Timing ASIC for LGAD sensors based on a Constant Fraction Discriminator – FCFD0

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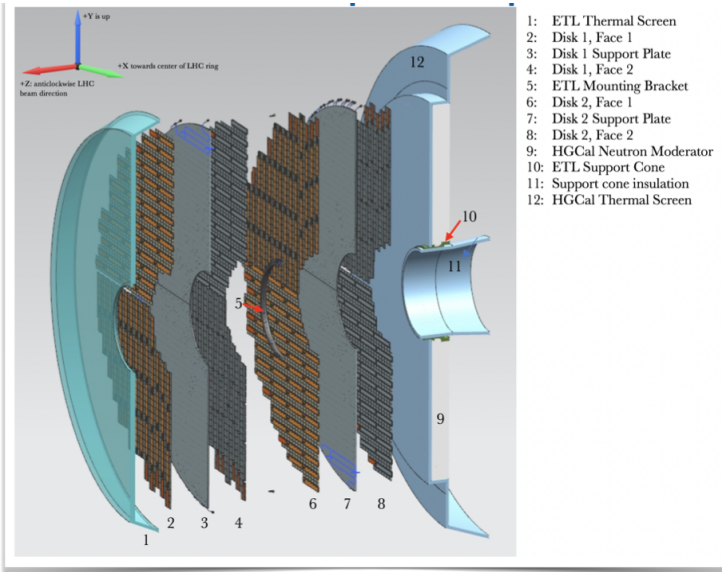
Motivation

- The 4D-trackers will play a key role at the future machines
  - Reduce backgrounds, track reconstruction, PID, triggering all will need precision timing information, in addition to the precision position
- Next generation detectors will be more sophisticated and replace tracker
  - Development of the technologies need to start now

Measurement	Technical requirement
Tracking for e^+e^-	Granularity: 25x50 μm^2 pixels
	5 μm single hit resolution
	Per track resolution of 10 ps
Tracking for 100 TeV pp	Generally the same as e^+e^-
	Radiation toleran up to $8x10^{17}$ n/cm^2
	Per track resolution of 5 ps

Technical requirements for future trackers: from DOE's HEP BRN



CMS endcap timing detector

FCFDv0: Fermilab CFD chip v0

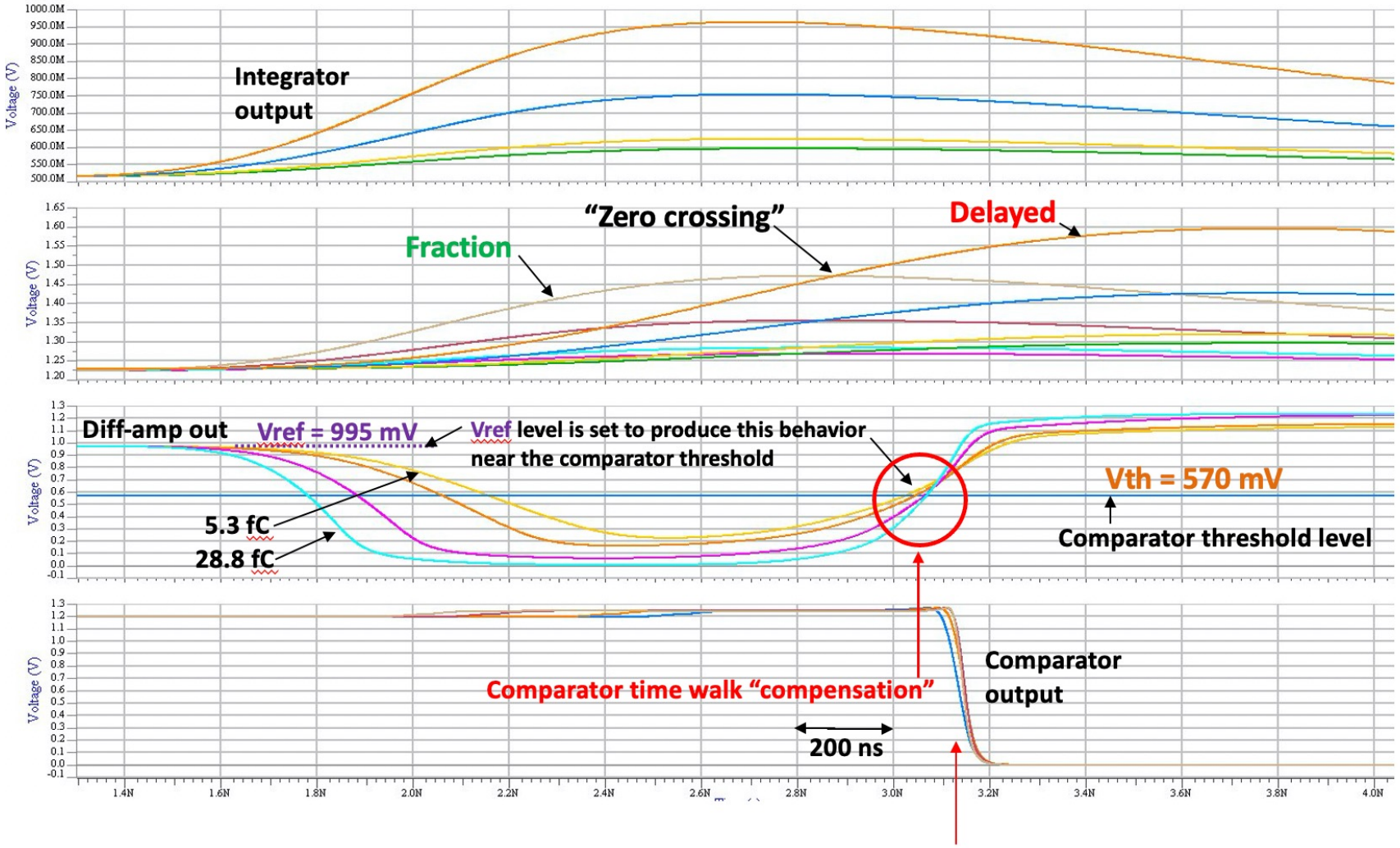
- Goals:
  - Develop a robust fast-timing measurement technique for fast detectors
  - 30 ps time resolution or better
  - Easy to use and stable: no corrections, or repeated calibrations and threshold adjustments
  - Dynamic range ~ 5 - 50 fC
  - Very low dead-time after a hit (< 25 ns)
- Our approach:
  - Studied both LE and CFD approaches for AC-LGAD: *"A simulation model of front-end electronics for high-precision timing measurements with low-gain avalanche detectors"*, **NIM A 940 (2019), pp 119-124**
  - Adapt the Constant Fraction Discriminator (CFD) principle for a pixel – when paired with a TDC, *one time measurement* gives the final answer
  - Modify the classical CFD approach to eliminate the need for pixel-by-pixel trimming or compensation
  - Tailor the first design to LGAD requirements (serve an existing need)
  - General principle could be useful for other applications (beyond LGADs)

Bench-testing

- Design an on-chip charge injection circuit that can deliver a wide range of charge pulses with well-known shape and amplitude to the FCFD0 input.
  - Implement an on-chip time-to-voltage converter with precision of ~ few pS to enable easy measurement of FCFD0 output delay and jitter.
  - Establish methods to accurately measure all relevant parameters of these test circuits (to ~1% level), and the FCFD0 input capacitance (so we can accurately mimic the LGAD capacitance).
  - These methods should use only readily available basic test equipment (pulse generator, oscilloscope, etc.)
- Detailed report at TWEPP21:
  https://indico.cern.ch/event/1019078/contributions/4443948/attachments/2277824/3938152/FCFD0_TWEPP_talk.pdf

Simulation

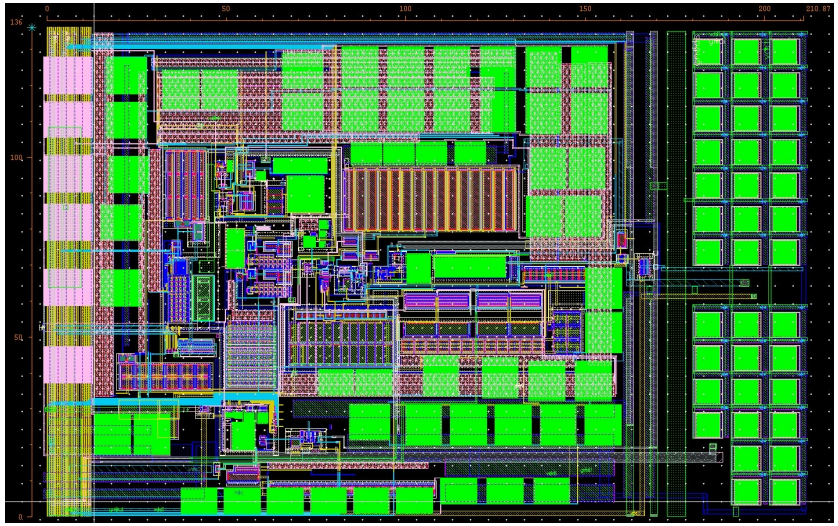
Apply LGAD-like charge pulse to FCFD0 input.
Inject 4 different amplitudes: Qin = 5.3 fC, 7.0 fC, 15.3 fC, 28.8 fC

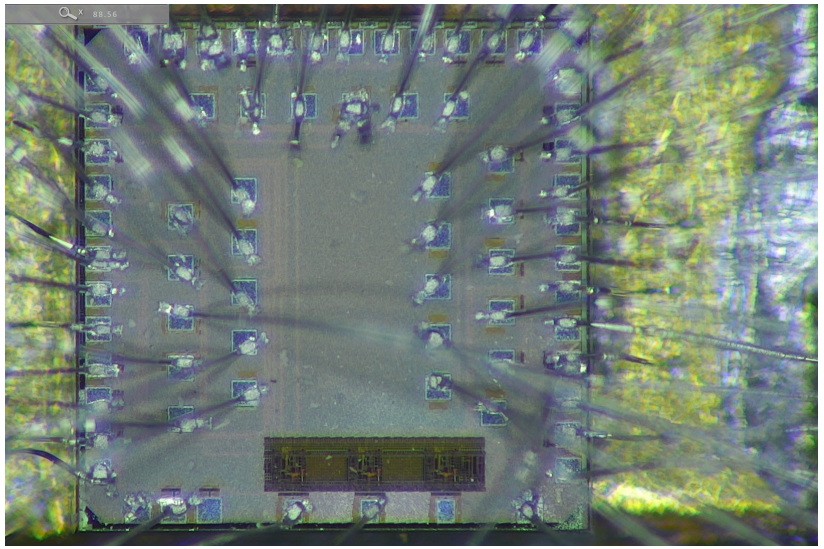


Comparator output has same delay for a range of input amplitudes

FCFDv0

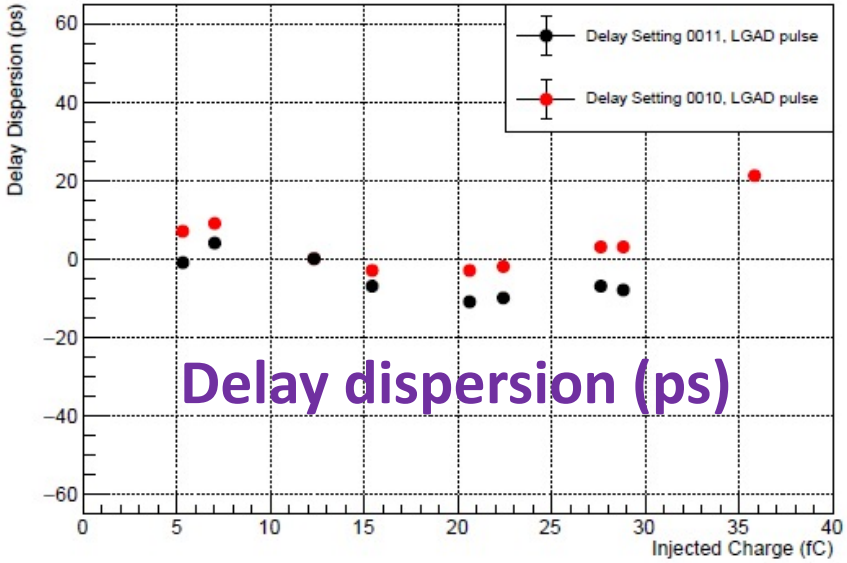
- First version of the chip to test and study the approach
  - Only analog output to measure the performance of the CFD approach
  - Measurements first performed using the internal charge injection circuit

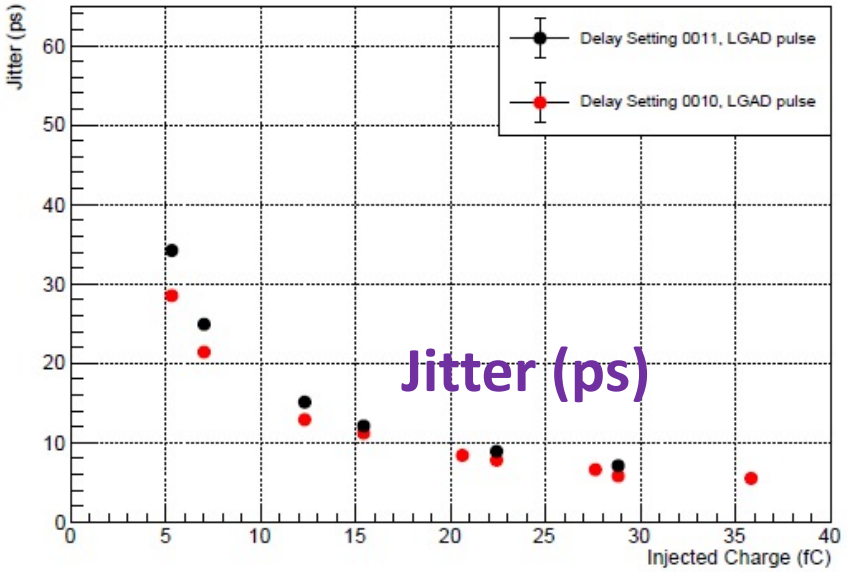




LGAD-shape injected pulse

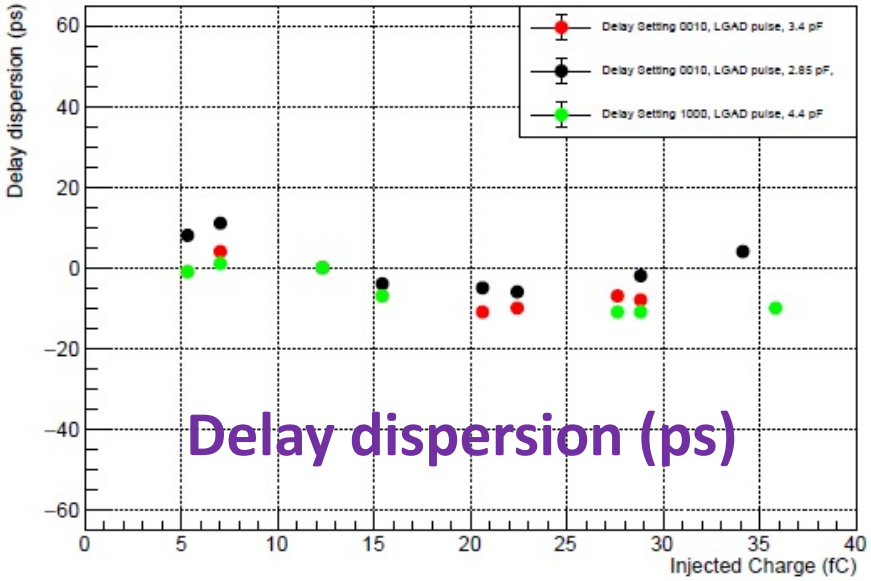
- Measured delay dispersion and jitter vs. input charge for two different power modes

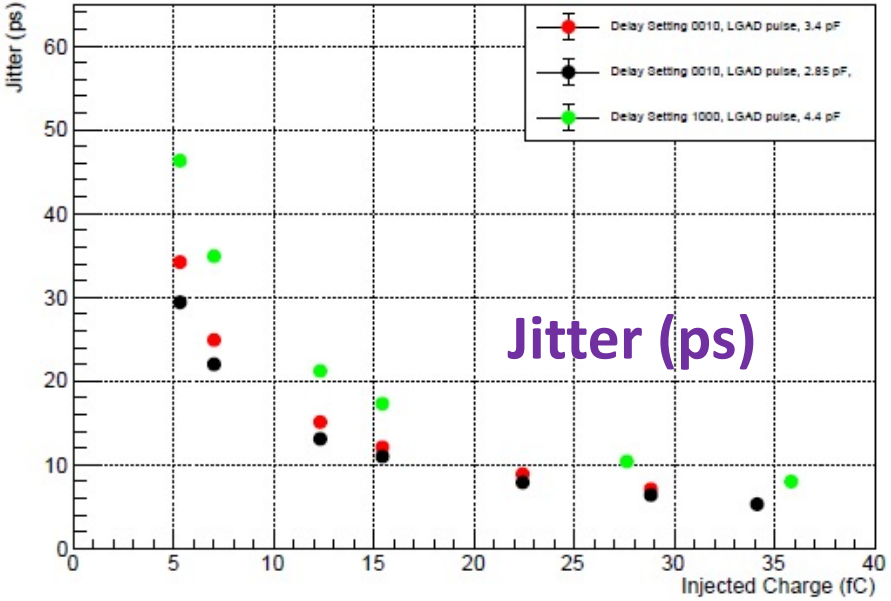




Effect of capacitance

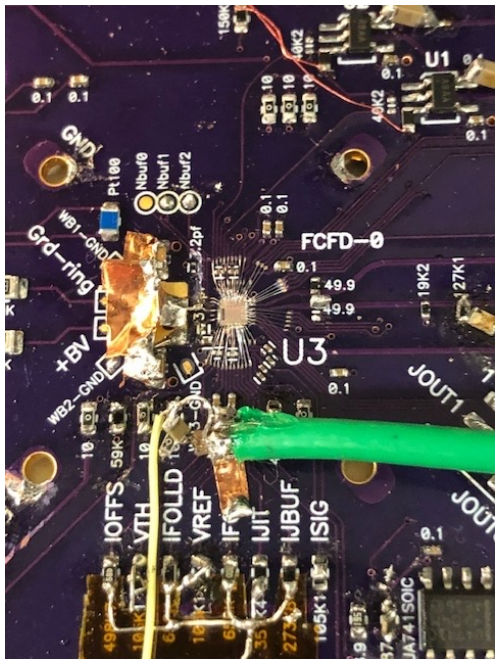
- Vary the input capacitance from 2.850 pF to 4.4 pF

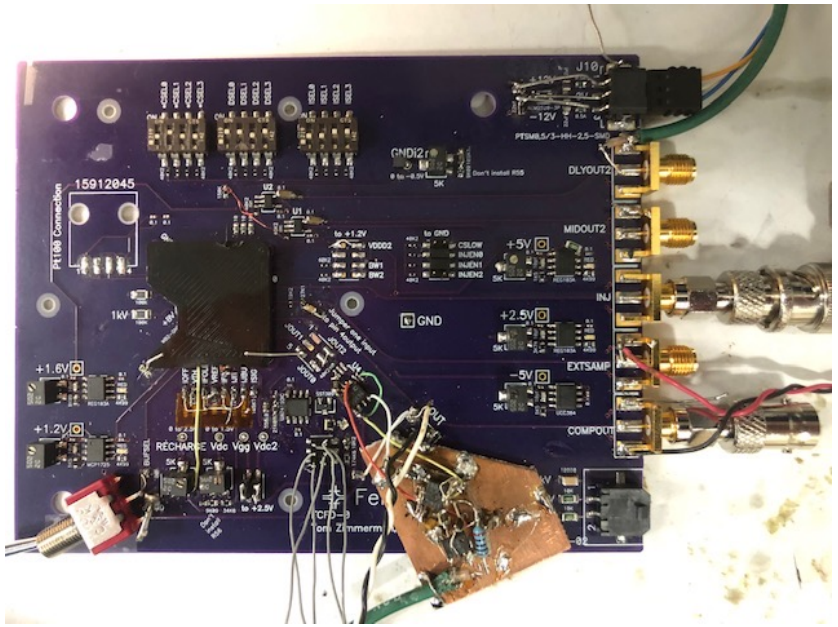




Next steps

- Characterization of FCFDv0 with beta source and test beam
  - Designed dedicated board for measurements with LGADs
  - Measurements during next two months





Next steps

- Simultaneously, working on the design of the next v1 version
  - Focus on AC-LGAD readout which needs both amplitude and timing information from each channel
  - Add measurements of amplitude
  - Multichannel chip for AC-LGAD strip detector, probably around 10 channels
- Preliminary specs from our studies of AC-LGADs

Min Charge	Max Charge	Min MPV Charge	Max MPV Charge	Capacitance	ADC Resolution
2 fC	64 fC	15 fC	25 fC	0.5-10 pF	10%

Summary for FCFDv0

- Good performance for the first generation CFD-chip produced in TSMC 65nm technology node
  - Precise measurements and calibrations of the chip on a bench, stable operations, low dead time
  - Consistent with simulations: ~30 ps at 5fC, and < 10 ps at 30 fC, with LGAD-like pulses
- Now moving on to testing with LGAD signals
- Development of the next version is starting, targeting specifically AC-LGAD signals to achieve good timing and position resolutions