RBS applications: from materials science to nuclear reactions targets

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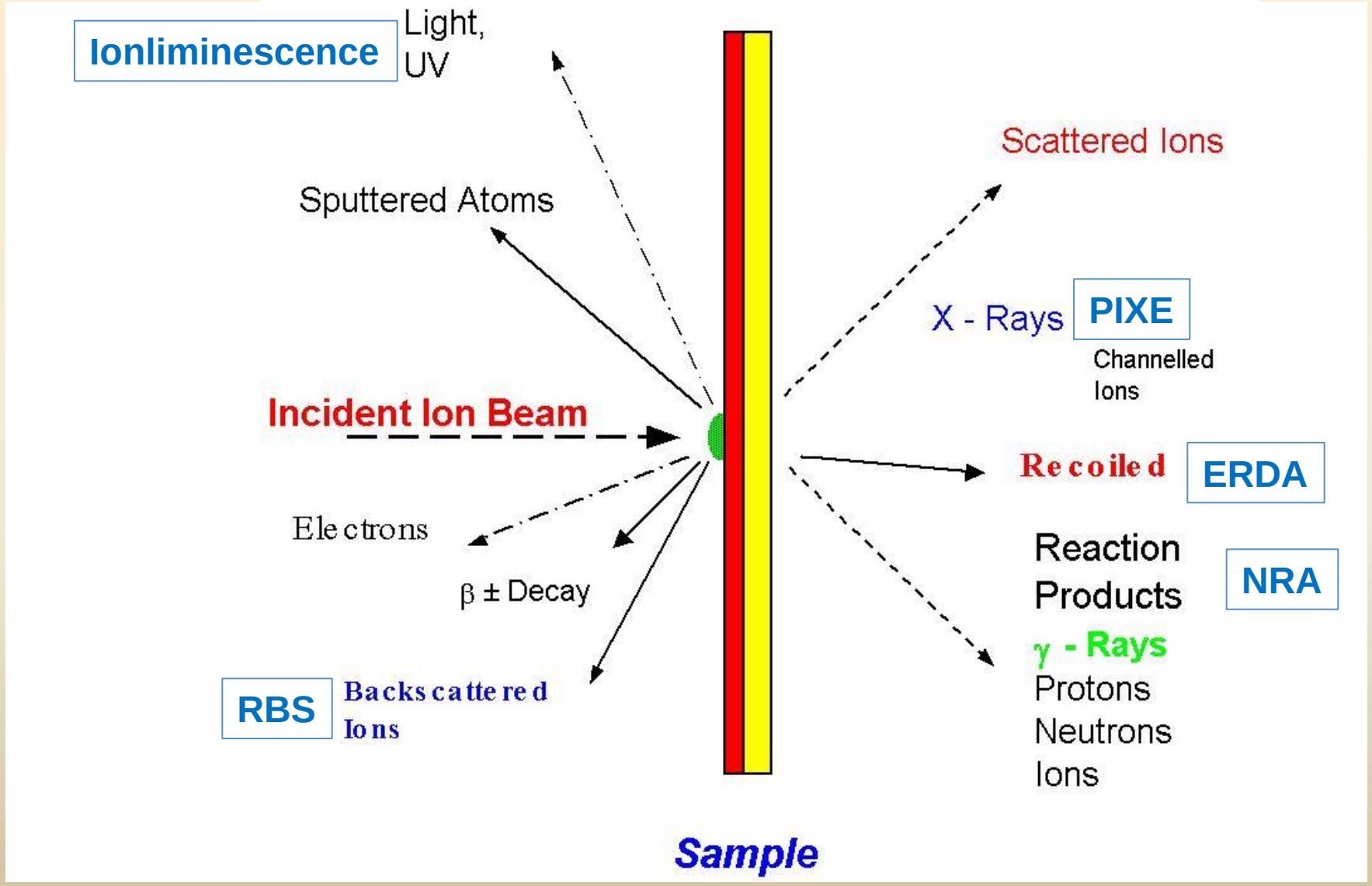
Ion Beam Analysis

Interaction of ion beams with a solid



Rutherford Backscattering Spectrometry (RBS)

Main characteristics

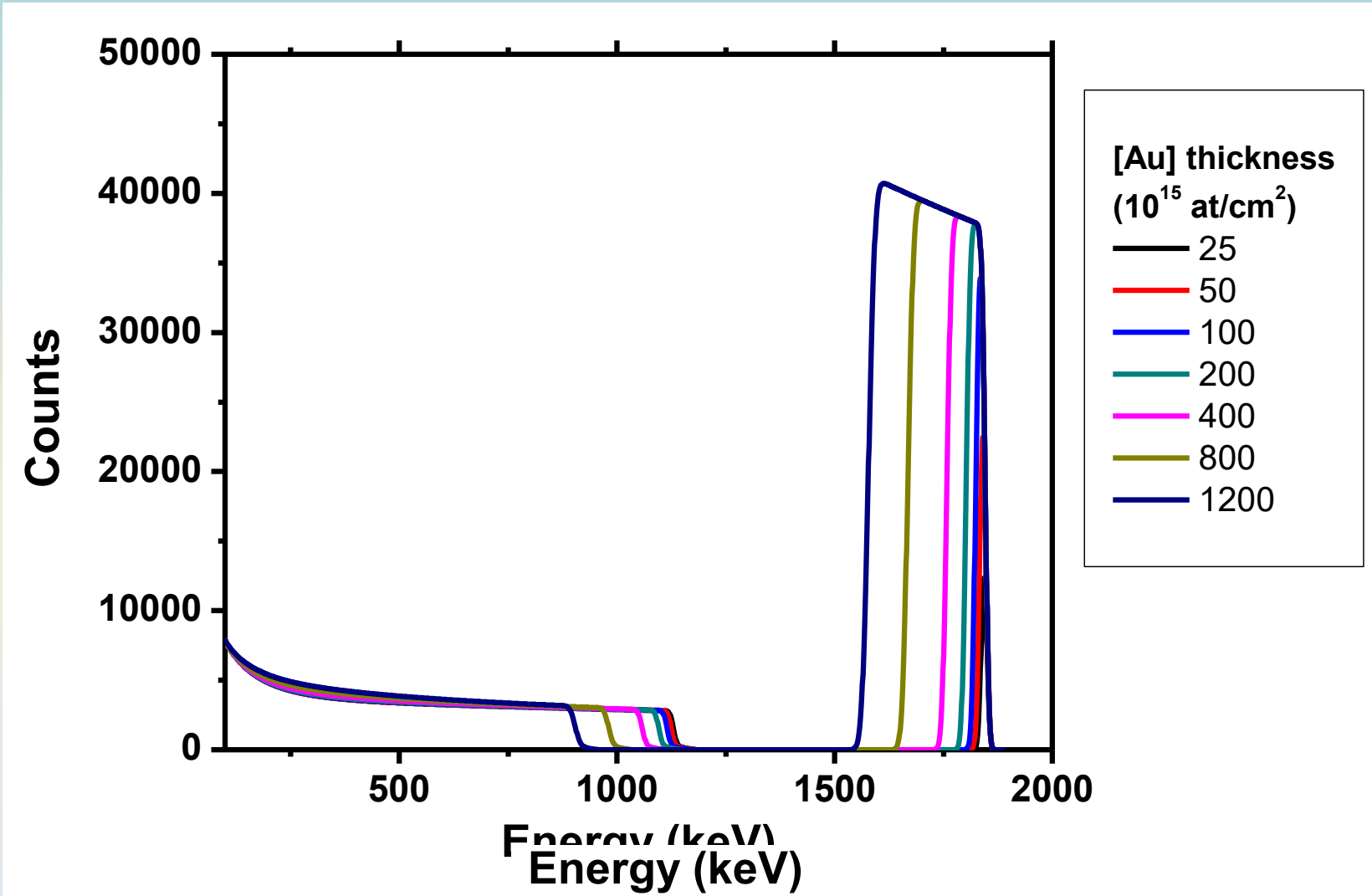
- **Isotopic information:** just for light ions
- **Depth of analysis:** from surface till few microns
- **Limit of detection**: about 10^{12} at/cm^2 (for heavy elements)
- **Depth resolution**: 10-20 nm (normal incidence)

  1-3 nm (glancing geometry)
- **Relative accuracy**: better than 1%
- **Absolute accuracy**: about 2%
- **No chemical information is given**

Rutherford Backscattering Spectrometry (RBS)

Thickness

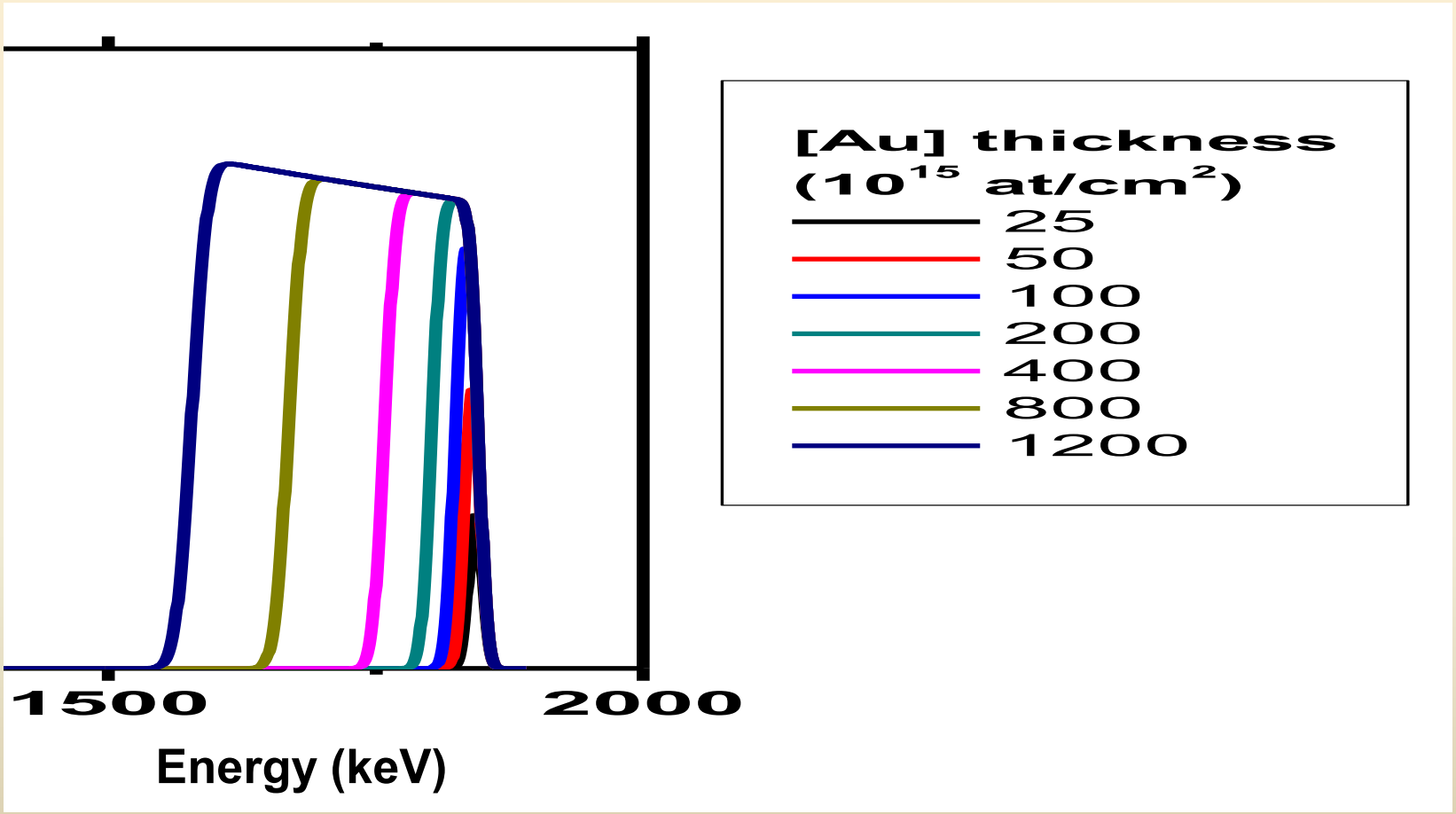
2000 keV ^{4}He, q = 165° backscattered from Au on Si substrate



Rutherford Backscattering Spectrometry (RBS)

Thickness

2000 keV ^{4}He, q = 165° backscattered from Au on Si substrate

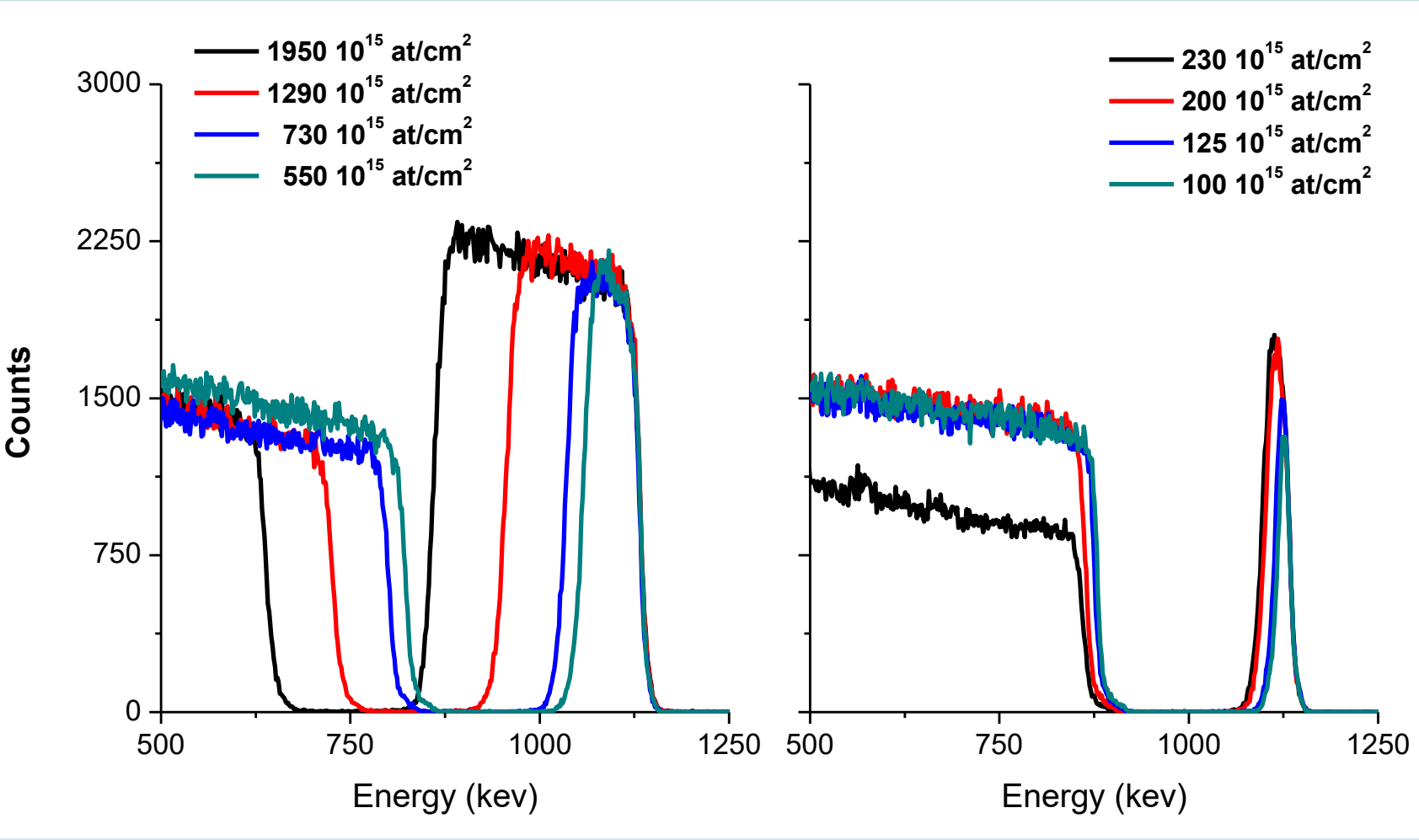


Rutherford Backscattering Spectrometry (RBS)

Thickness

"On the Deposition Rate of Magnetron Sputtered Thin Films at Oblique Angles", R. Alvarez, J.M. Garcia-Martin, M.C. Lopez-Santos, V.Rico, F.J. Ferrer, J. Cotrino, A.R. Gonzalez-Elipe, A. Palmero, Plasma Processes and Polymers 11 (2014) 571-576

1500 keV ^{4}He, q = 165° backscattered from Ti on Si substrate

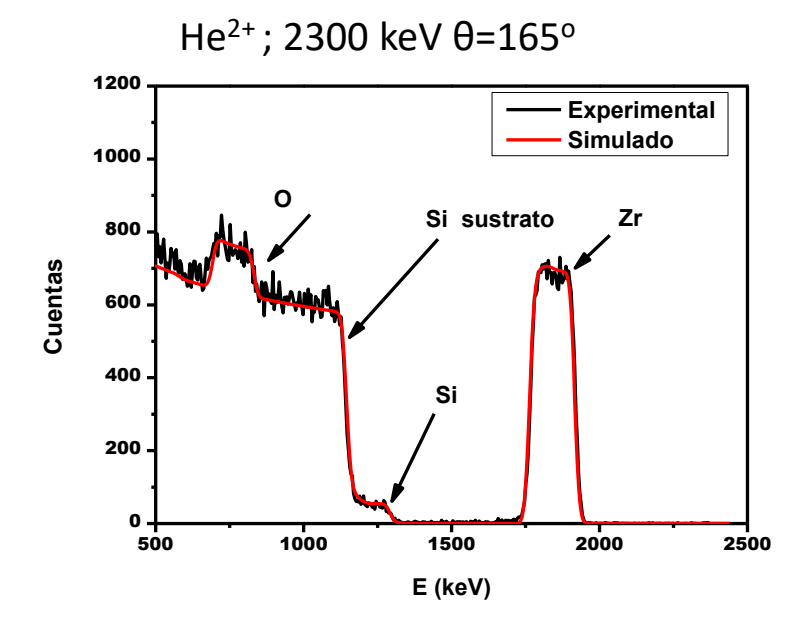


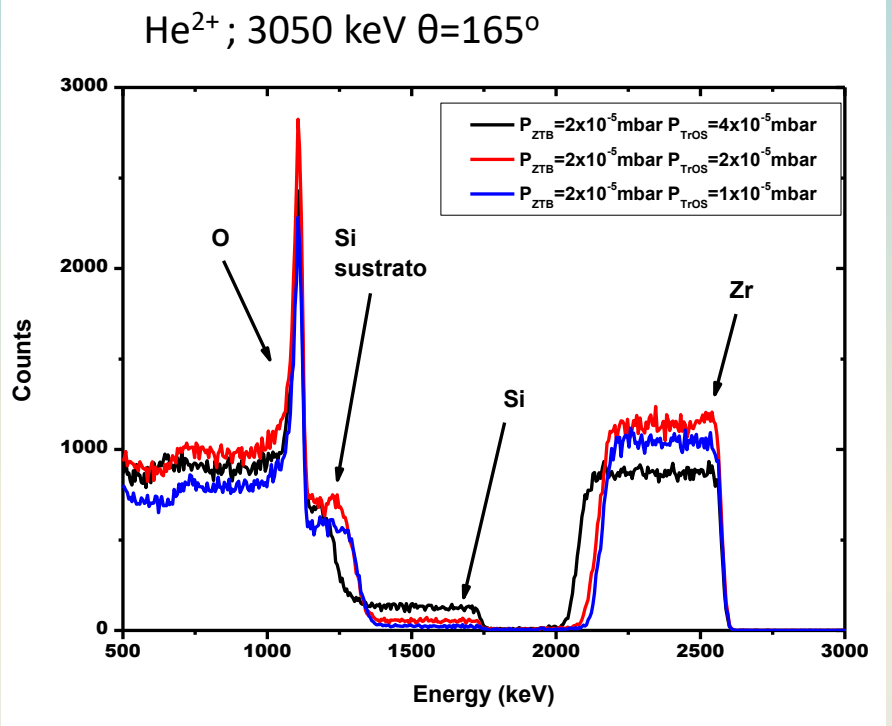
Rutherford Backscattering Spectrometry (RBS)

Stoichiometry

"Optical refractive index and static permittivity of mixed Zr-Si oxide thin films prepared by ion beam induced CVD",
F.J. Ferrer*, F. Frutos, J. García-López, A.R.González-Elipe, F. Yubero, Thin Solid Films 516 (2007) 481-485

$Zr_xSi_{1-x}O_2/Si$





x=0.45

x=0.65

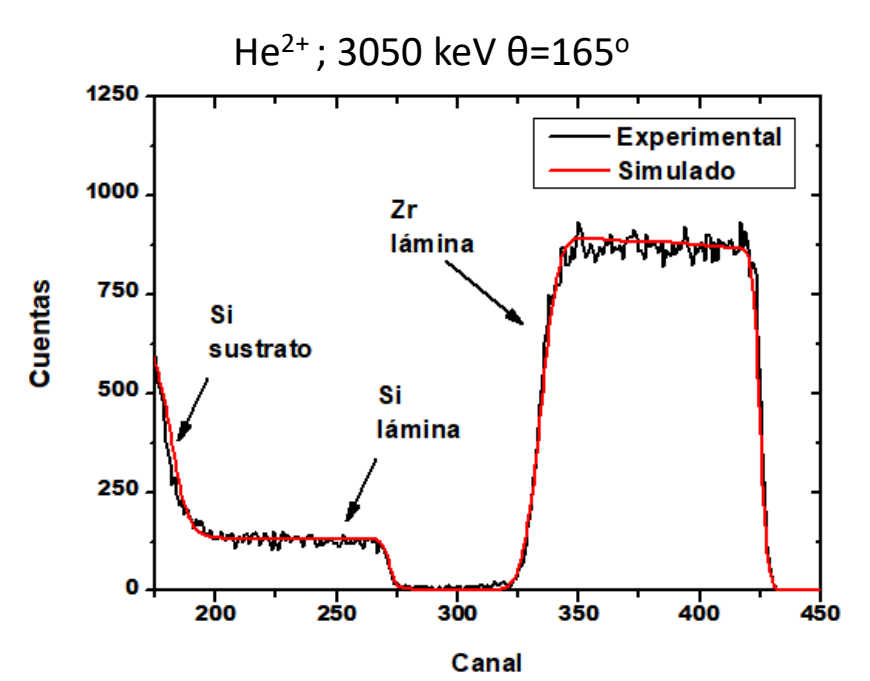
x=0.80

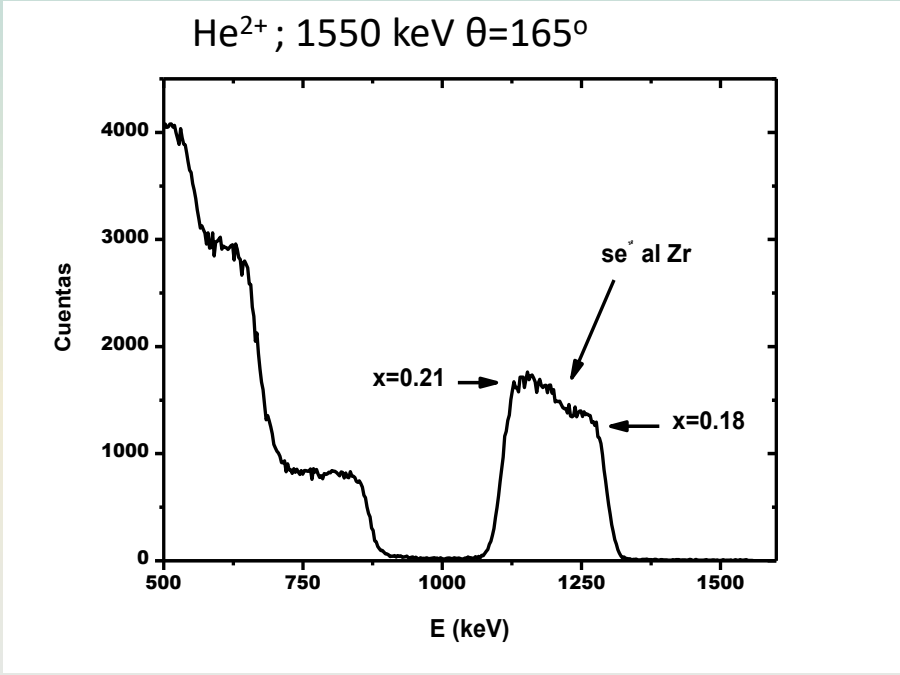
Rutherford Backscattering Spectrometry (RBS)

Homogeneity

"Optical refractive index and static permittivity of mixed Zr-Si oxide thin films prepared by ion beam induced CVD",
F.J. Ferrer*, F. Frutos, J. García-López, A.R.González-Elipe, F. Yubero, Thin Solid Films 516 (2007) 481-485

$Zr_xSi_{1-x}O_2/Si$





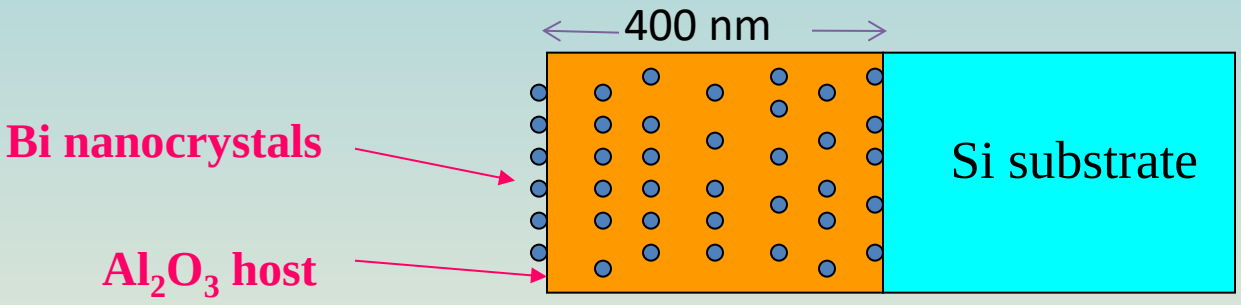
Rutherford Backscattering Spectrometry (RBS)

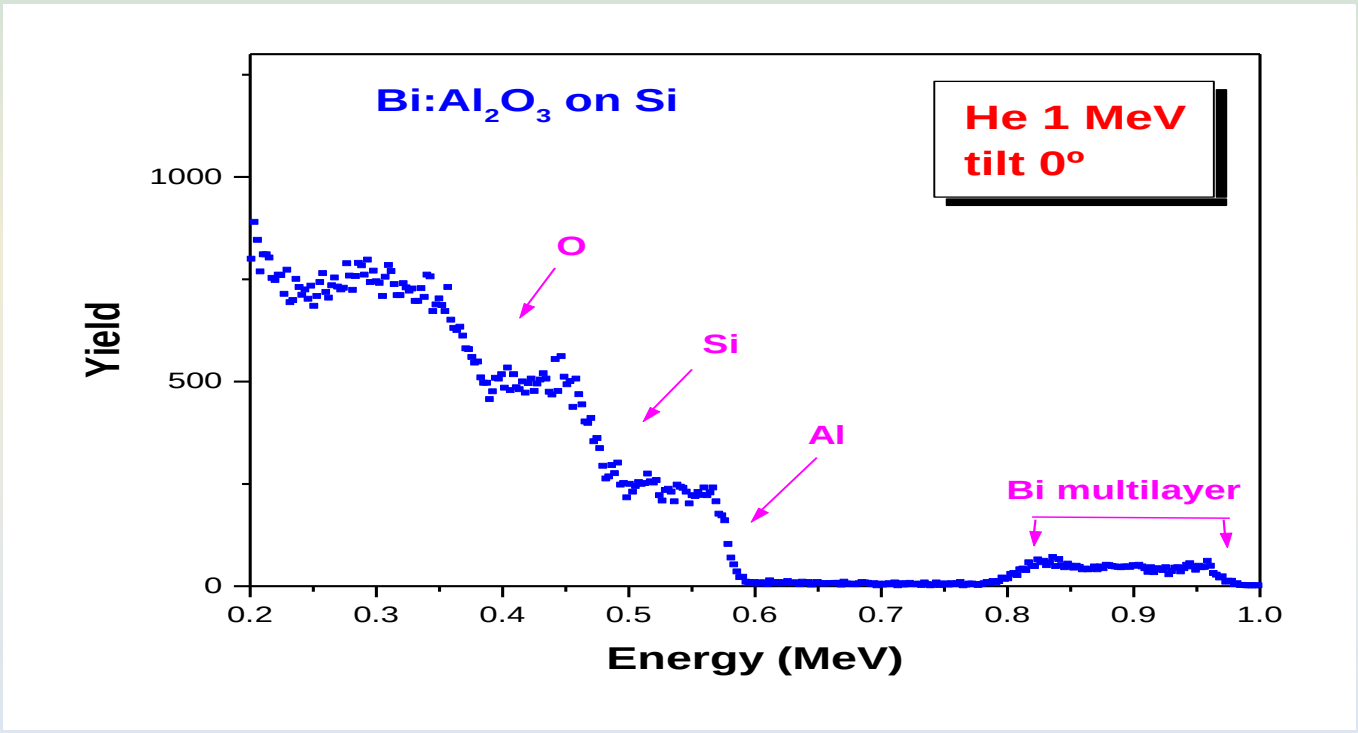
Very thin films/Multilayer

Nanocrystal composite thin film produced by PLD for nonlinear optical applications.

R. Serna, Instituto de Optica, CSIC.

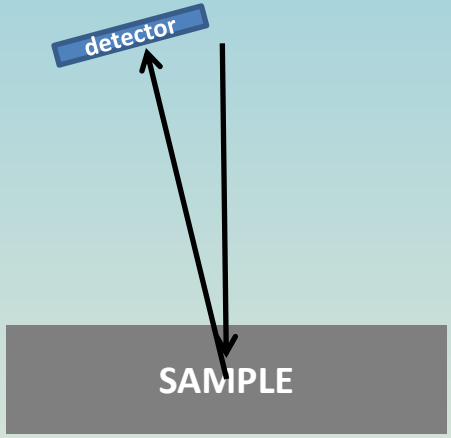
J. García López, CNA

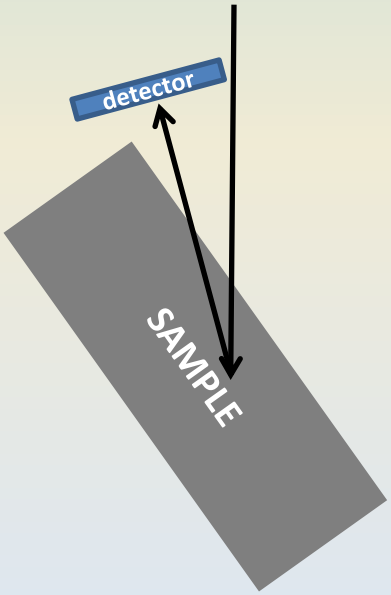


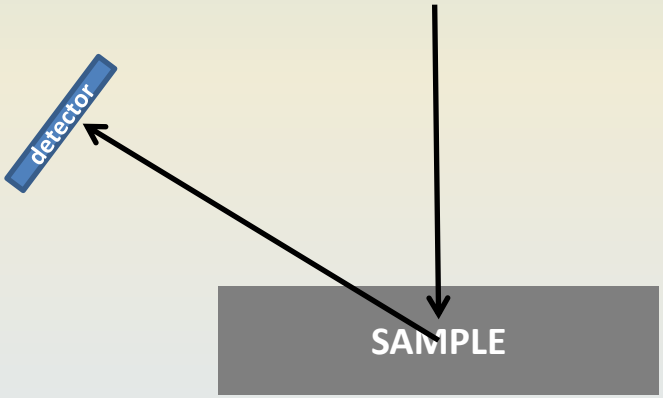


Rutherford Backscattering Spectrometry (RBS)

Very thin films/Multilayer

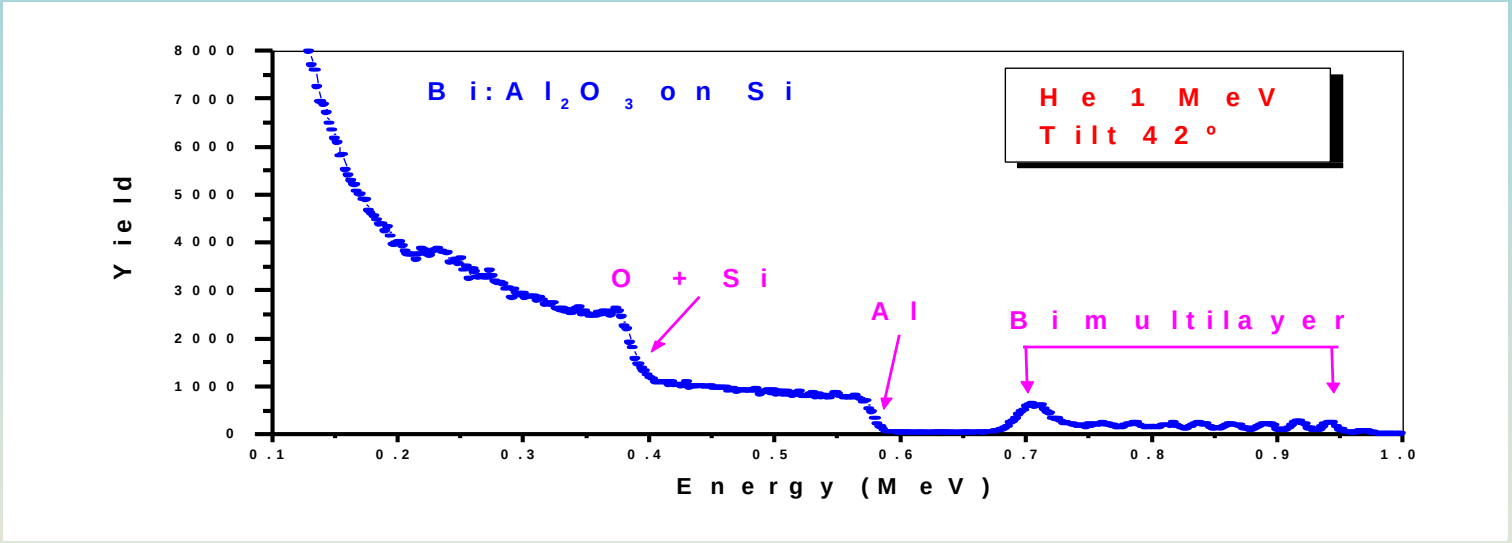


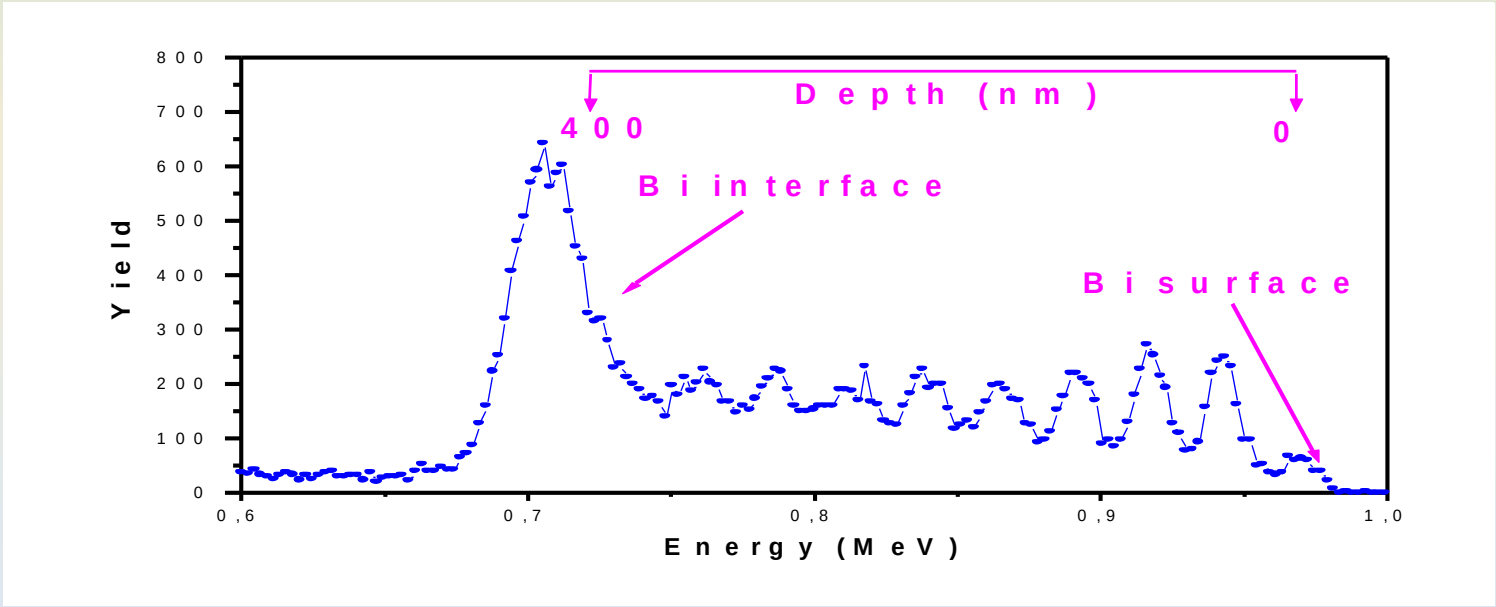




Rutherford Backscattering Spectrometry (RBS)

Very thin films/Multilayer

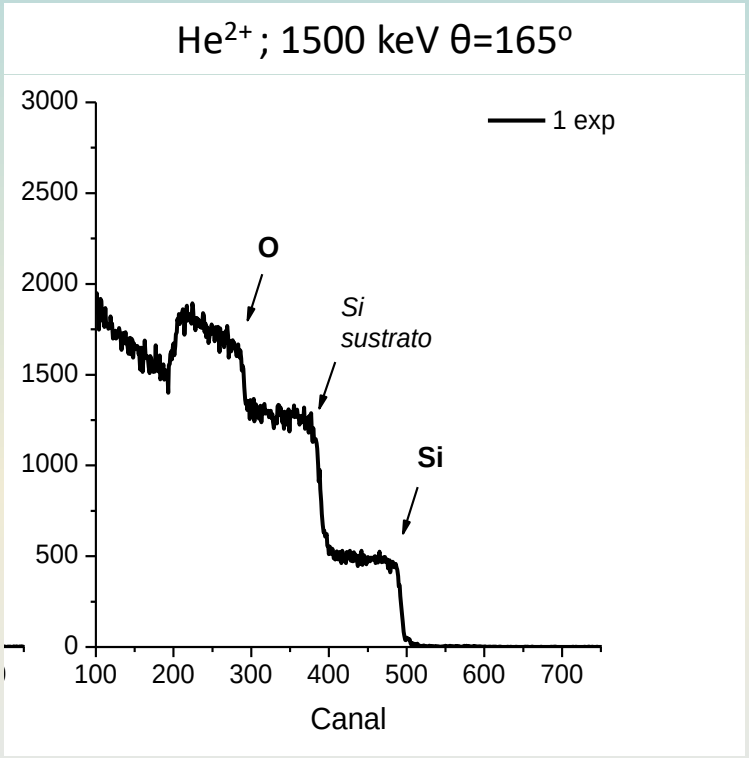


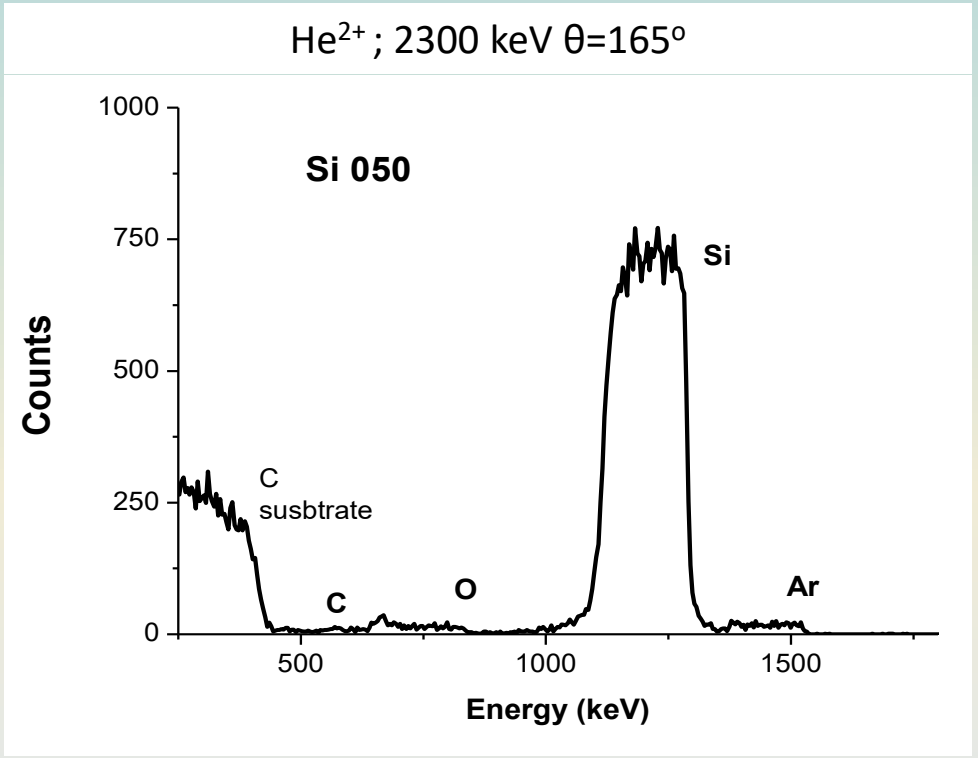


Rutherford Backscattering Spectrometry (RBS)

Substrate overlapping

"Stoichiometric Control of SiOx Thin Films Grown by Reactive Magnetron Sputtering at Oblique Angles", A. Garcia-Valenzuela, R. Alvarez, C. Lopez-Santos, F.J. Ferrer, V. Rico, E. Guillen, M. Alcon-Camas, R. Escobar-Galindo, A.R. Gonzalez-Elipe, A. Palmero, Plasma Processes and Polymers 13 (2016) 1242–1248

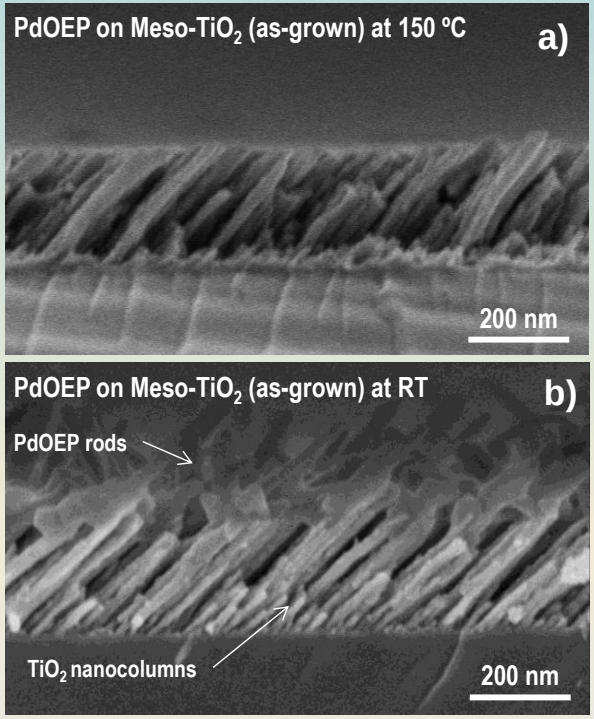


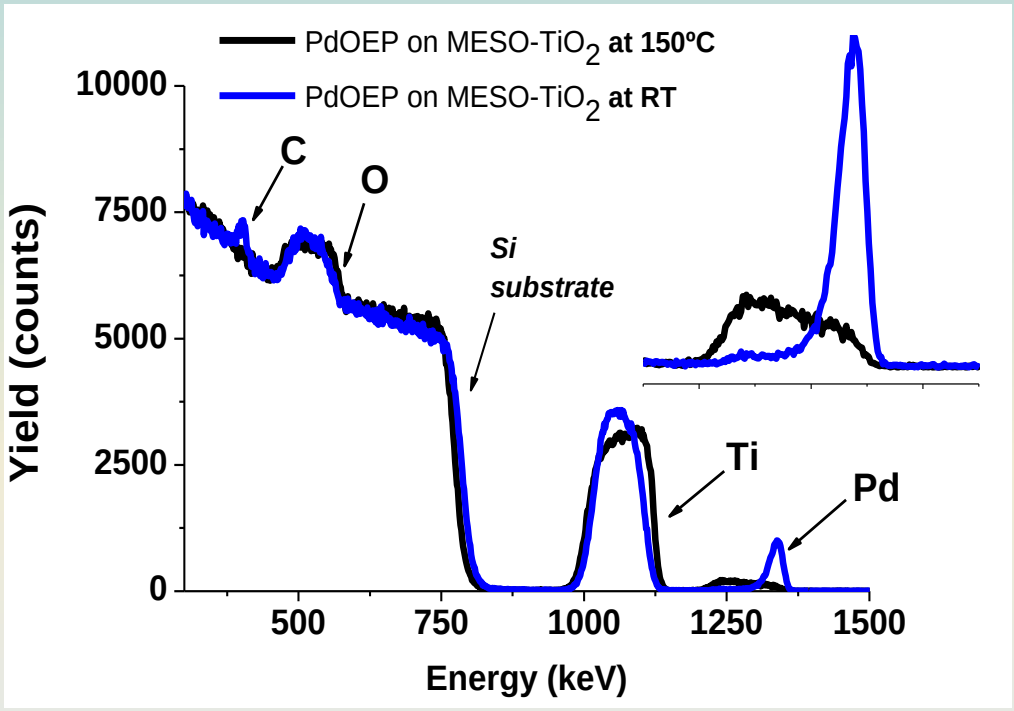


Rutherford Backscattering Spectrometry (RBS)

Difussion

"Ultraviolet pretreatment of titanium dioxide and tin-doped indium oxide surfaces as a promoter of the adsorption of organic molecules in dry deposition processes: light patterning of organic nanowires", Y. Oulad-Zian, J.R. Sanchez-Valencia, J. Parra-Barranco, S. Hamad, J.P. Espinos, A. Barranco, F. J. Ferrer, M. Coll, A. Borras, Langmuir 31 (2015) 8294–8302



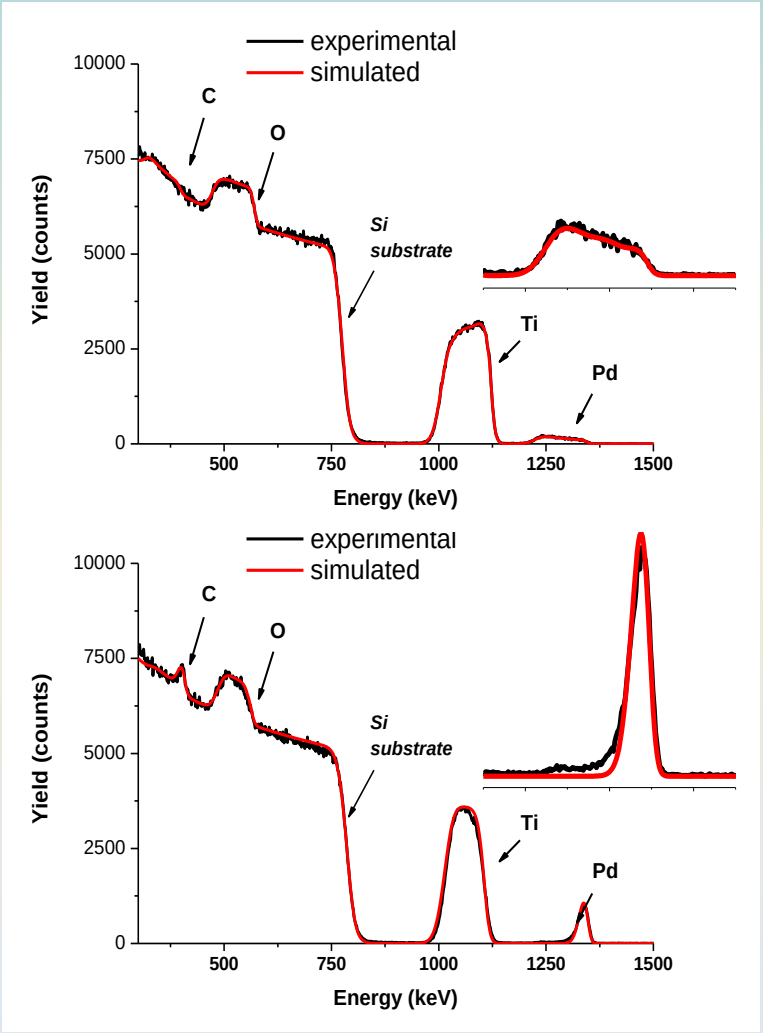


Cross section SEM micrographs characteristics of the deposition of PdOEP on MESO-TiO_2 nanocolumnar substrates at 150 ºC (a) and room temperature (b).

Rutherford Backscattering Spectrometry (RBS)

High sensitivity

“Ultraviolet pretreatment of titanium dioxide and tin-doped indium oxide surfaces as a promoter of the adsorption of organic molecules in dry deposition processes: light patterning of organic nanowires”, Y. Oulad-Zian, J.R. Sanchez-Valencia, J. Parra-Barranco, S. Hamad, J.P. Espinos, A. Barranco, F. J. Ferrer, M. Coll, A. Borras, Langmuir 31 (2015) 8294–8302



Espesor (10^{15}at/cm^2)	[Ti] %at	[O] %at	[Pd] %at	[C] %at	[H] %at
550	18.5	40.0	0.15	20.0	21.4
600	17.0	38.0	0.20	22.3	22.5
600	14.0	33.0	0.25	26.3	26.5

Espesor (10^{15}at/cm^2)	[Ti] %at	[O] %at	[Pd] %at	[C] %at	[H] %at
700	--	--	0.8	30.0	69.2
1250	22.0	45.9	--	15.0	17.1

Rutherford Backscattering Spectrometry (RBS)

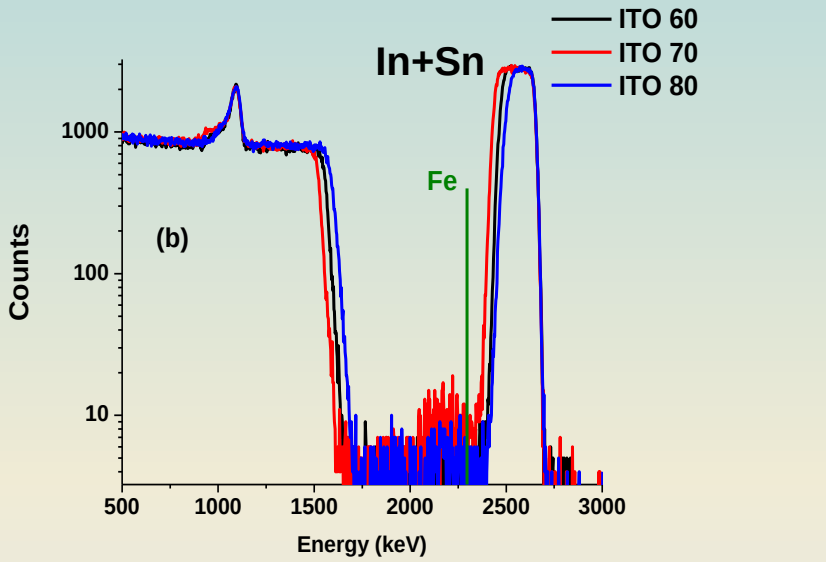
Nearby elements

“Plasma Assisted Oblique Angle Deposition of Transparent and Conductive in-Plane Anisotropic ITO Thin Films”, J. Parra-Barranco, J. R. Sanchez-Valencia, F. J. Aparicio, F. Garcia-Garcia, F. J. Ferrer, V. Rico, C. Lopez-Santos, A. Borras, A. R. Gonzalez-Elipe and A. Barranco, ECS Transactions 77 (2017) 9-15

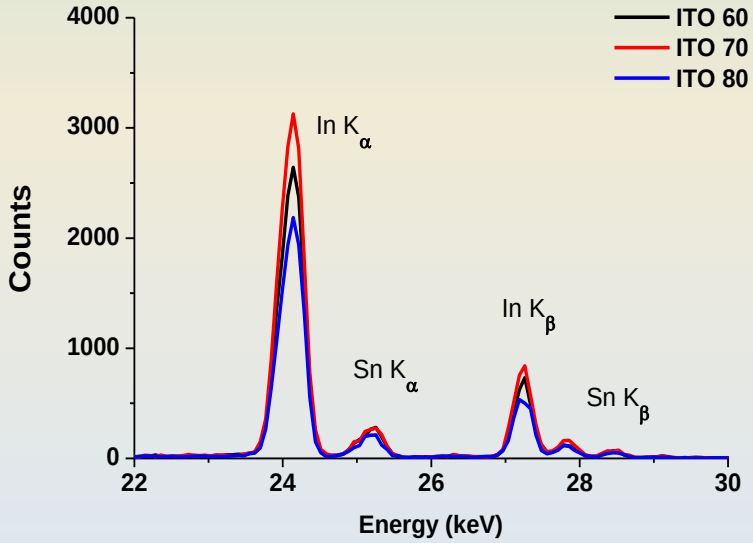
ITO: In, Sn, O

M_{In}=115; M_{Sn}=119

RBS **Beam: Helium; Energy 3,0 MeV; θ=165°**



PIXE **Beam: Protons; Energy 3,0 MeV; θ=135°**



Muestra	Espesor (10^{15}at/cm^2)	[In] %at.	[Sn] %at.	[O] %at.	[C] %at.	[Fe] %at.
ITO 60	1500	31	3	59	7	--
	500	34	4	55	7	--
ITO 70	2400	31	3	60	6	<0.2
ITO 80	1700	31	3	57	9	--

Rutherford Backscattering Spectrometry (RBS)

Rutherford cross-section?

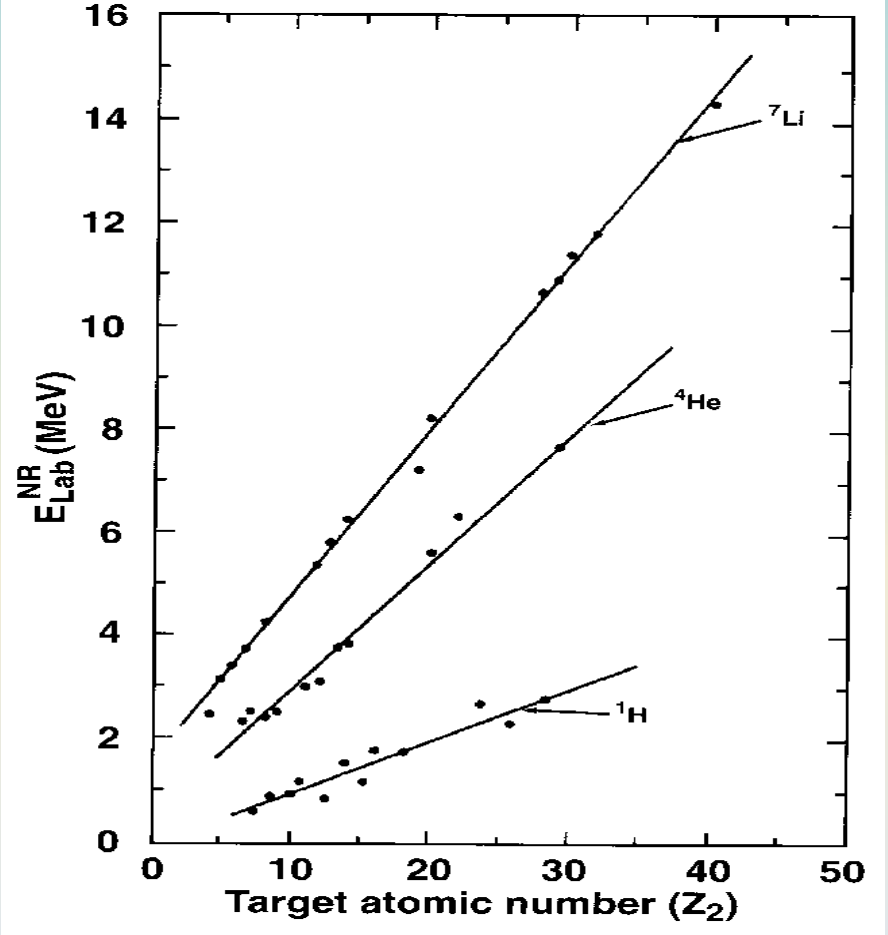
Thresholds for non-Rutherford scattering [MeV]

Bozoian, Hubbard

For ^{1}H: $E \approx 0.12\, Z_2 - 0.5$

For ^{4}He: $E \approx 0.25\, Z_2 + 0.4$

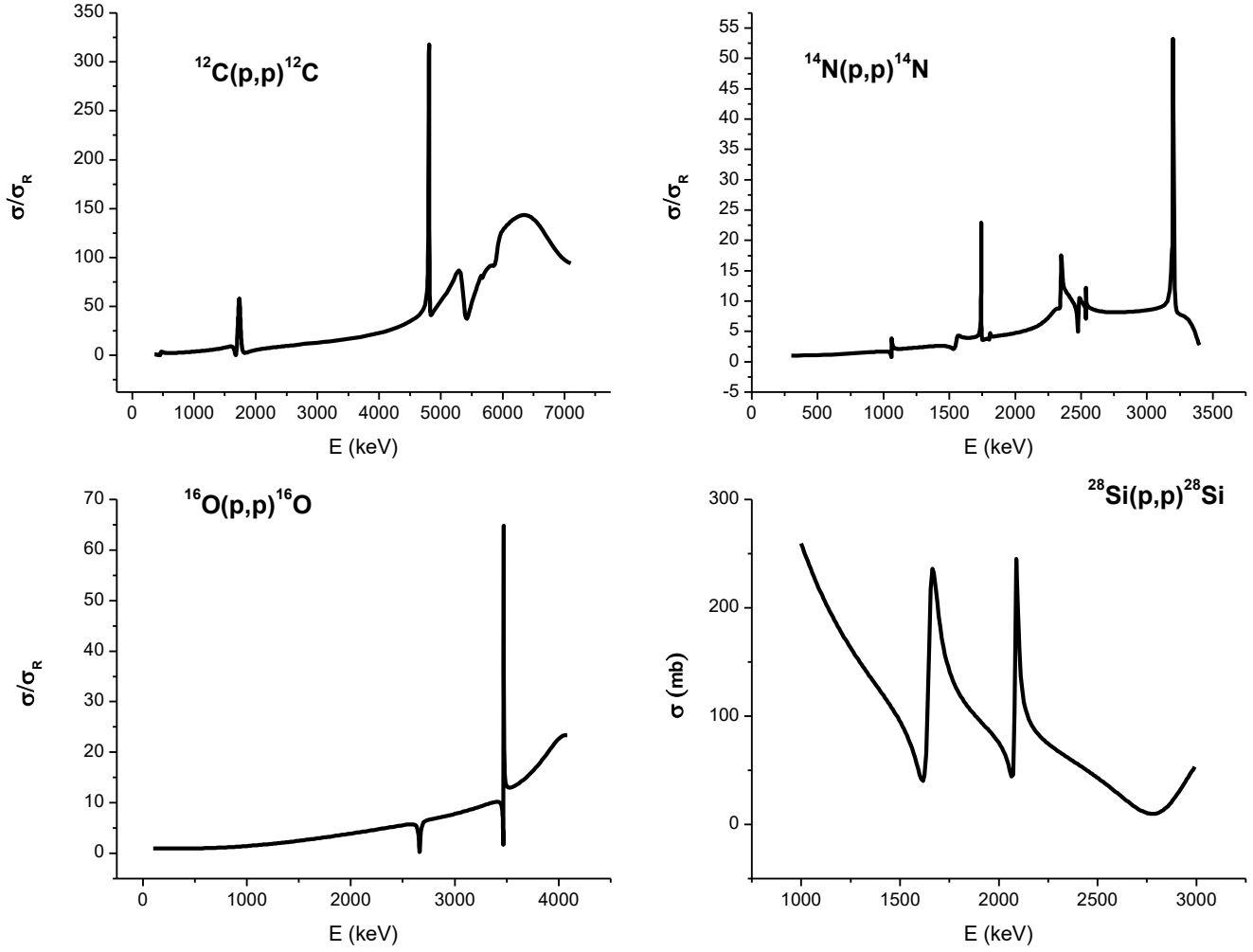
For ^{7}Li: $E \approx 0.33\, Z_2 + 1.4$



J.R. Tesmer and M. Nastasi,
Handbook of Modern Ion Beam Materials Analysis, MRS, 1995

Elastic Backscattering Spectrometry (EBS)

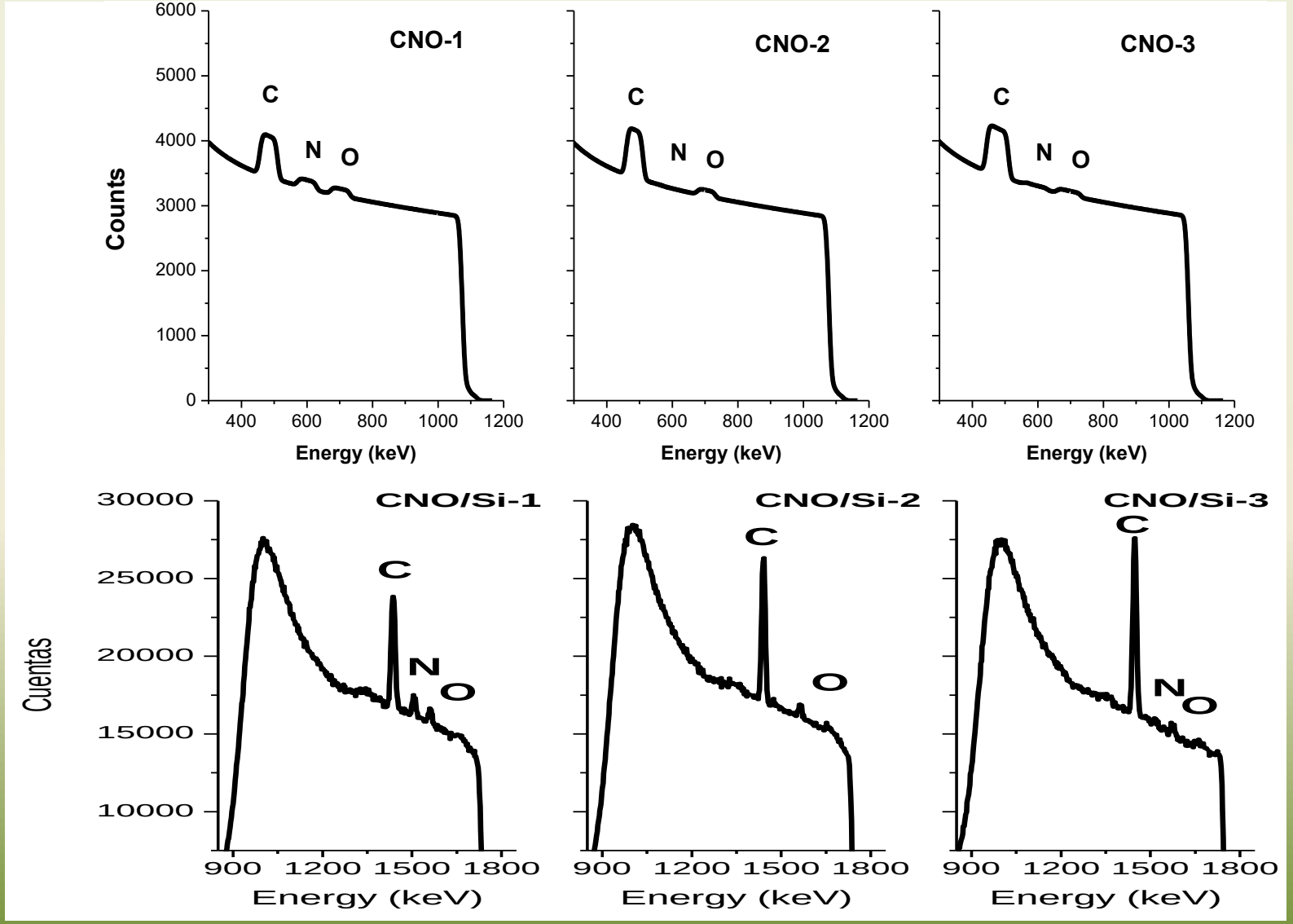
Proton beam: light elements



Elastic Backscattering Spectrometry (EBS)

Proton beam: light elements

"Simultaneous quantification of light elements in thin films deposited on Si substrates using proton EBS (Elastic Backscattering Spectroscopy)", F.J. Ferrer*, et al, Nuclear Instruments & Methods in Physics Research B 332 (2014) 449–453

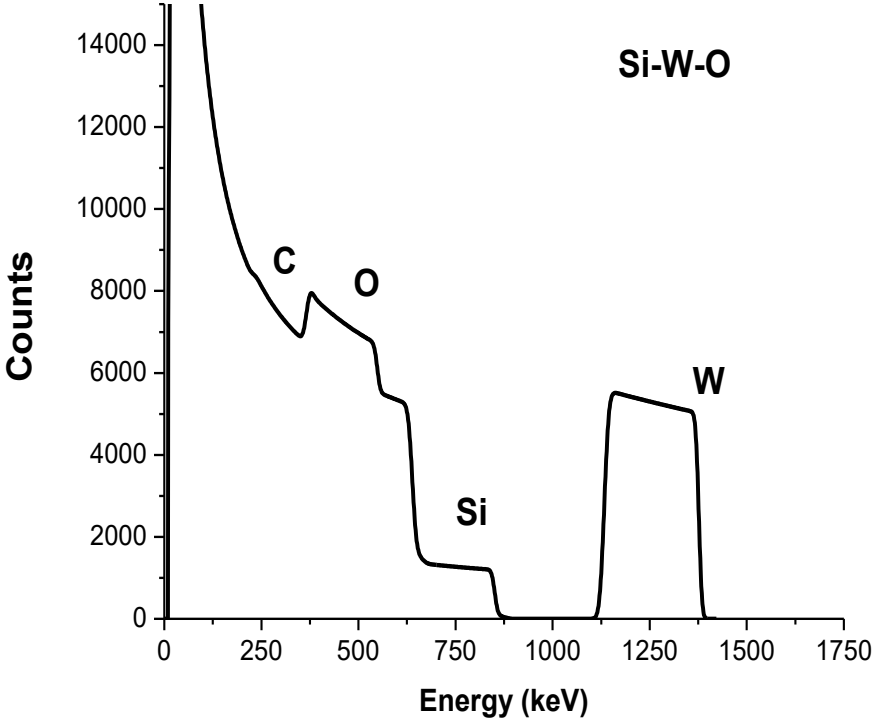


Elastic Backscattering Spectrometry (EBS)

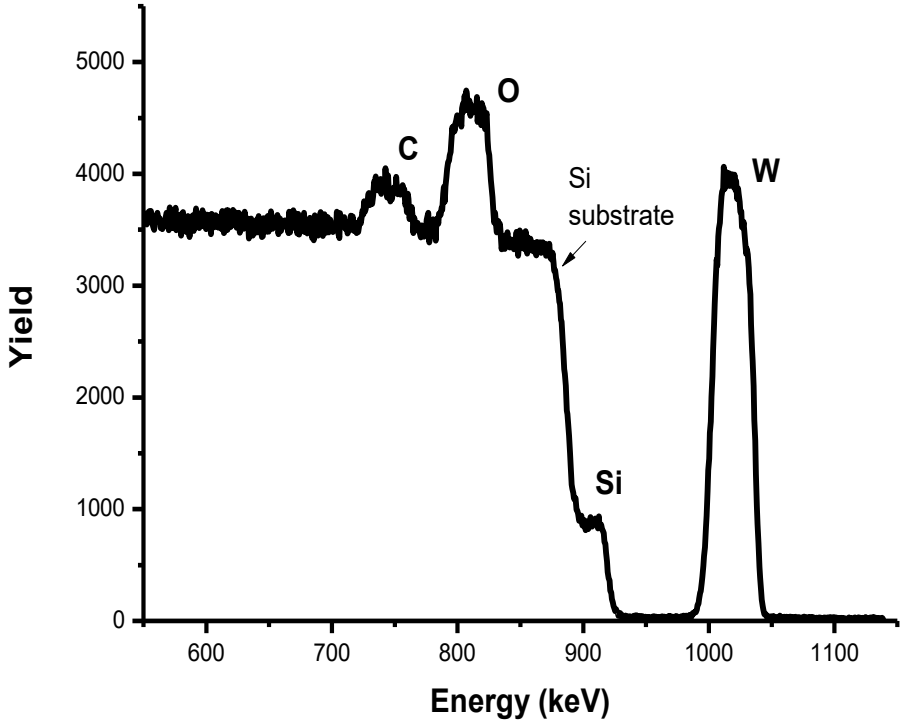
Proton beam: light elements

Si-W-O; 300 nm aprox

Beam: Helium; Energy 1,5 MeV; θ=165°



Beam: Protons; Energy 1,06 MeV; θ=165°



Elastic Backscattering Spectrometry (EBS)

Proton beam: Helium

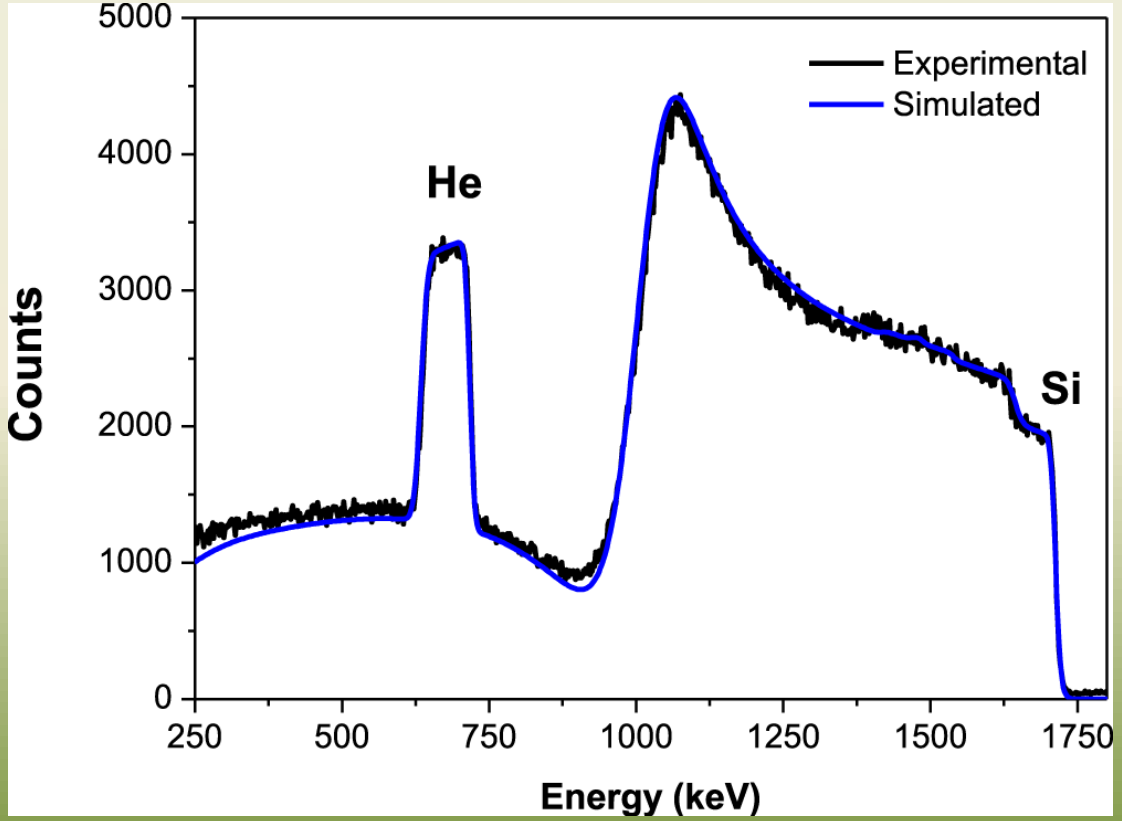
"Characterization and validation of a-Si magnetron sputtered thin films as solid He target with high stability for nuclear reactions", *V Godinho, F. Ferrer, et al.* ACS Omega, 1 (2016) 1229

$$K = \left[\frac{\left(M_2^2 - M_1^2 sin^2\theta\right)^{1/2} + M_1 cos\theta}{M_1 + M_2} \right]$$

Ion beam: He
$K_{He} = 0$

Ion beam: H
$K_{He} = 0{,}365$

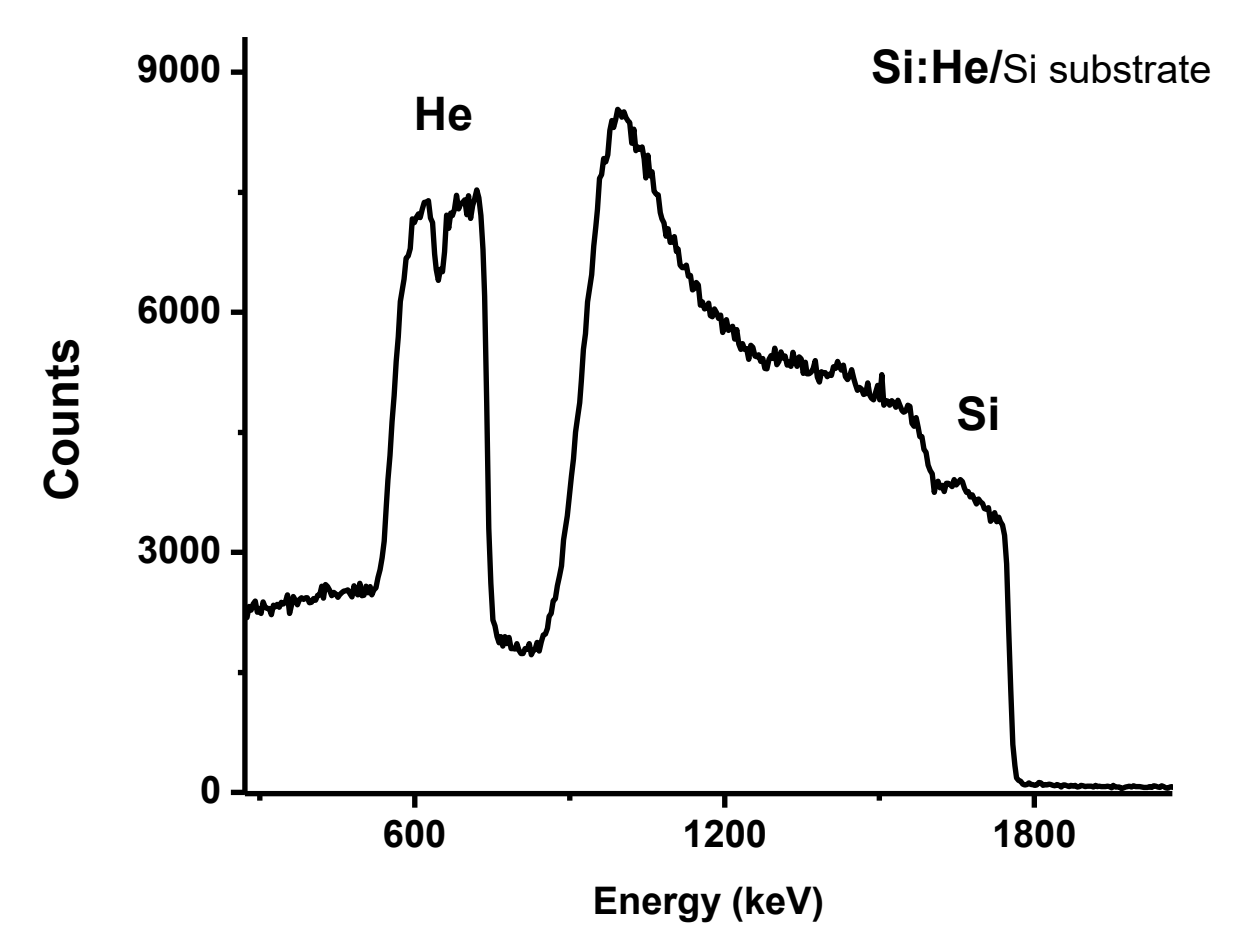
Beam: Protons; Energy 2,0 MeV; θ=165°



Elastic Backscattering Spectrometry (EBS)

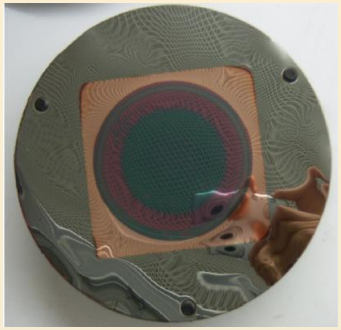
Proton beam: Helium

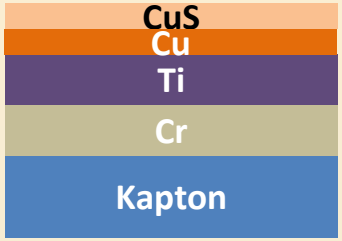
Beam: Protons; Energy 2,0 MeV; θ=165°



Characterization of targets for n TOF experiments

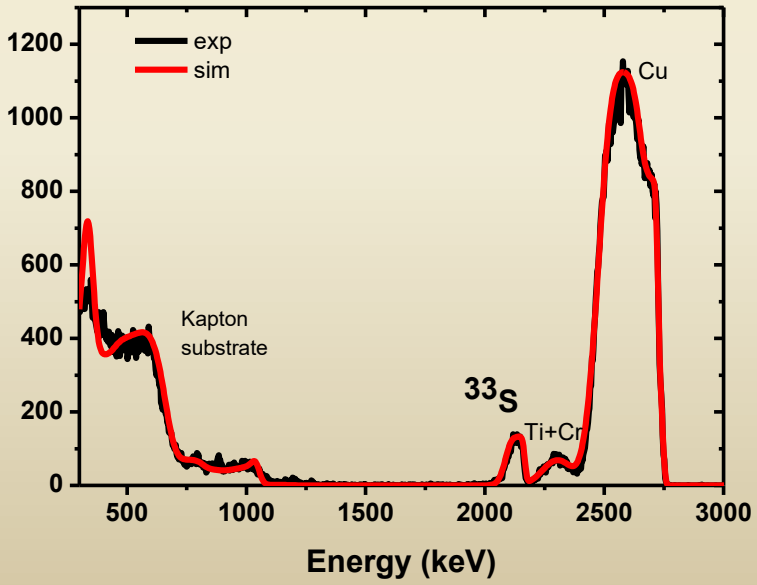
^{33}S Study of the ^{33}S(n,α)^{30}Si cross setion between 10 and 300 keV





"Preparation and characterisation of ^{33}S samples for ^{33}S(n,α)^{33}Si cross-section measurements at the n_TOF facility at CERN", *J. Praena, F. Ferrer, et al.* Nucl Inst. and Meths A, 890 (2018) 142-147229

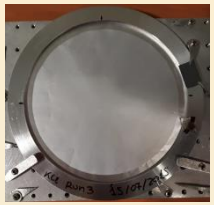
RBS; alfas; 3,5 MeV; θ = 165°



	33S (10^{15} at/cm^2)	33S (μg/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

Characterization of targets for n TOF experiments

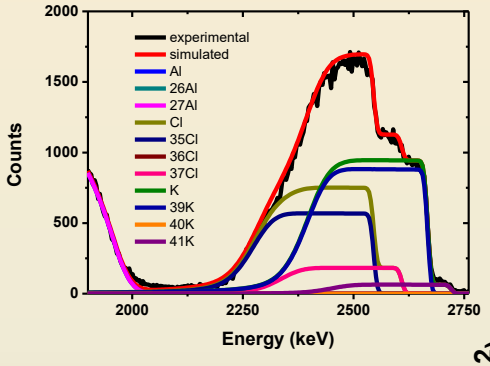
^{35}Cl Study of the $^{35}Cl(n,p)^{35}S$ cross setion between 50 a 1000 keV

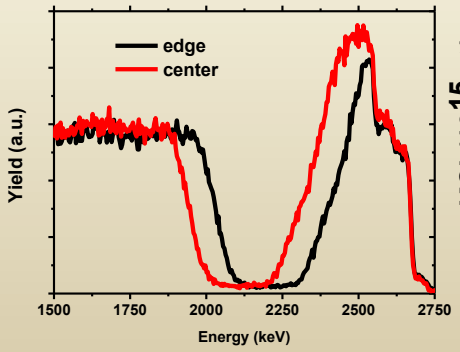


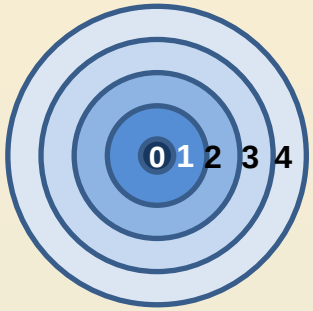
KCl

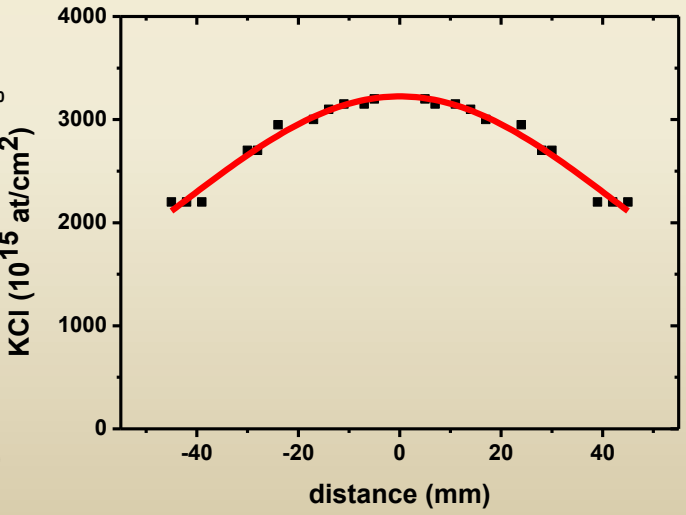
Aluminum

RBS; alfas; 4,1 MeV; θ = 165°







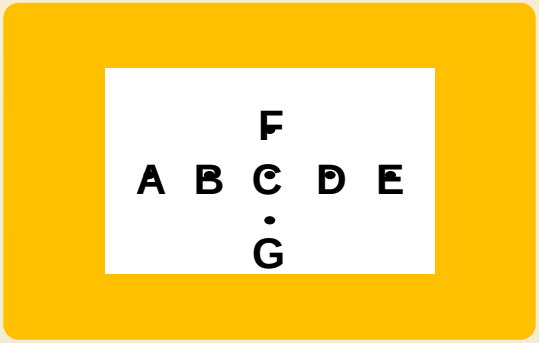


Point	KCl (10^{15} at/cm^2)
(0,0)	3800
(0,-1)	3750
(-1,0)	3700
(1,0)	3700
(0,-2)	3500
(2,0)	3400
(-2,0)	3400
(0,-3)	3150
(-3,0)	3000
(3,0)	3100
(0,-4)	2700
(-4,0)	2600
(4,0)	2600

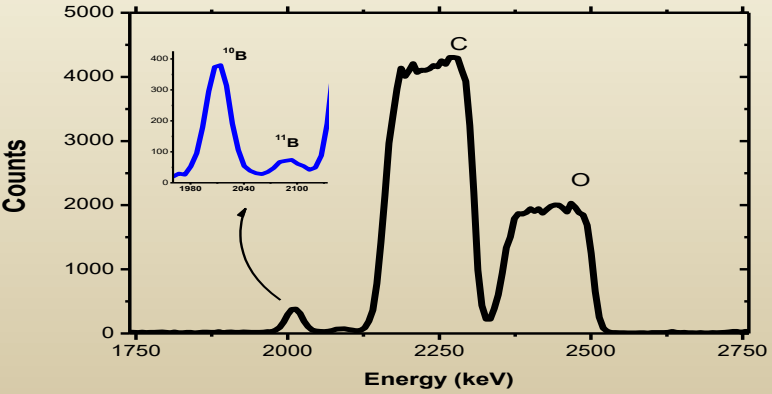
Characterization of targets for n TOF experiments

^{10}B Study of the $^{26}Al(n,p)$ and $^{26}Al(n,\alpha)$ cross setion refered to $^{10}B(n,\alpha)$

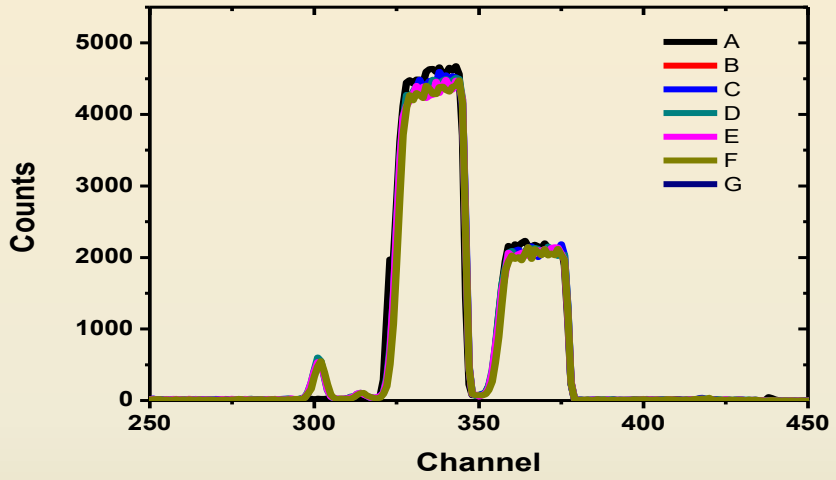
10B
Mylar



p-EBS; protons; 3,2 MeV; θ = 165°



"Destruction of the cosmic γ-ray emitter 26Al in massive stars: Study of the key 26Al(n,p) reaction", *C. Lederer-Woods, et al.* Phys. Rev. C 104, (2021) L022803 (1-7)

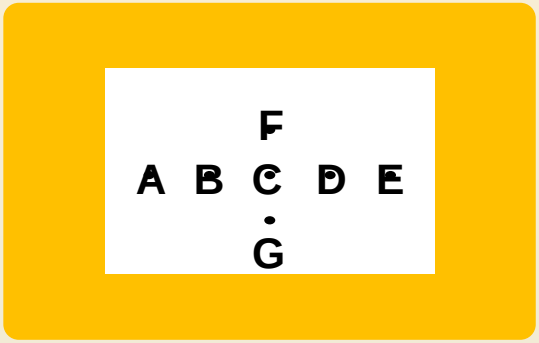


B1	Mylar (μm)	^{10}B (μg)	^{11}B (μg)
	4.5	8.97	1.10

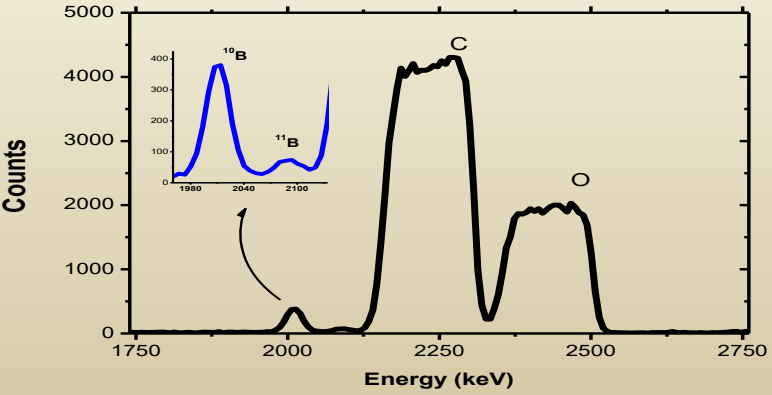
Characterization of targets for n TOF experiments

^{10}B — Study of the ^{26}Al(n,p) and ^{26}Al(n,α) cross setion refered to ^{10}B(n,α)

10B
Mylar



p-EBS; protons; 3,2 MeV; θ = 165°



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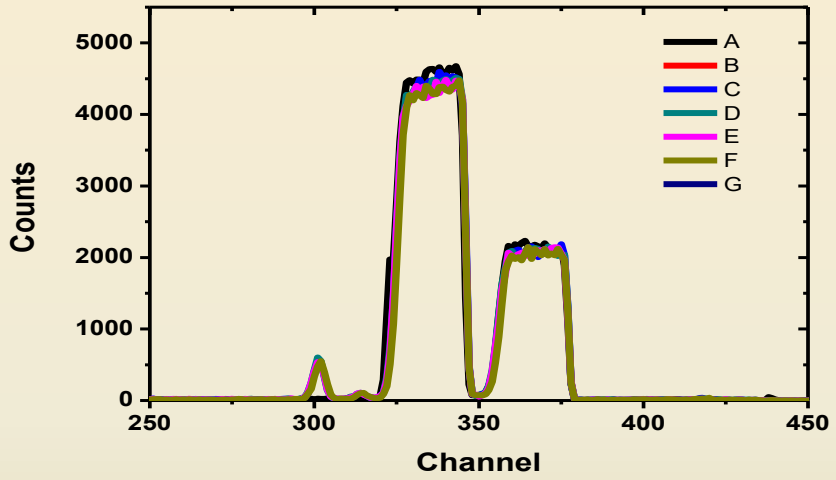

B1	Mylar (μm)	^{10}B (μg)	^{11}B (μg)
	4.5	8.97	1.10

THANK YOU FOR YOUR ATTENTION