Commissioning and performance of the CMS Global Calorimeter Trigger

A. Tapper, J. Brooke, C. Foudas, R. Frazier, M. Hansen, G. Heath, G. Iles, J. Marrouche, A. Rose, G. Sidiropoulos & M. Stettler

- Trigger challenges and the CMS L1 Trigger
- The Global Calorimeter Trigger
- Status of commissioning and performance

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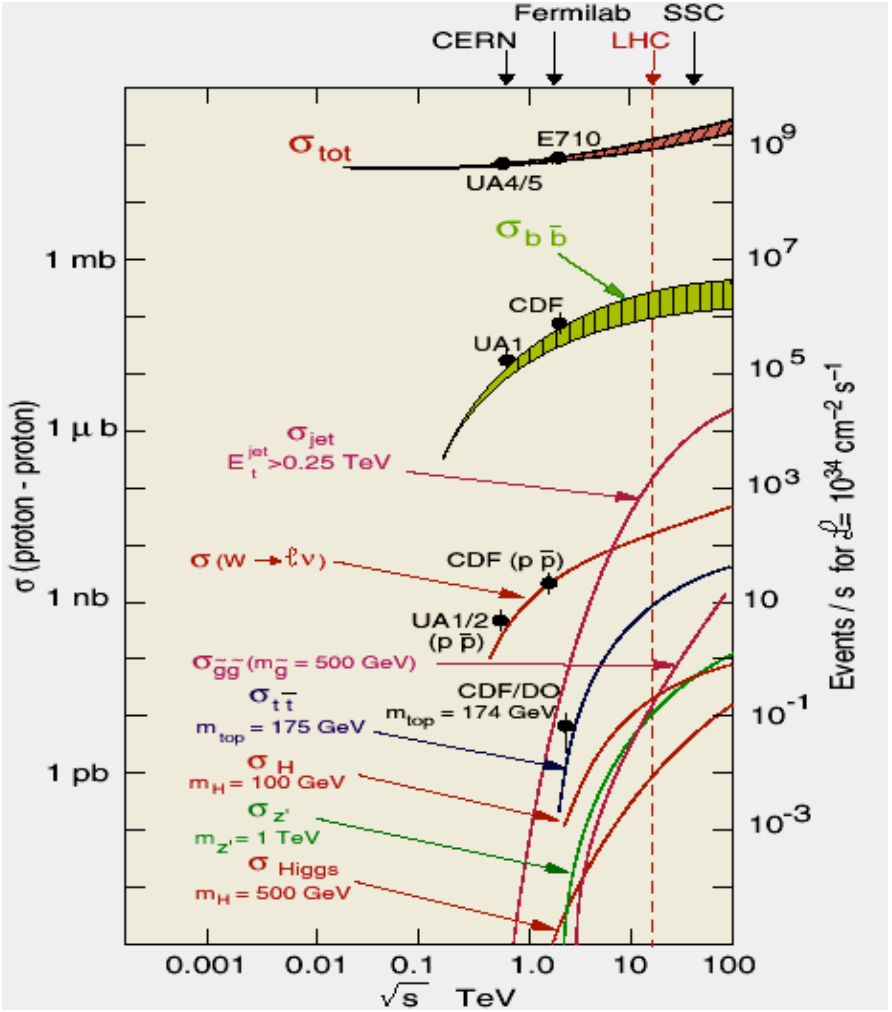
Trigger challenges at the LHC

- 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 overlaid
- 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!



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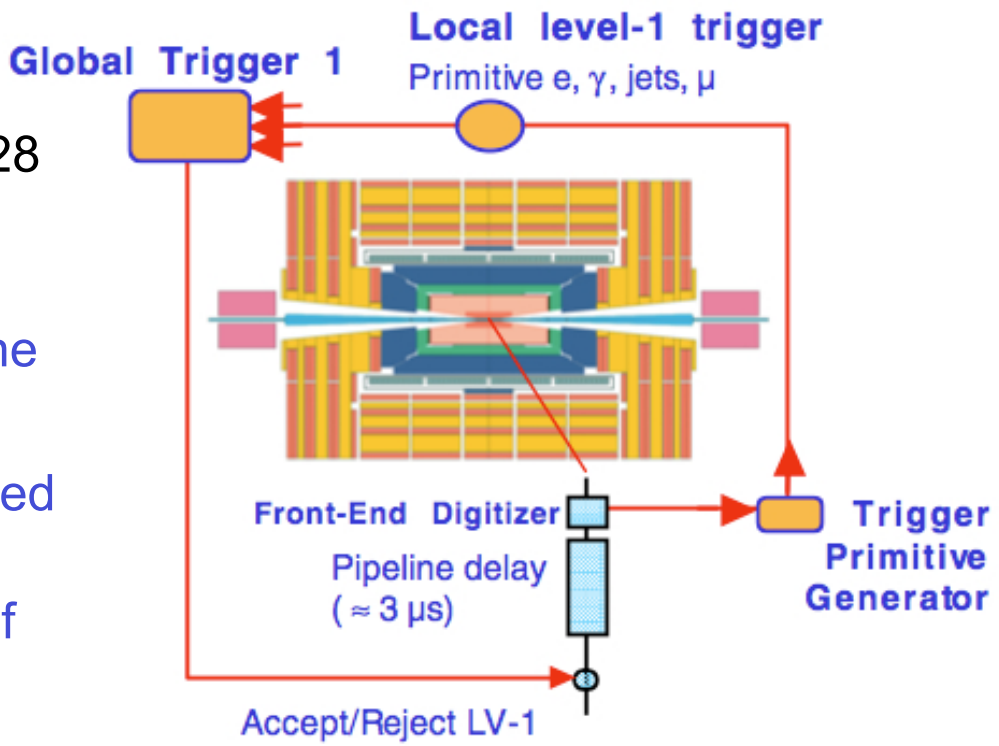
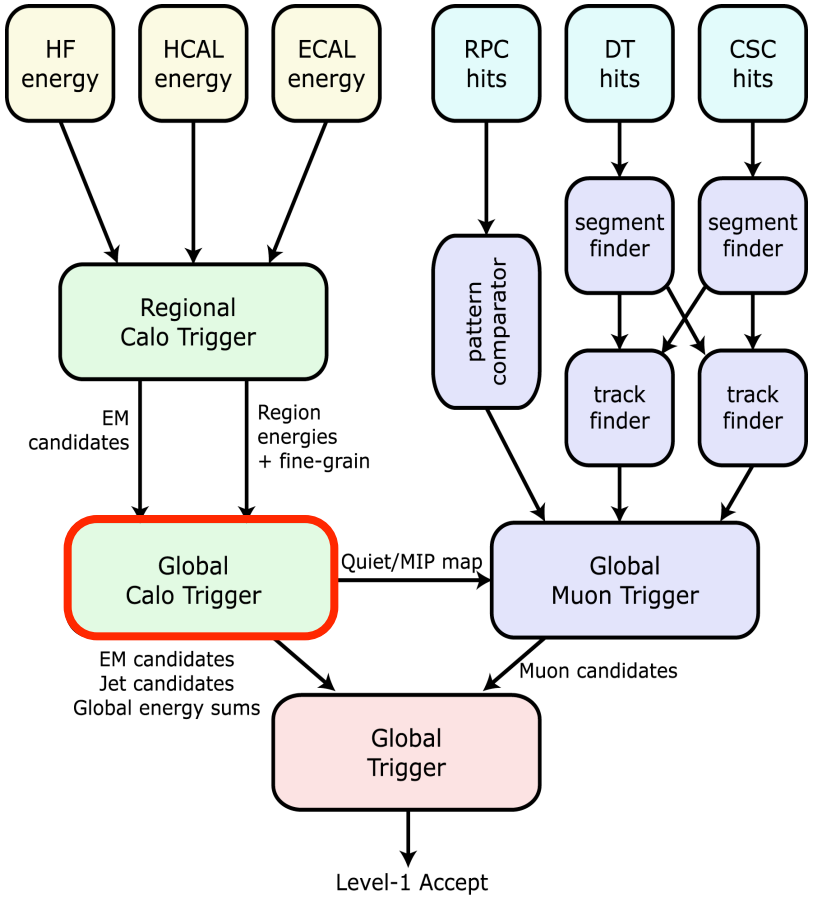
The CMS Level 1 Trigger

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



The CMS Level-1 Trigger

- Muons
  - Three complementary detector systems
  - Share hits when available in overlap regions
  - Find best combination of information in Global Muon Trigger
- Electrons, jets, energy sums etc.
  - Combine ECAL and HCAL energies in Regional Calo Trigger and do local electron finding
  - Global energy sums and jets in the Global Calo Trigger →
- All objects contribute to L1 accept



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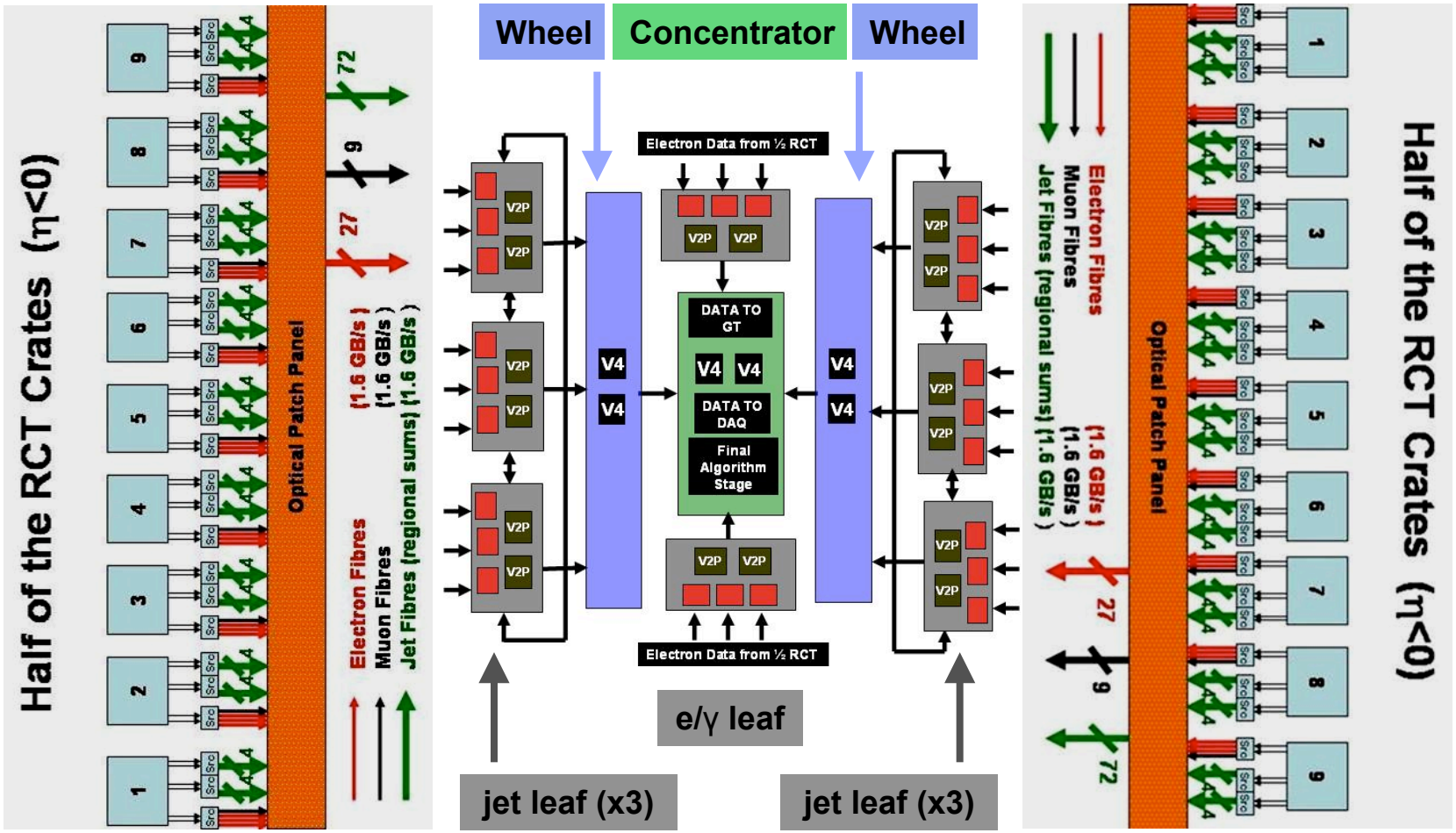
The Global Calorimeter Trigger

- Jet Triggers:
  - Central, Tau and Forward jet finding and sorting.
- Electron/γ triggers:
  - Select and sort the e/γ candidates from the Regional Calorimeter Trigger
- Energy sums:
  - Total Transverse (E_T), Missing Transverse (ME_T) and Total Jet Transverse Energy (H_T) calculation
- Min bias:
  - Sum rings and count towers above threshold in forward calorimeters to form minbias trigger
- Other tasks:
  - Receive the muon data and send them to the Global Muon Trigger (separate system based on μTCA hardware)
  - Readout all the RCT and GCT data for every L1 accept

The Global Calorimeter Trigger



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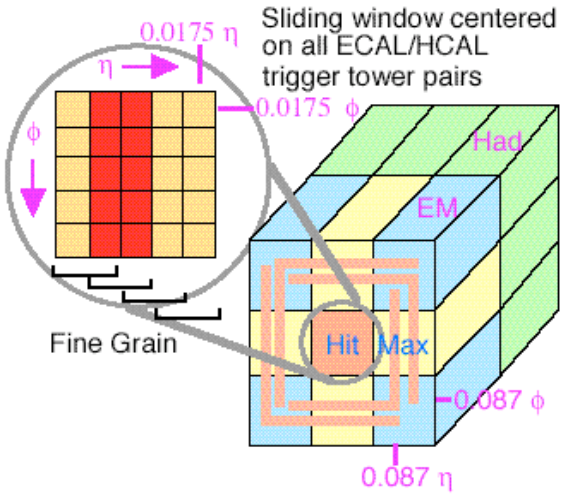
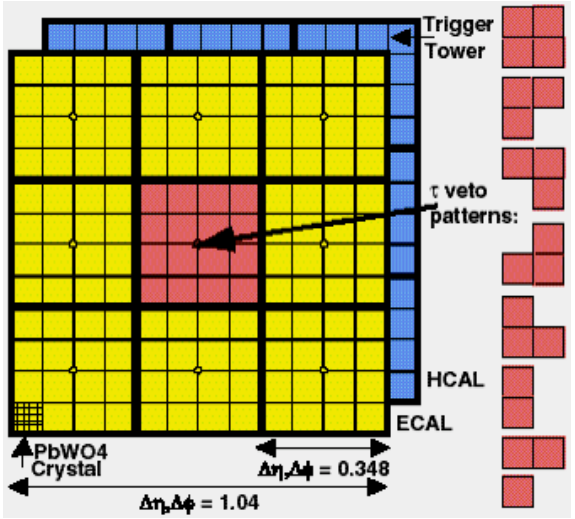
L1 trigger algorithms

Electron/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 and H/E
  - One group of 5 EM E_T < threshold

Jet Finder



- Jet E_T
  - 12x12 trigger tower ΣE_T sliding in 4x4 steps
  - Central 4x4 E_T > others
- Tau jet
  - Isolated narrow energy deposit
  - Energy outside veto pattern sets veto
  - Jet is tau if all nine 4x4 region vetoes off

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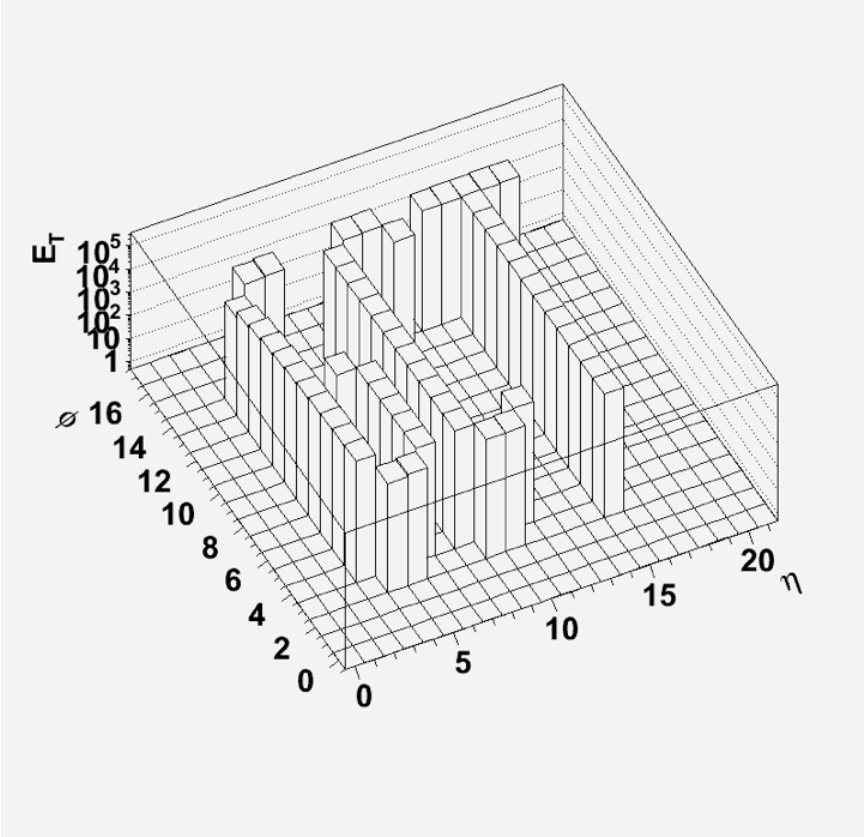
Status and commissioning

Three stages of commissioning planned:

- Pattern tests
  - Simple patterns to verify cabling map
  - Full Monte Carlo simulated events loaded into hardware. Compare to what is expected by software (C++) emulator.
- Cosmic tests
  - Run with cosmic-ray muons triggered by muon system or calorimeters
  - Compare to what is expected by emulator (comparison run online in DQM stream)
- ~~First running~~
  - ~~Single beam (beam-gas and beam-halo) events~~
  - ~~First collision data!~~

Pattern tests

- Comprehensive suite of test patterns, from simple to complex
  - For cabling an ID pattern
  - Random numbers, walking ones etc. for hardware corruption
  - For geometry various patterns with single towers of energy, building up to a fun example →
  - For algorithms groups of energy to test clustering, special cases at boundaries etc.
  - Finally full Monte Carlo events → next page.....



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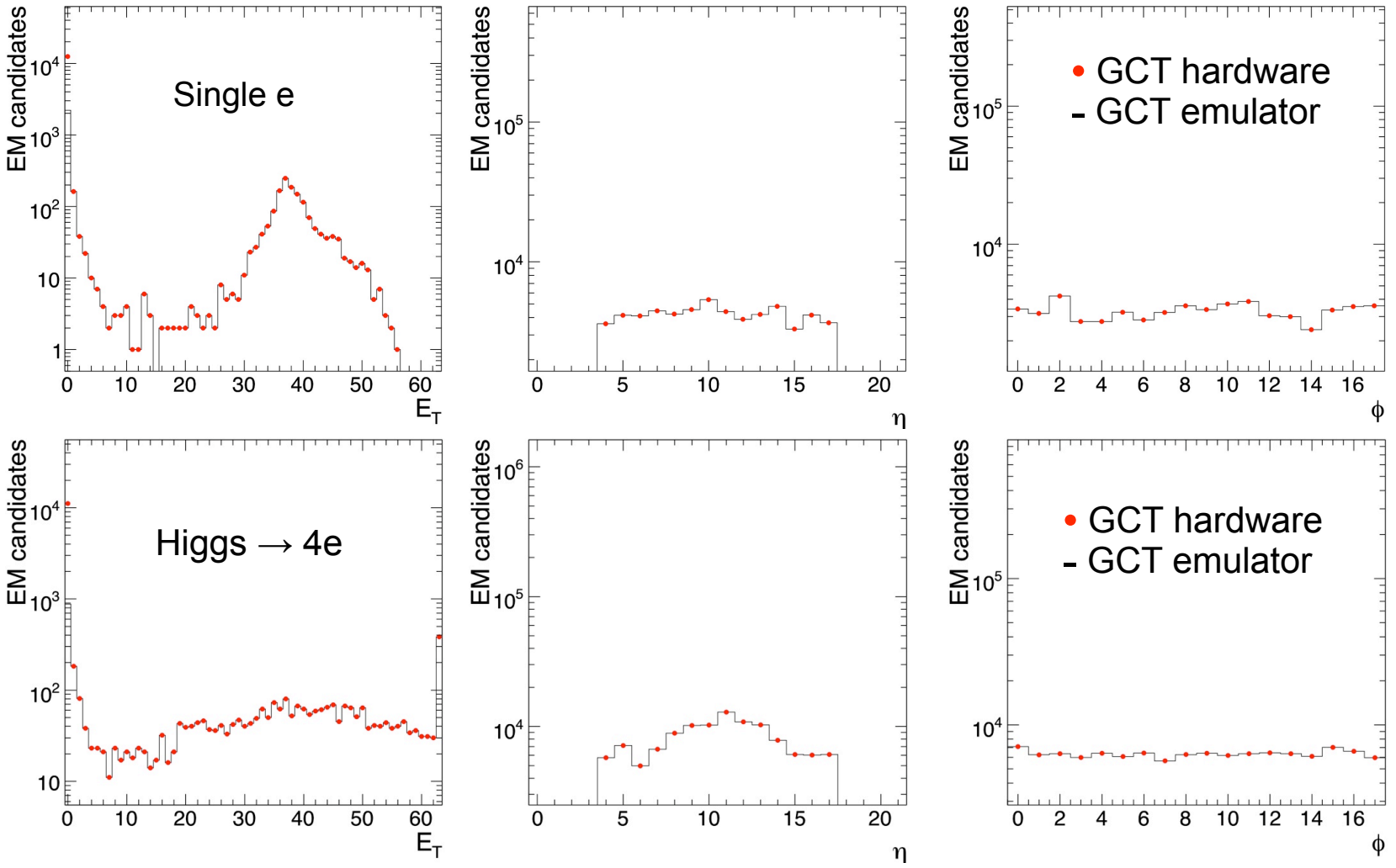
Pattern tests



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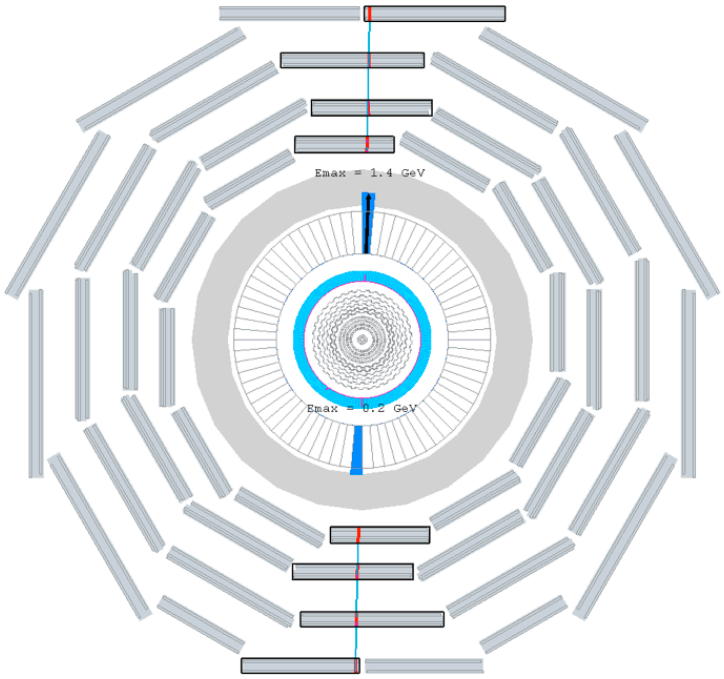
Cosmic muon running

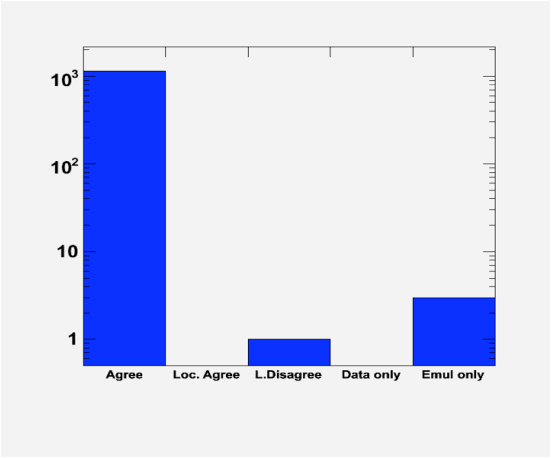


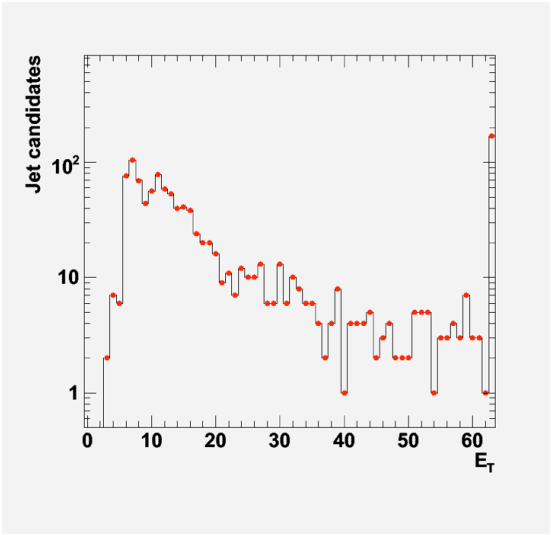
- Trigger on cosmic-ray muons
  - Muon chambers
  - MIP in ECAL or HCAL
- Commissioned electron trigger in November ’07
- Working on jet triggers now
- Some examples from a recent run →

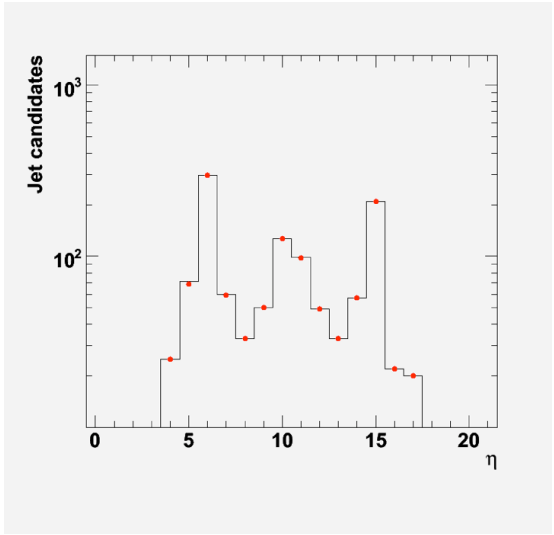
Cosmic muon running

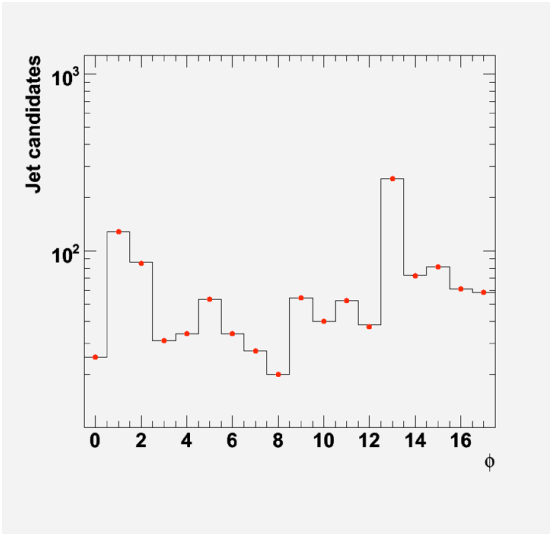
- Central jets (|η| < 3)

  - GCT hardware
  - GCT emulator









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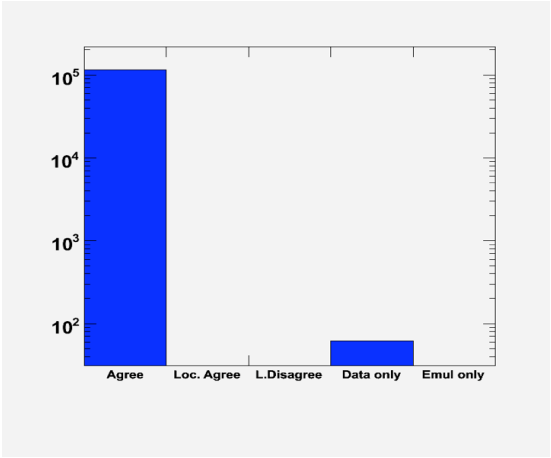
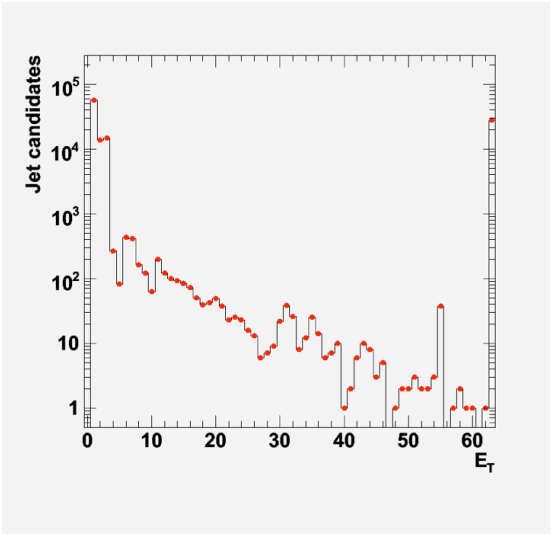
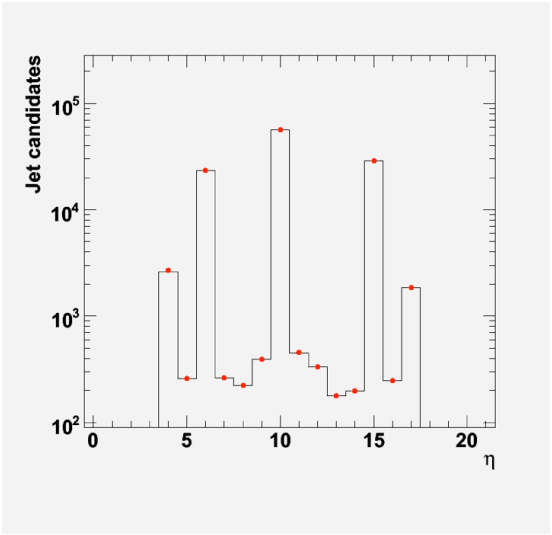
Cosmic muon running

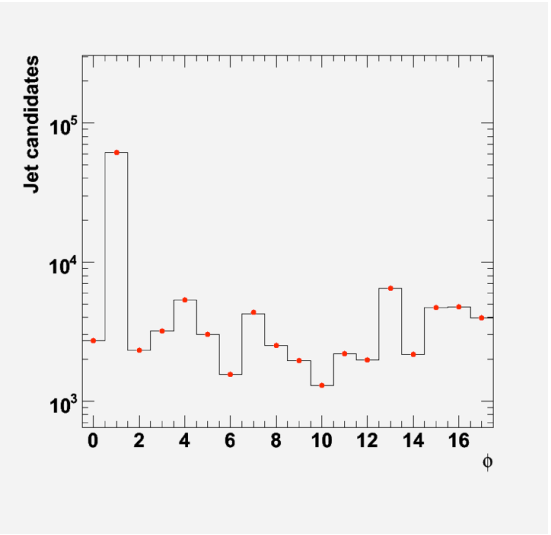
- Tau jets (|η| < 3)

  - GCT hardware
  - GCT emulator



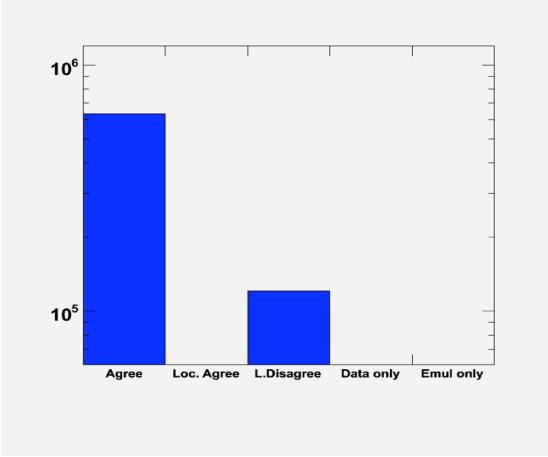


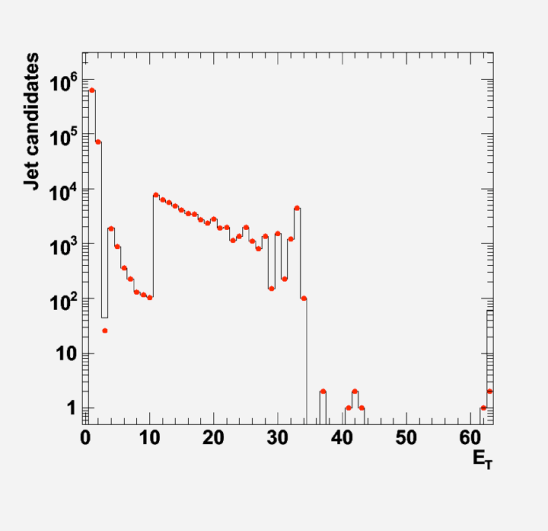


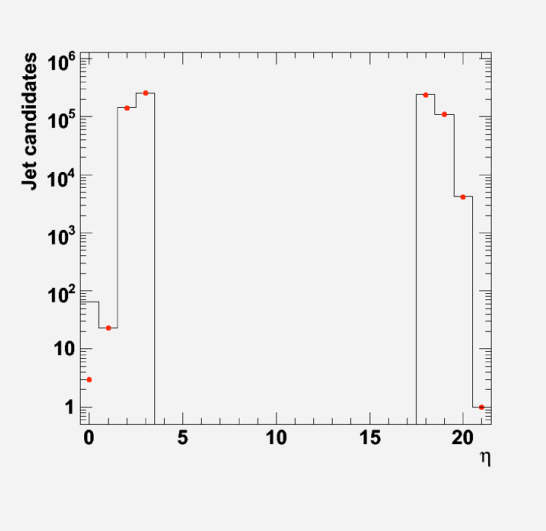


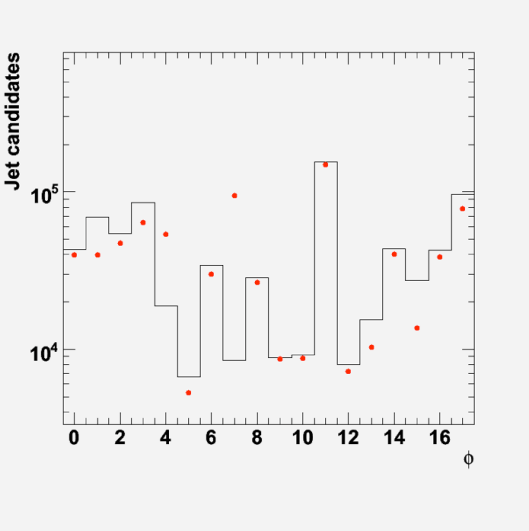
Cosmic muon running

- Forward jets ($3 < |\eta| < 5$)
  - GCT hardware
  - GCT emulator









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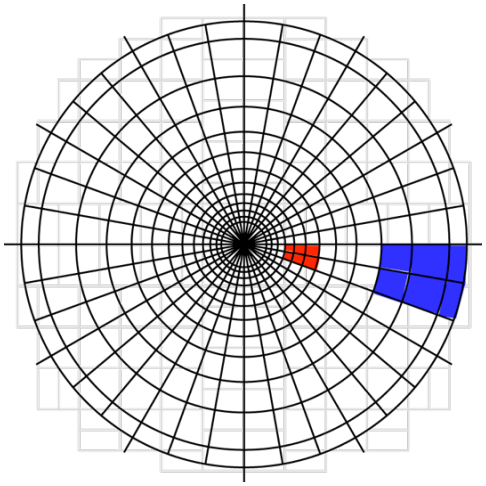
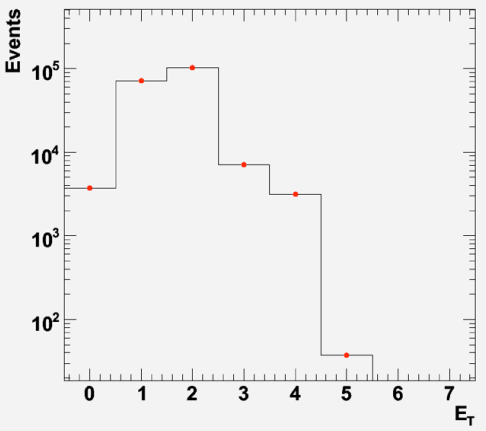
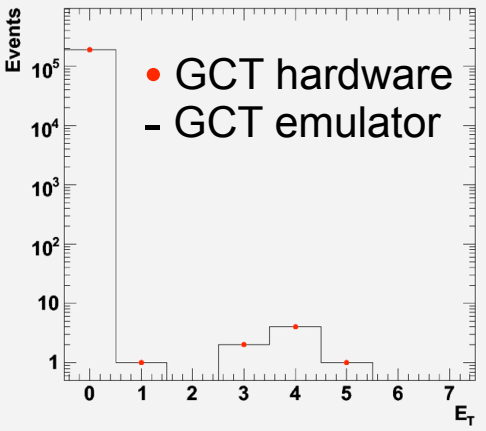
Cosmic muon running







- New idea for triggering low P_T events in early running
  - Consider inner two rings of trigger towers in the forward calorimeter
  - Make E_T sums and count towers over E threshold
  - Make coincidence in +/- η

Future plans

- Missing E_T, H_T and total E_T implemented
  - Need to be fully commissioned with patterns and cosmic data
  - That would complete the baseline specification

- Already implemented one new idea along the way, others waiting in the wings
  - Missing E_T from jets → Missing H_T (MH_T)
  - Hope is that MH_T will be more robust in the face of noise and bad beam conditions than ME_T and therefore particularly valuable in early running
  - Tau algorithm can be better optimised with more isolation

- Flexible enough to react to new ideas and conditions

Summary

- System runs stably and reliably
  - Huge amount of hardware detail omitted
- Electron, jet and minimum bias triggers commissioned
  - Tracking down final <1% bugs
- Missing E_T, H_T and total E_T implemented
  - Currently commissioning with cosmic muon data
- Baseline project almost finished, what we've found
  - Complex system designed and built in a quite short timescale
  - Since the firmware is complicated commissioning by comparison with software emulator has been enormously important
  - Huge flexibility in system allows improvements in algorithms and new ideas to be implemented → a blessing for CMS but a curse for us... already new ideas in the pipeline
- Looking forward to data from the LHC!