Fermilab Constant Fraction Discriminator Readout Chip

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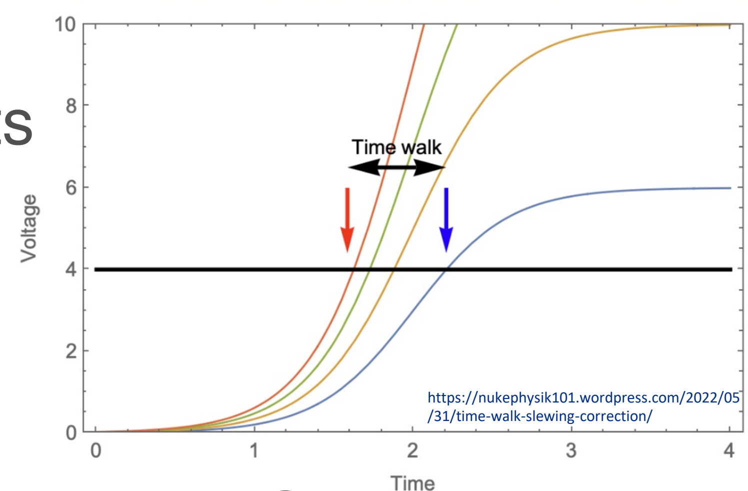
Hardware-enabled CFD Readout for Timing Detectors

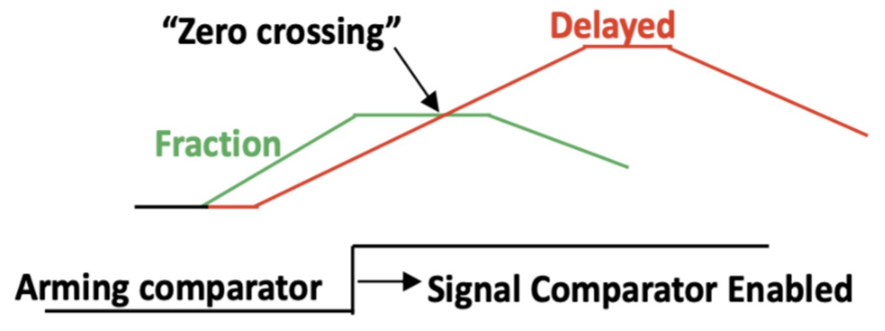
- Time-walk effect is well known & must be corrected for best performance
- Conventionally addressed with online or offline corrections via some type of LUT
- But under harsh radiation environments of future colliders, corrections may be time-dependent and messy!



- We propose a hardware-enabled correction via CFD built into the readout ASIC design

Fermilab CFD Chip Design

- Primary application is (AC-)LGAD sensors for MIP signals
- But can be used for many types of precision timing detectors
- Main features of the CFD are:
  - Integrator & Follower to create the “fraction” signal
  - Comparators for “arming” and timestamping



A. Apresyan et. al, **NIM A 1056, 2023, p168655**
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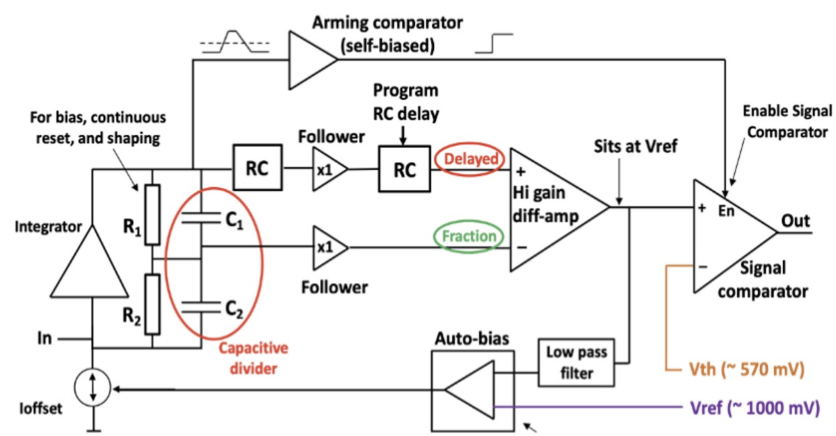

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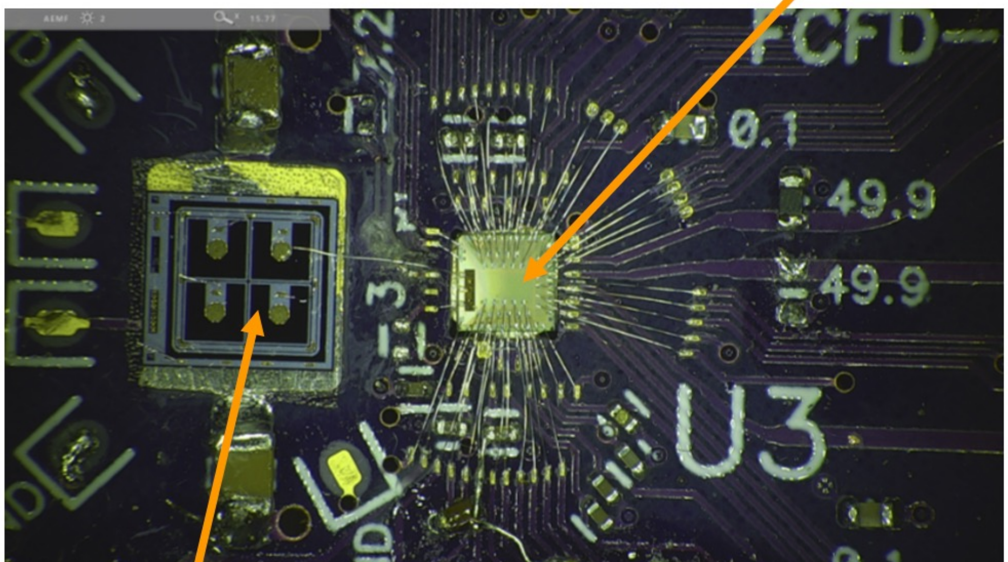
FCDF Chip Prototype v0

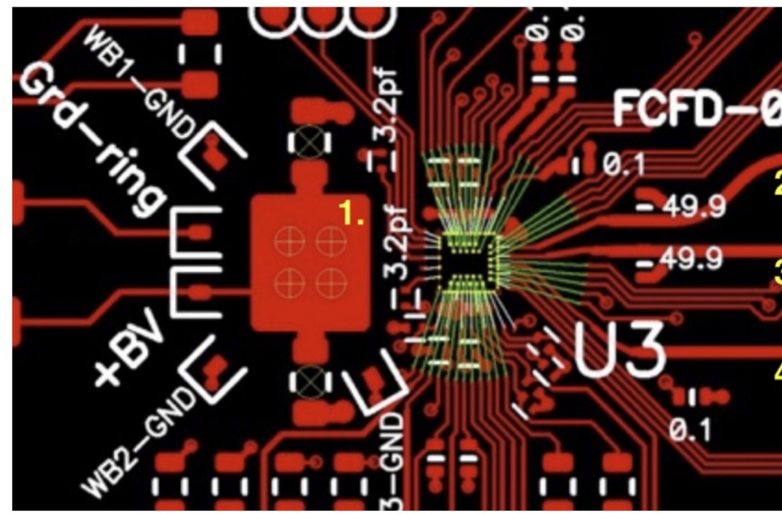
- First prototype designed and fabricated in 2021 & tested in 2022

FCFDv0 ASIC



LGAD Sensor

Schematic Diagram



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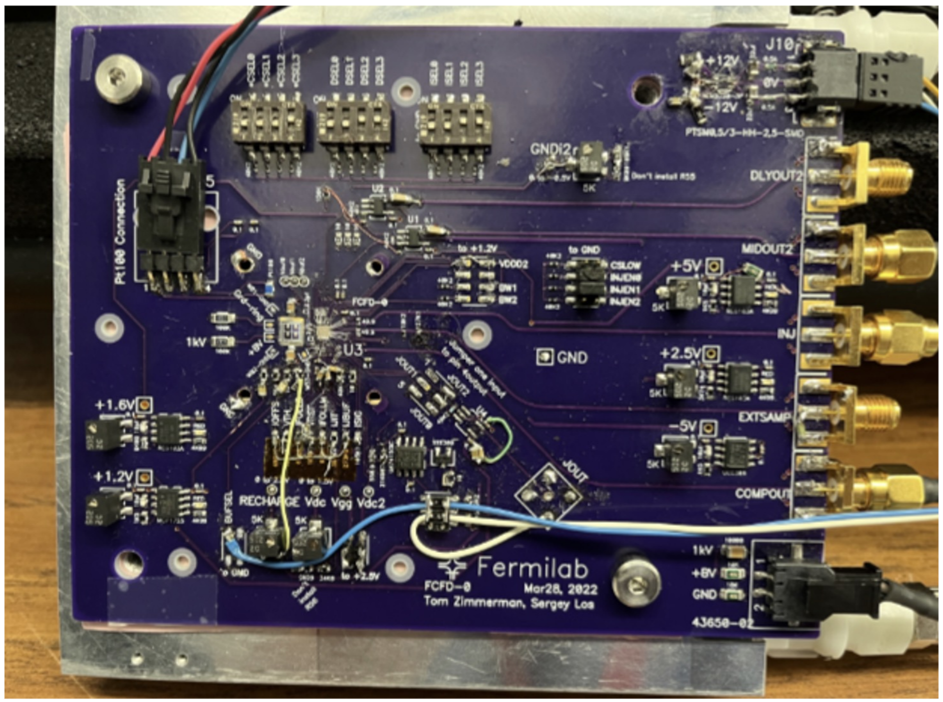


- Full test-board
- Key testing features:
  - Internal charge injection with 3-26 fC dynamic range
- Switch to enable spy on analog signal

Multi-Source Signal Testing Setup

- FCFD v0 performance evaluated using multiple types of signals:
  - Charge-injected signal
  - Picosecond Laser signal
  - Radioactive Source signal
  - Proton Beam signal

Charge Injection

- Inject range of signal sizes from 3-26 fC using built-in mechanism
- Time reference is clock signal used to trigger internal charge injection
- Injected waveforms are based on LGAD signals from simulation (confirmed by past measurements)
- Output waveforms look like this:
  - Spy waveform is small fractional copy of original signal
  - Discriminator waveform is CFD output and used for time-stamping

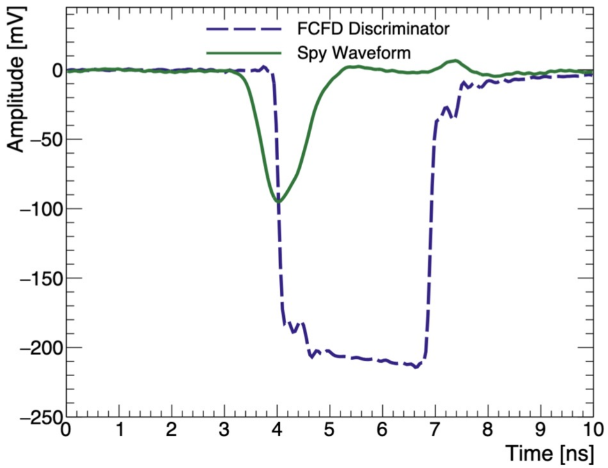
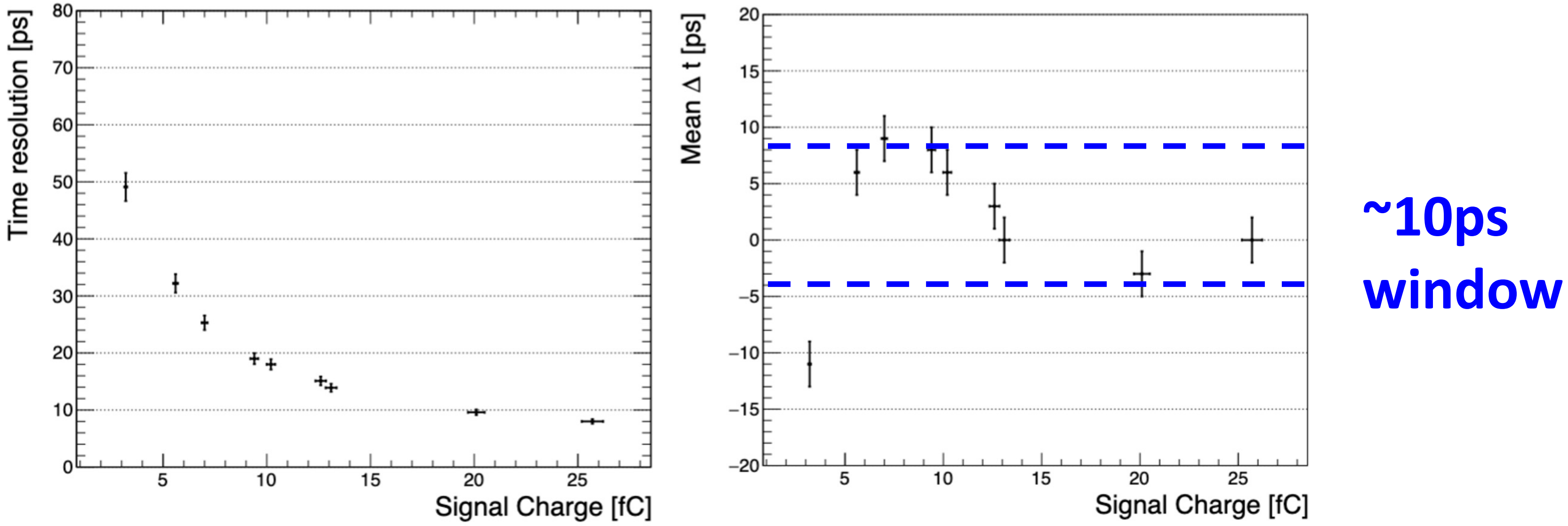


Figure 9: Candidate waveforms of the FCFDv0 discriminator output (blue) and the FCFDv0 input signal spy (green).

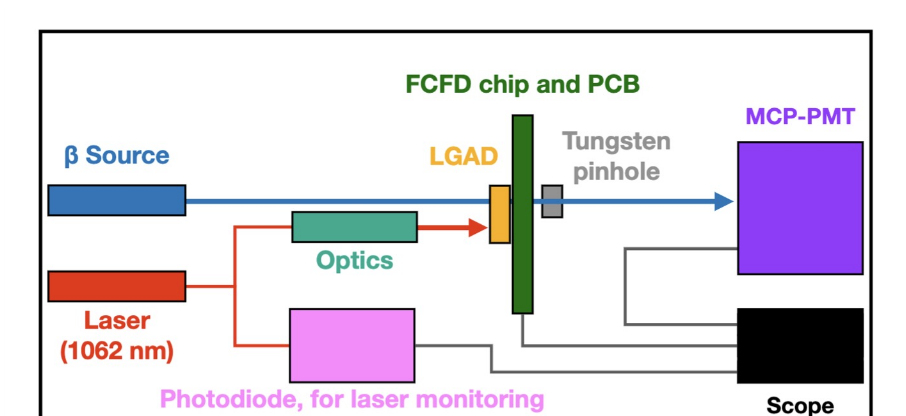
Charge Injection

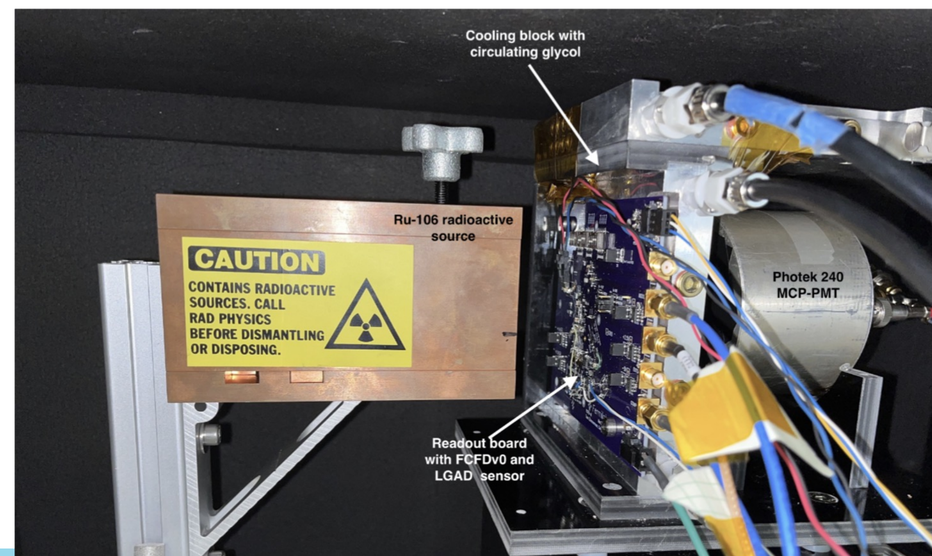
- Time resolution performance as expected
- For largest signal (before saturation) get ~8ps time resolution
- Time walk effect is reduced from 100s of ps to a ~10ps window



Picosecond Laser & Beta Source Setup

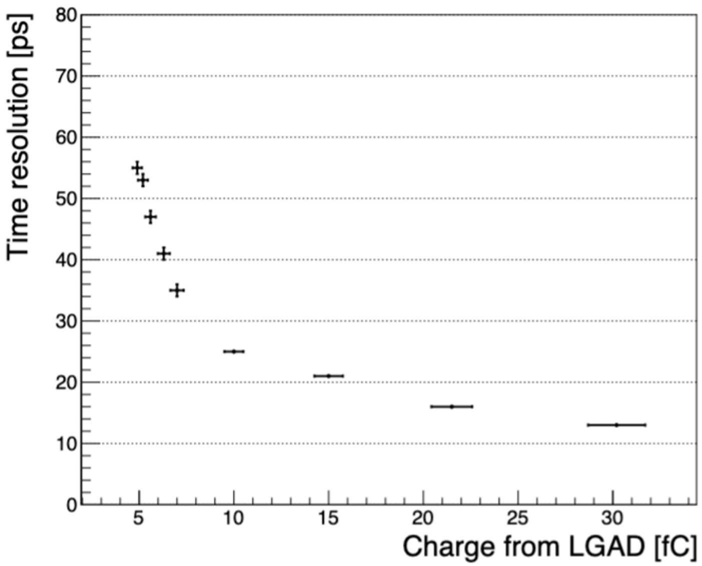
- Dark box with motorized stages, enabling laser injection and beta source
- Picosecond Laser trigger signal serves as time reference
- Collimator and MCP time reference detector ensures straight trajectories: get beta rates of about 2-3Hz at best alignment
- Temperature maintained at 20C by chiller and cooling block



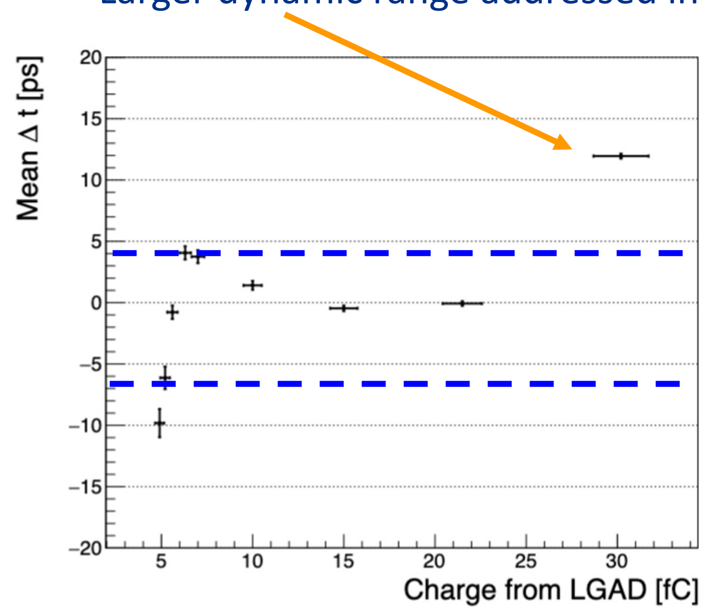


Picosecond Laser Measurements

- Laser measurements confirm similar performance as charge injection



Signal here starts to saturate CFD v0
Larger dynamic range addressed in next v1 chip



~10ps window

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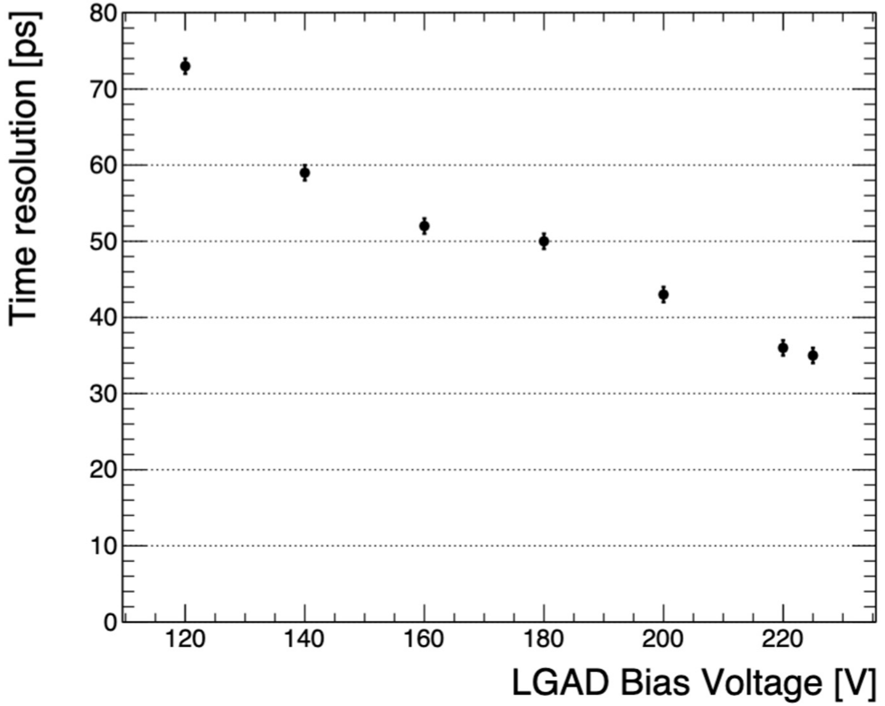
Beta Source Measurements

- Similar performance is also confirmed with beta source

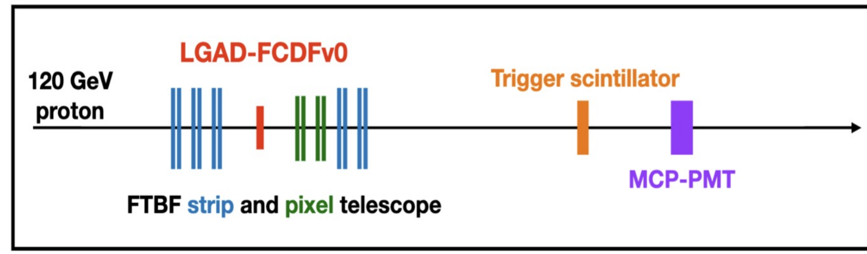
- The measured time resolution is consistent with a 8-10 ps contribution from the CFD chip, accounting for time jitter of LGAD sensor itself and imperfect collimator,

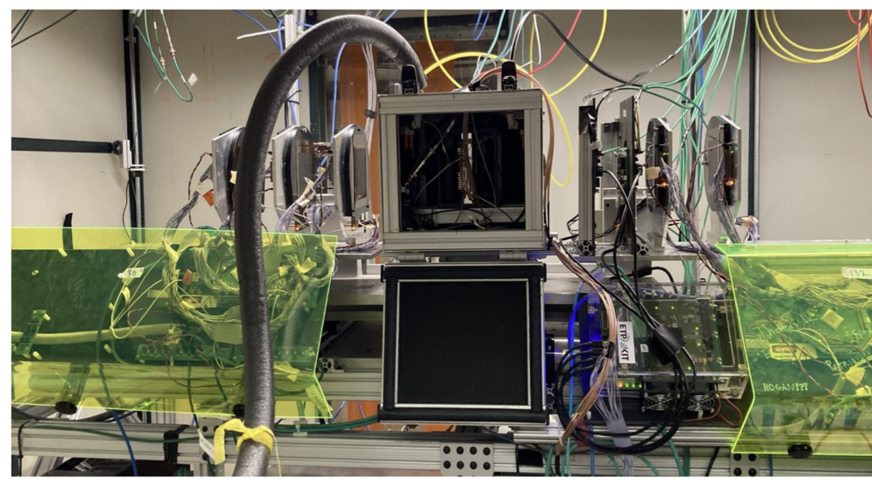


Proton Beam Measurements

- Use Fermilab Testbeam Facility to test CFD chip with 120 GeV protons

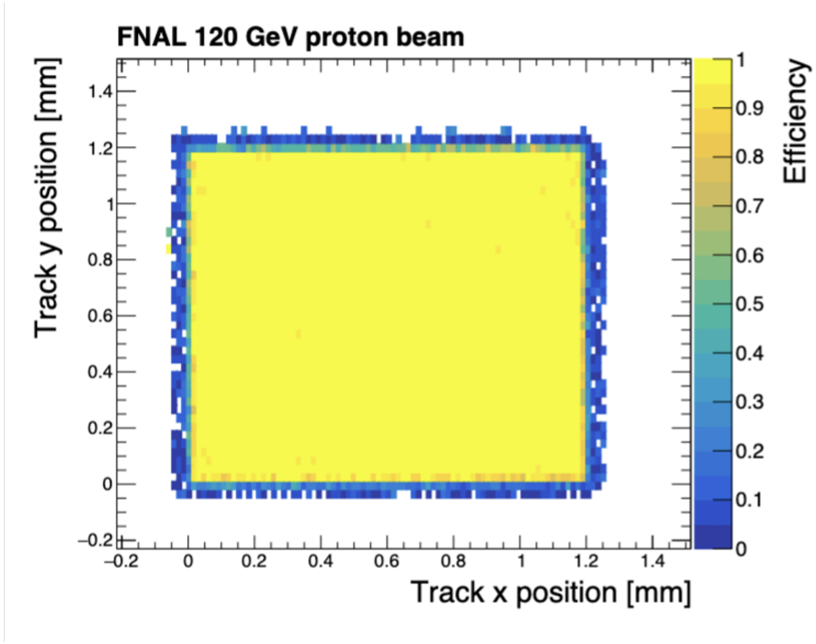
- MCP-PMT used as time reference detector
- Temperature maintained at 20C
- Tracking telescope used to measure hit positions and efficiency



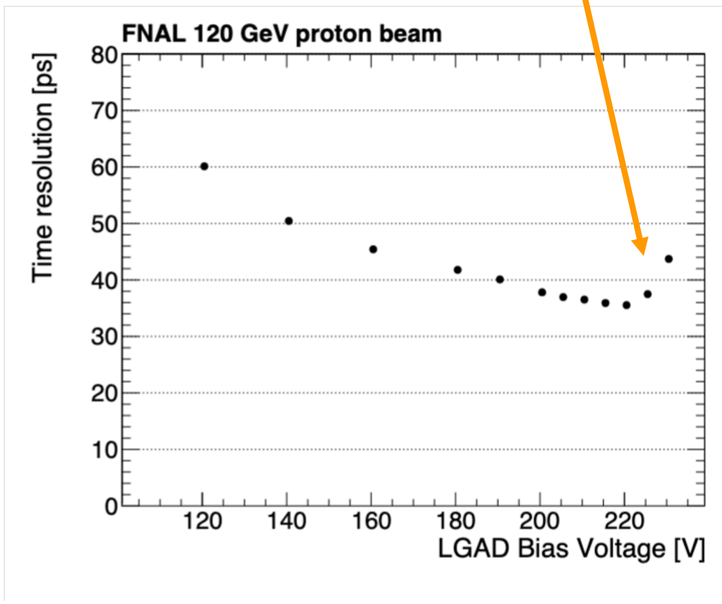


Proton Beam Measurements

- 100% Efficiency is maintained over full LGAD pixel sensor area
- Time resolution performance consistent with Beta Source measurement

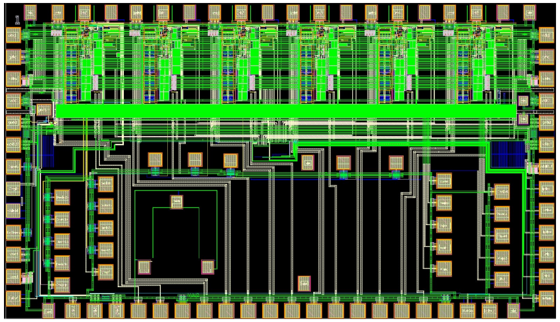


Saturation here again
Addressed with v1 chip



Summary

- Presented Motivation, Design, and Results of Fermilab CFD v0 chip
- Measured performance consistent with design expectation and between many types of signal source
- Next Steps:
  - Version v1 has been submitted for fab
    - includes more channels (6)
    - Larger dynamic range to cover full range of MIP LGAD signals
    - Includes signal amplitude measurement
  - Beyond v1, we plan to add digital components to readout to equip a fully functional AC-LGAD detector prototype



FCFDv1