Fermilab testbeam adventures

test-bean

Kehang Bai, Timon Heim, Maria Mironova

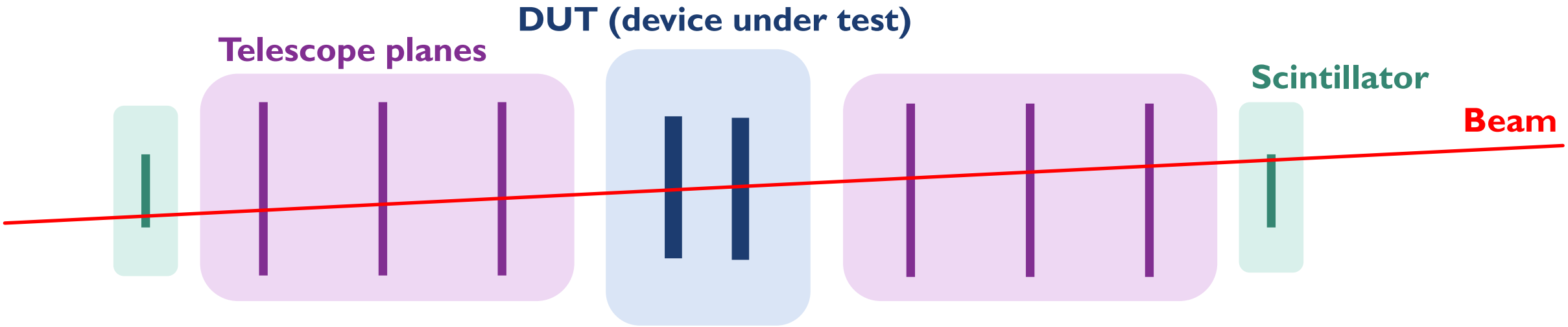
16/03/2023

Student instrumentation meeting

US-Japan collaboration

- Collaboration goal: Build first ITkPix testbeam telescope
- Advantages:
  - **High frequency readout and datataking (MHz)** (compared to kHz with EUDET)
  - Large area (4x4 cm)
- Minimal mass: used 150 μm sensor + thinned readout chip + dedicated PCB and cooling systems
- Collaboration: LBNL (Timon, Kehang and myself) + KEK (Koji Nakamura, w/ 6 undergrad students from Tokyo and Osaka)
- Testbeam activity:
  - First setup and operation at Fermilab (120 GeV protons)
    - → Two weeks of beamtime, first week as mostly parasitic user, second as main user
  - Next testbeam at KEK (hopefully in June)
  - Potential future operation at LBL, SLAC or CERN

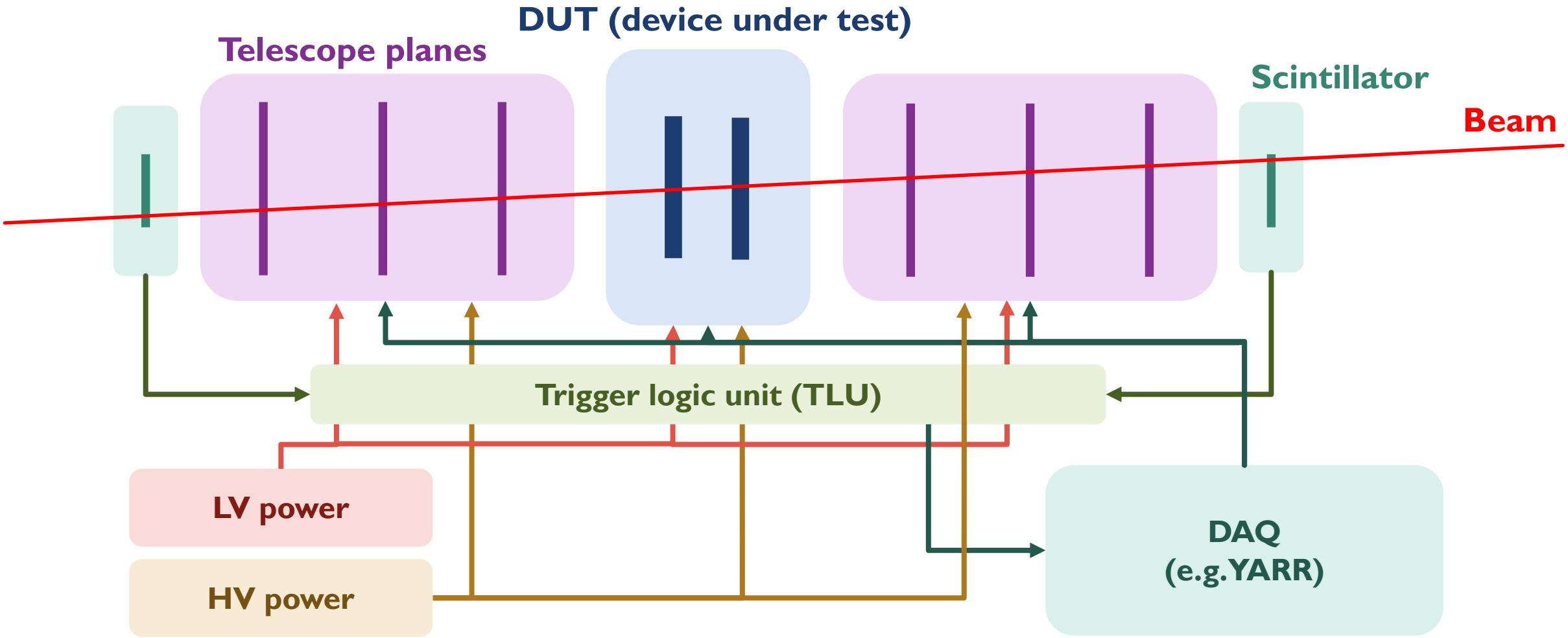
Recap: Testbeams



Testbeam telescope generally consists of:

- Scintillators for triggering (to check if there was a beam spill)
- Telescope planes
  - → Constructed with some reliable detectors, with good resolution and little material to reduce multiple scattering
  - → Used to reconstruct a track through the telescope
- DUT (device under test)
  - → Tested by extrapolating tracks to the DUT and checking if we see a hit in the expected region, e.g. to determine efficiency of the device

Recap: Testbeams

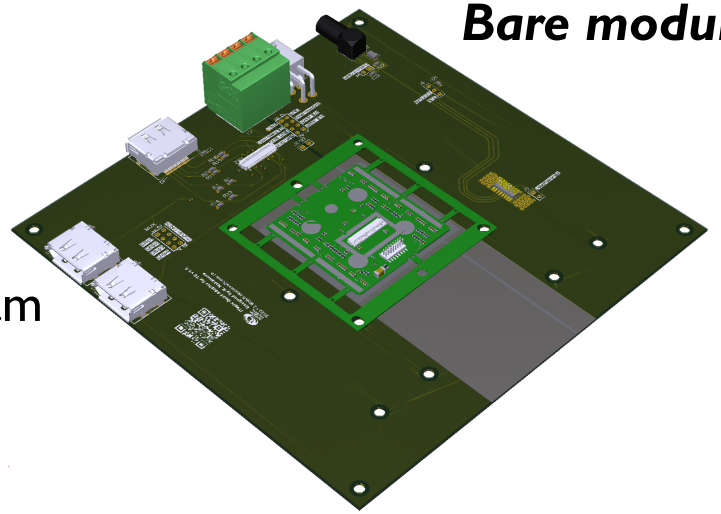


In practice, things are a lot more complicated - and 80% of testbeam is cable management…

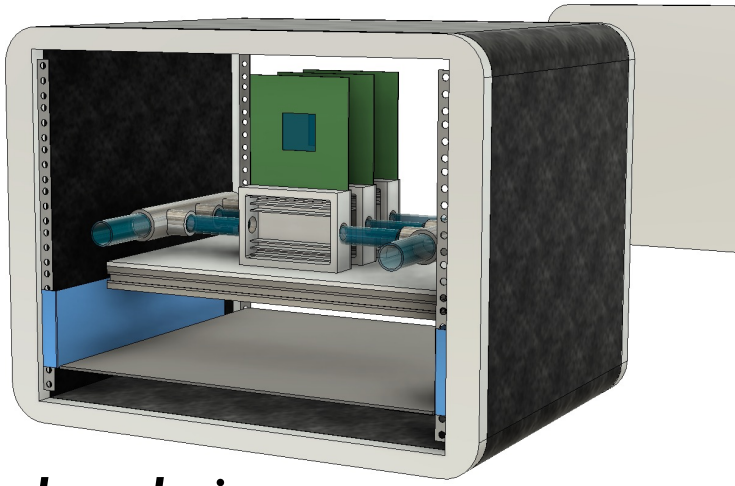
Proposed ITkPix telescope setup

In the long-term, the idea would be to have a telescope setup with:

- **Telescope layers:**
  - 6 ITkPixV1 quad modules on special quad PCBs for this testbeam
    - Either mounted in carrier
    - Or on ”bare module” PCB, directly wirebonded (reduces material, and PCB has capabilities for Hit-Or based triggering)
  - 3 on each side, in a “portable” setup
- **DUT layers:**
  - Irradiated ITkPixV1 modules
  - LGADs



Bare module PCB



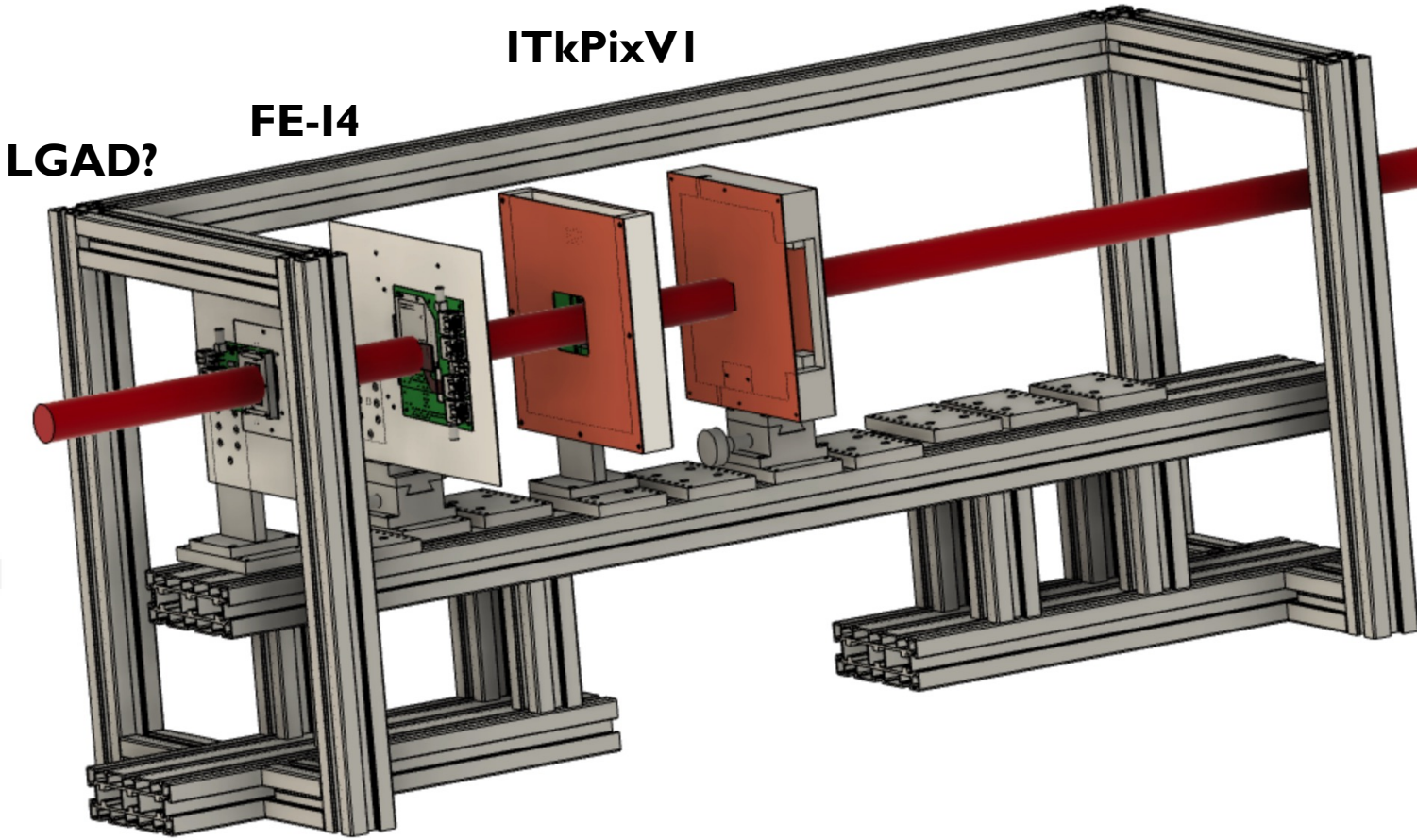
Telescope box design

Telescope design

Telescope setup was designed by the KEK group, including:

- ITkPix planes with support structures and cooling boxes
- FE-I4 reference planes
- Additional MALTA reference planes (monolithic detector prototype)
- LGADs as DUTs

KEK goal for Fermilab: **Set up and operate all planes, and collect some data**



LBNL crate

From the LBL side, a rack was prepared, assembled and shipped to Fermilab, with:

YARR PC for datataking

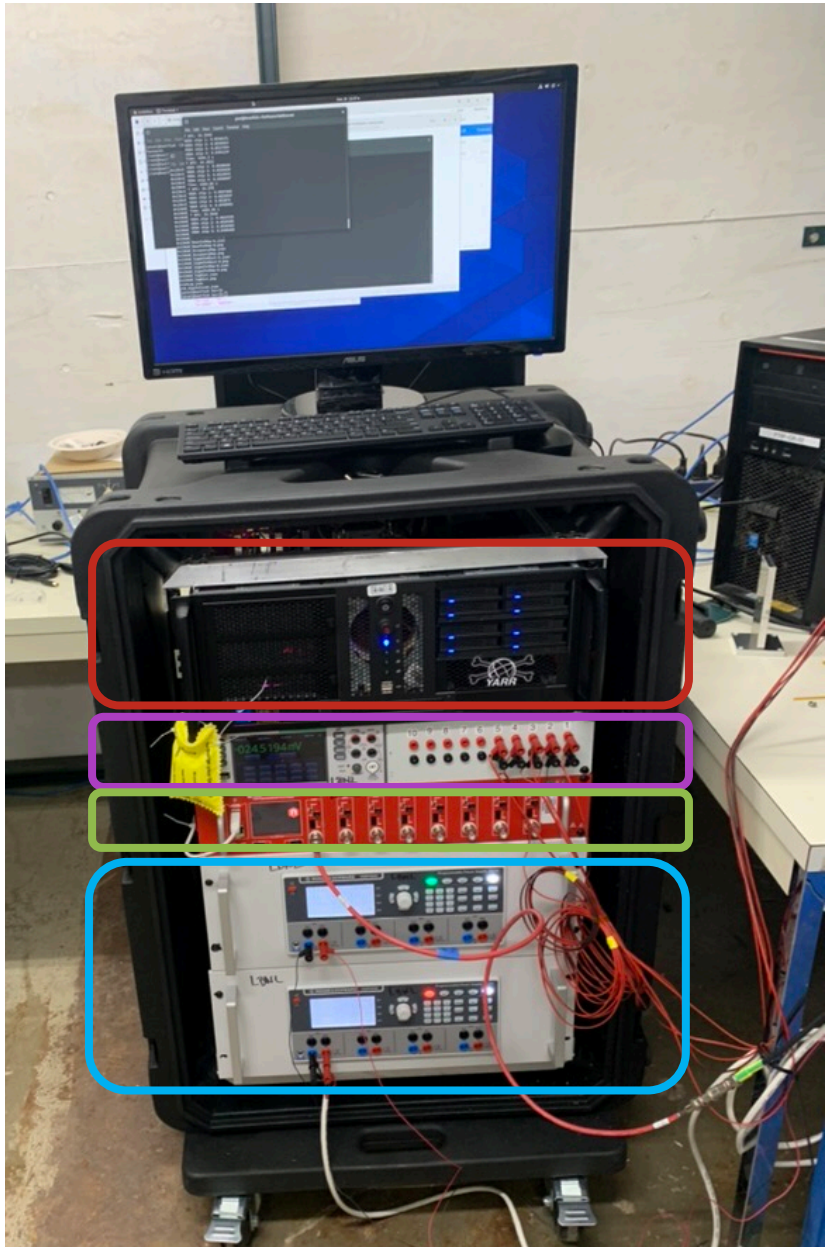
Digital multimeter with 10 channels for monitoring of temperature and voltages

High voltage power supply with 8 channels to supply sensor HV

Two LV power supplied to supply module LV

Our main goal for the testbeam: **Set up and commission the rack and operate it in the beamline**

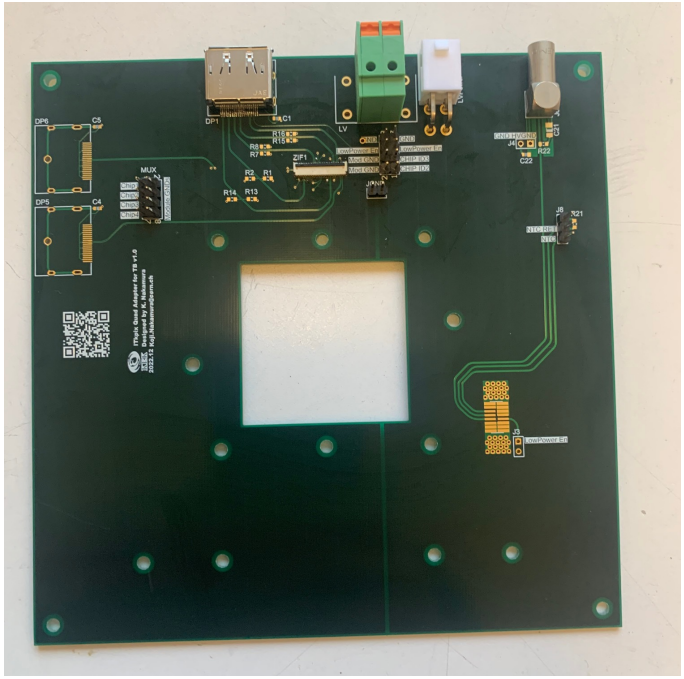
Long-term goal: use this setup to operate the telescope



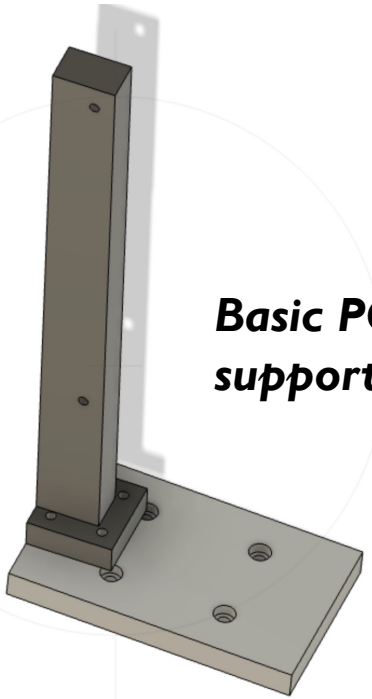
Testbeam preparations @ LBL

Before going to Fermilab, needed to prepare various components:

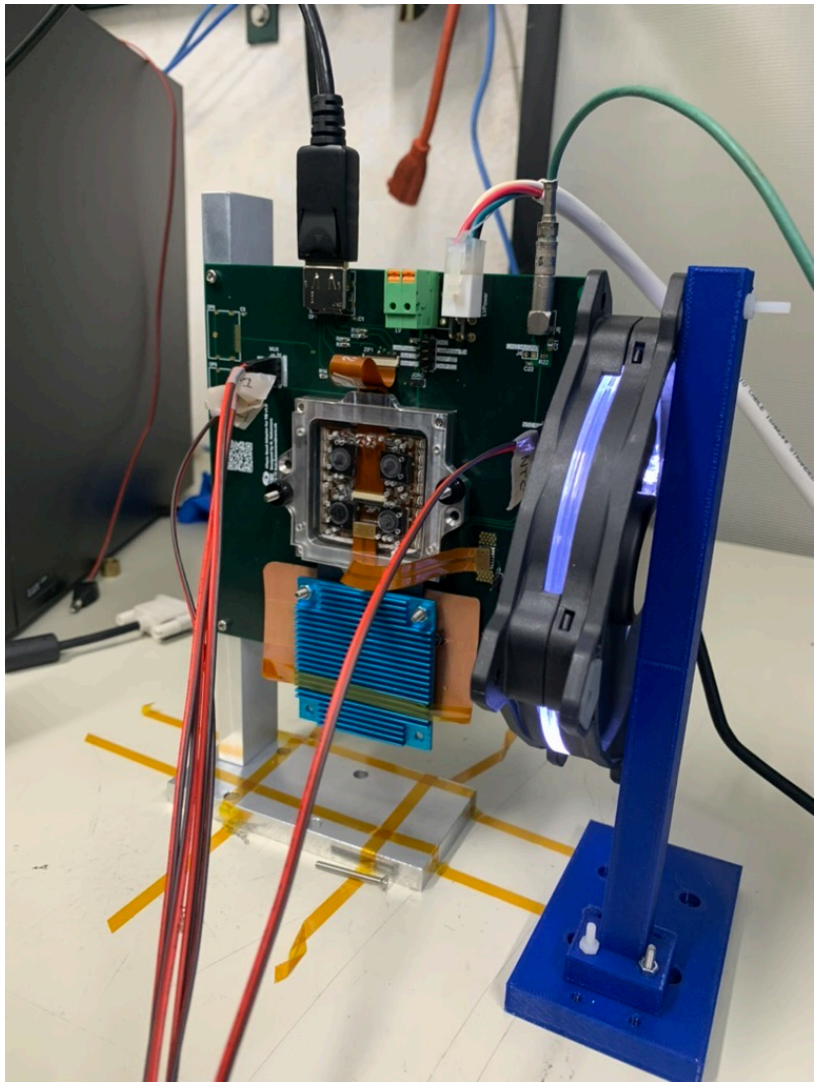
- Assembled module carrier PCB (i.e. mainly soldering connectors)
- Prepared some basic support structures (with the workshop, and also learning to use CAD and the 3D printer)
- Attempted to try and test some cooling → heatsink + fan seemed to work ok here, but more on that later



Quad module PCB



Basic PCB support



Off to Fermilab…

- Shipped the setup to Fermilab
- Went to Chicago with a suitcase full of cables

→ Both made it!

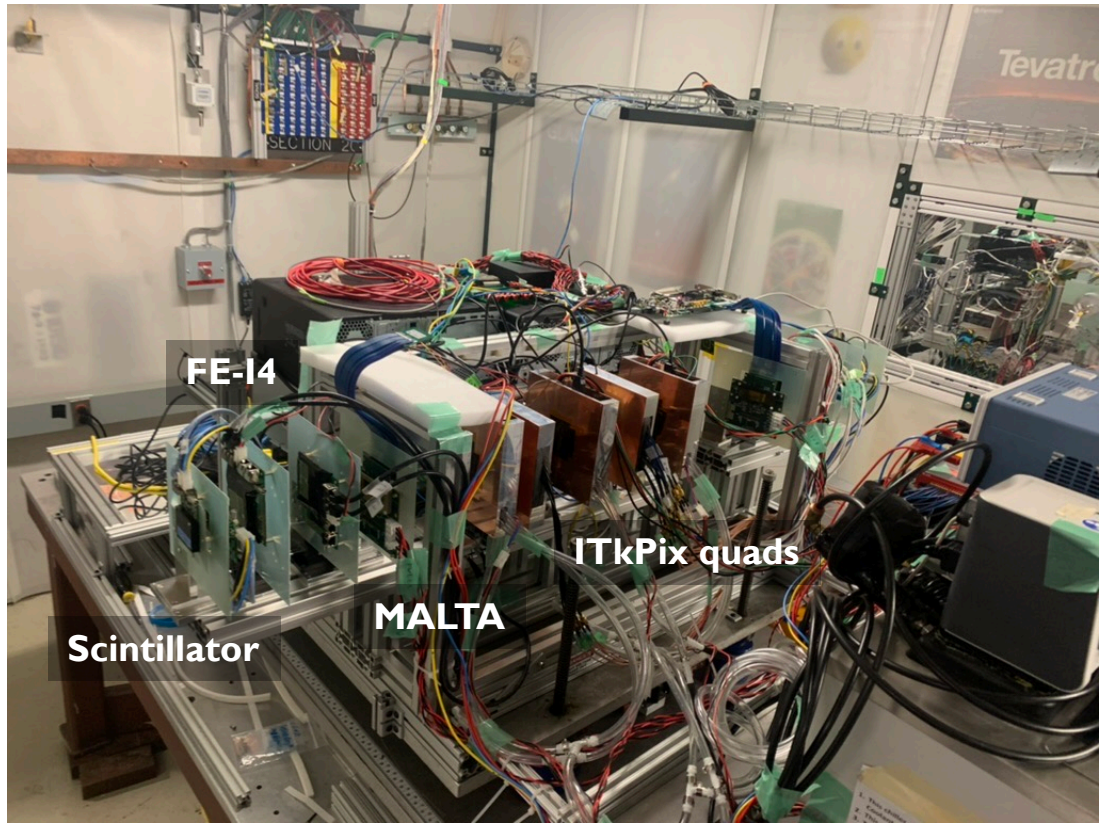
- But, LV power supplies suffered a bit

→ Spent the first day repairing and checking all the components

→ **Everything powered on ok!**

Telescope assembly

- Meanwhile, the telescope was being assembled from scratch in the beamline by the KEK group
- Including scintillator, FE-I4, MALTA and ITkPix planes
- Using a custom-made TLU and separate DAQ and powering system for data taking



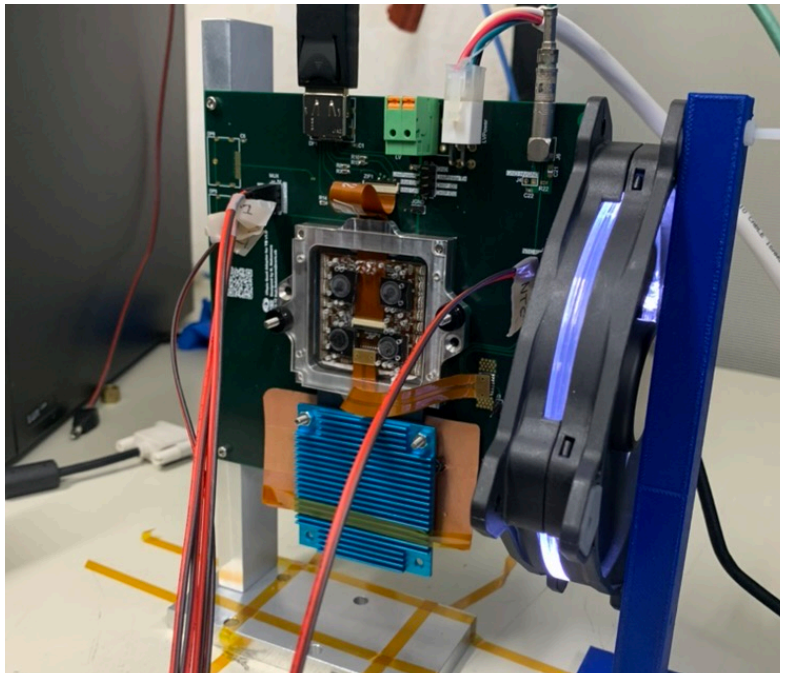
Setting up the crate

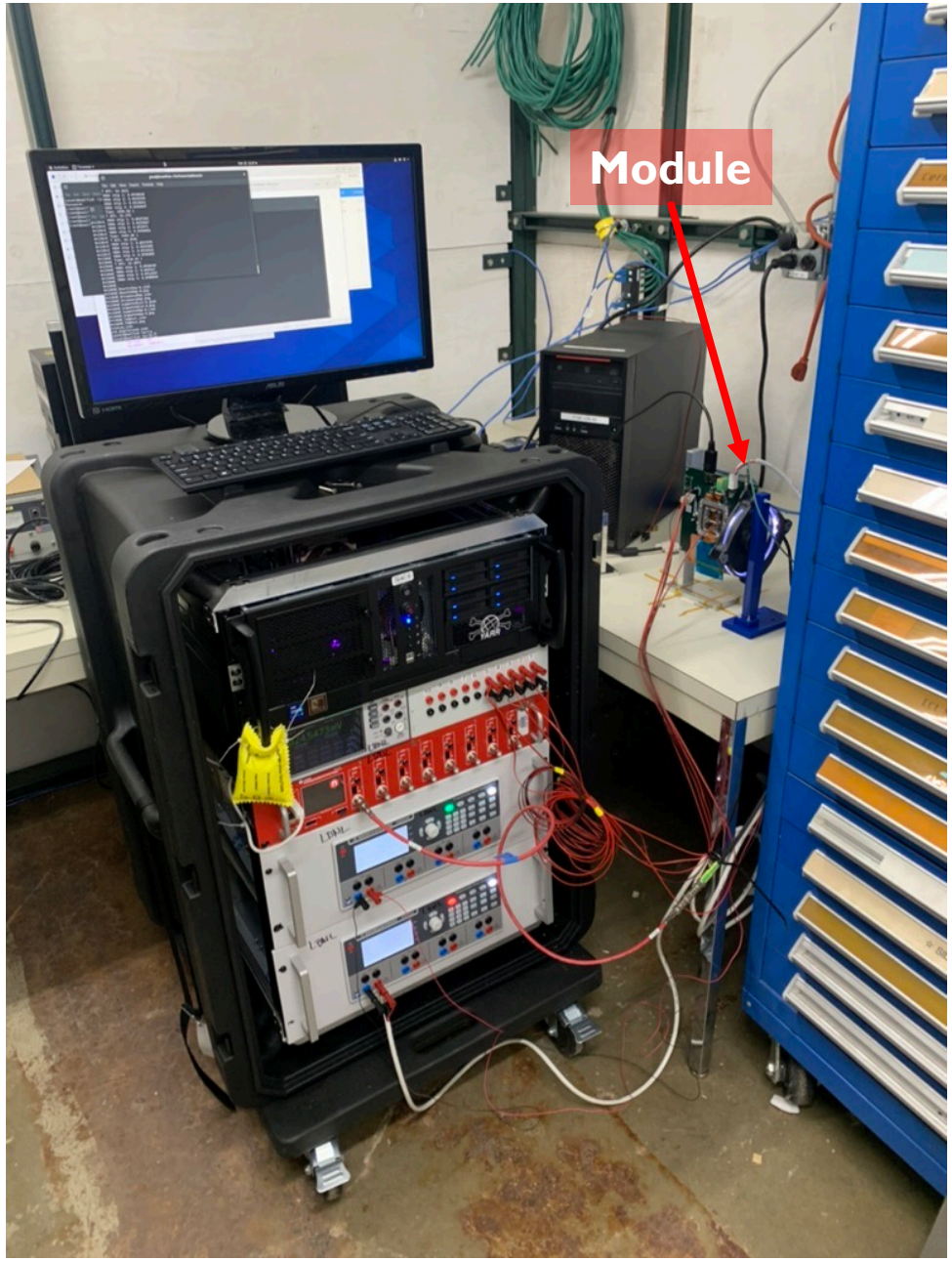
Set up the LBL crate with one module outside of the beamline step by step:

- Installed various necessary software packages (while fighting with the Fermilab network)
- Established communication with the multimeter, LV and HV power supplies via USB

- Established communication with the module using YARR
- Set up monitoring of module temperature and VMUX voltages
- Attempted cooling with headsink and fan

→ Was able to keep module at around 50 C outside of the beamline

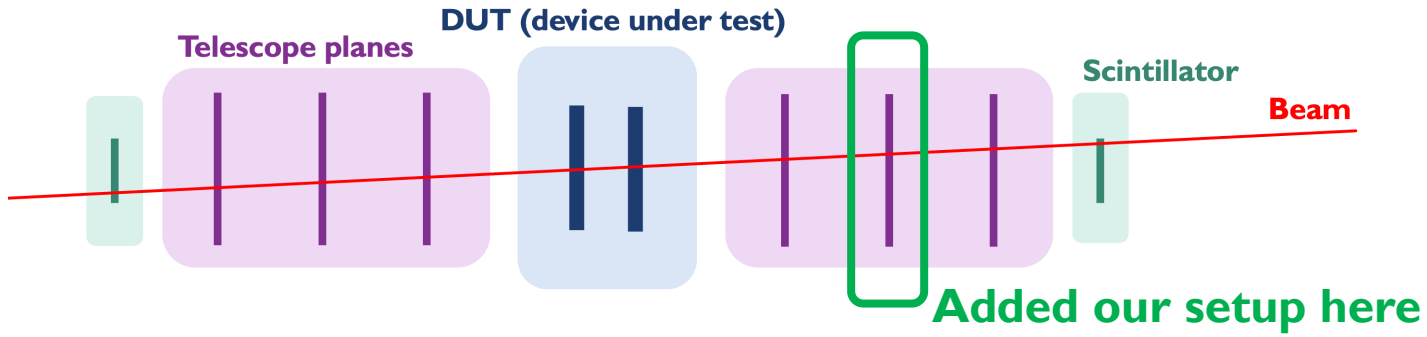




Monitoring

- Automatic monitoring established through a combination of
  - labRemote
  - influxDB
  - Grafana
- Allows to monitor HV and LV power supplies remotely
- Also monitoring chip temperature and voltages
- Many thanks to Kehang for the hard work on this!

Moving the setup



- Once happy with the setup, we move the crate into the beam area to test in beam operations
- Added our one module to the telescope

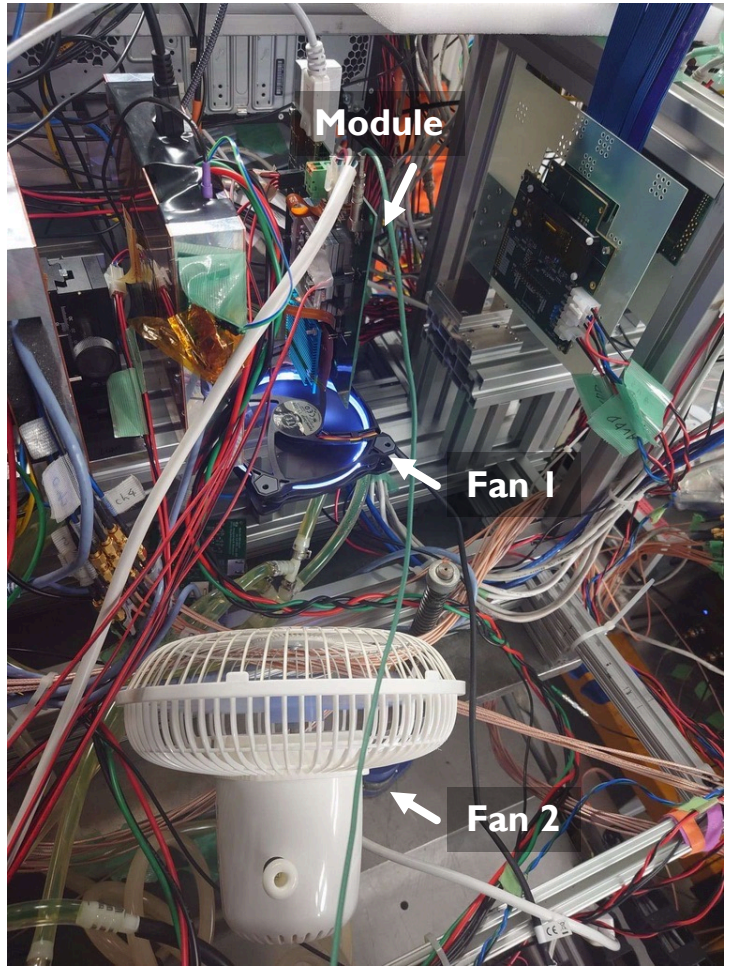
→ completely separate to the KEK setup in terms of powering and DAQ for testing

- Unexpected complication: FNAL beamline is already at ~30 C, making cooling difficult

→ First solution: Powercycle the module in sync with the beam spill

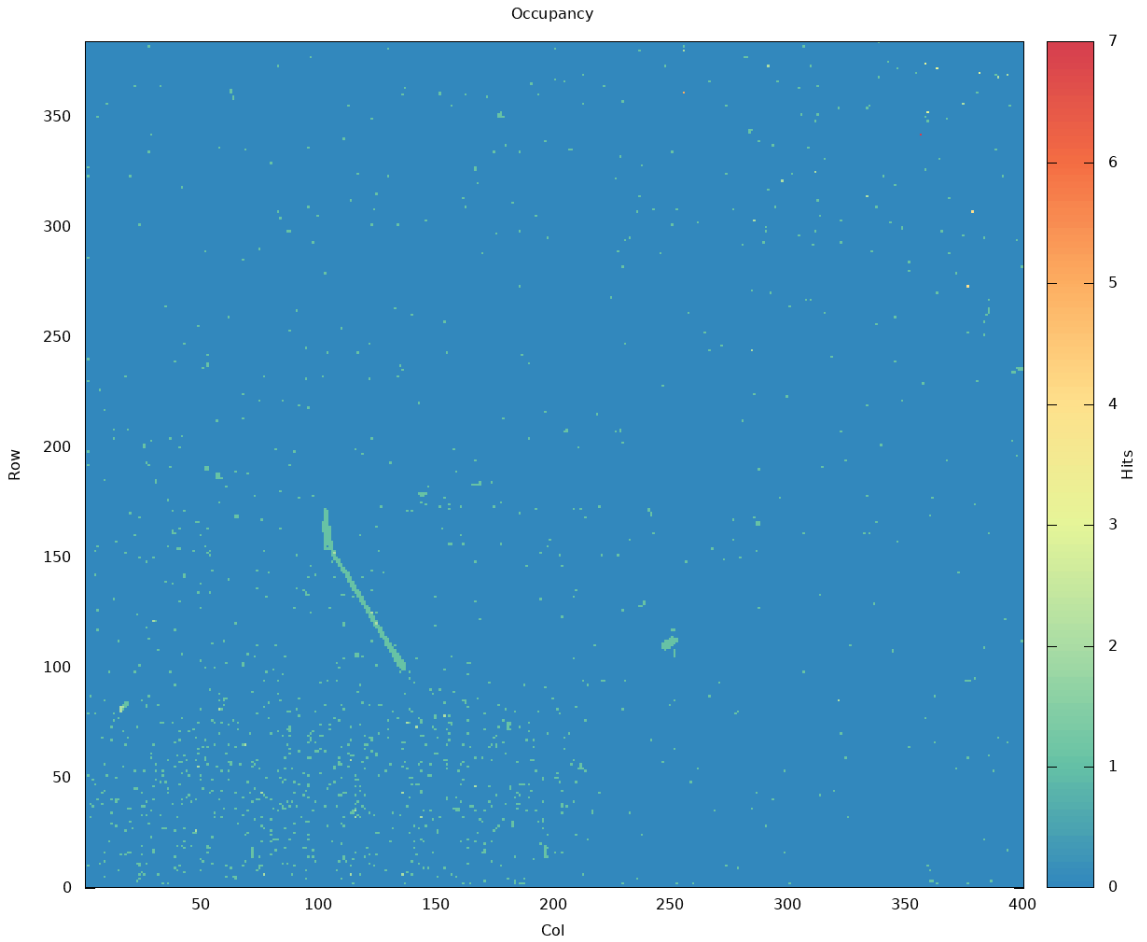
→ Second solution: twice the fan, twice the fun

→ Possible to keep the chip below 60 C consistently with two fans



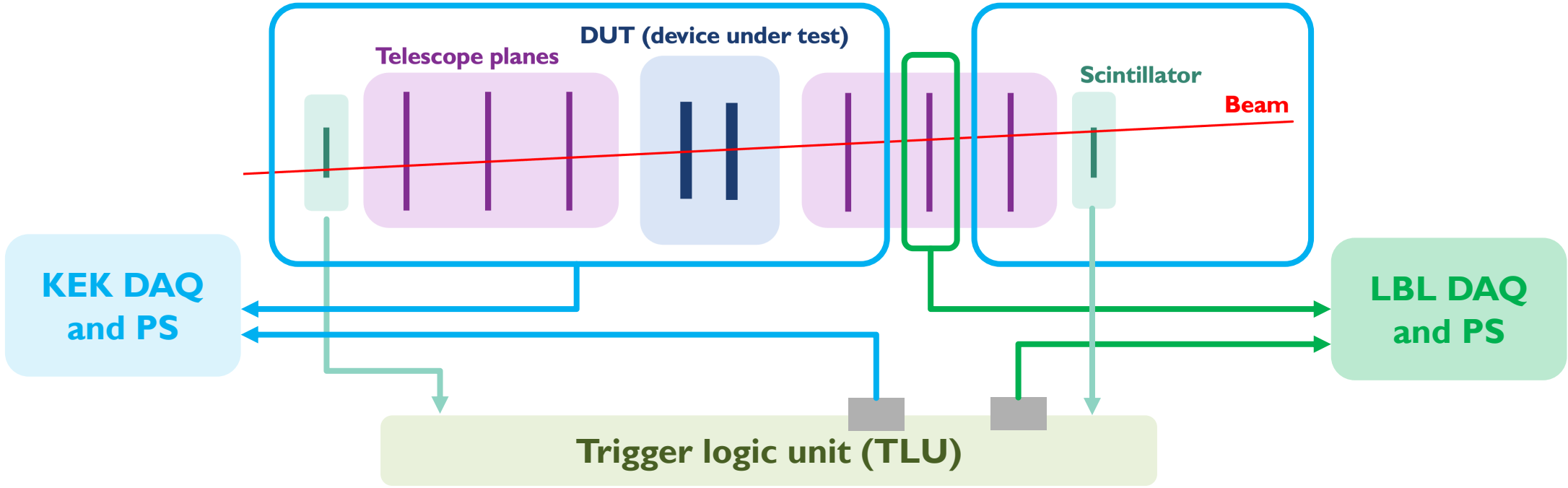
Beam

- Remote controlling our crate and setup worked well remotely from the control room
- After some tweaking of scan configuration we were able to see beam!



Integration of LBL and KEK setup

- Final step was to ensure we can operate LBL and KEK setup in parallel for datataking and debugging



- Required some modifications to the firmware of the TLU (custom TLU using KC705, designed by KEK)

→ After a day of debugging, were able to take data with both setups in parallel ☺

→ And then we had to leave ☹

```
[16:14:47:129][  info  ][AnalysisAlgorithm][42546]: Analysis done!
[16:14:47:131][  info  ][  StdAnalysis  ][42546]: [0] Received 14264 total trigger!
[16:14:47:131][  info  ][  StdAnalysis  ][42552]: [2] Received 14264 total trigger!
[16:14:47:131][  info  ][  StdAnalysis  ][42549]: [1] Received 14264 total trigger!
[16:14:47:131][  info  ][  StdAnalysis  ][42555]: [3] Received 14264 total trigger!
[16:14:47:133][  info  ][  ScanConsole  ][42541]: All done!
```

Conclusions and Outlook

- Testbeam at Fermilab as part of the US-Japan collaboration for building the first ITkPixV1 telescope → main motivation is the higher readout rate possible with ITkPix
- Worked mostly in parallel with the KEK group
  - KEK group focused on telescope operation and datataking
  - We focused on setting up a new crate of readout PC, multimeter and power supplies, which should replace the old setup
- **Successfully set up the crate: Powering, network, cables, automatic monitoring, YARR**
- Moved crate into the beamline and were able to take some data
- Integrated our setup with the existing one, so we can operate both in parallel while we finish debugging

- Next steps: Testbeam @ KEK
  - Focus on integrating everything into one system, including the bare module PCB
  - Set up HitOr-based triggering and push the readout rates
- In the meantime: Ship the crate back to LBL and continue working on the setup