A Game of Tag (and Probe)

Scale Factors for the ATLAS Muon Triggers

Surya Sundar Raman
Technical Supervisor : Callum McCracken
Advisor : Oliver Stelzer-Chilton

UBC/TRIUMF

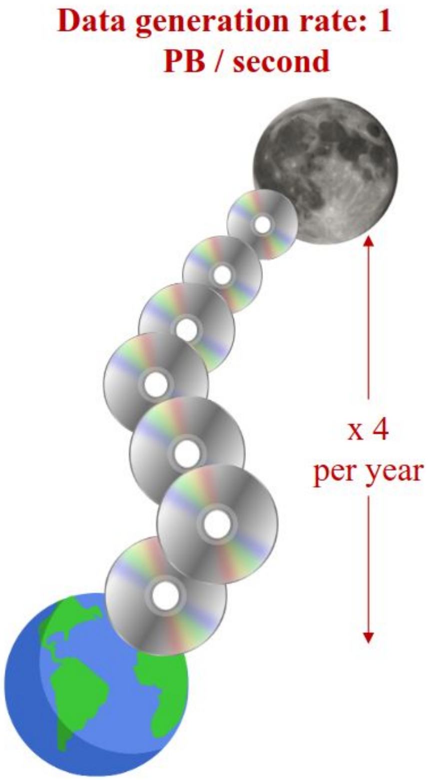
WNPPC
February 2025

Key Takeaways

- The what?
    - A “trigger system” refers to a complex chain of electronics and algorithms, designed to filter data according to the whims of finicky particle physicists.
- The why?
    - We need triggers because of the ridiculous amount of data we collect at ATLAS.
- Efficiencies and Scale Factors
    - A measure of the performance of triggers, and a way of calibrating our simulations of said triggers.
- Tagging and Probing
    - A data driven method of quantifying the efficiency of triggers.

ATLAS EXPERIMENT

A Bit Too Much Data



- ATLAS is a proton-proton collider
- Ginormous amounts of data collected at ATLAS every minute
- Rate at which BUNCHes of protons fly past each other : ~40MHz
  - 10 - 50 interactions per BUNCH CROSSING
  - Event size : ~ 1-2 MBs
- Works out to a billion collisions per second - almost 10 petabytes of data every year!
- Fool's errand to even attempt to save everything

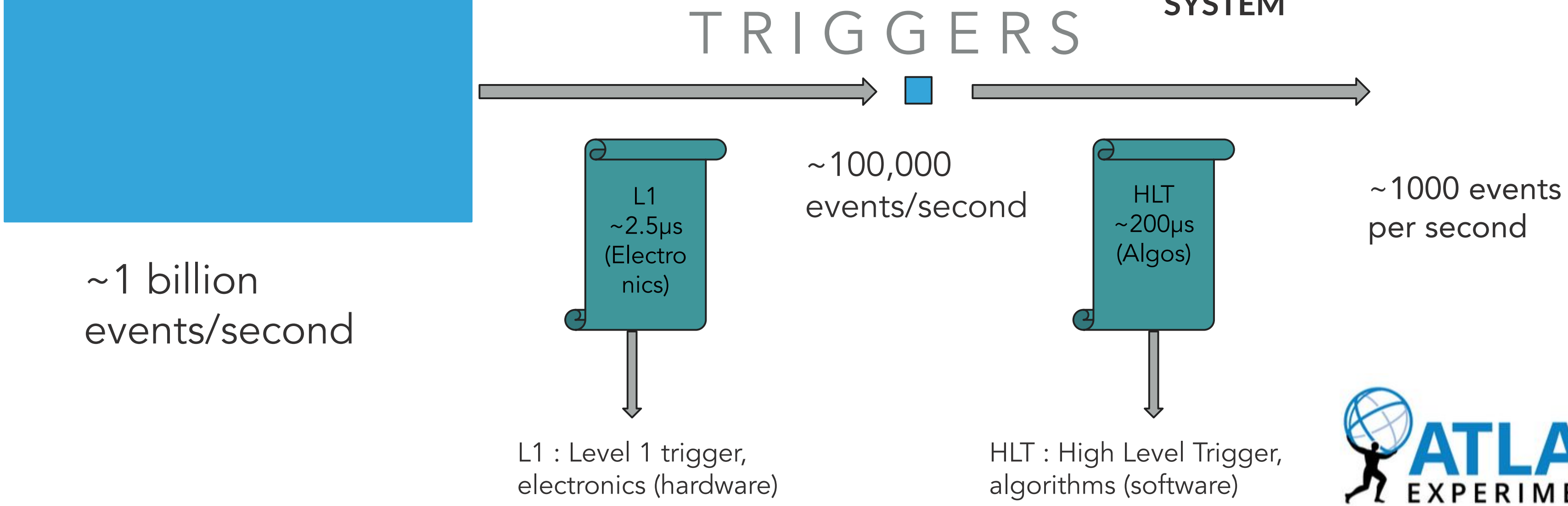
    ATLAS Fact Sheet likens this data rate to making 50 billion telephone calls per second!

[1] Illustration shamelessly lifted from Robin Hayes' talk at this conference many moons ago.
[2] ATLAS Tier 1 Data Centre

Needle in a Haystack

- Can't just blindly throw away events though!
  - So we only keeps events deemed *interesting*
  - **This is quite alright : cross-sections are typically tiny!**

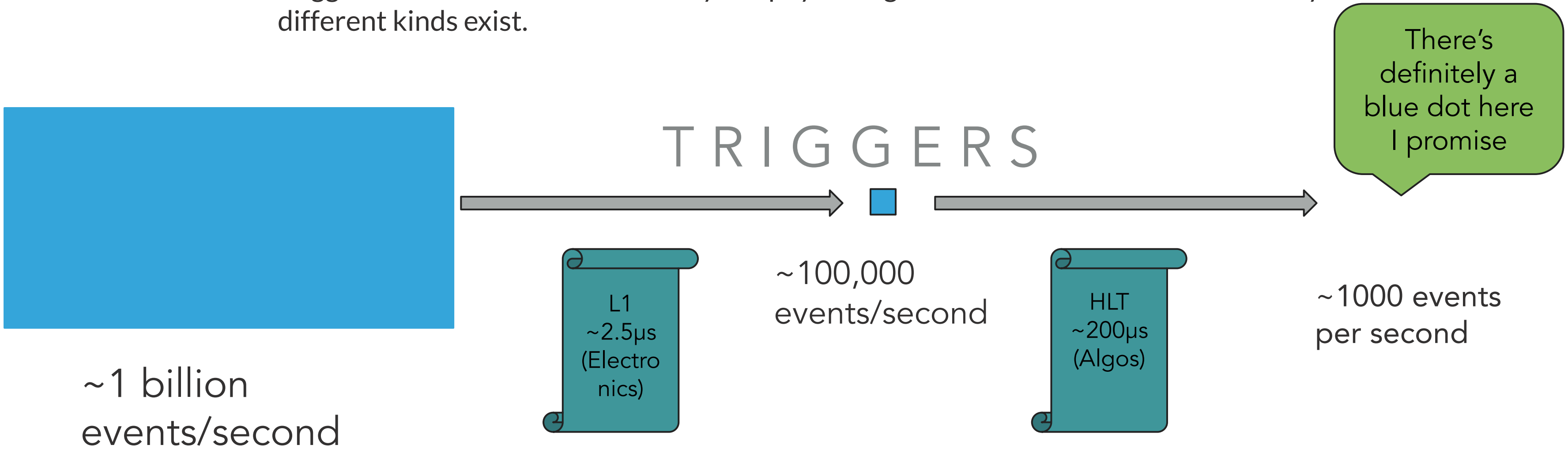
The complex system of electronics (hardware) and algorithms (software) that is utilised to *select these events* is called the **TRIGGER SYSTEM**



ATLAS EXPERIMENT

Needle in a Haystack

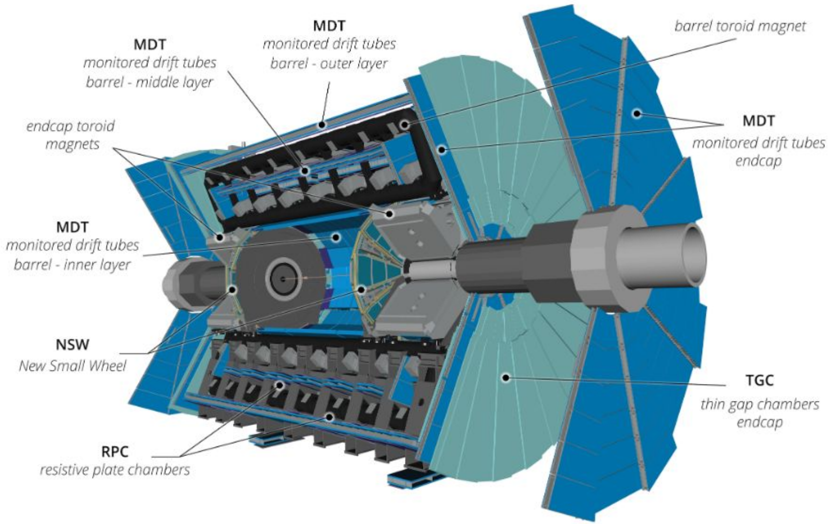
- Trigger decisions are determined by the physics signature under consideration - many different kinds exist.

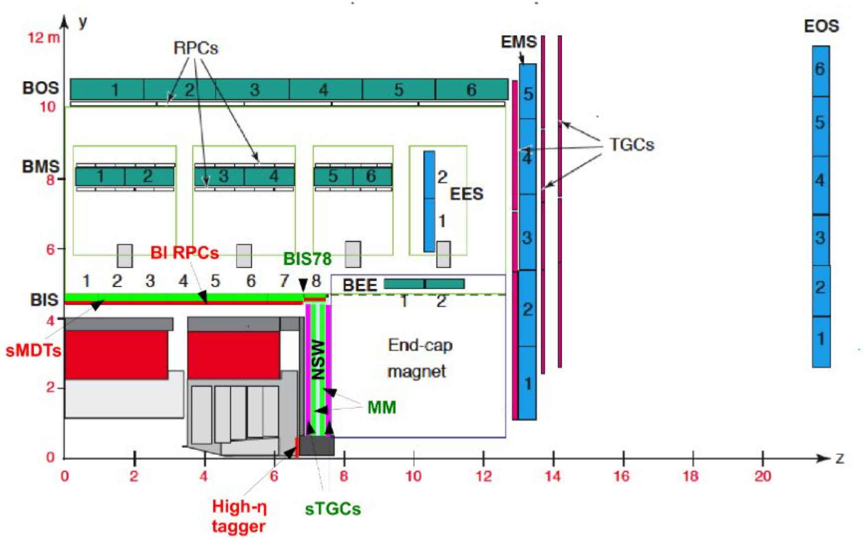


- L1 triggers look for physics signatures from muons, electrons, jets etc.
- HLT uses info from all sub-detectors : Inner Detector(ID), Calorimeter, Muon Spectrometer (MS)

ATLAS EXPERIMENT

A Cross-Section of the Muon Trigger System





MS : Specifically designed for muon measurements.

Muon triggers use info from MS and ID

L1 Muon Trigger : Resistive Plate Chambers (RPC) and Thin Gap Chambers (TGCs), New Small Wheel (NSW)

HLT : Combined MS and ID info

[2] The ATLAS Experiment at the CERN Large Hadron Collider: A Description of the Detector Configuration for Run 3

ATLAS EXPERIMENT

Why Study Muon Triggers?

- Prompt muons in final state is a distinctive signature of quite a bunch of physics processes we study at LHC
  - Measurements of properties of Higgs
  - Searches for new phenomena
  - B-physics and Light States program (BLS)

- Need to accurately model trigger performance in our simulations : TRIGGER CALIBRATION

- A concrete example : W boson mass measurement.
  - Muon trigger efficiency was an important source of systematic uncertainty in the 2024 measurement

[3] Measurement of the *W*-boson mass and width with the ATLAS detector using proton–proton collisions at $\sqrt{s}$ = 7 TeV

Of Efficiencies and Scale Factors

- One measure of trigger performance : Efficiency
- Defined as proportion of events correctly identified by the trigger

$$\text{Efficiency} = \frac{\text{Passing Events}}{\text{Total Events of Interest}}$$

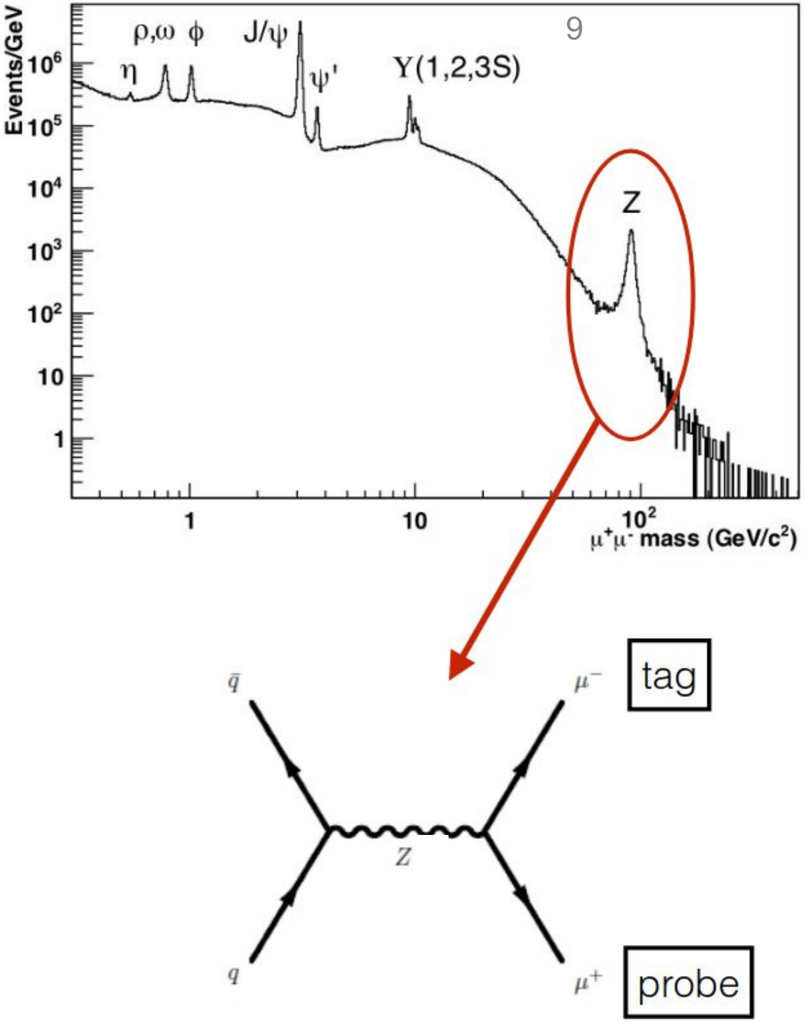
- Can similarly define efficiency of simulated trigger
  - Ratio of efficiencies in data and simulation : Scale Factors!

$$\text{Scale Factor} = \frac{\text{Data Efficiency}}{\text{MC Efficiency}}$$

- Why should there be a difference to begin with?
  - Can't model all real world detector conditions

Tagging and Probing

- The problem : can count up the number of times our trigger fires, but how do we quantify the number of times that the trigger did NOT fire but SHOULD have?
- Solution : use data-driven “Tag and Probe” method to calculate efficiencies
- Essential idea is to use a well-known resonance to construct an unbiased pool of events to work with.



Tag and Probe (II) : Overview

- Consider events with two muons : “tag” and “probe”
- By construction, the tag muon fires the trigger, while the probe may or may not.
    - They should be unrelated for results to be unbiased.
- We count the no. of times <u>both the tag and probe</u> fire the trigger.

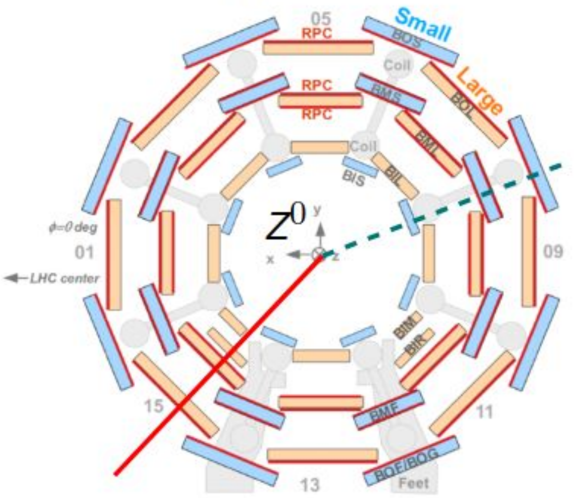
$$\varepsilon^{trigger} = \frac{N_{probe}^{trigger-matched}}{N_{probe}^{total}}$$

ATLAS EXPERIMENT

Tag and Probe III : Z decay specifics

Select Z^0-decay by requiring

$61 < m_{T\&P} < 121$ GeV



Tag Muons	• Tight selection criteria • Well identified and isolated
Probe Muons	• Very loose selection criteria • Transverse momentum above trigger threshold • Tracks compatible with Z resonance

In addition, both muons are required to originate from the same interaction vertex, have opposite charge, etc.

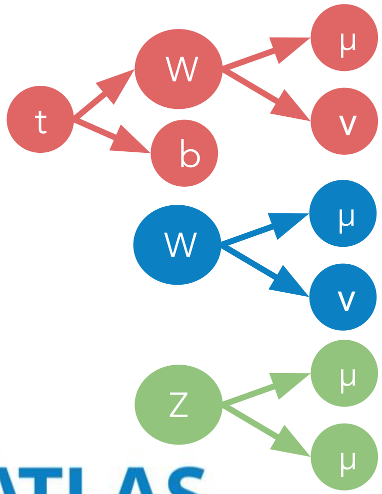
ATLAS EXPERIMENT

Tag and Probe IV : Example

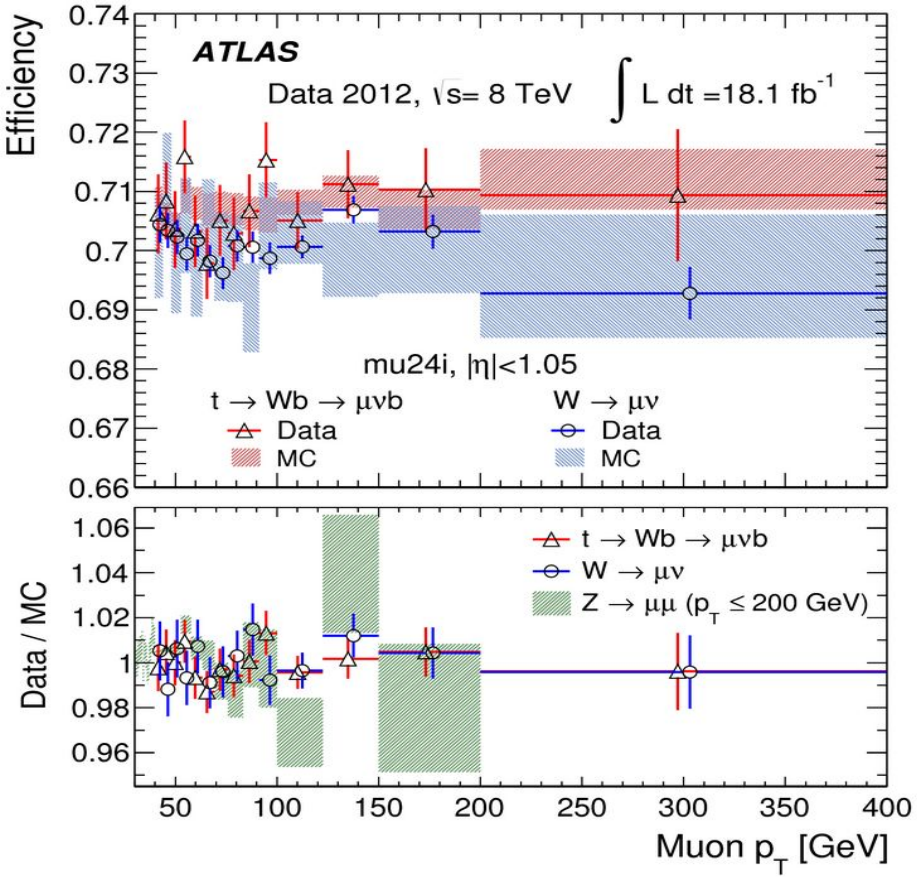
Tag to create unbiased pool of events.

Probe to check trigger efficiency.

Legend for processes on the right:



[5] Performance of the ATLAS muon trigger in pp collisions at √s = 8 TeV



For process in red, ~71% efficiency in both data and MC => Scale Factor ~1

[6] Tagging and Probing : Alex Held

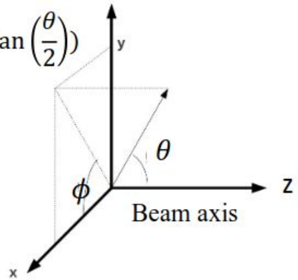
An Efficiency Plot

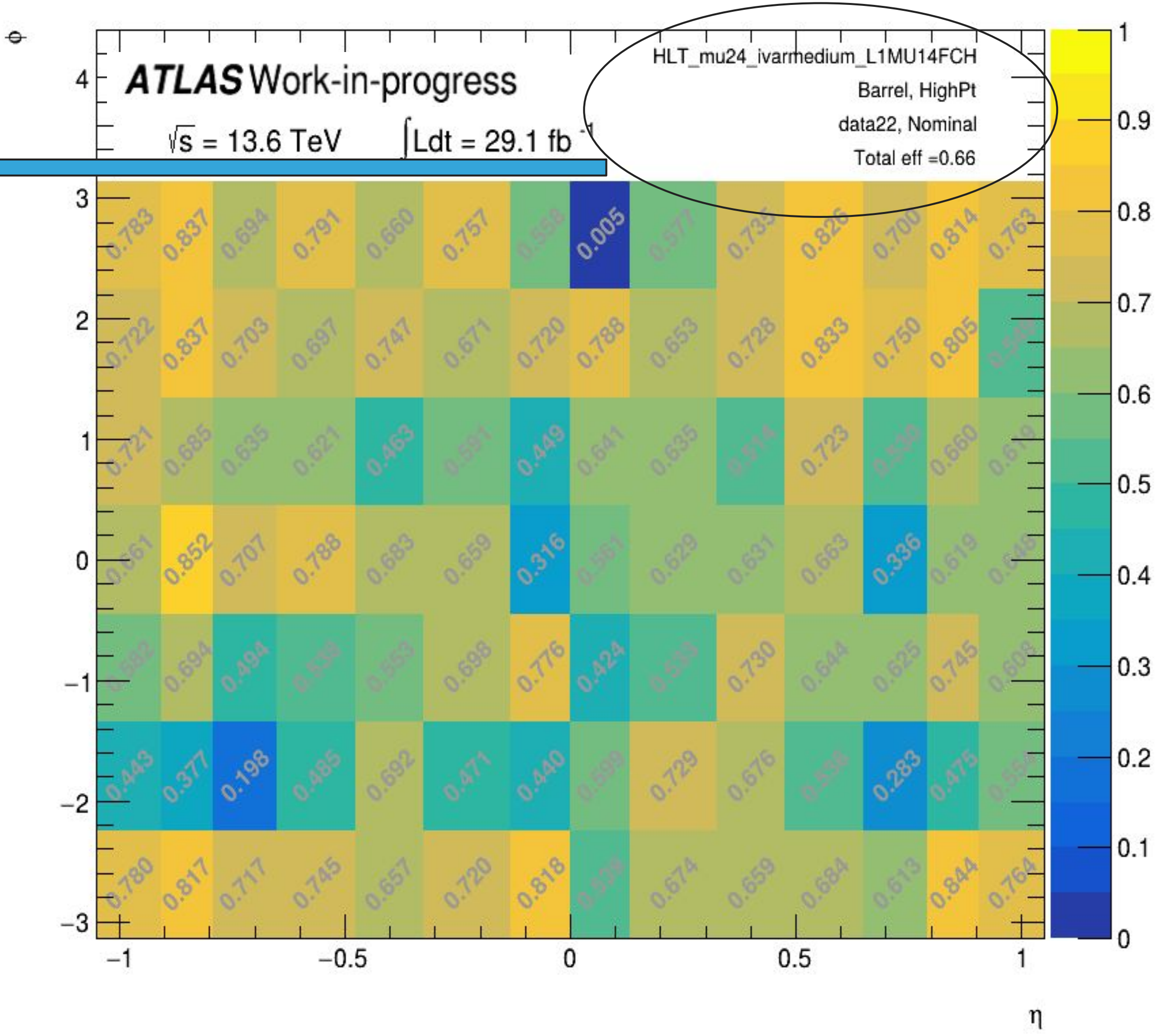
A 2-D efficiency map, made with 2022 datasets.

HLT_mu24… : naming convention specifying trigger menu

Nominal : without considering any systematic uncertainties

$$\eta = -\ln(\tan\left(\frac{\theta}{2}\right))$$





Detector Geometry Effects

$|\eta| < 0.1 \implies$ Detector Cracks

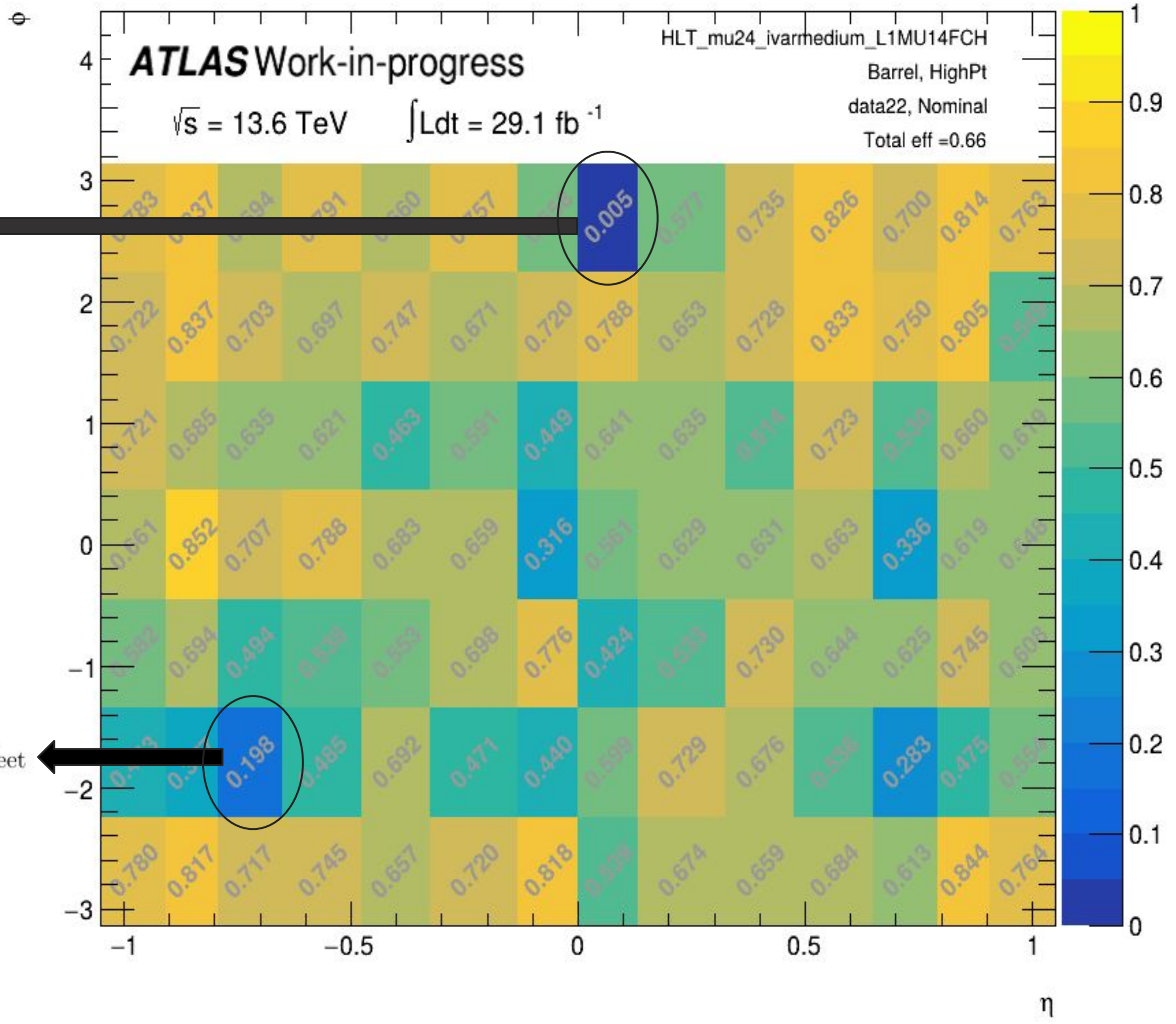
Crack : space in detector for wires etc

Feet : support structure

Note : a high-resolution efficiency plot will also show holes along the entire eta = 0 axis

$-2.6 < \phi < -1.77$ and $-1.37 < \phi < -0.98 \implies$ Detector Feet

We expect low stats in these bins/zones



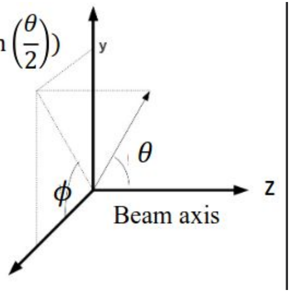
A Scale Factor Plot

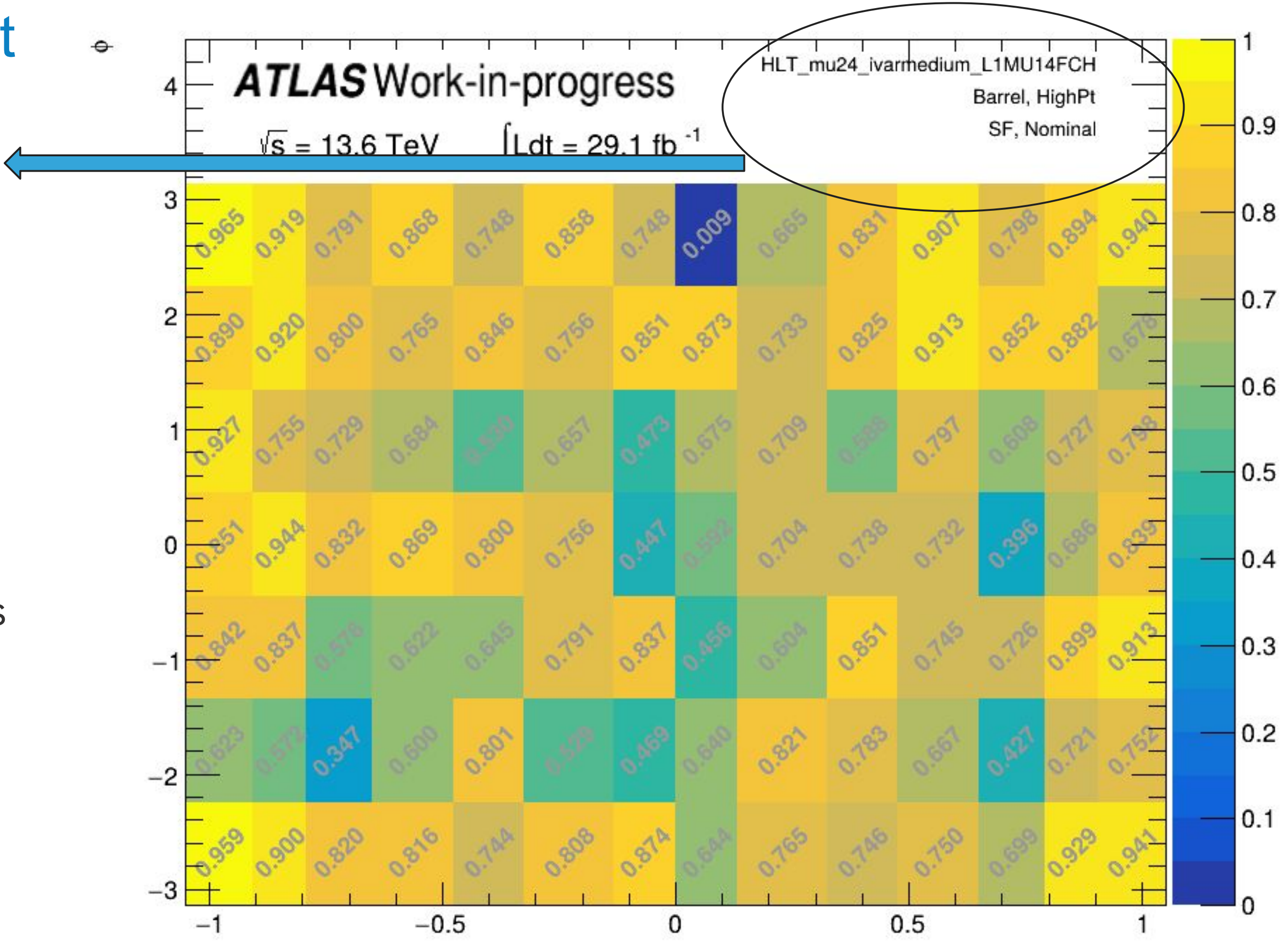
A 2-D SF map, made with 2022 datasets.

HLT_mu24… : naming convention specifying trigger menu

Nominal : without considering any systematic uncertainties

$$\eta = -\ln(\tan\left(\frac{\theta}{2}\right))$$





Here again the detector cracks and feet contribute to zones/bins of low SFs η

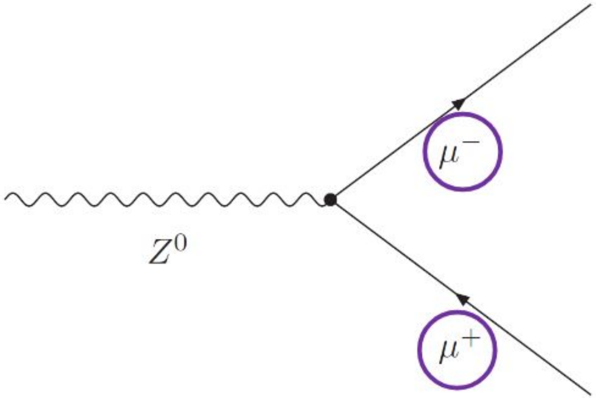
Next Steps

- Produce these efficiency and SF plots with 2022, 2023 and 2024 datasets
  - For a wide variety of working points
  - For single and di-muon triggers
  - For an array of possible sources of systematic uncertainty (pT dependence, isolation dependence etc.)
- Compare with previous iteration of trigger calibration (Run 2)
- Release to collaboration to be used for all analyses that use muons.

Your attention to detail is incredible if you read this far.

FIN.

BACKUP



Event Selection:

Tag:
- $|\eta| < 2.8$
- $p_T > 10$ GeV
- Caused a low p_T-threshold trigger to fire.

Probe:
- $|\eta| < 2.5$
- $p_T >$ (trigger threshold*1.05 GeV)
- Desired quality

Also: same interaction vertex, in Z mass window, opposite charge