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The Digital Hadron Calorimeter (DHC) Elements' Test.

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Abstract

The Calorimeter group at NICADD is designing a Digital Hadron Calorimeter (DHC) using scintillating material. A possible use for it is to be the Hadron Calorimeter for a Linear e+e- collider. For the design to be successful, it is necessary to have an accurate knowledge of the response of the scintillating elements (tiles) which will be used in such design. Thus, a raw of measurements and tests have been performed using several variations of the unitary cell. These are the core of this paper. More specifically, the tests results of small scintillating hexagonal shaped DHC calorimeter cells with wave length shifting fibers inserted into grooved channels and connected to light guide fibers are presented.

These tests use a Visible Light Photon Counter (VLPC) as photodetector, and preliminary results show that the number of detected photoelectrons generated by a minimum ionizing particle (MIP) passing through a 5 mm thick cell is more than 30 .

Other possible solutions are discussed in the paper.

Introduction

For a e^+e^- Linear Collider to fulfill its physics potential, final jet states will have to be extremely well measured. Many of the new quantum states of interest decay into gauge bosons or heavy quarks, which in turn, decay resulting predominantly into jet final states. Therefore, superior jet resolutions ($30\%/\sqrt{E}$) and missing energy measurements will be critical for the discovery and characterization of new physics as well as for precision tests of the Standard Model.

Today the most promising path to such unprecedented resolution appears to be the use of energy flow algorithms. These algorithms require calorimeters with fine lateral and longitudinal segmentation in order to efficiently associate cells with tracks. However, fine segmentation in a Hadron calorimeter poses a significant challenge in the form of complexity and costs associated with signal processing and data acquisition. Reducing the dynamic range of the readout is a potential solution. At the limit, a calorimeter with single-bit readout for each cell may be an attractive option. Such option, known as a 'digital' Hadron calorimeter (DHC) is been pursued at NICADD using cells as the one shown in Fig.1. In our design we have chosen a unit cell hexagonal in shape because of the three basic shapes that can be used to cover a plane, (triangular, rectangular and hexagonal), the hexagon has the minimum perimeter to area ratio. A minimization of this ratio reduces response variations due edge effects. The modularity afforded by the hexagonal cell provides high flexibility and minimum dead volume.

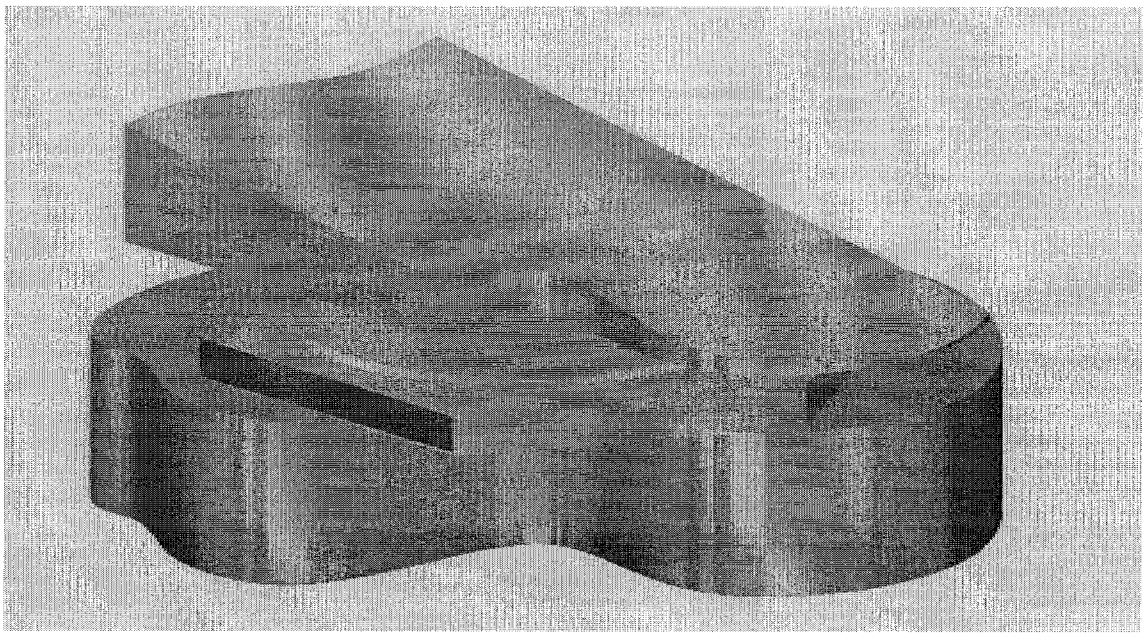


Fig.1

2. Experimental setup

A sketch of the experimental setup for measuring the cell response with cosmic rays is shown in Fig. 2.

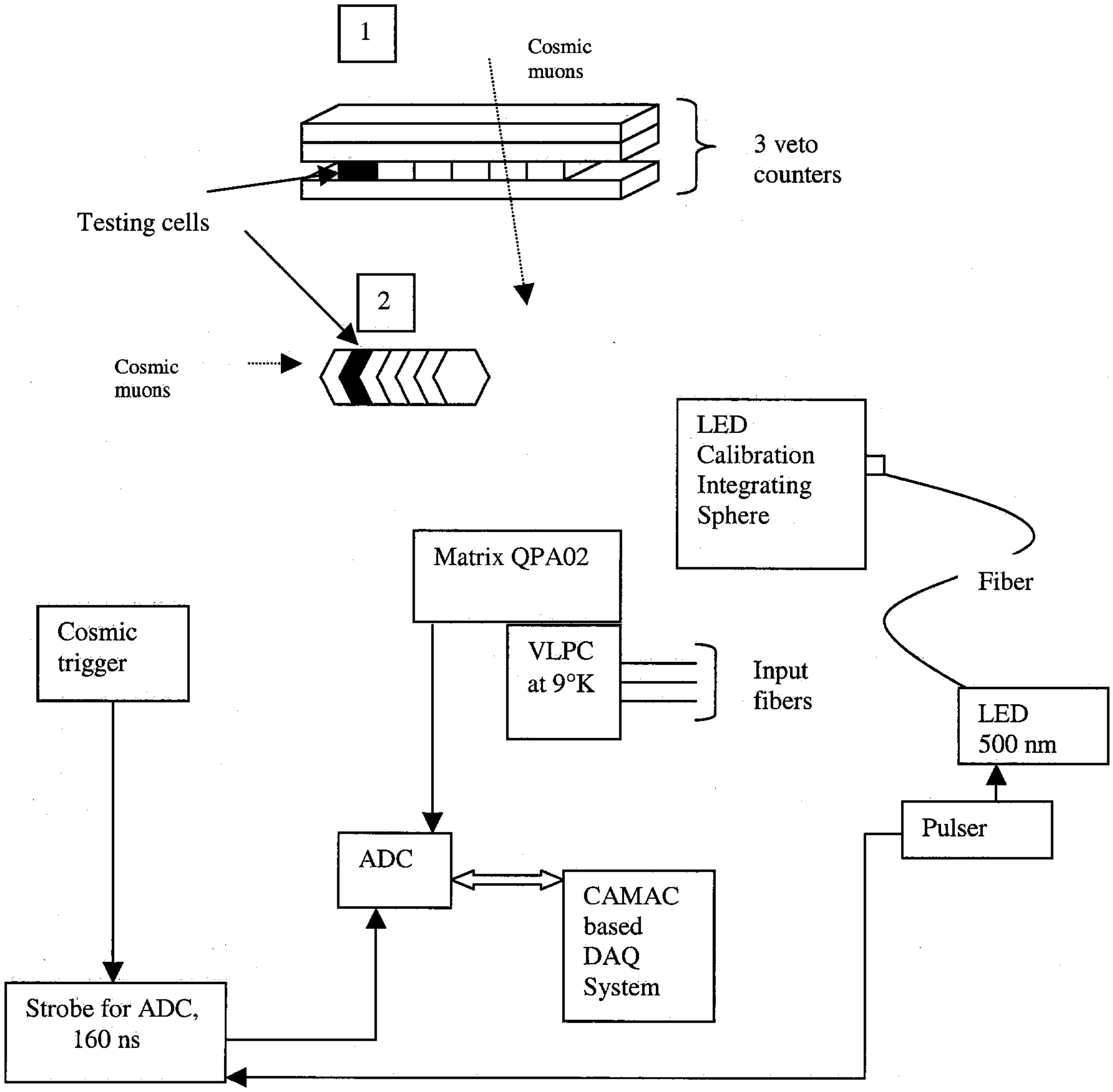

1
Cosmic muons
3 veto counters
Testing cells
2
Cosmic muons
LED Calibration Integrating Sphere
Matrix QPA02
Fiber
Cosmic trigger
VLPC at 9°K
Input fibers
LED 500 nm
Pulser
ADC
CAMAC based DAQ System
Strobe for ADC, 160 ns

FIG. 2

2.1 VLPC

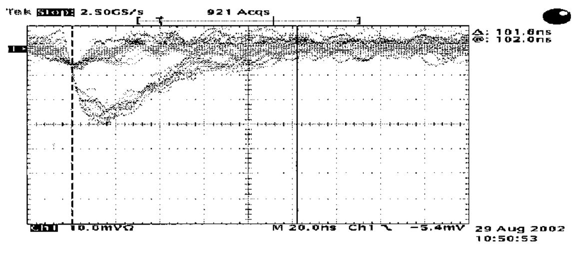
To test cell response to ionizing particles we used VLPCs, the most advanced phototransducers up today. With an internal gain of ~70,000 and quantum efficiency of 80 % for green light (~500 nm) we are able to work with any cell configuration and with a signal between a few and up to100 photons.

The photons produced in the hexagonal scintillator cell by the passage of an ionizing particle are collected by wave length shifter fiber (WLS), BCF 92. The length of the WLS fiber about 0.5 m. Then the light propagates through clear fiber of 2.5 m length and reaches the VLPC's. The operating principal of the VLPC is well known and we refer to publication [3]. In a VLPC's, photons are converted to the electron-holes pairs which are subject to avalanche multiplication. The optimum photon detection occurs at temperatures around 9 K. This temperature was fixed for our measurements with a precision of 0.1 %.

The VLPC cassete was positioned inside an Oxford 1204 continuous flow cryostat (CFC) that operates with continuous and controlled transfer of LHe from a separate storage vessel. The LHe flows through the heat exchanger of the CFC where the temperature is measured and heater controlled. The heat exchanger temperature can be maitained at any temperature above the boiling point of helium (4K). The cassete holds 168 channels VLPC in arrays of eight. Clear fiber pipes the light to the VLPCs within the cassete and 64 channel kapton flex circuits brings the electrical signals out from the cold-end of the cassete to the preamplifier card.

2.2 Preamplifier

A charge-sensitive preamplifier, the QPA02 [4], was used to read out the VLPCs and was mounted on room temperature end of the cassette. The preamplifier gain is measured to be 8 mV/fC. The nominal signal from the VLPC has a 10-15 ns rise time and 40 ns full



width at the base. The capacitance at the input is about 30 pF. A two photon signal from the VLPCs gives a 144 mV pulse into a 50 Ω load. The noise level of the current version of the preamplifier at 30 pF input capacitance is about 2000 electrons RMS. Typical noise pulses from the VLPC + preamplifier system are shown in Fig.3. These were obtained without optical signal input, ie, these are thermally generated pulses.

b Fig.3 Thermally generated pulses

One can clearly see a nice separation between the signal for a single electron and noise fluctuations from the detector and preamplifier system.

The QPA02 has a limited dynamic range of approximately 30 fC at the input before the output starts to saturate. We performed a calibration of the elecronics chain to determine a coefficient of nonlinearity at each point of the input signal. The result of the calibration is presented in Fig.4. For illustration, the scale of input signal for 1.6 P.E. and 25 P.E. are shown on the same plot.

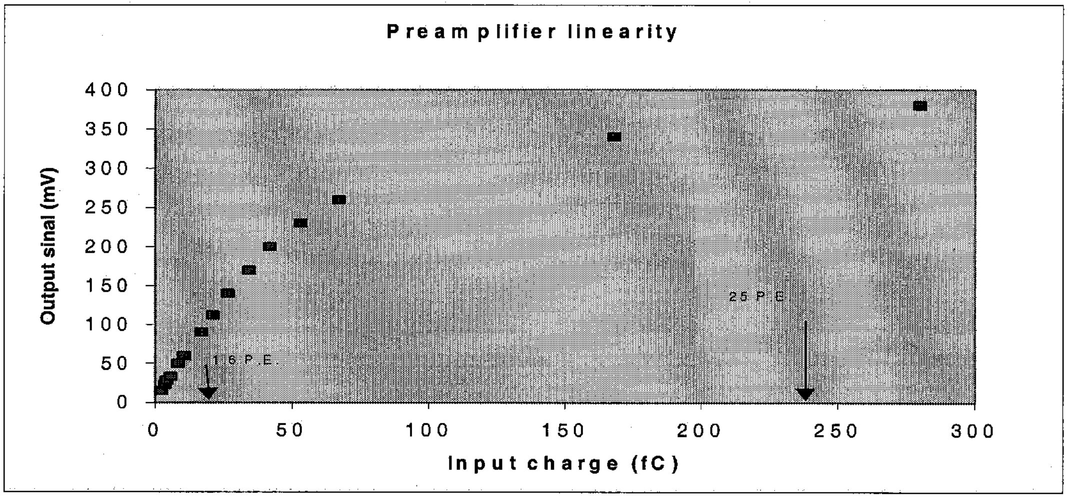


Fig.4 QPA02 Dynamic Range Calibration

The schematic for the VLPC + preamplifier is shown in Fig.5.

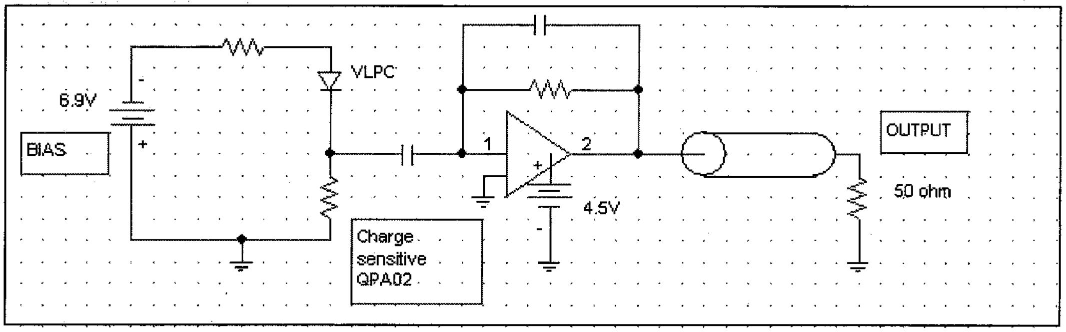


Fig.5 VLPC+QPA02 coupling

2.3 CAMAC based DAQ

For our measurements we used a 2249A Le Croy ADC, where the signals from the VLPC were integrated within a 160 ns gate that from the trigger system in the case of cosmic tests and from the trigger pulser in the case of the pulser-LED measurements. This model contains twelve ADCs in a single CAMAC module where,-each ADC has a resolution of ten bits and 0.1% resolution over its 1024-channel dynamic range. The input sensitivity of the ADC is 0.25 pC/channel and the full scale is 256 pC.

The data from the ADCs were read by an IBM/PC compatible computer and a DSP technologies CAMAC interface. The data were and analyzed within Microsoft Excel and Visual Basic.

2.4 Scintillating cells and WLS fibers

The hexagonal scintillating cells made of BC408 with 5 mm thickness. The WLS fibers were BSF 92 with a 0.9 mm diameter. The WLS fibers were glued with Bicron BC600 adhesive into grooves inside the cells. These cells were wrapped in Tyvek. Others were painted white, and others with sputter coated with aluminum. Table 1 lists the various groove types and coating technique combinations we examined.

Table 1

Al sputtered,vinyl and enamel painting	Tyvek wrapped	White acrylic painting
Straight groove	Straight groove	Sigma groove

The details of the scintillator and WLS connection are shown in Fig. 6. We used two types of grooves; a sigma groove and a straight groove shown in the figure.The connection between the WLS fiber and the clear fiber of the same diameter was performed using cylindical ferrules with a drilled through diameter of 0.91 mm. Both ends were polished with a diamond polisher and the Bicron optical grease was applied to the fiber contact faces.

Fig. 6

The grooves are a uniform 3 mm depth. The total area of the scintillator cell is 9 cm^2. In order to increase the light collection we used WLS fibers with mirrored ends. This increases the output signal by a factor of 1.5. The attenuation length of the WLS fiber was about 4 m, we can neglect the loss of light due to this factor.

2.5 LED calibration

The calibration of the VLPC gain was performed with 520 nm light from a LED. In order to distribute light homogeneously through all channels we used an integrating sphere.
An example of a multi-photoelectron distribution and the gain estimate is shown in Fig.7. The pedestal position is at channel 102, while the position of the first electron peak is at channel 124. The difference between the means of the first electron and the pedestal is 22 ADC counts. In the following we will call this as the gain of VLPC cell. After substracting the mean of pedestal, the average of the distribution divided by the gain gives the number of photoelectrons. The final average value was computed using the PAW environment and by fitting Gaussian peaks to the multi-photoelectron distribution.

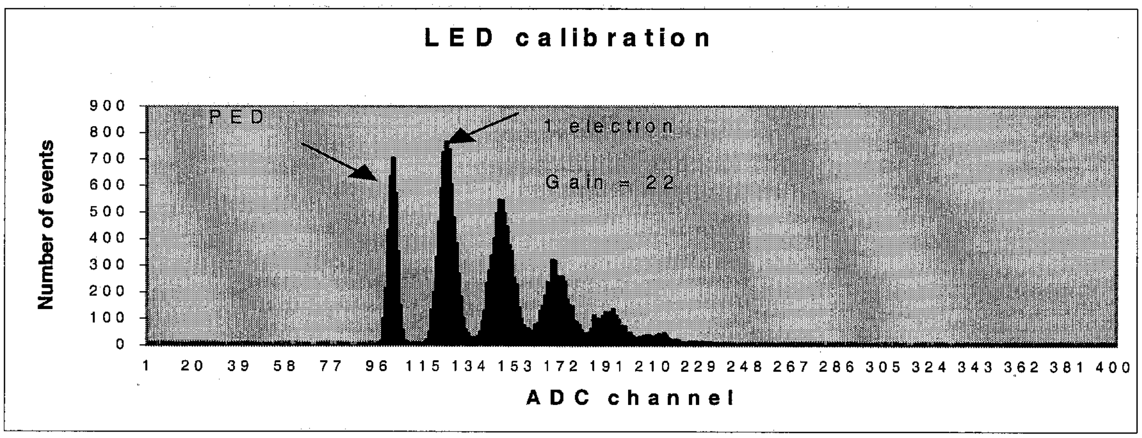


Fig.7 LED. Multi-photoelectron distribution

3.0 The results of the measurements

We used two types of triggers for our measurements:

1. Trigger scintillators significantly larger than the cell.

2. Trigger scintillator the same size as the cells.

Both cases are illustrated in Fig. 2
The trigger used in the first had additional gain calibration during the cosmic test. Due to the difference in the surface area between the trigger counters and the samples under test in this case there are many of "empty triggers" that permits observation of the single electron distribution. With this information, we can calculate the gain of the VLPC during the cosmic test run. The

spectrum of signals from mip obtained in the scintillator cells with Tyvek wrapping is shown in Fig.8. The gain is of a 22 ADC counts. The measured value of photo-electrons (PE) per MIP is 20.1. Correcting for the system nonlinearity with a factor of 1.9 from the data in Fig.4 we have a value of 38.2 photoelectrons.The result is shown in logarithmic scale. The LED calibration for the same channel is shown in Fig. 9.

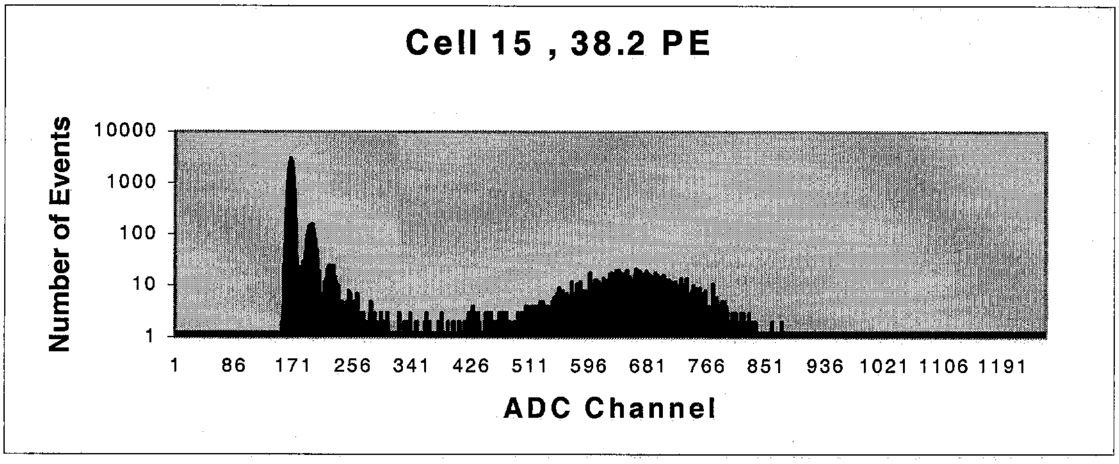


Fig.8 Cosmic test. Tyvek wrapped cell.

From the LED calibration the gain of VLPC is 23 ADC counts.

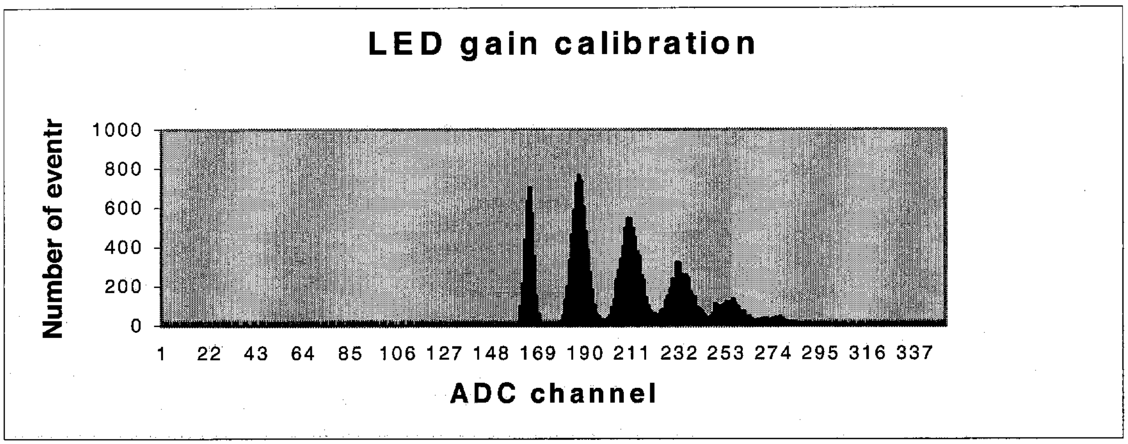


Fig.9 LED Calibration

The signal distribution with a trigger of the same size as the cells under test is shown in Fig. 10. The number of "0s" for this distribution is higher than expected from Poisson statistics and due to the slightly different size of trigger cells. Applying the same coefficient of nonlinearity we used above we find 43 PE/mip. The difference between these two measurements is attributed to fluctuations of the VLPC gain and reproducibility of the optical contact.

Tyvek wrapping is a well known and efficient reflector and should give one of the best light outputs. For the large number of channels that would exist in a DHC, white paint may serve as an alternative, more economical coating. We made measurements with different paints. Figure 11 shows the response for a cell painted with white enamel.

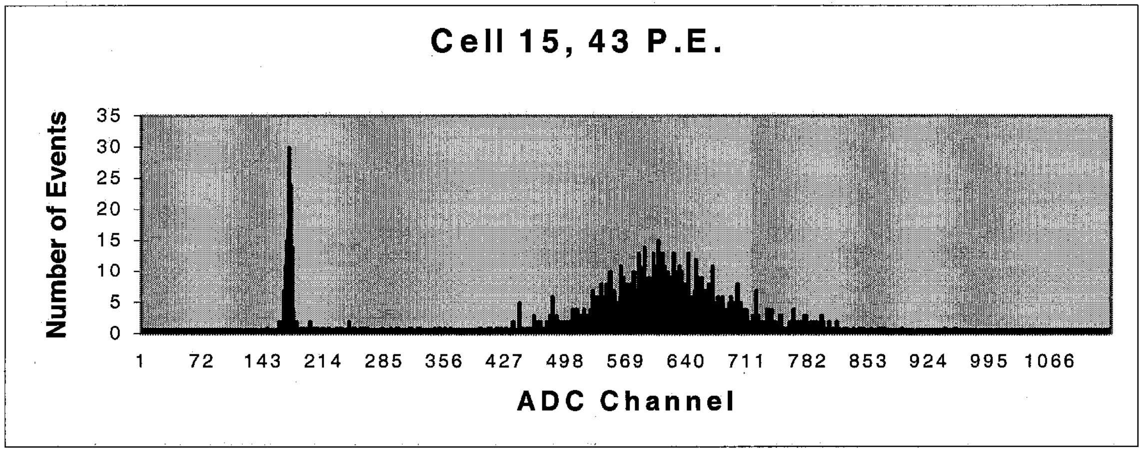


Fig.10 Cosmic test. The cell size trigger.

The trigger used is large scintillator paddles. The PE is 13.5.

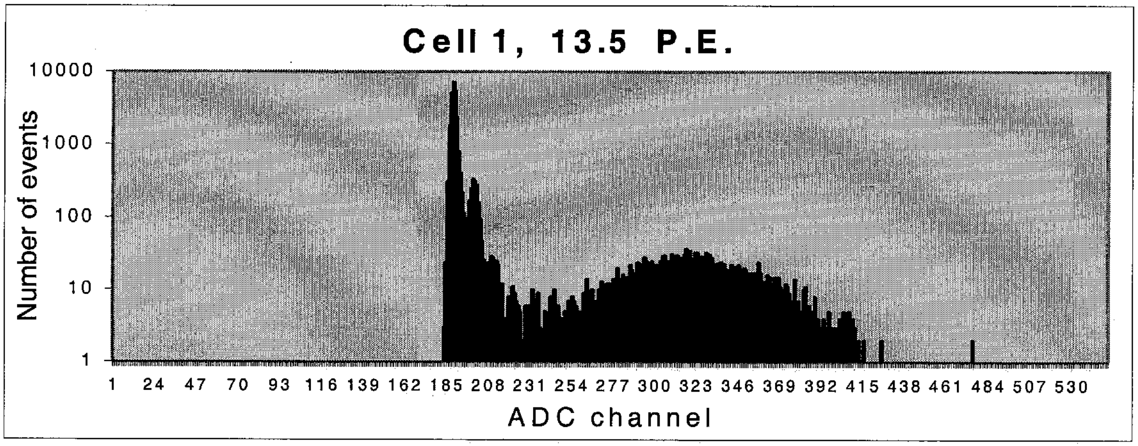


Fig.11 Cosmic test. The cell painted with white enamel.

A summary of measurements for different surface treatments and grooves profiles is presented in Table 2. The first variant of trigger was used to determine the number of PE/mip.

Table 2

Type of grooving	Type of wrapping/coating	Number of P.E. , Cosmic measurements. VLPC	Photocurrent, Sr ^{90}, PMT Hamam.R580-17, H.V.=1300 V.
Straight groove	Tyvek wrapped, Cell 15	38.0±1.9 P.E.	898±2 nA
Straight groove	Tyvek wrapped, Cell 5	34.7±1.7 P.E.	870±2 nA
Straight groove	White enamel painted, Cell 1	13.5±0.7 P.E.	425±2 nA
Straight groove	White vinyl painted, Cell 9	21.1±1.1 P.E.	474±2 nA
Sigma groove	White acrylic painted, Cell 213	35.3±1.7 P.E.	750±2 nA
Sigma groove	White acrylic painted, Cell 214	40.5±2.0 P.E.	770±2 nA
Straight groove	Al sputtered, Cell 1	10.8±0.5 P.E.	315±2 nA
Straight groove	Al sputtered, Cell 2	9.3±0.5 P.E.	220±2 nA

For the relative measurement of the light output we used the Hamamatsu R580-17 PMT and a radioactive source Sr^{90} positioned at the cell center.

Discussion

Plastic scintillator with a wavelength shifting fiber readout has became very popular due to the possibility of multichannel photosensor use. Our measurements show that VLPC's are a good candidate for a DHC and may be considered as a base line for a readout system if the price of the conversion chain (photosensor,preamplifier, and discriminator) can be made reasonably low. VLPC based readout chain costs ~ $50 per channel. There are three other candidates that could be considered for the DHC photosensor, taking into account cost considerations, the need for insensitivity to the magnetic field, the low light level, and other important parameters. We used references [5] and [6] to investigate feartures and disadvantages of other semiconductor phototransducer. The information is summarized in Table 3. All three candidates are immune to magnetic field.

Table 3

Parameter	APD (Hamamatsu)	MRS or Si PM	VLPC
Q.E. (500 nm)	~ 80 %	~ 15%	~ 80 %
Gain (Temperature)	100 (25° C) 500 (-50° C)	10^6 (25° C)	10^5 (9° K)
High Voltage (volts)	500 (at max gain)	30-60	7
Threshold sensitivity	12 photons	6 photons	1.2 photons
Dynamic range	Sufficient for DHC	Sufficient for DHC	Sufficient for DHC
Complexity	Low	Low	High (cryogenic system)
Cost	Can be $5-10/ch.	unknown	~ $50/ch.

Abbreviation:

APD-Avalanch Photodiode	Hamamatsu, Japan
MRS-Metal Resistive Semiconductor	CPTA, Russia
SiPM- Silicon Photomultiplier	Pulsar, Russia
VLPC-Visual Light Photon Counter	Rockwell International, USA

Conclusions

We performed absolute light output measurements of DHC prototype hexagonal cells using cosmic muons and with radioactive source. We found that sigma type grooving with acryllic painting has high light output and is comparable to the light yield obtained with tyvek wrapping. The measured yield of 35-40 PE/mip using VLPC censor is sufficient for 100 % hit efficiency when digital readout is applied. This should permit the use of less expensive fibers with a diameter of 0.5 mm or different low cost phototransducers. We are planning to continue our tests with APDs at low temperature and with MRS, SiPM sensors if they can be obtained at reasonable price.

Acknowledgments

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