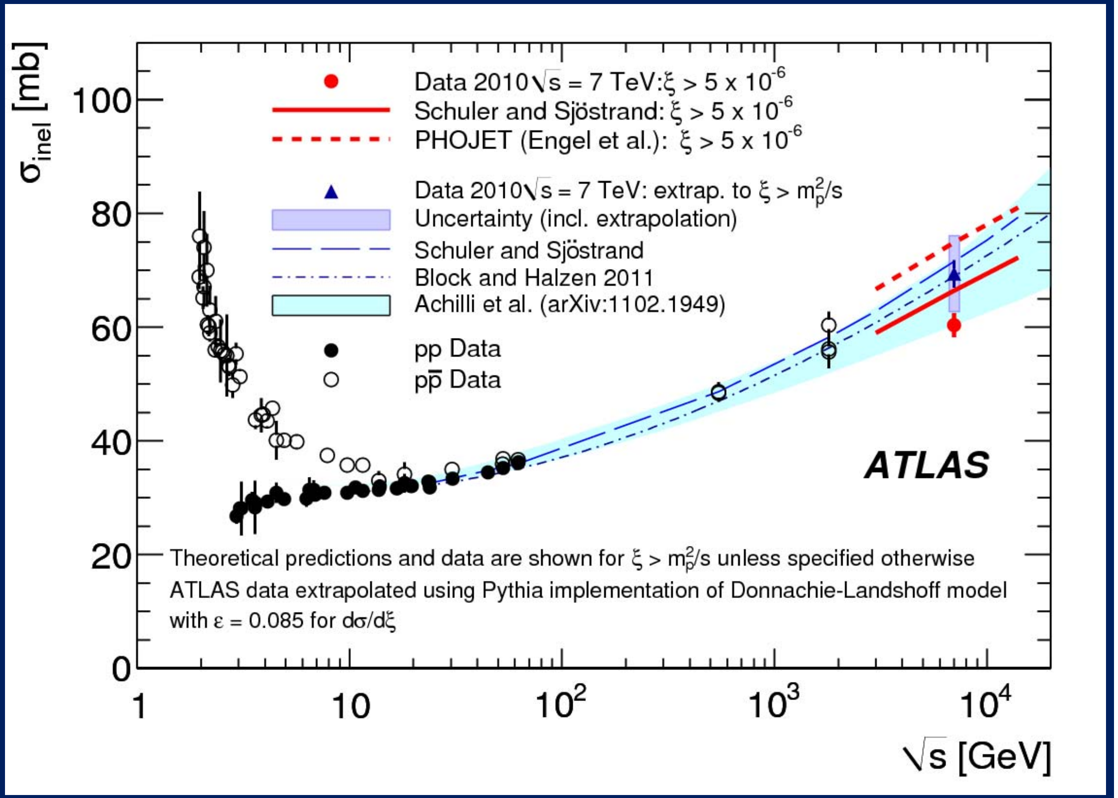
Use Donnachie-Landshoff MC to extrapolate to full range:

$\xi > m^2_p/s$

$\sigma(\xi > 5\times10^{-6}) = 60.33 \pm 2.10$ mb

($M_x > 15.7$ GeV)

$\sigma(\xi > m^2_p/s) = 69.4 \pm 2.4 \pm 6.9(\mathrm{extr})$ mb



Rapidity gap cross-section in pp interactions at $\sqrt{s}$=7 TeV

Eur. Phys. J. C72 (2012) 1926

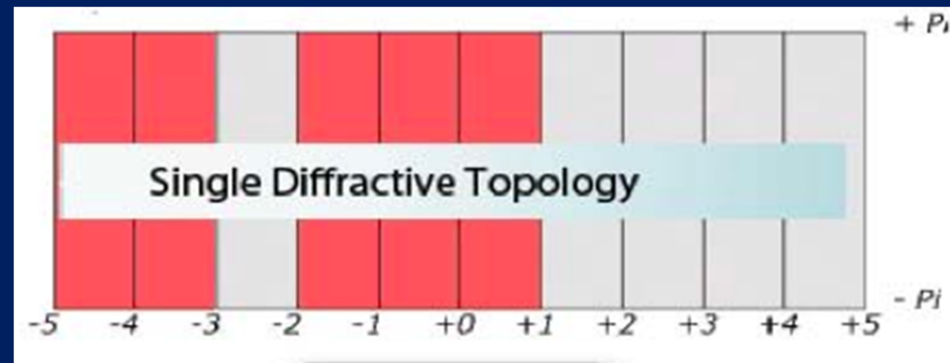
7.1 pb^{-1} , taken in March 2010, 2 bunches per beam (μ<0.005)

Select events with a large rapidity gap and compare with models based on Regge phenomenology (Triple Pomeron exchange)

Rapidity gap cross section

Rapidity gap definition at detector level

- Detector divided into η-rings of size 0.1 between $-4.9<\eta<4.9$
- Ring is empty if there is
  - No track with $p_T>200$ MeV (for $|\eta|<2.5$)
  - No calorimeter cell with E above noise level (for $|\eta|<4.9$)

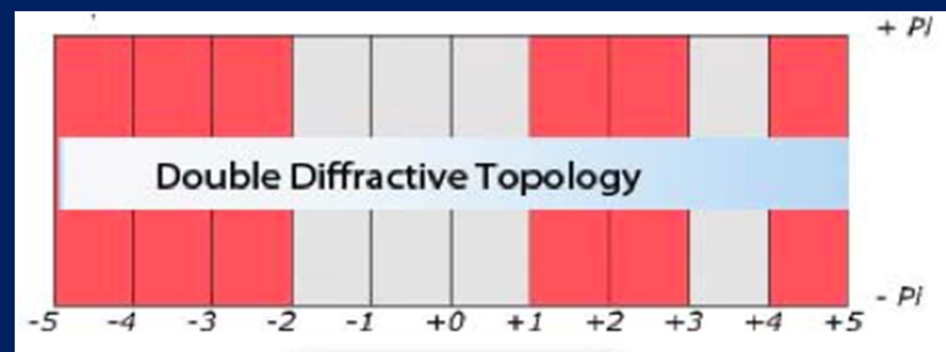


Hadron level gap definition

Phase space divided in the same η-rings

No stable particle with $p_T>200$ MeV and $|\eta|<4.9$

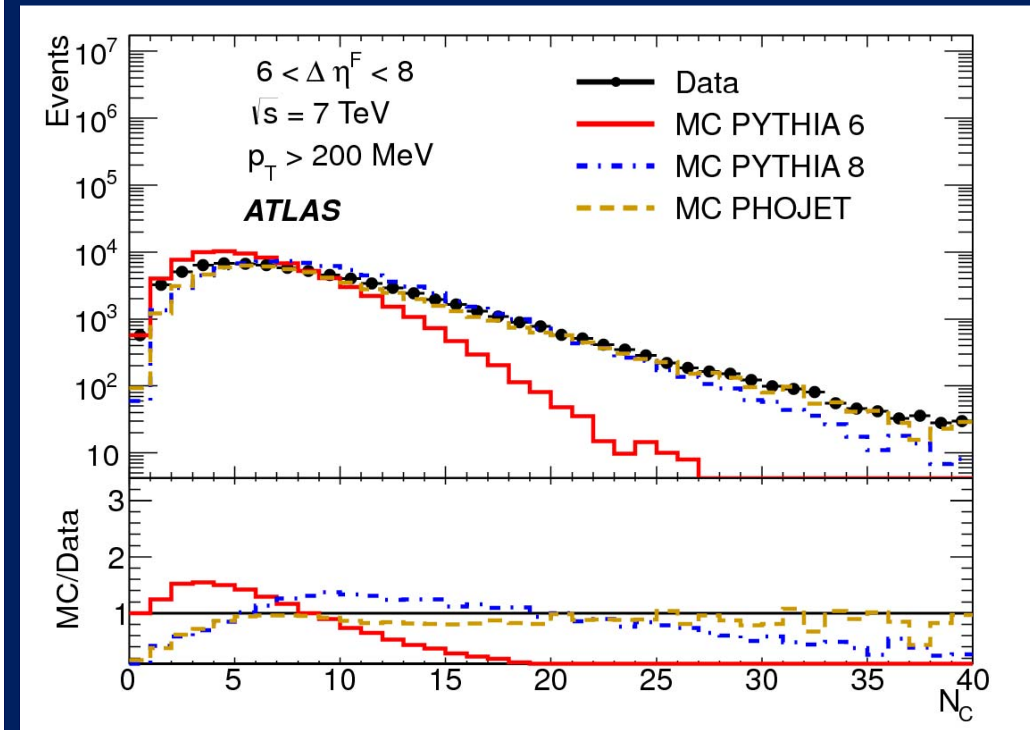
Data corrected back to hadron level



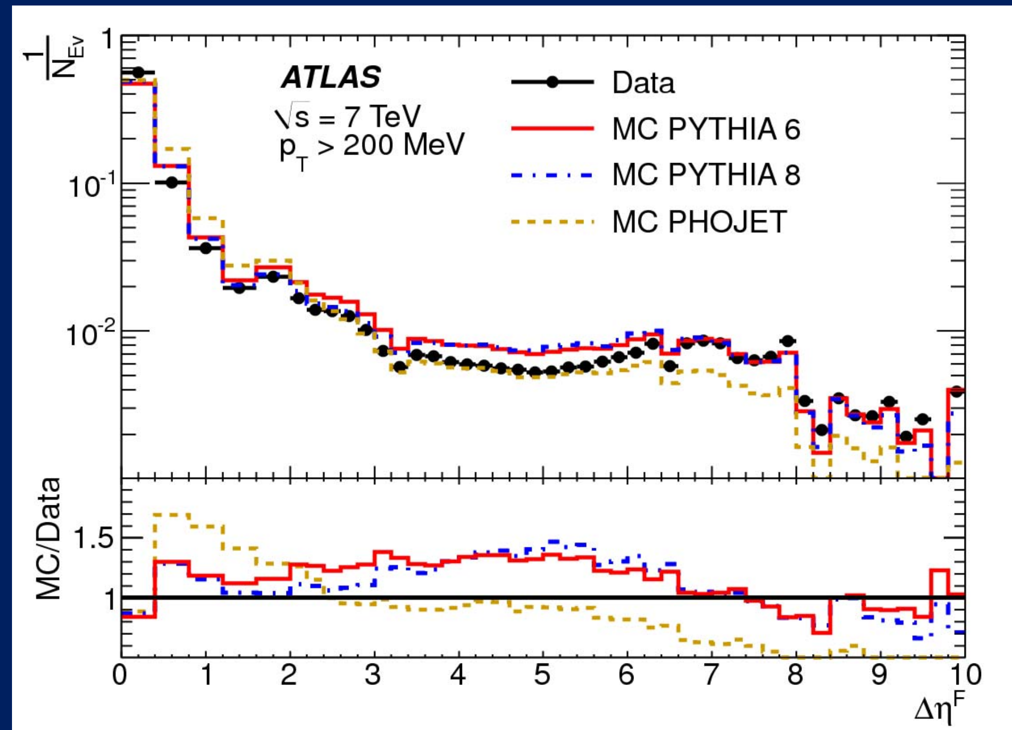
Forward gap $\Delta\eta_F$: largest consecutive set of empty rings starting from the edge of the acceptance (η = + - 4.9)

Cross section measured as a function of the largest forward rapidity gap

Rapidity gaps – data vs MC



Total calorimeter cluster multiplicity



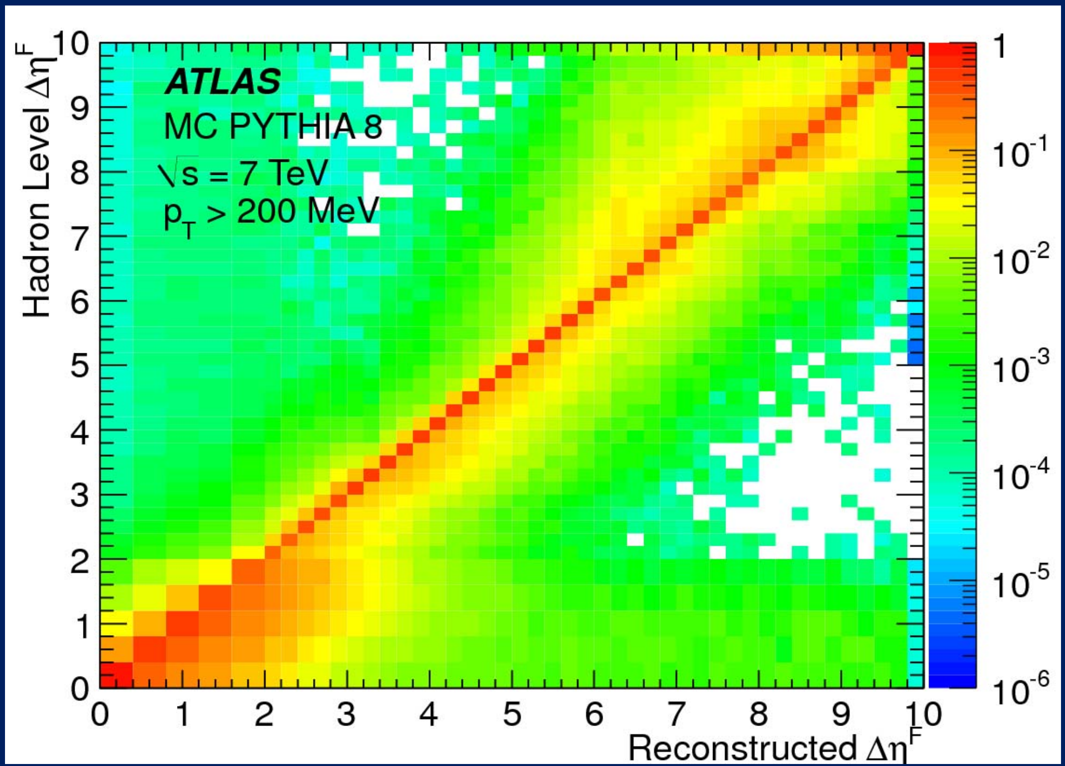
Size of forward gap

No MC models gives a perfect description over the full $\Delta\eta^F$, but description is reasonable

Pythia8 used to correct the data

Rapidity gap cross section – MC corrections

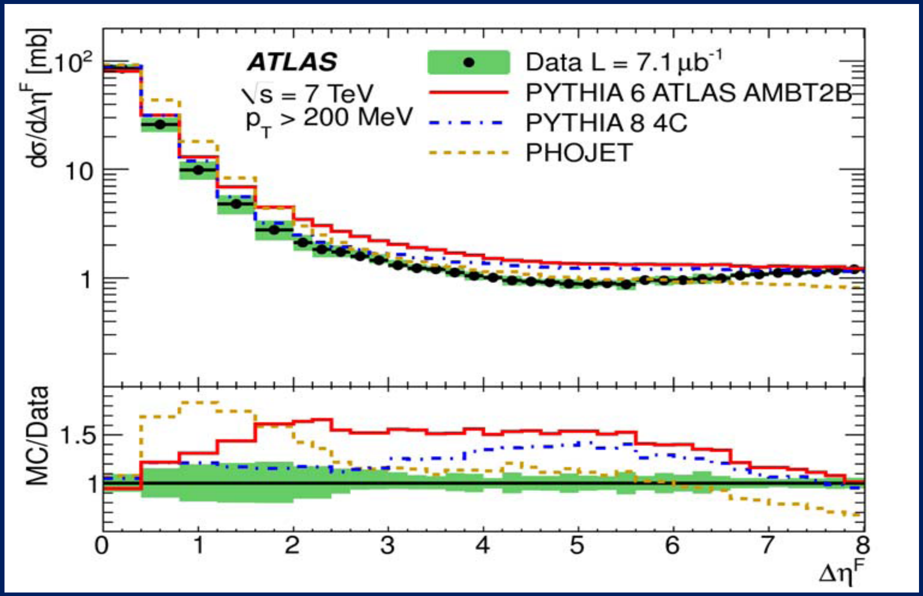
Data corrected back to hadron level (stable final state particles) using MC migration matrix, ~ diagonal for this p_T cut



Main sources of systematic uncertainties:

- Monte Carlo model, dependence and unfolding
- Modeling of Diffractive contributions
- Calorimeter energy scale ~20%
- MBTS and tracking efficiency
- Luminosity: ~3.4%

Cross section vs forward rapidity gaps compared to MC with default settings

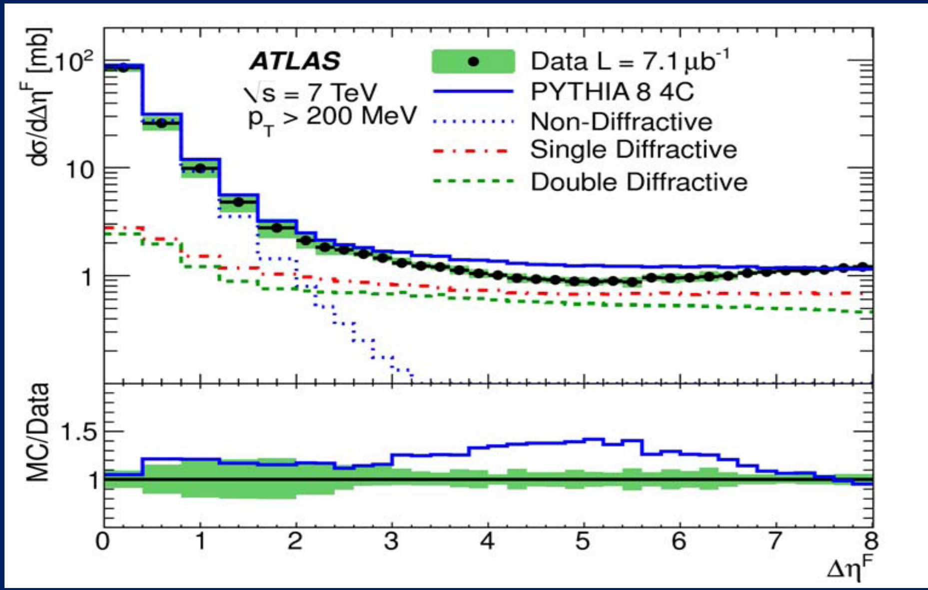


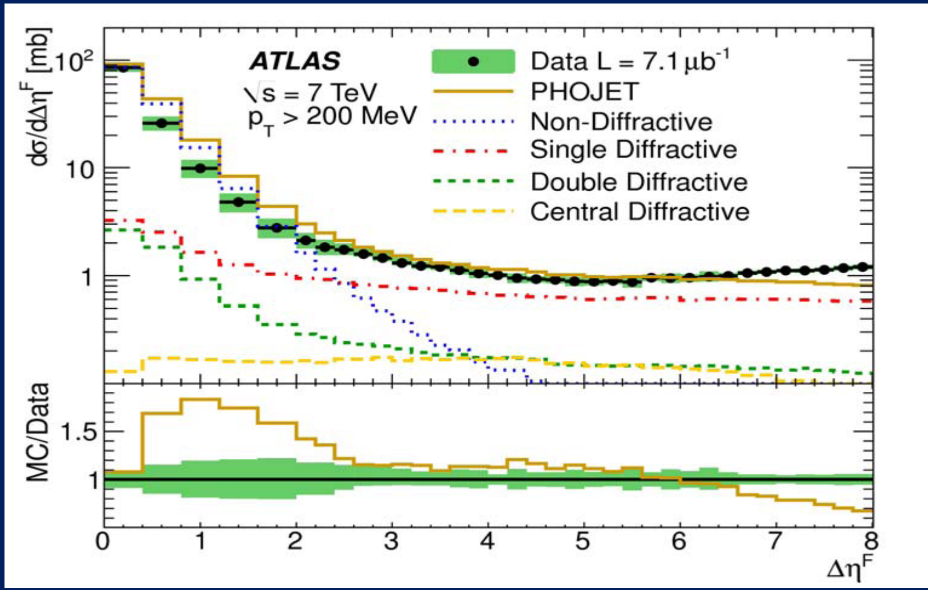
- Both PHOJET and PYTHIA 8 (no CD component in PYTHIA) reproduce trend but agreement not perfect:
- PHOJET better at large $\Delta\eta_F$
- PYTHIA better for smaller $\Delta\eta_F$

Low $\Delta\eta_F$ → ND dominant (exponential decrease)

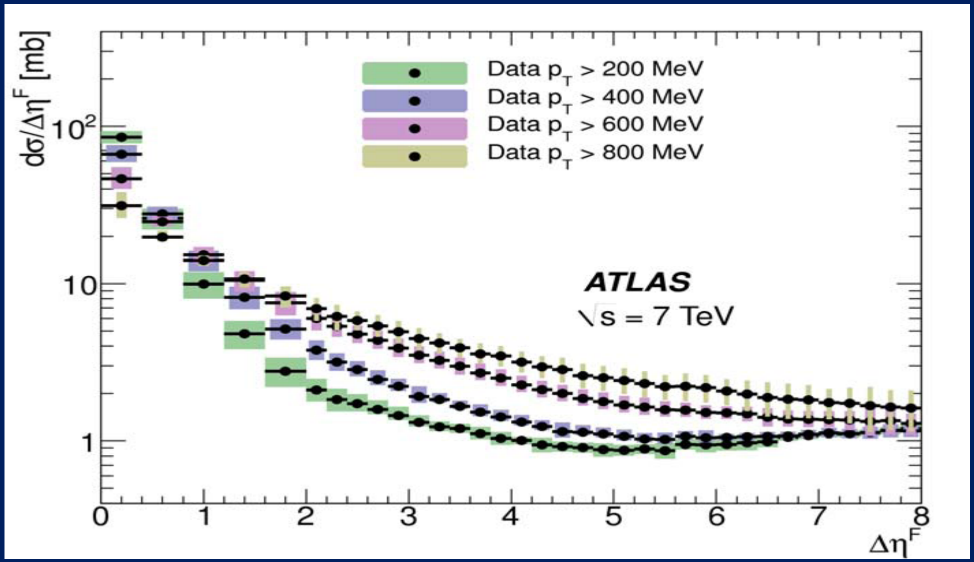
Overestimation of σ_{inel}

Large $\Delta\eta_F$ → flat contribution from diffraction

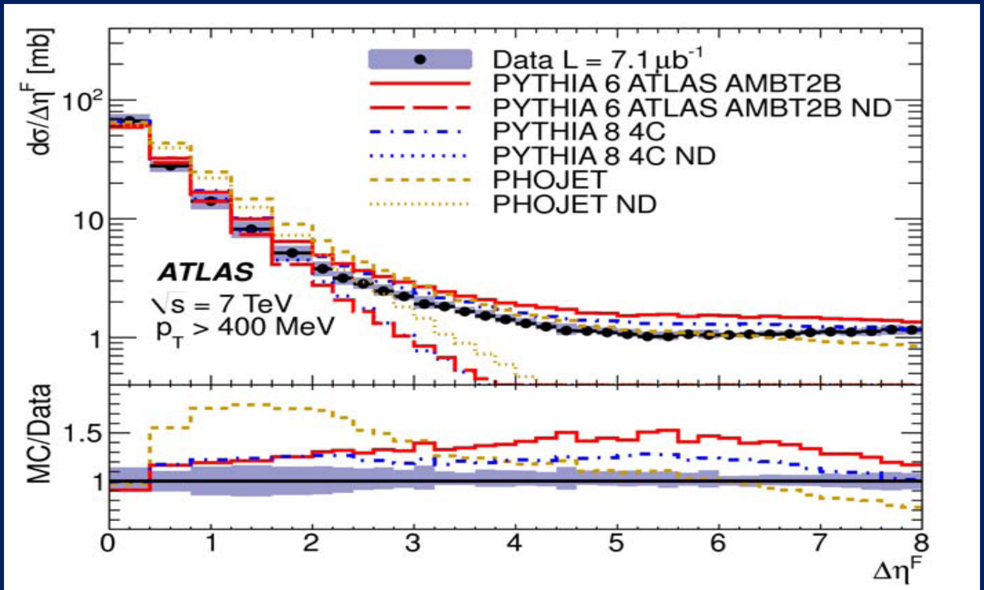


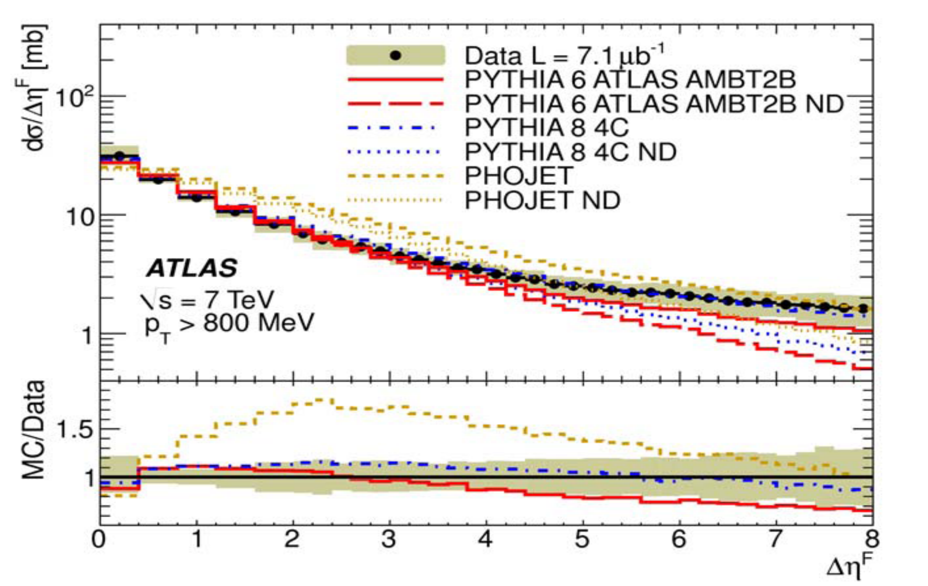


Uncertainty in the hadronisation fluctuations investigated for different models and p_T cut



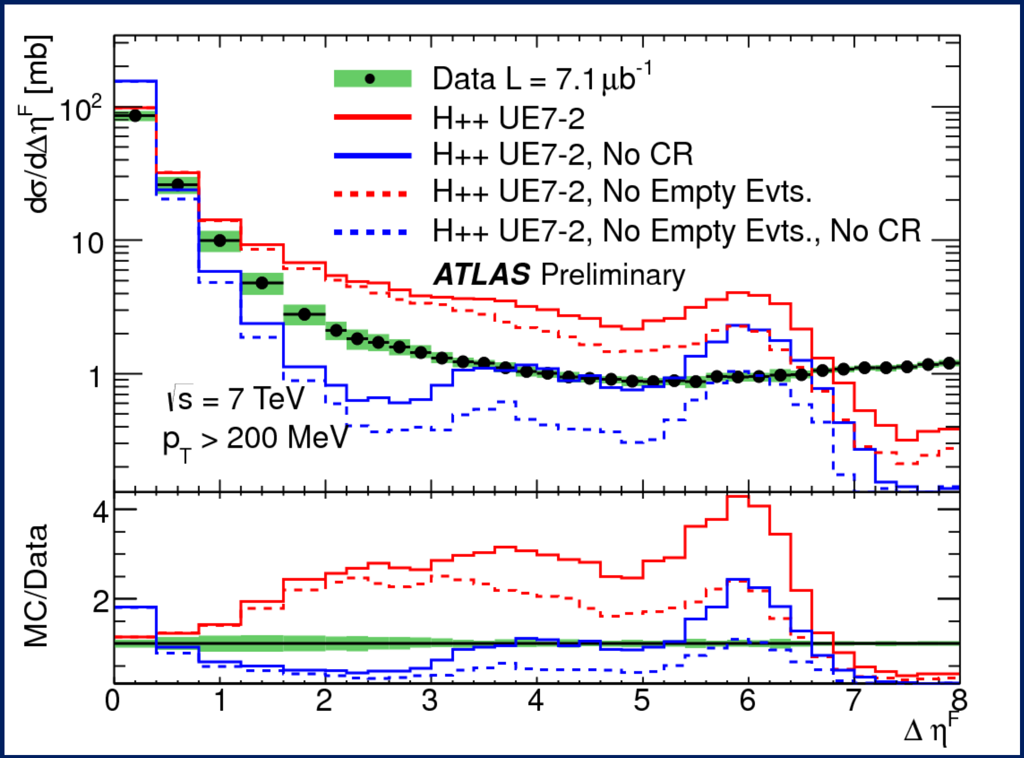
- Increasing P_T threshold
  → Increase ND contribution
- Exponential decrease for both ND and SD/DD contributions
- PYTHIA better in shape and value

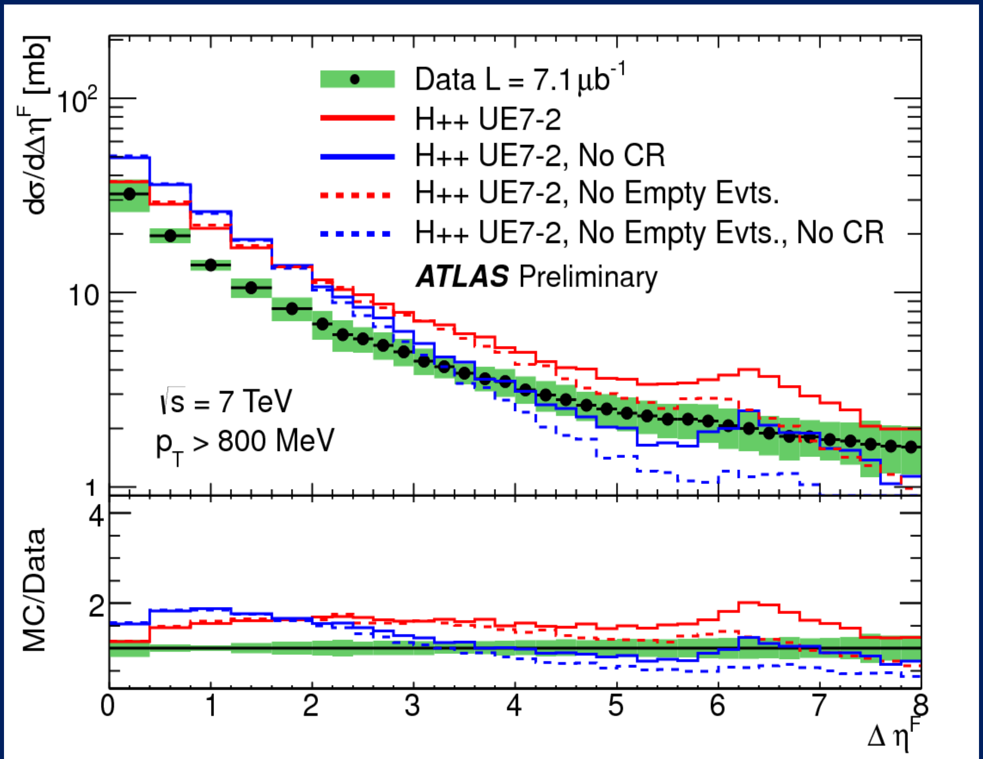




Uncertainty in the hadronisation fluctuations investigated for different models and p_T cut

- Herwig++ minimum bias does not contains an explicit diffractive components, but produces a sizeable fraction of events with large gaps
- Herwig++ with different models of Underlying Events, turning off the color reconnection (no CR), excluding soft events (no Empty)
- Herwig++ fails to describe the ND decrease vs the gap size

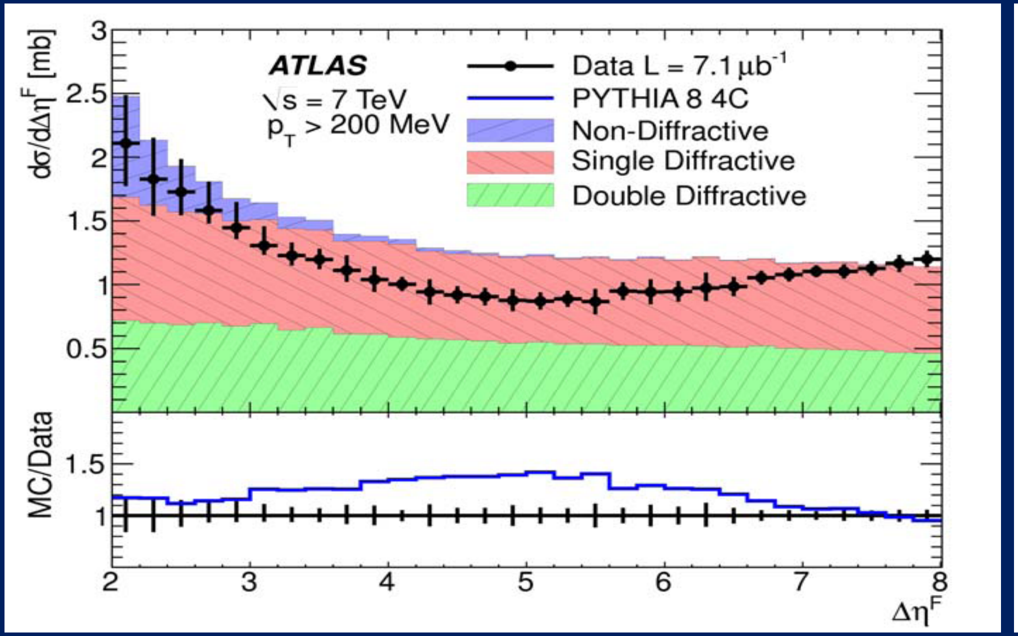


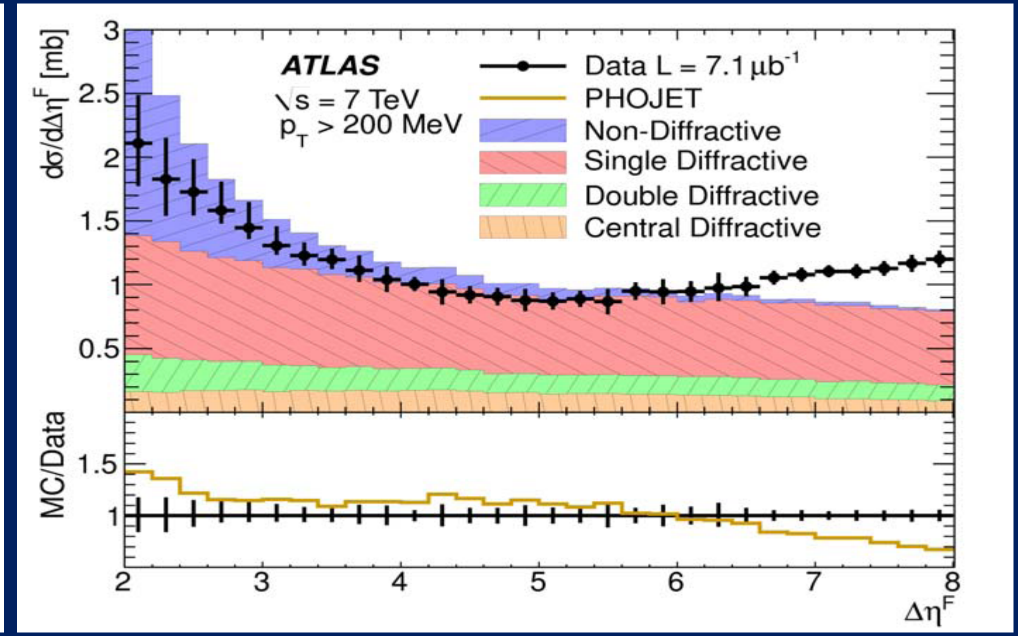


Cross section vs forward rapidity gaps for $\Delta\eta^F > 2$

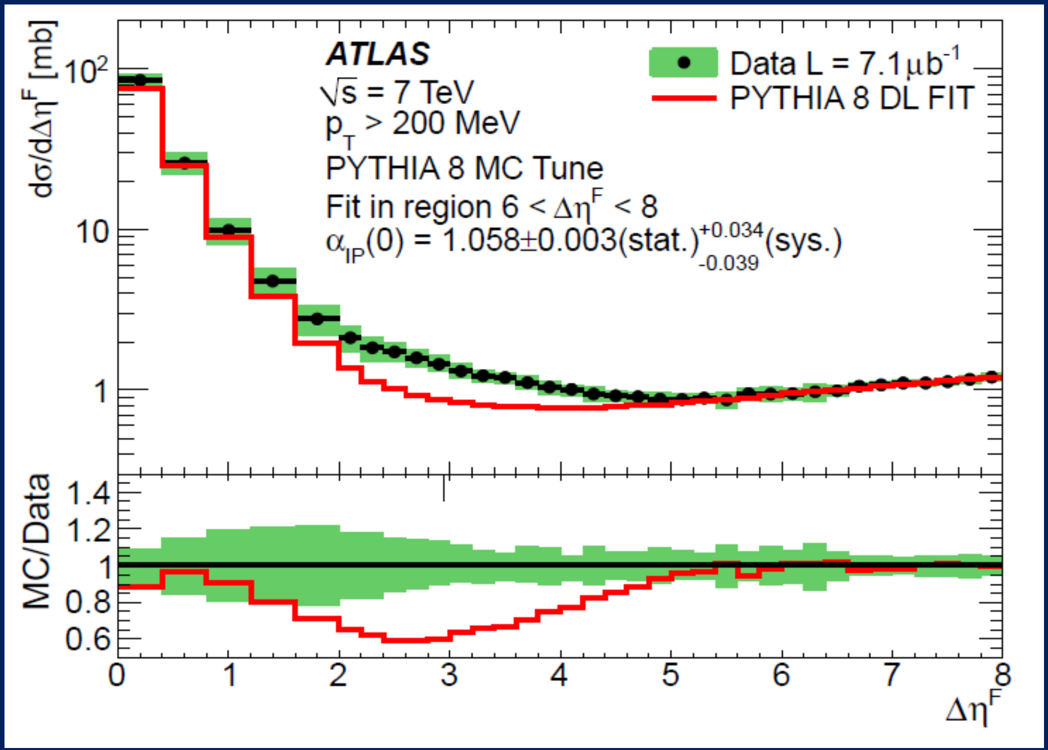
PYTHIA8 overshoots the data, probably due to an overestimation of DD (ie. PYTHIA compared to Tevatron data for DD). It described f_D

PHOJET has a CD contribution and a much smaller DD contribution with respect to PYTHIA. It overestimates of the total inelastic cross section



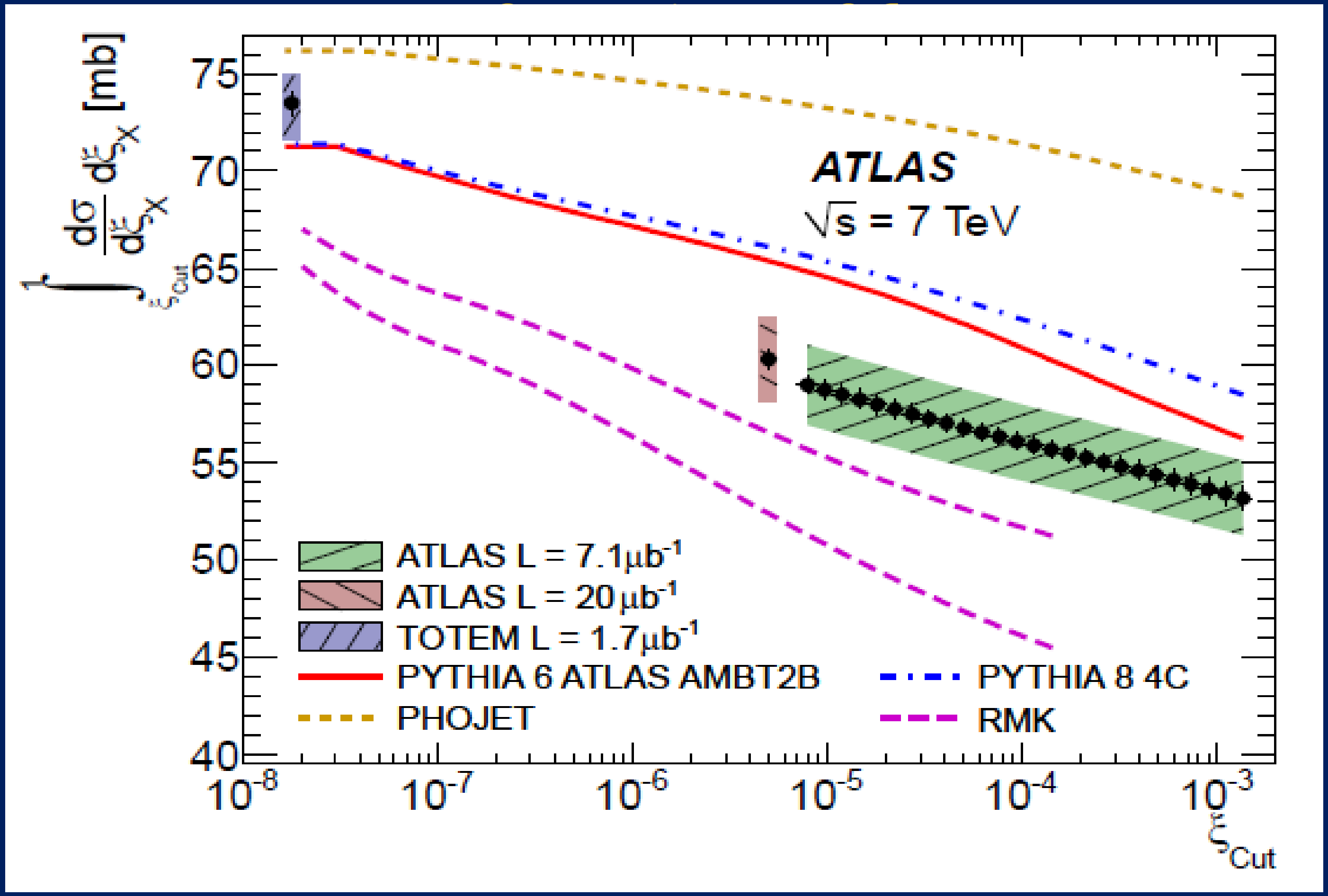


Cross section vs forward rapidity gaps for $\Delta\eta^F > 2$ and diffractive dynamics



- ND events decrease with $\Delta\eta^F$ and are supposed to be negligible for $\Delta\eta^F > 3$
- Increase at large $\Delta\eta^F$ due to $\alpha_{IP}(0)>1$ DL $\alpha_{IP}(0)=1.085$
- Fit in region $6 < \Delta\eta^F < 8$ ➔ $\alpha_{I\!P}(t=0) = 1.058 \pm 0.003(\text{stat})^{+0.034}_{-0.039}(\text{syst})$
- At large $\Delta\eta^F$ a plateau, flatness indicates a Pomeron intercept close to 1
- Cross-section of ~1mb per unit rapidity (cf. Ryskin Martin Khoze, arXiv:1102.2844)

Inelastic cross section integrated for $\xi > \xi_{cut}$



- ATLAS and TOTEM data compared to predictions
- RMK reproduces the enhancement at very low ξ, assuming a $\mathbb{P}\mathbb{P}\mathbb{R}$ term and not just the $\mathbb{P}\mathbb{P}\mathbb{P}$ term

Summary

- Inelastic cross-section measured for ξ>5.106, and extrapolated to $\xi > m_p 2/s$
- Large modeling uncertainty in the extrapolation, due to low-mass diffraction
- Rapidity gap studies give a diffractive fraction f_D=30.2±0.3(stat)±3.8 (syst) %

- Cross-section measured as a function of the forward rapidity gap, for $\Delta\eta^F$ up to 7 (ATLAS central detector)
- Data compared with models based on Triple Pomeron exchange, allow to validate MC and sensitive to diffractive dynamics
- Diffractive cross section $d\sigma/\Delta\eta^F \sim 1.0 \pm 0.2$ mb per unit of $\Delta\eta^F$ for $\Delta\eta^F > 3.5$

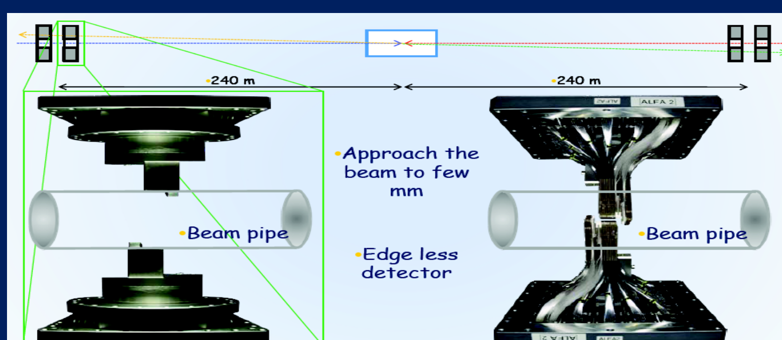
Backup

ALFA - Absolute Luminosity For ATLAS

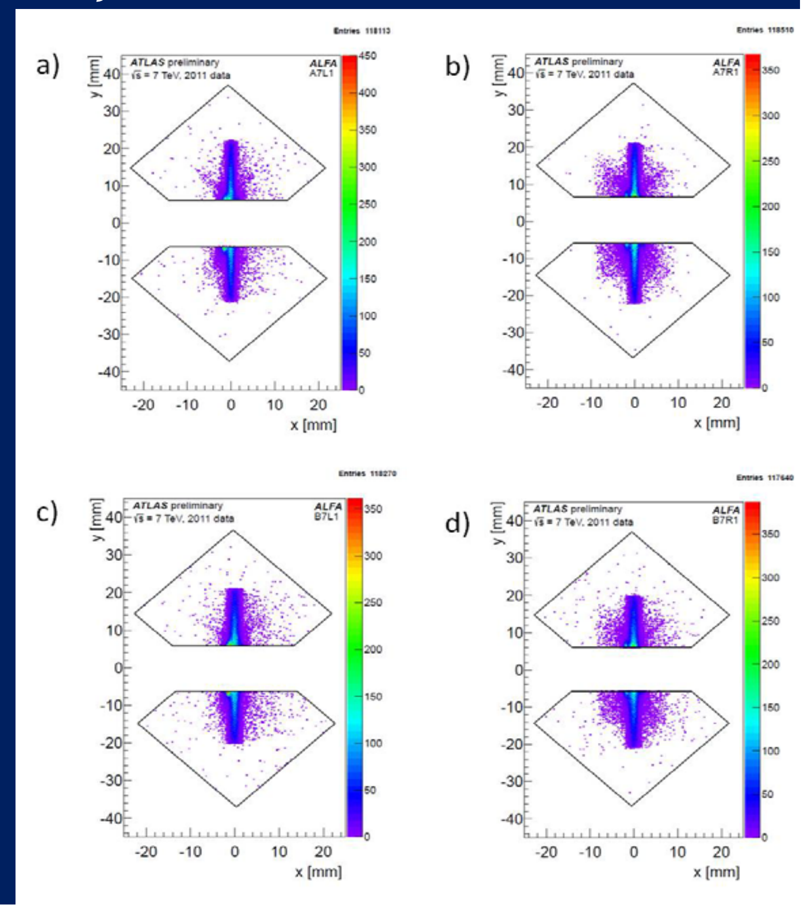
See talk by Sune Jakobsen

- Designed to detect protons t ~3.7 10^{-4} GeV^2
- primary goal is to measure absolute luminosity and to reach the level of a precision 2-3%
- Single diffractive measurements are possible for $\xi < 0.01$
- and non-diffractive proton measurements for $0.01 < \xi < 0.1$

- Dedicated high β^*= 90m run (October 2011)
- Track patterns of candidates of elastic scattering for a recent run in the LHC beam coordinate system with a preliminary alignment.



+/- 237 m +/- 241 m from IP.

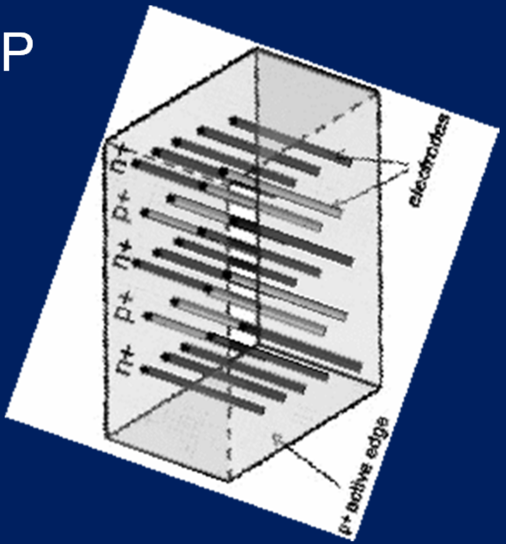


Plans for ATLAS Upgrade

See talk by Maciej Trzebinski

AFP: Atlas Forward Program (AFP1 and AFP2)

- AFP1 Detectors located in two stations: 206/214 m from IP
- AFP2 420m from IP (later)

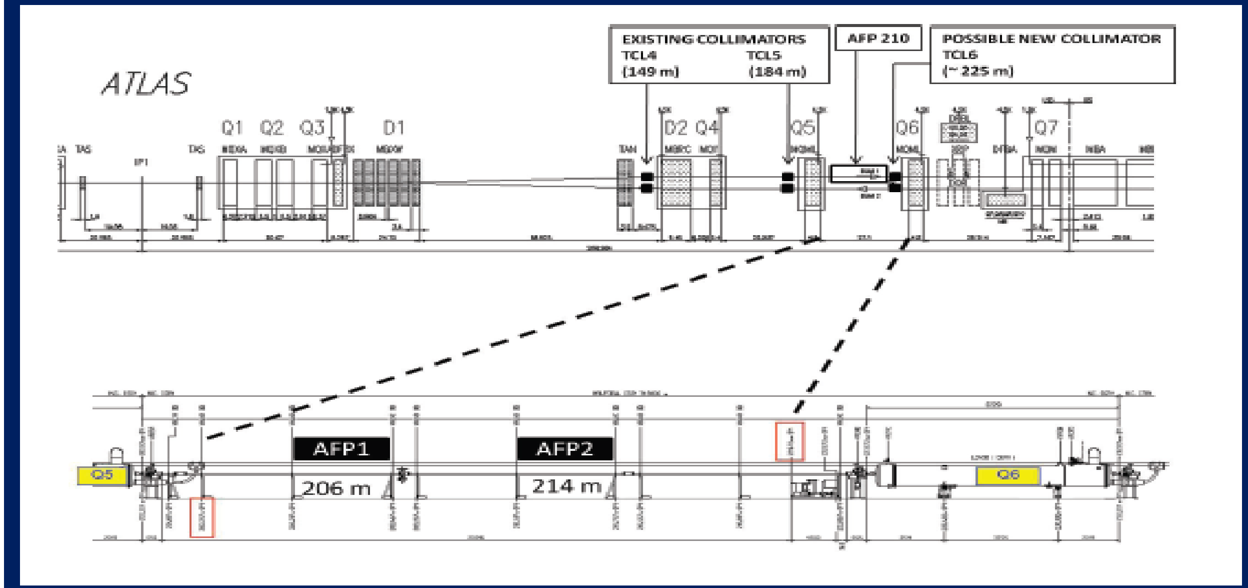


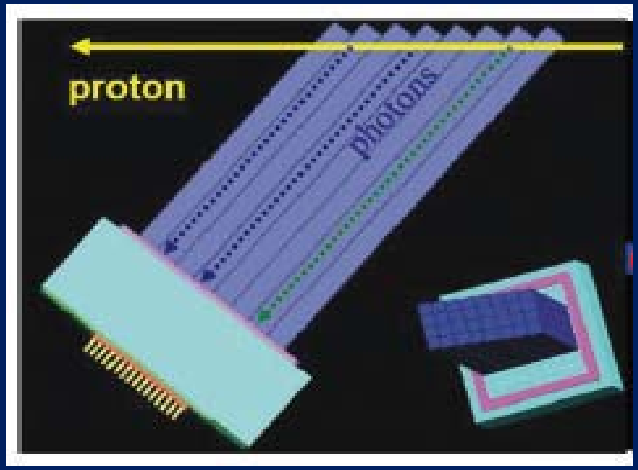
Silicon Tracking Detectors:

- measure position and angle
- Radiation hardness (~30 kGy/year @ 10^{34} $cm^{-2}s^{-1}$) → Silicon 3D detectors

Timing detectors:

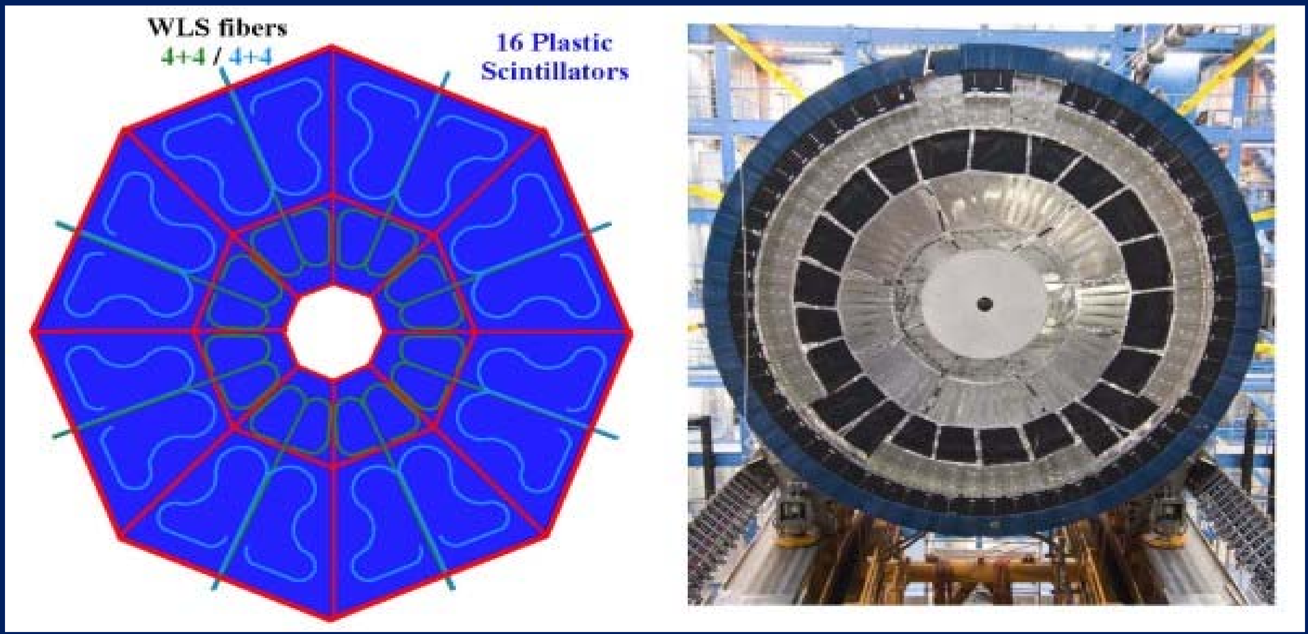
- Timing resolution: $\sigma(t)$~10~20ps → $\sigma(z)$ few mm
- MHz rate + Trigger capability
- Quartz based Cherenkov detector + Microchannel plate PMT





Minimum Bias Trigger Scintillator

- 32 independent wedge-shaped plastic scintillators (16 per side) read out by PMTs, $2.09<|\eta|<3.84$



- Designed to for triggering on min bias events, >99% efficiency
- MBTS timing used to veto halo and beam gas events
- Also being used as gap trigger for various diffractive subjects