Fermilab Test Beam Facility & Irradiation Test Area

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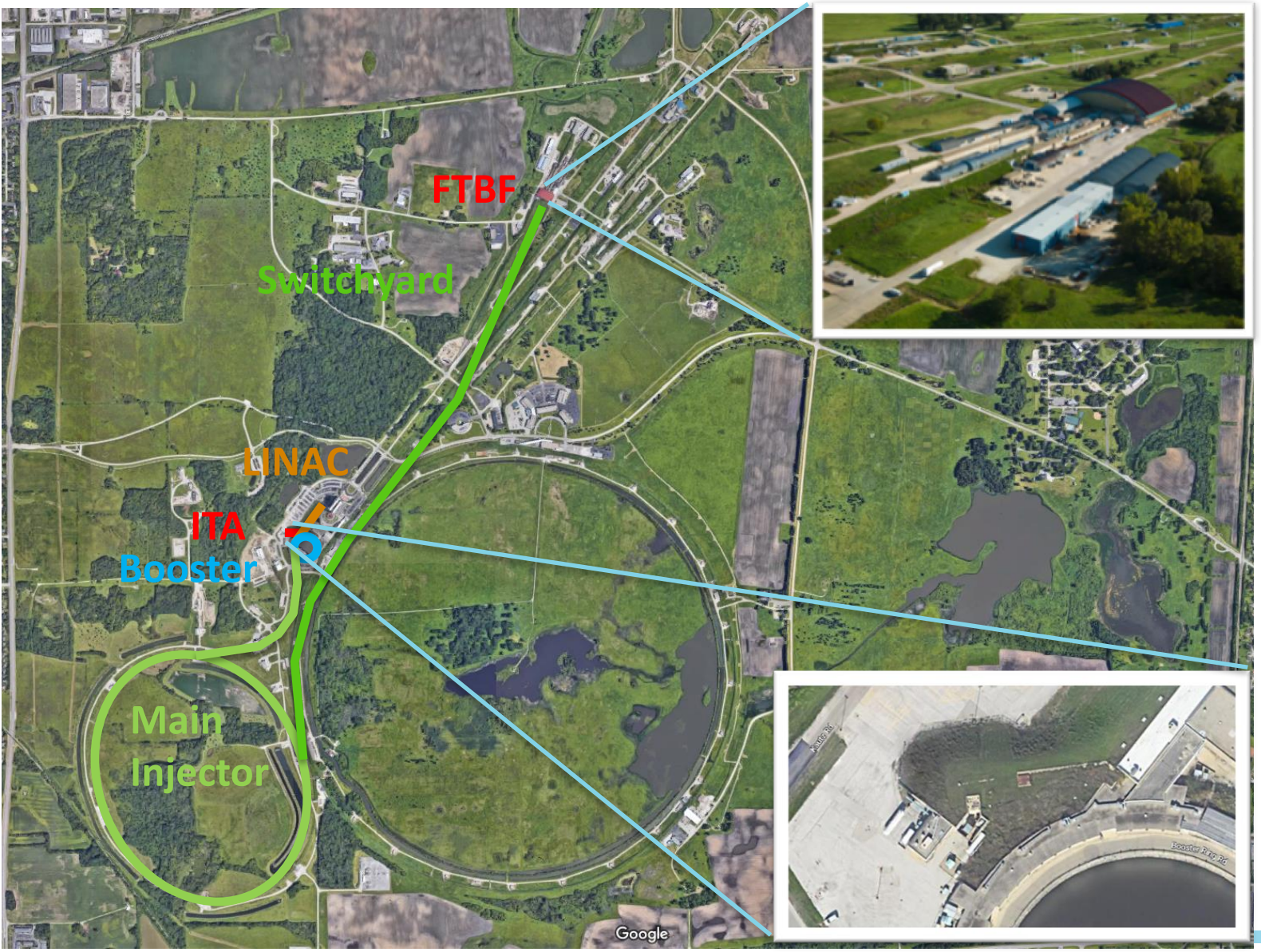
11th Beam Telescopes and Test Beams Workshop

Introduction

- Fermilab Test Beam Facility (FTBF) – Supports a wide program of research and detector R&D
  - 2 Beamlines (MTest and MCenter) – can provide particles from 120 GeV protons to secondaries of ~200 MeV to 60 GeV
- Irradiation Test Area (ITA) –
  - Low energy, high rate (~2.2e15 protons/hr)
- Beam is available ~9 months a year (roughly October through June)

Where are FTBF and ITA?

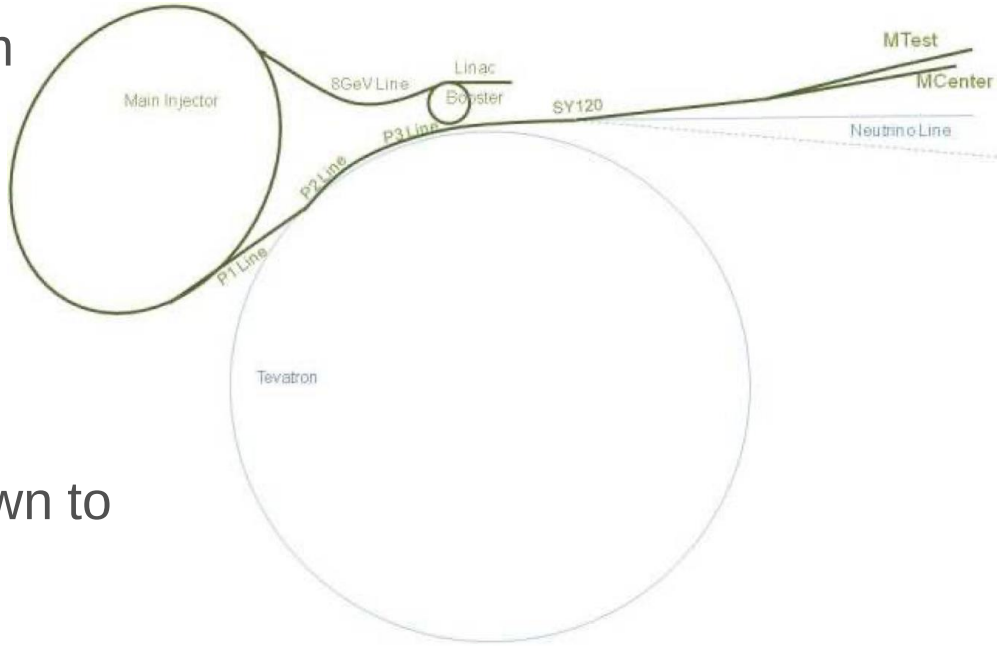


FTBF – Meson Detector Building

ITA – Irradiation Test Area

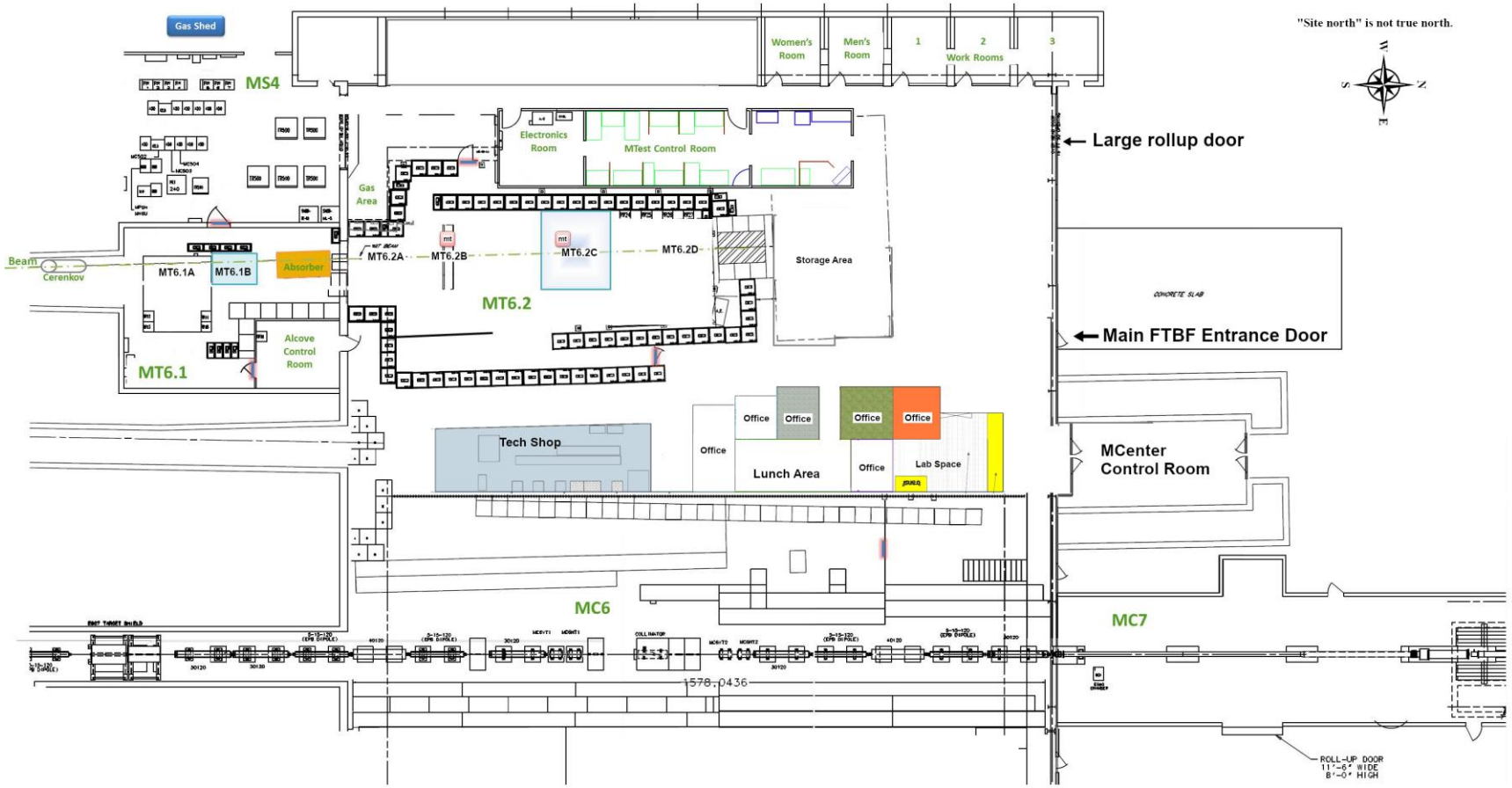
FTBF Beamline Details

- 4 second beam spill every 60 seconds, available 24/7
- ~1000 to 900,000 particles per spill
- MTest
  - 120 GeV primary protons
  - 1-66 GeV secondary beam
  - ~2cm spot size
  - 1-4 week runs
- MCenter
  - Secondary beam
  - Two tertiary beamlines down to 200 MeV
  - longer term experiments



Facility Layout

- MTest and MCenter beamline enclosures



Beam Performance – MTest

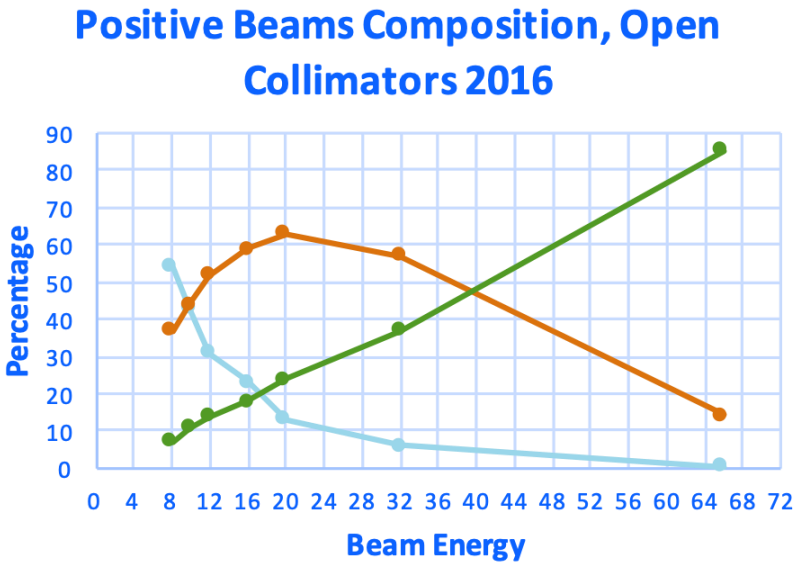
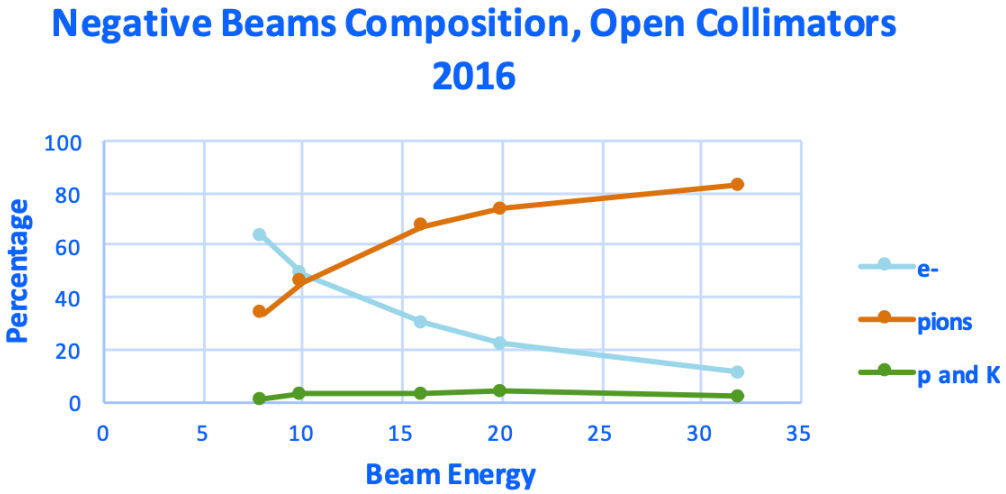
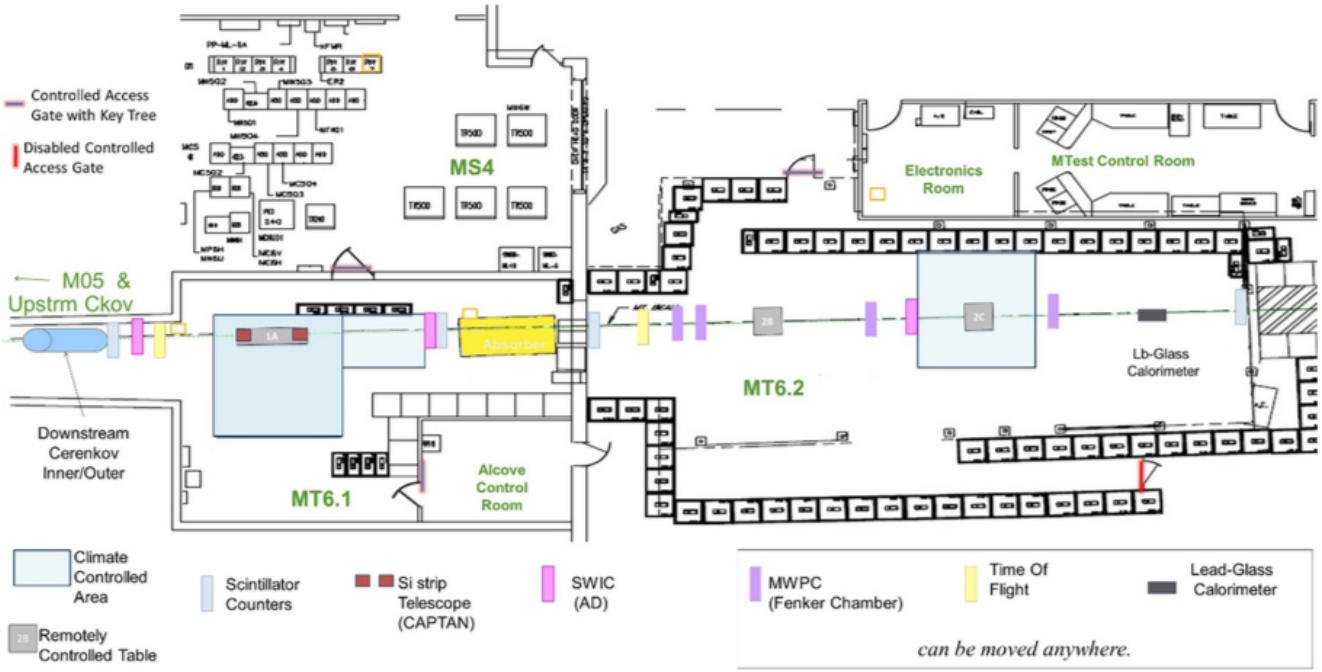


Table with energies, beam spread, percentages:
http://ftbf.fnal.gov/mtest-beam-details-2/

Studies by E. Skup and D. Jensen

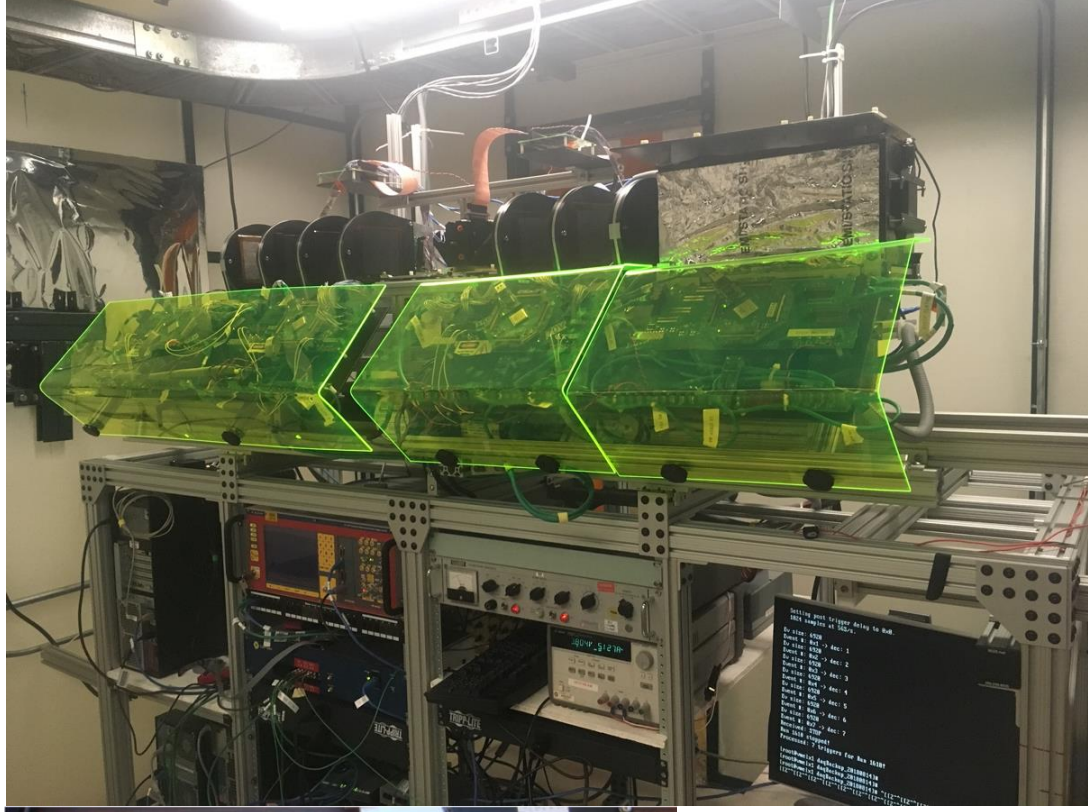


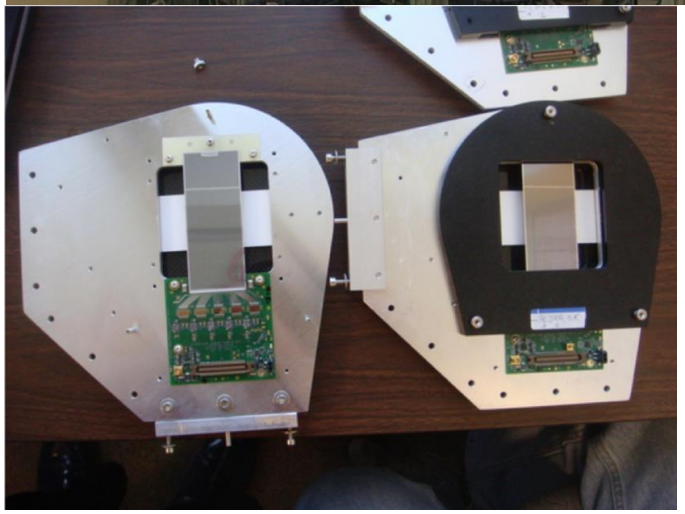
Instrumentation Layout - MTest



Silicon Telescope

- Tracking telescope based on silicon strips and pixel planes
  - http://www.sciencedirect.com/science/article/pii/S0168900215015521
- 5 μm resolution on DUT
- 3.8 x 3.8 cm coverage of silicon strips
- Moveable arms and motion table for sample positioning
- Recently upgraded pixel sensors

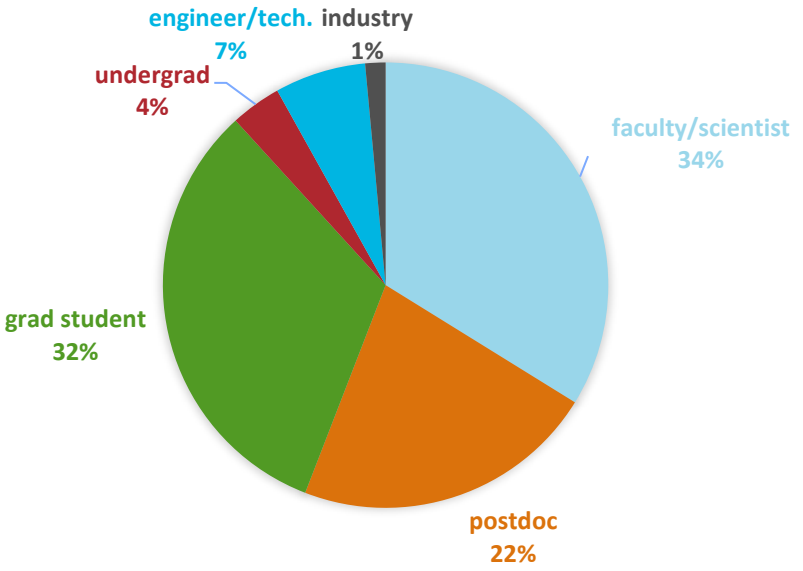




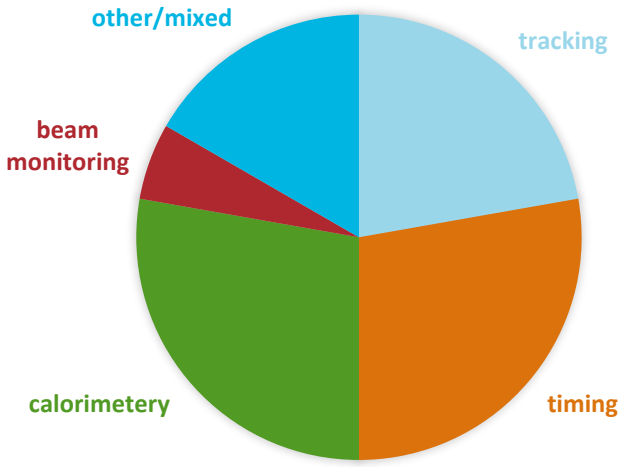
Who uses FTBF?

- 160 users from 18 different experimental efforts in FY22
- 18 Experimental efforts, 4 new efforts

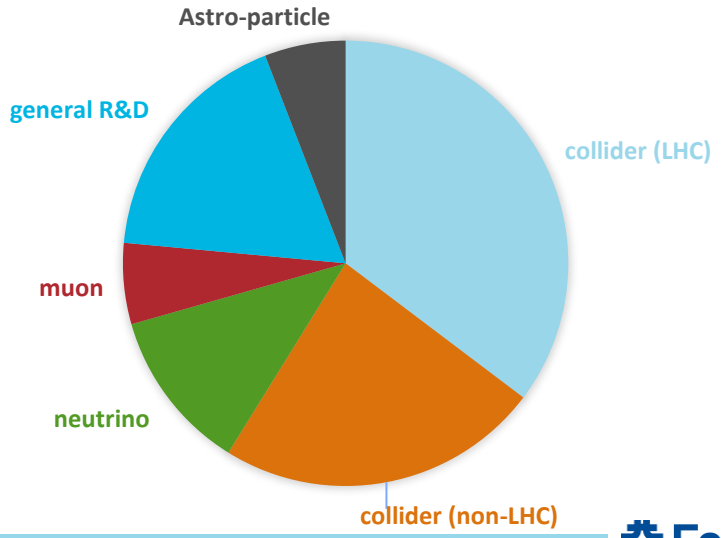
Users by professional category



Experiment by detector

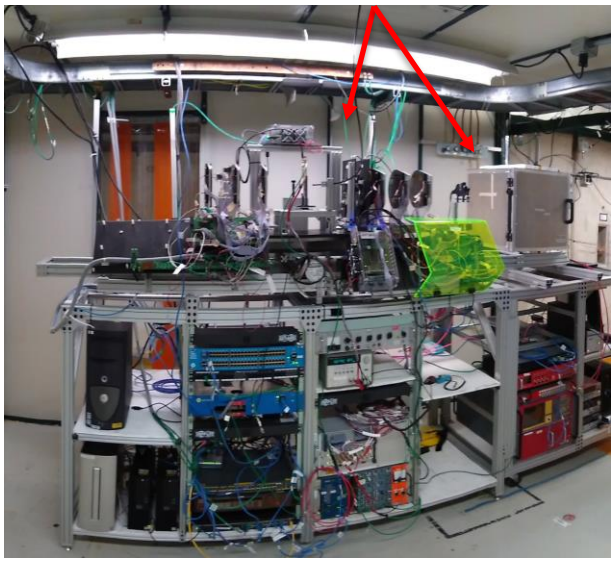


Experiment by research focus



Experiments at MTest

- FY23 MTest users have included experiments from the CMS, ATLAS, EIC, neutrino, and general R&D communities

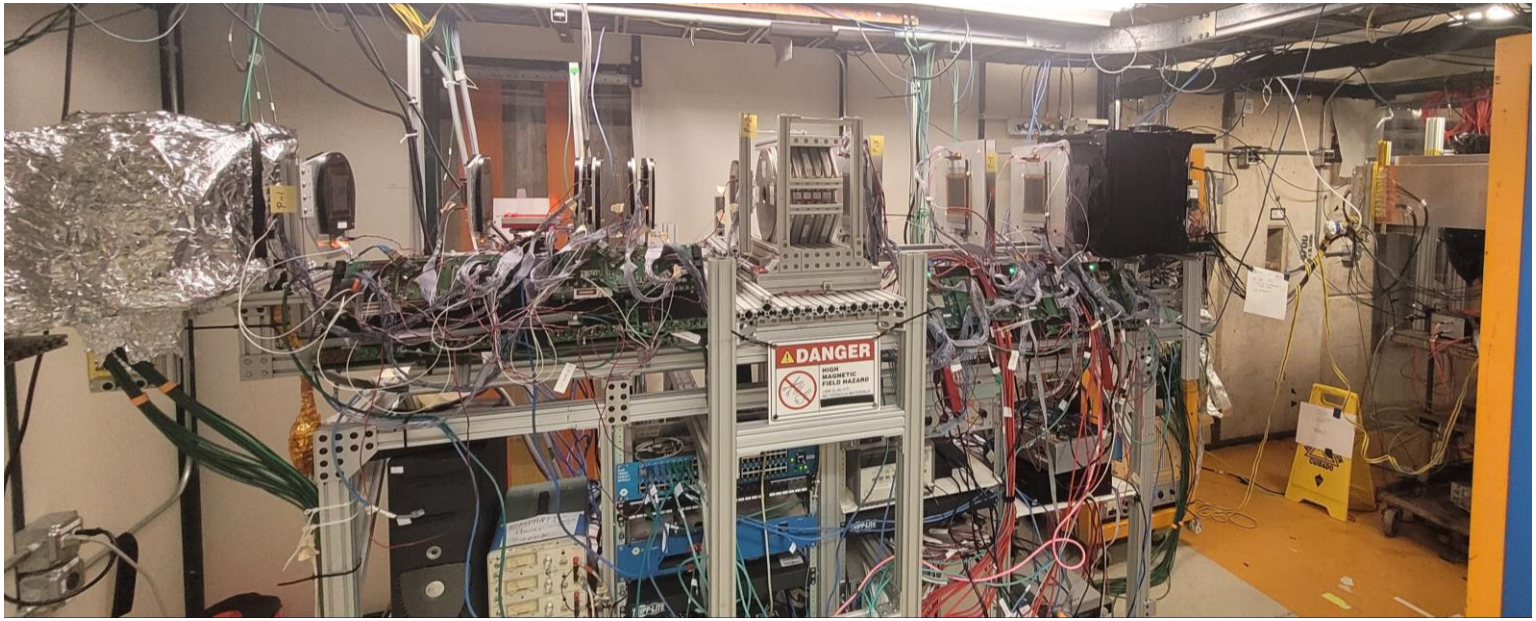


MT6.1

MT6.2

Experiments at MTest

- EMPHATIC experiment
  - Small scale experiment measuring hadron interaction cross sections to improve systematics on neutrino measurements
  - Recently completed 3 week long run in MTest, will move for longer run in MCenter next year



MCenter activities

- “Jolly Green Giant” magnet has been refurbished
  - 0.7 T magnet field
  - Large Bore (> 1m diameter)
- Two new detectors to be installed in MCenter for DUNE R&D
  - TOAD: High pressure gas TPC with MCPs will be tested
    - Install under way, should take beam this month
  - ArCS: liquid argon TPC will be operated in the Jolly Green Giant magnet, will run FY24

ITA Beam Details

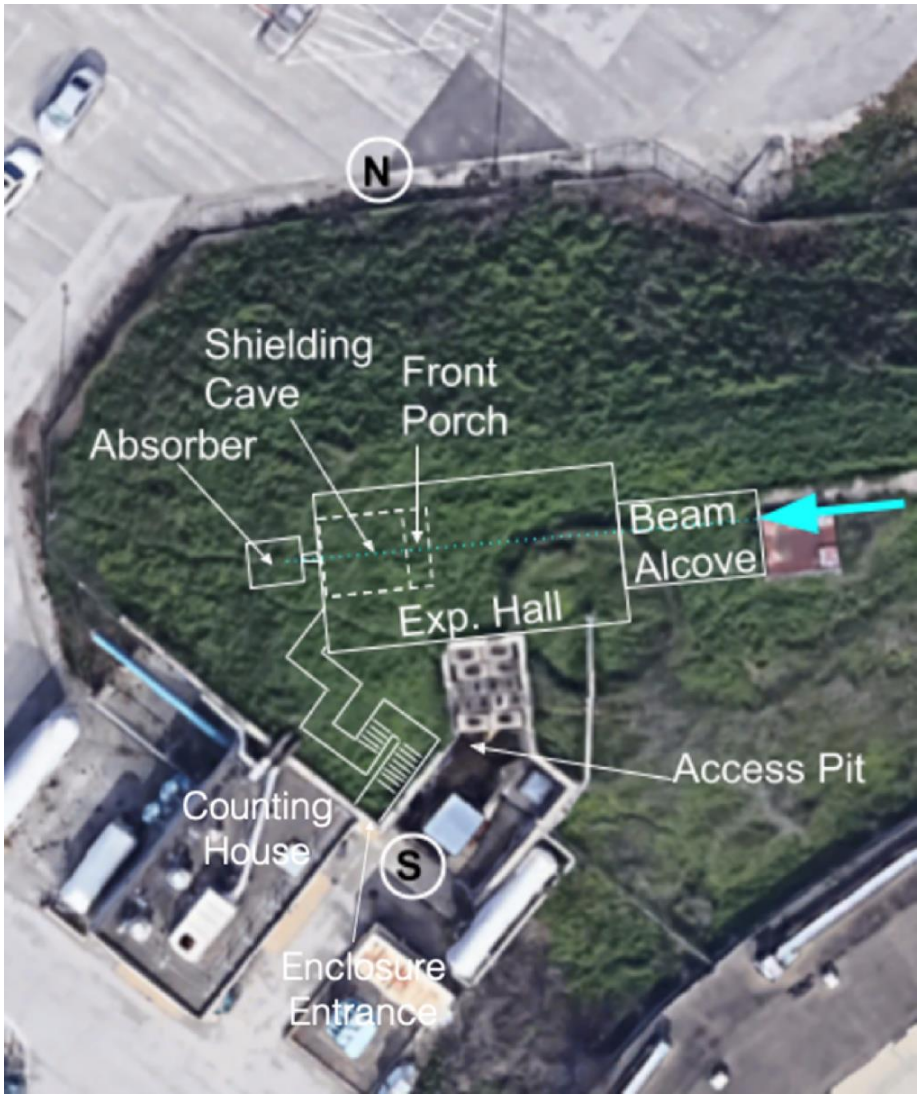
- MTA beam line is approved for a maximum intensity of 2.7e15 particles per hour per the current shielding.
  - Typical rates are around 2.2e15 particles per hour
  - Administrative limit of 1.3e18 particles per beam year.

- Beam delivered as multiple pulses in a 4 second window once per minute:
  - Individual pulses can be adjusted from ~6μs (~0.7e12 particles) to 32μs (~4.5e12 particles).
  - Number of pulses can be adjusted 1-8 that come in a train at 15 Hz

- Beam spot size nominally ~1cm 1 sigma 2D gaussian.
  - Magnets allow separate horizontal and vertical focusing.
  - Spot can be increased a few centimeters.
  - Multiwire chamber provides profiling at final beam window, ~2.5' from closest experiment position.
  - Additional multiwire chamber added on motion table ~ 6 inches from target box

MTA Facilities

- Counting house in service building next to beam enclosure.
  - Set of ~50’ penetrations connect the two spaces for cabling.
- Enclosure accessed by stairs directly from the parking lot.
- Equipment elevator available for use.



MTA Beam Line: Experimental Hall

Facility Infrastructure: Installing Samples

- Card cage available for sample installation
- Cave has interior dimensions 3’x3’x9’ with an additional 3’ depth on “front porch”
- Front porch supports x-y motion table, rail system to move samples into the cave.

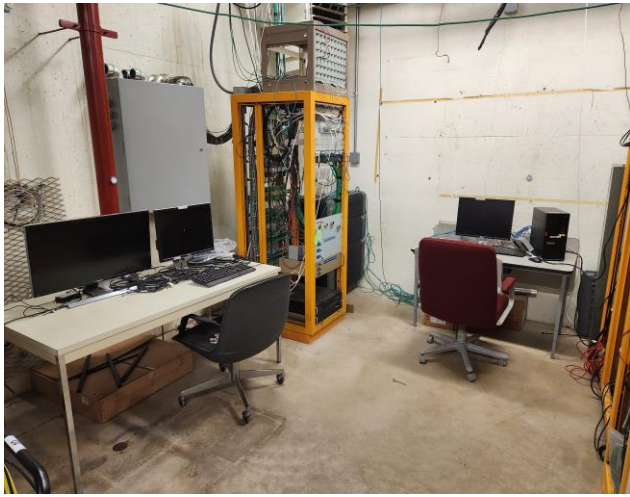
Photo courtesy Abhishek Bakshi

Very first samples from CMS and ATLAS ready for irradiation. Photo courtesy Corrinne Mills

Photo courtesy Todd Nebel

Facility Infrastructure: Counting House

- Active monitoring of samples and data possible from remote counting house. Experimental cave viewable via remote camera.
- RG-58 BNC, RG-58 SHV, and cat6 cable patch panels connect to enclosure. Additional cabling can be pulled upon request.
- Freezer storage onsite for irradiated samples.



Electronics testing for TID and NIEL

- For 400 MeV proton beam:
  - Achieve 1 Grad total ionizing dose (TID) in silicon ~= 2.6e16 protons/cm^2
  - Achieve 2e16 neq/cm^2 displacement damage from non-ionizing energy loss (NIEL) ~= 2.4e16 protons/cm^2
- Able to reach TID and NIEL levels expected at the HL-LHC inner trackers simultaneously.
- Reach these doses in ~2-3 days of continuous beam depending on Linac conditions.

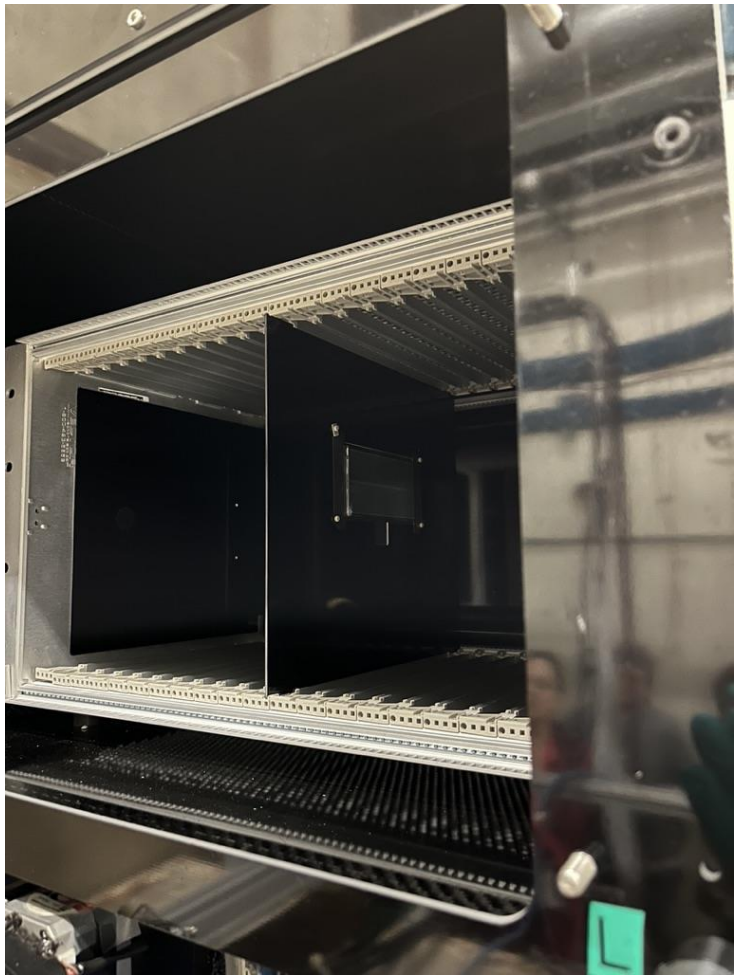
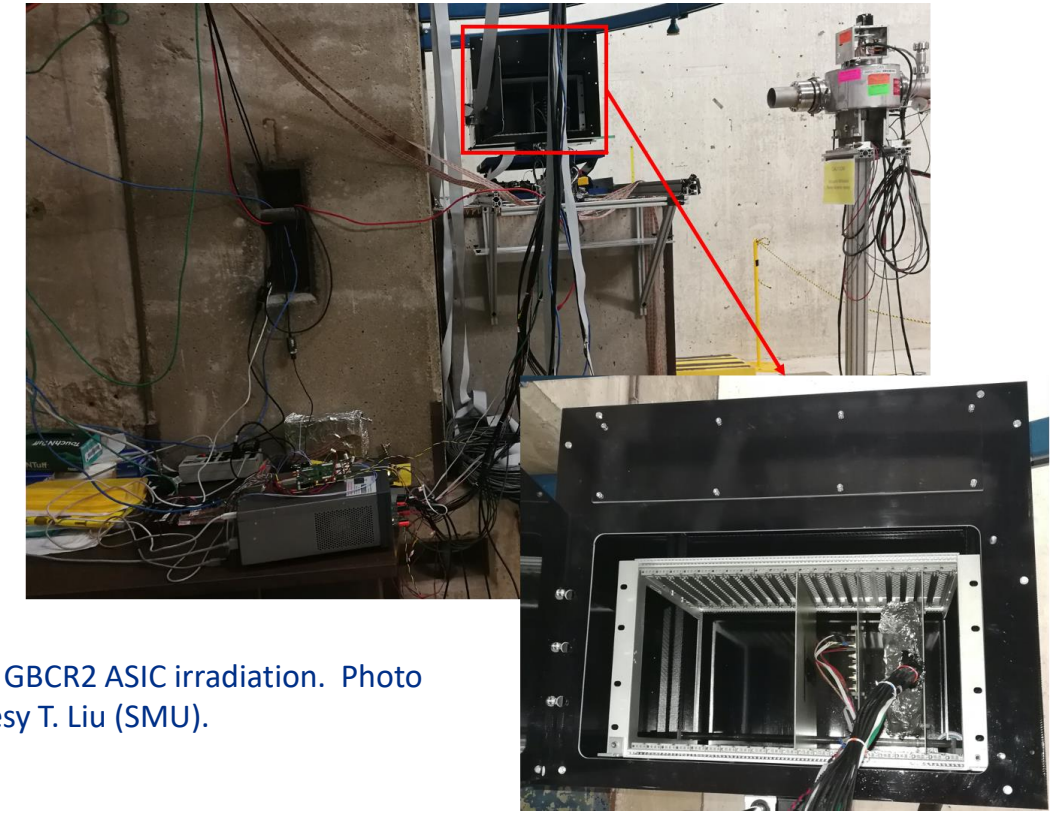


Photo by Jennet Dickinson

SEU and SEE Electronics Testing

CMS ECON-T ASIC irradiation. Photo courtesy D. Noonan (FNAL).

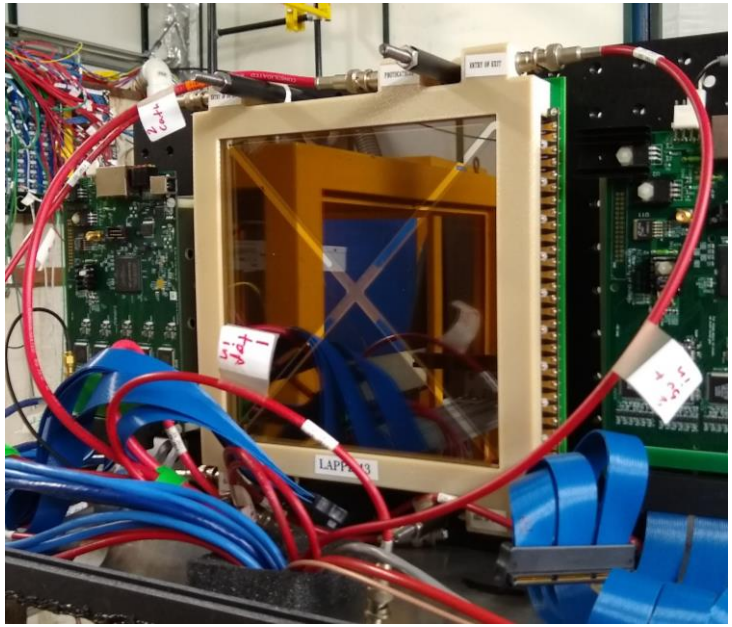


ATLAS GBCR2 ASIC irradiation. Photo courtesy T. Liu (SMU).

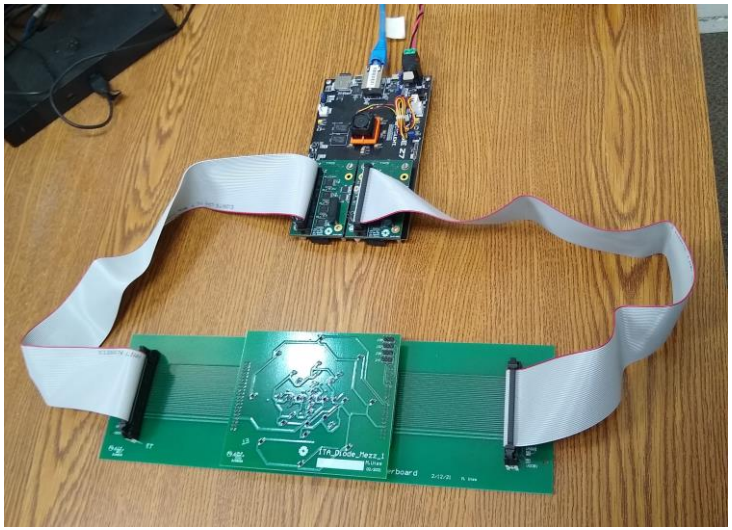
- Linac beam is fixed intensity, leaving an intense beam for electronics testing.
- Some success has been had locating samples off-axis and with shielding.

Upcoming plans for ITA and FTBF

- LAPPD based time of flight system
  - Concept tested in 2019
    Angelico, Evan. doi:10.2172/1637600.
  - Making use of ANNIE readout electronics, modified for use at FTBF
  - Measured time uncertainty of 19 ps



- ITA beam profile monitor
  - Eclypse-Z7 based readout solution
  - Diode based profile monitor
  - Working on IRRAD style secondary emission boards to replace diode as active media



Future test beam facility proposal

- ITA will end with the shutdown of the original LINAC in 2026
- Ongoing accelerator upgrades to PIP-II and booster provide a great opportunity for a new test beam facility
  - PIP-II linac will provide high intensity source of 800 MeV protons
  - New location closer to accelerators makes facility more convenient and have less beamline to maintain
  - 4-6 beamlines
    - 120 GeV from MI
    - 8 GeV from booster
    - High intensity 800 MeV irradiation area (>10e18 protons total dose on samples)
    - Clean secondary lines for Electrons, Muons, and Pions
  - Collocate test beam and irradiation facilities
  - Dedicated infrastructure for control rooms, experimental staging, facility infrastructure
  - Room for small medium/long term experiments
  - Snowmass white paper

Becoming an ITA or FTBF user

- Talk to the facility about a proposed experiment (ITA) and fill out a Technical Scope of Work
  - Agreement between test beam collaboration and the lab over what resources are used
  - Do you need significant engineering or tech support? Computing support? Will you have enough users to cover your shifts?
  - Document can be broad and cover multiple years and uses of the facility

- TSW information can be found here: http://programplanning.fnal.gov/tsw_orc/
  - Email us: rominsky@fnal.gov (Mandy), edniner@fnal.gov (Evan), pastika@fnal.gov (Joe)
  - Approvals typically take 4-6 weeks, depends on needs

- Scheduling for FTBF for FY24 beam run will start this summer, but reach out anytime!
  - MTest requests for typically 1-4 week periods with 12 hours of primary beam use, many groups can be accommodated at once
  - MCenter requests at lower energies, often longer periods, single user

- ITA is operational and has openings now, contact us for use requests in FY23 or 24

Summary

- The Fermilab Test Beam Facility and Irradiation Test Area are user-oriented facilities aimed at providing high energy/intensity particle beams for applications in particle, nuclear, and beyond

- We are always working to improve the facility and our user's experience, suggestions are welcome!

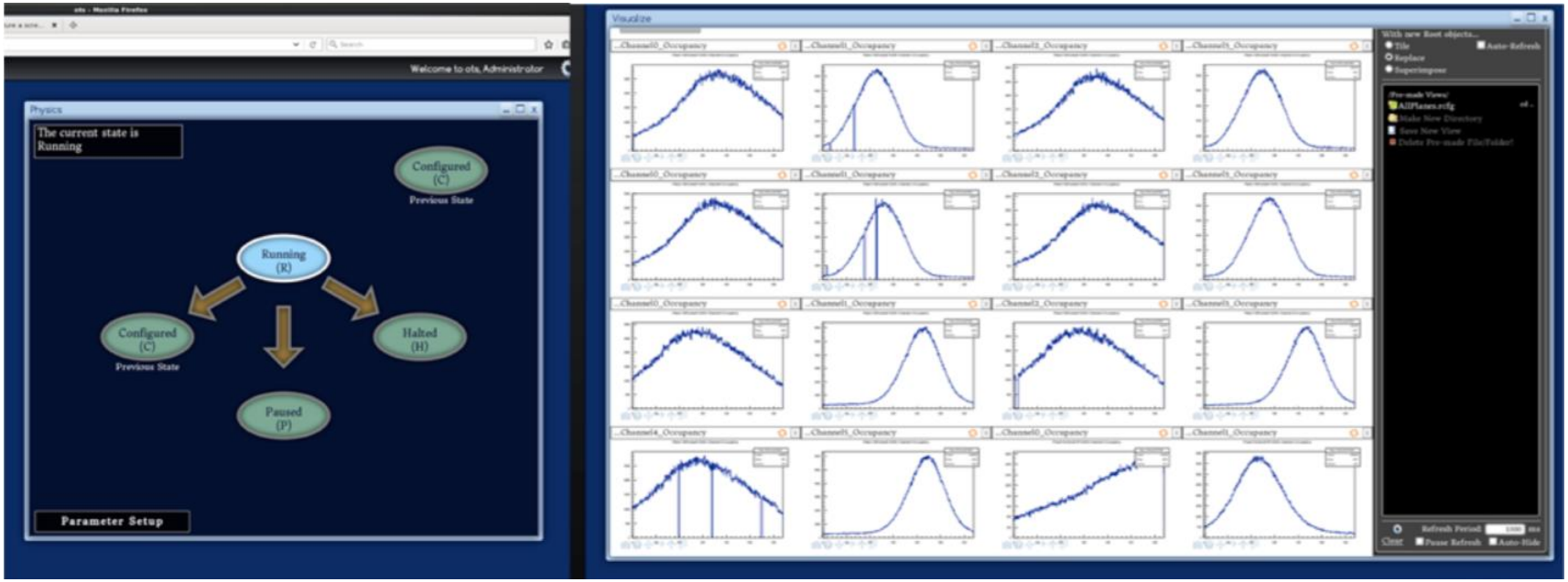
- A big part of our mission is outreach, we encourage students to come and we support interns over the summer (now restarted in person)

- We look forward to seeing you at Fermilab! To learn more:
  - Slack Team: fnal-testbeam
  - Webpage: ftbf.fnal.gov, ita.fnal.gov
  - Listserv: test_beam@fnal.gov

Evolving FTBF/ITA demands

- FTBF is in high demand with usage near capacity each year
  - High demand for 120 GeV beam and tracking to support collider needs
  - Increased interest in high purity electron/muon beams from muon, dark matter, neutrino communities
  - Emerging interest from APRA-E and NASA
- Long delivery beamline to maintain (over a mile) with no added benefit
- Potential space for months to year long small experiments
- MCenter provides secondary/tertiary beams, but with a large configuration overhead

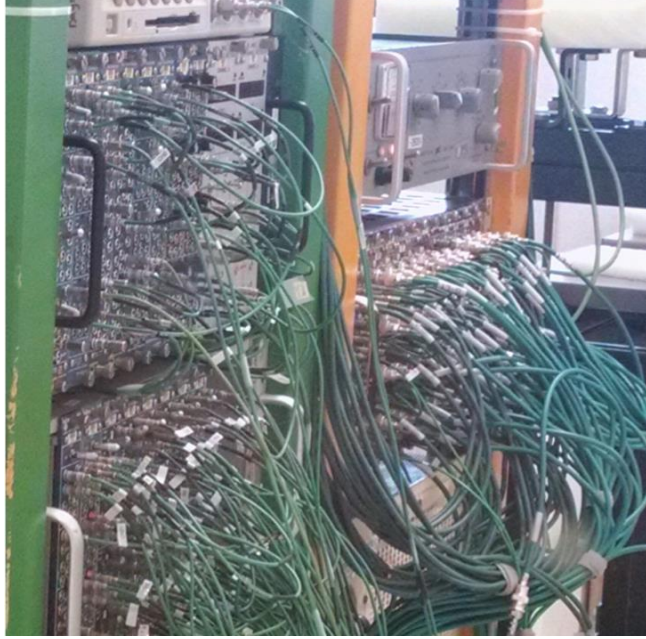
Off-The-Shelf Data Acquisition (OTSDAQ)

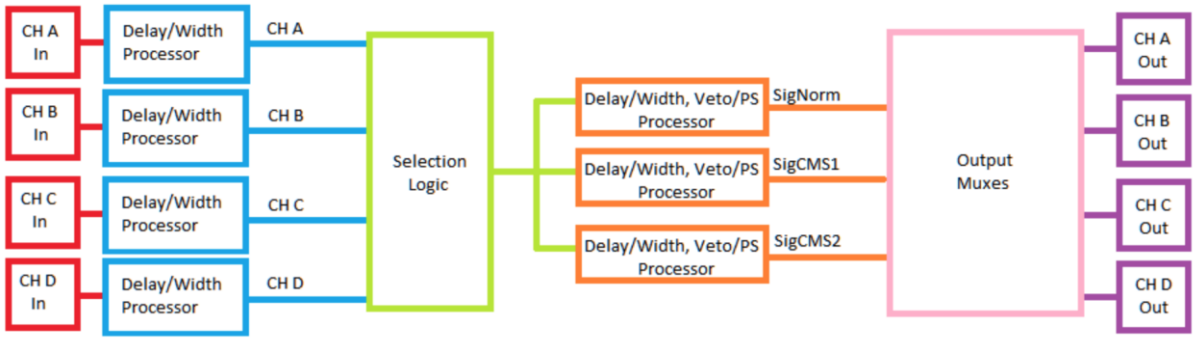


- FNAL computing division developed, flexible and scalable system allowing integration with other devices
  - Based on XDAQ (CMS) and ArtDAQ (Fermilab)
- Tied into facility MWPCs, Cherenkov detectors, silicon strip telescope.
- Several groups (CMS outer tracking, CMS Timing, RD53 chip, LHCb) have integrated and taken fully synchronized data with the telescope

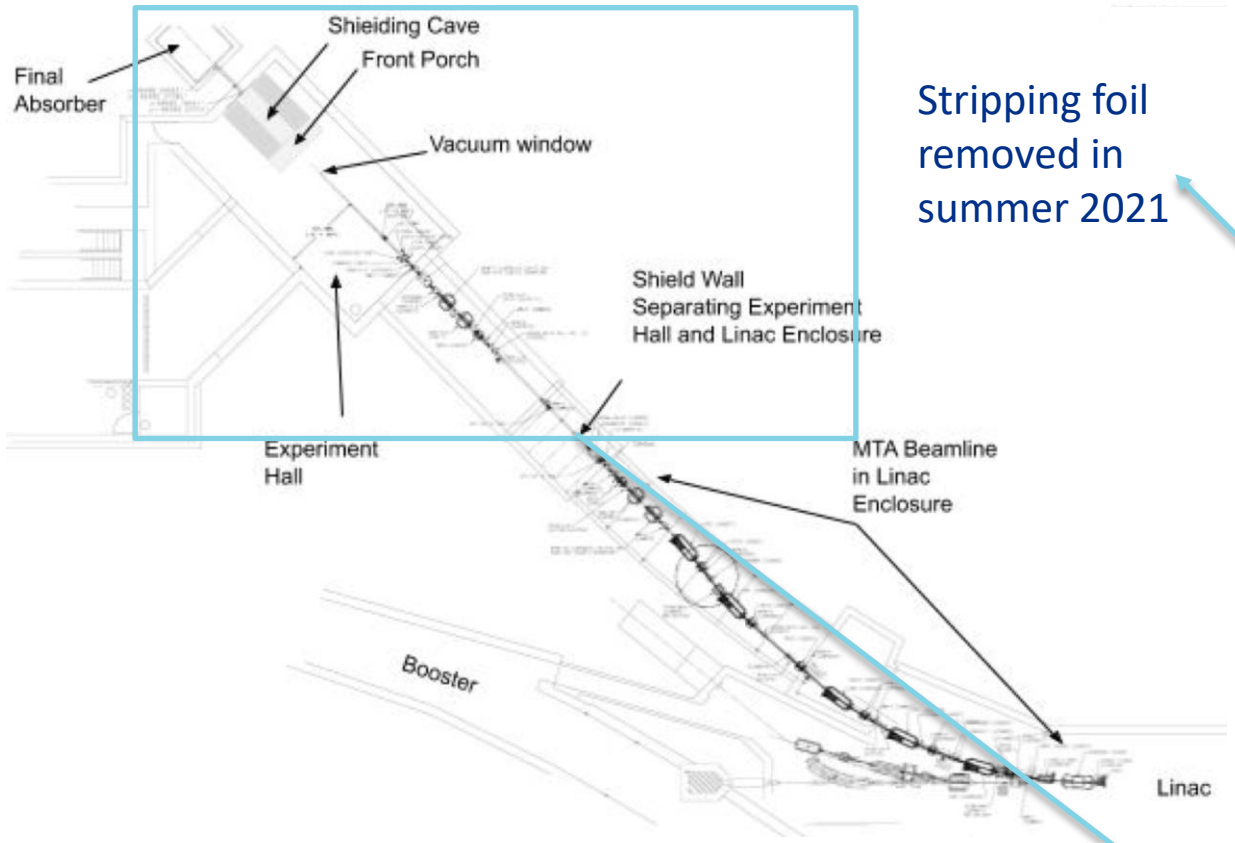
NIM+

- Fermilab built a board (NIM+) that accept NIM/TTL signals and it can be plugged in any FPGA board that has a standard FMC connector
- Firmware written to allow sync with a 40Mhz clock (LHC)
- Already used by multiple experiments
- Ethernet controlled can stay in enclosures
- Streams trigger data allowing multiple users to run at the same time with different trigger rates

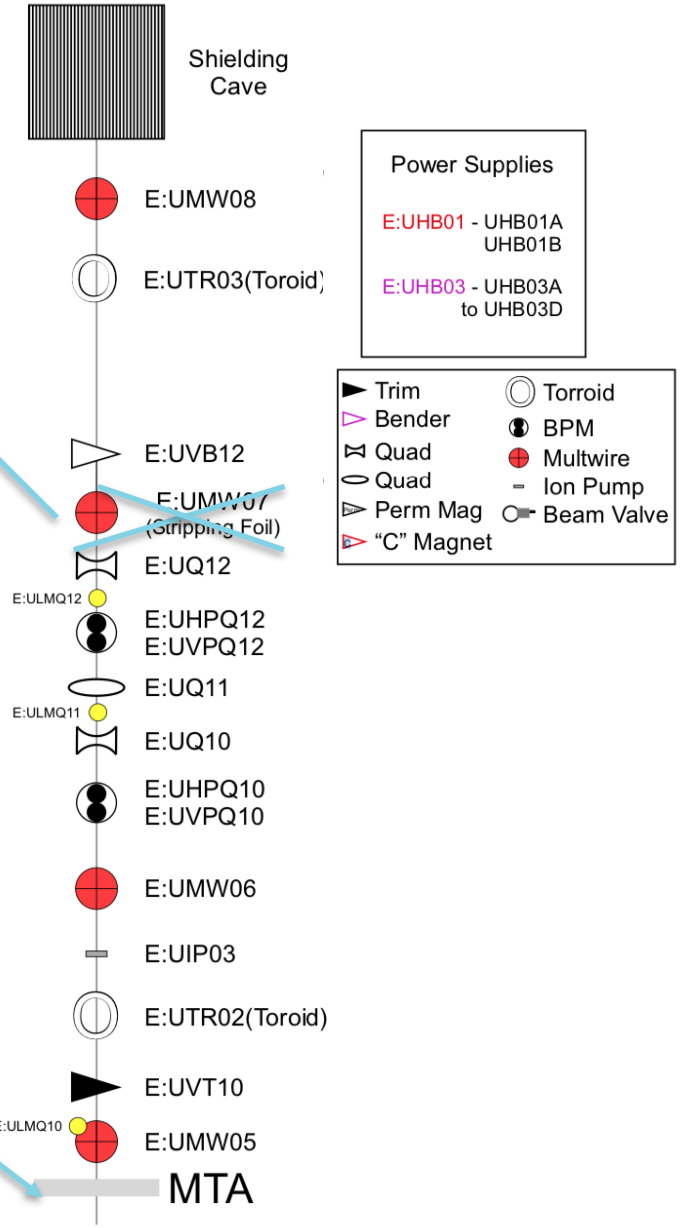




MTA Beam Line: Experimental Hall



Stripping foil removed in summer 2021

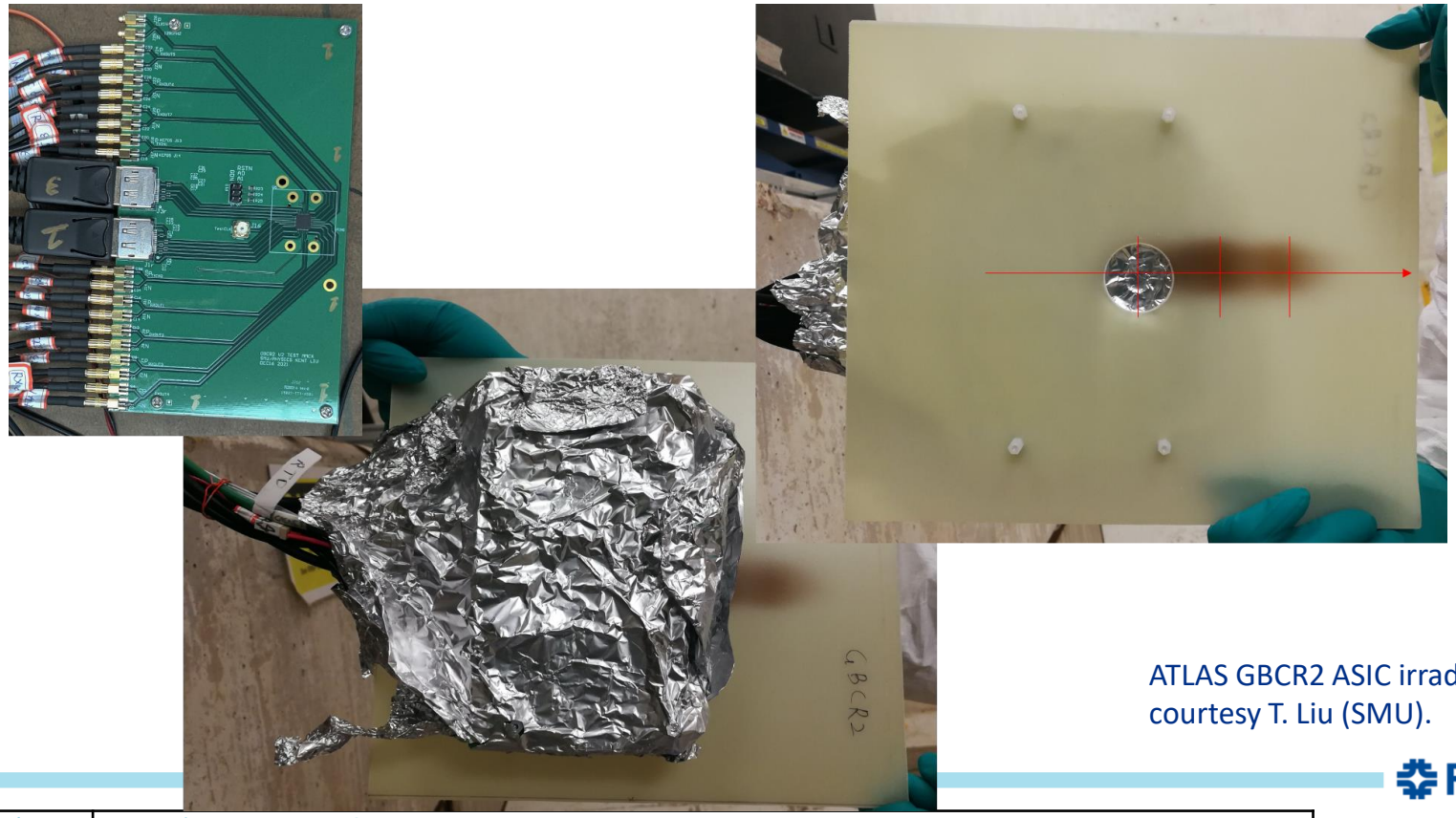


Facility Infrastructure: Shielding Cave

- Sample location dependent on materials involved.

SEU and SEE Electronics Testing

- Linac beam is fixed, leaving a rather intense beam for electronics testing.
- Some success has been had locating samples off-axis and with shielding.
- Groups continuing to gain experience understanding how to use the beam for electronics studies. Improved beam position monitoring will help.



ATLAS GBCR2 ASIC irradiation. Photo courtesy T. Liu (SMU).

ITA Beam Campaigns

- Four user groups in spring 2021
- Stripping foil removed summer 2021
- Be7 contamination from air activation observed on some higher fluence samples. Air flow and filtering system added to sample box in Summer 2021 which has reduced effect, optimization continues.
- Upstream linac added ceramic breaks allowing full intensity beam in February 2022.
- October 2021 - July 10, 2022 saw 10 user groups from CMS and ATLAS
  - 4 SEU and SEE groups (ATLAS inner tracker and LAr frontend, CMS HGCAL)
  - 5 groups passive radiation hardness tests (CMS and ATLAS pixel sensors+ROC, CMS outer tracker, CMS BTL LYSO crystals) up to ~2e16 neq/cm^2.
  - 1 exploratory study for future neutrino experiments