CAPIROSSI VITTORIA, POLITECNICO DI TORINO E INFN-TORINO

CHARACTERIZATION OF FIRST PROTOTYPES OF THIN TARGETS FOR THE NUMEN EXPERIMENT

HOW TO DESIGN AND CHARACTERIZE A TARGET THAT MUST BE THIN, UNIFORM AND COOLED DOWN?

POLITECNICO DI TORINO

106° CONGRESSO SIF

step 1

Are neutrinos Majorana or Dirac particles?

The NUMEN Experiment can help

The NUMEN Experiment, based in LNS-INFN Laboratories in Catania, aims to measure the cross sections of Double Charge Exchange (DCE) reactions

These measurements can help the Neutrinoless Double Beta Decay ($0\nu\beta\beta$) experiments to evaluate the Nuclear Matrix Element of the decay

DCE	$0\nu\beta\beta$
$^{116}Sn(^{18}O, ^{18}Ne)^{116}Cd$	/
$^{76}Se(^{18}O, ^{18}Ne)^{76}Ge$	/
$^{116}Cd(^{20}Ne, ^{20}O)^{116}Sn$	$^{116}Cd \rightarrow ^{116}Sn + 2e^-$
$^{130}Te(^{20}Ne, ^{20}O)^{130}Xe$	$^{130}Te \rightarrow ^{130}Xe + 2e^+$
$^{76}Ge(^{20}Ne, ^{20}O)^{76}Se$	$^{76}Ge \rightarrow ^{76}Se + 2e^-$

step 2

How about the Target design

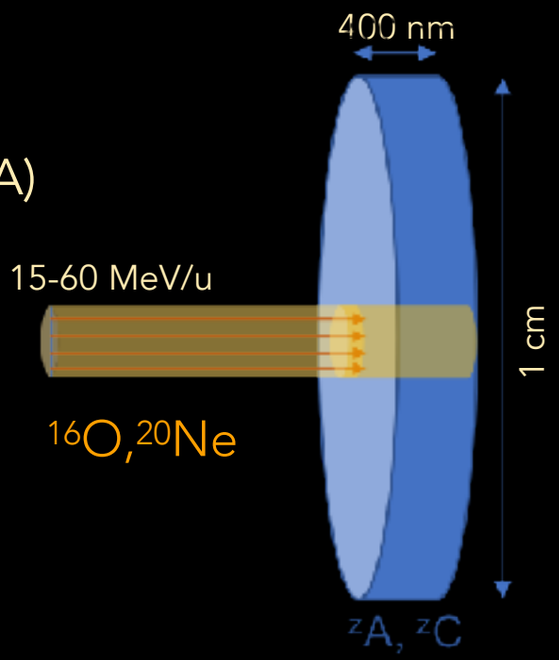
What are the requirements?

Target thickness uniformity allows accurate knowledge of the thickness crossed by the beam
Low target thickness makes negligible effects (straggling and dispersion) on the energy resolution of the products

Is a thin and uniform target enough?

DCE are rare reactions → Very intense ion beams (up to 50 μA) for a good statistics

The beam is a source of heat in the central region of the target and can cause damages (melting)



The temperature at the target center is largely above the melting point*:
a standalone target can not be used, an efficient target cooling is needed

**Verified by solving the heat equation, analytically (in the stationary state) and numerically (time-dependent solution)*

step 3

Target production

on a special substrate

How to cool the target?

5 μm of Highly Oriented Pyrolytic Graphite (HOPG) as substrate

+

Target deposition (by Electron-Beam Physical Vapor Deposition) of a few hundreds of nm

It works!*

This cooling system, thanks to the high in-plane thermal conductivity of HOPG (1950 W/(m*K)), is able to **quickly transfer the heat out of the target**

** The heat equation evaluated for a target on a HOPG substrate has been solved numerically (time-dependent solution). If the extremities of HOPG and target are maintained at 100K, the temperatures of the targets center are below the melting points (excepet for Se).*

step 4

Target thickness and uniformity

are crucial for energy resolution

DCE reactions are detected by measuring the energy of the ejectile and the relaxation energy (through gamma emission) of the target isotope.
The ejectile **energy resolution must be good enough** to clearly identify DCE.

The target thickness and its uniformity affects the ejectile energy, because of the energy **straggling** and **dispersion** effects.

Straggling: Statistical fluctuations on the energy loss (consequently, on the thickness evaluation) due to non-linear trajectories inside the target → Both in HOPG and target **Proportional to thickness**

Dispersion: The DCE reaction point of the projectile is **assumed** in the center → uncertainties on the energy of the ejectile and its energy loss in target (dispersion) → Only in target **Proportional to thickness**

The target has to be thin and as uniform as possible

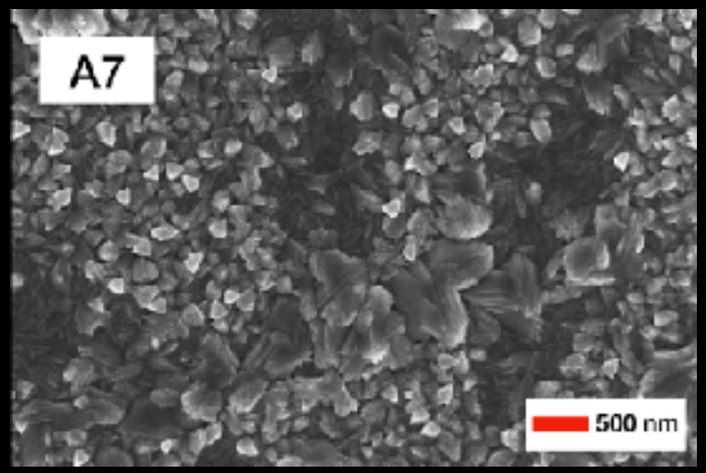
step 5

A qualitative target analysis with FESEM images

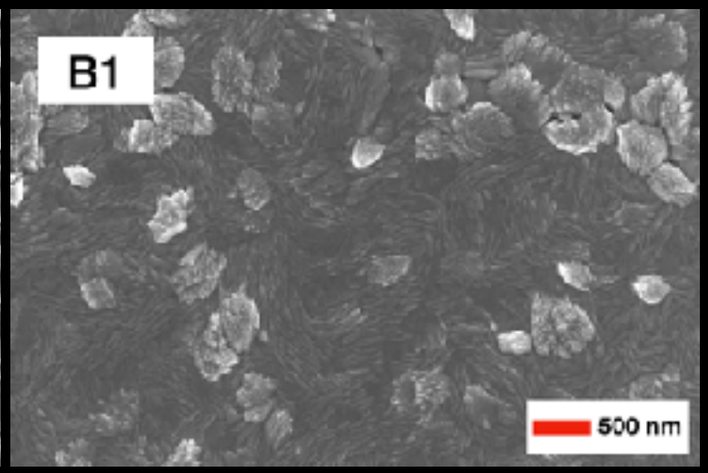
Analysis of the target planar dimensions by Field Emission Scanning Electron Microscopy (FESEM)

Tellurium targets

10 μm HOPG



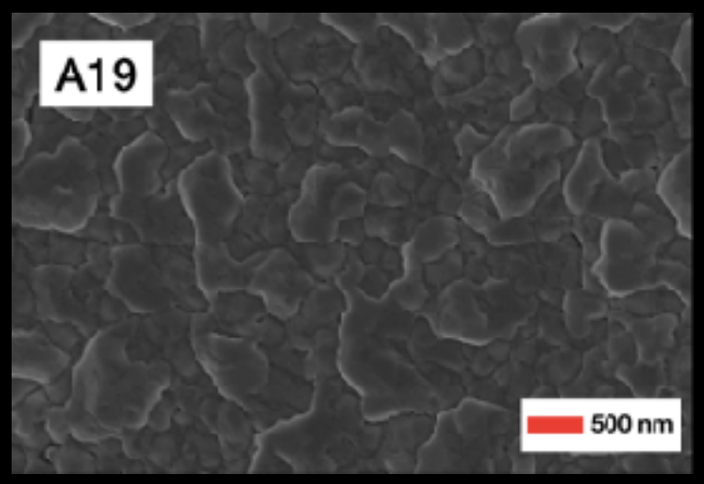
5 μm HOPG



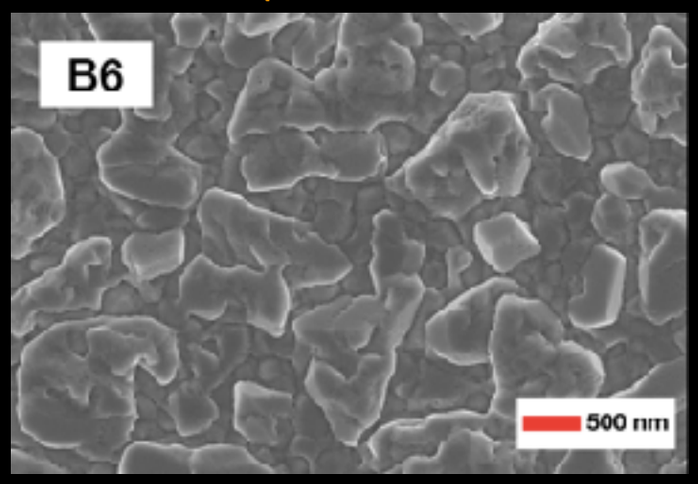
Temperature substrate ≃ 300K • No Chromium buffer

Tin targets

10 μm HOPG



5 μm HOPG



Temperature substrate ≃ 403K • Chromium buffer

step 6

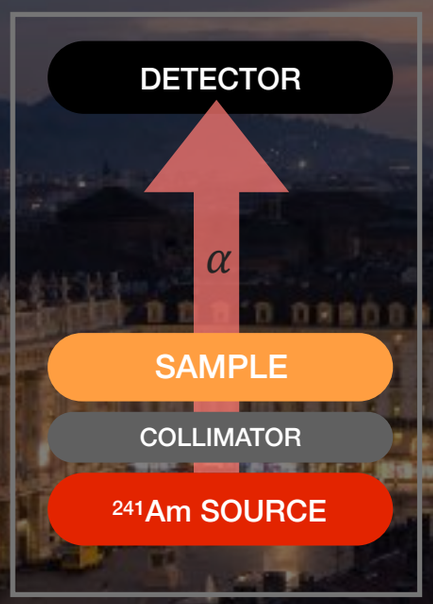
How target thickness and uniformity can be evaluated?

Alpha spectroscopy

is the best technique

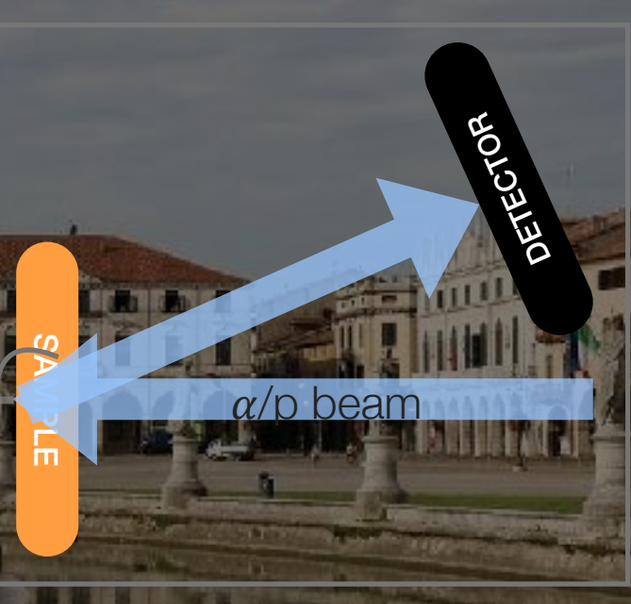
Low energy ion beam techniques are non-destructive tools to evaluate thicknesses, through the measurement of the energy loss by the beam

Alpha-Particle Transmission



We've built this set-up in Politecnico of Turin

Rutherford Backscattering



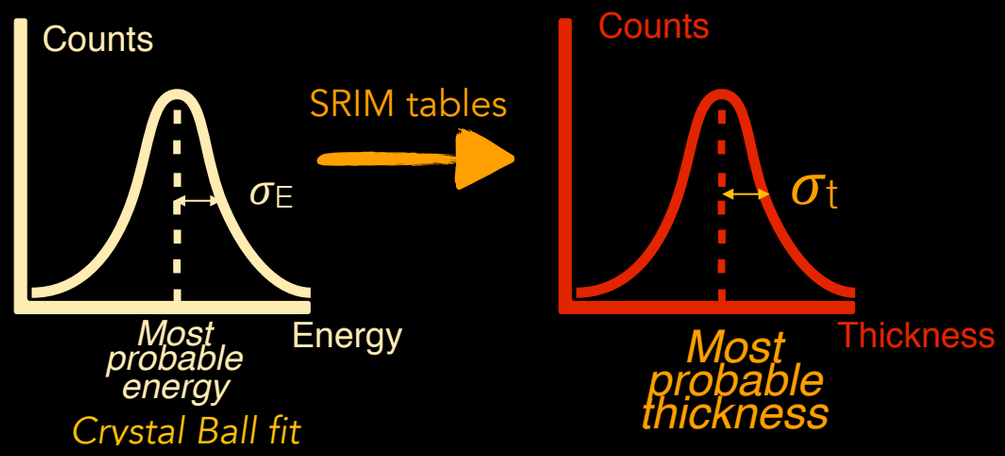
We have performed RBS measurements at AN2000 accelerator, in INFN laboratories of Legnaro

step 7

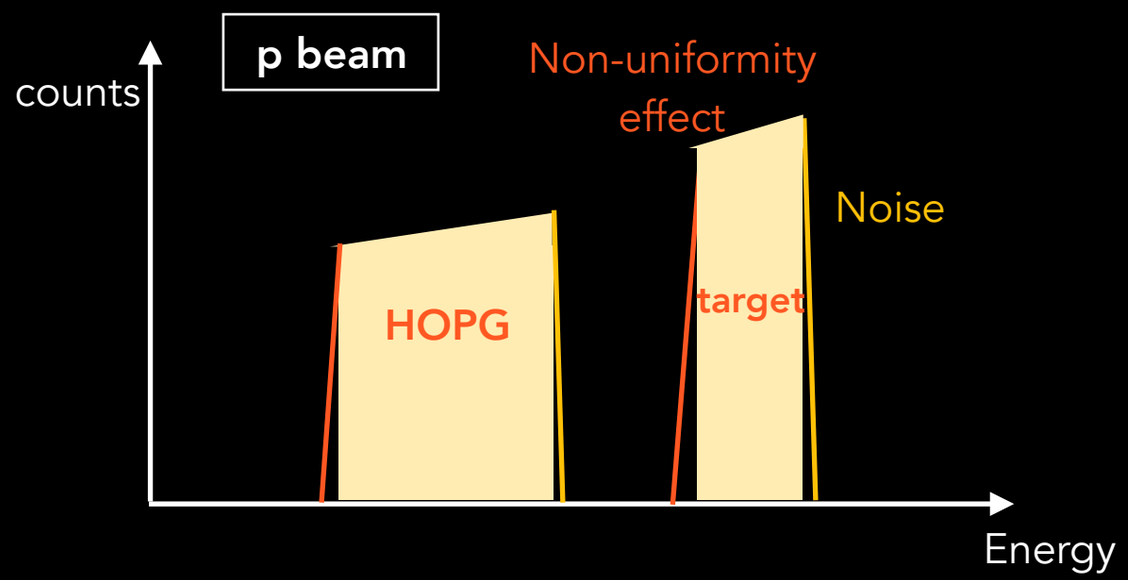
Data analysis

to start from energies and arrive to thicknesses

Alpha-Particle Transmission



Rutherford Backscattering



Good agreement (r>0.99) !

✔ Thickness
✔ Thickness uniformity

✔ Thickness
✘ Thickness uniformity

To obtain the target non-uniformity:

$$\sigma_{target\ non-uniformity} = \sqrt{\sigma^2_{total} - \sigma^2_{HOPG} - \sigma^2_{target\ straggling} - \sigma^2_{detector+noise}}$$

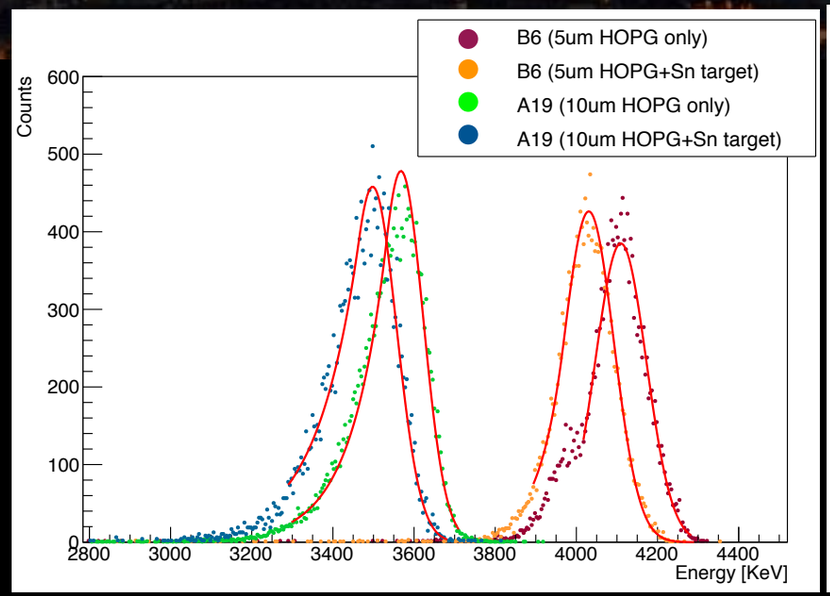
step 8

Finally,

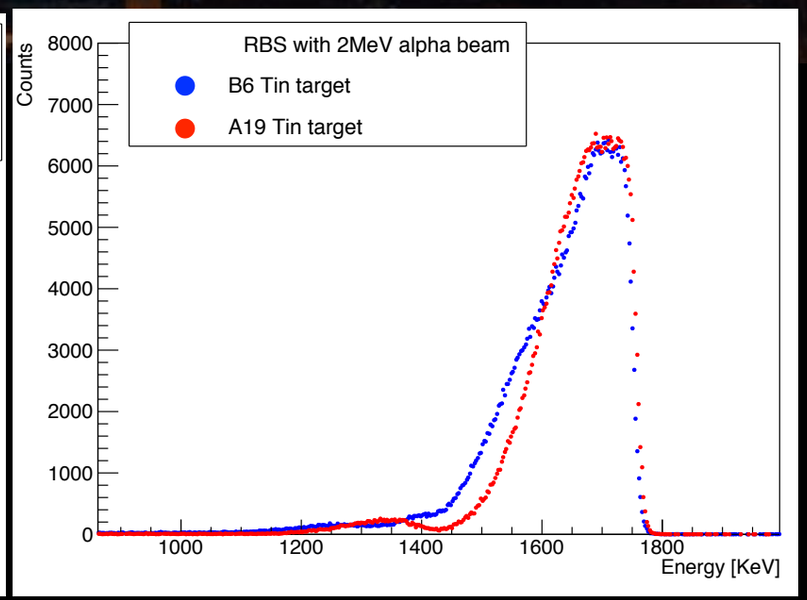
Thickness uniformity results

for Tin and Tellurium

Alpha Transmission



Rutherford Backscattering



		Thickness			Thickness uniformity
		α transmission	RBS	Disagreement %	α transmission (σ%)
Sn	B6	235 μg/cm^2	194 μg/cm^2	17%	28%
Sn	A19	175 μg/cm^2	178 μg/cm^2	1,7%	29%
Te	B1	472 μg/cm^2	480 μg/cm^2	1,6%	17%
Te	A7	436 μg/cm^2	442 μg/cm^2	1,4%	17%

The alpha spectroscopy technique is efficient to evaluate the target non-uniformity

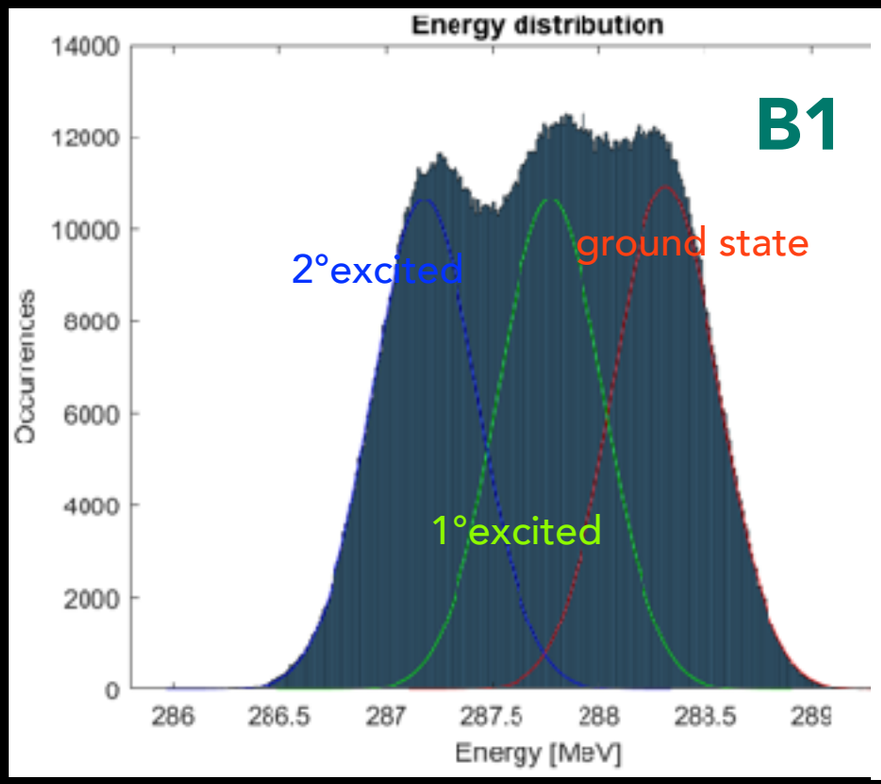
step 8

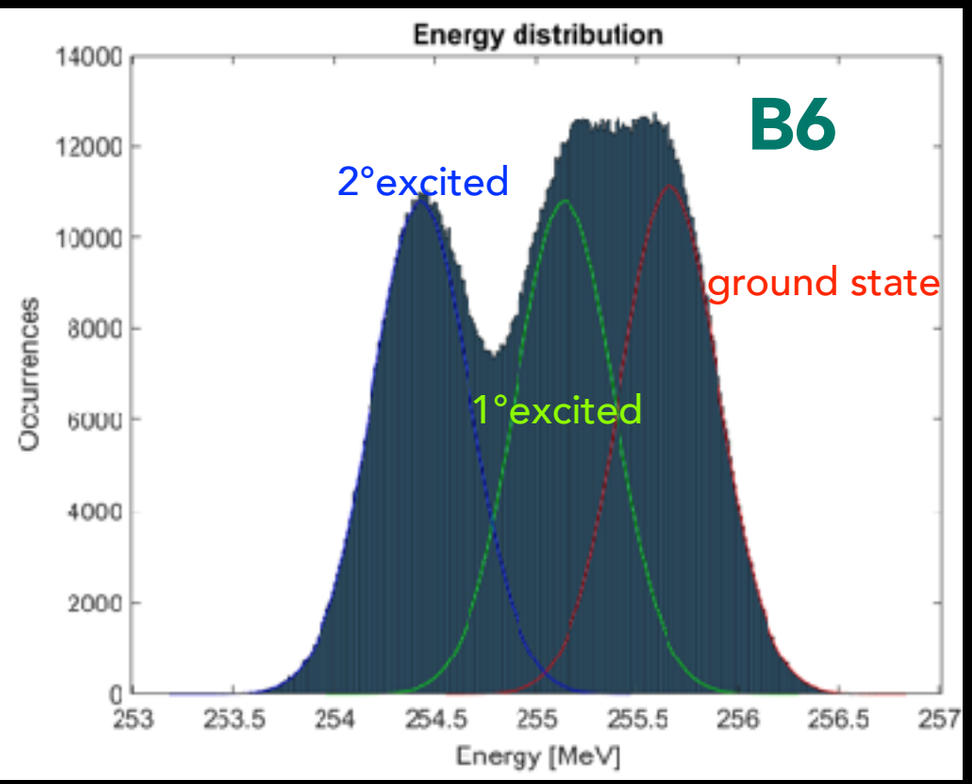
Finally,

Thickness uniformity results

for Tin and Tellurium

A Monte Carlo code has been written to simulate the energy distribution of DCE ejectile and evaluate the energy resolution.





→ Contributions to the ejectile energy distribution from NUMEN spectrometer, cyclotron, HOPG and target

→ Input of experimental data of thickness and non-uniformity of HOPG and target

→ Same branching ratio for ground state, first or second excited level of the target isotope

At the state of art, Tin and Tellurium targets non-uniformity allow to distinguish the ground state from the excited levels of the target daughter, not between ground state and first excited level

All the steps

to have a thin, uniform and cooled down target

The NUMEN Experiment aims to measure the cross sections of DCE reactions. To have good energy resolution, the target must be thin and uniform. Since DCE are rare, very intense ion beams are required. They heat and can damage the target, that must be cooled down.

step A — The target isotope (hundreds of nm) is deposited on a HOPG substrate to quickly transfer the heat outside the central zone.

step B — An alpha-particle transmission set-up has been designed and tested by RBS measurements. It can quantitatively measure thickness of thin targets, but also its thickness uniformity.

step C — First prototypes of the NUMEN target system have been produced and studied with alpha transmission, deducing the target thickness uniformity. This values have been used in a MonteCarlo simulation to evaluate the effects of the target on the NUMEN energy resolution.

At the state of art, Tin and Tellurium targets non-uniformity allow to distinguish the ground state from the excited levels of the target daughter, not between ground state and first excited level