Measurement of Diffraction and Underlying Event at ATLAS

James Kendrick, on behalf of ATLAS
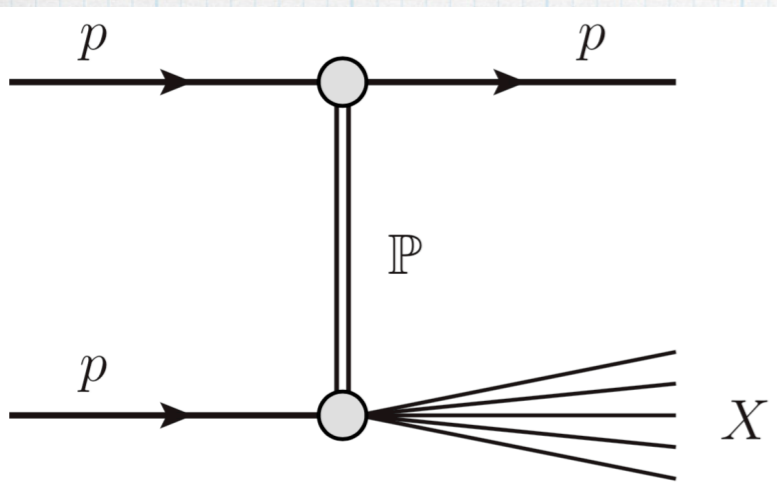eQCD2020, Krynica Zdrój, Poland

ATLAS EXPERIMENT

Analyses presented:

- "Measurement of differential cross sections for **single diffractive** dissociation in $\sqrt{s}$ = **8 TeV** pp collisions using the ATLAS ALFA spectrometer"
  - Accepted by JHEP
  - https://arxiv.org/abs/1911.00453
  - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2018-01/

- "Measurement of distributions sensitive to the **underlying event** in inclusive Z boson production in pp collisions at $\sqrt{s}$ = **13 TeV** with the ATLAS detector"
  - Eur. Phys. J. C 79 (2019) 666
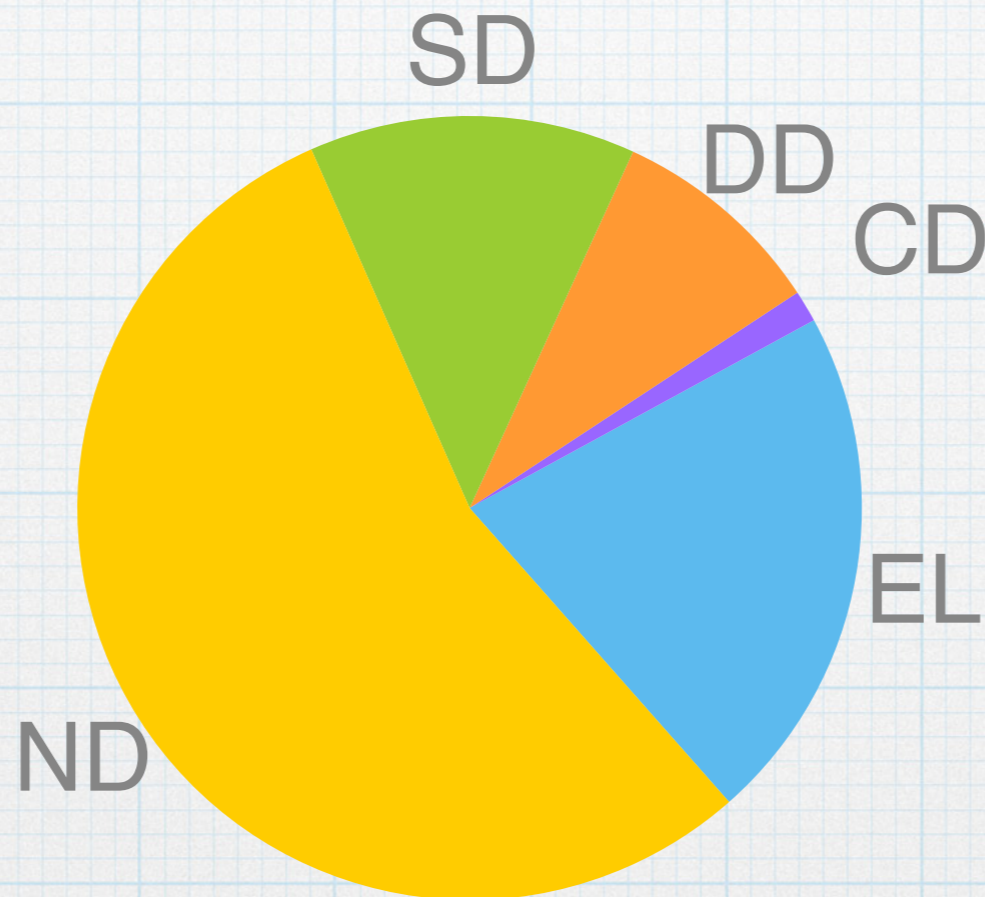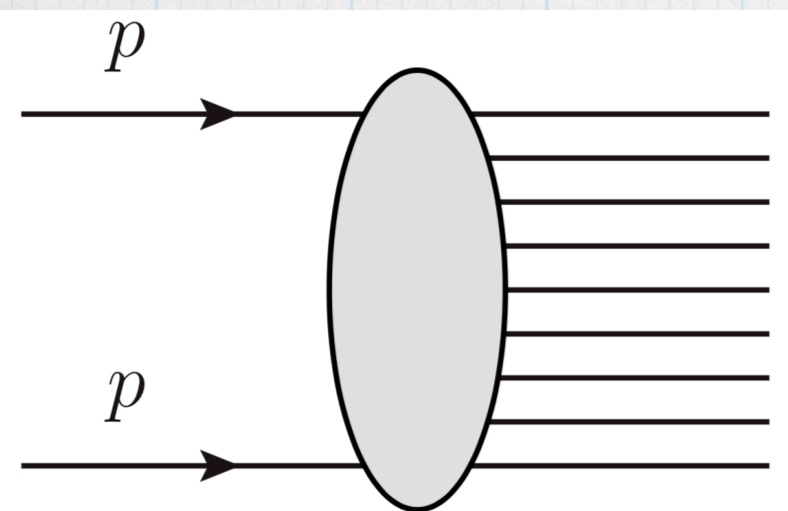 - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2017-28/

Measurement of differential cross sections for single diffractive dissociation in $\sqrt{s}$ = 8 TeV pp collisions using the ATLAS ALFA spectrometer
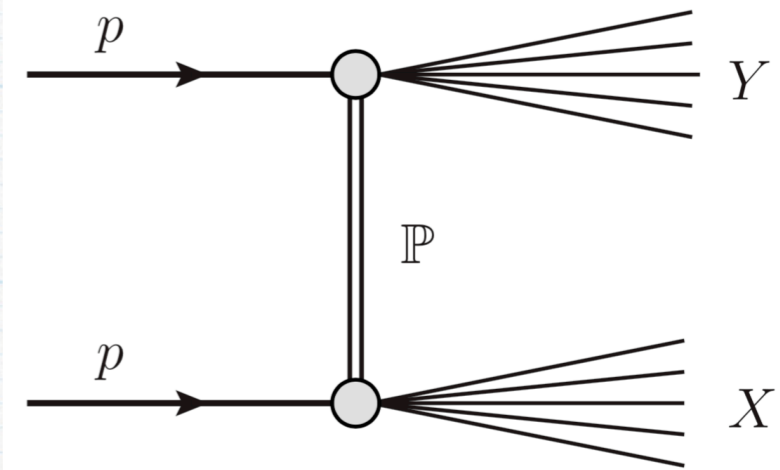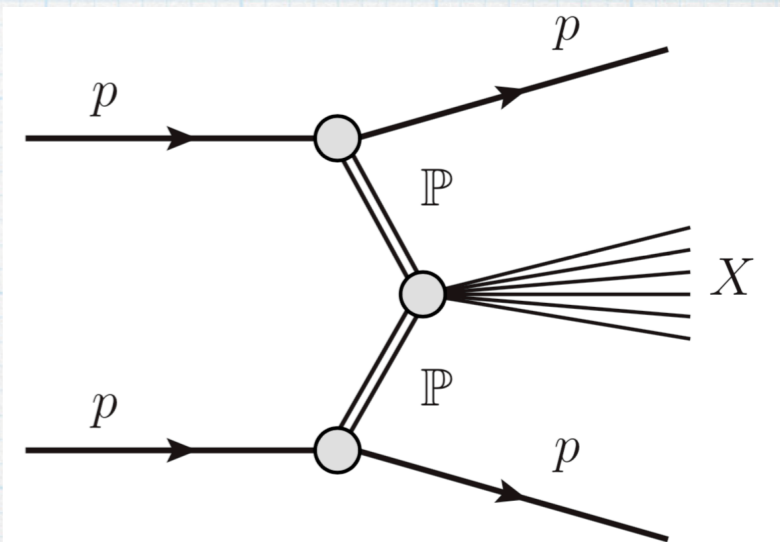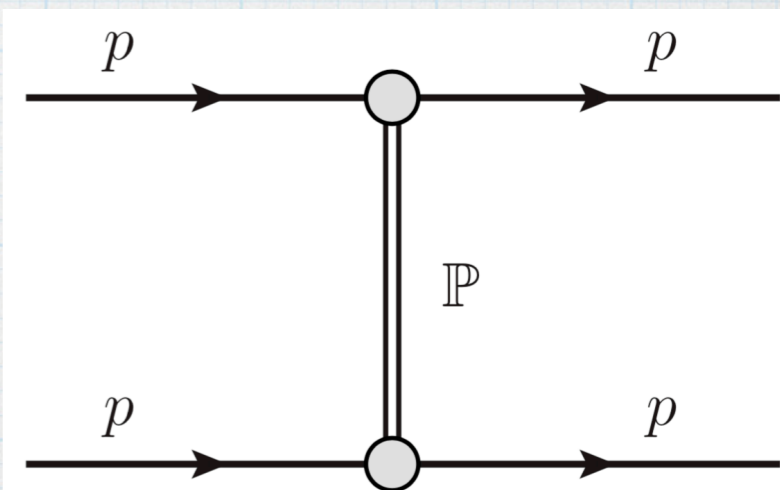
Total pp cross section

Double Diffraction

Single Diffraction

SD

DD

CD

Central Diffraction

EL

ND

Non-diffraction

Elastic

Analysis variables

$\Delta\eta$

P_1

$\mathbb{P}$

P_2

P_3

X
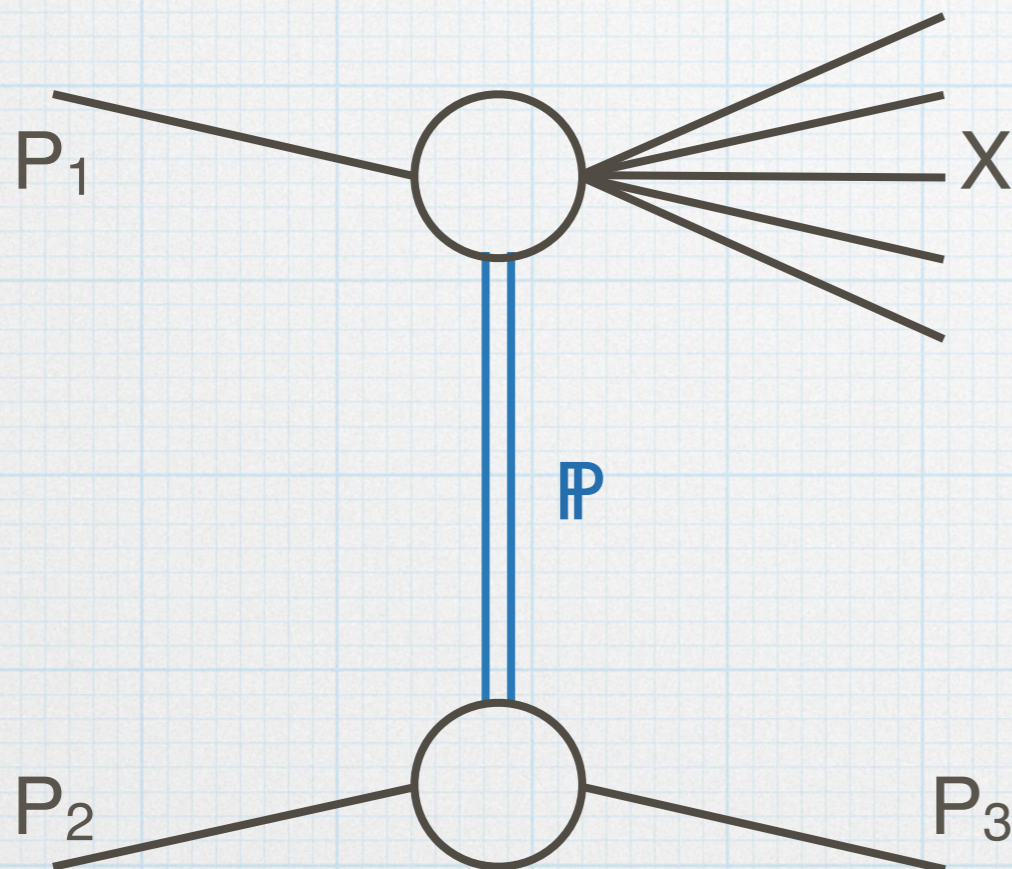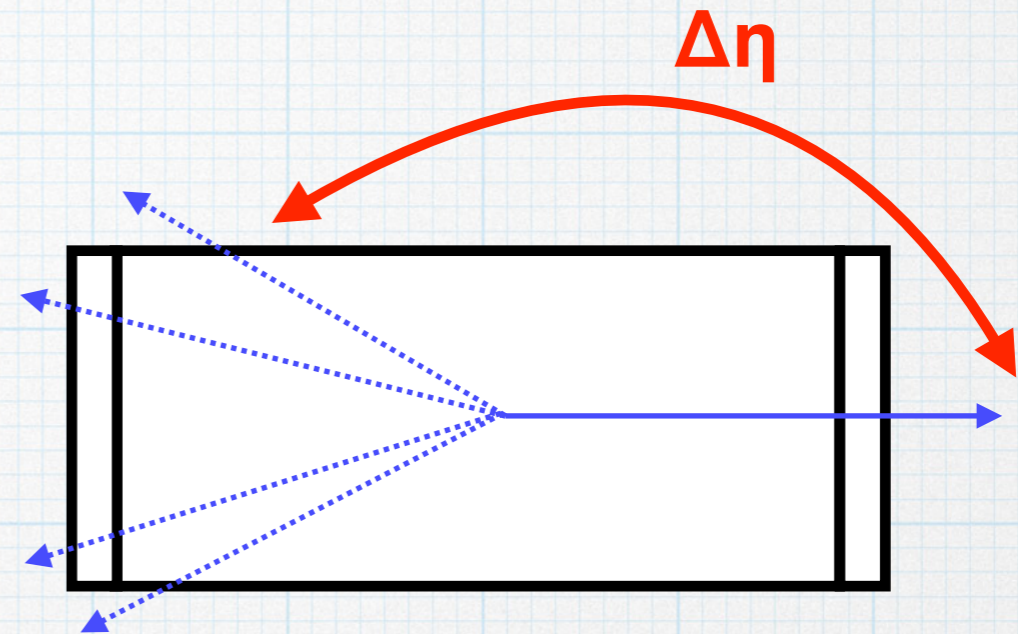
Fractional energy loss of proton

$$\xi = 1 - \frac{E_3}{E_2} = \frac{M_X^2}{s}$$

$$\xi_{EPz} \approx \frac{\Sigma_i(E^i \pm p_z^i)}{\sqrt{s}}$$

Mandelstam t exchange

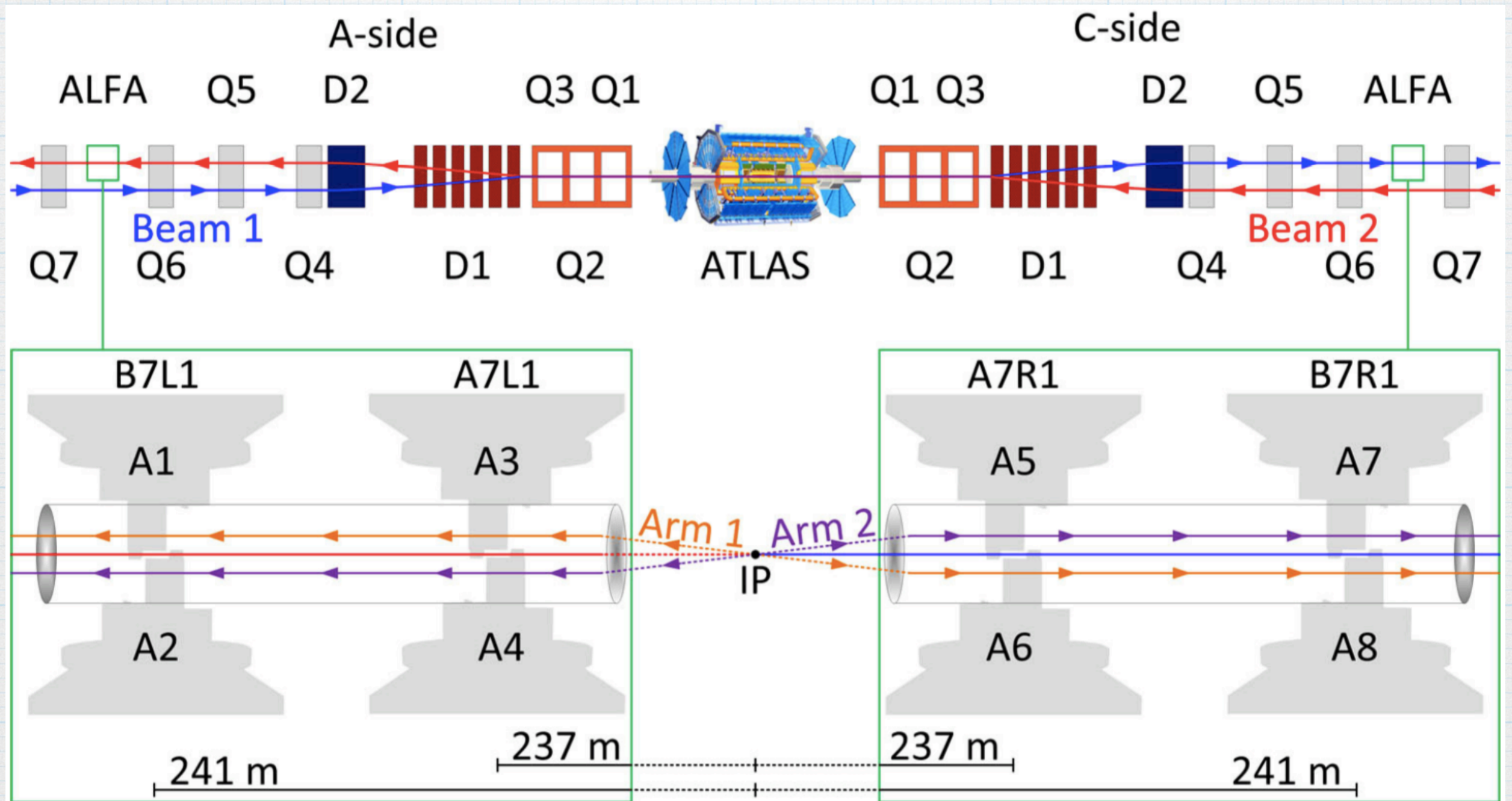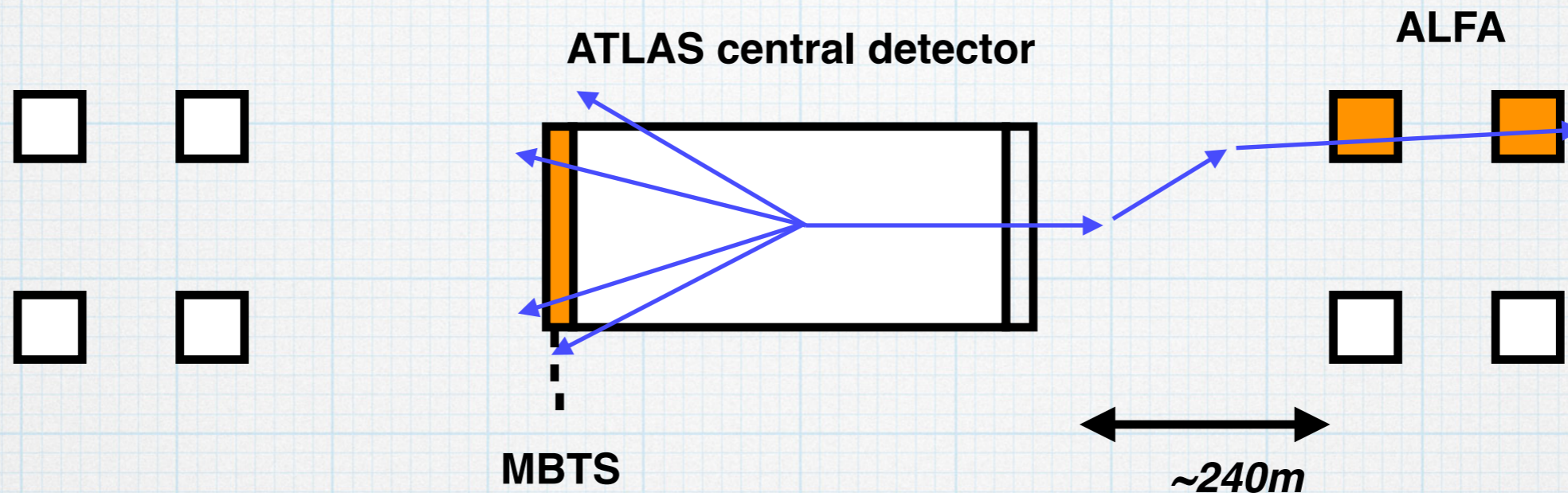$$t = (p_3 - p_2)^2$$

$$t \approx -p_T^2$$

ALFA

Use requires:

- High β*
- Low luminosity & pile-up

For the data in this analysis, β* = 90m & μ = 0.08

Same run as used by elastic cross-section analysis

Event selection

ATLAS central detector

ALFA

MBTS

~240m

- Online trigger
  - ALFA signal
  - MBTS on opposing side

- Offline selection:
  - Exactly one proton reconstructed in ALFA with additional selection
  - At least 5 MBTS counters above threshold
  - At least 1 ID track with $P_T > 200$ MeV
  - Only one reconstructed vertex

Backgrounds

- Single source backgrounds are small
    - CD biggest contribution

- 'Overlay background' is largest background
    - Due to uncorrelated ALFA activity (beam halo) and pile-up events
    - Estimated through data-driven model & ND-enriched sample
    - Provides t distributions
    - Provides normalisation to ξ & Δη MC distributions

- Performance of models assessed using control regions

SD

CD

Overlay
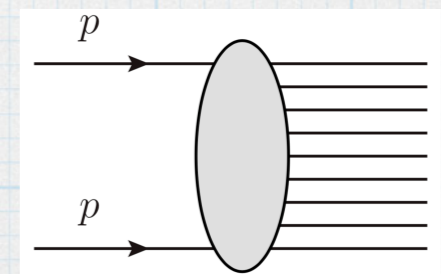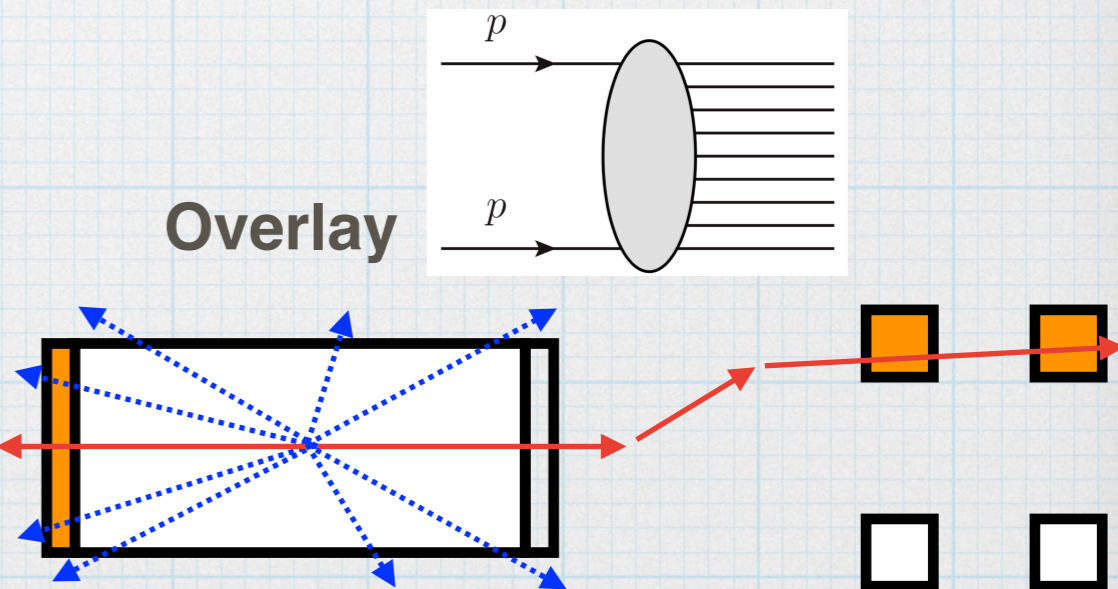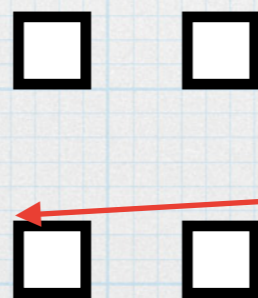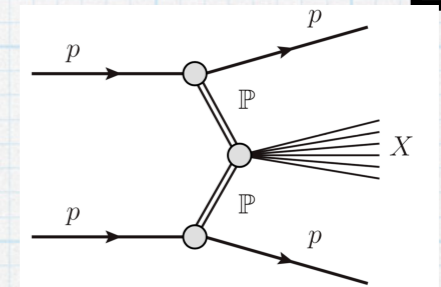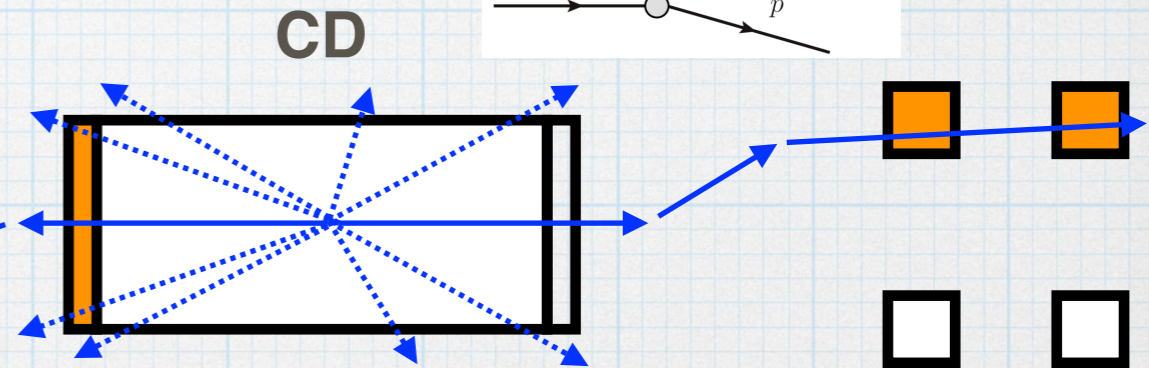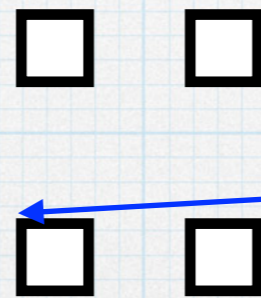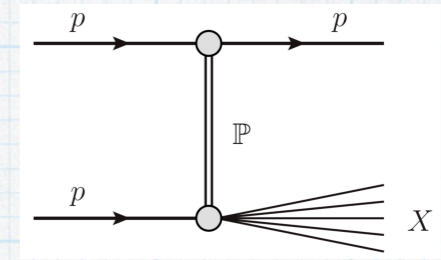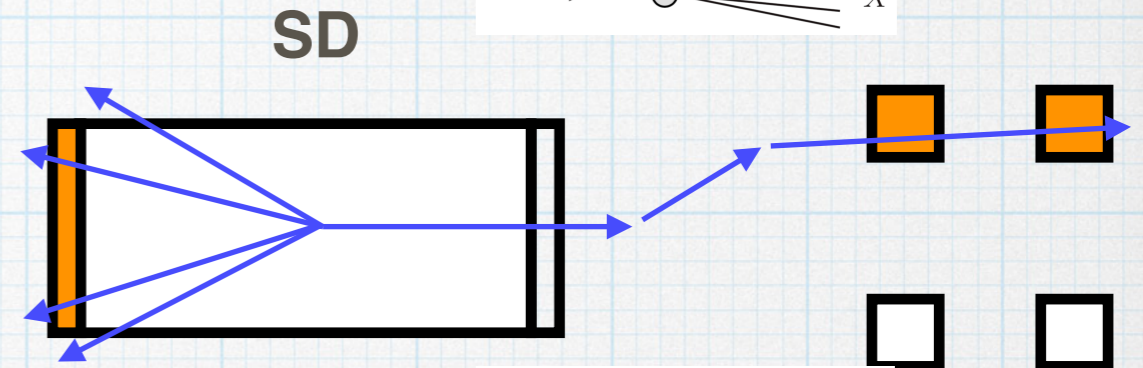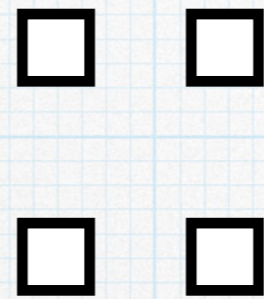
Reconstructed level distributions

Nominal selection with σ_{SD} scaled by 0.64

Background subtracted from data before iterative Bayesian unfolding
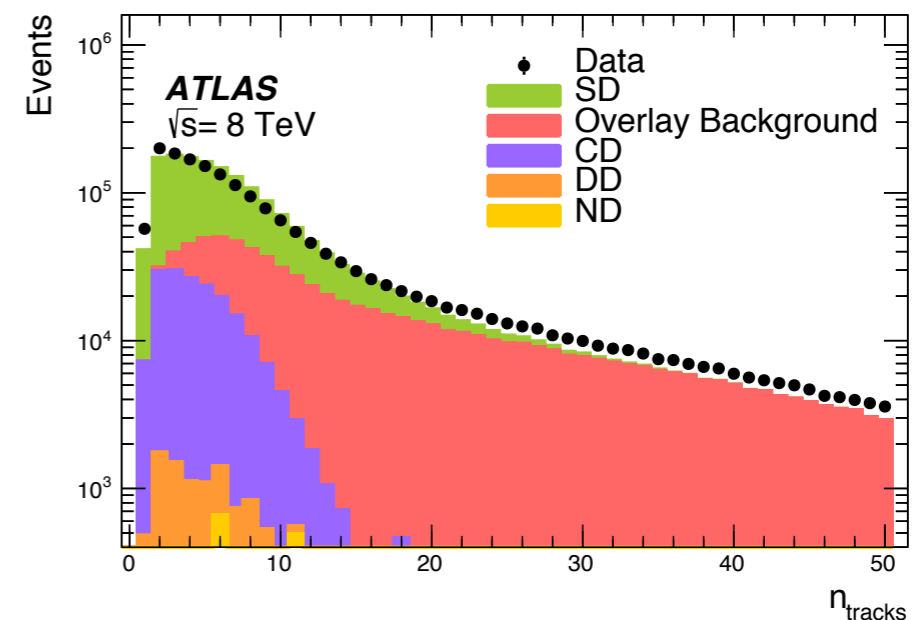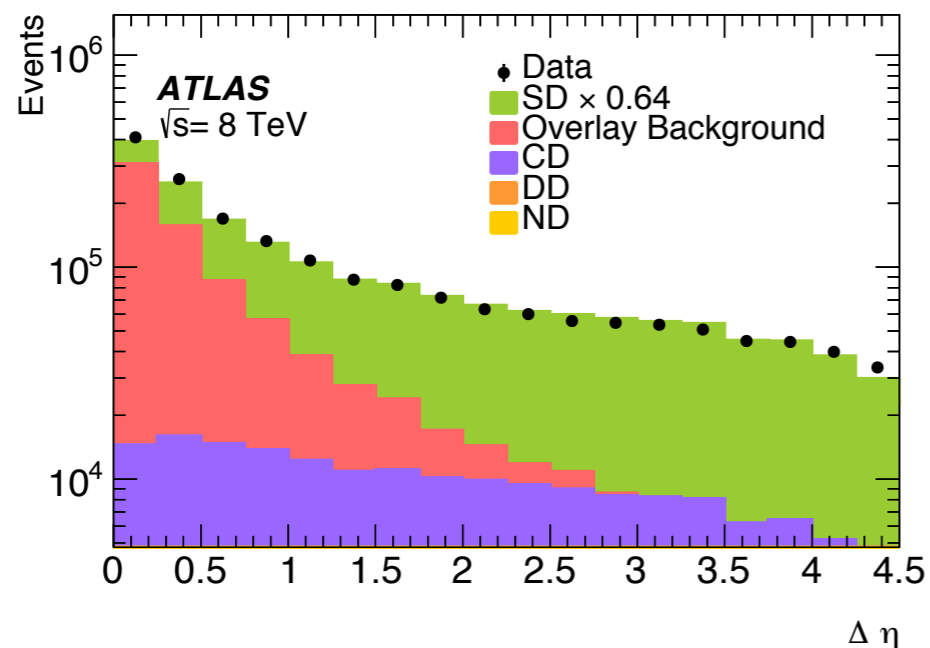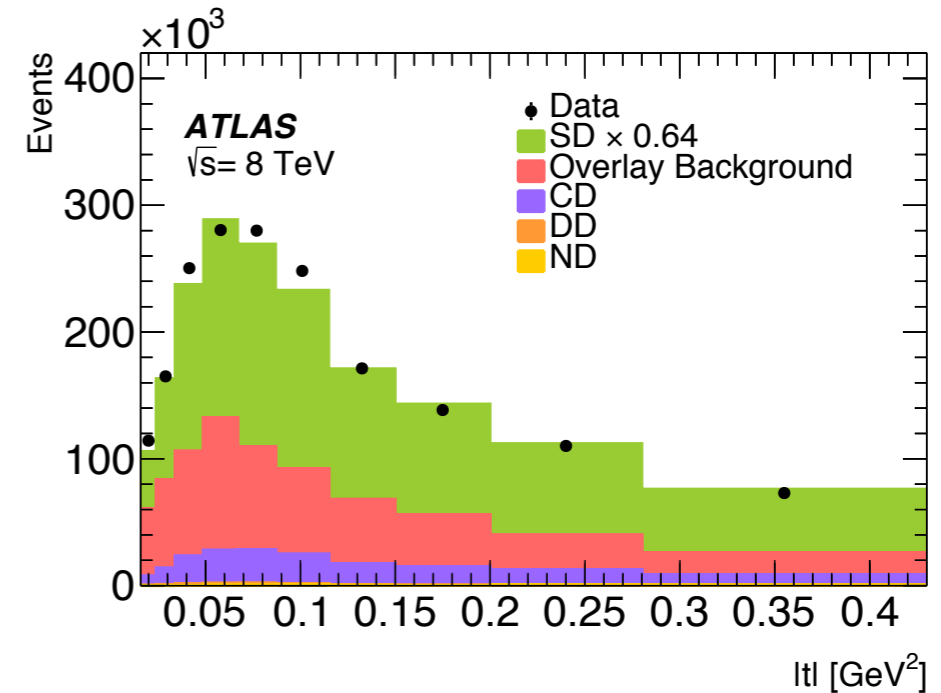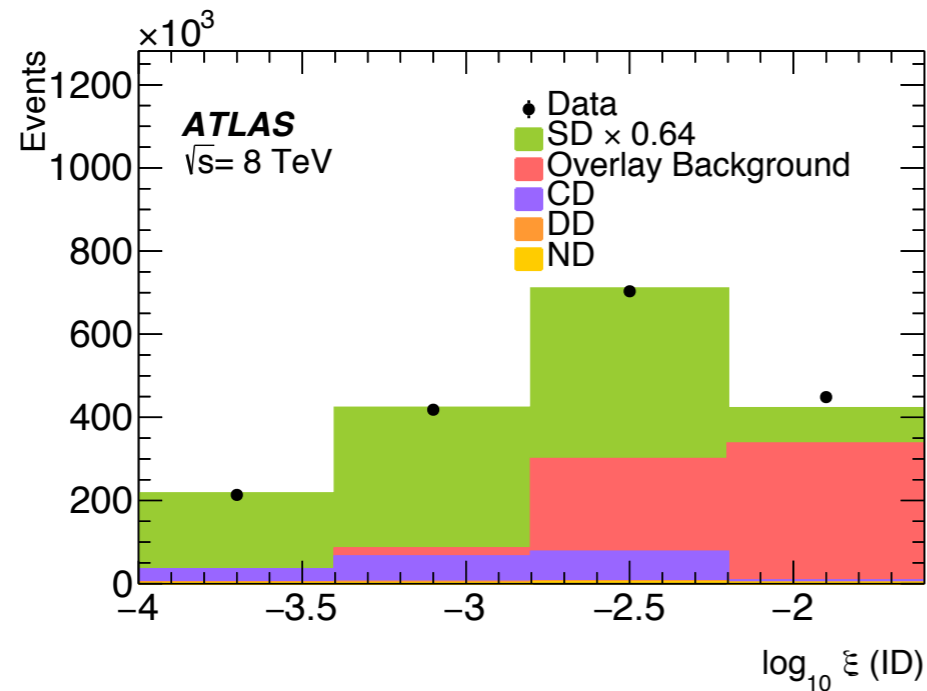
Integrated σ_{SD}

- Cross section integrated over fiducial region ($0.016 < |t| < 0.43$ GeV^2, $-4.0 < \log10\ \xi < -1.6$):

$$\sigma_{SD}(\xi, t\ \text{fiducial}) = 1.59 \pm 0.13\ \text{mb}$$

- Small extrapolation (factor 1.18) for $0 < |t| < 0.016$ GeV^2 and 0.43 GeV$^2 < |t| < \infty$ yields integrated σ for $-4.0 < \log10\ \xi < -1.6$:

$$\sigma_{SD}(\xi\ \text{fiducial}) = 1.88 \pm 0.15\ \text{mb}$$

Distribution	$\sigma_{SD}^{\text{fiducial}(\xi,t)}$ [mb]	$\sigma_{SD}^{t\text{-extrap}}$ [mb]
Data	1.59 ± 0.13	1.88 ± 0.15
Pythia8 A2 (Schuler–Sjöstrand)	3.69	4.35
Pythia8 A3 (Donnachie–Landshoff)	2.52	2.98
Herwig7	4.96	6.11

Unfolded Δη

- Gap defined by charged particles with $P_T > 200$ MeV within $|\eta| < 2.5$

- Cross-section lower than predicted by MC:
  - PYTHIA8 A3 ~1.5
  - PYTHIA8 A2 ~2.3
  - HERWIG7 ~3
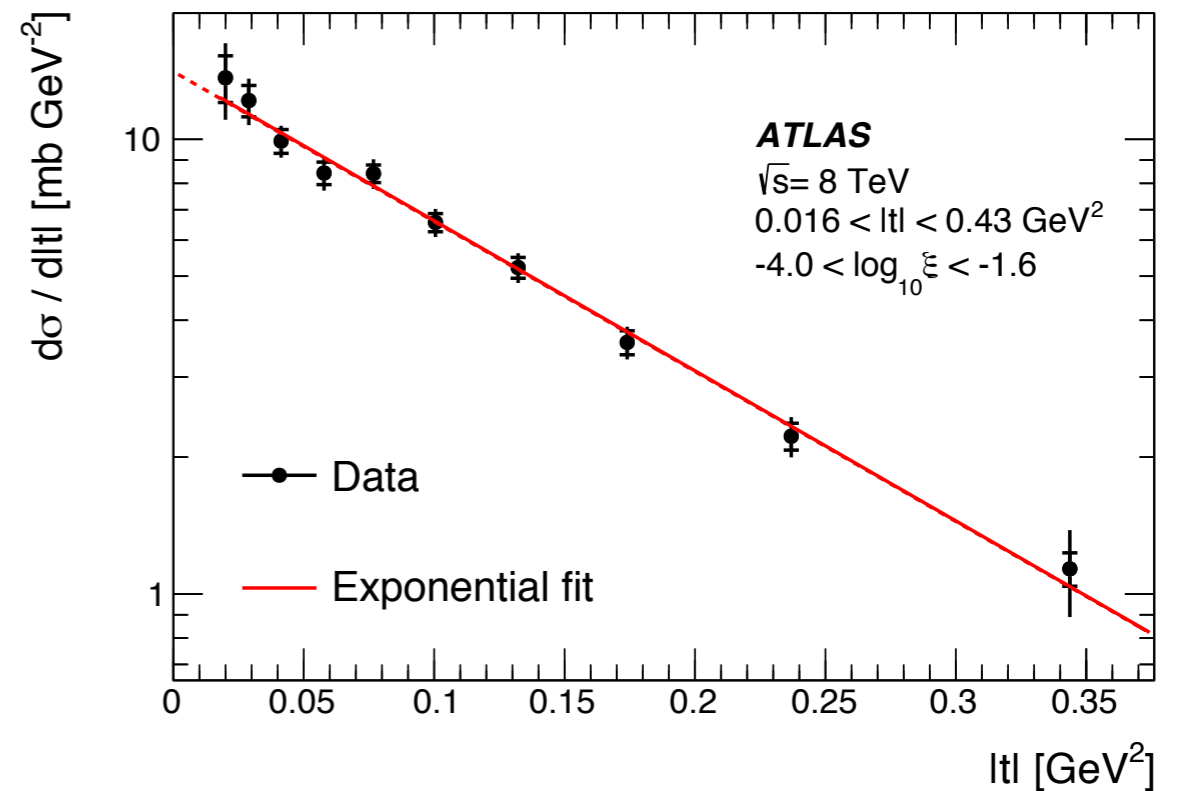
Δη
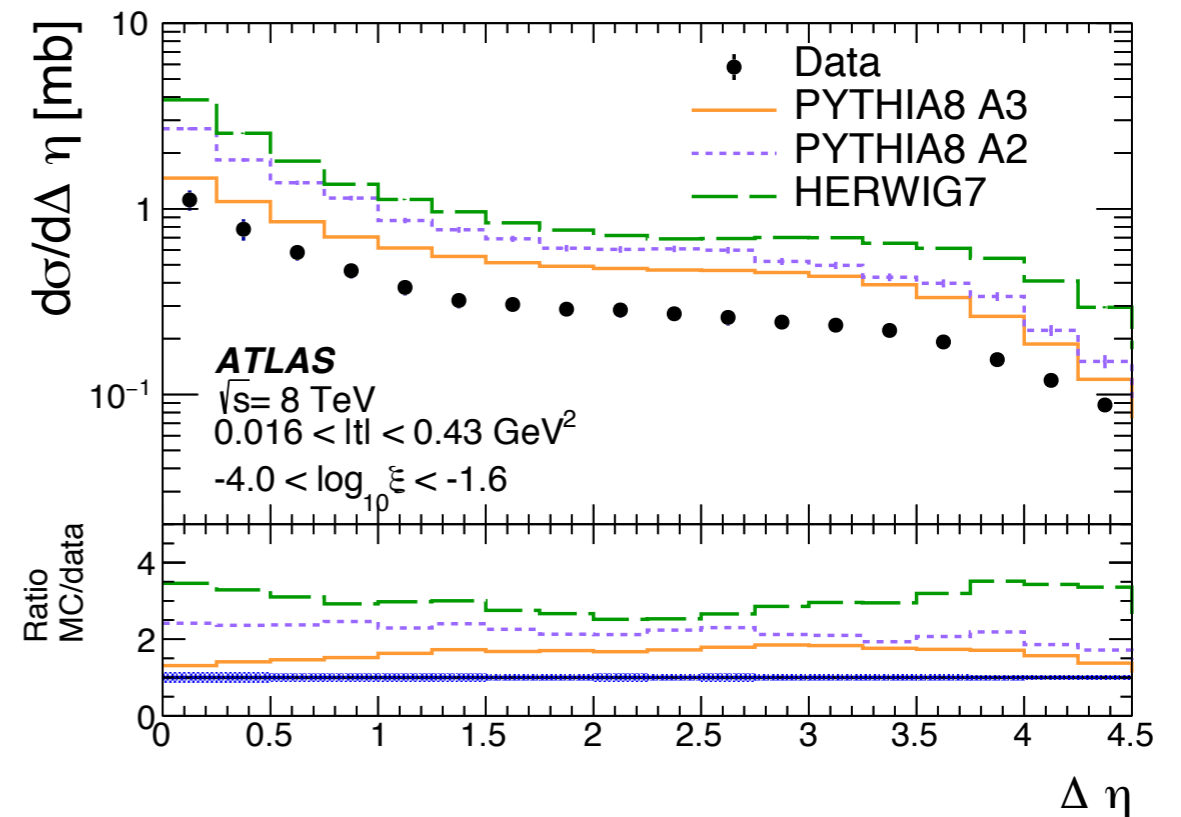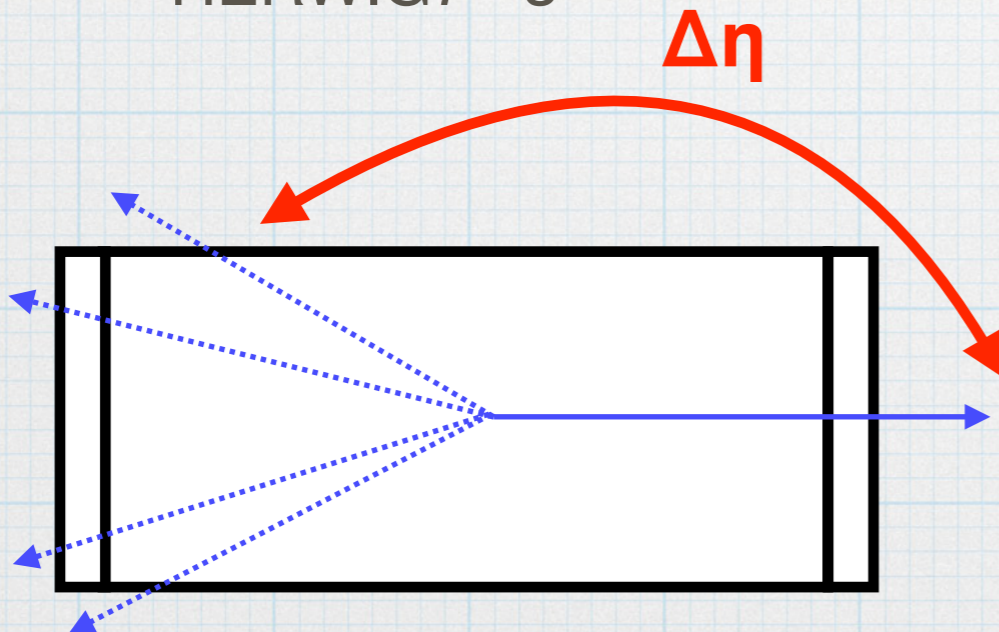
Unfolded |t|

- Data consistent with expected exponential form

$$\frac{d\sigma}{dt} = Ae^{Bt}$$

B = 7.65 ± 0.26 (stat.) ± 0.22 (syst) GeV⁻²

- Dominant uncertainty on B is from overlay background and statistics

- Compare with:
  - PYTHIA8 A2 B = 7.82 GeV⁻²
  - PYTHIA8 A3 B = 7.10 GeV⁻²

ATLAS
√s= 8 TeV
$0.016 <$ ltl < 0.43 GeV^2
$-4.0 < \log_{10}\xi < -1.6$

Data

Exponential fit

$d\sigma$ / dltl [mb GeV^{-2}]

ltl [GeV^2]

Unfolded ξ

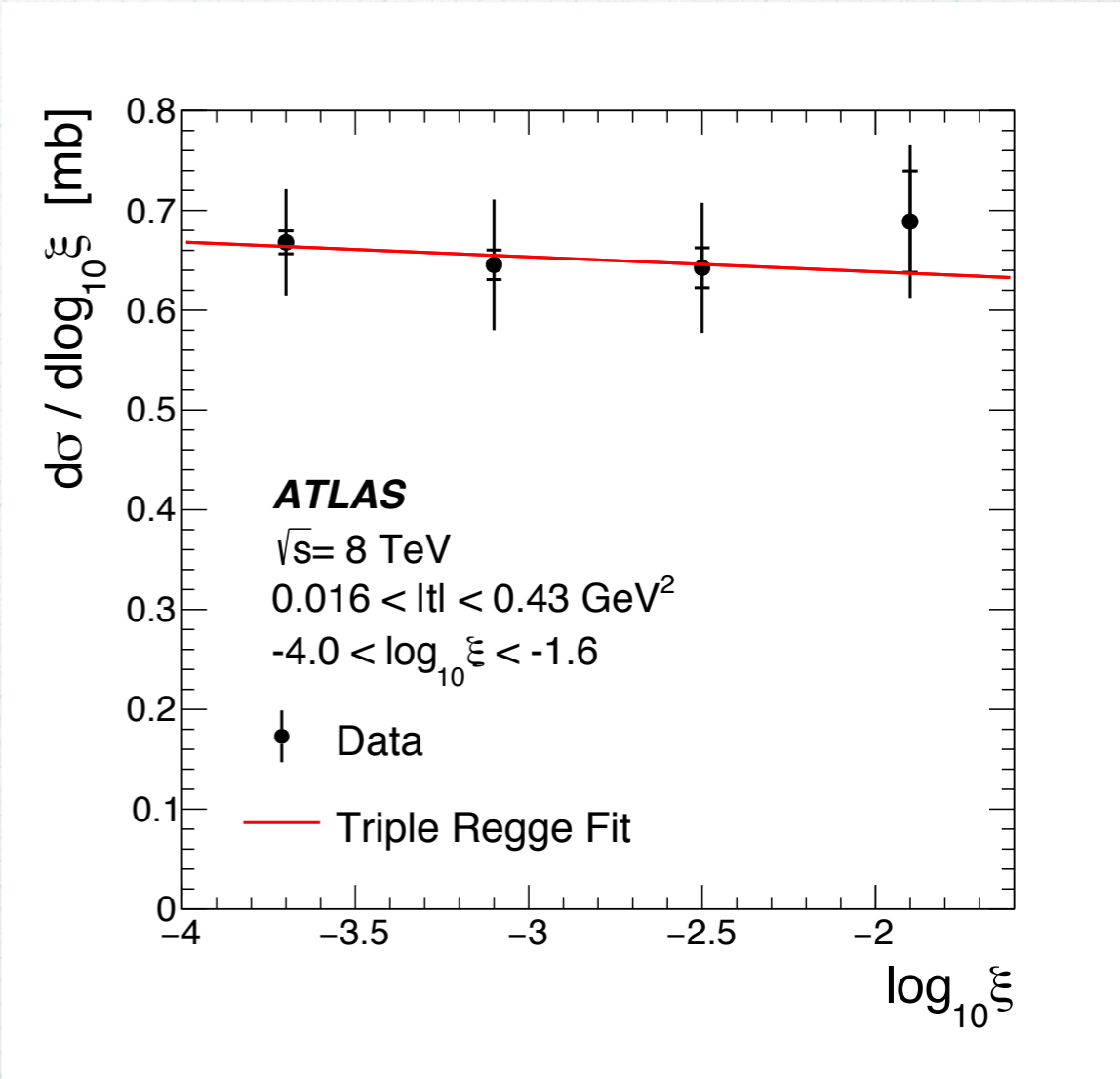- Follows $d\sigma/d\xi \propto 1/\xi$ approximate relationship

- Also interpreted in triple Pomeron model with $\longrightarrow$

$$\frac{d\sigma_{SD}}{d\log_{10}\xi} \propto \left(\frac{1}{\xi}\right)^{\alpha(0)-1}\frac{1}{B}\left(e^{Bt_{high}} - e^{Bt_{low}}\right)$$

  - $B = B_0 - 2\alpha' \ln\xi$
  - Fixed B_0
  - $\alpha(t) = \alpha(0) + \alpha' t$

**$\alpha(0) = 1.07 \pm 0.02$ (stat.) ± 0.06 (syst) ± 0.06 (α')**

- Dominant uncertainty is from extrapolation from lower $\sqrt{s}$ when using $\alpha' = 0.25 \pm 0.25$ GeV^{-2}

- Compare with:
  - PYTHIA8 A2 $\alpha(0) = 1.00$
  - PYTHIA8 A3 $\alpha(0) = 1.14$

- Data compatible with CMS result

ATLAS
$\sqrt{s}$= 8 TeV
$0.016 < |t| < 0.43$ GeV^2
$-4.0 < \log_{10}\xi < -1.6$

$\bullet$ Data

— Triple Regge Fit

Measurement of distributions sensitive to the underlying event in inclusive Z boson production in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

The Underlying Event

- Activity accompanying the hard scatter
- The UE:
  - Can be in the soft QCD regime
  - Is not distinguishable from the hard scatter on an event-by-event basis
  - Can be probed using topological observable
  - Can include contributions from additional hard parton scatters (MPI)

- Using Drell-yan z→μμ events, the transverse regions should have little activity from the hard scatter
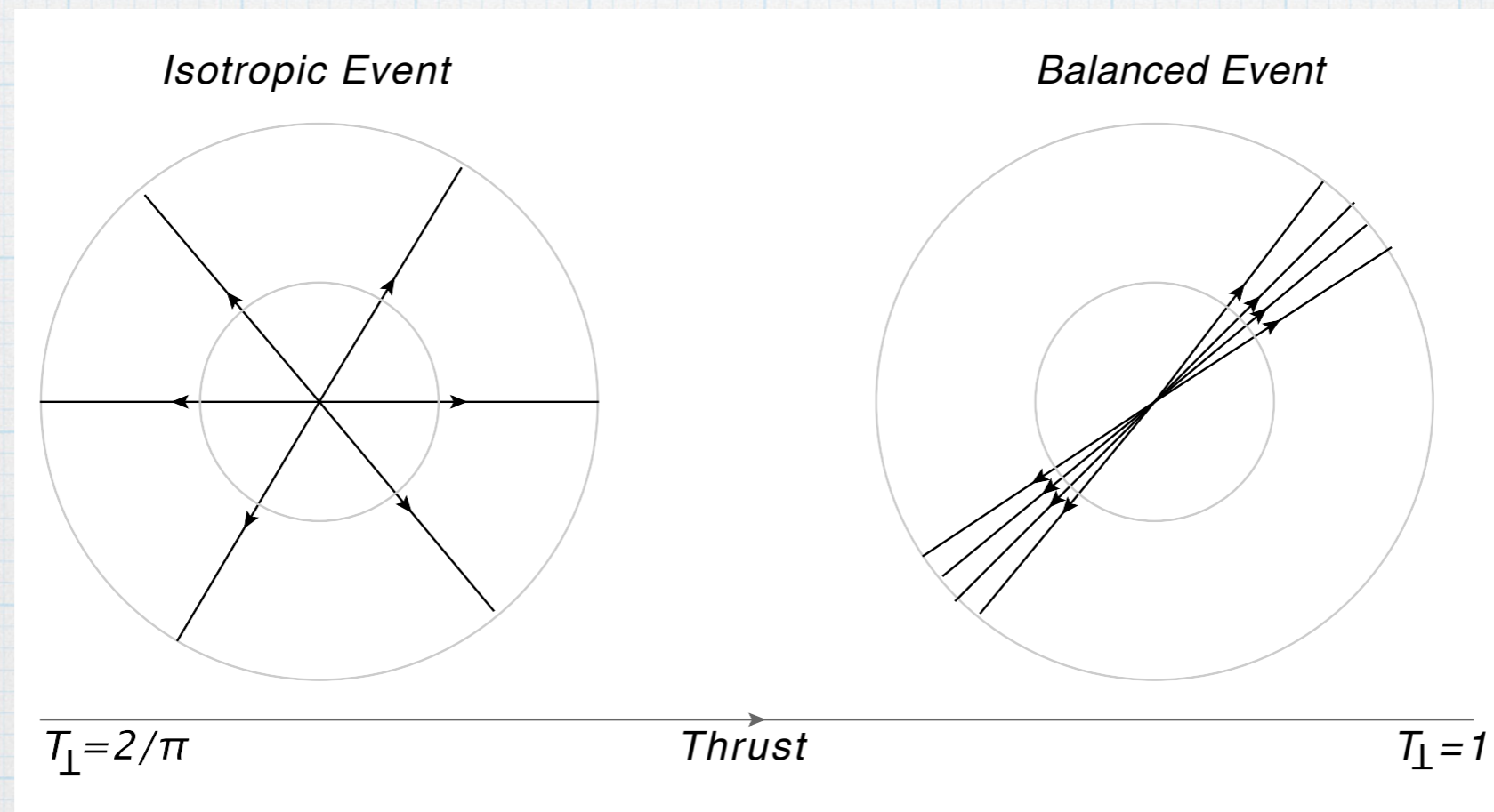 - Particularly in *trans-min*, the region with the smaller (scalar) Σp_T
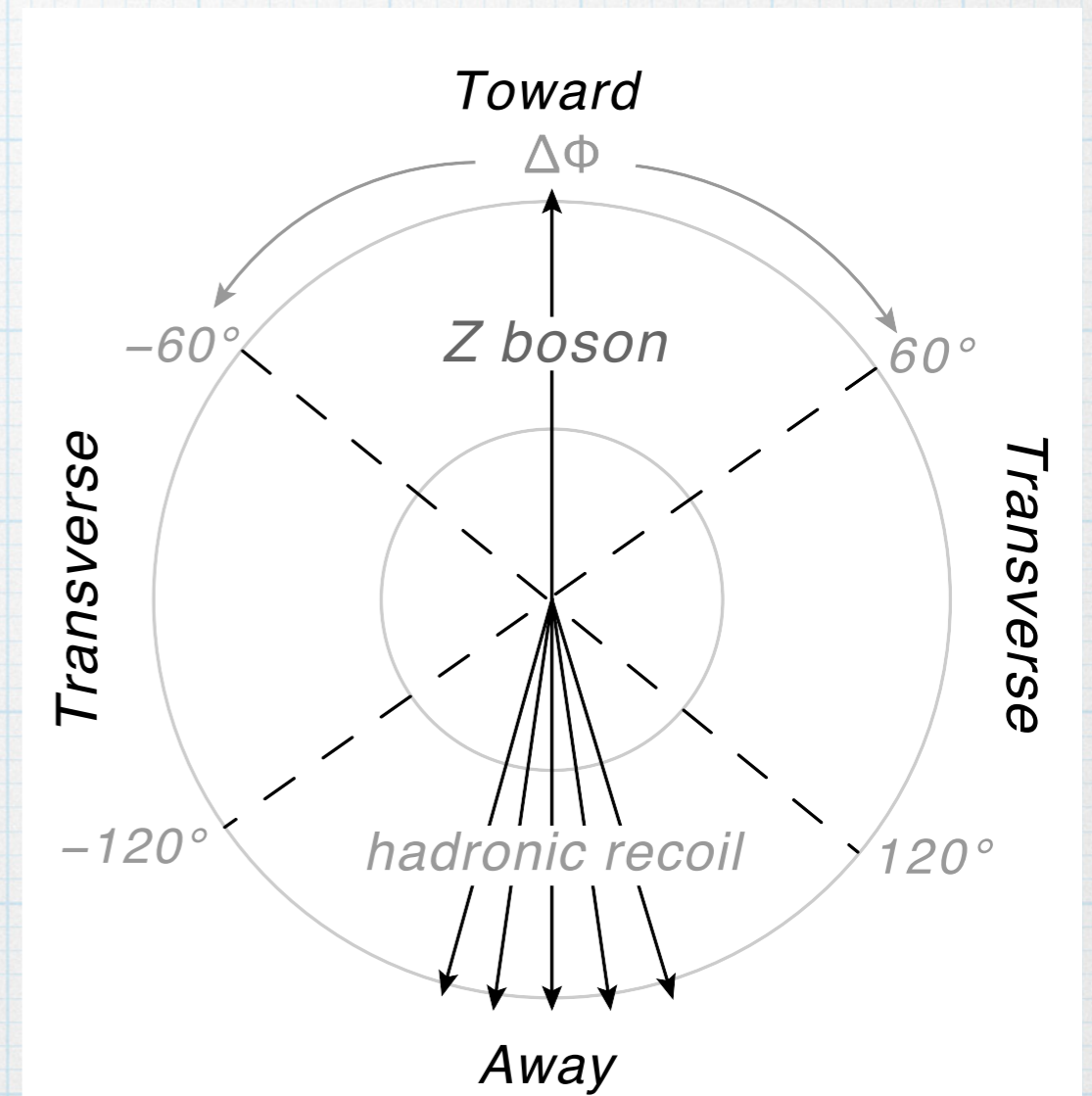
Transverse thrust

- Transverse thrust describes the event topology

$$T_\perp = \frac{\sum_i |\vec{p}_{\mathrm{T},i} \cdot \hat{n}|}{\sum_i |\vec{p}_{\mathrm{T},i}|}$$

- $\hat{n}$ is unit vector which maximises thrust
- Events with lower thrust are more sensitive to MPI
- Plots shown inclusive, ≤0.75 & ≥0.75

Isotropic Event   Balanced Event

$T_\perp = 2/\pi$ Thrust $T_\perp = 1$

Analysis variables

- Plots of:

  - Charged particle multiplicity

  - Scalar sum of transverse momenta

  - Mean transverse momentum of charged particles

  - Charged particle transverse momentum distribution (normalised)

- Separate regions of:

  - Thrust

  - P_T of Z boson

  - Transverse / toward regions

Event selection

- Online trigger, either:
  - Single high-p_T (> 40 GeV) muon
  - Single, isolated lower-p_T (> 20 GeV) muon

- Offline selection:
  - Primary vertex
  - Exactly 2 muons with p_T > 25 GeV & $|\eta|$ < 2.4
  - Muons must be from PV & not from heavy quark decays
  - 66 GeV < $m^{\mu\mu}$ < 116 GeV to reduce backgrounds

- Tracks:
  - p_T > 0.5 GeV & $|\eta|$ < 2.5
  - Come from PV

Backgrounds

- Assessed using MC:
  - Z -> ττ
  - Z-> tt
  - WW -> μν μν
- Contribute to ~0.7% of data events
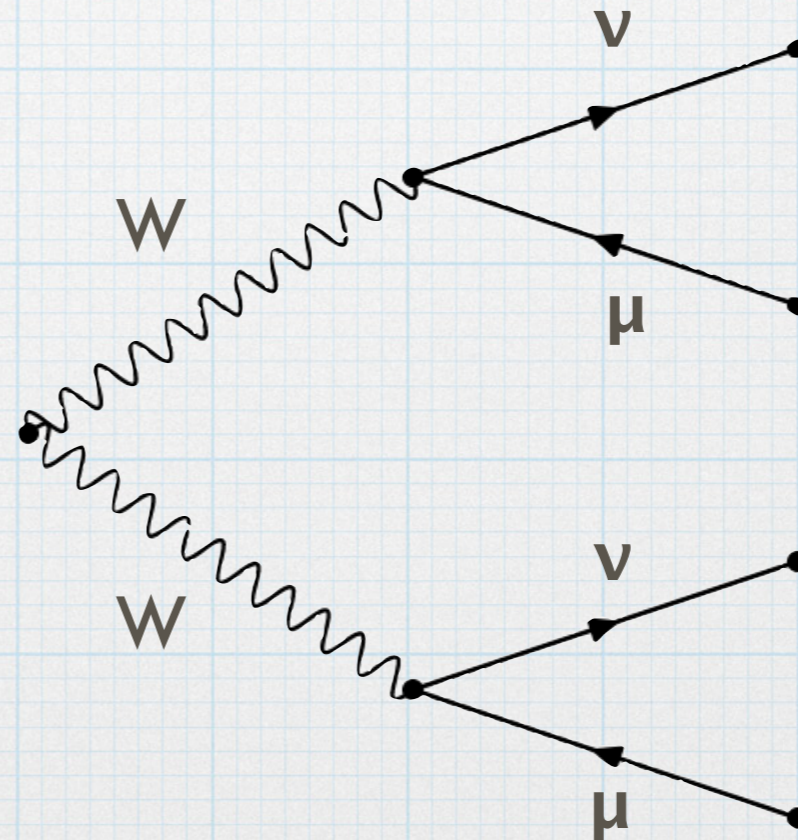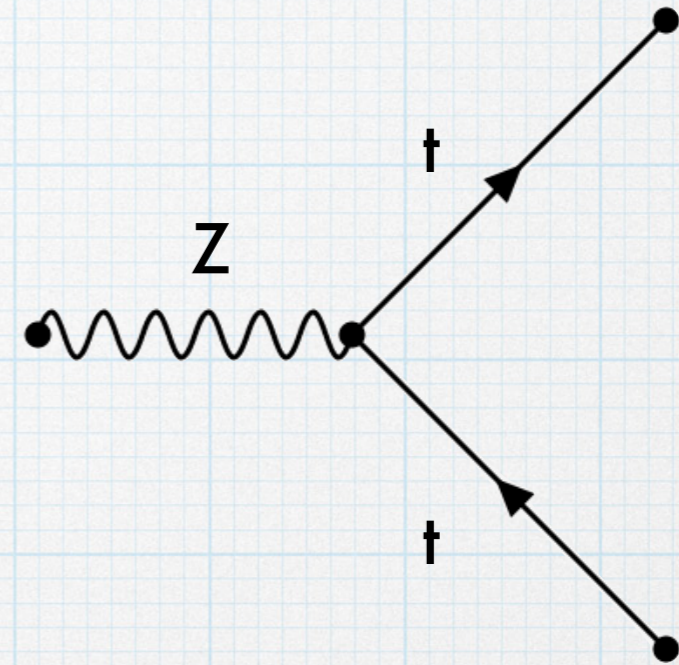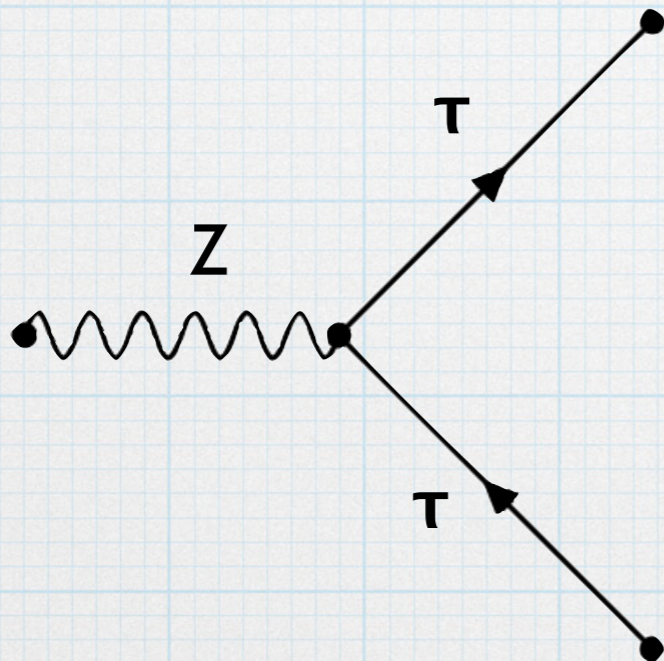
Differential distributions

All thrust

MC predicts lower number of charged particles

MC predicts lower values of mean P_T
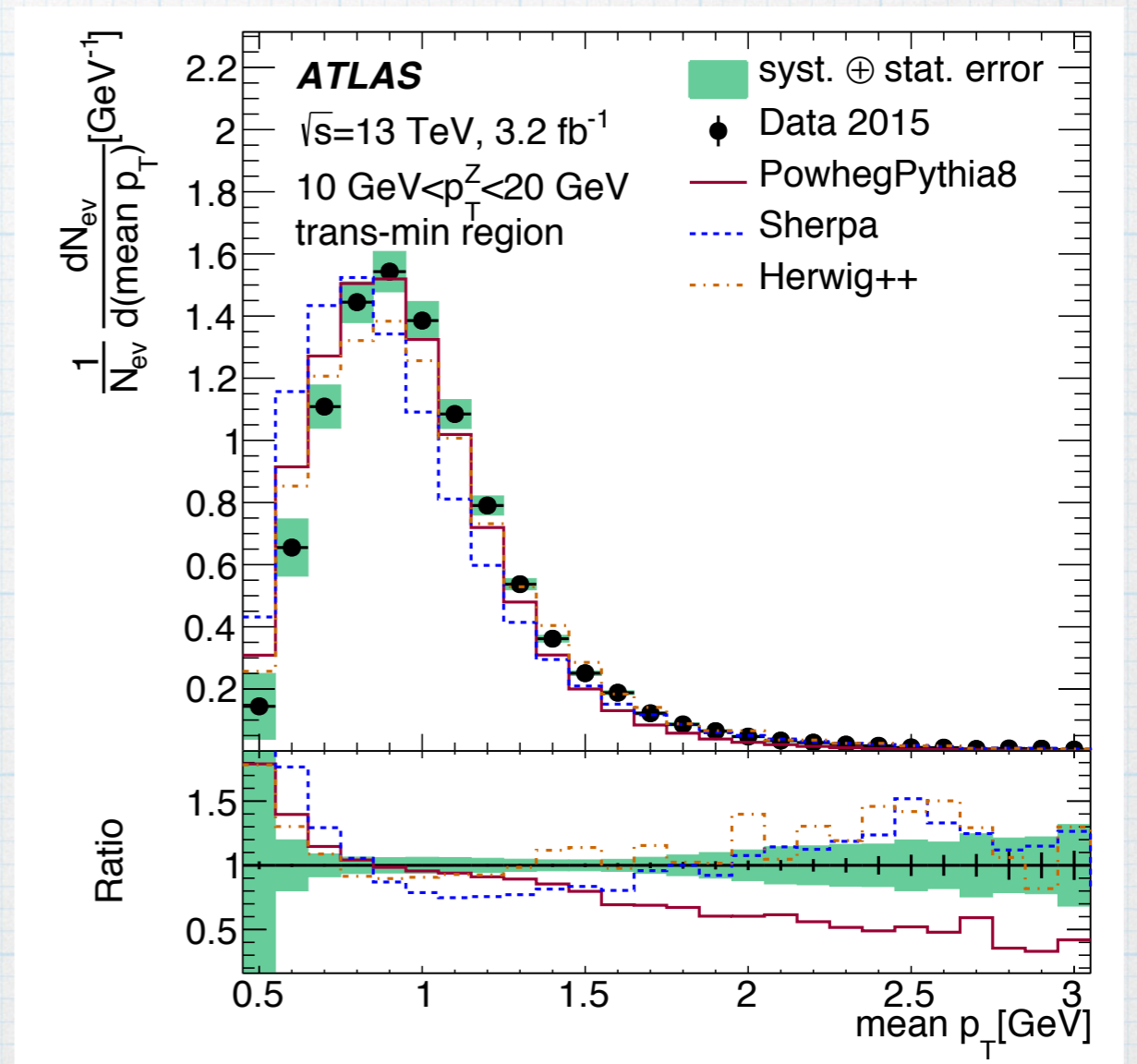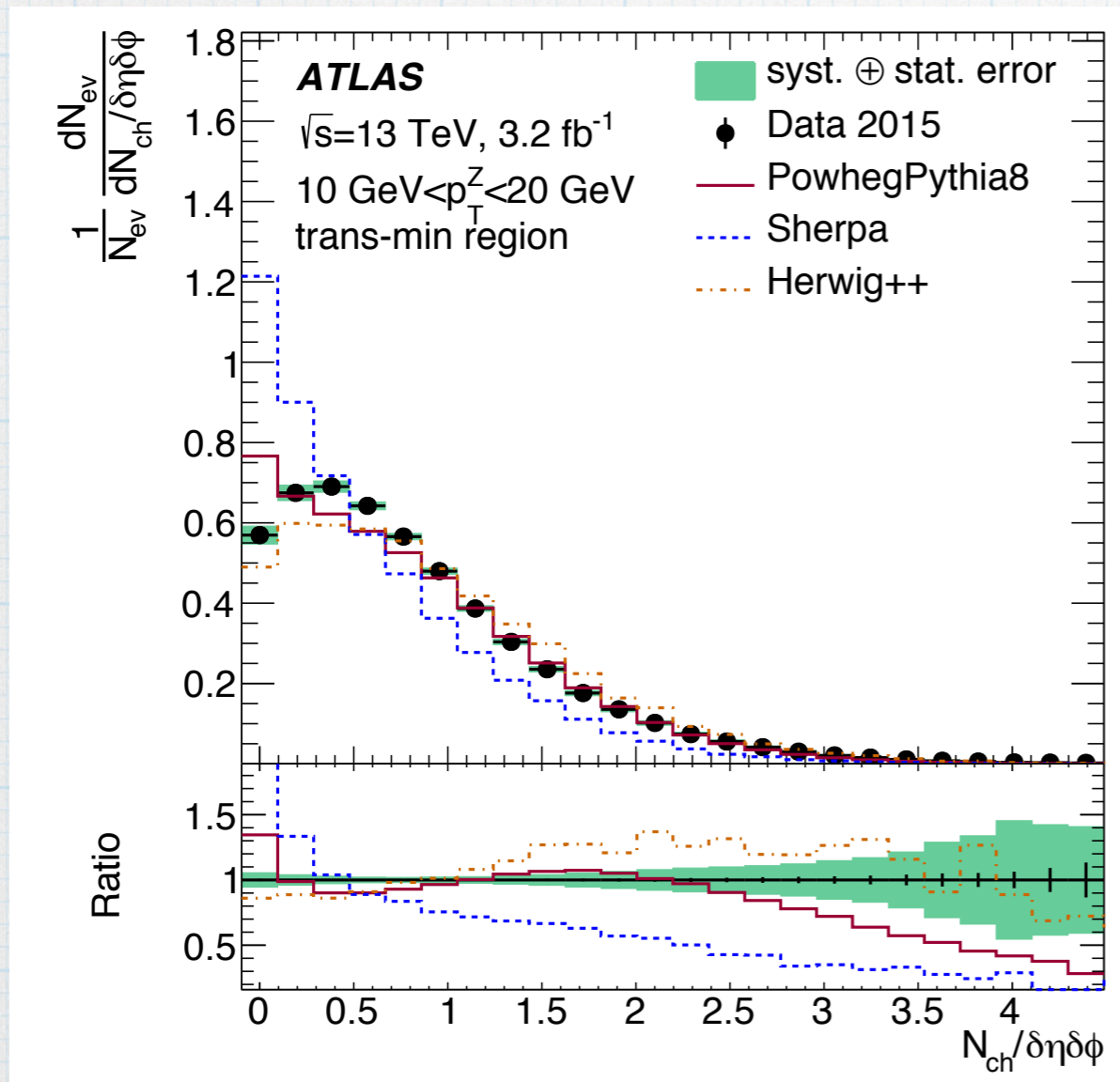
Differential distributions

Different thrust

PowhegPythia8 shows good agreement at low thrust, but not at high
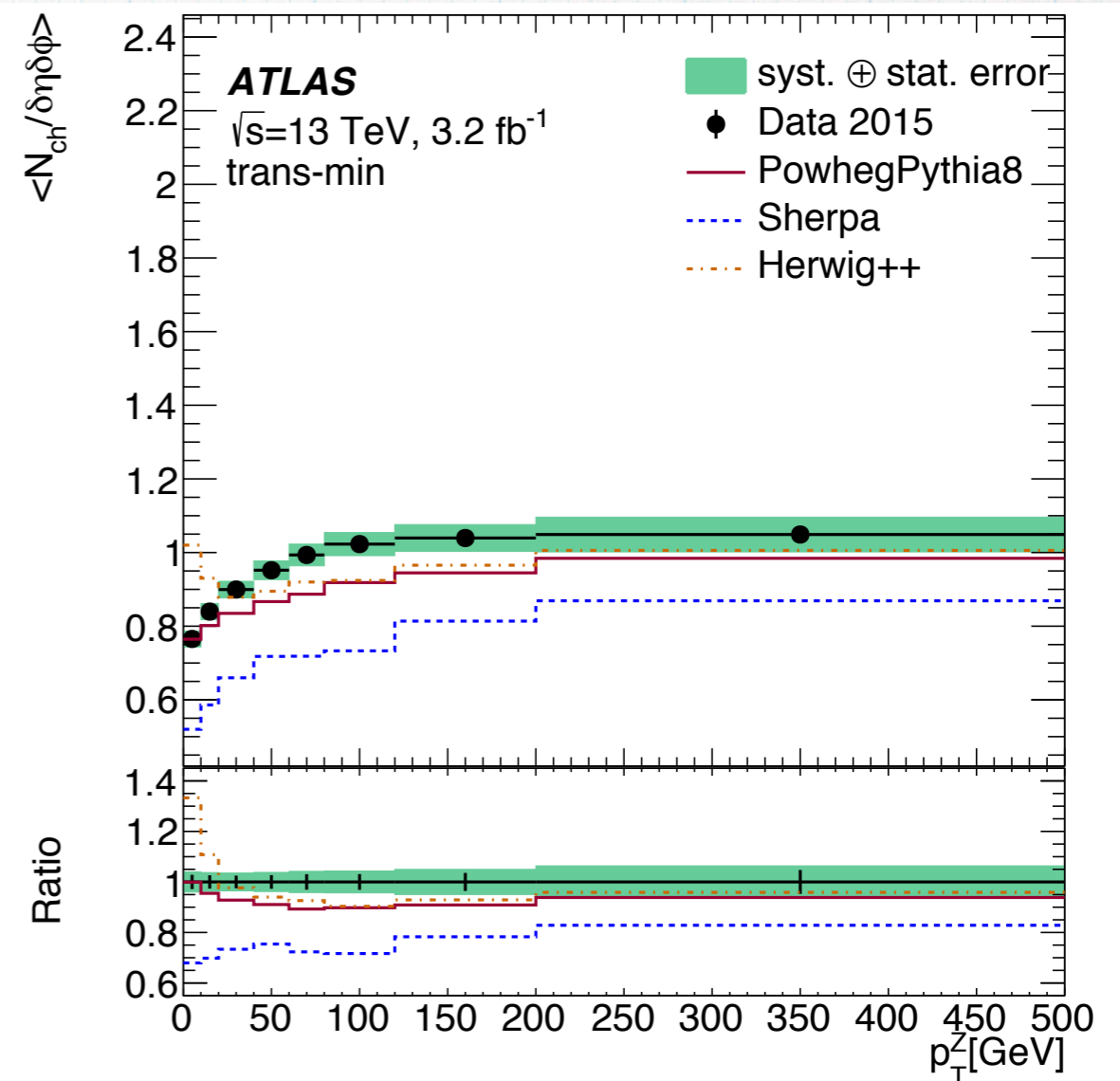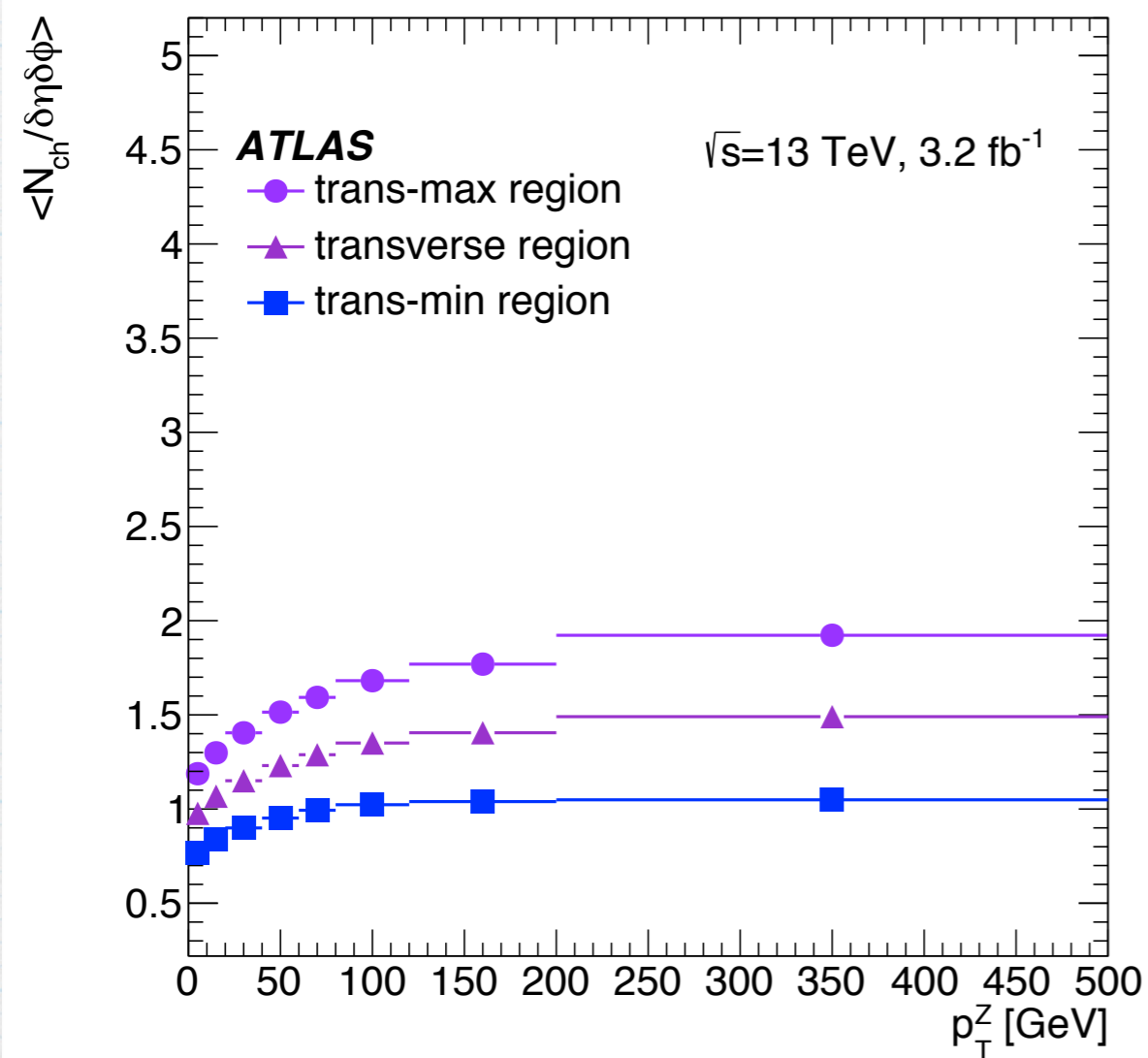
Sherpa & Herwig++ constantly across both thrust regions
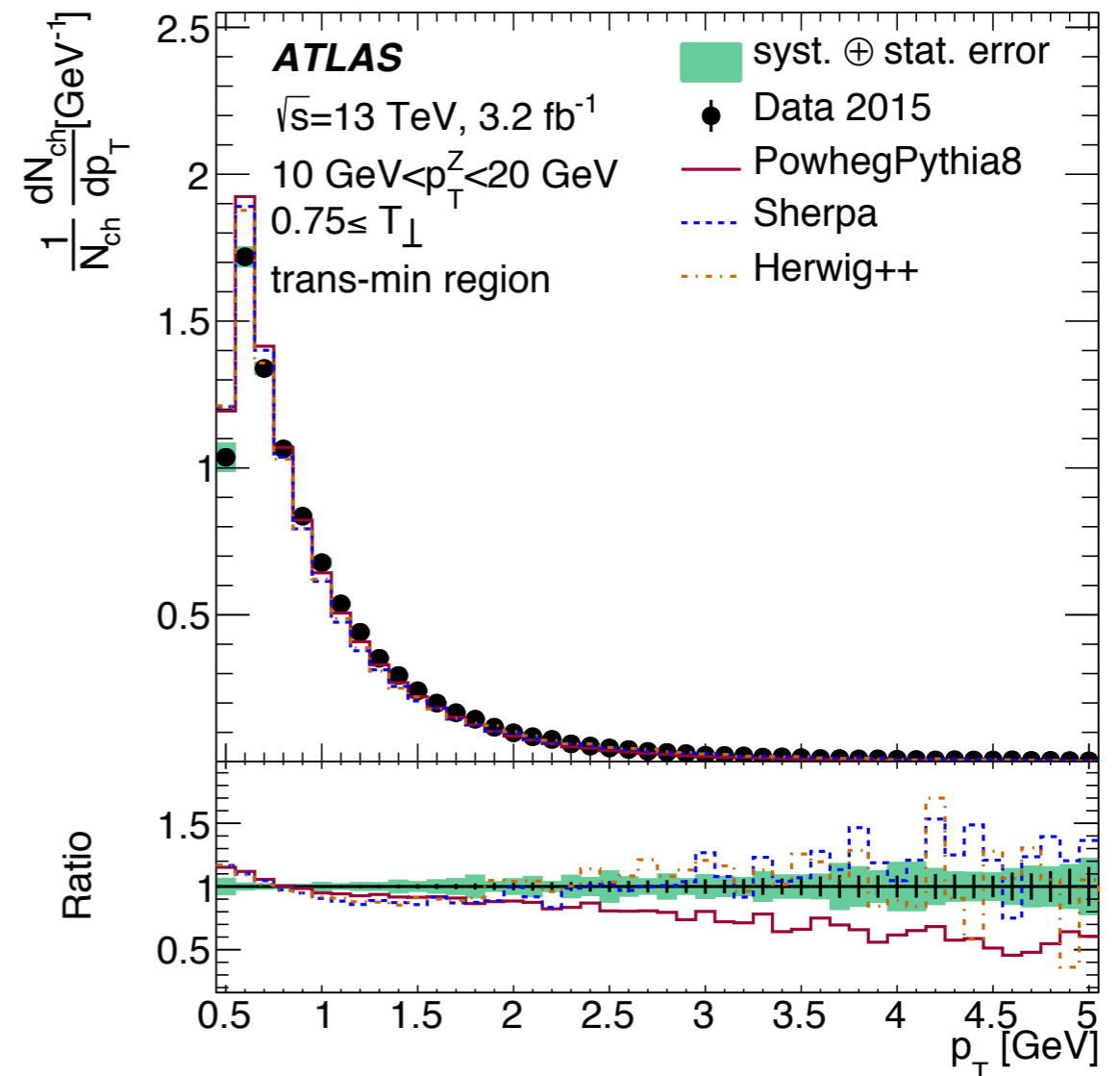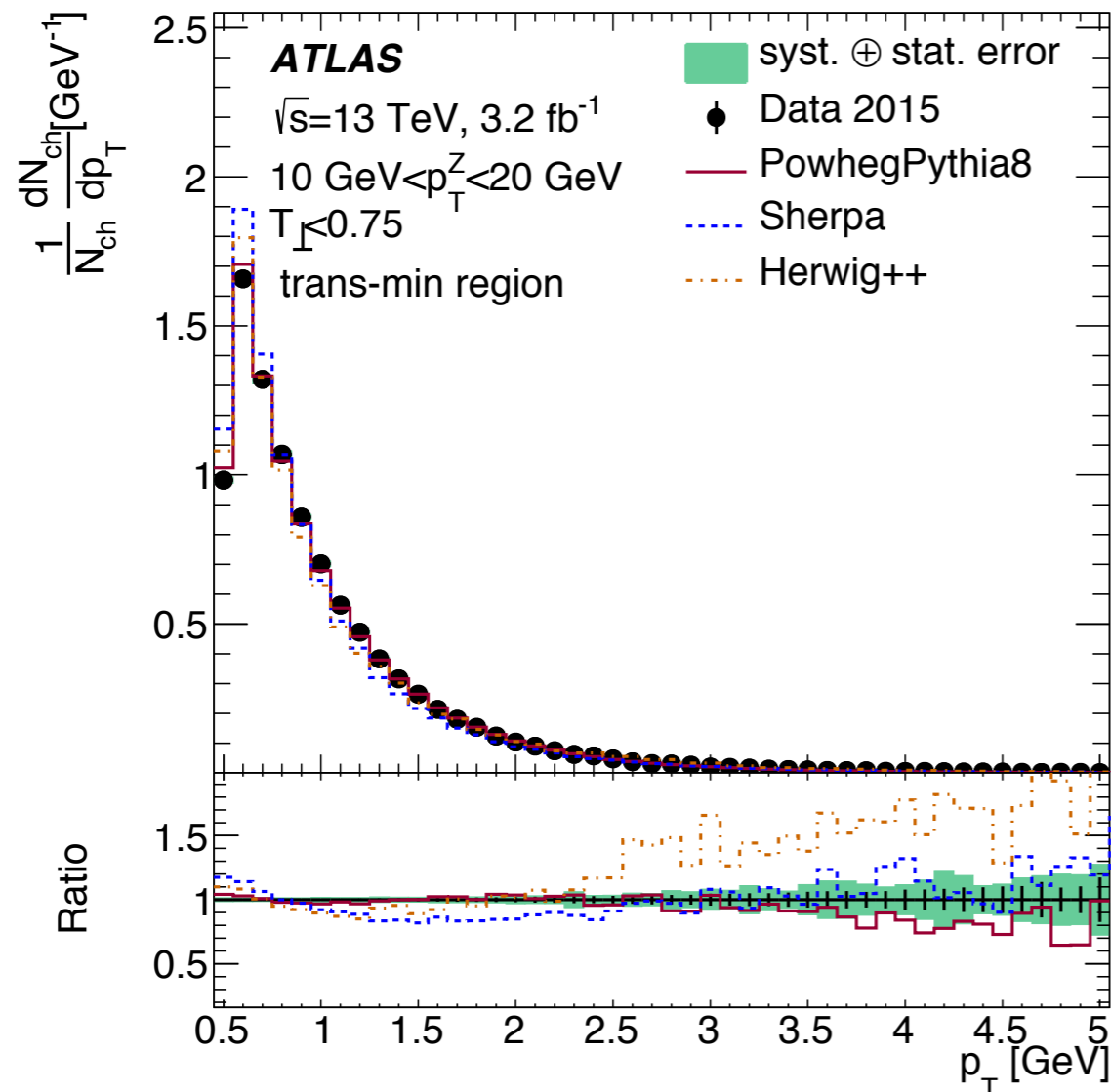
Underlying event activity as a function of p^Z_T

Increased UE as a function of p_T of z boson

Less activity & dependance in trans-min region

Under-prediction by MC, turn-on effect not shown by all

Comparison with other √s

Comparable, but slightly different, event selection

Growing UE activity with higher p_T^z
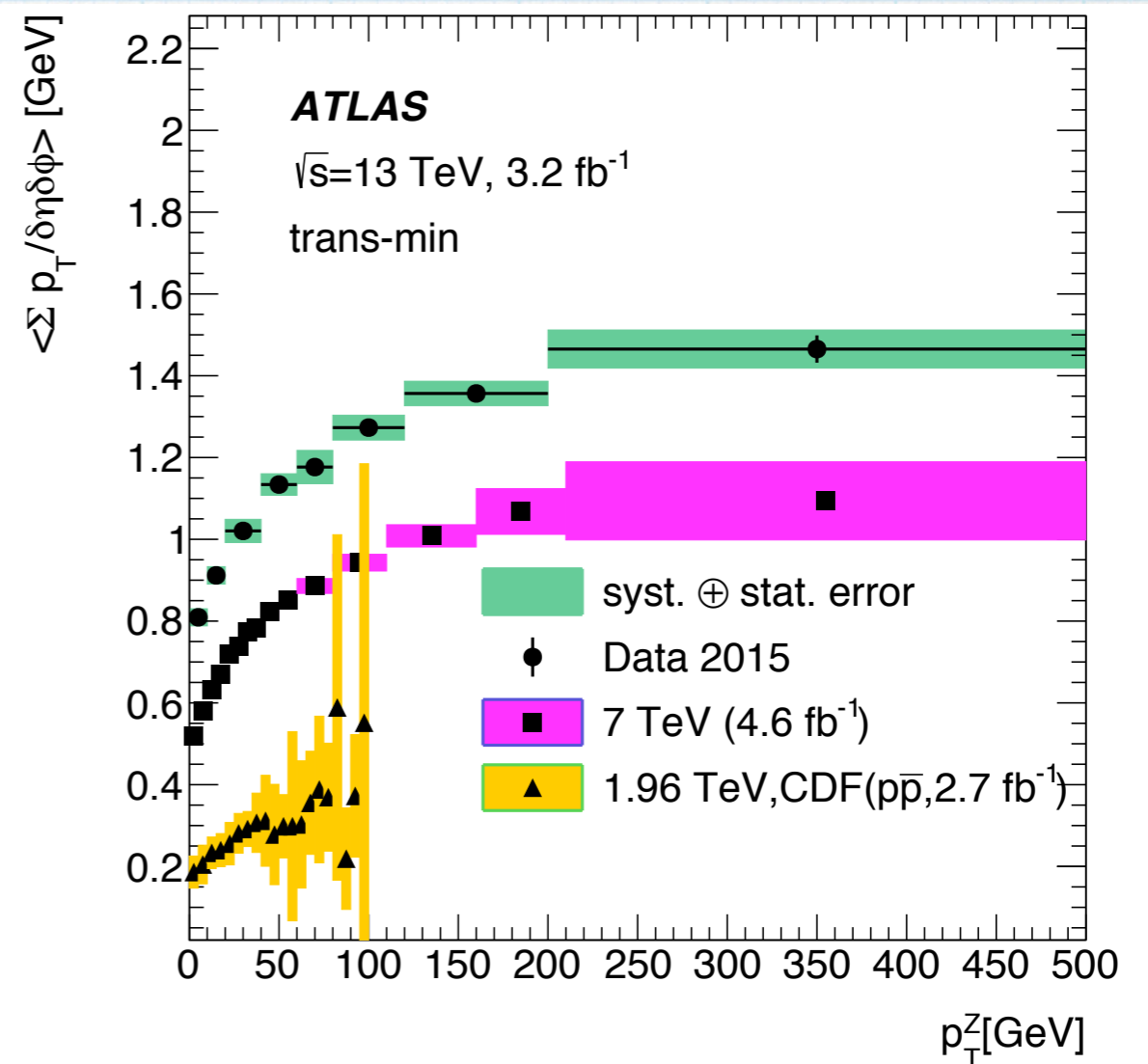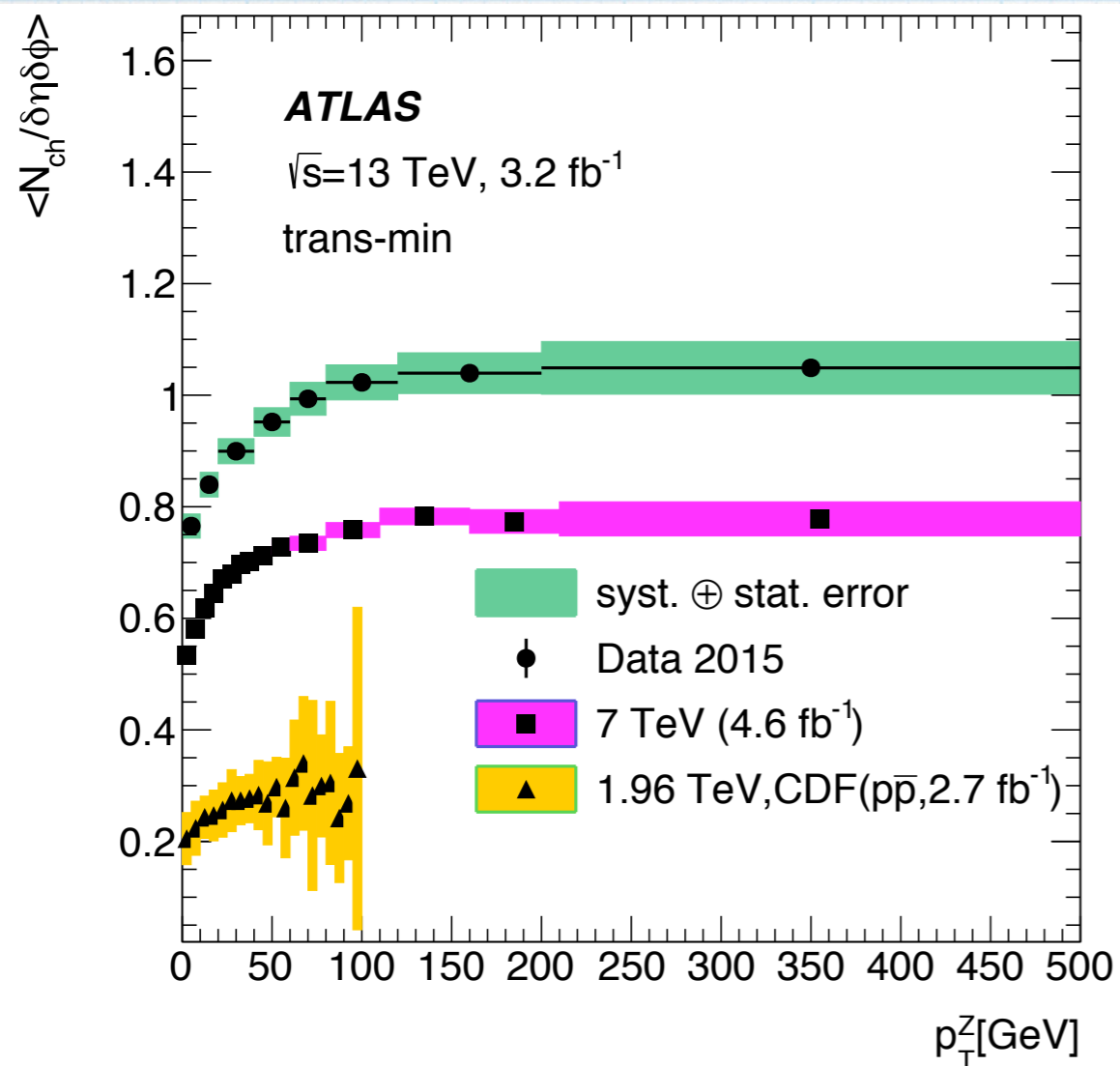
Summary

- **SD at $\sqrt{s}$ = 8 TeV**
  - All tested generators significantly over predict the SD cross-section
  - B & $\alpha(0)$ are consistent with PYTHIA8

- **UE at $\sqrt{s}$ = 13 TeV**
  - All tested generators show significant deviations with data for predicting UE activity
 - Herwig++ qualitatively performs best

Backup slides

Previous ATLAS result

- Previous ATLAS publication:

  - Measured inclusive rapidity gap spectra

  - Lack of proton tagging led to DD / SD / ND ambiguity

  - Eur. Phys. J. C72 (2012) 1926
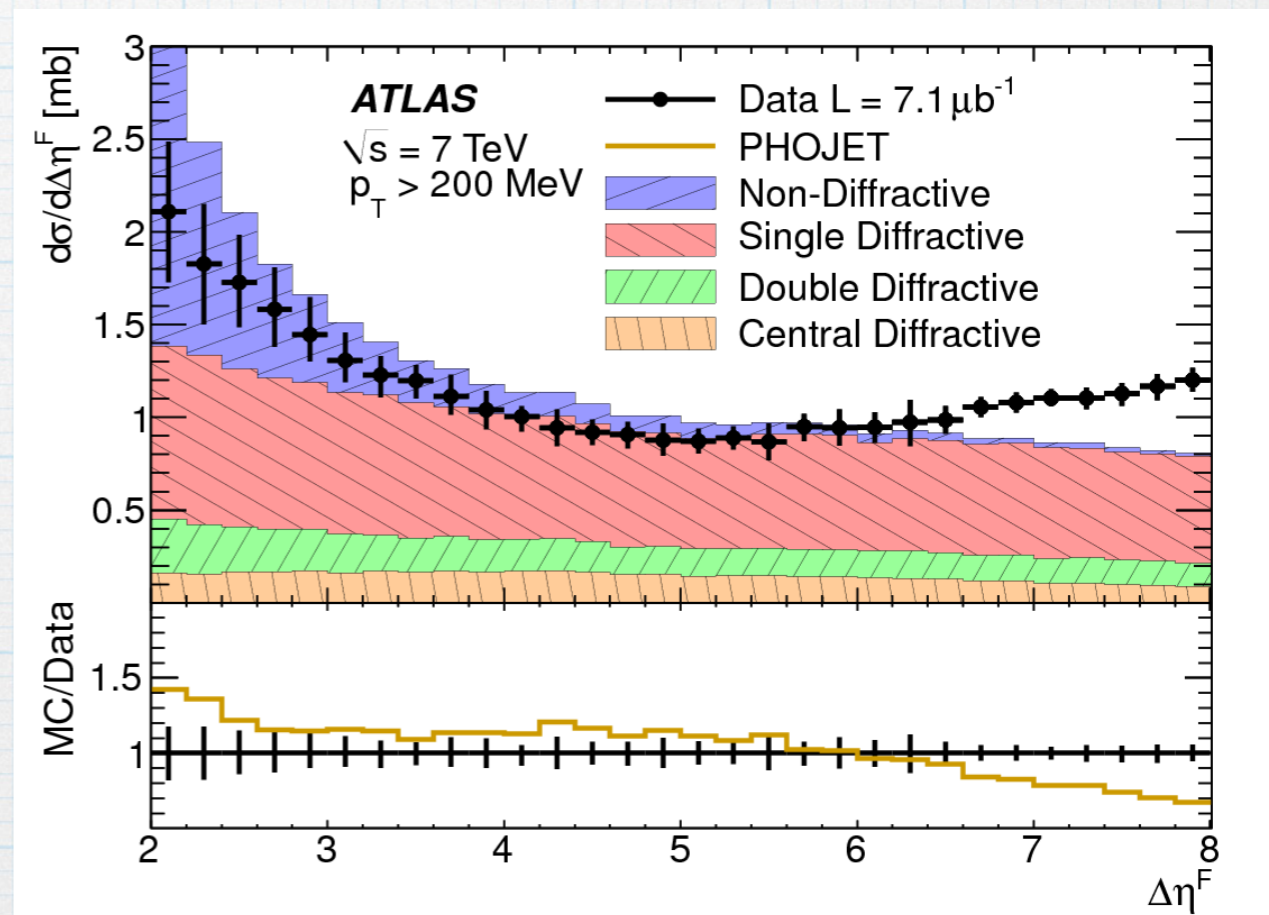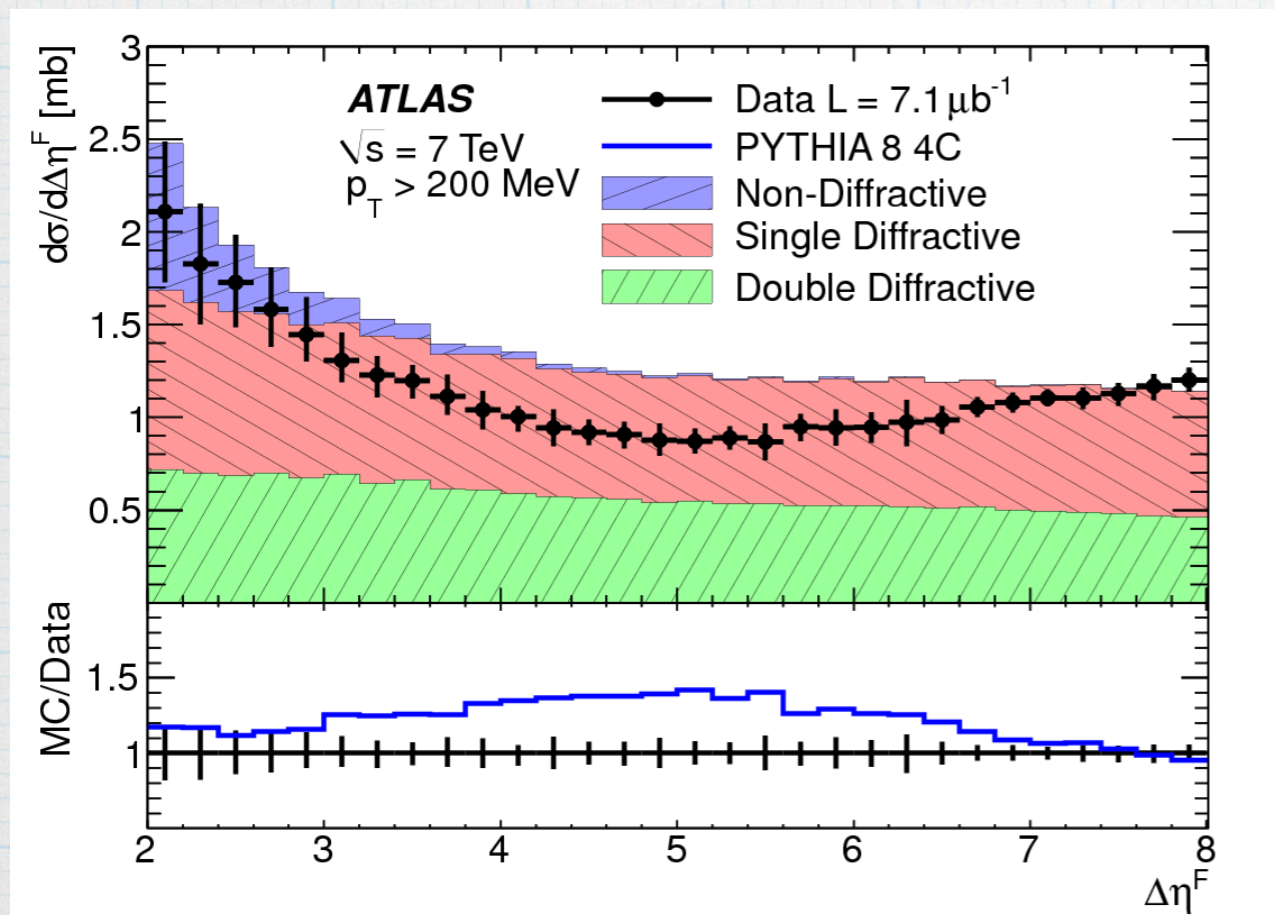
ALFA x̄ v θ

$$\bar{x} = \frac{x_{near} + x_{far}}{2} \qquad \theta = \frac{x_{far} - x_{near}}{z_{far} - z_{near}}$$

- SD distribution is centred on (0,0)
- Only accept events within 3σ of SD MC fit parameters
- Removes beam backgrounds & restricts ξ range
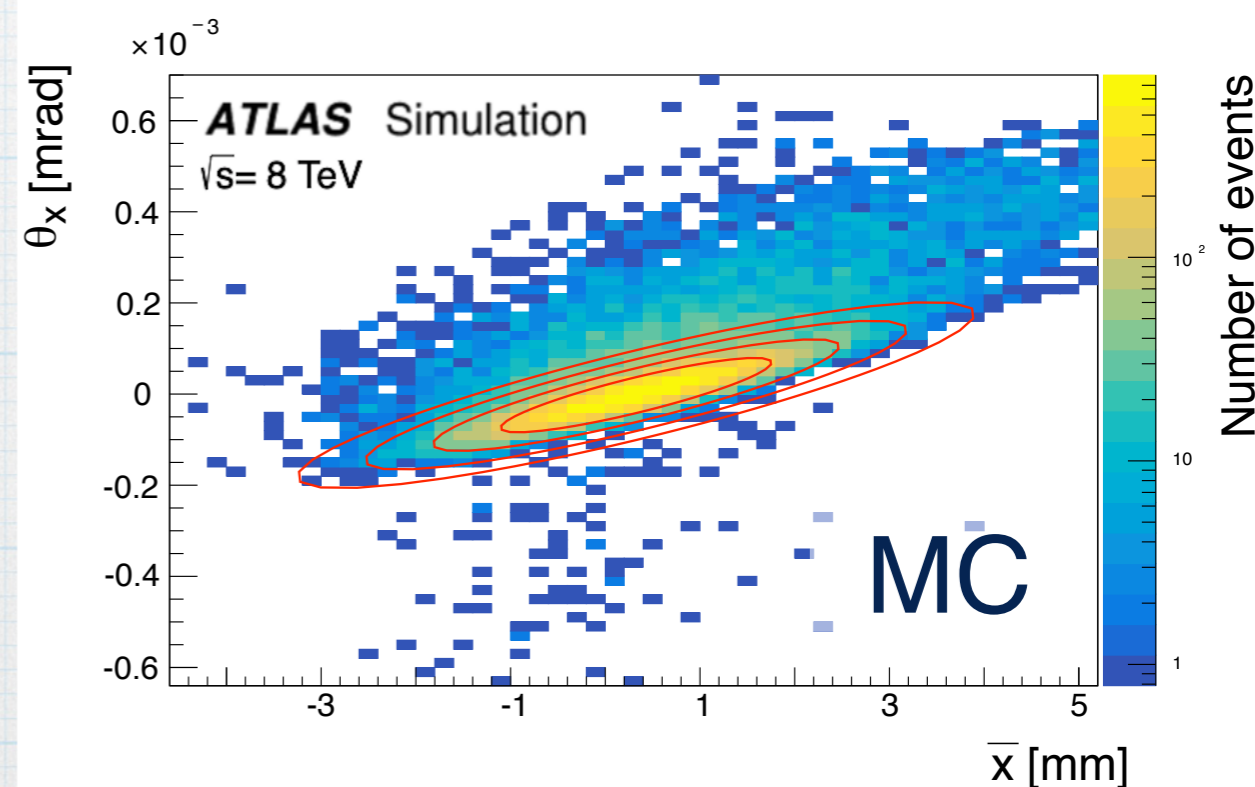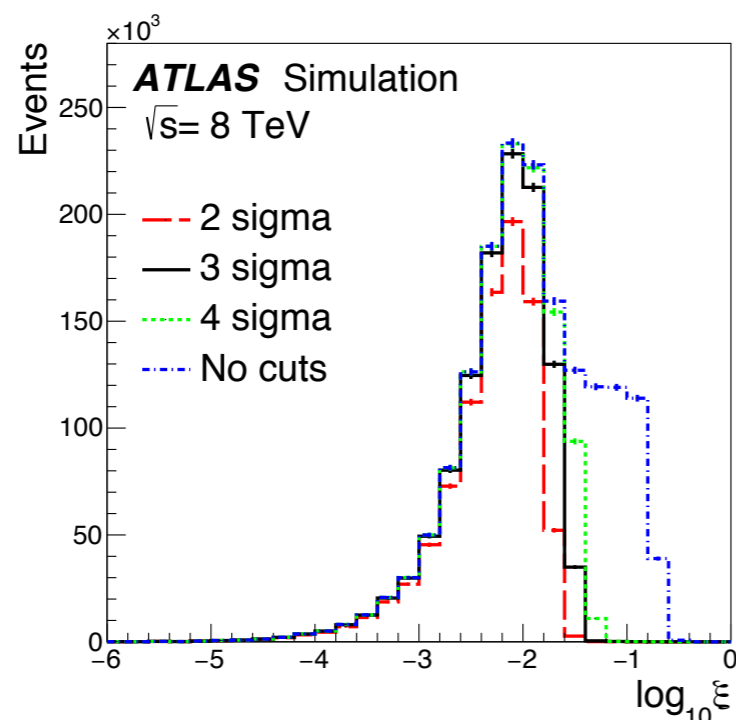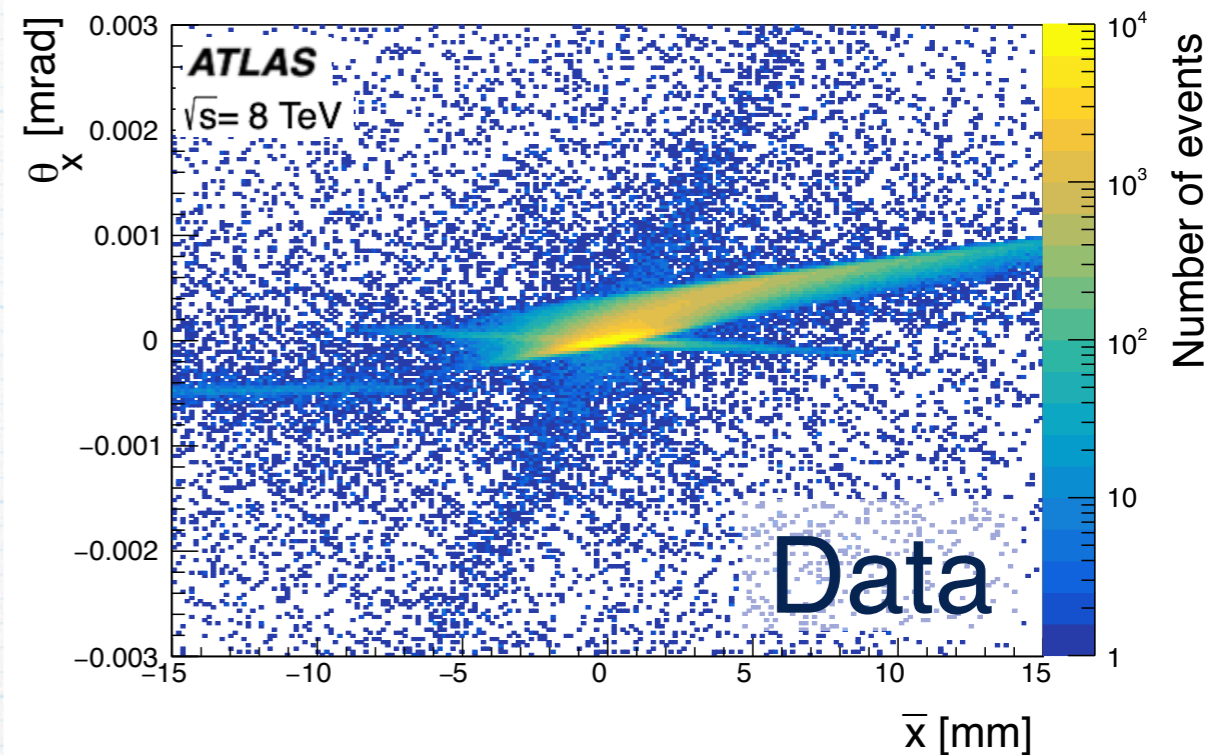
MC & Acceptance

- Main MC sample is PYTHIA8 A3 tune $\alpha(0) = 1.08$

- Also:
  - PYTHIA8 A2 with $\alpha(0) = 1$
  - HERWIG7

- Lower limits in ξ determined by MBTS requirements
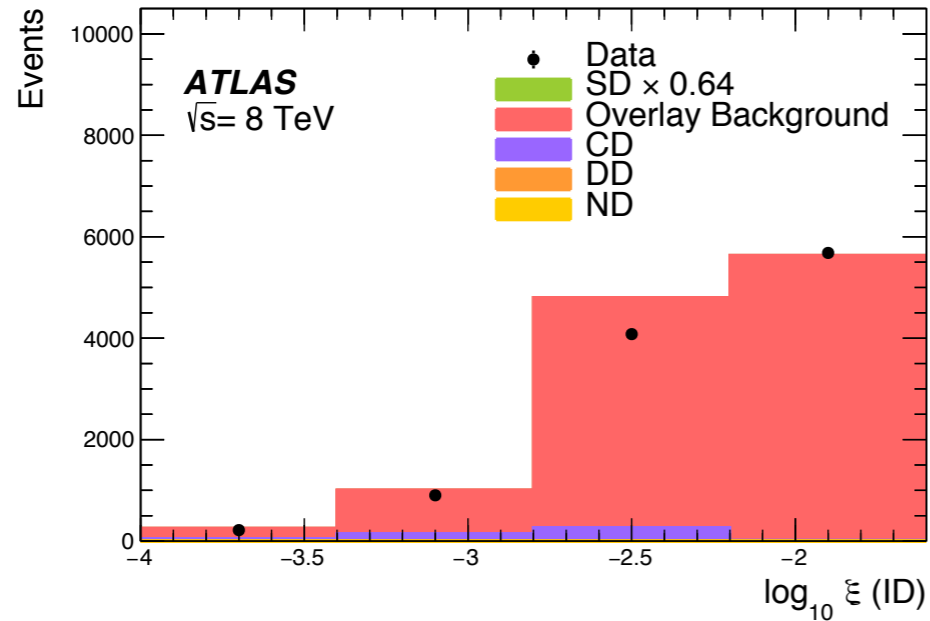
- Upper limit in ξ & t range determined by ALFA acceptance
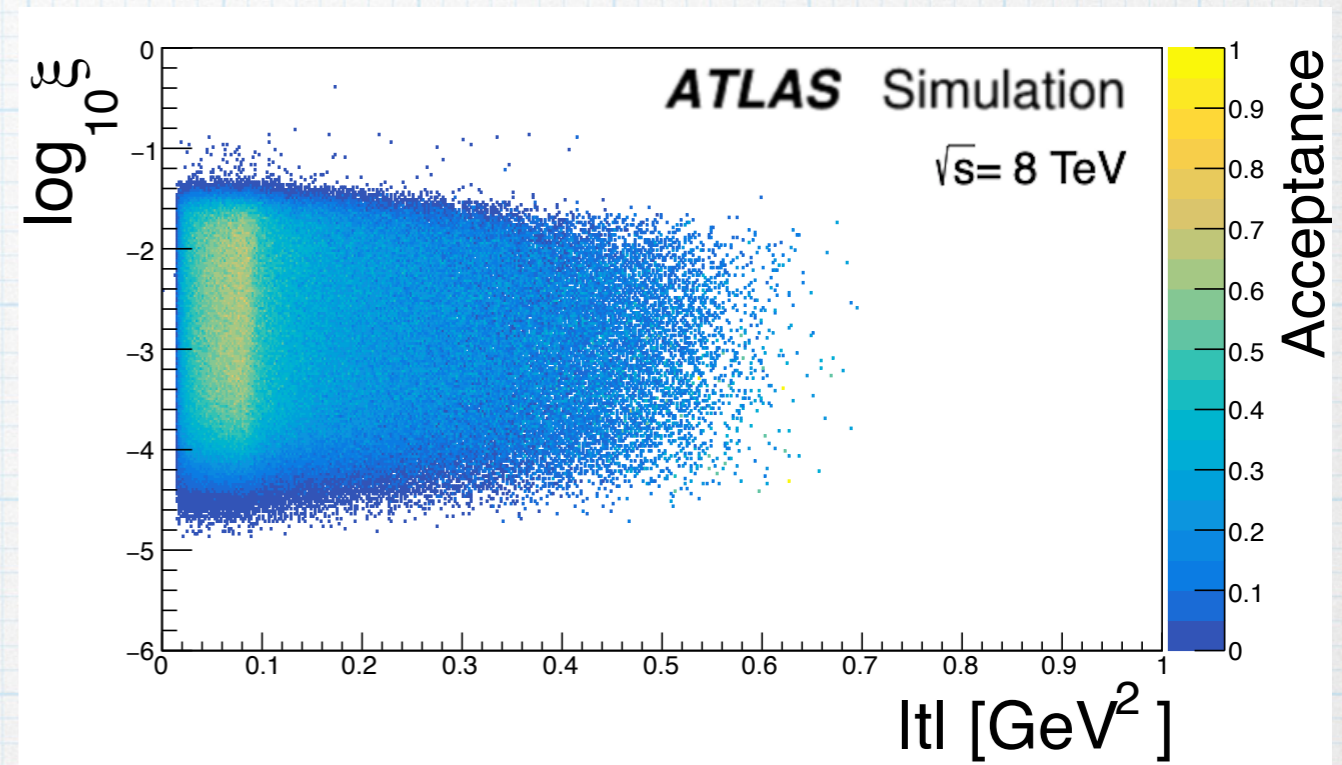
Fiducial range

$0.016 < |t| < 0.43$ GeV^2
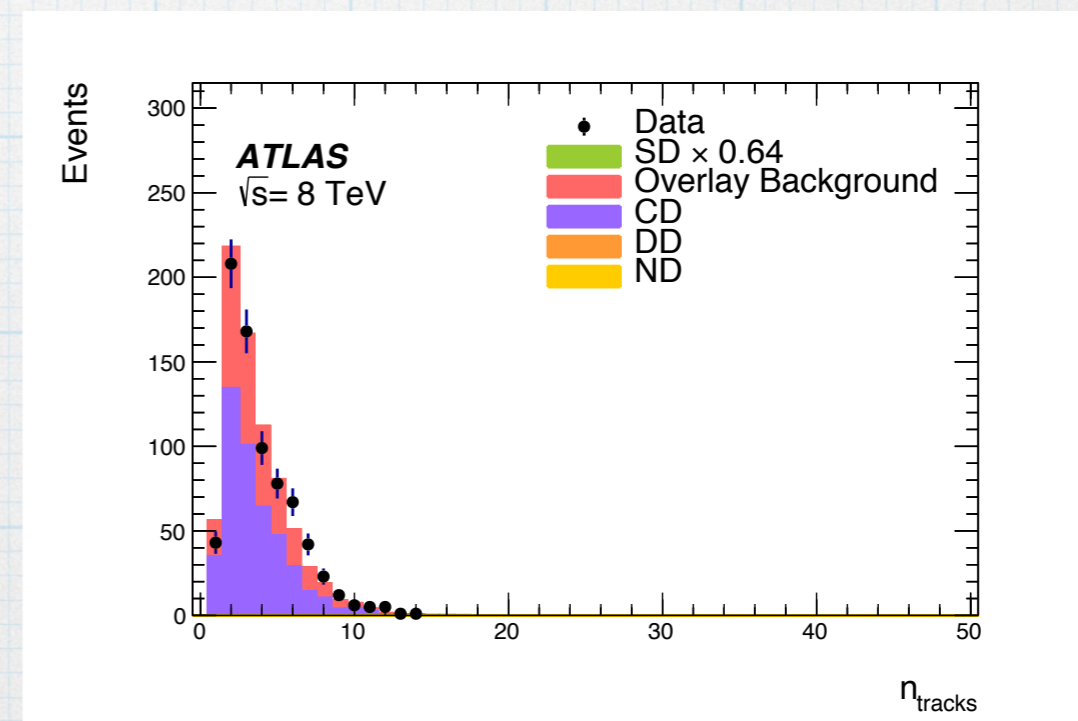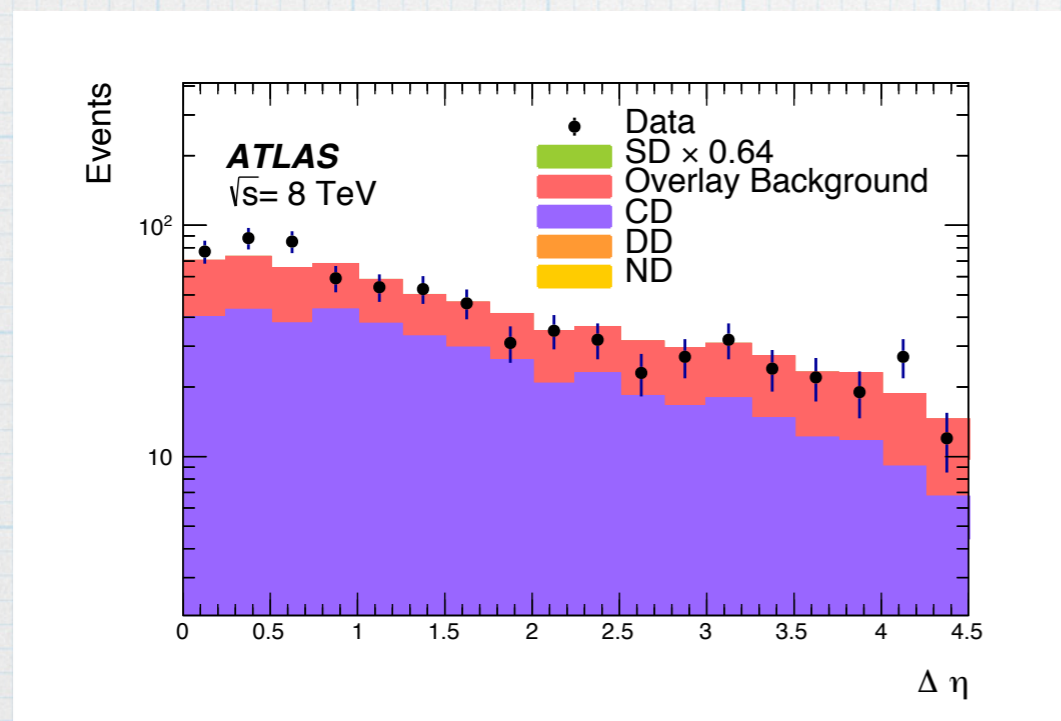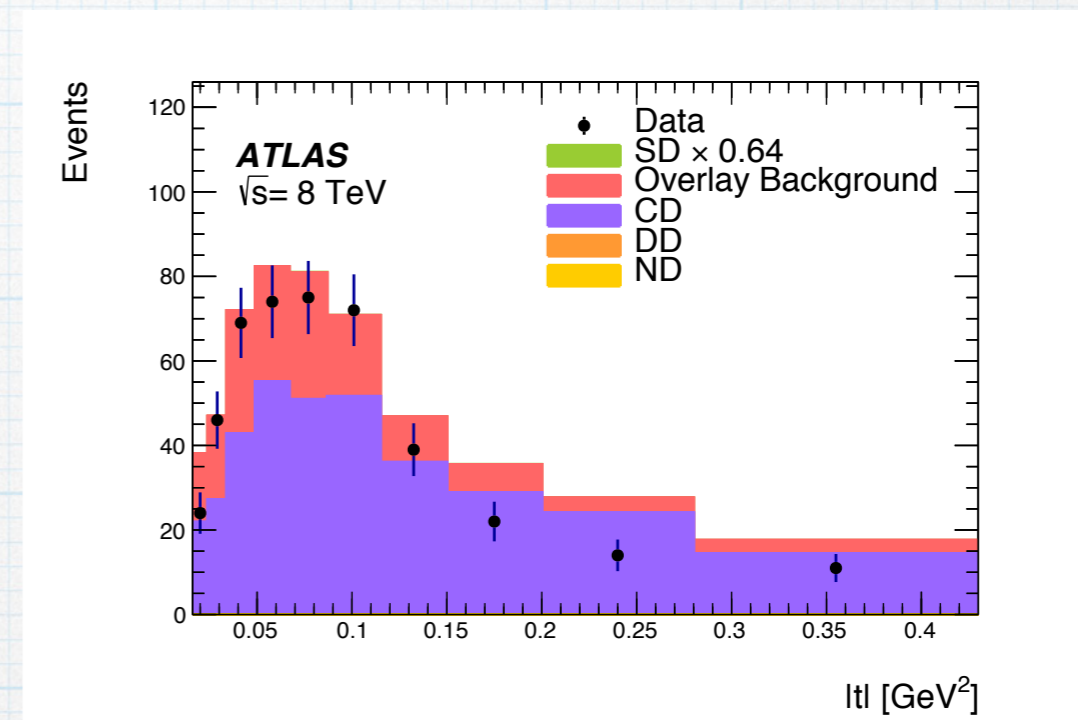
$-4.0 < \log_{10}\xi < -1.6$
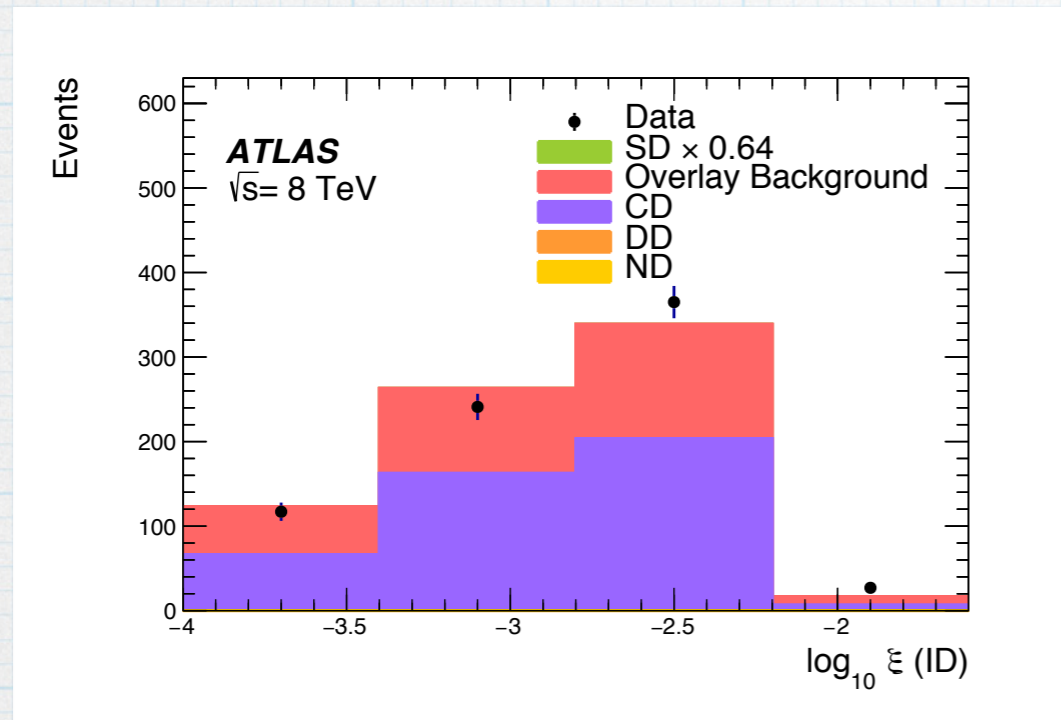
Control region: Overlay background

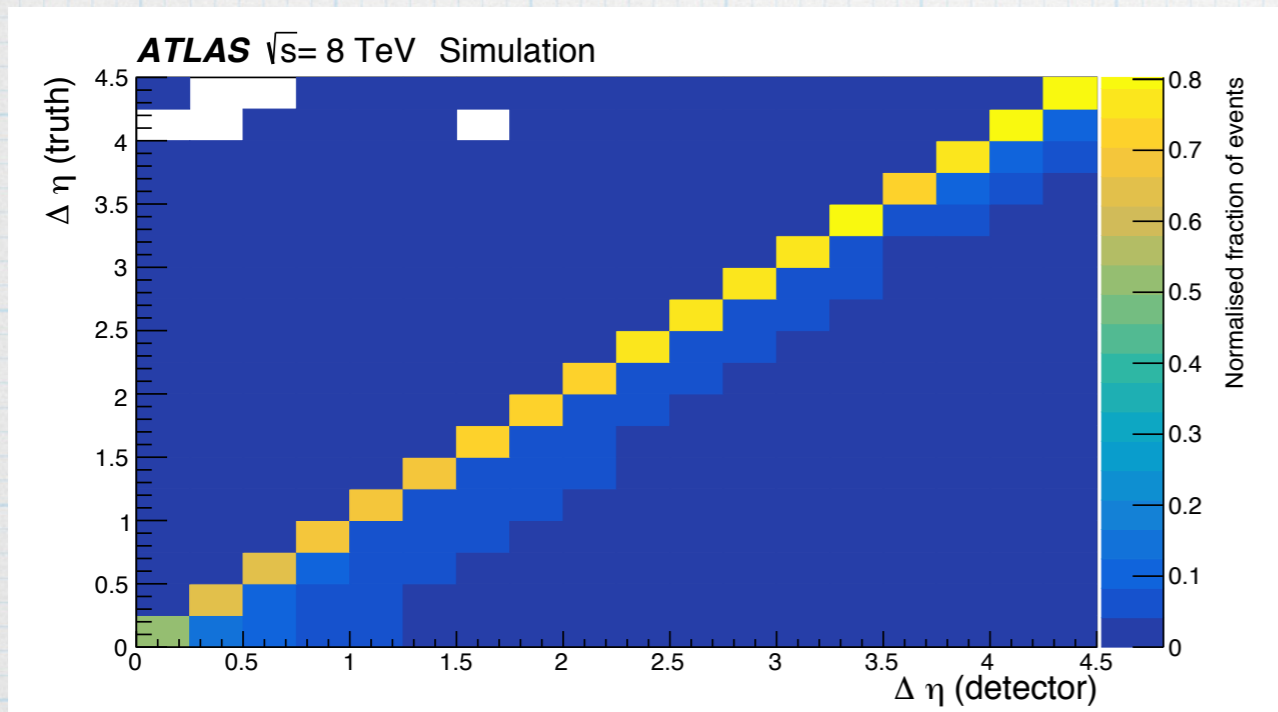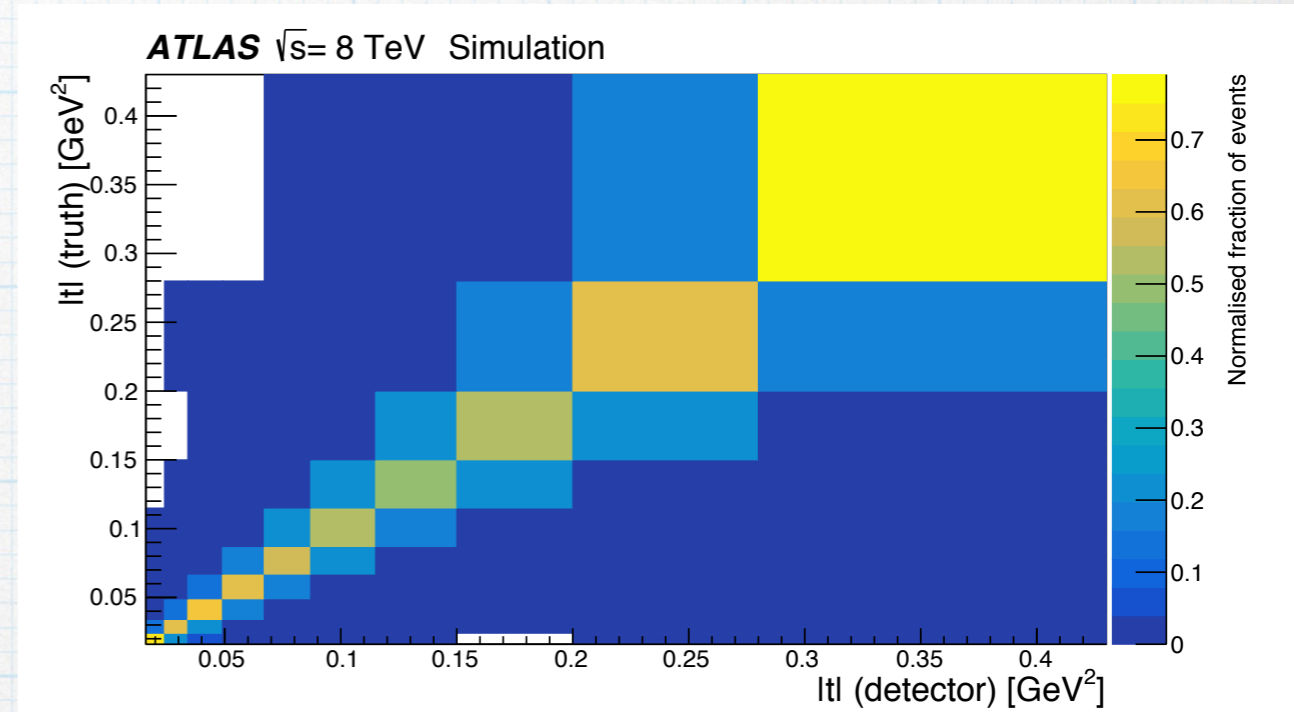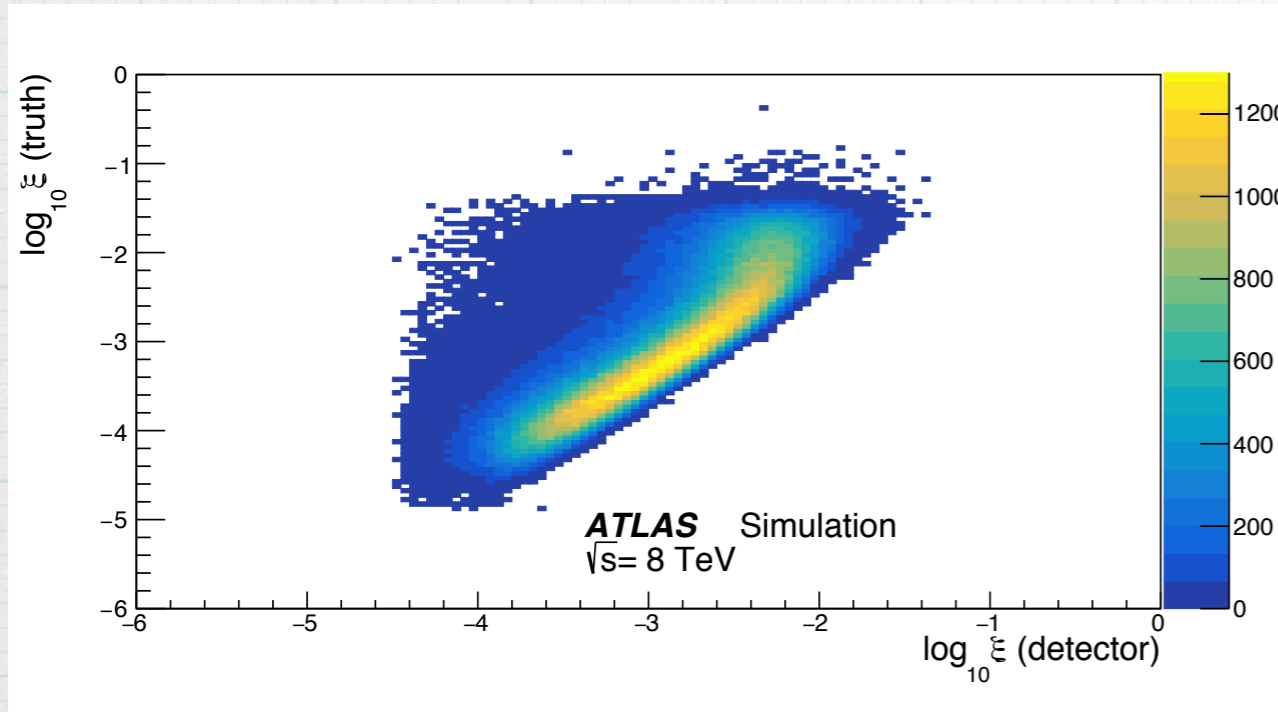## Nominal selection except 2 protons in ALFA
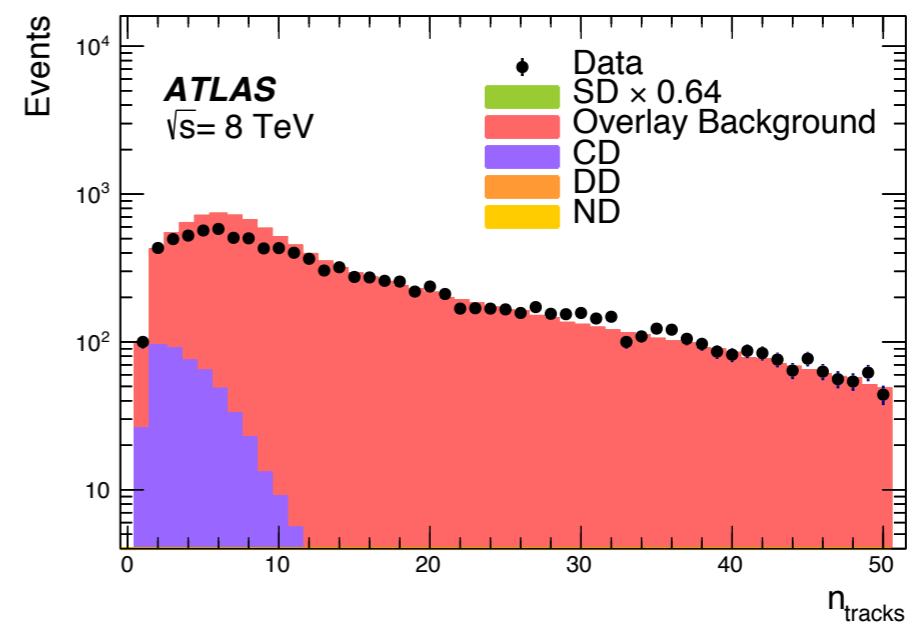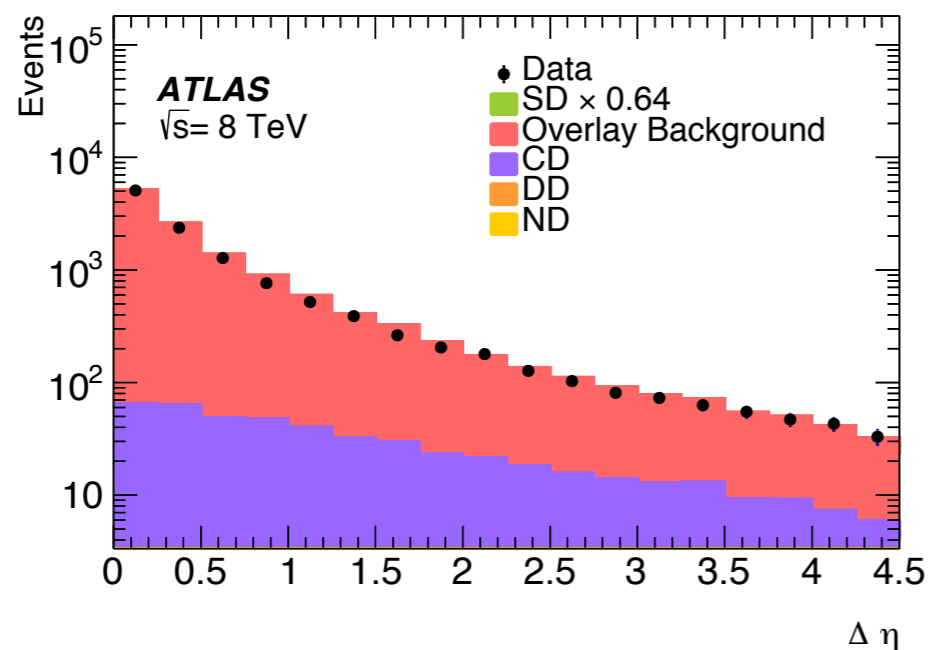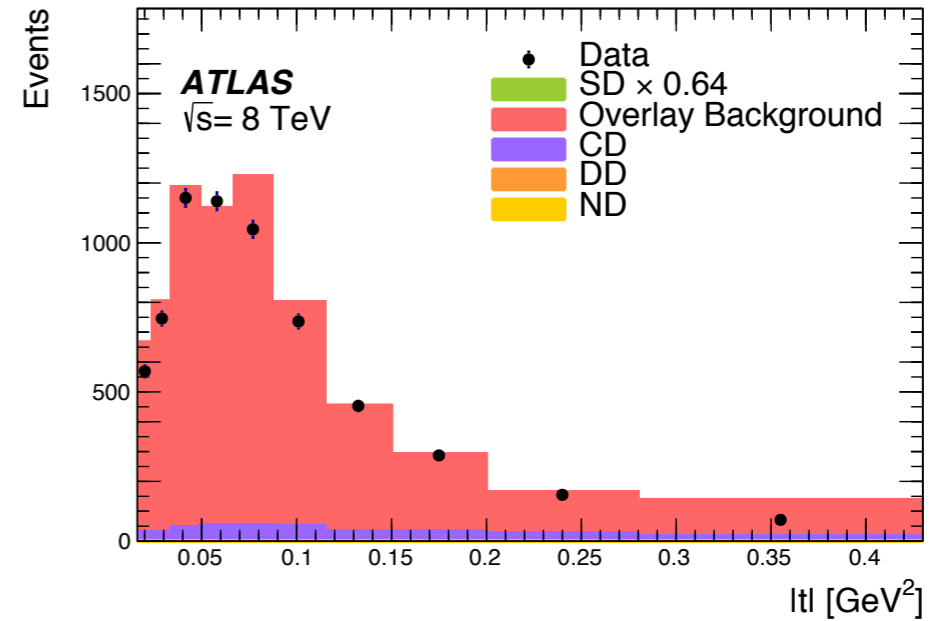
Control region: CD background

Nominal selection except 2 protons in ALFA & 2 < MBTS < 10

Reweighting applied

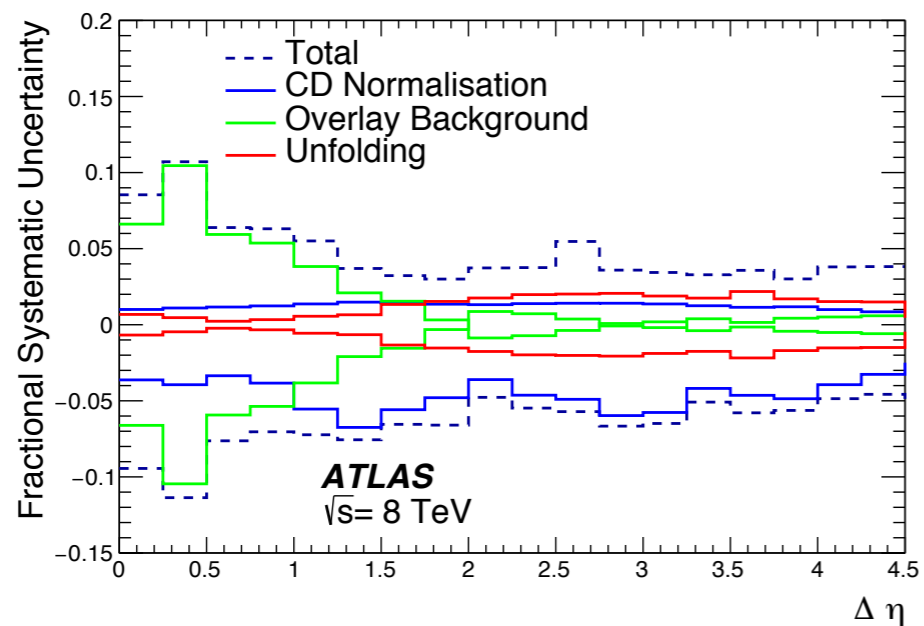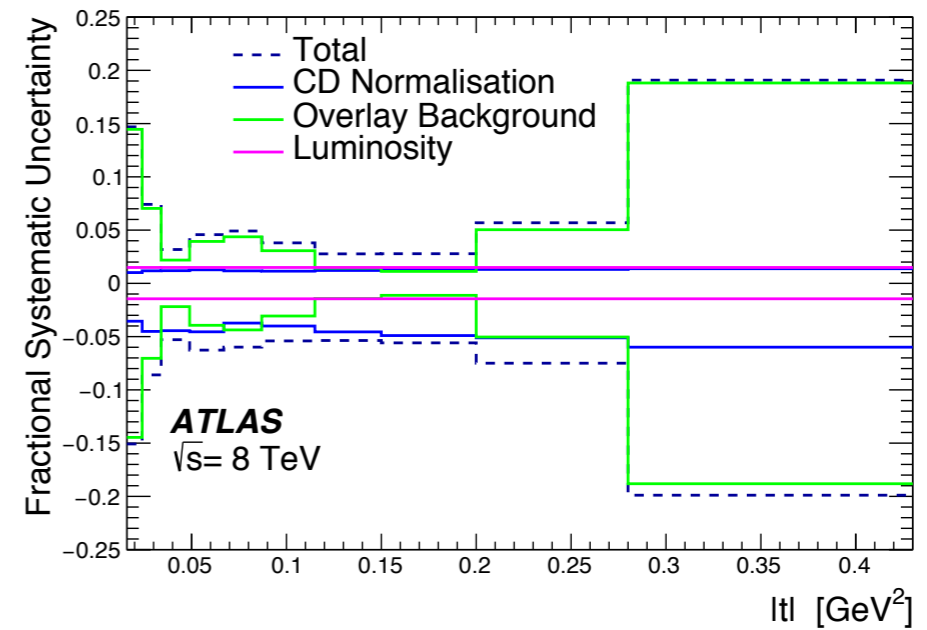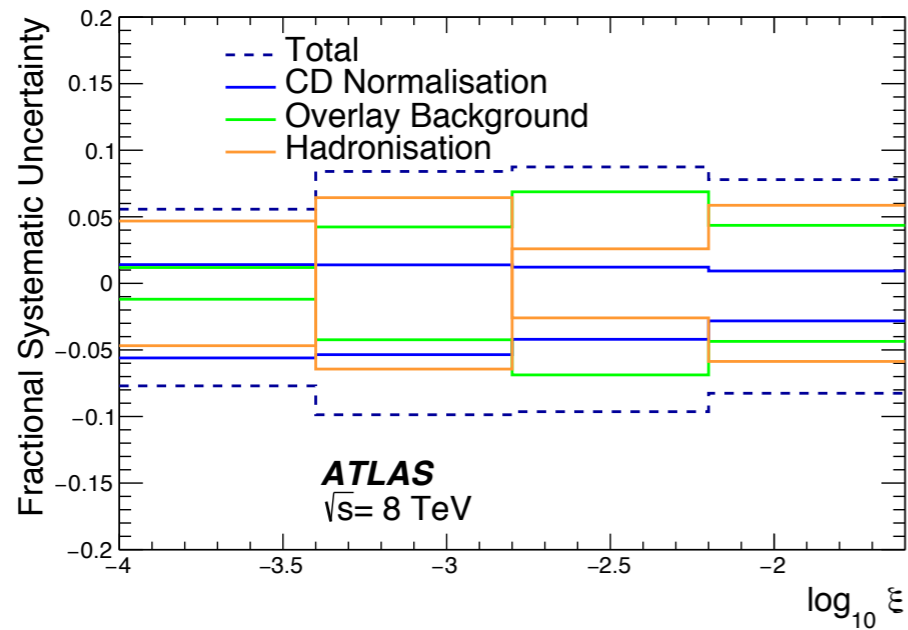# Response matrices

- t & Δη are approx. diagonal
- Linear calibration applied to ξ corrects for:
  - Charged particles outside ID range
  - Missing neutrals
- Iterative Bayesian unfolding used to remove detector effects

Systematic uncertainties

- Plots show dominant sources
- Many more evaluated & not shown
- Overlay background is largest uncertainty in many bins

ξ comparison with CMS result

- Results scaled by 1.18 to cover full t range

- Shown to be compatible with similar CMS result:
  - Gap based
  - Small DD contribution
  - 7 TeV
  - *Phys. Rev. D 92, 012003*