LowQ^2 Tracker Inspection and Test Plan

Simon Gardner, Ken Livingston

University of Glasgow

Abstract

The LowQ^2 trackers uses Timepix4 Hybrids (ASIC+sensor) developed by the CERN Medipix collaboration. These are tiled onto module PCBs which are combined to form the layers of the trackers. The inspection and test plan for the tracker is described here.

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1. TRACKER PROPERTIES

1.1. Overview:

The LowQ^2 detector is located in far backward region and consists of two taggers close to the electron beam line, each composed of an electron tracker and a calorimeter (Figure **Error! Reference source not found.**). The trackers have four layers of pixel detectors to provide the required position, timing resolution, and rate capability. Layers are build from module boards (PCBs), each of which houses a tiled array of Timepix4 hybrids (In the Timepix4 chip, each pixel is effectively a detector, preamp, shaping amp combination with discriminator and adjustable threshold, and, in data driven mode, the ToA (Time of Arrival), ToT (Time Over Threshold) are pushed out as a 64 bit event packet as soon as a threshold is crossed [1]. This results in very low noise and allows very high data rates. Furthermore, the chip has 16 data lines, and can be configured to send output to any number of these, depending on the rate requirement. The raw rates on the tracker are very high, and non-uniform, with the highest intensity on the pixels near the horizontal plane, closest to the beam line (Figure **Error! Reference source not found.**). Hence, for the sensors in this intense region, many or all, the data lines on the chip may be needed, whereas a sensor at the periphery may require only one or two data lines. The design of the readout and electronics must allow flexibility in the number of data lines configured for each chip and module board.

To facilitate tiling, the *4-side buttable* mode of Timepix4 is adopted by using TSV (through silicon vias) technology, and addition of an interstitial layer.

The total number of hybrids is 144.

The properties of each of the components are described below.

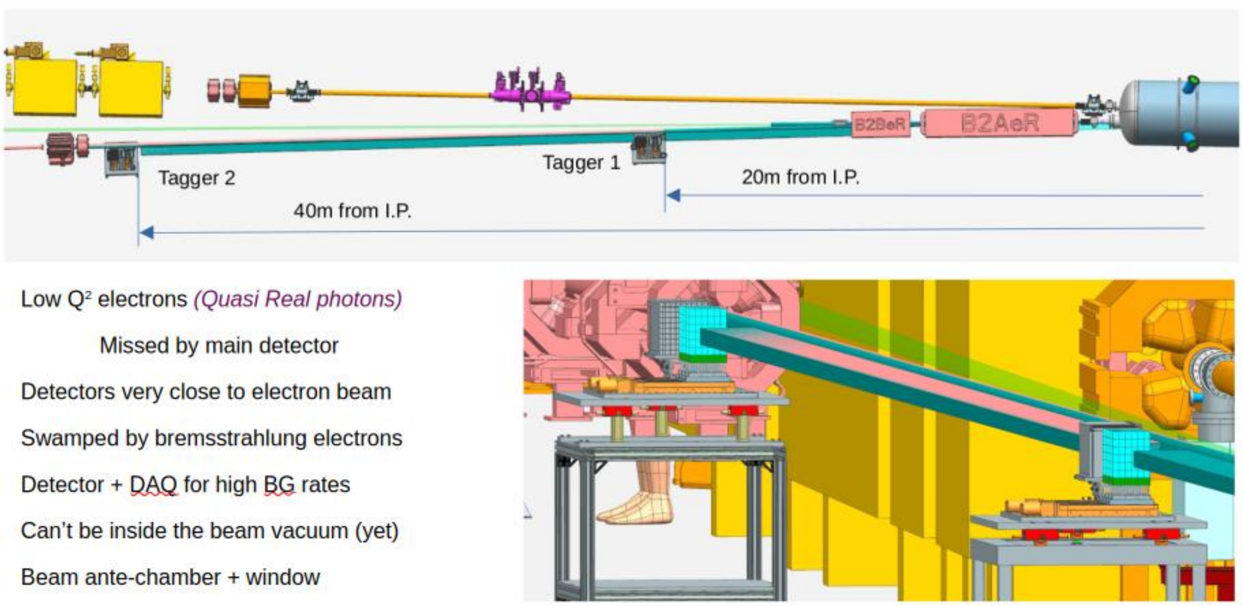


Figure 1. CAD representation of low Q2 Taggers in the far backward region.

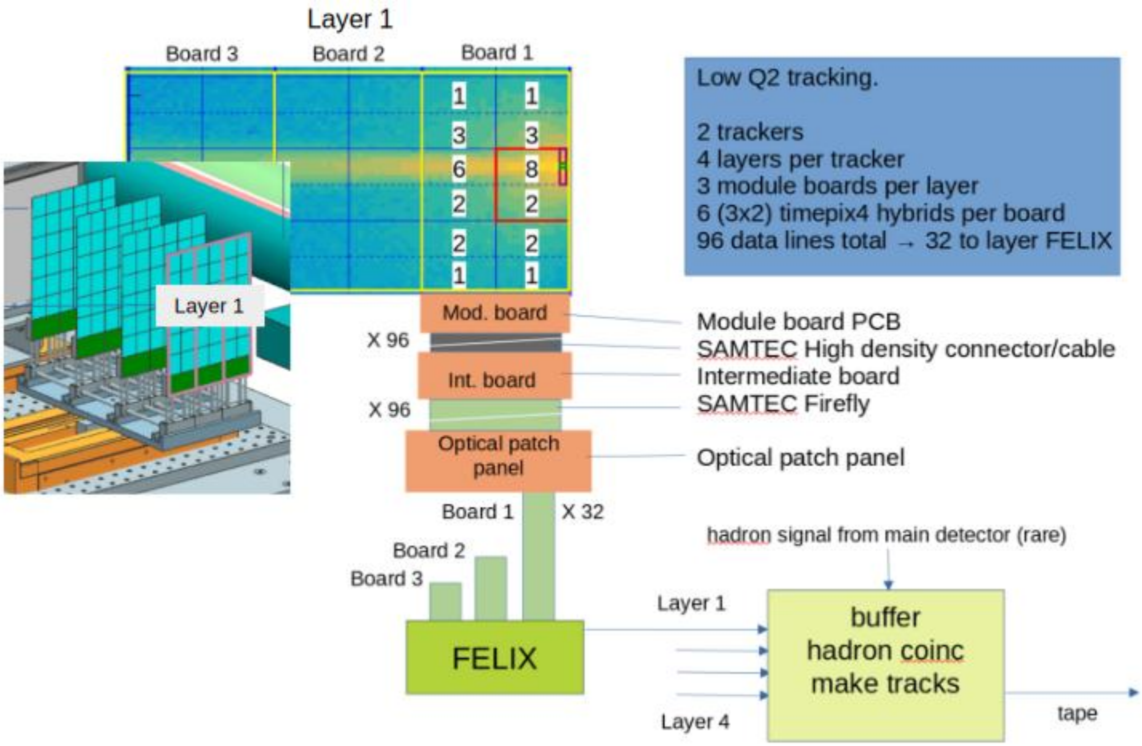


Figure 2. Data readout.

1.2. Timepix4 ASIC:

Timepix4 is a well-established ASIC based on 65 nm CMOS technology, developed by the CERN Medipix collaboration [ref] , and a *hybrid* consists of a Timepix4 ASIC together with a bump bonded silicon sensor. Relevant Timepix4 properties are:

- Pixel Matrix: 448 × 512 pixels.
- Pixel Size: 55 × 55 μm² pitch.
- Sensitive Area: Approximately 6.94 cm² (24.64 × 28.16 mm²).
- Power budget: 3.5 – 5.0 W
- 4-side buttable: Through use of TSV.
- Thickness after TSV-Last processing: 120 um
- Pixel rate: 10.8 kHz / pixel
- No of data lines: 16
- Readout bandwidth: 164 Gb / s (16 x 10.24 Gb / s)

1.3. TSV Intersticial Layer:

The Timepix4 wafer is thinned down to 120 um to expose the internal landing pads in the Back-end of Line (BEOL) of the ASIC for connection to PCB via an interstitial TSV layer. Relevant properties are:

- TSV layer thickness: 100 um ?? To confirm.
- Anything else?

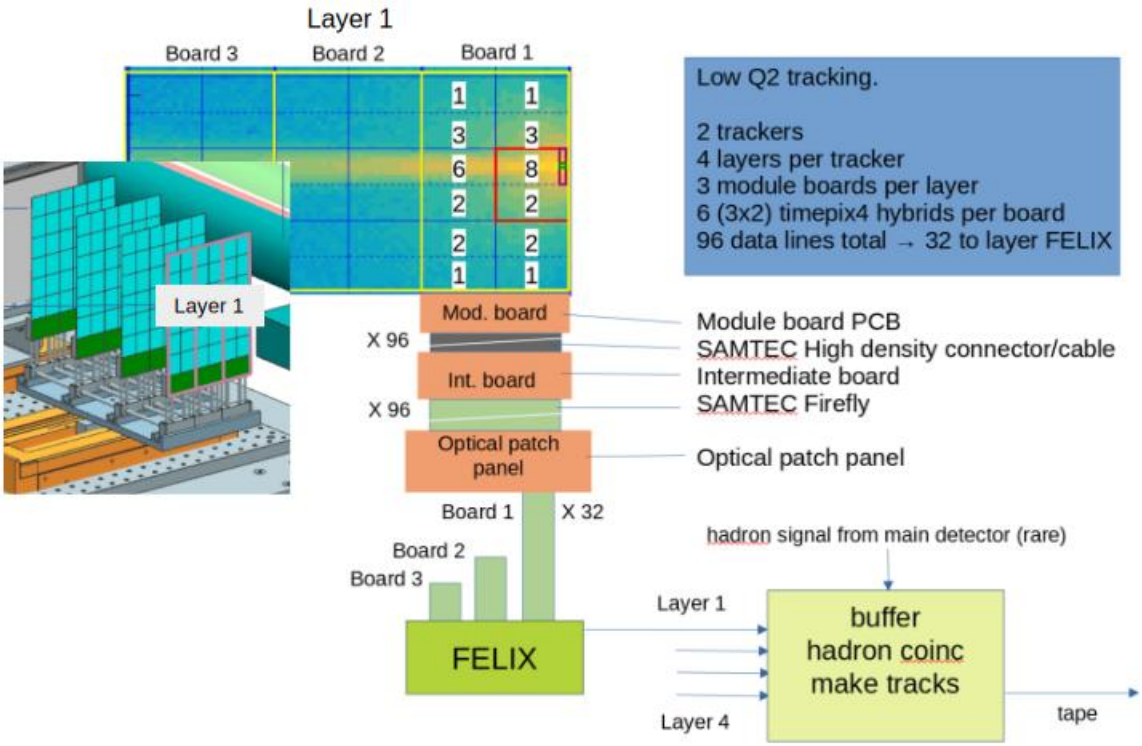
1.4. Silicon Sensor:

The silicon sensor

- Type: P-on-N
- Thickness: 100um +/- 5um
- Depletion Voltage: 100 – 150V

1.5. Electronics and Readout.

Timepix4 hybrids are bonded to a module board in a 3x2 tiled layout. The bottom end of the module board has a high density SAMTEC connector to take the control, data and power lines to an intermediate board, for connections to power and control connection, and conversion of the data lines to fibre with SAMTEC Firefly modules. The fibres are sent to a patch panel, where a subset are selected to go to the FELIX board for readout (Figure



Data readout.). Fibres from all layers connect to the same FELIX board to facilitate in-stream cluster and tracking.

Conceptual design only. Will not be designed before TDR.

1.6. Module Board:

A Module boards holds six Timepix4 hybrids in a 3x2 tiled arrangement. It needs bonding pads for the Timepix4/TSV hybrids, and must connect control, data and power lines for each ASIC, and bias fpr the Silicon sensors. A high density SAMTEC connector(s) with 500mm cables. leads to the intermediate board, to which I/O and power and data lines are attached.

- Thickness: 100um
- Timepix4 Locations: 6 (2x3)
- Data lines: 6x16 (split into 8 + 8 for top and bottom halves)
- Control lines: 12 to be checked
- Bias lines: 6
- Temp + misc lines: 6

- Connectors: SAMTEC High density → Intermediate board.

1.7. Intermediate Board:

This board interfaces connects to LV, HV, in addition to hosting the Firefly modules will convert the data signals from copper to fibre, and house a module to interface between Lab slow controls and Timepix4 control lines.

- Firefly 12 channel optical transceivers: 8
- Control Module: 1
- LV connection / distribution 1
- HV connection / distribution 6

2. PROCESSES AND PROCEDURES

The raw materials for the LowQ^2 electron tracker are Timepix4 ASICs, to be purchased from CERN, via membership of the CERN Medipix collaboration, and silicon sensors, to be procured from a commercial supplier. Module PCBs to house the tiled Timepix4 + Si hybrids will be developed in consultation with members of the Medipix collaboration, and production outsourced to a manufacturer. We work closely with the local ALTAS group, where there is considerable overlap with the Medipix collaboration. The ATLAS group were leading members of the team producing the Velopix detector, which is closely related to Timpix4, and we will follow as far as possible, the robust, approved test and QA procedures developed for Velopix. In particular, we will have access to the local group's probe stations, x-ray inspection chamber and bump bonding tools.

2.1. Wafers with Timepix4 ASICs

The wafers bearing the Timepix4 ASICS are obtained through the CERN Medipix collaboration. They are already graded before delivery, and come with a grade map.

2.1.1. In-Process Testing

Probing at CERN. ASICS on wafer graded, and a map produced.

2.1.2. Incoming Inspections or Acceptance Testing

Examination of grade map. Reject wafers with below threshold (40%) of top-grade ASICs.

2.1.3. Verification Testing

N/A. This is implicitly done in production of the grade map.

2.1.4. Failures and Non-Conformances

Return to vendor

2.2. Silicon Sensor

Silicon wafers are obtained from a commercial manufacturer. These must meet basic criteria of thickness, before being send for dicing into individual ASICS.

2.2.1. In-Process Testing

Wafer tested during manufacture.

2.2.2. Incoming Inspections or Acceptance Testing

Reception test. Visual, I/V, probe station.

2.2.3. Verification Testing

N/A

2.2.4. Failures and Non-Conformances

Return to vendor

2.3. TSV preparation

Carried out by contractor through CERN Medipix collaboration. Whole wafer is processed for TSV and returned to CERN for testing.

2.3.1. In-Process Testing

Thinning and addition of interstitial layer, testing by manufacturer.

2.3.2. Incoming Inspections or Acceptance Testing

Probing at CERN. ASICS on wafer, graded, and a map produced, as with pre-TSV wafers.

2.3.3. Verification Testing

N/A This is implicitly done in production of the grade map. Reject wafers with below threshold (40%)

2.3.4. Failures and Non-Conformances

Return to vendor

2.4. Hybrid preparation and bonding

Slicing and dicing of TSV prepared ASIC wafers and Silicon sensor wafers and bump bonding to produce hybrids are carried out by a contractor.

2.4.1. In-Process Testing

Carried out by contractor.

2.4.2. Incoming Inspections or Acceptance Testing

Probe tests of I vs sensor bias, in-house.

2.4.3. Verification Testing

Only possible after module board bonding.

2.4.4. Failures and Non-Conformances

Discard

2.5. Module board

Module board production from contractor.

2.5.1. In-Process Testing

By contractor.

2.5.2. Incoming Inspections or Acceptance Testing

Visual inspection

2.5.3. Verification Testing

On dedicated bench test station.

2.5.4. Failures and Non-Conformances

Return to vendor

2.6. Intermediate board

Module board production from contractor.

2.6.1. In-Process Testing

By contractor.

2.6.2. Incoming Inspections or Acceptance Testing

Visual inspection

2.6.3. Verification Testing

On dedicated bench test station.

2.6.4. Failures and Non-Conformance

Return to vendor

2.7. Bonding of Hybrids to module boards

To be done in-house as contracted service by ATLAS group.

2.7.1. In-Process Testing

Dedicated probe station. I/V tests.

2.7.2. Incoming Inspections or Acceptance Testing

N/A

2.7.3. Verification Testing

Connection to Timepix4 intermediate board and bench test readout system, with FELIX + mini DAQ.

2.7.4. Failures and Non-Conformance

Recovery of board / hybrid where possible. Otherwise, discard.

3. EXPERIMENTAL/TEST SETUPS

Testing of Timepix4 wafers and TSV will be carried out as a service by the CERN Medipix collaboration, and probing / testing of Silicon wafers before dicing will performed locally using dedicated facilities in the Glasgow ATLAS group.

Bonding of Timepix4 hybrids to module boards will be also be done locally in Glasgow, using clean room and services provide within the ATLAS group.

Pre-testing / verification of module boards and intermediate boards will be carried in Glasgow using dedicated test modules to be build in-house.

After verification of each module board, the six Timepix4 hybrids are bonded and the module is bench tested locally (Section 3.1). The full detector will have 24 modules, holding a total of 144 hybrids. When batches of 6 modules are completed, these will be taken to the SCAPA facility for beam tests (Section 3.2).

3.1. Bench testing of detector modules

The module tests are:

▪ Hybrid bonding:	Do all sensors draw expected current (~1.15A). No evidence of shorts.
▪ Control:	All sensor read / write and parameter check with control software.
▪ Equalization self-test:	Maps of pixel thresholds, dead channels pixels, noisy pixels.
▪ Test with internal noise:	Lower thresholds.
▪ Sensors function:	Bias current. Source tests. Cosmics.

3.1.1. Resource Requirements

- High current limit (30A) LV for module, HV supplies for 6 channels bias.
- Fibre patch panel; Mini ePIC DAQ with Slow control; FELIX board and DAQ software on local server.
- Cooling: Forced air cooling – module in sealed box with fans.

3.1.2. Test Conditions

Describe the necessary test conditions; i.e., temperature, humidity, lighting, etc.

- Standard lab conditions

3.1.3. Equipment

List all specialized equipment that will be required to conduct this test.

3.2. Beam testing of detector modules, intermediate modules and DAQ

Beam tests will be carried out at SCAPA (Scottish Centre for the Application of Plasma-based Accelerators) [2]. This is a newly available UK facility which is well suited to Low Q^2 tracker tests. It produces a quasi mono-energetic 600MeV electron beam in intense 10ps pulses are a rate of less than 1Hz. Each pulse has up to 10^9 electrons, so putting the detector in the direct beam is not possible. However, by using elastic electron scattering from a target, a secondary beam of variable intensity can be produced. Its use has already been demonstrated with the prototype Timepix4 telescope. The SCAPA beam makes an excellent proxy for the EIC electron beam in the far backward direction where the taggers will be located. There is a signal (elastically scattered electrons from the target) together with high background from scattering in the experimental area, all coming within one pulse, with no option to use timing information to separate tracks.

Up to 4 modules will be tested simultaneously in a mini-tracker configuration, with a subset of the Timepix4 hybrids enabled at any one time. This will allow testing of the full chain, including in-stream clustering and tracking.

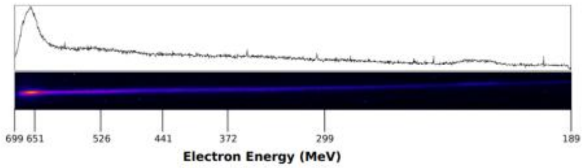
3.2.1. Resource Requirements

- As previous section. Equipment will be ported from Glasgow to SCAPA.
- Trigger sync pulse from accelerator, shielding and local tools for mounting and setup.

3.2.2. Test Conditions

As previous section

3.2.3. Equipment



Maximum electron energy (broadband energy spectrum)	600 MeV
Maximum bunch charge per shot (across entire energy spectrum)	200 pC
Maximum pulse repetition rate	1 Hz
Maximum shots in a day	18,000 (5 hours @ 1 Hz)
Beam diameter at 2 m from source (typical target sample location)	10 mm
Pulse duration at 2 m from source	10 ps

Up to ~10^9 electrons in a 10ps burst at 1Hz

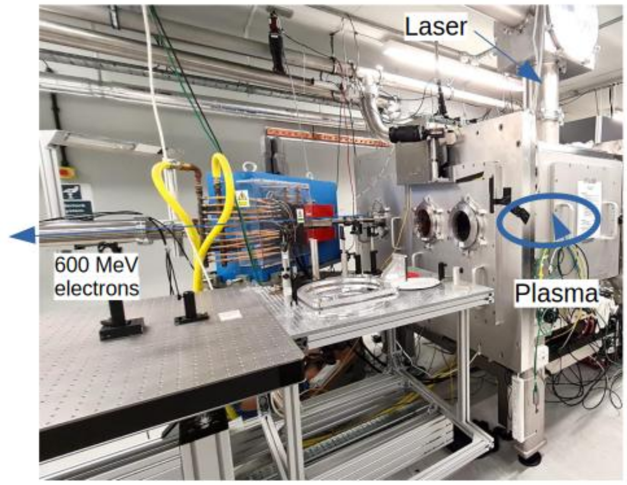


Figure 3. SCAPA accelerator and beamline.

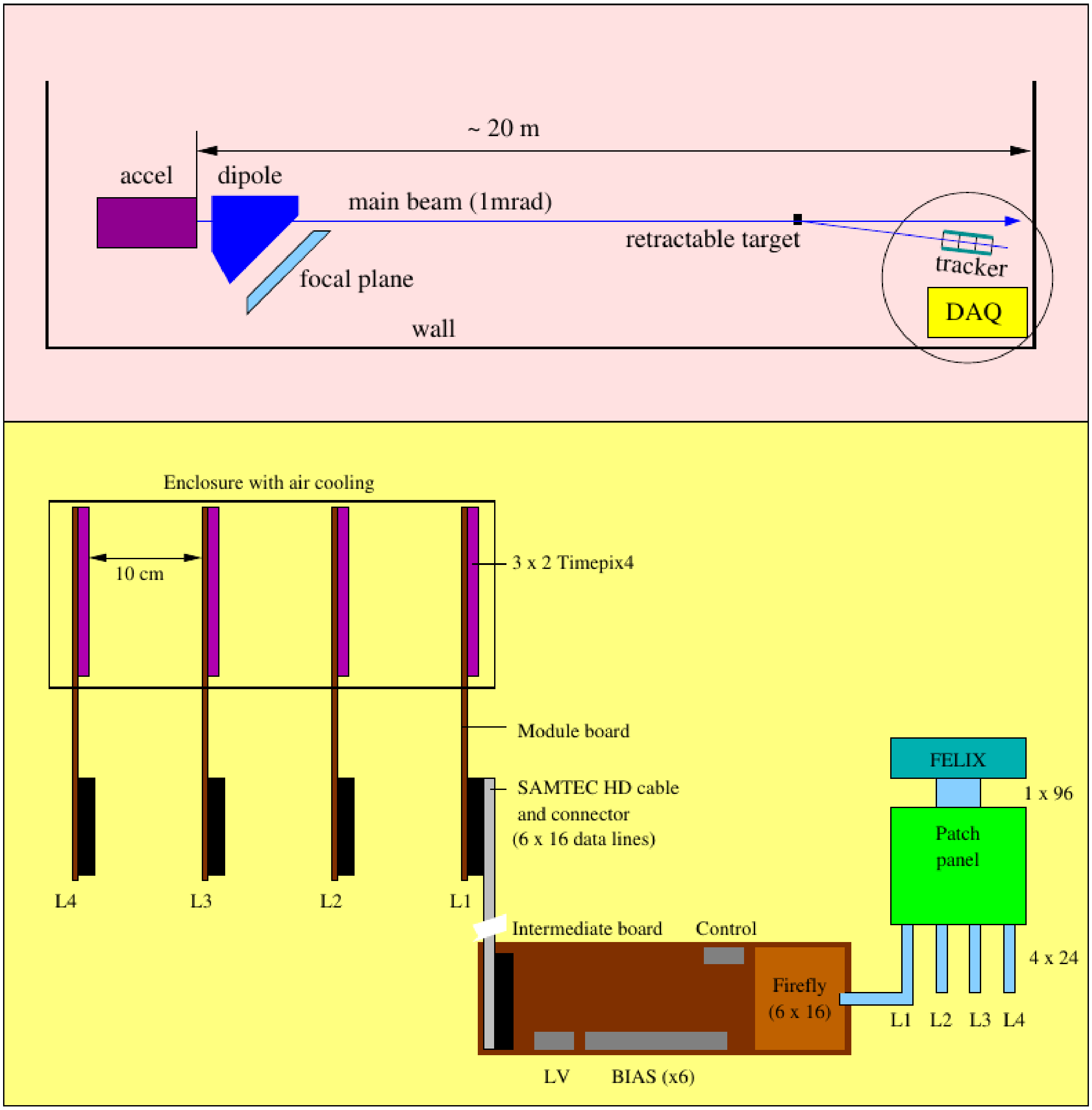


Figure 4. Top: SCAPA test configuration. Bottom: Schematic of Timepix4 layer board setup and readout.

4. ENVIRONMENT, SAFETY & HEALTH CONSIDERATIONS

The procedures will be implemented in a way consistent with the environment, safety, and health policies of the relevant work areas. Within Jefferson Lab the process is described in the ES&H manual Chapter 3200, Work Planning and Control Program and at BNL within the SBMS: "Work Planning & Control for Experiments and Operations". For this work following best work practices, the following personal protection equipment and materials are used:

- Powder Free Nitrile Gloves.
- Safety Glasses
- Hearing Protection

- Steel-Toe Shoes

5. RECORDS AND DOCUMENTATION

This section details all of the documentation that will be generated and exchanged during the manufacturing lifecycle. In all likelihood there will be many transient documents that are created that will not be collected or maintained as part of the project. This transient documentation need only be listed if it is pertinent to a specific experiment or test.

5.1. Manufacturer/Producer Records

For every item that is manufactured, the manufacturer will be responsible for maintaining records (travelers) of all raw material that are used in the fabrication process, and document the processes and procedures that were used for production. The resultant documentation will be compiled into a report and will be provided to the project as part of the deliverable, which will be reviewed, validated, and then placed in the central data repository.

List all pertinent manufacturer/producer records here.

5.2. Deliverable Documentation and Records

This includes test results, tables of measurements, parameter lists or other records that must be provided to the project. All testing and inspection data that is collected as part of the validation, verification and testing plan will be provided to the project as part of the final report.

List all deliverable documentation here.

6. REFERENCES

[1] Timepix4. X. Llopart ***et al*** 2022 ***JINST*** **17** C01044
[2] Scottish Centre for the Application of Plasma-based Accelerators (SCAPA) https://www.scapa.ac.uk/