manipulated with latex gloves to avoid scratches at all times. The fibers are glued with acrylic white paint with 10% in volume of water.

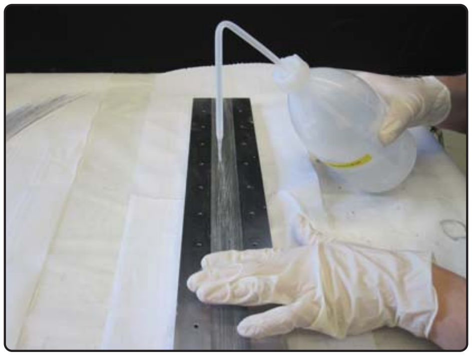
The process is as follows. First, over the position matrix is put a little bit of water, enough to moisten the surface where the fibers will be placed (fig. 2.32a). Putting water helps to keep the fibers in position and facilitates to remove the bundle after the paint is totally dry. Then, a first layer of 32 fibers are placed in the matrix, leaving a small length out of the matrix (fig. 2.32b). It helps to control the length of the fiber and remove the bundle from the matrix. Immediately, 6 dummies are placed contiguous to the layer, but in this case leaving a longer length than the normal fibers to identify clearly when they must be removed (fig. 2.32c). Once all fibers are placed, a light layer of paint is applied with a soft brush covering an area of ≈ 35 cm long (fig. 2.32d). Then a second layer of fibers is placed (fig. 2.32e). If it is necessary, more paint could be applied. It is important to apply an homogeneous quantity of paint in the internal part of the bundle since previous bundles built have been destroyed by the stress between zones painted and zones with lack of paint. The process is repeated two layers more until the desired layout is achieved (fig. 2.32f). The whole process takes between 20 - 30 minutes.

2.5.2 Polish of the end side of the bundle

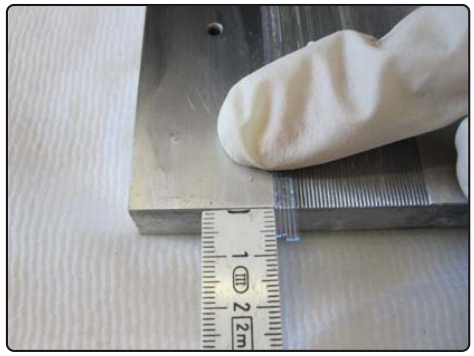
Once the bundle is built, it is left curing with the position jigs pressing the bundle for 24 hours. After this time, the bundle is carefully removed from the position matrix. The dummies are removed one by one taking care not to unglue the fibers (fig. 2.33a), specially the last one which only touches one fiber. Then a paint layer is applied in the surface which was in contact with the matrix and the edge where the dummies were. The bundle is placed in a plastic block with its shape to manipulate during the polishing process and not lose the position of the fibers. The first step is reducing the end of the bundle with a manual diamond saw (fig. 2.33b). The rest of the excess of the bundle (fig. 2.33c) is reduced to the level of the block with an electric sand paper machine (fig. 2.33d). Doing this facilitates the final polish with the high precision saw machine DIAPLAIN 6300 from MUTRONIC (fig. 2.33e). After the last polishing, the end of the bundle is ready (fig. 2.33f). The process takes around 20 minutes.

2.5.3 Assembly of the fiber bundle with the cookie

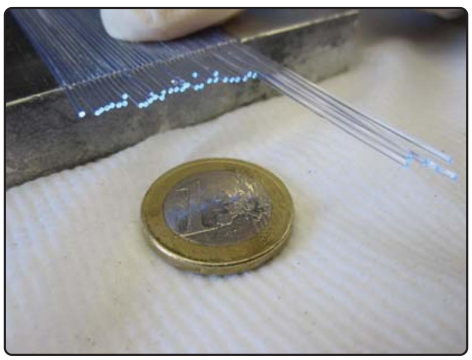
The bundle is now placed in an other plastic crimping block with its shape, but holding the whole body of the bundle, *i.e.* the corresponding part for detection. The polished end is leveled with the border of the crimping block (fig. 2.34a). The plastic block is attached to an aluminium plate and at the opposite side of the block is attached the cookie at the desired distance



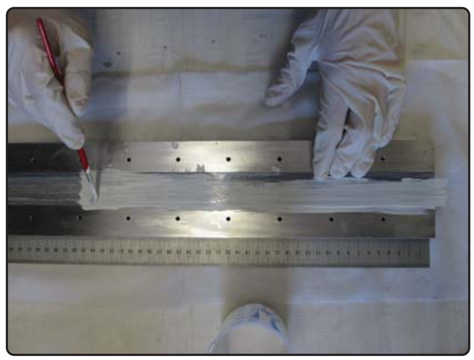
(a) Moisten of the matrix surface to hold the first layer.



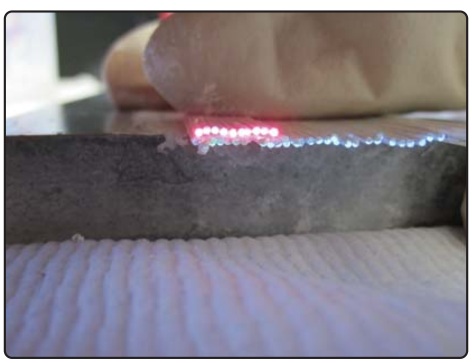
(b) Detail of the fibers in the matrix slightly out of the matrix.



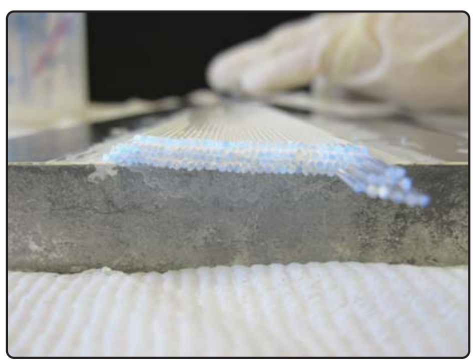
(c) First layer ready showing the fiber dummies remarkably out than the main fiber bundle.



(d) Application of the paint to the first layer.

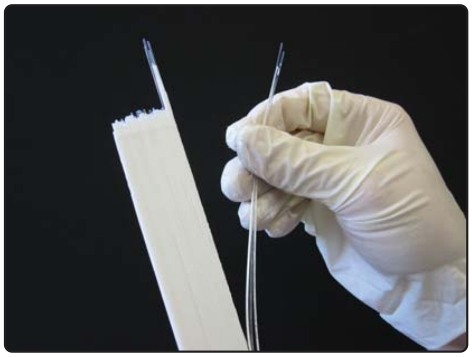


(e) Placing of the second layer, illuminated with red light for better identification.

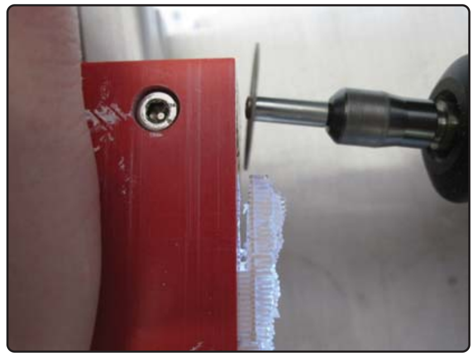


(f) Bundle finished and ready for curing.

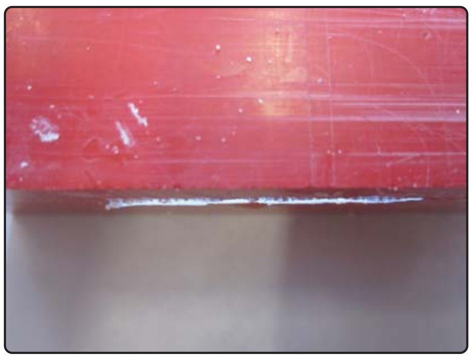
Figure 2.32: Steps of fiber bundle construction.



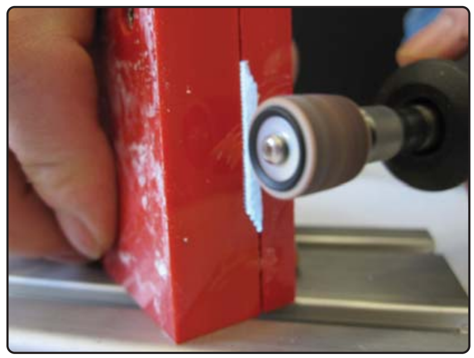
(a) Withdraw of the dummies fiber from the main bundle.



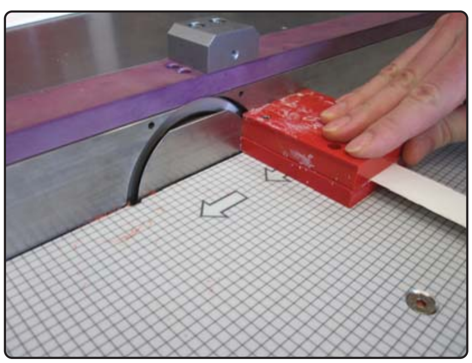
(b) Reduction of excess of fibers with a manual diamond saw.



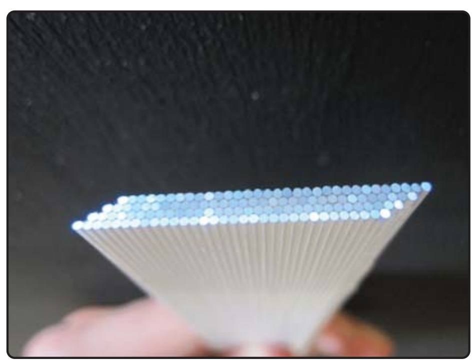
(c) Detail of the block containing the bundle after the cut.



(d) Leveling the rest of the bundle with rotating sand paper.



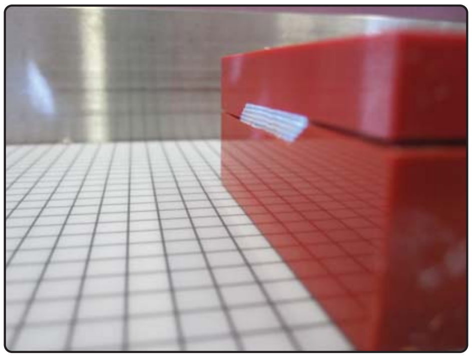
(e) Final polish with high precision saw machine.



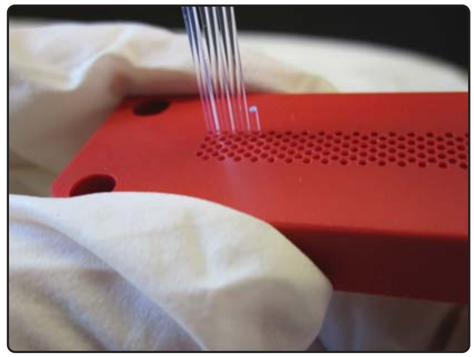
(f) Detail of the fiber bundle polished.

Figure 2.33: Polish phase of the end of the fiber bundle.

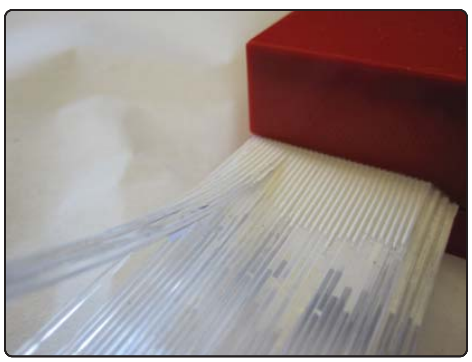
for the bundle length. The fibers are placed one by one in the corresponding hole of the cookie (fig. 2.34b). Since the bundle is made of four layers, is not complicated to identify the fibers consecutively (fig. 2.34c). The position can be checked with the use of light, covering the end of the bundle partially with a slit and observing how the light slit moves at the cookie side. It takes 40 - 50 minutes the entire assembly.



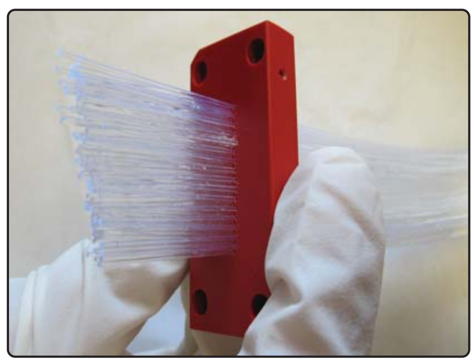
(a) The fiber bundle leveled with the plastic crimping tool.



(b) Allocation of the fibers one by one into the cookie.



(c) Detail of the fiber bundle attached in the crimping tool and how the layers is distinguishable from each other.



(d) The bundle assembled completely into the cookie.

Figure 2.34: Placing of the fibers into the cookie.

2.5.4 Bending of the fiber bundle and gluing to the cookie

With the fibers placed in the cookie, it is attached to the aluminium plate, mentioned before, straight to the bundle or shifted for the bent kind bundle (sec. 2.4.3). The plate with the bundle is placed in an air flow oven at 70°C for one hour (fig. 2.36 left). After cooling the whole set, the plate is placed vertically with the cookie at the bottom. In a flask is prepared a quantity of optical glue, BC-600 from Saint-Gobain, depending of the number of bundles to be glued. A quantity around 3 - 4 cc by bundle is enough for gluing purposes. The BC-600 is a two compound optical epoxy used normally to glue scintillators blocks with light guides, but since it is not aggressive with the fibers, it shows a good behavior for a vacuum seal and it is enough viscose for a slow flow through the fibers within the holes, making it an ideal choice as glue. It is used in a 3:1 resin-hardener mass proportion. It is applied with the use of syringes (fig. 2.36 right). It allows a more precise application without staining the surface. Enough glue should be applied to allow it flow through the holes of the cookie with the fibers[5], but keeping some extra glue over the surface of the holes matrix to provide more stability and reinforcement to the fastened fibers. After applying the glue, the bundle is left curing for 24 hours.

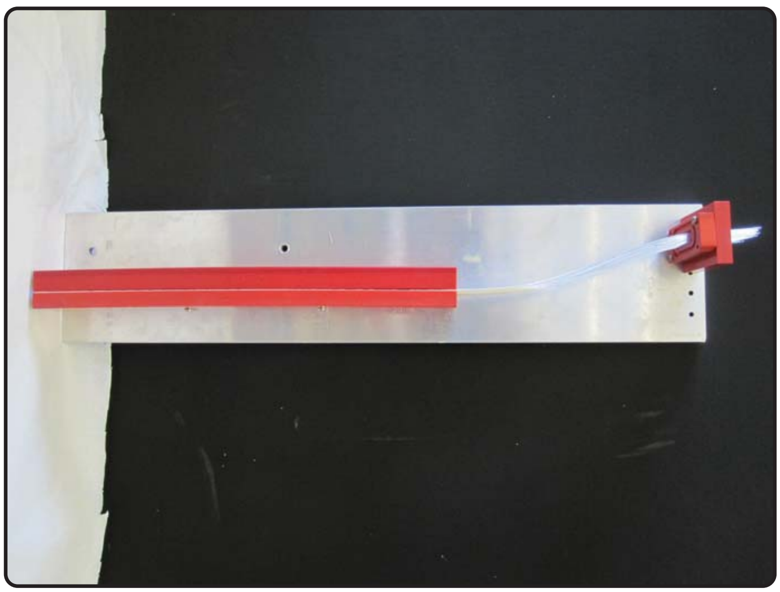


Figure 2.35: Photography of the aluminium plate and the crimping block with the bundle inside prepared to put into the air oven. the cookie (at right) is attached forcing the bent of the bundle. Note that there are some excess of fibers at the end of the cookie that should be removed.

Once the glue is cured, the excess of fibers out of the cookie are cut and the cookie is polished in the same way as explained in sec. 2.5.2. First with the manual diamond saw, then with a rotating sand paper to level the excess and finally with the high precision saw (fig. 2.37). In this case more care is necessary to avoid excess waste of the cookie since the thickness where the fibers are glued is only of 2.5 mm (app. A.1) and on average the high precision saw lowers the material about 0.5 mm.

[5]The fibers are 0.83 mm diameter and the holes through the fibers are placed are 0.9 mm diameter (app. A.1)

Figure 2.36: Left. Photography of the aluminium plate with the bundle into the air flow oven. The size of the oven allows to place three plates at time. Right. Detail of the application of the glue into the cookie with a syringe. The cookie has an O-ring placed.

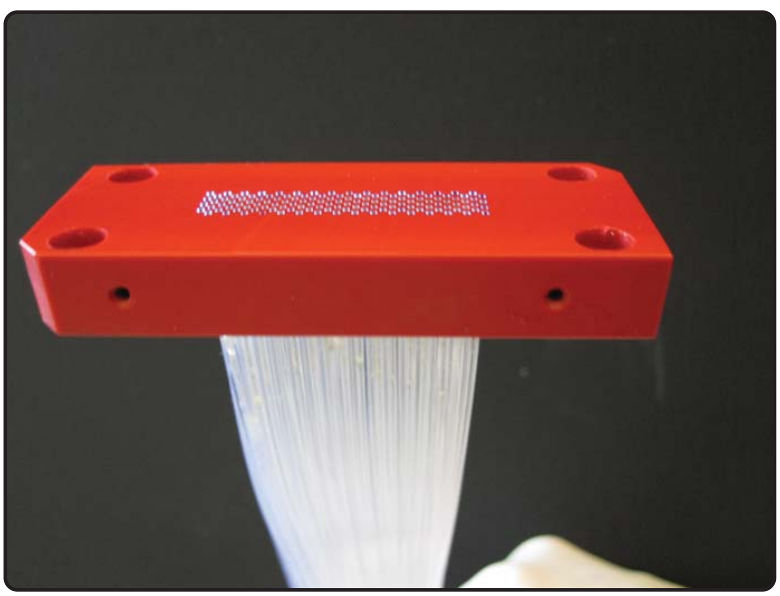


Figure 2.37: Detail of the cookie with fibers after polish.

The bundle is then tested for vacuum leaks in the vacuum workshop of the Institut für Kernphysik of Mainz. In case that the bundle does not pass the test, an extra layer of glue can be applied and then tested again.

2.5.5 Aluminization of the fiber bundles

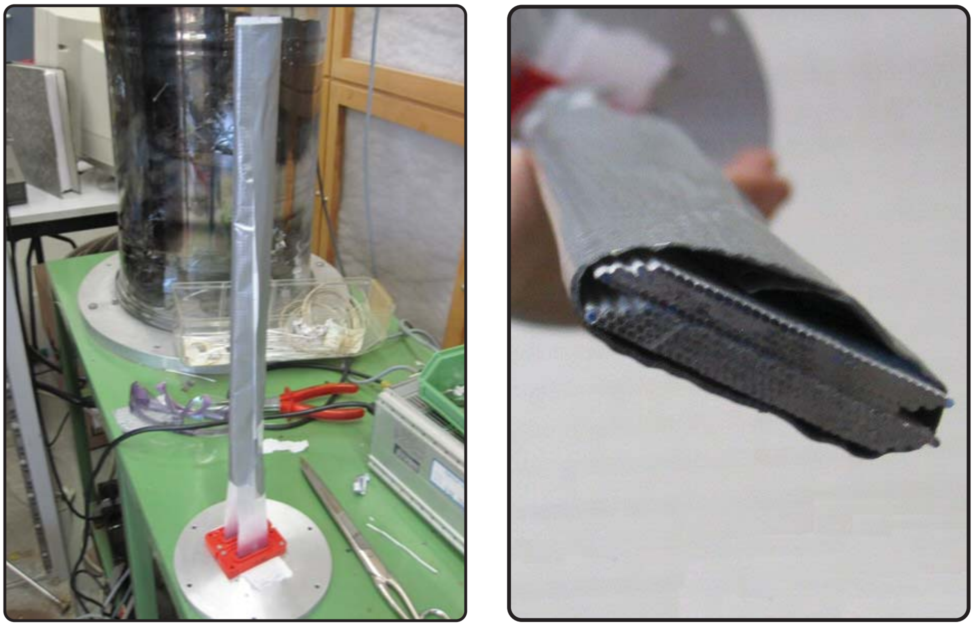
After the bundles are tested for vacuum, they are covered with plastic, except the end of the fiber, and attached to the aluminium cap and proceed to seal the system. The air pump is switched on and it should be waited until the air pressure inside is in the order of 10^{-2} mbar. Then the jet pump is switched on and when the pressure is in the order of 10^{-5} mbar, the current source is switched on and the amperemeter current is set to get 6 - 8 A. When the pellet is totally melted, the shutter should be open and it should be waited for the deposition of the aluminium vapor occur, watching how it is deposited in the wall of the glass cylinder, normally 3 - 4 seconds after the shutter was opened. After the deposition happens, the current source is switched off. The communication pipe between the compressor and the chamber is closed to avoid oil contamination from the compressor due to the vacuum. Then, the jet pump and the compressor can be turned off, the chamber open and the fiber bundles retired. The whole process takes around 3 - 4 hours.

2.5.6 Alignment of the PMT along the fiber bundle

The PMT is attached to the cookie through two aluminium plates (fig. 2.39 left) which are screwed to the cookie and they fast the PMT from the base with screws (fig. 2.39 right). The pressure of the screws should be enough to fix the PMT keeping it static at the position determined by the alignment, but not too much for a risk of break.

It has been proven that it is possible to align the PMT anodes to the corresponding 4-fiber channel of the cookie [121]. In a black box, the bundle with the PMT is attached to an align tool which allows to move the PMT gently along the channels of the bundle with a level screw. A diode laser illuminates a fiber of a given channel and the energy asymmetry in the neighboring channels is measured. The laser, from Horiba, produces blue light with pulses in the range of $10^{-12} - 10^{-9}$ s. The focalization and intensity of the laser can be manually adjusted directly in the light source and the pulse rate from the laser control module. The ADC gate is also produced by the laser control module through a NIM output. The laser is focused to one fiber, generally to channel 16, and the the channels 15 and 17 are connected to a LeCroy CAMAC Charge ADC 2249A and the DAQ was done with a standard set-up of the A1 collaboration. The output asymmetry A is calculated as:

$$A = \frac{ADC_{17} - ADC_{15}}{ADC_{17} + ADC_{15}} \tag{2.14}$$



(a) Photography of two bundles attached to the cap covered and ready for aluminization.

(b) Photography of the two bundles after the aluminization..

Figure 2.38: Preparation before the aluminization and photography after the process of vaporization.

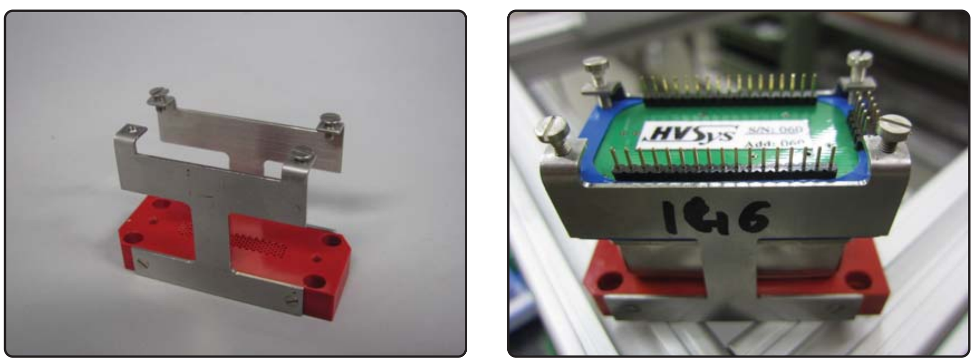


Figure 2.39: Left. Photography of the cookie with the aluminium clamping plates. Right. Detail of the fasten screws at bottom of the PMT base.

with the respective channels ADC_{17} andADC_{15} corrected to the anode output of the PMT used in the alignment (sec. 2.2.1). A small run is done and from the measurement of the asymmetry, the PMT is moved with the level screw to one side or the other depending of the sign of the result and then the DAQ is done again. When the plot shows an asymmetry <0.01, the alignment is done.

Figure 2.40 shows a typical output of a aligned module. When the alignment is achieved, the screws at the bottom of the PMT base are fastened and the module is ready (fig. 2.41)

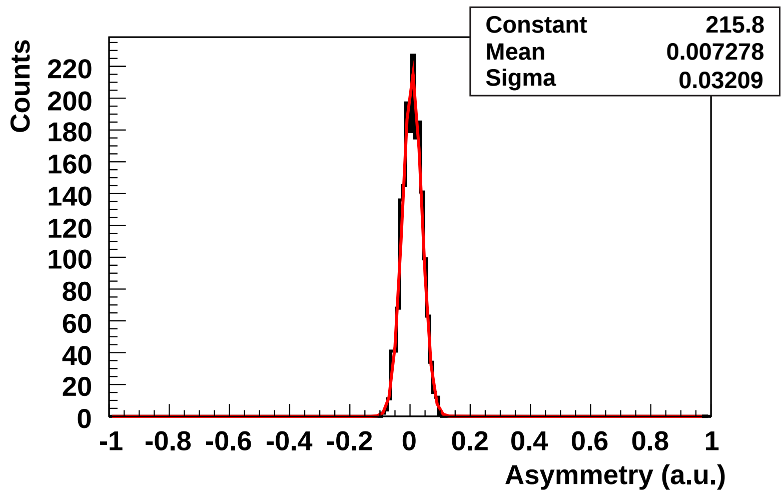


Figure 2.40: Typical asymmetry measurement from an aligned PMT. The red fit is made for orientation purposes. The mean value is zero, showing that the positioning of the fiber respect to the corresponding PMT channel is correct.

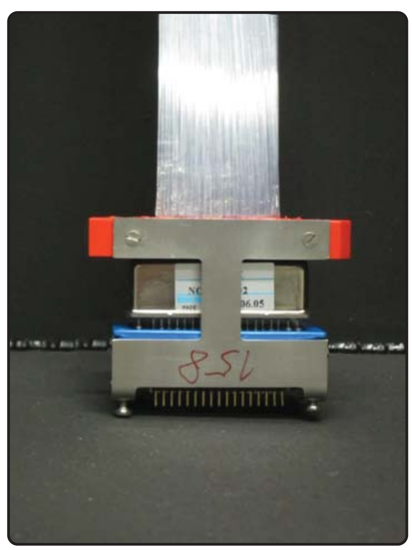


Figure 2.41: Photography of the module assembly and aligned. The PMT is fastened with the screws from the bottom preventing any movement from the desired alignment.