DAQ Systems and Technologies for Flavor Physics

FPCP Conference
Lake Placid
1 June 2009
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Acknowledgements

Many thanks to

- Hans Dijkstra
- Miriam Gandelman
- Roger Forty

For many useful discussions and data used in this presentation...

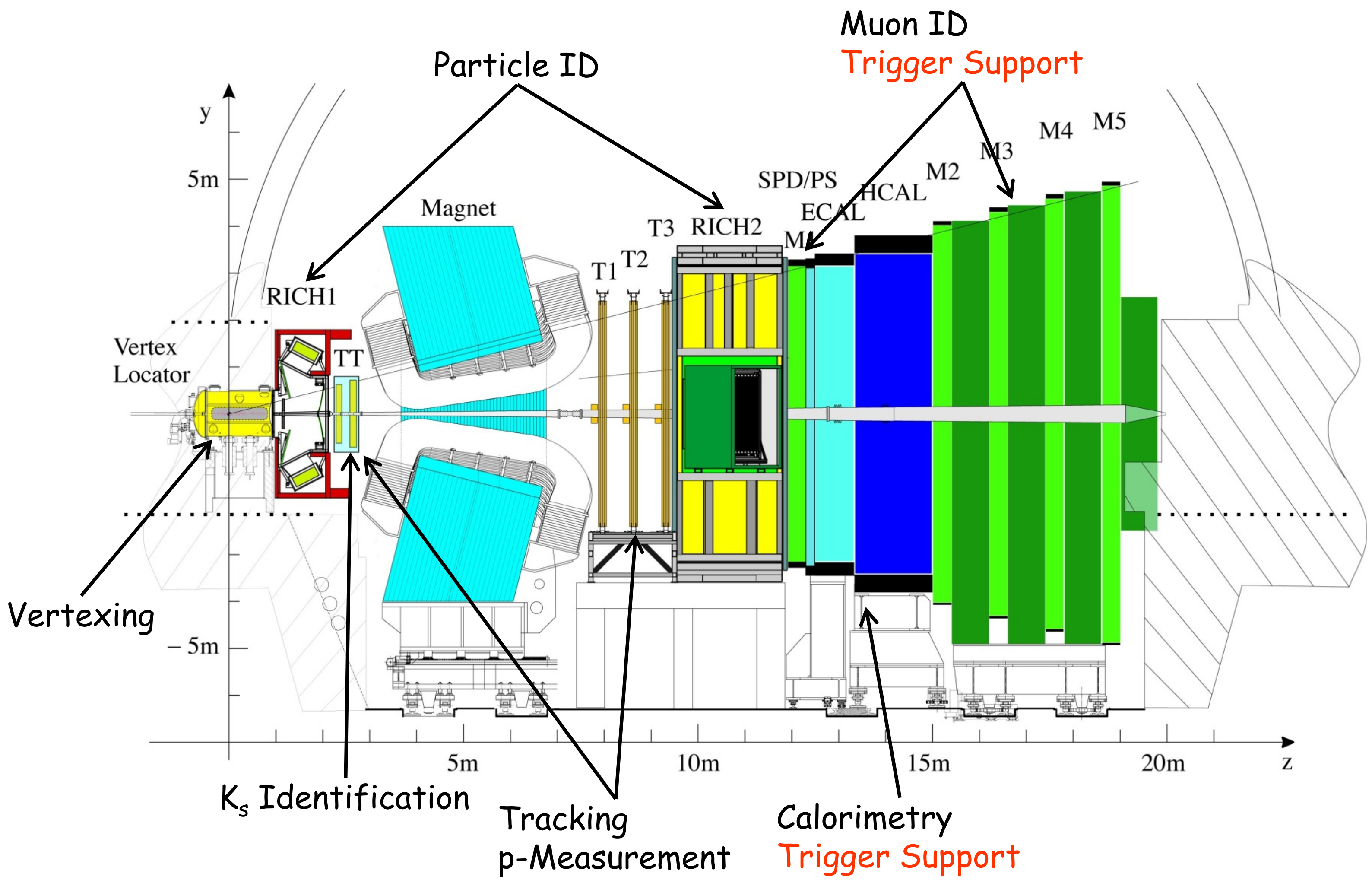
Introduction

- Challenges in Flavor/B-physics Experiments
  - **Particle Identification** (π-K, e-γ separation)
    - RICH detectors, ToF, Transition Radiation Trackers
    - Good electromagnetic Calorimeter
    - Not this talk…
  - **Vertex resolution**
    - Secondary vertex identification and determination
    - Not this talk either…
  - **Good momentum resolution**
    - Mass reconstruction
    - Good tracking system
    - Also not this talk…
  - **Superior Trigger Capabilities**
    - Distinguish interesting (rare) final states from "junk"
      - Vertexing (secondary vertices, B-vertex identification)
    - Not only limited region of detector, but 'entire' detector has to be scrutinized to identify interesting events
      - Need a lot of information…
    - This talk… based on the example of LHCb

Introduction

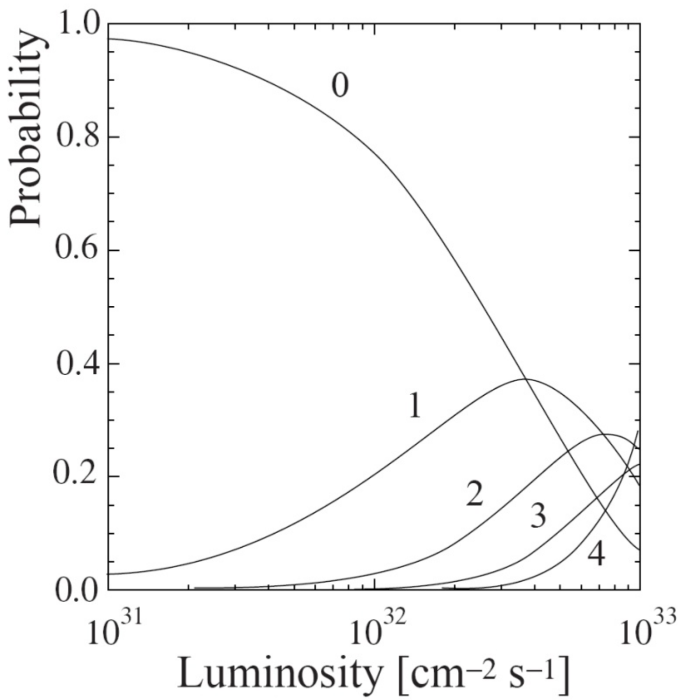
- The role of the DAQ system is mainly to support the trigger strategy and (of course) the physics analysis needs
  - Earlier Trigger drove the DAQ system
  - Nowadays the DAQ system can help defining the trigger strategy
- Will use LHCb as illustration for the following…
  - Three 'typical' channels to illustrate the development…
    - $B_s \rightarrow J/\Psi\ \varphi$
    - $B_s \rightarrow \varphi\varphi$
    - $B_d \rightarrow \pi\pi$

LHCb Detector



Choice of Working Point

- Contrary to Atlas/CMS which are designed to operate at Luminosities of ~$10^{34}cm^{-2}s^{-1}$, LHCb will operate at luminosity of ~$2x10^{32}cm^{-2}s^{-1}$. Why??
- Interactions as function of luminosity



- Want to avoid having too many multiple interactions per bunch crossing
  - Difficulty to distinguish multiple primary vertices from displaced vertices…
  - More complex events

LHCb Trigger/DAQ Evolution

LHCb Trigger/DAQ Evolution

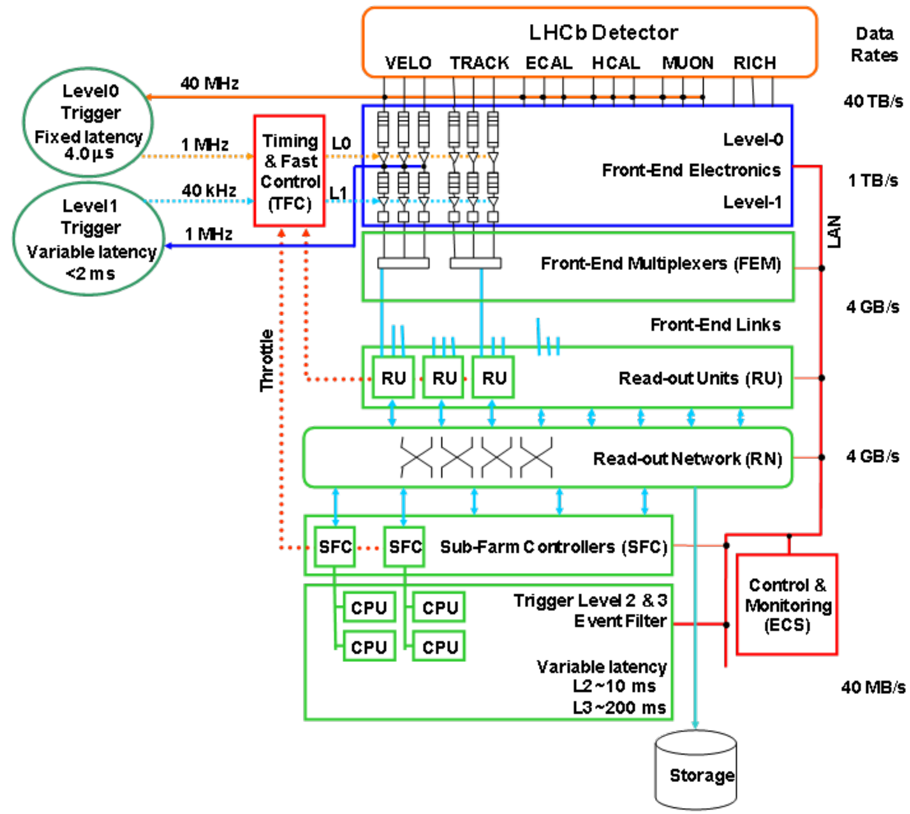
- 1998: LHCb Technical Proposal
- 2001: LHCb Online System Technical Design Report (TDR)
- 2001-2003: LHCb too fat
  - Redesign, slimming
- 2003: LHCb Trigger TDR
- 2005: Addendum to LHCb Online TDR
  - 1 MHz Readout
  - System as it is implemented today
- 2008: LHCb Upgrade discussions
  - 40 MHz Readout
  - System to be implemented ~2015 (or so…)

Trigger Inefficiencies,
Technological Development

2001: Online System TDR

- Three-level Trigger system
  - Level-0 (fixed latency 4.0 μs)
    - Hardware, unchangeable
    - high-p_t Electron, Hadron, Muon
    - 40 MHz → 1 MHz
  - Level-1 (var. latency <2ms)
    - Secondary Vertex 'identification' using Vertex Locator (VeLo)
    - Some ideas of using information of Level-0 trigger to improve efficiency…
      - Super Level-1…
    - 1 MHz → 40 kHz
    - Separate functional entity
  - High-Level Trigger (HLT) latency limited by CPU Power
    - (partial) reconstruction of full detector data selecting physics channels
    - Farm of commercial CPUs
    - 40 kHz → 200 Hz

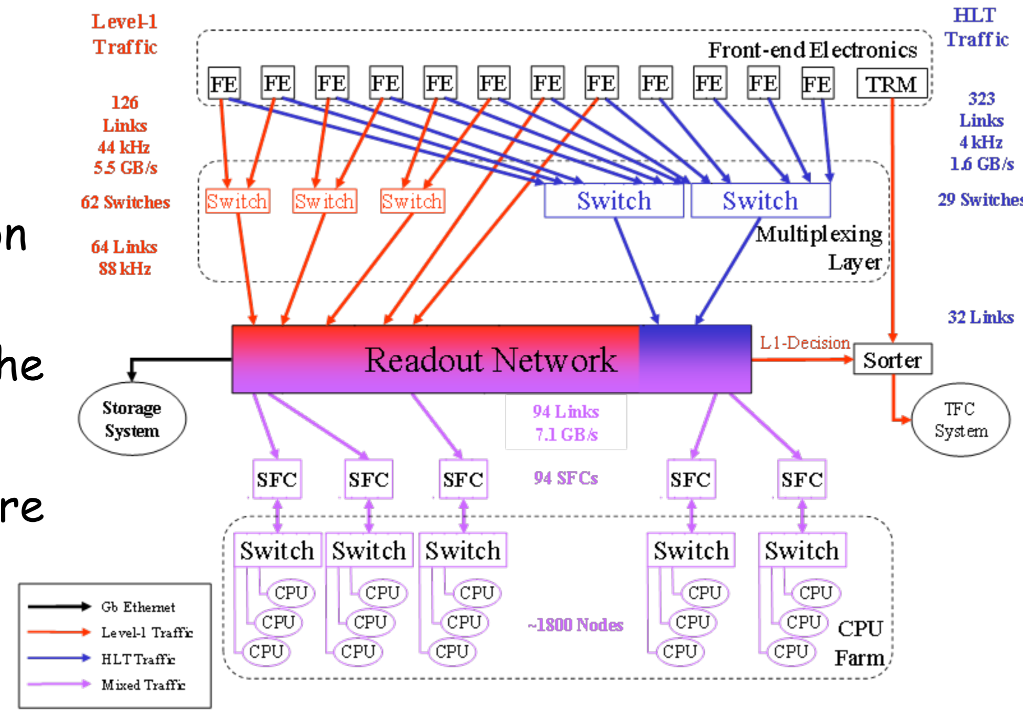
Baseline Architecture



2003: Trigger TDR

- Three-Level trigger system
  - Level-0:
    - unchanged
  - Level-1:
    - Removed as a separate architectural entity
    - Still present as separate dataflow through a common network
    - Add Trigger-Tracker station to Detector and Level-1 trigger to provide some momentum information to the vertex determination
    - Allows flexibility (within limits) to add data from more detectors
  - HLT:
    - unchanged

Baseline Architecture



Status after Trigger TDR

- ❑ Single Network for Level-1 and HLT traffic
  - ➢ Separate data flows
- ❑ Level-1 Trigger Performance
  - ➢ $B_s \rightarrow J/\Psi\ \varphi$
    - ↪64% efficiency (89.7% L0 ⊗ 71.4% L1)
  - ➢ $B_s \rightarrow \varphi\varphi$
    - ↪25.2% efficiency (41.8% L0 ⊗ 60.3% L1)
  - ➢ $B_d \rightarrow \pi\ \pi$
    - ↪33.6% efficiency (53.6% L0 ⊗ 62.7% L1)

Note:

Efficiencies are relative to offline selected events, i.e. selection after full reconstruction

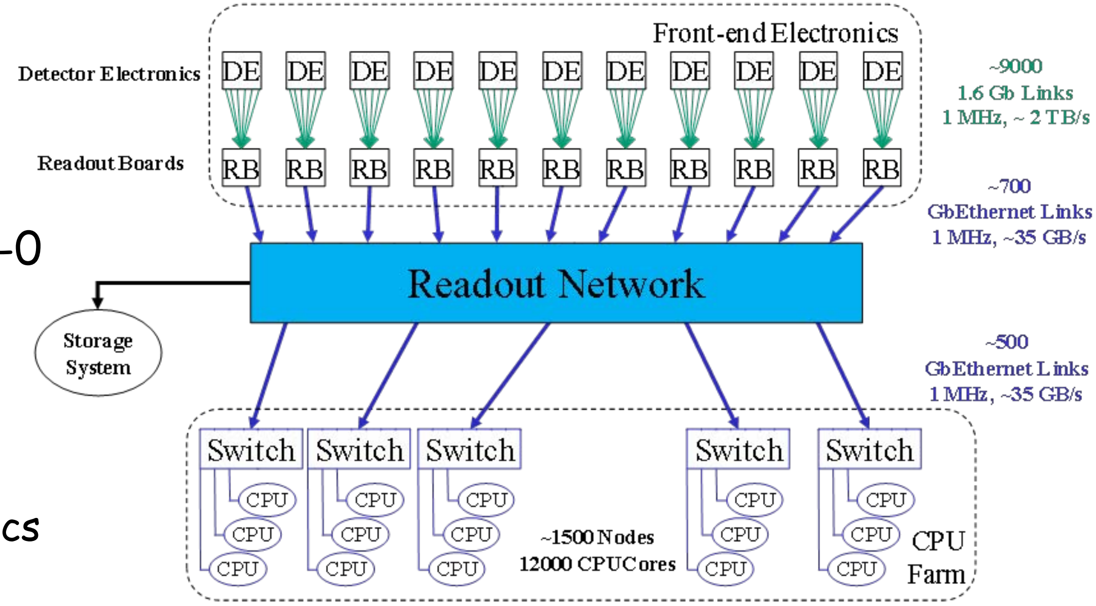
Limitation and Development

- The fact that the Level-1 trigger only had access some detector data made it susceptible especially to fake secondary vertices from multiple scattering
  - Also the introduction of magnetic field into the VeLo region and the trigger tracker station did not completely eliminate this
  - For a fraction of the events the addition of information from other detectors would be advantageous
- Delays in the LHC and the breath-taking development in network technology made it possible to think of the complete elimination of the Level-1 Trigger
  → 1 MHz readout

2005: 1 MHz Readout, Current system

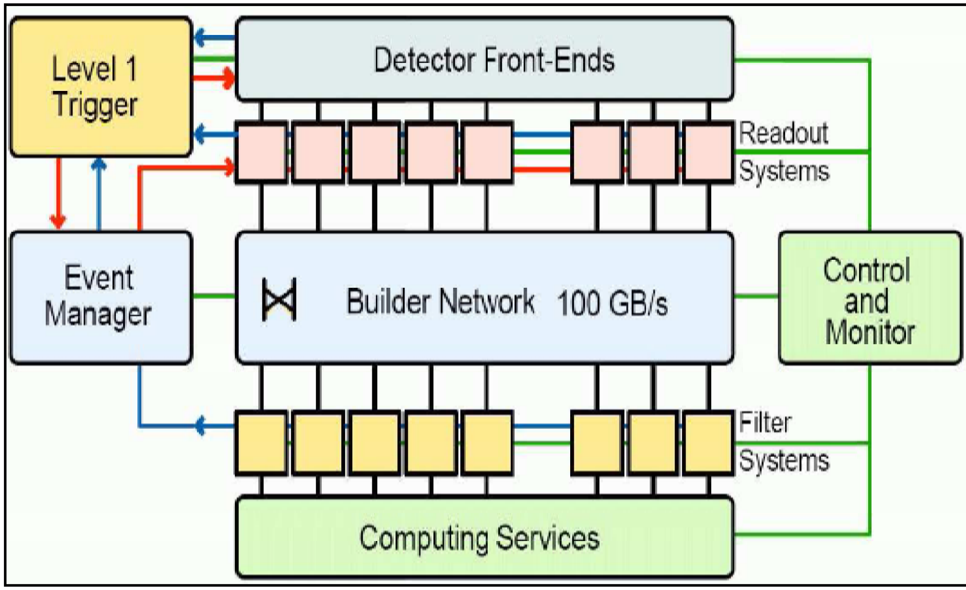
- Three-Level trigger system
  - Level-0:
    - unchanged
  - Level-1:
    - Removed
  - HLT:
    - Access to all data at Level-0 rate
    - Split into HLT1
      - 'verification' of L0 Trigger
    - And HLT2
      - Selection of specific physics channels
    - Full flexibility of algorithm design
    - Latency only limited by total CPU power available
    - Output rate: ~2 kHz

Architecture

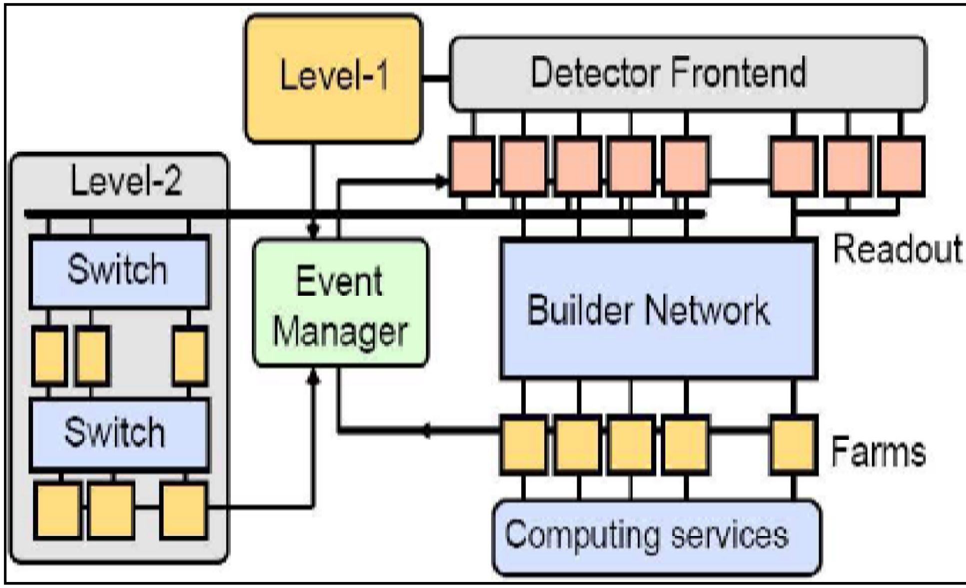


Comparison Atlas/CMS

- CMS: High BW school
  - Only one HLT level @ 100 kHz
  - Total BW: 100 GB/s.
  - Can stage network/CPU:
  - 8 x 12.5 GB/s.
  - To Storage: 100 Hz



- ATLAS: Low BW school
  - RoI in Level-2.
  - L2 "loads" 10% of data @100 kHz
  - Total BW: 20 GB/s.
  - Can load "full-event" at low L1-rate, i.e. low-L, B-physics signatures.
  - To Storage ~200 Hz



Where are we now…

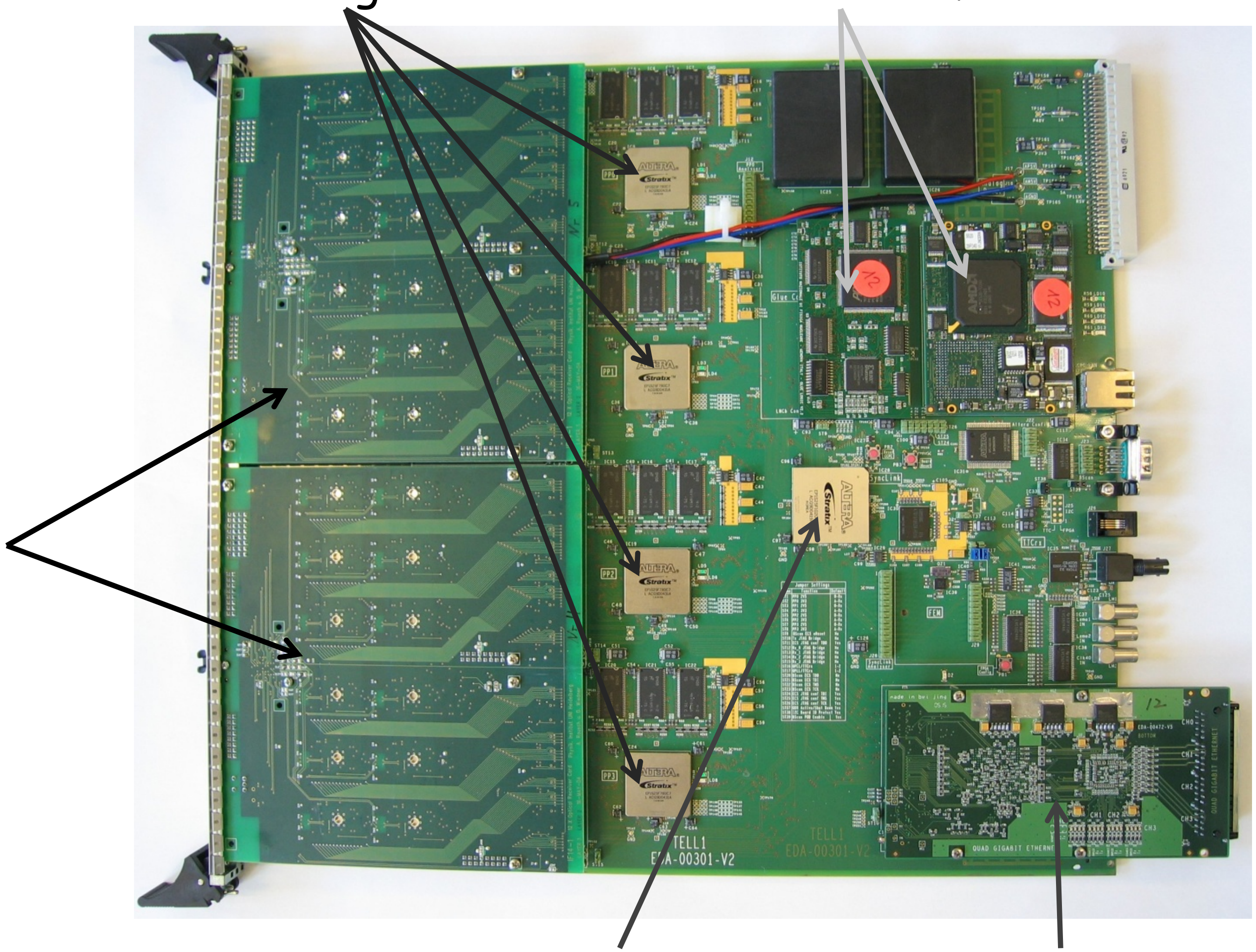
- Great simplification of the DAQ system
- Latest efficiencies for 'our' channels
  - $B_s \rightarrow J/\Psi\ \varphi$
    - ↳ 85% efficiency (93% L0 ⊗ 91% HLT1) ☺

    Compare to
    - ↳ 64% efficiency (89.7% L0 ⊗ 71.4% L1)
  - $B_s \rightarrow \varphi\varphi$
    - ↳ 22.0% efficiency (44% L0 ⊗ 50% HLT1) ☹

    Compare to
    - ↳ 25.2% efficiency (41.8% L0 ⊗ 60.3% L1)
  - $B_d \rightarrow \pi\ \pi$
    - ↳ 50% efficiency (65.0% L0 ⊗ 77.0% HLT1) 😐

    Compare to
    - ↳ 33.6% efficiency (53.6% L0 ⊗ 62.7% L1)
- The increase in Level-0 efficiency stems from the fact that the Global Event Cuts (such as Pile-up Veto) do not seem necessary anymore
- The drop in the HLT1 efficiency for $B_s \rightarrow \varphi\varphi$ is due to a change in trigger strategy (emphasis in Trigger on Signal, ToS)
- $B_s \rightarrow \varphi\varphi$ is still very saddening
  - Some ideas are around to get efficiency up to ~30% (CPU limited)

Pictures: LHCb Common Readout Board



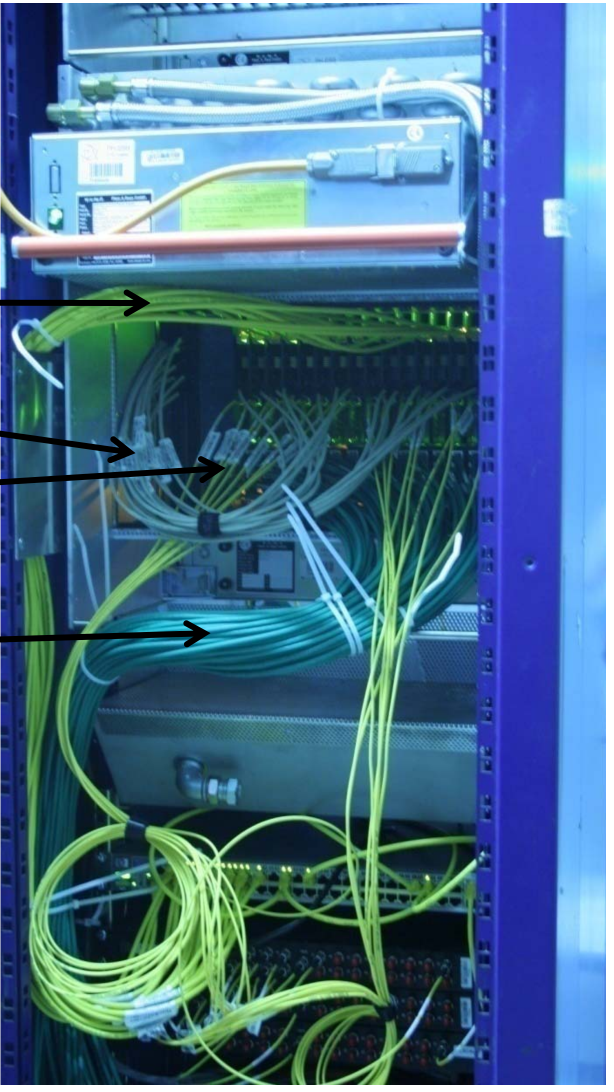
Pictures: Full Tell1 Crate (Cabling)

Controls Ethernet

Flow Control (Throttle)

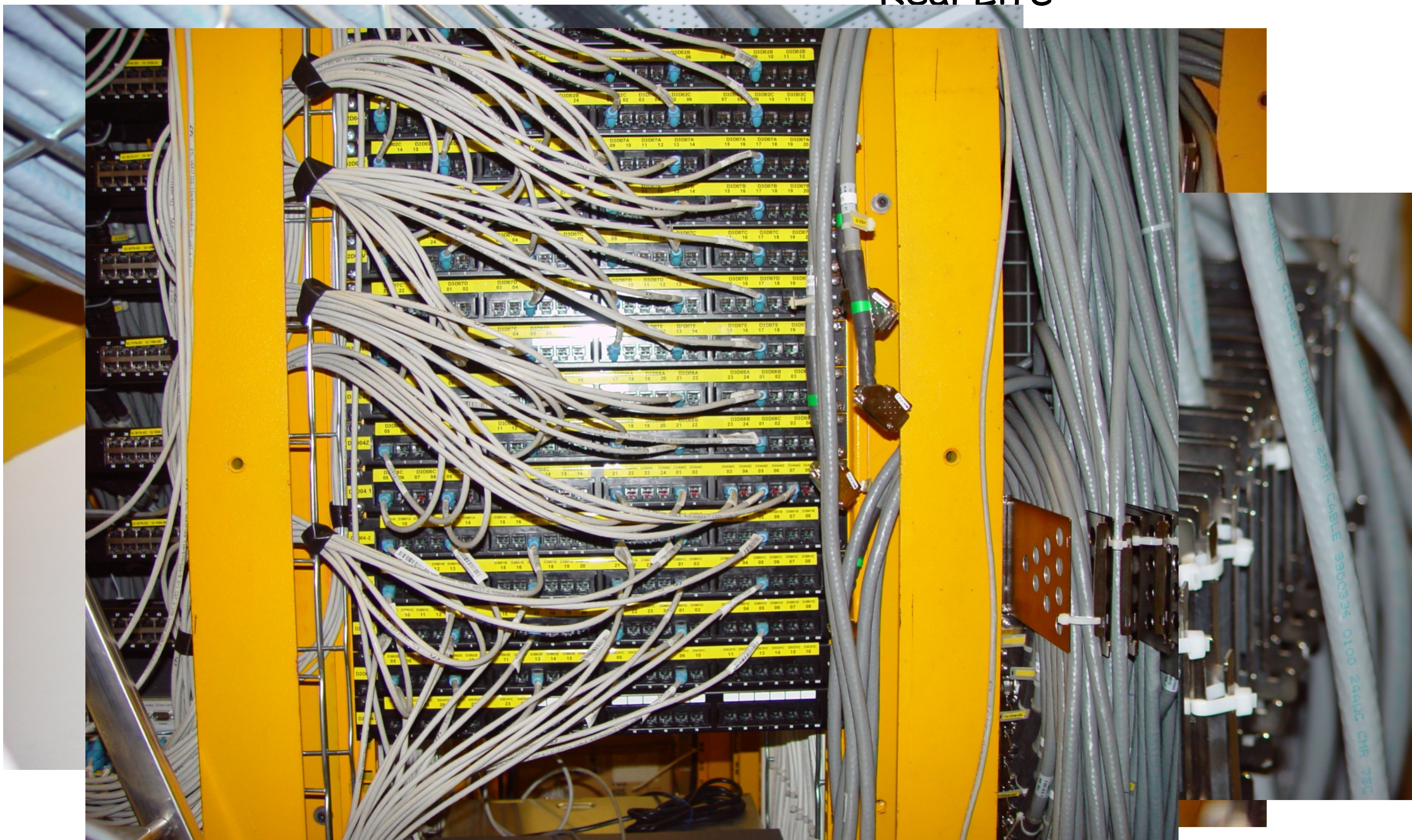
Timing and Fast Control

Quad GbEthernet Output



Pictures: Readout Network (Switch)

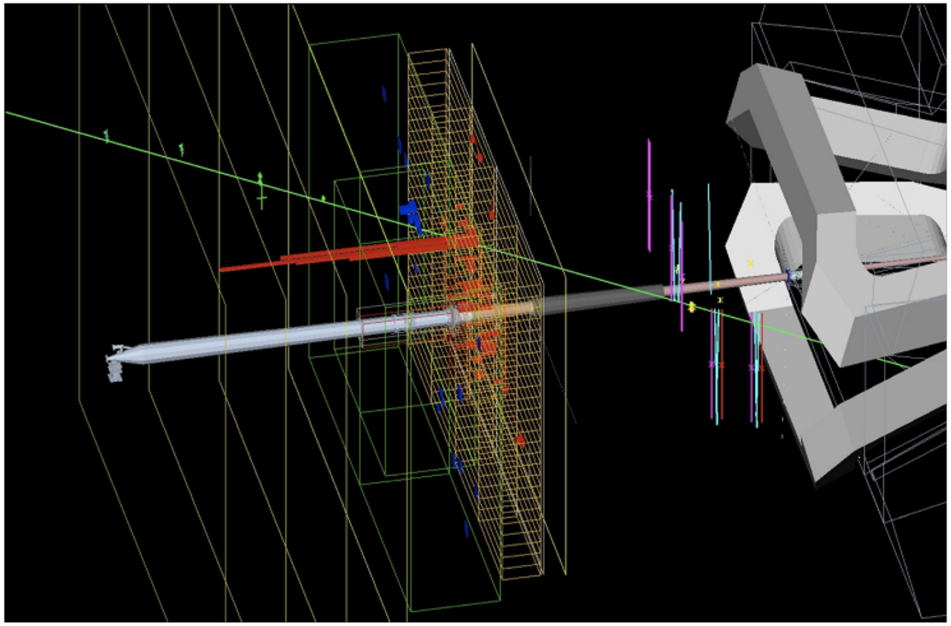
Real Life



Pictures: CPU Farm (Processors)

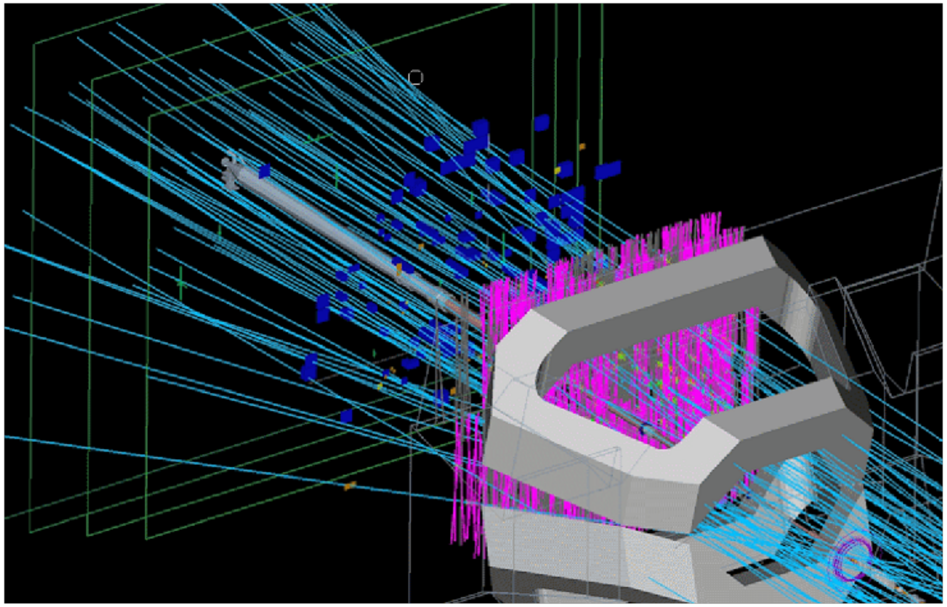
Pictures: CPU Farm (Cooling)

And... It Works!

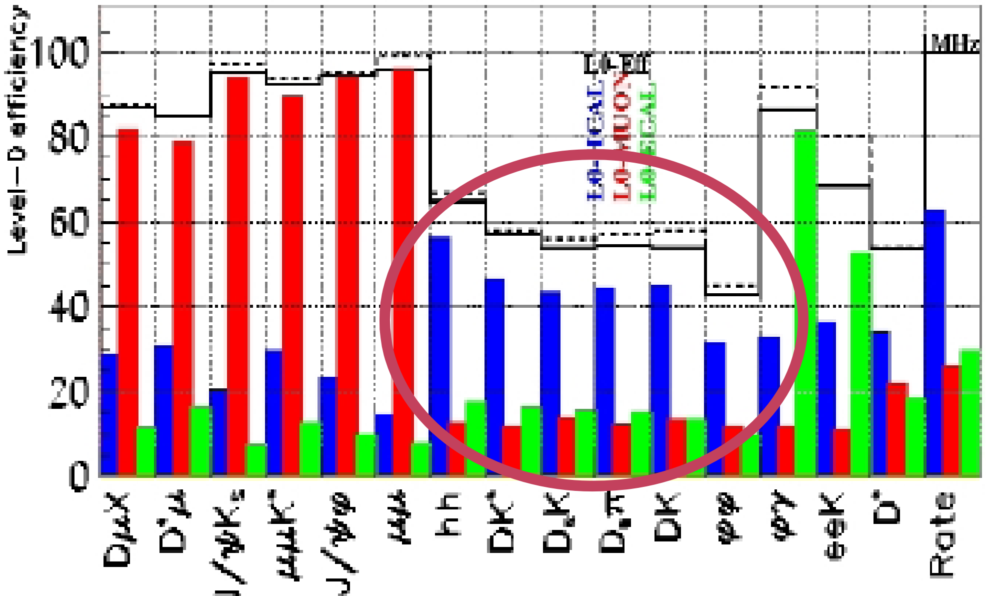


Cosmic Event

Injection Spray

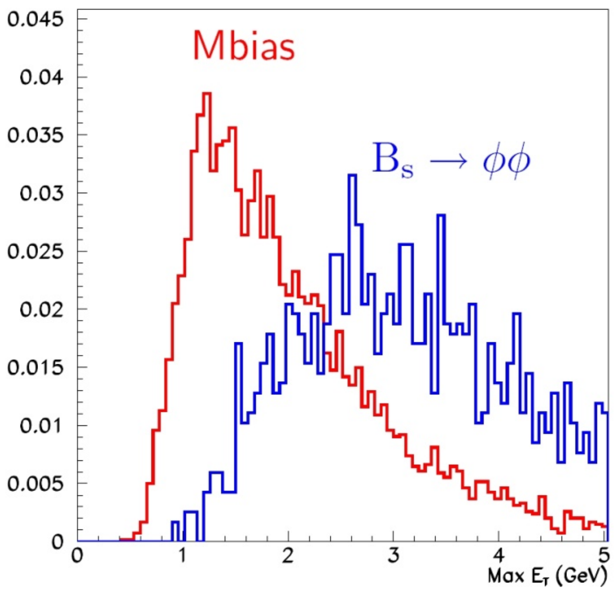


Level-0 Performance



- Level-0 Hadron efficiency is pathetically low compared to Muon or Electron channels
  - →eliminate Level-0
    - →40 MHz readout

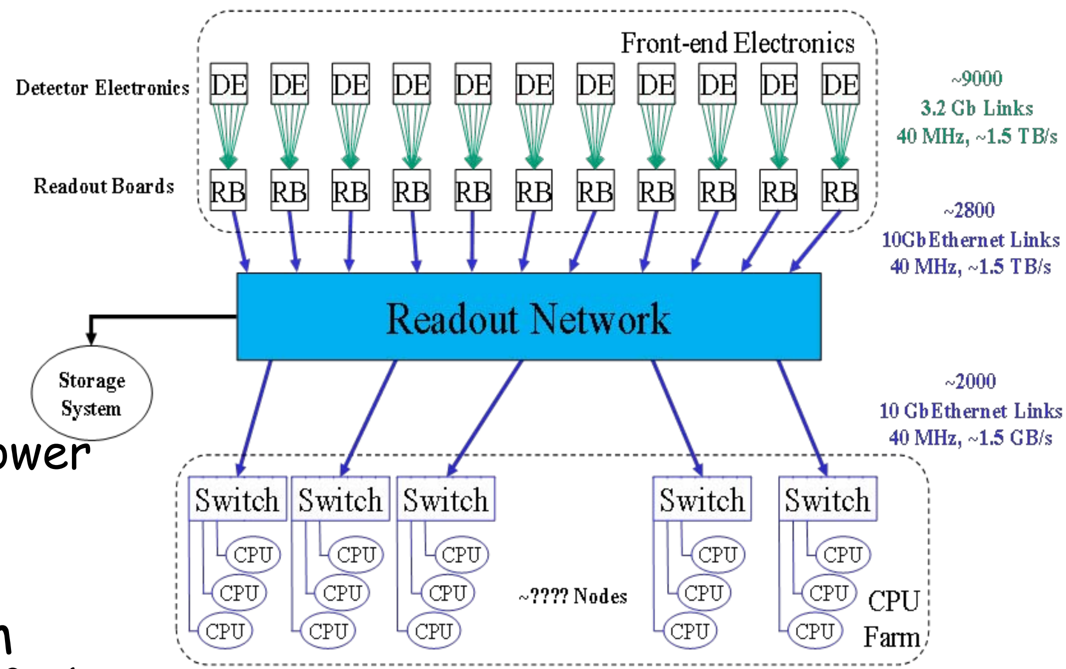
- In order to keep the minimum bias contamination low (<<1 MHz) have to cut severely into the signal (E_t cut ~3 GeV)



40-MHz Readout (LHCb upgrade)

- Features
  - No more hardware trigger
  - Full software flexibility for event selection
- Requirements
  - Detector Electronics has to implement Zero-Suppression
    - Keep cost for links bearable
  - Need ~10-fold increase in switching capacity
  - Need x-fold increase in CPU power (x >> 40).
  - New Front-End Electronics
- Also increase Luminosity from $2\times10^{32}cm^{-2}s^{-1} \rightarrow 10\text{-}20\times10^{32}cm^{-2}s^{-1}$
  - More pile-up → more complexity →bigger events

40-MHz Architecture



40-MHz Readout. Expected Performance

- Preliminary Studies
  - $B_s \rightarrow \varphi\varphi$ Efficiencies
    - ~57% @ $2x10^{32}cm^{-2}s^{-1}$
    - ~50% @ $10x10^{32}cm^{-2}s^{-1}$

    to be compared with
    - ~22% for the current System

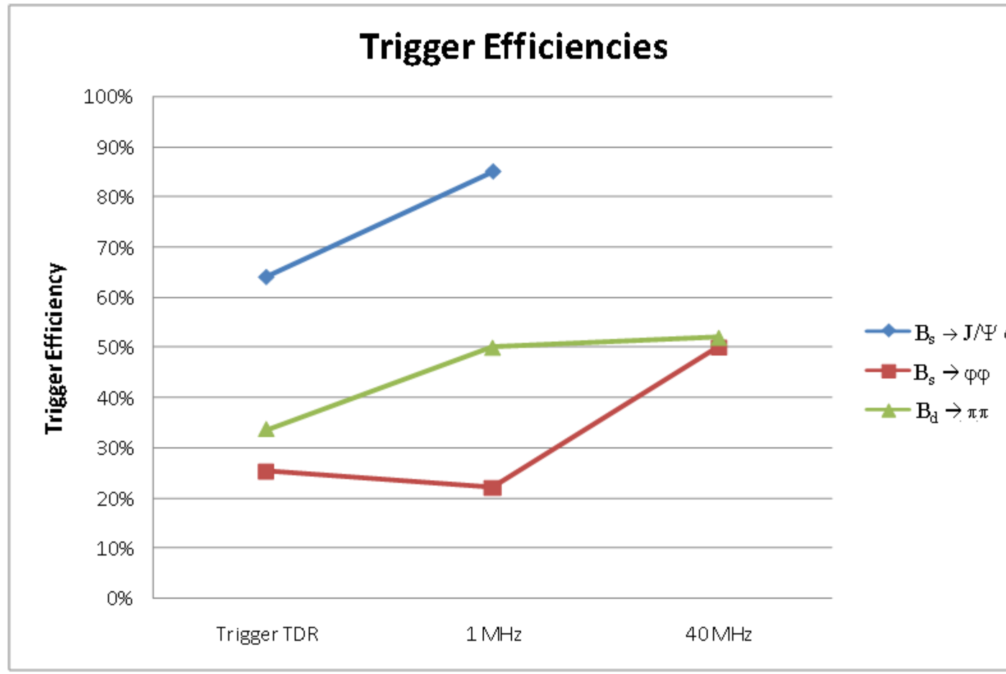
  Note: more than double the efficiency and at the same time 5-fold the Luminosity, i.e. 10-fold increase in rate!
  - $B_d \rightarrow \pi\ \pi$ Efficiency
    - ~52% @ $10x10^{32}cm^{-2}s^{-1}$ (Current system: ~50%)
- Critical Issues
  - Rad-(tolerant, hard) front-end electronics performing zero-suppression
  - Large Data rate through network
    - 1.5 TB/s is sizeable
    - Technological development seems to make it feasible at the time-scale of ~2015
      - Expect linecards of ~1Tbit/s capacity (100 10Gb ports)
  - CPU power needed…
    - First studies show an acceptable increase of factor ~50-70 @$10x10^{32}cm^{-2}s^{-1}$ (ok-ish)
    - @$20x10^{32}cm^{-2}s^{-1}$ studies are ongoing
    - From Moore's law we expect ~factor 10-20 (by ~2015)
      - Rest by increasing farm size…
      - And change detector and trigger strategy

Outlook on Future Accelerators

- The future will be in trigger-free DAQ systems
  - Either dictated by the bunch structure of the machine
    - 0.6 ns bunch spacing at CLIC
    - 'Digital Oscilloscope' connected to each channel
  - Or by choice since technology allows it (LHCb upgrade) because of flexibility and (possibly) improved efficiency and simplicity
- Special case might be continuous high-frequency accelerators
  - E.g. SuperB: 2 ns bunch spacing continuous operation relatively low interaction rate
    - 500 MHz collision rate
    - $\Upsilon(4S)$ Cross section ~5 nb
    - Luminosity $10^{36} cm^{-2} s^{-1}$ → hadronic event-rate ~5 kHz
    - Activity trigger might be indicated

Conclusion

- LHCb DAQ system has developed significantly over time
  - Partly driven by desire to simplify the system
  - Mainly driven by improving the trigger efficiency
    - ~50% improvement for non-hadronic channels
    - Some hadronic channels still poor



- Shift from 'hardware' triggers to software with full access to all detector information
- Latest step (LHCb upgrade) is trigger-free readout at full bunch-crossing rate (40 MHz)
  - Expect ~doubling of efficiency in difficult hadronic channels
  - In-line with possible other future experiments (e.g CLIC)