Illustration by Sandbox Studio, Chicago with Ariel Davis

UNIVERSITY OF OXFORD

Trigger Happy: Exploring the CMS Level-1 Trigger System

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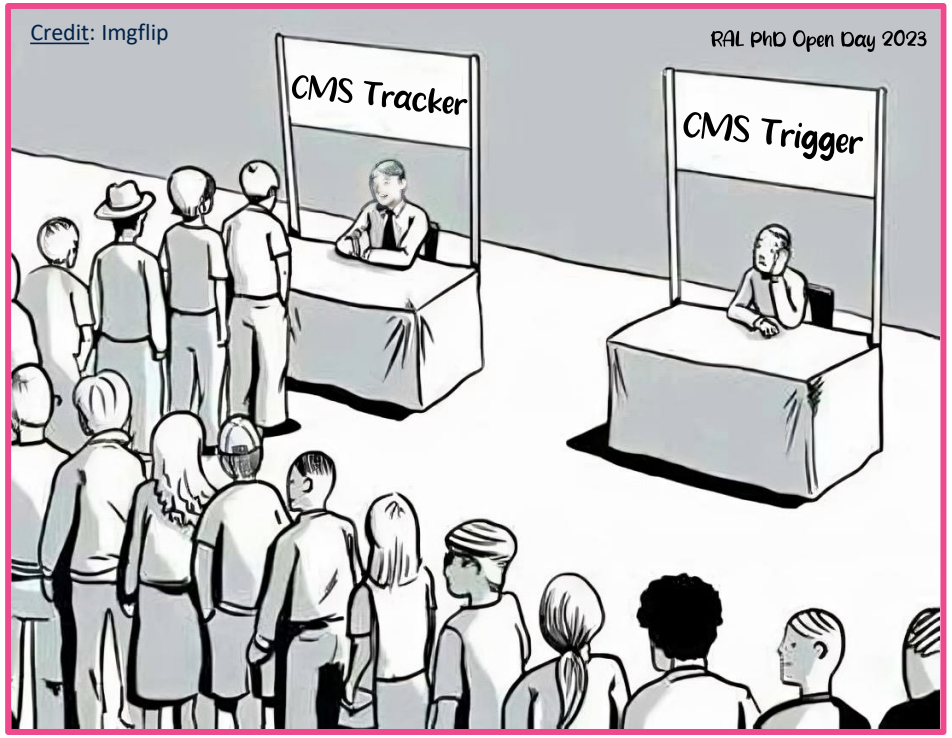
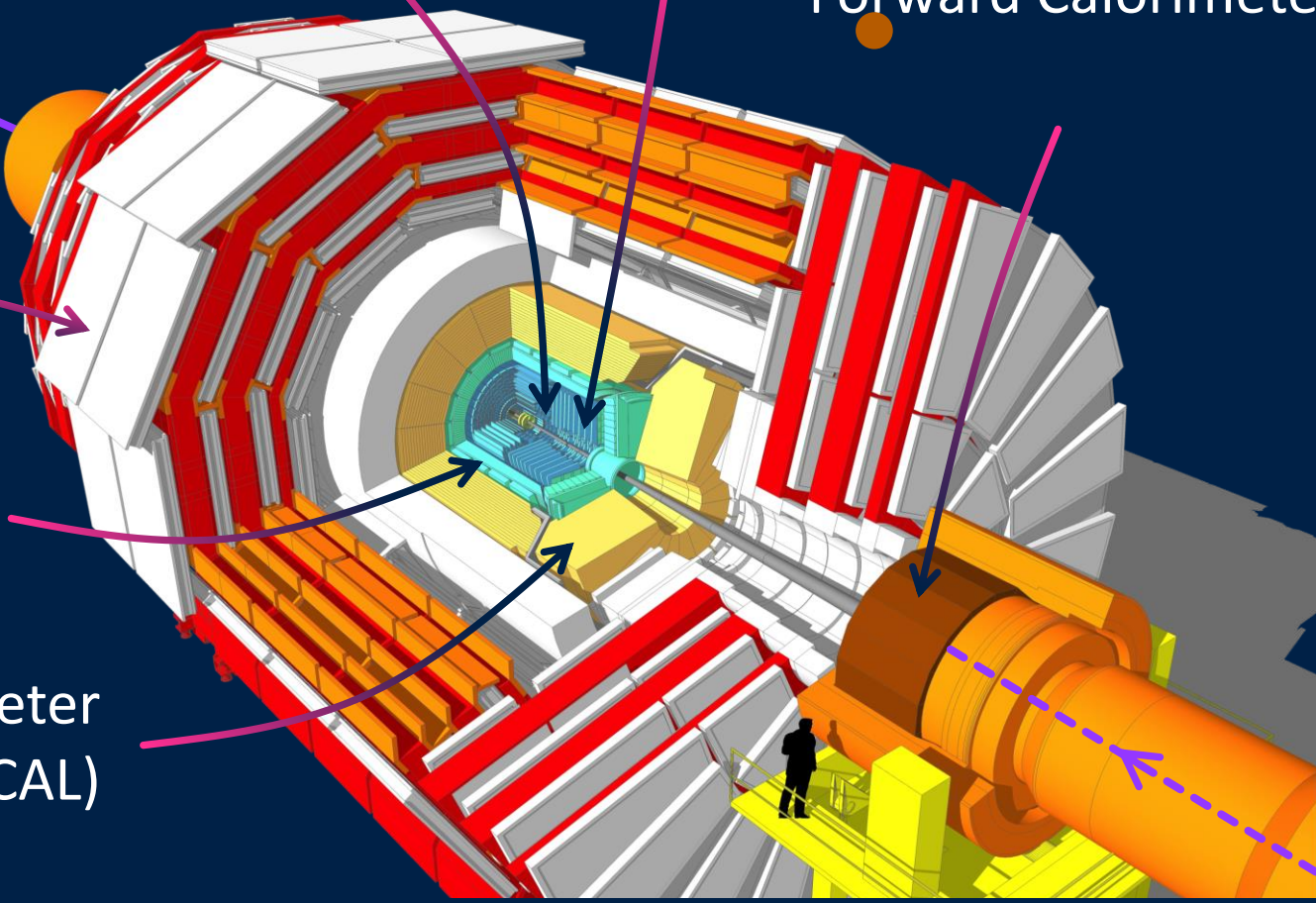
Outline

- ★ 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

- Proton Beam
- Silicon Trackers
- Preshowers
- Forward Calorimeter
- Muon Chambers
- Electromagnetic Calorimeter (ECAL)
- Hadronic Calorimeter (HCAL)



[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

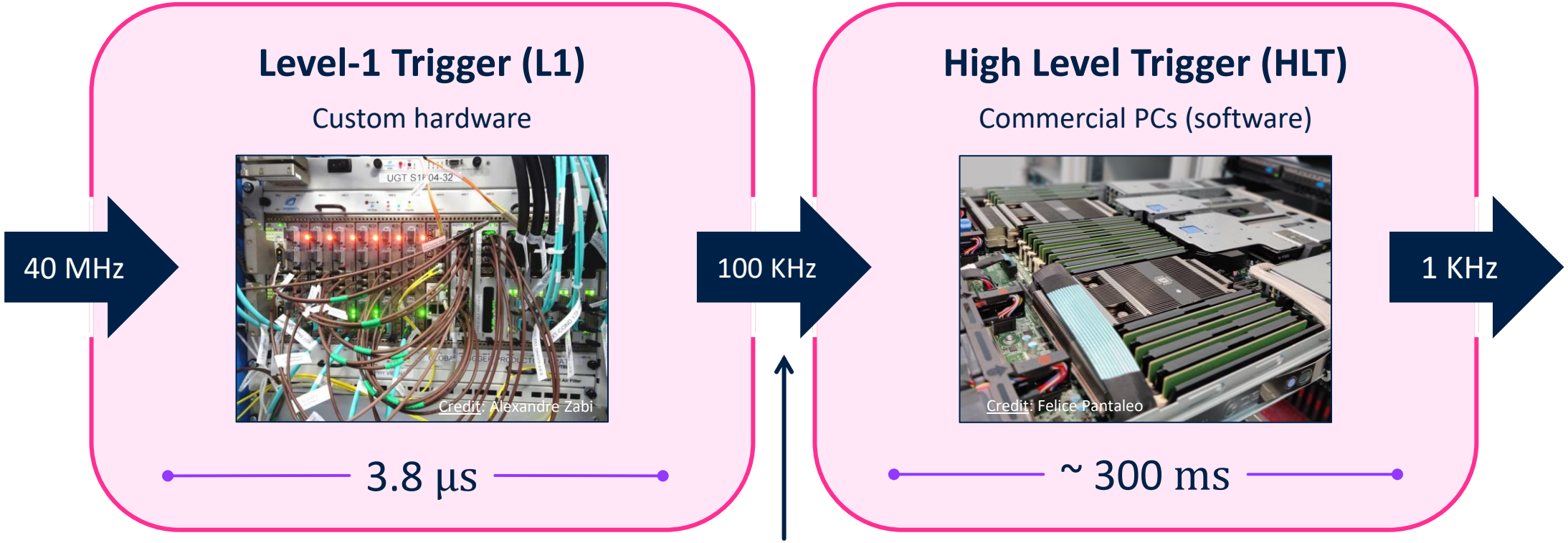
σ = cross-section

★ 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



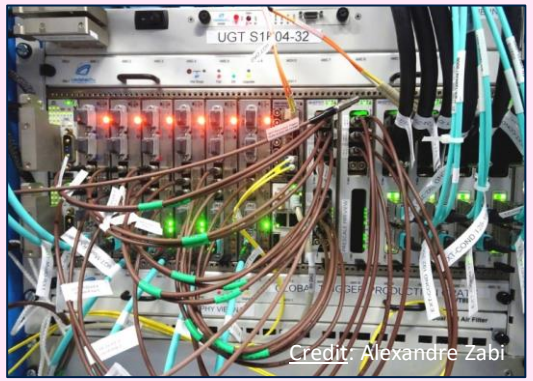
[2] Triggering Discoveries 2018

Upper limit constrained by readout electronics

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

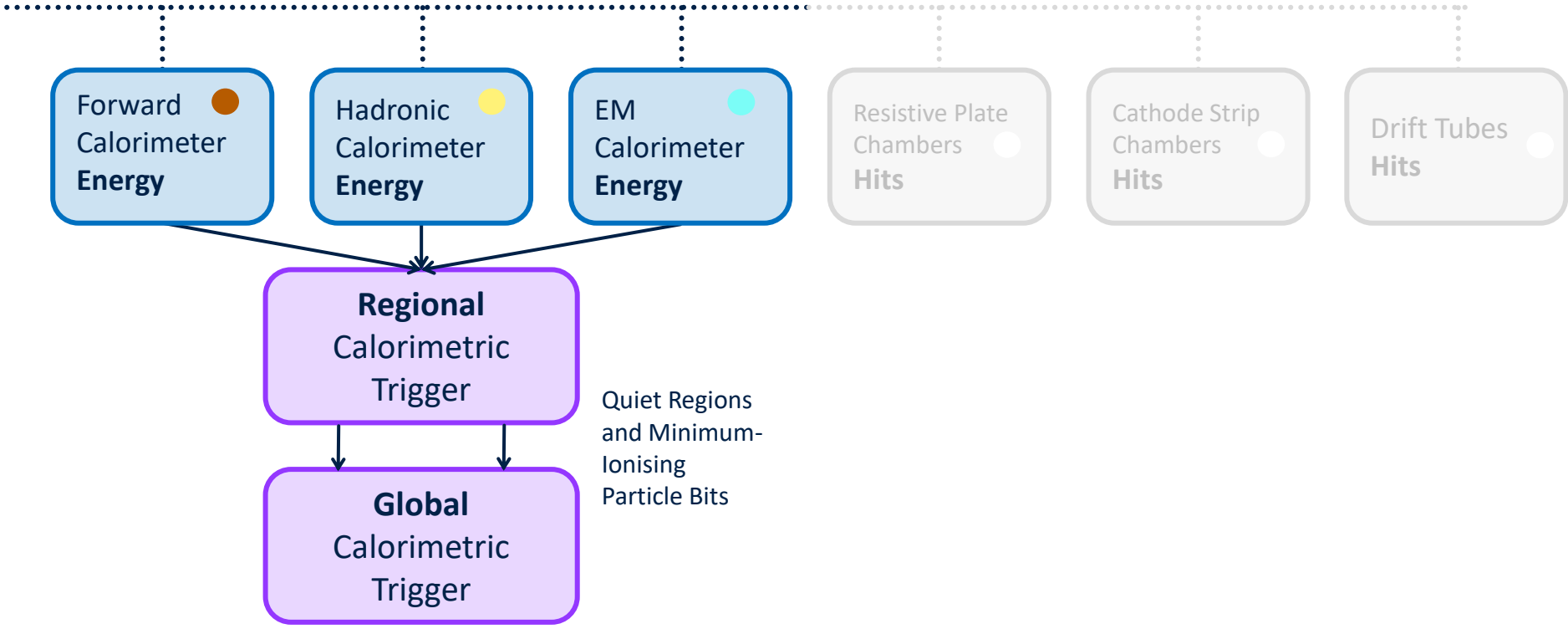
★ Use of up to 400 object-based algorithms to select desired events (Run 2)

★ 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**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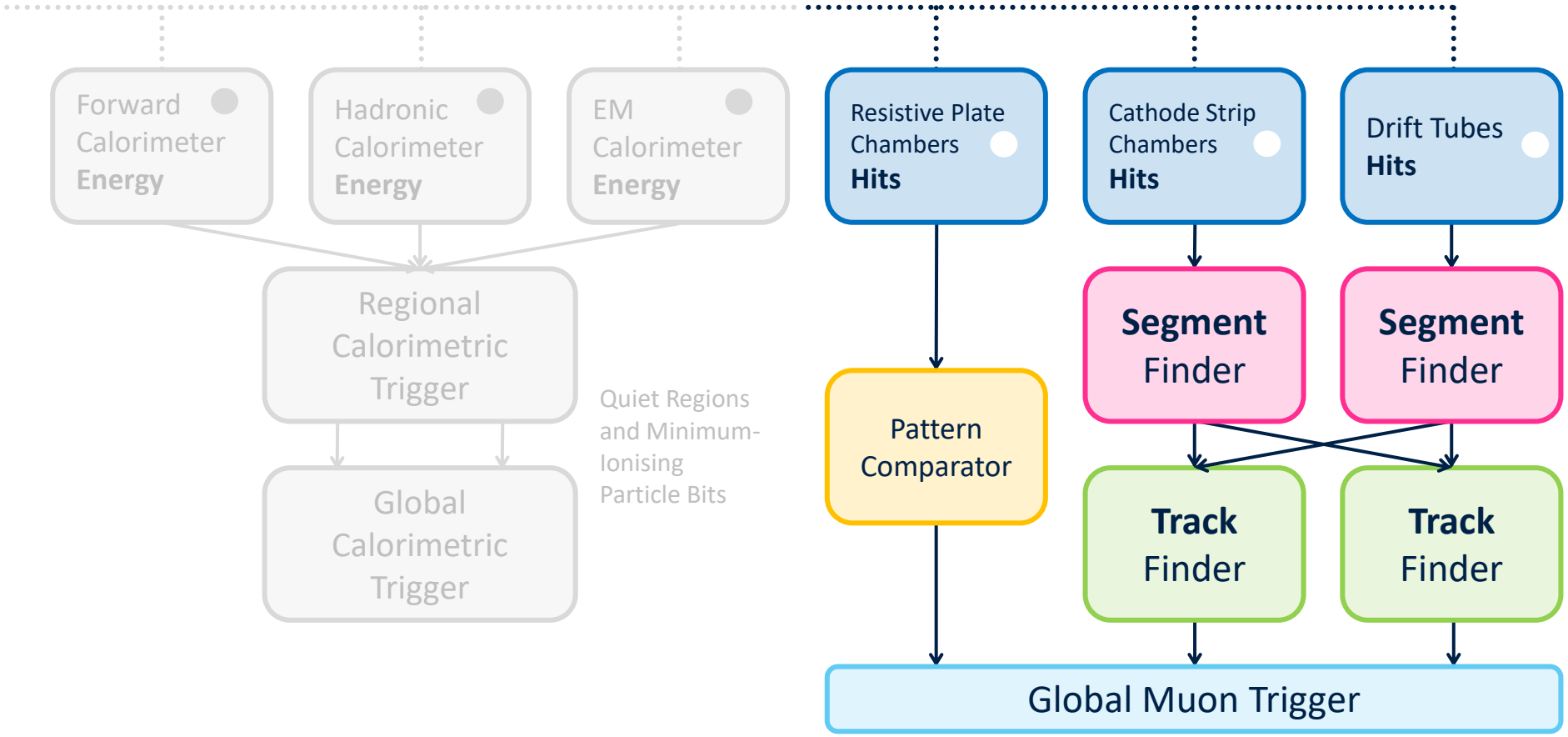
Regional Calorimetric Trigger
Global Calorimetric Trigger
Quiet Regions and Minimum-Ionising Particle Bits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Drift Tubes Hits
Pattern Comparator
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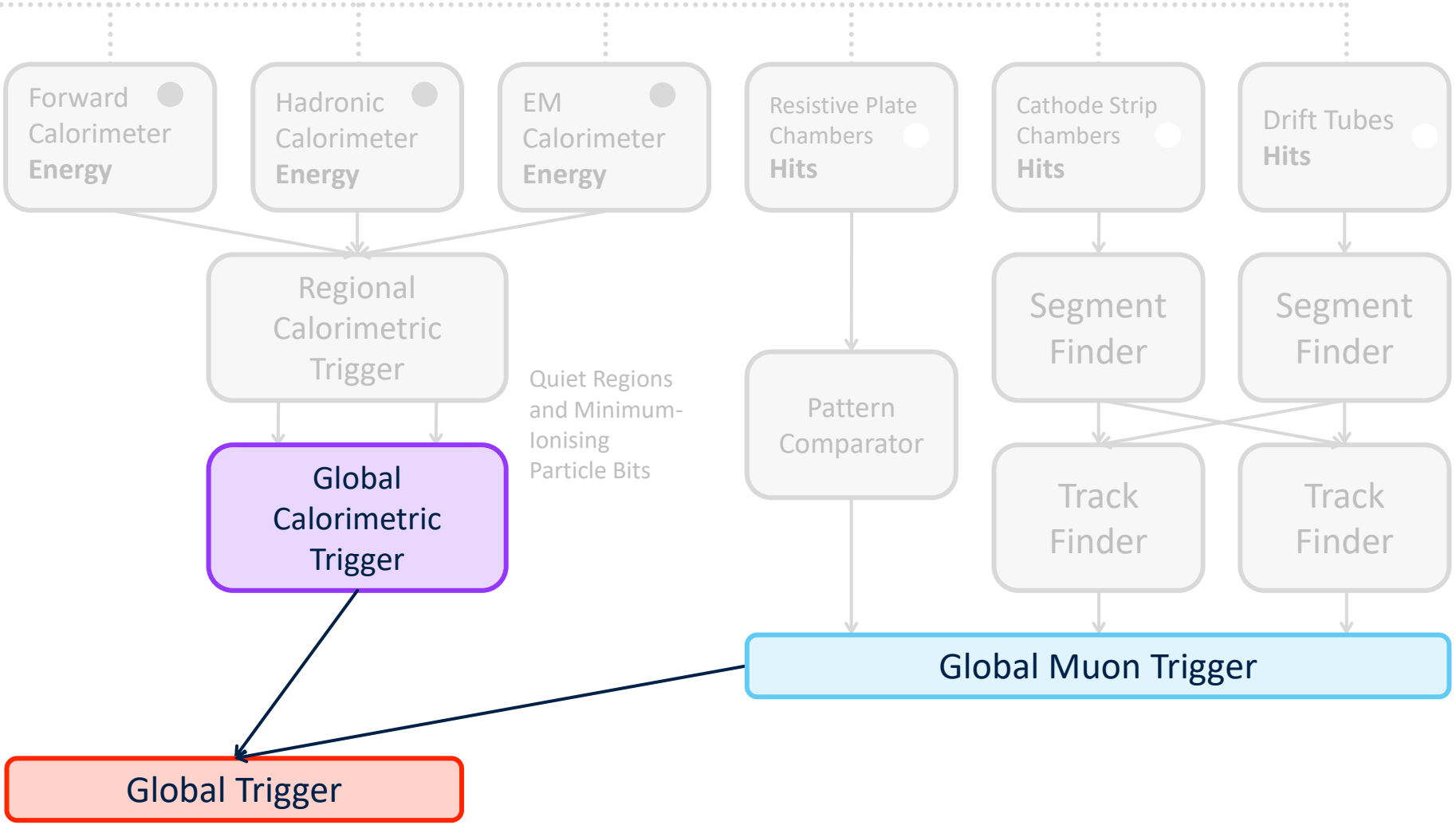
Segment Finder
Track Finder
Track Finder
Global Muon Trigger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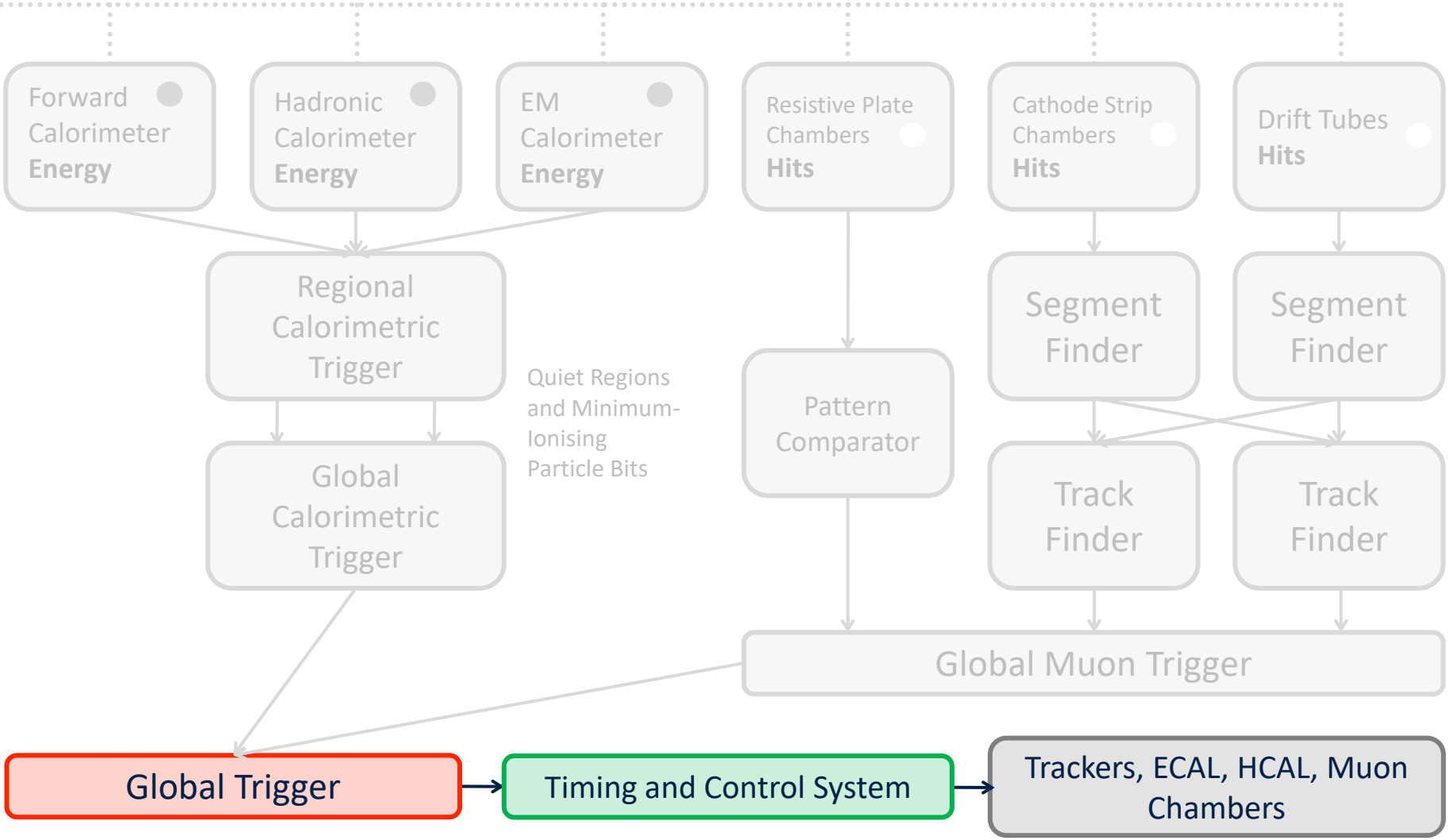
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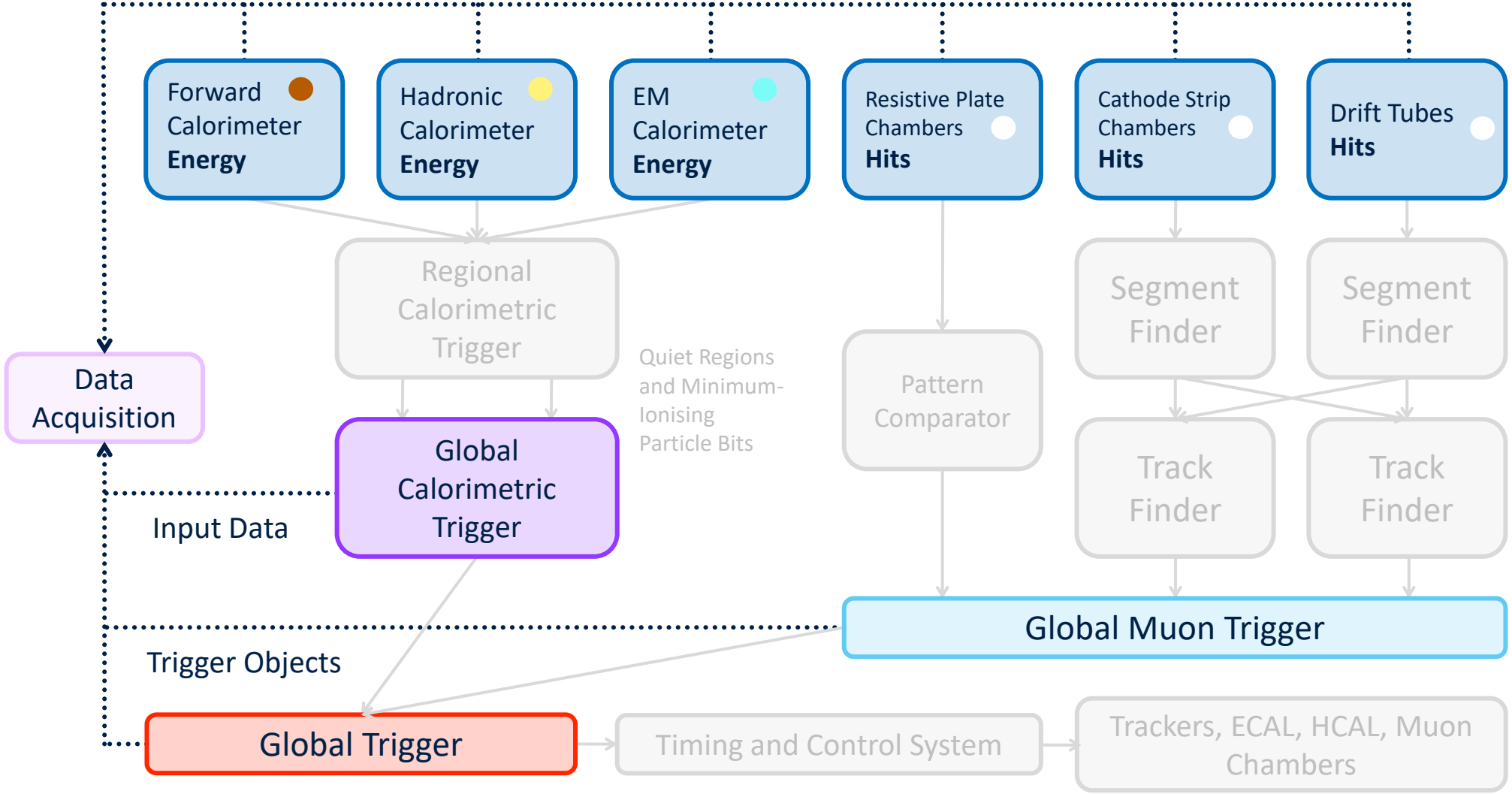
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Trigger Objects
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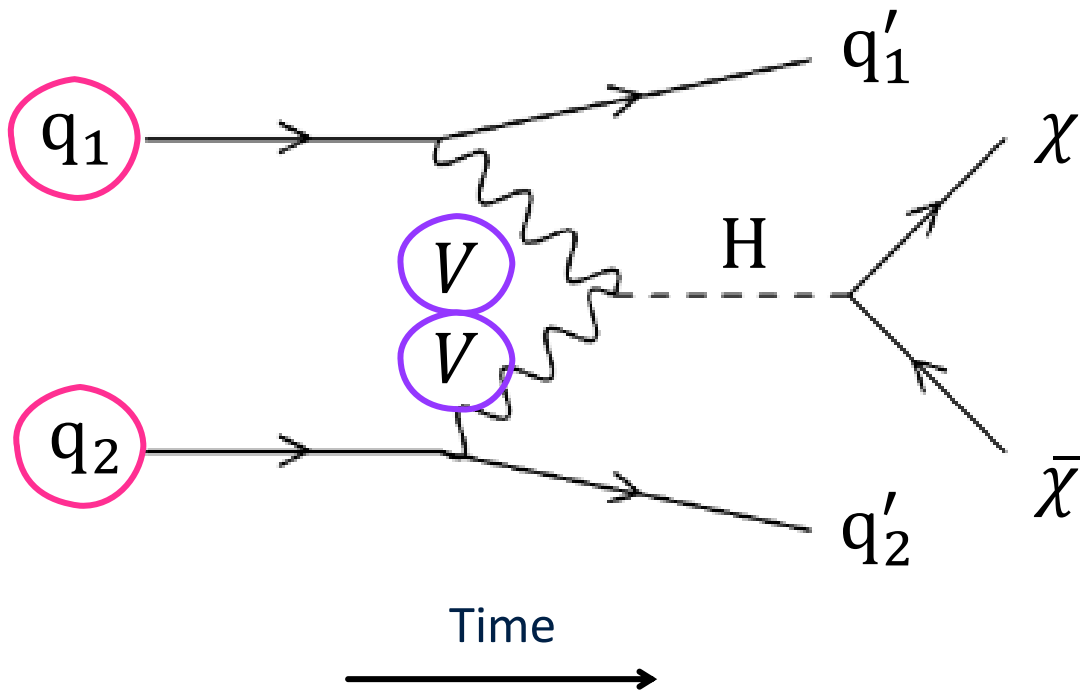
Higgs production from vector boson fusion (VBF) and invisible Higgs decay



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

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

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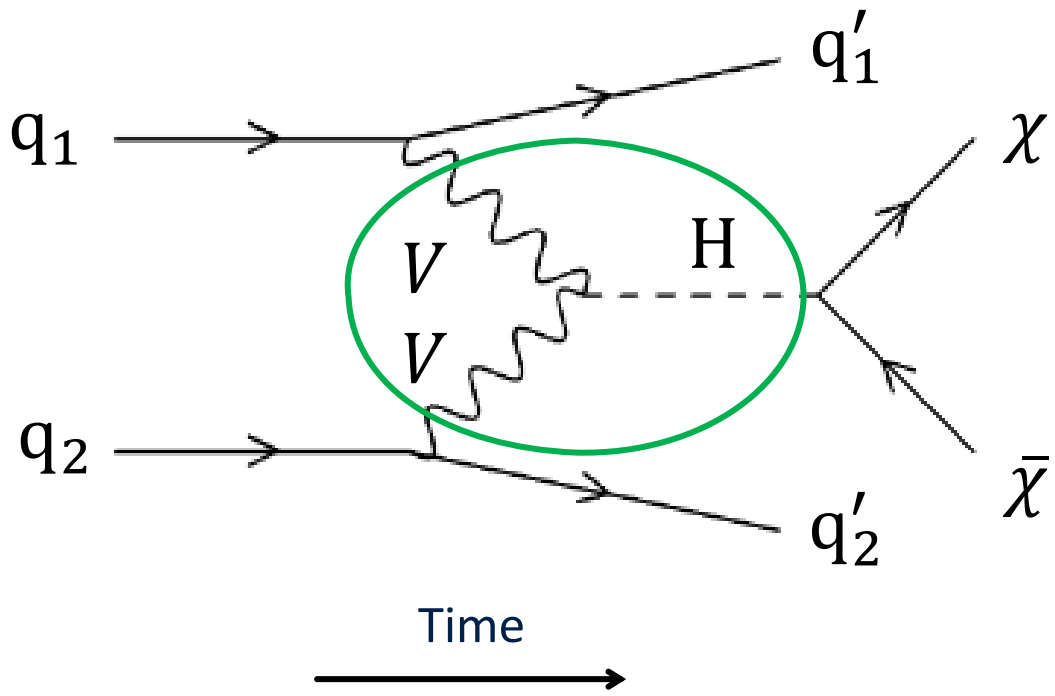

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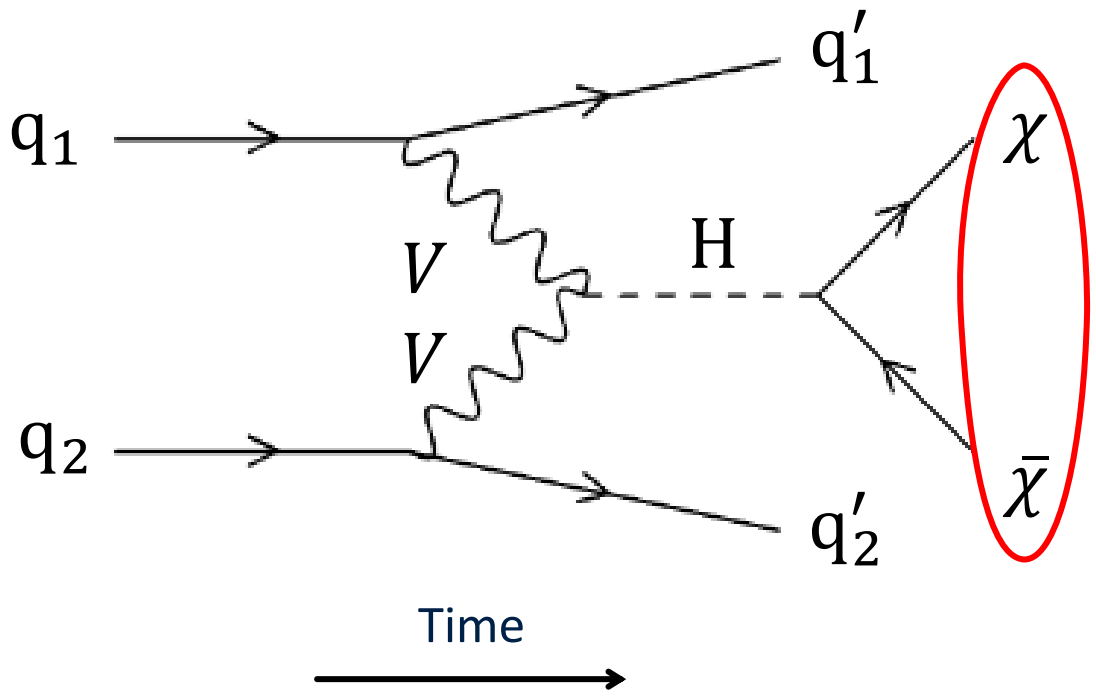

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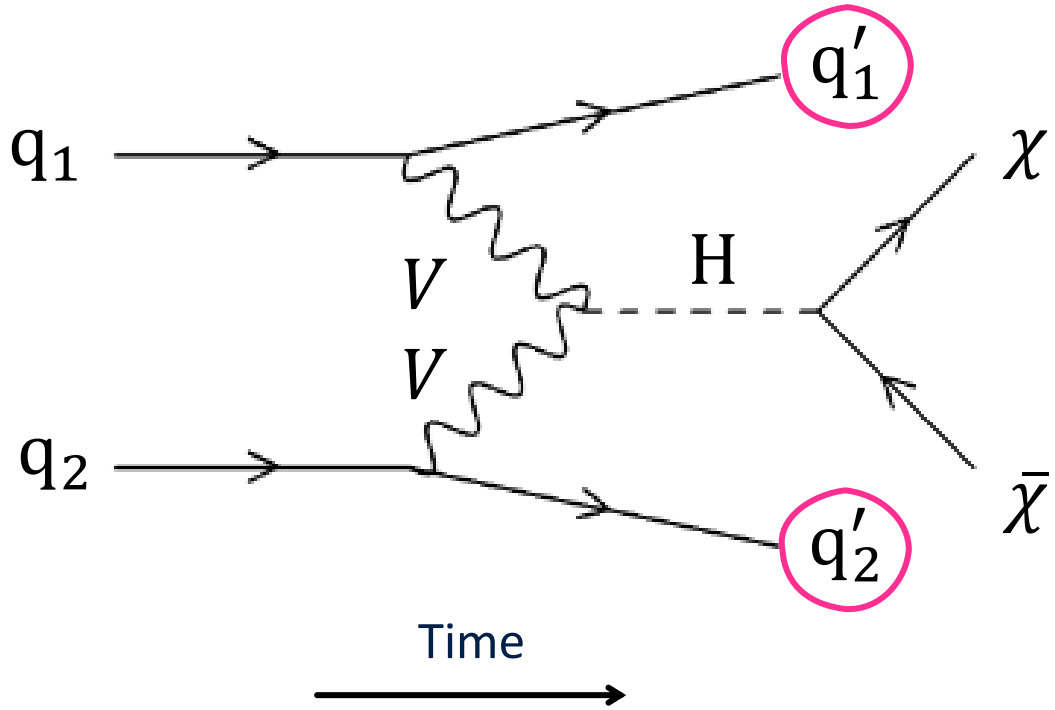

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★ Quarks detected as jets

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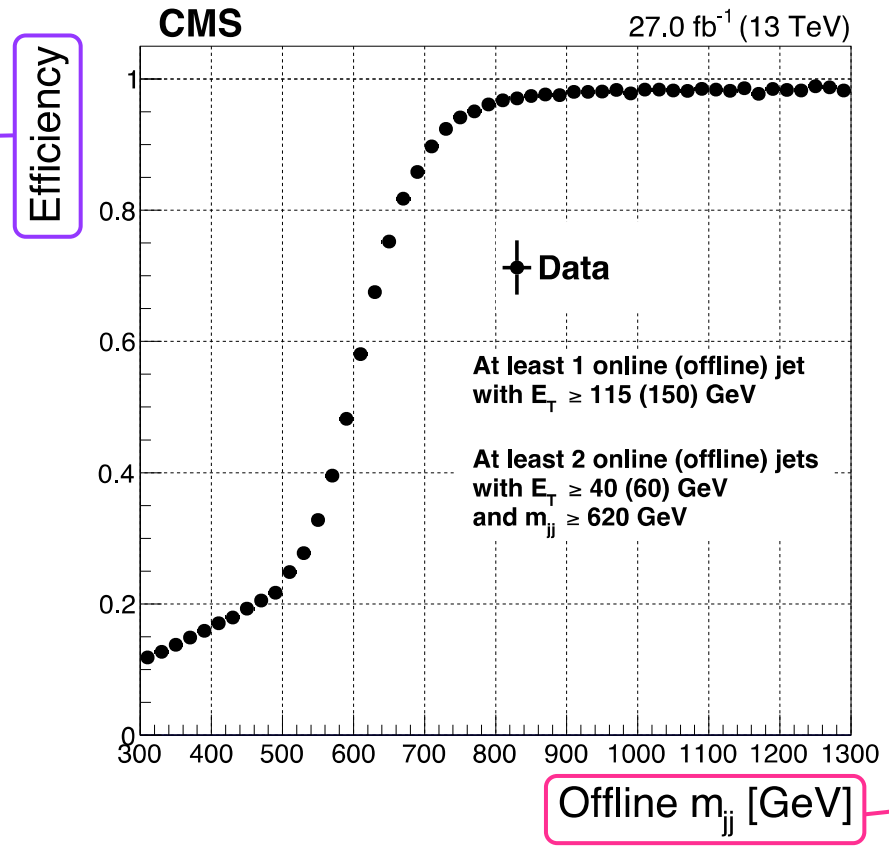
The Run-2 updated L1 analysis algorithms allow for triggering of the invisible Higgs decay through VBF

Measure of how well the L1 VBF trigger works



Maximum dijet invariant mass

Offline refers to stored data!

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

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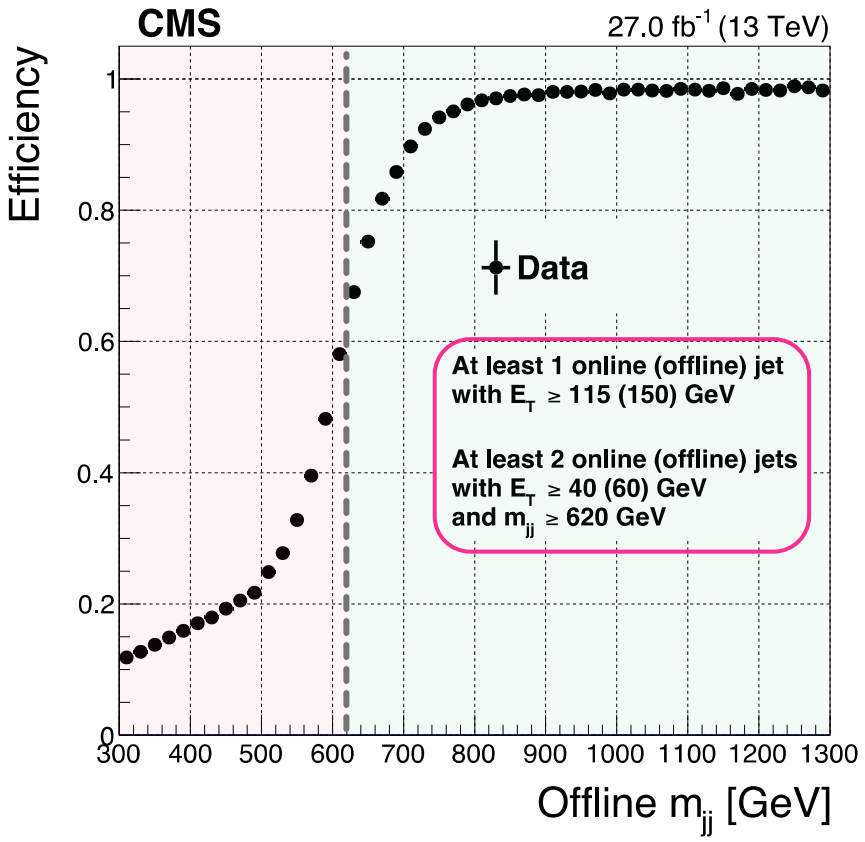

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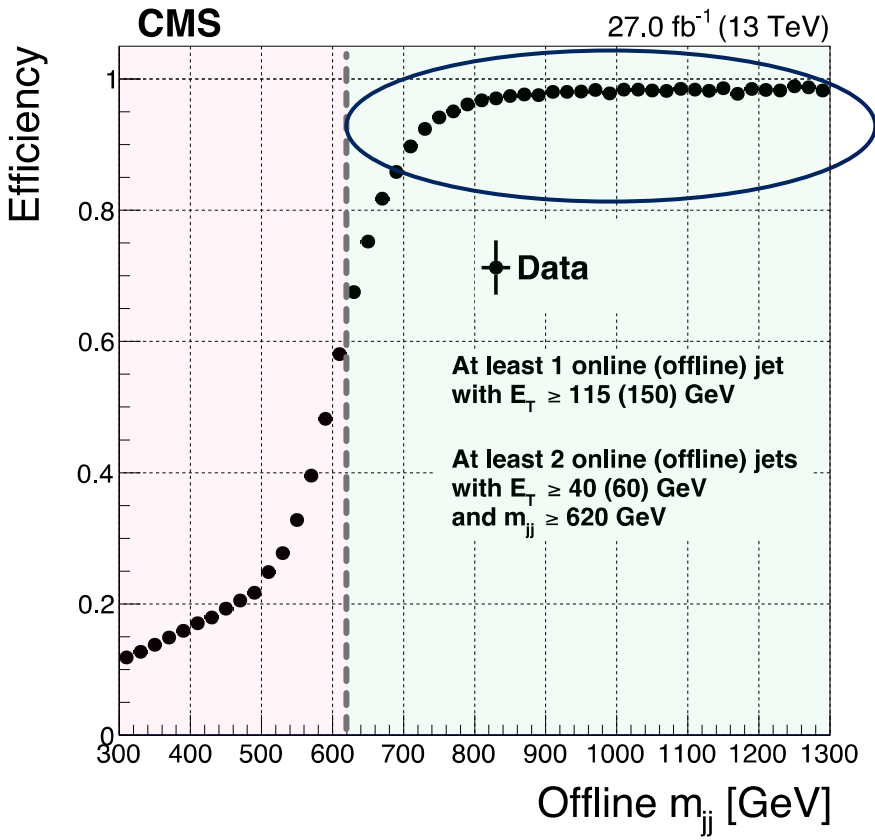


High-efficiency plateau for VBF-like events

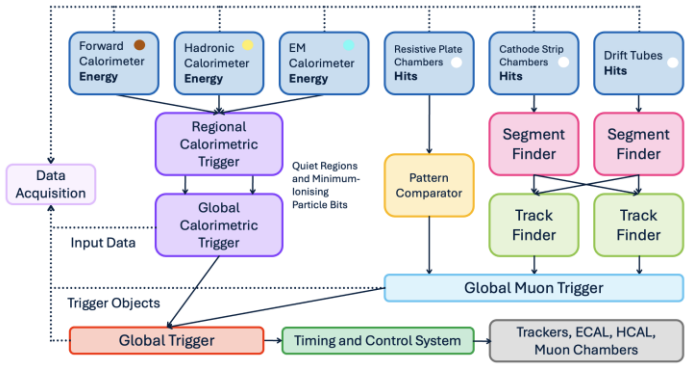
[b] arXiv:2006.10165 **[hep-ex]**

Summary

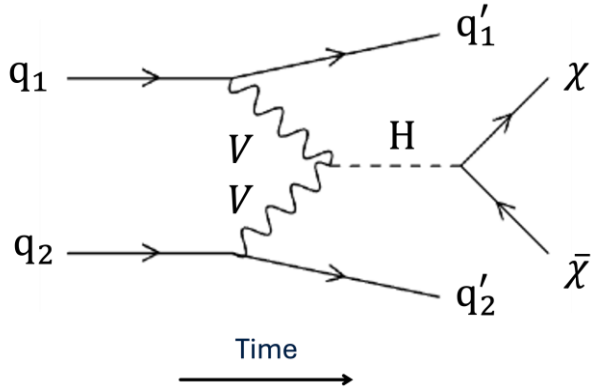
Effective triggering is extremely important in CMS

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

L1 trigger employs real-time algorithms and hardware logic for quick decision making



The upgraded L1 trigger uses specialised analysis triggers to look for interesting events



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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 $\sqrt{s} = 13\ \mathrm{TeV}$”, Journal of Instrumentation **15**, P10017 (2020).

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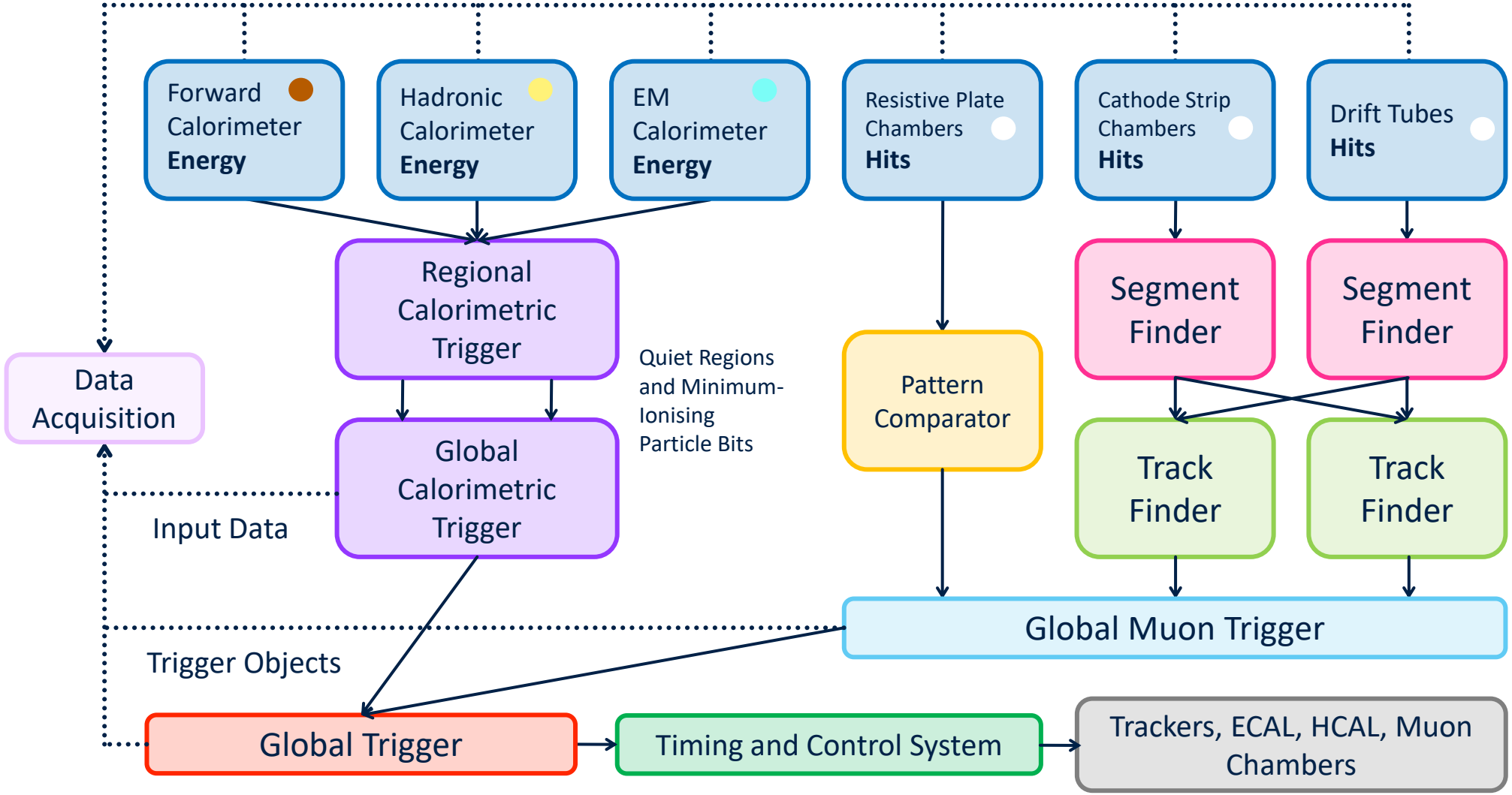
[1] T. Sakuma and T. McCauley, "Detector and Event Visualization with SketchUp at the CMS Experiment”, Journal of Physics: Conference Series **513,** 022032 (2014).

[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 $\sqrt{s} = 13\ \mathrm{TeV}$”, Physical Review D **105**, 092007 (2022).

Backup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