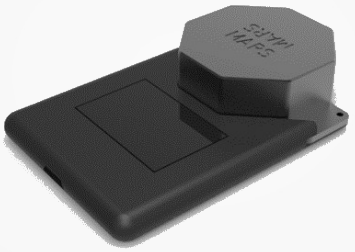
21st iWoRiD 2019

Miniature Neutron Spectrometer for Space



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Greek Atomic Energy Commission (GAEC)

Outline

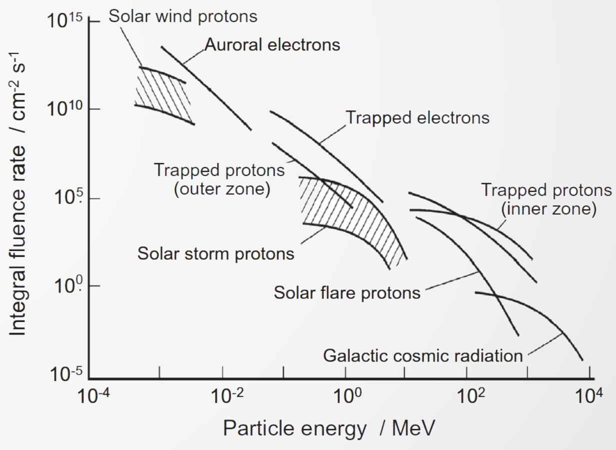
- General description
- Requirements
- Simulation results
- Neutron sub-system
  - Readout
  - Scintillator
  - SiPMT
  - Calibration with gamma sources
- Next steps

General description

MIDAS (formerly known as *MARS*-*M*iniaturized *A*sic for dosimet*R*y in *S*pace) is an active personal dometric device for alarming or real-time environmental monitoring of radiation in space.

There are mainly three radiation sources in space

- Galactic Cosmic Rays (GCR)
  highly energetic nuclei of atoms from hydrogen to uranium
- Solar Particle Events (SPE)
  consists of large pulses of primarily protons ranging from tens of MeV to a few GeV
- Celestial bodies with a magnetic moment (Earth) surrounded by toroidal belts
  trapped particles consist of lower-energy electrons and protons



ICRP 2013 Publication 123 “Assessment of Radiation Exposure of Astronauts in Space”

Additional secondary radiation (e.g. gamma radiation, muons, neutrons, and pions) is produced by interactions in the materials of a spacecraft, its equipment, and the astronauts.

MIDAS requirements

MIDAS aims at

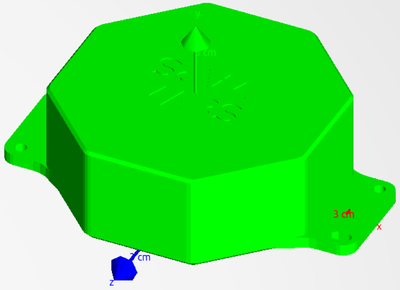
- Determining the direction of impinging particles
- Determining the energy spectrum of neutrons
- Identifying particles
- Operate in a 4 order of energy scale (0.1MeV-1GeV)
- Be a personal dosimeter, i.e. weight less than 50gr

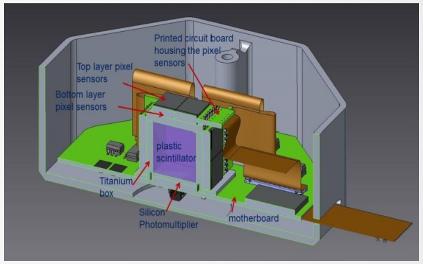
If the above requirements are met, then the absorbed dose and absorbed dose rate from charged particles in the detector's material at the dosimeter's location can be determined.

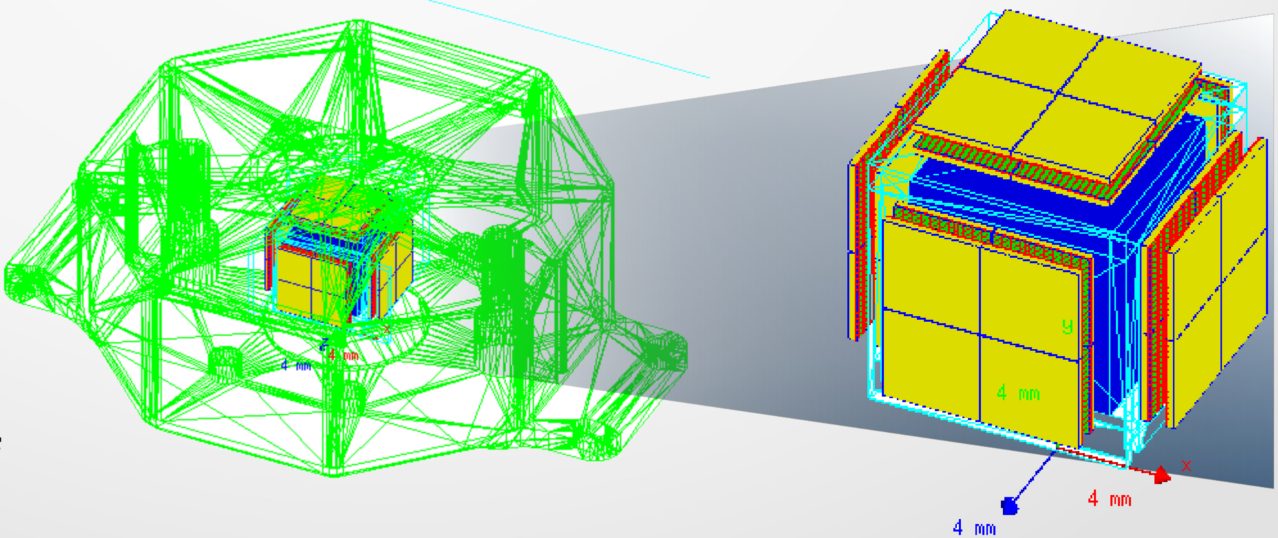
Basic structure of MIDAS

The active dosimeter is composed of

- an aluminum enclosure
- a polyimide layer 350 μm thick placed between two layers of silicon detectors
- 32x32 silicon pixels with dimensions 105 μm x 105 μm x 50 μm per ASIC, flipped over the polyimide layer
- a titanium cover box with 1 mm thickness enclosing the five out of six facets of the scintillator
    - A SiPMT is attached to the sixth facet
- a plastic scintillator (7 mm x 7 mm x 7 mm)



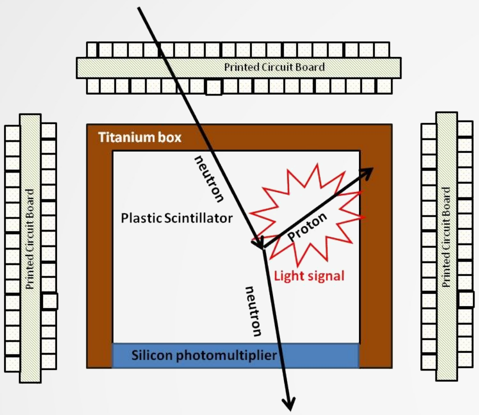




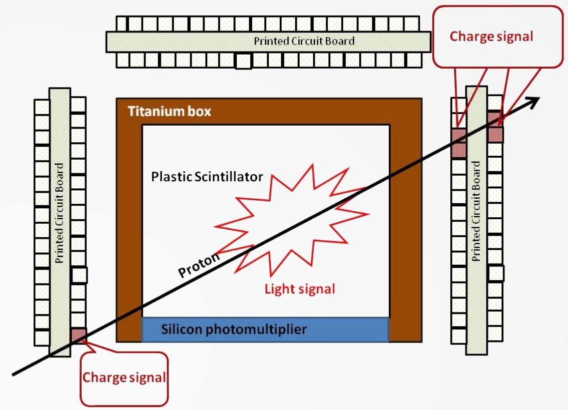
Images shown are from GEANT4 simulation of the dosimeter and are an exact replica (shape, dimensions) of the mechanical structure

Basic principle

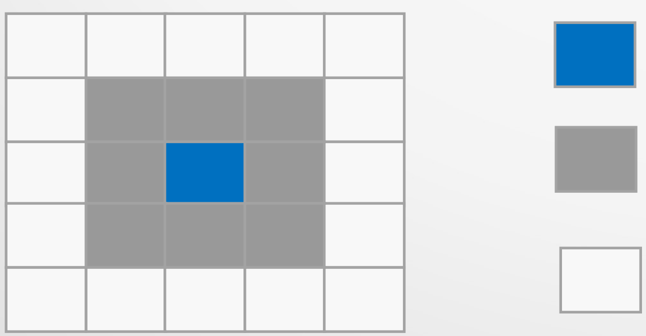
Example: impinging neutron



Example: impinging charged particle



Pixels are grouped (entrance, cluster-1, cluster-2)
ASICs are grouped to layers (4 ASICs, one layer)



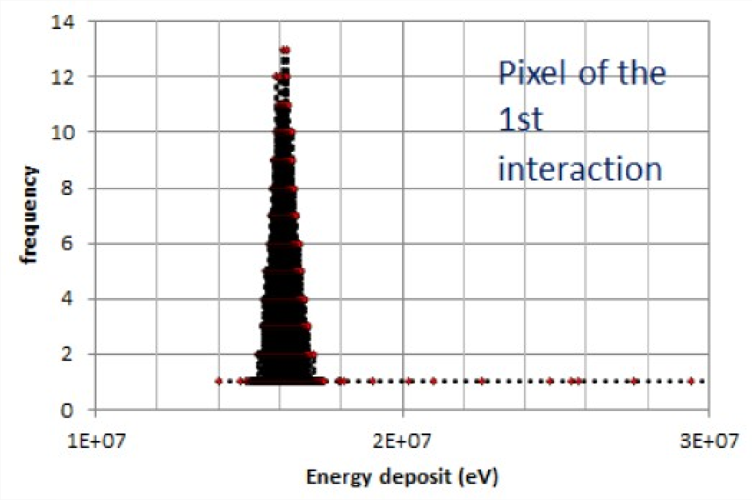
Entrance pixel

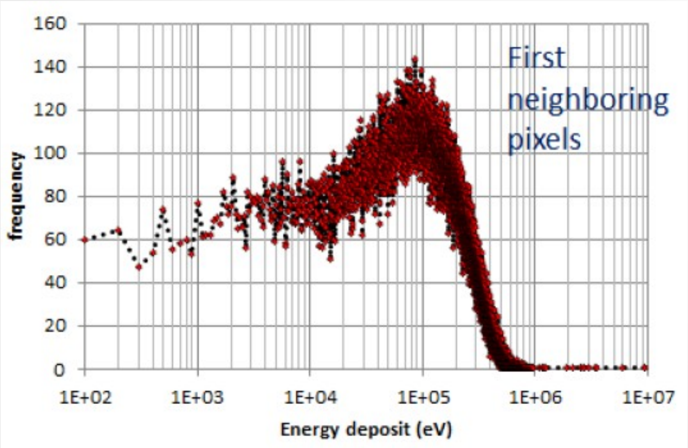
First neighbouring pixels (8, cluster-1)

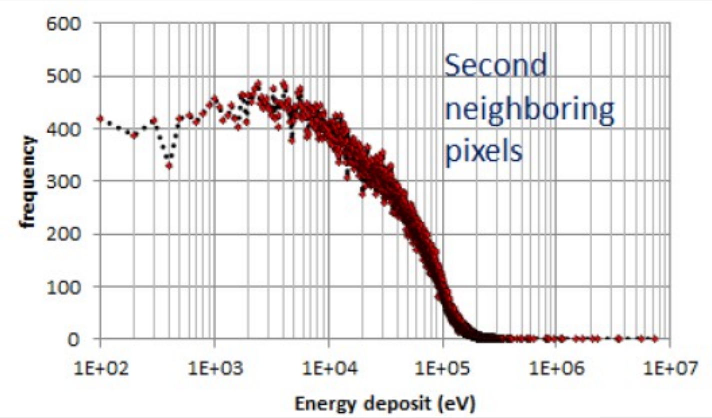
Second neighbouring pixels (16, cluster-2)

Simulation results

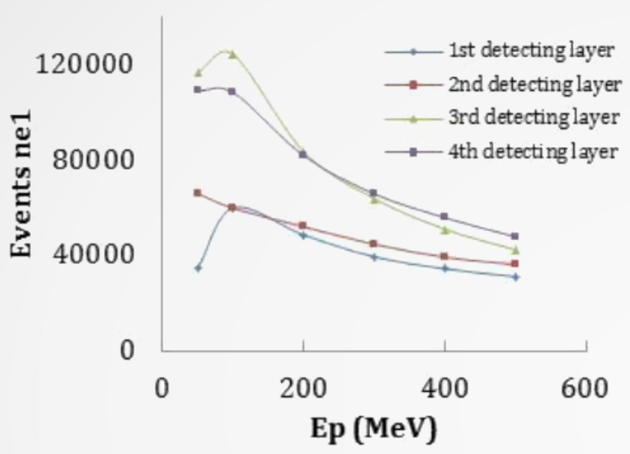
Energy deposition of a heavy ion (5.6Gev ^{56}Fe) impinging vertically into the detector material

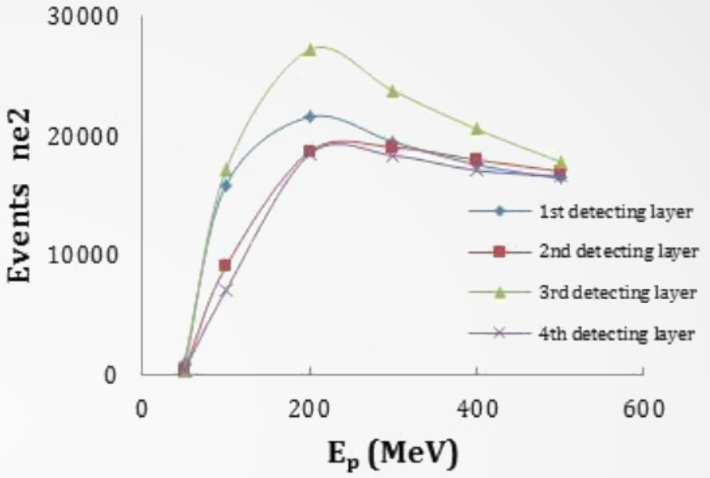


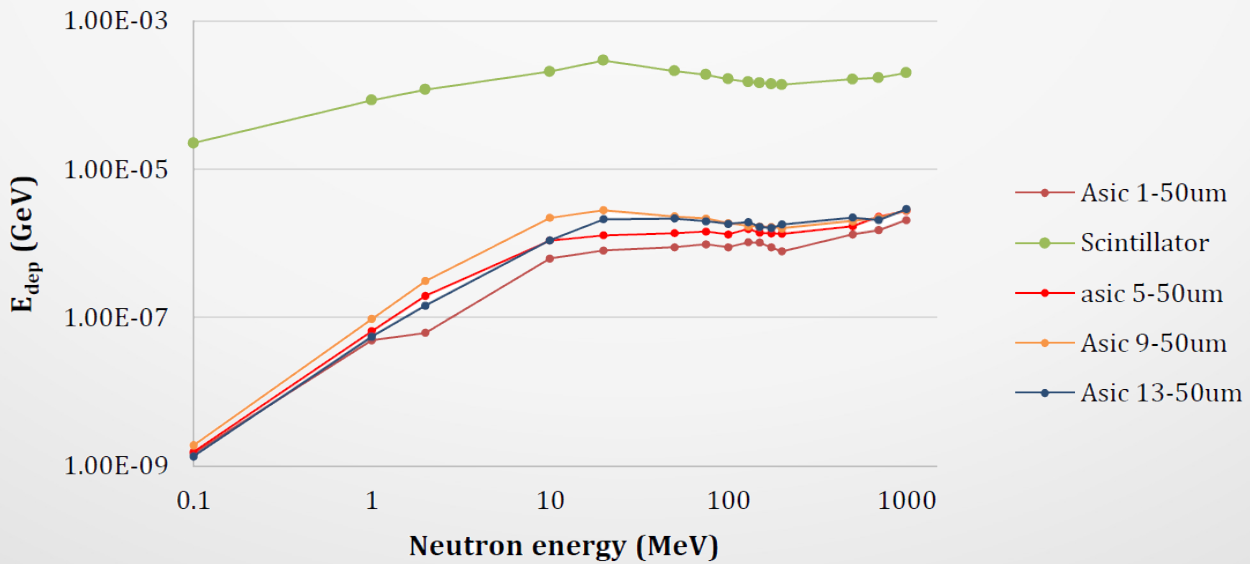




Simulation results (cnt'd)



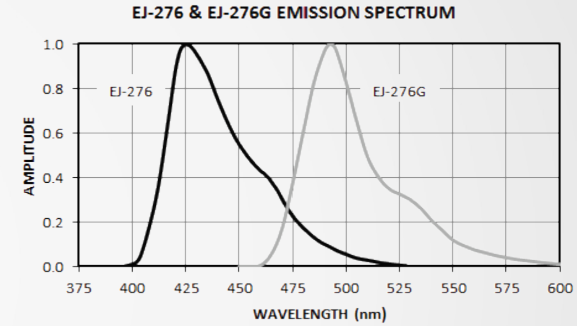




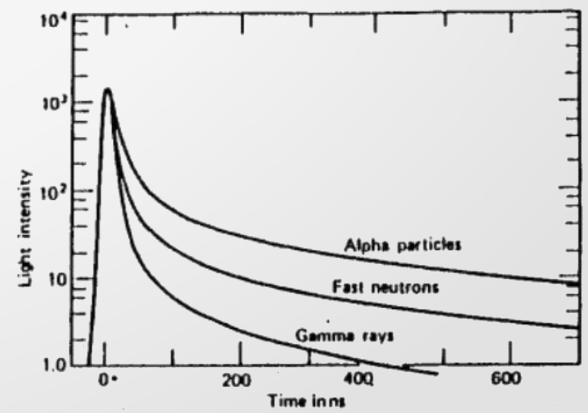
Neutron sub-system (Scintillator)

MIDAS uses the plastic scintillator from Eljen Technology: ***EJ276*** (0.7×0.7×0.7 cm^3)

PROPERTIES		EJ-276
Light Output (% Anthracene)		56
Scintillation Efficiency (photons/1 MeV e^-)		8,600
Wavelength of Maximum Emission (nm)		425
No. of H Atoms per cm^3 ($x10^{22}$)		4.546
No. of C Atoms per cm^3 ($x10^{22}$)		4.906
No. of Electrons per cm^3 ($x10^{23}$)		3.533
Density (g/cm^3)		1.096
Approx. Mean Decay Times of First 3 Components (ns)	Gamma Excitation	13, 35, 270
	Neutron Excitation	13, 59, 460

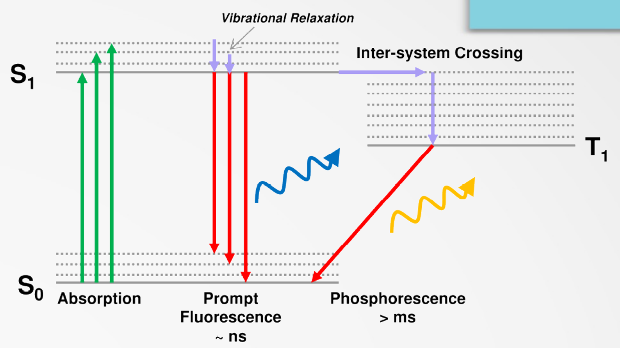


Heavier particles have longer decay times

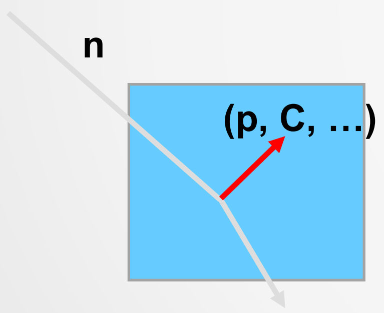


Scintillator (cnt'd)

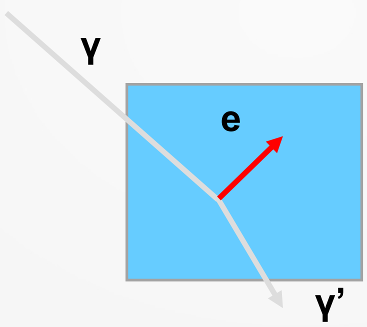
A scintillator is a material that produces prompt fluorescence when excited by ionising radiation.



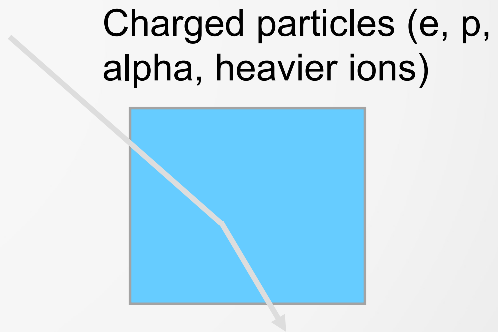
There are mainly 3 physical processes



i. Neutron-nucleus elastic scattering



ii. Compton scattering



iii. Energy loss by Coulomb interactions with atomic electrons

Light output:

- Linear for electrons (8600 photons for 1 MeVee)
- Non linear for heavier charged particles

Non-linear light output for charged particles

Quenching mechanism (molecules excited or ionized by the particle) increases the amount of energy lost due to the passage of a charged particle through the scintillator material.

For protons, a correction to the Birk's law is made with a 2^{nd} order polynomial that fits well the light output with the particle energy, for energies up to 20MeV.

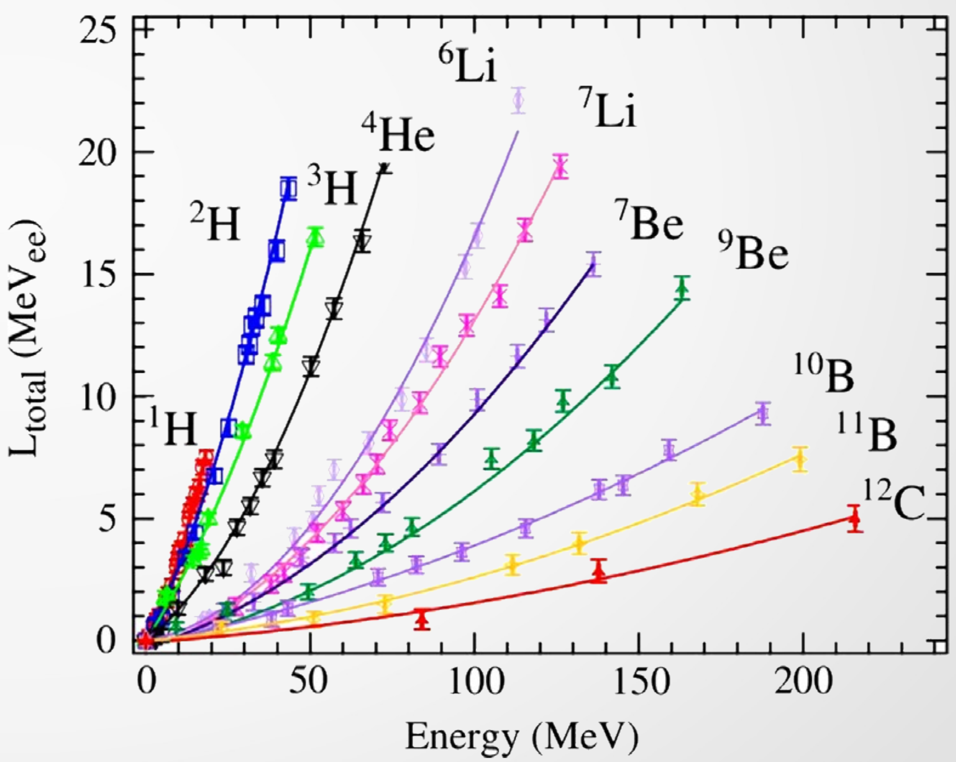
$$L=c_0+c_1E+c_2E^2$$

where

$c_0=-0.15$

$c_1=0.25$

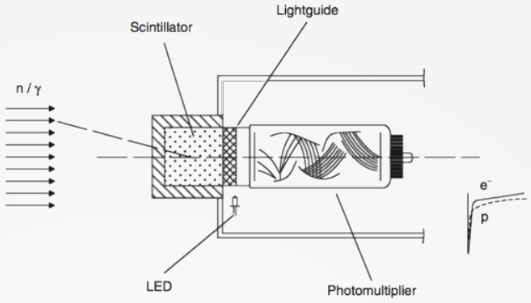
$c_2=0.0096$

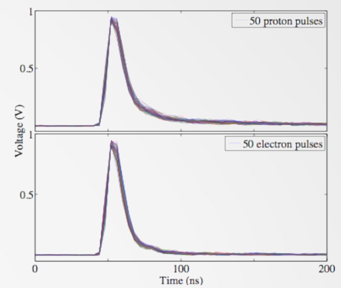


S. Nyibule, et al, "Radioluminescent characteristics of the EJ299-33 plastic scintillator", Nuclear Instruments and Methods in Phys. Res. A 728, pp.36-39 (2013).

SiPMT

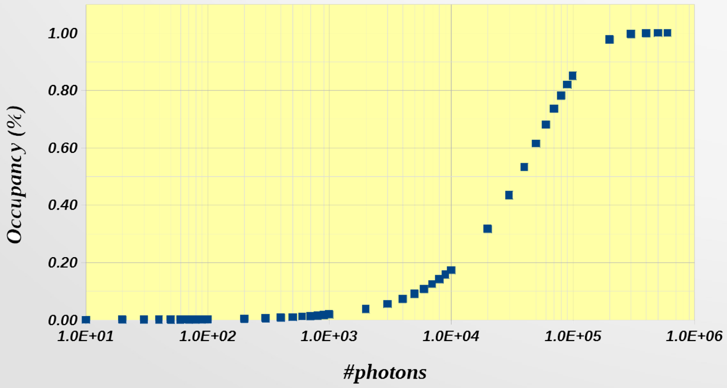
In general, scintillation light is collected by a photomultiplier tube and converted to an electrical pulse





- MIDAS uses MicroFC-60035 SiPMT from SensL
- Suffers from pixel saturation

$$N_{fired} = N_{total} \cdot \left(1 - \exp\left(\frac{-PDE \cdot N_{photons}}{N_{total}}\right)\right)$$



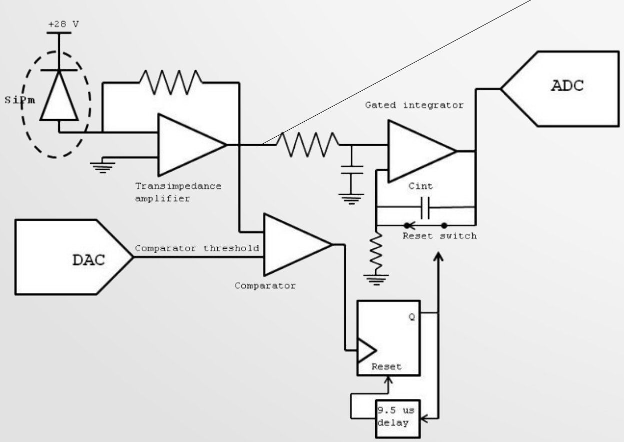
Package dimension	7 mm x 7 mm
Active area	6 mm x 6 mm
Number of pixels	18980
Pixel pitch	35 um
Pixel fill factor	64 %
Photon Detection Efficiency (PDE)	>40% @ 420 nm
Breakdown Voltage Vbr	24.2 V – 24.7 V
Temperature dependence of Vbr	21.5 mV/°C
Recommended overvoltage	1 V – 5 V
Gain	3×10^6
Temperature dependence of Gain	−0.8 %/°C
Dark current	618 nA – 1750 nA measured at 2.5 V overvoltage and 21°C

Readout electronics

Define 2 sampling times for each readout cycle (start of cycle: T_0)

- 0.5μs after T_0 (T_1)
- 6μs after T_0 (T_2)

T_1 T_2

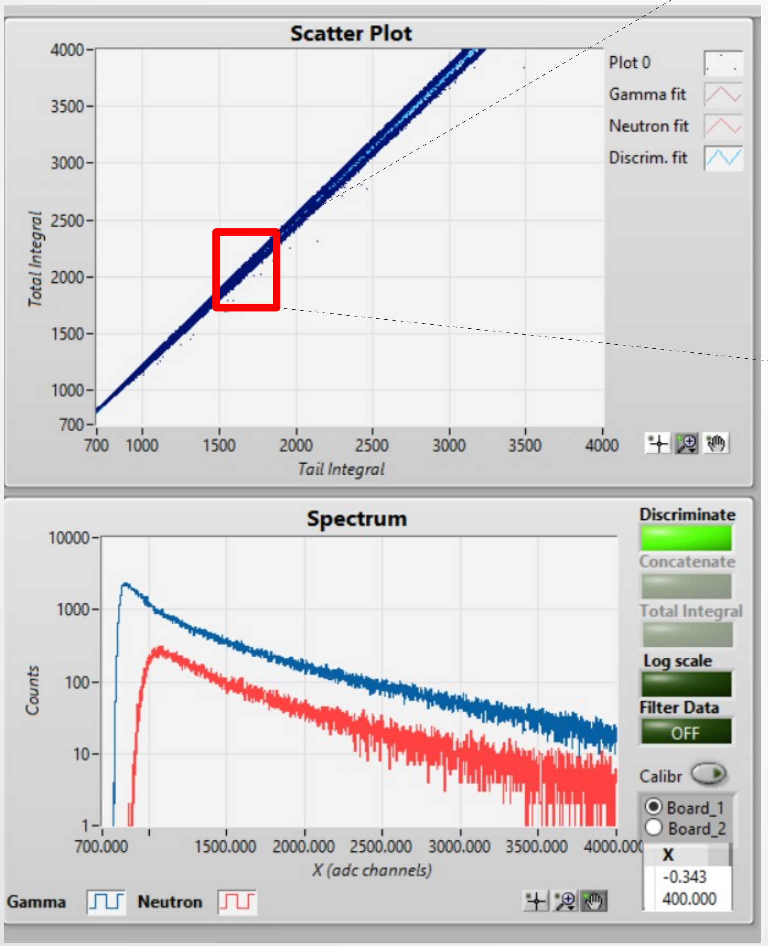


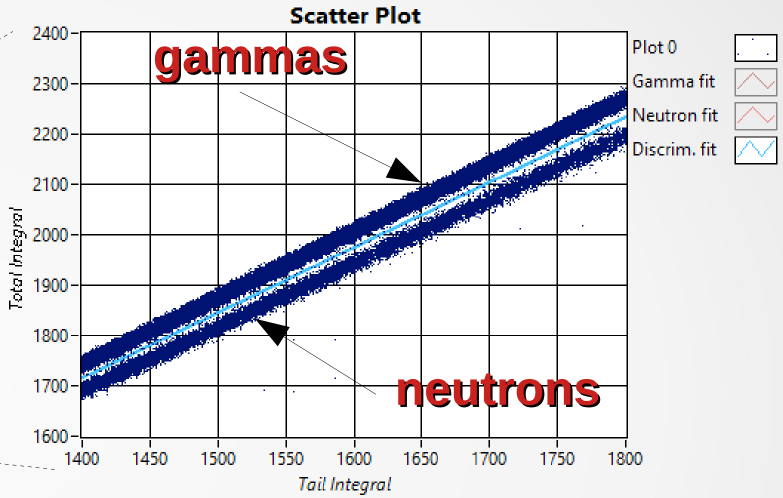
$$Q_{total} = \int_{T_0}^{T_2} V(pulse)$$

$$Q_{tail} = Q_{total} - \int_{T_0}^{T_1} V(pulse)$$

Discriminate neutrons from gammas

- Use of a ^{252}Cf source
- Scatter plot Q_{tail} vs Q_{total}

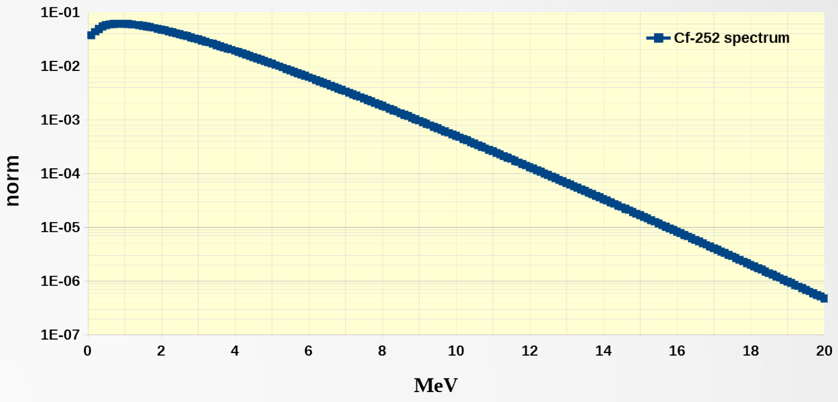




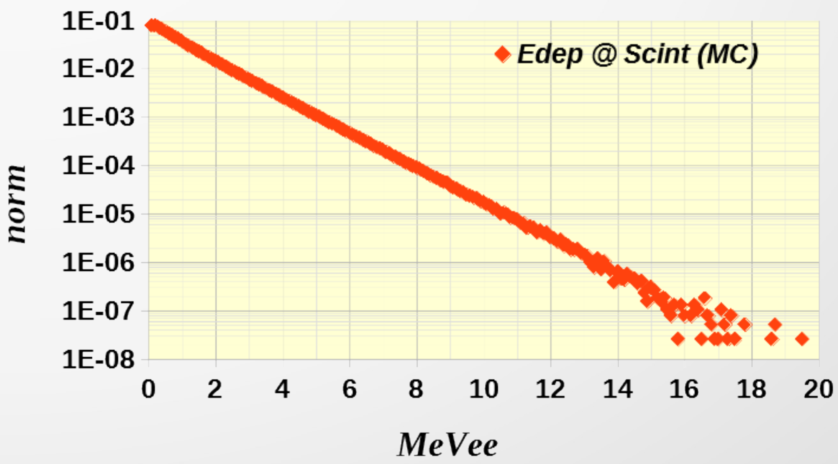
Reconstruct of ^{252}Cf spectrum (simulation)

Use of a ^{252}Cf source (NIST)

- Energy range: 0.1-20MeV
- For each energy channel, protons (neutrons) interact with the scintillator material depositing energy based on their interaction.

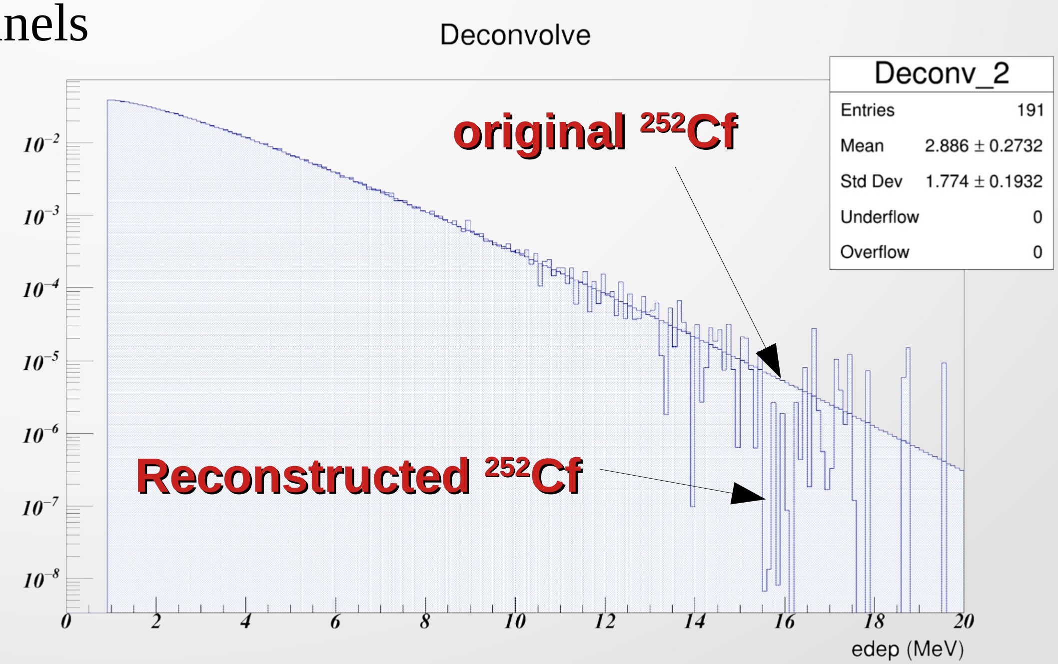


With Monte Carlo (GEANT4) we calculate the energy deposition (E_{dep}) at the scintillator for the ^{252}Cf energy spectrum.



Deconvolution method

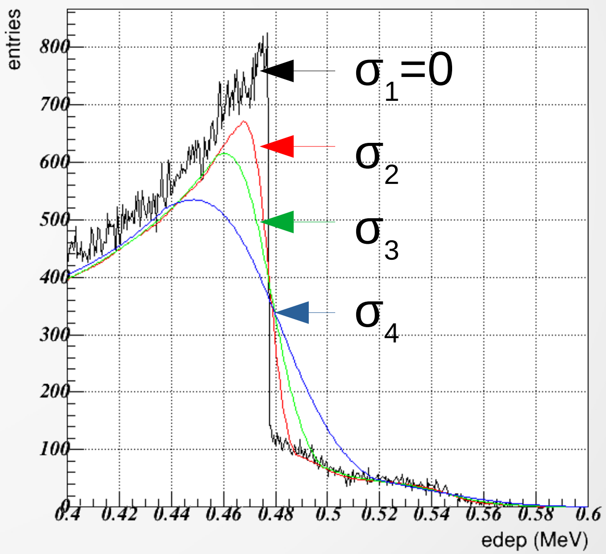
- Use a mono-energetic neutron beam in the range of 0.1-20MeV (0.1MeV energy bin channel)
- Calculate E_{dep} for each channel, e.g. 0.1, 0.2, 0.3 ...20MeV (~200 files)
- Starting from the highest channel, calculate the difference between the original spectrum of ^{252}Cf at E_j with the E_{dep} at scintillator for the j-st energy channel
- Repeat the above steps for all channels



Calibration with gamma sources

- Use gamma sources to calibrate the device (absence of Birk's correction factor)
- Seek for the Compton Edge (CE) of the gamma source
  - It is where the maximum energy transfer to the recoil electron occurs

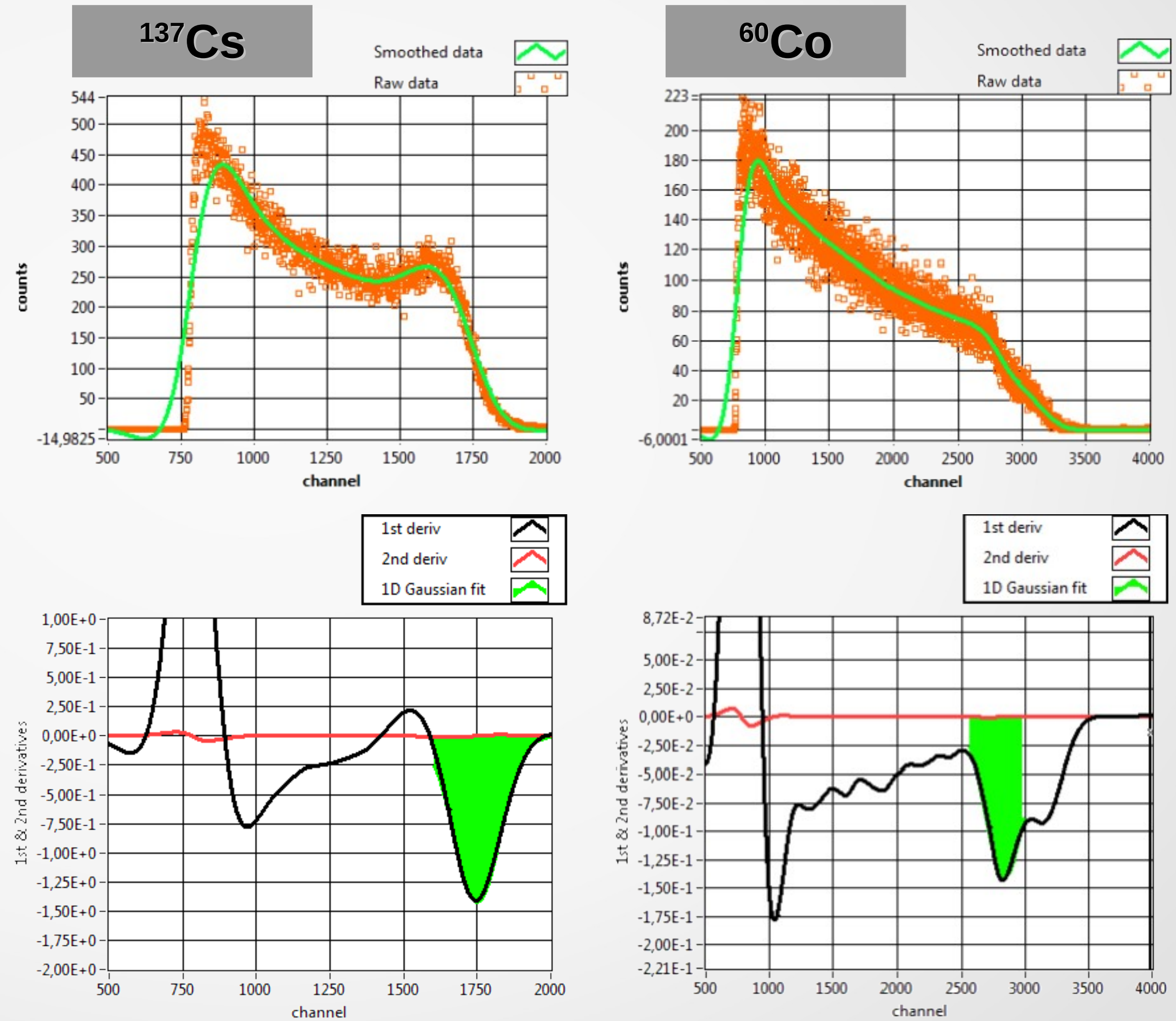
E_{dep} of ^{137}Cs @ scint



E_{dep} is convoluted with a Gaussian function (smeared) for several σ where $\sigma_1<\sigma_2<\sigma_3<\sigma_4$ ($\sigma_1=0$)

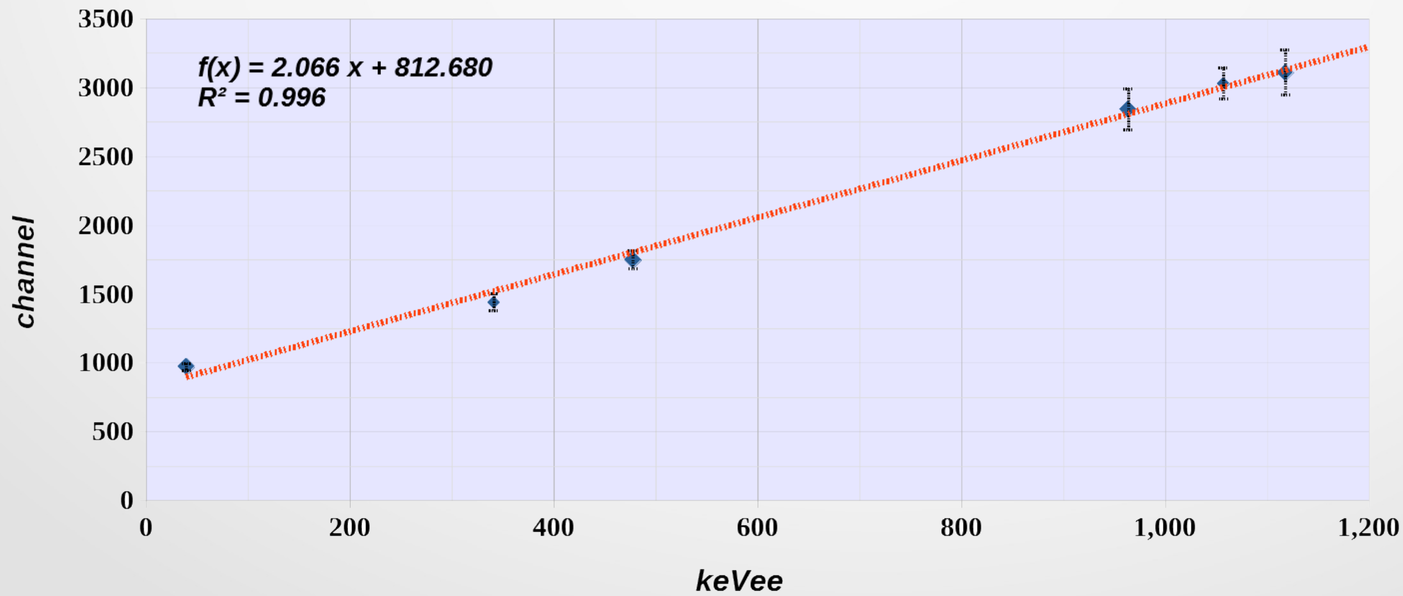
Calibration with gamma sources (cnt'd)

- Raw data are smoothed (Butterworth 2nd order LPF)
- 1st derivative is calculated
- 1-D Gaussian fit on the minimum



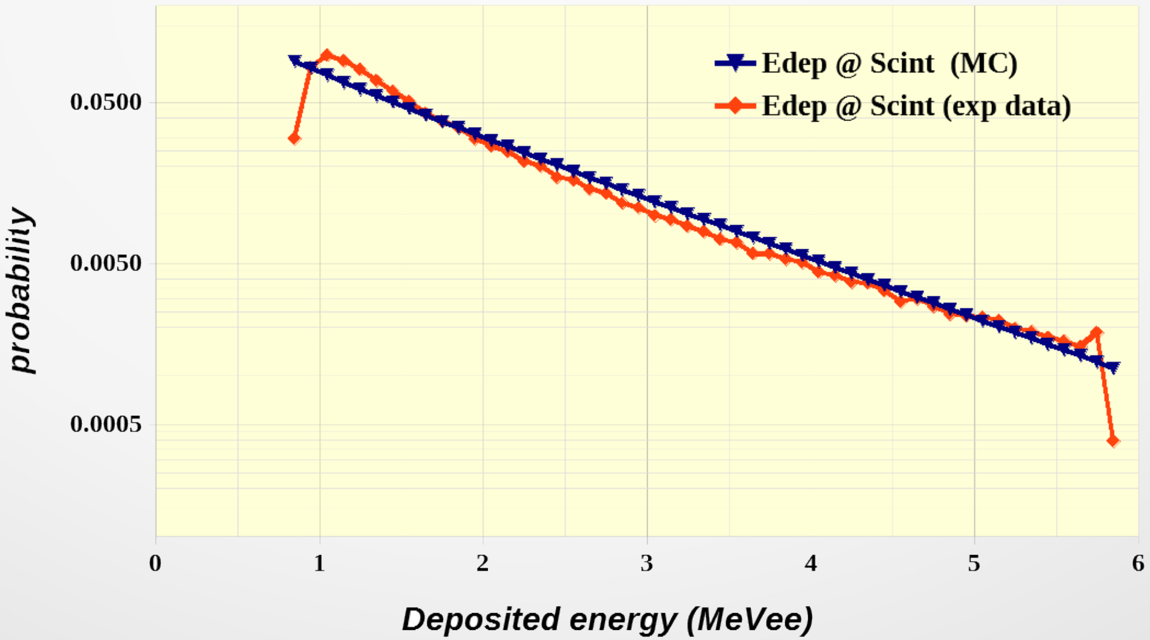
Calibration with gamma sources (cnt'd)

Source	Photo peak (keV)	Compton edge (keV)	channel
^{57}Co	122	39,4278	973,131
^{22}Na	511	340,6667	1447,92
	1270	1057,2927	3027,33
^{137}Cs	662	477,6501	1750,49
^{60}Co	1173,4	963,5857	2839,91
	1332,5	1118,1085	3106,88



Compare measured ^{252}Cf with simulated E_{dep} @ scint

- Convert adc channels to N_{fired} pixels using (reversed) previous fitting curve
- Calculate the number of photons entering the SiPMT based on pixel saturation (reversed)
- Apply Birk's law correction factor (reversed)



Next steps

- Change adc channels to comply with the full energy range of specs (use a logarithmic energy scale)
- Calculate the response matrix for the dosimeter (species, energy)
- Perform series of experiments to verify performance for higher energies
- Develop algorithms to automatically convert measured quantities (species, energy, direction) to absorbed dose and absorbed dose rates

Miniature Neutron Spectrometer for Space

MIDAS is a collaboration of

- an Industrial firm

ADVEOS

- a series of Universities/Institutes

GAEC

University of Cyprus

- This talk is presented on behalf of

Dr. Potiriadis Konstantinos (GAEC)
Kazas Ioannis, MSc. (NCSR Demokritos)
Prof. Lambropoulos Charalambos (UoA)

Miniature Neutron Spectrometer for Space

Thank you

Questions/Comments?