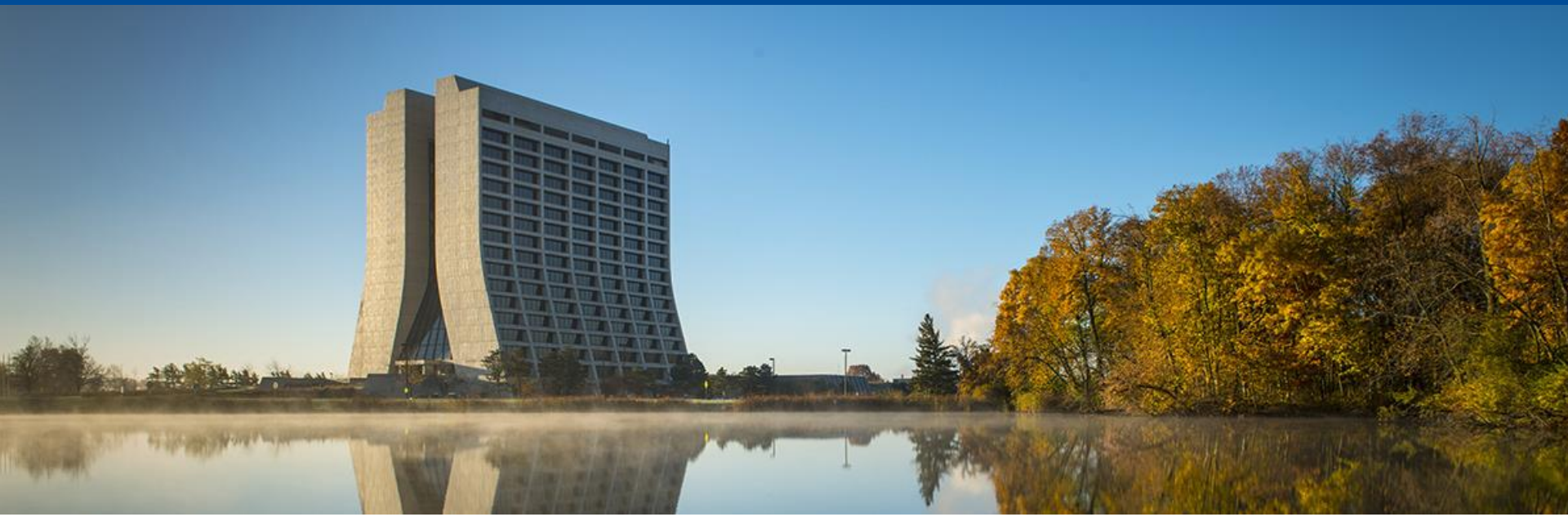


FTBF Time of Flight Upgrade

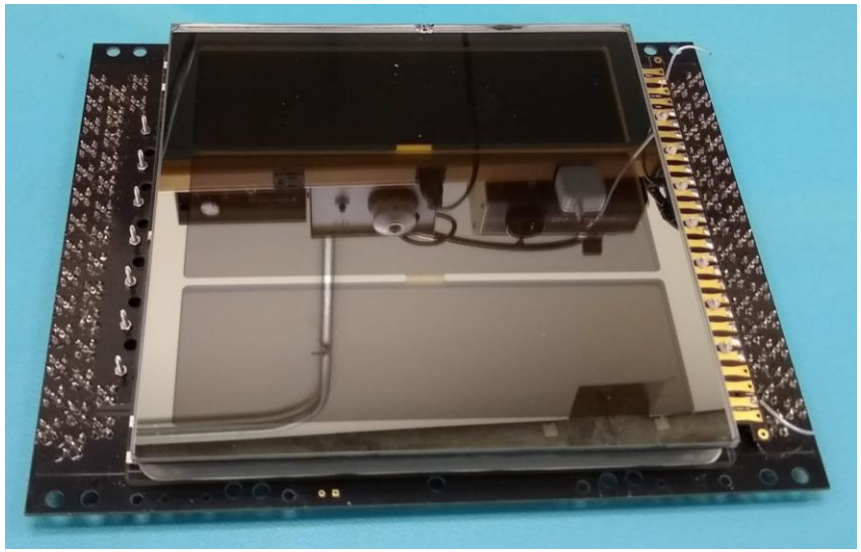
Joe Pastika[1], Evan Angelico[2], Henry Frisch[3], Ian Goldberg[3], Jinseo Park[3], Cameron Poe[3], Paul Rubinov[1]

CPAD 2023

1: Fermilab, 2: Stanford University, 3: Enrico Fermi Institute, U. Chicago

Introduction to FTBF

- Fermilab Test Beam Facility (FTBF) – Supports a wide program of research and detector R&D
  - 2 Beamlines can provide particles from 120 GeV protons to secondaries of ~200 MeV to 60 GeV
  - Beam is normally available ~9 months a year (roughly October through June)
  - Major delays in FY24 beam delivery, no beam in FTBF before March, 2024
- Existing Particle ID using PMT TOF system and Cherenkov detectors
- PID is crucial for testing modern particle detectors
- Large Area Picosecond Photodetector (LAPPD) based time of flight detector under development for FTBF

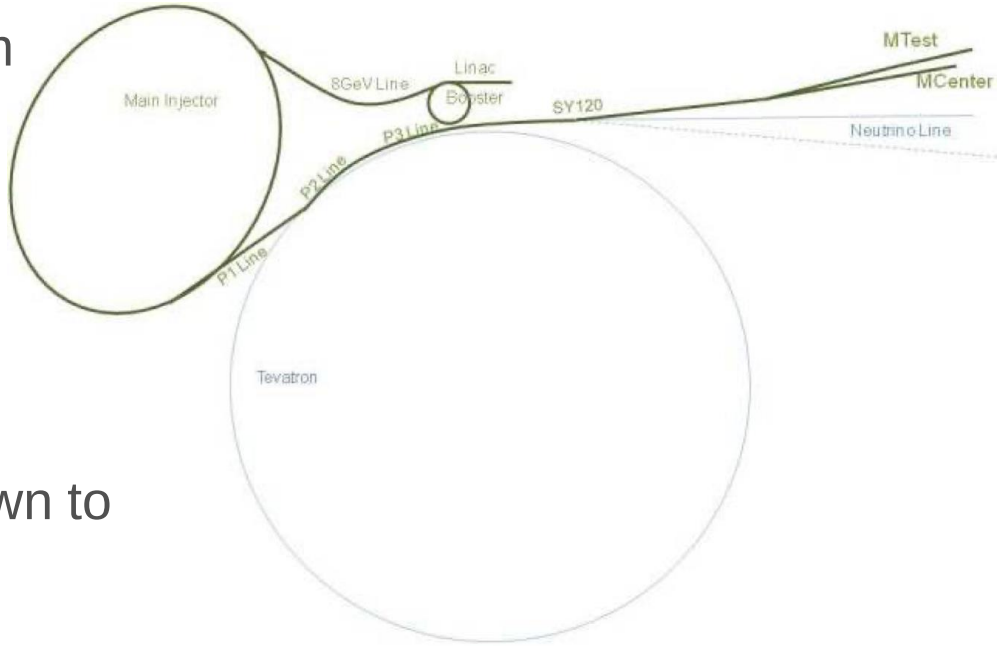


Where is FTBF?

FTBF – Meson Detector Building

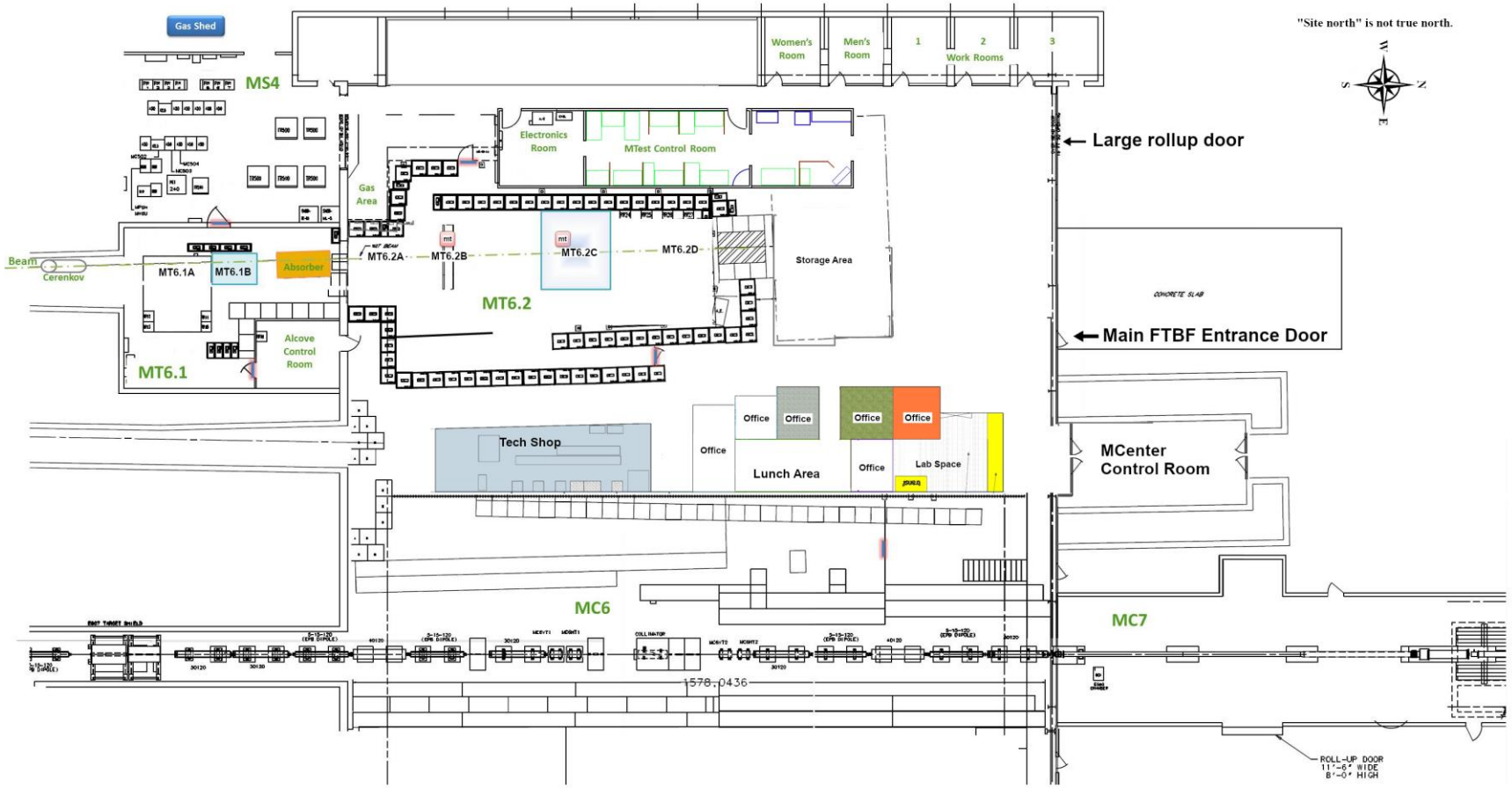
FTBF Beamline Details

- 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

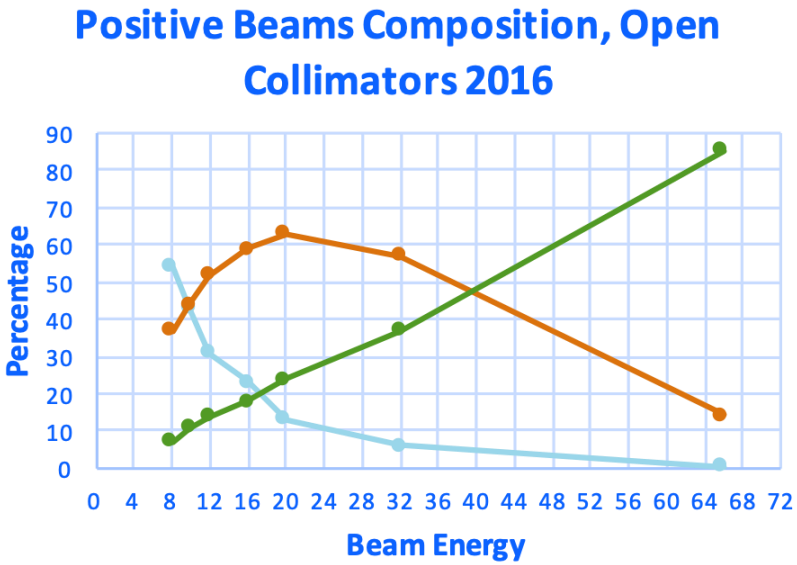
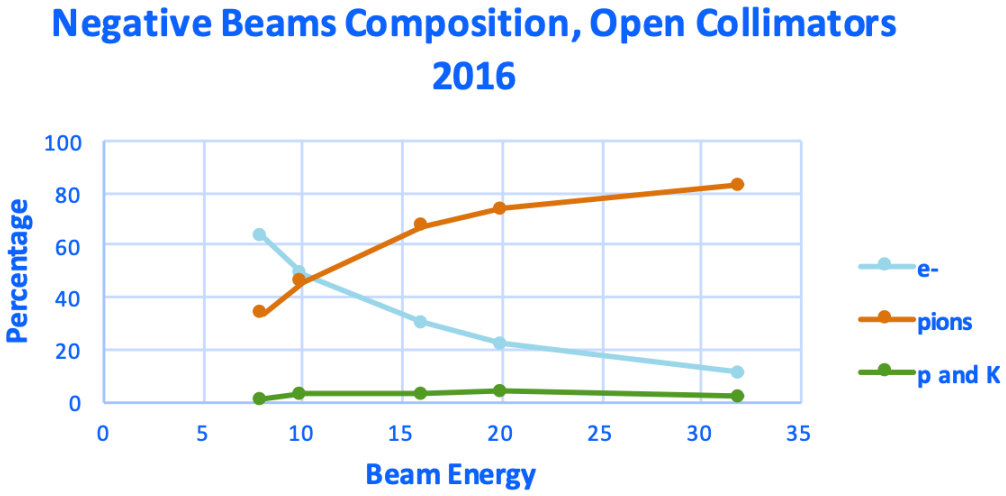


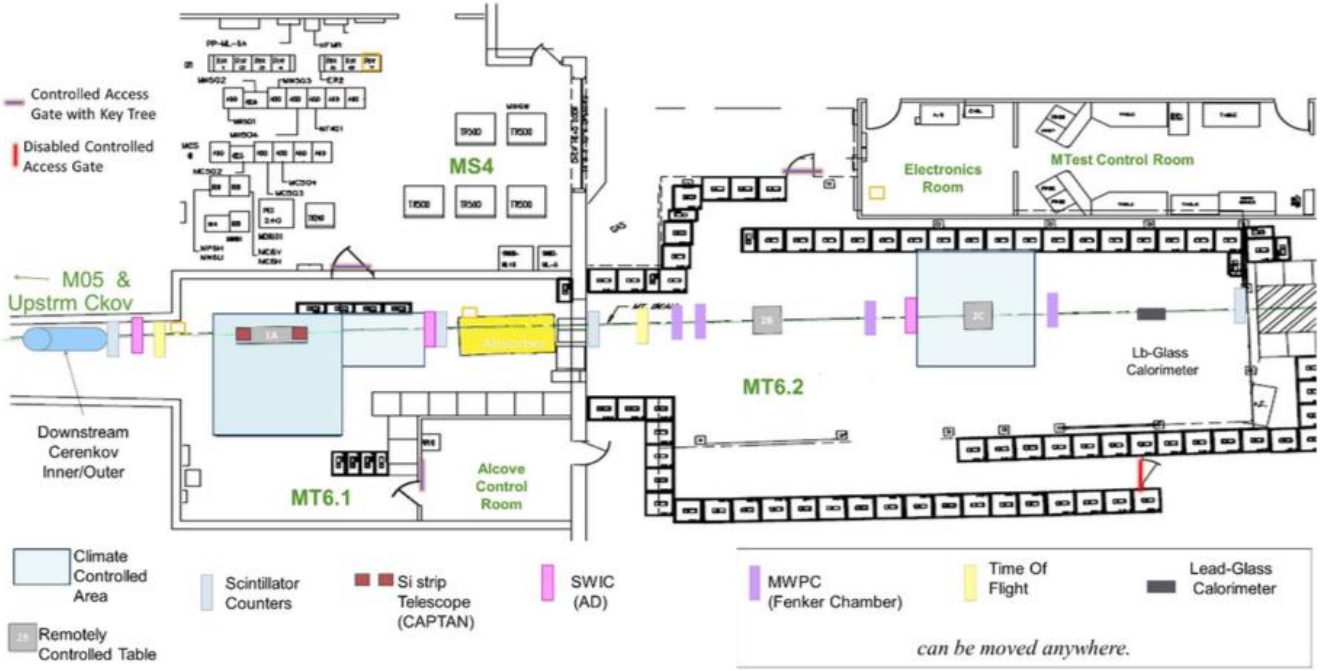
Table with energies, beam spread, percentages:
http://ftbf.fnal.gov/mtest-beam-details-2/

Studies by E. Skup and D. Jensen

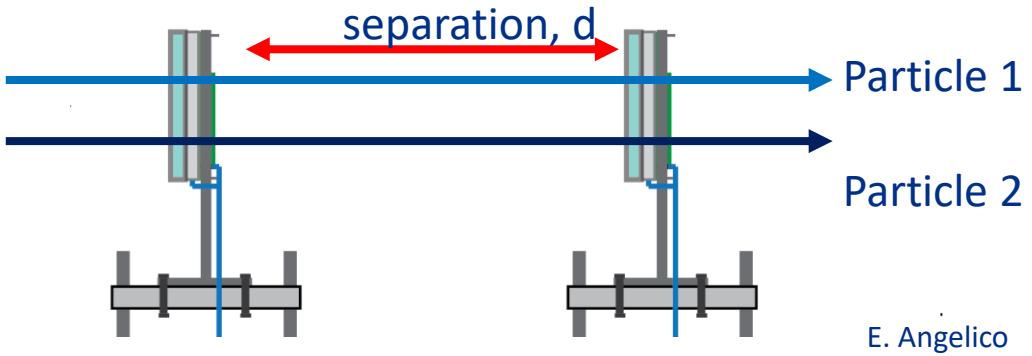


PID Options - MTest

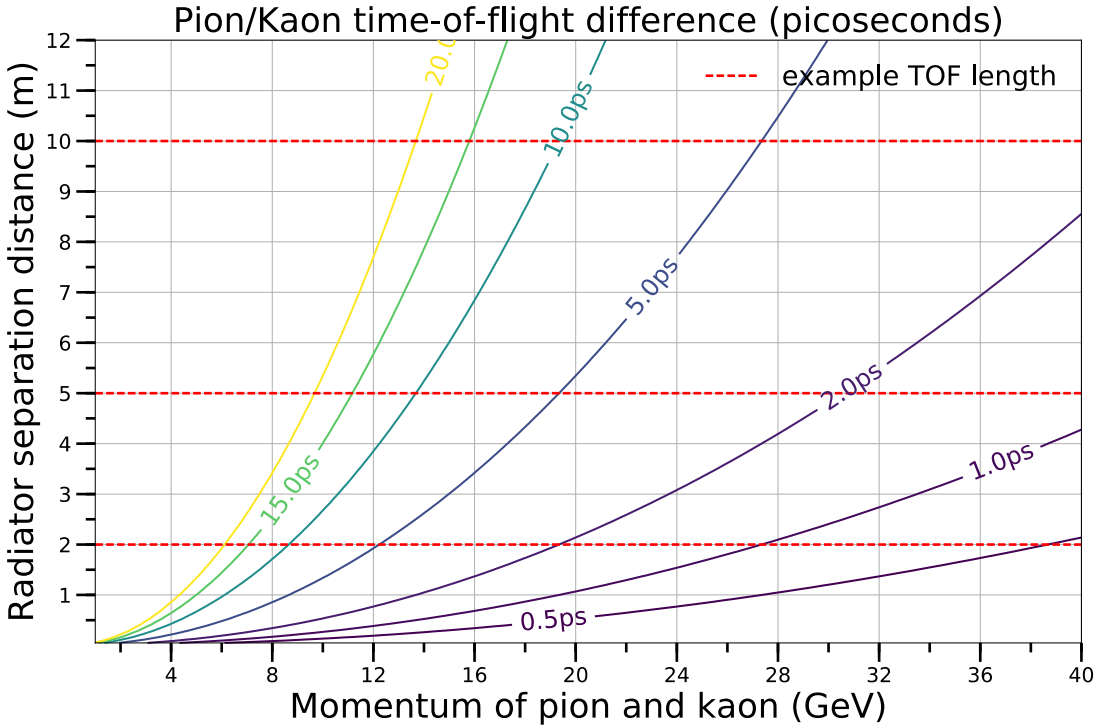
- Current PID options
  - Cherenkov
    - Used by several groups a year, Limited to threshold counting
  - TOF system
    - Rarely used, difficult to set up



Time-of-flight particle ID measurement principle



E. Angelico



Single particle TOF

$$\Delta t = d/\beta$$

$$\Delta t = d\sqrt{1 + \frac{m^2}{p^2}}$$

$$\Delta t = \frac{dE}{p}$$

TOF difference of two particles

$$\tau_{12} = \Delta t_1 - \Delta t_2$$

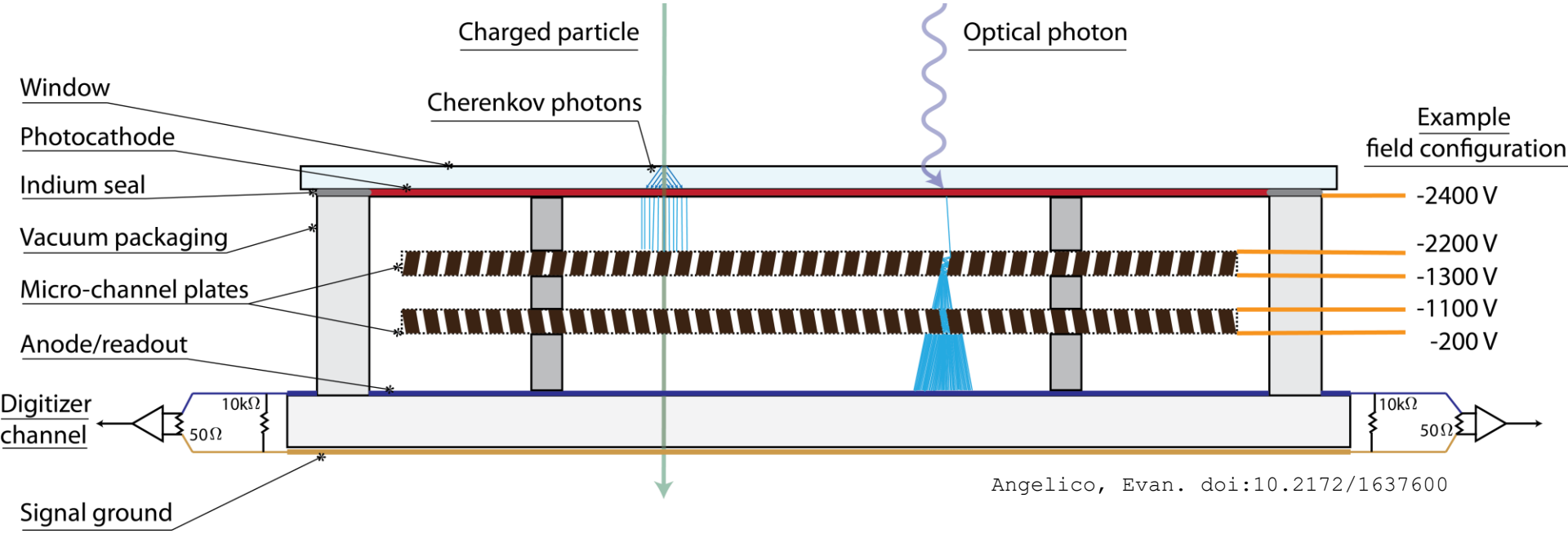
$$= d\left(\sqrt{1 + m_1^2/p_1^2} - \sqrt{1 + m_2^2/p_2^2}\right)$$

$$\tau_{12} \approx \frac{d}{2p^2}(m_1^2 - m_2^2)$$

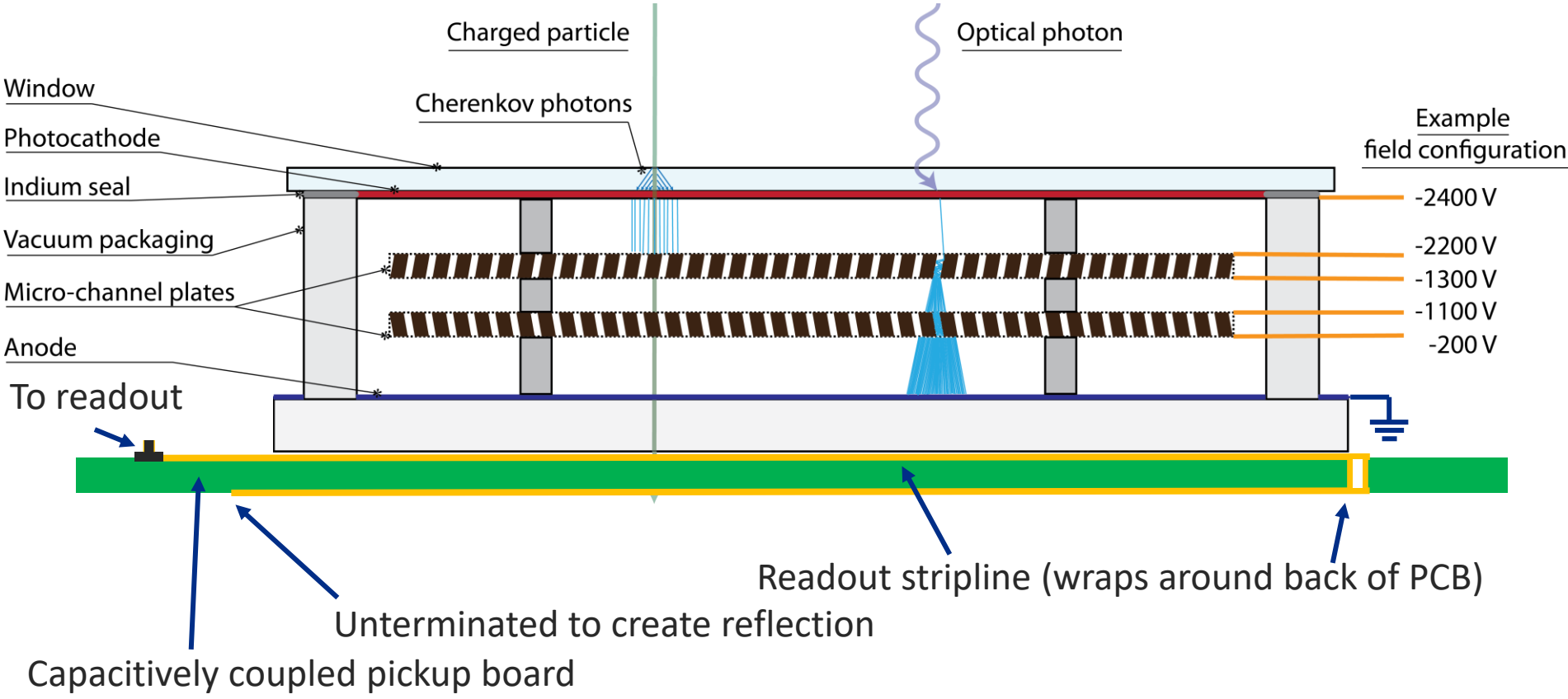
(when relativistic and p1=p2)

LAPPD Photodetection Principle

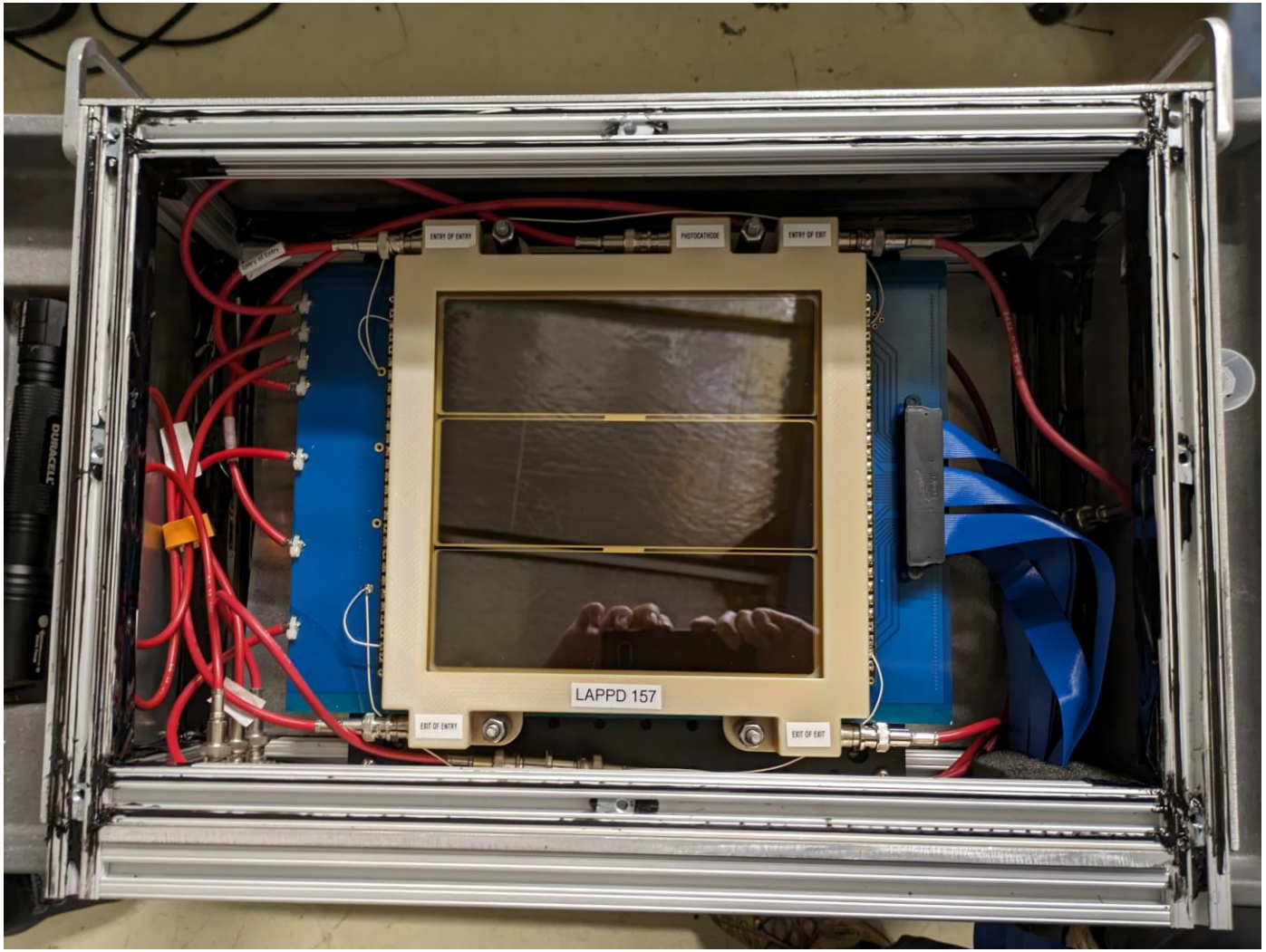
Large Area Picosecond Photodetector



Gen 2 LAPPD single ended stripline readout



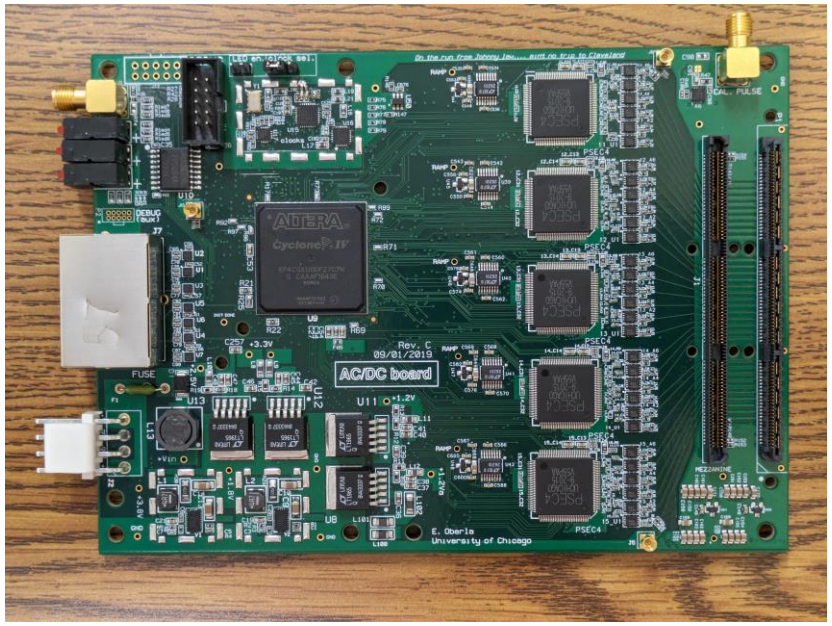
Gen 2 LAPPD in dark box

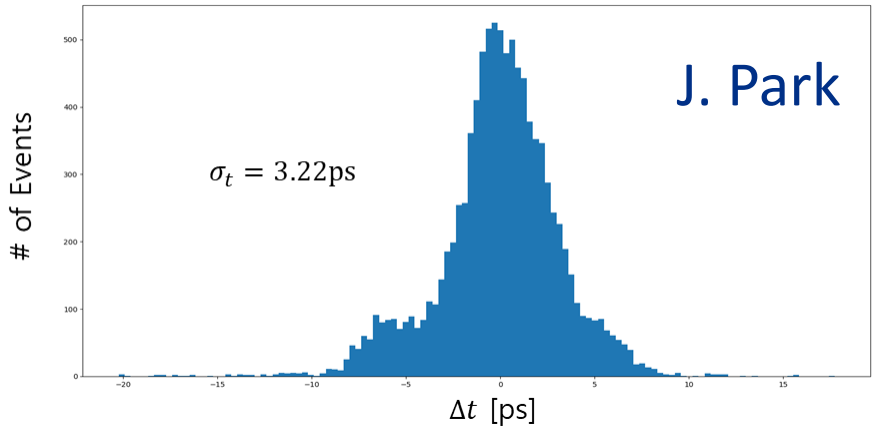


I. Goldberg

Data acquisition

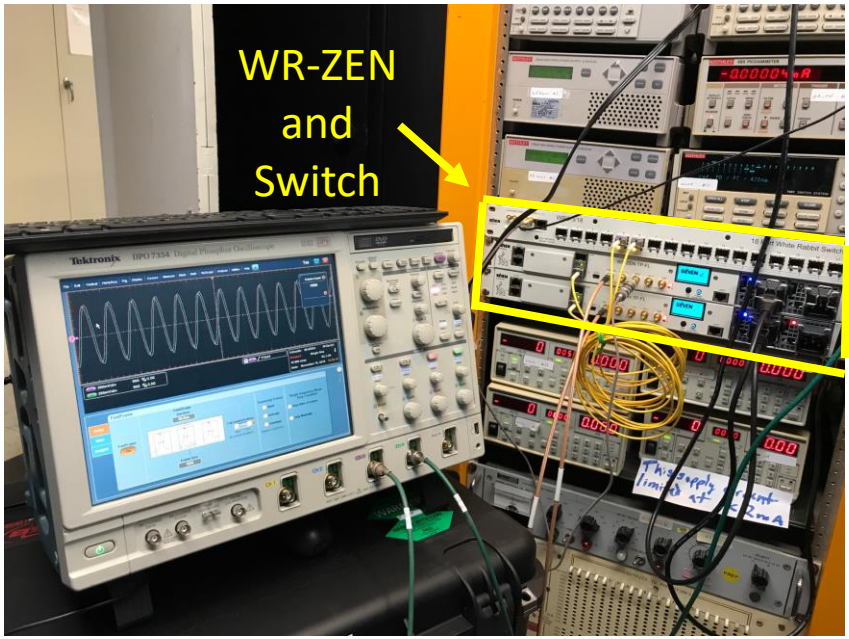
- LAPPD signals digitized with PSEC4 ASIC
  - 10 GSPS, 256 sample, 12 bit ADC
  - Self trigger
  - 6 channels per chip
  - See J. Park's talk and [1]
- ACDC Rev C front end card hosts 5 PSEC4 chips
- ANNIE Central Cards aggregate data from ACDC cards and transmit to DAQ computers
- Integrate with OTSDAQ

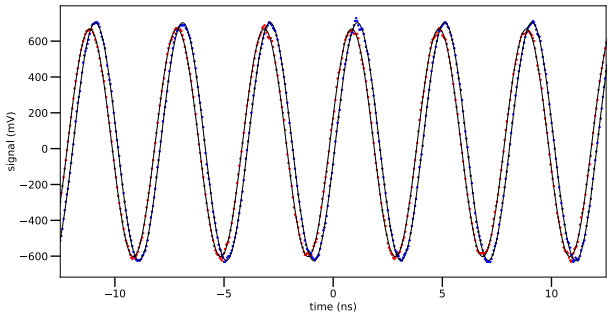


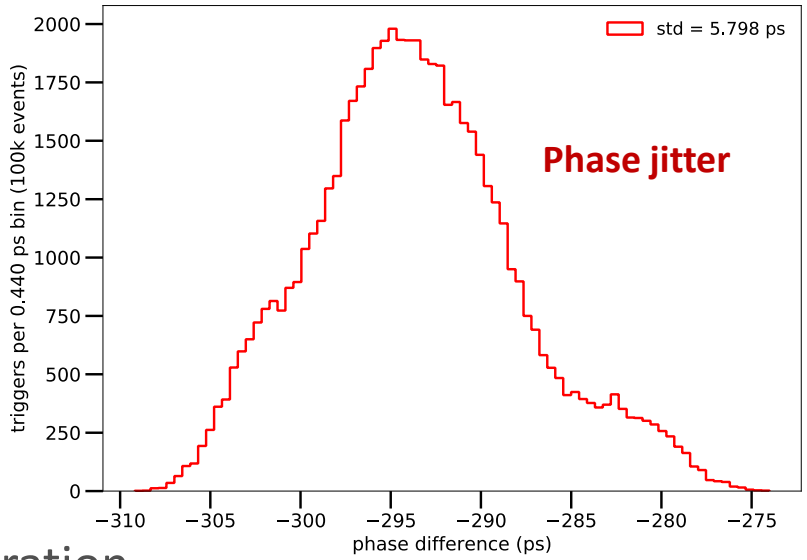


[1] E. Oberla et al. https://doi.org/10.1016/j.nima.2013.09.042

White rabbit (WR) time synchronization





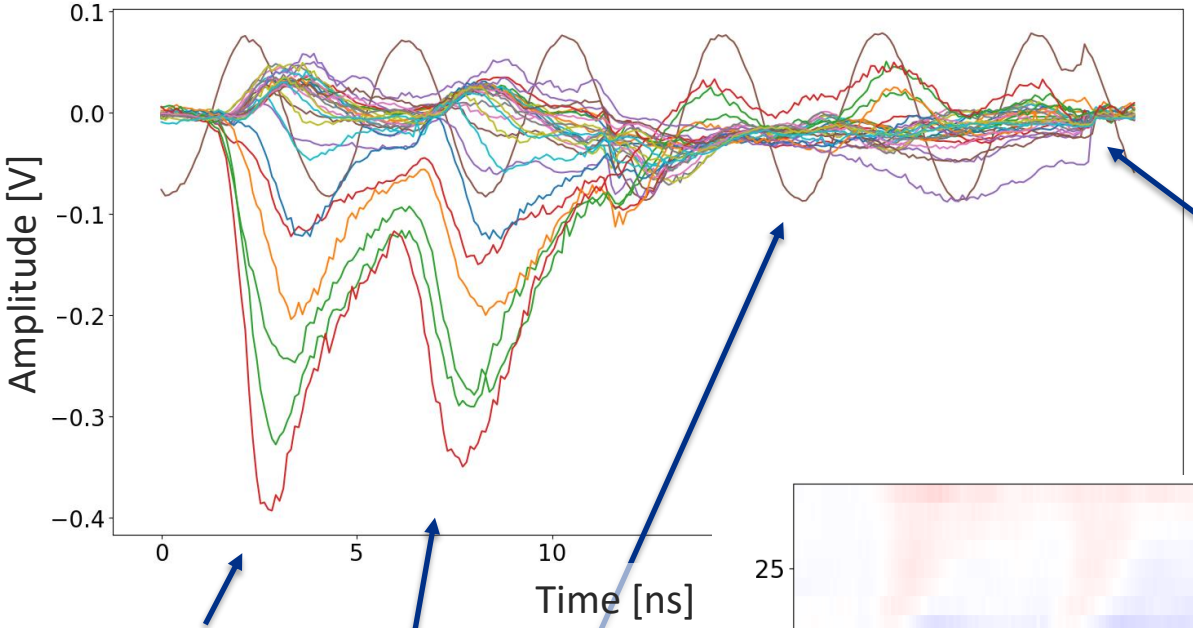


Angelico, Evan. doi:10.2172/1637600

- Worked easily out of the box
- 5-10 ps relative timing at kilometers separation
- Each ACDC receives a 250 MHz sine wave, a 100 MHz sync signal, and 1Hz sync signal from WR system

Measured with Tektronix DPO7354 at 3.5GHz 20GSPS and 10ft cables

Raw gen 2 LAPPD data



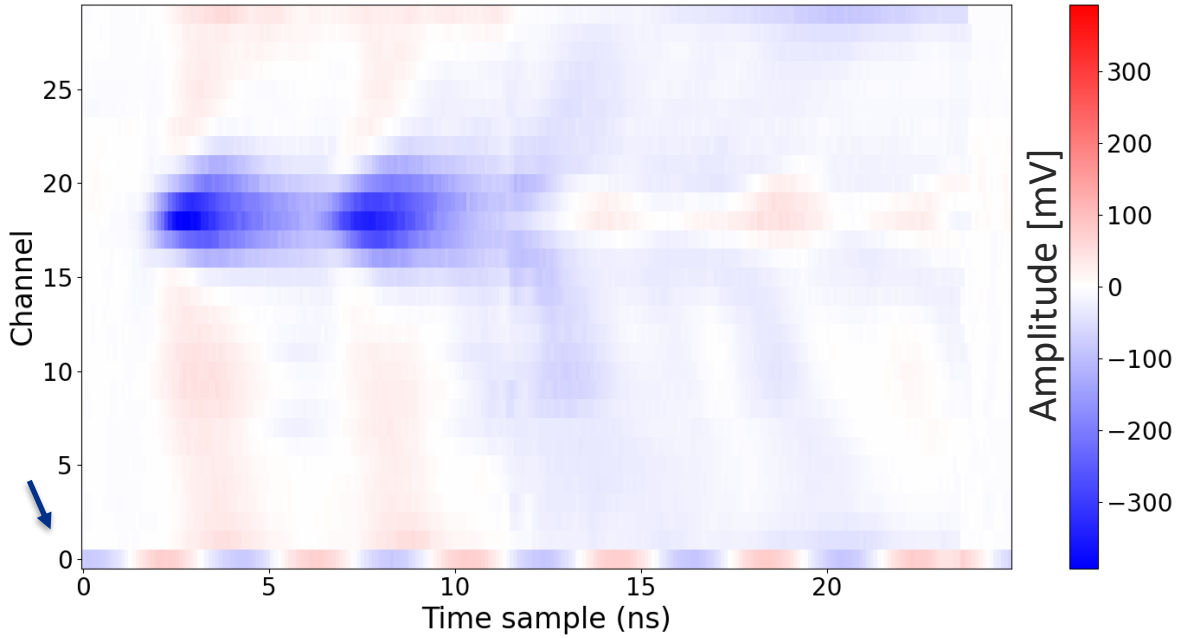
Proton signal in LAPPD 128

Trigger window

Prompt pulse

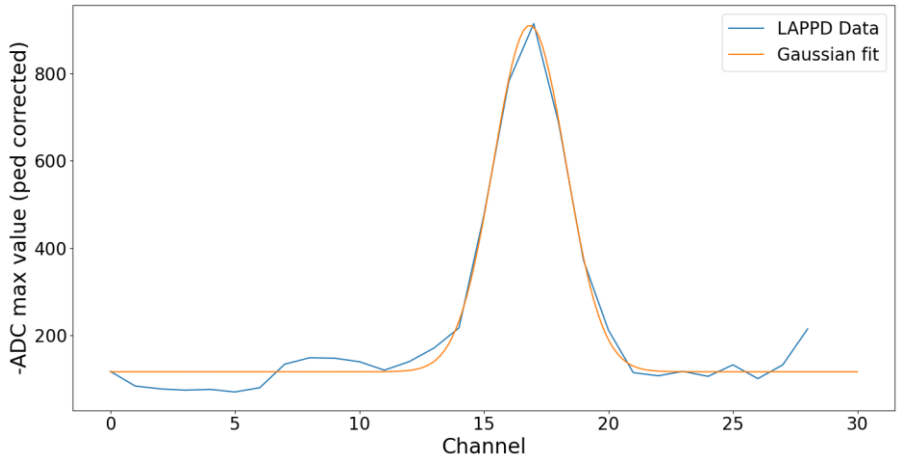
Reflection

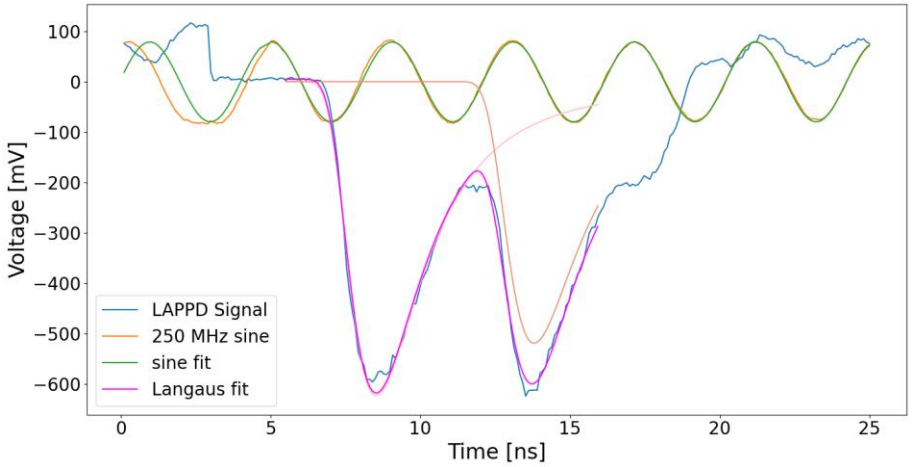
250 MHz timing reference



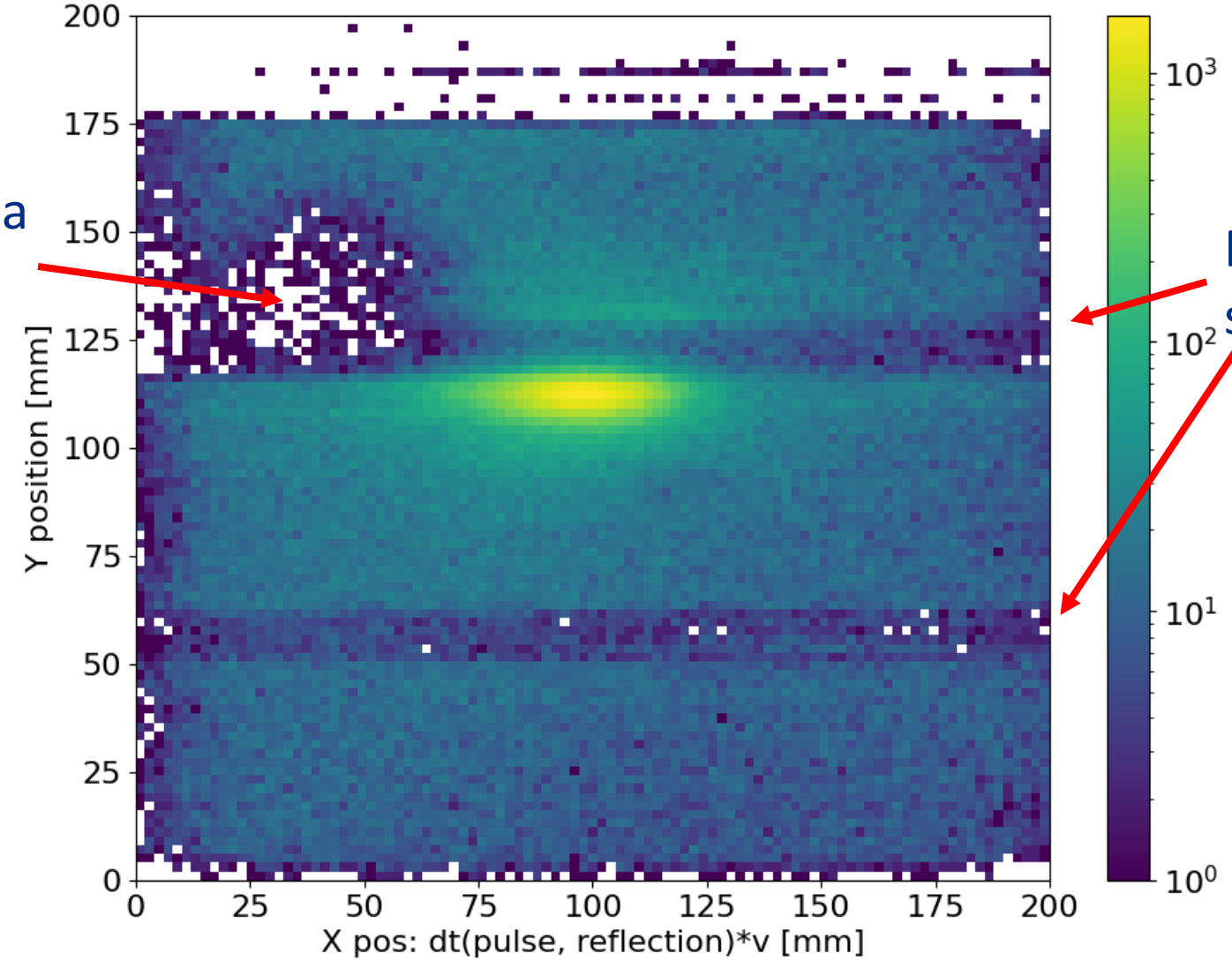
Reconstruction Techniques

- Position transverse to striplines
  - Gaussian fit to max adc measurement for each channel
- Longitudinal position, measure time difference between prompt and reflected peak
  - Method 1: LanGauss fits
  - Method 2: Least squares with shifted waveform (C. Poe)

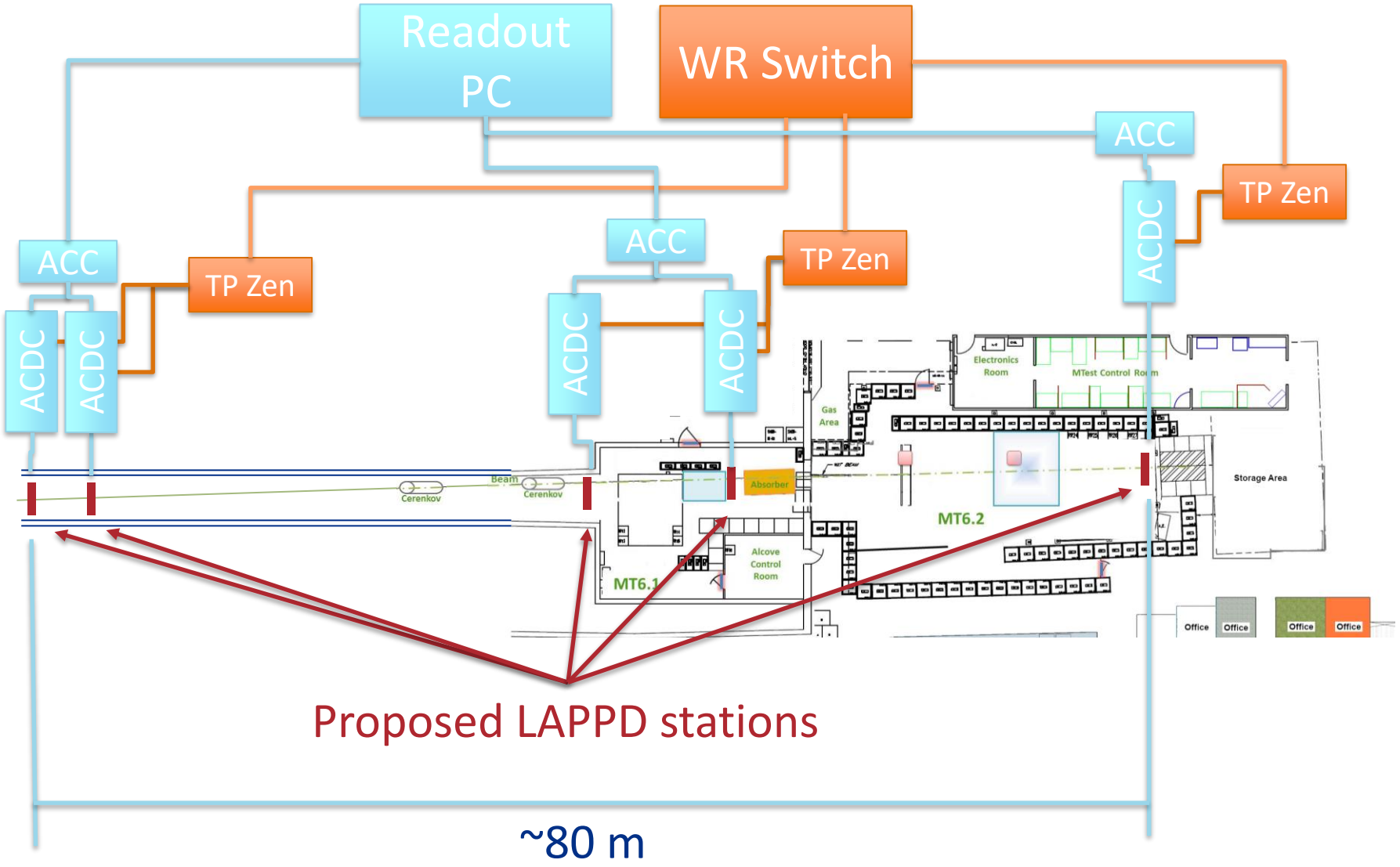




Results from Gen 2 LAPPDs

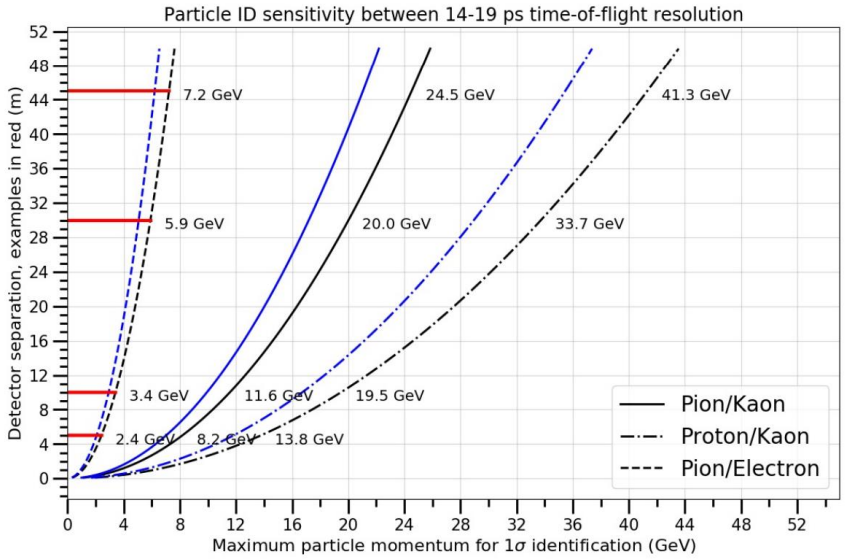


Proposed TOF system layout in MTest



Expected sensitivity

- Projected sensitivity based on calculations and measurements by E. Angelico
- Informs we want at least 40 m separation



Angelico, Evan. doi:10.2172/1637600

	$\sigma_L/\sqrt{N_{\text{pe}}}$ PE spread	σ_{pulse} readout	σ_{WR} Inter station timing	σ_{tof}	Maximum π/K momentum at 5 m / 45 m
Gen 1 LAPPD	55 ps / $\sqrt{30}$	7 ps	5 ps	19 ps	7.0 / 21 GeV/c
Use of fused silica window	55 ps / $\sqrt{200}$	7 ps	5 ps	14 ps	8.2 / 25 GeV/c
Low-jitter WR-ZEN	55 ps / $\sqrt{200}$	7 ps	< 0.5 ps	13 ps	8.5 / 25 GeV/c
10 μm pores and higher cathode voltages	10 ps / $\sqrt{200}$	7 ps	< 0.5 ps	11 ps	9.2 / 28 GeV/c
PSEC4 chip development	10 ps / $\sqrt{200}$	1 ps	< 0.5 ps	1.7 ps	24 / 70 GeV/c

5

Summary

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

- New LAPPD based TOF will provide event-by-event PID for users

- New improvements in LAPPDs and electronics can further improve the reach of this PID system

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

Becoming an ITA or FTBF user

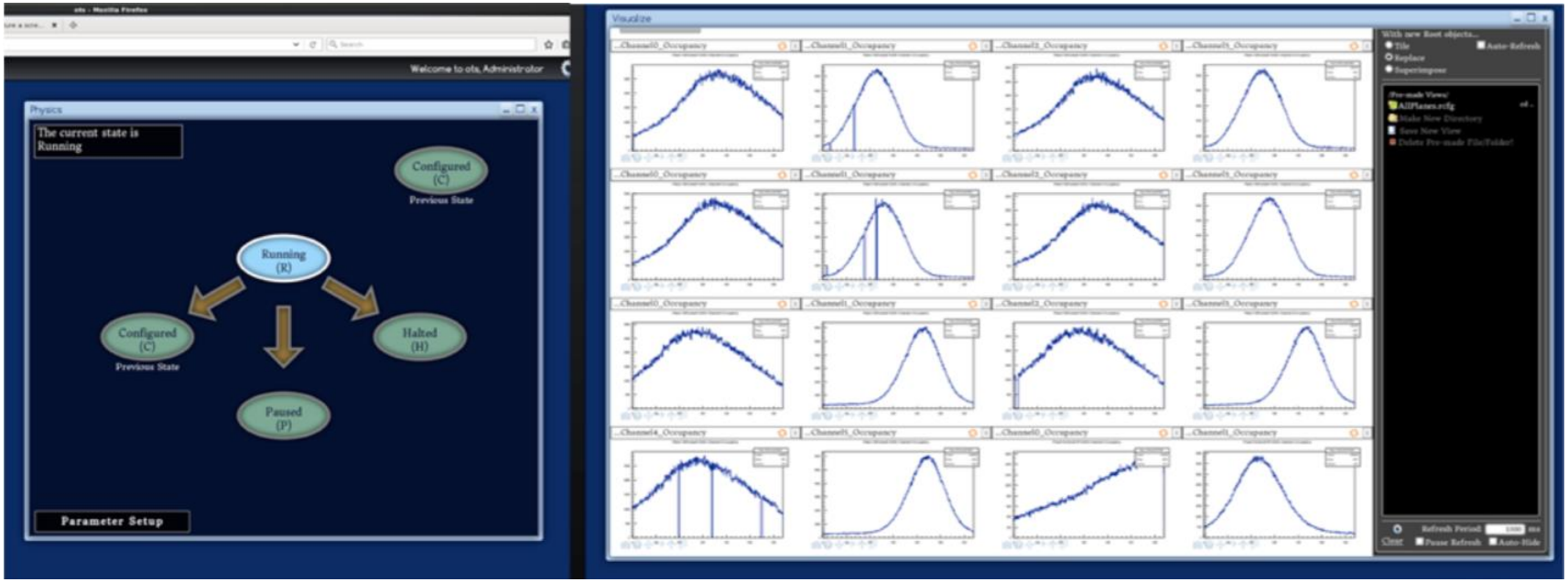
- Talk to the facility about a proposed experiment (ITA) and fill out a Technical Scope of Work
  - Agreement between test beam collaboration and the lab over what resources are used
  - Do you need significant engineering or tech support? Computing support? Will you have enough users to cover your shifts?
  - 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 beam runs open in 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 user requests

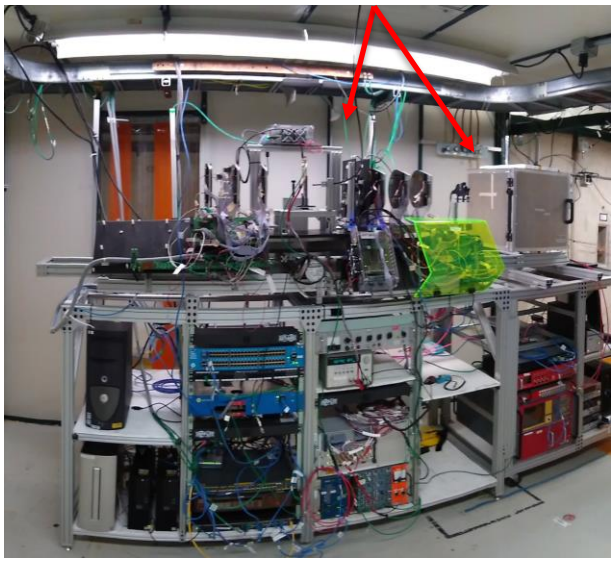
Off-The-Shelf Data Acquisition (OTSDAQ)



- 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

Experiments at MTest

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



MT6.1

MT6.2