

A DAQ readout for the digital HCAL

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Abstract:

Considerations on the size of the digital HCAL prototype and on the readout scheme are presented. A new cost estimate is deduced, far below the previous one, making the proposal very interesting for the coming prototype construction of digital HCAL.

1. Introduction

A gaseous detector like RPC's or gem's as active device for a digital hadron calorimeter is one of the possible option. Since a pad size of about 1 cm^2 seems to be optimal for what concerns the energy resolution [1], the overall number of channels is very large and therefore the electronics readout is the key point for the cost of such a detector. The original proposal for this readout comes from studies by A.Karar at LLR for the TDR [2], where the main philosophy is to do the zero suppress as early as possible. A study of the prototype size needed to fulfil the goal of the test beam and a detailed description of the readout is presented.

2. The needed size of the DHCAL prototype

The containment of the hadronic shower in the foreseen prototype is worse in the case of interaction of charged pion shooting the prototype perpendicular to the radiator. In order to visualise the worse case, a sample of 100 GeV/c charged pion has been simulated, within MOKKA framework [3], at 90 degrees in the middle of the ECAL and HCAL. Figure 1 shows a visual transverse view of the 1000 events in the sample.

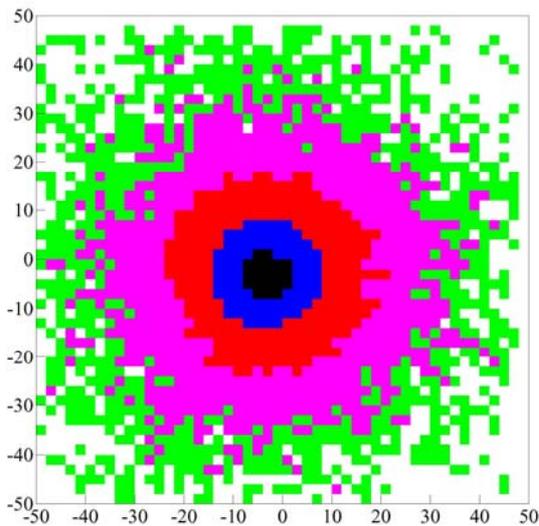


Figure 1: Transverse view of 100 GeV/c pion interaction

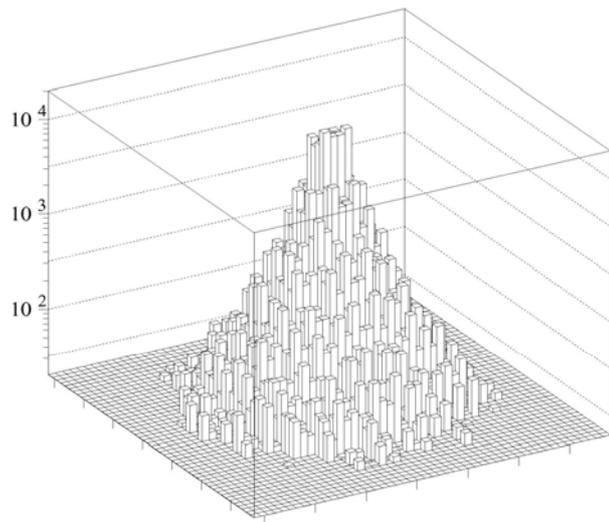


Figure 2: 1000 interaction of pions in 1m
Note the log scale on the energy cells contains.
x,y plane in this figure is the plane perpendicular to pion interaction

In order to reduce by a factor of 2 the number of channels, we define a “new size” for the prototype, with a size of $70 \times 70 \text{ cm}^2$.

From the distribution of the figure 1, we found that for 32% of the events, there is absolutely nothing outside this new size. When looking the number of cells outside, in fact less than 1% of the events have more than 1% of cells multiplicity outside our “new” prototype. If we assume a reasonable time for the test beam and taking into account the duty cycle of the RPC's, it is clear that the checking of the digital HCAL properties versus the GEANT4 simulation will be at best at the 1% level, and therefore a size of $70 \times 70 \text{ cm}$ seems appropriate in reducing the prototype cost. Similar study has been done with 10 GeV/c pion, it is shown on figure 3.

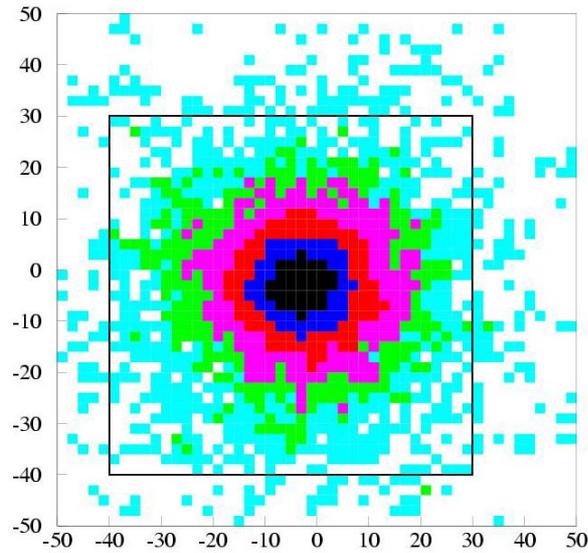


Figure 3: Transverse view of 10 GeV/c pion interaction. the square shows the proposed “new size” detector.

The containment is illustrated by fig. 4, which shows the fraction of the shower outside this new size detector.

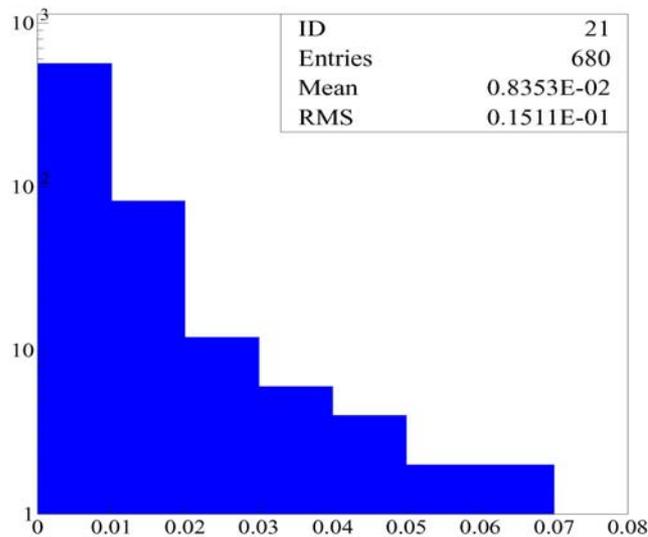


Figure 4: Fraction of the multiplicity outside the new size detector for 100 GeV/c pion interaction.

The proposed design is therefore 2 Boards of 40x72cm per layers, corresponding to about 230 000 channels for the 40 layers with a transverse size of 80x72 cm². Each Board corresponds to 45 ASIC’s.

3. The readout scheme

The overall scheme of the electronic readout is based on an VFE-chip ASIC with the signal pre-amplification, a set of discriminators, and a memory inserted at the level of the ASIC. The control and readout of all the ASIC of a plane is managed by an FPGA which contains VHDL network component, able to communicate together with the ASIC and with a dedicated DAQ computer. The detailed scheme is the following. The pads are located on a PCB or Kapton plane. The signal goes by strip line inserted in the board to the VFE, an ASIC reading 64 channels. A schematic view of the ASIC is shown on figure 5 [3]. An external trigger coming from beam hodoscopes is distributed to all ASIC's, starting the readout process. If at least one pad cell is above the threshold, the 64 bits of the ASIC's is stored in a digital memory together with the content of the trigger counter. In order to have a look to threshold effect, the level of the discriminator could be changed by external order. Another solution could be to "force" a storing by external order, even if no pad cell is above the threshold. In both case, the control of the ASIC must come from external line coming from the DAQ readout system. In order to know the memory size needed in the ASIC, the beam structure and hardware limitations can be taken into account.

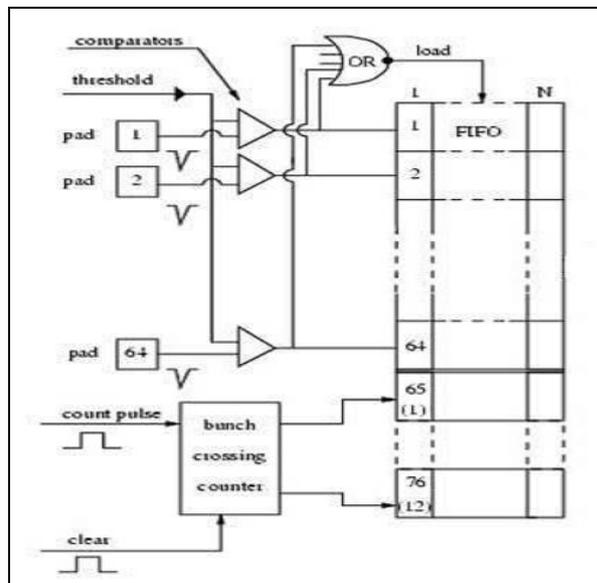


Figure 5: Schematic view of the VFE ASIC (here $N \approx 500$)

For the exercise, the FNAL- MTBF spill structure is used. The spill duration is about 0.7s with one spill per minute. However, with some work, an increase to 10 spills per minute is possible if needed. For the study, we take a spill duration is 0.7 s and a time between spill at 7s.

On the hardware side, since the RPC's in streamer mode are limited to a rate of 300Hz, it means that there are about 210 interactions per spill, which we have to store in a memory. Naturally, a safety factor could lead to a memory size corresponding to about 400 interactions, that is a memory of about 30 Kbits, when taking into account the storing of the trigger number (up to 500).

4. The simulation of hadronic interactions

GEANT4-MOKKA has been used to simulate 1000 interactions of 100 GeV/c pion in the ECAL(W-Si) and the 40 layers of the RPC's – Iron digital HCAL. The numbers of hits in the DHCAL is small with a maximum of 920 hits/interaction. Moreover, the transverse dispersion is modest with a maximum of 18 ASIC/layer with at least one hit. For 10 GeV/c pion, the number of ASIC is smaller as expected. However, it must be noted that the number of ASIC to be read per interaction depends on the hadronic shower model used in geant4, due to the different width of the shower with different model.

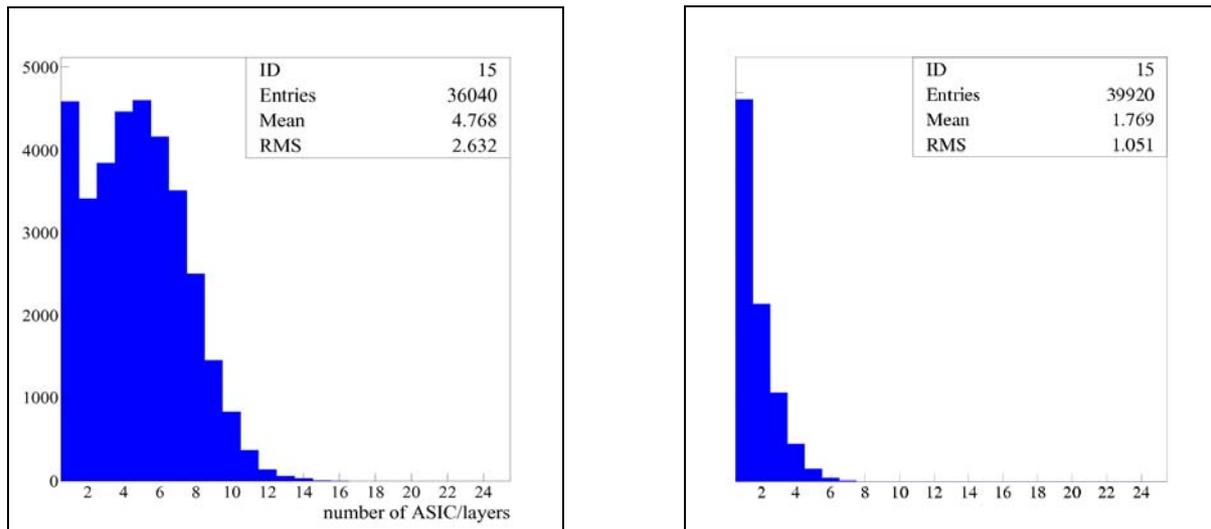


Figure 6: Distribution of the number of ASIC-VFE with ≥ 1 hit, for 100GeV/c pion (left) and 10 GeV/c pion (right) interaction.

5. DAQ based on FPGA's for RPC's active devices

The average VFE with at least one hit is 5 VFE ASIC/layer, with a maximum of 18 ASICs, which justified the token ring structure. Of course these numbers are dependant of the real hadronic shower extension, which are not known. For 100 GeV pion interactions, the average numbers of bits per layer is VERY small, at about 330 bits/interaction/layer. However, recently, the US groups as well as Russian groups measure in RPC the multiplicity per mip track to be about 1.5/hit, leading to **495 bits/interaction/layer**. Using again a safety factor of 2, it translate to a number of bits per interaction and per layer of about **1Kbits/interaction/layer**.

Taking into account the 210 interactions/spill, each FPGA will have to read about 210Kbits/**FPGA** located in about 4 ASIC's in the time between spills. The way to do it could be the following. At the end of the spill, the HCAL DAQ receives from Accelerator DAQ the information of the "end-of-spill". The DAQ starts there a reading of each FPGA located on planes, one after another, in token ring mode. Similarly, when one FPGA receives the "readout" order, it read the ASIC's one after another in token ring way. The overall information to be read is about 210Kbits time 40 layers, that is **8.4 Mbits**. With the 7s between spills, it means a transfer rate of about 1200 Kbits/s. This modest speed allows reducing the cost and complexity of the readout, using a single PC working in Ethernet or USB2.0, with just some development on the reading protocol.

6. Running with GEM's

Now, if the RPC's are replaced by GEM's, as proposed by UTA group, the rate limitation is no longer valid. One solution consists to have the local storage of the VFE ASIC accessible continuously by FPGA. Using, for example, a XLINX Virtex-II, the clock is at 420 MHz, and a readout at 50 MHz is not a problem. With one line per VFE chip, naively we can count about 80 clock counts to read the 45 ASICs per plane, leading to a rate of about 700 KHz. Even with a safety factor of 10, there is *a priori*, no problem to use the same DAQ to read the GEM's in test beam. A dedicated FPGA simulation is under way to give a more precise estimation. The only open question is the need of an external memory to store interaction up to the end of the spill, and the DAQ will then read this memory directly or through the FPGA.

7. Cost estimate

With the estimated rate of transfer, a single FPGA/layer could do the readout. A schematic view is shown on figure 9. The FPGA receive a trigger from external line, (from the beam hodoscopes), and read the 45 ASIC's (for 2 board and 2 FPGA per layer) storing the 64bits of one ASIC only when at least one bit is on. At the end of the spill, the FPGA receive through a network component (NC), the readout order. It enables the reading of the ASIC and transfer the memory to the NC. The protocol and the "end-of-spill" flag is managed by the NC, which send/receive the flag of readout from the DAQ-PC and make free the token-ring at the end of the FPGA readout.

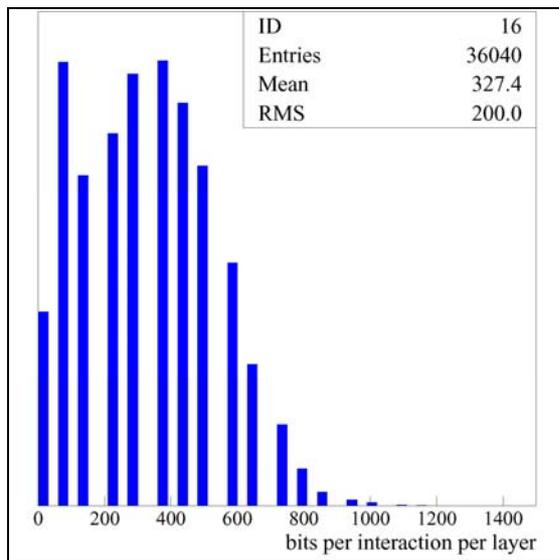


Figure 7: Distribution of the number of bits/interaction/layer for 100GeV/c.

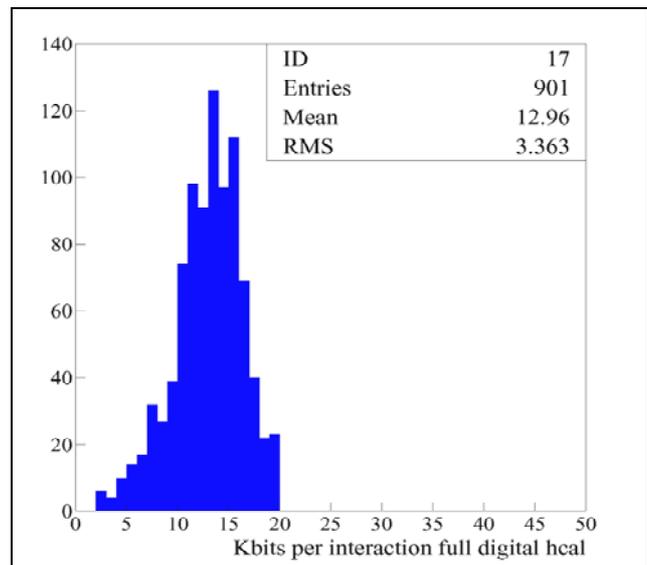


Figure 8: total number of Kbits to be read between 2 spills for 100 GeV/c

The FPGA estimation is based on XilinX or ALTERA on-shell FPGA, while the IP module of the FPGA is estimated at 20 euros/unit, cost taken from CMS experiments for their TPG cards for the ECAL. An estimation of the time needed for this development is about 2-3 engineers years. The engineers salary if therefore, using standard values used in CNRS - IN2P3, estimated to be about 300 K€.

8. Possible use for the final project

The intrinsic limitation of the RPC's counting rate can be translated to the ILC situation where in addition, the occupancy is expected to be well below the one for a test beam. Therefore, the overall readout for a DHCAL in the full scale detector can be just a copy of the one proposed here. However, a special care and dedicated study have to be done in the low angle region, where the production of hadrons due to photons-photons interaction could be very large.

9. Conclusions

A DAQ for the digital HCAL is proposed. The expected performances look adequate for RPC's or even GEM'S as active layer, while cost is very effective. The key point of the project is the capability of local storage of the VFE ASIC under development.

Acknowledgement:

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References

- [1] V. Zutshi (NIU) presented at Montpellier ECFA workshop, 2003
- [2] Tesla Technical Design Report, Part IV, calorimeter section 2001
- [3] MOKKA simulation package
- [4] A.Karar , presentation at SNU meeting, Korea, 2000

Table 1 : Cost estimation (not counting salary) for the readout of the prototype

ITEM	NUMBER	Unit cost €	Total per item €
FPGA's (1 FPGA per PCB , 2 PCBs layer)	80	150	12000
IP module	80	40	3200
PC, Cables	1	5000	5000
Optical transfer	1	800	800
Misc. + Contingency			4000
TOTAL			25000

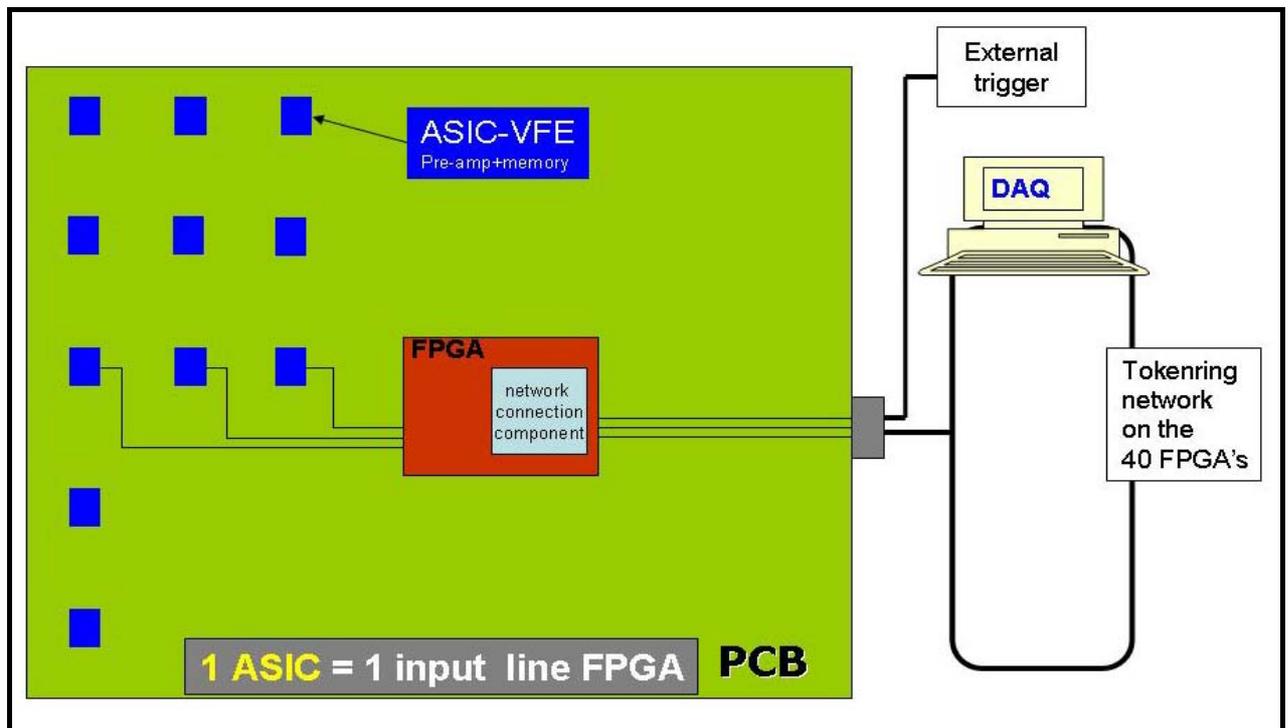


Figure 9: Schematic view of the PCB, the ASIC-VFE, the FPGA and the DAQ system.
There is 2 PCB per layer.