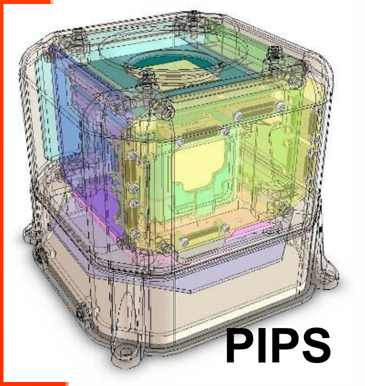
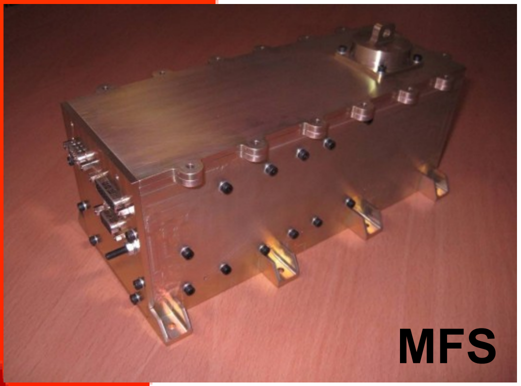
Space Radiation and Plasma Environment Monitoring Workshop





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Outline

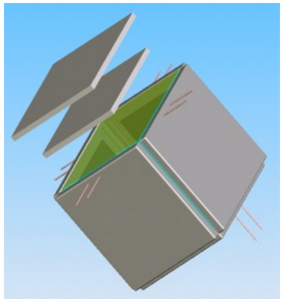
- Radiation Monitoring and Principles
- Radiation Monitor Architecture
- Simulation in GEANT4 and MCNPX of the Monitors
- Requirements/Specifications of EFACEC Radiation Monitors
- Qualification Status of the Radiation Monitors
- Test Campaign with Particle Beams
- Performances of the EFACEC Radiation Monitors
- Correlation and Fine Tuning
- Future Applications

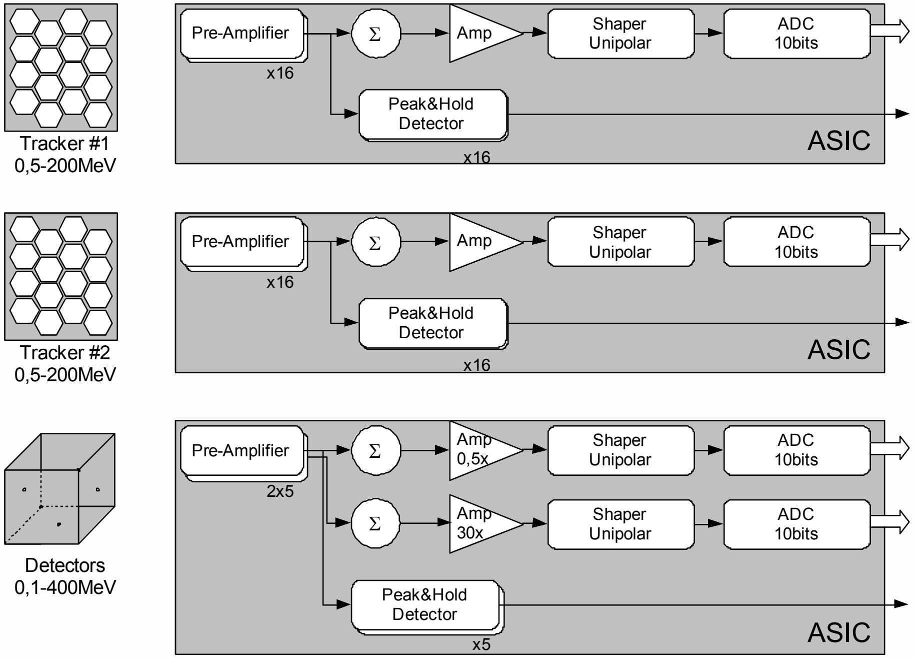
RADIATION MONITORING AND PRINCIPLES

- Detection of the ionization caused by the passage of charged particles is the basis of most types of particle detectors;
- The simplest class consists of gas filled ionization chambers;
- Other types of energy-loss detectors take the advantage of using denser materials than gases by the selection of semiconductors materials in which the particle could deliver their kinetic energy and being measured;
- Scintillant materials are also used to transform part of the kinetic energy into visible photons to be collected and amplified by the use of photomultiplier tubes;
- Other type of radiation monitors takes advantage of the Cherenkov radiation produced when a particle enters a medium with velocity greater than the velocity of light in that medium;
- The use of magnetic fields could help in the determination of the sign of the charge the incoming particles carries;

FROM PIPS TO MFS & BERM – RADIATION ARCHITECTURE

- PIPS concept was:
  - Physical Concept – 2 top Silicon detectors (pixelated), CsI(tl) Scintillant and anti-coincidence Photodiodes;
  - FE – Transimpedance amplifier followed by:
    - Unipolar shaper;
    - Bipolar shaper;
    - Peak detect;
  - BE – FPGA and memories running:
    - Particle recognition process;
    - Communications;
    - Health/housekeeping process;



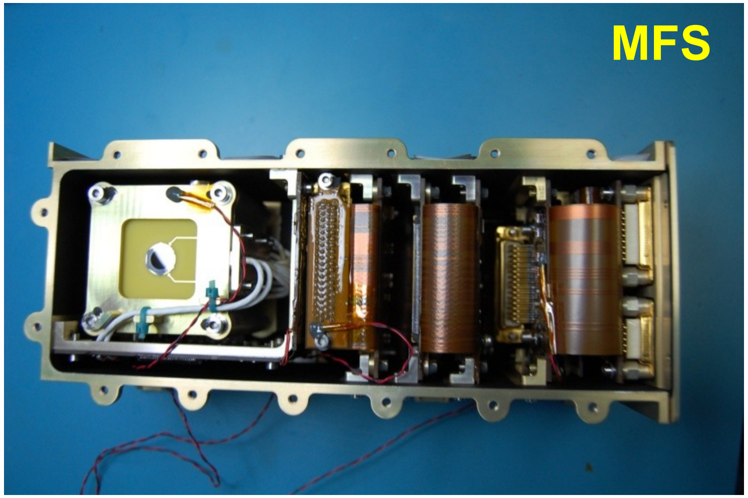


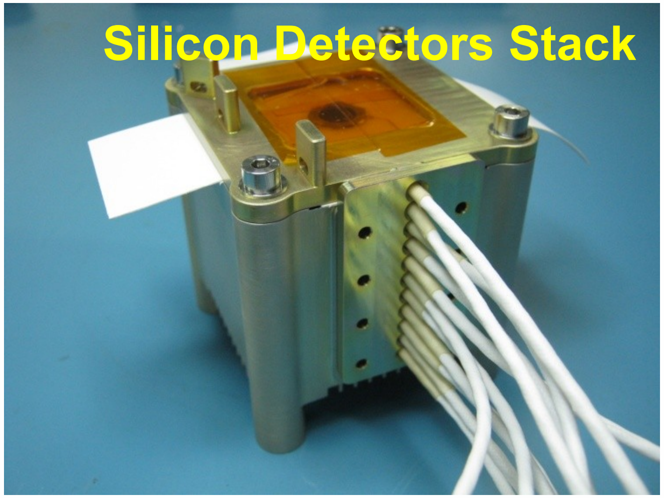
FROM PIPS TO MFS & BERM – RADIATION ARCHITECTURE

- Tips and Finds:
  - Scintillant coupling to readout photodiodes issues;
  - Required ultra-low equivalent noise level in the photodiodes;
  - No integrated solution available and discrete solution repeatability of discrete electronics difficult;
  - Development of a dedicated ASIC was not considered at the time;
- Workarounds:
  - Use of available ASIC;
  - Scintillant replaced by a stack of Silicon Detectors to overcome the coupling issues and required equivalent noise level;

MFS & BERM RADIATION ARCHITECTURE

- Efacec Radiation Monitors are based in:
  - Physical Concept – stack of Silicon Detectors;
  - Electronics – Ideas ASIC (FE) and FPGA with memories (BE);
    - FE – CSA with slow shaper for integration and fast shaper for trigger system;
      - ✓ Integration time 2μs and discharge time 10us;
      - ✓ Equivalent noise level 3-5 fC;
    - BE – FPGA and memories running:
      - ✓ Particle recognition process;
      - ✓ Communications;
      - ✓ Health/housekeeping process;
  - LUT – All functional parameters are TM/TC configurable by ground;
  - Default values stored in EEPROM;

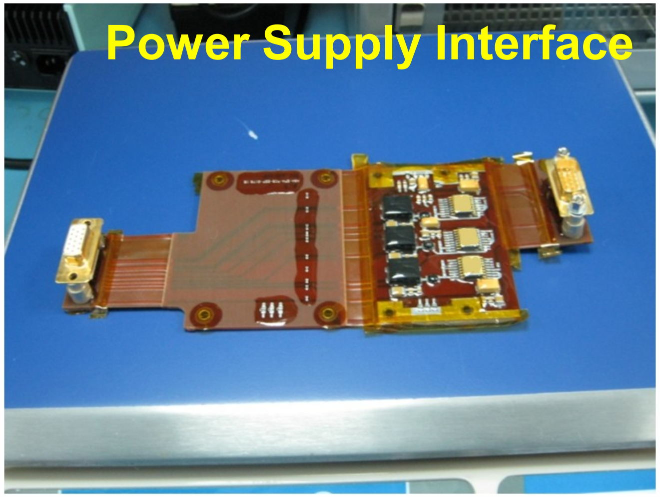


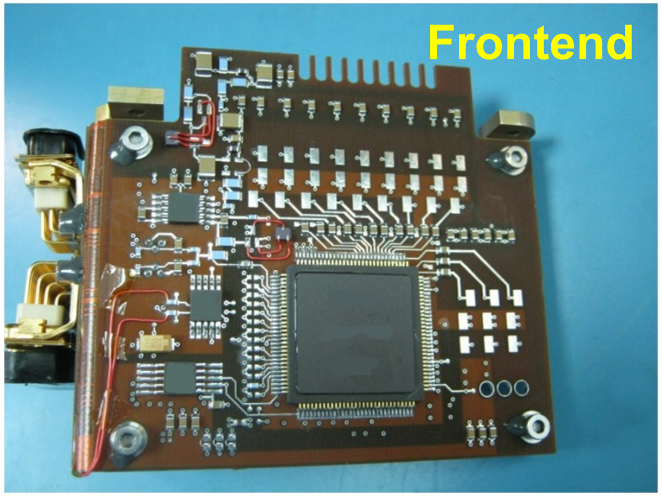


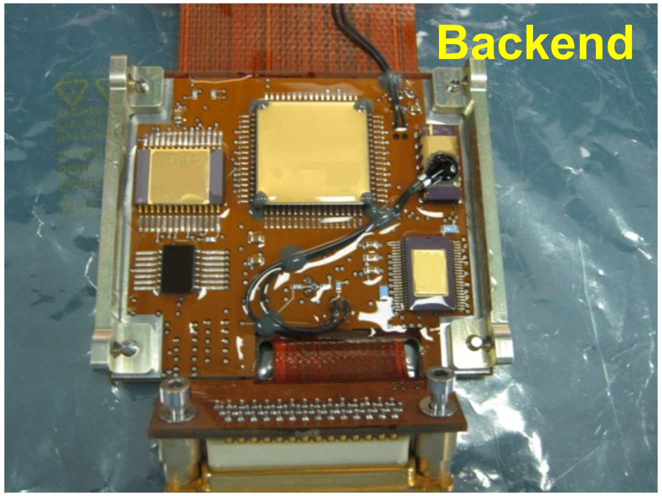
MFS & BERM – RADIATION ARCHITECTURE

- Main Operation Features:
  - Idle – only communications and housekeeping enabled;
  - Spectral Mode – default operating mode;
  - Frontend Test Mode – verifies operationally of the Silicon Detectors;
  - Backend Test Mode – allows validation of FPGA/Memories operationally;
  - Pedestal – Noise level measurement;
  - Veto System – rejects simultaneous multi-hits from recognition process;

MFS & BERM RADIATION ARCHITECTURE







PARTICLE IDENTIFICATION

- Particle species are characterized by its charge - q, mass - m and kinetic energy - $p^2/2m$;

- Particle detectors measure these quantities by different ways:
  - p/q from the trajectory in a magnetic field;
  - V from the time of flight between two detectors separated by a known distance;
  - q^2/v^2 from dE/dx in a thin detector;
  - $p^2/2m$ from the total energy deposit on a thick detector;

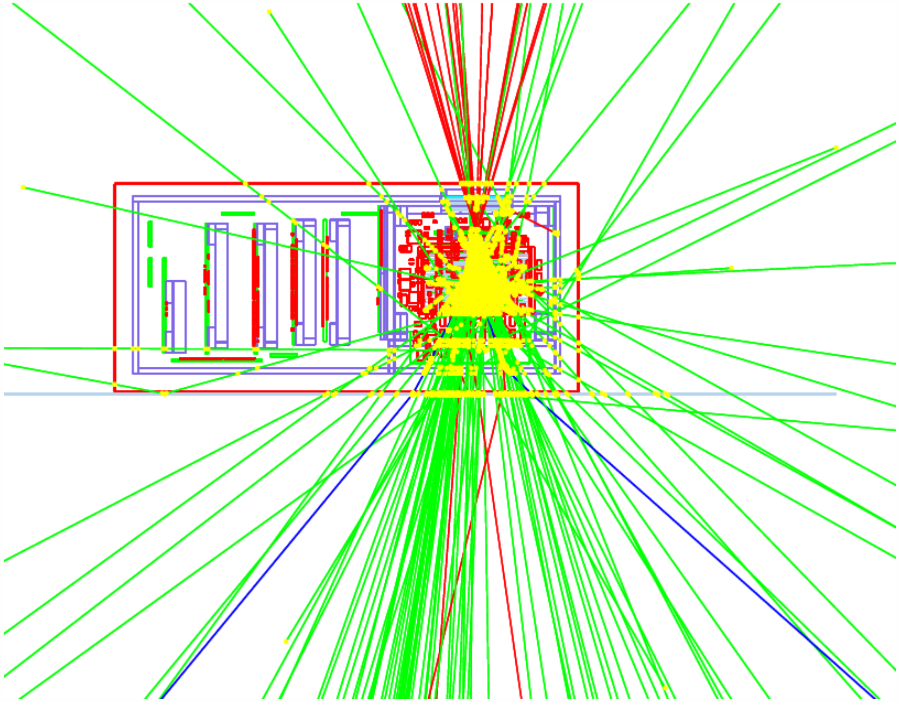
- A single type of measurement is insufficient to identify the type of species and thus a complex approach is needed in order to being capable of separating and identify particle species;

- EFACEC particle species are identified by the combination of several methods as the ones depicted above;

- EFACEC detectors are not prepared to detect high energy photons, nevertheless the use of scintillant materials could help in detecting them;

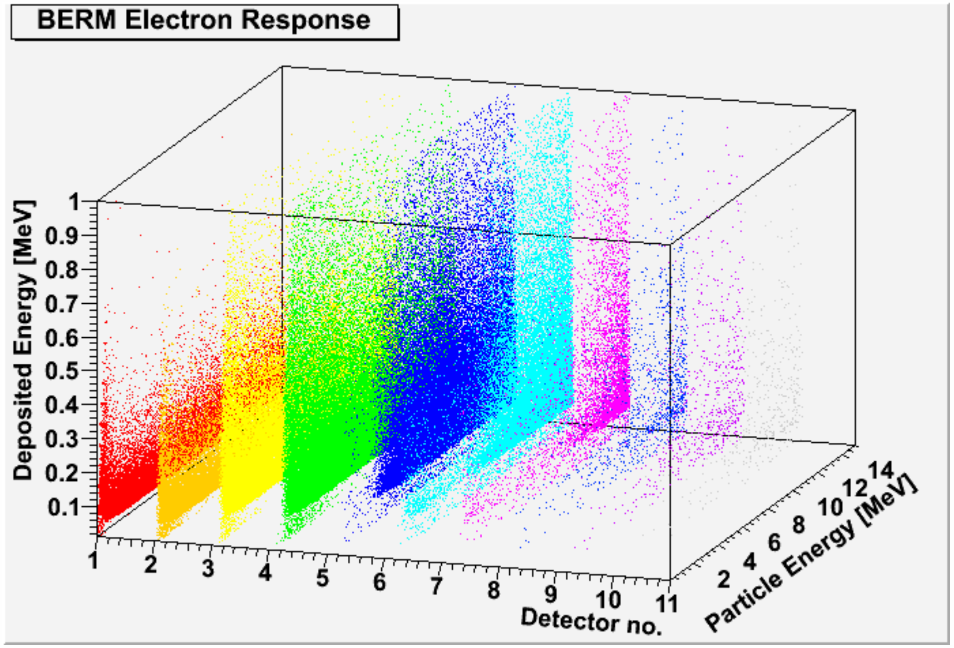
FULL GEANT4 MODEL VALIDATION

- Full GEANT4 model including small components has been analyzed;
- Simulation for test beam campaign has been performed for instrument calibration;
- After irradiation correlation analysis using GEANT4 has been extensively studied to understand instrument results at beam facilities;



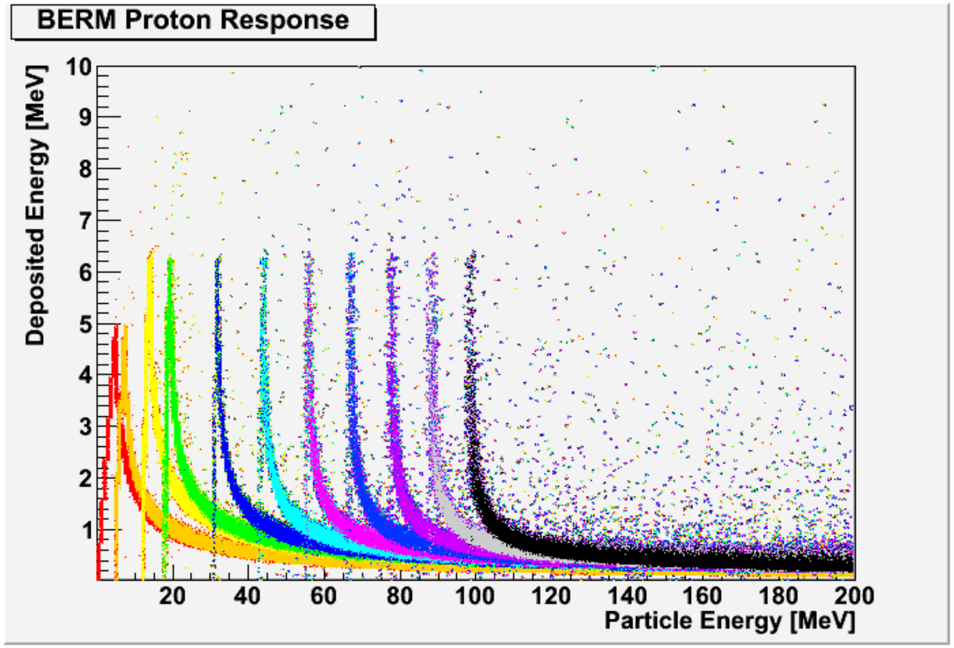
GEANT4 MODELIZATION

- GEANT4 simulation has been performed using GEANT4 version 9.4.p01
- Full 4Pi simulation performed
- Isotropic or fixed particle distribution
- Cosine-law particle momentum (biased or unbiased)
- Particle generation following on-orbit spectrum
- Simulation/(Realistic distribution) scaling factor correction



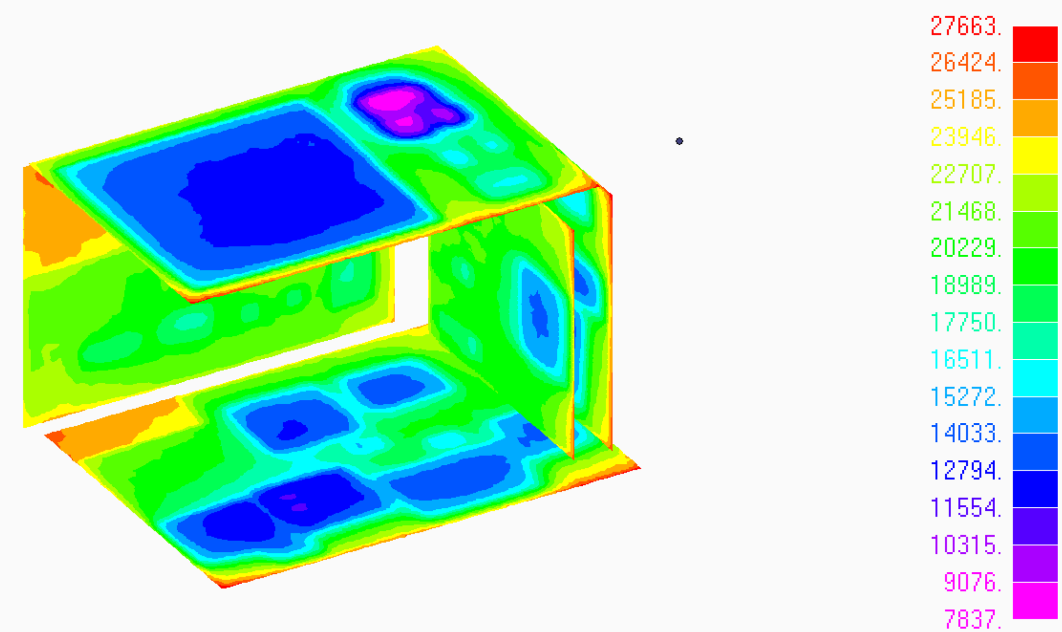
GEANT4 MODELIZATION

- Hadronic Process list used in the model QGSP_BERT_HP (Bertini Cascade)
- Particles simulated
  - Electrons
  - Protons
  - Alpha particles
- Deposited energy in detectors computed as ADC channel output for test campaign comparison
- Also output converted in Matlab format for post processing outside GEANT4



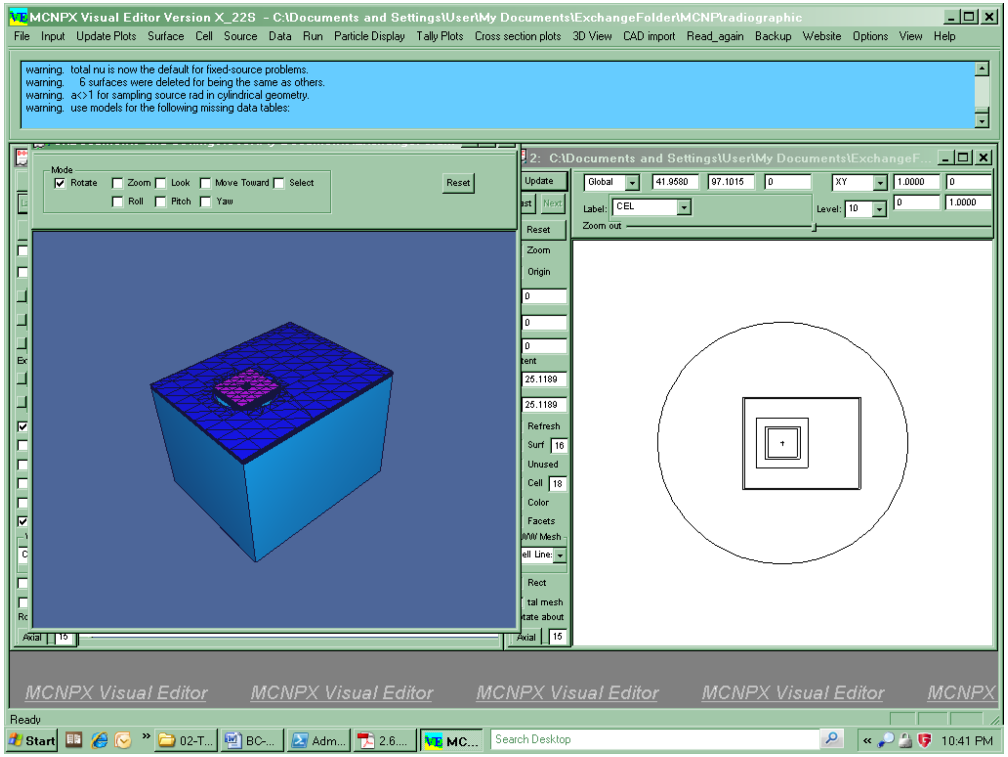
GEANT4 TID MAPS COMPUTED AT PCBS

- TID maps proved useful for components location based on the local shielding;
- The TID maps proved very useful for electronics components selection based on the TID at which the components will be subjected;
- Full GEANT4 at component level;



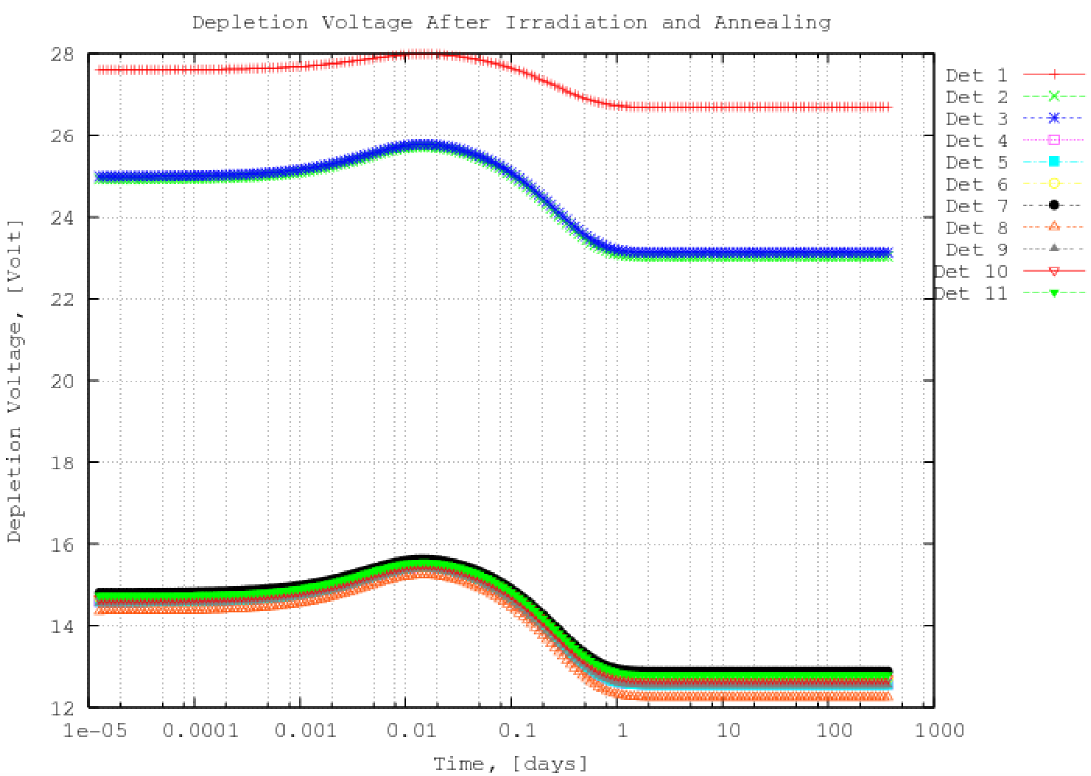
MCNPX ANALYSIS FOR NIEL DAMAGE ASSESSMENT

- NIEL damage assessment has been performed using MCNPX with the study of secondary particles interaction;
- Proton and Neutrons damage interaction has been analyzed;
- Particle fluence around Mercury has been analyzed;
- The radiation monitors design has been adapted to withstand the post damage leakage current;



MCNPX ANALYSIS FOR NIEL DAMAGE ASSESSMENT

- NIEL analysis includes after irradiation annealing at 70 degrees;
- Reverse annealing after irradiation for BepiColombo mission shows no critical damage;
- EFACEC radiation monitors are suitable for planetary missions in harsh environment as the one encountered around Mercury;

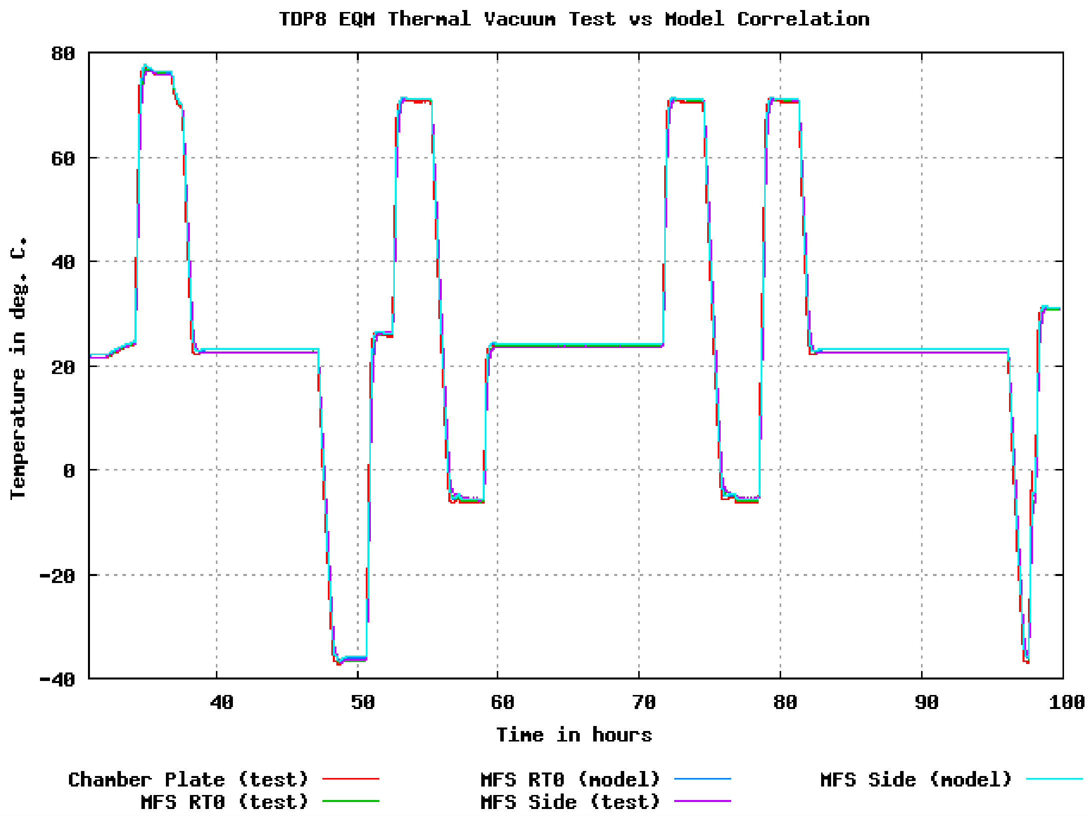


REQ./SPEC. OF EFACEC RADIATION MONITORS

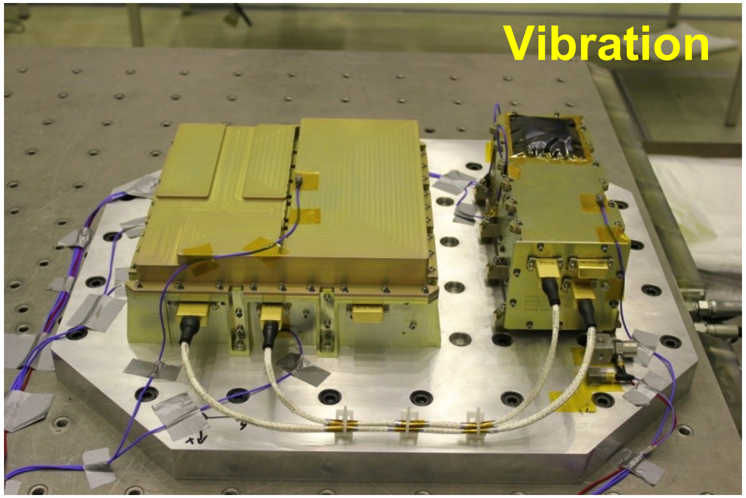
	MFS	BERM	Units
Power Consumption	4 (average)	5 (average)	W
Weight	2,930	1,7	kg
Envelope	260x120x110	175x120x110	mm^3
Electrons	0,5 to 7 (7 bins)	0,4 to 10 (5 bins)	MeV
Protons	1 to 120 (10 bins)	1 to 150 (8 bins)	MeV
Alphas	5 to 400 (10 bins)	n.a.	MeV
Heavy Ions	1 to 50 (10 bins)	1 to 50 (5 bins)	$MeV/(mg.cm^2)$
Measurements Rate	1e7	1e7	$\#/(cm^2.s)$
TID (Radfet Dosimetry)	Up to 50	Up to 50	krad
Field of View	40	40	º
Temporal Resolution	1 to 30 step 1	0,5	min.
Communications Protocol	I2C Slave (TPD8) RS485	1553	-
Link Budget	<45	<55	bps
Operating Temperature	-20 to +50	-20 to +50	ºC
Life Time	3 (expansible to 5)	7,6 (expansible to 8,6)	Years

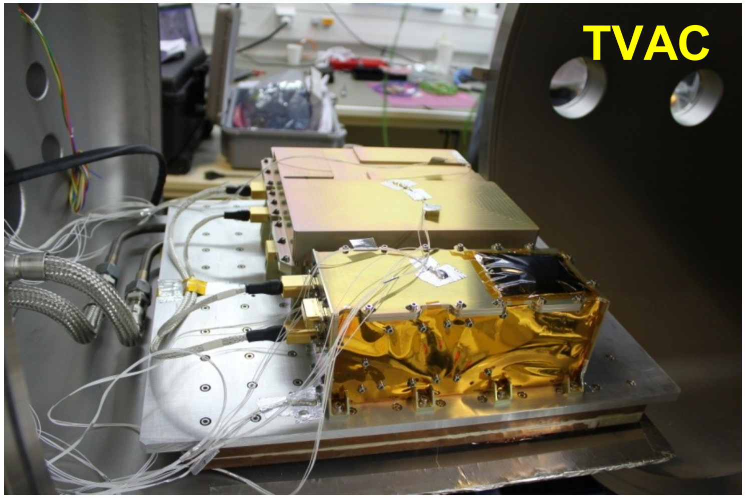
QUALIFICATION STATUS OF EFACEC DETECTORS

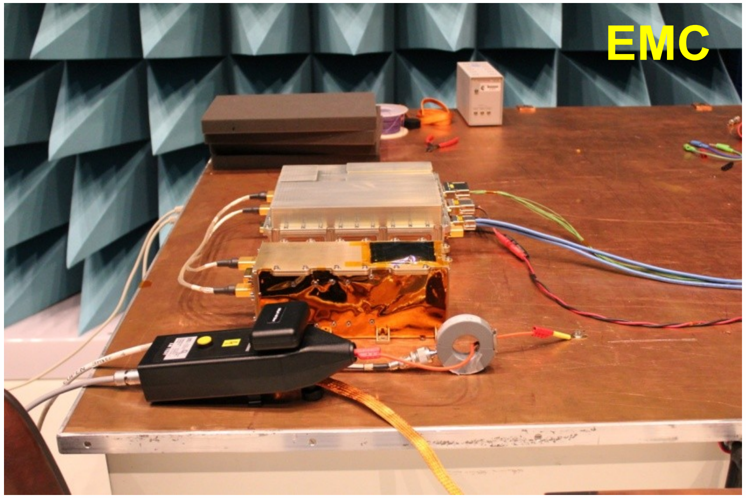
- Full space qualification campaign has been undertaken for EFACEC radiation monitors;
- Thermal, mechanical random, sine and shock tests campaign has been taken until full qualification status reached;
- Also EMC and Radiated and conducted susceptibility tests has been carried out;



QUALIFICATION STATUS OF EFACEC DETECTORS



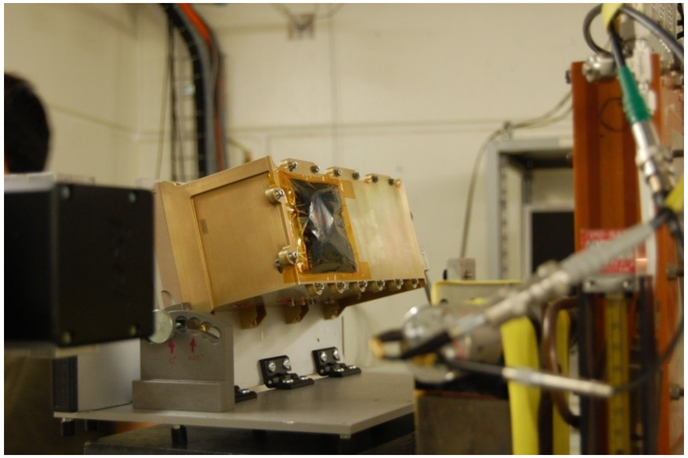


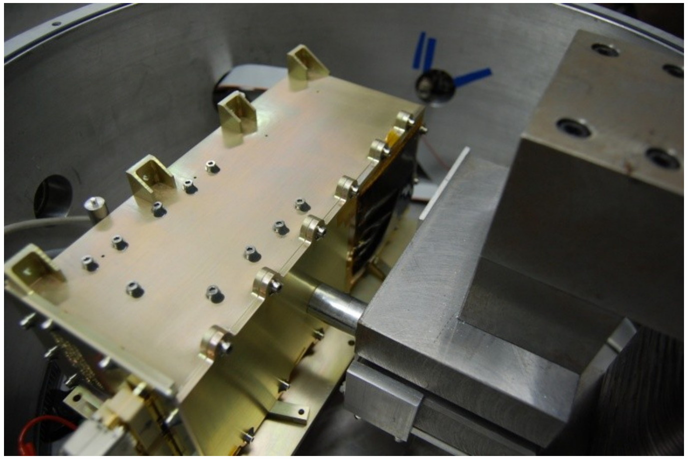


TEST CAMPAIGN WITH PARTICLE BEAMS

- MFS Engineering Model was submitted to several radiation test campaigns at PSI (Switzerland) and UCl (Belgium)

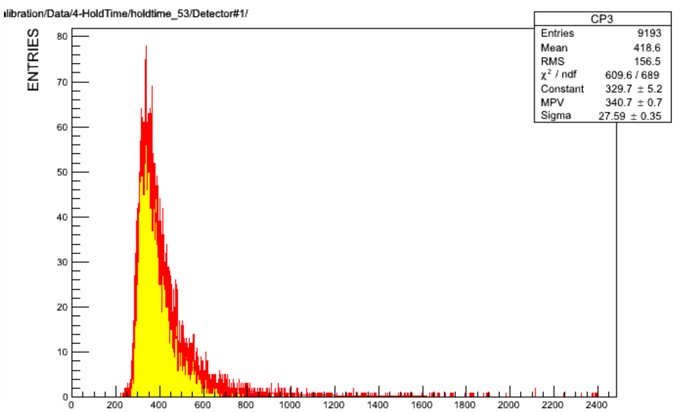
- MFS EQM and PFM were calibrated at PSI, under:
  - Protons;
    - From 10MeV to 150MeV;
  - Electrons;
    - From 250keV to 2,2MeV

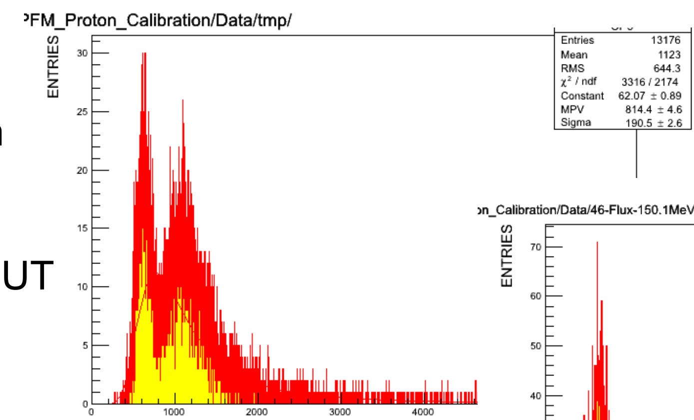


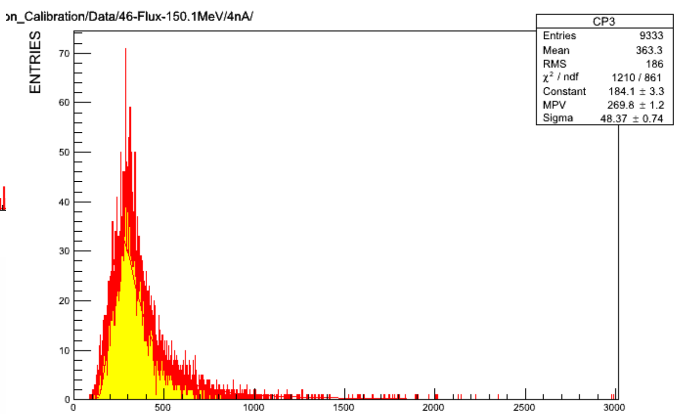


TEST CAMPAIGN WITH PARTICLE BEAMS

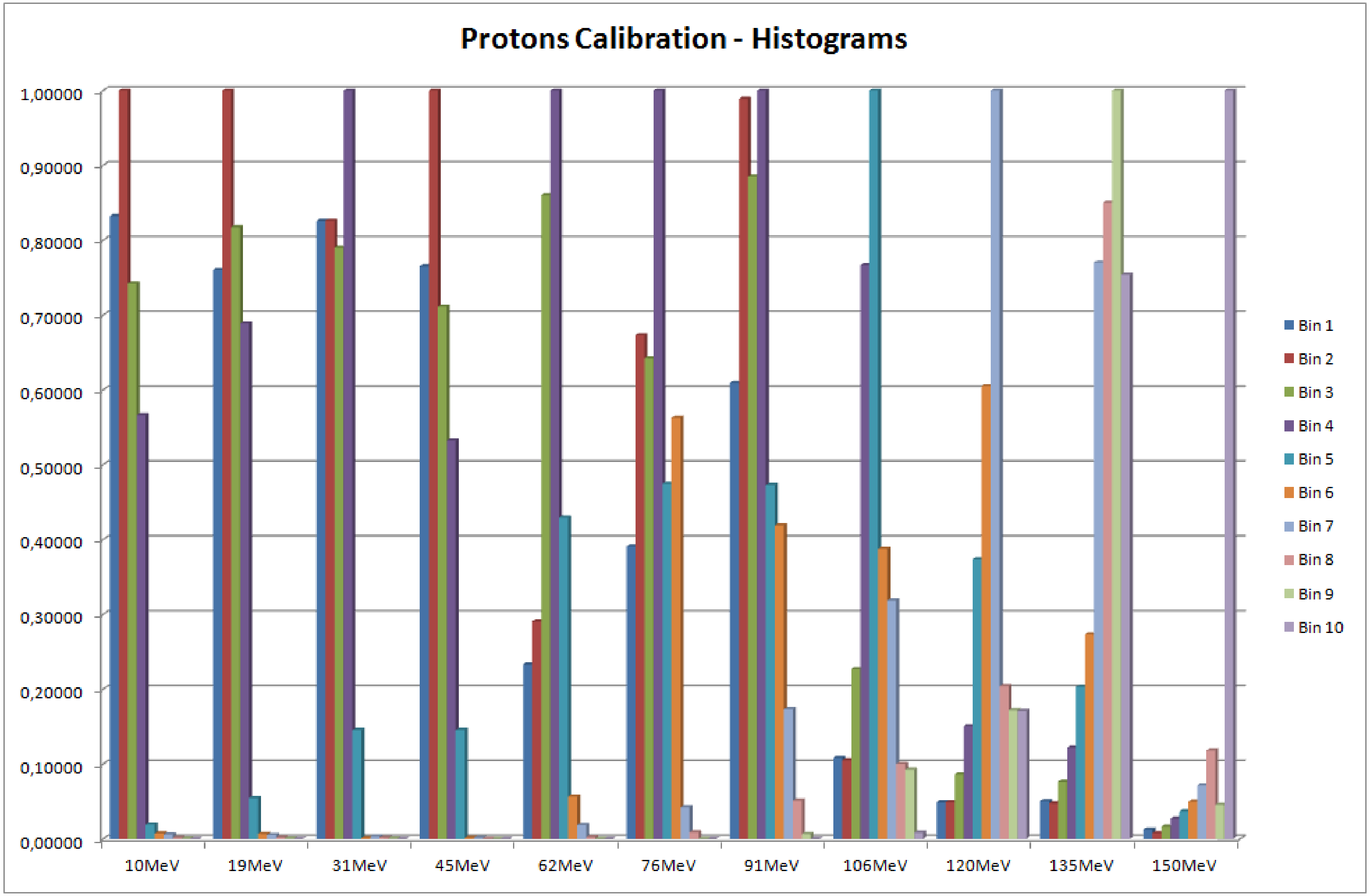
- MFS calibrated/verified for following features:
  - Integration time (hold time delay);
  - Count Rate – Flux;
  - Several Energies;
  - Background Noise;
  - Field-of-view (tilt);
- Simulations:
  - Particle recognition process fully implemented in Octave/Matlab for LUT optimization;
- LUT optimization:
  - Data smooth by moving Average with window of 5;
  - Landau Fit;







MFS PERFORMANCE UNDER RADIATION



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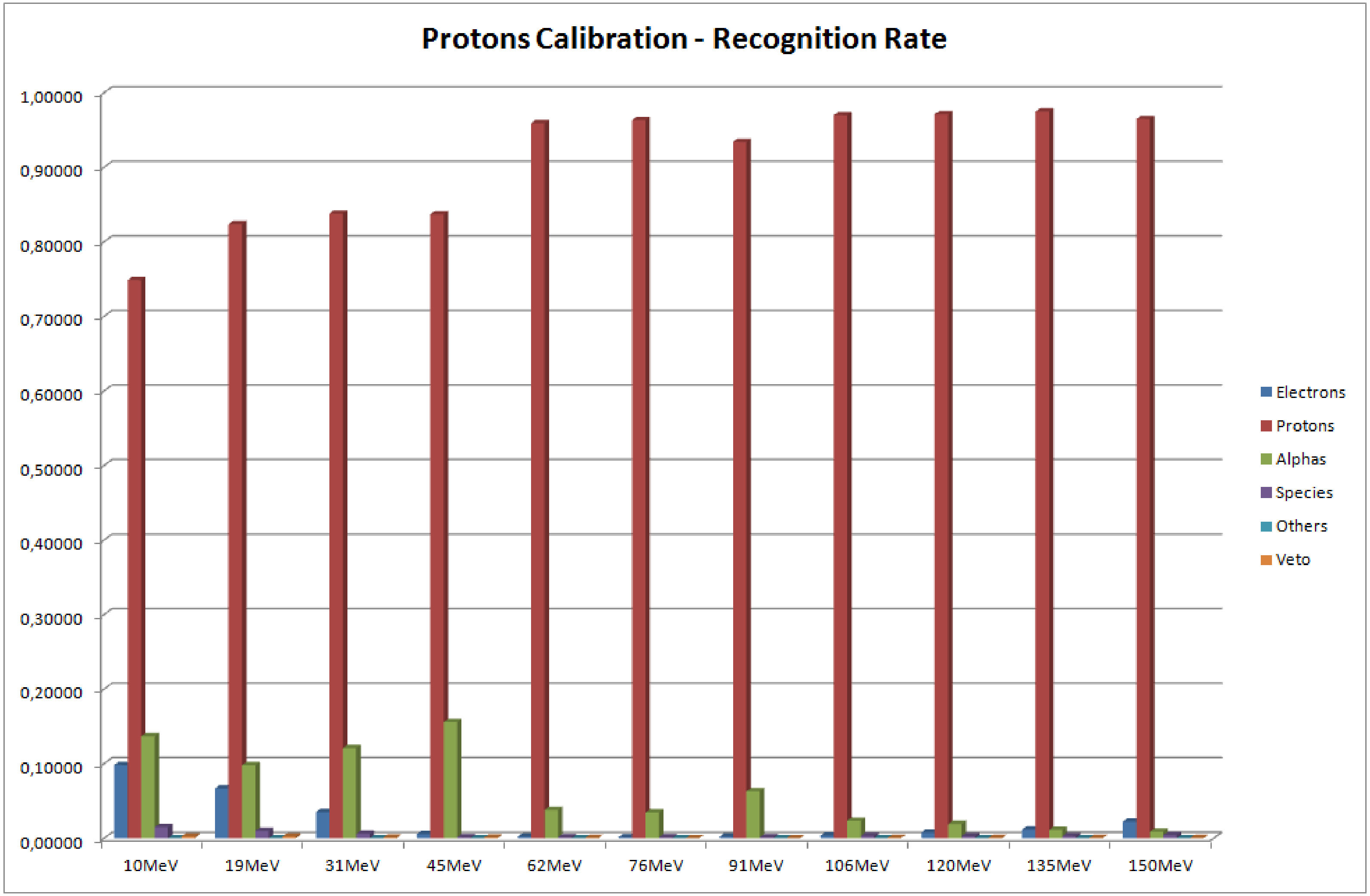
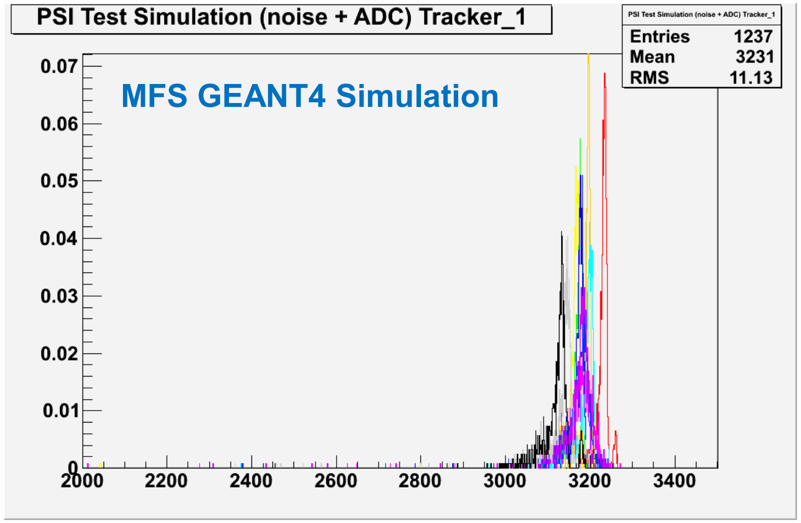
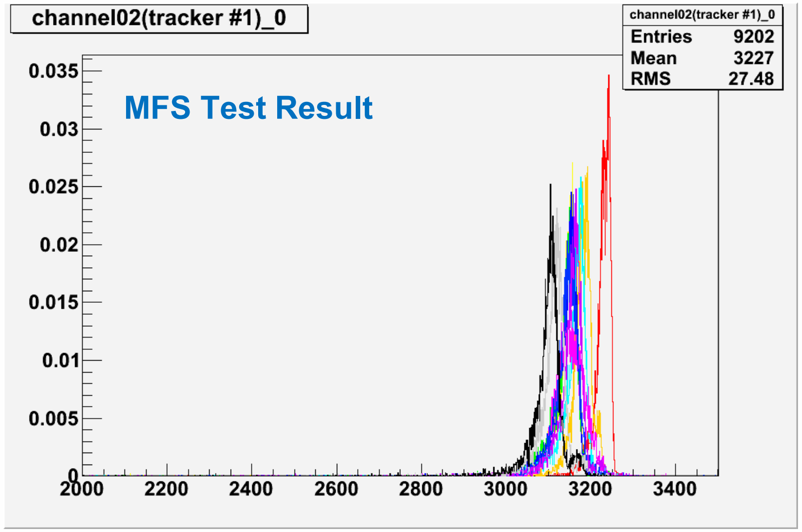


CORRELATION: SIMULATION VS TEST

- GEANT4 simulation comparison versus particle accelerometer campaign shows good correlation
- Test at PSI were checked against GEANT4 simulations in order to verify instrument performances and particle separation capability
- Full correlation exercise were performed at EFACEC premises with backlog data

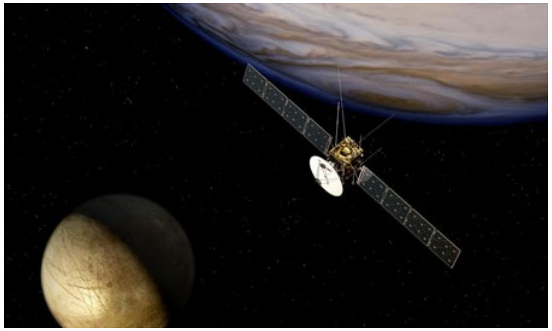




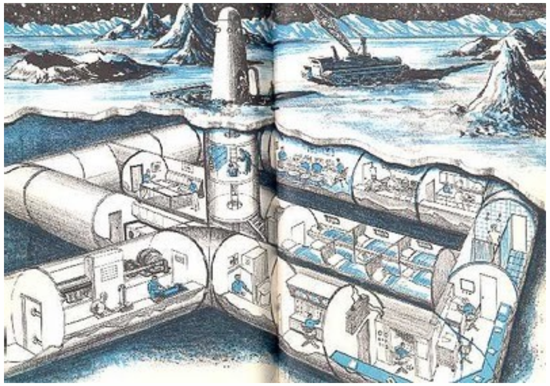
FUTURE APPLICATIONS

Radiation monitoring will always be a need in space environment:

- Jovian missions (to Ganymede, Europa and Callisto) will enhance this need due to the high energy particles trapped by Jupiter. More accurate and bigger dynamic ranges will be required. More radiation hardness will be needed.



- Moon stations will need radiation monitoring and alert systems. Study of long term radiation effects will be needed. Shielding techniques need to evolve.



- Mars missions will require similar needs due to the limited magnetic field of this planet.

- Earth applications will also be a need and can profit Space developments

- A long path to be performed…

THANK YOU