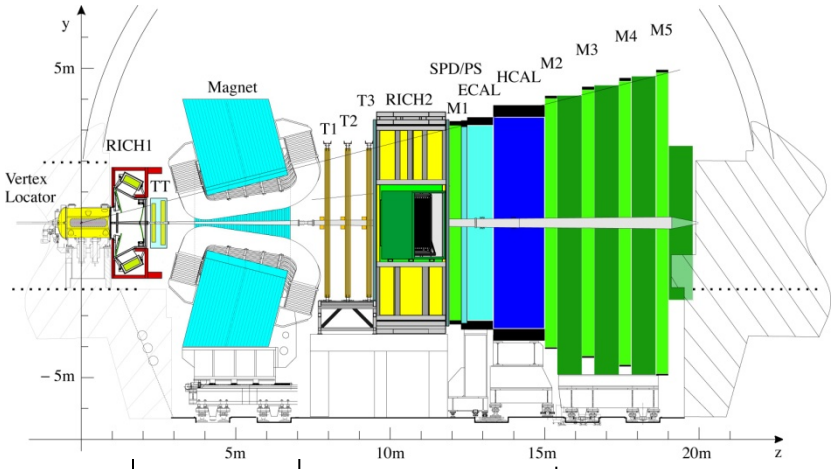
LHCb Trigger, Online and related Electronics

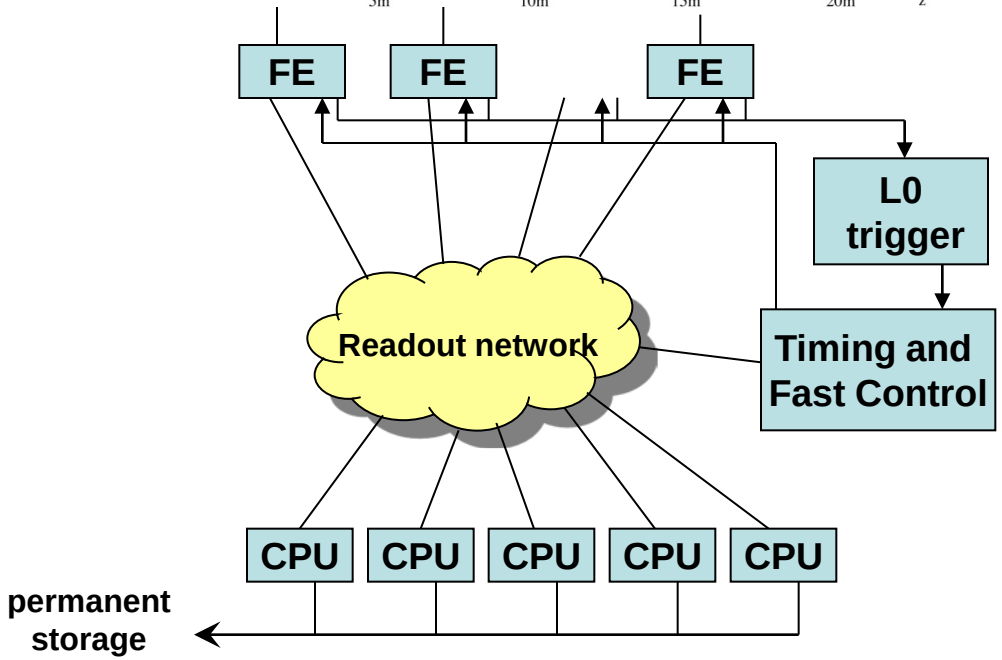
Artur Barczyk
CERN PH/LBC

on behalf of
the LHCb collaboration

LHCb Trigger-DAQ system overview

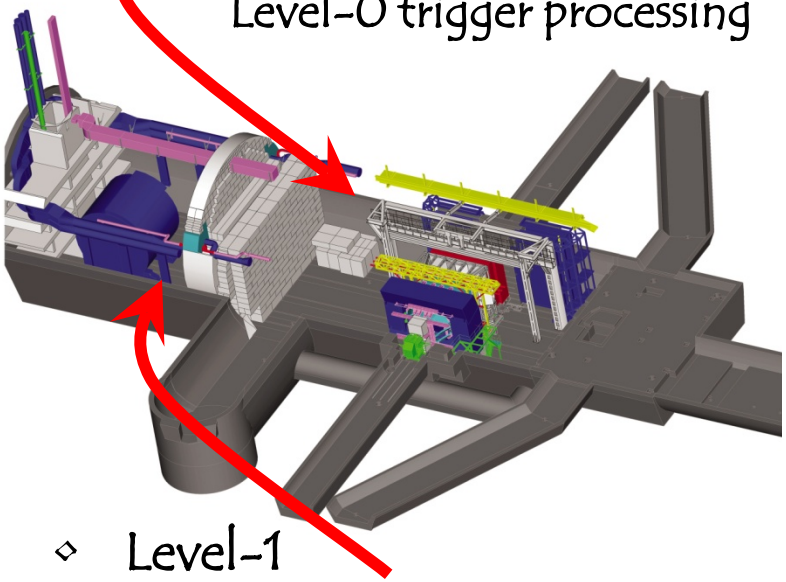
- Beam crossing rate: 40MHz
- Visible interaction rate: 10MHz
- Two stage trigger system
  - Level-0:
    - Hardware
    - Accept rate: 1MHz
  - High Level Trigger (HLT):
    - Software
    - Accept rate: 2kHz
- Level-1 Electronics: interface to Readout Network
- Readout network
  - Gigabit Ethernet
  - Full readout at 1MHz
- HLT trigger farm
  - ~1800 nodes



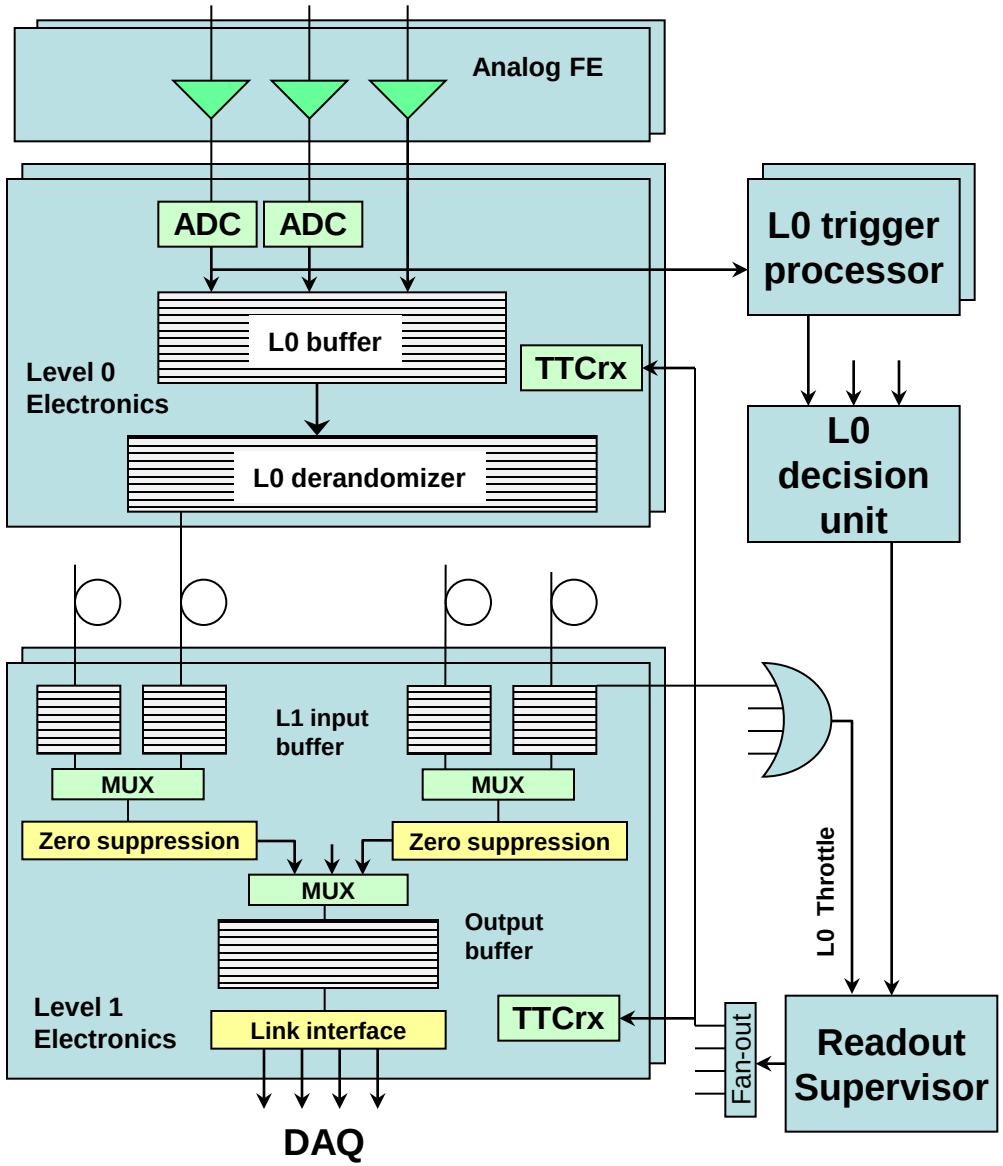


The Front-End system

- Level-0
  - Sub-detector specific implementation
  - On-detector → radiation hard
  - Event data buffered during Level-0 trigger processing

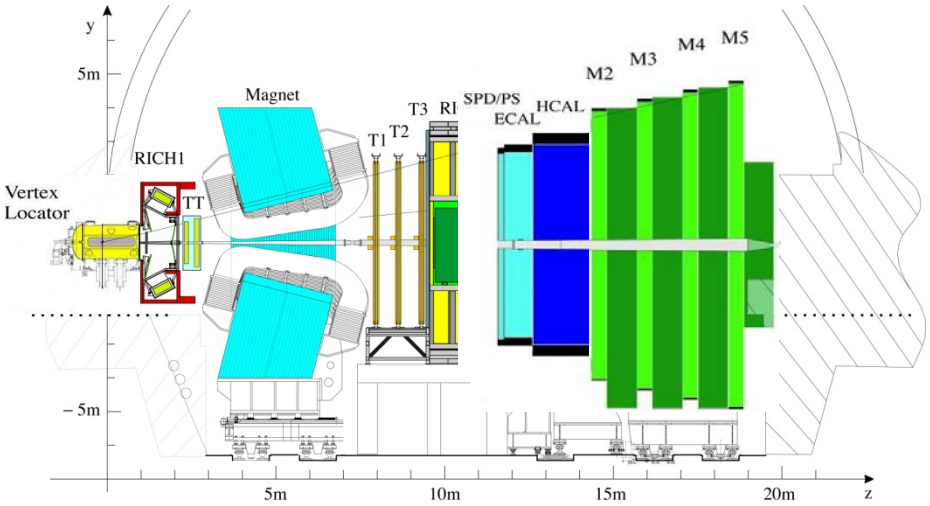


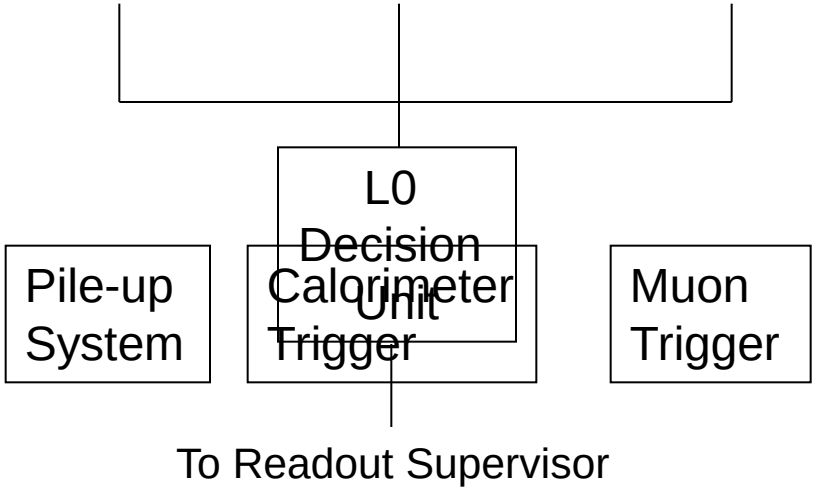
- Level-1
  - Behind radiation wall
  - Performs zero suppression
  - Interfaces to the Readout Network
    - Readout specific protocol



Level-0 Trigger

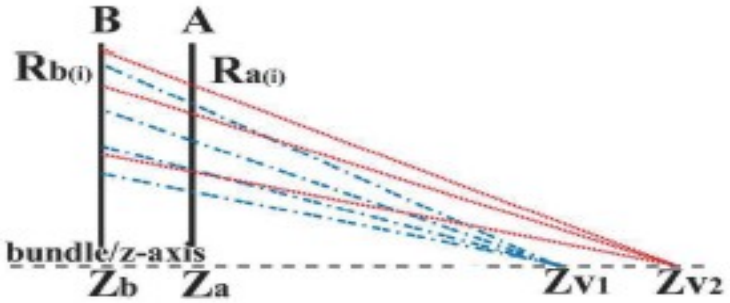
- Custom electronics
- Fixed latency: 4μs
  - Includes link delays, processing time: 2 μs
- Pile-up system
  - Determines number of interactions per crossing
- Calorimeter trigger
  - High E_T clusters
  - SPD multiplicity
- Muon Trigger
  - High p_T muons
- L0 Decision Unit
  - Evaluates trigger information
  - Presents L0 decision to Readout Supervisor



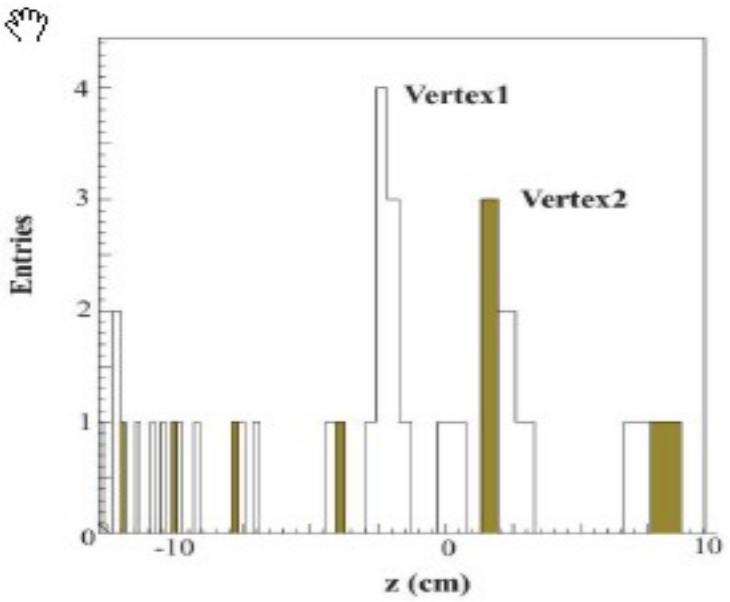


Level-0 Pile-up System

- Identifies bunch crossings with multiple interactions
- Use hits in two silicon planes upstream of IP
  - Histogram track origin on beam axis (ZV)
  - Hits belonging to highest peak are masked
  - Search for second peak
- Information sent to LO Decision Unit:
  - Nr of tracks in second peak
  - Hit multiplicity
- Performance:
  - $\varepsilon_{2\ \text{interactions}}$ = ~60% at 95% purity
  - Latency: ~ 1 μs

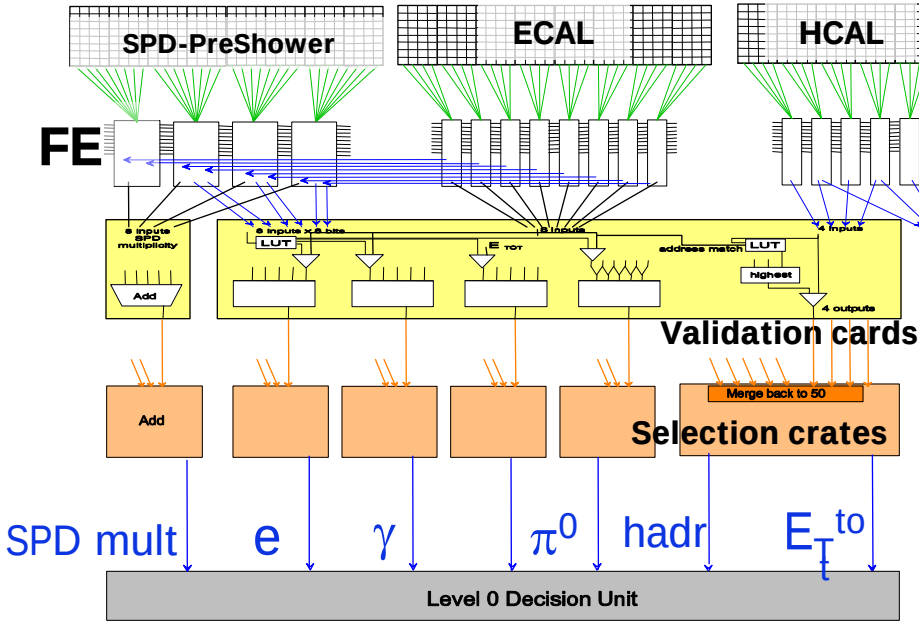


$$z_v = \frac{k \times z_a - z_b}{k-1} \text{ where } k = \frac{r_b(i)}{r_a(i)}$$



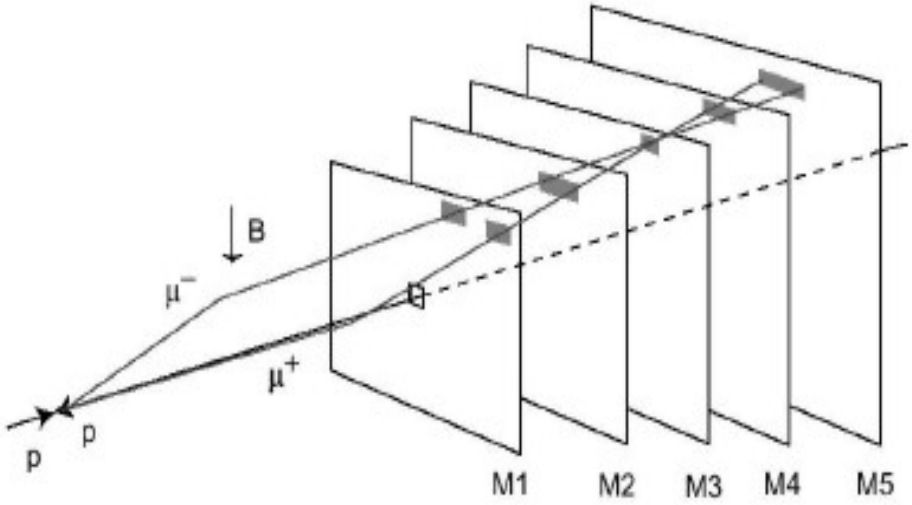
Level-0 Calorimeter Trigger

- Find high E_T candidates
  - Regions of 2x2 cells
  - PID from
    - ECAL, HCAL energy
    - Pre-shower information
    - SPD information
  - E_T threshold: ~3 GeV
- Information to L0-DU:
  - Highest E_T candidate
  - Total calorimeter energy
  - SPD multiplicity
- Performace:
  - $\varepsilon_{\text{hadronic channels}}$ = 30-50%
  - Latency: ~ 1 μs



Level-0 Muon Trigger

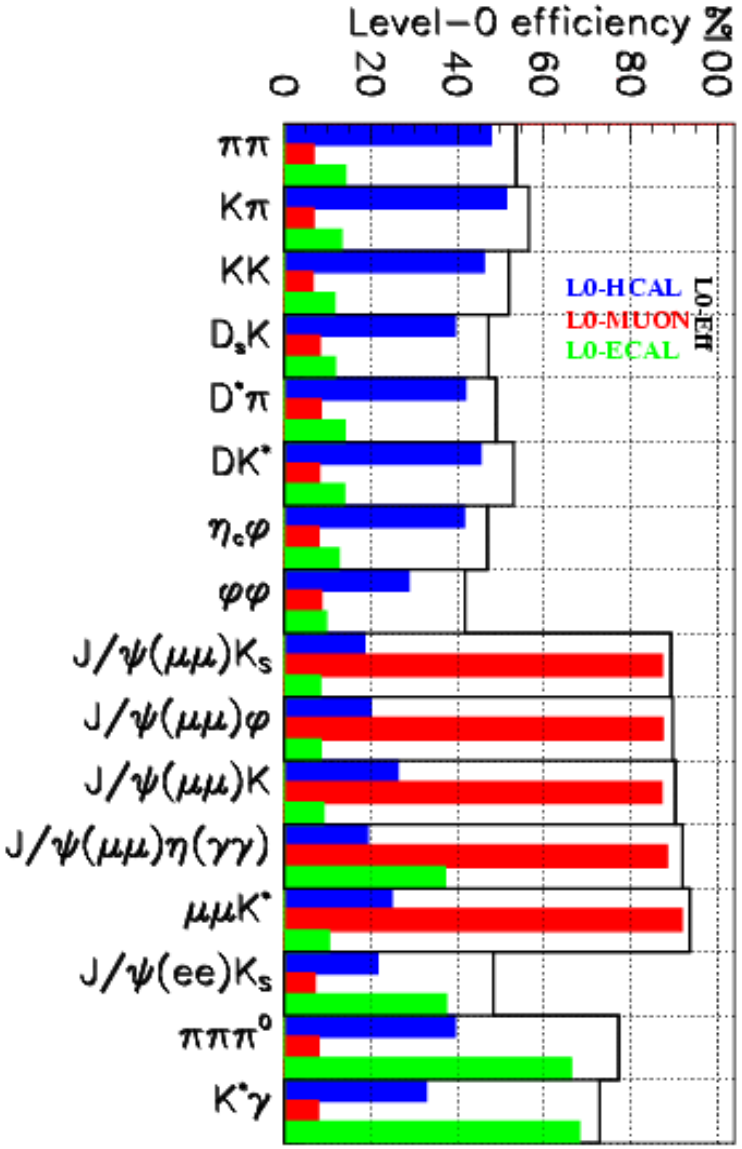
- Search for straight lines in M2-M5
- Find matching hits in M1
  - Momentum resolution: ~20% for b-decays
- Information sent to LODU:
  - 2 highest p_T candidates (per quadrant)
- Performance:
  - $\varepsilon_{B\to J/\Psi(\mu\mu)X}$ = ~ 88 %
  - Latency: ~ 1 μs



Level-0 Decision Unit

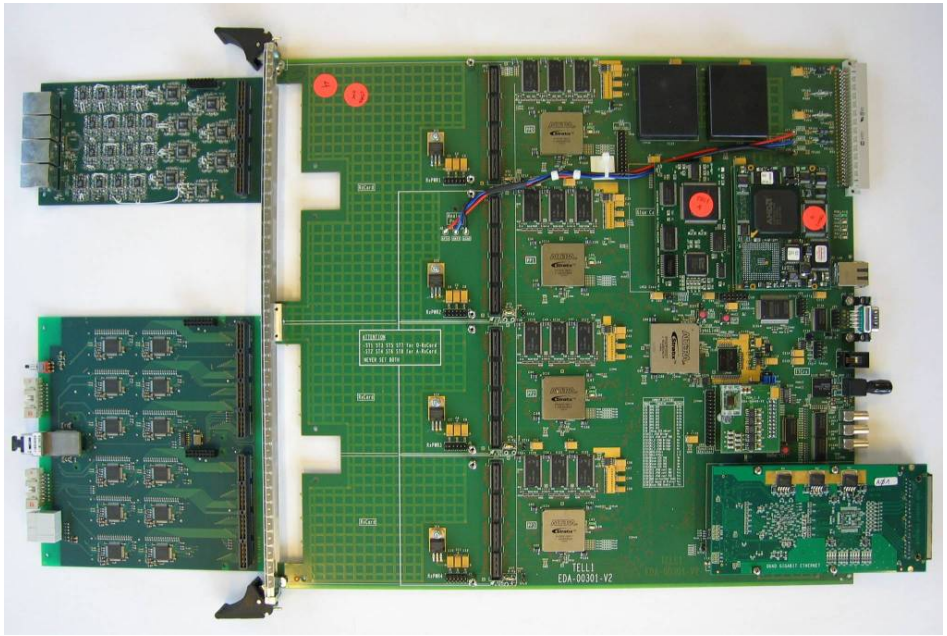
- Logical OR of high E_T candidates
- Cuts on global variables:
  - Tracks in second vertex: 3
  - Pile-up multiplicity: 112 hits
  - SPD multiplicity: 280 hits
  - Total E_T: 5 GeV
- Applied thresholds:

Channel	Threshold (GeV)	Incl. Rate (kHz)
Hadron	3.6	705
Electron	2.8	103
Photon	2.6	126
π^0 local	4.5	110
π^0 global	4.0	145
Muon	1.1	110
Di-muon Σp_T	1.3	145



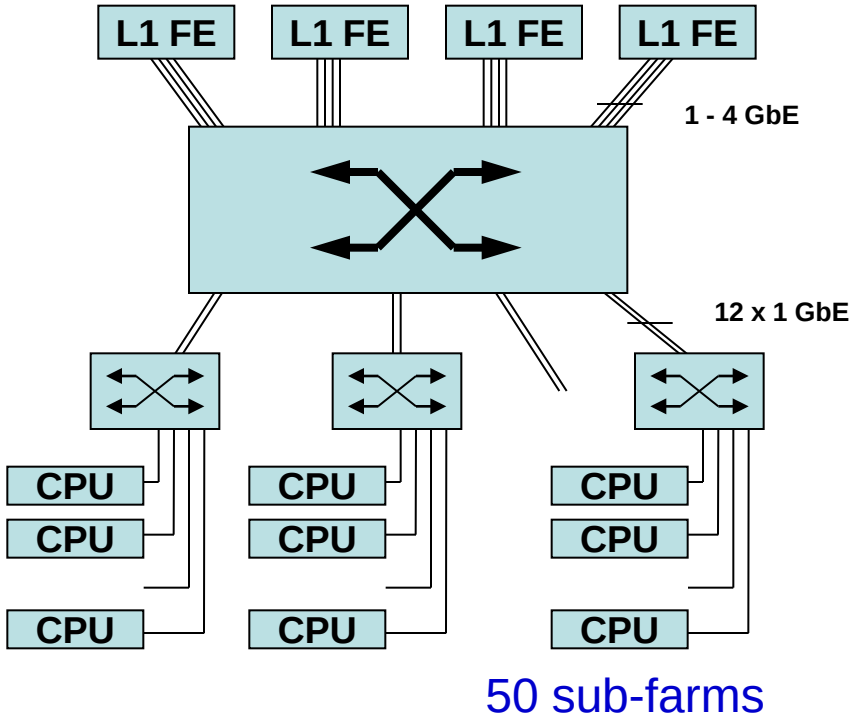
Level-1 Electronics

- Common Level-1 board
- Receives Level-0 accepted events
  - Sub-detector specific links
    - VELO: copper
    - Other SD: optical
- For analog signals, data is digitized
- Level-0 throttle signal on input buffer occupancy
- Performs zero suppression
- Event formatting for DAQ
- Quad-GbE NIC, plug-in card
  - ~475 MB/s output bandwidth per board



Readout Network

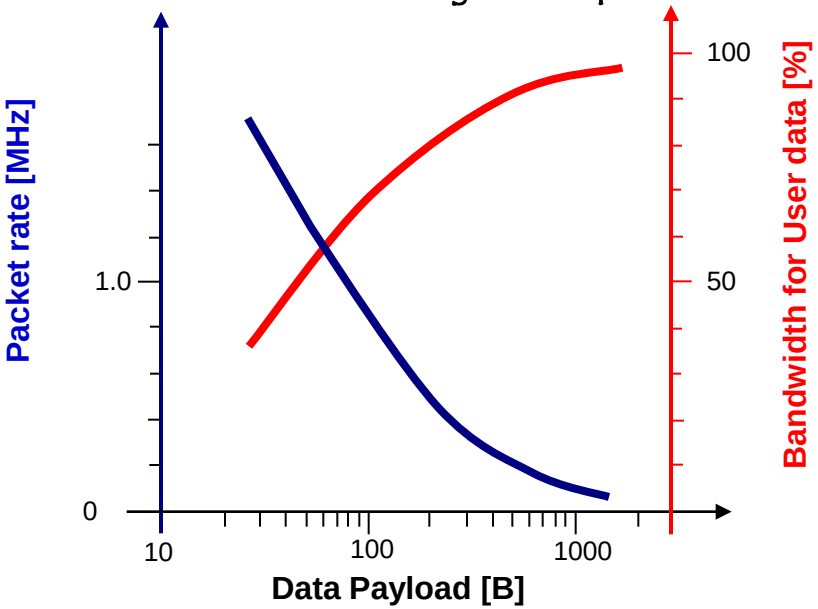
- Gigabit Ethernet from Level-1 to farm nodes
- ~300 L1 front-end modules
  - Not all use all 4 interfaces
  - ~750 input links
- Event Filter Farm
  - ~1800 nodes (estimated from 2005 Real-Time Trigger Challenge results)
  - Organised in sub-farms of up to 44 nodes each
- Total system throughput: 50 GB/s
  - Designed for 80% average output link utilisation



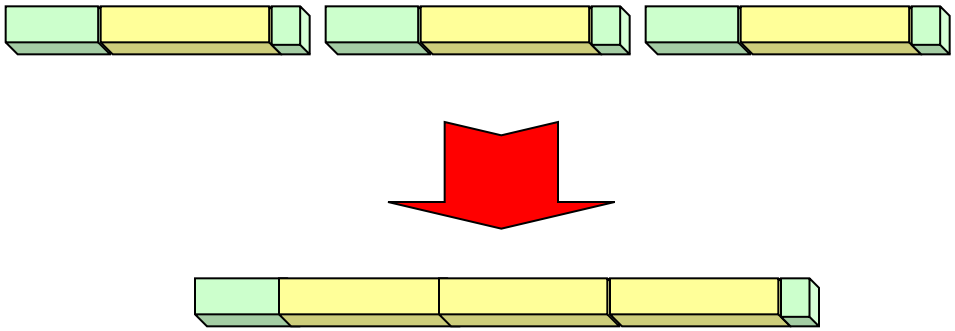
- Routed network
  - Single core router (Force10 E1200, 1260 GbE ports)
  - Routing switches in each sub-farm
  - Static routes

Event Building Traffic

- Each Level-1 module contains one fragment of a given event
- Readout supervisor broadcasts the address of destination node to all Level-1 boards
- Push protocol
- Readout Network guarantees delivery of all event fragments to a single node
  - Event-building traffic pattern



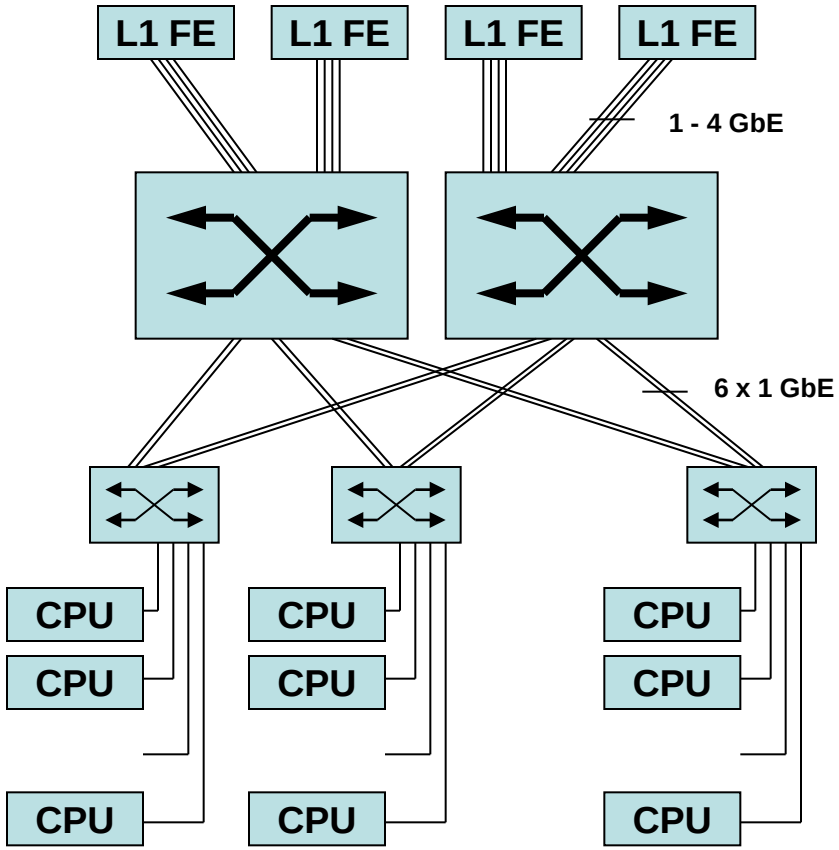
- Data is embedded in IP packets
- No transport layer protocol
- Multi-Event Packets
  - Several event fragments are packed into a single IP packet



  - Reduction in
    - Frame rate, interrupt rate, CPU load
    - Network protocol overhead → better bandwidth utilisation

Readout Network Scalability

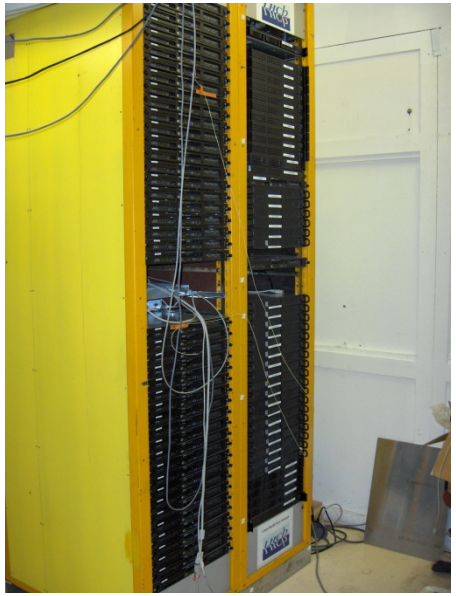
- Currently estimated event size: ~35kB
  → 50 GB/s network throughput
  (including safety margins)
- LHC pilot run in 2007
  → real data size
- Need a scalable design
  - Also for possible upgrade scenarios
- Achieved through
  - Modularity in FE design
  - Multiple interfaces from each Level-1 board
  - Modularity at sub-farm level

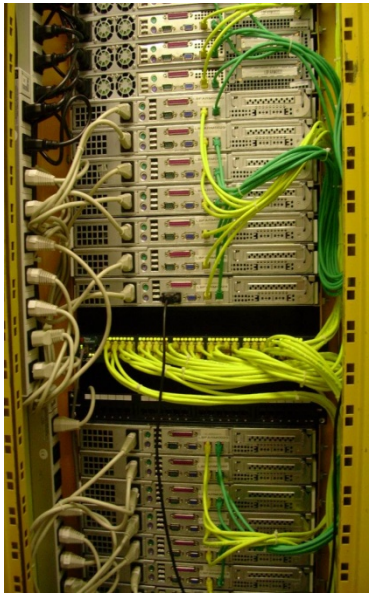


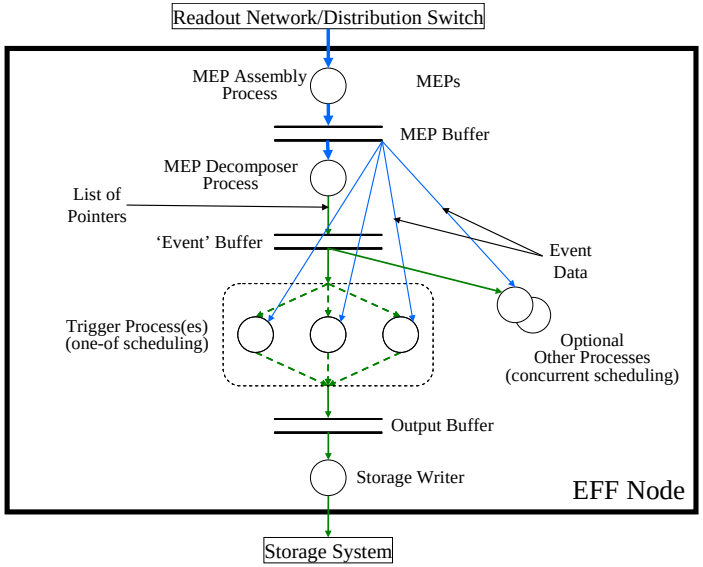
50 sub-farms

Event Filter Farm

- Farm composed of 1U rack-mountable PCs
  - Vendor independent
  - Horizontal cooling
    - Heat exchanger at back of the rack
- Dual-CPU nodes
  - One event-building process per node
  - One trigger process per CPU
- Same code running „on-line" and „off-line"
  - Change only running parameters
- Farm nodes running independent from each other
  - Partitioning
  - Can be dynamically included in the system

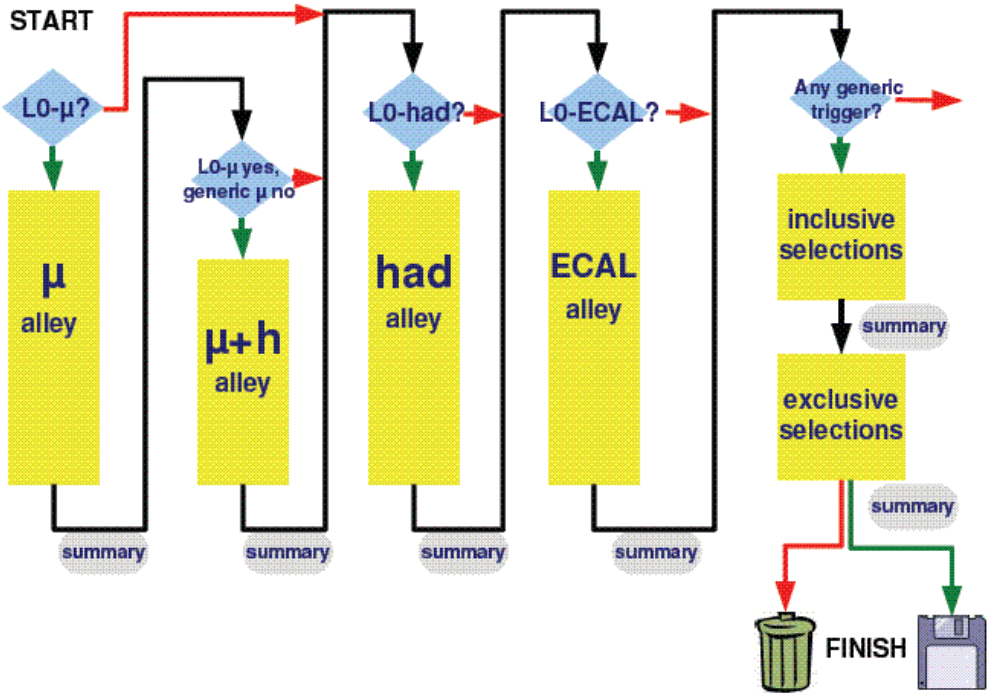






High Level Trigger

- Use final quality information from detector
- Combine tracking information with μ's, hadrons, electrons
- Starting point is the L0 decision
- 4 „alleys" defined
  - Depending on L0 decision
  - Each alley is independent
  - Each alley provides a summary to the selection algorithm
    - Decision
    - Type of trigger
    - Quantities used
    - Reconstructed objects
- Exclusive selection
  - Reconstructed B decays
- Inclusive selection
  - Used for systematic studies
  - Inclusive B or D*



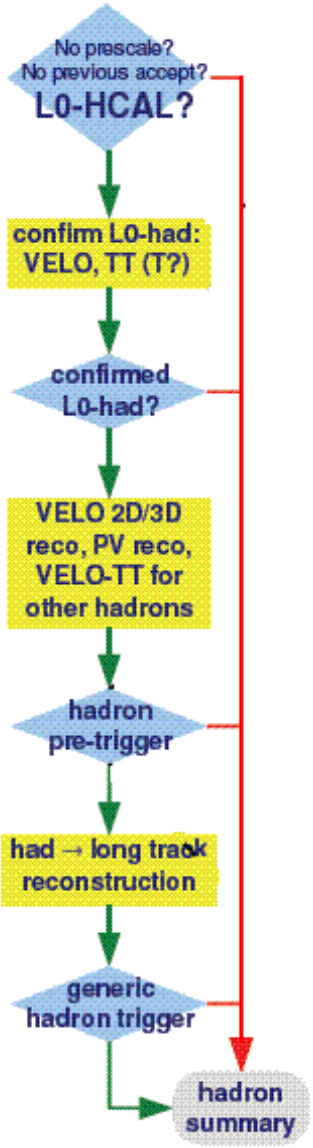
HLT Alleys

Example: Hadron alley

Level-0 confirmation

Pre-trigger (fast rejection)

Reconstruction And Decision



- Each alley consists of 3 major steps
  - Level-0 trigger confirmation
  - Fast rejection using reconstructed
    - VELO tracks, matching L0 objects
    - Primary Vertex
    - VELO-TT matched tracks
  - Alley-dependent trigger algorithm
    - Long tracking (all tracking detectors)

Summary

- LHCb trigger consists of 2 Levels
  - Level-0, hardware, custom electronics
    - 1 MHz accept rate
  - Hight Level Trigger, software, CPU farm
    - 2 kHz accept rate
- Readout Network based on copper Gigabit Ethernet
  - 50 GB/s throughput
  - Scalable
- Trigger farm
  - Process 1 MHz of events
  - ~1800 processing nodes
- Installation of the Trigger and DAQ systems has started
  - Commissioning from Q3 2006
  - Will be ready for the LHC pilot run in 2007