ATLAS EXPERIMENT

ATLAS Note

LAr Frontend Electronics

22nd August 2025

CERN

Draft version 0.2

LAr Optical Links on FEB2: Design and Quality Control

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This document describes the LAr FEB2 optical-link design for the HL-LHC upgrade, the arrangement of VTRx+ modules and fiber routing, VTRx+ installation guidelines for the FEB2 board, and the QA procedures developed at SMU.

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1 Introduction

After a brief overview of the HL-LHC LAr readout, this chapter focuses on the VTRx+ optical transceiver. CERN ships VTRx+ modules after baseline production QA (electro-optical checks) with standard identification labels and packaging.

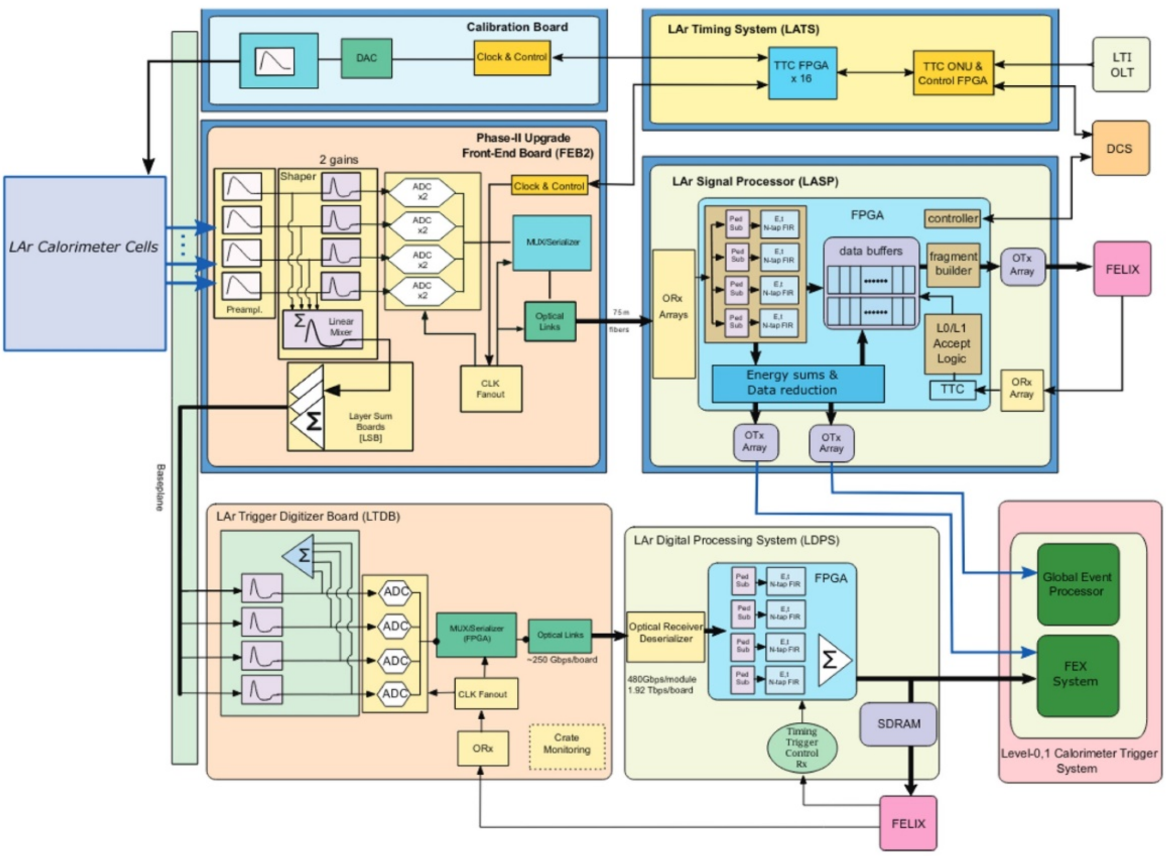

Figure 1.1: HL-LHC LAr readout overview. On-detector FEB2 boards send data upstream to off-detector processing; timing and control come downstream from LATS/TTC.

1.1 ATLAS LAr front-end readout in the HL-LHC era

This note describes the optical links on the ATLAS Liquid-Argon (LAr) Front-End Board 2 (FEB2) for the HL-LHC. The upgrade enables full-granularity readout of about 182 500 calorimeter channels (see Figure 1.1). Each FEB2 processes 128 channels: it shapes and digitizes the signals, then sends the data off-detector over 22 simplex *upstream* optical links (FEB2 Tx) at 10.24 Gb/s (see Figure 1.2). Configuration, timing, and monitoring use two duplex control links: the downstream leg (FEB2 Rx) runs at 2.56 Gb/s, and the upstream leg (FEB2 Tx) runs at 5.12 Gb/s (see Figure 1.2). All optical links use lpGBT ASICs and VTRx+ modules.

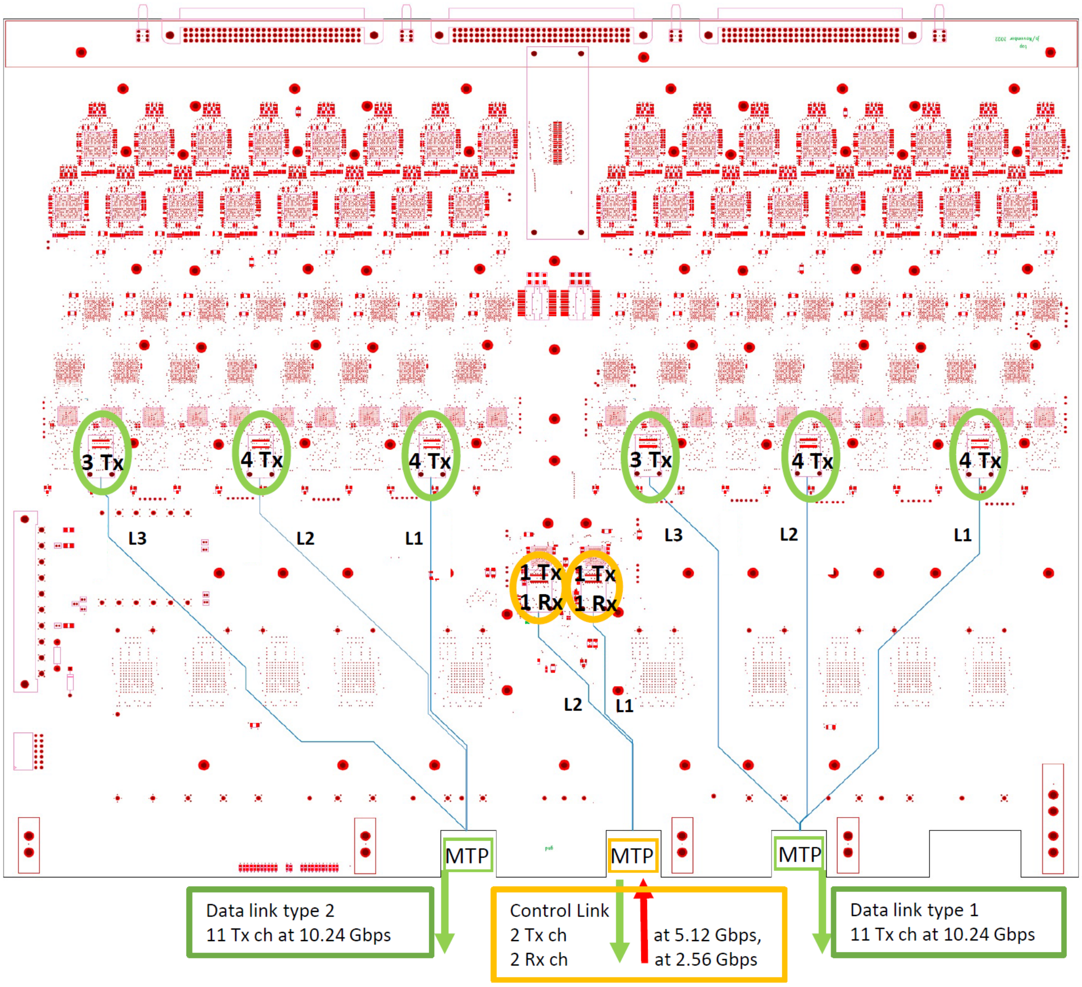

Figure 1.2: Optical links on the FEB2. Data: 22 simplex upstream links at 10.24 Gb/s. Control/timing: two duplex links with downstream 2.56 Gb/s and upstream 5.12 Gb/s. See Section 2.3 for a detailed description of the board.

The lpGBT is a low-power, radiation-tolerant serializer–deserializer ASIC. On FEB2 it collects digitized data and status from the front-end logic, applies line coding and error protection, then serializes the stream for the upstream link. On the downstream link it recovers the clock, deserializes the data, and distributes timing and commands to the board.

The VTRx+ is the matching optical transceiver. It converts lpGBT electrical lanes to light and back. Its transmit lasers carry upstream traffic (FEB2 Tx) to the off-detector side; its optical receiver brings downstream timing/control (FEB2 Rx) back to FEB2.

One FEB2 includes 24 lpGBTs and 8 VTRx+ modules. Across the full system of 1 524 FEB2s, the aggregate raw data rate exceeds 300 TB/s. The on-detector electronics are designed for a lifetime total ionizing dose of about 2.25 kGy.

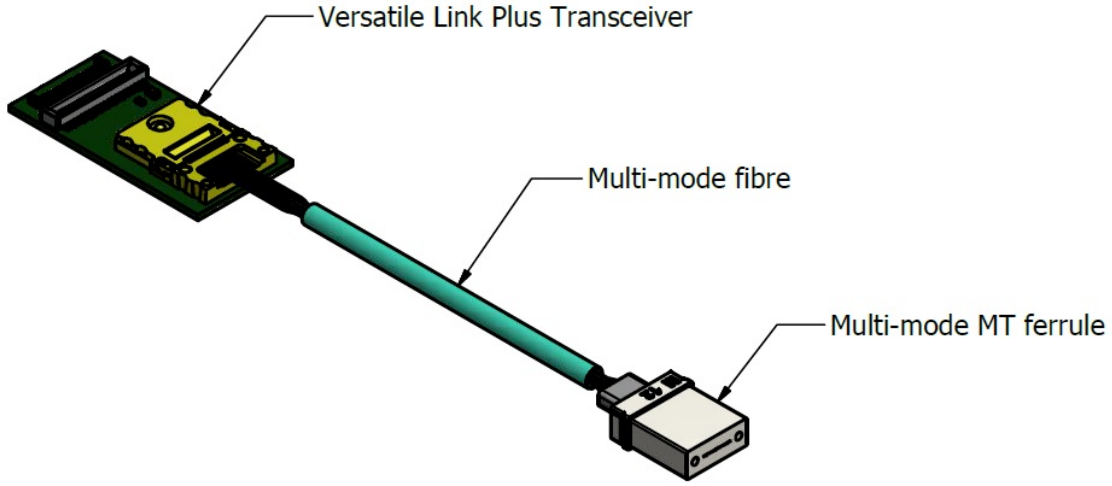

Figure 1.3: 3D rendering of the VTRx+ module with MT connector.

1.2 VTRx+ optical modules

VTRx+ is a radiation-tolerant optical transceiver for HL-LHC systems. On FEB2 it provides four transmit (Tx) channels for data and one receive (Rx) channel for control/clock. The module contains (see Figure 1.3):

- a small PCB with a vertical-cavity surface-emitting laser (VCSEL) array and a quad laser driver (4×Tx);
- a single PIN photodiode with a transimpedance amplifier (1×Rx);
- an optical pigtail with an MT ferrule at the end.

CERN produces the VTRx+ modules and runs baseline production QA to verify compliance with the VTRx+ electro–optical specifications (see Figure 1.4). In addition to the baseline specification, the LAr project receives a higher-margin subset: modules with transmit optical-modulation amplitude (OMA) > 600 µW that meet tighter requirements.

Each VTRx+ is supplied in a dedicated black plastic case that protects the PCB, as shown in Figure 1.5. The case is sealed in an antistatic bag. The bag label lists the pigtail length and a unique pigtail ID. CERN maintains a mapping from the pigtail ID to the module's internal VTRx+ ID, so the module can be identified without opening the case.

#	Specification	Min.	Typ.	Max.	Unit
4.1.1	Tx OMA	-5.2			dBm
4.1.2	Tx Extinction Ratio	3			dB
4.1.3	Tx Eye Opening	60			%[a]
4.1.4	Tx rise/fall time[b]			44	ps
4.1.5	Tx Total Jitter[c,d]			25	ps
4.1.6	Tx Deterministic Jitter[e]			12	ps
4.1.7	Tx Output Eye Mask	*see Table 6 & Figure 5*			
4.1.8	Tx output wavelength	840	850	860	nm
4.2.1	Tx Differential input voltage	200		1200	mV
4.2.2	Tx Input rise/fall time[b]		30	40	ps
4.2.3	Tx Input Total Jitter[c]			0.26	UI
4.2.4	Tx Input Deterministic Jitter			0.14	UI
4.2.5	Tx Input Eye Mask	*see Table 6 & Figure 6*			
4.2.6	Tx Differential input impedance	90	100	110	Ω
4.3.1	Rx input Total Jitter[c]			0.48	UI
4.3.2	Rx input Deterministic Jitter			0.28	UI
4.3.3	Rx Sensitivity[c]			-13.1	dBm
4.3.4	Rx input wavelength	840		860	nm
4.3.5	Rx input OMA			2.0	dBm
4.3.6	Rx input AOP			2.4	dBm
4.4.1	Rx Differential output voltage	200		600	mV
4.4.2	Rx rise/fall time[b]			40	ps
4.4.3	Rx Total Jitter[c,f]			34	ps
4.4.4	Rx Deterministic Jitter[g]			14	ps
4.4.5	Rx Eye Mask	*see Table 6 & Figure 6*			

[a] Eye Opening is a fraction of OMA.
[b] 20-80%
[c] at BER = 1×10^{-12}.
[d] Output of VL+ up to this point is 0.44 UI (at 10.24 Gb/s).
[e] Output of VL+ up to this point is 0.26 UI (at 10.24 Gb/s).
[f] Output of VL+ up to this point is 0.175 UI (at 2.56 Gb/s).
[g] Output of VL+ up to this point is 0.105 UI (at 2.56 Gb/s).

Figure 1.4: VTRx+ module electro-optical specifications.

Figure 1.5: The VTRx+ with module id (011849) on its PCB inside opened black plastic case and antistatic bag with pigtail length (37 cm) and pigtail id (J-SD55345162) label.

2 VTRx+ on FEB2: Layout and Interfaces

This chapter describes the mechanical layout of VTRx+ modules on FEB2 and the routing to the MTP interfaces. It also gives handling rules for the electrical connector used to attach the VTRx+ to the board.

2.1 Hirose connector

The VTRx+ mates to FEB2 through a fine-pitch mezzanine connector, Hirose DF40C–40DP–0.4V. The connector is rated for about 30 mating cycles. It is fragile and requires careful handling. Insertion and removal must be performed strictly perpendicular to the PCB. Twisting, bending or rocking can damage the connector housing and its solder joints on either board and can increase contact resistance.

Figure 2.1 shows the VTRx+ module and its two interfaces: the DF40C electrical connector and the optical pigtail. On the electrical side, a Hirose DF40C–40DP–0.4V mezzanine connector provides 40 contacts in two rows (0.4 mm pitch). Pins are numbered according to the Hirose DF40C scheme. On the optical side, the pigtail terminates in a 12-fiber MT ferrule (MT-12), where four fibers carry the transmit channels (Tx1–Tx4) and one fiber carries the receive channel (Rx). The remaining fibers are not used.

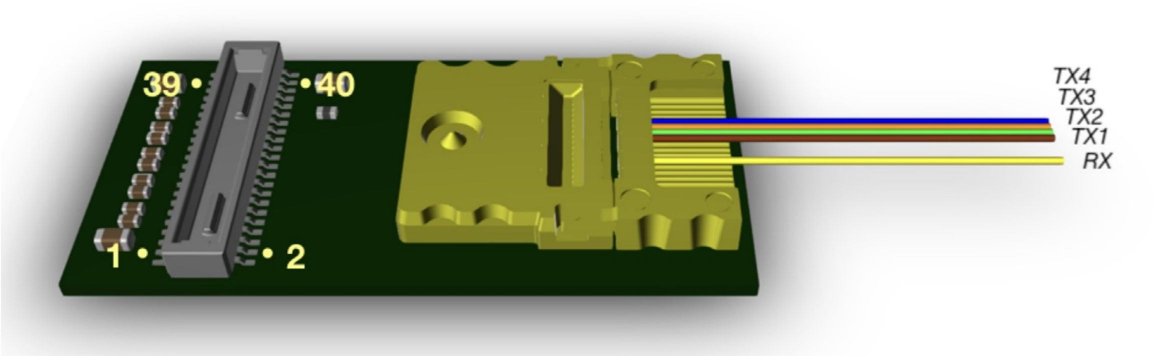

Figure 2.1: VTRx+ reference view: DF40C–40DP–0.4V pin numbering and optical channels (Tx1–Tx4, Rx).

Figure 2.2 illustrates correct and incorrect Hirose handling. In the correct case, the halves are aligned without force and kept parallel to the PCB. Insertion is vertical with the parts held parallel. Sliding or tilting characterizes the incorrect cases. Figure 2.3 illustrates removal: the connector is lifted vertically and evenly. If needed, a small, symmetric force is applied at both ends to avoid rocking.

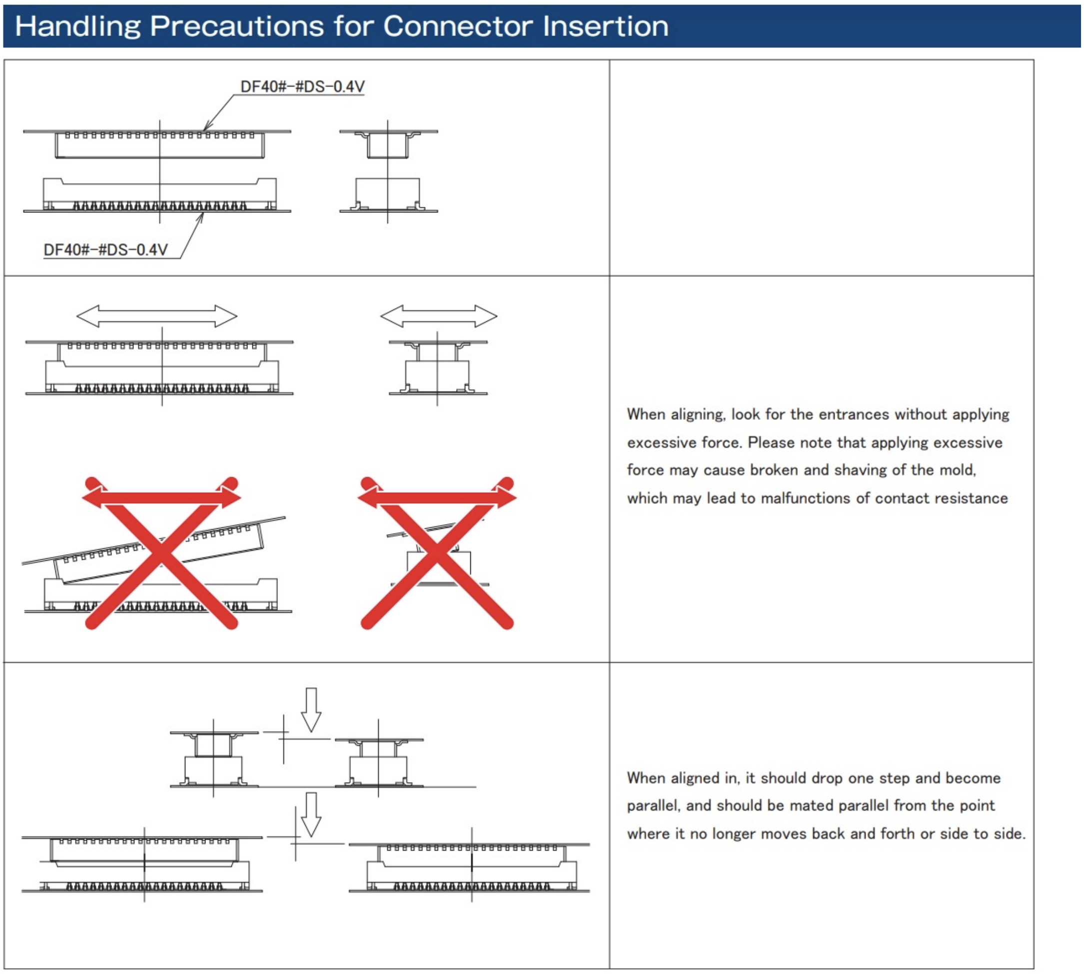

Figure 2.2: Correct insertion procedure for the Hirose DF40C–40DP–0.4V connector.

2.2 Standoff and mechanical retention

The VTRx+ is mechanically retained on FEB2 by a custom plastic standoff designed at SMU (see Figure 2.4). The standoff holds the VTRx+ PCB edges near the optical subassembly and restricts side-to-side and up-down movement. Production standoffs are made from UL94 V-0, halogen-free nylon (Vydyne ECO-315) and are supplied by Essentra Components. Key dimensions are shown in Figure 2.5.

2.3 VTRx+ placement and MTP front-panel interfaces on the FEB2 board

Figure 2.6 shows the placement of eight VTRx+ modules on FEB2 (black markers) and the three front-panel MTP-12 adapters (red markers). Only three MTP-12 adapters fit on the front panel. This mechanical limit drives the grouping and the pigtail routing. These three adapters divide the eight modules into the following functional groups:

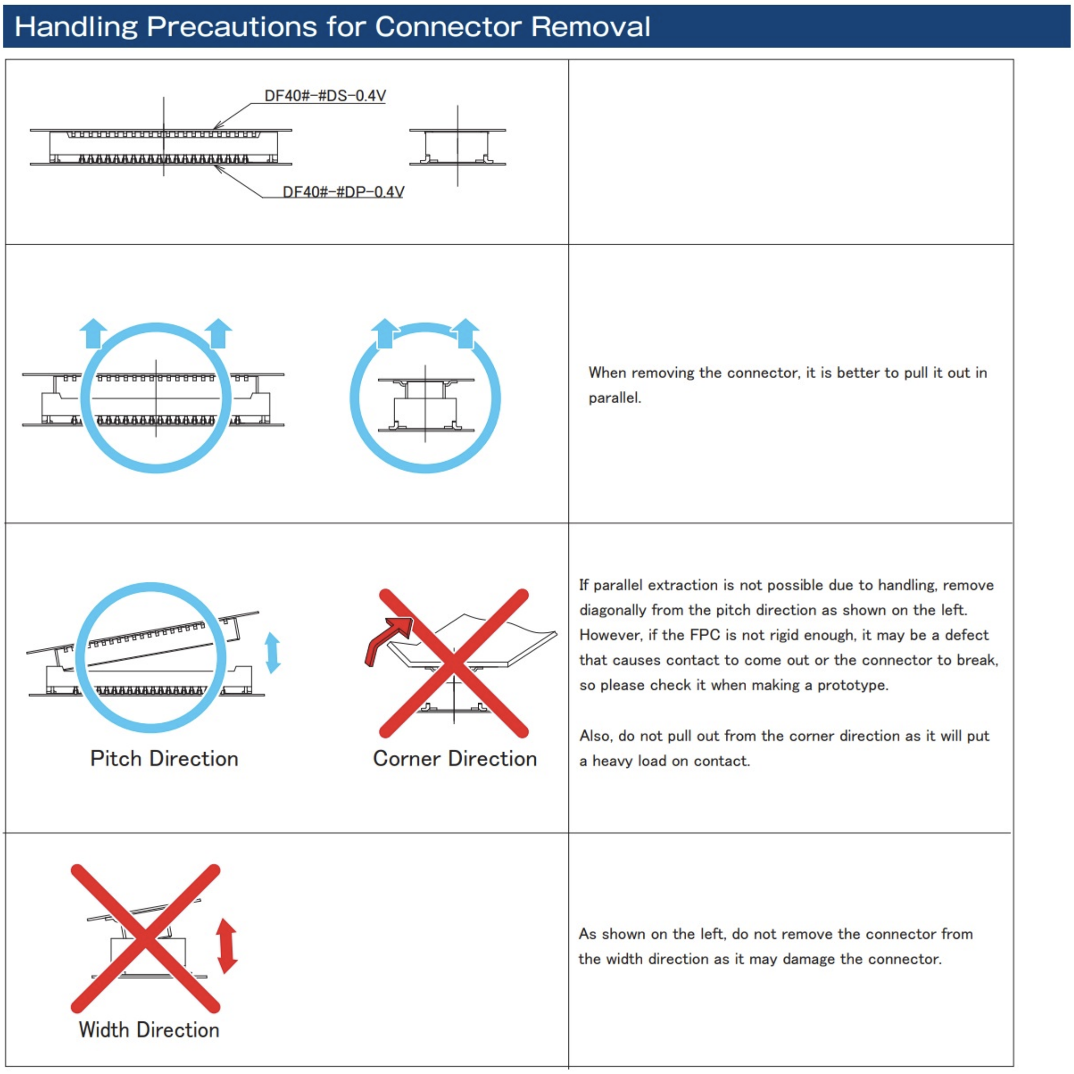

Figure 2.3: Correct removal procedure for the Hirose DF40C–40DP–0.4V connector.

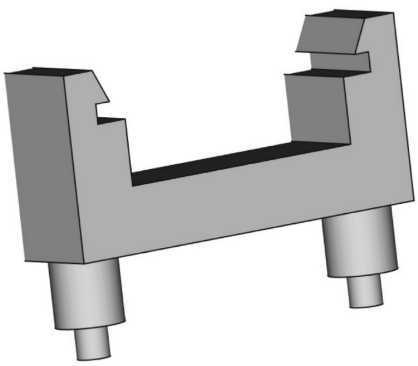

Figure 2.4: 3D-printed prototype of the VTRx+ standoff for the FEB2 board.

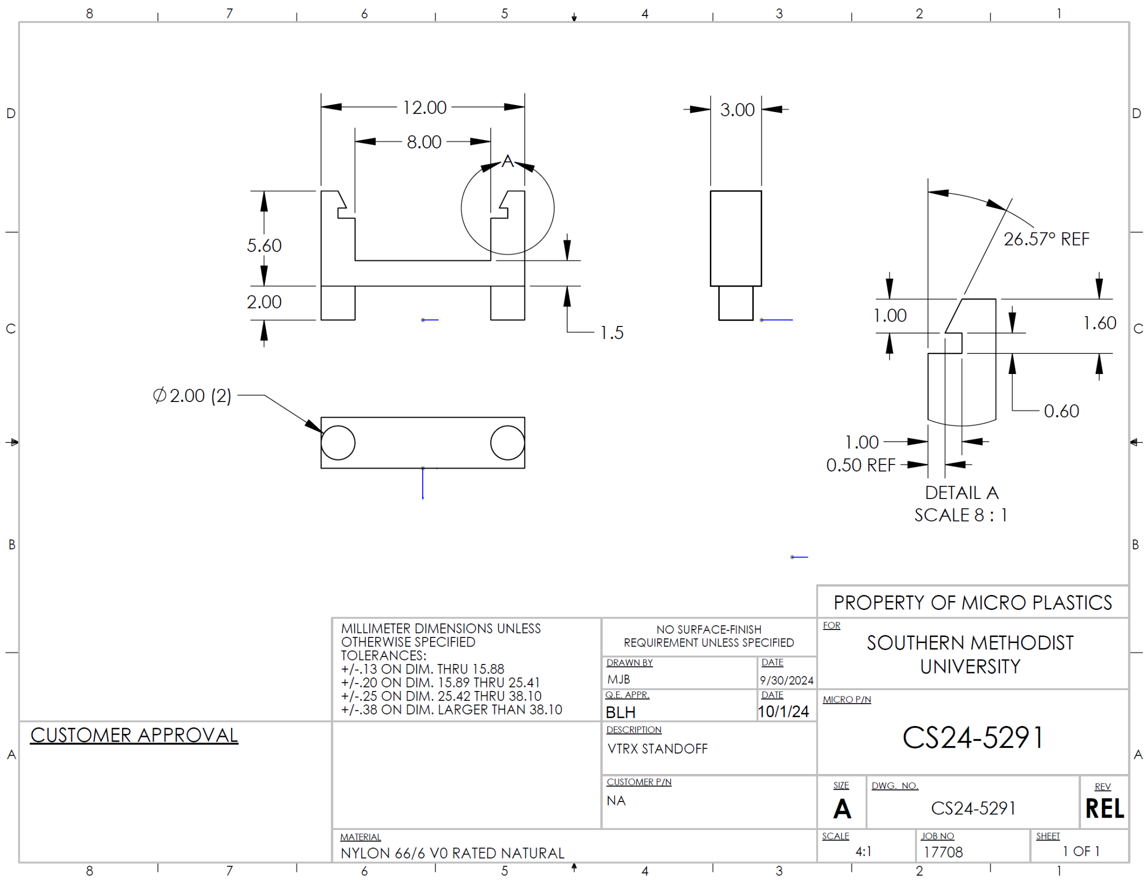

Figure 2.5: Mechanical drawing of the production standoff (UL94 V-0, halogen-free).

1. *Control link:* the two middle VTRx+ modules form the duplex control/timing link.
2. *Data link type 1:* the three right-side modules form one data group. This link carries 11 simplex *upstream* channels (FEB2 Tx) at 10.24 Gb/s.
3. *Data link type 2:* the three left-side modules form the other data group. This link carries 11 simplex *upstream* channels (FEB2 Tx) at 10.24 Gb/s.

Type 1 and type 2 have identical fiber mappings, and the only difference is the pigtail fiber lengths.

2.4 Connection topology

Each VTRx+ pigtail ends in an MT ferrule (see Section 1.2). There are two practical ways to connect eight MT pigtails to three front-panel MTP-12 adapters on FEB2:

1. *Splitter harness:* use 3(2)×MT→1×MTP fiber splitters to combine three (two) modules into a single MTP-12 connector, which then mates to a front-panel MTP-12 adapter (right-hand concept in Figure 2.7).

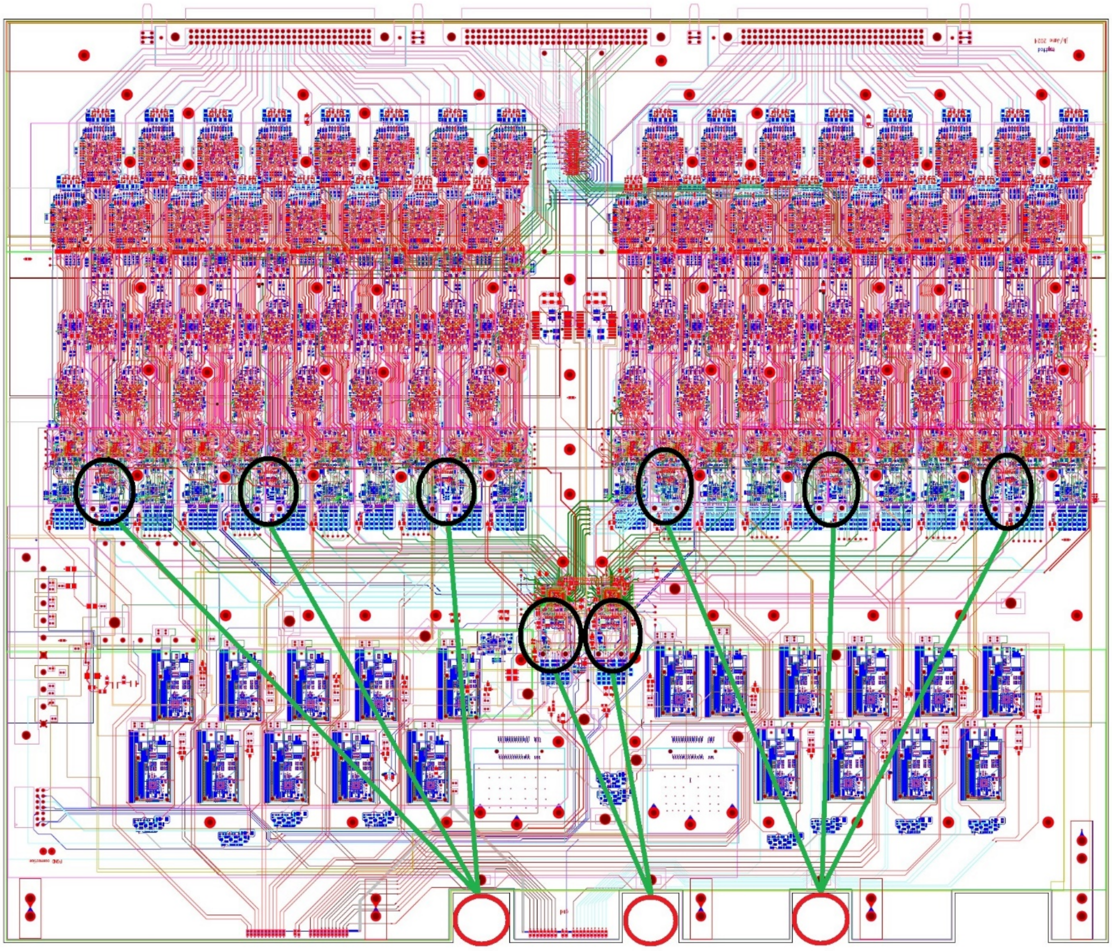

Figure 2.6: FEB2 placement: eight VTRx+ modules (black), three front-panel MTP-12 adapters (red), and schematic pigtail routing (green).

2. *Direct retermination:* re-terminate three or two VTRx+ pigtails directly into an MTP-12 connector, which then plugs directly into the front-panel MTP-12 adapters (left and middle in Figure 2.7).

The second option is used for production. It avoids extra fiber segments and MT-to-MT junctions, reduces insertion loss, saves board area otherwise needed for MT–MT clamps, and simplifies assembly.

2.5 Risks of making MTP connectors

Direct retermination of VTRx+ pigtails with MTP connectors is handled by the Fiber Optics Division of Computer Crafts Inc., selected after a vendor comparison and pilot pre-production runs.

The MTP connector assembly requires at least 30 mm of pigtail fiber to be trimmed and discarded. In addition, cutting and preparation are manual operations that increase scrap rates. In two backup trial orders from alternative vendors, the observed error rate was about 9%.

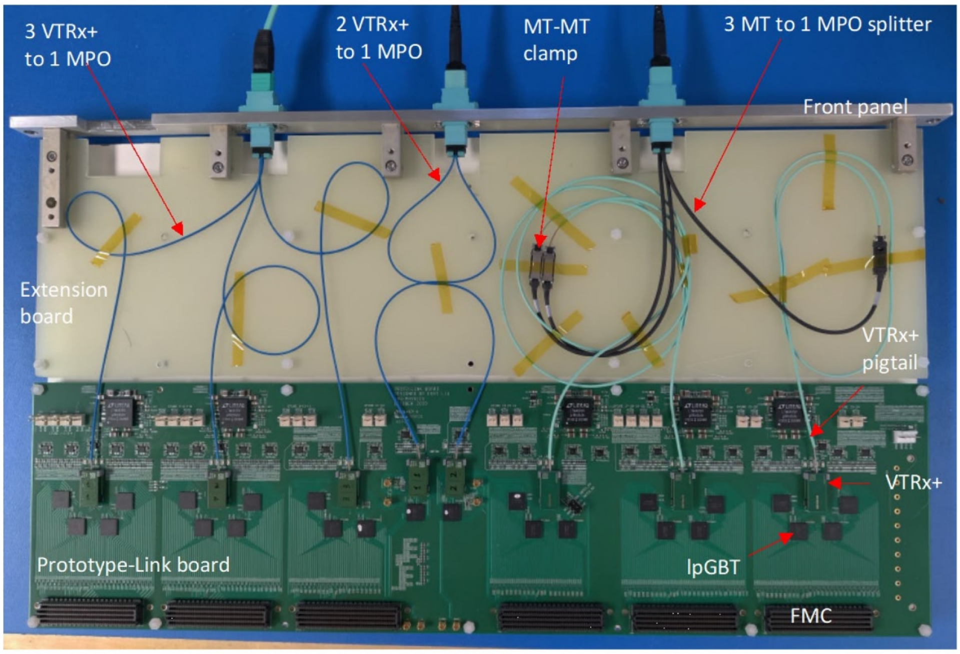

Figure 2.7: Prototype-link board at SMU with VTRx+ modules and front-panel MTP-12 adapters. Connection options for routing eight VTRx+ pigtails to three MTP-12 front-panel adapters: splitter harness (right) vs direct retermination (left and middle). The production design uses direct retermination.

To prevent module rejection due to assembly errors and to simplify maintenance, the design defines a reduced ('re-work') variant in which all fibers in a link are 30 mm shorter than nominal. If a nominal-length VTRx+ fails during detector operation, the module can be replaced and the entire group link (control or data) converted to the rework variant, without replacing the remaining good modules in that link.

Figures 2.8 to 2.10 show the mechanical outlines and fiber mapping for the links. The external label encodes both a unique ID and a common link code:

1. M2–VAR1 — control link (two modules),
2. M3–VAR1 — data link type 1 (three modules),
3. M3–VAR2 — data link type 2 (three modules).

2.6 Fibers routing scheme

Considering the risks associated with MTP-12 manufacturing and assembly, the SMU team defined an elegant fiber-routing scheme on the FEB2 board that uses as few saddles as practical. The nominal routing is shown in Figure 2.11. The reduced ('re-work') routing is shown in Figure 2.12. Both variants pass through the same saddle locations, so the saddle layout on FEB2 remains identical for the nominal and rework configurations. The scheme addresses the following points:

1. Near the front-panel MTP adapter and each VTRx+ module, the fiber runs straight with no immediate bend, avoiding excessive tension at the terminations.

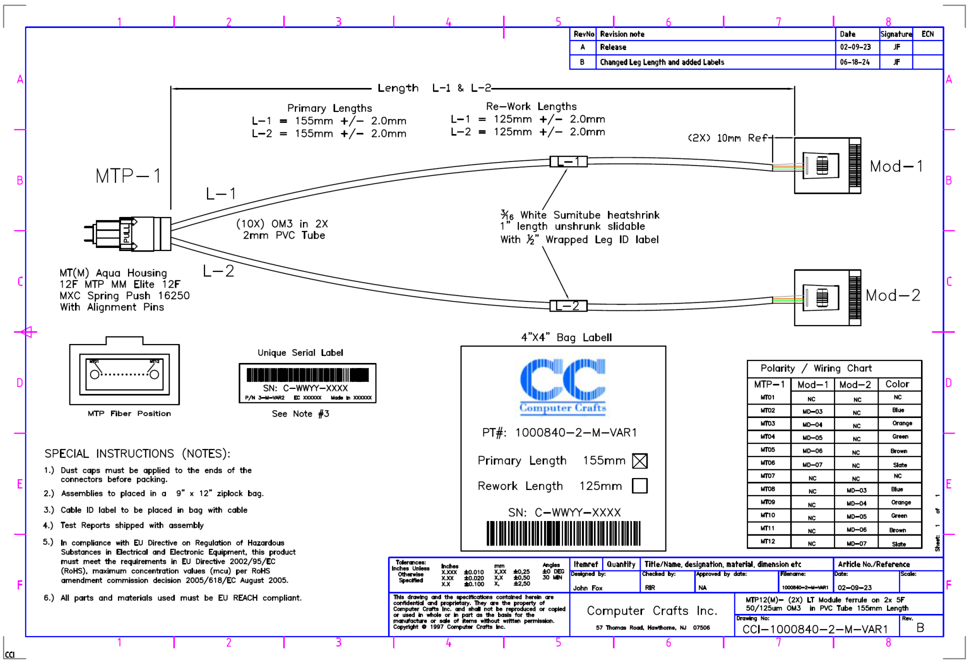

Figure 2.8: Control-link optical fiber assembly (MTP-12 to two VTRx+ modules) with fiber mapping/polarity.

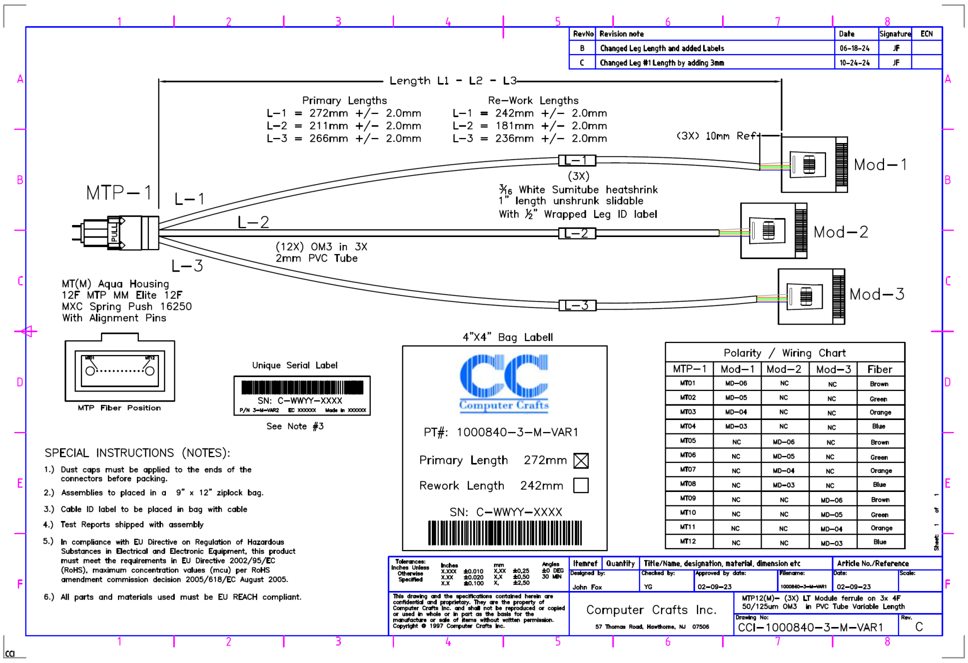

Figure 2.9: Data-link type 1 optical fiber assembly (MTP-12 to three VTRx+ modules) with fiber mapping/polarity.

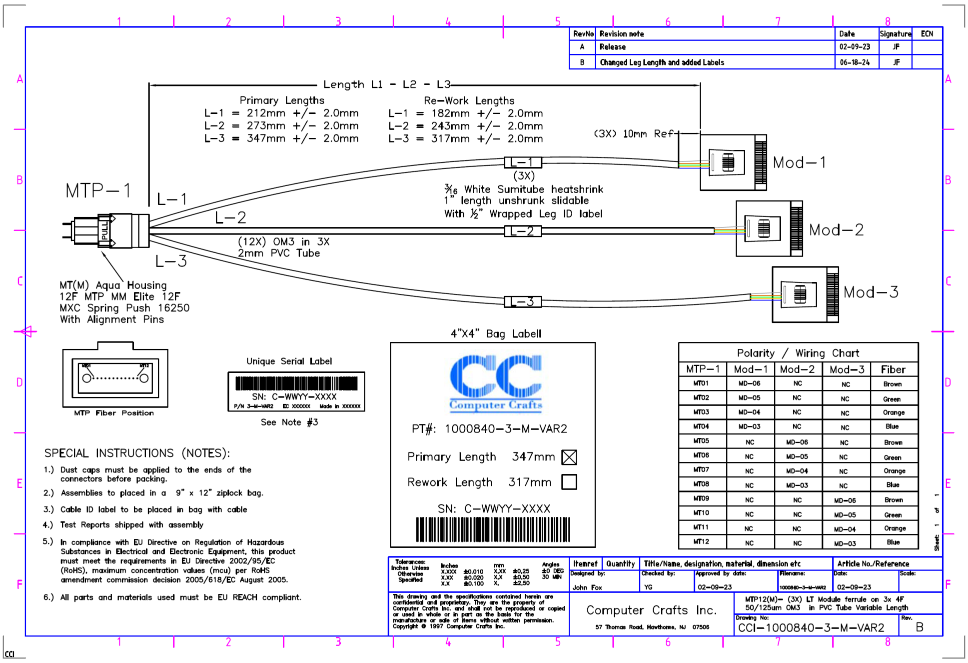

Figure 2.10: Data-link type 2 optical fiber assembly (MTP-12 to three VTRx+ modules) with fiber mapping/polarity.

2. The curvature meets the recommended minimum bend radius for OM3 fiber (>15 mm), minimizing bend loss.
3. The design uses a small number of saddles (and hence a small number of holes in the FEB2 board). Saddles guide a smooth bend and fix the fibers to the board without pinching.
4. Stand-offs for the cooling plate do not conflict with the fiber routing. In several locations they act as natural guides that help keep the fibers in place.
5. The selected saddle `MBHWSSE-1-19` has a height of 5.1 mm, which matches the 6 mm stand-off height between the board and the cooling plate.
6. Saddles are made of UL94 V-0, halogen-free nylon (Vydyne ECO-315), are supplied by Essentra Components, and were selected to meet CERN fire-safety requirements for low-flammability, halogen-free materials (see Figure 2.13).
7. The saddle is specified for board thickness from 1 mm to 4 mm. It seats firmly in the 2 mm FEB2 board and does not rotate unintentionally.
8. The saddle latch design prevents fibers from slipping out when the board is handled.
9. A fixed saddle can be opened easily with a fingernail or a small screwdriver.

2.7 Fiber lengths

Fiber leg lengths were tuned so that, within the ±2 mm cut-length tolerance, the fibers are neither tight nor loose in the saddles. After several iterations, the lengths below were approved (nominal values with

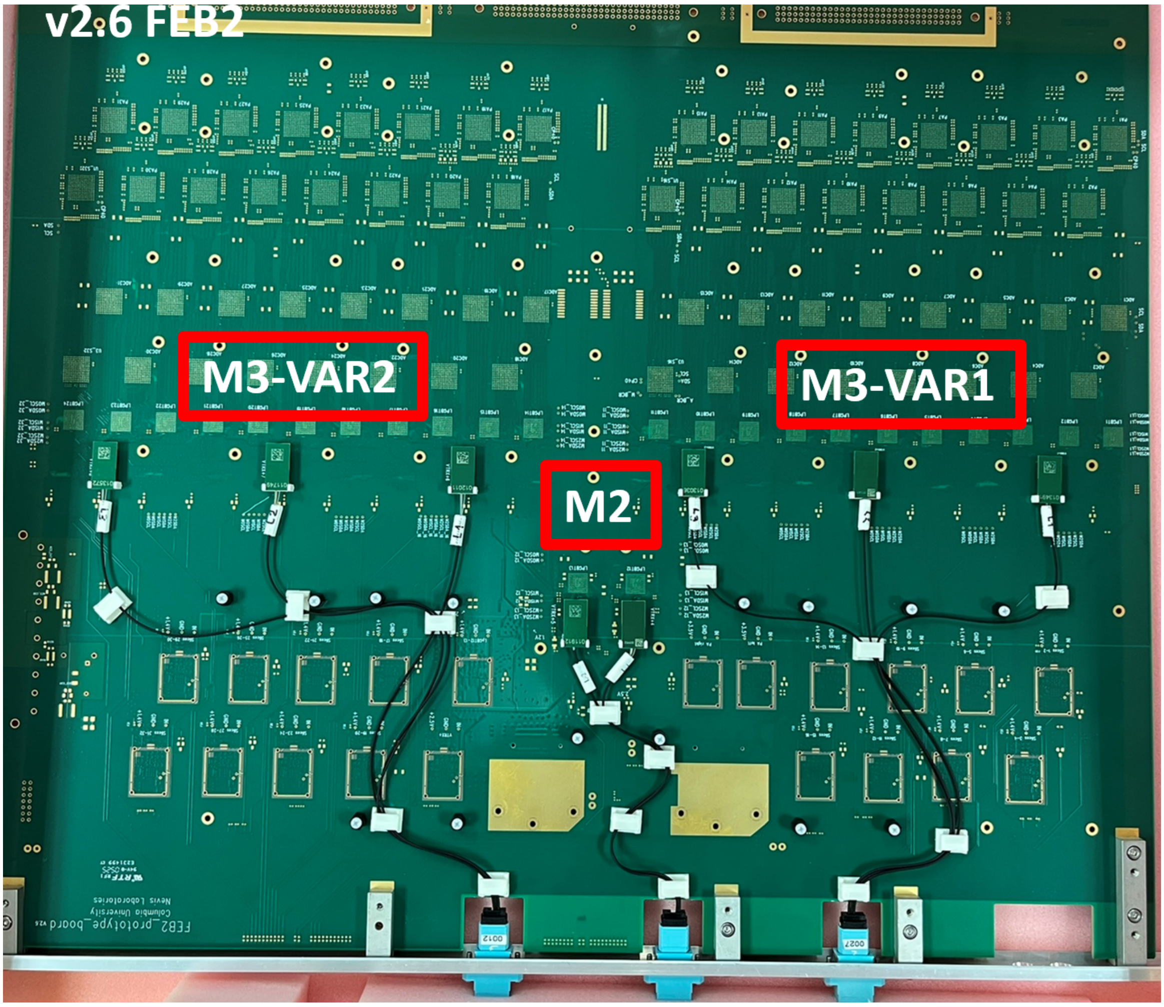

Figure 2.11: Fiber routing on FEB2 (nominal lengths).

're-work' values in parentheses). See Figures 2.8 to 2.10 for context.

Right set (M3–VAR1).

- Right VTRx+ (L1): 272 mm (242 mm)
- Middle VTRx+ (L2): 211 mm (181 mm)
- Left VTRx+ (L3): 266 mm (236 mm)

Middle set (M2–VAR1).

- Right VTRx+ (L1): 155 mm (125 mm)
- Left VTRx+ (L2): 155 mm (125 mm)

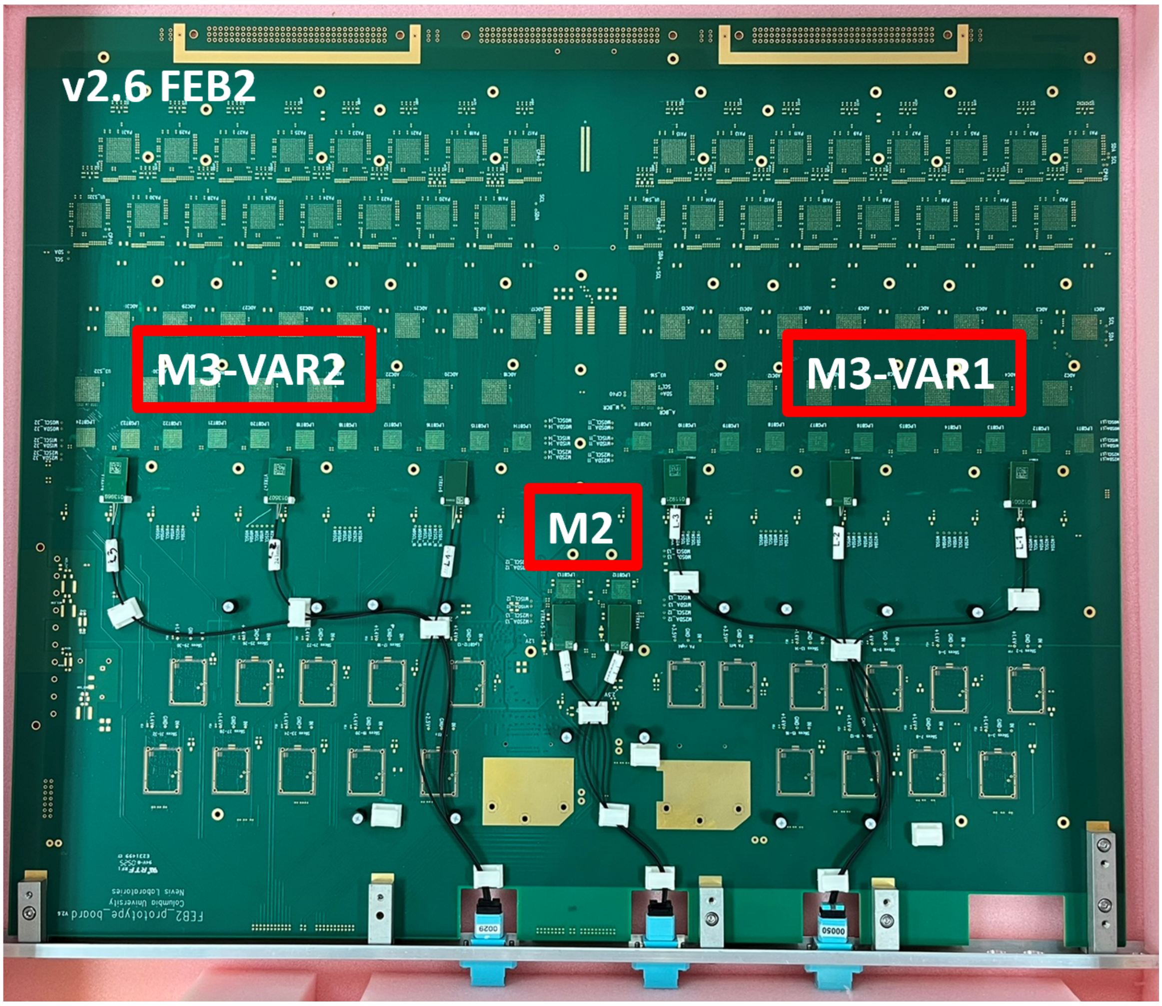

Figure 2.12: Fiber routing on FEB2 (reduced, ‘re-work’ lengths).

Left set (M3–VAR2).

- Right VTRx+ (L1): 212 mm (182 mm)
- Middle VTRx+ (L2): 273 mm (243 mm)
- Left VTRx+ (L3): 347 mm (317 mm)

In the proposed routing, half of the fibers are short: 4 of 8 legs have lengths below 250 mm.

2.8 Control and data link production

The CERN production of VTRx+ modules for the LAr upgrade includes two pigtail lengths:

- 300 mm pigtail: 3 480 modules,
- 400 mm pigtail: 10 425 modules,

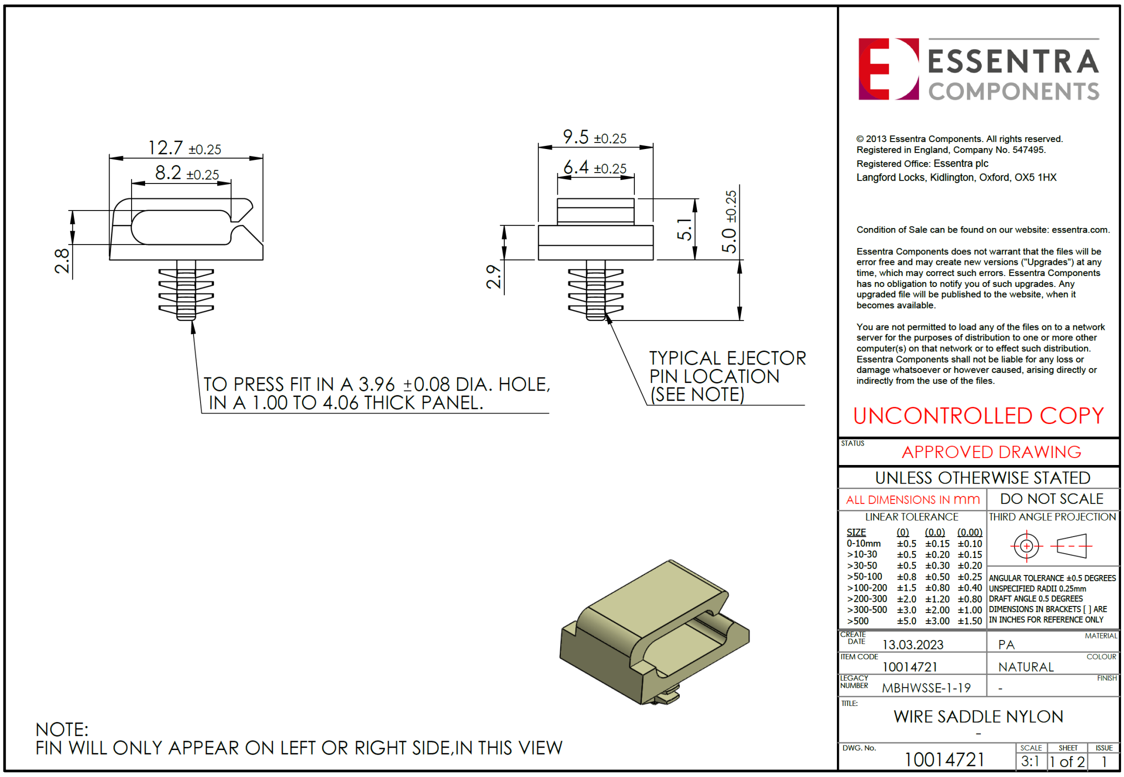

Figure 2.13: Plastic saddle for FEB2, UL94 V-0 and halogen-free material (`MBHWSSE-1-19`).

for a total of 13 905 modules. The 300 mm lot therefore represents approximately 25% of the supply.

For optical link assembly, the modules are assigned according to the following policy:

1. Control links. Select modules with the highest Tx1 OMA across both pigtail lengths. These parts are used for M2–VAR1–L1 and M2–VAR1–L2.
2. Data links. Allocate the remaining short-pigtail modules for M3–VAR1–L2 and M3–VAR2–L1; fill other positions from the 400 mm stock.

This approach maximizes upstream Tx OMA on the control links and is required by the routing constraints: the 25% short-pigtail stock must be used only on the short legs (see Section 2.7).

List of contributions

Pablo Arroliga Mejia	Student; development of fiber routing design on FEB2 (Section 2.6); pre-production QA runs.
Giovanni Boscan	Student; development of pattern-generator and spectrum-analyzer control software for the QA test system; pre-production QA runs.
Alex Chen	Student; development of attenuator-control software for the QA test system.
Alonso Gurrola	Student; prototyping of 3D-printed VTRx+ supports and standoffs (Section 2.2); development of oscilloscope-control software for the QA test system; pre-production QA runs.