

# Measurements of single diffraction using forward proton tagging at ATLAS

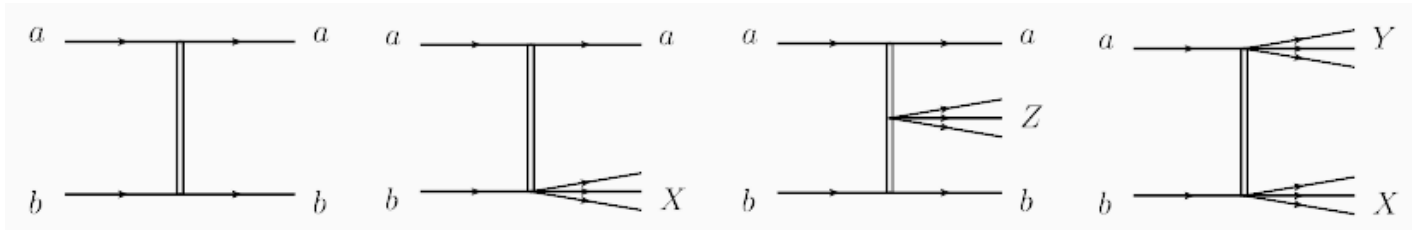
J. J. Chwastowski (IFJ PAN)  
on behalf of the ATLAS Collaboration

Workshop on Forward Physics and QCD at the LHC, the future Electron  
Ion Collider and Cosmic Ray Physics

Ciudad de Guanajuato, Mexico, 18-21 November, 2019

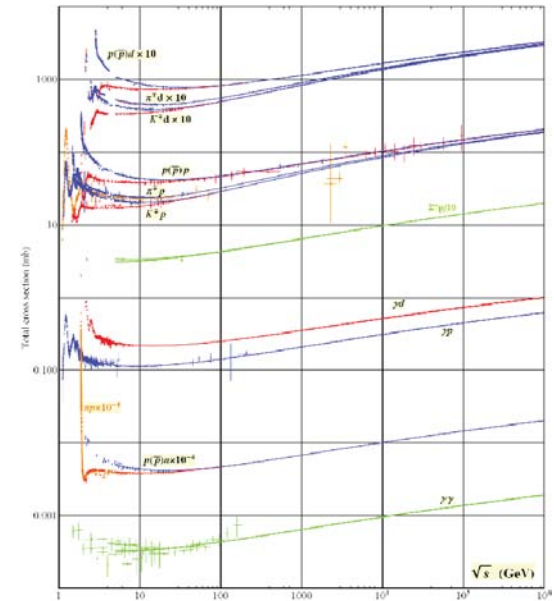
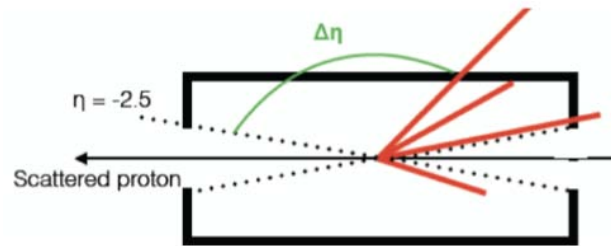
# Diffraction

Colourless exchange motivated by the high-energy universal behaviour of the cross-sections



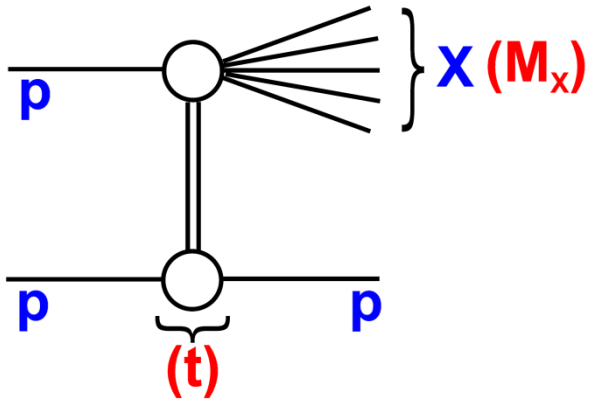
Signatures:

- a region devoid of particles -- (pseudo)rapidity gap
- a presence of an intact leading particle



Two-gluon system – Pomeron  
 (EM exchange important for  $\sigma_{\text{elas}}$ )  
 Typically requires low luminosity

# Diffraction Kinematics



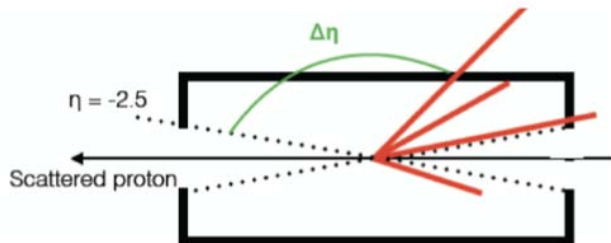
$t$  – the four-momentum transfer squared

$$t \approx -p_T^2$$

$\xi$  – the fractional energy loss of a proton

$$\begin{aligned} \xi &= 1 - E/E_{\text{beam}} \\ &= M_x^2/s \approx \sum_j (E_j + p_j)/vs \end{aligned}$$

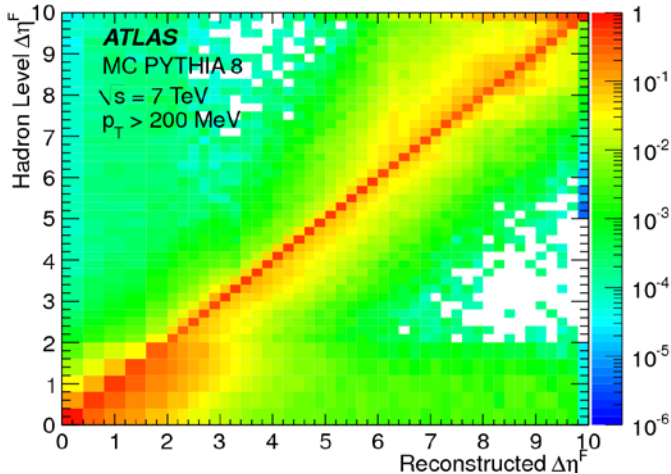
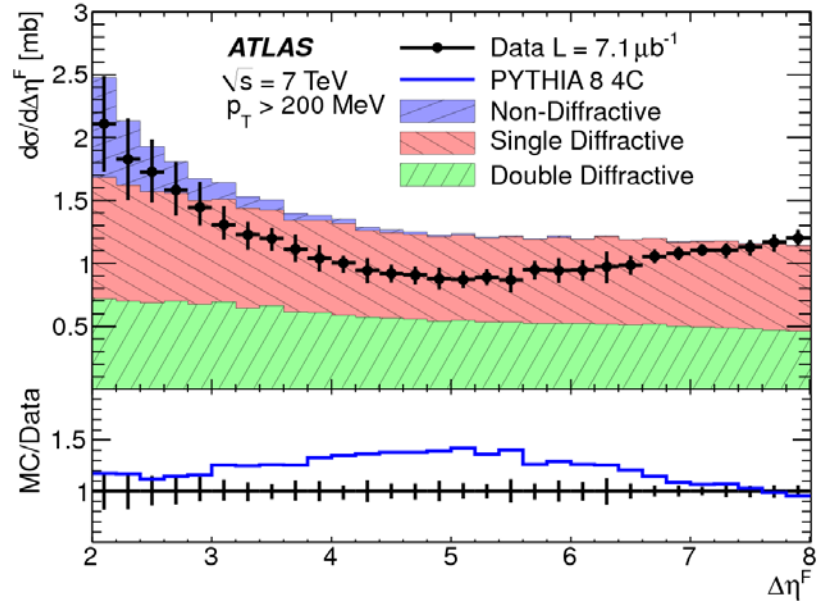
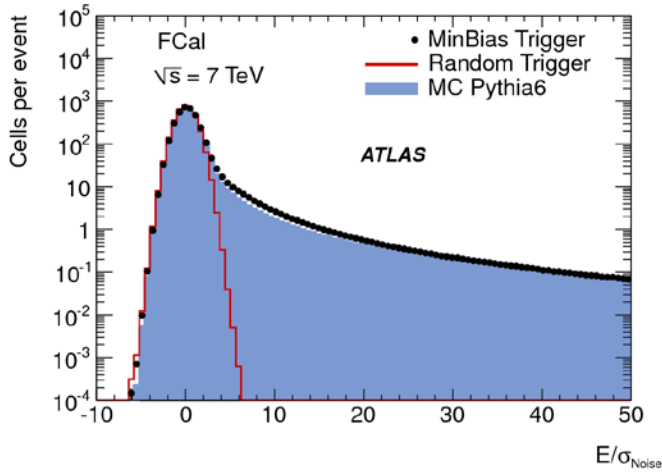
$\Delta\eta$  – the rapidity gap measured from some edge (tracker, calorimeter)



# Diffraction using the gap tag @ ATLAS

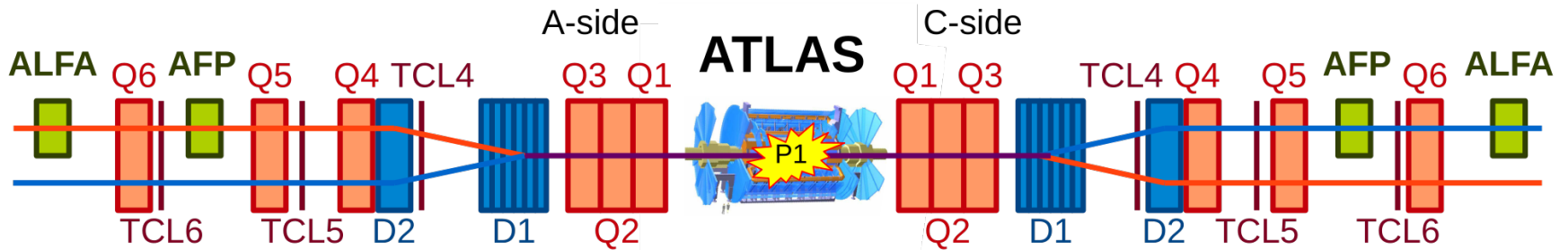
Rapidity gap measured by calorimeter

EPJ C72 (2012) 1926

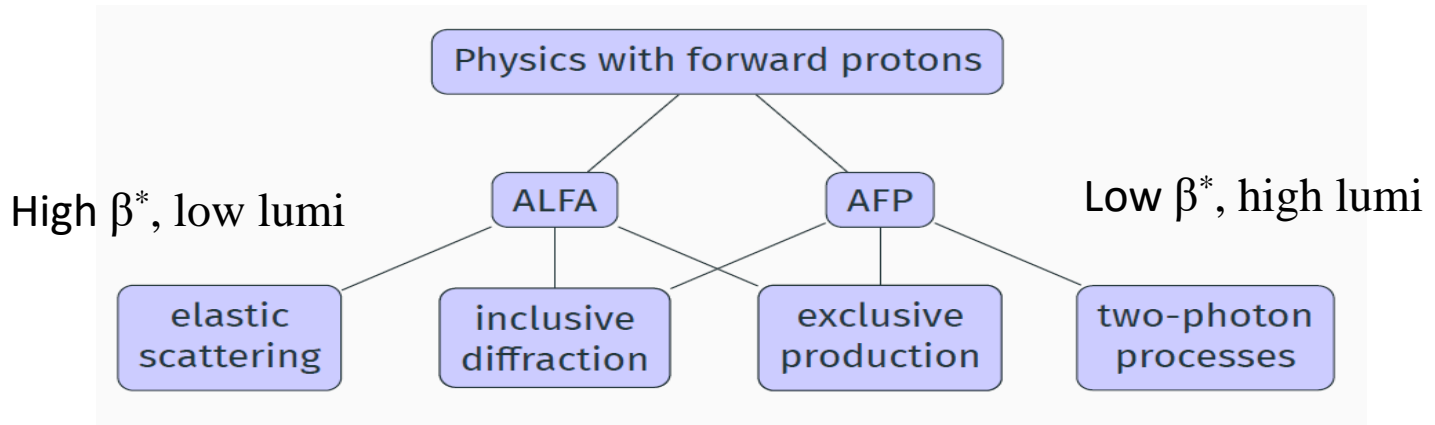


- separation of non-diffractive and diffractive components
- full separation of single and double diffraction is not feasible

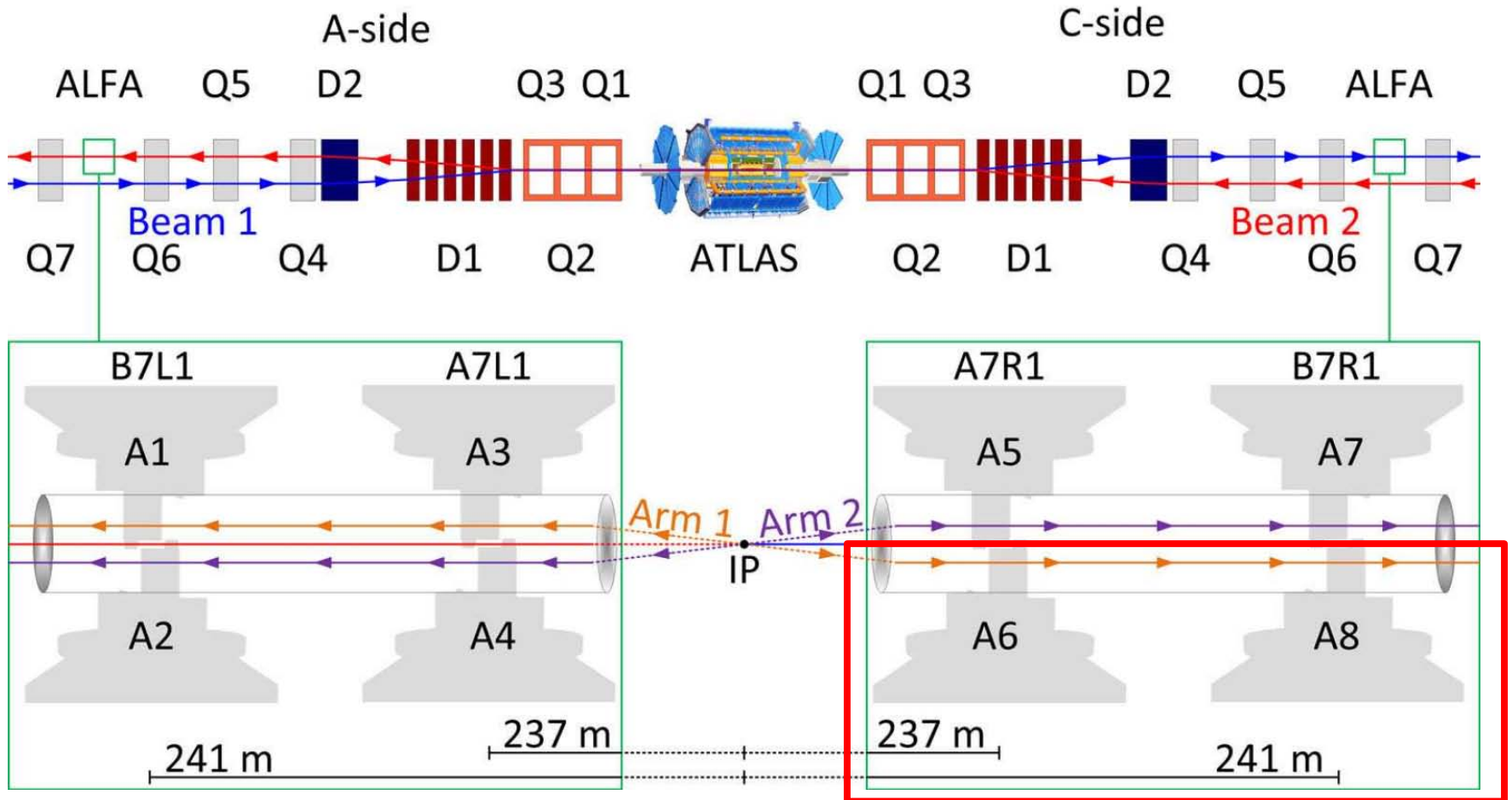
# Proton tagging apparatus @ ATLAS



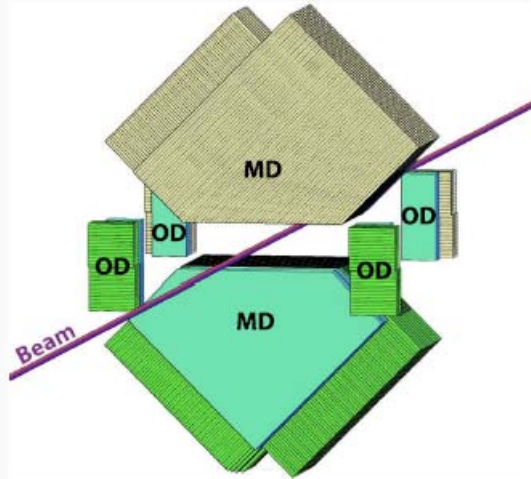
## Proton tagging apparatus physics processes



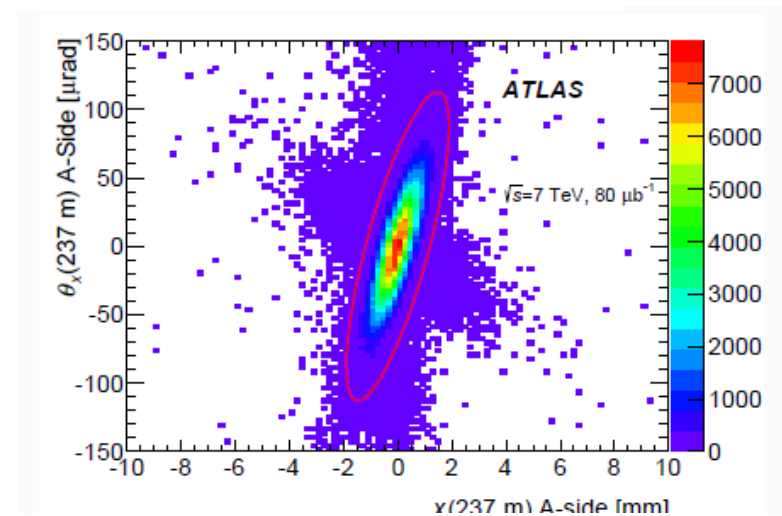
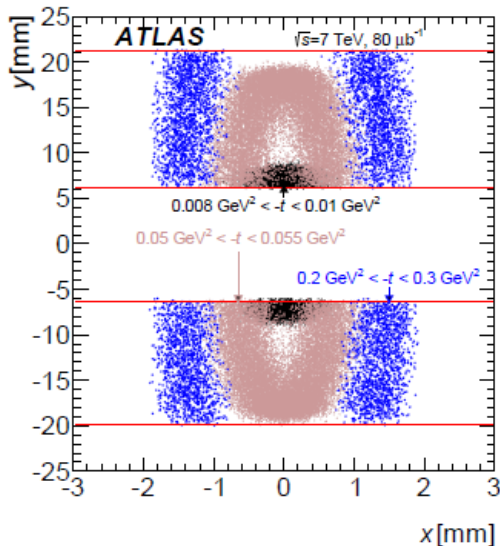
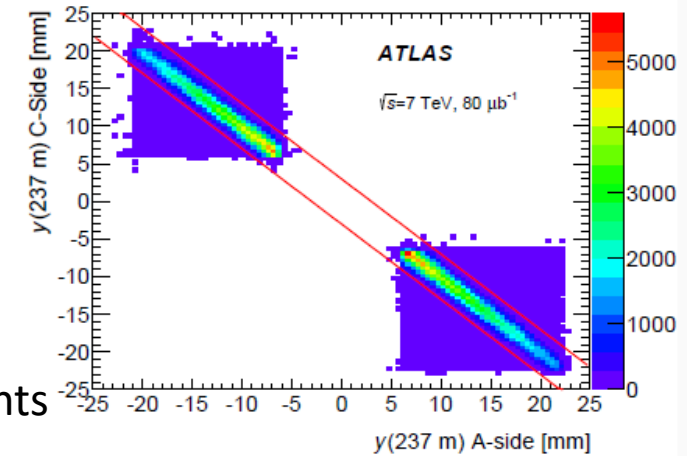
# ALFA @ ATLAS



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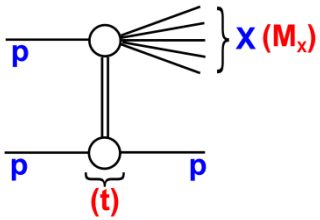


- U-V fibers in 20 planes
- Spatial resolution:  $\sim 30 \mu\text{m}$
- Mainly elastic pp
- Pronounced correlations allow efficient selection of events

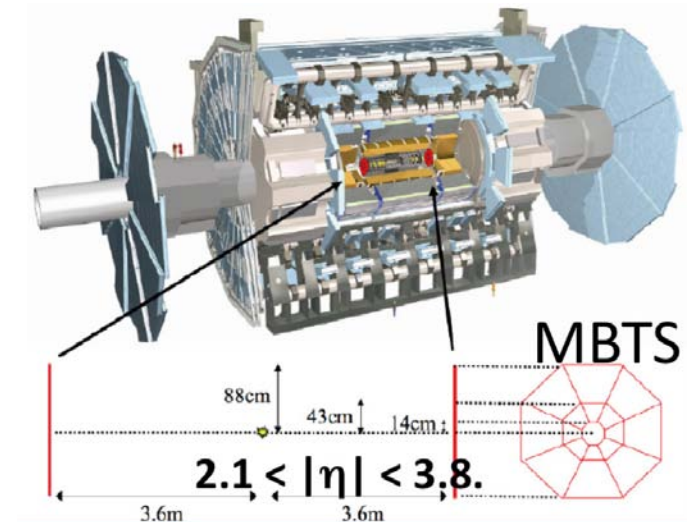


# SD Measurement with Proton Tagging in ALFA

ATLAS Collab., arXiv:1911.00453



- Special run:  $\sqrt{s} = 8 \text{ TeV}$ ,  $\beta^* = 90 \text{ m}$ ,  $\mu < 0.08$ ,  $\mathcal{L} = 1.67 \text{ nb}^{-1}$
- Intact proton measured in ALFA
- Dissociated proton measured using ATLAS tracking Detector
- Trigger: coincidence of the Minimum Bias Trigger Scintillator (MBTS) detector and the ALFA signal on opposite side of the IP
- Kinematic range:
  - MBTS: charged particles with  $2.1 < |\eta| < 3.8$
  - ALFA proton:
    - $0.016 < -t < 0.43 \text{ GeV}^2$
    - $-4.0 < \log_{10} \xi < -1.6$
  - tracker: charged particles with:
    - $p_T > 0.2 \text{ GeV}$
    - $|\eta| < 2.5$

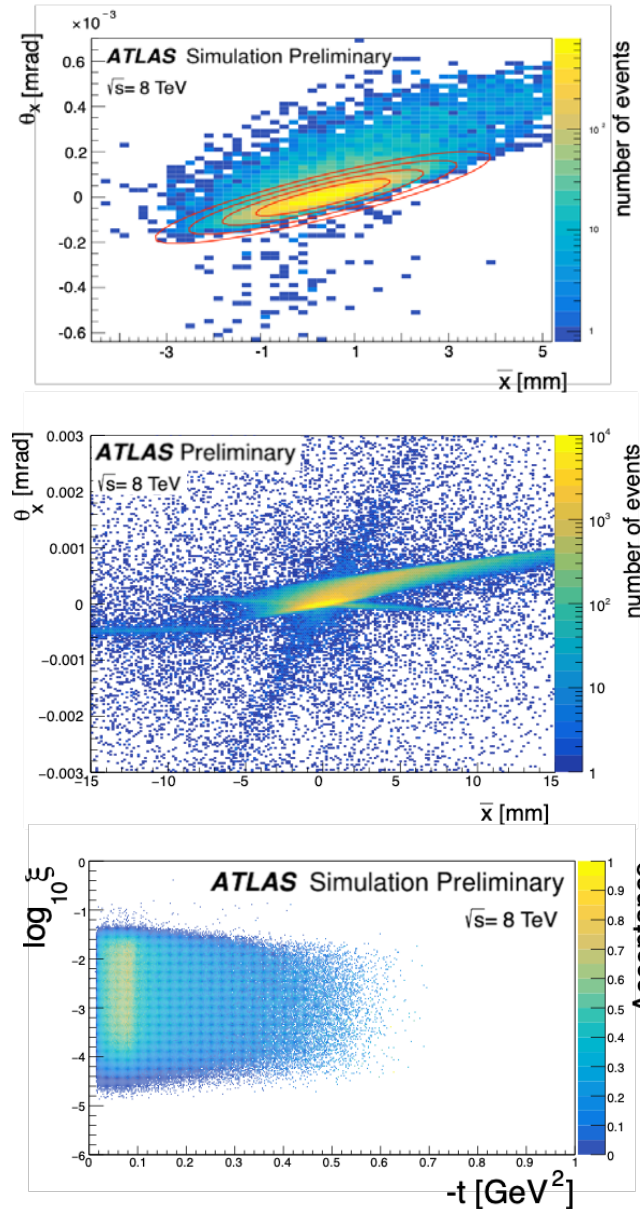




# Measurement – Event Selection

- ALFA: exactly one proton in an armlet
- $3\sigma$  cut on the ellipse in  $(x, \Theta_x)$  plane
- MBTS on the opposite side to the armlet at least 5 (out of 16) counters above the noise threshold
- Tracker: at least one track and a reconstructed vertex
- Fiducial region of the measurement:
  - $0.016 < -t < 0.43 \text{ GeV}^2$
  - $-4.0 < \log_{10} \xi < -1.6$
- Resulting range of the diffractive system mass:

$$80 \text{ GeV} < M_x < 1370 \text{ GeV}$$



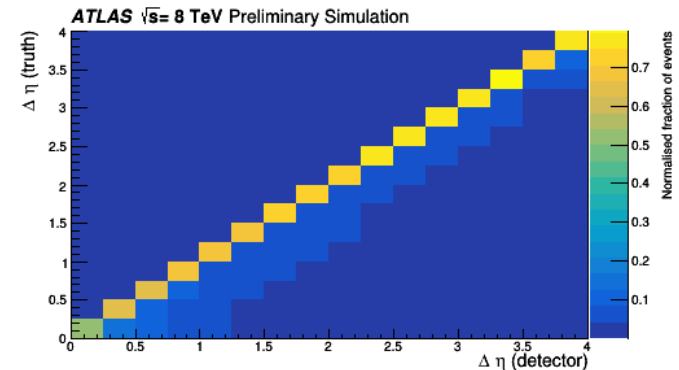
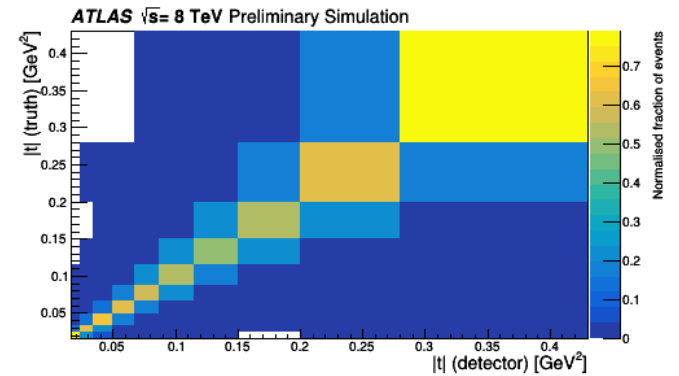
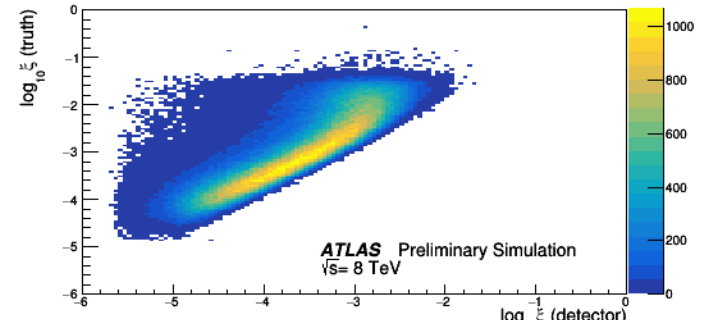
# Monte Carlo Tools

- Basic:

- PYTHIA 8 tune A3 (ATL-PHYS-PUB-2016-017)
  - PDF: NNPDF23 LO
  - Pomeron: PDF H1 2006 Fit B, flux: intercept 1.06, slope 0.25 (DL)
- SD to unfold the data
- CD, DD, ND for the background subtraction
- Elastic pp: ALFA reconstruction efficiency

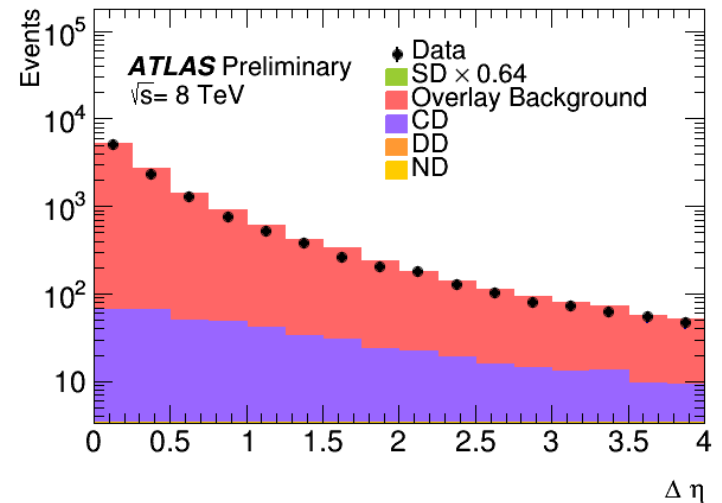
- Systematics:

- PYTHIA 8 A2 (ATL-PHYS-PUB-2012-003)
- HERWIG 7.1.3:
  - PDF: MMHT2014lo58cl
  - Pomeron PDF: H1 2006 fit A
  - Flux: intercept: 1.00, slope: 0.25



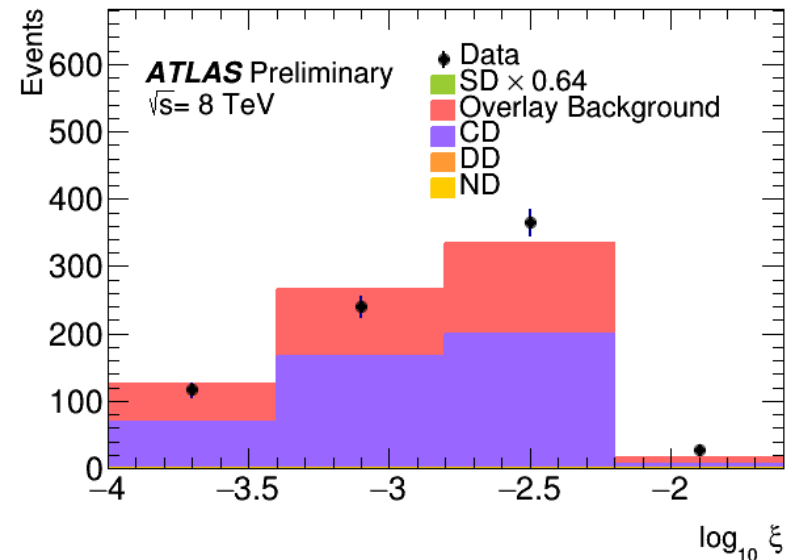
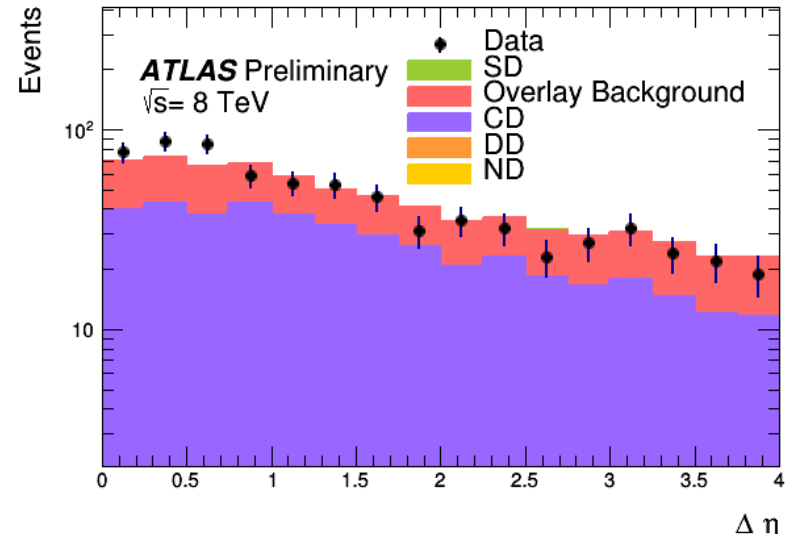
# Backgrounds – Overlay

- Source: coincidence of an ALFA proton and the central ATLAS activity
  - Protons: elastic pp, beam halo
  - Central: minimum bias events
- Dominant background
- Data driven estimate – ND-processes enriched sample:
  - 32 MBTS segments fired
  - t-distribution shape from ALFA
  - $\Delta\eta$  and  $\xi$  from MC events passing analysis selection
- Control region:
  - nominal selection + protons in two armlets
- Dominated by elastics overlaid with ND

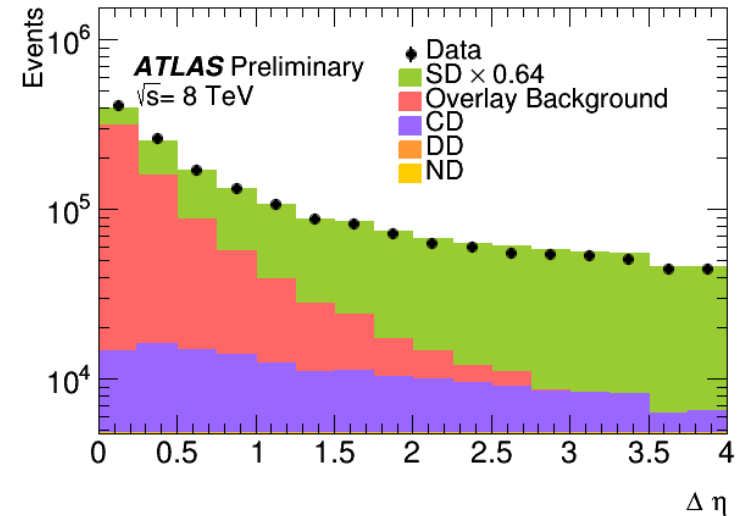
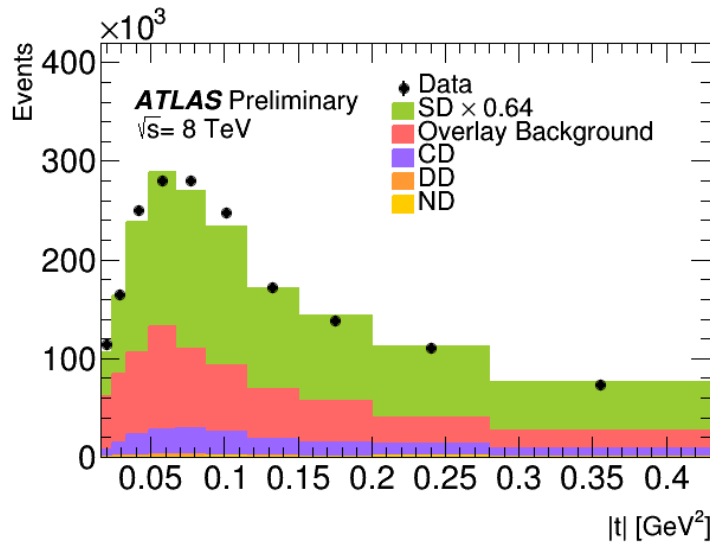
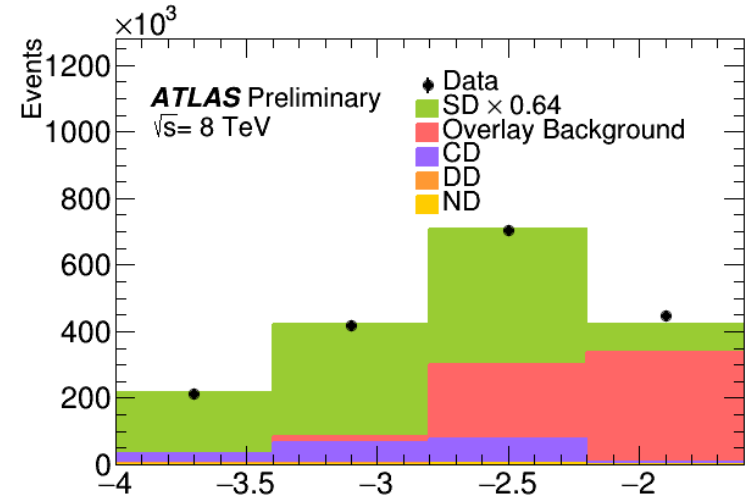
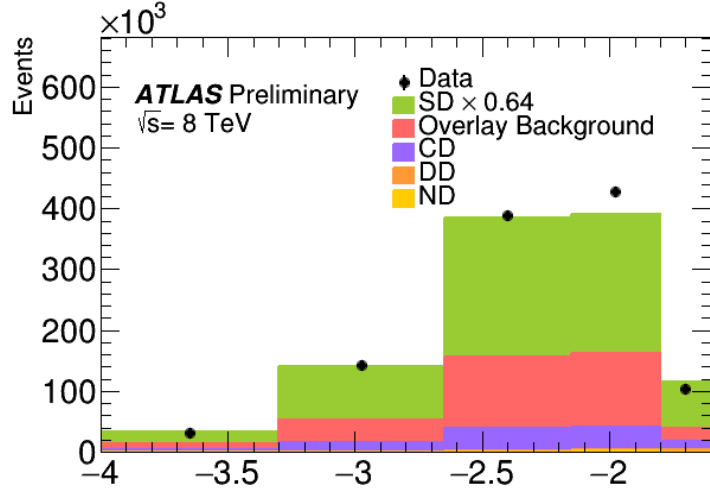


# Backgrounds – Central Diffraction

- Dominant physics background type
- Estimation: Monte Carlo based
- Control region definition:
  - MBTS segments: 2 -10
  - Protons in two armlets
- Shape and normalisation well described
- $\xi$ -distribution reweighted to match the data, normalisation preserved



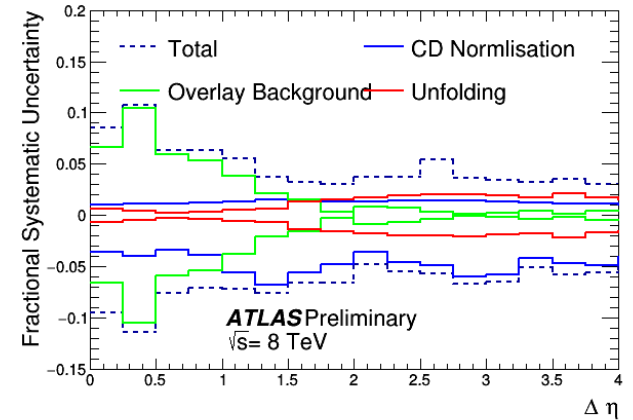
# Control Plots (detector level)



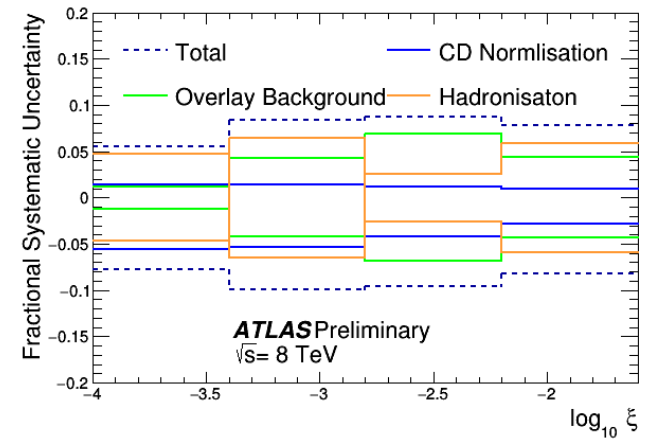
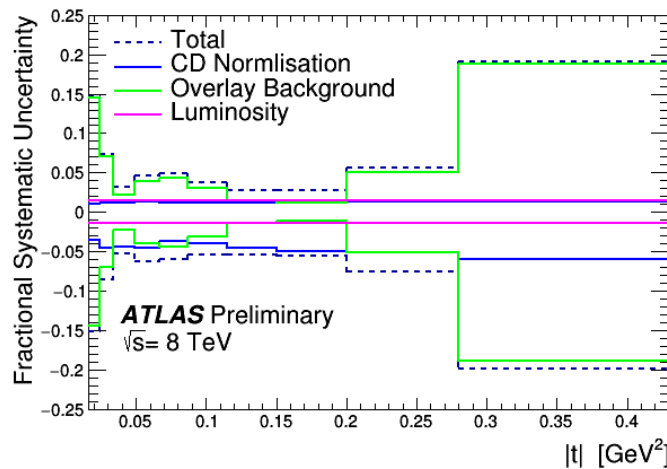
Rescaling SD by 0.64 leads to a good description of the distributions – shapes & normalisation

# Systematics

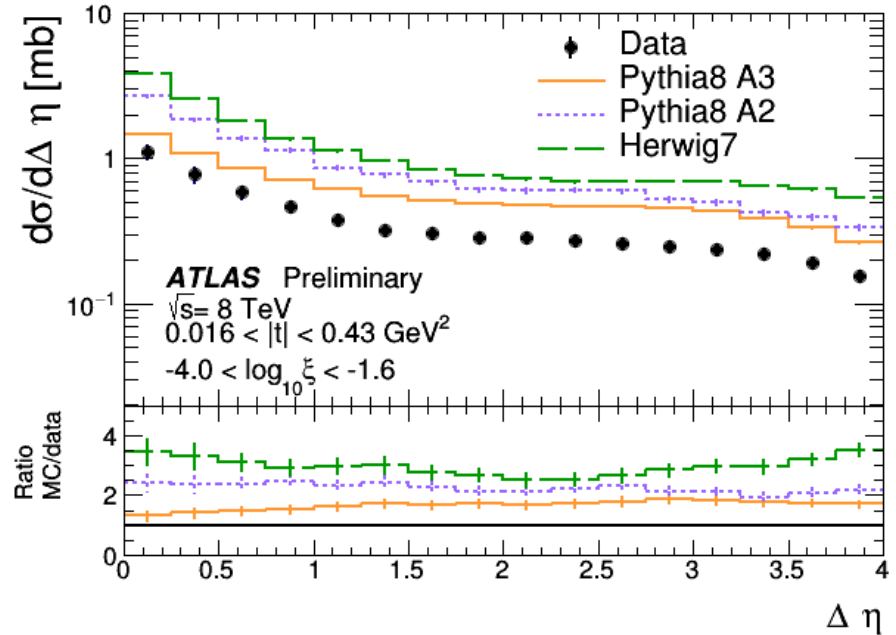
- Dominant contribution – overlay background
- CD –shape (reweighted or not) & normalisation
- Hadronisation model: PYTHIA, HERWIG



- Unfolding
- Luminosity



# Results: $\Delta\eta$ – distribution



- Unfolded to hadron level
- Diffractive plateau visible (deviation from  $e^{-\Delta\eta}$ )
- Increase at small gaps: rapidity restrictions of the ID
- Decrease at larger gaps:

fiducial range,  
loss of small- $\xi$  events close to  $\xi$  edge ( $10^{-4}$ )

- Monte Carlos do not describe the data

	$\sigma_{MC}/\sigma_{data}$
PYTHIA 8, A2	2.3
PYTHIA 8, A3	1.5
HERWIG 7.1	3

# Results: $t$ – distribution

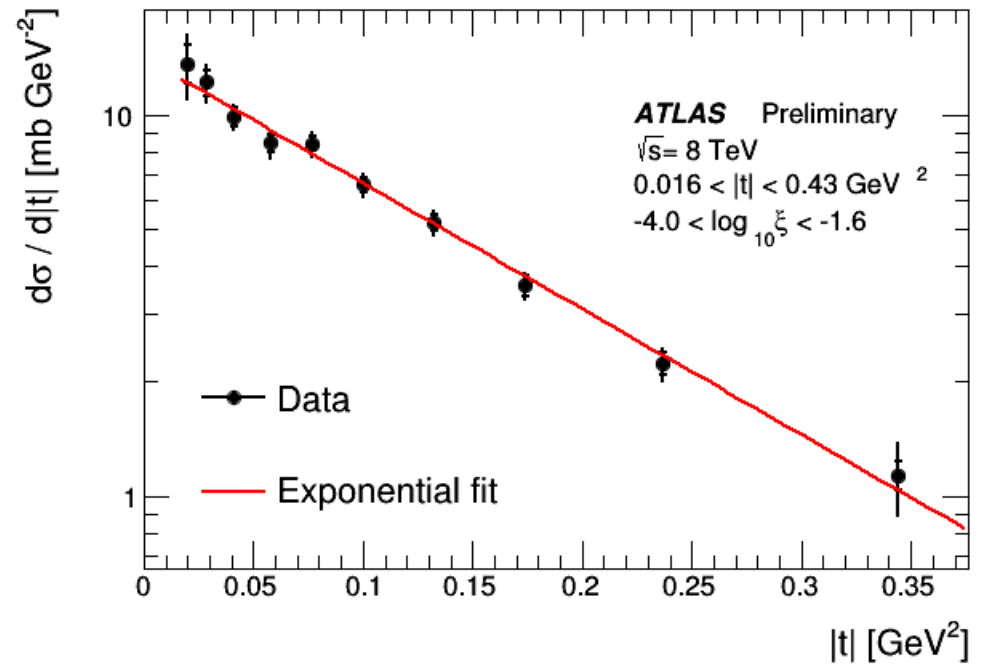
- Exponential fit results slope:

$$B = 7.60 \pm 0.23(\text{stat.}) \pm 0.26(\text{syst.}) \text{ GeV}^{-2}$$

- In agreement with PYTHIA8:

- A2:  $7.82 \text{ GeV}^{-2}$
- A3:  $7.10 \text{ GeV}^{-2}$

- Largest systematic uncertainty due to overlay background

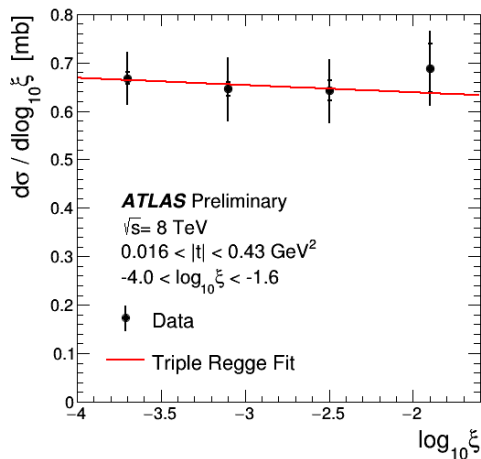




# Results: $\xi$ – distribution

- Fit of: 
$$\frac{d\sigma}{d\xi} = \left(\frac{1}{\xi}\right)^{\alpha(0)-1} \frac{e^{Bt_{high}} - e^{Bt_{low}}}{B}, B = B_0 - 2\alpha' \ln \xi, -0.43 \text{ GeV}^2 \leq t \leq 0.016 \text{ GeV}^2$$

- gives Pomeron intercept:  $\alpha(0) = 1.07 \pm 0.02(\text{stat.}) \pm 0.06(\text{syst.}) \pm 0.06(\alpha')$

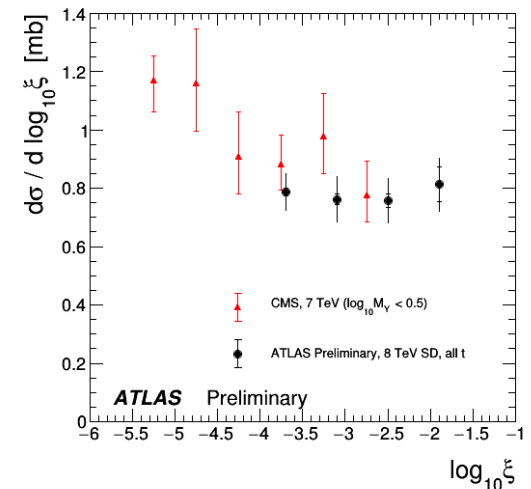


largest syst. contribution from:  $\alpha' = (0.25 \pm 0.25) \text{ GeV}^{-2}$

PYTHIA8 tunes:

A2: 1.00

A3: 1.14



- Data extrapolation to full  $t$ -range (factor 1.18)
- Compared to CMS@7TeV (Phys. Rev.D92 (2015) 012003) with CASTOR serving veto

- Reasonable agreement despite the DD contribution in CMS data and different  $\sqrt{s}$

# Results: cross-sections

- The fiducial cross-section integrated over  $-4.0 \leq \log_{10} \xi \leq -1.6$  and  $0.16 \leq |t| \leq 0.43 \text{ GeV}^2$ :

$$1.59 \pm 0.03 \text{ (stat.)} \pm 0.13 \text{ (syst.) mb}$$

- • Extrapolation to the full t-range using the measured B value:

$$1.88 \pm 0.15 \text{ mb}$$

- • Extrapolation to the full kinematic range using the average of PYTHIA8 A2 and A3 tunes:

$$6.6. \text{ mb}$$

Distribution	$\sigma_{SD}^{\text{fiducial}(\xi,t)}$ [mb]	$\sigma_{SD}^{t\text{-extrap}}$ [mb]	$\sigma_{SD}^{\xi,t\text{-extrap}}$ [mb]
Data	$1.59 \pm 0.13$	$1.88 \pm 0.15$	6.6
PYTHIA8 A2 (Schüler-Sjostrand)	3.69	4.35	12.48
PYTHIA8 A3 (Donnachie-Landshoff)	2.52	2.98	12.48
HERWIG7	4.96	6.11	24.0

# Summary

- A measurement of single diffractive dissociation  $pp \rightarrow X+p$  at  $\sqrt{s} = 8$  TeV was performed by ATLAS
- Diffractively scattered proton was directly reconstructed from ALFA measurements
- Differential cross-sections in  $t$ ,  $\xi$  and  $\Delta\eta$  were measured
- Measured distributions are quite well reproduced by the Monte Carlo predictions only if SD component is rescaled by a factor of 0.64
- MC predicted  $d\sigma/d\Delta\eta$  cross-section overruns the measured one by a factor of 1.5 to 3
- Nuclear slope form a fit to  $t$  distribution:  
$$\mathbf{B = 7.60 \pm 0.23 (stat.) \pm 0.22 (syst.) GeV^2}$$
- Pomeron intercept from a fit to  $\xi$ -distribution  
$$\mathbf{\alpha(0) = 1.07 \pm 0.02 (stat.) \pm 0.06 (syst.) \pm 0.06 (\alpha')}$$
- Comparison shows a reasonable agreement with CMS results in the  $\xi$  overlap region