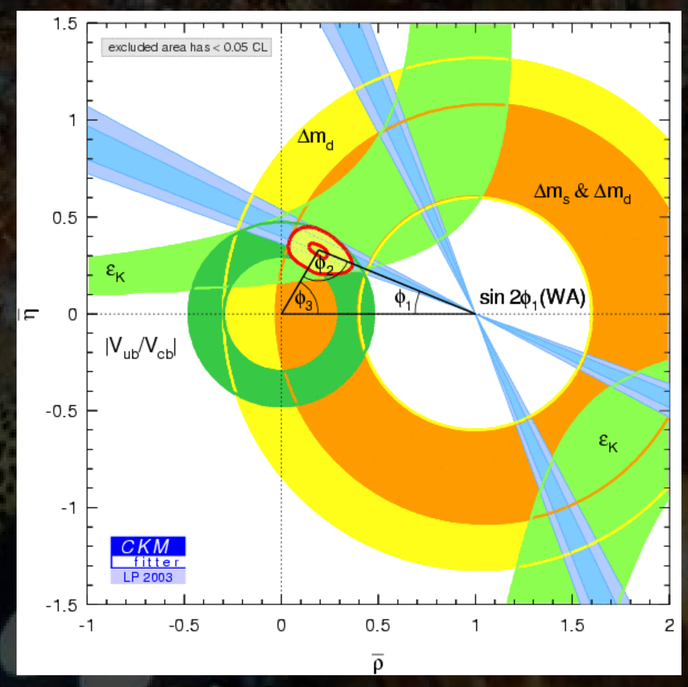
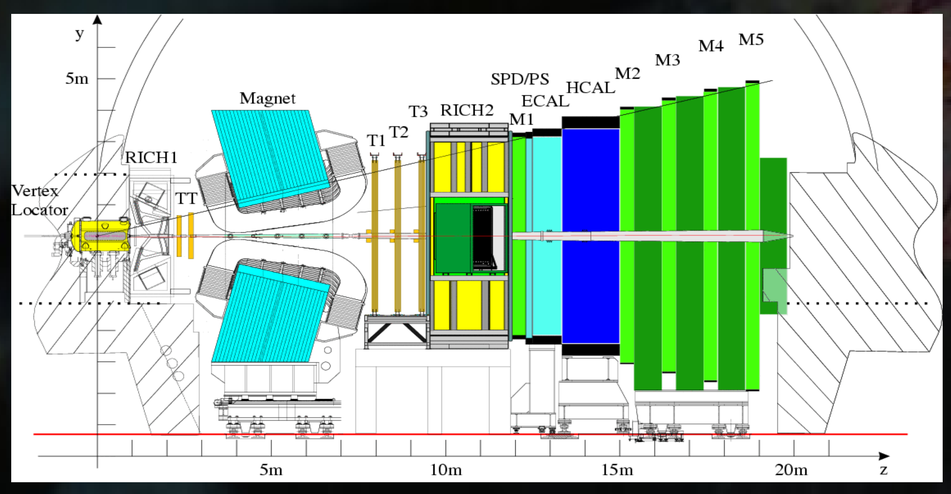
LHCb

for precise measurement of CP violation and rare B decays

Trigger System



The LHCb experiment



Vertex Locator (VELO)
Dipole magnet
2 RICH detectors
4 tracking stations (TT & T1-T3)
Scintillating Pad Detector (SPD)
Preshower (PS)
Electromagnetic calorimeter (ECAL)
Hadronic calorimeter (HCAL)
5 muon stations (M1-M5)

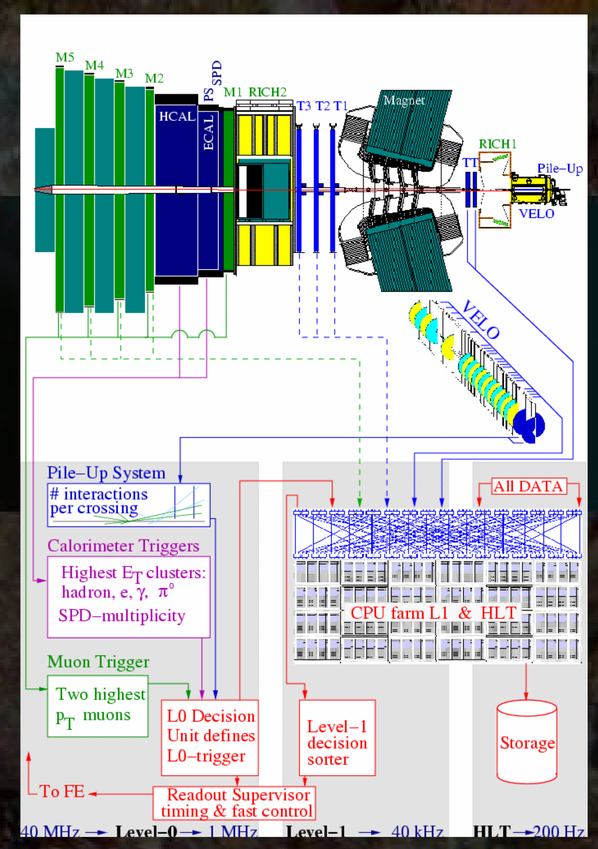
- Design Luminosity: $L = 2 \times 10^{32}\ cm^{-2}\ s^{-1} = 200\ \mu b^{-1}/s$
- $\sigma_{total} \approx 100$ mb, $\sigma_{inel} \approx 80$ mb, $\sigma_{vis} \approx$ **60 mb**
  - 12 MHz total (visible) interaction rate
  - **10 MHz total (visible) event rate (pile-up)**
- Assumed $\sigma_{bb} \approx 500\ \mu b$
  - **100 kHz B event rate!**
- But low branching fractions! Expect (offline reconstructable events):
  - $B_d \rightarrow J/\psi(\mu^+\mu^-)\ K_S(\pi^+\pi^-)$: 1 per minute
  - $B_d \rightarrow \pi^+\pi^-$: 1 in two minutes
  - $B_s \rightarrow D_s^-(K^+K^-\mu^-)\ K^+$: 1 in six minutes
  - $B_s \rightarrow \mu^+\mu^-$: 1 per week (?)

Trigger overview

Three trigger levels:

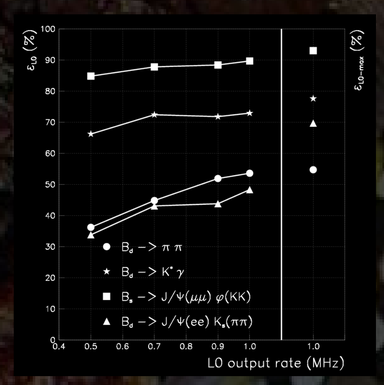
Level-0
Level-1
High Level Trigger

- Stations M1-M5 are used to reconstruct two muons per quadrant.
- The SPD, PS ECAL and HCAL are used to reconstruct the hadron, e, γ and π^0 with the largest transverse energy, the charged particle multiplicity, and the total energy.
- The Pile-Up detector is used to recognize multiple interactions per crossing.
- Level-1 uses the information from VELO, TT, and Level-0 to reduce the rate to 40 kHz. T1-T3 and M2-M4 could be included in Level-1.
- The HLT uses all data in the event apart from the RICH to reduce the rate to 200 Hz.
- Level-0 is executed in full custom electronics, while Level-1 and HLT are software triggers which share a commodity farm of 1800 CPUs.



Level-0 Trigger (L0)

- **Fully synchronous** and **pipelined** hardware trigger
- **~10 MHz** visible event rate (30 MHz bunch crossing)
- Global event variables (10 MHz → 7 Mhz):
  - **pile-up detector** (two backward-looking silicon disks): reject events with multiple primary vertices
  - **multiplicity** in pile-up detector and SPDs in front of calorimeter (scintillator pad detectors for e/γ separation): reject too complicated events
  - **minimum ΣE_T** in all **HCAL** cells (avoid "empty" events)
- B signatures (7 MHz → 1 MHz):
  - **high-p_T muons**: track segments in muon chambers (MWPC)
  - **high-E_T electrons, photons, π^0**: ECAL clusters (+SPD/PS)
  - **high-E_T hadrons**: HCAL clusters



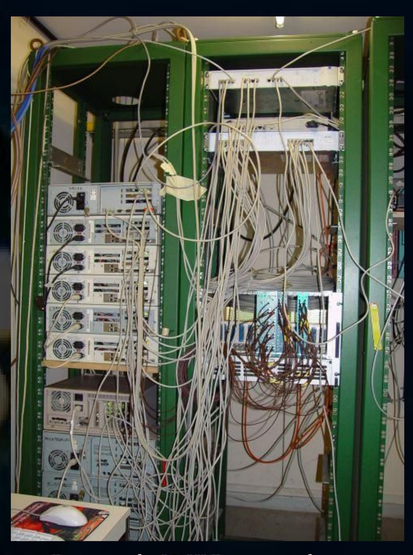
L0 efficiencies as a function of L0 output rate. The rightmost set of data points refers to the efficiency obtained after individual optimization of each channel

Level-1 Trigger (L1)

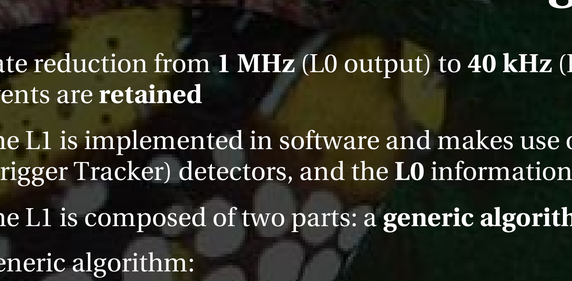
- Rate reduction from **1 MHz** (L0 output) to **40 kHz** (HLT input) such that **4% of minimum bias** events are **retained**
- The L1 is implemented in software and makes use of the **VELO** (Vertex Locator) and **TT** (Trigger Tracker) detectors, and the **L0** information
- The L1 is composed of two parts: a **generic algorithm** and a **specific** algorithm
- Generic algorithm:
  - Requires **two tracks with high transverse momentum** (p_{T1} and p_{T2}) and **large impact parameter** (IP)
  - IP measured with VELO, p_T with TT and also obtained from L0
- Specific algorithm ("Bonus system")
  - The efficiency for some specific benchmark channels such as: $B^0_d \rightarrow \mu^+\mu^- K^*$, $B^0_d \rightarrow K^*\gamma$, $B^0_d \rightarrow J/\psi\ K^0_s$ is enhanced based on L0 information:
    - $m_{\mu\mu}^{max}$: highest invariant **dimuon** mass → bonus $\beta_{\mu\mu}$
    - $E_T^{\gamma,max}$: highest **photon** transverse energy found by L0, if above 3 GeV → bonus β_γ
    - $E_T^{e,max}$: highest **electron** transverse energy found by L0, if above 3 GeV → bonus β_e
  - Bonuses are **cumulative** ($\beta = \Sigma_i \beta_i$)

High Level Trigger (HLT)

- A second layer of **software trigger** for final decision on whether to write event to storage (~200 Hz foreseen)
- **Full detector information available** at this level (except RICH)
- Algorithms are **still under development**; current strategy:
  - **Confirmation of Level-1 decision** with momentum resolution from all tracking stations (T1–T3): 40 kHz → 20 kHz
  - **Full reconstruction** of (long) tracks.
  - **Exclusive selection** of priority channels (simplified offline selections): 10–20 Hz per channel
  - **Inclusive selection** of other channels (exploit common features in offline selections): fill remaining bandwidth
- ⇒ **hadron colliders force us to run the physics selection algorithms in the trigger!**



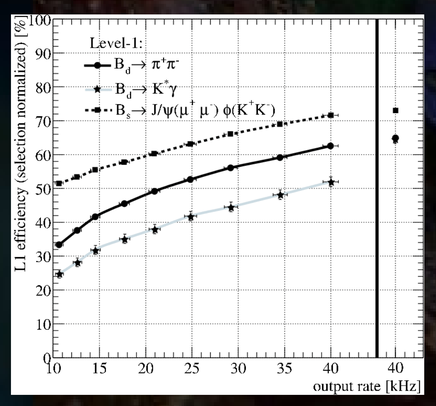
Test setup for L1-HLT computer farm



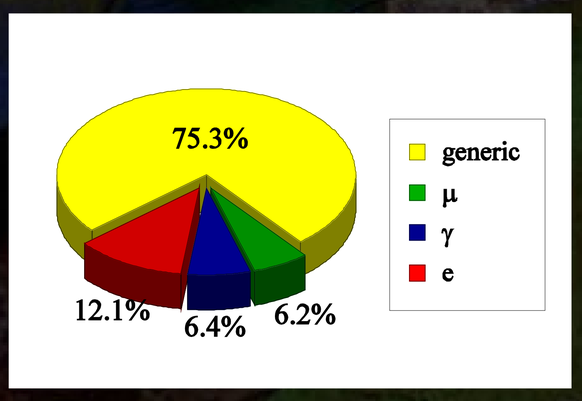
Signal

Minimum Bias

Distribution of offline selected signal events and minimum bias events in the plane of the two variables ln(PT1)+ln(PT2) versus ln(IPS1)+ln(IPS2). The solid line is an example of the vertical diagonal discriminant applied to determine the Level-1 trigger variable. IPS means impact parameter significance (σ_{IP}/IP). A bonus is then added two this trigger variable.



L1 efficiencies as a function of the L1 output rate. The last bin refers to the maximum efficiency obtained after individual optimization of each channel. The efficiencies are normalized to L0-triggered events that have been selected by the offline analysis. Indicated errors are statistical.



Bandwidth division among the various trigger components: generic part, muon, electron and photon bonus.

Interesting fact: The fishes shown in the background of the poster are called "triggerfish". They have acquired their common name from the characteristic locking and unlocking of their dorsal fin.