Ultrafast LGAD Detectors with High-SNR Electronics Read-out for FLASH Radiotherapy

Christophe Royon
University of Kansas, Lawrence, USA

Workshop on Radiation Detection, JLab, USA

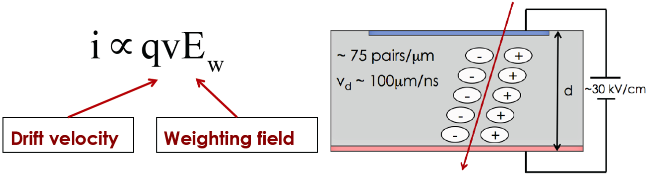
March 16-17 2023

- Starting point: Fast Silicon Detectors and AGILE project with NASA (arXiv:2103.00613 , NIM A, Vol. 1012 (2021) 165599)
- Medical application: Measuring beams in Dublin hospital (arXiv:2101.07134, Phys. Med. 131 Biol. 66 135002)
- Measuring doses in flash beam therapy

Which detectors? Silicon Low Gain Avalanche Detectors

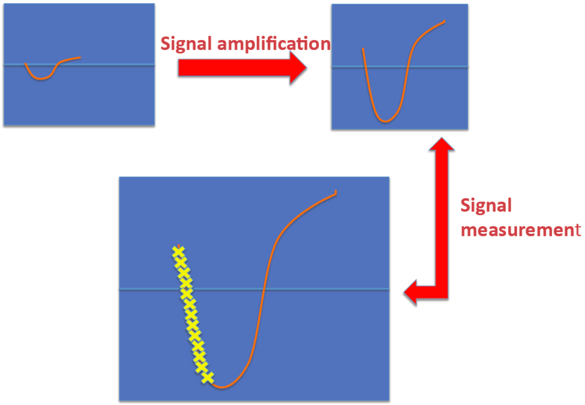
Signal shape is determined by Ramo's Theorem:

$$i \propto qvE_w$$



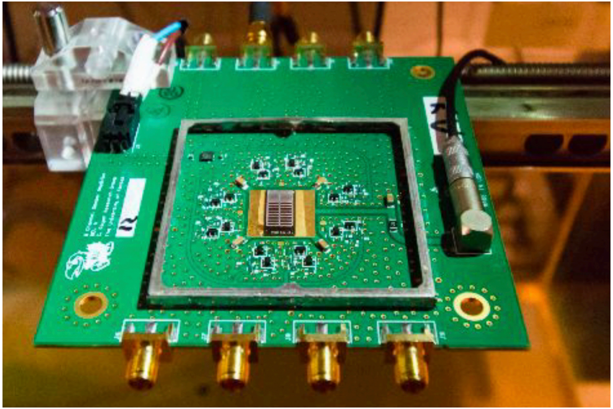
- Idea: Measuring radiation using fast silicon detectors
- Large velocity needed, which means fast detector
- Large fields and large pad to have uniform field
- Lots of charge
- We use fast silicon detectors, essential for medical and cosmic ray applications

Signal amplification and measurement



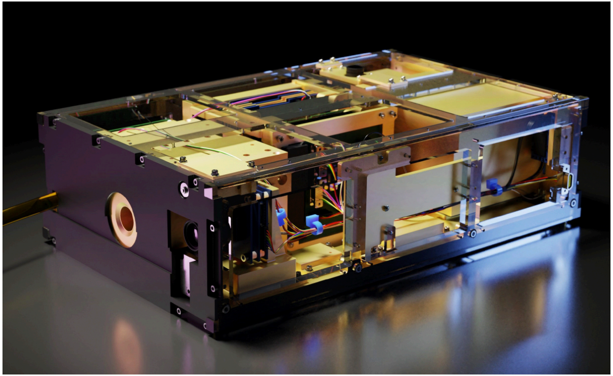
- Signal originating from a Si detector: signal duration of a few nanoseconds (fast detector)
- 1st step: Amplify the signal using an amplifier designed at KU using standard components (price: a few 10's of Euros per channel)
- 2nd step: Very fast digitization of the signal: measure many points on the fast increasing signal as an example
- Allows to measure simultanously time-of-flight, pulse amplitude and shape

Starting point: the readout board developed at the University of KS



- Plug and play hybrid board (hosts the Si sensor and the read-out electronics) that can be used for many applications
- Discrete components are used: cheap
- 8 identical two-stage transimpedance amplifiers with adjustable gain
- Adjustable input RC to adapt it to different solid state sensors
- 20 mm x 20mm HV pad with stable bias up to 500V
- Designed to convert a current input into a voltage output, the Input resistance decides the gain of the amplification stage

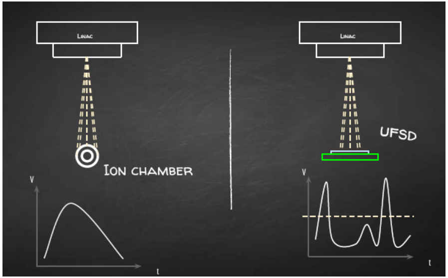
Method developed for AGILE (Advanced Energetic Ion Electron Telescope) with NASA



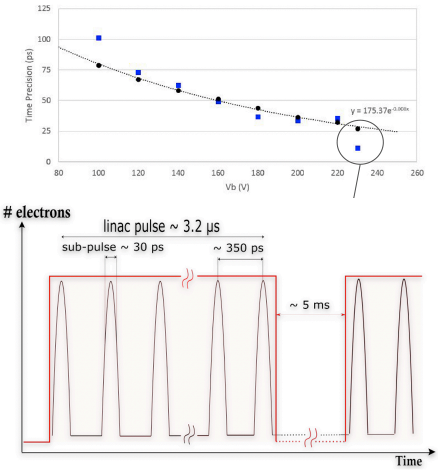
- 3 layers of fast Si detectors as a prototype
- Measurement of the signal in each layer using the fast sampling technique (1st time fast sampling will be performed in space)
- Identification of ion type (*p*, *He*, *Au*, *Pb*, etc) and measurement of their energies by measuring the maximum amplitude and duration of signal
- What is needed? Fast signal and fast electronics to measure the full signal

Measuring radiation in cancer treatment

- Ultra fast silicon detectors and readout system were put in an electron beam used in the past for photon therapy at St Luke Hospital, Dublin, Ireland
- Precise and instantaneous measurements of dose during cancer treatment (especially for flash proton beam treatment)
- Develop a fast and efficient detector to count the particles up to a high rate: very precise instantaneous dose measurement, no need of calibration, high granularity (mm^2)

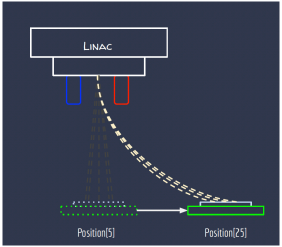


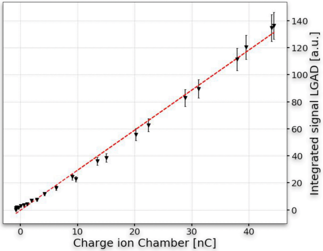
Measuring beam properties in an hospital environment



- Possible time resolution down to 10 ps (using Constant Fraction Discriminator method)
- ELEKTATM Precise Linac with pulse length about 3.2 μs long
- Each pulse sequence contains thousands of 30 ps sub-pulses separated by 350 ps (frequency of 2.858 GHz) -
- Electron beam: energy 4-18 MeV, dose rates up to 600MU/min, pulse repetition frequency of 200 Hz

Medical application: method to measure the beam properties

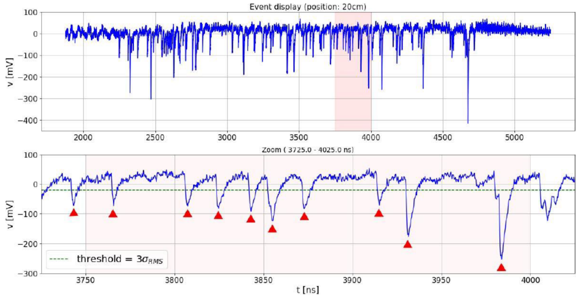


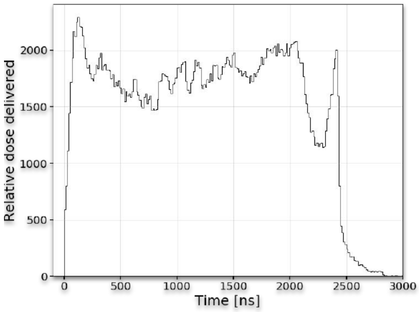


- The detector was mounted on a moving support to provide the monitoring of the beam as a function of its location
- Neodymium N40 permanent magnet 12 cm below the collimator to separate the charged and neutral particles
- The average signal in the LGAD correlates well with the ion-chamber signal!

What Si detector can do better: Single particle Id in Dublin hospital

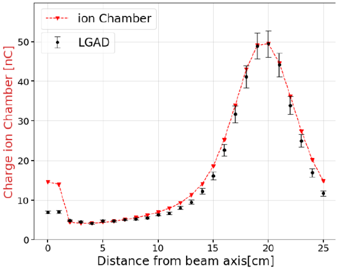
- Use UFSD and their fast signal in order to identify and measure spikes in signal due to particles passing by
- Allows measuring doses almost instantaneously

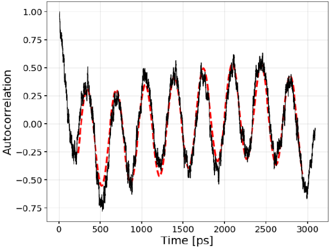




- Very precise dose measurement allowing to adapt better treatment to patients especially for flash dose treatments (brain cancer for instance)

Tests performed at St Luke hospital, University of Dublin, Ireland





- Measurement of charge deposited in Si detector compared to standard measurement using an ion chamber: good correlation
- Our detectors see in addition the beam structure (periodicity of the beam of ∼330 ps, contrary to a few seconds for the ion chamber): measure single particles from the beam
- Fundamental to measure instantaneous doses for high intensity proton therapy as example
- For more details: Arxiv 2101.07134, Phys. Med. Biol. 66 (2021) 135002

The future: use this method in flash beam therapy

- Goal 1: Design and build a fast Si dosimetry prototype
  - Develop and test a 8/16 channel readout board using the fast sampling method
  - Characterize the fast Si detectors and choose the best one for medical applications (different widths, sizes) using laser, radioactive sources
- Goal 2: Can Fast Si detector be used for dosimetry in flash beam therapy?
  - Build and test the prototype in a proton flash beam facility at the University of Kansas and count the number of electrons/protons that are produced by the accelerator
  - Measure the instantaneous dose rate dependance, linearity and dynamic range
  - Monitor a single flash pulse in order to study its structure benefitting from the good timing resolution of the Si detector
- Longer term goals: Move from a 8/16 channel readout board to a 100 or 1000 channel board that could have some commercial applications

Conclusion

- Fast timing detectors originally developed for high energy physics at KU: development of a readout electronic card using standard components for different applications
- Reconstruct full spectrum of signal coming from a fast Si detector using the fast sampling technique
- 1st application: Measure cosmic ray particles (both identify type of particles and measure their energies) in a cube sat in collaboration with NASA using the Bragg peak technique
- 2nd application: Measure doses in flash therapy received by a patient during cancer treatment instantaneously with high accuracy by counting the number of particles
- First results in Dublin hospital show already that we see the beam structure benefitting from the fast signal properties (duration of a few ns)