5 CONSTRUCTION OF THE DETECTOR Caroline Robson

5.1 Optical Components

Scintillating material

The material used was Kuraray SCSN 61T, the base material of which is optically transparent granulated polystyrene. This is doped with two scintillating fluors, paretephenyl (PTP) and bis-2-(5-phenyloxazolyl)-benzene (POPOP). These give the scintillator its characteristic blue tint when observed in daylight.

Connections

It was decided that the scintillator tiles should each hold one length of wavelength-shifting fibre. If the tiles were of a larger width they may have needed more fibres in order to retain all of the light but at 50mm and 65mm it was unlikely that this would have been a considerable problem. It was planned that the wavelength-shifting fibres would be fed into optical connectors in pairs (each is a small, light plastic piece that can connect four fibres) so that only eight would be needed. The optical fibres could then be glued into the 'cookie', a plastic piece that fits onto the end of the PMT and guides the ends of the optical fibres onto the pixels.

PMT: The Hamamatsu M16

The photomultiplier tube used in this project, both in the test stand and in the detector, was a Hamamatsu H6568 Multianode Photomultiplier Tube Assembly, otherwise known as the M16. It is a miniature array of 16 PMTs contained within one module with a weight of 130g. Each of the 16 channels has a separate pixel input to which can be attached an optical fibre and an output for an electrical cable. The electron multipliers are of the metal channel type, which consists of tiny stages from which the electrons are scattered, then caught by the next one. Due to the small spacing between the dynodes the electrons have a shorter distance to travel and hence the tubes have a fast response time. In this particular assembly there are 12 stages for each channel. The response is wavelength-dependent, with range of 300 – 600nm and a peak response at 420nm *(http://usa.hamamatsu.com)*.

The resistance of the tube assembly was tested with a resistance meter in order to determine the current required from the power supply. This was done on the test stand and was measured between the pin of the power cable input and that on the output of one of the LEMO cables. Several cables were used and a consistent result obtained. The resistance was measured as 2.56×10^6? and using $V = IR$ the minimum current was calculated to be 371µA. It was assumed in this calculation that the resistors that form the potential divider inside the PMT are Ohmic. In reality the current was likely to be out by a maximum of around 10%* at any point and as power supplies that could provive 750µA to 1mA were being considered for the detector it would not matter.

**private communication, Mr B. Anderson*

5.2 Making the Scintillators

Machining and Polishing

It was decided that 20 scintillator tiles would be produced from the bulk material. This provided 16 for the barrel of the detector and allowed for two spares of each size. The pieces were sawed roughly to size and were then cut to the precise dimensions of 5 x 50 x 170 and 5 x 65 x 170mm using a fly cutter. The 50mm pieces were all cut together at the same time, as were the 65mm ones, in order to ensure even cutting. Once all of the pieces were the correct size, each one had to have a groove cut along the centre of its length on one of the large sides. Designed to hold wavelength-shifting fibre of diameter 1mm, each groove was cut with a cross section of 1.2 x 1.2 mm in order to leave space for the glue.

The sides of each scintillator were polished where the material had been cut in order to create a smooth surface for the light inside the tile to be reflected from. A rough surface would cause an incident photon to be scattered out of the material into the surrounding medium and therefore be undetectable. Firstly sanding and smoothing was carried out using wet-and-dry sandpaper. Then the sides of the tiles were polished using four successively finer grades of optical lapping film, a type of very fine sandpaper (see fig.62, below). The first had a grain size of 30 microns, progressing through 12 and five microns to the last sheet with a grain of one micron. Finally the surfaces were polished using a chemical fine scratch remover. The protective paper on the bottom surface of each tile was removed (that on the top had been removed to cut the groove) and all of the surfaces cleaned of debris using a soft cloth soaked with ethanol.

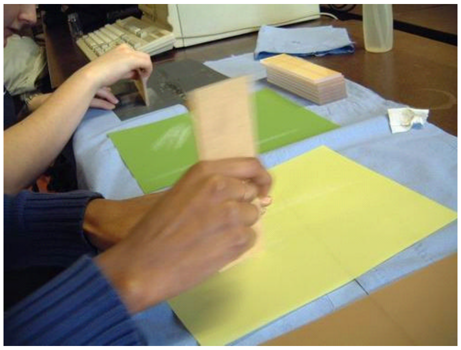

Fig.62: Polishing the scintillators

Preparation and Gluing of the Wavelength-shifting Fibres

A piece of wavelength-shifting fibre with a length of approximately 30cm was cut for each tile. Each was then prepared by checking its whole length for scratches, which appear to sparkle in the light and then checking that it transmits along its whole length. This was carried out by covering the length of the fibre with a black cloth and then exposing and occluding one end while observing the other to see if it ‘blinked’. One end of each fibre was then polished using first the wet-and-dry paper then the four optical papers. The other end was left unpolished as it was to be subsequently cut down to the correct size once glued.

The optical cement used for the gluing of the fibres consists of a resin and a hardener, which must be mixed together in the ratio 25:7. Using an electric balance, 5g of resin and 1.4g of hardener were measured then stirred together. In order for the cement to be accurately applied to the groove a syringe was used. After a final cleaning of the groove with ethanol the cement was carefully piped along its length and smoothed out using a small spatula before a length of fibre was laid along it, the polished end at the end of the tile. Once in place, the fibre was secured using Scotch tape, which the cement does not adhere to. This process was carried out with the tiles resting on a sheet of polythene, which will also not adhere to the cement. The leftover cement and its mixing container were kept beside the tiles in order to see when it had dried without needing to touch the scintillators. The cement took 24 hours to set before wrapping could commence. Fig.63, below, shows the scintillators with the wavelength-shifting fibres cemented into the grooves, ready for wrapping.

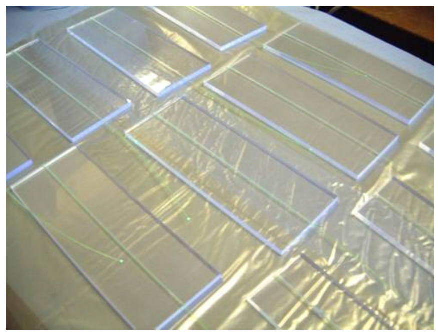

Fig.63: Scintillators after the gluing process

Wrapping and Light Sealing

The scintillators and the optical fibres have to be sealed from daylight in order that they only detect the photons produced by the scintillating dopant. Firstly each scintillator was wrapped in a single layer of aluminium foil with the reflective side on the inside. Pressure-sensitive tape was used to hold the foil in place before a layer of black insulating tape was applied (see fig.64, below). As the tape easily exceeds its plastic limit each length was stretched before it was applied in order to prevent later distortion. A small gap of approximately 1mm was left around each fibre to make space for the sheath.

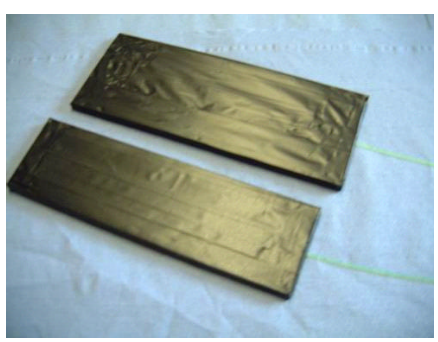

Fig.64: Two of the wrapped scintillators

5.3 Machining the Octagonal Plates

Two of the three octagonal plates that form the main structure of the detector are made from clear polycarbonate which is a strong plastic that doesn't shatter easily. This was considered particularly important as one of them (the back plate) had to undergo a lot of delicate machining in order to cut the slots for the scintillators. Both of them also have holes for the studding to pass through. Situated at each end of the detector, they are more likely to suffer impacts from general usage and must be able to withstand this. Perspex was rejected as a material because it is difficult to machine and would be at a high risk of shattering either during the machining process or transport.

The central plate was machined from black acetal homopolymer (Delrin), which is a softer plastic but due to the colour helped in the light sealing of the join between the scintillator, the optical fibre and the plate.

5.4 Assembly

The first problem encountered in the assembly of the barrel was the fact that all 16 scintillators had to be fitted into the slots at the same time without creating stresses on the wavelength-shifting fibres. The contact points between the ends of the tiles and the slots also had to be light-sealed, which required beading with black RTV (Room Temperature Vulcanising) sealant, otherwise known as mastic.

Firstly the four 1m lengths of studding were inserted into the holes in the middle of the Delrin plate, their positions measured and then nuts used to hold them in place. The structure was then screwed into a vice with the slots on the Delrin facing upwards. Mastic was then applied to the slots and the scintillators carefully placed in their positions with the fibres going downwards through the holes that had been drilled for them. With more mastic applied to the slots on the polycarbonate plate, this was carefully placed on top and a crochet hook used to slowly push or pull each scintillator into position. With all scintillators correctly placed in their slots, nuts were used to hold the polycarbonate in place on the studding and to apply a gentle pressure on the scintillators to hold them in position (see fig.65, below) This was required as the mastic is not strong enough and was only used for the purpose of light sealing.

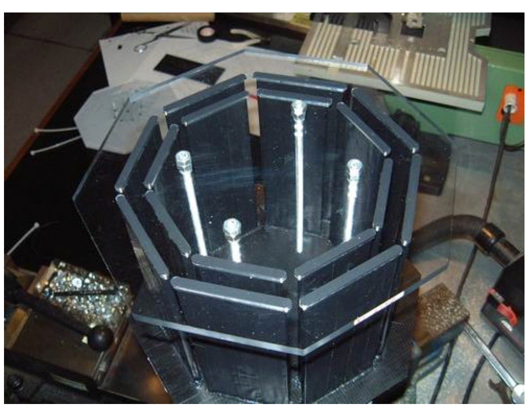

Fig.65: Construction of the barrel

The barrel was left for 24 hours to allow the mastic to set. It was then turned on its end so that the fibres were facing upwards. A 3mm diameter cover was then applied to each of the 16 fibres before one half of an optical conector was applied to each pair at approximately 5cm along its lengh. The fibre and covering were then sealed with mastic at the Delrin end and then sealed with black epoxy resin at the connector. The epoxy was used partly for light-sealing but mainly to hold the fibres firmly in place in the connectors. Eight small brackets were the screwed into the Delrin to hold the conectors in place. These were to be a permanent feature so that if someone were to hit the fibres by mistake the likelihood of breaking the fibre would be reduced. The epoxy had to be left over a weekend to dry, with the mixing container and leftover epoxy kept with the apparatus to test if it had set without disturbing the fibres.

The uncovered fibres emerging from the other side of the connectors were then cut as close to the edge of the connector as possible in preparation for sanding then polishing down to the plane of the connector surface. For this delicate operation a small jig was made to hold the connector and create a larger plane surface upon which to polish (see fig.66, below). This prevented the polishing process resulting in curvature of the edges of the connector and hence light leaking. The fibres were first sanded using wet-and-dry paper then polished using the same optical films as before down to a 1 micron grain. As the brackets had to be removed for this process the jig had to be held carefully at all times in order not to stress the fibres.

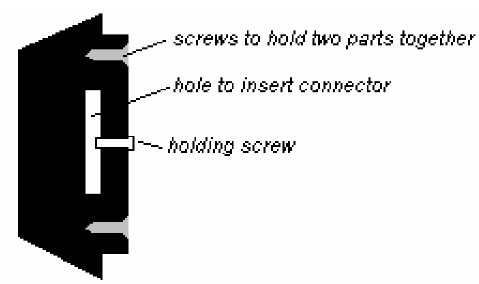

Fig.66: Jig used to polish the wavelength-shifting fibres

The other halves of the connectors were applied to optical fibres in the same way but without the need for the jig as they were not attached to the apparatus. They were polished by using a small holder which held the fibre at 90º to a flat surface (a table) upon which the polishing papers were placed. The fibres were cut to a length of approximately 20cm and the other ends glued into a plastic guide called the 'cookie' which fits onto the end of the PMT and guides the fibres onto the correct points of the pixels. All 16 could then be polished together until they were plane to the cookie surface.

The connectors were designed so that when the fibres were polished plane the two halves just screw together and hold the ends of the fibres in contact with each other. Fig.67, overleaf, shows a schematic of the optical connections.

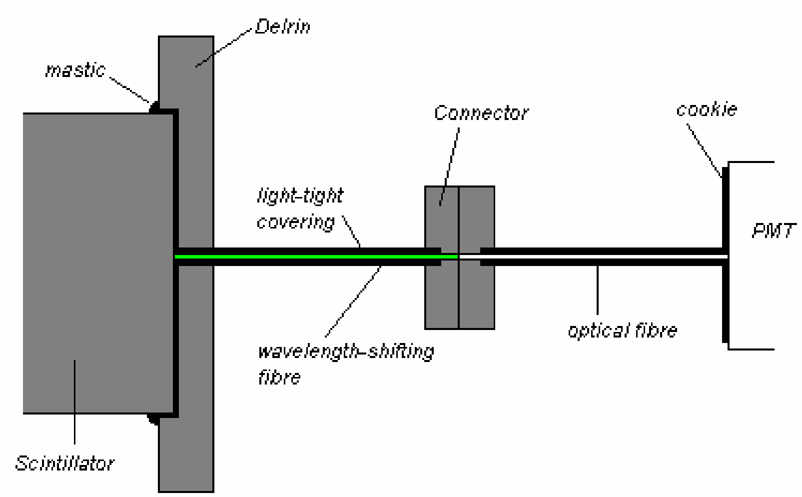

Fig.67: Schematic diagram of the optical connections. This is shown for a single fibre but in the detector the fibres were connected in pairs to reduce the number of connectors required.

A small plate was cut from the remaining Delrin upon which to mount the PMT. Screwed onto the four lengths of studding, it enabled the transition between the optical and electrical components to be made on the central axis of the detector. A mapping scheme was drawn up in order that the optical fibres be connected to the correct pixels of the PMT.

A summary of the materials used is shown below in fig.68, below.

Material	**Supplier**
Room-temperature vulcanising non-acetoxy silicone mastic 512 783	RS Components
Black low viscosity epoxy resin PX672/BK	Robnor Resins
Polycarbonate sheet 258 6629	RS Components
Black acetal copolymer sheet 282 0893	RS Components
1mm dia. Y11 double clad wavelength-shifting fibre (n = 1.6, 1.49, 1.42) 1mm dia. black-sleeved single clad clear fibre SH6001 (n = 1.60, 1.49)	Kuraray Mitsubishi
Plastic scintillator SCSN61T	Kuraray
Optical cement BC600	Bicron

Fig.68: Table showing the main materials used in the construction of the optical and structural components of the detector *(Brian Anderson)*