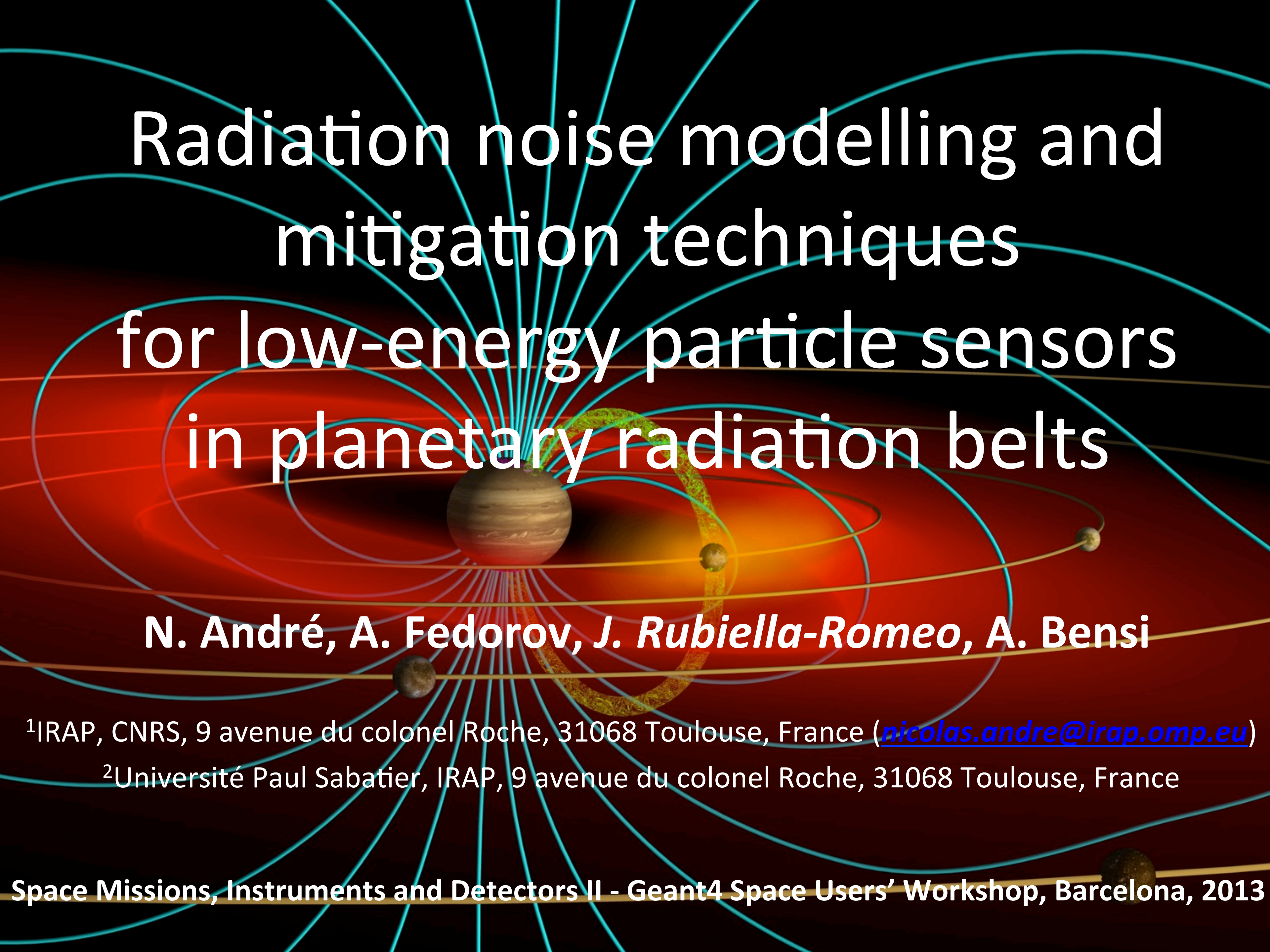

Radiation noise modelling and mitigation techniques for low-energy particle sensors in planetary radiation belts

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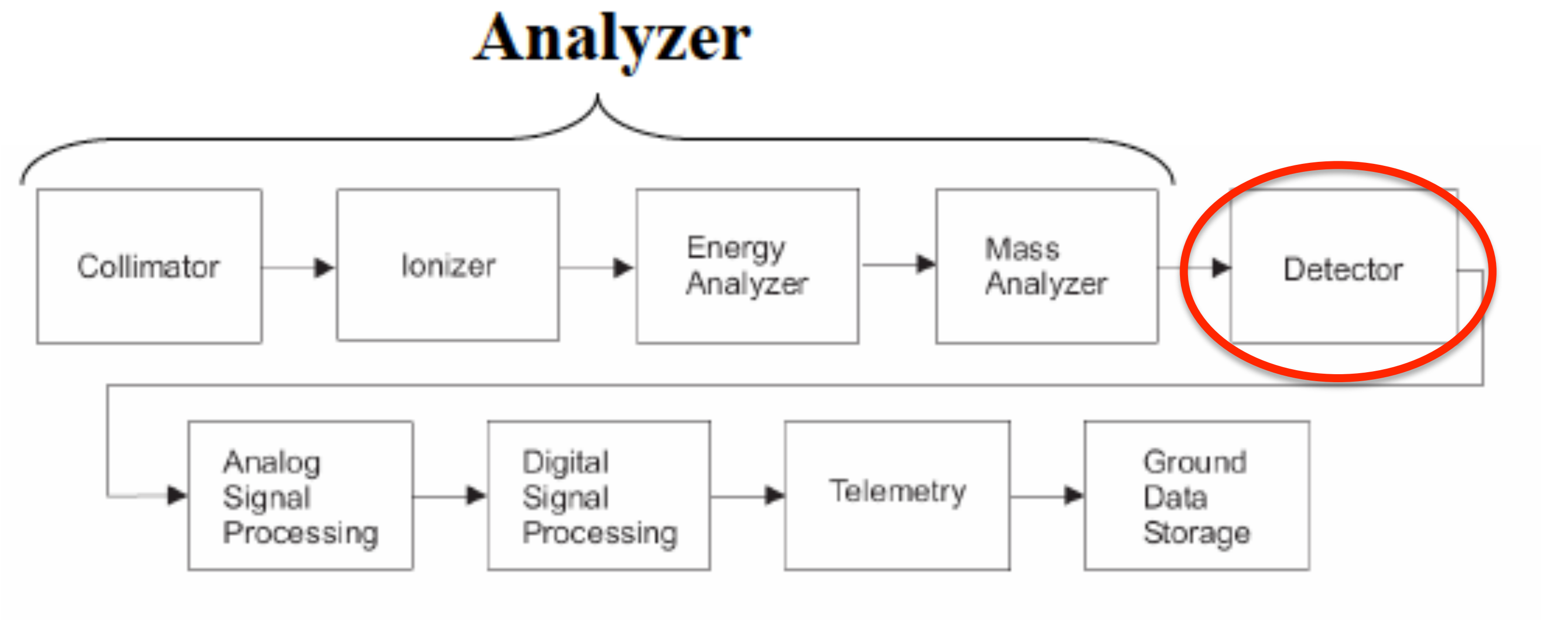
Space Missions, Instruments and Detectors II - Geant4 Space Users' Workshop, Barcelona, 2013

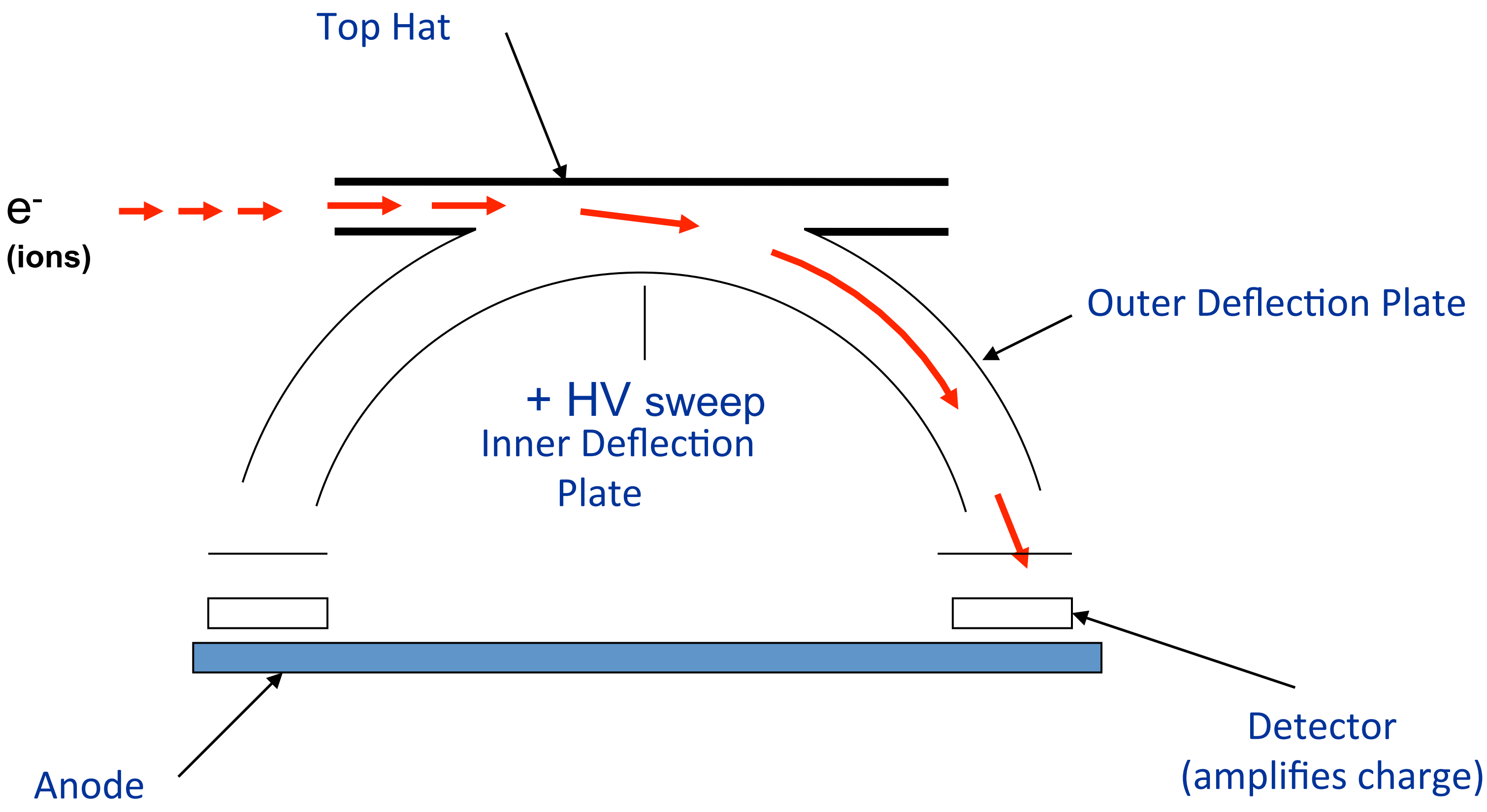
(Charged) Particle sensors

- Principle of operations



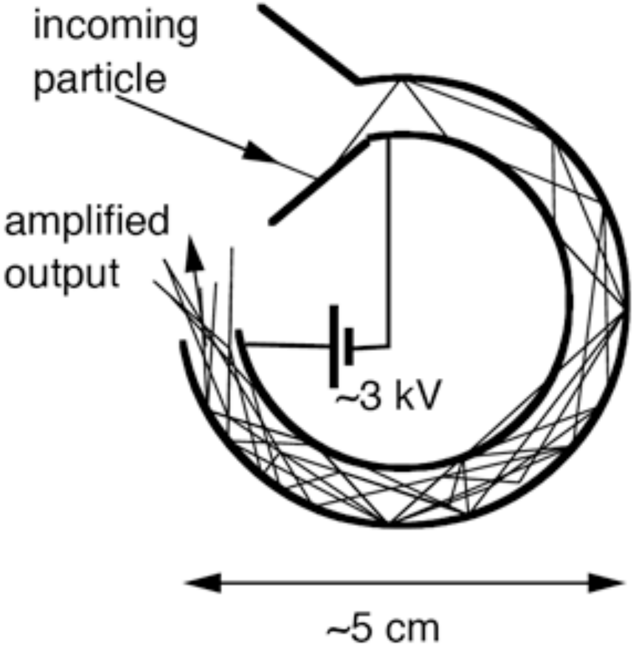
Top-Hat Analyzer

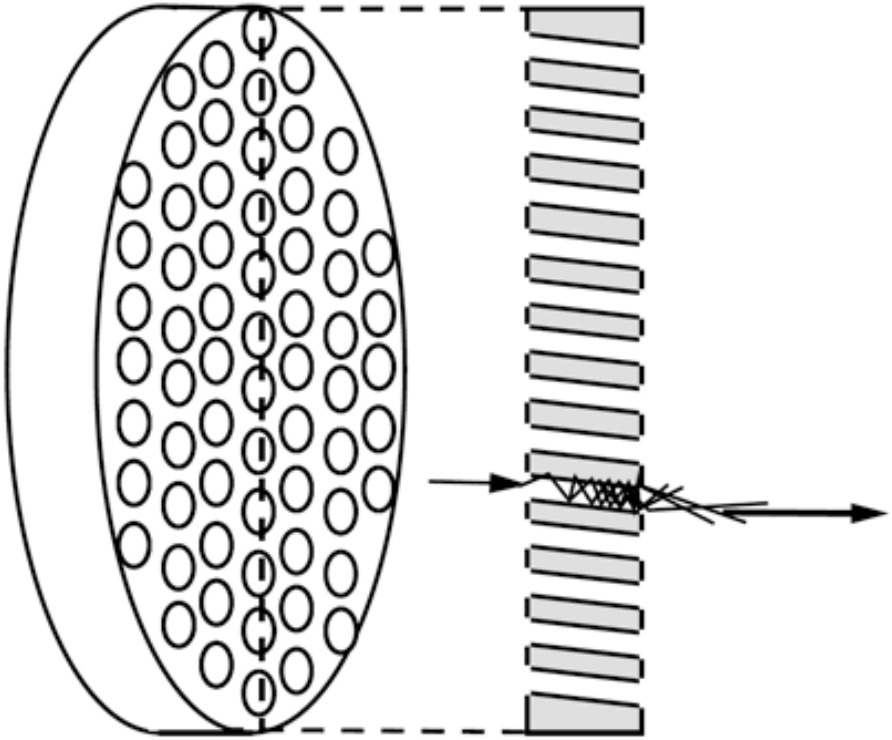
- Enables simultaneous angle-resolved measurements over 360° FOV
- Selects particles by E/q (e.g., 1 eV-30 keV)



Detectors

- Channeltrons (CEM) / MicroChannel Plate (MCP)





- Secondary electron multiplication from one incident particle

Penetrating particles/Background noise in real space environment

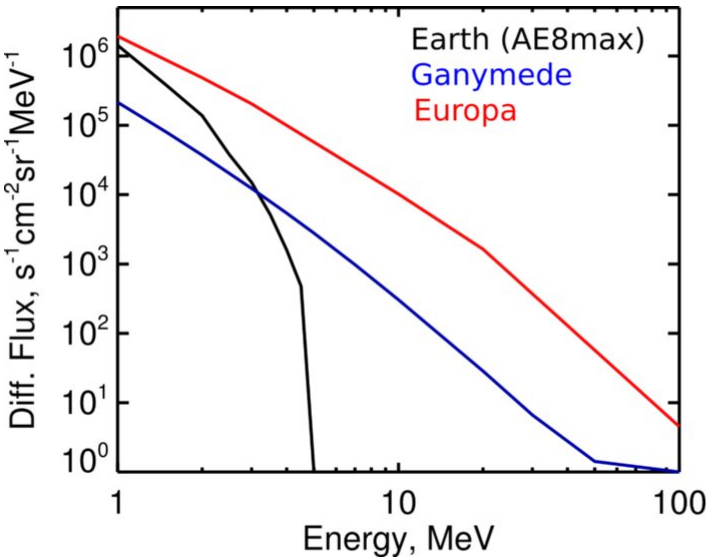
GEANT 4 simulation
Of the full sensor removed

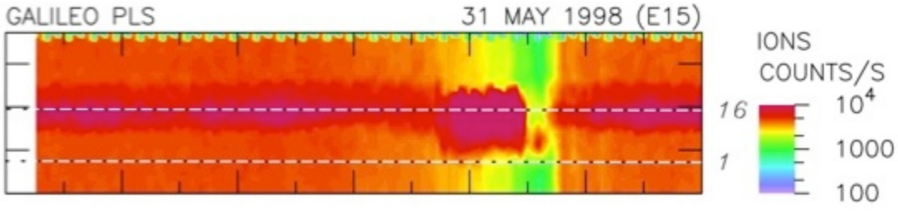
in red: electrons.
in green: photons.

- Signal: particles in a well-defined energy range
- Background Noise: high-energy incident penetrating particles
  + secondary electrons (interactions)
  + photons - X-rays, gammas (interactions)

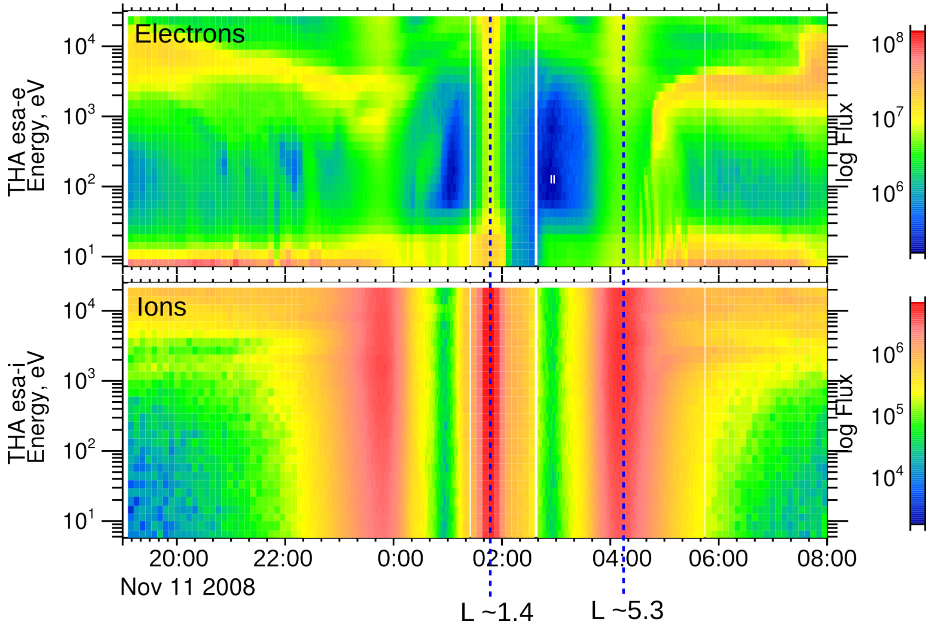
Galileo @ Jupiter

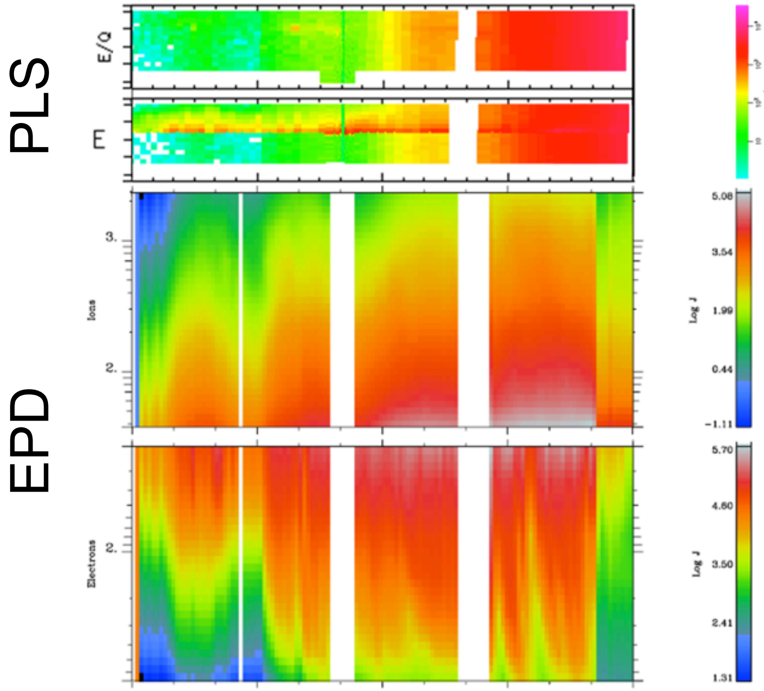
Europa and Ganymede flybys





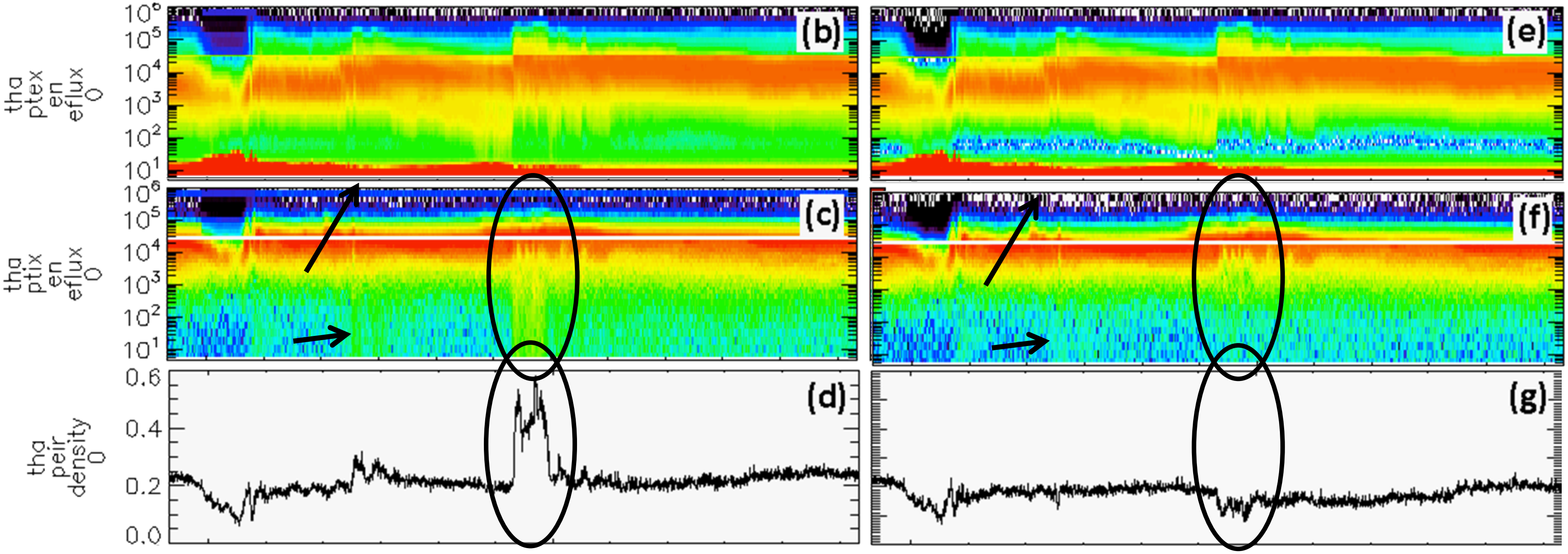
THEMIS @ Earth





THEMIS A @ Earth

Courtesy Laurianne Palin, IRAP



w/o penetrating particle correction

with penetrating particle correction

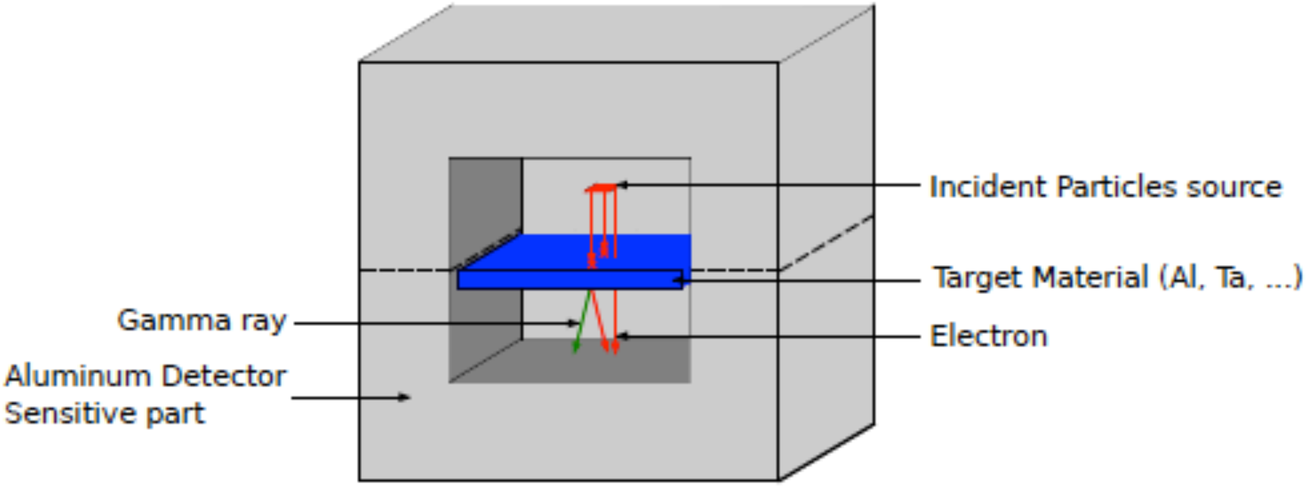
Physical understanding of particle-matter interactions

1) Response of a simplified model (slab) under an electronic or photonic beam (effects of material and thickness)

2) Combination of different layers of different material and thickness (multi-layered shielding) under realistic environmental conditions

3) Integration of the identified shielding strategy into a modelled sensor and worst-case analysis (Jupiter)

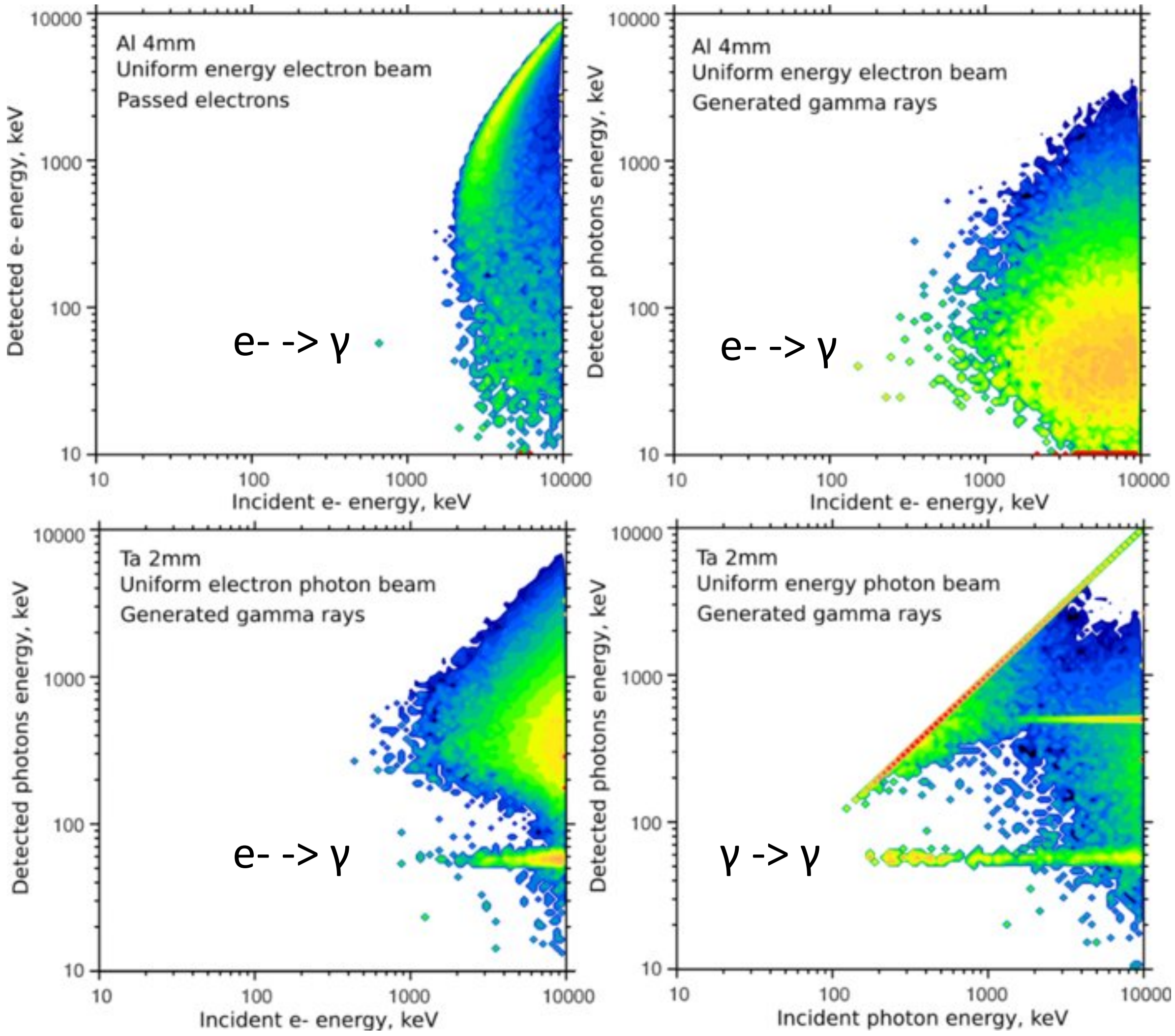
Physical understanding of particle-matter interactions



Work done by J. Rubiella

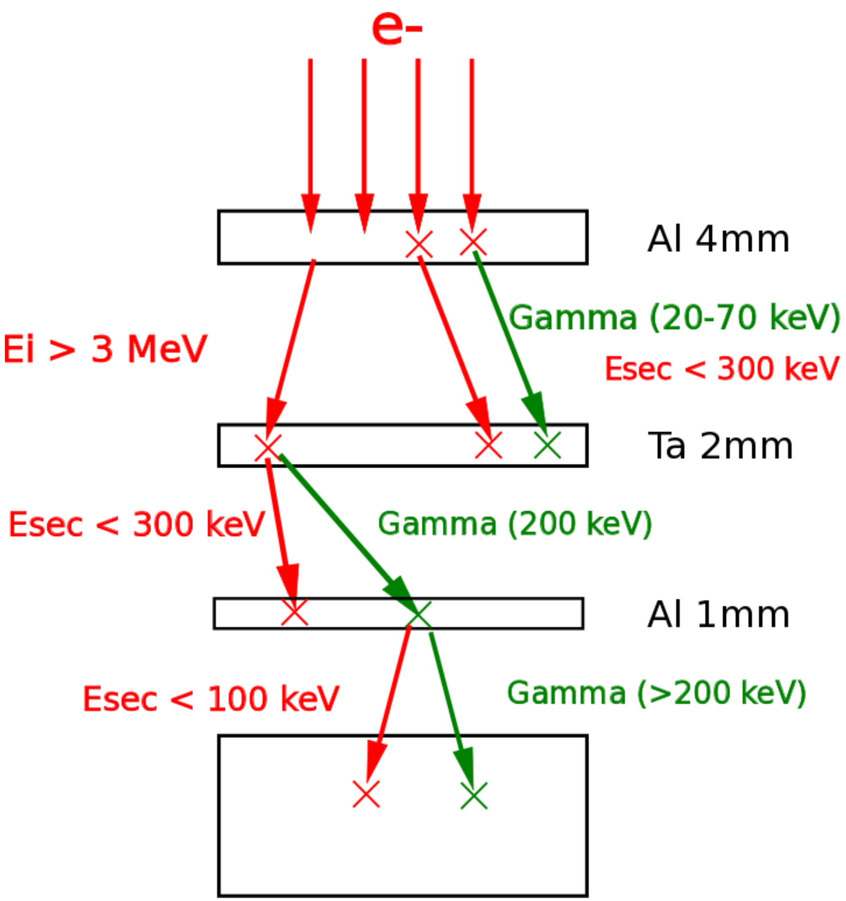
Method: GEANT-4
Source: Planar
Incident particle: Isotropic, electrons or photons
Target: Semi-infinite slab with variable material and thickness
Detector: Thick hollow cube of Aluminium

Aluminium & Tantalum under e- and γ beams



- Al: γ produced around 50 keV, from high-energy e- (>1 MeV); not very efficient to stop γ
- Ta: stops efficiently very high-energy e-, but creates a lot of γ around 60 and 300-500 keV

Multi-layered shielding



Aluminum:

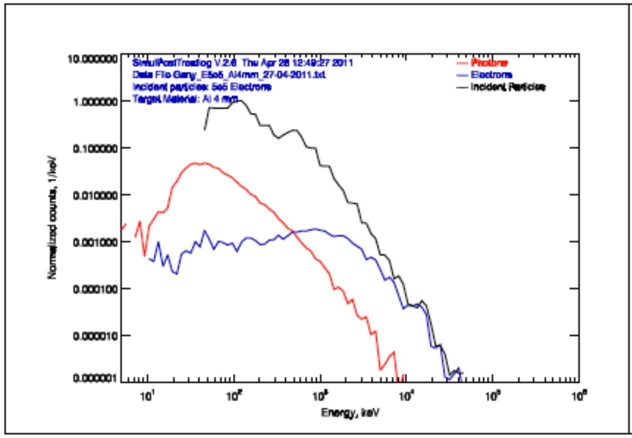
- Absorbs e- of high-energies
- Produces gammas of lower energy (60-70 keV)

Tantalum:

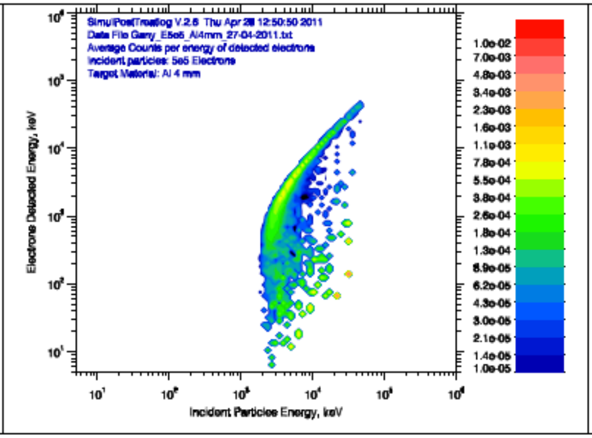
- Absorbs e- of very high energies
- Stops gammas up to 100 keV
- Produces unstoppable high-energy gammas (>200 keV) under e- beam

Multi-layered (Grad-Z) shielding

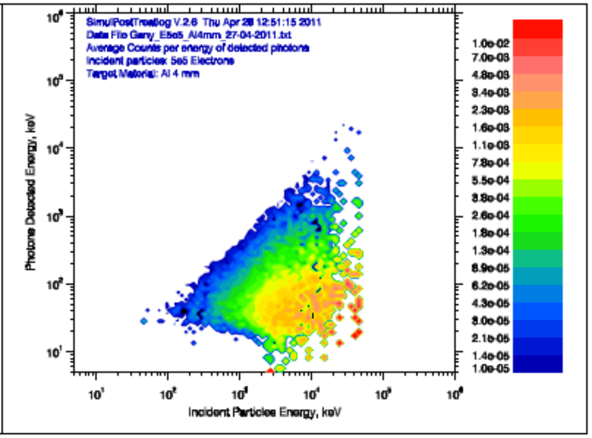
- Add a layer of high-Z material to stop e- > 3 MeV & γ around 60 keV
- Tantalum creates unstoppable gammas of 100s keV



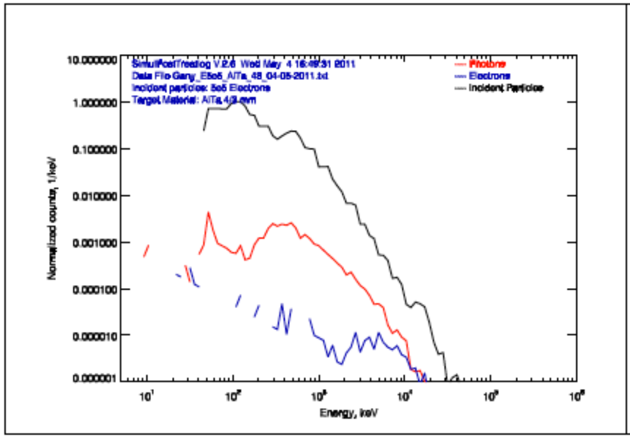
Distribution of detected particles



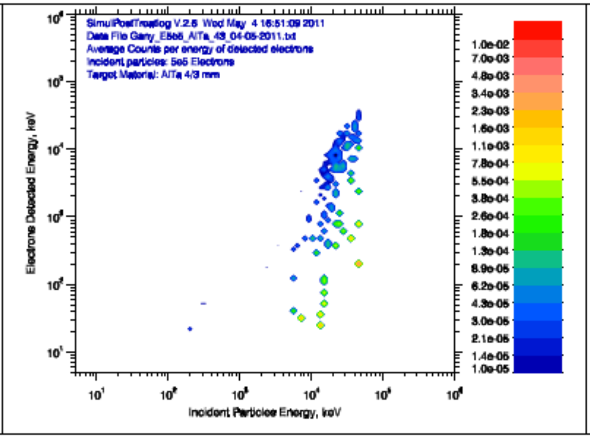
Source : e- , Detected: e-



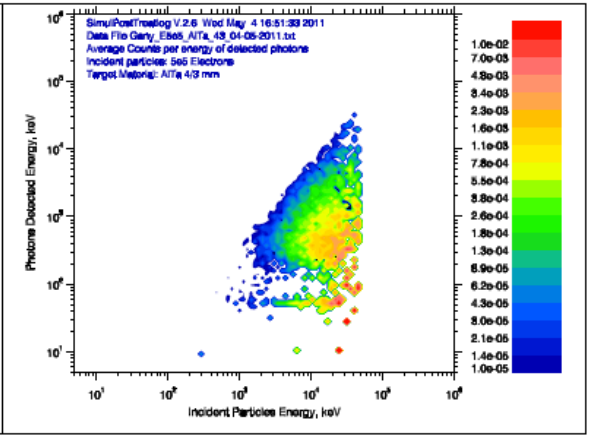
Source : e- , Detected: P



Distribution of detected particles



Source : e- , Detected: e-



Source : e- , Detected: P

Passive shielding at sensor level

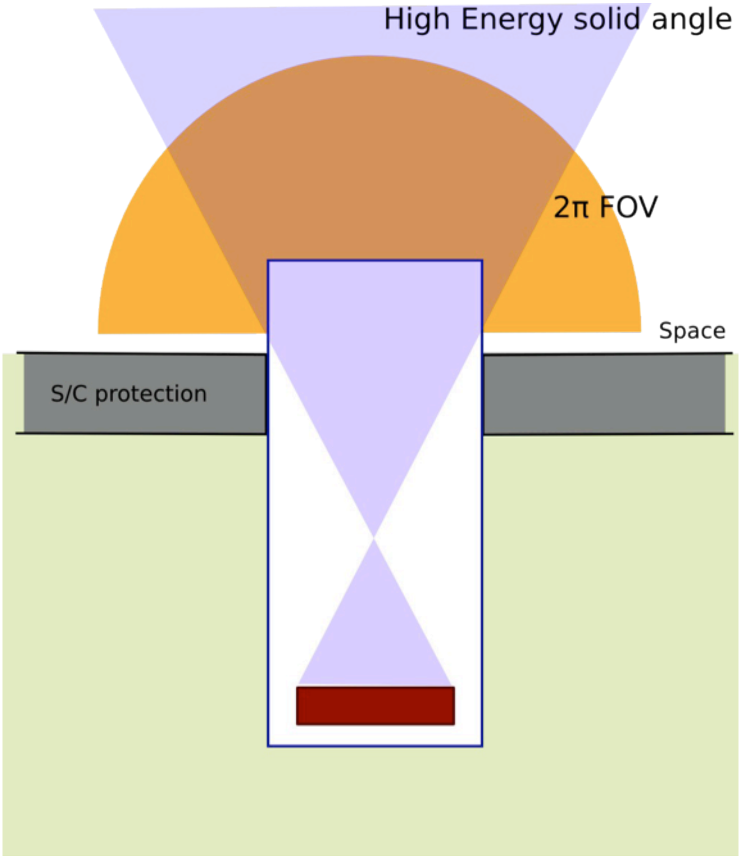


Figure of the full sensor removed

IRAP proposed PASTELS sensor for JUICE (*A. Fedorov*)

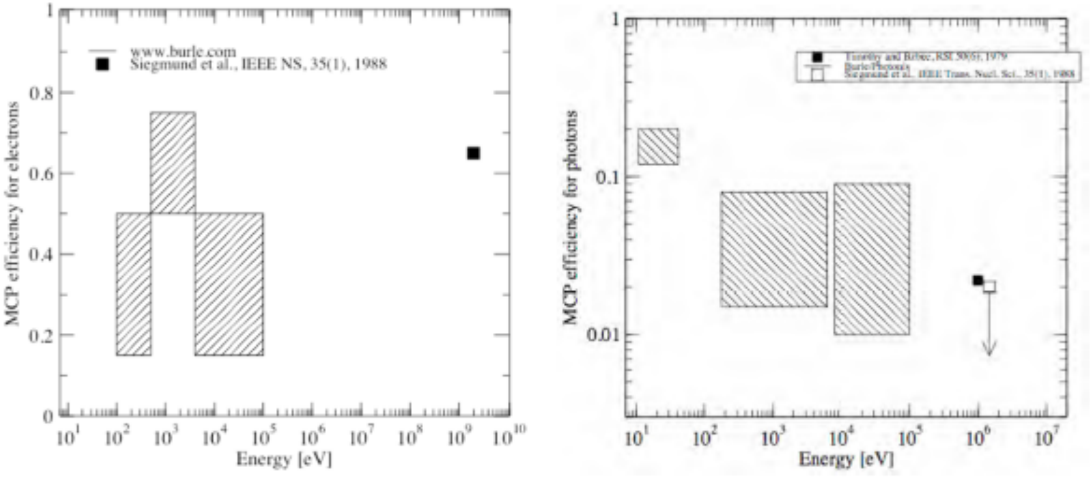
One further step required to obtain the real background noise

- GEANT-4 simulations give the electron and gammas/X-rays count rate for an ‘idealised’ detector
- Efficiency of the detector to incoming particles (heterogeneous source) to be taken into account to obtain the real background that will be measured

i.e., to calculate the real detector count rate, we have to make a convolution of this function with the incident electron distribution, and normalize the resulting count rate to the real CEM “effective aperture”

Efficiency of the detector ?

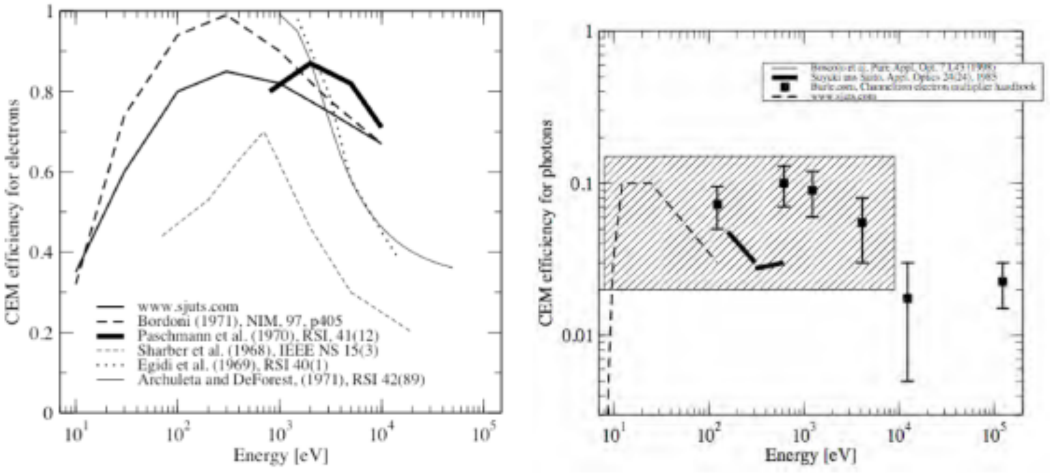
MCP



(a) électrons

(b) photons gammas

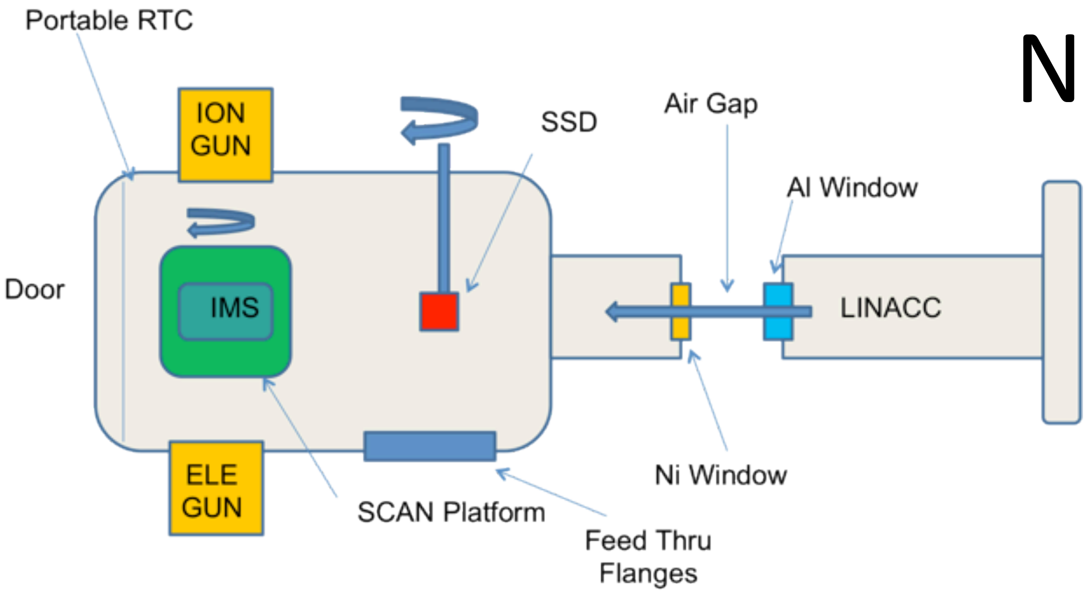
CEM



(a) électrons

(b) photons gammas

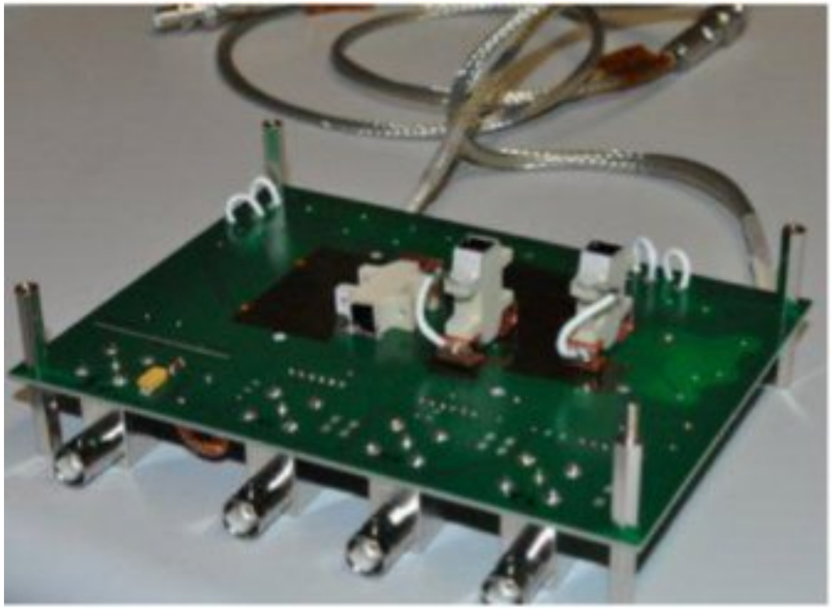
Tests in NIST/LINAC (USA)

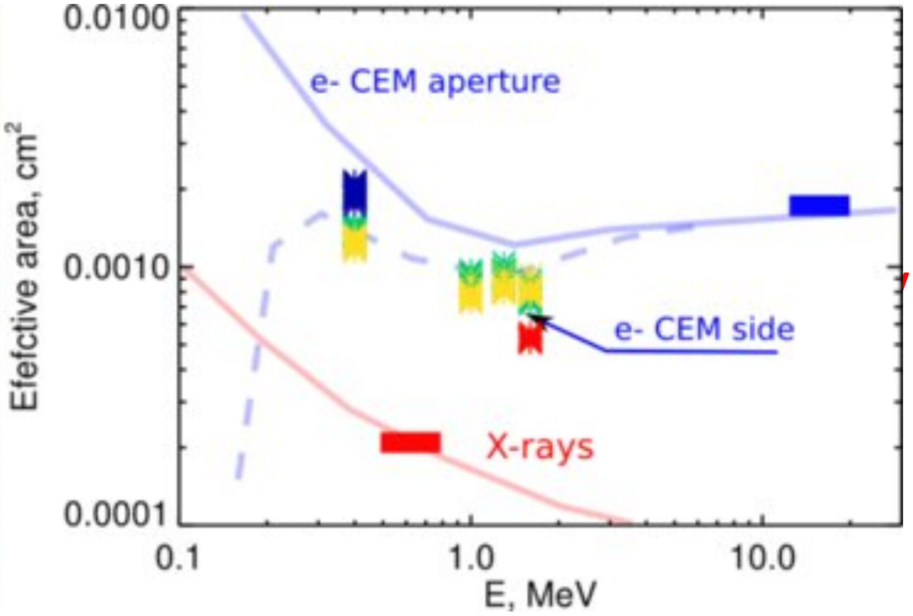


Collaboration with NASA/GSFC

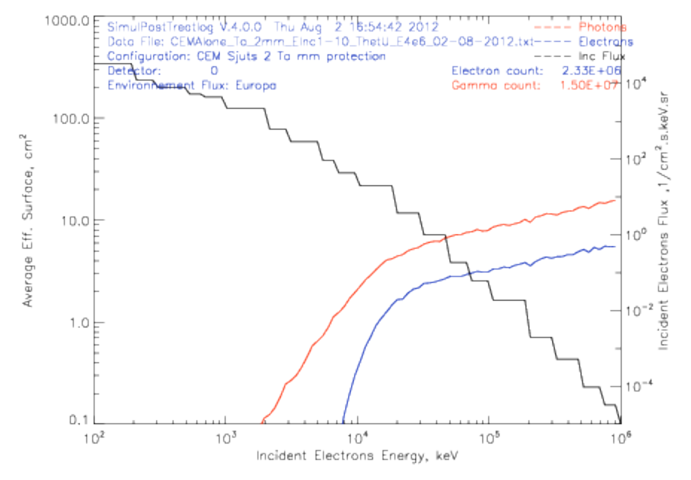
0.4-19 MeV

CEM efficiency determined

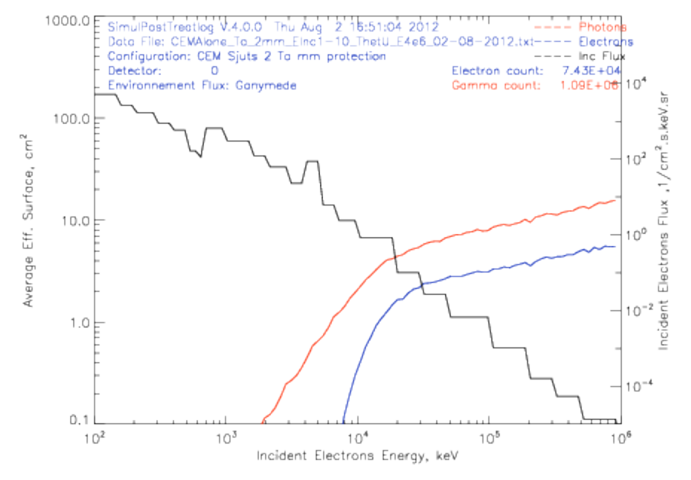




Effective Surface – Galileo PLS



Environnement : Europe



Environnement : Ganymède

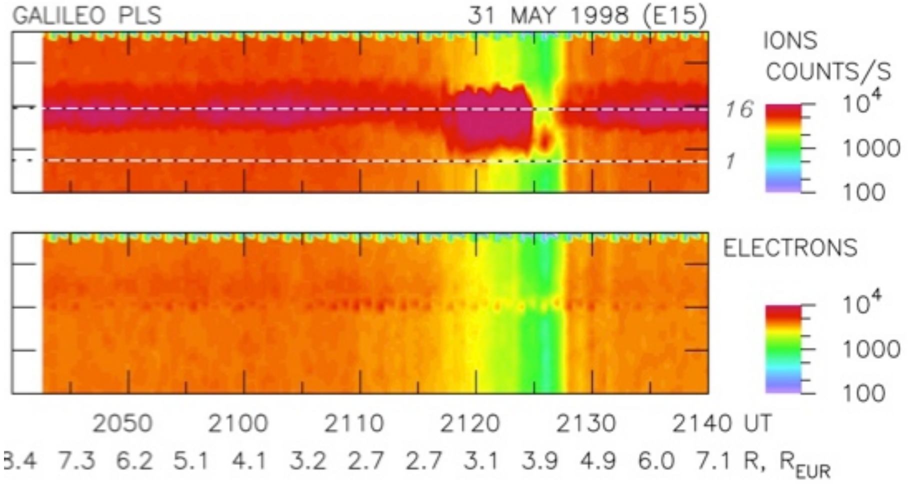
Environnement	Europe	Ganymède
Coups totaux photons	1.50e07	1.09e06
Coups totaux électrons	2.33e06	7.43e04
Coups totaux	1.73e07	1.16e06

GEANT-4 simulation/modelling of the shielded detector

Comparison with measurements

- Galileo PLS

The background rate for one spiraltron as deduced from Galileo PLS measurements during E15 is 4 kHz.



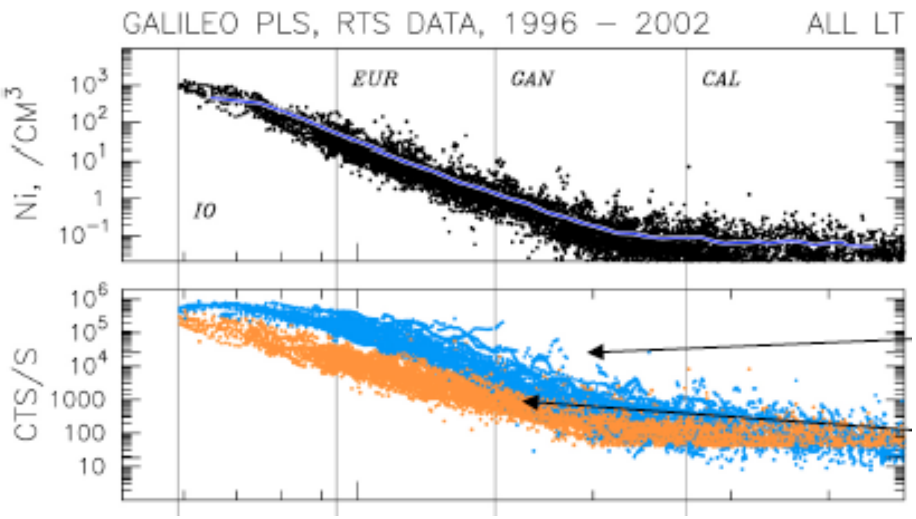
Method: GEANT-4
Detector: CEM
Shielding: 2 mm Tantalum

Total counts for photons : 1.5e07
Total counts for electrons : 2.33e06

With our measured effective surface:

Total counts for photons : 4050
Total counts for electrons : 629
hence a background rate of 4.67 kHz which is close to the deduced Galileo PLS value.

Comparison with measurements



Penetrating background

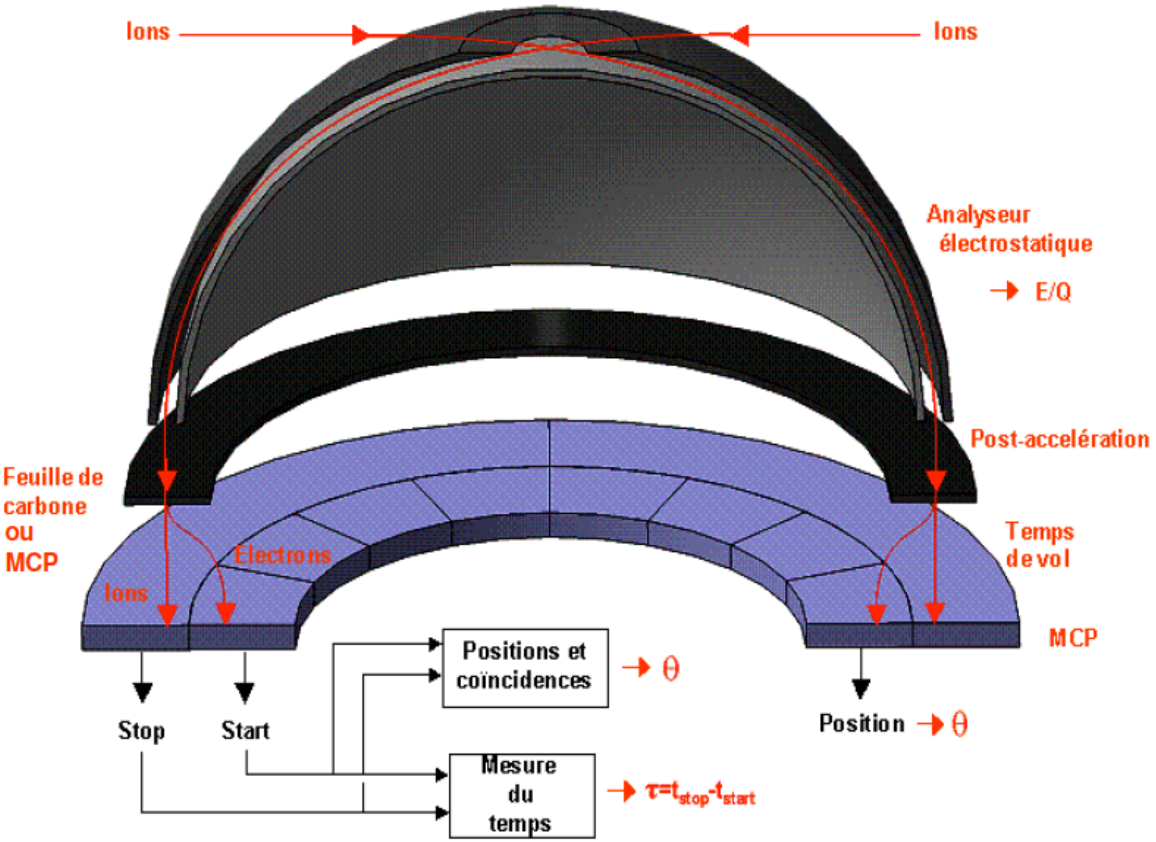
Signal

The average background rates at the orbits of the Galilean moons are listed below in units /cm^2 – s

Io	402071.3	42 SAMPLES
Europa	133236.1	483 SAMPLES
Ganymede	7786.524	325 SAMPLES
Callisto	195.9424	188 SAMPLES

Even with rather effective (passive) protection (e.g., Ta = 9 mm Al) the background noise can be unacceptable (low SNR, saturation) !

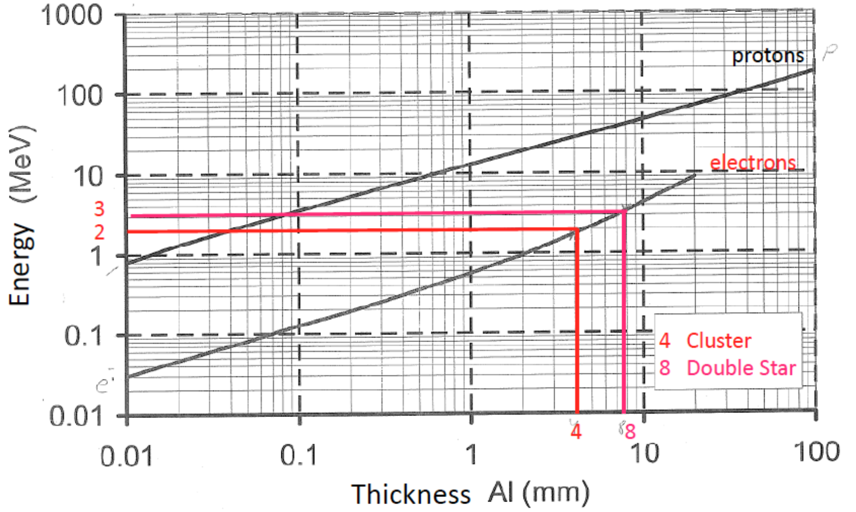
Coincidence

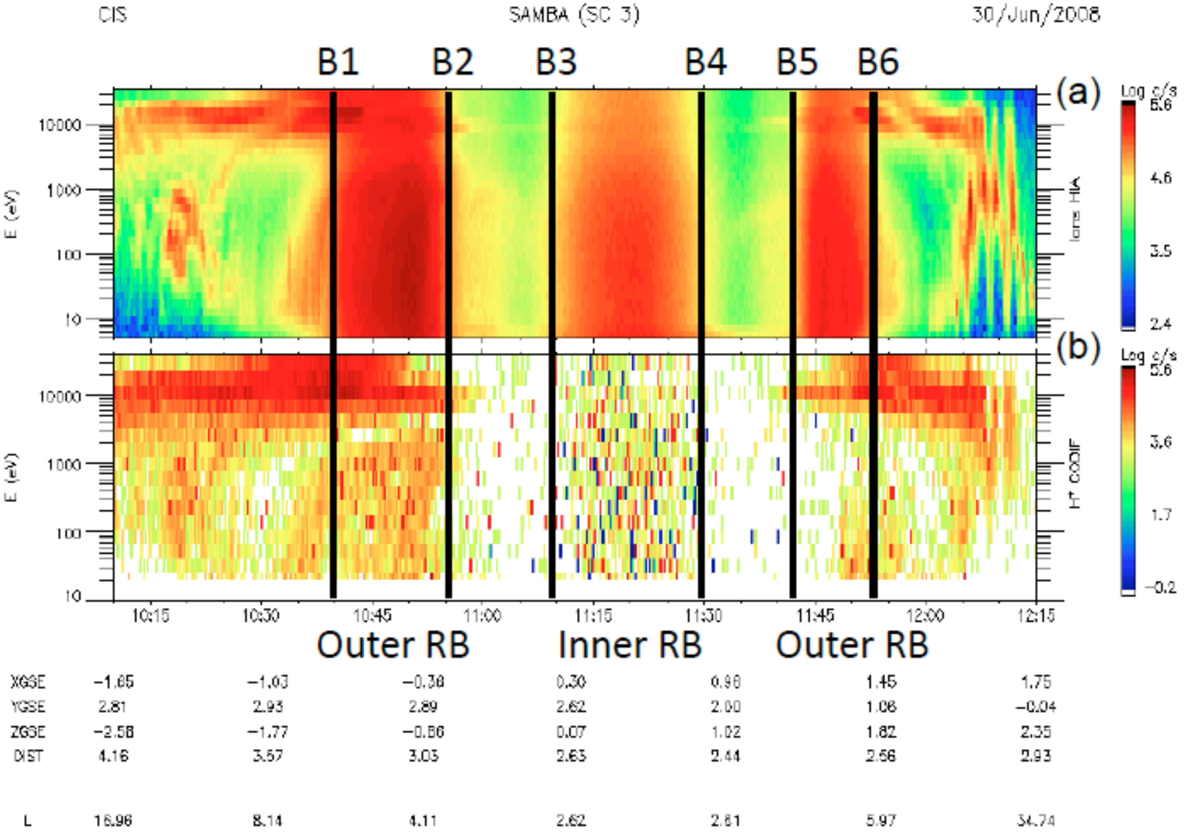


Rates = $R_{start} \times R_{stop} \times \Delta\tau$

Radiation mitigation

Benefices of coincidence clearly demonstrated here





Without
the coincidence signal

Using the coincidence signal

Cluster CIS CODIF/HIA

Conclusions

The combination of

1. an efficient passive multi-layered shielding,
2. a customized coincidence scheme,
3. ceramic channeltrons (CEMs) and
4. radiation-hardened ASIC front-end electronics (FEE),

allows optimal science performances for a low-energy electron spectrometer in planetary radiation belts

Figure of the full sensor removed

Protection	Europa (raw/coinc)	Ganymede (raw/coinc)
Behind 2 mm Al	9000 s^{-1} / 1.6 s^{-1}	850 s^{-1} / 0.01 s^{-1}
Behind 8 mm Al	3500 s^{-1} / 0.3 s^{-1}	150 s^{-1} / 0