

# New CMS Trigger Strategies for the Run 3 of the LHC

Andrew Loeliger

On behalf of the CMS Collaboration

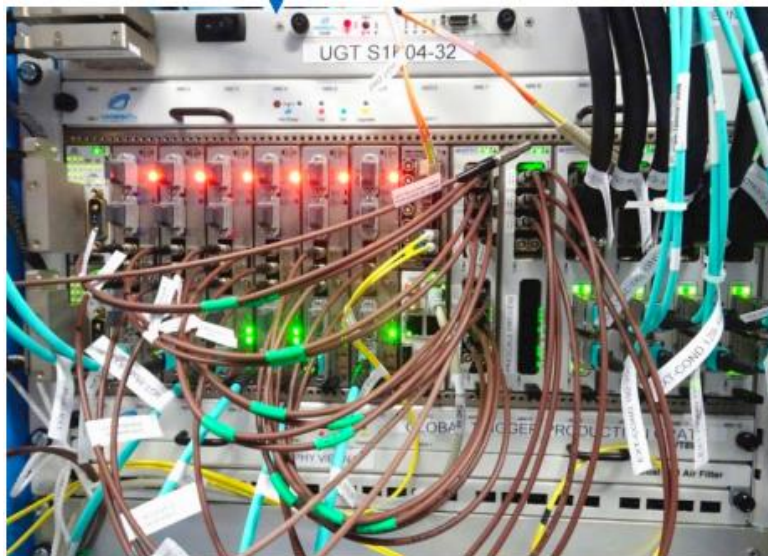
# The CMS Trigger System



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## Level 1 Trigger (L1T)

- First pass trigger system
  - Calo & muon information only
- Hardware system run on FPGAs
- Designed to reduce rate from 40 MHz to  $\sim 110$  kHz
- **Talk will focus here**



7/18/2024

## High Level Trigger (HLT)

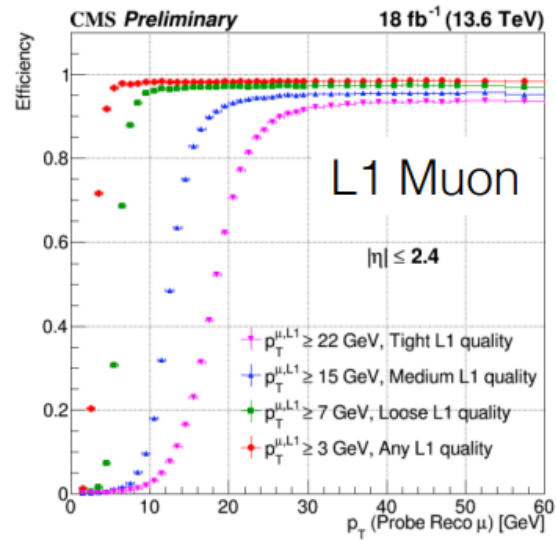
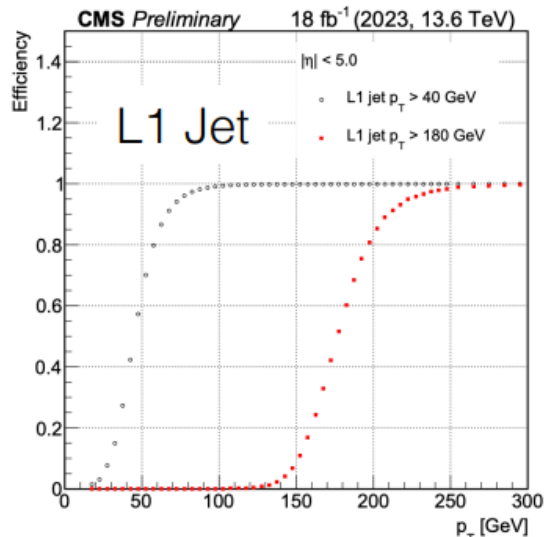
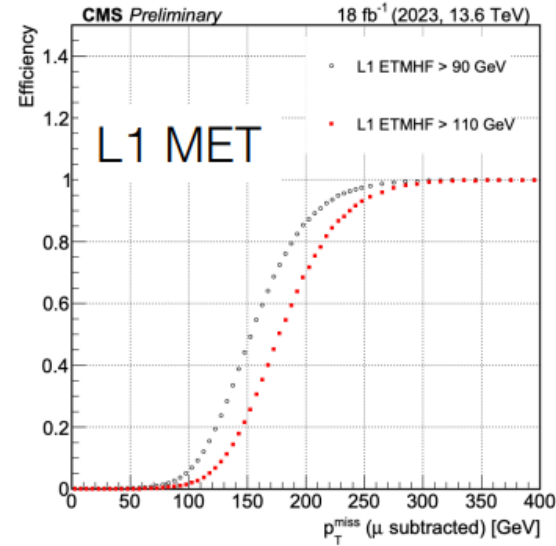
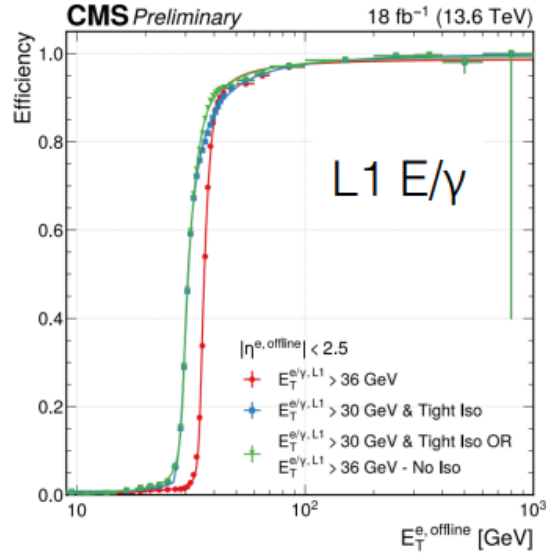
- Second Pass Trigger System
  - Full event information
- Software system run on CPU+GPU farm
- Designed to further reduce rate to  $\sim 5$  kHz



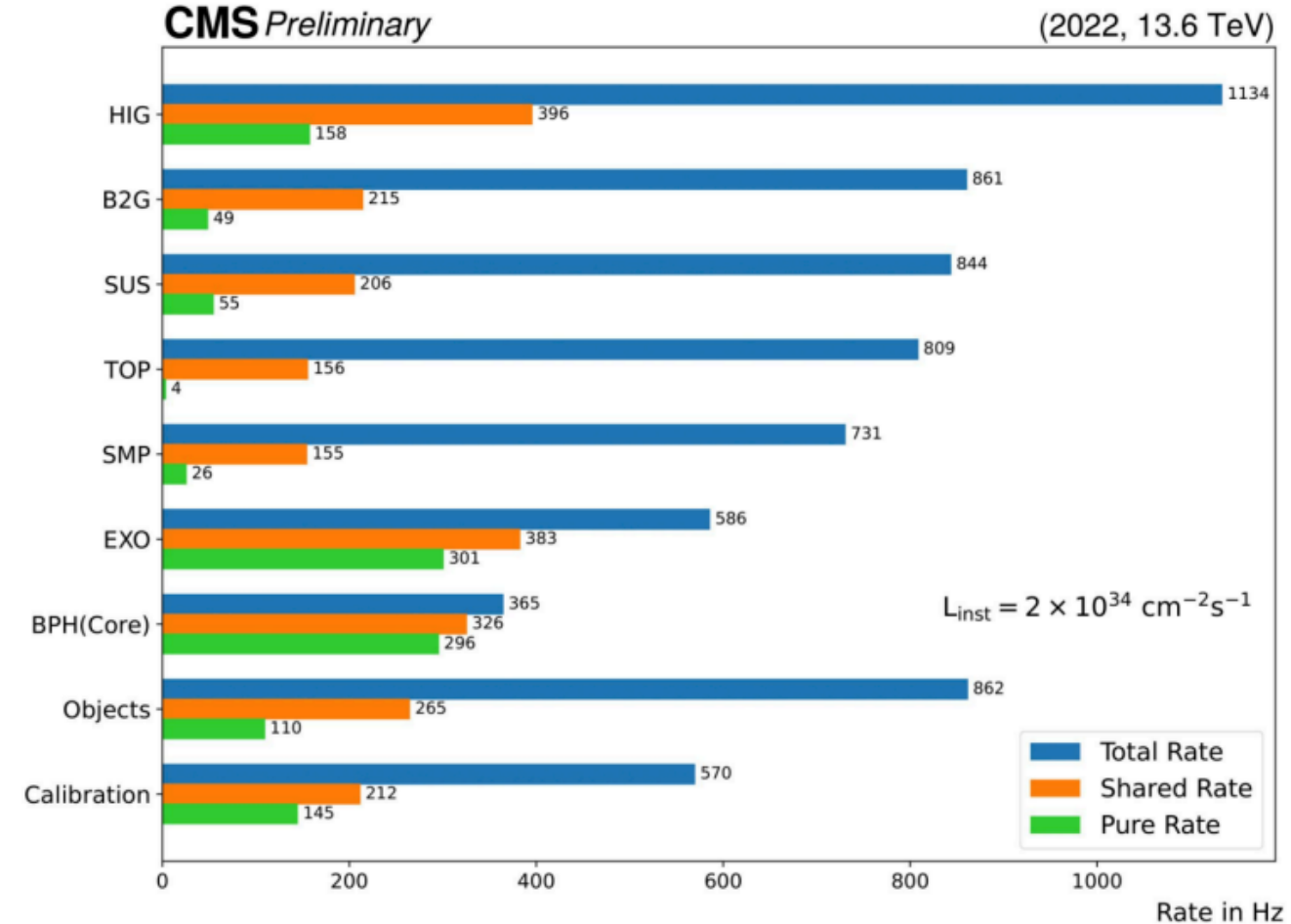
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# A Brief Summary of Trigger Status Before Our New Strategies



HLT rate per physics group in 2022



# Level 1 Trigger

# The Broad Future of L1T Trigger Ideas

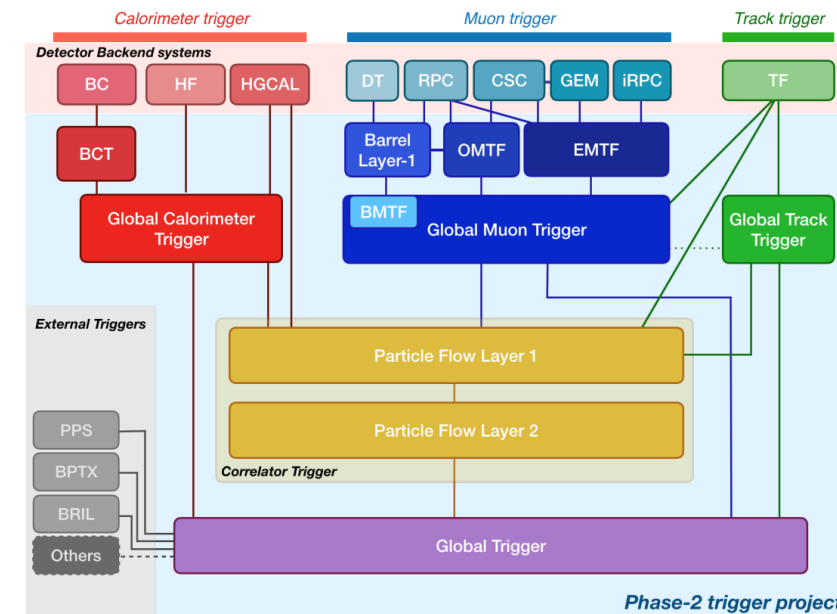


- Trigger going beyond it's design
  - Complicated methods now required to stretch physics goals
- Powerful minimal bias physics?
  - Machine Learning is becoming important for trigger physics now
    - **Neural Nets** → *HLS4ML*
    - **Boosted Decision Trees** → *Conifer*
- Long lived particles and other exotic physics?
  - Increased detector information
  - Borrow HL-LHC ("phase 2") ideas for Run 3!
    - Proof of concept for tomorrow, and powerful new triggers today!
    - See Sioni's talk!



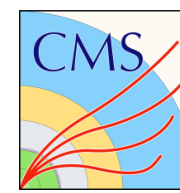
[Github](#), [Paper](#)

[GitHub](#)



TP Initial draft of the Phase 2 design of the Level 1 Trigger,  
Local  
Global  
PF Taken from the [Phase 2 L1T design report](#)  
GT

# Anomaly Detection



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**Where's the new physics?**

To find anything, you need a trigger

**If we knew what we were looking for,  
we'd build a trigger for it!**

**Absent that, cast a wide, model-independent net**

**How do we do that?**

Learn what an average event looks like,

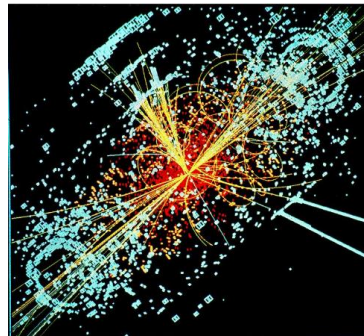
pick things that are rare

**Basic idea:**

Autoencoder, trained on random beam events

Reconstruction error is a metric for anomalous-ness

Typical Event



Signal/BSM  
Event

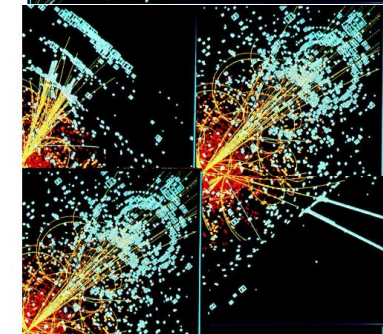
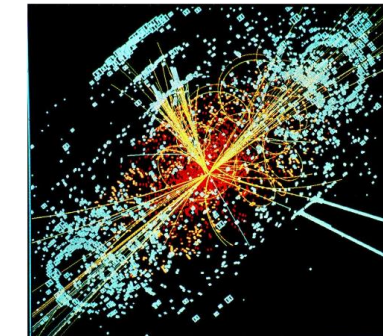
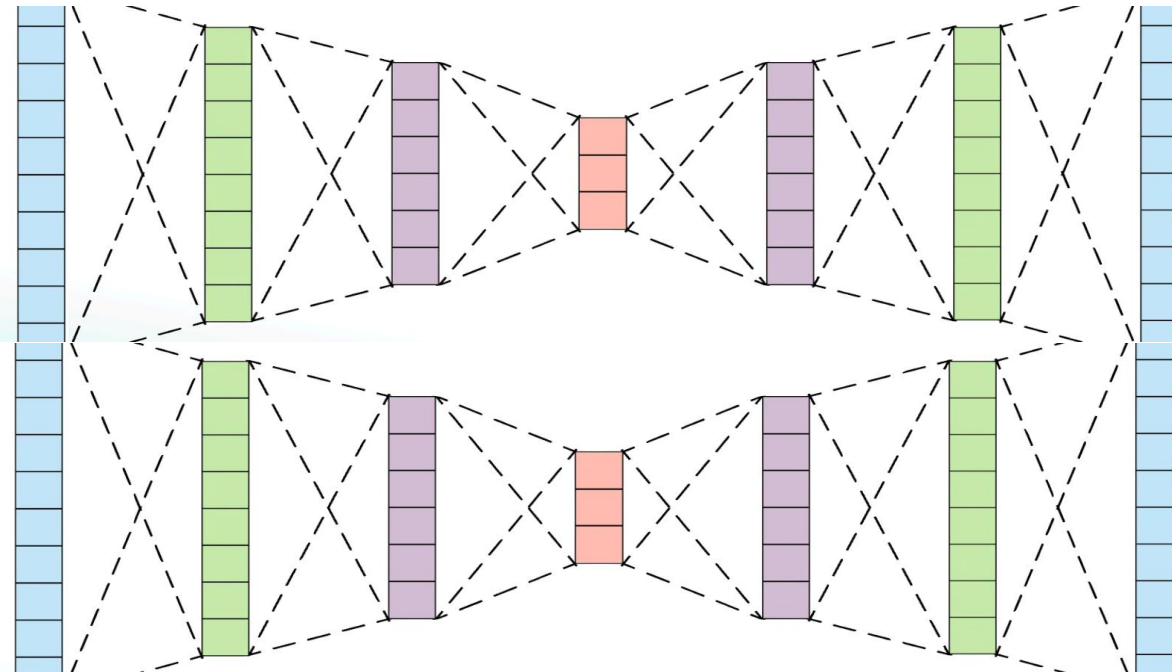
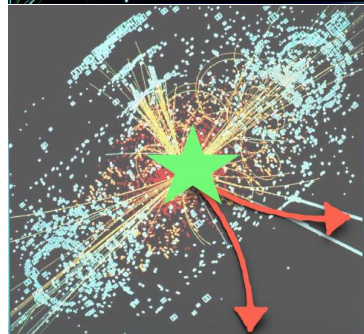
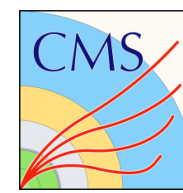


Image credit to Abhijith Gandrakota

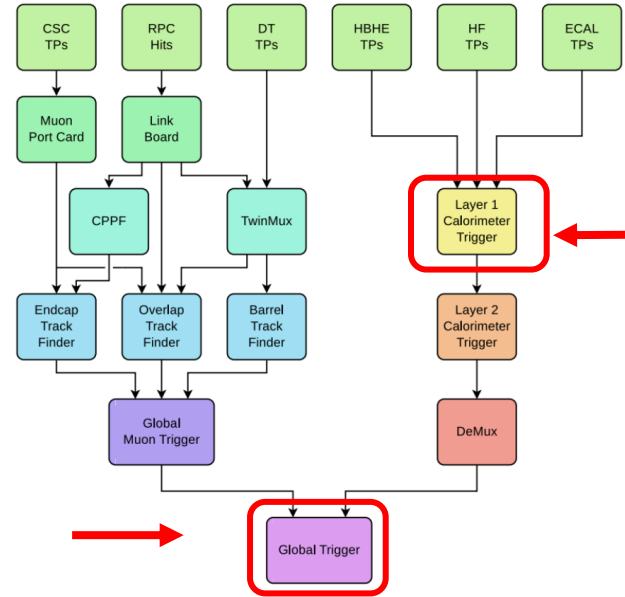
# CICADA and AXOL1TL



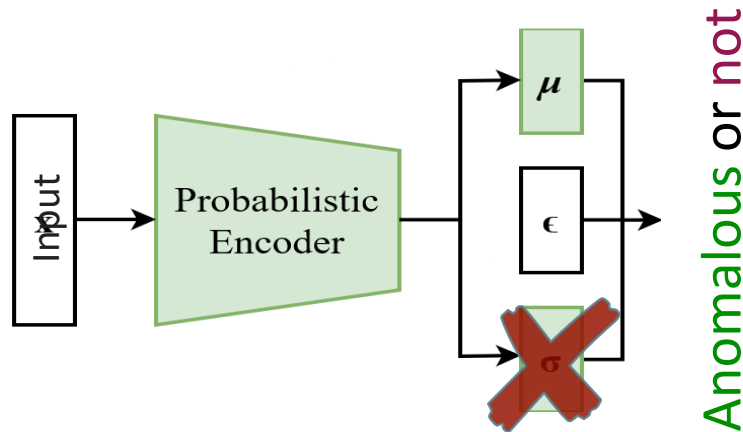
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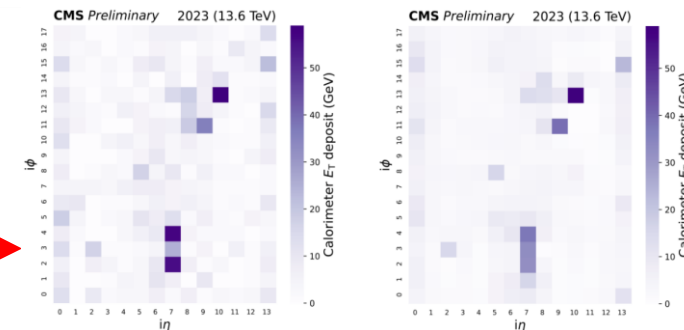
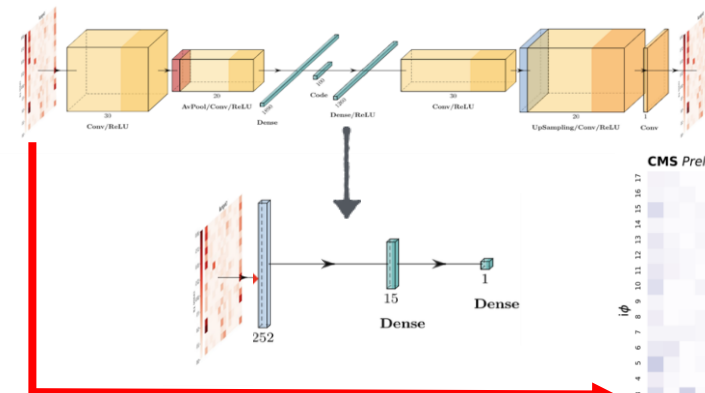
- Uses L1T objects as input
- Uses variational autoencoder
  - Latent space is Gaussian distributed
- Uses anomaly metric  $\mu^2$



- Uses bare calorimeter inputs
- Uses convolutional autoencoder
  - Suited for image inputs
- Uses mean squared error as metric, and smaller model to predict final score



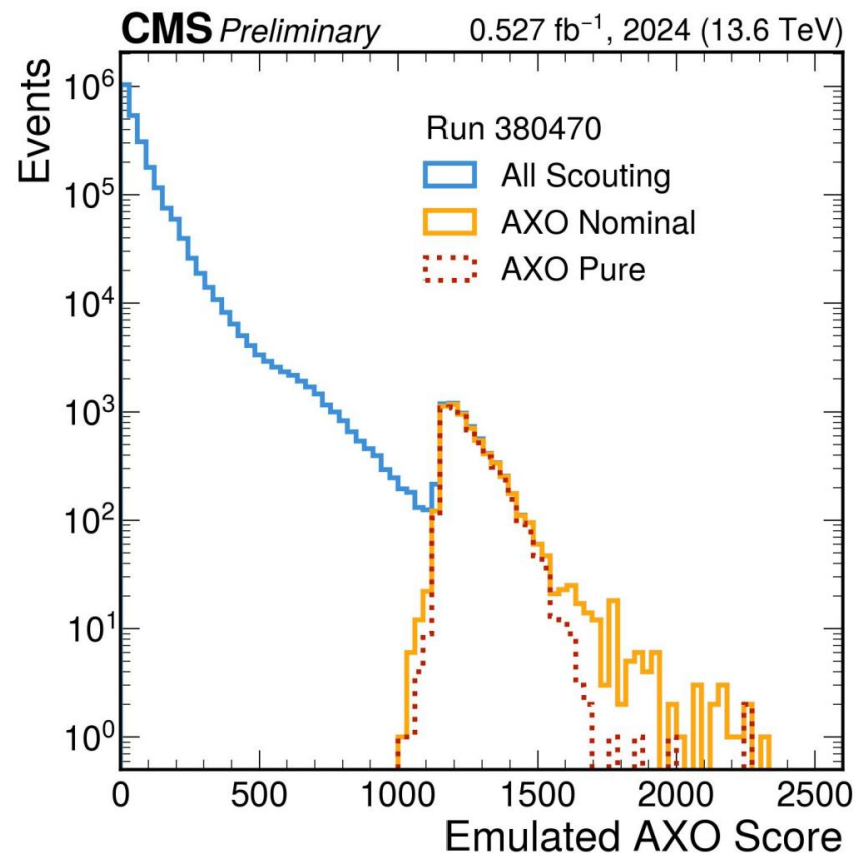
See [Abhijith's Talk!](#)



# AD Score Characteristics

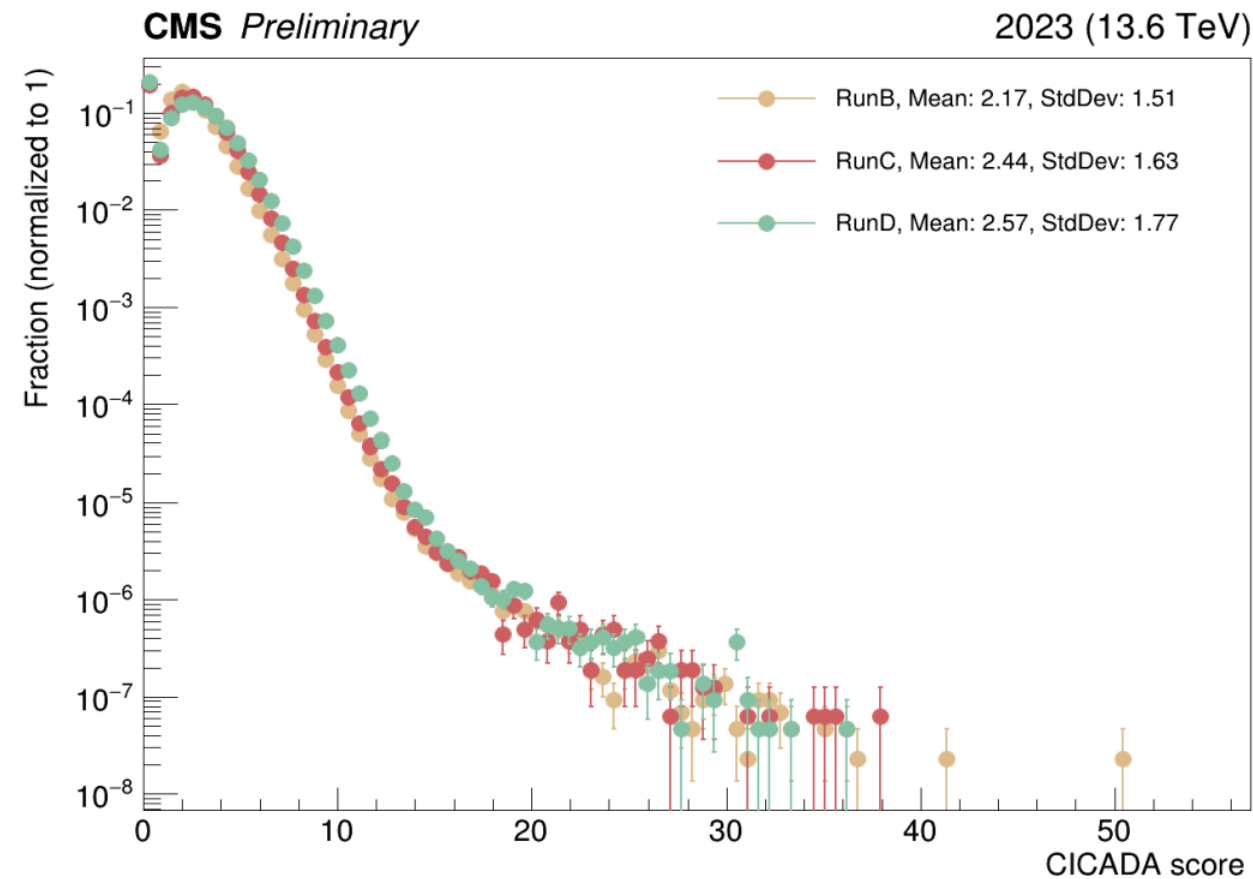


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Distribution of AXOL1TL emulated scores for AXOL1TL triggered events. Scores are shown for the nominal triggered bit, as well as the events where AXOL1TL is the only event

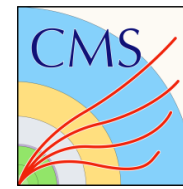
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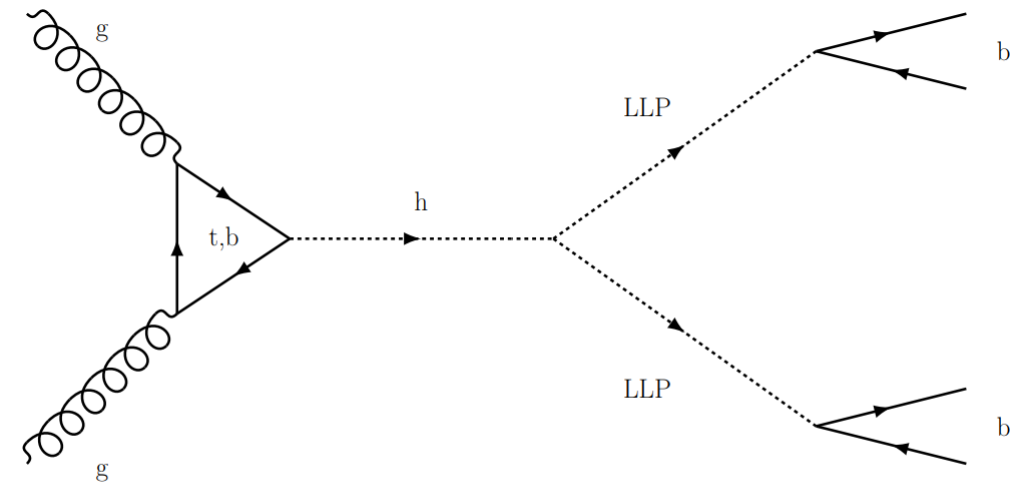
Distribution of Emulated CICADA scores for various 2023 periods. The average CICADA score is resilient to era based effects. Note: the model shown is not the final version



# Long Lived Particles: Impetus

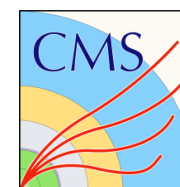


- Many models predict the existence of **long lived exotic particles** (LLPs)
  - Many Exotic scenarios not envisioned when the trigger system was being designed!
- Long lived particles transit layers at later times,
  - Precise timing information
- LLPs can decay to displaced particles
  - Precise position information

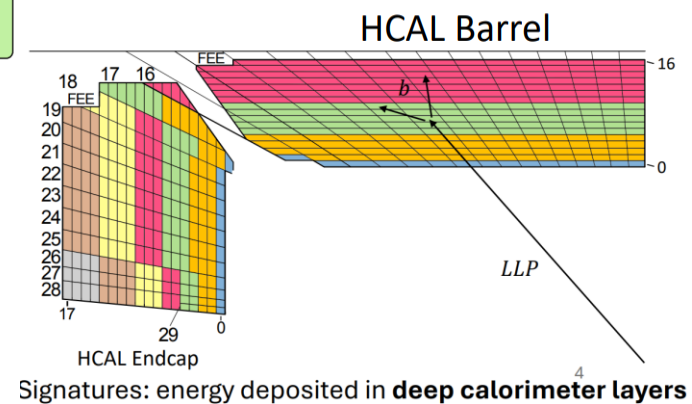
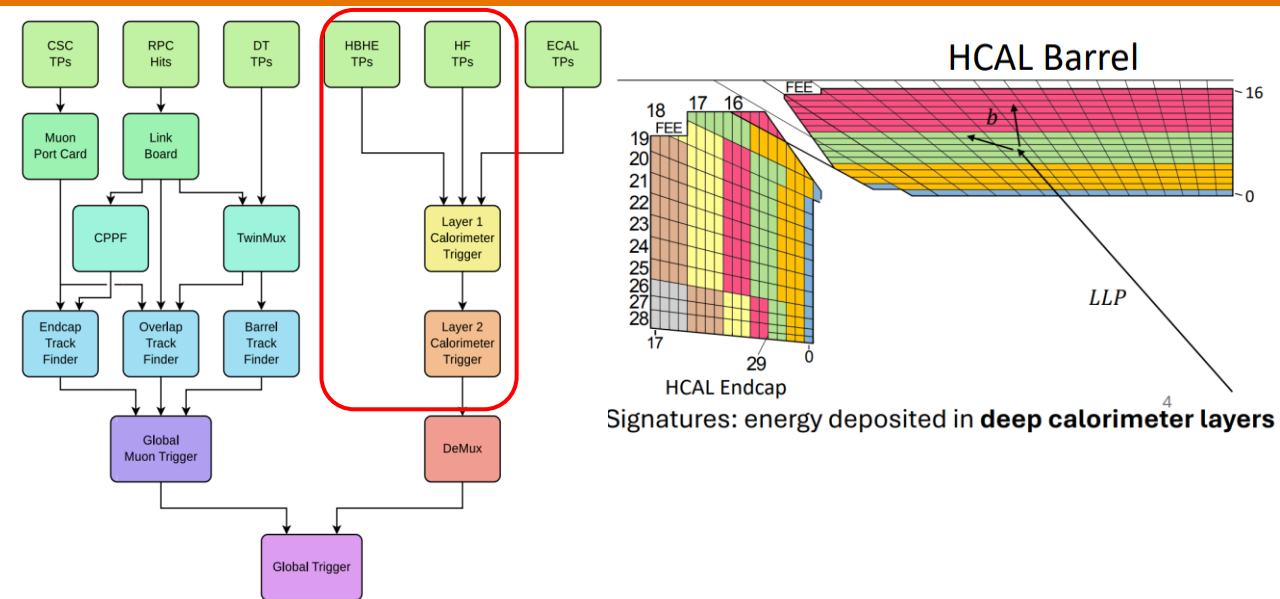


$$H \rightarrow SS \rightarrow \bar{b}b\bar{b}b$$

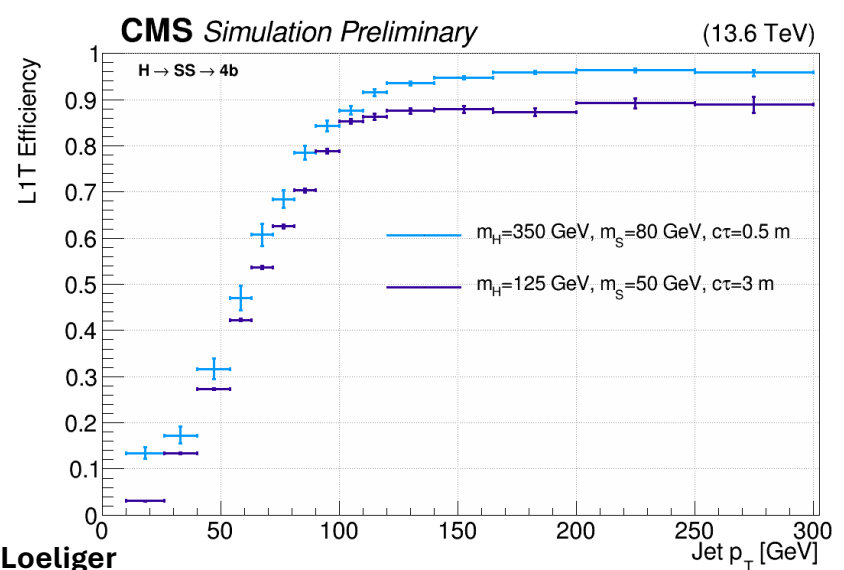
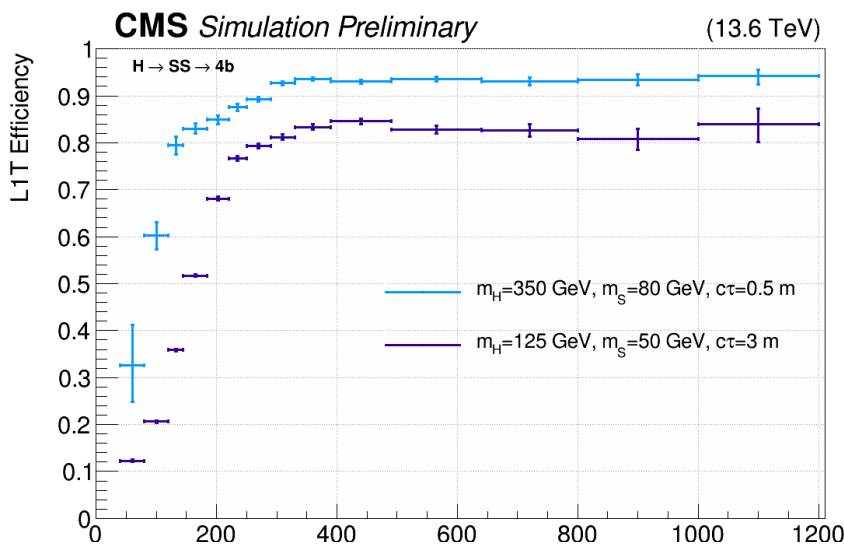
# HCAL+Trigger Upgrades for LLP



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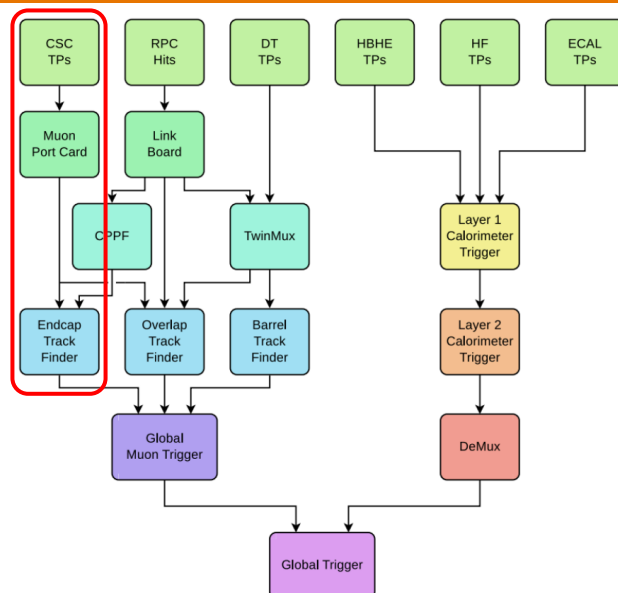
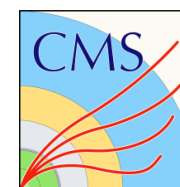


- HCAL timing alignment necessary to time incoming LLP products
  - **Timing** and **depth** both used to flag LLPs in trigger
  - First use of upgraded HCAL information at L1T



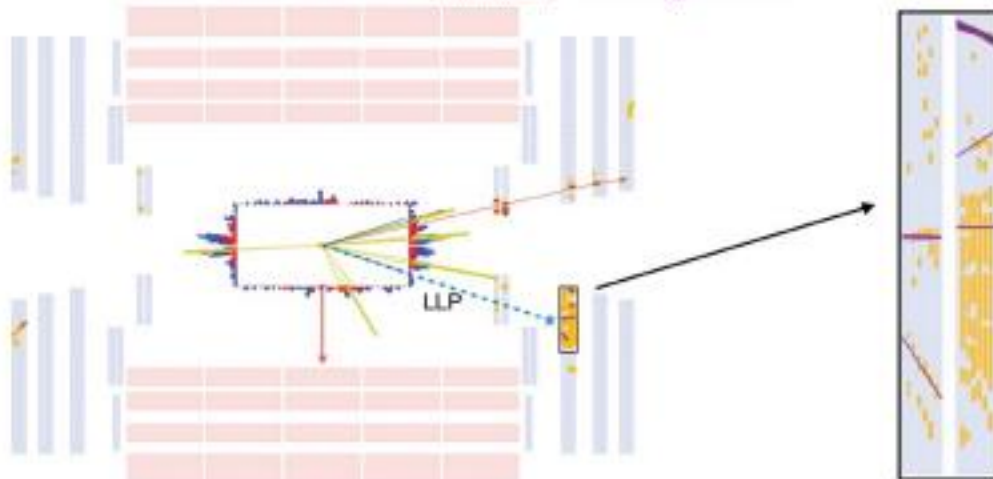
Peak Efficiency of the Depth + Timing LLP triggers is achieved at 300 GeV for HT, and 125 GeV for Jet PT, which allows sensitivity to events that other traditional triggers (or even LLP focused triggers) would not allow.

# High Multiplicity Trigger For LLPs



- Another recent trigger idea is **high multiplicity triggers for LLPs**
- LLP interacts in muon detector systems
  - Result: shower of charged particles that get picked up as muon chamber hits
- Count chamber hits to find high multiplicity muon events to fire the trigger
- Proof of concept for HL-LHC muon system triggers!

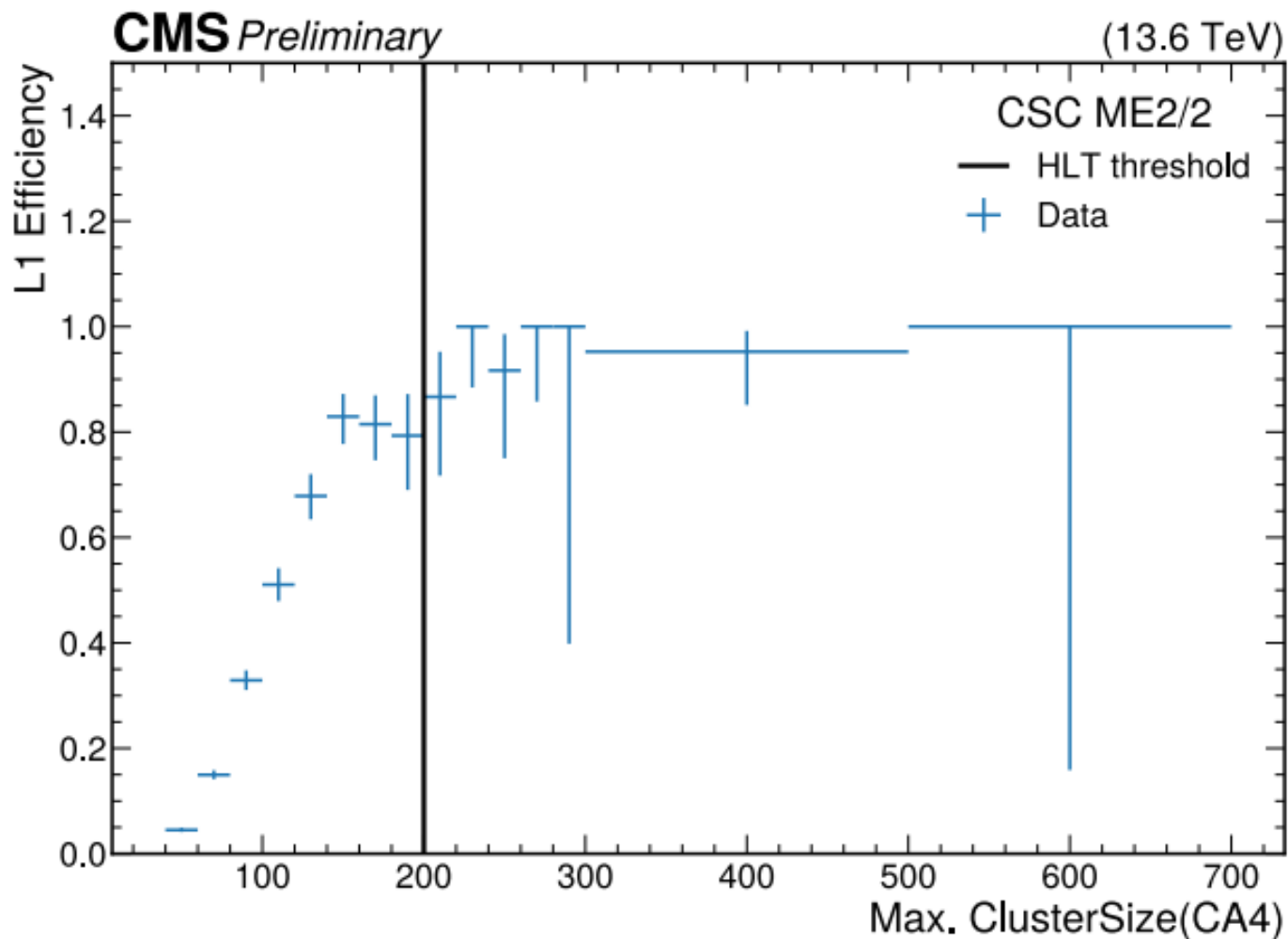
-1100 rechits & 33 segments in ME-2/1



MC Summer16

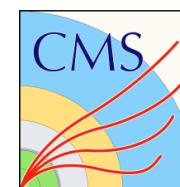
[CDS link](#)

# Multiplicity Trigger Results

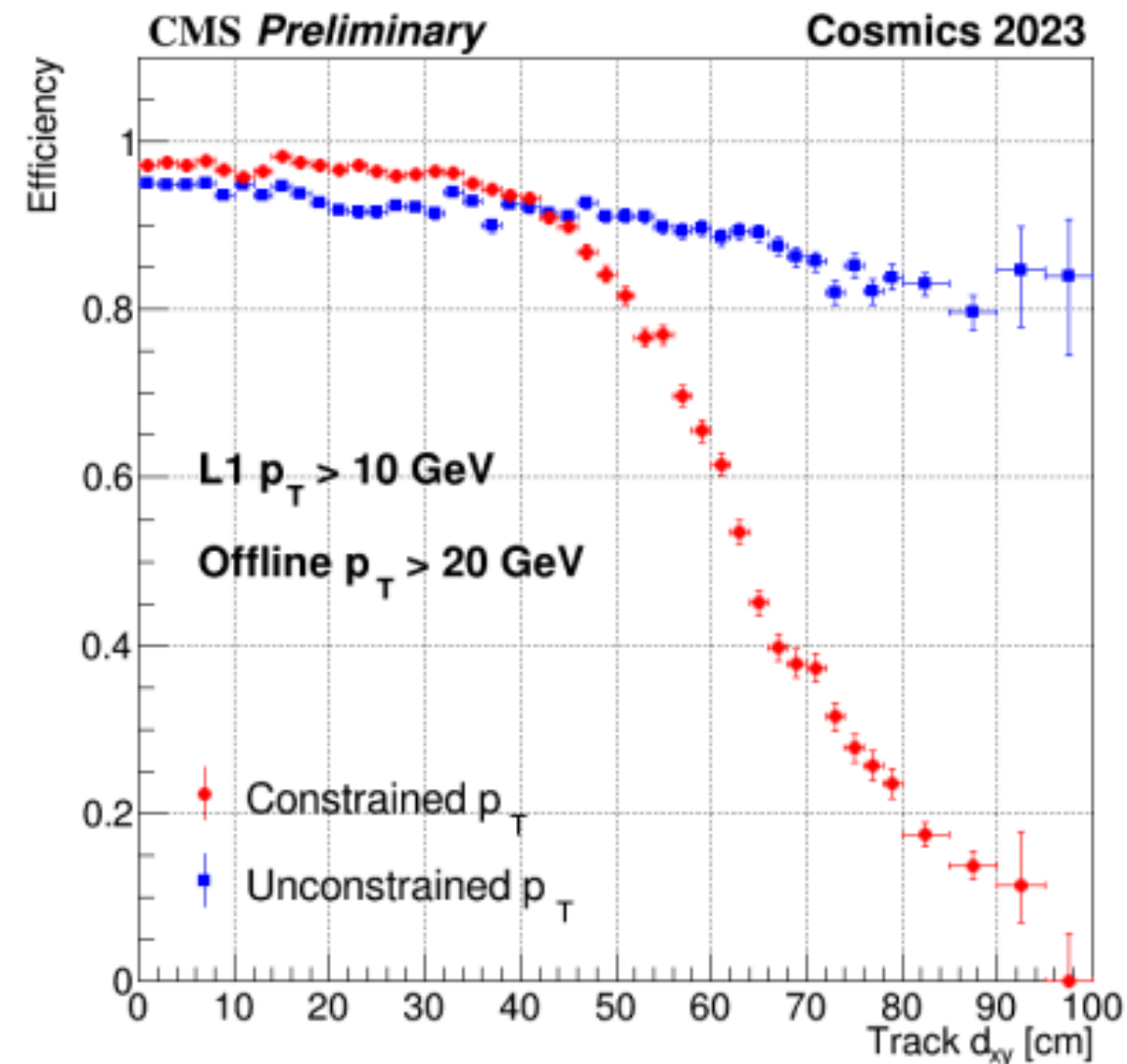
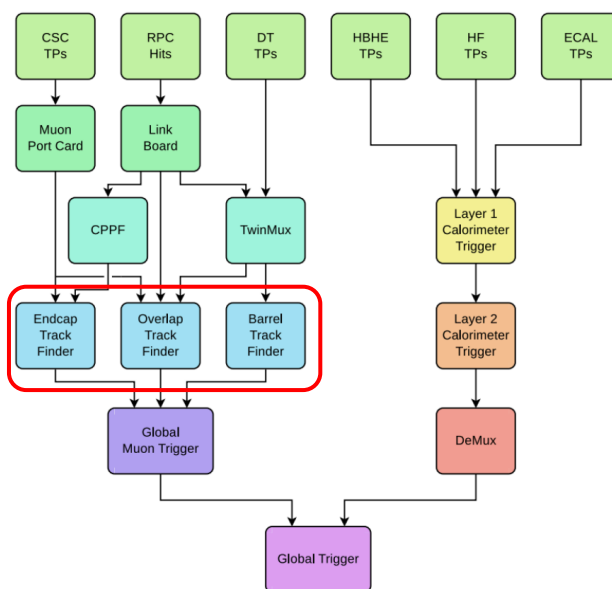


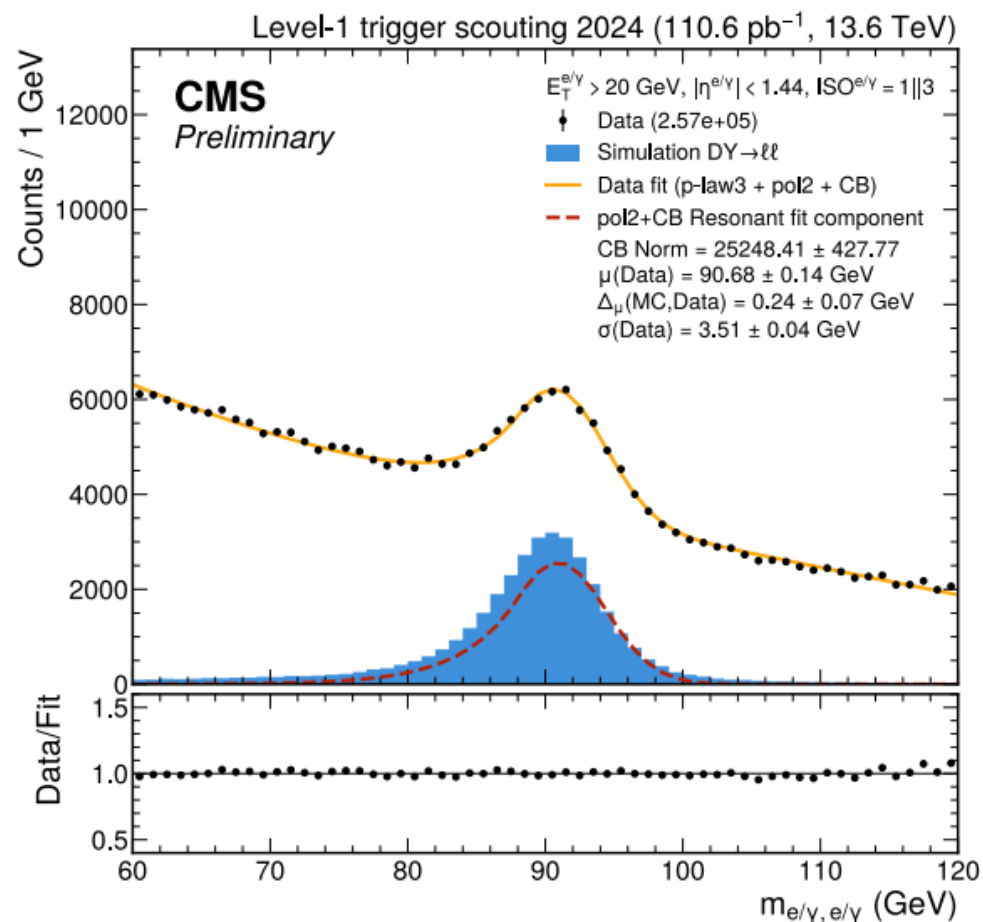
Efficiency of multiplicity trigger versus size of reconstructed HLT hits

# Displaced Muons

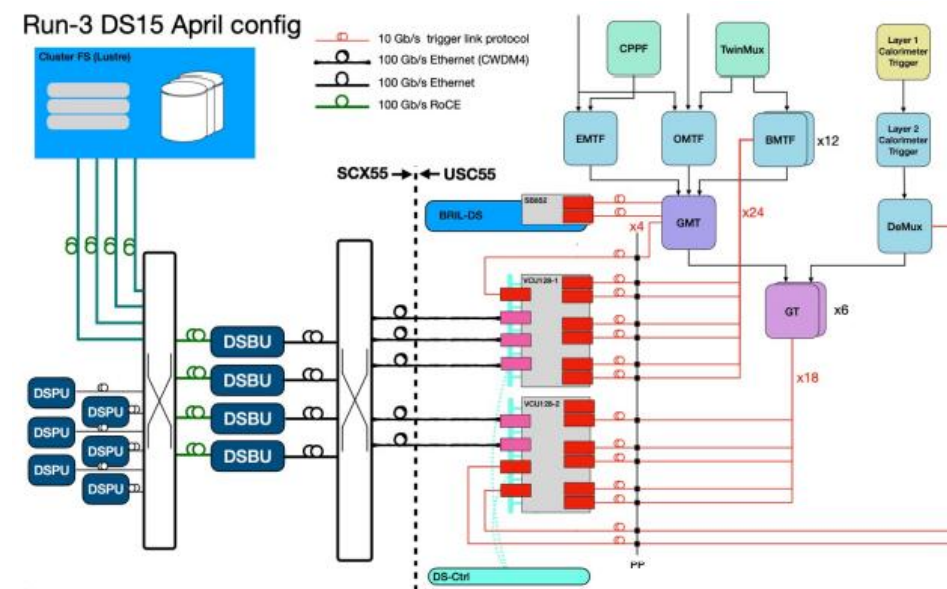


- A related idea: search for displaced muon vertices
  - Extended to overlap and endcap regions recently
- Traditional muon  $p_T$  assignment uses beam spot as a constraint.
- New vertex unconstrained  $p_T$  assignment methods improve trigger sensitivity to highly displaced muon



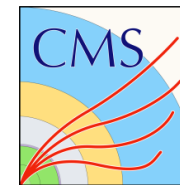


- L1T data scouting is a new L1T-Objects-As-Reconstruction data-taking system
  - Proof of concept for HL-LHC system
    - Proof of concept measurement (left)
  - Up to 8 Muons per bunch crossing, and up to 12  $e/\gamma$ , jets and  $\tau$ 's per event
  - 40 MHz Scouting. “Real time data analysis”

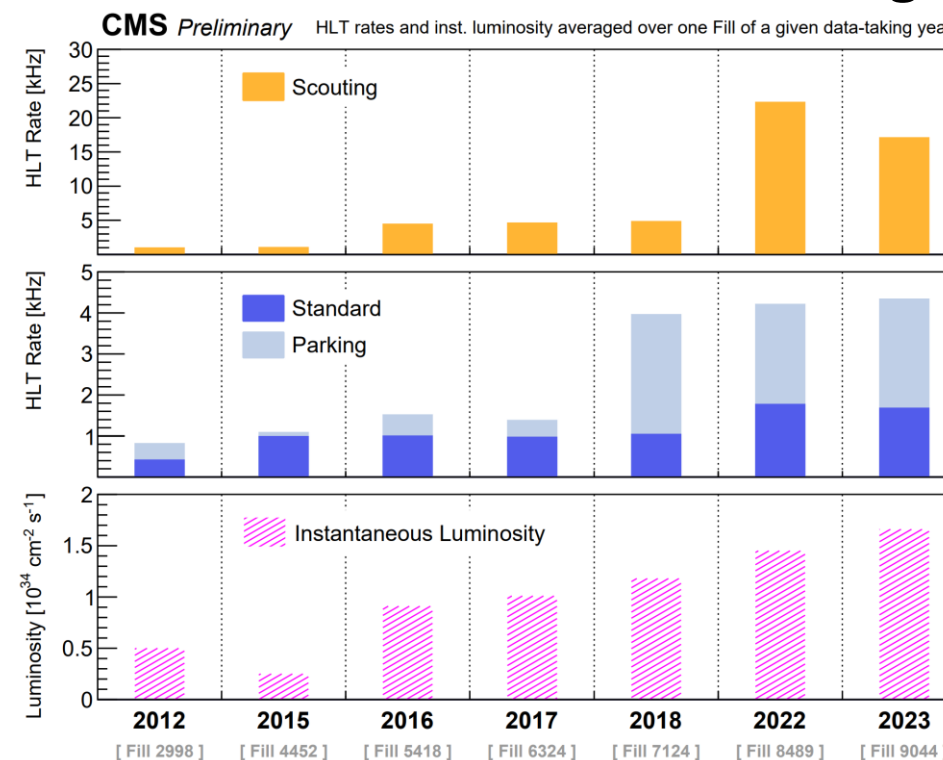


# High Level Trigger

# HLT: Parking & Scouting



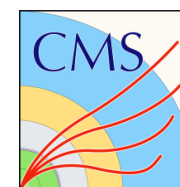
- The Trigger is already performing beyond it's design parameters
  - Can try to get more out of it with trigger-level-analysis (scouting) or delayed/opportunistic reconstruction (parking)
  - Run 3 has drastically expanded the rate/data afforded to both strategies!
- Of note: single muon parking added, based on B-physics proposal & L1T very high quality muons
  - Higher purity is achieved at L1T by using tighter muon track quality requirements. This allows looser muon pT thresholds to be used in 2024



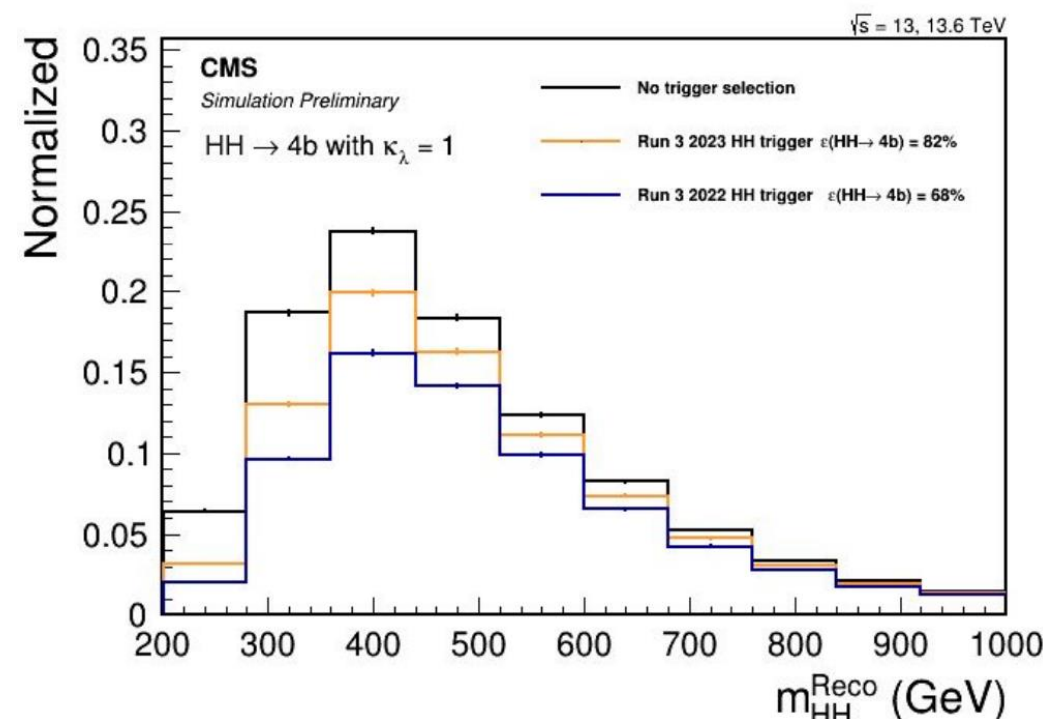
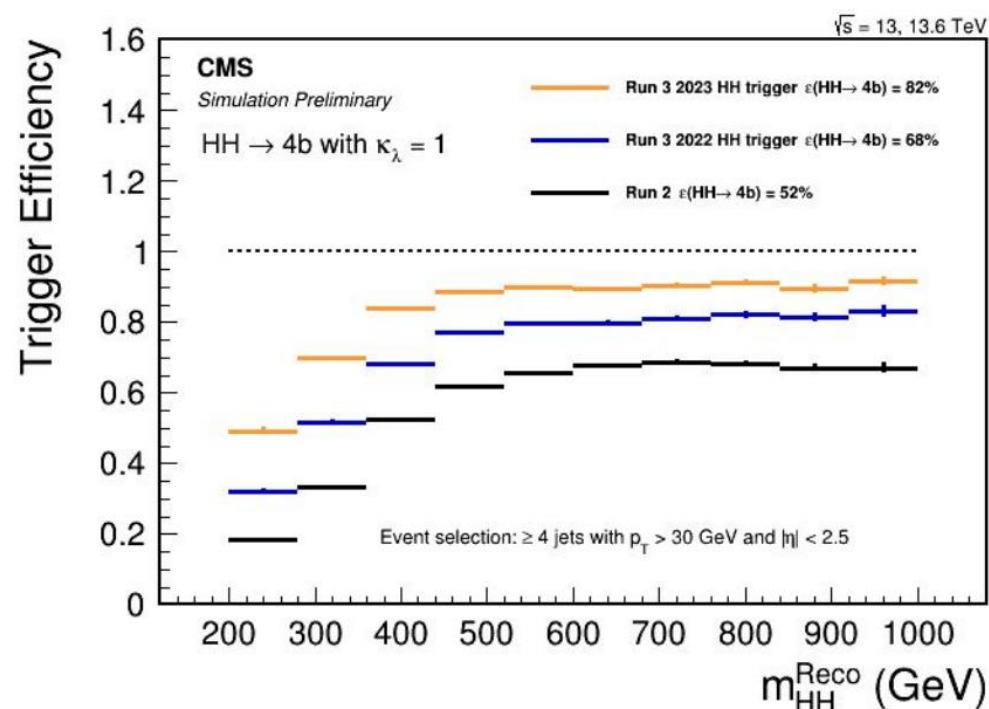
[Paper](#)



# HLT: HH & HHH Triggers



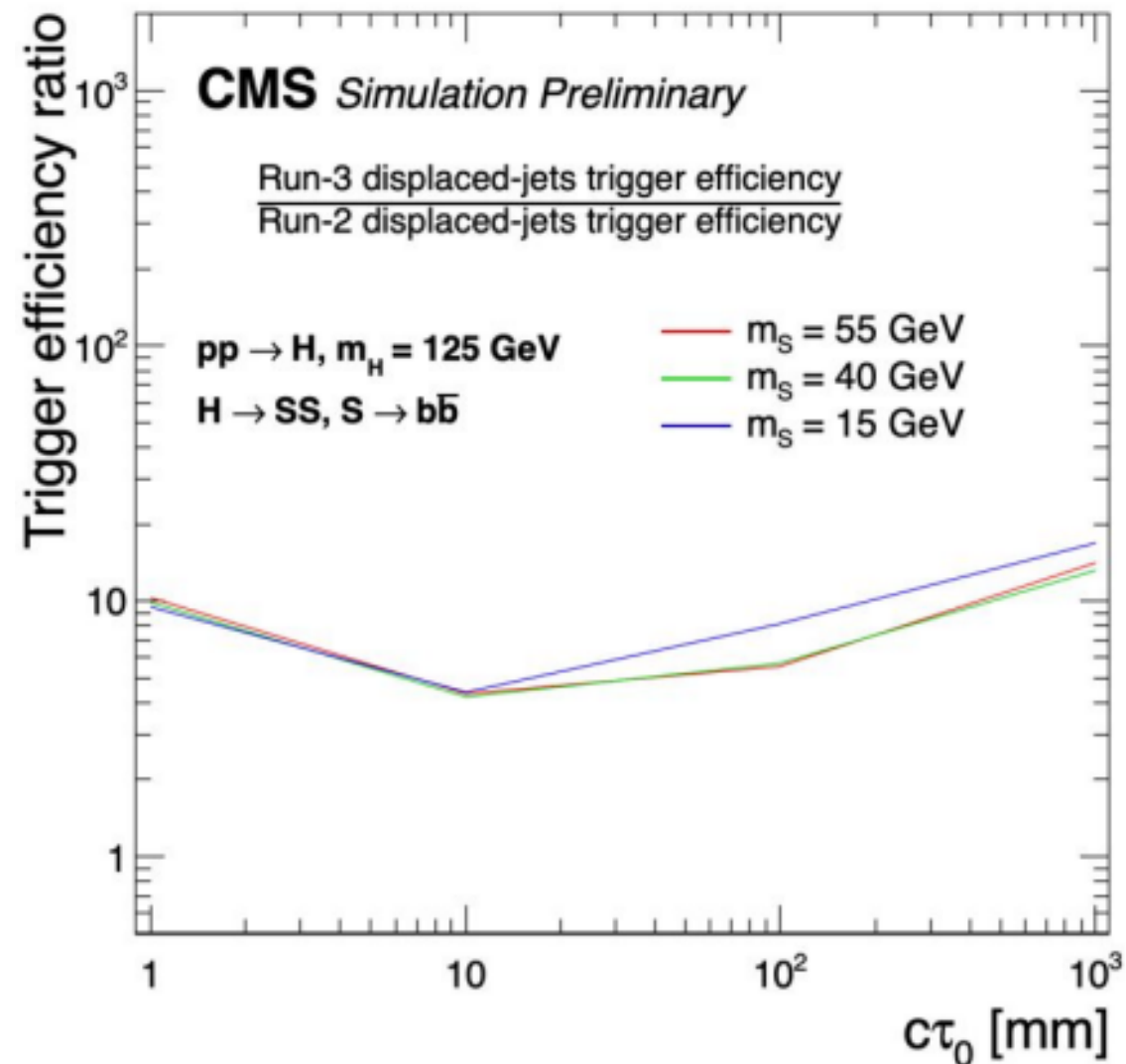
- Still room to improve the measurement of Higgs self coupling
- New HLT trigger using Particle Net b-tagging scores & multiple jets
- Combined with parking strategy and L1T changes improves multi-Higgs signal efficiency



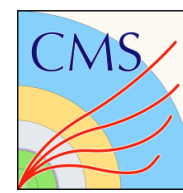
# HLT: LLP Displaced Jet Trigger



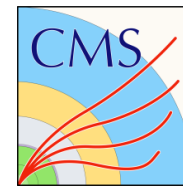
- One of the first dedicated CMS LLP triggers
- Uses tracking capabilities of HLT to find displaced jets
- Idea has been used since Run 2 but Run 3 capabilities have improved the Run 3 trigger over run 2 by a factor of  $\sim 4-11$ 
  - Loosened trigger requirements



# Further Afield: Other ideas, and towards the HL-LHC



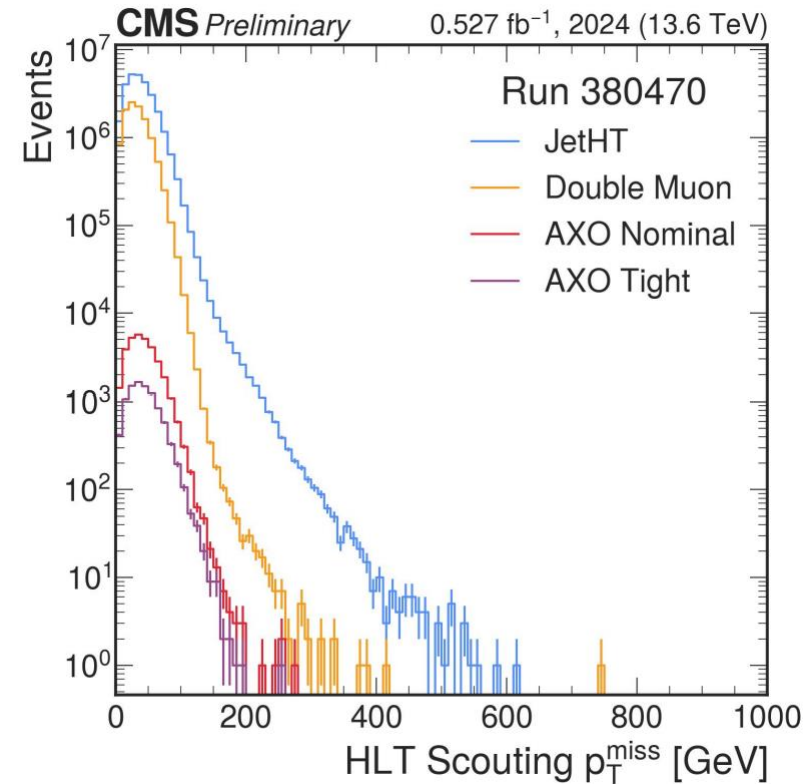
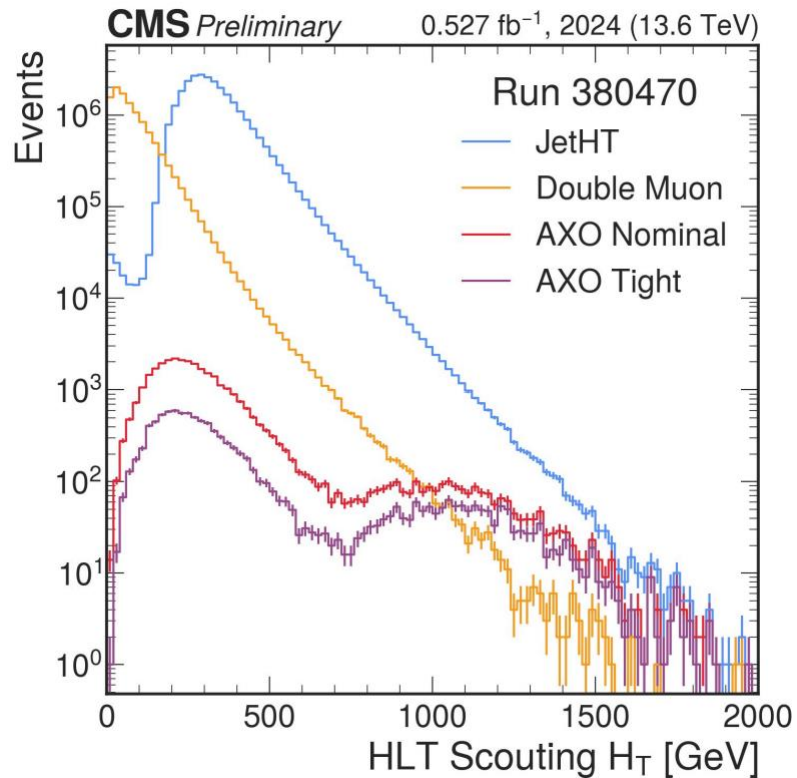
- L1T
  - Some ideas I will mention that are still in various stages of development
    - More complicated multiplicity triggers for calo objects
      - Inspired by anomaly detection triggers
    - Boosted jet triggers
  - Run 3 methods (in particular the anomaly triggers) are using methods that will become common in phase 2
    - HLS4ML
    - HLS4ML emulation
      - Firmware as emulator!
    - Displaced trigger ideas will get more powerful with the addition of tracker information to trigger systems
- HLT
  - Increased use of GPU (& other) hardware
- [See Sioni's talk](#)



- **L1T**
  - **In General**
    - HLS algorithm strategies, particularly ML/AI strategies
    - Designs mirroring or advancing HL-LHC triggers
  - **Anomaly Detection** an exciting new idea about to be launched
    - AXOL1TL
    - CICADA
  - Multiple **Long Lived Particle** strategies
    - Timing based trigger
    - Multiplicity trigger
  - **Displaced Muons**
  - **Scouting**
- **HLT**
  - **Parking and Scouting**
  - **Multi-Higgs triggers**
  - **Long Lived Particle** strategies
- Other new ideas leading towards the HL-LHC!

# Backup

# AXOL1TL Preferences



# L1T Scouting Occupancy



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