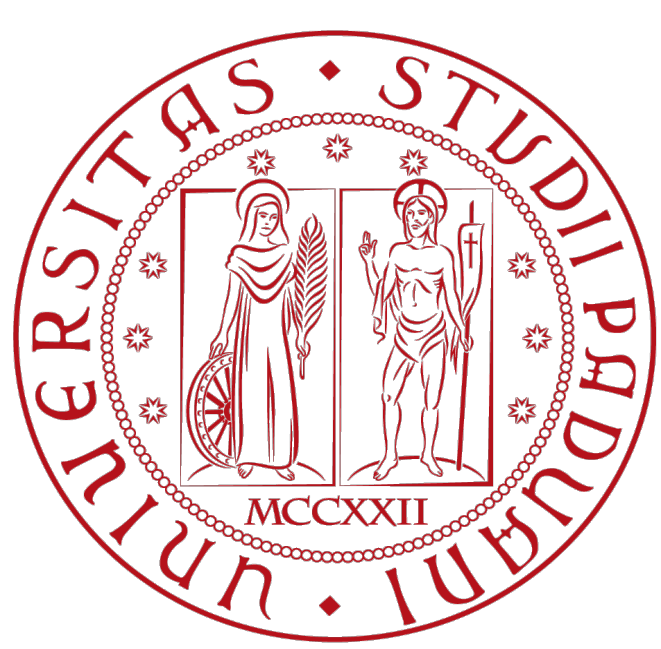




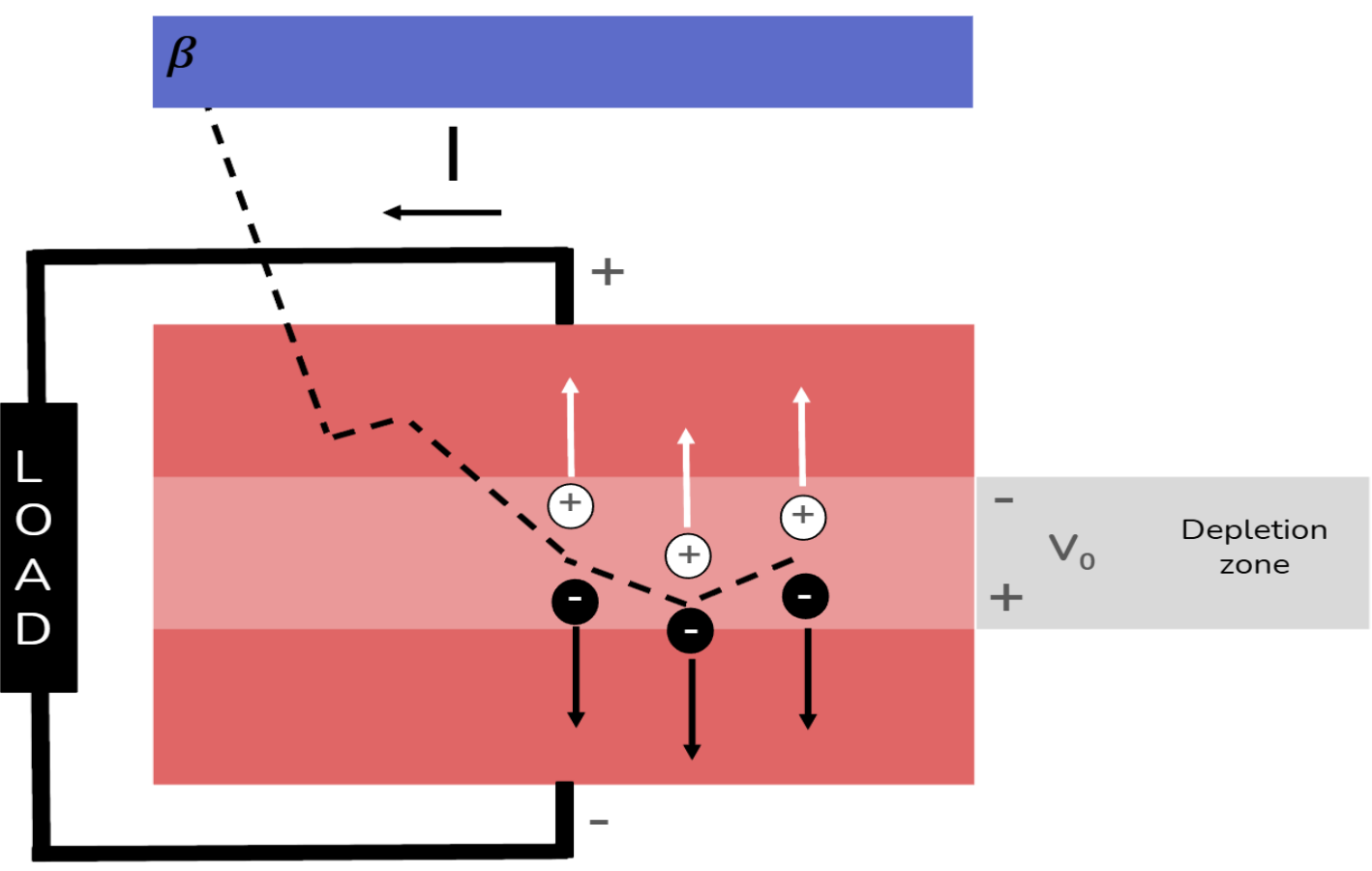
Innovative batteries for space, environment and medicine: the case of betavoltaic devices

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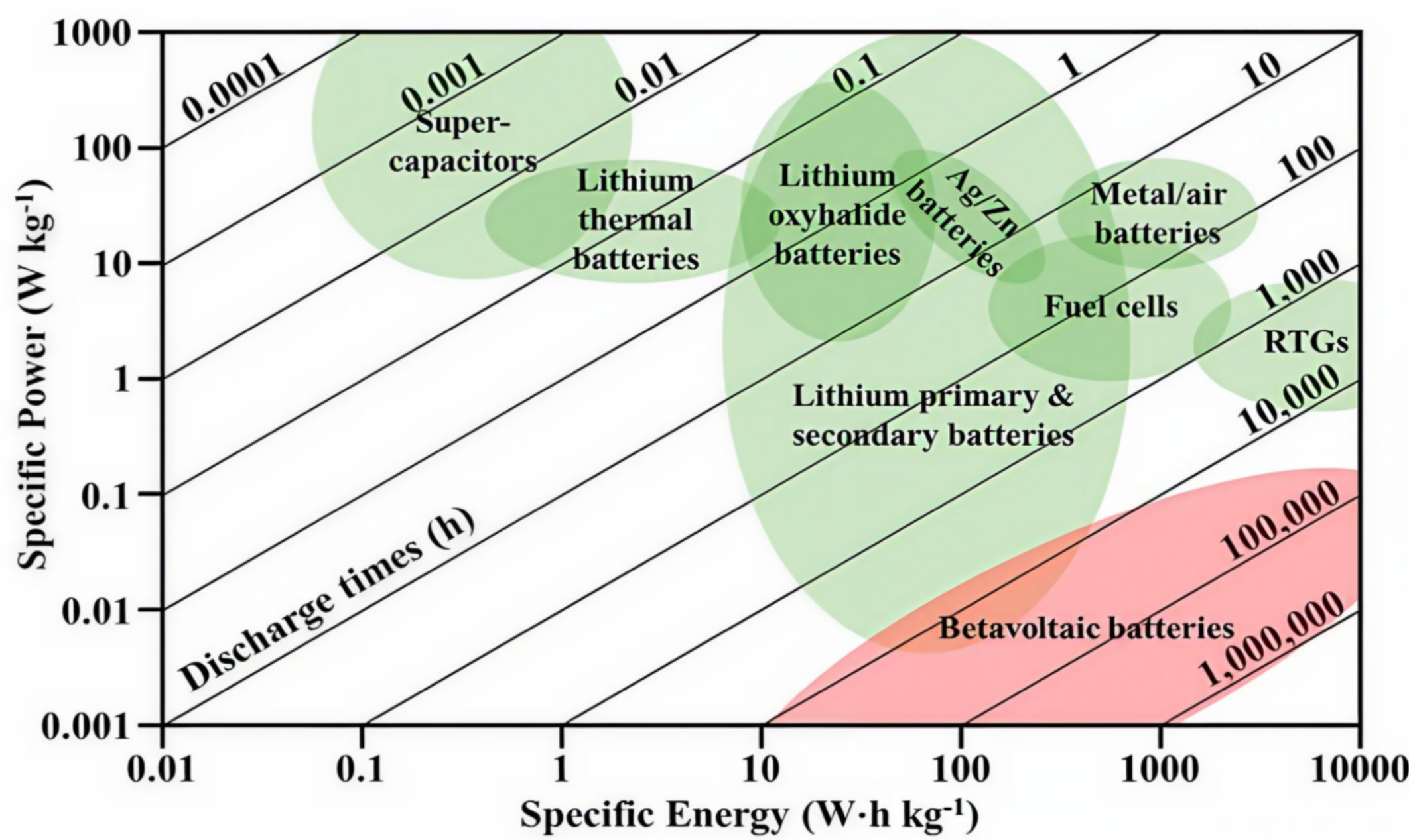
CONTEXT



Betavoltaic batteries (BVB): a type of nuclear battery that generates electric current from beta particles. Formed by a **radioactive source** and a **semiconductor device**

- **Pure beta emitter:** other radiation would damage the lattice structure, reducing device life
- **Long half-life:** keeping in mind it determines the maximum activity of the source and the effective device lifetime
- **Controlled maximum beta-energy:** along with the activity it determines the effective source power density and the possibility of defect formation in the device
- **Production method:** it affects the costs

Source	ρ [g/cm ³]	M [g/mol]	Q-value [keV]	T _{1/2} [years]
⁶³ Ni	8.908	63	66.7	100.1
⁹⁰ Sr	2.64	90	2278.5	28.8
TiTi _{1.66}	4.502	52.88	18.6	12.3



PROS

- Energy density is higher than that of chemical batteries or fuel cells by 100-1000 times
- Long service life that can range from several tens to several hundreds years
- Stable output even in harvest environment
- Can be integrated into a chip of an integrated circuit and energize it without recourse to an external power source

CONS

- Low power output (and density)

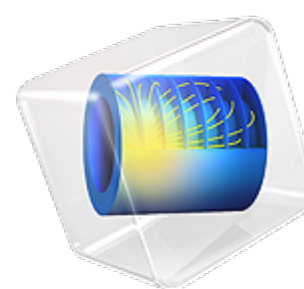
- **Proper material:** it should be adaptable to streamlined production, and widely used in nano- and microelectronics. Together with topological configuration and layer thickness, it must be adapted to radioisotope considered. Also costs, characteristics, availability and manufacturability must be taken into account;
- **High threshold energy:** at least with respect to the maximum energy of the beta source
- **Optimized design of depletion region:** it must match as much as possible the energy release region of incident electrons

Semic. mat.	Ioniz. En. [eV]	Min. carrier lifet. - n [s]	Min. carrier lifet. - p [s]
Si	3.63	10 ⁻³	10 ⁻³
SiC	6.88	5·10 ⁻⁷	5·10 ⁻⁸
C	12.4	10 ⁻⁹	10 ⁻⁹

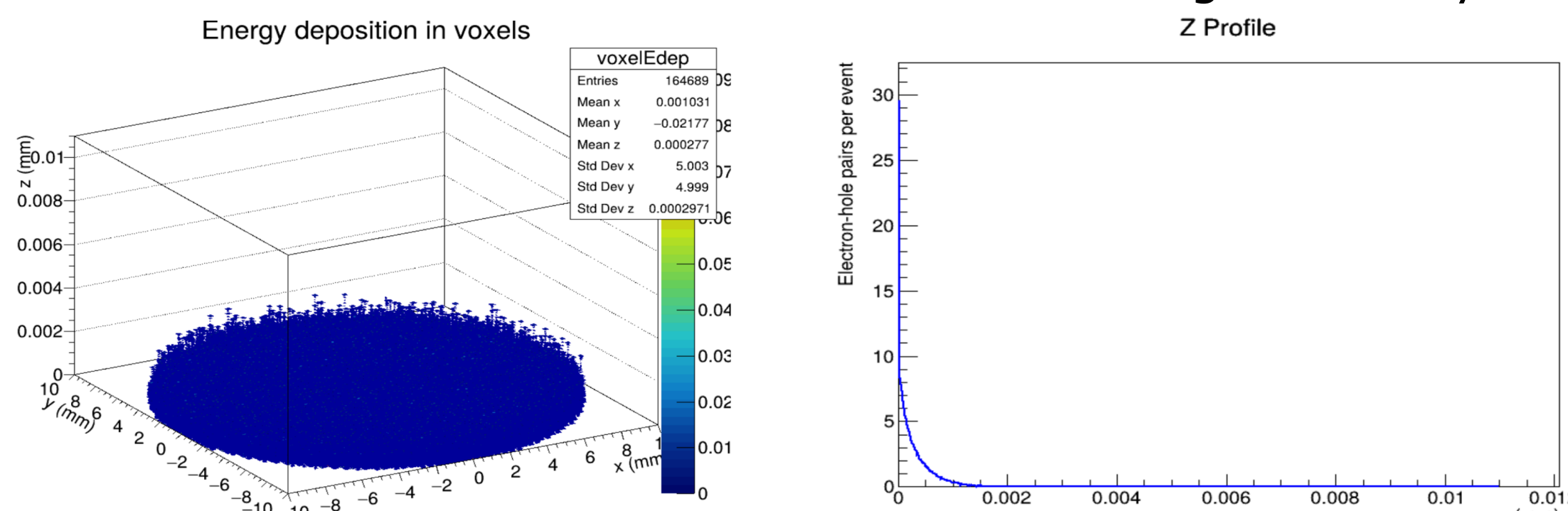
SIMULATIONS



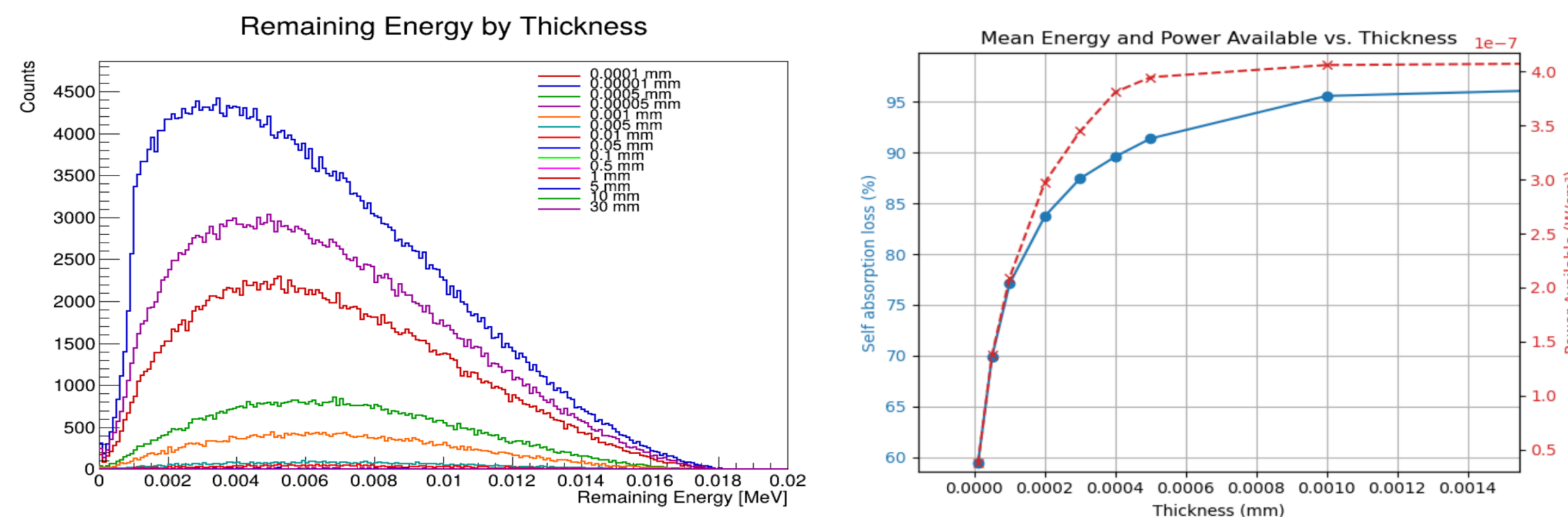
.csv file with EHP
Generation map



Necessary to determine the penetration depth and energy distribution of electrons into the betavoltaic converter with high accuracy

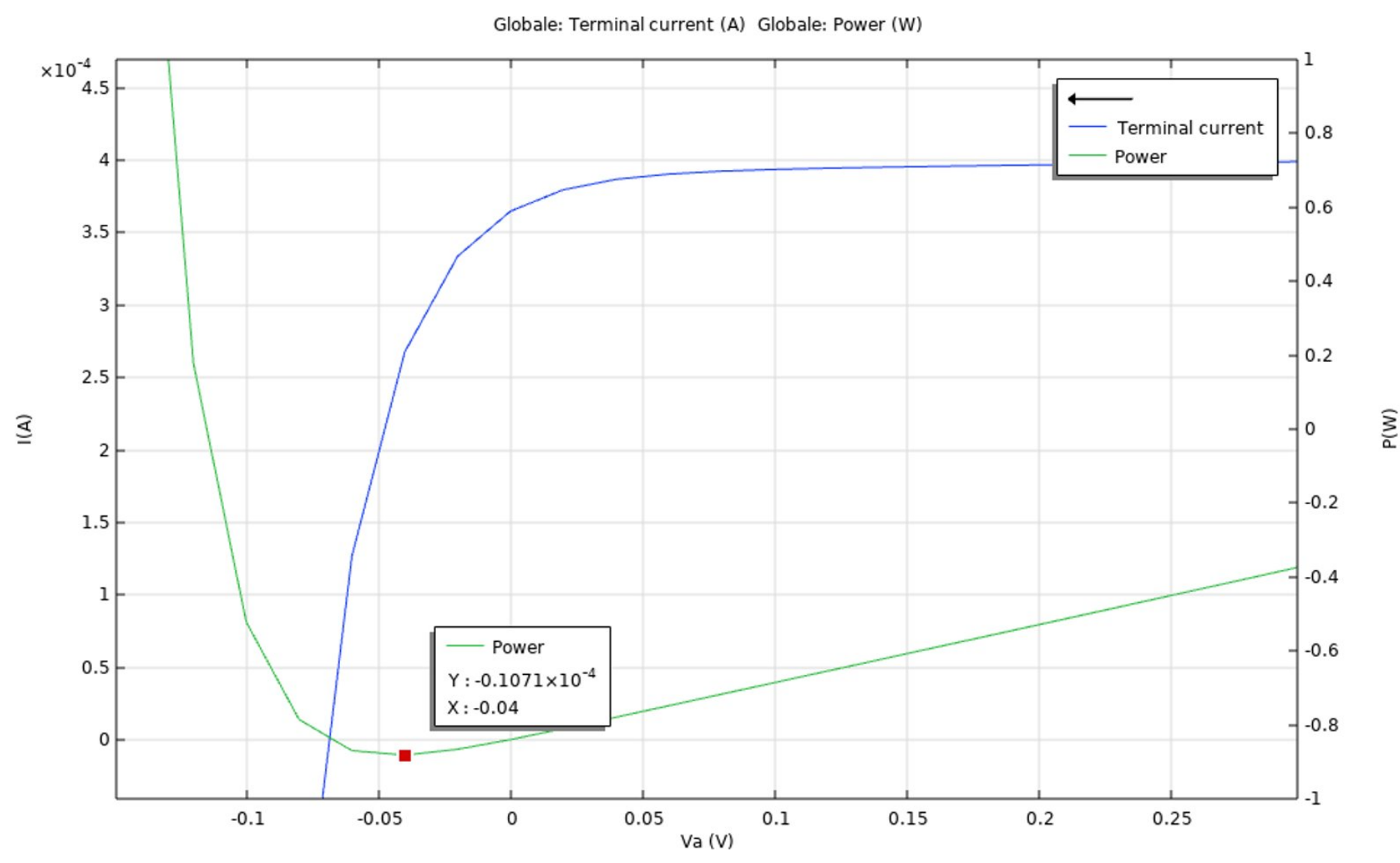


Very important also to study effects like the self-absorption inside the source, and therefore to improve design optimization



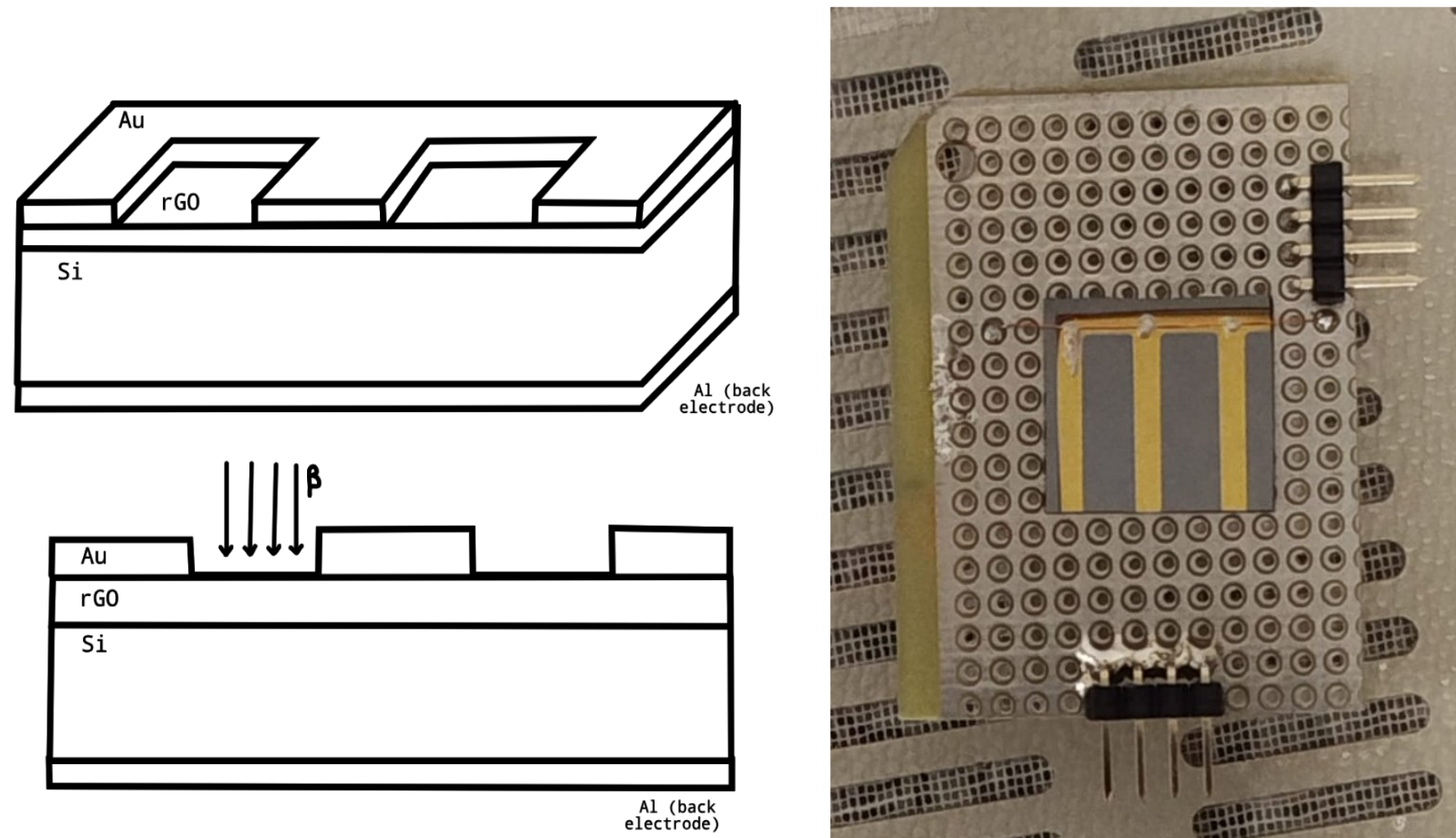
Finite Element Analysis (FEA) software that enables the modeling and solution of physics-based problems across a wide range of domains

Its multiphysics capabilities allow the coupling of different physical phenomena within a single simulation, facilitating the study of carrier transport, recombination, current flow, doping profiles and electric field of semiconductor devices



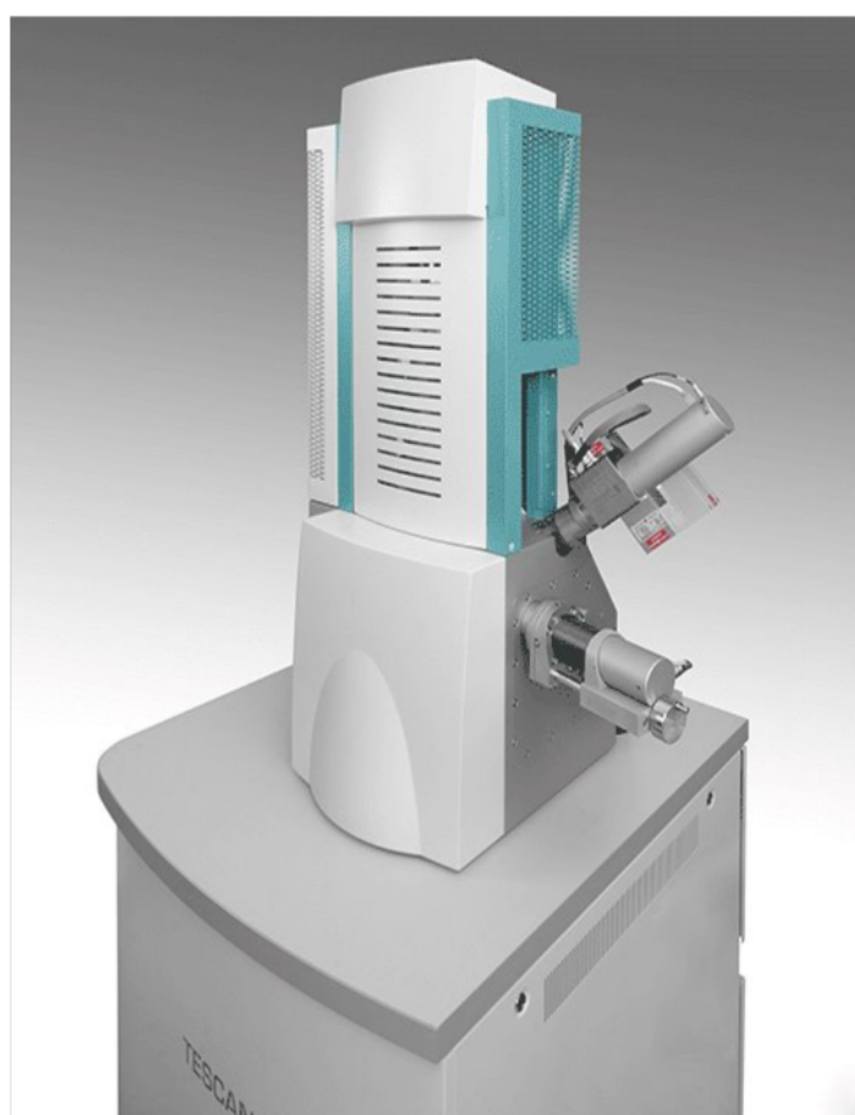
EXPERIMENTAL RESULTS

We considered prototypes produced at MINE Lab (UniPg), composed by a Schottky junction made by rGO (reduced graphene oxide) and p-type Silicon layers. A fingers shape Au electrode was considered on top of it, while on the back an Al one.



The reasons behind this choice are the following:

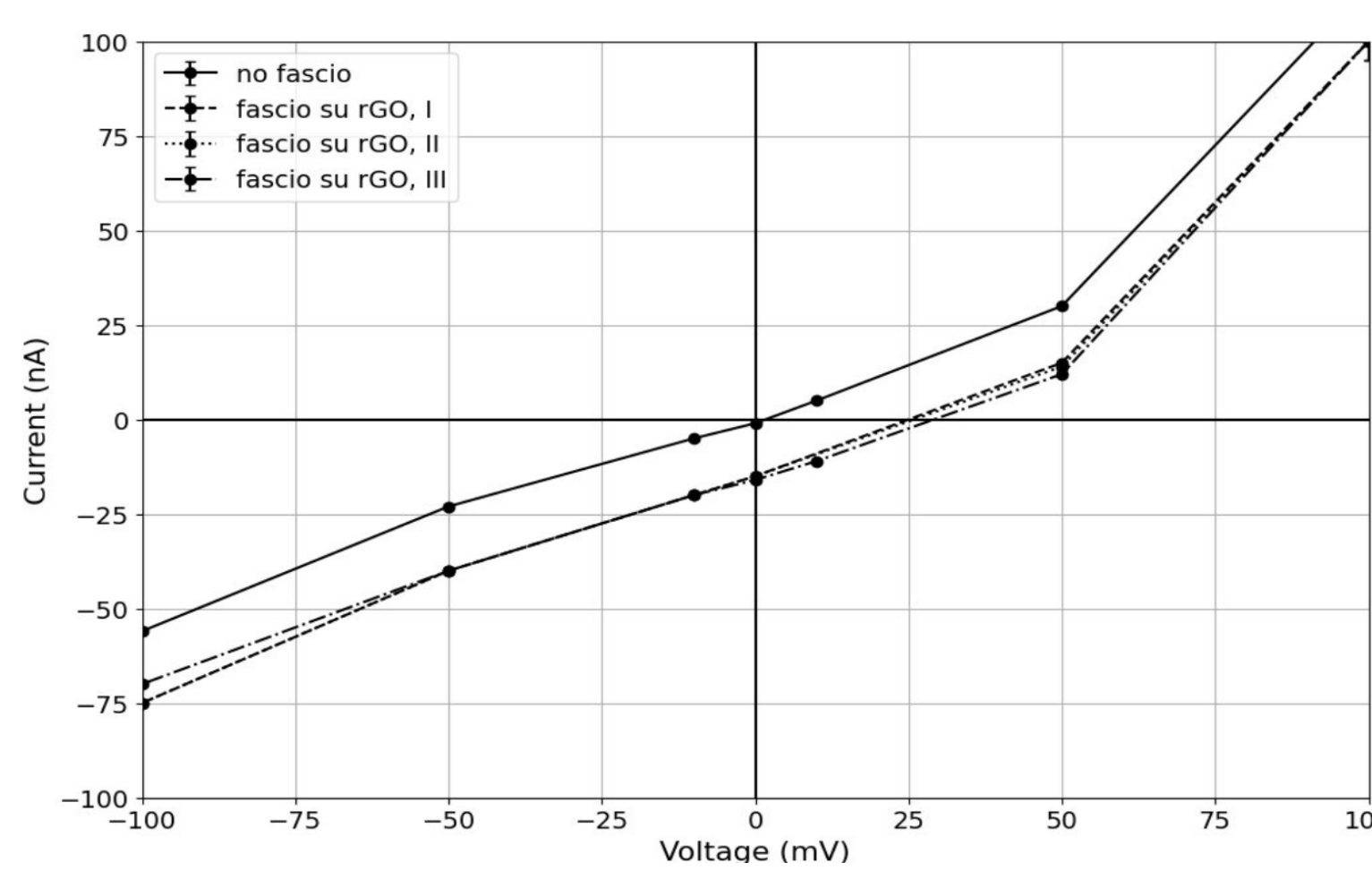
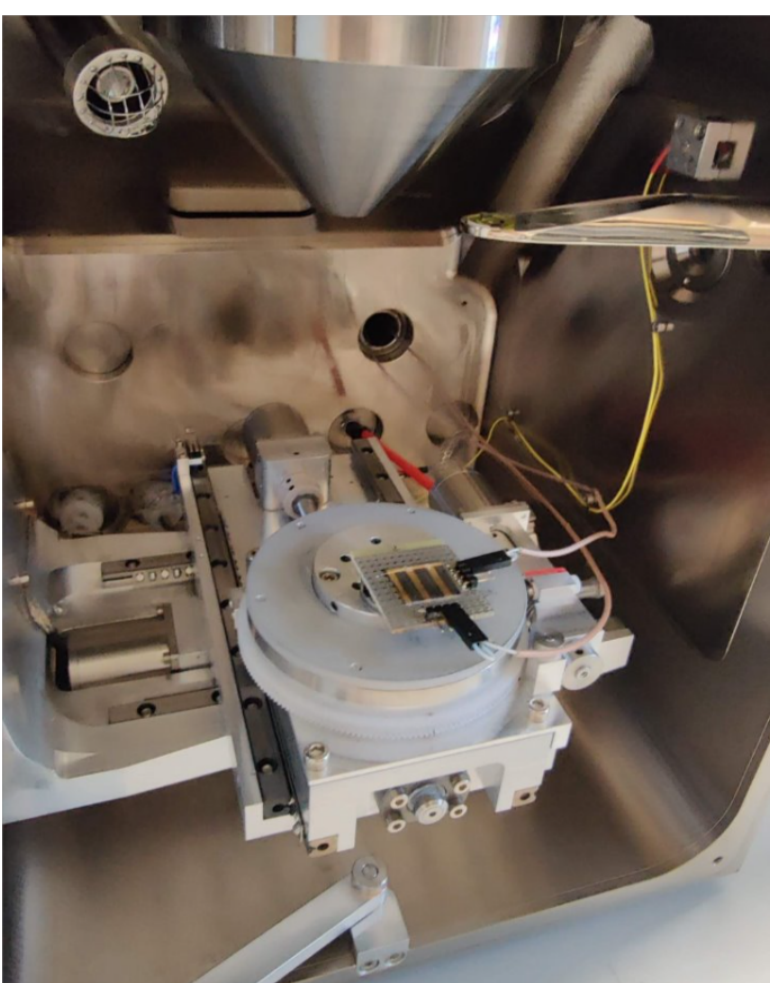
- Good Schottky contact between Si and rGO
- Radiations can generate electron-hole pairs in graphene, which can increase the efficiency of the cell
- Good candidate for tritium introduction



The main advantages are:

- Comparable to high intensity source
 $I_{SEM} \approx 20 \text{ nA} \rightarrow A_{SEM} \approx 10^8 \text{ kBq}$
- Energy in the ³H range
 $E_{SEM} \in (3 \text{ keV}; 30 \text{ keV})$
- Capable to study material composition through Energy Dispersive X-ray Spectroscopy

Because of unavailability of high intensity source, a Scanning Electron Microscope (SEM) has been considered. It's capable of providing an electron beam, making it a good candidate to represent the source of interest.



Though we clearly see a current, output powers (Table) are much lower with respect to the input one. Therefore, measured efficiencies are much lower than simulated ones

	P_{max} (nW)
no fascio	0.01 ± 0.02
fascio su rGO, I	0.08 ± 0.04
fascio su rGO, II	0.09 ± 0.04
fascio su rGO, III	0.11 ± 0.03

$P_{SEM} \approx 0.45 \text{ mW}$

$$\eta_{meas} \ll 0.1 \% \quad \eta_{sim} \approx 2.38 \%$$

New prototypes will soon be produced in collaboration with Fondazione Bruno Kessler (FBK), featuring well-characterized properties and technologies

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