Measurements and Geant4 simulations of the back-scattered electrons for the ATHENA Mission

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On behalf of the EXACRAD project team

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- Geant4 simulations and comparisons
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Introduction and background

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- EXACRAD is an ATHENA mission r&d project funded by ESA
  - More details in Silvano's presentation
- One of the tasks of the project is to characterise the backscattered electrons off the detector surroundings
  - Design and perform measurements of the
    - Backscattered electron emission yields (BSEEY)
    - Backscattered electron emission spectrum (BSEES)
    - In the 10s to 100s keV range, for ATHENA related materials.
  - Perform detailed Geant4 simulations of the experiments
    - To validate the relevant Geant4 physics
    - To test the ATHENA background simulation framework (ASF) developed in a parallel project AREMBES.

Experiments

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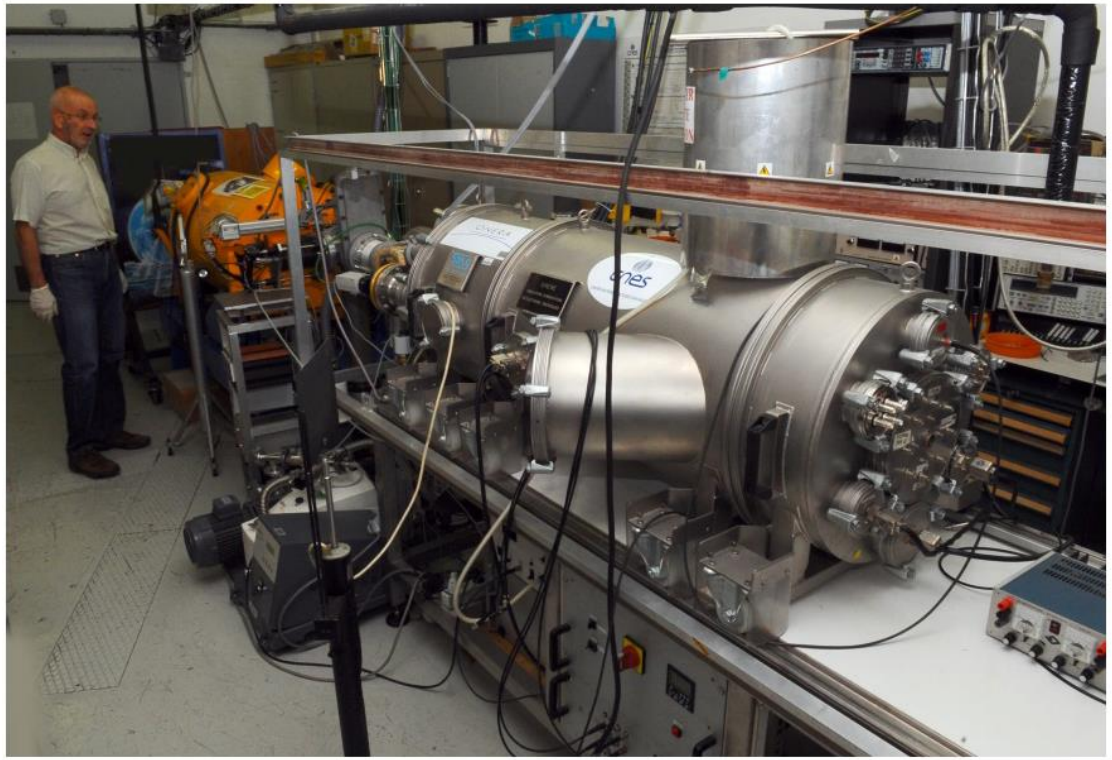

Figure 1. The SIRENE irradiation test facility

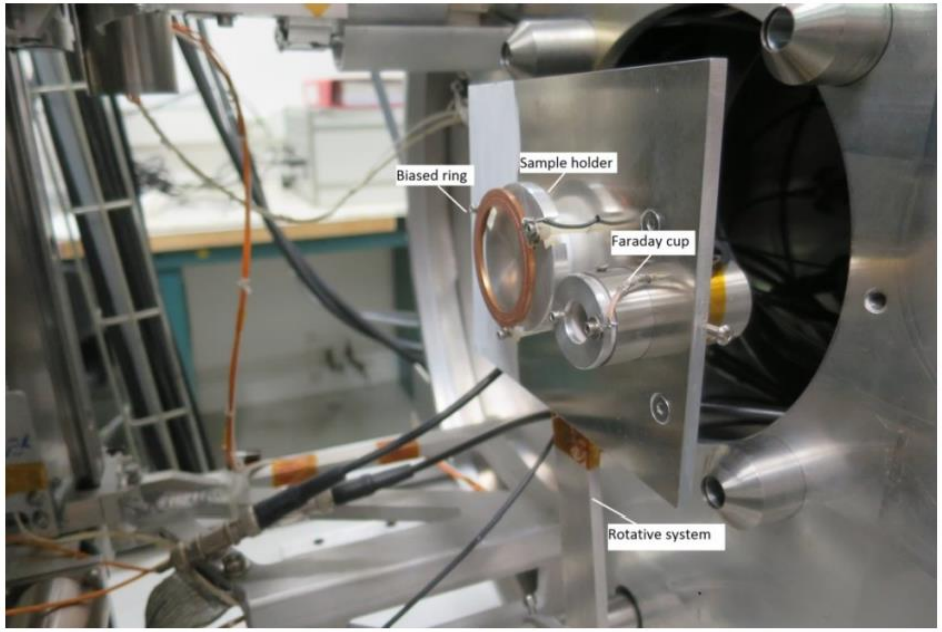

Figure 3. View of the rotative sample holder with Faraday cup, sample and biased system

SIRENE facility in ONERA: 7-400keV monochromatic e- beam

Backscattered electron emission yield measurements

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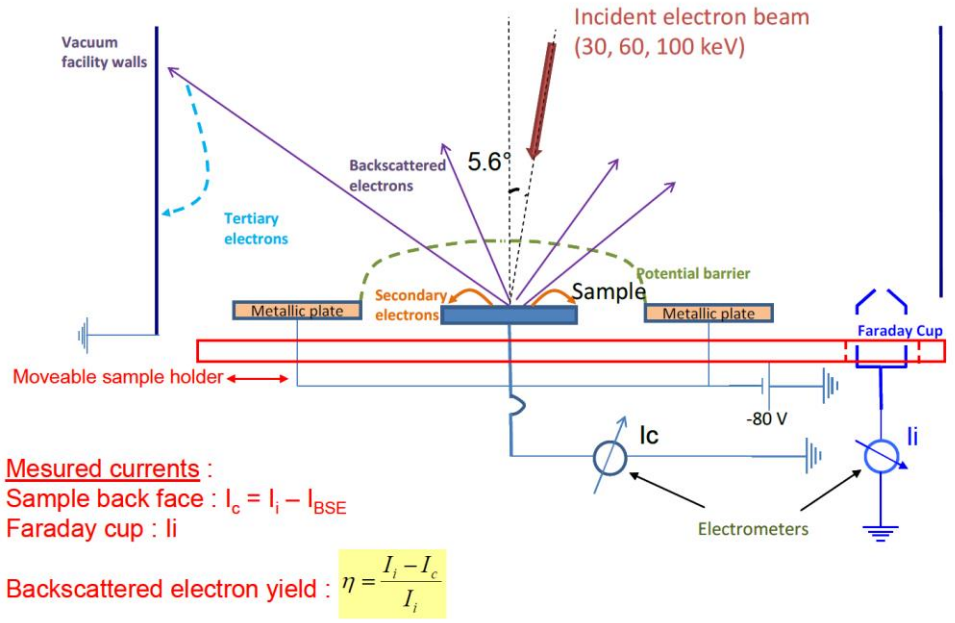

Figure 2. Schematic of the experimental set-up that has been developed and installed in SIRENE for backscattered electron yield measurement

Energy (keV)	Incident Angle (°, in regard to the normal direction of the sample)	Incident current ($pA.cm^{-2}$)	Electron beam size (cm^2)	Temperature	Measurements
30	5.6	450-500	1	Room temperature	Induced and incident current
60	5.6	450-500	1	Room temperature	Induced and incident current
90	5.6	450-500	1	Room temperature	Induced and incident current

Tested Samples

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- Gold : 25x25 mm, 50 µm thickness, 99.99% purity, one sample tested
- Bismuth : 25x25 mm, 250 µm thickness, 99.999% purity
- Silicon : 35x35 mm, 500 µm thickness, 99.999% purity
- Composite sample: representative of the actual detector's absorber

  from top to sample bottom:

  - [redacted]
  - [redacted]
  - [redacted]
  - [redacted]
  - [redacted]

Backscattered electron emission yield (BSEEY %)

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Table 1 : Backscattered electron emission yield (%) as a function of incident energy for Au, Bi, Si and composite

Energy (keV)	30	60	90
Au	51.5	52.4	52.6
Bi	52.7	52.9	53
Si	18.7	16	14.4
Composite	53.4	54.3	53.7

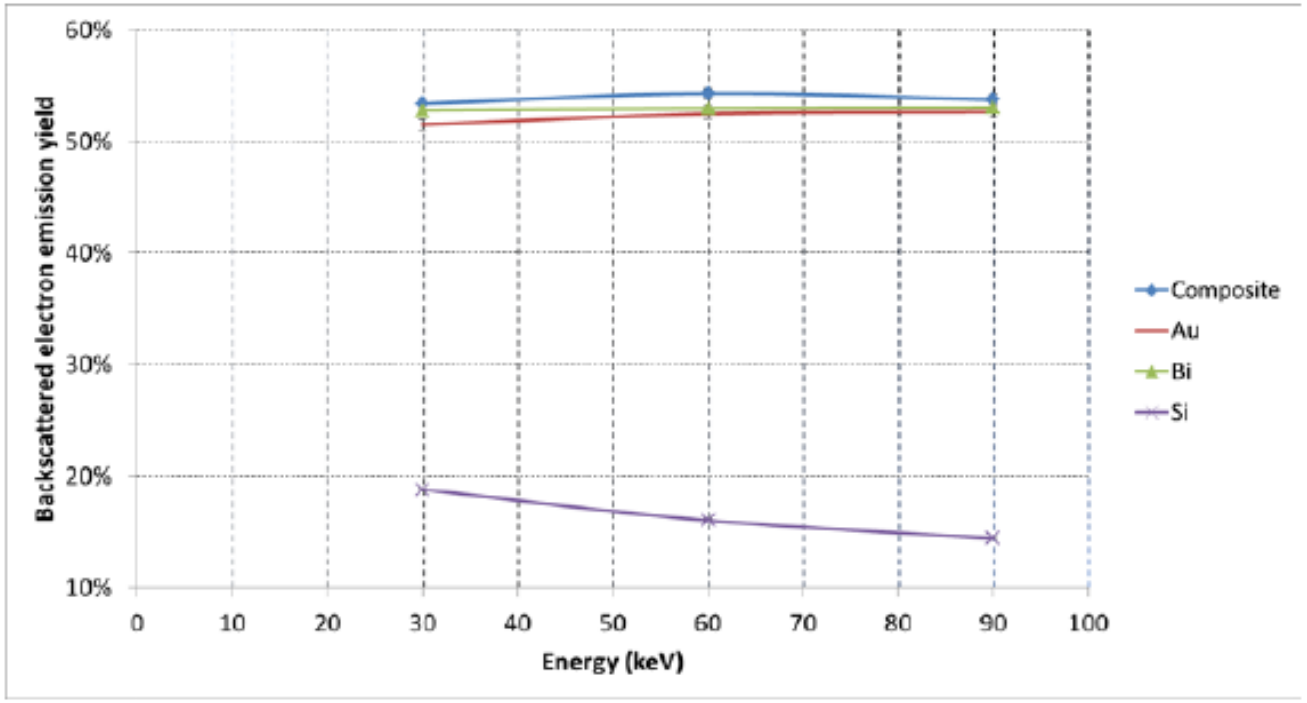

Figure 12 : BSE yield of the different materials as a function of incident energy

Backscattered electron emission spectrum (BSEES) measurements

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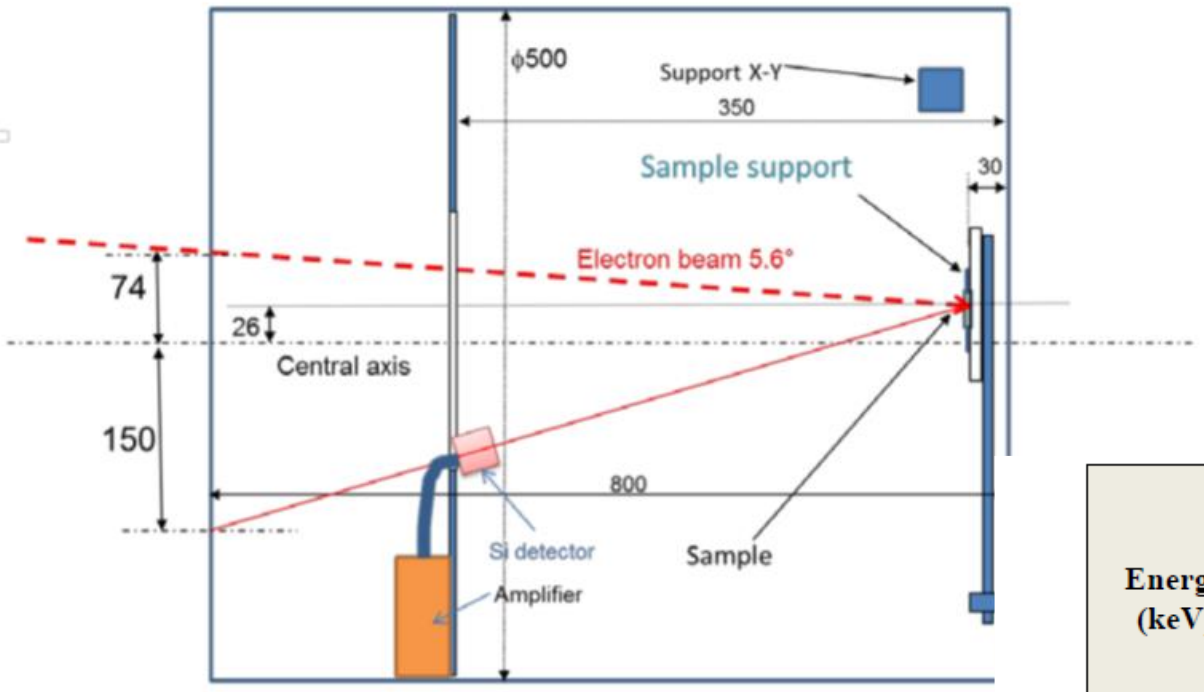

Figure 10 : Top View of the experimental set-up with Si detector

- Si Detector location:
- 12.4° off-axis,
- 40mm or 285 mm from sample
- surface area : 25 mm²
- thickness : 700 microns

Energy (keV)	Incident Angle (°, in regard to the normal direction of the sample)	Incident current ($nA.cm^{-2}$)	Electron beam size (cm^2)	Temperature	Measurements
90	5.6	1	1	Room temperature	- Incident current - Electron spectrum

Due to the efficiency and accuracy of the set-up, ten additional tests have been performed at 50, 55, 60, 65, 70, 75, 80, 85, 95, 100 keV.

BSEES measurement results

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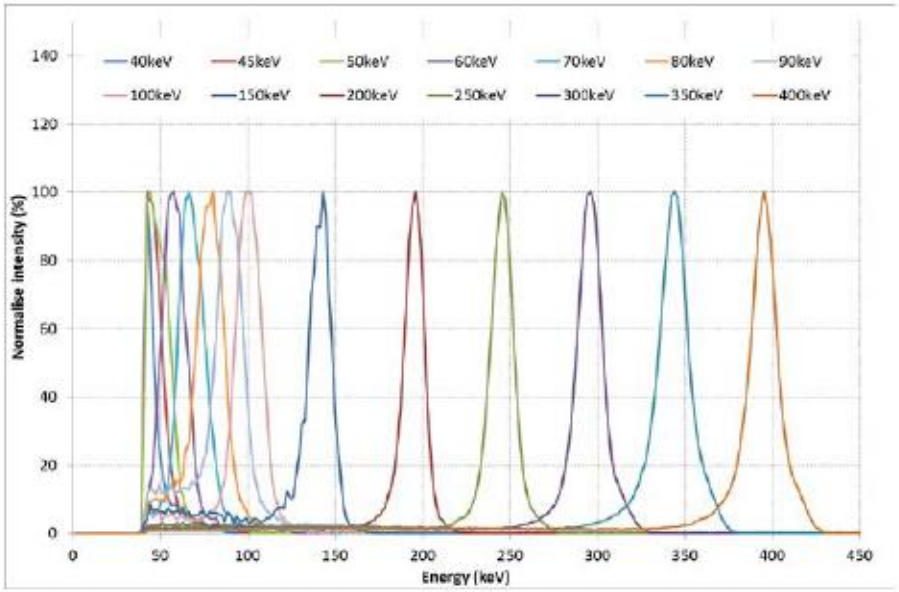
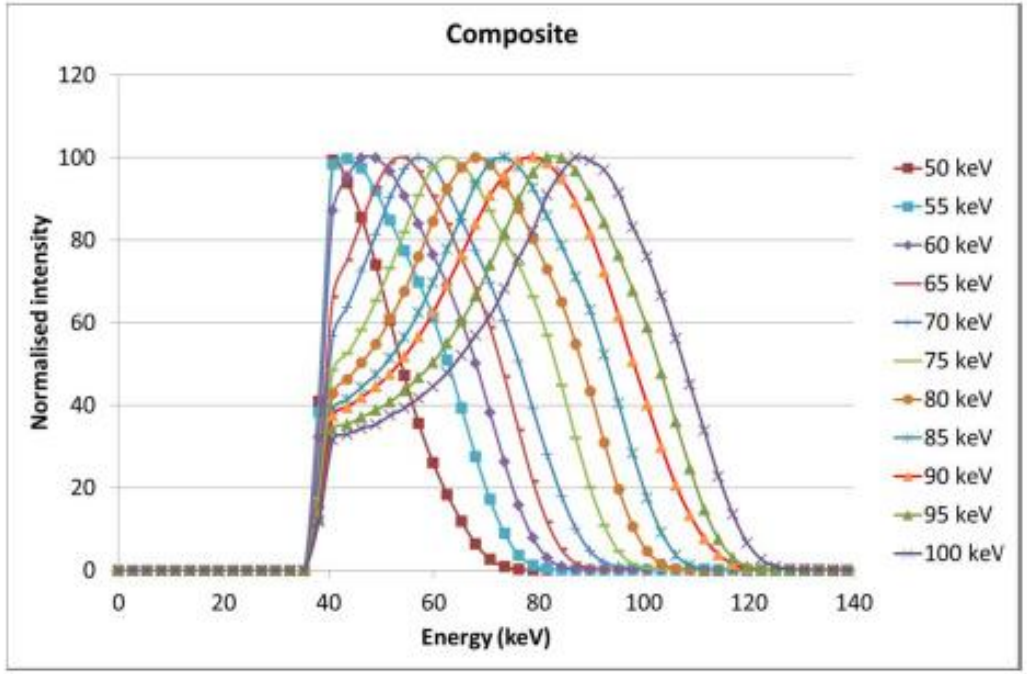


Figure 19 : Calibration of the Si detector with mono-kinetic electron beams

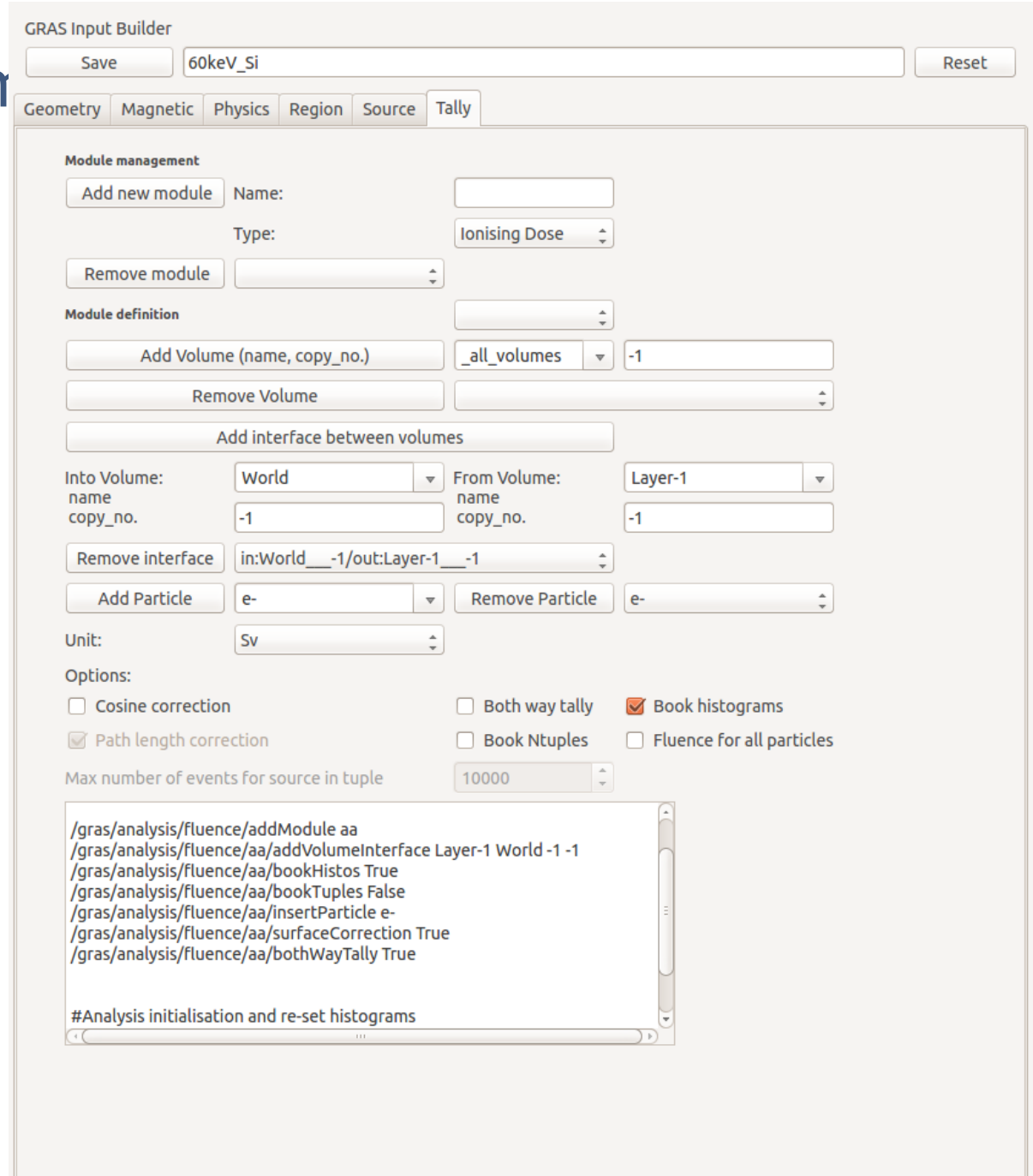
Detector energy resolution:
FWHM ~ 15 keV @ all energies



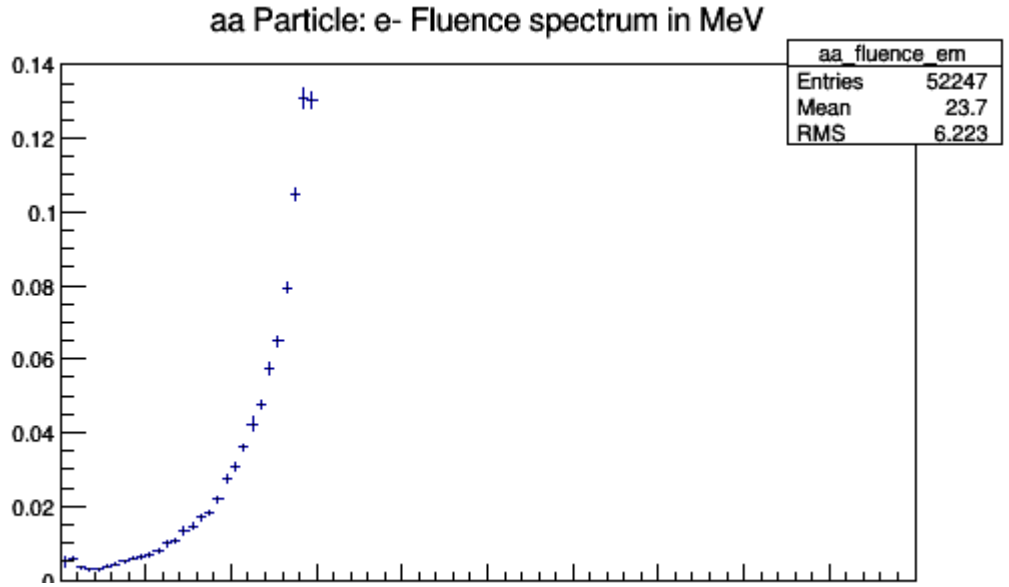
BSEES measured at 285 mm away on the composite sample at incident energies ranging between 50 and 100 keV

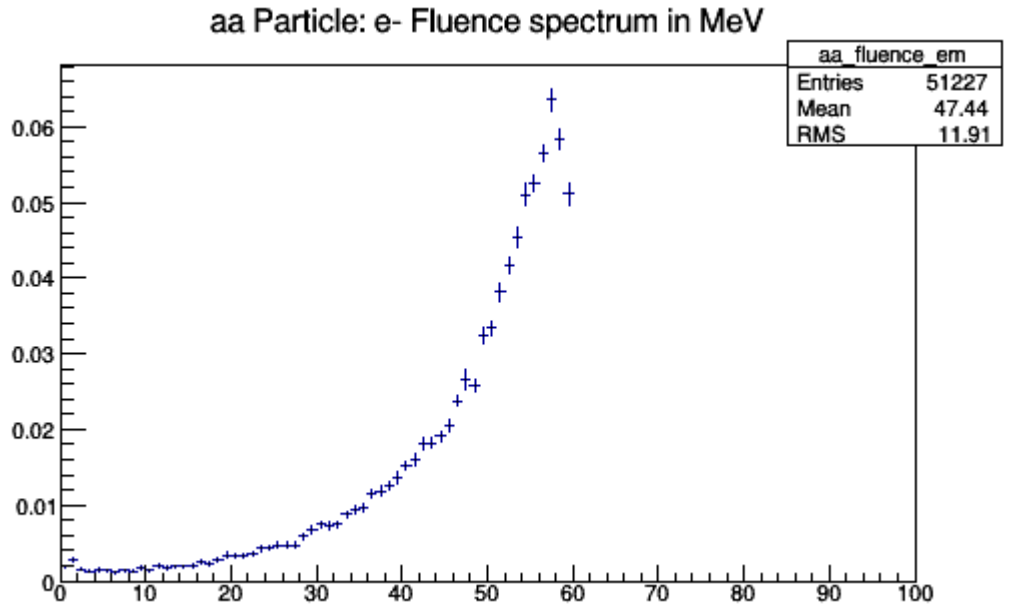
Backscattered Emission Yield Sim

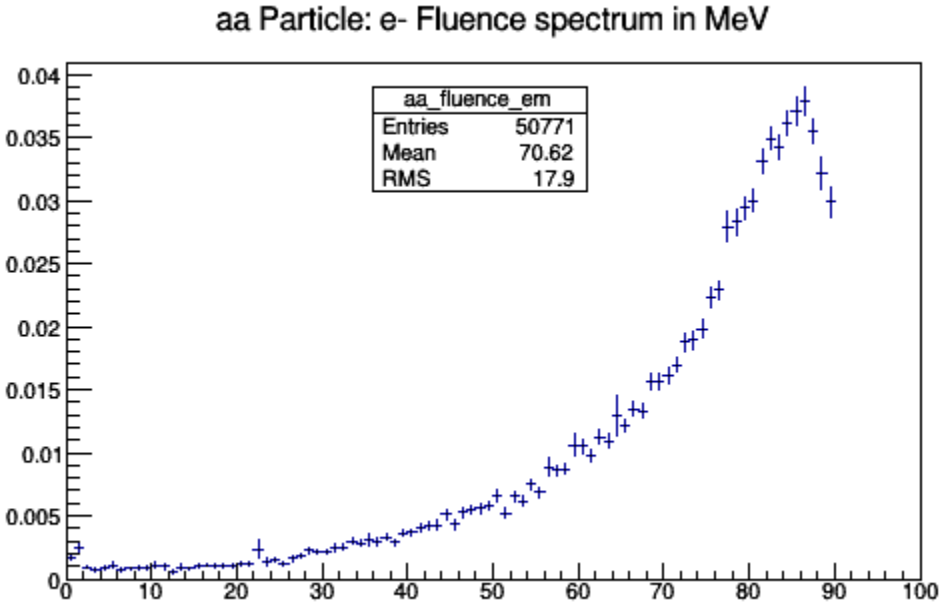
- Tools for the simulations:
  - GRAS/CIRSOS (ASF) with G4 10.3 (updated with space physics list)
- Geometry setup
  - 1D Layer(s) in MULASSIS format
- e- beams
  - 30,60,90keV,
  - at 5.6° incident angle
- Physics lists:
  - Standard-em
- Fluence Tally
  - Yield = Backscatterd/Incidence



BSEEY Simulation: Composite sample results







Bi sample:

Top-l: 30 keV	Yield:	0.5225
Top-r: 60 keV		0.5123
Left: 90 keV		0.5077

Backscattered electron emission yield(%)
Simulation results and comparison with experiments:

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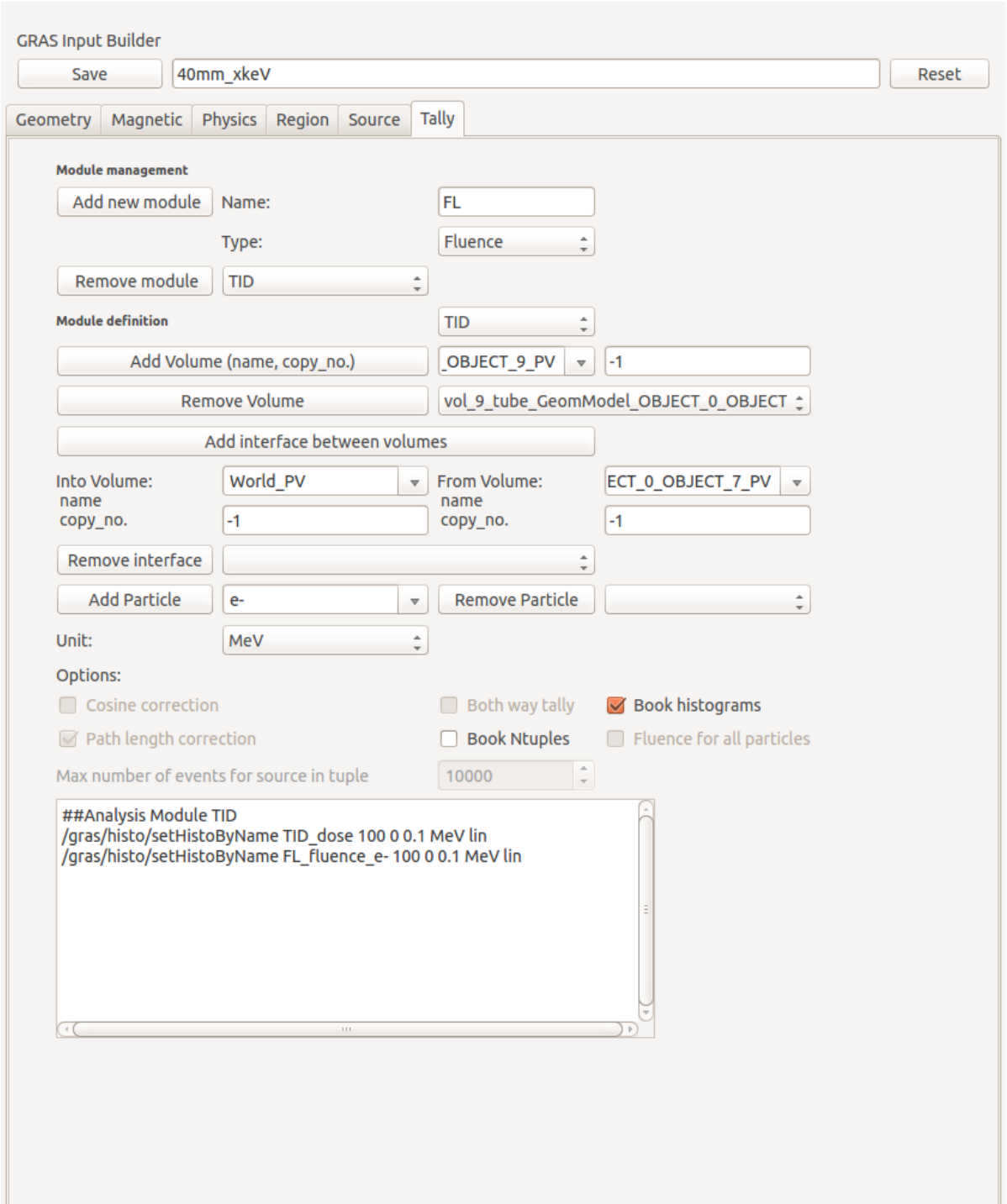
Energy (keV)	30		60		90	
	Exp	Sim	Exp	Sim	Exp	Sim
Au	51.5	51.65	52.4	51.30	52.6	50.95
Bi	52.7	52.76	52.9	52.45	53	51.80
Si	18.7	16.49	16	15.96	14.4	15.53
Comp.	53.4	52.25	54.3	51.23	53.7	50.77

Backscattered Emission Spectra Si

- Tools for the simulations:
  - GRAS/CIRSOS (ASF) with G4 10.3 (updated with space physics list)
- Geometry setup
  - The Vacuum tube only
  - Composite sample
  - Si Detector
    - surface area : 25 mm² (increased 25cm²), thickness : 700 microns
    - 12.4° off-axis, 40mm and 285mm above the sample
- e- beams of 50,55,60,65,70,75,80,85,90.95,100 keV, at 5.6° incident angle
- Tally – Energy deposition spectrum in the Si Detector
- Physics lists:
  - Standard-em



Geometry Model

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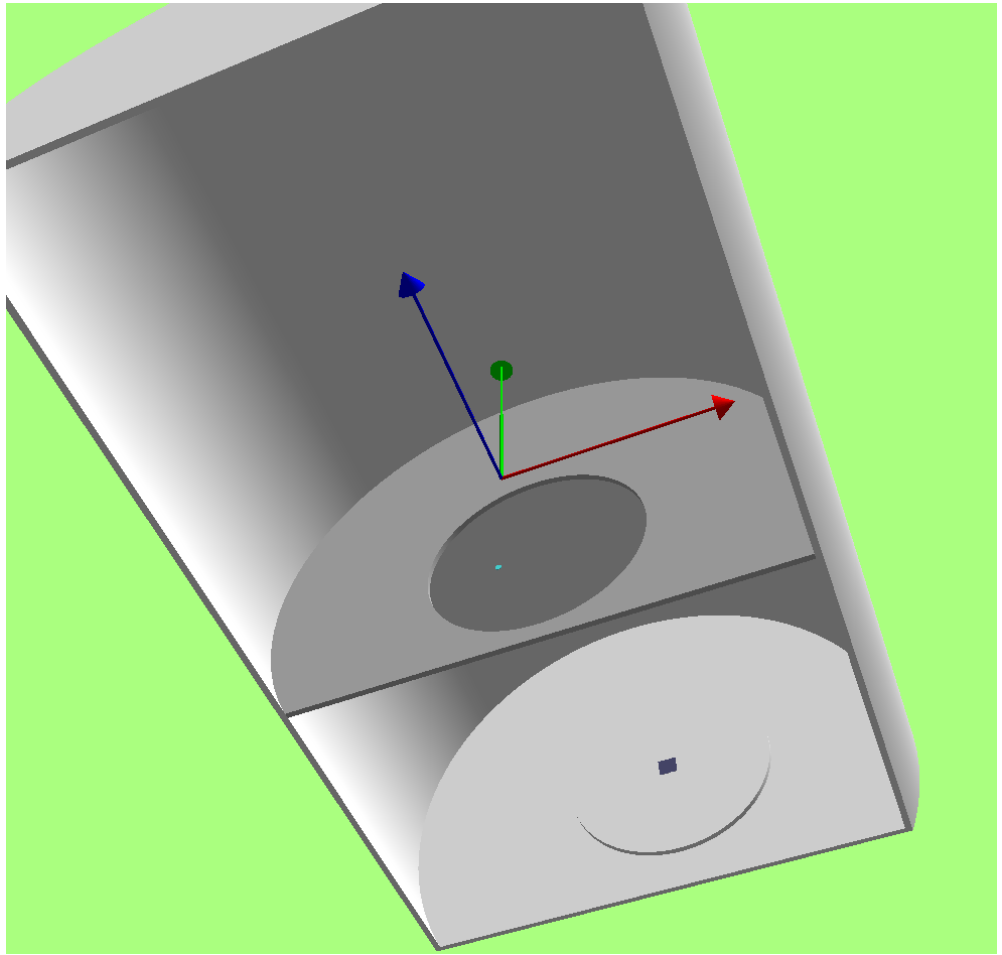

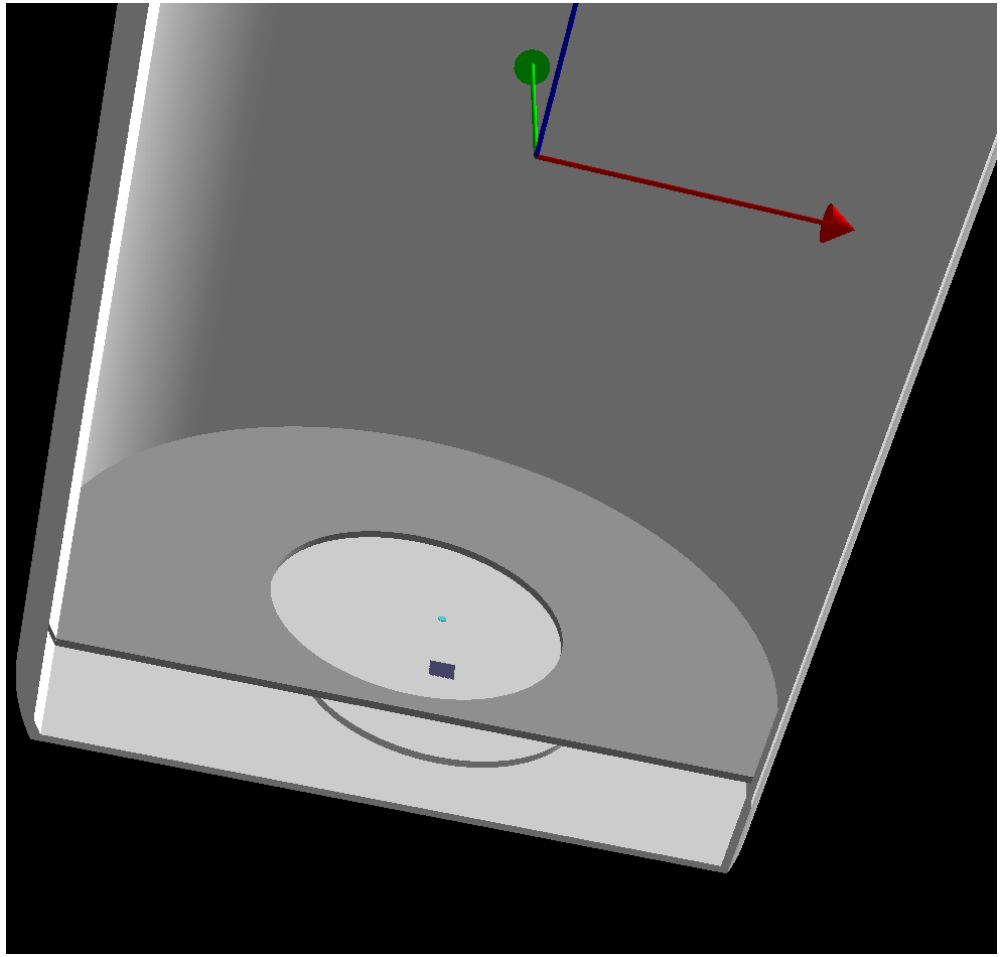

The need to improve simulation efficiency

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- Test run with 40mm distance geometry, 10^6 90keV e-
  - Only 10000 hits detected by the detector
  - Need ~100000 hits to build a good spectrum
- The beam spot size is 1cm^2, while the detector size is only 25 mm^2
  - The beam spot size in simulation is a dot, we can increase the size of the detector 1cm^2 without compromising the solid angle coverage
  - Increase the radius from 2.8 mm to 28 mm -> 100x improvement
- In the 285 mm case the efficiency is even worse

- Test run results show increasing the detector size to 25cm2 has no significant impact to the detected spectrum shape!

40mm_90KeV with different detectors: 25mm^2, 1cm^2, 25cm^2

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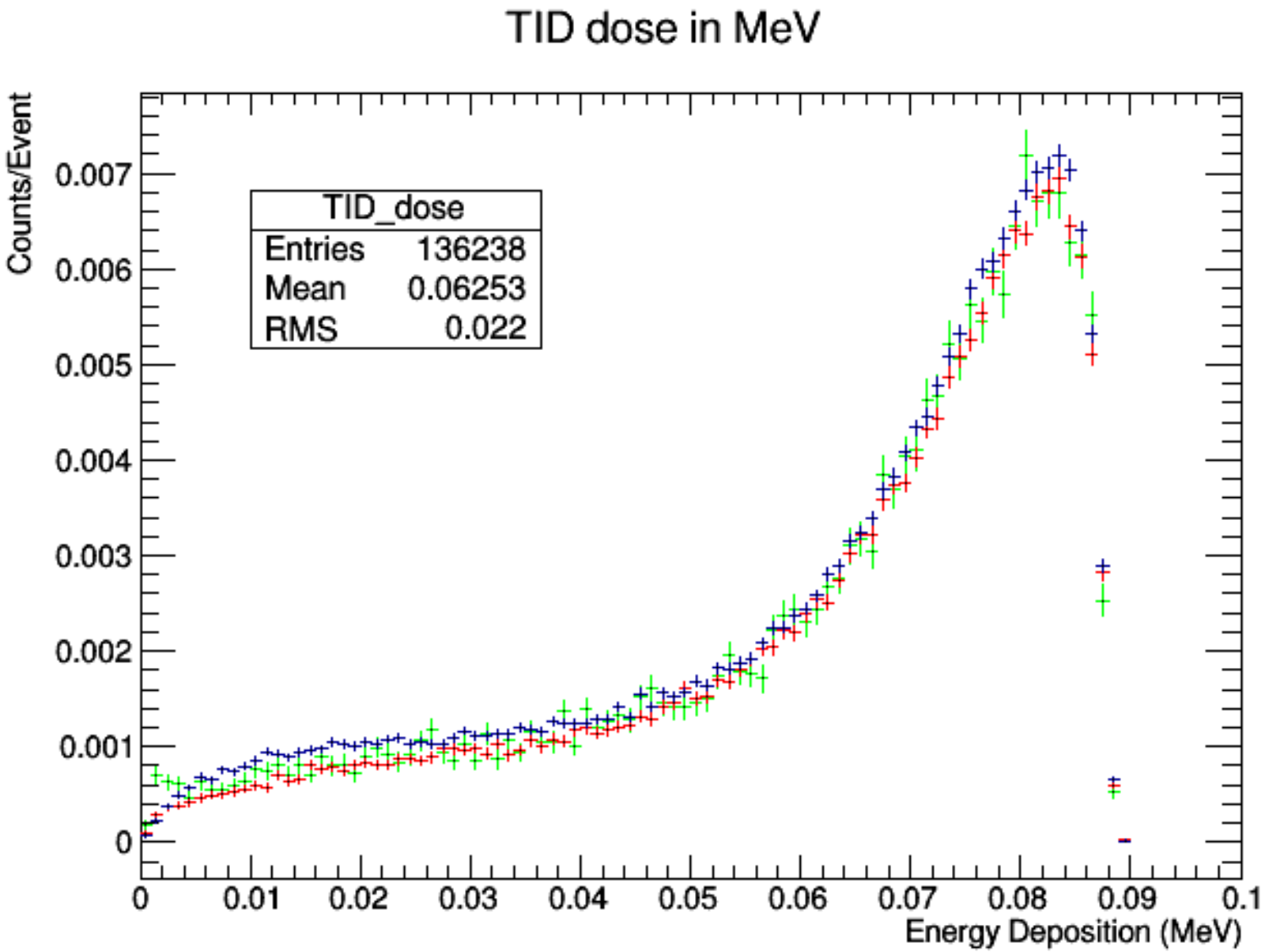

Simulation results: 40mm case

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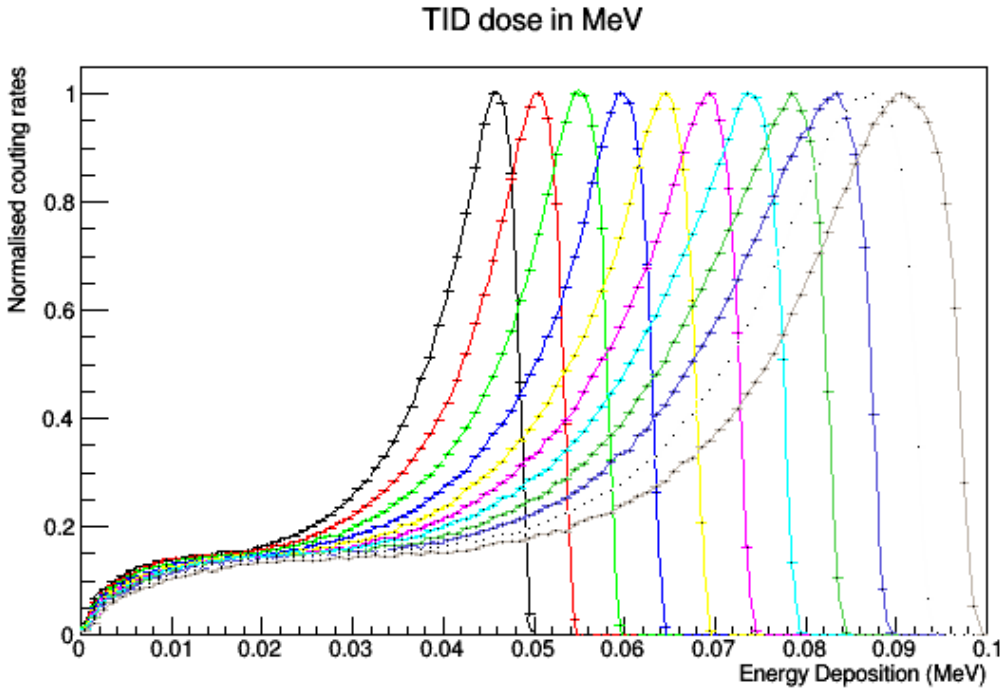

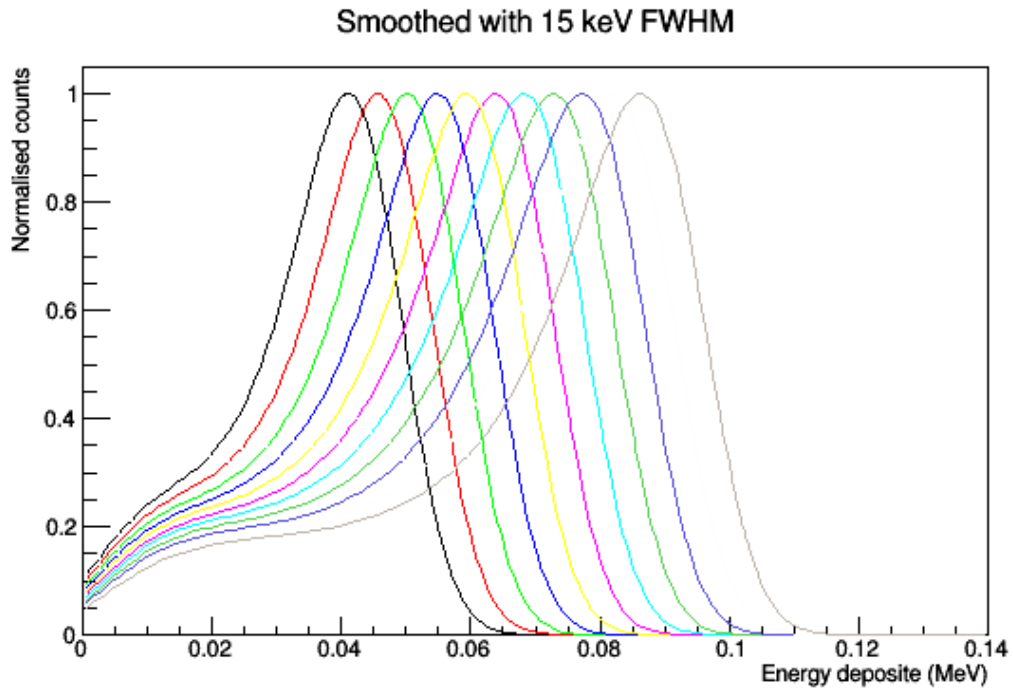

10^7 events simulated at each energy

Simulation results: 285mm case

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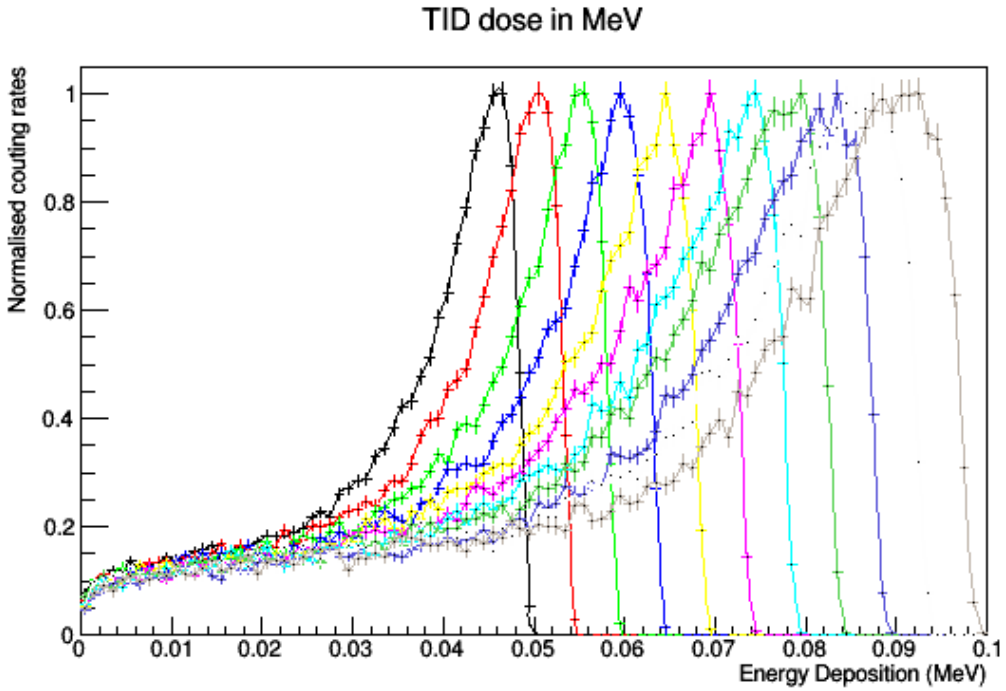

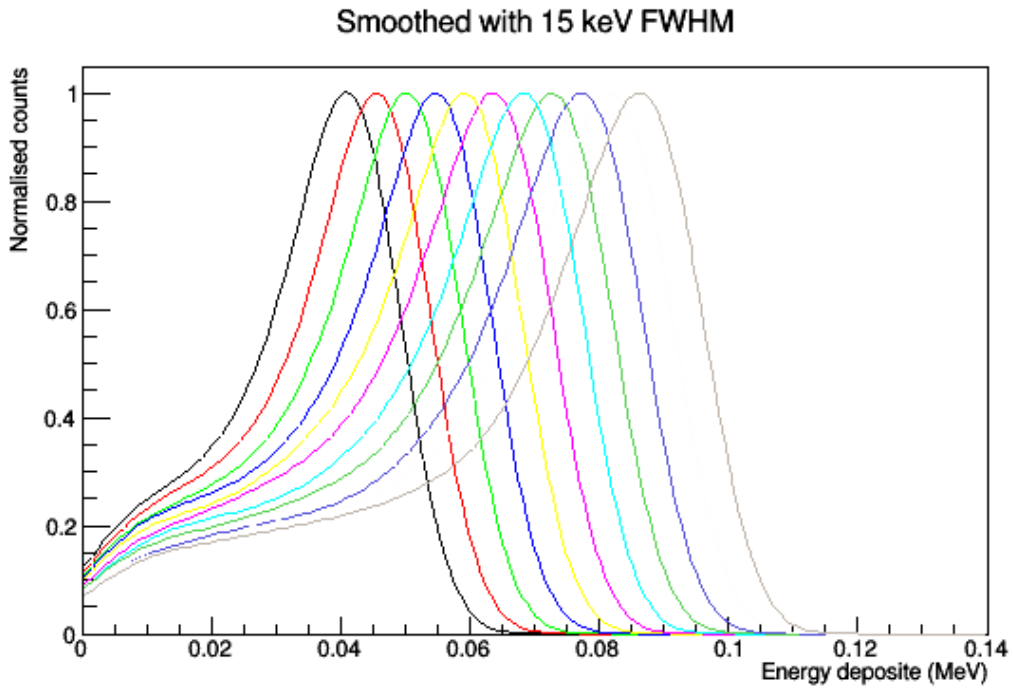

10^7 events simulated at each energy

285mm case: comparison between simulations and experiments

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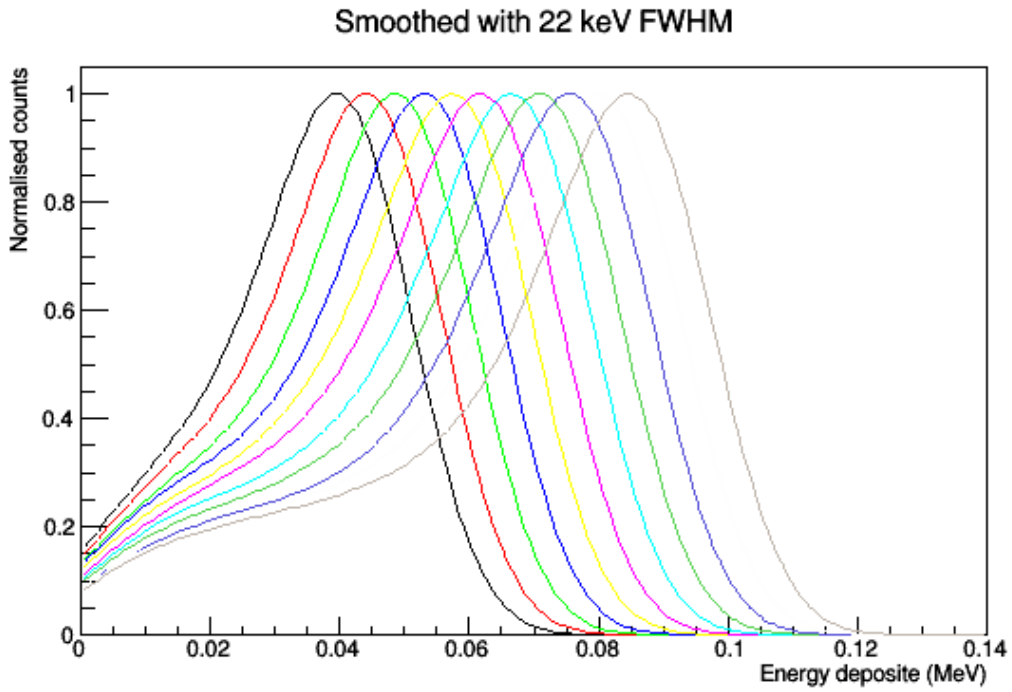

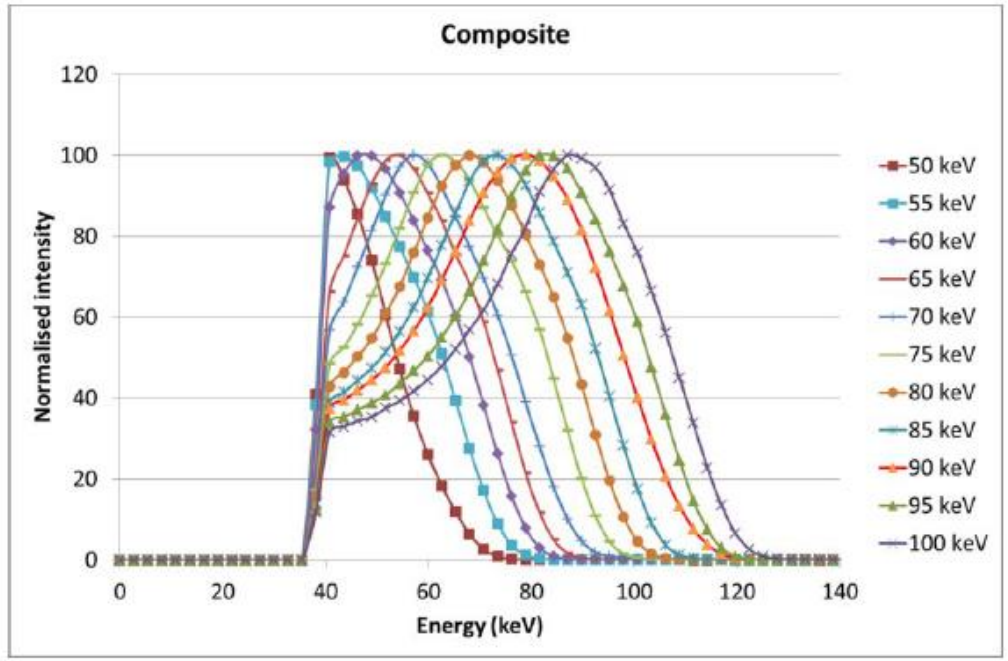

It seems sim. results with a 22 keV FWHM resolution is in better agreement with the measured data

Discussions

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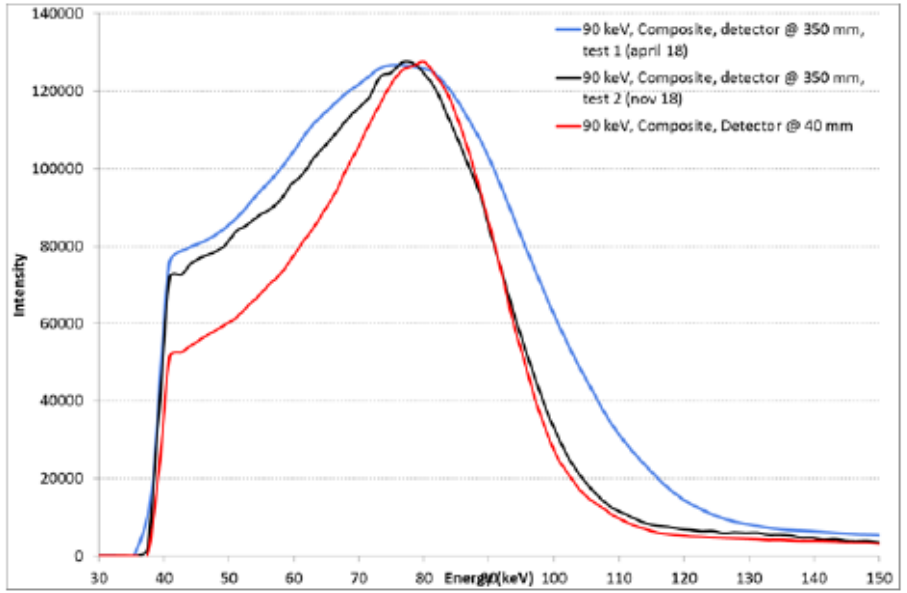
- The big difference in the BSEEY between Si and the other samples could be due to the difference in their density, or in their Z numbers
- The energy resolution of the measured backscattered electron spectra for the 285 mm case is perhaps worse than the nominal 15 keV FWHM.



Comparison between the experimental spectra measured on the composite sample at 90 keV with detector at 40 mm and 285 (350) mm from the sample. Test1 performed in April/18 has a poorer resolution.

Conclusions

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- Experiments designed to measure of the backscattered electron emission yield (BSEEY) and spectrum (BSEES) have been carried out successfully with samples of relevant ATHENA mirror materials and at the interested energy range.
- High quality BSEEYs and BSEESs measured data have been obtained
- The experiments have been simulated in Geant4 using the ASF/CIRSOS framework.
- There is an excellent agreement between the measured and simulated BSEEYs
- There is also a very good agreement in between the BSEESs, although that's dependent on the assumed energy resolution of the detector.
- Overall the good results validated Geant4 and ASF/CIRSOS as a tool for simulating the electron backscattering issue in the development of the ATHENA mission, as well as in other applications.