Page: 118

Number: 1 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:38:35

(Ueli):

1. As far a I can judge, the relevant information is given. But the level of details in the different subsection is rather inconsistent. For instance there are many details on electronics (which I personally find interesting,but the average reader may be not), but there is only a very short summary of a Pile-up study, which is certainly of utmost importance to judge, which instantanous lumi LHCb should run with.

Most of the activity concerns the electronics as we have to re-design it.

2. There is a lot of room for improvement in the spelling and grammar, there are too many corrections to give by email.

3. The page format is wrong for European printers, such that all the page numbers are cut off. Furthermore page 128 is unreadable on the printout, and page 130 is missing completely in the printout.

Sheldon's compilation in US Letter ?

Number: 2 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:35:37

3379-3380, (Ken) change to

'The interaction trigger foreseen to replace our present L0 trigger does not require a very strict selection and therefore it can be operated without the PS and SPD.'

Done

Number: 3 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:38:40

3382(Ueli)

It remains to be studied whether the necessary electron and photon identification needed for

Number: 4 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:38:47

3383(Ueli)

parts of our upgrade physics program can be achieved without the PS.

I could not find any other mentioning of this. Also I don't understand it. From the earlier context the reader gets the impression, that the PS will not be needed anymore for the pure interaction trigger. Why is this study then needed? Or is it planned to get rid of the PS altogether? Then this study is certainly very important.

Done

Number: 5 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:38:52

3384-3386(Ueli)

Please reformulate!

Done

Number: 6 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:01

3385, (Ken)

Change 'high Et cluster' to 'high Et clusters'

Done

Number: 7 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:04

3386(Ken)

Done

Comments from page 118 continued on next page

For RICH-1, it will be ascertained whether a less focused optical mirror system is beneficial to spread the C_4F_{10} rings over a greater number of MaPMTs. For the TORCH, the design of the stand-off will be optimised, the detector modularity, and the optical tolerances of the quartz studied.

Optimized photon pattern recognition and ring reconstruction will be vital to maximize the PID performance at the highest luminosities. The necessary software tools for pattern recognition will be developed for the upgraded RICH and TORCH detectors. Finally we will also study the possibilities of a global PID algorithm incorporating both RICH and TORCH.

VI. CALORIMETRY

A. Introduction

The present calorimeter system of LHCb is composed of a Scintillating Pad Detector (SPD), a Preshower (PS), an Electromagnetic Calorimeter (ECAL) and a Hadronic Calorimeter (HCAL). The HCAL is based on the Tilecal technology and contains 1600 cells. It is preceded by the ECAL based on the Shaslik technology and containing 6016 cells. In front of the ECAL, the PS is composed of 6016 tiles matching the geometry of the ECAL. The PS is placed after a lead sheet of 2.5 radiation length and is preceded by another layer of 6016 scintillator tiles, the SPD.

The detailed description of the calorimeter system can be found in [264].

The calorimeter system plays a role in photon reconstruction (ECAL), in photon and electron identification (ECAL, PS, SPD), and in the trigger system (HCAL, ECAL, PS, SPD).

For the LOI we have concentrated the studies on the upgrade of the ECAL and HCAL readout at 40 MHz. The foreseen interaction trigger replacing our present L0 trigger does not request a very selective selection and therefore it can be operated without the PS and SPD. It remains to be studied whether the necessary electron and photon identification needed for parts of our upgrade physics program can be achieved without the PS.

The HCAL is essentially used for the trigger in the present system; however it is not only essential in selecting events with high Et particles at the L0 level. The HCAL is also used to provide candidate high Et cluster. In the higher level trigger HLT1, these clusters define roads in the tracker which decrease in an important way the number of track elements to be combined for track reconstruction, and therefore reduce the computing time in the event filter farm. A similar procedure exists for electron or photon candidates where ECAL clusters are used.

To minimize the required modifications, it is planned, for the upgrade, to keep the present ECAL and HCAL calorimeter modules, their PMTs, Cockroft Walton bases and coaxial cables. However, to keep the same average anode current of the phototubes at the higher luminosity, their HV is reduced and therefore the gain of the amplifier integrator in the Front End card will be increased. This is described in section VI B.

The racks and crates situated at the top of the calorimeter can be kept as they are, however of course the Front end cards have to be modified to allow a read out at 40MHz. To minimize the number of fibers necessary to read the calorimeters the ADC information is packed using an algorithm similar to the one presently used in the TELL1 calorimeter cards. The new Front End cards are described in section VI C.

Number: 8 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:08

3391(Ken)
I guess we should define the acronym PMT, to be correct.. (I couldn't find a definition earlier in the LoI).
Insert (CW) after Cockcroft Walton - you use the acronym CW later on.

Done

Number: 9 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:38:56

line 3392:(Ueli)
replace "Cockroft Walton bases" by "Cockroft-Walton (CW) high
voltage generators"

Prefer "Cockcroft Walton base"
The usual terminalogy.

The decision to keep the calorimeter modules their PMTs and CW bases assumes that they can operate with the radiation damage corresponding to the foreseen integrated luminosity. This is discussed in section VI D.

Because of the higher luminosity, there will be a higher occupancy in the calorimeter cells. It will cause an increase in calorimeter noise due to statistical fluctuation in these underlying events. While the effect is small for the measurement of high E_t photons it is important in the case of low E_t photons. In section VI E an estimate of this equivalent noise is given.

B. ECAL/HCAL electronics upgrade: analogue front-end

The analogue signal processing in the present ECAL Front End (FE) board ([263], [264], [265]) is mostly performed by a shaper ASIC that integrates the PMT pulse, which has been clipped at the PMT base. The PMT is located at the detector; the signal is transmitted through a 12m 50Ω coaxial cable to the FE board located in the crates at the calorimeter platform.

	Values	Comments
Energy range	0-10 GeV/c (ECAL) Transverse energy	1-3 Kphe / GeV Total energy
Calibration	4fC/2.5MeV/ADC count	12fC/ADC count if no clipping
Dynamic range	4096-256 = 3840 cnts: 12 bits	
Noise	$\lesssim 1$ ADC cnt or ENC $< 5-6$ fC	With clipping in PM base
Termination	$50 \pm 5\Omega$	Passive vs. active
AC coupling	Needed	Low freq. (pick up) noise
Baseline shift prevention	Dynamic pedestal subtraction (also needed for LF pick-up)	How to compute baseline ? Number of samples needed ?
Max. peak current	4-5 mA over 50Ω	50pC in charge (before clipping)
Spill-over correction	Clipping	Residue level: $2\% \pm 1\%$?
Spill-over noise	$\ll$ ADC count	Relevant after clipping ?
Linearity	$< 1\%$	
Cross-talk	$< 0.5\%$	
Timing	Individual (per channel)	PMT dependent

TABLE VI. Summary of the requirements for the calorimeter analogue FE.

The PMT gain has to be decreased by a factor 5 in order to tolerate the increase in luminosity, as severe ageing problems may be encountered if total integrated charge exceeds 100 C. Therefore, the preamplifier input equivalent noise must be decreased accordingly.

Noise after integration and pedestal subtraction should be at the level of 1 ADC count approximately, this corresponds to an input charge of 5fC RMS. Detailed noise analysis shows that total input referred noise voltage of the front-end should be smaller than $1\mathrm{nV}/\sqrt{\mathrm{Hz}}$. This requirement includes not only the input referred noise of the amplifier but any other noise source, i.e. the 50Ω termination resistor; therefore, a passive termination is not acceptable. Active termination schemes are under study. Because the implementation of an active termination requires a transistor level approach and because the FE board has 32 channels; an ASIC development is under study. It will be described below.

Page: 119

Number: 1 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:11

3400(Ken)
insert comma after "calorimeter modules"

Done

Number: 2 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:39:03

3401-3402 (Ueli)
Please reformulate

Number: 3 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:39:07

line 3404 (Ueli)
It -> This

Done

Number: 4 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:39:15

line 3413, (Ueli)
Table VI
I believe the style of this table is not appropriate for an official document. it looks like a copy of a slide from a presentation. Please formulate the relevant comments as text. Also, a lot of details could be left out, probably.

Done (see also comment 6 from Ken)

Number: 5 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:39:19

3414-3415-3416 (Ueli)
What is the basis for the number ~~5~~ (reference). Give reference for the 100 Coulombs.

should be "4" : corrected in text

No reference. Hamamatsu PMT specifications (now indicated in the text).

Also: cross reference this to the radiation issues in Section D.

PMT ageing problem. Not radiation

In addition: Later it says by removing the clipping one could gain a factor three. Please make these considerations consistent. Make up your mind, whether you want remove the clipping or improve the termination or both.

Different solutions are looked at. This is a LOI and we think that we have time to decide on the best one. Text modified to make it clearer.

Number: 6 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:13

3417(Ken)
Change 'this corresponds to' to 'corresponding to' Done
Table VI on page 119: do you want to include the third column of Comments? Many of these things are discussed in the text, and I think the table would be better with just the parameters and their required values (first and second columns).

Number: 7 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:12:33

Line 3417 to 3422:
The order of arguments is confusing. Normally a requirement of relative and absolute resolution in femtoCoulombs and nv/sqrt(Hz) is calculated first. Then the preamp gain is adapted to the ADC resolution.
Also what is the detailed noise analysis in line 3418 about? Please give a reference.

The noise estimation is based on the present system : 20fC/5=4fc

The detailed analysis is part of the upgrade studies. Not published.

Comments from page 119 continued on next page

The decision to keep the calorimeter modules their PMTs and CW bases assumes that they can operate with the radiation damage corresponding to the foreseen integrated luminosity. This is discussed in section VI D.

Because of the higher luminosity, there will be a higher occupancy in the calorimeter cells. It will cause an increase in calorimeter noise due to statistical fluctuation in these underlying events. While the effect is small for the measurement of high E_t photons it is important in the case of low E_t photons. In section VI E an estimate of this equivalent noise is given.

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	Values	Comments
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Dynamic range	4096-256 = 3840 cnts: 12 bits	
Noise	$\lesssim$ 1 ADC cnt or ENC $< 5 - 6$ fC	With clipping in PM base
Termination	$50 \pm 5\Omega$	Passive vs. active
AC coupling	Needed	Low freq. (pick up) noise
Baseline shift prevention	Dynamic pedestal subtraction (also needed for LF pick-up)	How to compute baseline ? Number of samples needed ?
Max. peak current	4-5 mA over 50Ω	50pC in charge (before clipping)
Spill-over correction	Clipping	Residue level: $2\% \pm 1\%$?
Spill-over noise	$\ll$ ADC count	Relevant after clipping ?
Linearity	$< 1\%$	
Cross-talk	$< 0.5\%$	
Timing	Individual (per channel)	PMT dependent

TABLE VI. Summary of the requirements for the calorimeter analogue FE.

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Noise after integration and pedestal subtraction should be at the level of 1 ADC count approximately, this corresponds to an input charge of 5fC RMS. Detailed noise analysis shows that total input referred noise voltage of the front-end should be smaller than $1\mathrm{nV}/\sqrt{\mathrm{Hz}}$. This requirement includes not only the input referred noise of the amplifier but any other noise source, i.e. the 50Ω termination resistor; therefore, a passive termination is not acceptable. Active termination schemes are under study. Because the implementation of an active termination requires a transistor level approach and because the FE board has 32 channels; an ASIC development is under study. It will be described below.

However, it is important to take into account that currently the PMT signal is clipped in the base, i.e. at the detector, and about 2/3 of the signal charge are lost. An alternative solution could consist on removing the clipping of the PM base and perform it after amplifying the signal in the FE card. This would relax by a factor 3 the noise requirement of the front end amplifier, thus allowing a passive termination. Although this solution requires intervention in the detector, the solution seems feasible. A discrete implementation based on COTS Op Amps and analogue delay lines is also described.

After analogue signal processing, either with an ASIC either using COTS, the signal must be digitized through a 12 bit ADC at 40 MHz. Baseline candidate is the AD9238 ADC, which is a dual pipeline ADC. Its sampling frequency ranges from 20 to 65 MHz.

Table VI summarizes main requirements for the analogue FE of the calorimeter system. Except for PMT current and noise, the other requirements are similar to the ones for the current ECAL front end ([263], [264], [265]).

1. Integrated implementation

Active termination avoiding resistor termination and its thermal noise is usually referred as electronically “cooled termination“. Conventionally it is created by an operational amplifier with capacitive feedback. This solution works well, provided that the input signal amplitude is not large enough to produce significant changes in the input amplifier transconductance. In the case of calorimeters on high energy experiments, this may not be the case as large dynamic range is usually required. The ATLAS LAr calorimeter preamplifier creates the electronically cooled termination through a ”super common base” input stage with an additional feedback loop [267]. An ASIC in IBM’s 8WL 130nm SiGe process is being designed for the LHC upgrade [268].

The LHCb Preshower chip is also based on the super common gate stage [264], however no cooled termination is used in this case because the chip is located in the PM base. The input current is amplified and converted to differential signalling in order to be integrated through a fully differential amplifier with capacitive feedback. Since no dead time is allowed and high quality delay lines can not be easily integrated, the solution adopted for the PS is to alternate every 25 ns between two integrators and to reset one integrator when the other one is active.

The proposed implementation of the ASIC for the calorimeter electronics upgrade is based on a combination of the two previous solutions. In the first place a ”super common base” input stage with additional current feedback creates the electronically cooled termination as shown in figure 89. Then two alternated switched signal paths are used to integrate and sample the input current with no dead time, as in the Preshower sub-detector.

A first prototype of input stage of the chip including preamplifier and switched integrators has been designed in Austriamicrosystems 0.35 um SiGe BiCMOS technology and submitted to the foundry in June 2010 (figure 90). There are a number of key issues to be tested, corresponding to some innovations with respect to the ASICs referred above. On the one hand the amplifier uses current feedback (figure 89, left) for several reasons:

- The output is a mirrored current.
- Additional I/O pads are needed for standard voltage feedback [269], but not for current feedback. This makes easier the implementation of a fully differential channel (with

Page: 120

Number: 1 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:16
3426(Ken)
Change 'consist on' to 'consist of' Done

Number: 2 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:19
3430(Ken)
Define acronym COTS Done

Number: 3 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:22
3431(Ken)
Change 'either with an ASIC either using COTS' to 'either with an ASIC or using COTS' Done

Number: 4 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:39:34
3439: (Ueli)
add "to" ??? as to "electronically... does not sound better. Keep as "electronically...

Number: 5 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:39:38
line 3440: (Ueli)
advance first quote, such that it reads "electronically
cooled termination"
Done

Number: 6 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:39:42
line 3442:
(Ueli) large enough -> as large as "large enough" modified to "so large as"

Number: 7 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:39:46
line 3443: (Ueli)
on -> for Done

Number: 8 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:25
3447(Ken)
You say the preshower chip has a 'super common gate stage' - should it be a 'super common base stage'?
Done

Number: 9 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:15:04
3462-3464
reasons for the innovations?
Is the current mirror output really an innovation or just a simple change?

Changes that improve the system but requires some tests. Innovation kept.
(innovation: second current feedback to set 50 ohm input impedance)

pseudo differential input), which may be critical in a FE board with large amount of digital circuitry.

- All nodes have low impedance, and hence less prone to pick up noise.
- ESD robustness is improved since no MOS transistor gate or bipolar base is connected to the input pad (series resistors are not allowed for noise reasons).

Current mirrors are based on HF active cascode circuits in order to be able to achieve the required linearity, noise and bandwidth.

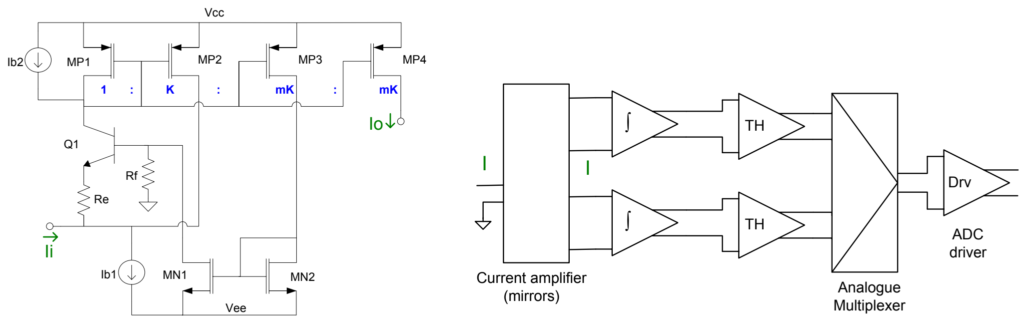

FIG. 89. Super common base amplifier with current feedback (left) and interleaved switched paths (right).

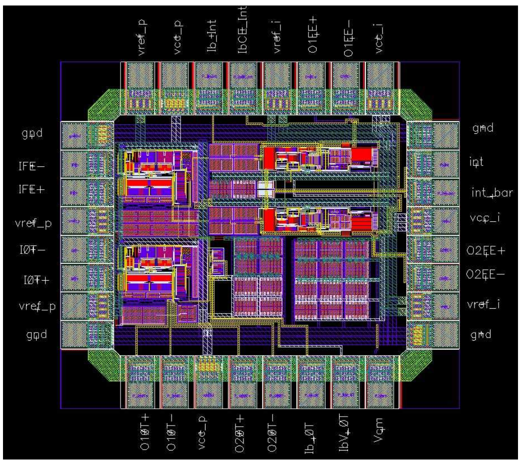

FIG. 90. First ASIC prototype of the input part of the channel.

2. Discrete component implementation

Provided that the clipping line in the base of the PMTs (figure 91, top left) is removed noise requirements can be relaxed and line termination can be performed with a resistor. With COTS it is possible to implement a similar scheme as the one already working in the

Page: 121

Number: 1 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:28

3472(Ken)

Define acronym HF

HF is removed from the sentence

current ECAL. However, there are two modifications compared to the present design: an input low noise amplifier is used, thus reducing the total noise and the clipping is performed on the electronic card after the input amplifier rather than in the PMT's base. The clipping principle is preserved but the scheme must be adapted because of different output impedances between the high PMT tube impedance and the low output impedance of an operational amplifier.

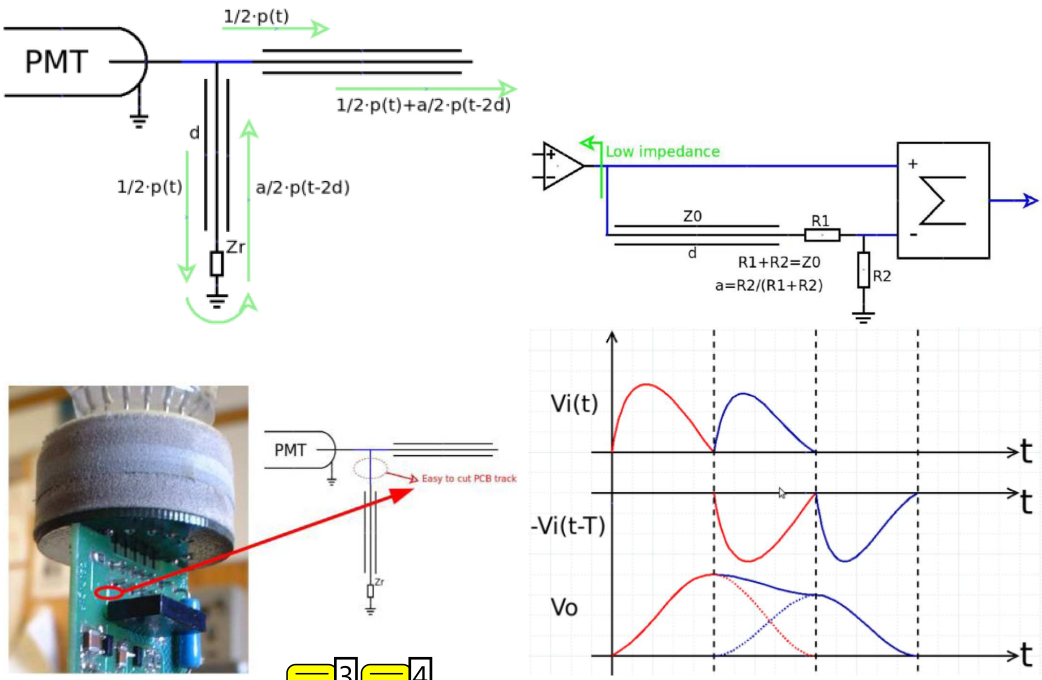

FIG. 91. Principles of Operation for COTS solution.

This option implies an intervention on the PMT's base, but it is reasonably easy to cut a track of the PCB (figure 91, bottom left). This reduces the contribution of the Cockcroft-Walton induced noise, in case it was coupled after the clipping, since the outgoing signal is greater.

The integration of the signal is done in an operational amplifier and 25ns later a "disintegration" is performed in such a way that at the sampling instant the result of the previous integration is cancelled (figure 91, right).

The circuit is made with differential operational amplifiers. This gives two polarities of the signal easing the implementation of the circuit described in figure 92.

This scheme helps reducing the pedestal and helps the subtraction algorithm. It also avoids switching currents in the analog power supplies.

A first prototype of the board is already built and the first measurements are being performed.

C. ECAL/HCAL electronics upgrade: the new front-end board

The present front end cards are used for 32 PMT signals. They are described in the note [266]. The card main components are

Page: 122

Number: 1 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:31

3483(Ken)
Insert comma after 'thus reducing the total noise'

Done

Number: 2 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:34

3485(Ken)
Maybe reword the sentence: "The clipping principle is preserved ..of an operational amplifier" to "The clipping principle is preserved but the scheme must be adapted because the operational amplifier has a much lower output impedance than the PMT tube."

Done

Number: 3 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:40:06

Figure 91: (Ueli)
Figure Caption: Please add some figure caption text, which explains the figure.

caption modified

Also: the way it is drawn, one would expect a negative signal at the third sampling point. Explain why this is irrelevant (the grade of irrelevance depends possibly on the channel occupancy)

The negative signals are opposite sign copies of the real signal. Permits to reset the integrator, but full integration is >=0.

Number: 4 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:40:00

Fig 91/92(Ueli)
I would suggest to combine Fig 91 and 92 into one single figure.

Done. 92 is removed.

Number: 5 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:40:09

line 3491: (Ueli)
greater -> larger

Done

Number: 6 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:40:15

line 3504 (Ueli)
are used for -> can handle up to

modified to "are connected to 32 PMT"

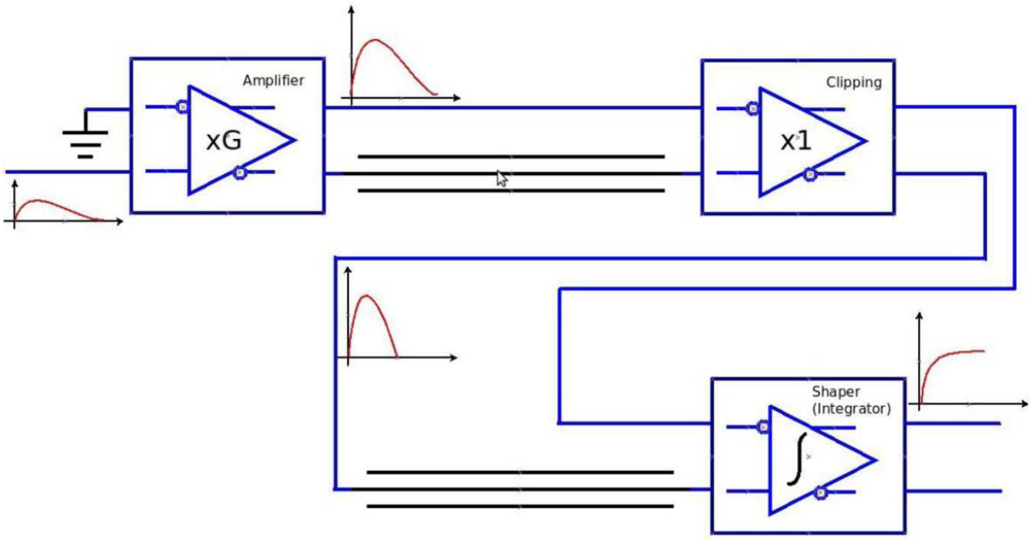

FIG. 92. Simplified Scheme of analogical signal treatment.

- 8 ASICs each with 4 amplifier integrator.
- 32 Analog devices ADC AD9042.
- 8 FEPGA: FPGA AX250 of ACTEL for signal processing (pedestal subtraction and gain correction in the trigger path). A latency buffer and a derandomiser are used for preparing the data to be read out after reception of a L0 trigger. Injection of test pattern instead of ADC data is foreseen. Each FPGA processes 4 channels.
- 1 TRIGPGA: FPGA AX500 of ACTEL which collects at 40 MHz data, processed in the FEPGAs, from the 32 cells of the card and from $8 + 4 + 1$ cells from neighbouring cards. It selects the highest transverse energy in a cluster of 2x2 cells and sends this information in the trigger path, through the crate backplane and through two Validation cards per crate.
- 1 SEQPGA: FPGA APA300 of ACTEL gathers the data readout from the 8 FEPGA serialises them and send them through the backplane to a controller board and then through a fibre to the TELL1 cards.
- 1 FPGA APA150 of ACTEL is used as an interface for ECS between the control board of the crate and the front end card to load constants in FPGA, load test patterns, perform spying of data, etc...

In the cards foreseen for the upgrade, the TRIGPGA functionality and therefore probably the device will be kept unchanged. This will allow to transmit the high E_t clusters which will be used as seeds for B candidate track reconstruction in the HLT1 trigger. This data will also be used in the interaction trigger (see Section ??).

The Glue PGA and its functionality for ECS will probably be kept, while the SEQPGA has no role in a 40MHz readout system.

Page: 123

Number: 1 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:41

3506(Ken)
'integrator' should be 'integrators'

Done

Number: 2 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:46

Lines 3506 - 3522:(Ken)
should we include so much detail on the existing Calo FE boards? Maybe this could be condensed.

Starting point to explain upgrade. Many similarities -> keep.

Number: 3 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:40:20

line 3516: (Ueli)
Validation -> validation

Done

Number: 4 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:40:28

line 3521: (Ueli)
add "(glue PGA)"

Done

Number: 5 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:52

3522 (Ken)
change 'etc..' to 'and other functions'

Done

Number: 6 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:40:31

line 3524:(Ueli)
"the device". Which device. Please rewrite this sentence.

Done : "Device" modified in "FPGA and its firmware"

Number: 7 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:40:34

3525:(Ueli)
remove "B candidate"

Done

Number: 8 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:40:41

3526: (Ueli)
section ??

External link : this was indicated to Sheldon.

Number: 9 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:55

3526 (Ken)
Section ???, you can refer to the sub-section called Interaction Trigger. It's declared in the electronics chapter as \subsection{Interaction Trigger}

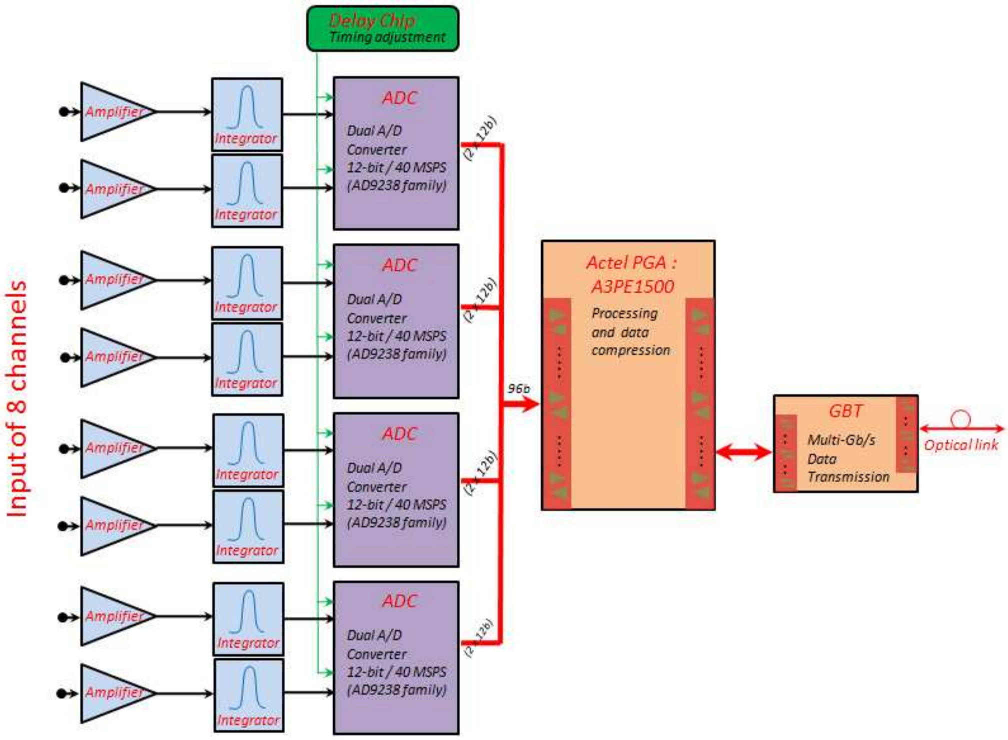

FIG. 93. One front-end block of 8 channels.

In the new cards the 32 channels will be grouped in 4 groups of 8 channels. In each of the four groups the PMT pulses are amplified and integrated as explained in section ECAL/HCAL electronics upgrade: analogue front end. They are then converted with 12bit 40MS/s ADC. The ADCs' data will be processed by a single reprogrammable Flash based FPGA of ACTEL. Preliminary studies show that the A3PE1500 has the necessary resources for an 8 channel group. The data will then be sent to the TELL40 boards (see Section VIII) by one GBT Fibre system per 8 channel group with a useful bandwidth of 3.2 Gbit/s or 80 bits every 25ns .

A schematic diagram of one such group is shown in figure VI C.

If one would send the 12 bits for each channel, 96 bits/25ns would be needed with in addition extra information like the BXID some fibre numbering, etc... One GBT would then not be enough. However in most cases the ADC data corresponds only to small pulses due to pedestal fluctuation (noise or pile-up). One possibility would be to send only data above a certain Zero-Suppress threshold; however this Zero-Suppression can cause non linearity when measuring calorimeter energy in a 3x3 cluster. In the present calorimeter system a compression of the ADC data is done in the TELL1 and a two dimensional Zero-Suppression is performed in the computer farm where all channels are available, by forcing the readout of all 8 cells around a central cluster seed which is above a certain threshold.

In the upgraded cards we propose to compress the ADC information of 8 channels in a similar way, in the A3PE1500 FPGA. For each event an 8bit pattern word describe if each ADC is of short data (5 bits transmitted) or long data (the full 12 bits are transmitted). Simulations have shown that using this scheme one GBT per 8 channels is sufficient to transmit the information even in the highest occupancy region of the calorimeter and at the

Page: 124

Number: 1 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:57:58

3530-3531(Ken)
Put the latex reference to the "section ECAL/HCAL electronics upgrade: analogue front end." Done

Number: 2 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:40:48

3531(4)?: (Ueli)
use correct section reference

Number: 3 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:58:01

3537(Ken)
This line should be at the end of the previous paragraph, I think? Done
Change figure reference.. There is no figure VIC !

Number: 4 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:40:53

remove line 3537 (Ueli)
and add a reference for figure 93 to line 3529.

Done

Number: 5 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:58:05

3538 (Ken)
Rewording '96 bits/25ns would be needed with in addition extra information like the BXID some fibre numbering, etc...'
'96 bits/25ns would be needed together with extra information such as the BXID and link identifier'

Done

Number: 6 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:40:58

line 3542 to 3546(Ueli)
are not needed here, I think.

Done

Number: 7 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:22:16

line 3547: remove "in a similar way"

Done

highest luminosity, if the event to event fluctuations are averaged over a large number of events, including events with empty proton bunches in the LHC. It has been verified that the multiplexer cells and memory blocks of the A3PE1500 are sufficient to implement such a scheme.

A prototype of an 8 channel slice of the front end card has been built for test of the analog and digital part in 2010 and 2011. It is shown in figure 94.

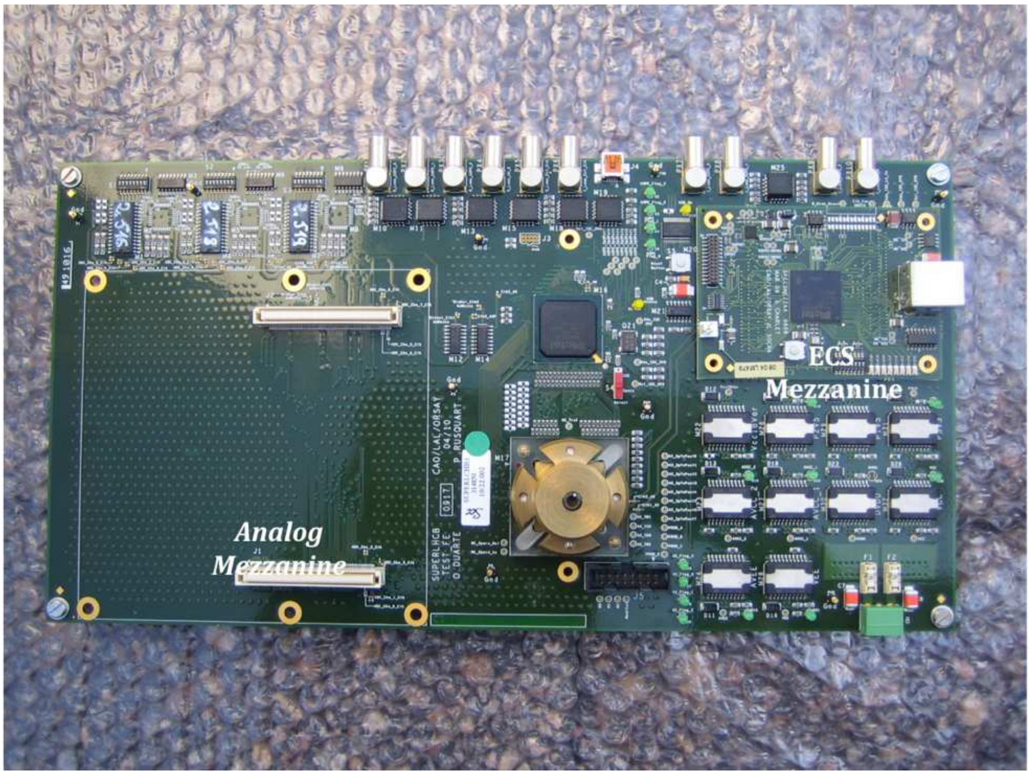

FIG. 94. Picture of the digital electronics first prototype.

D. Radiation issues

At high luminosity operation, the central cells of both ECAL and HCAL will receive significant radiation doses, and their performance will be deteriorated. As the resolution of HCAL central cells is not of critical importance for the detector operation, we consider hereafter only the ECAL performance degradation. The ECAL and HCAL front-end electronics is located above the detector. The dose expected at $\mathcal{L} = 10^{33}\text{cm}^{-2}.\text{s}^{-1}$ is of 2krad/year in the crate vicinity. The components will be radiation tested and chosen to cope with this level[264].

The predictions for the doses received by ECAL can be found in [264], [270]. After 1 year of operation at $\mathcal{L} = 10^{33}\text{cm}^{-2}.\text{s}^{-1}$, at the innermost cells it reaches ~ 1.2Mrad at the depth of $6 - 10$cm from the front face of the detector (electromagnetic shower maximum), and is ~ 0.6Mrad at its rear surface, where photomultipliers are installed (see figure 3.10 of [264]). Most of the dose ($\sim 75\%$) comes from hadrons.

Page: 125

Number: 1 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:58:08

3556(Ken)
'test' should be 'tests'

Done

Number: 2 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:58:13

3556-3557 (Ken)
(? line was 3456)
Why start a new paragraph here?

Because this does not only concern the digital but also the analog part. Keep.

Number: 3 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:58:16

3568(Ken)
Remove the dot in the luminosity units?

Done

From the point of view of radiation tolerance, the following parts of ECAL should be concerned:

- Optical elements of the calorimeter modules: loss of transparency and light yield of the scintillator tiles and WLS fibers;
- Photomultipliers: degradation of entrance window transparency;
- CW bases of photomultipliers: radiation damage of electronic parts.

The radiation damage of the optical elements of the modules, as well as that of the PMT entrance window, will lead to the degradation of the detector sensitivity and energy resolution (now $N_{PHE} \sim 3000$ph.el./GeV and $\sigma(E)/E = 10\%/\sqrt{E(\mathrm{GeV})} \oplus 0.8$, [271], [272]).

In case of degradation below certain limit, the innermost modules can be replaced: such possibility is implemented in the mechanical design of ECAL [264].

The radiation damage of the CW bases leads to incorrect (and, in general, unstable) HV values at PMTs.

1. Outcome of the previous tests

Module optics

The radiation resistance of the LHCb ECAL modules was studied during the R&D phase of the project[271]. The most important test was carried out at LIL (LEP Injector Linac) in 2002.

Two modules were irradiated with 500 MeV electron beam up to $\sim$ 5Mrad dose at shower maximum, which, according to the simulation, corresponds to 4 years of operation at $\mathcal{L} = 10^{33}\mathrm{cm}^{-2}.\mathrm{s}^{-1}$. Then the light yield and transparency of scintillator tiles and WLS fibres were determined by means of radioactive source scan. The measurements were performed several times from 7 to 2000 hours after the irradiation; a significant annealing effect was observed.

The values taken after 2000 h annealing were used as an input to the simulation of response to electromagnetic showers obtained with GEANT4. For the calculation of the light yield at intermediate doses, the exponential interpolation was used. The results are shown in figure 3.12 of [264]. One can see that at 5Mrad the predicted degradation is such that the light yield becomes 40% of that before irradiation. The degradation of the resolution consists mainly in an increase of the constant term, showing approximately a linear dependence on the dose. At 5 Mrad the constant term becomes $\sim$ 3% (0.8% before irradiation), which is at the margin of acceptability for the LHCb operation.

There are 32 spare modules of the inner type, which is, according to these results, enough for the replacement of the most irradiated modules, if it will be found necessary.

PMT entrance window and CW bases

The HAMAMATSU R7899-20 PMTs used in the LHCb ECAL are specially designed to work in high radiation background and their entrance window is made of special material. The CW generator circuit is also radiation tolerant: it is designed such that it is

Page: 126

Number: 1 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:58:18

3573(Ken)
Maybe 'considered' is better than 'concerned'?

Done

Number: 2 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:58:22

3575(Ken)
Define WLS

Done

Number: 3 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:58:24

3581(Ken)
'below certain limit' should be 'below a certain limit'
'such possibility' should be 'such a possibility'

Done

Number: 4 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:41:10

3581--3582 (Ueli)
Please rewrite. Which limit?

Depends on physics goals, rapidity of the degradation, effect on the reconstruction/selection,... Cannot decide now

Number: 5 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:58:27

3592(Ken)
Remove the dot in the luminosity units?

Done

Number: 6 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:58:30

3593(Ken)
Should be 'of a radioactive source scan'

Done

Number: 7 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:41:16

line 3602: (Ueli)
Why is 3% for the constant error term the limit, that can be accepted.

Reference to any "acceptable limit" has been removed.

not sensitive to the characteristics of its active elements, and remains operational even with significantly damaged components. In addition, the components with lower degradation rate were specially selected[273].

In order to measure the radiation tolerance of photomultipliers and CW bases, the irradiation tests were conducted at IHEP (Protvino) in 2010. The samples were installed behind 22cm thick steel converter and irradiated by the 50GeV proton beam of the IHEP U-70 accelerator up to the doses of 1-2Mrad, depending on the sample position. The duration of the test was 3 days; the parameters of the samples were then measured in several days after the end of the irradiation, without long annealing period. These results can be considered only as a lower limit for the radiation tolerance.

During the test, the HAMAMATSU PMT sample received $\sim$ 1.9Mrad (3 years of work at $\mathcal{L} = 10^{33}\text{cm}^{-2}.\text{s}^{-1}$); then, after 11 days, its window transmittance was measured with a spectrophotometer, and compared to the window of a non-irradiated sample. In the wavelength range from 500 to 550nm the loss of transmittance did not exceed 5%. The conclusion is therefore that the radiation tolerance of the PMT entrance window is sufficient to work during 4 years at $\mathcal{L} = 10^{33}\text{cm}^{-2}.\text{s}^{-1}$.

To study the radiation hardness of CW bases, three samples were installed at the beam and powered up. The output voltage (initially $\sim$ 950V) was monitored during the tests. The failure occurred at doses between 1.4 and 1.7 Mrad. Our conclusion is that the CW bases of photomultipliers are radiation tolerant at least till the dose of 1 Mrad, which is sufficient even for the innermost cells to survive during 1 year at $\mathcal{L} = 10^{33}\text{cm}^{-2}.\text{s}^{-1}$. The replacement of CW bases can be performed during annual shutdown periods; our estimate is that $\sim$ 500 spare CW bases will be required to ensure 4 years of operation.

2. *Already planned new tests*

The results on the radiation tolerance of the ECAL modules can be considered accurate to not better than ±50%. First, the tested optical components are not of exactly the same type as the ones finally used in the ECAL construction. Second, the irradiation was performed in the electron beam, while in real conditions it will be mostly hadronic; this may imply different degree of damage and different depth of annealing. Third, the final result on the module radiation hardness was obtained by simulations and not by direct tests, which can be another source of inaccuracy.

Practically, it translates into the uncertainty in module replacement frequency and total number of spares needed.

Taking into account all the facts mentioned above, it was decided to perform a new series of tests, irradiating spare ECAL modules in the hadron beam. Two ECAL modules of inner type were placed for irradiation into the LHC tunnel. The position (near the LHCb interaction point, at a distance of $\sim$ 4m along the Beam 2 direction, and at 15cm from the beam line) is chosen such that the dose received by the test modules during the LHC operation will be $\sim$ 10 times more than that for the innermost modules of ECAL. It is therefore expected that by the end of 2011 the test modules will get a dose corresponding to approximately 1 year at $\mathcal{L} = 10^{33}\text{cm}^{-2}.\text{s}^{-1}$. The decision will be taken after measurement of characteristics of the test modules, which will take place in 2012 at the SPS electron beam. At this point, there is still enough time to produce extra spare modules if it is found necessary.

Page: 127

Number: 1 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:58:33

3614(Ken)
Should be 'a 22cm thick' Done

Number: 2 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:58:37

3617(Ken)
Should be 'without a long annealing period' Done

Number: 3 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:41:21

line 3619 (Ueli)
(3 years of work at L = 1033cm2:s• • 1); Done
what does this mean? May be 3 years of operation?
and then line 3624 it says 4 years. Why?
In view of the 10^7 second discussion it would be probably more adequate
to talk about integrated lumi

Correct. Luminosity effects have been scaled to 5fb^-1 in the text.

Number: 4 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:41:34

line 3626: (Ueli)
CW generator failed at 1.4 to 1.7 Mrad. Was the voltage
stable before the failure?

Yes. Text modified.

Number: 5 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:41:43

3632 (Ueli)
2. Already planned new tests
replace by "Planned additional tests"

Number: 6 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:58:40

3632(Ken)
Maybe reword to 'Future tests'?

Done

Number: 7 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:58:43

3633(Ken)
I'm not sure you can say that the accuracy is +- 50%...... especially if the final optical components are not the same as those used in the radiation tests...
How about re-wording to: Done
'Following these initial tests, there remained some uncertainty on the radiation tolerance of the ECAL modules for the following reasons.'

Number: 8 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:41:46

line 3637 (Ueli)
"final result on the module radiation hardness was obtained by
simulations and not by direct test"
I am confused. So far beam tests were described, no simulations were
mentioned in the text. Text was not clear. Rewriting.

Number: 9 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:41:51

Text modified. SPS electron -> a SPS electron...

E. Pile-Up effect

The luminosity increase foreseen for the LHCb upgrade will lead to a large average number of interactions per crossing and therefore to an increase of the event multiplicity. This may affect the electromagnetic calorimeter (ECAL) energy and position resolutions by shifting on average the energy measurements and smearing the reconstructed energy and position of the clusters. This has to be looked at in order to know if the calorimeter system may cope with the luminosity planned for the phase 1 of the upgrade and reaching $10^{33}\mathrm{cm}^{-2}.\mathrm{s}^{-1}$.

Several methods have been used to estimate the effect and the one presented here relies on real data recorded with the calorimeter system at 3.5TeV. The energy is lower than what is expected for the upgrade but the estimation is based on real data and on that aspect it is more realistic than estimations from simulations.

1. Noise estimation method:

The method consists in storing the signal seen by the 6010 cells of the ECAL for a large minimum-bias data sample and before zero-suppression. This is possible as the LHCb electronics and acquisition only perform a compression of the data without loss of information, the zero-suppression being done at the reconstruction level. Using the raw data that are presently available, the reconstruction is run again after relaxing the zero-suppression threshold. To generate a high luminosity event, several minimum-bias events are piled-up by adding the ADC counts measured for each cell of the calorimeter.

The number of events to add depends on the LHC bunch structure and a Poisson law giving the number of interactions with respect to the luminosity. Two quantities are finally extracted per cell: the average number of ADC counts seen that is a measurement of the transverse energy (the photo-multipliers gains are adjusted with a $\sin(\theta)$ law in order to provide at the trigger level an E_t measurement) and the RMS of the fluctuations of this signal. The ECAL cells are such that a typical electromagnetic shower is contained in a cluster made of 3x3 cells. The same quantities as previously mentioned are also extracted for such clusters.

2. Results

Figure 95 shows the results at the maximum luminosity expected for the first phase of the upgrade, $10^{33}\mathrm{cm}^{-2}.\mathrm{s}^{-1}$. The electromagnetic calorimeter energy resolution may be expressed by

$$\frac{\sigma(E)}{E} = \frac{10\%}{\sqrt{E(\mathrm{GeV})}} \oplus 1.5\% \oplus \frac{0.0025 \times \mathrm{RMS}}{E\theta}(\mathrm{Pile-up}) \oplus \frac{0.01}{\mathrm{E}\theta}(\mathrm{Noise}) \qquad (8)$$

where the pile-up and electronics noise contributions are given. Notice that the ADC count being in E_t those contributions depend on the angle of the cell with respect to the beam axis. The extra energy measured can on average be removed, but the resolution is degraded according to the RMS of the pile-up contribution. Table VII lists the numerators to the pile-up contribution to the ECAL resolution for luminosities ranging from 2×10^{32} up to $2 \times 10^{33}\mathrm{cm}^{-2}.\mathrm{s}^{-1}$ and averaged over the calorimeter cells.

Page: 128

Number: 1 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:41:56

3658 (Ueli)

...........This has to be looked at in order to know if the calorimeter system may cope

3659 with the luminosity planned for the phase 1 of the upgrade and reaching 1033cm• • 2:s1.

Remove this sentence.

Done

Number: 2 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:41:59

line 3662:(Ueli)

give a quantitative estimation of the effect of the energy change

Given in a new foot note.

Number: 3 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:42:02

line 3672-3673:(Ueli)

Please reformulate.

Done

Number: 4 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:42:06

line 3683. (Ueli)

Constant term is 1.5%, was 0.8% in line 3580. What is correct?

Formula is inconsistent with text: Text has sin(\theta), formula has \theta

0.8% : from test beam - single module

1.5% : what is expected from the Calo

Text modified to be clearer

sin(th) ~ th , but formula modified nevertheless.

Number: 5 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:42:10

line 3684 (Ueli)

"noise contributions are given". Where? Can't find numbers on this

Noise is expressed in the formula and correspond both to what is presently measured and what we expect for the upgrade.

The text is modified to make it clearer.

$\mathcal{L}(\text{cm}^{-2}.\text{s}^{-1})$	2×10^{32}	5×10^{32}	10^{33}	2×10^{33}
RMS	12	15	18	22
$0.0025 \times RMS$	0.030	0.038	0.045	0.055

TABLE VII. Average RMS of the pile-up contribution to the signal of the ECAL cell signal at different luminosities. The numerator of the contribution to the resolution is also given.

$\mathcal{L}(cm^{-2}.s^{-1})$	2×10^{32}		10^{33}	
Resolution	Total	Pile-up	Total	Pile-up
$B \to D^* K$	7.4%	4.7%	14.3%	13.1%
$B \to \phi\gamma$	2.3%	0.5%	2.7%	1.5%

TABLE VIII. Energy resolution for two types of photon reconstructions at low (400MeV, $B \to D^* K$) and high (3.5GeV, $B \to \phi\gamma$) E_t. The overall resolution and the pile-up contribution are given at the present nominal luminosity and at the expected one for the first phase of the upgrade.

The degradation on the resolution could also be viewed for two different photon reconstructions, at low and high E_t. The typical E_t for the channel $B \to D^* K$ is 400MeV and it is more 3.5GeV in the $B \to \phi\gamma$ decay. Table VIII shows the degradation of the energy resolution at an angle of 100mrad (the total angular acceptance covering the region $[30, 250]$mrad) and for luminosities of 2×10^{32} and $10^{33}\text{cm}^{-2}.\text{s}^{-1}$. As expected, the high E_t reconstruction does not suffer from the pile-up effect. At low E_t, it becomes the largest contribution to the resolution.

VII. THE MUON SYSTEM

A. Introduction

The muon system [274–276] is the most shielded sub-detector of LHCb and the primary component of particle flux is less dominant than in other subsystems. Nevertheless, aging of detectors, their rate capabilities, the long term reliability of present electronics and the performances of muon identification in a high rate environment are concerns for the system when operated with a luminosity of 10^{33} cm^{-2}s^{-1} . Muon station M1 will not be needed in the upgrade, as the improvement in the L0 muon momentum resolution will be performed by the tracking stations, and the very high rate expected will make it useless.

Most of the hits recorded by the muon chambers in the stations M2-M5 are produced by secondary particles coming from electromagnetic and hadronic showers and by the low energy neutron background. The actual values of these components, simulated in the LHCb MC with safety factors, can be studied in the first year of operation of the detector. Anyhow, the extrapolation of these values to a luminosity up to ten times higher has to be taken with caution, as the neutron background induced in the cavern will change due to the higher beam energy of 14 TeV.

Another key element for a successful running of the system in the years 2017-21 will be the availability of spare chambers and electronic components. In case of

Page: 129

Number: 1 Author: rlindner Subject: Sticky Note Date: 31/01/2011 09:58:53

3692(Ken)
Should be 'more than 3.5GeV'

Was bad english. Modified to "around 3.5GeV"

Number: 2 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:42:15

line 3693:(Ueli)
degradation is given at 100 mrad. How does it depend on the angle?
Also: add this probably relevant information to Table VIII capture.
Also: This seems to me a critical degradation of the performance. Can we really live with factor two worse resolution? Please give an argument why.

Because the Calo measurement is done in Pt, the effect depends on the angle, as seen from the formula and table VII.
Text has been modified to make it clearer and caption of table VIII has also been adapted.

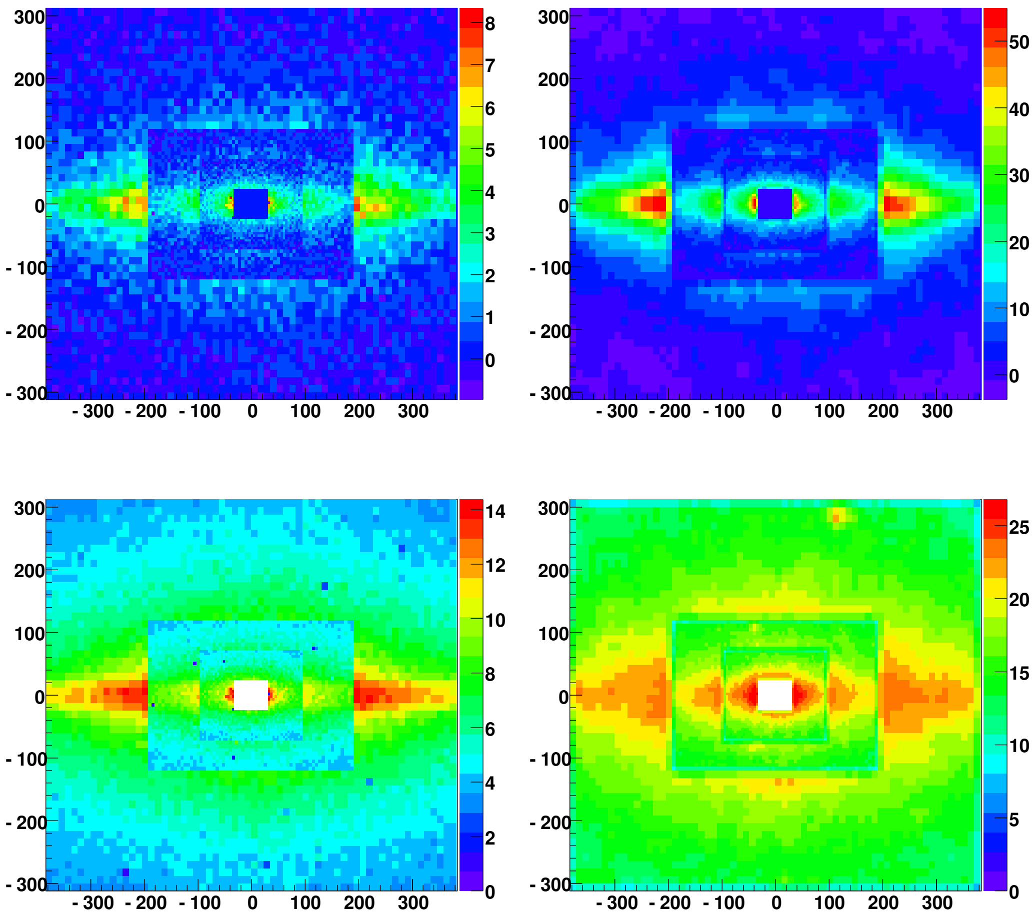

FIG. 95. 2D maps (x and y axis are in cm) of the average signal in ADC counts (top) and of its distribution RMS (bottom) for the 6010 cells of the ECAL. The maps are produced from a sample of 100000 generated events faking a luminosity of $10^{33}\text{cm}^{-2}.\text{s}^{-1}$. The left maps show the average signal and RMS per cell, the right ones represent the same quantities for 3x3 clusters, the position of the cluster on the map being the one of the central cell of the cluster.

B. The Muon System at High Luminosity

1. Particle flux and effects on the detectors

The particle rates in the muon system are estimated on the basis of a full GEANT simulation [277] of proton proton interactions at the nominal LHC energy of 14 TeV and at the nominal LHCb luminosity of $2 \cdot 10^{32}$ $\text{cm}^{-2}\text{s}^{-1}$. The simulation uses a detailed description of the LHCb detector and the cavern hosting it. Great attention has been paid to the choice of the low energy physics processes included in the simulation, since a large fraction of particles crossing the muon detector have very low energy. The kinetic energy thresholds below which the particle tracking is

Number: 1 Author: rlindner Subject: Sticky Note Date: 31/01/2011 10:42:21

Fig 95: (Ueli)
figure caption: Please give some indication, what this means in terms of energy.

Measures the Pt fluctuations on the calorimeter surface. Caption modified to give the information.