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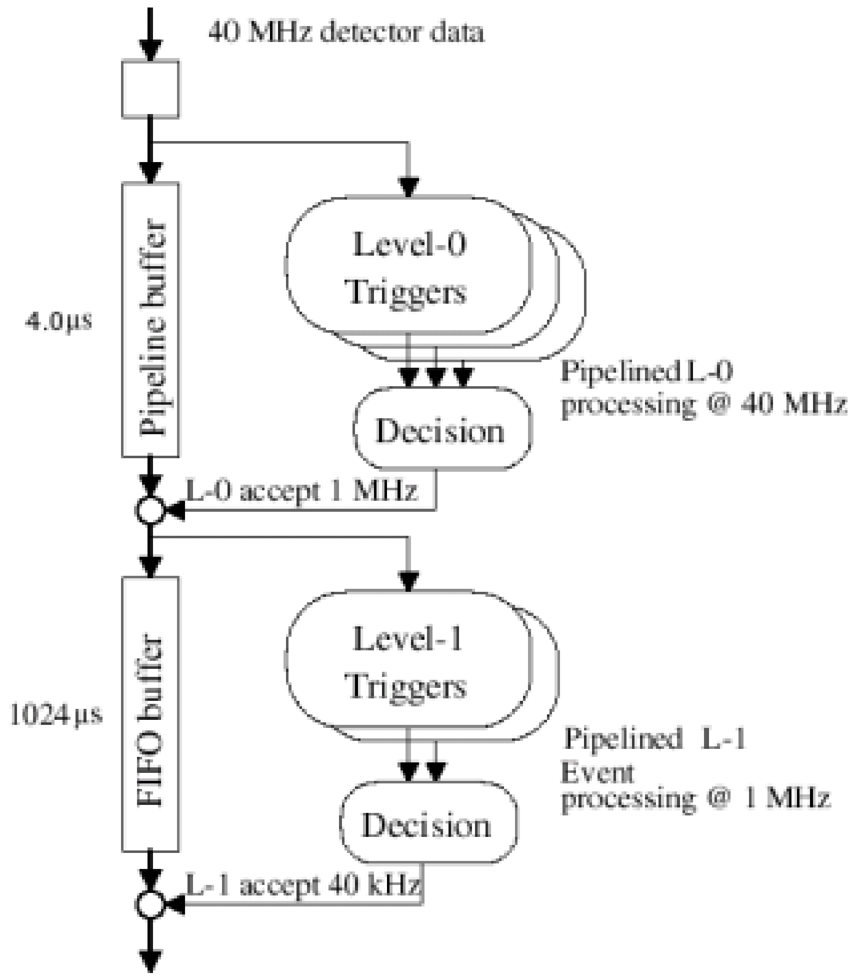
The LHCb Calorimeter Triggers

- Overview of the LHCb triggers
- General principles
- Hardware implementation
- Performances
- Conclusions

Overview of the LHCb triggers

Two hardware levels

- Level 0 reduces the rate to 1 MHz in 4 μs
  - Select high P_T particles
  - Reject multiple interactions
- Level 1 reduces the rate to 40 kHz in 1000 μs
  - Identification of a secondary vertex
- DAQ input at 40 kHz

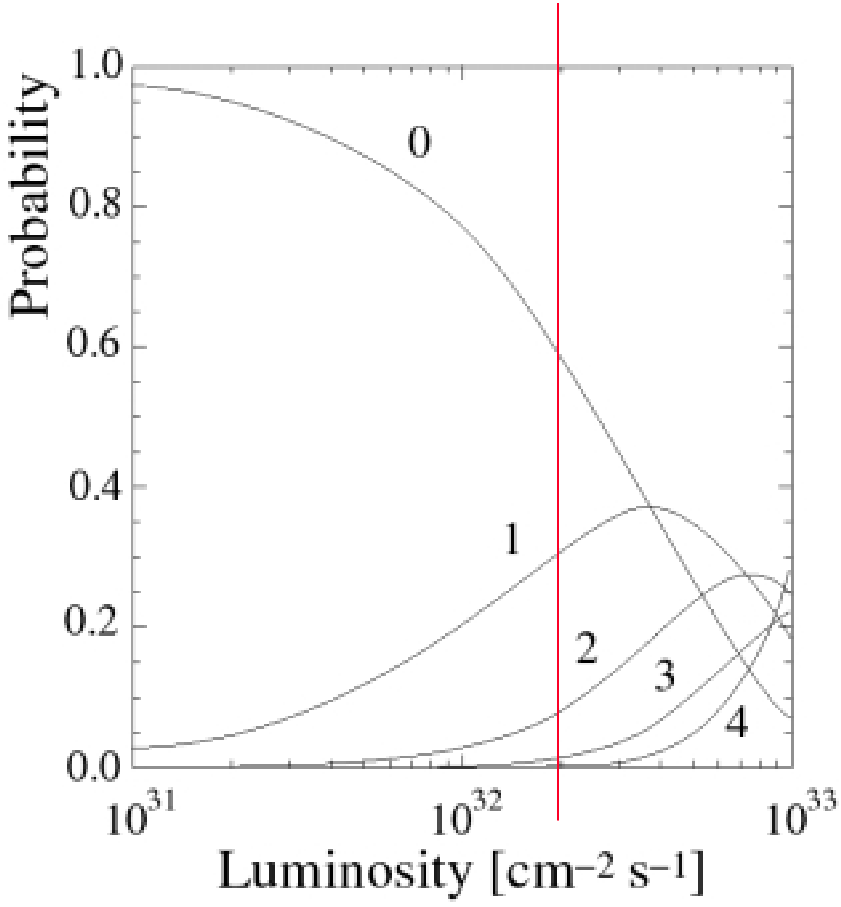


Software filtering

- Two software filtering stages to reduce the rate to 200 Hz

◆Level 0 Trigger parameters

- LHC repetition rate 40 MHz
  - But only ~76 % have colliding bunches at LHCb
- LHCb works at 'low' luminosity, to have a single interaction per crossing
  - Nominally 2 x10^{32} $cm^{-2}s^{-1}$
  - Double and multiple interactions are rejected as soon as possible, using a pile-up VETO at Level 0
- Rate of interaction:
  - Single : 9.4 MHz
  - Multiple : 3.0 MHz
- Accepted rate 1 MHz
  - Factor 10 reduction on single interactions
  - In fact a bit more as multiple interactions are not all vetoed.



◆Level 0 Architecture

- Selection of high P_T particles
  - Electrons, photons, hadrons, $\pi 0$ — This is the subject of this talk.
  - Muons — See Andrei Tsaregorodtsev talk later this morning
  - Total (transverse) energy may also be used.
- Detection of multiple interactions : Pile up-veto
  - Two dedicated VELO detectors upstream the interaction point
  - Histogram the Z impact of all radial hit combinations
    - ➨ Search for a second peak.
  - Rejects ~80% of the double interactions, >95% when 3 or more interactions.
- Combination and decision: the L0 Decision Unit
  - Mainly E_T cuts on the various particle types
    - ➨ Adjusted during the fill to keep the output rate at 1 MHz
  - It can combine several particle types if useful.
    - ➨ It can also ignore the pile-up veto for rare cases like $B \rightarrow \mu\mu$
  - Sends decision to the Readout Supervisor
    - ➨ Accept two consecutive BX, but no more than 15 events in 900 ns due to the size of the de-randomisation buffer in the front-end cards.

Calorimeter Triggers
General principles

◆Identify hot spots

- A shower has a ’small’ size
  - Detect a high energy in a small surface
  - Use a square of 2 x 2 cells area
    - 8 x 8 cm^2 in the central region of ECAL (may loose a few % of the energy)
    - more than 50 x 50 cm^2 in the outer region of HCAL

◆Select the particles with the highest E_T

- Due to its high mass, a B particle decays into high P_T particles
  - ’High P_T ’ is a few GeV
  - For the Level 0 decision, we need only the particle with the highest P_T.
    - Maybe also the second highest in HCAL, see later

- One can then select locally the highest candidate
  - Process further only these candidates
    - Reduced complexity and cabling
    - Only ~200 for ECAL and ~50 for HCAL starting from 6000 and 1500 cells.

Validate the candidates

- Electron, photon, π^0:
  - Electromagnetic nature using the PreShower, charge using the SPD
  - Same granularity, projective
    - Look only at the cells with the same number in the other detectors

- Hadron
  - Would like to add the energy lost in ECAL, in front of the candidate
    - Complex connectivity, expensive
  - Useful only if the ECAL contribution is important
    - If small, it can be ignored without too much harm
  - Look only at ECAL candidates !
    - Manageable number of connections

◆Select the highest validated candidate

- One wants simple decisions at this early level
- Using the second highest hadron was shown to improve marginally the efficiency in some cases.
  - The studied implementation allows to produce this second highest.
  - No need for a second highest electron or photon.
- The number of links, and consequently the cost is by far smaller if one reduces locally the number of candidates…

◆Processing entirely synchronous

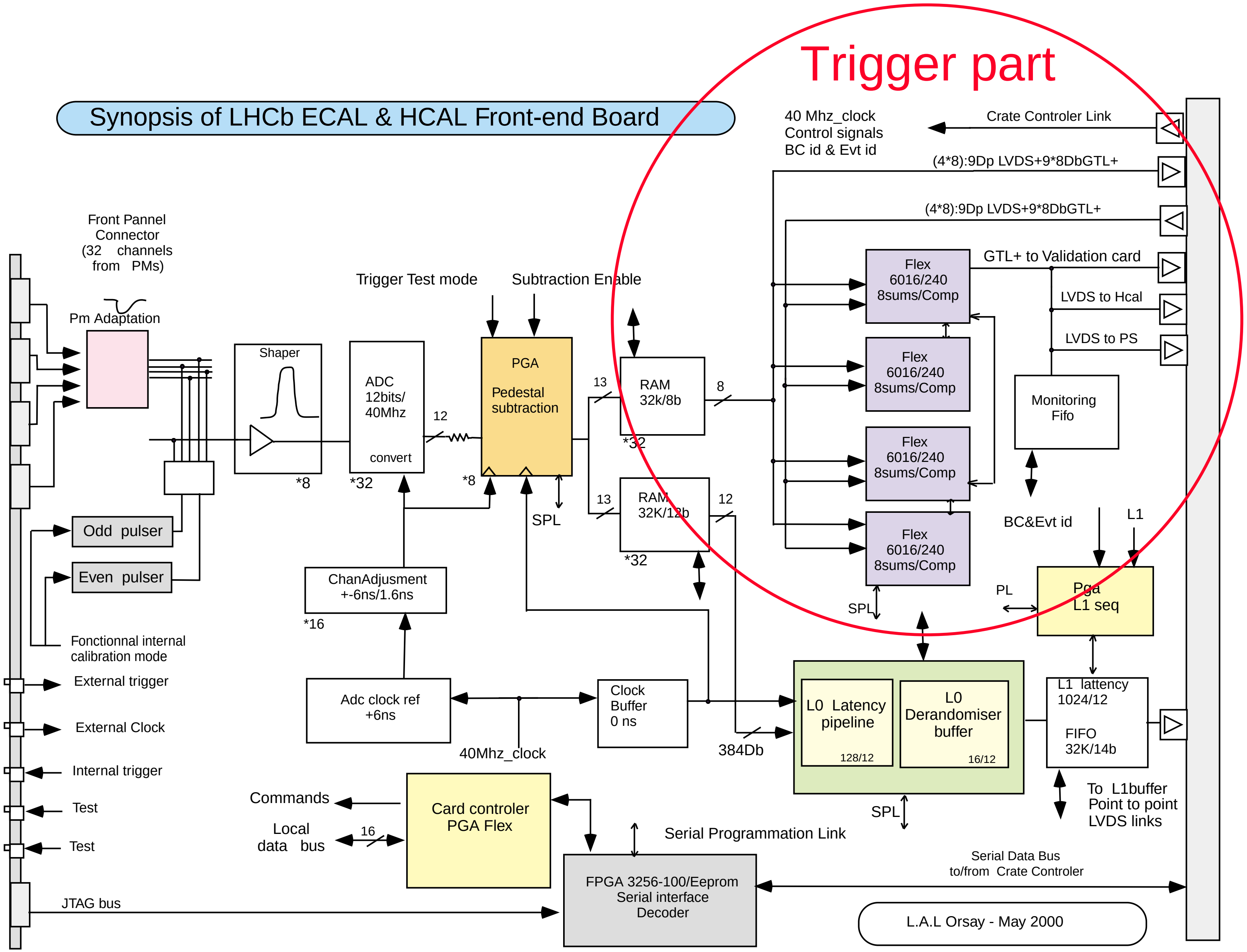
- No dependence on occupancy and on history
  - Easier to understand and to debug
- Pipeline processing at all stages.

Hardware implementation

◆Inputs

- About 6000 ECAL cells (same number for PreShower and SPD)
- Front-end electronics located on top of the detector
  - Order of 100 rads / 10 years
- We want to minimise cabling complexity
  - Integrate the first selection in the front-end card.
- Quantity to manipulate: E_T, converted from the ADC by a dedicated LUT.
  - 8 bits are OK, with full scale around 5 GeV.
- Use a dedicated backplane for as many connections as possible
  - Use LVDS levels, multiplexed signals, as soon as there are several bits

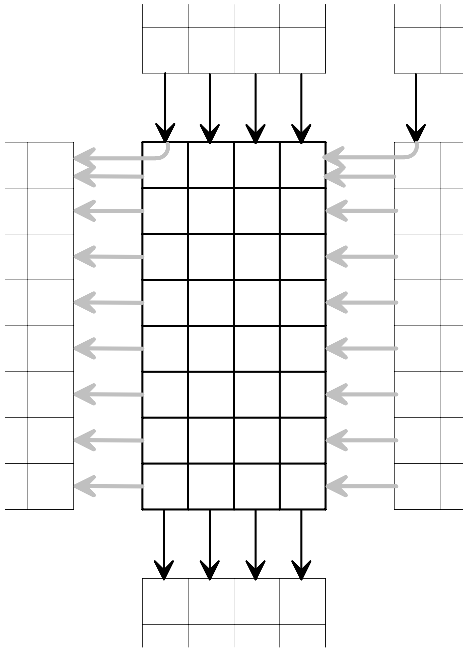
Synopsis of LHCb ECAL & HCAL Front-end Board

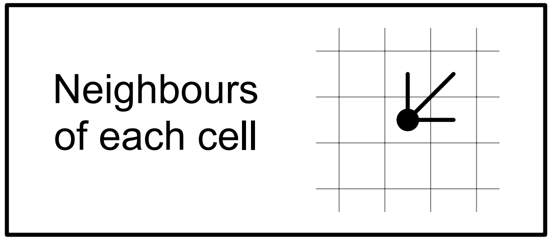


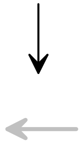
First selection

◆Build the 2x2 sums

- Work inside a 32 channels (8x4) front-end card
  - To obtain the 32 2x2 sums, one needs to get the 8 + 1 + 4 neighbours
  - Via the backplane (9) or dedicated point-to-point cables(4)

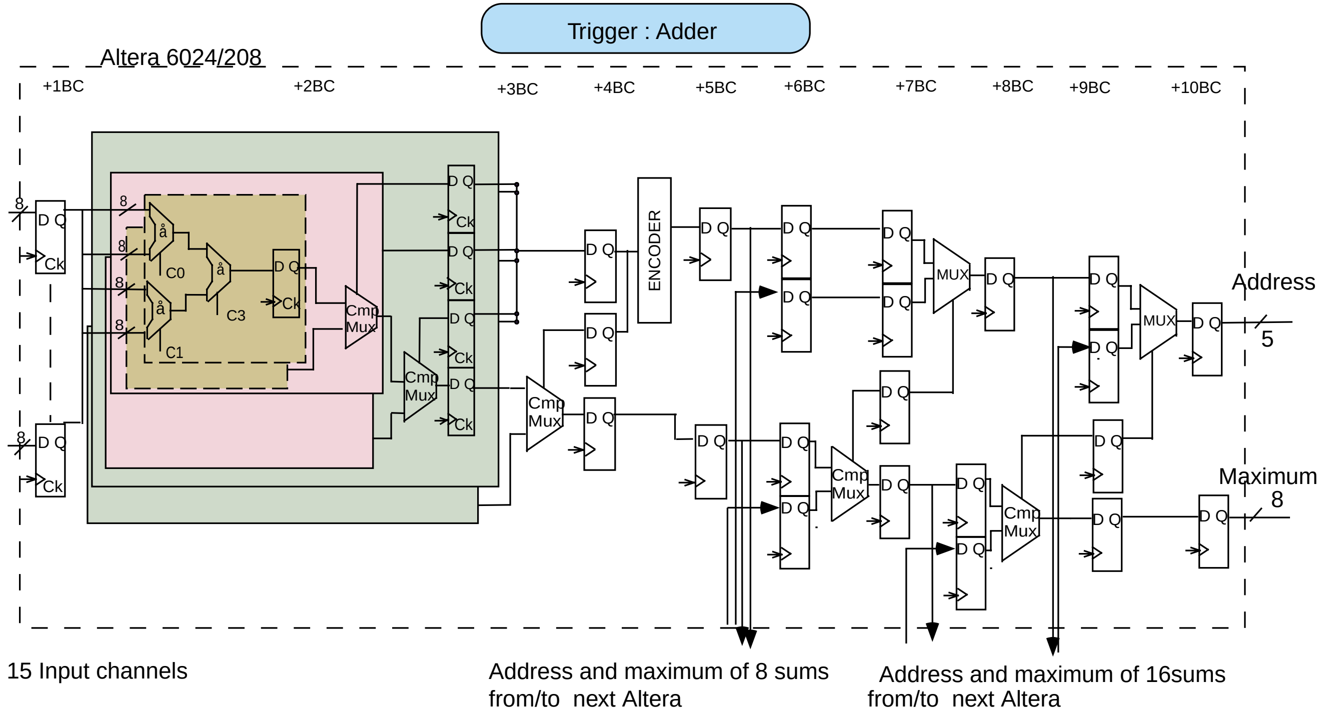






◆Select the local maximum in the card

- Simple comparison of the summed E_T.
- Currently implemented in 4 ALTERA FPGA's, could be simplified when bigger FPGA's are available.



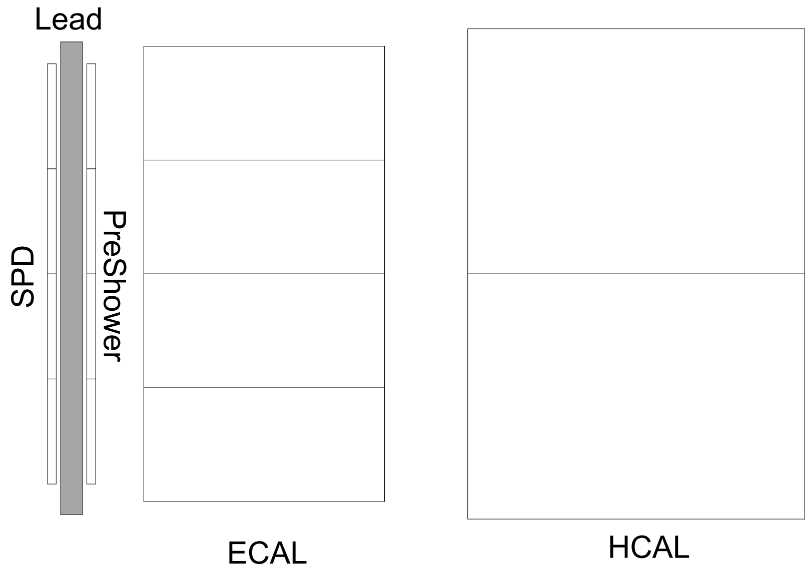
The 32 2*2 sums are compared and the highest one selected by 4 FPGAs. This is performed in 10 clock cycles, without taking into account the time. to get the neighbour information

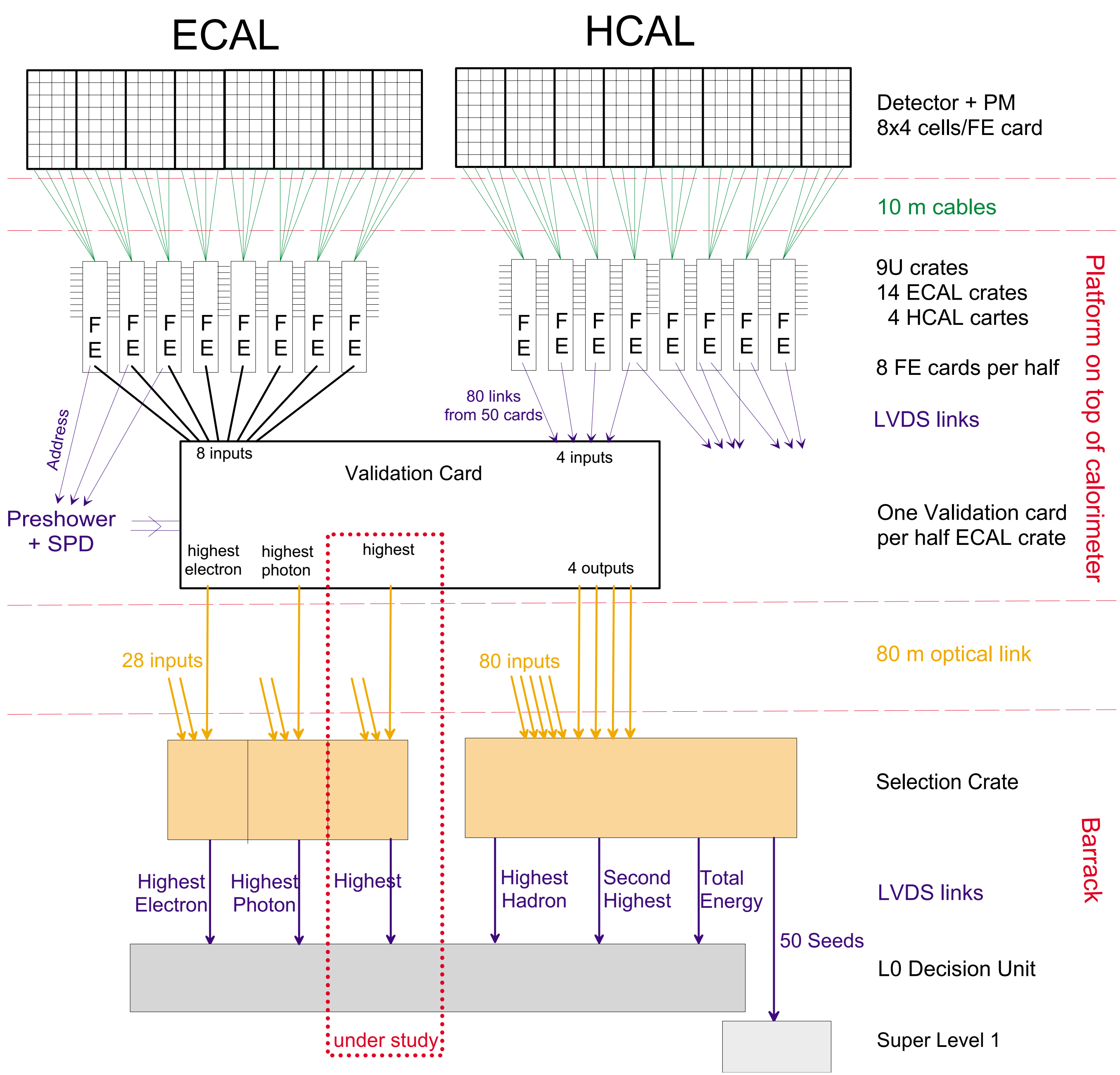
L.A.L Orsay - Feb 2000

Validate

◆ECAL validation

- For each candidate, one needs to access the PSD+PreShower information, i.e. 2 times 4 bits.
  - The address of the candidate is sent from the ECAL to the PreShower FE card
    - One PreShower card handles 64 channels, exactly 2 ECAL cards.
  - The 2x4 bits are extracted synchronously at each BX and sent to the Validation Card



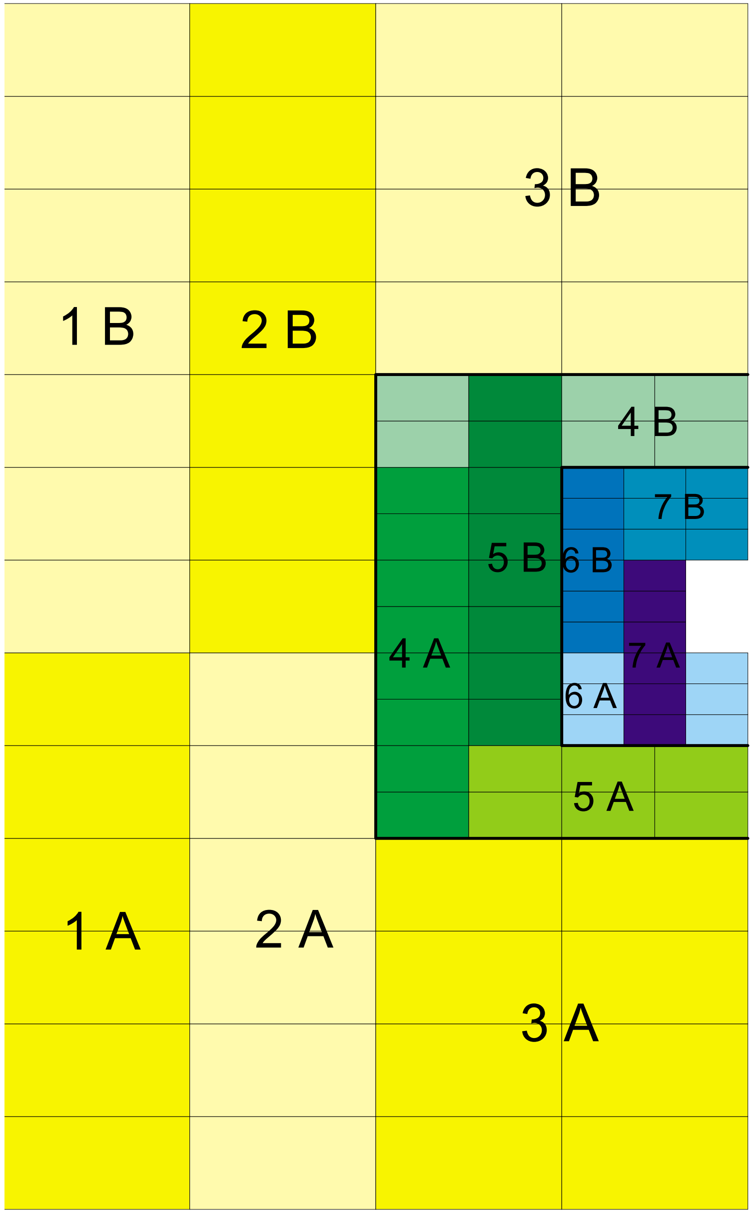

ECAL
HCAL
Detector + PM
8x4 cells/FE card
10 m cables
9U crates
14 ECAL crates
4 HCAL cartes
8 FE cards per half
LVDS links
Platform on top of calorimeter
Address
80 links
from 50 cards
8 inputs
Validation Card
4 inputs
Preshower
+ SPD
One Validation card
per half ECAL crate
highest
electron
highest
photon
highest
4 outputs
80 m optical link
28 inputs
80 inputs
Selection Crate
Barrack
Highest
Electron
Highest
Photon
Highest
Highest
Hadron
Second
Highest
Total
Energy
LVDS links
50 Seeds
L0 Decision Unit
under study
Super Level 1

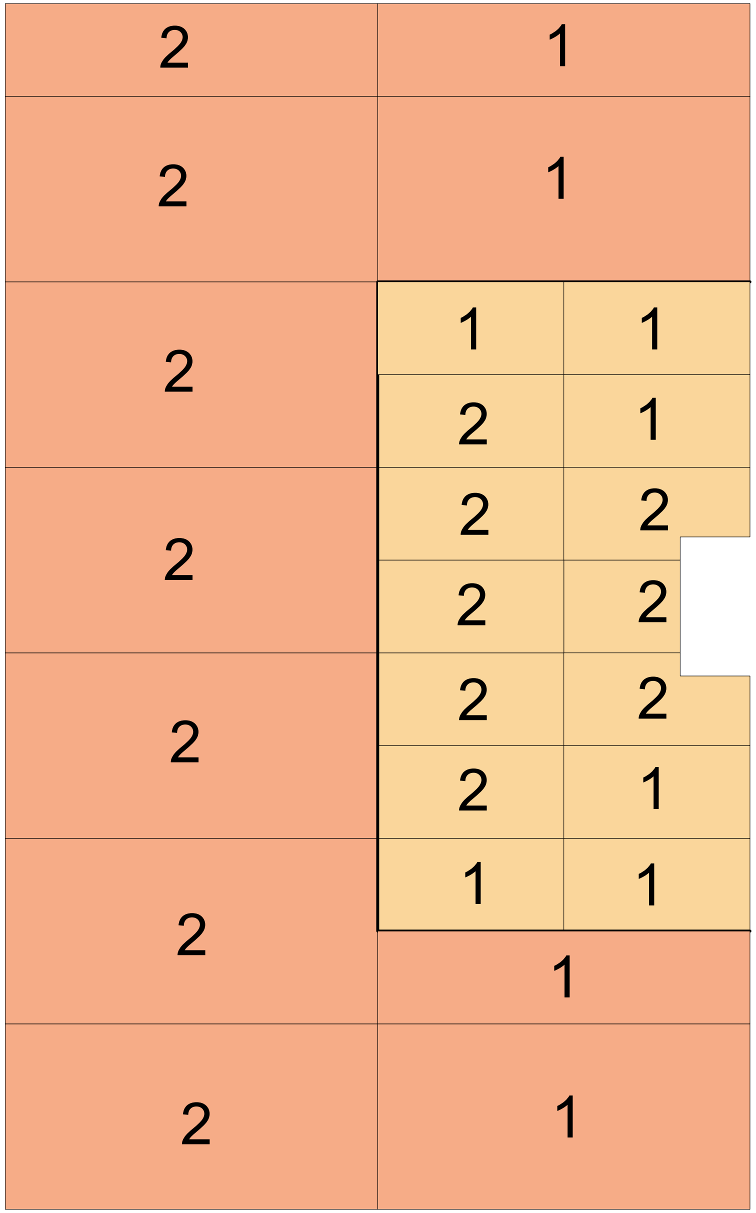
- A decision is then taken to validate the ECAL candidate as photon, electron or nothing.
  - PreShower + SPD => electron
  - PreShower alone   => photon
  - Possible VETO on dirty cases, to reject splashes
  - Validation by a LUT (8 bits input, 2 outputs) => flexibility

- Only the highest electron and the highest photon are kept.

◆π^0 trigger

- Combine two photons from neighbouring ECAL cards
- Not very efficient, but selects easy-to-reconstruct π^0s
- This idea is still under study.





ECAL Validation Card number

HCAL Number of links to ECAL

◆HCAL validation

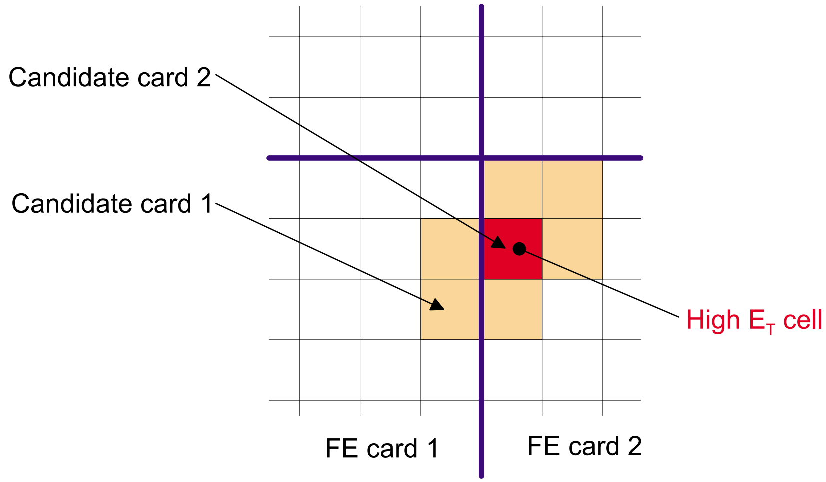
- One wants to add the ECAL candidate in front of the HCAL one
- It was found easier to bring the HCAL candidates to a place where the ECAL candidates are available ! Even if some have to be duplicated
  - About 200 ECAL candidates
  - About 50 HCAL candidates
  - Including the needed duplication, one has 80 links HCAL to ECAL, instead of 200 links ECAL to HCAL
- The ECAL and HCAL addresses are matched (LUT) and the E_T of the highest matching ECAL candidate is added to the HCAL one.
- All candidates are sent to the barracks, for later processing.

Selection crate

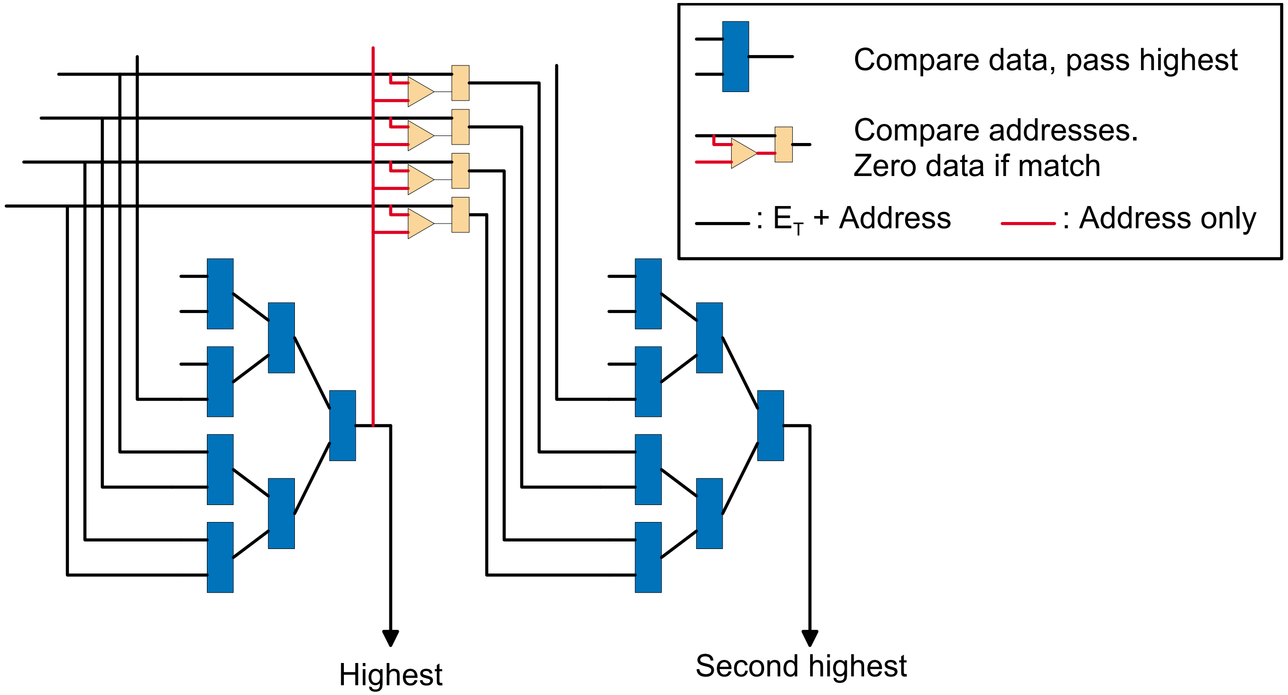
◆Select the final candidates

- Easy for electron, photon, π^0 : Only the one with highest E_T is kept.

- For HCAL: The highest is also easy.
- The second highest implies to remove 'ghosts'
  - 1- The same HCAL candidate may go to two Validation Cards.
  - 2- The same cell can be used by two candidates in neighbouring FE cards



- Removing ghosts is just checking if the addresses differs by no more than ±1 in row and column.



- We want the total E_T and the seeds for 'super-L1', where the first type of ghosts (from the same HCAL card) have to be always removed
  - We know where are the two candidates coming from the same HCAL card.
    - Just select the one with highest E_T.

Performances

◆Latency is OK

- The number of clock cycles needed is sensibly below the allowed budget.

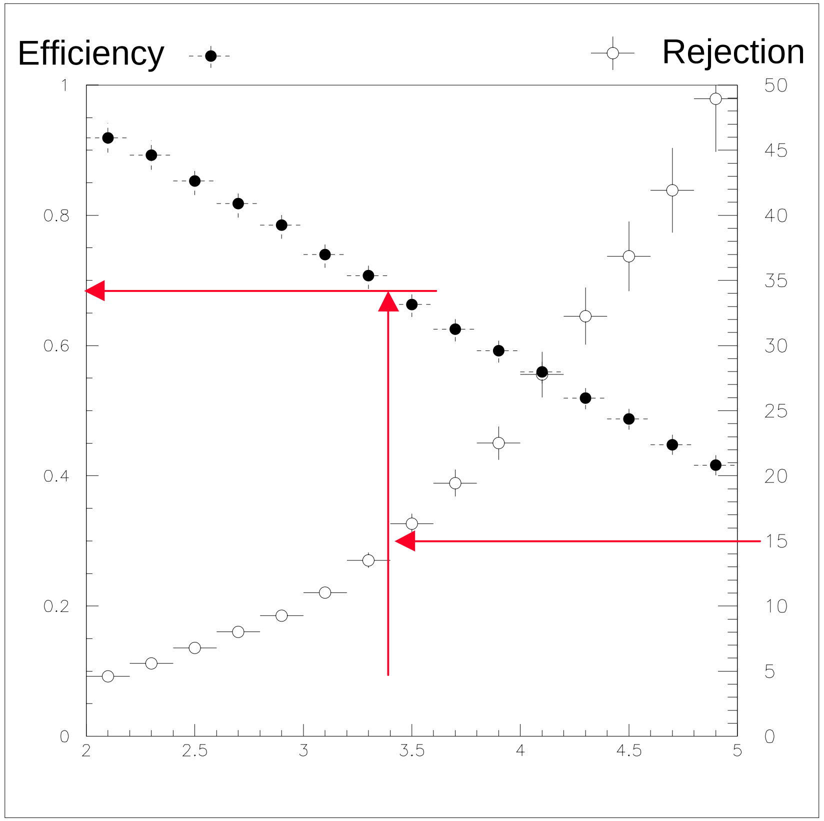
◆Compare to minimum bias retention

- The constraint is to keep the Level 0 rate to 1 MHz
  - This defines the rejection factor on minimum bias
  - The sharing between the various types of particles is being optimised.
    - The rejection should be about 15 for hadron, 100 for electron and 200 for photon / π^0
- The plots show the minimum bias rejection and the signal acceptance versus the E_T cut.
  - 'Signal' is normalised to events which can be reconstructed in LHCb
- This is only the Level 0 acceptance.

◆From right to left on the figure:

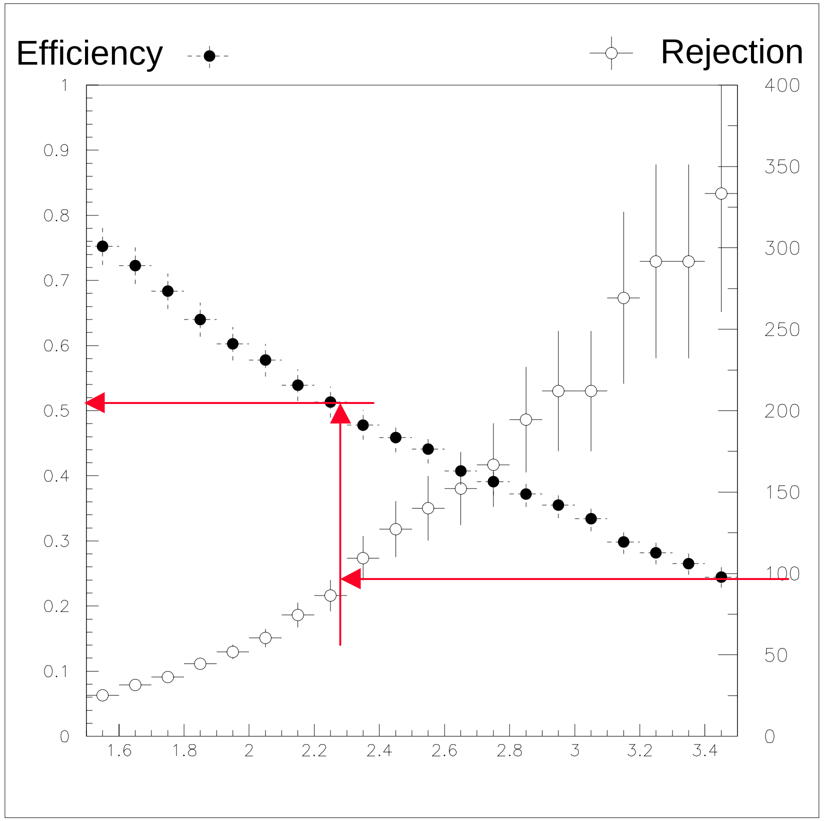
- For a given rejection, read the E_T threshold
- For this threshold, read the signal efficiency

Hadron trigger



$B_d \rightarrow \pi\pi$

Electron trigger



$B_d \rightarrow J/\Psi(e^+e^-)\ K^0_S$

Conclusions

◆We have a powerful Calorimeter Trigger

- It minimises the number of connections.
  - Less that 1000 LVDS links between cards on the same Calorimeter platform
  - About 150 optical links to the barracks.

- Many connections on the backplane
  - Same crates for ECAL, HCAL and PreShower electronics.

- It could be built almost now
  - But no need to hurry, we need it in 2004 only
  - New FPGA's may simplify the design, and gain some speed, even if this doesn't seem to be needed

- It performs very well.