

SYNTHESIS AND CHARACTERIZATION BY IBA (ION BEAM ANALYSIS) TECHNIQUES OF TARGETS USED IN NUCLEAR PHYSICS REACTION EXPERIMENTS

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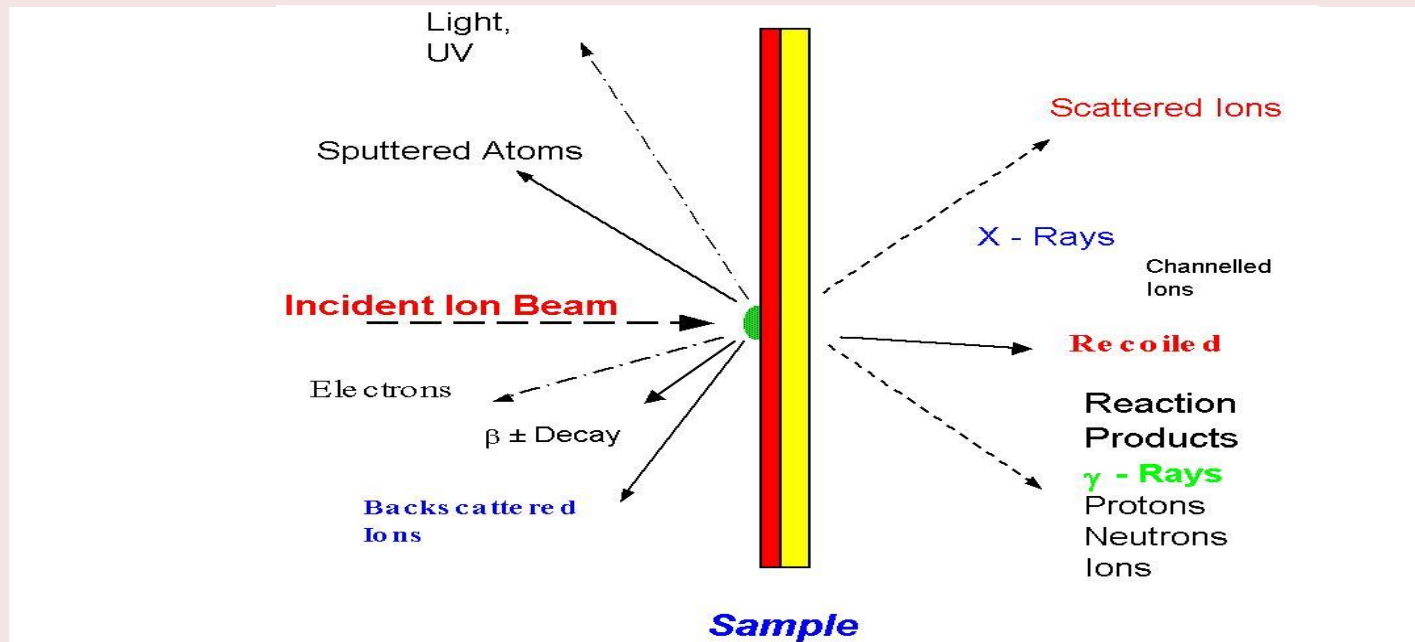
Índex

- Motivation
- Targets in collaboration with n_TOF
- Solid Si:He targets (ICMS-CNA)
- Al:⁶Li Implanted targets (CNA)

Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

Motivation

- The characterization (elements, distribution, etc.) of the targets used in nuclear physics experiments is essential in the interpretation of their results.



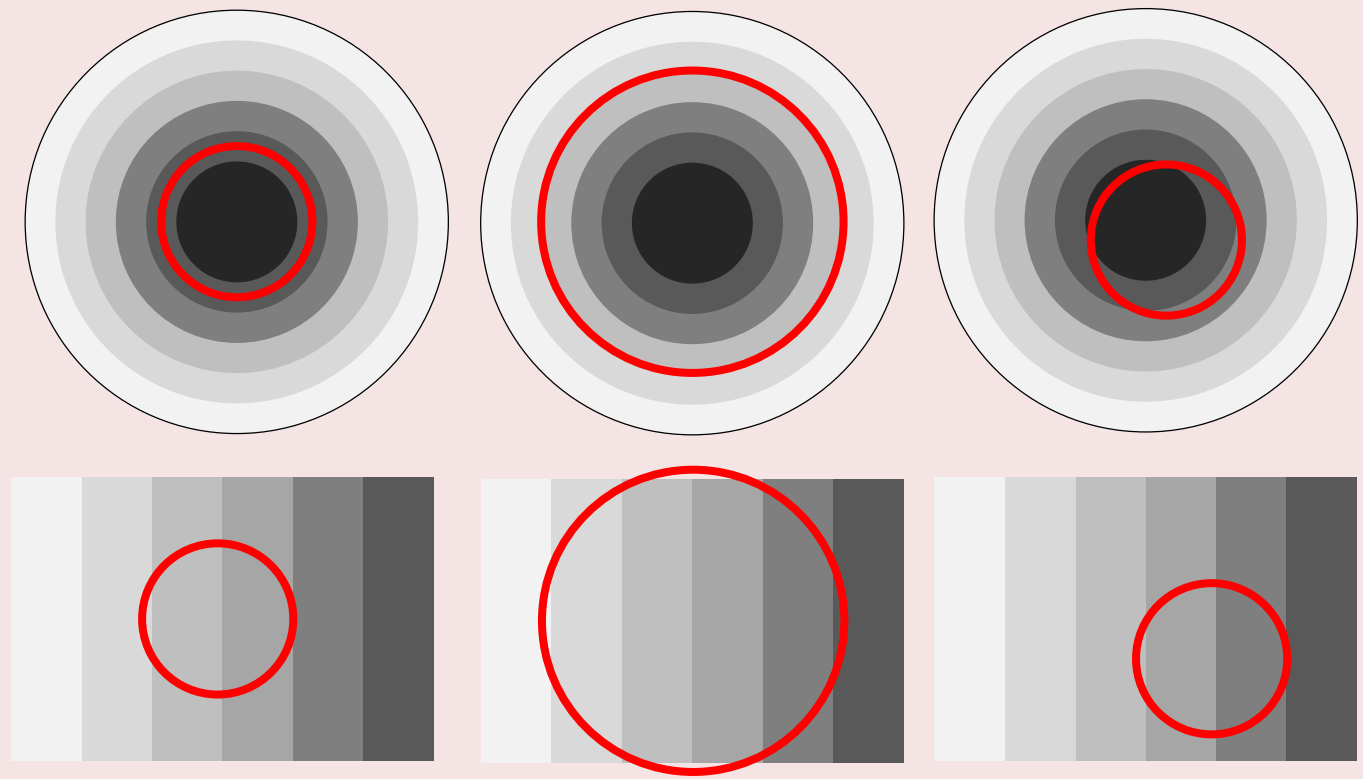
Motivation

- Main deviations from the “desired” target
 - Inhomogeneities
 - Contamination

Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

Motivation

Inhomogeneities

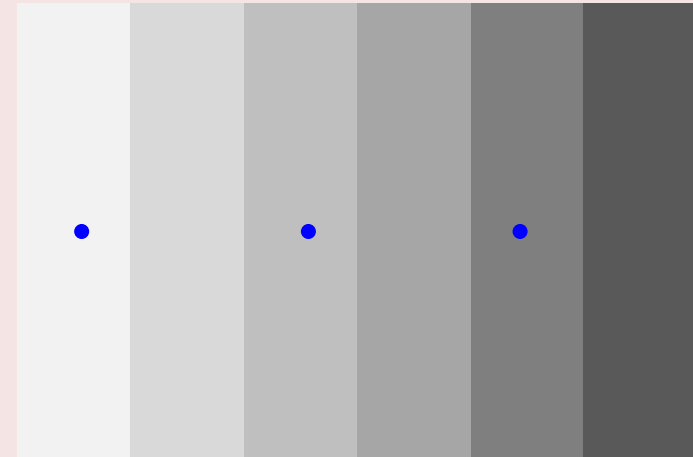
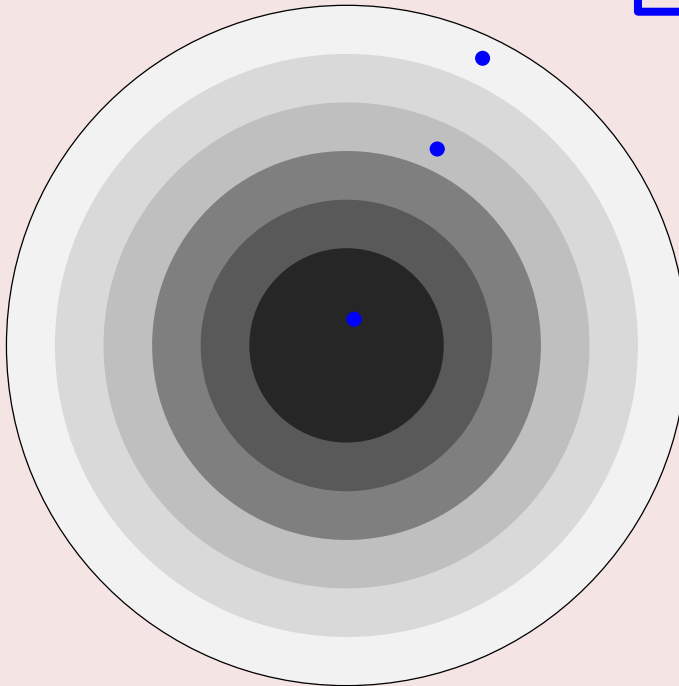


Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

Motivation

Inhomogeneities

Beam diameter (IBA): 0,5 mm – 3,0 mm



Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

Motivation

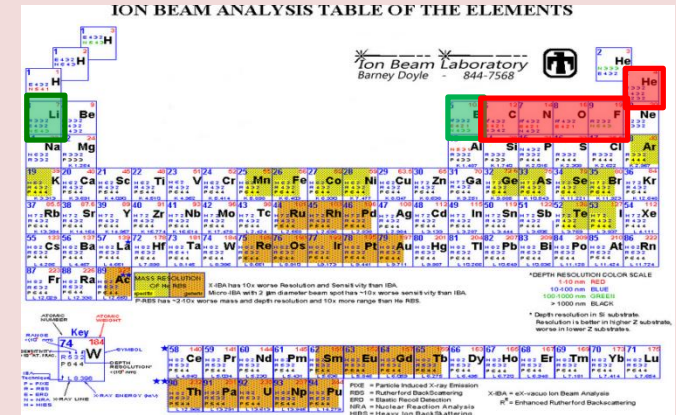
Contamination (light elements)

Low Coulomb barrier



Interfering reaction product
with light elements

- Spurious elements chamber for targets preparation
- Hydrocarbon deposition due to beam-target interaction during nuclear reactions experiment

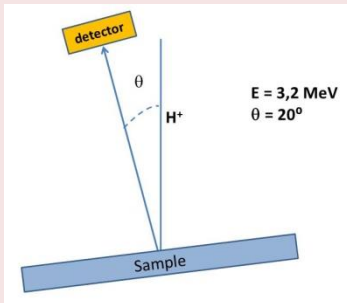
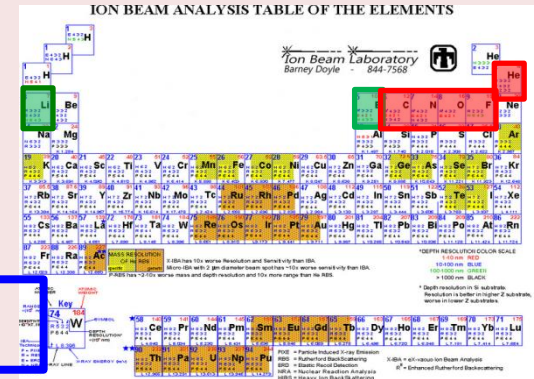


Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

Motivation

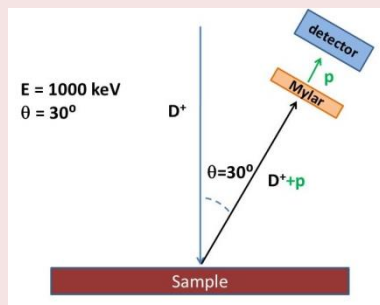
Contamination (light elements)

Proton Elastic Backscattering Spectroscopy (p-EBS)



Helium, Lithium, Carbon, Nitrogen, Oxygen, Fluorine

Nuclear Reaction Analysis (NRA)



Helium, Lithium, Carbon, Nitrogen, Oxygen, Fluorine

Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

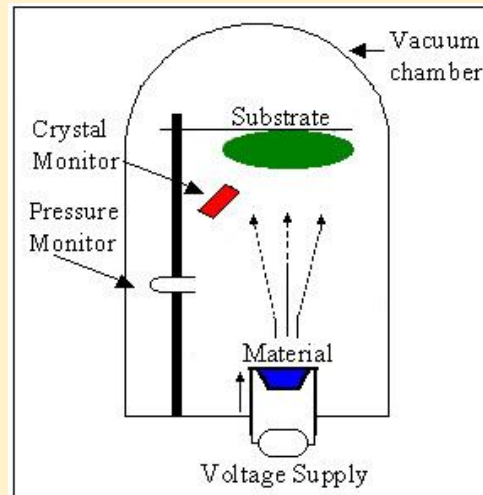
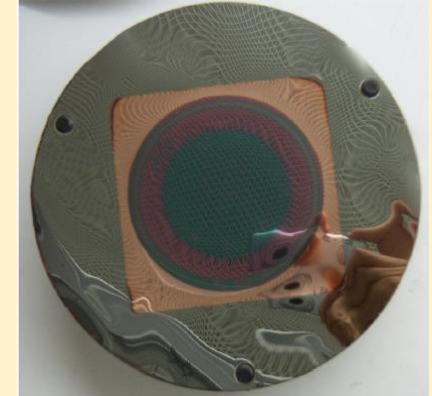
n_TOF: 33S

$^{33}\text{S}(n,\alpha)^{30}\text{Si}$ cross section ; 10 a 300 keV

S sublimes in vacuum at room temperature
S adheres poorly to most solid supports

CuS TARGETS $\varnothing = 9 \text{ cm}$

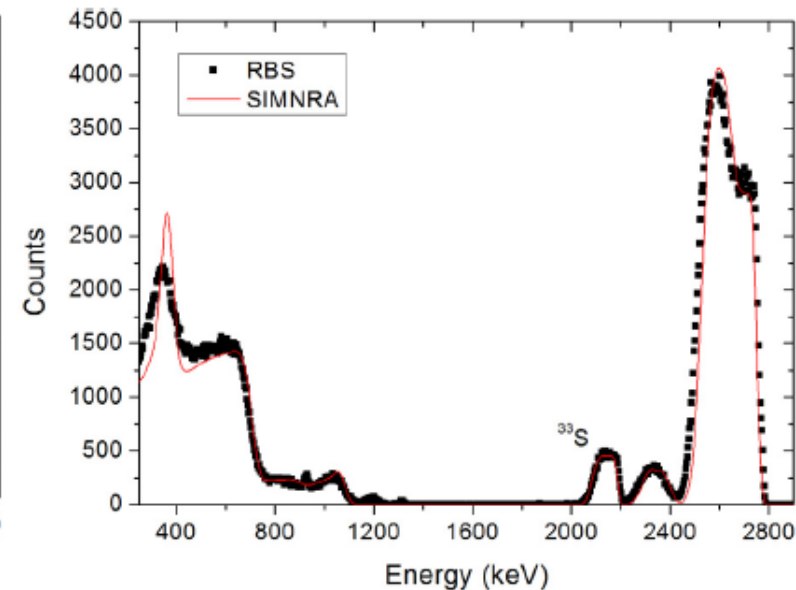
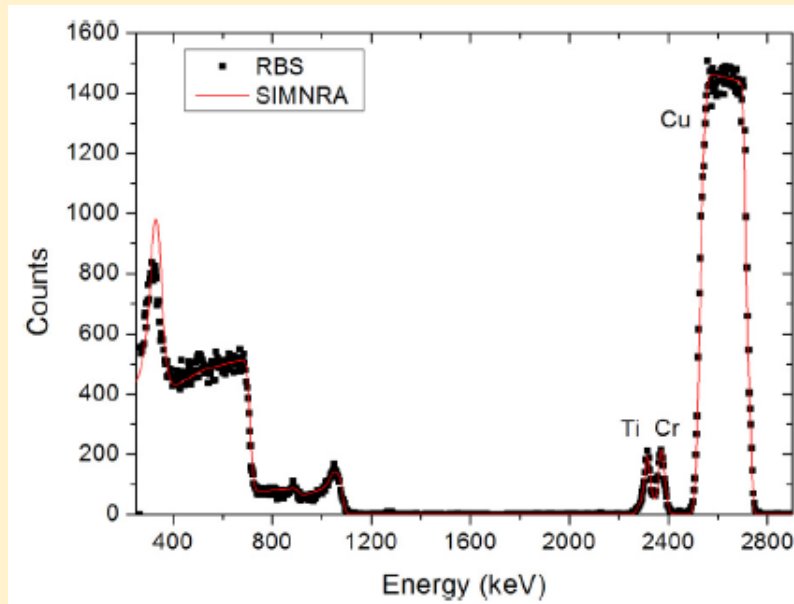
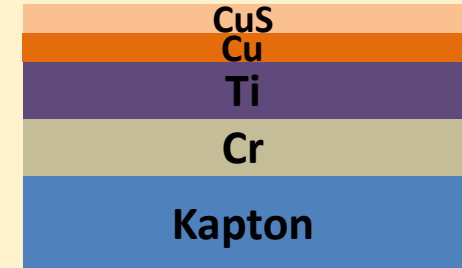
Evaporate a few 5 or 10 mg of ^{33}S at $120 \text{ }^\circ\text{C}$
Substrate maintained at $60 \text{ }^\circ\text{C}$
Store all films produced under vacuum or N_2 .



Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

n_TOF: 33S

RBS
alphas; 3,5 MeV; $\theta = 165^\circ$



Statistical uncertainty in the number of ³³S atoms 3-5%

Maximum difference of 4-5%.

We consider **homogeneous** samples with 5% uncertainty

J. Praena, F.J. Ferrer et al., Nucl Inst. and Meths A, 890 (2018) 142-147

Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

n_TOF: 33S

	33S (10^{15} at/cm ²)	33S ($\mu\text{g}/\text{cm}^2$)	33S BOAT (mg)
Sample 1	379 ± 31	20.8 ± 1.7	10
Sample 2	349 ± 28	19.1 ± 1.5	10
Sample 5	376 ± 31	20.6 ± 1.7	10
Sample 6	365 ± 29	20.0 ± 1.6	10
Sample 3	259 ± 23	14.2 ± 1.3	5
Sample 4	215 ± 20	11.8 ± 1.1	5

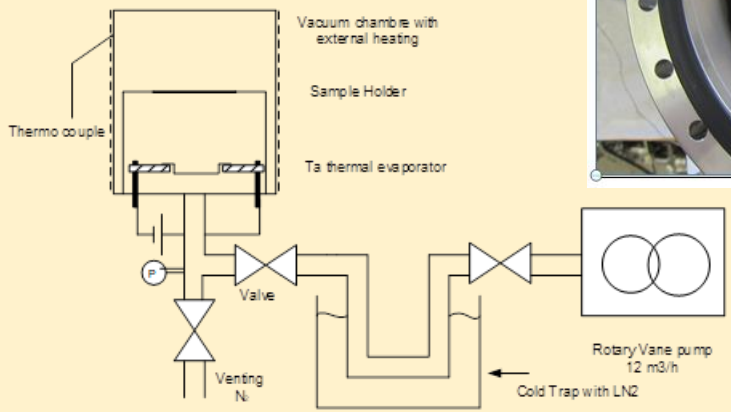
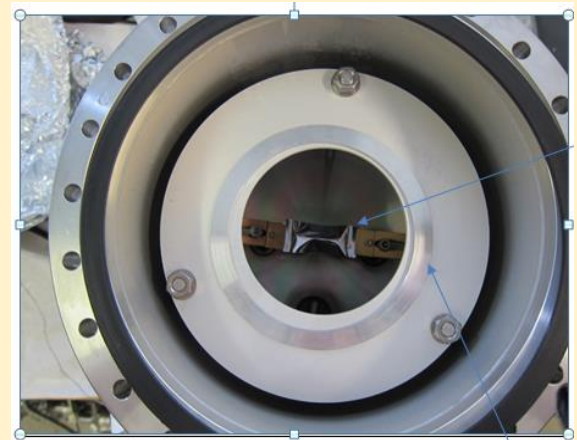
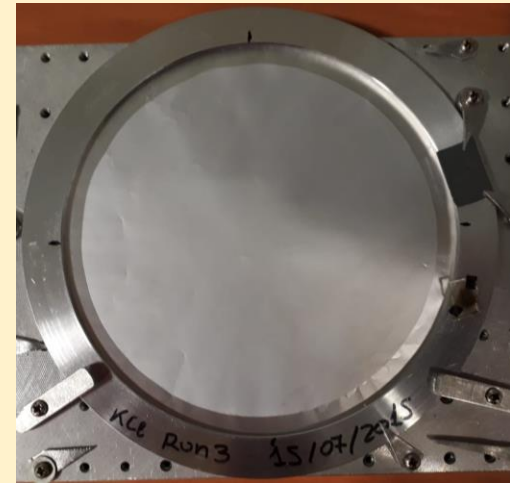
Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

n_TOF: 35Cl

$^{35}\text{Cl}(n,p)^{35}\text{S}$ cross section; 50 a 1000 keV

KCl TARGETS $\varnothing = 9 \text{ cm}$

Evaporate a few $\approx 120 \text{ mg}$ KCl; 80 A vessel
100 °C chamber
Targets were weighted before and after evaporation



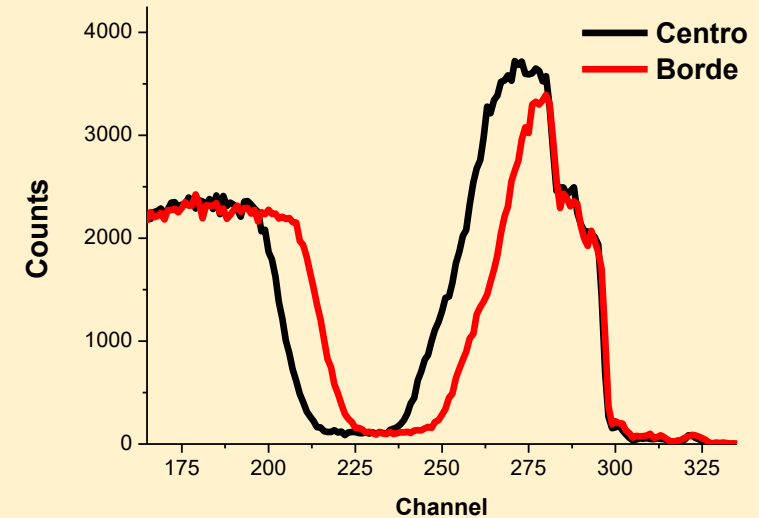
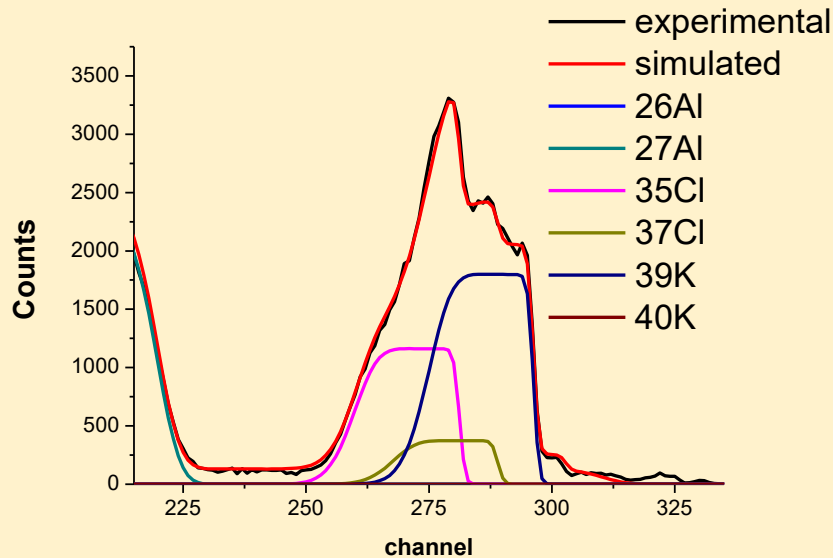
Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

n_TOF: 35Cl

RBS
alphas; 4,1 MeV; $\theta = 165^\circ$

KCl

Aluminum



Uncertainty in the number of atoms of ^{35}Cl 3-5%

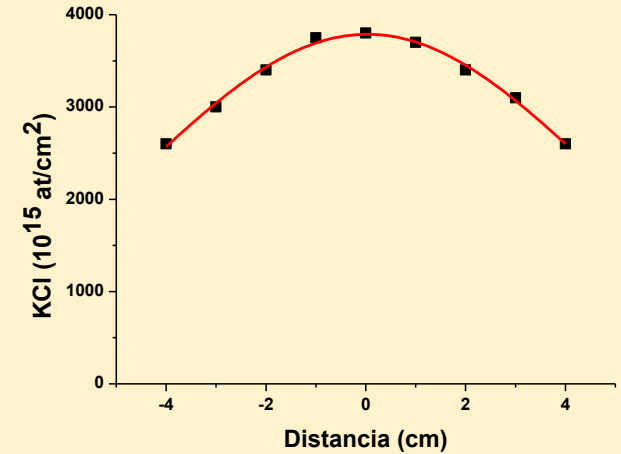
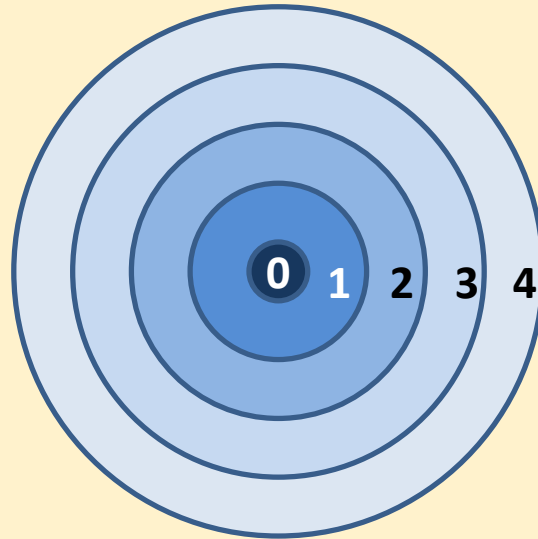
Maximum difference of 4-5%.

We conclude **inhomogeneous** samples

Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

n_TOF: 35Cl

KCl	
Point	Thickness (10^{15} at/cm 2)
(0,0)	3800
(0,-1)	3750
(-1,0)	3700
(1,0)	3700
(0,-2)	3500
(2,0)	3400
(-2,0)	3400
(0,-3)	3150
(-3,0)	3000
(3,0)	3100
(0,-4)	2700
(-4,0)	2600
(4,0)	2600



KCl			KCl	KCl	
			e15 at/cm2	e15 at	
Punto		área (cm2)			
0	Anillo 0	0.79	3800	2985	
1	Anillo 1	6.28	3717	23355	
2	Anillo 2	12.57	3433	43140	
3	Anillo 3	18.85	3083	58113	
4	Anillo 4	25.13	2633	66175	
	TOTAL	63.62		193767	
				3046	e15 at/cm2
				188.4	μ g/cm2

Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

n_TOF: 10B

26Al(n,p) y 26Al(n, α) cross section
referred to 10B(n, α) cross section

10B TARGETS $\varnothing = 4,5 \times 5,0 \text{ cm}^2$

Enriched 10B (99%) target



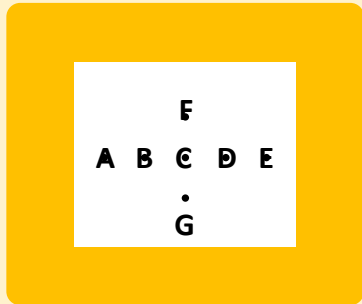
10B

Mylar

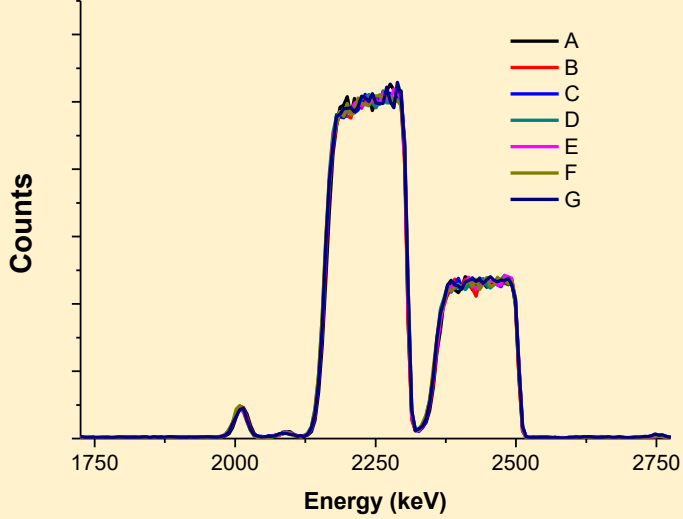
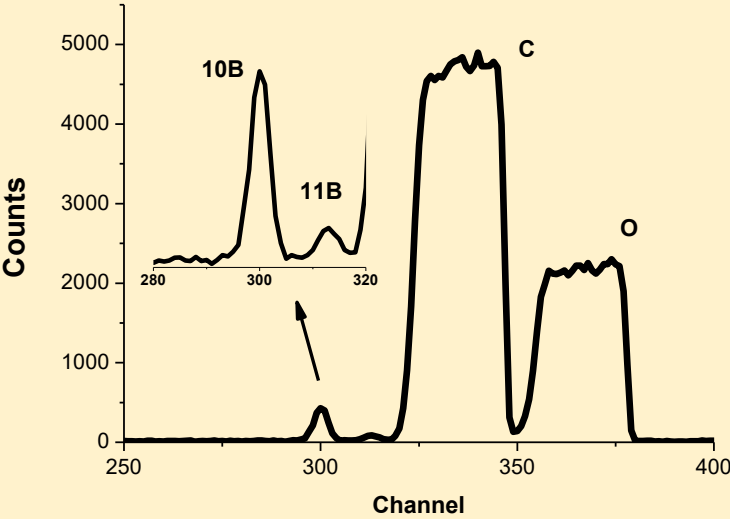
Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

n_TOF: 10B

p-EBS
 protons; 3,2 MeV; $\theta = 165^\circ$



B1	Mylar	^{10}B	^{11}B
	4.5 μm	8.97 μg	1.10 μg



Statistical uncertainty in the number of atoms of ^{10}B 3%

Maximum difference of 2%.

We conclude **homogeneous** samples

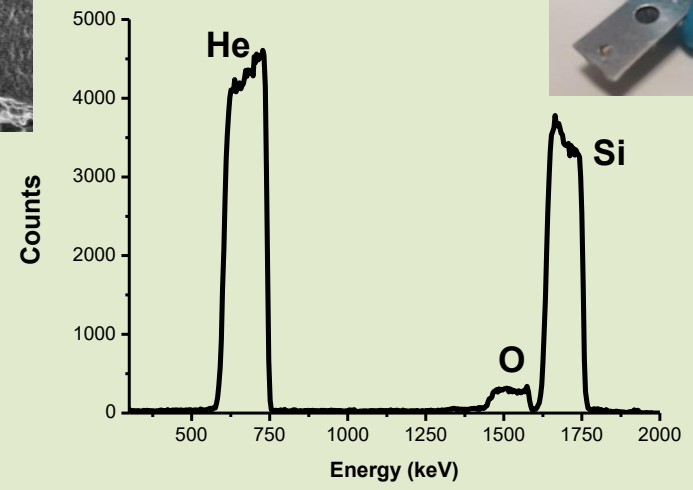
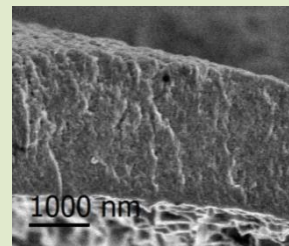
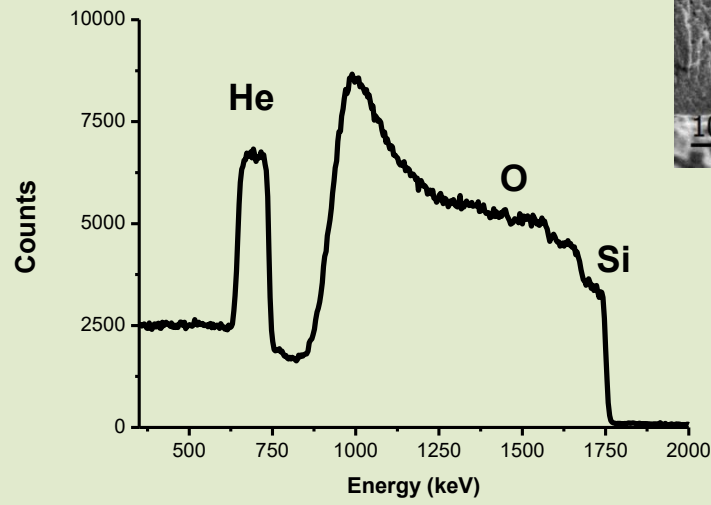
Substrate thickness

Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

CNA-ICMS: Si:He



p-EBS protons; 3,2 MeV; $\theta = 165^\circ$



	ISCM-CNA (MS)	Vanderbist et al. (Ionic implant.)	Raabe et al. (Ionic implant.)	Ujic et al. (Ionic implant.)
Metal ($\times 10^{15}$ at/cm ²)	9250 (Si)	1100 (Al)	4200 (Al)	1200 (Al)
He ($\times 10^{15}$ at/cm ²)	4060	275	270	130
O ($\times 10^{15}$ at/cm ²)	700	60	100	Not mentioned
He/M	0.44	0.25	0.06	0.11
O/He	0.17	0.22	0.37	Not mentioned

Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

CNA-ICMS: Si:He

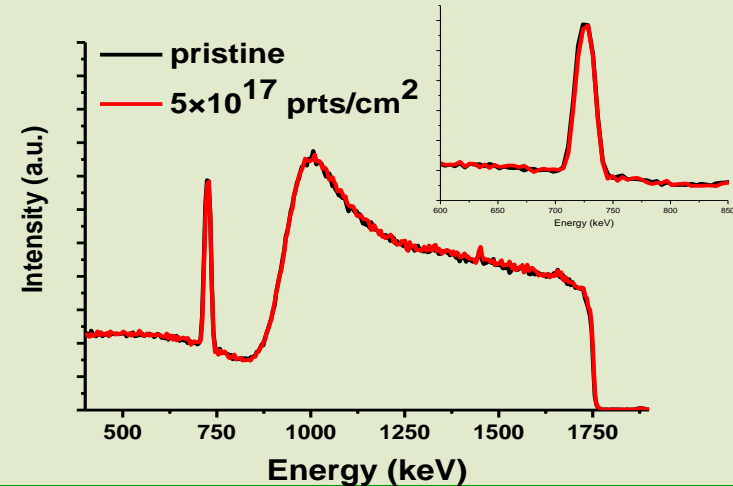
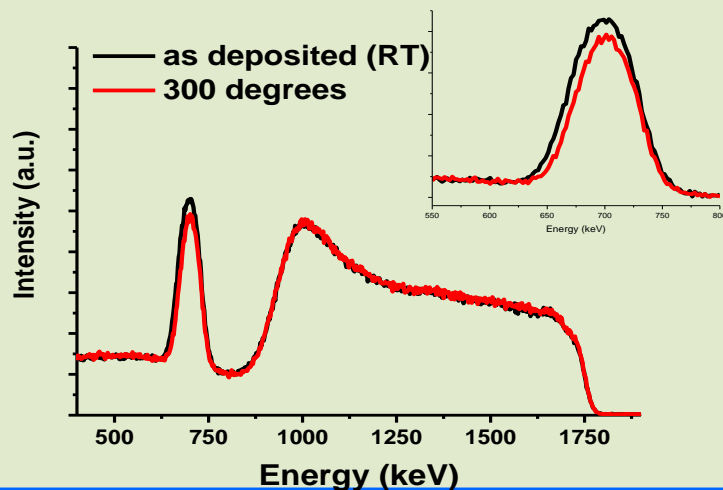
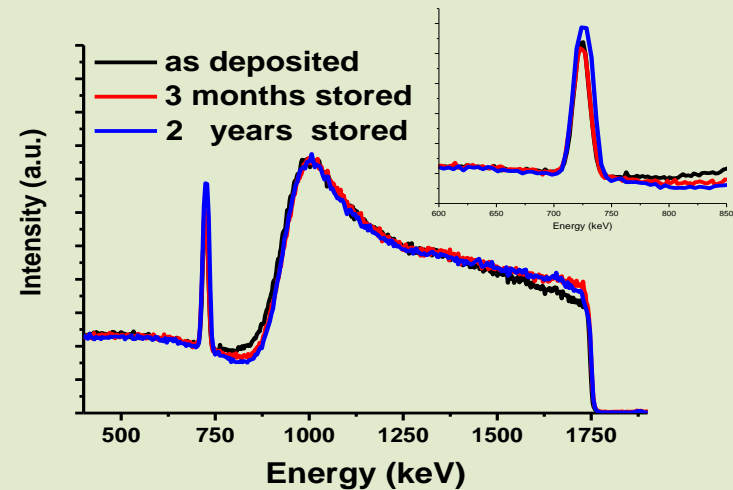


Stability of the targets

➤ Temperature

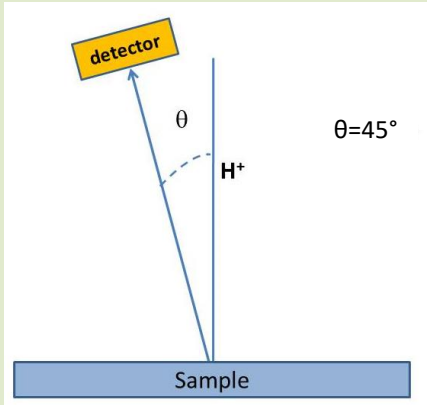
➤ Radiation

➤ Aging

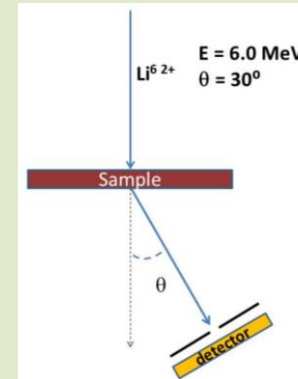


Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

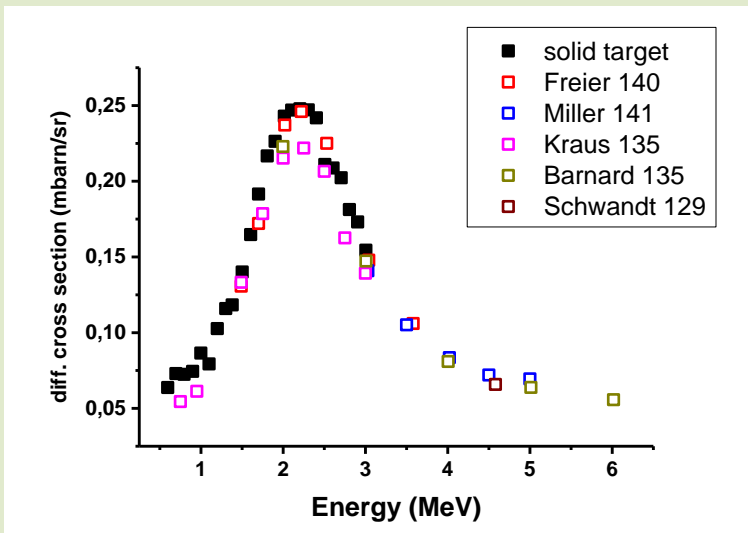
CNA-ICMS: Si:He



□ ${}^4\text{He}(p, p){}^4\text{He}$
elastic scattering

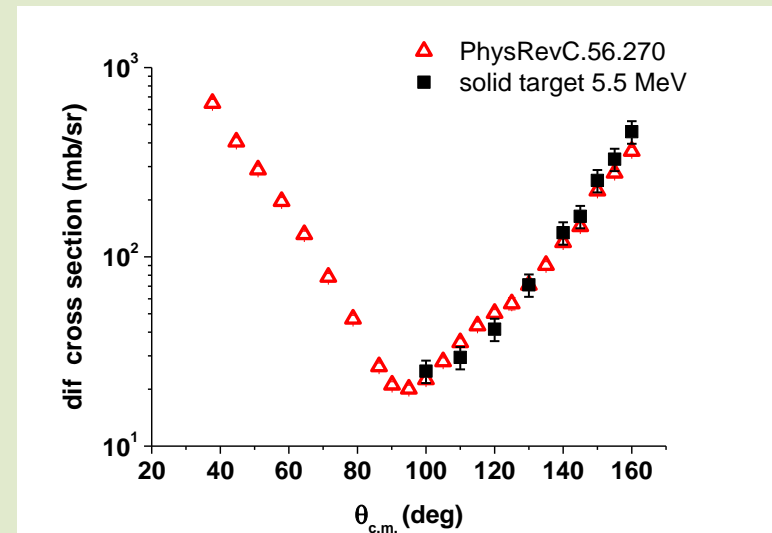


□ ${}^4\text{He}({}^6\text{Li}, {}^6\text{Li}){}^4\text{He}$
elastic scattering



Experimental elastic scattering differential cross-section at scattering angles of 135°

V Godinho, F. J. Ferrer, et al ACS Omega, 1 (2016) 1229



Experimental elastic scattering differential cross-section at 5,5 MeV

F. J. Ferrer, et al. Eur. Phys. J. Plus135 (2020) 465

Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

CNA-ICMS: Si:He



Ciências ULisboa



FÍSICA MATEMÁTICAS COMPUTACION

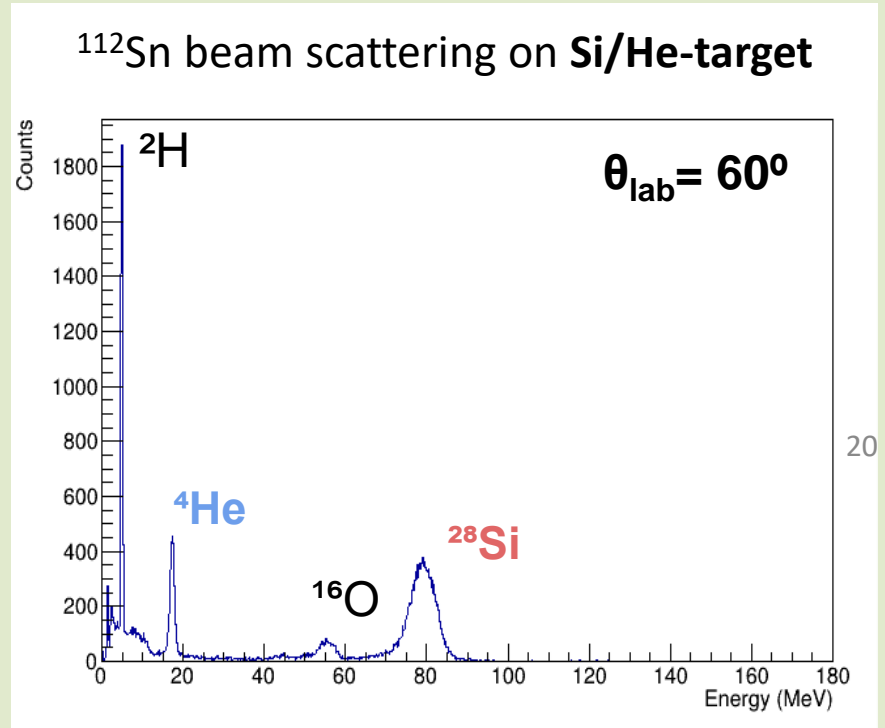
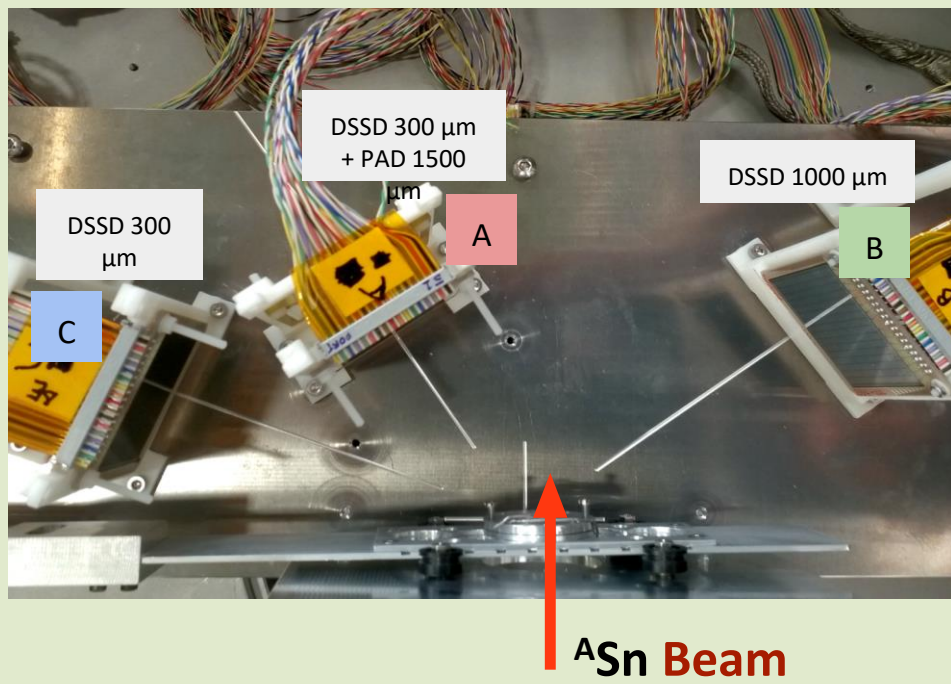
uhu.es

First ever α -scattering with radioactive ion beams

$^4\text{He}(^A\text{Sn}, ^4\text{He})^A\text{Sn}$ @ 4.9 MeV/u

Stability of the targets

➤ **Radiation**



Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

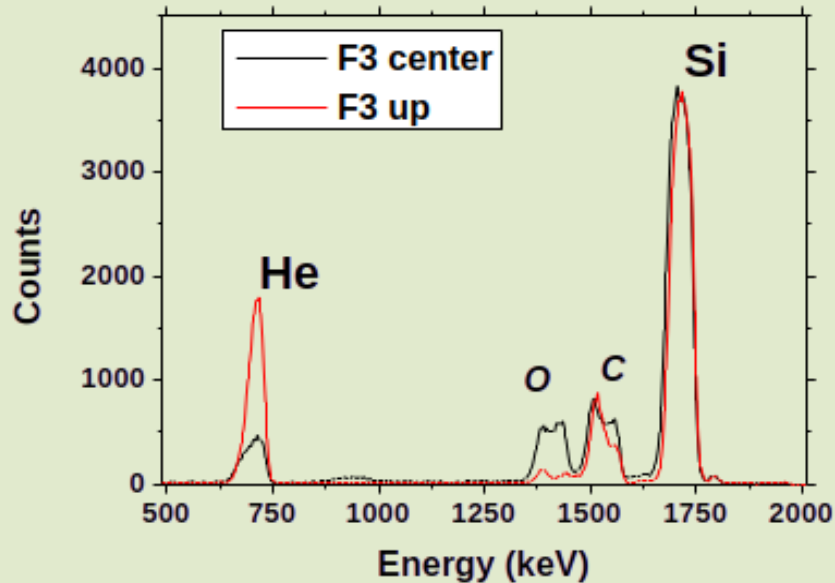
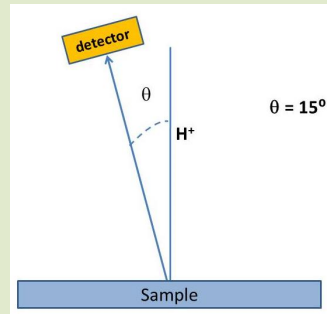
CNA-ICMS: Si:He



First ever α -scattering with radioactive ion beams

$^4\text{He}(^A\text{Sn}, ^4\text{He})^A\text{Sn}$ @ 4.9 MeV/u

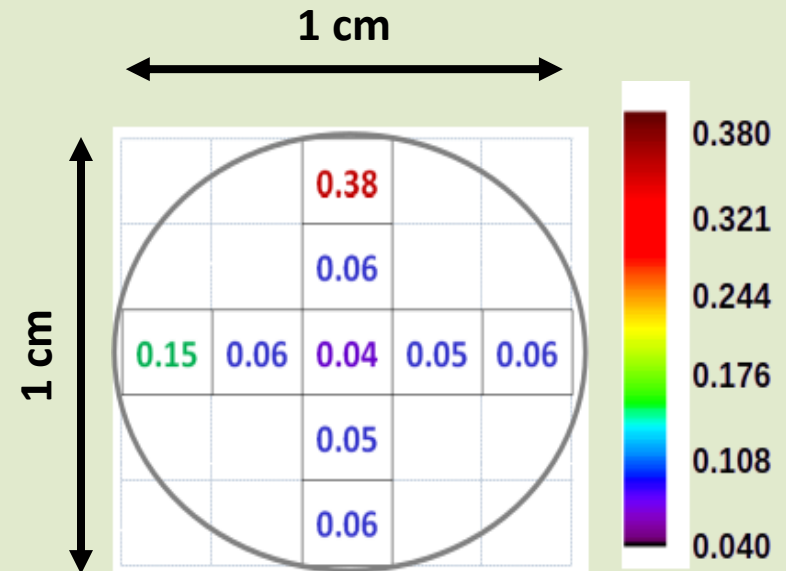
Amount of ^4He over time



p-EBS spectrum of the F3 Si:He in different target points after IS698

Stability of the targets

Radiation



He/Si ratio obtained from p-EBS analysis of the F3 Si:He after IS698

Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

CNA-ICMS: Si:He

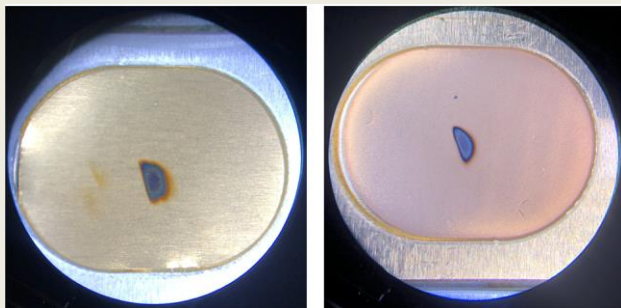


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DI PADOVA

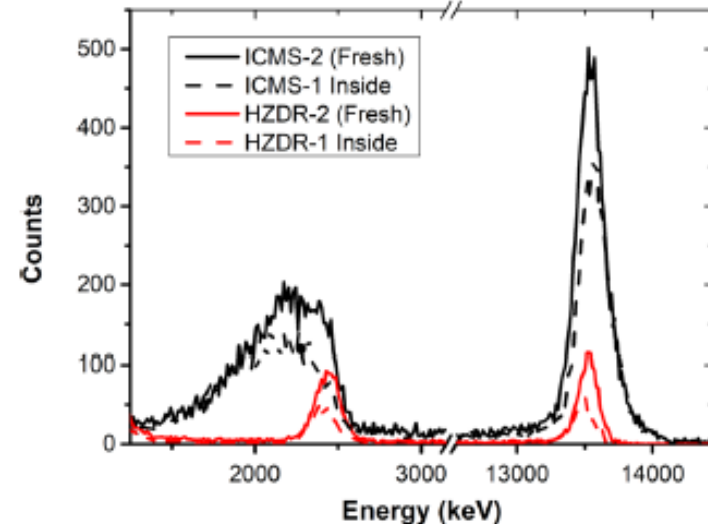
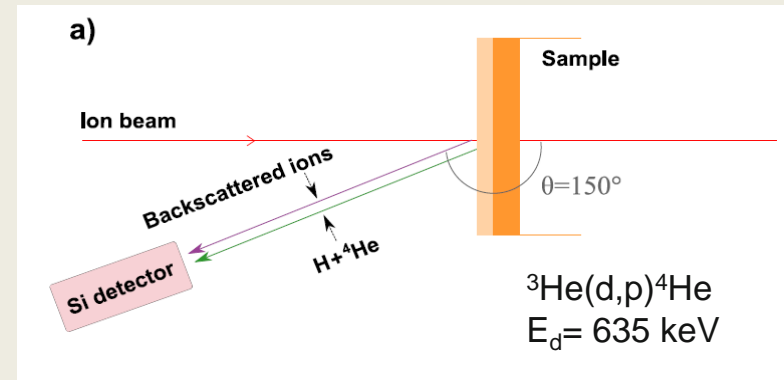
Legnaro National Laboratories, INFN, , Italy,

New lifetime measurement of the ^{15}O state exploiting the $^{16}\text{O}(^3\text{He},^4\text{He})^{15}\text{O}$ reaction in inverse kinematics.

Beam: ^{16}O at 50 MeV
Targets: Au- ^3He
(MS, implanted)



Pictures of the implanted target HZDR-1 (left) and the sputtered target ICMS-1 (right) after irradiation with a 50MeV ^{16}O -beam at AGATA (LNL). The scale was added for comparison



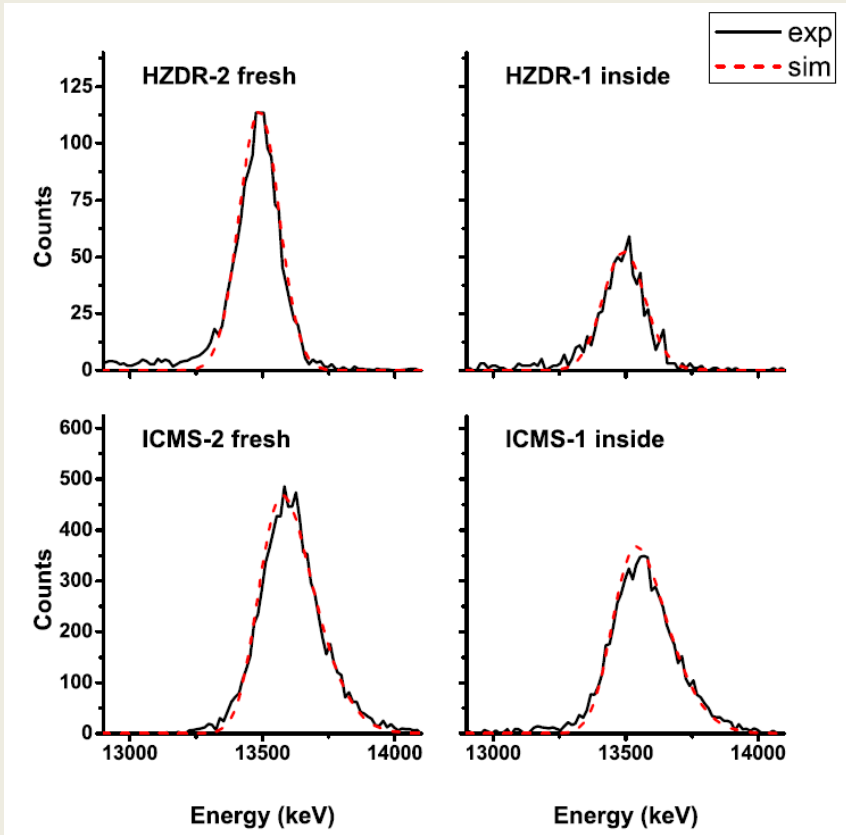
NRA spectra of the targets ICMS-1 and HZDR-1, inside the area impinged by the ^{16}O beam, and ICMS-2 and HZDR-2.

Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

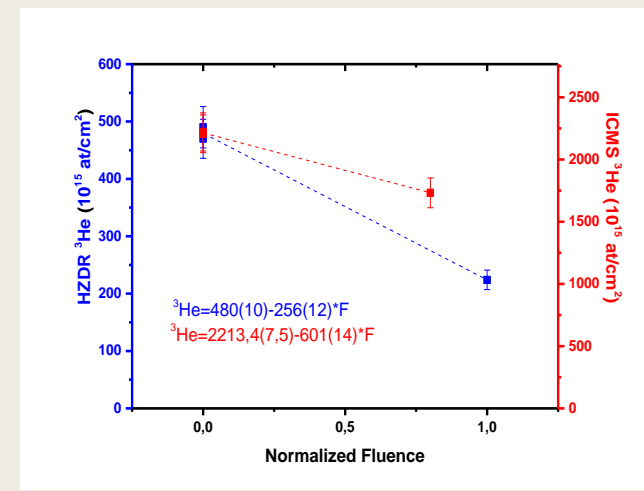
CNA-ICMS: Si:He



Legnaro National Laboratories, INFN, , Italy,



Target	^3He areal density NRA [10^{15} at/cm 2]
HZDR-2 (Fresh)	478 ± 35
HZDR-1 - Outside	470 ± 34
HZDR-1 - Inside	224 ± 17
ICMS-2 (Fresh)	2221 ± 153
ICMS-1 - Outside	2206 ± 152
ICMS-1 - Inside	1732 ± 120



Comparison between experimental and simulated spectra of the targets ICMS-1 and HZDR-1, inside the area impinged by the 16O beam, and ICMS-2 and HZDR-2

Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

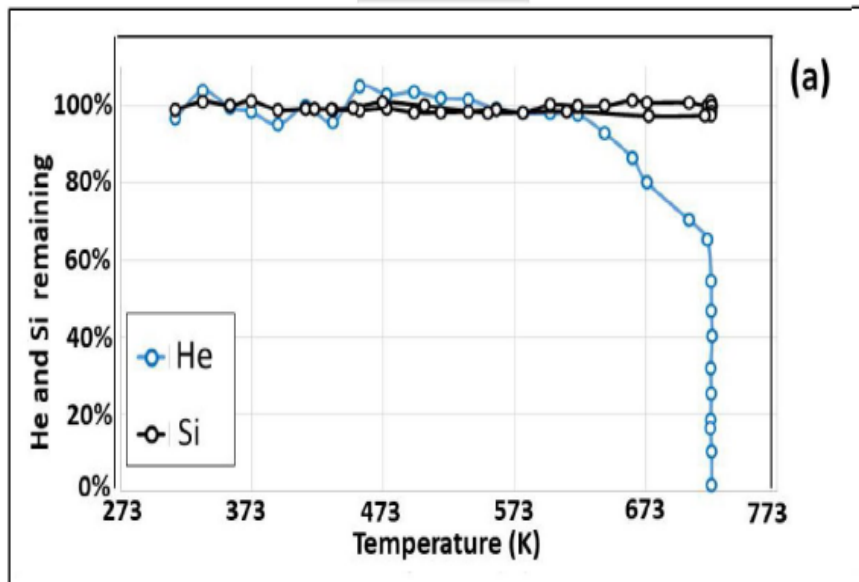
CNA-ICMS: Si:He



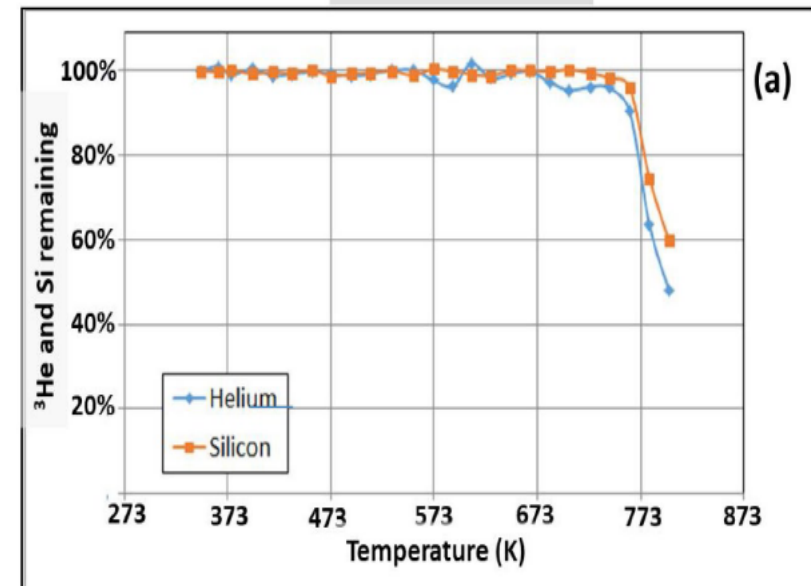
Stability of the targets

➤ Temperature

3. Si:He-RF



4. Si:³He-RF(static)



Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

CNA Si:He



Leybold

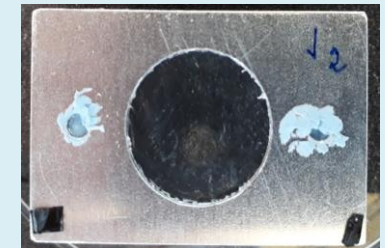
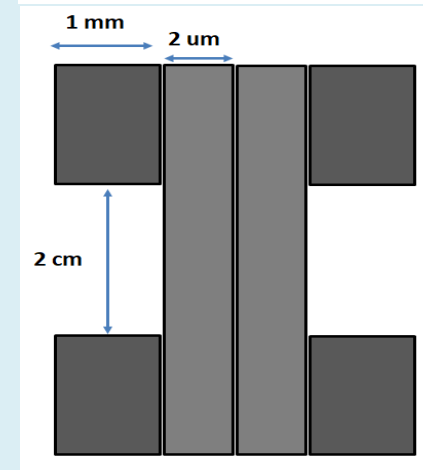
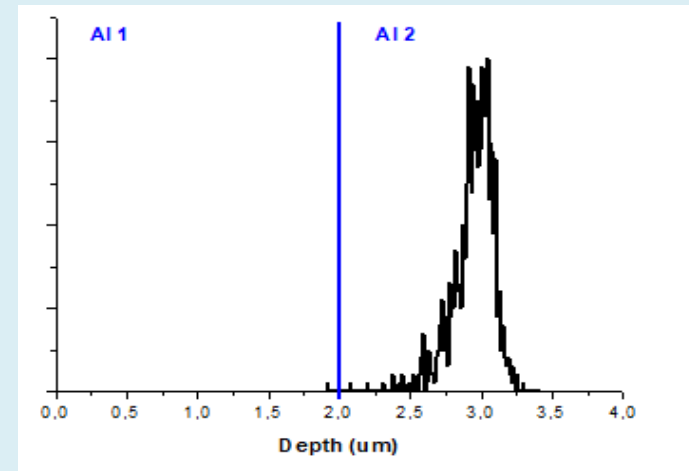
**UNIVEX 250
for RF sputtering**

Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

CNA: Al:6Li

- Calibration of channels vs. energy of Si or gaseous detectors for reactions (n,x)
- Using $\text{Li6}(n,t)$ as standard in other measurements
 - Tritium (2.73 MeV) and Alpha (2.05 MeV) particles.
- Advantages
 - Standard up to 1 MeV
 - Very high cross section, so high counting rate
 - It has no resonances and is very comfortable to use.
 - **Problemas:**
- Conocer la masa de Li6 con una precisión alta (menor del 3%, algo del 5% sería un éxito)

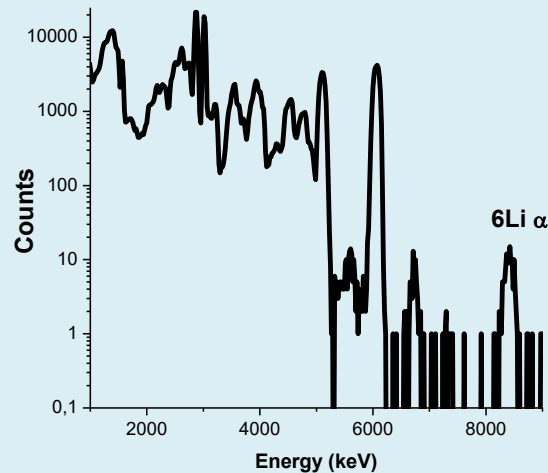
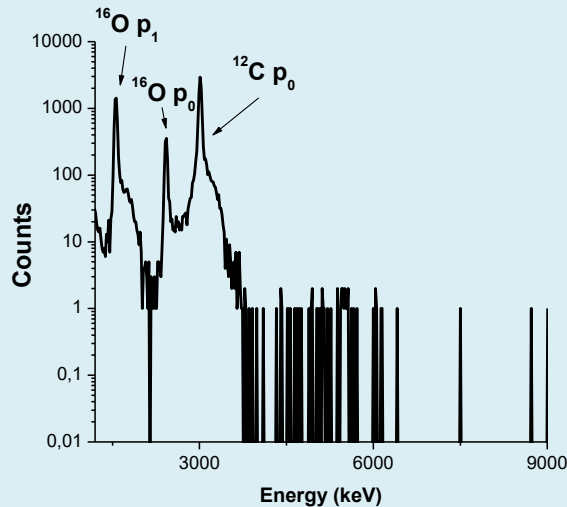
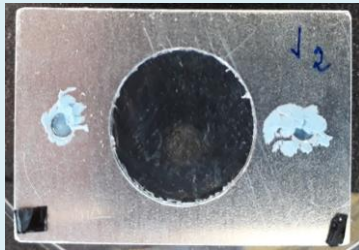
Ionic implantation of 6Li at 900keV



Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

CNA: Al:6Li

$6\text{Li}(d,\alpha)4\text{He}$ with deuterium ions with energy of 1275 keV



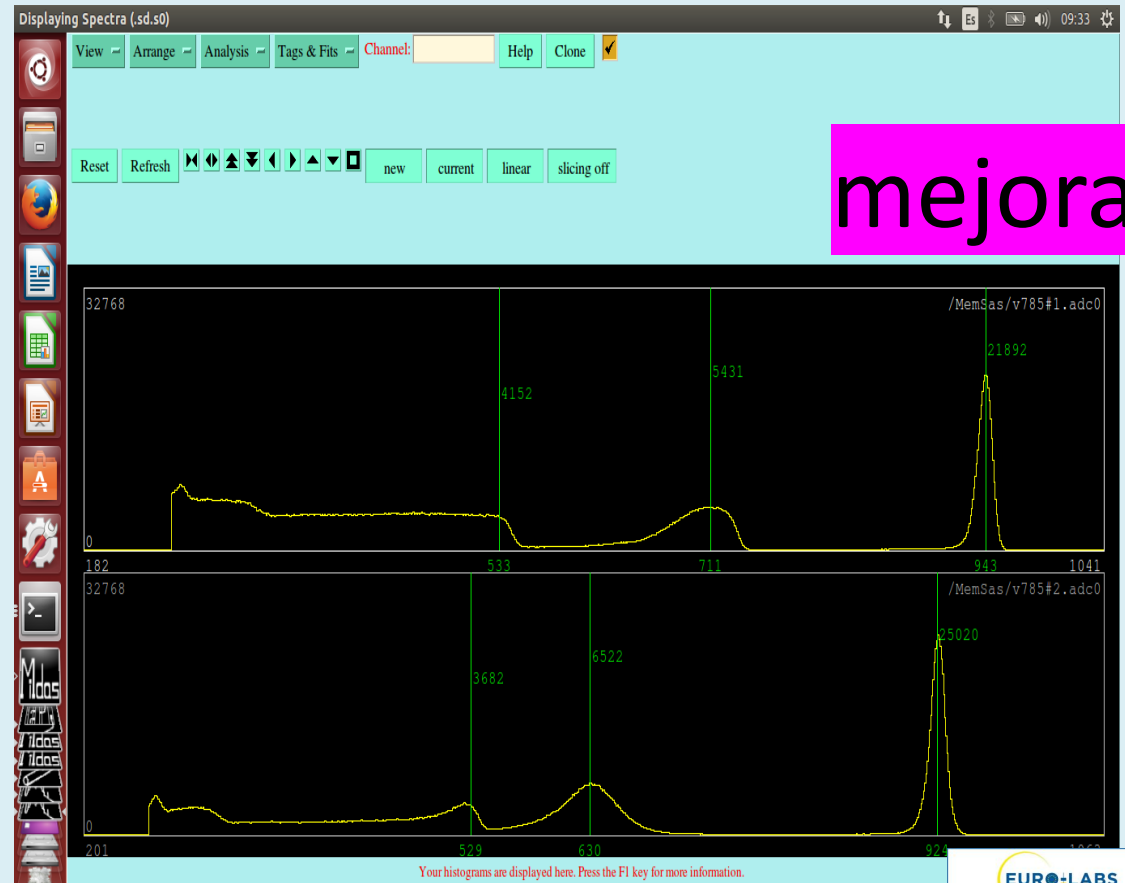
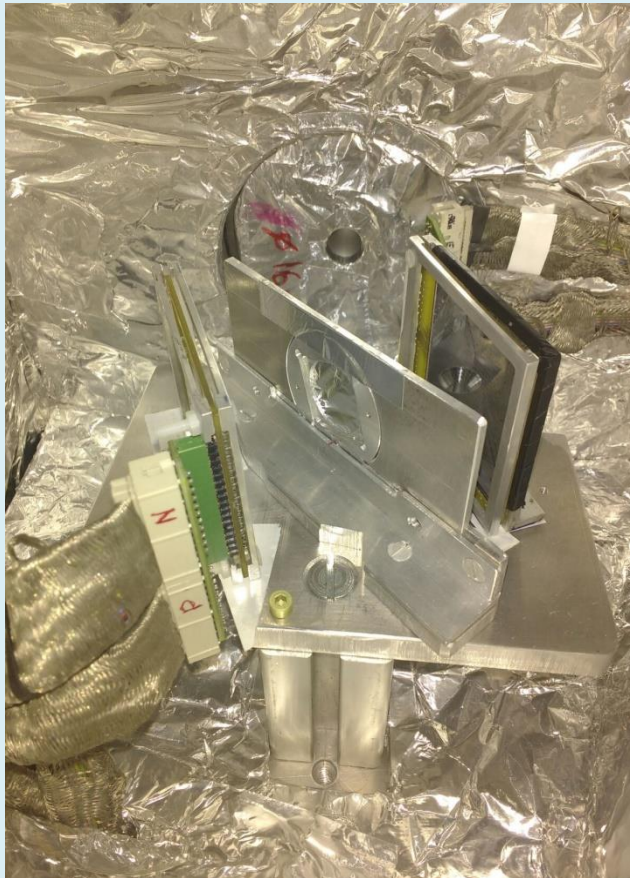
	[Li] (10^{15} at/cm 2)
Center	0,96
UL	0,89
UR	1,02
DL	1,07
DR	1,12

Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

CNA: Al:6Li

Preliminary results ILL

tritium particles at 2.73 MeV
alpha particles at 2.05 MeV.



Conclusiones:

- **IBA techniques elemental characterization capacity**
 - ❑ **Light and heavy elements**
 - ❑ **different isotopes**
- **CNA capabilities**
 - ❑ **Collaboration development of targets for nuclear reaction experiments**
 - **Characterization**
 - **Experiments at low energy**
 - ❑ **Preparation of targets by ion implantation.**
 - ❑ **Preparation of targets by magnetron sputtering.**

Synthesis and characterization by IBA (ion beam analysis) techniques of targets used in nuclear physics reaction experiments

Gracias a todos los investigadores involucrados:

CNA

- F.J. Ferrer
- B. Fernández-Martínez
- J.P. Fernández-García
- A. Vegas
- J. Gómez-Camacho

NanoMatMicro group (ICMS)

- V. Godinho
- A. Fernández-Camacho
- D. Hufschmidt

nTOF

- J. Praena
- P. Torres
- I. Porras
- M. Sabate-Gilarte
- J.M. Quesada
- B. Fernandez
- C. Lederer-Woods
- S. Lonsdale

Others

- D. Galaviz
- A.Sánchez-Benítez
- Francisco G. Barba
- O. Tengblad
- J. Valiente
- E. Pilotto

**Thankyou for your
attention**