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U.S. DEPARTMENT of ENERGY

Optical Characterization of Low-Gain Avalanche Diodes

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CPAD 2025 at Penn

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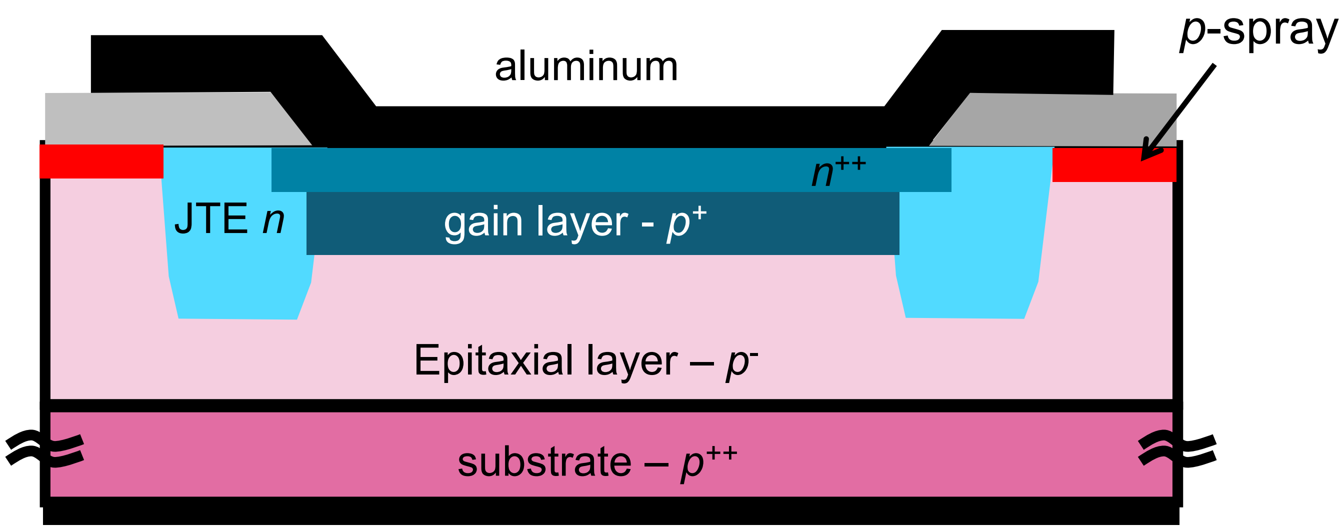
@BrookhavenLab

Std LGAD structure

Std LGAD



- Fabrication on 20, 30, 50 μm thick HR p-type epi substrates (4”)
- Migrating to 6”

- Uniform unpatterned p-spray to compensate for oxide charge and isolate n+ electrodes
  - Tested with gamma/protons and OK to high fluences
- Deep Junction Termination Extension for n+ edge protection against BreakDowns
- N++ to make good ohmic contact
- Gain energy as per external supplier and dose calibrated to have specific breakdown voltage
  - 20 μm → V_{BD} ~ < 100V
  - 30 μm → V_{BD} ~ 120V
  - 50 μm → V_{BD} ~ 200V (at RT)

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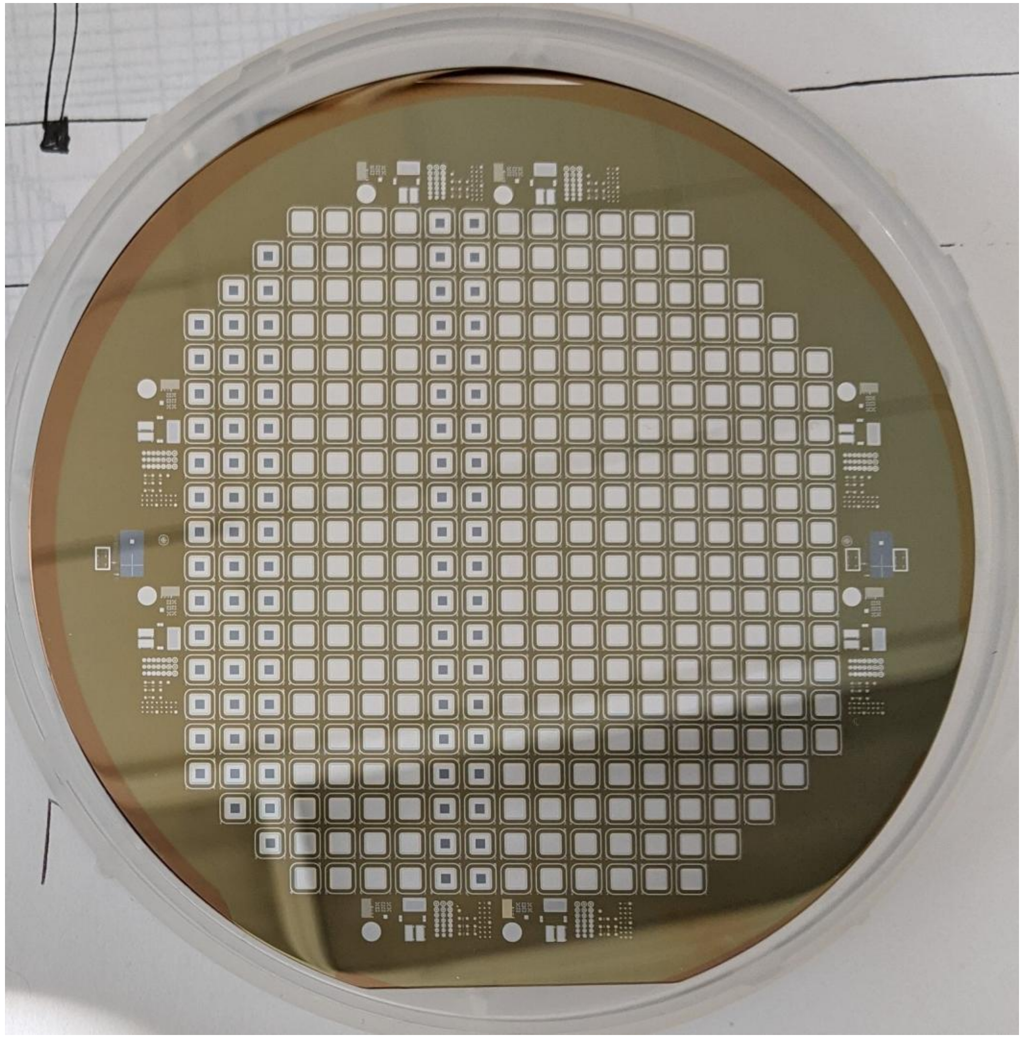
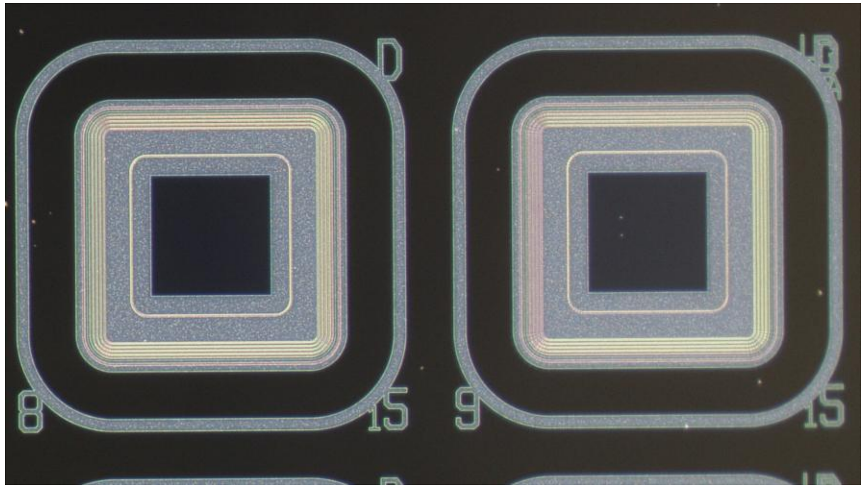
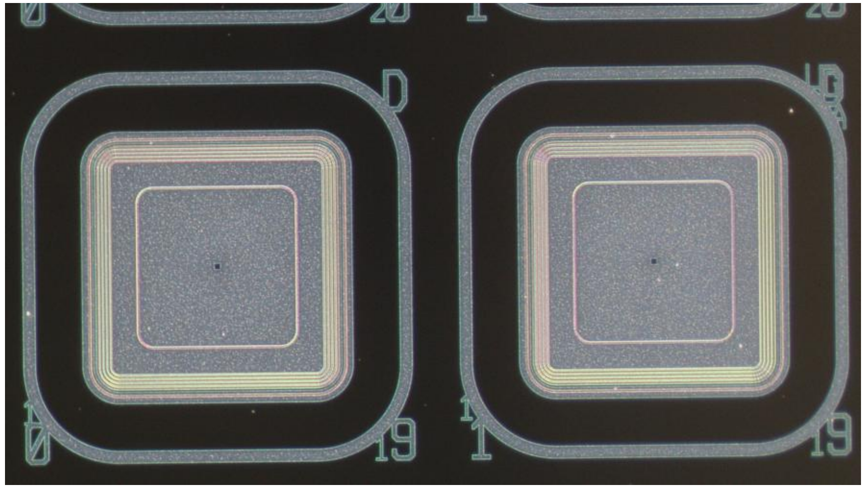
Std LGAD layout

Single channels (1.3mm x1.3mm), mainly for test purposes







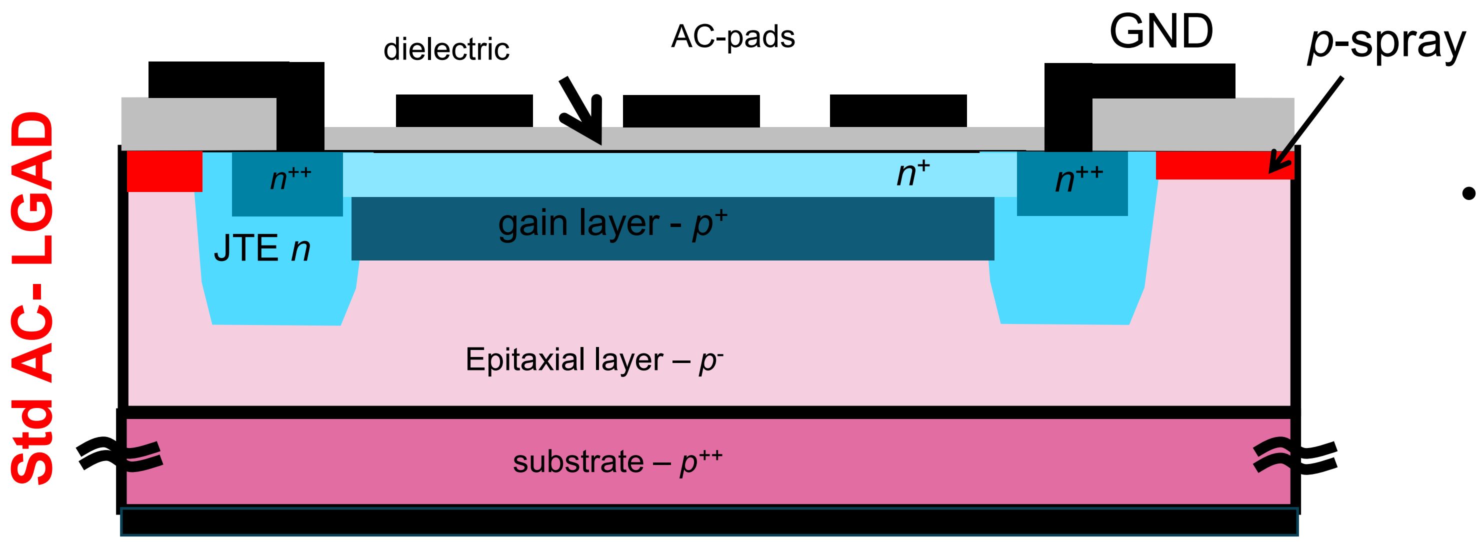
Std AC-LGAD structure

Two main differences wrt LGAD:

1. one large low-doped high-ρ ***n*⁺** implant running overall the active area, instead of a high-doped low-ρ ***n*⁺⁺**
2. A thin insulator over the ***n*⁺**, where fine-pitch electrodes are placed.

100% Fill Factor and **fast timing information at a per-pixel level** both achieved!!!

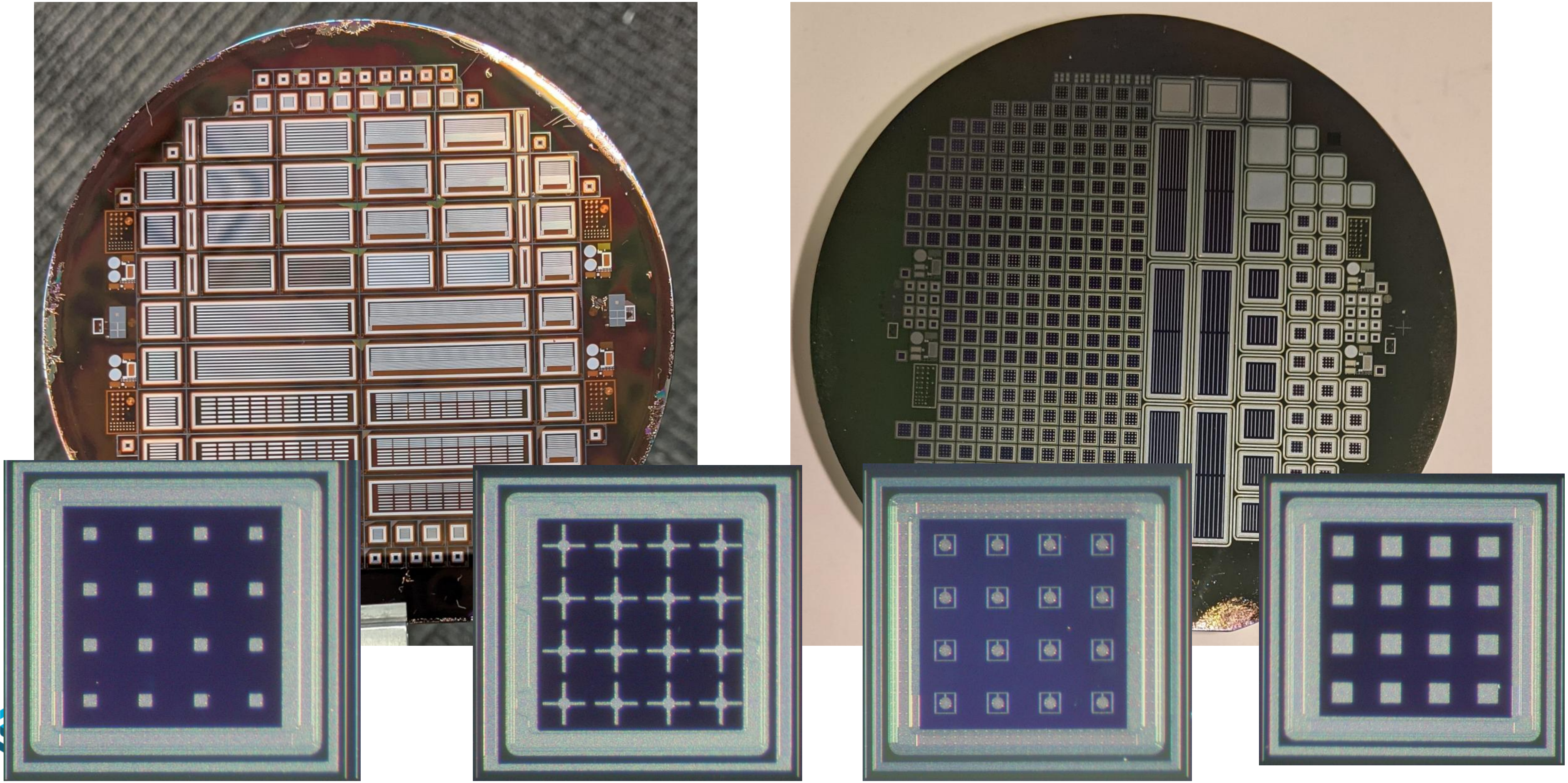
- Signal is still generated by drift of multiplied holes into the substrate and AC-coupled through dielectric
- Electrons collect at the resistive ***n*⁺** and then slowly flow to an ohmic contact at the edge.



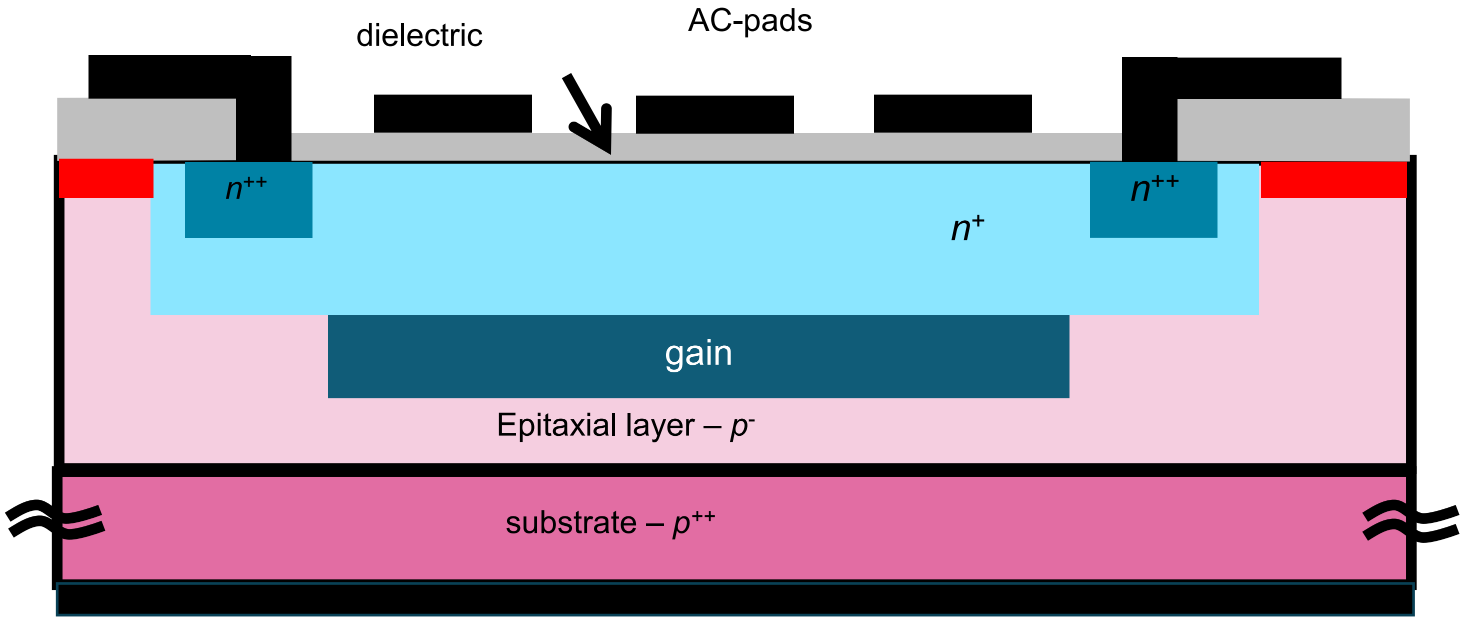
- p-spray as in LGADs
- Deep Junction Termination Extension for n+ edge protection against BreakDowns with embedded N++ to make good ohmic contact
- Gain dose re-calibrated wrt LGADs to keep the same breakdown voltage as in LGADs
  - 20 μm → V_{BD} ~ < 100V
  - 30 μm → V_{BD} ~ 120V
  - 50 μm → V_{BD} ~ 200V

    (at RT)

Some std AC-LGAD layouts



Proposed AC-LGAD structure



- No JTE
- Resistive n+ layer as deep as JTE self-protects from high electric fields at the edge
- Gain layer very deep to offset for the deeper n+
- N++ embedded into n+ does not cause yield issues
- Process compatible with LGAD

Preliminary production done, now able to calibrate the dose of the gain layer to achieve “correct” VBD.
Project with UCSC

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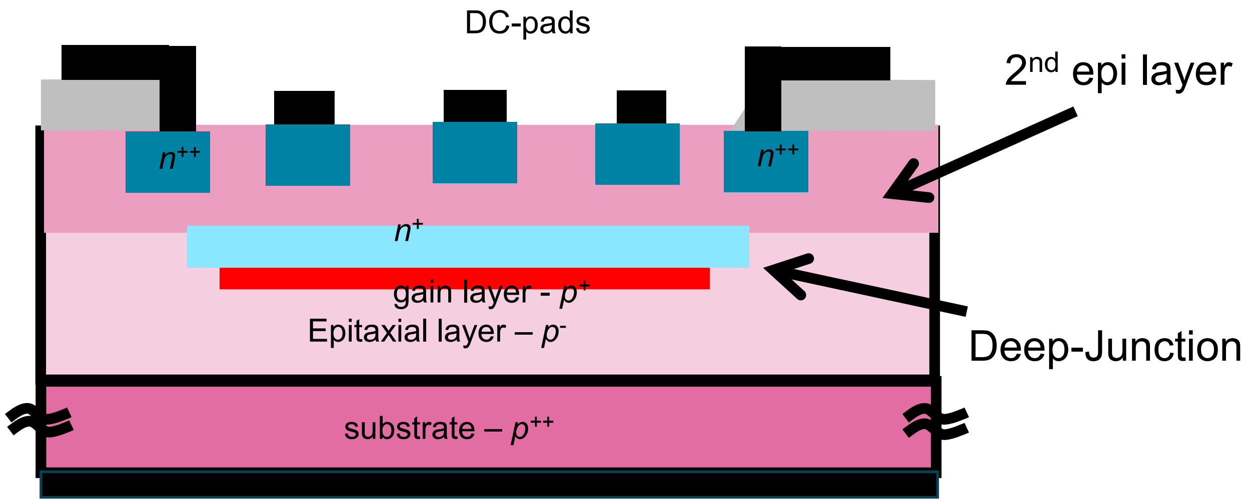
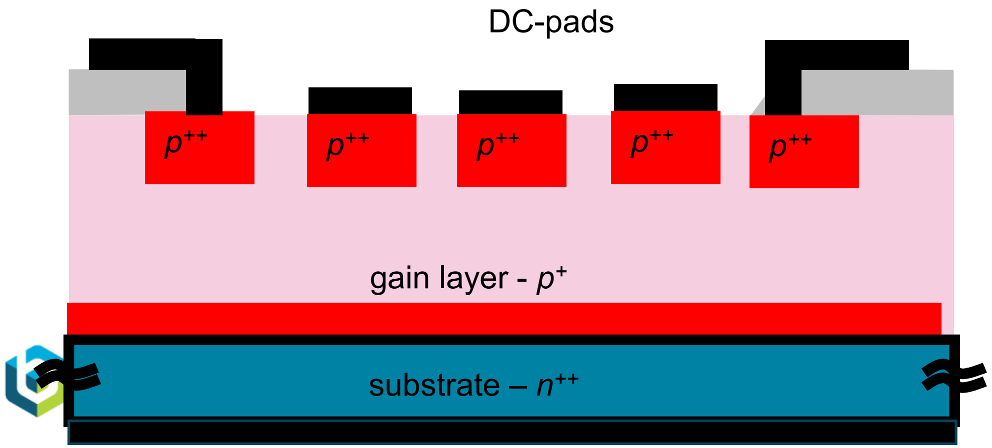
Some other LGAD projects

Deep-Junction LGAD



High-electric field responsible for impact ionization embedded into the substrate (buried under a few um of epitaxial layer).
N+ electrodes are DC-coupled.

"Simplified LGAD"

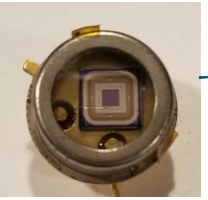


Starting wafer is n++ substrate, and a n or p type wafer is wafer bonded on it, then thinned for timing.
Gain layer is implanted on one of the wafers.
P+ electrodes are DC-coupled.

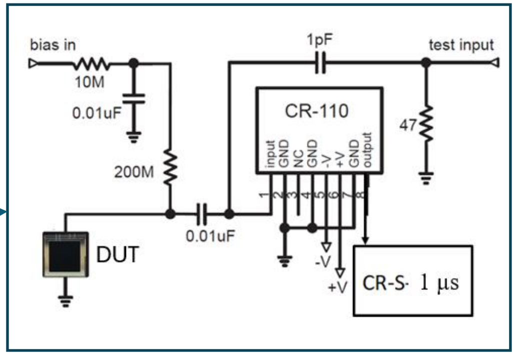
Response to 60keV from ^{241}Am

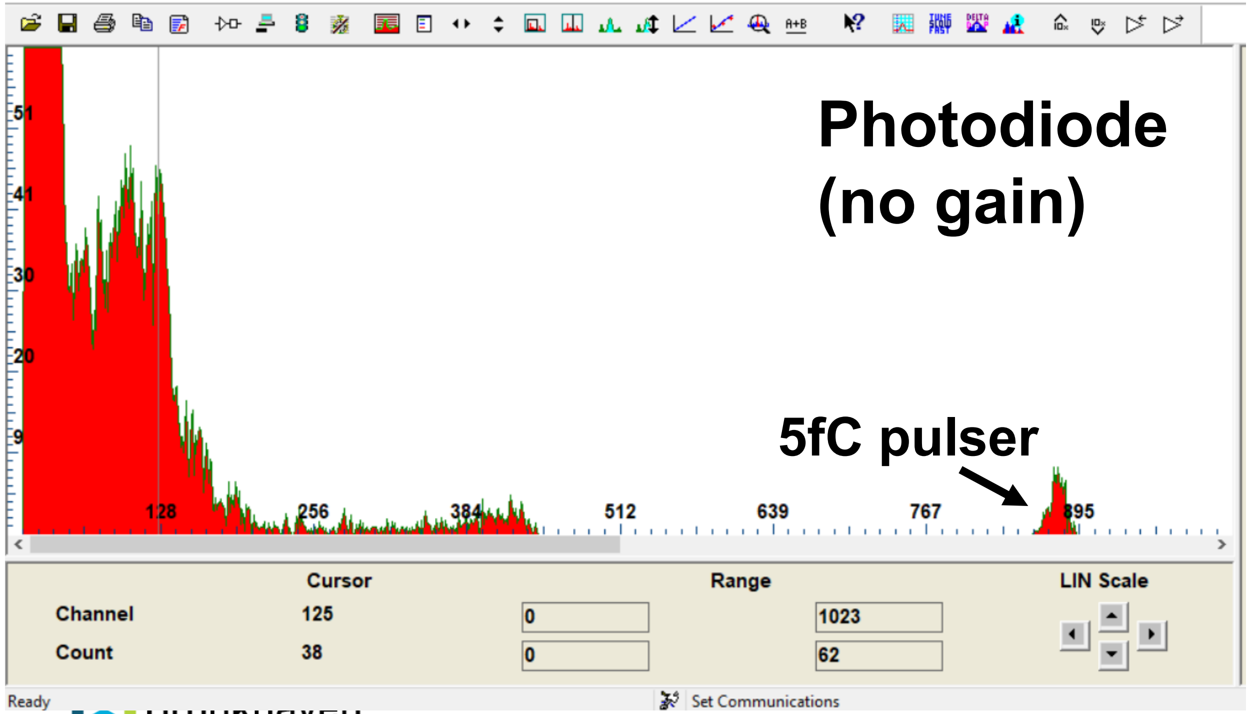
Low-noise charge collection measurement with commercial single-channel, Charge Sensitive Amplifier.
S/R better with LGAD than diode – at low gain.
Gain on signal compensates for electronics noise

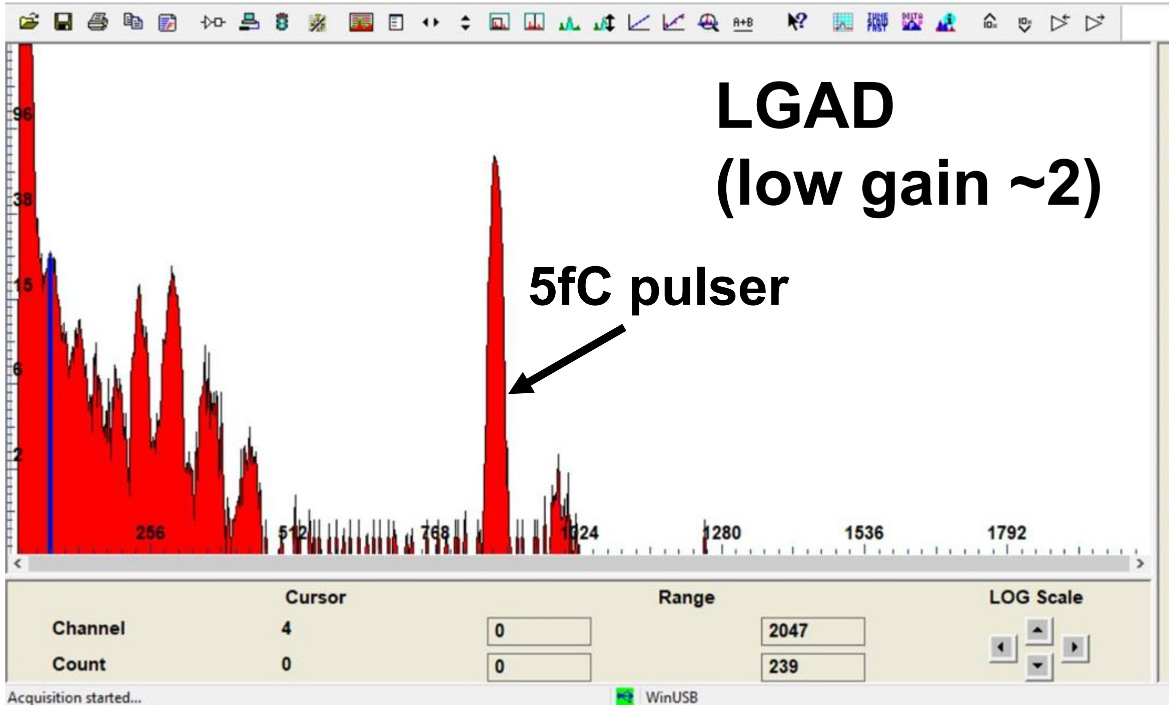
glass window
Si-LGAD



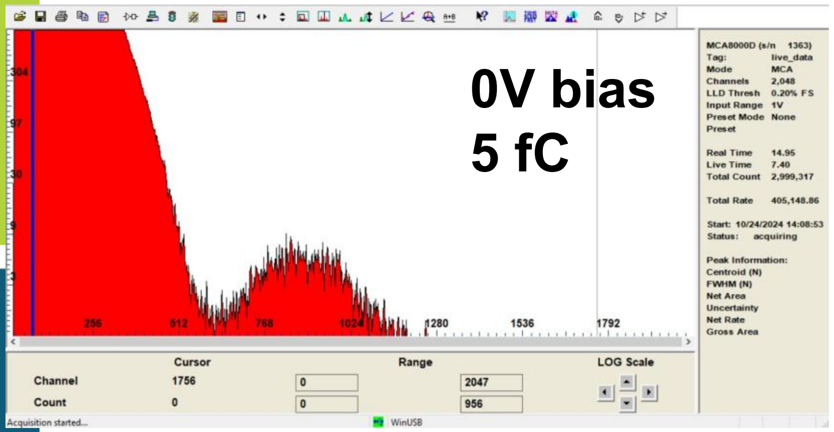
preamp + 1-µs shaper

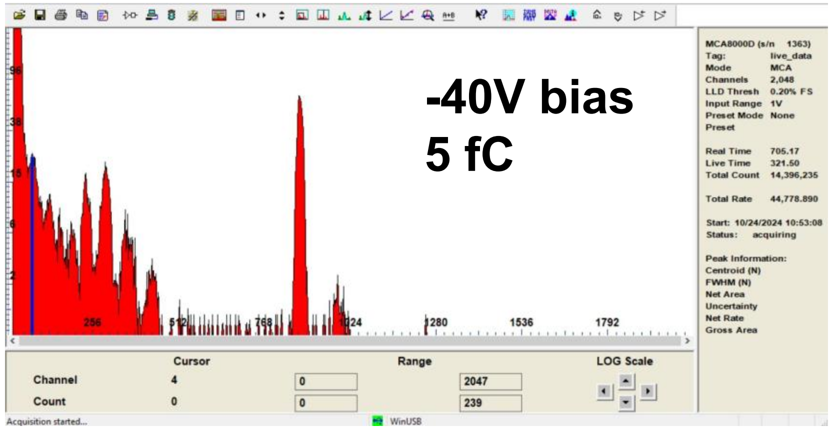


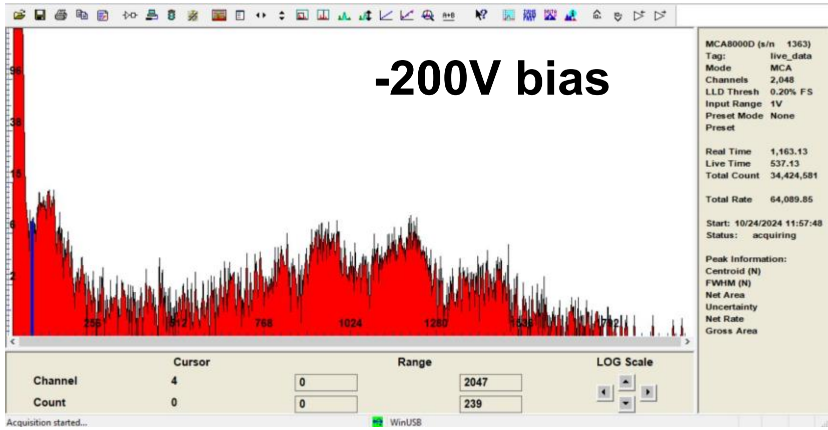


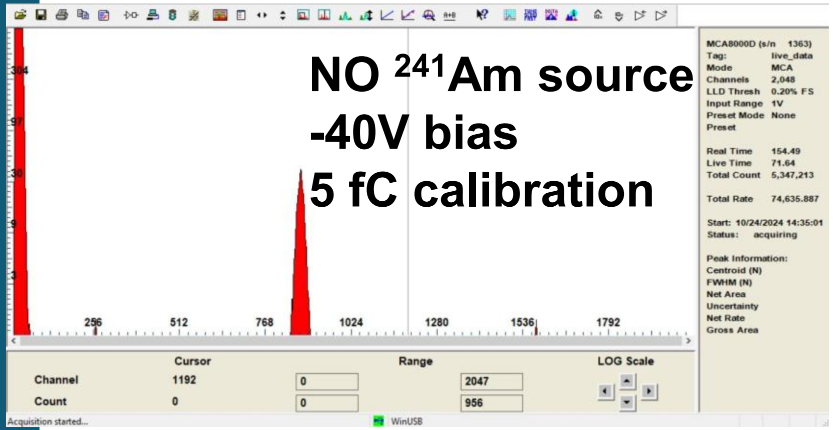


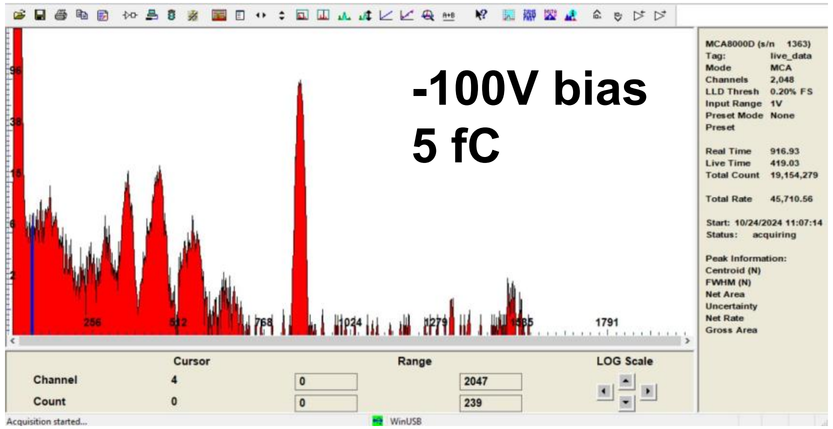
Response to 60keV from ^{241}Am

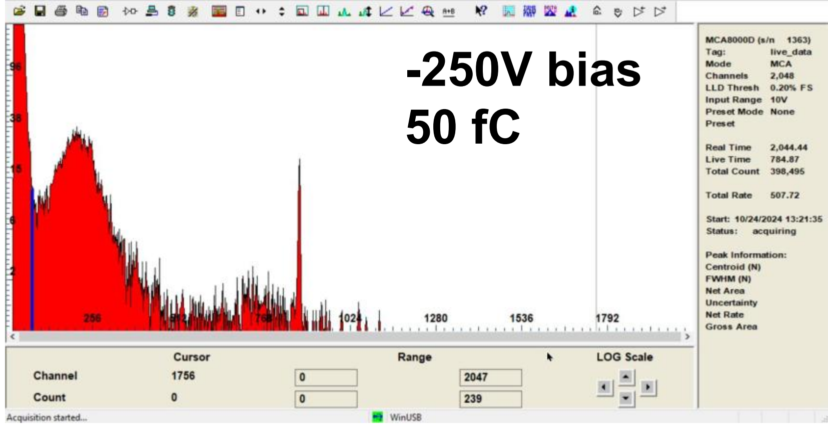


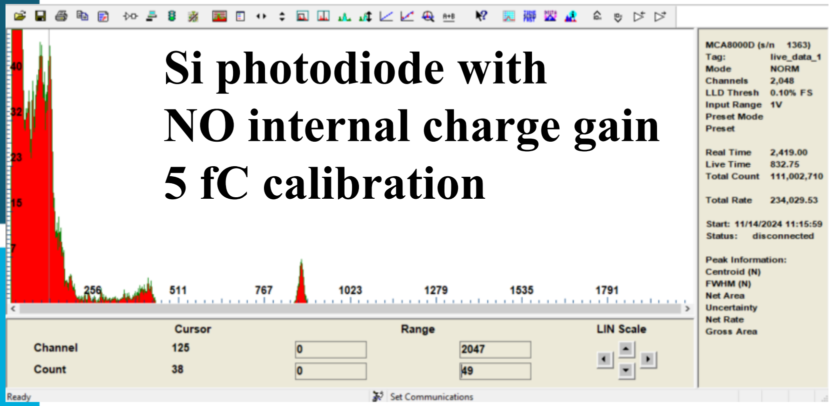


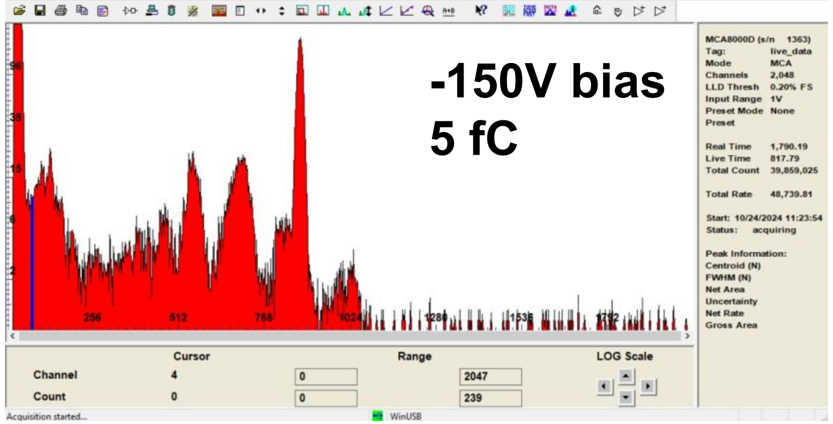


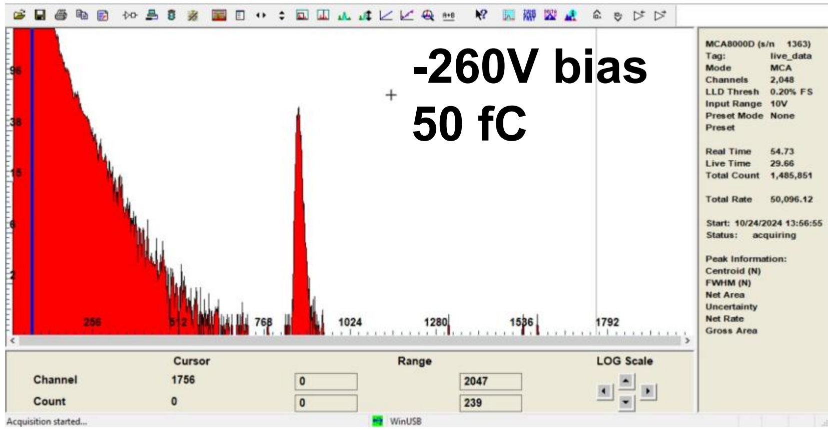




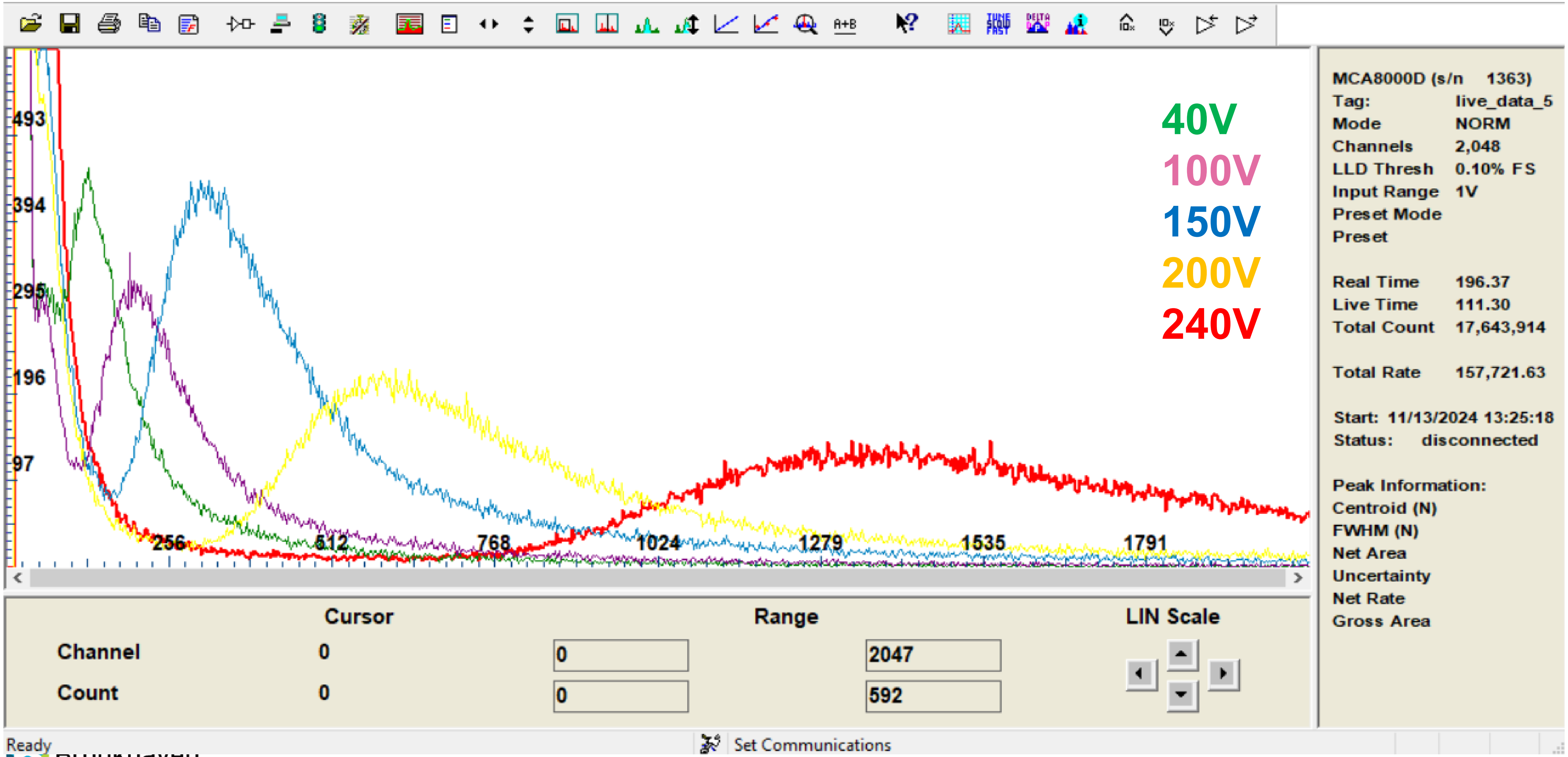








Response to betas from ^{90}Sr



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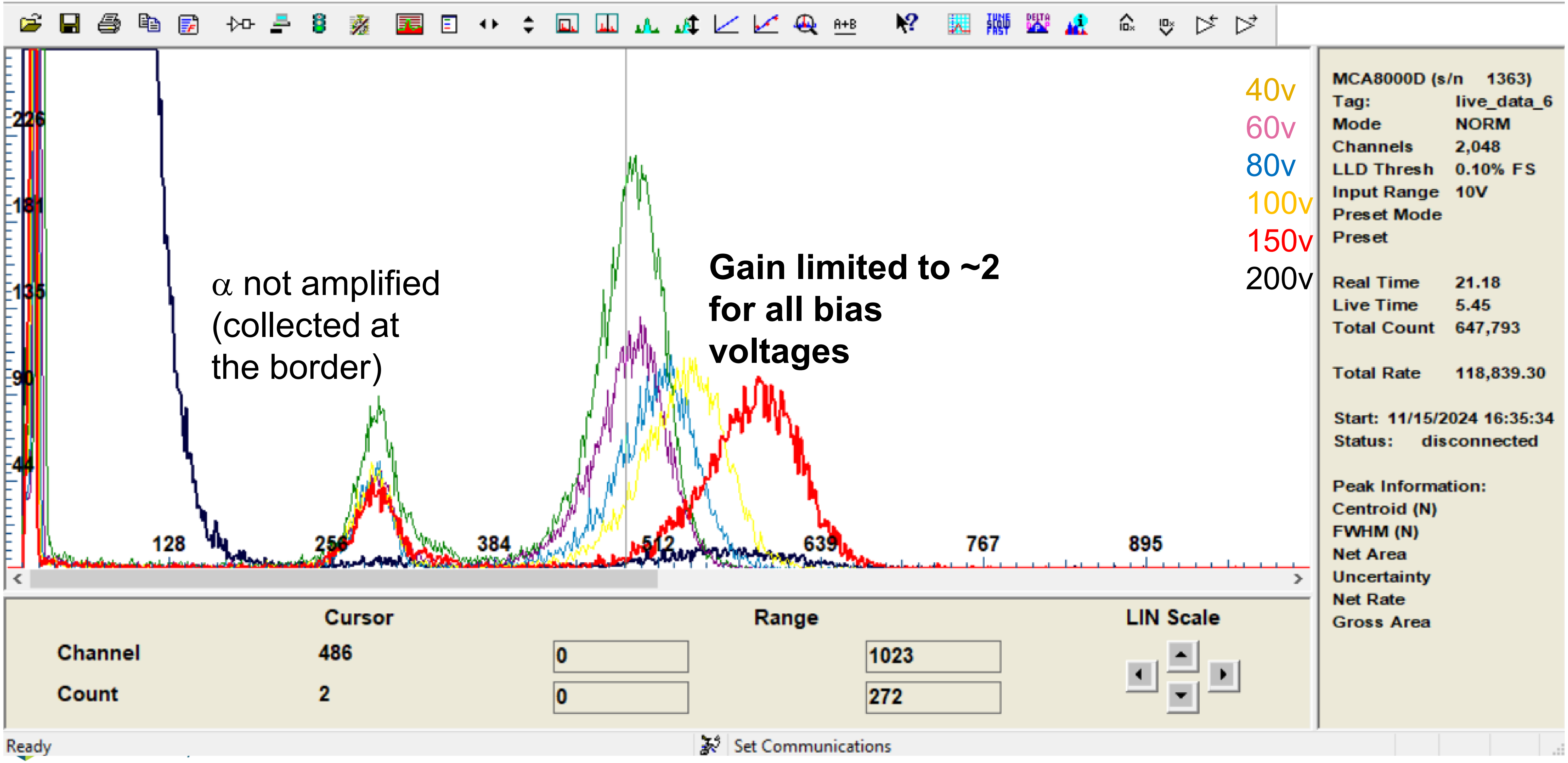
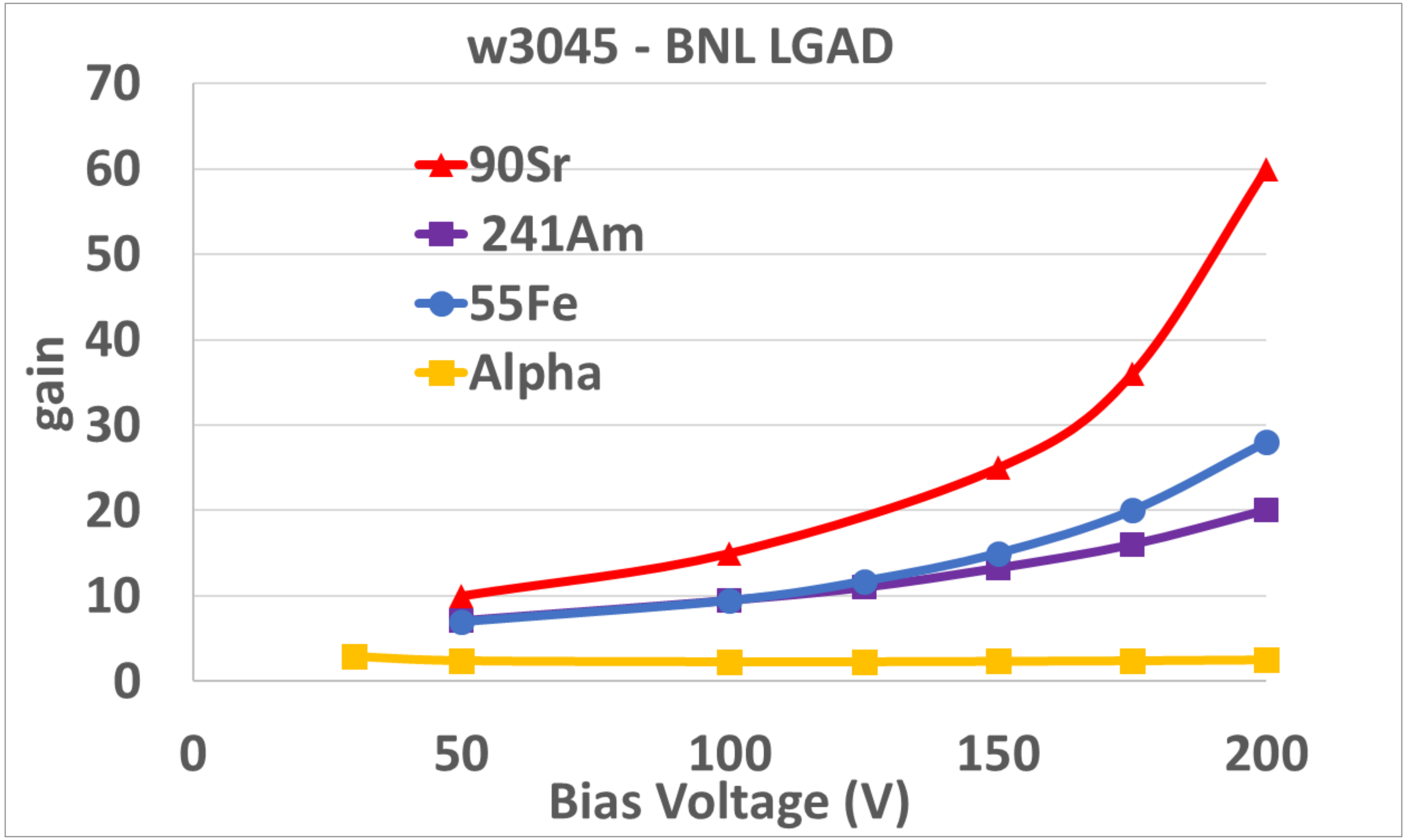
Response to alphas from ^{241}Am



Typical Gain of an LGAD for different particles



Highest gain for mips

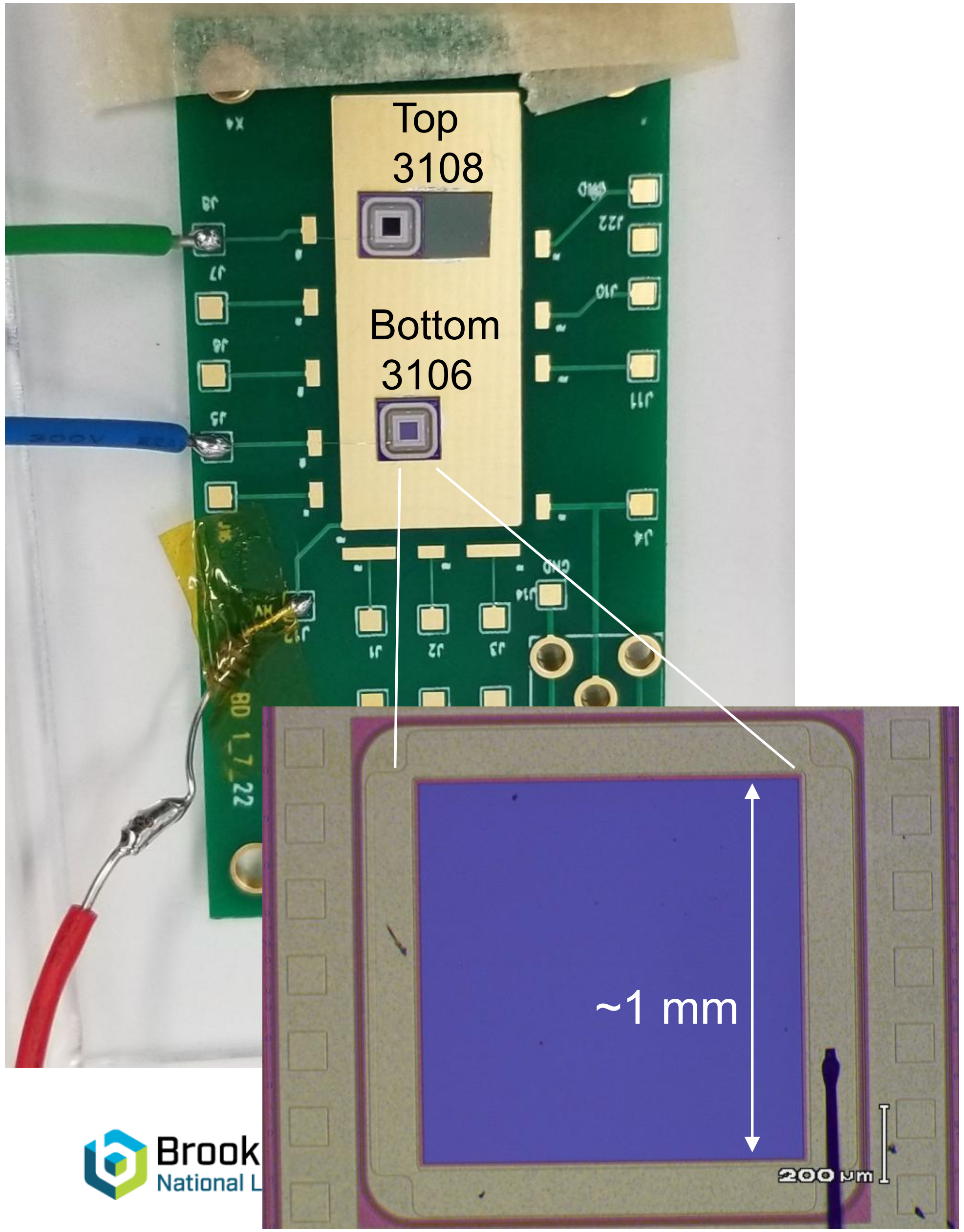
Lowest for alphas

Other talks at this workshop on gain suppression:

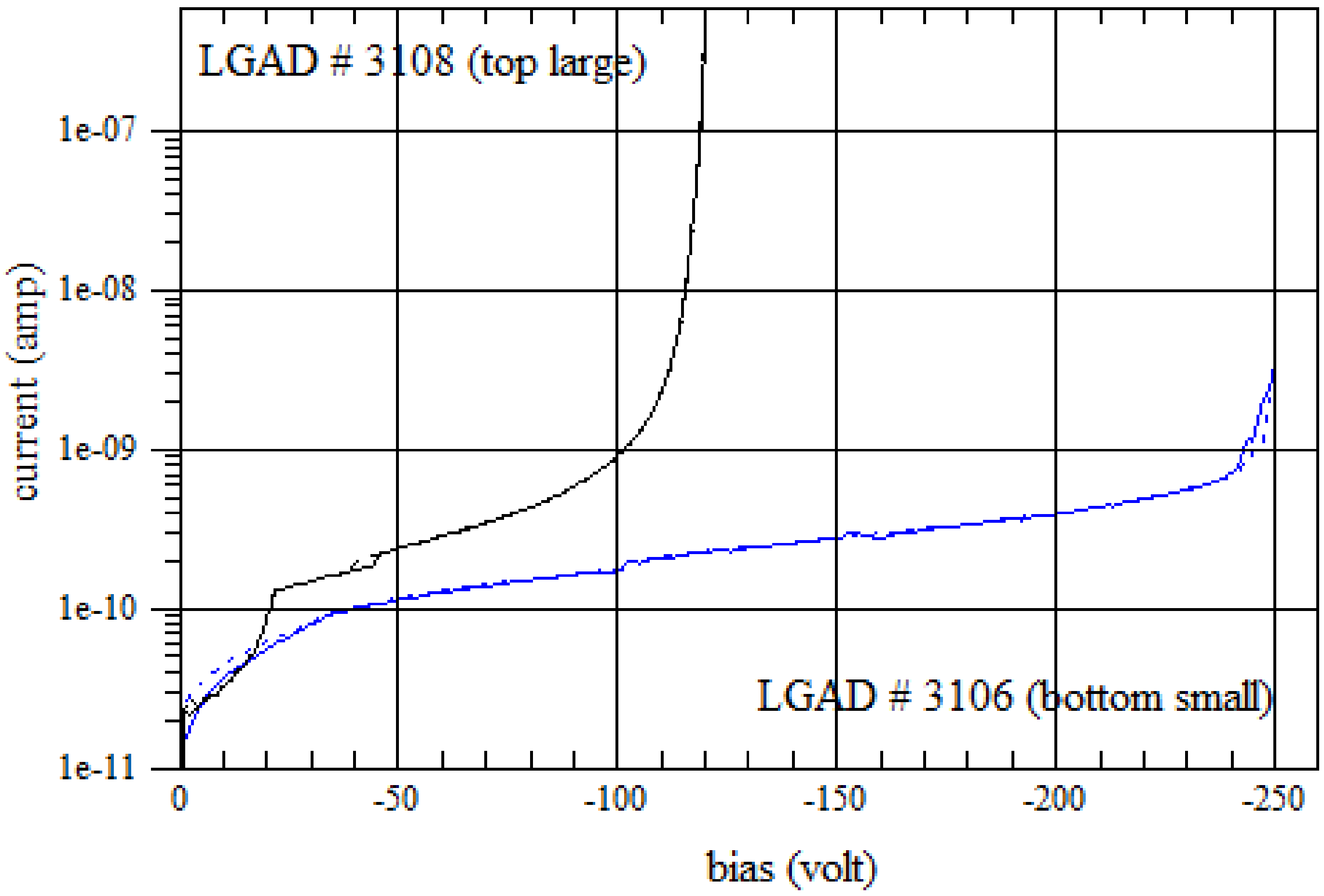
M.H. Farook: [Characterization of Low Gain Avalanche Diodes Using Diverse Particle Beams]

S. Mazza: [5D tracking active target development for the PIONEER experiment]

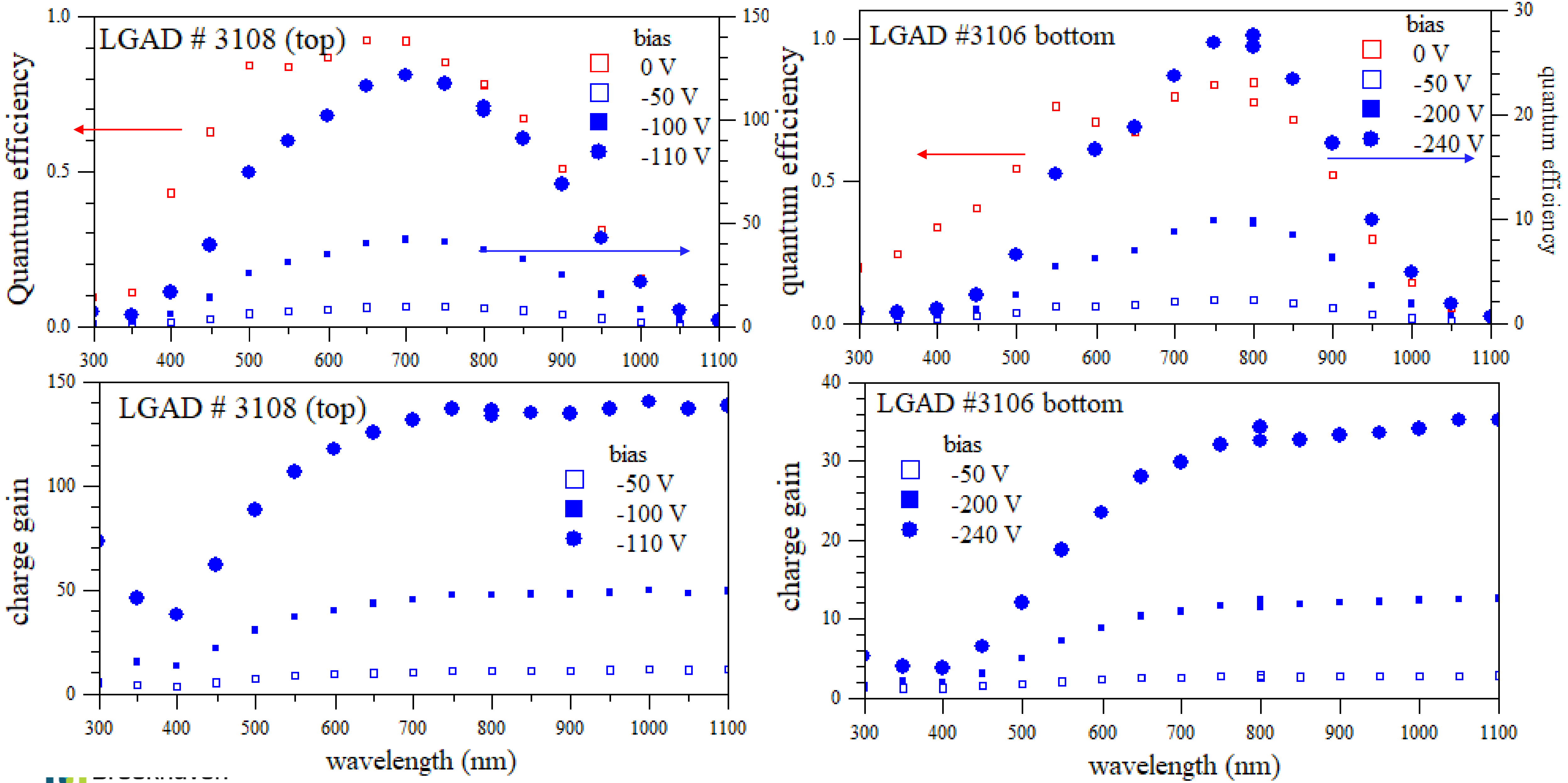
Optical characterization



IV dark

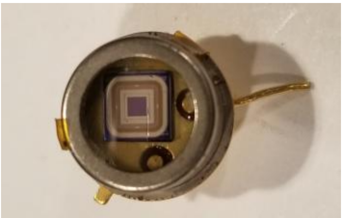


QE (gain) vs λ



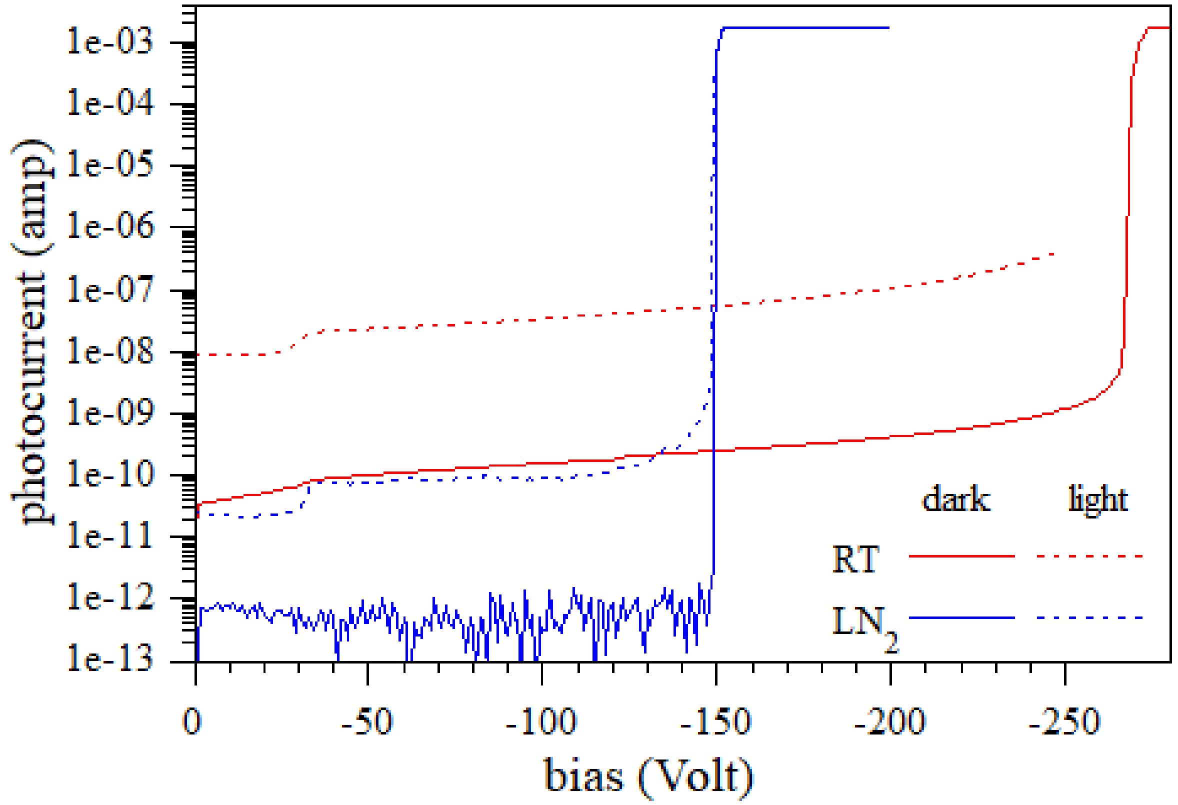
beyond ~700nm photon penetrates to the gain layer

Characterization in LN_2

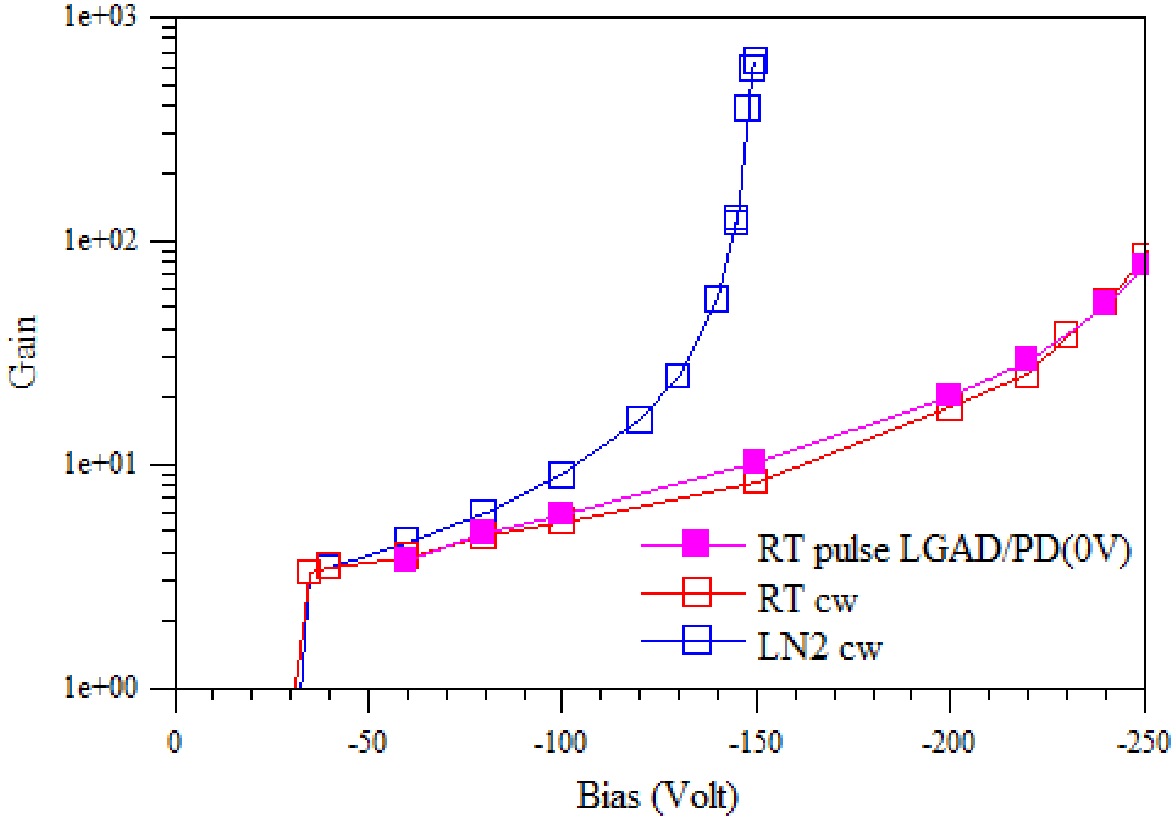


LGAD charge gain with NIR 980 nm photon pulses

#3106 (0-250V)



#3106 RT & LN_2 - log scale



$V_{depletion}$ remains at ~30V

$V_{break\text{-}down}$ drops to ~150V

charge gain in LN_2 ~ charge gain at RT

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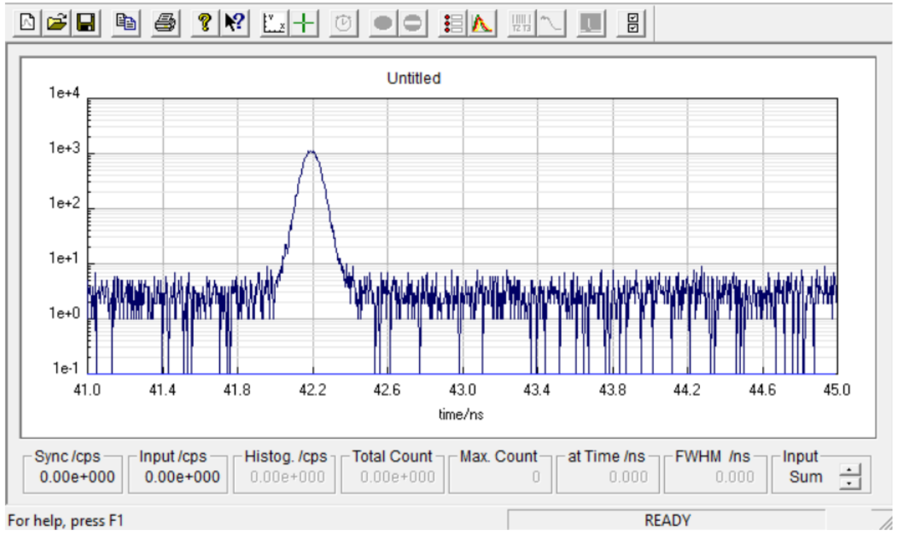
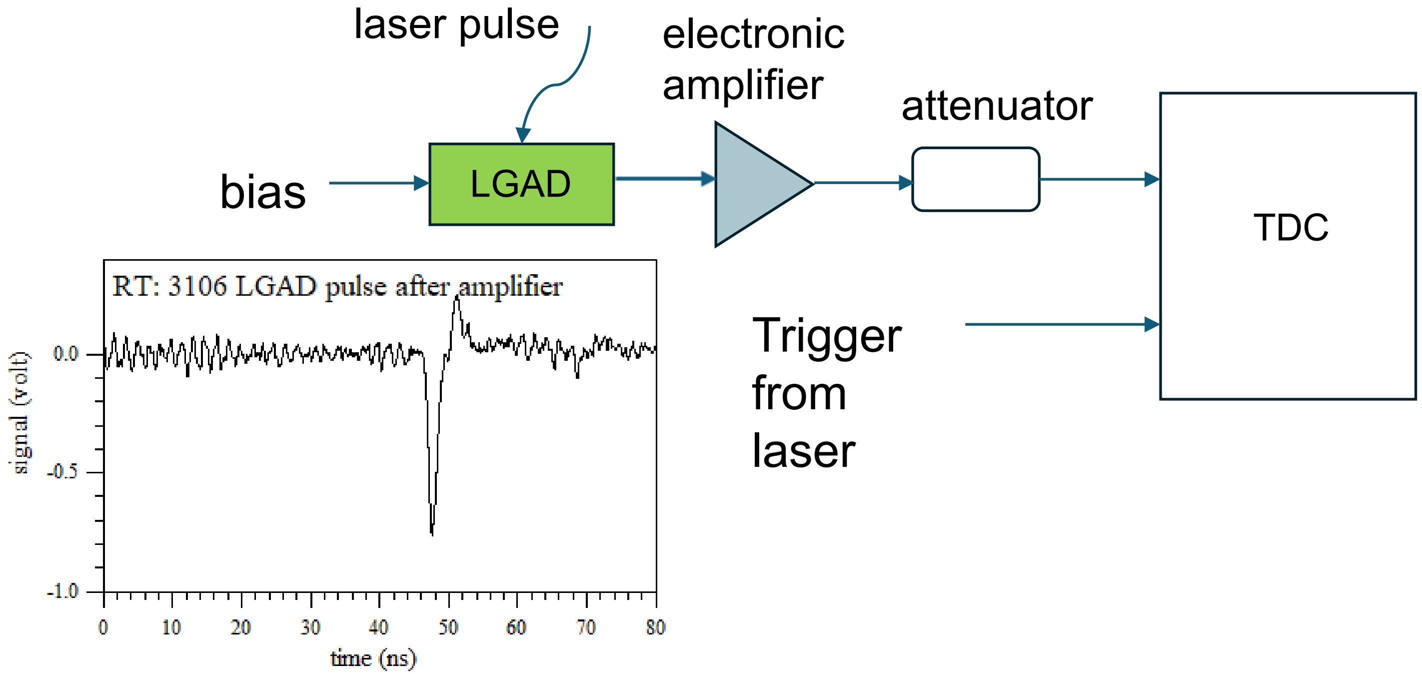
Timing resolution

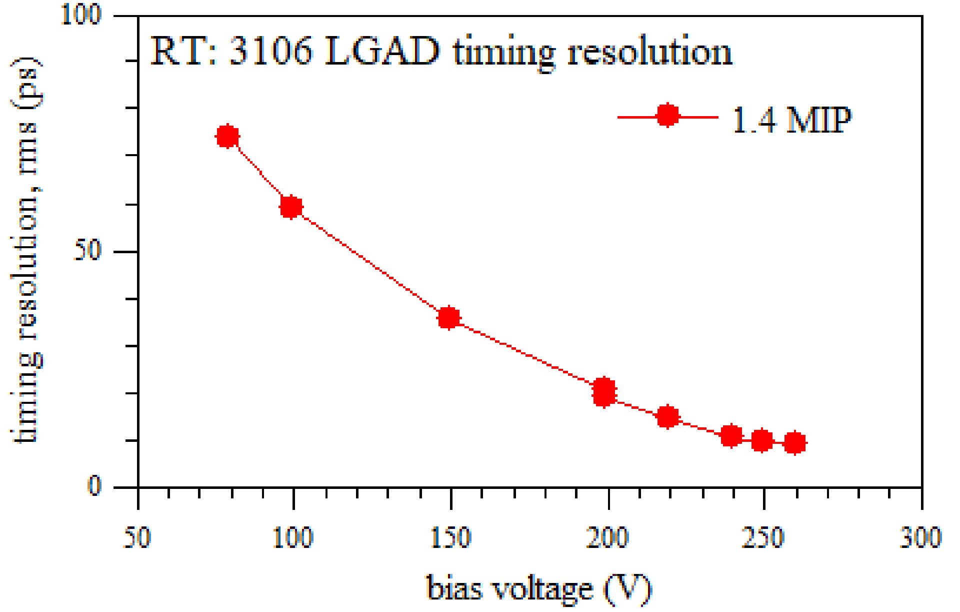
850 nm laser tuned to simulate ~ one mip
Not the usual optical set-up (no Particulars TCT, FNAL/UCSC boards, offline analysis with scope, etc)

Timing does not include Landau noise, which is dominant in LGADs
~ < 10ps for high gains.

Histogram of the pulse arrival time







Thanks

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