Future instrumentation upgrades at the Fermilab Test Beam Facility and Irradiation Test Area

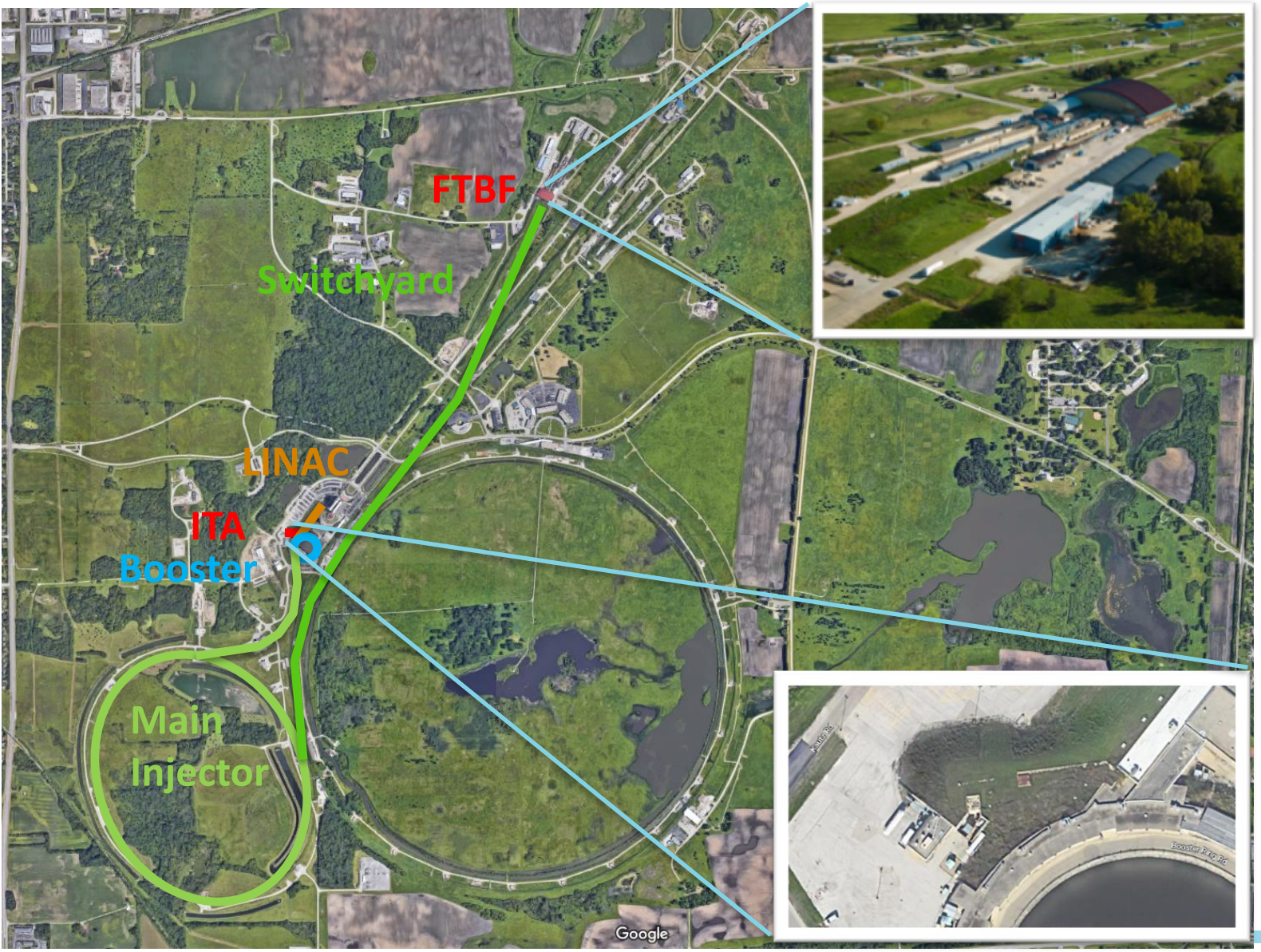
Joe Pastika

BTTB12

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 (400 MeV), high rate (~2.2e15 protons/hr)
- Beam off since July 2023, expect beam in May-July, Normal start for FY25 ~Oct/Nov

Where are FTBF and ITA?

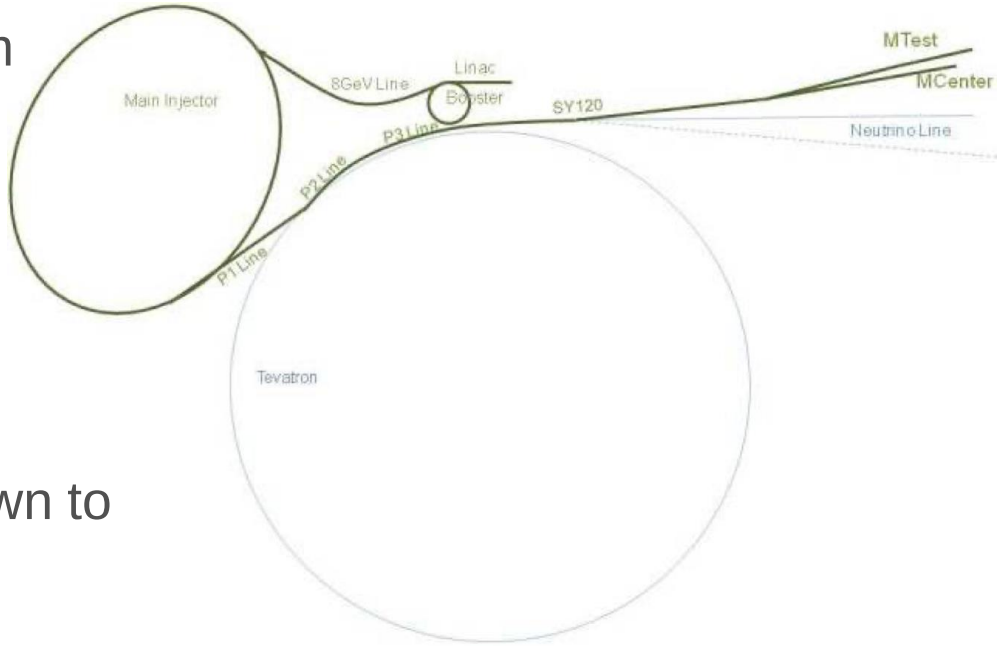


FTBF – Meson Detector Building

ITA – Irradiation Test Area

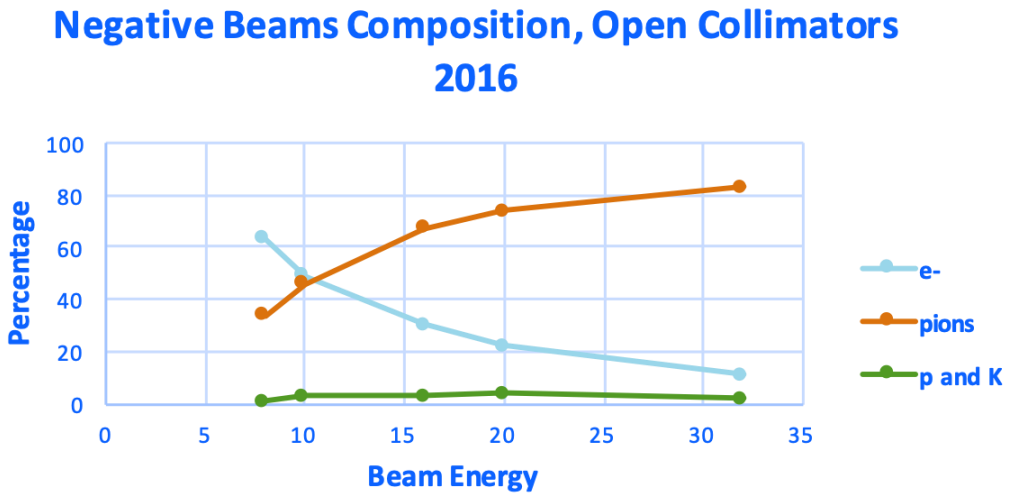
FTBF Beamline Details

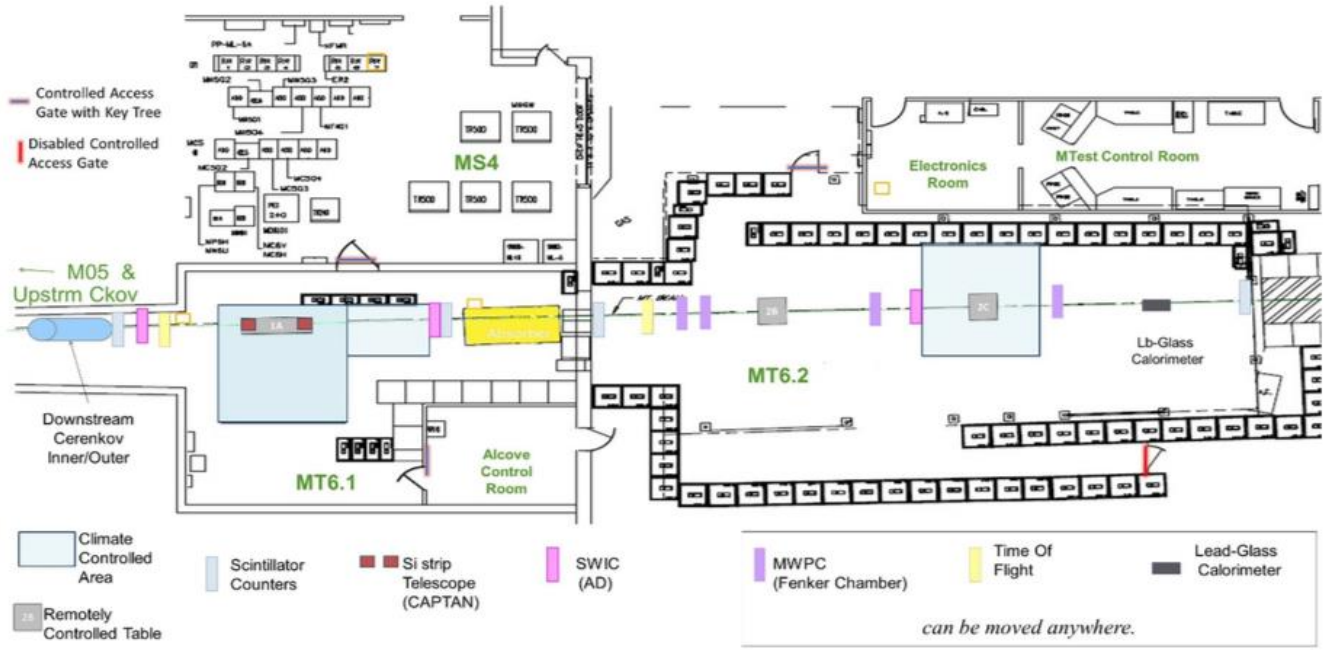
- 4 second beam spill every 60 seconds, available 24/7
- ~1000 to 900,000 particles per spill
- MTest
  - 120 GeV primary protons
  - 1-66 GeV secondary beam
  - ~2cm spot size
  - 1-4 week runs
- MCenter
  - Secondary beam
  - Two tertiary beamlines down to 200 MeV
  - longer term experiments



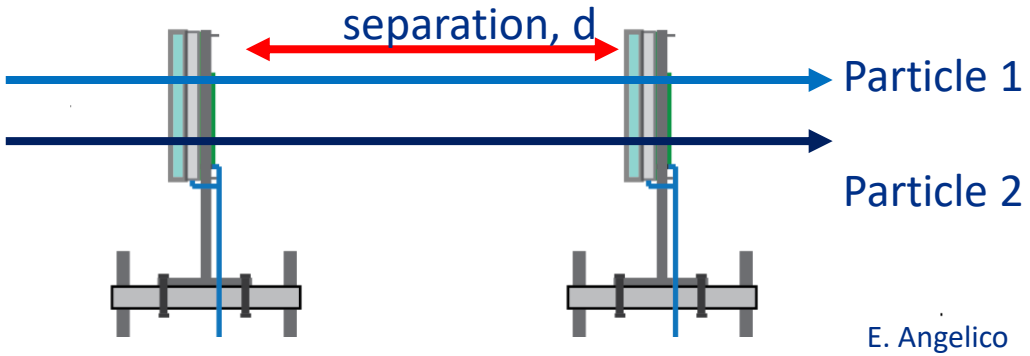
PID Options - MTest

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

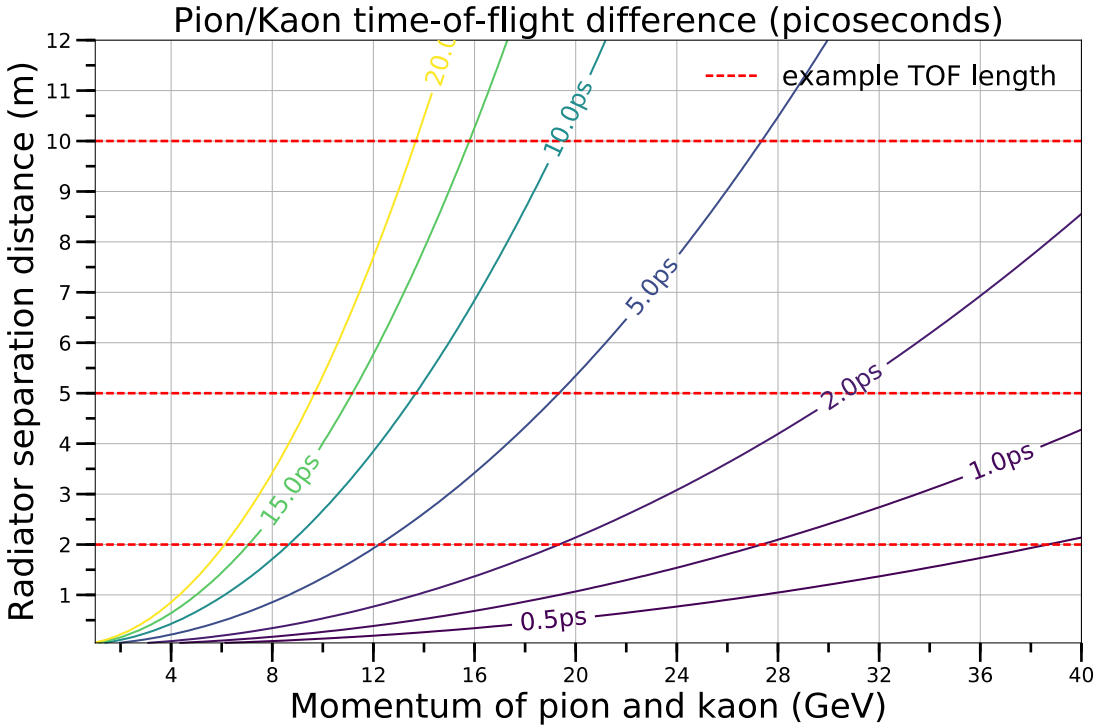




Time-of-flight particle ID measurement principle



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

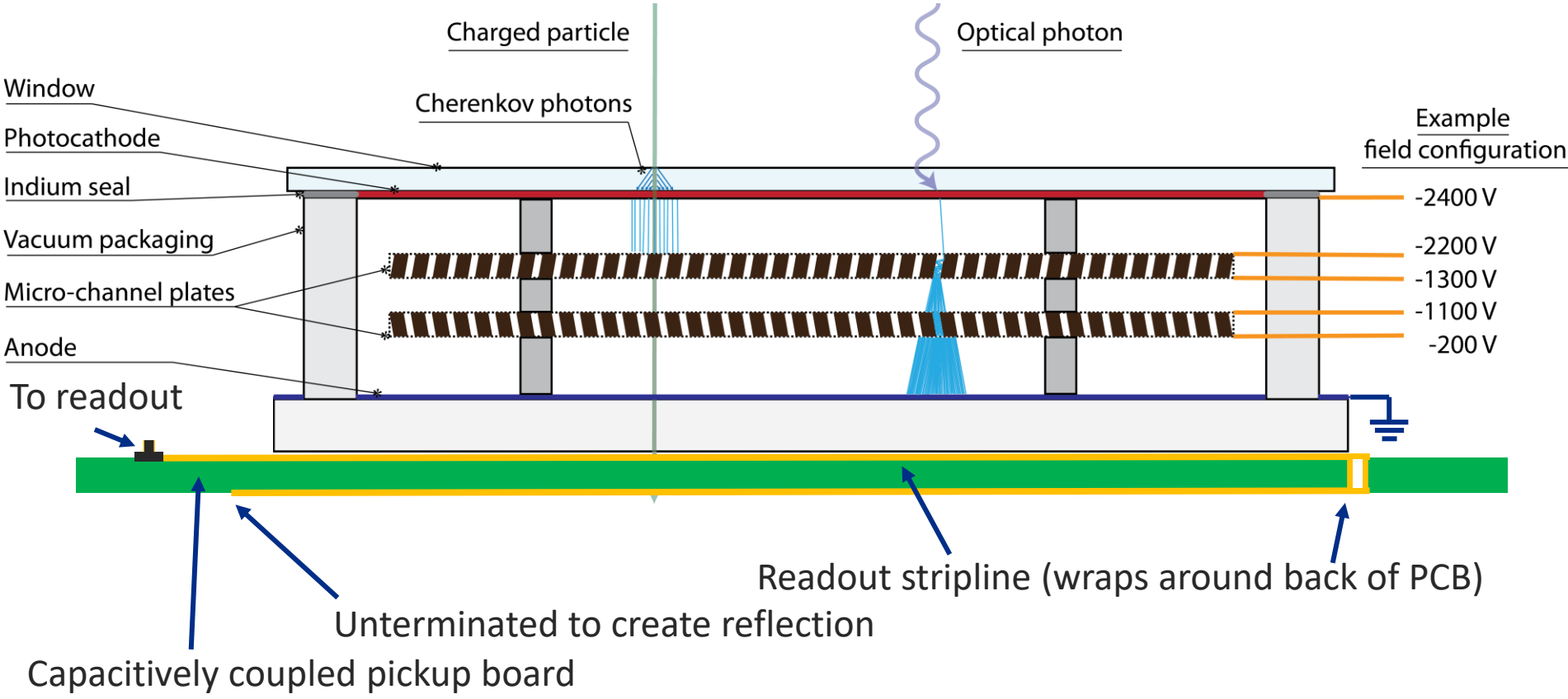
$$\tau_{12} = \Delta t_1 - \Delta t_2$$

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

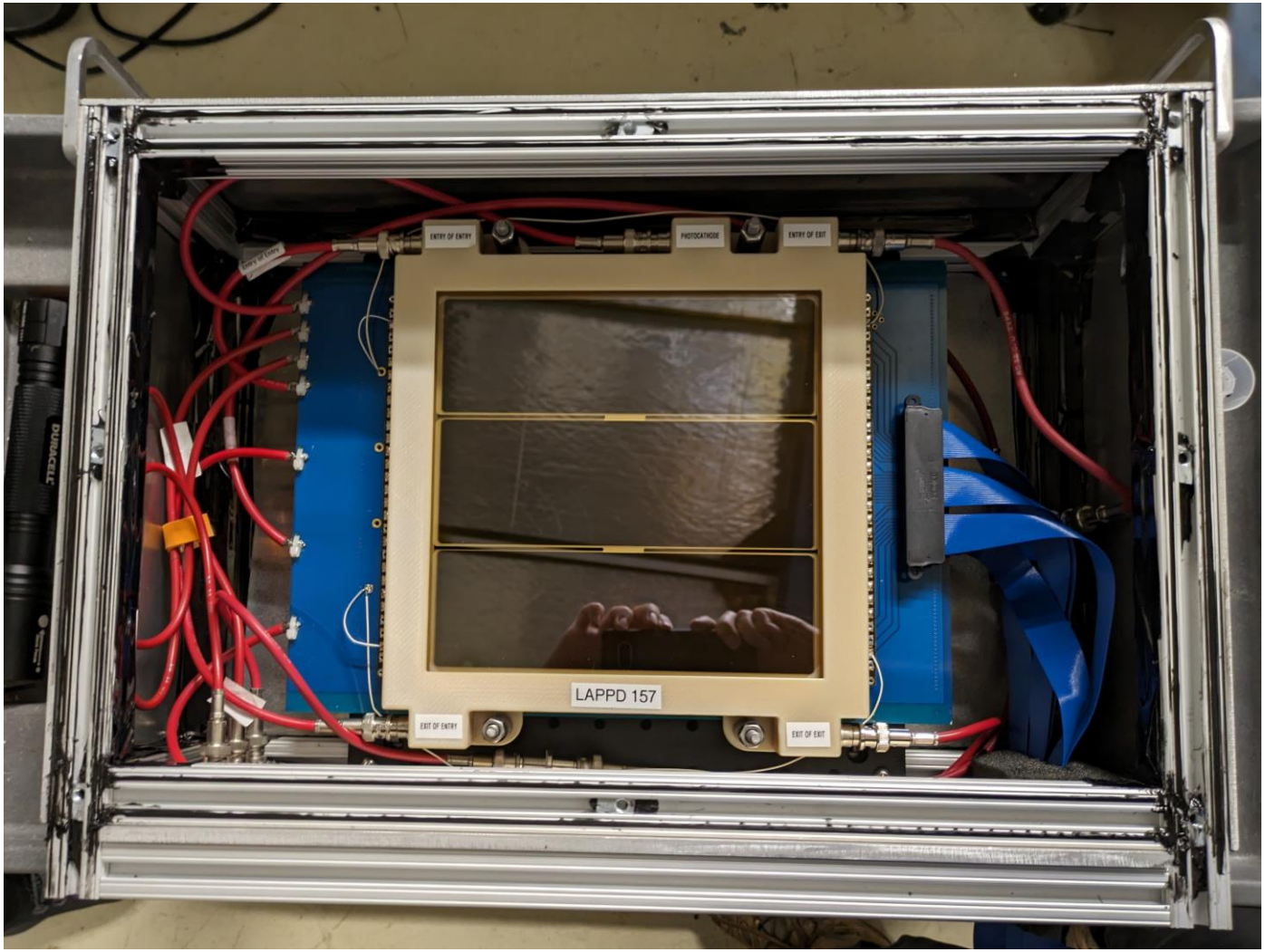
$$\tau_{12} \approx \frac{d}{2p^2}(m_1^2 - m_2^2)$$

(when relativistic and p1=p2)

Gen 2 LAPPD single ended stripline readout

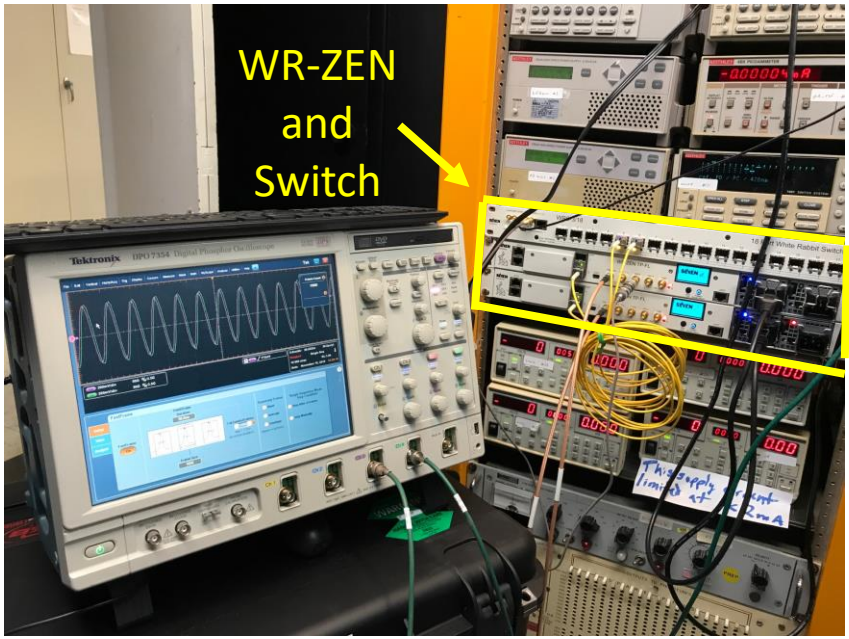


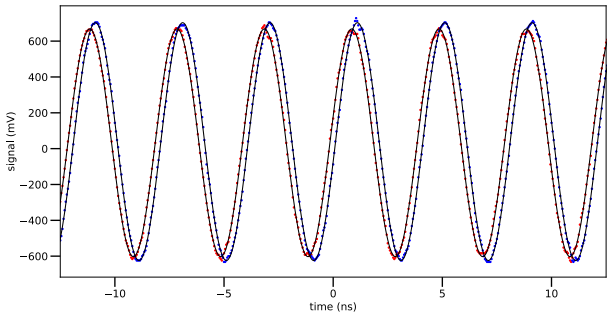
Gen 2 LAPPD in dark box

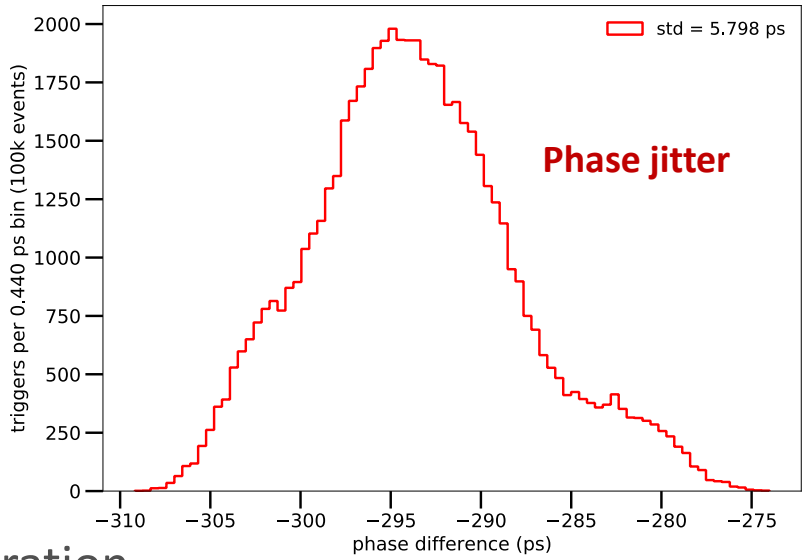


I. Goldberg

White rabbit (WR) time synchronization





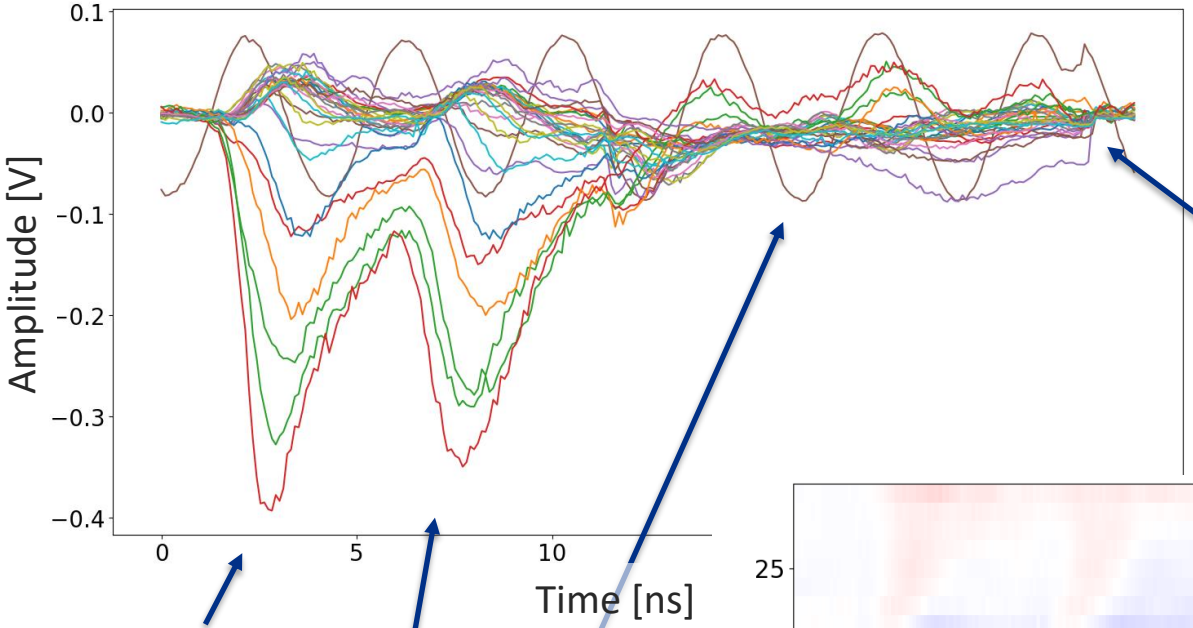


Angelico, Evan. doi:10.2172/1637600

- 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



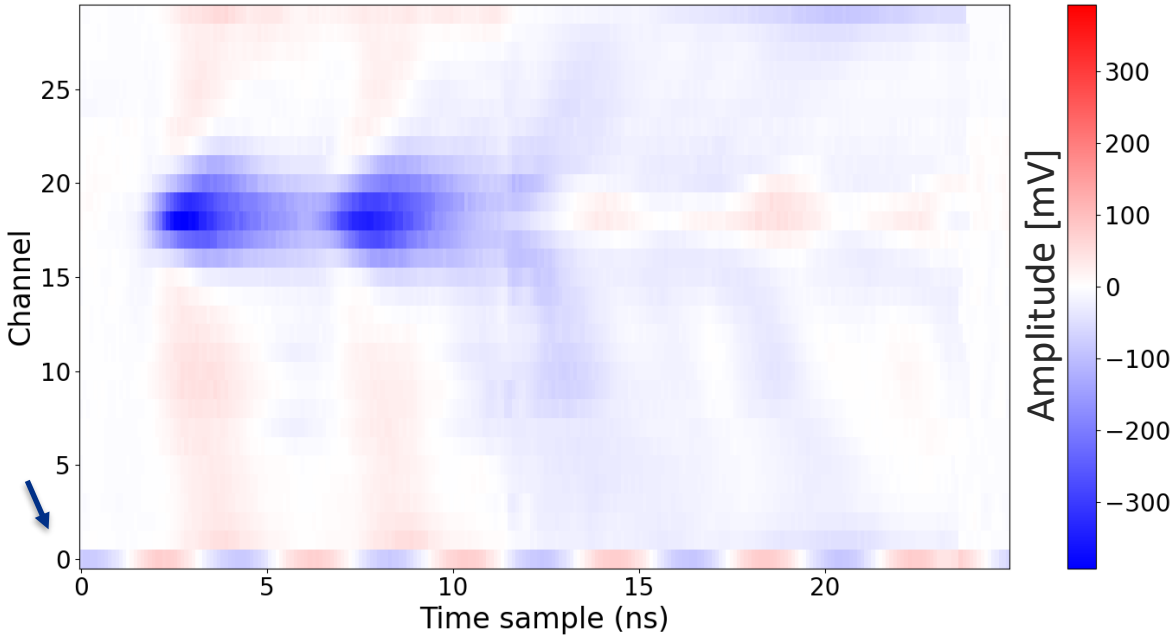
Proton signal in LAPPD 128

Trigger window

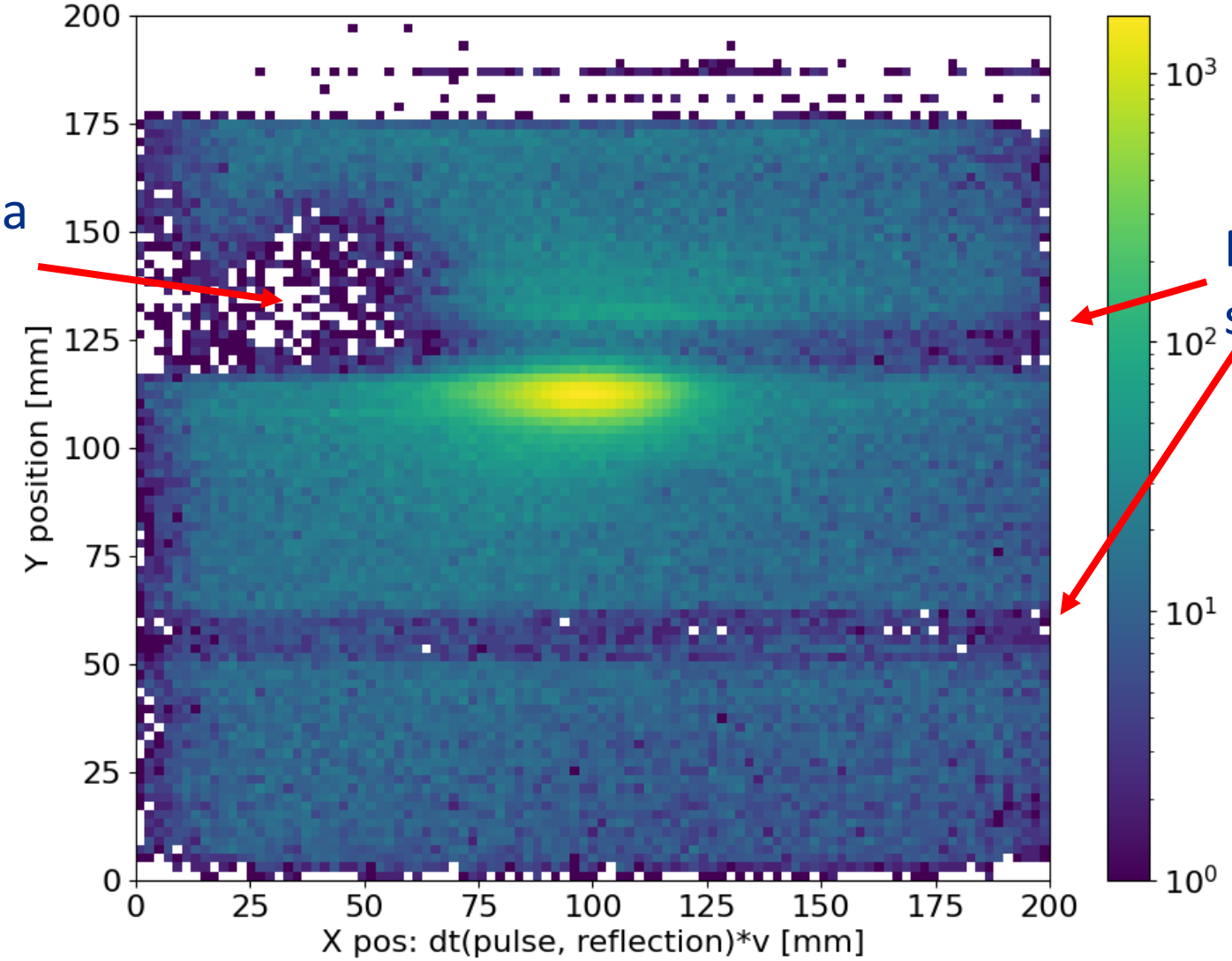
Prompt pulse

Reflection

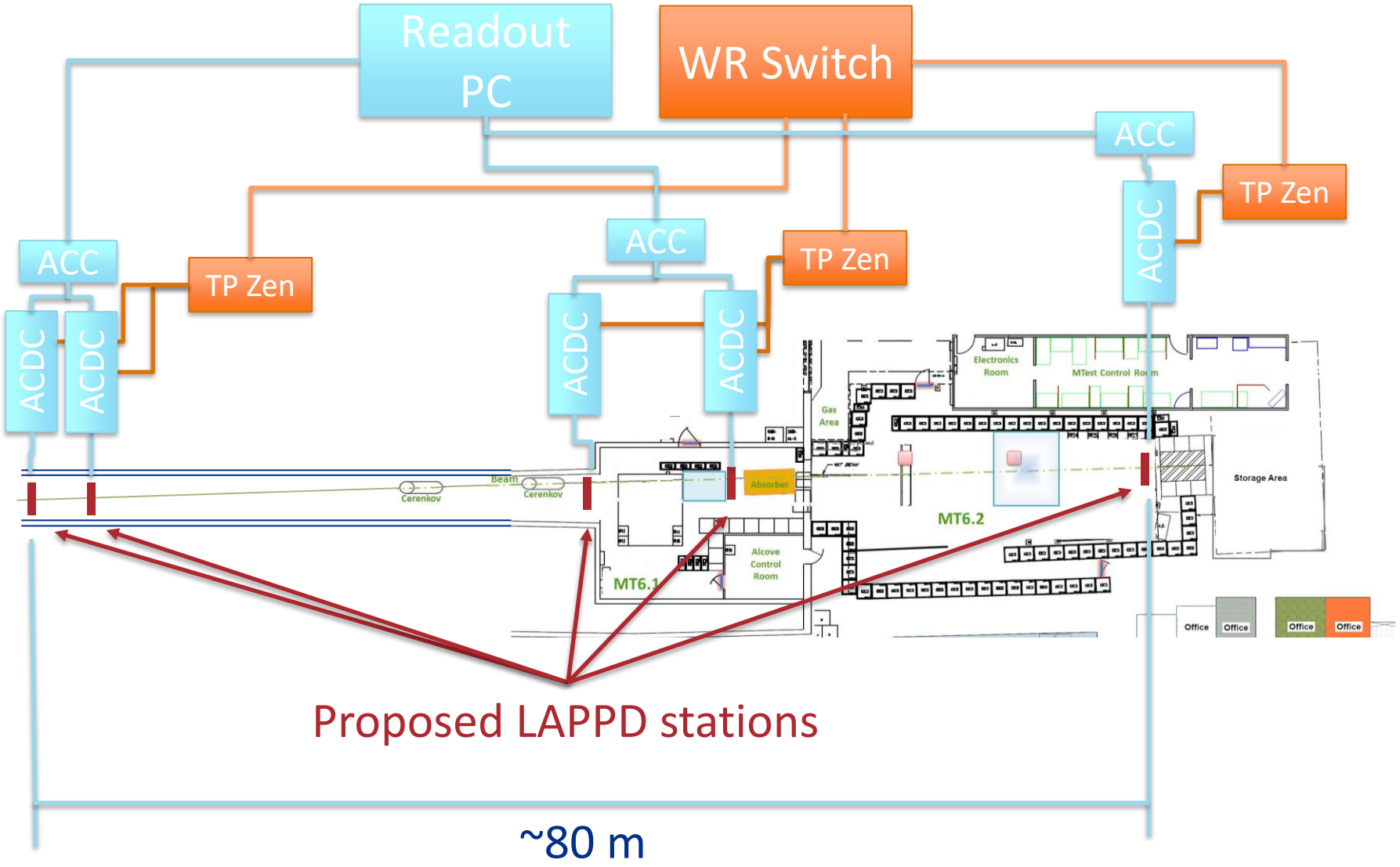
250 MHz timing reference



Results from Gen 2 LAPPDs

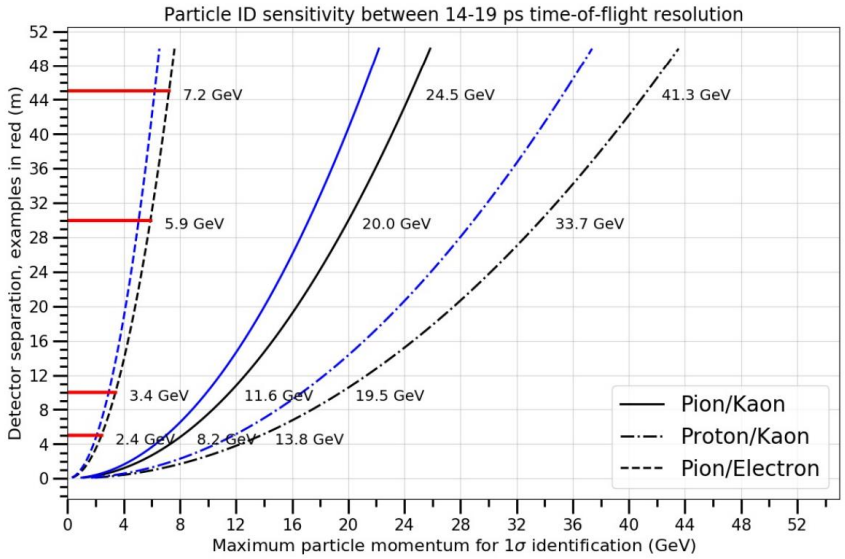


Proposed TOF system layout in MTest



Expected sensitivity

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



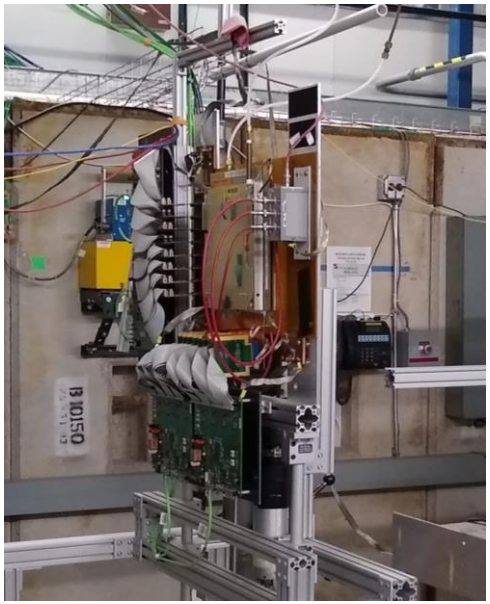
Angelico, Evan. doi:10.2172/1637600

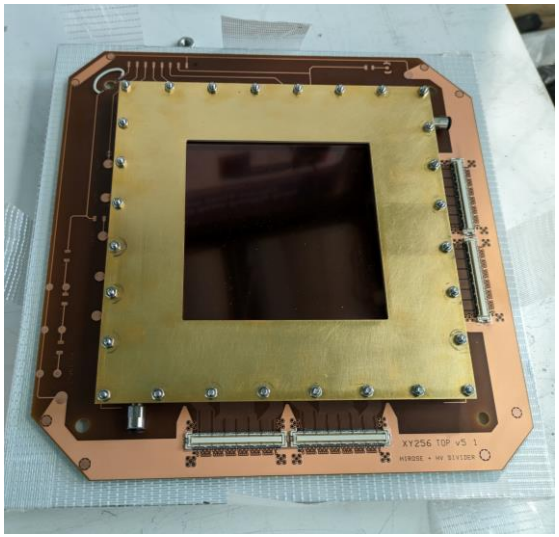
	$\sigma_L/\sqrt{N_{\text{pe}}}$ PE spread	σ_{pulse} readout	σ_{WR} Inter station timing	σ_{tof}	Maximum π/K momentum at 5 m / 45 m
Gen 1 LAPPD	55 ps / $\sqrt{30}$	7 ps	5 ps	19 ps	7.0 / 21 GeV/c
Use of fused silica window	55 ps / $\sqrt{200}$	7 ps	5 ps	14 ps	8.2 / 25 GeV/c
Low-jitter WR-ZEN	55 ps / $\sqrt{200}$	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

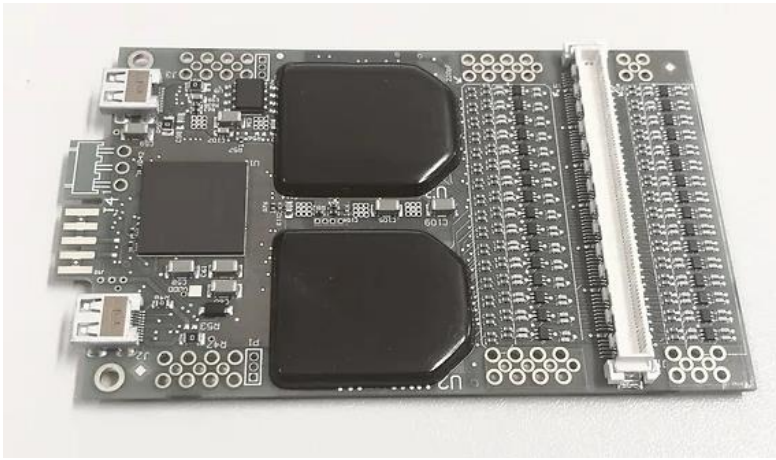
5

Tracking upgrade

- Replacing Fenker chambers use for particle tracking in MT6.2 with CERN GEM chambers
- GEM chambers are in hand at FTBF
- Will use Scalable Readout System developed by RD51 collaboration (system ordered, waiting on delivery)







Facility gas mixing system

- Developed in collaboration with Northern Illinois University
- Designed to mix up to 4 input gases
  - Large flexibility in input gas types and flow rates
  - Compatible with “traditional” and “eco” RPC gasses
- Available for use at FTBF

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 ~7μs (~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

Facility Infrastructure: Installing Samples

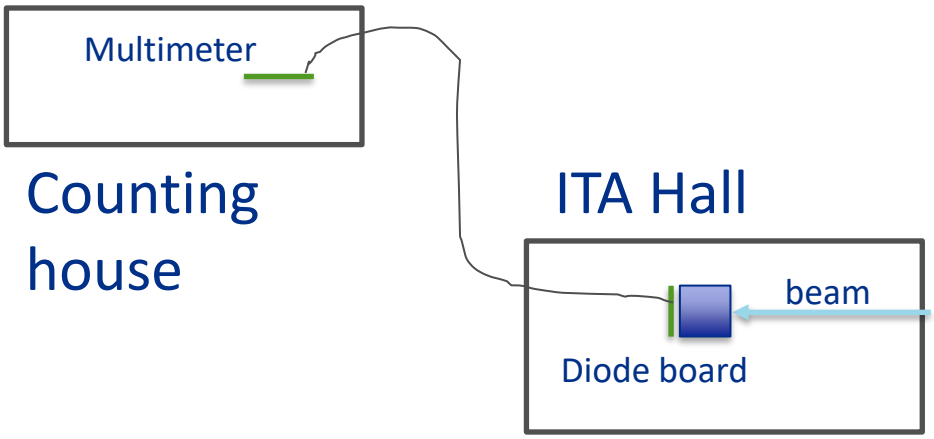
- Card cage available for sample installation
- Cave has interior dimensions 3’x3’x9’ with an additional 3’ depth on “front porch”
- Front porch supports x-y motion table, rail system to move samples into the cave.

Photo courtesy Abhishek Bakshi

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

ITA Beam Profile Monitor

- We are currently working on more advanced beam profile monitoring for ITA.
- Make use of silicon diodes to monitor beam profile
  - TID in silicon damages diodes causing leakage current in diodes to increase
  - Monitor leakage current in diodes to measure total does in diode
- Tested design with basic readout using multimeter
  - Successful proof of concept design
  - Multimeter too slow when reading out 60 diodes



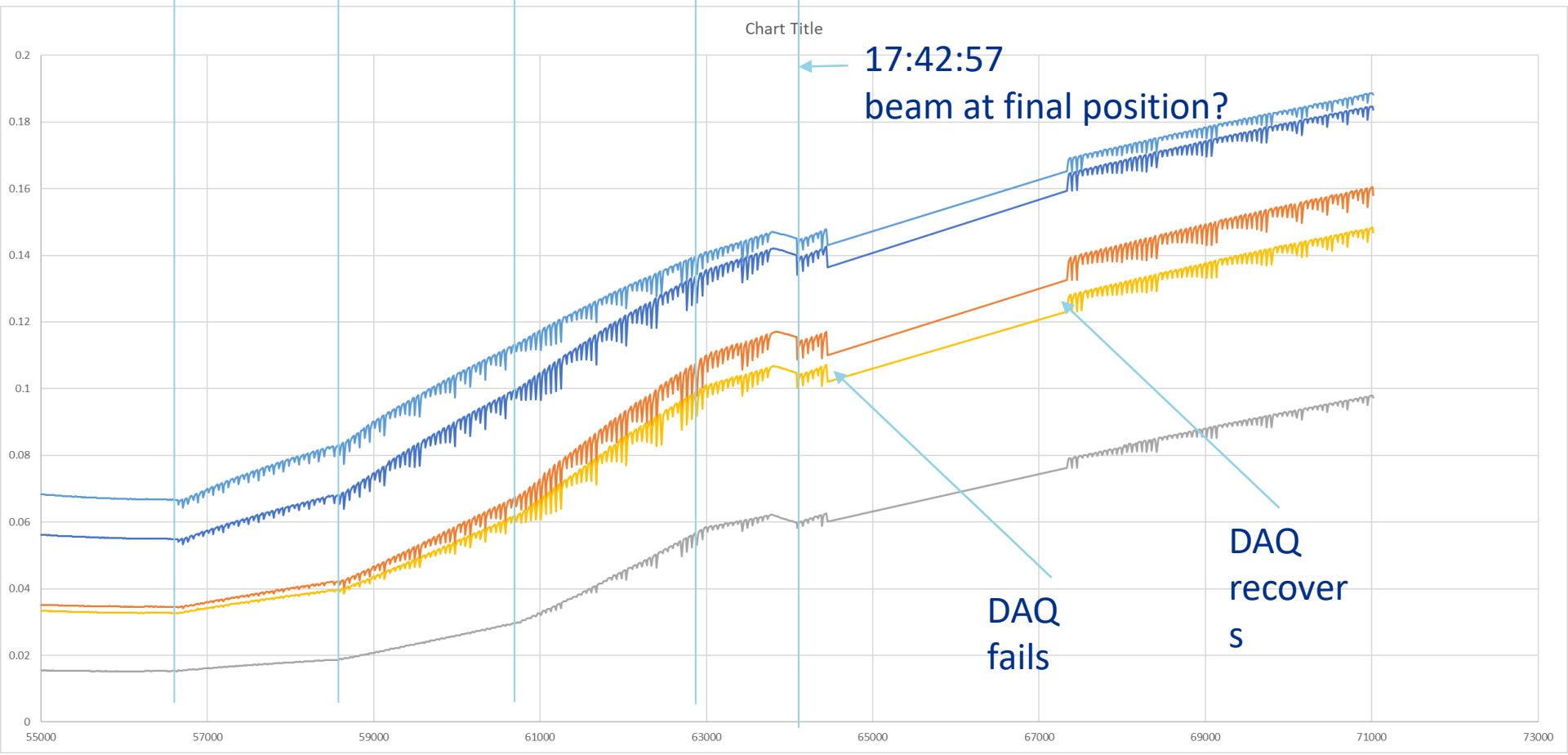
ITA BPM Proof of Conceot

15:44:13 beam starts

16:17:23 Move 1

16:52:29 Move 2

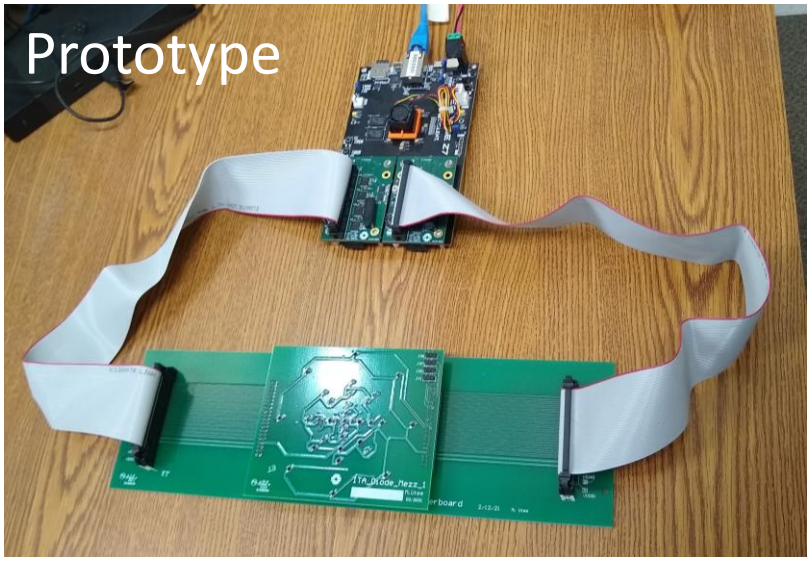
17:31:15 Move 3



Seconds since 15:00
Apr 6

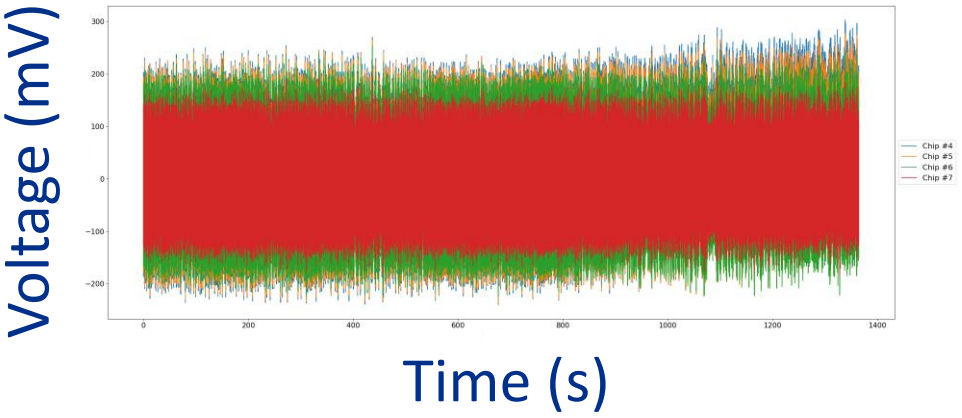
ITA BPM design

- We designed a dedicated DAQ board to digitize the current from 64 diodes at 100 kHz
  - Based on commercial ADC (LTC2333) and Eclypse-Z7 FPGA board
  - Use additional ADC for temperature readout of board in ITA hall

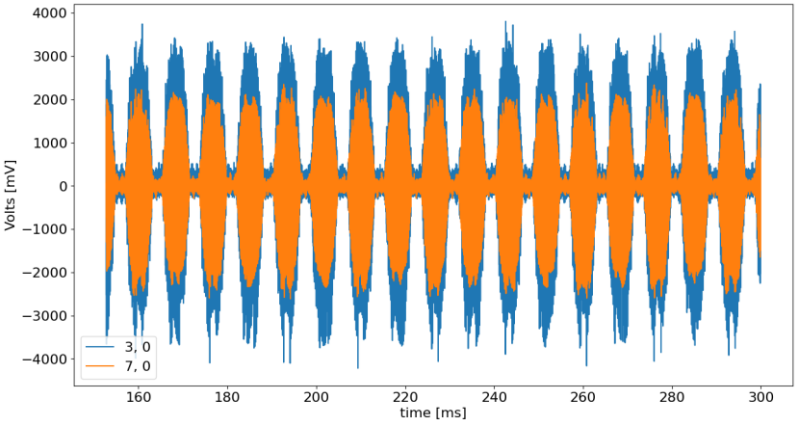


ITA BPM Data

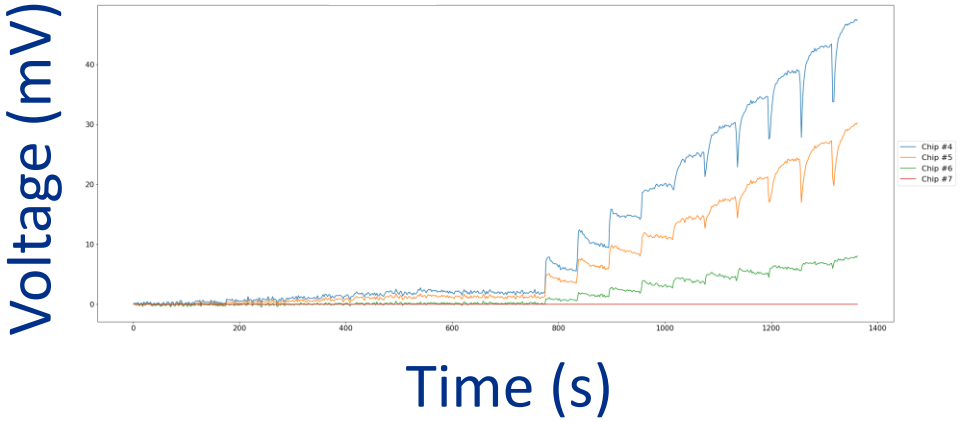
Averaging only

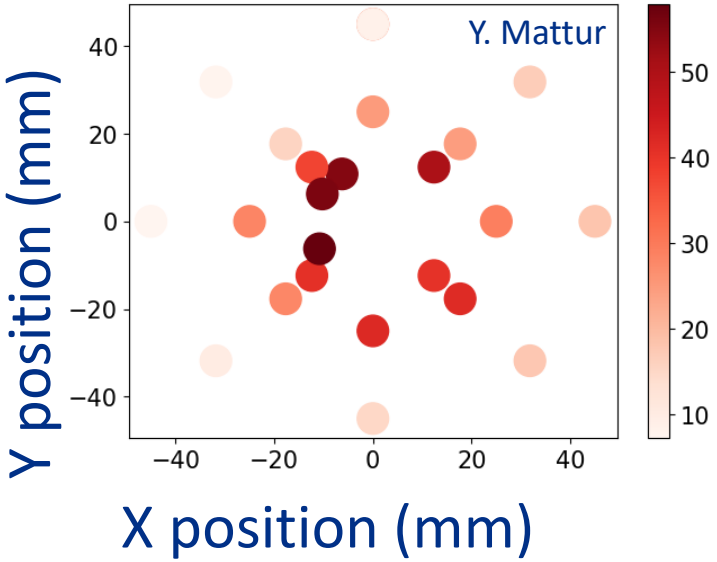


Raw data



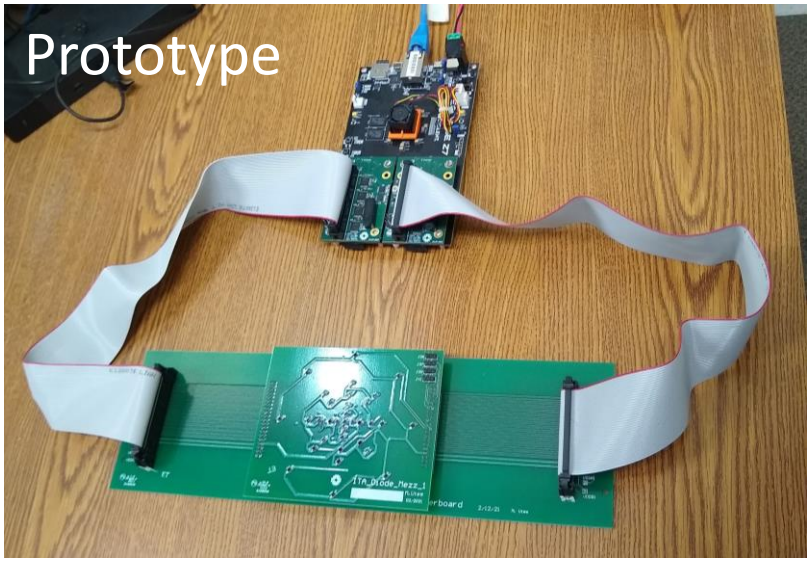
Full filtering & BG subtraction

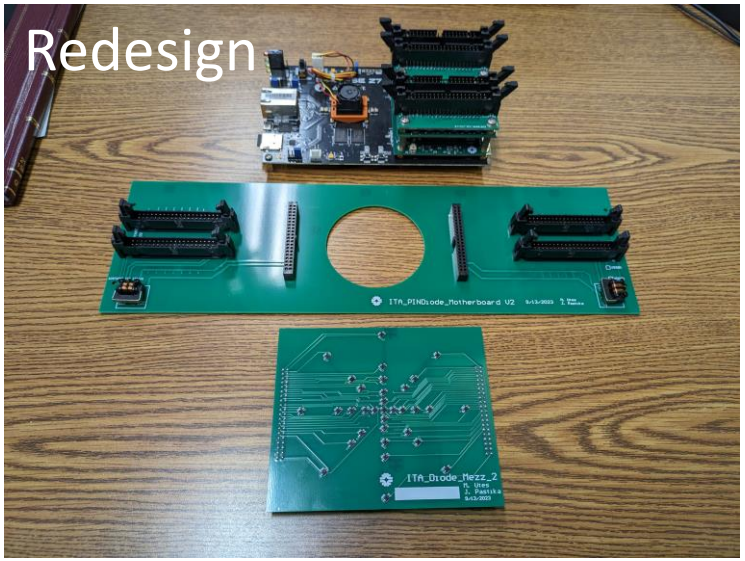




ITA BPM design

- ADC Board was redesigned to do differential measurements
  - Same ADC chip (but used as differential instead of single ended) and Zynq board
  - Added additional filtering against differential noise
  - Added low pass filtering to further reduce noise
  - Shows much better performance on bench, waiting on test in beam





Future test beam facility proposal

- 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
  - Collocate test beam and irradiation facilities
  - 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
  - Dedicated infrastructure for control rooms, experimental staging, facility infrastructure
  - Room for small medium/long term experiments
  - Snowmass white paper

P5 on US test facilities

6.3

Detector Instrumentation

In order to enable groundbreaking detector innovation and US leadership in this field, we need to invest in a coherent set of modernized facilities with enhanced capabilities. These include test beam and irradiation facilities with beam properties and intensities appropriate for future experimental demands, low-background and underground facilities, cleanroom space, access to nano-fabrication facilities, and microelectronics foundries.

6.6.2 – Fermilab Accelerator Complex

Area Recommendation 12: Form a dedicated task force, to be led by Fermilab with broad community membership. This task force is to be charged with defining a roadmap for upgrade efforts and delivering a strategic 20-year plan for the Fermilab accelerator complex within the next five years for consideration (Recommendation 6). Direct task force funding of up to $10M should be provided.

https://www.usparticlephysics.org/

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 modern instrumentation being installed in improve facility infrastructure

- New beam profile monitor has been developed to ITA

- 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

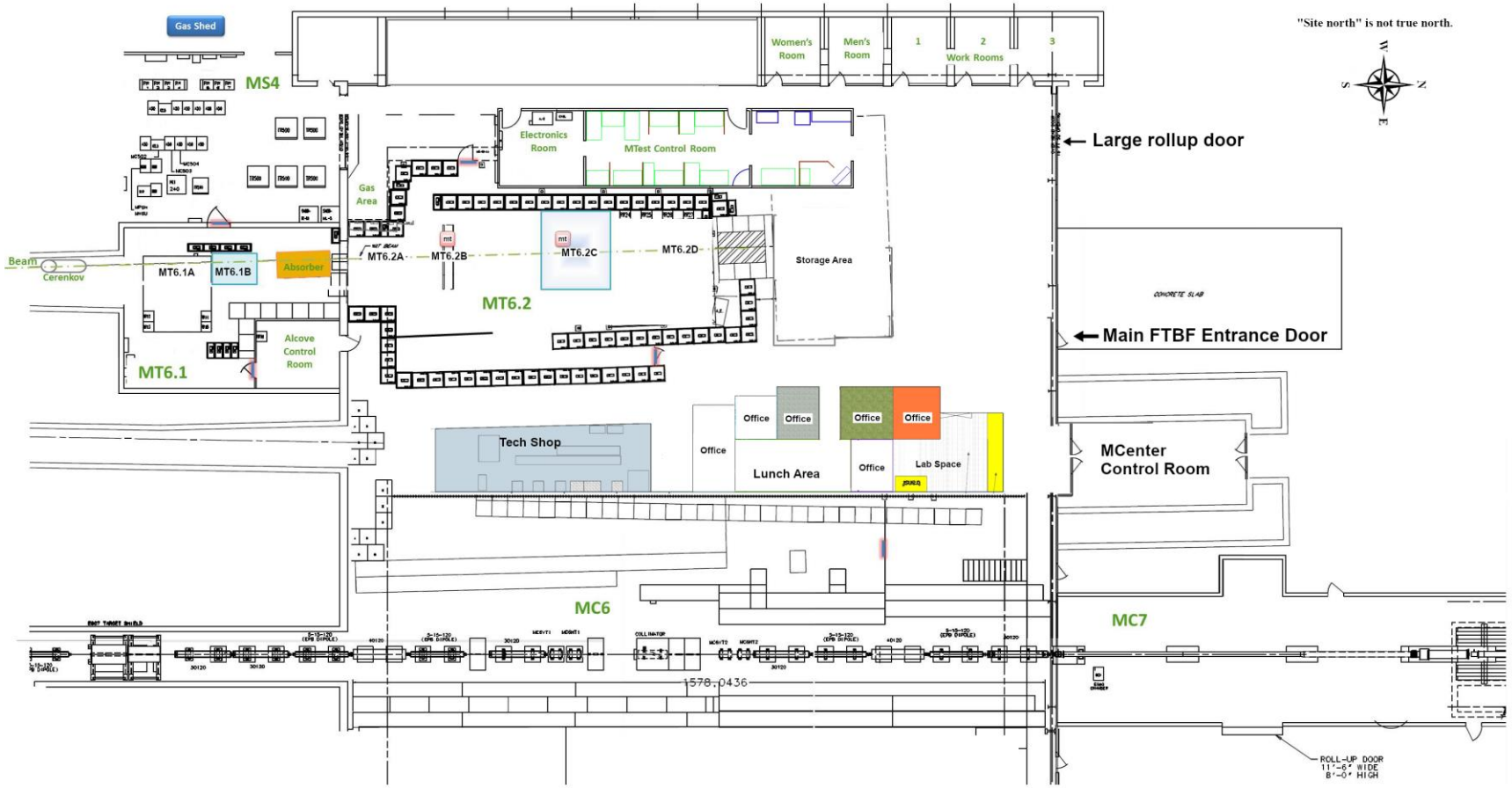
- TSW information can be found here: http://programplanning.fnal.gov/tsw_orc/
  - Email us: rominsky@fnal.gov (Mandy), edniner@fnal.gov (Evan), pastika@fnal.gov (Joe)
  - Approvals typically take 4-6 weeks, depends on needs

- 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

Facility Layout

- MTest and MCenter beamline enclosures



Beam Performance – MTest

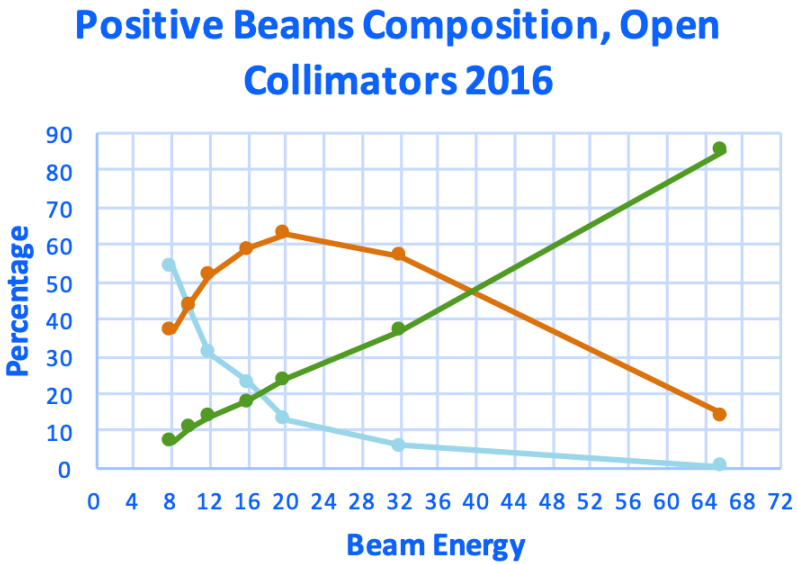
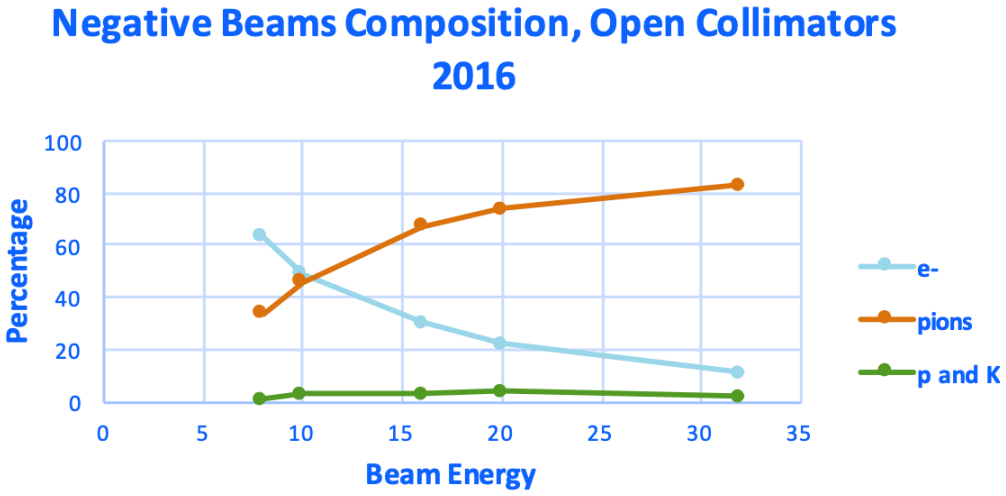


Table with energies, beam spread, percentages:
http://ftbf.fnal.gov/mtest-beam-details-2/

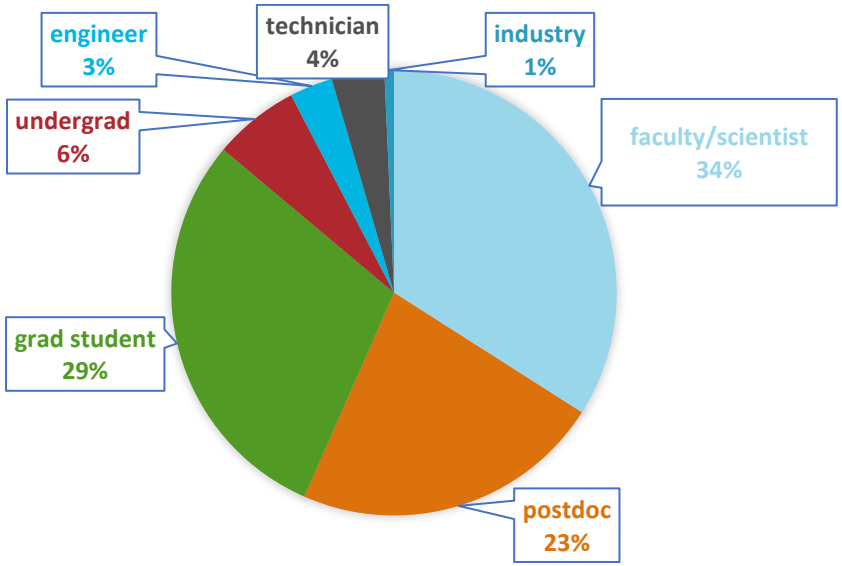
Studies by E. Skup and D. Jensen



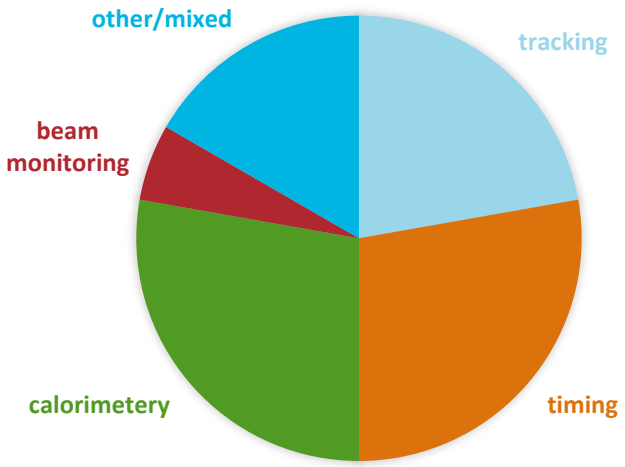
Who uses FTBF?

- 223 users from in FY23
- 20 Experimental efforts, 4 new efforts

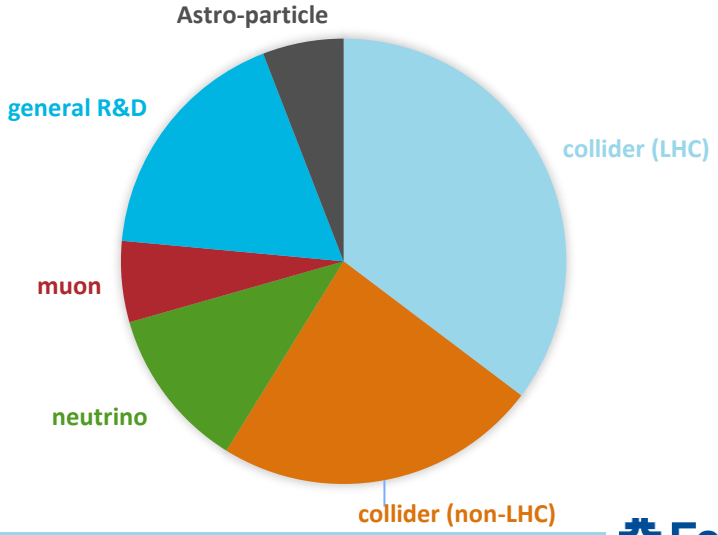
Users by professional category



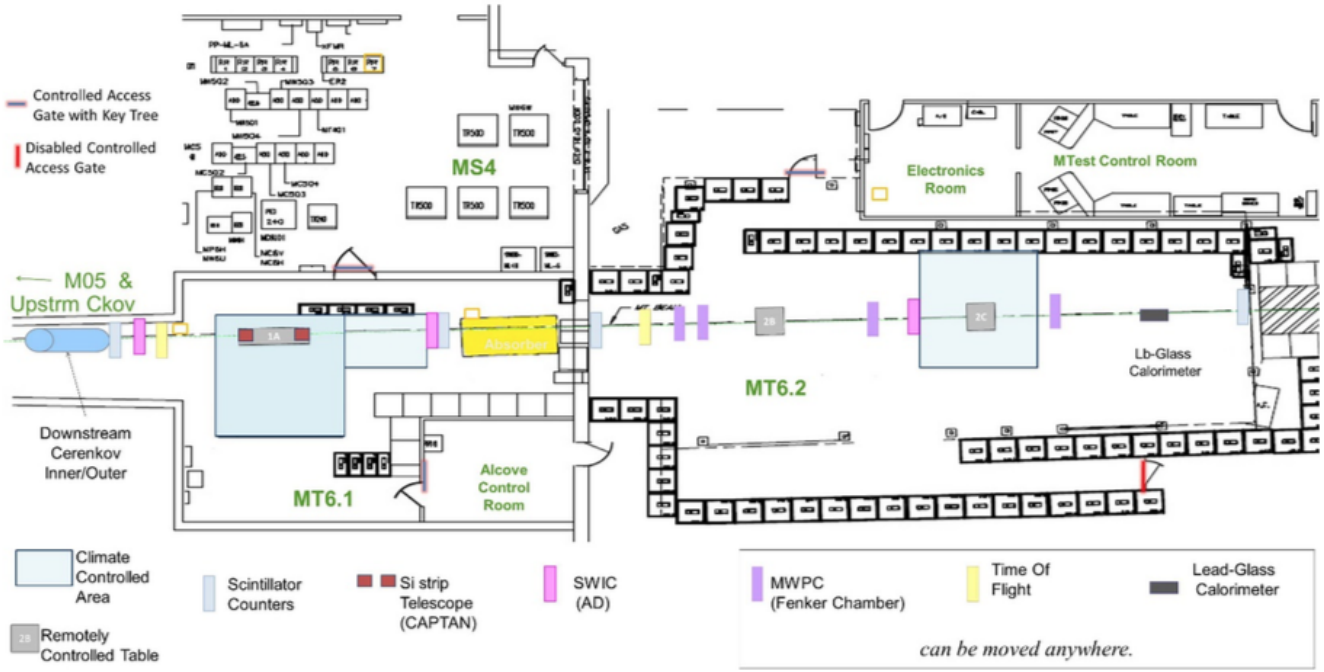
Experiment by detector



Experiment by research focus

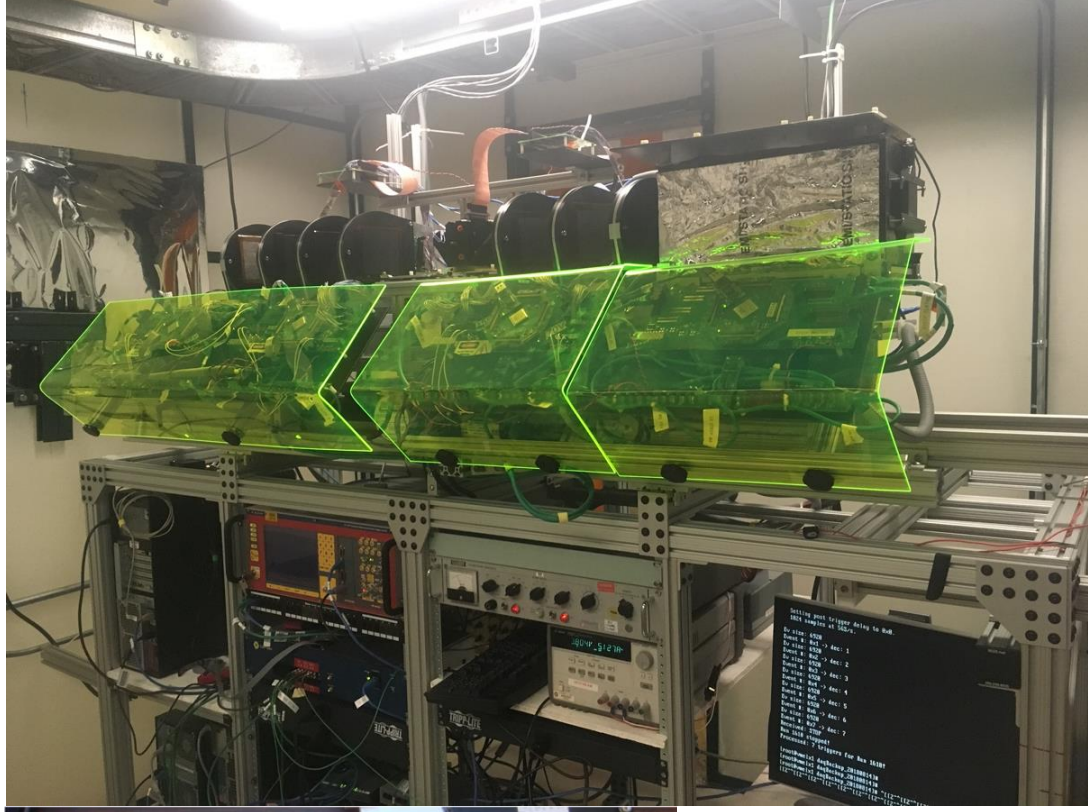


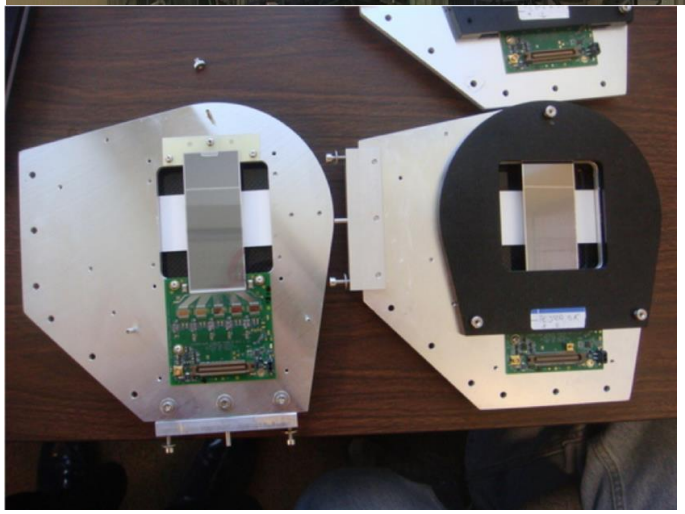
Instrumentation Layout - MTest



Silicon Telescope

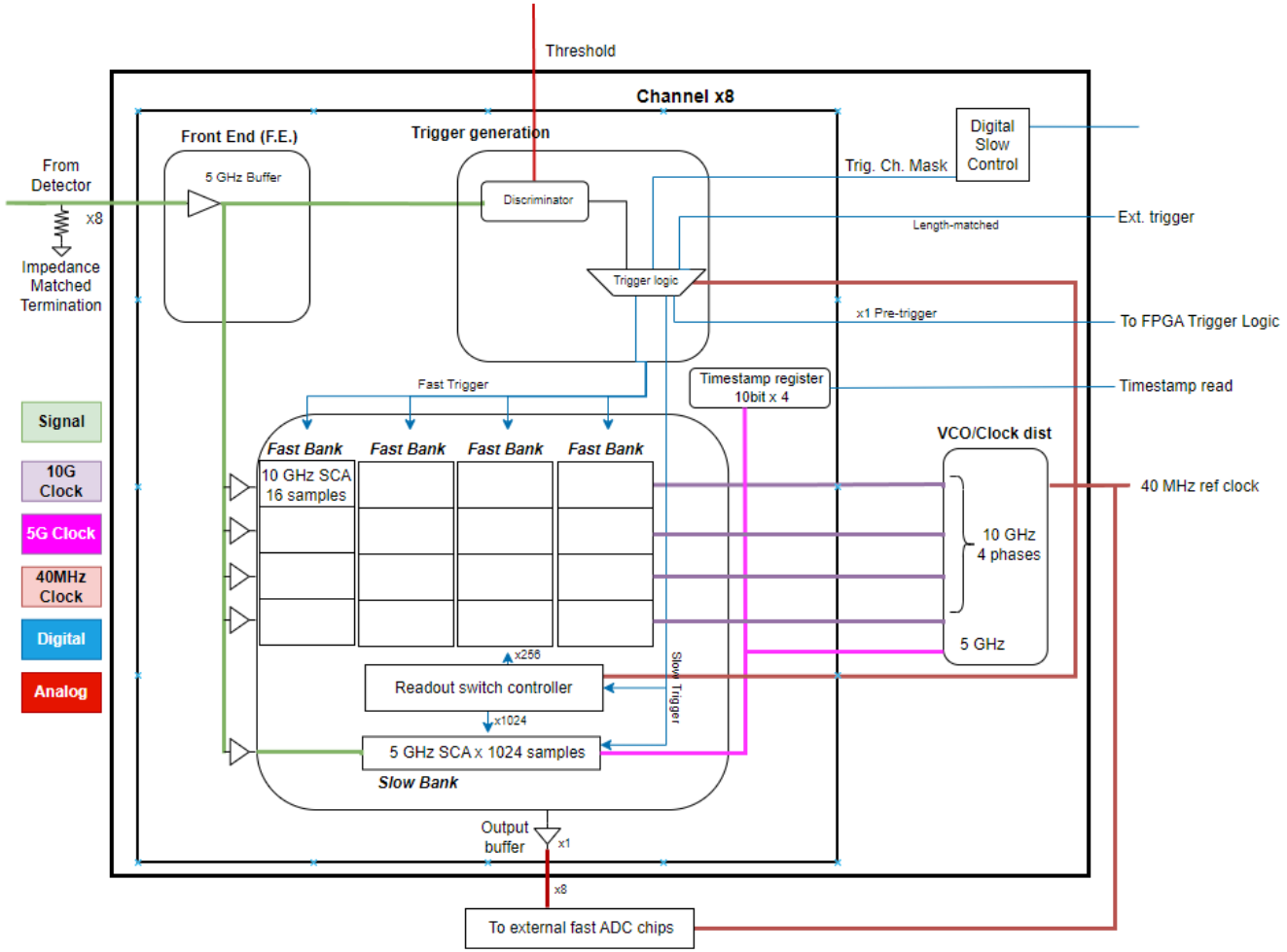
- Tracking telescope based on silicon strips and pixel planes
  - http://www.sciencedirect.com/science/article/pii/S0168900215015521
- 5 μm resolution on DUT
- 3.8 x 3.8 cm coverage of silicon strips
- Moveable arms and motion table for sample positioning
- Recently upgraded pixel sensors



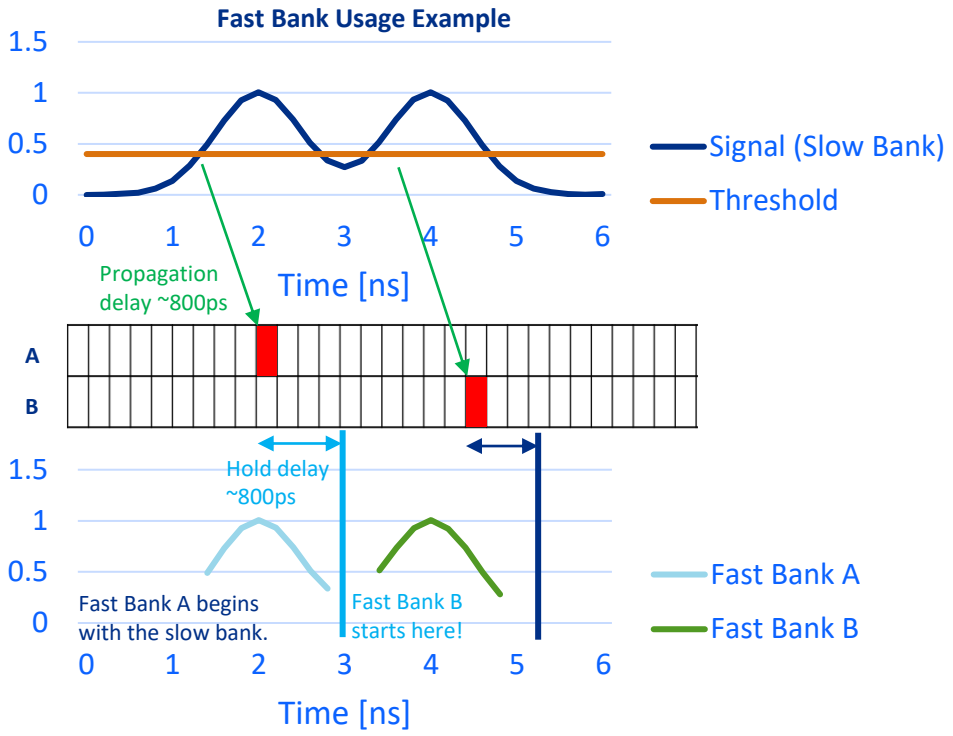


PSEC5

- 65nm TSMC
- 10-bit depth
- 40GSa/s
- 5GHz Analog BW
- 8 channel/chip
- 20mW/ch
- UChicago & Fermilab



PSEC5 sampling



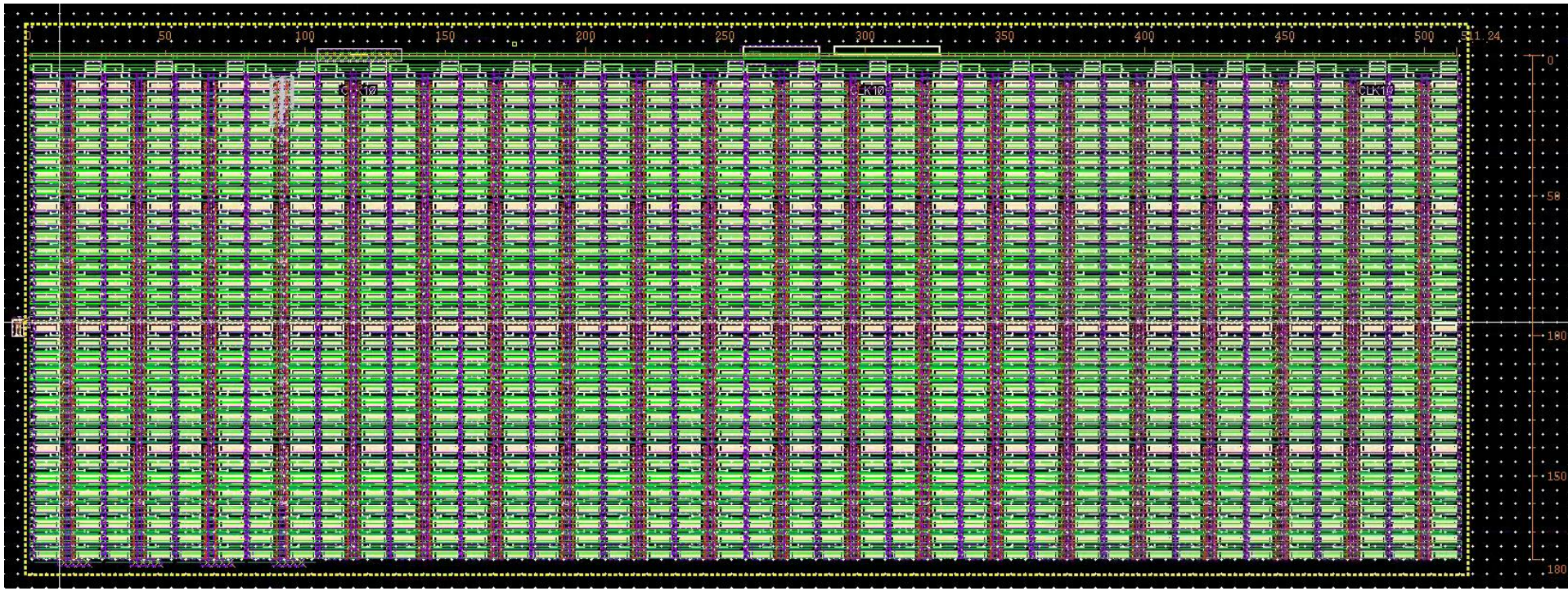
Fast Bank: 4 of them

64 samples
1.6ns of sampling window
High power consumption
Run sequentially

Slow Bank (Timestamp)

1024 samples
204.8ns of sampling window
Low power consumption
Fast banks are triggered within the sampling window

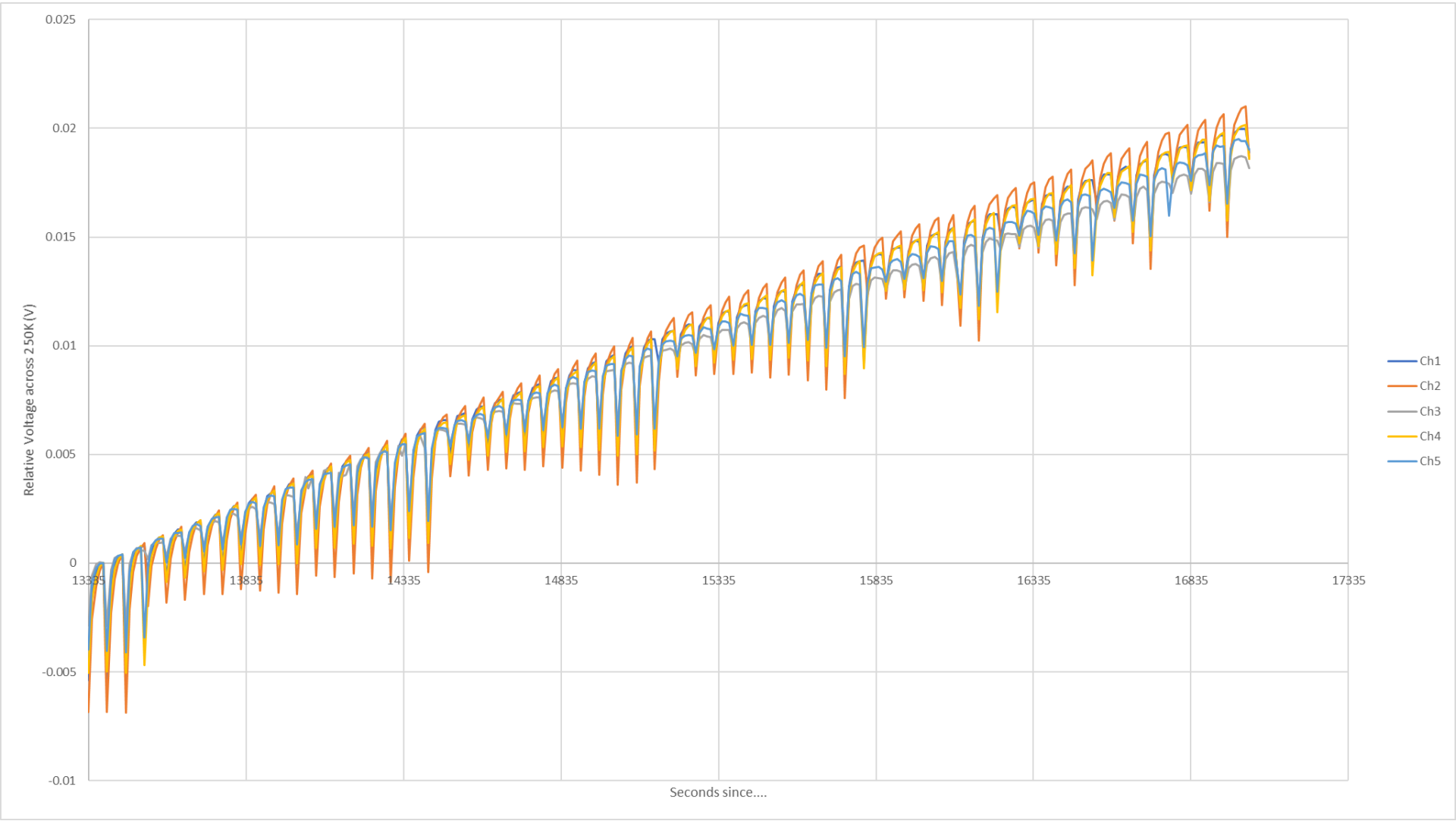
PSEC5 – Single channel layout



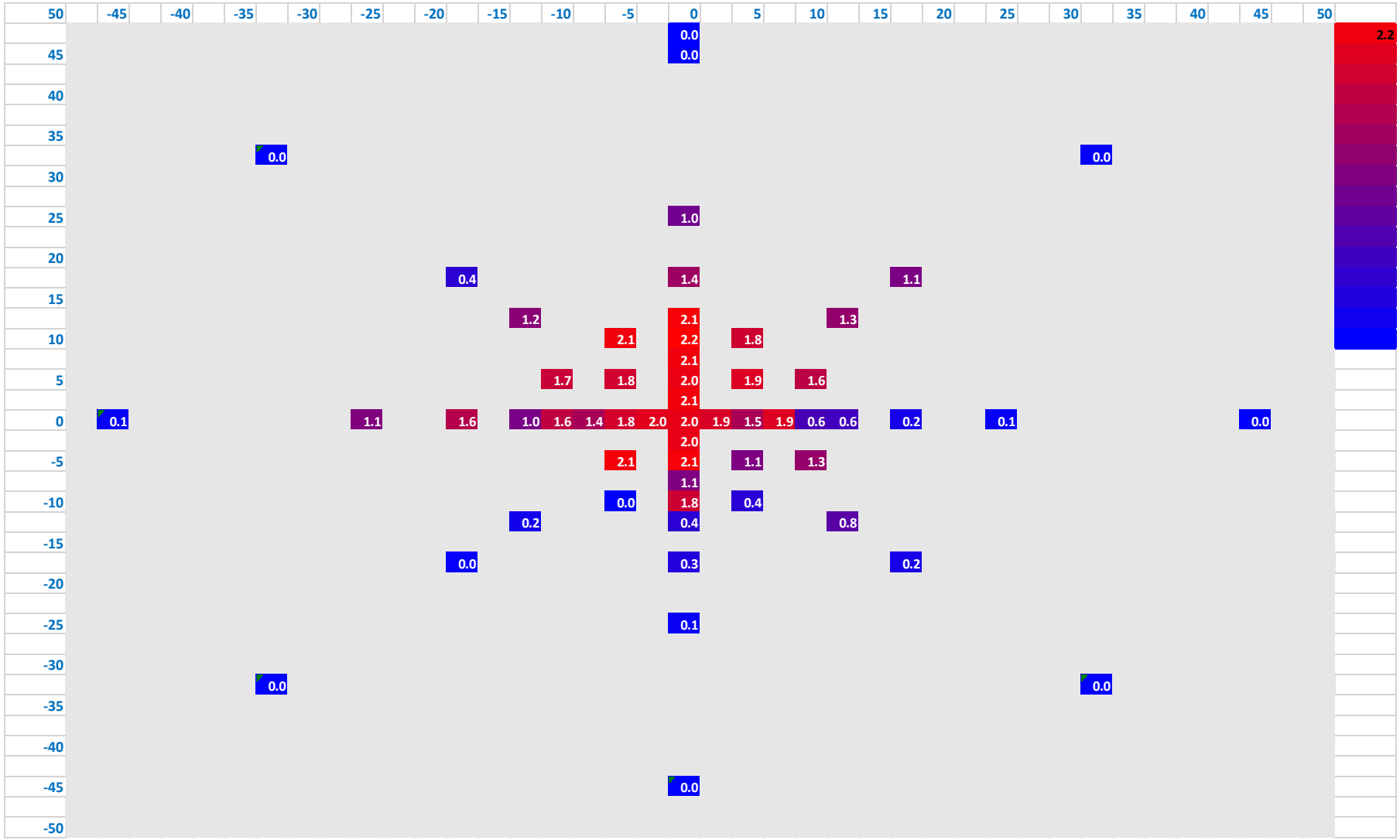
Size: $520\mu m \times 200\mu m$
Power: 20mW

Capacitor: 35fF
1024+256 Samples

Sampling Switch:
2.5V NMOS
Size: $4\mu m \times 280nm$


0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
Relative Voltage across 250K (V)
13335
13835
14335
14835
15335
15835
16335
16835
17335
Seconds since....
Ch1
Ch2
Ch3
Ch4
Ch5

Fermilab


50 -45 -40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35 40 45 50
45 40 35 30 25 20 15 10 5 0 -5 -10 -15 -20 -25 -30 -35 -40 -45 -50
2.2
0.0 0.0
0.0 0.0
1.0
0.4 1.4 1.1
1.2 2.1 1.3
2.1 2.2 1.8
2.1
1.7 1.8 2.0 1.9 1.6
2.1
0.1 1.1 1.6 1.0 1.6 1.4 1.8 2.0 2.0 1.9 1.5 1.9 0.6 0.6 0.2 0.1 0.0
2.0
2.1 2.1 1.1 1.3
1.1
0.0 1.8 0.4
0.2 0.4 0.8
0.0 0.3 0.2
0.1
0.0 0.0
0.0