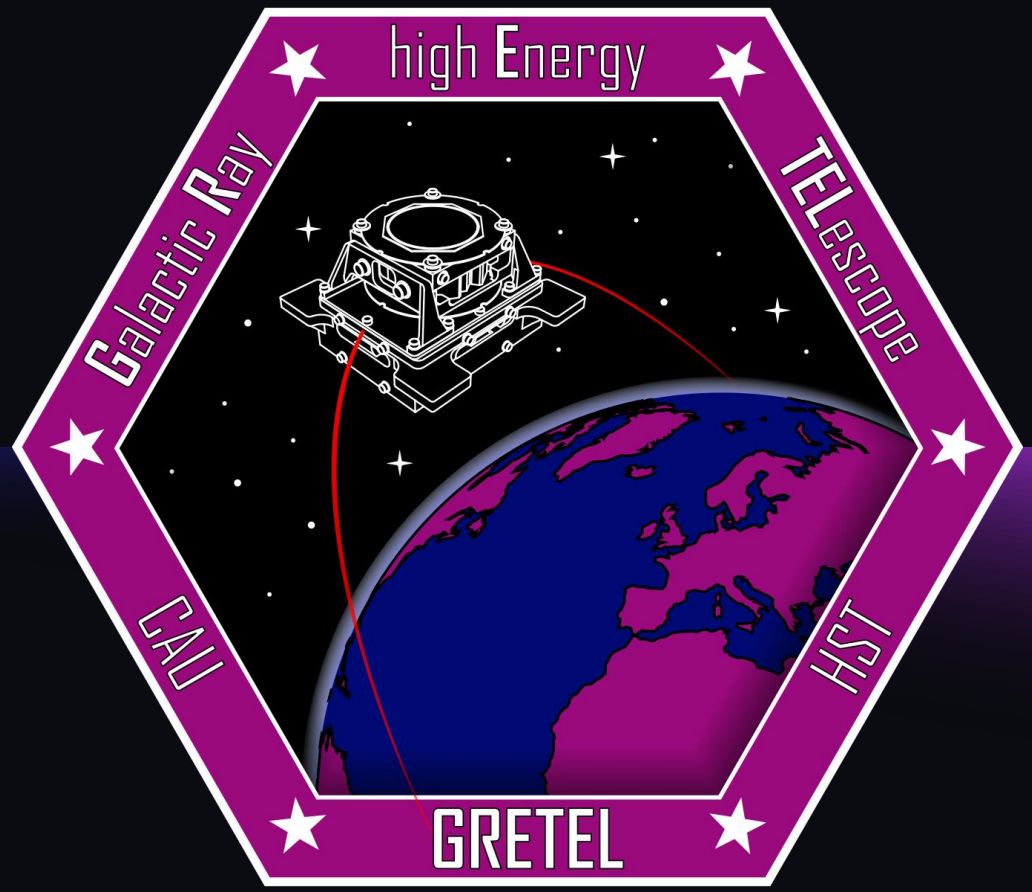
The Galactic Radiation high-Energy Telescope

GRETEL

WRMISS29

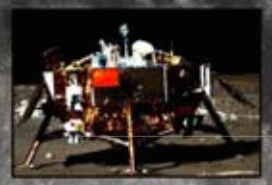


CAU Kiel

Mathis Mewes

From Kiel to Space

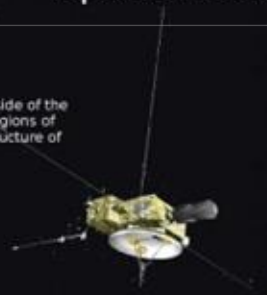
Space missions with contributions from CAU Kiel



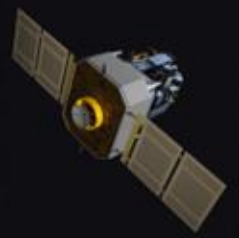
Chang'e 4 (2018-?)
Chinese lander to the far side of the moon
Lunar Lander Neutrons & Dosimetry (LND)



Apollo 16 and 17 (1972)
The last two moon landings
Cosmic Ray Detector Experiment



Ulysses (1990-2009)
Solar mission, which went outside of the ecliptic to observe the polar regions of the sun and explore the 3D structure of the heliosphere
Kiel Electron Telescope





Advanced Composition Explorer (ACE, 1997-today)
Specialises in detailed in-situ measurements of the solar wind





MSL/Curiosity (2011-today)
Mars mission to determine the suitability of Mars for the development of life in the past
Radiation Assessment Detector (RAD)

SOlar and Heliospheric Observatory (SOHO, 1995-today)
Allows a wide range of optical and in-situ measurements of the sun
Electron Proton Helium Instrument (EPHIN), CELIAS



Galileo (1989-2003)
NASA mission, which explored Jupiter and its moons. Also carried a probe which descended into Jupiter's atmosphere
Energetic Particles Investigation (EPI) on board of the probe





Space Shuttle (1981-2011)
American spacecraft, which was used for a wide variety of experiments and other tasks
Several dosimetry experiments starting in 1982



STEREO A and B (2006-today)
Two spacecraft observing the sun from different angles, allowing a stereoscopic view of the sun, with optical and in-situ instruments
Solar Electron and Proton Telescope (SEPT), Plasma and Suprathermal Ion Composition (PLASTIC)





Long Duration Exposure Facility (1984-1990)
Various materials and some biological cells were exposed to open space and cosmic radiation
Free-Flyer Biostack Experiment



International Sun-Earth Explorer (ISEE-2, 1977-1987)
Studied the interaction between solar wind and Earth magnetic field
Charged particle spectrometer

Helios 1 and 2 (1974-1986)
Inner heliosphere missions, which approached the sun closer than any other spacecraft so far
E6 Cosmic Ray Experiment



International Space Station (1998-today)
Permanently occupied space station used for a wide variety of scientific experiments
Dosimetry experiments including Matroshka and DOSTEL



Chandra X-Ray Observatory (1999-today)
Observes supernovas, black holes and other high-energy cosmic events
Includes EPHIN as a radiation monitor



Solar Orbiter (2020-?)
Inner heliosphere mission, successor to Helios, which will observe the sun with in-situ and optical instruments from a distance of only 0.28 AU
Electron Proton Telescope (EPT), High Energy Telescope (HET) and SupraThermal Electrons and Protons (STEP)

Azur (1969-1970)
The first German satellite studied the magnetosphere and the Van-Allen radiation belts



Mir (1986-2001)
Russian space station, which enabled the first long-term stays of humans in space
Dosimetry experiments



What is GRETEL

High-Energy Particle Telescope (SEP, GCR) designed for a CubeSat mission

→ Low power usage < 1 W

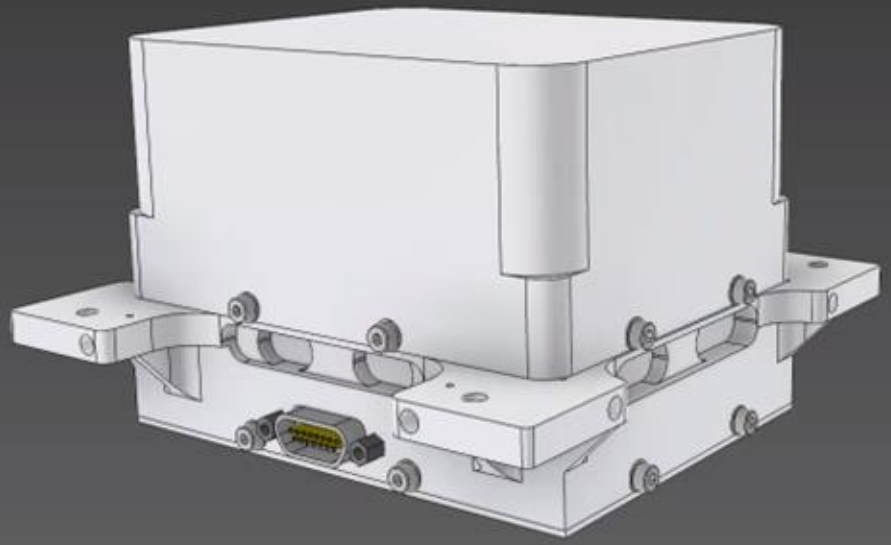
→ Low weight < 500 g

→ Low bandwidth < 10 kbps

⟶ Heavy Ion Spectroscopy

High Heritage: Detectors similar to

- Solar Orbiter's High Energy Telescope (HET)
- The Cherenkov Atmospheric Observation System (CHAOS, CHAOSjunior)

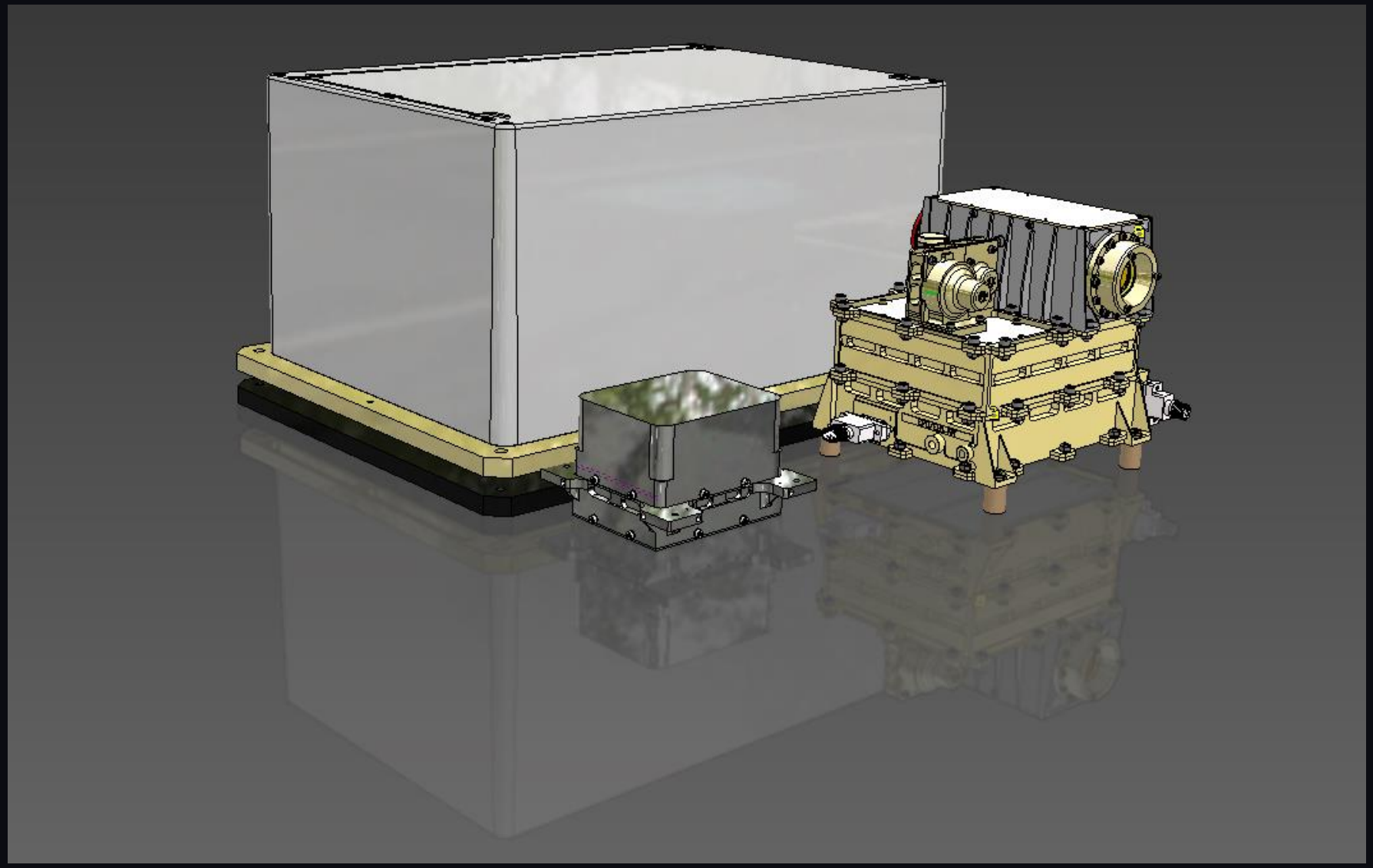


EPT/HET, CHAOS, and GRETEL

GRETEL: ca. 400 g

EPT+HET: ca 1560 g

CHAOS: ≈11 kg



The HANS Mission

Hamburg Autonomous Northern Lights Survey

- Realtime aurora detection, automatic image capture
- Onboard prioritizing of images for downlink
- Pathfinder for THHOR





The 1.5 U prototype

Stats

- Polar LEO, ~500 km
- Launch ~ 2030 …?
- Duration ~ 2 years

HAMBURG SPACE TEAM

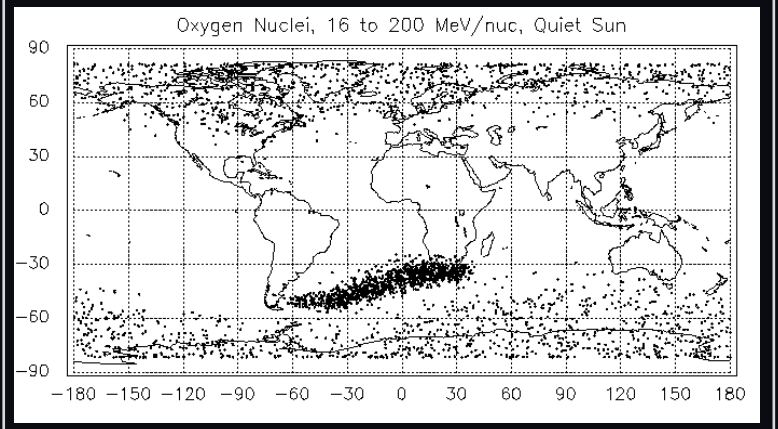
RESEARCH TUHH ORBITAL

Example Science: SAMPEX

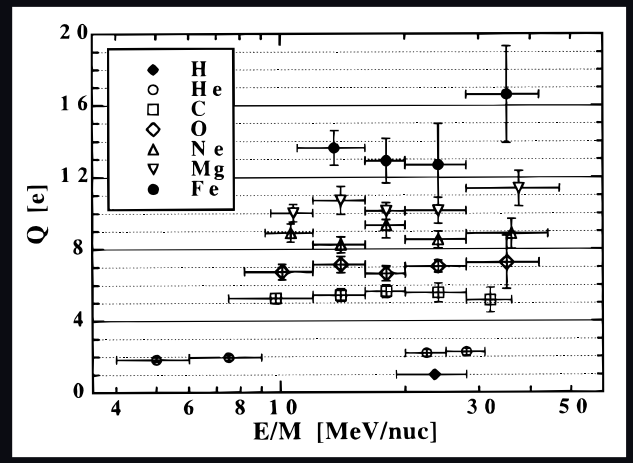
Solar Anomalous and Magnetospheric Particle Explorer

- 1992-2004
- 520...670 km orbit, 82° inclination
- ~0.4 MeV/nuc … >100 MeV/nuc
- Earth‘s mag field used as giant magnetic spectrometer

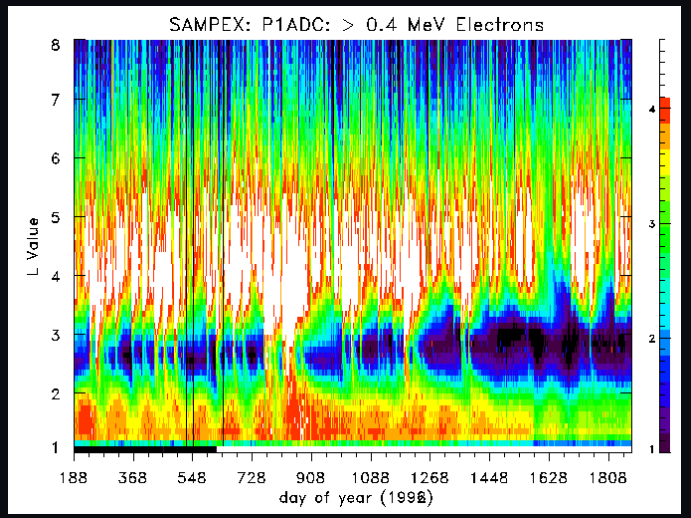
Cosmic Rays



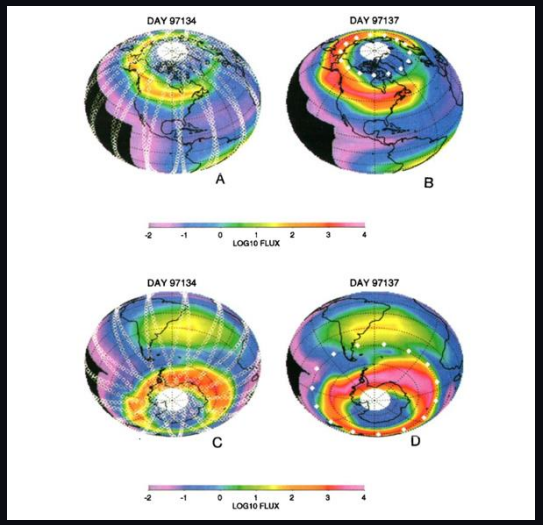
SEP



Magnetosphere



Magneto-Atmosphere Coupling



https://lasp.colorado.edu/sampex/science/#cosmic-rays

Reasons to Measure Heavy Ions in Low Earth Orbit

- Low Earth Orbit, CubeSat → cheap, easy to implement
- Full sky coverage
- Polar magnetic cusps → access to the full particle spectrum

- Build a better understanding of Galactic Cosmic Rays (GCR) and Solar Energetic Particle (SEP) impact at low altitudes
- Space safety: Radiation hazards imposed by GCR, SEP
  - Heavy ions have a significant impact on electronics (single event effects) and biological tissue (dense energy deposition)

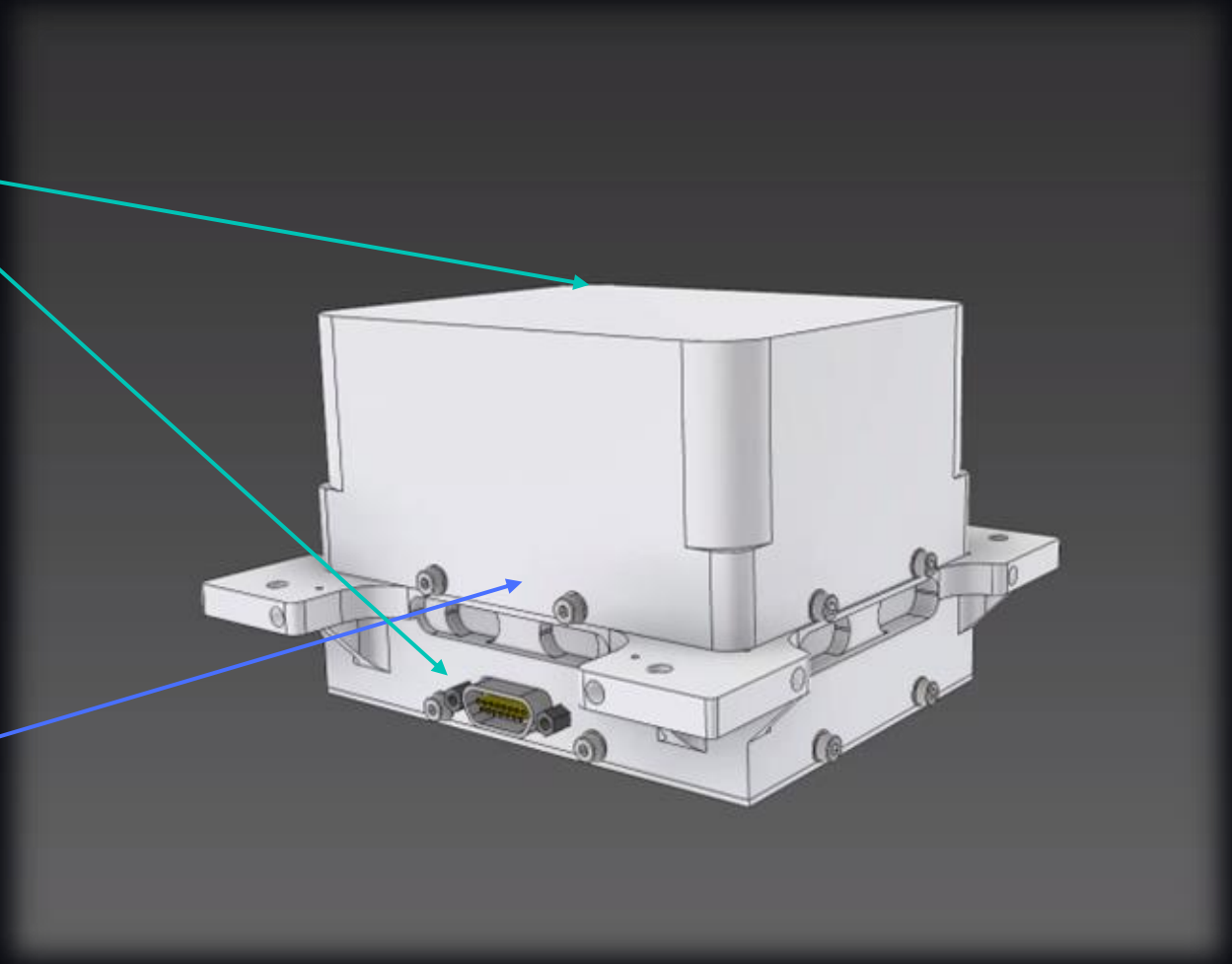
GRETEL's Detectors

4 Solid State Detectors (SSD)

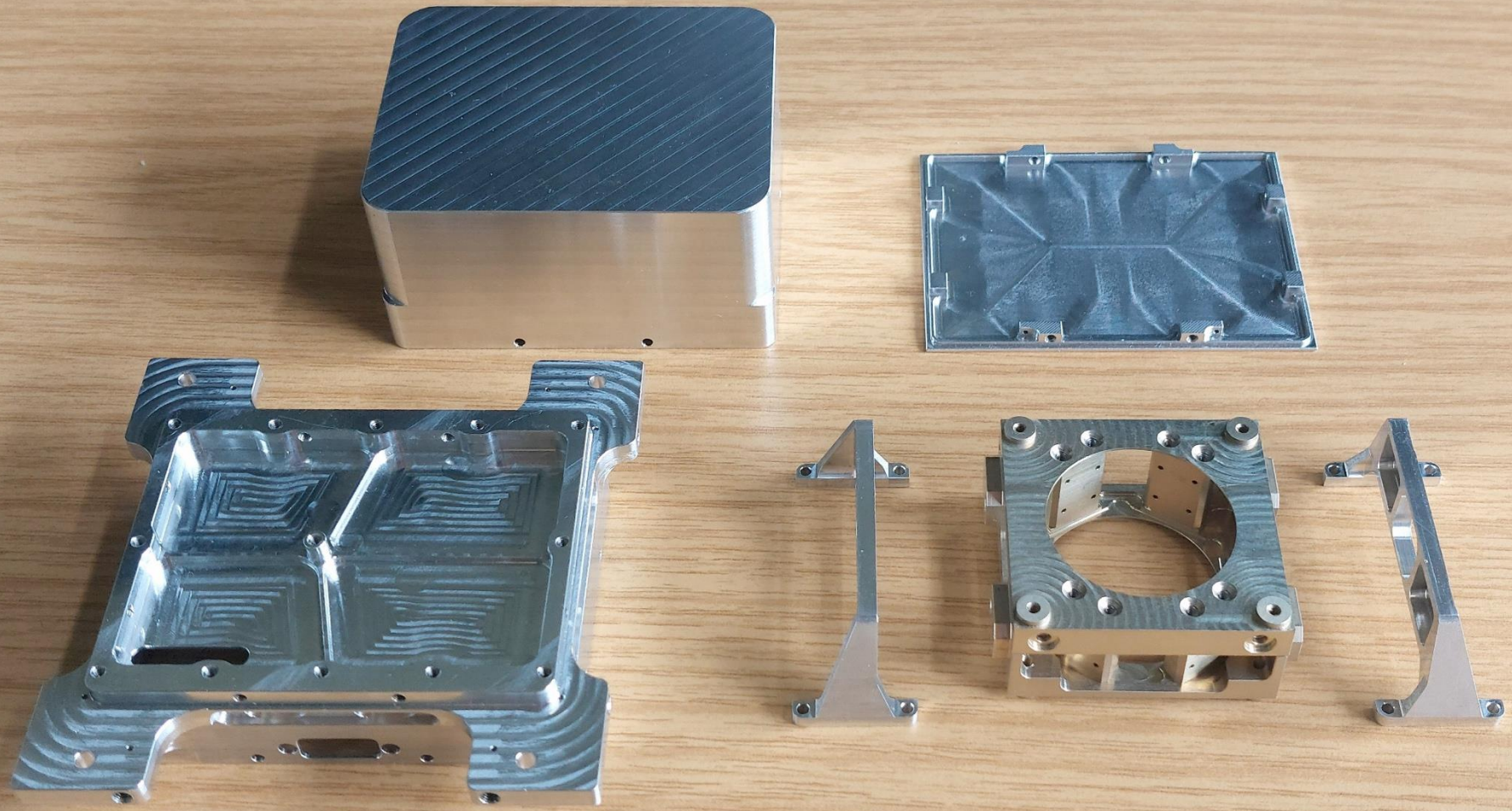
- Reverse biased diode (~70 V)
- Passing charged particles create free electrons and holes, proportional to deposited energy
- Charges are collected and read out

Scintillation Detector

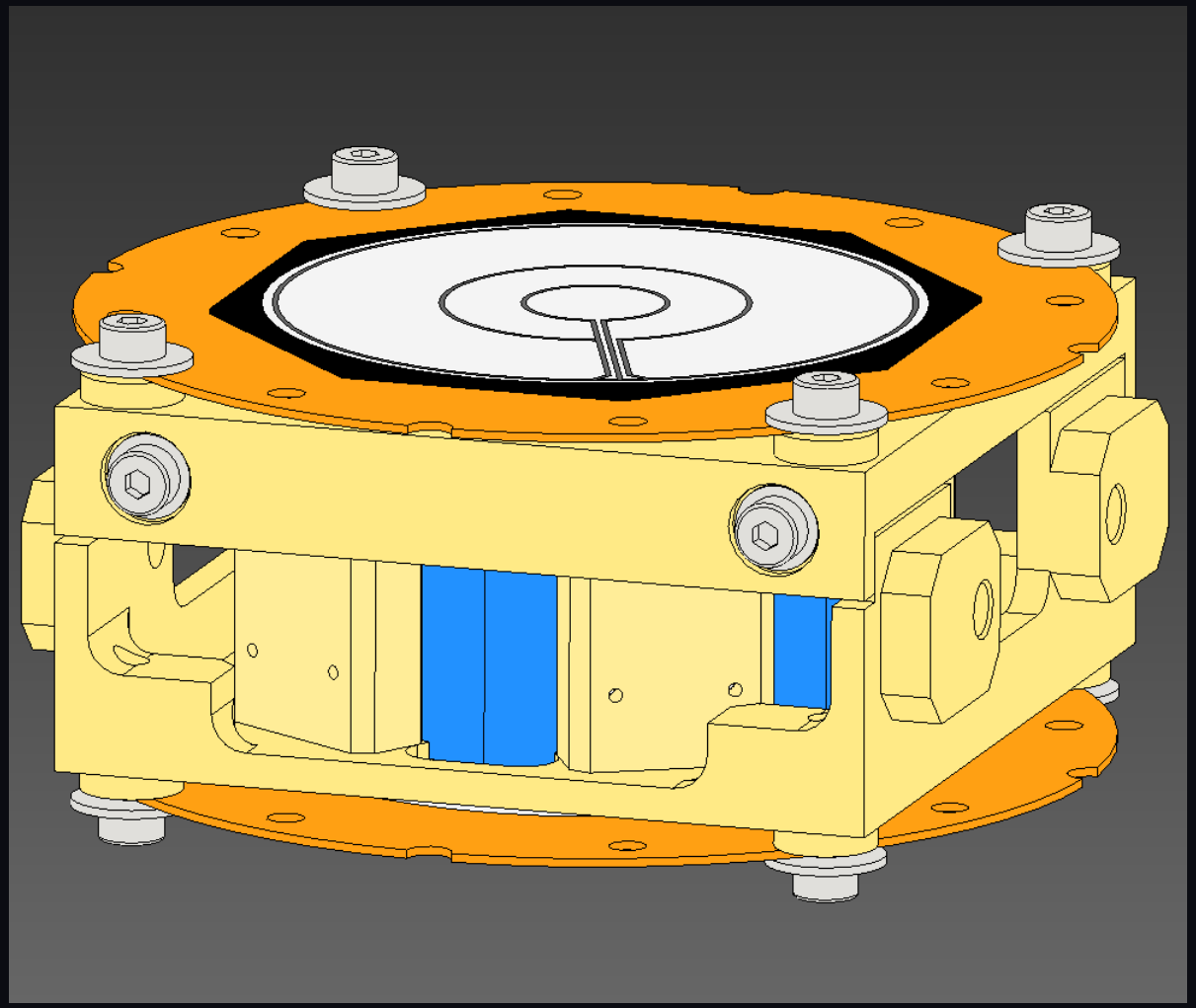
- Emits light when excited by ionising radiation
- Emitted photons are measured using 2 photodiodes
- We use Bismuth Germanium Oxide (BGO) at 7.1 g / cm³

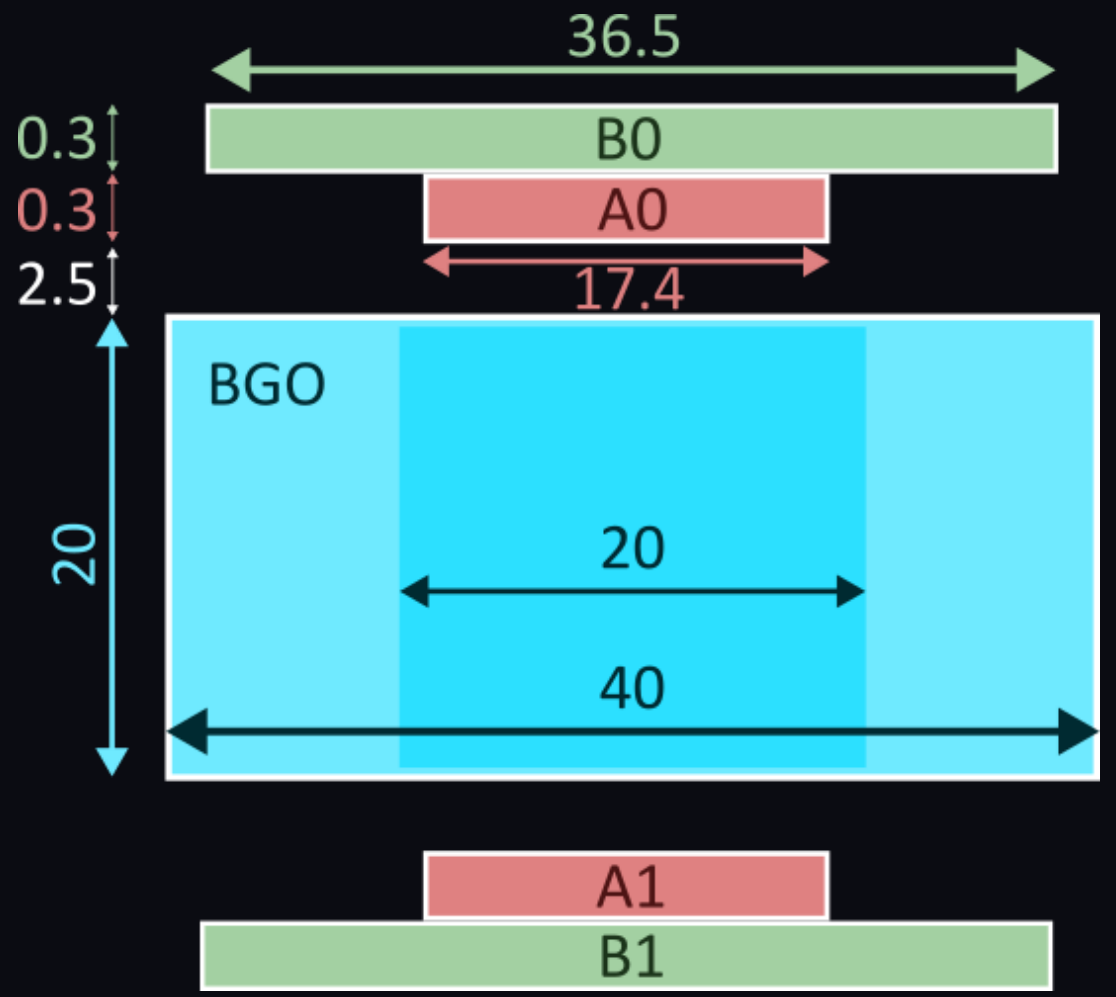


GRETEL Mechanics



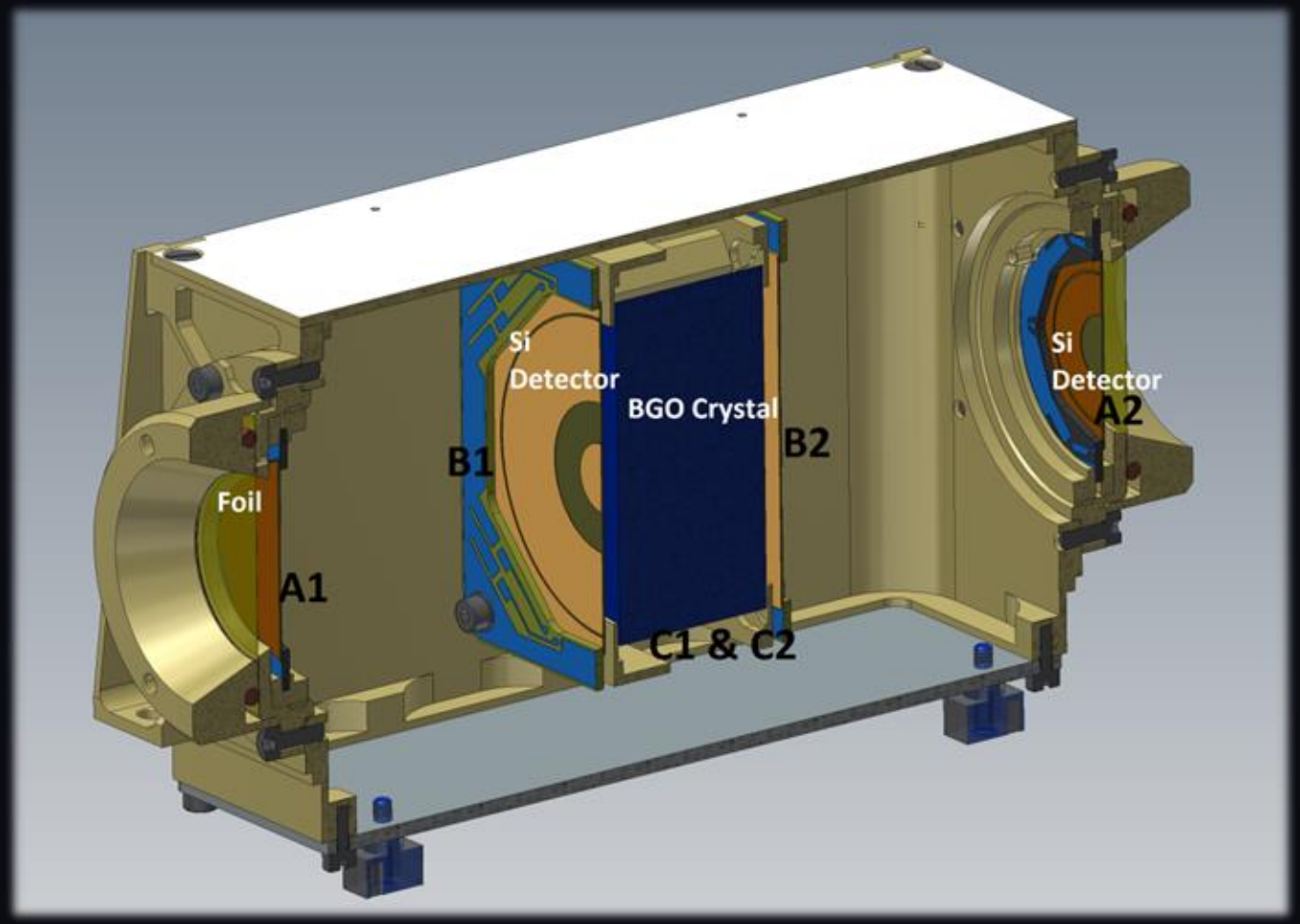
GRETEL Detector Stack





Solar Orbiter‘s High Energy Telescope (HET)

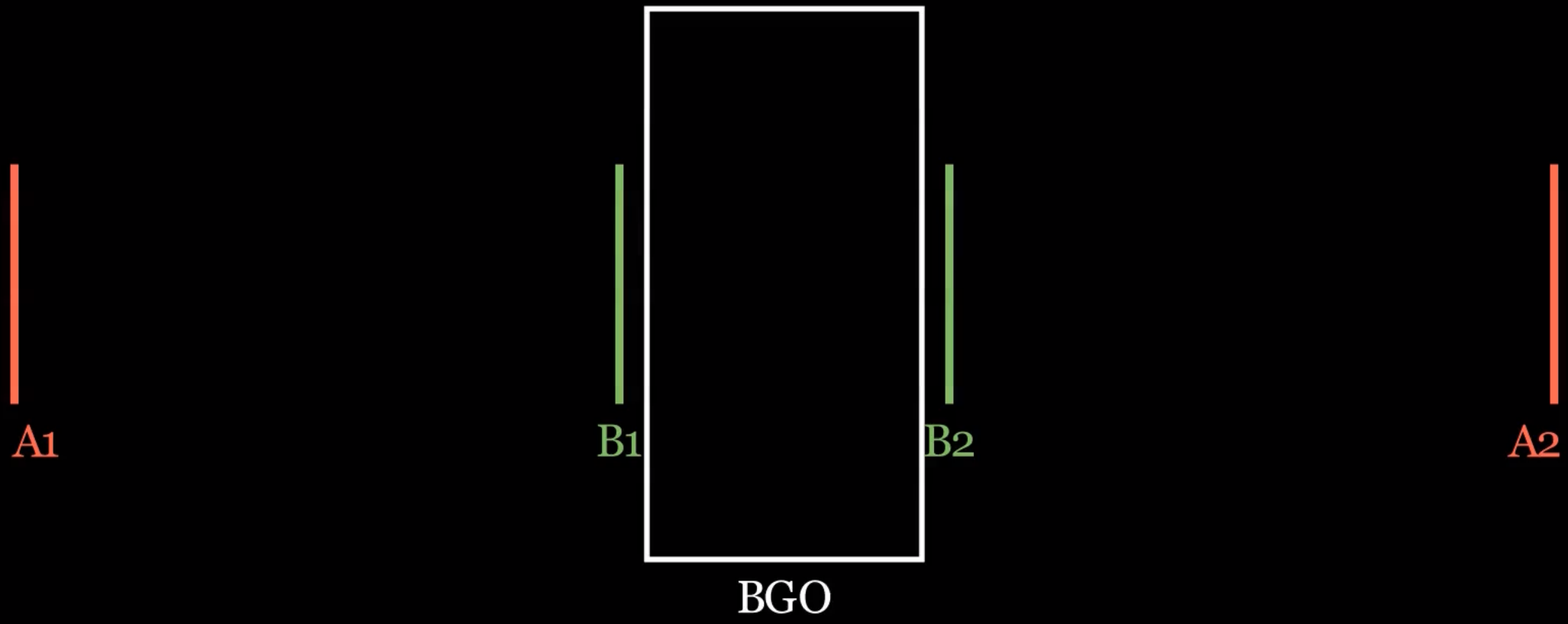
- Measures up to ~100 MeV/n (protons), ~ 500 MeV/n (Ar-Ni)
- Temporal resolution up to 1s
- GF: 0.27 cm² sr



Rodríguez-Pacheco et.al. 2020

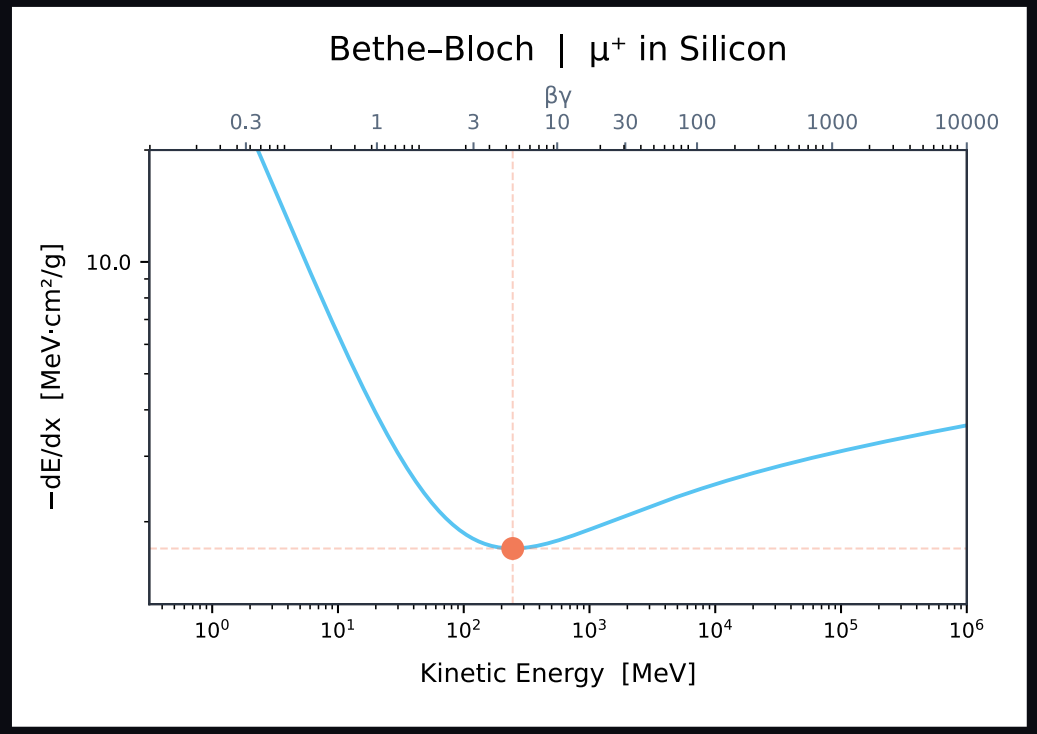
HET

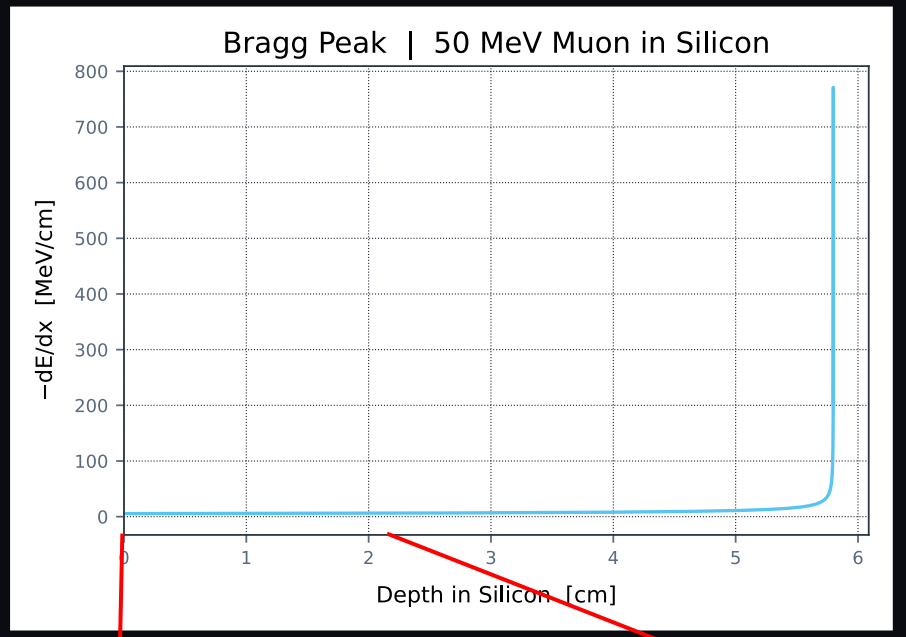
Geometry Factors

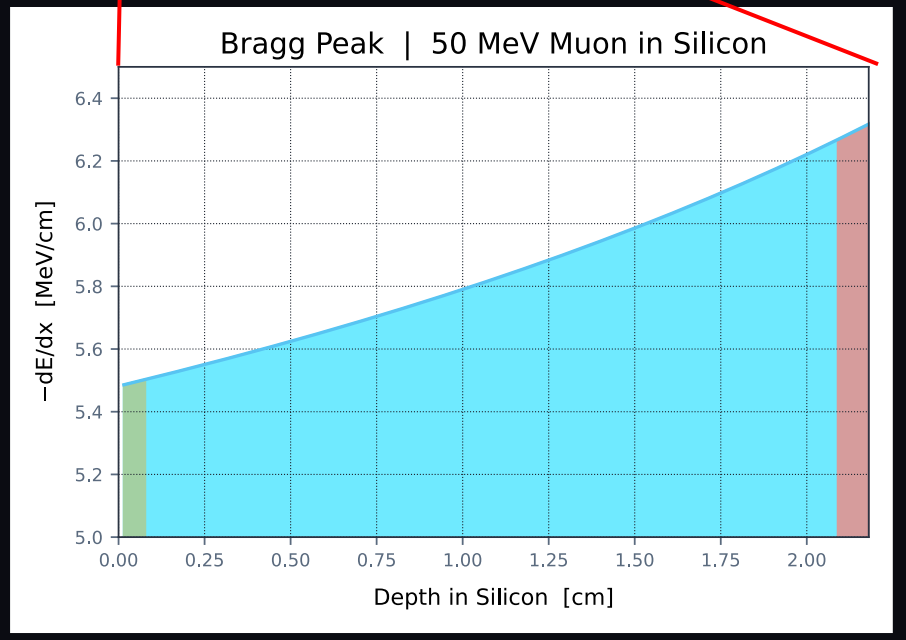


Bethe-Bloch

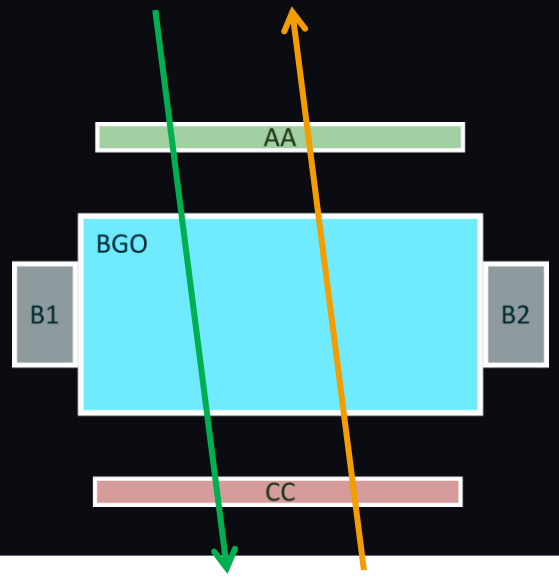
$$-\frac{\mathrm{d}E}{\mathrm{d}x} = f(E) \quad \xrightarrow{\text{integrate}} \quad -\frac{\mathrm{d}E}{\mathrm{d}x} = g(x)$$

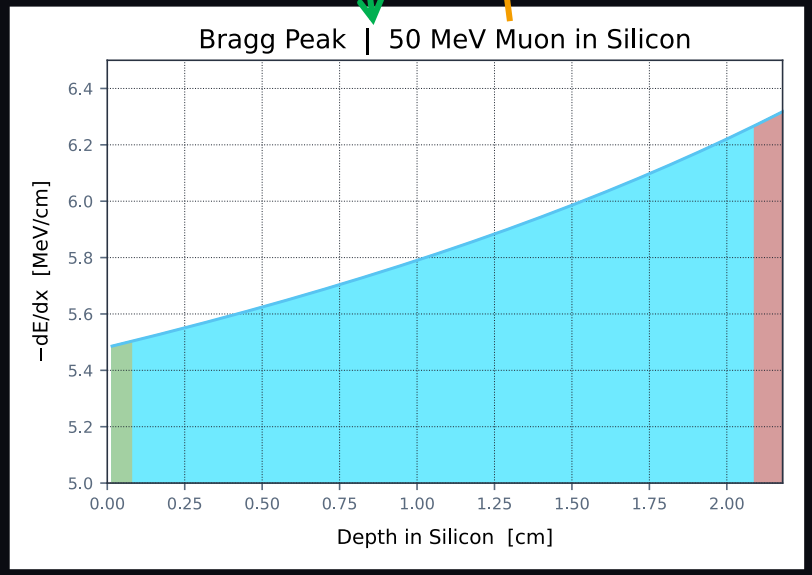


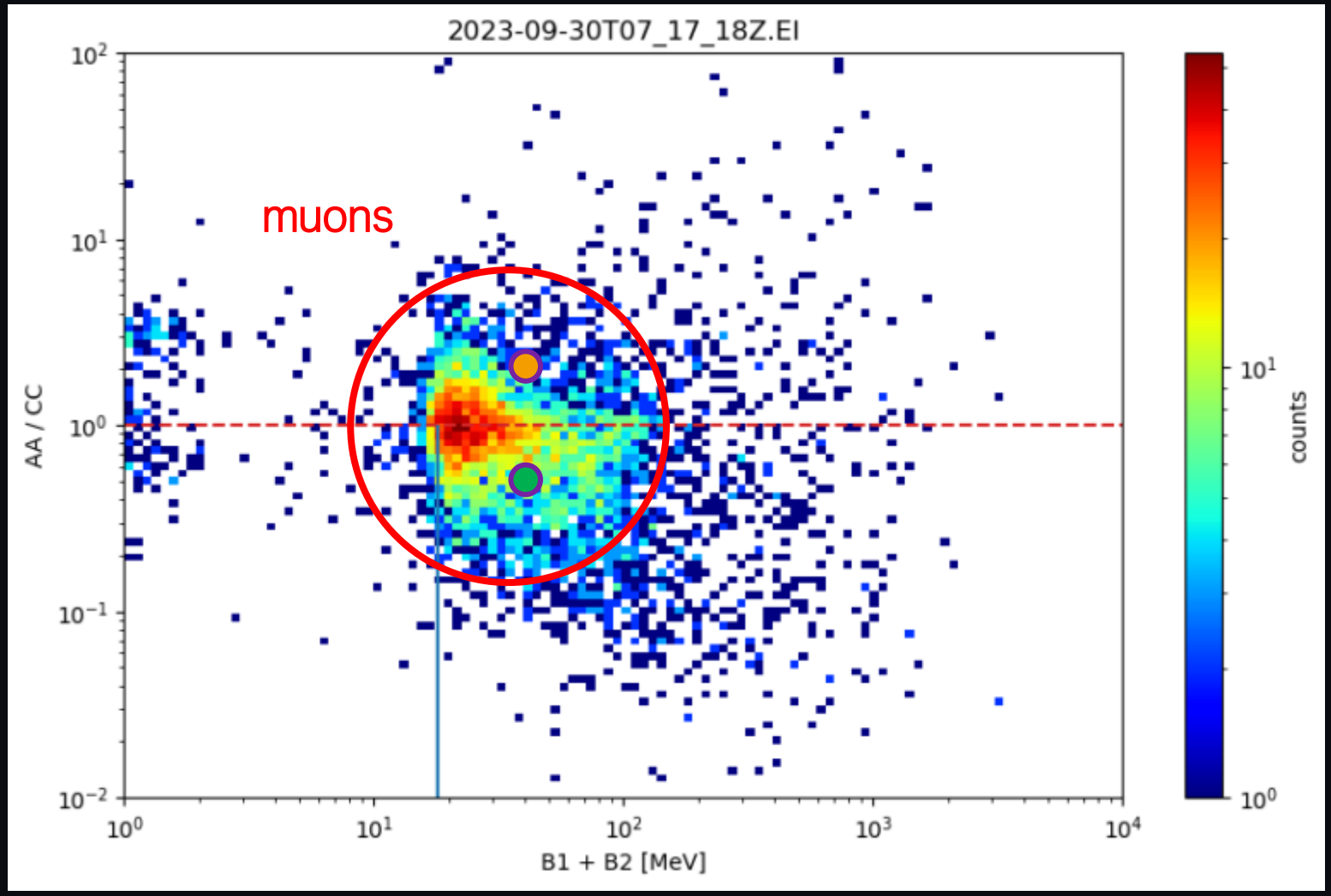




Sample CHAOSjunior balloon flight data („fish plot“)







Geant4 Simulations

We want to simulate **detector response** to differe

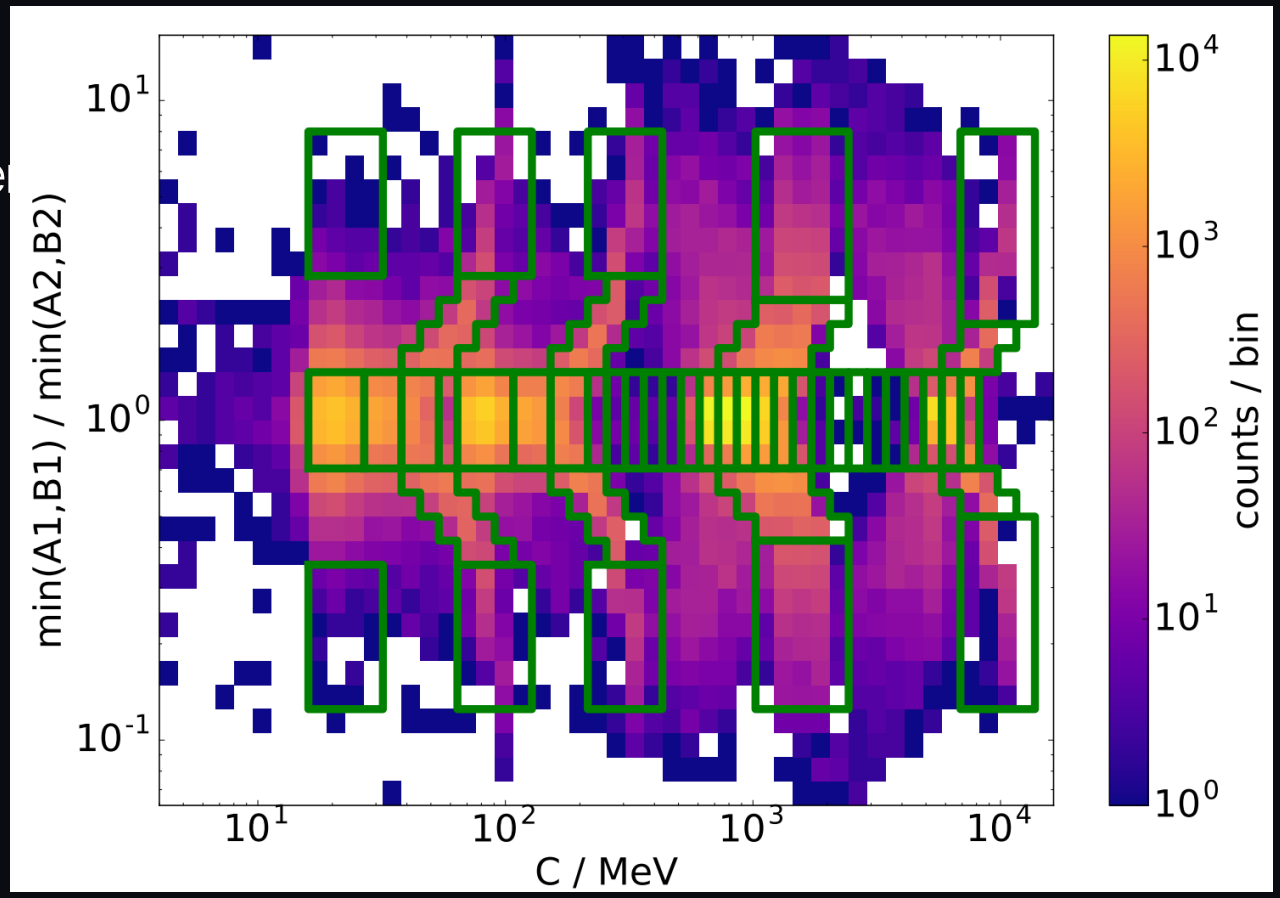
- Species
- Energies
- Angles

Input:

- Geometry layout
- Physics lists

Output:

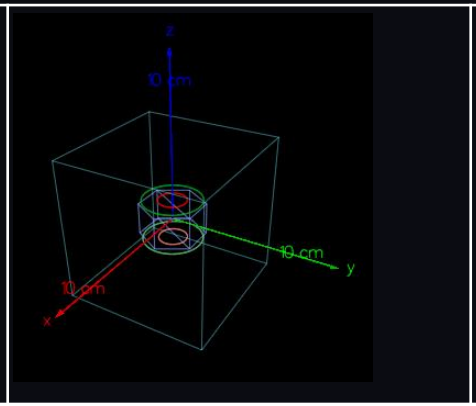
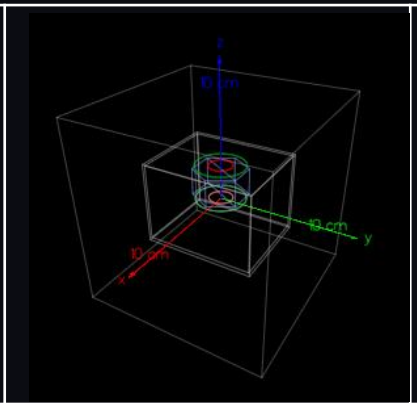
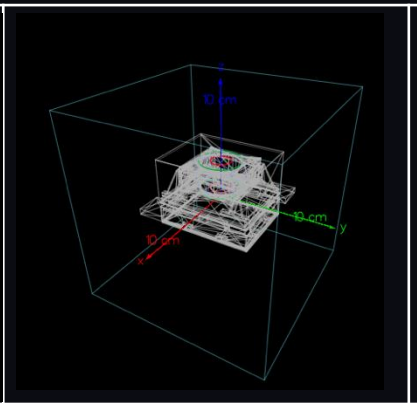
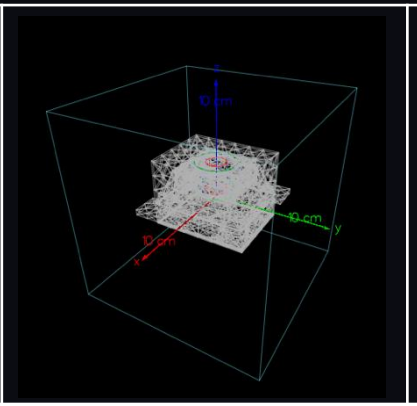
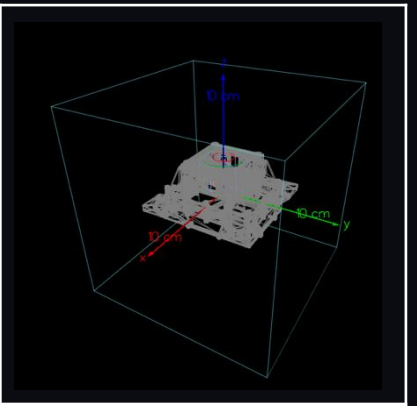
- E.g. list of deposited energies per detector



Geant4 simulated data of SolO/HET

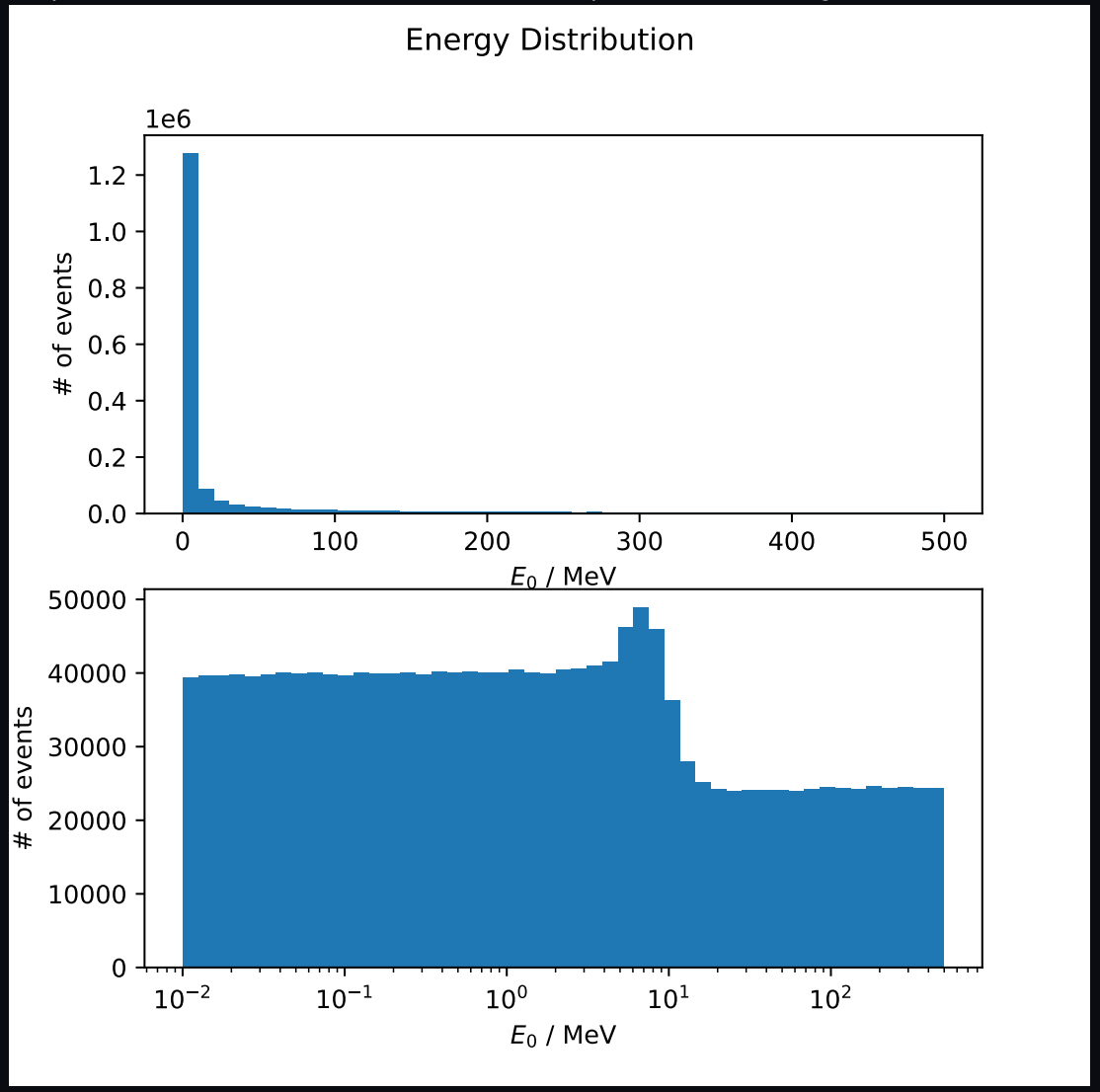
Rodríguez-Pacheco et.al. 2020

GDML representations: Comparison for 1E7 geantinos on 60 threads

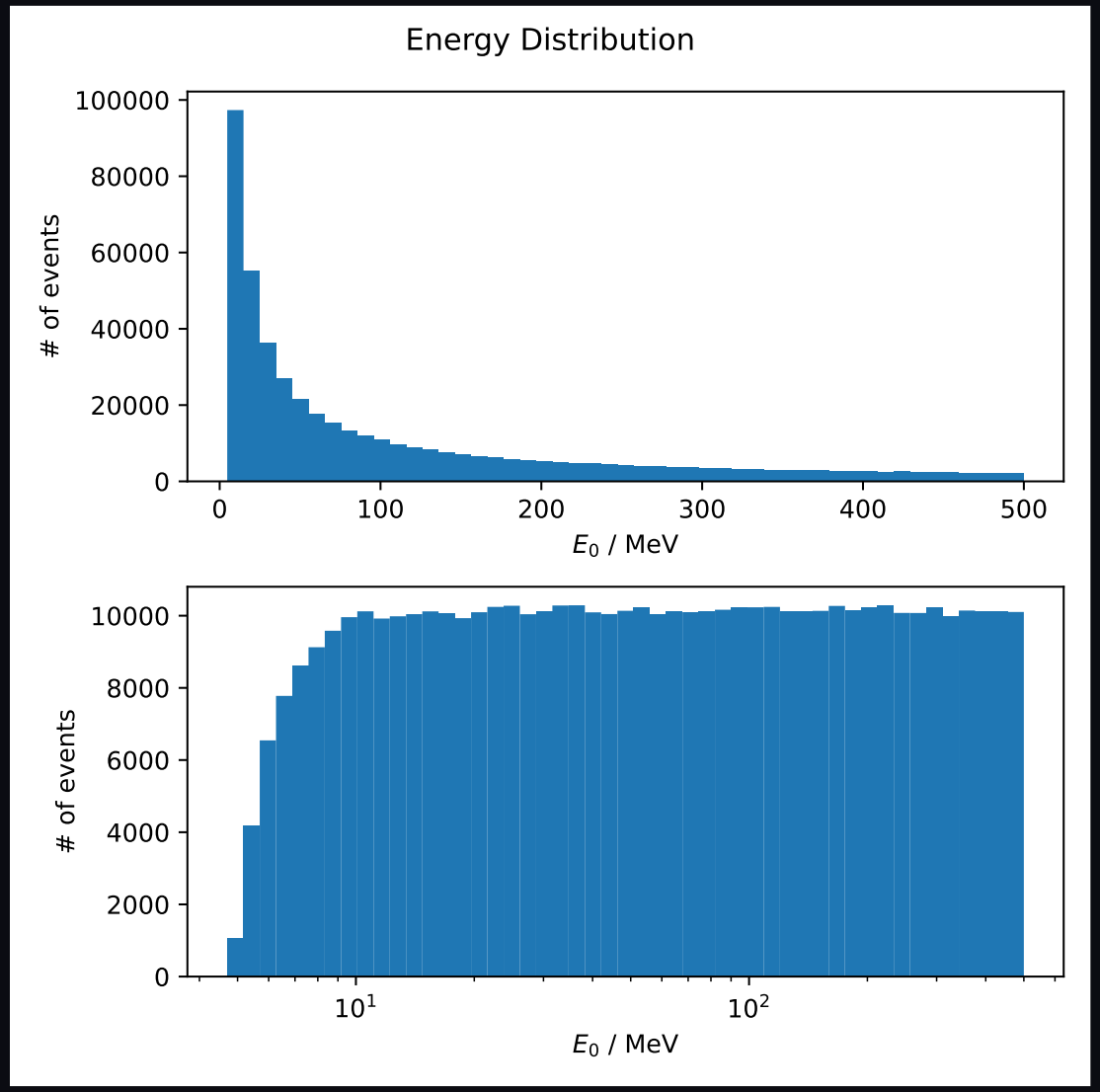
					
	light	simple	native	gmsh	complex
Vertices			980	14069	35848
Triangulars			1901	4689	71205
Runtime / s	16.2	15.0	31.3	51.2	45.2
GF / (mm² sr)	148.4 ± 1.0	145.2 ± 1.6	0.03 ± 0.03	146.8 ± 0.2	146.8 ± 0.2

Geant4: Muons

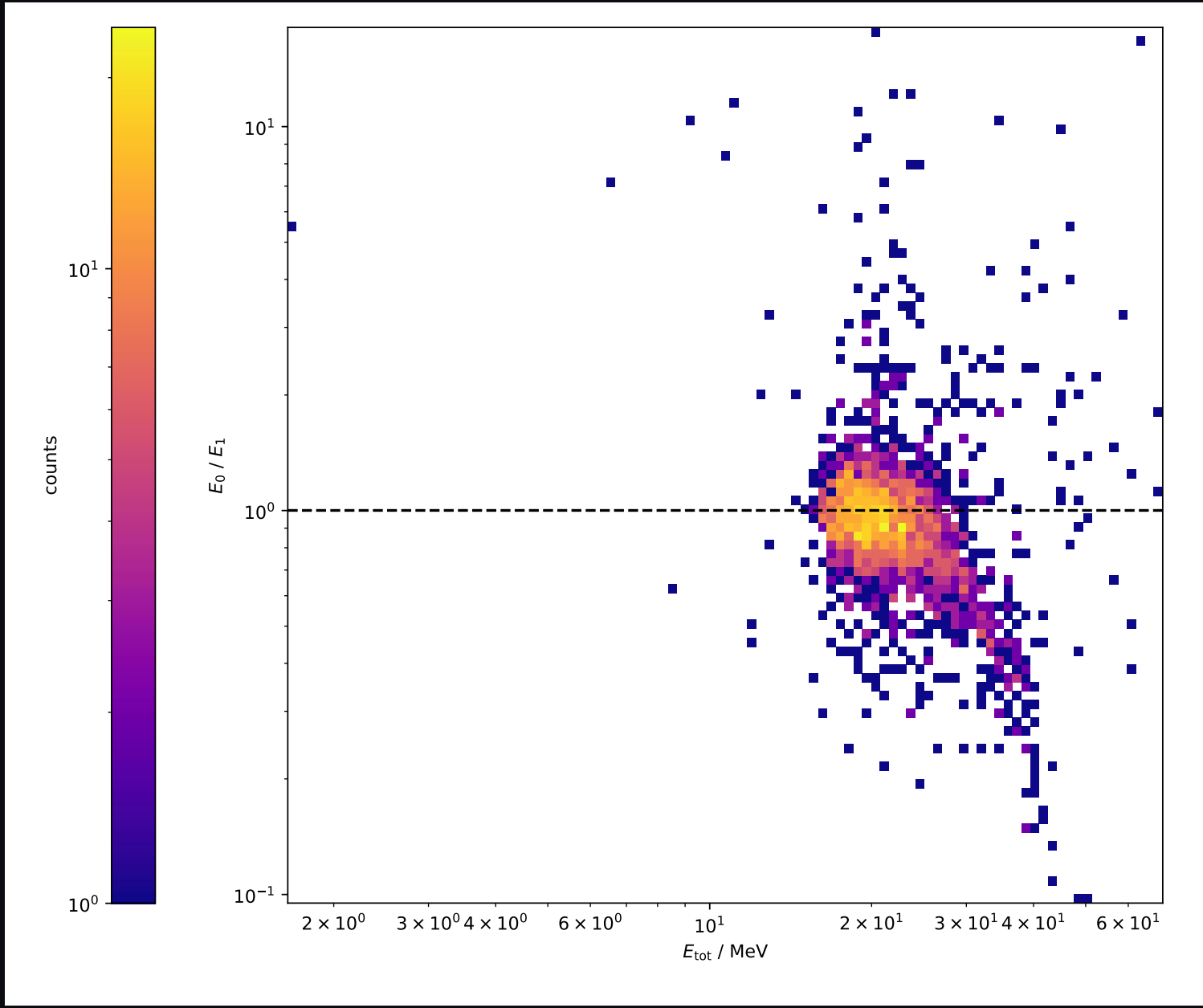
Primary vertex kinetic energy of all particles (primaries, secondaries, …) that hit any detector



Primary vertex kinetic energy of primaries that hit any detector

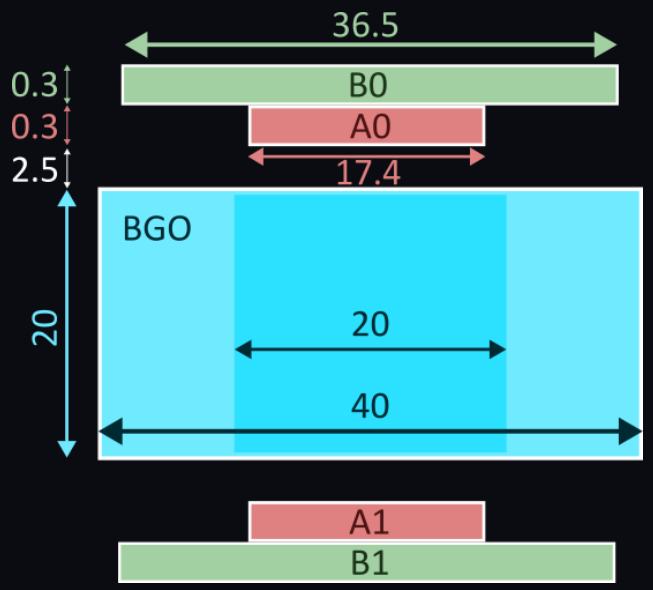


Geant4: Muon Sample Fishplot



Readout Scheme

Dual gain: Low gain at 1 / pF (SSD),
4.3 / pF (photodiode)
High gain: Multiplied x15



6 wires

Preamp Board
thhor_csa

6 channels

charge sensitive amplifier

Sallen-Key filter

12 pins

FPGA Board
thhor_crs

x12

Shaper

x12

analog-digital converter

FPGA software

L1
ADC diff trigger

L2
digital filter

L3
phase correction

L4
Event processing

Digital Processing

L1: Trigger

- Incoming samples are stored in a buffer
- We trigger on a surpassed threshold between samples s_i and s_{i+8}

L2: Digital Processing

- Windows of 16 coefficients A_i are multiplied with the last samples:

$$A = \sum_{i=0}^{15} a_i s_{i+i_0}\,, \text{amplitude}$$

$$B \text{ the same way, phase}$$

- Largest A is found and passed together with B and timestamp

L3: Phase Correction

$$\phi = B/A$$

$$b(\phi) \ldots \text{polynomial}$$

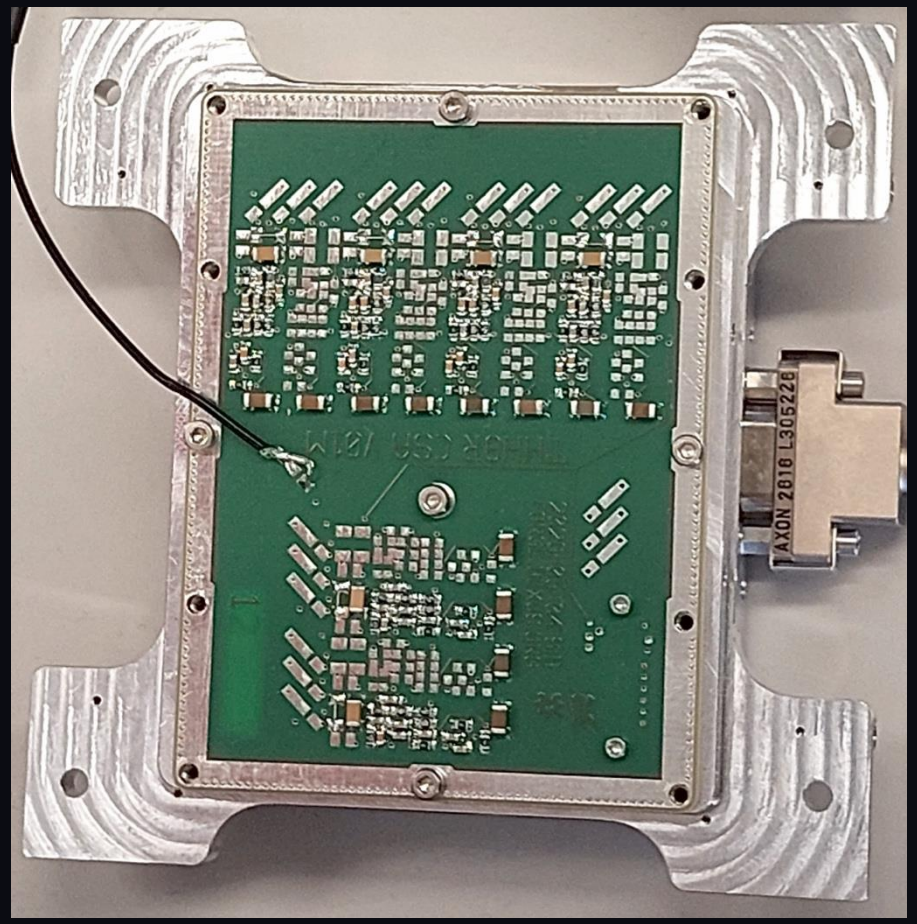
$$\text{PHA} = b \cdot A$$

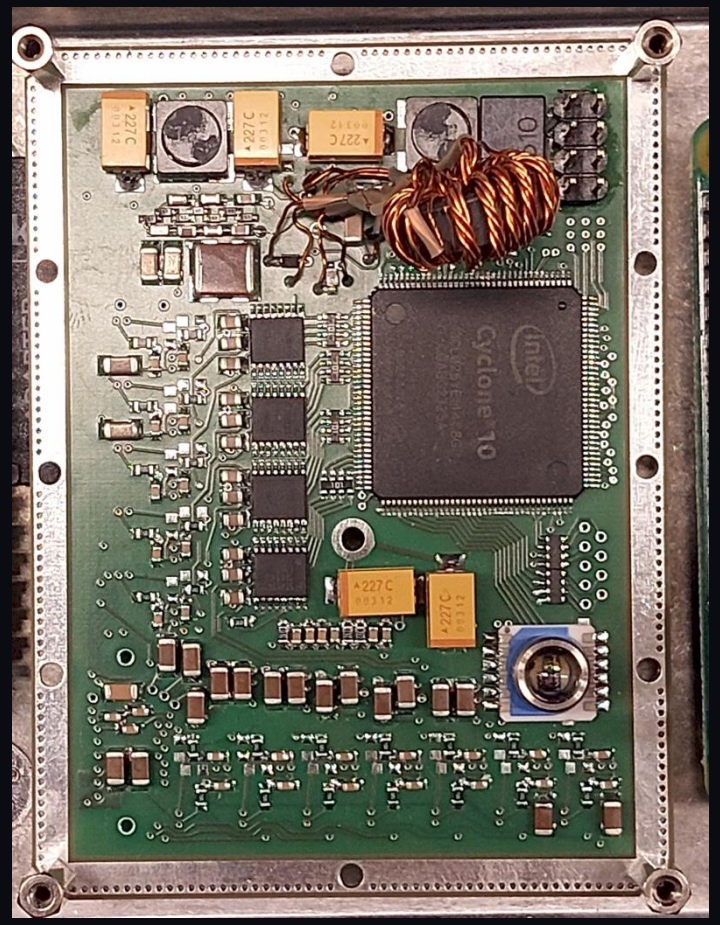
A, B, ϕ, P are the output of the FPGA, passed to the microcontroller

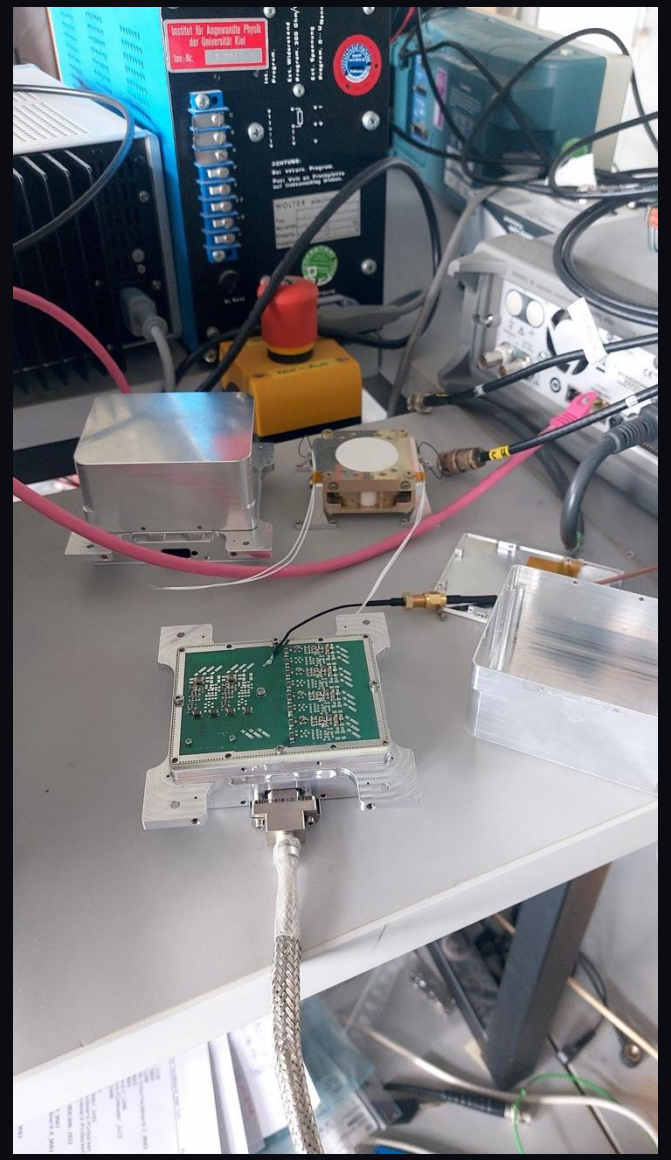
L4: Event Processing

- Gain Selection
- Processing of coincidences
- Histograms

GRETEL Electronics

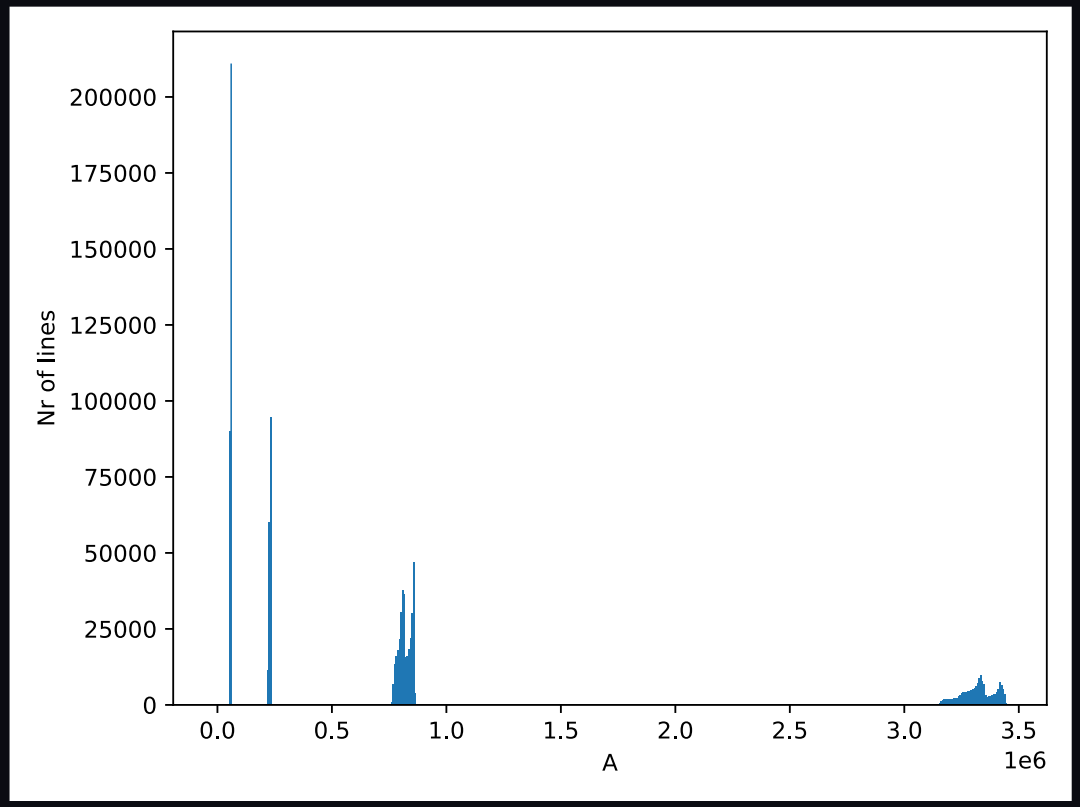


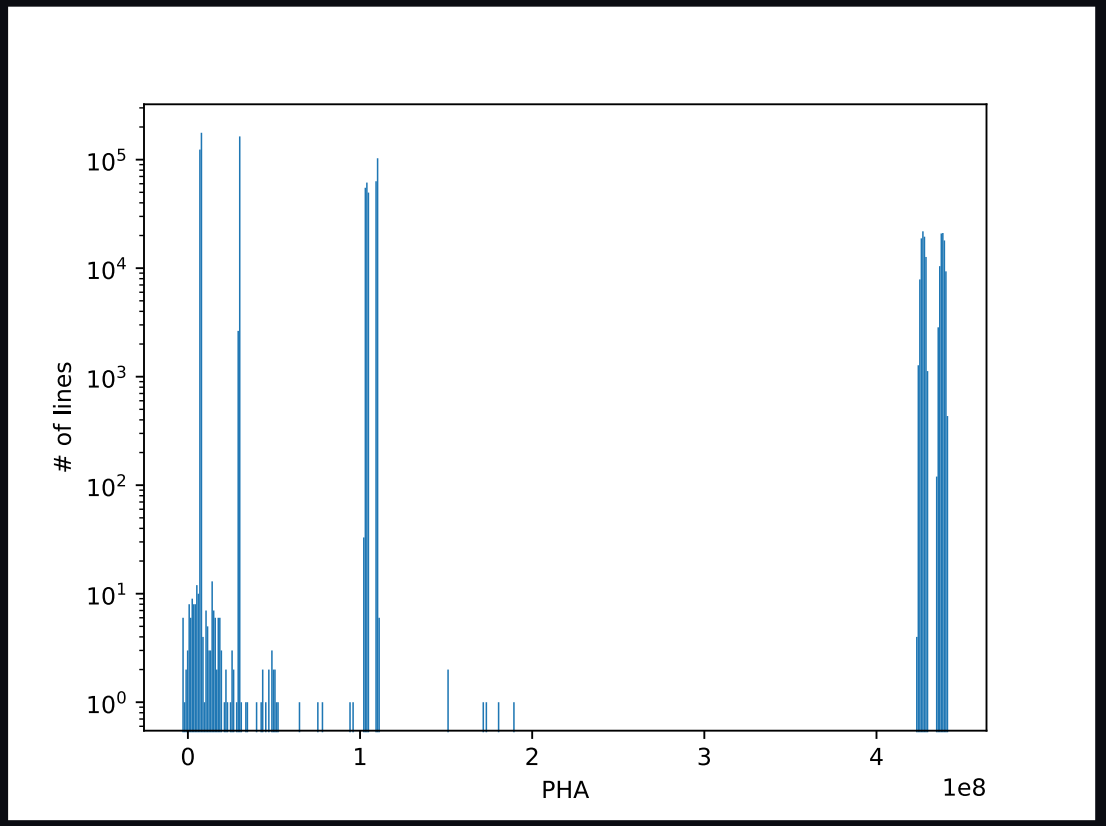




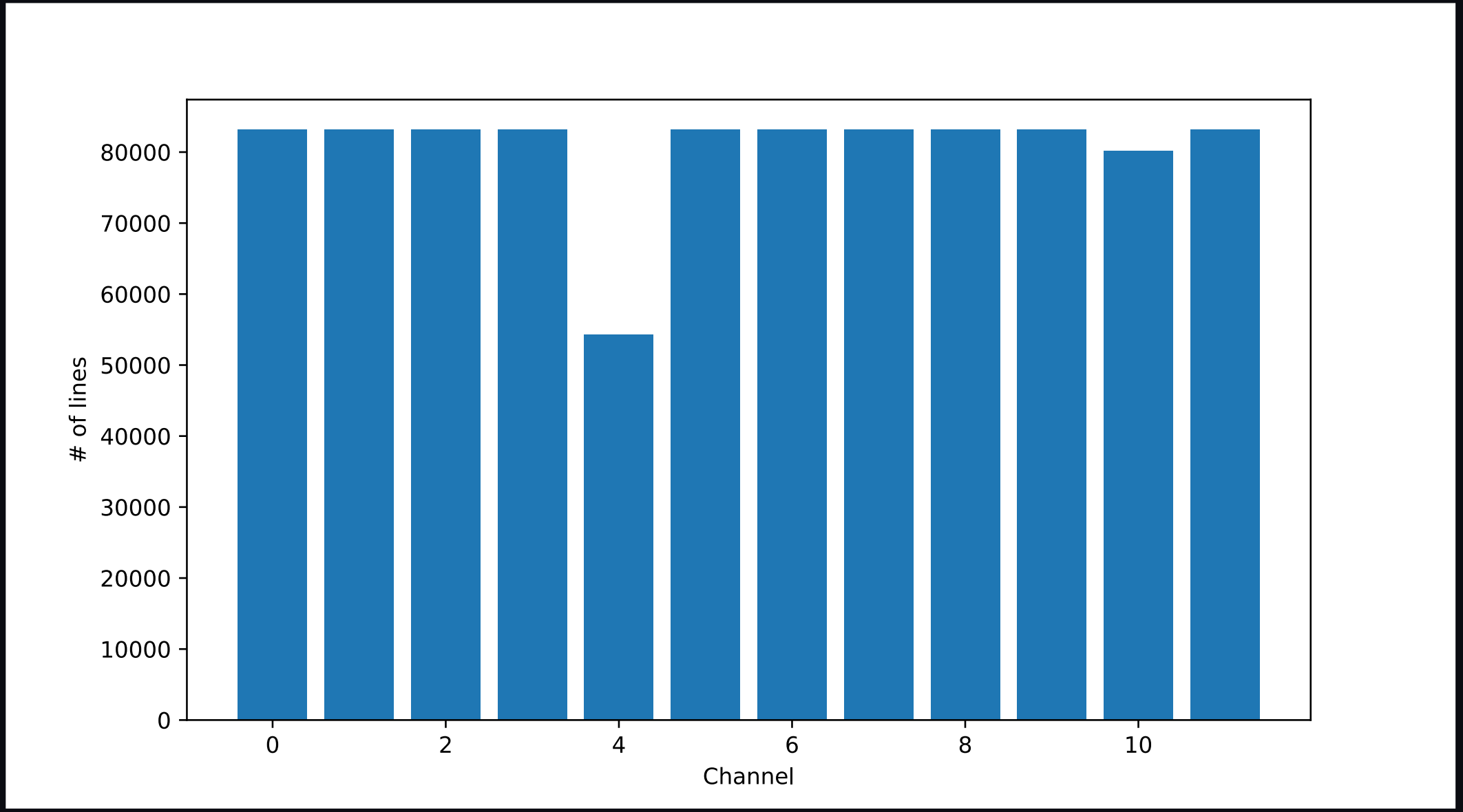
First Electronics Tests: Pulse Generator


```
EDB 463435849 0 10 0 0  55255 -23778  -7050.56 17025.92 7349744.09
EDB 463435849 0 11 0 0  57846 -25020  -7086.53 17039.59 7700564.11
EDB 463435850 0 0 1 0  60842 -16463  -4433.28 16416.78 7803358.51
P 0xba7e 0xfff7 0xa881 0x4997 0xa660 0xb058 0x483d 0x7d17
EDB 463769190 0 2 65279 0  3216388 -1353263  -6893.40 16967.91 426370149.81
EDB 463769190 0 3 0 0  830289 -344991  -6807.67 16937.43 109866901.99
```

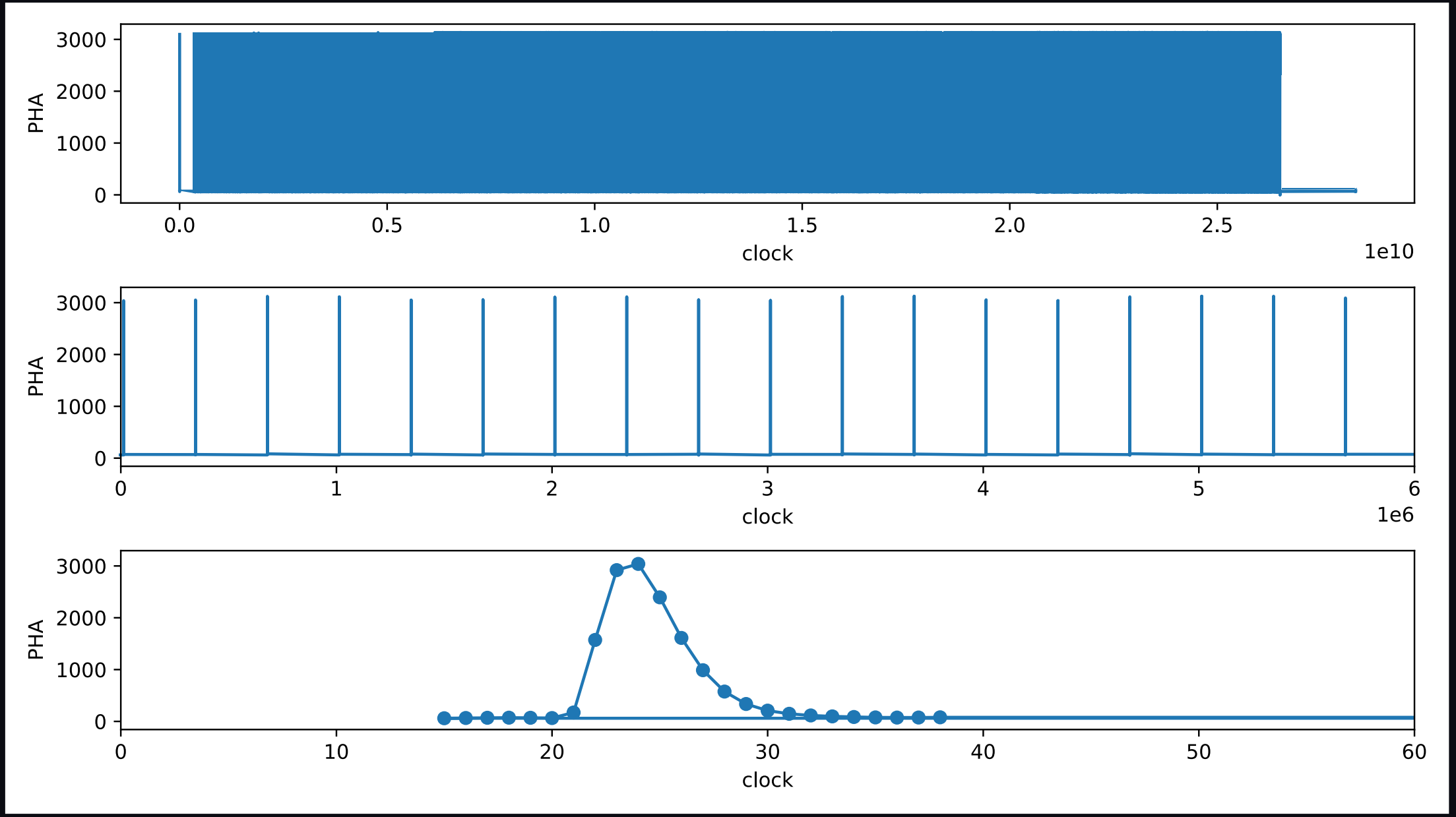




First Electronics Tests: Pulse Generator Events

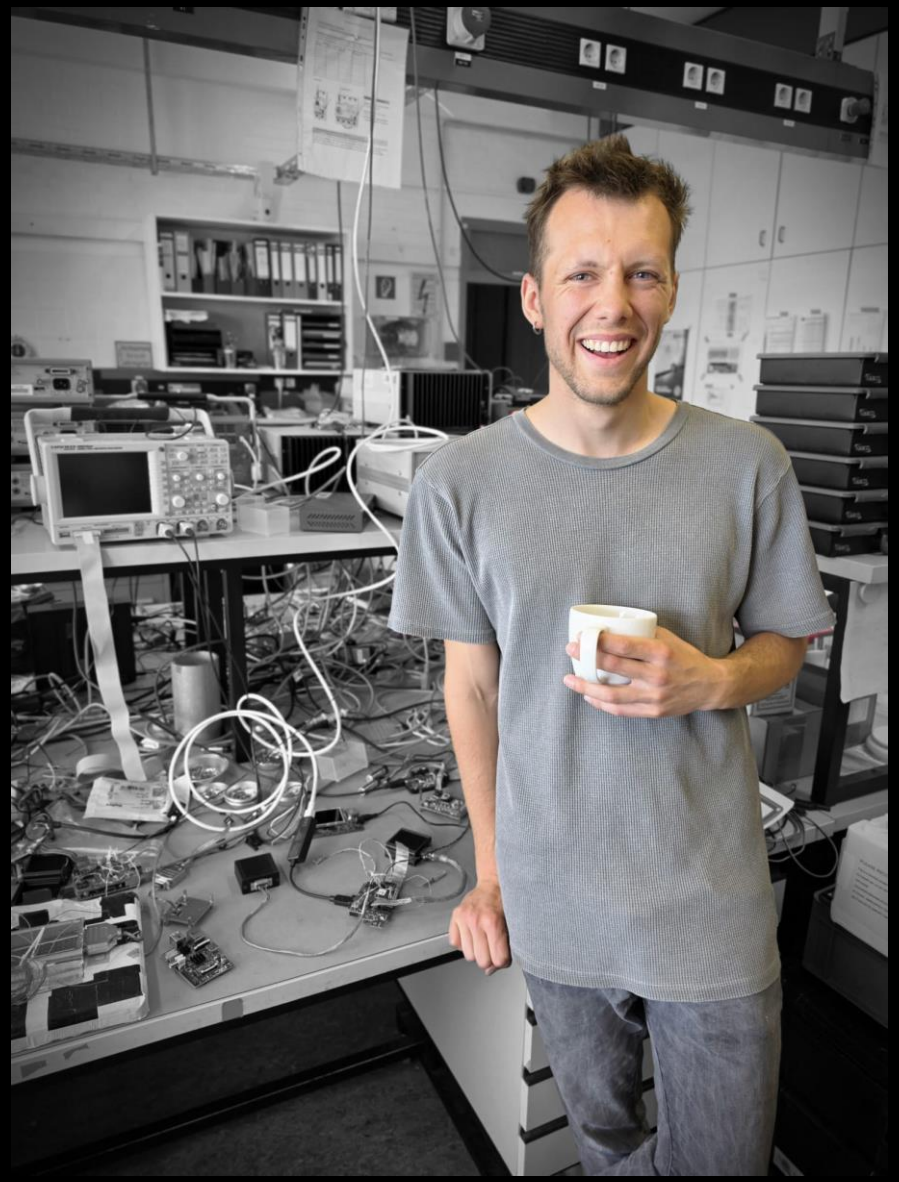


First Electronics Tests: Oscilloscope Mode



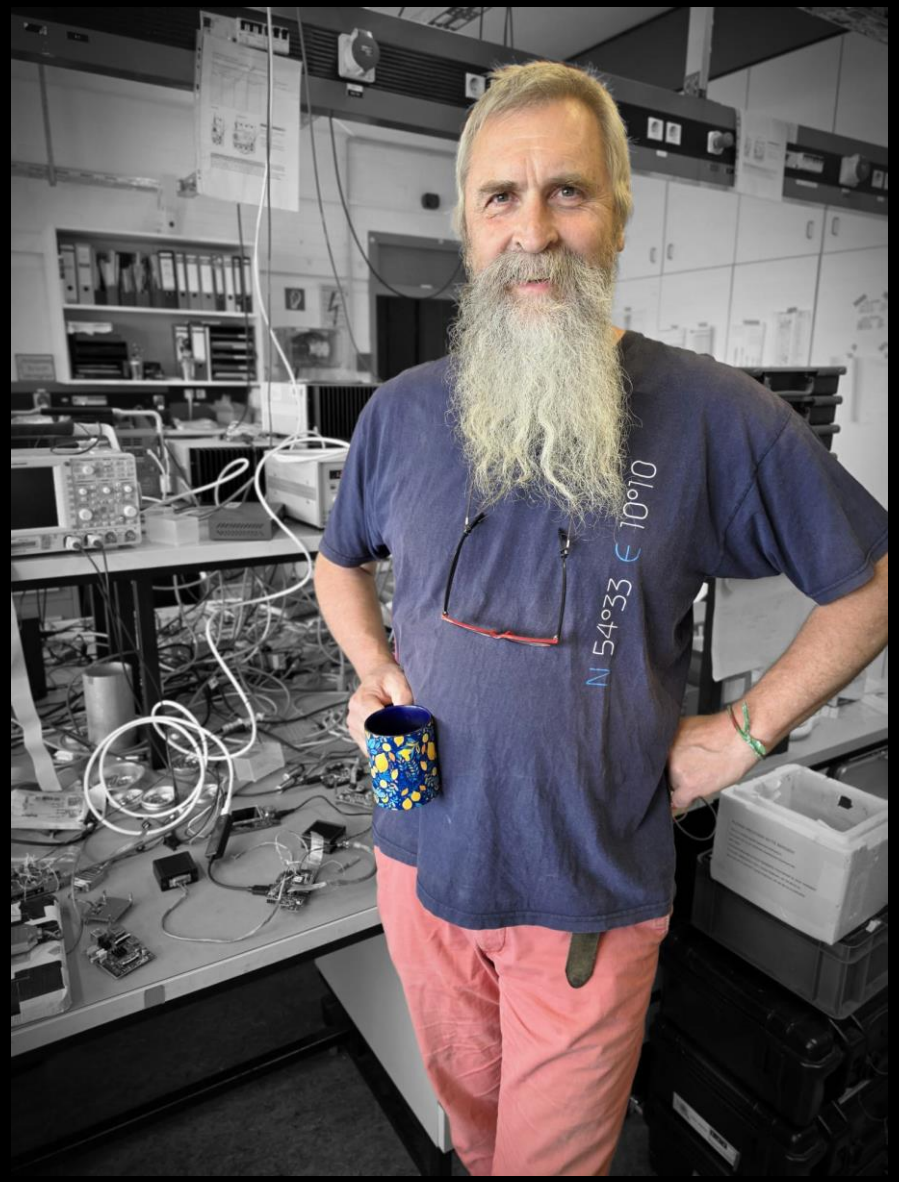
ToDo‘s

- Run more Geant4 simulations (protons, electrons, ions, quenching, select physics lists, production cuts, …)
- Write a pipeline to add electronic effects to Geant4 output (chance coincidences, pileup, detection thresholds)
- Test in-orbit conditions (find suitable input spectra)
- Define and implement GRETEL‘s readoud logic and data products
- Integrate detector stack
- Calibration with muons / source / beam
- Find synergies with HANS: How can aurora and particle observations work together?
- …



Thank You

for Listening!



Extra Slides…

Geant4 Simulations

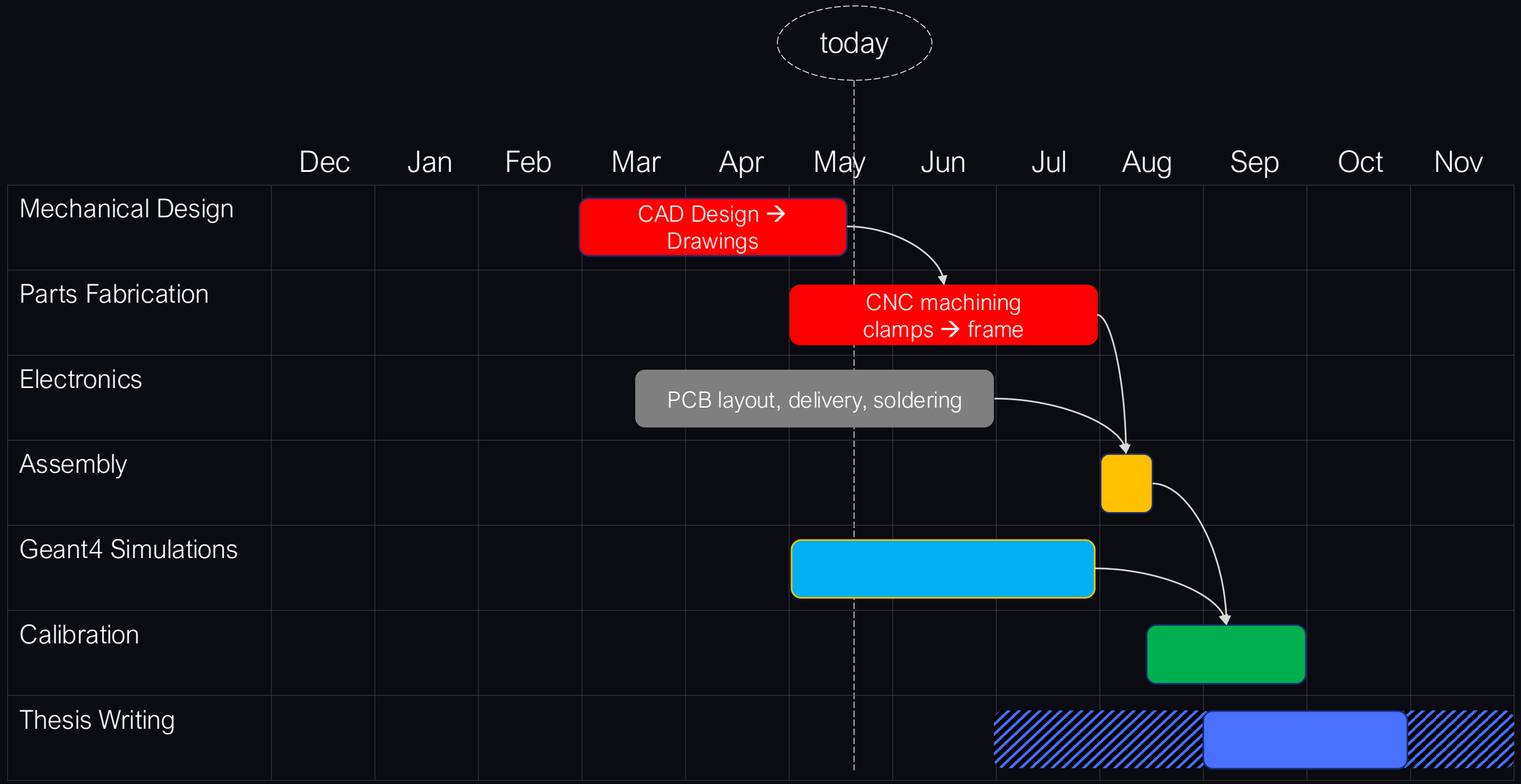
Geometry And Tracking

- Developed at CERN
- Toolkit to simulate particles passing through matter
- Commonly used for
  - Particle Accelerators
  - Nuclear / medical /astrophysics
  - Space applications

Who builds HANS and GRETEL



When is GRETEL made



Detector Math

Electronics

Mechanics

???

$$C(\vec{x}, t_0) = \frac{1}{T} \int_{t_0}^{t_0+T} \mathrm{d}t \int_S \mathrm{d}\vec{\sigma} \cdot \vec{r} \int_\Omega \mathrm{d}\omega \int_0^\infty \mathrm{d}E \sum_\alpha \epsilon_\alpha(E, \vec{\sigma}, \omega, t) J_\alpha(E, \omega, \vec{x}, t)$$

Counts at point $\vec{x}$ at time t_0

Time interval

Area of detector

FOV

Energy interval

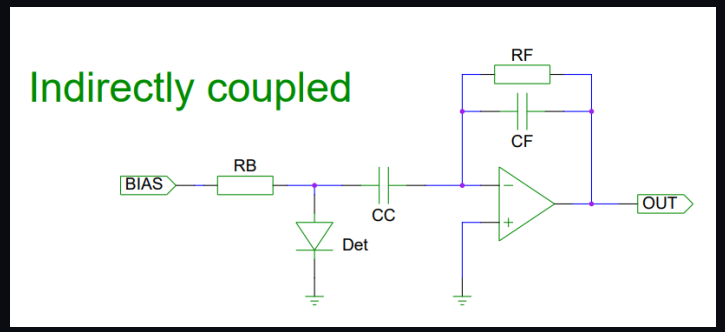
Species

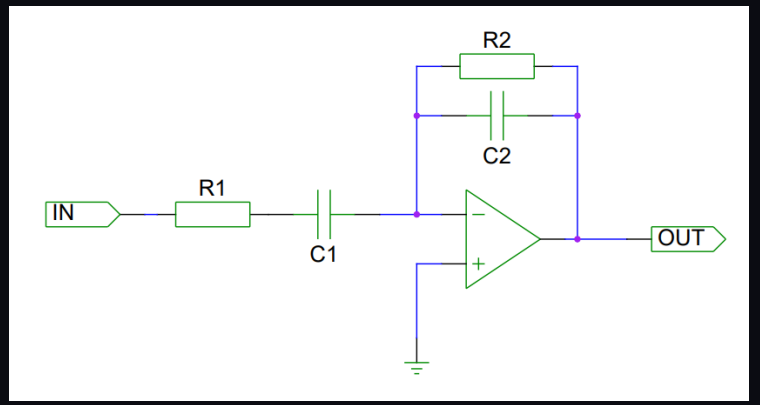
Detector efficiency

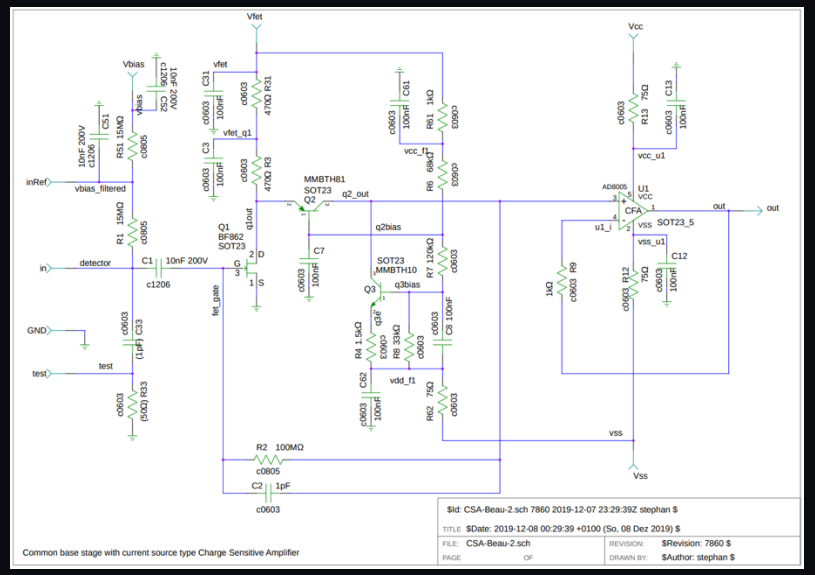
Spectral intensity

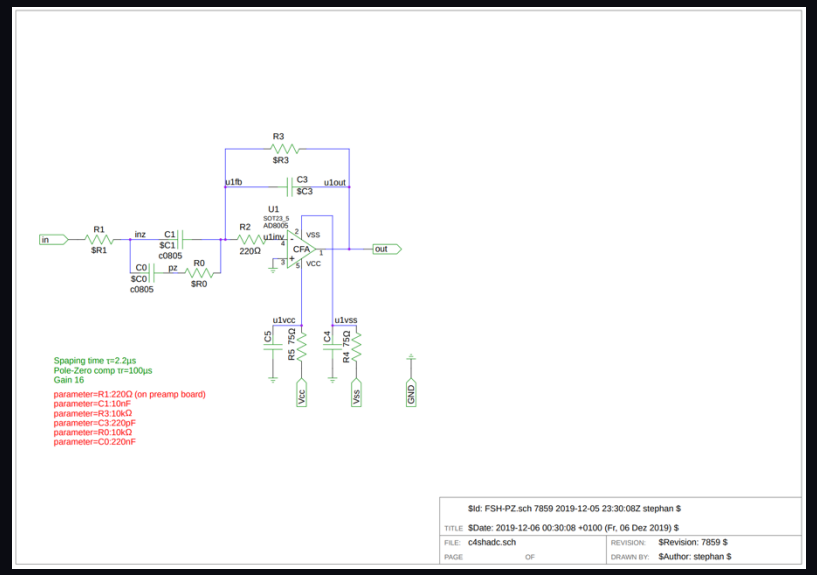
Sullivan 1971

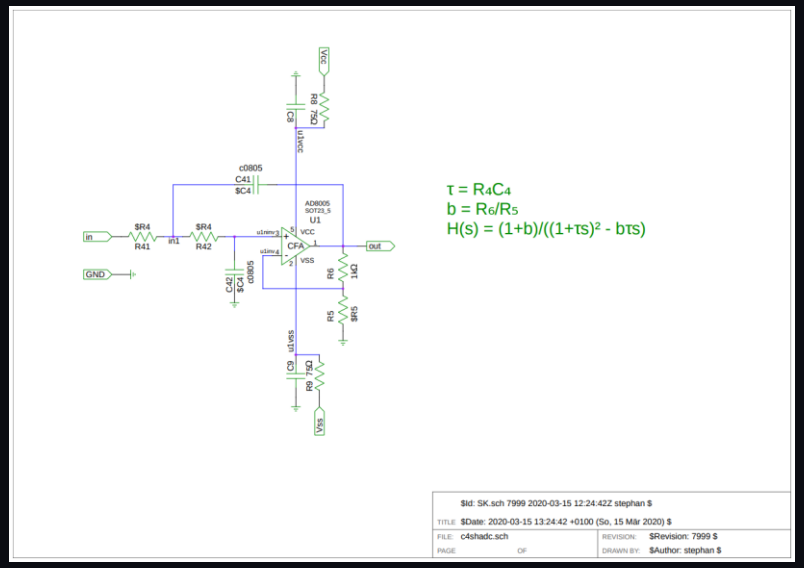
Some more electronics…











First Electronics Tests: Oscilloscope Mode

