Investigating a Mystery

Poor Modelling of Forward Jet Production Rate For Recent ATLAS Data

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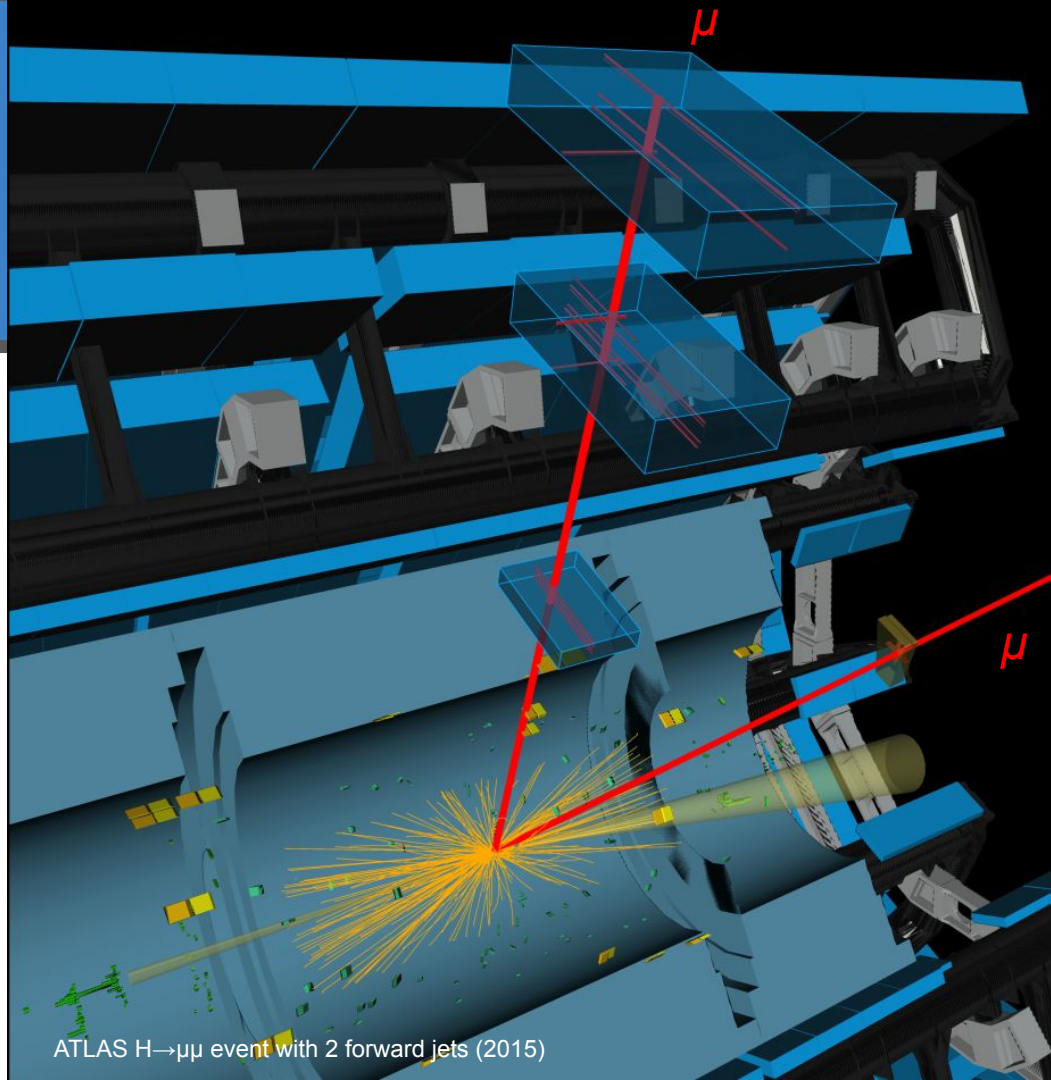
ATLAS Carleton



ATLAS H→μμ event with 2 forward jets (2015)

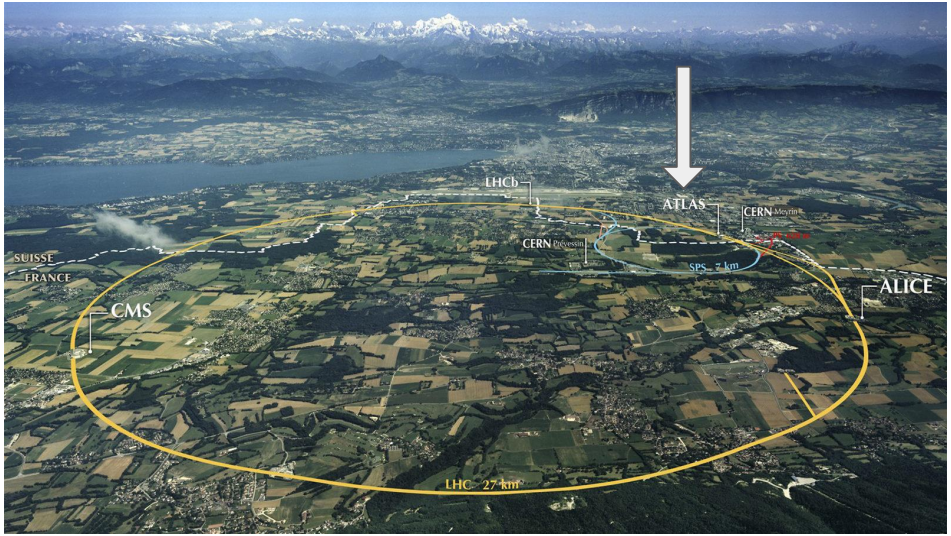
Outline

- Setting the Scene
  - Background and introduction to the issue
- Whodunnit?
  - Looking at possible sources of the issue
- Concluding the Investigation
  - Current investigation results and solutions

Setting the Scene

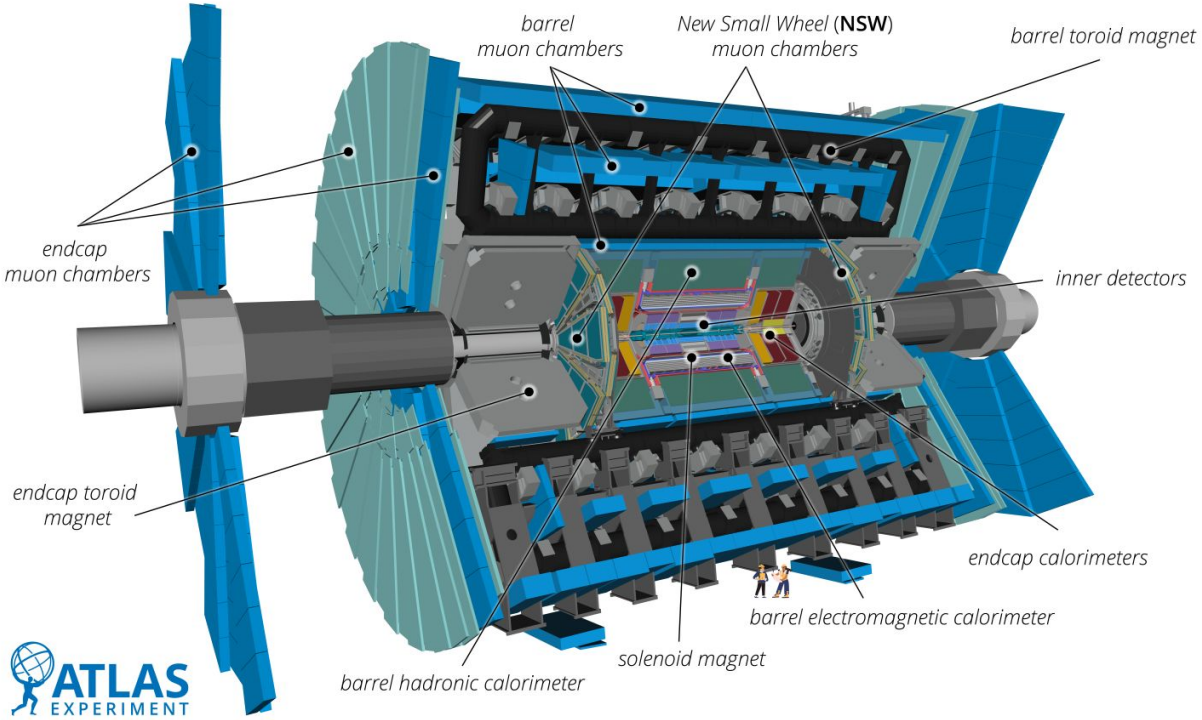
Large Hadron Collider, LHC

- World's largest particle accelerator
- Located at CERN, Geneva
- Running at 13.6 TeV
- Proton–proton collider
  - As well as heavy ions
- Run periods
  - Run 1 (2009-2013)
  - Run 2 (2015-2018)
  - **Run 3 (2022-2026)**



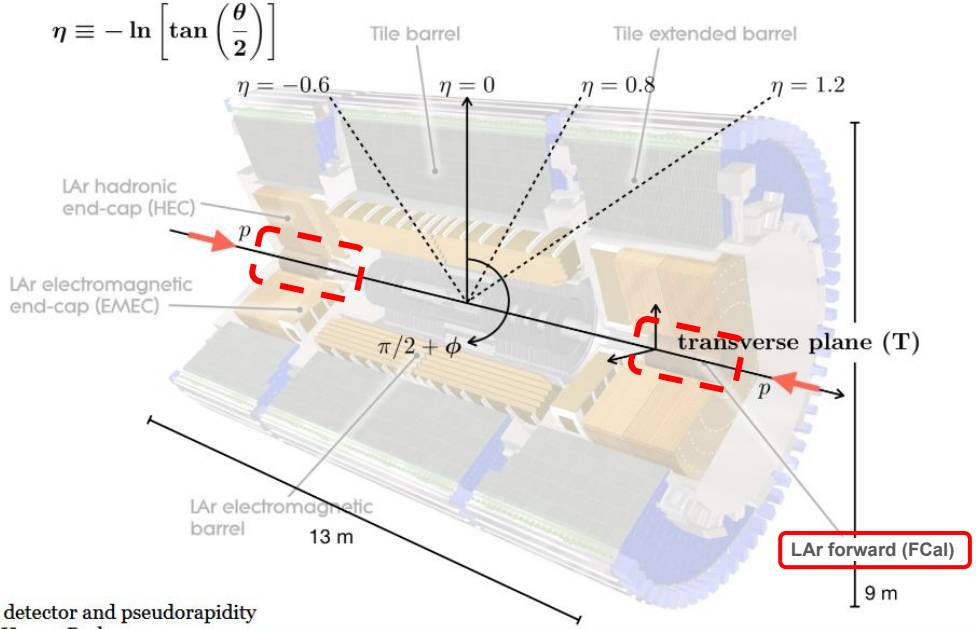
The LHC from above. Arrow points to ATLAS

ATLAS Detector



Pseudorapidity at ATLAS

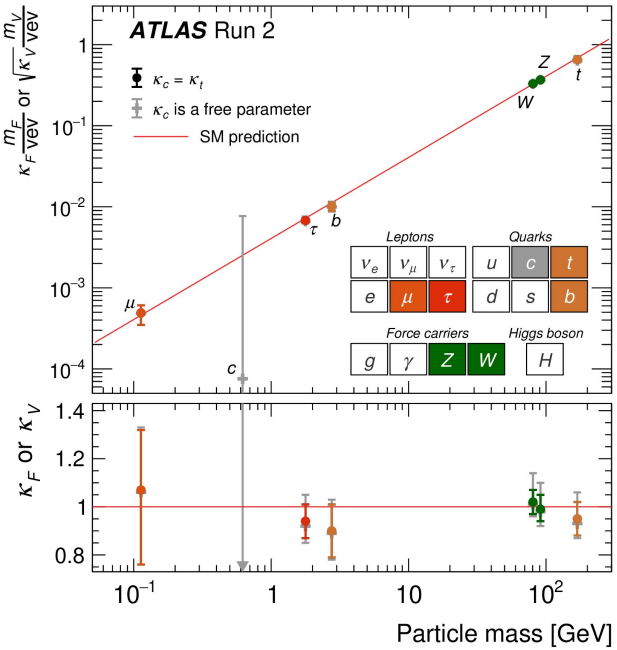
- At ATLAS we use pseudorapidity η instead of polar angle θ
- The issue we will investigate occurs in the forward region, |η|>3
- This is the location of the forward calorimeters (FCal)
  - |η|>3.2



The ATLAS detector and pseudorapidity
Credit: Tae Hyoun Park

Learning About the Higgs at the LHC

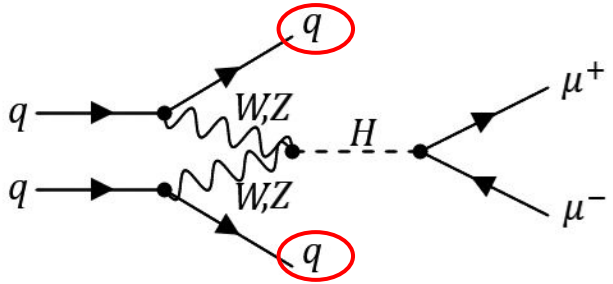
- Higgs boson was discovered by ATLAS and CMS in 2012
- We want to see if the properties of the Higgs follows the Standard Model predictions
- We have precisely measured how often Higgs interacts with heavy particles
- Haven't measured the interaction for lighter particles



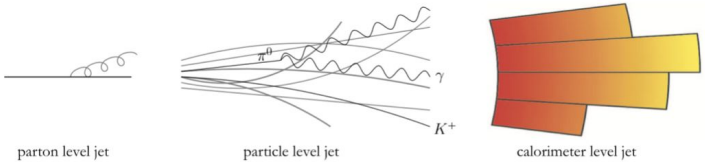
Higgs boson coupling modifiers and their uncertainties. (Nature 607 52 (2022), Figure 5)

Higgs Dimuon Analysis

- Goal: measure the Higgs boson interactions with muons
  - Look for **very rare** *H→μμ* process
  - No ATLAS 3-sigma measurement as of yet
- Signature
  - 2 muons produced from the Higgs
  - 2 forward jets for Vector Boson Fusion (VBF) production
- Crucial to simulate signals and background processes!
  - Done using MC event generator + GEANT for detector simulation



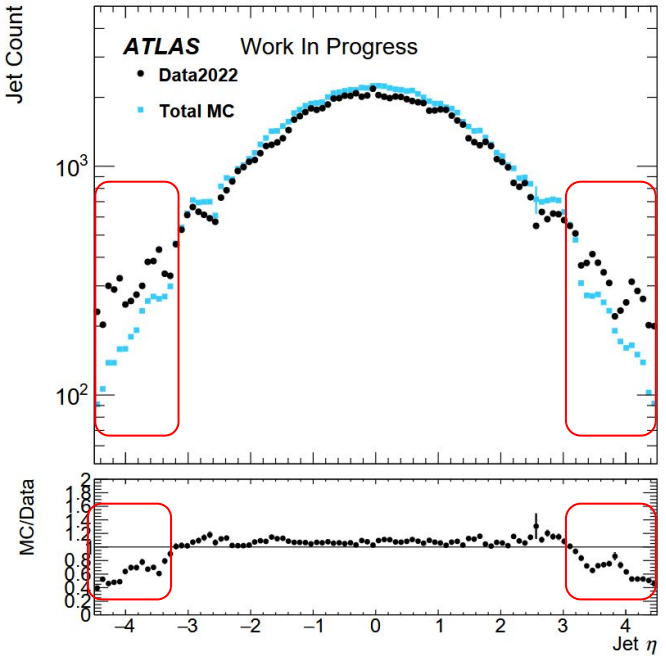
Vector Boson Fusion (VBF) Higgs production to *H→μμ*



The Forward Jet Issue

- Plots shows rate of jet production vs jet pseudorapidity
- Major discrepancy in forward region
  - MC prediction is half of observed rate
  - Corresponds to the forward calorimeter location
- Only seen in Run 3 data (2022-present)
- **Run 2 MC agrees with data**

Why are we seeing this?



Pseudorapidity of highest-p_T jet in each event
Black: observed spectrum in Run 3 data
Blue: predicted spectrum from Run 3 MC

Whodunnit?

What might be causing this?

Noise (Pileup)?

Issue with the Detector?

Checked by experts: no issue found

A Mix of Several?

MC Event Modeling?

Detector Simulation and Calibration?

Noise (Pileup)

- Collision environment causes ATLAS to suffer from significant noise, especially additional proton-proton interactions
- Signals from pileup and other noise sources can create jets that tend to occur at low energy

If this is the source:

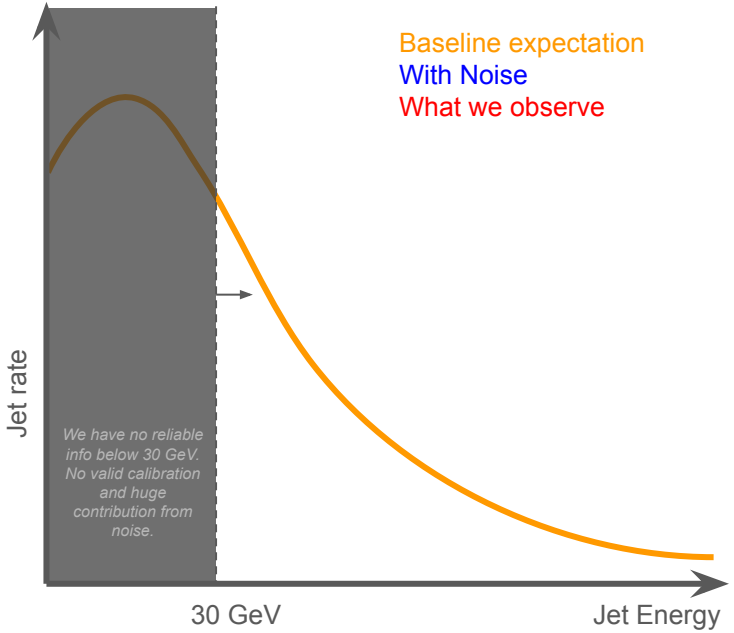
MC is underestimating the contribution from noise

What we should see:

There should be more low energy jets noise

What we see:

The extra jets are not only in the low energy limit noise



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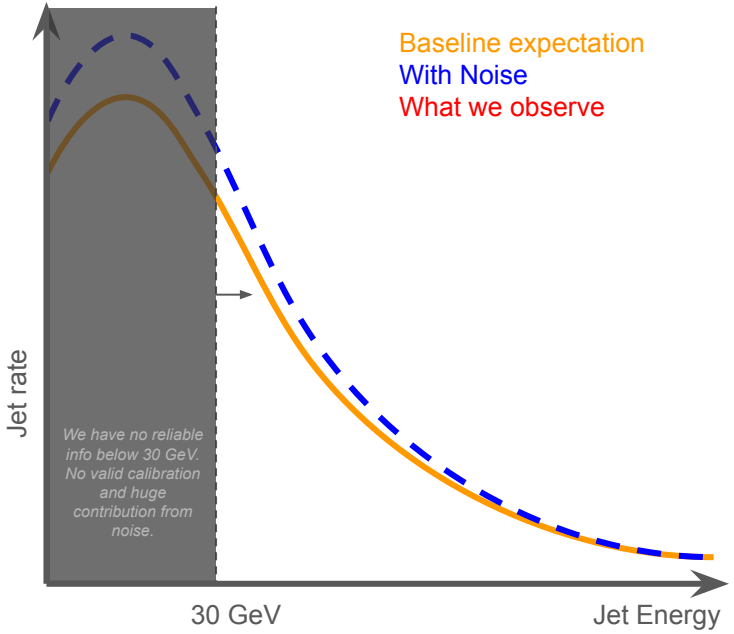

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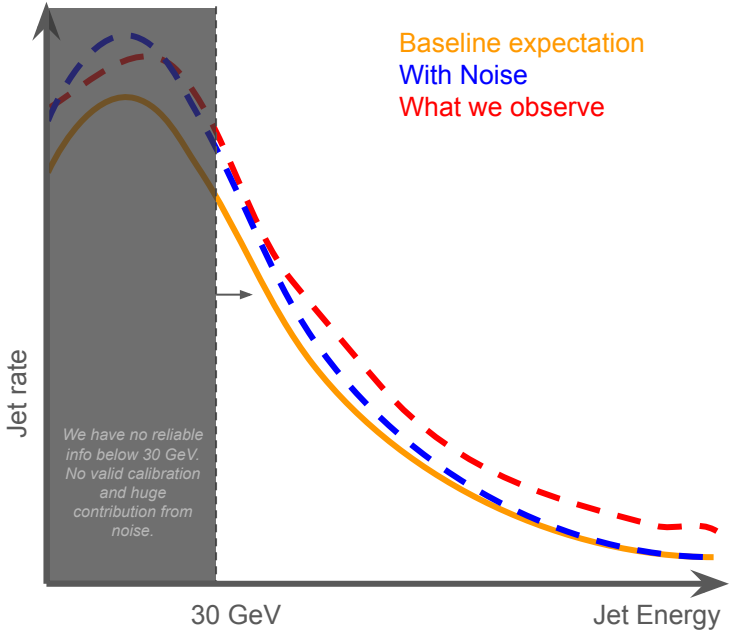


MC Event Modeling

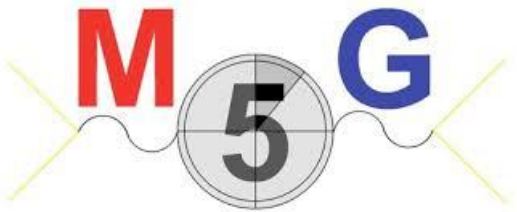
- We rely on MC event generators to produce predictions of physics processes

If this is the source:
The MC underestimates the rate of forward jet production

What we should see:
A major difference in MC generator used between Run3 and Run 2

What we see:
Difference in MC generators is not large enough to explain

MC generators for Run 2 and Run 3 are the same and give **consistent results prior to detector simulation**



Detector Simulation and Calibration

- GEANT is used to simulate the detectors response to simulated events
  - In particular energy response
- Calibrations are applied to account for imperfections from GEANT modelling

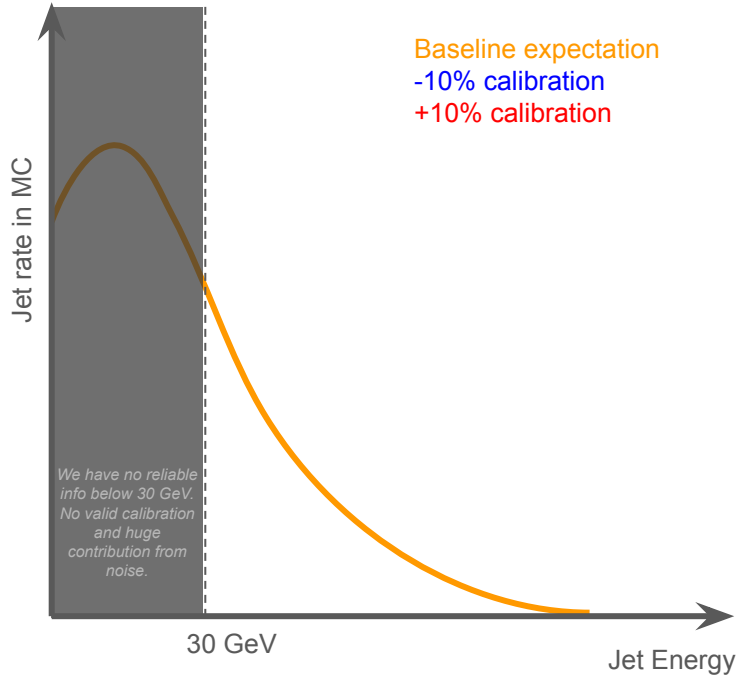
If this is the source:

Detector simulation underpredicts energy of forward jets

What we should see:

A shift in energy of all jets in MC

We see this!



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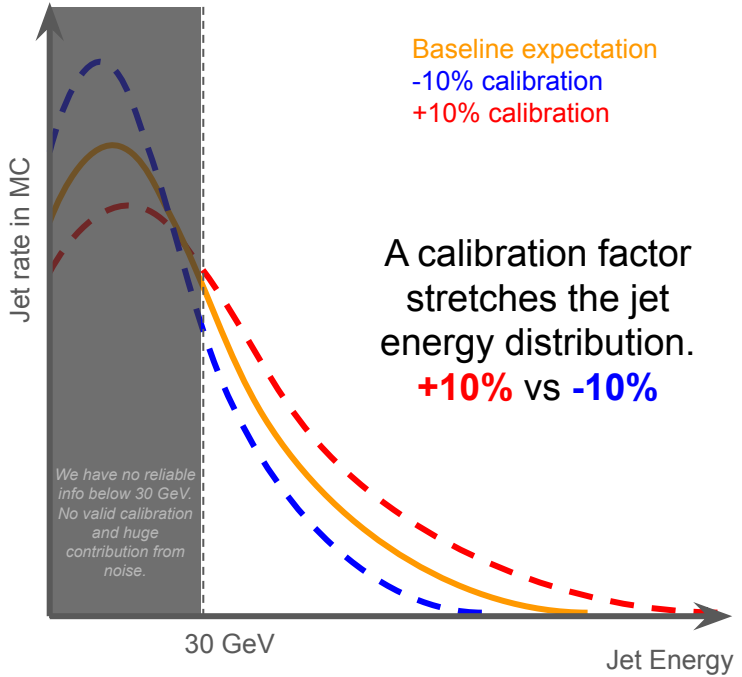


Concluding the Investigation

Toy Calibration

- Investigating overall calibration solution
- Calibrate energy of **real jets** down by 10% in the forward region (|η|>3.2) to account for GEANT mismodeled energy response
- This achieves good agreement

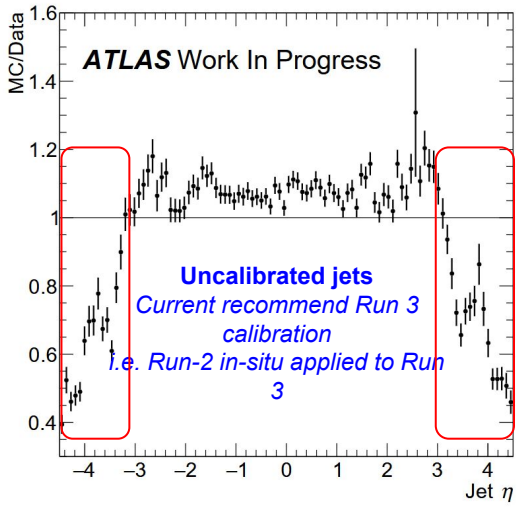
Current understanding:

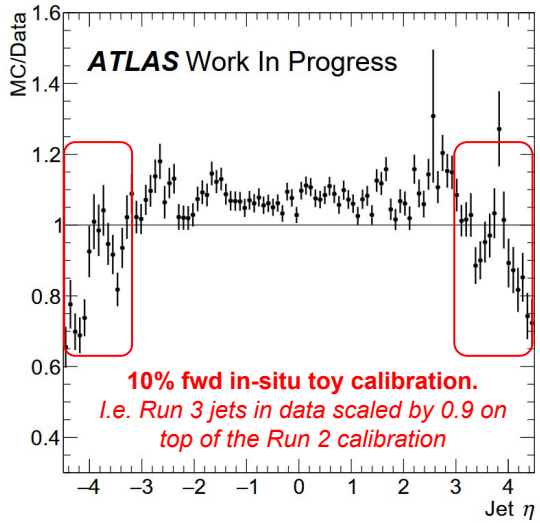
In Run 3 major update using GEANT introduced to fix a long standing issue of energy modeling in the central region

In dense materials (like FCal) new GEANT underpredicts energy

Can explain most of the issue

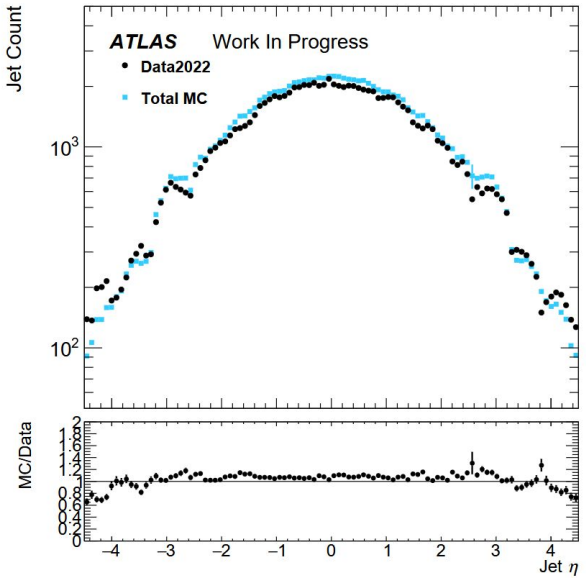
Other effects may contribute to half of it





The Future

- Primary source is from GEANT model underpredicting jet energy in the FCal
  - Upcoming update to GEANT may resolve this issue
- A new calibration has been released by the ATLAS JetETMiss group aiming to correct the issue
  - Similar to my identified 10% calibration
- Run 3 ends in 2026
  - Help improve analysis of the forward jets until it can be address in simulation



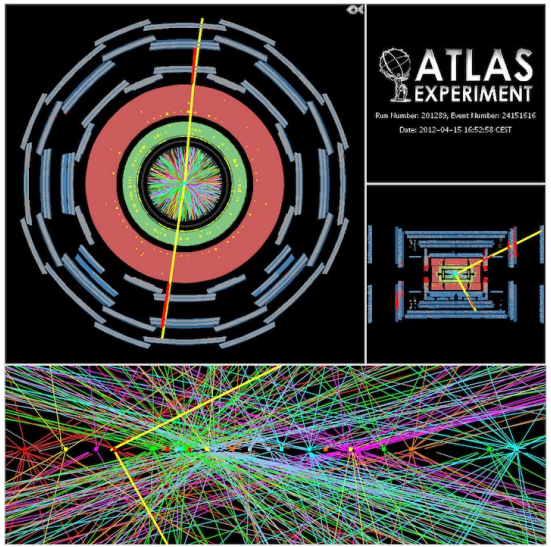
Pseudorapidity of highest-p_T jet in each event
Black: observed spectrum in Run 3 data with -10% calibration to p_T
Blue: predicted spectrum from Run 3 MC

Thank you!

Backup

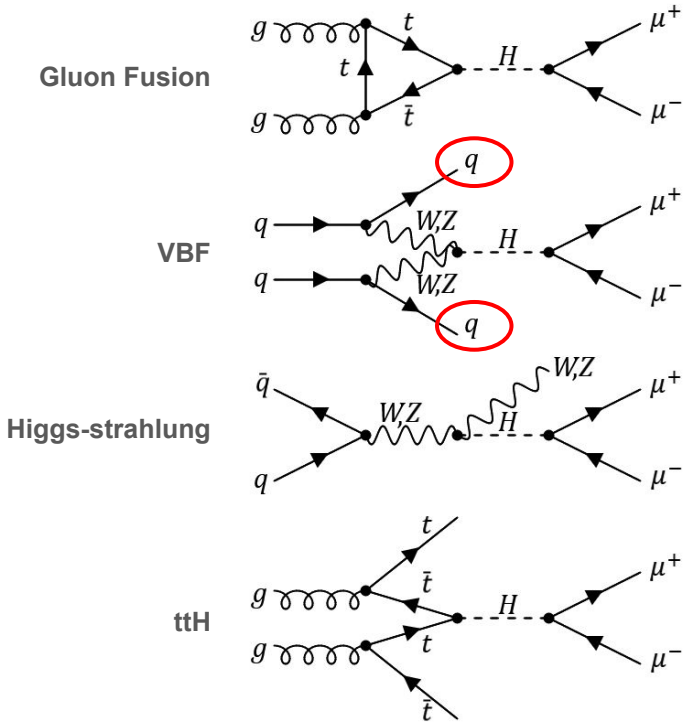
Collisions at the LHC - Pile up

- 8 interaction points along the LHC
- When beams collide we get multiple pp collisions along the beam line
- These bunches of collisions are pile up
- These pile up events are background noise



Pileup ATLAS experiment
(ATLAS Software Documentation, Pileup analysis configuration. 19 Nov 2024)

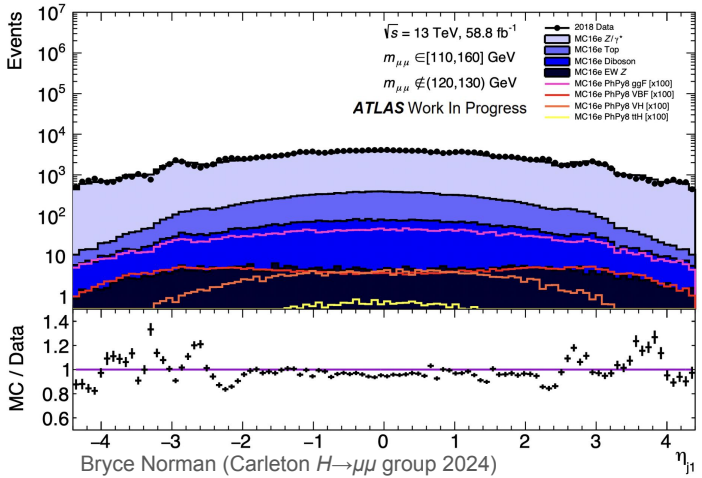
Main higgs production methods



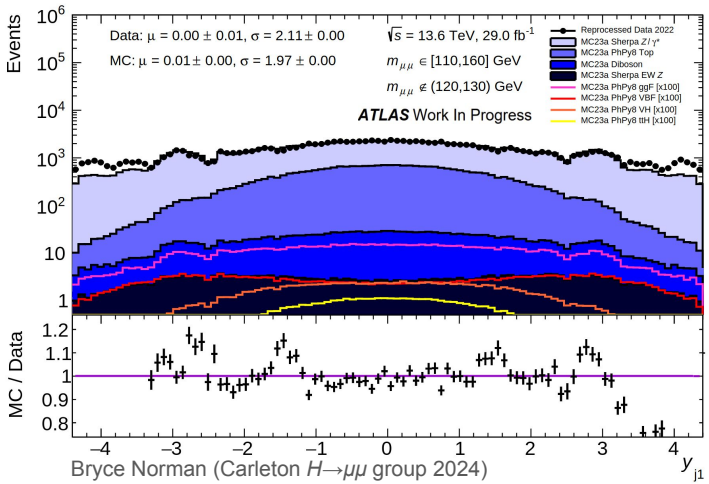
Main Higgs production mechanism

Comparison to Run 2

Run 2



Run 3



- Run 2 did not apply any fJVT cut either
- Agreement looks much better for Run 2
  - Something is different in Run 3

Problem with detector?

- Might there be a problem with the detector itself?
- Maybe with the low level calibration constants used when we read from the detector?
- Careful checks by LAr team found no issues
  - Also confirmed electrons gave the right energy to FCal1