Development of an X-ray detection system for particle identification of Super Heavy nuclei

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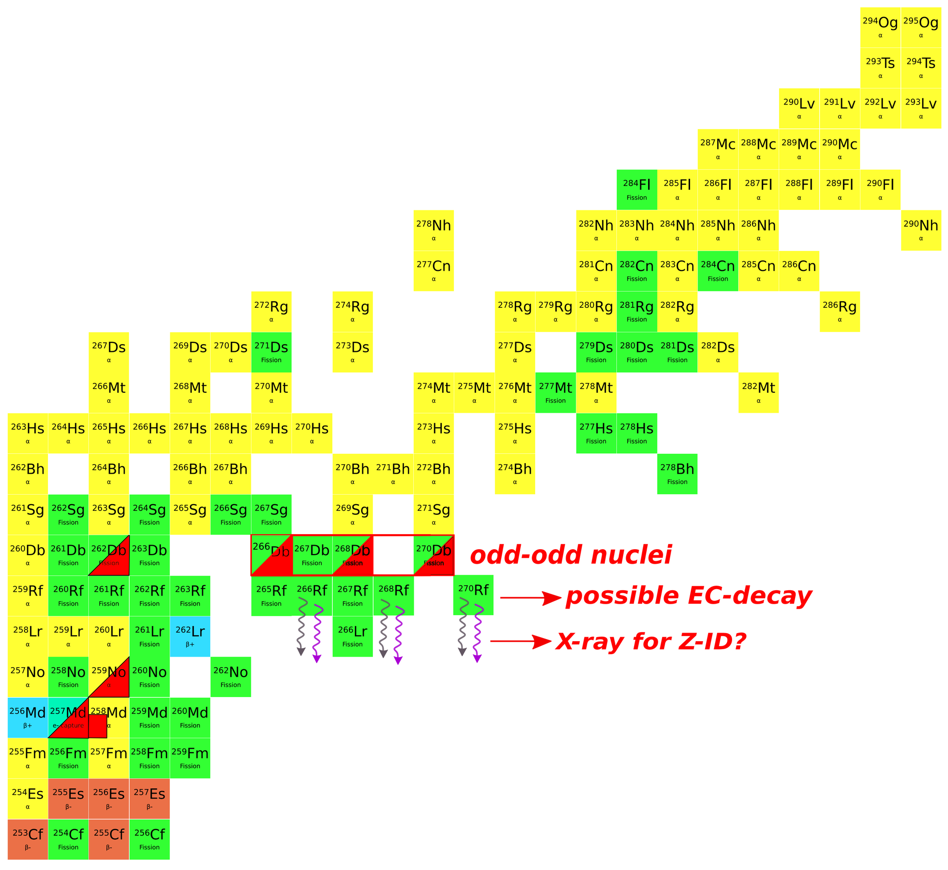
Introduction



Scientific Objective:

The synthesis , spectroscopy , structure and properties of the heavy and super heavy elements.

Synthesis and ID of new isotope

- Production: Fusion Evaporation reaction.
- Detection:
  - Energy and $T_{1/2}$ of the α
  - Energy of electrons and gammas.
- Identification:
  - Characteristic α- decay
  - Evaporation Residue – α -γ correlations and linking to known α decay chains.

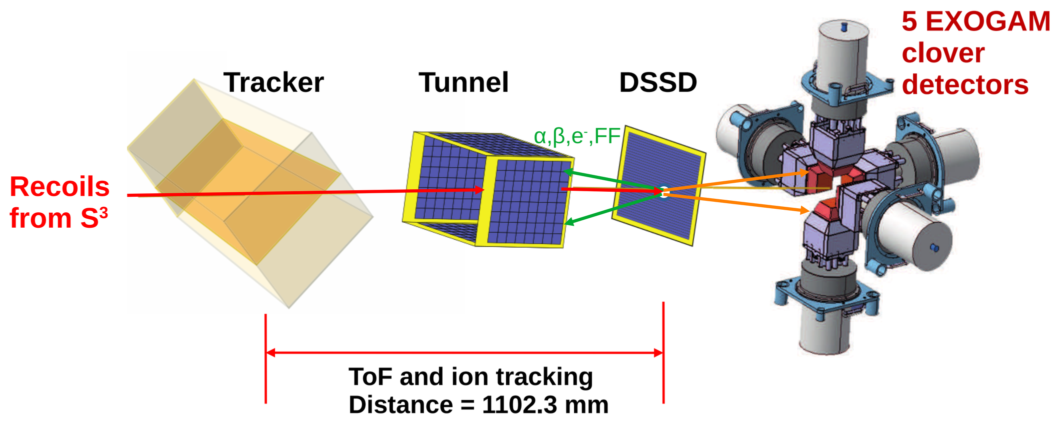
Why the X-rays ?

- Isotopes in the newer nuclear chart region are challenging to identify due to decay chains ending in spontaneous fission .
- Advancement in understanding of atomic shell models lead to an unambiguous prediction of the "Z" dependent X-ray energies .
- Detection of X-rays following de-excitation through internal conversion provides a reliable "Z" identification method for these exotic nuclei.

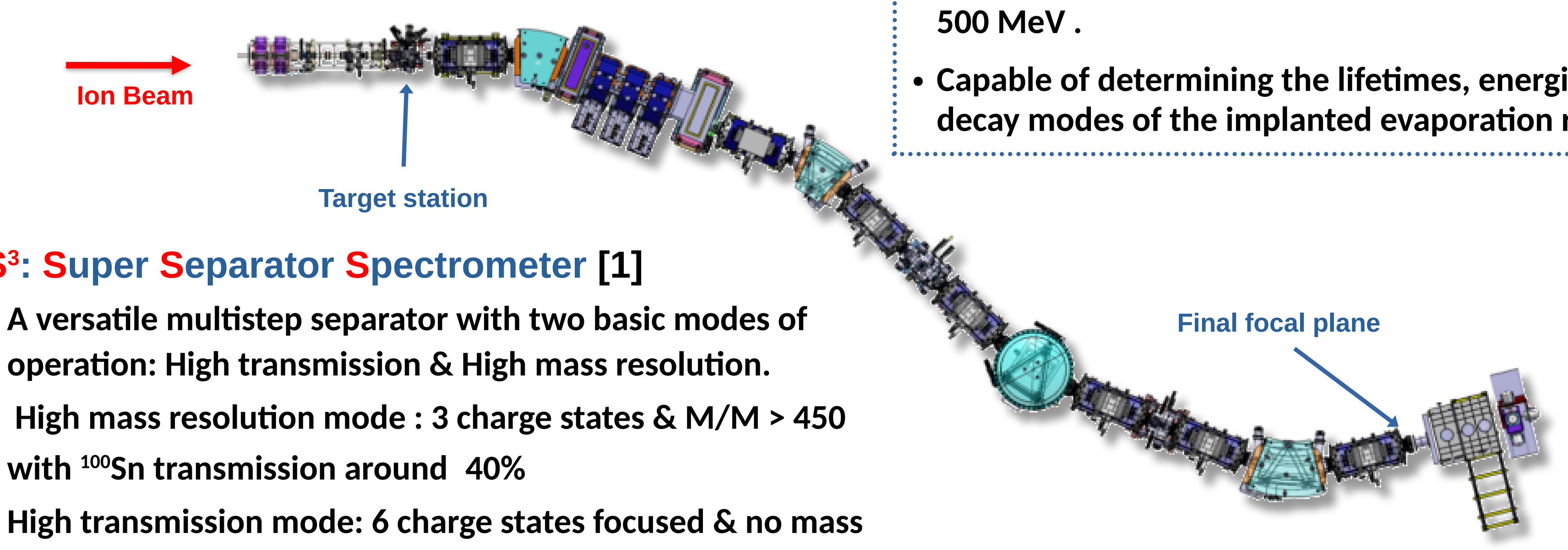
Spectroscopy and Identification of Rare Isotopes Using S^3 (SIRIUS)

SIRIUS instrumentation [1]:

- A large area tracker detector for time-of-flight and ion-tracking measurements.
- A Double- sided Silicon Strip Detector (DSSD) of 10x10 cm² & 128 x 128 strips.
- 4 Tunnel composed of Strippy Pad silicon detectors with 8 x 8 pixels each.
- 5 Germanium detectors for gamma spectroscopy.



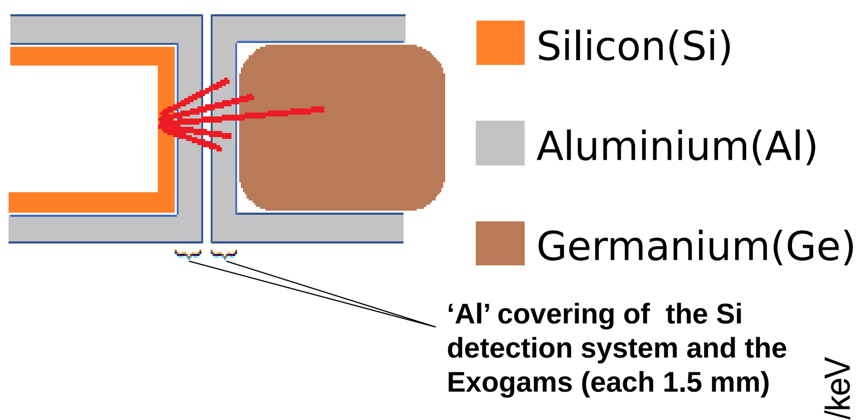
- The implantation decay station for decay spectroscopy after separation at the focal plane of S^3 .
- Set-up with compact geometry and has energy measurement capacity varying from 50 keV to over 500 MeV .
- Capable of determining the lifetimes, energies and decay modes of the implanted evaporation residues .



S^3: Super Separator Spectrometer [1]

- A versatile multistep separator with two basic modes of operation: High transmission & High mass resolution.
- High mass resolution mode : 3 charge states & M/M > 450 with ^{100}Sn transmission around 40%
- High transmission mode: 6 charge states focused & no mass resolution but ^{100}Sn transmission around 65%

X-ray detection at the Focal Plane detection system:



Focal plane decay spectroscopy setup with thick covers (for example SIRIUS)

- These focal plane detection systems are blind to the X-rays of energy below 50 keV.
- About ~96% of the photons of energy around 50 keV are absorbed in these aluminium covers.
- This hurdle can be overcome with modifications in the current detection setup.

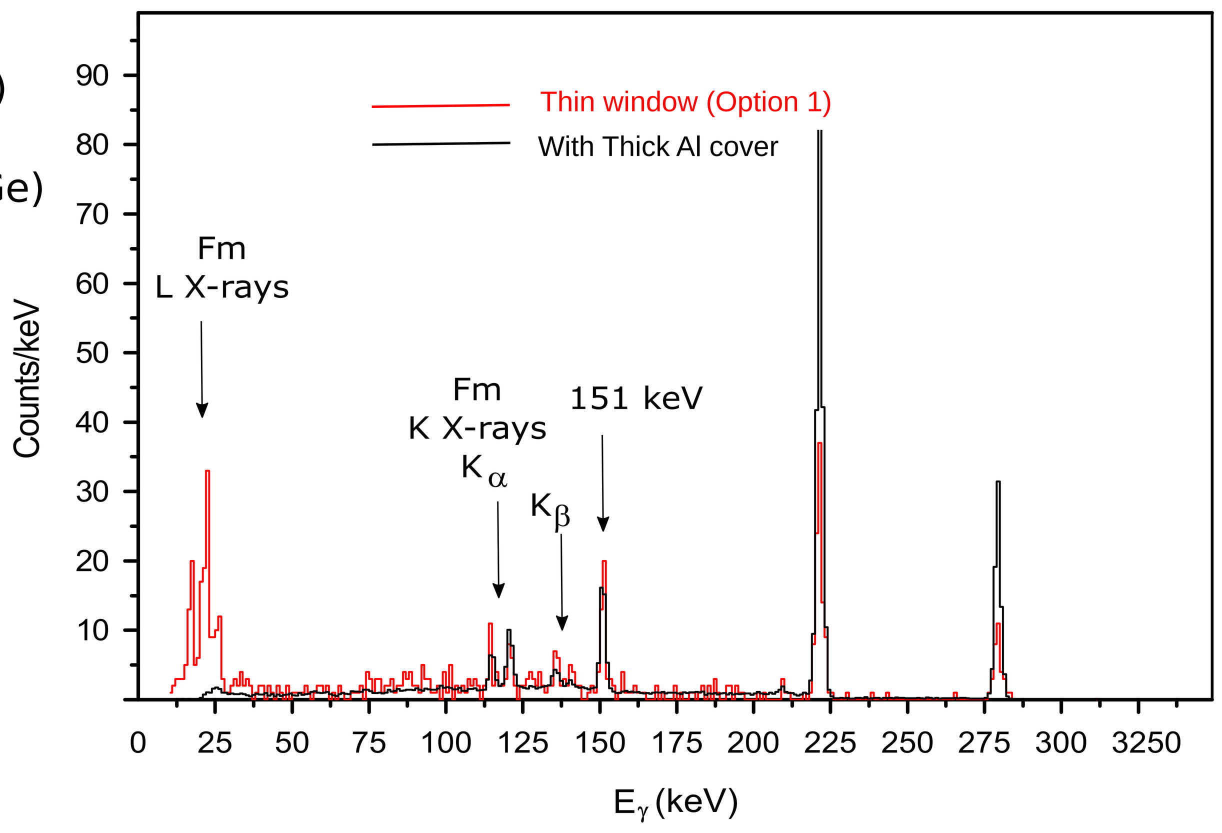
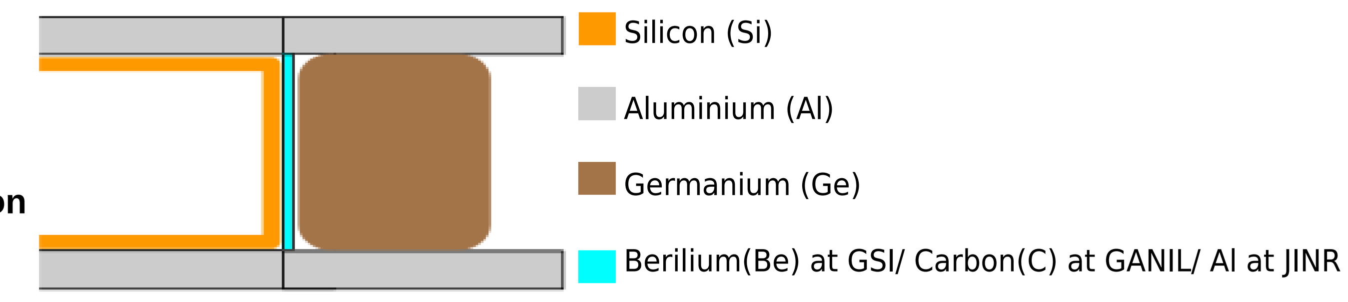


Fig. : Spectra obtained from reaction ^{207}Pb(^{48}Ca,2n) ^{253}No [2]

Thin Separation window configuration (Option 1) :

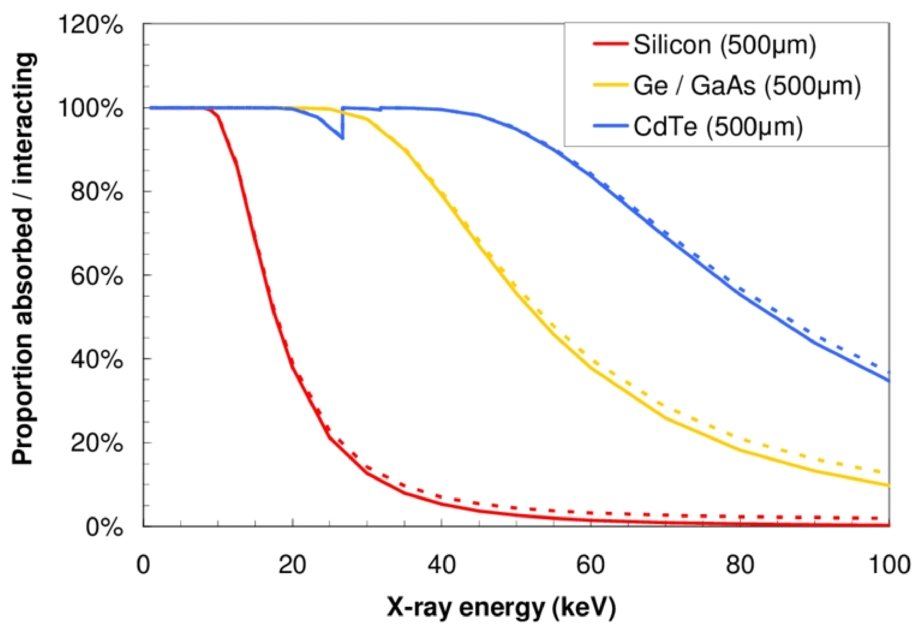


Solutions	Pros	Cons
Option 1: Enhance Detection Configuration: • Minimize the gap between detector crystals with a thin window. • Employ photon detector to capture both low and high-energy photons .	The same focal plane detectors can be used without the change in the associated electronics.	Difficult to detect the high energy gamma photons along with the low energy X-rays.
Option 2 (**): Enhance Detector System: • Replace current "Si" detectors in the vacuum chamber with advanced detectors. • New detectors capable of detecting both the position and energy of charged particles as well as low-energy X-rays.	Possible to detect almost all the charged particles along with a full range of emitted electromagnetic radiations.	The focal plane "Si" detectors as well as the associated electronics need to be changed.

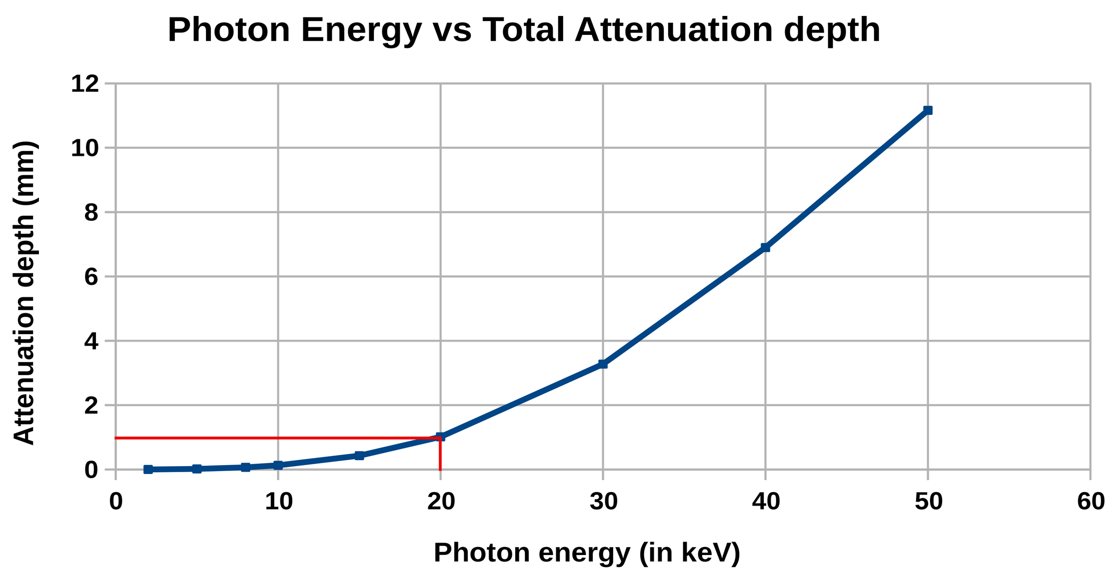
Detector materials and GEANT4 simulations

Semiconductor detector materials for new detectors (**):

Detector type	Material /filler gas	FWHM at 5.9 keV (in eV)	FWHM at 59.5 keV (in eV)	Energy range (keV)
Proportional counter	Ar /methane	840		<1-10
Scintillation	NaI (TI)	3150		3-100
Semi conductor	Si @-15°C	250	524	1-60
	Ge @-185°C	235	460	1-200
	$Cd_{0.9}Zn_{0.1}Te$ @-37°C	311	824	1-350
	CdTe @-60°C	310	600	2-250
	GaAs @-22°C	450	670	3-200

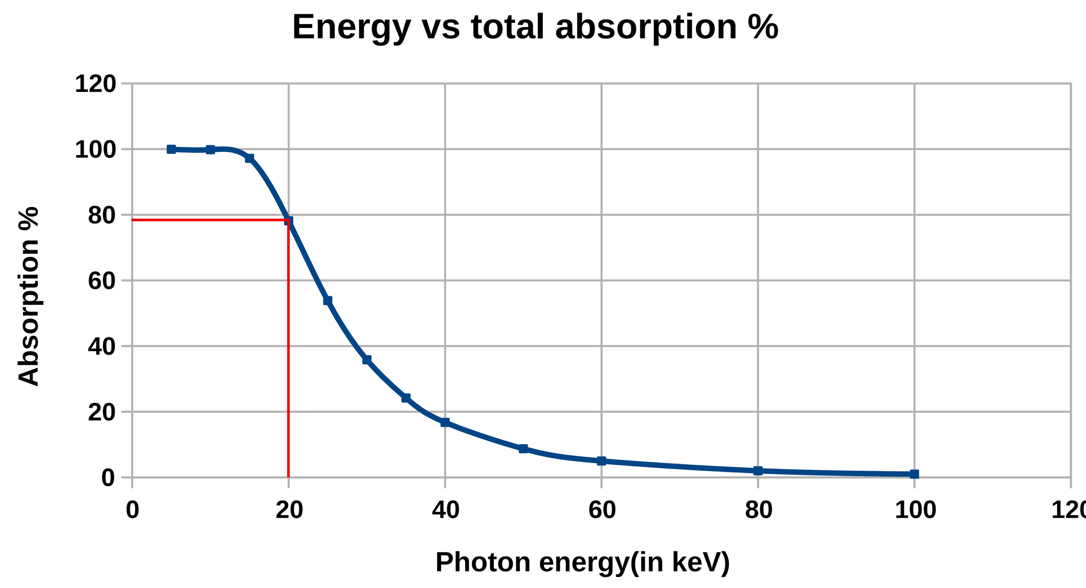


Si detector attenuation depth calculation for photons(**):



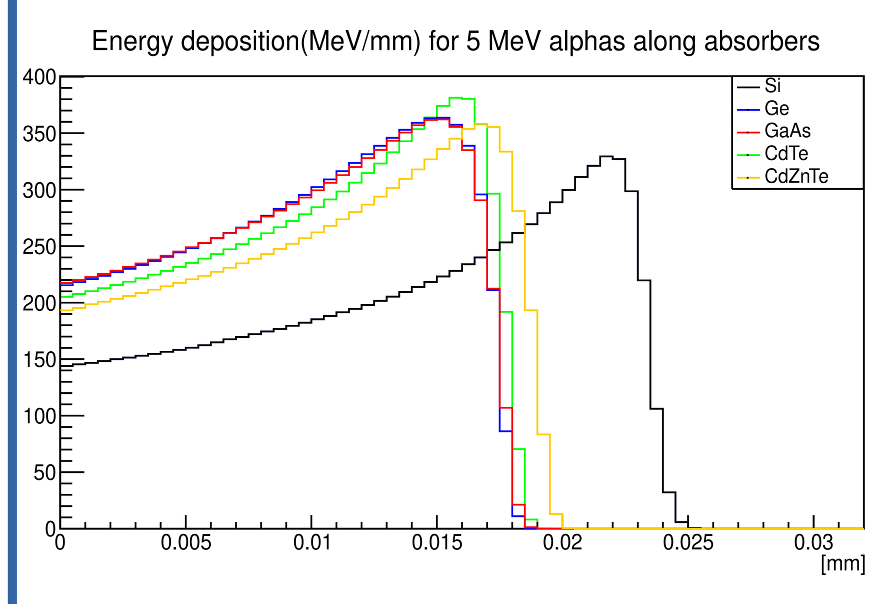
Necessary attenuation coefficients taken from NIST:XCOM data base [4].

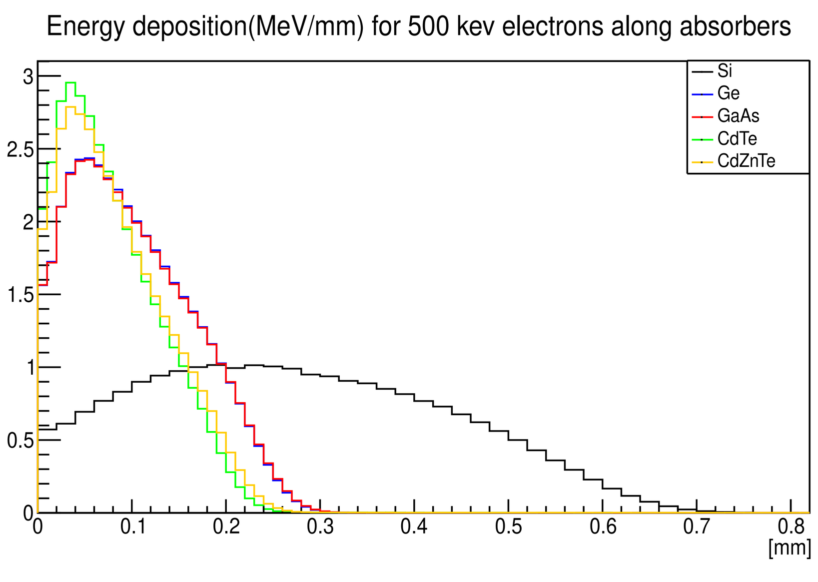
Absorption% vs photon energy for 1.5 mm Si detector(**):

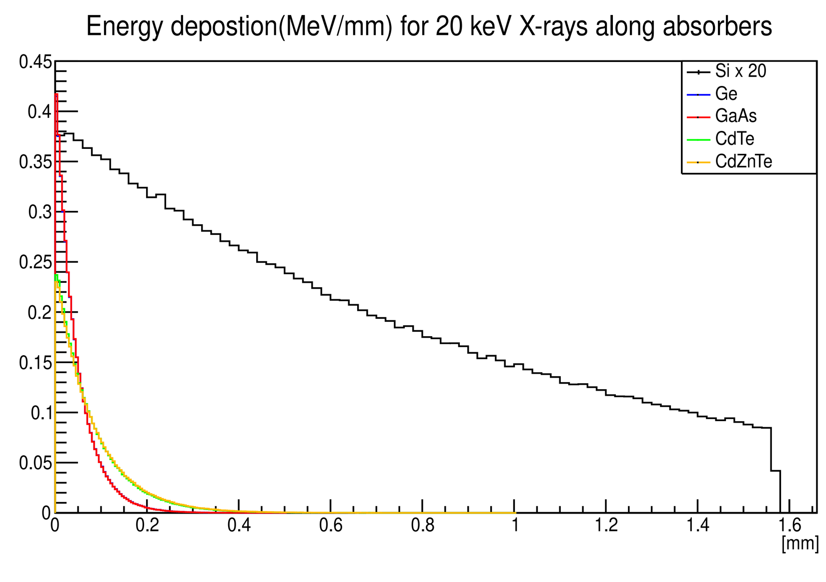


The plotted data is obtained from GEANT4 simulation.

GEANT4 simulations of the different semi-conductor detectors of thickness of 1.5 mm (**):







Upcoming work and Outlook

- The viability of "Option1 " has been tested both at GSI [2] , at GANIL [5] and at FLNR facility of JINR [3] .
- More simulations to implement and test "Option 2" are going on.
- Calculations of the detection efficiency with all the detection components for "Option 2".
- Comparing the detection efficiency of both the options.
- Testing and characterization of the new detectors (Option 2).
- Testing compatible electronics (including pre-amplifiers) for the new detectors to attain a FWHM energy resolution of < 1 keV.
- Pulse shape analysis of the energy spectra (of alpha particles, e- s and X-rays) from these detectors' offline testing using a radioactive source [6].
- Integration of these detectors in the current focal plane detection setup of S^3.

References:

[1] Déchery, F., et al. "The Super Separator Spectrometer S3 and the associated detection systems: SIRIUS & LEB-REGLIS3." NIM. B 376 (2016): 125-130

[2] D. Ackermann et al. "COMPASS—A COMPAct decay spectroscopy set-up" Nuclear Inst. and Methods in Physics Research, A 907 (2018) 81–89

[3] R. Chakma et al. "Gamma and conversion electron spectroscopy using GABRIELA", Eur. Phys. J.A (2020) 56:245

[4] https://physics.nist.gov/PhysRefData/Xcom/html/xcom1.html

[5] PhD thesis Ablaihan Utepov, "Multinucleon transfer reactions in the 238U+238U system studied with the VAMOS + AGATA + ID-Fix". [physics]. Normandie Université, 2023.

[6] M. von Schmid et al., "First application of pulse-shape analysis to silicon micro-strip detectors", Nuclear Inst. and Methods in Physics Research, A 629 (2011) 197–201

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