Fast timing detectors with applications in cosmic ray physics, medical science and other domains

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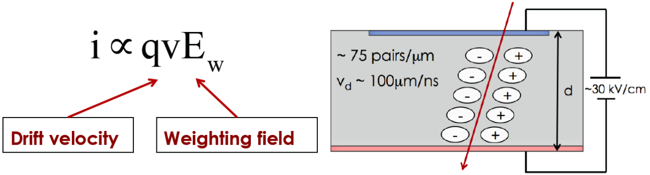
- Fast Silicon Detectors
- Signal analysis
- Medical applications
- Cosmic-ray applications in collaboration with NASA

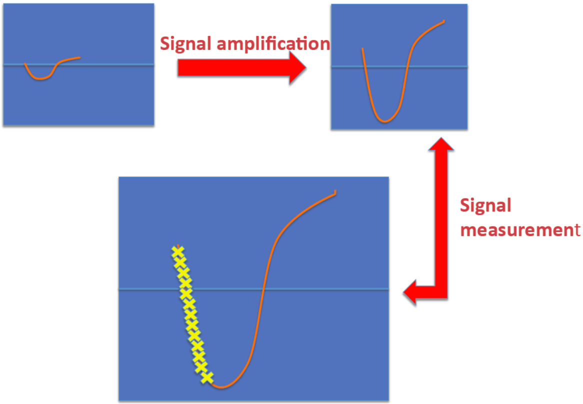
Which detectors? Silicon Low Gain Avalanche Detectors

Signal shape is determined by Ramo's Theorem:



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

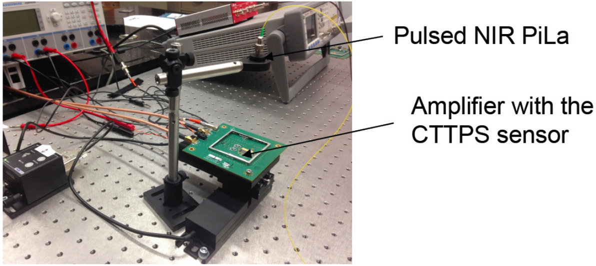
Signal amplification and measurement

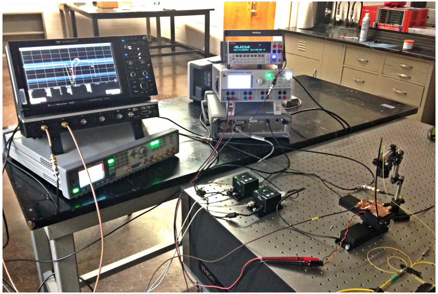


- Signal originating from a Si detector: signal duration of a few nanoseconds (fast detector)
- 1st step: Amplify the signal using an amplifier designed at KU using standard components (price: a few 10's of Euros per channel)
- 2nd step: Very fast digitization of the signal: measure many points on the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

Timing measurements at KU: Test stand

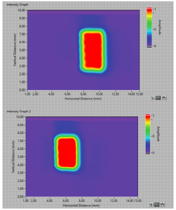
Preliminary time measurements currently being performed at KU

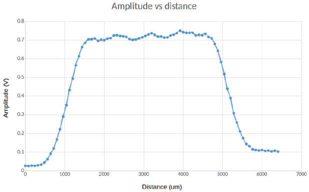


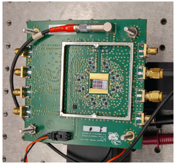


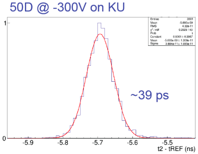
- Design of a new multi-purpose electronics board for testing, many different applications, and lower cost compared to commercially available solutions (patent in progress)
- Full test stand installed at the University of Kansas: readout of a Si detector
- Using laser or radioactive source in front of the detector

Test stand at the University of Kansas





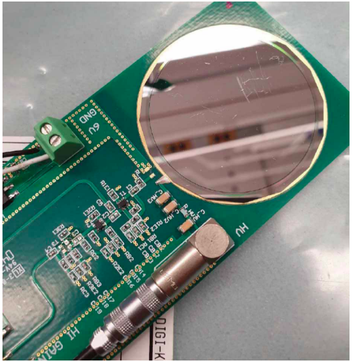




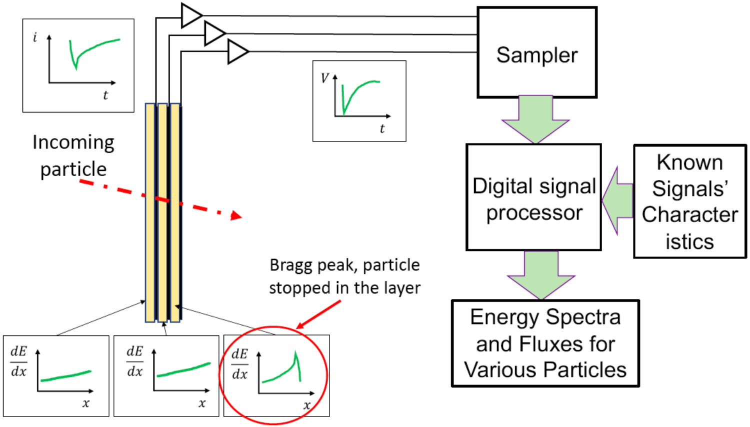
- Visualize pixels from Si detectors: Pixel size: ∼3 mm
- Test timing detectors at Fermilab: Timing resolution per layer of Si detector: ∼ 25 ps
- The main idea is to reconstruct the full signal by performing very fast sampling → Many applications

Measuring cosmic ray in space: the AGILE project

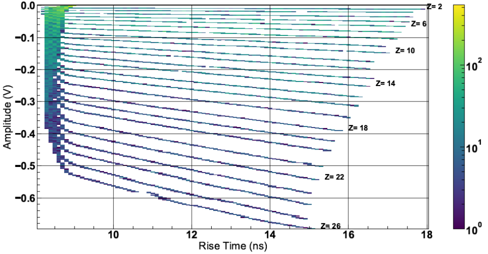
- We want to measure the type of particles (*p*, *He*, *Fe*, *Pb*, ...) and at the same time their energies
- Analysis of cosmic ray particles: using a cube sat, cheap to be sent into space
- Use similar technics: measure the signal (Bragg peak) where the particle stops in a Si detector, and use fast sampling
- Allows extracting type/energy of particles: project in collaboration with NASA, to be launched in Spring 2022, https://arxiv.org/abs/2103.00613

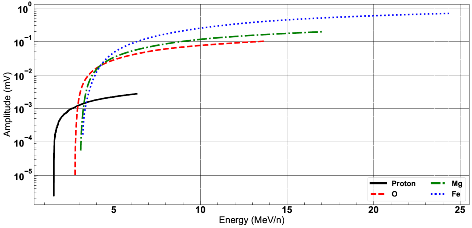


AGILE: Measuring type and energy of particles (simulation)



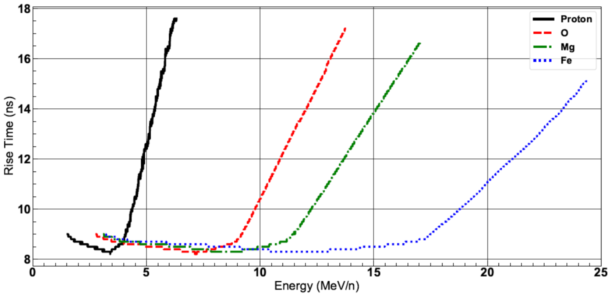
AGILE: Measuring type and energy of particles





- Simulation using GEANT (particles), Weightfield (Si detector), LTspice (electronics): Leads to a database of rise time, amplitude
- Amplitude vs rise time: allows to obtain Particle Id (key plot)
- Signal amplitude (or integral) gives access to energy

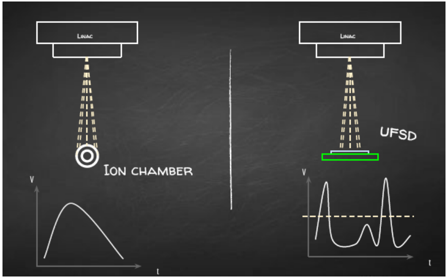
AGILE: Measuring type and energy of particles



- Rise time plot: Inefficiency at low rise time
- Allows identifying different particles (Z) and measure their energy for a wide range of particles and energies
- Launch in Spring 2022

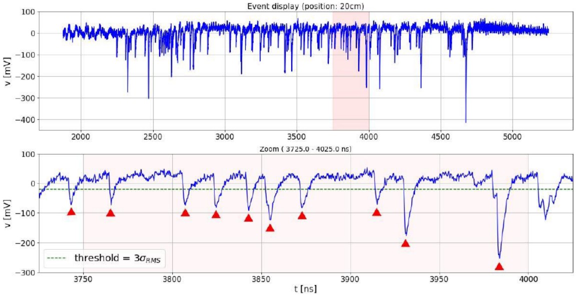
Measuring radiation in cancer treatment

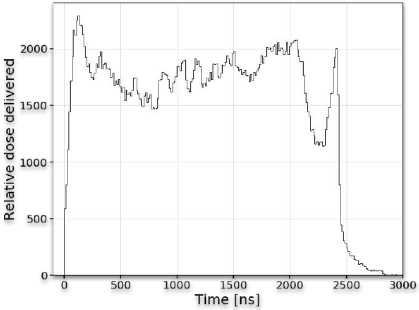
- Ultra fast silicon detectors and readout system were put in an electron beam used in the past for photon therapy at St Luke Hospital, Dublin, Ireland
- Precise and instantaneous measurements of dose during cancer treatment (especially for flash proton beam treatment)
- develop a fast and efficient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



Single particle Id in Dublin hospital

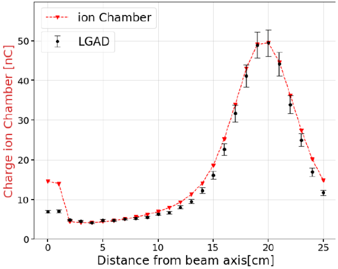
- Use UFSD and their fast signal in order to identify and measure spikes in signal due to particles passing by
- Allows measuring doses almost instantaneously

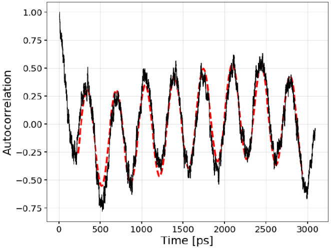




- Very precise dose measurement allowing to adapt better treatment to patients especially for flash dose treatments (brain cancer for instance)

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

Conclusion

- Fast timing detectors originally developed for high energy physics at KU: development of an amplifier using standard components
- 1st application: Measure cosmic ray particles (both type of particles and their energies) in a cube sat in collaboration with NASA using the Bragg peak technique
- 2nd application: Measure doses received by a patient during cancer treatment instantaneously, with high accuracy
- Innovation article: https://edition.pagesuite-professional.co.uk/html5/reader/production/default.aspx?pubname=&edid=e3d49584-51a4-4ec2-a99d-98a0800a4de7&pnum=74