Exclusive and Diffractive Processes with the ATLAS detector

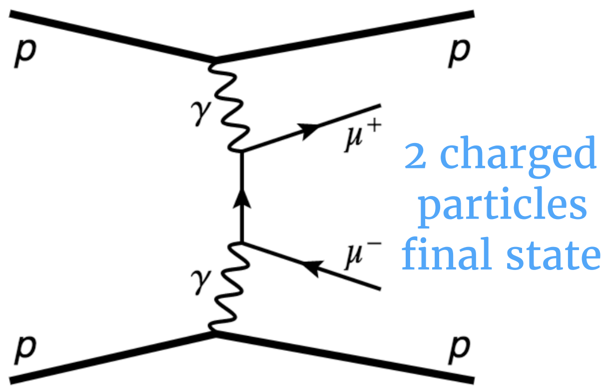
Andrew Foster (University of Birmingham)
On behalf of the ATLAS Collaboration

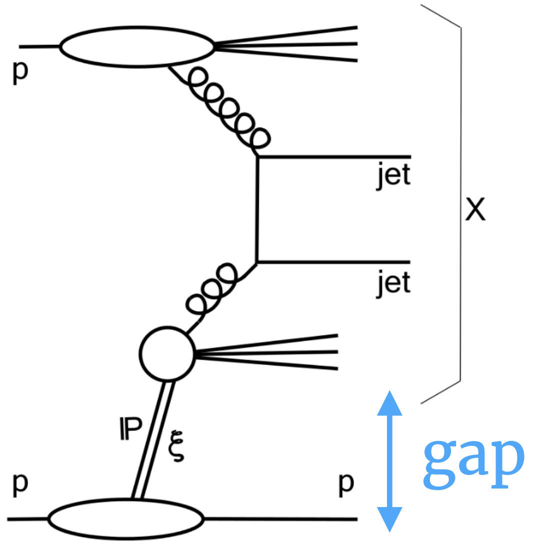
DIS 2018 - 16-20th April 2018 - Kobe, Japan

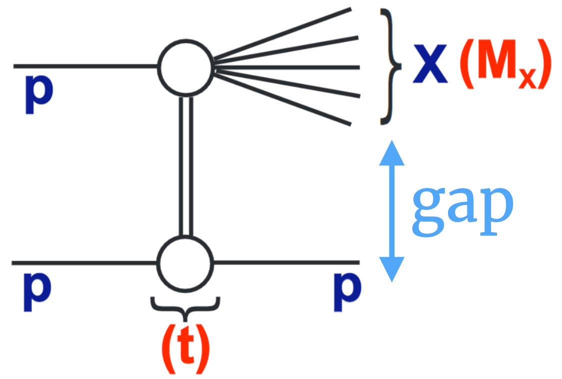
DIS 2018

Exclusive and Diffractive Processes

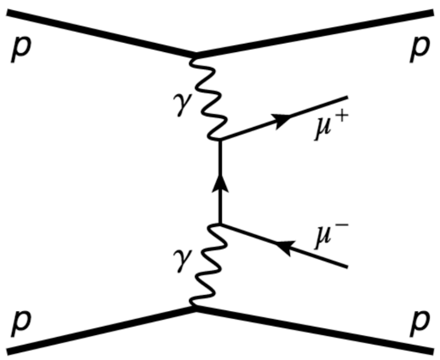
- Identified through the presence of rapidity gaps, forward protons and the absence of charged particles in the tracking detector
- In the absence of proton tagging, part of signature and corresponding information 'lost' with the proton(s)
- Present overview of previous ATLAS exclusive and diffractive analyses and outline prospects for the use of 'proton-tagging'



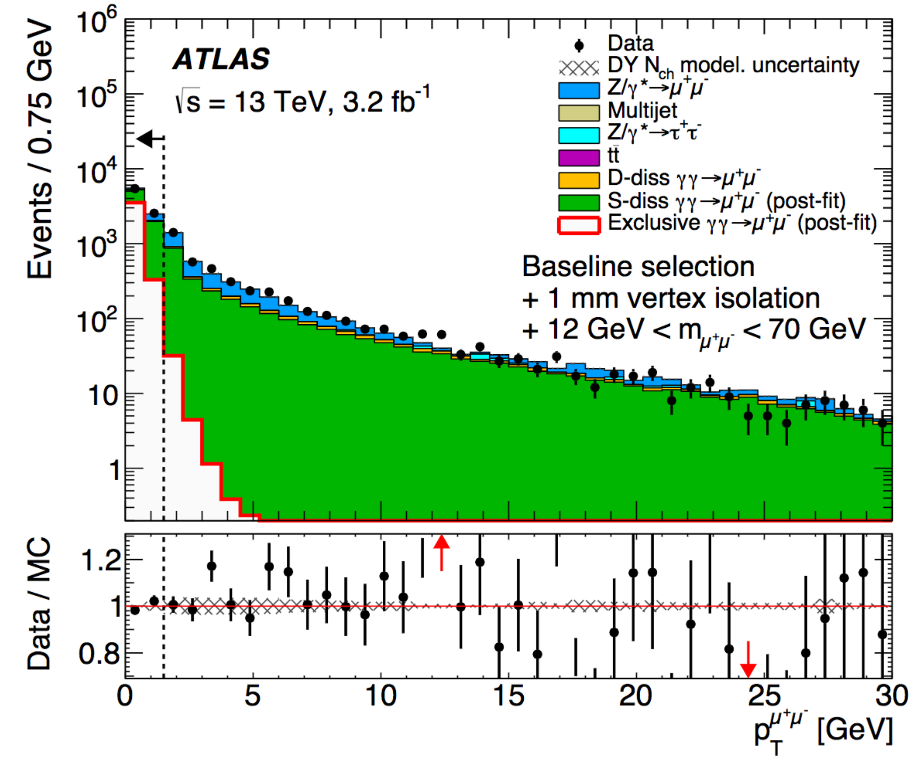




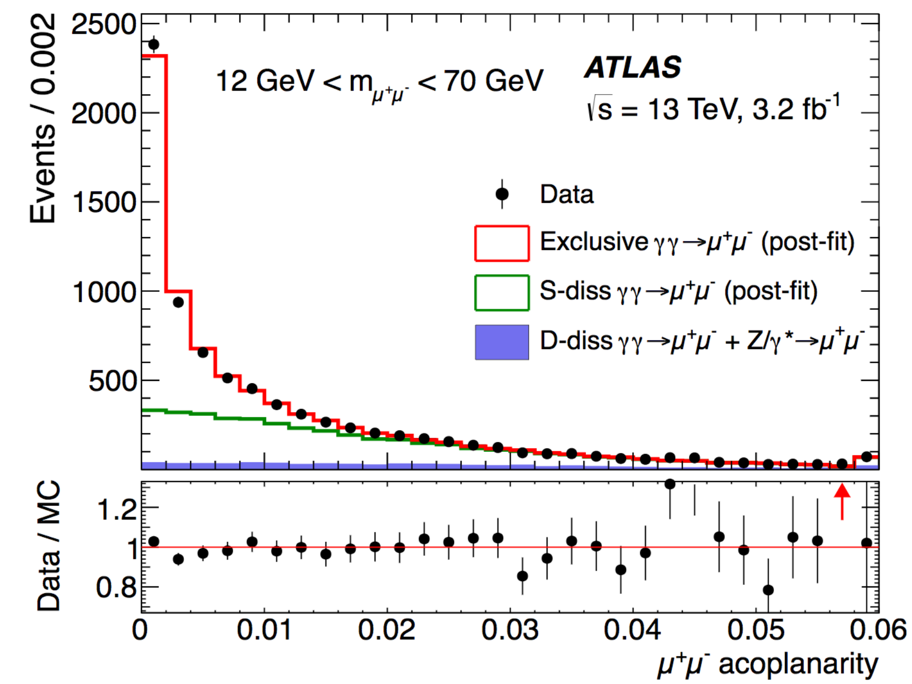
$\sqrt{s}$ = 7 & 13 TeV Exclusive Dilepton Production



EM field of colliding protons acts as γ beam



- LHC can be treated as a **high energy γγ collider** using the photons produced by the protons' EM fields as a quasi-real beam of photons with small virtuality of $Q^2 < 0.1$ GeV^2 (Equivalent photon approximation – EPA)



- Exclusivity requirement on charged particle tracks with near dilepton vertex;
  - Remove $70 < m(l^+l^-) < 105$ GeV;
  - $p_T(l^+l^-) < 1.5$ GeV to remove dissociative backgrounds

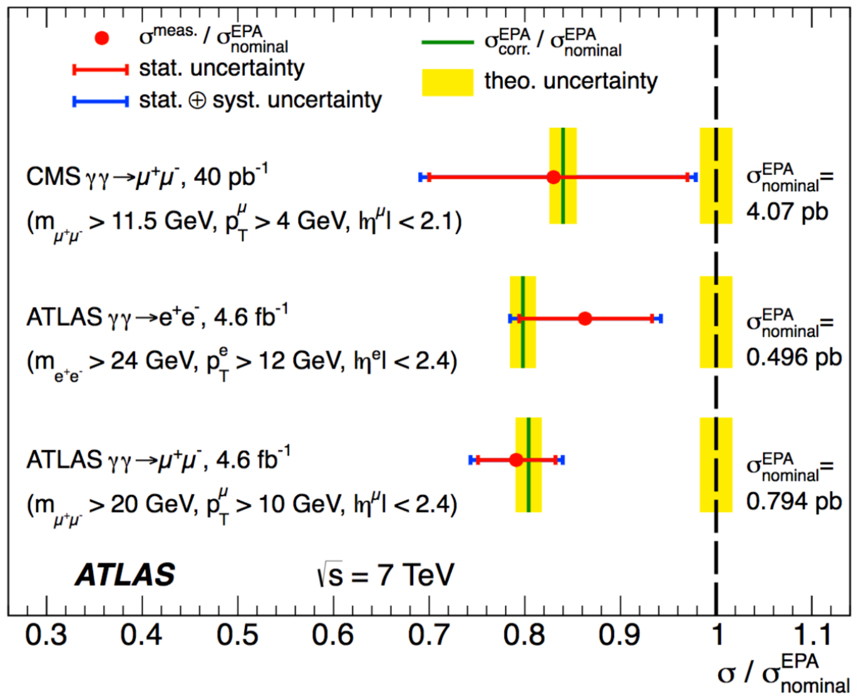
- Fit to acoplanarity distribution used to scale background contributions

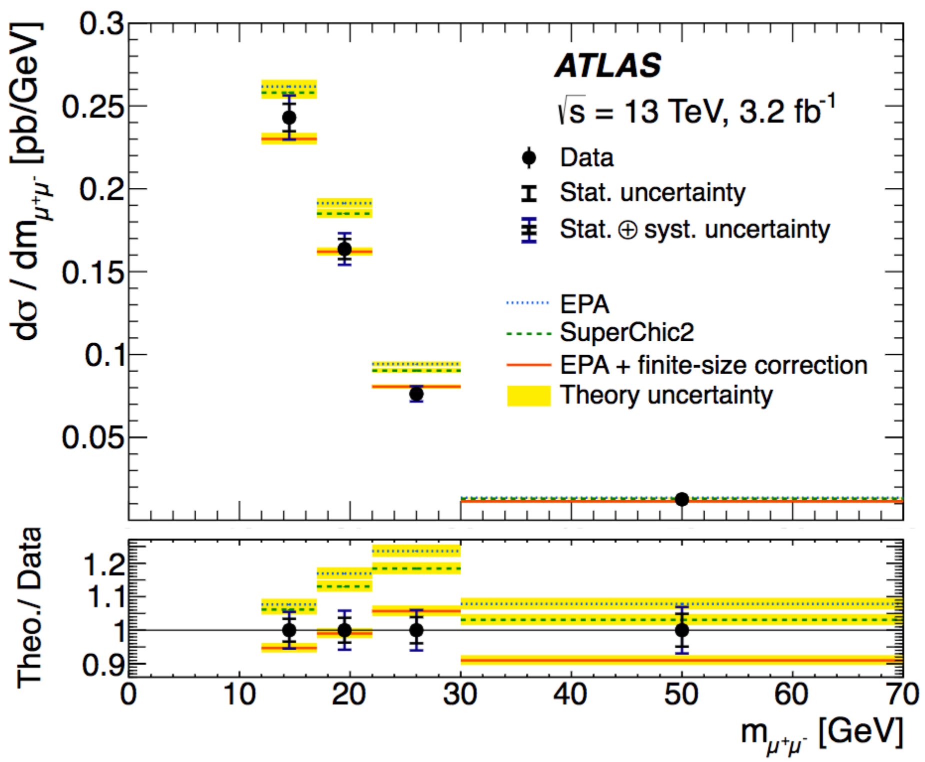
[7 TeV] Phys.Lett. B749 (2015) 242-261; [13 TeV] Phys.Lett. B777 (2018) 303-323

$\sqrt{s}$ = 7 & 13 TeV Exclusive Dilepton Production

Cross-section measured, and $d\sigma/dm(\mu\mu)$

- Exclusive dilepton cross-section predicted within QED with less than 2% uncertainty
- 10-20% suppression due to proton absorptive effects
  - Largely due to additional interactions between gluons in the protons/remnants
  - **Good agreement** provided by finite-size approach to correction which only allows photons outside of r_p = 0.64 fm to initiate two-photon interaction
- Dominant uncertainty from template fit to acoplanarity shape (**reducible with proton tagging**)



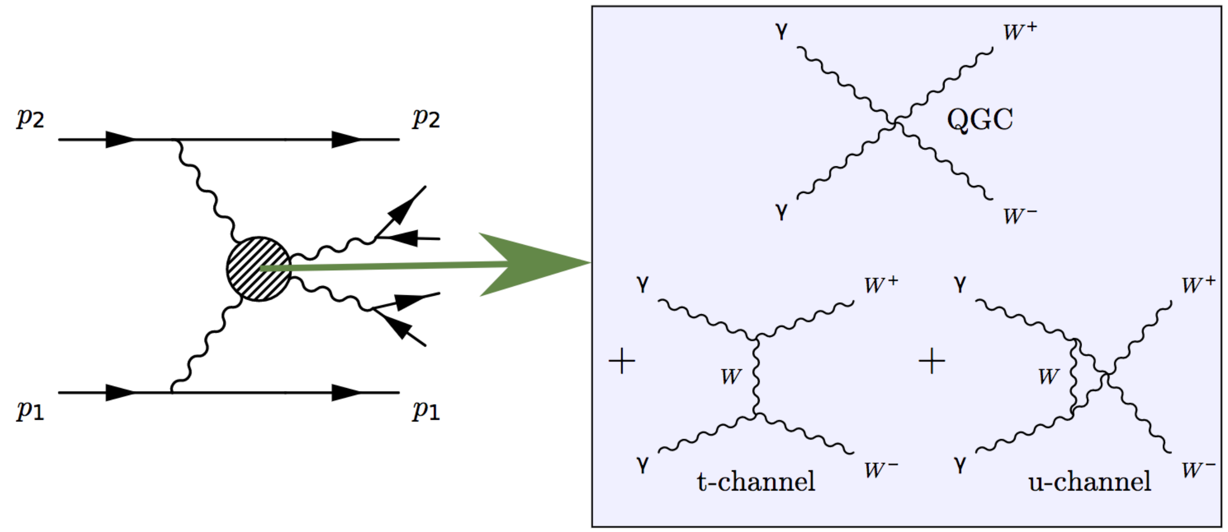


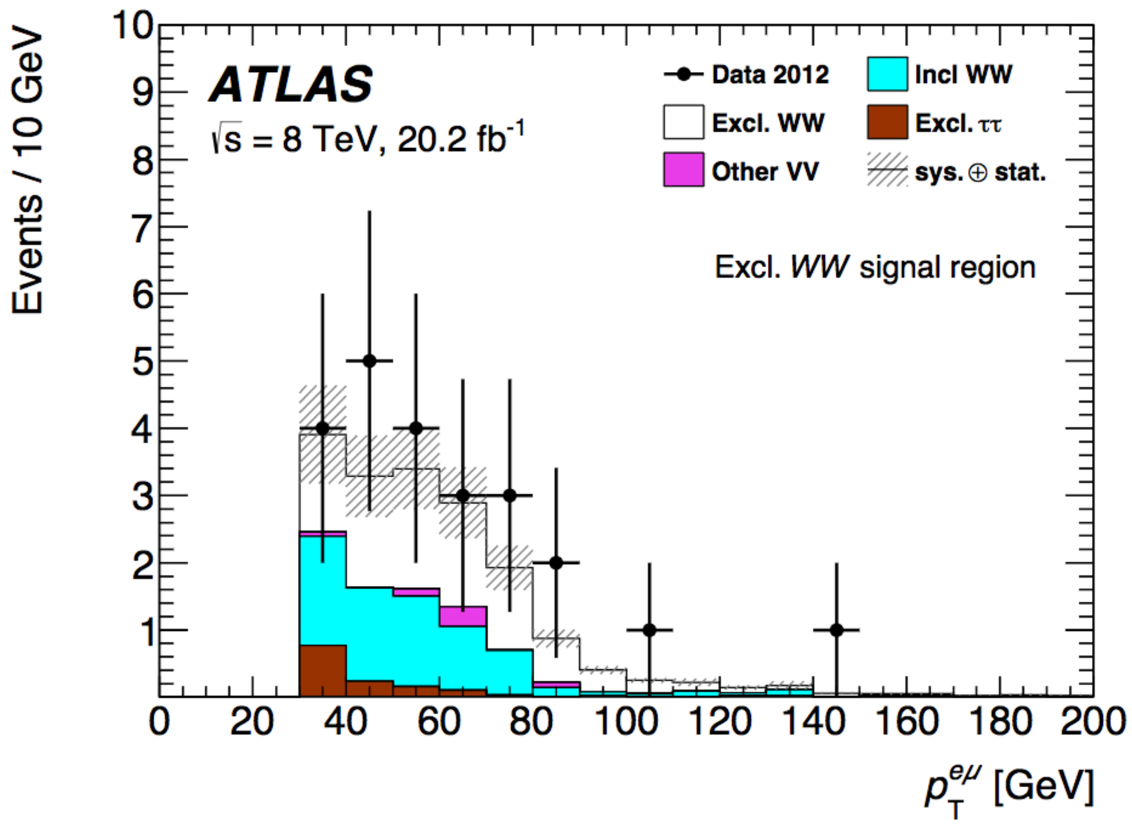
[7 TeV] Phys.Lett. B749 (2015) 242-261; [13 TeV] Phys.Lett. B777 (2018) 303-323

$\sqrt{s}$ = 8 TeV Exclusive W^+W^- Production

Can search for aQGC

- Measure rate of opposite sign/flavour charged leptons in final state
  - Rejects same-sign Drell-Yann and exclusive production
- Exclusivity requirement on charged particle tracks
- To reduce $\gamma\gamma/Z/\gamma^* \to \tau\tau$, require $p_T^{e\mu} > 30$ GeV
- $\sigma(\gamma\gamma \to W^+W^- \to e^{\pm}\mu^{\mp}) = 6.9 \pm 2.2(\text{stat.}) \pm 1.4(\text{syst.})$ fb
  - Corresponds to 3σ **evidence for SM production**
  - **No evidence of excess in the anomalous Quartic Gauge Coupling (aQGC)** enhanced region (extracted at $p_T^{e\mu} > 120$ GeV to reduce SM contribution)





Phys.Rev. D94 (2016) no.3, 032011

$\sqrt{s}$ = 7 TeV Diffractive Dijets

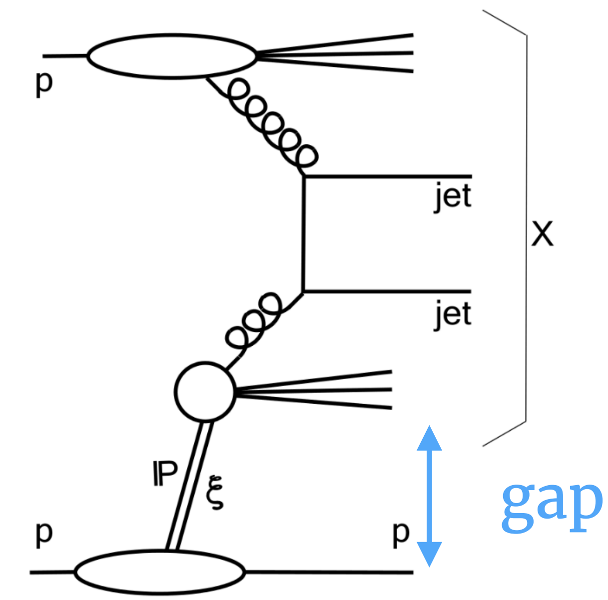
Dijet cross-section measured as a function of rapidity gap and ξ

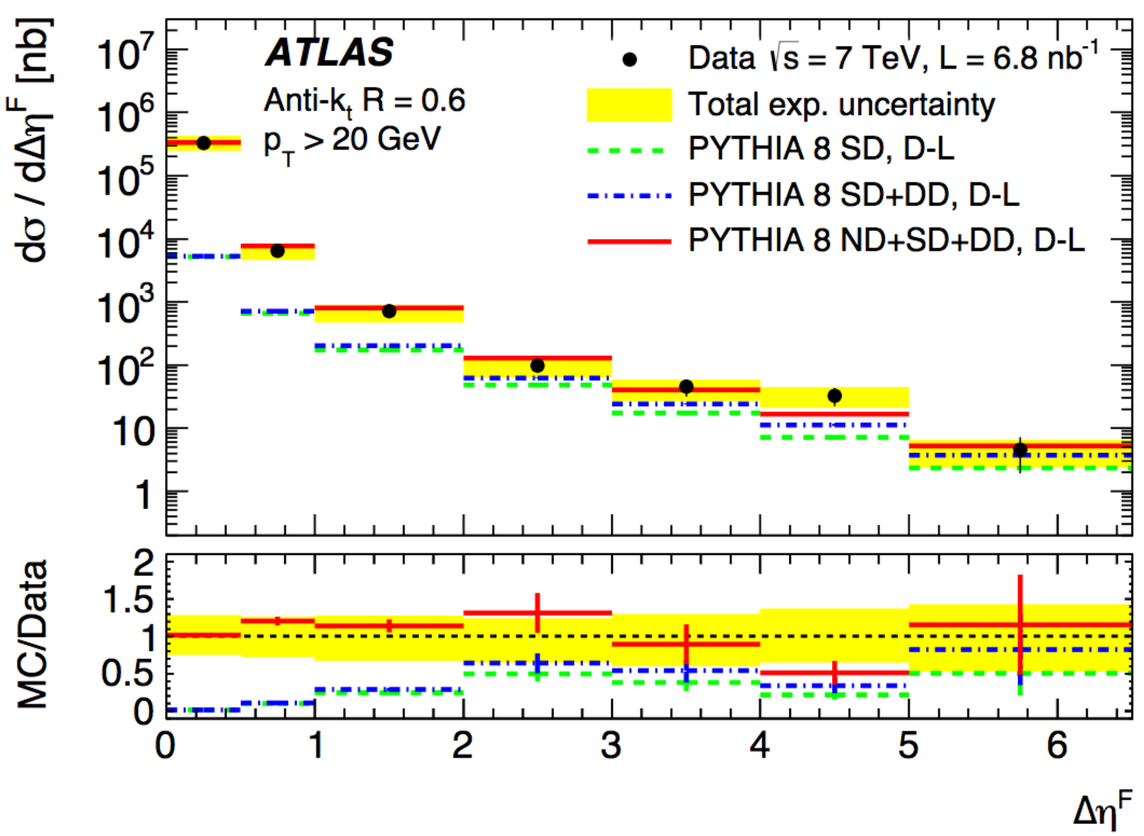
- Single dissociative diffraction topology but with hard scattering between Pomeron and proton

- **Dijet cross-section measurement as a function rapidity gap and ξ**
  - ξ calculated from calorimeter clusters
  - $\Delta\eta^F$ measured between calorimeter edge and clusters/tracks with p_T > 200 MeV
  - Performed at low pile up, $\sqrt{s}$ = 7 TeV

- **Diffraction dominant** at $\Delta\eta > 2$

$$\tilde{\xi} \simeq M_X^2/s = \sum p_T e^{\pm\eta}/\sqrt{s}$$





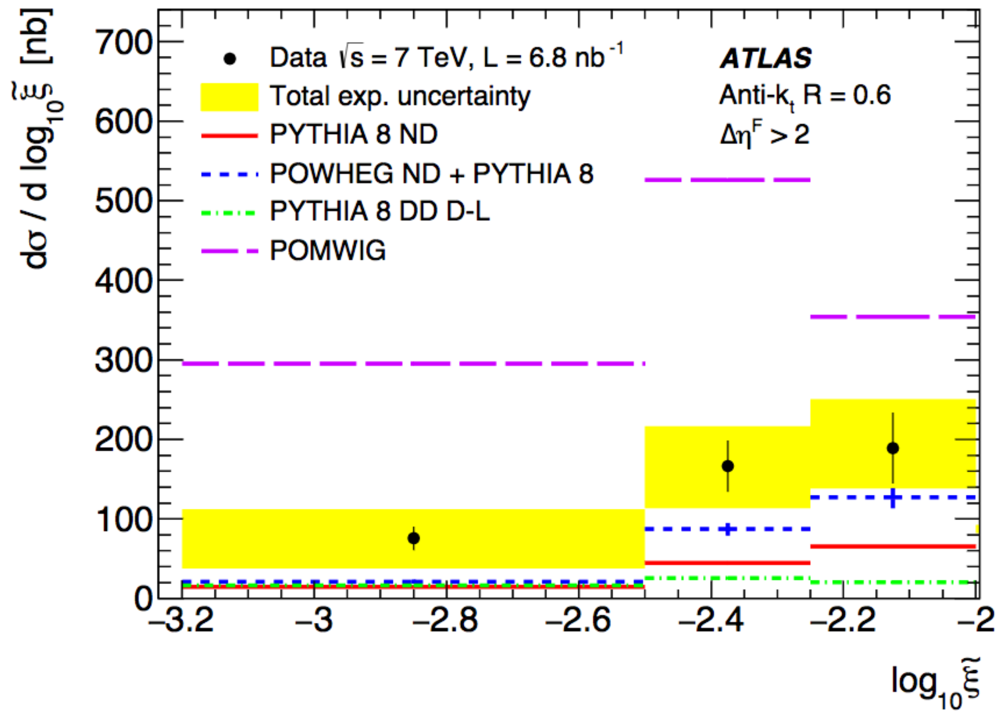
Phys.Lett. B754 (2016) 214-234

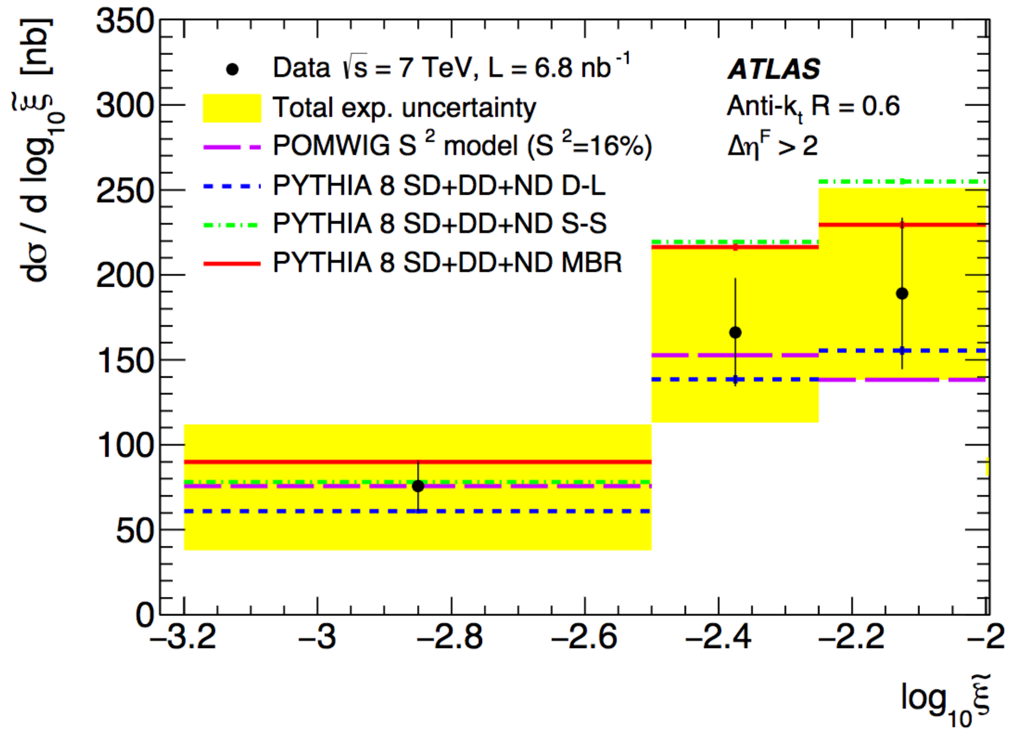
√s = 7 TeV Diffractive Dijets

Rapidity gap survival probability measured

- Rapidity gap survival probability accounts for additional exchanges 'spoiling' the rapidity gap
  - Same as proton absorptive effects considered in exclusive dilepton analyses

- Extracted from lowest ξ bin due to smallest ND contribution using POMWIG (not modelled in POMWIG, but exists in data)
  - **S^2 = 0.16 ± 0.04(stat.) ±0.08 (syst.)**
    - Large model uncertainties
  - Consistent with CMS, S^2 = 0.12 ± 0.05 (LO) (https://arxiv.org/pdf/1209.1805.pdf)

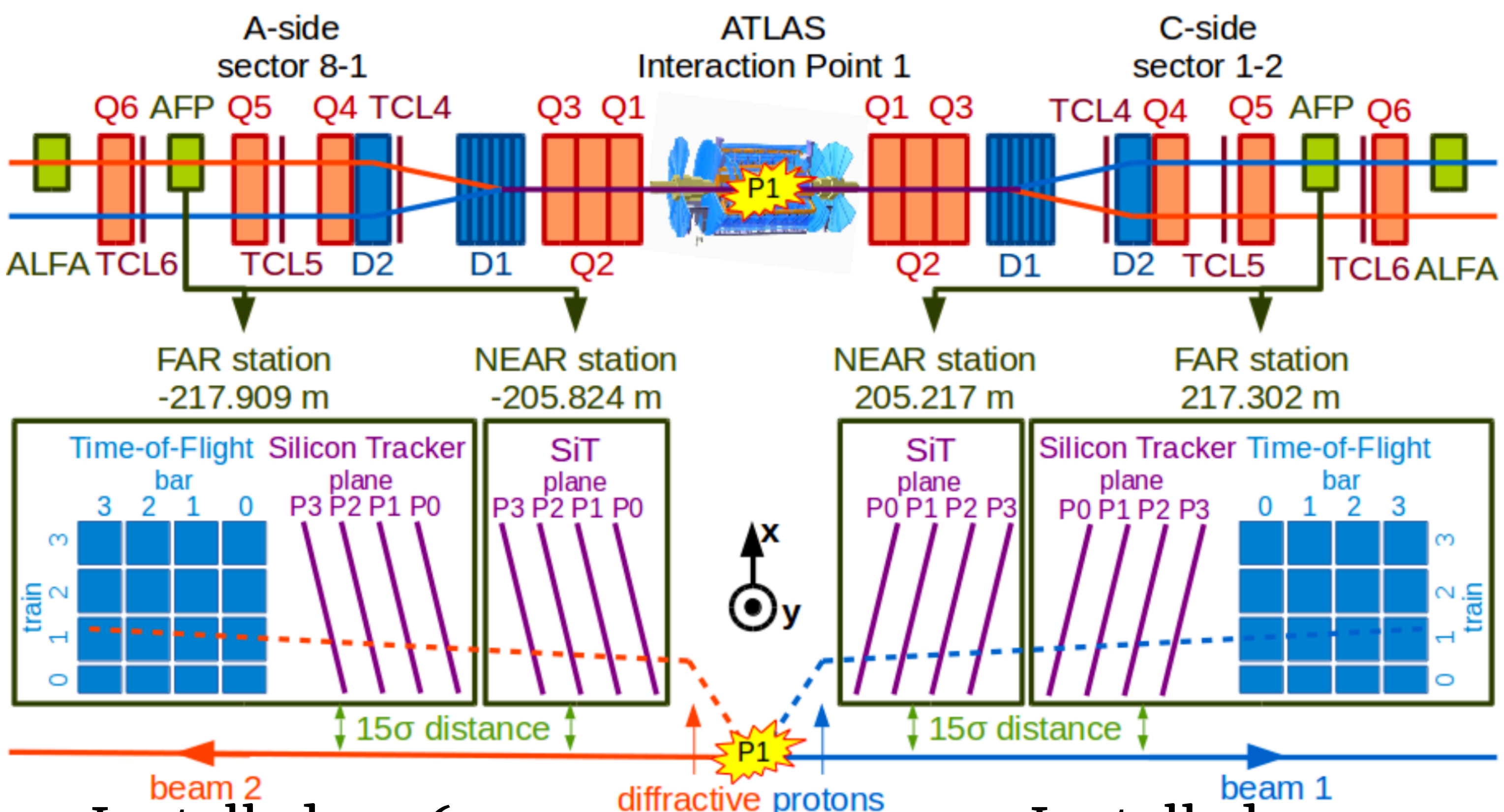




Phys.Lett. B754 (2016) 214-234

AFP Overview

New ATLAS Forward Proton Detectors



Installed 2016

Installed 2017

- Operates in compliment to other ATLAS forward detectors (especially ALFA)
- Pairs of Roman Pot detectors with **silicon precision tracking detectors and Cerenkov time of flight detectors**
- AFP fully integrated into ATLAS TDAQ system
  - **Can deliver first level triggers** within 85 bunch crossing latency (fast air-core cables)

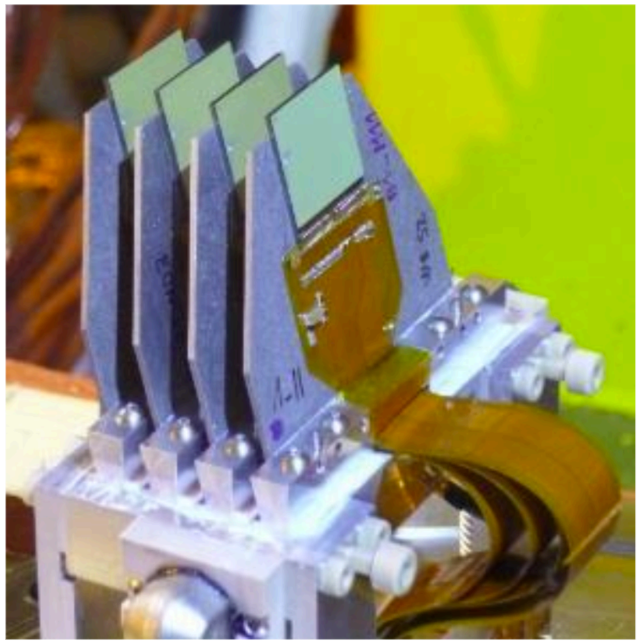
CERN-LHCC-2015-009, ATLAS-TDR-024

AFP Detectors

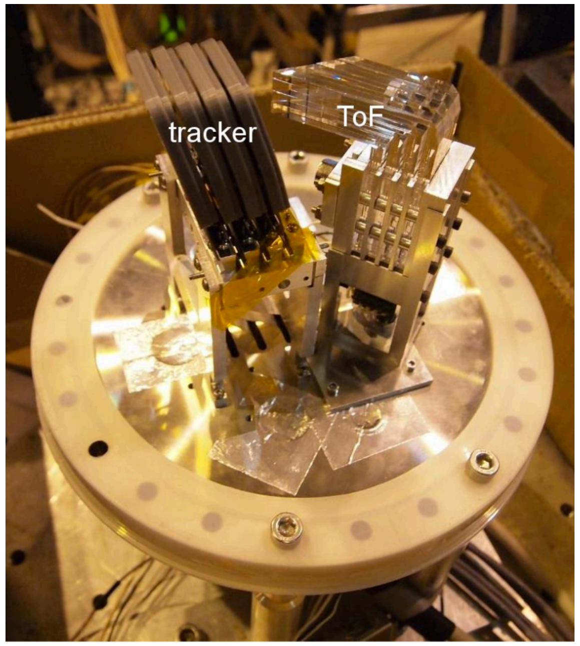
Tracking detectors in operation; Timing detectors to be installed

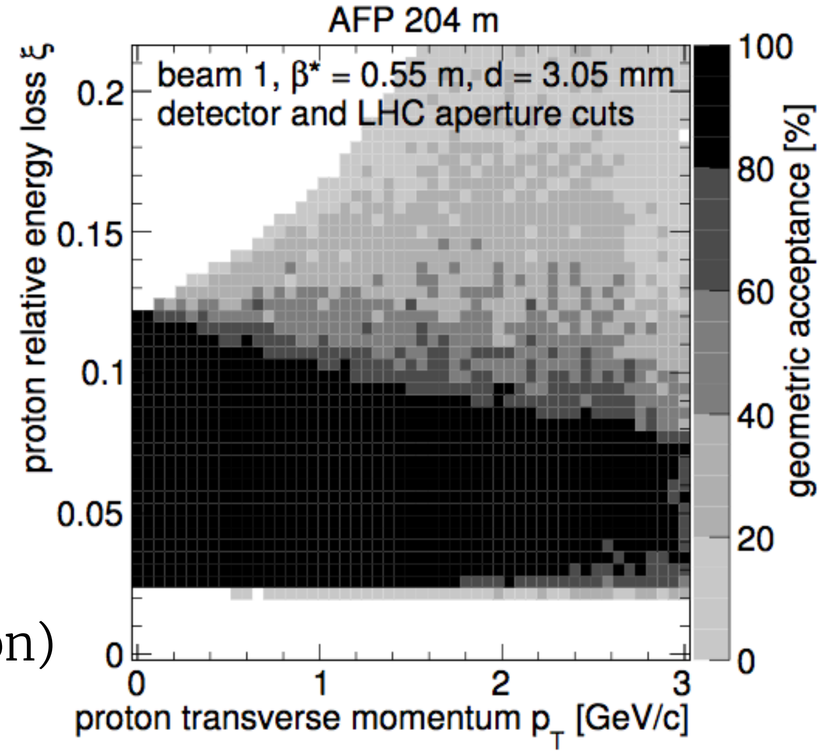
- Tracking detectors performed well in 2017
  - 3D silicon pixels (50 x 250 μm)
  - **Resolution: in x ~ 6μm; in y ~ 30μm**
  - Tilted by 14° to improve x (ξ) resolution
- Time of flight system is being commissioned - plans for this year
  - Will provide **time of arrival resolution of ~ 25ps**
  - Enables vertex discrimination in high pile up events of several mm

AFP tracker module



Tracker + TOF



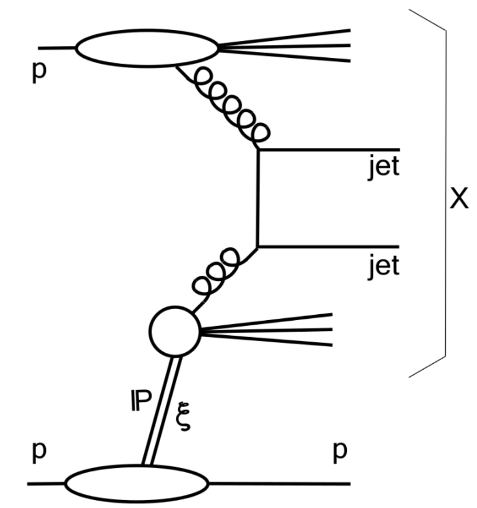


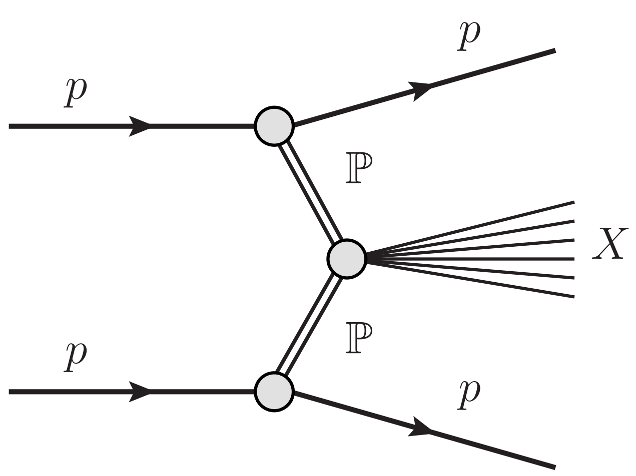
β* = 0.55 m
nominal (collision) distance: 15σ

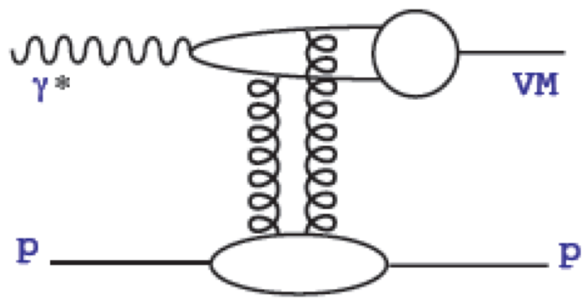
AFP Prospects: Special Runs

Low pile up enables inclusive studies

- Improvements on previous **diffractive analyses with a single tag**:
  - Single diffractive dissociation with rapidity gaps
  - Diffractive dijets
- Use double tag to measure inclusive central diffraction and exclusive production
  - Resonance searches eg. glueballs
- Charged particle distributions in diffractive collisions
- Ultraperipheral collisions -> diffractive photoproduction

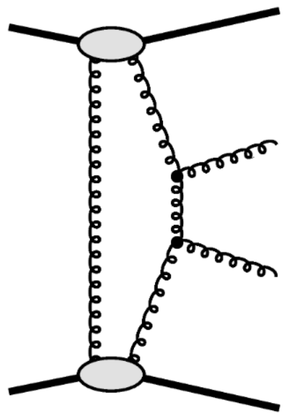


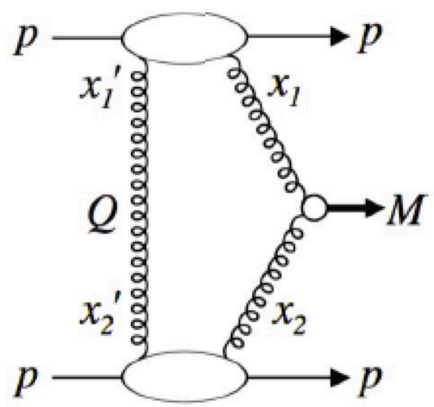


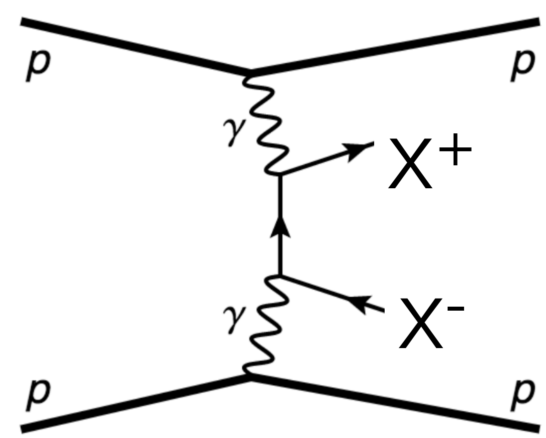


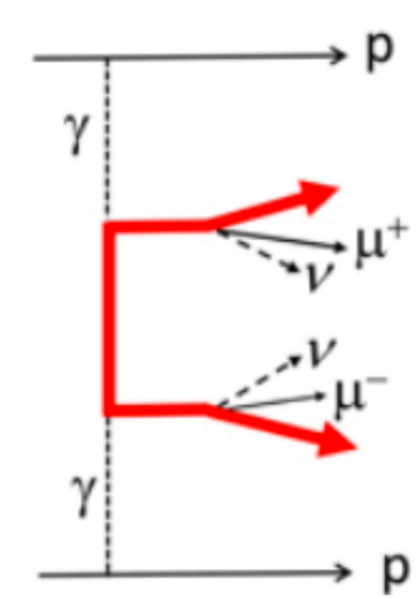
AFP Prospects: Nominal Runs

Testing new regions of QCD; rare EW physics; new physics









- **Central exclusive QCD production** (dijets)

- **Exclusive production from γγ**
  - Dilepton; diboson (aQGC)
  - **AFP can provide large background and systematic uncertainty reduction** on previous measurements (dominant uncertainties in 7TeV dilepton, 8TeV WW and 13TeV dimuon)

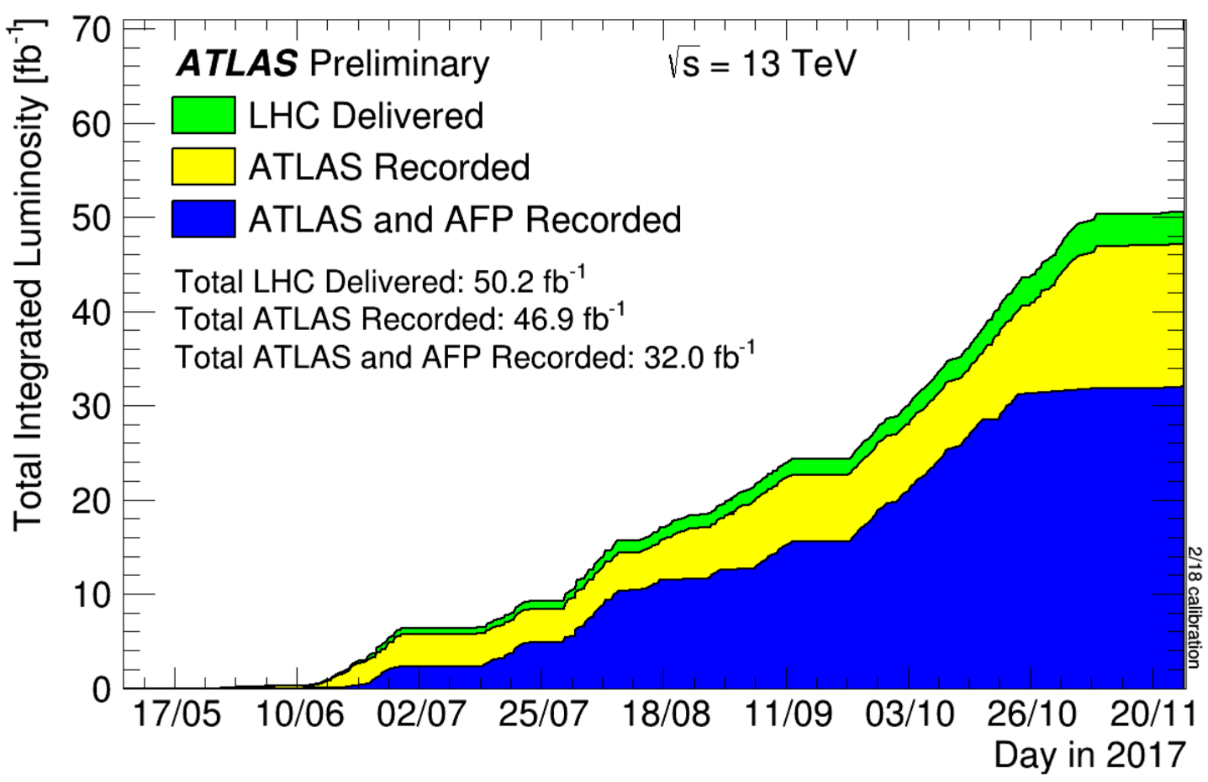
- Searches for heavy new particles (heavy axions, WIMPS, charged Higgs, pair-produced BSM)

AFP Operation thus far

Data collected during special runs and nominal running

- **Data collected during special runs** (low pile up)
  - 2016 ($\sqrt{s}$ = 13 TeV), only **one** sided tagging available
  - 2017 ($\sqrt{s}$ = 13 TeV), **one** and **two** sided tagging available

- **2017 Nominal Running** ($\sqrt{s}$ = 13 TeV):
  - Fully installed (one and two sided tagging)
    - **~32fb^{-1} with μ ~ 50**
  - Tracking and DAQ working well
  - TOF still commissioning



AFP First Analysis

First physics study: Single diffractive dijets

- Special run taken in October 2016, **$\mu \sim 0.3$, $\beta^* = 0.4$**
- **Analysis strategy:** compare an AFP + jet (p_T > 10 GeV) triggered sample with minbias (scintillating tiles within central detector) + jet (p_T > 10 GeV) triggered sample
- Event selection:
  - At least **one jet with p_T > 20GeV and $|\eta| < 3.0$**
  - Exactly one reconstructed primary vertex
  - ≥ 2 tracks associated with primary vertex
  - Offline clean track in AFP required in AFP triggered sample

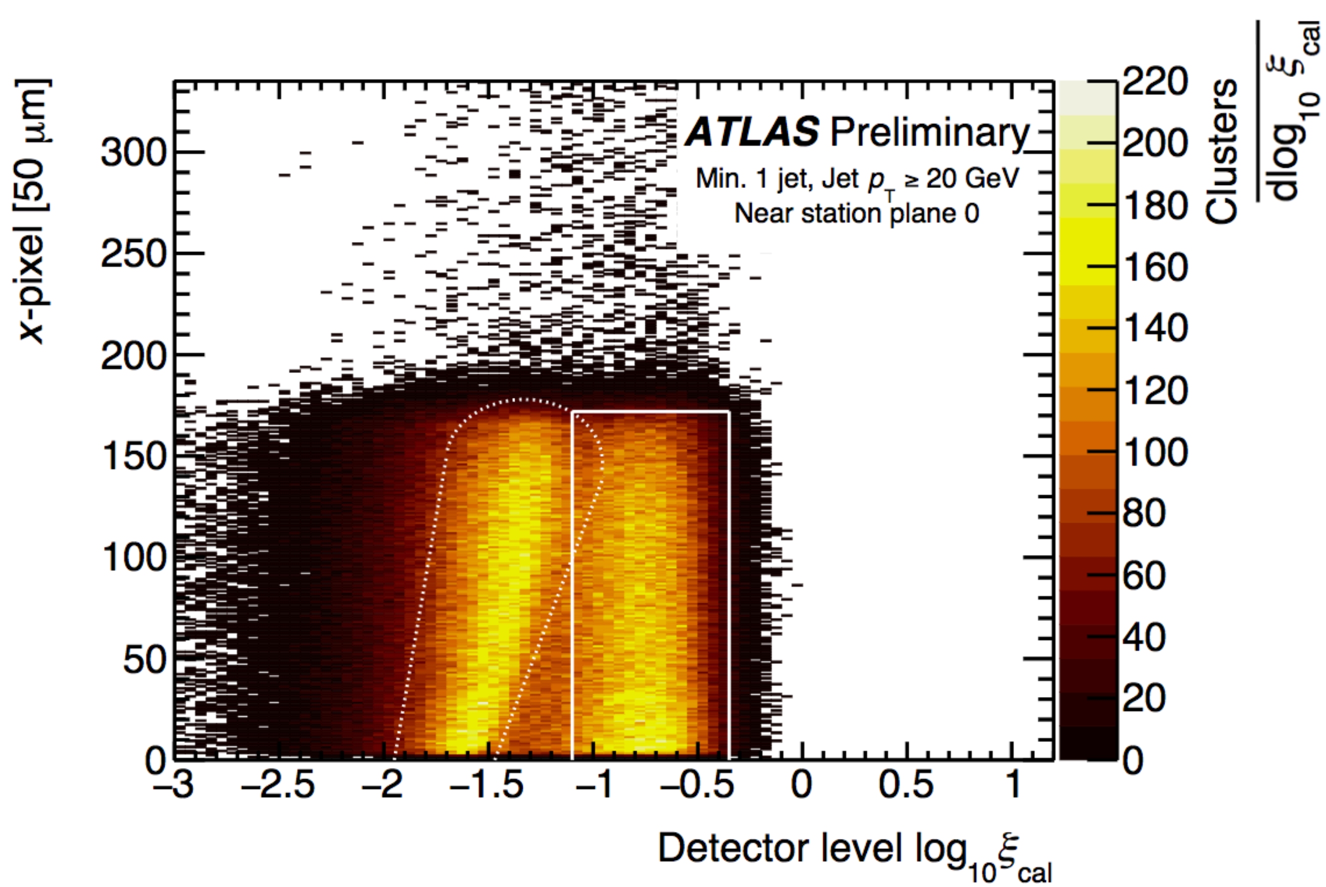
ATL-PHYS-PUB-2017-012

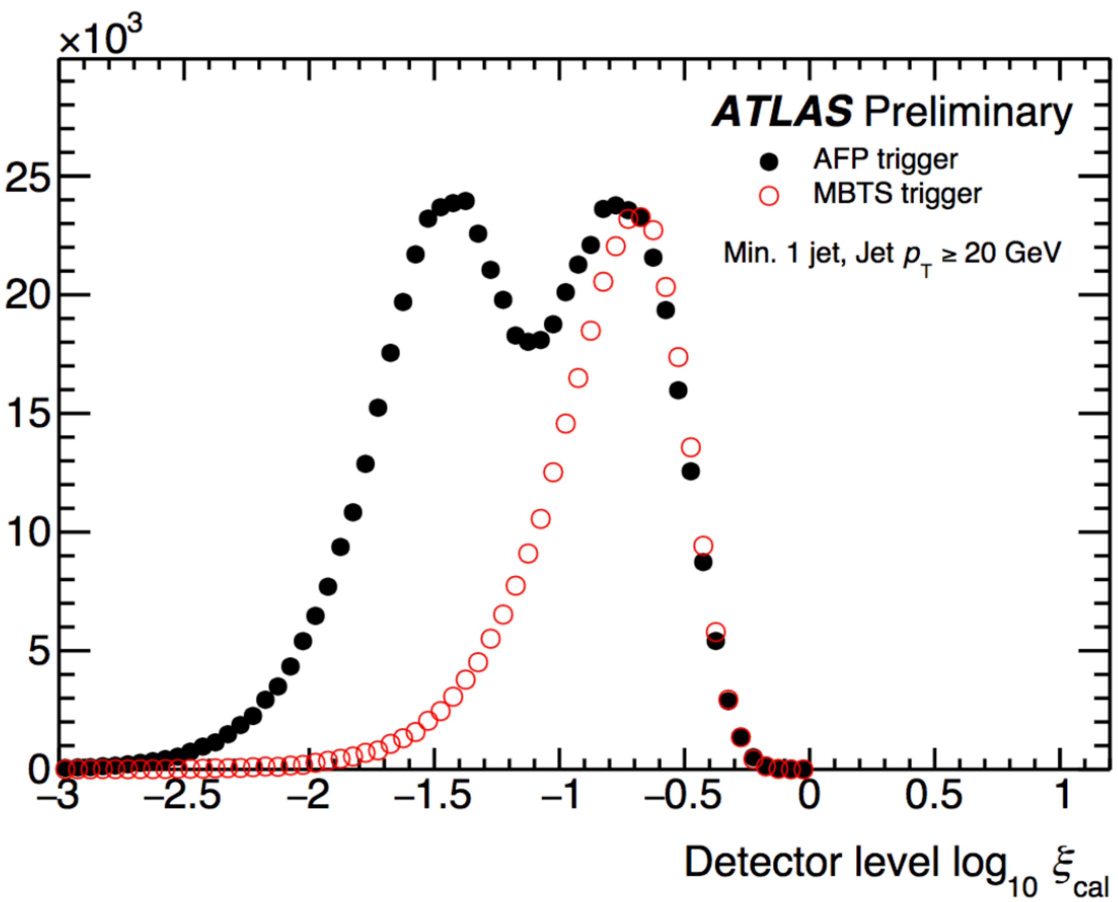
AFP First Analysis

AFP selects diffractively scattered events

- Same method of ξ reconstruction as in √s = 7 TeV dijets analysis
- **Observe clear enhancement in low ξ region** in AFP triggered sample, when compared to minbias sample
- Correlation between x-pixel position and ξ

$$\xi_{\mathrm{cal}} = \frac{1}{\sqrt{s}} \sum_i p_{\mathrm{T}}^i e^{-\eta i}$$



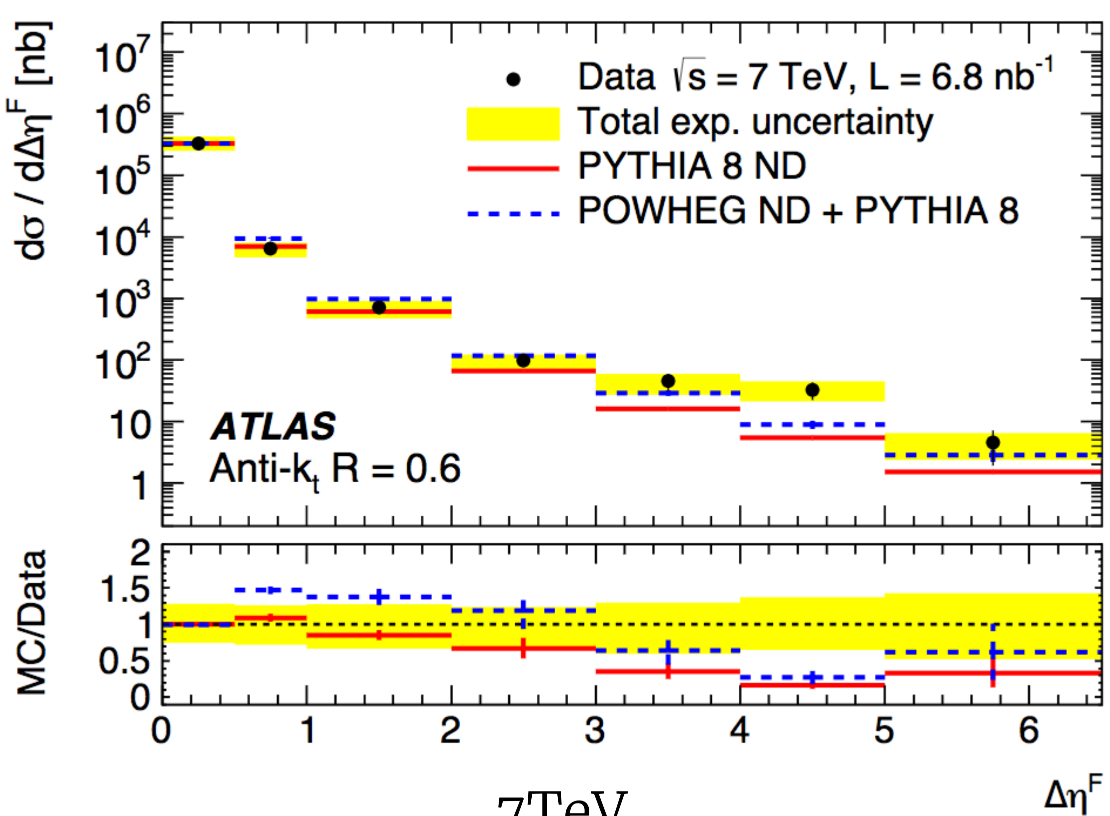


AFP First Analysis

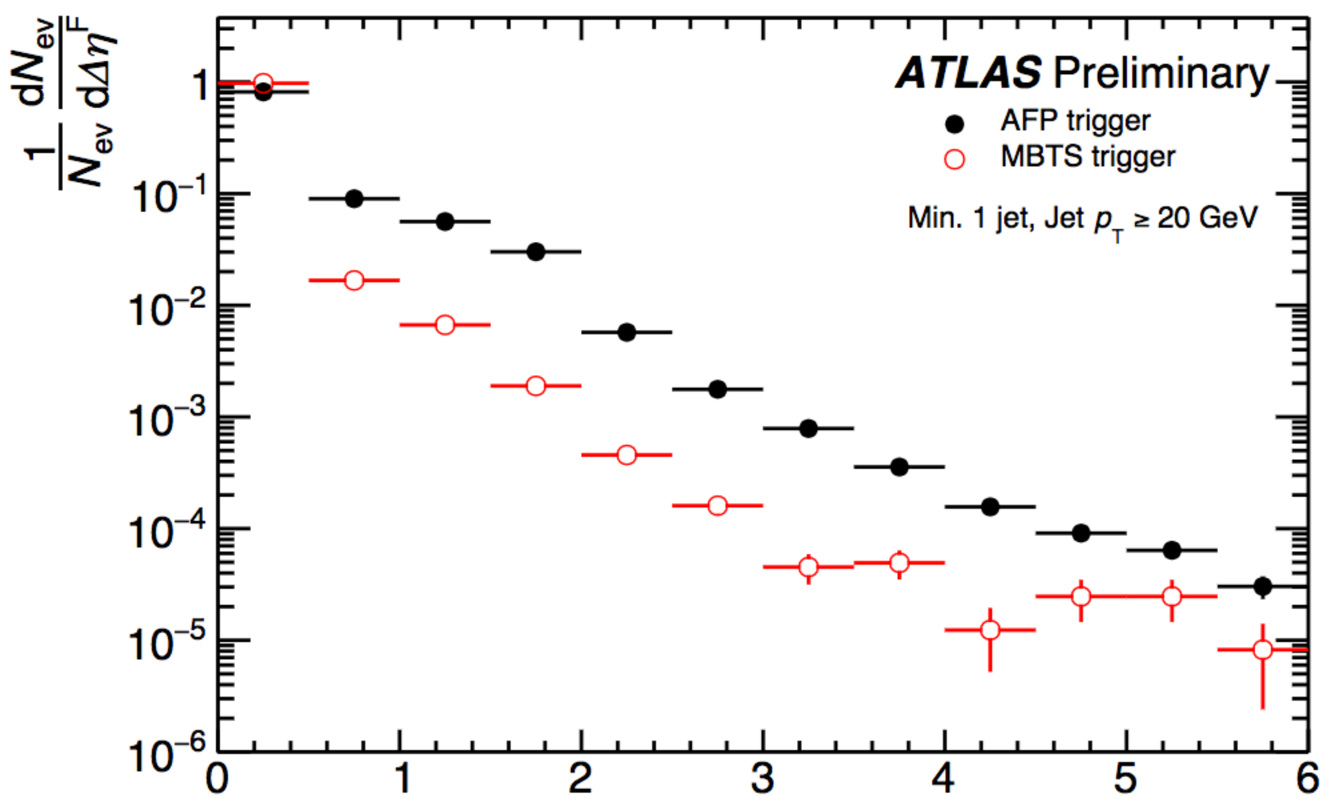
Observe diffractive events at large rapidity gaps

- $\Delta\eta^F$ defined by size of region in η between calorimeter acceptance (η = -4.9) and first cluster/track with p_T > 200 MeV (very similar to $\sqrt{s}$ = 7 TeV analysis $\Delta\eta^F$)

- See clear **enhancement in large gaps region** in AFP triggered sample
  - Displays **correlation between gaps and proton tags**, as expected in diffractive scattering



7TeV



13TeV with AFP

Summary

Things are looking good for forward physics at ATLAS!

- Exclusive and diffractive processes measured at ATLAS
  - Exclusive dilepton production cross-sections in good agreement with theory, 3σ evidence for exclusive WW production; rapidity gap survival probability estimated in diffractive dijets

- **AFP installed** on both sides of ATLAS in 2017
  - Collected 32 fb^{-1} data during nominal (high pile up) running as well as special (low pile up) runs
  - Time of flight detectors still being commissioned

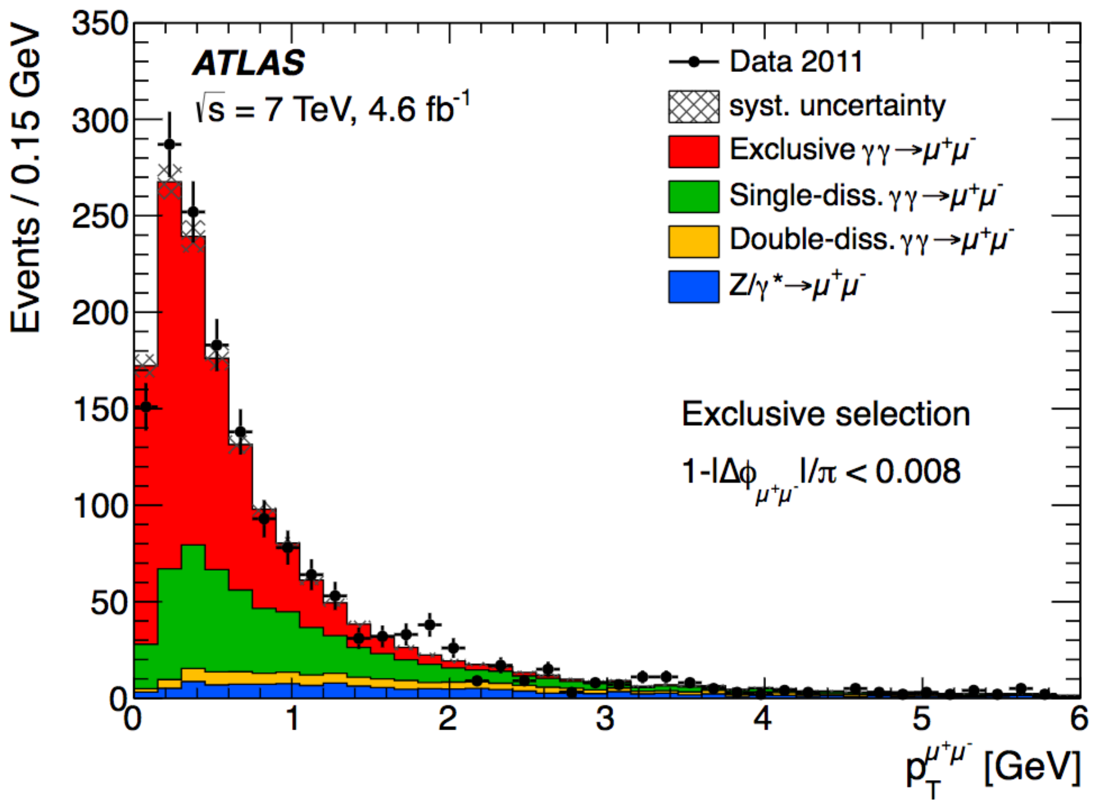
- Demonstrated that **AFP is capable of selecting a highly diffractive-enriched sample**

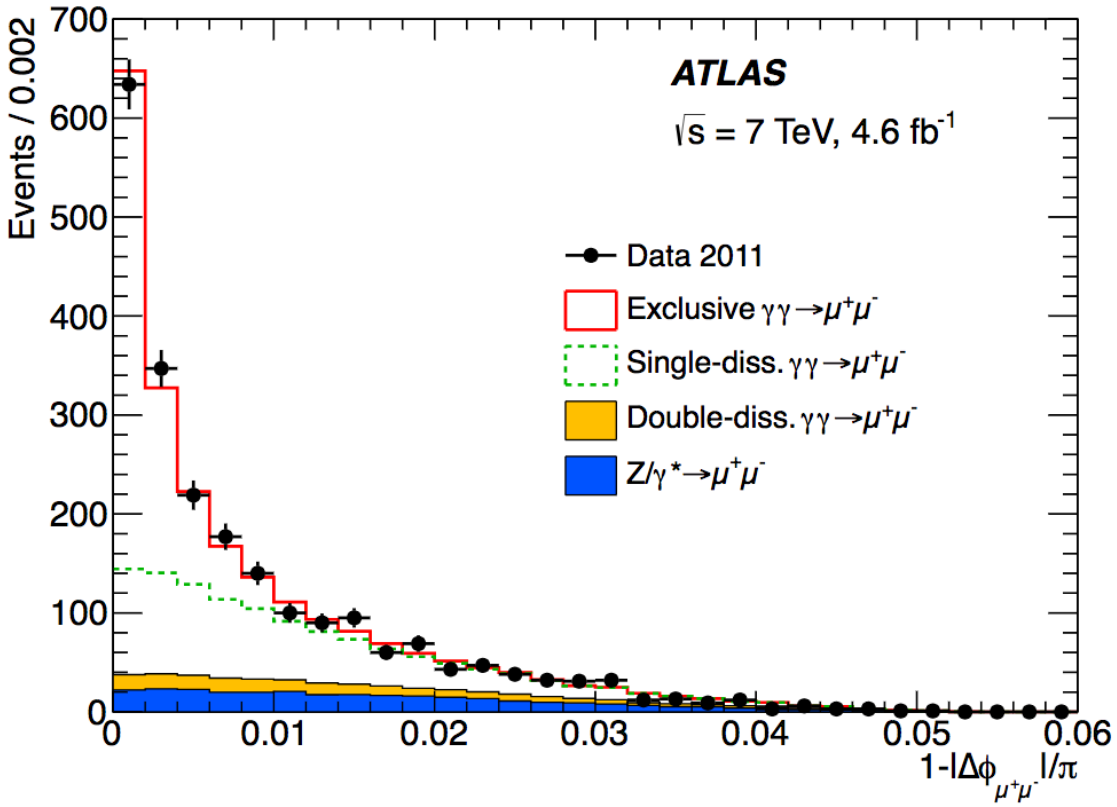
- Lots of prospects for improvement on current measurements and brand new analysis with AFP during LHC Run-II and beyond!

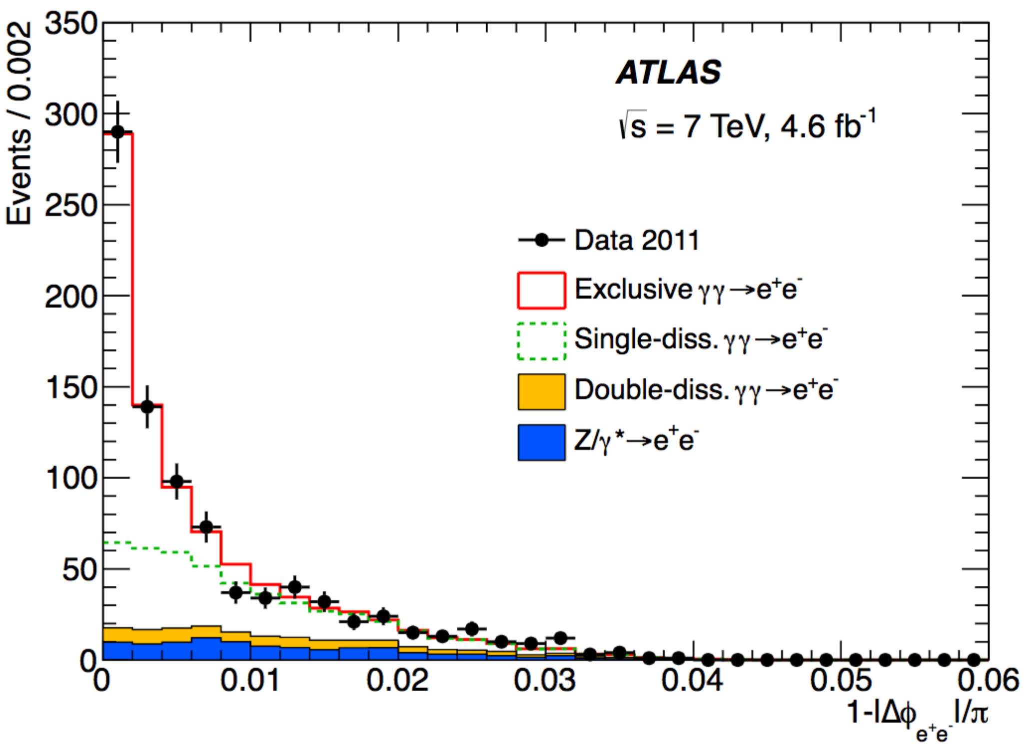
Backups

7TeV Dilepton

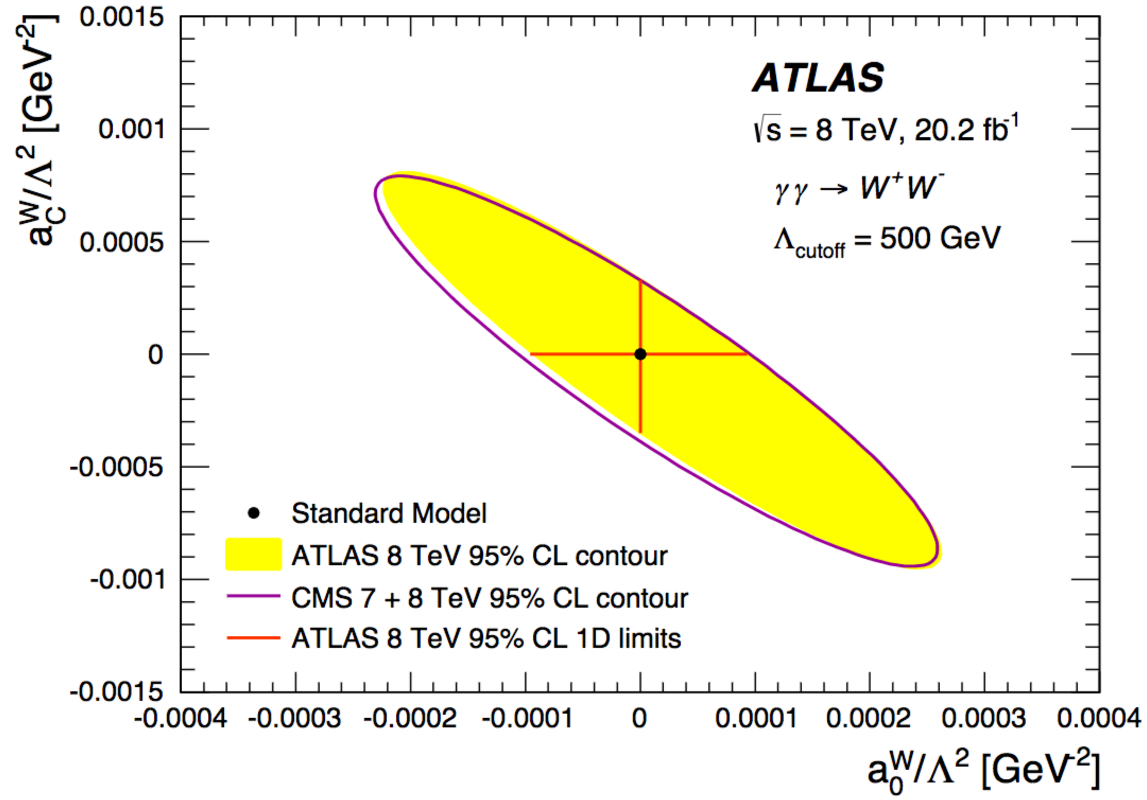
- Dominant uncertainty: Background modelling





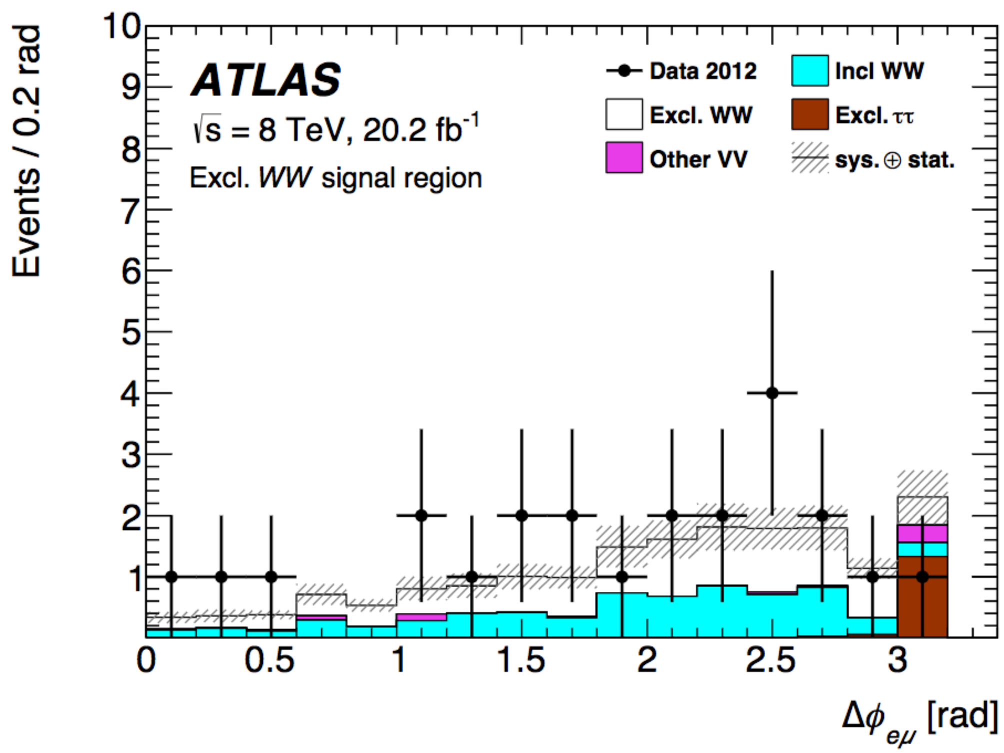


8TeV WW production



Dominant systematic: Background determination and exclusivity selection

$$a^W_{0,C}/\Lambda^2 \rightarrow \frac{a^W_{0,C}}{\Lambda^2}\frac{1}{\left(1+\frac{m^2_{\gamma\gamma}}{\Lambda^2_{\text{cutoff}}}\right)^2}$$



	W^+W^- selection	Higgs boson selection
Preselection	Oppositely charged $e\mu$ final states	
	$p_T^{\ell 1} > 25$ GeV and $p_T^{\ell 2} > 20$ GeV	$p_T^{\ell 1} > 25$ GeV and $p_T^{\ell 2} > 15$ GeV
	$m_{e\mu} > 20$ GeV	$m_{e\mu} > 10$ GeV
	$p_T^{e\mu} > 30$ GeV	
	Exclusivity selection, Δz_0^{iso}	
aQGC signal	$p_T^{e\mu} > 120$ GeV	–
Spin-0 Higgs boson	–	$m_{e\mu} < 55$ GeV
	–	$\Delta\phi_{e\mu} < 1.8$
	–	$m_T < 140$ GeV

Table 3: Selection criteria for the two analysis channels.

8TeV WW production

Why $p_T^{e\mu} > 30$ GeV:

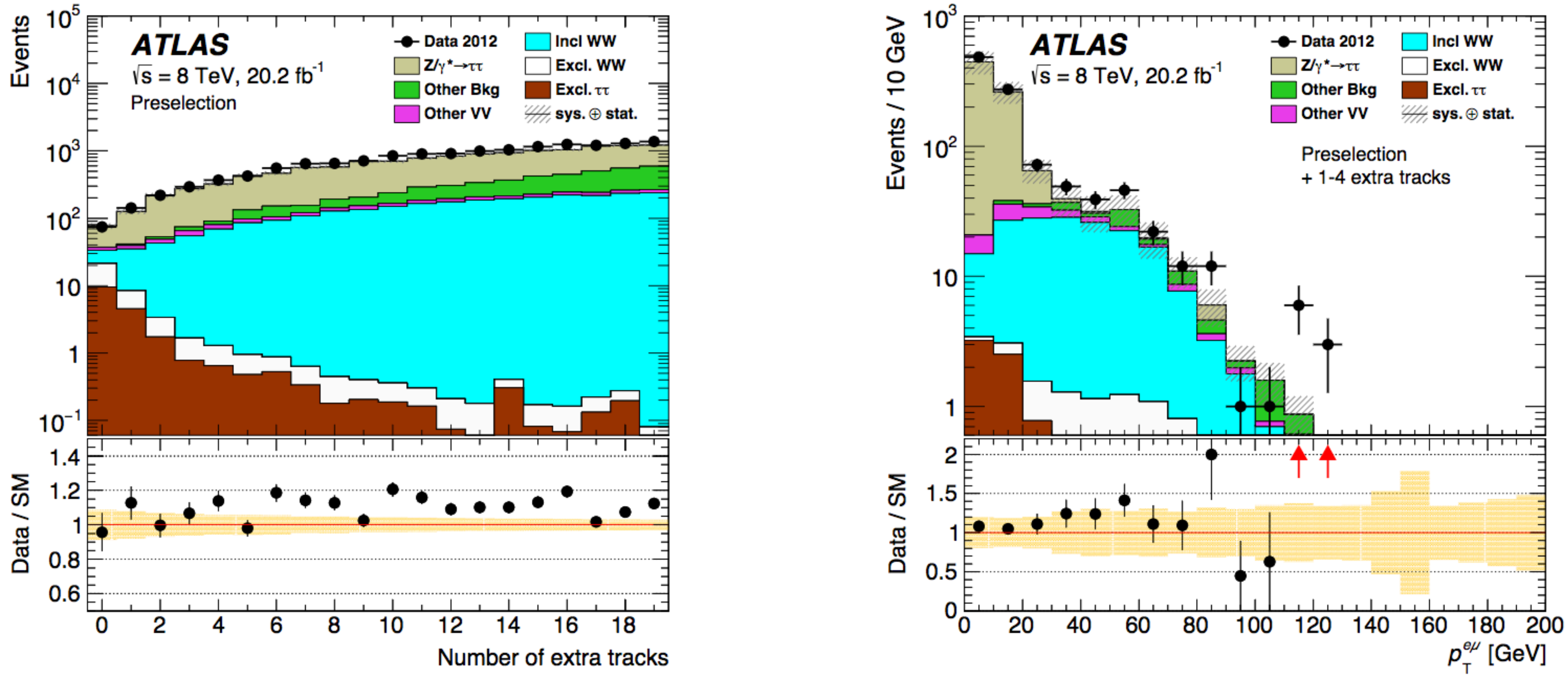
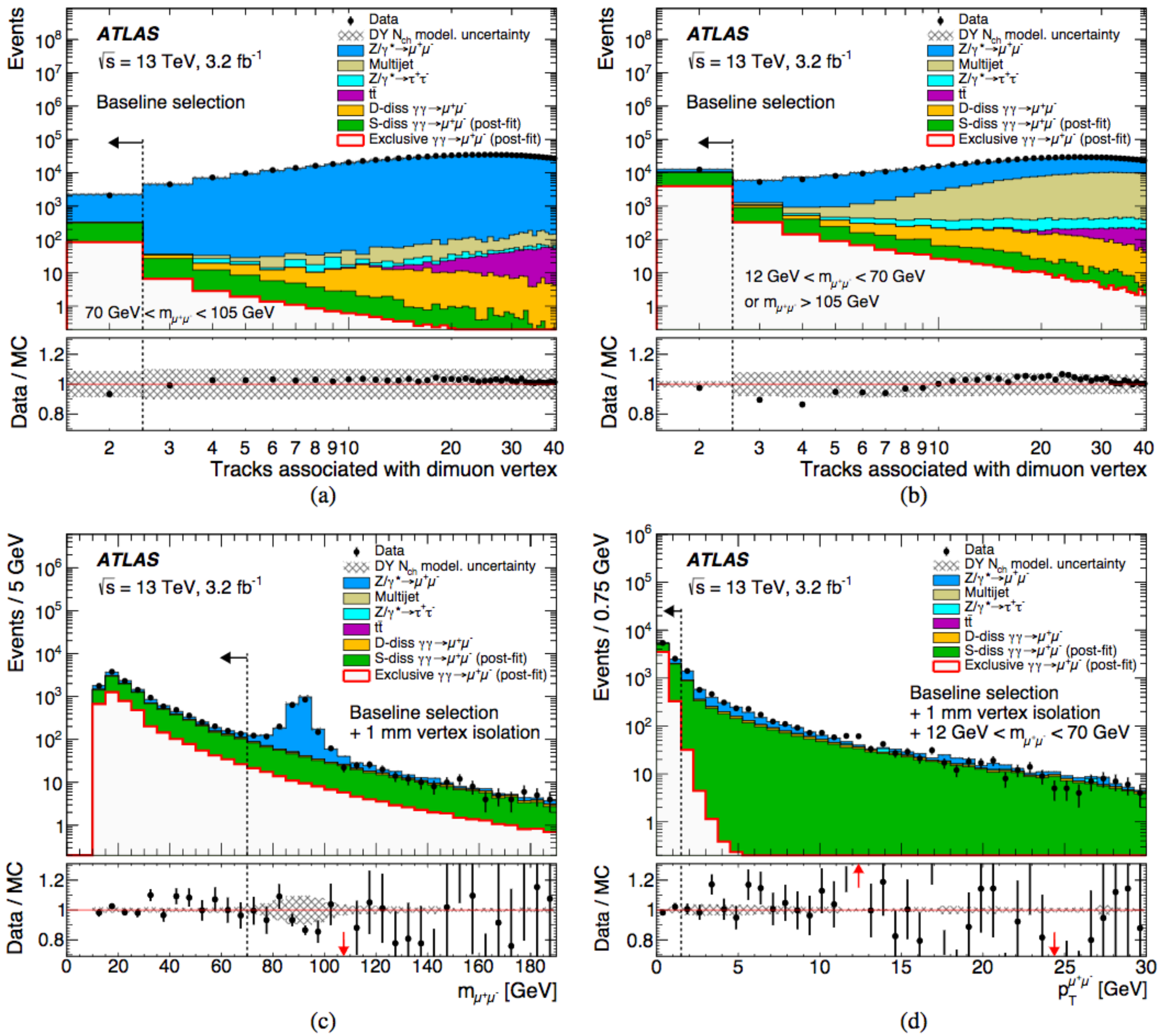


Figure 7: Distribution of track multiplicities after requiring the exclusive W^+W^- preselection (left) with no number of track dependent correction, and the $p_T^{e\mu}$ distribution of candidates that have 1–4 extra tracks (right), with the simulation including all appropriate correction factors such as $f^{\mathrm{sim}}_{\mathrm{nTracks}}$ (Table 4) for Drell-Yan and inclusive W^+W^- production. The enriched inclusive W^+W^- control region is the 1–4 extra-track region above $p_T^{e\mu} > 30$ GeV. The band around the Data/SM ratio of one illustrates the systemic uncertainties. The upward red arrows indicate ratios outside the plotting range.

13TeV Dimuon

Event selection



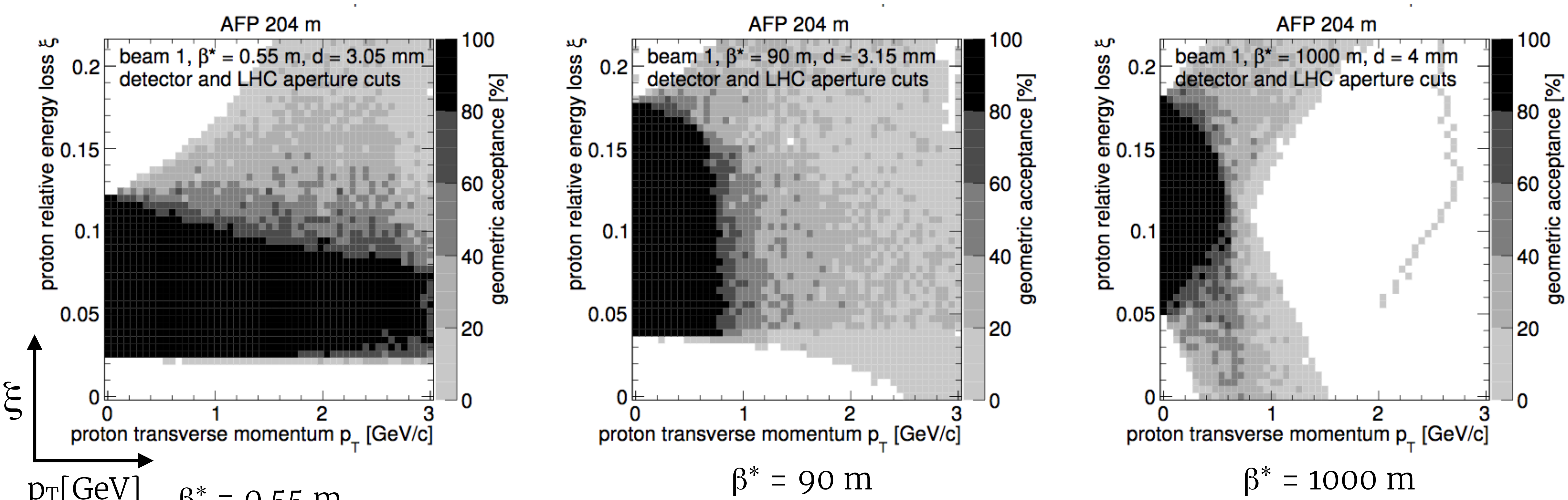
AFP Acceptance

Good acceptance at high ξ

- Acceptance varies with LHC beam conditions
  - High β^* results in small beam divergence
    - Reduces focussing at IP but enables closer approach of Roman Pots

$$\text{divergence} \propto \frac{1}{\sqrt{\beta^*}}$$

- Acceptances shown for different setups (without LHC collimator restriction at high ξ)

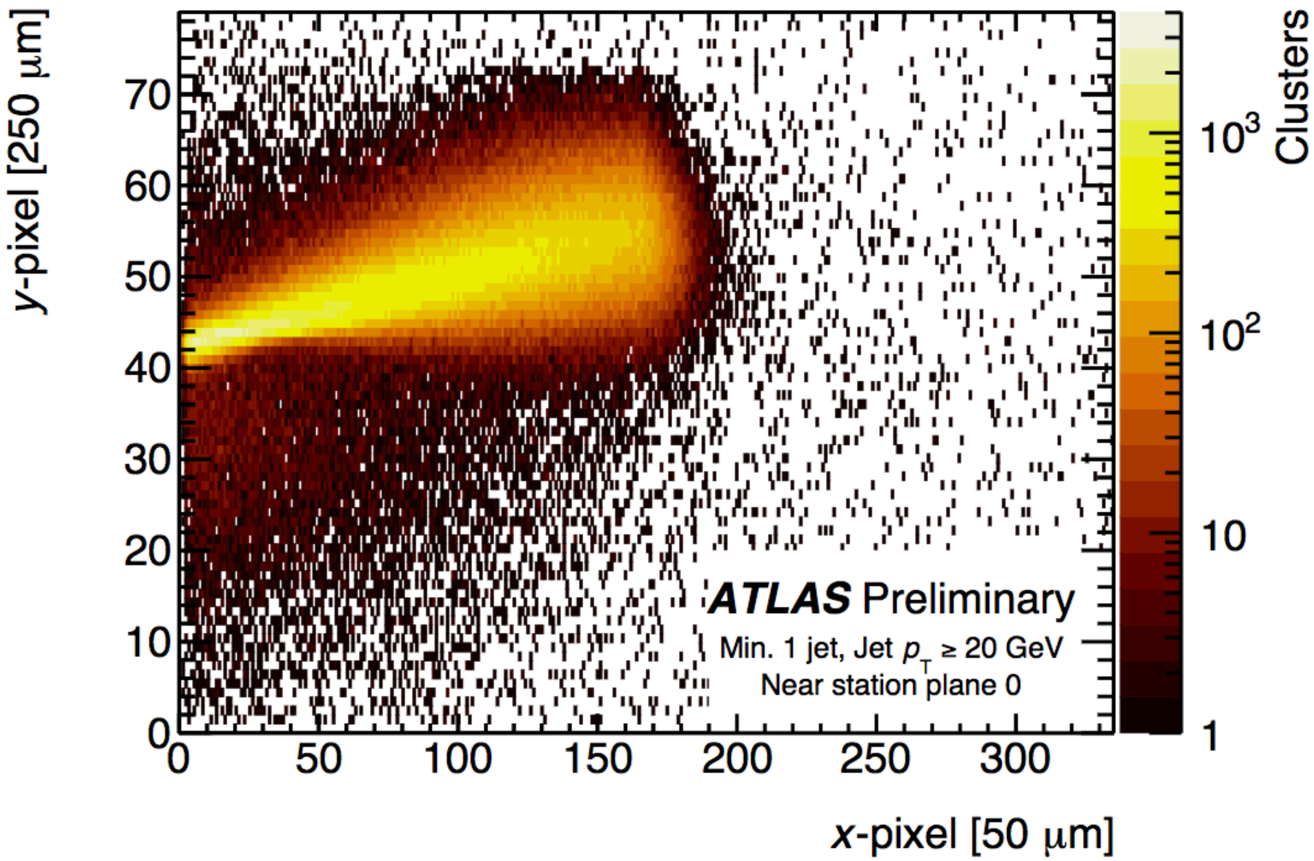


β^* = 0.55 m
nominal (collision)
distance: 15σ

β^* = 90 m
special (high-β^*)
low pile up
distance: 5σ

β^* = 1000 m
special (high-β^*)
low pile up
distance: 5σ

Pixel hit distribution in AFP



From AFP tagged sample in dijets analysis