6.6 HF OPTICAL SYSTEM

6.6.1 HF fibre insertion tooling

Fibre insertion into the absorber matrix is one of the critical parts of HF construction. The past experience in constructing the EM module suggests that about two man-years would be required for manual fibre insertion per detector. Fibre bundling for each tower and bundle installation behind the absorber would certainly require additional time. A programmable semi-automatic fibre insertion tooling is presently contemplated for this repetitive task. A robotic arm would pick an already cleaned fibre and insert it into a groove by the required length and move by groove-to-groove spacing to repeat the same task until a tower is completely finished. A manual intervention would be required if an insertion or another problem is encountered. The engineering aspects of this design are currently under study.

Fibre insertion will be done in a clean tent where a positive air pressure will be present to avoid dust particles accumulating in the grooves and on the fibre bundles over time.

One of the requirements for the absorber matrix is such that all the grooves are tested with a steel wire gauge for clear passage before the insertion of the quartz fibres. After this test, dry pressurised air is blown into the grooves to clean out possible burrs and dust particles. This procedure will reduce time consuming interventions if a robotic arm is used.

Once a tower is completed, a visual inspection from the far end (front face of HF) of the calorimeter will be conducted to make sure the uniformity of fibre insertion lengths. A light source will be used to inject light into each fibre from the same end to make sure that there was no fibre breakage during fibre installation. The acceptable rate of failure is one fibre in thousand.

6.6.2 HF fibre bundling, cutting and polishing

The fibres will be bundled to form towers at the back of the absorber. The fibre bundles will be made to form thin ribbons in order to minimise optical pickup noise from background radiation. At the very end of the bundle, fibres will be closely packed into cylindrical ferrules for mechanical mounting into the photodetector housing.

There are three types of fibre bundles that emerge from each tower; long fibres that run the entire length of the absorber (EM section) will be bundled separately from the medium length fibres (HAD section). The short fibres (TC section) will form yet another bundle. There are two different sizes of towers, the smaller ones (5 cm by 5 cm) and the larger ones (10 cm by 10 cm) depending on the eta region. For TC, superimposed towers will be formed in 20 cm by 20 cm square sections.

EM fibres will alternate with HAD fibres in the absorber, *i.e.* every other fibre will go either to EM bundle or HAD bundle. TC fibres will be inserted 30 cm into the absorber in the same groove as the EM fibres but at every second groove.

The experience with the previous prototypes has provided information in distinct ways; the fibres that constitute a tower are bundled at one end first and the free ends are inserted into the absorber as in the case of EM prototype that was built in 1996. During various stages of prototype construction, fibre bundles were glued, cut and polished several times and this experience proved extremely valuable. A new type of a wire saw that is recently introduced into the market makes cutting and polishing fibre bundles easier as shown in Fig. 6.33. The samples that are cut in this fashion require less time and effort to polish the bundle adequately.

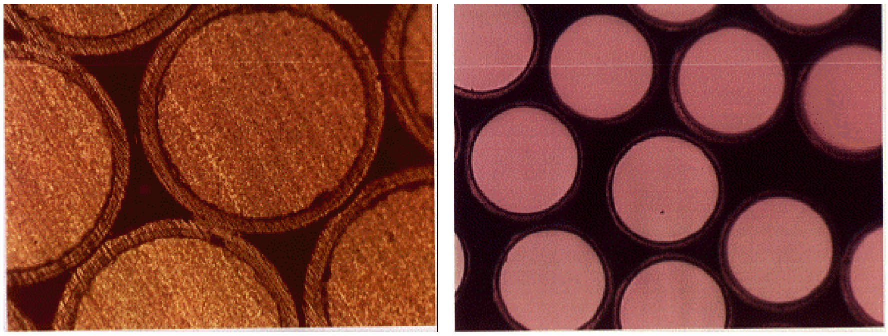

Fig. 6.33: The photograph on the left illustrates the surface quality of the fibre ends after they have been cut with a diamond saw. Note that the core, cladding and the buffer are clearly visible. The photograph on the right shows the fibre ends after they have been polished.

Once a crack-free cut is established with the ferrule, wet polishing procedure starts with 33 micron grit silicon carbide. This is followed by a set of finer aluminium oxide polishing powders; *i.e.* 18, 12 and 3 micron grit sizes. The final polish is done using a 2 micron cerium oxide powder until the fibre ends are clearly reflective.

Before the ferrules are mounted into the holding grid, the polish will be visually inspected under magnification. In case of unacceptable polish (cracks, scratches, glue smears, *etc.*), the polishing procedure is repeated until an acceptable result is accomplished. After polishing, the bundle will be cleaned with a cleaning agent to remove small particles and dust and a protective cover will be placed over the ferrule. The failure rate of 1 cracked or deeply scratched fibre per hundred in a bundle is acceptable.

6.7 MANUFACTURING (HB/HE/HOB/HOE)

6.7.1 HB manufacturing

Machining of scintillator and plastic covers

Each megatile sub-assembly is constructed from a single plate of scintillator. The processing of the scintillator plates is done over several steps. First, the protective paper removed from top side of the plate. The thickness of the plate is measured at two points at the edges using a micrometer. All machining operations are done on this top side only. The protective paper is left on the bottom scintillator until just before the scintillator pan is assembled. Since the separation grooves are cut so that only 0.25 mm of material remain, the scintillator plate with separation grooves machined onto it is fragile. However, as the protective paper on the other side is left intact on the bottom side, it gives additional structural support to the plate when it is handled. In addition, the paper prevents surface scratching when the scintillator is moved about.

The plate is positioned on the Thermwood x-y milling table. Next, reference holes are drilled along the edges for realignment in later operations. A “long reach” 0.90 mm end mill is then used to cut the tower separation grooves 3.75 mm into the scintillator (the last 0.25 mm is left uncut). The outer boundary of the megatile is not cut, just the inner tile separation grooves. The fibre grooves are not milled along with the tile separation grooves because of a risk of epoxy seeping into the fibre grooves from the separation grooves in the epoxying operation. This is because the fibre grooves are 3 mm away from the separation grooves, and a tape seal in such a small gap is not robust enough.

The scintillator plate is then removed from the milling table and white, opaque, epoxy is injected into the separation grooves. This is done by first taping over the grooves and then injecting epoxy into the channels. The epoxy is cured at room temperature for one day. The scintillator plate is put in a oven which is at 38 C for one day to harden the epoxy. The epoxy provides optical separation of the tiles, mechanical support, and a reflective surface at the tile edges. The plate is taken back to the milling machine and the megatiles are re-registered to the milling machine's co-ordinate system. The milling machine cuts the fibre groove routing, machines the rivet holes, and cuts the edges of megatile from the scintillator plate. The 1.52 mm deep fibre grooves are routed with a 1.35 mm end mill. The groove's circular shape, Fig. 6.19, is cut with a 1.14 mm ball mill. Since the neck of the groove is smaller than the diameter of the fibre, the fibre is trapped in the groove.

The megatile is removed from the milling table. A fibre is inserted into each groove to insure that each fibre groove is clear. The megatile edges are painted with white TiO_2 paint to provide a reflective surface on the outside edges of the megatile. In addition, the side of the separation groove with the leftover 0.25 mm of scintillator is "painted" with a black marker pen. This reduces the adjacent tile-to-tile crosstalk to an acceptable 1–.6% per side. Fig. 6.18 shows the mechanical configuration of the separation groove. The construction produces a large megatile that contains individual tiles which are optically isolated but are mechanically one unit.

Each scintillator tray consists of two or three scintillator megatile sub-assemblies. The largest piece of scintillator that manufacturer can supply is 2 m by 1.1 m. In order to minimise the total amount of scintillator used, the tiles are cut from the scintillator in the following way for layers 1-16. The scintillator plates are 2m long. We start with layer 1 tower 1 on the edge of a plate. Next the Thermwood goes to layer 1 tower 2. It continues sequentially until the next tile does not have enough space to fit on the plate. The next tower is on a new plate. At the end of the layer, the Thermwood goes to tower 1 of the next layer. If this tower fits on the old piece of scintillator, it puts it on the old piece of scintillator. Otherwise, it goes to a new plate of scintillator. The process proceeds to the last tower of layer 16. In this procedure, megatile sub-assemblies from separate layers can be cut from the same piece of scintillator. This procedure reduces the amount of scintillator we need to buy and reduces the cost. The thickness for layer 0 and 17 are different from the rest. Hence, a separate size plate is devoted to layers 0 and layer 17. The scintillator for 20° will be cut from a single plate. Each plate will have two side megatiles and one Middlemegatile cut from it.

The top and bottom black plastic plates are grooved on the Thermwood milling machine. The code for the milling machine is prepared from the database. Reference holes are drilled along the edges for realignment in later operations. Next the Thermwood cuts the grooves and holes on the black plastic. The Thermwood can cut plastic which is as long as 3.5 m. However, the longest scintillator tray is 4.5 m. Hence, after the cutting operation is over the plastic is repositioned on the milling machine using the reference holes. The rest of the plastic is machined to form a 4.5 m long single piece.

The milling of black polystyrene plastic cover plates are independent of the scintillator machining. However, the black plastic cover plates must be produced at the same pace at which the scintillator megatiles are cut. The scintillator, plastic (polystyrene), white paperlike reflector (Tyvek), light tightening black wrapping (Tedlar), and top and bottom black cover plates (black polystyrene) are assembled into a partially finished megatile-tray unit. This is the megatile-tray pre-assembly step. The fibre insertion is done later for the final finished scintillator tray pans.

Table 6. 10 shows the material needed to produce one wedge and the full calorimeter. 2052 scintillator trays are needed for the HB calorimeter. Note that before 36 wedges for HB are constructed, a single wedge pre-production prototype will be built.

The scintillator thickness of layer 0 is 9 mm. The scintillator thickness of layer 1-16 is 4 mm. The thickness of layer 17 is 9 mm. Since, the width of the scintillator pans is the smallest for the innermost layer and largest for the outermost layer, we can reduce cost by ordering plates with different width. We have decided to order scintillator plates of 3 different width for layers 1-16. Table 6.11 lists the sizes of the plates and the number we need to order.

Table 6. 10:

Summary of materials for the hadron calorimeter construction.

Material	1 wedge	36 wedges
Scintillator, SCSN81, 4 mm (m^2)	73.5	2683
Scintillator, SCSN81, 9 mm (m^2) (layer 17)	5.5	164
Scintillator, SCSN81, 9 mm (m^2) (layer 0)	4.2	110
Black plastic, 2.0 mm(m^2)	67.7	2170.0
Black plastic, 1.0 mm(m^2)	67.7	2170.0
Reflective paper: Tyvek 0.15 mm(m^2)	180.	4340.0
Black wrapping: Tedlar, 0.04 mm(m^2)	210.	4882.5
Y11 WLS multiclad fibre, 0.94 mm(km)	1.5	53.9
Clear multiclad fibre, 0.94 mm(km)	2.5	91.1
Clear 18 fibre cable, 0.90mm(1.2x15mm)(m)	53.	1900.0
Source calibration tubes, SS(0.050”OD)(km)	0.3	10.7
Epoxy: TiO2 loaded resin(kg)	15.	560
Rivets	2400	86400
Polyester tape, .15 mm(km)	0.5	16

Table 6. 11

Scintillator Order. The sizes of the pieces of scintillator that are used to cut each layer.

scintillator thickness(m	scintillator length(mm)	scintillator width (mm)	1 wedge	barrel total
4	2000	1085	13	475
4	2000	930	14	514
4	2000	800	12	435
9	1600	860	4	119
9	2000	692	3	79

Times and manpower

The scintillator and plastic cover plates will be cut in Lab 8 at FNAL. The time to cut the scintillator and plastic cover plates for HB are based on the amount of time it took CDF to cut the scintillator and plastic cover plates for the CDF Hadron Plug Upgrade. We start by trying to estimate the amount of time CDF took to complete its Thermwood machining. These time estimates include both cut time and set-up time. The cut times were estimated form the total length of cuts and the cut speeds that were used. From the comparison of the CDF estimate and the actual CDF times we get a fudge factor. The fudge factor is an estimate of how much our time estimates are off. Next using the same methods, we estimate how much time it will take to cut the CMS plastic cover plates and scintillator. We have measured the machining speeds for the CMS grooves. We then multiply the CMS time by the fudge factor to get the CMS production time. The total times should be fairly accurate.

The actual time CDF spent was 1 calendar year. That calendar year consisted of 2 consecutive Thermwood shifts , 16 hours, on one Thermwood machine. The actual cut time available was 12.5 hours. The 3.5 hour overhead is due to turning the machine on, turning the machine off, cleaning the machines, and preparing the machines for the next day. Lab 8 has two Thermwood machines, and the technician had to prepare both machines for the next day. The CMS estimates will assume that we get the same machine time/day as CDF did.

We estimate that it should have taken CDF 0.58 years to cut the scintillator, 0.22 years to cut the plastic cover plates , and 0.13 years for set-up for each layer. We are off in our CDF estimate by 7%, as it took CDF one year of cutting time. Hence ,we multiply our CMS time calculations by 1.07. For CMS, we obtain the cut times of 1.44 years for the scintillator, 0.54 years for the top plastic cover plates and 0.34 years for the bottom plastic cover plates. We estimate 0.22 years for set-up time for each layer, for a total of 2.55 years of production cutting.

Next we estimate start-up times for the cutting. It took CDF 0.5 years from the time it tried to start cutting to full production. We give the same estimate, but we break it up into two components. We estimate 0.25 years of start-up for the preproduction wedge and .25 years for start-up for the full production. Hence, total barrel cutting time will be 2.80 years.

For the preproduction prototype we assume 0.25 years for start-up time. We also assume 0.22 years for the set-up time and transition between layers. These were the same times which we used to calculate the total production time. For the cutting time we take the total cut times and divide by 36. This gives us a total time of .55 years for the preproduction prototype.

Scintillator tray production cannot go faster than the Thermwood time, but with enough people hired it should go at the same rate. The assembly steps need to assemble the CMS megatiles are very similar to CDF. CDF needed about 3 people to do the assembly up to the fibre assembly. Hence, we estimate the 3 people are needed to do the preassembly up to the fibres. In addition we estimate this part of the project needs at least one full-time production manager.

Quality control

An important quality control item in this step of the production is tracking the quality and uniformity of the scintillator plates used for each megatile. As part of the SCSN81 scintillator purchase agreement for CDF Upgrade project, Kuraray marked each plate delivered with an ID number that specified the production history of the plate. This information is included in the manufacturing protocol for the megatiles. Plates from different production batches are also tested and the results included in the protocol. Both the attenuation length and the light yield are monitored using tests described in the scintillator specification document. With this protocol, the megatile performance having to do with scintillator quality can easily be monitored as the megatile production proceeds.

Several checks of the scintillator plates are done. From each plate a 1 cm by 1 cm piece of scintillator is cut out of the sheet. This piece will be stored with the information as to which scintillator tray it is associated with. If a problem is found with the scintillator tray this piece can be retrieved and measured with a bismuth source. A fraction of the 1 cm by 1 cm pieces will be measured to determine the overall scintillator quality. The thickness of the plates will be measured in three places. Any plate with a the thickness outside the tolerance will be rejected. However, it is very important that the thickness of the plates not exceed 4.5 mm. To ensure they do not exceed 4.5 mm, a gauge with a 4.5 mm gap will be made. This gauge will be run down the edges of the plates. Any plate with a point that is thicker than 4.5 mm will be rejected.

After the scintillator is machined, a fibre is passes through each groove to insure each groove is clear. From knowledge gained from manufacturing the megatiles for CDF, we know that the dominate variation in the response of the scintillator trays is due to the variation of the fibre groove of the scintillator. The cutting of the scintillator gives a 5.5% rms for the light output and the distribution is gaussian with no tails. There are no manufacturing problems from cutting which give rise to low light yield tails. This information was determined by manufacturing 20000 tiles in 594 scintillator trays for CDF and measuring them. Hence, a visual inspection of the scintillator is sufficient to determine the quality of the megatile. The visual inspection determines the following: The scintillator is clean with no scratches, the edges are painted white, the fibre groove is clear, and the epoxy fills the separation groove.

The difference in grooves between low light yield tiles and high light yield tiles cannot by determined by inspecting the grooves. It can only measured when the trays is completely assembled with fibres. Hence, a sample of the preassembled pans will be stuffed immediately with fibres and measured. Production schedules will dictate whether all the pans can immediately stuffed with fibres.

The preassembly of the scintillator pan is done very quickly after that parts are available. This preassembly checks the whether the plastic is milled correctly.

Each scintillator tray will contain a traveller. The traveller will contain information about the tray at each step in production. It will contain information about the scintillator pieces used in the tray. Using the data from Kuraray, we can reconstruct information such as the thickness of the scintillator, the batch of the fluors, etc.

Preassembly of megatiles

The preassembly of the scintillator pan done very quickly after the scintillator megatile sub-assemblies are prepared. This protects the megatiles from damage. First the rivets are snapped into the rivet holes in the bottom plastic plate. The plastic is laid on a table and the sheet of Tedlar is put down over the plastic. The Tedlar has holes in the position where the rivets are. Next the Tyvek is put down over the Tedlar. The scintillator is put down over the Tyvek and positioned with the rivets. a piece of Tyvek is placed over the scintillator. The bottom sheet of Tedlar has been cut big enough so that it can fold around the edge of the scintillator. The sheet on one side is taped onto the top sheet of Tyvek. The sheet on the other side is folded around the scintillator and is taped onto the Tedlar. This forms a light seal for the scintillator. Next the top black plastic cover is put on the Tedlar. 4-40 flat head screws are put through the holes in the black plastic and are screwed into the rivets. A electric screwdriver with controlled torque is used to tighten the screws. The optical fibres are not part of this assembly. After this assembly, the scintillator is well protected and can be safely stored or shipped anywhere. The preassembly trays are stored in boxes awaiting the fibres.

Quality control

Quality Control of the preassembled tray is visual. We look at them to determine that all the tasks are performed. A traveller is checked off for the steps for the preassembly. The thickness of the scintillator pan must not exceed 8 mm. A special gauge will be made which has a air gap of 8 mm. The tray will be measured with the gauge along all edges to ensure the tray thickness does not exceed 8 mm. A sample of the preassembled trays have fibre installed and they are measured them with the scanner after the production.

The technology of production of the tiles was developed and tested for more then thousand tiles by SDC and CDF groups. New results were obtained during R&D at CERN by CMS collaboration. All the information and experience which we have give us confidence that the tile will satisfy the CMS requirements.

Fibre cutting/polishing/splicing/assembly

The WLS fibres are cut to length. A template will enable to fibres to be cut to the correct length. Next both ends of the fibres are polished. Next the one end of the fibre is mirrored. The clear fibres are cut using a template to a length two inches longer than the length the fibre will be in the connector. The fibres are spliced together with an automated fusion splicer. The set of 17 polystyrene fibres + one quartz fibre are then assembled into a connector.

The pigtails are made using a plastic template with fibre grooves set to the correct length of the fibre run in the actual megatile. At one end of the template, a connector is secured onto the template. The template for the side pigtail has location for the connector offset from the fibres. Fig. 6.21 shows the curve the pigtail must make at the connector. First, each spliced WLS+clear fibre for a specific tower is inserted into its hole in the connector insert and then laid into its corresponding groove on the template. As there are tick marks in the template at the location of the splice for each fibre groove, it is clear if a fibre from a wrong tower is laid into a groove. After the fibres are in place, kapton tape is put on the bottom and top of the pigtail. This retains the shape of the pigtail and keep the pigtail flat. For the pigtails for the side trays another operation must be done to put in the curve near the connector. The kapton tape to hold the fibres is put on up to 30 cm (6 inches) away from the connector. A total of 15 cm of fibre away from the connector is left free of tape. The fibres are inserted in to connector. The connector and fibres are rotated to put in the bend that the pigtail fibres need for the side trays. The connector is then inserted into its position on the template and the fibres near the connector are taped in place. Hence, the fibres will easily follow the pattern they must follow in the scintillator tray. The fibres are secured with kapton to the connector and then glued. After the glue cures, the connector insert is faced off with a diamond cutter to form a clean, uniform optical surface. The combination of the fibre fusion splice, the WLS fibre mirroring, and the optical connector produce a light transmission rms spread of 3.5%.

We assume that the same steps that were needed for CDF to assemble the pigtails will be used by CMS. In order to estimate the assembly time for the pigtails we have used assembly times taken from CDF. The steps needed for building the fibres are the following:

engraving the connectors, cutting the fibres, polishing the fibres, coating the mirrors with epoxy, splicing, cutting the protective tube used on the fibres, laying out the pigtail, gluing the pigtail, polishing the connector after gluing and testing the pigtail. Since the pigtails are bigger for CMS we estimate that it will take 20% longer to do the following steps: laying out the pigtail, gluing the pigtail, splicing the fibres, and testing the pigtail. We assume that it takes 10% longer to polish the pigtail. With the above estimates , we estimates it takes 4.9 man hours to make a pigtail for 5 degrees. This gives 350 hours needed to make the pigtails for a wedge. With 7 man hours in a day, this amounts to 50 days. For the entire barrel, it takes 12600 man hours. With 240 days in a year, this amounts to 7.5 man years of production

It took CDF about 6 months of start-up time for the pigtail production. During this period, one full time CDF physicist and 2 technicians worked on fibre R & D. We estimate that it will takes 0.30 years of start-up for the preproduction prototype and 0.30 years for the barrel.

For the preproduction prototype we estimate we need 1 production manager and 2 technicians. The time is 0.3 years of start-up + 0.2 year = 0.5 years of production. With 4 technicians and a production manager, it will take 0.3 of start-up + 1.9 years = 2.2 years to produce the pigtails for CMS.

Quality control

Unlike the scintillator, low light tails in the tile response can come from bad fibres. Almost all of the problems in the tile/fibre assembly occur from bad splices or WLS fibre problems. Therefore, fibres are checked and tested prior to use. Several fibres from every batch of Kuraray are visually inspected for defects. If defects are found in these fibres then all the fibres of the batch are inspected. For WLS fibres, a sample is scanned with the UV scanner to assure that the light yield and attenuation length are within specifications. The fibres for each tower (fixed length green) are cut to length. The WLS fibres are cut in bulk, polished, and mirrored on one end. Each batch of mirrored WLS fibres has several control fibres which are checked to assure uniformity in the mirroring. The reflectivity of the mirror is measured by measuring the mirrored fibre with the UV scanner. Next, for a small sample of test fibres, the mirror is cut off, and the fibre is remeasured. From these two scans the reflectivity is calculated. We expect a reflectivity of 0.85 – 1.5%.

Each week the splicing quality is checked. This is done by taking a WLS fibre, cutting it in the Middleof the fibre, and splicing it there. Next this fibre is scanned with the UV scanner. By measuring difference in light output across the splice the transmission across the splice is measured. The transmission across the splice expected to be 92% with an RMS of 1.8 %. In this measurement, the cladding light is removed by putting black tape on the fibre cladding before photodetector.

After the WLS and clear fibres are spliced and assembled into fibre-connector assemblies (pigtails), all fibres for all pigtails tested. They are tested in an automated UV-scanner box that is controlled by a PC. Those that are out of specifications are either reworked, or rejected outright. The results of these pigtail scans are saved in a data base for future reference.

Quality assurance

The main quality assurance tool is the UV fibre scanner. The light yield of all the fibres in a layer is compared and all bad fibres are replaced.

Source tube preparation and routing

The source tubes in the megatiles will be 18 gauge thin wall stainless steel hypodermic tubing, needle-grade fully hardened. The nominal OD is 1.27 mm to 1.32 and the ID is 0.965 mm. The source-carrying "wire" is 22 gauge stainless steel hypodermic tubing, 0.71 mm OD, with a bullet-shaped enlargement of approx. 0.833 diameter closing the active end of the tubing. As discussed elsewhere, the source wire is given a NICOTEF antifriction coating. All this is done before the active element is loaded and a keeper wire inserted, followed by closure of the inactive end of the source "wire".

The metal source tubes will be cleanly finished at one end, probably by EDM cutting. Each tube is crimped, or crimp-cut to length, and laid into the black plastic groove. The clean-cut end is secured in the pan-edge coupler with a nylon-tipped 2-56 set screw. The tubing is then taped in place with 0.1 mm thick polyester backed clear tape. The depth of the groove in the black plastic is nominally identical to the OD of the metal source tubing. The width of the groove is at least 0.065 mm to provide tolerance (especially against kinking) and the groove will flare near the edge of the pan to provide tolerance going into the pan-edge tube coupler. The tube should end near the edge of the last tile (at η=0), but should end approximately 1 cm short of the end of the groove in the plastic, for tolerance and to accommodate some degree of thermal contraction of the plastic (the coefficient of thermal expansion of plastic is some ten times that of steel). The pans should be protected from large thermal excursions at all times.

Quality control

After cutting and before closure of one end, each metal tube will be flushed and/or blown-out, and probed with a 0.89 mm diameter wire to guarantee clearance for the source wire.

The tube must be securely fastened to the coupler. Tightening of the nylon-tipped set screw must be done firmly but not excessively, or the tube will be distorted or dimpled.

Test: The coupled tube must resist a pull of at least 3 kg-weight before being laid into the groove. If it fails, the set screw will be backed off and the tube recoupled more tightly.

Test: The tube and coupler must also still freely pass the 0.89 mm probe wire. Any tube failing this probe will be either repaired or replaced. Satisfactory repair can be made by carefully forcing an approximately full-diameter probe into the tube. The person doing the coupling will do the tests immediately. This will provide rapid feedback. The probe test will be repeated by another person, as a cross check.

It is important that the distance of the tube to the scintillator, and the degree of embedding of the tube in the plastic, not change with time, or the accuracy of the collimated source to wire source ratio will be degraded. We will rely on QC/QA of the depth of the groove in the plastic, and the tight manufacturing tolerance of the steel tubing. We believe that taping the tube into a nominally same-depth groove will locate it adequately. We will rely on QC/QA of the megatile assembly and riveting procedure. We will rely on the support-springs which locate the megatiles to the back of the copper slot, to help keep the megatile packages in a compressed state.

The coupling of the plastic tubes to the pan edge and to the indexer of the wire source driver will be checked by a 3 kg weight pull test.

Quality assurance

Travellers will accompany batches of tubes, and will have checkout lists detailing procedural steps, including probing and testing. Similarly, tube installation and the testing thereof will be made part of the travellers which accompany megatiles.

The plastic tubes connecting pan source tubes to the source driver indexers will be colour coded at both ends, to help prevent scrambled couplings.

Final scintillator tray assembly

In the megatile final assembly, the pigtails are installed and the connector piece of the pigtail is attached to the scintillator tray with rivets. The fibres in a pigtail are stuffed into their corresponding scintillator tiles, and the rest of the fibre laid and secured in its black plastic cover routing groove. The fibres are taped over with 6 mil polyester tape. To insure uniform compression, all rivets are torqued to fixed, specified level.

Quality control

After installation of the optical fibres in the scintillator tray, the tray is put through a QA/QC test to assure that the light yields from each tile are within specifications. Light yields from tiles are required to be –20% of nominal. Those that are not within specifications typically have fibre damage in either the splice or WLS fibre. The QA/QC test is there to detect and correct these problems. Light yield results from these tests are also stored in a data base for future reference.

Each scintillator tray will be scanned by the Megatile Scanner using a photon source. If any individual tile light yield is outside of tolerance, due for example to broken WLS fibre, corrective action will be taken. The light yield information of each tile of each tray will be saved in computer files. There are 18 wedges in each half barrel of HB, so there are 36 identical wedges. Each layer in a wedge includes one two-j wide Middle(M) tray, and two singe-j wide trays. Therefore, there are 36 identical middle, side-left and side-right trays for each layer. The mean light yield of all the layers can be matched by ordering each layer based on its mean light yield, and matching the lowest and highest mean light yield layers, respectively in corresponding wedges. Three megatile scanners will be constructed, one for HB, one for HE and the last one for HOB. The HOE tiles will be scanned by the HB megatile scanner. Each megatile scanner has a photon source that scans the megatile in x-y motion and stores the information in a computer. The HB scanner has a scan of 450 cm· 110 cm.

The relative tile-to-tile light yields from completed megatiles for CDF is shown in Fig. 6. . As the plot is shown for large scale production, we expect the same result for the CMS tiles. The correlation between the light yield variations measured here and the pigtail light yield variations are shown in Fig. 6. .

The light yield measurements are taken with a collimated ^{137}Cs g source positioned over the centre of each tile. This is taken on an automated x-y scanning table controlled by a PC. The optical readout of scintillator trays, is done using mass-terminated optical cables which go to an optical patch panel which takes the light to a Hamamatsu R580-17 PMTs. The photomultiplier tube gains are monitored by two systems. One is a set of reference SCSN81 tiles (read out with Kuraray Y11 fibres) permanently connected to the PMTs. These are scanned by the g source to provide a tile/fibre reference system. The second monitor is a set of NaI (with Am^{241} "light pulsers" directly mounted on the face of the PMTs. The megatiles, the x-y scanner table, and the optical system are within a large dark box. Measurement errors are

1% or less and the PMT gain monitoring system tracks the gain to better than 1%.

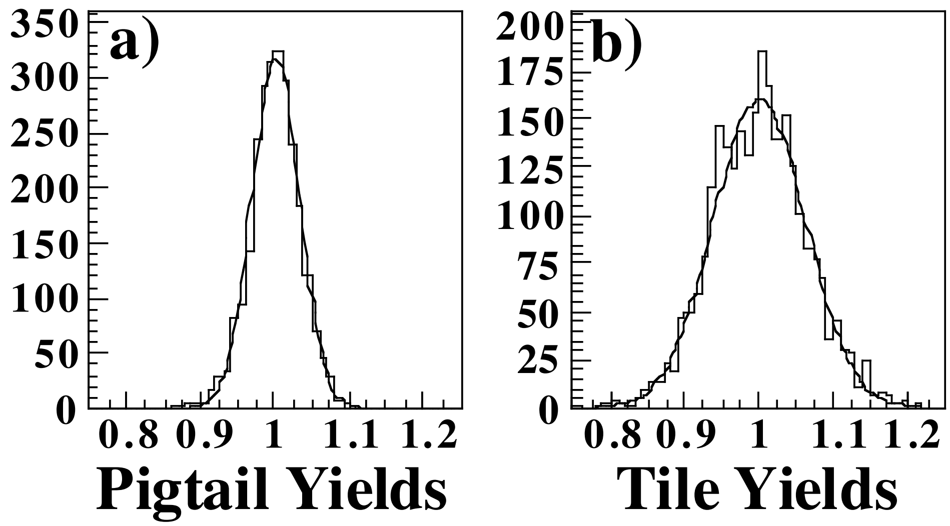

Fig. 6. 34: a) Relative light yield of fibre/connector assemblies (pigtails) before insertion into megatiles. The rms of this distributions is 3.5%. b) Relative light yield of individual tiles after the final assembly of fibres into megatiles. The rms of this distributions is 6.5%.[4]

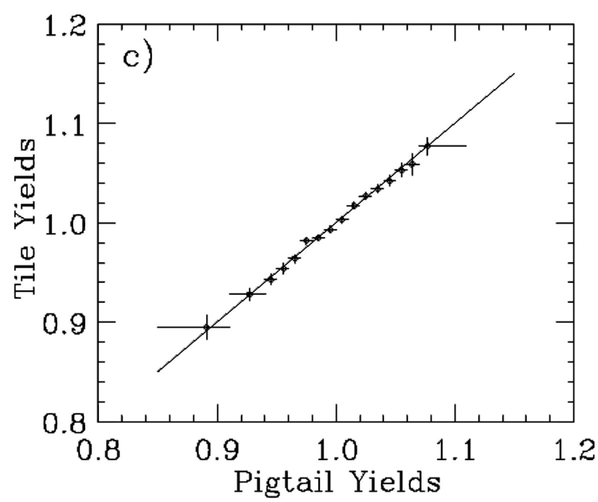

Fig. 6. 35: Correlation between average fibre light yield (x axis) and average tile light yield (y axis). CDF data.)

In addition to the collimated g source measurements, pointlike source measurements are taken using the source calibration tubes and a ^{137}Cs wire source. The correlation between the collimated and point source measurements is good to ~1 % for a given size and shape of tile, indicating that the source tube locations, especially their heights above the scintillator, are very reproducible. There is a ~20% systematic variation of the tile response to the pointlike source as a function of tile size and shape. Large tiles have greater path lengths for the g rays. On the other hand, the collimated g source uses a lead cone such that the direct g radiation falls entirely within a tile. This makes the collimated source response less dependent on source height and tile size. Since only the wire source can enter the assembled calorimeter, a data base is maintained of both the pointlike and collimated source responses.

Using a similar volume integral calculation for the pointlike source responses, the calculated pointlike to collimated response ratios (averaged, for each tile, over all megatiles in a layer) track the measured ratios with a rms of better than 2%. The calculation attempts to model the actual tile geometry in detail. For the final calibrations, the use of measured ratios is preferred because they should reflect any variations in source tube placement, etc., from one megatile to another.

Below are the measurements taken for quality control and quality assurance during production of the pizza pans.

a) Record information on each plate of scintillator from the manufacturer. Take and save samples of the scintillator as megatiles are made.
b) Measure the light yield of control samples from each batch of scintillator sheet. Measure attenuation lengths from batches.
c) Inspect each batch of optical fibres, and measure the attenuation lengths and light yield from samples of each batch.
d) Measure the combined light yield and transmission of each fibre-connector assemblies (pigtails).
e) Measure the light yield of each assembled megatile with a collimated and a wire (pointlike) ^{137}Cs γ source.

The key to production quality control is contained in Steps 4 and 5. Production information kept in a data base includes:

a) The information sent from the manufacturer about the scintillator pieces.
b) Measure of the light yield and attenuation of the scintillator control pieces.
c) The results of the UV pigtail scans.
d) The results of the collimated and wire source scan of the megatiles.

Final assembly manufacturing

The total calendar time for the final assembly is determined the amount of time it takes to cut the plastic cover plates and scintillator. Production can not go faster than this time. Hence, we will assume that enough technicians will be hired to keep up with rate of production of the preassembled trays and pigtails. We estimate the number of technicians need for final assembly by looking at what CDF needed. CDF needed one technician to put in fibres, one technician to test the pans and one technician to do the final assembly and do other jobs that were necessary. Hence we estimate we need a production manager and three technicians for the final assembly.

6.7.2 HE manufacturing

The end cap hadron calorimeter must have about 27500 scintillation tiles (4 mm thick) with different size and configuration. Only 1/36 part of them are identical. The mean size of the tile is about 15x15 cm^2. The total area of the plastic scintillator is about 620 m^2. The total length of the tiles edges and key shape grooves is about 16.5 km. Cutting and grooving of the tiles will be done with high speed milling machines. Technology tested ensures success of key shape groove production at revolution speed 20000 rpm and at the speed 20 cm/min via two milling passes. The edges cutting speed is 40 cm/min via one milling pass. So the mean size tile will be fabricated during 8 min. To finish all the 27500 tiles it will be needed about 1.3 year with one milling machine working 8 hours per day. We plan to use at least two milling machines.

6.7.3 HOB manufacturing

Machining of scintillator and plastic covers

For HOB, as described earlier, there will be one tile per tray in the f direction. But in the z direction, a tray will cover an entire muon ring. This means that one tray will contain 4-6 tiles. The individual tiles will be part of a big piece (similar to a megatile for HB). Deep grooves will mark the z boundaries of these tiles. Due to physical constraints there will be several different sizes of the tiles (see section 4.5.1 for the table of sizes). All these sizes will be kept in a data base, which will be referred to while machining the scintillator plates. The procedure of making the scintillator plates will be similar to that for HB, as described in section 6.7.1. However, since the thickness of the scintillator for HO is 10 mm, the grooves that separate the tiles optically will be 9.5 mm deep, leaving 0.5 mm material at the bottom. The scintillator plate is fragile at this point of the production and therefore has to be handled with care. A CNC machine of appropriate capacity will be used for milling the grooves. A vacuum bed will hold the scintillator in place with rubber gaskets during grooving. The position of the scintillator on the vacuum bed will be marked accurately. This way, the scintillator piece can be brought back to the same position if it is removed.

Grooving will be done in two stages. The deep, separator grooves will be milled first with a 0.89 mm(width) cutter. These grooves will be 9.5 mm deep leaving only 0.5 mm material at the bottom. The scintillator plate will then be taken out and the deep grooves will be filled with epoxy as described for HB in Section 6.7.1. Until the epoxy dries the scintillator plate will be fragile and has to be handled with care. After the epoxy dries, the scintillator plate will be put back on the vacuum bed again in the same position. Then the sigma grooves will be made with a keyhole type design and the procedure will be as described in 6.7.1.1. The length of the grooves will vary according to the sizes of the tiles. These lengths will also be kept in the data base.

The 2 mm piece of black polystyrene plates which will be used for routing the fibres coming from the scintillator tiles, will also be grooved by the CNC machine. There will be one 2 mm and one 1 mm polystyrene plate corresponding to each tray. Therefore these plates will also be of different sizes as given in section 6.5.3.1 Each of the 2 mm plates will be grooved for fibre routing, passage of source tube and quartz fibre routing. The sizes of grooves for each plastic cover plate will be kept in the data base. The CNC machine will be programmed for different grooving using the data base for both the cover plate and the scintillator. Holes will be drilled at regular intervals on the scintillators and the cover plates for rivets which will hold the whole assembly together.

Material needed

HOB will have 360 trays per layer, i.e. 720 in total. Each tray will be roughly 5 degrees in f (0.41 m) and 2.536 m in the z (h) direction. Scintillators will be ordered in pieces having roughly the dimension of a tray i.e. 0.41 m by 2.6 m. Table 6. 12 below shows the material needed for the production of 720 HOB scintillator trays.

Time estimate

In order to give a realistic time estimate for the production of the two layers of HOB, an estimate has to be made of the amount of grooving necessary. The following is an estimate of the total length of grooves in HOB for fibre laying.

If one assumes each groove to be roughly of the size 0.18 m x 0.25 m in layer 1 and

0.21 m x 0.28 m in layer 2 then the total groove lengths will be 6842 m and 6912 m for layers 1 and 2 respectively. Similarly, for the tiles with two grooves, the total groove length will be 126 m and 138 m for layers 1 and 2 respectively. Thus, we will have to mill about 14 km to make all the grooves in the scintillator. This will be the major portion of the production work.

Table 6. 12

Material for HOB.

Material	Quantity
Scintillator, BC408, 10 mm (m2)	770
Black Plastic, 2.0 mm thick (m^2)	770
Black Plastic, 1.0 mm thick (m^2)	770
Reflective paper: Tyvek 0.15 mm (m^2)	1570
Black wrapping: Tedlar, 0.05 mm (m^2)	1650
Y11 WLS multiclad Fibre, 0.94 mm (Km)	15.
Clear Multiclad Fibre, 0.94 mm (Km)	30.
Clear 18-fibre Cable, 0.94 mm (1.2 x 15 mm)(m)	1600.0
Epoxy: TiO_2 loaded resin (Kg)	100
Kapton tape: 0.15 mm (Km)	4

The length of the separator grooves can be estimated similarly. Every tray has typically 6 tiles and hence 5 deep separator grooves. Therefore for 720 trays total number of deep grooves will be 3600. Each deep groove will be roughly 0.4 m long (j length of a tile). Therefore, total length of the deep grooves will be 1.44 km.

The 2 mm polystyrene plate will have two wide pathways for fibre routing and one groove each for laser signal and radioactive source tube. This can be considered as four grooves, each of length 2.56 m. The total length of grooves on 720 such polystyrene plates will be about 7.4 km.

The following production times are based on simple calculations that break down the total operation into steps whose timing has been measured. The times are given for the machining of all the tiles in the two layers of HOB. A CNC day is one 8 hour shift. A year is 200 working days. A summary of the HOB labour time is presented in Table 6.13.

Table 6. 13

Time Estimate for HOB Production

Scintillator	One tray
0.94 mm ball groove 0.5 da	ys
Separation groove	0.1 days
Total	0.6 days
Top black plastic	
Grooving	0.2 days
Total CNC time	0.8 days

Therefore for 720 trays we need 600 CNC days, i.e. 3 years in real time.

Quality Control during production of scintillator plates

The scintillator pieces will first be examined for any damage, like scratches or breaks. After some superficial cleaning it will be sent for grooving. Next will come fibre laying and packing. A quality control sheet will be filled at each stage of the production on each piece of scintillator. The information on these sheets will be then be entered into a data base in the computer.

The following steps will be taken to check the quality of the tiles.

- Record information on each plate of scintillator from the manufacturer.
- Measure the light yield of control samples from each batch of scintillator sheet. Measure attenuation lengths from batches.
- Inspect each batch of optical fibres, and measure the attenuation lengths and light yield from samples of each batch.
- Measure the combined light yield and transmission of each fibre-connector assemblies (pigtails).
- Measure the light yield of each assembled scintillator tray with a collimated and a wire (pointlike) ^{137}Cs gamma source.

The following production information will be kept in the data base.

- The information sent from the manufacturer about the scintillator pieces.
- Measurement of the light yield and attenuation of the scintillator control pieces.
- The results of the UV pigtail scans.
- The results of the collimated and wire source scan of the scintillator trays.

Fibre cutting/polishing/splicing/assembly

Essentially the same steps will be followed for HOB as described for HB in chapter 6.7.1. Two fibre splicing machines will be set up along with a single fibre polisher. These will be used to polish the WLS fibres and splice them to clear fibres.

Quality control

A UV scanner will be set up which will be able scan and measure the attenuation length of several fibres simultaneously. Fibres will be tested at regular time intervals to monitor the uniformity of their performance.

6.8 OPTICAL CONNECTORS AND CABLES (HB/HE/HOB/HOE)

6.8.1 Connector and cable design

All the connectors, one at each end of the optical cable, one at the pigtail exit and one at the HPD Box entrance have essentially the same design. Fig. 6.20 is a schematic sketch of these connectors showing 18 fibre holes, the alignment pin holes, the dimensions w, the width, h, the height, d the depth and the location of mounting holes. The alignment of two joined connectors is maintained by two pin/screw elements within the alignment holes which bracket the 18 fibre holes. The alignment holes are different sizes to allow only one possible pin numbering. We have chosen to number the fibre holes 1-18 and require the 1 pin be next to the largest of the alignment holes. The overall arrangement is sketched in Fig. 6.36. With this arrangement the two ends of the optical cable may be interchanged without danger of mixing up the fibre numbering.

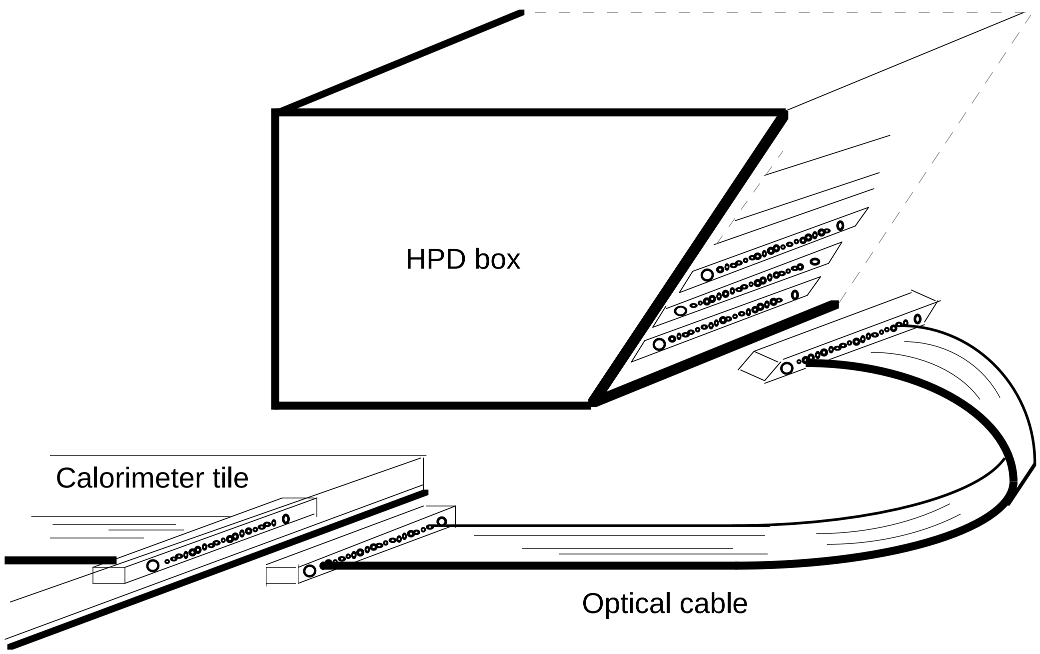

Fig. 6. 36: Schematic drawing of the overall optical arrangement.

The connectors on the ends of the cable will use the mounting hole region for attachment to a strain-relief boot and a light tight cable jacket. Similar optical connectors will be used for HB, HE, HOB and HOE calorimeters with only the channel count modified for HE and HOE. The overall sizes of the connectors for the other calorimeters vary according the mounting needs, but the basic design of the fibre holes and alignment holes will be the same.

After studying various prototypes and materials it was decided to have the connectors made by injection moulding. We could have a reliable, precise product (within tolerance) at a reasonable price. The material chosen was acrylonitrile-butadiene-styrene (ABS) plastic which has a shrinkage during injection moulding of less than 0.5%. Delrin, another possible candidate material, was found to have a shrinkage of 2% and was rejected.

In order to do the injection moulding a stainless steel mould is required. Aluminium moulds will not produce the required number of connectors. In the following we describe the tests that were made which lead to these decisions.

In the past we found that alignment tolerances have been met for moulded connectors as long as the moulds are initially calibrated and monitored occasionally throughout production. Measurements made on 1100 moulded connectors (with 0.835-to-0.835 mm fibre matching), produced for the D0 preshower detector determined light transmission to be 81% with sigma=3%. An air gap was used between connectors. Fibres were illuminated by green LED bargraphs with diffusers. The diameter step-up design would improve transmission slightly (85%) however light loss is dominated by a 9% transmission drop due the air gap. Transmission through connectors have been monitored for two years and found stable to – 1%.

6.8.2 Connector production

The connectors will be injection moulded from a mould made of steel. The useful life of an aluminium mould is about 1000 pairs of connectors. The construction of the mould will be farmed out to an external vendor. Production of the connectors could take place at the vendor. However, we are also contemplating doing the production on an existing commercial quality moulding machine located at UIC.

Clear fibres and ribbons will be held in place with BC-600 epoxy and then fly-cut using a diamond to polish the ends at the P3 facility at FNAL. Approximately ten connectors can be polished simultaneously in one twenty minute run on the P3 facility.

6.8.3 Quality control

Transmission depends on careful fibre-to-fibre alignment. The holes for the fibres are fixed during creation of the mould and misalignment must be kept below 50 microns in order to keep the transmission high. Initial alignment will be checked with measurements of the mould and measurement of the first moulded pieces. Several connectors will be assembled with clear multiclad fibre and the transmission directly measured. Green LEDs are used as light sources and the output of silicon photodiodes are measured with a picoammeter.

Other quality factors which must be monitored include thin layers of plastic blocking holes and bubbles in the connector material which can affect strength and optical isolation characteristics. Both are obvious upon visual inspection.

The entire production run can take less than a week in a commercial facility so most monitoring throughout the production run will actually take place after the run and if a problem is discovered, a new run will be performed.

6.8.4 Quality assurance

We have produced injection moulded connectors for the D0 upgrade central fibre and preshower detectors. We have the expertise in mould design and injection moulding so connectors for the HCAL prototypes will be produced in house. However, commercial vendors with larger injection moulding machines will be required for production runs for the final detector.

6.9 HF AIRCORE LIGHT GUIDES

The quartz fibre bundle are formed by loosely gathering together the fibres emerging from the back of the calorimeter using PEEK plastic tie-wraps. The fibre bundle is turned between 75°-90° and routed towards the outer radius of the calorimeter. The first row of PMT are located at about 100 cm in radius from the beam, whereas the first fibres emerge from the calorimeter absorber matrix at about 7 cm from the beam. The bend radius of the fibre bundle is at least 200 times the fibre radius, or ~8 cm minimum. The length of a typical bundle is about 1 m, including the bends. The fibre bundles terminate in a highly polished, hexagonally close-packed bundle held in place by a snugly-fitting stainless steel ferrule (cylindrical) collar (from 6 mm-18 mm in diameter, depending on eta) and about 7 cm long) which is epoxied in place. The fibre bundle light guide is bent a second time at the ferrule end, so that the fibre ferrule is oriented parallel to the collider beam (along z), pointing towards the photomultiplier windows, through mirrored air light guides. The ferrules all terminate in holes in a rigid annular plate, held by a pressure collet around the conical holes. The steel plate, about 1.4 m in outer radius, is oriented perpendicularly to the beam direction.

The purpose of the air-core lightguide is to:

a) mix the light,
b) save costs of fibres,
c) provide a method to enable heavy shielding around the PMT to be conveniently penetrated, and
d) avoid Cerenkov background generated by mips in a solid light guide.

6.9.1 Design description

The lightguide consists of a hexagonal cross-section hollow regular parallelopiped mirror which is at minimum 3.5 times longer than the useable photocathode diameter. This minimum length ensures that the meridonal light emerging from the fibres (NA=0.22=sinq) centred in the hexagon illuminates the entire cathode with only at most 1 bounce, while only allowing the bulk of the skew rays to have only at most 2 bounces from the mirror. The major diagonal of the hexagon is 1.5 mm less than diameter of the photocathode (15 mm) for a tolerance. The maximal length of the light guide is <35 cm, chosen as a compromise between transmission and shielding.

The shape of the mirror - square or hexagonal - will be optimised before final design in order to maximise transmission, provide good mixing, and minimise needed photocathode area. In the test beam, hexagonal mirrors provided good performance and were a better match to round PMT photocathodes, as described below.

The mirror material has been tested and consists of Alzac (Alcoa Metals), an aluminium sheet material (75-1,000 mm typical available thicknesses). The purified aluminium substrate has been anodised with a special non-porous anodisation, designed for mirrors used in indoor and outdoor commercial lighting fixtures, which survive outdoors in temperate climates. The anodisation produces a sealed film of boehmite, a form of transparent amorphous sapphire (alumina) that is a typical alumina ceramic, and in film coatings highly resistant to radiation damage[5,6]. The total reflectance is guaranteed to be 95% at normal incidence in sunlight. (Note: this process is not normally used for optical mirror protection because the surface finish is not able to reach the wavelength tolerances necessary for high quality imaging - the reflectance has a small ~ few % diffuse component at normal incidence. In the quartz fibre transmission case, at nearly grazing incidence, this is largely irrelevant and contributes to the mixing.) In the HF case, the minimum angle to the normal is about 75°, where the reflectance in the blue (440 nm) averages above 98% in bench tests. These bench tests used a blue LED and the same quartz fibre used in the calorimeter. The light cone from the quartz fibre was oriented onto the mirror material at variable angles and the resulting light measured with Si photodetectors. The mirror materials were fashioned into light guides for bench and beam tests.

In test beam and bench tests, a 1 m long similar cylindrical mirror ~2.5 cm in diameter transmits 65% of the light injected at the emission angle of the fibres (about 15° max.). It is because the emission from the fibres is <13° from the axis of the fibre that good light collection is possible using specular reflection. Fig. 6. shows the design of a slightly tapered light guide used in the test beam with the prototype calorimeter.Fig. 6. shows the measured transmission through these ~ 1m long guides. Fig. 6.39 shows the ADC distribution of the response to 80 GeV electrons in the test beam through a 1 m long air light guide, confirming the 65% measured in bench tests and calculated with ray tracing.

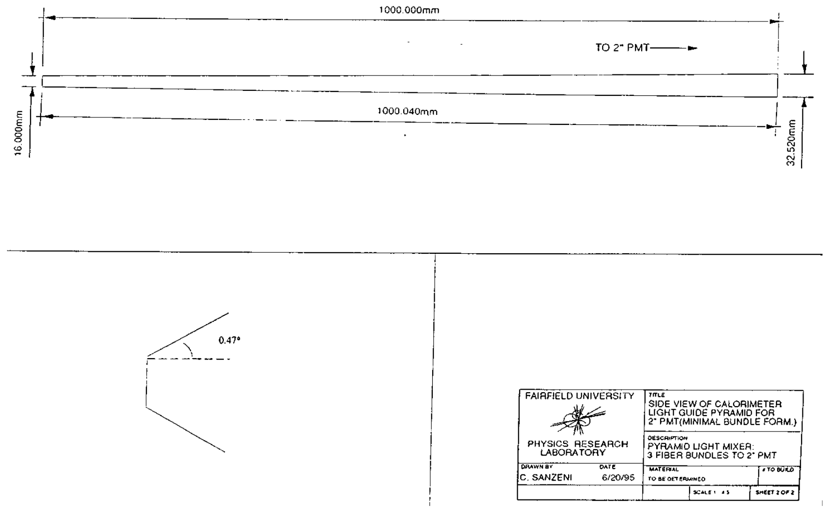

Fig. 6. 37: Tapered light guide design with a 16 mm and 32 mm aperture.

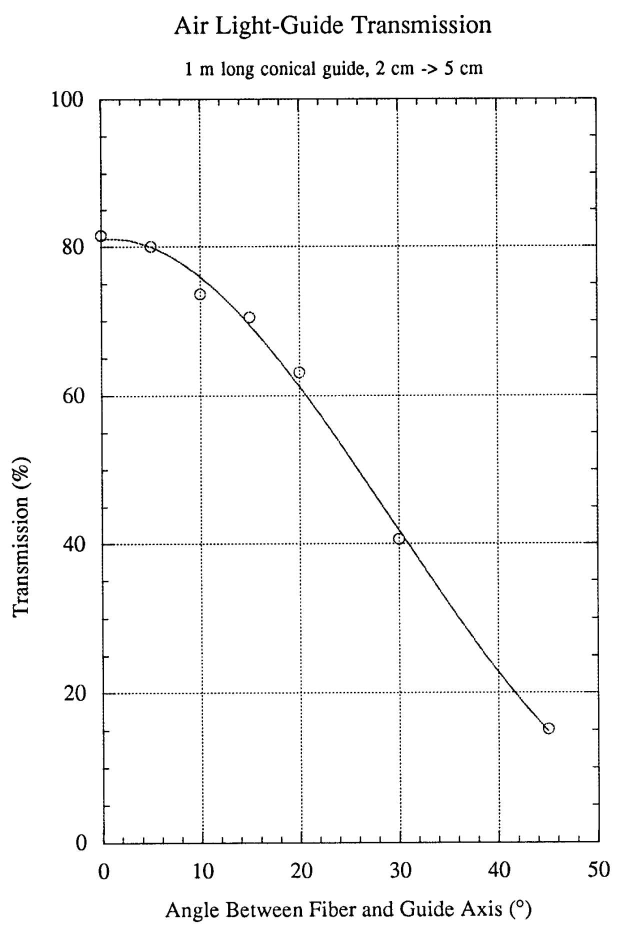

Fig. 6.38: Measured light transmission through a conical 2.8 cm-> 4.5 cm aperture mirrored air light guide using a quartz fibre as the light source vs the angle of the fibre WRT the axis of the air guide. At ~12° (~78° to the surface) about 65% of the light is transmitted.

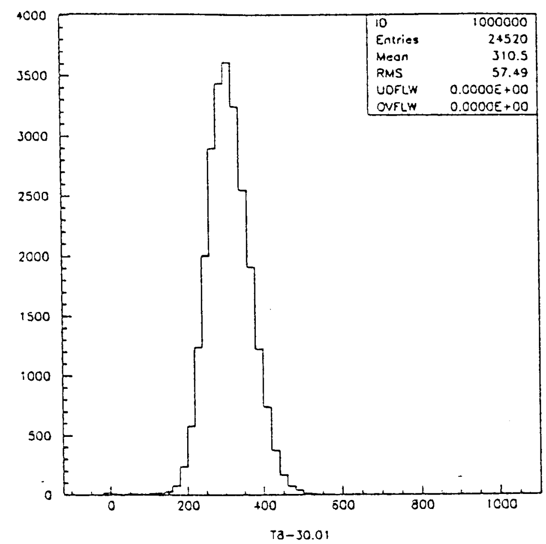

Fig. 6. 39: The ADC distribution of the response to 80 GeV electrons in the test beam through a 1 m long air light guide, confirming the ~65% transmission measured in bench tests and calculated with ray tracing.

For the test beam, hexagonal light mixers as shown in Fig. 6.40, were built using aluminised plastic. Measurements confirmed a reflectivity similar to the Alzac materials. The data shown for the test beam was taken mainly through these guides.

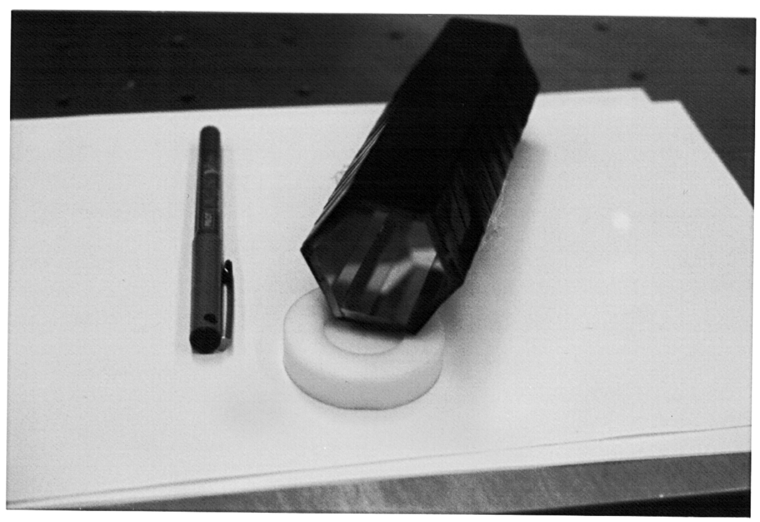

Fig. 6.40: Photograph of a 13.2 cm long x 3.6 cm diagonal hex mirror.

For the HF design, we have specified a short air light guide. This guide is ~31 cm long and 15 mm in diagonal. A photon emitted from the compressed phase space of the fibre will bounce at most 5 times in this guide, and be transmitted at a level of 70% with 93% reflectivity; the average photon will have ~4 bounces and be transmitted at 75%. At 95% reflectivity, typical for the (grazing) angle of incidences >78° emitted from the fibre bundle, the average transmission is >80%.

Full radiation damage tests will be conducted over the next 2 years. If any reason should be found to reject these mirrors, aluminium mirrors overcoated with a film of radiation hard magnesium fluoride, silicon monoxide, or all-metal nickel or rhodium plated mirrors with a reflectance of >90%, are alternates which are known to survive high radiation levels[7,8].

6.9.2 Performance requirements

The minimum acceptable transmission requirement of the air light guides is 50%, which are met by the guides constructed heretofore. This requirement is set so that the least count in a hadronic physics tower is not greater than 5 GeV at h=3. The average energy of a particle at an average p_T of 0.5 GeV, low for LHC , is 5 GeV.

6.9.3 Quality control

The mirrors will be constructed in an assembly line with a precision slitting apparatus to cut the mirror material with a bevelled edge (60°). 3-sided halves of the hex mirror structural element are constructed from 3 mm thick bent and machine-finished steel. CERN-spec epoxy will be used to fasten the mirror skin to the structural elements. The non-reflective seam between the 6 mirror elements must be less than 250 mm in width. The manufacturing process will be designed to ensure that the mirror dimensions are the same with 1% from mirror to mirror, a tolerance of about –0.15 mm. The flatness tolerance is –0.1 mm across each panel of the hexagon. The design parameters are inherently not critical, as the number of mirror bounces is small, so that dimensional changes as high as a few % have negligible effect, so long as the output area is within the photocathode area.

6.9.4 Quality assurance

The first 10% of all mirrors will be tested fully with angle (0°-15°) and transverse scans using fibre light sources. Transmission less than 2% from nominal will be rejected. All others will be tagged for selection. If most of the first mirrors pass testing, all mirrors will be visually inspected, and put in a very simple go/no-go jig, made of fibre light sources and a photodiode array connected to a simple yes/no discriminator consistent with the 10% full testing. In any case, the mirror and PMT assembly will undergo a separate optical test later in the assembly process.

6.10 CABLE AND FIBRE LAYOUT

6.10.1 HB layout

The light from the scintillator pans are brought to the HPD box with optical cables. These optical cables consist of 18 clear 0.94 mm, s type Kuraray fibres with optical connectors at both ends. The optical fibres are covered with Tedlar to make the optical cables light tight. Nissei Opto Co. takes the clear fibre and makes the 18 fibre cables covered by Tedlar. Nissei made a 10 fibre cable consisting of 0.9 mm clear fibre for CDF.

Fig. 6.3 is a view of the CMS hadron barrel at the large h boundary looking in the direction of the beam. It shows the routing of the optical cables from the scintillator pans to the HPD box. The optical cables and source tube are enclosed in a hadron cable channel consisting of 1 mm aluminium. The hadron cable channel surrounds the cables from layer 0 to the photodetector box. The channel protects the cables and forms a light tight seal for the cables and optical connectors.

The optical connectors and source tubes connectors protrude into the 53 degree crack. This is done for 2 reasons. If the optical connector were inside the copper, then the top of the optical connector must lie below the top of the scintillator pan. Since the optical connector is 4 mm high and the top plastic is 2 mm high, we would have to route out the scintillator where the connector is. The fibre for this tile would have to move in 4 cm way from the edge of the tile. The best location of the source tube connector is outside the copper. The source tube connector connects the source tube in the pan for the tube for the driver. Since the tube in the pan is on top of the plastic, the source tube connector must stick above the scintillator pan. Hence, if the connector is inside the copper the copper must be milled out where the connector is. The source tube connector must be 8 mm in depth. Hence, the scintillator must be removed where the source tube connector is if it is inside the copper. This degrades the uniformity of the edge tiles.

Fig. 6.21 shows a top view of the scintillator tray at the end of the megatile. The figure gives a detailed view of the routing of the cables and source tubes at the pan.

Fig. 6.41 is a clasp of this region looking in the direction of the beam. The clear fibres for the pigtail for the Middletray are straight to the connector. while the clear fibres for the pigtail for the side tray are curved. The curve enables the optical connectors for the Middletrays and side trays to overlap in phi. This reduces the amount of space need to route the cables in the 53 degree gap. The source tubes cannot cross the optical fibres on the pan. Hence, at the edge of the pan source tubes route out on both sides of the cables. As shown in the figure, the width across the optical connector and source tube connector is 6.05 cm. To further reduce the space needed to route the cables and source tubes in the 53 degree crack, the optical cables are offset with respect to each other, see Fig. 6.41. Therefore, the optical and source tube connectors take up 6.05 cm in the j dimension for routing. The thickness of the hadron cable channel is 1.1 mm and 3 mm of tolerance separate the edge of the connectors from the inner edge of the hadron cables channel aluminium. The hadron cable channel is 7 cm wide at the lowest radial point. At the photodetector, the cables for the side and Middlelayers plug into different columns. The total j width needed for 10 degrees is 11 cm at the photodetector box. Hence, the hadron cable channel will start out with a j width of 6.85 cm and grows to a width of 11 cm at the photodetector box.

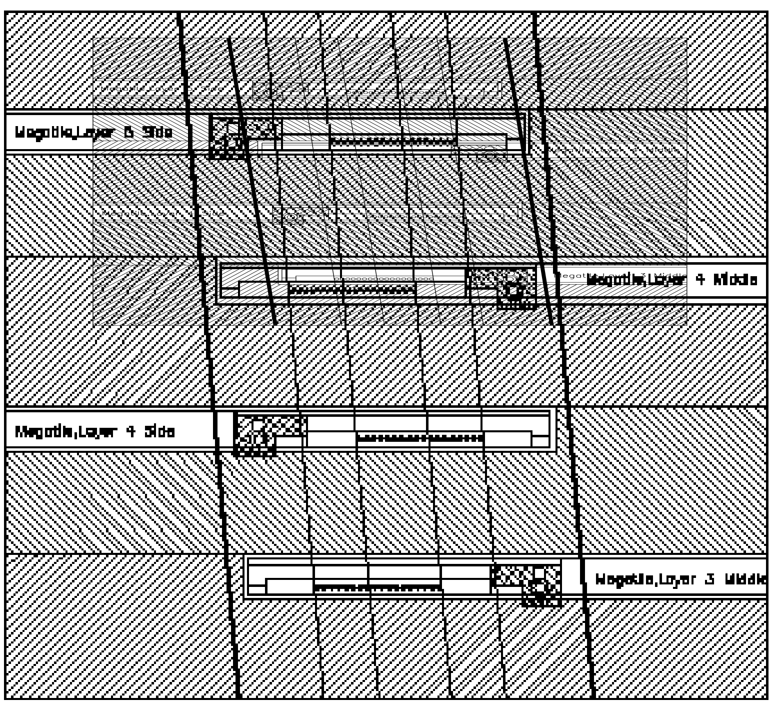

Fig. 6.41: Front view of the optical connectors and wire source connectors.

Fig. 6.42 shows a r-z view of the routing of the cables along the 53 degree crack. The optical connector on the pan and connector for the source tube protrude into the 53 degree crack by 1.9 cm. A 0.7 cm cable connector connects to the pan connector. The total protrusion of the optical connectors is 1.9 cm. The 1.9 cm protrusion of the optical connectors is 1.5 cm normal to the 53 degree line. The optical cables bend to follow the 53 degree line. We have verified that the optical fibres are not damaged if their bend diameter is greater than 3.8 cm Taking the minimum bend radius for the optical cables as 3.8 cm, the optical cables bend to be a minimum of 2.9 cm normal to the 53 degree line. The cables are 0.11 cm thick. Near the photodetector box, the cable bundle will be about 28 cables high, and so the cable bundle is be 3.1 cm thick. 7.0 cm of space perpendicular to the 53 degree line will be needed to route the cables at the photodetector box.

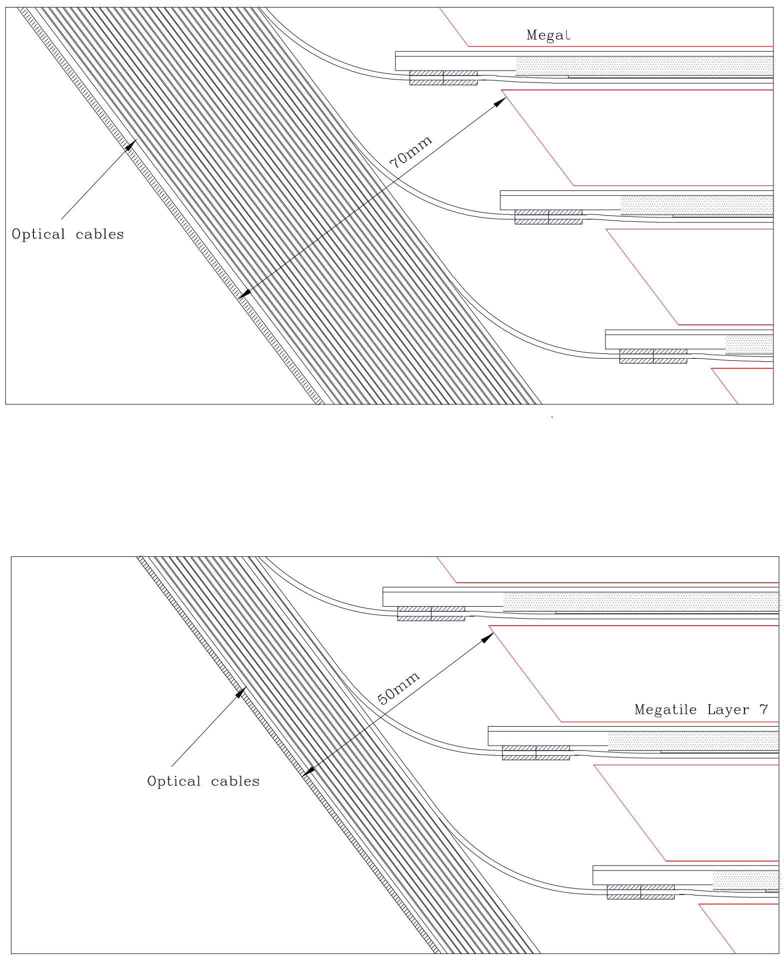

Fig. 6.42: r-z view of the routing of the cables along the 53° crack.

The permanent source tubes start bending approximately 1.5 cm (in z) from the pan and 1.2 cm (in the direction perpendicularly across the HB-HE gap) from the copper. With a minimum bend radius of 10 cm, these source tubes will rise to be 5 cm away from the HB copper perpendicular to the 53 degree line. Hence, the cover for the hadron cable channel will be 5 cm perpendicular away from the HB 53 degree line At layer 0 the channel contains both the optical cables and the source tubes, with the height of the channel determined by the source tubes. At layer 15 the channel will be 7 cm away from the 53 degree line, with the height determined by the optical cables.

6.10.2 HE layout

Each tray (covering 10^0 in j) has two optical connectors (10 fibres in each), two connectors-mixers for laser calibration and two connectors for radioactive source tubes. Optical cables from the trays go to decoding boxes. In each tray the optical connectors are shifted in such a way that all optical cables can be laid in four layers only not to exceed the space allocated for HE cables, as shown of Fig. 6.43. The quartz fibres in protective skin go from connectors-mixers on the trays to connectors-mixers where the laser light is fanned into 36 fibres corresponding to 36 trays in each layer, see Fig. 6.44. The plastic tubes from radioactive source tubes go around the HE in each layer and end up at the same (protruding from the HE cover plate. The basic idea is shown in Fig. 6.45 and Fig. 6. 46. In this way it will be easy to connect them to control system to check the performance of active elements without interfering with other cables when the calorimeter is moved outside of the magnet coil during a shut down period of collider run.

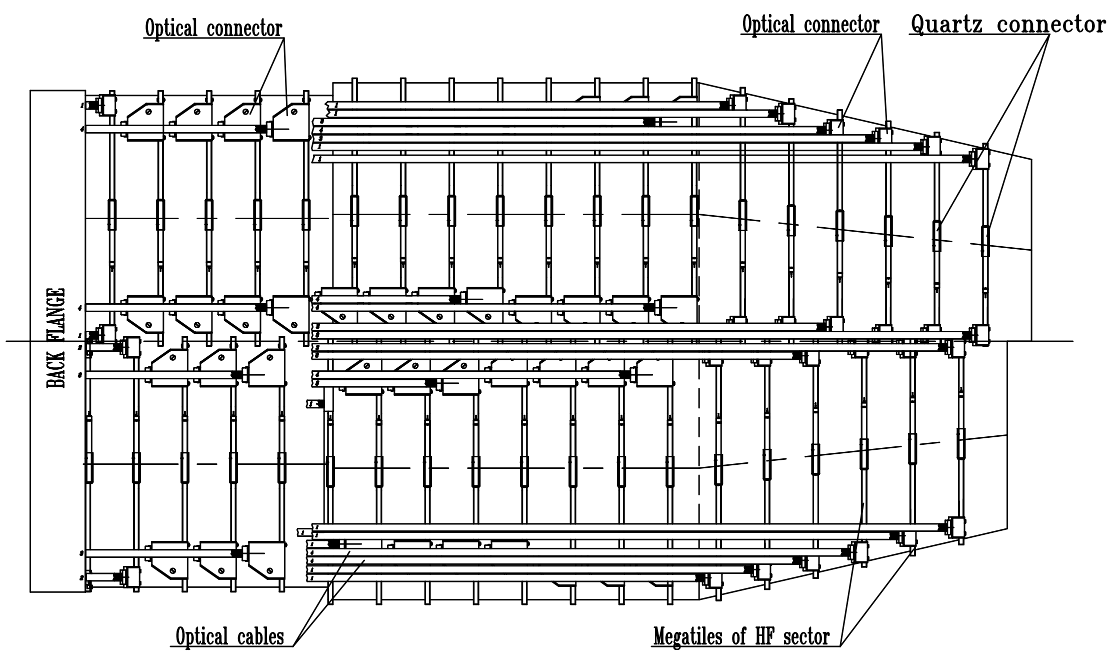

Fig. 6. 43: Layout of the scintillator tray cables.

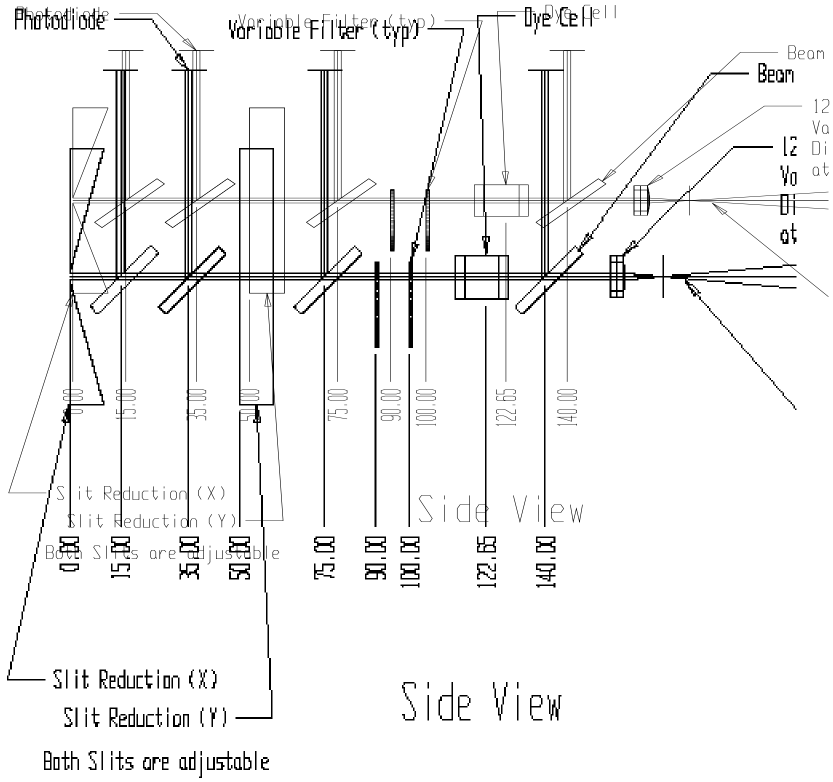

Fig. 6. 44: Layout of the optical cables (side view).

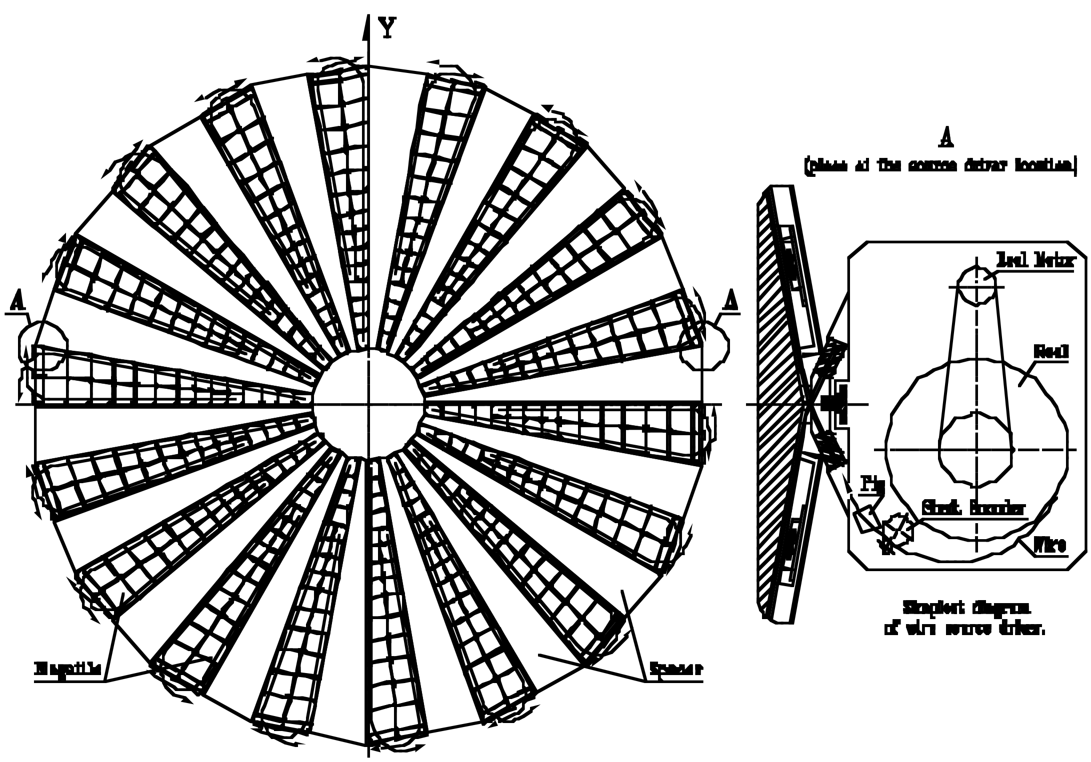

Fig. 6. 45: Layout of the radioactive source tubes.

6.10.3 HOB cable layout

Light from individual tiles in a tray is brought through optical fibre cables to the decoder box, located above the outer most layer of muon station. In each tray there are 4, 5 or 6 tiles depending upon its location. Generally there are 4 fibres per tile (some smaller tiles will have 2 fibres), making a maximum of 25 fibres per tray (24 fibres from the 6 tiles and an additional fibre for transporting laser light to the scintillator tiles). The standard HCAL optical connectors could accommodate 18 fibres. Thus two such connectors per tray will be used. These two fibre connectors will be fixed at one side. Since there are 6 trays in each 30º j sector, 12 pairs of optical cables (6 pair from six trays of Layer 1 and remaining 6 pairs from layer 2) runs vertically upwards and transport the light to a decoder box located at the outer edge of the muon rings. A 30 mm wide and 5 mm thick corridor in the Middleof every 5º j sector on one side of each muon ring is required to route these cables from the tray edge to the decoder box. The total number of calorimeter towers in a 30º j sector for ring 0, 1 and -1 is 36. For ring 2 and -2 the corresponding number is 30. There will be a maximum of 8 fibres for each tower (combining layer 1 and 2).

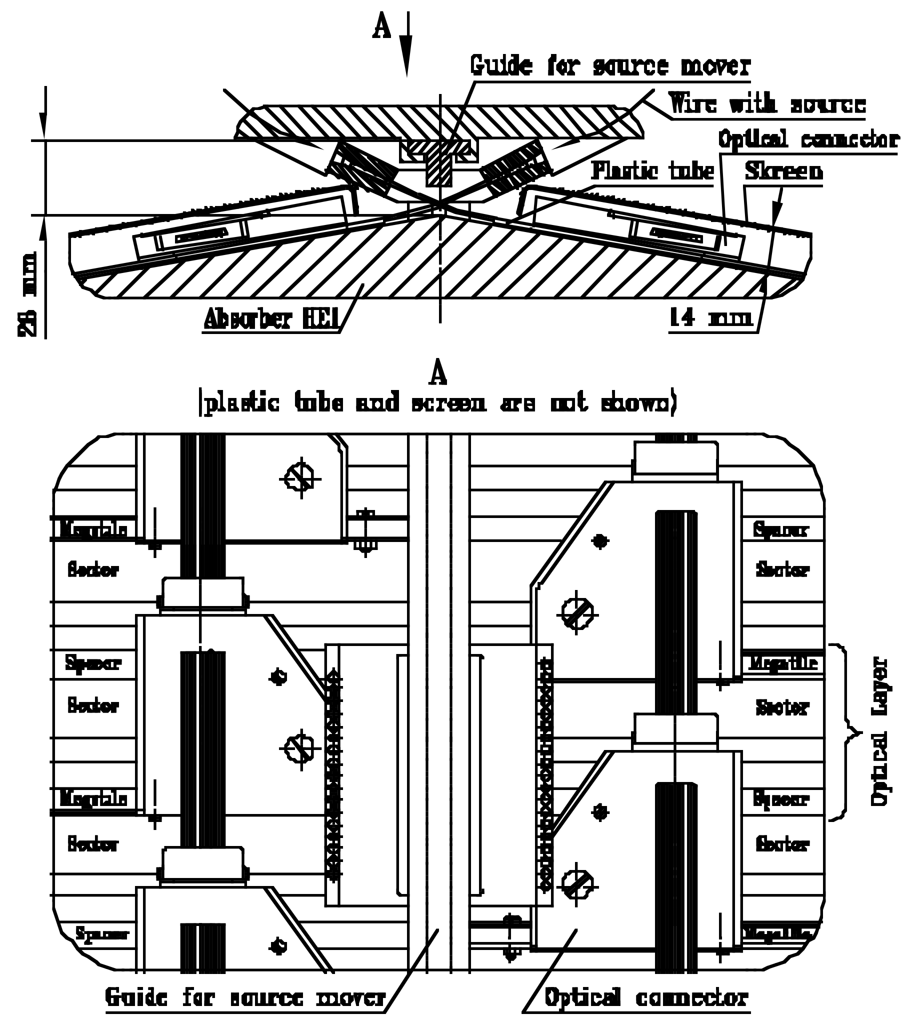

Fig. 6. 46: Layout of source tubes (side view).

6.10.4 HF layout

The umbilical cord of cables and cooling hoses is laid in the 50 cm by 50 cm trench between the transporter tracks. The cables are looped and bound into a bicycle-chain type cable tray. This avoids the triple depth trench which would be required if the bundle were folded back on itself beneath the detector in the running position.

In the garage position the cable bundles are fully extended, while in the operational position approximately 2 meters of slack must be accommodated. This extra 2 meters remains in the trench during beam operation. In intermediate positions 2-7 meters of slack must be accommodated. Since this amount of bundled cable cannot be accommodated in the trench, the trench will be uncovered and the cable bundle looped above it during horizontal moves of the detector. The flexible cable tray is attached to the support structure and will move with it during vertical moves.

6.11 SHIPPING/INSTALLATION

6.11.1 HB shipping/installation

The scintillator pans will be assembled and tested at Fermilab. They will be boxed in wooden boxes at Fermilab and shipped to CERN. The scintillator pan is fairly robust. We have shipped 2 testbeam modules to CERN with no damage to the pans or optical cables. The pans will be shipped to Building 168 where the pans will be installed in the wedges.

At CERN a small sample of pans will be tested with a megatile scanner. This will verify that no damage has taken place. If a small sample of pans are fine, then all the pans will not be scanned.

The pans will be removed from the box and the 'venetian blind', which pushes the pan up against the top of the slot in the copper absorbers will be taped on. The copper wedges will be in Building 168 with the slots for the pans parallel to the floor. The pans will be put on a stretcher and the stretcher will be put up to the slot of the wedge. The pan will be slid into the slot.

6.11.2 HE shipping/installation

HE modules will be manufactured in Russia and shipped by rail to CERN for installation.

6.11.3 HOB shipping/installation

HOB modules will be manufactured in India and transported by ship/rail to CERN for installation.

6.11.4 HOE shipping/installation

HOE modules will be shipped to CERN along with the HB modules.

6.11.5 HF shipping/installation

We anticipate that HF modules will be assembled in Hungary and shipped by rail to CERN.

6.12 ACCESS, MAINTENANCE AND OPERATIONS

6.12.1 HB/HE access, maintenance and operations

The optical system is sealed. Other services will be covering the optical system. Hence, we will have no access to the optical system. We anticipate that no access is needed. If we need to access optical system, other services can be removed and we can get at the optical cables and scintillator pans.

During the access period we will do a full source scan of all the tiles. This will determine whether any part of the optical system has deteriorated from radiation or other sources. The expected radiation levels are small enough that we expect the light output from the system to decrease no more than 7% over 10 year lifetime of the detector.

6.12.2 HOB access, maintenance and operations

One end of HOB modules will be untrapped, so trays could be removed, if needed.

6.12.3 HOE access, maintenance and operations

HOE will be attached to the Endcap muon chambers and could be only repaired when muon chambers are removed.

6.12.4 HF access, maintenance and operations

Alignment of the detector and maintenance of the optical systems will be carried out from the platform support of the detector or in the garage position. At beam height, access is provided by a portable scissors. This device is stored in the garage during beam operation to protect the hydraulics from radiation. The electronic modules in the racks are accessed and maintained easily in the garage position. In the case of a need to access the electronics racks when the detector is in the elevated beam position, the portable scissors will be used. The PMT boxes are protected by endplug shielding in operational position. Access to the PMT boxes requires no removal of heavy shielding elements.

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TABLE OF CONTENTS

Endnotes