The ATLAS Muon Trigger

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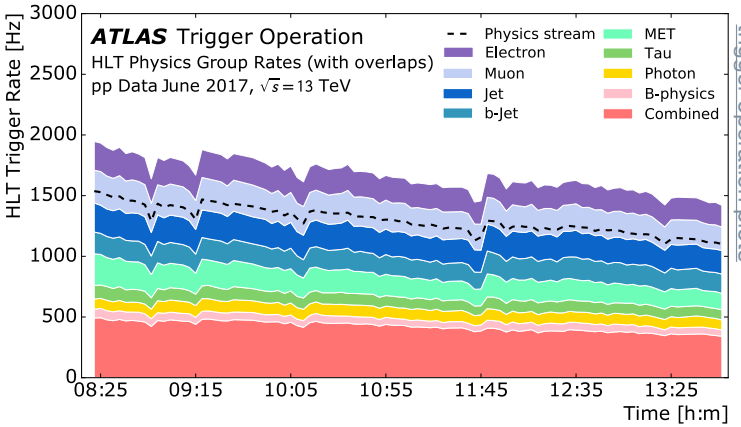
Triggering on muons at ATLAS

- The **muon trigger** ( ) is one of many ATLAS trigger systems

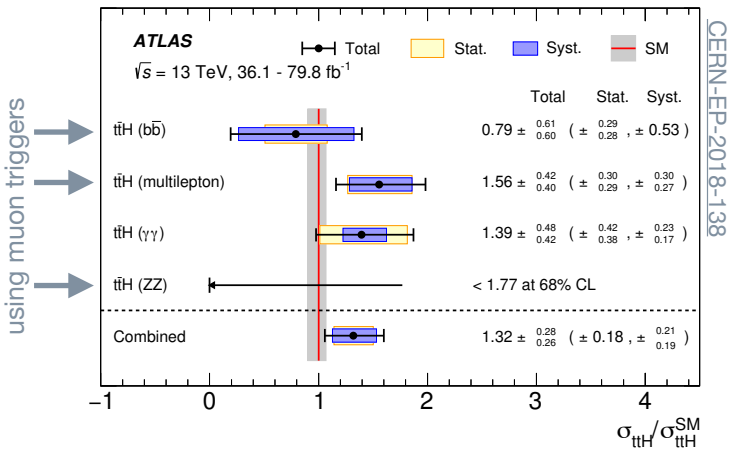
- **Complex design** and **continuous improvements** in order to:
  - Handle high luminosity and pile-up conditions
  - Balance trigger rate and efficiencies
  - Provide high quality muon events over a large p_T spectrum



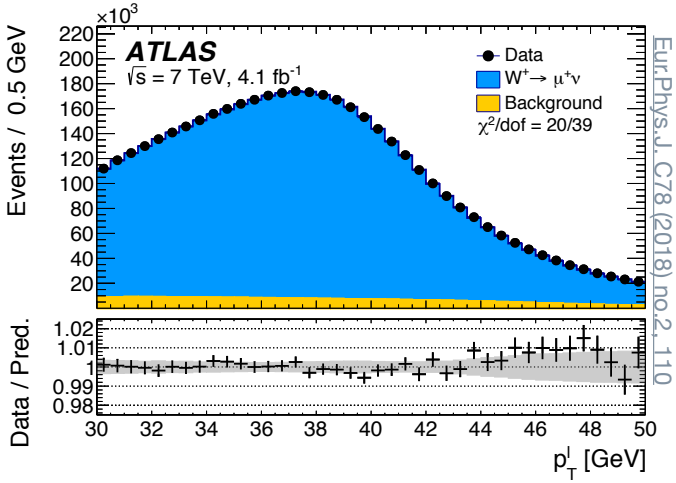
Trigger rates from a June 2017 LHC fill

- **Muon trigger system** is **crucial** ingredient to the **ATLAS physics campaign**, some examples below:

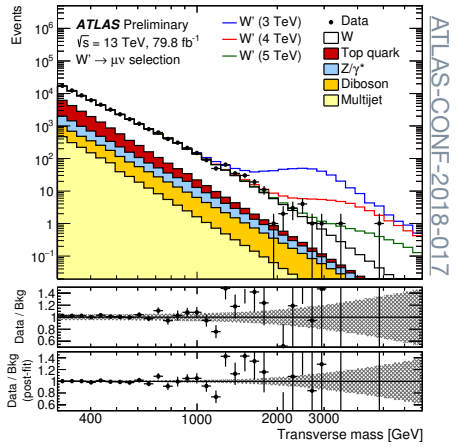
ttH observation



W mass measurement

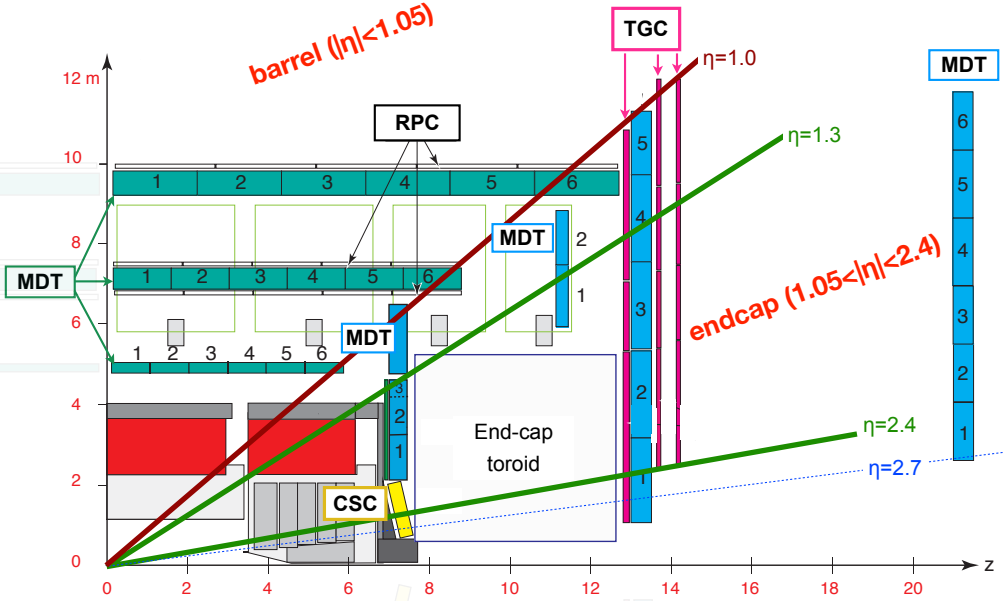


search for W'

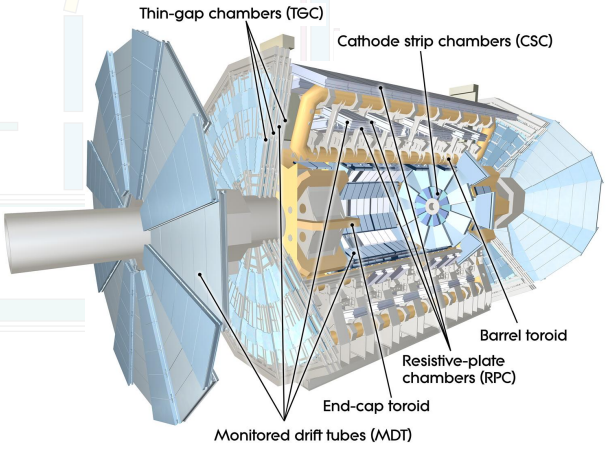


ATLAS muon spectrometer (MS)

- **Four different sub-detectors** in ATLAS muon spectrometer (MS):
  - **Fast read-out** for initial trigger decision:
    - **RPC:** Resistive Plate Chamber
    - **TGC:** Thin Gap Chamber
  - **High resolution**, precise tracking:
    - **MDT:** Monitored Drift Tube
    - **CSC:** Cathode Strip Chamber



- Trigger requires hit **coincidence** in **multiple detector layers**
  - 2 (3) layer coincidence required for low (high) p_T muons
    - Exceptions in certain detector regions
- **Toroidal magnets** provide average magnetic field of 0.5 T

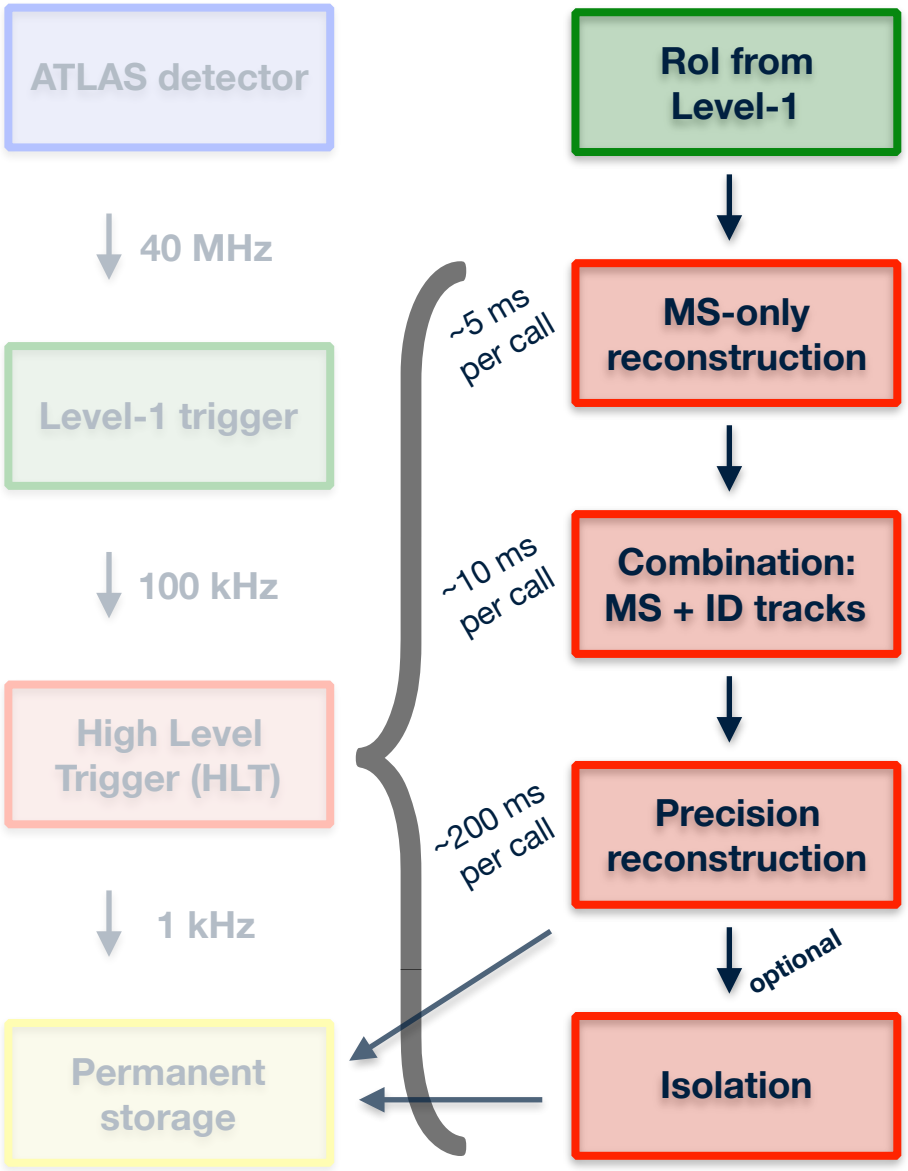


Two stage approach

- **Level-1 muon trigger:**
  - **Fast** and **coarse, hardware-based** system
  - Requiring coincidence of hits in **RPCs** or **TGCs**
  - p_T estimate by comparison to expected track of muon with infinite p_T
  - Finds **Regions of Interest (RoI)** for further processing
    - RoI size: 0.1 x 0.1 in η x ϕ
  - Coverage: 99% in endcaps, 80% in barrel (limited by detector geometry)

- **High Level Trigger (HLT):**
  - **Software-based** system
  - Starting from **RoI** defined at Level-1
    - Reduces data amount needing to be transferred and processed
  - **Fast reconstruction** step, followed by **precision reconstruction**
  - Close to 100% trigger efficiency (with respect to Level-1)

High Level Trigger (HLT)

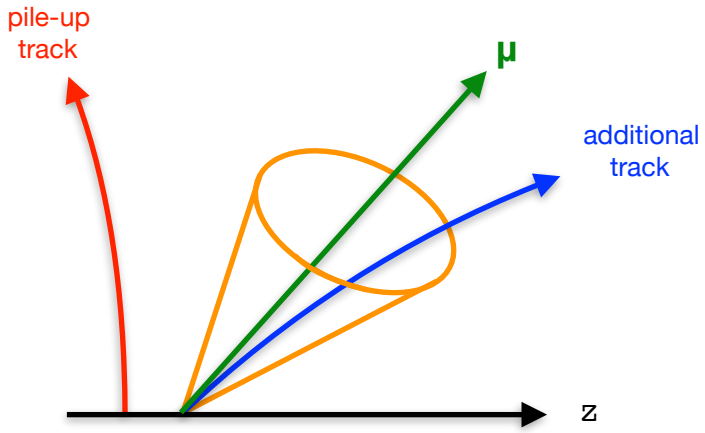


- Start with **RoI** defined at Level-1
- **Fast reconstruction** of tracks in **muon spectrometer** (MS) only
- p_T measurement with look-up tables
- **Combined fit** of **MS** and **inner detector (ID)** tracks
- **High resolution** reconstruction
  - Starting outside-in: MS→ ID
  - Inside-out recovers low-p_T inefficiencies
- Optional: other requirements like isolation

Muon isolation

- **Isolation requirements** at trigger level allow **lower muon p_T threshold** and **reasonable trigger rate**
  - Crucial for many physics analyses

- **Isolation:**
  - Define p_T-dependent **isolation cone** around **muon candidate**
  - **Cut** on **scalar sum of track p_T** in **cone** around **muon candidate**



- **Changes for 2018:**
  - Efficiency loss observed in 2017 at high **pile-up**
  - Reduction from $dz < 6$ mm to $dz < 2$ mm for 2018 data-taking
    - Significant **performance improvement** in high pile-up conditions, **small rate increase**

Muon trigger menu

- **Many muon-related triggers available:**
  - Single muon, multi-muon
  - Muon + electron, muon + tau, muon + photon
  - Muon + additional B-physics requirements
  - Additional triggers for specific analysis topologies

- **Trigger examples:**

	Level-1 p_T threshold [GeV]	HLT p_T threshold [GeV]	Level-1 rate [kHz]	HLT rate [Hz]
Single isolated muon	20	26	15	180
Single muon	20	50	15	61
Two muons	10, 10	14, 14	1.8	26
Two muons	20	22, 8 (FS)	15	42
Three muons	6, 6, 6	6, 6, 6	0.2	6

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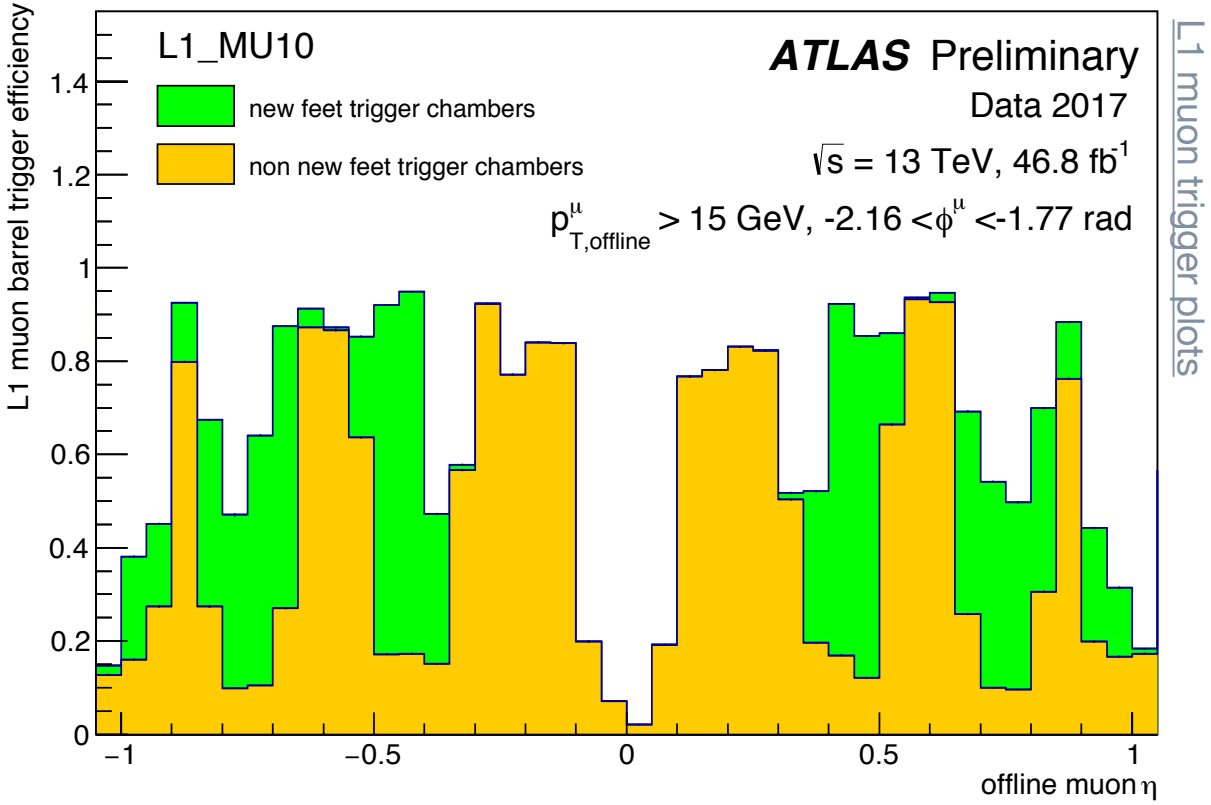
- **FS (full-scan):** search entire MS for additional muons in precision HLT step
  - Very high trigger efficiency, but computationally expensive

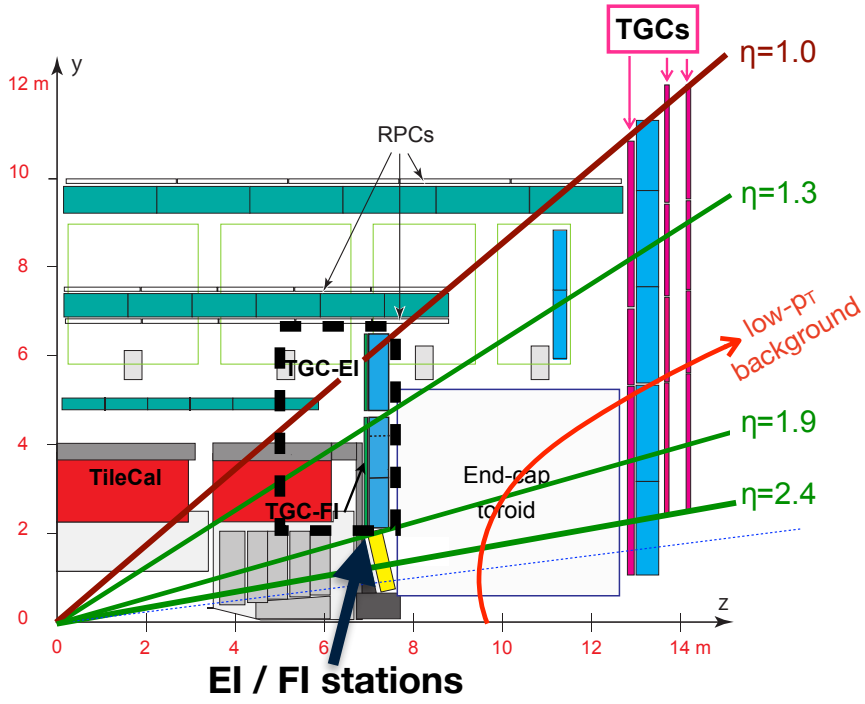
Level-1 muon barrel upgrade

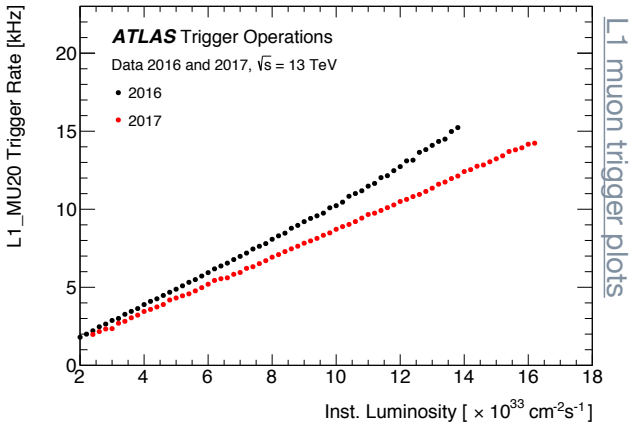
- **Additional RPC chambers** in **ATLAS "feet" region** commissioned and in use since 2016
  - **20% trigger efficiency increase** in this region
  - Overall **4% trigger efficiency increase in barrel**

Level-1 muon trigger efficiency in "feet" region, 2017 data



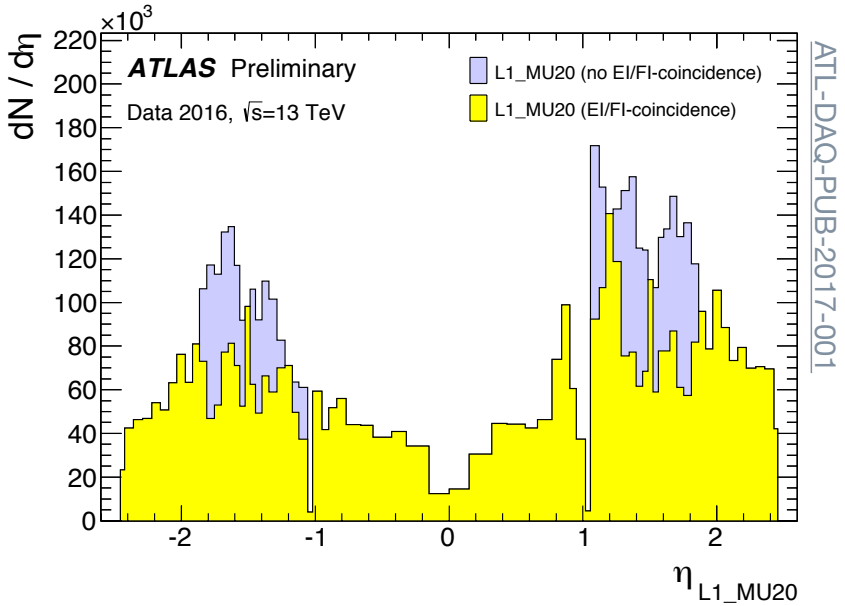
Level-1 endcap coincidence requirement





Reduced Level-1 trigger rate in 2017 after improved coincidence requirements

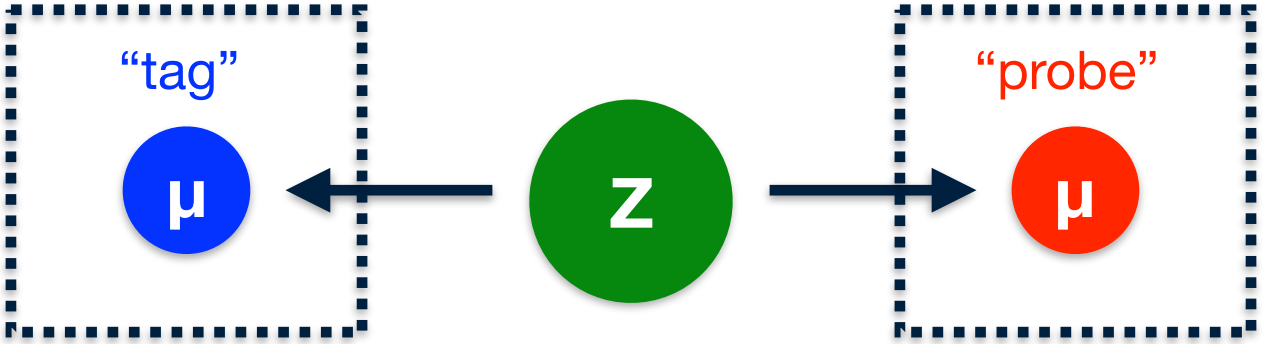
- **Level-1 trigger rates** in forward region dominated by **low-p_T backgrounds**
- **New coincidence requirements** added in 2015+2016:
  - Require Endcap Inner (EI) / Forward Inner (FI) hit
- 20% rate reduction, for only 1% trigger efficiency loss



- Additional improvements of **coincidence requirements** in 2016 further **decrease rate** and **pile-up dependence**

Trigger efficiency measurement

- **Trigger efficiency** is measured via **"tag & probe"** method:
  - Target ***Z→μμ*** topology (**J/Ψ** for low p_T muons)
  - Select events by triggering on tag muon
  - Count how many probe muons are also triggered on
  - Allows for unbiased efficiency measurement



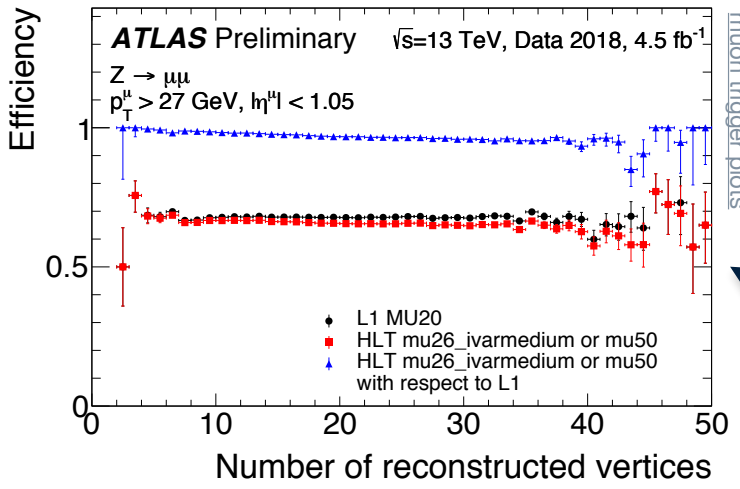
identified by trigger,
used to select events

trigger efficiency:
fraction of probes identified by trigger

- **Trigger efficiency:** fraction of probe muons identified by muon trigger

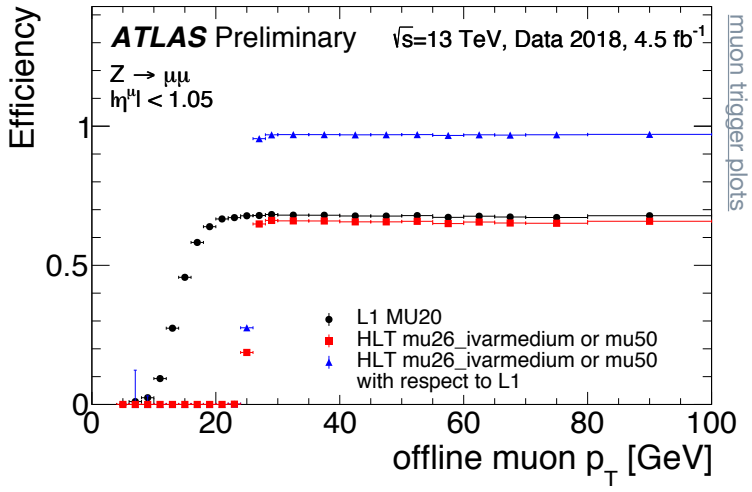
Trigger efficiencies with 2018 data

Barrel trigger efficiency

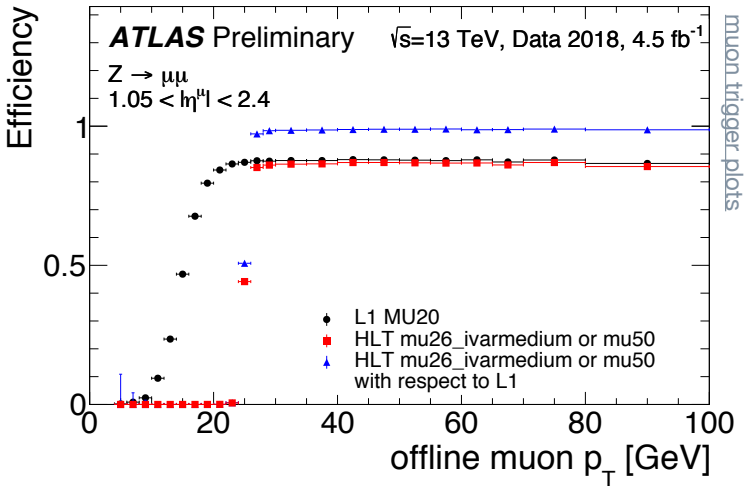


- Efficiency losses mainly coming from **Level-1**
  - Limited by hit efficiency and geometric coverage
- **HLT relative to Level-1** almost 100% efficient
  - While reducing rate by factor 100
- Trigger efficiency is rather stable with respect to pile-up
- Sharp turn-on in p_T dependence for **HLT**
- Higher efficiencies in endcap than in barrel

Barrel trigger efficiency



Endcap trigger efficiency



Summary

- **Muon trigger system** is **crucial** ingredient to the **ATLAS physics campaign**
  - **Very successful operations** and great performance during Run-2
  - **Continuous upgrades** to handle high luminosity and pile-up conditions
    - Resulting in efficiency gains and rate reductions

Backup

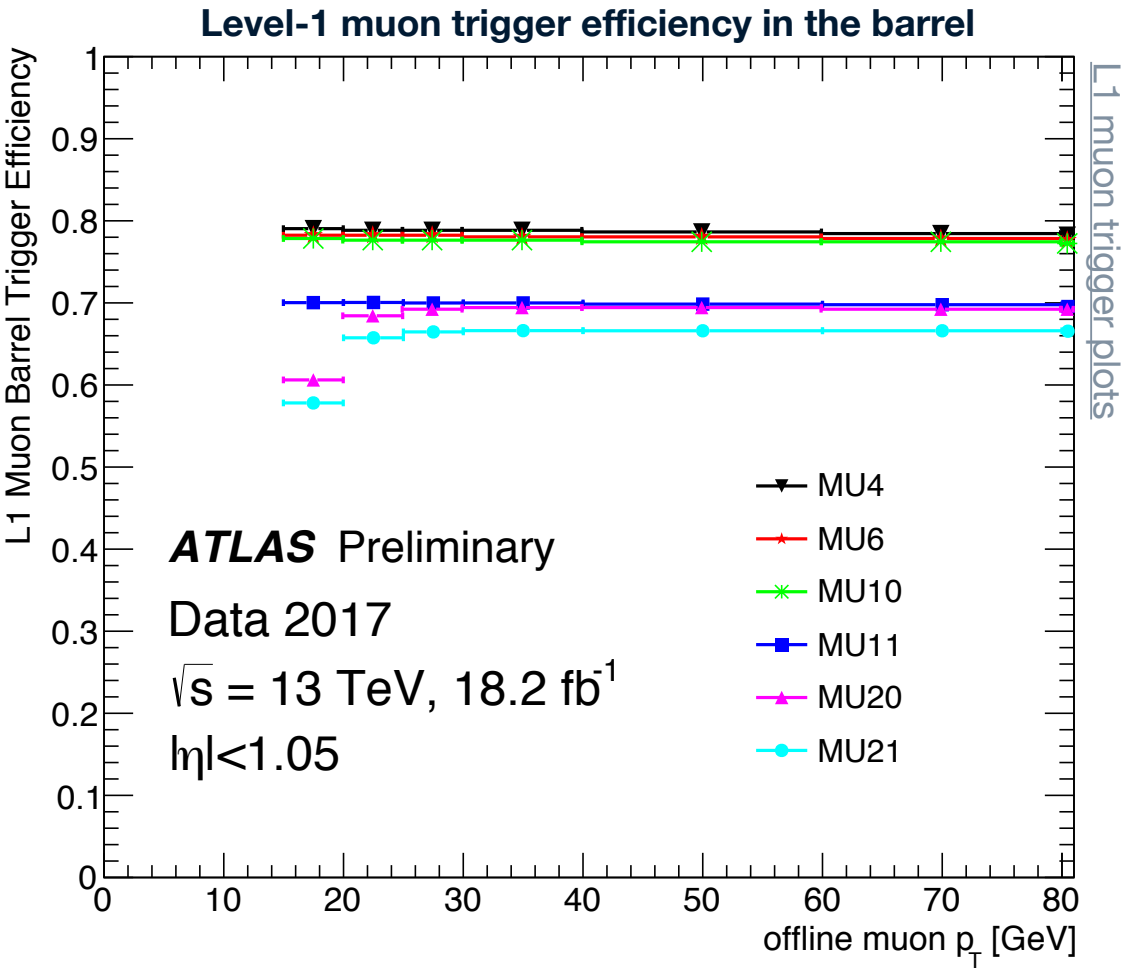
Level-1 muon barrel upgrade

- Additional **RPC chambers** in **ATLAS "feet" region** commissioned and in use since 2016

- **Overall 4% muon trigger efficiency increase in the barrel**

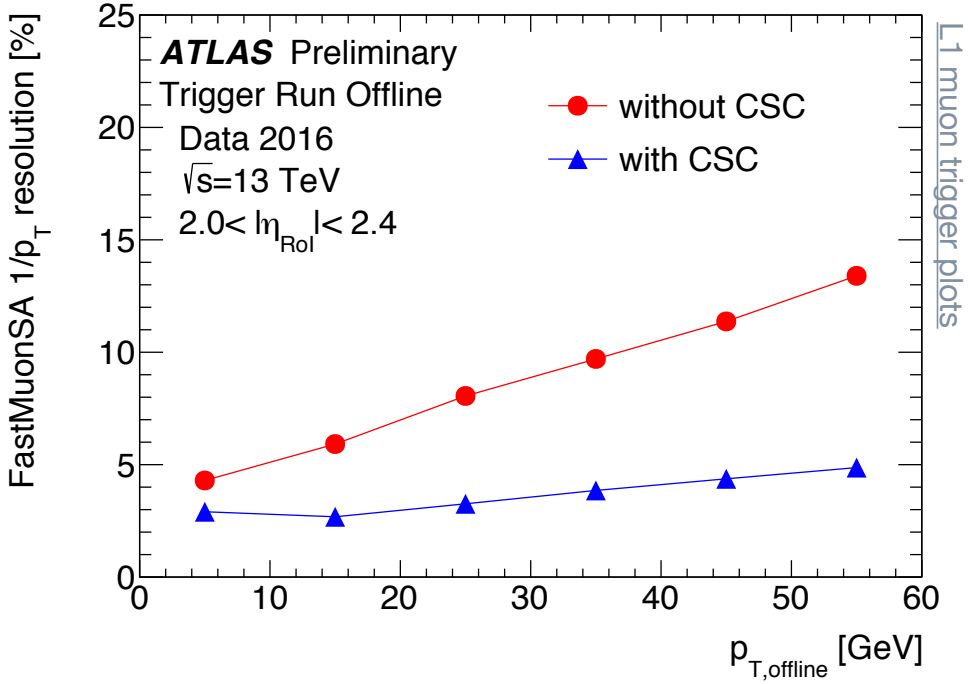
  - **MU20:** including new chambers in feet region

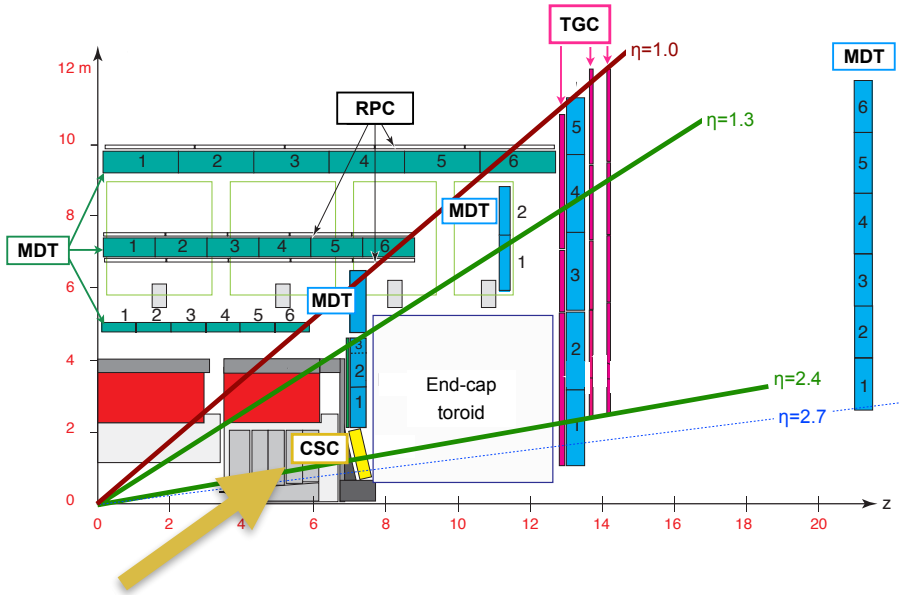
  - MU21: like MU20, but excluding new chambers



Improved p_T resolution at HLT

- **Improvement** to **fast MS-only muon reconstruction** (first step of HLT chain)
  - **CSC hits improve p_T resolution** in $2.0 < |\eta| < 2.4$ region



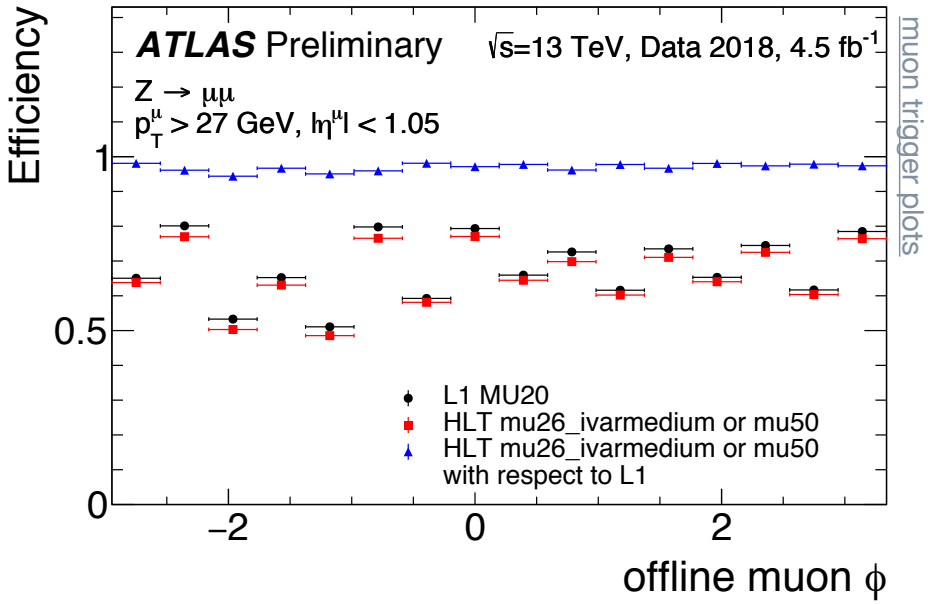


- **Increased resolution** results in **improved early event rejection**
  - Saving valuable CPU time before expensive precision reconstruction runs

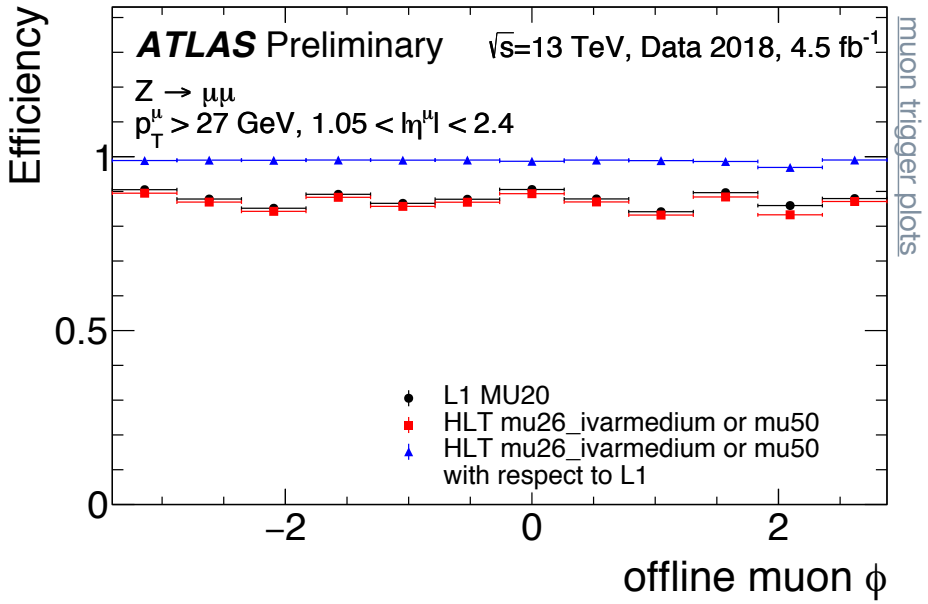
Trigger efficiencies with 2018 data

- Trigger efficiencies determined via tag & probe with ***Z→μμ*** events, here shown for muon ϕ
- Losses due to detector geometry, especially visible in the barrel

Barrel trigger efficiency



Endcap trigger efficiency



More information

- Performance of the ATLAS muon trigger in pp collisions at √s=8 TeV (Eur.Phys.J. C75 (2015) 120)
- Performance of the ATLAS Trigger System in 2015 (Eur.Phys.J. C77 (2017) no.5, 317)
- Trigger Menu in 2016 (ATL-DAQ-PUB-2017-001)
- Trigger Menu in 2017 (ATL-DAQ-PUB-2018-002)
- L1 Muon Trigger Public Results
- Muon Trigger Public Results
- Trigger Operation Public Results
- Computer generated image of the ATLAS Muons subsystem

Abstract

The ATLAS Muon Trigger

Events containing muons in the final state are an important signature for many analyses being carried out at the Large Hadron Collider (LHC), including both standard model measurements and searches for new physics. To be able to study such events, it is required to have an efficient and well-understood muon trigger. The ATLAS muon trigger consists of a hardware based system (Level 1), as well as a software based reconstruction (High Level Trigger). Due to high luminosity and pile up conditions in Run 2, several improvements have been implemented to keep the trigger rate low while still maintaining a high efficiency. Some examples of recent improvements include requiring coincidence hits between different layers of the muon spectrometer, improvements for handling overlapping muons, and optimised muon isolation. We will present an overview of how we trigger on muons, recent improvements, and the performance of the muon trigger in Run-2 data.