# Inclusive Single Diffraction Measurement at ATLAS $\sqrt{s}$ = 8 TeV

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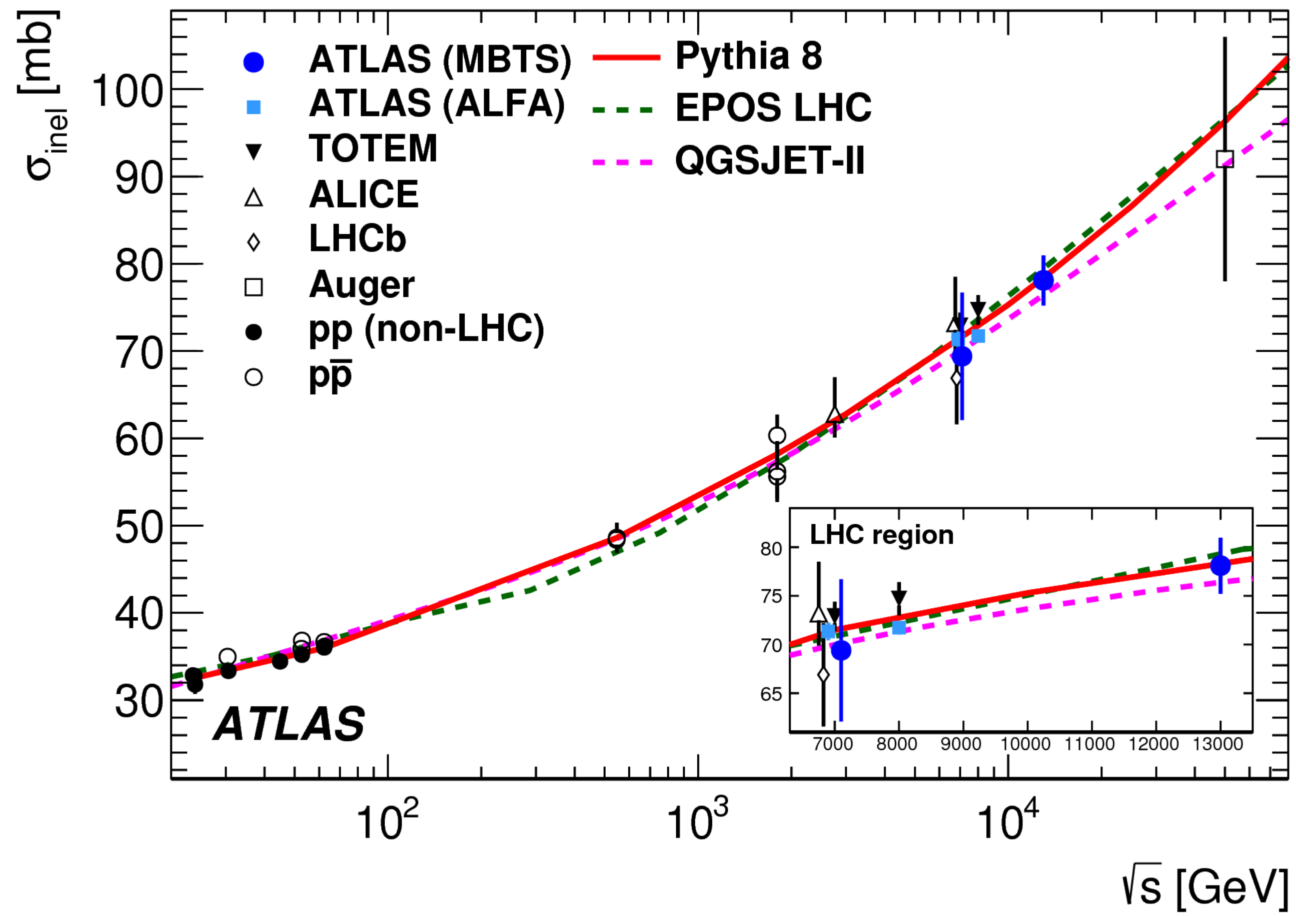
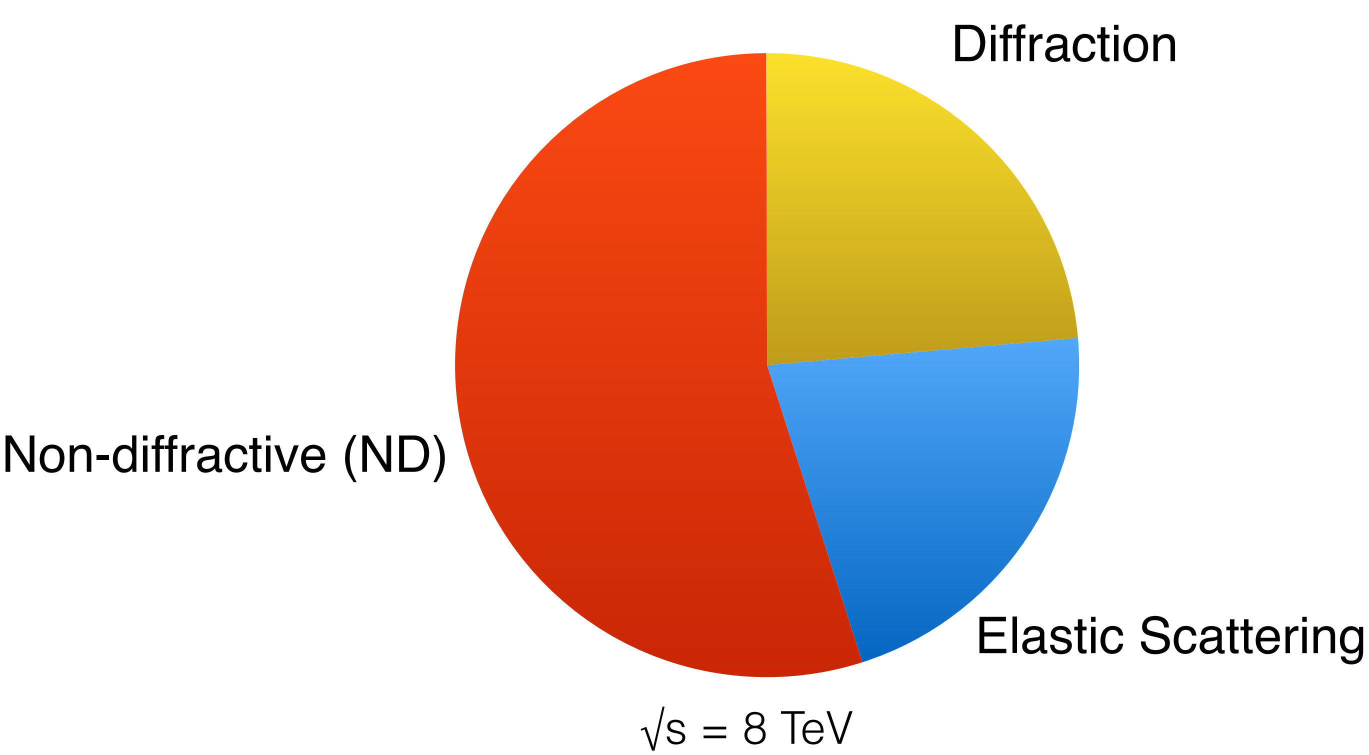
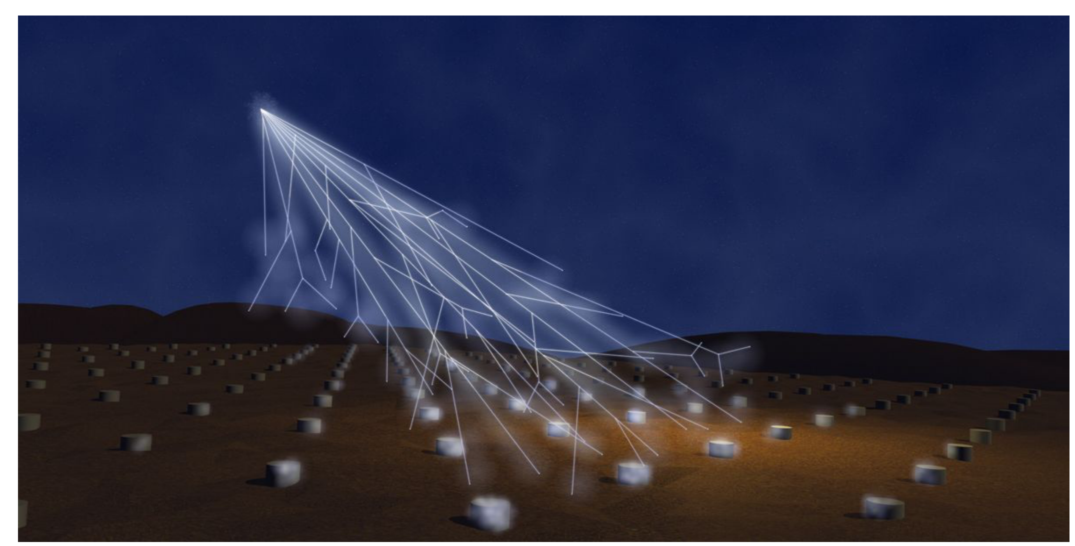
# Proton-Proton Cross-section

- At the LHC, we are probing the understanding of strong interaction in proton-proton collisions
  - Aids understanding of confinement, hadronic mass generation, cosmic ray air showers, pile up…

Phys.Rev.Lett. 117 (2016) no.18, 182002



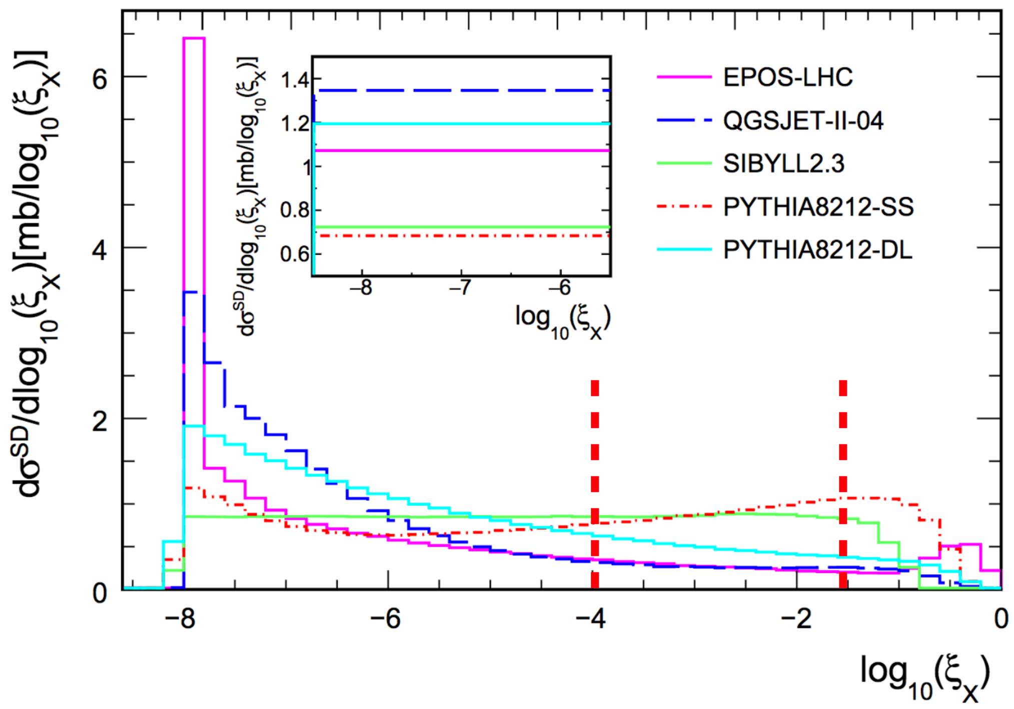



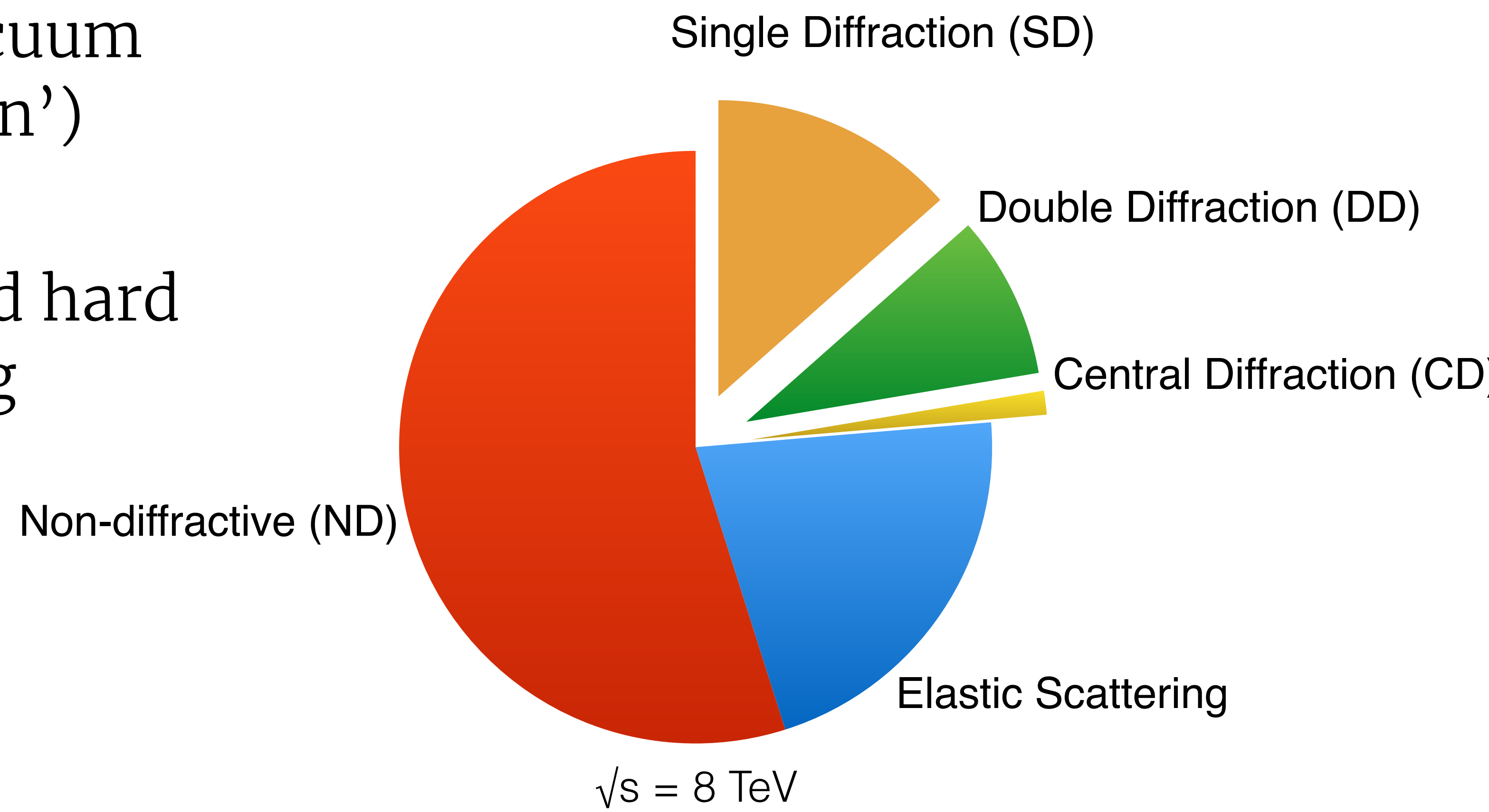



# Diffraction

- Large cross sections, not well constrained
- Typified by large regions in rapidity in the final state devoid of outgoing particles
- Mediated by exchange of vacuum quantum numbers (‘Pomeron’)
- Bridges gap between soft and hard understandings of the strong interaction

Eur. Phys. J. C77:212(2017) ($\sqrt{s}$ = 13 TeV)

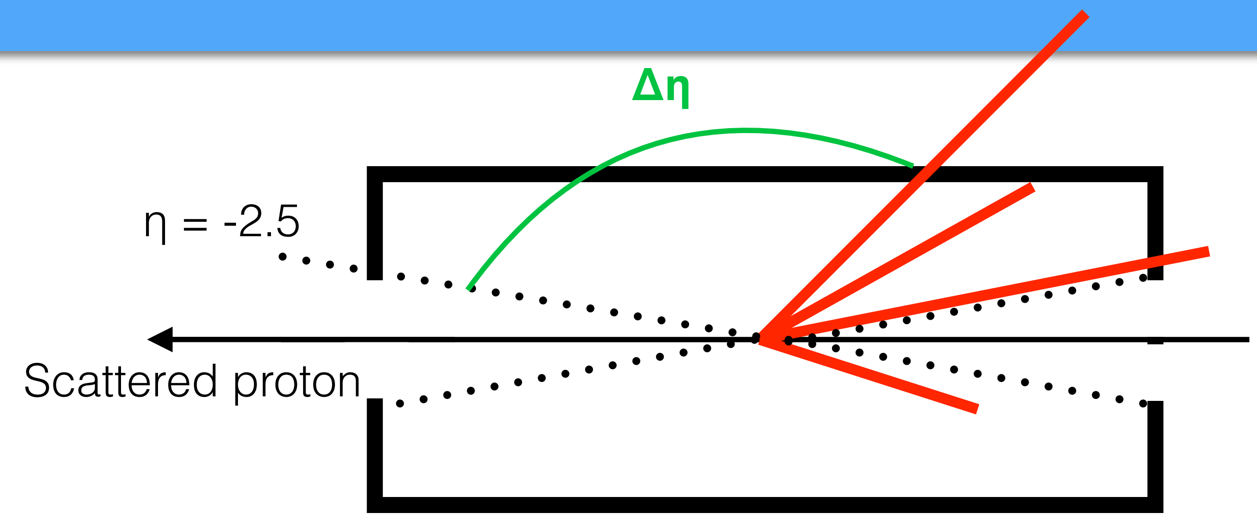


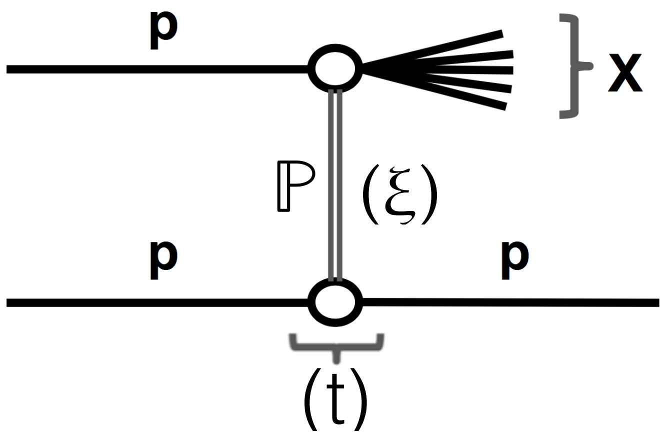
# Single Dissociation in ATLAS

- Measure $\sigma_{SD}$ differentially in Mandelstam **t**, ξ and **Δη**

- ξ can be calculated from proton ($\xi_p$) and X-system ($\xi_{ID}$)

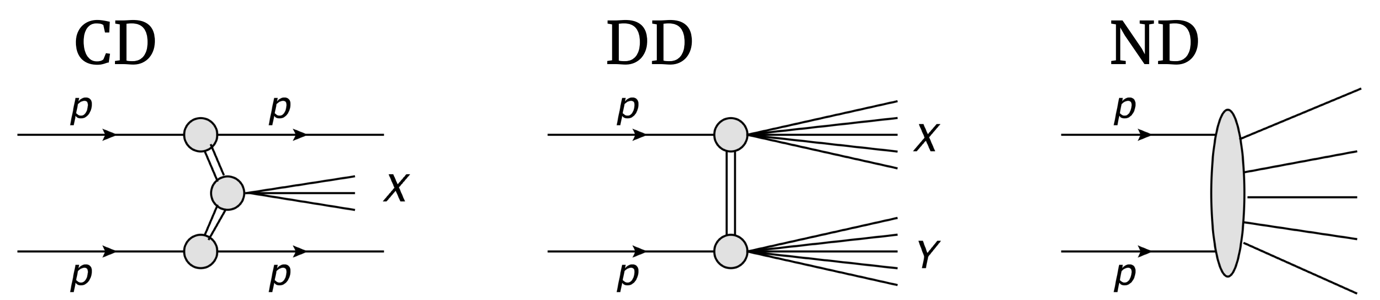


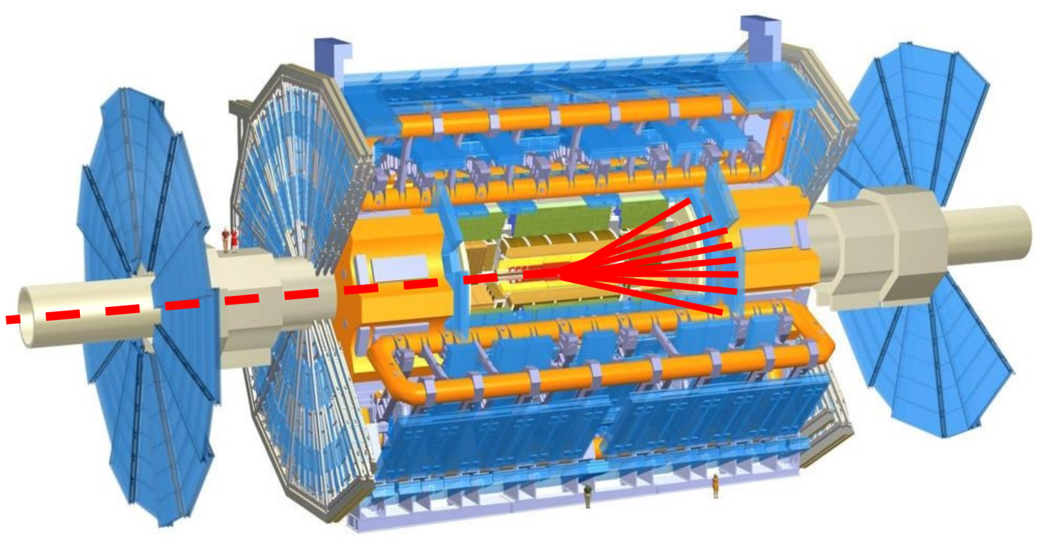

$$\xi = 1 - \frac{E_{p'}}{E_p} \quad , \quad \xi^{\pm}_{EP_z} = \frac{\Sigma_i (E_i \mp p_{z,i})}{\sqrt{s}}$$




$$t = (P_1 - P_3)^2 \approx -(p_T^{\text{scattered proton}})^2$$

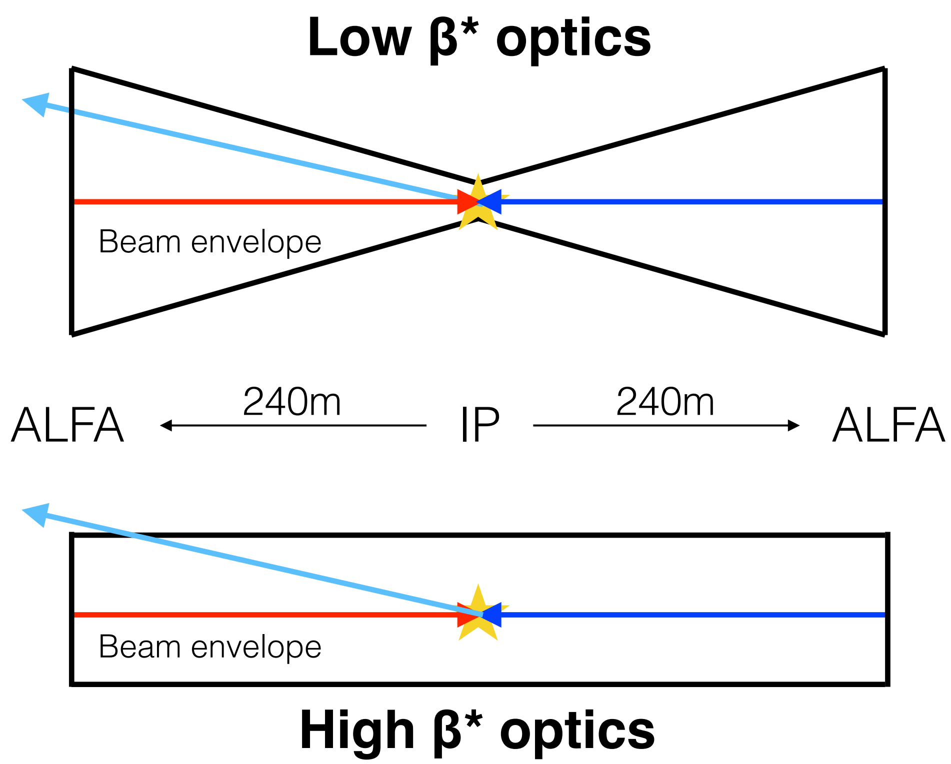
Backgrounds:

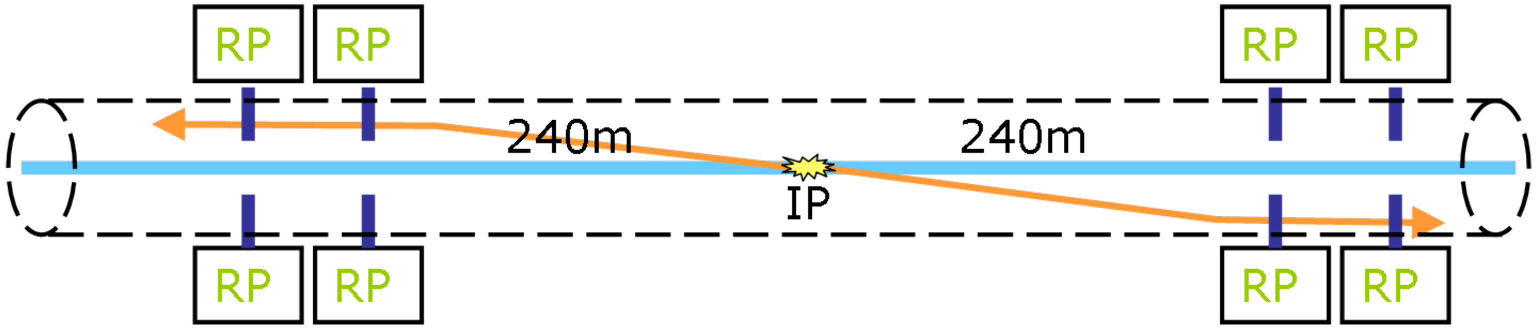


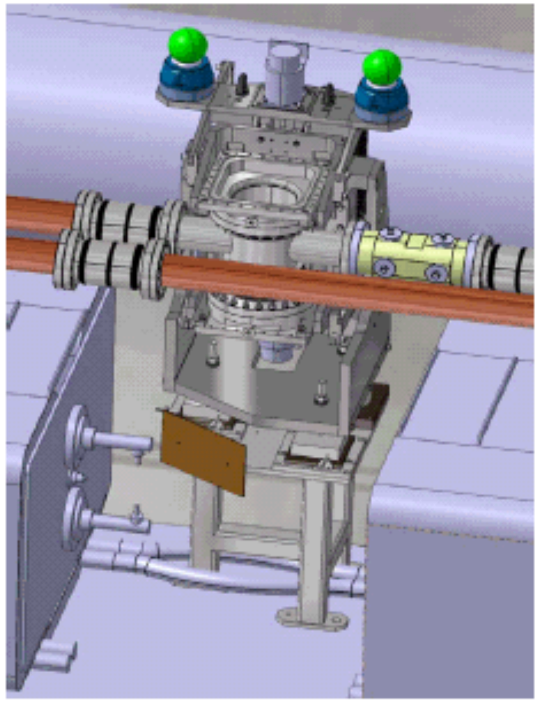



# The ALFA sub-detector

- ALFA (Absolute Luminosity For ATLAS)
- Roman Pot (RP) detector using scintillating fibres
- Situated ~240m down the beam from interaction point in both directions
- Used with special high β*, parallel to point optics with low pile up
  - Provides access to scattering angle

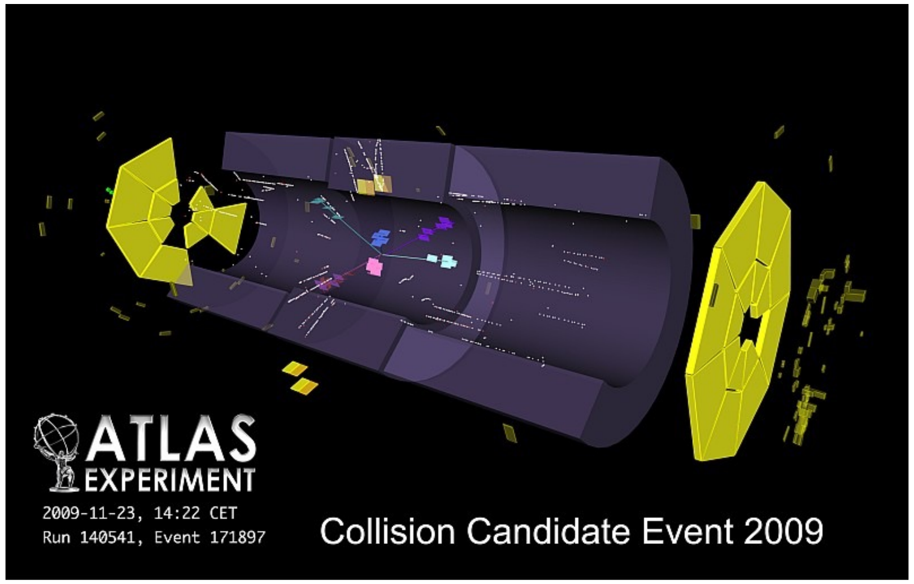


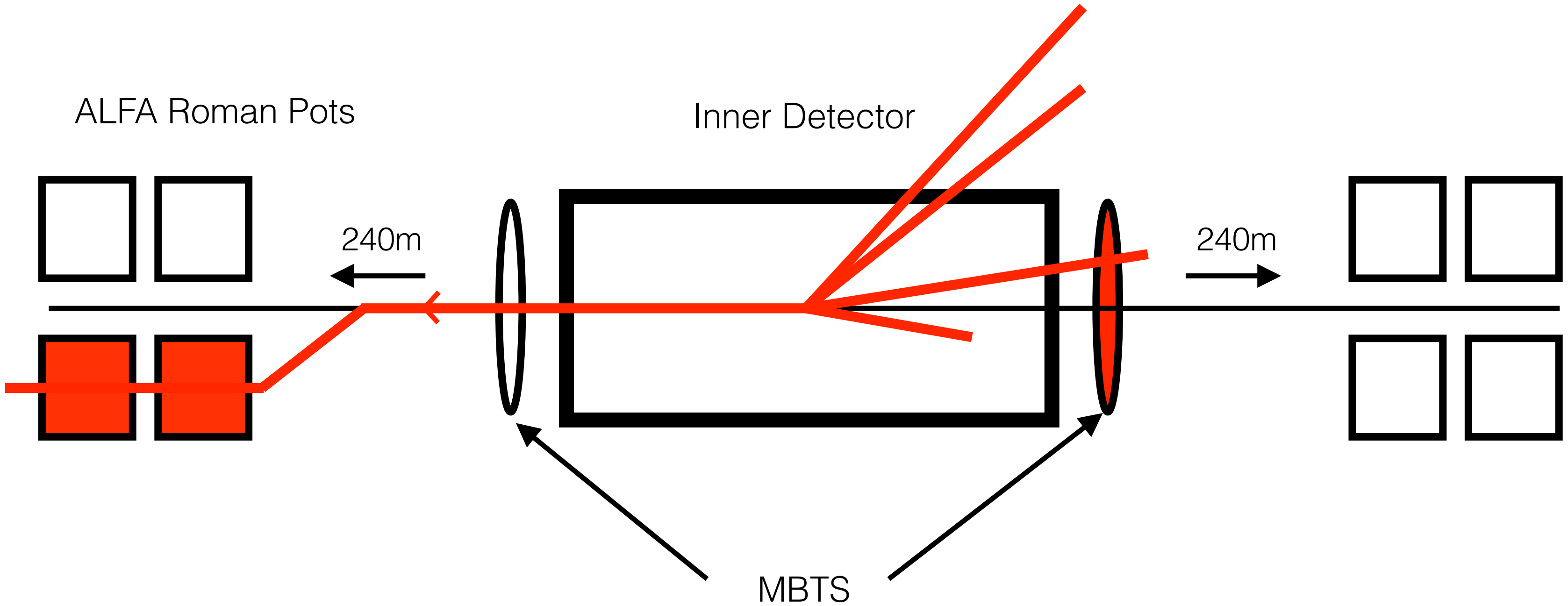



# Event selection

- L1_MBTS_2_A(C)_ALFA_C(A) triggers
- 1 'tagged' proton
- 5 MBTS counters above noise threshold (low trigger efficiencies below this)
- $\geq 1$ track with $p_T > 200$ MeV

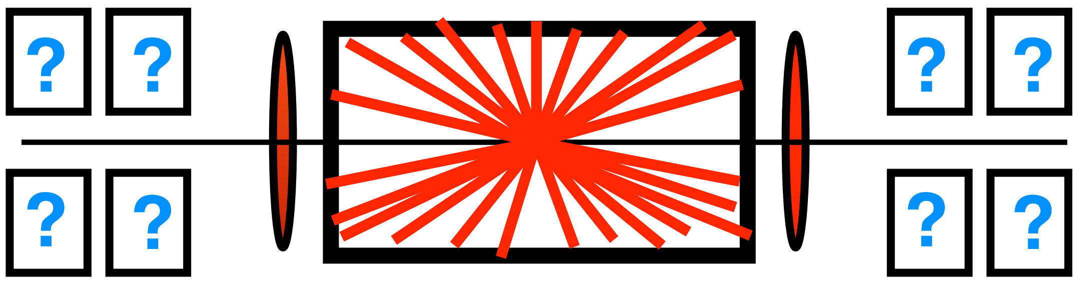



Minimum Bias Trigger Scintillators (MBTS)




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

# Data Driven Background




- ND, CD and DD modelled with MC
- Possible for **two separate overlaid processes** to produce **SD-like signal**
  - eg. ND + elastics/halo
- Random rate of protons measured in background dominated region
- ~1% chance of one random proton overlaid on an event
  - Referred to as "Proton Overlay" in plots

| Contributing Process | % of total |
|---|---|
| ND | 99.273 |
| SD | 0.714 |
| DD | 0.012 |
| CD | 0.001 |

Composition of ND-enriched sample

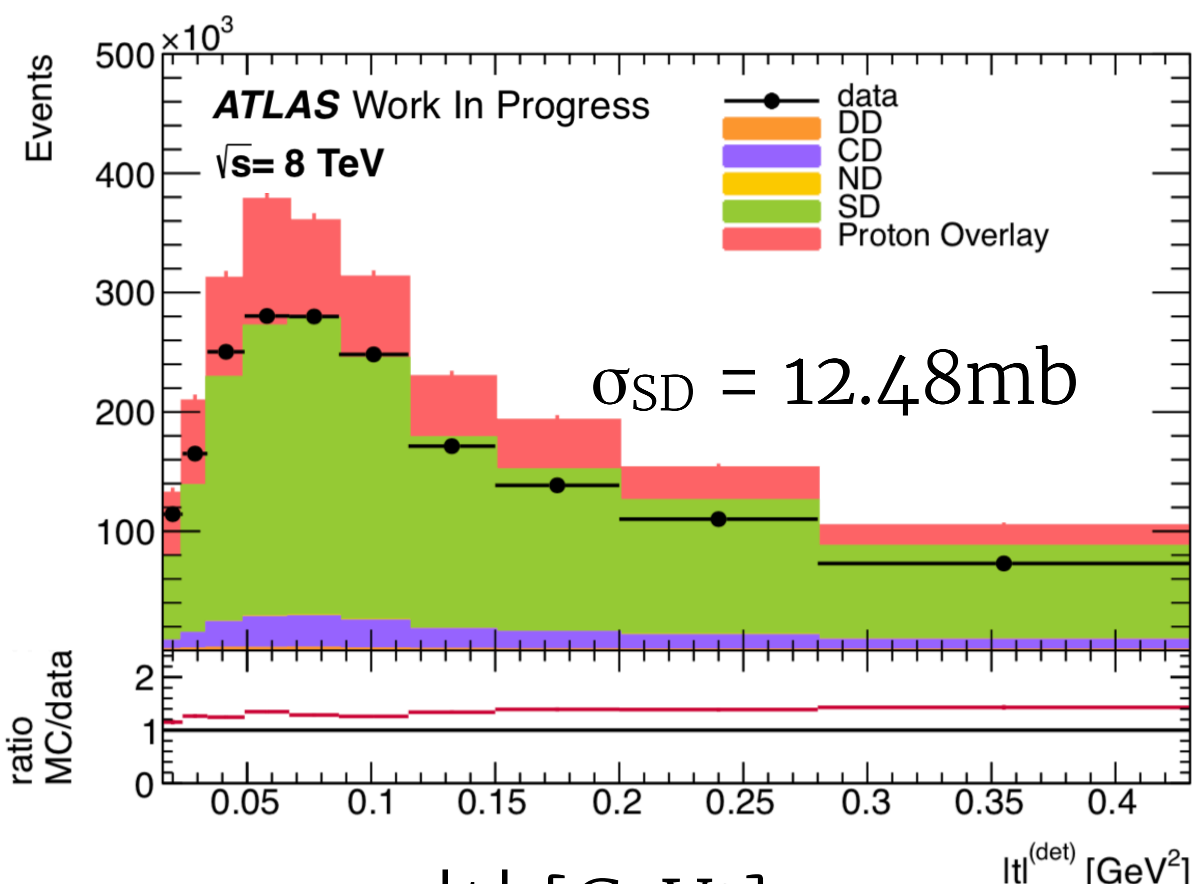
| Number of protons | Probability |
|---|---|
| 0 | 0.9850 |
| 1 | 0.0077 |
| 2 | 0.0073 |
| 3 | <0.0001 |
| 4 | <0.0001 |

Probability of 'proton' in ALFA that is not directly linked to event

# Control Plots

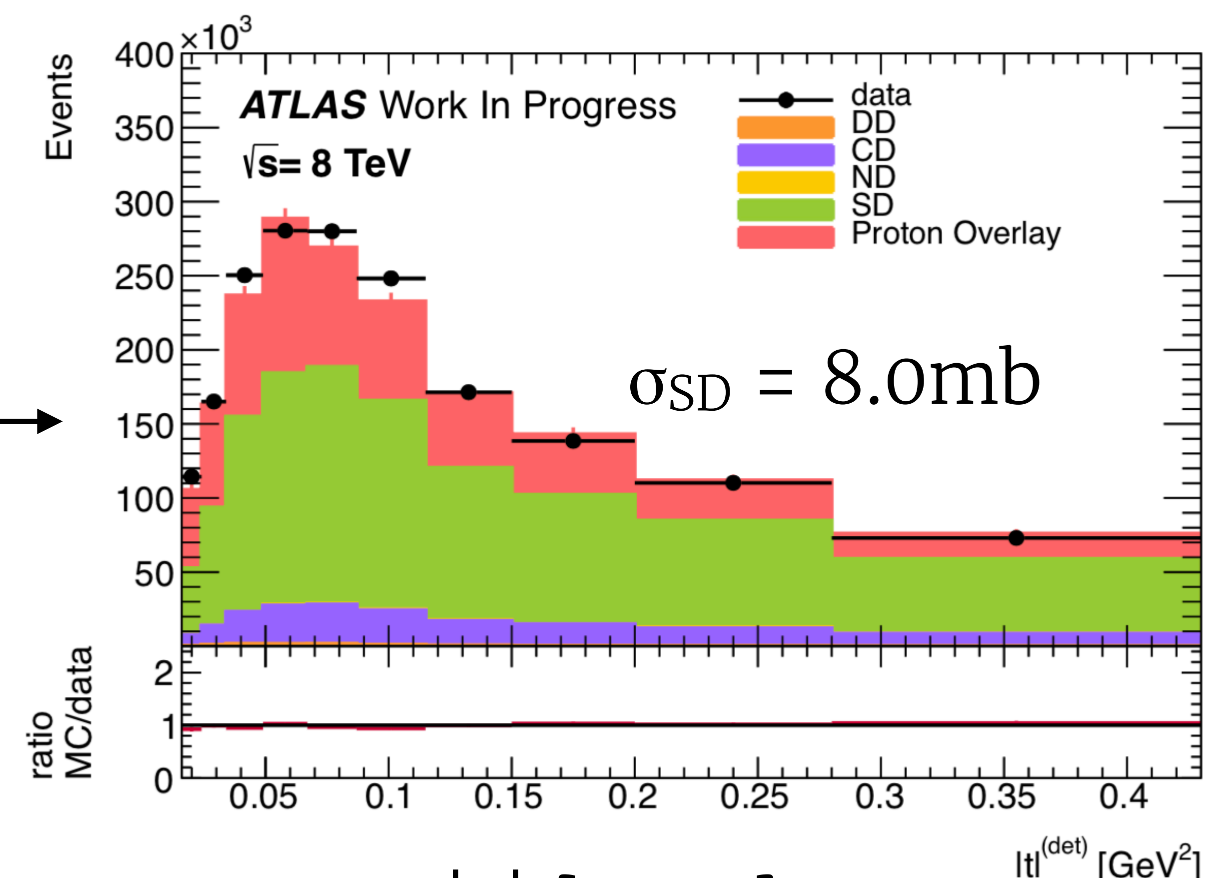
- Observe poor normalisation agreement
  - **Good shape agreement**
  - Stat. uncertainties only
- **Renormalise SD MC** to have measured cross section from this analysis (~8mb)

| | Fraction of total |
|---|---|
| **SD** | 70% |
| **Proton Overlay** | 22% |
| **CD** | 7% |
| **DD** | < 1% |
| **ND** | < 1% |




|t| [GeV²]

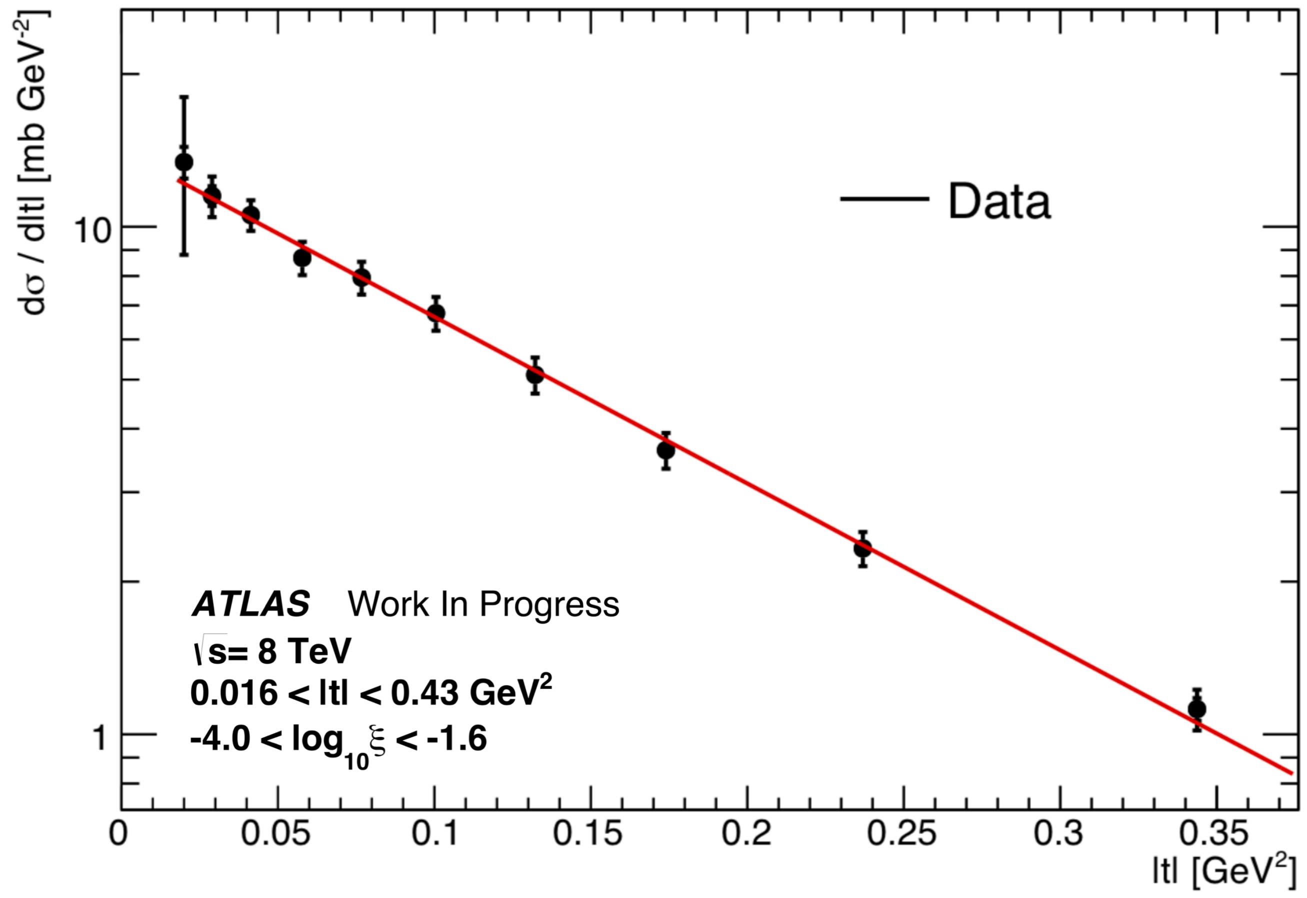
→




|t| [GeV²]

# Results t

- |t| unfolded to hadron level
- Data points plotted at **mean of bin** (due to non-flat shape of distribution)
- Fit accounts for correlation between uncertainties
- **B = 7.55±0.23 GeV$^{-2}$**
  - Dominant uncertainty is **proton overlay background**
  - B(PYTHIA8 A2) = 7.82 GeV$^{-2}$
  - B(PYTHIA8 A3) = 7.10 GeV$^{-2}$




|t| [GeV$^2$]

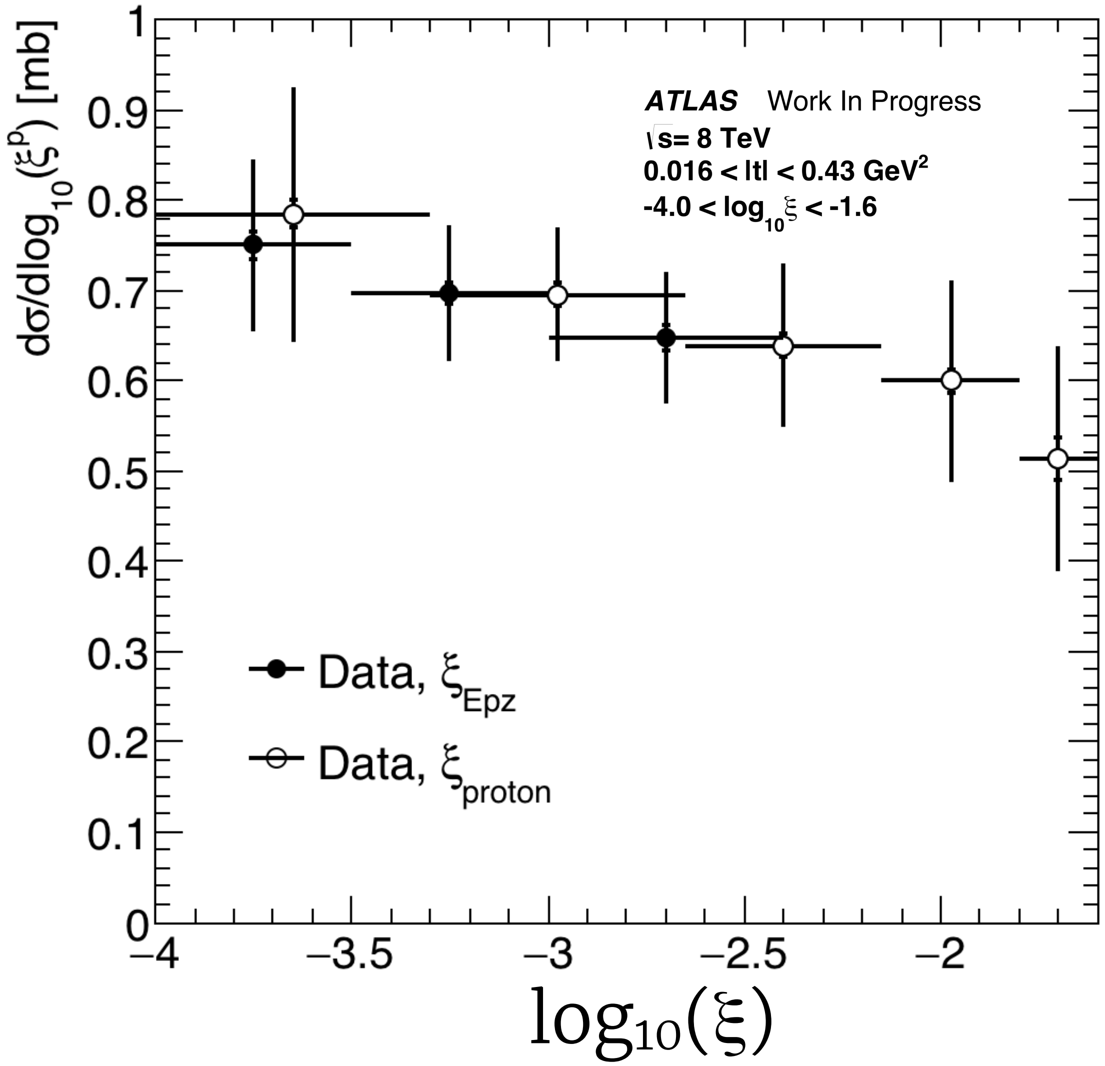
$$\frac{d\sigma}{dt} = e^{A+Bt}$$

$$\text{Note: } t < 0; B > 0$$

# Results ξ

- $\xi_p$ and $\xi_{Epz}$ unfolded to **true** ξ
- Observe very good agreement despite very different backgrounds, systematics and unfolding matrices
- Fit using Regge theory predictions, where $\alpha(t) = \alpha(0) + \alpha' t$
- Fits yield:

| Distribution | $< t >$ | $\alpha(< t >)$ |
|---|---|---|
| PYTHIA8 A2 (SS) | -0.129 | 0.971 ± 0.001 |
| PYTHIA8 A3 (DL) | -0.136 | 1.036 ± 0.000 |
| Data(ALFA) | -0.1325 | 1.038 ± 0.028 |
| Data(ID) | -0.1325 | 1.030 ± 0.020 |




- Using <t>=0.13GeV$^2$ and $\alpha'$ = 0.25GeV$^{-2}$ (DL[(1)]), extract $\alpha(0)$

| Distribution | $\alpha(0)$ |
|---|---|
| PYTHIA8 A2 (SS) | 1.003 ± 0.001 |
| PYTHIA8 A3 (DL) | 1.070 ± 0.001 |
| Data(ALFA) | 1.071 ± 0.028 |
| Data(ID) | 1.063 ± 0.021 |

$$\sigma_{\mathrm{TOT}}(s) \propto s^{\alpha(0)-1}$$

(1) Physics Letters B, vol. 296, no. 1, pp. 227 – 232, 1992

# Results $\sigma_{SD}$

- The cross section is measured within the **fiducial region**, $0.016 < |t| < 0.43$ GeV$^2$, $-4.0 < \log_{10}(\xi) < -1.6$ (corresponding to $80 < M_X < 1270$GeV)
  - $\sigma_{SD}$(fiducial) = **1.58 ± 0.13 mb**
- Using t slope from data, can **extrapolate to $0 \le |t| \le \infty$**,
  - $\sigma_{SD}$(all t, $-4.0 < \log_{10}(\xi) < -1.6$) = **1.86 ± 0.16 mb**
- As $\alpha(0)$ consistent with Pythia8 A3, can simplistically scale the Pythia8 A3 cross section by the normalisation factor observed within the measured range
  - $\sigma_{SD}$ = 7.8mb (uncertainty inestimable, due to very poorly constrained low and high $\xi$ behaviour)

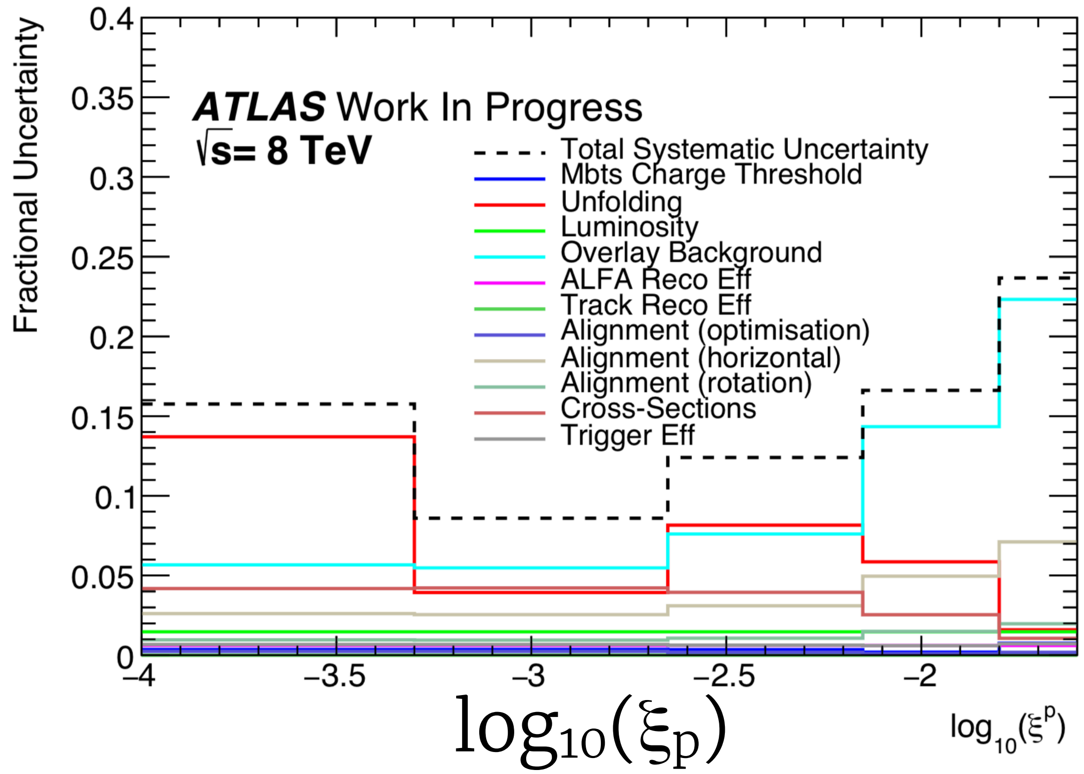
| Distribution | $\sigma_{SD}^{\text{fiducial}(\xi,t)}$ [mb] | $\sigma_{SD}^{\text{fiducial}(\xi)}$ [mb] | $\sigma_{SD}$ [mb] |
|---|---|---|---|
| Pythia8 A2 (SS) | $3.69 \pm 0.00$ | $4.35 \pm 0.00$ | 12.48 |
| Pythia8 A3 (DL) | $2.52 \pm 0.00$ | $2.98 \pm 0.00$ | 12.48 |
| Data | $1.58 \pm 0.13$ | $1.86 \pm 0.16$ | 7.8 |

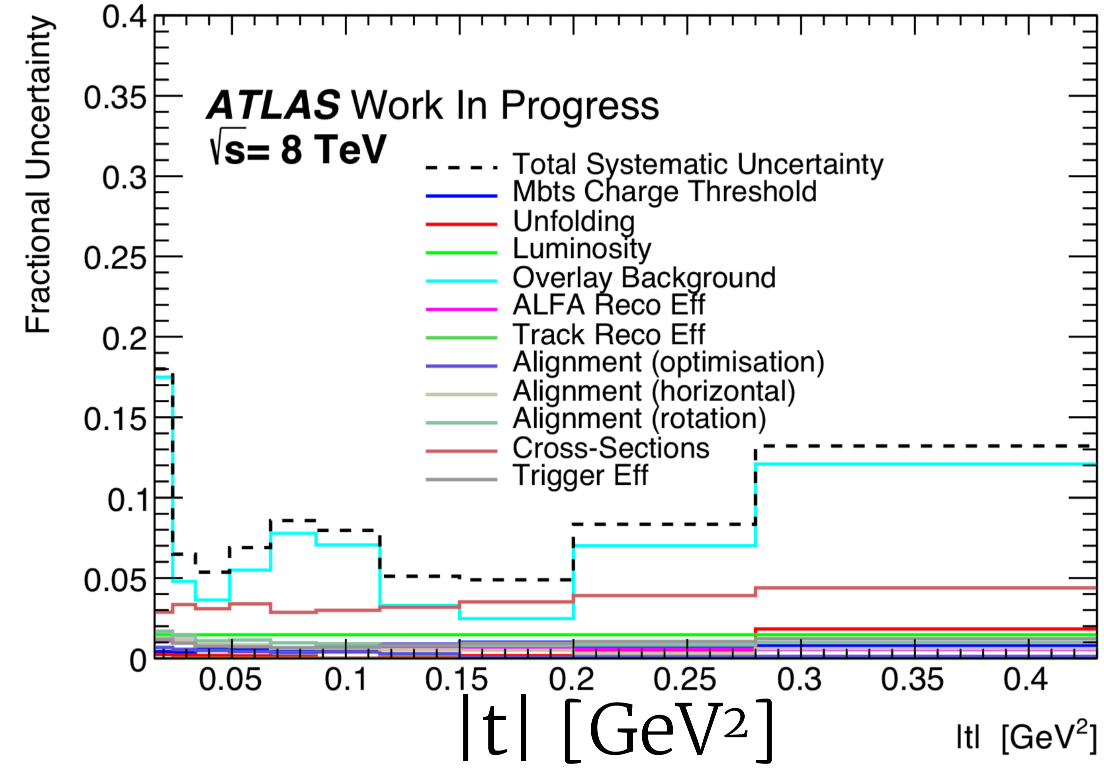
# Summary

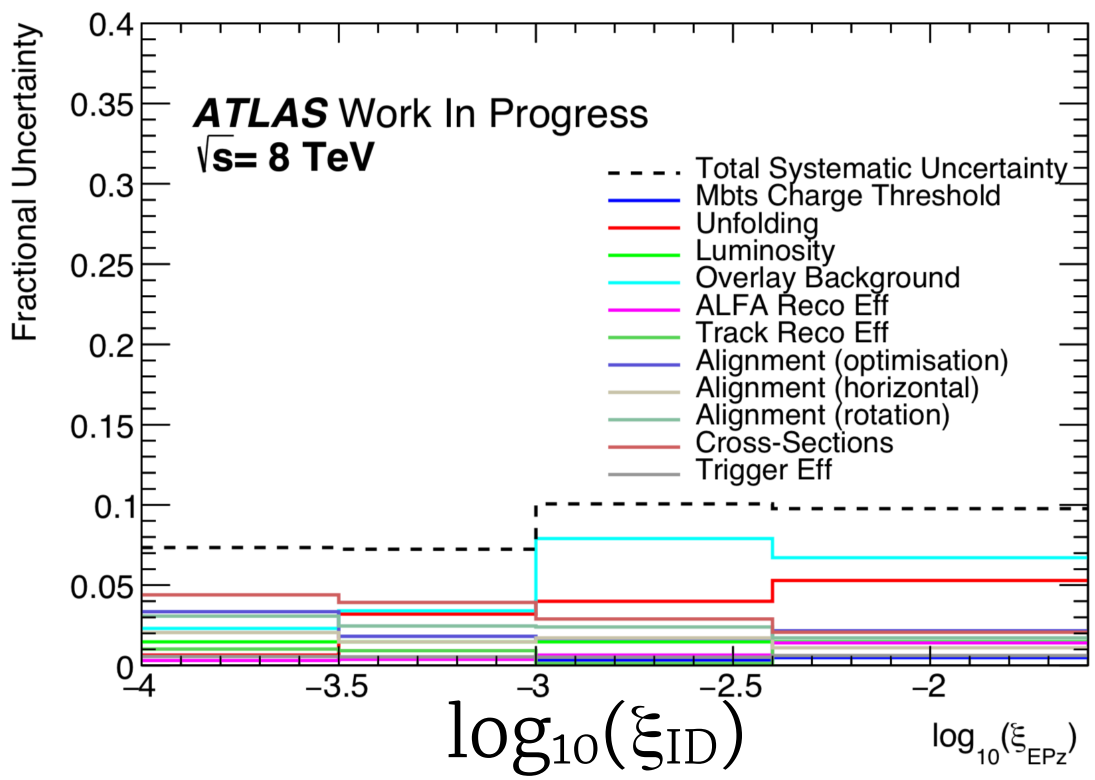
- Hadron level differential cross sections presented in $|t|$ and $\xi$
  - Measure a B slope of **7.55 ± 0.18 GeV$^{-2}$** (PYTHIA8 A3 pred. 7.10 GeV$^{-2}$)
  - Extract $\alpha(0)$ from **two measurements**, consistent with each other and PYTHIA8 A3
    - $\alpha(0)$ extracted from $\xi$ dependence of SD consistent with that from s dependence of $\sigma_{Tot}$ and $\sigma_{el}$
- SD **normalisation lower** than predicted by PYTHIA8

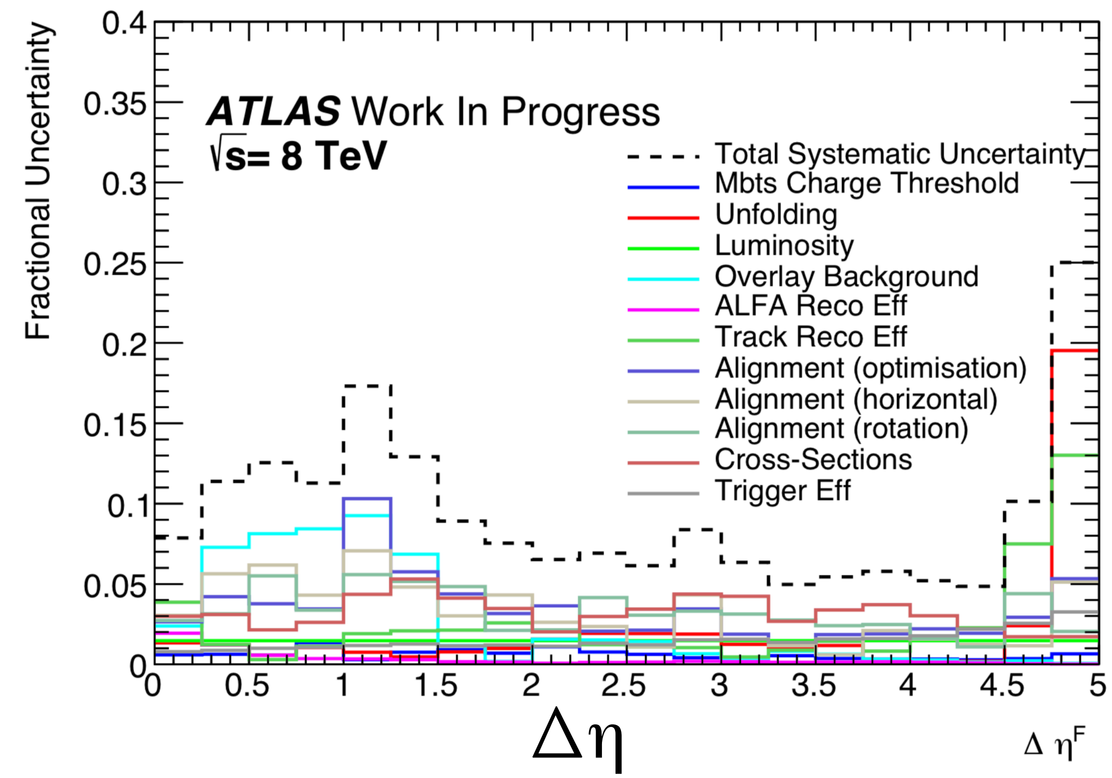
# Backups

# Systematic Uncertainties



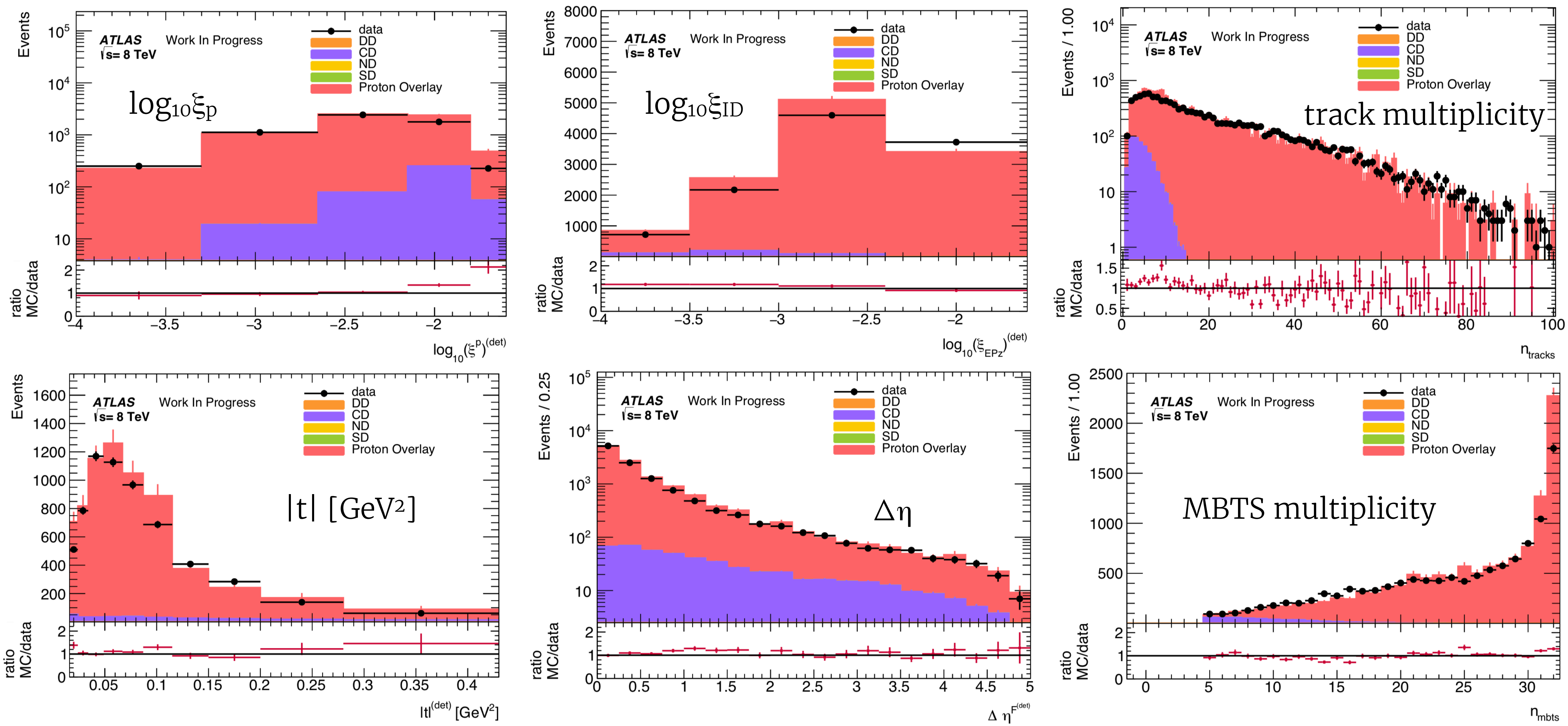



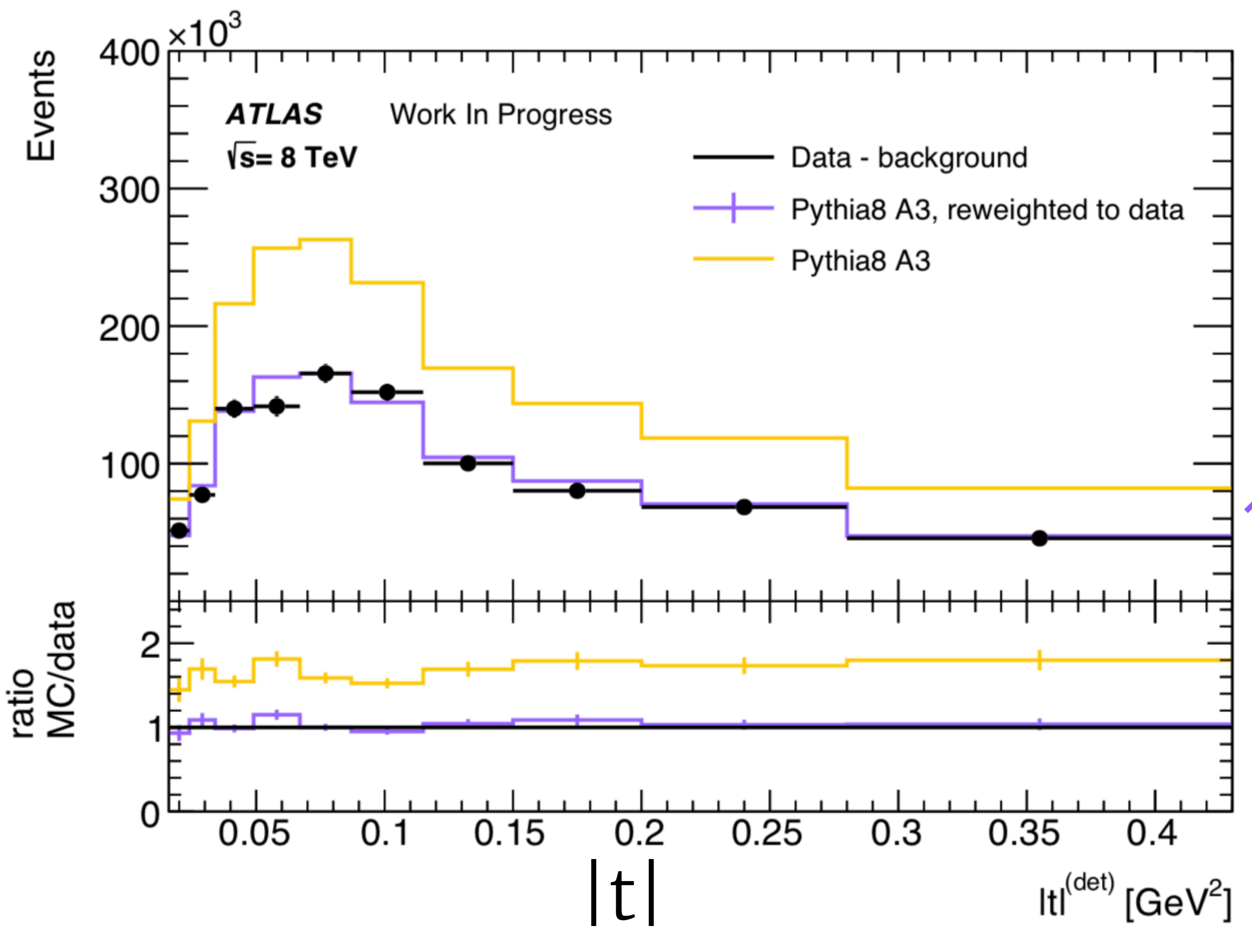
# 2 proton control region

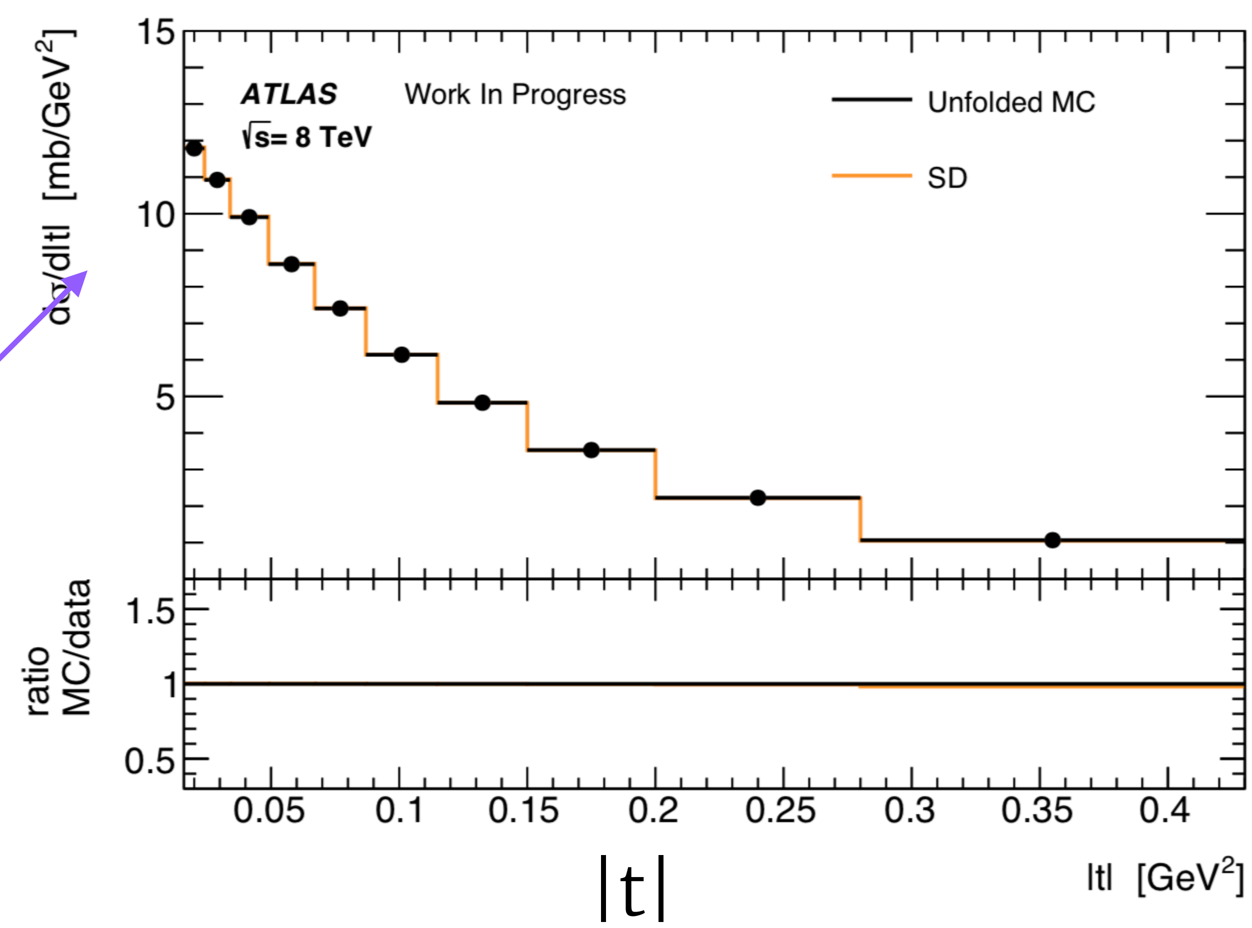
- Analysis selection same as nominal but with **two ALFA armlets requiring a proton**
  - Dominated by overlay of **elastic scattering in ALFA and ND in the ID**
  - Used to evaluate systematic uncertainty on proton overlay background
  - Observe good normalisation of overlay method



# Systematic Uncertainty on Unfolding (|t|)

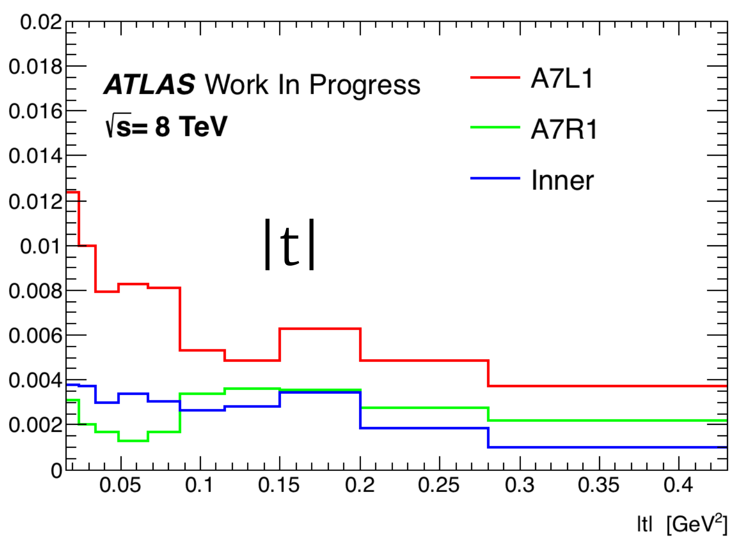
- MC re-weighted so that MC (reco) matches **data**. MC (truth) re-weighted to same function
- MC (reco) unfolded using nominal response matrix
- Difference between MC (reco) and MC (truth) is the uncertainty

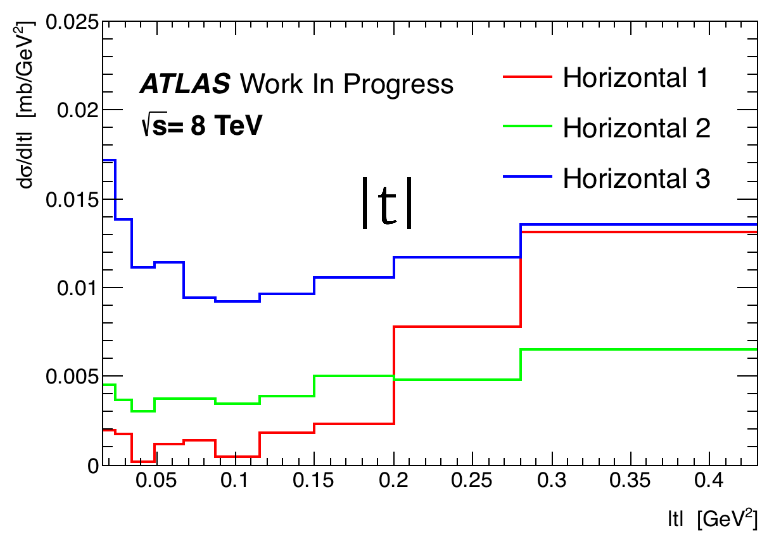


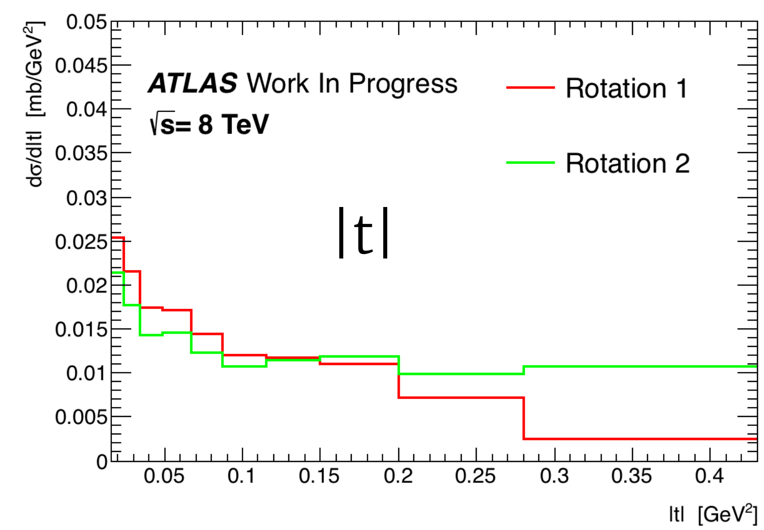



# Systematic Uncertainties (ALFA Alignment)

- Used method (and alignment files) from **8TeV elastics** analysis
- **Three separate systematic variations considered**: horizontal, rotation and optimisation (using multiple variations for each method)
- Conservatively take the envelope for each of the systematics



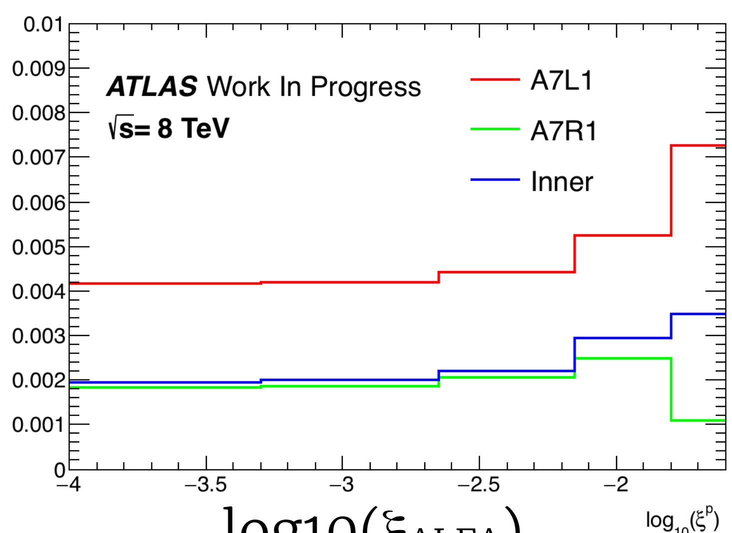



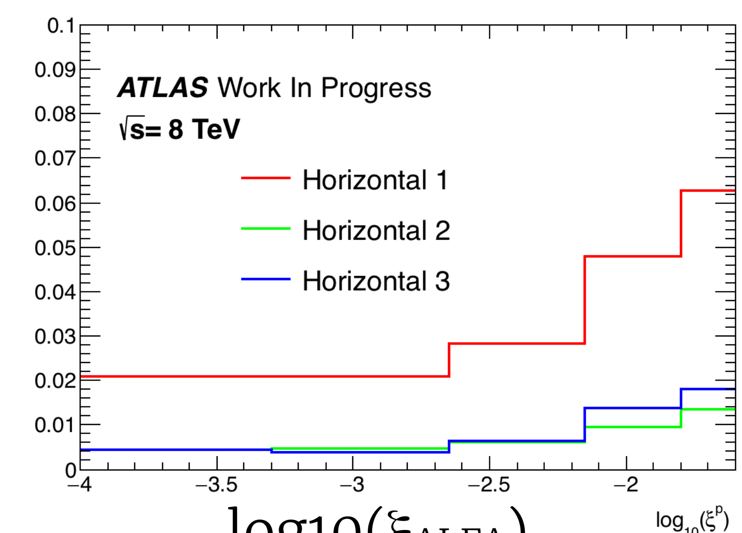



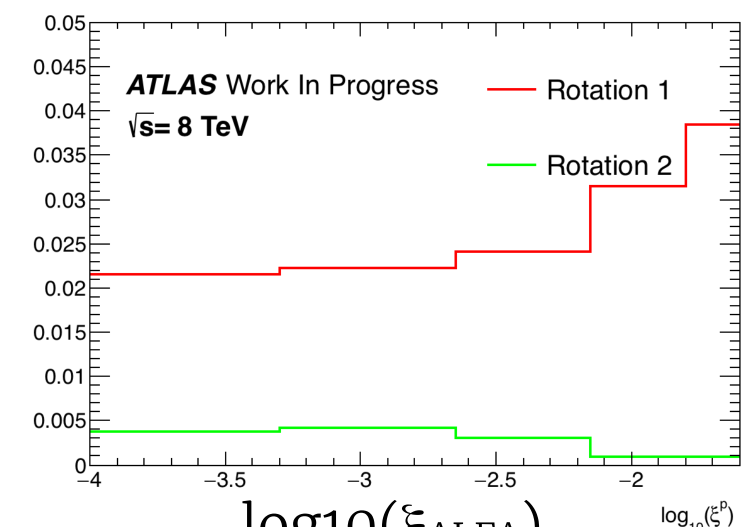

Optimisation

Horizontal

Rotation



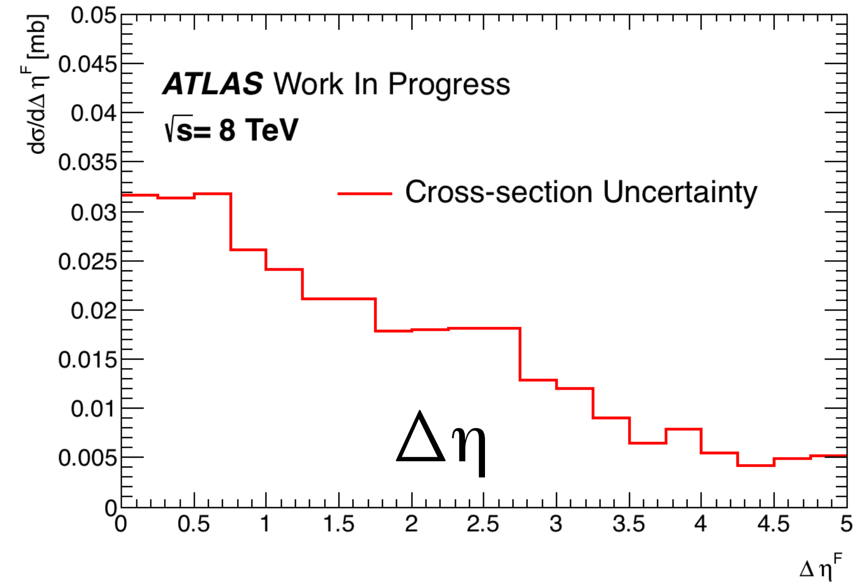



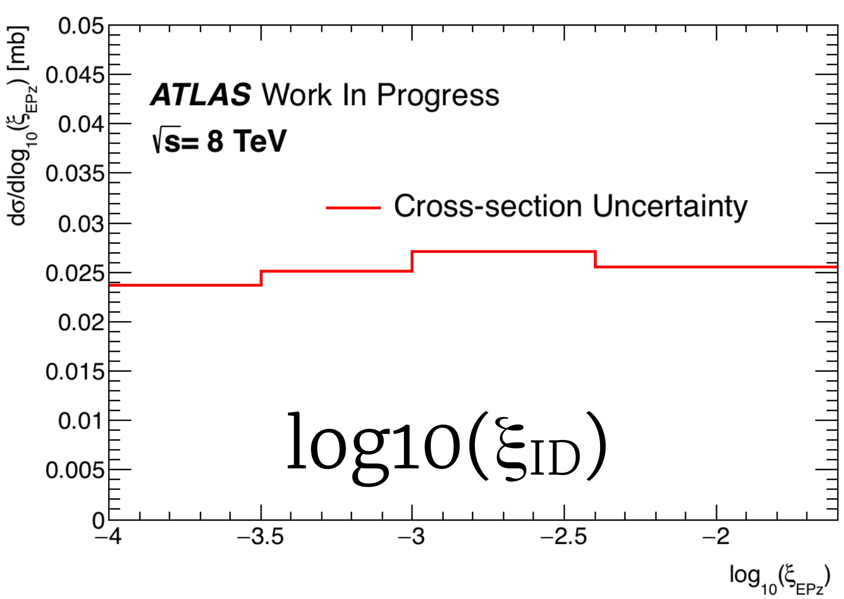



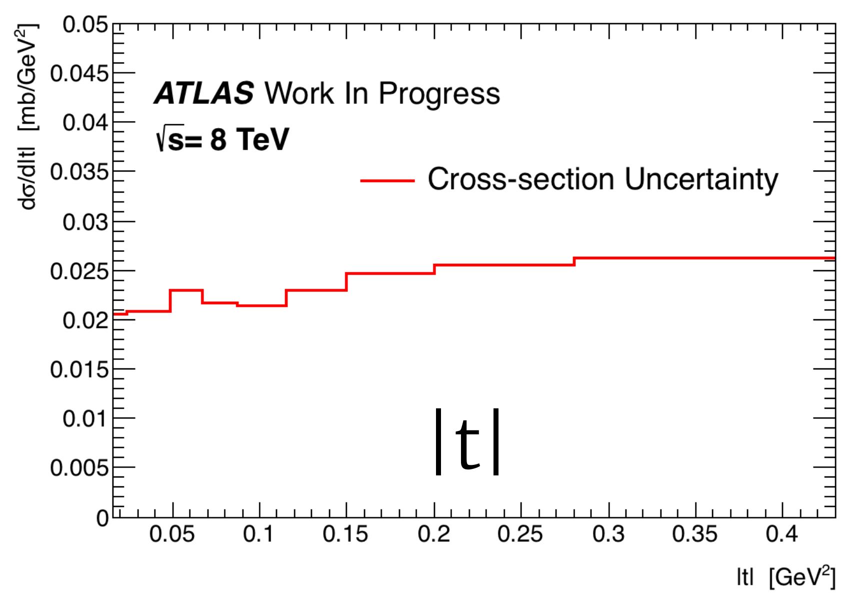

$\log10(\xi_{ALFA})$ $\log10(\xi_{ALFA})$ $\log10(\xi_{ALFA})$

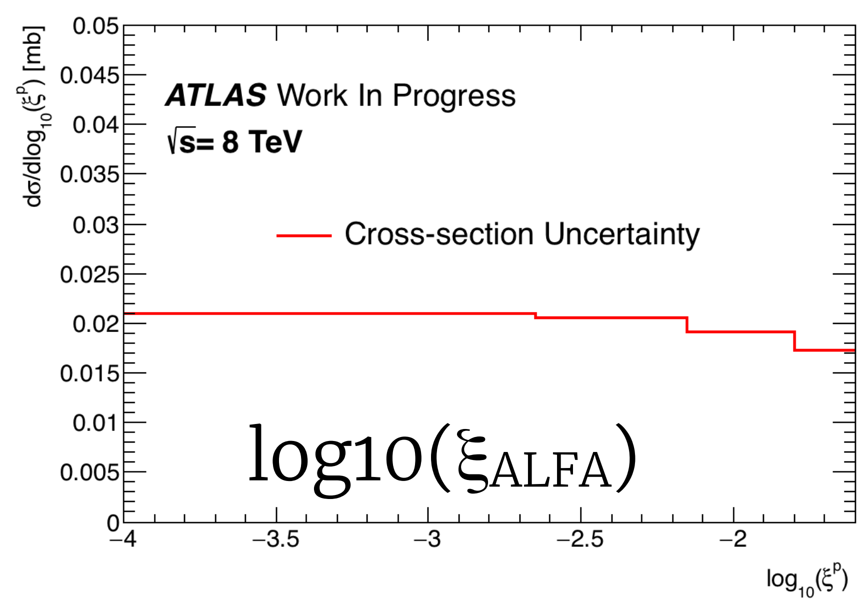
# Systematic Uncertainties (Cross-section)

- Background cross-sections **not well constrained**
- Following 7TeV rapidity gaps paper[1] method, vary ratio of $\sigma_{DD}/\sigma_{SD}$ between the limits derived from CDF measurements of $\sigma_{SD}$[3] and $\sigma_{DD}$[2] extrapolated to the **full diffractive kinematic range** of PYTHIA8: $0.29 < \sigma_{DD}/\sigma_{SD} < 0.68$
- Move $\sigma_{CD}$ coherently with $\sigma_{SD}$, fixed at 9.3% of $\sigma_{SD}$ and to extremities of CDF uncertainty
- Can vary $\sigma_{DD}/\sigma_{SD}$ to the full range without the uncertainties becoming too large, since very little DD in sample.
- CD presents as kinematically similar to SD, thus **relatively flat uncertainties** ~2%



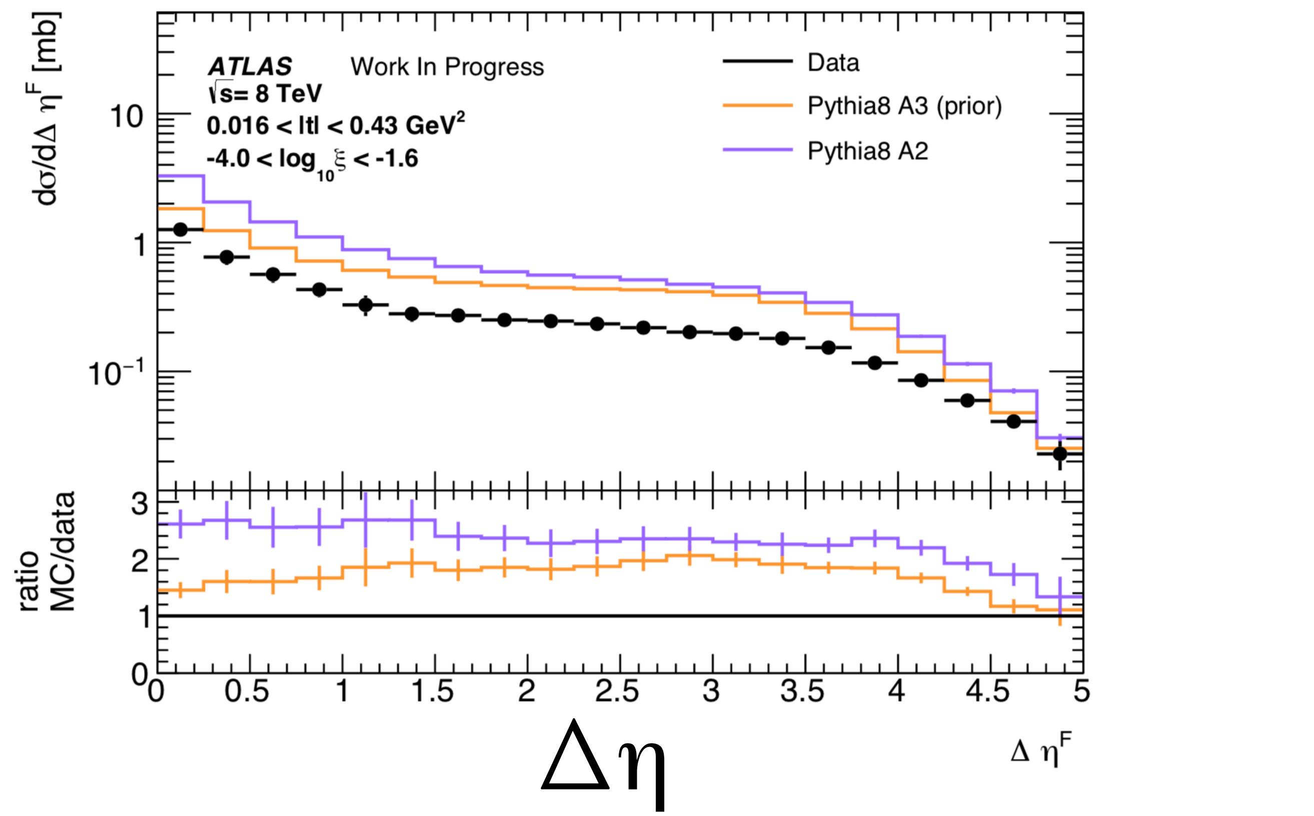



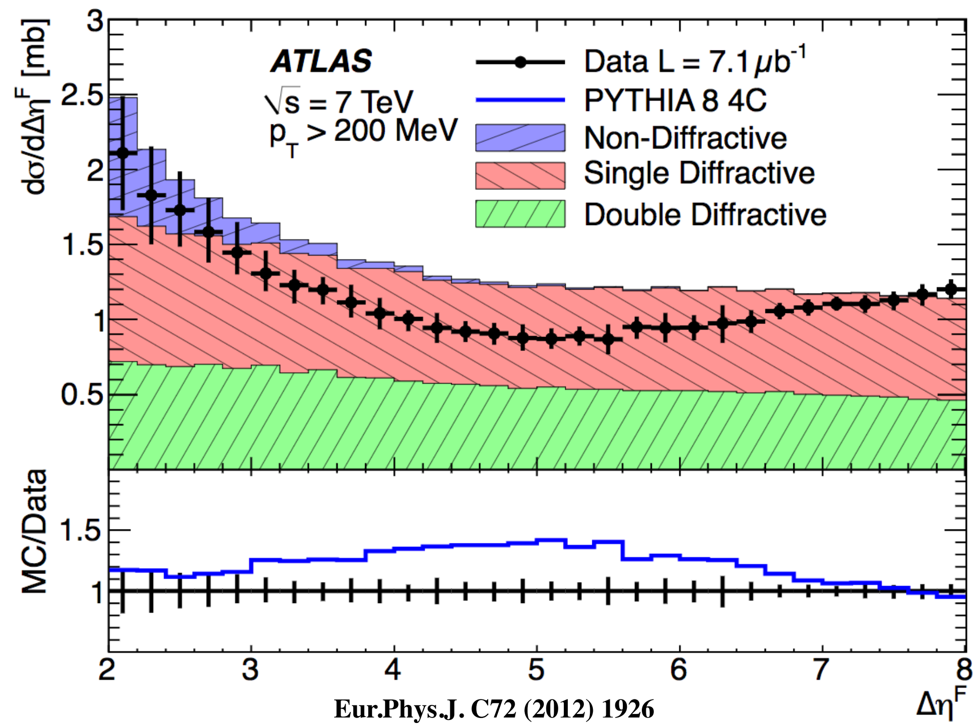




(2) CDF Collaboration, Phys. Rev. Lett. 87 (2001) 141802 [hep-ex/0107070]
(3) CDF Collaboration, Phys. Rev. D50 (1994) 5535
(1) https://arxiv.org/pdf/1201.2808.pdf

# Comparison to 7TeV Gaps analysis




- Different gap definition
- DD included in 7TeV paper
- If removing DD, see similar over-estimation by PYTHIA8