THICKNESS AND UNIFORMITY ANALYSIS OF THIN AND HEAT RESISTANT TARGETS

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PRESENTATION LAYOUT

- NUMEN Project
- NUMEN target system
- Target characterisation techniques
- HOPG characterisation
- Ge and Te characterisation
- Conclusions

NUclear Matrix Elements for Neutrinoless double β decay

Use Heavy Ion Double Charge Exchange (DCE) reactions to obtain experimental information on Nuclear Matrix Elements involved in Neutrinoless double beta decay (0νββ)

Nuclear Matrix Element (NME): $M_{\varepsilon}^{0\nu\beta\beta} = \langle \Psi_f | \hat{O}_{\varepsilon}^{0\nu\beta\beta} | \Psi_i \rangle$

Probability of 0νββ transition proportional to: $\left| M_{\varepsilon}^{0\nu\beta\beta} \right|^2 = \left| \langle \Psi_f | \hat{O}_{\varepsilon}^{0\nu\beta\beta} | \Psi_i \rangle \right|^2$

0νββ: ${}_{Z}^{A}X_{N} \rightarrow {}_{Z+2}^{A}Y_{N-2} + 2e^{-}$

DCE: ${}_{Z}^{A}X_{N} + {}_{z}^{a}x_{n} \rightarrow {}_{Z+2}^{A}Y_{N-2} + {}_{z-2}^{a}y_{n+2}$

Important similarities between the two processes

- Same initial and final states
- Similar mathematical structure of transition operators

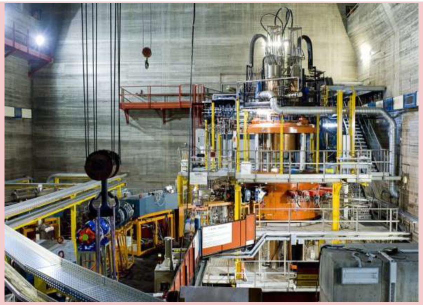
NUMEN DCE reactions

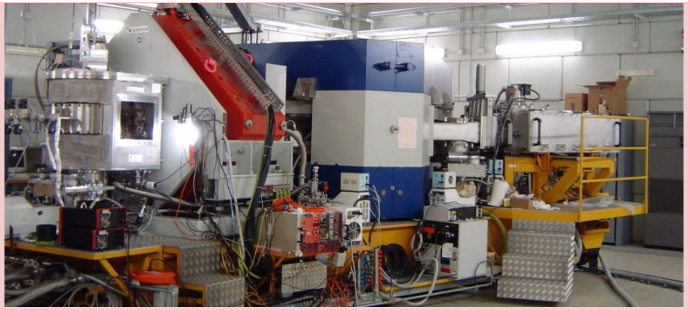
(^{20}Ne,^{20}O) on ^{76}Ge, ^{116}Cd, ^{124}Sn, ^{130}Te, ^{136}Xe …

(^{18}O,^{18}Ne) on ^{76}Se, ^{100}Mo, ^{106}Cd, ^{116}Sn, ^{124}Te, …

@ LNS

K800 Superconducting Cyclotron





MAGNEX magnetic spectrometer

DRAWBACK : DCE reactions have small cross-section (nb) !

HOW TO OVERCOME THIS LIMIT ? Use high intensity beams (up to 10^{13} pps) !!

… **BUT** … high beam intensity require very high performance for the whole experimental apparatus !!!

- Upgrade of the cyclotron: POTLNS
- Upgrade of the MAGNEX detector system
- **Upgrade of the MAGNEX target system**

Upgrade of the MAGNEX target system

High power density (100 kW /cm^3) released in target → How to dissipate it?

1. Evaporate isotopic material of the target on a high thermal conductivity (1950 $Wm^{-1}K^{-1}$) **Highly Oriented Pyrolytic Graphite** (HOPG) substrate to quickly dissipate the heat.

   HOPG thickness at least **450 μg/cm^2**

2. Target encased in a Cu holder, mounted on top of a cryocooler and kept at 40 K

Details in F. Pinna's talk

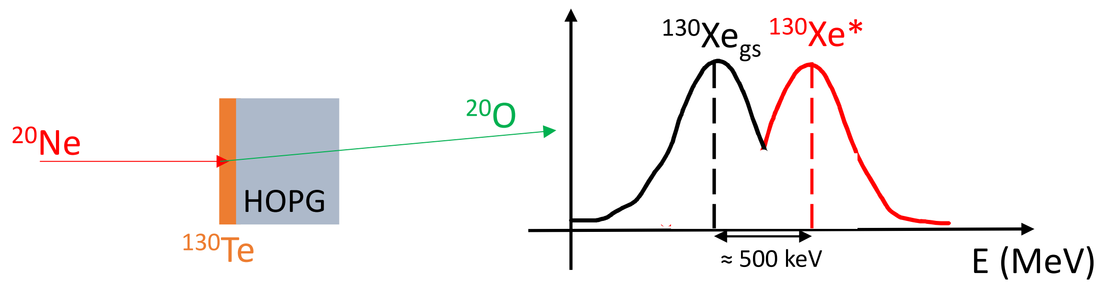
Moreover … studies of

- **HOPG radiation damage**
- **HOPG properties**

Target system characteristics

450 μg/cm² HOPG ➡ **straggling** ➡ **degrading energy resolution**

- To disentangle the ground state from the first excited state of the residual nucleus, **energy resolution < 500 keV**



➡

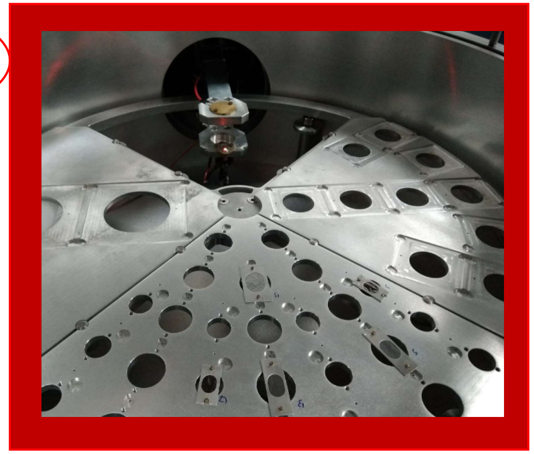
- the thickness of the **target** ranges between **250 – 500 μg/cm²**
- **target and backing have to be "as uniform as possible"!**

What is the uniformity that can be reached ?
Is it good enough?

Target system characterisation

To characterise the backing and the target:

NEW system for target thickness measurement and characterisation @ LNS . See A. Massara's talk



Alpha Particle Transmission (APT) : thickness, local and global uniformity

Rutherford Backscattering (RBS) : thickness, purity

Field Emission Scanning Electron Microscopy (FESEM) : analysis of the surface

HOPG CHARACTERISATION

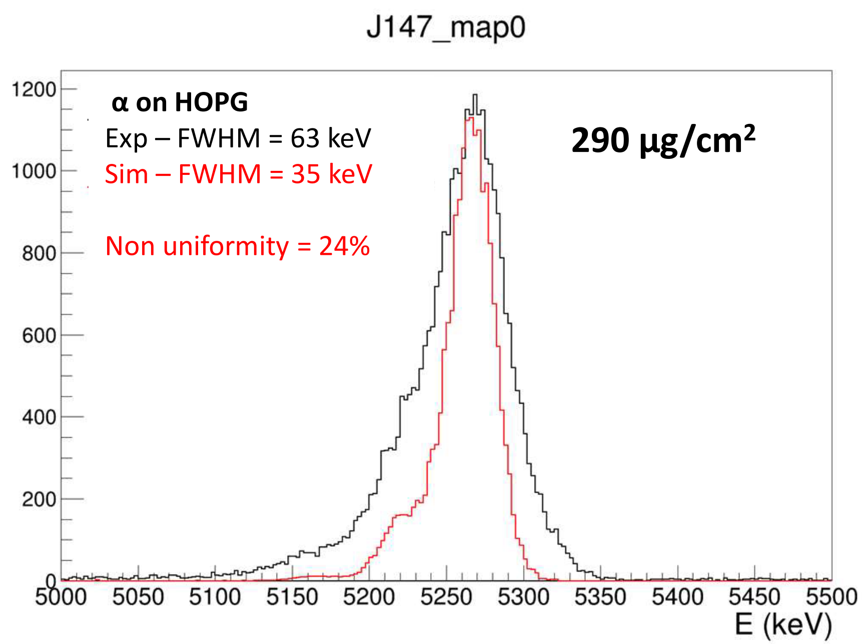
HOPG characterisation with APT

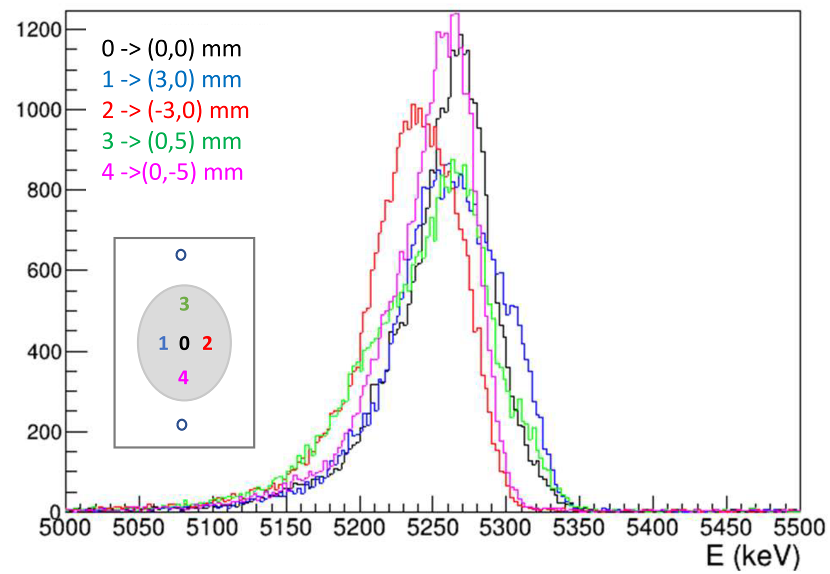
OPTIGRAPH HOPG :

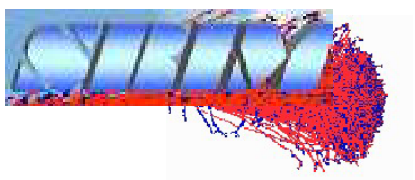
- 450 µg/cm² (nominal) :
- Foil of 20 mm x 15 mm

$$FWHM_{exp}^2 = FWHM_{sim}^2 + FWHM_{det}^2 + FWHM_{non-unif}^2$$

$$Non\text{-}uniformity = \frac{FWHM_{non-unif}}{\Delta E}$$







➡ Average thickness ranges between 250 µg/cm² - 900 µg/cm²

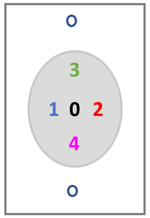
➡ **Local FWHM non-uniformity of 10% - 25%**

HOPG characterisation with APT

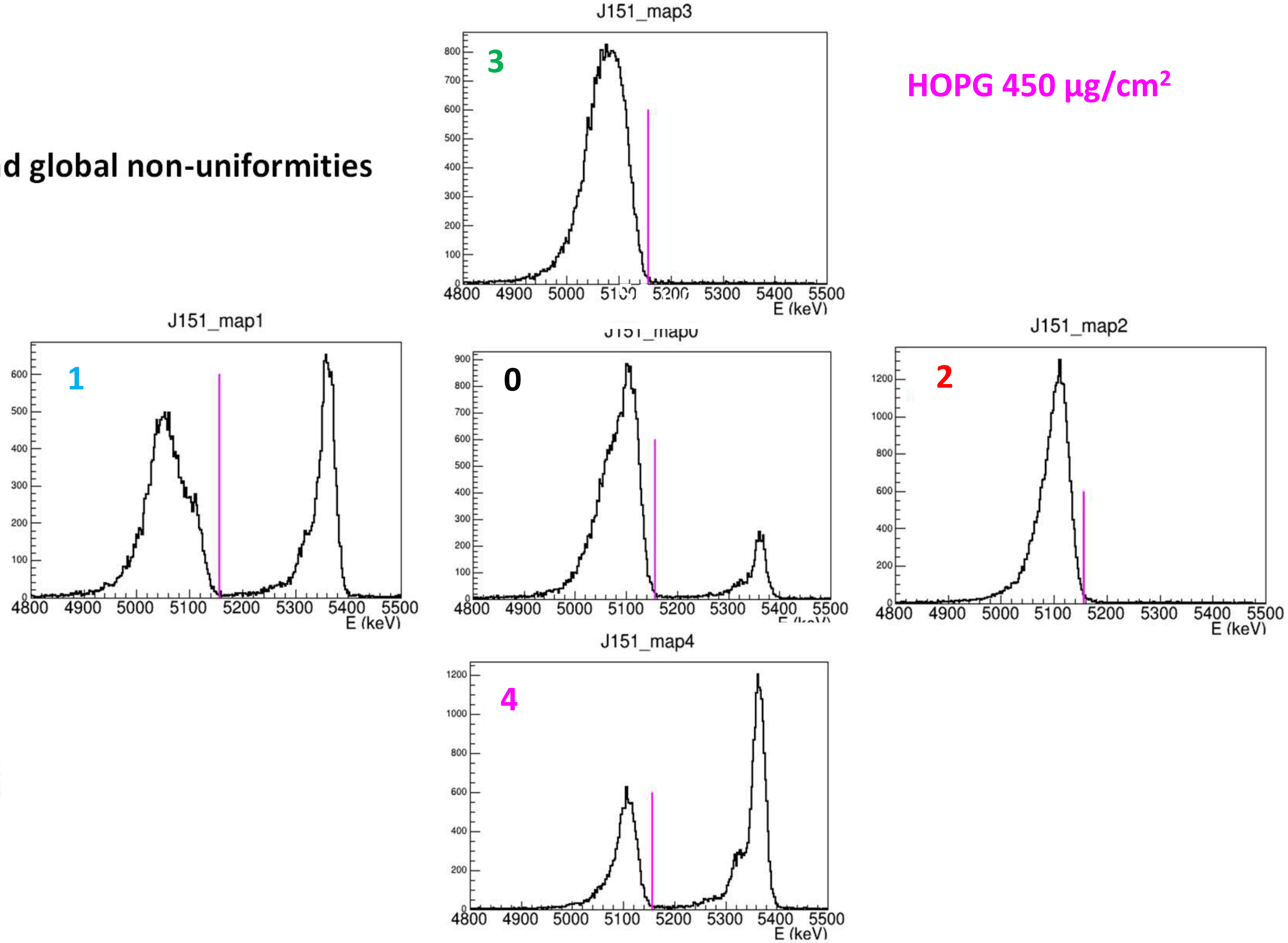
OPTIGRAPH HOPG :

- 450 µg/cm^2 (nominal) :
- Foil of 20 mm x 15 mm
- For some foils **important local and global non-uniformities are present**

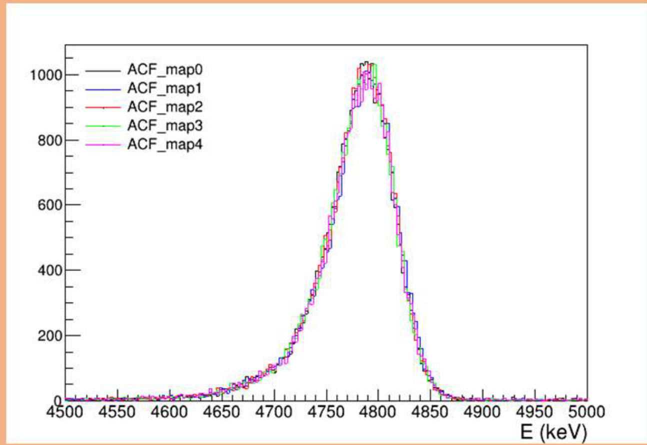
0 -> (0,0) mm
1 -> (3,0) mm
2 -> (-3,0) mm
3 -> (0,5) mm
4 ->(0,-5) mm

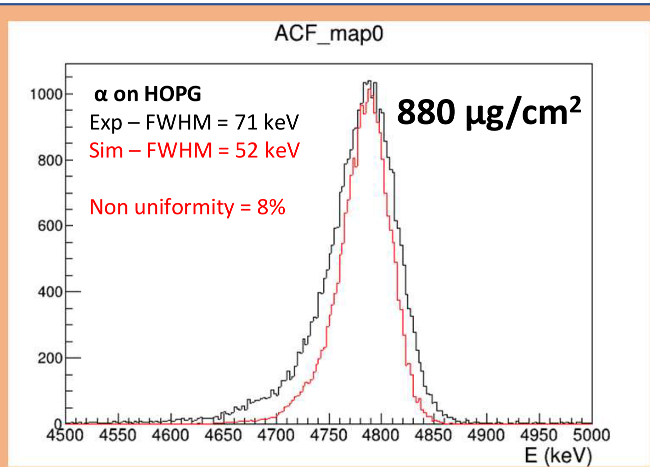


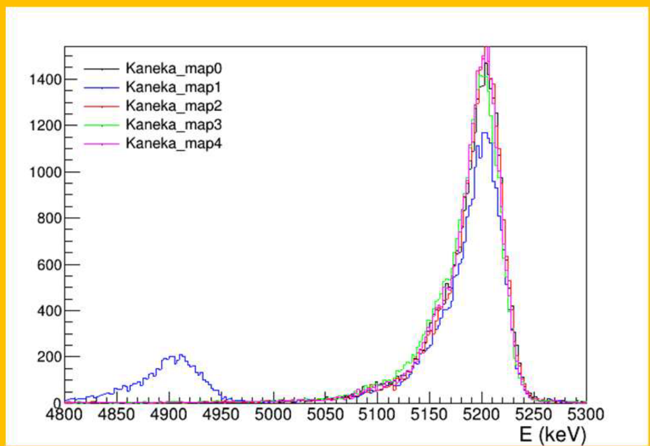
HOPG 450 µg/cm^2

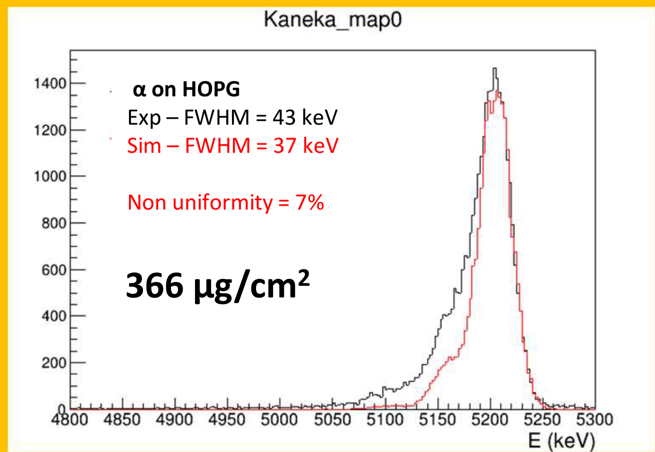


NEW HOPG samples from other manufacturers









They seem promising …
but more samples are needed

Ge and Te CHARACTERISATION

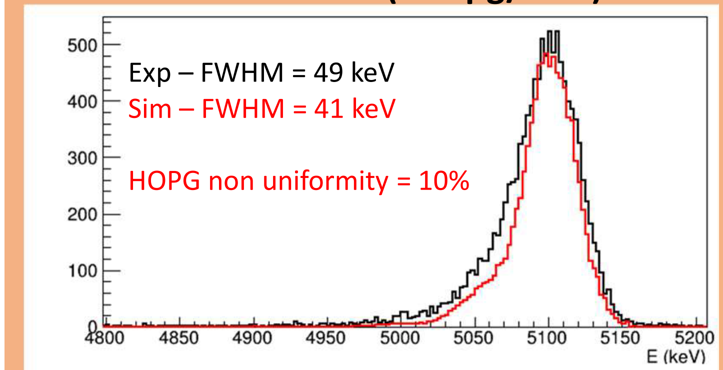
@ TRUSTEC (Turin): electron-beam source. Several trials with natural element

Germanium target

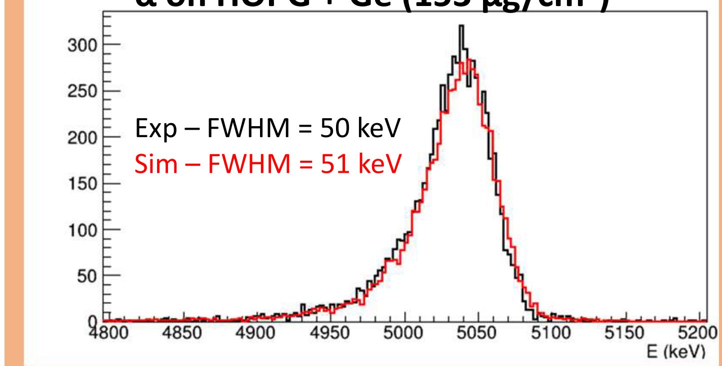
Ge @ TRUSTEC (Turin): electron-beam source. Several trials with natural Ge.

Standard conditions: low evaporation rate,
no background heating, no buffer

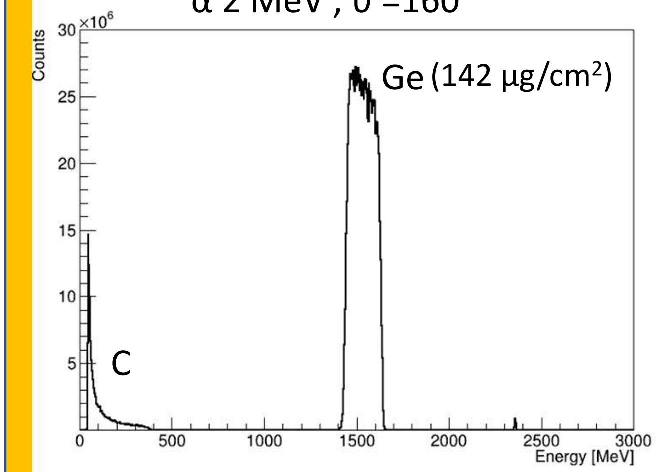
α on HOPG (496 μg/cm²)



α on HOPG + Ge (153 μg/cm²)

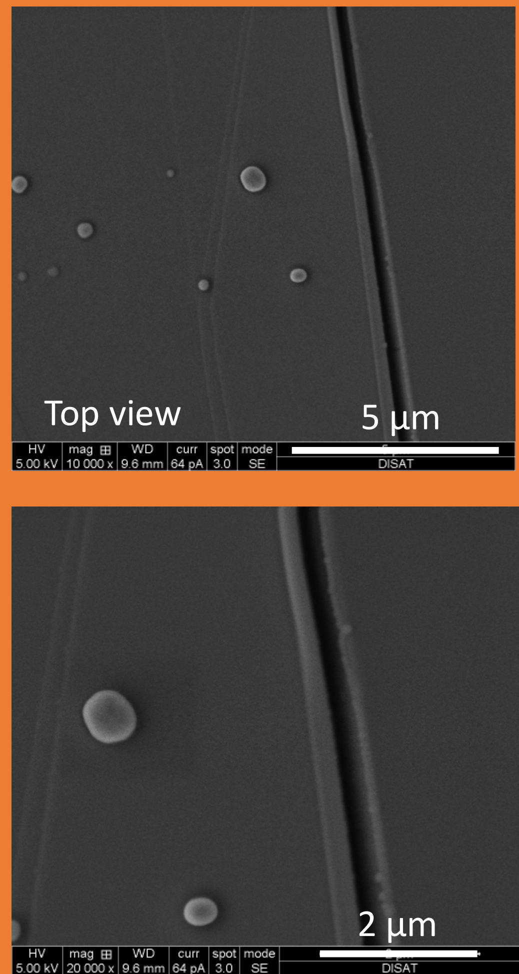


RBS @ AN2000 LNL –
α 2 MeV , ϑ =160°



No contaminants

Germanium non-uniformity: < 15%



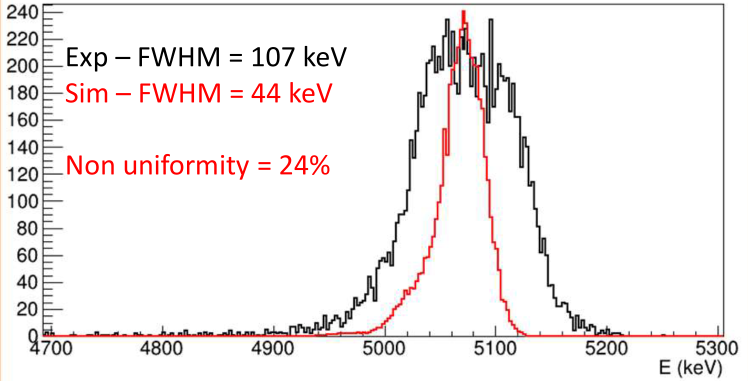
Homogeneus surface

Tellurium target

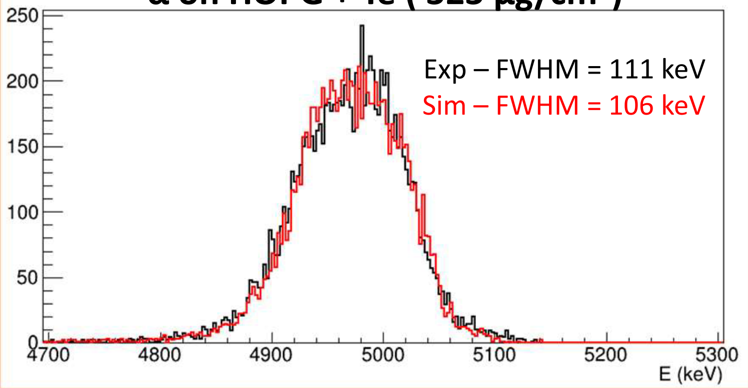
Standard condition: low evaporation rate, no background heating, no buffer

Te @ TRUSTEC: electron-beam source.
Several trials with natural Te.

α on HOPG (533 μg/cm²)

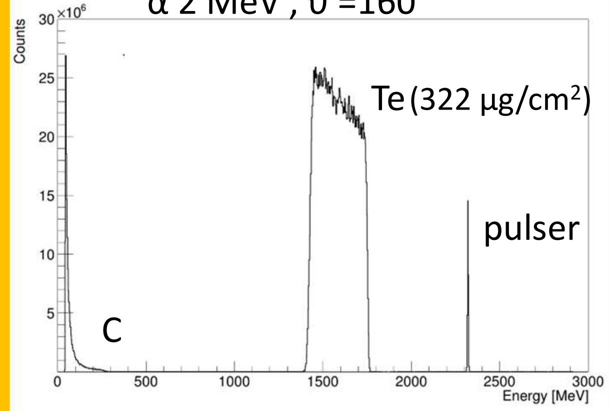


α on HOPG + Te (323 μg/cm²)



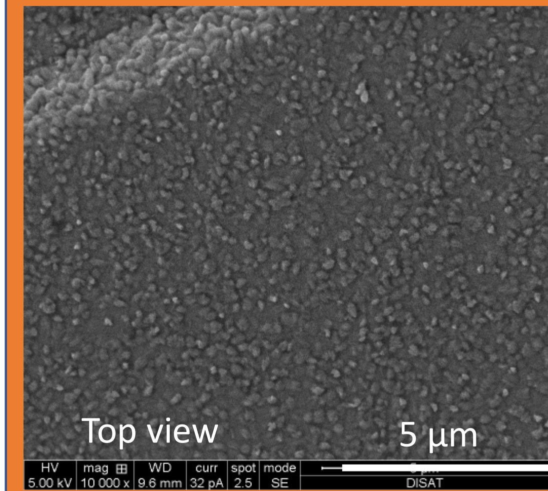
RBS @ AN2000 LNL –

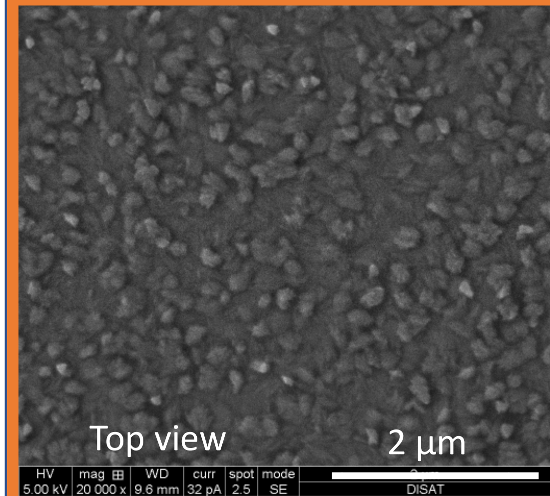
α 2 MeV , ϑ =160°



No contaminants

Tellurium non-uniformity : 35%





Some structures are present, but uniformily distributed

Germanium and Tellurium targets @ LNS

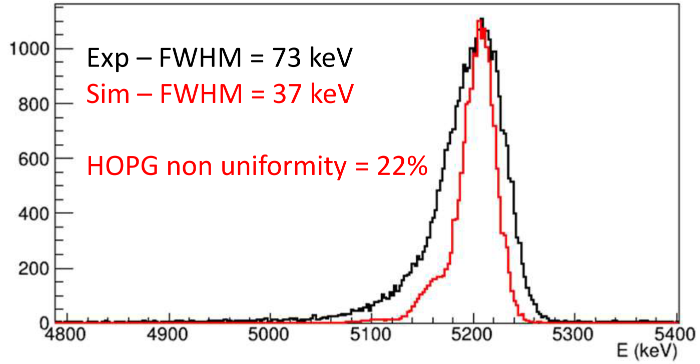
Germanium @ L560 **with resistive source.**

- 3.6 g Ge deposited on W boat --- 0.6 g of Ge used
- Distance source - backing = 250 mm
- Evaporation rate = 0.2 Å/s
- Thickness @ the quartz : 250 μg/cm^2

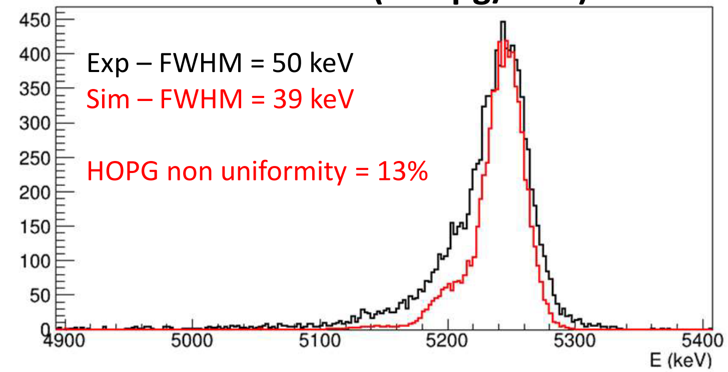
Tellurium @ **L300 resistive source**

- 0.6 g Te deposited on W boat --- 0.4 g of Te used
- Distance source - backing = 210 mm
- Evaporation rate = 0.2 Å/s
- Thickness @ the quartz : 250 μg/cm^2

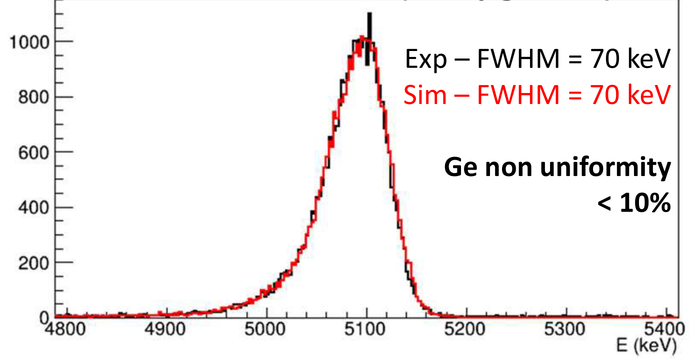
α on HOPG (362 μg/cm²)



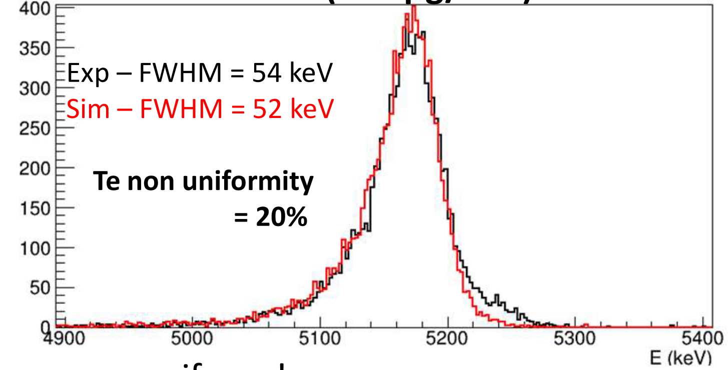
α on HOPG (313 μg/cm²)



α on HOPG + Ge (280 μg/cm²)



α on HOPG + Te (239 μg/cm²)



Thickness average values closer to the required one, more uniform !

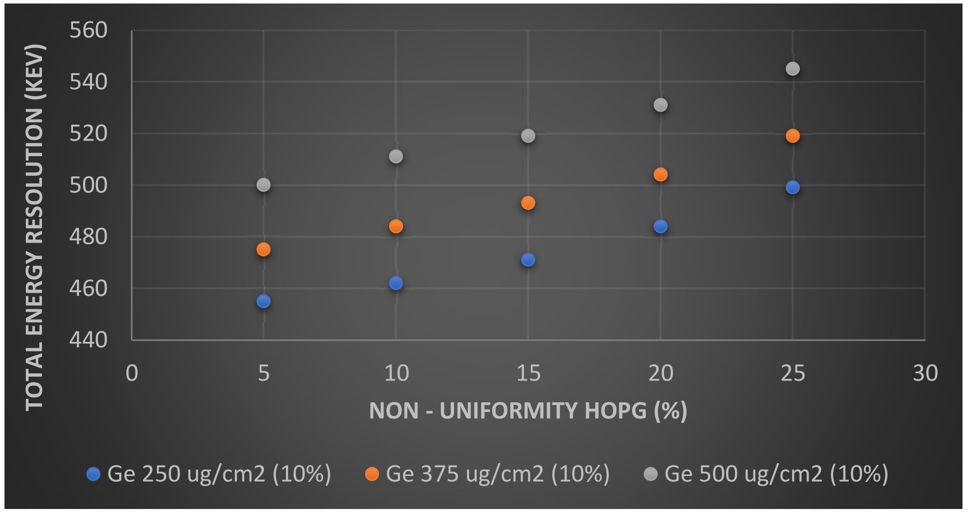
What about energy resolution?

Summarising:

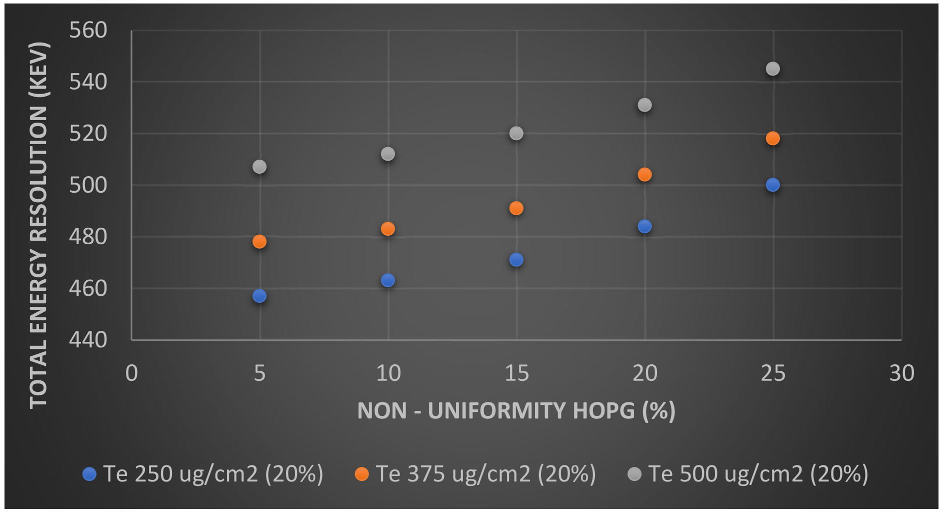
Requested	Non – Uniformity measured
450 μg/cm² HOPG	10-25%
250 - 500 μg/cm² Ge	< 10 %
250 - 500 μg/cm² Te	20%

TOTAL ENERGY RESOLUTION:
- Cyclotron
- Magnex
- Target+backing

^{20}Ne @ 15 MeV/ amu
^{76}Ge(^{20}Ne,^{20}O)^{76}Se --- ^{76}Se* (559 keV)



^{20}Ne @ 15 MeV/ amu
^{130}Te(^{20}Ne,^{20}O)^{130}Xe ---- ^{130}Xe* (536 keV)



By reducing HOPG non-uniformities, thicker targets can be used!

Conclusions

- Characterisation of HOPG backing and Ge and Te target: APT, RBS and FESEM.
- APT is particularly usefull for uniformity studies

HOPG

- variations in the average thickness between different samples: 250 $\mu g/cm^2$ - 900 $\mu g/cm^2$
- important global uniformities
- local FWHM non-uniformities: 10% - 25%
- Important contribution of HOPG in the final energy resolution

Germanium and Tellurium targets

- deposition with good uniformity can be obtained in "standard condition": low evaporation rate, no heating backing, no buffer
- the target contribution in the energy resolution is negligible compared the HOPG one

NEXT : Study of new sample of HOPG or … is it possible to produce it «at home»?

Thanks for your attention !!