Measurements of soft-QCD and diffractive processes with ATLAS

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on behalf of the ATLAS Collaboration

ICHEP 2020

Contents

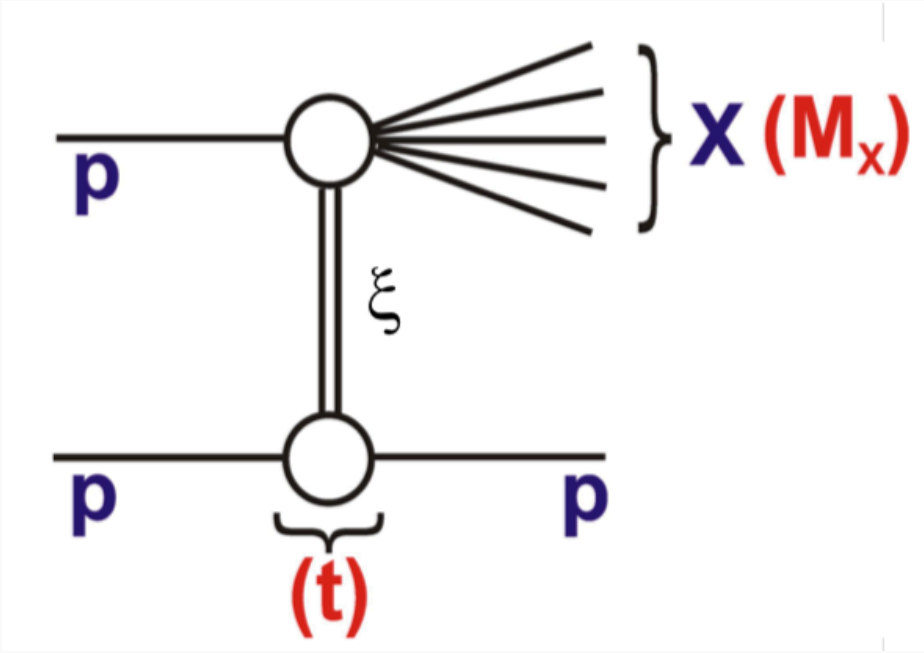
Measurement of differential cross sections for single diffractive dissociation in $\sqrt{s}$ = 8 TeV pp collisions using the ATLAS ALFA spectrometer

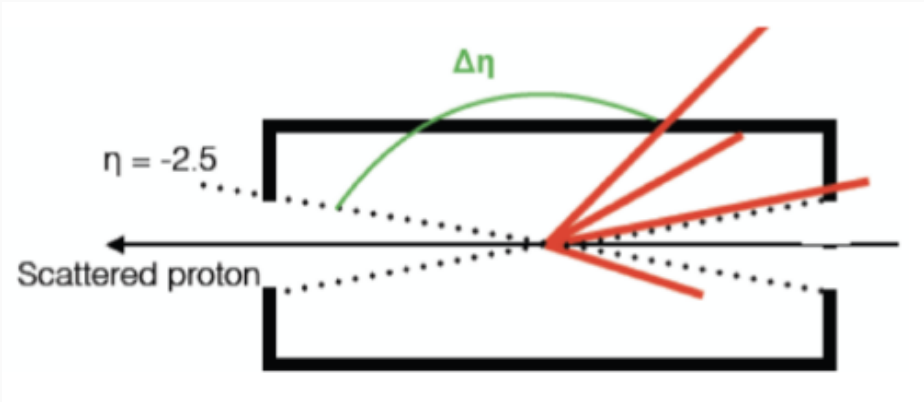
JHEP 02 (2020) 042

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

Kinematic variables





- t – squared four-momentum transferred from the proton (related to proton transverse momentum)

$$t \approx -p_T^2$$

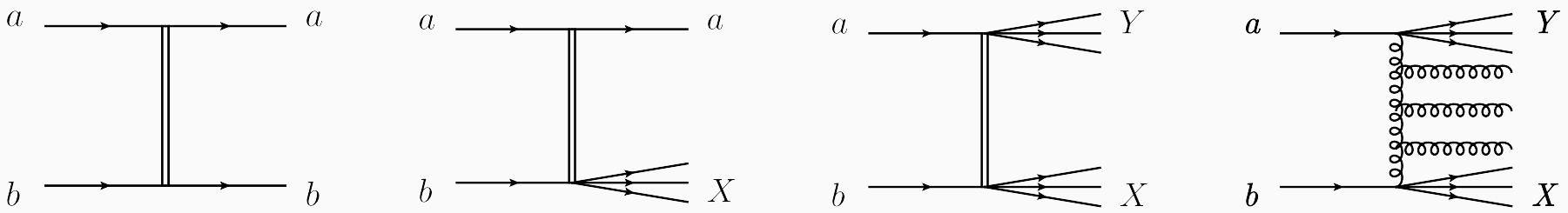
- ξ – momentum fraction of the proton carried by the pomeron

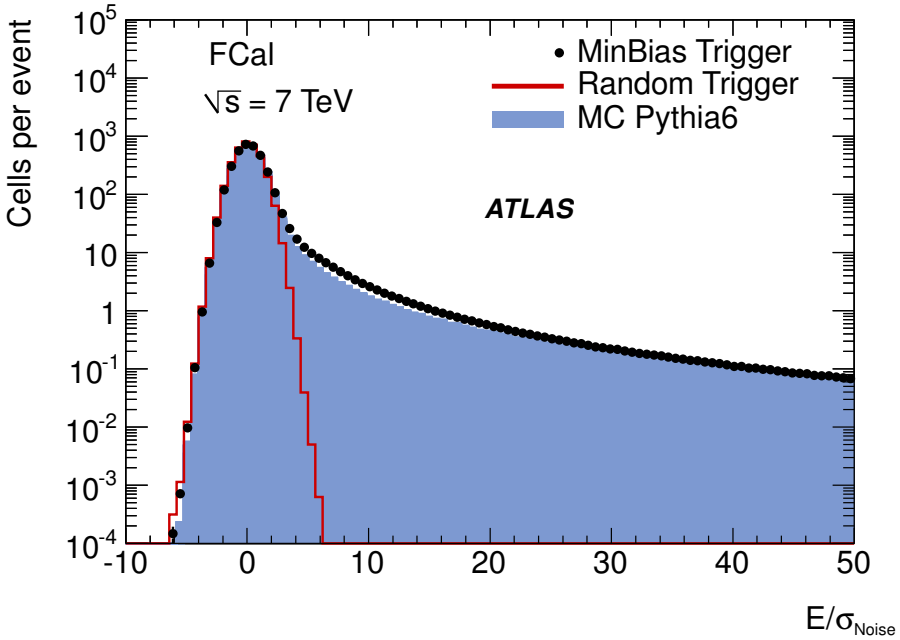
$$\begin{aligned}\xi &= 1 - E/E_0 \\ &= M_X^2/s \approx \sum_i (E^i \pm p_z^i)/\sqrt{s}\end{aligned}$$

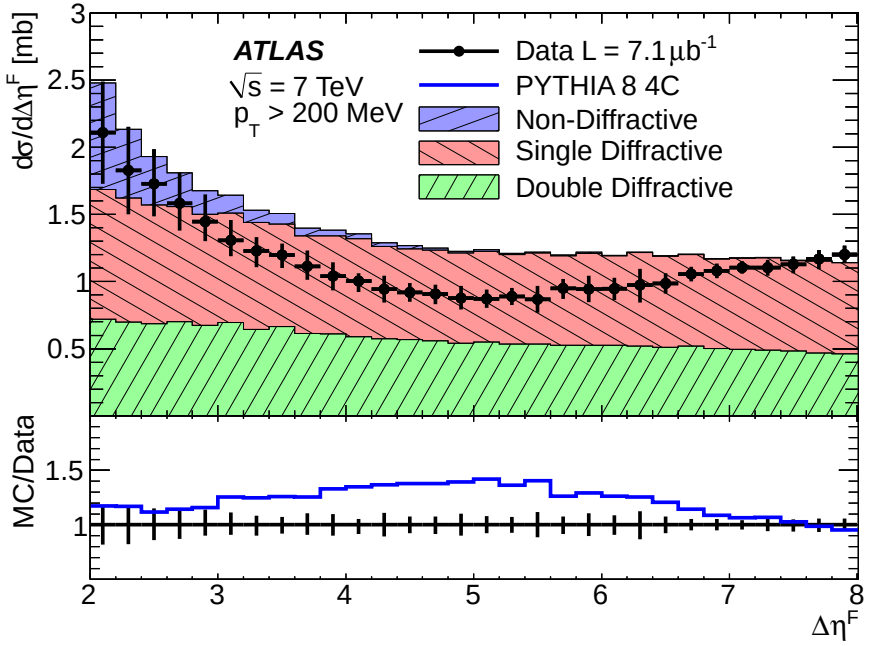
E – proton energy
$E_0 0$ – proton initial energy
E^i, p_z^i – energy and longitudinal momentum of particles in the dissociated state
s – centre-of-mass energy

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

Diffraction measurements w/o proton tagging (Eur. Phys. J. C (2012) 72 1926)

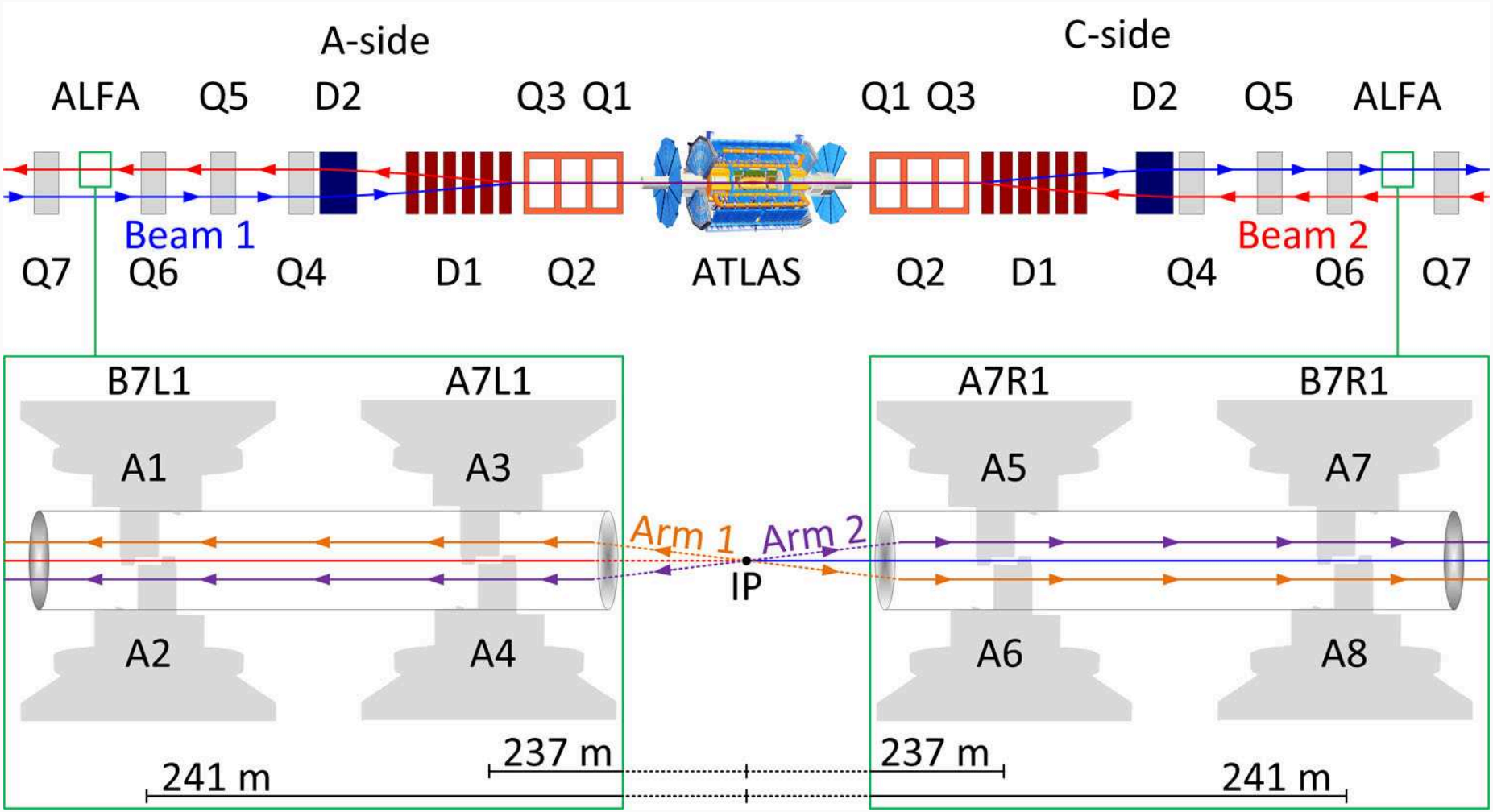






- Calorimeter used to measure rapidity gaps
- Separation of diffractive processes from non-diffractive processes
- Full separation of single and double diffraction not possible

ALFA Detectors



Measurement overview

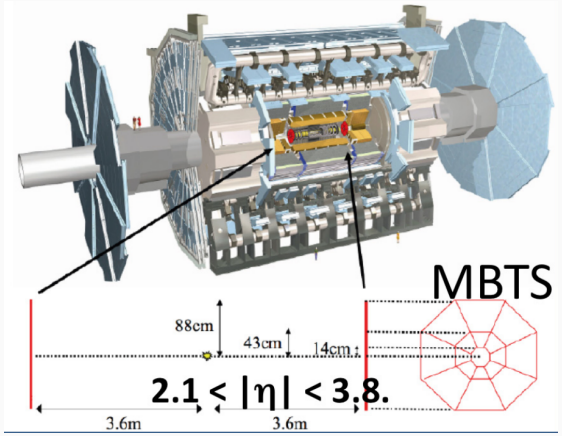
- Data from special run: $\sqrt{s}$ = 8 TeV, β^* = 90 m, L = 1.67/nb, μ < 0.08

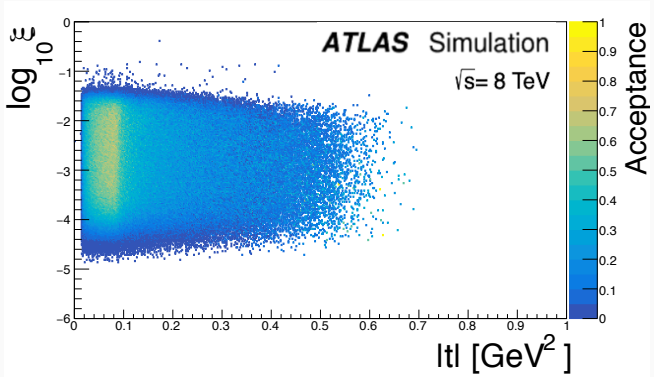
- Intact proton measured in ALFA
- Dissociated proton measured using ATLAS tracking detector
- Trigger: opposite side coincidence of the signal in ALFA and Minimum Bias Trigger Scintilator (MBTS)
- Acceptance
  - tracker: charged particles with
    - p_T > 0.2 GeV
    - |η| < 2.5
  - MBTS: charged particles with 2.1 < |η| < 3.8
  - Fiducial region for the proton

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

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

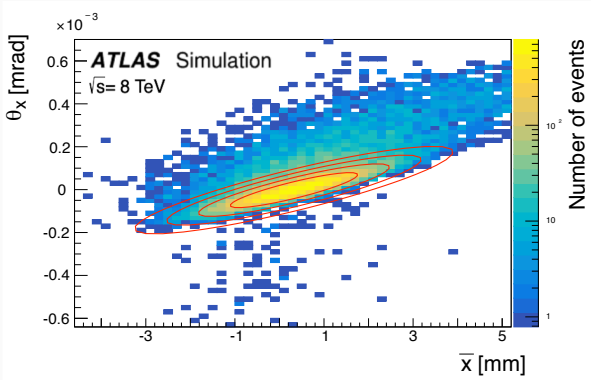
$$(\text{i.e. } 80 < M_X < 1270 \text{ GeV})$$

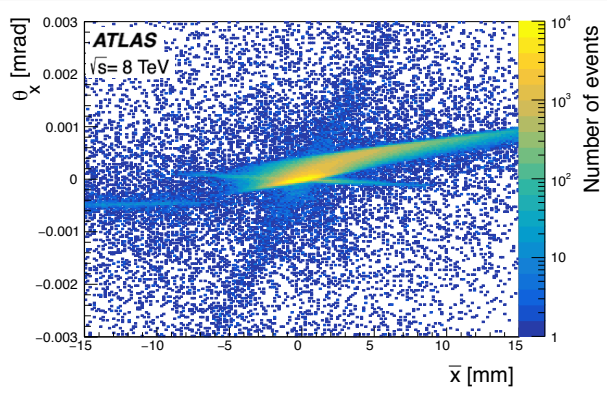




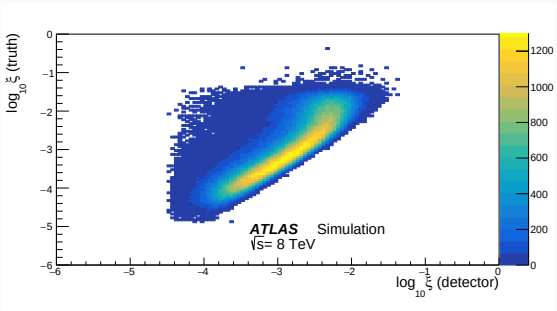
Event selection

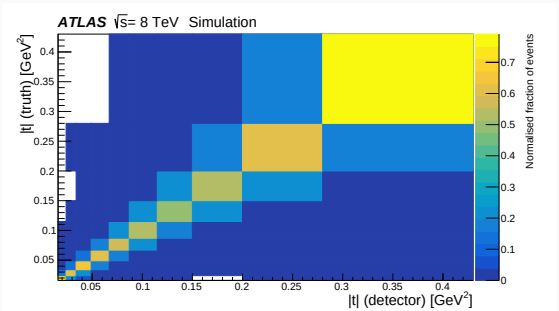
- Exactly one reconstructed proton in two ALFA stations of the same armlet
- ALFA: 3σ ellipse cut in (x, θ_x) plane
- ID: at least one track and a reconstructed vertex
- MBTS: at least 5 (out of 16) counters above noise threshold

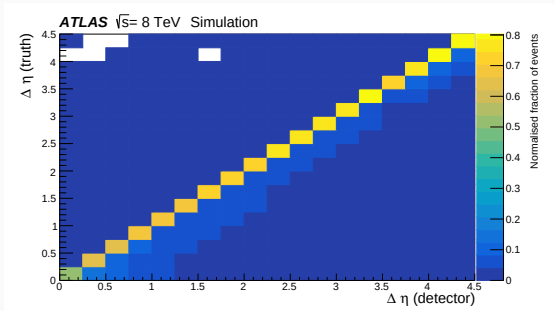




Detector effects



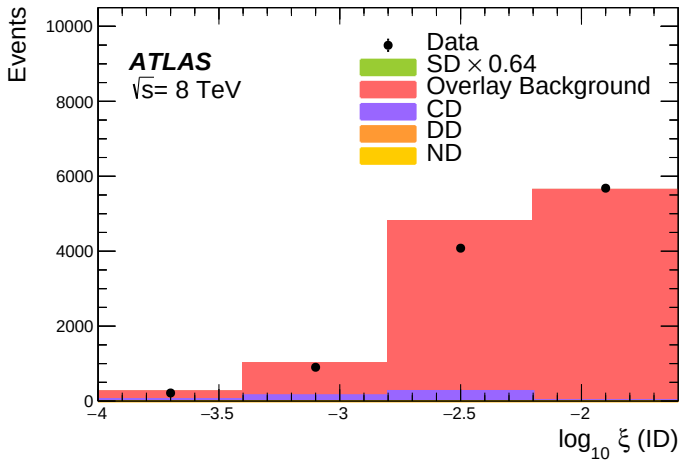




Background

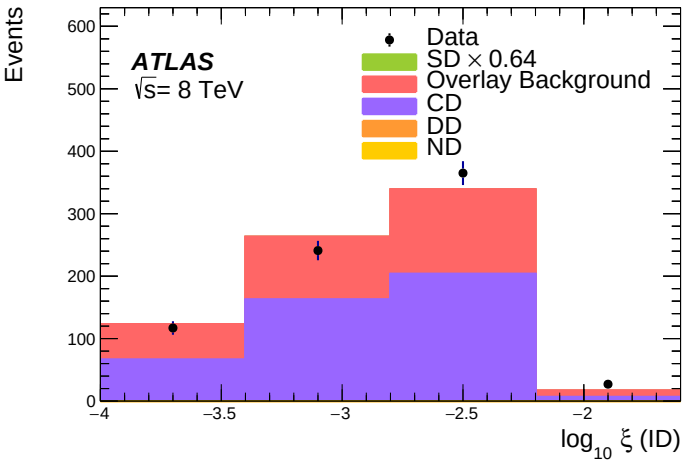
Overlay background

- Coincidence between a proton in ALFA (elastic, halo) and activity in central ATLAS (minimum bias interaction)
- Largest background
- Data-driven estimate using strongly ND-enriched events
- Control region: nominal selection, but with protons in two armlets (dominated by elastics + ND)

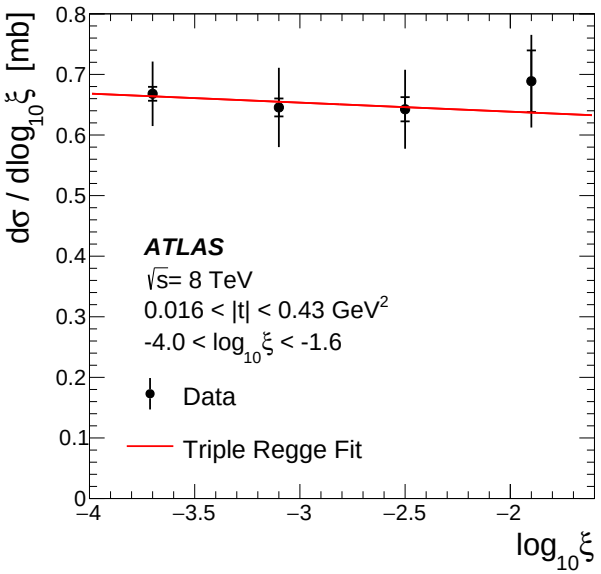


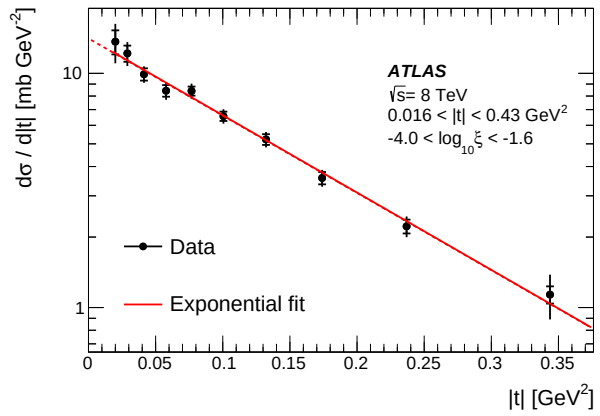
Central diffraction

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



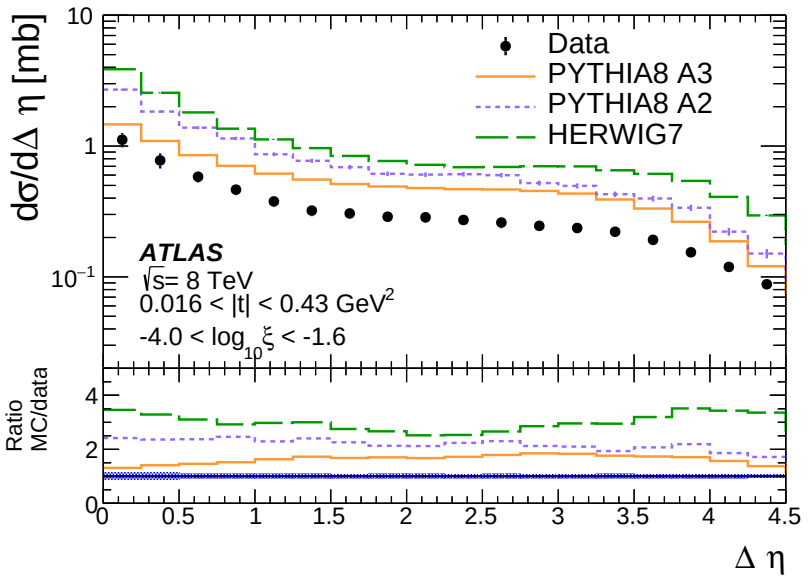
Proton kinematics distribution





- Distribution fitted with:
  $\frac{\mathrm{d}\sigma}{\mathrm{d}\log_{10}\xi} = \left(\frac{1}{\xi}\right)^{\alpha(0)-1} \frac{\exp(Bt_{\mathrm{high}}) - \exp(Bt_{\mathrm{low}})}{B}$,
  where $B = B_0 - 2\alpha' \log \xi$
- Measured Pomeron intercept
  $\alpha(0) = 1.07 \pm 0.02\,(stat.) \pm 0.06\,(\mathrm{syst.}) \pm 0.06\,(\alpha')$
- Main systematic uncertainty from
  $\alpha' = 0.25 \pm 0.25\ \mathrm{GeV}^{-2}$
- PYTHIA 8 A3 (Donnachie-Landshoff): α(0) = 1.14
  PYTHIA 8 A2 (Schuler-Sjostrand): α(0) = 1.00
- Measured exponential slope:
  $B = 7.60 \pm 0.23\,(\mathrm{stat.}) \pm 0.22\,(\mathrm{syst.})\ \mathrm{GeV}^{-2}$
- 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

Integrated cross sections and rapidity gap size



- 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 describe the shape but not the overall cross section:

Distribution	$\sigma_{\mathrm{SD}}^{\mathrm{fiducial}(\xi,t)}$ [mb]	$\sigma_{\mathrm{SD}}^{t\text{-extrap}}$ [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

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Eur. Phys. J. C 79 (2019) 666

Underlying event

- Complex structure of hadron-hadron interaction
- Underlying event – activity in addition to the hard interaction:
  - initial state radiation
  - final state radiation
  - multiple parton interaction
  - colour reconnections with beam remnants
- Non-perturbative effects
- No clear soft/hard separation
- Phenomenological model in MC generators
- A need for tuning models to experimental data

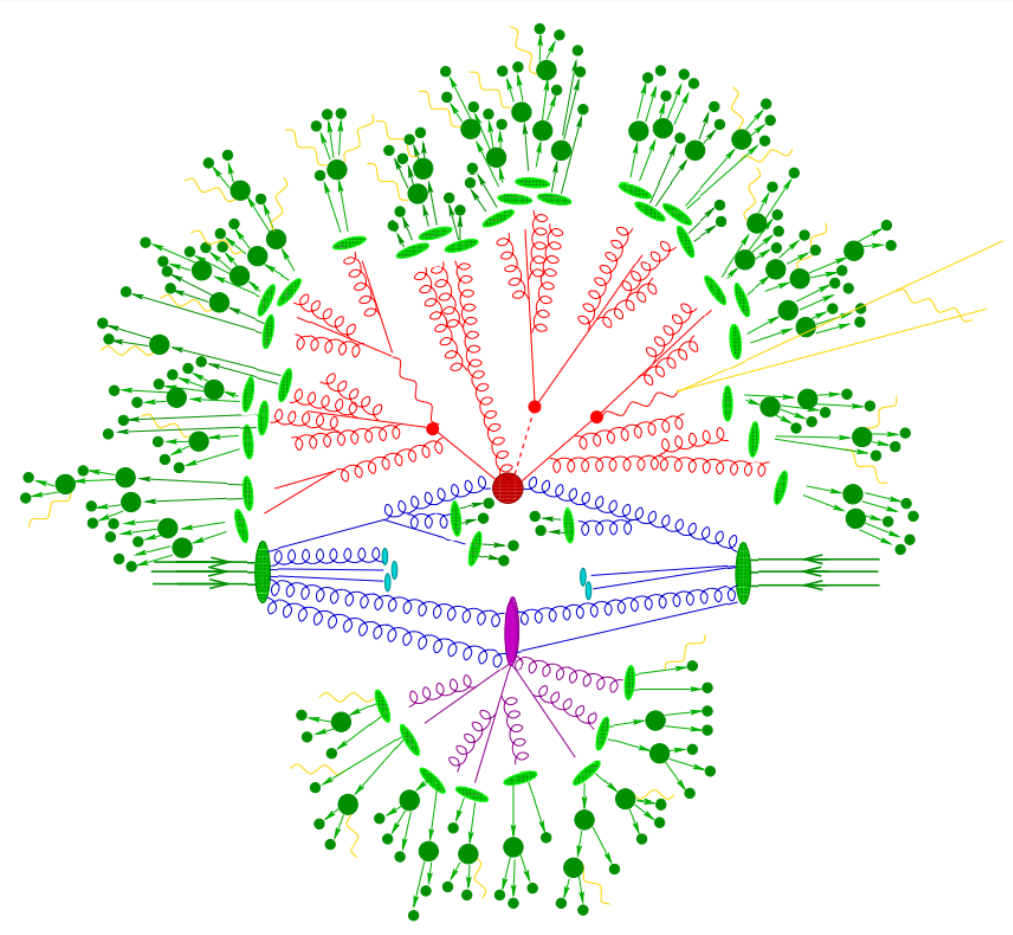
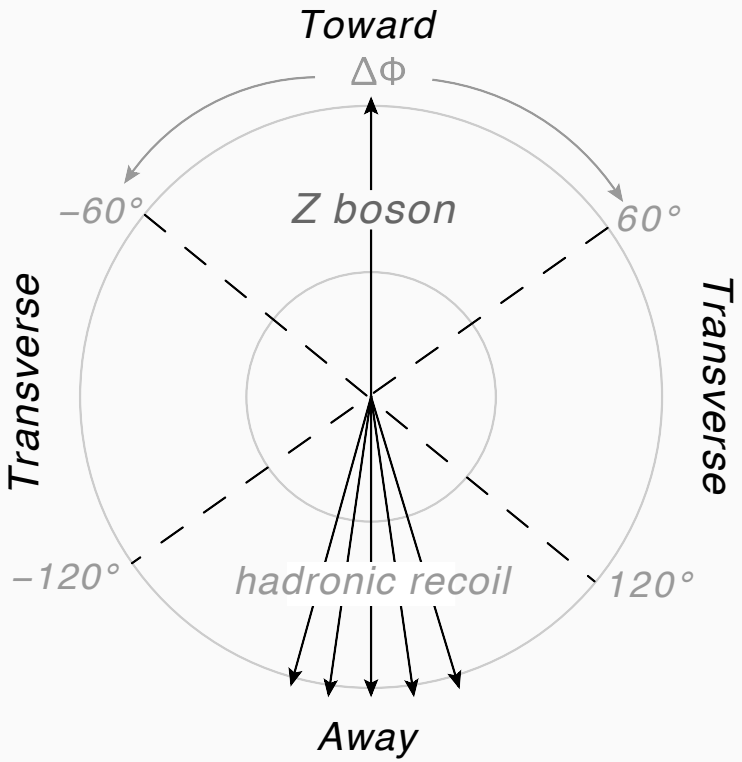
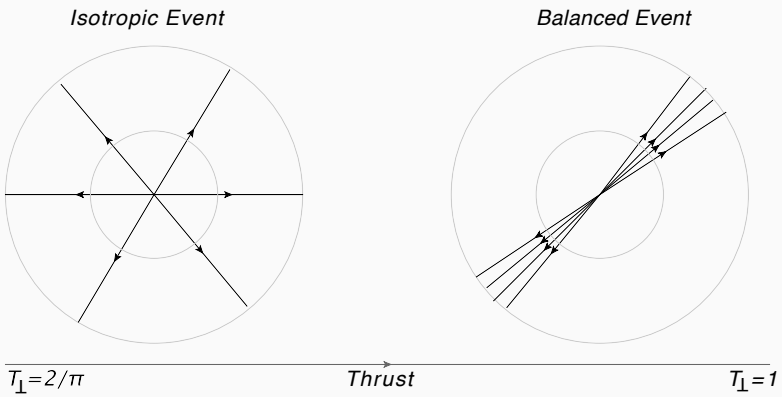


Figure from [arXiv:1411.4085]

Measurement overview





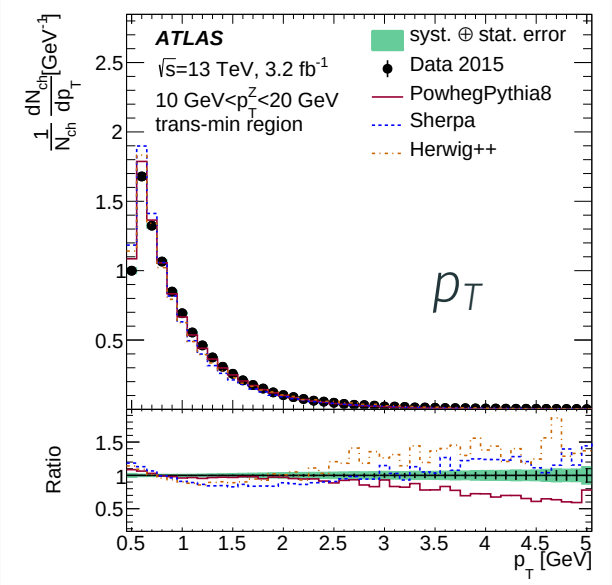
- Selecting $Z \to \mu\mu$ events
- Regions in the transverse plane defined relative to the Z direction
- Observables:
  - number of charged particles
  - p_T of charged particles
  - $\sum p_T$ of charged particles
  - mean p_T of charged particles
- Two transverse regions: *trans-min* and *trans-max* (defined based on $\sum p_T$)
- Measurements in different regions, in bins of Z transverse momentum and bins of transverse thrust

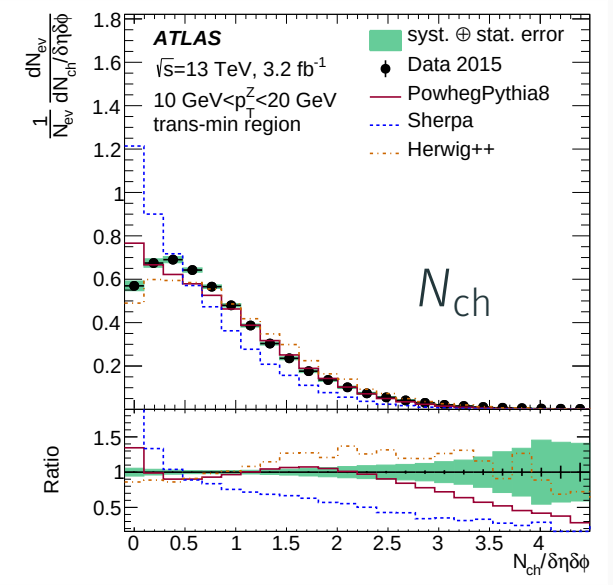
Transverse thrust:

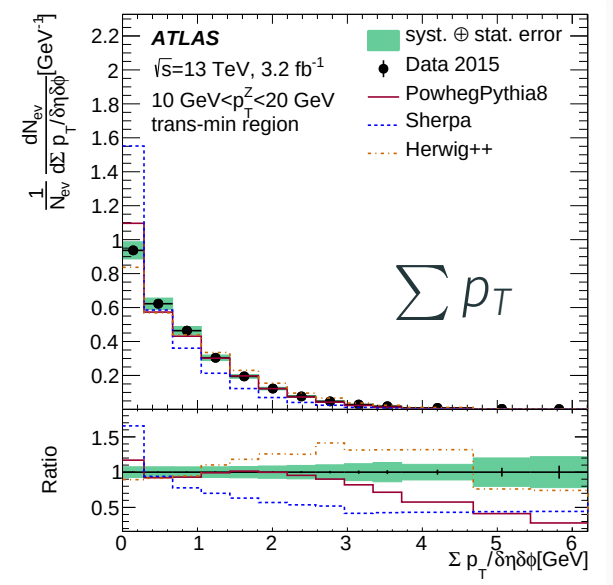
$$T_\perp = \max_{\hat{n}} \frac{\sum_i |\vec{p}_{T,i} \cdot \hat{n}|}{\sum_i |\vec{p}_{T,i}|}$$

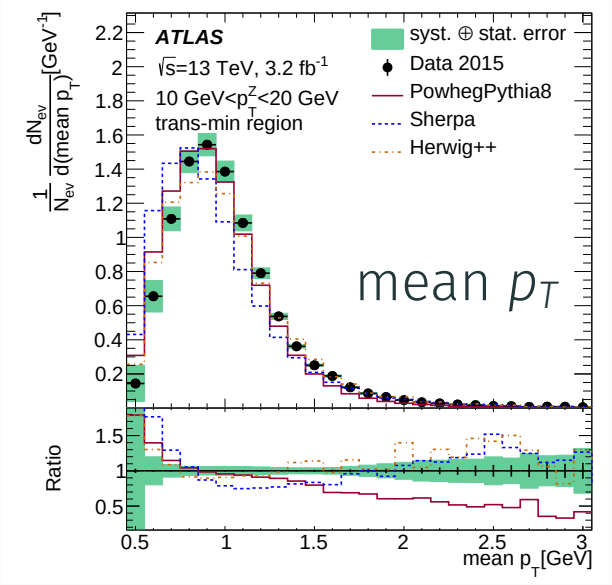
(sums are over all charged particles except the two muons from Z decay)

Distributions of different observables



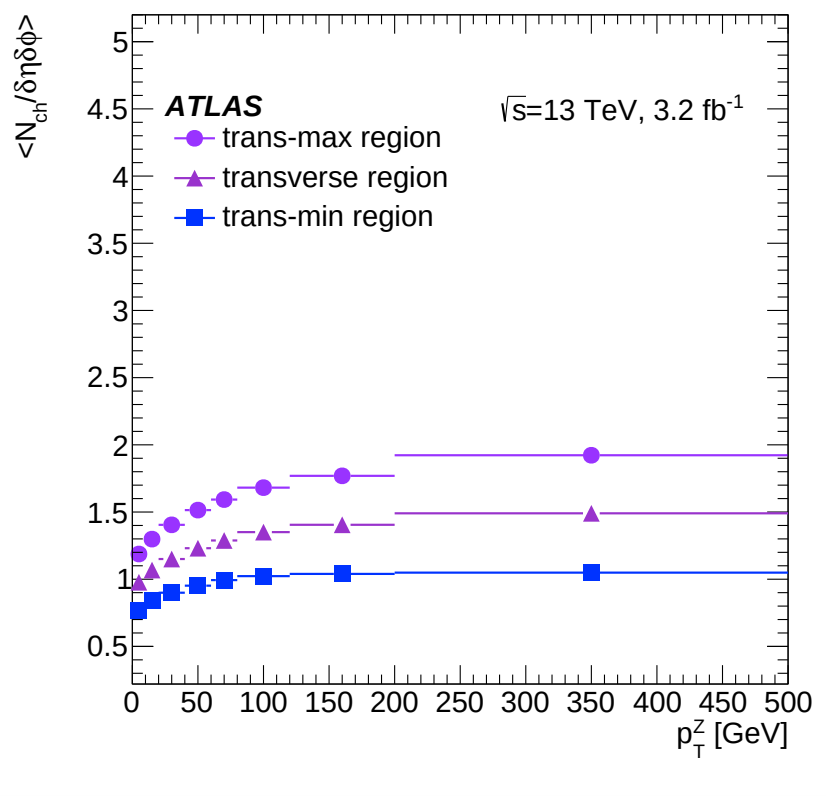


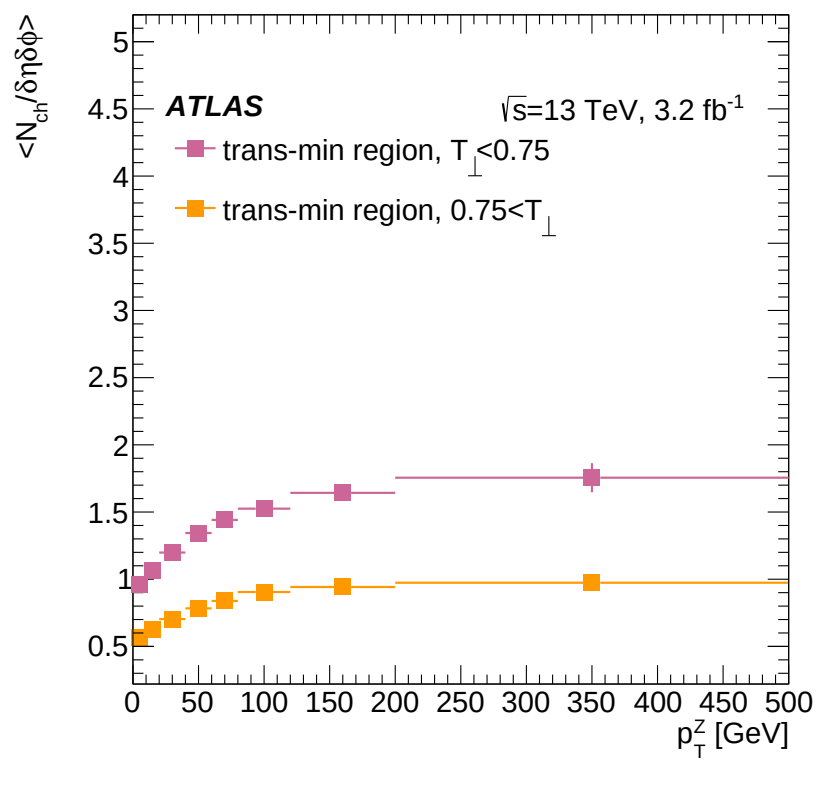




- All distributions corrected for detector effects
- None of the tested MC describes the data well
- All observables not well described
- Too steep p_T distribution in MC models
- Input for MC tuning

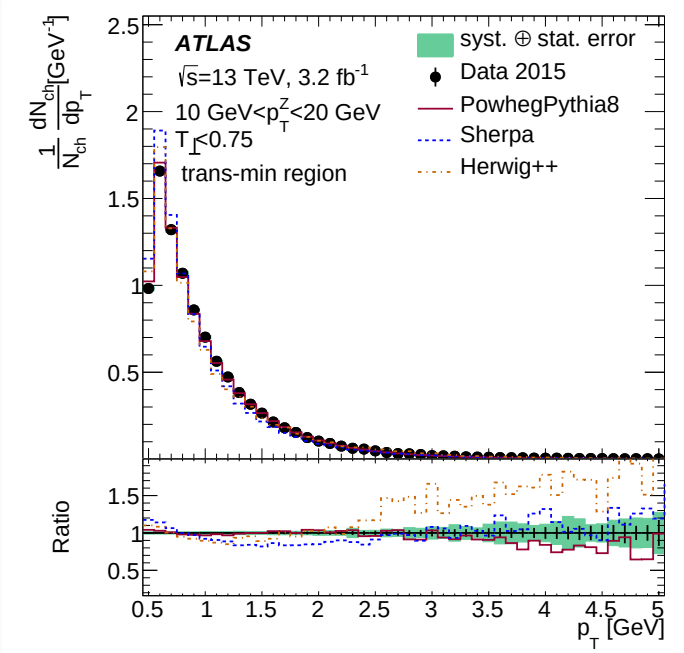
Dependence on region, transverse momentum, thrust

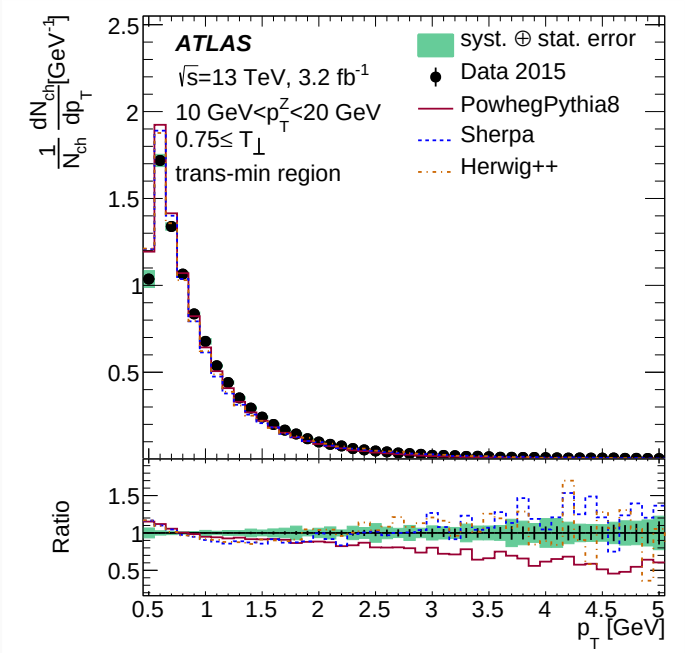


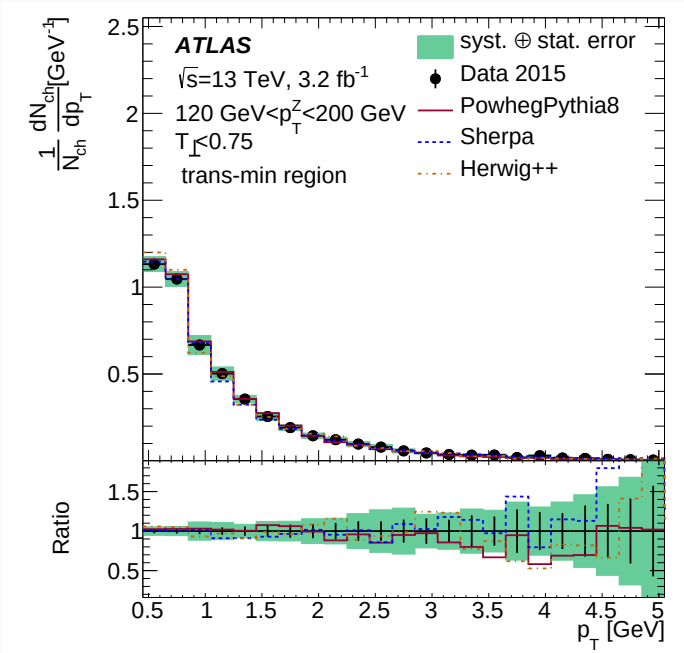


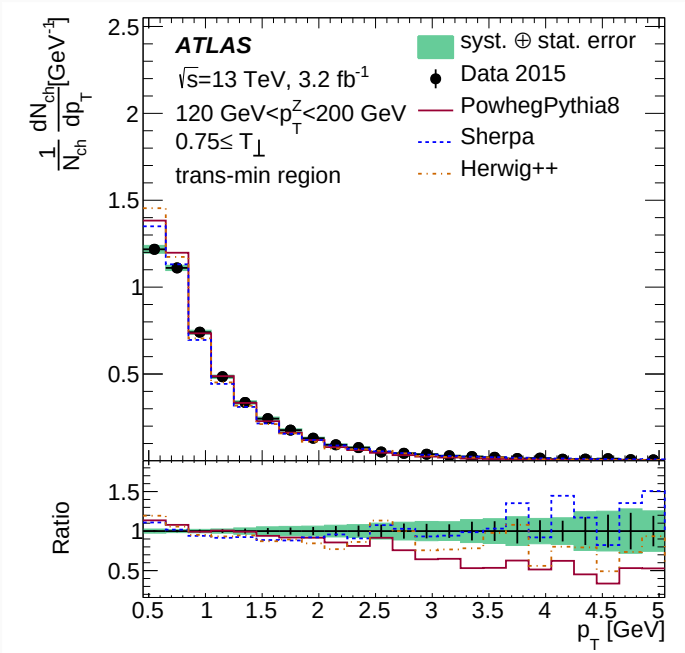
- Activity grows with p_T^Z, the growth slows down with p_T^Z
- Significant difference between trans-min and trans-max regions (trans-max more affected by the hadronic recoil of the Z boson)
- Higher activity in low-thrust events

Distributions for different p_T^Z and thrust









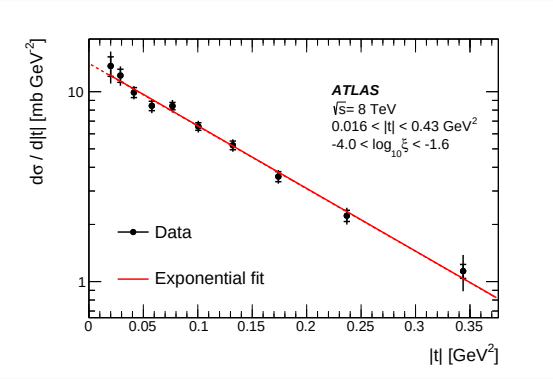
Summary

1. Measurement of single diffractive dissociation with a proton tag

- Fiducial cross section over predicted by MC generators
- Extracted parameters describing proton distributions:

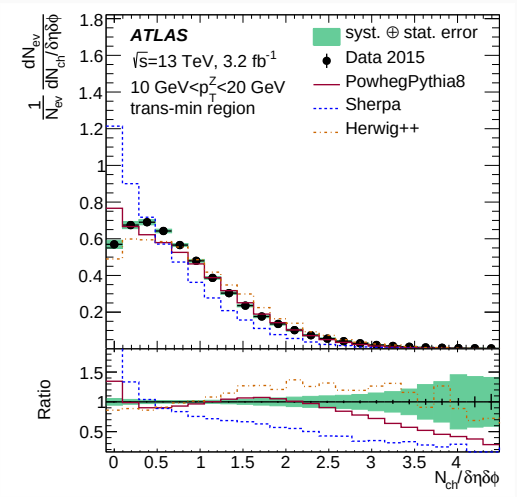
$$B = 7.60 \pm 0.23\ (\text{stat.}) \pm 0.22\ (\text{syst.})\ \text{GeV}^{-2}$$

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



See also other talks about forward proton tagging in ATLAS:

- *The Alignment of the ATLAS Forward Proton Detectors*, Jesse Liu
  Thu 30 Jul, 09:00am [Operation, Performance and Upgrade of Present Detectors]
- *The ATLAS Forward Proton Time-of-Flight Detector System*, Karel Černý
  Thu 30 Jul 09:15am [Operation, Performance and Upgrade of Present Detectors]
- *Measurements of photon-photon fusion at ATLAS*, Mateusz Dyndał
  Thu 30 Jul 10:50am [Top quark and electroweak physics]

2. Measurement of UE-sensitive observables in Z events

- four different observables studied
- measurements in different regions,
  in several transverse momentum and thrust bins
- important imput for tuning MC generators