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outer face is 5.6 C (assuming the inner area as the conduction area).

d) The quartz fibres have a thermal conductivity of 32×10^{-4}cal/cm-s-°C, so no power is conducted down/along the fibres. Consequently, no discernible thermal effects on the quartz fibres and none on the PMTs.

7.5.7 Slow controls

An extensive set of conditions must be monitored in the HF system. All sensors will ultimately be treated in a similar way; connected to multiplexed ADC inputs which are read out by a local microprocessor and transmitted to the CMS detector control and monitoring system. A Field Bus standard (i.e. CAN) will hopefully be adopted CMS-wide, and will be used for HF. A small crate dedicated to control and monitoring will be mounted in each electronics rack. A summary of HF control and monitoring requirements is given in Table 7. 5.

Table 7.5
HF slow controls requirements.

Item	Count	Notes
High Voltage	100 per end	set V, monitor I, V
Low Voltage	80 per end	monitor I, V
Temperature	100 per end	

7.5.4 High voltage services

No high voltage is delivered externally to the HF. The biasing for the PMTs is accomplished locally using a Cockroft-Walton type voltage multiplier. Radiation levels inside the shield may require that the Cockroft-Walton generator be located outside in the electronics racks.

7.5.5 Low voltage services

The LV power requirements for on-detector HF electronics are summarised in Table 7.4.

The total power dissipated by one PMT and it's associated front-end electronics is about 5 watts. This corresponds to a total of 9 kW per detector end. We propose to distribute 350 VDC from the underground electronics area to the detector, then use DC-DC converters to supply the required voltages locally.

Table 7. 4

LV power requirements for HF front-end electronics.

PMT (Cockroft-Walton HV)	250 mW
dual QIE+ADC	3.0 W
control ASIC	100 mW
laser serialiser	500 mW
laser	500 mW
Total Per PMT	5.0 watt

The DC-DC converters are mounted in the electronics racks on the detector platform. The converters (typically in flat packages about 1 cm thick) are mounted on heatsinks, which are installed vertically in a crate. A single rack-mount crate of dimensions equal to a 9 U Eurocard enclosure will suffice for one half of an HF detector end.

7.5.6 Cooling

The total power dissipated by the PMT with Cockroft-Walton generator is about 250 mW. This heat must be removed from inside the shielding. The total power dissipated by one channel of front-end electronics is estimated at 5 W per channel. This power is dissipated entirely outside the HF calorimeter shielding in the electronics racks, which are water cooled in a conventional manner The total power dissipation for the FE electronics is about 4.5 kW per rack.

The baseline transducer is a Hamamatsu R5380 and the power consumption is about 9 kW per end as enumerated in Section 8.5.5. For the tubes:

a) PMT temperature coefficient for bialkali <600~nm is -0.4%/°C whence for a 10°C temperature change only 4% change in PMT gain; to get a 10% change, ΔT=25°C.
b) HCAL is to be cooled by chilled water at 18°C held to ±1°C; thus, there is no problem with PMT gain change; the temperature of the electronics and the PMTs are routinely measured.
c) The thermal conductivity of iron is about 0.2 kcal/cm-s-°C and copper is 1.7 in the same units. Assuming, for a worst case, we leak 1 kW on the inner diameter (0.3 m) along the EM compartment (0.3 m) and conduct the heat to the outer radius, then the ΔT inner face to

Table 7. 3

Number of fibres required for each of the towers and bundles. The numbers in parentheses indicate the internal diameter of ferrules when 30% packing fraction is assumed for 0.345 mm diameter fibres.

Type of Bundles	No. Fibres 5×5 cm^2	No. Fibres 10×10 cm^2	No. Fibres 30×30 cm^2
EM Bundle	313 (7)	1250 (14)	-
HAD Bundle	313 (7)	1250 (14)	-
TC Bundle	-	-	1406 (15)

Manufacture, QC/QA, installation, monitoring

Fibre are inserted into the absorber as described in Section 6.6.1. The fibre bundles are glued into the ferrules, cut and polished. The polishing is performed using the industry techniques and equipment. The final polish is accomplished with one micron grit size.

Each end after being polished will be inspected under magnification for obvious scratches and cracks in the fibres before connections to the light guides are made.

7.5.2 Layout of light guide/tower

Aircore light guides are used to transport the light generated in the calorimeter to the photodetectors. Light guides are mechanically attached at one end to the fibre bundles and at the other to the photodetectors. The beam tests show that 65% of the light can be transported over 1.1 meters with an aircore light guide that is constructed out of aluminised mylar. The optimisation of this system is still being studied since it affects background radiation shielding, photodetector matrix design, maintenance, etc.

Manufacture, QC/QA, installation, monitoring

Light guides are manufactured using a polycarbonate shell with a enhanced reflective aluminium surface interior. A hard single dielectric layer of halfwave optical thickness will provide better than 90% reflection on average for all incidence angles and wavelengths and will increase resistance against abrasion, tarnish and oxidation.

Each light guide will be tested before installation for light transportation performance on a test bench using identical NA fibre bundles at some fixed wavelengths.

Each light guide will be installed individually. It will be mechanically connected to the ferrule and the PMT box structure. A fixture will position and fix the light guides in position. In order to monitor their reflectivity in time, a calibration fibre and an LED will be installed at the far end of the light guides.

7.5.3 Layout of transducer/preamp

The packaging of the PMT and HV bias circuit are described in chapter 8. A radiation tolerant preamplifier is also packaged within the PMT shield, and drives a coaxial cable to the electronics racks.

Ring HOB-0:

There are 48 tower bundles of up to 12 fibres, covering eight intervals of $\Delta\eta$ and six intervals of $\Delta\phi$. The bundles are sorted and then inserted into tubes and routed to the HPDs. Again, two extra multiclad fibres of 300 μm diameter are inserted into each bundle which are optically connected to the Y11 mixer block of the laser/LED calibration system to provide an independent monitor of the sensitivity and gain of each HPD pixel. The 48 tower bundles can be mapped onto three 19-channel HPDs or onto two 25-channel HPDs. The difficulty with mapping onto the 25-channel option is that it would allow only 40 microns of alignment tolerance, which is unrealistic. Hence the option of three 19-channel HPDs is specified.

Mapping to hybrid photodiodes

Registration of the fibre bundles to the HPD pixels is performed in a similar fashion to the HB decoder boxes. Choices of pixel position are driven by the need to keep fibre bend radii as large as possible within the space constraints and for "simplicity" of the pattern of fibre routing.

As for HB, alignment concerns include: misalignment of fibre bundles in the cookies; misalignment of the cookies relative to the HPD pixel structure; optical effects at the cookie/fibre-optic faceplate interface; and offset of the photoelectron image due to stray magnetic field. The cookie is registered with alignment pins provided on the HPD which will allow for an alignment tolerance of ~100 μm between fibre bundles and HPD pixels. Numerical aperture effects lead to an additional ~50 μm. Magnetic shielding of the boxes will be essential to eliminate any leakage fields from penetrating within. However, given the small fibre count being mapped to a given HPD19 pixel, alignment issues are less critical for the HOB decoder boxes than for the other HCAL subsystems.

7.5 HF OVERVIEW

7.5.1 Layout of optical fibre bundles

The quartz fibres will be bundled to form towers at the back of the absorber. The fibre bundles will be made such that they 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 steel ferrules for mechanical mounting to photodetectors.

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 then 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×5 cm) and the larger ones (10 cm×10 cm). Especially for TC, superimposed towers will be formed in 30 cm×30 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 third groove/plate. Table 7. 3 below summarises the main features of these fibre bundles.

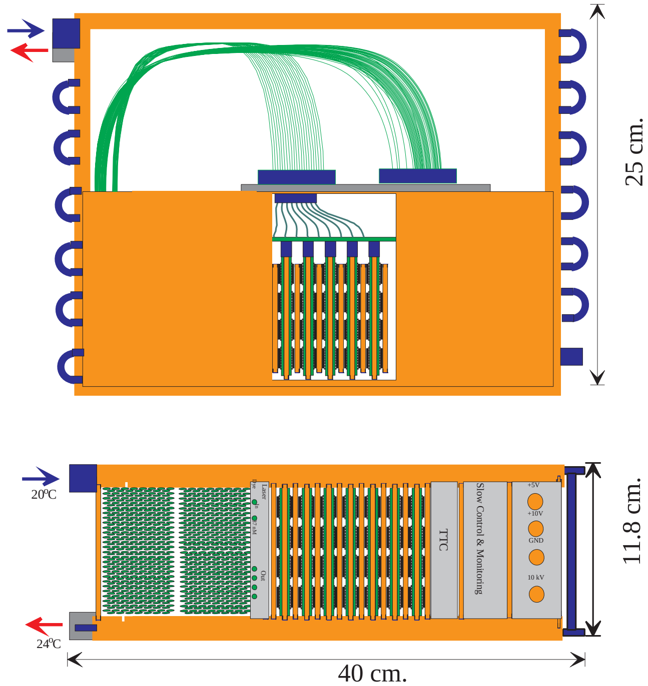

Fig. 7. 20: Schematic of the mechanical and electrical layout of a HOB±1 or HOB±2 decoder box.

7.4.2 HOB fibre decoder tower structure and mapping

There are 12 HOB decoder boxes per barrel muon ring and 60 in all.

Formation of HOB towers

Within the optical compartment and ~8 cm behind the optical patch panel is a Delrin sorting plate through which the interior optical fibres are organised into tower geometry. For HOB, the number of these tower "bundles" depends upon the ring.

Ring HOB±2:

There are 30 tower bundles of up to eight fibres, covering five intervals of $\Delta\eta$ and six intervals of $\Delta\phi$. The bundles are sorted and then inserted into tubes and routed to the HPDs. Additionally, two extra multiclad fibres of 300 μm diameter are inserted into each bundle which are optically connected to the Y11 mixer block of the laser/LED calibration system to provide an independent monitor of the sensitivity and gain of each HPD pixel. The 30 tower bundles are mapped onto two 19-channel HPDs.

Ring HOB±1:

There are 36 tower bundles of up to eight fibres, covering six intervals of $\Delta\eta$ and six intervals of $\Delta\phi$. The bundles are sorted and then inserted into tubes and routed to the HPDs. Again, two extra multiclad fibres of 300 μm diameter are inserted into each bundle which are optically connected to the Y11 mixer block of the laser/LED calibration system to provide an independent monitor of the sensitivity and gain of each HPD pixel. The 36 tower bundles are mapped onto two 19-channel HPDs.

two compartments which are optically isolated: a fibre-optic compartment and an electronics compartment. The two or three 19-channel HPDs are mounted on the interior wall between the two compartments.

Access to the fibre-optic compartment is via optical connectors at one optical patch panel. The patch panel is of 9.5 cm×9.5 cm×0.6 cm thick aluminium, and serves as the mounting surface for optical connectors arranged in two columns of twelve connectors (for YB/±1 and YB/±2 rings), and two columns of eighteen connectors (for the YB/0 ring). Each connector supports up to 18 multiclad fibres of 940 μm diameter on a pitch of 1.4 mm, and typically twelve of the 18 fibres within a connector correspond to active elements within a megatile. Two connectors are required to read out a $\Delta\phi$=5° "tray" of a megatile. Each of the optical connectors is optically finished by diamond flycutting.

All optical signal fibres used within the HOB decoder box are of 940 μm diameter, multiclad construction. Similar to HB, HE, and HOE, Kuraray S-type fibre is specified for all interior optical interconnections.

Additionally, on the optical patch panel there are six connectors supporting six quartz fibres of 200 micron diameter for transmission of laser calibration signals to each megatile.

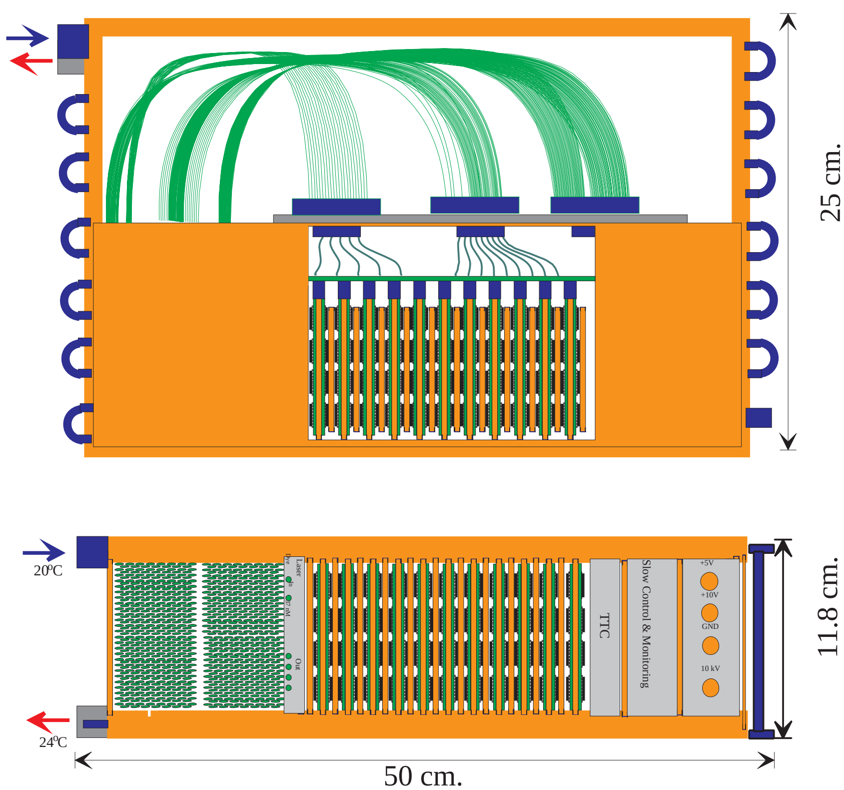

Fig. 7. 19: Schematic of the mechanical and electrical layout of a HOB-0 decoder box.

7.3.6 HE/HOE system interfaces.

Identical with HB. The decoder boxes must maintain appropriate operating voltages, temperature controls, and diagnostic information to monitor and maintain stable operation of HE1 and HE2-HE5 elements. A TTC interface is included in each DBX.

7.3.7 Monitors and controls system

Identical with HB. Numerous monitor and controls functions are required in every DBX. It is expected that these will be served via the TTC.

7.3.8 Access, maintenance, and operations

Similar to HB, the HE/HOE decoder boxes will be designed to be maintenance free. Because of the large array of electrical, optical, plumbing and other services directly over the top of the decoder boxes, only simple adjustments can be made without functional disassembly of services atop the boxes. Extensive servicing of the boxes could be effected when an endcap is withdrawn.

7.4. HOB OVERVIEW

HOB refers to the hadronic calorimeter in the central (barrel) region that is situated outside the coil and attached to the inner and outer faces of the five muon steel “rings”, YB/0/1, YB/±1/1, YB/±2/1, and on the inside face of the steel absorber at r ~ 3.8 m, which we label YB/0/0. One hundred thirty-two megatiles comprise the system.

On each muon ring, HOB is divided into twelve $\Delta\phi$=30° sectors (matching the muon steel segmentation). The number of $\Delta\eta$ intervals covered (5, 6 or 8) depends upon the ring. Each $\Delta\phi$ sector is served by a decoder box (DBX) which is located radially outside the last muon chamber station in each ring (MB/0/1, MB/±1/1, MB/±2/4 at r ~7.43 m).

Optical signals from the megatiles are conveyed via ribbon cables of fibre-optic waveguides up the radial cracks at |z| ~1.27 m and 4.0 m between rings to the DBX for signal processing. Laser calibration signals are conveyed in the opposite direction from the DBX to the megatiles via quartz fibre.

Power, cooling, and high voltage services are supplied from outside the detector, as are laser calibration signals. Digitised, optical signals destined for the DAQ system follow similar routing. These services are assumed to be located adjacent to those supplying HB, HE, and HOE subsystems.

7.4.1 HOB front-end optical layout

Fig. 7. 19 and Fig. 7. 20 show the layouts for HOB decoder boxes, with dimensions of 50 cm×25 cm×11.8 cm and 40 cm×25 cm×11.8 cm. These structures are functionally similar to HB/HE decoder boxes, except that the box size is reduced since either two or three 19-channel format HPDs need to be supported per box. Also the electrical and optical patch panels are modified to account for orientation differences, and magnetic shielding of the boxes are required to screen out the leakage field from the muon steel. Structures within the interior of the box will be fabricated of non-magnetic materials: aluminium, copper, brass and plastics. Each DBX is mounted onto the radially-outer surface of an MB chamber module and consists of

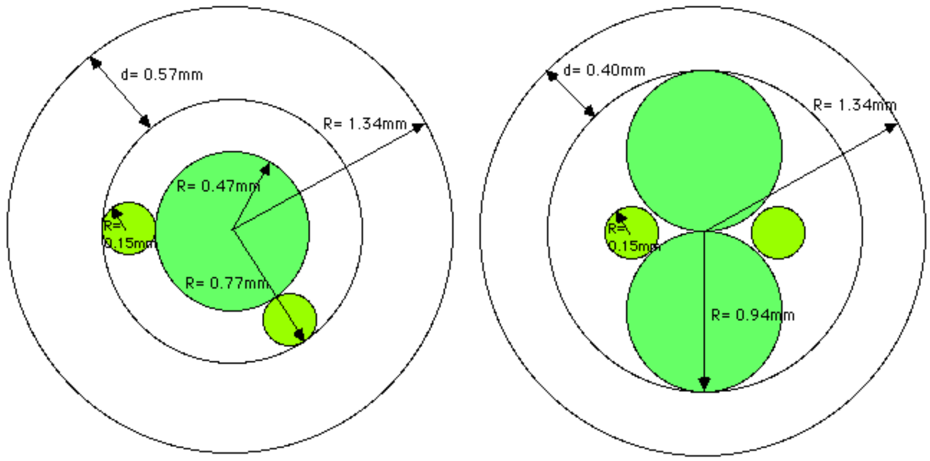

Fig. 7. 18: HE1 and HOE fibre configurations presented to pixels of 73-channel HPD tubes. For HE1 one fibre is imaged per pixel; for HOE two fibres are imaged per pixel. Small diameter fibres are for calibration signals. The outer circle indicates the position of the nearest edge (or flat) of the hex-shaped pixel. An alignment tolerance of 570 μm is indicated for HE1 and 400 μm for HOE.

7.3.5 HE/HOE front-end electronics layout

The HE front-ends are functionally identical to those of HB. Approximately half the decoder box volume is allocated for electrical and support services for the HPDs, for signal amplification, digitisation, and optical signal drivers, for calibration and slow controls functions, and for water cooling and thermal monitoring. All of the output signals from the 168 available HPD channels (162 of which correspond to active detection elements) are routed to readout boards located in a internal custom crate structure, with lead lengths kept as short as possible. The ceiling and floor of the electronics compartment are water-cooled copper plates to maintain all regions of the decoder box at or below a temperature of 26° C.

Services to the HPDs include: Photocathode high voltage (-10 kV), bias voltage to the silicon (typically 100 V), and supply voltages for the QIE preamp/digitiser/driver boards (+5 V and +10 V). These are supplied to the decoder box via a panel on the “top face” (see Fig. 7. 13).

All HPDs used in HE will be operated at a photocathode voltage near -10 kV. These will be fed individually from outside the detector over a minicoax to each HPD. Similarly, LV bias (~100 V) for the silicon substrates of each HPD will also be supplied individually via minicoax from supplies located outside the detector. These electrical power services are routed to the decoder boxes through the radial crack (near |z| ~ 6.7 m) at the end of the solenoid magnet.

Water temperature and flow sensors are placed on the entrance and exit ports of the water lines outside the detector.

The electronics layout is similar to HB decoder boxes and includes HV distribution, two LV systems, and ancillary controls, calibration, and monitoring systems. Each HPD channel is amplified and digitised in a QIE chip. HPD outputs are multiplexed (three channels per optical link) and driven via laser diodes off-detector to the trigger and data acquisition system. Water cooling is required for the electronics compartment because of power dissipation in the QIE chips and the laser diodes which are used to drive the digital signals off detector.

the cookies; misalignment of the cookies relative to the HPD pixel structure; numerical aperture effects in the air gap between the cookie and the fibre-optic window of the HPD; and misalignment of tube axes relative to the direction of the local magnetic field direction.

Mechanical: The cookie is registered to the HPD faceplate with alignment pins provided on the HPD which should allow for a placement tolerance of ~100 μm between fibre bundles and HPD pixels.

Optical: Because of surface imperfections (surfaces of the cookies are not optically flat), the light exiting a fibre bundle will diverge according to the numerical aperture of the fibre as it passes through an airgap between the cookie and the fibre-optic faceplate of the HPD. To compensate for local surface imperfections, the Cookies and HPD faceplates will be shimmed apart by a 50 μm spacer. Crossing this gap this will lead to an "expansion" of the optical image by ~ 50 μm in radius, as the exit angle is slightly larger than 45°.

Magnetic Field: Assuming a 2 mm gap between the photocathode and the silicon in the HPD, 3° of axial misalignment of the HPD axis relative to the local field direction would lead to a systematic shift by 100 μm of the photoelectron image on a given pixel.

If up to 18 fibres are imaged per pixel (as is the case for HE2.7 to HE2.14), we can accommodate a total misalignment of <405 μm in the 19-channel HPD tube (Fig. 7. 17). For HOE (HE5.1-HE5.28), two fibres are imaged per pixel per 73-channel HPD tube (Fig. 7. 18). Here a similar misalignment tolerance of 400 μm is indicated. Hence the HE/HOE decoder boxes must maintain the alignment of the HPDs to within a 3.0° angle of the field, to fit safely within the allowed alignment tolerances.

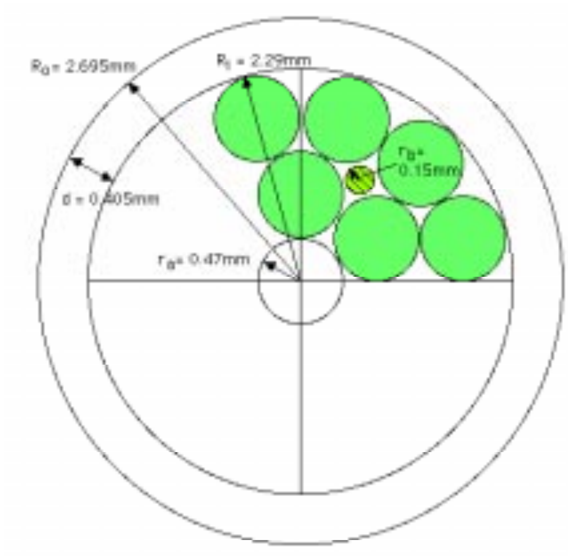

Fig. 7. 17: HE2 fibre layout presented to a pixel of a 19-channel HPD, for a case where 18 fibres of 940 μm diameter are mapped to a pixel. The small 300 μm diameter fibre is for calibration. Here the outer circle indicates the position of the nearest edge (or flat) of the hex-shaped pixel. An alignment tolerance of 405 μm is indicated for this configuration. Note that this is 80 μm less than for HB2, where 17 fibres are mapped to a pixel (Fig. 7. 10).

Formation of HOE tower geometry

A $\Delta\phi$=10° calorimeter sector of HOE consists of a single plane megatile composed of 14 individual tiles. There are two bins in ϕ and seven bins in η. Because of their physical size, each tile is read out with four waveshifter fibres. However because of the small pixel size available in the HPD73 tubes, it is inadvisable to map four 940 µm diameter fibres to a single pixel. Instead, pairs of fibres are mapped to an HPD73 pixel, and then pairs of pixels are connected electrically and read out through a single electronic channel. To illustrate this, Fig. 7. 14 displays a HOE sector. Elements 5.1 and 5.2 are readouts from the same HOE tile. Element 5.1 consists of two fibres mapped to an HPD-73-1 pixel. Element 5.2 consists of two fibres mapped to another HPD-73-1 pixel (Fig. 7. 15). The electrical signals derived from these pixels are electrically combined prior to amplification and digitisation by a single QIE channel. Hence the 28 pixels elements of HOE indicated in Fig. 7. 14 are readout by 14 QIE channels.

Mapping to hybrid photodiodes

To implement the mapping scenario presented above, fibres are routed from the patch panels through sorting plates in the optical compartment of the decoder box (Fig. 7. 16). The holes in the sorting plates are oversized, so that the fibres simply pass through with no constraint. The bundles are then inserted into tubes and routed to the HPDs. Additionally, an extra pair of multiclad fibres of 300 µm diameter are inserted into each bundle which are optically connected to the Y11 mixer block of the Dye Laser/LED calibration system to provide an independent monitor of the sensitivity and gain of the HPD pixels. Choices of HPD location and pixel position are driven by the need to keep fibre bend radii as large as possible within the space constraints and for “simplicity” of the pattern of fibre routing.

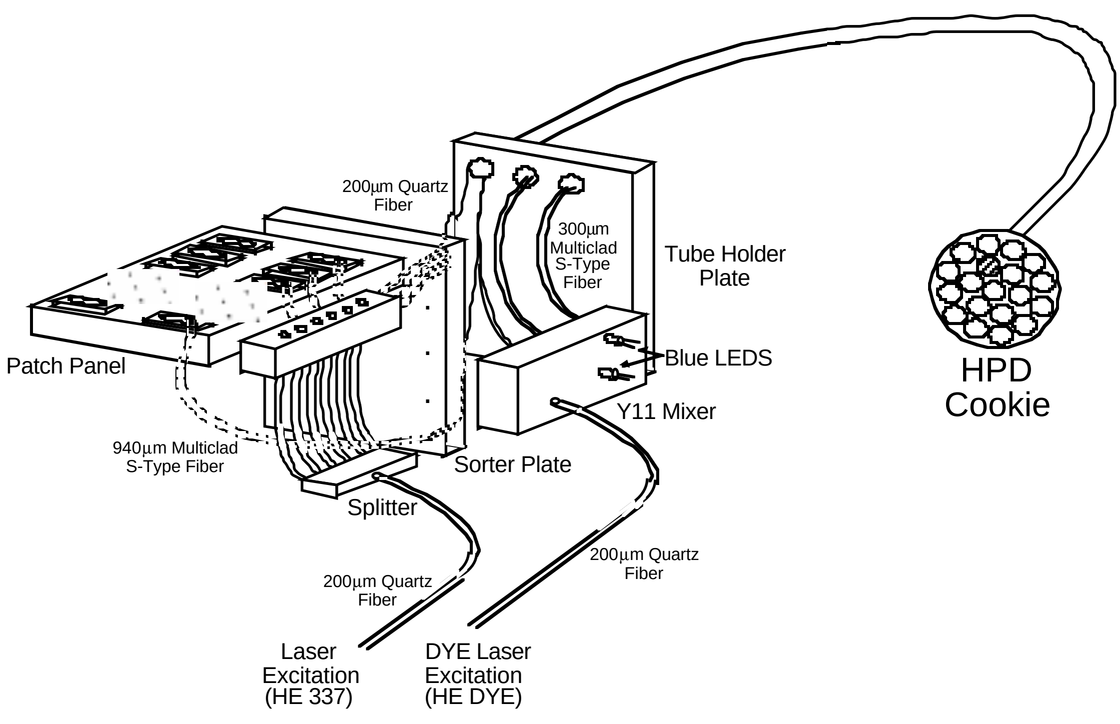

Fig. 7. 16: HE decoder box optical compartment elements.

Registration of the fibre bundles to the HPD pixels is performed in a similar fashion to the HB decoder boxes. As for HB, alignment concerns include: misalignment of fibre bundles in

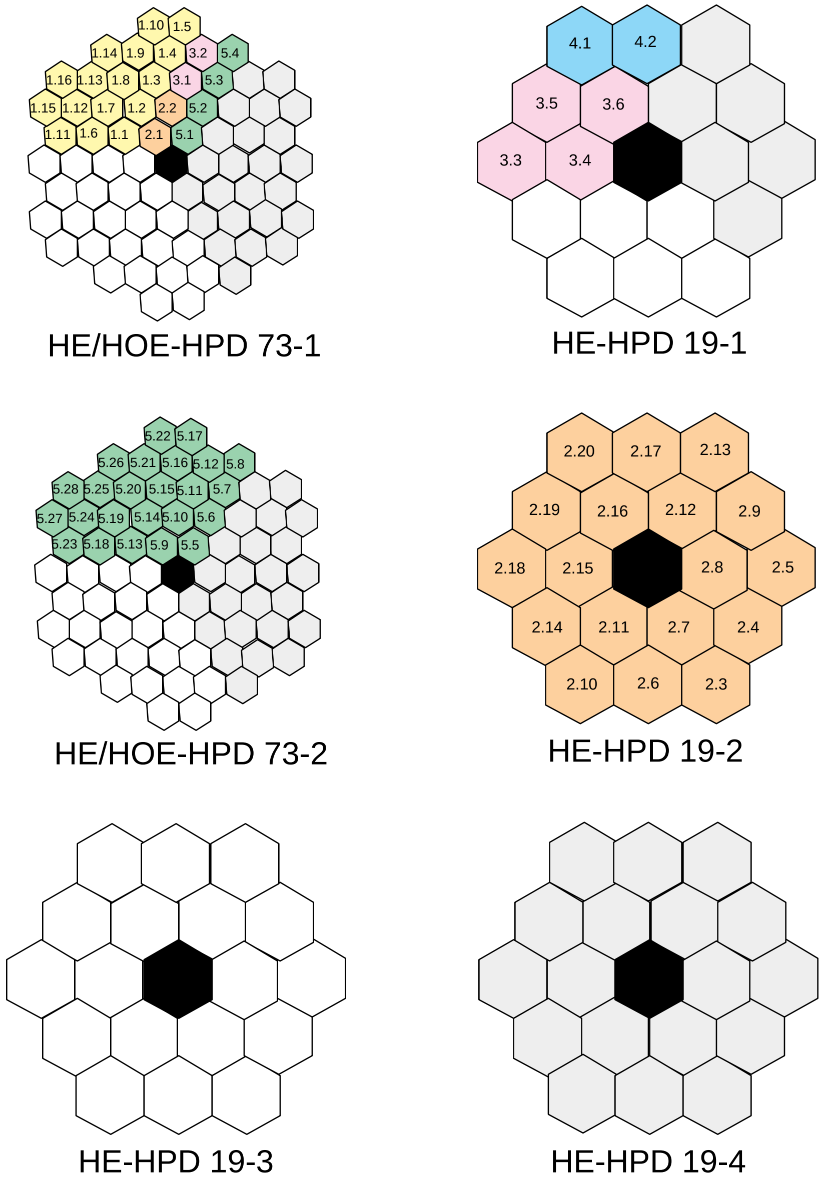

Fig. 7. 15: Fibre/pixel mapping scenario for an HE/HOE decoder box. Towers from 1/3 of the channels are indicated corresponding to a $\Delta\phi$=10° section. A schematic of the corresponding tower positions are indicated in Fig. 7. 14.

- 4 tower sums over 4 sampling layers – labelled HE2.3 to HE2.6. These are mapped onto the HPD19-2 tube.
- 4 tower sums over 14 sampling layers – labelled HE3.3 and HE3.6. These are mapped onto the HPD19-1 tube.

For $2.5 < |\eta| < 3.0$, the layer summation is provided over three samples in depth.

- 2 tower sums over 2 sampling layers – labelled HE2.1 and HE2.2. These are mapped onto the HPD73-1 tube.
- 2 tower sums over 2 sampling layers – labelled HE3.1 and HE3.2. These are mapped onto the HPD73-1 tube.
- 2 tower sums over 14 sampling layers – labelled HE4.1 through HE4.2. These are mapped onto the HPD19-1 tube.

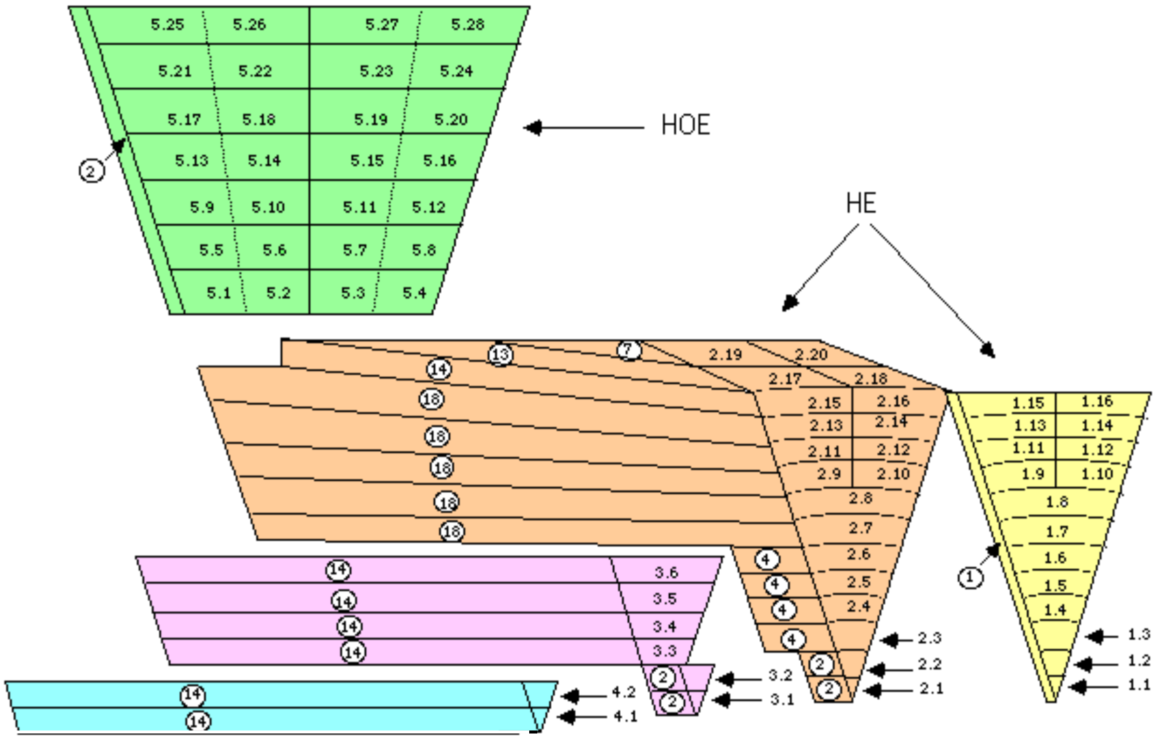

Fig. 7. 14: Schematic “exploded” view of a HE/HOE $\Delta\phi$ = 10° calorimeter sector, indicating the sampling subsections. The tower labelling is indicated on the front face of each section. These labels correspond to HPD pixels displayed in Fig. 7. 15. The numbers in circles indicate either the number of layers combined per HPD pixel (for HE) or the number of fibres per tile combined onto a HPD pixel (for HOE). Additionally, for the HE case the number of independent depth samples is a function of η, to compensate for radiation damage effects. For $|\eta|<1.98$ (η bin number greater than 6) there are two samples in depth; for $1.98<|\eta|<2.5$ (η bins 3-6) there are three samples in depth; and for $|\eta|>2.5$ (η bins 1-2) there are four samples in depth.

Formation of HE tower geometry

Within the optical compartment of the decoder box and ~8 cm behind the optical patch panel is a Delrin “sorting” plate through which the interior optical fibres are organised into HE1 and HE2-HE4 subgroups and also into tower geometry. The elements of a $\Delta\phi$ = 10° calorimeter sector are now described.

For HE1 there are 16 “towers” of single-layer sampling. These towers are labelled HE1.1 through HE1.16 and are mapped onto the pixels of a HPD73 tube, labelled HPD-73-1 in Fig. 7. 15.

For HE2-HE4, the number of layers summed in depth (and mapped to a given HPD pixel) depends upon the η bin.

For $|\eta|<1.98$ (corresponding to η bins 7-20), there are 14 towers formed by summing up to 18 available samples over the full depth of HE. These towers are labelled HE2.7 through HE2.20, and are mapped onto a 19-channel HPD labelled HPD19-2 in Fig. 7. 15.

For $1.98<|\eta|<2.5$, the layer summation is provided over two samples in depth, so that radiation damage effects can be compensated for by reweighting of the samples. For mapping to HPD tubes, refer to Fig. 7. 15.

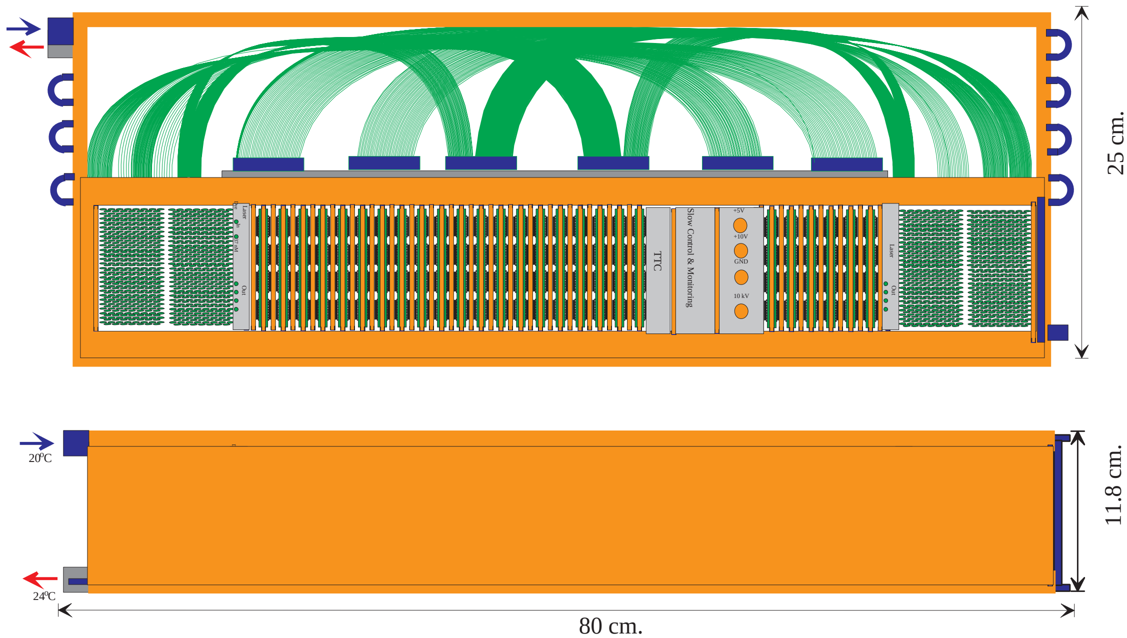

Fig. 7. 13: Schematic of the mechanical and electrical layout of a HE/HOE decoder box.

Certain of the megatiles of HE2 require special consideration in optical routing, because they are located directly adjacent to or beneath the decoder box, and hence optical connectors would be trapped or blocked. Layers 15 through 18 are those affected. For these, as in the case of the trapped layers of HB2, special fibre-optic cables will be prepared which are of cylindrical cross section and more flexible than the standard, flat ribbon connectors.

Additionally, on each optical patch panel there are nine connectors for quartz fibres that provide transmission of laser calibration signals to selected HE megatiles (layer 1 corresponding to HE1 and layer 9) and three signals to HOE megatiles.

7.3.4 HE/HOE fibre decoder tower structure and mapping

A HE/HOE decoder box receives the information from 30° in azimuth (three 10° sectors). There are a total of 12 HE/HOE decoder boxes at each end of the CMS detector and 24 in all. Within these boxes, the layer sums are formed corresponding to tower geometry. The summations in the HE region are more involved than for the HB (barrel) case, because for $|\eta|>1.98$ multiple depth samplings are required to correct for radiation damage effects over time. For $|\eta|<1.98$, there are two depth samples, HE1 and HE2. For $|\eta|>1.98$, there are three or four depth samples: HE1, HE2-HE4. HOE consists of a single plane in depth, but four waveshifter fibres are used to read out a given component tile within the plane. The HOE elements are labelled HE5. The basic readout structure for a 10° sector is indicated in Fig. 7. 14.

Power, cooling, high voltage, and low voltage services are supplied via the radial crack just beyond the solenoid (near |z| ~6.7 m), as are laser calibration signals. Digitised, optical signals destined for the DAQ system follow similar routing.

7.3.2 The outer endcap calorimeter (HOE) layout

HOE refers to the hadronic calorimeter in the endcap region that is situated beyond the coil and on the inside face of YE/1. There are two such assemblies, one at each end of the CMS detector and labelled HOE+ and HOE-. Here we consider only one end of the detector and refer to it generically as HOE. HOE consists of 72 sector subassemblies, each subtending 5° in ϕ. Every six sectors ($\Delta\phi$ = 30°) are served by an HE/HOE decoder box. Each HOE sector assembly consists of a single megatile layer, a portion of which is mounted onto the back (large |z|) face of a ME1/2 muon chamber and the remainder of which is mounted directly onto the YE/1 face. Each megatile is subdivided into seven $\Delta\eta$ intervals, with four waveshifter fibres to reach out each interval.

Optical signals from the megatiles are conveyed via ribbon cables of fibre-optic waveguides inward along YE/1 to the HE decoder boxes. Laser calibration signals are conveyed in the opposite direction from the DBXs to the megatiles via quartz fibre.

Power, cooling, and high voltage services are supplied from outside the detector and via the HE DBXs.

7.3.3 HE/HOE front-end optical layout

Fig. 7. 13 shows the layout of an HE/HOE decoder box, with dimensions 80 cm×25 cm×11.8 cm. This structure is functionally identical to HB decoder boxes, except that an additional 73 channel HPD must be accommodated, and the electrical and optical patch panels must account for a different orientation of access in the endcap region. The materials from which the box will be fabricated are non-magnetic: aluminium, copper, brass and plastics. Each decoder box is mounted to the steel backing flange of the calorimeter wedge. The DBX consists of two compartments which are optically isolated: a fibre-optic compartment and an electronics compartment. Six HPDs are mounted on the lateral interior wall between the two compartments.

Access to the fibre-optic compartment is via optical connectors at two optical patch panels, one at each end of the box. Each patch panel is of 9.5 cm×9.5 cm×0.6 cm thick aluminium, and serves as the mounting surface for eighty optical connectors arranged in four columns of twenty connectors. Each connector supports ten multiclad fibres of 940 μm diameter on a pitch of 1.4 mm, and each fibre within a connector corresponds to one of the elements within a megatile. Each of the optical connectors is optically finished by diamond flycutting.

All optical signal fibres used in the interior of a HE/HOE decoder box are of 940 μm diameter, multiclad construction. Kuraray S-type fibre is specified because of its flexibility.

Water flow monitor

Water flow indicators and temperature sensors will be located outside the detector in the return lines.

Laser and LED monitors

For the 337 nm laser, a photodiode will be used to monitor laser timing and laser power. For dye laser and blue LED excitation of the Y11 mixers used in direct tests of HPD photocathodes, photodiodes will be used to monitor the light directly in the Y11 mixer, and will be common to both systems. A photodiode will be used to monitor each individual Y11 mixer block, of which there are two for each HB decoder box. These photodiodes will be read out via the same readout boards (QIE boards) just as other data signals.

QIE controls

Interfacing capability is required to download thresholds and timing trims to the QIE circuitry. This will be accomplished via the TTC network.

7.2.6 Access, maintenance, and operations

The decoder boxes will be designed to be maintenance free. However, currently the actual effective “lifetime” of an HPD tube (time to failure) is unknown. Eventually, one might expect some tubes to be replaced over the lifetime of the experiment. Because of the large array of electrical, optical, plumbing and other services which are routed up the 53° crack, and which effectively obscure any substantial access to the decoder boxes, only simple adjustments can be made without functional disassembly of services in front of the boxes. Service to the boxes could be effected when an endcap is withdrawn and “easier” access is available.

7.3 HE/HOE OVERVIEW

7.3.1 The inner endcap calorimeter (HE) layout

HE refers to the hadronic calorimeter in the endcap regions that is situated within the 4 T field. There are two such structures, one at each end of the CMS detector and labelled HE+ and HE-. Here we consider only one end of the detector and refer to it generically as HE. HE consists of 36 sector assemblies, each subtending 10° in ϕ, and every three sectors are served by a decoder box (DBX) which is located at the outer radius of the sector (large r and small $|\eta|$ region). Sampling layers comprise HE, and the individual layers (or megatiles) are mechanically subdivided into 5° or 10° intervals in $\Delta\phi$ and up to 14 intervals in $\Delta\eta$. HE is also logically divided into longitudinal (depth) sections. HE1 consists of a single layer of sampling of a shower just at the exit of the endcap ECAL. The sampling in depth behind HE1 is more complex than for the barrel calorimeter (HB) case, because of the increased radiation field. In the high $|\eta|$ region where integrated radiation levels are expected to reach several Mrads during the course of the experiment, additional sampling in depth is required to correct for the effects of radiation damage to the scintillator over time. This applies particularly to the six $\Delta\eta$ intervals covering the kinematic region $1.98<|\eta|<3.0$. Specifics are presented in Section 7.3.4 below.

Optical signals from the megatiles are conveyed via ribbon cables of fibre-optic waveguides up the 53° crack that delimits the barrel/endcap region and/or through the horizontal opening between the magnet and the endcap to the DBX for signal processing. Laser calibration signals are conveyed in the opposite direction from the DBX to select megatiles via quartz fibre.

This calibration task of the HPD pixels is also shared with a blue LED (430-450 nm) pulser system. Test pulses received from the counting room via a twisted pair driver can excite the LEDs which are optically connected to the same Y11 mixers as the laser system. This provides an independent measure of the single photon response of the HPDs and, additionally, provides for a full test capability of the DBX during fabrication and bench testing, when there will likely be no laser access.

7.2.4 HB system interfaces

The decoder boxes must maintain appropriate operating voltages, temperature controls, and diagnostic information to monitor and maintain stable operation of HB1 and HB2 elements. A TTC interface is included in each DBX.

7.2.5 HB monitors and controls system

Numerous monitor and controls functions are required in every DBX. It is expected that these will be served via the TTC.

Temperature monitor

Temperature monitoring is required to protect the electronics and especially to prevent temperature excursions which could damage the optical fibres resident in the optical compartment. Six temperature sensors will be provided per DBX: two in the optical compartment and four in the electronics compartment. Temperature excursions would result in a shutdown of the LV feeds to the QIE boards. A similar shutdown would occur if temperature indicators or flow indicators on the return lines of the cooling water show an excursion.

HPD HV and LV monitors

The photocathode high voltage, low-voltage silicon bias and associated currents will be independently controlled and monitored for each HPD from crates outside the detector. For HB, five individual HV lines and five individual LV lines will be supplied to each decoder box. Voltage or current excursions or faults will result in the shutdown of the offending HPD from the system.

LV monitor

Low voltage (+5 V and +10 V) will be supplied from outside the detector by two separate input lines to the bus of the crate structure within the DBX. These services will be used to support the QIE preamp/digitiser/driver cards, for the LED drivers, and for photodiode operation. Current and voltage values will be controlled and monitored from the outside the detector. The bus lines in the electronics compartment which provide LV internally to the QIE boards, will be fused with resettable polyfuses. Individual QIE boards will be similarly fused.

Optical fault/DBX closure

Monitors will be provided to assure that HPD high voltage cannot be activated when any of the decoder box covers are removed. This essential safety requirement will be provided by three distinct systems: light sensing using photodiodes: current monitoring of spare HPD pixels: and by sense switches to assure continuity of material (box closure).

Gas monitor

To prevent helium gas poisoning of the HPDs, dry nitrogen gas at slight overpressure will be circulated within the DBX.

Nitrogen laser calibration at 337 nm

Laser pulses from the CMS calorimeter laser calibration system are input into each DBX. (Refer to Fig. 7. 12). Two 200 µm diameter quartz fibres are utilised. One set of laser pulses excites the megatiles directly, to monitor scintillator and waveshifter ageing. This excitation wavelength is 337 nm and is derived from the primary (nitrogen) laser. This calibration pulse is supplied to two selected layers of the HB at selected depths within the tower structure: HB1.1, the first sampling layer of HB, and HB2.9 which is located approximately midway in depth in a tower. An additional requirement of this link is to set and monitor the relative timing of the megatiles. The incoming 337 nm laser lightguide is divided into nine individual quartz waveguides on a receiver card located within the electronics compartment of the DBX. Eight of these waveguides are exported via the patch panels (four through each) to megatile layers HB1.1 and HB2.9. The remaining waveguide is coupled to a photodiodes situated on the receiver card to monitor the laser timing and light intensity.

The optically-induced pulses in the megatile scintillator will be used to cross-check source tube measurements in the same megatile layers and to facilitate time-slewing corrections for each channel.

Dye laser and LED calibration at 430-450 nm

The second laser link (Fig. 7. 12) transmits pulses from a dye laser at a wavelength of 430-450 nm, which will activate two Y11 waveshifter mixers located within the DBX. The Y11 mixers are fibre-optically coupled directly onto each HPD pixel. (Refer to Fig. 7. 6.) These pulses measure the HPD cathode responsivity and provide a monitoring measurement independent of the characteristics of the megatiles.

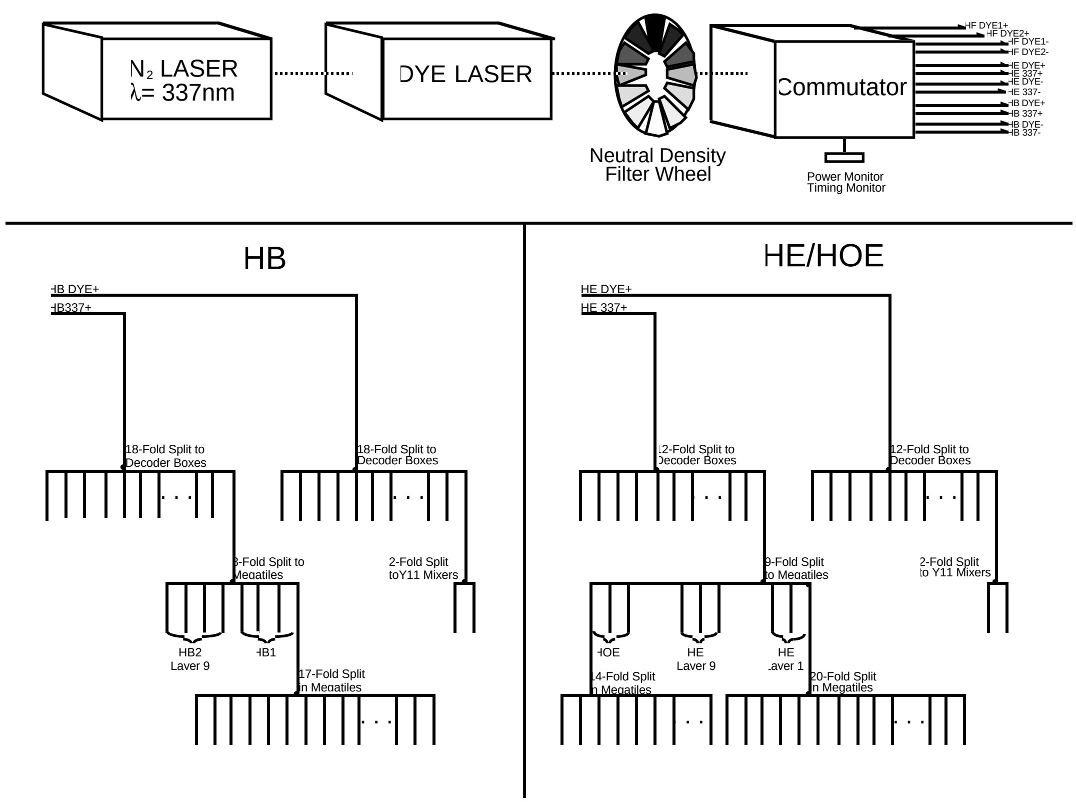

Fig. 7. 12: HCAL laser calibration system, as it applies to HB and HE subsystems.

position, the decoder boxes are essentially permanently fixed and, should a Box need to be removed, unsoldering the water lines would be a minor addition to the complexity of the task.

The cooling of the circuitry in the electronics compartment is performed primarily via conduction through PC boards and air to copper plates in physical contact with the cooling water. The volume of the electronics compartment is basically divided into < 100 separate compartments, each of which is surrounded on six sides by copper walls which provide a low thermal impedance to the cooling water. Each compartment dissipates about 1.0 W. This scheme should keep the entire heat load away from the fibres which are heat sensitive and should keep the chips cool enough to keep lifetimes long. We estimate the maximum chip package temperature to be 40° C.

The readout scheme uses a QIE chip followed by a commercial five bit FADC and a DCS (digital clocking synchroniser) chip. The QIE is a pipelined chip which has no dead time and basically provides two outputs which are valid four clock cycles after the cycle of interest. Its pipeline length is four ticks plus one for the output. In every clock cycle, the QIE outputs a three bit digital number which corresponds to the exponent of the input current and an analog voltage which corresponds to the mantissa of the input current. The exponents go directly to the DCS while the analog voltage is sent to the FADC. The QIE also sends to the DCS a two bit capacitor ID number which corresponds to the capacitor (one of four) which tells the user which cap in the pipeline was used. Since capacitors can differ slightly in value, this number is needed for calibration and correction of the data off-line. Experience with KTeV has shown that the caps are equal to within a few percent without any correction, and that the value can be measured to ~ 0.1% off-line.

One clock tick later, the FADC has produced a five bit digital mantissa for the analog input from the QIE. This mantissa is sent to the DCS which receives it and synchronises it with the exponent data from the QIE. The synchronisation takes another two clock ticks and with one tick for the FADC, the total latency of the pipeline is eight ticks.

At this point the DCS has a complete data word: a two bit Cap-ID, a three bit exponent, and a five bit mantissa. The data is then sent to a parallel-to-serial converter chip and a laser diode driver which drives the data from the decoder box to the counting room. There the data is split: part to make a trigger, the other part stored locally awaiting a trigger decision. Every clock tick, another full data word is sent from the decoder box. Note: since the speed of the laser optical link is 1.2 Gigabits/sec, it is possible to multiplex three channels of HCAL data onto one optical link. Thus the number of laser drivers needed is 1/3 the number of active channels in the decoder box.

Calibration layout

Two optical calibration systems, laser and LED, are supported within the DBX. A schematic is indicated in Fig. 7. 6. These, together with a source-tube calibration system, are used to correlate absolute calibration measurements from the test-beam with signals from in situ calorimeter megatile layers and to monitor and maintain the relative calibration of these calorimeter elements over time.

Laser calibration of scintillation elements is provided for selected megatile layers HB1.1 and HB2.9 only: the first, because it is the primary (and presently the only) layer of the first sample and near shower maximum; the second, because it provides a monitor deep in the calorimeter, relatively far from shower max, yet which samples most of the towers in $\Delta\eta$.

link) and driven via laser diodes off-detector to the trigger and data acquisition system. Forty-eight optical cables are required to transfer the digital signal information. Water cooling is required for the electronics compartment because of power dissipation in the QIE chips and the laser diodes which are used to drive the digital signals off-detector..

HV layout

Five commercial minicoax cables import the required 10 kV photocathode voltage to each HPD within the decoder box. Power supplies are located outside the detector.

LV layout

There are two distinct LV systems supplied to the decoder box. One provides bias to the HPD silicon substrates and is supplied by minicoax. The other involves high current feeds for amplification, digitisation and signal processing, and for calibration and monitoring.

LV for HPD bias

Five commercial minicoax cables import the required 100 V bias to each HPD substrate in the decoder box. The cables should be rated to supply 200 V max. at a very small (nanoamps) standing current. Power supplies are located outside the detector.

LV for signal processing and monitoring

The low voltage requirements for the QIE, FADC, DBC and drivers are based upon the experience of KTeV and work done for CDF on the new QIE6. We estimate that the requirements for each crate would be 75 amps at +5V and 15 amps at +10V. The high current will require the back plane of the electronic compartment to be supported with adequate bus bars to distribute and handle the supply and return current paths.

The backplane located in the decoder box will have a connection to the slow control network via a J-TAG which will use a low speed (1 MHz) serial link to send and receive data. Implemented on the backplane will be voltage and current monitors to sense low voltage supply status. This information can be read back to the control room every few minutes for monitoring purposes. A micro-controller on the backplane could shut down the system in the event of excursions in voltage, current or temperature limits are exceeded. Note: It is expected that individual boards within the crate will be protected by “poly-fuses” which open on an overcurrent and close once power is removed.

As in the case of supply voltages and currents above, the backplane will also support temperature sensors, four in the electronics compartment and two within the optical compartment. These will allow the system to monitor the decoder box temperature and to shut power services down if limits are exceeded.

Due to the large currents involved in the low voltage supply, it is assumed that the supply leads will be hardwired to the crate using adequate cable for the currents specified.

The connection to the slow control network would be via a 3- or 5-wire serial link which could be daisy-chained from crate to crate or supplied directly to each crate. In either case, the connector would likely be very small and captive locking so that it would not disconnect accidentally.

The water supply for the cooling system needs to provide about 1.0 US gal/min of cooling water. This could be made via hard connections or quick disconnects. We prefer the hard-line connections since the quick disconnects might leak or come uncoupled. Once in

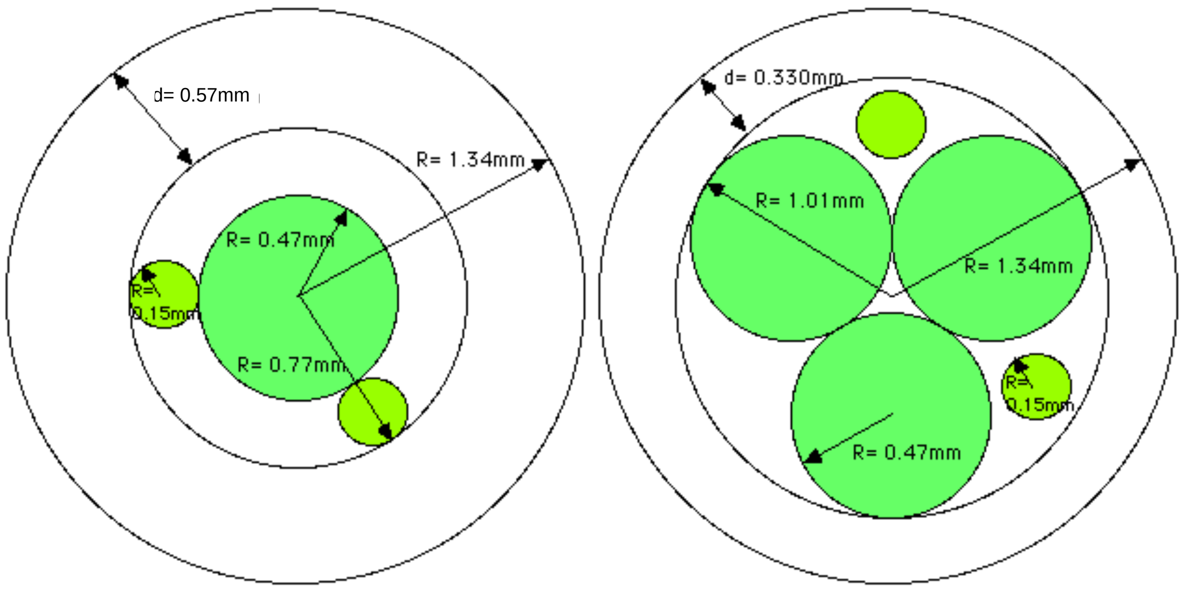

Fig. 7. 11: HB1 fibre configuration presented to a pixel of a 73-channel HPD, in the baseline case where a single layer is imaged per pixel, and for a hypothetical case of three layers combined per pixel. Small diameter fibres are for calibration signals. Here the outer circle indicates the position of the nearest edge (or flat) of the hex-shaped pixel. An alignment tolerance of 570 µm is indicated for the single-fibre configuration, and 330 µm for the three-fibre configuration.

7.2.3 HB front-end electronics layout

Approximately half the decoder box volume is allocated for electrical and support services for the HPDs, for signal amplification, digitisation, and optical signal drivers, for calibration and slow controls functions, and for water cooling and thermal monitoring. The output signals from the active HPD channels (136 of the available 149 channels are associated with active detection elements) are routed to readout boards located in an internal custom crate structure, with signal lead lengths kept as short as possible. The ceiling and floor of the electronics compartment are water-cooled copper plates to maintain all regions of the decoder box at or below a temperature of 26° C.

Services to the HPDs include: Photocathode high voltage (-10 kV), bias voltage to the silicon (typically 100 V), and supply voltages for the QIE preamp/digitiser/driver boards (+5 V and +10 V). These are supplied to the decoder box via a panel on the "front face" (Fig. 7. 2).

All HPDs used in HB will be operated at a photocathode voltage near -10 kV. These will be fed individually from outside the detector over minicoax to each HPD. Similarly, LV bias (~100 V) for the silicon substrates of each HPD will also be supplied individually via minicoax from supplies located outside the detector. These electrical power services are routed to the decoder boxes through the radial crack (|z| ~6.7 m) at the end of the solenoid magnet.

Water temperature and flow sensors are placed on the entrance and exit ports of the water lines outside the detector.

The electronics layout (Fig. 7. 2 and Fig. 7. 3) includes HV distribution, two LV systems, and ancillary controls, calibration, and monitoring systems. Each HPD channel is amplified and digitised in a QIE chip. HPD outputs are multiplexed (three channels per optical

The 27.5 mm format HPD is tolerant of misalignments: up to 485 µm in the 19-channel tube for HB2 (Fig. 7. 10) and up to 570 µm in the 73-channel tube for HB1 (Fig. 7. 11). In the event that three layers of HB1 must be combined, the misalignment tolerance is 330 µm in the 73-channel tube (Fig. 7. 11).

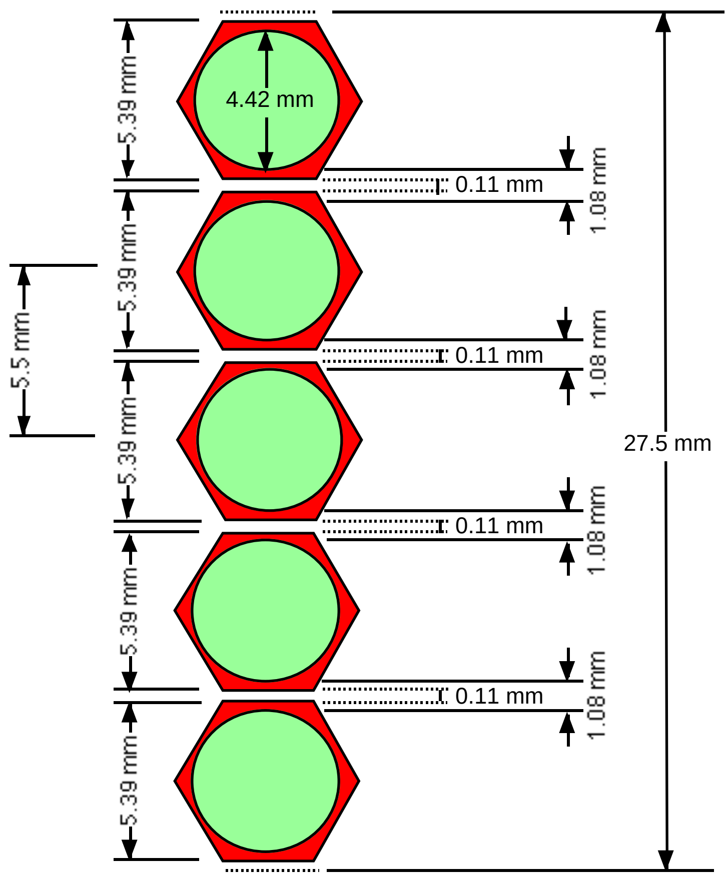

Fig. 7. 10: Flat-to-flat pixel layout across a 27.5 mm format HPD for a tube design supporting 19 channels. The circular area is the region within which a perfectly aligned optical image of a bundle of 17 fibres of 940 µm diameter is located. This is representative of the HB2 configuration. This optical image can be shifted by mechanical misalignments, optical effects, and magnetic field effects. There is 485 µm of tolerance to the edge of a pixel. This includes room for one or two 300 µm calibration fibres.

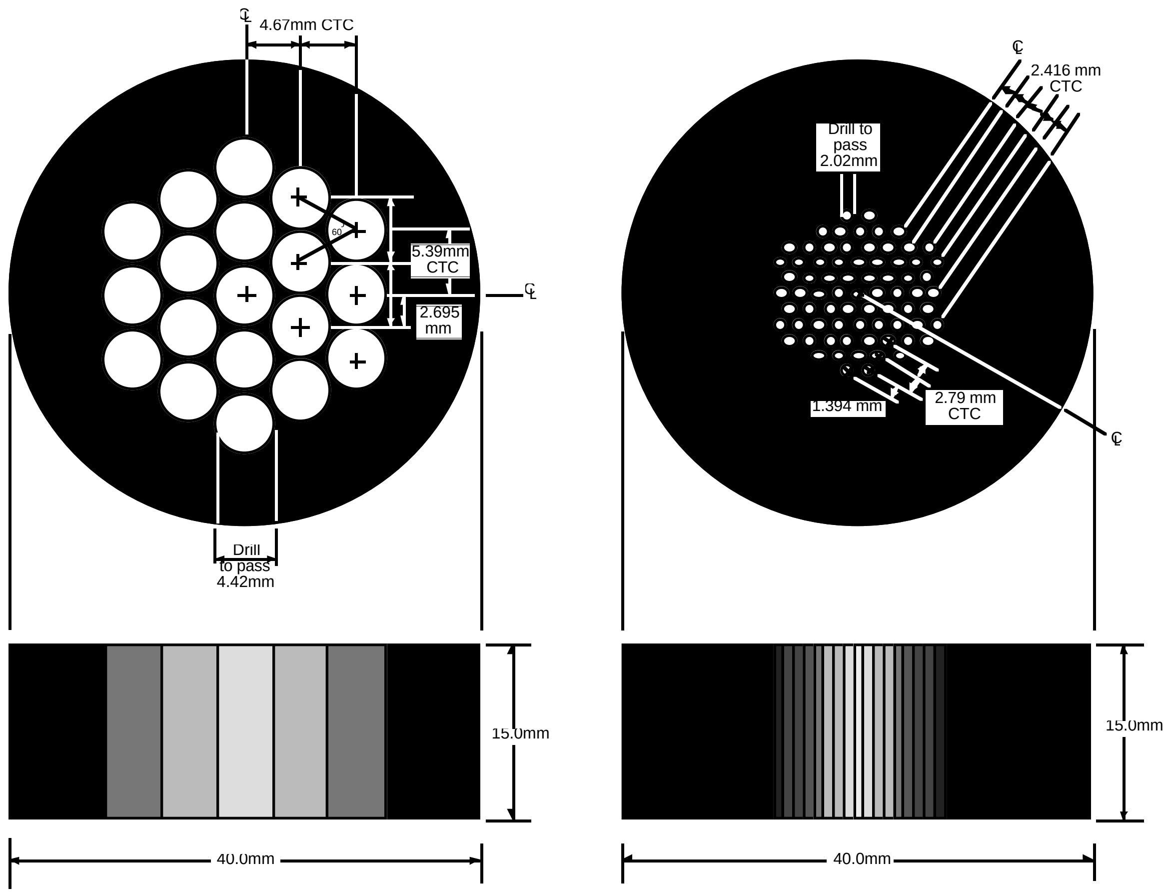

Fig. 7. 9: Delrin cookies which provide alignment of fibre bundles to the HPD faceplates in HB decoder boxes. Schematics for 19-channel and 73-channel HPDs are indicated. The 19-channel design supports up to 17 fibres of 940 µm diameter plus one or two 300 µm diameter calibration fibres per hole. The 73-channel plate supports up to three fibres of 940 µm diameter plus one or two 300 µm diameter calibration fibres per hole. [Holes for alignment pins and mounting bolts are not shown.]

Alignment concerns include: misalignment of fibre bundles relative to the HPD pixels; effects of numerical aperture of the light exiting the fibre bundles; and misalignment of tube axes relative to the direction of the local magnetic field direction.

Mechanical: The cookie is registered with alignment pins provided on the HPD which will allow for a placement tolerance of <100 µm between fibre bundles and HPD pixels.

Optical: Because of surface imperfections (surfaces of the cookies are not optically flat), the light exiting a fibre bundle will diverge according to the numerical aperture of the fibre as it passes through an airgap between the cookie and the fibre-optic faceplate of the HPD. To compensate for local surface imperfections, the Cookies and HPD faceplates will be shimmed apart by a 50 µm spacer. Crossing this gap this will lead to an “expansion” of the optical image by ~50 µm in radius, as the exit angle is slightly larger than 45°.

Magnetic: The mounting structures for the HPDs are expected to hold the HPD symmetry axes in alignment with the magnetic field direction to within 3°. Every 3° of misalignment of the HPD axis relative to the B-field will lead to a 100 µm offset of the photoelectron image in the HPD.

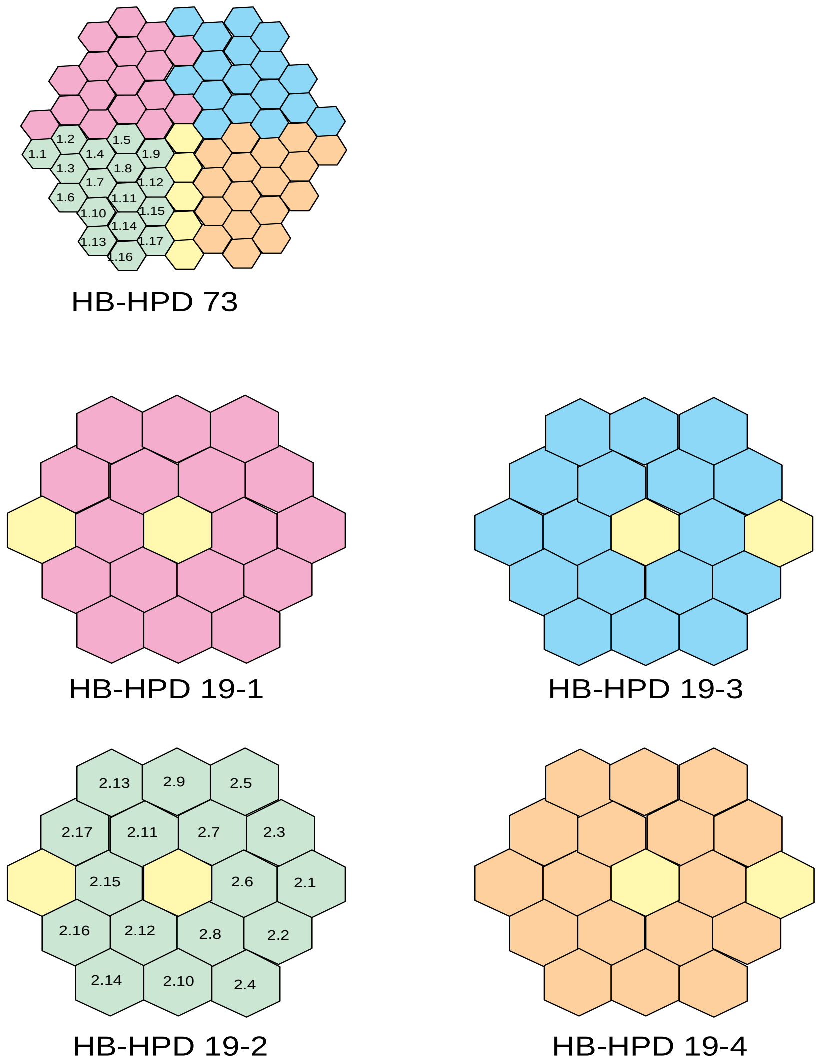

Fig. 7. 8: HB Fibre/pixel mapping scenario. The mapping of 1/4 of the channels within the decoder box is indicated, corresponding to 17 η towers in a $\Delta\phi = 5°$ interval. The HB1 towers are mapped to the HPD73 tube; the HB2 towers are mapped to one of four HPD19 tubes.

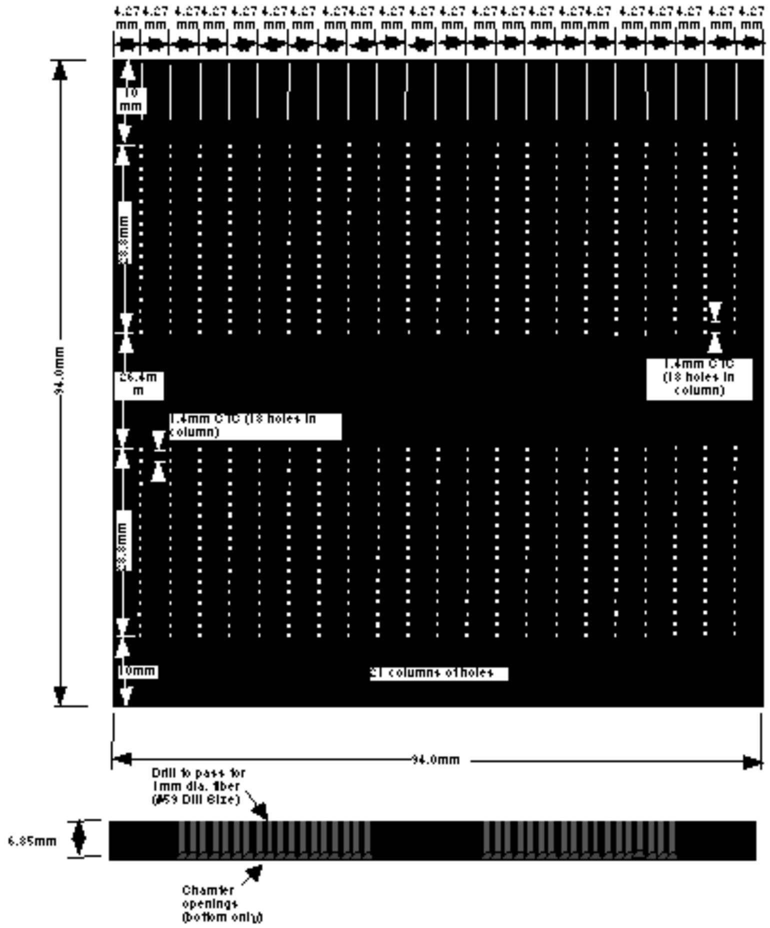

Fig. 7. 7: Delrin sorting plate format.

A mapping scenario is presented in Fig. 7. 8, which indicates a pixel mapping for one of the four $\Delta\phi = 5°$ intervals onto the HPDs within the HB decoder box. Choices of HPD location and pixel position are driven by the need to keep fibre bend radii as large as possible within the space constraints and for "simplicity" of the pattern of fibre routing.

To provide accurate alignment of the fibre bundles to the pixels of the HPD tubes, the fibre bundles are gathered into thin-wall sleeves (100 µm thick wall), that are routed from the sorting plates. The sleeves stop short of the cookies. Only the fibres are inserted and glued into holes in 1.5 cm thick Delrin cookies. (See Fig. 7. 9.) The faces of the cookies are optically finished by diamond flycutting and are held in proximate contact with the HPD fibre-optic entrance windows by 50 µm thick spacers. The cookies are physically mounted onto the interior lateral dividing wall that separates the optical and electronic compartments of the decoder box. The HPDs are spring loaded into sockets to hold them in alignment with the cookies.

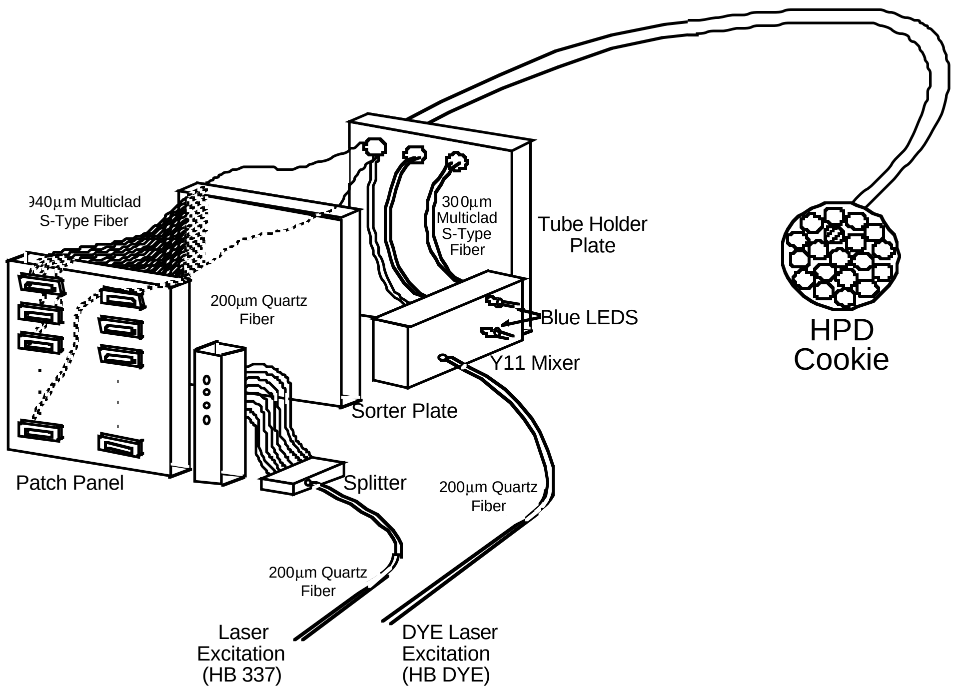

Fig. 7. 6: Decoder box optical compartment elements.

HB mapping to hybrid photodiodes

The HB2 bundles from one of the patch panels are mapped onto two 19-channel-format HPDs, designated HPD19-1 and HPD19-2 in Fig. 7. 3. Note that these are located on the far side of the optical compartment from the patch panel to allow for more adiabatic routing of the fibre bundles. The HB1 bundles from the patch panel are mapped onto half of the available pixels of a 73-channel-format HPD, designated HPD73 and positioned centrally relative to the optical compartment.

In a similar fashion, the HB2 bundles from the opposite-side optical patch panel are mapped onto the two remaining 19-channel HPDs (HPD19-3 and HPD19-4), and the HB1 bundles from that side are mapped onto the remaining pixels of HPD73.

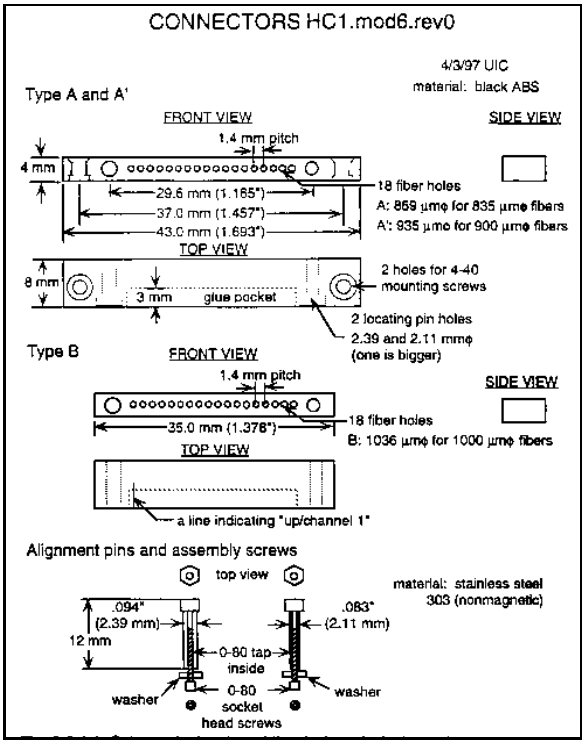

Fig. 7. 5: Optical connector design specifications for 18-fibre connector.

Certain of the megatiles of HB2 require special consideration in the placement and routing of their optical waveguides, because they are located either directly behind or immediately beneath the decoder box, and hence optical connectors would be trapped (or blocked) as is the case for layers 13-16, or because they are located on the outer surface of the wedge and are mounted to the back of the stainless steel plate (layer 17). These special waveguides will have identical optical connectors to the normal flat-ribbon waveguide connections, but the fibre bundles of the guides will be of cylindrical cross section over most of their length and hence will be more flexible than are the standard, flat ribbons.

Additionally on the optical patch panel, there are four connectors each supporting a quartz optical fibre for transmission of laser calibration signals to selected megatiles, to monitor timing and scintillator/waveshifter ageing.

7.2.2 HB fibre decoder structure and mapping

HB formation of tower geometry

Within the optical compartment, and ~10 cm behind the optical patch panel (Fig. 7. 6), is a Delrin “sorting” plate through which the interior optical fibres are organised into HB1 and HB2 subgroups and also into tower geometry. A plate schematic is displayed in Fig. 7. 7. For HB1 there are 34 “tower bundles” of up to three fibres, and for HB2 there are 34 tower bundles of 17 fibres. The holes in the sorting plate are oversized, so that the fibres simply pass through with no constraint. The bundles are then inserted into tubes held in a tube holder plate and routed to the HPDs. Additionally, a pair of multiclad fibres of 300 μm diameter are inserted into each bundle. These are optically connected to the Y11 mixers of the dye laser/LED calibration system to provide an independent monitor of the sensitivity and gain of the HPD pixels. Fig. 7. 6 also displays schematically this implementation.

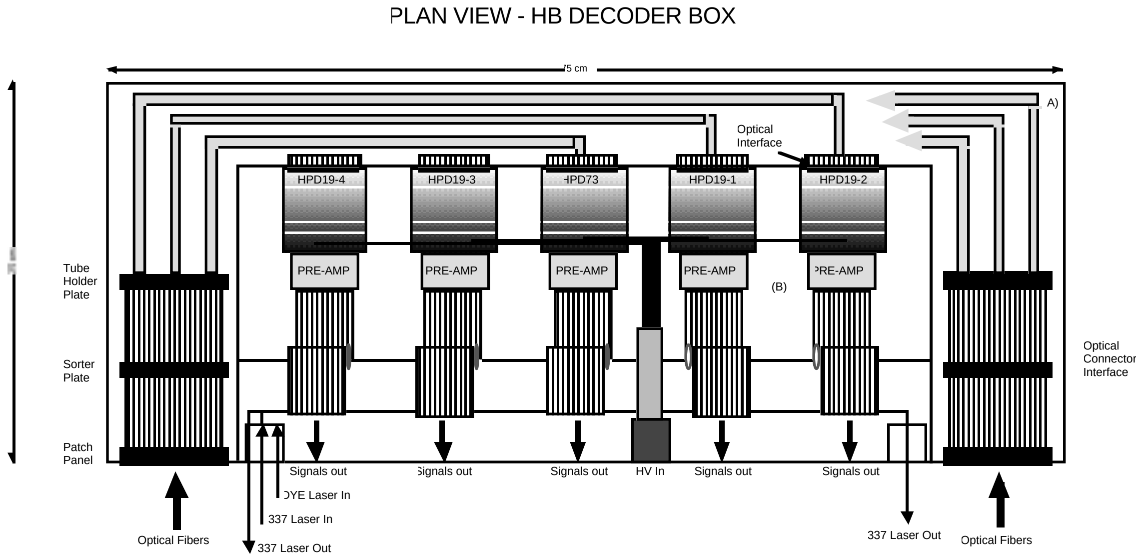

Fig. 7. 3: Schematic of the optical paths within a HB decoder box.

All optical signal fibres used in the overall HCAL system and within the decoder boxes are of 940 μm diameter, multiclad construction, with polystyrene core, PMMA and fluorinated acrylic claddings. Because of the tight turning radii within the box (r~4 cm) and the need for flexibility, Kuraray S-type fibre is used for all interior optical interconnections.

Fig. 7. 4: Schematic of an optical patch panel for a HB decoder box.

ancillary control signals are supplied via the radial crack (at |z| ~ 6.7 m) just beyond the end of solenoid, as are laser calibration signals. Digitised, optical signals destined for the DAQ system follow a similar routing.

7.2.1 HB front-end optical layout

Fig. 7. 2 shows a schematic of the mechanical and electrical layout of an HB decoder box (or DBX), and Fig. 7. 3 shows the optical layout. The DBX has external dimensions: 75 cm×25 cm×11.8 cm. The materials from which the box will be fabricated are non-magnetic: aluminium, copper, brass and plastics. The DBX is mounted onto the steel backing plate of the calorimeter wedge. It consists of two compartments which are optically isolated: a fibre-optic compartment and an electronics compartment. Five HPDs are mounted on the lateral interior wall between the two compartments.

Access to the fibre-optic compartment is via optical connectors at two optical patch panels, one at each end of the box. Each patch panel (Fig. 7. 4) is of 9.5 cm×9.5 cm×0.6 cm thick aluminium, and serves as the mounting surface for up to forty-two optical connectors arranged in two columns of twenty-one connectors. Each column corresponds to a 5° $\Delta\phi$ interval. Each connector (Fig. 7. 5) supports 18 multiclad fibres of 940 μm diameter on a pitch of 1.4 mm, and each fibre within a connector corresponds to one of 17 $\Delta\eta$ subintervals within a megatile. The extra fibre is either a spare or a calibration fibre. Each of the optical connectors is surface finished by diamond flycutting - to provide for excellent optical transmission through the connector (>85%).

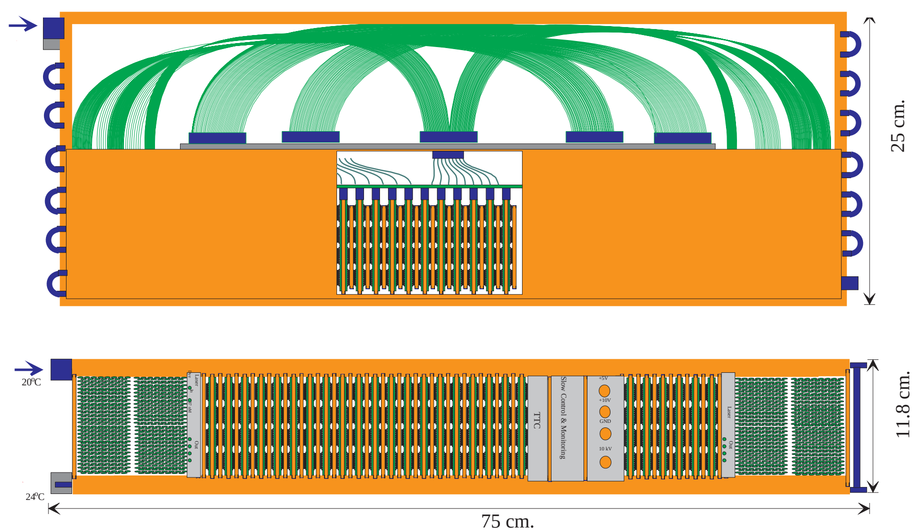

Fig. 7. 2: Schematic of the mechanical and electrical layout of a HB decoder box.

detector are similar, there are regional differences in channel counts, configurations of sampling layers, numbers sampling layers to summed, and calibration requirements. Table 7. 1 summarises the number of decoder boxes and HPDs per HCAL subsystem. Overall there are 120 decoder boxes supporting a total of 456 HPDs. Table 7. 2 summarises the number of active pixels, calibration monitors (PIN diodes), and readout (QIE) channels for each subsystem. In the following sections we enumerate the design considerations appropriate to each subsystem.

Table 7. 1

Subsystem decoder box/hybrid photodiode summary.

HCAL Subsystem	# Sites	#DBX per site	#HPD73 per DBX	#HPD19 per DBX	Total #HPD73	Total #HPD19	Total #HPD
HB+, HB-	2	18	1	4	36	144	180
HE+-, HOE+-	2	12	2	4	48	96	144
HBO-2,-1,+1,+2	4	12	0	2	0	96	96
HBO - 0	1	12	0	3	0	36	36
Total Count	9	120			84	372	456

Table 7. 2

Decoder box HPD pixel and readout electronics summary.

HCAL Subsystem	Number of Decoder Boxes	Number of HPD19 Tubes per Decoder Box	Number of Active Pixels per HPD19 Tube	Number of HPD73 Tubes per Decoder Box	Number of Active Pixels per HPD73 Tube	Number of Electronically Merged Pixels per Decoder Box	Number of Detector Electronic Channels per Decoder Box	Number of Detector Electronic Channels per Subsystem	Number of PIN Diodes per Decoder Box	Number of PIN Diodes per Subsystem	Total Number of Electronics Channels per Subsystem	Number of QIE Cards per Decoder Box	Number of QIE Cards per Subsystem
HB	36	4	17	1	68	0	136	4896	3	108	5004	47	1692
HE/HOE	24	4	18	2	72	84	174	4176	3	72	4248	59	1416
HBO-0	12	3	16	0	0	0	48	576	2	24	600	17	204
HBO+-1	24	2	18	0	0	0	36	864	2	48	912	13	312
HBO+-2	24	2	15	0	0	0	30	720	2	48	768	11	264
Totals	120							11232		300	11532		3888

7.2 HB OVERVIEW

HB refers to the hadronic calorimetry in the barrel region and within the 4 Tesla solenoid field. HB is constructed in wedge assemblies that are functionally divided at the midplane of the detector into two halves HB+ and HB-. For purposes of this discussion, we consider only one end of the detector and refer to it generically as HB. HB consists of 18 wedges, subtending 20° in ϕ, and each wedge is served by a decoder box which is located in the corner of the wedge at largest r and $|z|$. Additionally, HB is operationally divided into two longitudinal (depth) sections: HB1 which provides for up to three layers of initial sampling of a shower just at the exit of ECAL, and HB2 which consists of 17 sampling layers. Each sampling layer of HB1 and HB2 is subdivided into four $\Delta\phi$ intervals and up to 17 $\Delta\eta$ intervals. This planar unit of 68 elements is called a megatile.

Optical signals from the megatiles are conveyed via ribbon cables of fibre-optic waveguides up the 53° crack that delimits the barrel region to the decoder box for signal processing. Laser calibration signals are conveyed in the opposite direction from the decoder box to the megatiles via quartz fibre.

Low voltage power, high voltage services, cooling water, nitrogen gas, TTC and

7. OPTICAL-ELECTRONIC INTERFACE SYSTEM

7.1 OVERVIEW AND REQUIREMENTS

The front-end interfaces of the hadron calorimeter consist of a distributed set of units called “decoder” boxes, which are located strategically “on detector”. While the name is derived from the optical function performed by these interfaces, in reality the units serve as a control point for a variety of functions, including: light collection and optical signal processing using fibre-optic light guides, operation of the phototransducers which are multi-channel Hybrid Photodiodes (HPDs) which detect and amplify the calorimetric signals, digitisation of the signals to 15-bit precision, and transmission of these digitised signals “off detector” to the Trigger/DAQ system. Additionally, the decoder boxes are the optical calibration interface, receiving input laser calibration signals and routing these to test HPD pixels and to test the scintillation tiles for response and ageing. An additional LED test feature for calibration of the HPDs is also provided which is independent of the Laser system and useful in the construction and assembly phase when the laser is unavailable.

To provide this functionality, decoder boxes support numerous interconnections. A schematic is shown in Fig. 7. 1. These include: input of optical signals from the detector; input of laser calibration signals from the counting room; input of HV to operate the HPDs; input of LV for HPD bias and separate LV inputs for operation of the preamps, digitisers, and line drivers; input of test pulses for the LED drivers; input of TTC (slow controls signals); connection to cooling water for temperature control; and connection to dry N_2 gas flow to protect the HPD cathodes from He poisoning. [Control and operation of the source tube driver is independent of the decoder box and is described elsewhere.]

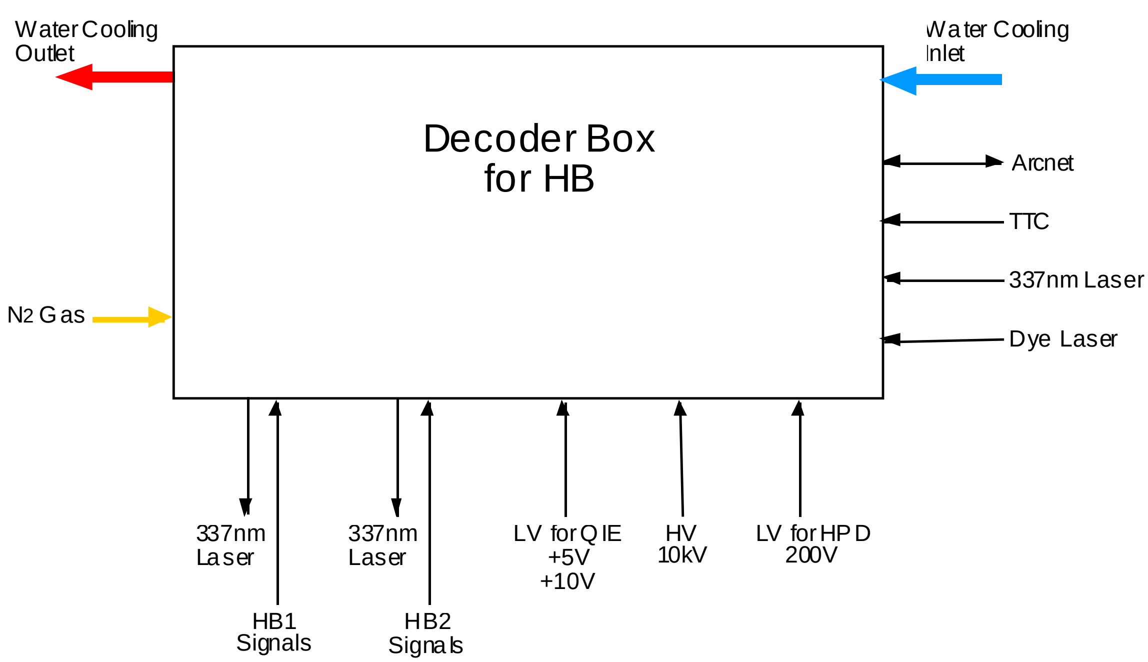

Fig. 7. 1: A system/interface schematic of a HCAL decoder box (or DBX). The example is for the HB subsystem, but is representative of all HCAL subsystems.

The actual configuration of the decoder boxes depends upon the HCAL subsystem involved: HB, HE/HOE, HOB-0, HOB±1 and HOB±2. While the global requirements for each