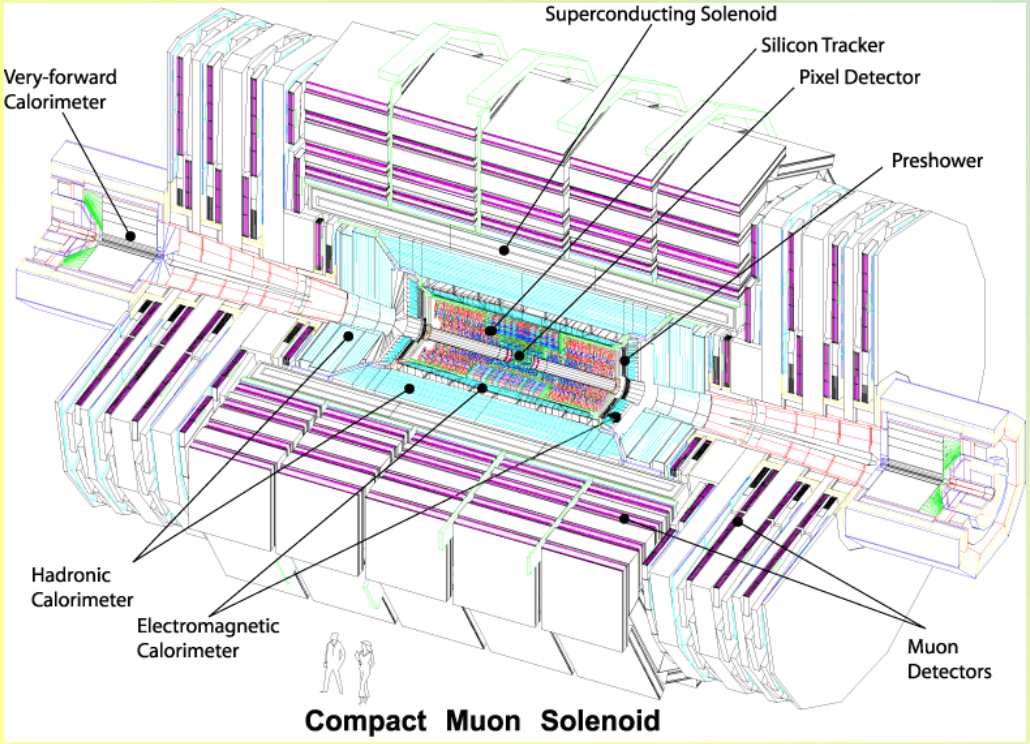
The CMS L1 Trigger Emulation Software

Vasile Mihai Ghete
Institute for High Energy Physics, Vienna, Austria

on behalf of CMS Collaboration, CERN

17th International Conference on Computing in High Energy and Nuclear Physics
21 - 27 March 2009 Prague, Czech Republic

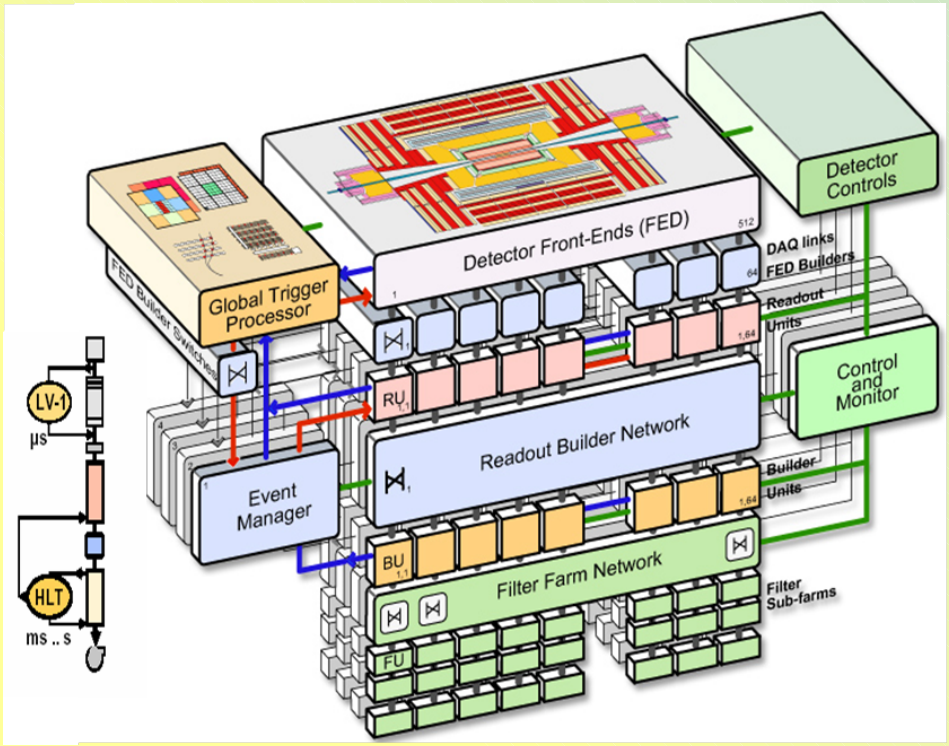
CMS experiment



- CMS
  - General purpose experiment
  - LHC, CERN
  - Interaction Point 5 (IP5)

- Tracker
  - pixel detector:
    - 3 barrel layers, 2 discs / endcap
  - silicon strip detector:
    - Barrel: layers: 4/inner, 6/outer
    - Endcaps: discs: 3/inner, 9/outer
  - inside the solenoid: 4 T magnetic field.
- Calorimetry: inside the solenoid
  - high resolution lead-tungstate crystal EM calorimeter: $|\eta| < 3$
  - endcap preshower
  - hadron calorimeter: $|\eta| < 5$
- Muon spectrometer:
  - superconducting solenoid, 4 T.
  - barrel: DTs and RPCs
  - endcaps: CSCs and RPCs.

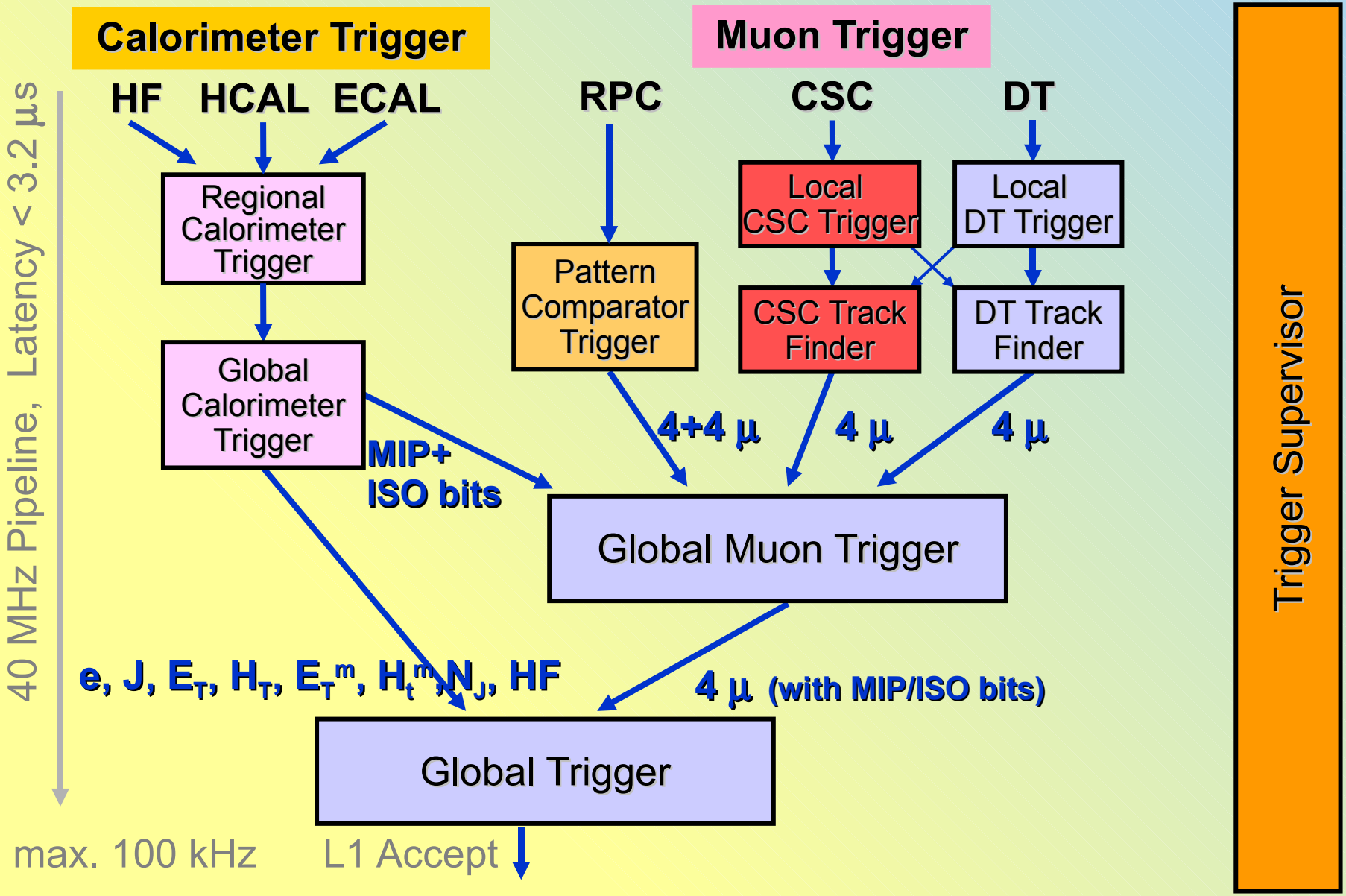
Triggering at CMS



- Trigger tasks:
  - reduce the event rate to O(100) Hz
  - cover widest possible range of discovery physics
- Main characteristics:
  - 8 slices, each slice allow 12.5 kHz

- Level-1Trigger (L1)
  - Custom hardware trigger
  - Reduce event rate from 40 MHz to 100 kHz (complete) or 50 kHz (DAQ staged).
  - Total processing time: 3 µs.
  - Selection: based on coarse information from calorimeter and muon detector
- High Level Trigger (HLT)
  - Software trigger:
    - use the offline software framework
  - Output event rate: 100 Hz
  - Average processing time: ~ 40 ms.
  - Has access to all event data, with full precision and granularity
  - L1 seeded (conditional reconstruction)
    - partial (regional) reconstruction

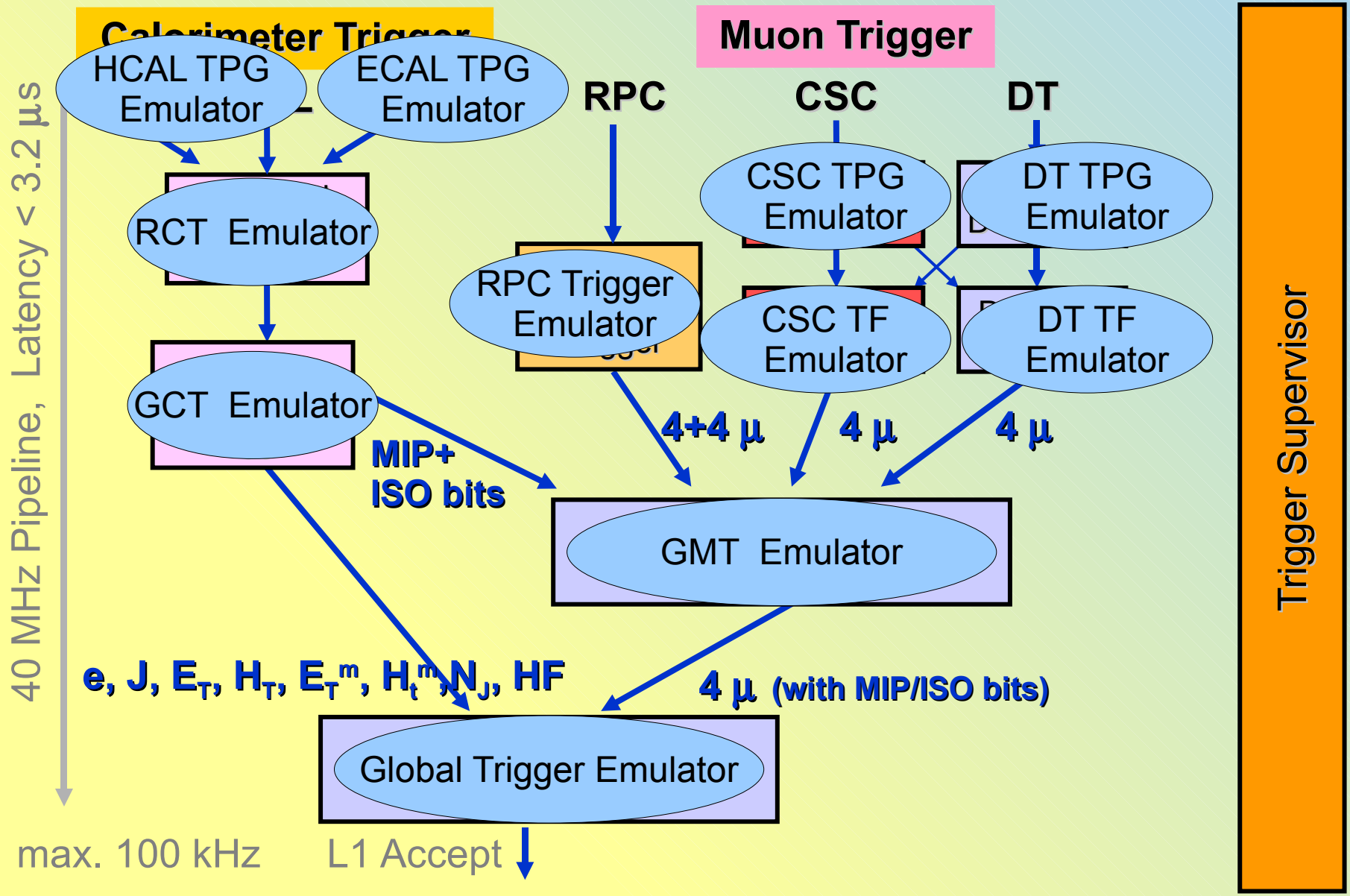
Level-1 Trigger System



L1 Trigger Emulation

- L1 Trigger emulation task
  - Emulate bit by bit each L1 Trigger subsystem
- Requirements
  - Modular design
    - Follow the modularity of the hardware subsystems
    - Integrated in CMS modular offline software framework
  - Use the same input and the same input format as the hardware
  - Produce same output as hardware, with identical format
  - If possible and required, produce additional information, not saved by the hardware
    - Intermediate information
    - Information not made available in the hardware
  - Configuration – see separate slide
  - Stringent timing requirements for all modules, especially those running online for each event.

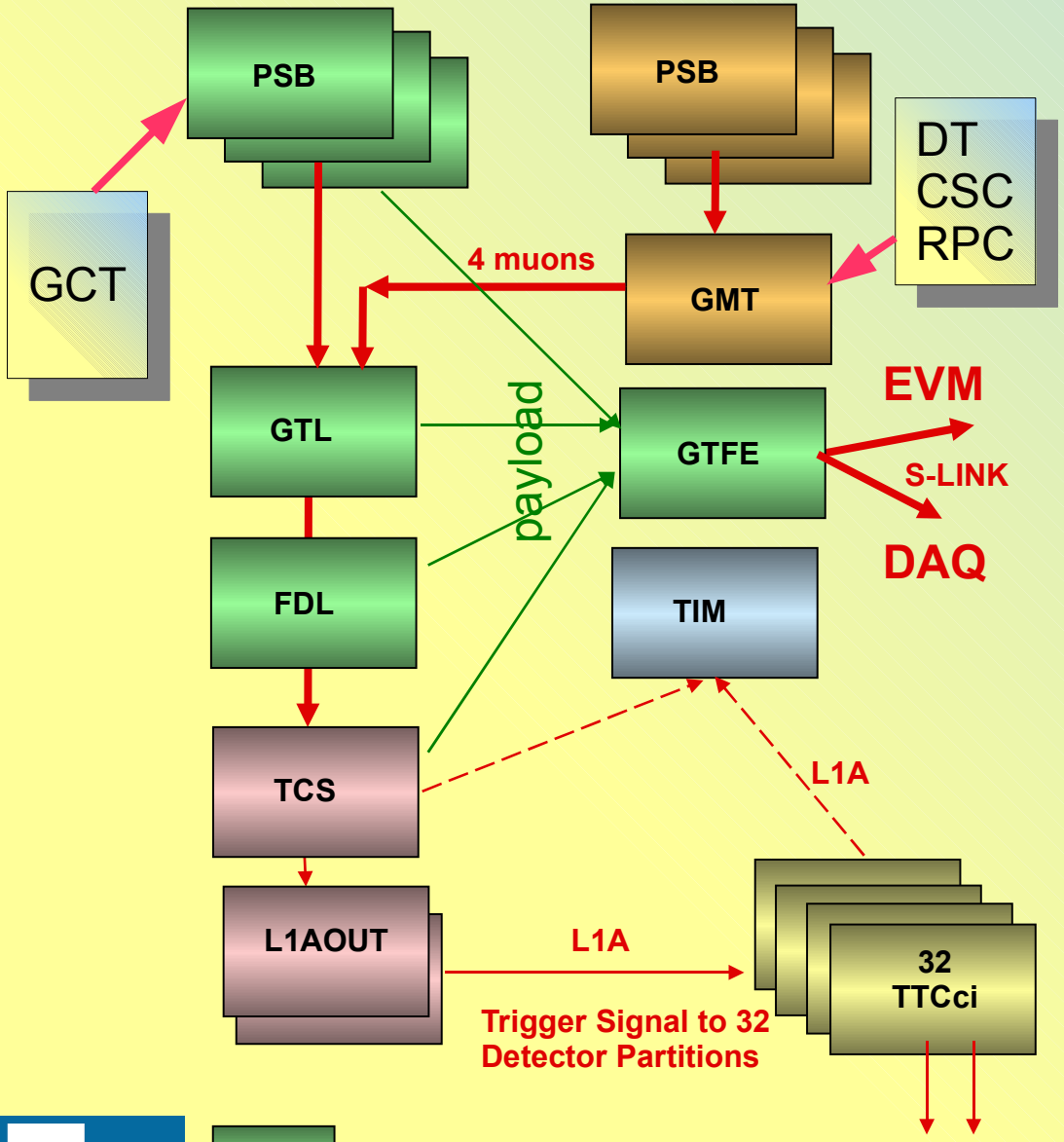
L1 Trigger Emulation - Components



L1 Trigger Emulation – Configuration

- Configuration requirements
  - Use the same configuration as the hardware
  - Enable to overwrite for emulators some hardware parameters
- L1 Hardware configured from OMDS database
  - Not accessible offline
- Transfer of the configuration – special O2O application to run in Run Control
  - From OMDS to offline DB (ORCOF)
  - From OMDS to DB used for CMSSW online (ORCON)
  - Set also the Interval of Validity (IoV) - run dependent
    - Associate configuration with data

Example: L1 Global Trigger



- L1 Global Trigger
  - Hardware design - cards
  - Input
    - Trigger objects: GCT, GMT
    - Technical triggers - no objects
    - Logical conditions - no objects
  - Task
    - evaluates in parallel up to 128 algorithms (physics trigger requirements, given in the L1 Menu) based on input objects
    - Algorithm = logical expression of “conditions”
    - Condition= object template for physics requirement (up to 4 objects in a condition)
  - Produce L1 Accept, GT DAQ and EVM records
- (Acronyms in backup slides)

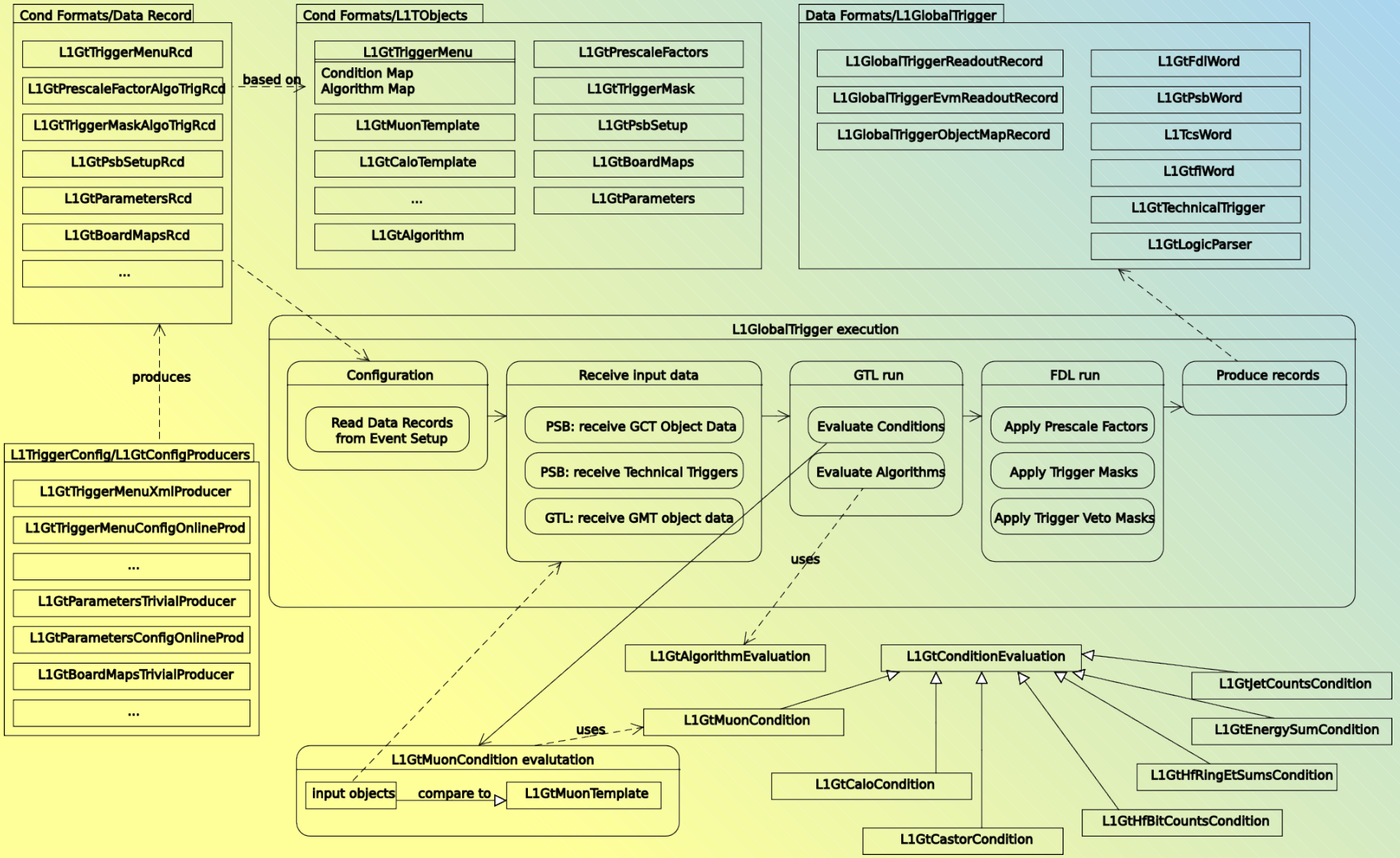
L1 Global Trigger Emulator

Configuration definition

Configuration producers

Data format definition

Emulator execution logic



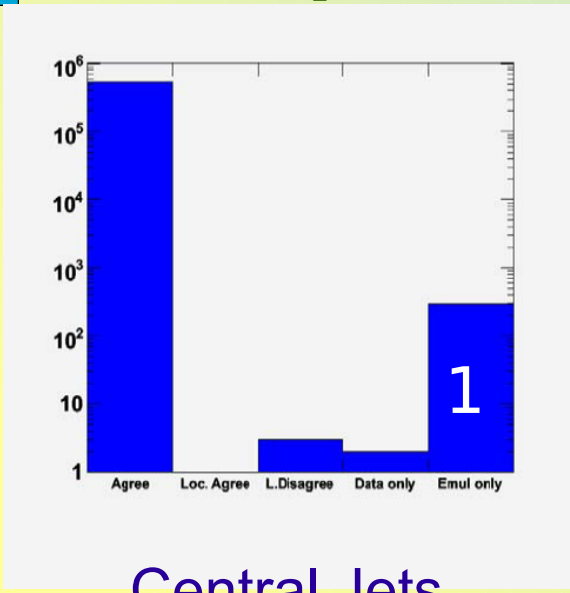
Use Cases for L1 Trigger Emulators

- Validation of trigger hardware
  - Run emulator on same input data as hardware and compare results
  - Run pattern tests in emulator and trigger hardware and compare results
    - Can test thoroughly choosing adequate pattern tests
- Monitoring of trigger hardware
  - Use validated emulators to monitor trigger hardware
  - Implies running the emulators during data taking
    - Probably not all emulators for each event due to timing constraints
- Monte Carlo simulation of L1 Trigger
  - For existing hardware and configuration
  - For new proposed objects
  - Trigger menu development
    - Determine expected rates
    - Propose prescale factors
- L1 seeding of HLT
  - Use the GT emulator to find L1 objects which actually triggered
    - Too complex task to be done on FPGA
  - Start HLT algorithms from these L1 objects
    - Conditional and regional reconstruction
    - Avoid volunteers

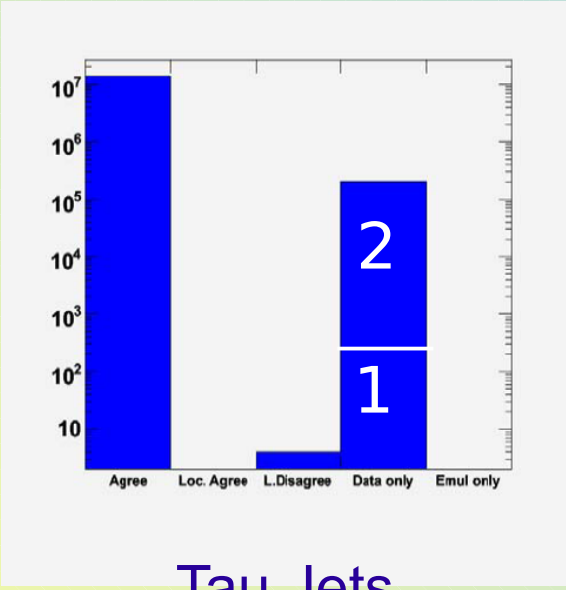
Validation and Performance Improvement

- Modules running online have stringent timing requirements
- Average HLT time per event
  - 40 ms
- Methods
  - Streamline the code
  - Tailored configuration: use only what is needed online
  - Avoid string comparisons, string parsing
  - Avoid useless copying
  - Careful declaration of container size to avoid resizing
  - Choose carefully standard containers
  - Extensive caching of event setup
- Tools used for optimization
  - IgProf (Ignominious Profiler)
  - Valgrind
- Example: Global Trigger
  - Initial release: ~40 ms !
  - Next optimization: ~14 ms
    - Streamlined code
    - Run only 1 bunch cross in event (L1A) instead of 3
  - Next optimization: ~7 ms
    - Mix of changes (see link column)
  - Next optimization: 1- 3 ms
- Validation - iterative process
  - Use data collected in cosmic Global Runs, MC samples
  - Compare results

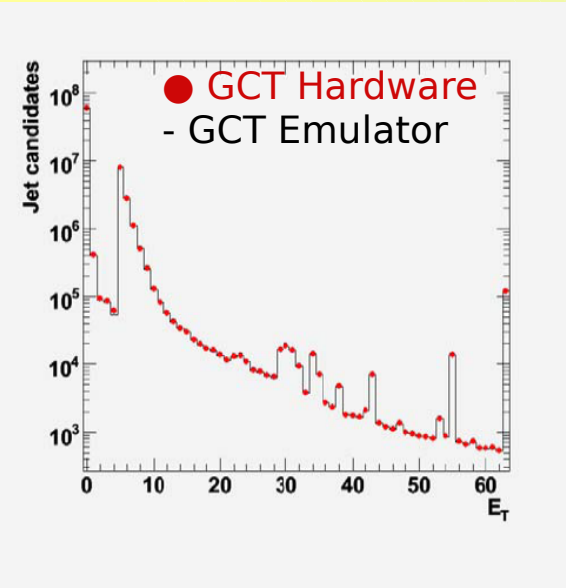
Examples: GCT Central and Tau Jets

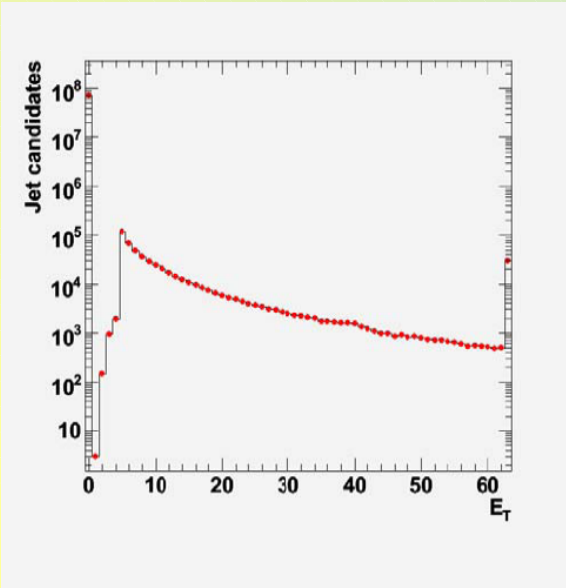


Central Jets



Tau Jets

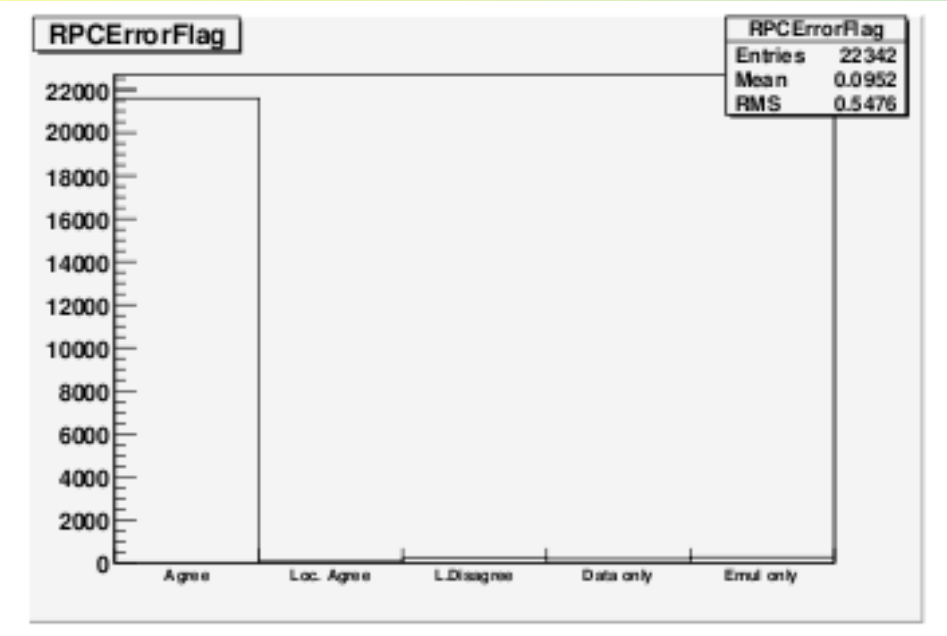


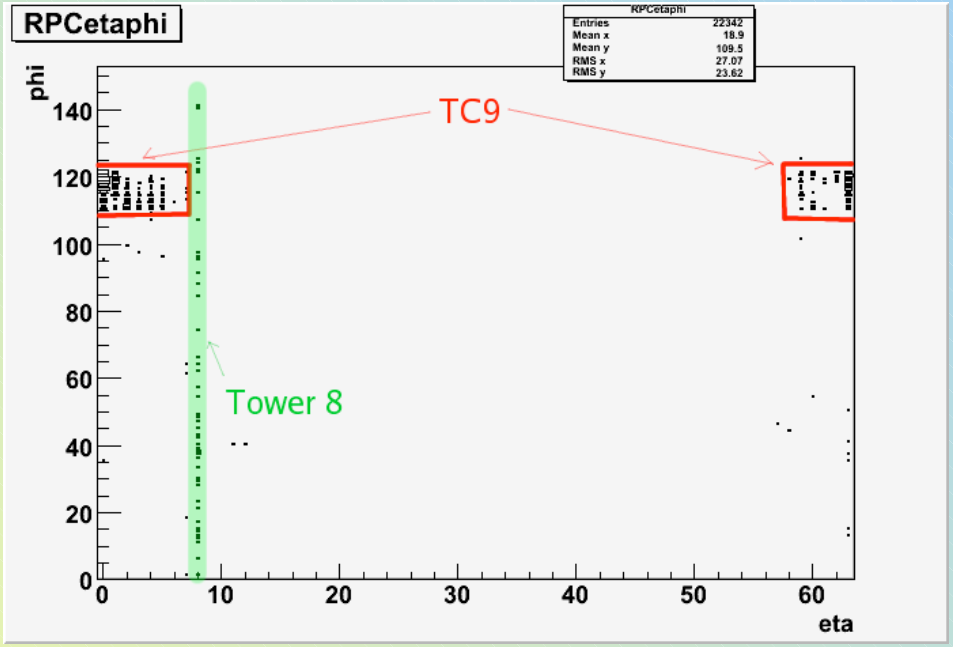


- Two major effects
  1. misidentified jets due to tau-veto bit handling errors → hardware updated
  2. bug in jet finding algorithm (extra candidates at η = 0 boundary) → emulator and hardware updated (plots show patch in emulator only).

CRAFT Global Run 2008

Example: RPC Trigger





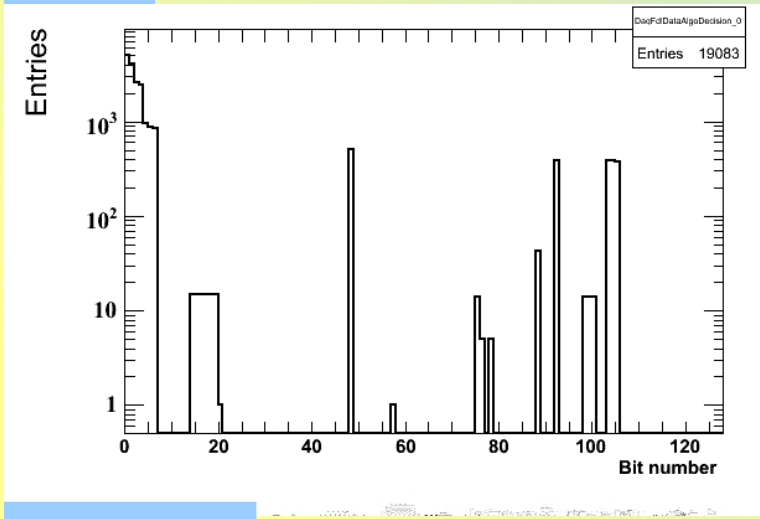
- Agreement data – emulator 98%

- Disagreements in the trigger crate TC9
- Probably transmission errors
  - New firmware with better transmission

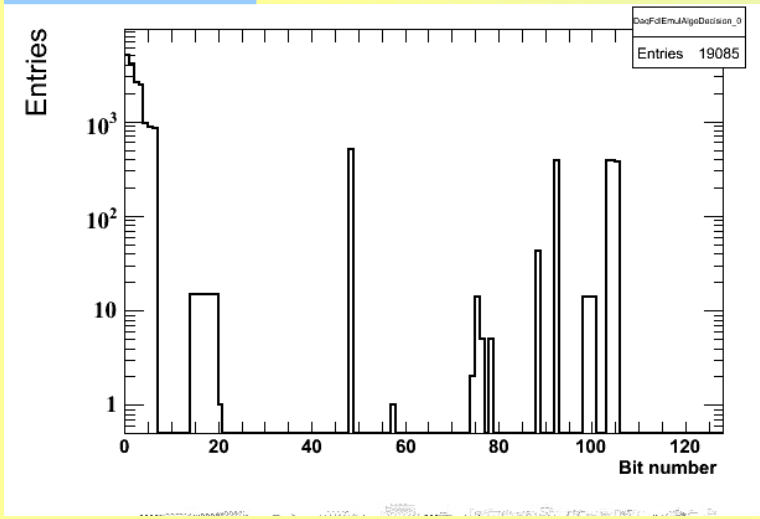
CRAFT Global Run 2008

Example: Global Trigger

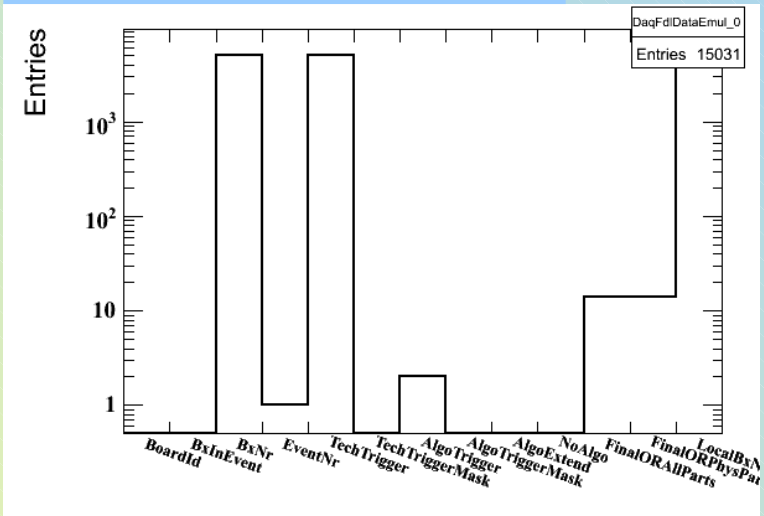
Data



Emulator



FDL Data vs Emulator



- Discrepancies: all fixed
  - No Bx number in Emulator
  - Technical triggers in hardware
  - FinalOR – wrong key for emulator
  - Local Bx in emulator

CRUZET Global Run early 2008

Summary

- CMS has developed an extensive system of L1Trigger emulation
  - Bit-level emulation of L1 Trigger data processing
  - For each L1 trigger subsystem an emulator was developed
- L1 Trigger emulators are actively used for
  - Validating and monitoring the L1 trigger hardware
  - Monte Carlo simulation of the L1 trigger response
    - Development of the L1 trigger menu
  - L1 seeding of HLT
- Results from the Global Runs (cosmic data taking 2007 -)
  - Prove usefulness of L1 Trigger emulation for debugging L1 Trigger
    - Problem spotted and solved in hardware configuration and running
- Used in MC studies, L1 Trigger emulation allows to define and refine the CMS physics program.

Backup slides

Acronyms

- HCAL – Hadronic Calorimeter
- HF – Hadronic Calorimeter Forward
- ECAL – Electromagnetic Calorimeter
- RPC – Resistive Plate Chambers
- CSC – Cathode Strip Chambers
- DT – Drift Tubes Chambers
- TF – Track Finder
- TP – Trigger Primitives
- TPG – Trigger Primitive Generator
- RCT – Regional Calorimeter Trigger
- GCT – Global Calorimeter Trigger
- GMT – Global Muon Trigger
- GT – Global Trigger

Acronyms (*contd.*)

- e, μ, E_t^m, H_T^m, HF, - trigger objects (electron, muon, missing transverse energy, missing calibrated transverse energy, HF objects)
- ISO, MIP – isolation and “minimum ionizing particle” quantities
- Bx – bunch crossing
- FED – Front End Data
- DAQ – Data Acquisition System
- EVM – Event Manager: controls data flow of events in DAQ
- GTL – Global Trigger Logic card
- FDL – Final Decision Logic card
- PSB – Pipeline Synchronize Buffer card
- GTFE – Global Trigger Front End card
- TCS – Central Trigger Control System
- TIM – Timing card

Acronyms (*contd.*)

- L1A - Trigger signal to read all Front End buffers of CMS
- S-LINK64 – Fast data Link extended to 64 bits
- FPGA – Fully Programmable Gate Array
- OMDS – Online Master Data Storage database
- ORCON – Offline Reconstruction Online subset database
- ORCOF – Offline Reconstruction Offline subset database
- CRUZET – CMS Run at Zero Tesla global run
- CRAFT – CMS Run at Four Tesla global run