Nalu Scientific
Data Acquisition Systems

Design and Development of TRBHM: Time Resolved Beam Halo Monitor

Ben Rotter, Project PI, Lead Physicist at Nalu Scientific, LLC

August 10th, 2022

Partially supported by DOE SBIR - DE-SC0019531 Grant (PoP: 4/6/2020- 12/31/2022)

Phase II Motivation and Objectives

Nalu Scientific
Data Acquisition Systems

Non-destructive electron beam halo monitoring on a bunch by bunch basis

- Ability to monitor up to 100s of MHz rep rate with sensitivity down to tens of incident accelerated electrons
- LCLS-II, any future electron accelerator facility, possibly EIC

Technical Objectives:

1. Assessment of integration requirements and definition of desired product characteristics.
2. Design, Manufacturing, and Integration of the discrete detector components into a single easily deployable and testable device
3. Testing, validation, and characterization of the integrated TRBHM module at a commercial electron beam facility.

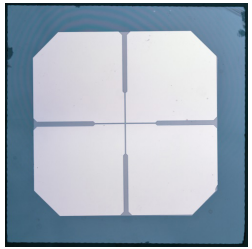
Diamonds as a particle imager

Nalu Scientific
Data Acquisition Systems

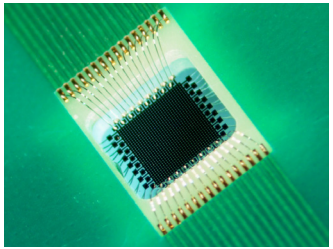
Advantages:

- High Thermal Conductivity
- Mechanically Strong
- Radiation Hard
- Indirect Bandgap

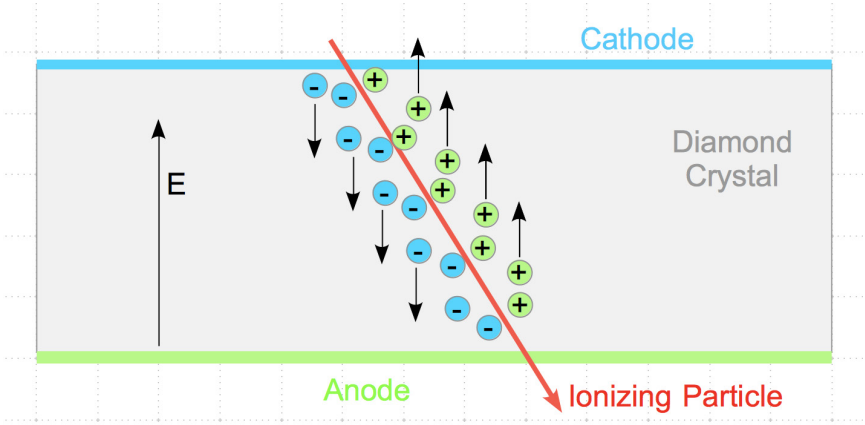
Diamond BPMs already widely used for X-ray beams



Sydor Inc.

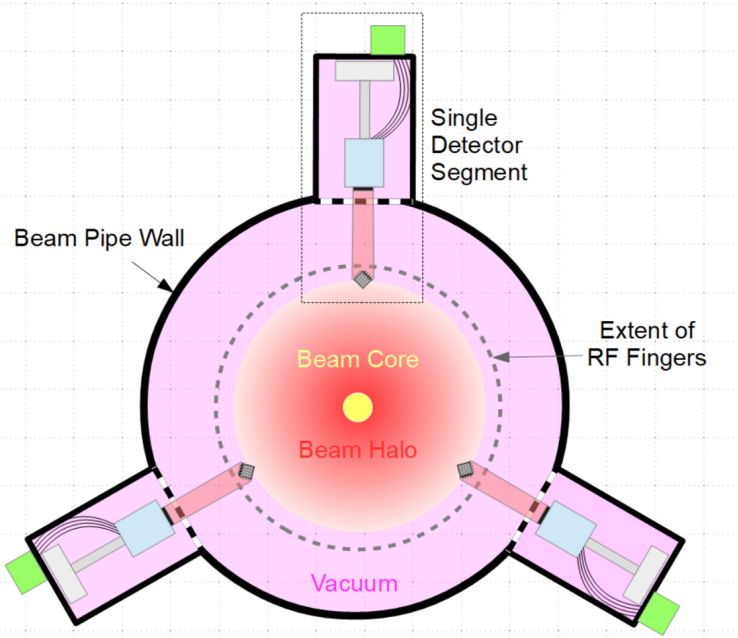


Highly Pixelated Detector

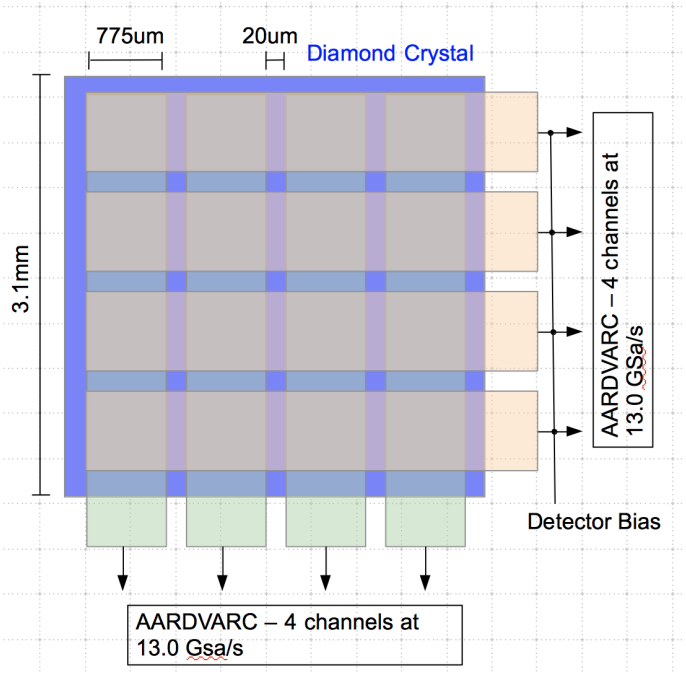


Current induced on both top and bottom electrodes with opposing polarity

Multi-Detector Integration



Cross-strip lithography patterning



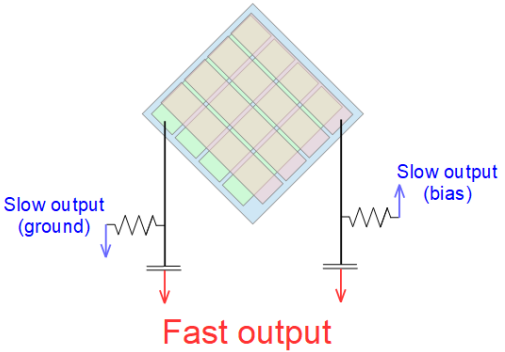
Frequency Splitting

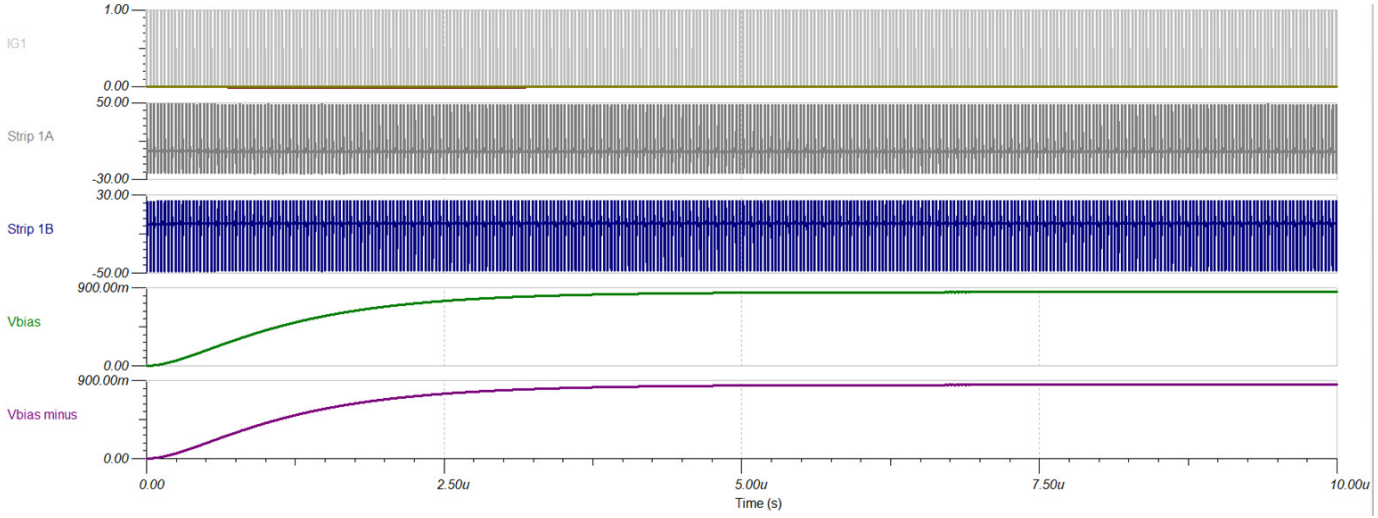
Induced current has both an impulsive broad-band component as well as a DC component

Broadband measurement gives more precise timing (~10ps) and time-compression of signal power gives larger voltage spike

DC component is unavoidable and allows for long time-scale integrated measurement

Can measure both!





Currently implemented using simple RC filter, however experimenting with using a multi-pole complex filter

Diamond thickness

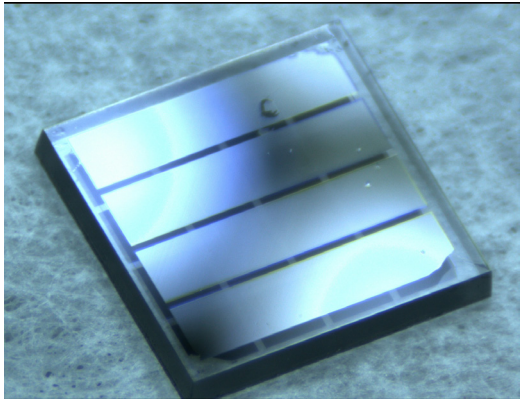
Also bias voltage

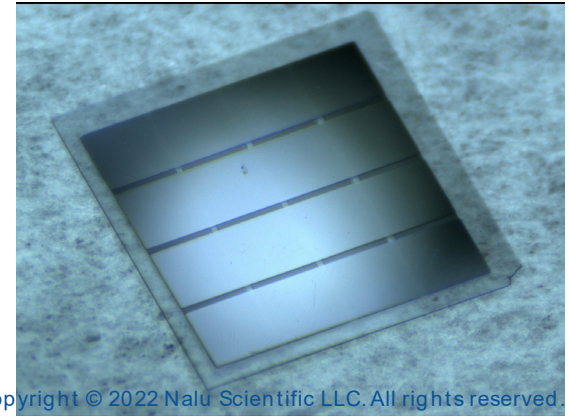
Thicker diamond means more induced charge from more interaction volume

Thinner diamond requires lower bias for full charge collection and faster “clearing” time

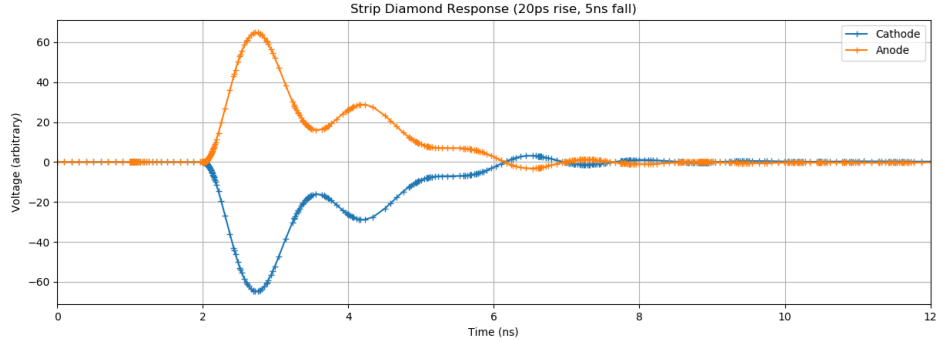
Possible to do some analog pulse shaping, match spectral power to digitizer analog bandwidth

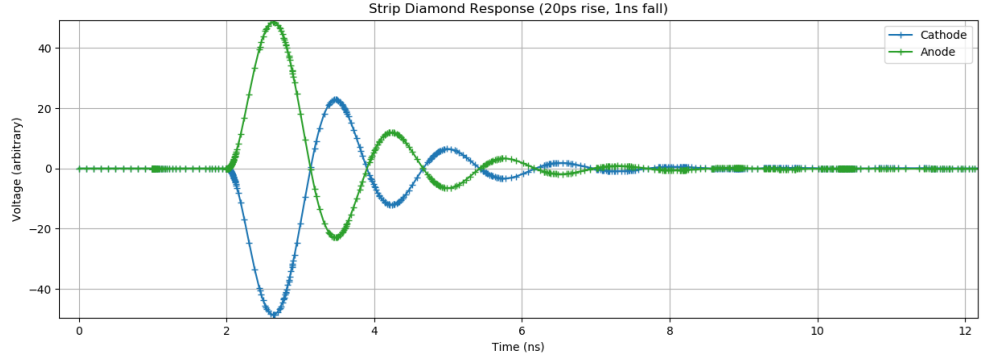
500um





50um





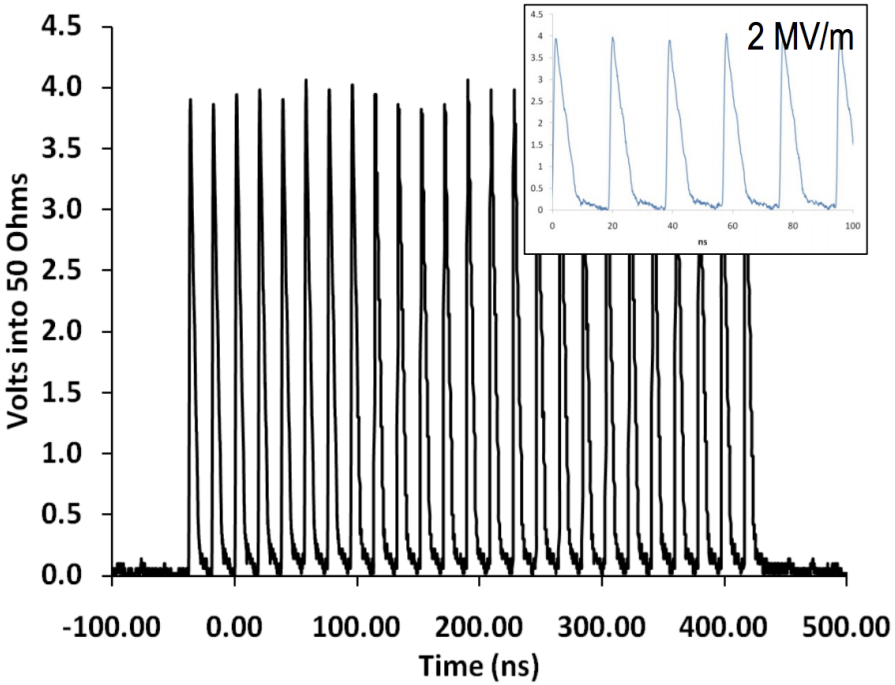
*simulation, 50MHz cutoff frequency

Detectable Signal

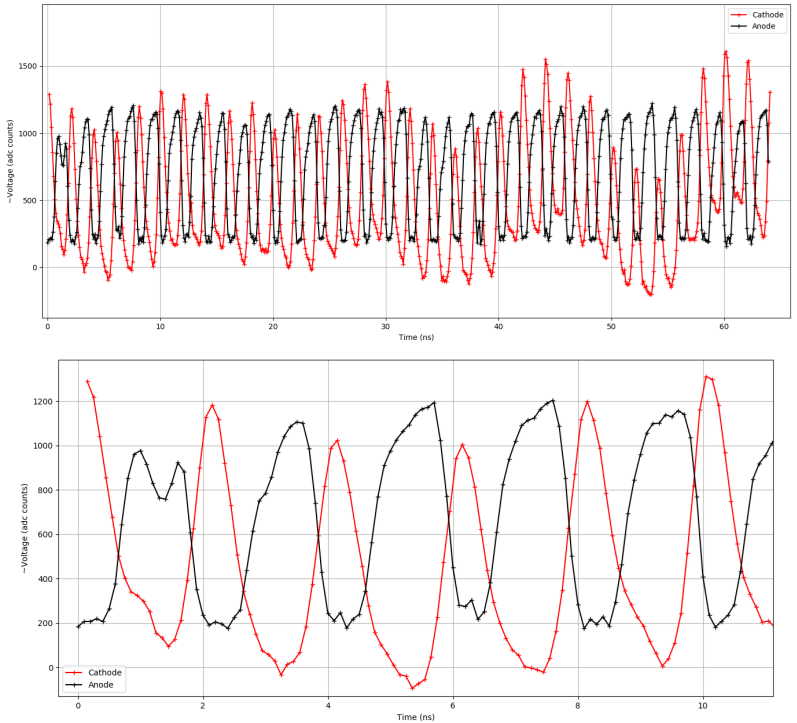
Low charge, high bandwidth current impulses from multiple channels

(rise is electronics limited, fall is carrier mobility inside diamond (e- = 2e7cm/s, holes= 1.6e7 cm/s)

Scope Measurement



AARDVARCv3 measurement (NSLS-II)



"Development of diamond-based x-ray detection for high flux beamline diagnostics", Bohon, Muller, Smedley in preparation.

Diamond Readout using AARDVARCv3

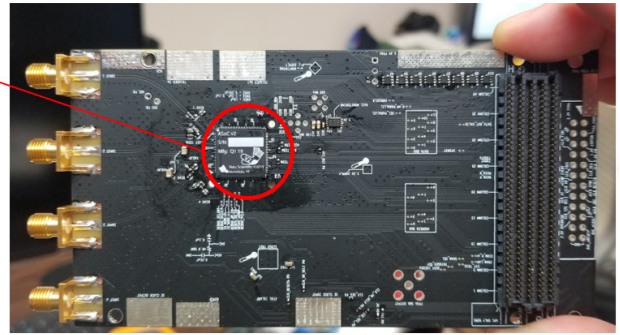
Nalu Scientific
Data Acquisition Systems

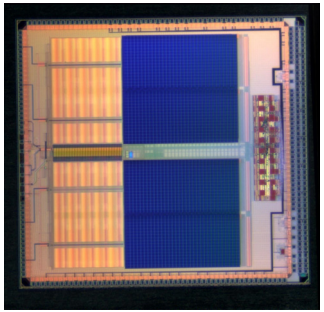
10GSaps waveform digitizer

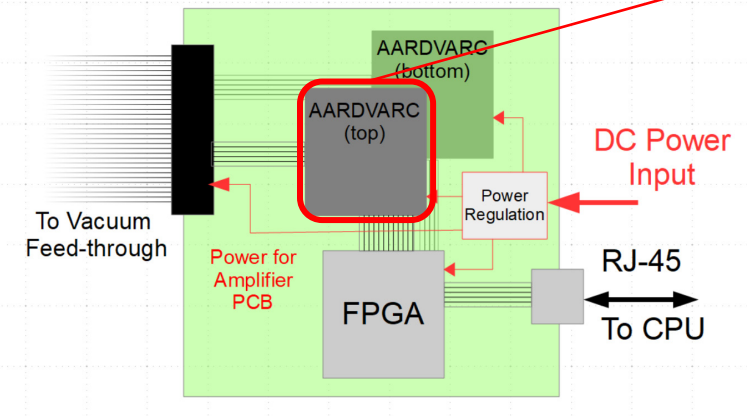
130nm CMOS mixed-signal low size, weight and power ASIC, suitable for operation in high radiation

Currently being used in other projects, so very derisked

High analog bandwidth (1.6GHz) will allow for good timing precision (~10ps), and larger signal acceptance





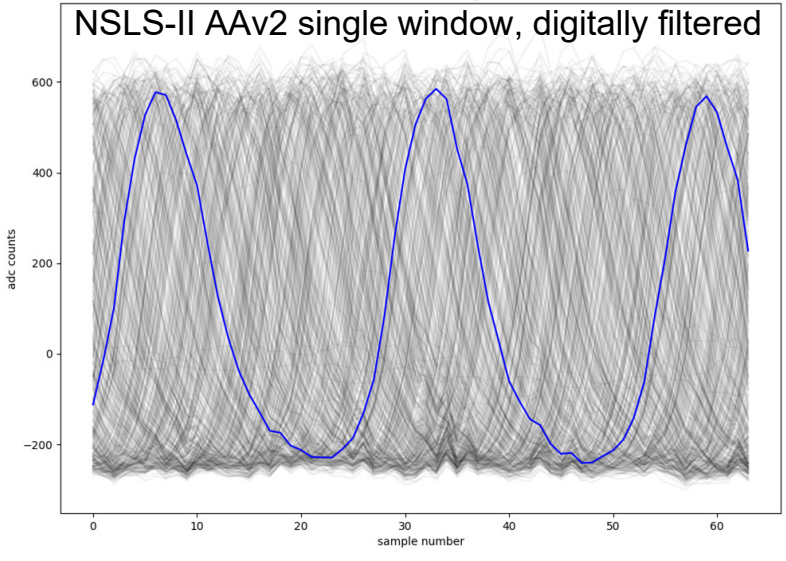


AARDVARC provides sufficient time fidelity

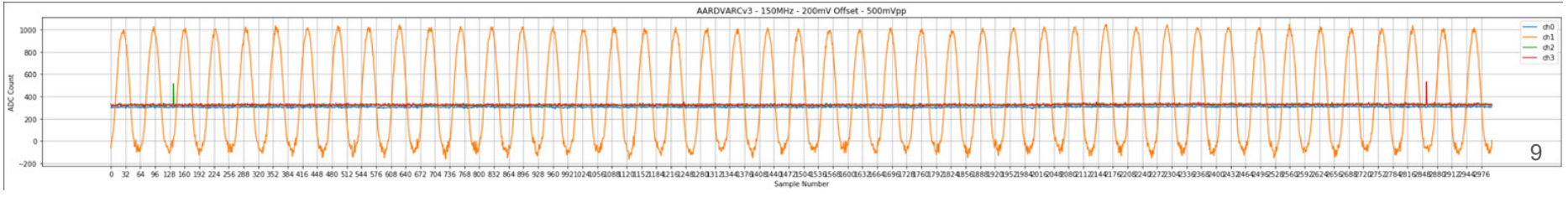
AARDVARCv3 seems to have little to no leakage, so it is a perfect candidate

Currently being used in other project, so very derisked

High analog bandwidth will allow for better timing precision

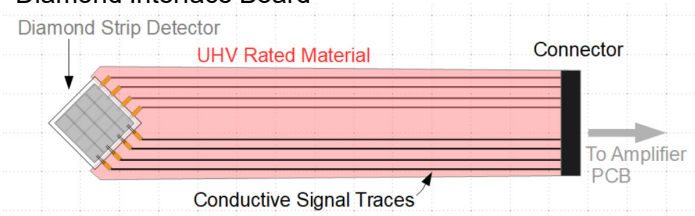


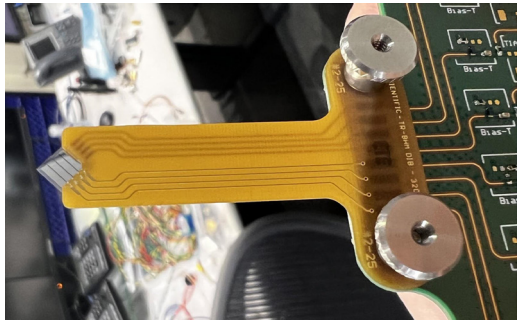
AAv3 multi-window readout



Additional Custom PCBs

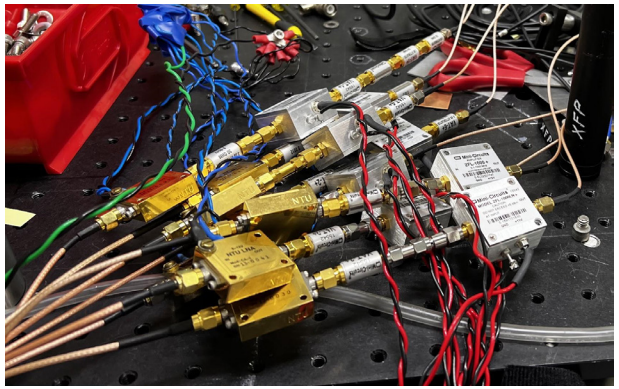
Diamond Interface Board

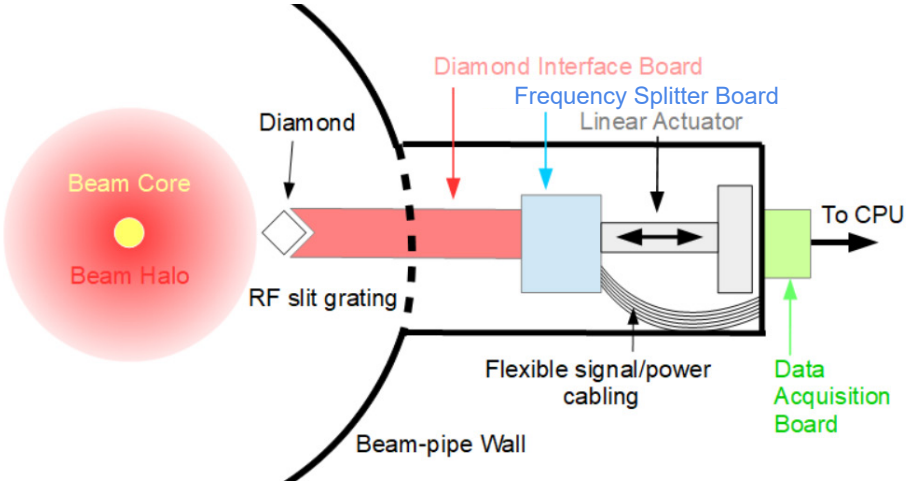




Frequency splitter and coaxial cabling

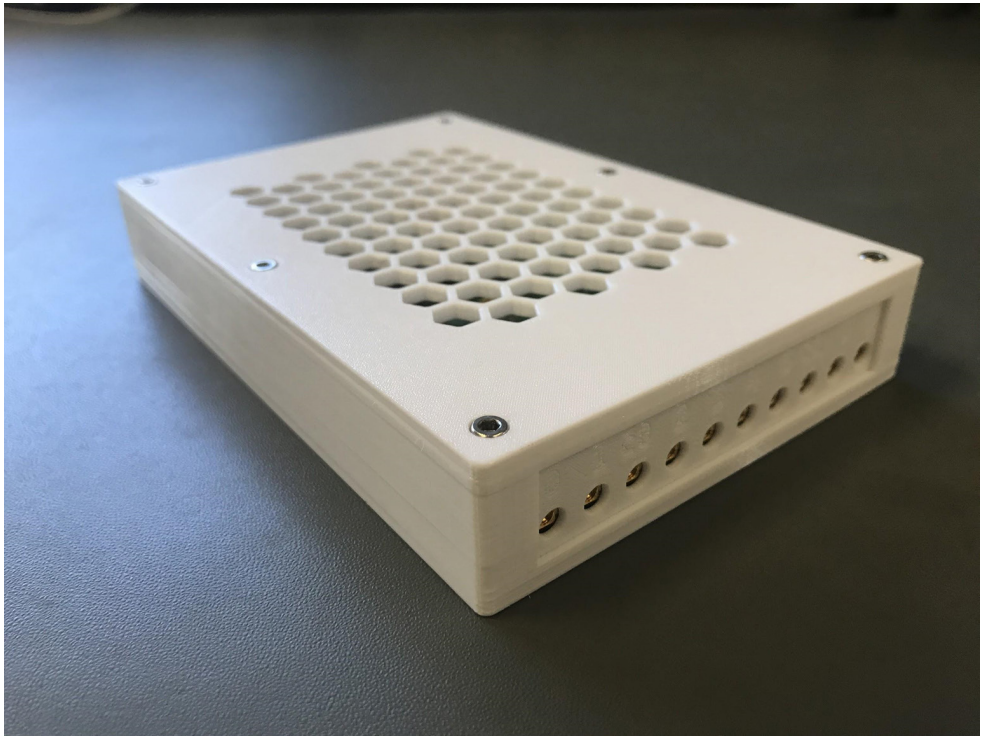
COTS broadband amplifiers
(to be integrated into single board)

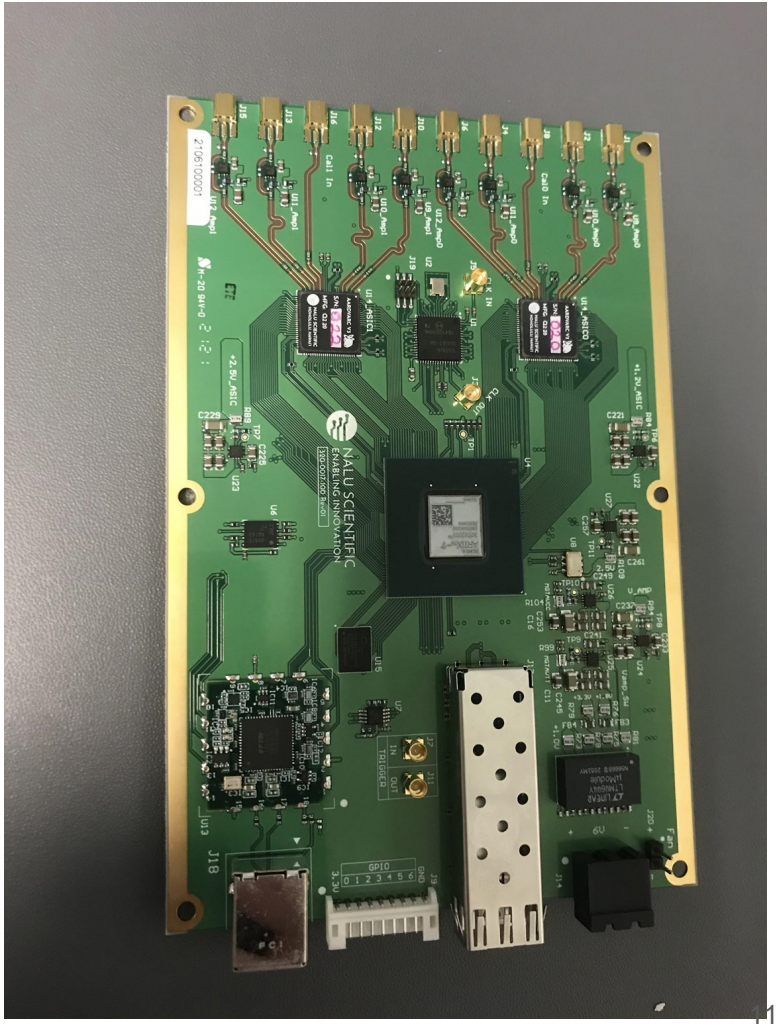




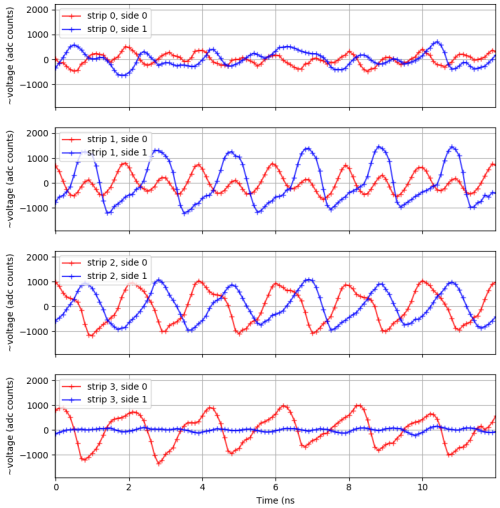
Digital Acquisition Board

2x AARDVARCv3 10GSaps waveform digitizers
FPGA control with basic on chip feature extraction
On-board EEPROM for calibration constants
Ethernet data output
External and self triggering capability

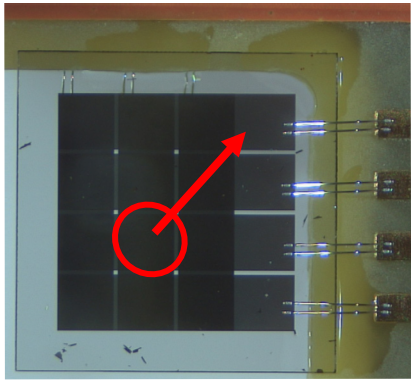


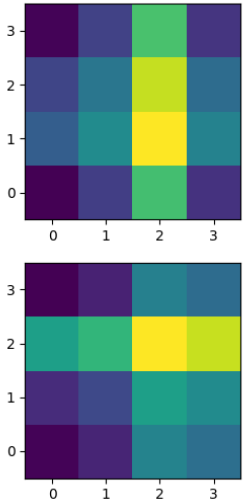


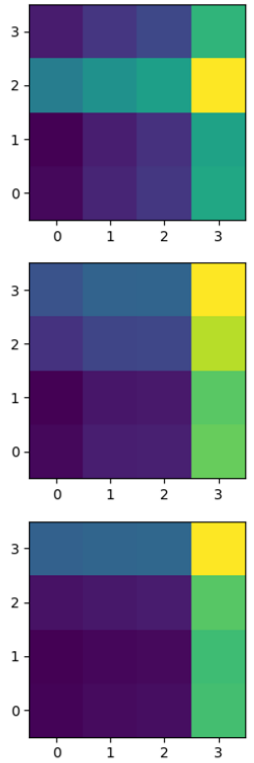
Initial data from NSLS-II: vertical scan across diamond



Averaging event peak-to-peak voltage per position (downward movement of 500um per step)

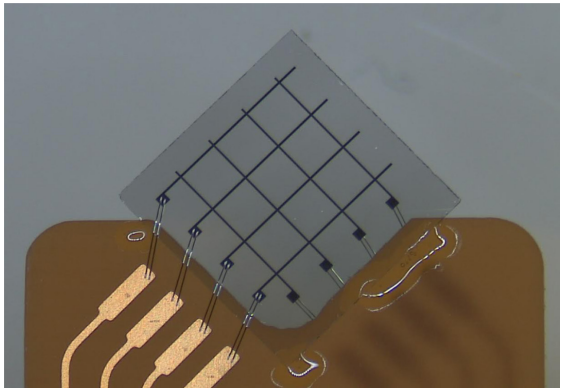


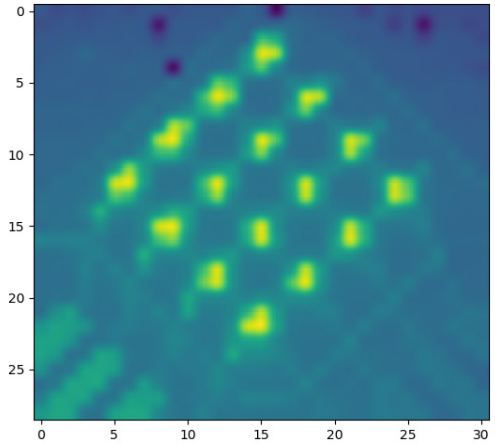




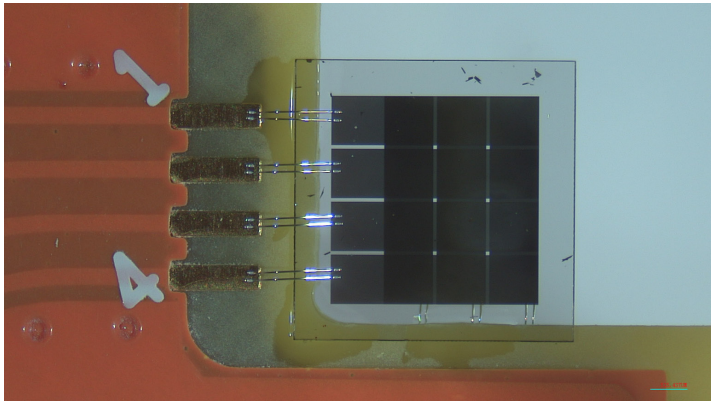
Electrode lithography pattern

DC response of “thin wire” diamond





“Fat strip” lithography



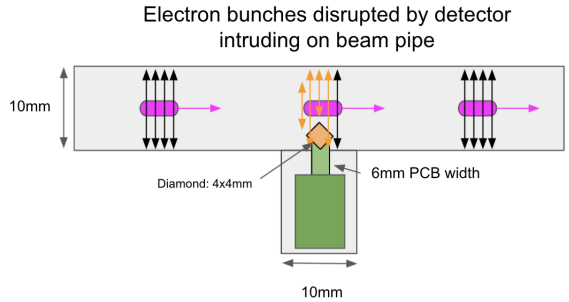
Thin electrodes reduce device capacitance, which allows for a faster impulsive rise, as well as reduce cross talk between channels.

Require much higher bias voltages however, and spaces between have low collection efficiency

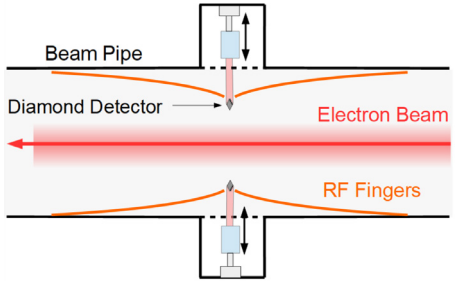
Optimal is somewhere in the middle

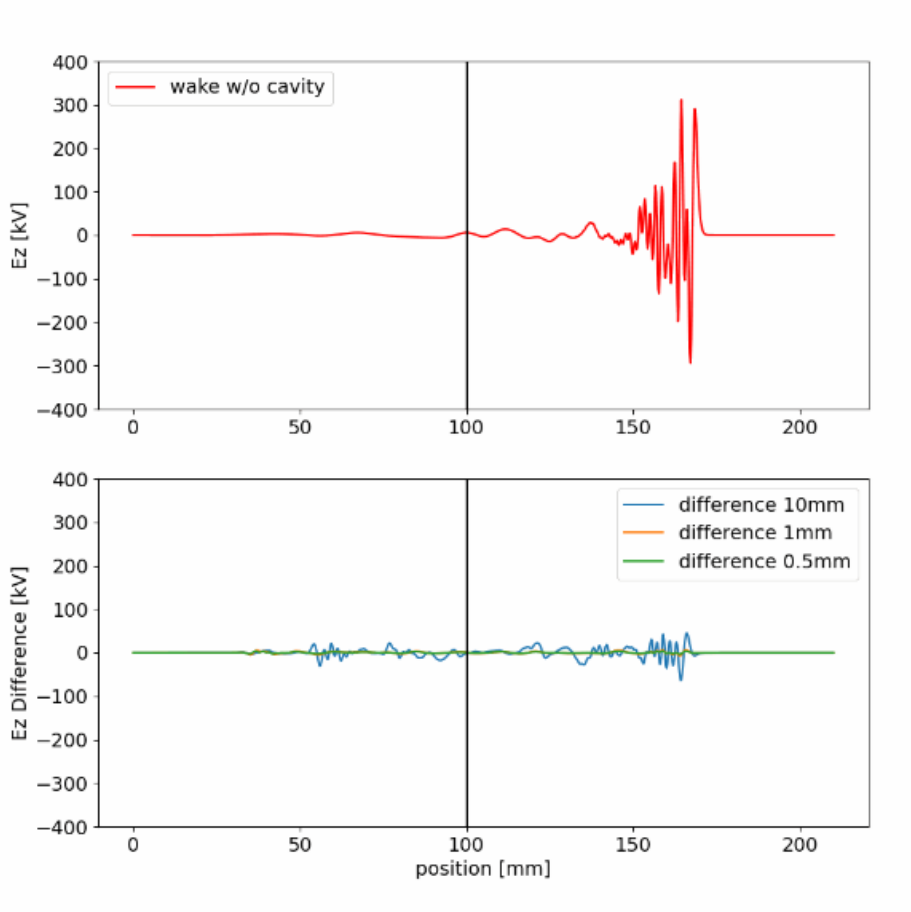
Wakefield Simulation

Simulating effect that diamond intrusion will have on wakefield accomplished through partnership with Radiasoft

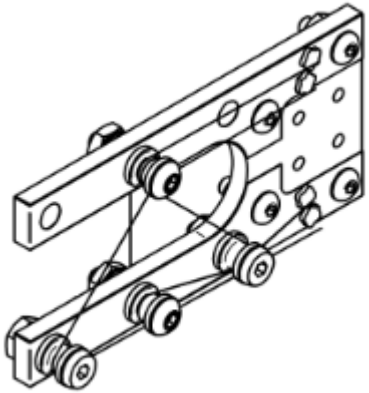


Possibility to add RF fingers to smooth impedance transition

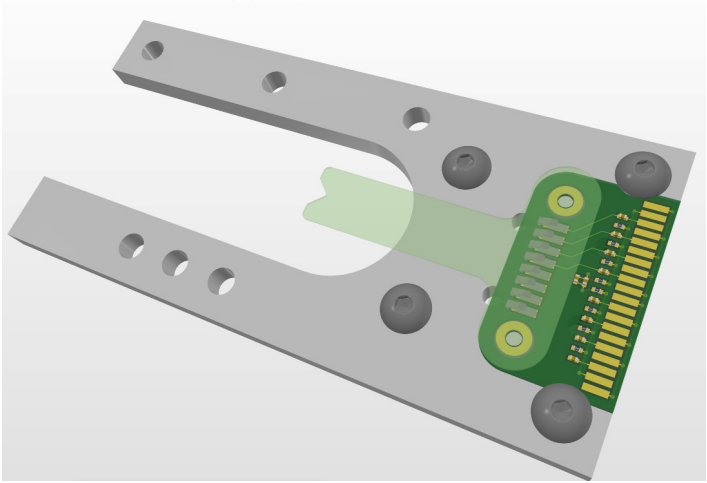


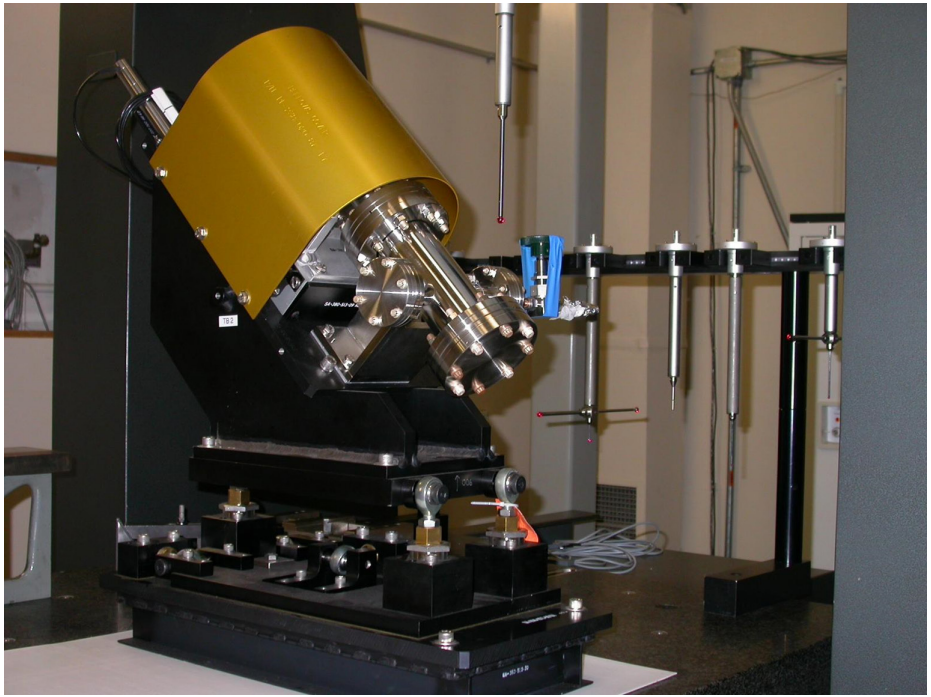


Future testing at SLAC



ISOMETRIC VIEW - TOP



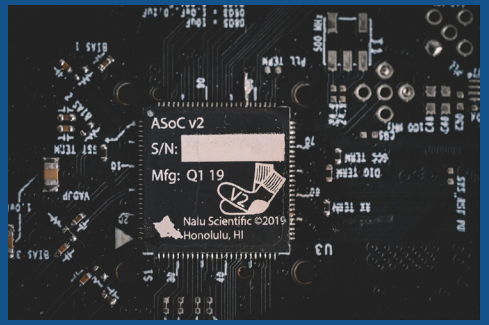


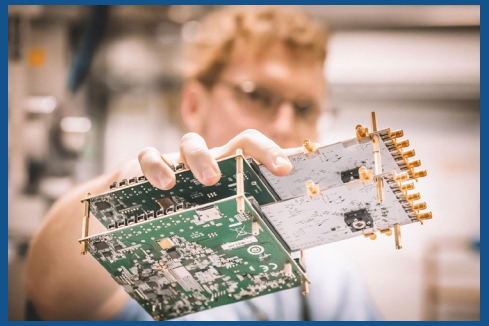
Plans to mount diamond board on existing actuated wire scanner beam monitor at FACET beamline at SLAC

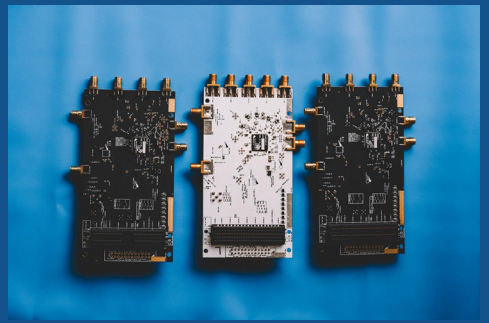
Next Steps and Work in Progress

Nalu Scientific
Data Acquisition Systems

1. Manufacturing of Diamond Interface Board
    a. Requires low outgas materials and low capacitance traces
    b. Re-bond diamond to new board (currently requires Brookhaven)
    c. “Spring compression” interconnect to enable modular testing
2. Manufacturing of Frequency Splitter Board
    a. Requires low outgas materials
    b. Simulation of diamond output current pulse along with measured values to determine optimal cutoff frequency
    c. Cabling to vacuum housing bulkhead
3. Manufacturing of multi-stage broadband amplifier board
    a. Using COTS low noise Minicircuits amplifiers
4. Test with new electronics at NSLS II
    a. July 27th, just completed
    b. Analysis currently in progress
5. Future e-beam testing at SLAC’s FACET







ABOUT NALU SCIENTIFIC

Fast Growing Startup in Honolulu, Hawai'i

- Located at the Manoa Innovation Center near U. of Hawaii
- 18 staff members-diverse background
- Access to advanced design tools
- Rapid prototyping and testing lab

Technical Expertise

- IC design: Analog + digital System-on-Chip (SoC)
- Hardware design: Complex multi-layer PCBs
- Firmware design: FPGAs, CPUs
- Software design: GUI, analysis, documentation

Scientific Expertise - NP/HEP subject matter experts

- Physicists (3x) - Application experts
- Electronics for large scientific instruments

Exclusive Distributor Agreement for North

- Sales of ASICs, eval boards
- Enhanced OEM opportunities

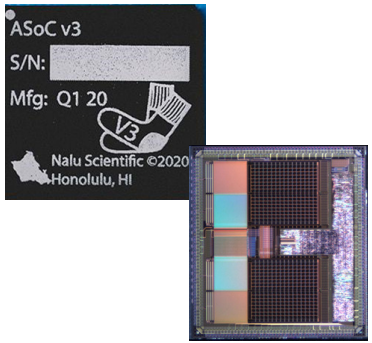
CAEN Technologies Inc.

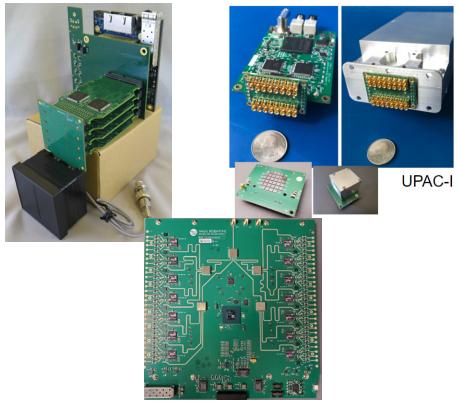
Nalu = 'wave' in native Hawaiian language

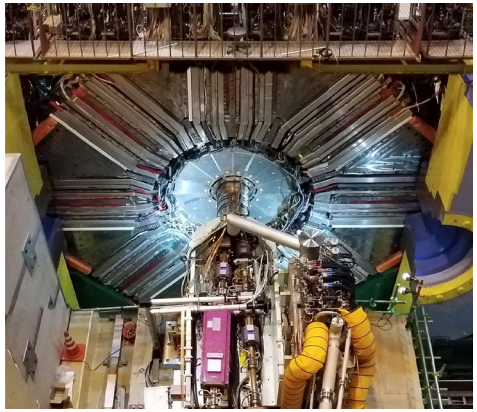
Backup slides

NALU SCIENTIFIC
ENABLING INNOVATION

WAVEFORM DIGITIZER SoCs
FOR PRECISE TIME OF FLIGHT ESTIMATION







1. Front-end Chips:

- Event based digitizer+DSP
- 4-32 channel scope on chip
- 1-15 Gsa/s, 12 bit res.
- Low SWaP-C
- User friendly: FW/SW tools

2. Integration:

- SiPM
- M/A PMTs
- LAPPD
- Detector arrays

3a. Main application:

- NP/HEP experiments
- Particle astrophysics

3b. Other applications:

- Beam Diagnostics
- Plasma/fusion diagnostics
- Lidar
- PET imaging

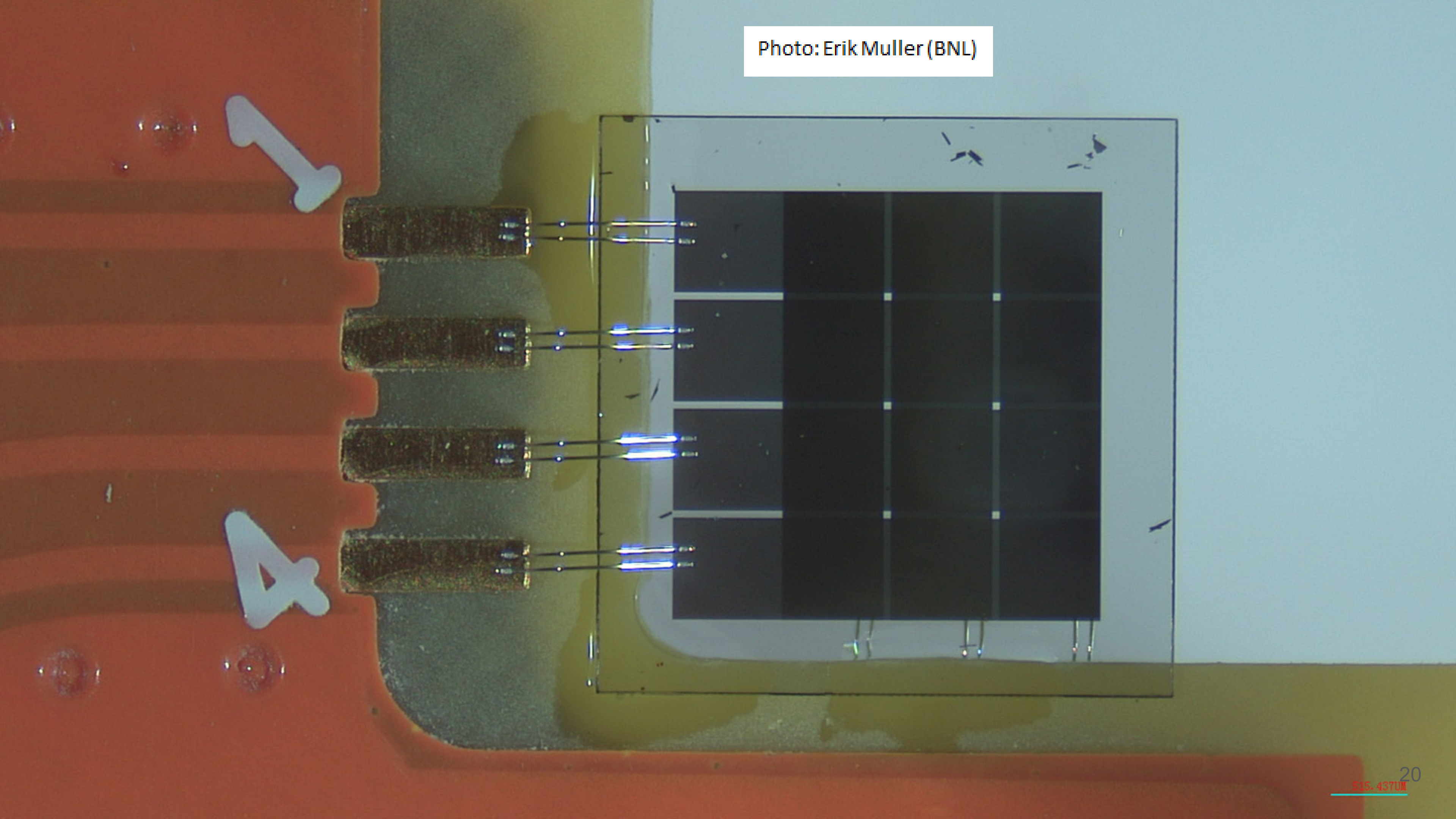
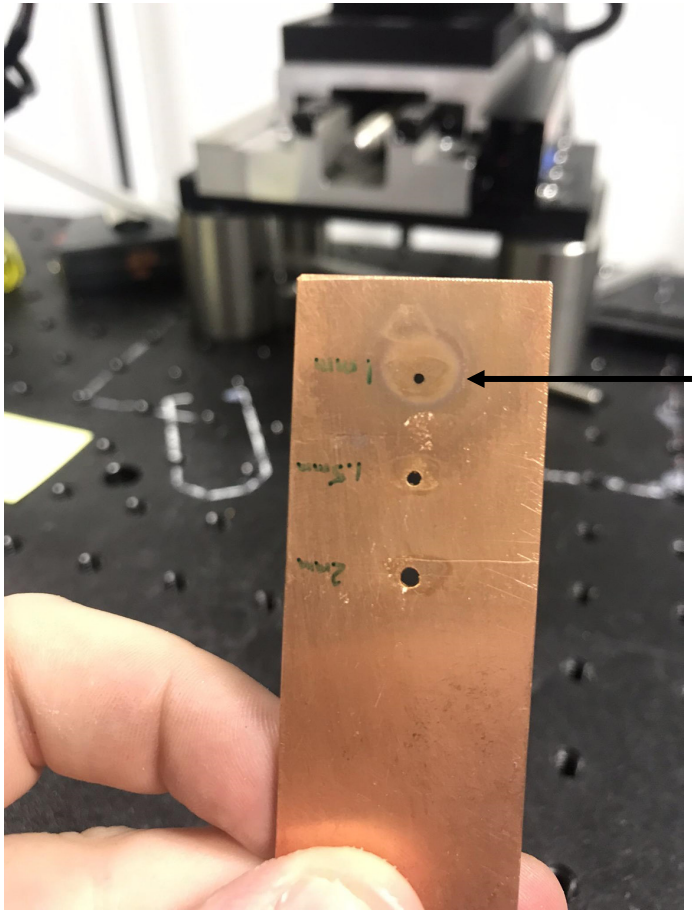


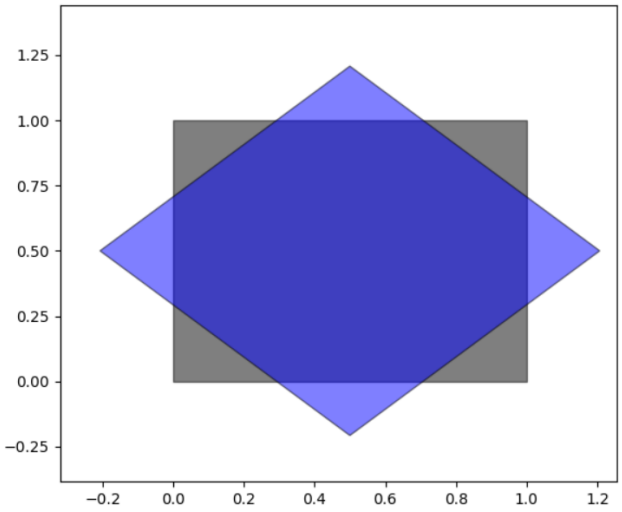
Photo: Erik Muller (BNL)

Pinhole X-ray aperture



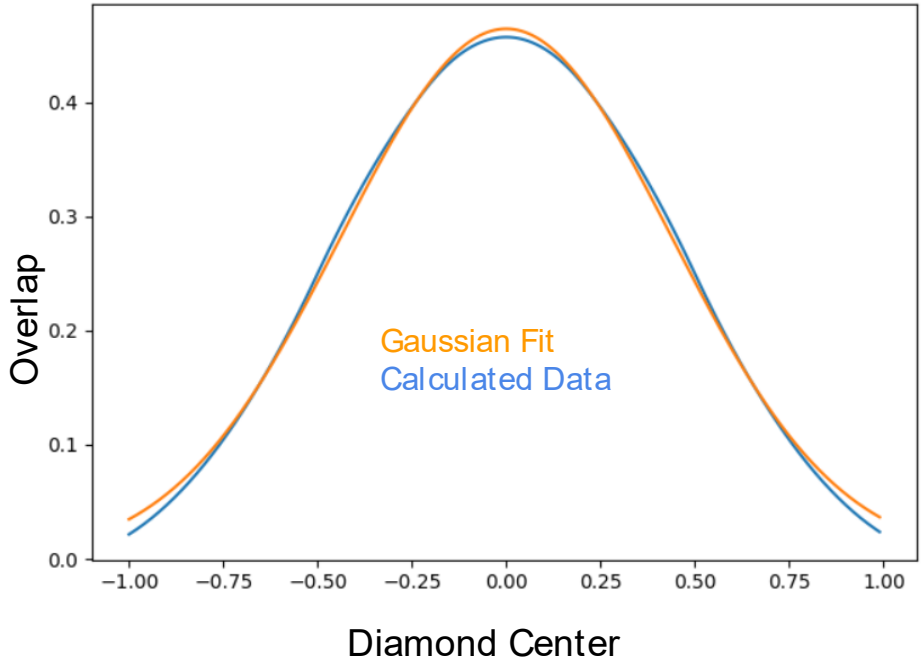
1mm spot size

Covers slightly more than 1 pixel

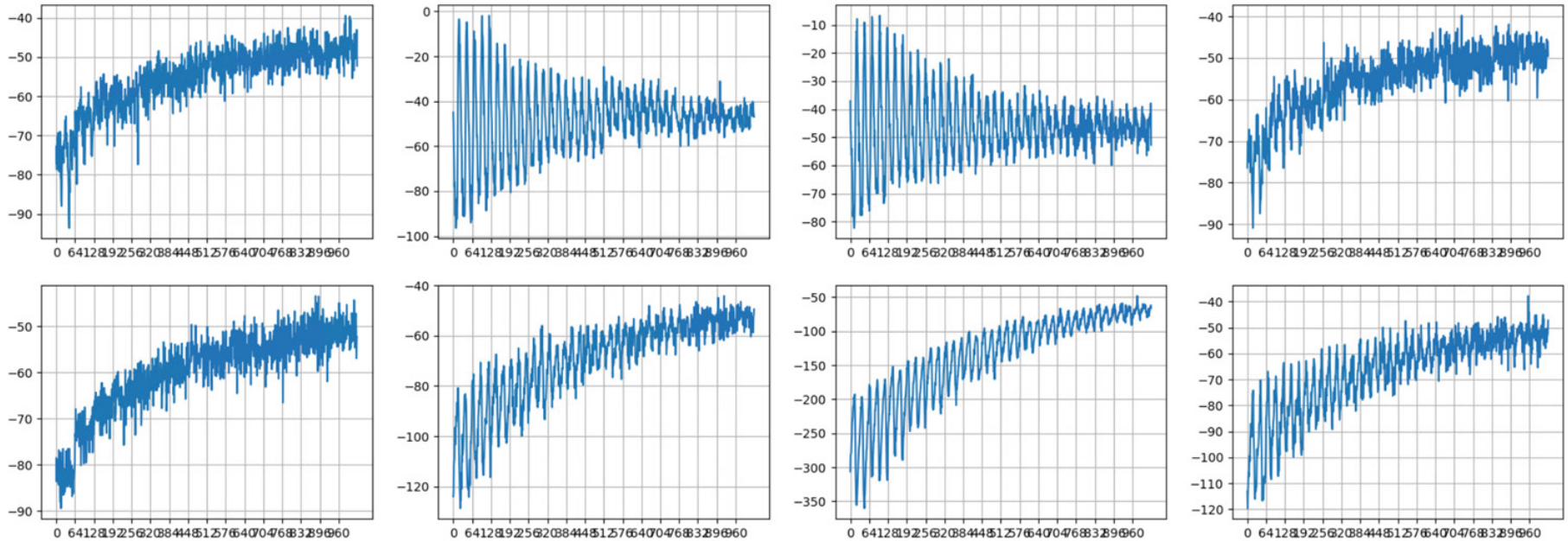


Not quite a gaussian, but pretty close

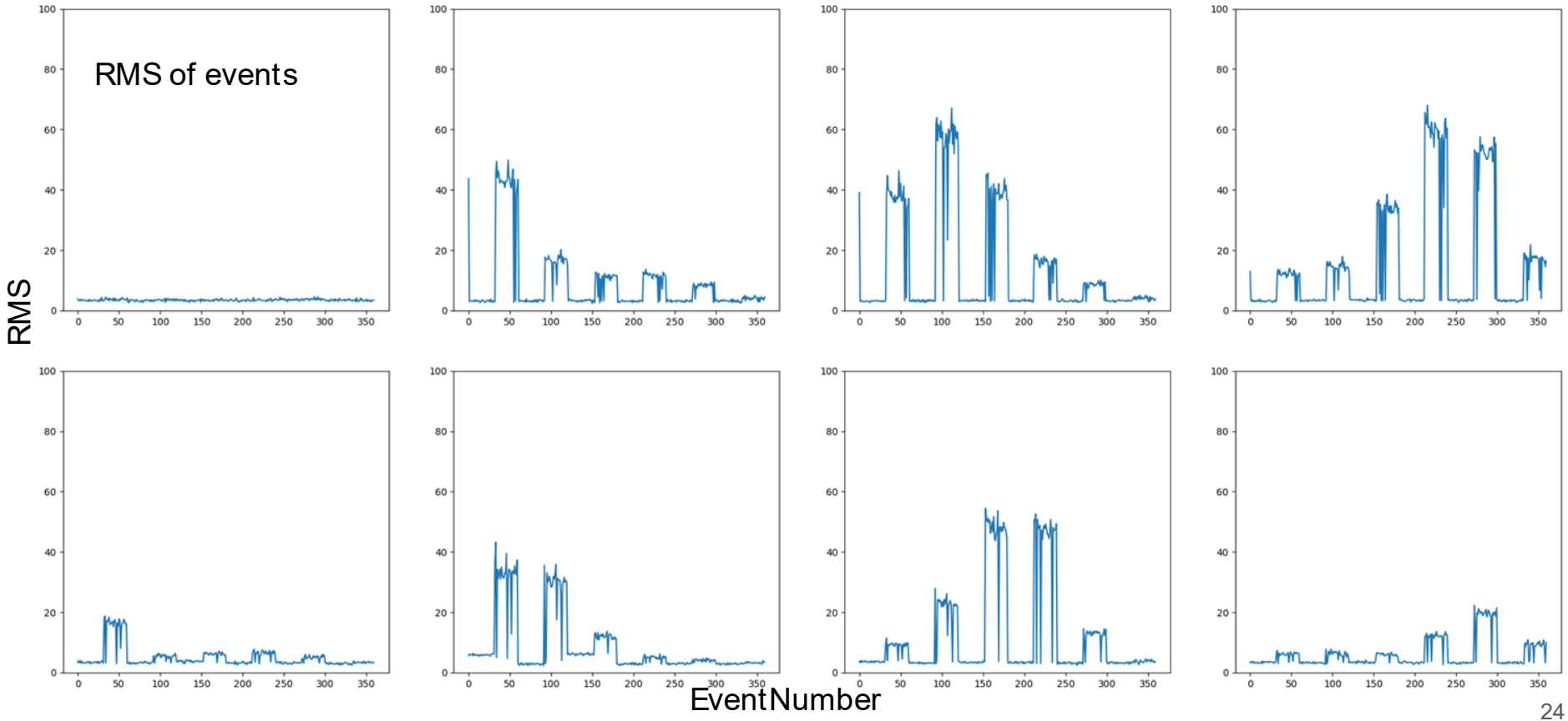
u



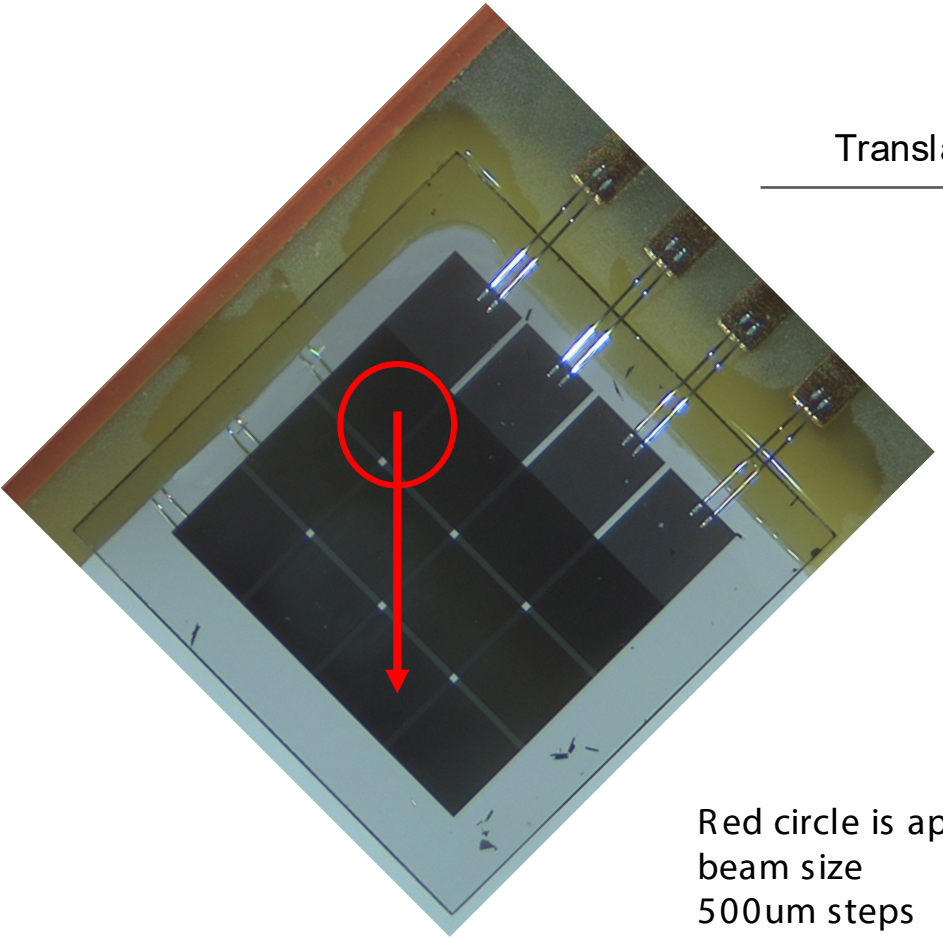
The aperture was actually a circle!!!



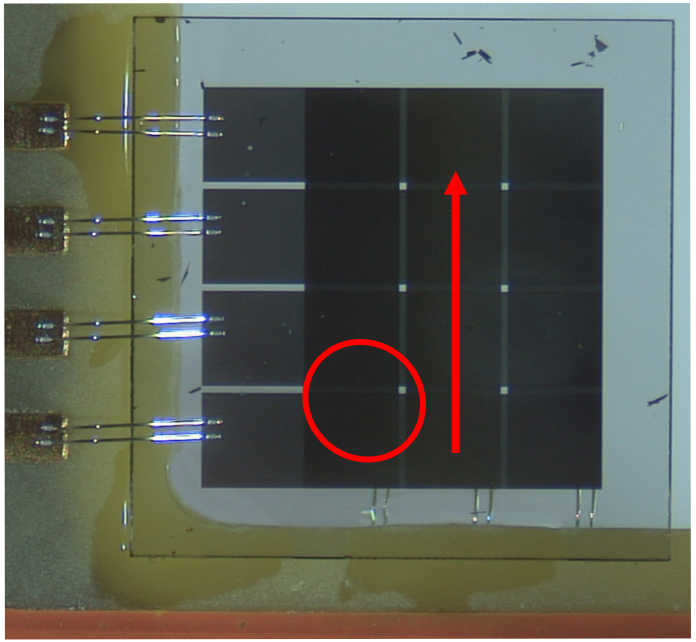
Read out with 2x AARDVARCv2 eval boards @ 13GSaps
“Curve” and amplitude decrease caused by SCA leakage (known 130nm issue)


RMS of events
RMS
Event Number

Vertical scan across diamond



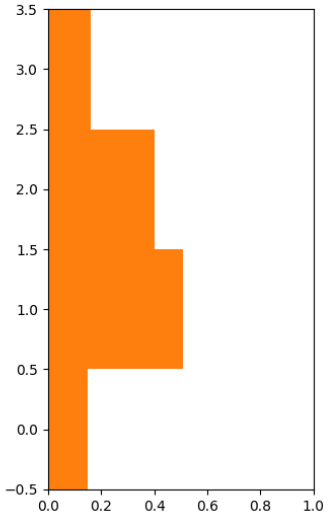
Translates to:

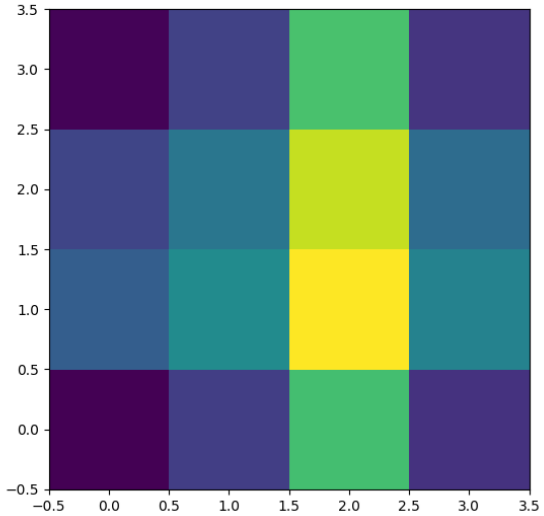


Red circle is approximate beam size
500um steps

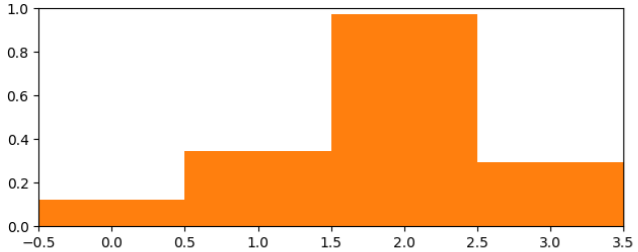
Overlaying orthogonal strips to make a pixel map

Average RMS of waveforms across “run” (~50 events)

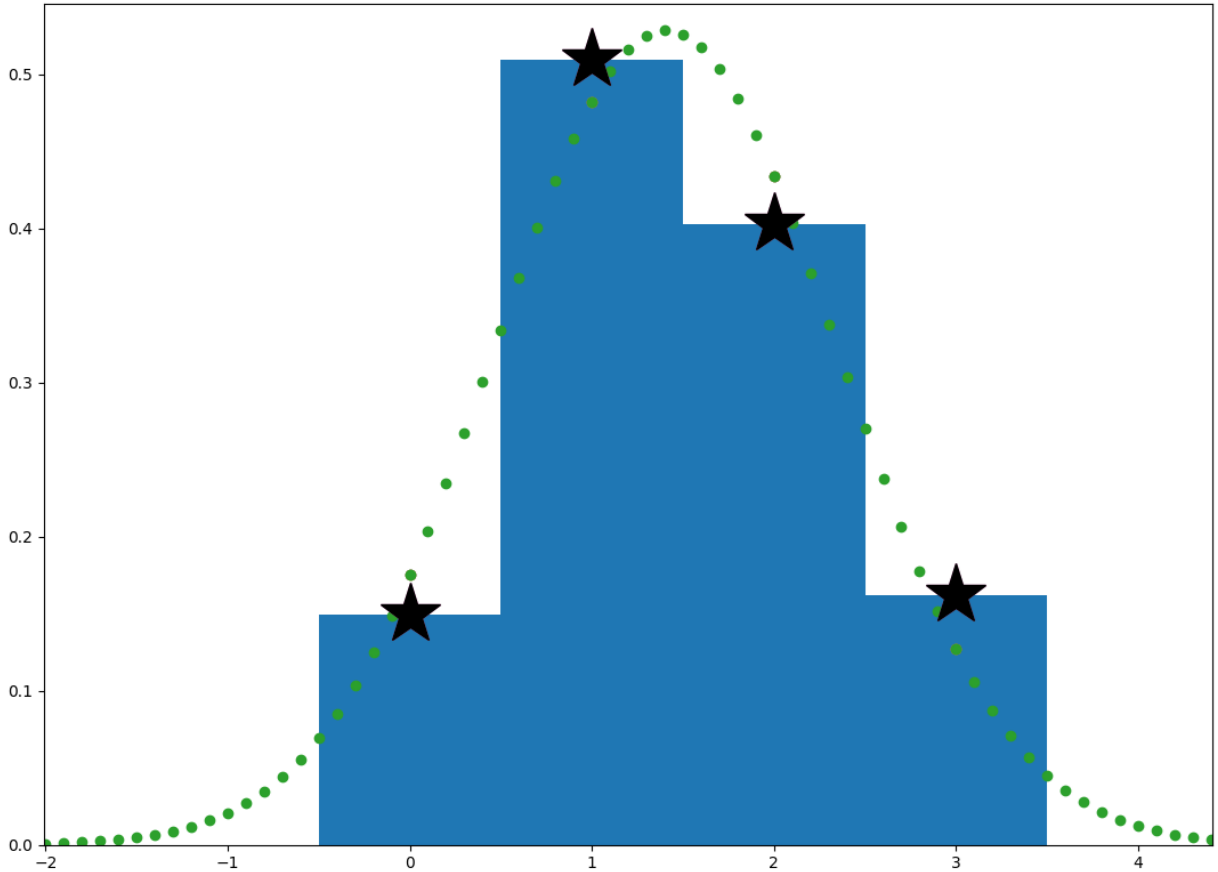




Position 0



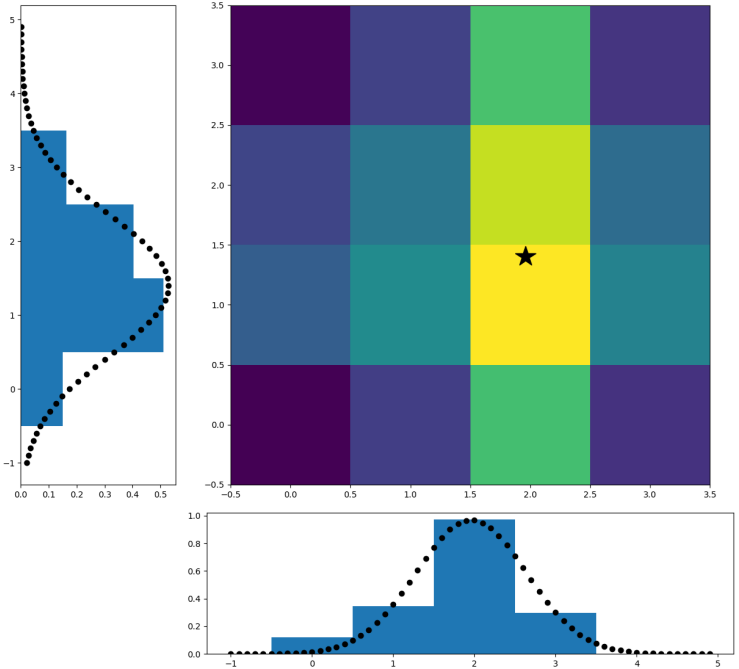
Fit to a normal distribution



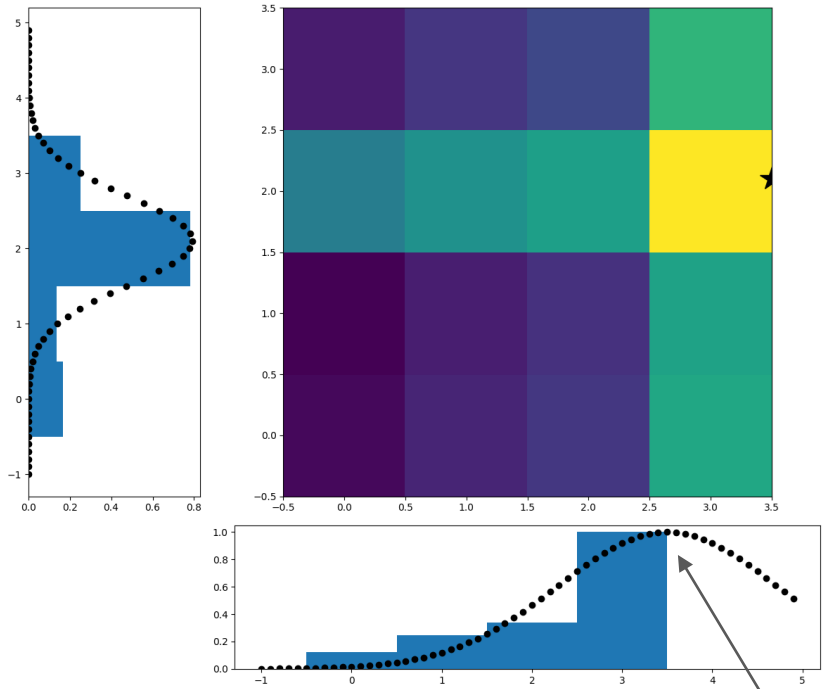
Harder to fit at the edges though

Actually normalizing the signal correctly might help? (constant across channels)

Keep sigma constant?

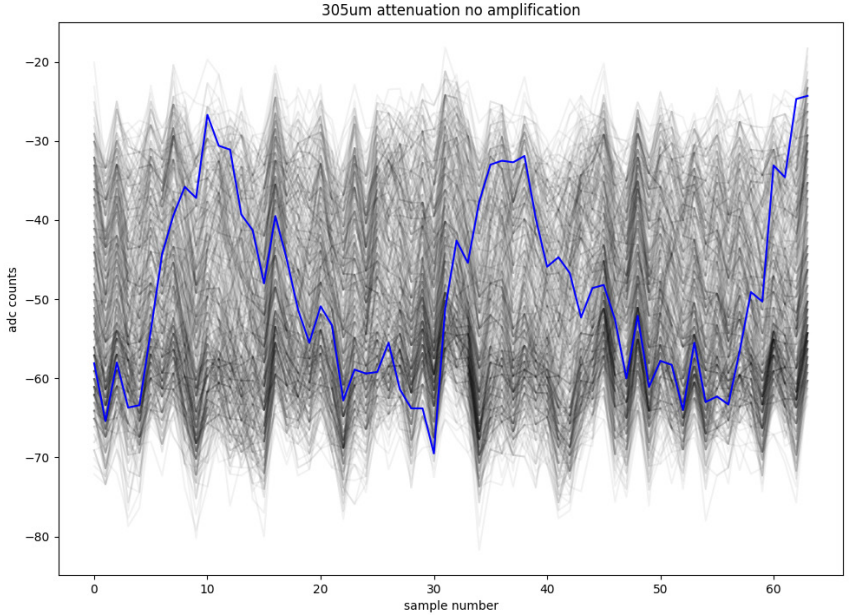


Good

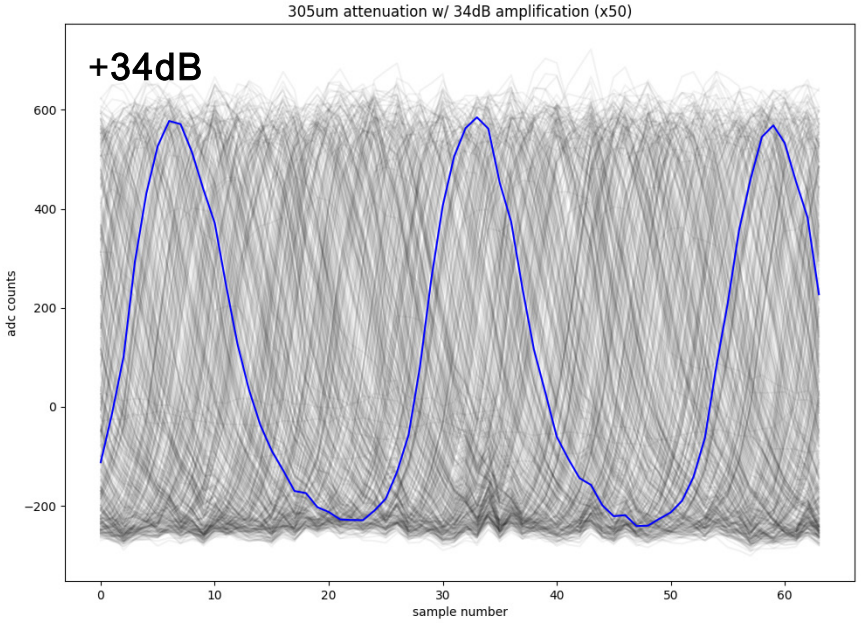


Not good

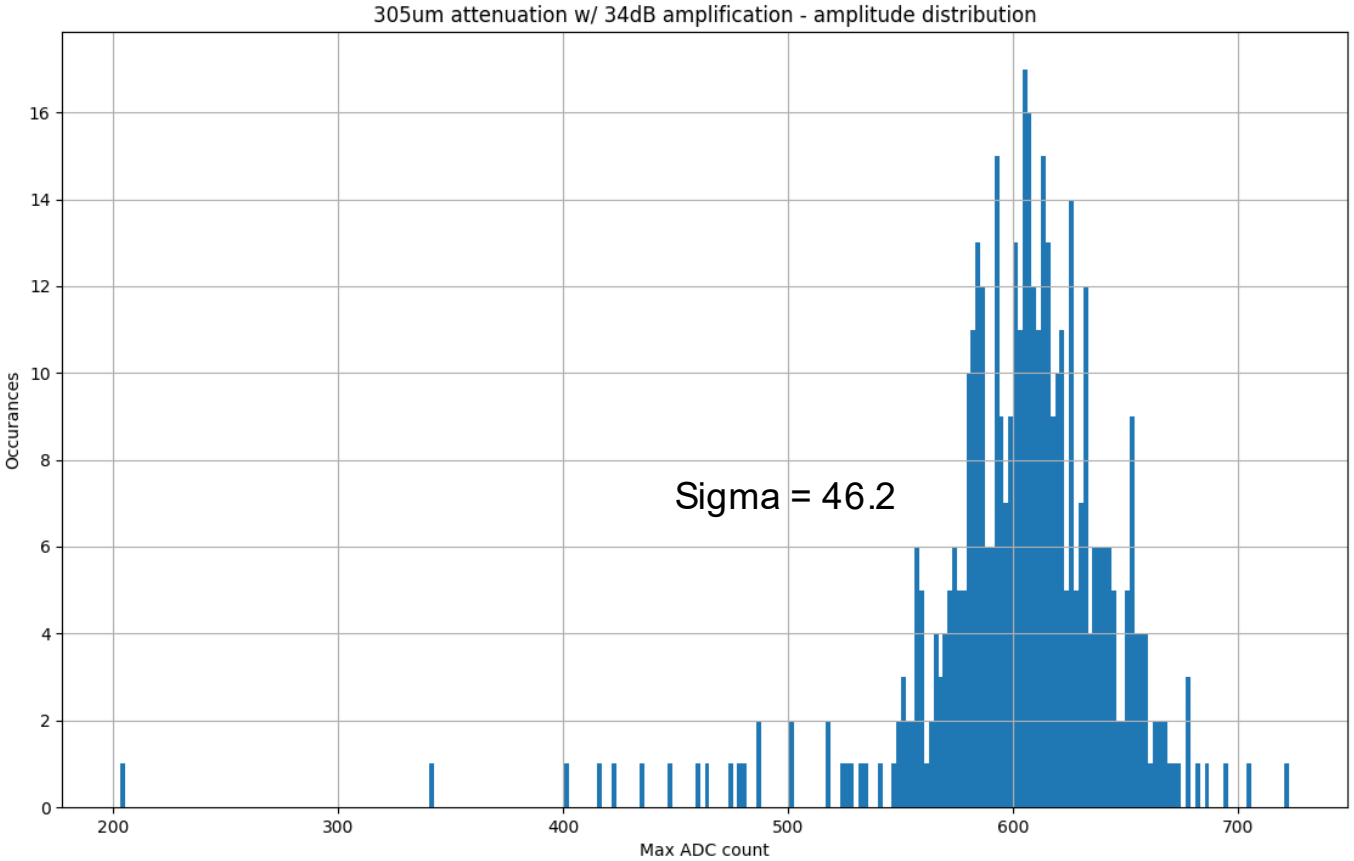
Fit bounded to 3.5



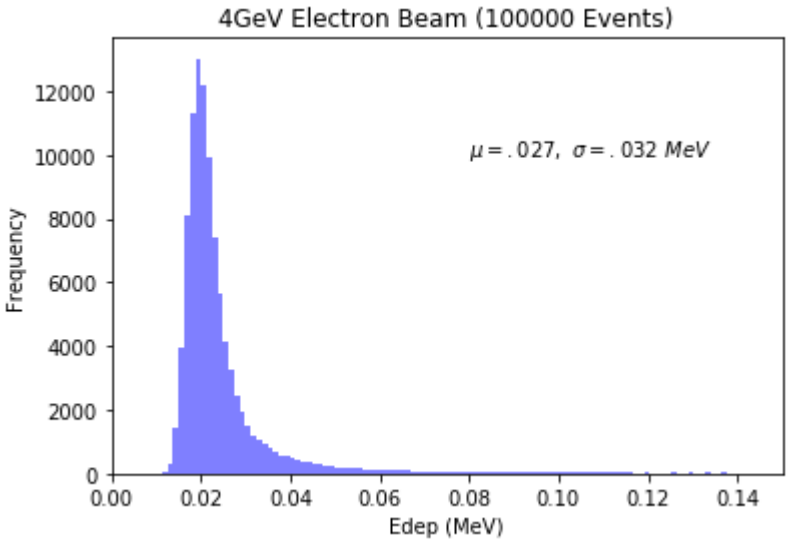
f a

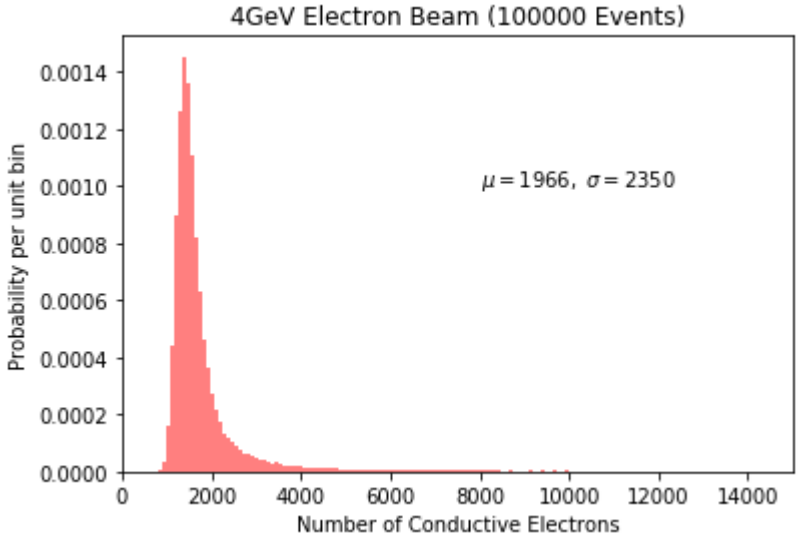


We need amplifiers most likely

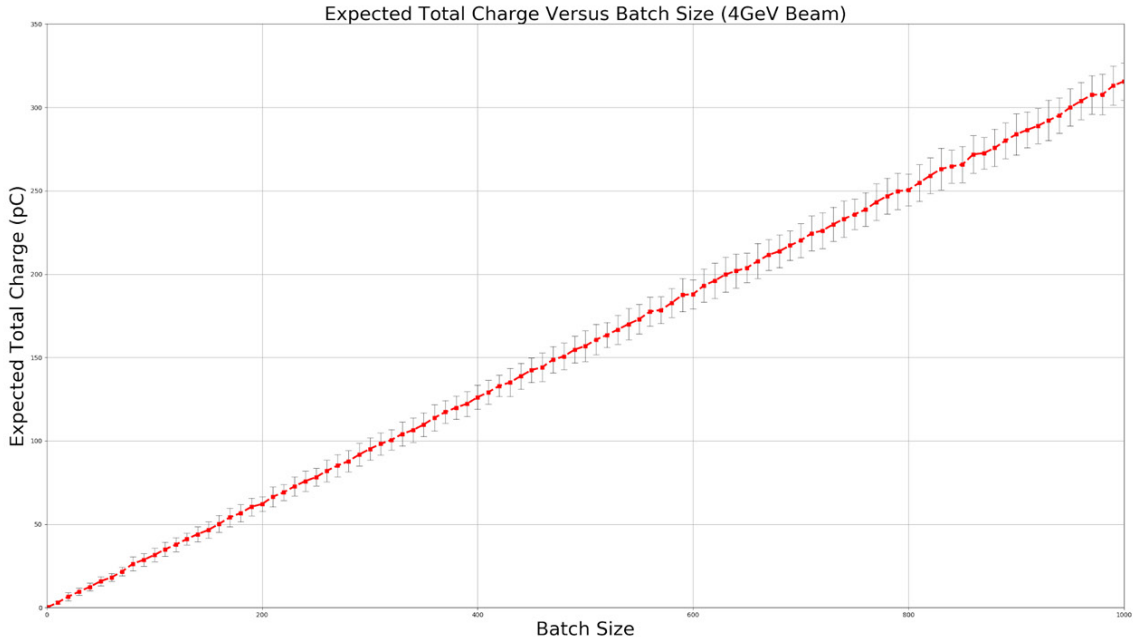

305um attenuation w/ 34dB amplification - amplitude distribution
Occurances
Max ADC count
Sigma = 46.2
0
2
4
6
8
10
12
14
16
200
300
400
500
600
700

4 GeV (SLAC Simulation)

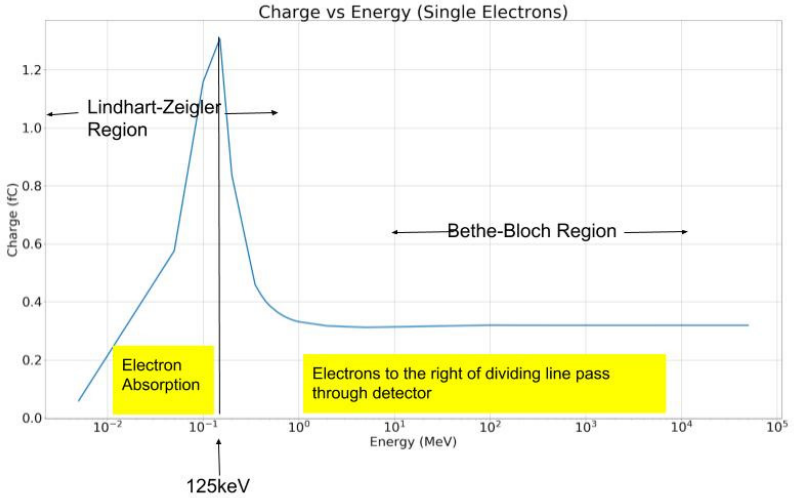




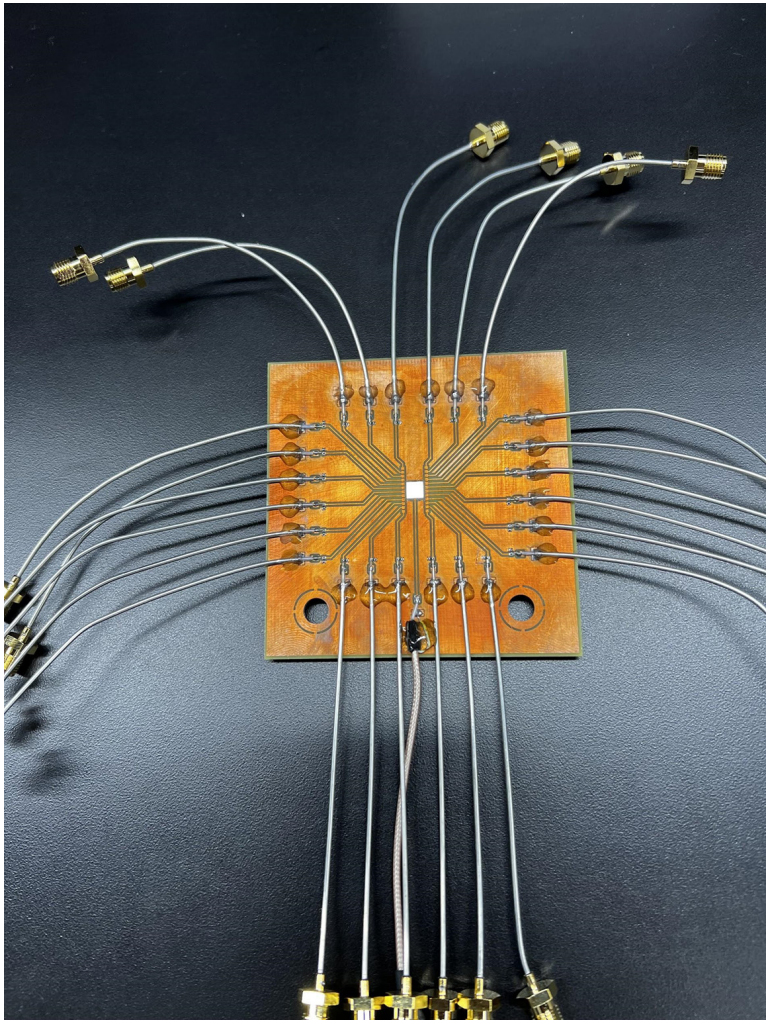
Expected Charge versus Batch size (4GeV)

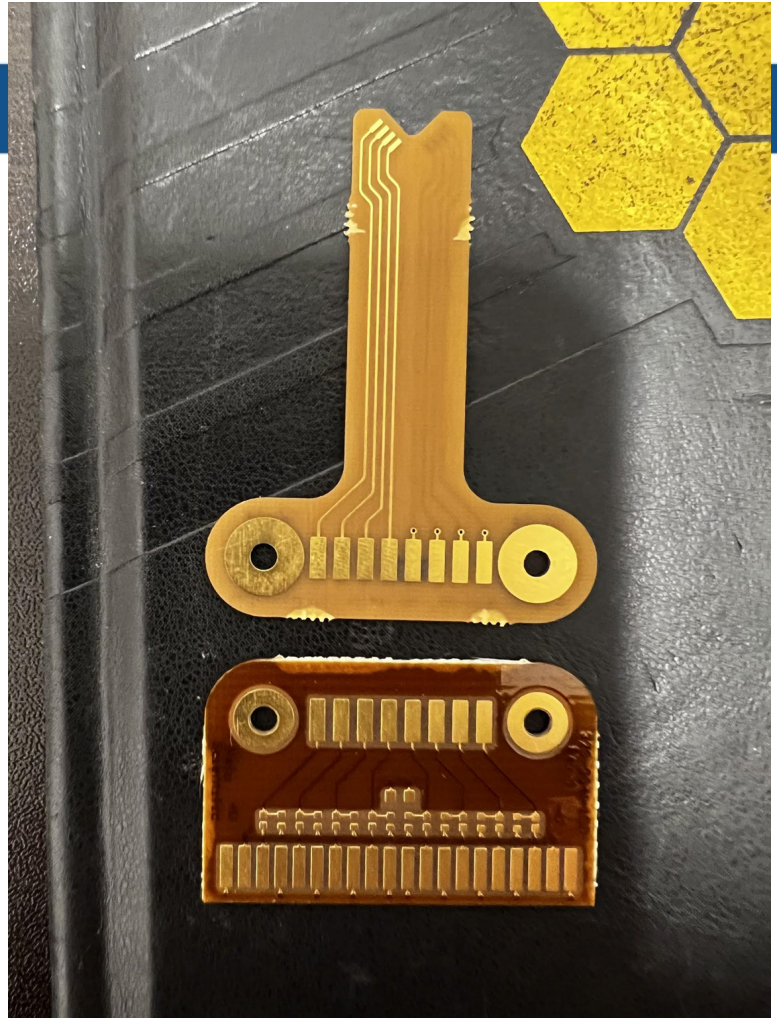


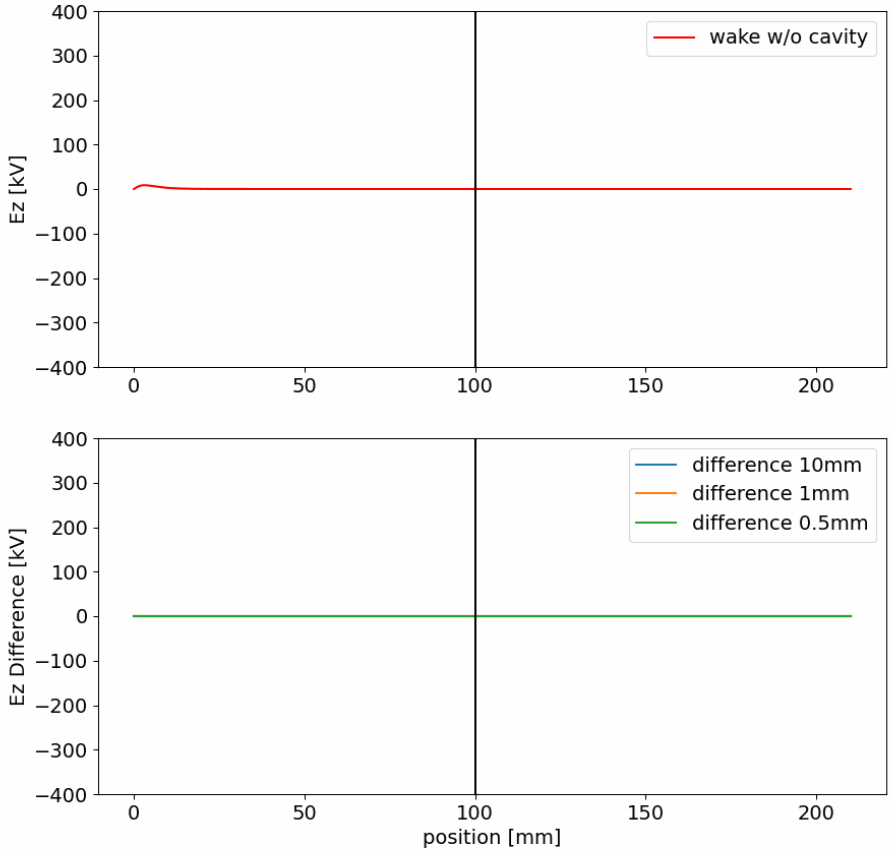
Induced Charge Simulation (100V bias)



50 micrometer diamond






wake w/o cavity
Ez [kV]
400
300
200
100
0
−100
−200
−300
−400
0
50
100
150
200
difference 10mm
difference 1mm
difference 0.5mm
Ez Difference [kV]
position [mm]