AGILE: Advanced enerGetic Ion eLectron tElescope

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Workshop on pico-second timing detectors for physics, Sept 11 2021

AGILE Collaboration

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Overview

AGILE Mission

Objectives

AGILE (Advanced enerGetic Ion eLectron tElescope)

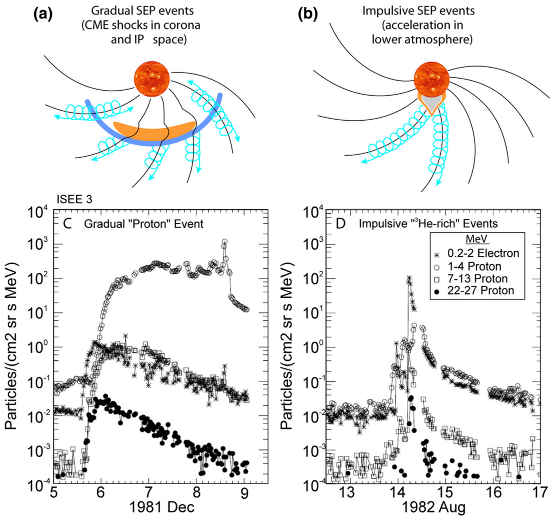
AGILE will:

- be a compact low power and low-cost instrument for characterization of solar and anomalous cosmic ray (ACR) particles.
- focus on:
  - **Ions (H-Fe), E=(1-100)MeV/nucl;**
  - Electrons, E=(1-10)MeV.

Main Goal

Robust real-time particle identification and energy measurement

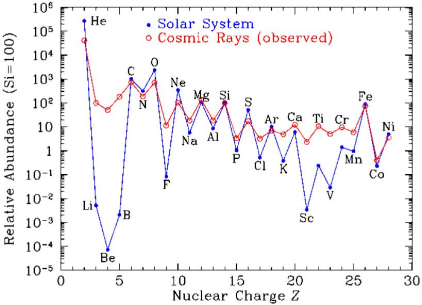
Science Motivation: Solar Energetic Particles (SEPs)

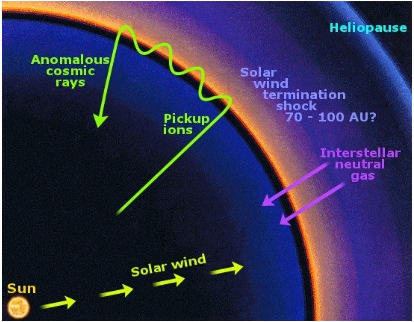


Characterization of:

- Impulsive (He-3-rich) events;
- Gradual (proton-rich) events;

Science Motivation: Anomalous Cosmic Rays (ACRs)

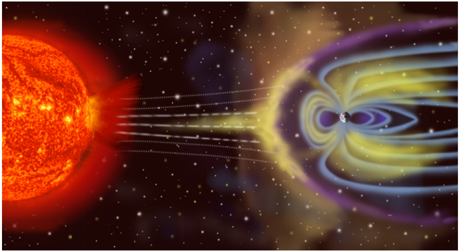


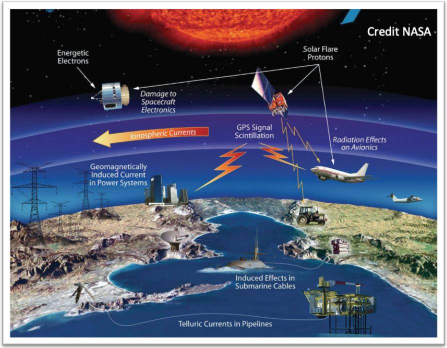


ACRs studies help to:

- understand dynamics of energetic particles within the solar system;
- Improve characterization of the heliosphere;
- Probe the interstellar medium.

Science application: Monitoring Space Weather





Monitoring

- Monitoring and protection of Earth activities;
- Monitoring of radiation for space exploration.

Science Motivation: Summary

<table>
<tr><td colspan="2">Dynamics of radiation belts</td><td colspan="2">Energization, transport and modulation of IP charged particles</td><td rowspan="2">Space weather</td></tr>
<tr><td>Relativistic electrons in the inner and outer belts</td><td>Energetic ions in the outer belt</td><td>SEP energization at IP shocks</td><td>ACR: transport and modulation</td></tr>
<tr><td>Electrons, E=(1-10) MeV</td><td colspan="4">Ions (H-Fe) E=(1-100) MeV/nucl</td></tr>
<tr><td colspan="2">High inclination LEO or Near equatorial GTO</td><td colspan="2">Interplanetary Space (e.g. L1) or High inclination LEO</td><td>High inclination LEO</td></tr>
</table>

Robust **real-time particle identification and energy measurement** is very important!

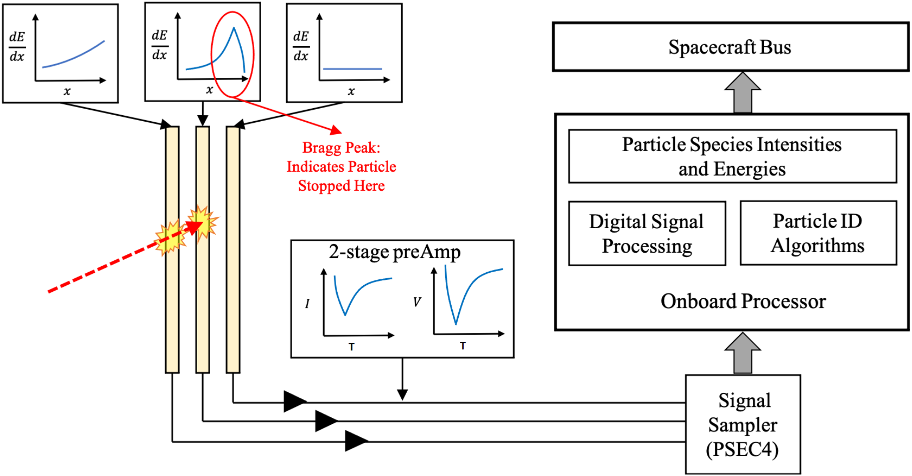
Pulse Shape Discrimination

Pulse Shape Discrimination (PSD)

- If a particle (ion) completely stops in detector medium (e.g. Si) its type and energy can be identified using **both time and amplitude characteristics of the produced signal**:
  - Pulse Rise Time (charge collection time) is an indicator of the depth at which the particle completely stops;
  - Amplitude is an indicator of the total energy deposited by a particle;
  - The combination of "Rise Time & Amplitude" is unique for a specific particle with specific energy;
- In contrast to "classic" $\Delta E - E$ method only one detector layer may be used;
- Fast and robust sampling is required.

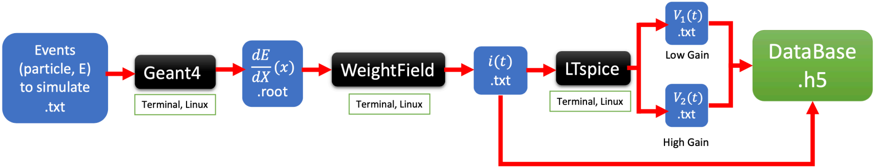
AGILE will use the real-time PSD technique for the first time in space based instrumentation.

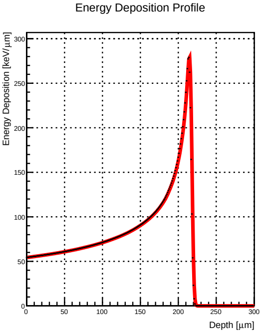
General Method

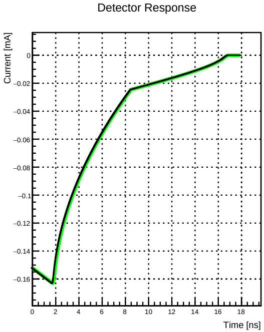


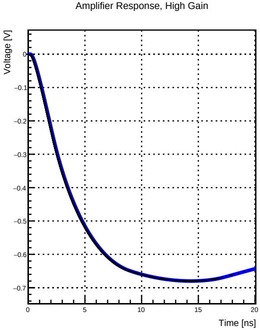
PSD Simulation

- "Real" hardware (commercially available Si-sensors and custom made electronics) is simulated;
- Statistical fluctuations, electronics' noise, sampling rate, temperature dependencies etc. are taken into account;
- Incoming particles are randomly generated:
  - Ions: H-Fe;
  - Energy: (1-100) MeV/n;
  - Angle: 0-90 degree.

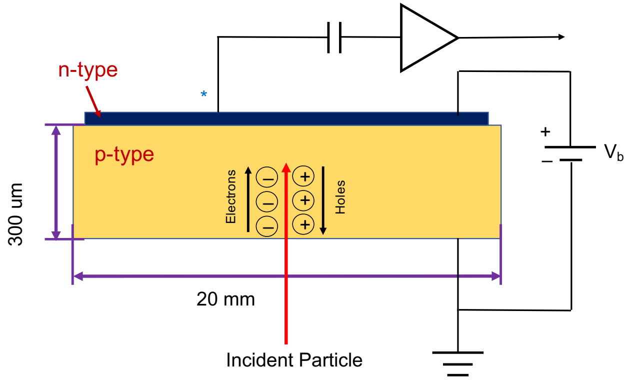

Events
(particle, E)
to simulate
.txt
Geant4
Terminal, Linux
$\frac{dE}{dX}(x)$
.root
WeightField
Terminal, Linux
$i(t)$
.txt
LTspice
Terminal, Linux
$V_1(t)$
.txt
Low Gain
$V_2(t)$
.txt
High Gain
DataBase
.h5


Energy Deposition Profile
Energy Deposition [keV/µm]
Depth [µm]


Detector Response
Current [mA]
Time [ns]


Amplifier Response, High Gain
Voltage [V]
Time [ns]

PSD Simulation: Si-Detector

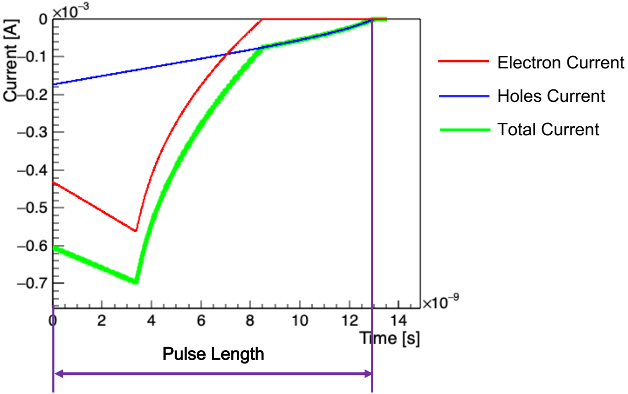


$V_{bias} = 110V;\ V_{depletion} = 60V$

A stack of three 300 μm Si-detectors is simulated

PSD Simulation: Rise Time

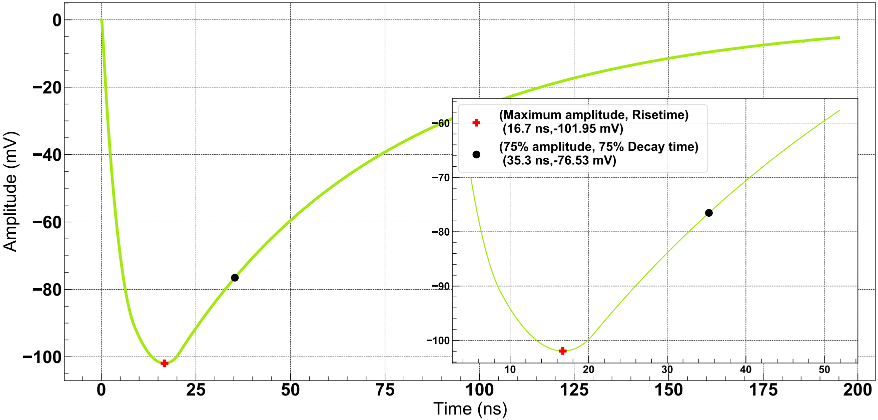
Pulse Rise Time ("Total Charge Collection Time" or "Pulse Length") is an indicator of the depth at which the particle stops completely



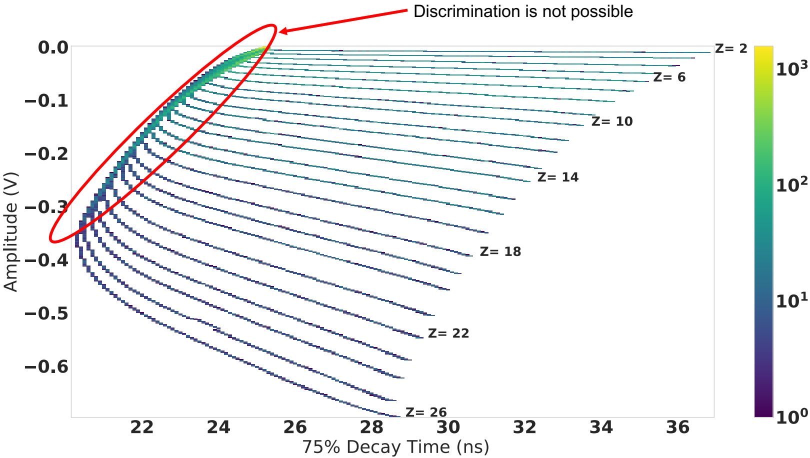
Electrons are $\sim$3 time faster than holes

PSD Simulation: Stopping Layer signal

Amplifiers response requires a longer sampling of the signal to extract key time and amplitude characteristics ($\sim$ 40 ns).

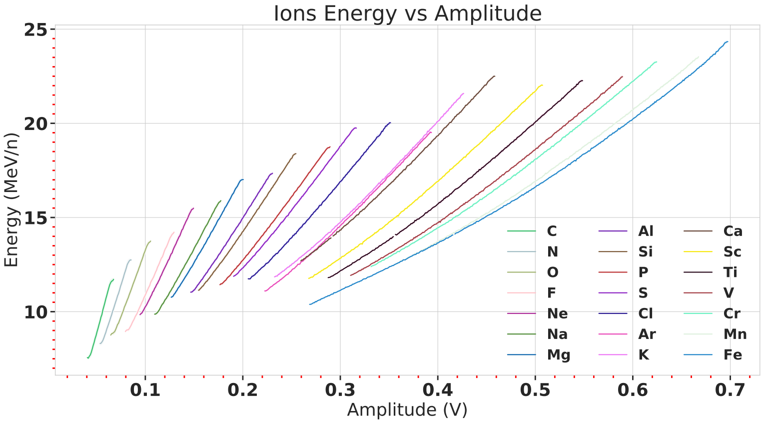


ID discrimination



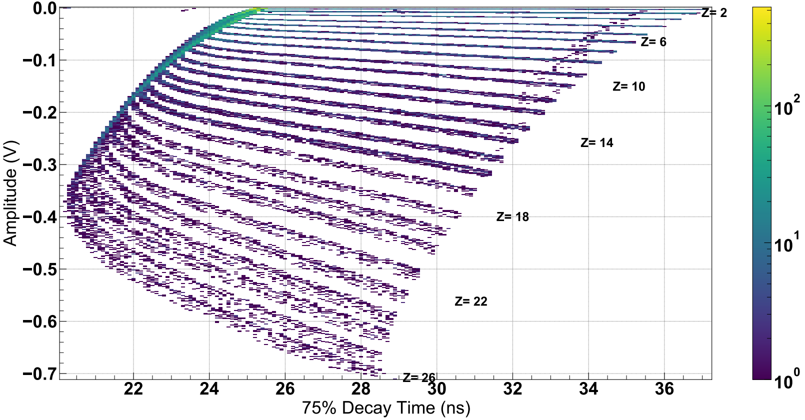
"Rise Time & Amplitude" is unique for a specific particle. Due to the specifics of the read-out electronics, the "75% Decay time" is more effective.

Energy measurement



Once particle type is determined, its energy is measured from only the amplitude of the signal.

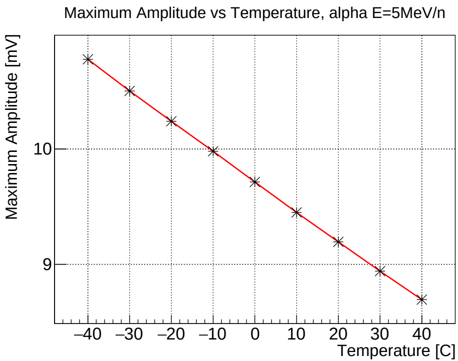
Angle Effect

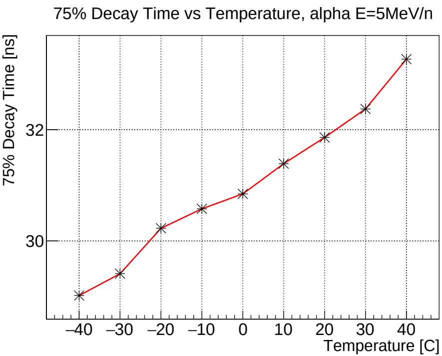


A field of view of 40° (20° of half angle) is manageable for all ions. A wider angle makes discrimination more challenging for heavy ions.

PSD Simulation: Temperature Effects

The key signal characteristics are proportional to temperature and thus can be "corrected" on-board if the ambient temperature is known.



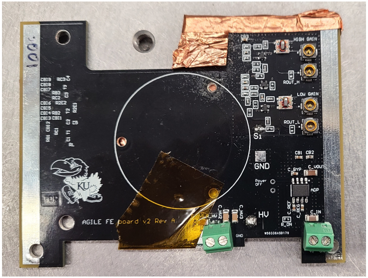


Hardware

Si-Detector:

- NASA Heritage;
- MSD020 (Micron Semiconductor);
- Thickness: 300 μm;
- Diameter: 20 mm.

Amplifier Board:



- Wide range of input current (10^{-6}A to 10^{-2}A);
- Low and High Gains;
- Low noise (<1mV).

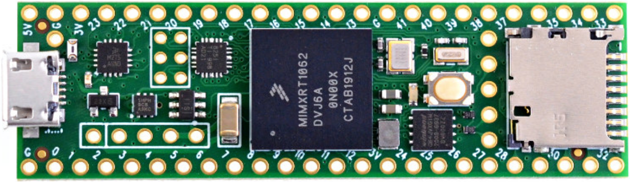
Hardware: PSEC4

Fast and robust sampling is required!
Typical pulse length ("Rise Time") is $\sim$ 10 ns.

arXiv:1309.4397

- Number of channels: 6;
- Sampling Rate: (4-15) GSa/s;
- SCA Depth: 256 samples;
- Power Consumption: $<$ 100 mW;
- ADC DC Dynamic range: 10.5 bits;
- Bandwith: 1.5 GHz.

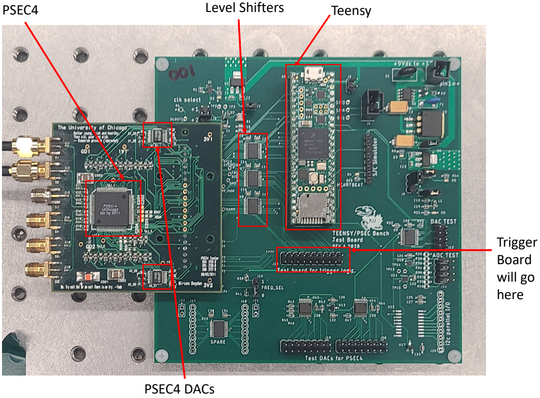
Controller: Teensy 4.1

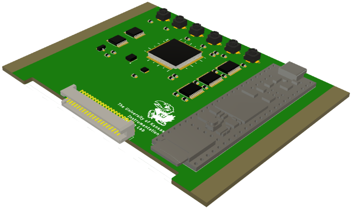


https://www.pjrc.com/store/teensy41.html

- ARM Cortex-M7 at 600 MHz;
- 1024K RAM (512K tightly coupled), 4K EEPROM (emulated);
- QSPI memory expansion, locations for 2 extra RAM or Flash chips;
- 55 digital input/output pins, 35 PWM output pins;
- 18 analog input pins;
- 8 serial, 3 SPI, 3 I2C ports;
- **Can be programmed in C/C++;**
- **Low power (∼ 100 mA @ 5V)**

PSEC4-Teensy Board

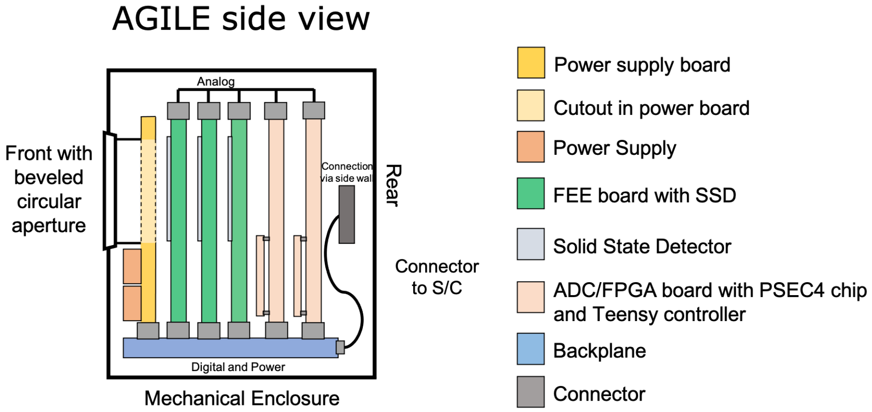




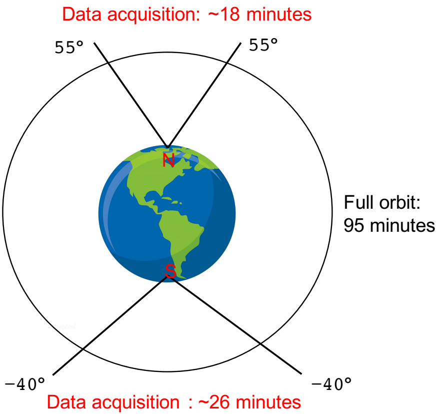
1st prototype

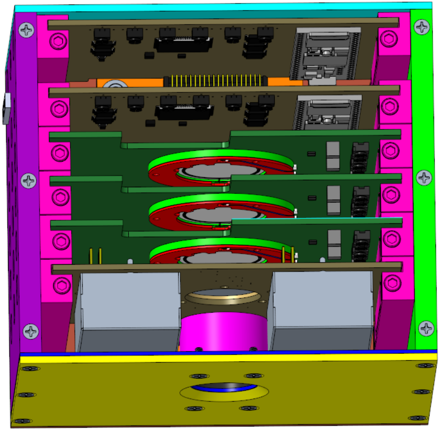
1st prototype

- Planned for launch on board a CubeSat in fall 2022;
- 3 layers of 300 μm Si-detectors.

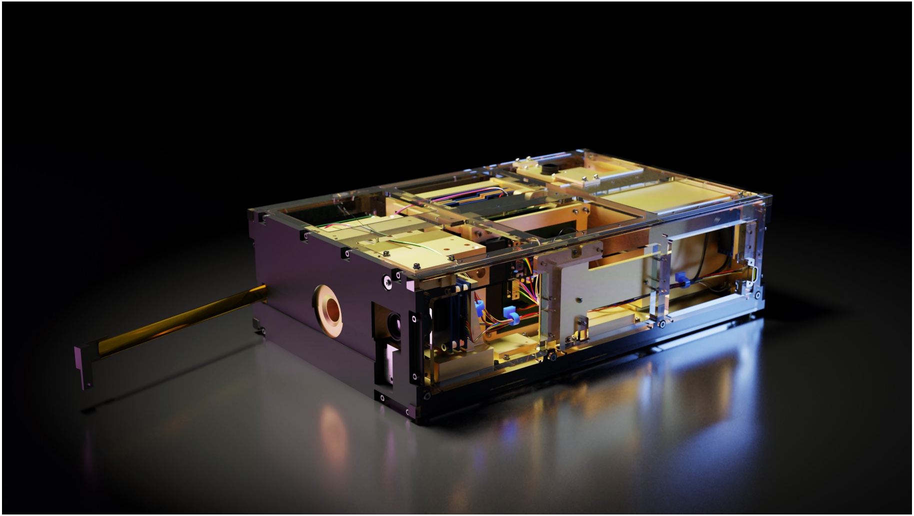


1st prototype





GenSat: AGILE carrier



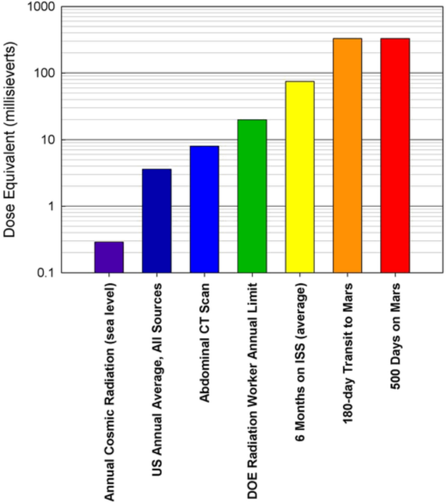
Future Directions

- Beam Test at Brookhaven National Laboratory (Spring 2022);
- First prototype launch on-board CubeSat in fall 2022;
- More layers $\rightarrow$ wider energy range (High Energy Cosmic Rays);
- Better usage of the information from the layers where particles are passing through;
- Network of multiple AGILE instruments;

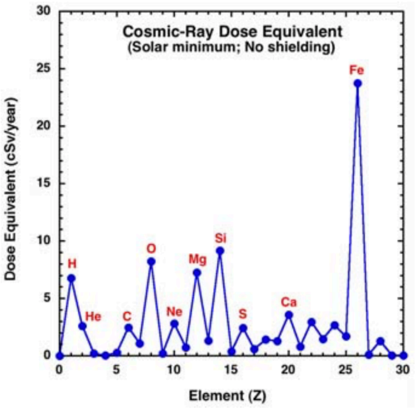
Thank You!

Back up

Science Motivation: Space Weather and Space Travels



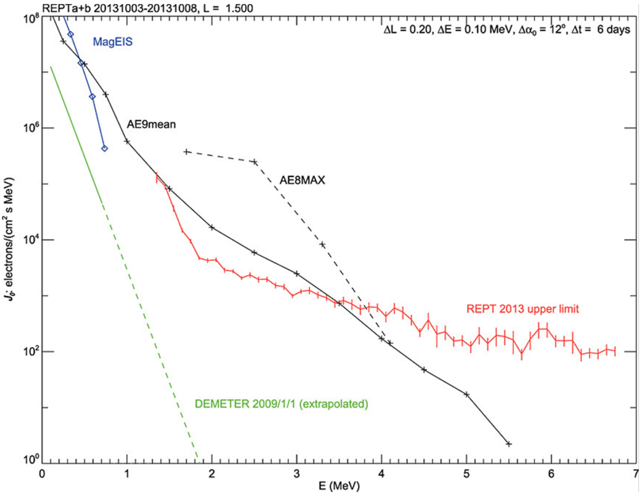
Hassler, D. M. et al, Science 343(6169), 1244797 (2014)



R.A. Mewaldt et al. 29th International Cosmic Ray Conference

Pune (2005) 00, 101-104

Science Motivation: Relativistic Electrons in the Inner Van Allen Belt



Li, X. et al, J. Geophys. Res. Space Physics, 120: 1215– 1228 (2015)

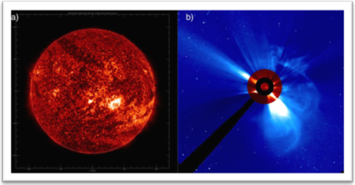
'Contaminated' by Protons

Goals

- Presence or absence;
- Dynamics (geomagnetic activity).

Science Motivation: Relativistic Electrons in the Outer Van Allen Belt

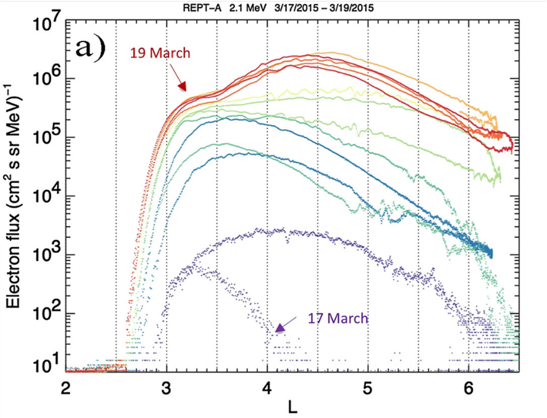
March 2015 Solar Storm



a) SDO image; b) SOHO/LASCO corona-graph

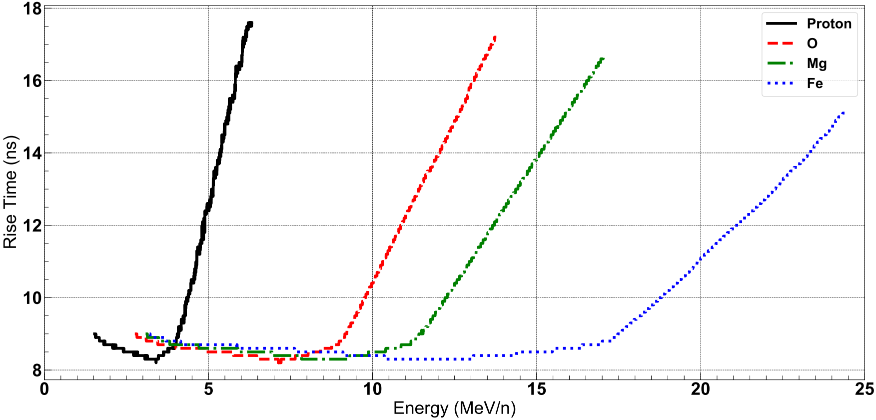
Goals

- To observe both seed and accelerated populations;
- To examine the nature of various competing acceleration, transport, loss processes.



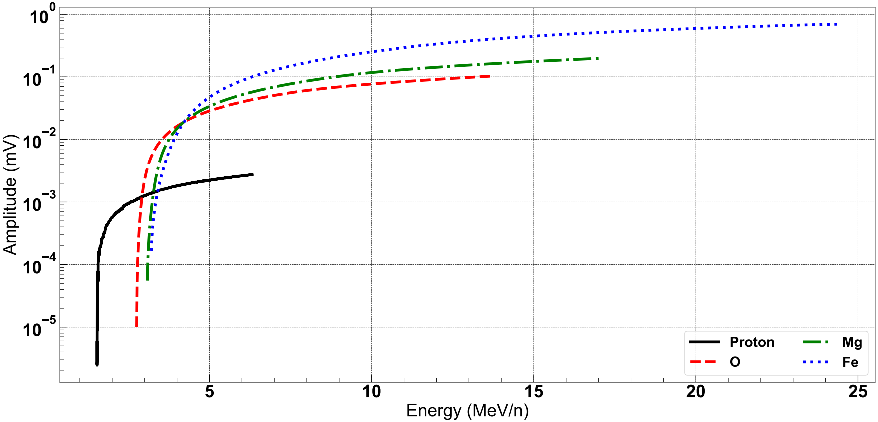
Baker, D. N., et al. J. Geophys. Res. Space Physics, 121, 6647– 6660 (2016)

PSD Simulation: Rise Time

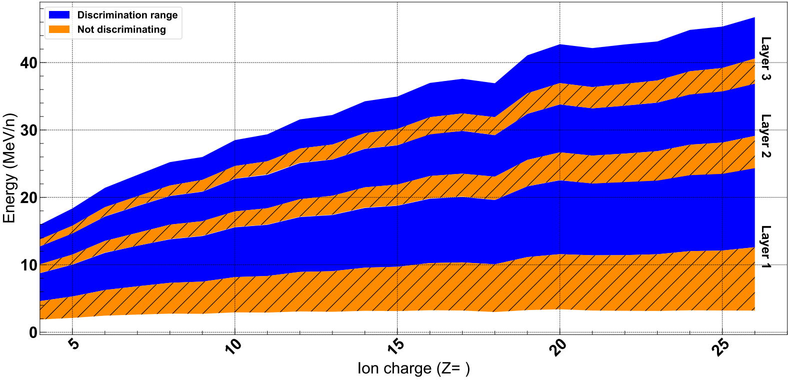


"Rise Time vs Energy" behaviour is different for different ions
(only particles that completely stop in the detector are shown)

Signal Amplitude (or integral) is an indicator of the total energy deposited by a particle.



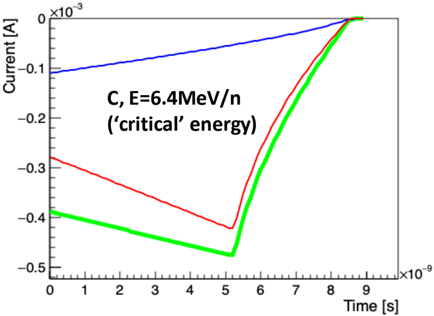
PSD Simulation: Energy Acceptance

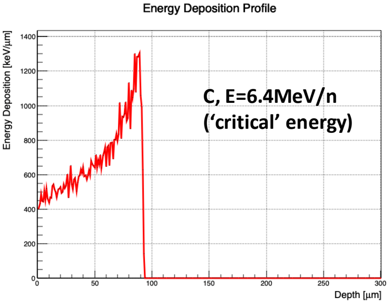


In the energy ranges where discrimination is possible its efficiency is close to 100%.

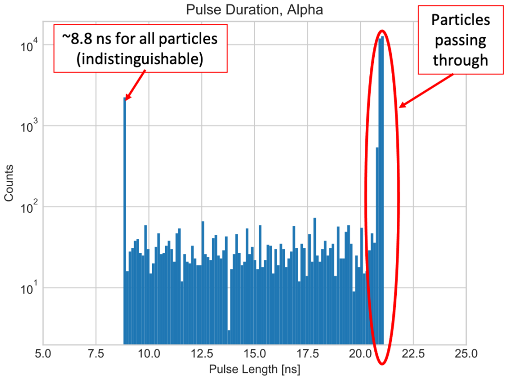
PSD Simulation: Energy Acceptance

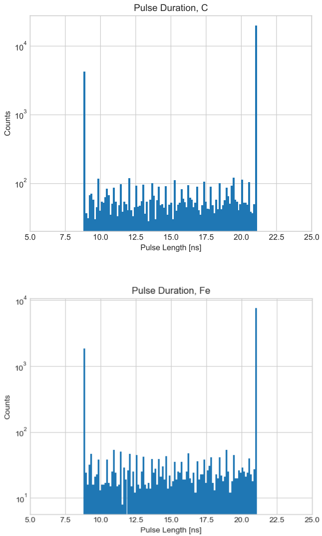
When a particle stops near a negative electrode/entrance side (low energy) the holes component of the current signal is shorter than the electrons component, thus the length of the pulses is defined only by the electron component and thus will be the same for all particles.





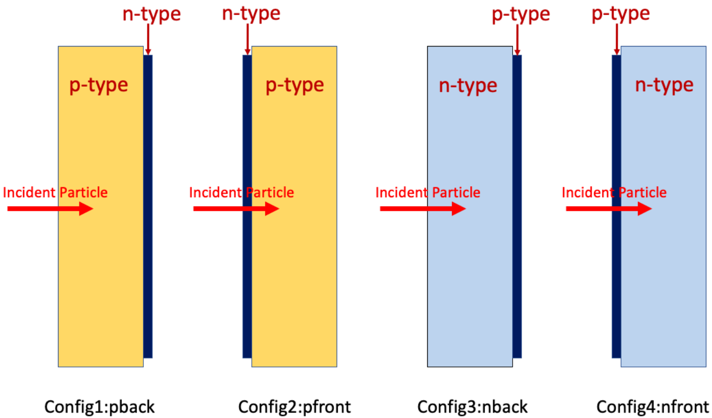
PSD Simulation: Energy Acceptance





PSD Simulation: Energy Acceptance

Potential ways of improvement



PSD Simulation: Energy Acceptance

Potential ways of improvement