Functional test studies for the Engineering Qualification Model of RADEM

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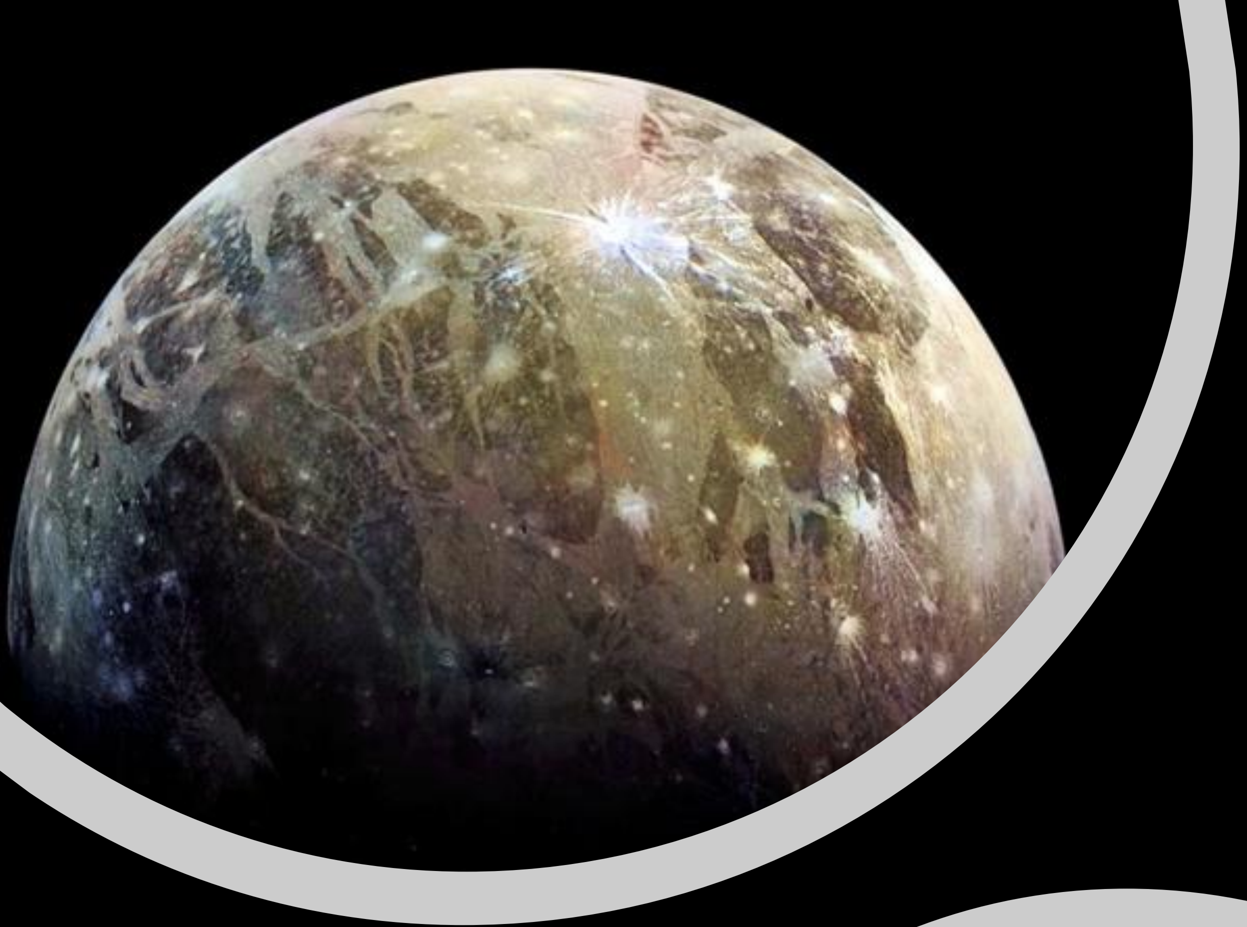
10/09/2020



ESA JUICE Mission

***Ju**piter **Ic**y Moons **E**xplorer*

Mission to the Jovian System

Exploring the emergence of habitable worlds around gas giants:

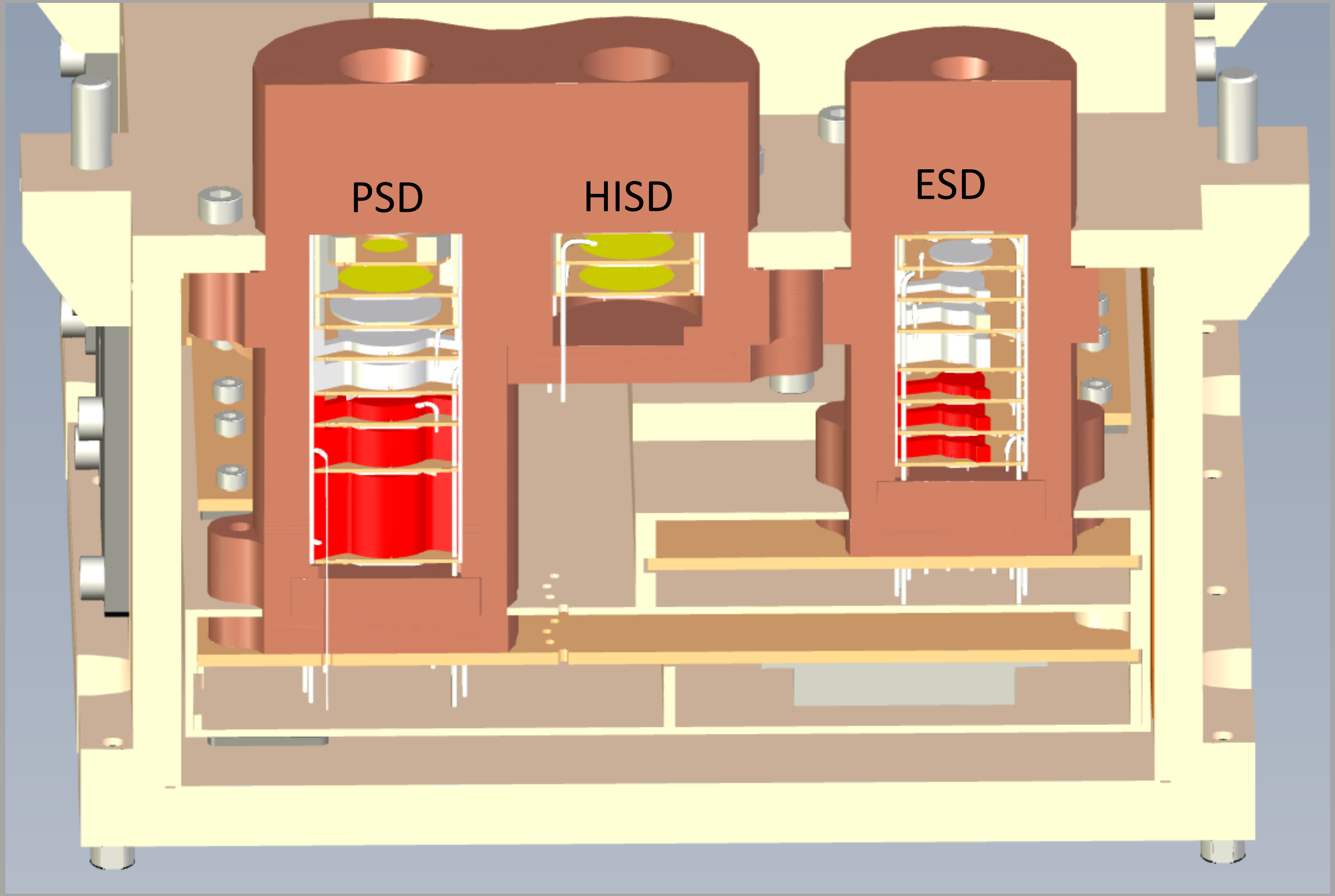
- Special emphasis on the ocean bearing moons, specifically Ganymede due to it’s unique magnetic and plasma interactions with the surrounding Jovian system.

juice

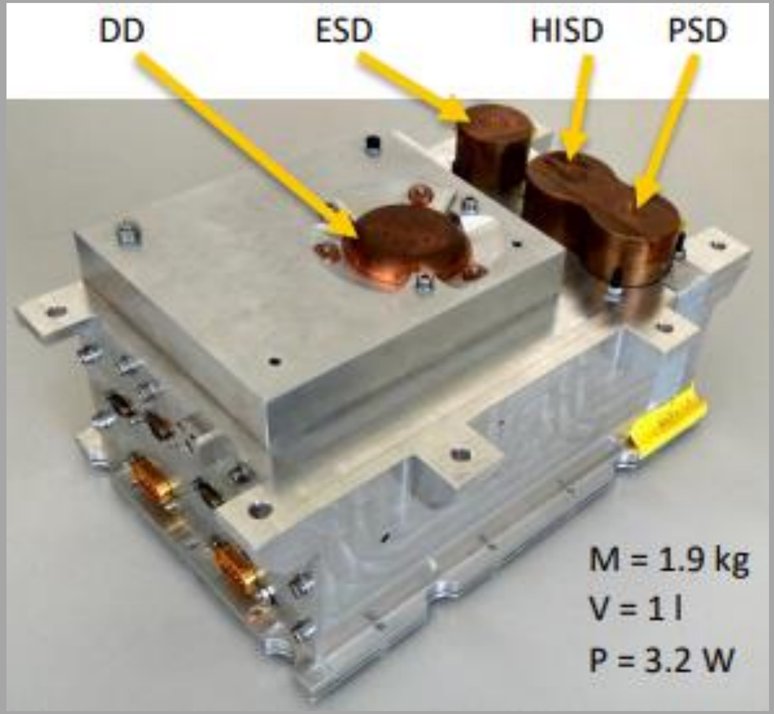
RADEM

Radiation-hard Electron Monitor

Detection and characterisation of highly energetic particles;
Capable of discriminating between types of particles and energy levels;



Cross-sectional view of the Detector Stacks

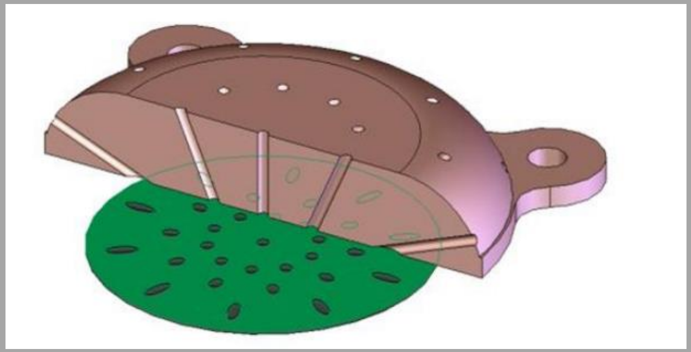


RADEM Engineering Model

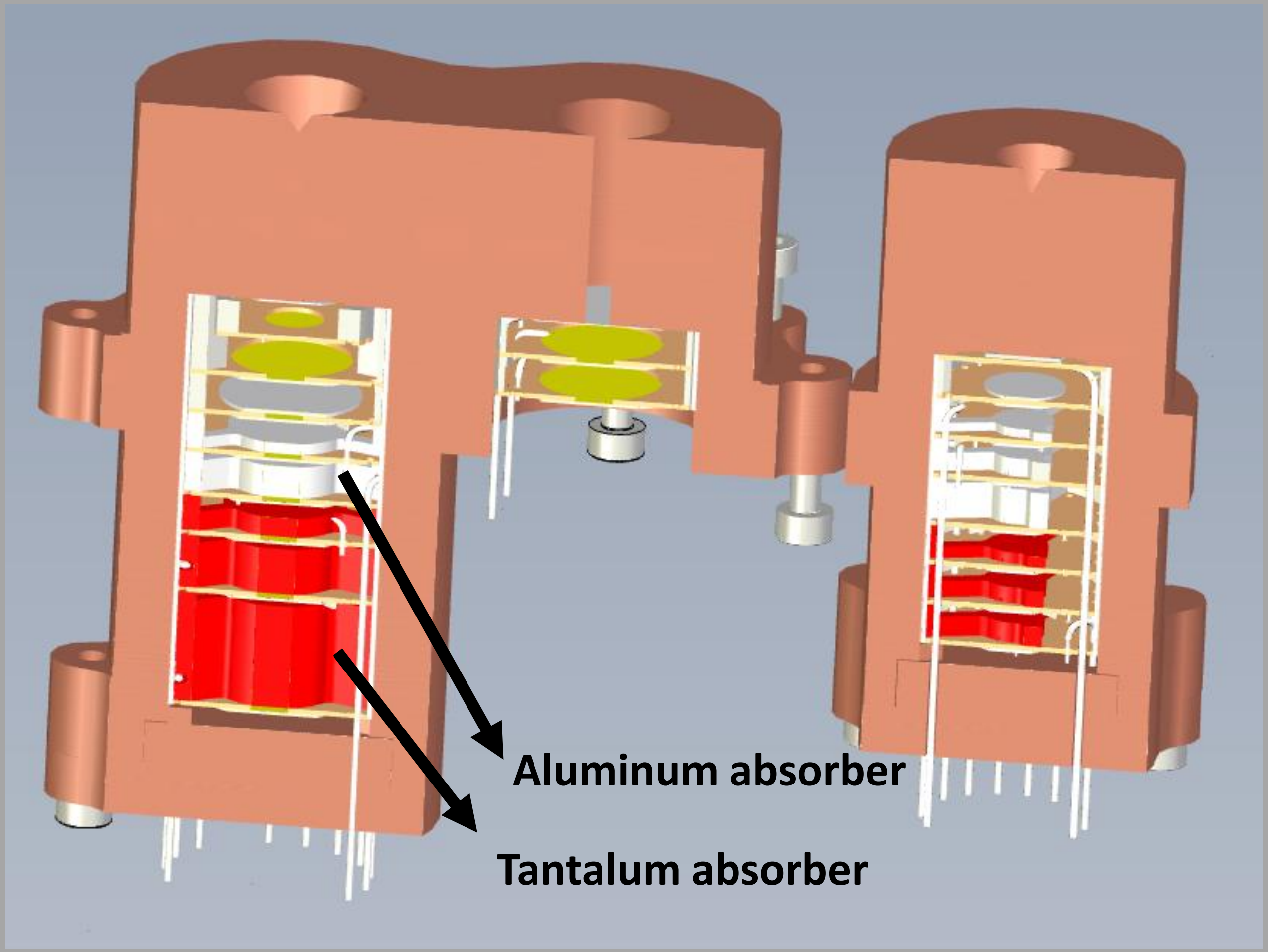
- **DD**- Directionality Detector;
- **ESD**- Electron Stack Detector;
- **HISD**- Heavy Ion Stack Detector;
- **PSD**- Proton Stack Detector.

RADEM Composition

- Copper colimators;
- 0.3 mm thick Silicon diodes arranged in stacks;
- Aluminum and Tantalum absorbers between detectors;



Directionality Detector- Designed to analyse the angular distribution of electrons



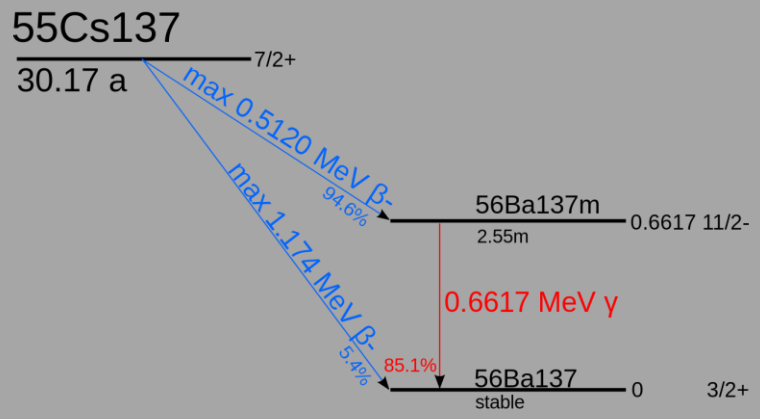
Motivation

- Detector testing perfomed between qualification tests:
    - Faster testing;
    - Simpler to implement;
- After each **environmental test** it is necessary to make sure the instrument is still working properly.
    - Temperature;
    - Vibration;
- Not always practical (or possible) to use a particle beam for testing;
- Ideal to use a cheap and readily available testing method.

Setup

- Common source for radiation-detection equipment calibration;

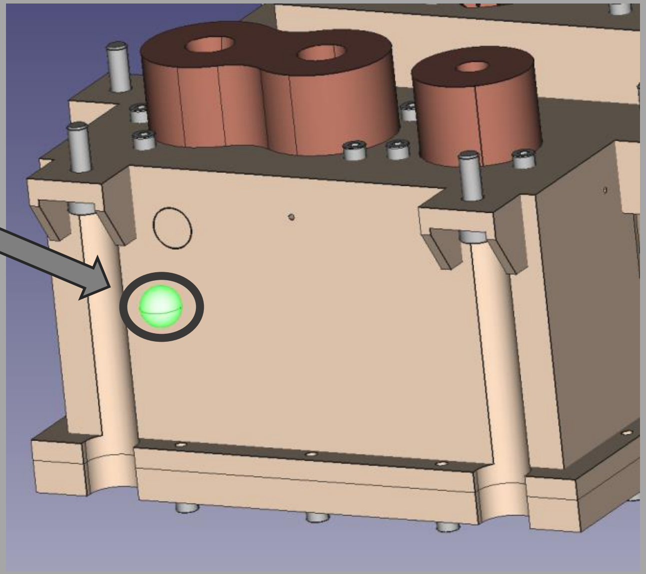
$$^{137}_{55}Cs$$

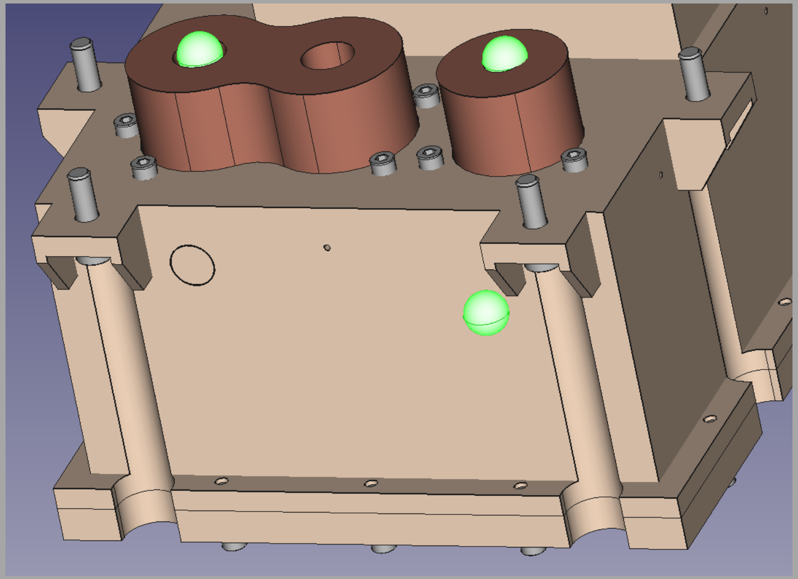


- Most significant decays:
  - $\beta^{-}\ (max\ 0.512\ MeV)$;
  - $\gamma\ (0.662\ MeV)$;

- **But where do we place the source?**

$^{137}_{55}Cs$ *Source*





Experimental setup examples (green spheres represent source positions)

Project Workflow

Obtaining the Data

$$\frac{Hits}{N.\,Particles\ Simulated}$$

$$Hits_{detector} = Activity \times time_{detector} \times \sum_{simulations} weight_i \times Detection\ Efficiency_{detector}$$

time spent at specific position

Solving for time and expliciting for all detectors

Geant4 Simulations

Output: Detection Efficiency

Get Matrix

Output: Coefficient Matrix

Detection Efficiency for each simulation and for each detector

Optimize

Combination of ideal weights

$$\sum_{detectors} \frac{Hits_{detector}}{Activity \times \sum_{simulations} weight_i \times Detection\ Efficiency_{detector}} = \sum_{detectors} time_{detector}$$

Geant4 Simulation Data aquisition

- Simulation Toolkit using Monte Carlo analysis;
- Simulation of Cs137 nuclei decay and its interaction with RADEM;
- Complete modelling of geometry and materials that make up the RADEM.

Simulation n.	Position Relative to Detector Stacks
1	Top of PSD
2	Top of HISD
3	Top of ESD
4	Bottom of PSD
5	Bottom of HISD
6	Bottom of ESD
7	Middle of PSD
8	Middle of ESD
9	Middle of PSD (+13mm up)

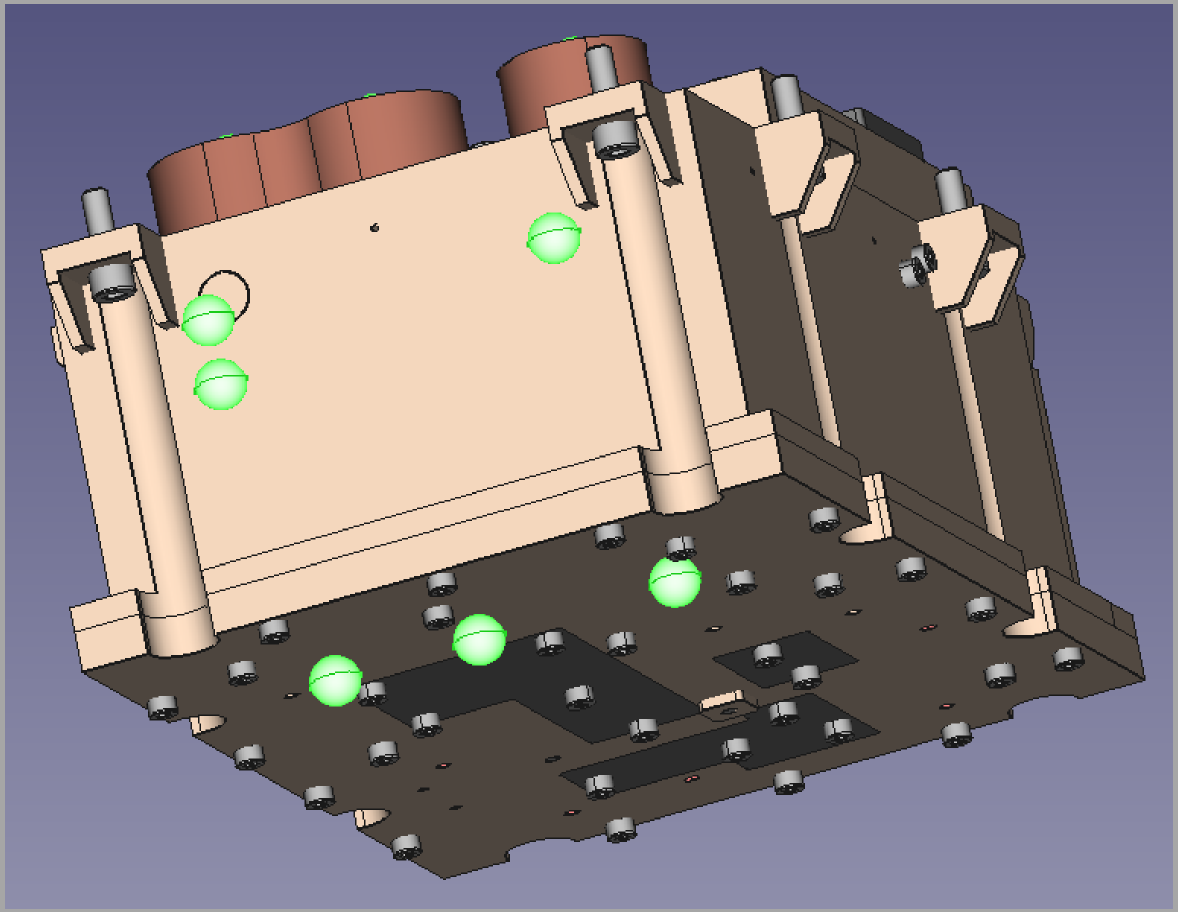
N. of Simulated Particles
10 000 000

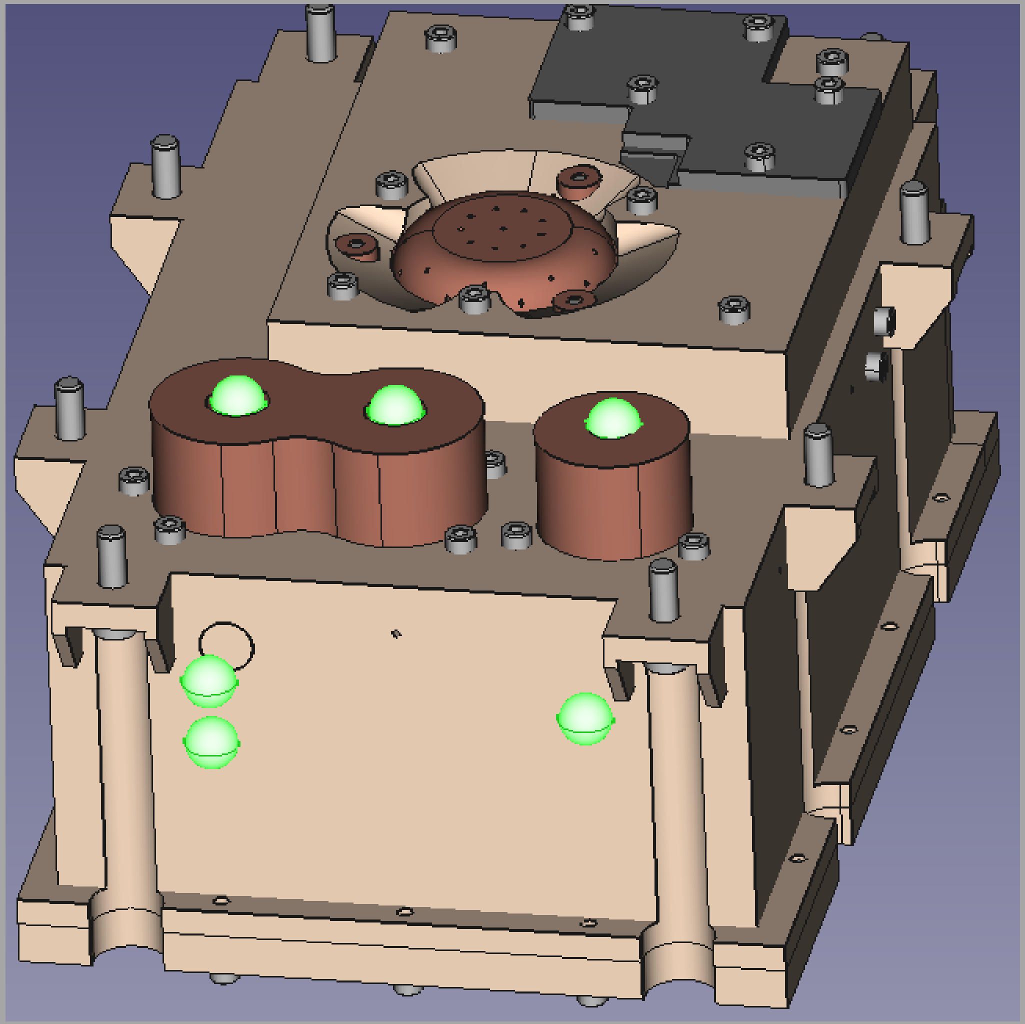
Used to simulate the interaction of each decay with the RADEM detectors:

- Each simulation produces a .root file containing all the necessary data.

Geant4 Simulation

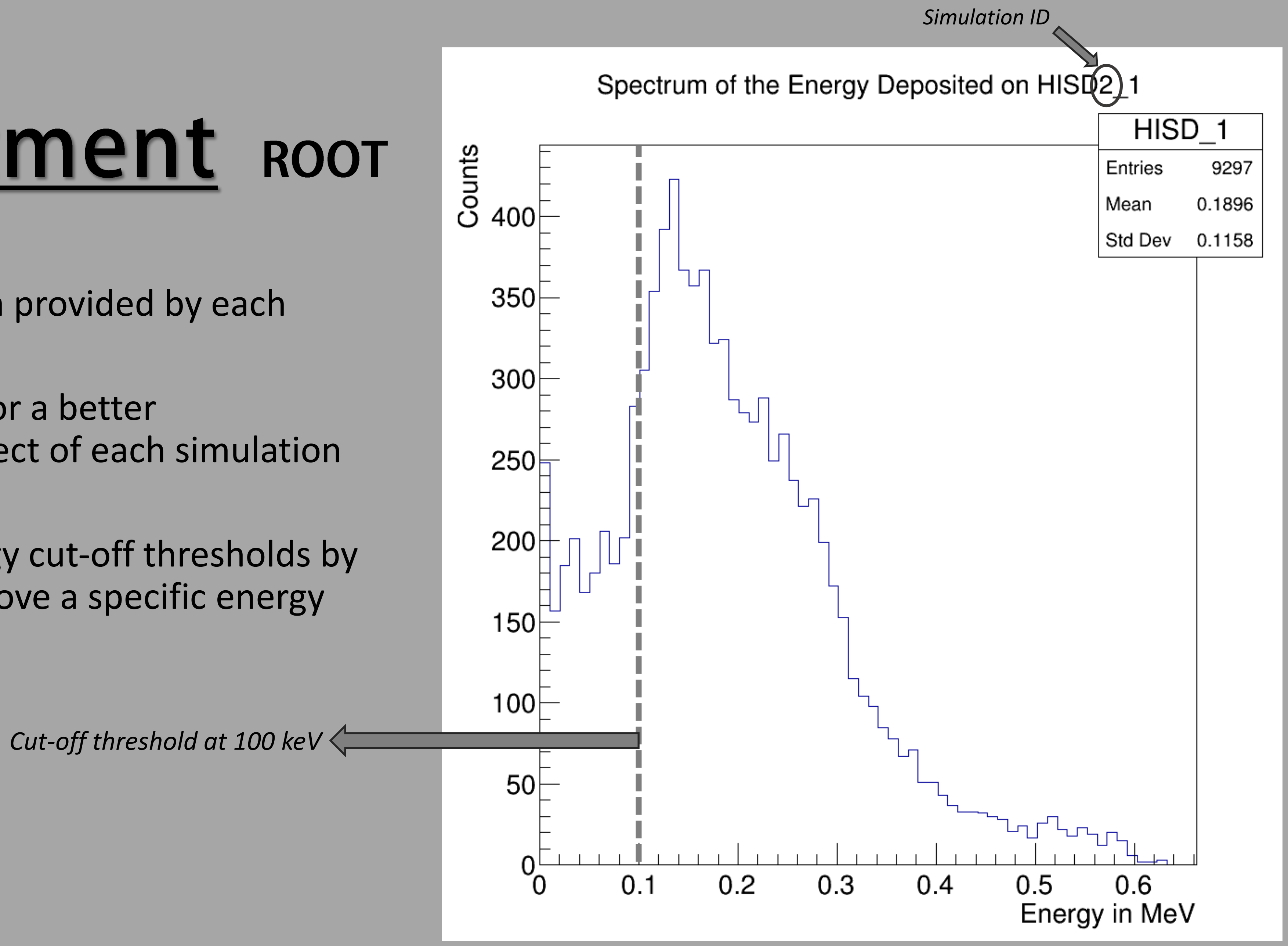
Data aquisition





Data Treatment ROOT

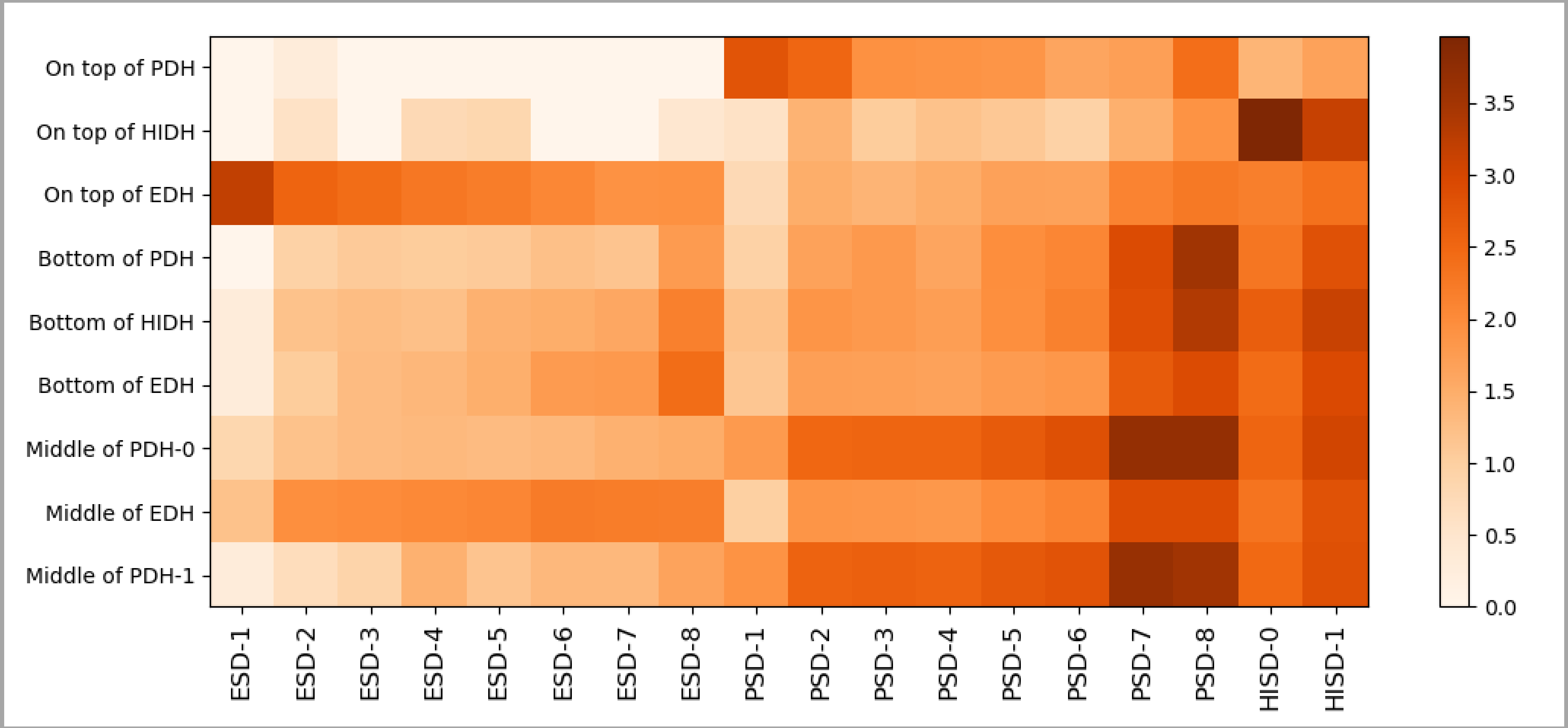
- Used to retrieve the data provided by each simulation;
- Creation of histograms for a better understanding of the effect of each simulation on each of the stacks.
- Capability to apply energy cut-off thresholds by selecting interactions above a specific energy



Example of a histogram for one of the HISD detectors

Detection Efficiency

Implementation



Hitmap of all particles detected on every detector (Log10 scale)

Cut-off Threshold: 0 keV

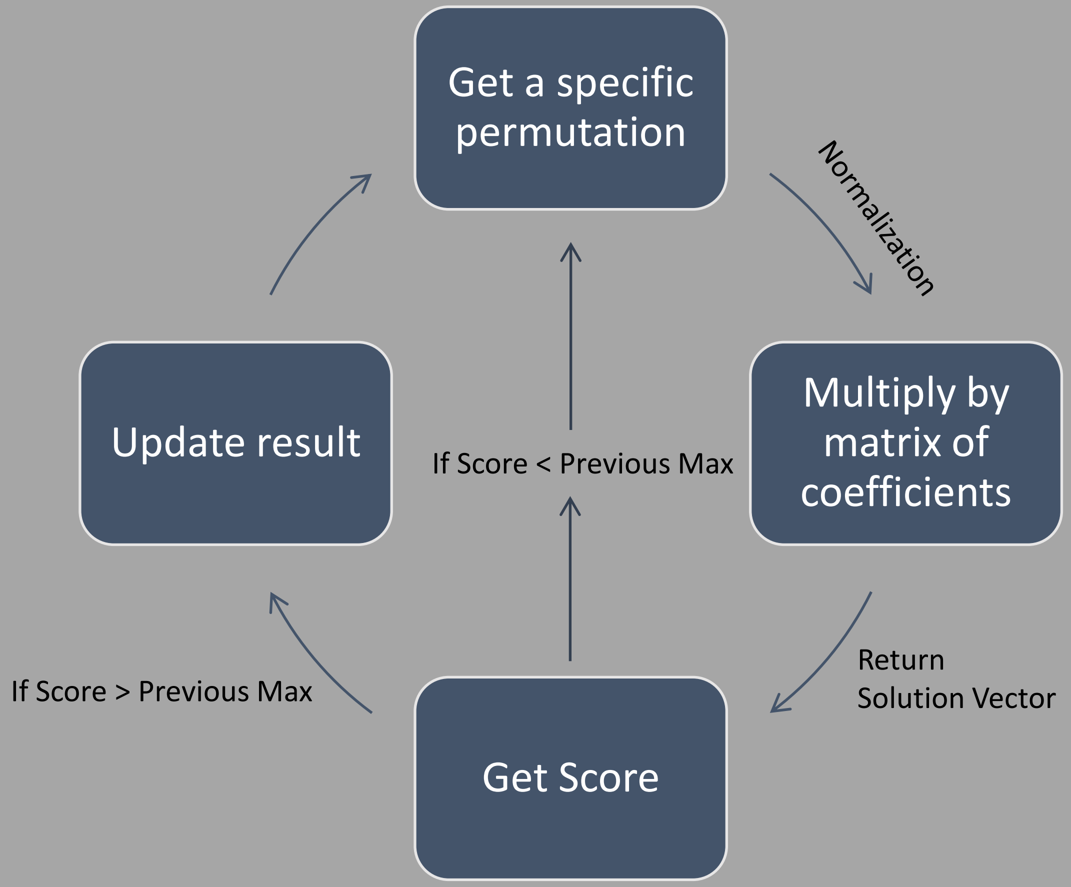
Weighting Algorithm

Implementation

Finding the best combination of positions for source activity exposure.

Possible algorithms	Pros	Cons	
Brute force	Easy to Implement	Slower	✓
Bayesian Optimization	Fewer calculations necessary	Need to speculate a function as reference as a starting point	✕
Gradient Ascent (Gradient Descent)	Fast	Need more data points	✕

Weighting Algorithm



Example

Get all possible permutations

Degrees of liberty:

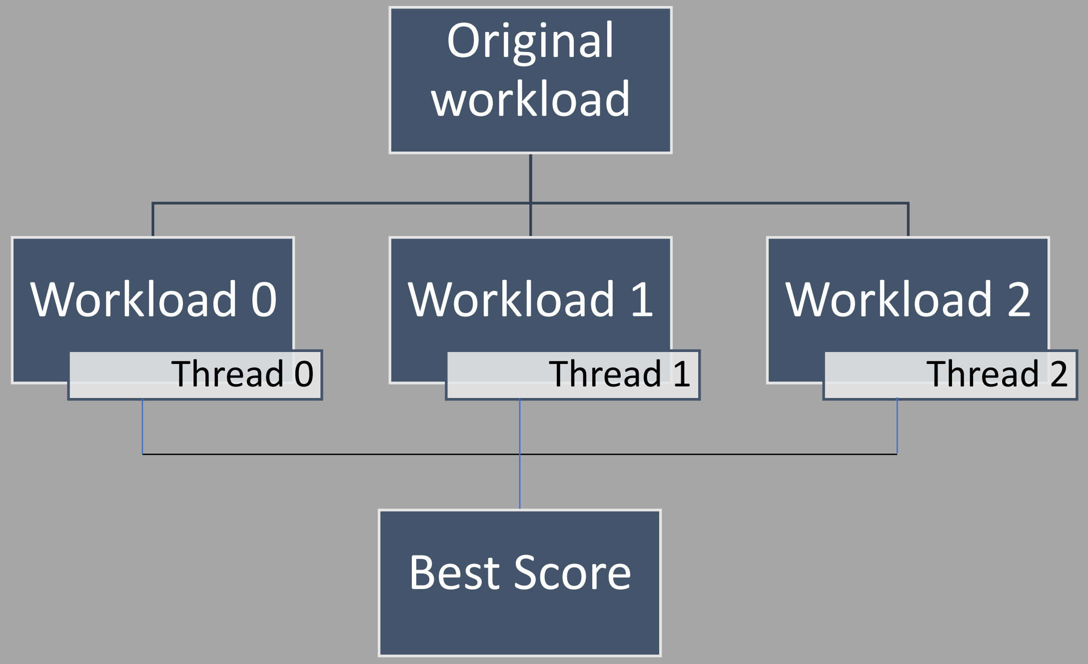
- Weights Resolution (=10%);
- Number of simulated positions;

Multiple solution vectors

Solution Vector containing total weighted counts per detector

Weighting Algorithm Optimization

- Multithreading *(using std::thread)* :
  - Several concurrent threads;
  - Distributed workload;
  - All threads compete for the best overall score.

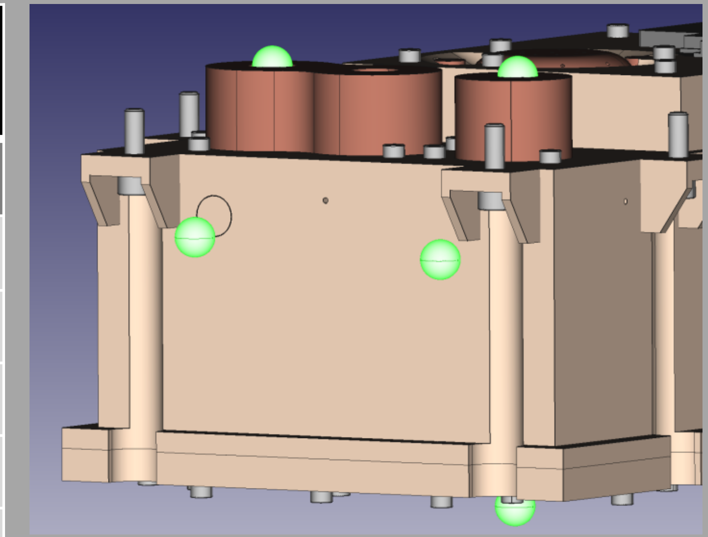


Runtime	
Unoptimized	Fully Optimized
1h 47m 13s	<2 s

Weighting Algorithm

Results

Simulated Position	Time Spent in each position for each cut-off threshold				
	0 keV	100 keV	200 keV	300 keV	400 keV
Top of PSD	**13.3 %**	**9.5%**	**9.5 %**	**10.5 %**	**7.7 %**
Top of HISD	0.0 %	0.0%	0.0 %	0.0 %	0.0 %
Top of ESD	**20 %**	**28.6%**	**28.6 %**	**26.3 %**	**23.1 %**
Bottom of PSD	0.0 %	0.0%	0.0 %	0.0 %	0.0 %
Bottom of HISD	0.0 %	0.0%	**4.8 %**	0.0 %	0.0 %
Bottom of ESD	0.0 %	**4.8%**	**4.8 %**	0.0 %	0.0 %
Middle of PSD	0.0 %	0.0%	0.0 %	0.0 %	0.0 %
Middle of ESD	**53.3 %**	**42.9%**	**38.1 %**	**47.4 %**	**46.2 %**
Middle of PSD (+13mm up)	**13.4 %**	**14.2%**	**14.2 %**	**15.8 %**	**23.0 %**
Total exposure time (s)	**3 392**	**7 011**	**14 189**	**36 190**	**157 575**



Example of selected positions for the cut-off energy of 100 keV

Future objectives/ further improvements

- Run more particle simulations to further improve statistical significance;
- Automation of the optimization process;
- Repeat the optimization procedure for the Directionality Detector;
- Account for β^- casing on the ${}^{137}_{55}Cs$ source;
- Experiment with different radiation sources (${}^{60}Co$ & ${}^{22}Na$);
- Running actual tests in person to compare to expected results.

Backup

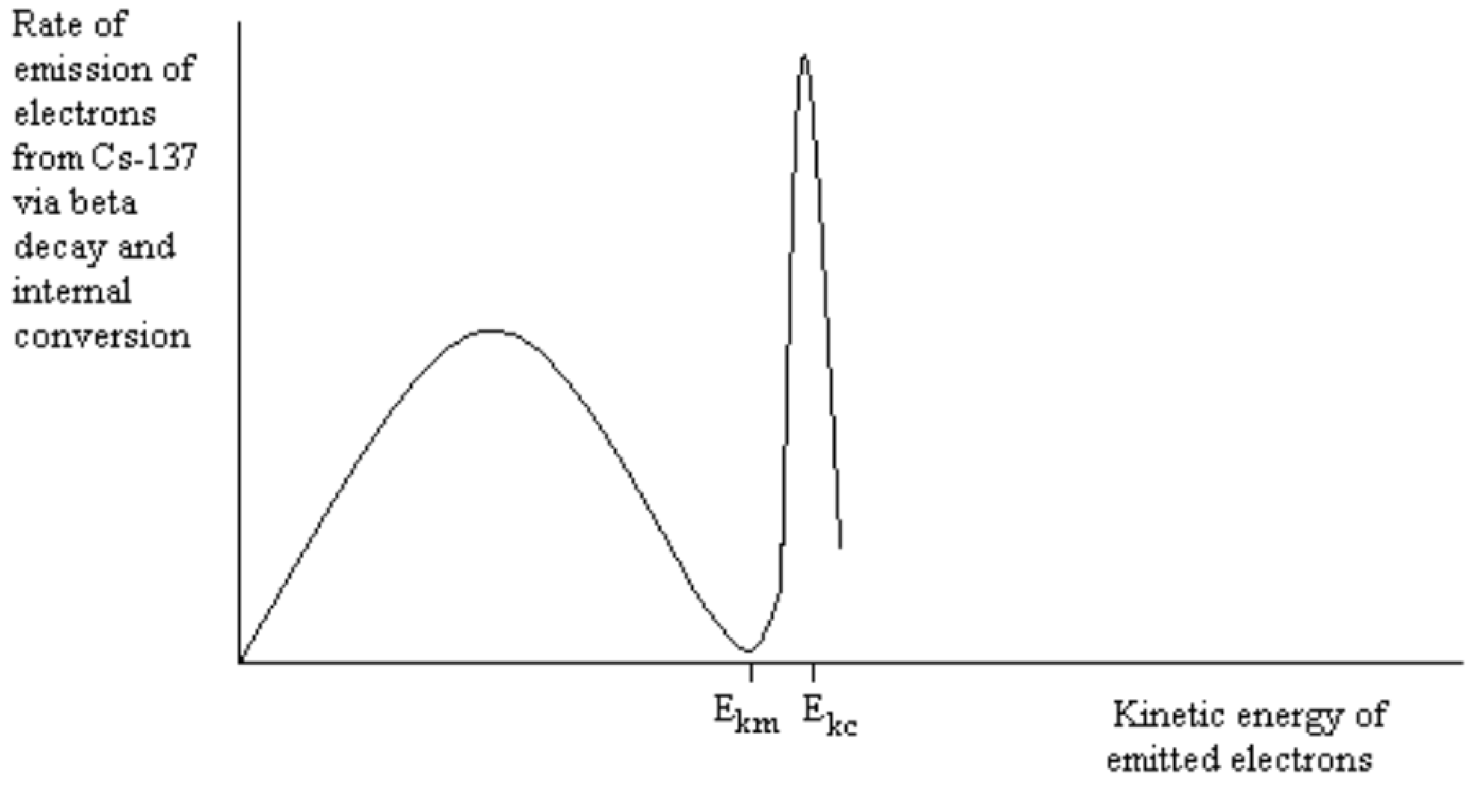


Figure 2. Schematic spectrum of electrons emitted from Cs-137