Measurements of single diffraction using the ALFA forward spectrometer at ATLAS
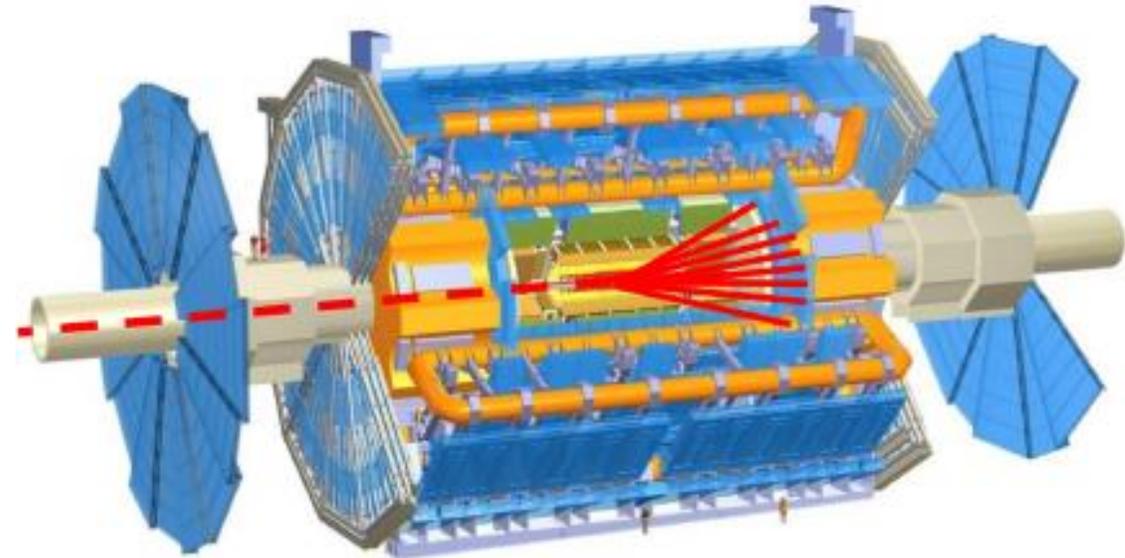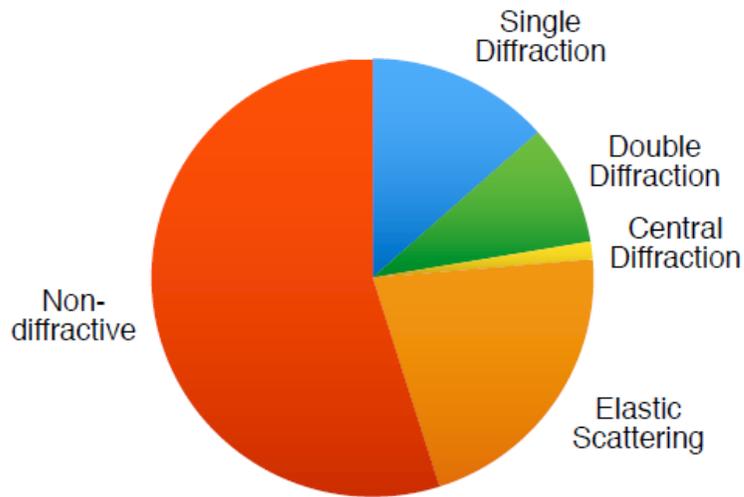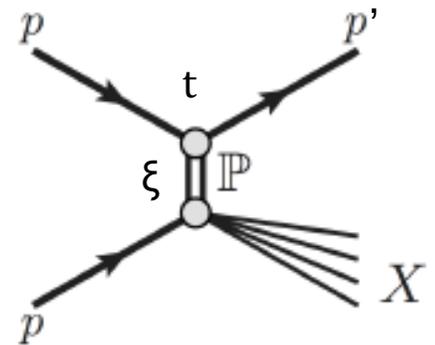
Marek Taševský

Institute of Physics of the Czech Academy of Sciences, Prague

On behalf of the ATLAS Collaboration

Single Proton Diffraction at LHC

Single Diffraction

Double Diffraction

Central Diffraction

Non-diffractive

Elastic Scattering

❑ Large cross section but not well constrained

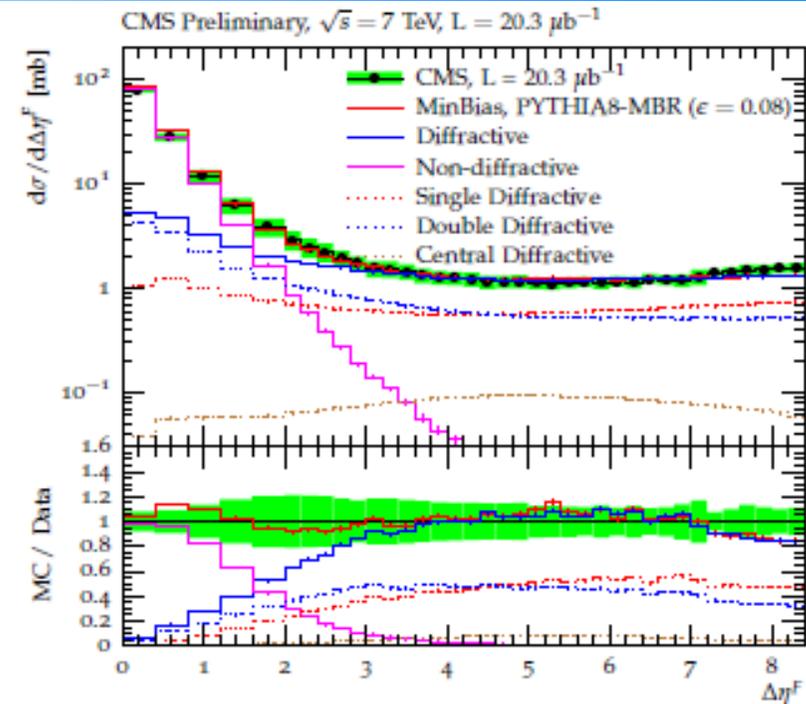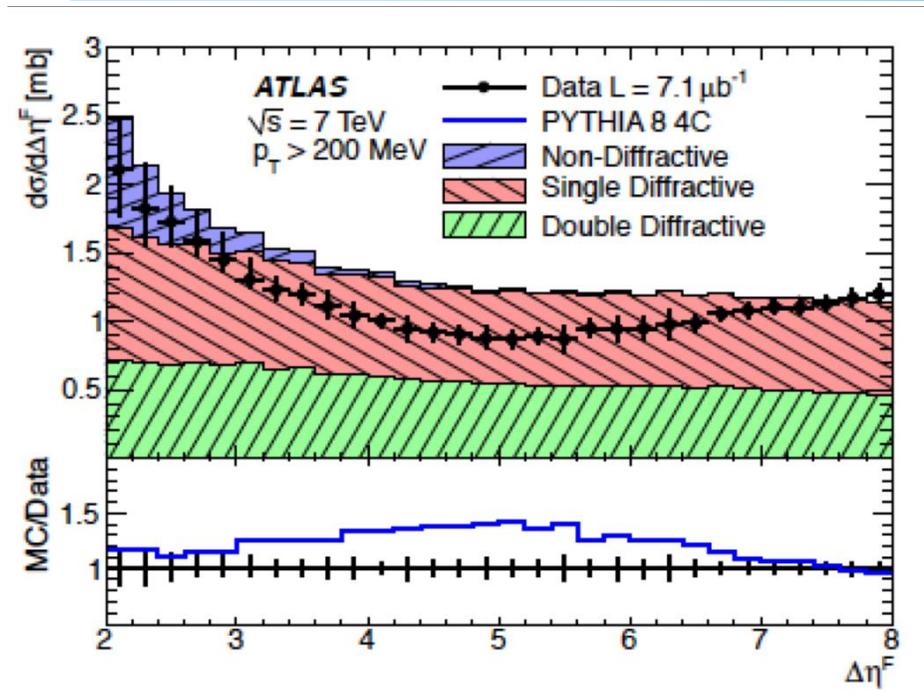❑ Previous analyses based on rapidity gaps, this analysis based on proton tagging

Measure as a function of t, ξ and rapidity gap Δη

$$t = (p\text{-}p') \qquad \xi = M_X^2/s$$

$$\Delta\eta \approx -\ln\xi$$

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Previous soft SD constraints come from rapidity gap measurements (protons not tagged): Large ambiguities w.r.t. ND and CD

Motivations for better soft SD constraints:
o Precision on σ_{inel} o Soft – Hard transition
o Pile-up modelling   o Confinement
o Cosmic-ray air showers   o String theory duality (AdS/CFT)

Variables studied

□ Four-momentum squared t
- reconstructed from $t = -p_T^2$ of proton in ALFA

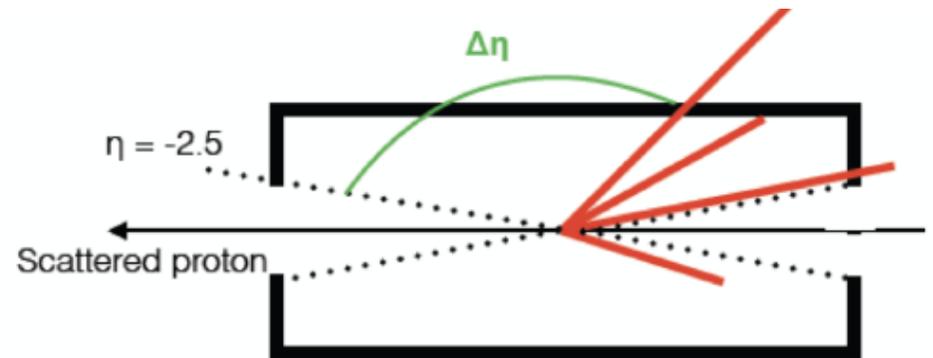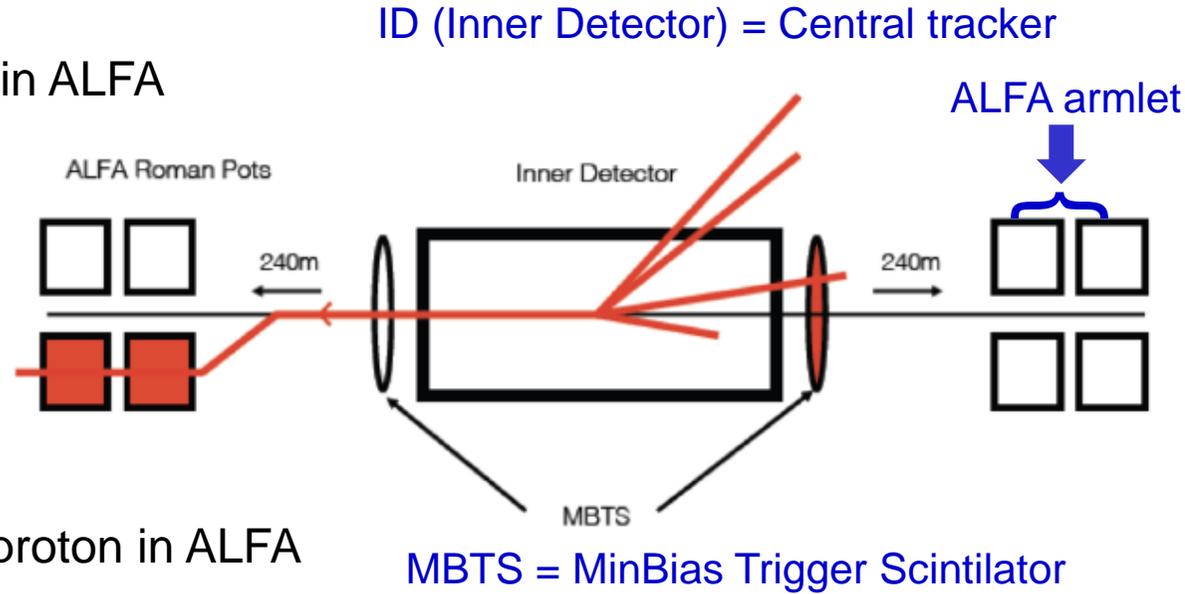□ Fractional proton energy loss ξ
$$\xi = M_X^2/s$$
- reconstructed from ID tracks as
$$\xi_{EP_z}^{\pm} = \frac{\Sigma_i(E_i \mp p_{z,i})}{\sqrt{s}}$$
- cross-checked using reconstructed proton in ALFA
$$\xi_p = 1 - \frac{E_{p'}}{E_p}$$
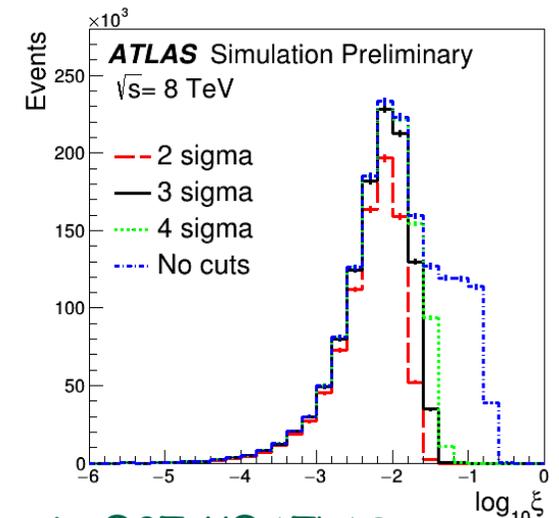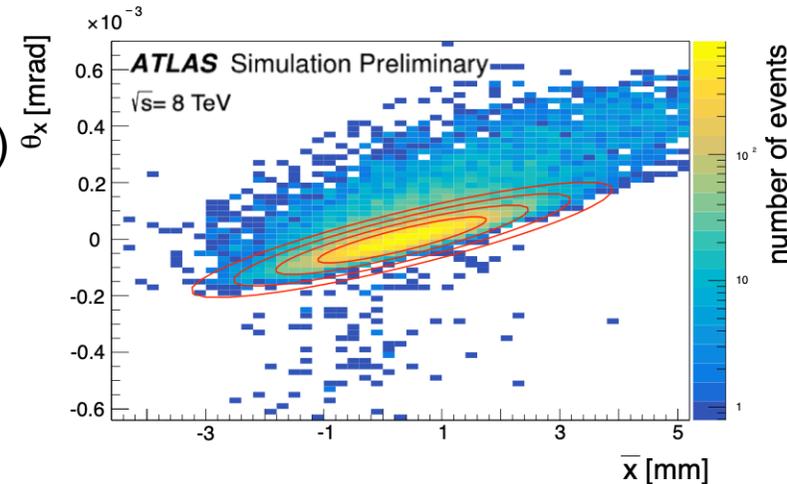
□ Visible size of rapidity gap Δη
- between tracker edge on side with proton
(η = +2.5 or -2.5) and first ID track with
p_T > 200 MeV

ID (Inner Detector) = Central tracker

ALFA armlet

ALFA Roman Pots

Inner Detector

240m

240m

MBTS

MBTS = MinBias Trigger Scintilator

Δη

η = -2.5

Scattered proton

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Event selection

- Data from one run ($\beta^* = 90$m, $\mu = 0.08$, L=1.7nb-1) (same as ALFA $\sigma_{tot}, \sigma_{el}$ measurement)

- L1 trigger: MBTS(A/C) .and. ALFA(C/A)

[Phys. Lett. B761 (2016) 158]
(benefit from reusing some of the work)

- ALFA: exactly one reconstructed proton
  geometrical cut: $(\bar{x}, \theta_x)$ within 3σ ellipse around (0,0)
  ($\bar{x}$ = mean x position, θ_x= angle between stations)

- MBTS: at least 5 counters above threshold

- ID: at least 1 track with $p_T > 200$ MeV & $|\eta| < 2.5$

- Reconstructed vertex

Fiducial region of measurement: $0.016 < |t| < 0.43$ GeV^2, $-4.0 < log_{10}(\xi) < -1.6$ ($80 < M_X < 1270$ GeV)

Marek Taševský   Single Diffaction@8TeV@ATLAS

MC generators used

❑ PYTHIA 8 A2 - main model:
- Proton PDF = NNPDF23 LO
- Pomeron : PDF = H1 2006 Fit B L; Flux: $\alpha(0) = 1.06, \alpha' = 0.25$ (Donnachie-Landshoff)
  - ○ SD for unfolding
  - ○ CD, DD, ND for background subtraction
  - ○ Elastics for ALFA Reconstruction efficiency
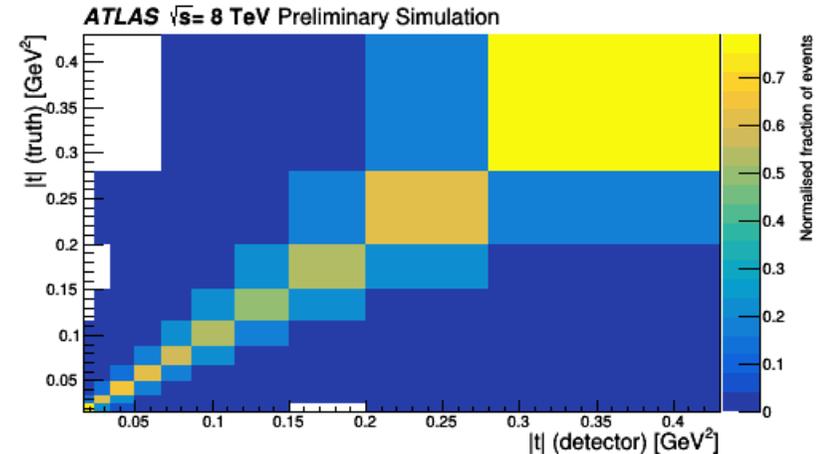
For comparisons and systematics:

❑ PYTHIA 8 A3: same as A2 tune but with Schuler-Sjöstrand Pomeron flux: $\alpha(0) = 1.00$

❑ HERWIG 7.1:
Proton PDF = MMHT2014lo68cl
Pomeron : PDF = H1 2006 Fit A; Flux : $\alpha(0) = 1.00, \alpha' = 0.25$

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Backgrounds

❑ Single-source contaminations from ND, CD and DD modelled by MC

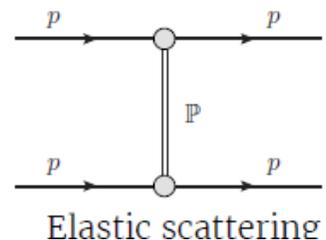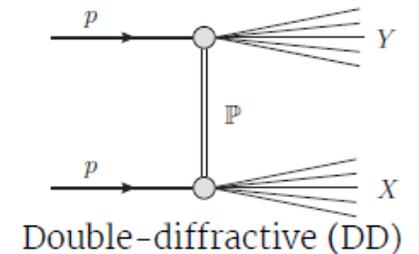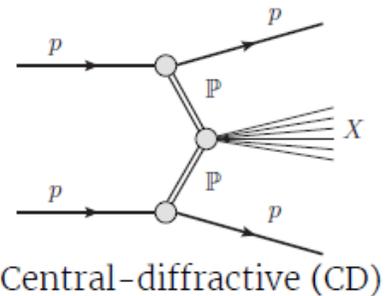❑ Overlay background (~25%)
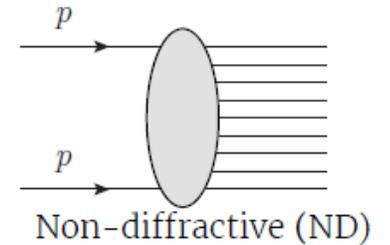   CD (~9%)
    ND (<1%)
    DD (<1%)

❑ Largest background from an overlay of two processes:
uncorrelated ALFA + ID/MBTS activity
(elastics / beam halo proton) + ND (pile-up) → Overlay background

- estimated by data-driven technique

Non-diffractive (ND)

Central-diffractive (CD)

Double-diffractive (DD)

Elastic scattering

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Overlay Background

❑ Data-driven estimate using strongly ND-enriched events:
ND: all 32 MBTS segments fired, at least 1 track with p_T > 200 MeV & |Δη| < 0.5

ALFA: 1 proton (0.8% of such events) → normalization

- shape in t from ALFA in ND-enriched sample
- shapes in ξ & Δη from MC events that pass full analysis selection except for number of protons
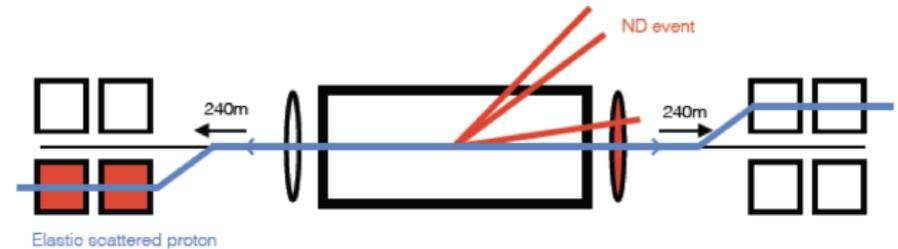
❑ Control region for overlay background:
same as nominal selection, but with protons in exactly two ALFA armlets

-   dominated by elastics in ALFA + ND in ID
-   serves to assess systematics

•   Good description of normalizations and shapes
•   Systematics from residual differences between data and model
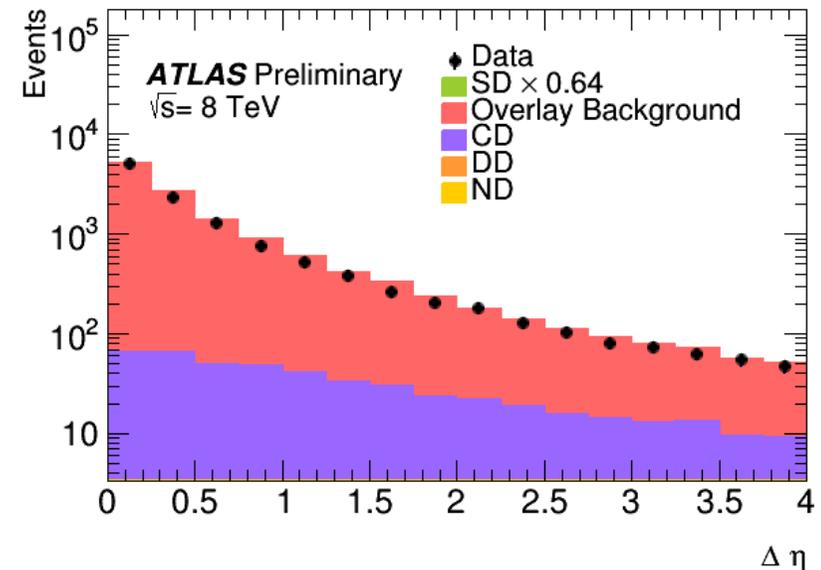
CD Background
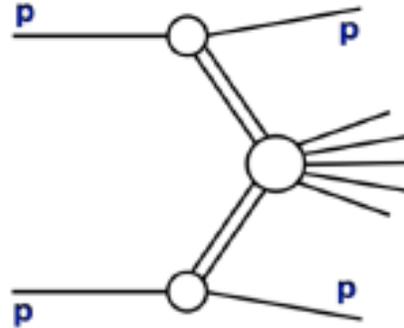
□ Second largest background

□ Obtained from MC

□ Control region (CD-enriched sample):
- protons in exactly two ALFA armlets
- 2-10 MBTS segments fired
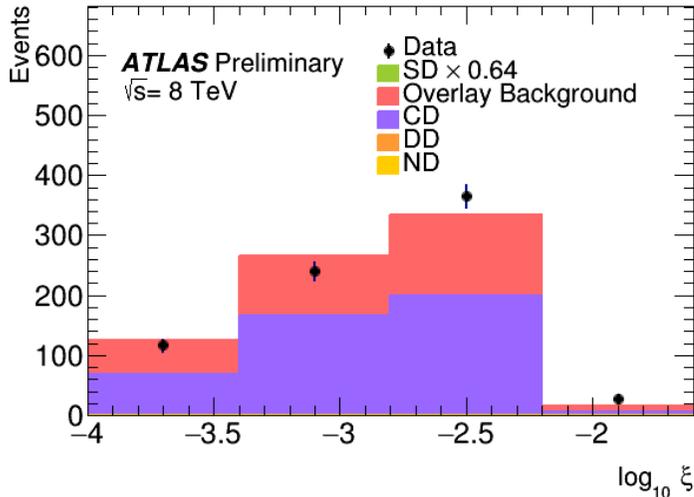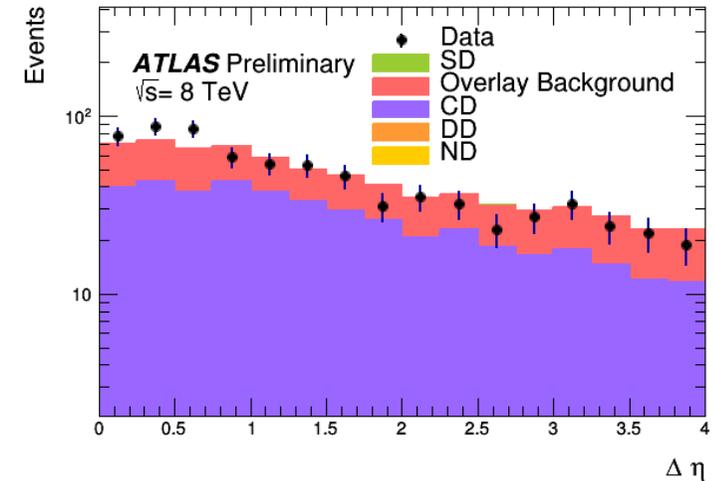
- Good description of normalizations and shapes

- Reweight ξ_p(ALFA) and ξ (ID) distributions to match the data, preserving normalization

- Systematics from either reweighting or not

Control plots: uncorrected level
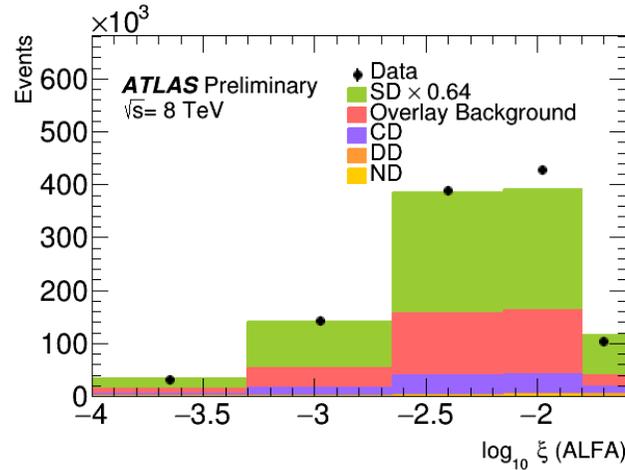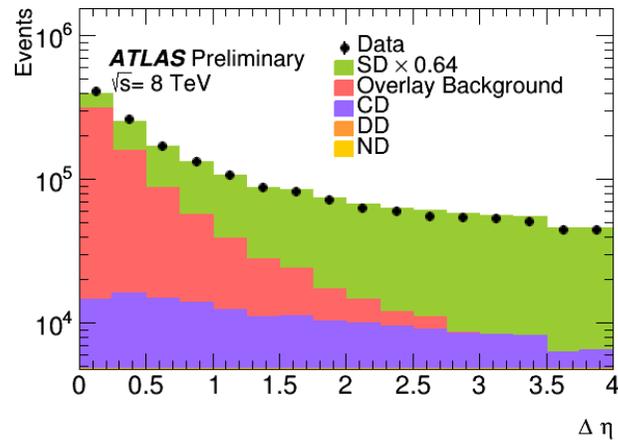
Poor description with default PYTHIA8 normalization.

Adjust SD total cross section to the result of this measurement:
➤ scale by 0.64

After scaling: good description of $\xi_p(ALFA), \xi(\text{ID}), t$ and $\Delta\eta$
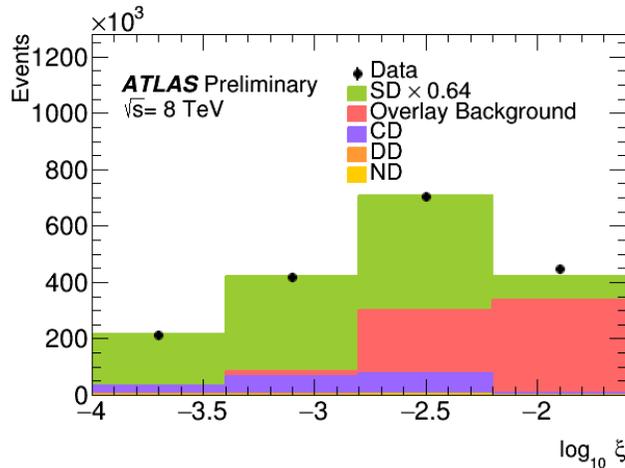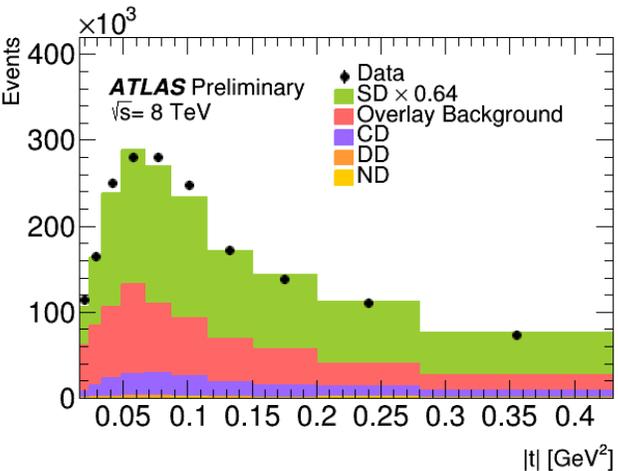
Systematic uncertainties

1) Overlay background subtraction (from control region)

2) Unfolding (residual non-closure in unfolding PYTHIA 8 after reweight to match data using un-reweighted MC)

3) Hadronization uncertainty (PYTHIA vs HERWIG at particle level)

4) CD background shape (reweight or not) and normalization (CDF data)

5) ALFA alignment and reconstruction (followed ALFA elastics analysis from the same data)

6) Luminosity (1.5%)

7) MBTS thresholds (vary threshold)

8) ID track reconstruction

9) Trigger efficiencies (vary reference sample)

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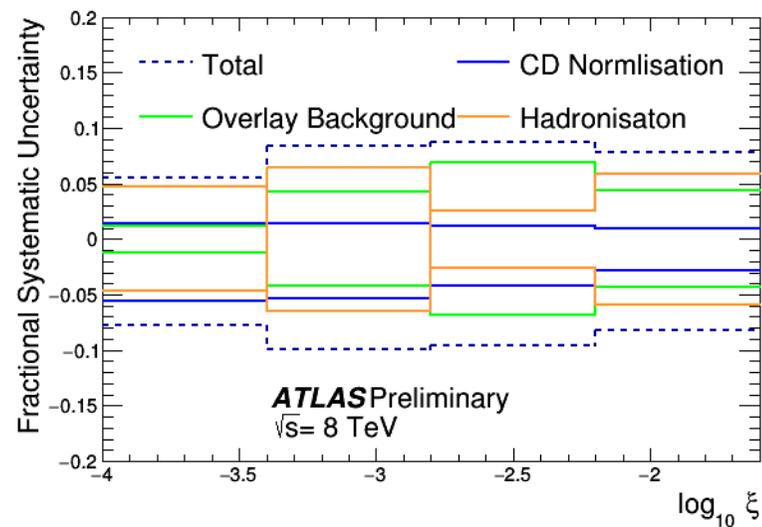
RESULTS: Δη
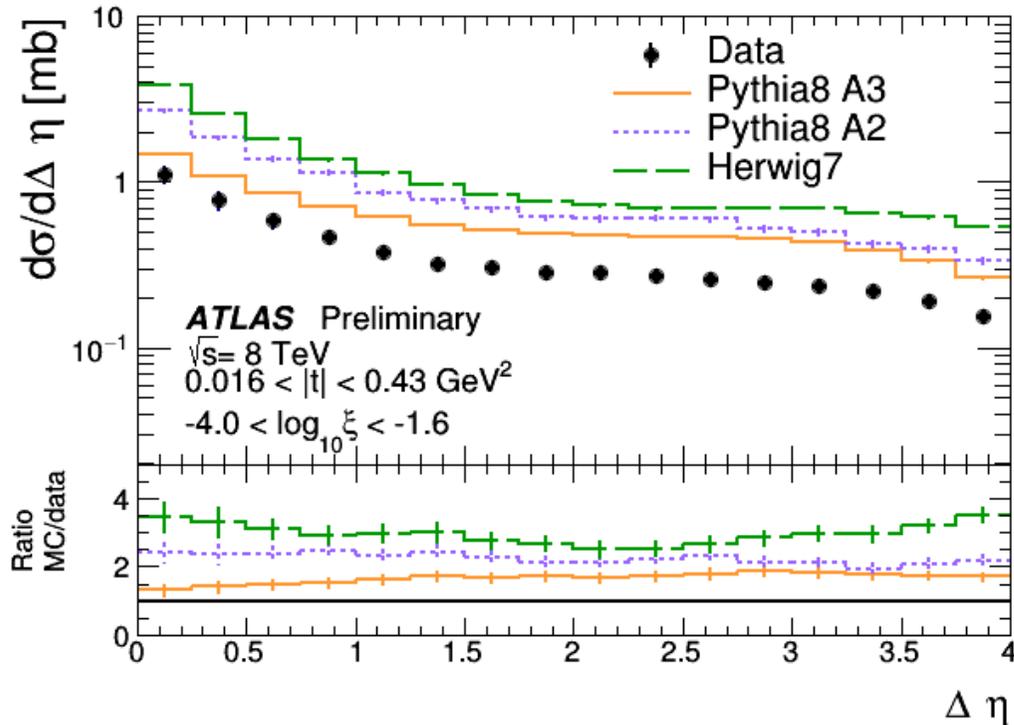
- Data corrected using Bayesian unfolding

- Gap defined by particles with $p_T > 200$ MeV & $|\eta| < 2.5$

- Diffractive plateau visible

- Shape at low gaps due to stacking up of high-ξ events with small gaps beyond acceptance

- Shape at high gaps due to edge of ξ fiducial region ($\xi = 10^{-4} \rightarrow \Delta\eta \approx 4$)

➢ MC generator tunes predict larger cross sections than data:
PYTHIA 8 A3: 1.5
PYTHIA 8 A2: 2.3
HERWIG 7.1: 3.0

RESULTS: |t|

ATLAS Preliminary
$\sqrt{s} = 8$ TeV
$0.016 < |t| < 0.43$ GeV^2
$-4.0 < \log_{10} \xi < -1.6$
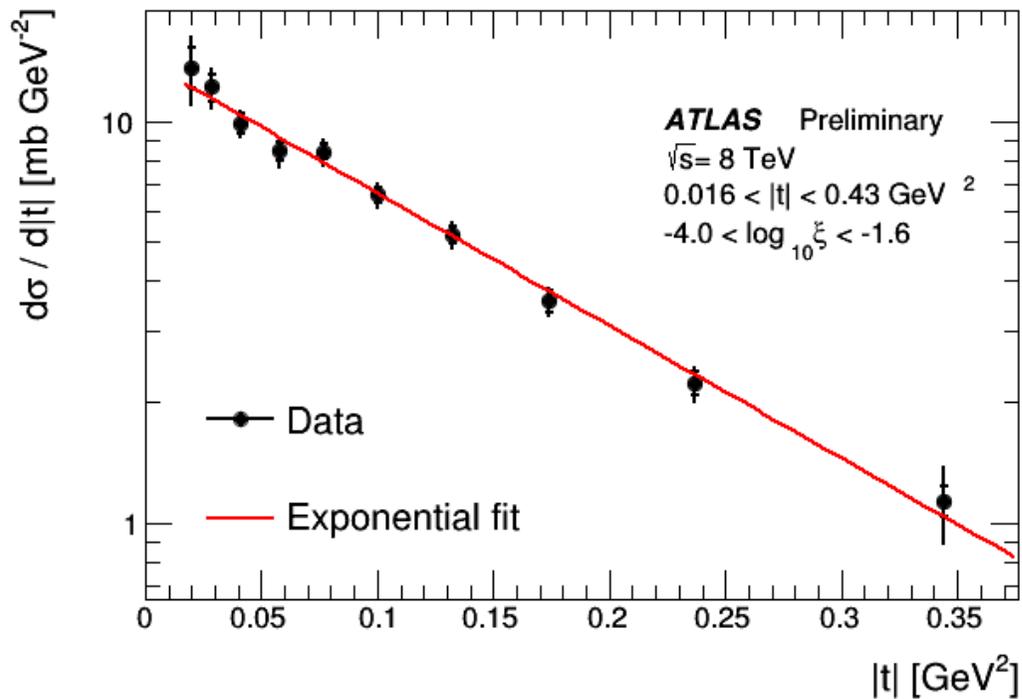
- Data corrected using Bayesian unfolding
- Data consistent with expected
  exponential form

$$\frac{d\sigma}{dt} = A e^{Bt}$$

- Exponential fit:

B = 7.60 ± 0.23(stat) ± 0.22(syst) GeV^{-2}

- Dominant uncertainty on fit:
Overlay background and statistics (from
overlay background subtraction)

➢ MC generator tunes predict similar values:
PYTHIA 8 A3:   B = 7.10 GeV^{-2}
PYTHIA 8 A2:   B = 7.82 GeV^{-2}

No previous published data from LHC,
but broadly in line with expectations

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RESULTS: ξ

- Data corrected using Bayesian unfolding

- Data consistent with expected approximate form

$$\frac{d\sigma}{d\xi} \sim \frac{1}{\xi}$$

- Interpreted in triple Pomeron model:
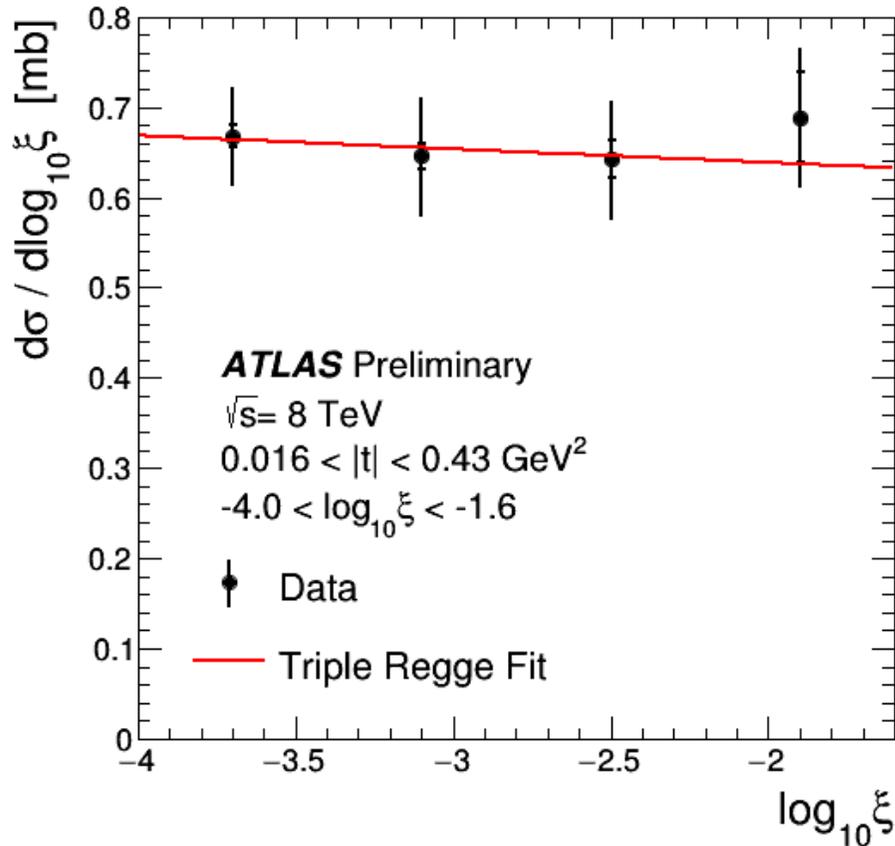
$$\frac{d\sigma_{SD}}{d\log_{10}(\xi)} \propto \left(\frac{1}{\xi}\right)^{\alpha(0)-1} \frac{1}{B} \left(e^{Bt_{\text{high}}} - e^{Bt_{\text{low}}}\right)$$

where B = B_0 - $2\alpha'\ln(\xi)$; $\alpha(t) = \alpha(0) + \alpha't$
$\alpha(0)$ = Pomeron intercept

t_{high} = -0.016
t_{low} = -0.43

Fit yields:

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

➤ MC generator tunes predict:
PYTHIA 8 A3 (Donnachie-Landshoff): $\alpha(0)$=1.14
PYTHIA 8 A2 (Schuler-Sjöstrand): $\alpha(0)$=1.00

Dominant systematics:
from using $\alpha' = 0.25 \pm 0.25\ GeV^{-2}$ in the fit

RESULTS: comparison with LHC data
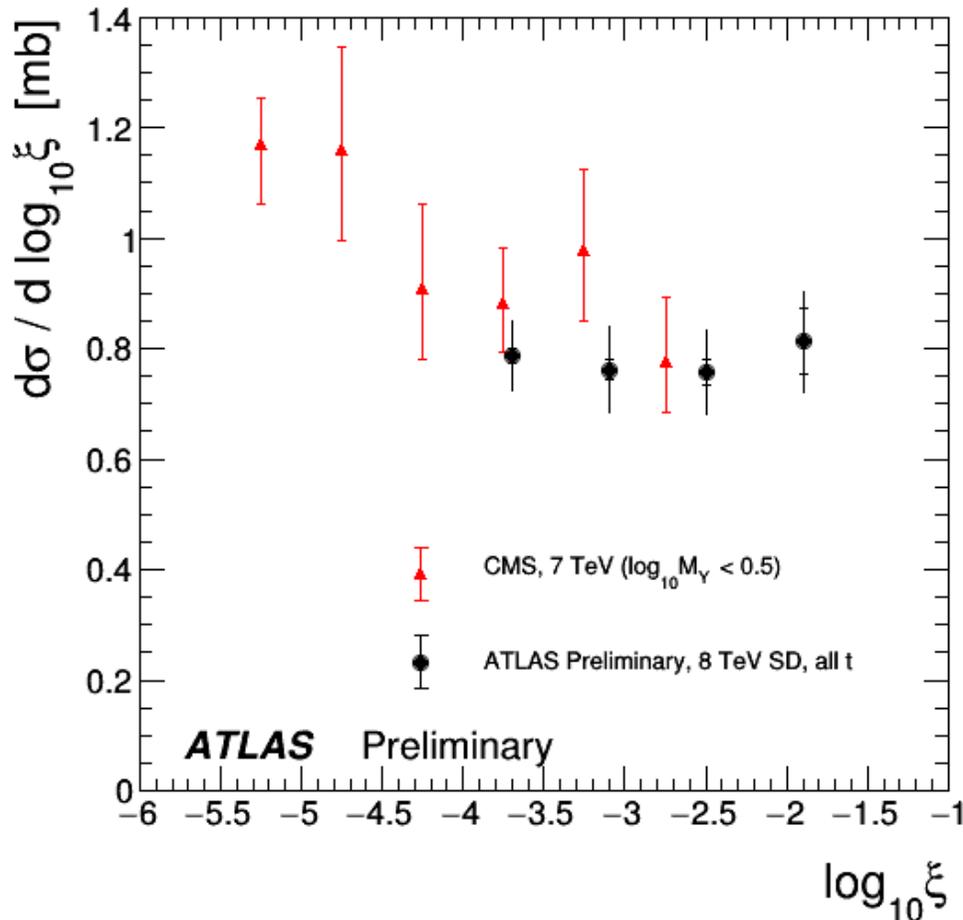
- ATLAS data extrapolated to full t-range using the t-slope measured in this analysis (this gives a factor 1.18)

- Closest available data: CMS 7TeV rapidity gap analysis using CASTOR as a veto (with some contamination from DD, assumed to be small)
  [Phys. Rev. D92 (2015) 012003]

  ➢ Fair agreement
  ➢ Complementary ξ ranges

RESULTS: integrated cross sections

❑ The cross section is measured in the fiducial region :

$0.016 < |t| < 0.43$ GeV^2, $-4.0 < log_{10}(\xi) < -1.6$ (corresponding to $80 < M_X < 1270$ GeV)

σ_{SD}(fiducial) = **1.59 ± 0.03(stat) ± 0.13(syst) mb**

❑ Using measured t-slope from data, it can be extrapolated to $0 \leq |t| \leq \infty$:

σ_{SD}(all t, $-4.0 < log_{10}(\xi) < -1.6$) = **1.88 ± 0.15 mb**

❑ Since ξ –dependence ($\alpha(0)$) in data lies between PYTHIA 8 A2 and PYTHIA 8 A3:
- extrapolation to the full t and full ξ range done by scaling data by averaged extrapolation factors from A2 and A3 in the measured range:

σ_{SD}(all t, all ξ) = **6.6 mb**   This quantity is ill-defined since not clear up to which $\xi \rightarrow$ no attempt to evaluate uncertainties

Distribution	$\sigma_{SD}^{fiducial(\xi,t)}$ [mb]	$\sigma_{SD}^{fiducial(\xi)}$ [mb]	σ_{SD} [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

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Summary

❏ ATLAS measured soft Single-Diffraction at 8 TeV with tagged protons
  - tagged protons:
    a) used for the first time at LHC for SD signal
    b) greatly reduce backgrounds from Non-Diffraction and Central Diffraction
       compared to previous LHC analyses based on rapidity gaps

❏ Measurements in gap size Δη, fractional proton energy loss ξ and
  momentum transfer squared t

❏ Normalization of PYTHIA 8 A2, A3, and HERWIG 7 significantly exceed the data

❏ Shapes more or less described by models

  - from a fit to t-slope the measured **B = 7.60 ± 0.23(stat) ± 0.22(syst) GeV^{-2}**

  - from a fit to ξ slope the measured $\alpha(0)$ **= 1.07±0.02(stat)±0.06(syst)±0.06(α')**

❏ ξ -dependence found compatible with previous CMS measurement

❏ Details available in ATLAS-CONF-2019-012
  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-012/

BACKUP SLIDES

ALFA proton reconstruction efficiency

Tag and Probe method, modelled on elastics analysis method, exploiting back-to-back configuration of elastic events, but with current ALFA selection.

- Require elastic L1 trigger

- Veto on L1_MBTS, or L1_LUCID (very forward trackers)

- Tag a reconstructed proton and Probe the corresponding elastic armlet

- MC corrected to data (small inefficiencies mainly due to showering)
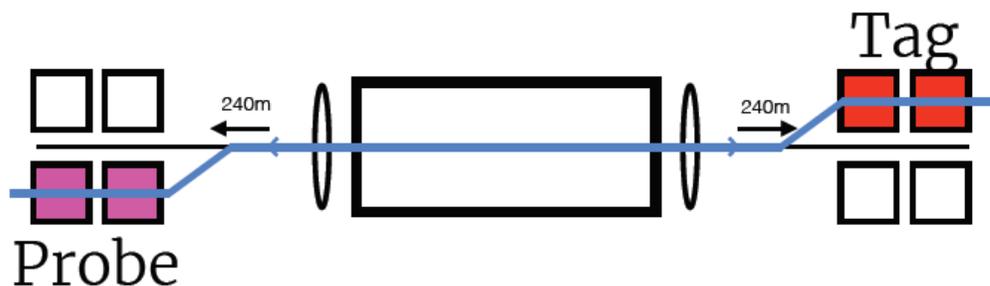
ε_{rec}/armlet	L1U	L1L	R1U	R1L
DATA	0.943	0.912	0.925	0.918
MC	0.949	0.918	0.941	0.939