PAUL SCHERRER INSTITUT
PSI

Patryk Socha :: PhD student :: Paul Scherrer Institut

Radiation-hard Electron Monitor (RADEM) for ESA JUICE mission

LTP Seminar, PSI, 25.11.2019

Agenda

1. Introduction
2. Radiation monitors development
3. RADEM requirements and properties
4. Scientific output
5. RADEM build and models
6. Particle detection and discrimination
7. Performance tests
8. Future plans for radiation monitors
9. Summary

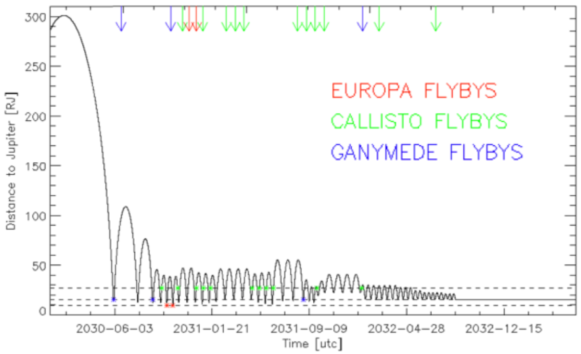
1. Introduction

JUpiter ICy moons Explorer (JUICE) is a part of ESA’s Cosmic Vision programme.

It’s a large-class spacecraft dedicated for observations of Jupiter and it’s three largest moons: Ganymede, Callisto and Europa.

JUICE will explore the conditions of the planet formation, life emergence and mechanisms of the Solar System.

Launch of JUICE is planned for 2022. With 7 years of transfer, it will spend 3 years studying Jovian system.

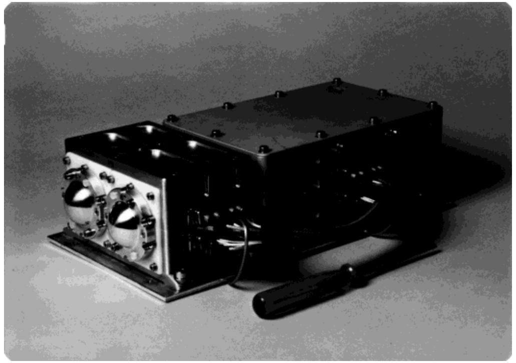


Jupiter Galilean Moons [www.deography.com] (top) and planned flybys during the mission (bottom)

2. Radiation monitors development

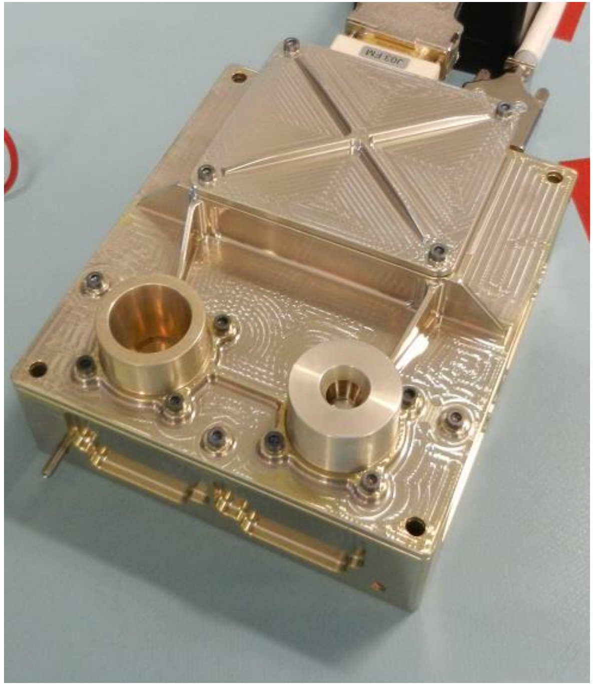
Long term experience with radiation monitors at PSI.

First model, Radiation Environment Monitor, developed in ‘90s, followed by SREM and NGRM.



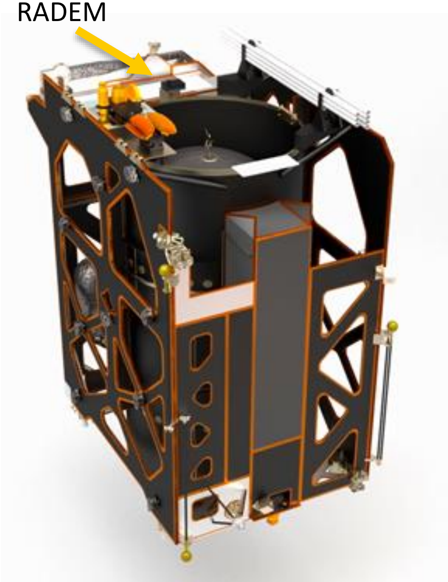
Radiation Environment Monitor (REM)

Standard Radiation Environment Monitor (SREM)



Next Generation Radiation Monitor (NGRM)

3. RADEM requirements and properties



RADEM location onboard the satellite

RADiation-hard Electron Monitor (RADEM) is lead by EFACEC, with PSI and LIP responsible for design and calibration, and IDEAS developing an Application-Specific Integrated Circuit (ASIC).

Development based on deep-rooted know-how with radiation monitors at PSI (REM, SREM, NGRM).

Onboard the spacecraft RADEM will serve two functions:
– Contributing to the JUICE science packages,
– Being a part of mission health monitoring system.

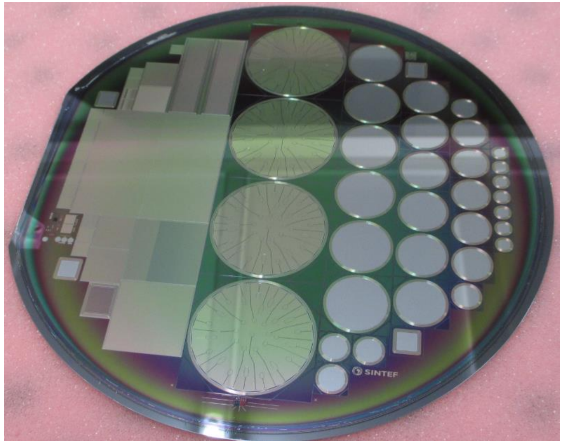
The instrument will provide information on electron, proton and heavy ion fluxes, spectra and incoming directions.

3. RADEM requirements and properties

RADEM will send the information on particle fluxes, spectra and total radiation dose.

RADEM most important functional requirements are:

- Detection of electrons, protons and heavy ions,
- Energy coverage:
  - 0.3 – 40 MeV for electrons,
  - 5 – 250 MeV for protons,
  - 8 – 670 MeV for heavy ions,
- Peak fluxes:
  - 10^9 #/cm^2/s (E > 100 keV) for electrons,
  - 10^8 #/cm^2/s (E > 1 MeV) for protons
- Radiation dose on rad-hard components: 100 krad,
- Information on dose rate and total dose.

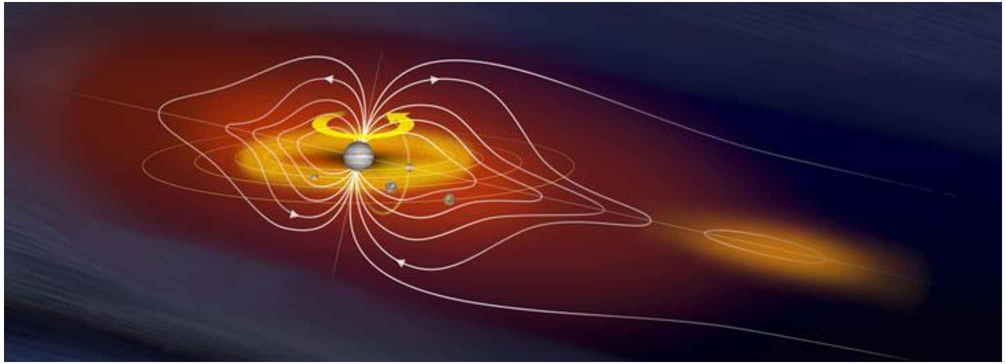


Wafer with RADEM diodes, designed at PSI

PAUL SCHERRER INSTITUT

4. Scientific output

Main scientific goals for RADEM are:
– Characterization of Jupiter's harsh radiation environment,
– Study of dynamics in Jovian radiation belts,
– Understanding of trapped particle energy gain and loss,
– Space weather monitoring across the Solar System,
– Comparison between Jupiter and Earth radiation environment

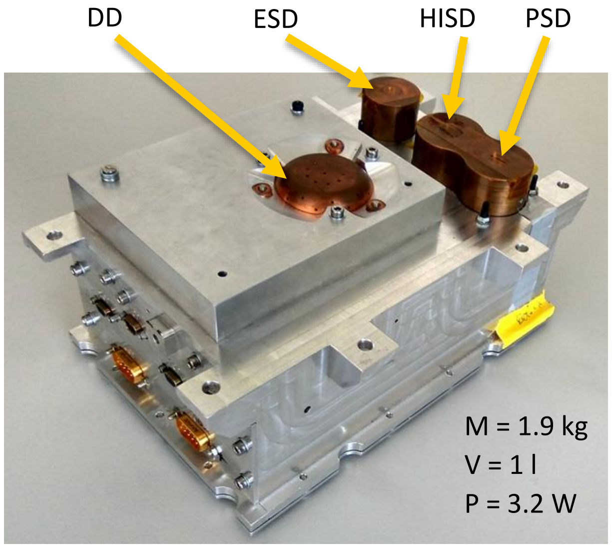


Jupiter's magnetic field and radiation belts [www.machinedesign.com]

5. RADEM build and models

RADEM consists of:

– Electron Stack Detector (ESD),
– Proton Stack Detector (PSD),
– Heavy Ion Stack Detector (HISD),
– Directional Detector (DD),
– three Application-Specific Integrated Circuits (ASIC) designed especially for RADEM on JUICE.



RADEM Engineering Model

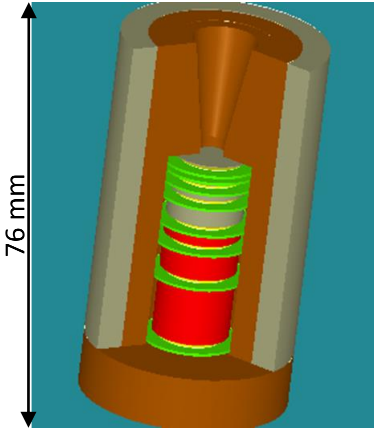
RADEM models:

– Bread-Board (BBM) – developed and tested 2017,
– Engineering (EM) – developed and tested 2019,
– Engineering Qualification (EQM) – tests currently undergoing,
– Proto-Flight (PFM) – currently under development.

5. RADEM build and models

Stack Detectors

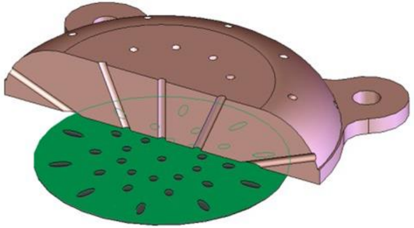
- 0.3 mm thick Si diodes arranged in stacks
- Single collimated entry
- 8 diodes for ESD and PSD, 2 for HISD
- Al and Ta absorbers between diodes



Proton Stack Detector

Directional Detector

- Single 0.3 mm thick Si diode with 28 sensitive areas
- 28 collimator holes with Kapton entrance windows
- Theta angle: 70^0



Directional Detector

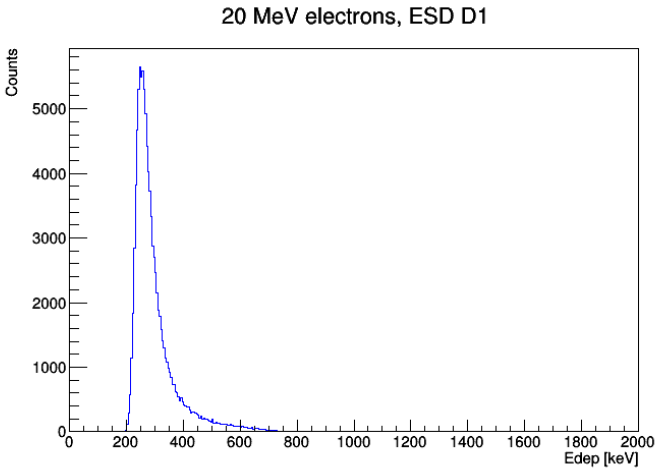
Both designs based on Monte Carlo simulation results done by PSI

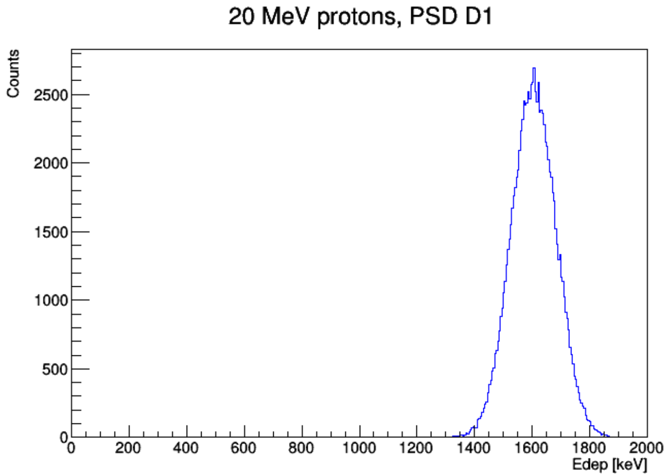
6. Particle detection and discrimination

Particles deposit energy travelling through the detector following Vavilov distribution.

Spread and mean value differs with particle type and its energy.

Low and high threshold mechanism allows for particle discrimination.

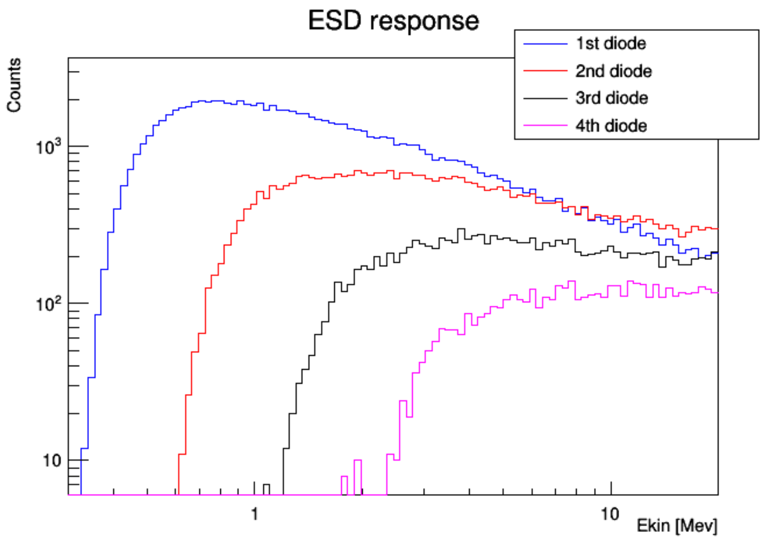


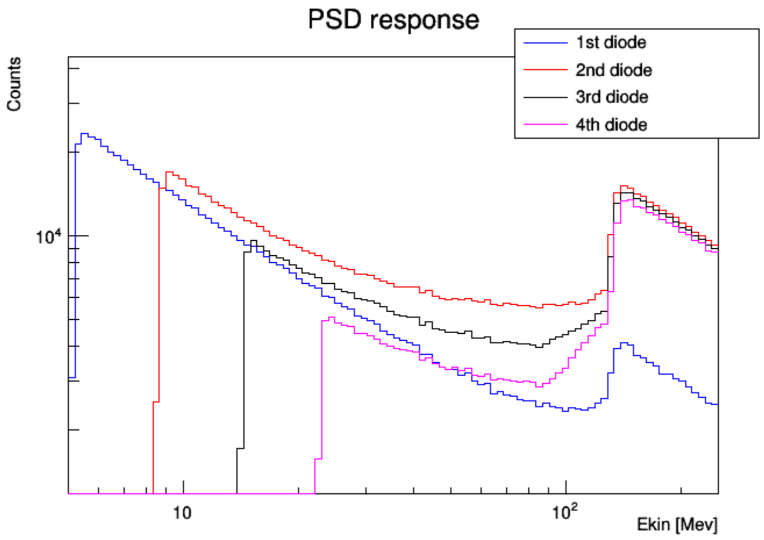


6. Particle detection and discrimination

Detector stacks designed to cover energy spectra in quasi-logarithmic bins.

Plots present response to spectra of particles following $f(x)=x^{-2}$ distribution.





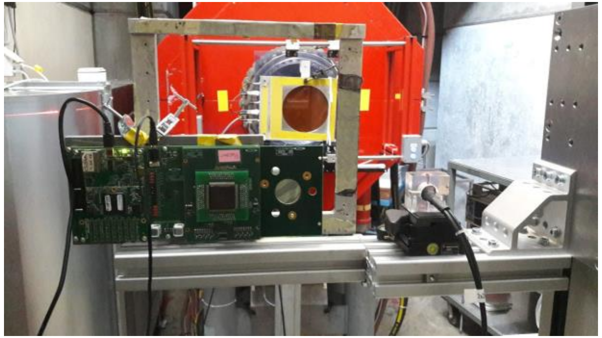
7. Performance tests

RADEM BBM and EM performance was tested to verify:

- Response to different ionizing radiation sources,
- Threshold gain factor of Low and High Gain channels,
- Linearity of flux scaling,
- Coincidence logic mechanism,
- Alignment of Directional Detector pixels.

Instrument was tested with proton beam at Proton Irradiation Facility (PIF), electrons at PiM1 and different radioactive sources.

Measurements were followed by Geant4 Monte Carlo simulations to compare and verify obtained results.



RADEM BBM at PiM1 beamline

Proton Irradiation Facility area

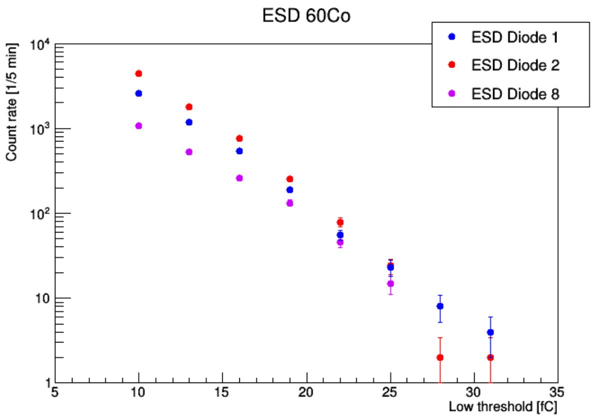
7. RADEM performance tests

^{60}Co γ source

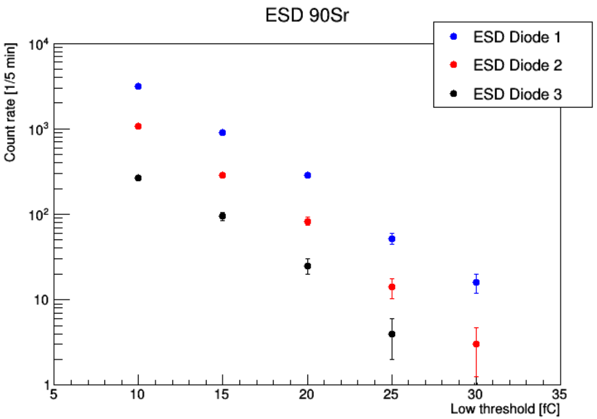
- Can penetrate through RADEM shielding
- Response simultaneously verified in all diodes of the stack

^{90}Sr β^- source

- Expected response to electron radiation in first three diodes
- Descending count rate due to geometry factor and energy cut-off



ESD response to 60Co radioactive source

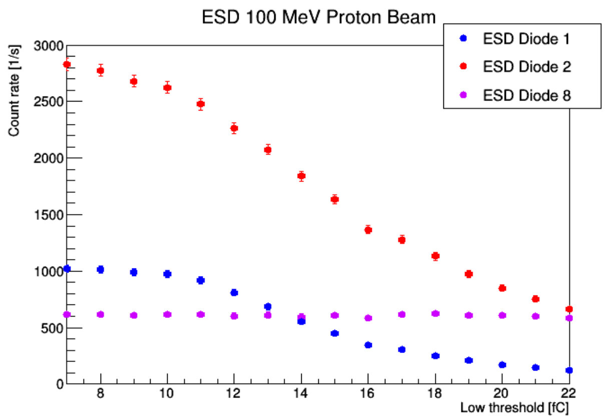


ESD response to 90Sr radioactive source

7. Performance tests

High Gain channels response

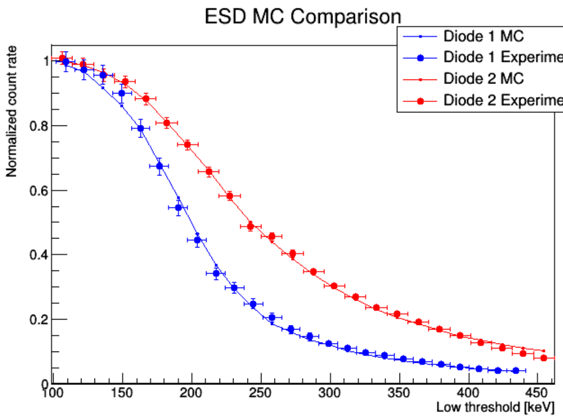
- Low and High Threshold scan of High Gain channels of the ASIC
- 200 and 100 MeV proton beam
- Simultaneous test of all stack diodes



High Gain channels response to 100 MeV protons

Verification with Monte Carlo simulations

- Detailed geometry and radiation models
- Detector noise impact included in results
- Simulation results in good agreement with experimental data

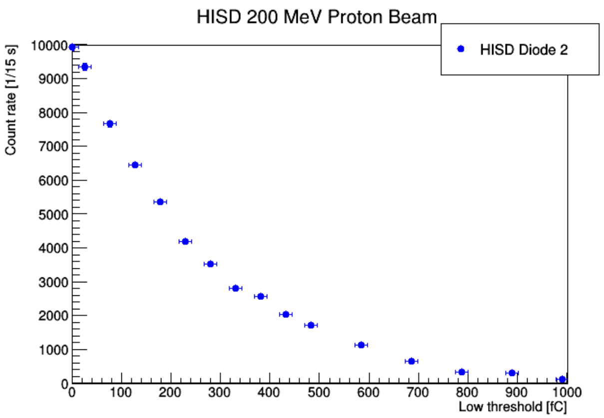


MC simulation comparison with ESD proton scan

7. Performance tests

Low Gain channels response

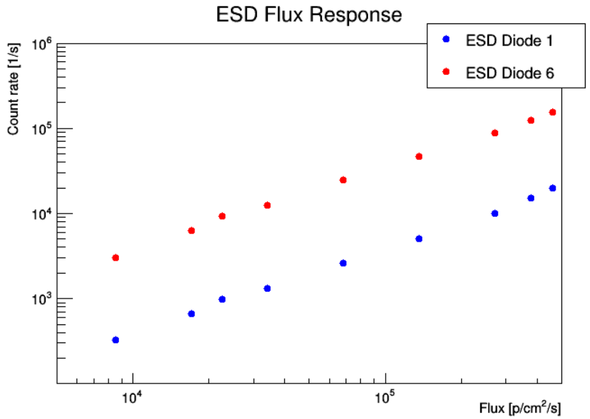
- Low Threshold scan of Low Gain channels of the ASIC
- 200 MeV proton beam
- Energy deposition imitating heavy ions



Low Gain channel response to proton beam

Flux scaling

- Tests done with 200 MeV proton beam
- Counting rate above 10^5/s
- Linear response to changing flux within tested range

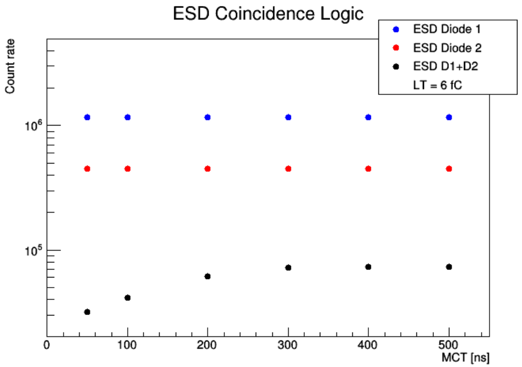


Electron Stack Detector flux test preliminary results

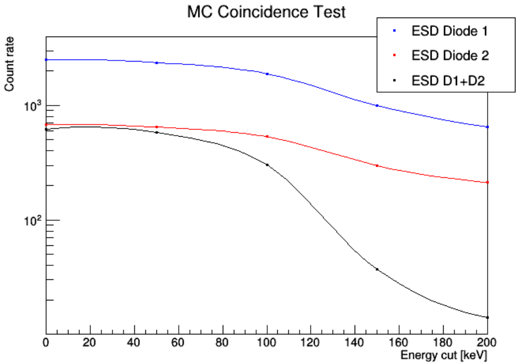
7. Performance tests

Collimated ^{90}Sr source

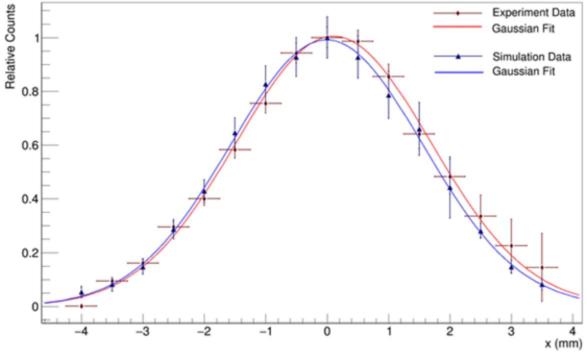
- Electron detectors were tested with ^{90}Sr source to verify mechanism of coincidence and the alignment of DD sensitive areas
- Coincidence window width was tested on ESD and observed behavior was supported by Monte Carlo simulations
- DD pixel alignment matches the theoretical position within error bars



Coincidence width test of ESD



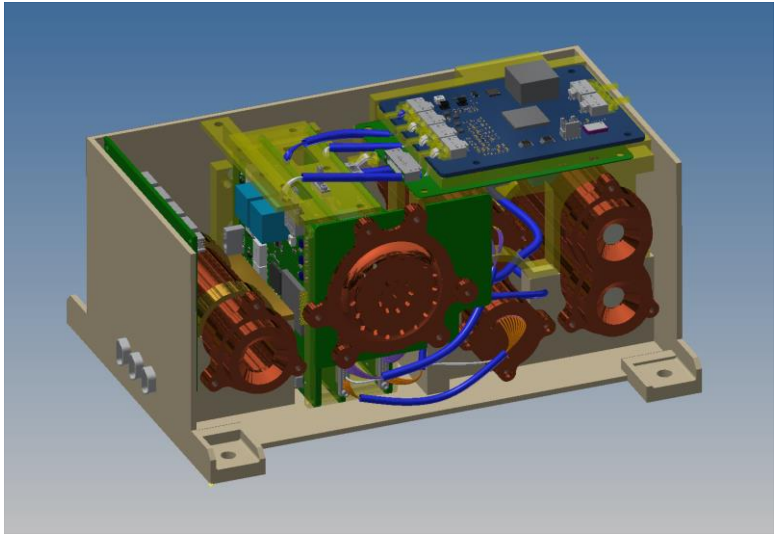
MC simulation results of coincidence test



DD pixel alignment comparison with MC

8. Future plans for radiation monitors

Radiation Monitor for Lagrange mission



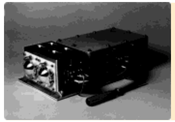
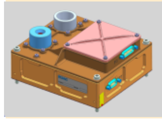
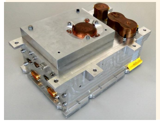
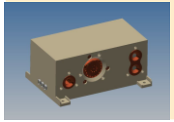
Radiation Monitor for Lagrange mission concept drawing

Detector range:
- Electron Stack Detector: 0.1 – 8 MeV,
- Proton Stack Detector: 2 – 1000 MeV,
- Heavy Ion Detector: 10 – 1000 MeV/nuclei,
- Directional Detector theta angle: 70^0.

Modularity allows for dedicated construction even for CubeSats.

Physical parameters:
- Total mass: 2.4 kg,
- Power: 4.0 W,
- Size: 80 x 178 x 128 mm.

8. Future plans for radiation monitors

Instrument	Electron thr [MeV]	Proton thr [MeV]	Heavy Ion counter	ASIC	Missions so far
 REM	1	35	X	X	2
 SREM	0.75	12	X	X	7
 NGRM	0.1	2	Yes	VATA465	1
 RADEM	0.3	5	Yes (with discrimination)	VATA466	X
 LGR	0.1	2	Yes (with discrimination)	VATA466 + DRS4	X

9. Summary

RADEM functionalities were verified and compared with MC simulations

Final models are currently under development

The instrument is planned to be delivered by the end of 2020

Continuous development of radiation monitors at PSI