The 3DEES concept

by

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Outline:

- Introduction
  - Motivation
  - Requirements
  - Basic concepts
- The 3DEES concept
- 3DEES concept validation
- Conclusion

The "High-Fidelity 3D Energetic Electron Spectrometer" (3DEES) concept

Motivation (Do angular distributions matter ?)

- Energetic electrons are sources of hazardous effects on spaceborne systems including TID, DD and Internal Charging;
- Studies show that the physical process leading to the production of these energetic electrons affect (initial population) electrons in ways that depend on their pitch angle.

Mostly in inner belt

Mostly in outer belt

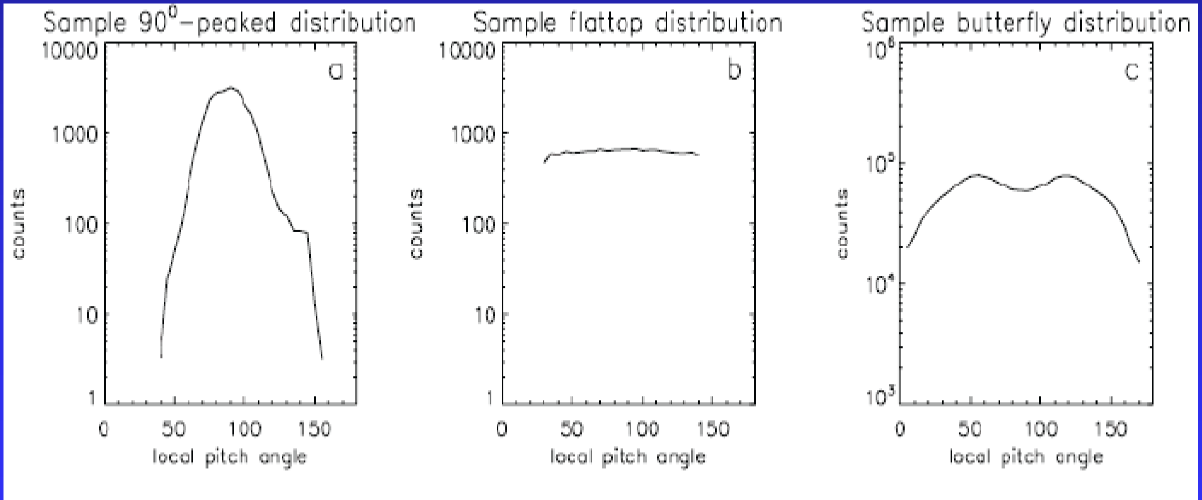


Figure 1: Typical pitch angle distributions of 510 keV electrons in the radiation belt.

(Gannon et al., 2007)

(Benck et al., 2010)

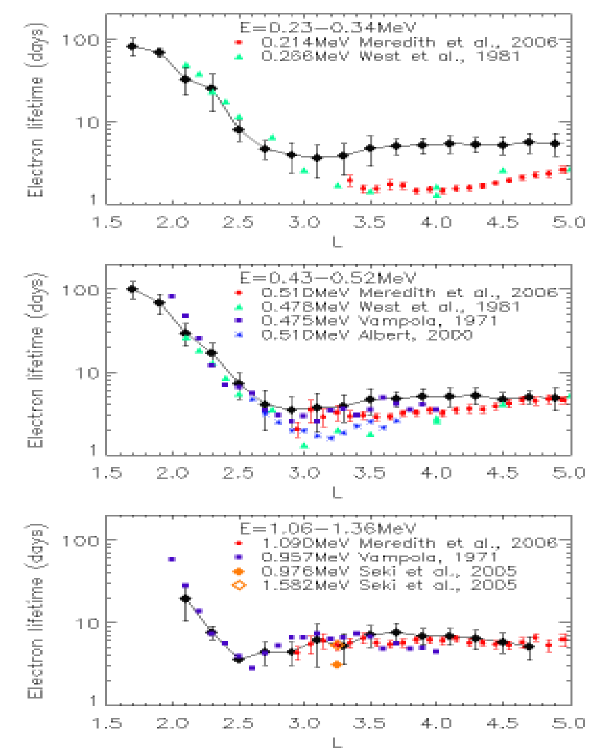


Fig. 4. Observed lifetimes (black dots) versus L for three different energy ranges. Comparison to other measured decay timescales taken from the indicated references.

Requirements - Functional

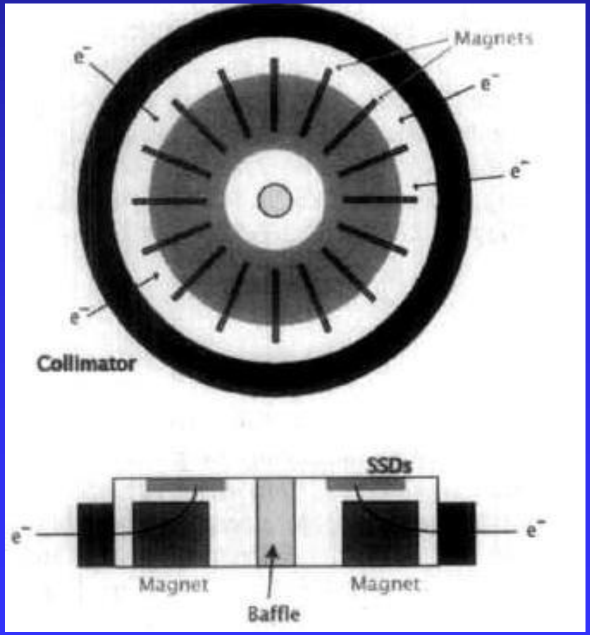
	Functional requirements		Compliance
FR1.	Particle discrimination	The 3DEES shall be equipped with an in-flight particle discrimination capability for most of the energy channels	Yes
FR2.	Directional coverage	The 3DEES shall be able to measure the directional energy spectra covering a quasi-complete angular distribution (at least 12 angles (wrt the magnetic field) distributed within two planes).	Yes
FR3.	Magnetic Field measurement	The 3DEES shall be able to deduce the local magnetic field direction to accuracy sufficient for creating pitch-angle dependent electron flux models.	Yes
FR4.	Energy coverage	The 3DEES shall be able to measure directional spectra of highly energetic electrons: 100 keV – max 10 MeV.	Yes
FR5.	Space Weather services	The 3DEES shall provide near –real-time electron flux information	Yes
FR6.	S/C Alarm	The 3DEES shall provide a radiation alarm function to the hosting spacecraft. Within this context, in addition to flux measurements, the contribution of particles of a given energy to the dose in the gate sensor shall be monitored and provide, through cross-calibration, real-time data on the doses in other components onboard the S/C.	Yes
FR7.	Data reduction/storage	The 3DEES shall have capabilities of data reduction and storage in line with autonomy and data rate requirements for the target mission.	Yes
FR8.	TM/TC	The 3DEES shall include a spacecraft TM/TC interface compatible with the target mission baseline.	Yes
FR9.	Built-in test	3DEES design shall include built-in test functions for front-end detector and in-flight health check.	Yes
FR10.	Sensor	The 3DEES shall include the ability to isolate erroneous sensor elements.	Yes
FR11.	Auto-calibration	The 3DEES shall continuously acquire the average value of the energy deposited in critical sensors by particles recorded in a dedicated channel. These averages will be monitored all along the instrument operation time so as to detect any calibration degradation.	Added

Requirements - Performances

	Performance requirements		**Compliance**
PR1.	Mass	≤4kg + ~20%margin (12 angles)	Yes
PR2.	Power consumption	≤6W	Yes
PR3.	Volume	limited by the mass	partly (4 dm^3)
PR4.	Energy measurement range	lower limit: ≤100keV upper limit: 10 MeV (except LEO: 5 MeV)	Yes
PR5.	Energy resolution	0.1-2 MeV: 8-10 quasi-logarithmic bins > 2 MeV: 4-6 quasi-logarithmic bins	partly (16 or 32)
PR6.	Energy accuracy	10-20% depending on the energy	partly (≤10%)
PR7.	Angular resolution	10-15°, 25° are acceptable if there is no impact on the particle discrimination capability	No (5°)
PR8.	Angular binning	at least 12 angles	partly (18)
PR9.	Angular coverage	pitch angle coverage: 7.5°- 172.5° for PAD determination; 0° - 180° if loss cone studies are foreseen.	Yes
PR10.	3D-coverage	Assuming a 3-axis stabilized S/C: distribute the various viewing angles (polar angles with respect to the magnetic field) of the detector in at least two perpendicular planes	Yes
PR11.	Electron detection rate	lower limit (LL): <10^3#/(cm^2 s) upper limit (UL): 10^9#/(cm^2 s) (LL:10#/(cm^2 s), UL: 10^8#/(cm^2 s) for LEO)	Yes
PR12.	Purity of electron channels	≥90% in the final electron energy channel	Yes
PR13.	Time resolution	10 seconds – max 5 min (except LEO: 1 sec for the lower limit)	Yes
PR14.	Instrument lifetime	≥ 5 years in GTO	Yes
PR 15.	Target orbit	GTO or GEO, MEO	Yes

Basic concepts - Magnetic deflection-based systems

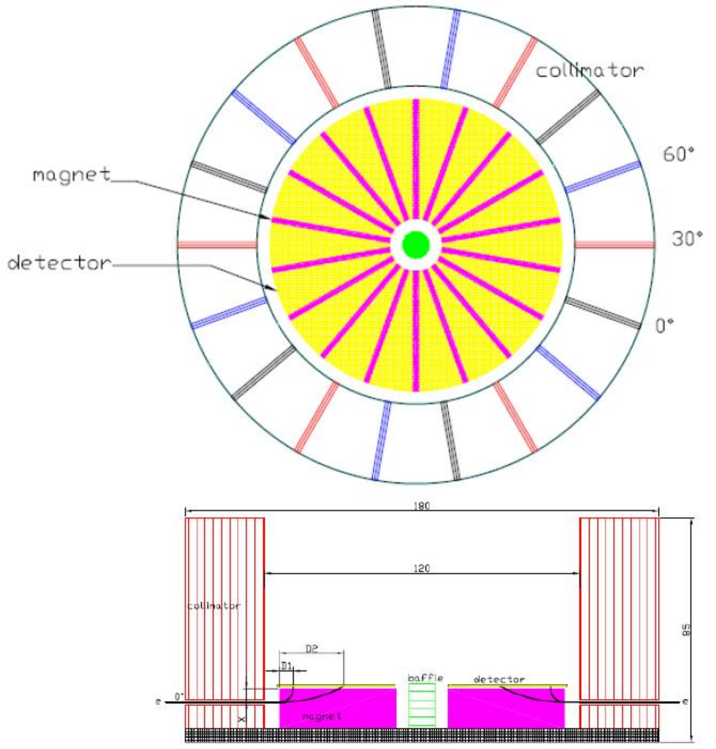
Magnetic deflection-based systems are know to perform excellent e-/p discrimination. What are their performances for energetic electrons?



(G.C Ho et al., 2003)

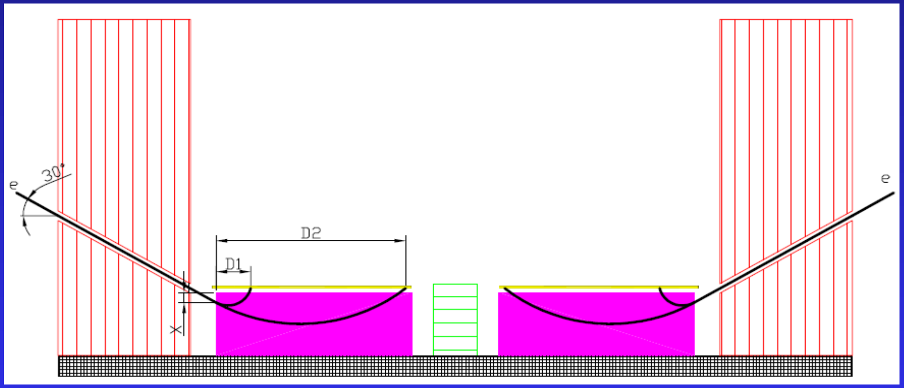
The Miniaturized Electron Magnetic Spectrometer (MEMS) was designed to measure 0.05 – 1.5 MeV electrons using PSD along a 360° range of azimuth angles.

Is it suitable as a starting point for a 2π Field Of View coverage with 18 boresight angles (2 kGauss magnetic field required for 0° incidence angle) ?

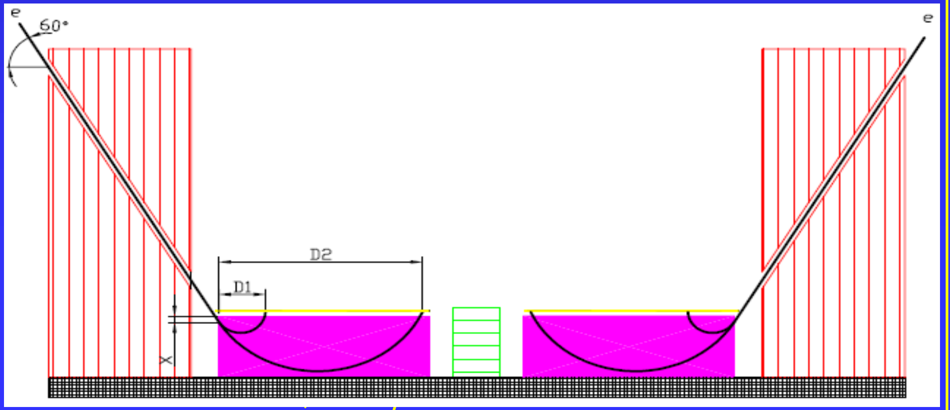


Basic concepts - Magnetic deflection-based systems (ctd)

2 kGauss bend up to 5 MeV electrons onto the PSD, when the incidence angle is 30° wrt instrument axis.



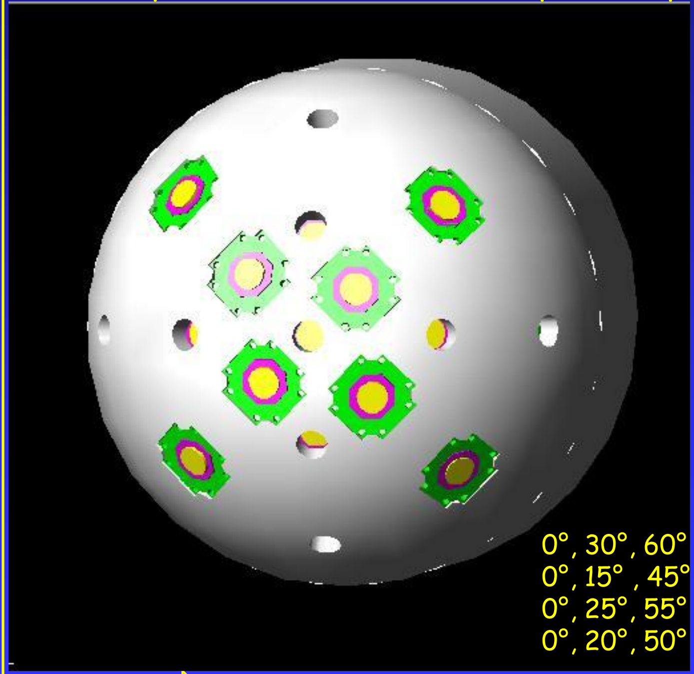
2 kGauss bend up to 2 MeV electrons onto the PSD, when the incidence angle is 60° wrt instrument axis.

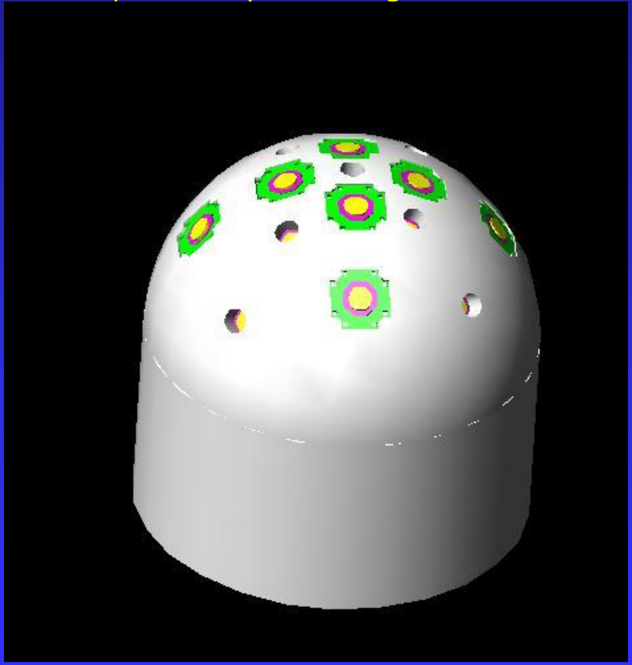


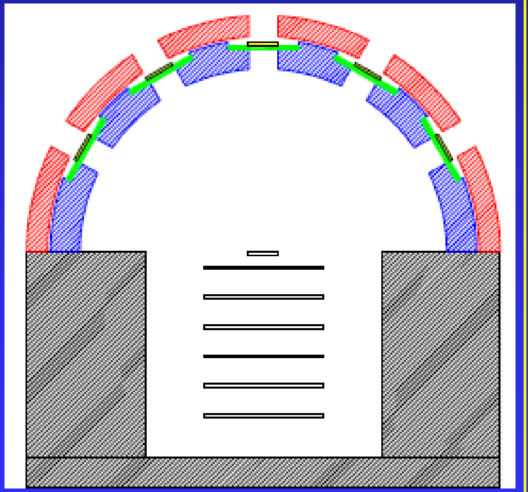
This solution is discarded since it does not comply with the upper energy limit (10 MeV) requirement for all incidence angles.

Basic concepts – Dome-shaped systems with common central "calorimeter"

Domes are mechanical structure that come in mind whenever angular distributions have to be measured, but they are not easy to manufacture, and they do not provide equivalent processing for all incidence angles.



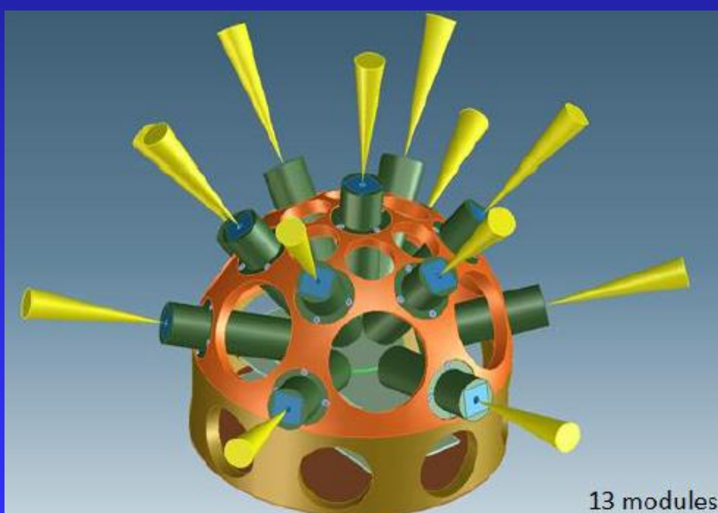


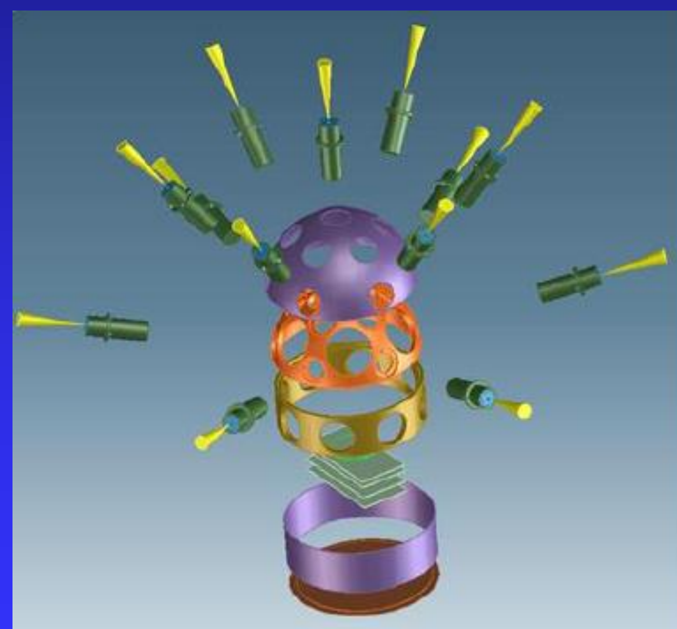


This solution is discarded since it does not comply with the upper energy limit (10 MeV) requirement for all incidence angles.

Basic concepts – Dome-shaped systems with standalone single spectrometer modules

Even when standalone small modules are used, they can lead to cumbersome structures that get out of mass, volume and power consumption contraints.





Mass (gr)

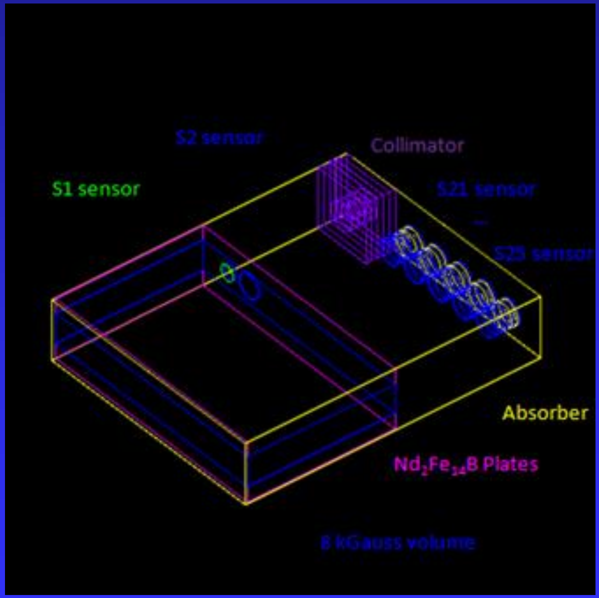
Modules : 13 x 130 =	1690
Dome :	0940
Cylinder :	0850
Bottom :	0370
Shielding :	0750
Electronics :	0700
Total :	5300

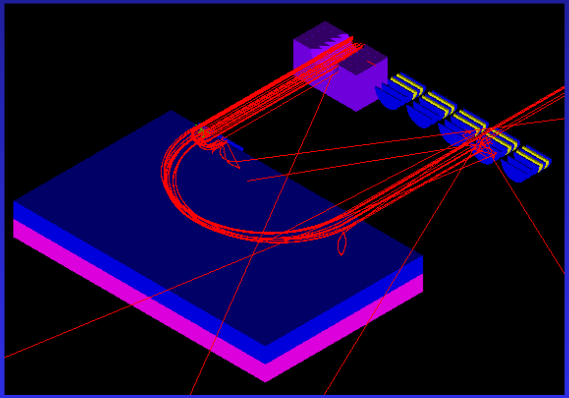
The dome can be reduced in diameter
(It depends on the space needed for Electronics)

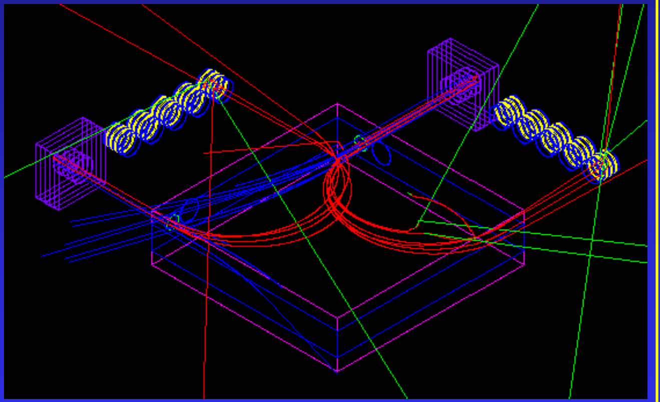
This solution is discarded since it does not comply with the upper volume (27 cm x 22 cm x 20 cm) and mass limits.

Basic concepts – Multiple aperture standalone spectrometer modules

Multiple aperture standalone modules efficiently reduce the mass budget per angle channel…





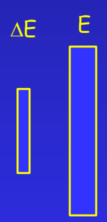


Usually good at providing uncontaminated spectra of energetic electrons.

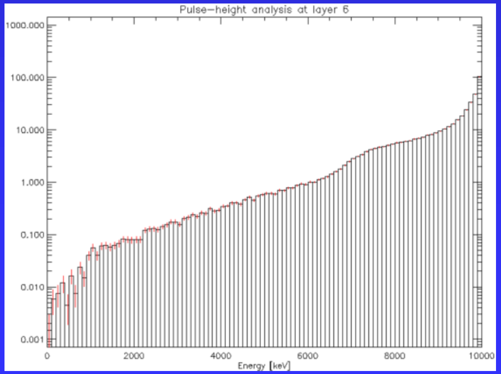
This solution is discarded due to magnetic pollution (>2 kG magnetic field). Moreover ~500 gr must be budgeted for magnet plates only in every double module.

Basic principles and setup

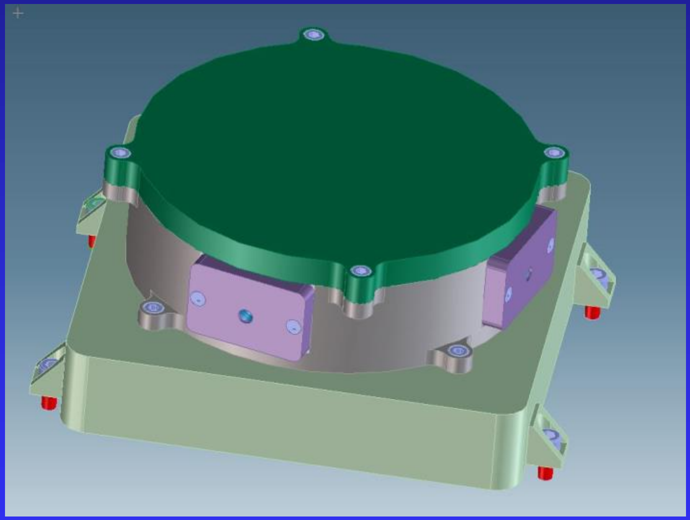
- Keep similarity in all angular channels/apertures;
- Reduce the number of sensors by making some of them shared by many angular channels;
- Design the instrument as an assembly of standalone modules;



- 10 MeV electrons are stopped by a 2 cm thick Si detector (E) or equivalently a combination of Si sensor and energy degrader materials arranged so as to stop 10 MeV electrons;



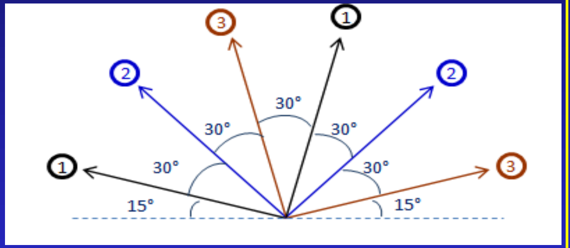
- However, even monoenergetic electrons (10 MeV in example at left) will deposit 0 < E < 10 MeV in the sensor, preventing direct spectrum extraction by differential method;

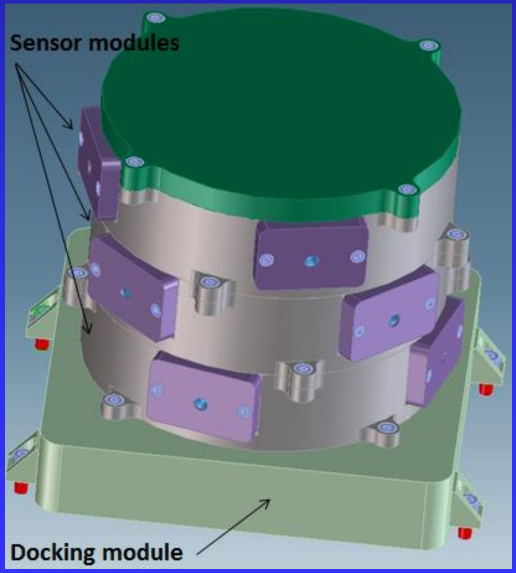


Basic principles and setup (ctd)

- Two orthogonal boresights are implemented within the so-called Orthogonal Sensor Module (OSM);
- Gate sensors (S1) are accommodated on each boresight to provide information on the direction of the incoming electron momentum and to perform e-/p discrimination;
- A validator sensor (S2) is implemented within a stack of Detector & Absorber Modules (DAM). The stack is interrupted by an energy degrader in front of DAM3;
- The 5 mm diameter aperture is followed by a collimator that defines a 7.5° half FOV angle in combination with S1;

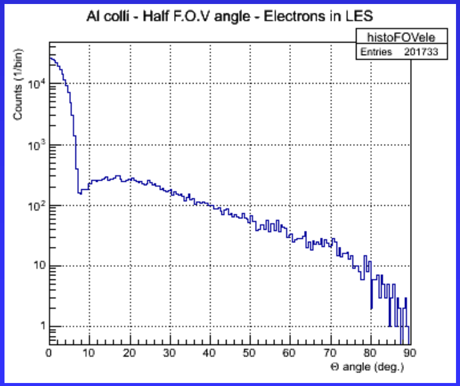
Angle coverage of a PSM



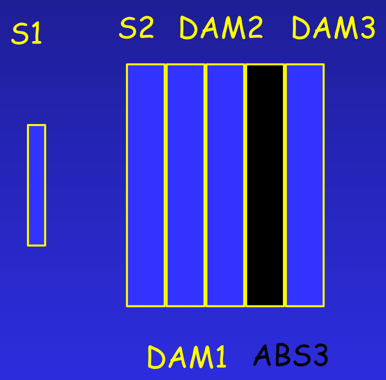


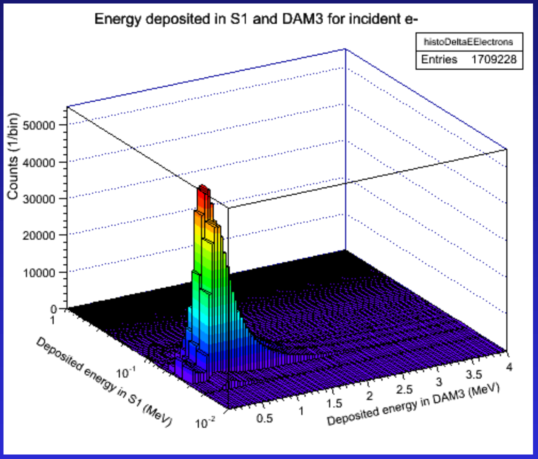
PSM

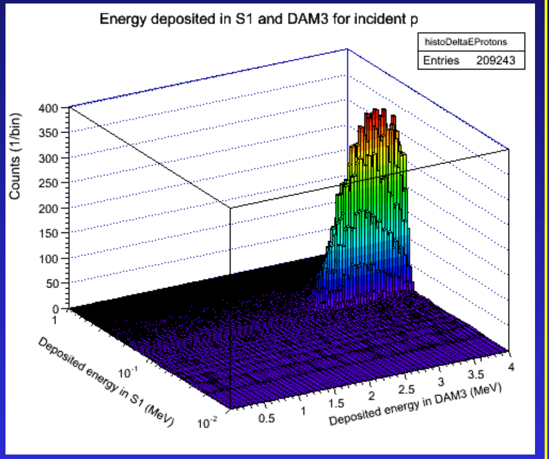
- The OSM diameter does not exceed 150 mm and a 30 mm height.
- The Panoramic Spectrometer Module (PSM) has a ~2 kgs mass and ~2 dm^3 volume. Its target power consumption is <3.9 Watts.

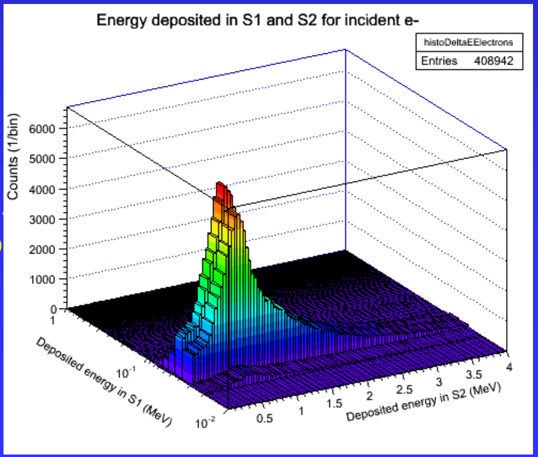


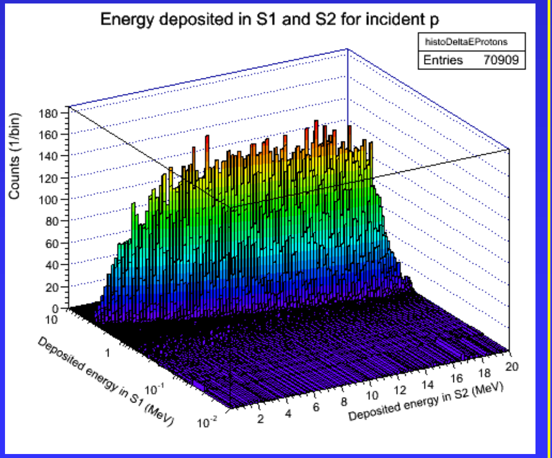
3DEES functionality – e-/p discrimination





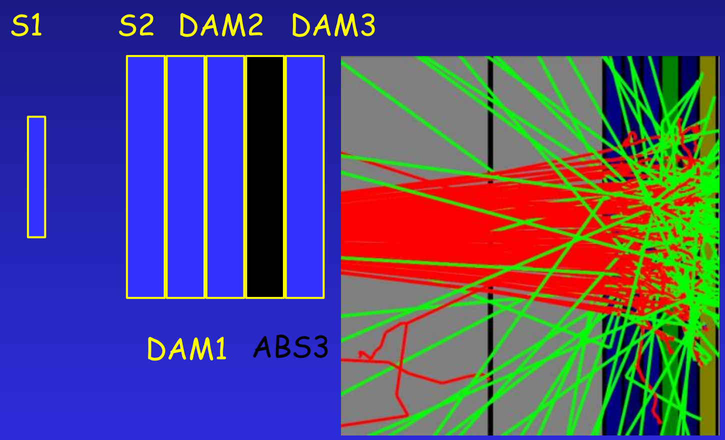






e-/p discrimination is achieved by use of the S1 sensor: the energy deposited by electrons in thi sensor does not exceed 200 keV, whereas proto deposit > 200 keV even at 100 MeV.

3DEES functionality – energy and flux measurement

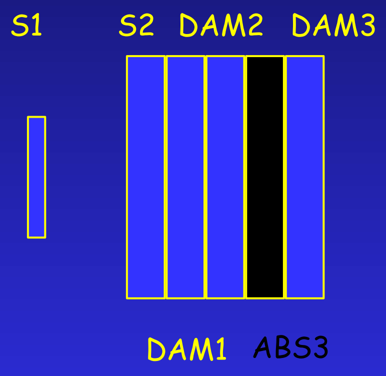


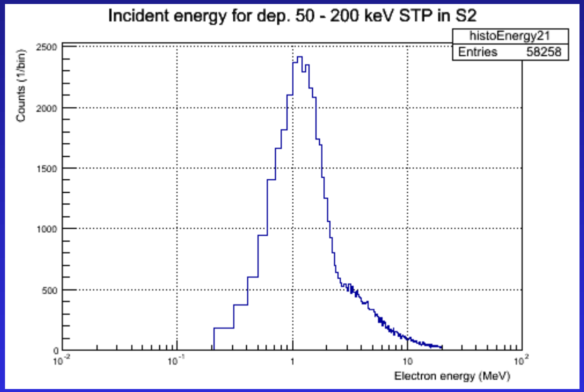
Sensor	Channel	Deposited energy threshold (MeV)	Incident energy threshold (MeV)
S2	S2_1	0.05	0.1
	S2_2	0.15	0.2
	S2_3	0.25	0.3
	S2_4	0.38	0.4
DAM1	DAM1_1	0.50	0.6
	DAM1_2	0.67	0.8
	DAM1_3	0.85	1.0
	DAM1_4	1.16	1.4
DAM2	DAM2_1	1.26	1.9
	DAM2_2	1.76	2.5
	DAM2_3	2.50	3.3
	DAM2_4	3.50	4.5
DAM3	DAM3_1	2.50	6.0
	DAM3_2	3.00	6.5
	DAM3_3	3.50	7.0
	DAM3_4	4.00	8.0

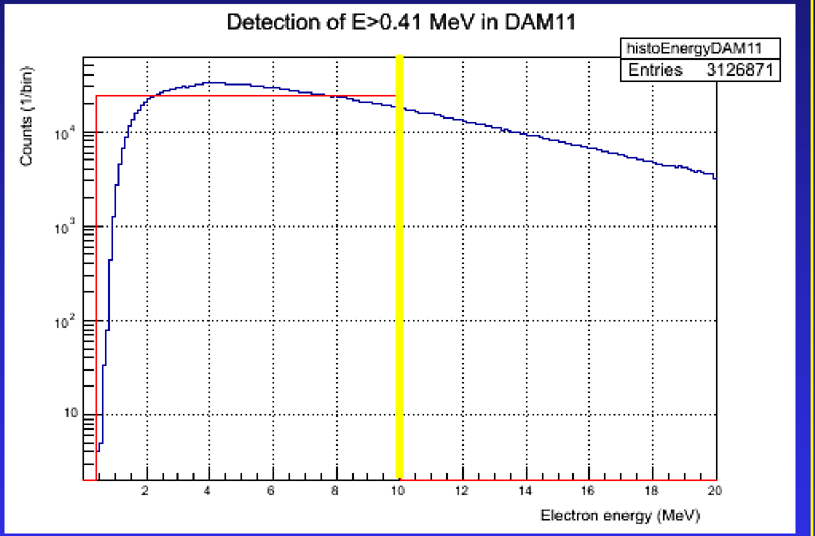
Table 5: Energy thresholds for quasi-logarithmically spaced channels

- Deposited energy thresholds are defined for S2 and DAM sensors;
- Each of these thresholds corresponds to an incident energy threshold;
- Particles are classified into channels defined for the last hit sensor;
- 16 channels are defined for electrons and 16 others for protons;

3DEES functionality – energy and flux measurement – Efficiency calculation

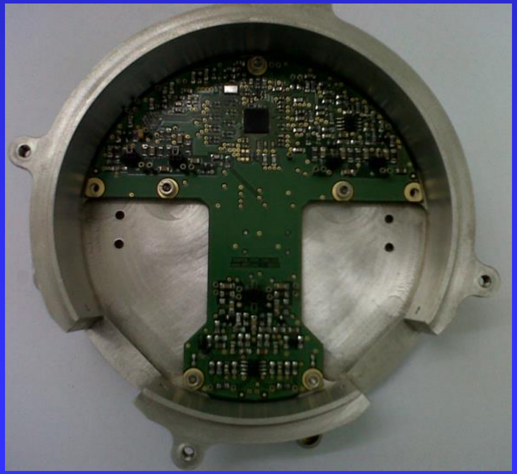






- Channels defined using deposited energy intervals contain contributions from a huge energy range;
- Thereby, efficiency calculation for a given channel requires information on the upper limit of the spectrum in addition to threshold incident energy;
- Such upper energy limit is measured by the 3DEES and is used in efficiency evaluations.

Measurements performed with the 3DEES breadboard



Summary of measurement source Sr SERP

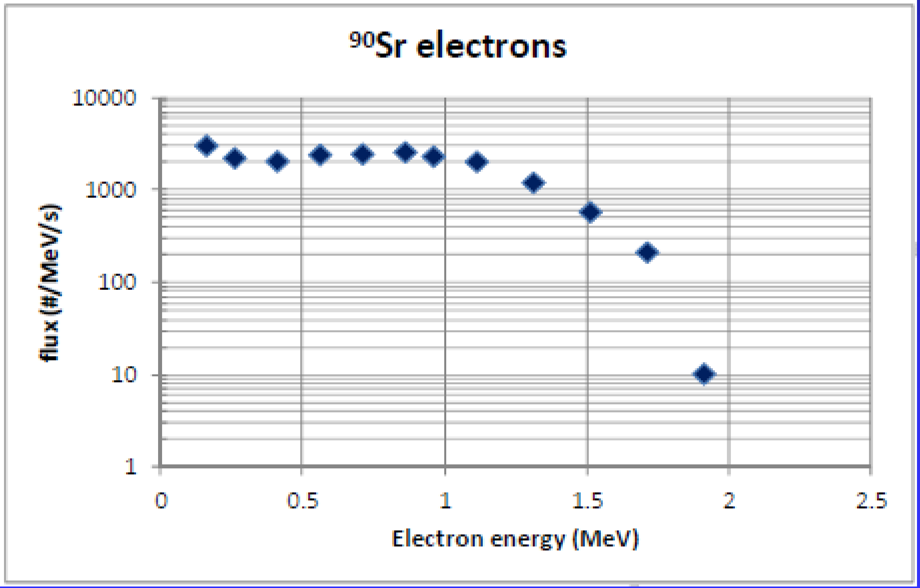
Threshold	counts S2	incident Eth	Efficiency	counts/eff	E (MeV)	Ebin(MeV)	flux
0.05	4540	0.11	0.031781	142853	0.16	0.05	137791
0.1	4240	0.21	0.032848	129074	0.16	0.05	231816
0.2	3652	0.21	0.030517	119671	0.31	0.1	160738
0.4	2531	0.41	0.028918	87523	0.51	0.1	156801
0.6	1448	0.61	0.025782	56163	0.71	0.1	122901
0.8	715	0.81	0.022642	31583	0.91	0.1	87610
1	271	1.01	0.019294	14061	1.11	0.1	43847
1.2	84	1.21	0.015915	5292	1.31	0.1	21255
1.4	13	1.41	0.012614	1041	1.46	0.05	8379
1.5	2	1.51	0.010699	203	1.56	0.05	2028
1.6	0	1.61	0.008338	0	1.66	0.05	0
1.7	0	1.71	0.008338	0	1.76	0.05	0
1.8	0	1.81	0.008338	0			

Threshold	counts DAM1	incident Eth	Efficiency	counts/eff	E (MeV)	Ebin(MeV)	flux
0.05	1220	0.31	0.012228	99789	0.36	0.05	113656
0.2	1022	0.41	0.011558	88423	0.51	0.1	155213
0.4	613	0.61	0.010683	57381	0.66	0.05	229242
0.6	273	0.71	0.007923	34457	0.81	0.1	92874
0.8	86	0.91	0.005415	15882	1.11	0.2	27057
1	14	1.31	0.002759	5059	1.36	0.05	38906
1.2	1	1.41	0.000706	1168	1.51	0.1	5842
1.4	0	1.61	0.000022				

- Measurements of the ^{90}Sr energy spectra show that sensors can cross-check each other, whenever they cover the same energy range;
- Agreement between measurements from two sensors validates part of efficiency calculations and FEE calibrations.

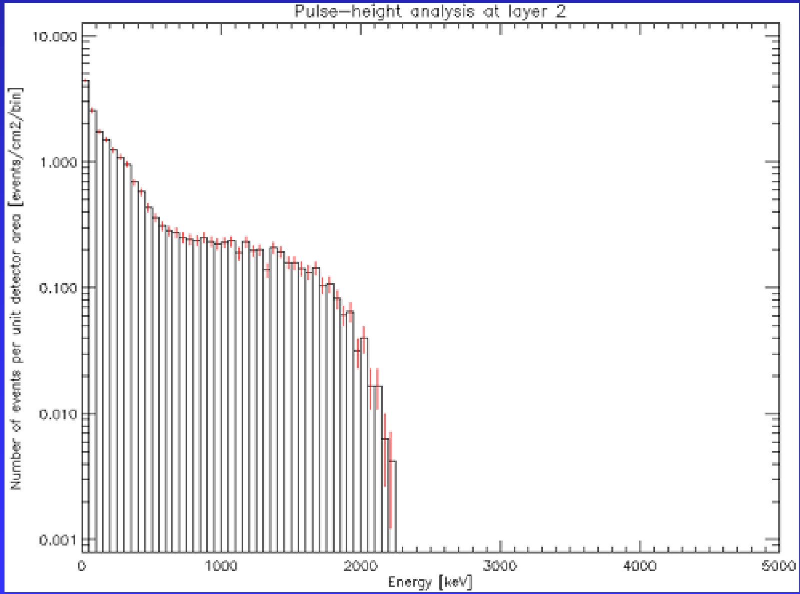
Measurements performed with the 3DEES breadboard (ctd)

^{90}Sr electron spectrum measured using S2 channels



^{90}Sr electron spectrum expected out of a 50μm iron shielding

Slightly more shielded source would likely lead to a spectrum similar to that of our source (see Figure at left).

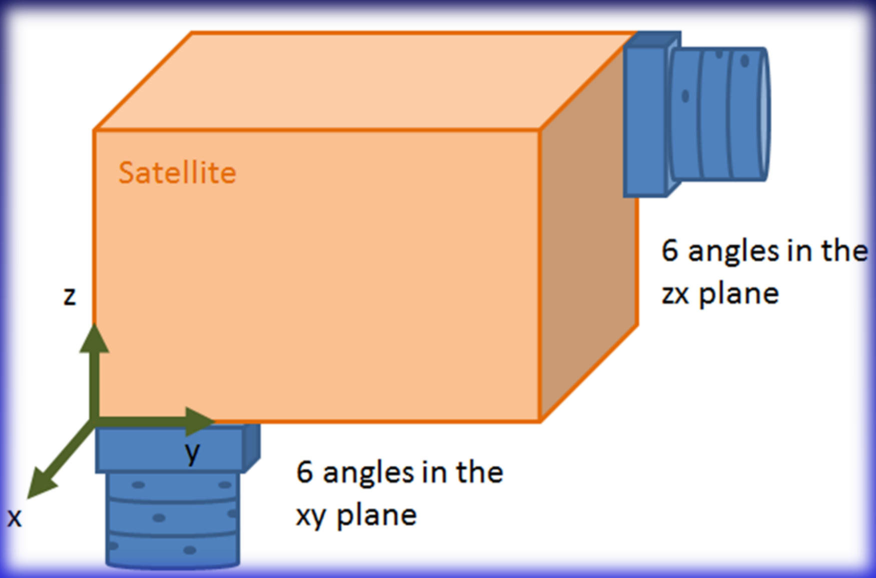


Conclusion and perspectives

- Combined measurements of electron energy spectra and angular distributions require optimized devices in particular when constraints on mass, volume and power consumption are strictly set;
- Extraction of electron energy spectra requires a thorough evaluation of the efficiency of every channel;
- High performance collimators and adequate sensor setup need to be designed so as to provide accurate F.O.V angle definition;
- The 3DEES was designed so as to address each of these constraints;
- The modularity of the 3DEES allows that a single PSM can be developed for in-orbit demo. Any flight opportunity that would allow such a demo is welcome;
- The 3DEES concept is mature and can be fully implemented provided that the used components/materials (multichannel ADC, sensor stack structure, etc…) are demonstrated to be suitable for application in the space environment;
- Phase A/B activities are expected to be completed before June 2014.

Acknowledgments

The 3DEES team (BIRA, QinetiQ Space and UCL/CSR) is grateful to ESA for support of Phase A/B activities through Contract Nr. 4000105532. Advices from the Technical Officer (D. Rodgers) and his colleagues at ESTEC are appreciated.


Satellite
z
y
x
6 angles in the zx plane
6 angles in the xy plane

Thank you!