The CMS Trigger

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- Trigger objectives and challenges at the LHC
- An overview of the CMS trigger
- The Global Calorimeter Trigger

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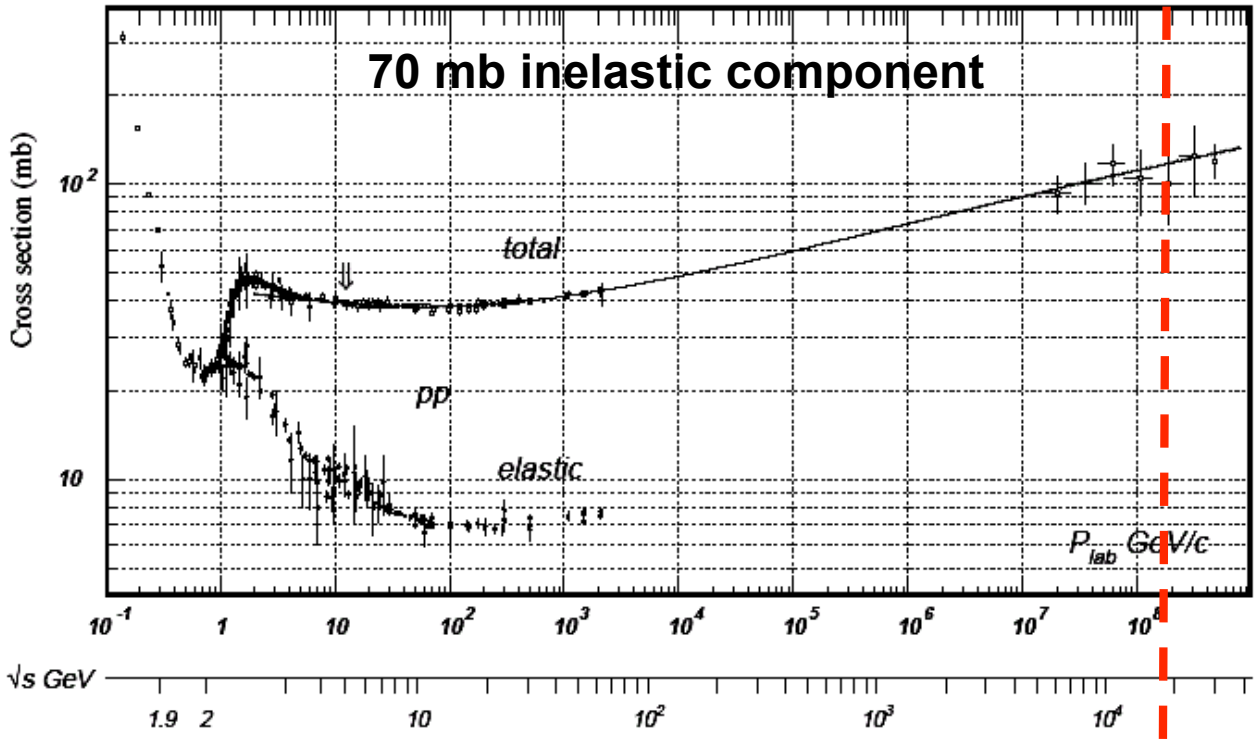
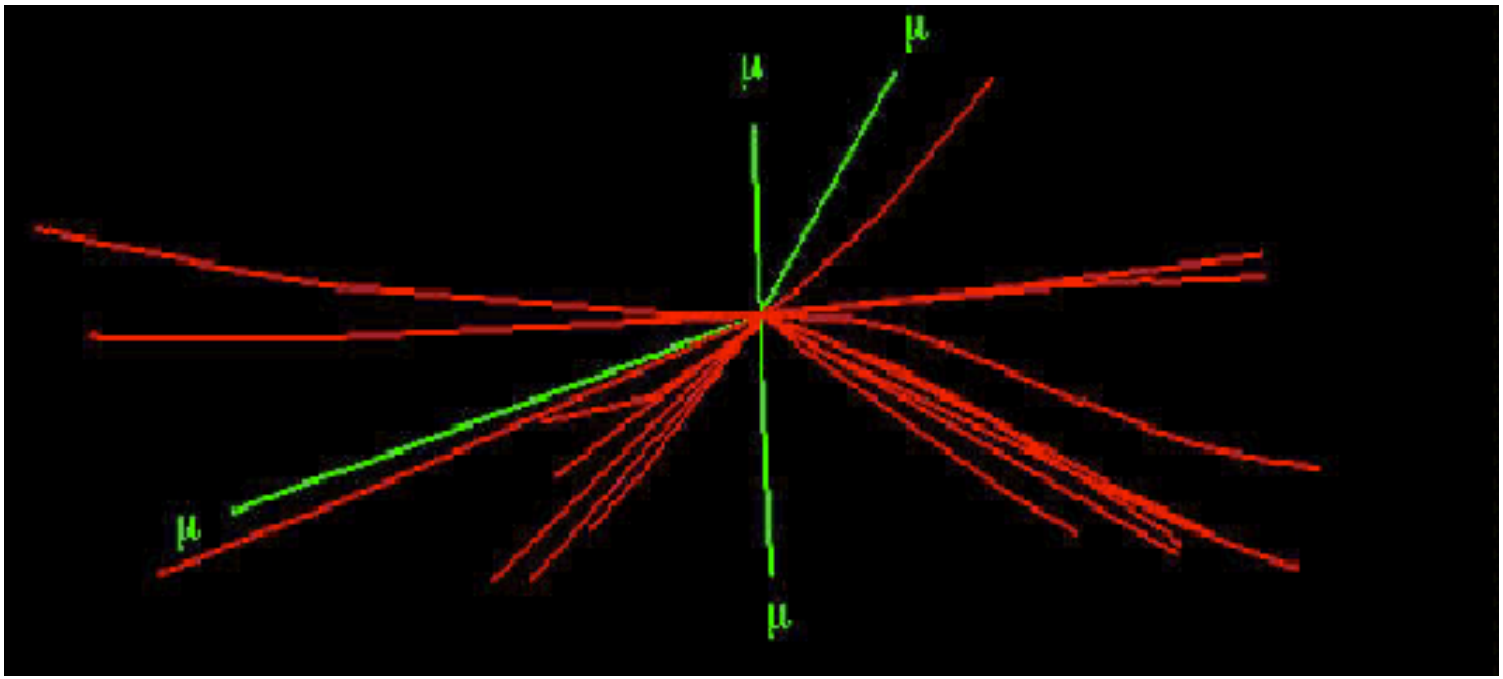
LHC trigger challenges - data rate



- $L = 10^{34}\ cm^{-2}\ s^{-1} = 10^{7}\ mb^{-1}\ Hz$
- σ_{inel} (pp) ≈ 70 mb
  → **Event Rate = 7 x 10^{8} Hz**
- $\Delta t = 25\ ns = 25 \times 10^{-9}\ Hz^{-1}$
  → **Events/25ns =7 x 2.5 = 17.5**
- Not all bunches full (2835/3564)
  → **Events/crossing = 22**

- At full LHC luminosity we have 22 events superimposed on any discovery signal
- 10^{9} events per second x typical event size of 1-2 Mbytes > 1TByte/sec
- Enormous data rate. Need super-fast algorithms to select interesting events while suppressing less interesting events

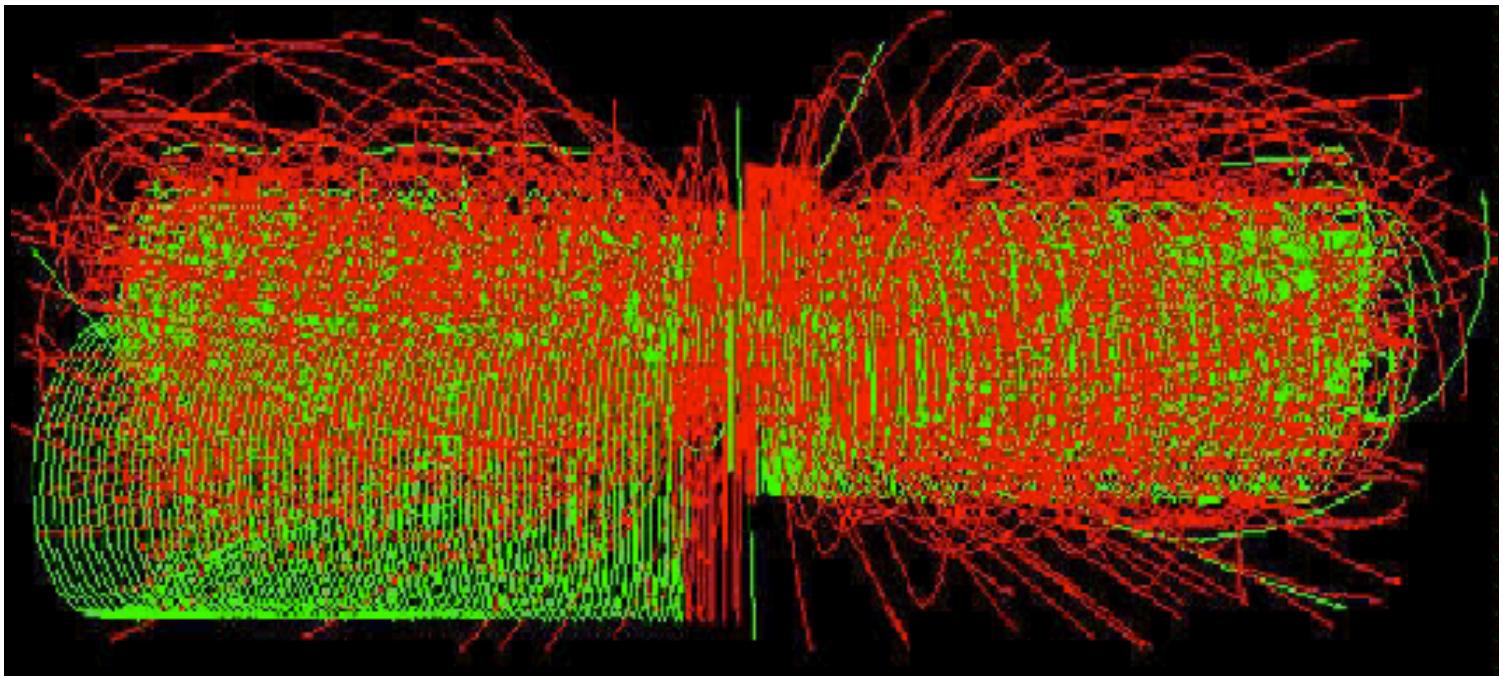
LHC trigger challenges - pile-up



Higgs -> 4μ

- We want to select this type of event (for example Higgs to 4 muons)

LHC trigger challenges - pile-up

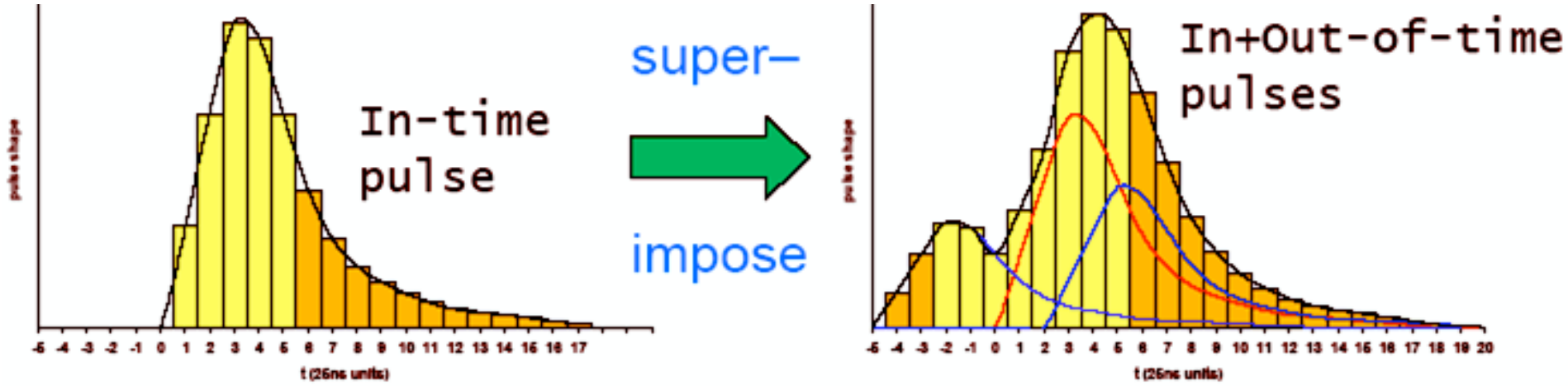


Higgs -> 4μ

+30 MinBias

- We want to select this type of event (for example Higgs to 4 muons) which has this superimposed on it……
- Sophisticated algorithms necessary

LHC trigger challenges - pile-up



- In-time pile up: Same crossing different interactions
- New events come every 25 nsec → 7.5 m separation
- Out-of-time pile up: Due to events from different crossings
- Need a to identify the bunch crossing that a given event comes from

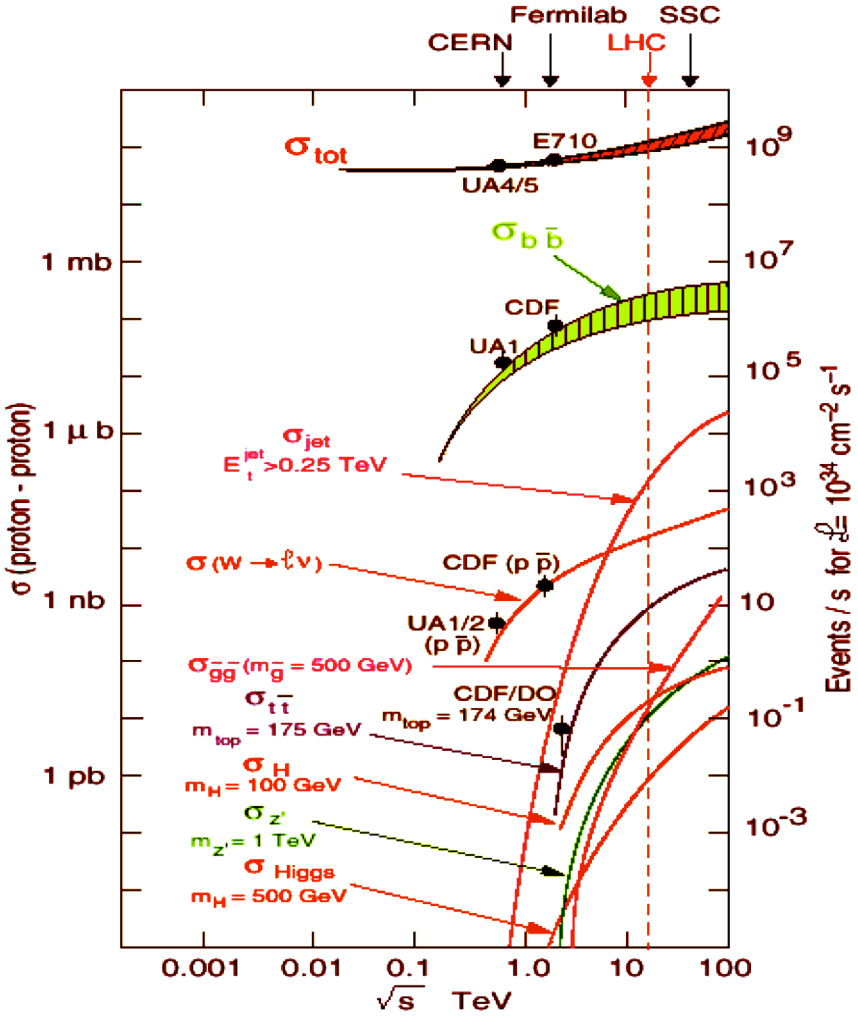
Trigger goals at the LHC

QCD cross sections are orders of magnitude larger than electroweak or any exotic channels

Event rates

1. **Inelastic: 10^9 Hz**
2. **W→lν : 100 Hz**
3. **t-tbar:10 Hz**
4. **H(100 GeV): 0.1 Hz**
5. **H(600 GeV): 0.01 Hz**

⇒ Need to select events at the 1:10^{11} level



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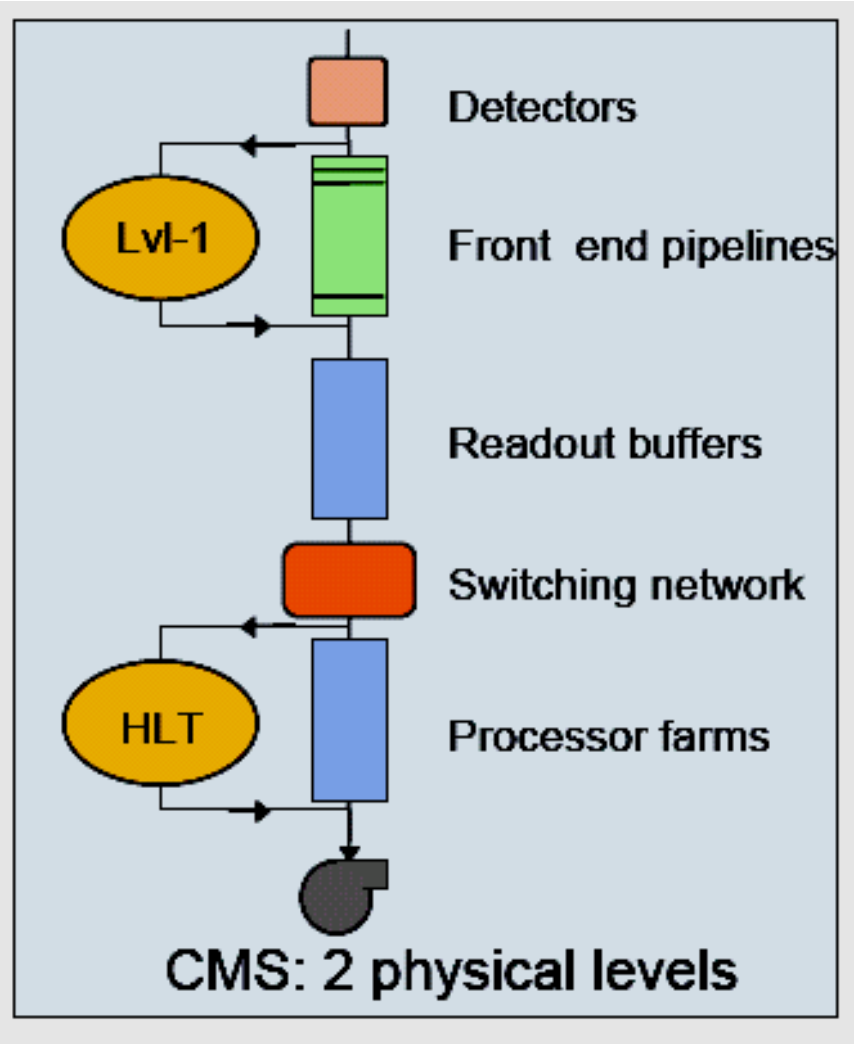
Challenges

- Enormous data rate: 10^9 Hz ⇒ more than 1TByte/s
- Minimum bias in-time pile-up ⇒ 22 events per bunch crossing
- Out-of-time pile-up ⇒ events from different bunch crossings overlayed
- Tiny cross sections for Higgs and new physics ⇒ selection 1:10^{11}
- All online ⇒ can't go back and fix it. Events are lost forever!

The CMS trigger system



- 40 MHz input rate to Level 1
- Selection cannot be done in 25ns so pipelined trigger
- 100 KHz Level 1 output rate
- 100 Hz written at the output
- Event Size 1-2 Mbytes

Level-1 Trigger:

⇒ Custom made hardware system

⇒ The topic of the rest of this talk

High Level Trigger:

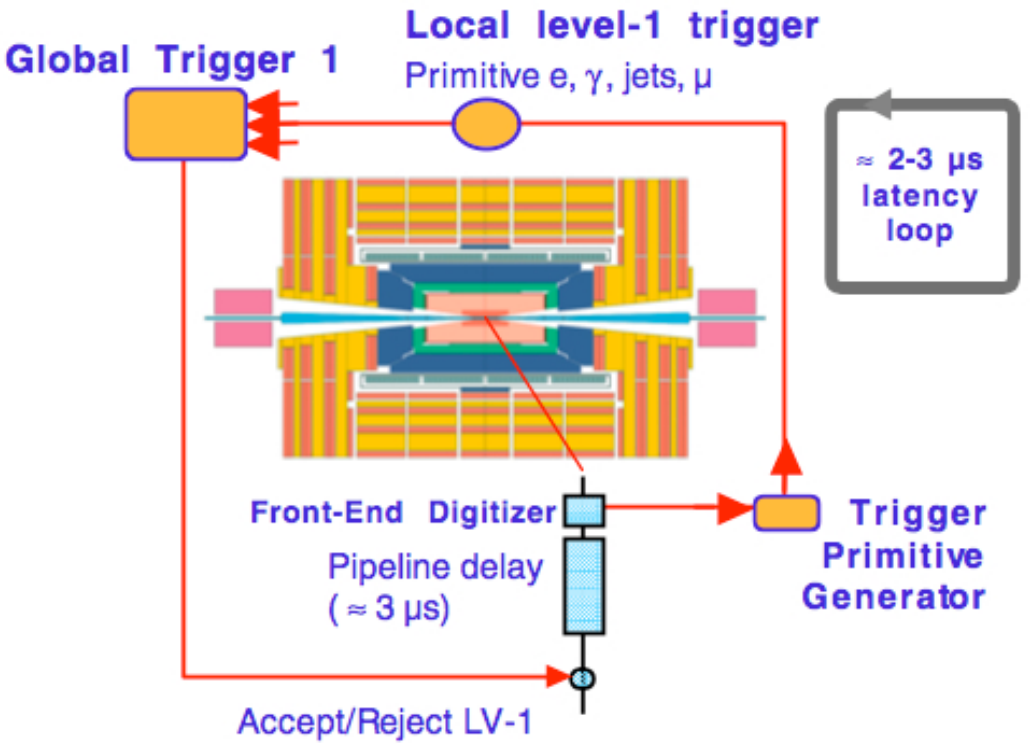
⇒ PC farm (~1000 units) using reconstruction software and event filters similar to the offline analysis.

The CMS Level 1 Trigger

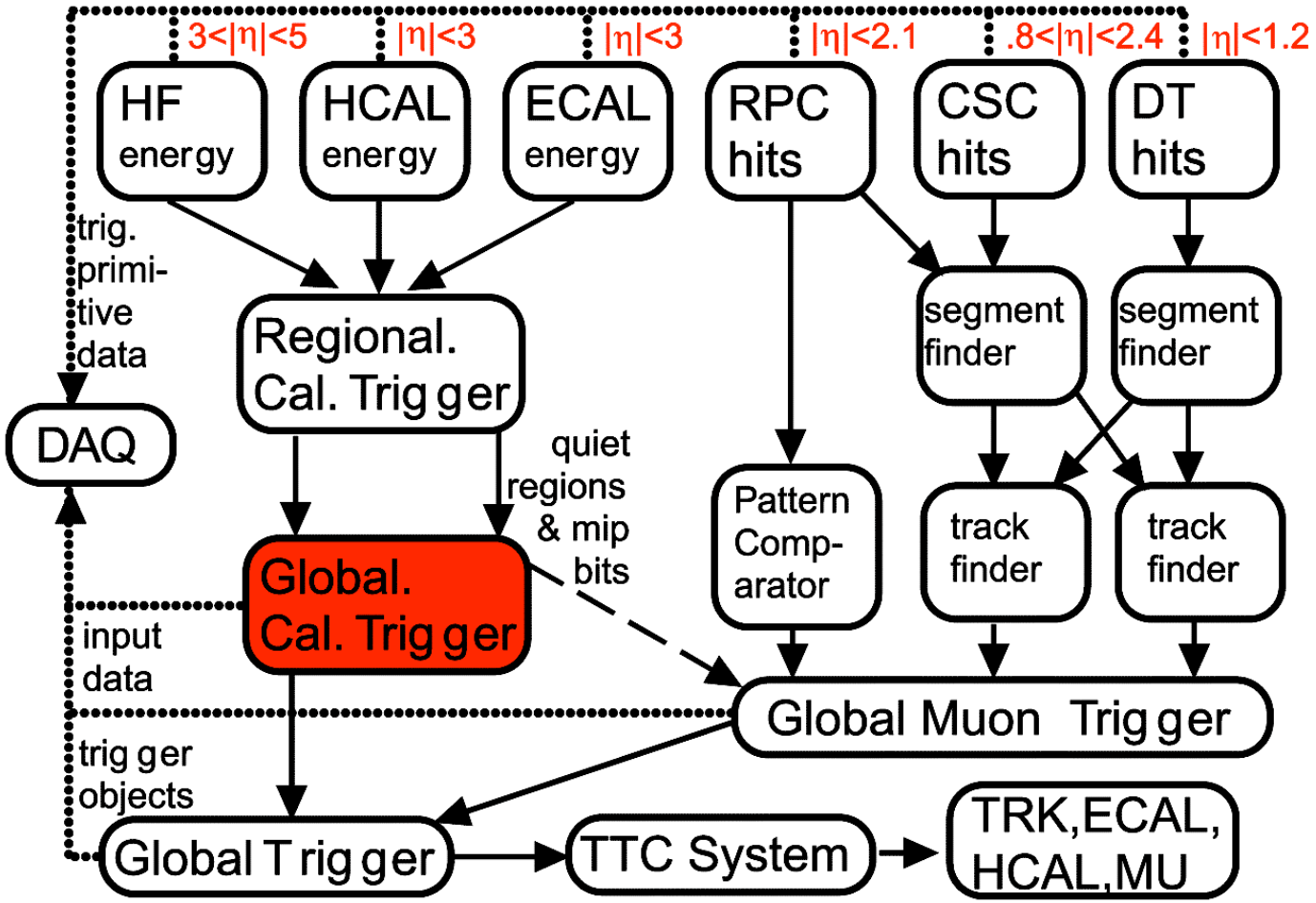
Huge rejection necessary
⇒ sophisticated algorithms

1. Detector data stored in front-end pipelines. Pipelines deep enough for 128 bunch crossings (3.2μs)
2. Trigger decision derived from trigger primitives generated on the detector
3. Regional triggers search for Isolated e, γ, μ, jets and compute the transverse and missing energy of the event. GCT ⇒ next slide.
4. Event selection algorithms run on the global triggers. Must give a trigger decision every 25ns.

Can only use CAL and muon systems.



Level 1 trigger components



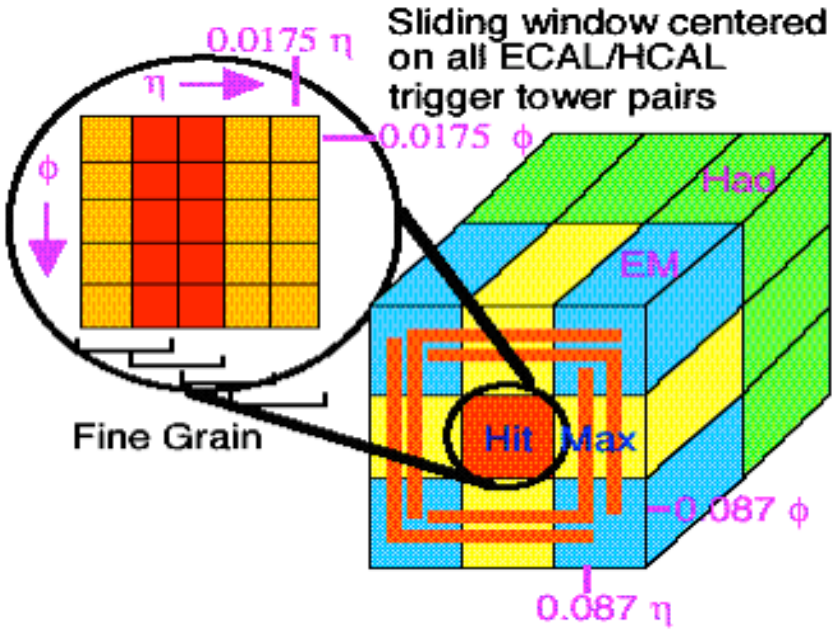
The Global Calorimeter Trigger

- **Jet Triggers:** Central, Tau and Forward jet finding and sorting.
- **Jet Counters:** Count Jets in 12 different regions of the detector or 12 different thresholds within the detector.
- **Electron/γ triggers:** Select and sort the e/γ candidates from the Regional Calorimeter Trigger
- **Total Transverse, Total Missing Transverse and Total Jet Transverse Energy** calculation
- Receive the muon data and send them to the Global Muon Trigger.
- Luminosity monitoring and readout all the RCT and GCT data for every L1 accept.

GCT is the responsibility of Imperial, CERN and Bristol groups

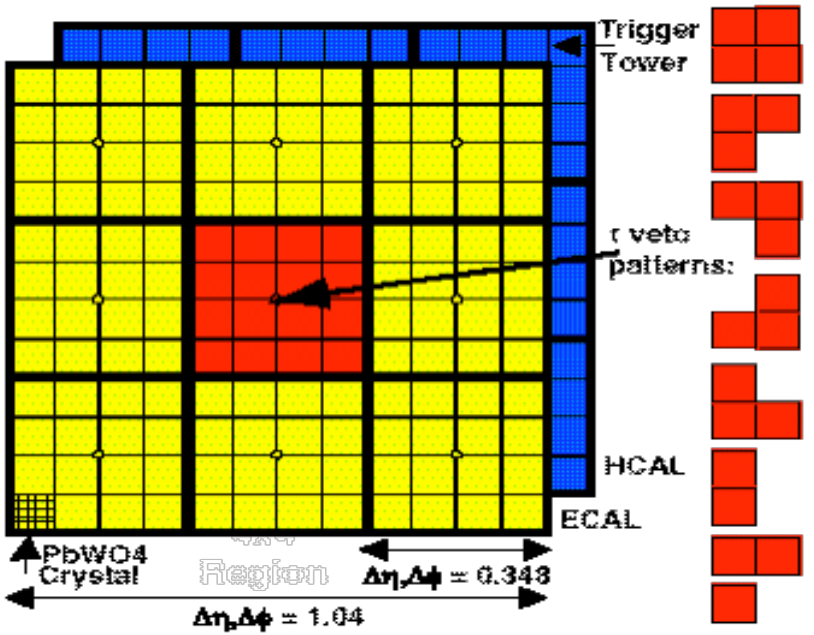
Example algorithms

Electrons/photon finder



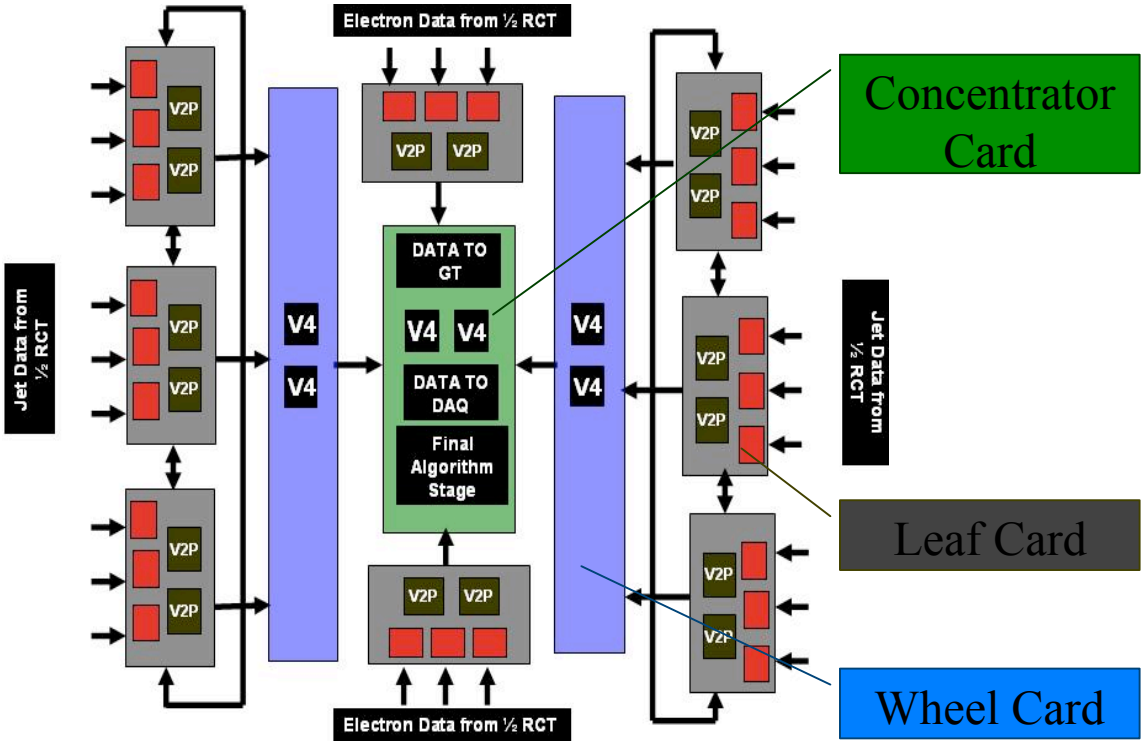
- **Electron (Hit Tower + Max)**
  - **2-tower ΣE_T + Hit tower H/E**
  - **Hit tower 2x5-crystal strips >90% E_T in 5x5 (Fine Grain)**
- **Isolated Electron (3x3 Tower)**
  - **Quiet neighbours: all towers pass Fine Grain & H/E**
  - **One group of 5 EM E_T < Thr.**

Jet Finder



- **Jet E_T**
  - **12x12 trig. tower ΣE_T sliding in 4x4 steps w/central 4x4 E_T > others**
- **τ Jet**
  - **Isolated narrow energy deposits**
  - **Energy spread outside τ veto pattern sets veto**
  - **Jet ≡ τ if all 9 4x4 region τ vetoes off**

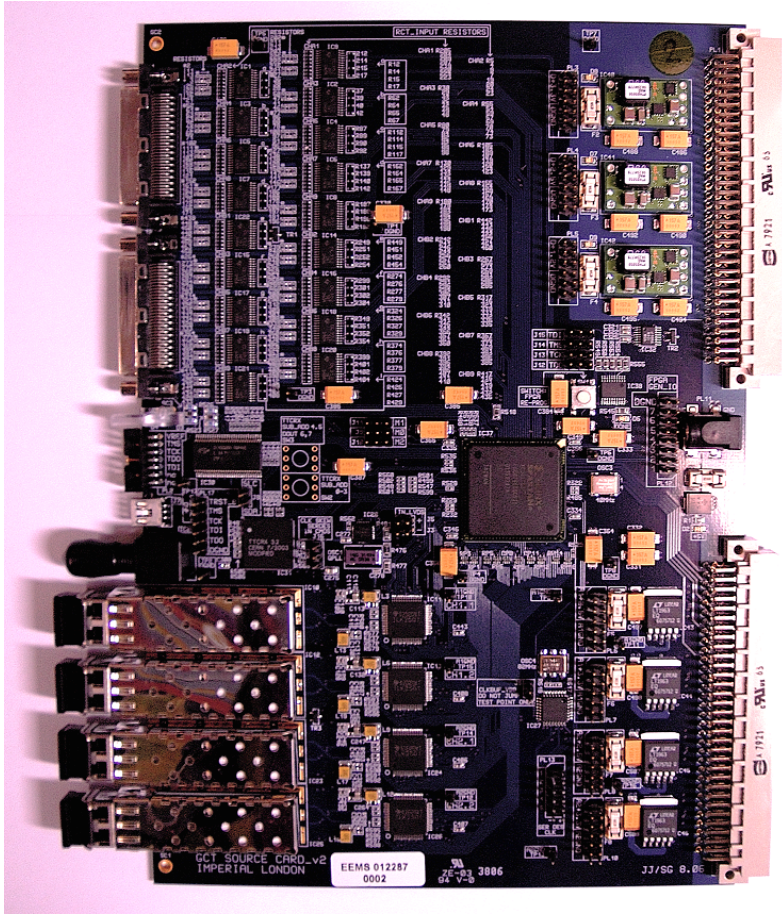
The GCT design



Key points are:

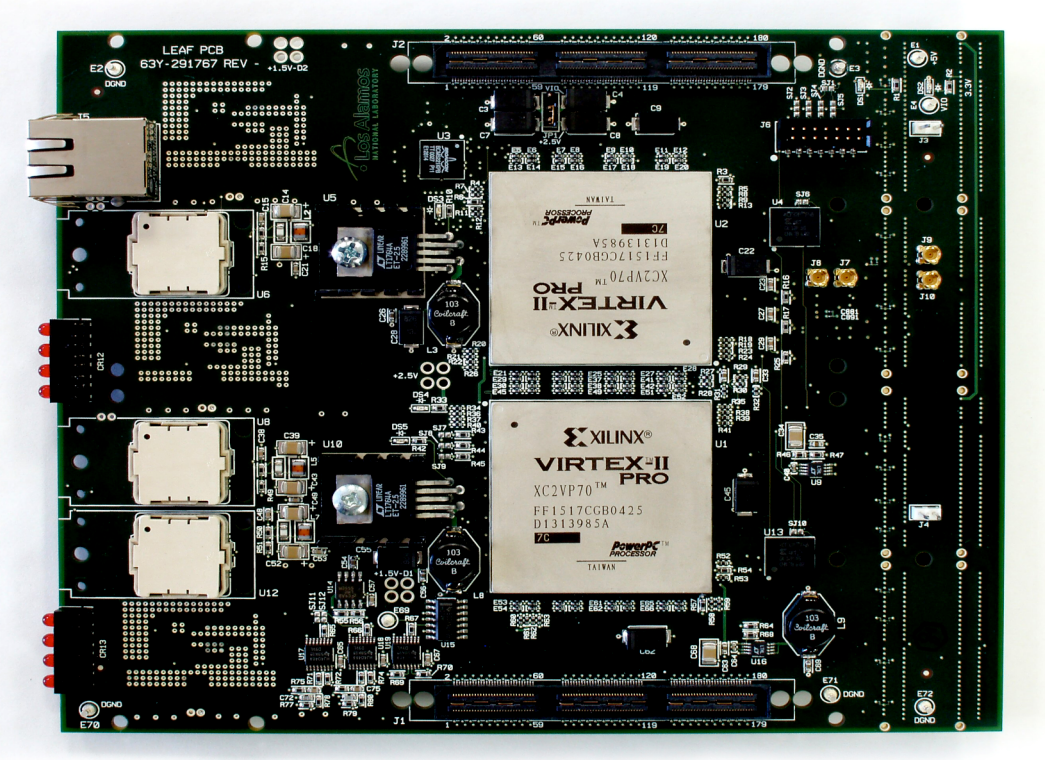
- Density of signals and the bandwidth ~250 Gbit/s
- Data sharing - need all the data in one place to do seamless jetfinding

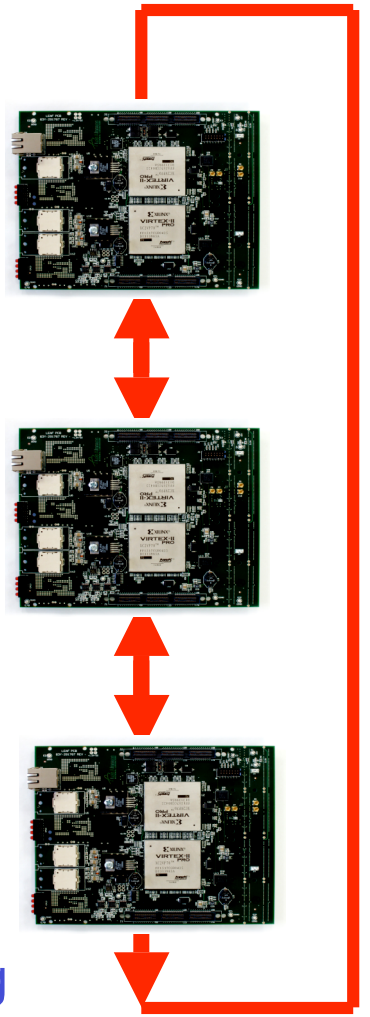
The Source Card



- Designed at Imperial
- Converts input from RCT to optical ouput to be sent to leaf card for processing

The Leaf Card





- The main work horse of the GCT
- Main task jet finding but also sorts electrons and sums E_T
- Leaf cards are chained together to share data for jet finding

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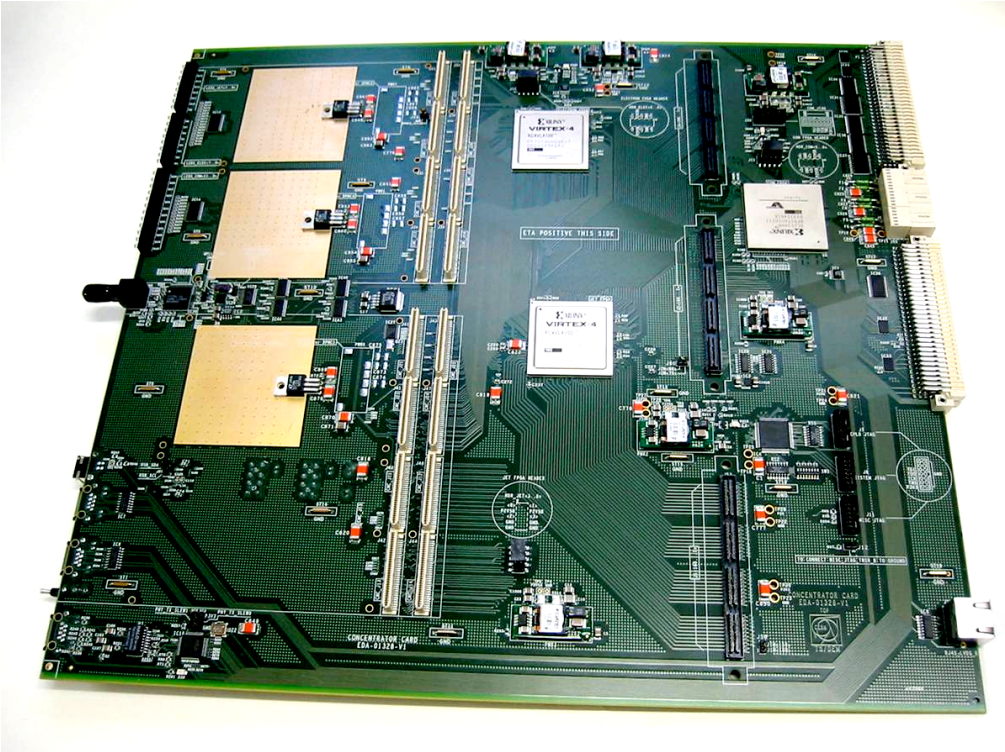
The Concentrator Card



- Final processing stage
- Sorts electrons and jets
- Calculated global quantities (missing E_T, total E_T etc.)

Status

- The GCT was redesigned from scratch around the turn of the year to take advantage of new technology.
- One of the few (only?) CMS components still really in a design phase. Still room for improvements and clever ideas in most aspects of the design.

- Status now
  - Source card design finished and in production.
  - Leaf card prototype under testing. Expect production soon.
  - Concentrator card prototype under testing.
  - Wheel card designed but no prototype yet.
  - Ongoing software work. Simulation and development of algorithms, commissioning and testing tools, control systems….

Summary

- Triggering at the LHC is a huge challenge
- The CMS trigger is highly complex
- The GCT is a key component in the trigger
- Redesign makes the project late/exciting (good/bad depending on your spin)

- In the next year we'll be doing all these things
  - Install electron trigger early next year
  - Physics studies and finalise jet finding algorithm
  - Install jet trigger middle of next year
  - Commission triggers without beam and then with beams in 2007 test run

- Understanding the trigger and taking the right data samples will be the key to early discovery of new physics
- Working on the trigger you get your hands on the data first