



Measurement of Large-Area Ultrafast Silicon Detectors for Embedded Timing/Imaging Layers in Sampling Calorimeters

BRIDGET MACK

SYRACUSE UNIVERSITY LHCb GROUP

Why Timing?

Timing information becomes very important in high luminosity experiments

- Background separation in high pileup environments
- Suppression of out-of-time backgrounds
- Time-of-flight measurements for low momenta particle identification (PID)
- **Hadron identification**

Hadrons from b decays

Charm from B decay

Flavor Tagging

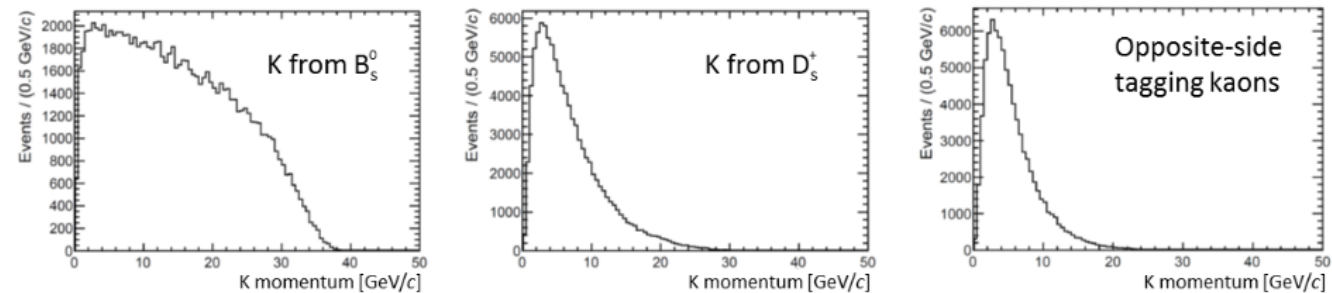
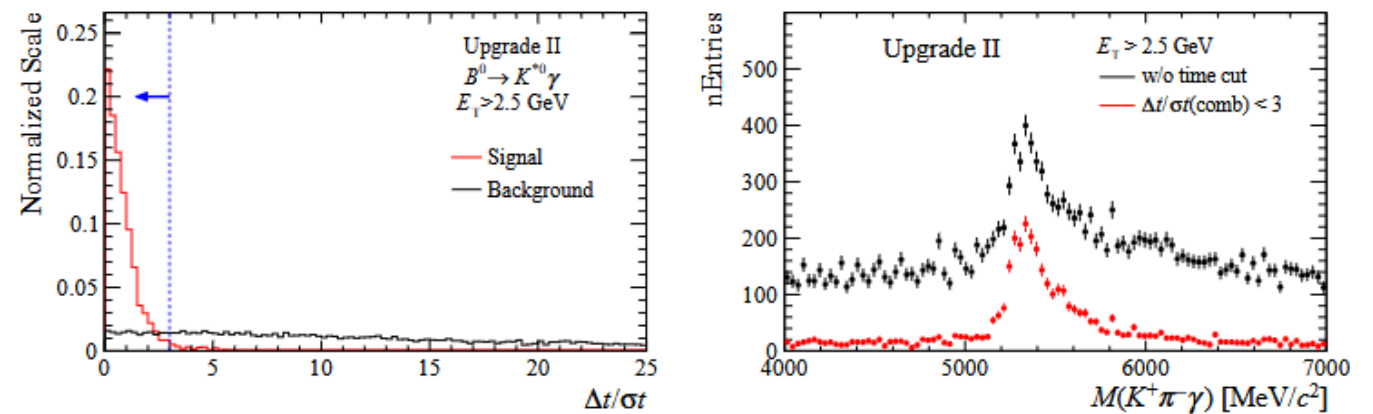


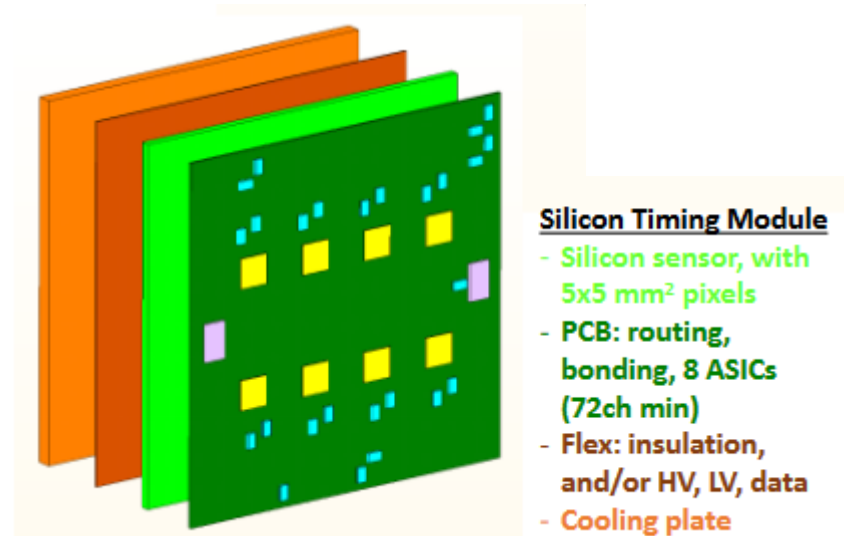
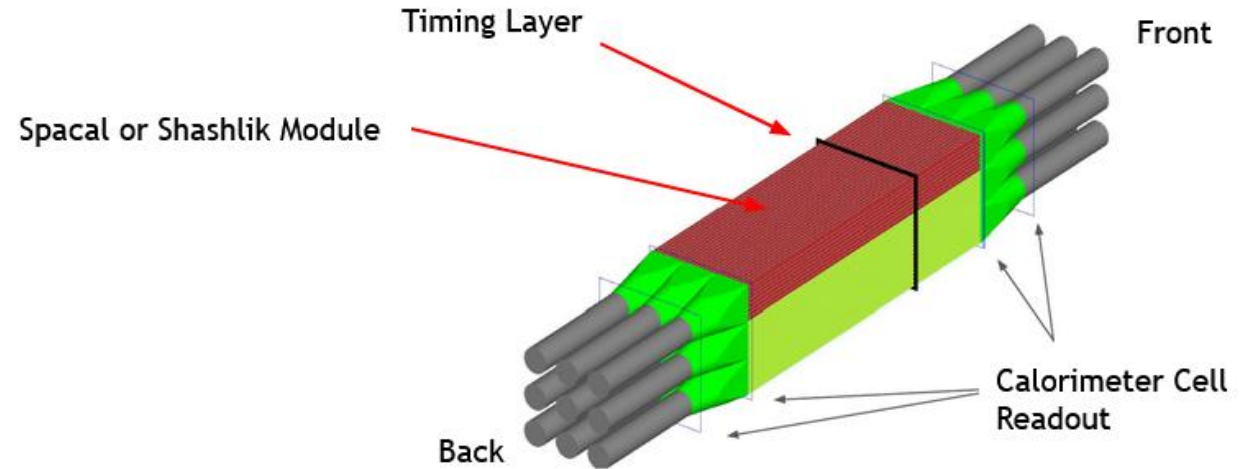
Figure 1: Momentum spectra for kaons occurring in Z^0 events containing a $B_s^0 \rightarrow D_s^\pm K^\mp$ decay.



5D Calorimetry

- Need to be able to maintain energy resolution and reconstruction efficiency with higher pile-up, occupancy, and radiation dose
- Introduce timing via
 - Sampling Calorimeter with Si and W
 - Timing layer (sometimes referred to as imaging layer) inserted as part of calorimeter

Our focus will be on a timing layer inserted at the shower maximum.



Concept

5D calorimeters can be useful in many of the new detectors at future high luminosity colliders, but there are other reasons for doing this research.

1. Modular design and cost-effective upgrades – use existing materials, upgrade or hot-swap components more easily
2. Timing information is the main goal, but an imaging layer may also give a more granular spatial picture of showers, especially in regions where high occupancy can lead to overlapping showers
3. We can learn a lot about both calorimeter construction and solid-state detector fabrication, which will be helpful to the broader detector community

Challenges

- Adding mass and radiation length does not help your calorimetry
 - Not only would we be adding silicon detectors, but also mechanical supports, cooling, cabling for front-end ASICs, etc.
 - This adds up fast, especially for large numbers of channels
- Not only high cost to material budget, but also to overall monetary cost

Challenges

- Adding mass and radiation length does not help your calorimetry
 - Not only would we be adding silicon detectors, but also mechanical supports, cooling, cabling for front-end ASICs, etc.
 - This adds up fast, especially for large numbers of channels
- Not only high cost to material budget, but also to overall monetary cost

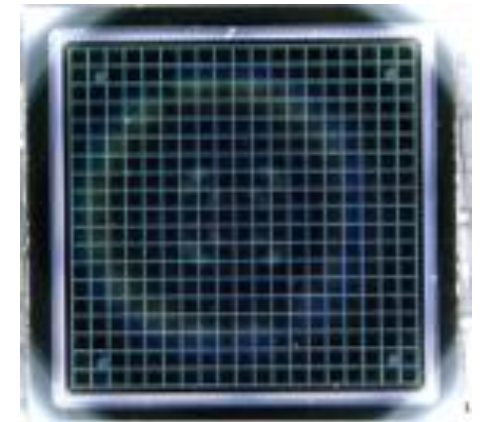
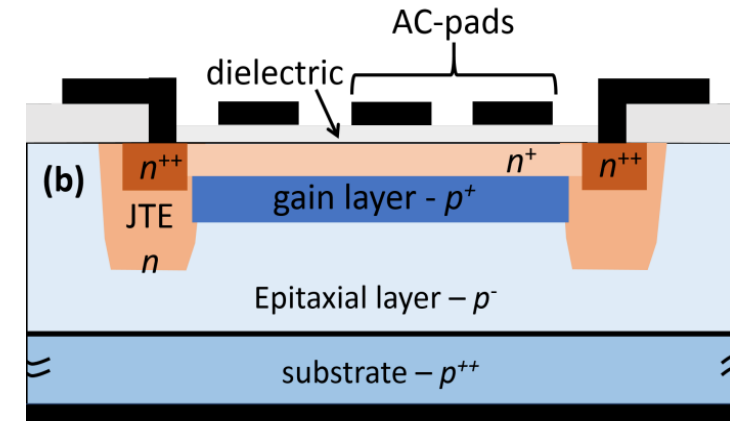
Can we use larger pixel sizes, effectively lowering number of channels, and still achieve good timing resolution?

Can we optimize our fabrication parameters to make effective devices for large scale detectors?

Ultrafast Silicon Detectors

We are studying AC-LGADs (Low Gain Avalanche Diodes) with different fabrication parameters:

- Larger pad sizes (up to 1 square centimeter!)
- Three different thicknesses: 20, 30, and 50 microns
- Three different gain implantation energies: zero, 380keV and 1MeV
- Several metallization schemes (both solid and grid contacts to see effects on sensor capacitance)
- Capability for single pad devices and pixel arrays

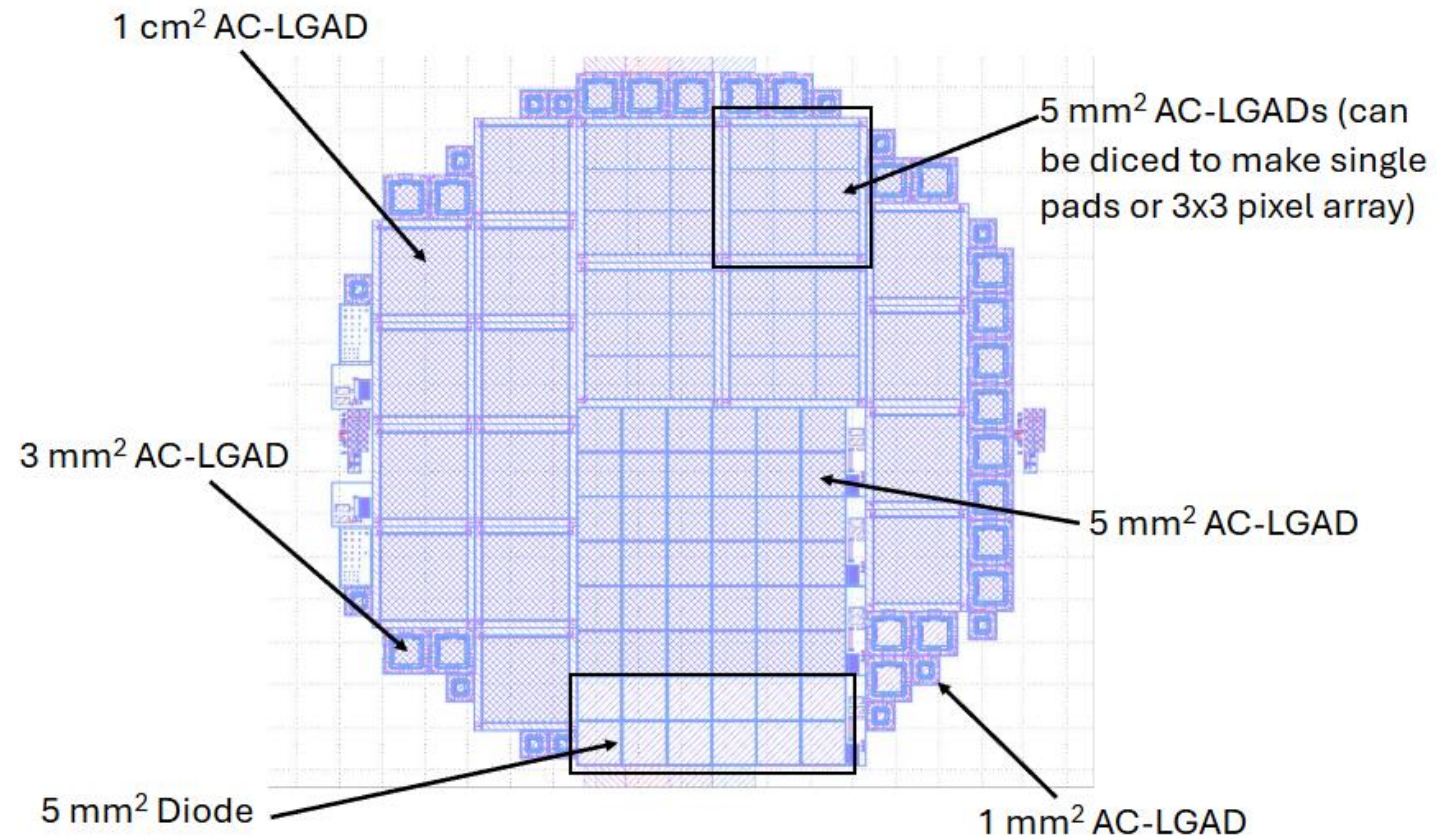


R&D Phase 1

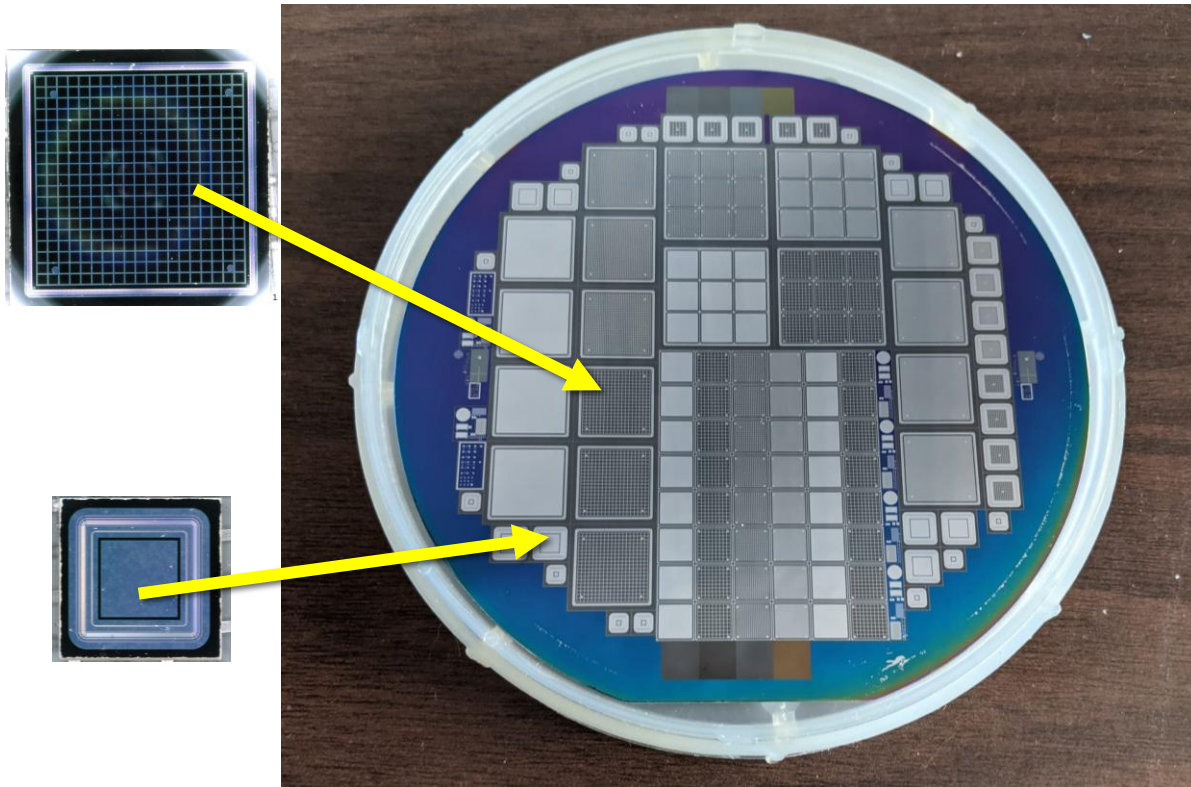
We have developed a set of wafer masks with BNL that contains different sized pads and different metallization geometries.

Different combinations of epitaxial thicknesses and implant energies are used in fabrication to create a full set of AC-LGADs and standard diodes with all combinations of parameters.

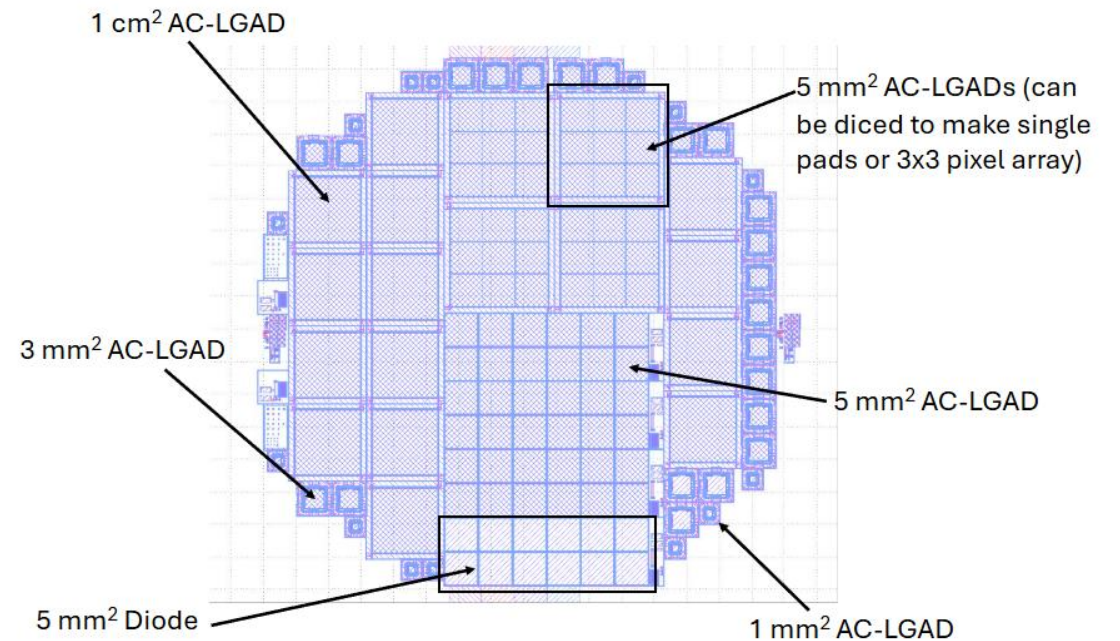
On the basis of this work, we will develop full sized devices with our preferred geometry.



BNL wafers currently under study



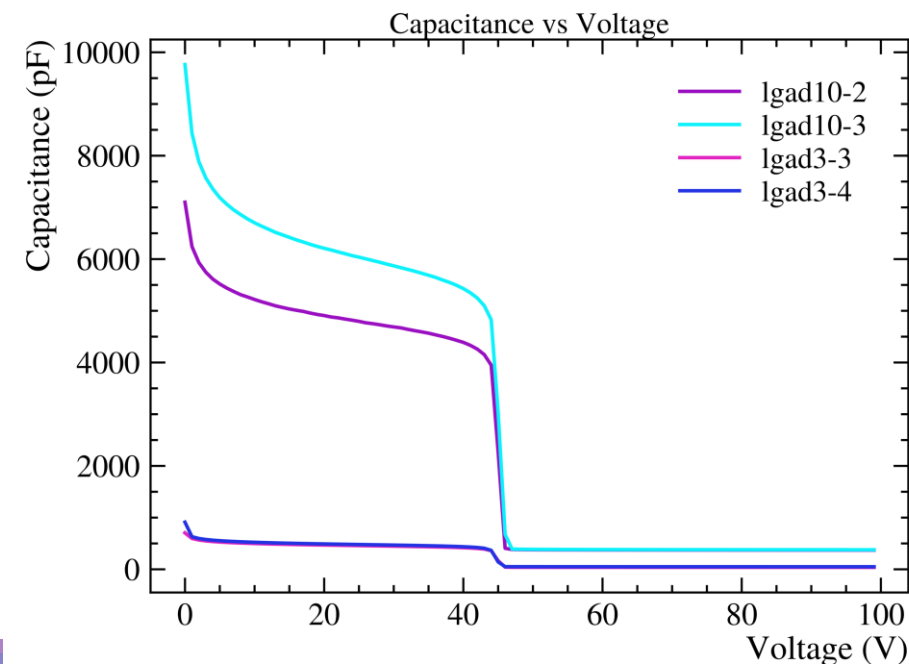
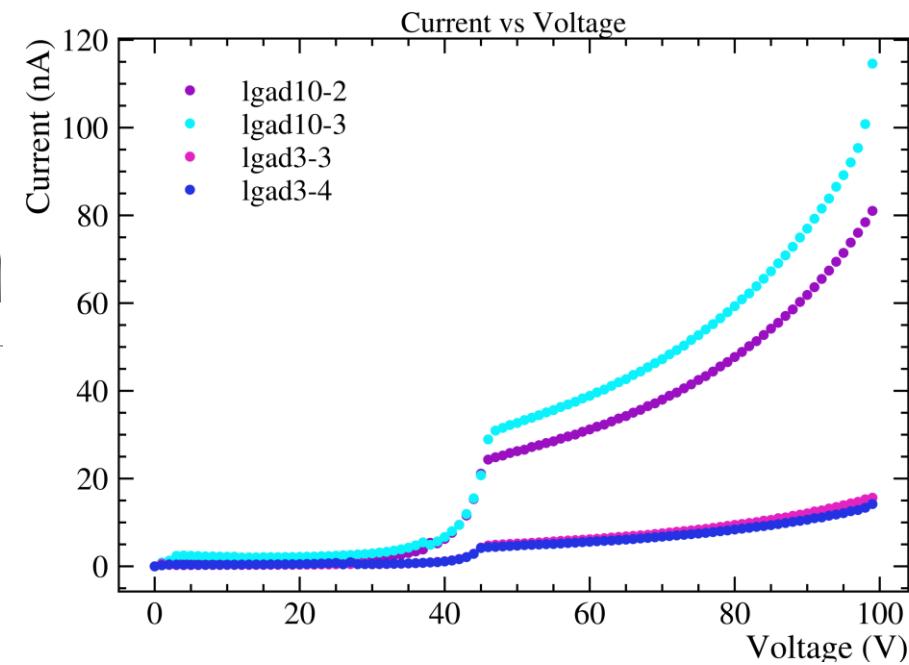
30-micron thickness, 1 MeV gain implant



IV and CV Characterization

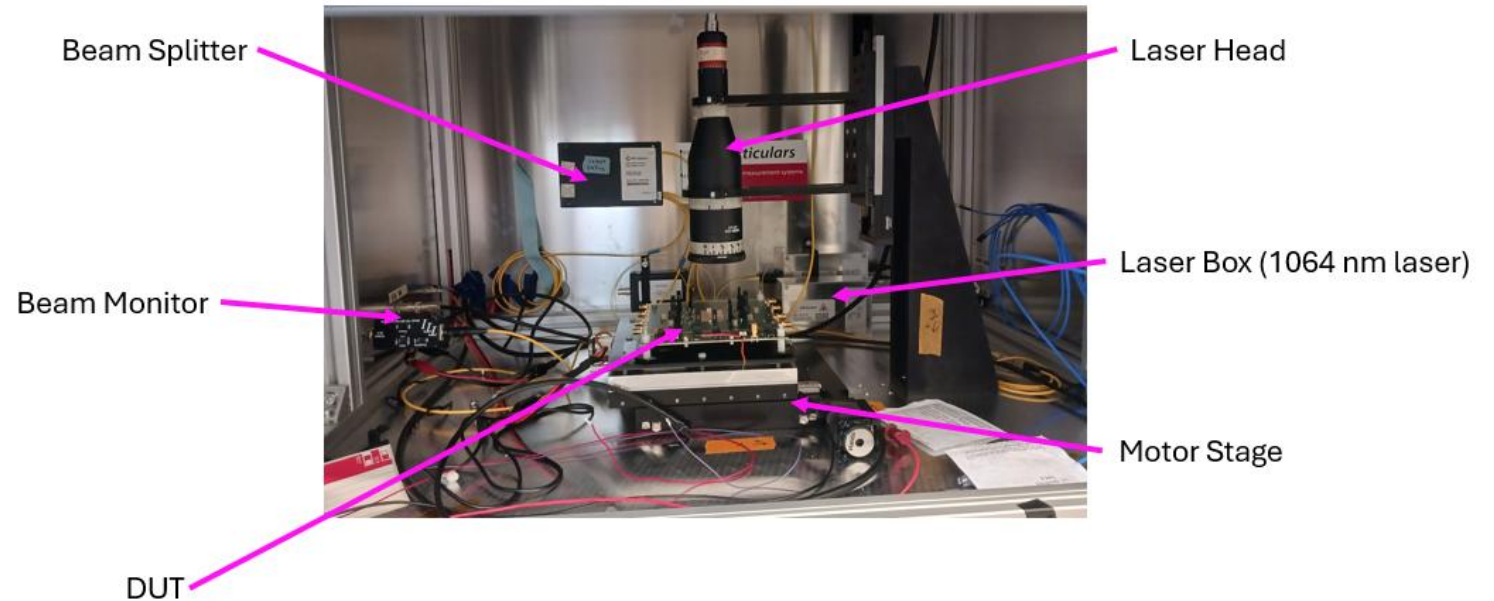
Characterization is done to find depletion, operating, and breakdown voltages

- Showing characteristic curves for 10 mm² and 3 mm² pads taken from a 30-micron wafer with a gain implantation energy of 1 MeV
- The curves follow the patterns we expect
- Approximate capacitances:
 - 10 mm²: ~400 pF
 - 3 mm²: ~40 – 50 pF



Timing and Spatial Resolution Performance with Transient Current Technique

- Further testing done with TCT
- 660nm and 1064nm lasers; spot size $\sim 30\text{ }\mu\text{m}$
- Fully automated with a python script
- Can read out signals either on oscilloscope or with custom boards from Nalu Scientific -- can read out between 8 and 64 channels at once!



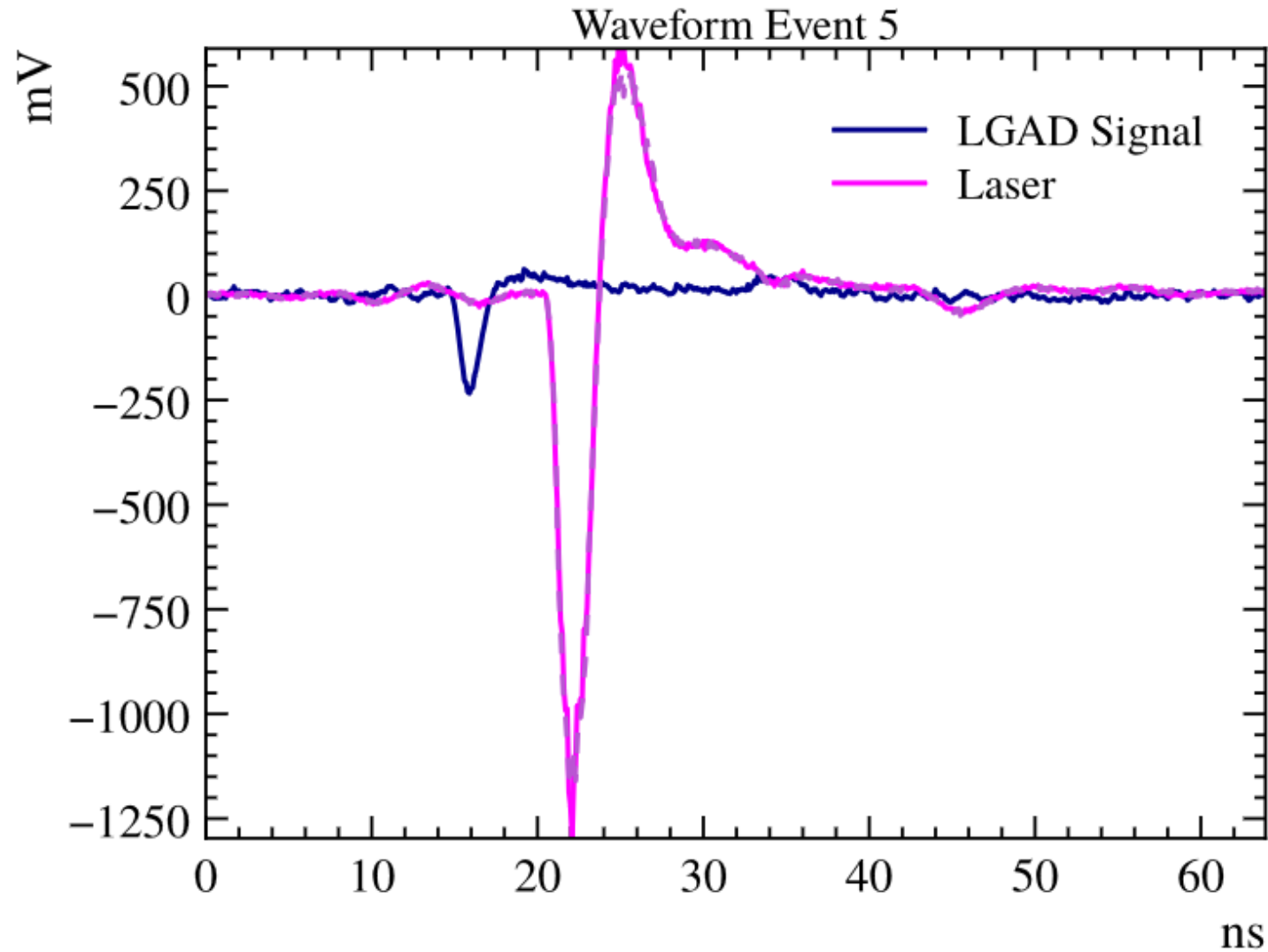
Setup

- 3mm square single pixel detector mounted and wirebonded to a SCIPP single-channel LGAD readout board
- We are using the AARDVARCv3 board from Nalu Scientific
- We use the trigger output from the laser as our trigger input on the AARDVARC

Thank you to the team and Nalu Scientific and to Andrew Dowling from Syracuse University for helping set up our AARDVARC!



Preliminary Measurements with 3mm AC-LGAD

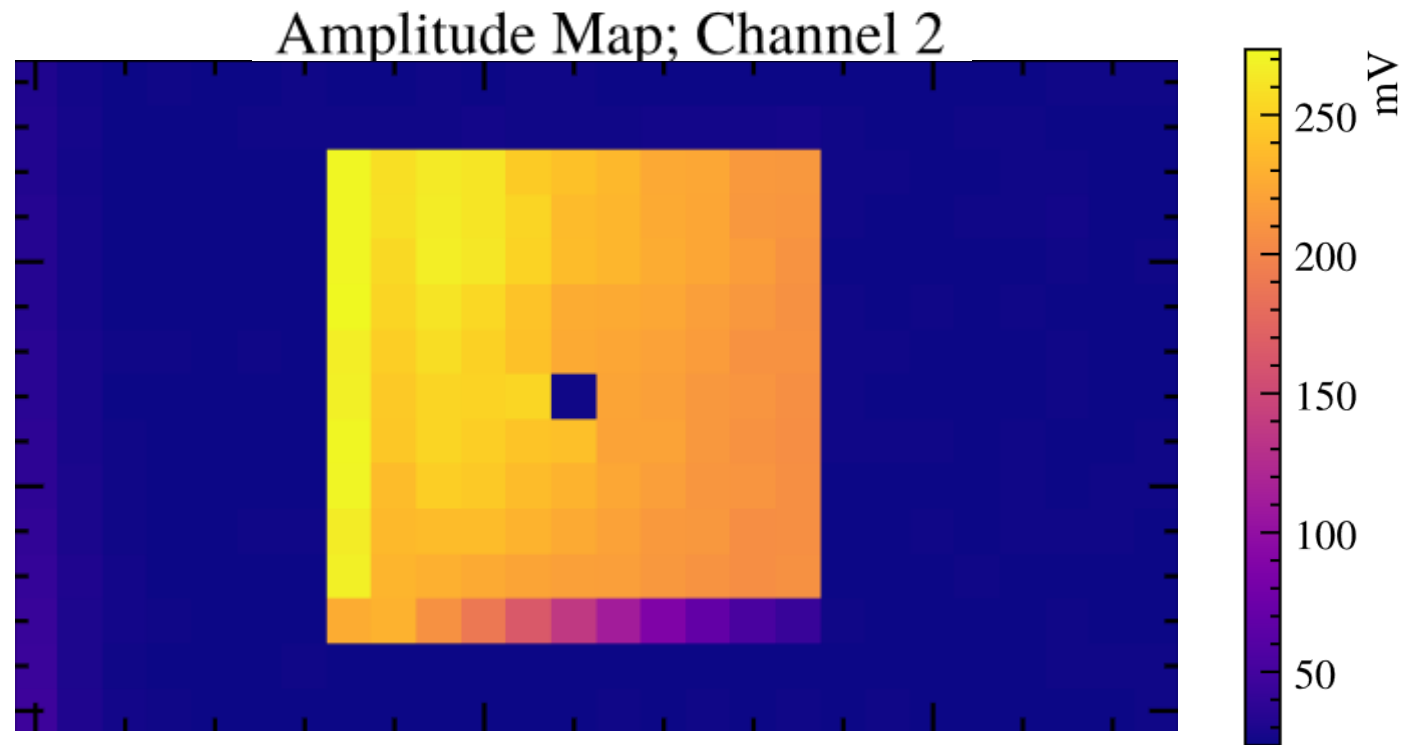


Preliminary Measurements with 3mm AC-LGAD

A scan of the entire active area was performed to check for gain uniformity.

We need to investigate further why we consistently see higher amplitudes in the top left corner and side of the LGAD.

We are also looking to do a finer scan of the area to see if we can find any small imperfections in the gain or in the metallization.

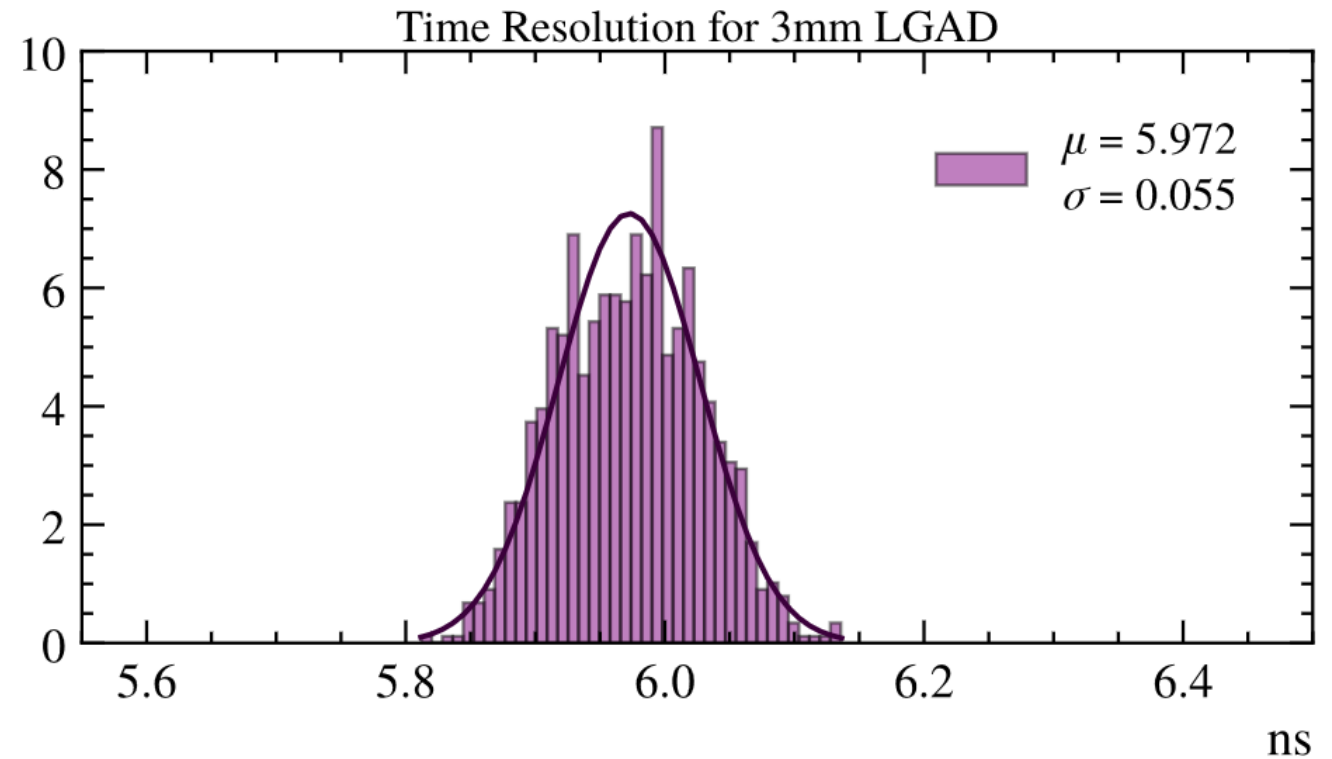


Preliminary Timing Measurements with 3mm AC-LGAD

Timing measurements were performed using CFD, yielding a time resolution of 55 ps.

This number could be lowered by performing an advanced timing calibration with the AARDVARC.

We are also investigating using an optimal filtering method for finding time of arrival, which could give better resolution. More to come!



Future Plans

For this LGAD:

- ❑ Perform fine scan of active area to study gain uniformity
- ❑ Experiment with waveform processing and optimal filtering for further time resolution measurements

For our other LGADs:

- ❑ Repeat process of performing timing and uniformity measurements and compare
- ❑ Use TCAD to simulate our fabrication parameters

Summary

- Timing information will be important for future detectors at high luminosity experiments
- A 5D sampling calorimeter with a dedicated silicon (LGAD) timing layer at shower maximum can be helpful, but a larger pixel size will be needed
- Preliminary results when studying a 3mm X 3mm single-channel AC-LGAD show a timing resolution of 55ps.
- Further investigation in the future will determine the viability of using large-area LGADs for timing/imaging layers in sampling calorimeters.

Backup

