Illustration by Sandbox Studio, Chicago with Ariel Davis

UNIVERSITY OF OXFORD

Trigger Happy: Exploring the CMS Level-1 Trigger System

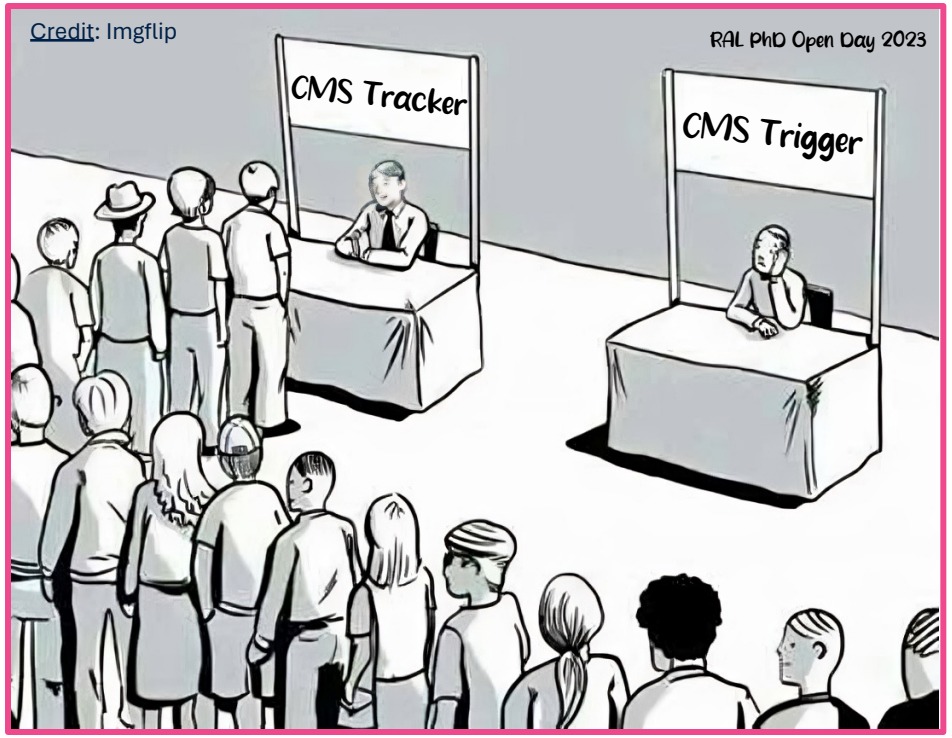
Abbey Barnard

abbey.barnard@physics.ox.ac.uk

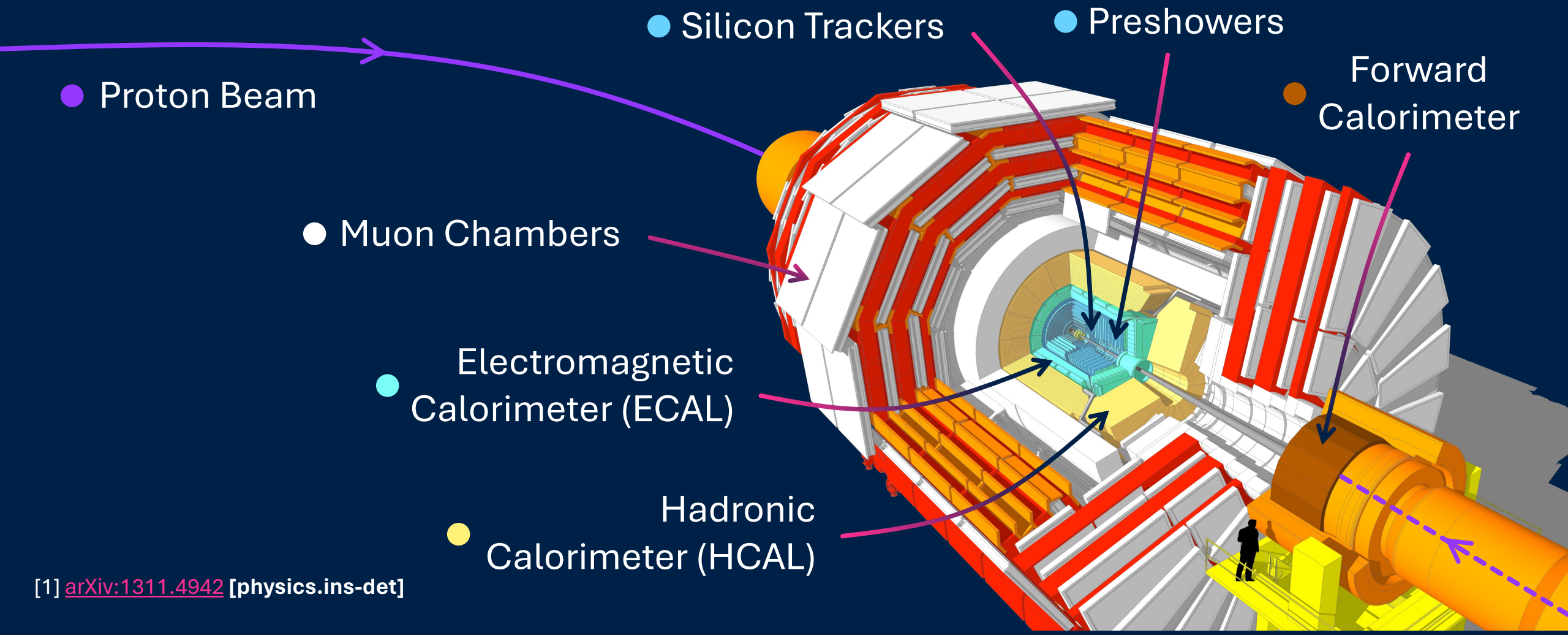
Wednesday 13th March 2024

Outline

- ★ Introduction to CMS
- ★ The CMS Trigger System
- ★ The Level-1 Trigger System
- ★ Triggering for Higgs Using the Level-1 Trigger System



The Compact Muon Solenoid (CMS) Experiment



[1] arXiv:1311.4942 **[physics.ins-det]**

Blink and you'll miss it...

★ Proton bunch collision rate ~ 40 MHz in CMS

$$\frac{dN}{dt} = \mathcal{L}\sigma$$

$\frac{dN}{dt}$ = collision rate

$\mathcal{L}$ = luminosity

σ = cross-section

★ CMS can only save ~ 1000 events per second, and they are not all useful

Blink and you'll miss it...

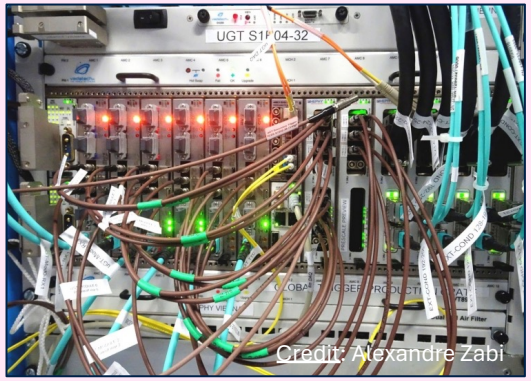
How do we select the most interesting events, fast?

The two-tier trigger system allows us to quickly select events of interest and store them for later use

40 MHz

Level-1 Trigger (L1)

Custom hardware



3.8 μs

100 KHz

High Level Trigger (HLT)

Commercial PCs (software)

~ 300 ms

1 KHz

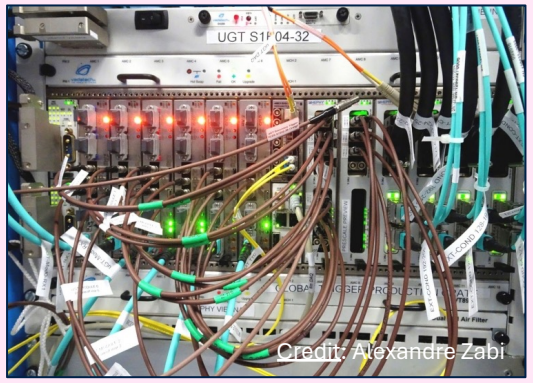
Upper limit constrained by readout electronics

[2] Triggering Discoveries 2018

The L1 trigger design is cleverly optimised for quick thinking, but it comes at a cost...

Level-1 Trigger (L1)

Custom hardware



3.8 μs

† Trigger primitives, discussed on the next slide

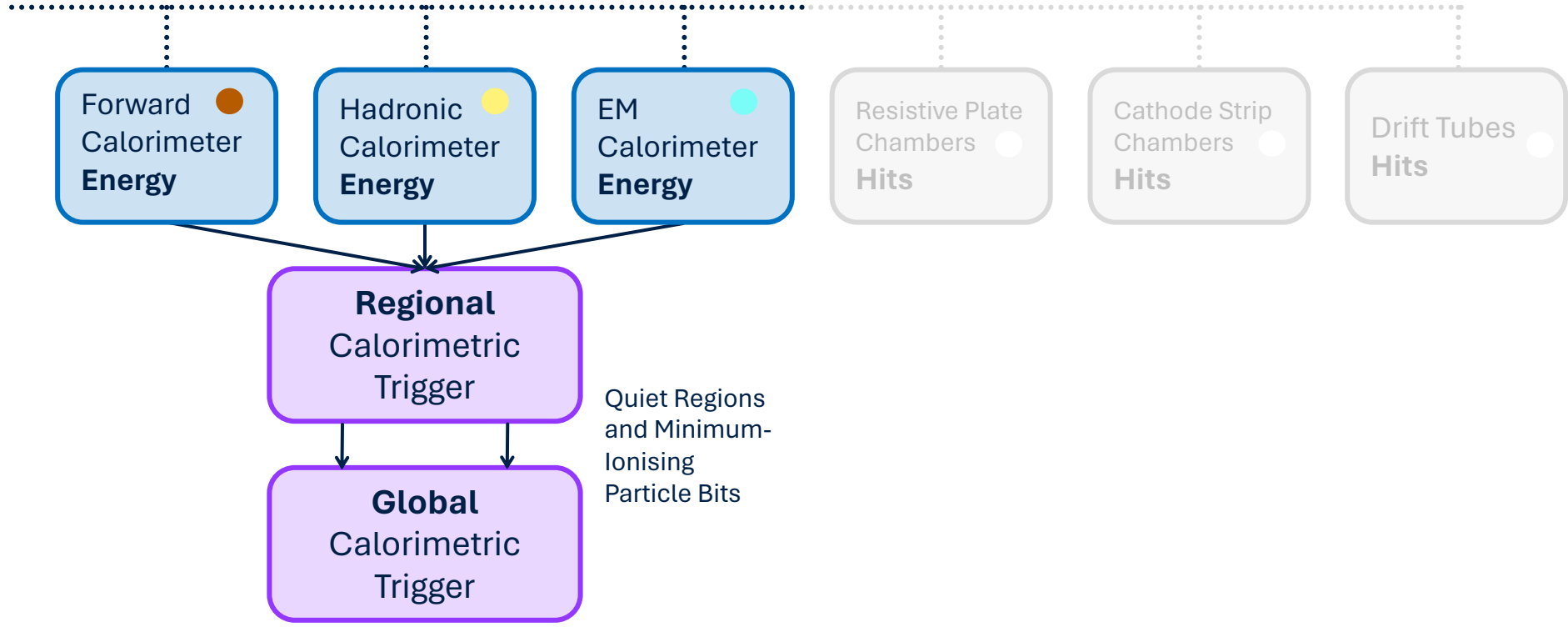
★ Use of up to 400 object-based algorithms to select desired events (Run 2)

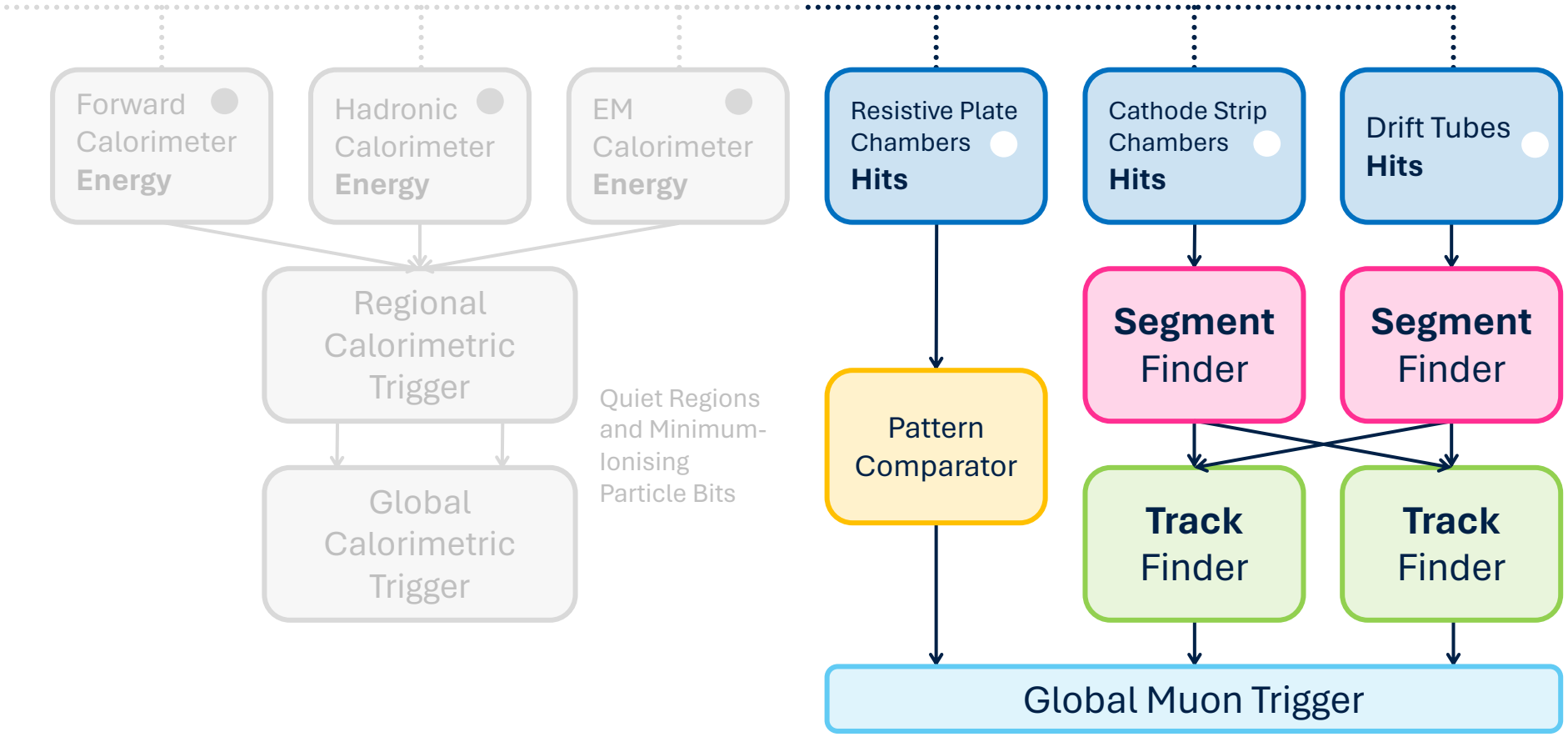
★ Compression of event data† increases reconstruction speed:

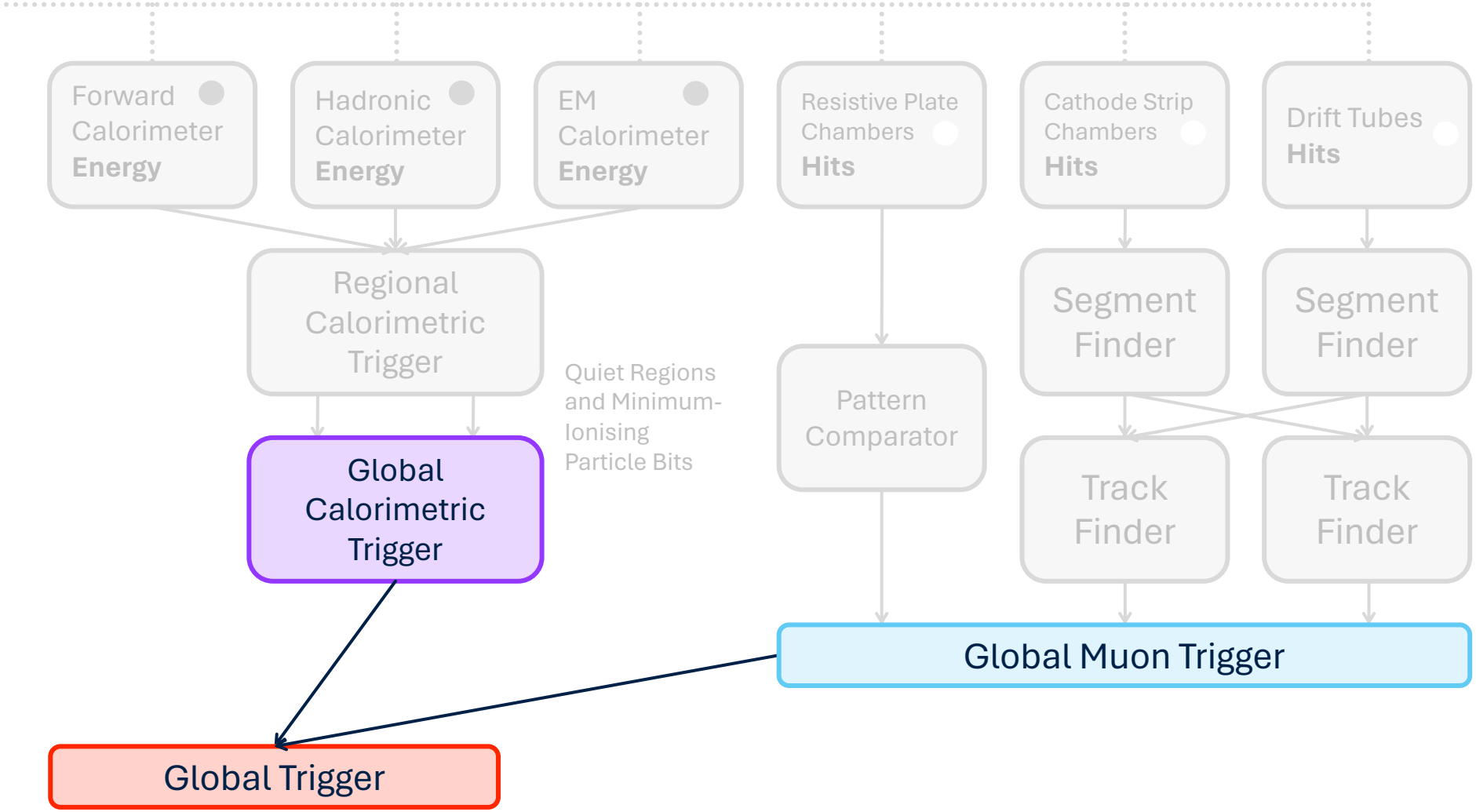
Reconstruction with L1T

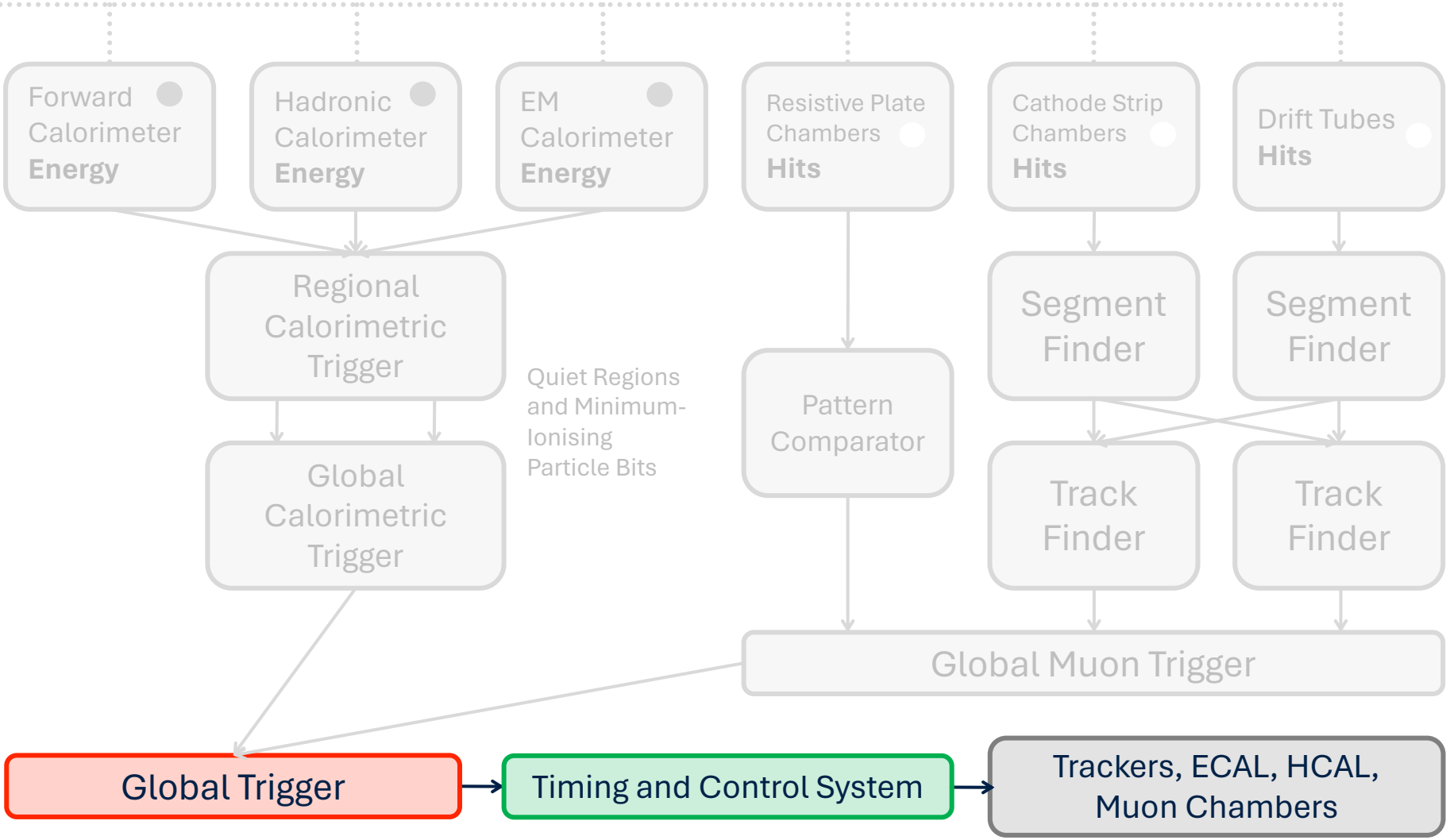
Reconstruction without L1T

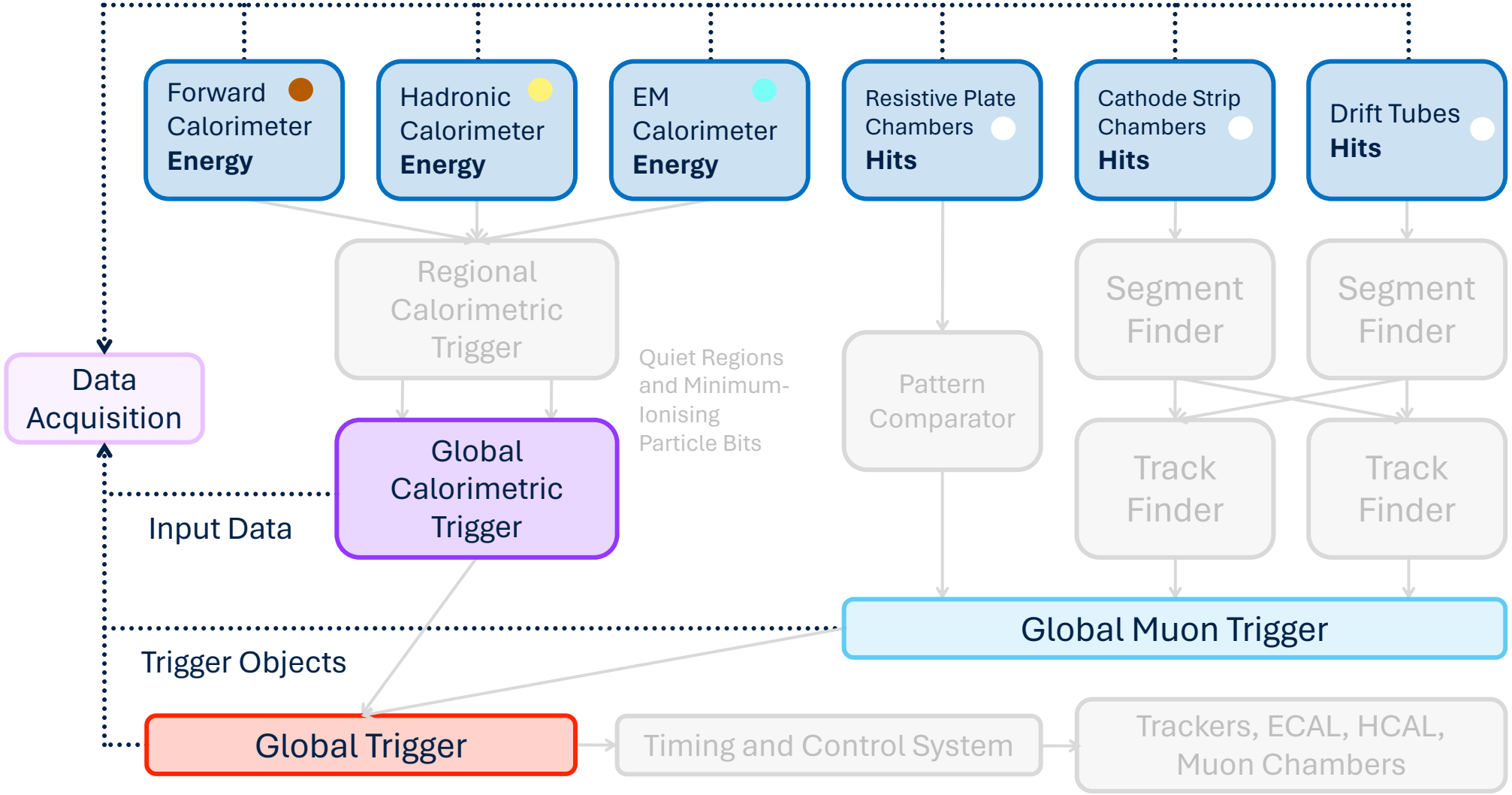

Forward Calorimeter **Energy**
Hadronic Calorimeter **Energy**
EM Calorimeter **Energy**
Resistive Plate Chambers **Hits**
Cathode Strip Chambers **Hits**
Drift Tubes **Hits**


Forward Calorimeter **Energy**
Hadronic Calorimeter **Energy**
EM Calorimeter **Energy**
Resistive Plate Chambers **Hits**
Cathode Strip Chambers **Hits**
Drift Tubes **Hits**
Regional Calorimetric Trigger
Global Calorimetric Trigger
Quiet Regions and Minimum-Ionising Particle Bits

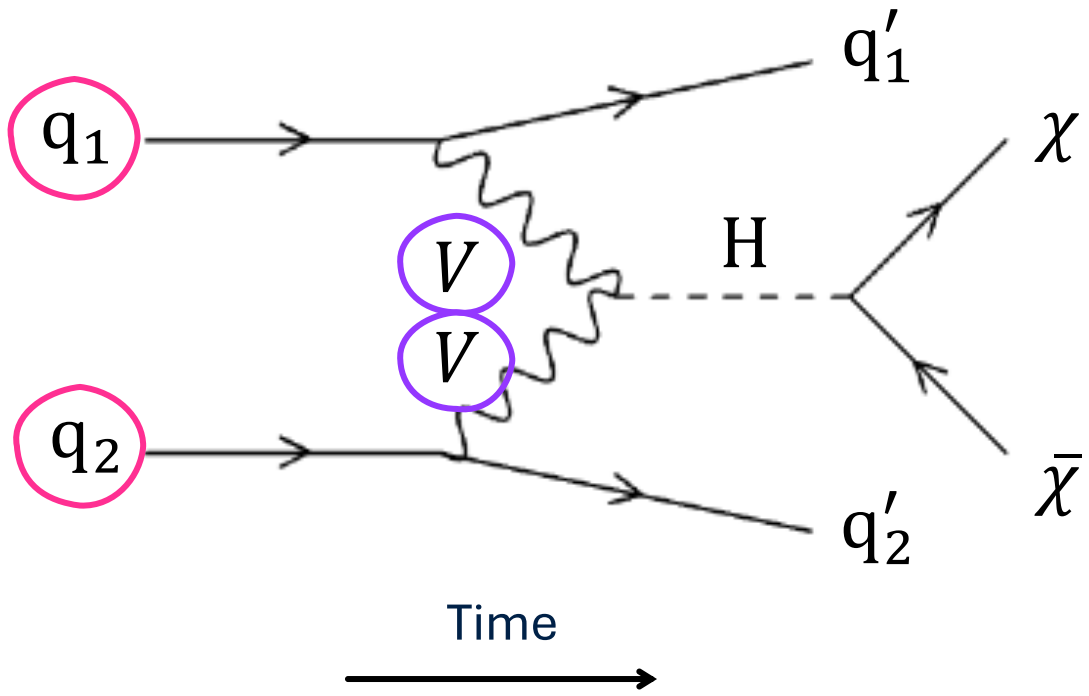

Forward Calorimeter Energy
Hadronic Calorimeter Energy
EM Calorimeter Energy
Regional Calorimetric Trigger
Global Calorimetric Trigger
Quiet Regions and Minimum-Ionising Particle Bits
Resistive Plate Chambers Hits
Cathode Strip Chambers Hits
Drift Tubes Hits
Pattern Comparator
Segment Finder
Segment Finder
Track Finder
Track Finder
Global Muon Trigger


Forward Calorimeter Energy
Hadronic Calorimeter Energy
EM Calorimeter Energy
Resistive Plate Chambers Hits
Cathode Strip Chambers Hits
Drift Tubes Hits
Regional Calorimetric Trigger
Quiet Regions and Minimum-Ionising Particle Bits
Segment Finder
Segment Finder
Pattern Comparator
Global Calorimetric Trigger
Track Finder
Track Finder
Global Muon Trigger
Global Trigger


Forward Calorimeter Energy
Hadronic Calorimeter Energy
EM Calorimeter Energy
Resistive Plate Chambers Hits
Cathode Strip Chambers Hits
Drift Tubes Hits
Regional Calorimetric Trigger
Global Calorimetric Trigger
Quiet Regions and Minimum-Ionising Particle Bits
Pattern Comparator
Segment Finder
Segment Finder
Track Finder
Track Finder
Global Muon Trigger
Global Trigger
Timing and Control System
Trackers, ECAL, HCAL, Muon Chambers


Forward Calorimeter Energy
Hadronic Calorimeter Energy
EM Calorimeter Energy
Resistive Plate Chambers Hits
Cathode Strip Chambers Hits
Drift Tubes Hits
Regional Calorimetric Trigger
Segment Finder
Segment Finder
Data Acquisition
Quiet Regions and Minimum-Ionising Particle Bits
Pattern Comparator
Global Calorimetric Trigger
Track Finder
Track Finder
Input Data
Global Muon Trigger
Trigger Objects
Global Trigger
Timing and Control System
Trackers, ECAL, HCAL, Muon Chambers

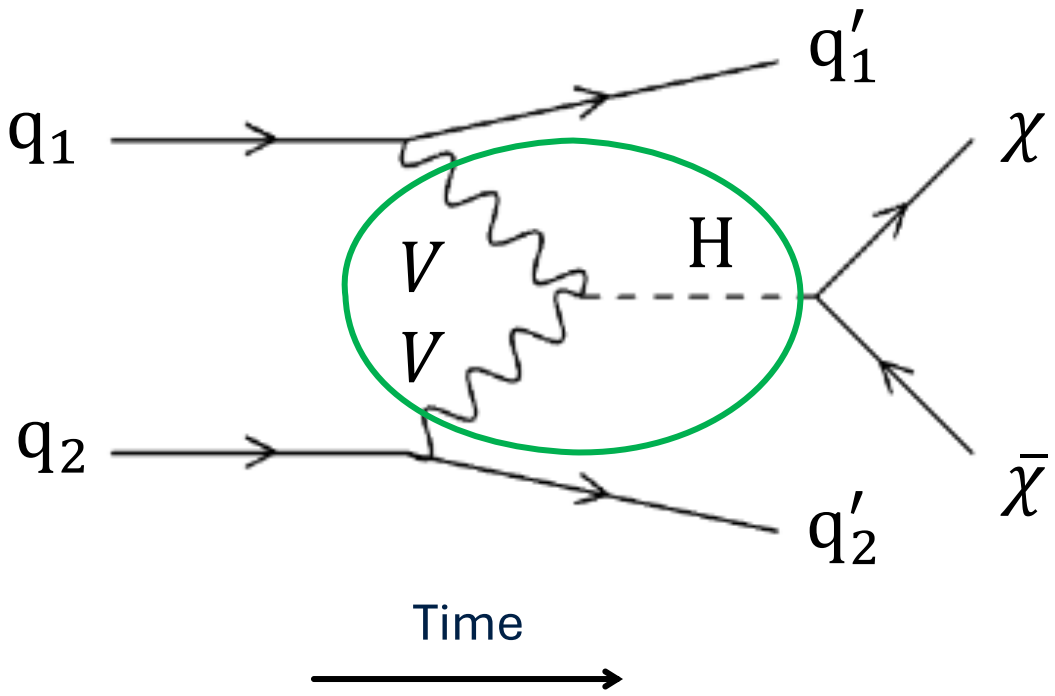
Higgs production from vector boson fusion (VBF) and invisible Higgs decay



★ Quarks from LHC protons radiate a heavy vector-boson *V* (W or Z)

[3] arXiv:2201.11585 **[hep-ex]**

Higgs production from vector boson fusion (VBF) and invisible Higgs decay

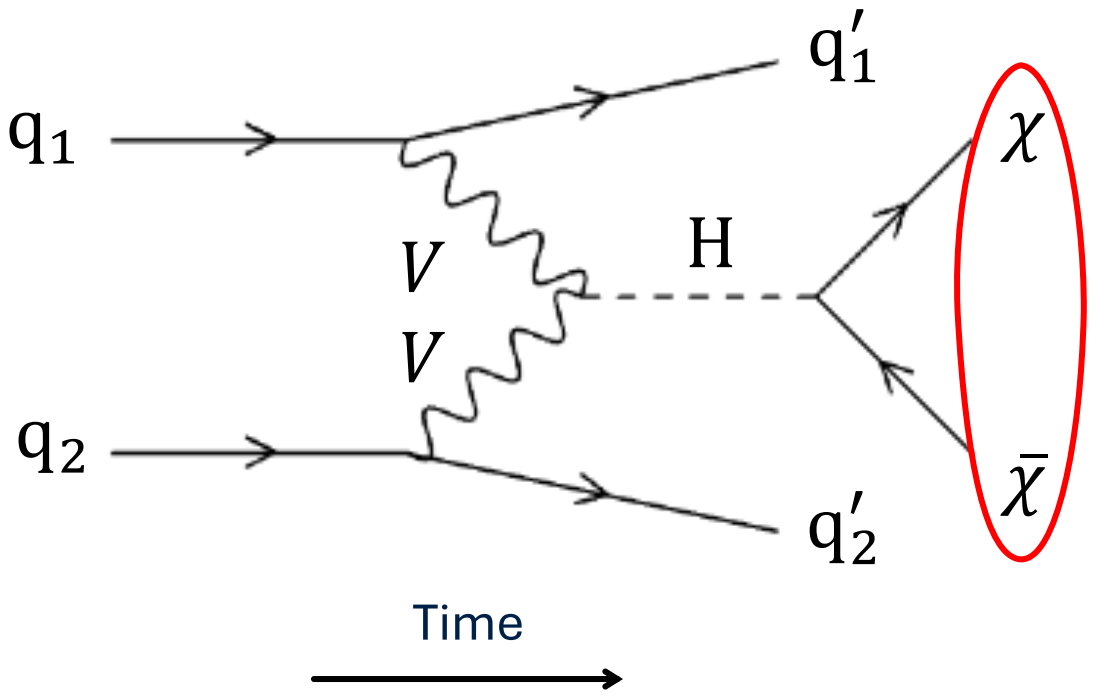


★ Quarks from LHC protons radiate a heavy vector-boson *V* (W or Z)

★ Heavy vector bosons fuse, producing a Higgs

[3] arXiv:2201.11585 **[hep-ex]**

Higgs production from vector boson fusion (VBF) and invisible Higgs decay



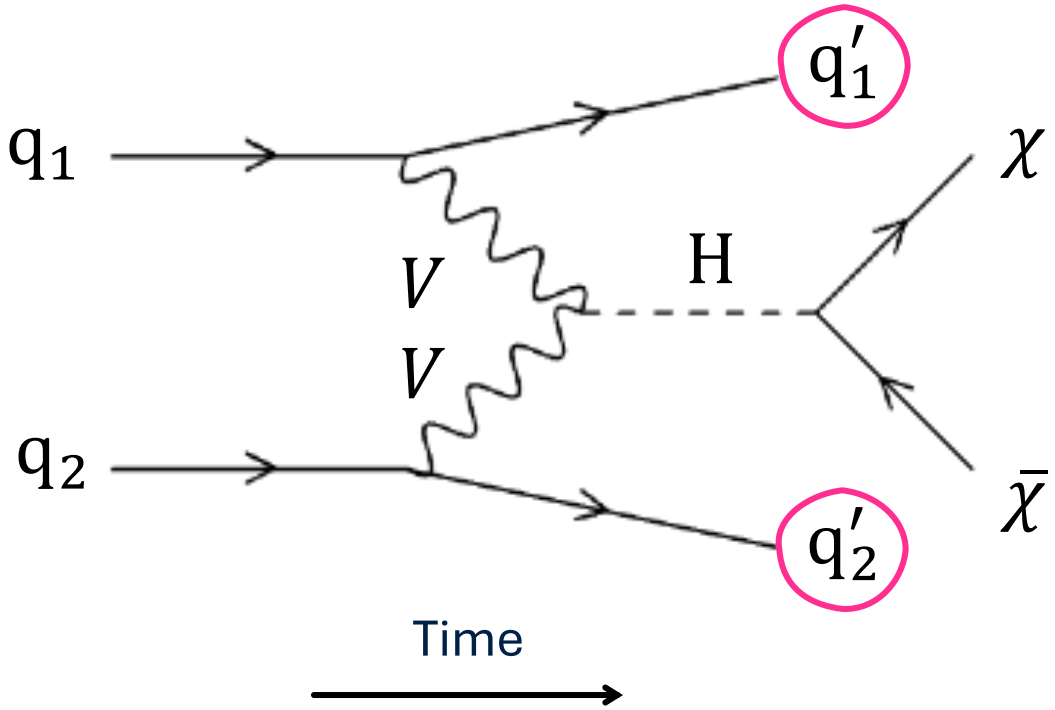
★ Quarks from LHC protons radiate a heavy vector-boson *V* (W or Z)

★ Heavy vector bosons fuse, producing a Higgs

★ Higgs decays into 'invisible' particles via $H \rightarrow ZZ \rightarrow 4\nu$ (Standard Model!)

[3] arXiv:2201.11585 **[hep-ex]**

An aside: Higgs production from vector boson fusion (VBF) and invisible Higgs decay



★ Quarks from LHC protons radiate a heavy vector-boson *V* (W or Z)

★ Heavy vector bosons fuse, producing a Higgs

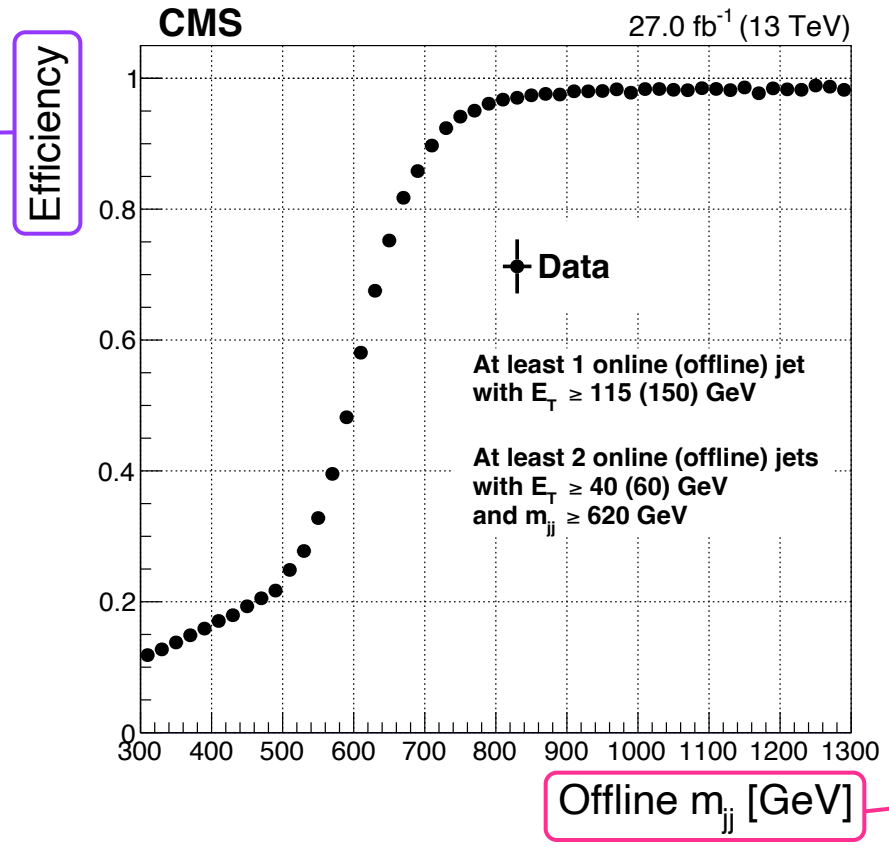
★ Higgs decays into 'invisible' particles via $H \rightarrow ZZ \rightarrow 4\nu$ (Standard Model!)

★ Quarks detected as jets

[3] arXiv:2201.11585 **[hep-ex]**

The Run-2 updated L1 analysis algorithms allow for triggering of the invisible Higgs decay through VBF

Measure of how well the L1 VBF trigger works

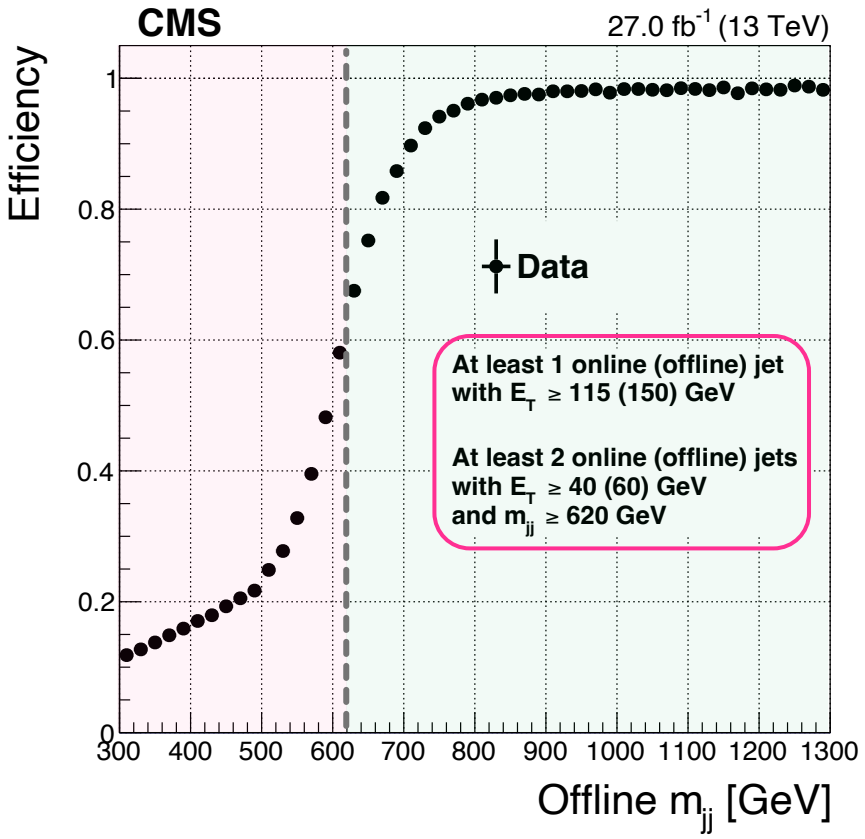


Maximum dijet invariant mass

Offline refers to stored data!

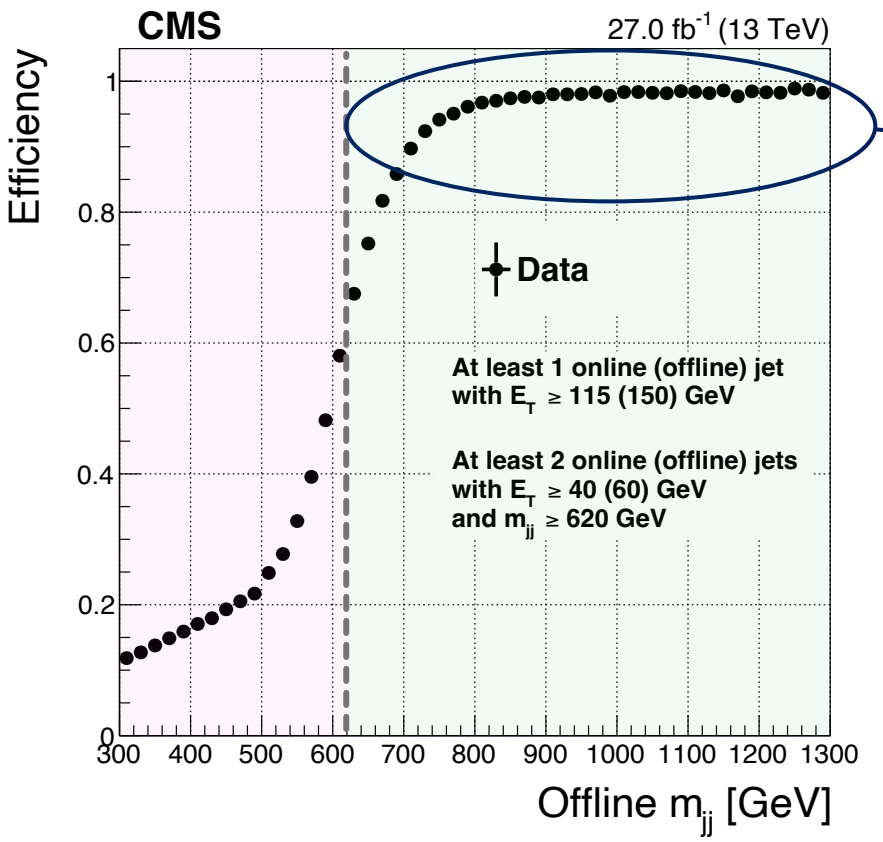
[b] arXiv:2006.10165 **[hep-ex]**

The Run-2 updated L1 analysis algorithms allow for triggering of the invisible Higgs decay through VBF



[b] arXiv:2006.10165 **[hep-ex]**

The Run-2 updated L1 analysis algorithms allow for triggering of the invisible Higgs decay through VBF



High-efficiency plateau for VBF-like events

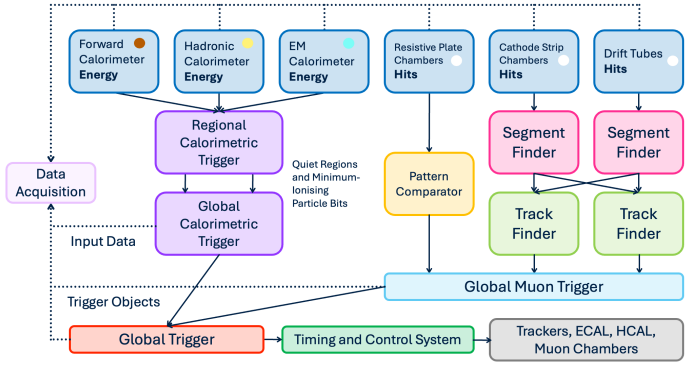
[b] arXiv:2006.10165 **[hep-ex]**

Summary

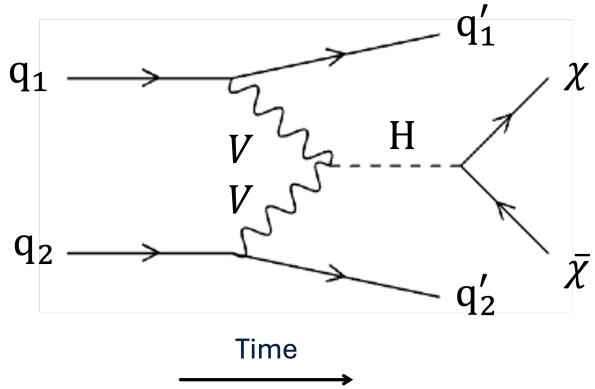
Effective triggering is extremely important

$$\frac{dN}{dt} = \mathcal{L}\sigma$$

L1 trigger utilises real-time selection algorithms and hardware logic for rapid decision-making



The upgraded L1 trigger employs dedicated analysis triggers to look for interesting events



UNIVERSITY OF OXFORD

Thanks for listening!

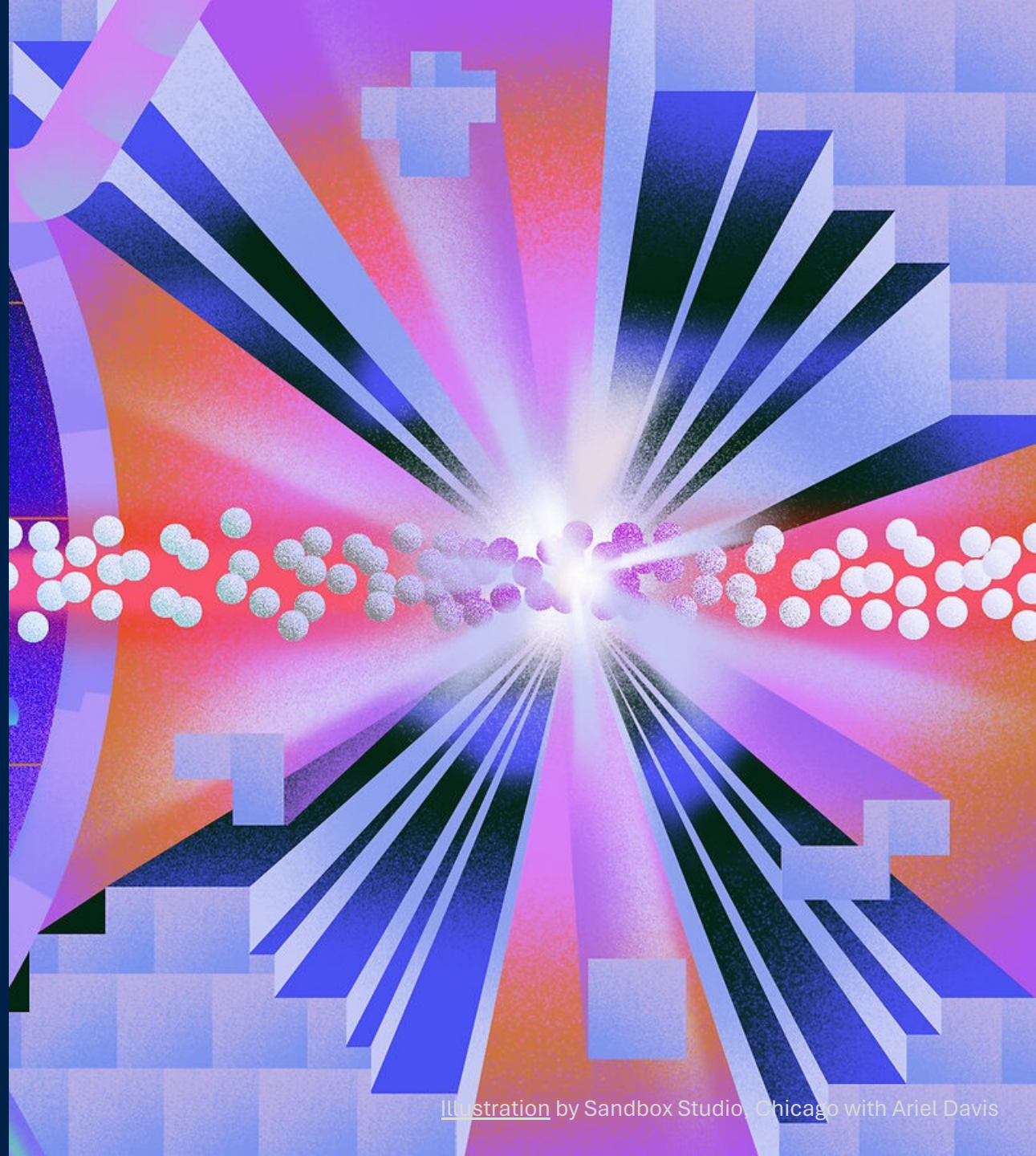


Illustration by Sandbox Studio, Chicago with Ariel Davis

References

This presentation is based on the following two papers:

[a] V. Khachatryan *et al*. (CMS Collaboration), “The CMS trigger system”, Journal of Instrumentation **12**, P01020 (2017).

[b] A. M. Sirunyan *et al*. (CMS Collaboration), “Performance of the CMS Level-1 trigger in proton-proton collisions at $\sqrt{s} = 13$ TeV”, Journal of Instrumentation **15**, P10017 (2020).

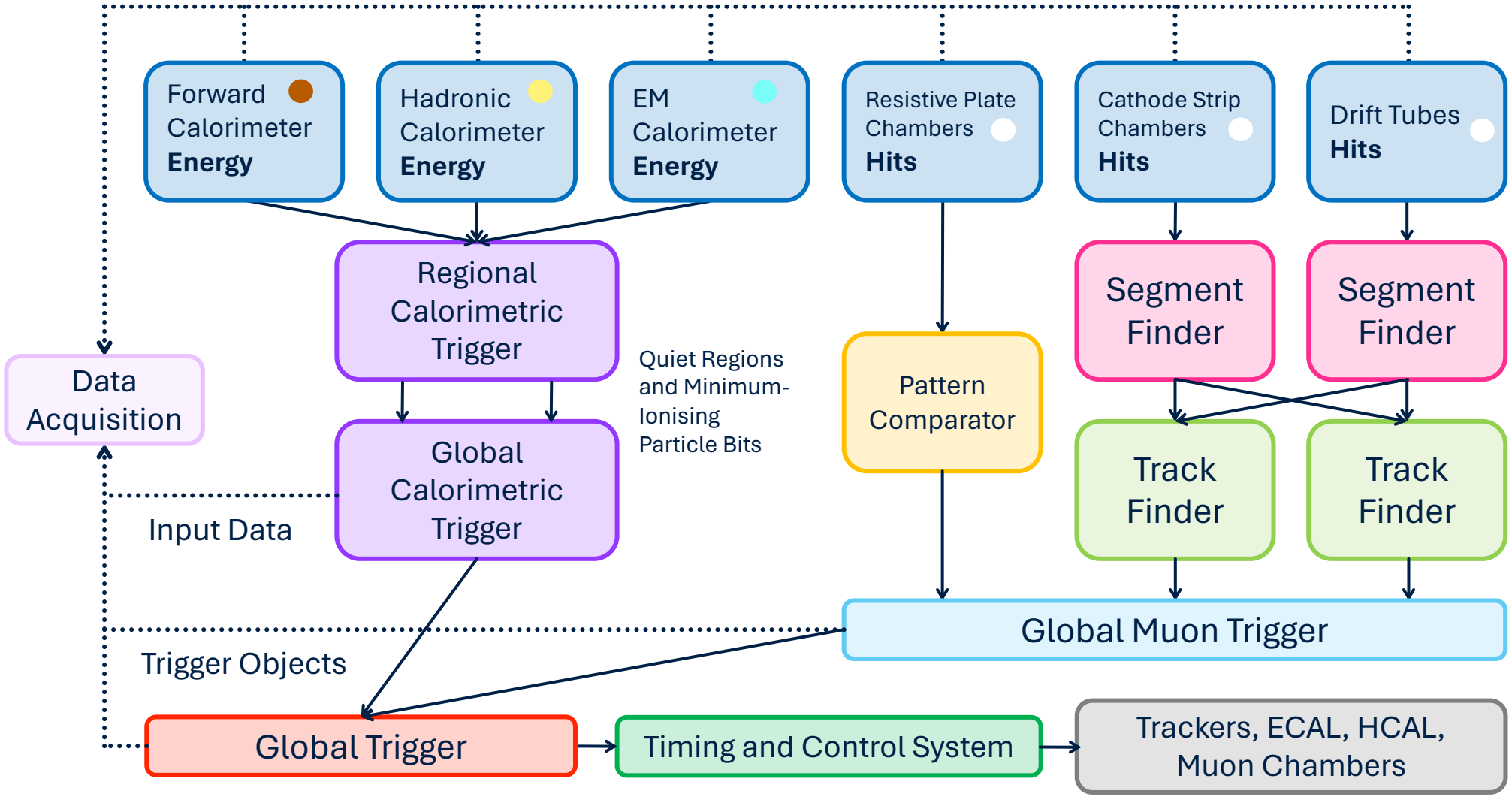
---

[1] T. Sakuma and T. McCauley, "Detector and Event Visualization with SketchUp at the CMS Experiment”, Journal of Physics: Conference Series **513,** 022032 (2014).

[2] P. Bortignon, “Description of the CMS Trigger Design and Performance”, Triggering Discoveries 2018, Puebla, Mexico (2018).

[3] A. Tumasyan *et al.* (CMS Collaboration), “Search for invisible decays of the Higgs boson produced via vector boson fusion in proton-proton collisions at $\sqrt{s} = 13$ TeV”, Physical Review D **105**, 092007 (2022).

Backup


Forward Calorimeter Energy
Hadronic Calorimeter Energy
EM Calorimeter Energy
Resistive Plate Chambers Hits
Cathode Strip Chambers Hits
Drift Tubes Hits
Regional Calorimetric Trigger
Segment Finder
Segment Finder
Data Acquisition
Quiet Regions and Minimum-Ionising Particle Bits
Pattern Comparator
Global Calorimetric Trigger
Track Finder
Track Finder
Input Data
Global Muon Trigger
Trigger Objects
Global Trigger
Timing and Control System
Trackers, ECAL, HCAL, Muon Chambers