Measurements of single diffraction using forward proton tagging at ATLAS

(based on ATLAS-CONF-2019-012)

and the status of ATLAS elastic scattering measurements

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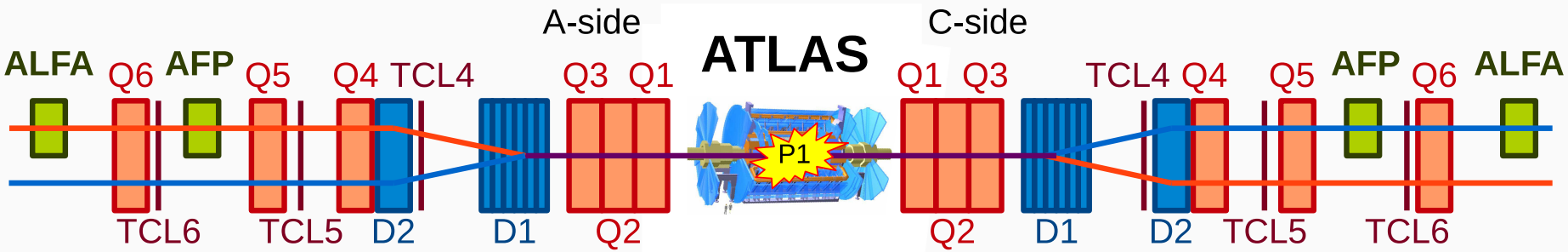
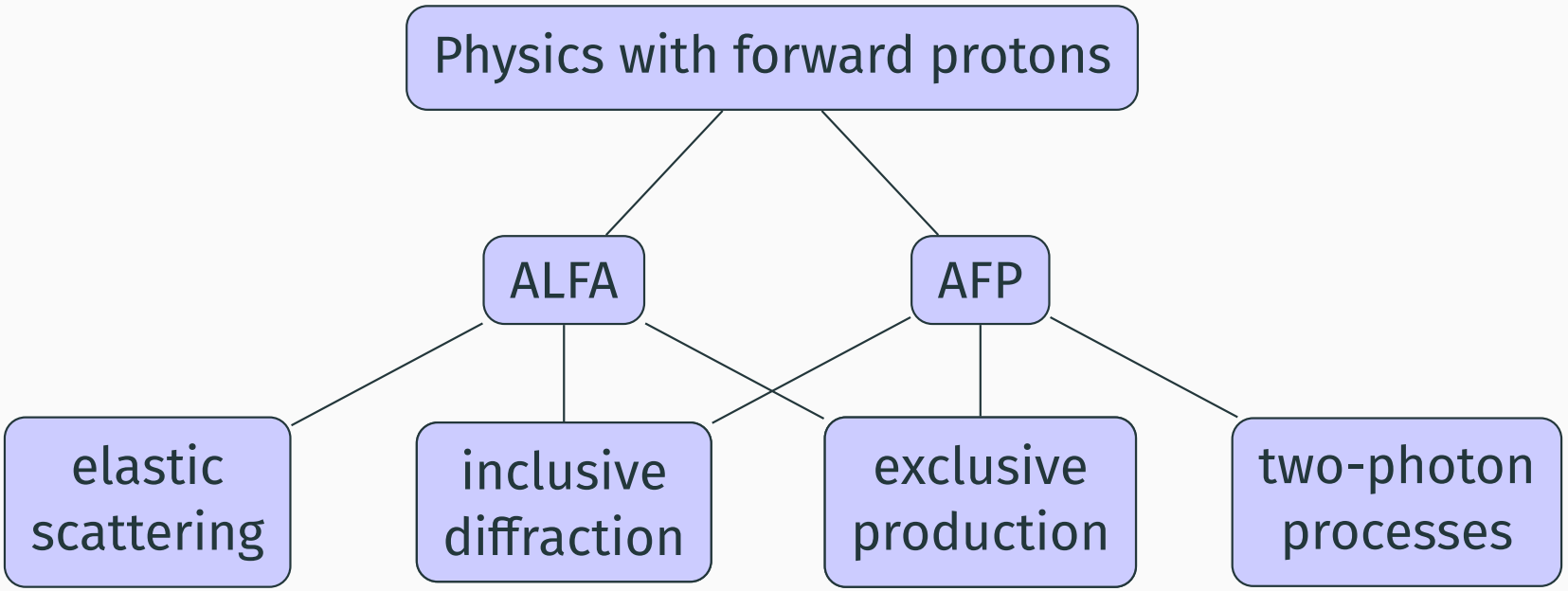
on behalf of the ATLAS Collaboration

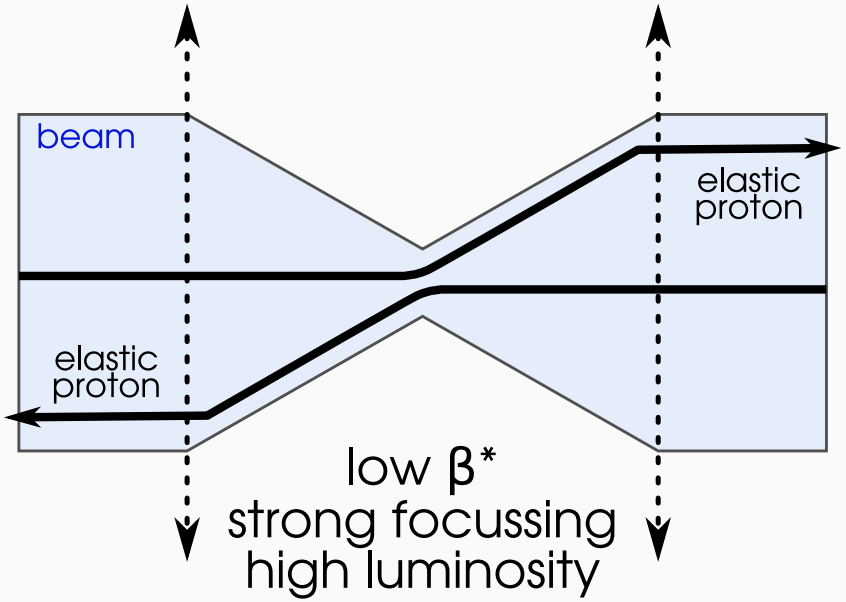
Low-x 2019, 26 – 31 August 2019, Nicosia, Cyprus

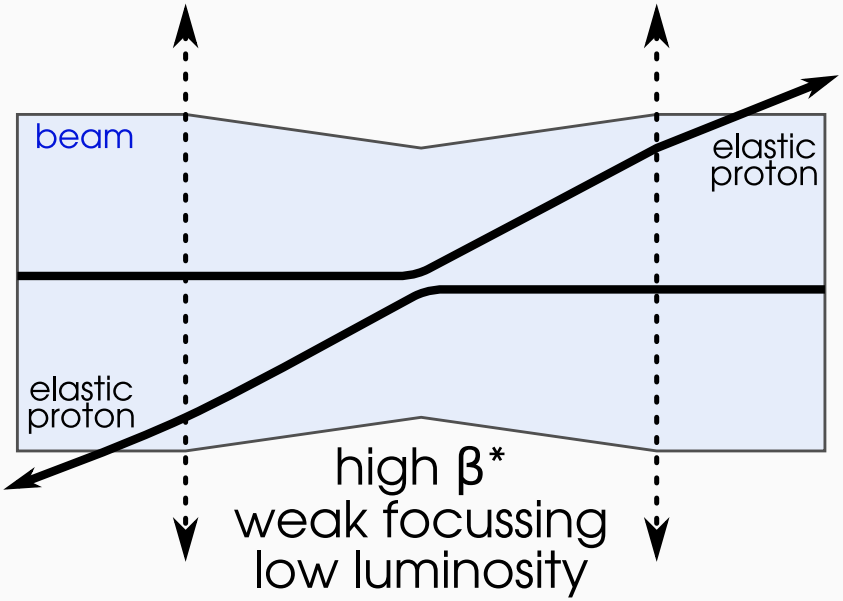
Forward protons tagging in ATLAS

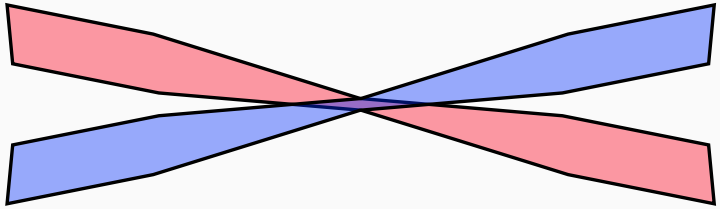




High-β optics



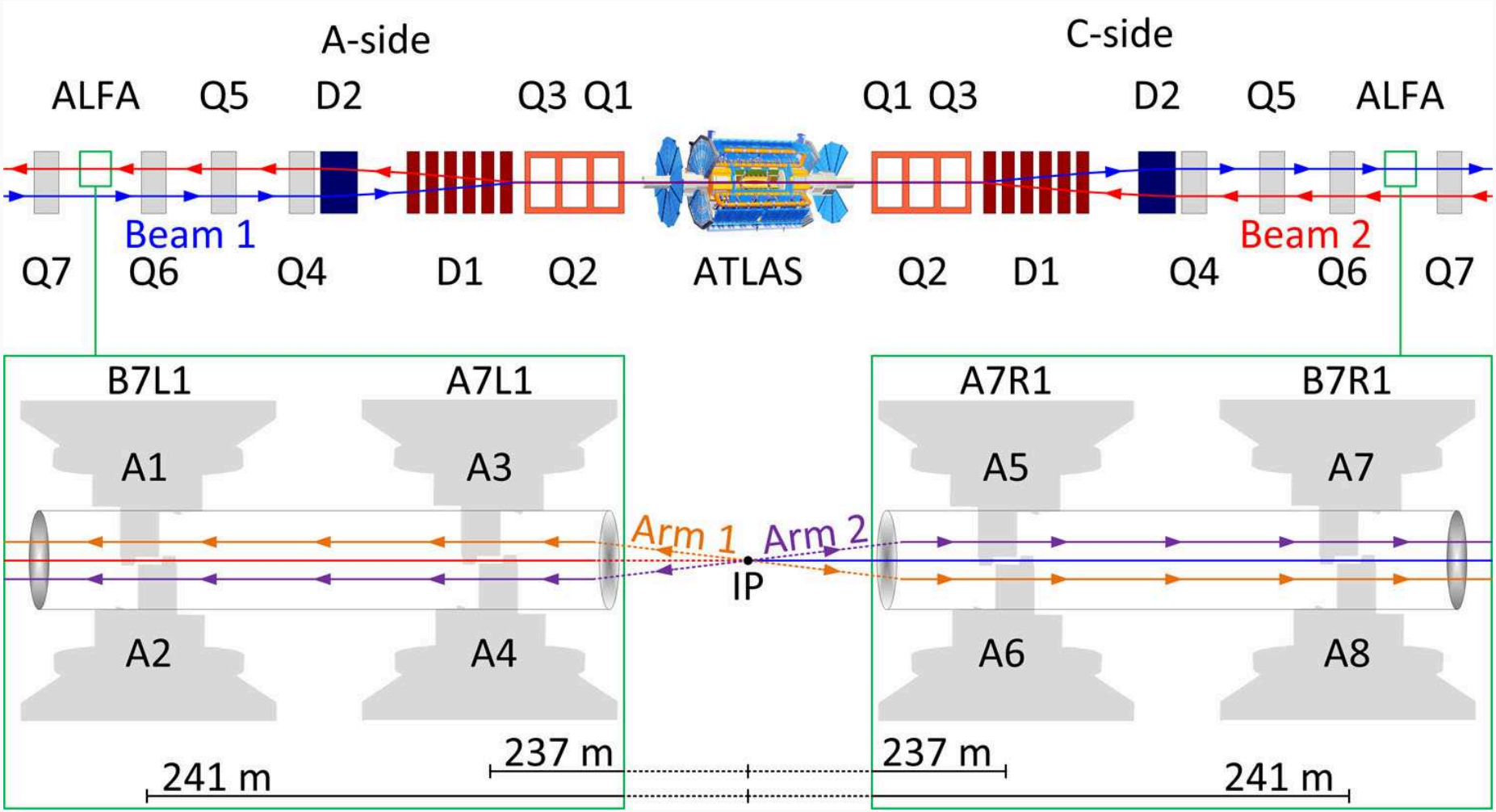




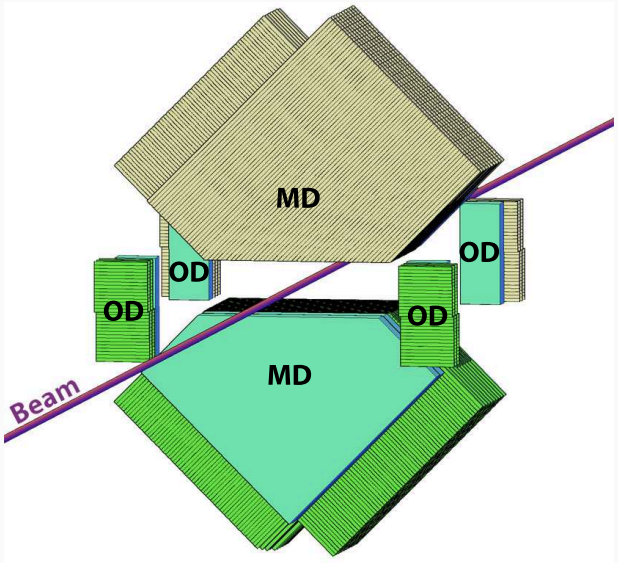
beam crossing angle

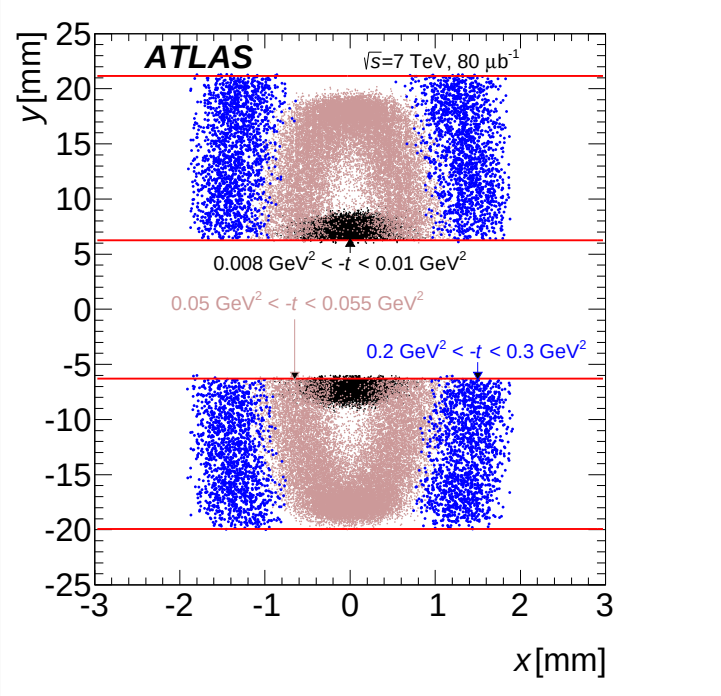
head-on beams

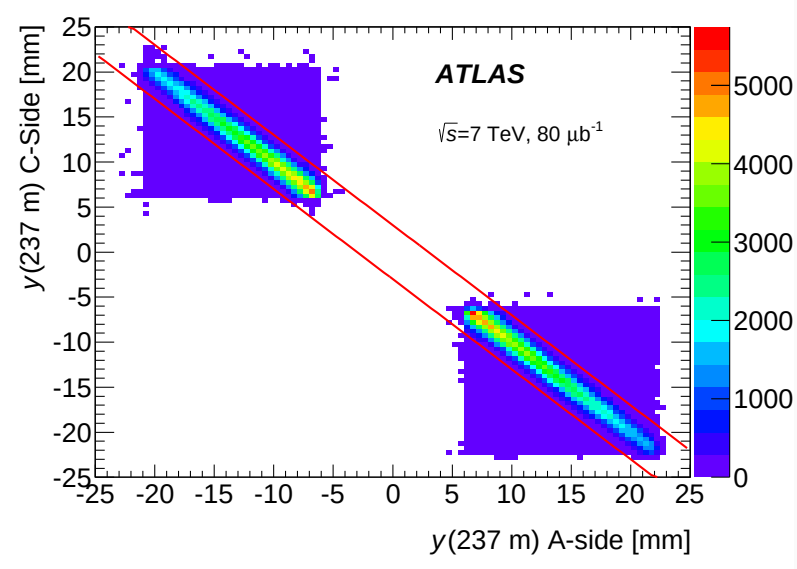
ALFA Detectors

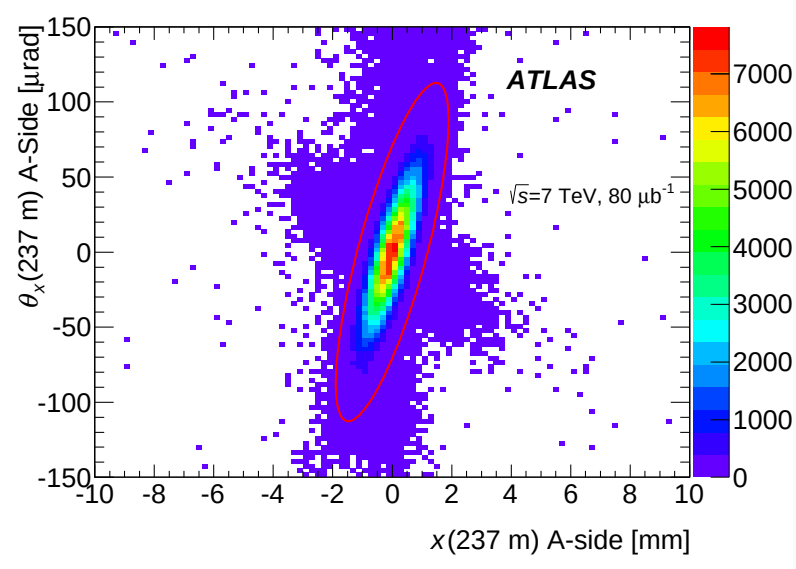


Elastic events in ALFA

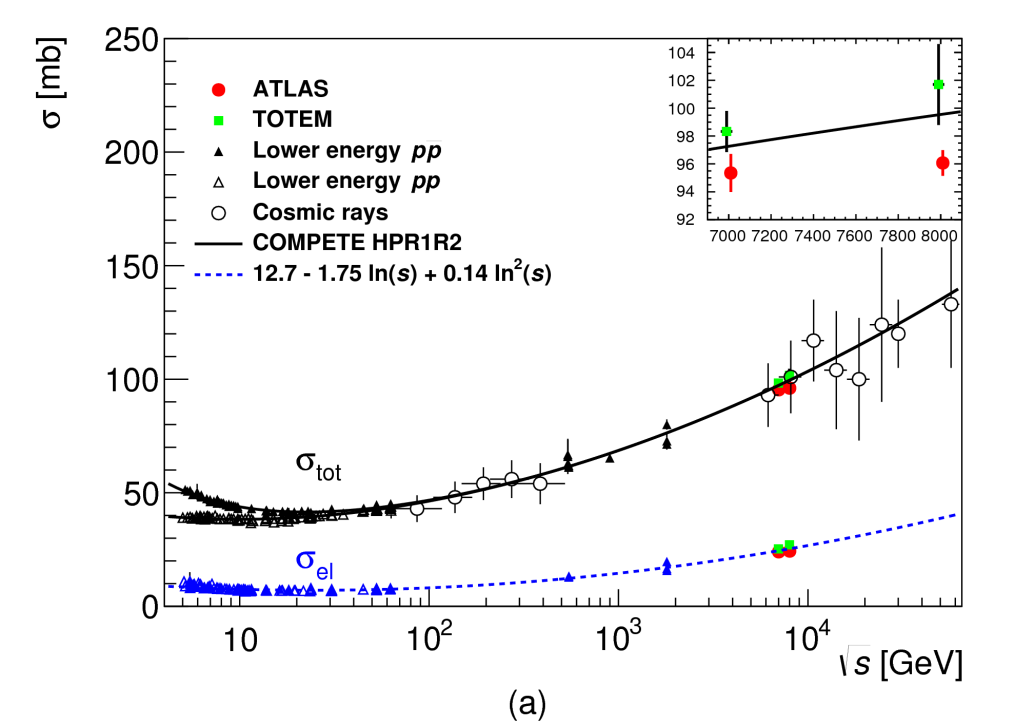








Status of elastic analyses with ALFA

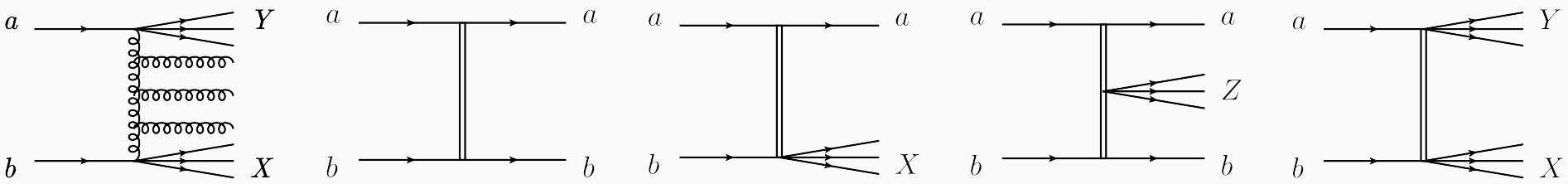


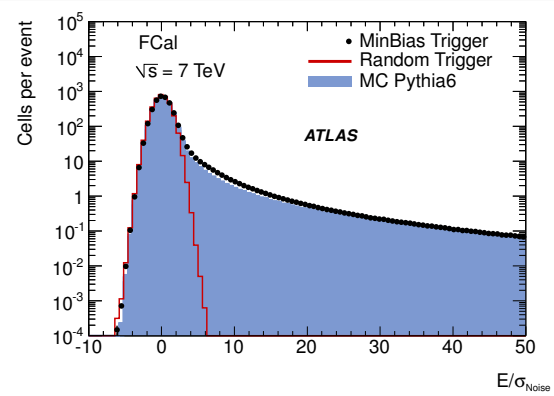
Nucl. Phys. B 889 (2014) 486
Phys. Lett. B (2016) 158

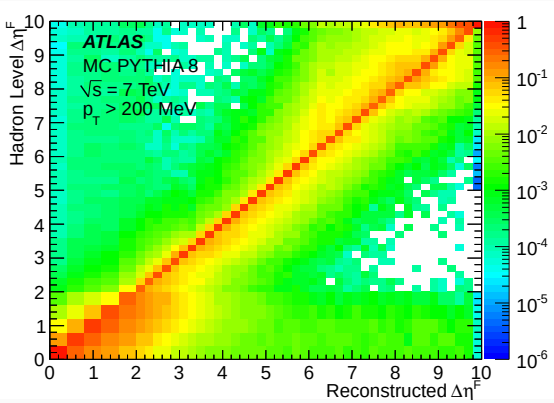
Ongoing elastic analyses:

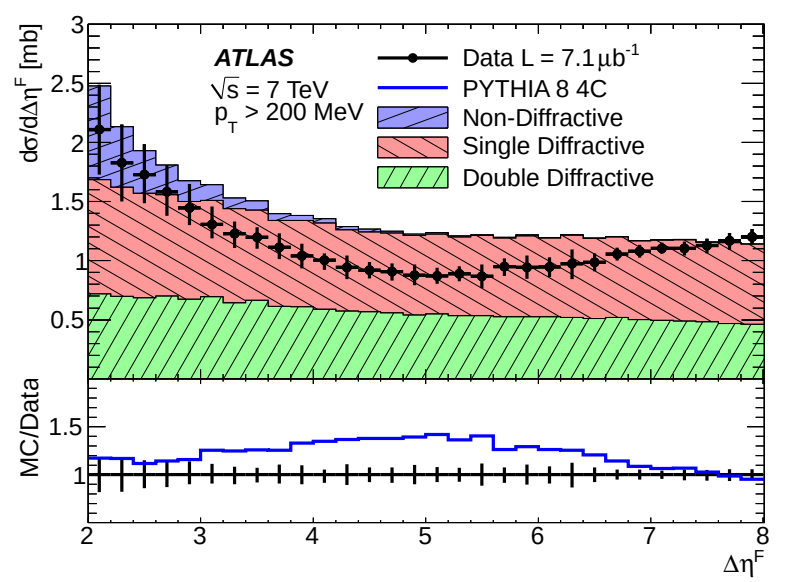
- $\sqrt{s}$ = 8 TeV, β^* = 1000 m – Coulomb-Nuclear Interference (CNI) region
  - final cross checks of systematic uncertainties
- $\sqrt{s}$ = 13 TeV, β^* = 2500 m & 90 m – CNI and dip region
  - working on vertical alignment
- $\sqrt{s}$ = 900 GeV, β^* = 100 m – CNI regions
  - early stage

Diffraction measurements w/o proton tagging (Eur. Phys. J. C (2012) 72)









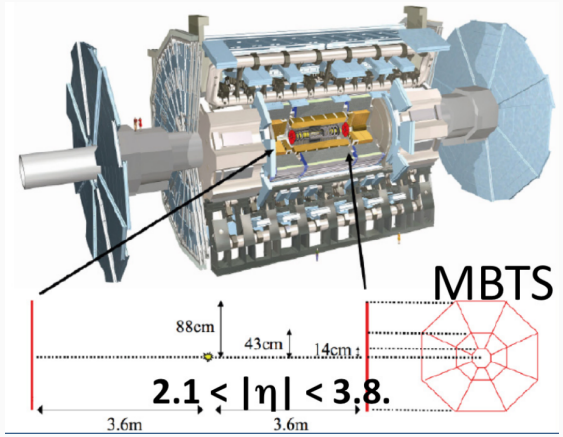
- Calorimeter used to measure rapidity gaps

- Separation of diffractive processes from non-diffractive processes
- Full separation of single and double diffraction not possible

Measurement overview

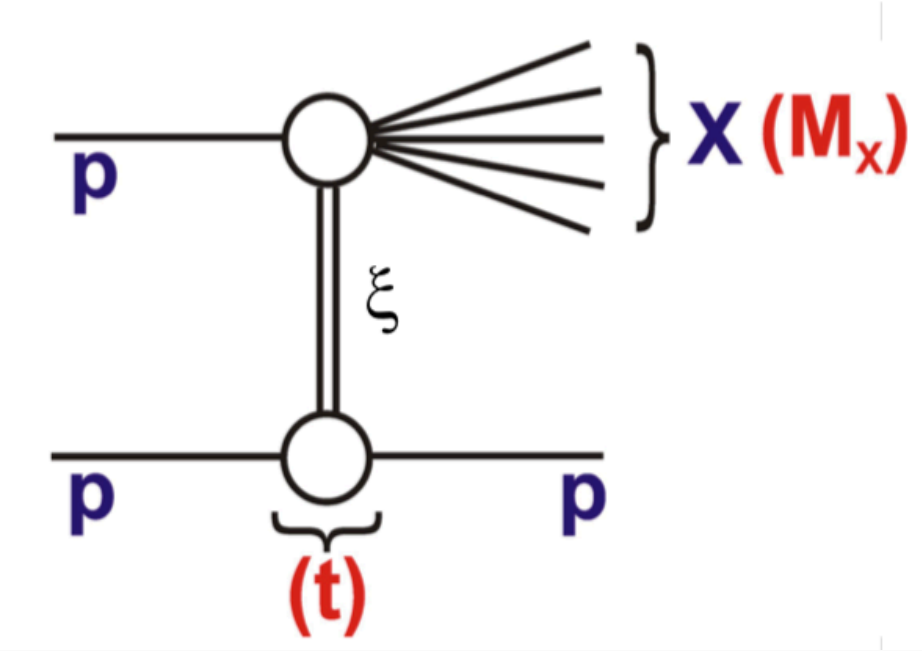
- Data from special run: $\sqrt{s}$ = 8 TeV, β^* = 90 m, L = 1.67/nb, μ < 0.08

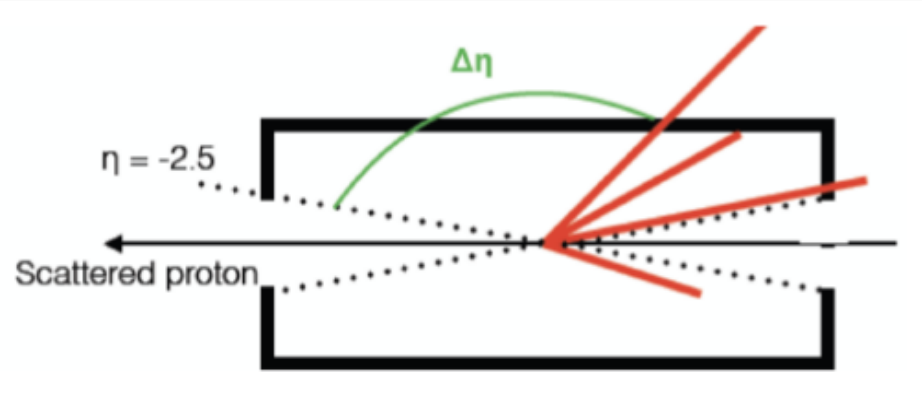
- Intact proton measured in ALFA
- Dissociated proton measured using ATLAS tracking detector
- Trigger: opposite side coincidence of the signal in ALFA and Minimum Bias Trigger Scintilator (MBTS)



- Acceptance
  - tracker: charged particles with
    - p_T > 0.2 GeV
    - |η| < 2.5
  - MBTS: charged particles with 2.1 < |η| < 3.8
  - ALFA: protons with
    - $0.016 < |t| < 0.43$ GeV^2
    - $-4.0 < \log_{10} \xi < -1.6$

Kinematic variables





- t – squared four-momentum transferred from the proton

$$t \approx -p_T^2$$

- ξ – momentum fraction of the proton carried by the pomeron

$$\begin{aligned}\xi &= 1 - E/E_0 \\ &= M_X^2/s \approx \sum_i (E^i \pm p_z^i)/\sqrt{s}\end{aligned}$$

- $\Delta\eta$ – (pseudo)rapidity gap from the tracker edge

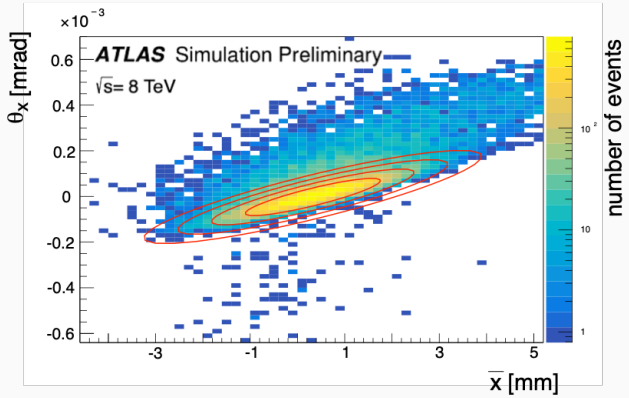
Event selection

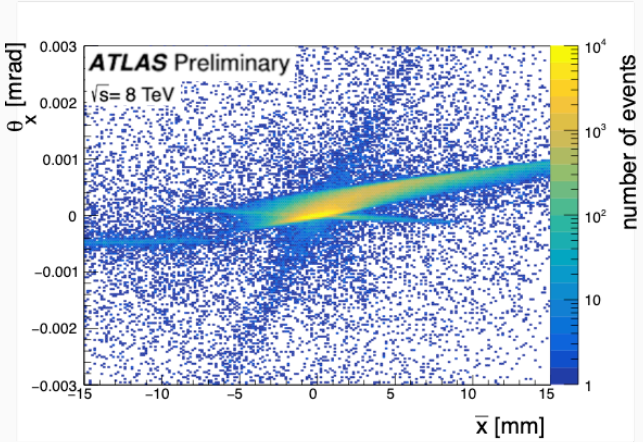
- Exactly one reconstructed proton in two ALFA stations of the same armlet
- 3σ ellipse cut in (x, θ_x) plane
- ID: at least one track and a reconstructed vertex
- MBTS: at least 5 (out of 16) counters above noise threshold
- Fiducial region of the mesurement:

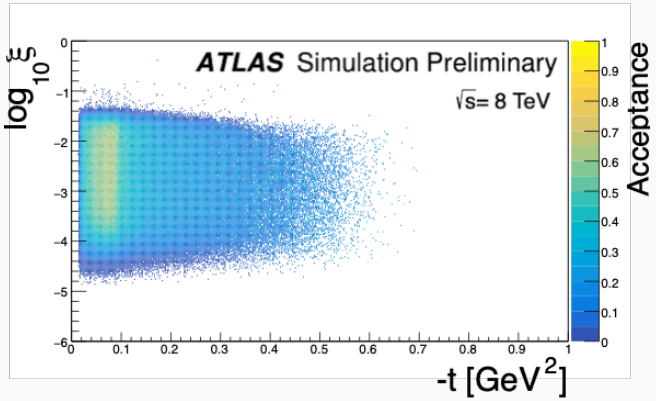
$$0.016 < |t| < 0.43 \text{ GeV}^2$$

$$-4.0 < \log_{10} \xi < -1.6$$

$$(\text{i.e. } 80 < M_X < 1270 \text{ GeV})$$







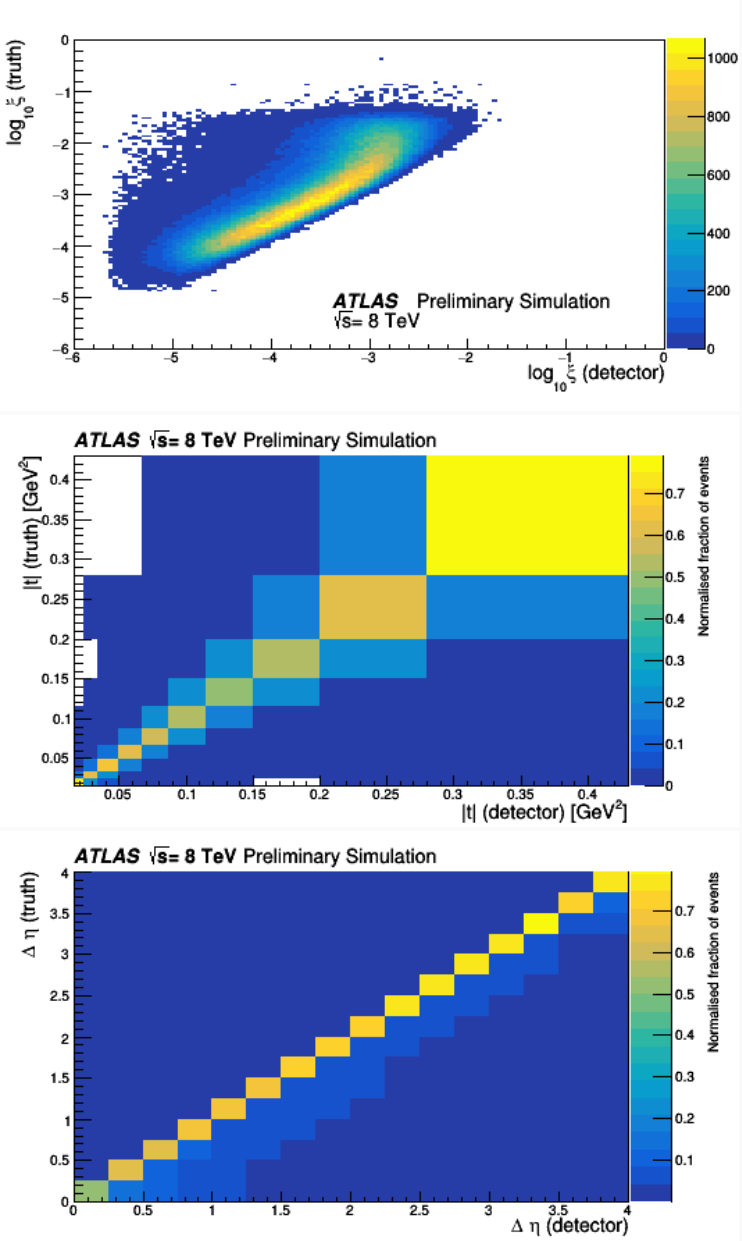
Monte Carlo Generators

Main MC:

- PYTHIA8 A3 tune (ATL-PHYS-PUB-2016-017):
- Proton PDF = NNPDF23 LO
- Pomeron : PDF = H1 2006 Fit B; Flux: intercept: 1.06, slope: 0.25 (Donnachie-Landshoff)
- SD for unfolding
- CD, DD, ND for background subtraction
- Elastics for ALFA Reconstruction efficiency

For systematics:

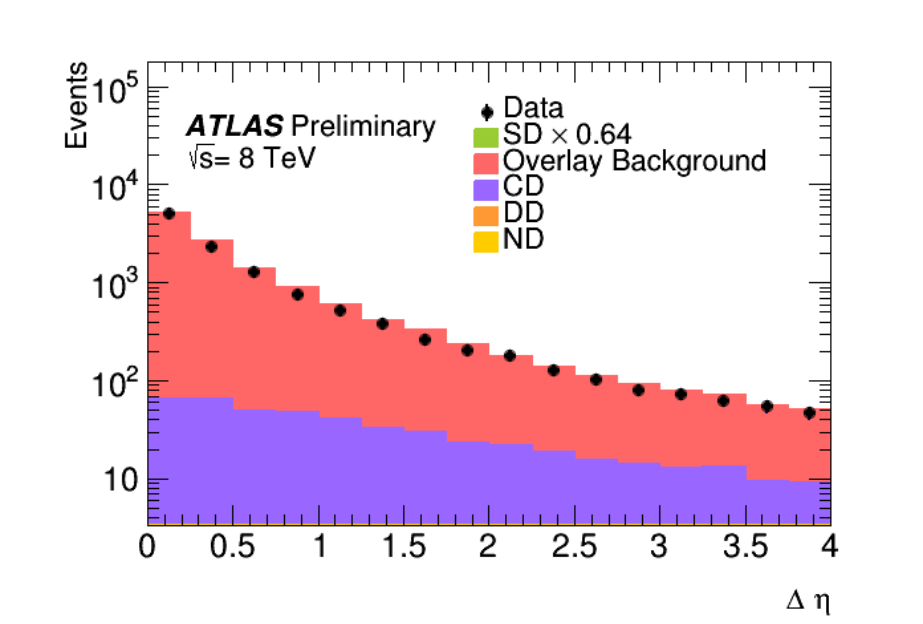
- PYTHIA 8 A2 tune (ATL-PHYS-PUB-2012-003)
- HERWIG 7.1:
  - Proton PDF = MMHT2014lo68cl
  - Pomeron : PDF = H1 2006 Fit A; Flux: intercept: 1.00, slope: 0.25



Overlay Background

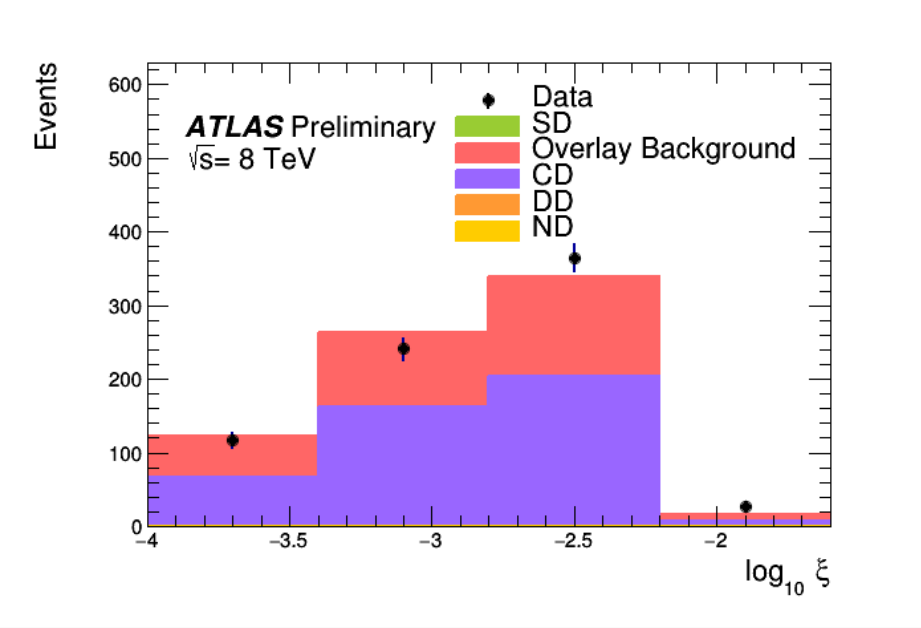
- Coincidence between a proton in ALFA and activity in central ATLAS
- Source of protons: elastic scattering, beam halo
- Source of central activity: minimum bias events
- Largest background
- Data-driven estimate using strongly ND-enriched events
  - all 32 MBTS segments fired
  - shape in t from ALFA in ND-enriched sample
  - shapes in ξ and $\Delta\eta$ from MC events that pass full analysis selection

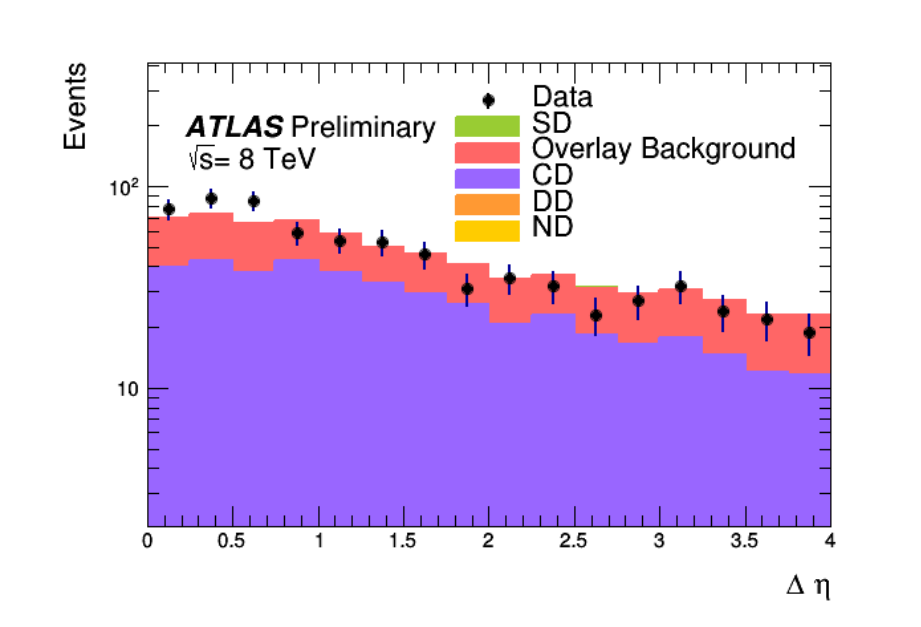
- Control region:
  nominal selection, but with
  protons in two armlets
  (dominated by elastics + ND)



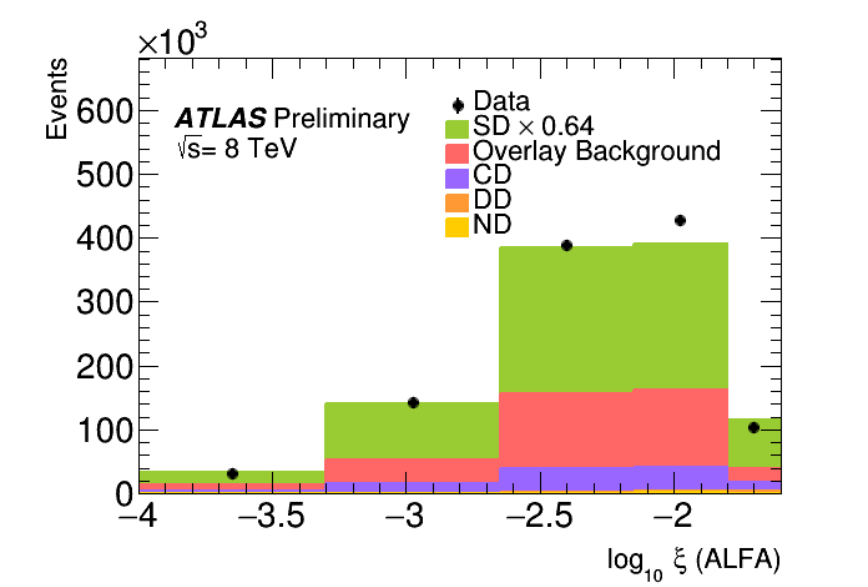
Central Diffraction Background

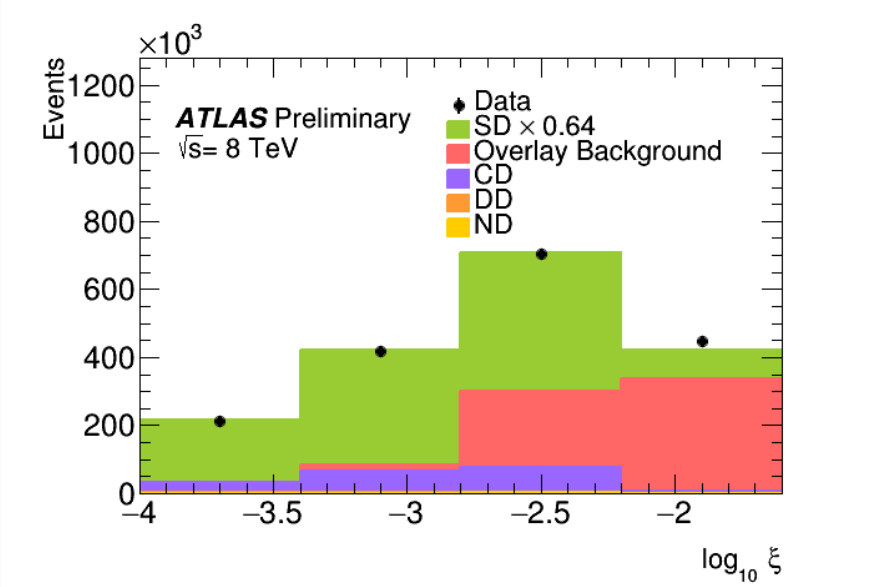
- Dominant physics background: central diffraction
- Estimated from simulations
- Control region:
  - protons in two armlets
  - 2–10 MBTS segments fired
- Good description of normalizations and shapes
- Reweighting ξ distributions to match the data, preserving normalization

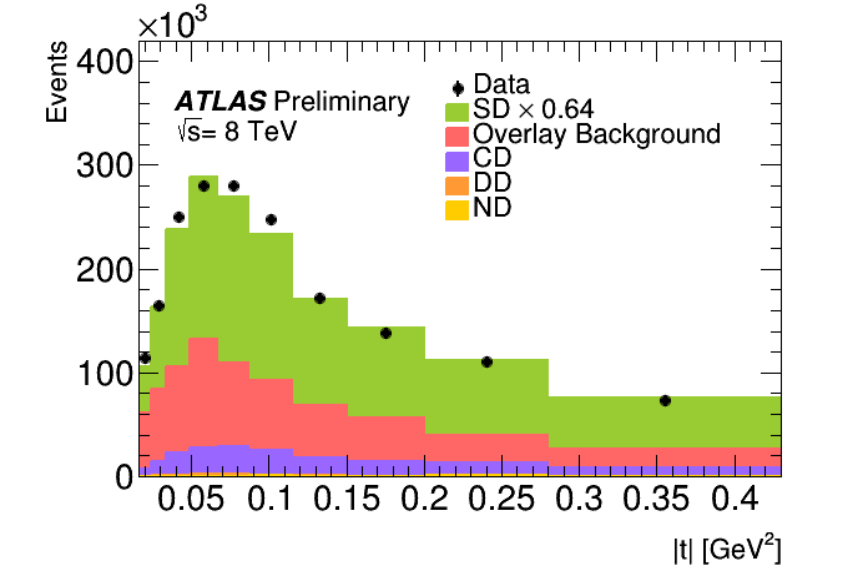


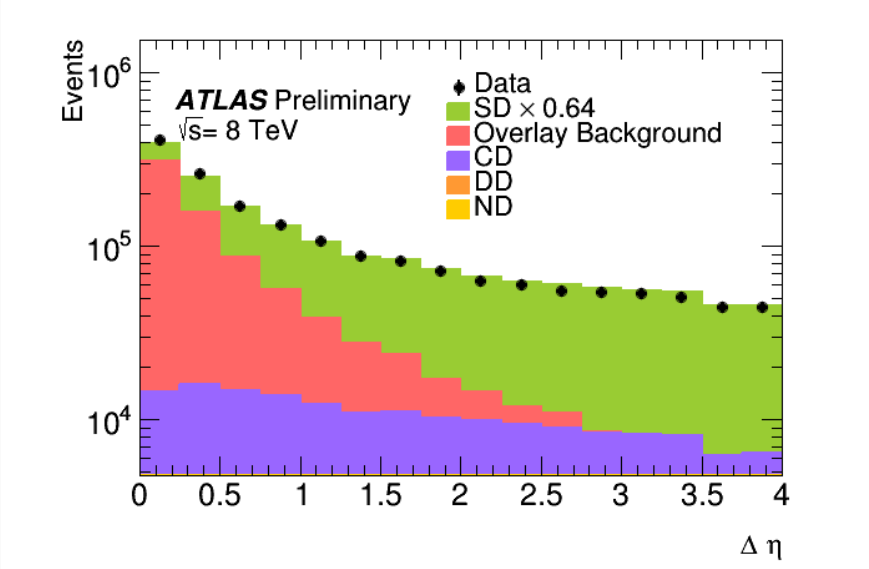


Uncorrected control plots





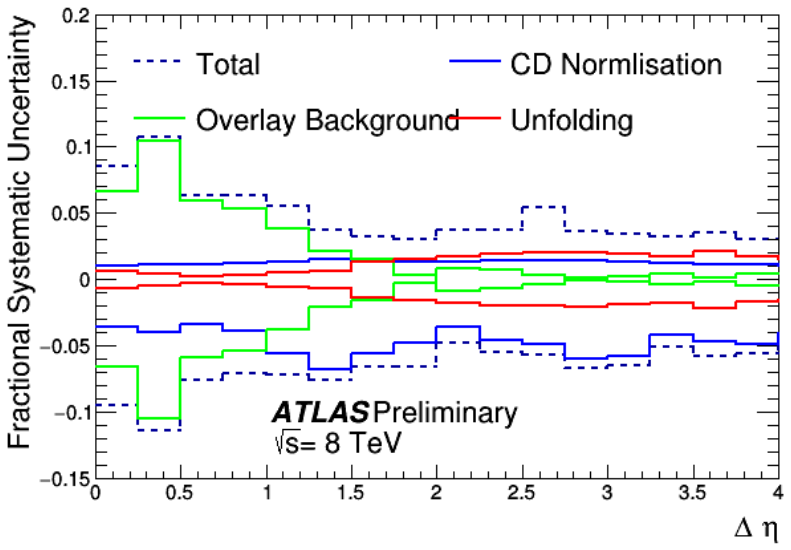


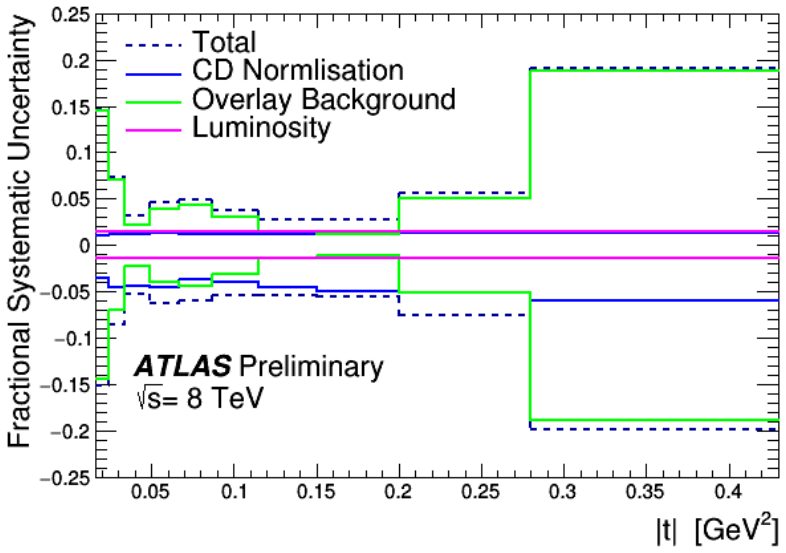


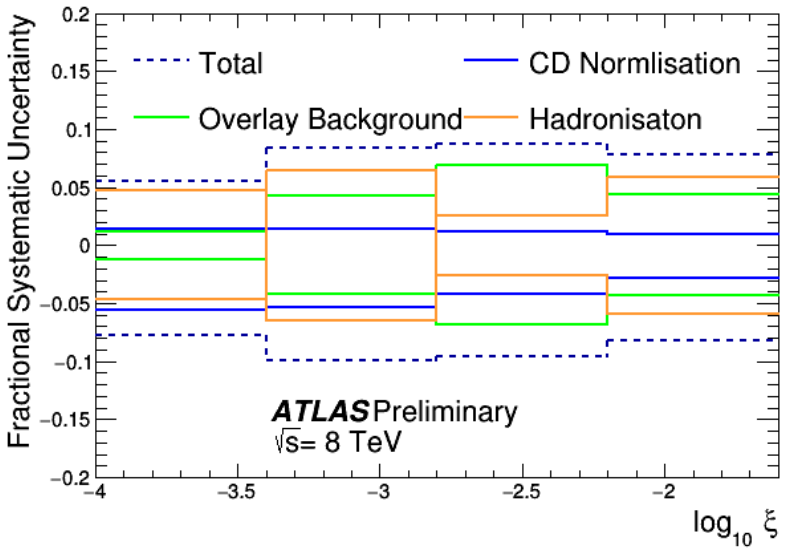
Good description of shape and normalization after SD rescaling by 0.64

Systematic uncertainties

- Dominant: overlay background
- CD background shape (reweighting or not) and normalization (CDF data)
- Hadronisation model (PYTHIA vs HERWIG)
- Unfolding of instrumental effects
- Luminosity precision

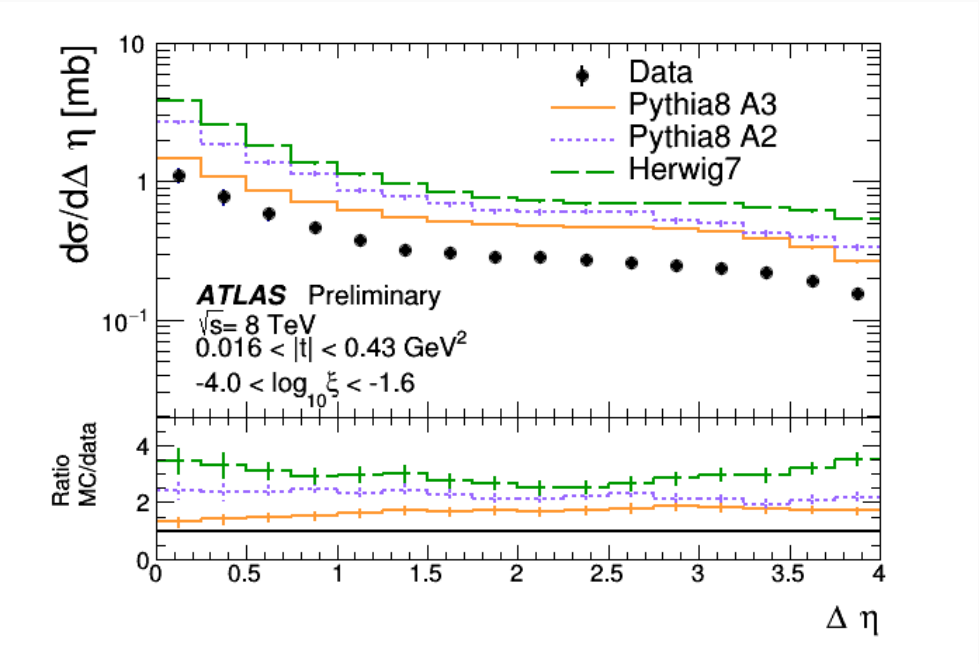






Rapidity gap size distribution

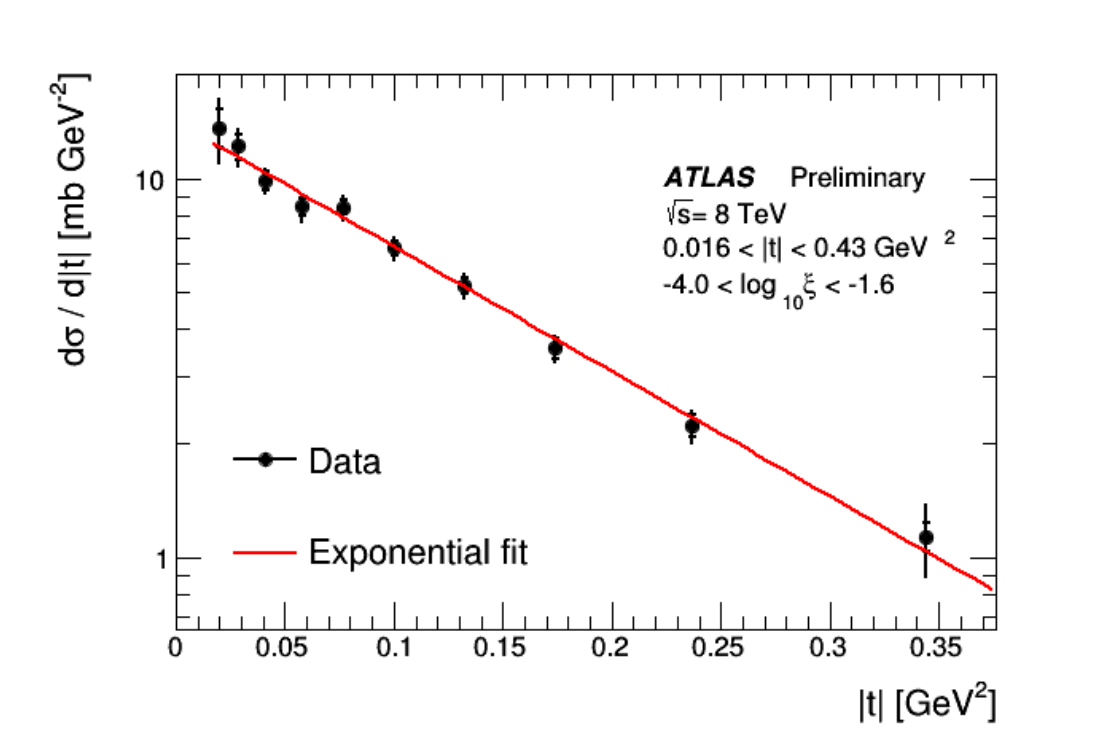
- Unfolded hadron level cross sections after background subtraction
- Diffractive plateau is visible
- Increase at small rapidity gaps – limited acceptance of ATLAS tracker
- Decrease at large rapidity gaps – Loss of small-ξ events close to the ξ-edge (10^{-4})



MCs do not describe the overall cross section:

Monte Carlo model	$\sigma_{MC}/\sigma_{data}$
PYTHIA 8, A2 tune	2.3
PYTHIA 8, A3 tune	1.5
HERWIG 7.1	3.0

t distribution



- Measured exponential slope:

$$B = 7.60 \pm 0.23\ (\text{stat.}) \pm 0.22\ (\text{syst.})\ \text{GeV}^{-2}$$

- In agreement with Pythia 8 prediction:
  PYTHIA8 A2: 7.82 GeV^{-2}, PYTHIA8 A3: 7.10 GeV^{-2}
- Main systematic uncertainty from overlay background subtraction

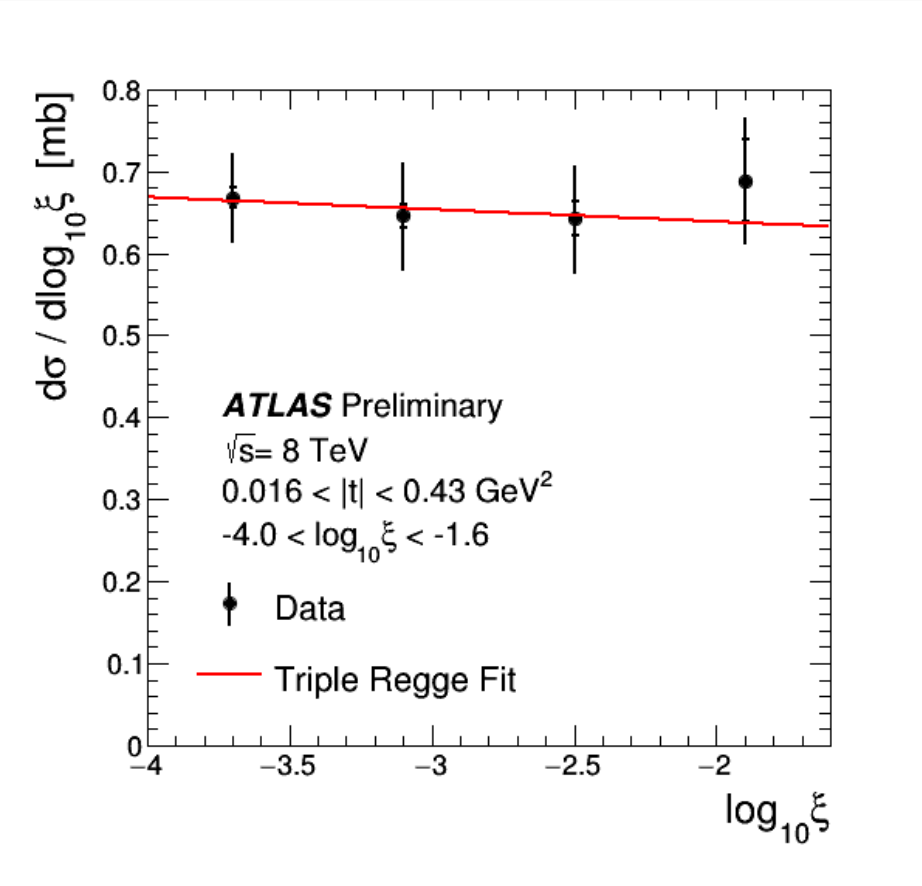
ξ distribution

- Distribution fitted with:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\log_{10}\xi} = \left(\frac{1}{\xi}\right)^{\alpha(0)-1} \frac{\exp(Bt_{\text{high}}) - \exp(Bt_{\text{low}})}{B}, \quad \text{with} \quad B = B_0 - 2\alpha' \log\xi$$

- Measured Pomeron intercept

$$\alpha(0) = 1.07 \pm 0.02\ (stat.) \pm 0.06\ (\text{syst.}) \pm 0.06\ (\alpha')$$



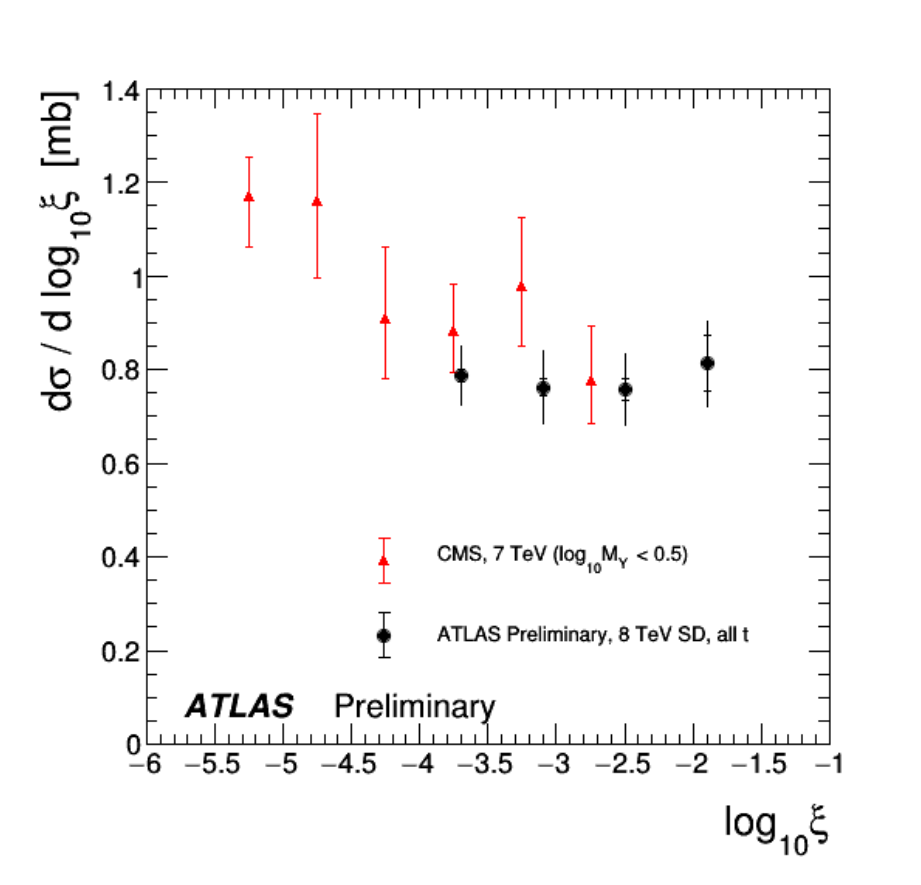
- Main systematic uncertainty from

$$\alpha' = 0.25 \pm 0.25\ \text{GeV}^{-2}$$

- MC generators:
  PYTHIA 8 A3 (Donnachie-Landshoff):
  α(0) = 1.14
  PYTHIA 8 A2 (Schuler-Sjostrand):
  α(0) = 1.00

Extrapolation to full t range

- ATLAS data extrapolated to full t-range (gives a factor 1.18)
- Closest available data: CMS 7 TeV rapidity gap analysis using CASTOR as a veto (Phys. Rev. D92 (2015) 012003)
- A reasonable agreement in the overlap region
- Despite DD contribution in CMS results and different energies



Integrated cross sections

- The cross section integrated over the full fiducial range of the analysis

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

- Extrapolating to the full *t* range assuming the measured *B* value:

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

- Extrapolating to full kinematic range using Pythia A2 and A3 (average):

$$6.6 \text{ mb}$$

Distribution	$\sigma_{SD}^{\text{fiducial}(\xi,t)}$ [mb]	$\sigma_{SD}^{t-\text{extrap}}$ [mb]	$\sigma_{SD}^{\xi,t-\text{extrap}}$ [mb]
Data	1.59 ± 0.13	1.88 ± 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 and conclusions

- ATLAS performed a measurement of the inclusive single diffractive dissociation process $p + p \to X + p$ at $\sqrt{s} = 8$ TeV
- The final state protons are directly reconstructed
- Differential cross sections are measured as a function of ξ, t and $\Delta\eta$
- Normalizations of tested MC generators significantly exceed the data
- Shapes reasonably described by models
- From a fit to t distribution:

$$B = 7.60 \pm 0.23 \text{ (stat.)} \pm 0.22 \text{ (syst.) GeV}^{-2}$$

- From a fit to ξ distribution:

$$\alpha(0) = 1.07 \pm 0.02 \text{ (}stat.\text{)} \pm 0.06 \text{ (syst.)} \pm 0.06 \ (\alpha')$$

- A good agreement in the overlap ξ region with the CMS results