FCAL II: Design and Construction

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Abstract

Purpose of this memo, mainly based on the presentation prepared for the march 11, 1997 collaboration meeting at FNAL, is to report on the design and performance of the new Lead Glass Forward Calorimeter, and to document the work done on the detector module prior to installation.

1 Design of the detector

We had two main constraints in designing the new detector. The first one was the availability of enough lead glass blocks, readily shippable to Fermilab (or, better still, already there); the second was not to have more than 144 channels, in order to use the existing readout electronics (shaper boards, FERAs and TDCs) while covering more or less the same geometrical acceptance.

Furthermore, the installation had to take place during the 10 days scheduled maintenance shutdown, leaving less than two months for getting the blocks ready and for the preliminary tests.

Eventually, an arrangement was devised to use 144 blocks, of three different sizes, to cover the full acceptance of the old detector, except for a small region around the beam pipe; the geometry of the device is depicted in fig. 1. The full coverage acceptance is thus from $3.3°$ to $11°$.

The detector is composed by 48 "small" blocks ($6.3 \times 6.3 \times 58.6$ cm^3), 80 "medium" blocks ($10 \times 10 \times 38$ cm^3) and 16 "large" ($15 \times 15 \times 36$ cm^3), described in detail in the next few sections. The characteristics of the blocks are also summarized in tab. 1.

	Size [cm]		R.L.	Glass type	PM type
	Cross sect.	Length			
48 "small"	6.3×6.3	58.6	21	SF2	RCA 6342A (2 ½")
80 "medium"	10×10	38	14	Schott SF2	RCA 6342A (2 ½")
16 "large"	15×15	36	13	SF2 (?)	RCA 4335? (5")

Table 1: Summary of the block characteristics.

1.1 The "small" blocks

These 48 blocks, $6.3 \times 6.3 \times 58.6$ cm^3, nearly 21 radiation lengths, were found, when unwrapped, to be in fairly good condition; none was found seriously chipped or yellowed. When shipped from Tufts University to Fermilab, they had a smaller ($3.8 \times 3.8 \times 10.1$ cm^3) glass block glued to one face, acting as a light guide coupling the block to a Philips/Amperex XP2020 photomultiplier glued to it. On some of the blocks, the front face (the one without the PM) was not polished.

Since we could not find bases for the XP2020 tubes (and to get rid of the old, yellowed epoxy), the lightguides along with the existing PM's were detached from the blocks heating them in an oven for 5 hours at 170°C. When the blocks cooled, they were cleaned and wrapped in aluminum foil and black Tyvek; an RCA 6342A PM was glued directly to the face, using optical quality epoxy[1]. Due to the small space left around the photomultiplier, no μ-metal screen was used.

1.2 The "medium" blocks

These blocks were already at Fermilab, so they were the most thoroughly tested; since they make up most of the detector, they are also the most important. They are 80, $10 \times 10 \times 38$ cm^3 in size, thus arriving at some 14 radiation lengths; nearly all of the blocks were more or less severely chipped (mainly at the corners or in the centre of one of the small faces; the worst few blocks were discarded), and around 10 of them were yellowed. The yellowed blocks were exposed for ~ 20 hours to direct sunlight, and have shown some improvement. All of the blocks were unwrapped, cleaned and wrapped again with aluminum foil and black Tyvek.

The PM's are held in place by means of a small plexiglas support glued to the face of the block; the cylindrical μ-metal screen is then glued to this support, as is a plastic female threaded flange. A mating (male) flange is glued on the photomultiplier, that is then screwed to the support; optical contact is achieved by use of a layer of optical grease[2].

Each block is equipped with one RCA 6342A PM [3]. The tubes are equipped with two types of base, the first being the same of the "small" blocks, while the second type (around 60% of the PM's) have a splitter (that we do not use) and a connector with a signal from the last dynode, that can be sent to a summer.

1.3 The "large" blocks

These blocks, the last to arrive at Fermilab from Nevis Labs, were treated in a slightly different manner, due to the lack of time. The blocks, $15 \times 15 \times 36$ cm^3 in size corresponding to 13 radiation lengths, came with an RCA 4335 5" photomultiplier glued to one face, complete with μ-metal screen and base. Since the wrapping (black plastic, aluminized on the inner side) was found to be in good condition in the two blocks we opened for inspection, they were not open and wrapped again. Inspection from a small aperture (opened in the wrapping to remove the radioactive source, see below) showed that the glass was slightly yellowed.

On the front face of the block was glued a light source, originally used for performance monitoring purposes, composed by an ^{241}Am radioactive source coupled to a NaI(Tl) scintillating crystal housed in a small aluminum cup sealed with epoxy. After using pulses from the device to test the PM, however, the source was removed from the blocks prior to installation.

[1] Epo-Tek 301 was used on around half of the blocks; Epo-Tek 305, with a very slightly better optical performance, was used on the rest of the blocks.

[2] Dow Corning standard optical couplant.

[3] Some of the tubes are manufactured by Amperex instead, but no substantial difference was found in the performance

1.4 The readout electronics

Like the old FCAL, the readout of the new detector is the same as the one for CCAL [1].

The signal coming from downstairs, widened by the $\sim$300 nS cable from the pit to the counting room is shaped by a circuit derived from that designed for CCAL, but with different gains and time constant values. Each size of block has a different set of values (but the ones for the small and medium blocks, having these the same PM's, are very similar); the system is composed by 9 boards, with 16 channels each, housed in a VME-like crate and powered by a small bus carrying $\pm$6 V on the back of the crate. Each channel of the boards has both an analog output (the shaped signal, sent to the FERAs) and a digital one (generated by an internal discriminator, sent to the TDCs). The threshold values for the discriminator (the same for all the 16 channels of each board) can be adjusted by means of a screw in the front of the module.

In the final configuration, the shapers for the small and medium blocks have a $\times 2$ gain, while the board for the 16 large blocks has a $\times 1$ gain; the first tests, however, were made with prototypes having all a $\times 1$ gain.

1.5 A note on the numbering

Due the different size of the blocks, as can be seen from fig. 1 there is no obvious way of numering the blocks in a "cartesian" sequence, since the rows of small, medium and large blocks are not aligned. Thus, the blocks were grouped by size and consequently numbered row-wise, the small blocks being n. 1 through 48, the medium ones 49 through 128 and the large ones 129 through 144.

Another problem, arousing also from the lack of alignment of rows and columns, was the technique to select neighboring blocks for the clustering routine. Since no simple algorithm was found, Jonathan Streets devised a look-up table with, for each block, the list of the surrounding blocks in a 3×3 grid.

2 Pre-installation tests

A few tests were performed on each block prior to installation: the photomultipliers' gain curves were determined using light pulses from an LED, in order to roughly equalize the gains; then the complete modules were tested using cosmic rays, to obtain a preliminary calibration.

2.1 PM characterization

All of the 2364A tubes were tested using light pulses prior to installing them on the blocks, to obtain a full set of relative gain curves. This was necessary since the tubes were not new ones and we did not know how much fatigue they suffered in the past.

To test the blocks a blue LED encased in a rigid support frame was shone at the centre of the PM, driven by a 17 nS$\times$5.0 V pulse, at around 50 Hz. The PM signal was fed into a LeCroy 2249W ADC, read out by a SGI Indigo (the old fn760b) via CAMAC and Jorway. The gate for the ADC was provided by a signal from the same pulser that drove the LED, fed through a gate generator and a short delay line.

The long term stability of the test setup (and the reproducibility of the results) was assessed by testing repeatedly a "control" tube. The results of all these "stability" measures are plotted in fig. 2.

As can be seen from fig. 2, the relative difference between subsequent measures and the average is always less than 10%.

The tubes proved themselves very different from each other; the plot in fig. 3 shows the spread in relative gain and four gain curves.

Since the large blocks' PMs were glued to the glass and we decided not to unwrap them, we used the pulse from the ^{241}Am/CsI light source to test them; this way the transparency of the block being tested affects the gain curve, since the light from the source must cross the full length of the block to reach the photocathode. The light source had a very long ($\sim$1 μS) decay time, so we had to use a very long gate on the ADC.

2.2 Cosmic ray tests

Each assembled module, with its own PM and base, was tested with cosmic ray muons. The blocks were held vertically with the PM facing up, so a reasonable fraction of the Cherenkov photons emitted by the muons in the glass was collected by the photocathode.

A trigger was provided by two scintillator paddles, cut to size to cover the correct number and size of the blocks (7 small, 4 medium or 2 large blocks were tested at the same time); the signal from the scintillators went to a concidence unit that, through a gate generator, provided a 300 nS gate to a LeCroy 2249W ADC. The signals from the blocks came to the ADC thru $\sim$150 nS of RG-213 delay cable; the ADC was then read out by fn760b through CAMAC and Jorway interface.

That way we collected some 6000 raw cosmic muon events for each block; to obtain a narrow peak, events were selected, for each block, with no signal in the adjacent one(s), thus rejecting "slant" muons with a shorter path in the glass. Almost all of the blocks showed a well defined peak somewhere around 60 ADC channels over the pedestal; some such peaks can be seen in the plots in fig. 4. As can be seen from the plots, the peak was sometimes visible before applying the selection cuts.

While being useful for the relative equalization of the blocks, the cosmic ray peak can provide only a very rough absolute calibration, since the light collected is the Cherenkov light emitted by the passing muon only, while for electrons and photons one have to take into account the electromagnetic shower; furthermore, the geometrical collection efficiency can be different in the two situations.

2.3 The Electron Equivalent.

To obtain some preliminary absolute calibration constants, we used results obtained by Keith Gollwitzer on the CCAL blocks [2] by means of on-beam test data and Montecarlo simulation (the "single-block Montecarlo").

With a technique described in detail there, he obtained the "electron equivalent" of the cosmic muon, i.e. the energy that an electron must have to produce the same signal in the PM as the muon, for the various shapes of the CCAL blocks.

As an example, we make a comparison between our medium-sized blocks and the closest (in cross section) block shape from CCAL, shape #9. The effects taken into account are as follows.

1. We assume that the different shape of the blocks (the CCAL block is tapered) has no effect; the punchthrough signal is proportional only to the length of the block. This is by far the most important effect.

2. We assume that the percentage of EM shower contained in the two blocks is the same.

3. We assume that the difference in fractional coverage of the counter face by the PM affects muon and shower signals in the same way.

4. The type of wrapping affects differently punch-throughs and EM showers; the CCAL blocks are wrapped in white paper, while FCAL ones have aluminum. This effect accounts for a $K_{Wrap} = 1.11$ factor.

5. The radiation damage (as mentioned before, our blocks are slightly yellowed, while the calculation was made for a new CCAL block) also affects differently punchtrhoughs and showers, contributing with a factor $K_{RD} = 0.96$.

Thus, the electron equivalent for our blocks is

$$E_{\mathrm{FCAL}} = E_{\mathrm{CCAL}} \times \frac{L_{\mathrm{FCAL}}}{L_{\mathrm{CCAL}}} \times K_{\mathrm{Wrap}} \times K_{RD} =$$

$$= 500\mathrm{MeV} \times \frac{38\mathrm{cm}}{50\mathrm{cm}} \times 1.11 \times 0.96 \sim 404\mathrm{MeV}$$

3 Installation and first tests results

The new detector was installed in the AP50 pit during the 1997 Easter shutdown, from march 29 to april 6.

3.1 Installation

Due to the tightness of the schedule, it was impossible to provide a proper adjustable stand structure for the detector. The blocks were thus stacked on a simple stand made from plywood and Unistrut bars (see fig. 1), resting on two aluminum rails bolted to the concrete floor of the Accumulator tunnel. Planarity of the rails was ensured by means of thin aluminum shims inserted below the rails where needed. More shims[4] were used to ensure proper centering and leveling of the blocks.

An aluminum “box” provides the internal support for the beam pipe; 4 vertical Unistrut bars, bolted to the floor and joined at the top by steel threaded bar, provide some lateral support. More Unistrut was used to build a cable rack that holds the weight of the cables coming form the PM bases and going to a patch panel on the wall.

Alignment and positioning of the blocks was done simply by tape measure, and no surveying was, for lack of time, performed on the detector; care was nevertheless taken to ensure a ± 5 mm positioning of the detector.

3.2 First on-beam tests

The results from these early tests are superseded by the subsequent calibration work [3], but are nevertheless briefly reported here for completeness.

Right after the installation, when beam was again available for the experiment, not all of the shaper boards were ready, so we had to take different runs recabling the system to cover all the detector with just three modules, summing up to 28 channels for medium blocks (which we used for the small blocks too) and 6 for the large ones.

Running at injection energy, we took data with a modified $\phi\phi$ trigger, from which the Forward Charged Veto condition was removed, looking for punchthrough pions.

[4]Made from aluminum or G-10 fiberglass.

The offline selection mechanism required, for each block, some signal in the corresponding octant of the Forward Veto, selecting charged particles, and no signal at all in the neighboring blocks, rejecting electromagneting showers larger than a single block and “slant” tracks, crossing more than one block. It should be noted that this technique is fully efficient only for blocks surrounded by “good” blocks; nevertheless, we were very quickly able to see well-defined punchthrough peaks for a good fraction of the medium blocks.

Fig. 5 shows some such peaks, for the same blocks represented in fig. 4. It can be clearly seen that not always the punchthrough peaks are evident; it was this consideration that led to the use of the “virtual peak”technique, described elsewhere [3], for the first calibration.

References

[1] L. Bartoszek et al., Nuc. Instr. Met. **A301** (1991)

[2] K. E. G. Gollwitzer, Ph.D. Thesis, University of California at Irvine (1989)

[3] G. Garzoglio, F. Marchetto, P. Rumerio, E835 Internal Memo Apr. 97 (1997)