The Production of SciFi TDR Modules

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1 Design Concept

This design concept is a result of the following:

- The experience of constructing the LHCb Outer Tracker, which was of the same area and modular structure, built by NIKHEF and Heidelberg. The use of a single precision template to align the fibre mats results in the reproducablity of the alignment and flatness of every module.
- The experience gained from handling the fragile fibre mats once they are removed from the winding wheel and transported; considering the number of fibre mats that will have to be produced (1300+) and the fact that they will need to be produced at multiple sites by different institutes and then transported, a simple and robust method was developed to protect the mats by casting them in a thin layer of flexible epoxy.
- The requirements on the stiffness and stability of the detector, along with the large number of modules to be produced with precision has lead to the decision to use a simple honeycomb core half-panel, which requires little to no machining, such that when two half panels are bonded on either side of a fibre mat, the result is a simple, flat, light and stiff detector. The skin on inner-facing side of the honeycomb has been removed as it does not contribute to the final module stiffness and only adds extra material.

Figure 1: A drawing of the cross-section of a SciFi Tracker module. Two single-skin half-panels are bonded on either side of a fibre mat. The endplugs and endpieces are required for interfacing the frame, Read-out Box and SiPMs.

A cross-section along the 5-m length of a module is shown in Fig. **??**. Two half-panels (a honeycomb core with a single carbon fibre (CFRP) skin) are bonded on either side of the eight fibre mats. The 2.5 m long fibre mats are arranged four across, and two down with the mirrored ends nearly touching. This produces a module with a width of 52 cm wide and 5 m long. Thermoplastic endplugs are added to provide mechanical interfaces to the Read-out Box and frame, and also limit the thermal load on the cooling system. The process of the bonding the module is described later in Section [assembly].

2 Material Budget

The panel material has been chosen to provide the maximum strength while having the lowest material budget. A sandwich of two 0.2 mm carbon-fibre reinforced polymer (CFRP) layers separated by two 20 mm layers of light core material (Nomex® honeycomb,)[1] on either side of the scintillating fibre mats will produce a simple, light and robust tracking module. Given the large amount of material, the honeycomb core is chosen for its low density, good strength, low water absorption, and its excellent fire, smoke and toxicity (FST) properties.

The prototype module material budget [2] is shown in Table **??**. The lowest total radiation length for this design is X/X_0= 0.90% for one module of 5-layers of fibre or 3.6% for one tracking station of four module layers. The majority of the material budget is a result of the fibres mat, as described in the TDR. The glue used during winding contains TiO_2 while the casting glue does not, but both are a variant of Epotek 301. [3] The IT and OT would be replaced completely by the nearly uniform SciFi Tracker which would contribute approximately 11% of a radiation length to the LHCb detector.

Table 1: The material budget for a single module. Core material budgets for 24 / 32 kg/m^3 Nomex are listed. The fibre mat is the current cast 5 layer (6-layer) prototype thickness. The fibre mat glue contains $Ti0_2$ while the casting glue does not.

Material	Thickness(μm)	Layers	X_0(cm)	X/X_0 (%)
Nomex Core 24/32	20000	2	1750/1310	0.229/0.305
CF skin	200	2	23.3	0.172
Panel assembly glue	75	4	36.1	0.083
Fibre mat 5(6)-layer	1200 (1350)	1	33.2	0.361 (0.407)
Casting glue	120	2	36.1	0.066
Total	4220			0.91/0.99 (0.96/1.02)

3 Sub-modules

The "sub-module" in this design concept, which is the first object after fibre mat winding to be tested and to pass quality-assurance checks, is a casted mat with endpieces bonded to the ends, that has been cut transversely along the face of the mat at the endpieces to check for the light yield, and overall quality of optical finishing and mirroring. If the

[1] Nomex is a registered trademark of E.I. du Pont de Nemours and Company (DuPont®).

[2] The radiation length for the Nomex® core is calculated as in Ref. [**?**]

[3] Total radiation lengths should be compared to the Inner and Outer Tracker material budgets. The OT has a material budget of 0.744% per layer plus 0.191% for sidewalls, which is 3.17% per station [**?**]. The IT contributes between 2 and 7% per station. Averaged over the T-stations, and averaged over ϕ and for $2.0 < \eta < 4.8$ for minimum bias events, a particle sees around 17.5% of a radiation length coming from the IT and OT material [**?**].

mat meets specifications, it can then be used to assemble a module. A cast mat is easy to handle without fear of damaging the fibre mat inside. If it is rejected, the loss is the fibre, some glue and the time to produce it.

Table 2: Summary of steps to produce a Sub-Module (casted fibre mat with endpiece and mirror including all transversal optical cuts.)

Step#	Process	Labour	#People	To next step	Cost/mat (CHF)
1	Casting	2 hours	2	2 days	180
2	Transversal Cut	1 hour	1	1 hour	∼25
3	Glue Mirror	0.5	1	1 day	1
4	Longitudinal Cut	1 hour	1	1 hour	5
5	Last Endpiece glueing	0.5	2	2 hours	25
Total		5 hours		3.5 days	∼236

3.1 Steps to produce a Sub-Module:

1. Cast Fibre mat: Work load:

- clean mould (cleaning, applying non-sticking layer, heating)
- glue fishing lines
- close casting form
- mix glue
- fill glue
- remove mat from mould (after curing)

Estimated working time per fibre mat: 2 hours for two technicians
Curing time: 2 days

Tools:

- casting jig/winding centre (to cast two fibre mats at once). Price estimate: ??? Euro/jig
- one water heating circuit (e.g. JULABO MC-4) Price estimate: 1646Euro

2. Transversal cut to Polish fibre ends Work load:

- Align fibre mat on milling machine
- cut fibre ends

- same for second end

Estimated working time per fibre mat: 1 hour for one technician Tools:

1. 1 Standard milling machine / winding centre 2. 1 Diamond milling head / winding centre cost estimate: ??? Euro Glue mirror Work load: 1. Align fibre mat in gluing jig 2. prepare glue 3. glue mirror Estimated working time pre fibre mat: 0.5 hours for one technician Curing time: 1 day Tools: 1. 1 jig / winding centre cost estimate: 500Euro / jig Total work load for 1 fibre mat: 6hours (winding excluded) At Module Assembly Centre (MAC) Longitudinal cut: Work load: 1. Align fibre mat on milling machine 2. cut fibre mat Estimated working time per fibre mat: 1 hour for one technician Tools: 1. Milling machine with long table (1.5m) / MAC 2. 1 Double blade 'Kreisfräse' / MAC cost estimate: 500Euro Glue end-pieces: Work load: 1. prepare gluing jig (cleaning) 2. prepare end-pieces (grinding) 3. prepare glue 4. align and glue end-pieces in jig 5. apply pressure Estimated working time pre fibre mat: 0.5 hours for two technicians Curing time: 2 hours Tools: 2 templates / MAC (assuming it can be used to glue 4 fibre mats at once) cost estimate: 5000Euro / template

4 End-pieces and End-plugs

5 Panels

6 Sub-module preparation

7 Module Assembly

8 Tools and Technologies

9 Resource and Serial Production