Surface scan of the two meter BCAL module

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Abstract

The results from the surface scan of the polished ends of the two-meter BCAL Pb/Scintillating Fiber module are presented here. The measurements were performed carefully and with adequate statistics. Overall light transmission was found to be uniform, demonstrating the good quality of the prototype.

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1 Introduction

The two - meter prototype module for the Gluex Experiment's barrel calorimeter (BCAL) is a 17 cm × 12.5 cm × 200 cm block composed of lead sheets and scintillating fibers embedded in the lead. The fibers will guide the scintillating light emitted from traversing particles to the readout system, so it is desirable not to have significant changes in the transmission of the light by the different fibers. There is no need to test each fiber separately, because each read-out device will collect the light of several fibers. For this reason, the total area of the polished ends was divided into several small areas and their light output was compared, resulting in a surface map of the module. Knowing how the module was built, this information can be possibly used for improving the building technique of the next prototype.

2 The setup

An ^{241}Am (E = 5.5 MeV) source + 1 cm^3 NaI (Tl) was placed at the one end of the module. The diameter of the source was 1 cm, covering approximately 50 fibers. The produced scintillating light in the crystal propagates only along the fibers directly under it, thus allowing the examination of only this sector of the module that. The light is collected at the other end of the module using a light pipe (diameter of 4 cm) and guided into a PMT (type BURLE 8575). The light pipe and the PMT were adjusted so that the measured sector remained at their centers. If the measured signal at one sector is significantly different than the signal at another then the quality of the module may not be uniform. One explanation can be that the fibers were damaged in some way - broken or exposed to light. Another reason could be found in imperfections during the construction of the module.

The PMT was at first connected to an oscilloscope but initially the signal from the source could not be seen. Thinking that the light from the source was not intense enough to traverse the two-meter long fibers, a change in the source was considered. An LED gives more light but is difficult to control and its light-output is unstable. This is critical for the test which needs the same intensity of the light at each sector. In the end, the signal from ^{241}Am (NaI) was detected and this was some proof of the quality of the detector. The electronic setup is shown on Fig. 1.

The signal from the PMT had amplitude of about 50 mV and duration about 600 ns.

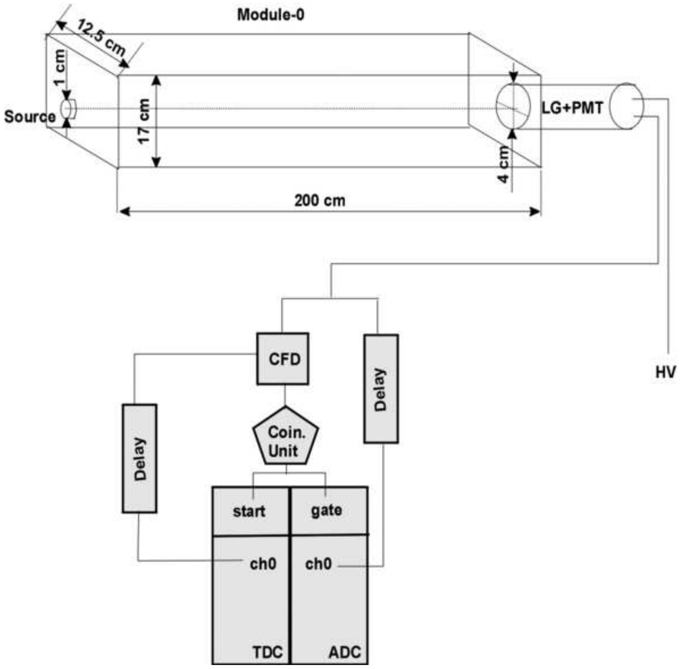


Figure 1: The electronics schematics diagram of the experimental setup. To generate the light an ^{241}Am source, embeded in a NaI (Tl) crystal, was used. The signal should fall at the center of the light guide placed on the other side of the module. The HV on the PMT was 1800 V.

The signal was split; one branch was fed to an ADC (LeCroy 2249W) and the other to a Constant Fraction Discriminator (Tennelec TC455). From the CFD, the signal went to a Coincidence unit (LeCroy 465) and then into a TDC (LeCroy 2228A). The CU produced a signal with duration of several hundred nanoseconds, which is the lenght we need for the ADC-gate. The TDC was measuring the self-timing signal that has only 2-3 channels in the TDC-spectrum, always the same ones (see Fig. 2). The self-timing peak was used only as reference that the electronics worked properly, and it remained constant for all the points measured.

After adjusting the ADC and TDC gates an ADC-spectrum was obtained using Midas $http://midas.triumf.ca$ and Paw++. In order to substract the noise and obtain only the signal from the source a second measurement was made, but this time without the source. The shape of the new ADC-spectrum was approximated with an exponential curve. The two spectra are shown in Fig. 3. It was evident now that the noise of the PMT was very well separated from the signal from the source and could be eliminated easily by either

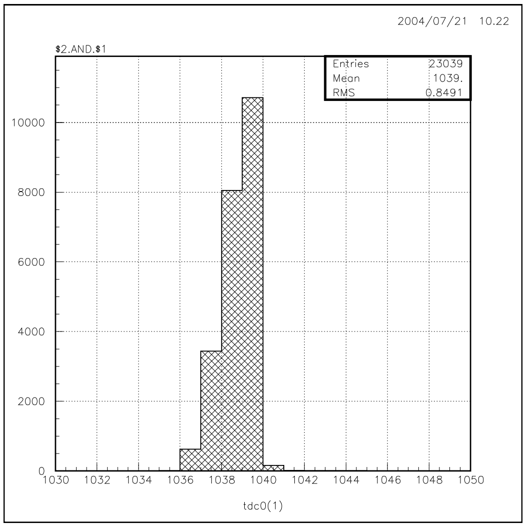


Figure 2: The time distributuion of the signal. The value of the mean channel is 1039 or using the conversion factor of 50 ps/channel ≈ 52ns. That was the time of the delay of the signal.

setting higher CFD threshold (hardware means), or numerically. The numerical method was chosen since the noise from the PMT was measured for all the points to ensure that there is no straimge behavior indicating nonuniformity in the module. This noise-exponent was extracted from the first ADC-spectrum. The resulting spectrum had a Gaussian shape. Since the noise component remained relatively constant the spectrum obtained with the source in place was fitted with an exponential curve (which gives the noise) and Gaussian (which gives the amplitude of the signal from the source). This double fitting was used later instead of the substraction method. (Fig 4).

The Gaussian mean and RMS were recorded. Comparing the means reveals how the signal changes, depending on the position of the source on the surface of the module and reveals the quality of the module at that sector.

Before starting the scan, the HV of the PMT was varied in order to choose the optimal value. HV values between 1700-2100 V were tested and the ADC-spectra compared. HV of 1800 V was chosen because it gave the highest mean value of the amplitude of the signal and the least spread. The threshold of the CFD was set on 8 mV because lower values did not result in an exponential form of the noise spectrum. After that, in order to test the entire area of the module's end, and for the scan to be complete in a reasonable time, the

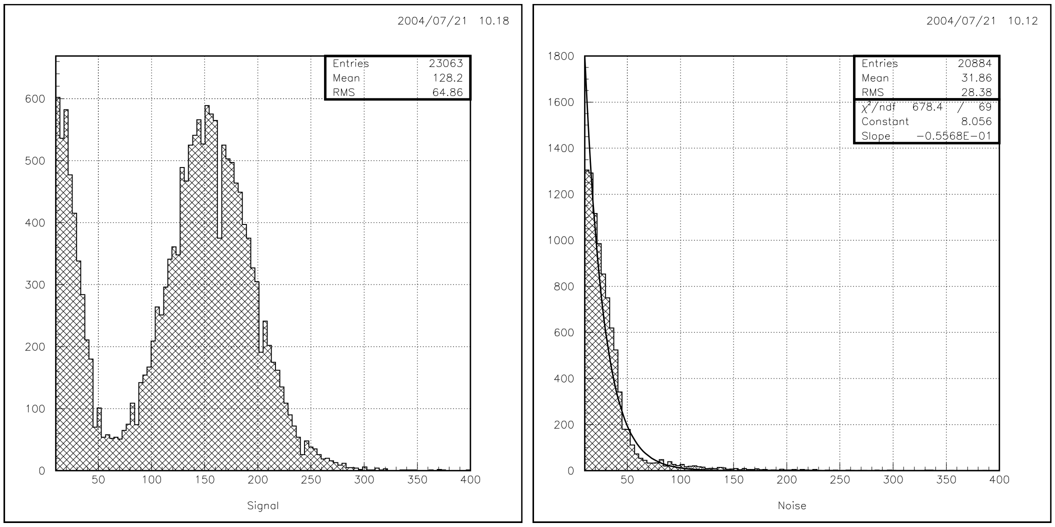


Figure 3: The left histogram ('Signal') shows the amplitude distribution obtained with the source at place, the right one ('Noise') - when the source is removed. The latter looks the same for all the sectors measured without big diferences in the value of the parameters of the exponential curve with which it is approximated.)

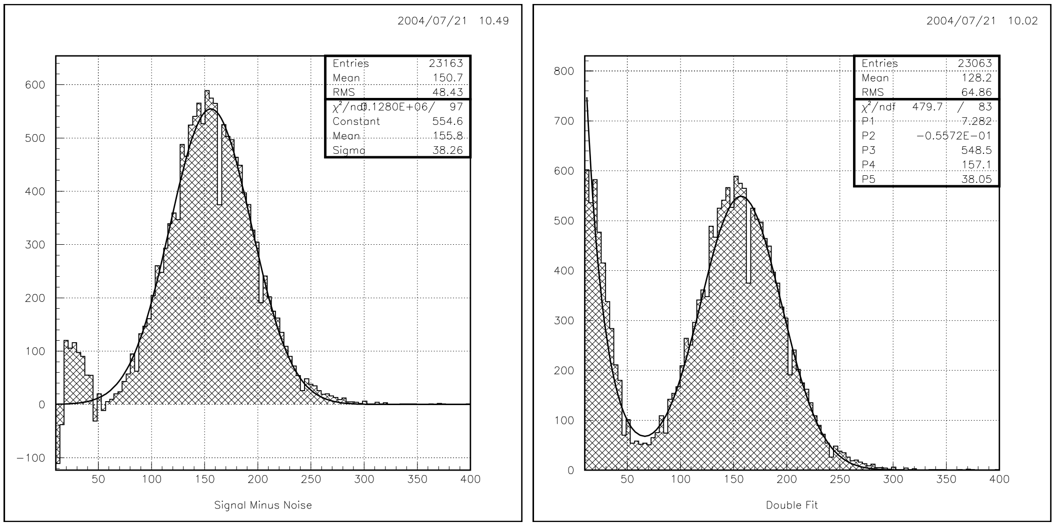
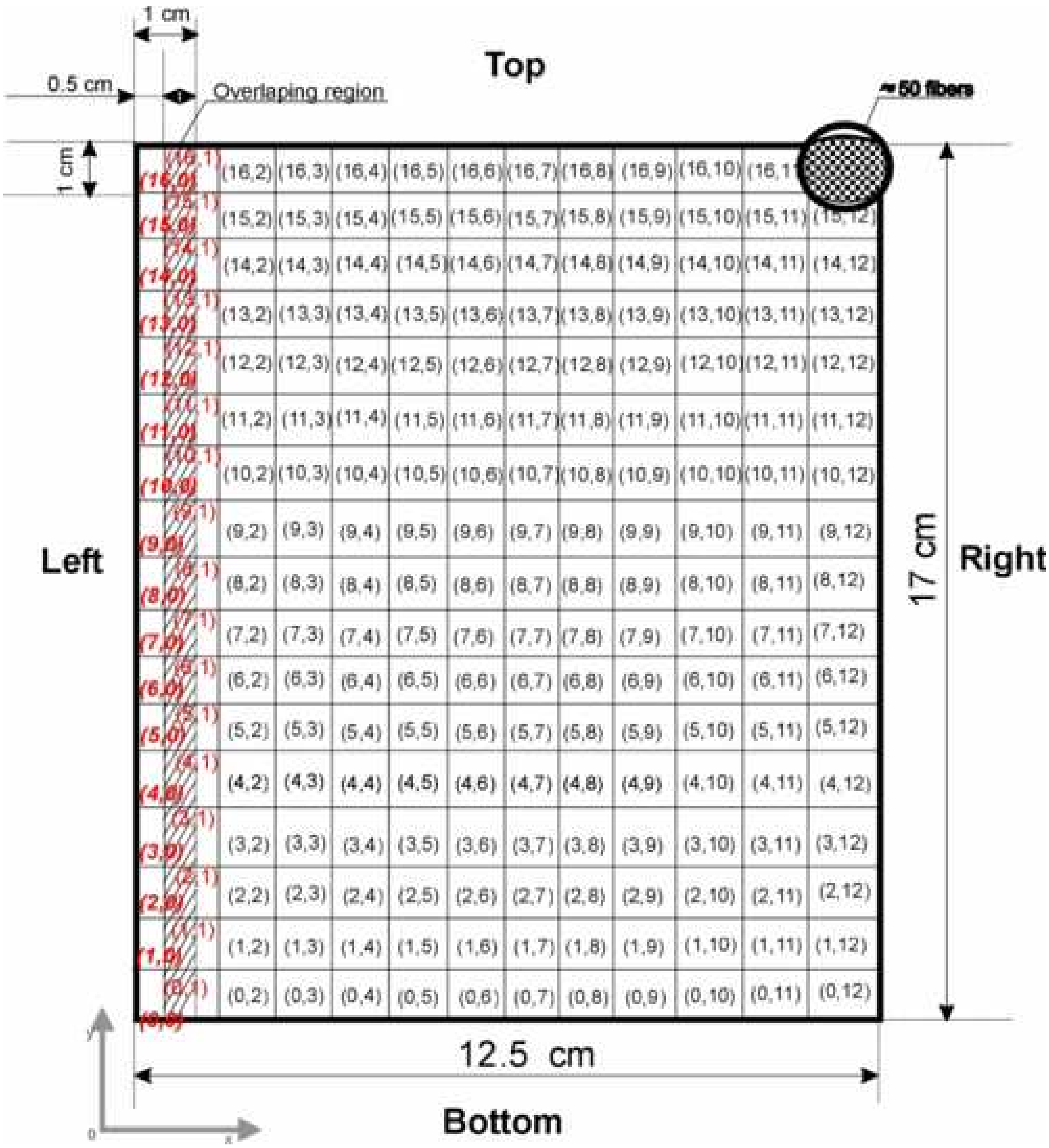


Figure 4: The two different ways to obtain the mean amplitude give the same value: Left - substracting two histograms: the noise-exponent and the signal and approximating the resulting histogram with Gaussian; Right - aproximating the amplitude spectrum with exponent (the noise) and Gaussian (the source). The double fitting was used in the remainder of the analysis to extract the signal.



(16,0)	(16,1)	(16,2)	(16,3)	(16,4)	(16,5)	(16,6)	(16,7)	(16,8)	(16,9)	(16,10)	(16,1	
(15,0)	(15,1)	(15,2)	(15,3)	(15,4)	(15,5)	(15,6)	(15,7)	(15,8)	(15,9)	(15,10)	(15,11)	(15,12)
(14,0)	(14,1)	(14,2)	(14,3)	(14,4)	(14,5)	(14,6)	(14,7)	(14,8)	(14,9)	(14,10)	(14,11)	(14,12)
(13,0)	(13,1)	(13,2)	(13,3)	(13,4)	(13,5)	(13,6)	(13,7)	(13,8)	(13,9)	(13,10)	(13,11)	(13,12)
(12,0)	(12,1)	(12,2)	(12,3)	(12,4)	(12,5)	(12,6)	(12,7)	(12,8)	(12,9)	(12,10)	(12,11)	(12,12)
(11,0)	(11,1)	(11,2)	(11,3)	(11,4)	(11,5)	(11,6)	(11,7)	(11,8)	(11,9)	(11,10)	(11,11)	(11,12)
(10,0)	(10,1)	(10,2)	(10,3)	(10,4)	(10,5)	(10,6)	(10,7)	(10,8)	(10,9)	(10,10)	(10,11)	(10,12)
(9,0)	(9,1)	(9,2)	(9,3)	(9,4)	(9,5)	(9,6)	(9,7)	(9,8)	(9,9)	(9,10)	(9,11)	(9,12)
(8,0)	(8,1)	(8,2)	(8,3)	(8,4)	(8,5)	(8,6)	(8,7)	(8,8)	(8,9)	(8,10)	(8,11)	(8,12)
(7,0)	(7,1)	(7,2)	(7,3)	(7,4)	(7,5)	(7,6)	(7,7)	(7,8)	(7,9)	(7,10)	(7,11)	(7,12)
(6,0)	(6,1)	(6,2)	(6,3)	(6,4)	(6,5)	(6,6)	(6,7)	(6,8)	(6,9)	(6,10)	(6,11)	(6,12)
(5,0)	(5,1)	(5,2)	(5,3)	(5,4)	(5,5)	(5,6)	(5,7)	(5,8)	(5,9)	(5,10)	(5,11)	(5,12)
(4,0)	(4,1)	(4,2)	(4,3)	(4,4)	(4,5)	(4,6)	(4,7)	(4,8)	(4,9)	(4,10)	(4,11)	(4,12)
(3,0)	(3,1)	(3,2)	(3,3)	(3,4)	(3,5)	(3,6)	(3,7)	(3,8)	(3,9)	(3,10)	(3,11)	(3,12)
(2,0)	(2,1)	(2,2)	(2,3)	(2,4)	(2,5)	(2,6)	(2,7)	(2,8)	(2,9)	(2,10)	(2,11)	(2,12)
(1,0)	(1,1)	(1,2)	(1,3)	(1,4)	(1,5)	(1,6)	(1,7)	(1,8)	(1,9)	(1,10)	(1,11)	(1,12)
(0,0)	(0,1)	(0,2)	(0,3)	(0,4)	(0,5)	(0,6)	(0,7)	(0,8)	(0,9)	(0,10)	(0,11)	(0,12)

Figure 5: The end of the module where the source was placed. The scanning started from the top left corner.

ends of the module were divided into 17 rows and 13 columns (see Fig. 5) forming a grid of small sectors of ≈ 1 cm^2, so that the source covered each sector almost entirely, without overlapping; only the zeroeth column overlapped with the first one by about 0.5 cm (see Fig. 5).

The source was moved from sector to sector. The PMT was also moved for each measurement to ensure that the light from the fibers went straight in the center of the PMT. At each point the ADC-spectrum of the noise was measured as well.

Results were very encouraging after the first row was taken. The differences in the signal within this row were less than 5% if the end points were excluded. The latter were not taken into account because they lay along the edges of the module where many broken fibers exist as a result of machining the module to a tapered shaped, leading to an artificially large decrease of the signal.

3 Estimating the error

To ensure that the data were reproducible, the same row was measured again the following day, but now only every other column. Comparing the means with those obtained the previous day it was found that the difference at the same spot did not exceed 6%, usually being $\approx$ 2% and sometimes even $\approx$ 0%.

In trying to estimate the error in the measurements more reliably initially four series of ten consecutive measurements of the signal at a single point were made during two - hour interval. The error evaluated was only $\approx$ 1%. Next, in order to simulate the different conditions arising while doing the scan, ten consecutive measurements were made at the same point but now by trying to emulate the different measuring conditions and even make them deliberately extreme by misplacing the source and PMT, leaving an air-gap between the PMT and the module, displacing the source such as to be positioned between two sectors, using a very small amount of optical grease and so on ... Now the error was estimated at $\approx$ 6%. The main sources of error were found to arise from:

- Too little optical grease. Several measurements were made using lots of optical grease and repeated almost without any grease. Even if the PMT appears to be firmly stuck to the module, the lack of optical grease resulted in decrease of the signal of $\approx$ 6%

every time.

- Not placing the source at exactly the same position. Displacing the source by 30% of the total area it covers, for example 0.2 cm up and 0.2 cm left resulted in change of the signal of the order of 5%.
- An air-gap between the PMT and the module. If the air-gap was too large the decrease in the signal could be as much as 15%.
- Measurements repeated on different days. No difference bigger than 6% was seen.

In other words, the measurements were carried with extreme care under these conditions. The source was centered very carefully on each section and the PMT was aligned accordingly. After that, a check for air-gap was performed. That was the tricky part, for it was difficult to see if there was an air-gap and at some points it was impossible to stick the PMT to the module because the sides appeared not to be perfectly even. Spreading lots of optical grease, enough to fill this air gap was the only solution, so after every 2-3 measurements optical grease was added on the PMT and on the source. Each day the last point of the scan from the previous day was repeated. Finally, many sector measurements were repeated several times on different days, especially for those points differing more than 6% from the main value of the signal, or where sharp changes or tendencies were discovered. No differences larger than 6% were found at the measurement of a single point, so this estimation of the error was right. All the graphs show error bars of 6%.

The measurements were performed row by row, sliding the source and the PMT from left to right and then backward, starting from the top to the bottom of the module. The scanning was performed over four days. Two more days were spent checking the data again. At first, ten random points were measured and the signal was compared to the old data. The difference did not exceed our error. After that, one row was measured: the source was moved from top to bottom of the module, to see if the data obtained will differ from the profile of the module revealed by the old data. There were no differences larger than the error. Finally, the source and the PMT were switched and again the same row was measured, this time from the bottom to top. The differences in the signal again did not exceed 6% (see Fig 6).

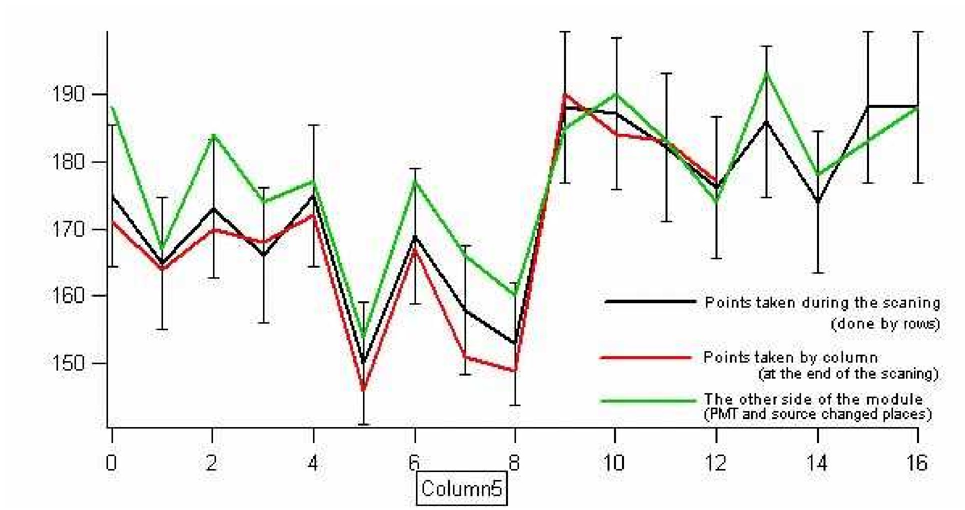


Figure 6: Cheking the reproducibility of the results: one day after the scan was completed column 5 was measured again (red line) and once again after switching the location of the source and the PMT (green line). The results agree very well with the data obtained during the scanning. The error bars show the estimated error of 6%

4 Results

The analysis of the data (more than 250 points) was made using the macro shown in Appendix A. The plots were made with IGOR. In Table 1 the Gaussian mean and Sigma are shown for all the points.

A surface plot of these data was made (see Fig.7), revealing the light - transmission profile of the module. A close look (top left corner) shows that the transmission of the light through the module is not perfectly uniform. There is higher (yellow) and lower (red) values of the signal. If we consider also the cross-section, showing the signal by columns (bottom left corner) and the view from above (bottom right corner) we see that there are entire rows where the signal decreases (the dark stripes at rows 11, 8, 4, 2). Also the upper part of the module shows a stronger signal. The change is sharp - it is clearly seen line at row 7. But all these differences are only a few percent of the signal. The mean amplitude is usually between 160 - 180 channels and the upper right corner reveals that the difference in the signal is not very large - the surface appears to be almost flat.

The data are also displayed row by row in Fig.8 and show that the diference in the signal from sector to sector almost never goes above 6%.

Row	*Column*	0	1	2	3	4	5	6	7	8	9	10	11	12
0	Mean	179	181	179	182	184	188	184	184	180	186	181	170	169
	σ	43.8	43.8	43.7	43.6	42.6	44.1	43.3	43.0	43.6	42.6	41.8	42.3	42.4
1	Mean	181	189	185	190	185	188	186	189	188	186	186	189	186
	σ	42.9	42.4	43.0	43.6	43.5	43.8	43.7	43.9	43.5	44.0	43.8	44.0	43.9
2	Mean	172	176	177	175	171	174	171	173	169	169	171	175	166
	σ	42.8	42.8	41.9	42.6	42.8	42.3	42.5	43.6	42.7	42.2	43.4	42.4	41.4
3	Mean	180	183	180	183	184	186	182	156	179	181	182	181	160
	σ	43.8	43.4	43.1	43.7	43.5	44.5	43.5	40.8	42.7	43.6	43.2	43.0	42.1
4	Mean	170	176	172	171	182	176	165	174	172	175	163	169	162
	σ	41.9	42.9	43.2	42.4	42.8	42.9	41.8	41.9	41.8	41.5	41.4	40.8	39.8
5	Mean	182	184	180	184	182	182	181	182	181	186	184	184	172
	σ	43.3	44.2	43.0	42.3	43.4	42.6	43.1	43.3	42.7	42.7	42.8	42.2	40.6
6	Mean	179	189	186	187	188	187	191	189	187	191	185	186	183
	σ	43.0	40.7	43.3	43.5	43.4	44.0	43.3	43.6	43.5	43.7	42.5	42.7	42.9
7	Mean	173	187	182	188	189	188	188	181	184	182	172	181	177
	σ	41.9	42.7	43.0	41.7	42.4	43.3	43.8	43.0	43.3	43.6	42.9	42.9	42.8
8	Mean	159	159	154	152	154	153	156	158	164	150	153	158	151
	σ	38.9	41.4	41.0	40.8	41.2	41.2	41.6	42.4	41.6	40.7	40.6	40.4	36.4
9	Mean	156	160	160	157	160	158	159	163	163	165	165	168	160
	σ	37.9	41.5	42.1	40.1	41.8	41.1	39.9	40.8	40.9	40.9	40.8	41.9	38.2
10	Mean	161	169	169	165	165	169	165	169	168	168	167	166	162
	σ	39.8	41.0	41.0	42.0	40.1	41.1	41.2	41.8	41.7	41.0	41.1	40.1	39.0
11	Mean	144	146	144	146	148	150	147	146	147	143	144	148	143
	σ	39.1	38.9	38.9	39.0	39.8	40.9	40.4	38.9	39.3	38.4	38.7	36.2	37.2
12	Mean	168	173	174	173	174	175	179	176	178	172	174	172	160
	σ	40.8	41.1	41.3	43.0	41.2	41.7	41.6	41.6	42.2	42.2	41.9	40.9	39.8
13	Mean	149	163	170	162	166	166	165	164	162	166	165	168	160
	σ	39.2	40.1	41.2	40.9	40.7	41.0	40.8	41.4	41.3	41.0	41.0	41.1	36.6
14	Mean	157	170	170	165	166	173	169	175	163	170	173	172	155
	σ	38.8	41.1	40.9	41.0	40.6	41.2	42.0	42.0	40.8	41.8	41.5	41.2	40.4
15	Mean	155	166	162	165	164	165	164	162	163	162	160	160	143
	σ	38.7	40.8	40.2	41.4	40.9	40.5	40.4	41.0	40.2	40.9	40.6	40.9	36.6
16	Mean	171	176	174	179	181	175	176	177	174	176	175	179	158
	σ	41.8	42.0	41.4	41.3	41.7	42.3	42.4	42.2	41.8	41.2	41.6	42.3	40.1

Table 1: The Gaussian mean and sigma of the energy distribution are shown here for all the points.

5 Conclusions

After considering the data the following conclusions were made:

- The error range in which the signal varies within a row is about 6% (which is the error). So, starting from left to right the signal is the same within the error, which is satisfactory. Taking into account the geometry of the future calorimeter (48 modules, side by side, in a hollow cylindrical configuration) a possible left-right dependence of the signal would cause big problems, because it will be almost impossible to take that into account in the readout system.

- The differences from row to row were larger. The largest (and sharpest) change in the signal is at row 11 - about 17% decrease from the average signal. There is also 11% decrease in row 8 and 2% decrease in rows 4 and 2. This can be explained considering

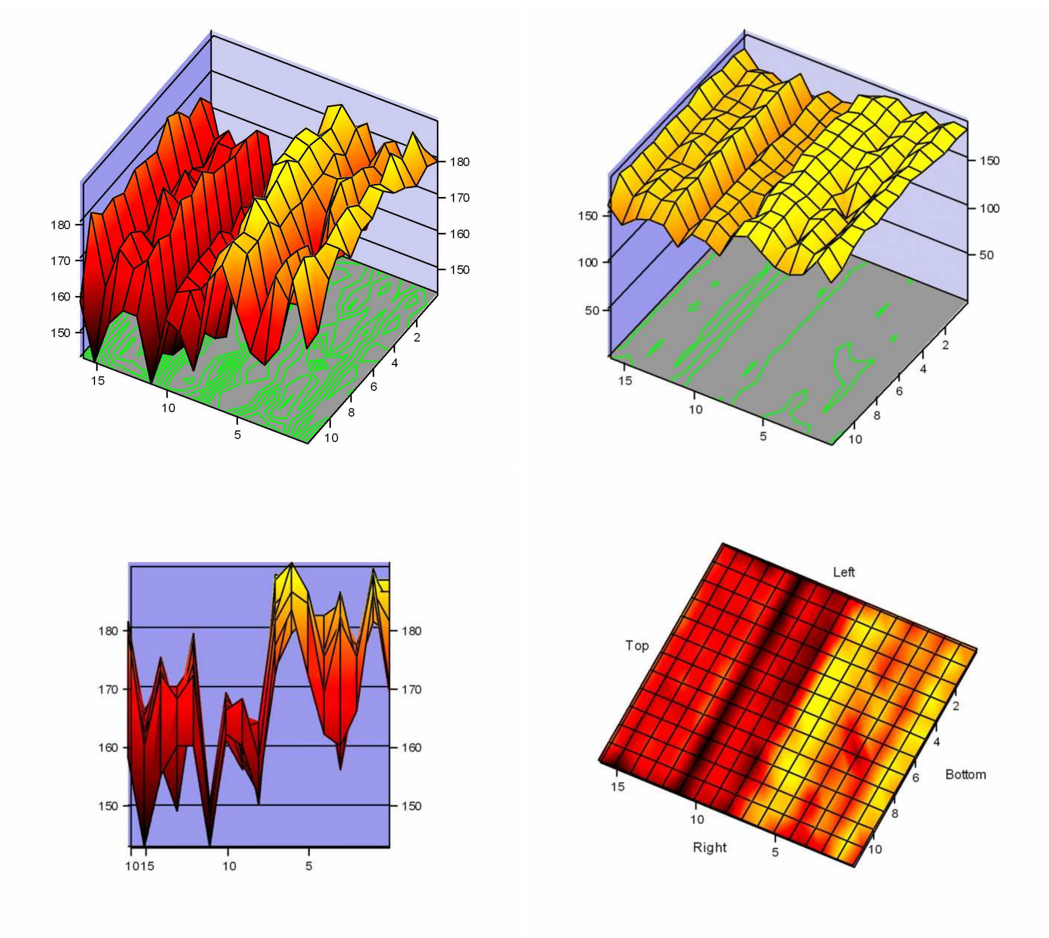


Figure 7: The surface of the module, different views

that the fibers in a row came from the same bundle (there is ≈ 97 fibers in a bundle), so that a row can be damaged as a whole.

- There is a tendency of having higher signal at the bottom than at the top of the module. The change is sharp, taking place at row 7. The signal from row 0 to 7 is higher and then it decreases with about 7% in the rows from 8 till 16. This behaviour is odd, because during the gluing we were getting more experienced going to the top of the module. A possible cause may be the fact that the upper fibers were exposed to light more, or that the two ends of module were not perfectlly even.

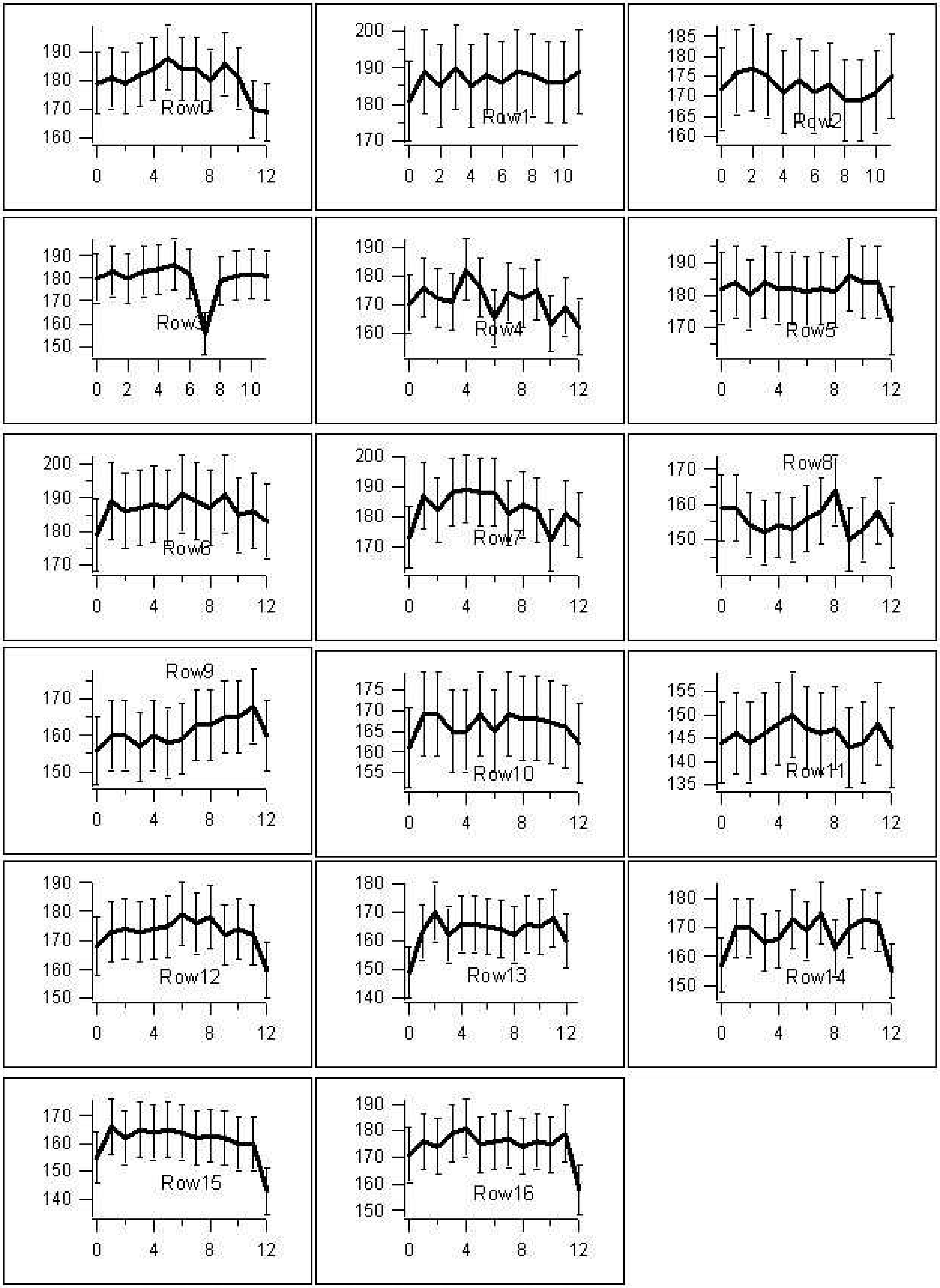


Figure 8: The signal by rows. There is no big variations.

6 Acknowledgements

I wish to thank Dr. V. Kovaltchuk for his assistance during the measurements, as well as Drs. Lolos and Papandreou for their supervision.

A Appendix A

```
MACRO DoubleFit
    **************************************************
    * FITTING THE ADC-SPECTRUM *
    * WITH EXPONENT AND GAUSSIAN *
    **************************************************
    **** Input the name of the File with the signal ****
    MESSAGE ’Insert the file with the signal’
    READ SIGNAL
    MESSAGE ’The file with the signal is...’ run0[SIGNAL]
    **** Input the name of the File with the noise ****
    MESSAGE ’Insert the file with the noise’
    READ NOISE
    MESSAGE ’The file with the signal is...’ run0[NOISE]
    **** Open the files with the signal and determine ****
    ****the logical units numbers assossiated with it ****
    histo/file 0 /raid2/r5d1/home/halld/gluex/run0[SIGNAL].hbook 0 -X
    **** Open the files with the noise and determine ****
    **** the logical units numbers assossiated with it ****
    histo/file 0 /raid2/r5d1/home/halld/gluex/run0[NOISE].hbook 0 -X
    **** Creating two histograms with the same binning ****
    hi/cre/1dhi 100 ’Signal’ 100 10. 400.
    hi/cre/1dhi 110 ’Noise’ 100 10. 400.
    **** Filling the histograms with data ****
    nt/proj 100 //LUN1/1.adc0(1) * The signal
    nt/proj 110 //LUN2/1.adc0(1) * The noise
    **** Creating vector to store the parameters ****
    **** of the Exponent and the Gaussin fit ****
    ve/cre PAR(5)
    **** Fitting the histogram of the noise with Exponent ****
```

```
hi/fit 110(10.:400.) e ! 0 PAR
**** Double fit of the histogram of the signal ****
**** using Exponent and Gaussian ****
hi/fit 100(50.:400.) g 0 0 PAR(3:5)
hi/fit 100(10.:400.) e+g ! 5 PAR
**** Displaying the vector with the parameters ****
ve/print PAR(1:5)
**** Closing the files with the signal and the noise ****
cl 1
cl 2
RETURN
```