WP2 – Research Infrastructures for Nuclear Physics
Task 2.5 – Service Improvements
Subtask C2 – Targets for high intense beams

Targets for Nuclear Physics within EURO-LABS: activities at INFN – LNS

Vasilis Soukeras[1], **Manuela Cavallaro**[1], **Antonio Massara**[1], **Daniela Calvo**[2], **Antonio Comite**[3], **Maria Fisichella**[1,4], **Mauro Giovannini**[3], **Martina Ursino**[1]
for the WP2.5.2 Collaboration

[1]Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud (INFN – LNS), Catania, Italy

[2]INFN– Sezione di Torino, Torino, Italy

[3]University of Genova and INFN – Sezione di Genova, Genova, Italy

[4]*Present address:* Grand Accelerateur National d'Ions Lourds (GANIL), Caen, France

One – day meeting on "Targets for Nuclear Physics"
15 May 2025

Targets for Nuclear Physics experiments: solid, gas or liquid ?

- Solid targets are the most common case

  Why ? →

  - Most elements and materials useful as targets are solid in standard conditions of pressure and temperature.
  - Much simpler setup

- Gas and liquid targets may be used in some cases

  Why ? →

  - Need of an active target
  - Specific properties of some targets

- *In this presentation the focus will be on solid targets developed and characterised at INFN –LNS*

The target lab at INFN – LNS: fabrication

- The target laboratory at INFN –LNS in Catania has over thirty years of experience in target preparation for nuclear physics experiments and interdisciplinary physics
- Users are not only local scientists but also researchers from other universities and laboratories worldwide

A. Massara et al., EPJ Web of Conferences 285, 06003 (2023)

L300 TBJ evaporator

Equipment for target production

- ✓ L300 Thermal Bell Jar (TBJ) evaporator
- ✓ L560 Leybold-Heraeus evaporator
- ✓ UNIVEX 400 Leybold evaporator
- ✓ Cold rolling mill

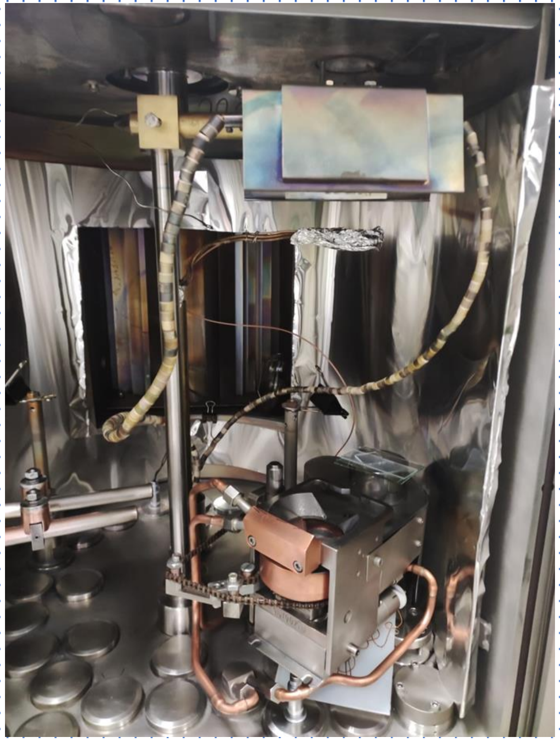
- 2 resistive sources
- A probe to monitor the backing temperature
- A quartz crystal micro balances

The target lab at INFN – LNS: fabrication

- The target laboratory at INFN –LNS in Catania has over thirty years of experience in target preparation for nuclear physics experiments and interdisciplinary physics
- Users are not only local scientists but also researchers from other universities and laboratories worldwide

A. Massara et al., EPJ Web of Conferences 285, 06003 (2023)

L560 Leybold-Heraeus



Equipment for target production

- ✓ L300 Thermal Bell Jar (TBJ) evaporator
- ✓ L560 Leybold-Heraeus evaporator
- ✓ UNIVEX 400 Leybold evaporator
- ✓ Cold rolling mill

- Evaporation by
  - ✓ e-beam heating source
  - ✓ resistive heating source
- Quartz crystal micro balance
- Halogen heating elements to fix temperature

The target lab at INFN – LNS: fabrication

- The target laboratory at INFN –LNS in Catania has over thirty years of experience in target preparation for nuclear physics experiments and interdisciplinary physics
- Users are not only local scientists but also researchers from other universities and laboratories worldwide

A. Massara et al., EPJ Web of Conferences 285, 06003 (2023)

UNIVEX 400 Leybold evaporator

New

Equipment for target production

- ✓ L300 Thermal Bell Jar (TBJ) evaporator
- ✓ L560 Leybold-Heraeus evaporator
- ✓ UNIVEX 400 Leybold evaporator
- ✓ Cold rolling mill

The target lab at INFN – LNS: fabrication

- The target laboratory at INFN –LNS in Catania has over thirty years of experience in target preparation for nuclear physics experiments and interdisciplinary physics
- Users are not only local scientists but also researchers from other universities and laboratories worldwide

A. Massara et al., EPJ Web of Conferences 285, 06003 (2023)

Cold rolling mill

Equipment for target production

- ✓ L300 Thermal Bell Jar (TBJ) evaporator
- ✓ L560 Leybold-Heraeus evaporator
- ✓ UNIVEX 400 Leybold evaporator
- ✓ Cold rolling mill

LNS Target lab website with some examples of targets produced in the lab:
https://www.lns.infn.it/en/targets.html

The target lab at INFN – LNS: characterisation

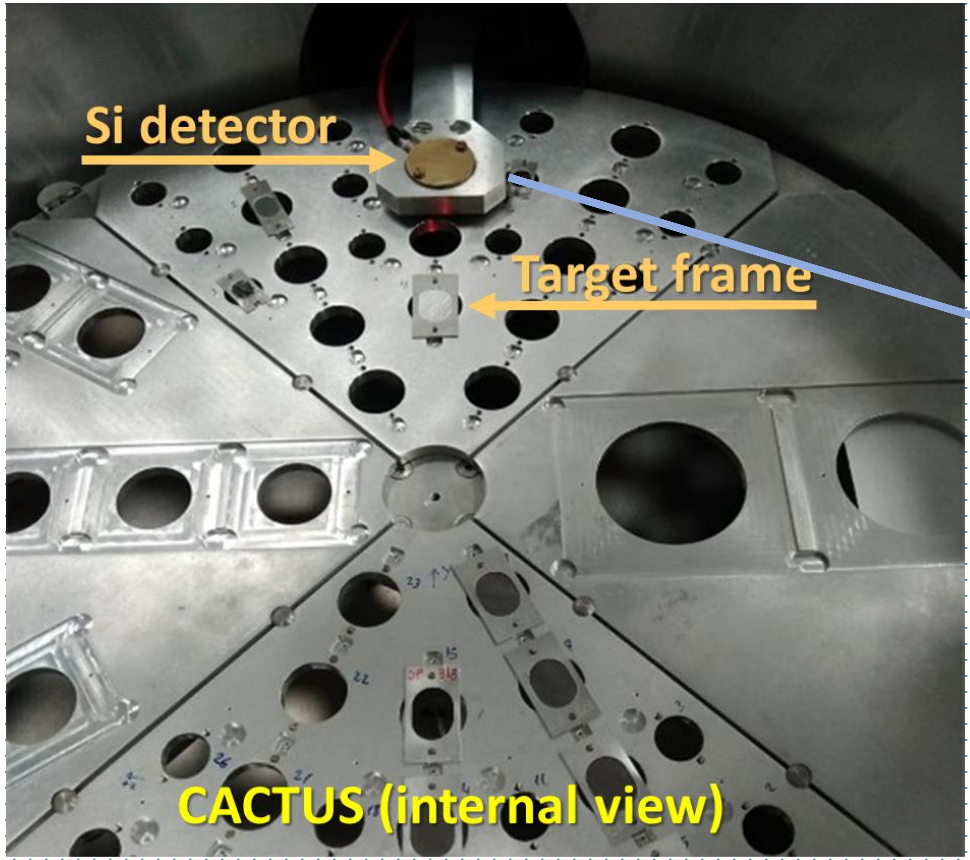
Equipment for target characterisation

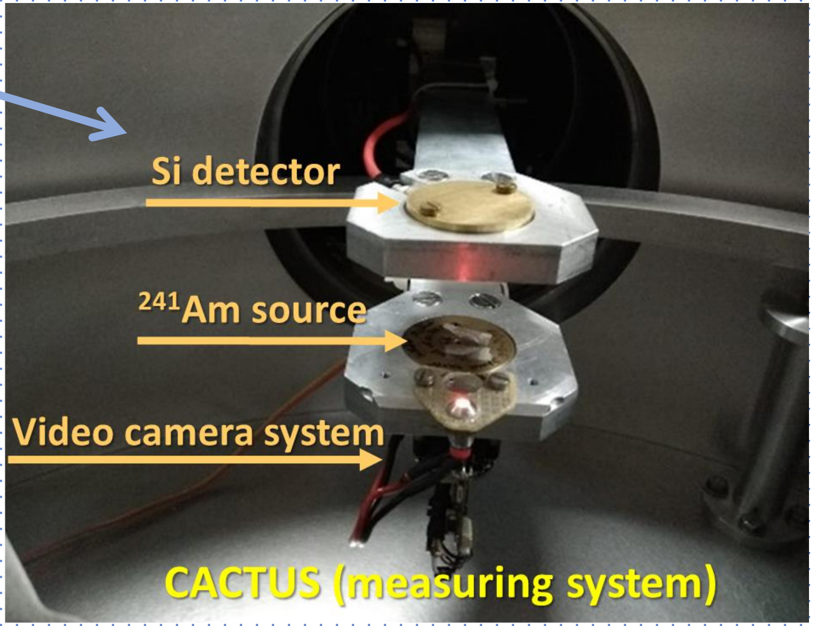
A. Massara et al., EPJ Web of Conferences 285, 06003 (2023)

✓ Chamber for Alpha-particle Characterisation of target Thickness and Uniformity by Scanning (CACTUS)

✓ CACTUS allows for the characterisation of the targets in terms of thickness, local and global non – uniformity.

➢ Technique: Alpha – particle spectroscopy (APS)





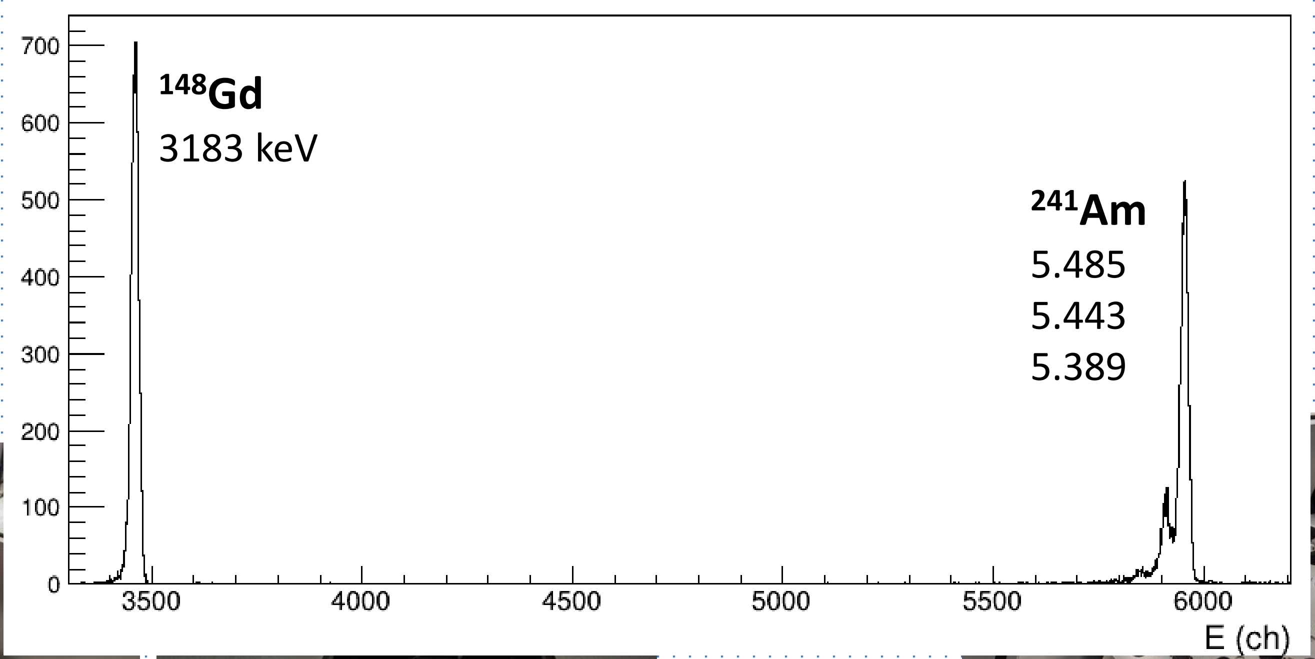
- ➢ Chamber diameter ~1m
- ➢ Host different types of target frame
- ➢ Scan different regions of the target surface with a **high precision** (1 mm) thanks to a rotational system and a video camera

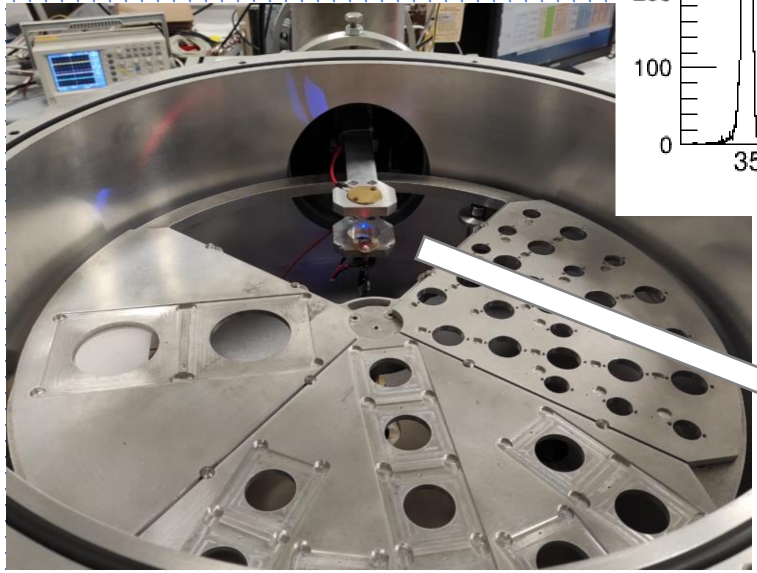
The target lab at INFN – LNS: characterisation

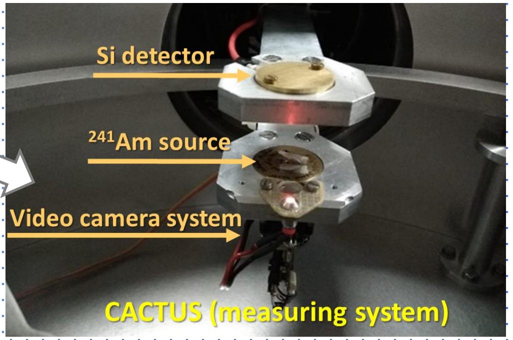
Equipment for target characterisation

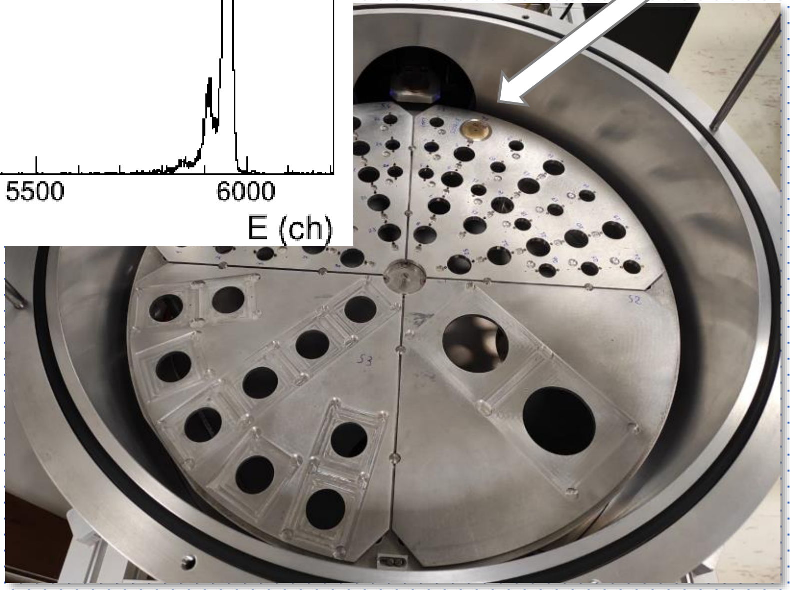
A. Massara et al., EPJ Web of Conferences 285, 06003 (2023)

- ✓ **Energy calibration** based on **2 α-sources** (**^{148}Gd** & **^{241}Am**) covering a broad energy range









Target characterisation at INFN – LNS

Why characterisation ?

- ✓ measure the average thickness
- ✓ determine the non – uniformity of the samples

Characterisation is essential towards the selection of the most suitable manufacturing procedure !

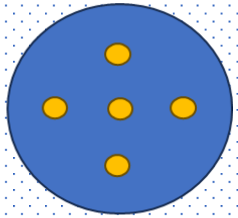
How ?

- Alpha Particle Spectroscopy (APS) technique using the CACTUS facility
- Comparison with simulations to determine the **local non – uniformity** in a specific irradiated area of the sample. The thickness deviation (σ_t/t) is related to the non – uniformity as follows:

$$\frac{\sigma_t}{t} = \frac{\sigma_{non-unif}}{\Delta E} = \frac{\sqrt{\sigma_{meas}^2 - \sigma_{sim}^2}}{\Delta E}$$

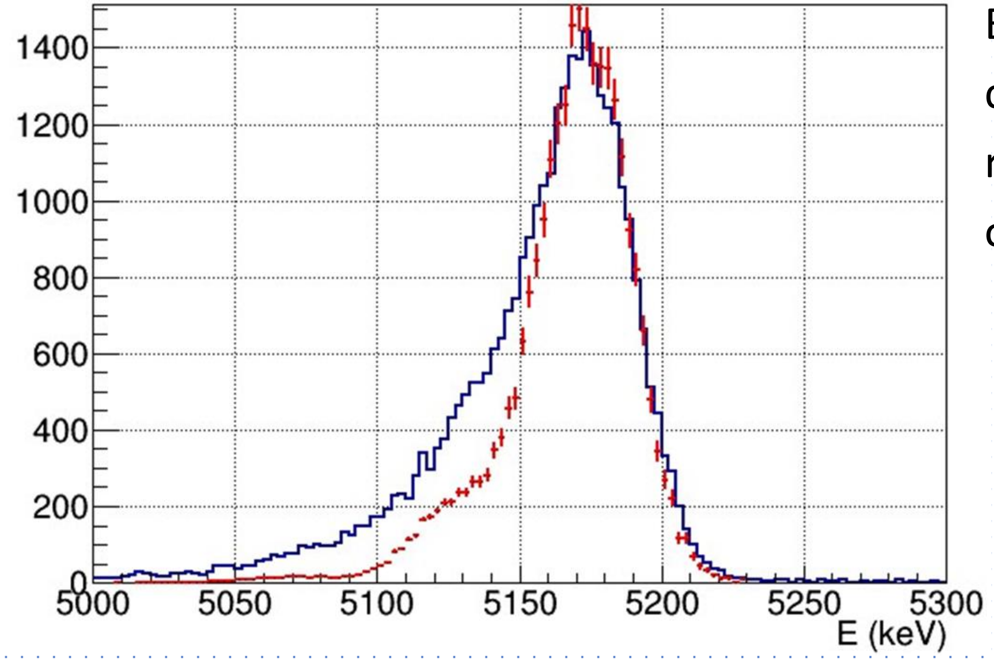
M. Fisichella et al., submitted for publication in Eur. Phys. J. A (2025)

- Irradiation of different areas of the sample to determine the **global non – uniformity**



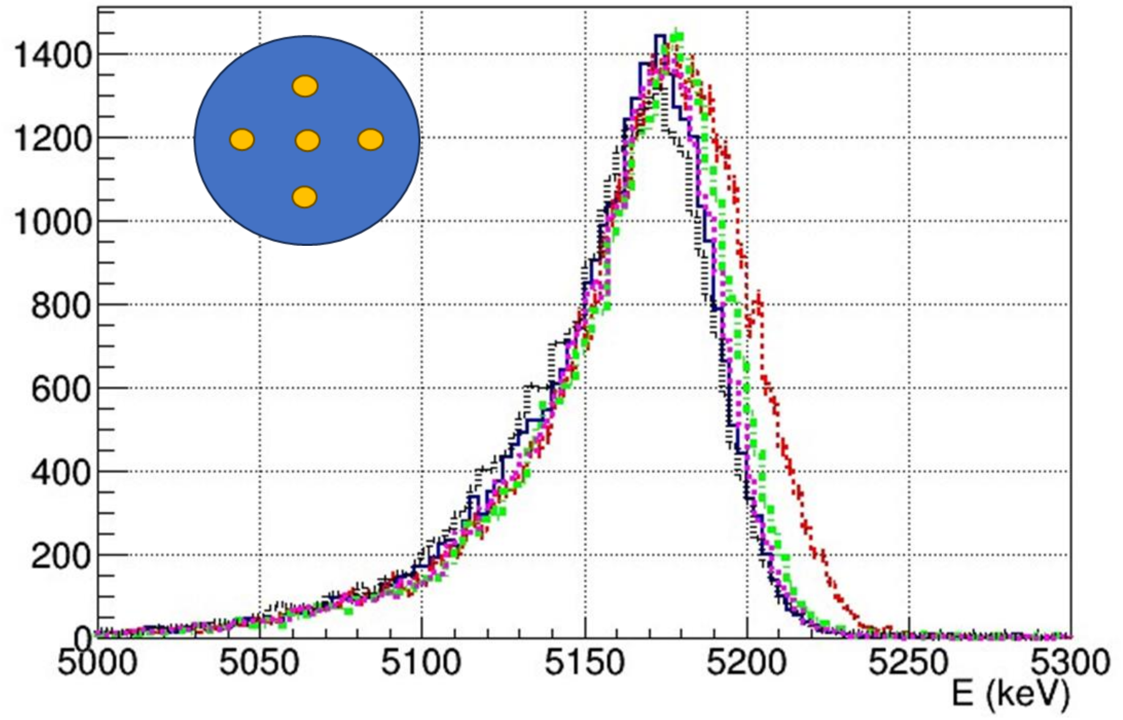
Global non – uniformity ≡ deviation thickness between the different irradiation points

Target characterisation at INFN – LNS:
characterisation of a multilayer graphene sample



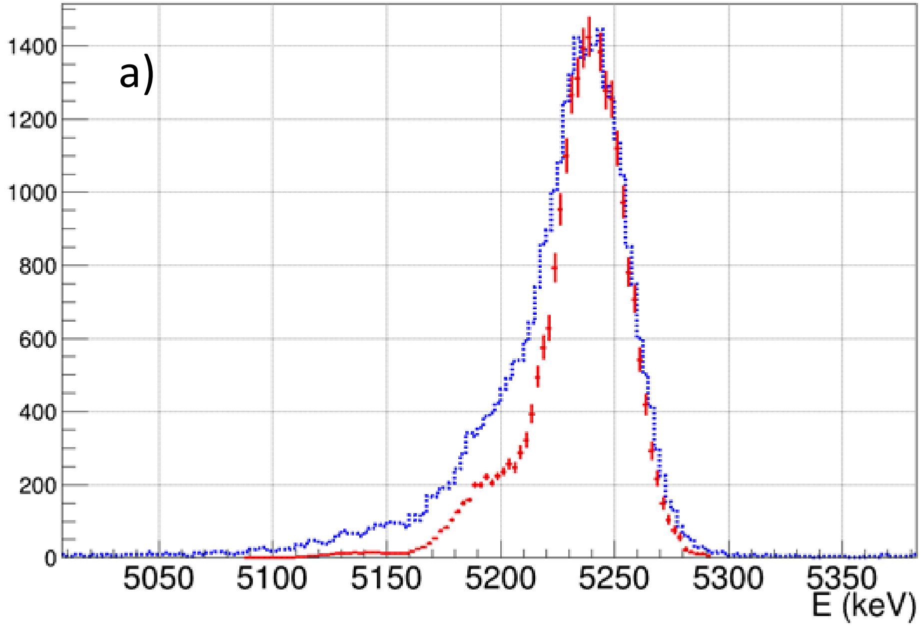
Experimental α – spectrum presented in blue in comparison with the simulated one presented in red. From the σ_{meas} and σ_{sim} we can determine the $\sigma_{non\text{-}unif}$

Typical experimental α – spectra in 5 different irradiated points of the same sample

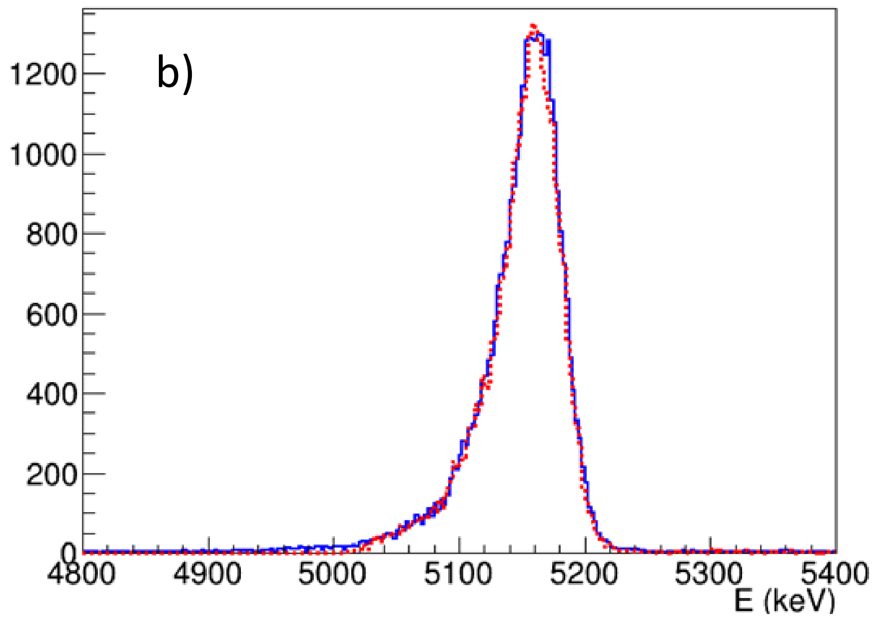


Target characterisation at INFN – LNS:
characterisation of a target evaporated onto a substrate

1) APS and characterisation of the substrate
2) Evaporation of the target material onto the substrate
3) APS using (target + substrate) and characterisation of the target



C (graphene) 0.321 mg/cm^2 (1.59 um)
dE=247keV



Te evaporated on a) with a thickness of 0.253 mg/cm^2
dE=77keV

Target production with evaporation in standard conditions

Standard evaporation conditions:

1. Low evaporation rate
2. No backing heating
3. No buffer

LNS Target lab website with some examples of targets produced in the lab:
https://www.lns.infn.it/en/targets.html

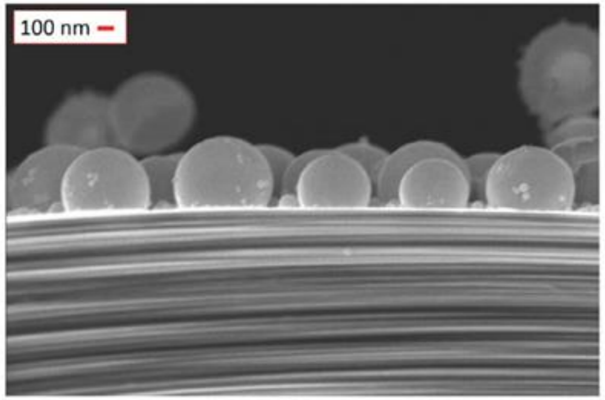
Standard evaporation conditions (Tellurium, Germanium, Selenium)

	Tellurium	Germanium	Selenium	Molybdenum
Evaporator	L300 resistive source	L560 resistive source	L300 resistive source	L560 e-beam
Used material	0.4 g	0.6 g	0.5 g	0.6 g
Distance source – backing	210 mm	250 mm	250 mm	200 mm
Heating substrate	NO	NO	NO	**300 °C**
Buffer	NO	NO	NO	NO
Evaporation rate	0.2 Å/s	0.2 Å/s	1 Å/s	0.3 - 0.4 Å/s

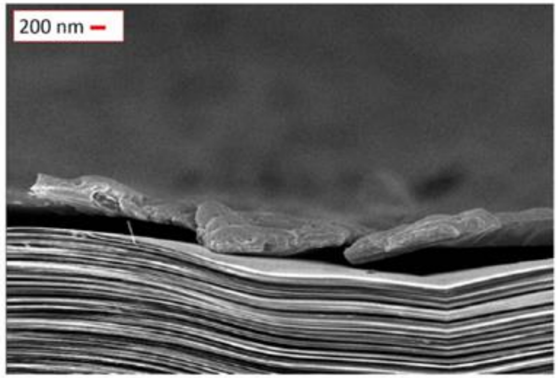
M. Fisichella et al., submitted for publication in Eur. Phys. J. A (2025)

Target production : some particular cases

- There are several materials on which the application of standard evaporation conditions did not provide satisfactory results.
- Depending on our needs, the conditions may be modified accordingly (e.g. the **Mo** case) with satisfactory results
- One of the particular case is the **Sn** : development of Sn targets at standard or even at non-standard conditions is a difficult task!

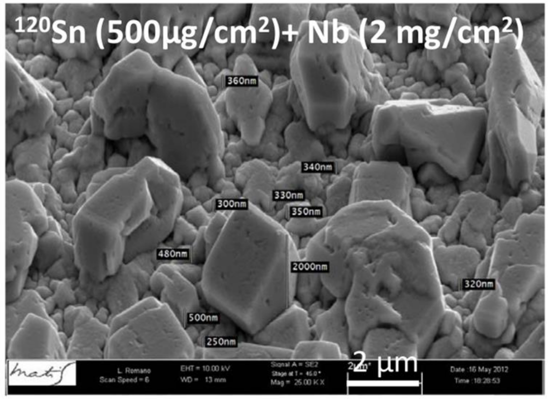


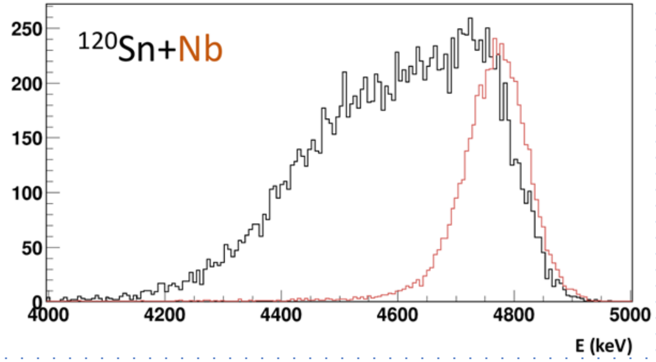
Sn (300 µg/cm²) on HOPG @ **150°**



Sn (300 µg/cm²) on HOPG @ **130°** with 100 Å Cr buffer

@ TRUSTECH, F. Pinna, PhD thesis

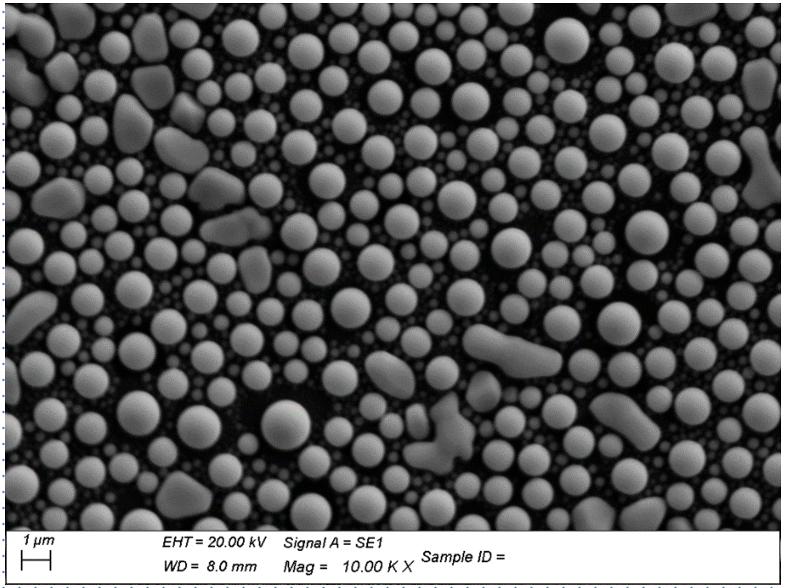


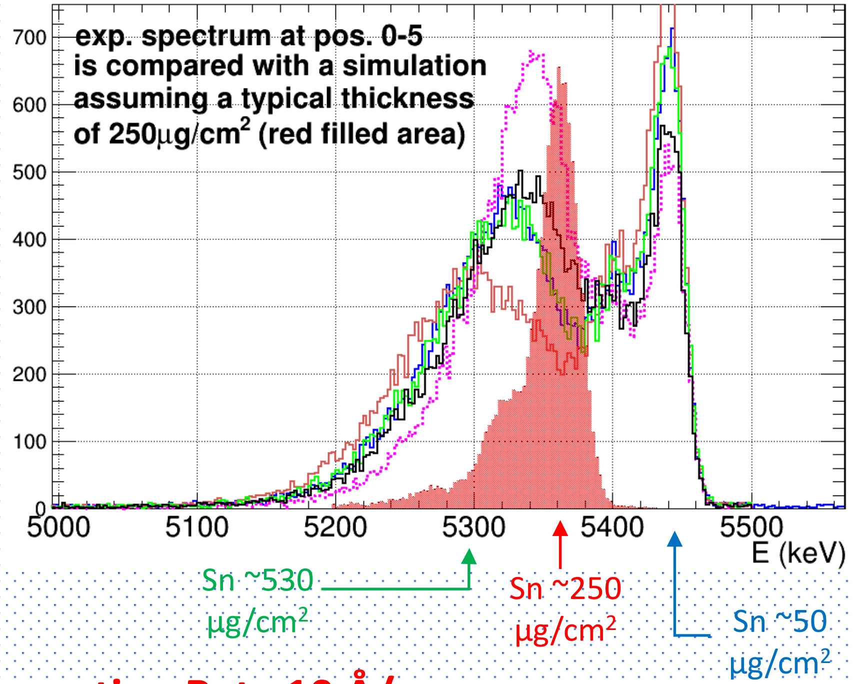


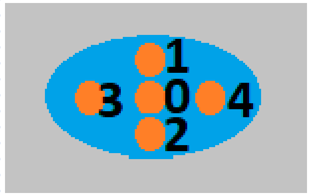
@ LNS, M. Fisichella, PhD thesis (standard evaporation conditions)

Target production : the case of Sn

➢One of the particular case is the **Sn** : development of Sn targets at standard or even at non-standard conditions is a difficult task!



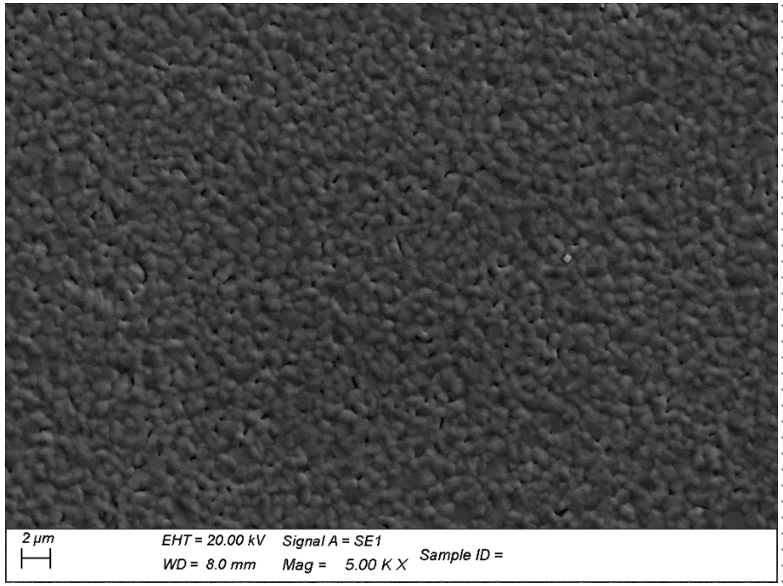


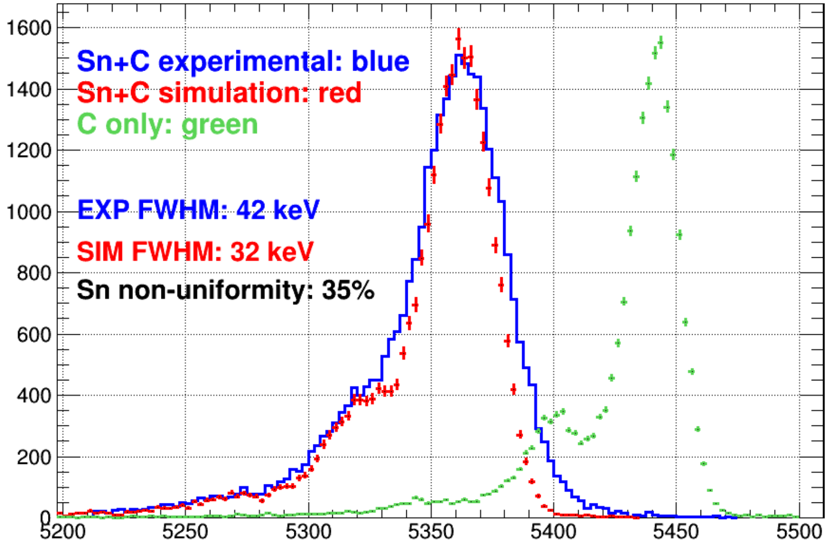


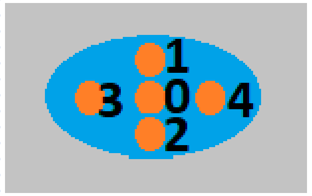
- ❑ **Sn (250 µg/cm²) + C (40 µg/cm²) - Evaporation Rate 10 Å/s**
- ❑ ***Evaporation at standard conditions***
- ❑ *Similar behaviour for all 5 samples of the same evaporation*

Target production : the case of Sn

➢ One of the particular case is the **Sn** : development of Sn targets at standard or even at non-standard conditions is a difficult task!







- **Repeatability tests to be performed**
- **Evaporation with and without Bi buffer to be performed with the new UNIVEX 400 evaporator**

- ❑ **Sn (250 µg/cm²) + Bi (100 Å) + C (40 µg/cm²) - Evaporation Rate 10 Å/s**
- ❑ ***Evaporation at low evaporation rate and without target heating but, with a buffer***
- ❑ *Similar behaviour for all 6 samples of the same evaporation*

Please note:

Bi 100 Å = 2.8×10^{16} at/cm^2
C 40 µg/cm^2 = 2.0×10^{18} at/cm^2
Sn 250 µg/cm^2 = 1.2×10^{18} at/cm^2

Targets for high – intense beams

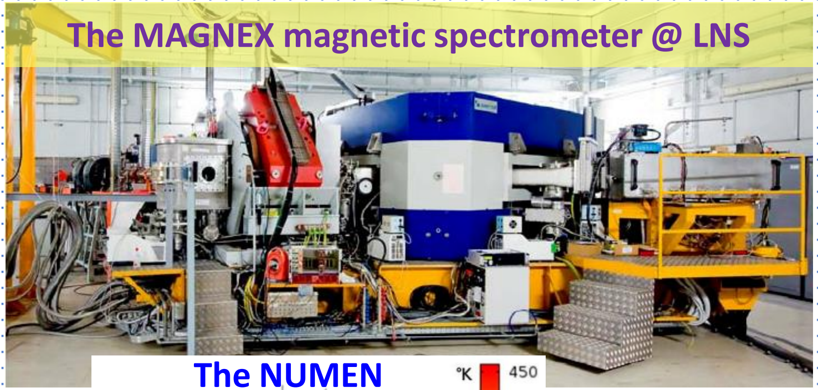
- Experimental campaigns with high – intensity beams are planned at INFN – LNS

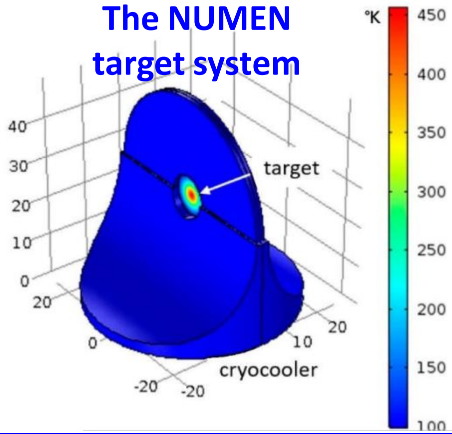
- The case of NUMEN experimental campaign:
  - ^{18}O and ^{20}Ne beams at energies >15MeV/u, beam intensity up to **10^{13} ions/sec** → deposition of **several W/cm² in the target**
  - Isotopically enriched target will be deposited on a **highly thermally conductive foil of graphene**
  - A **cooling system** for the target will be used
  - Target materials: Ca, Ge, Se, Zr, Mo, Cd, Pd, Sn, Te, Sm, Pt and many other with a **typical thickness of ~ 250 – 500 μg/cm²**
  - Both target and substrate should be as uniform as possible to maintain **high energy resolution**
  - If possible, we should **avoid buffer materials**

- Intense activity on target development and characterisation is ongoing in collaboration with INFN-Torino, INFN-Genova, University of Genova, INFN-LNL and University of Catania

See also next talk by Daniela Calvo !

F. Cappuzzello et al., Int. J. Mod. Phys. A 36, 2130018 (2021)





Summary and future perspectives

- The development of the appropriate target is essential for the success of nuclear physics experiments

- The target characterisation:
  - ✓ Provide a tool to examine if the target produced is indeed suitable for the experiment
  - ✓ is of great importance towards the selection of the most suitable manufacturing procedure

- Target development and characterisation are essential towards the success of large – scale experimental campaigns with high – intensity beams, scheduled in the near future at INFN – LNS

- A protocol was established for the characterisation of both self – supported and (target + substrate) samples by means of the determination of local and global non – uniformity

- New opportunities with the new evaporator recently installed at INFN – LNS