NIM+ muon test stands for evaluation of HGCAL Hexaboards

Chris Cosby, Jason Li, Mikhail Sharov, Y. Situ, Hasung Song, L. Sulak
and
BU students: N. Adams, A. Akpinar, L. Beckschi, M. Bellitti, H. Bouchamaoui, A. Donald, C. Gerontis, A. Intili, R. McCarthy, M. Pandey, S. Rosen, D. Simon, A. Singh, V. Ursekar, C. Wedin

CERN '18 interns: Aggie Quesada (BU/Johns Hopkins), Kathryn Coldham (Queen Mary, London)

Our participation recruited by Dave Barney, Andre David

CERN CMS collaborators Bora Akgun, Arnaud Steen

NIM+ motivated by Lorenzo Uplegger (PREP at FNAL), Tiziano Camporesi

I/O daughter-cards invented by A. Prosser, R. Rivera, Paul Rubinov, M. Utes (FNAL)

BU Consultants - D. Arcaro, Dan Gastler, S. Girgis, Eric Hazen

Overview

- NIM+ for HGCAL
  - Full testing of Zedboard & both versions of FNAL NIM+ daughter card
- Results on performance as a cosmic muon trigger for CMS's hexaboards
  - Also applicable to test beams
- Current status of test stands*: original at BU, & clone at CERN since August '19
  - Prototypes for HGCAL hexaboard module testing at remote assembly sites with novice operators
- NEW: GUI control software for use without VHDL experience…it's invisible to user

What is NIM+?

1000s of NIM units: cables, screwdrivers, switches…from the ‘70s, no longer supportable

NIM+: A laptop-driven, FPGA-based replacement (we use ZedBoards)

- Selecting & discriminating coincidence/anticoincidence from 8 independent input channels
- 4 TTL & 4 NIM (coupled) output channels providing arbitrarily complex logic signals from any 3 inputs
- Input/output interface: a “pair of V2 daughter cards” funded by Fermilab PREP Electronics Pool
  - replace traditional NIM due to difficulty maintaining legacy NIM modules
  - “CERN’s biggest technical vulnerability…what if a fire in a beam line?”, T. Camporesi
- Many Wiener, LeCroy, *etc.* modules discontinued, labs without spares, spare parts no longer available
- Last NIM service tech retired from CERN in 2019
- Off the shelf alternatives very expensive, *O*(10k€)

Want a modern interface to any experiment, test beam, or test stand currently using NIM

Current implementation is a portable, stand-alone, multi-channel trigger system

The ZedBoard

- Available off-the-shelf from Xilinx: ~$450 as singles from Digilent,
  Less expensive in bulk or from CERN store
- Powered by a Zynq-7000 “System on a Chip”, with a built-in FPGA
- Connects to FNAL daughter card which accepts fast analog signals from a custom front-end & outputs Boolean logic

The NIM+ Daughter Card

- Created by Paul Rubinov, Alan Prosser, Ryan Rivera, & Mike Utes
  a joint Fermilab/CERN project

- Accepts & discriminates fast analog signals from PMTs (CMS use) or SiPMs

- We have fully tested two versions
  V1 supported up to 4 input channels
  V2 supports up to 8 inputs, currently in operation both at BU & at CERN

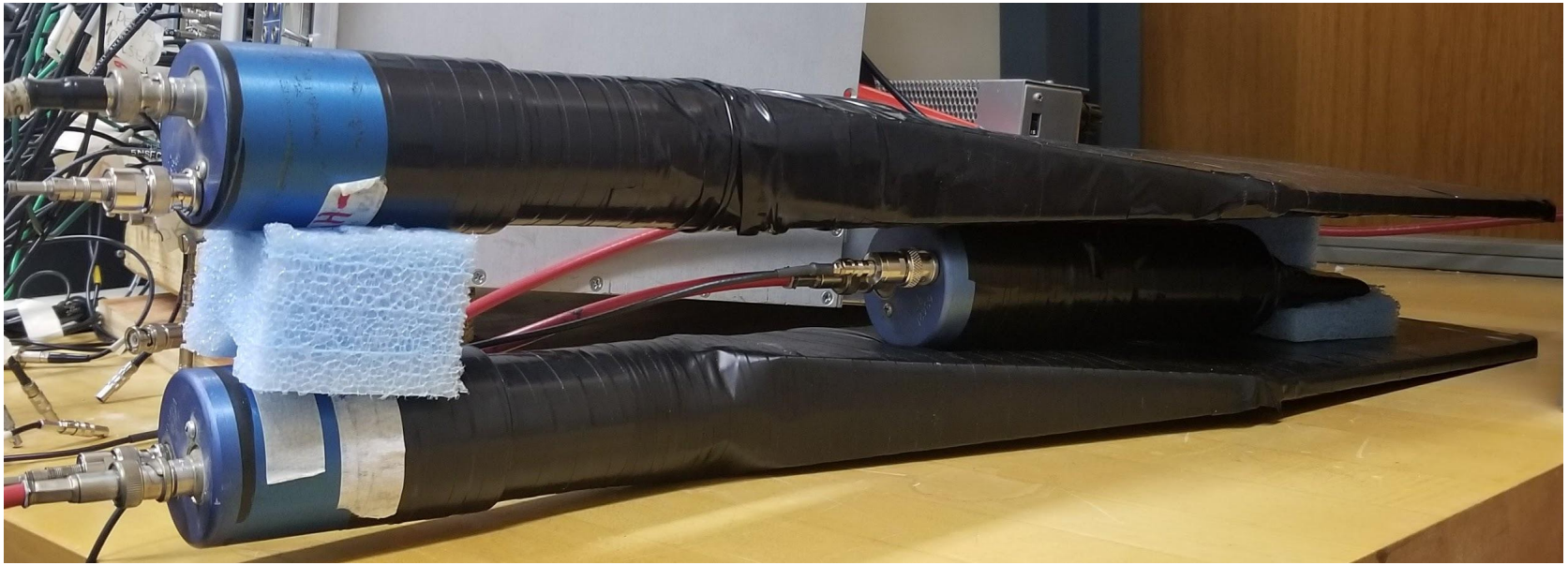
  Total singles cost of a daughter is ~$850

- selection of input channels & 8 independent discriminator thresholds
  controlled by the ZedBoard via the BU GUI running on a PC

The BU Test Stand

- Developed since summer of 2018 by BU interns
  Most of the work was performed by BU undergraduates & a few grad students
- NIM+ performs equivalently, or better than, LeCroy
- Testing done on ZedBoard alone & combined with each of the daughter card versions

BU cosmic muon telescope



3 muon scintillators (two 20x20cm and one 5x5cm):

Single photoelectron ~ 6mV; muon MIP ~ 100 mV;

NIM+ & LeCroy discriminators set at 50 mV

2-fold coincidence (top & mini) rate ~200/min with cosmic signal

3-fold coincidence (top & mini & bottom) ~15/min

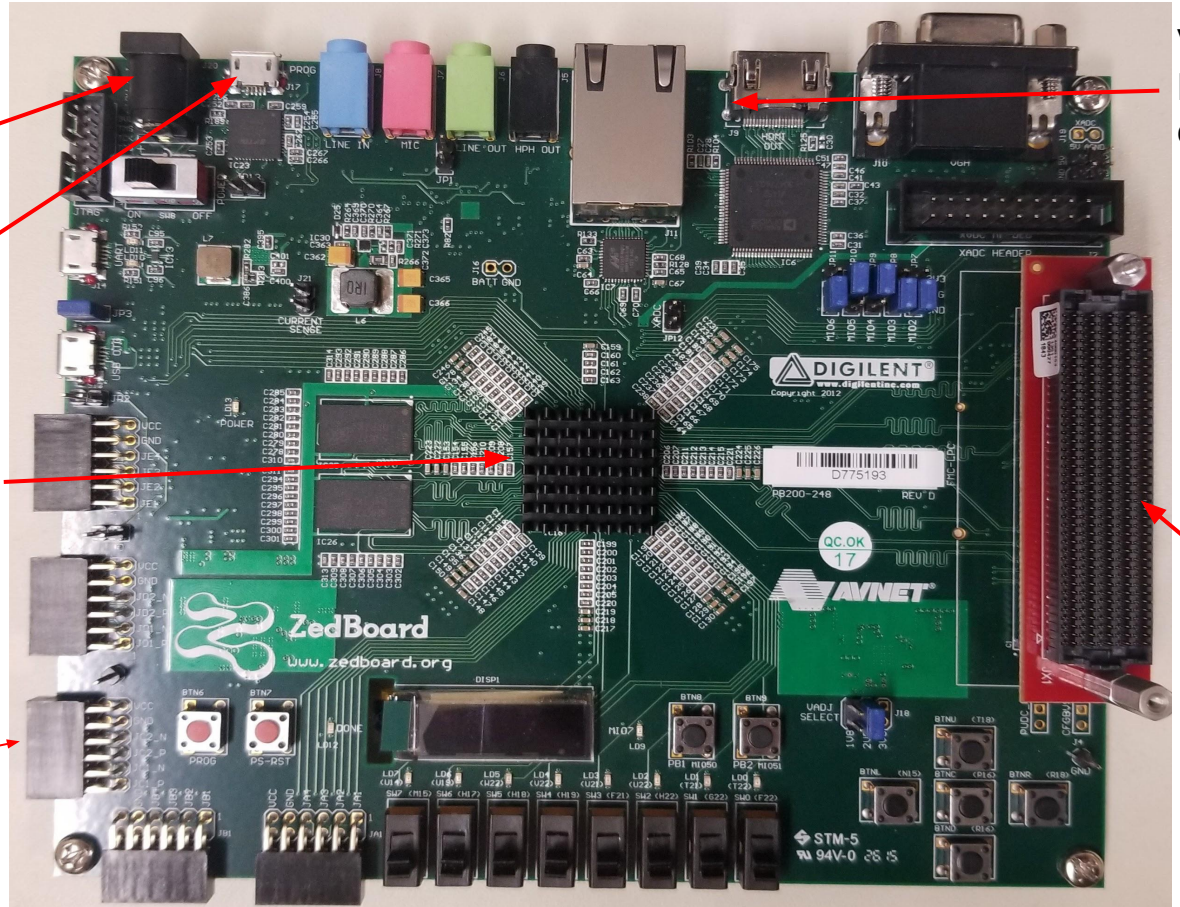
The BU test stand: ZedBoard Architecture

+12V Power Supply

USB Port for PC control

ZYNQ 7000 SoC w/ Artix-7 FPGA & On board, 1-core CPU

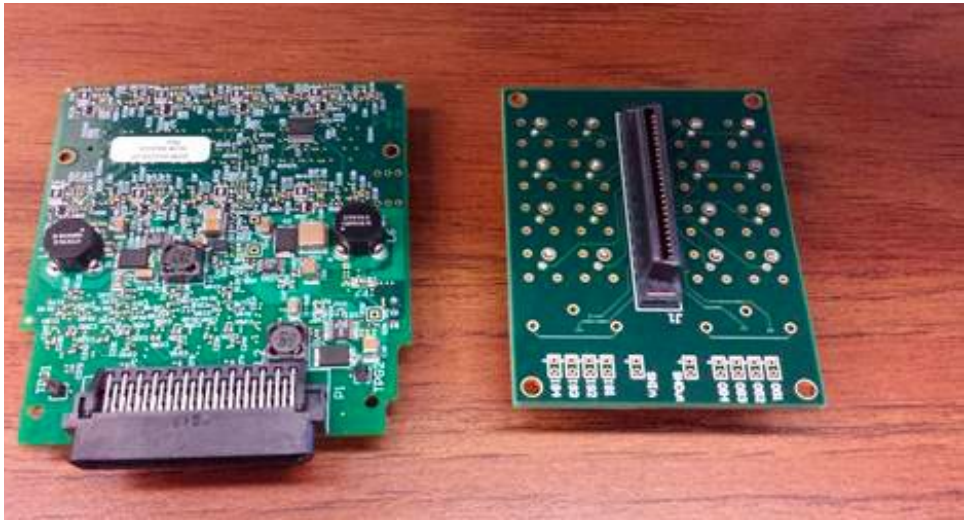
PMOD input/output (+3.3V)



Various connectors: Ethernet, HDMI, VGA, etc.

FMC Daughter card socket 160 pin input/output

Version 2, two connected daughter cards, both sides:



Installed both at BU & at CERN

Courtesy Mike Utes

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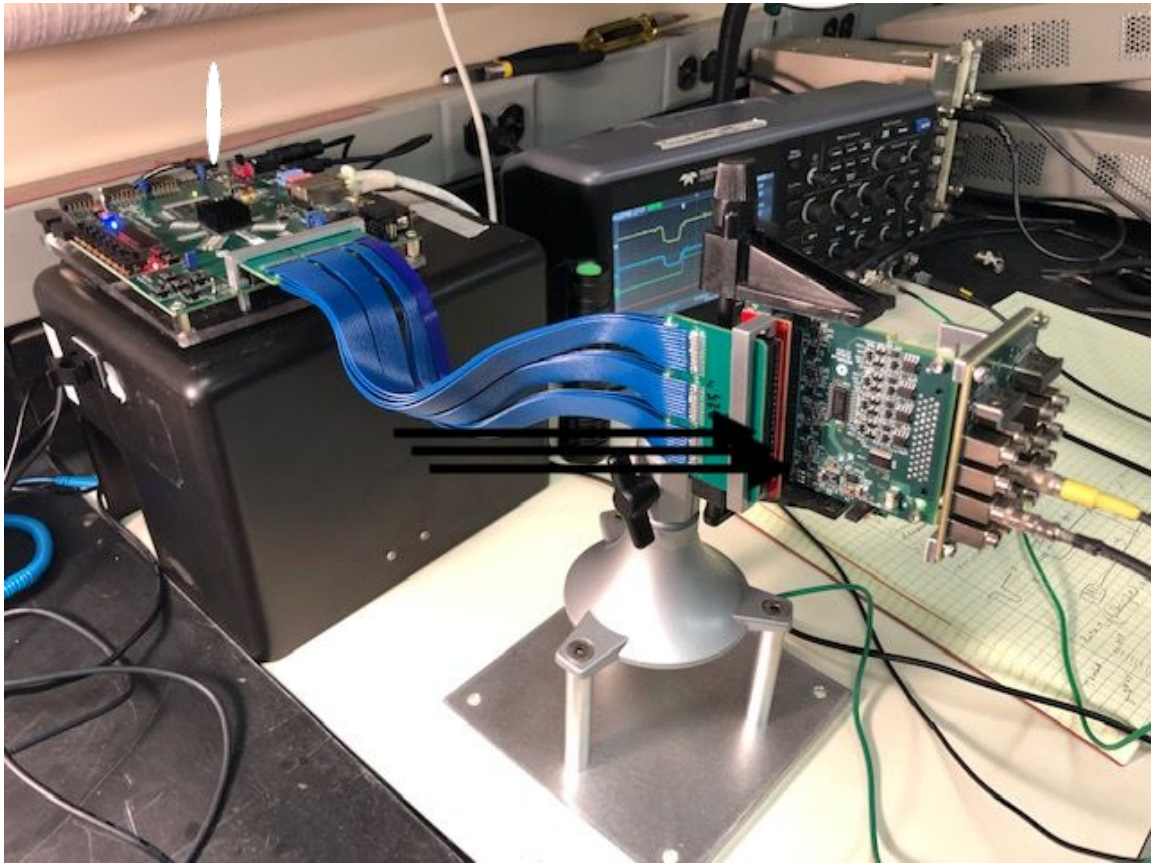
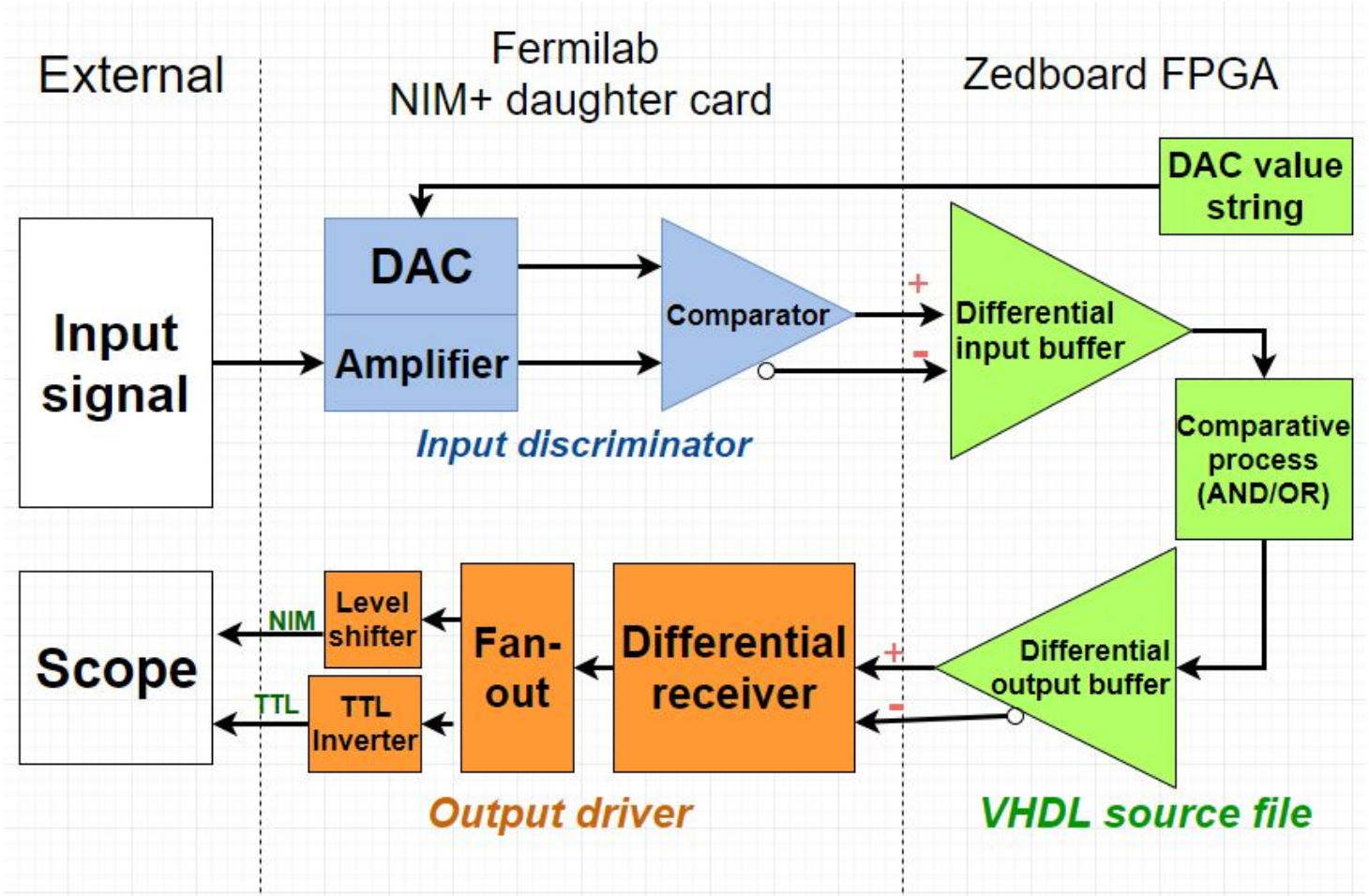
The BU test stand of V2 (2) daughter cards, with FMC extender

Mechanically secured with BU custom clamps:

on Zedboard,
on first Daughter card &
on Lemo I/O card



NIM+ & daughter card electronic block diagram



Current BU test stand: ZedBoard Performance

PMT inputs are used to determine a coincidence

PMT Input 1 (TOP)

PMT Input 2 (BOTTOM)

AND output from ZedBoard

Rise time ≈ 4ns

Decision time ≈ 20 ns

- no delay between overlap of pulses
- comparable to LeCroy 622 coincidence

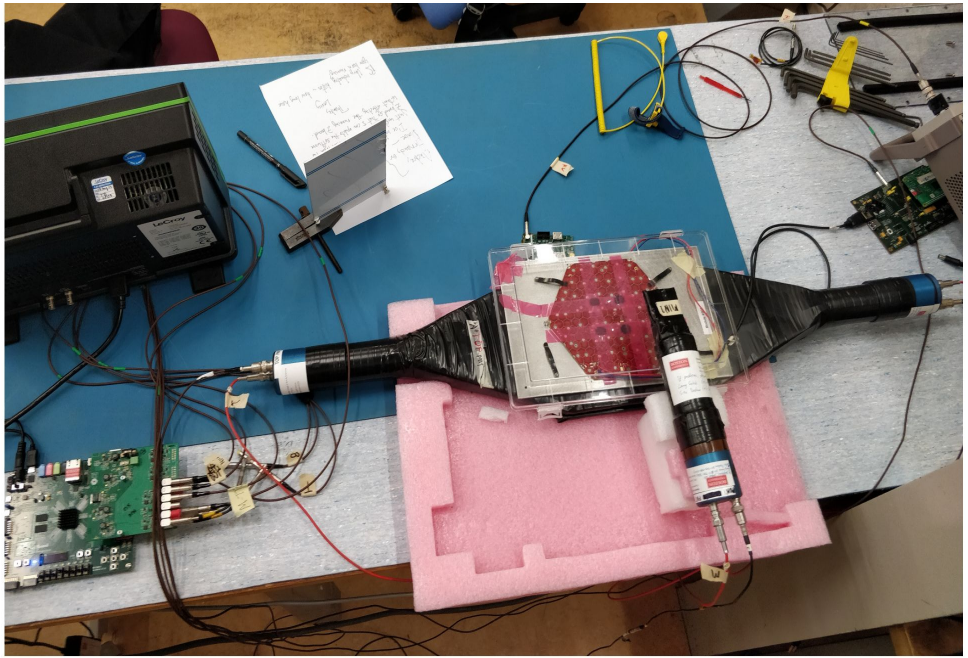
BU test stand at CERN , a close-up, August 2019

Testing an early hexaboard by A. Steen

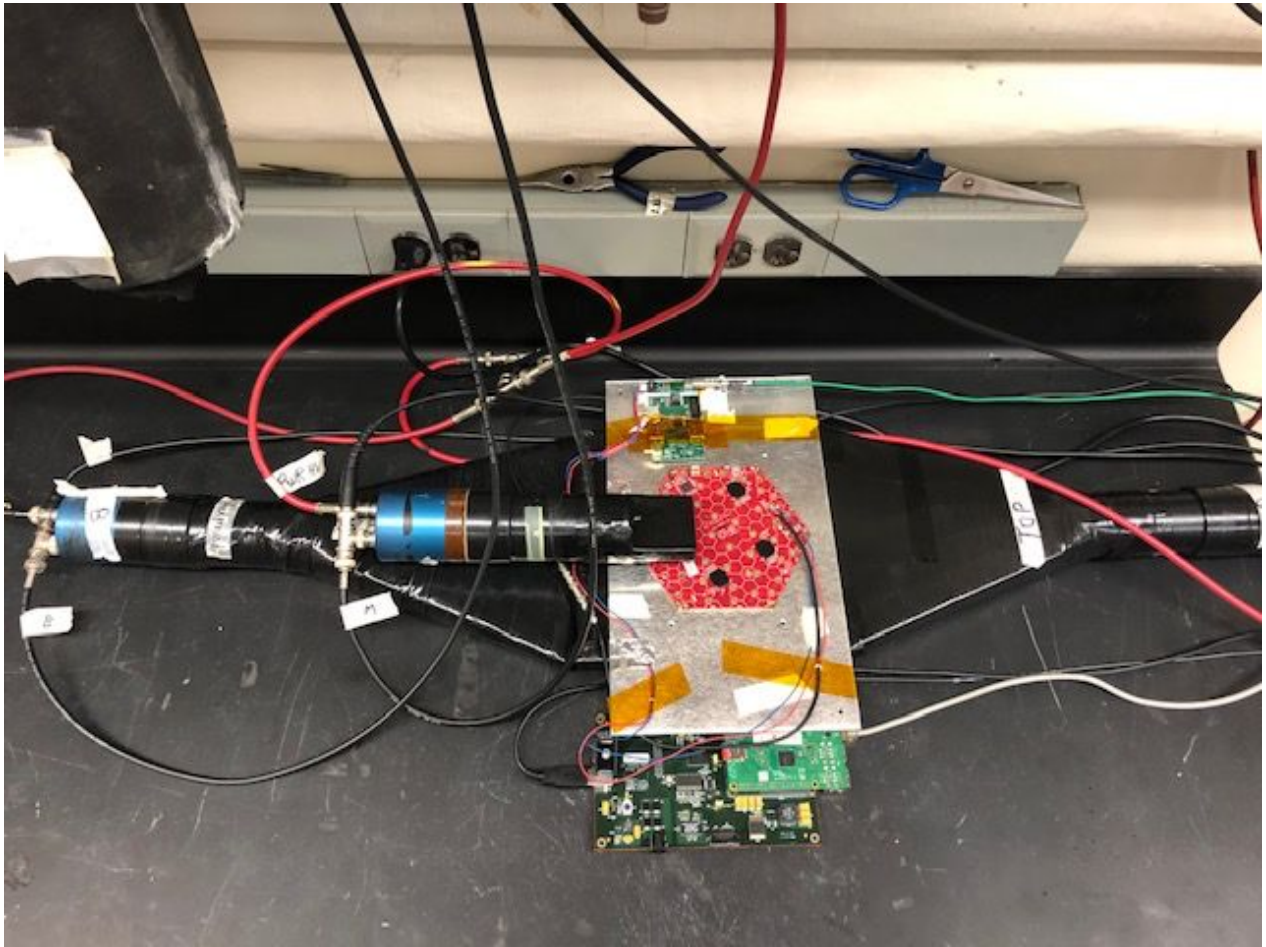
Still located in Bât. 27/R-002, Andre's lab.

Can go to test beams anywhere.

ZedBoard with V1 daughter



The hexaboard evaluation facility at BU today



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Toward “commercialization”… FNAL Prototype Packaging:

- NIM mechanics:
  - plugged directly into wall AC
  - No NIM crate required

Courtesy Mike Utes

In Summary

BU facility: fully tested both daughter card versions

Initially with V1, then V2

BU system has been running for ~2 years

- Triggering on coincidence of a two or three scintillator cosmic ray telescope

The third scintillator shadows a few HGCAL cells of the hexaboard

- Andre has suggested, a fourth channel might be helpful, with either a big or small scintillator, which we have, but have not yet investigated

Direct comparison of complete chain of NIM+ with LeCroy:

- efficiency of the two ~equivalent with completely new code, to be installed soon at CERN

Recent Developments: Python GUI

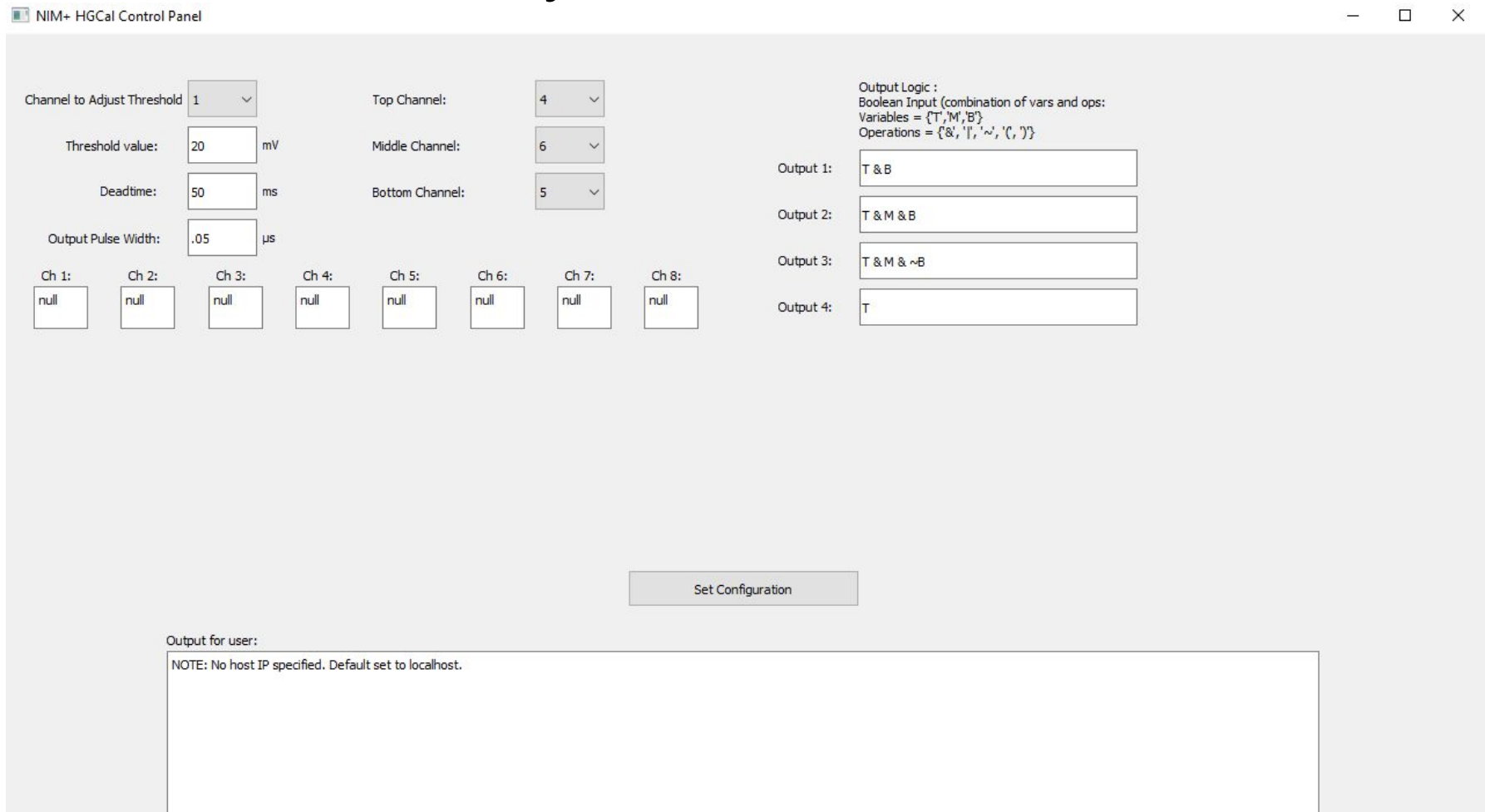
A GUI Python script sends chosen parameters via local network

- Individually sets thresholds for each of the 8 input channels
- Selects 3 inputs for use in output logic
- Sets a deadtime to suppress output rate [in 10ns increments]
- Sets output pulse width [in 10ns increments]
- Configures Output Logic (ANDs, ORs, XORs of the 3 chosen inputs)

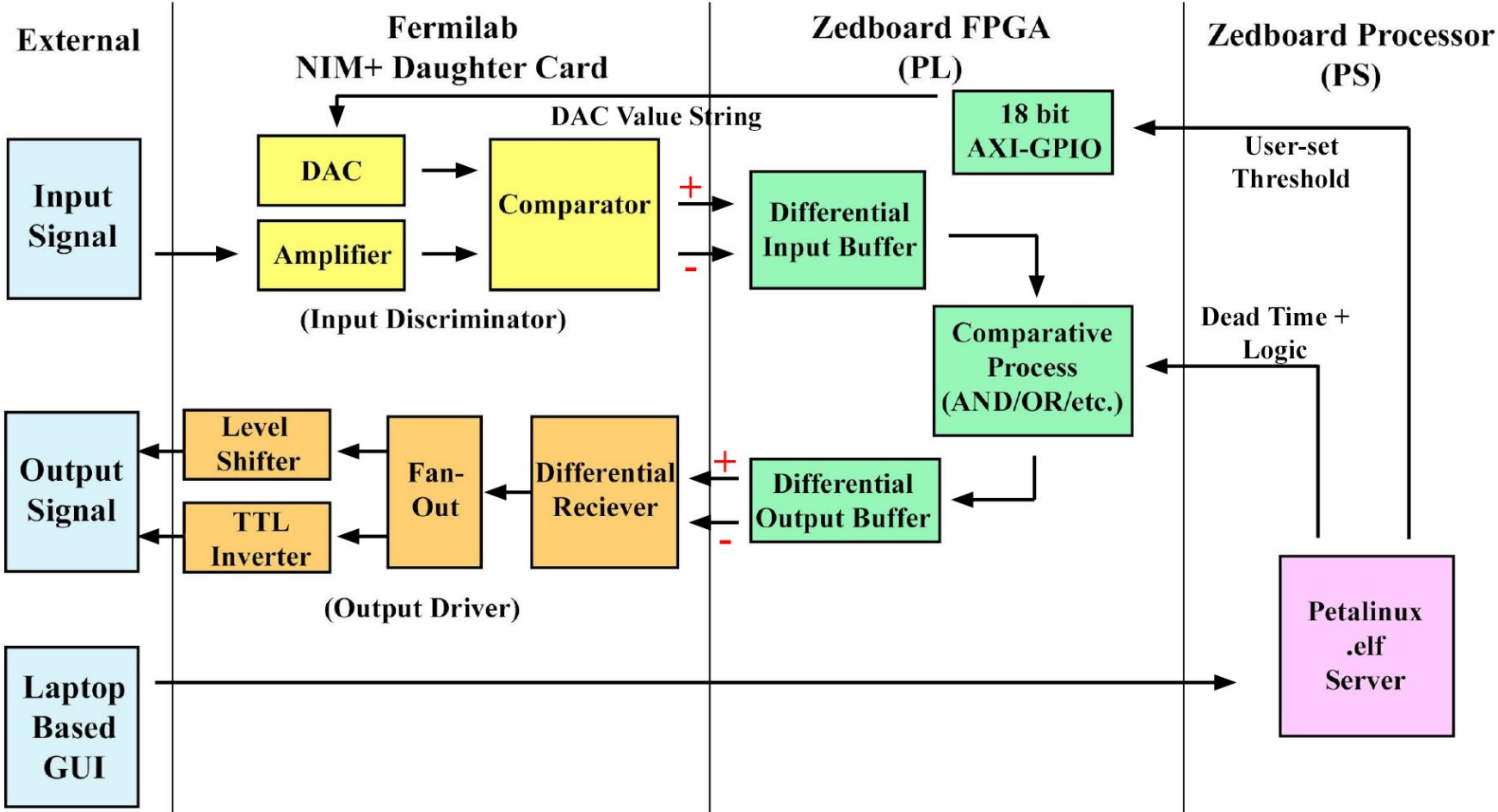
A server program runs on the ZedBoard processor:
receives the configuration
sends parameters via special reserved GPIO (General-Purpose Input/Output) memory slots to FPGA

Our GUI controls NIM+ which sends the trigger signals to a CERN data acquisition system

NIM+ HGCAL Python GUI Dashboard



Current Block Diagram



Next Steps: Performance Studies

Continuing to study the capabilities & limitations of our setup:

- Input threshold resolution & limits
- NIM+ efficiency within 2% compared to LeCroy 622 Quad Coincidence Module
  - With both systems set to 50mV threshold
- Timing resolution
- Implementing suggestions for improvement from CERN colleagues

Summary of HGCAL Hexaboard Testing Developments at BU

- NIM+ trigger system well integrated at CERN
- Ready to go to remote hexaboard testing sites,
- V2 daughter card debugged by team at BU with FNAL engineers
- Python-based User Interface up and running for controlling any test stand
- Various hardware parameters can be configured in real-time via GUI
  input selection, thresholds, output logic, deadtime
- Detailed performance studies ongoing

Special Acknowledgements

Thanks to all collaborators at:

- CERN
  - Dave Barney, Andre David, Arnaud Steen, Bora Akgun
- Boston University
  - Dan Arcaro, Dan Gastler, Eric Hazen
- FNAL
  - Paul Rubinov, Alan Prosser, Ryan Rivera, and Mike Utes

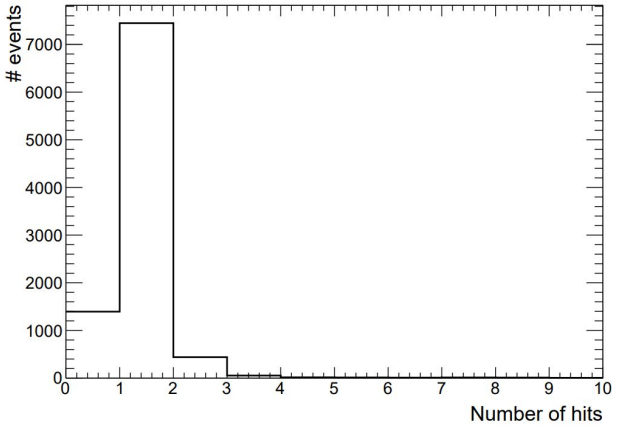
Thank you for your attention!

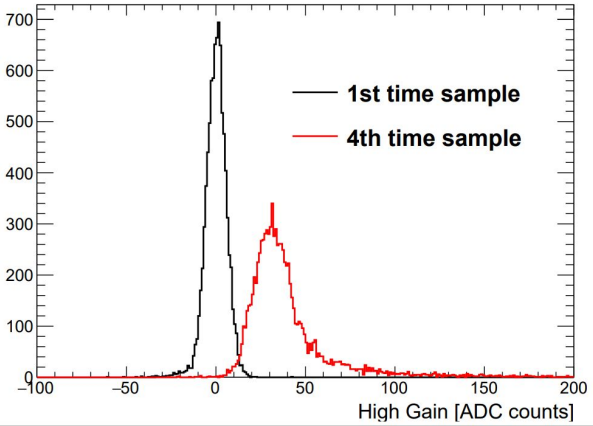
Questions?

Backup

Cosmic bench at CERN using NIM+

- 4 Skiroc2-CMS 8" modules
- Hexaboard RPI test stand DAQ board
  - Software : https://gitlab.cern.ch/cms-hgcal-tb/rpi-daq/, using the python-server (this is the default now)
  - Using the external_trigger option : A readout (stop acquisition) is triggered by a TTL signal in the LEMO connector of the test stand
- Cosmic trigger
  - Coincidence of the 3 scintillator
  - Trigger rate: $\approx$ 600 per hour
- Data analysis:
  - rpi-daq-analyzer : https://gitlab.cern.ch/asteen/rpi-daq-analyzer (no cmssw any more)
  - Pedestal subtraction using data from pedestal run
  - CM subtraction using all connected channels (49-50 per chip are connected)
  - A hit is considered if : $hg[TS3] + hg[TS4] - 0.6hg[TS6] > 40$
  - MIP $\approx$ 30 ADC counts, noise $\approx$ 5 ADC counts





Possible alternative host boards:

CAPTAN FPGA developed and used at FNAL

Ultra96 from 96 Boards (~$250 as singles)

ZynqBerry from Trenz Electronic (~$150 as singles)

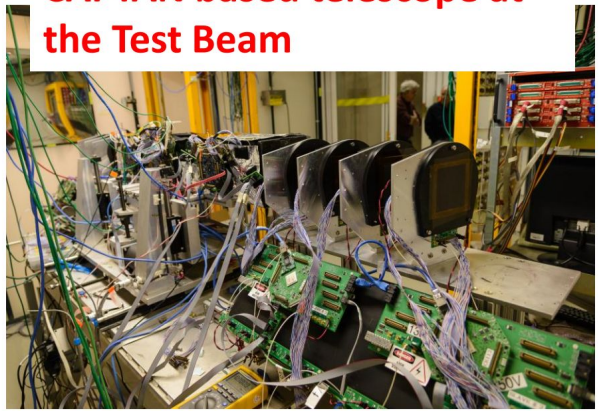
Both would require FMC adapters to interface with daughter card

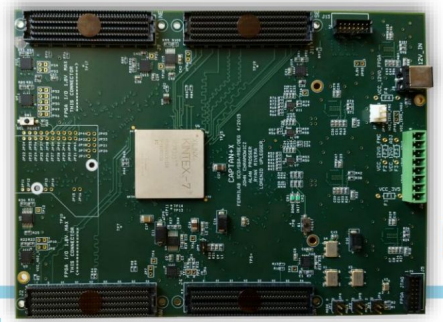
NIM+ in Fermilab Engineers Retreat

The CAPTAN+/OTS system for the Test beam

- CAPTAN+ is a general purpose board based on a Xilinx 7 series and up to 10 Gbps data transfers. Featuring:
  - Gigabit Ethernet, 4 FMC connectors, 400 GPIO
  - Single DC 12V Input Power Block
- CAPTAN user community:
  - Fermilab: PPD, SCD, Test Beam Facility
  - Purdue University
  - University of Colorado Boulder
  - INFN Milano and Lecce
  - UNAM, Mexico
  - Universidad Nacional del Sur, Argentina
  - Instituto Balseiro, CNEA, Argentina
  - Universidad Nacional de Asuncion, Paraguay

CAPTAN based telescope at the Test Beam





Also used in the Replacement of old NIM modules

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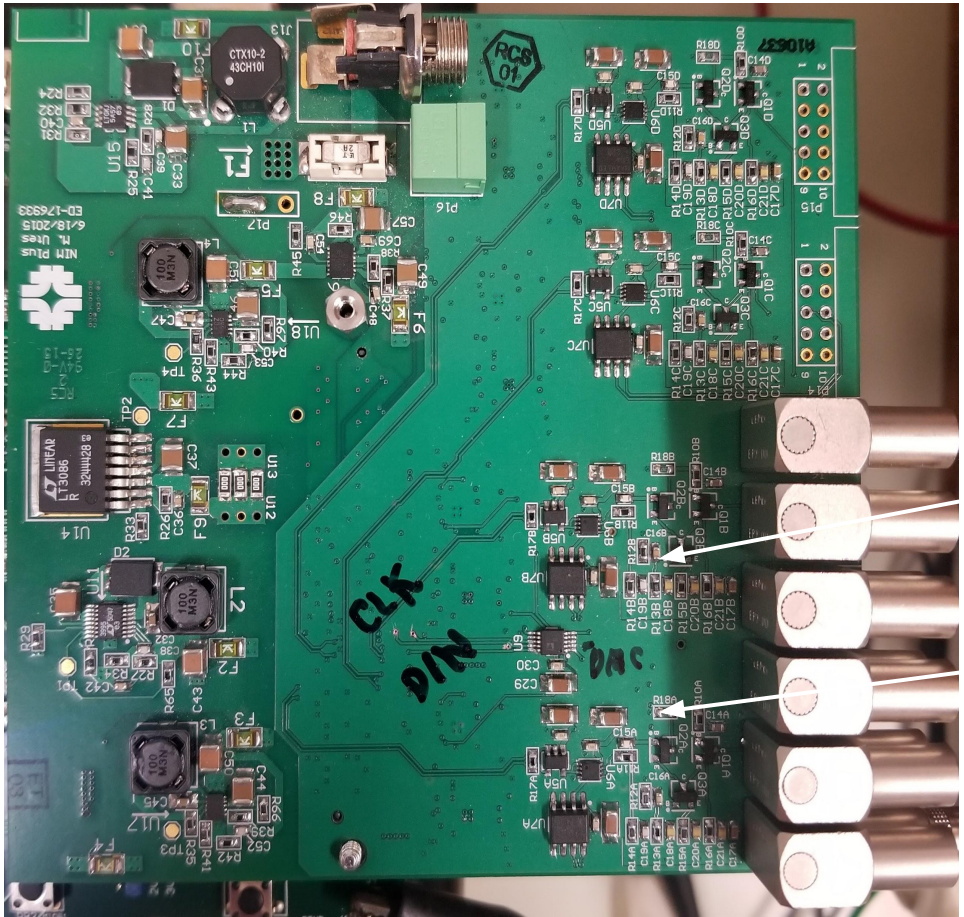
The FNAL Daughter Card, Version 1 Closeup



Bare Hex Module