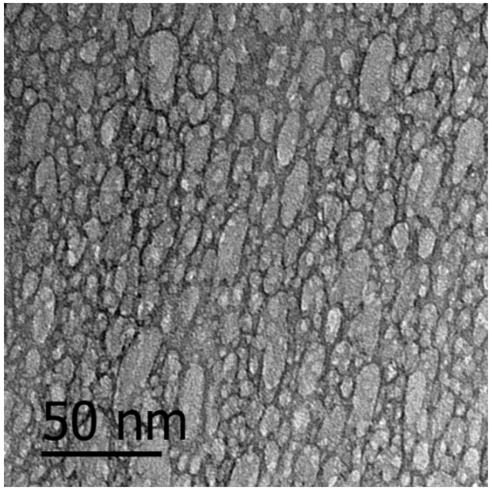
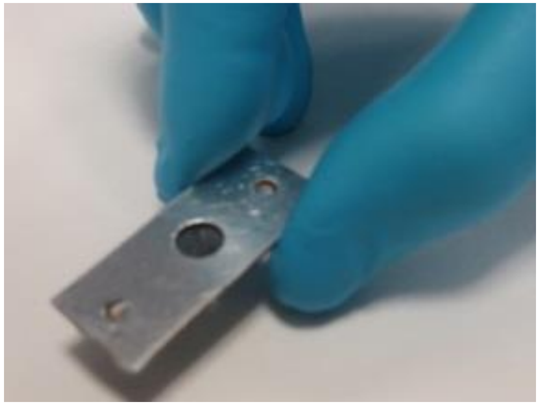
Solid targets containing high amount of ^{4}He for Nuclear Physics Experiments

F.J. Ferrer, B. Fernández, V. Godinho, J.P. Fernández-García,
A. Fernández, D. Galaviz, J. Gómez-Camacho





Third Workshop on Gas-Filled Detectors and Systems (GDS) ENSAR2 - WP6

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TEAM

Laboratory for Nanostructured Materials and Microstructure

- Dr. Vanda Godinho
- Dr. D Hufschmidt
- Dr. M.C. Jiménez de Haro
- Prof. Asunción Fernández

- **Material synthesis (Magnetron sputtering)**
- **Morphological characterization (SEM, TEM)**
- **Elemental Characterization (EELS)**

TEAM

Centro Nacional de Aceleradores

- Dr. F. Javier Ferrer
- Dr. Begoña Fernández
- Dr. J.P. Fernández-García
- Prof. Joaquín Gómez

Dr. D. Galaviz

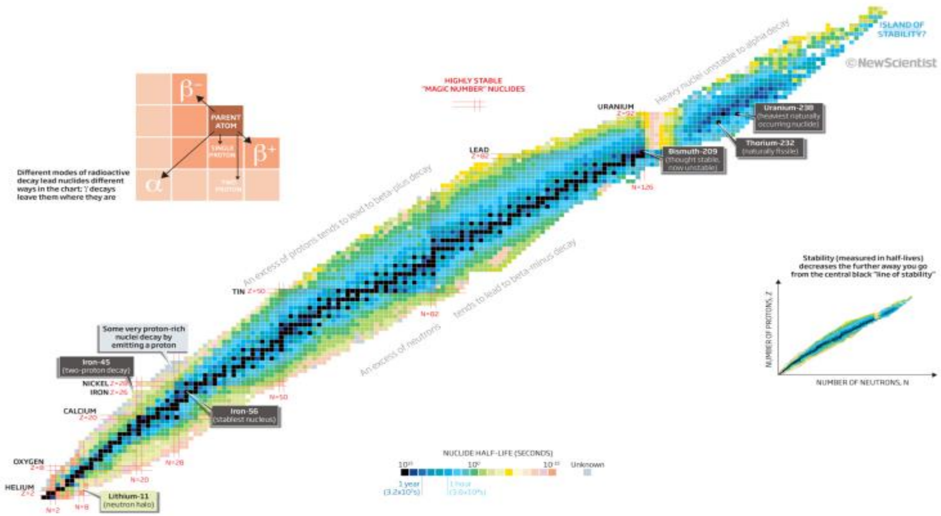
LIP

Ciências ULisboa
Faculdade de Ciências da Universidade de Lisboa

- Elemental characterization
- Nuclear Physics Experiments

- Nuclear Physics Experiments

GOAL



Using nuclear reactions for investigating properties of nuclei far from the stability line ("exotic" nuclei).

Protons		Alphas
(^{1}H, ^{1}H)	Elastic scattering	(^{4}He,^{4}He)
(^{1}H, ^{3}H)	Two neutron transfer	(^{4}He,^{6}He)
(^{1}H, ^{5}H)	Four neutron transfer	(^{4}He,^{8}He)

unstable exotic nucleus

↓

exotic nucleus = projectil
p or ^{4}He = target

INVERSE KINEMATIC

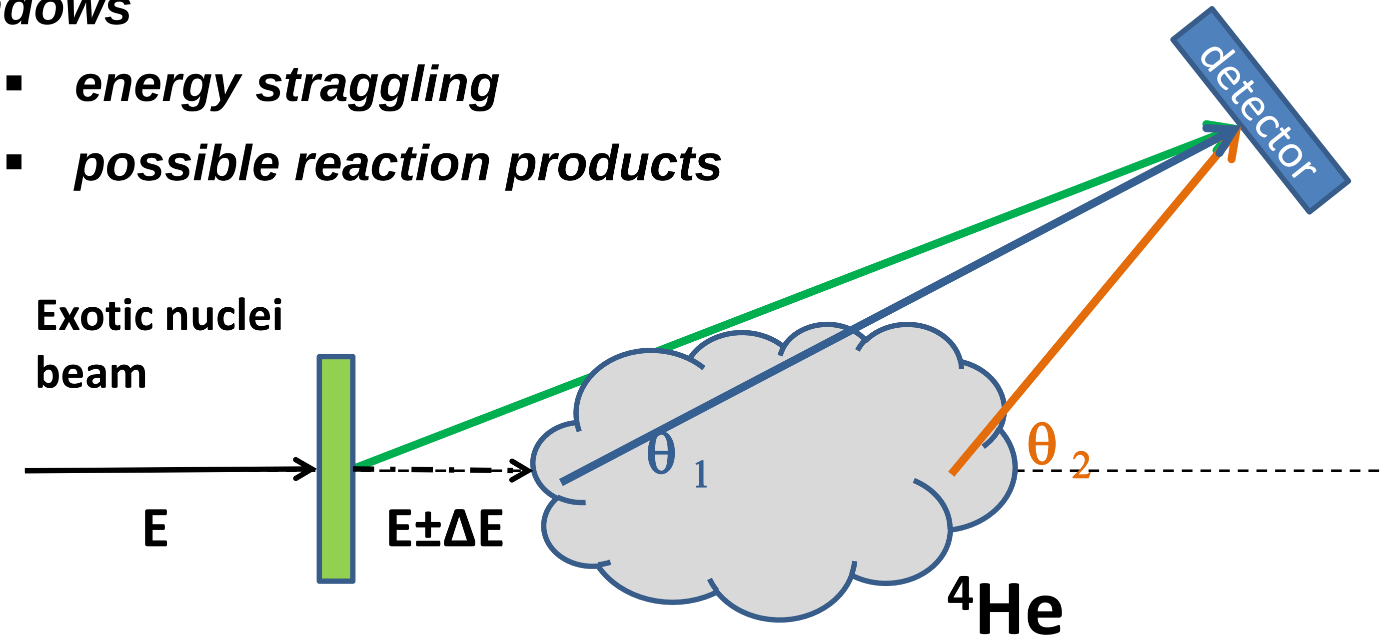
He filled chamber problems

Protons → **polyethylene $(CH_2)n$**

Alphas → **GAS, no solid molecules**

Problems:

- ***angular resolution***
- ***windows***
  - ***energy straggling***
  - ***possible reaction products***



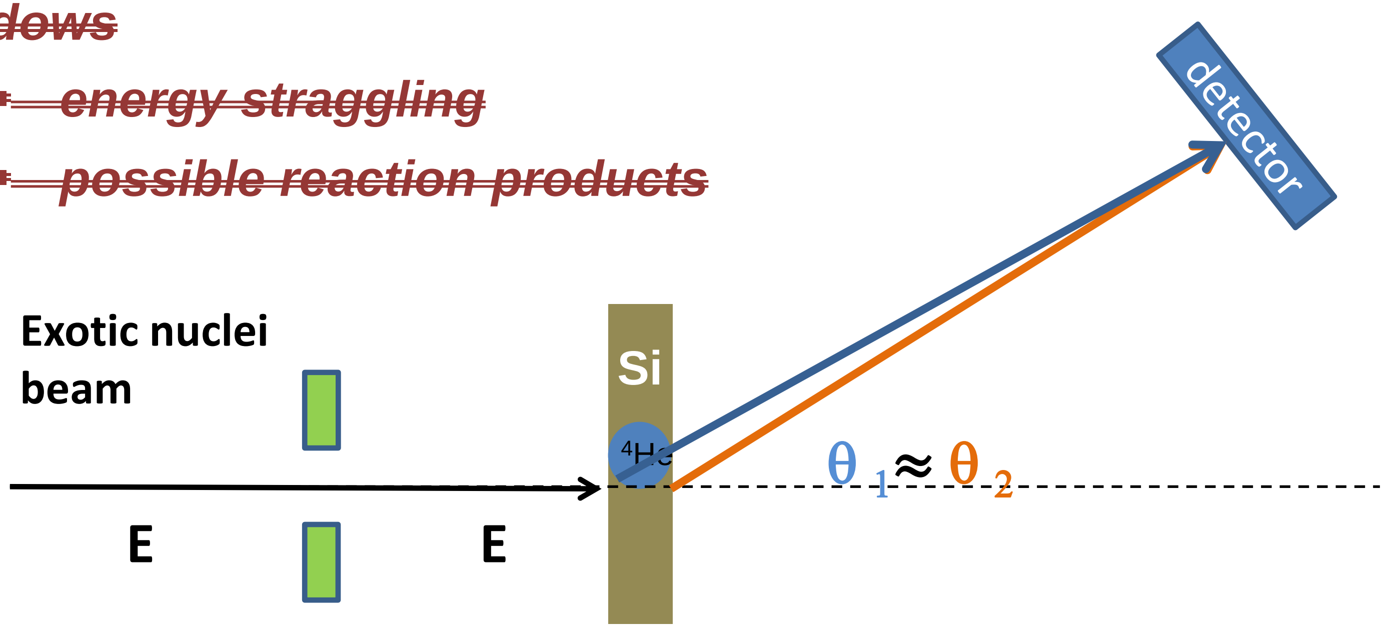
He solid targets soutions

Protons → polyethylene $(CH_2)n$

Alphas → GAS, no solid molecules

Problems:

- ~~*angular resolution*~~
- ~~*windows*~~
  - ~~*energy straggling*~~
  - ~~*possible reaction products*~~



Implantation Alternative

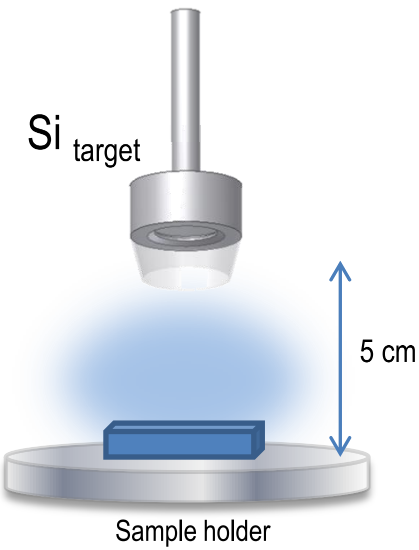
Problems:

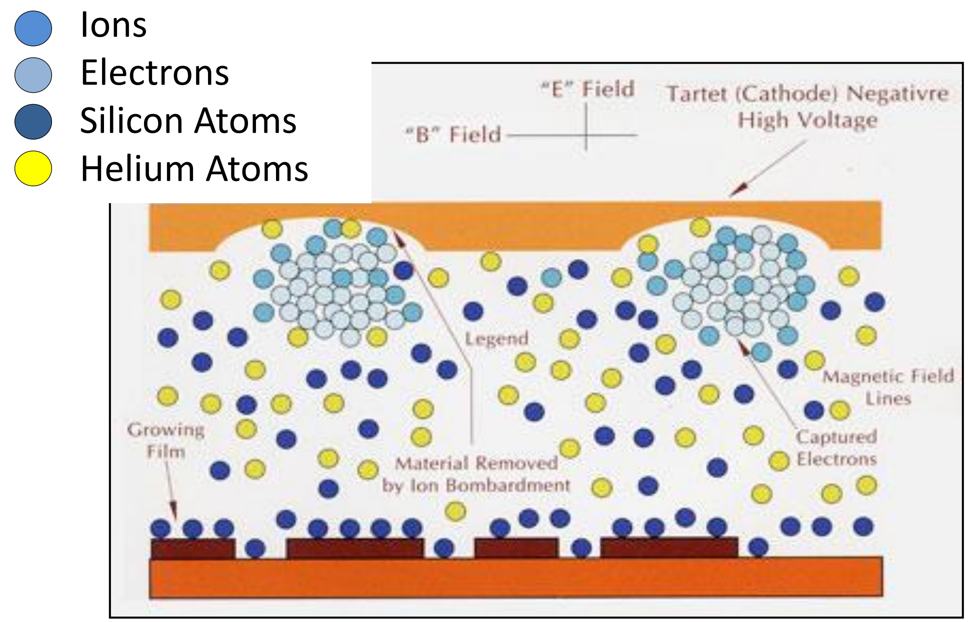
- *Expensive use of implanter*
- *Hardly achieved "homogeneous" profile*
- *"Low" amount of ^{4}He*
- *"High" (same order of ^{4}He) contamination (C, O)*

Solid targets containing high amount of ^{4}He for Nuclear Physics Experiments

Sample preparation

Magnetron Sputtering





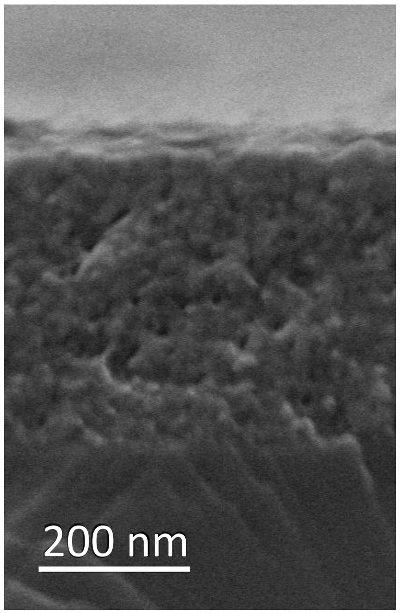
Adjustable parameters:

- **RF/DC Power**
- **Substrate bias**
- **Gas type and Pressure**
- **Target material**

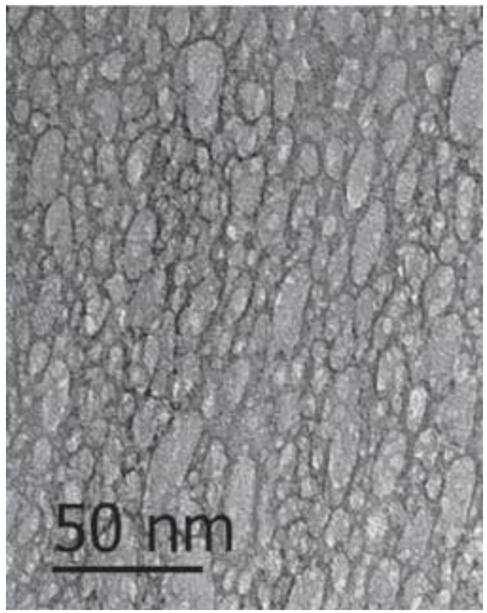
Magnetron sputtering:

- **Wide extended technique in industry**
- **Very versatile allowing to deposit on large areas**
- **Deposition on different kinds of substrates**
- **Controlling deposition parameters is possible to control the microstructure and composition**

Morphological Characterization
SEM and TEM



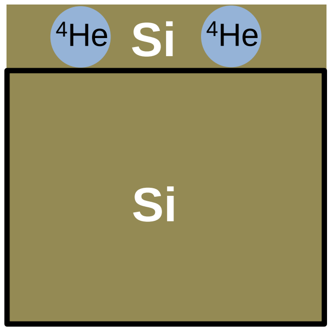
SEM
cross-setional view



TEM
cross-setional view

Control of porosity and ^{4}He amount inside the coating

- **Homogeneously distributed pores structure**

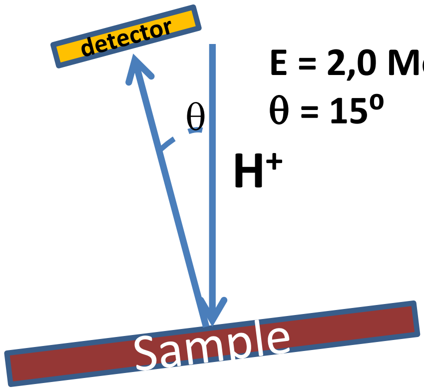


Control of parameters:

- RF/DC Power
- Substrate bias
- Gas type and Pressure
- Target material

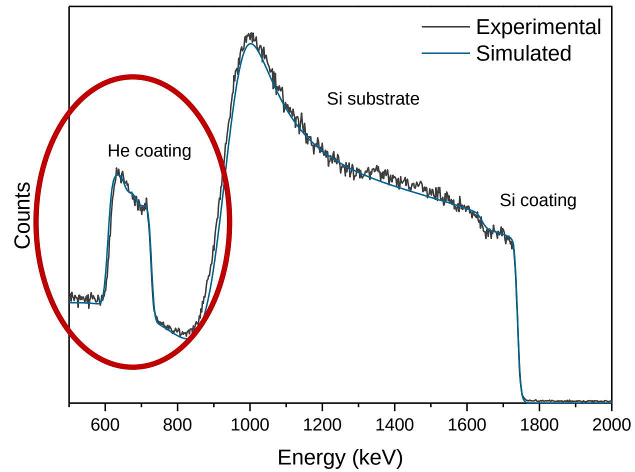
Elemental Characterization

Elastic Backscattering Spectroscopy

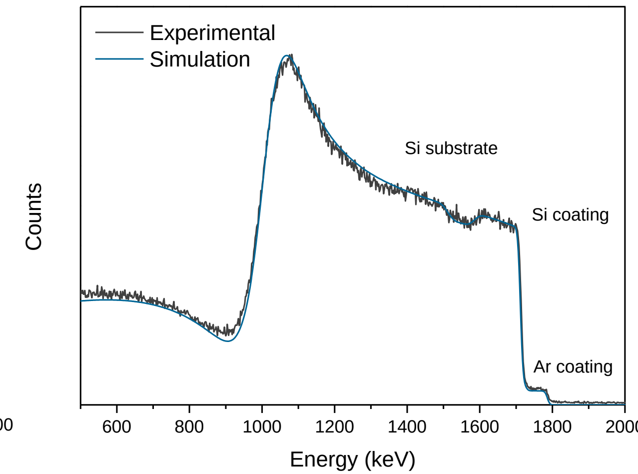


E = 2,0 MeV
θ = 15º

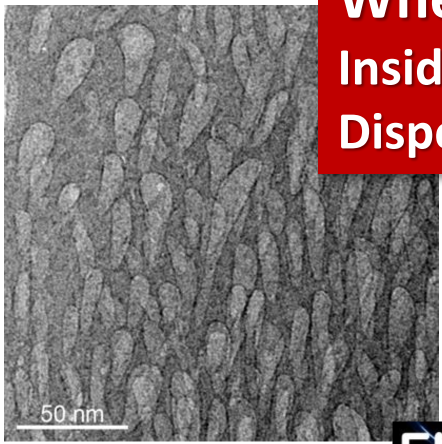
porous coating



dense coating



Sample	thickness (10^{15}at/cm^2)	Si (%at)	^4He (%at)	Ar (%at)
porous	11000	78.7	21.3	--
dense	9500	92.0	--	6.0



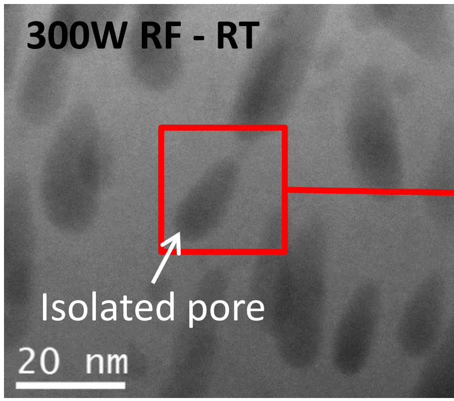
Where is ^4He?
Inside the pores?
Dispersed?

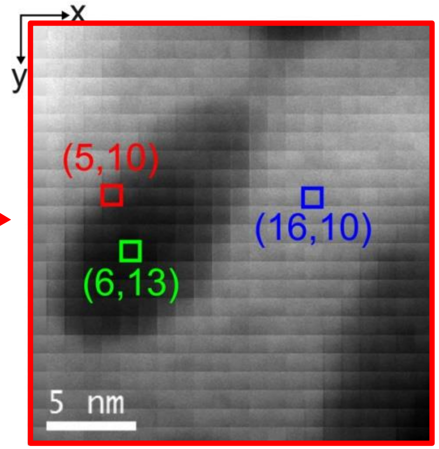
High amount of ^4He!!!
$^4He/Si$ = 0,27

Elemental Characterization

EELS (electron energy loss spectroscopy)

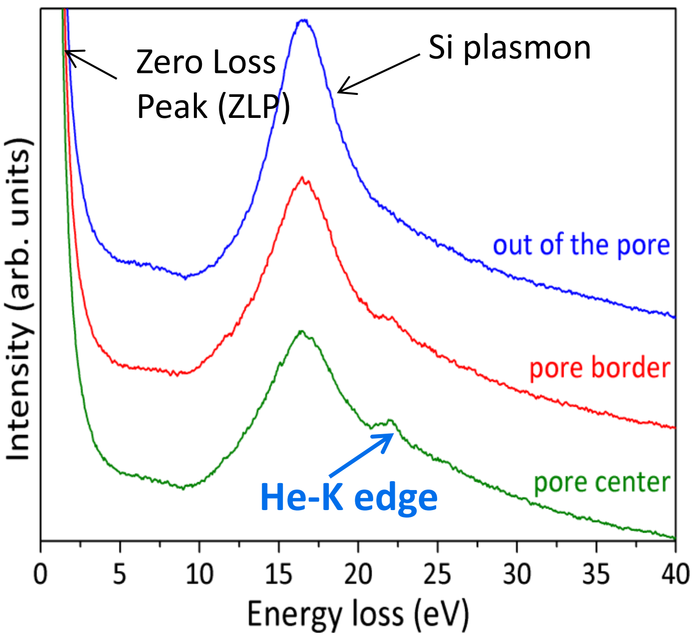
He localization and quantification at the nanoscale in porous Si





STEM-HAADF (Z-contrast)
Intensity proportional to Z^2
Pores are darker than the matrix

Spectrum image dataset:
Pixel size: 1nm
Each pixel contains one EELS spectrum



EELS acquired in the Low Loss region

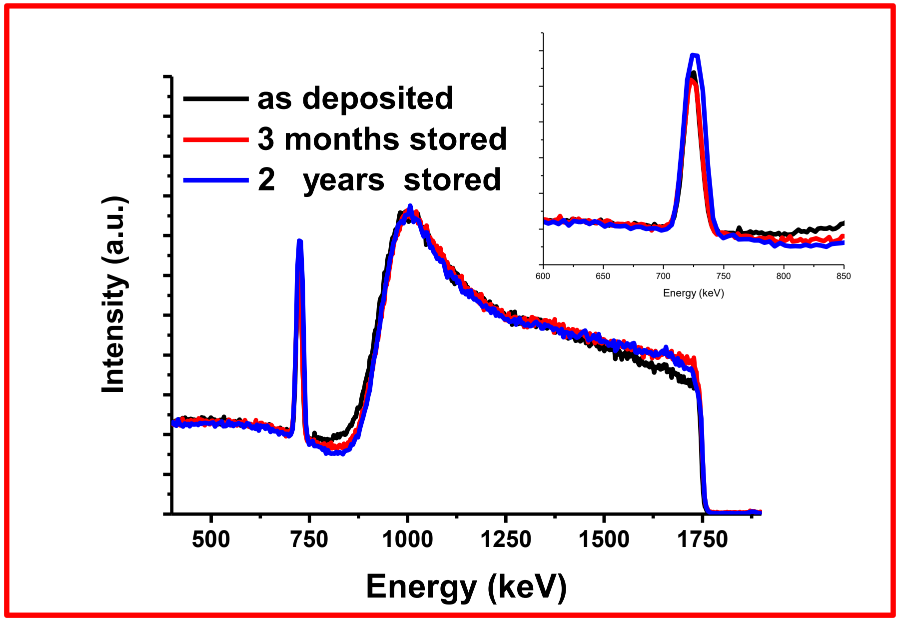
In the pore region:
additional peak around 22 eV ➔ **He-K edge**

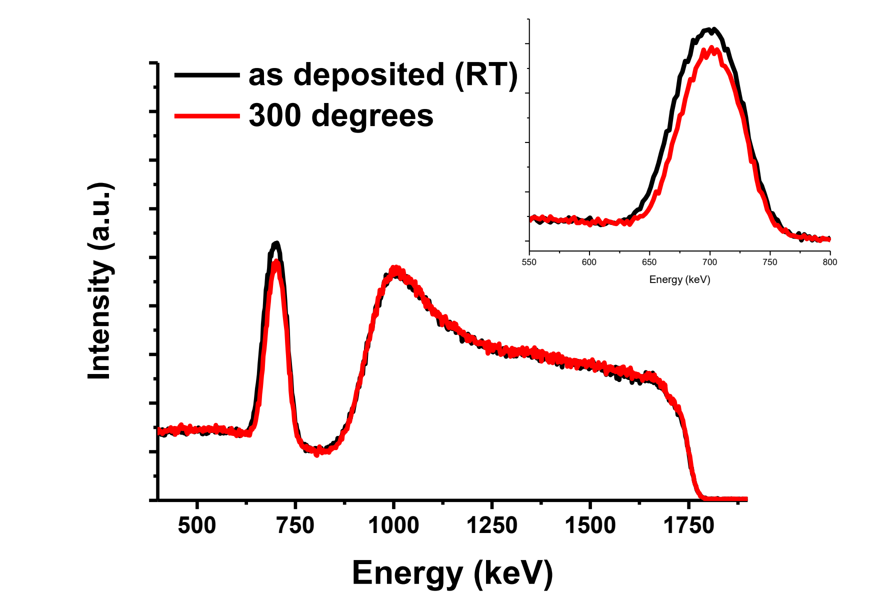
Helium localized inside the pores

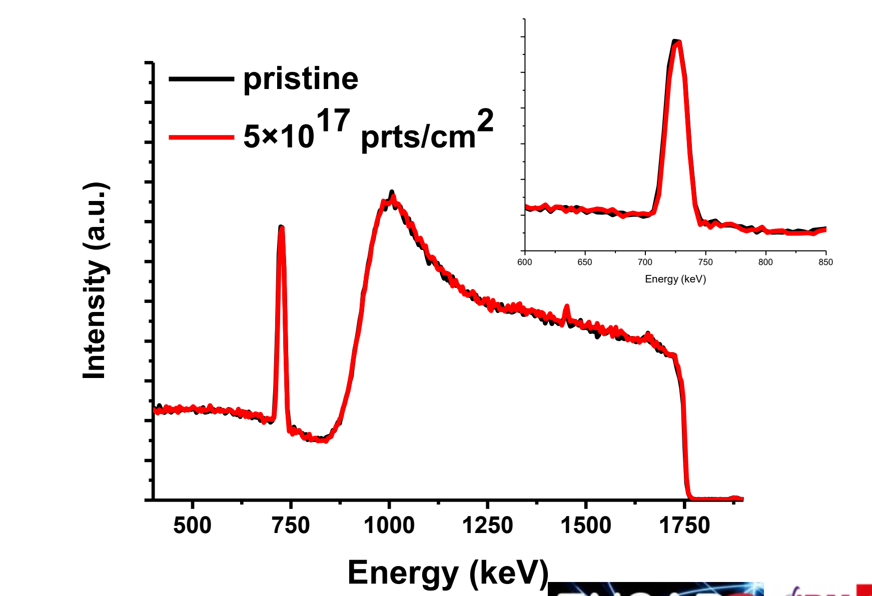
R. Schierholz et al, Nanotechnology 26 (2015) 075703

Stability of the targets

- ➢ Temperature
- ➢ Radiation
- ➢ Aging







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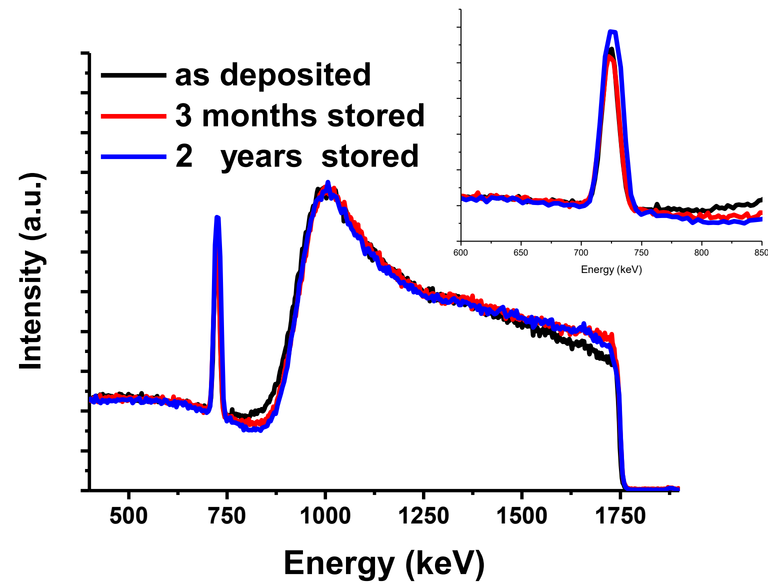
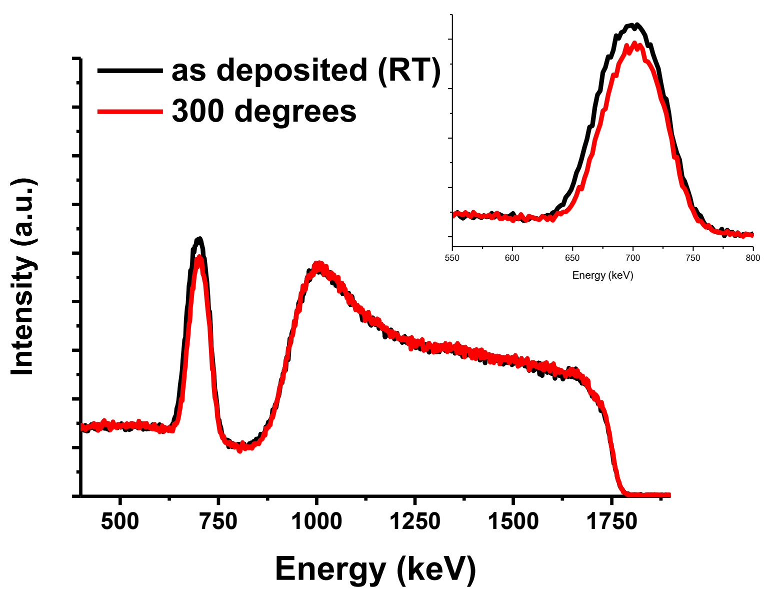
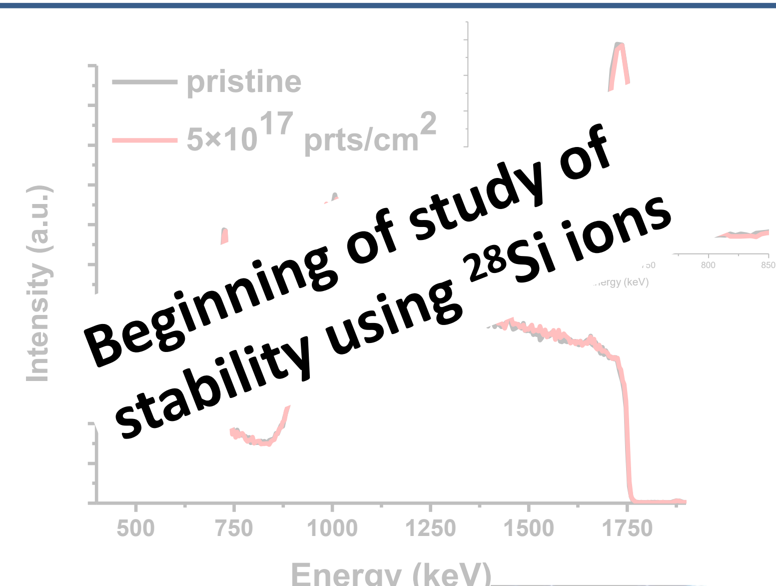


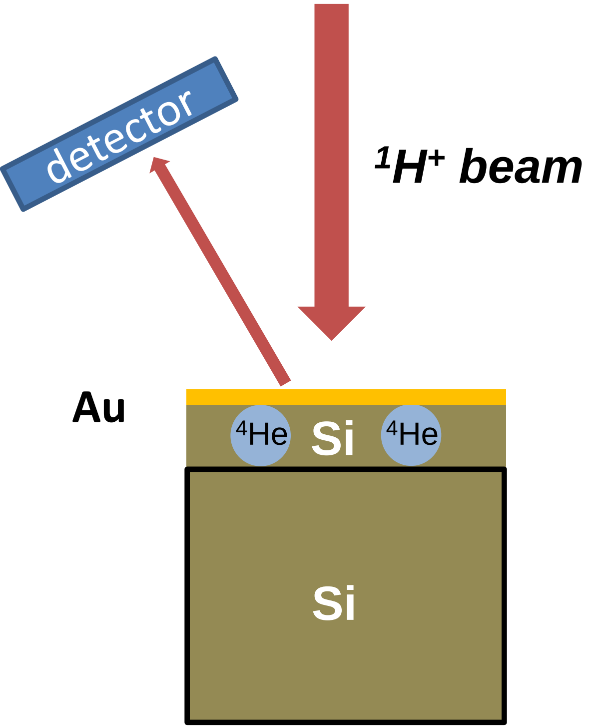


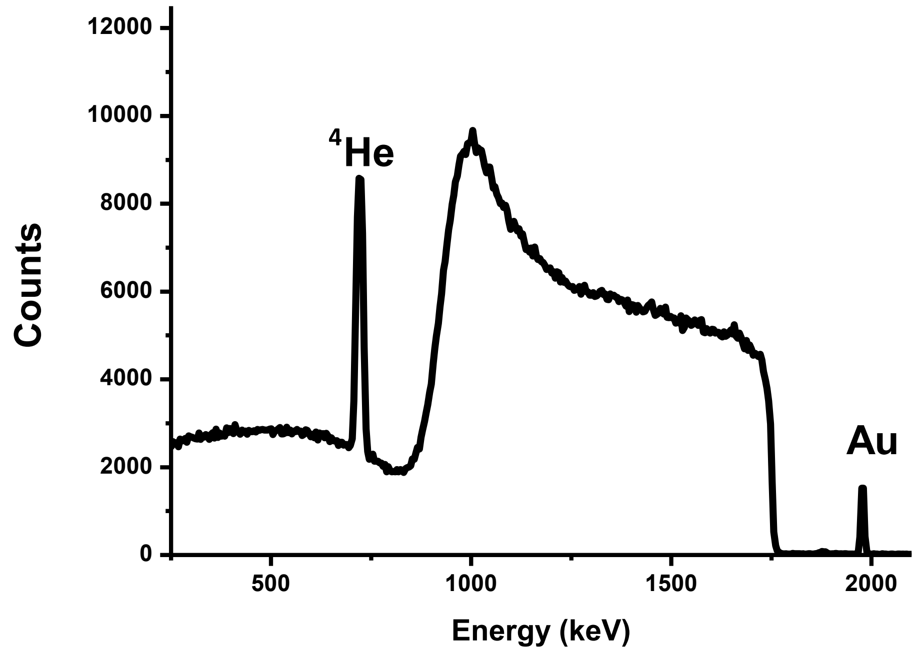


Example 1: $^{4}He(^{1}H,^{1}H)^{4}He$ Elastic scattering

Backscattering (θ > 90°)

Si: 1000 x10^{15} at/cm^2
^{4}He: 550 x10^{15} at/cm^2





$$\frac{d\sigma}{dE_{He}}(E,\theta) = \frac{d\sigma}{dE_{Au,Ruth}}(E_0,\theta)\cdot\left(\frac{A_{He}}{A_{Au}}\right)\cdot\left(\frac{Nt_{Au}}{Nt_{He}}\right)$$

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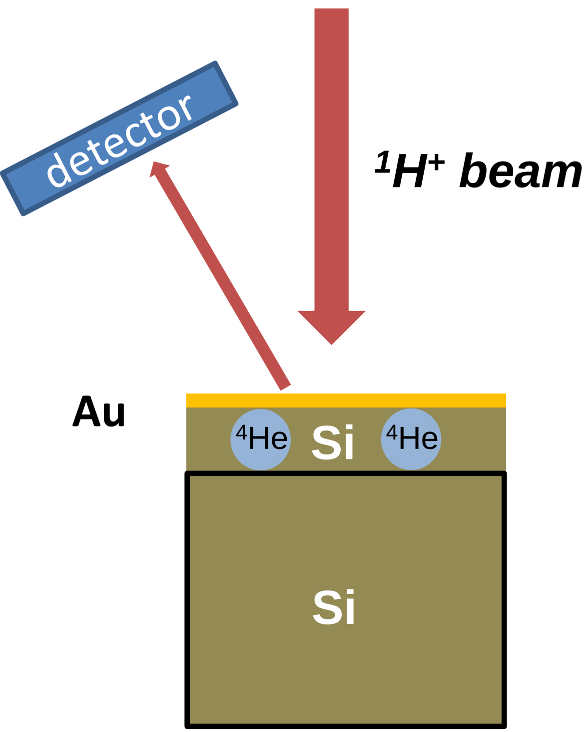

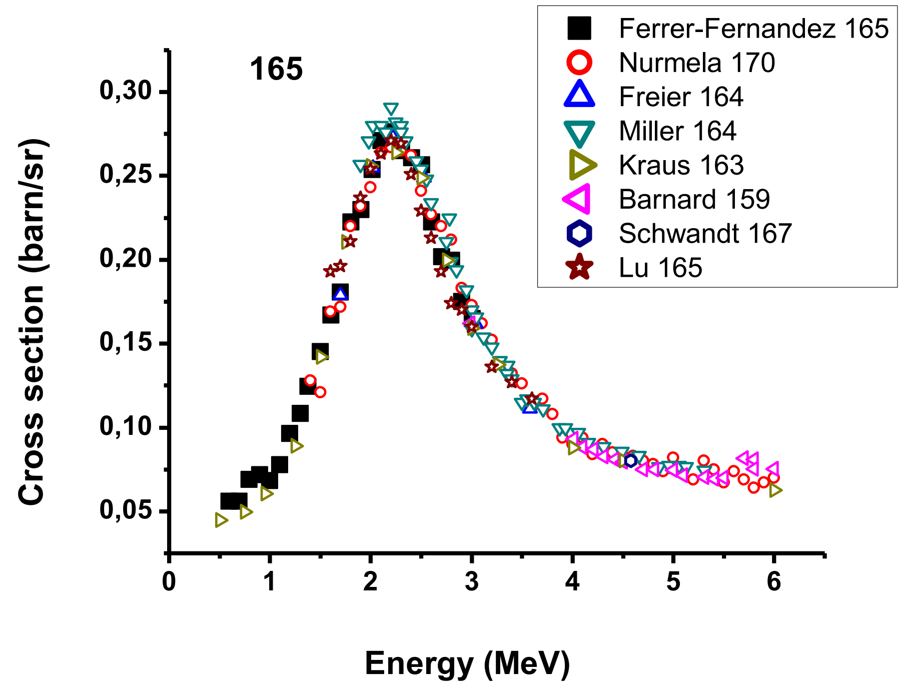

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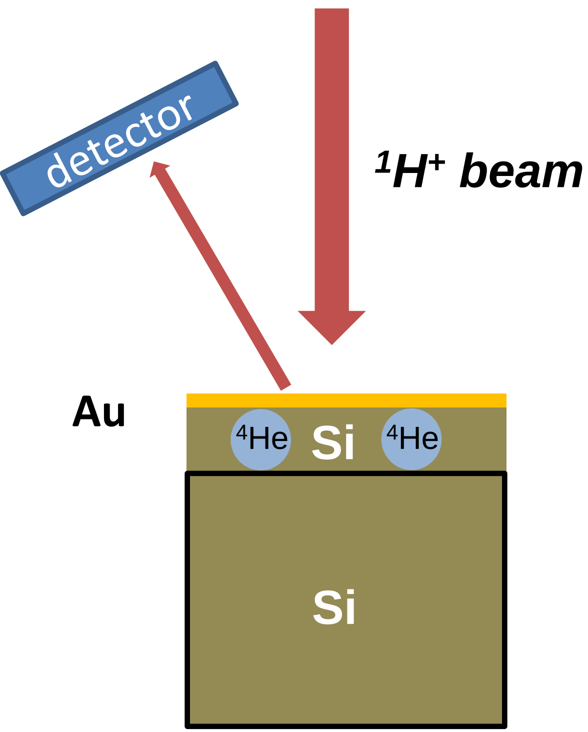
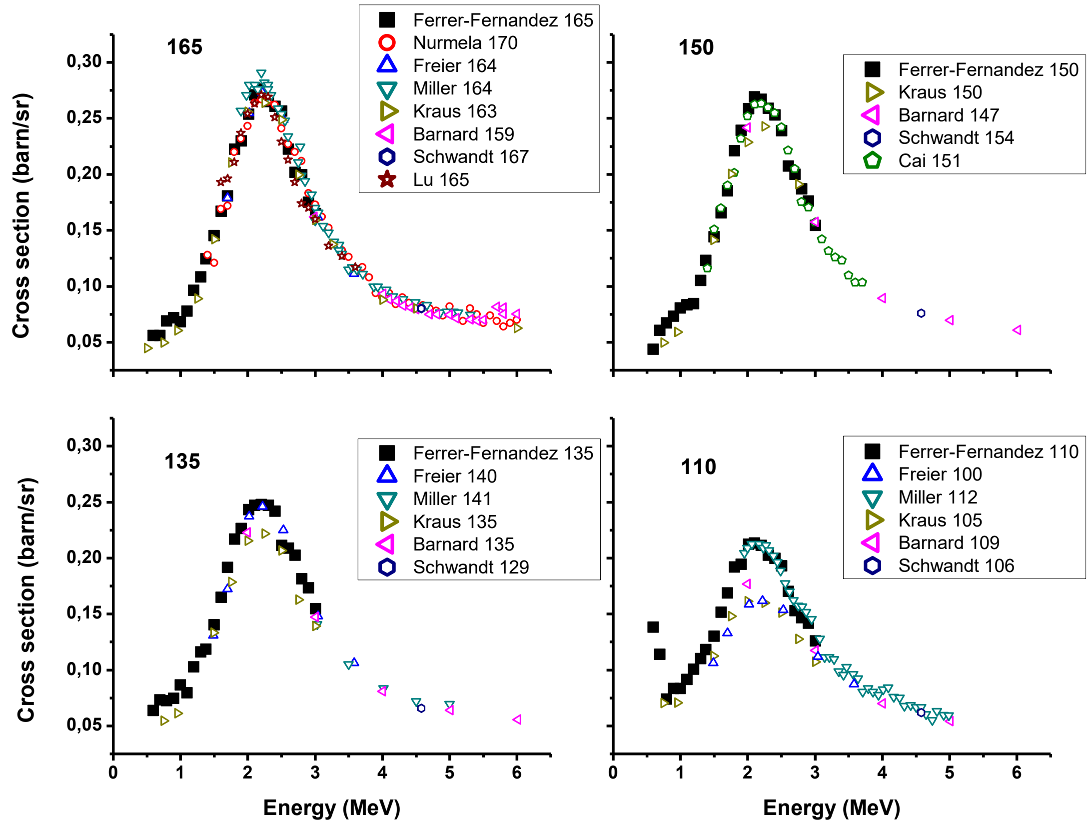
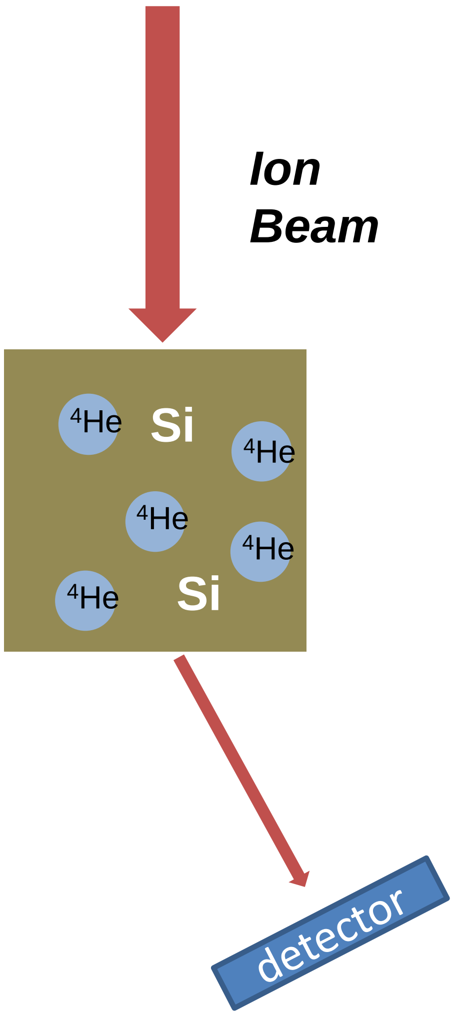


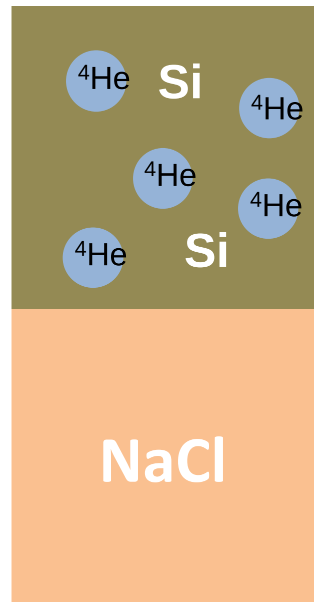


$^{4}He(^{1}H,^{1}H)\,^{4}He$ elastic scattering cross section included at **Ion Beam Analysis Nuclear Data Library (IBANDL) and Experimental Nuclear Reaction Data (Exfor)** from **International Atomic Energy Agency** (IAEA)

International Atomic Energy Agency
Nuclear Data Services

Example 2: ^{4}He(^{6}Li, ^{6}Li) ^{4}He Elastic scattering
Forward scattering (θ < 90°). Self-supported.





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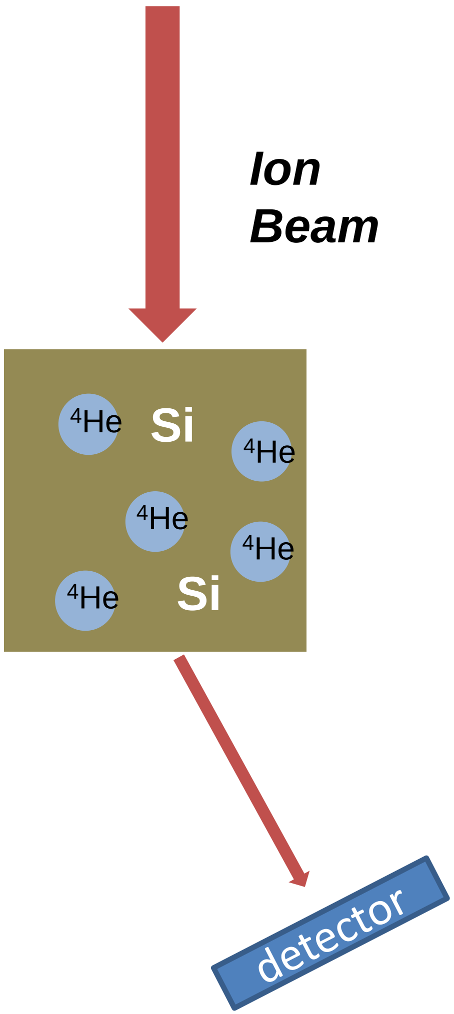

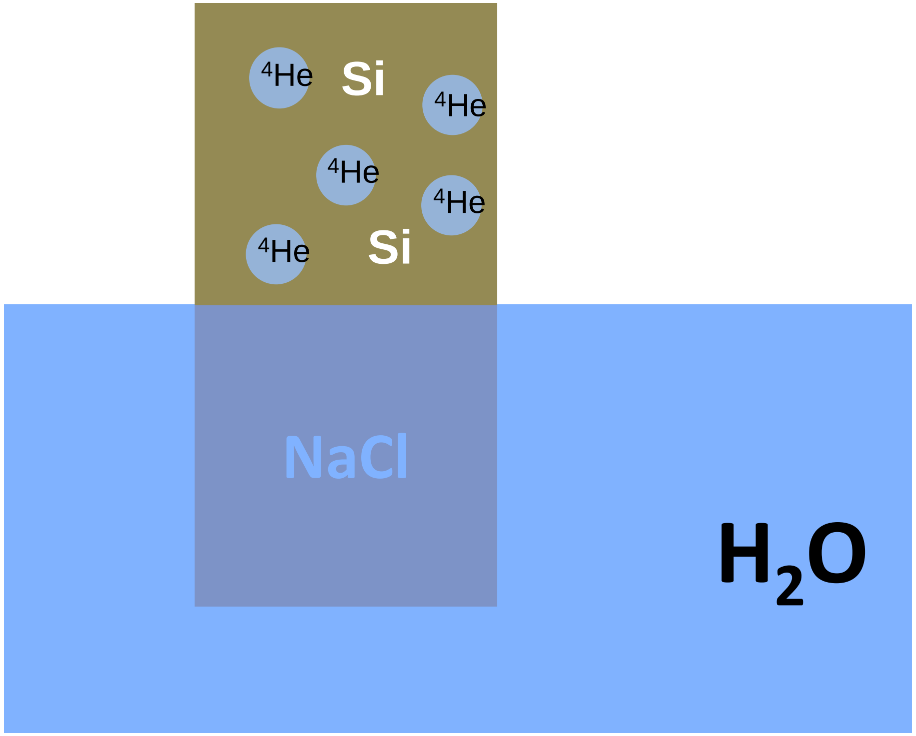

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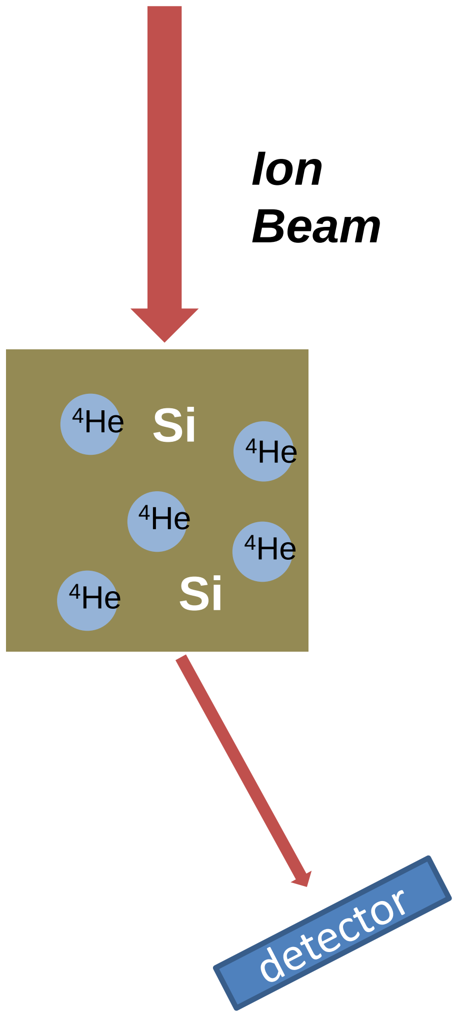

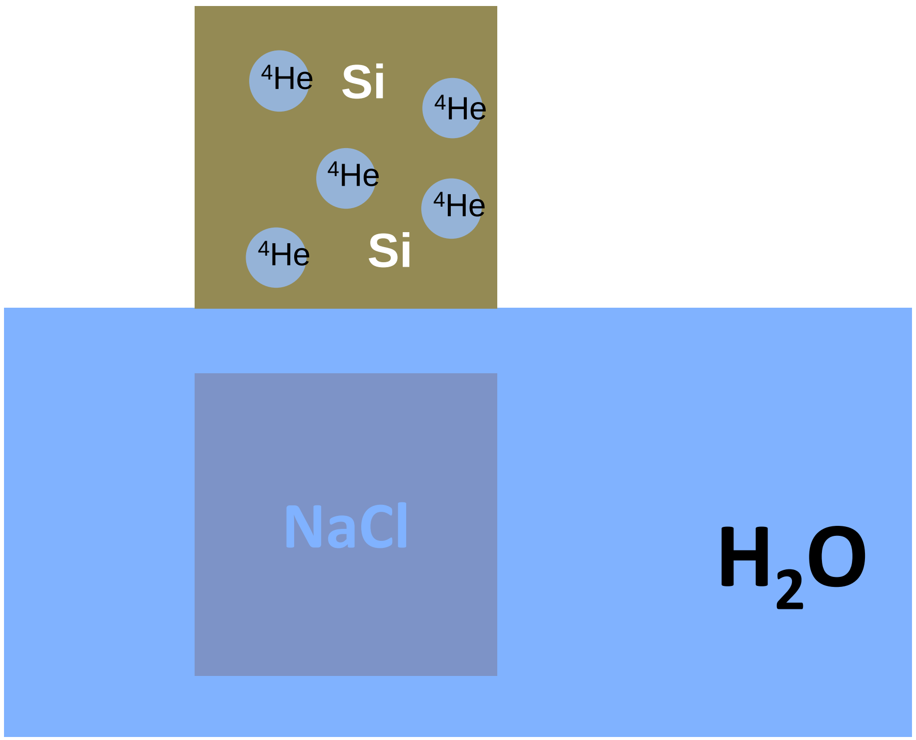

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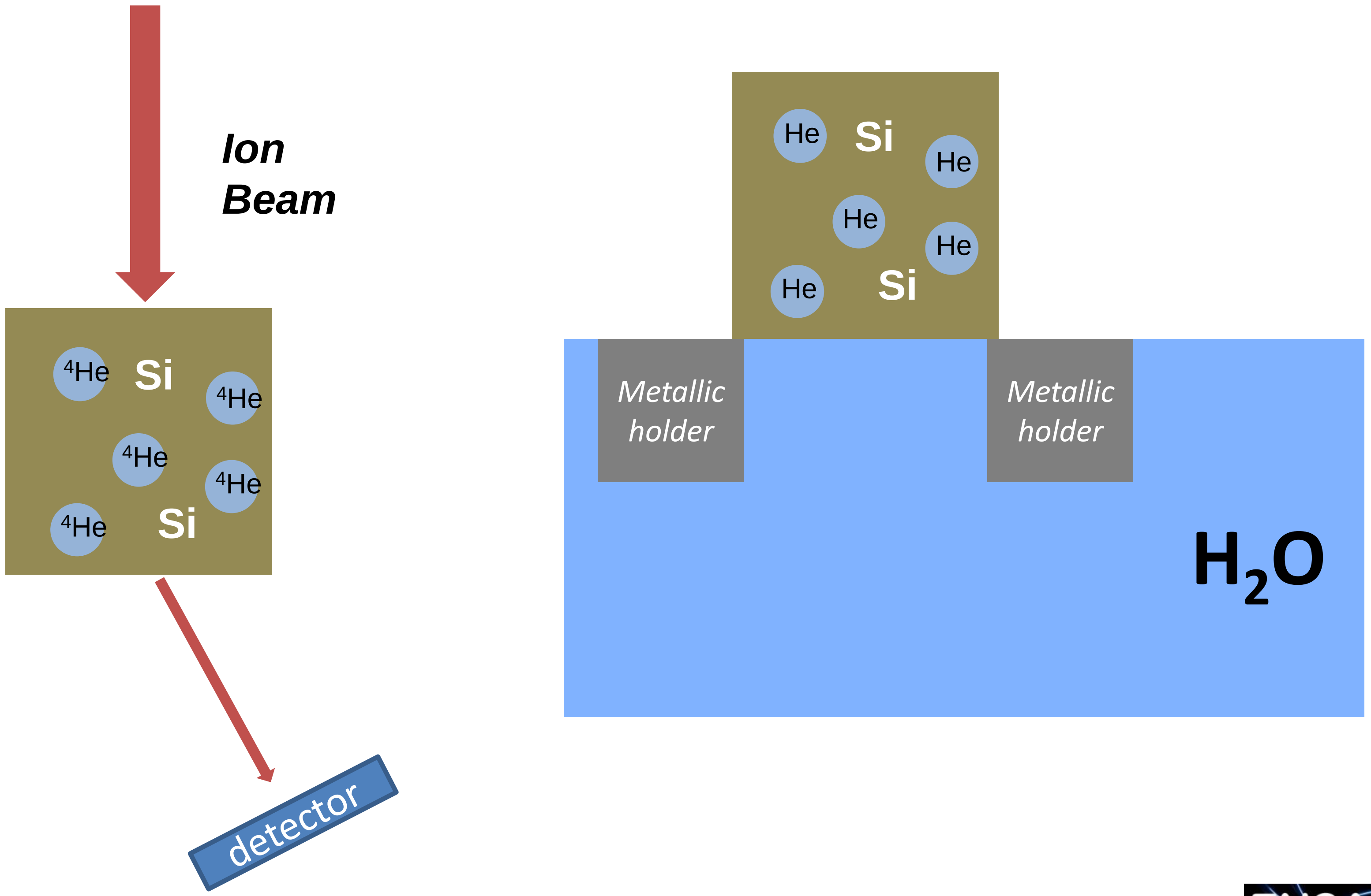

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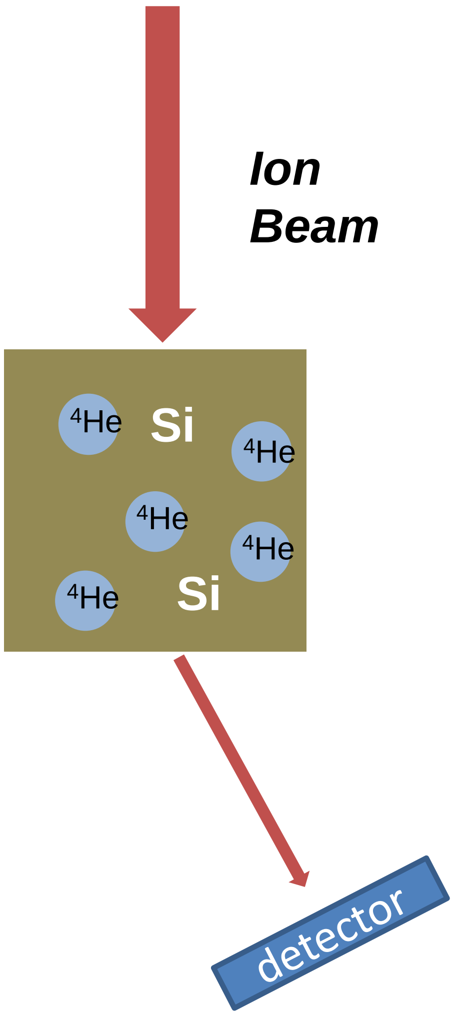

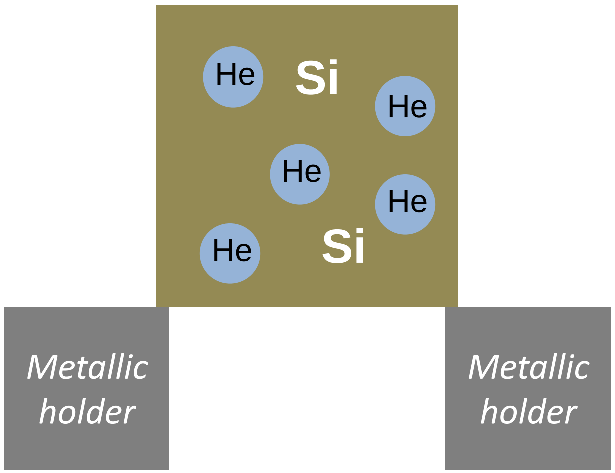

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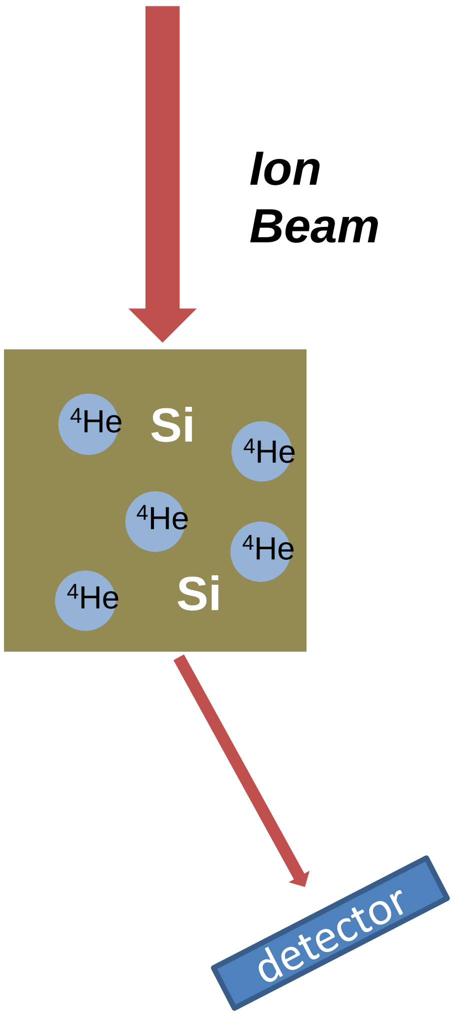
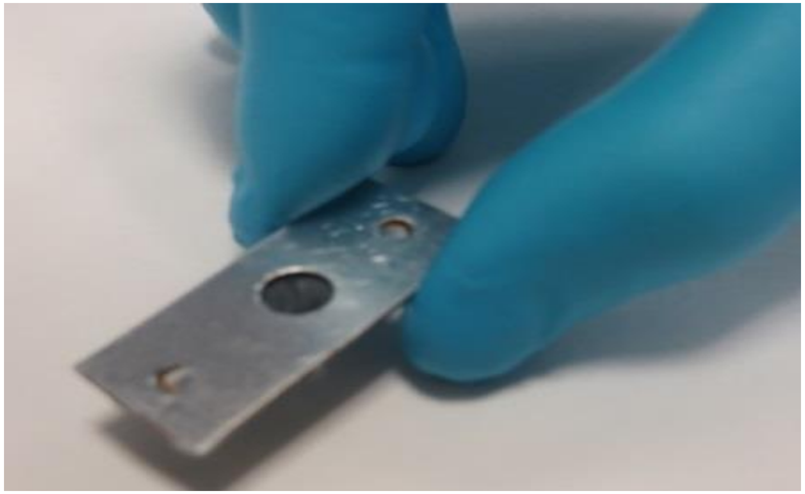
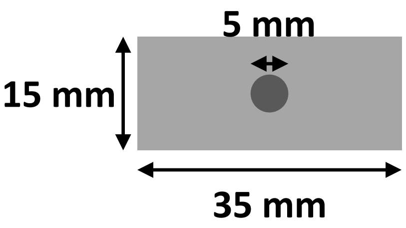
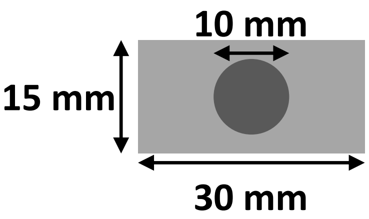




Self-supported Si:^4He target

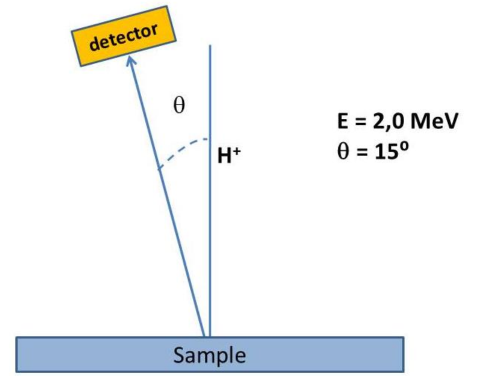


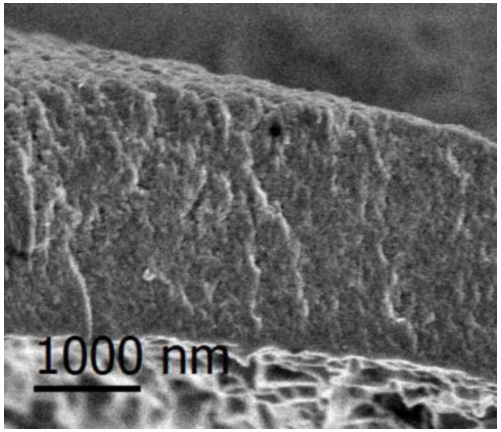


Example 2: ^{4}He(^{6}Li, ^{6}Li) ^{4}He Elastic scattering

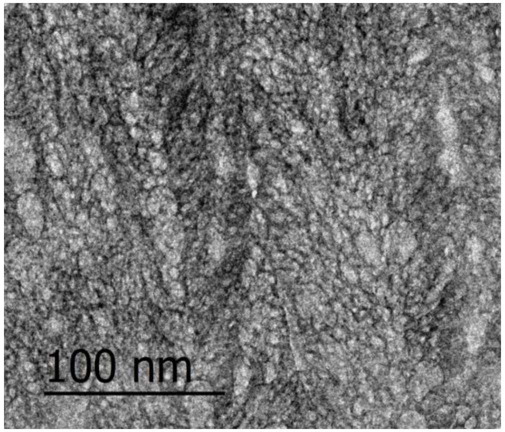
Forward scattering (θ < 90°). Self-supported.

Self-supported porous a-Si:^{4}He target

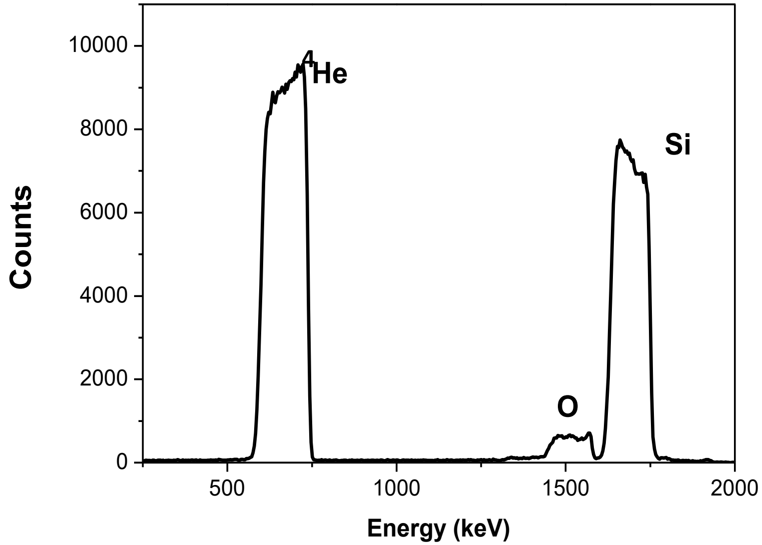




SEM cross-sectional view



TEM cross-sectional view



p-EBS spectrum

Example 2: $^4He(^6Li, ^6Li)\,^4He$ Elastic scattering
Forward scattering ($\theta < 90°$). Self-supported.

	Present work	Vanderbist et al. (2002)	Raabe et al. (2003)	Ujic et al. (2011)
Technique	Magnetron sputtering	Ion implantation	Ion implantation	Ion implantation
Metal ($\times10^{15}$ at/cm^2)	(Si) 9250	(Al) 1100	(Al) 4200	(Al) 1200
^4He ($\times10^{15}$ at/cm^2)	4060	275	270	130
O ($\times10^{15}$ at/cm^2)	700	60	100	Not mentioned
$^4He/M$	0.44	0.25	0.06	0.11
O/He	0.17	0.22	0.37	Not mentioned

High amount of ^4He!!!

$^4He/Si = 0{,}44$

Example 2: ^{4}He(^{6}Li, ^{6}Li) ^{4}He Elastic scattering
Forward scattering (θ < 90°). Self-supported.

	Present work	Vanderbist et al. (2002)	Raabe et al. (2003)	Ujic et al. (2011)
Technique	Magnetron sputtering	Ion implantation	Ion implantation	Ion implantation
Target (µm)	(Si) 2.3	(Al) 0.2	(Al) 0.7	(Al) 0.2
Metal (µg/cm^2)	430	50	200	50
^{4}He (µg/cm^2)	27	1.8	1.8	0.9
O (µg/cm^2)	19	1.6	2.7	Not mentioned

High amount of ^{4}He!!!

^{4}He/Si = 0,44

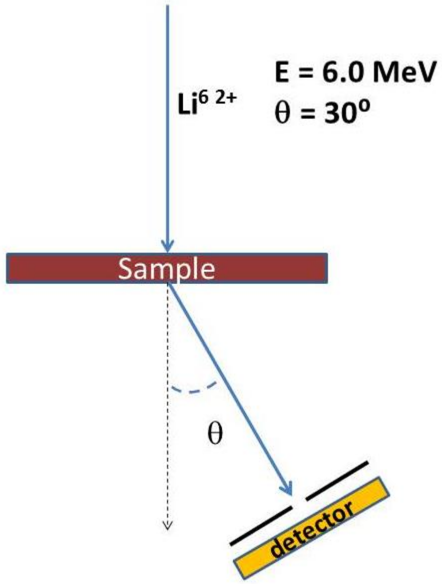
Example 2: ^{4}He(^{6}Li, ^{6}Li) ^{4}He Elastic scattering

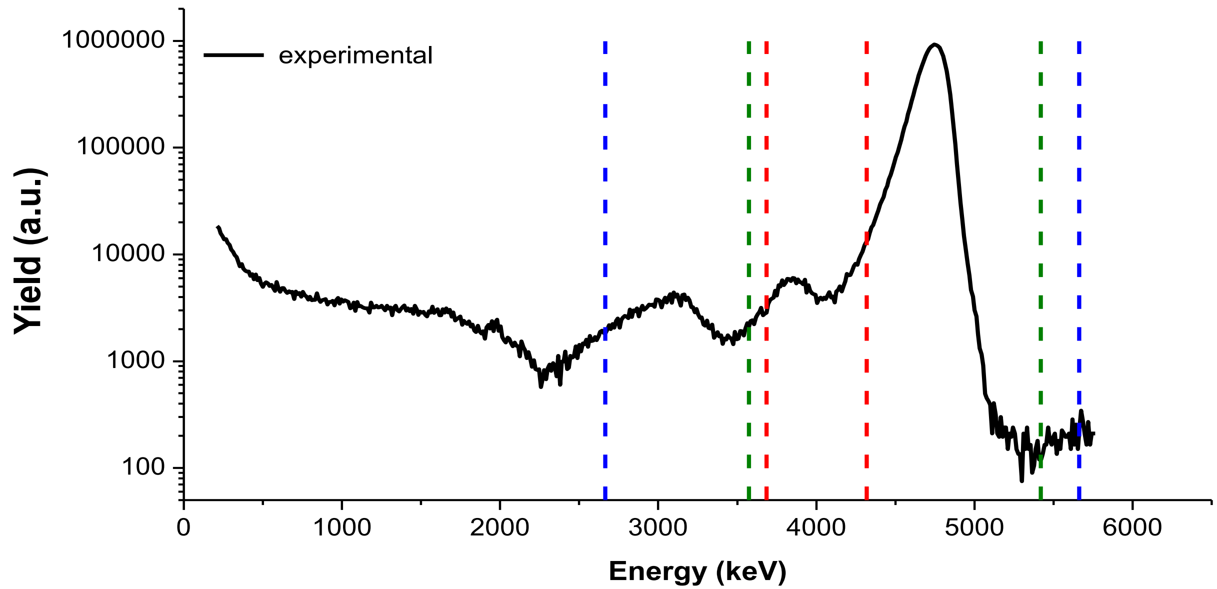
Forward scattering (θ < 90°). Self-supported.

- ^{4}He(^{6}Li, ^{6}Li) ^{4}He Elastic scattering

Si: 9250 x10^{15} at/cm^2 = 430 μg/cm^2
^{4}He: 4060 x10^{15} at/cm^2 = 27 μg/cm^2
O: 700 x10^{15} at/cm^2 = 19 μg/cm^2

KINEMATICS
Li scattered by Si; Li (S Si) = 5664 keV
Si recoiled by Li; Si (R Li) = 2615 keV
Li scattered by ^{4}He; Li (S ^{4}He) = 3684 keV
^{4}He recoiled by Li; ^{4}He (R Li) = 4318 keV
Li scattered by O; Li (S O) = 5419 keV
O recoiled by Li; O (R Li) = 3574 keV





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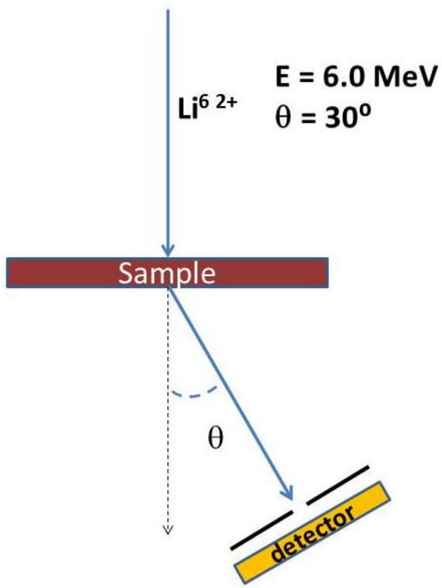
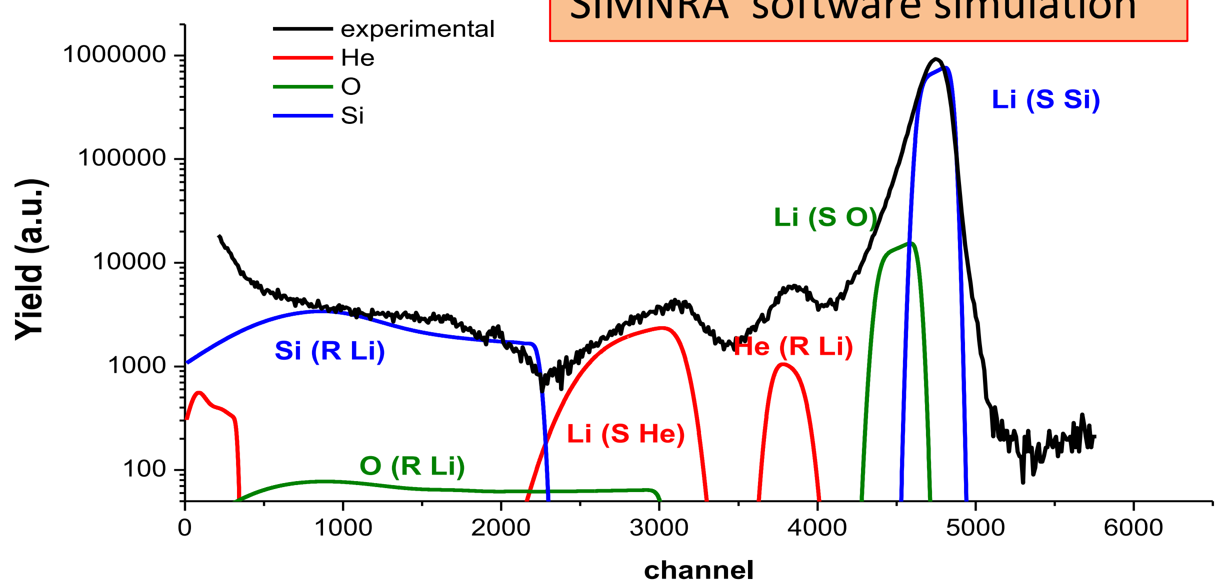
- $^{4}He(^{6}Li, ^{6}Li)\,^{4}He$ Elastic scattering

Stopping power In the sample!!!



SIMNRA software simulation



Example 2: $^4He(^6Li, ^6Li)\,^4He$ Elastic scattering

Forward scattering (θ < 90°). Self-supported.

Si: 9250 x10^{15} at/cm^2 = 430 µg/cm^2 → ***Stopping power In the sample!!!***

	uma	E0	Ef	FWHM	FWHM/Ef	ΔE/E0	MeV/uma
6Li 6 MeV	6	6,00	5,32	0,04	0,008	0,11	1,0
12C 15 MeV	12	15,00	13,18	0,09	0,006	0,12	1,3
28Si 21 MeV	28	21,00	15,03	0,20	0,013	0,28	0,8
64Ni 196 MeV	64	196,00	182,79	0,41	0,002	0,07	3,1
150Gd 900 MeV	150	900,00	866,91	0,89	0,001	0,04	6,0

Conclusions

- MS to produce Si:He targets He trapped in closed porosity
  - with high He/Si low O/Si content
- He homogeneously distributed throughout the film thickness
- Control of the MS parameters => control of the He content and morphology
- Reproducibility of the targets
- Targets deposited over a variety of substrates
- Self-supported targets

Conclusions

- **Stability against fluence, temperature and aging.**
- **Validity for calculation of the differential cross-section for the elastic scattering of proton-helium in the energy range from 0.6 to 3.0 MeV at laboratory angles from 110 to 165°**
- **Proofs in forward geometry using ^6Li beam and self-supported coatings**
- **He solid targets for experiments with radioactive beams at LARGE FACILITIES**

Perspectives: Next future

- nuclear reactions at low energy (close to the Coulomb barrier)
  - Targets: solid He targets
  - Stable Beams: ^{4}He, ^{6}Li, ^{7}Li, ^{8}Be, ^{10}B y ^{12}C
  - Forward geometry
  - ΔE-E telescope with Si detectors

- Verify the experimental setup
  - Detection system
  - Electronic and data acquisition system

- Optimization of targets: higher He/Si and lower O/Si ratio

- nuclear reactions
  - Targets: solid He targets
  - Exotic Beams: ^{6}He, ^{8}He, ^{11}Li, ^{7}Be, ^{11}Be, ^{10}C y^{11}C

LARGE FACILITIES

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Thank you for your attention