Optimization of Ultrafast Silicon Detectors for Timing Applications in Future High Luminosity Collider Experiments

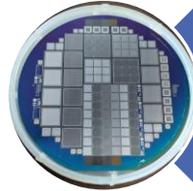BRIDGET MACK

SYRACUSE UNIVERSITY LHCB GROUP

Outline

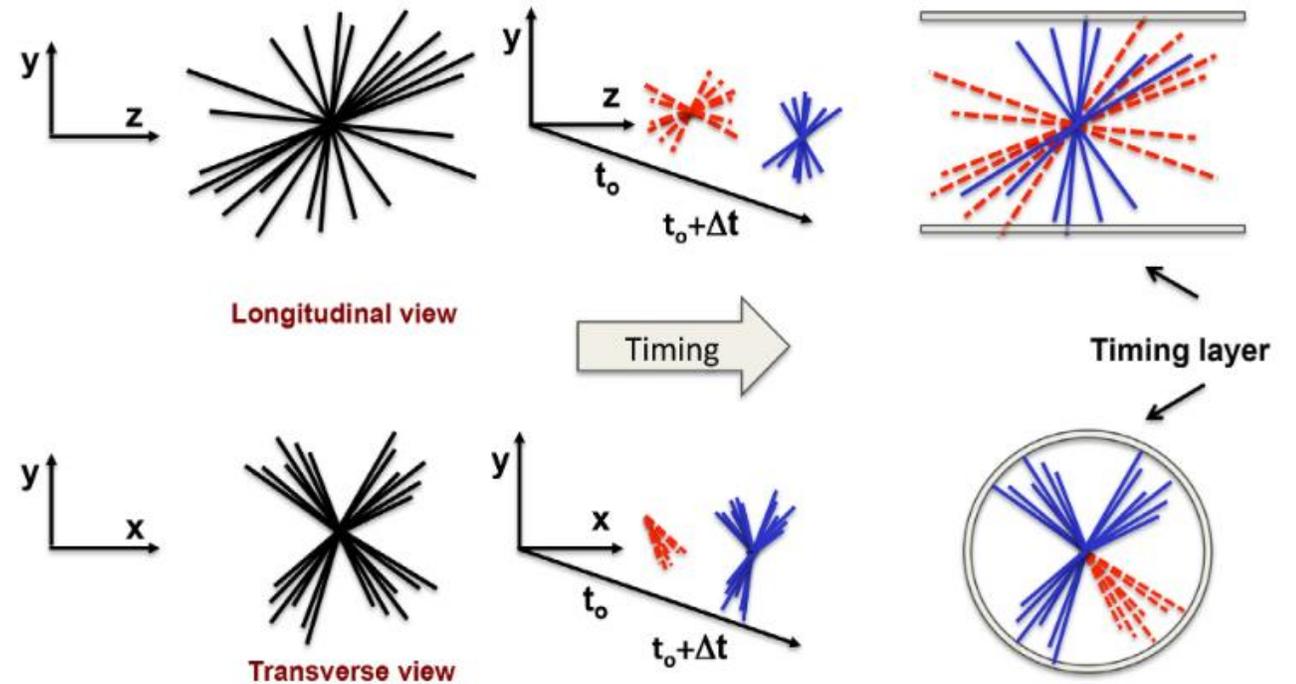Motivations and Background

Optimization

Preliminary Results

Future Work

BRIDGET MACK SYRACUSE UNIVERSITY

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

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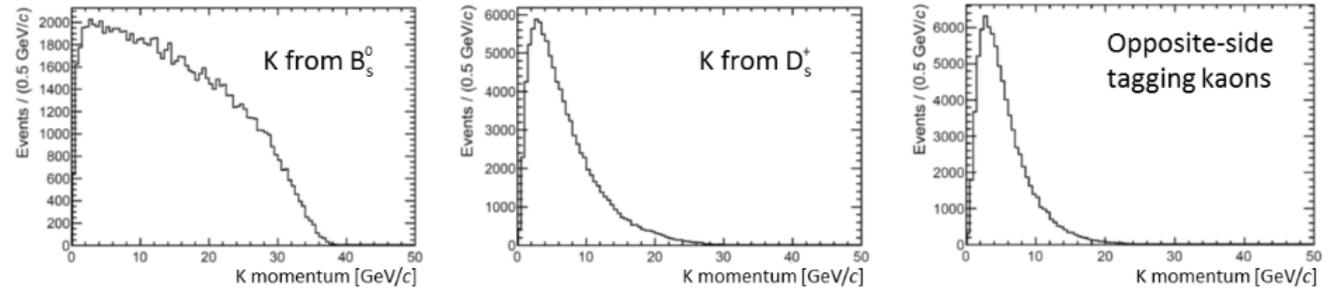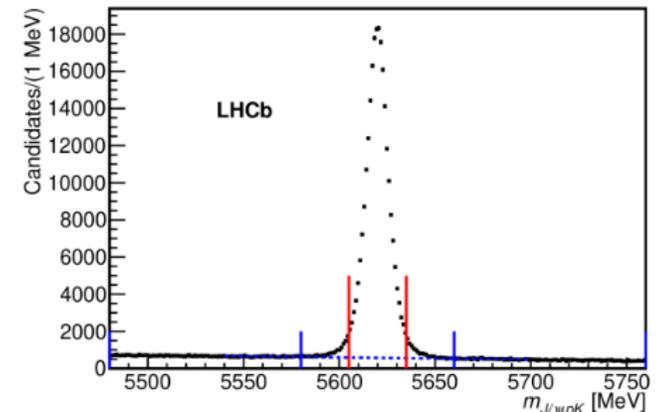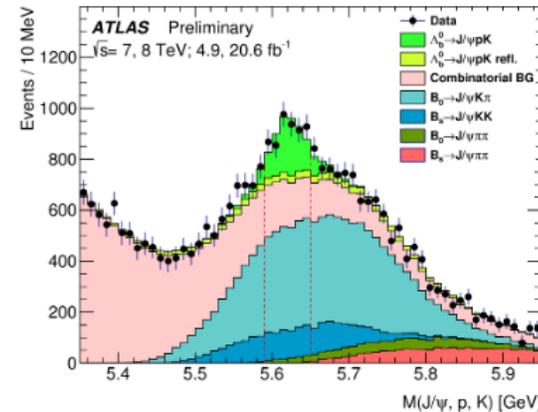

Figure 1: Momentum spectra for kaons occurring in Z^0 events containing a $B_s^0 \to D_s^\pm K^\mp$ decay.
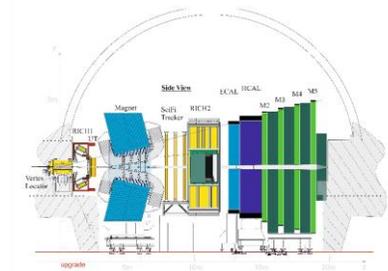
Motivations (Near and Far)

Major physics goals of the next couple decades dictate requirements for future detectors
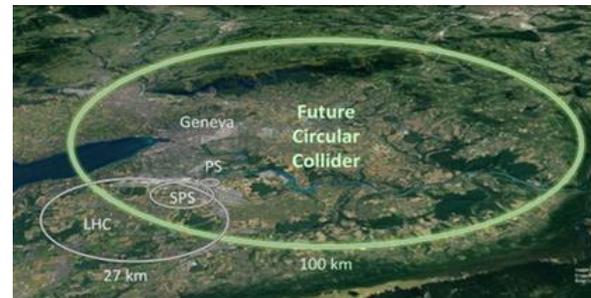
Timing Layers for Calorimeters

LHCb Upgrade 2 ECAL
- Large amounts of pileup will need to be disentangled
- Proposed timing layer in calorimeter to the time stamping of showers

4D Tracking Detectors

FCC-ee and FCC-hh
- PID of hadrons will be important for many of the physics goals
- Time of flight measurements can aid with flavor physics, CP-violation studies, spectroscopy studies, jet physics, and more

Muon Collider
- Reduction of in- and out-of-time pileup, beam induced background
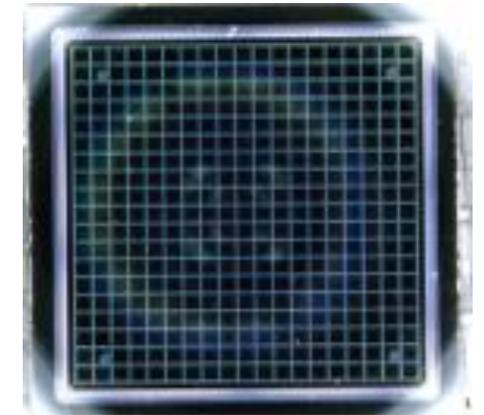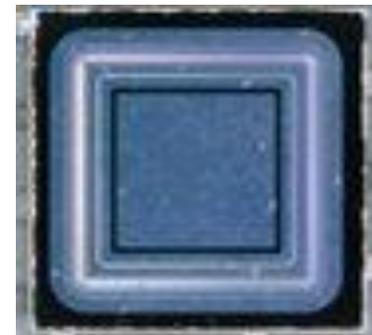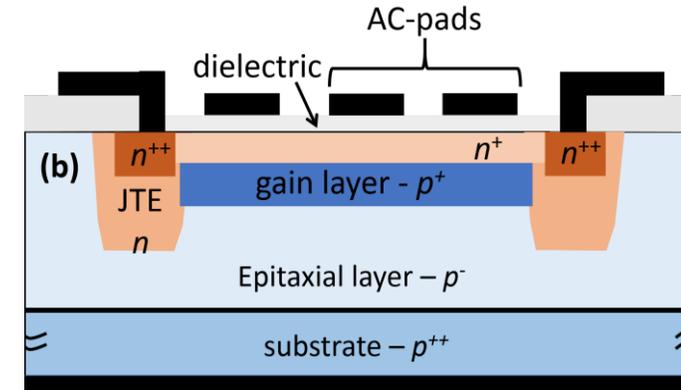
How do we optimize between spatial and time resolutions?

- We are looking into how feature size and fabrication parameters affect both spatial and time resolutions.

- We do not want to have feature size to be determined by the acceptable detector capacitance

- We are looking to:
  - Design layouts to minimize capacitance for a given geometry
  - Design electronics that can help control the increase of noise with increased detector capacitance

Ultrafast Silicon Detectors

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

- Larger pad sizes (up to 1 cm2)
- Three different thicknesses: 20, 30, and 50 microns
- Two different gain implantation energies: 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

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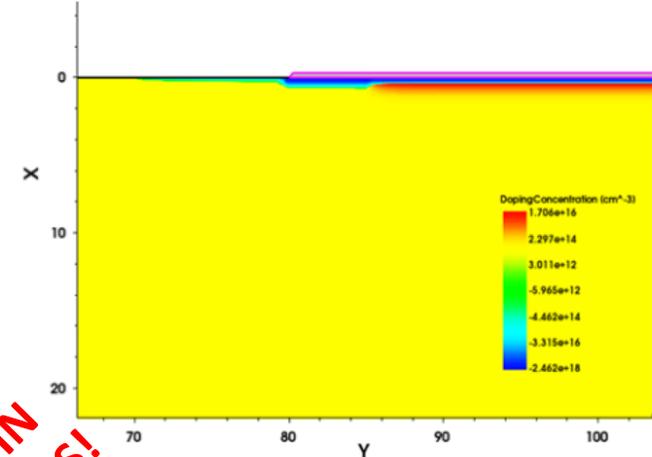
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We are using Synopsys TCAD to emulate the different fabrication processes

- Using sprocess tool to emulate complete fabrication processes
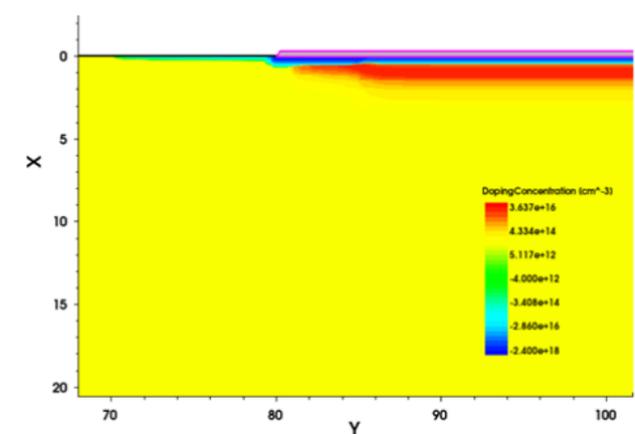- Goal: use heavyion to generate current pulses produced by MIPs

Low Energy Implant Doping Concentration

High Energy Implant Doping Concentration
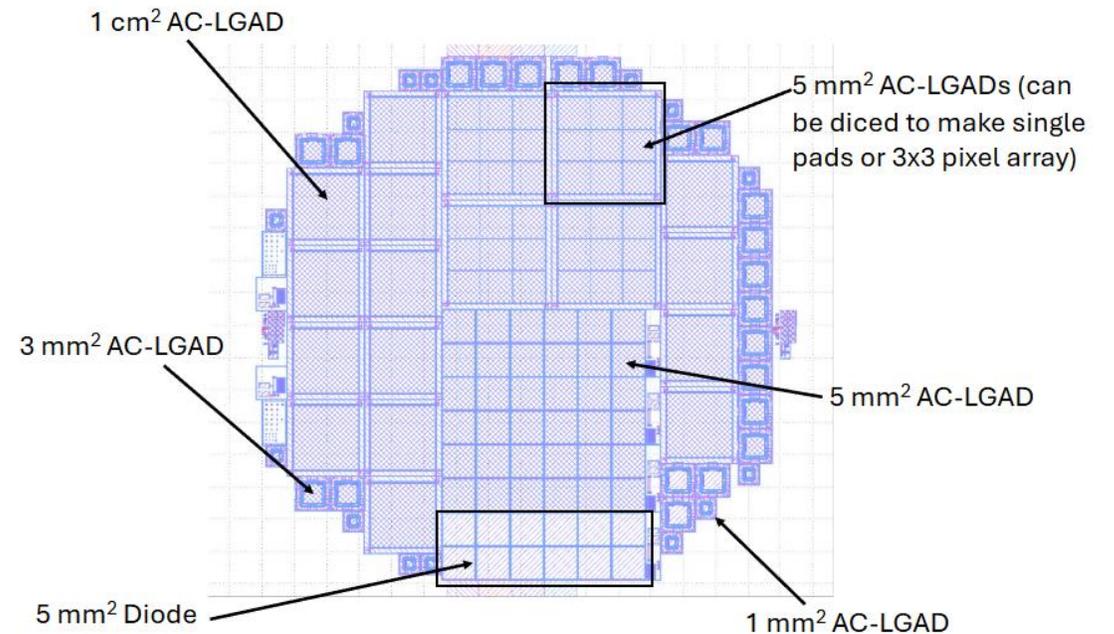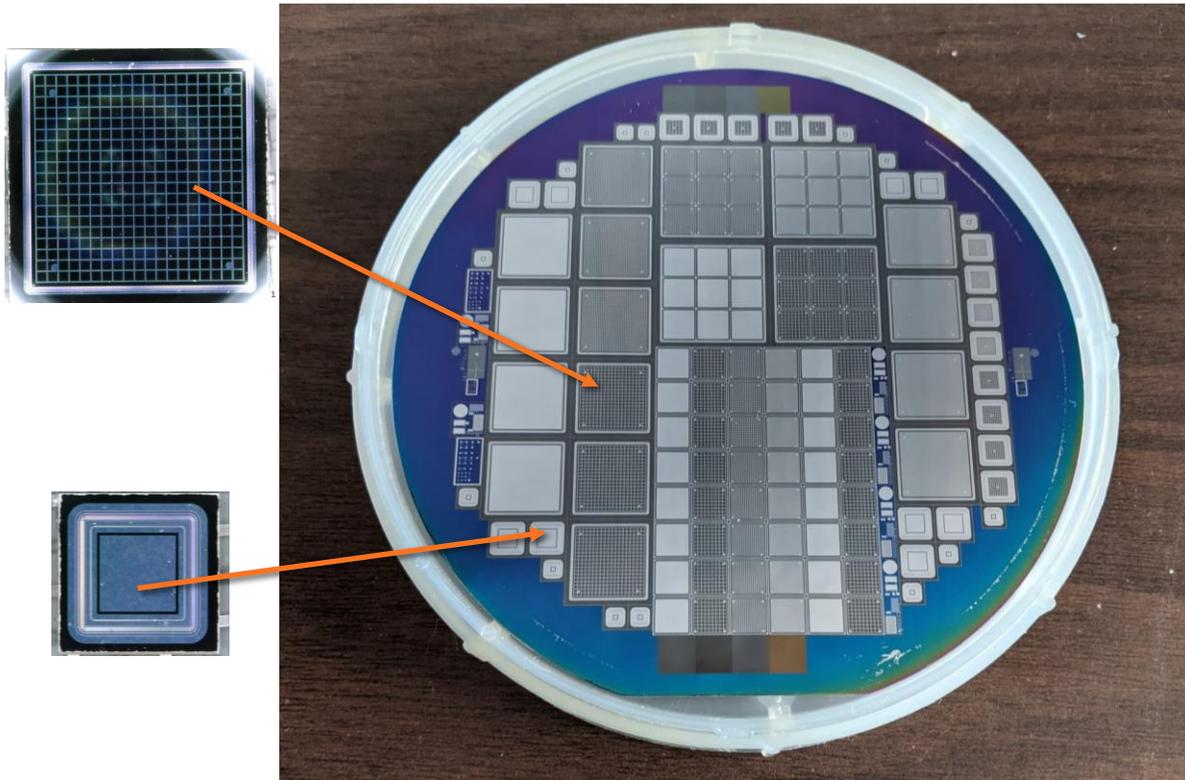
WORK IN PROGRESS!

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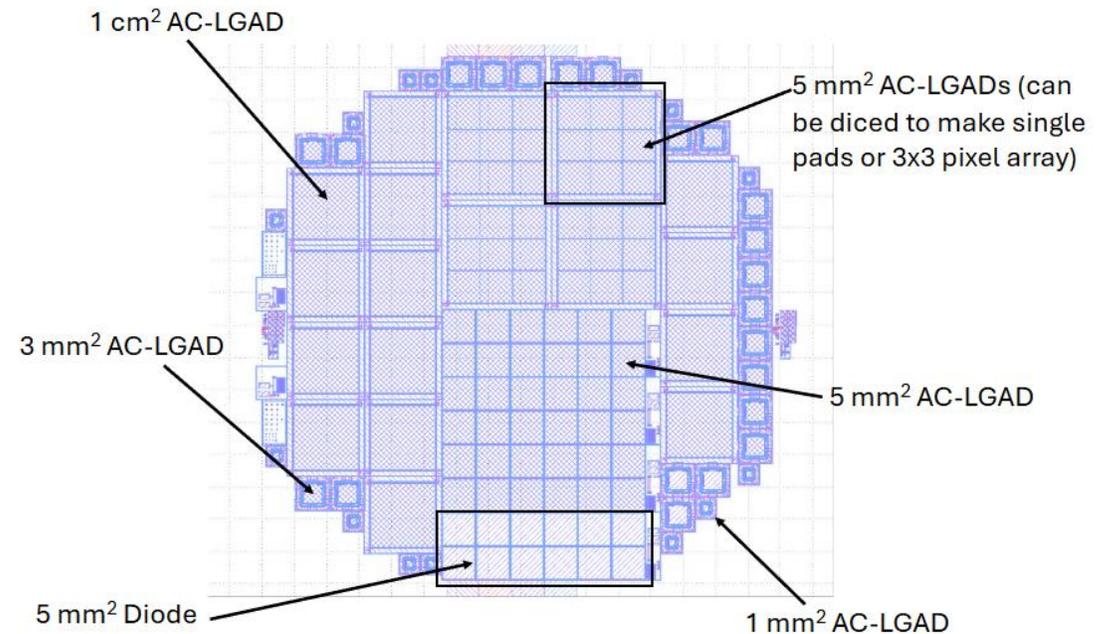
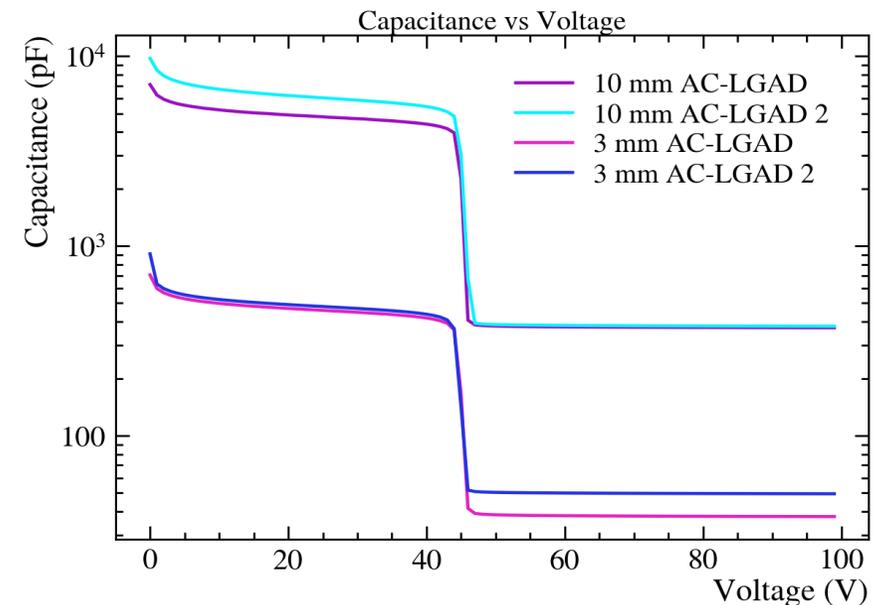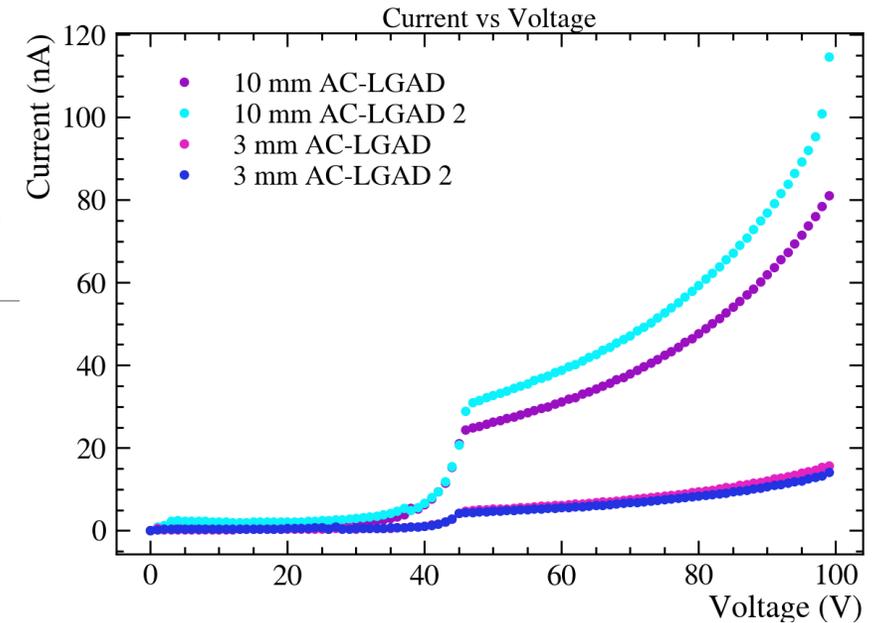On the basis of this work, we will develop full sized devices with our preferred geometry

1 cm² AC-LGAD

5 mm² AC-LGADs (can be diced to make single pads or 3x3 pixel array)

3 mm² AC-LGAD

5 mm² AC-LGAD

5 mm² Diode

1 mm² AC-LGAD

BNL wafers currently under study

30-micron thickness, 1 MeV gain implant

1 cm² AC-LGAD

5 mm² AC-LGADs (can be diced to make single pads or 3x3 pixel array)

3 mm² AC-LGAD

5 mm² AC-LGAD

5 mm² Diode

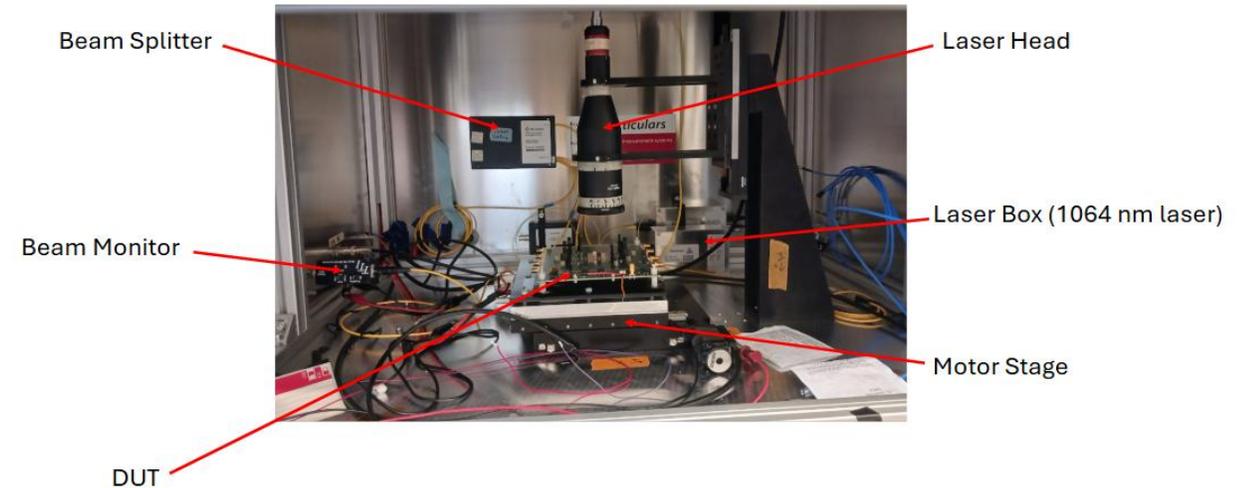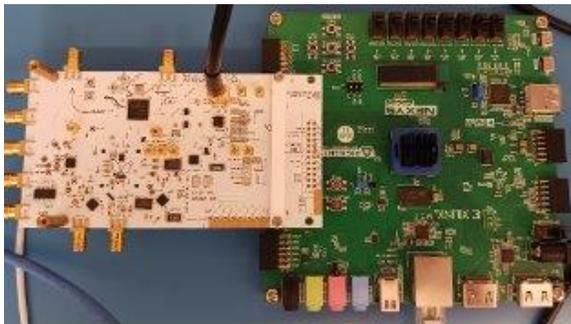1 mm² AC-LGAD

IV and CV Characterization

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

- Showing characteristic curves for 10 mm^2 and 3 mm^2 pads taken from a 30-micron wafer with a gain implantation energy of 1 MeV

- The curves follow the patterns we expect

- We have decided on an operating voltage of 80V for both devices

Timing and Spatial Resolution Performance with Transient Current Technique

- Further testing done with TCT

- 660nm and 1064nm lasers; spot size ~30 um

- Motor stages and oscilloscope readings are fully automated with a python script

- Can read out signals either on oscilloscope or with custom boards from Nalu Scientific that can read out between 8 and 64 channels at once
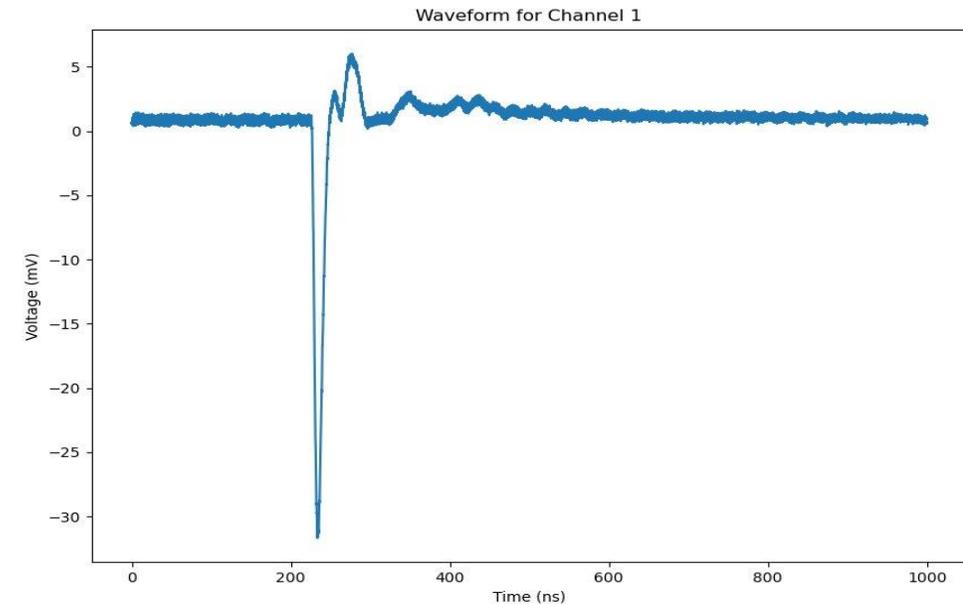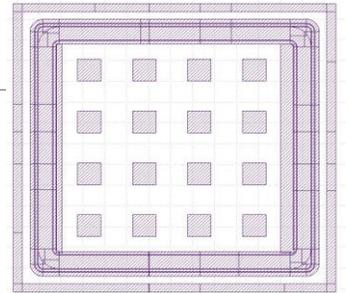
Preliminary Measurements

Our first tests using the TCT with the AARDVARC board from Nalu Scientific have been successful. We are able to read out a diode's response using one of the channels on the board.

We are prepping to do more in-depth TCT measurements with our various diodes and AC-LGADs to study time resolution and signal formation as functions of the various fabrication parameters.
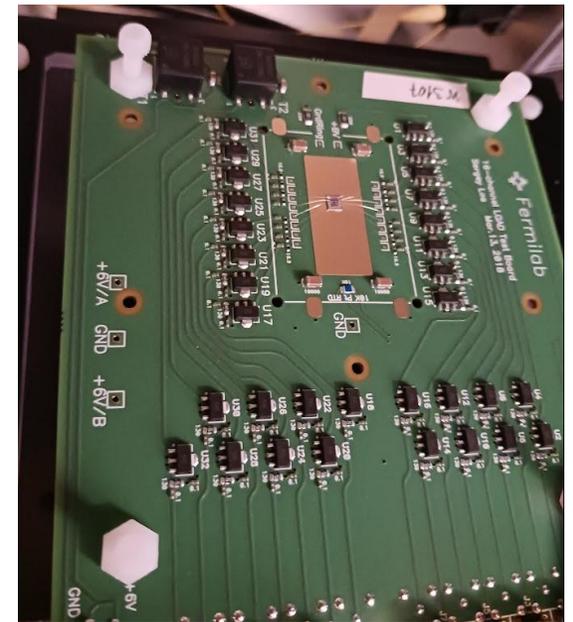
Spatial Resolution Studies of 16-pixel device from BNL

In addition to our optimization studies, we are always open to collaboration.

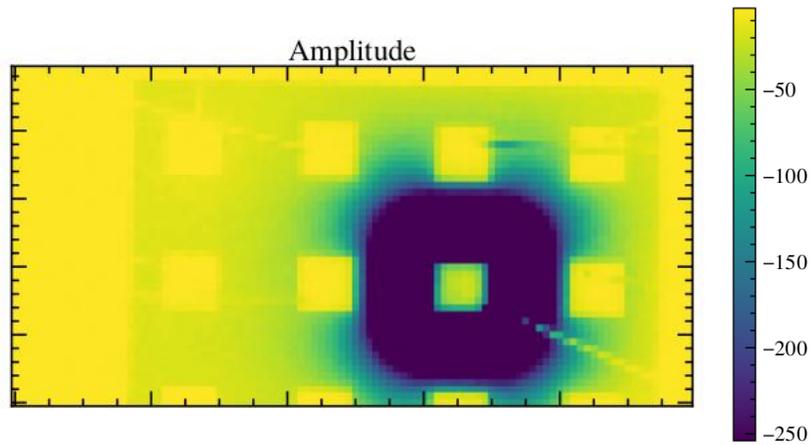We are collaborating with BNL to study a 16-pixel AC-LGAD with our TCT setup.

- AC-LGAD mounted on 16-channel [board](#) from Fermilab

- 2 mm x 2 mm device, with a pitch of 500 um

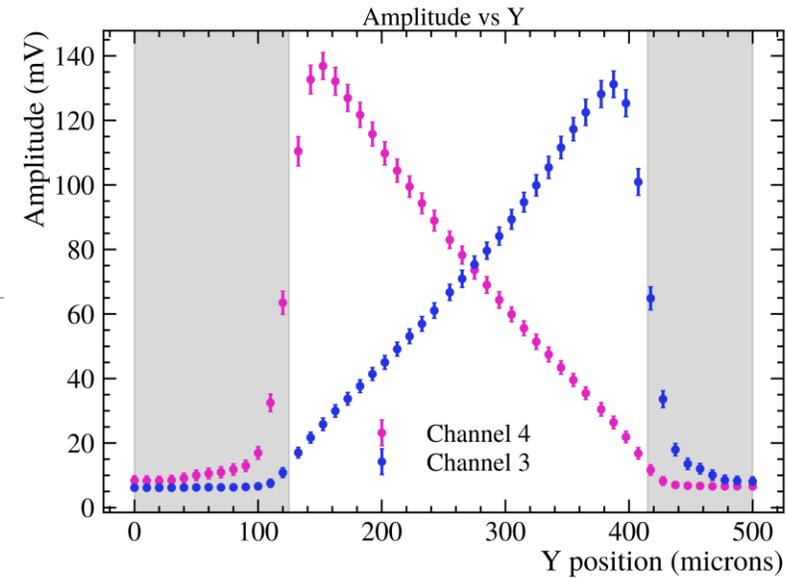- Performing scans to determine two-dimensional spatial resolution

TCT Measurements

- Scanning across the device, we can see the response of different channels to the laser hitting different areas of the device. We are interested in:
  - 2D spatial resolution and time resolution measurements
  - The effects of signal sharing on spatial resolution
  - Any cross-talk between channels

Amplitudes on two pixels as a function of position

Amplitude of signal collected on one pixel (mV)

Signal waveform at different points across the device, as measured on one pixel
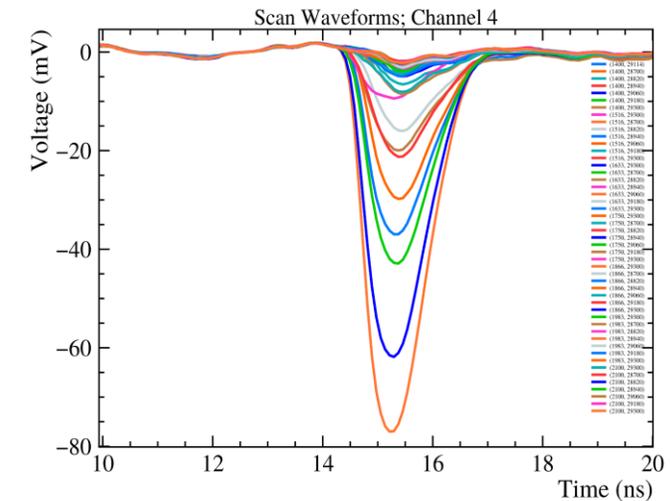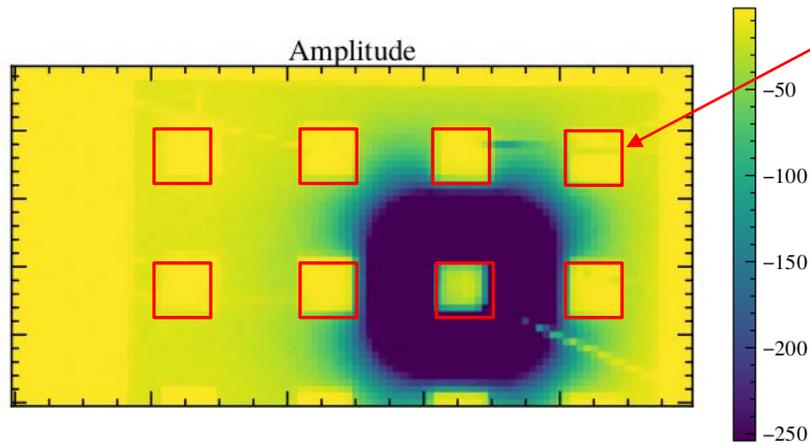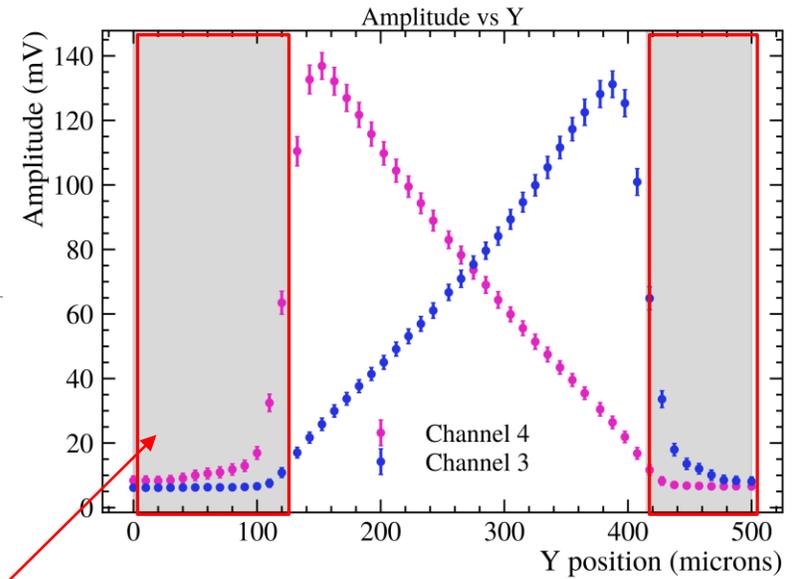
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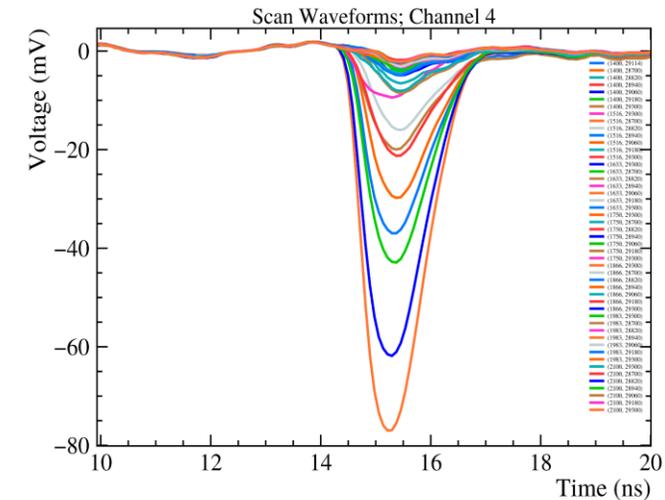 - Any cross-talk between channels

Amplitudes on two pixels as a function of position

Metallization

Amplitude of signal collected on one pixel (mV)

Signal waveform at different points across the device, as measured on one pixel

Future Work

- More complete simulations of static and signal development properties of different processes

- We have received just recently several AC-LGAD samples and have just started characterization and study

- In addition, we have received custom PCBs (Nalu Scientific) with discrete component amplifiers that will work with the high input capacitance of our devices

- Our first AC-LGADs have been mounted and wire bonded and are ready to be put into our TCT setup for measurements!

Conclusions

- The Syracuse team, after completing a big silicon detector construction project, the upstream tracker for the LHCb Upgrade 1, is turning its attention to ultrafast silicon detectors applicable to PID or to timing layers in calorimetry

- Our starting point is the investigation of the sensitivity to geometrical and process parameters tailored to specific applications

- We just received wafers with the devices needed for this study

- We are engaged in a fruitful collaborative effort with BNL and we hope to extend our study to ultrafast silicon detectors aimed at tracking devices and possibly manufactured with materials other than Silicon