Design Of Thin Targets For The NUMEN Experiment

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NUMEN Project

- The aim of the NUMEN project is to measure the cross section of ***Double Charge Exchange*** (**DCE**) reactions and to evaluate their *Nuclear Matrix Elements* (NME)

DCE

$$\begin{cases} {}^{A}_{Z}X + {}^{a}_{z}x \rightarrow {}_{Z+2}^{A}Y + {}_{z-2}^{a}y \\ {}^{A}_{Z}X + {}^{a}_{z}x \rightarrow {}_{Z-2}^{A}Y + {}_{z+2}^{a}y \end{cases}$$

NUMEN Project

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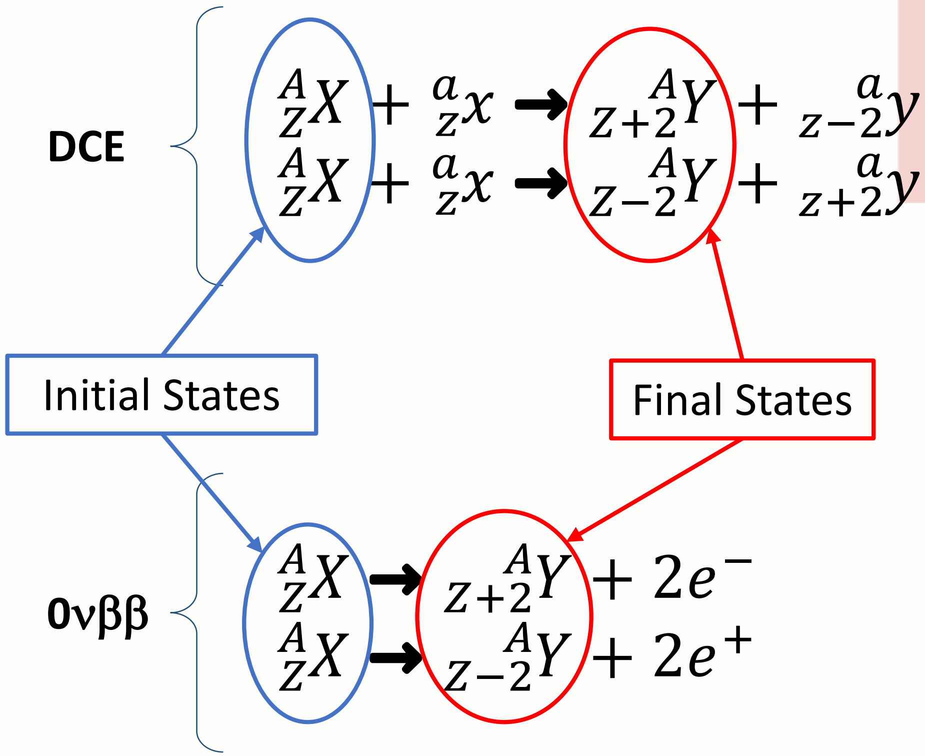
- NME of DCE can help to evaluate the NME of ***Neutrinoless Double β-Decay* (0νββ)**: the two processes share some important features, such as the same *initial* and *final* states of target isotopes

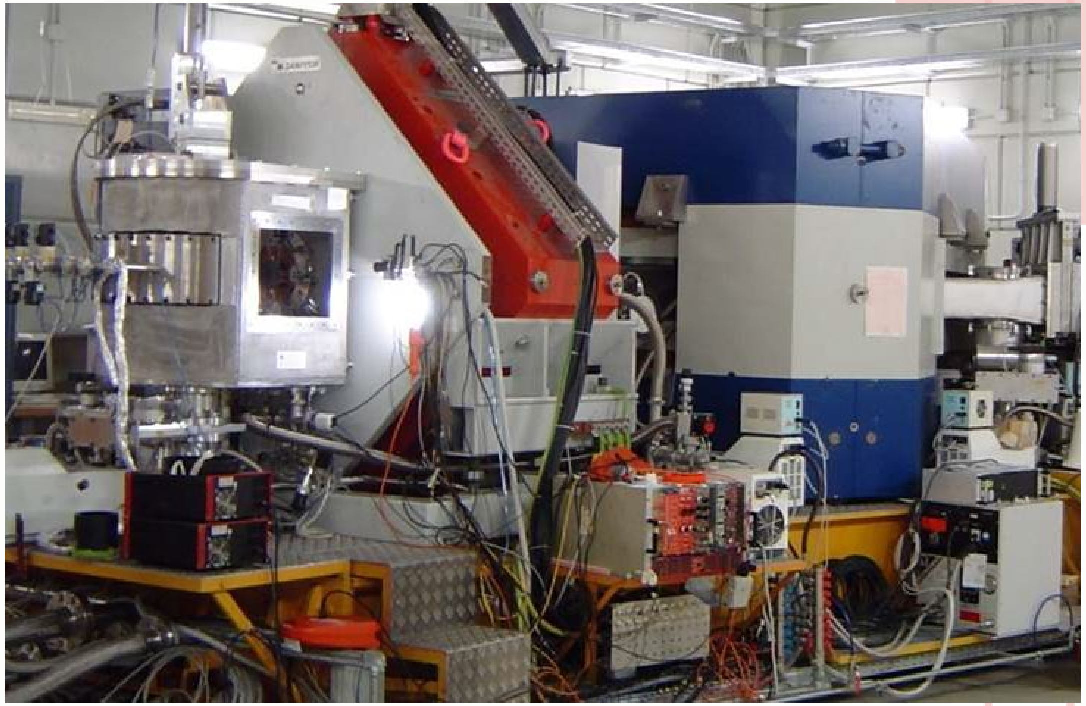


NUMEN Project

- NUMEN is hosted at Laboratori Nazionali del Sud, INFN, Italy
- Run at low intensity beam ($I_{beam} \approx 10\ nA$) already perfomed, data taking planned until **2033**
- It's currently in the **upgrade phase**: everything from the cyclotron to the acquisition system is being improved
- Ion beams will have energy range 15-60 MeV/u and intensity up to $I_{beam} \approx 50 - 60\ \mu A$

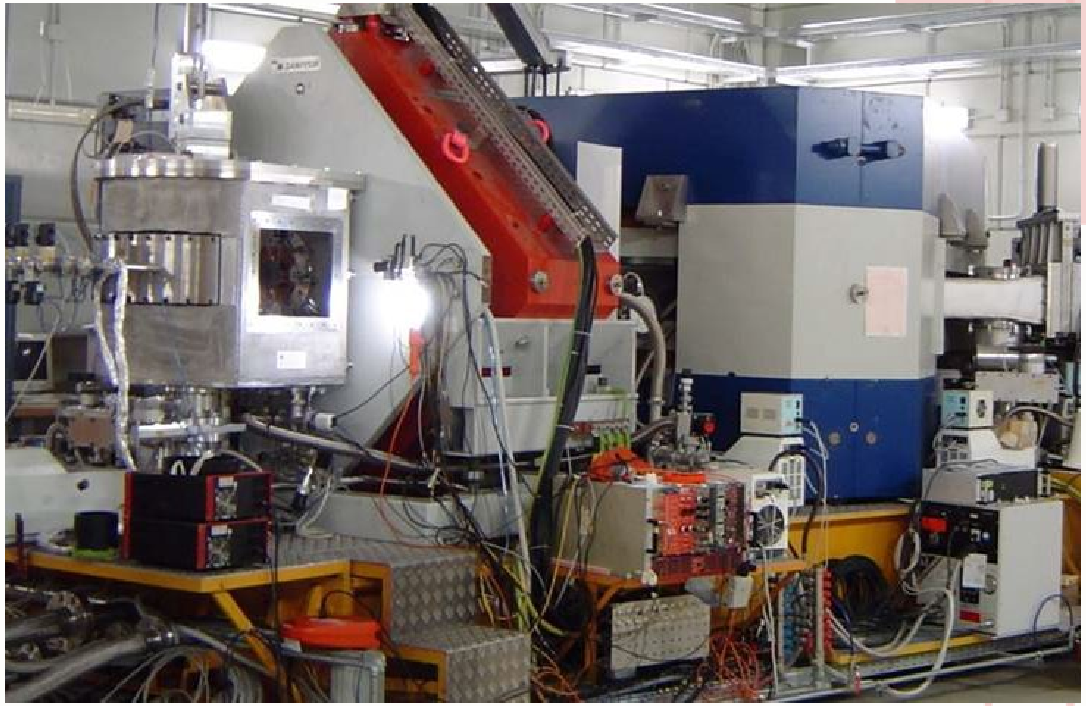
NUMEN Requirements

- The broad experimental campaign involves **0νββ** candidates: ^{130}Te, ^{76}Ge, ^{160}Gd, ^{100}Mo, ^{116}Sn, ^{76}Se, …, whose **DCE reactions** have a **low cross section** (few nb)
- Large amount of data are required for having a good statistics: need of **high intensity ion beam** of ^{18}O and ^{20}Ne (more than 13 μA)



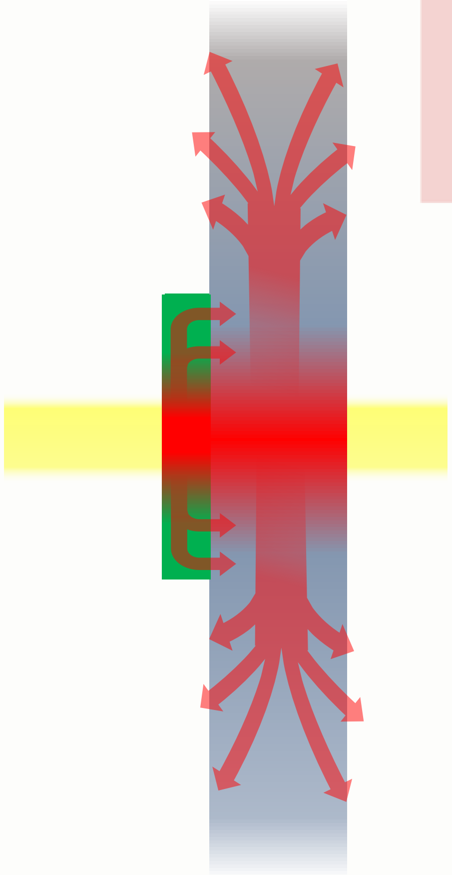
NUMEN Requirements

- A good energy resolution is required too, in order to clearly distinguish the energy levels of recoiling nuclei: targets must be thin, below 1 μm
- High intensity beams produce a lot of heat by energy loss, which standalone thin targets cannot withstand



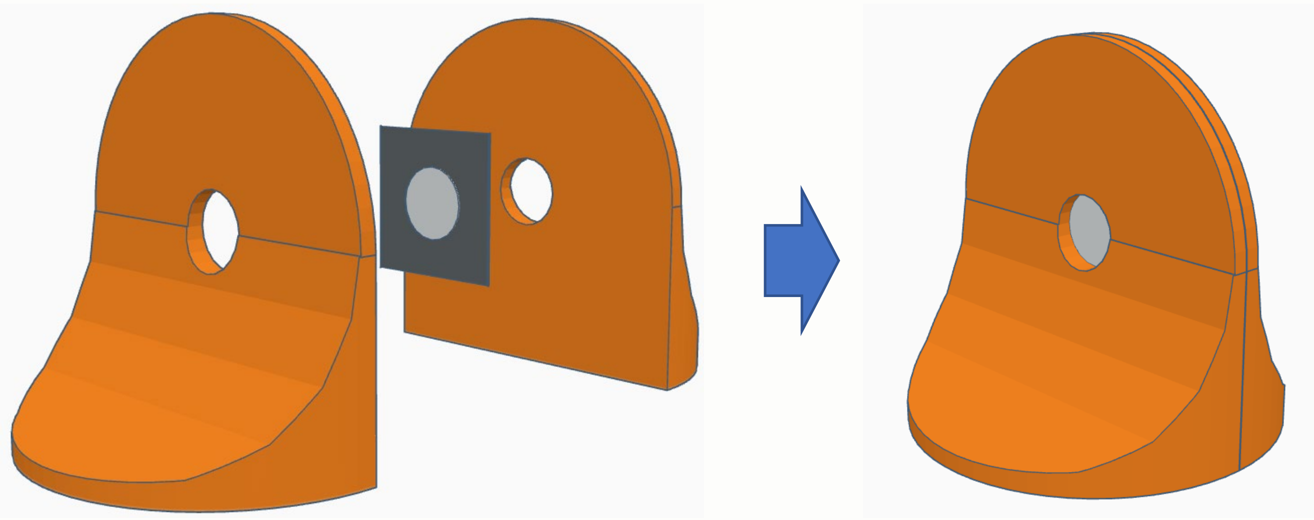
HOPG backing

- Thermal stress is addressed by backing the targets with ***Highly Oriented Pyrolytic Graphite*** (**HOPG**)
- **HOPG** is a special kind of highly conductive graphite ($k_{//}$=1700-1950 $Wm^{-1}K^{-1}$) which is produced in μm-thick sheets. It serves to dissipate heat toward the cooling system, as post-stripper and mechanical support



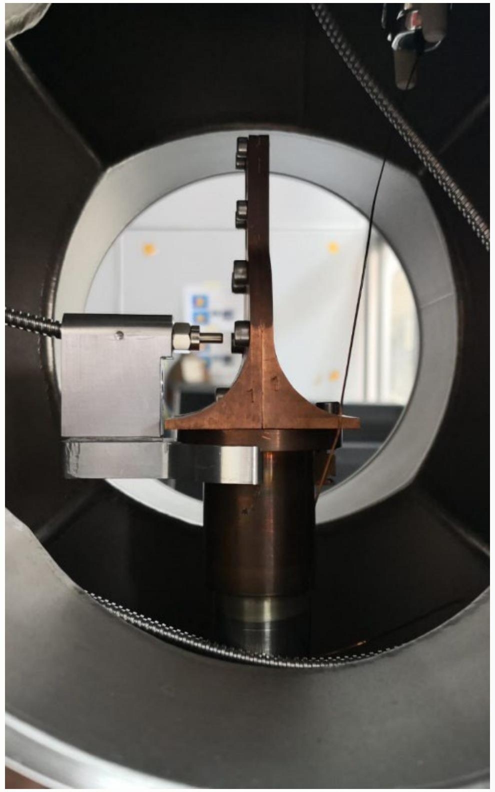
Target System

The **target** (1 cm in diameter, about 250 $\mu g/cm^2$ in thickness) is **deposited on a HOPG substrate** (side of 2 cm, 450 $\mu g/cm^2$ thick) and then <u>clamped between two copper halves</u>



Target System

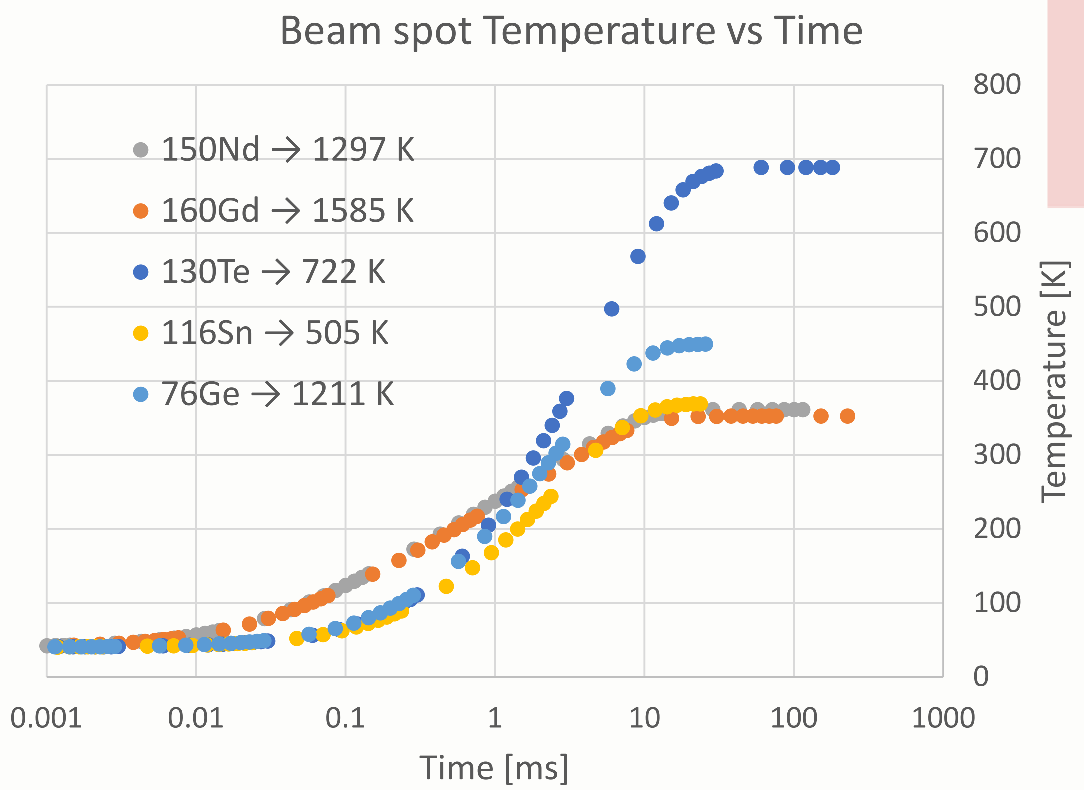
The whole object is fixed on top of a cryocooler (fastened by screws or bayonet mount)



Target heat resistance

Numerical calculations show that the assembly **can withstand** the **highest beam current** used in the experiment (10^{13} pps) thanks to the high thermal conductivity of the backing

Beam spot size: 1 x 2,5 mm²



^{18}O beam at 15 MeV/u, 10^{13} pps

^{20}Ne beam at 15 MeV/u, 10^{13} pps

HOPG Downside

Few drawbacks:

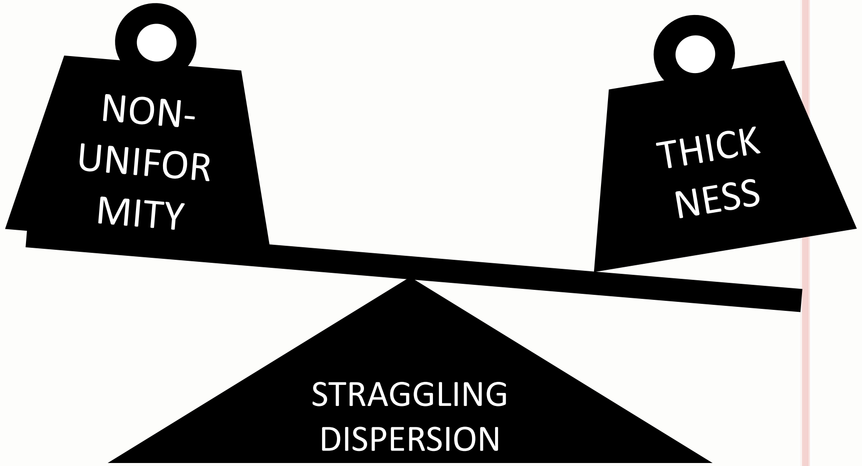
- The HOPG/target assembly affects the energy of the reaction products and the experimental energy resolution: they must be carefully designed to reduce their impact as much as possible
- There is scarce literature on HOPG as substrate; it is rather inert, which makes depositing the isotopes on it more challenging

Target & HOPG Thickness and Uniformity

Several phenomena in target and HOPG affect energy resolution (like Energy straggling and dispersion error);

Both are worsened by thickness and non-uniformity: the two must be carefully balanced.

The smoother the target, the thicker it can be (and higher reaction rate!)



Target production

Very important to have <u>uniform targets</u>!

Very costly isotopes,
<u>only few grams available</u>

→ Targets are deposited by **e-beam** deposition or **thermal evaporation**,

→ **Buffer** to improve homogeneity

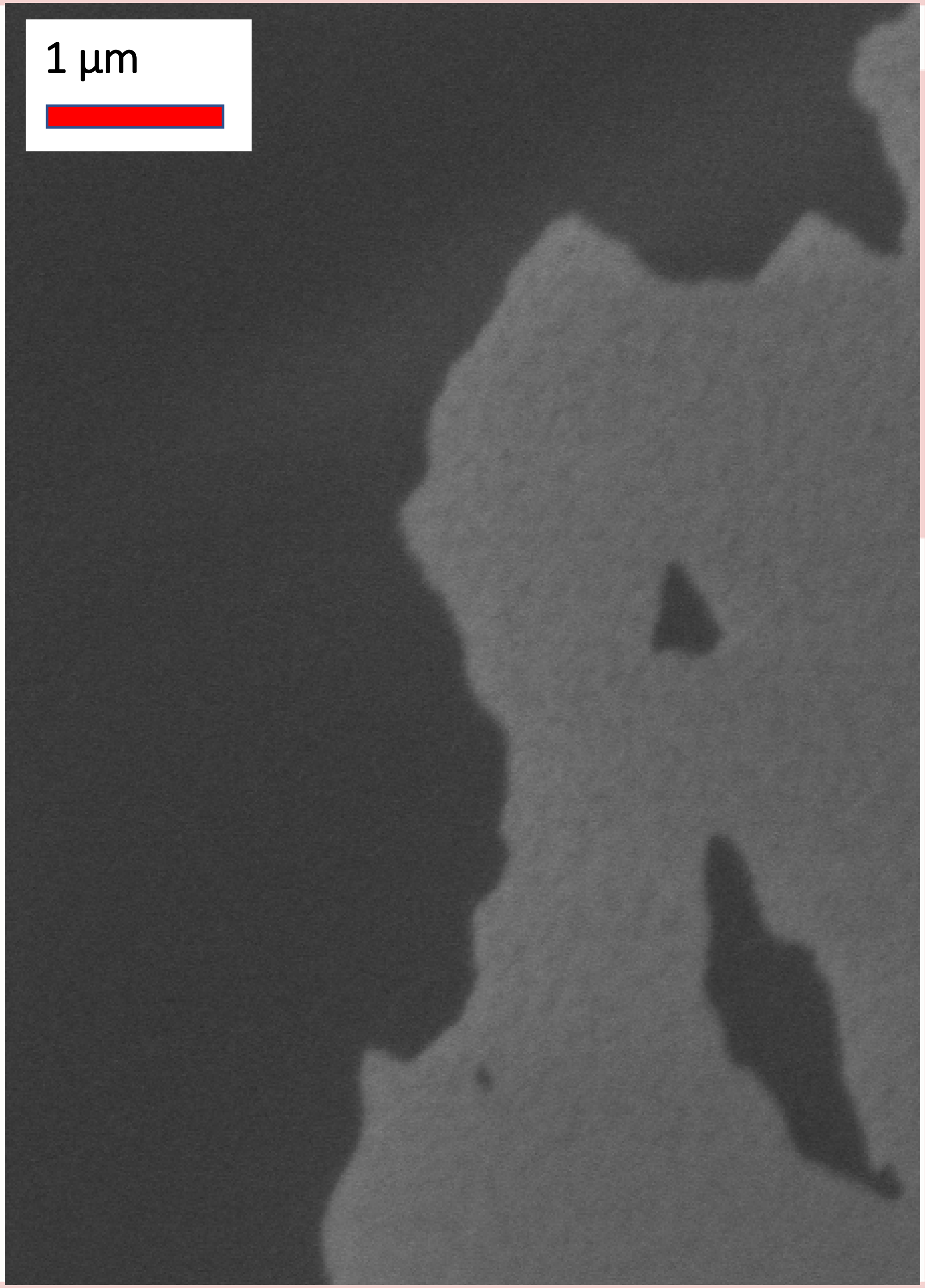
→ **Heated substrate** to improve coverage

Target characterization

SEM can be used to **qualitatively study** the deposition's **surface**

It's a quick method to distinguish promising prototypes…

Se on HOPG, Mn buffer

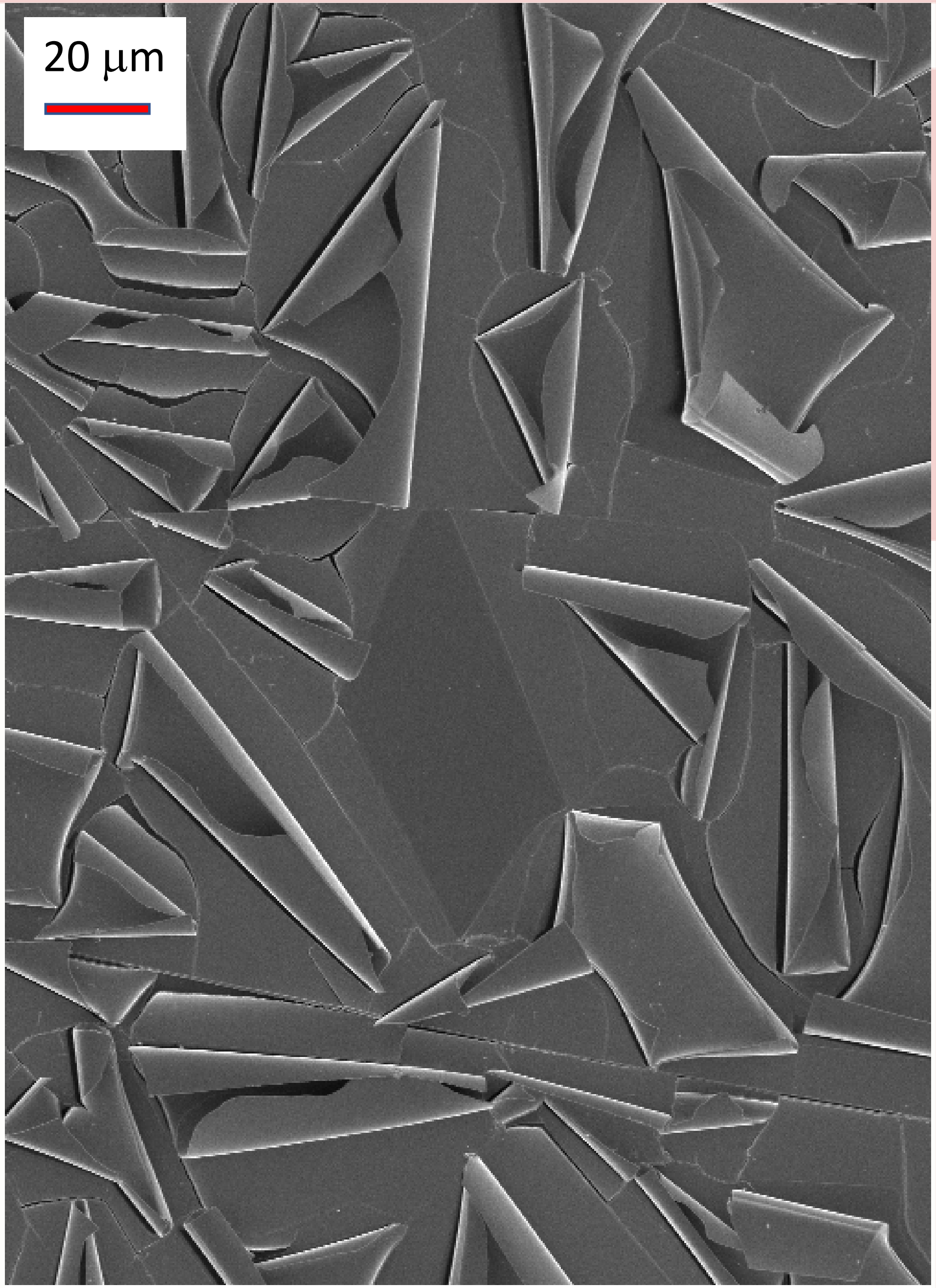


Target characterization

SEM can be used to **qualitatively study** the deposition's **surface**

It's a quick method to distinguish promising prototypes…
… from bad samples

Mo on HOPG @RT

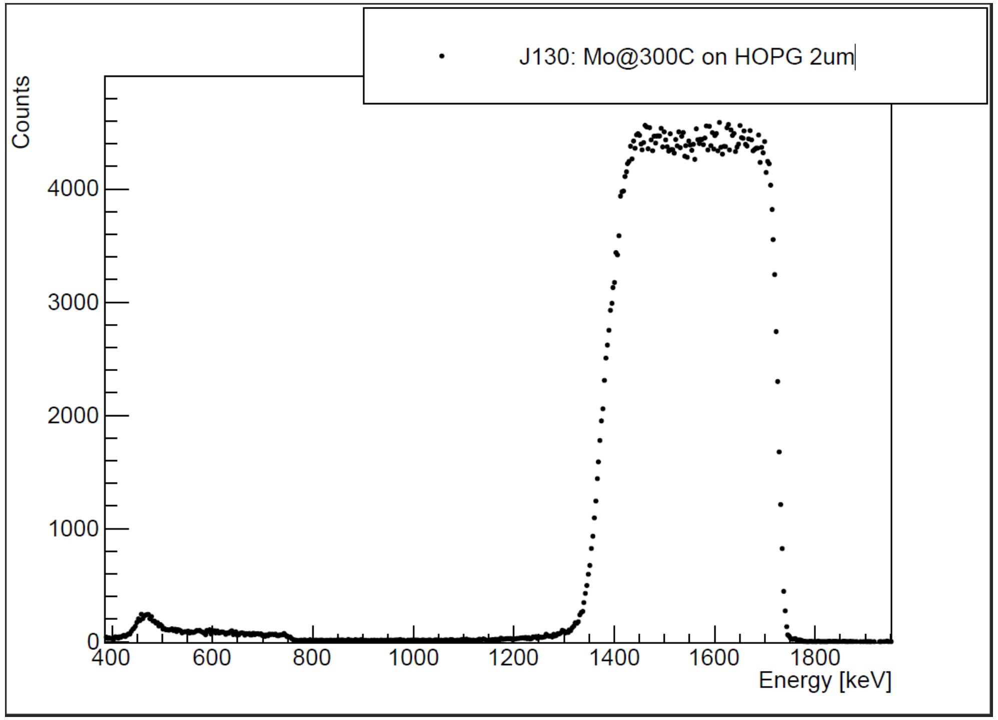


Target characterization

Rutherford Backscattering Spectroscopy (RBS) and Alpha Particle Transmission (APT) are being used to quantify thickness and uniformity

RBS:

- Thickness measurement of individual layers
- Check elemental purity

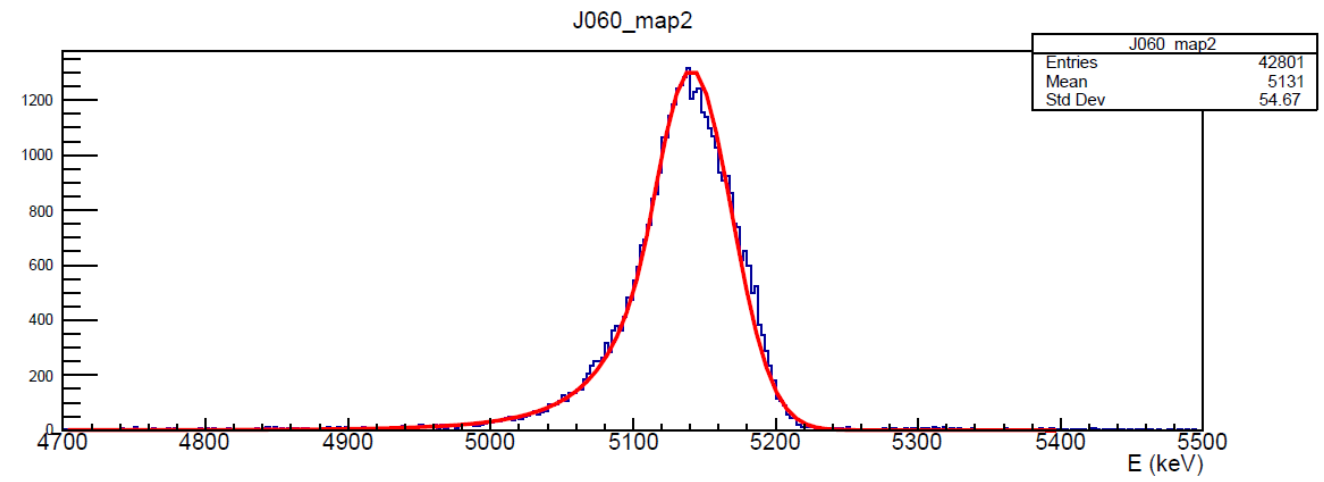


Target characterization

Rutherford Backscattering Spectroscopy (RBS) and Alpha Particle Transmission (APT) are being used to quantify thickness and uniformity

APT:

- Thickness measurement
- Evaluation of uniformity

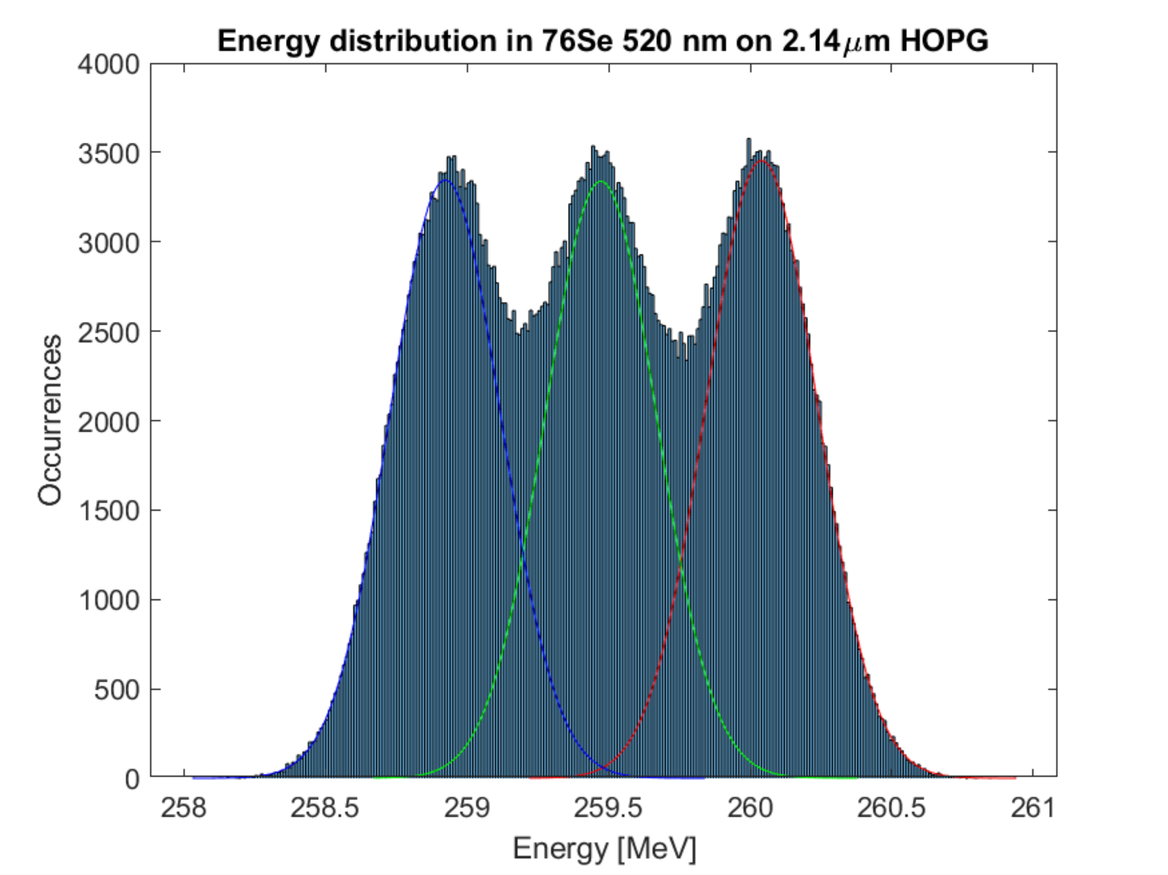


Target resolution

Results from RBS and APT(of both HOPG and target) measurements are used as input data in a Monte Carlo code for evaluate the **energy resolution**

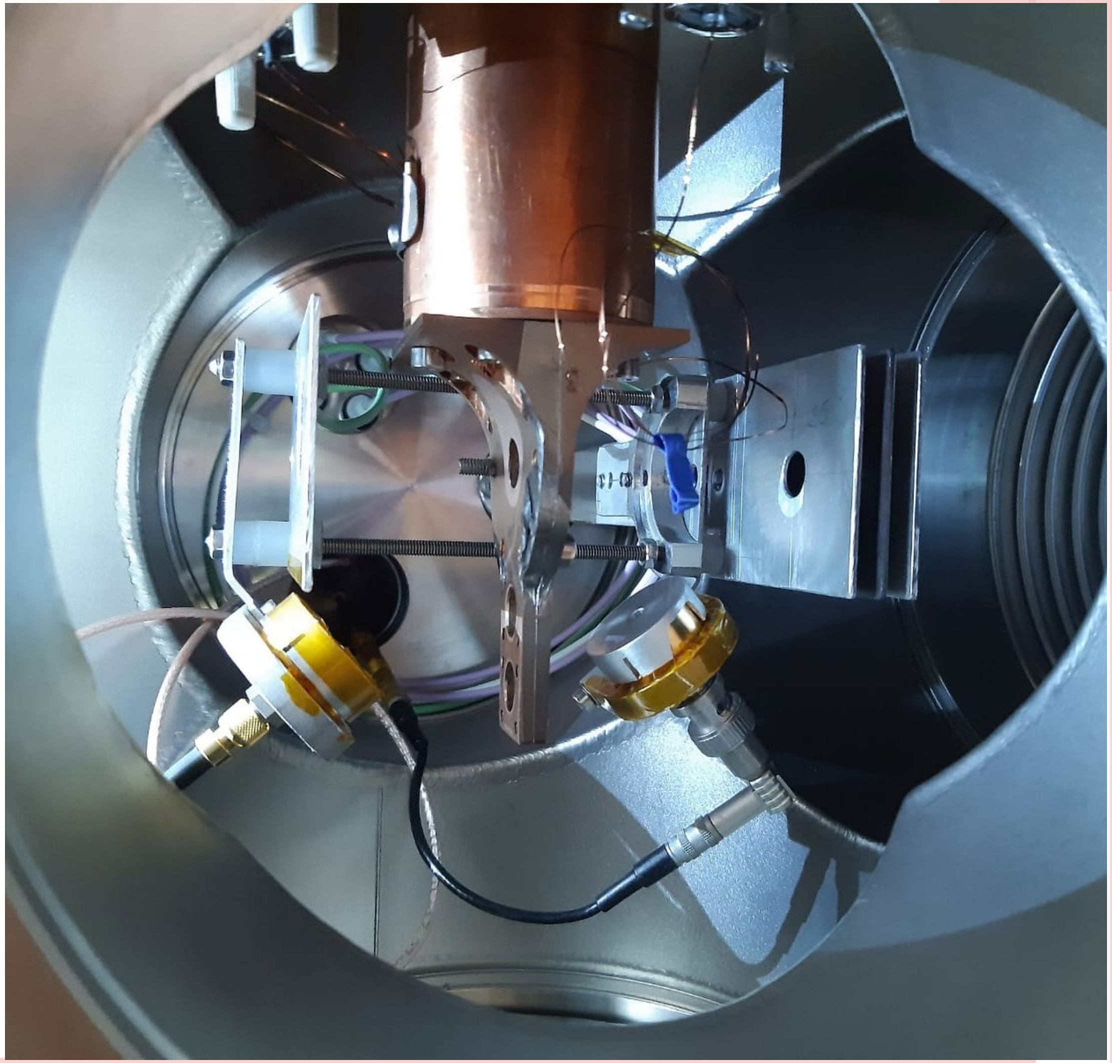
Energy resolution must be smaller than the ΔE of adjacent energy levels of recoiling nucleus (for most isotopes ~ 500 keV)

$^{76}Se(^{18}O, ^{18}Ne)^{76}Ge$ (Mn buffer)
Backing: HOPG, 2,14 ± 0,107 µm (5% uniformity)
Target: ^{76}Se, 520 ± 38 nm (8% uniformity)
ΔE ($^{76}Ge^{2+}$) = 563 keV
FWHM = 463 keV



Beam test HERETIC

- Performed in INFN-LNL
- Targets of HOPG, Te, and Ge irradiated with 1 µA of ^{16}O @50 MeV
- Temperature monitored with thermal camera, target integrity monitored with Si detectors
- Targets not visibly damaged
- Data analysis ongoing



Next steps

- HOPG thermal conductivity decreases with radiation-induced defects; targets may evaporate under irradiation. Need to find how HOPG properties change when irradiated
- Establishing of a protocol for measurements of thermal conductivity
- Implanted Xe targets
- **Perform test of the complete cooling system** in experimental conditions similar to NUMEN (E_{beam} > 15 MeV/u, 10^{13} pps, $Z_{beam} \sim$ 8-10)

Conclusion

NUMEN is an ambitious experiment hosted in INFN-LNS, Catania, Italy, aimed to measure the (very low!) cross sections of DCE events.

The broad experimental campaign involves the usage of several targets, which must endure harsh conditions during data taking: many challenges in their design and production.

A HOPG backing **dissipates** the heat deposited by the beam in the target.

Results from characterization techniques (SEM, APT, RBS, …) are used to evaluate the impact of the target on the energy resolution.

First beam test seems **promising**.

Thanks for your attention!

On behalf of the NUMEN Collaboration

… and the NUMEN Target group

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Institutions

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SPARES

Crucial points

Heat dissipation: numerical calculations show that the system can tolerate the incoming heat – Calculations still to be confimed by experiment;

Target sputtering: given the modest deposited power (less than 1 keV/nm), it would take several days to etch away the target at the highest beam intesity – Very few data for sputtering at NUMEN energies;

HOPG radiation damage: due to the modest energy loss in HOPG, ion tracks can be excluded – no data for this material, amorphization rate uncertain, most critical point.

Fesem of Mo samples

- Mo deposited at RT by e-beam evaporation