LGAD For Radiotherapeutic Beams

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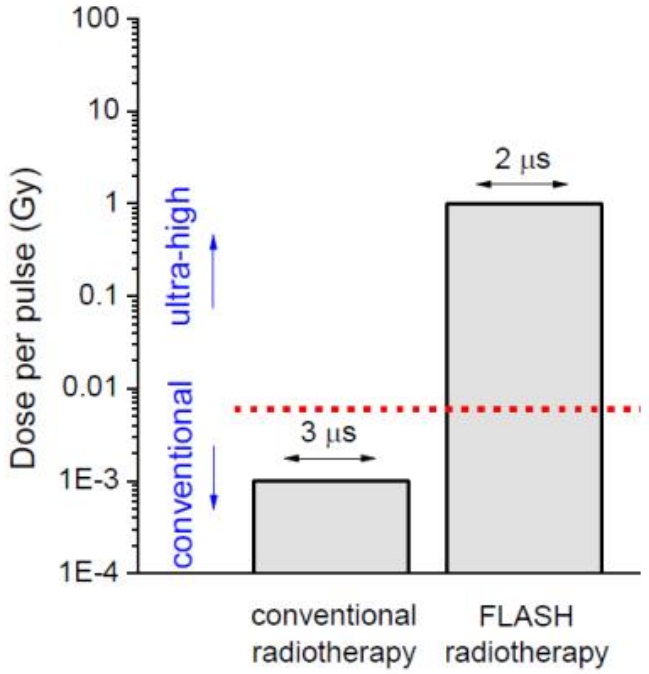
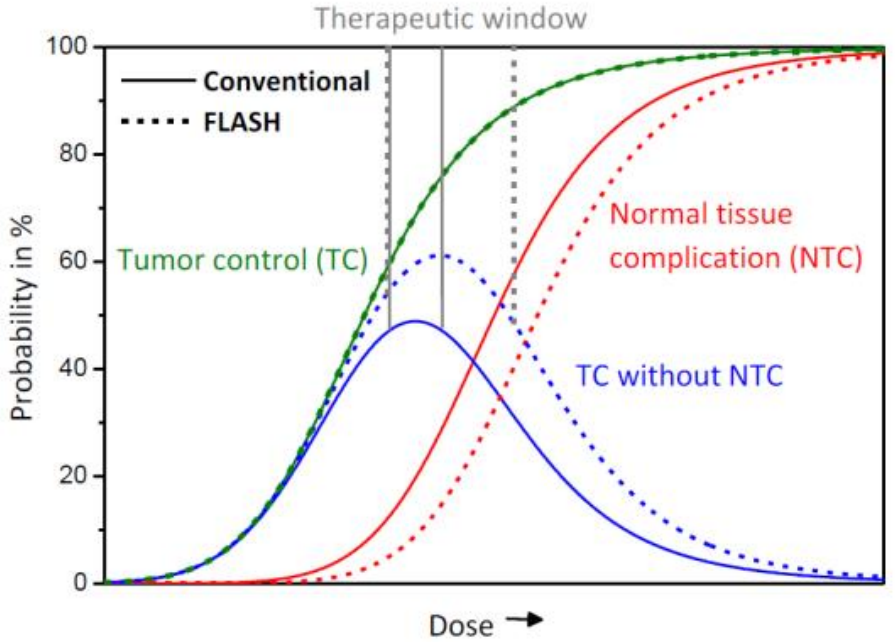
The First Day at the Hospital

Part of our team

FLASH Therapy

- FLASH effect: Irradiations with UHDR (Ultra-high Dose Rates) > 40 Gy/s reduced toxicity in healthy tissue while preserving the effect on the tumor (Favaudon et al, Sci Transl. Med 2014 6 2014)
- There is a need for real-time dosimetry



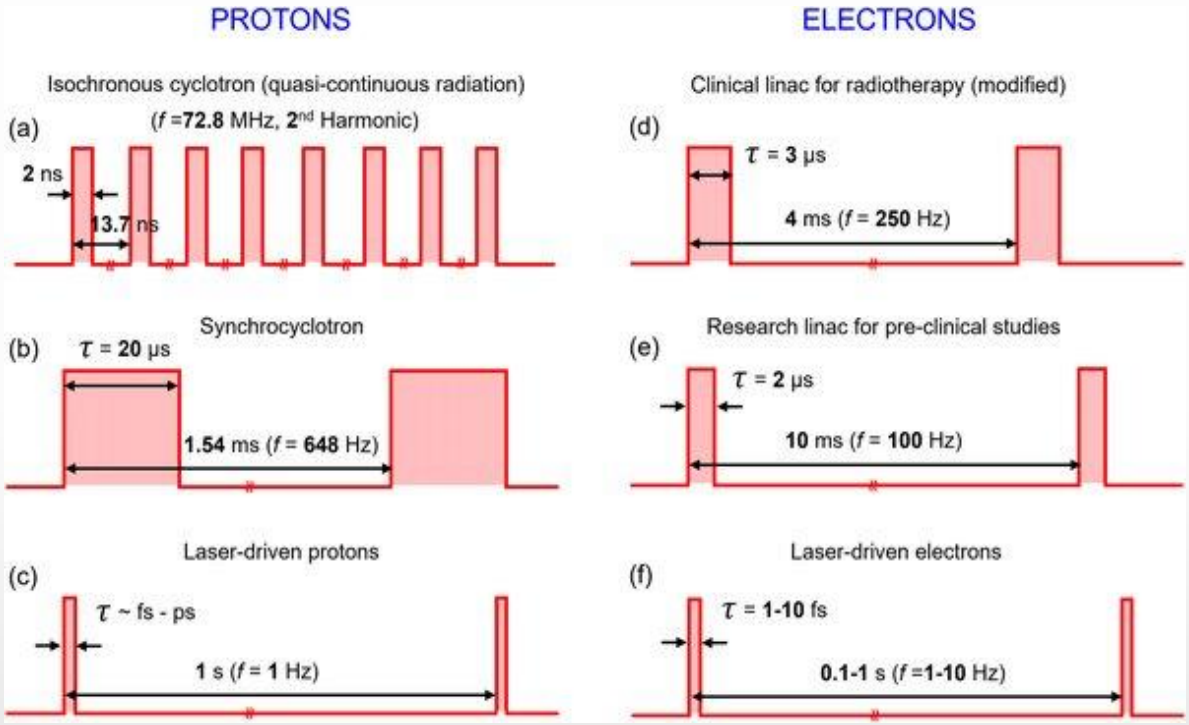


Schuller et al., Physica Medica 80 (2020) 135

FLASH Therapy in Action

Schuller et al., Physica Medica 80 (2020) 135

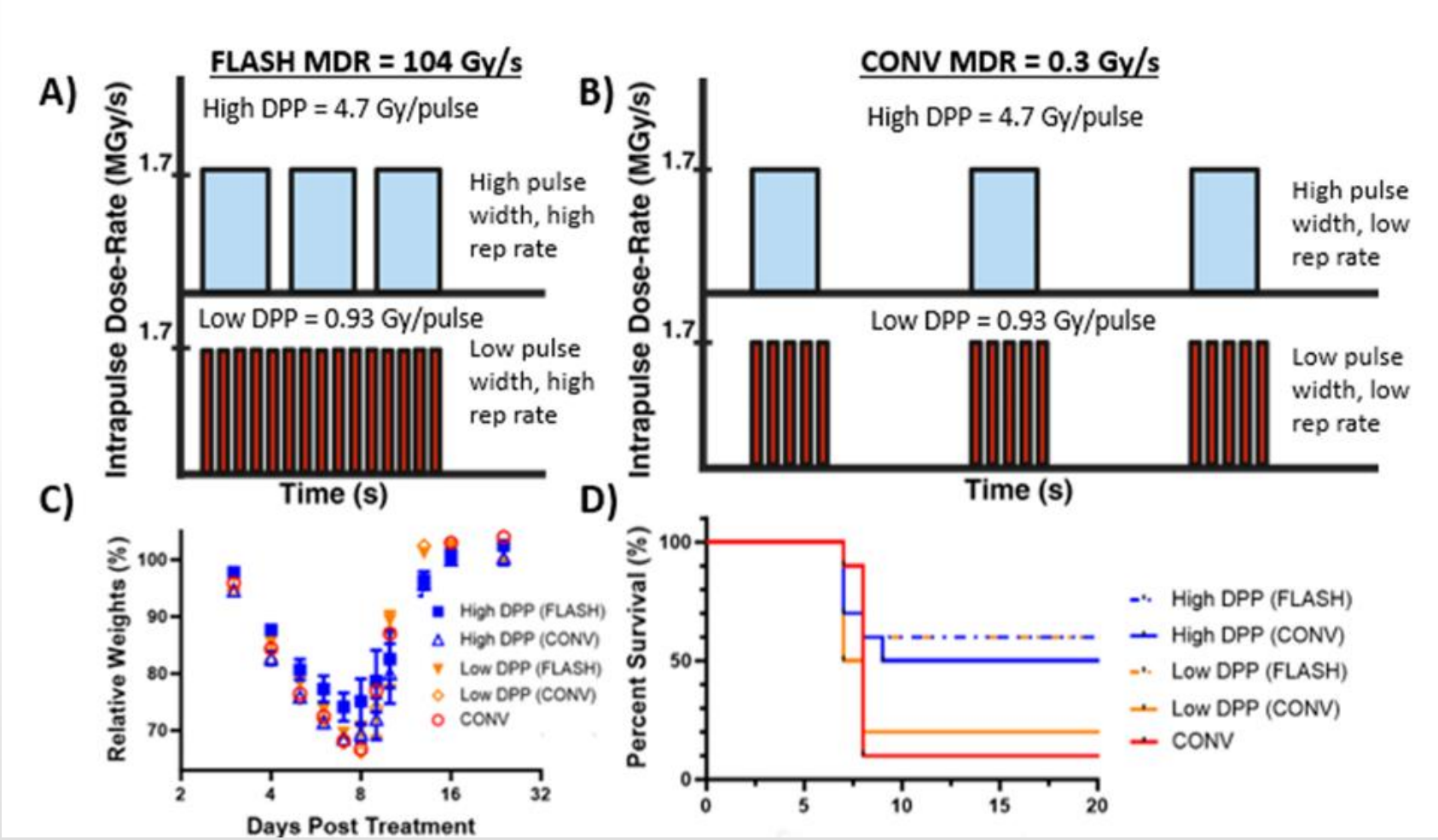
Beams come in all shapes and Structures



- Two kinds of dose rates:
  - Average: over basic irradiation time (fraction)
  - Instantaneous: over the smallest beam structure (pulse, spill)
- Most results seem to favored average dose, but some results seem to indicate otherwise (Schueler et al.)

Romano et al., Medical Physics 49(7) , May 2022

Temporal Structure of the Beam Matters



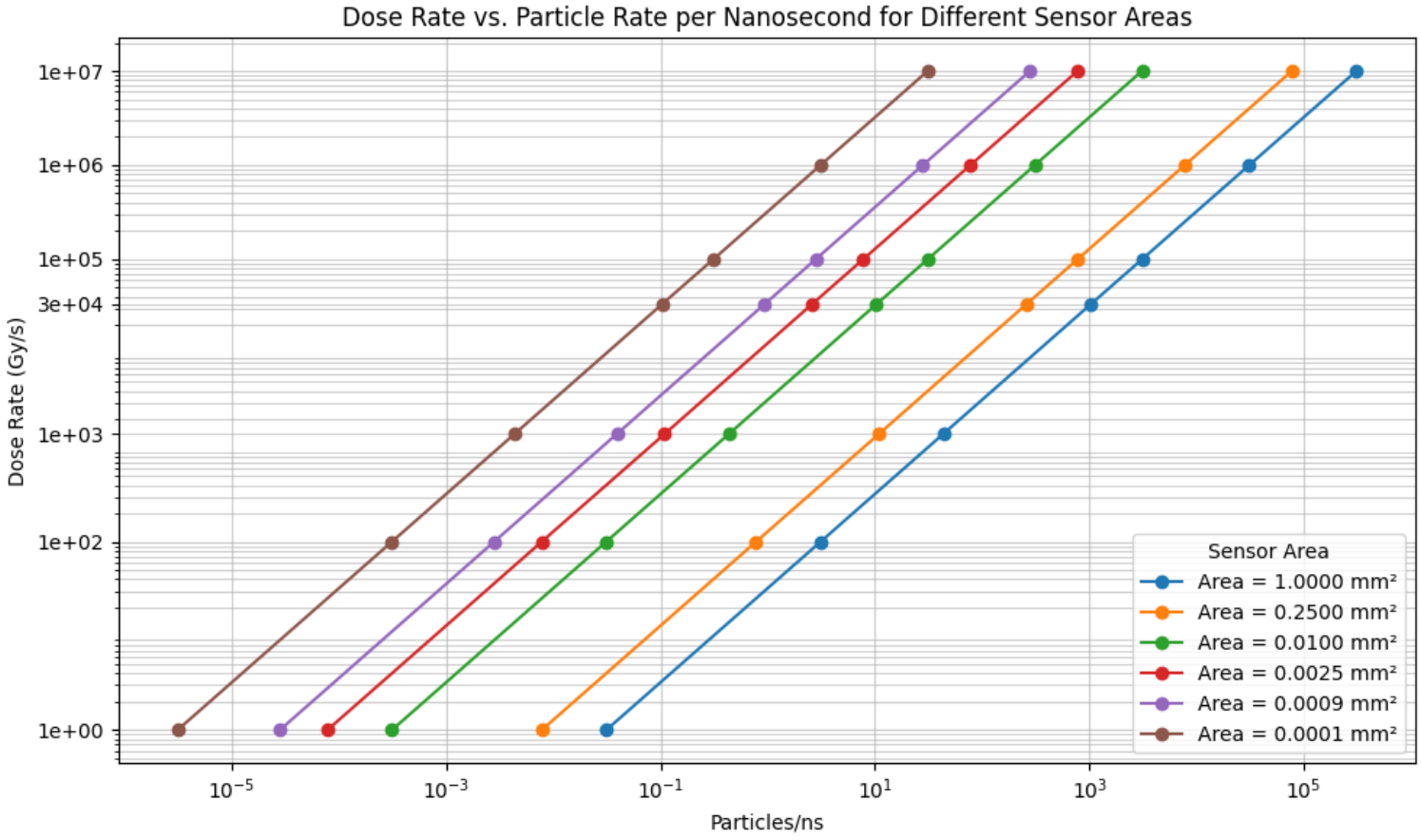
K. Liu *et al.*, Redefining FLASH RT: the impact of mean dose rate and dose per pulse in the gastrointestinal tract. *Int J Radiat Oncol Biol Phys*, (2024).

LGAD Signal Versus Time

T. Isidori et al., Performance of a low gain avalanche detector in a medical linac and characterization of the beam profile. Phys Med Biol 66, (2021).

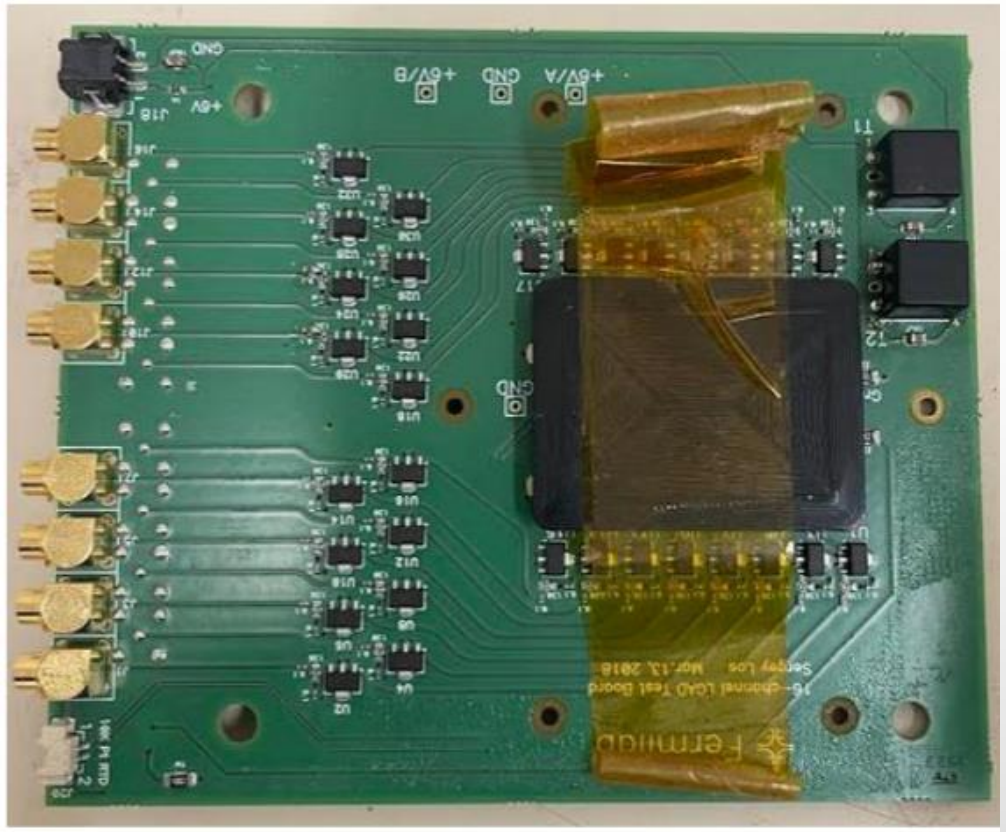
Dose Rates to Particles Fluxes

- Radiation Therapy Dose unit is Gray= 1 Joule / Kilogram
- Typical patient dose is 50-70 Gy on target (tumor), 2 Gy/fraction



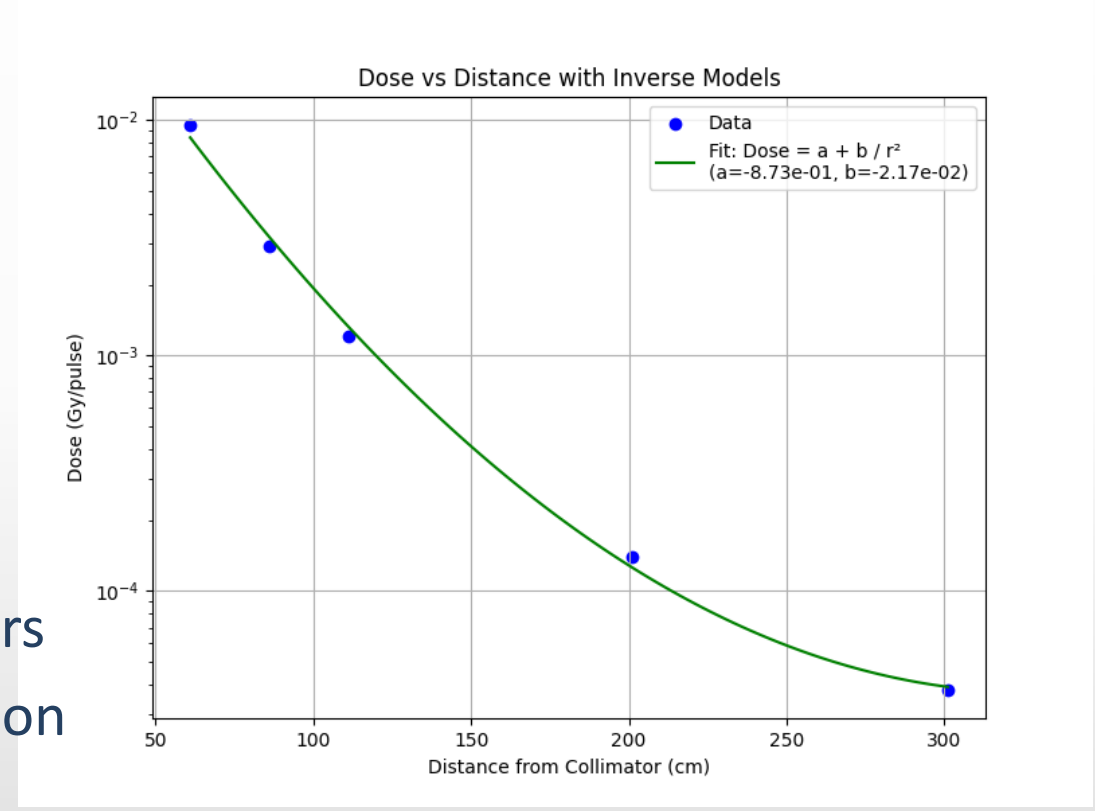
LGAD Detector

- Various sensors available to us in the context of the Encap TOF for CMS at the HL-LHC (2028), Wei Li
- Most results were obtained with an Si LGAD on Fermilab board (Italy made) provided by BNL (Gabriele Giacomini et al)
- LGAD:
  - Voltage ~100 V
  - 30 um thick
  - Active area 1.3x1.3 mm^2
- Tested the sensor with Sr90 source and even cosmics (one an hour)

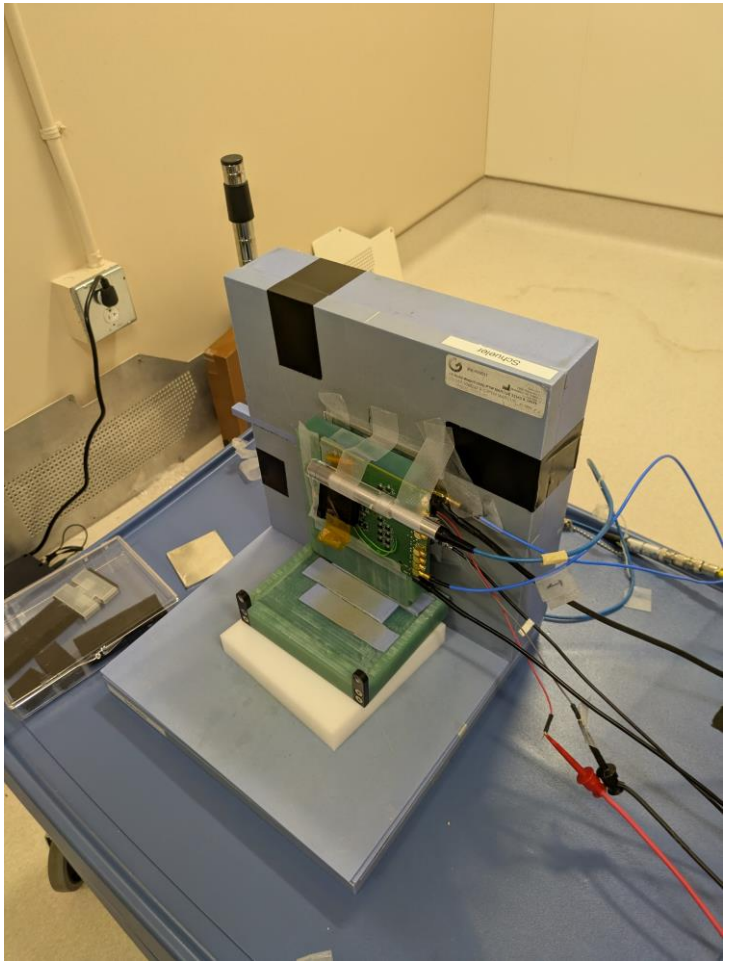


Electron Beam Parameters

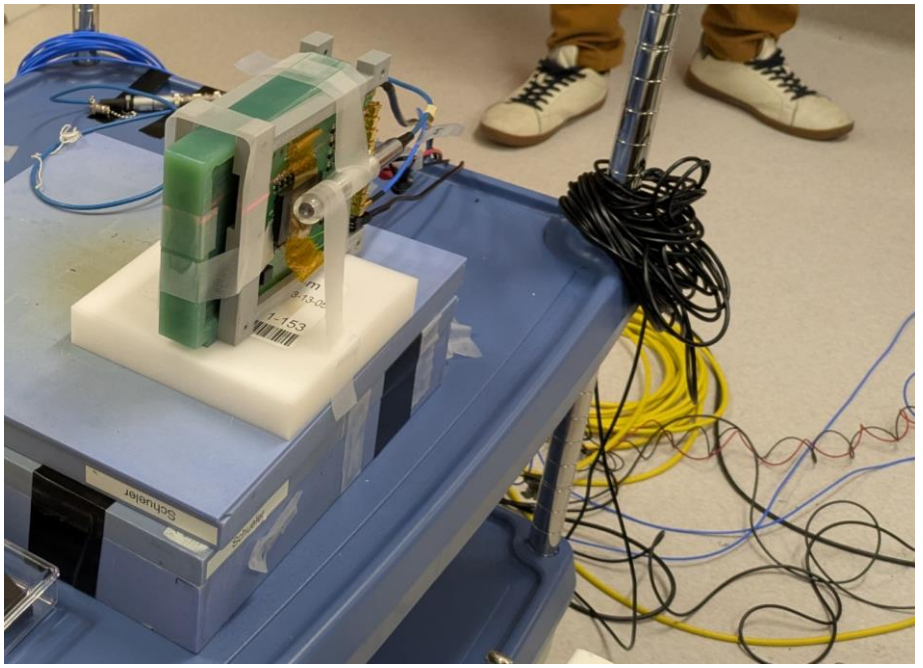
- Vault dedicated at FLASH Research at the University of Texas MD Anderson Cancer Center (Schueler's group)
- Three levels of dose rates depending on the machine HV=85, 110, 190 V
- 7MeV Electrons
- Without and with 2 or 5 cm diameter, 50 cm long collimators
- Dose provided with an ionization chamber, standard for dose measurements, but with no timing information.



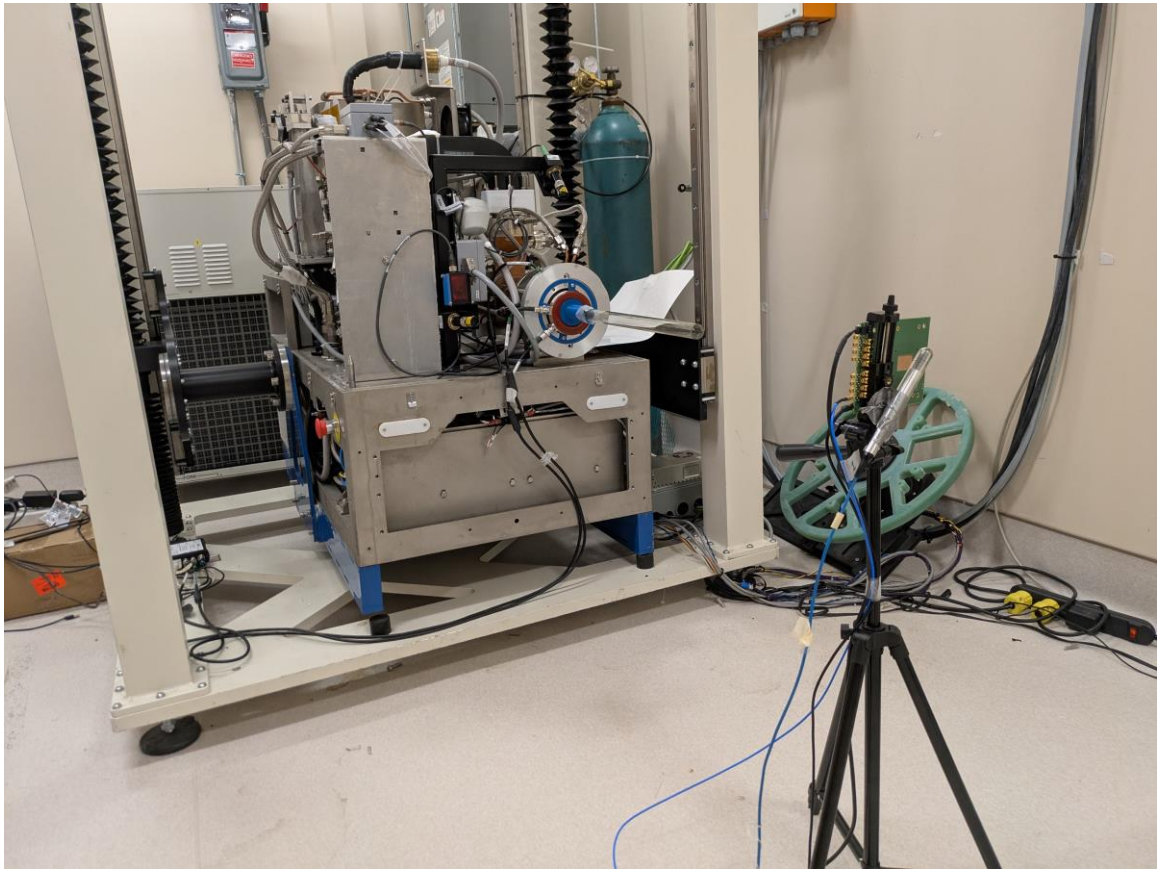
Electron Setup First Tests



With Holders



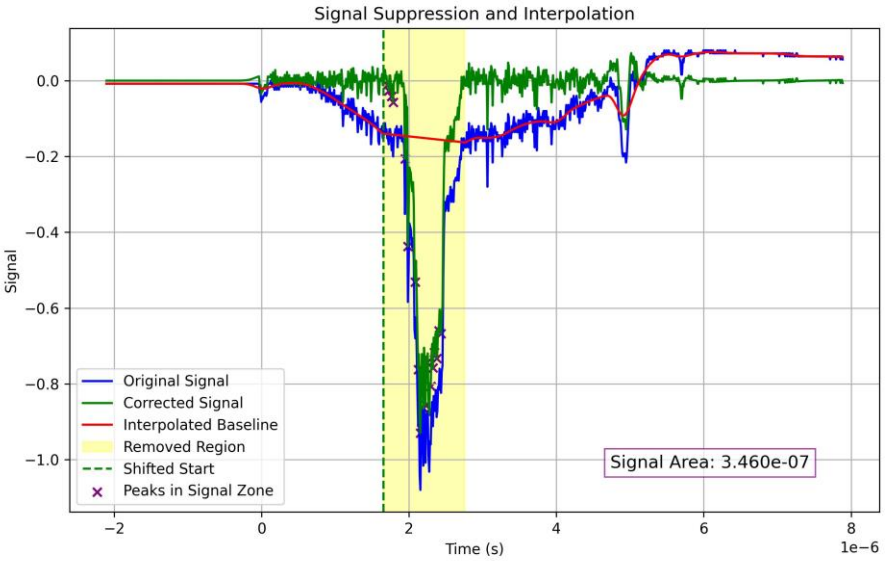
Simplified Setup in Later Tests

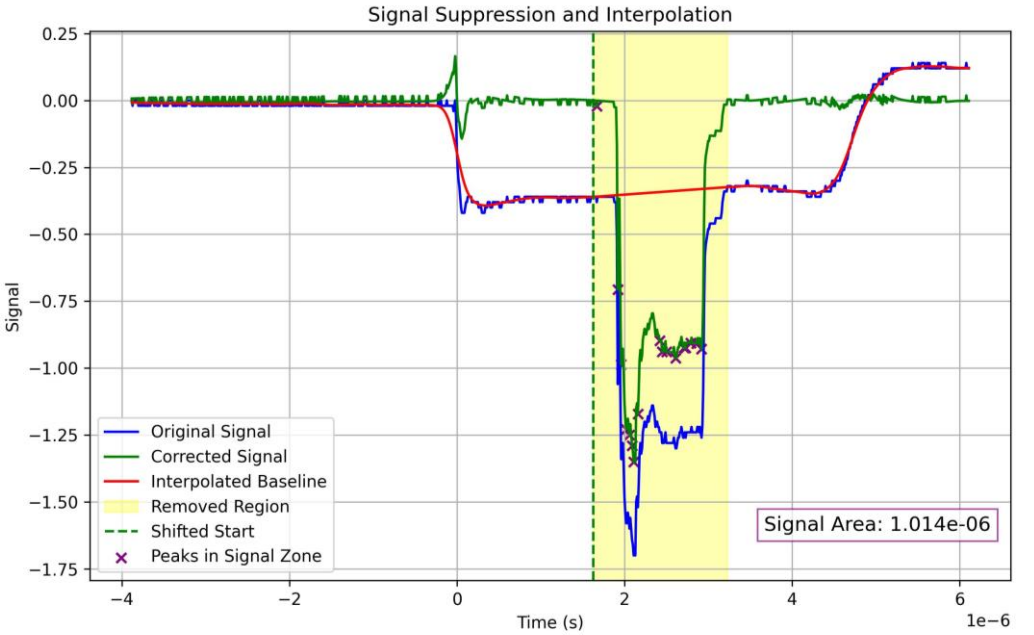


Varying Parameters

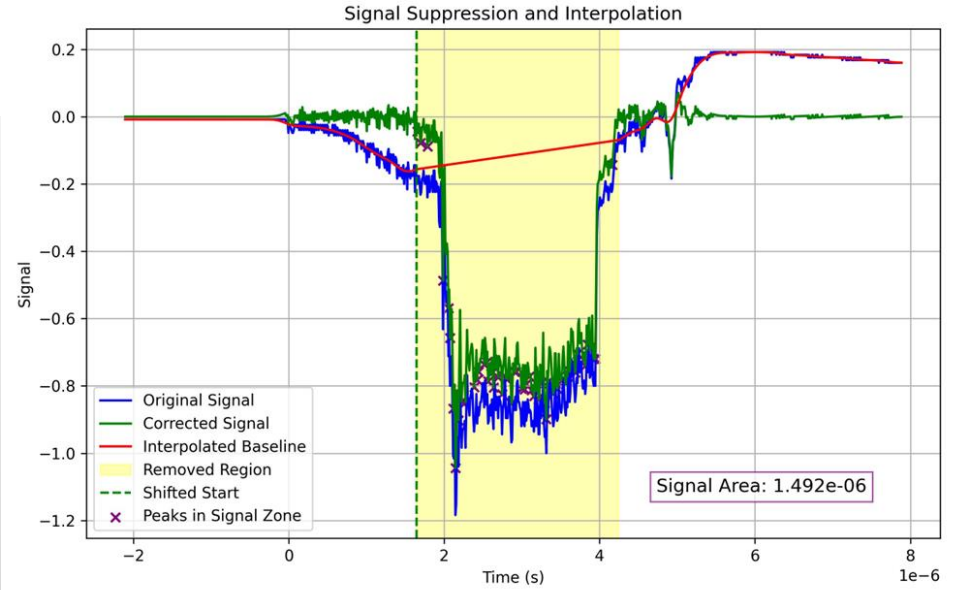
- LGAD Bias Voltage=0-100 V
- LV=5.5-6 V
- Position (Z)=-26-250 cm (End of collimator Z=0)
- Electron Beams:
  - Conventional: HV=85 V
  - Low Flash: HV=110 V
  - High Flash: HV=190V
- Pulses: 0.5, 1, 2, 3 μs

Signal examples

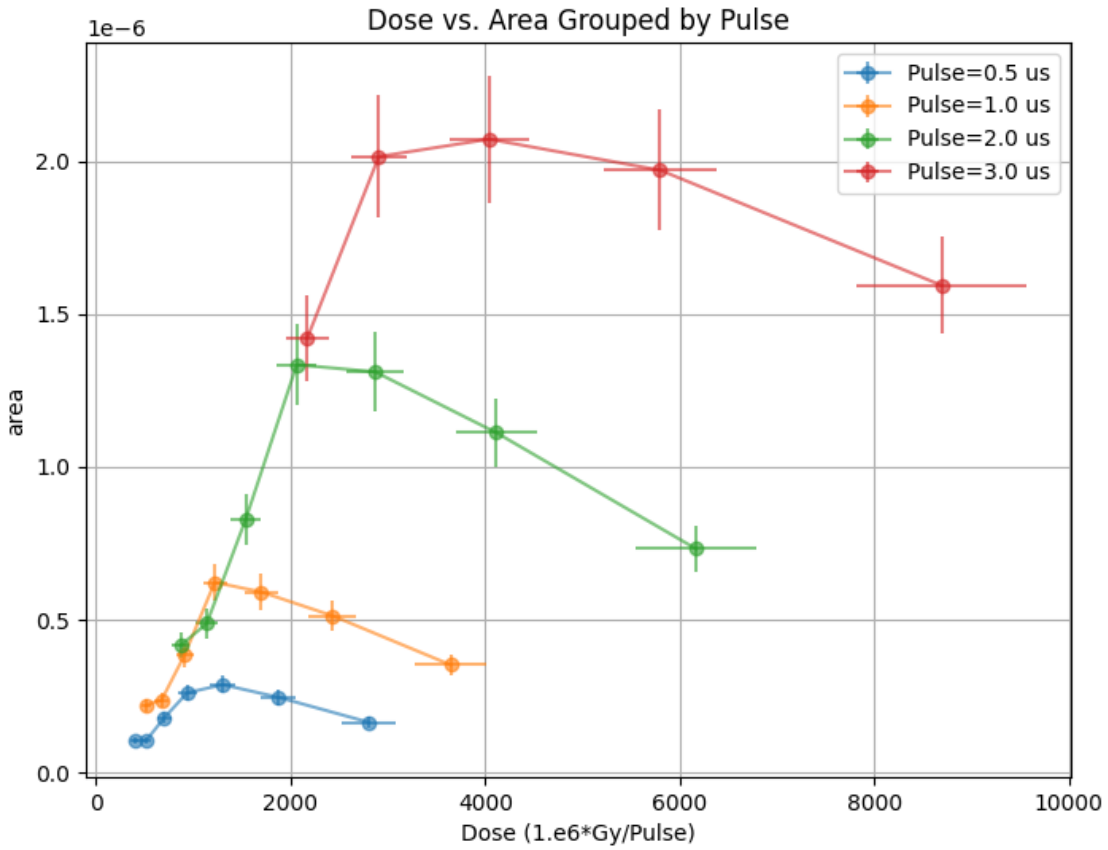




- Baseline is stable for a set of conditions
- Seems to change significantly with position and beam intensity

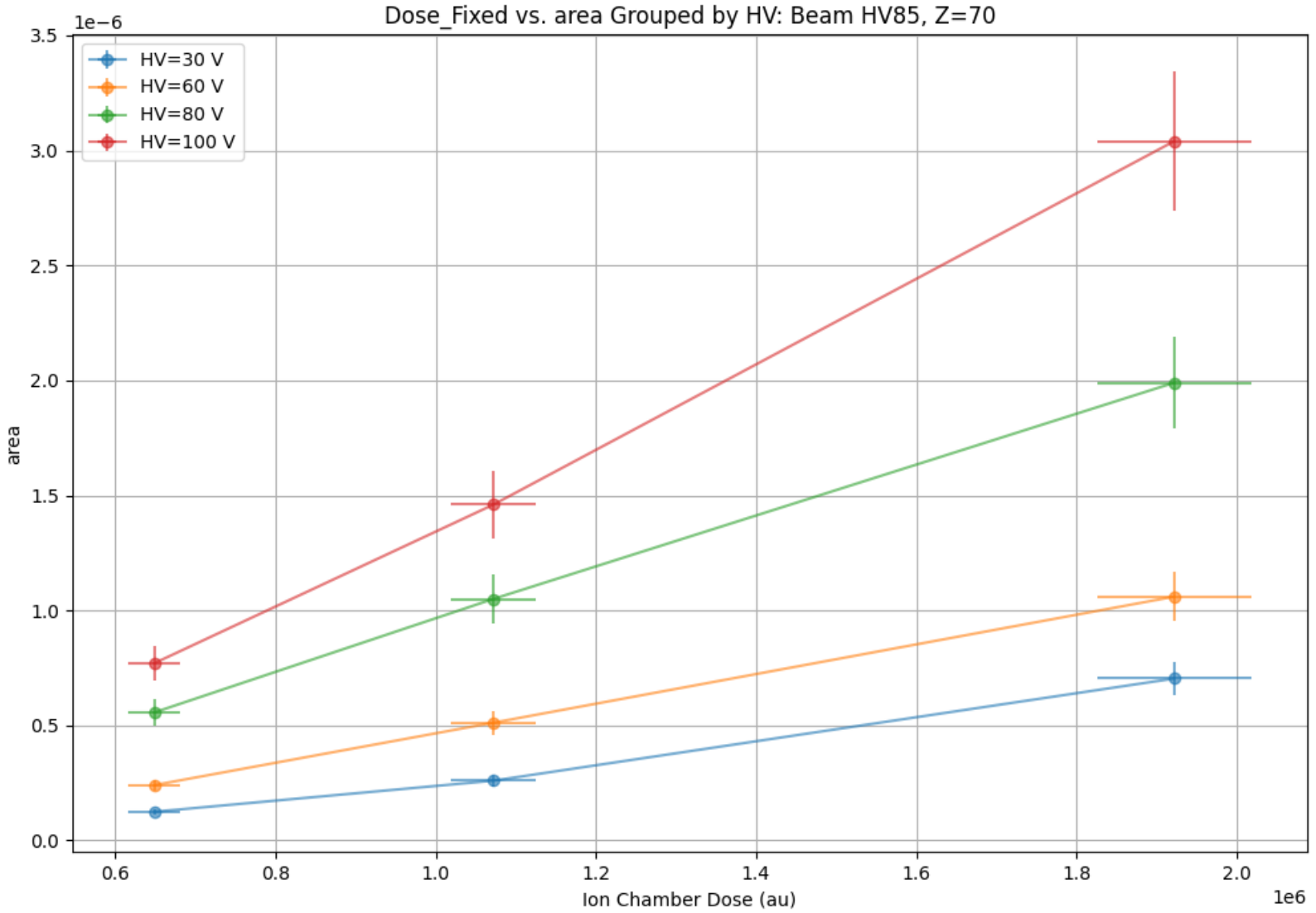


Charge Integration versus Measure Dose

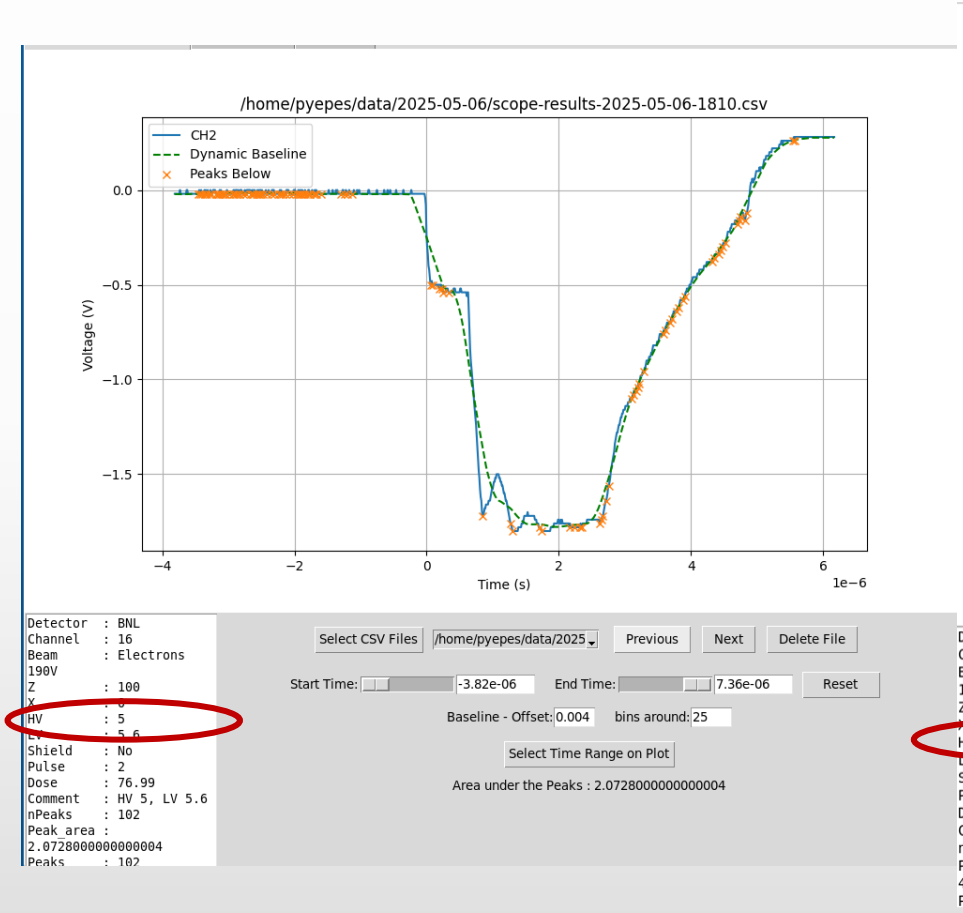


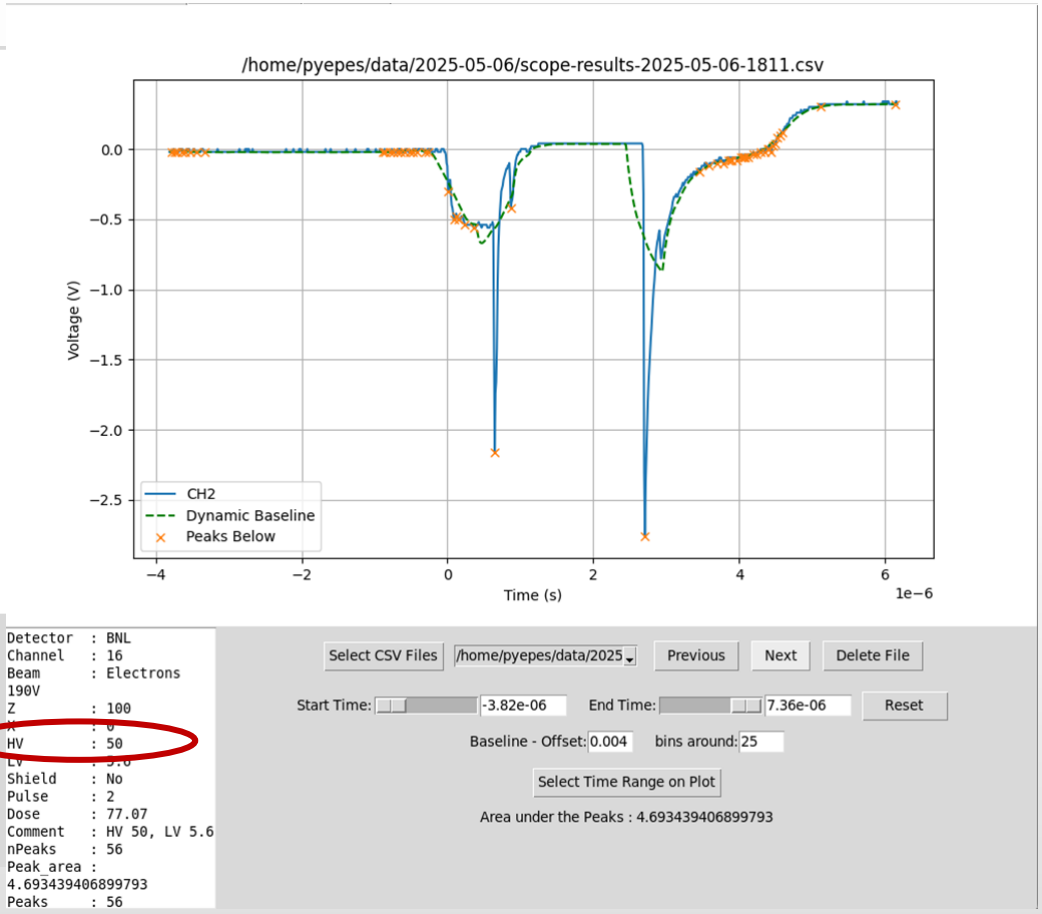
- With Standard operations conditions
- LGAD BV=100 V
- Saturation at about 1000 Gy/s
- That would correspond to around 30 particles/ns on the sensor.

Gain Versus Voltage

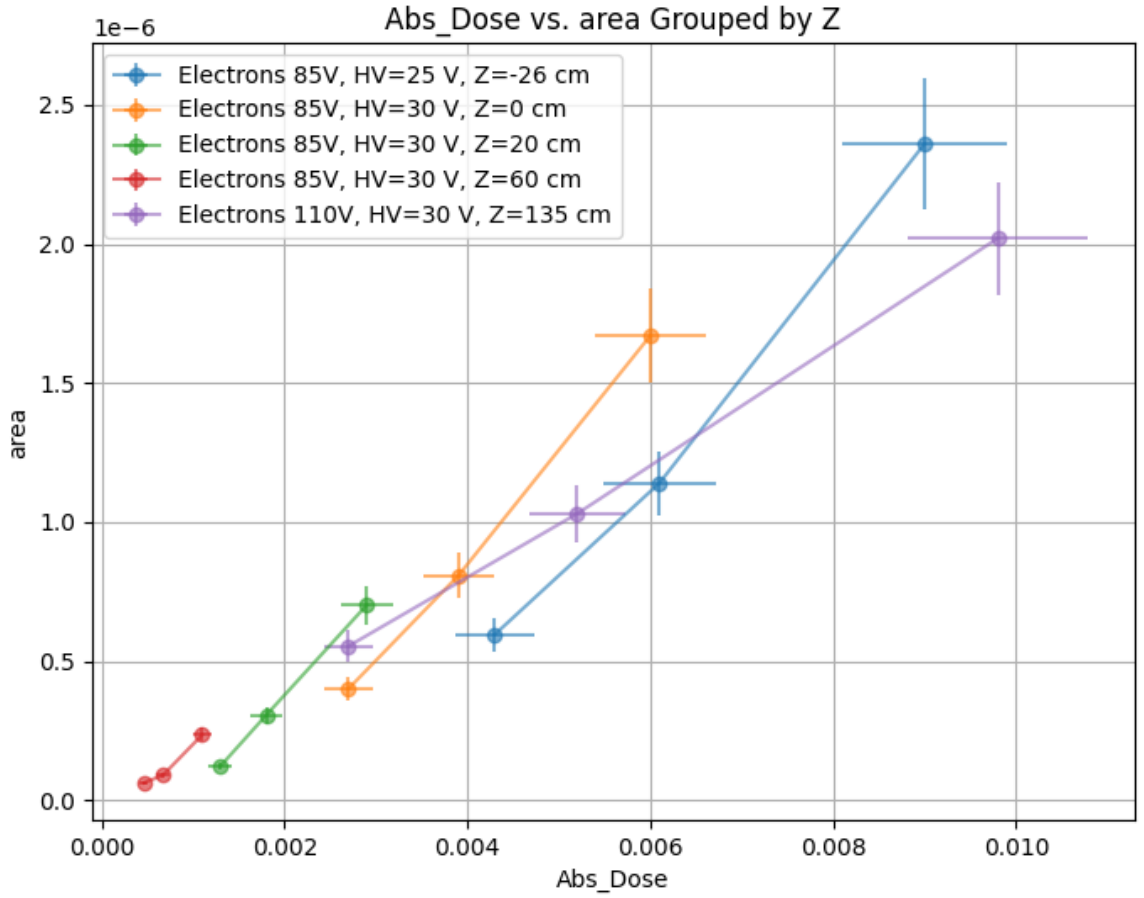


High Dose Rate Signal “Collapses” from BV=5 to 50 Volts



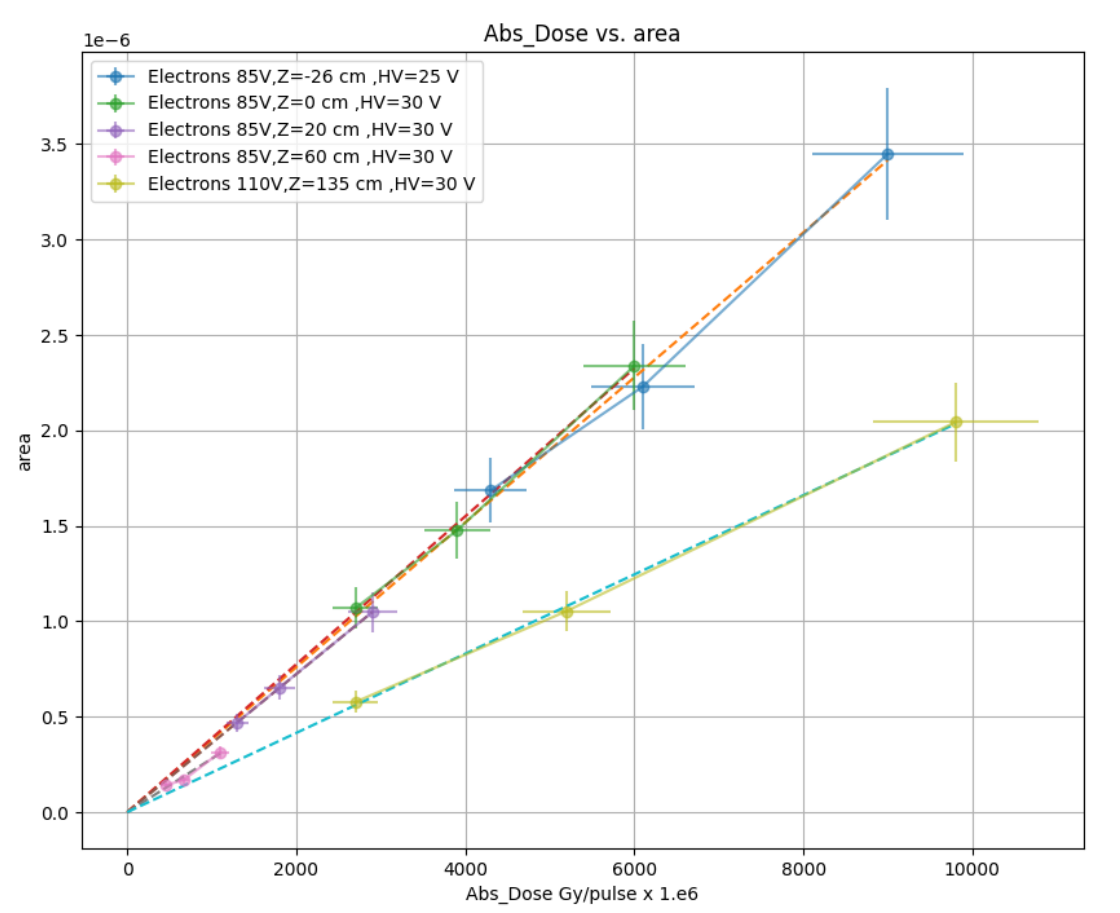


Integrated Charged versus Dose Various Conditions (Distance and Beam Intensity)



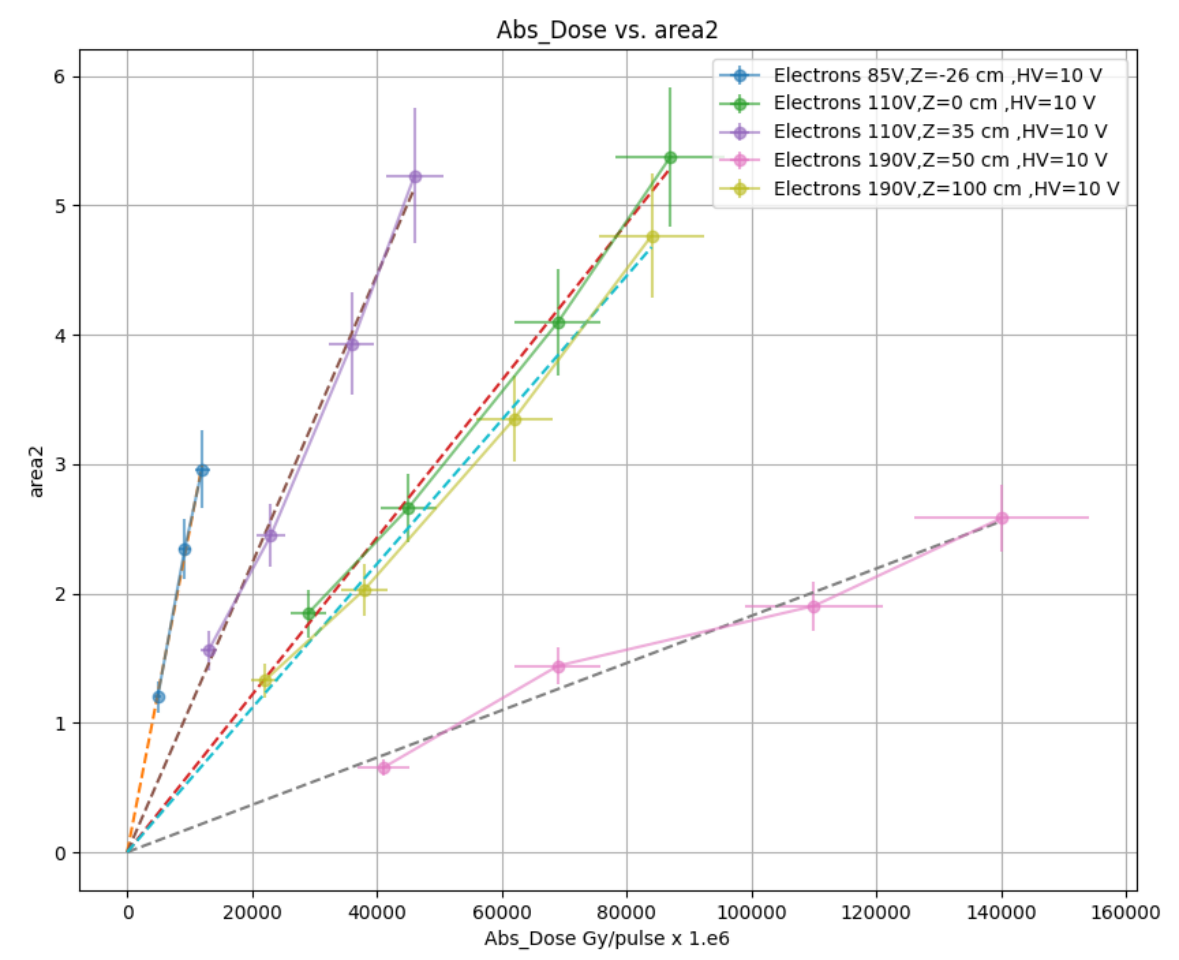
- Higher Dose Rates
- Lower BV=25-30 V

Corrected Signals



- Require integrated charge to be null for zero measured dose
- Actually, it looks like the selected area is underestimating the charge (negative intercept)

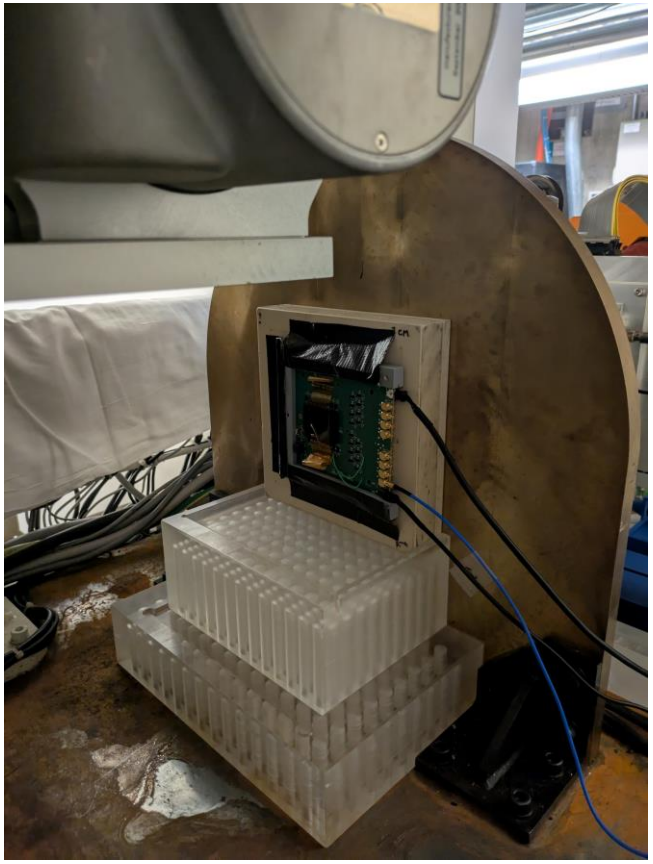
LGAD at BV=10 V Linear Within Conditions

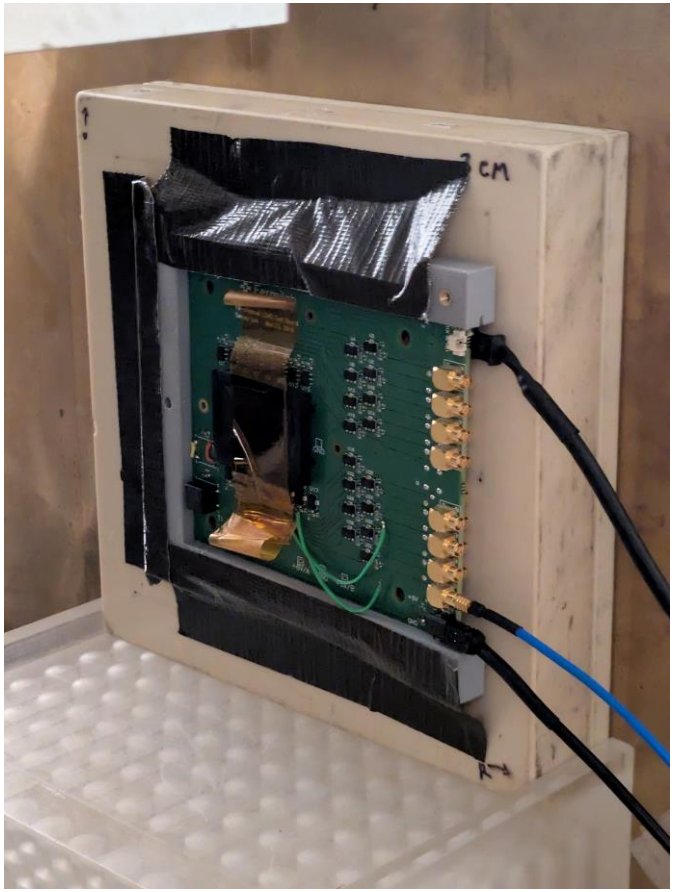


Proton Beam

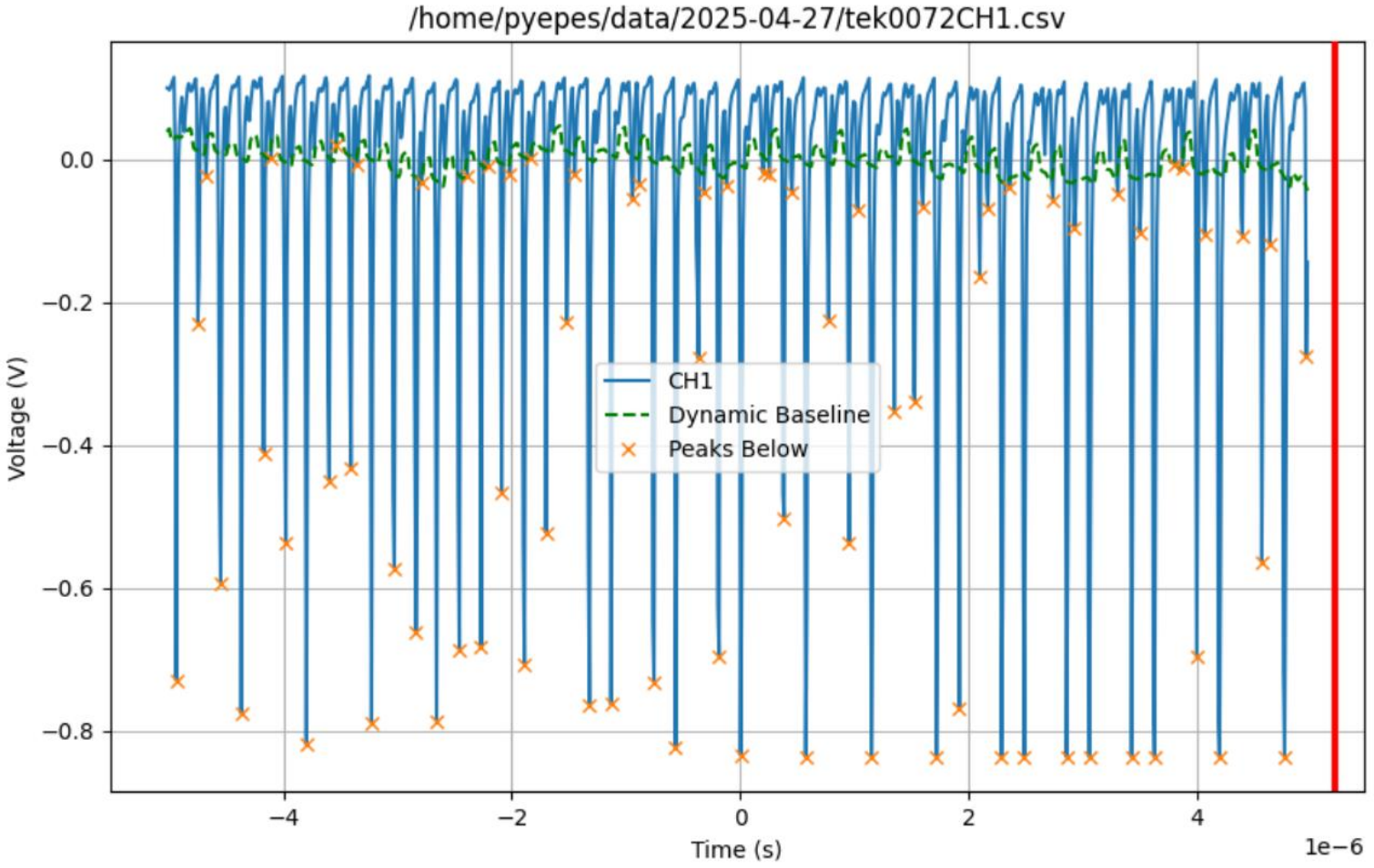
- Proton Therapy Center 1 at University of Texas MD Anderson Cancer Center
- A new PTC(2) has started operations in the last year
- Line used exclusively for research
- Hitachi Cyclotron
- A FLASH beam achieved in small volumes with beam shaping elements (collimators, etc)
- Beam is delivered in spills ranging 30-100 ms.

Proton Setup



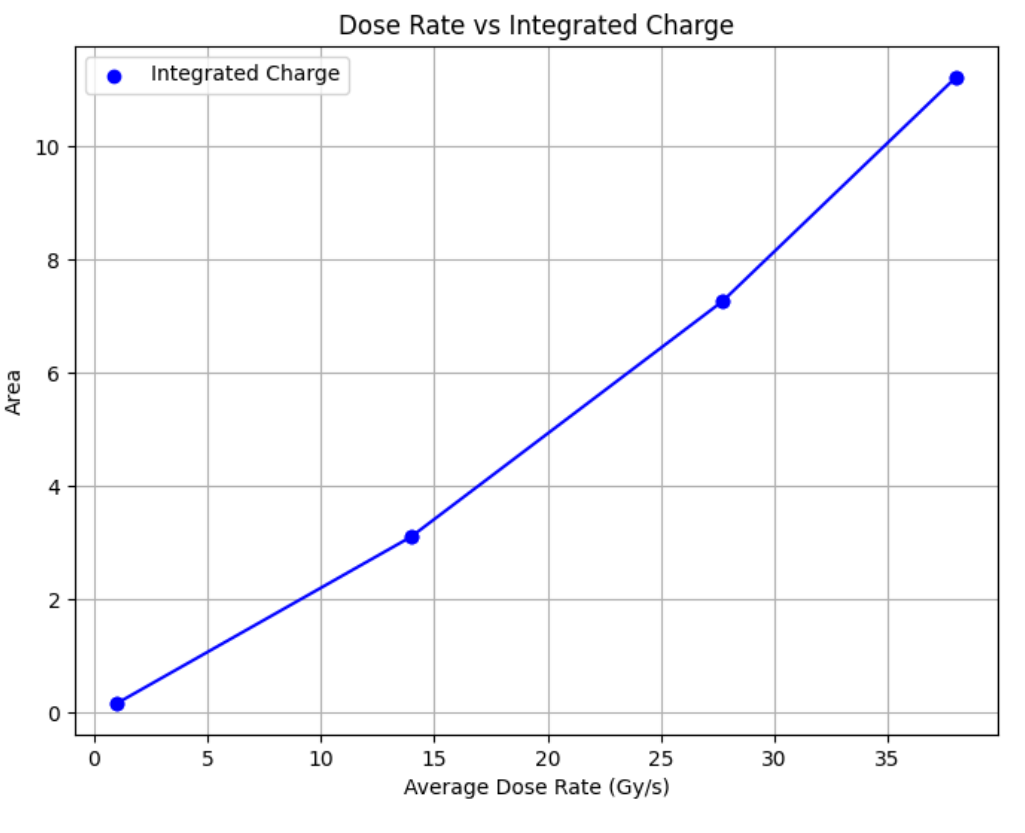


Typical Proton Signal



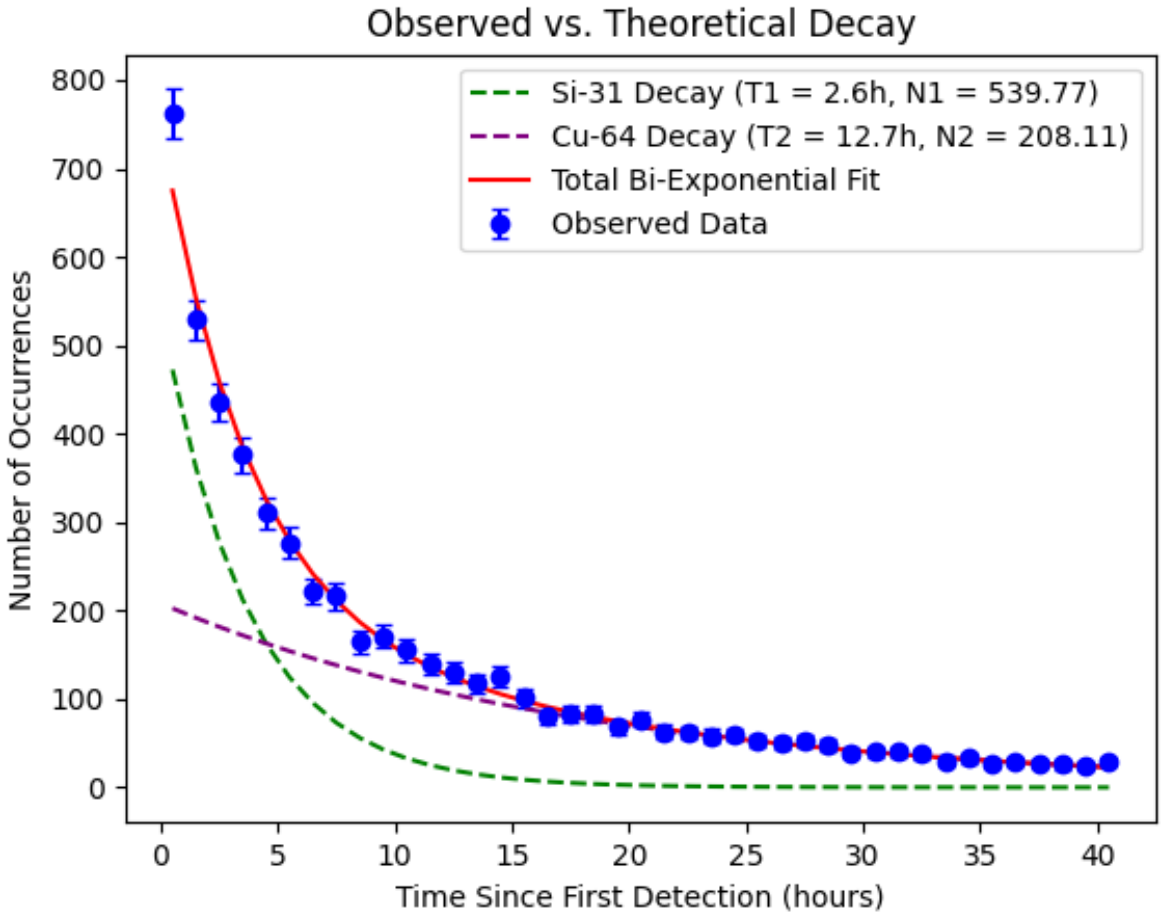
- We are only seeing one small window of the spill
- Baseline is essentially flat
- Peaks seem to contain more than one particle
- Peaks related to cyclotron revolutions?

Integrated Charge versus Dose for Protons



- Integrated charge under peaks is linear with “Average Dose” up to ~40 Gy/s
- However, dose is concentrated in peaks of around 10 ns every 200 ns.
- Instantaneous dose is about a factor of 20 times higher
- Detector saturates at about 20 * 50 Gy/s = 800 Gy/s of instantaneous dose. Roughly the same as for electrons for BV=100 V.

The Sensor/Board was radioactive after Proton Irradiation



- Sensor saw signals before irradiation from radioactivity in materials around it.
- After tests detector itself kept seeing signals back at the lab
- Left detector running for a couple of days
- Counted occurrences and fitted with possible radioactive decays with life-time in appropriate range
- After a few days, activity completely ceased

Conclusions

- Tested response of LGAD in conventional and FLASH electron and proton therapeutic beams
- Particle counting is challenging for dose rates above a few Gy/s
- Electrons:
  - Integrated charge linear with pulse length
  - Signal at BV=100 V (standard operations) saturates at ~1000 Gy/s
  - For lower BV~30 V linearity can be increased ~5.
- Protons:
  - The beam has a time substructure
  - Instantaneous dose should be around ~20 higher
  - Signal saturates for average dose rate ~40 Gy/s. Instantaneous dose seems to saturate at a value compatible with that for electrons.