AN ALTERNATIVE METHOD FOR PIGE ANALYSIS OF LIGHT ELEMENTS WITHOUT STANDARDS

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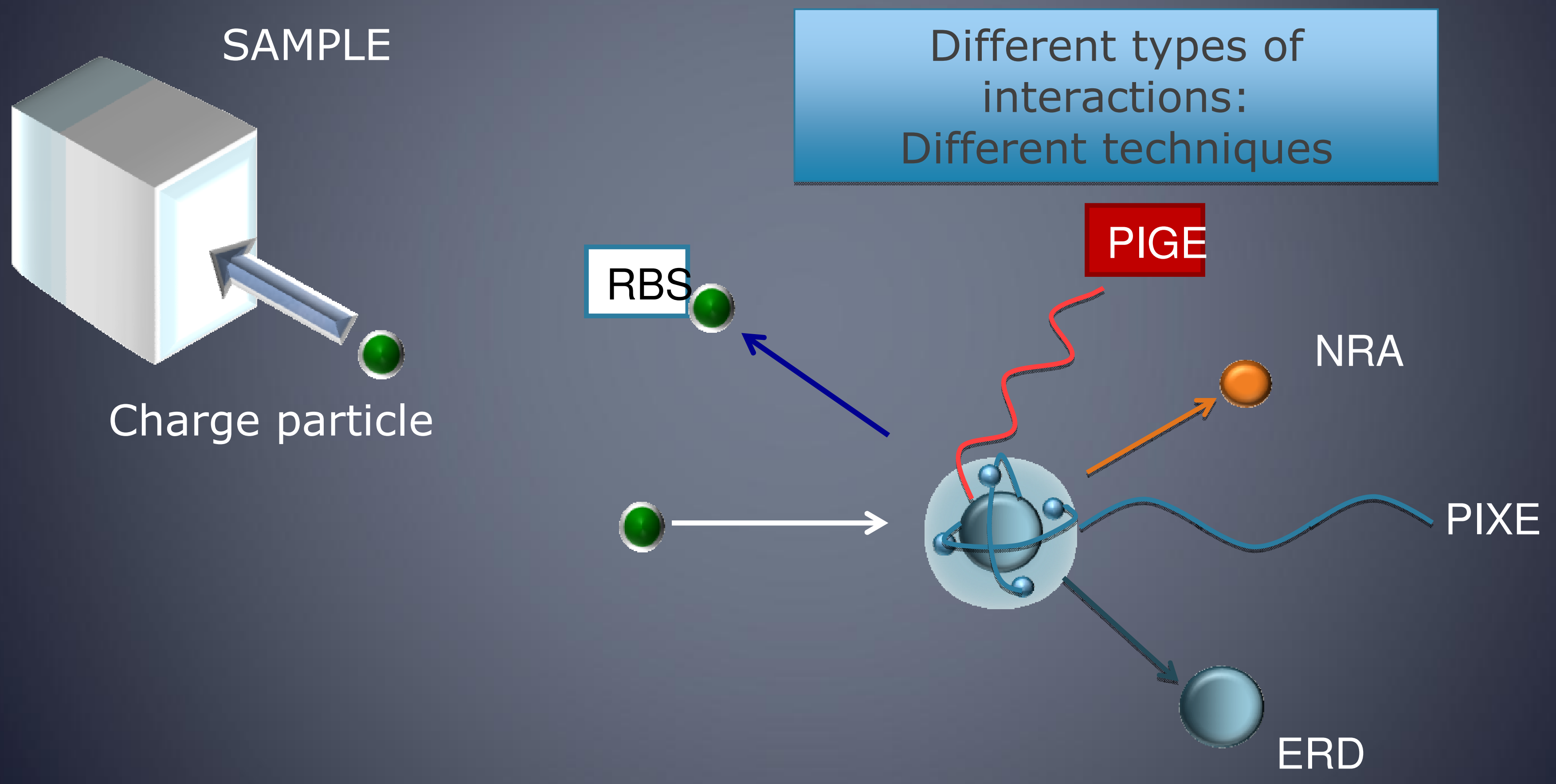
11th November 2011, Frankfurt

An alternative method for PIGE analysis

- Motivation
- Introduction to PIGE (Particle-Induced Gamma-ray Emission)
- ERYA Code (Emitted Radiation Yield Analysis)
- Experimental Setup
- PIGE analysis: Be, B, Li, F, Na e Mg
- Applications

Motivation

Sample – Unknown composition



Motivation

1980 Borderie: (B. Borderie, Nucl. Instr. and Meth. 175 (1980) 465)

Yield of the γ-ray emission depends of the integrated cross section of the nuclear reaction

Few measurements of the relevant cross sections

Solution so far: Use **standard samples** with thickness and compositions known.

⇓

This method is always dependent on the availability of standards and gives only good results when the standards composition is very similar to the samples to be analyzed

Motivation

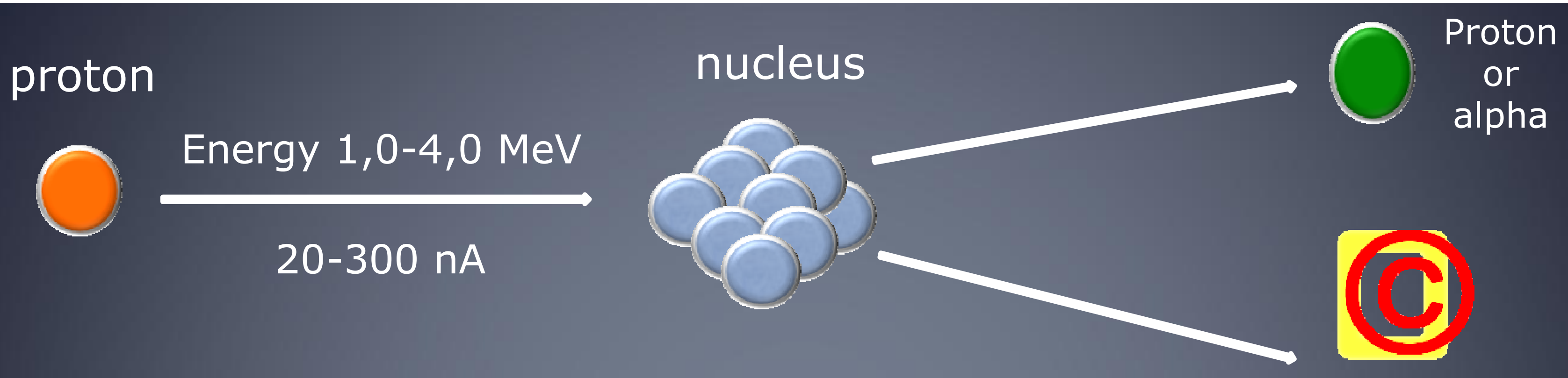
Last years:

- Developed an alternative method for the PIGE technique without standards.
  - Measurement of the cross sections: Be, B, Li, F, Al, Mg and Na

An alternative method for PIGE analysis

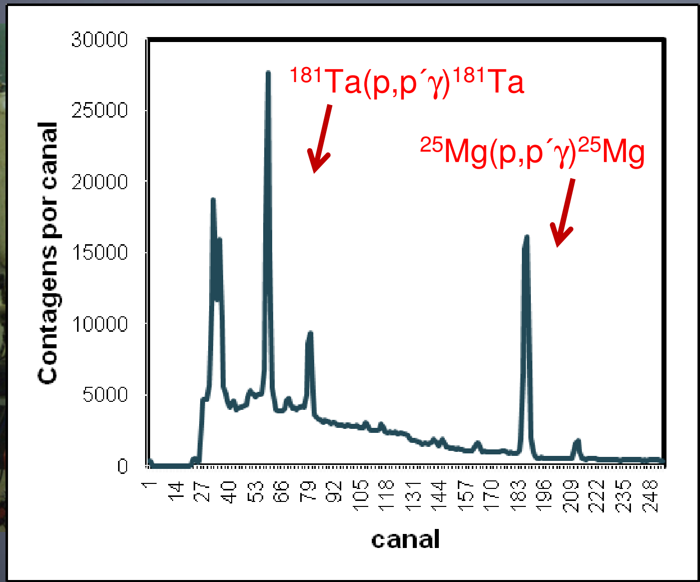
- Motivation
- Introduction to PIGE (Particle-induced γ-ray emission)

Introduction to PIGE



10 uC

$^{25}Mg(p,p'\gamma)^{25}Mg$ E=2,4 MeV



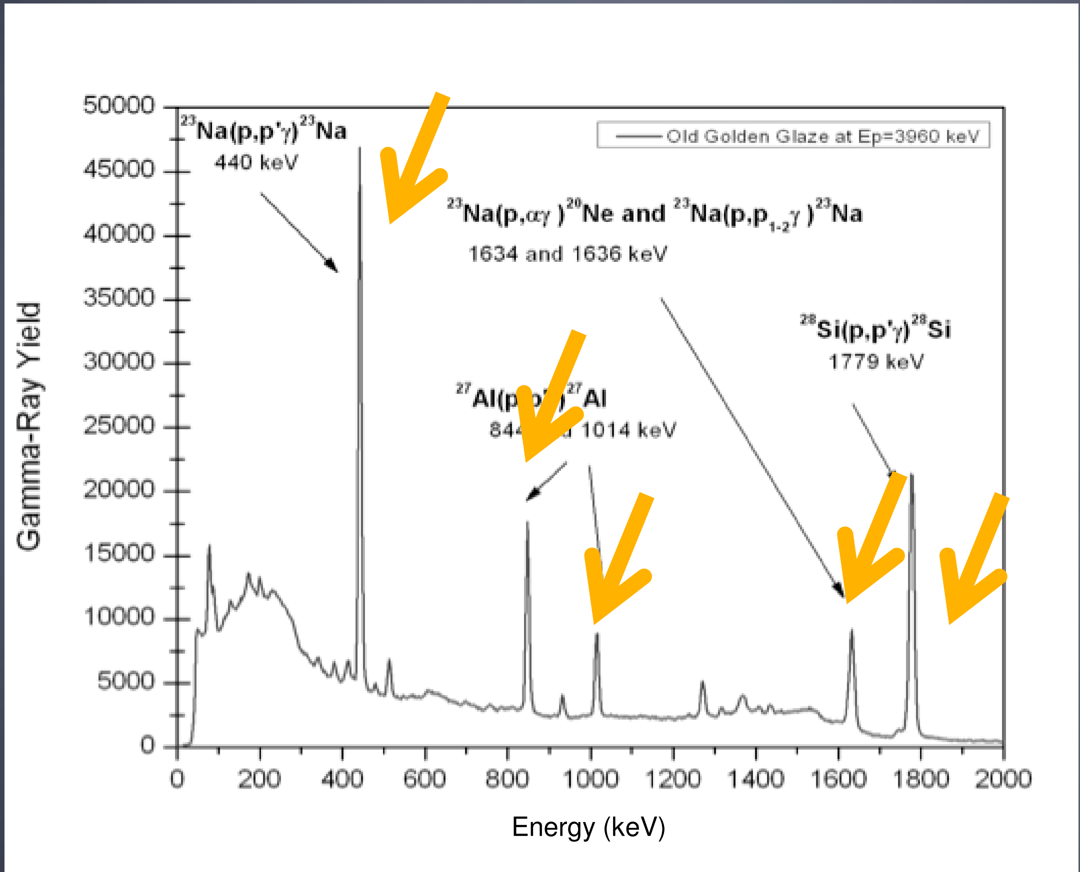
Gamma Detector Ge(HP) 45%

Introduction to PIGE

PIGE → Particle-induced γ-ray emission

- Simultaneous analysis of all light elements in the sample;

Simultaneous analysis of all light elements in the sample



ONE SPECTRA

Quantify:

Na
Al
Si

No elements:

Li
F
Mg

M. Fonseca et al NIMB (2011)

DOI:10.1016/J.NIMB.2011.04.060

Introduction to PIGE

PIGE

- Nondestructive analysis;
- Providing accurate concentration values for light elements;
- PIGE is complementary to PIXE analysis (usually for Z > Na);
- The cross section of nuclear reactions exhibit narrow and large resonances → Depth Profiling

Introduction to PIGE

$$Y(E) = \varepsilon_{abs}(E_\gamma)\left(\frac{Q}{e}\right).f_m.f_i.N_{av}.A^{-1}\int_0^{E_0}\frac{\sigma(E)}{\varepsilon(E)}dE$$

Absolute efficiency of the detection system

Experimental Yield

Q/e Number of incident protons

A^{-1} – inverse of atomic mass

σ(E)-Nuclear reaction cross section related to the gamma emission

f_i- isotopic abundance ‘i’

f_m – mass fraction

ε(E)-Stopping cross section of the sample in units of energy area per mass

N_{av}- Avogadro’s number

Introduction to PIGE

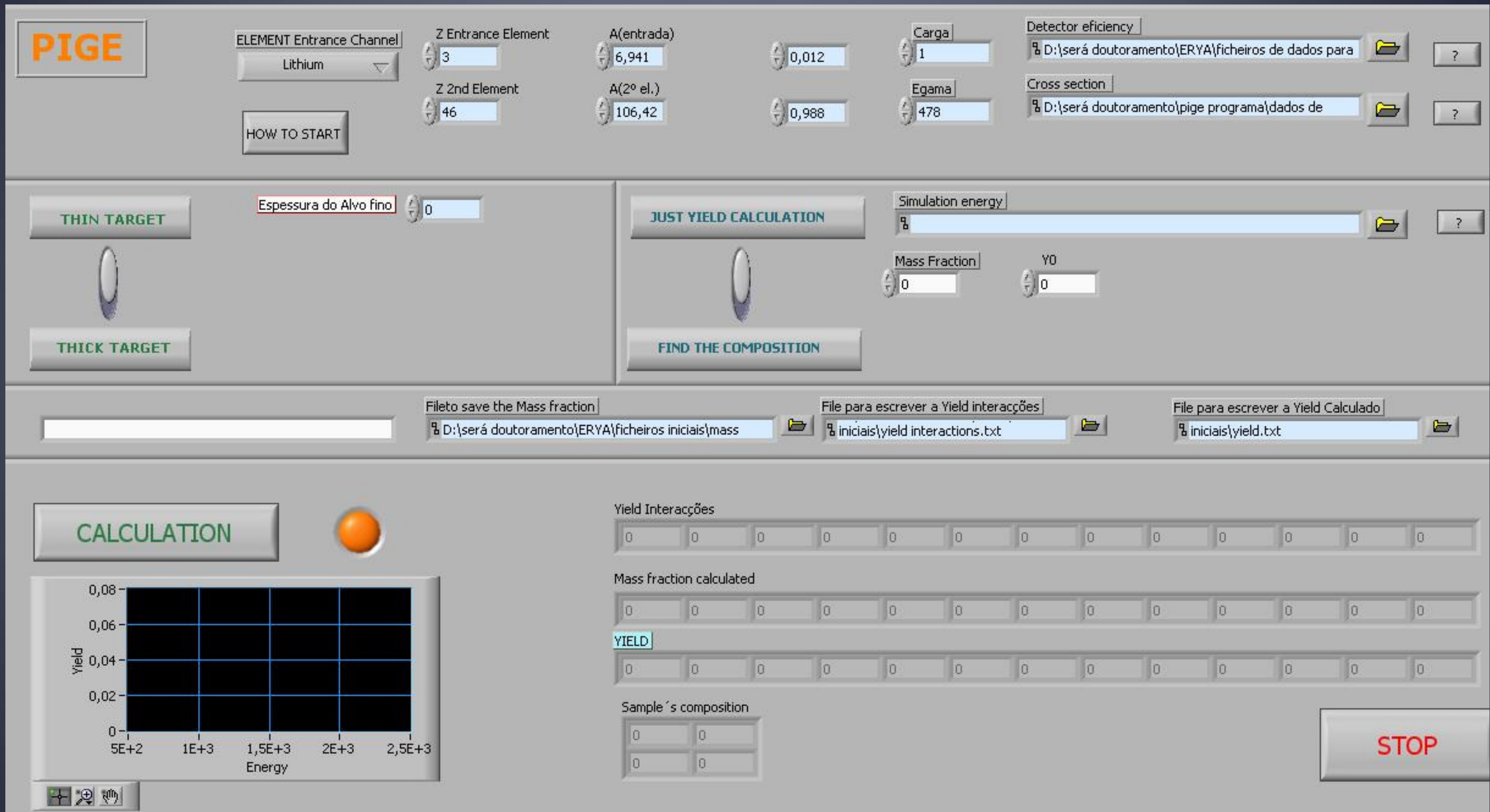
Use a formalism similar to the one used for PIXE (but the cross section has narrow and large resonances)

↳ ERYA CODE

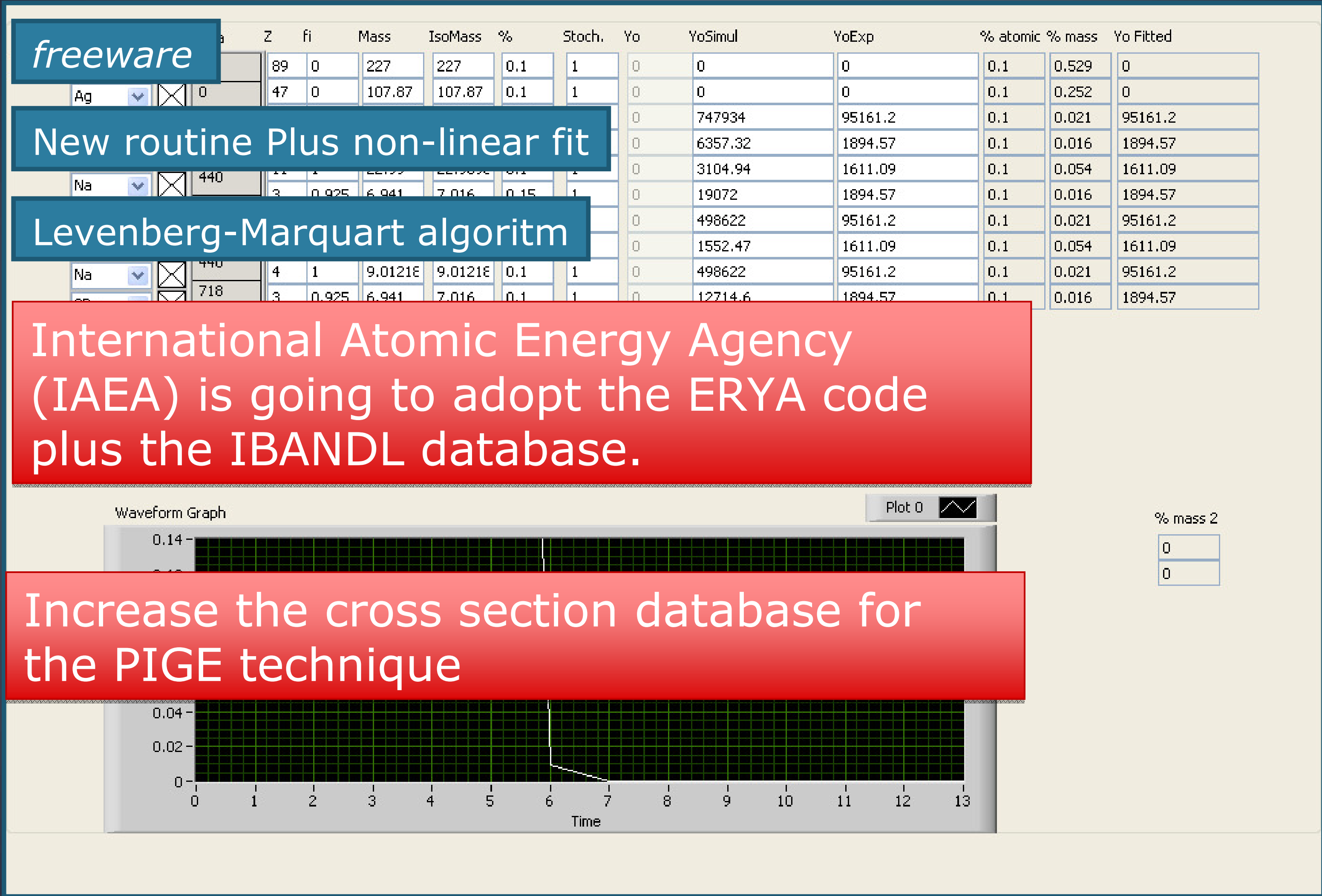
An alternative method for PIGE analysis

- Motivation
- Introduction to PIGE
- ERYA Code (Emitted Radiation Yield Analysis)

ERYA CODE


PIGE
ELEMENT Entrance Channel
Lithium
HOW TO START
Z Entrance Element
3
Z 2nd Element
46
A(entrada)
6,941
A(2º el.)
106,42
0,012
0,988
Carga
1
Egama
478
Detector eficiency
D:\será doutoramento\ERYA\ficheiros de dados para
Cross section
D:\será doutoramento\pige programa\dados de
THIN TARGET
THICK TARGET
Espessura do Alvo fino
JUST YIELD CALCULATION
FIND THE COMPOSITION
Simulation energy
Mass Fraction
Y0
Fileto save the Mass fraction
D:\será doutoramento\ERYA\ficheiros iniciais\mass
File para escrever a Yield interacções
iniciais\yield interactions.txt
File para escrever a Yield Calculado
iniciais\yield.txt
CALCULATION
Yield Interacções
Mass fraction calculated
YIELD
Sample´s composition
STOP
Yield
Energy

ERYA Code



freeware

New routine Plus non-linear fit

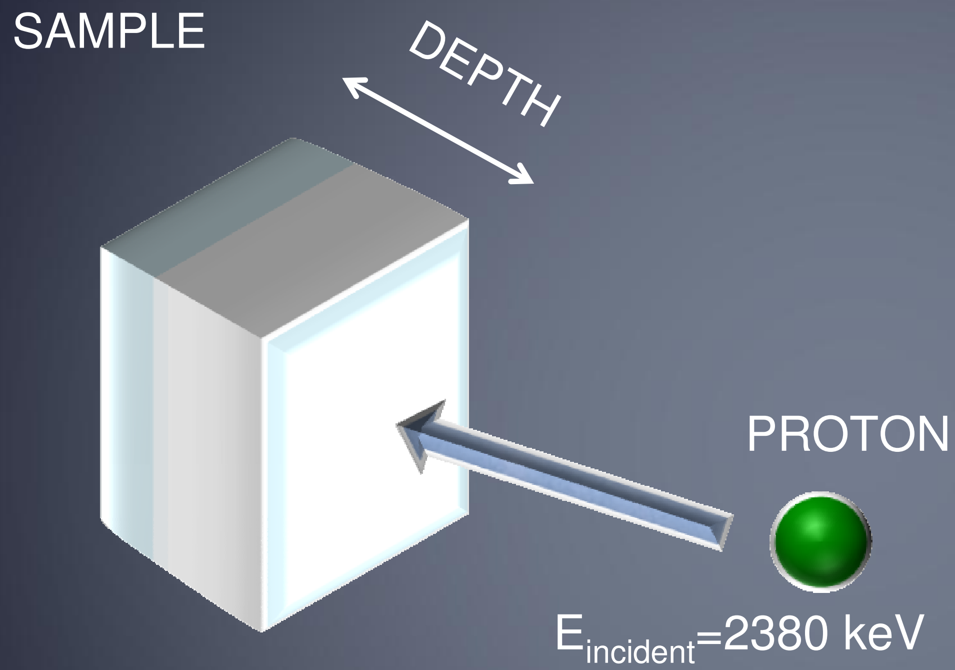
Levenberg-Marquart algoritm

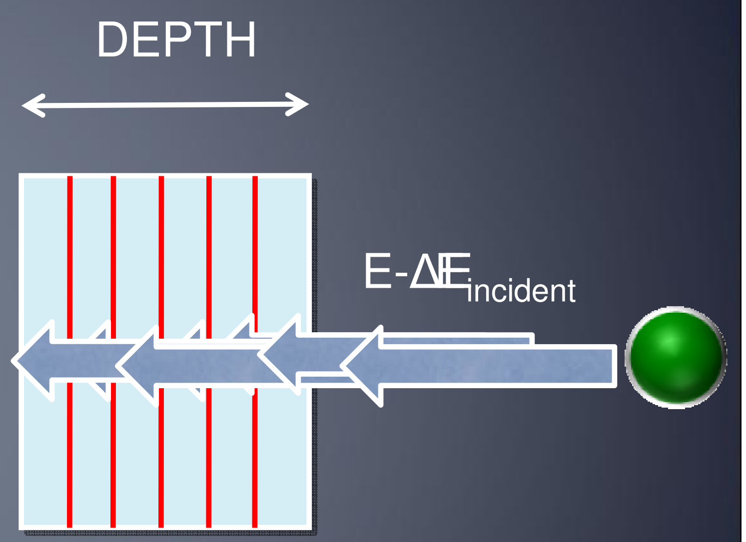
International Atomic Energy Agency (IAEA) is going to adopt the ERYA code plus the IBANDL database.

Increase the cross section database for the PIGE technique

ERYA CODE - Principles

Divided the sample in sublayers



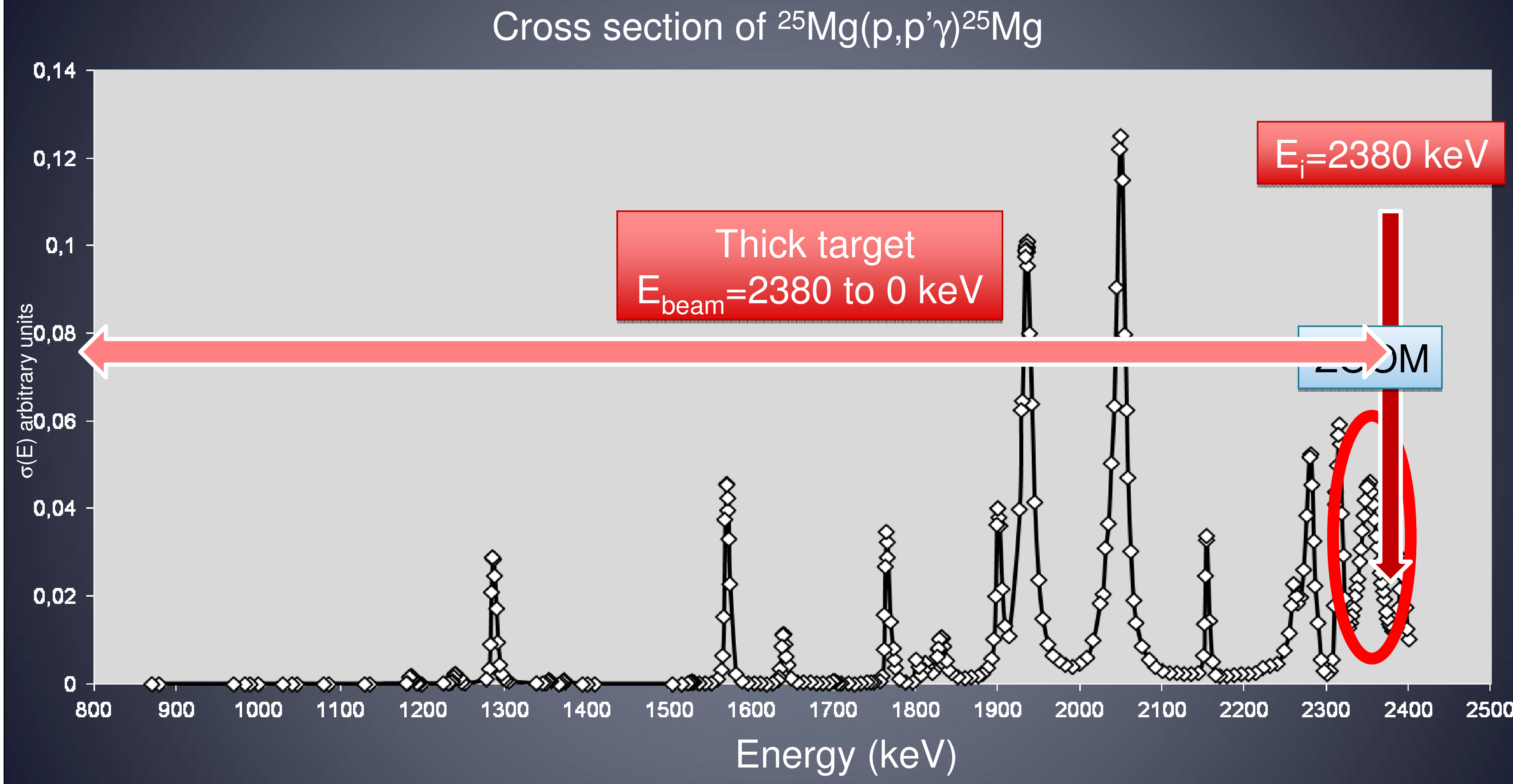


Yield calculated by ERYA

Within each sublayer the stopping power cross sections may be assumed as constant.

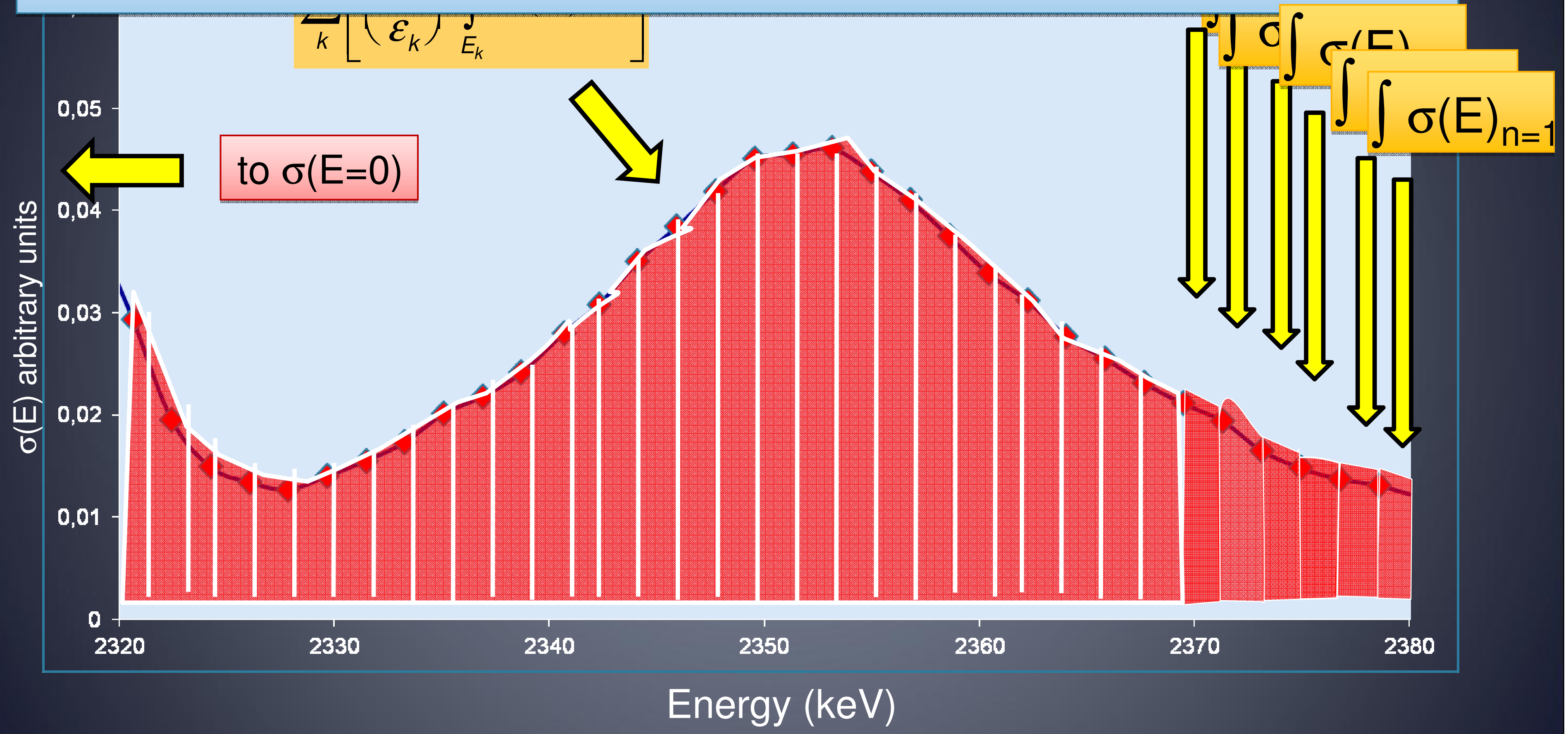
$$Y(E) = \varepsilon_{abs}(E_{\gamma}).\left(\frac{Q}{e}\right).f_m.f_i.N_{av}.A\int_0^{E_0}\frac{\sigma(E)}{\varepsilon(E)}dE$$

ERYA CODE -Sublayers



ERYA CODE -Sublayers

Number of sublayers is chosen equal to the number of energy steps in the cross section



ERYA Code

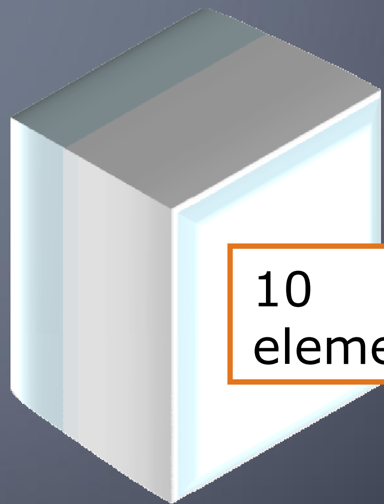
Mass Fraction – first guess

Number	Elem.	Fit	Mass Fraction – first guess
10	Al	☒	0.10
	Ag	☐	PIXE
	9Be	☒	0.05
	7Li	☒	0.05
	Na	☒	0.20
	11B	☒	0.05
	25Mg	☒	0.10
	Mo	☐	PIXE
	Zn	☐	PIXE
	Ca	☐	PIXE

ERYA FIT

improving iteratively the first guess of the sample major composition.

fits simultaneously the yields of all elements present in the PIGE spectra



10 elements

ERYA CODE

In order to test the ERYA code

Measure the Gamma-ray yields from thick samples made of inorganic compounds-

Experimental Yield

Compare Experimental Yield the corresponding

Yield calculated by ERYA

Ratio=1

An alternative method for PIGE analysis

- Motivation
- Introduction to PIGE
- ERYA Code
- Experimental Setup

Experimental

- Range of energy : 0.5 up to 4.5 MeV

- To measure the cross sections: thin target
  - No energy loss through the target
  - Target must be stable
    - Measurements take more than 10 days normally

Experimental

- Incident Energy
  - Precise energy calibration
  - Beam spot ~2 mm
  - Beam line aligned

Experimental

$$Y(E) = \varepsilon_{abs}(E_\gamma).\left(\frac{Q}{e}\right).f_m.f_i.N_{av}.A^{-1}\int_0^{E_0}\frac{\sigma(E)}{\varepsilon(E)}dE$$

Q/e Number of incident protons

Different proton beam currents during the experiment

I= 50 nA I= 500 nA

Chamber Faraday Cup?

Target holder?

Isolated flanges?

Experimental Setup

3 MV Tandem accelerator

Protons beam : 0.5 up to 4.5 MeV

ITN/CFNUL Laboratory at Lisbon

Experimental Setup

2,5 MV Van de Graaff accelerator

Protons and alpha beams : 0.1 up to 2.4 MeV

Preparation of Thin targets

1º Evaporation ... m

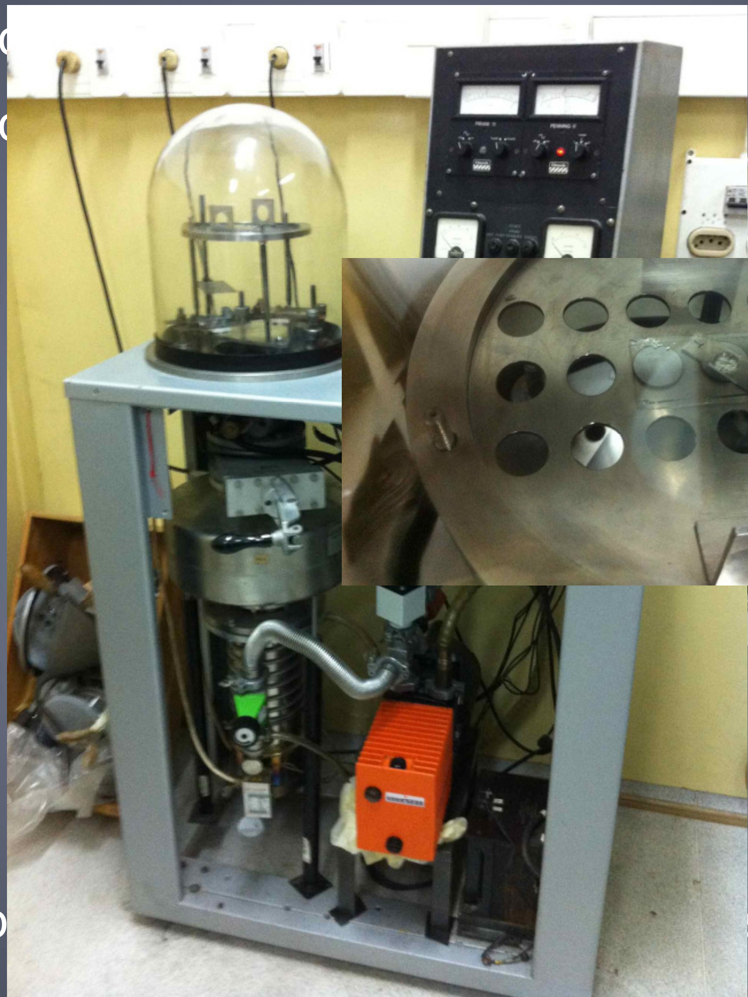
2ª Evaporation ...

$MgWO_4$
$MgNO_3$
MgN_2
MgO
MgF_2
LiF
$NaCl$
NaF

Or:

Be foil
Mg foil

3ª Evaporation o... ect the previous thin film

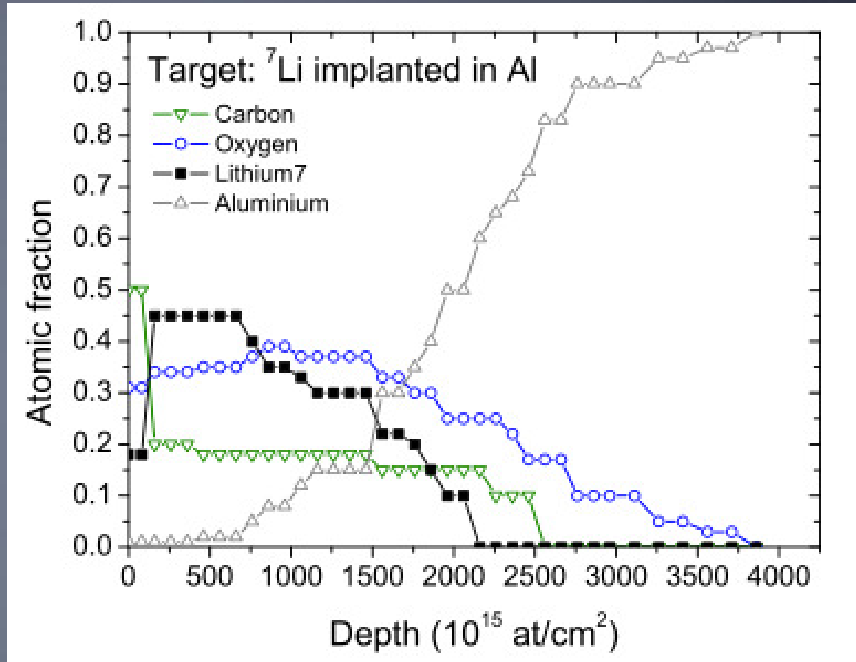


EVAPORATION SETUP

Experimental Setup– Thin targets

210 kV Ion implanter

^{7}Li implanted in Al target



Thesis. João Duarte Neves Cruz. FCT/UNL (2006)

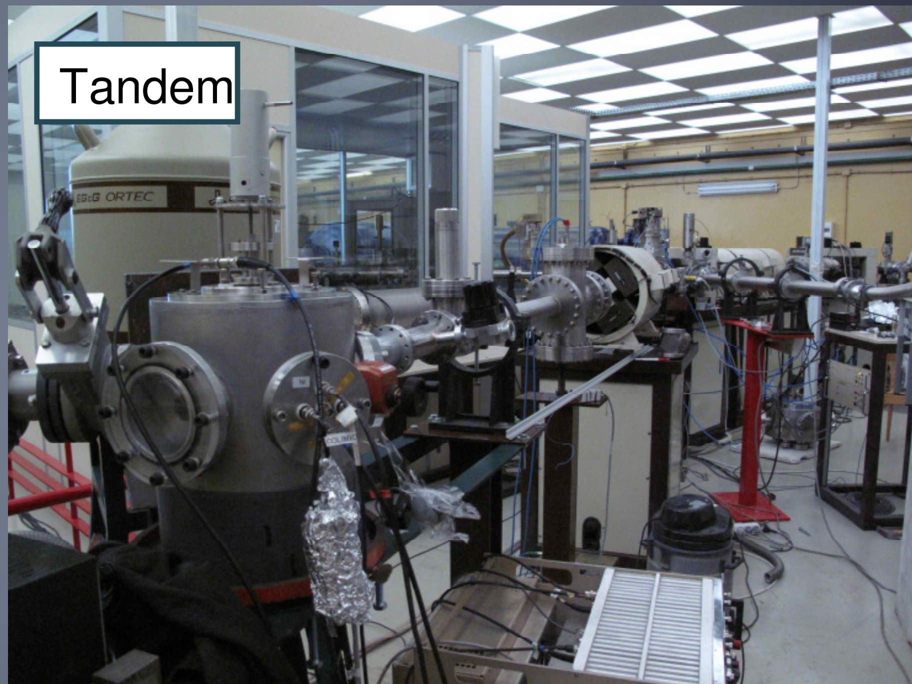
Experimental Setup– Thin targets

210 kV Ion implanter

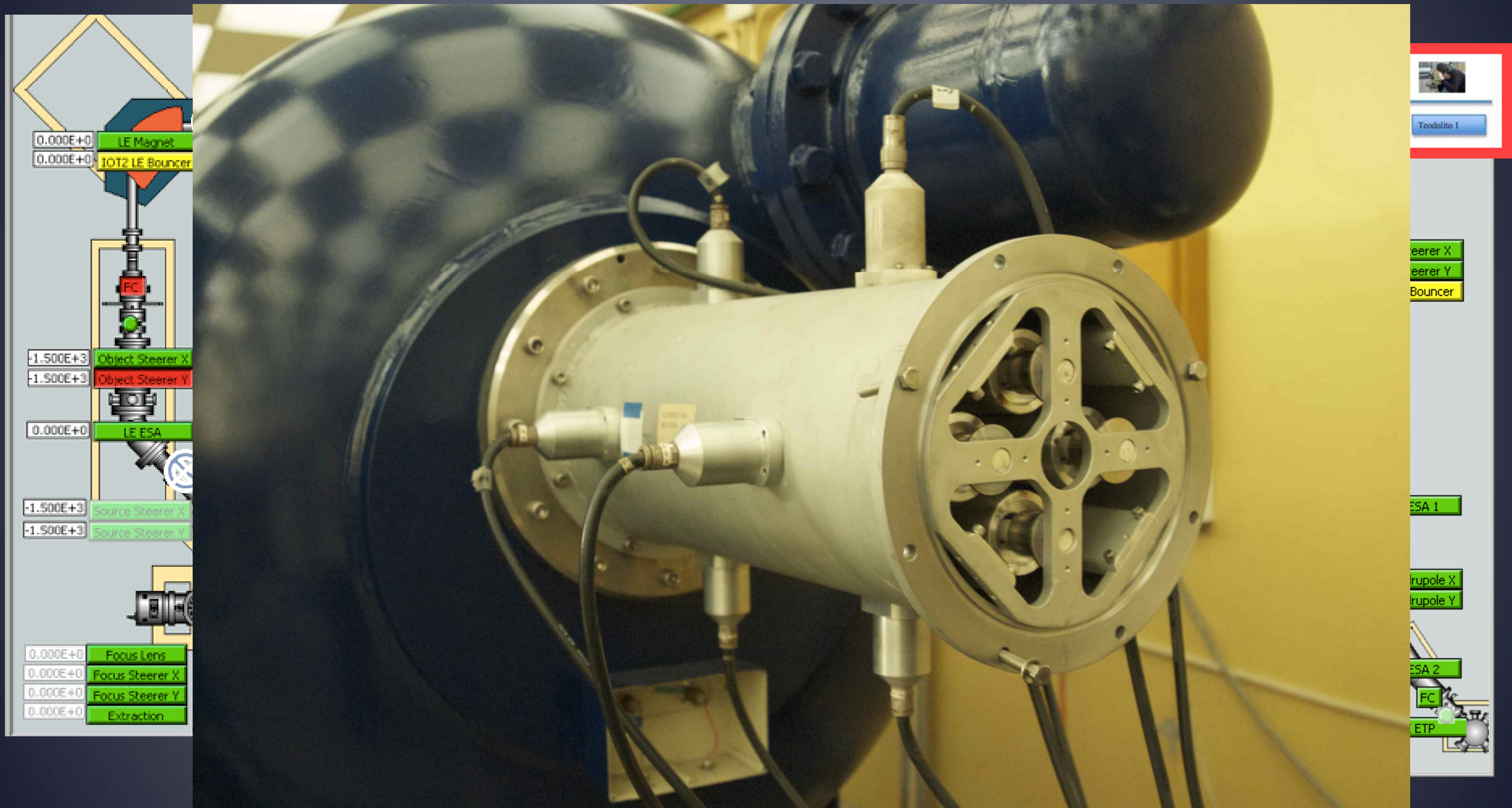
Not stable

Magnesium diffuses at room temperature.

Experimental Setup



Experimental Setup: New Nuclear Reactions Beam Line



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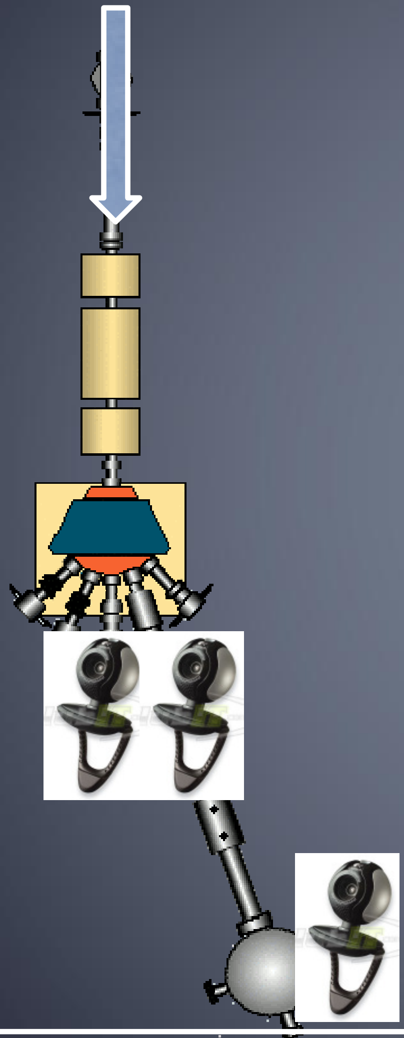

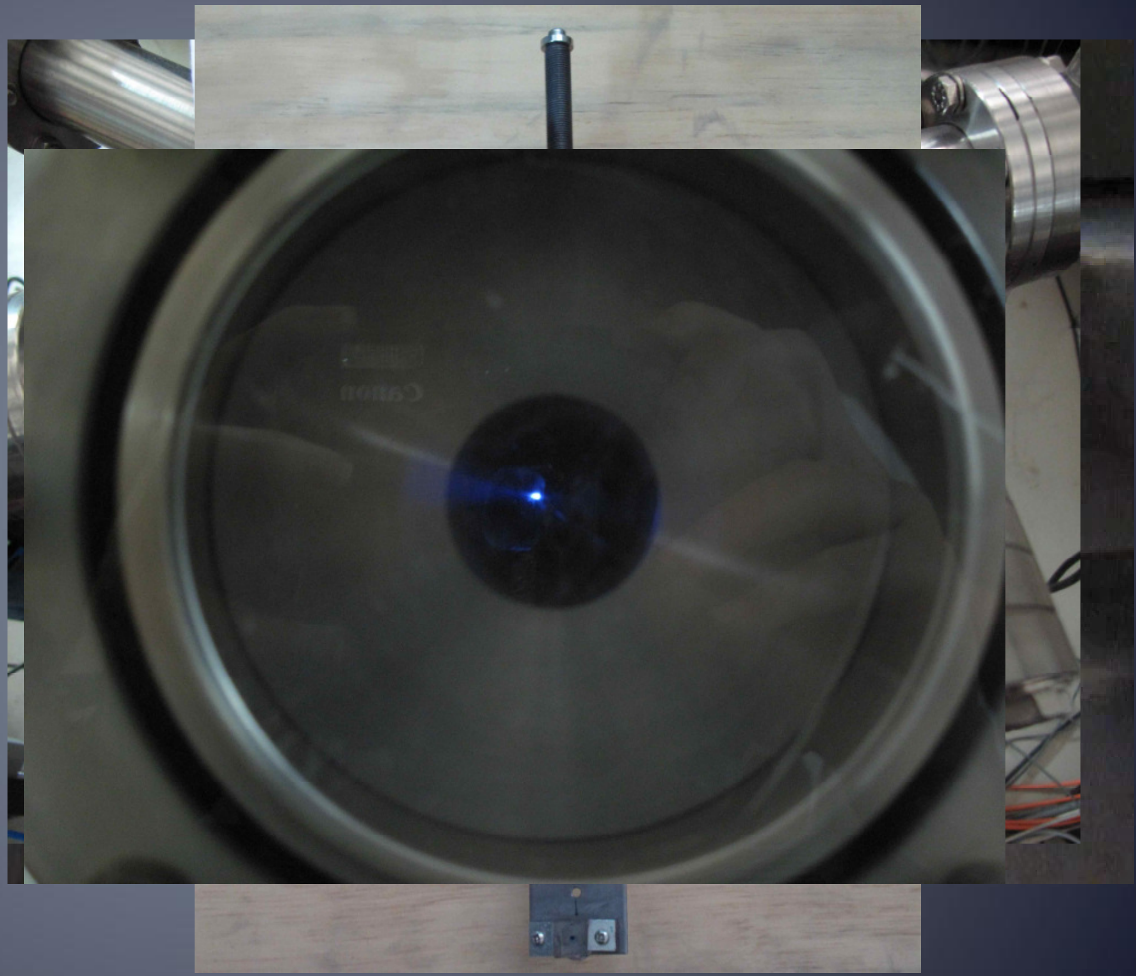

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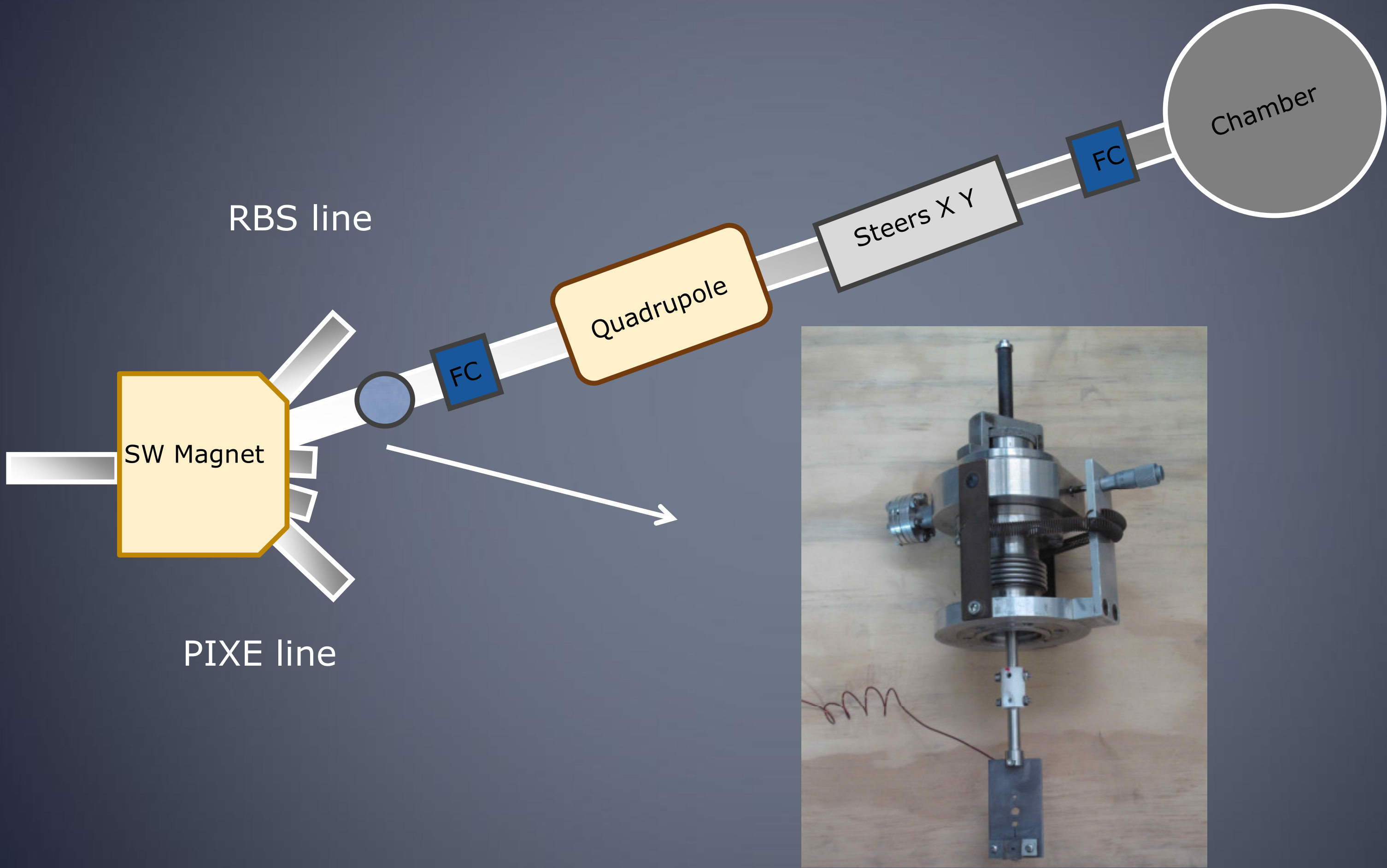

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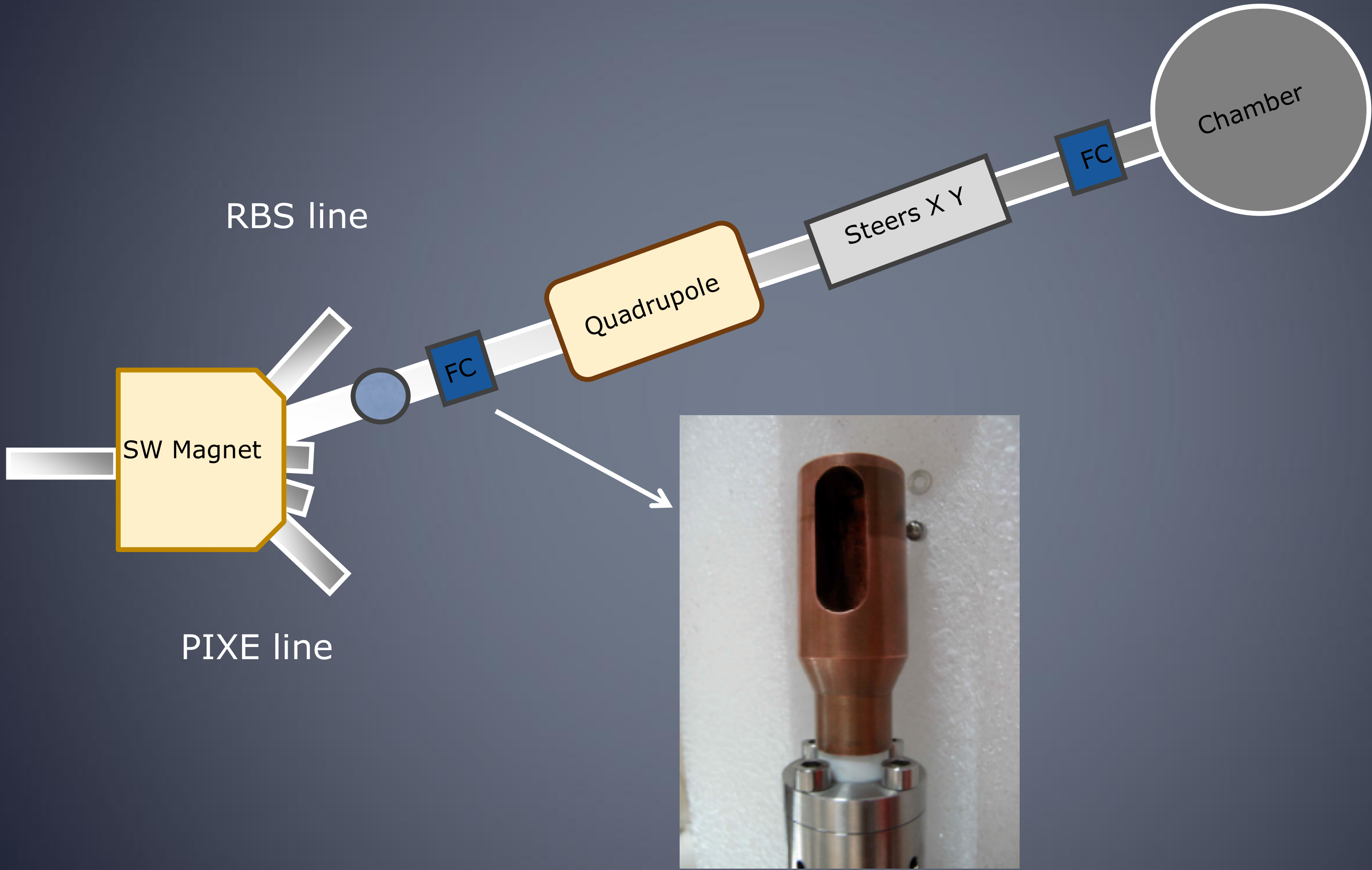
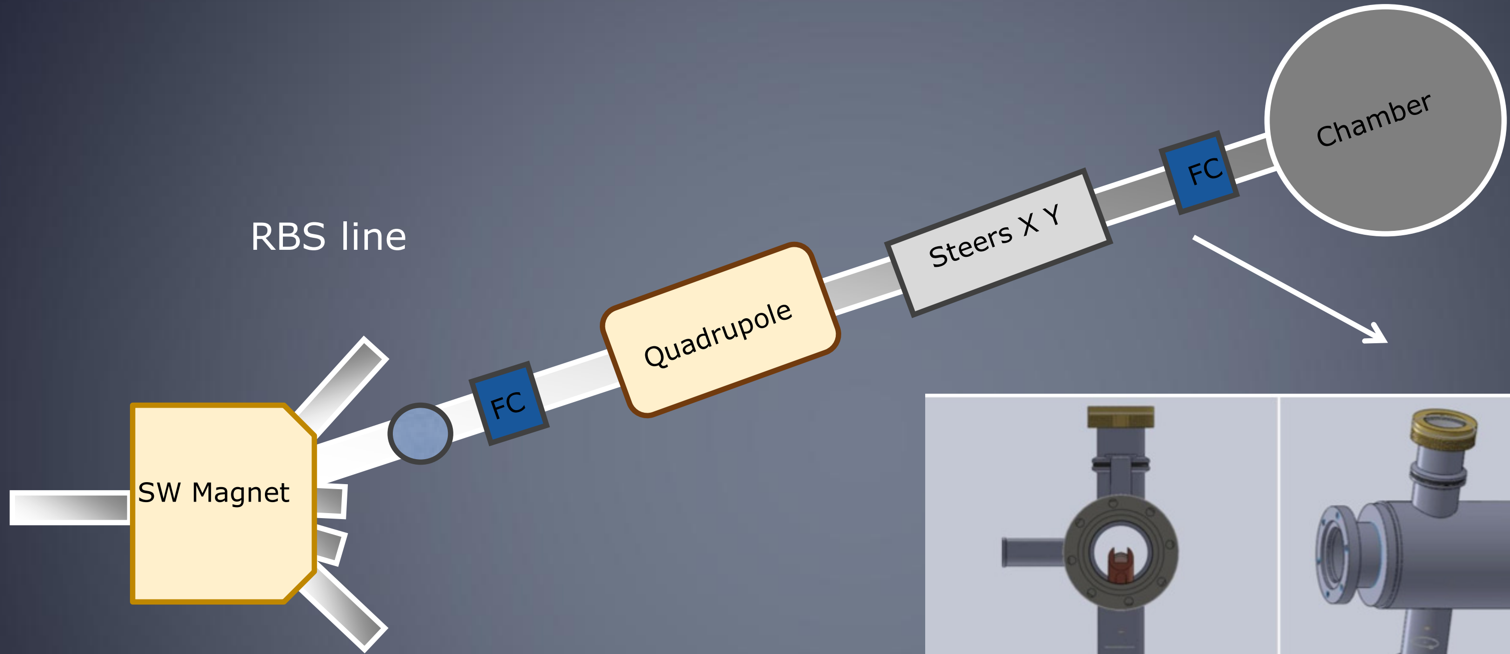
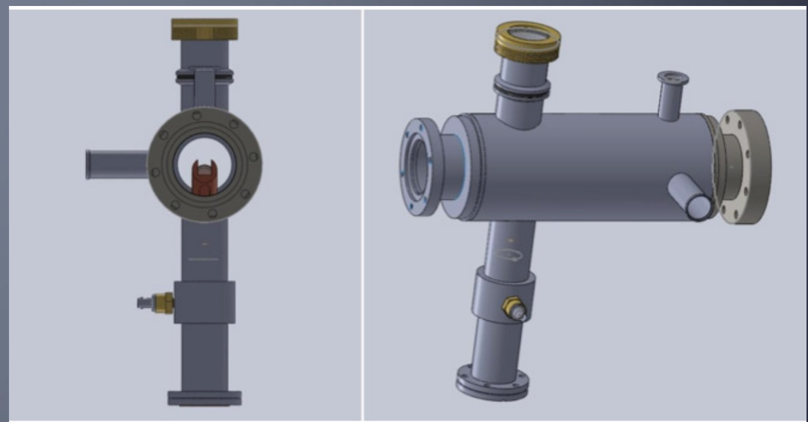


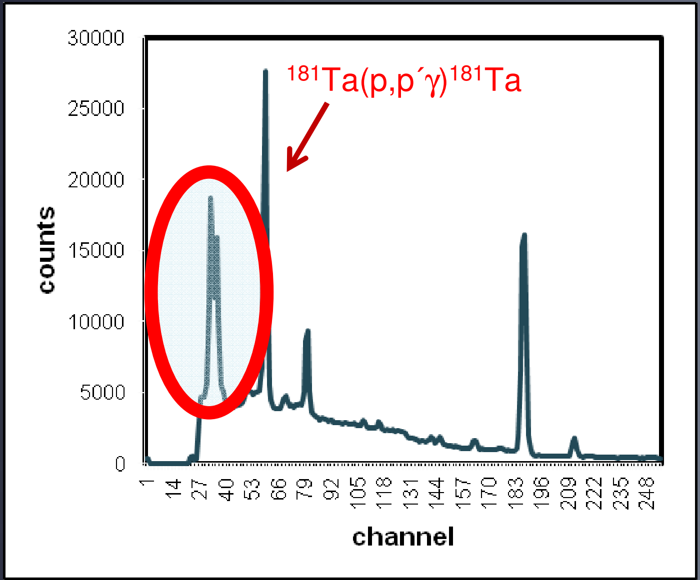
Experimental Setup: New Nuclear Reactions Beam Line





Experimental Setup: New Nuclear Reactions Beam Line

Collimator System



~~Ta collimator~~

110, 197 keV $^{19}F(p,p'\gamma)^{19}F$

Element ?

Background low as possible in the Gamma-ray Spectra

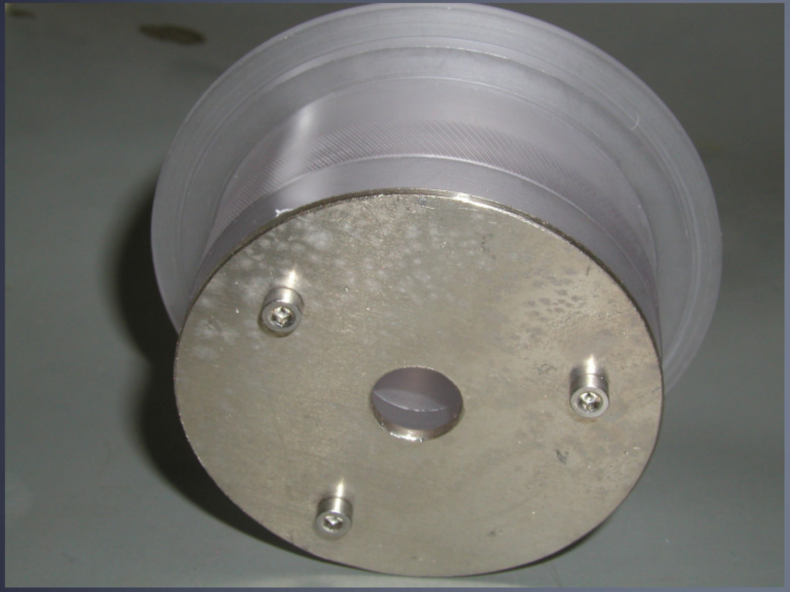
Au collimator

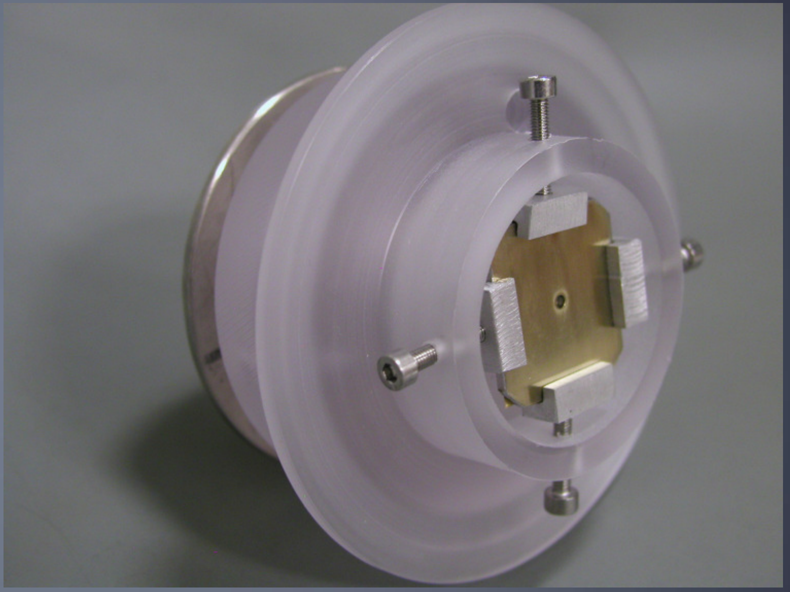
↳ X-rays

↳ Lead foil

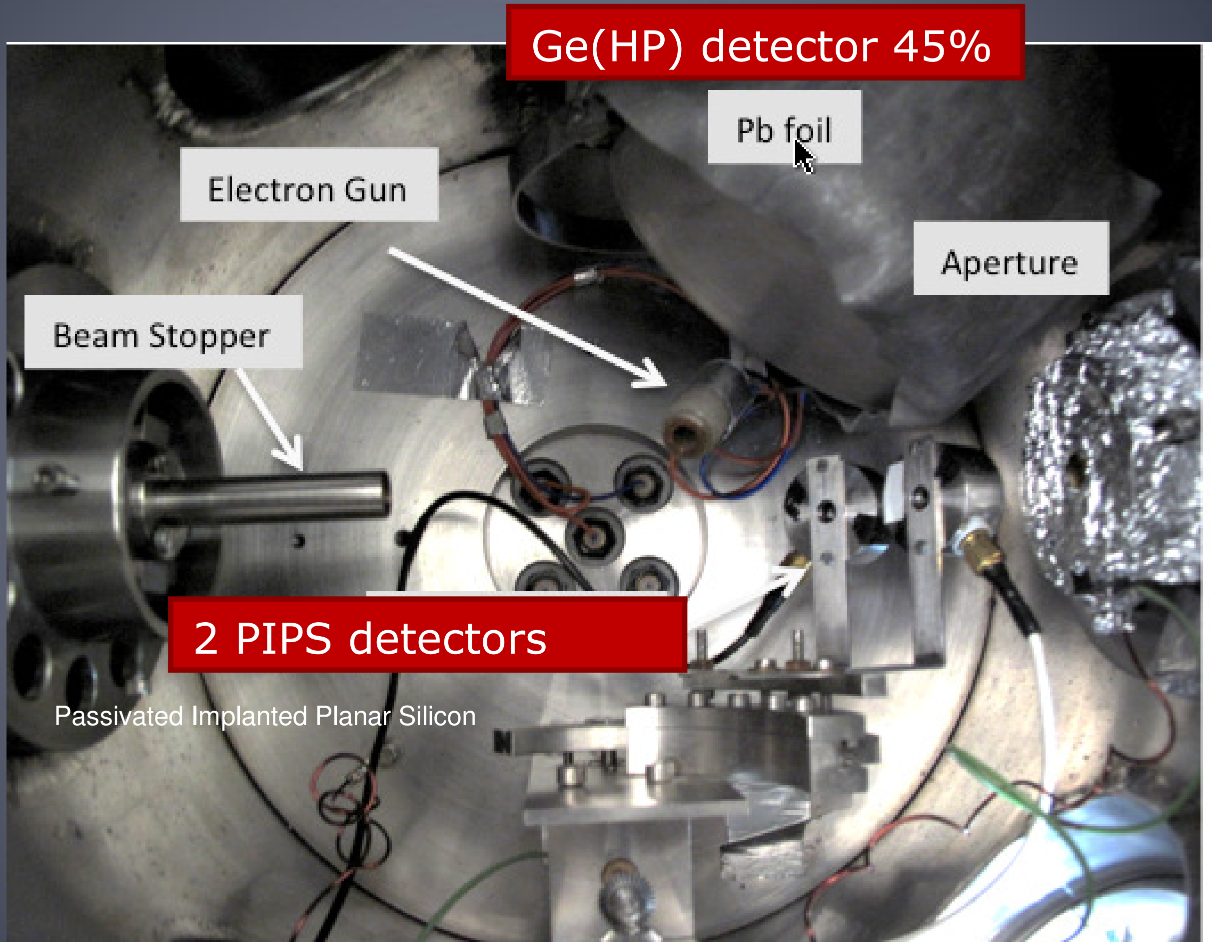
Experimental Setup: New Nuclear Reactions Beam Line

Collimator System





Number of incident protons



Number of incident protons

Chamber Faraday Cup

Stable thin target → EVAPORATION SETUP

LiF/Cu

478 keV $^{7}Li(p,p'\gamma)^{7}Li$

Same collected charge 100μC

I (nA)	Counts for γ-ray emission: 478 keV
50	2059
100	[illegible]
200	[illegible]024
300	1994
450	1990
600	1993

Uncertainty < 3%

Energy Calibration

Target: NaF/Ag
LiF/Cu
Mg/Ag

$$E = 0,976(TV_{nominal} \times 2) + 41,45 \quad [\text{keV}]$$

Protons: (1 + □)V

Incident Energy (keV)	γ-ray emission (keV)	Nuclear Reaction
668.0	6130; 6290; 7120	$^{19}F(p,\alpha\gamma)^{16}O$
872.11	6130; 6290; 7120	$^{19}F(p,\alpha\gamma)^{16}O$
1373.2	6130; 6290; 7120	$^{19}F(p,\alpha\gamma)^{16}O$
1645.1	440	$^{23}Na(p,p'\gamma)^{23}Na$
1930.7	440	$^{23}Na(p,p'\gamma)^{23}Na$
2413.0	1369	$^{24}Mg(p,p'\gamma)^{24}$

Gamma Detector Ge(HP) 45%

Experimenal Setup

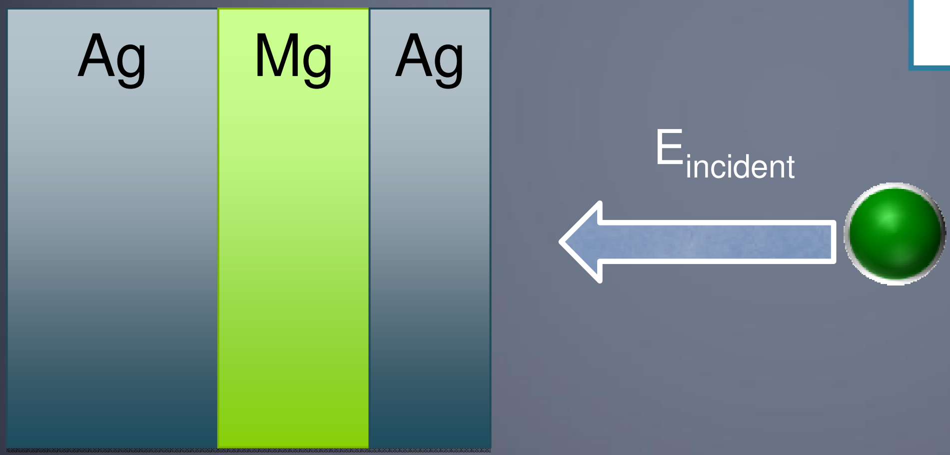
585 keV	**$^{25}Mg(p,p'\gamma)^{25}Mg$**
718 keV	**$^{9}Be(p,\gamma)^{10}B$**
1634 keV	**$^{23}Na(p,p'\gamma)^{23}Na$**
478 keV	**$^{7}Li(p,p'\gamma)^{7}Li$**
429 keV	**$^{10}B(p,\alpha\gamma)^{7}Be$**
110, 197 keV $^{19}F(p,p'\gamma)^{19}F$	
440 keV	**$^{23}Na(p,p'\gamma)^{23}Na$**

An alternative method for PIGE analysis

- Motivation
- Introdution to PIGE
- ERYA Code
- Experimental Setup
- PIGE analysis: Be, B, Li, F, Na e Mg

Analysis of Mg

$$Y_{\gamma}^{^{25}Mg}(E_0,\theta_{lab}) = N_p N_{^{25}Mg}\,\sigma(E_{lab},\theta_{lab})\,\Omega_{\gamma}\,\varepsilon_{\gamma}$$



How much ^{25}Mg do we have?

⇓

stoichiometry

⇓

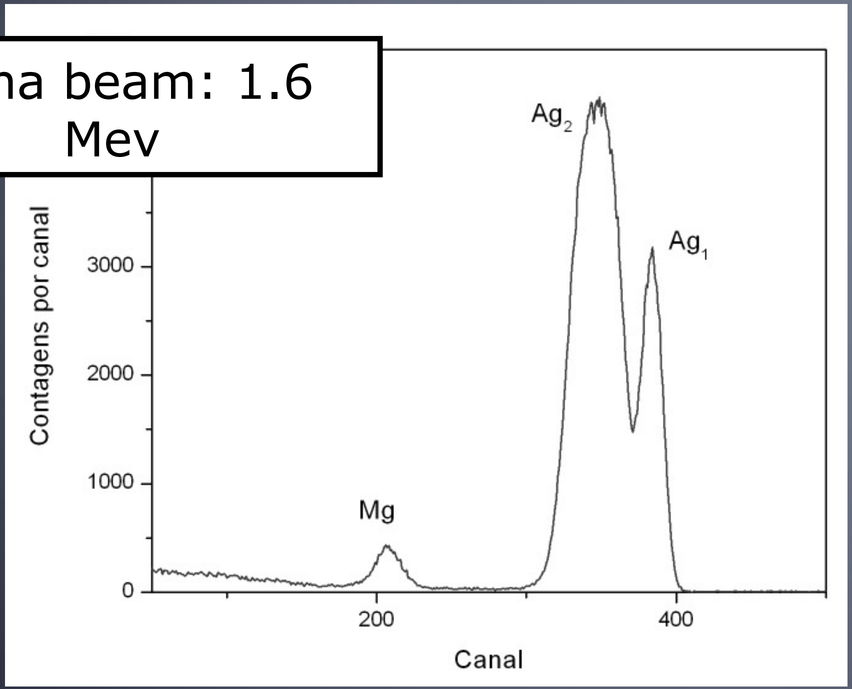
RUTHERFORD BACKSCATTERING SPECTROMETRY

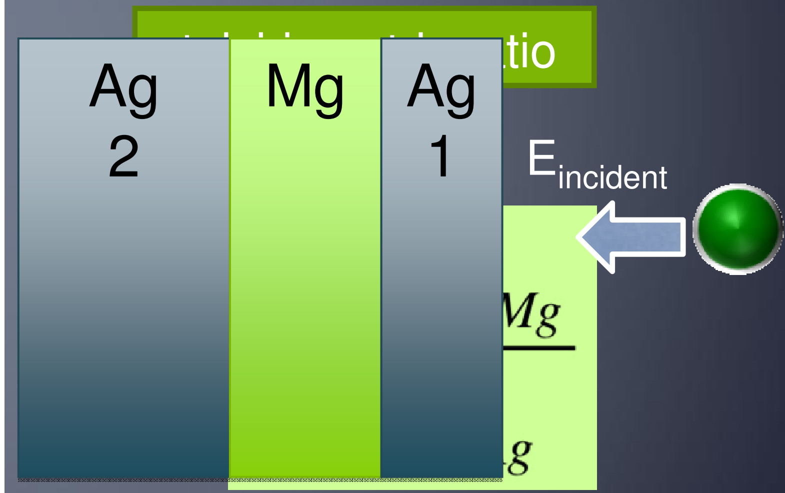
Analysis of Mg

$$Y_{^{25}Mg}(E_0,\theta_{lab}) = N_\alpha N_{^{25}Mg}\sigma_{ruth}^{^{25}Mg}(E_{lab},\theta_{lab})\Omega_p\varepsilon_p$$

$$Y_{Ag}(E_0,\theta_{lab}) = N_\alpha N_{Ag}\sigma_{ruth}^{Ag}(E_{lab}-\Delta E,\theta_{lab})\Omega_p\varepsilon_p$$

Alpha beam: 1.6 Mev





Analysis of Mg

Two spectrum simultaneously :

$$Y_{\gamma}^{^{25}Mg}(E_0,\theta_{lab}) = N_p N_{^{25}Mg}\,\sigma(E_{lab},\theta_{lab})\,\Omega_{\gamma}\varepsilon_{\gamma}$$

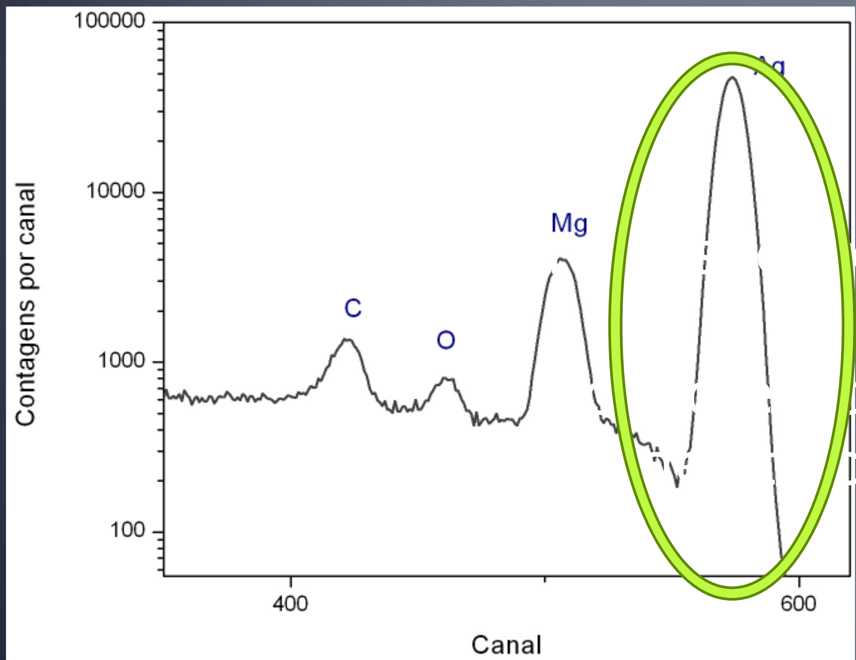
$$Y_{Ag}(E_0,\theta_{lab}) = N_p N_{Ag}\sigma_{ruth}^{Ag}(E_{lab}-\Delta E,\theta_{lab})\Omega_p\varepsilon_p$$

Analysis of Mg

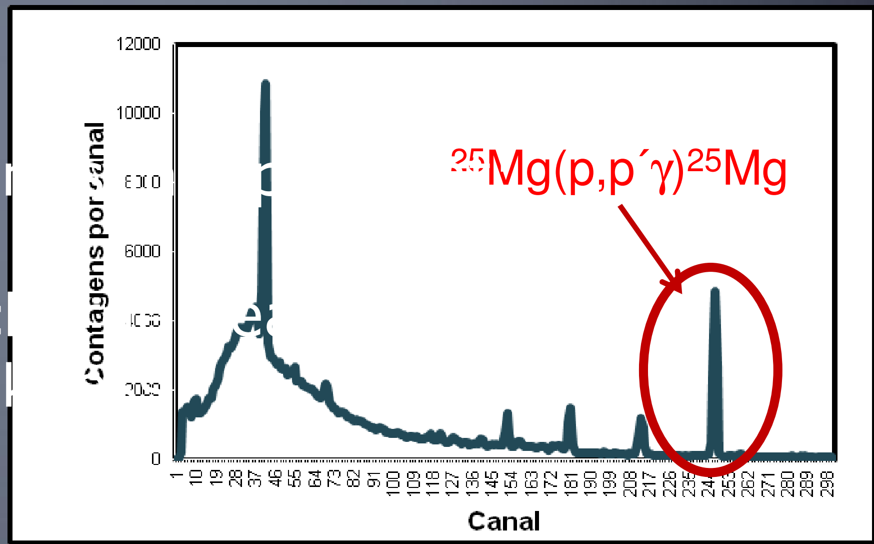
$$\sigma(E_{lab},\theta_{lab}) = \frac{1}{r}\frac{Y_{\gamma}^{25\,Mg}(E_{lab},\theta_{lab})\,\sigma_{ruth}^{Ag}(E_{lab}-\Delta E,\theta_{lab})\,\Omega_{p}\,\varepsilon_{p}}{Y_{p}^{Ag}(E_{lab},\theta_{lab})\,\varepsilon_{absoluta}}$$

Two spectrum simultaneously :

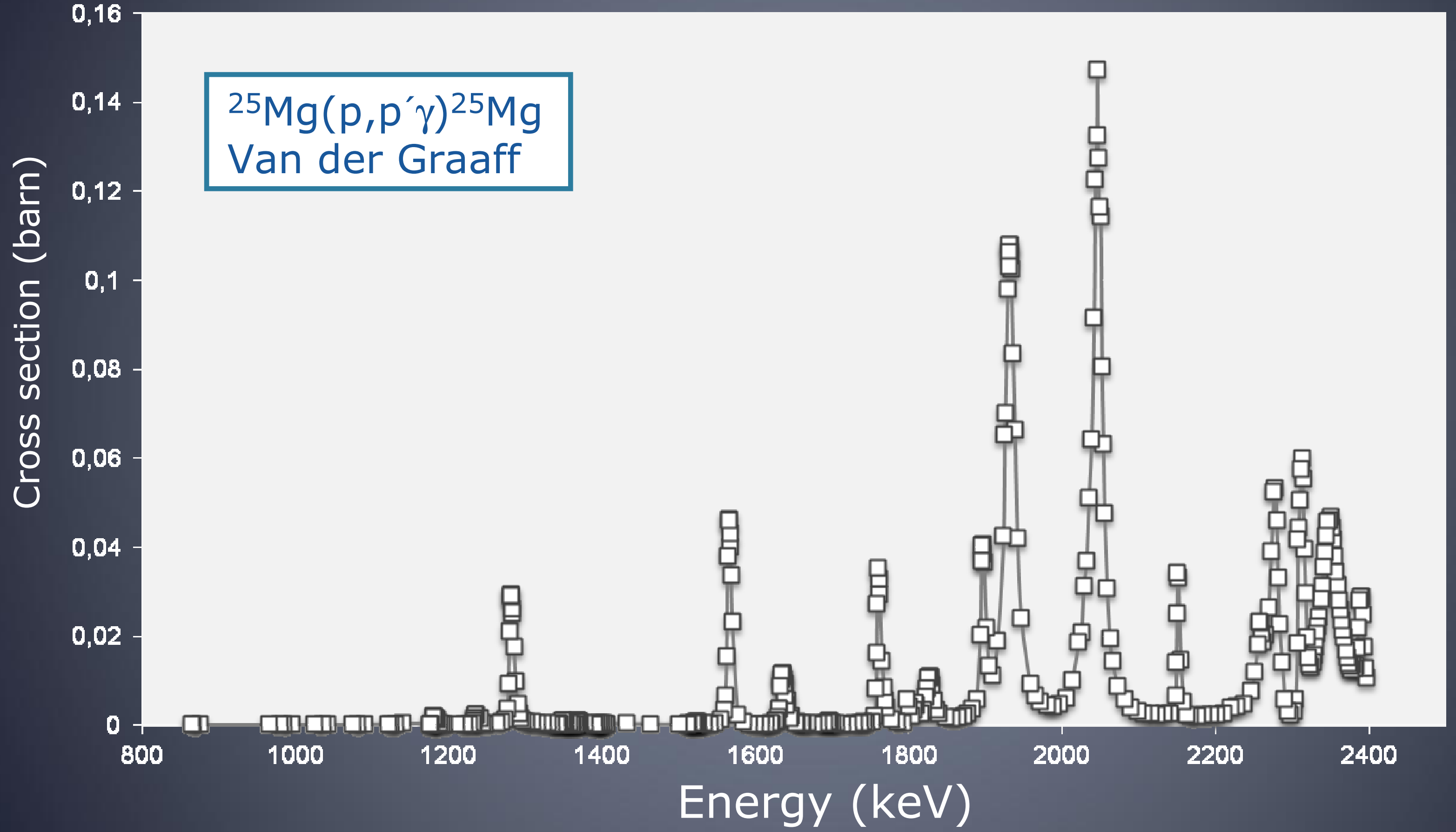
Particle spectra



γ–ray Spectra



Analysis of Mg

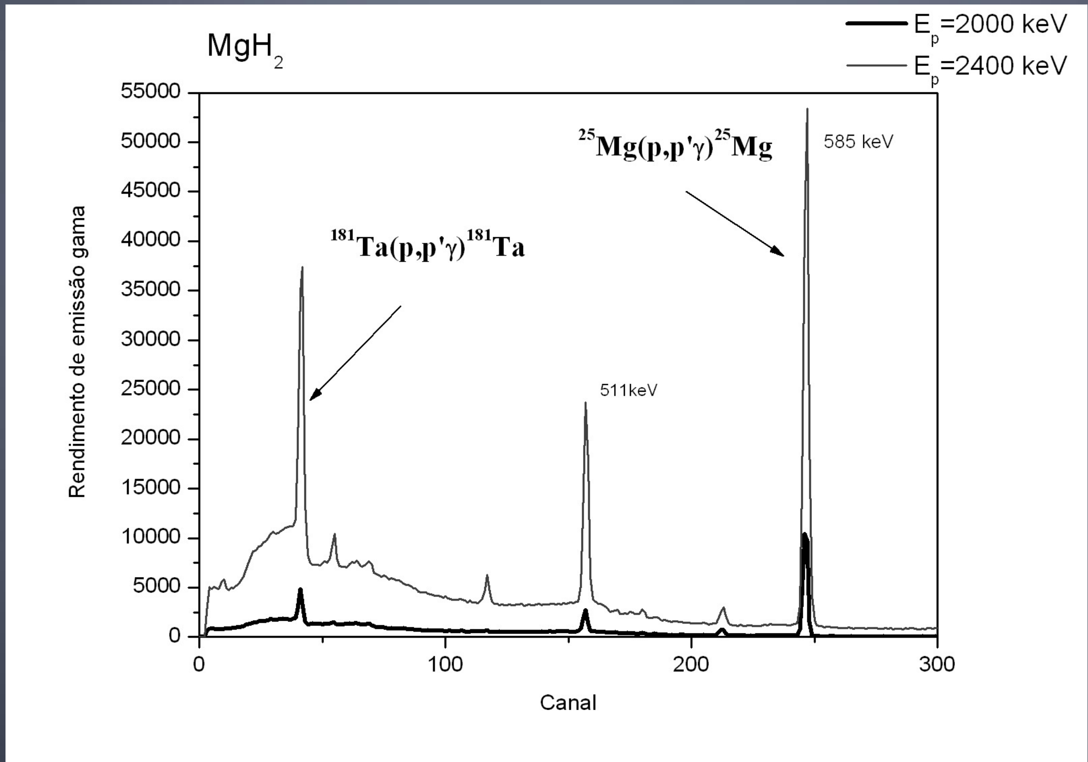


M. Fonseca et al, NIMB 268 (2010) 1806.

Analysis of Mg

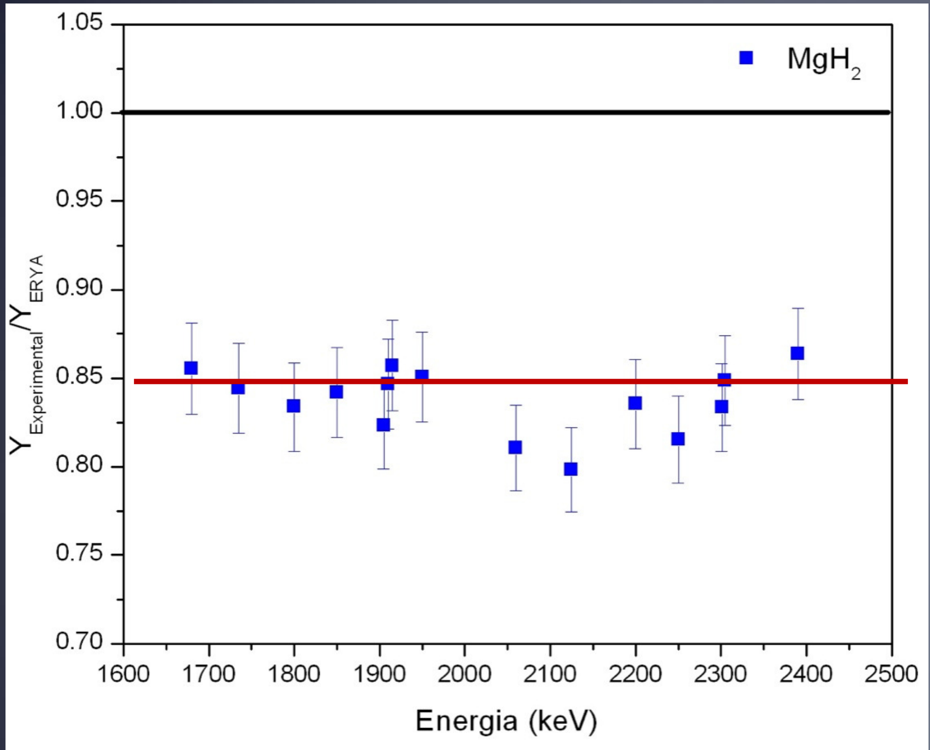
Pressed Pellets Analysis of inorganic compounds with known composition

$Mg(OH)_2$; MgH_2; $MgSO_4$



M. Fonseca et al, NIMB 268 (2010) 1806.

Analysis of Mg



Ratio=1

The points follow trend lines parallel to the straight line corresponding to the ratio equal to 1

The deviations results from systematic uncertainties on the values of the collected beam charge

The average ratio was introduced as correction factor in the ERYA code.

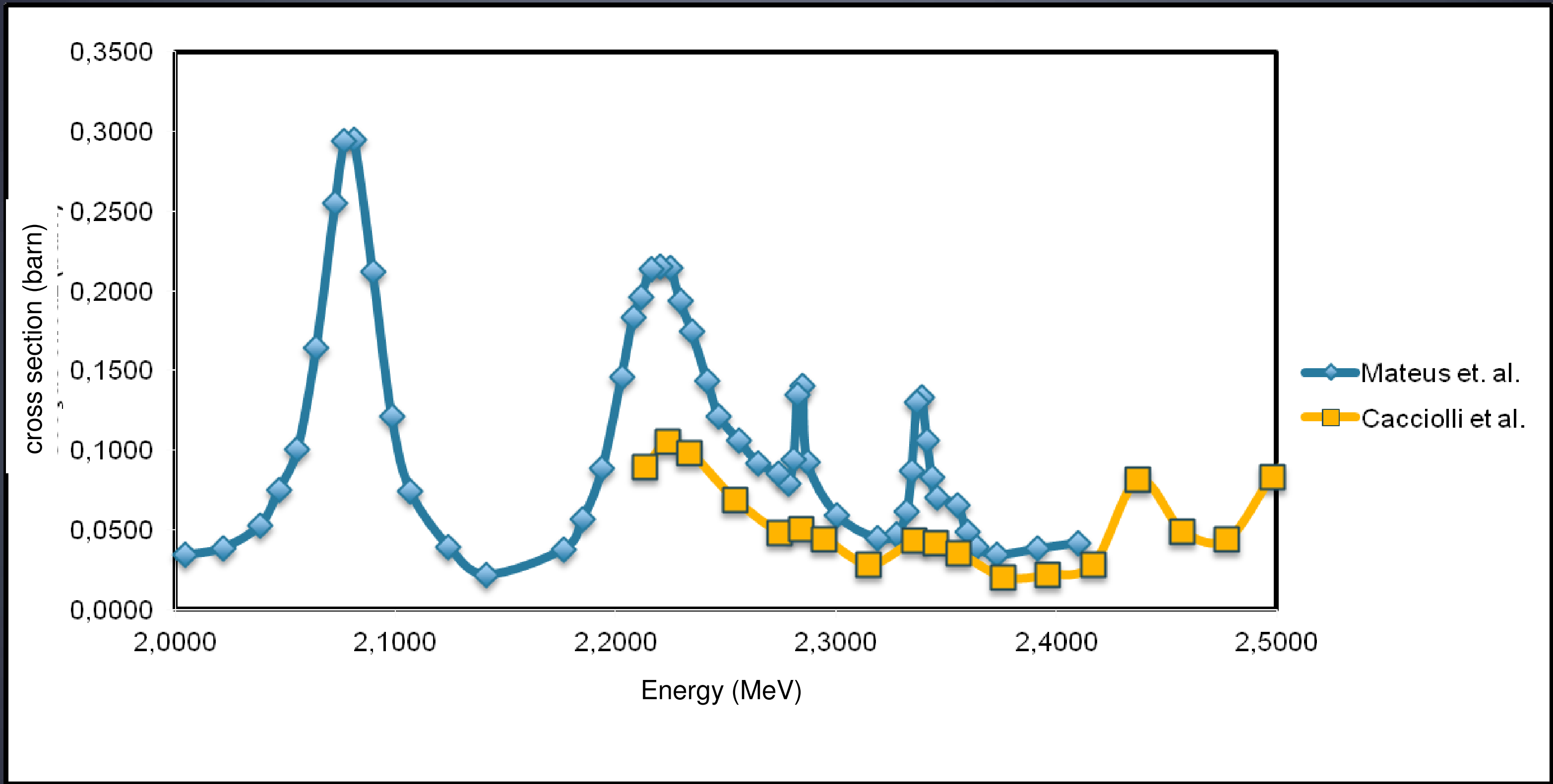
Analysis of Mg

Energy (keV)	Sample	Ratio Yexp/Ycal
3962	MgH_2	0,940
3762	MgH_2	0,900
2414	MgH_2	1,010
2400	$Mg(OH)_2$ MgH_2 $MgSO_4$	1,020 1,030 1,032
2200	$Mg(OH)_2$ MgH_2 $MgSO_4$	1,043 1,046 1,052
2000	$Mg(OH)_2$ MgH_2 $MgSO_4$	1,007 1,099 1,054

PIGE analysis: Be, B, Li, F and Mg

Element	Energy (keV)	Sample	Ratio Y_{exp}/Y_{cal}
^{10}B	2400-3960	B+Ag	Uncertainty < 5%
^{7}Li	3619-3962	LiF+Ag	Uncertainty < 5%
^{9}Be	1218-1708	BeO	Uncertainty < 5%
^{19}F (197 keV)	3619-3962	LiF+Ag	Uncertainty < 8%

Analysis ^{23}Na – 440 keV

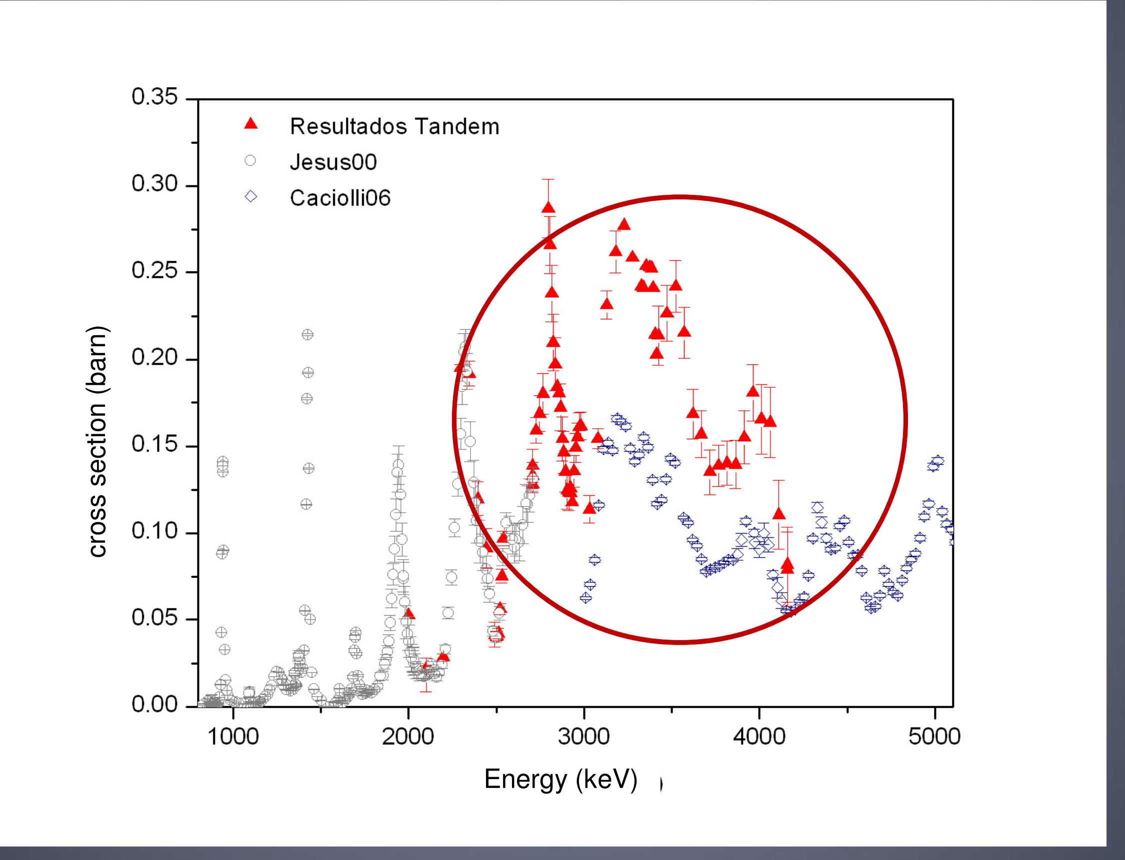


A. Caciolli et al, NIMB 266 (2008) 1392

R. Mateus et al, NIMB 219-220 (2004) 307

Analysis ^{19}F – 110 keV

^{19}F, 110keV:



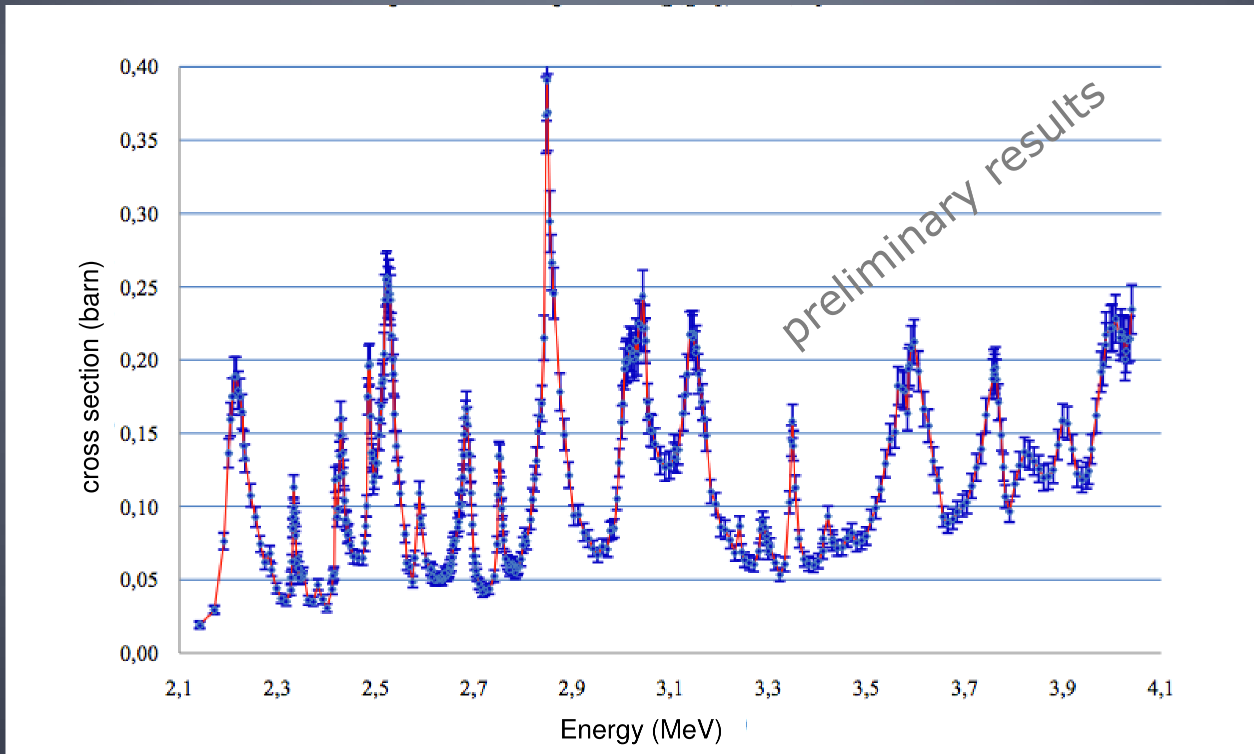
A. Caciolli et al, NIMB 249 (2006) 98

A. P. Jesus et al, NIMB 161-163 (2000) 186

Analysis ^{19}F and ^{23}Na

Target: NaF/Ag → Simultaneous analysis of F and Na

Measurements at Portugal ITN/CFNUL and Italy INFN



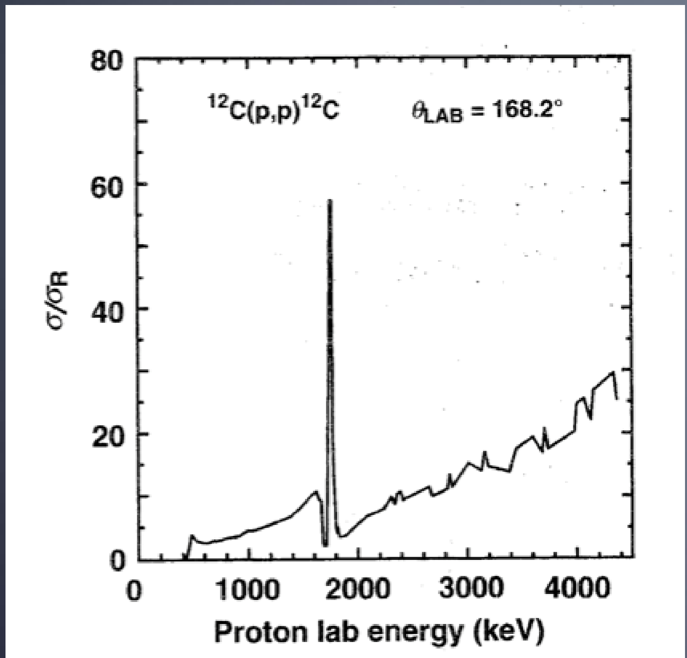
Thesis. Filipa Lourenço. FCT/UNL (2006)

PIGE analysis of C

$^{12}C(p,\gamma)^{13}N$ $^{12}C(p,p'\gamma)^{12}C$ ⇨ Very difficult to measure

$^{12}C(p,p)^{12}C$

Resonances take place for specific energies

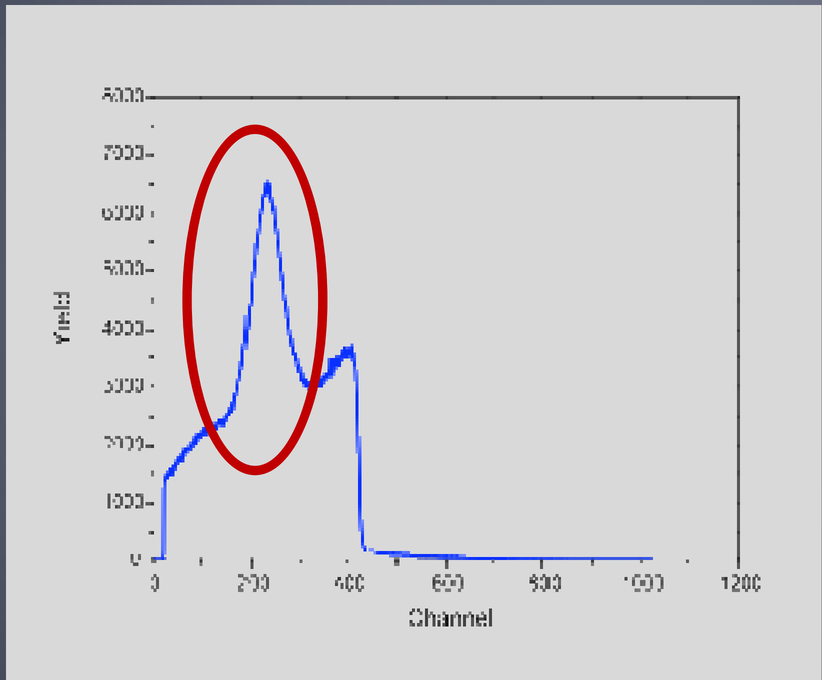


non–Rutherford cross section of C at 4.0 MeV is 128 greater than Rutherford´s one

J. R. Tesmer, M. Nastasi, Handbook of modern ion beam material analysis. (MRS,Pitssburg,1995)

PIGE analysis of C

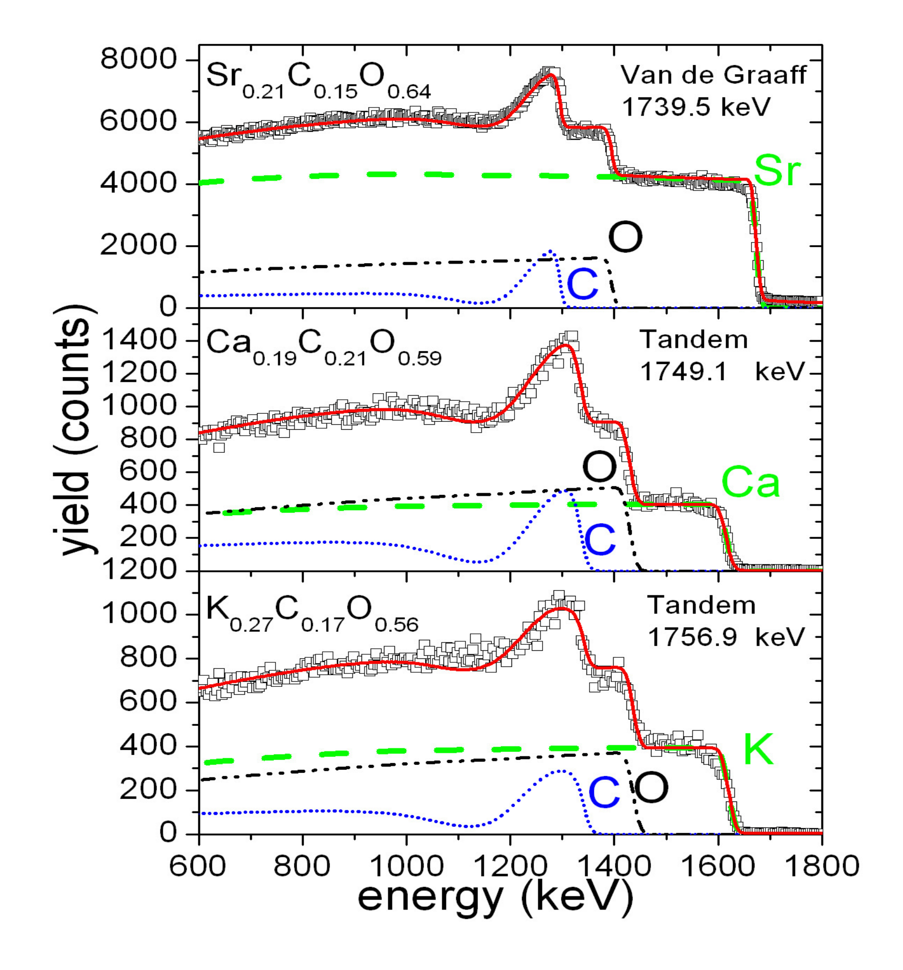
$^{12}C(p,p)^{12}C$



PIPS:140º ; E=1979 keV

Target: Graphitte

PIGE analysis of C



$^{12}C(p,p)^{12}C$

Pressed pellets
$SrCO_3$, $CaCO_3$ and K_2CO_3

NDF program ⇨ Mass concentration

M. Fonseca et al NIMB (2011)

DOI:10.1016/J.NIMB.2011.04.060

PIGE analysis of C

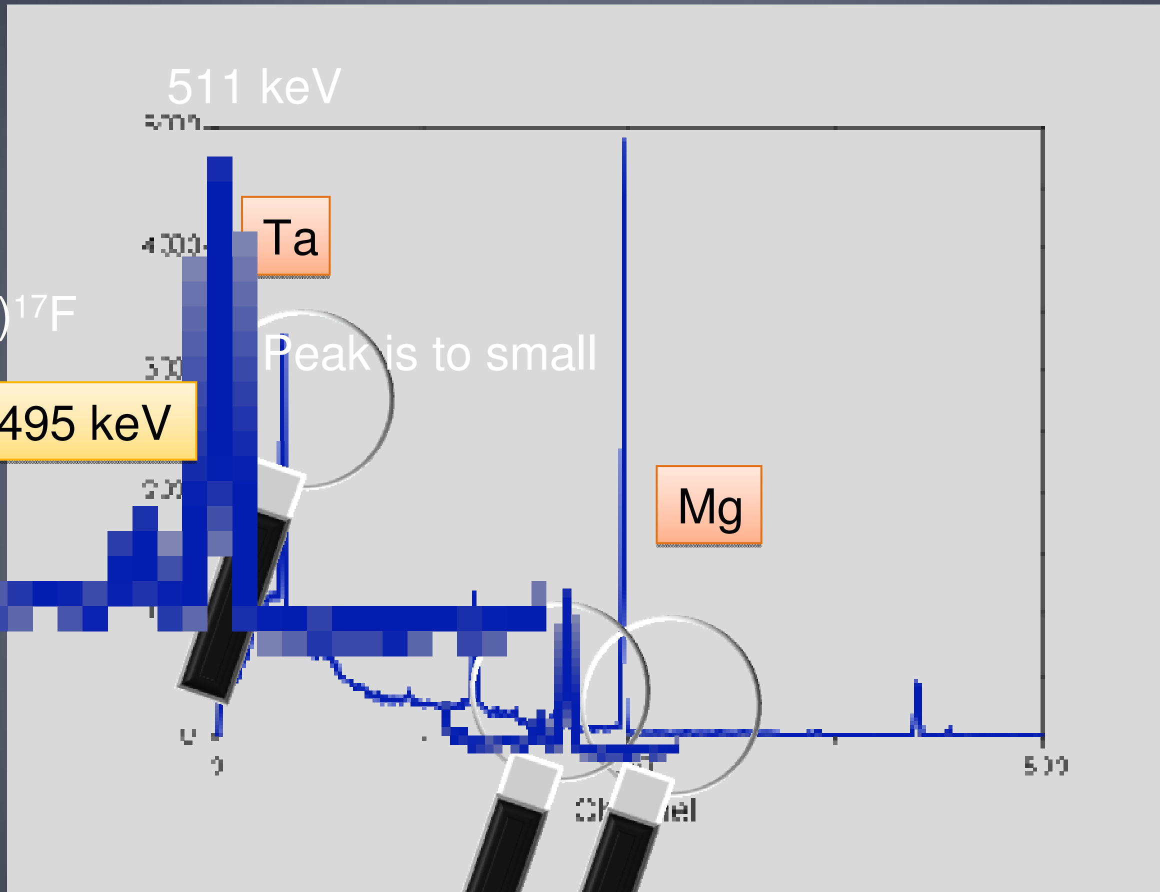
Number: 11

Elem.	Fit	Mass Fraction – first guess
Al	X	0.10
Ag		PIXE
9Be	X	0.05
7Li	X	0.05
Na	X	0.20
11B	X	0.05
25Mg	X	0.10
Mo		PIXE
Zn		PIXE
Ca		PIXE
C		Elastic Backscattering

ERYA FIT

PIGE analysis of O

$Mg(OH)_2$
E=2.0 MeV



FCT

An alternative method for PIGE analysis

$$Y(E) = \varepsilon_{abs}(E_\gamma).\left(\frac{Q}{e}\right).f_m.f_i.N_{av}.A^{-1}\int_0^{E_0}\frac{\sigma(E)}{\varepsilon(E)}dE$$

Experimental Yield

Yield calculated by ERYA

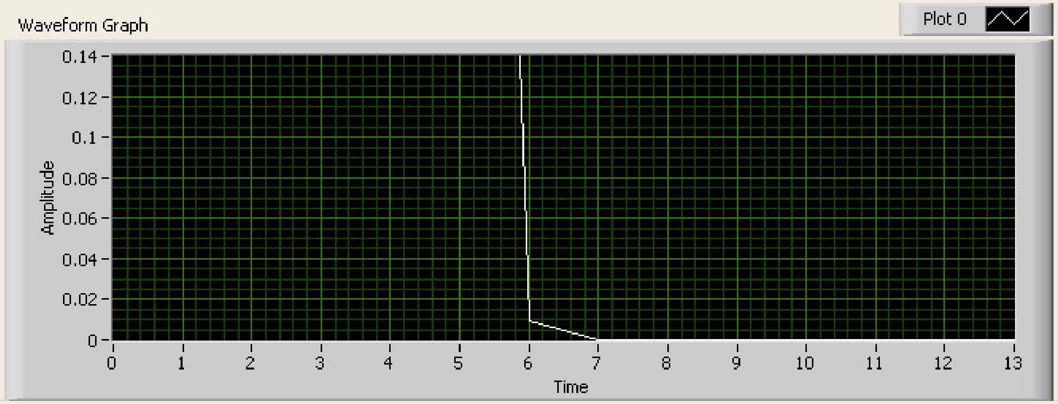
σ(E)-Nuclear reaction cross section related to the gamma emission

ERYA Code

Number	Elem.	Fit	gama	Z	fi	Mass	IsoMass	%	Stoch.	Yo	YoSimul	YoExp	% atomic	% mass	Yo Fitted
10	Ac	X	0	89	0	227	227	0.1	1	0	0	0	0.1	0.529	0
	Ag	X	0	47	0	107.87	107.87	0.1	1	0	0	0	0.1	0.252	0
	9Be	X	718	4	1	9.0121ε	9.0121ε	0.15	1	0	747934	95161.2	0.1	0.021	95161.2
	7Li	X	478	3	0.925	6.941	7.016	0.05	1	0	6357.32	1894.57	0.1	0.016	1894.57
	Na	X	440	11	1	22.99	22.989ε	0.1	1	0	3104.94	1611.09	0.1	0.054	1611.09
	7Li	X	478	3	0.925	6.941	7.016	0.15	1	0	19072	1894.57	0.1	0.016	1894.57
	9Be	X	718	4	1	9.0121ε	9.0121ε	0.1	1	0	498622	95161.2	0.1	0.021	95161.2
	Na	X	440	11	1	22.99	22.989ε	0.05	1	0	1552.47	1611.09	0.1	0.054	1611.09
	9Be	X	718	4	1	9.0121ε	9.0121ε	0.1	1	0	498622	95161.2	0.1	0.021	95161.2
	7Li	X	478	3	0.925	6.941	7.016	0.1	1	0	12714.6	1894.57	0.1	0.016	1894.57

Energy	Energy 2	Size	Perc
2000	1950	5	5.000

FIT STOP



% mass 2

0
0

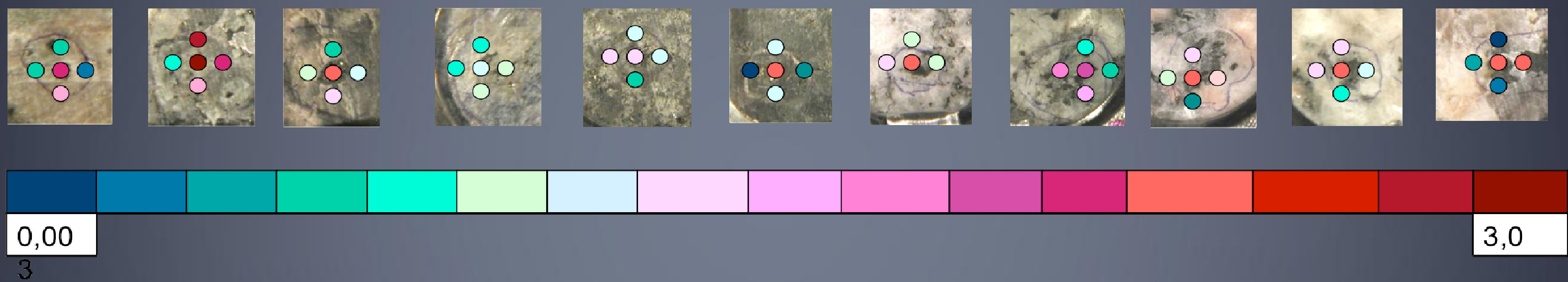
An alternative method for PIGE analysis

- Motivation
- Introdution to PIGE
- ERYA Code
- Experimental Setup
- PIGE analysis: Be, B, Li, F, Na and Mg
- Applications

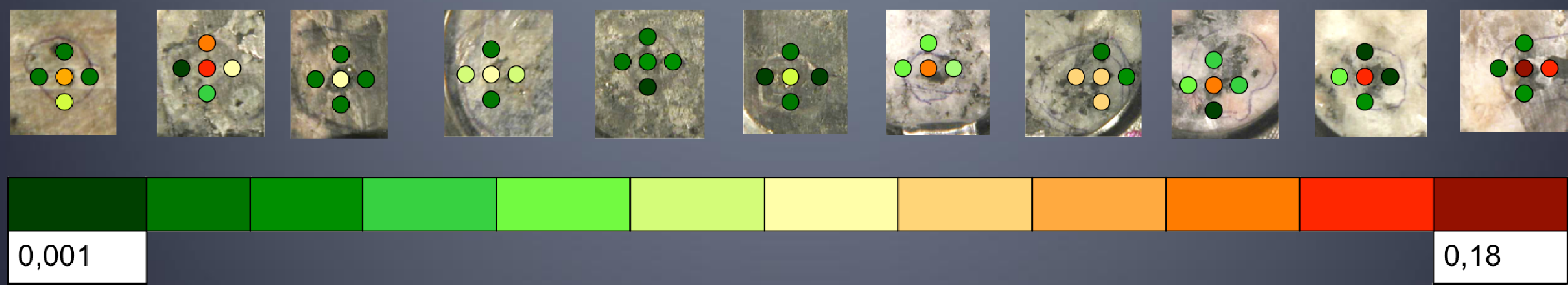
PIGE analysis of Li, F-ornamental stones

11 ornamental stones

For F



For Li



Applications

† B Quantification

Custódia de Belém

Mosaic Glass

Applications

http://helenaabrantes.com/

Applications

A ceramic glaze contains three necessary components:

- Body Kaolin ($Al_2O_3.2SiO_2.2H_2O$)
- Flint Silica
- Flux Depending on the glaze

borax (where Boron is the main element)
barium carbonate,
calcium carbonate,
lead bisilicate,
lithium oxide,
magnesium carbonate,
sodium oxide,
potassium oxide
zinc oxide

Applications

ceramic glaze

Applications

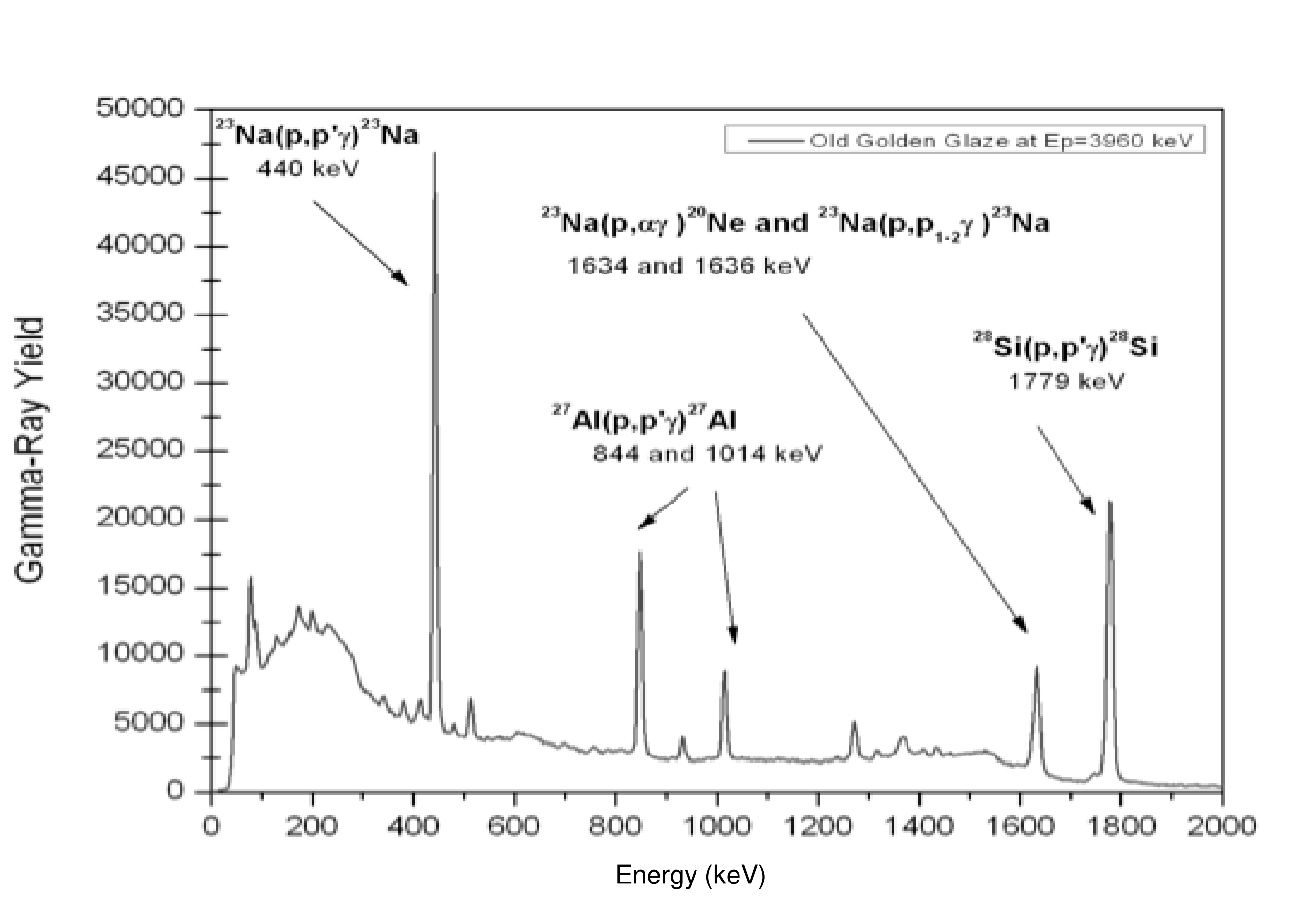
Portuguese sellers do not supply the composition of these frits

Nowadays, there are no golden glazes at low temperatures commercially available

two new, supposed to be, golden glazes show a metallic black color at those temperatures

Our work aims at providing the chemical information needed by the ceramists in order to obtain the desired golden glaze

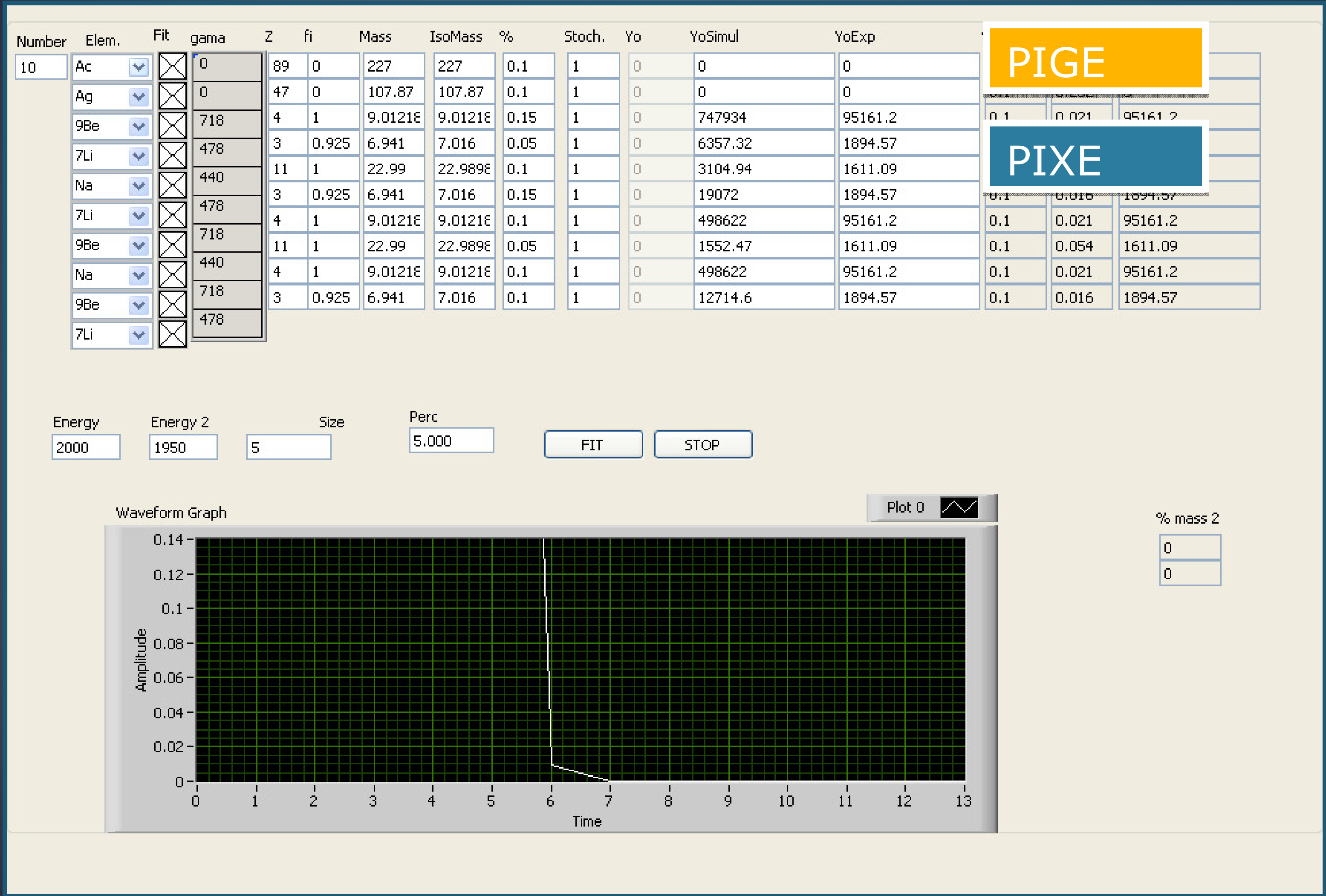
Applications



M. Fonseca et al NIMB (2011)

DOI:10.1016/J.NIMB.2011.04.060

Applications



Elem.	Fit	gama	Z	fi	Mass	IsoMass	%	Stoch.	Yo	YoSimul	YoExp			
Ac	☒	0	89	0	227	227	0.1	1	0	0	0			
Ag	☒	0	47	0	107.87	107.87	0.1	1	0	0	0			
9Be	☒	718	4	1	9.01218	9.01218	0.15	1	0	747934	95161.2	0.1	0.021	95161.2
7Li	☒	478	3	0.925	6.941	7.016	0.05	1	0	6357.32	1894.57			
Na	☒	440	11	1	22.99	22.9898	0.1	1	0	3104.94	1611.09			
7Li	☒	478	3	0.925	6.941	7.016	0.15	1	0	19072	1894.57	0.1	0.016	1894.57
9Be	☒	718	4	1	9.01218	9.01218	0.1	1	0	498622	95161.2	0.1	0.021	95161.2
Na	☒	440	11	1	22.99	22.9898	0.05	1	0	1552.47	1611.09	0.1	0.054	1611.09
9Be	☒	718	4	1	9.01218	9.01218	0.1	1	0	498622	95161.2	0.1	0.021	95161.2
7Li	☒	478	3	0.925	6.941	7.016	0.1	1	0	12714.6	1894.57	0.1	0.016	1894.57
7Li	☒	478												

Applications

Flux: sodium oxide
lead bisilicate

Old golden glaze: Mo e Co

Element	Old Golden Glaze Mass Fraction(%)	11646 Glaze Mass Fraction (%)	6910 Glaze Mass Fraction(%)
Al	0,60	1,53	1,61
Si	4,51	6,40	6,10
K	0,29	0,76	0,57
Ca	0,15	2,02	1,00
Ti	$1{,}43 \times 10^{-3}$	0,21	$2{,}27 \times 10^{-2}$
Cr	$1{,}27 \times 10^{-3}$	$1{,}35 \times 10^{-2}$	$1{,}56 \times 10^{-2}$
Mn	0,36	1,76	1,48
Fe	0,37	0,19	0,21
Co	0,19	-	-
Ni	$4{,}75 \times 10^{-3}$	0,51	$9{,}80 \times 10^{-3}$
Cu	0,28	0,27	0,22
Mo	0,34	-	-
Pb	18,1	23,7	22,5
O	45,03	49,26	46,00
Na	34,11	15,70	22,96

Conclusions

- The ERYA code is a reliable and accurate method for PIGE analysis of ^{25}Mg, ^{9}Be, ^{7}Li, ^{19}F-197 keV, ^{10}B in thick samples, without the use of standards;

- For ^{23}Na and ^{19}F-110 keV further measurements are needed.

- Same targets will be used in differents Laboratories to compare cross sections measurements and calibration energy of the differents accelerators.

- The IBA techniques proved to be highly suitable to help Portuguese ceramists in the understanding of the composition of different glazes, as well as helping lowering the costs associated to the process of obtaining a golden glaze;

An alternative method for PIGE analysis

THANK YOU FOR YOUR ATTENTION !!!

Nuclear Rections Group:

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Dr. Pamela Teubig
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Pedro Reis
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Jorge Machado
Filipa Lourenço

Análise por PIGE: Be, B, Li, F e Na

Be: A secção eficaz foi determinada para a emissão de radiação γ de 718 keV a partir de um alvo fino de Be;

Pastilha BeO: resultados concordantes com uma incerteza inferior a 4%.

^{10}B: A secção eficaz foi normalizada pelos resultados de Day *et al.* (1954);

Pastilha Mistura Ag+B: resultados concordantes com uma incerteza inferior a 5%.

^{7}Li: A secção eficaz foi normalizada pelos resultados de Mateus *et al.* (2002);

Pastilha Mistura Ag+LiF: resultados concordantes com uma incerteza inferior a 5%.

^{19}F 197 keV: A secção eficaz foi determinada para a emissão de radiação γ de 197 keV a partir de um alvo fino de LiF/Ag;

Pastilha Mistura Ag+LiF: resultados concordantes com uma incerteza inferior a 8%.

Análise ^{10}B

Energia (keV)	Amostra	Razão Yexp/Ycal
3962	B+Ag	1,05
3766	B+Ag	1,02
3374	B+Ag	1,02
2400	B+Ag	1,05

Análise ^{7}Li

Energia (keV)	Amostra	Razão Yexp/Ycal
3962	LiF+Ag	0,95
3913	LiF+Ag	0,93
3864	LiF+Ag	0,99
3815	LiF+Ag	0,98
3619	LiF+Ag	0,94

Análise ^{19}F – 197 keV

Energia (keV)	Amostra	Razão Yexp/Ycal
3962	LiF+Ag	1,15
3913	LiF+Ag	0,96
3864	LiF+Ag	0,94
3815	LiF+Ag	0,95
3619	LiF+Ag	1,00

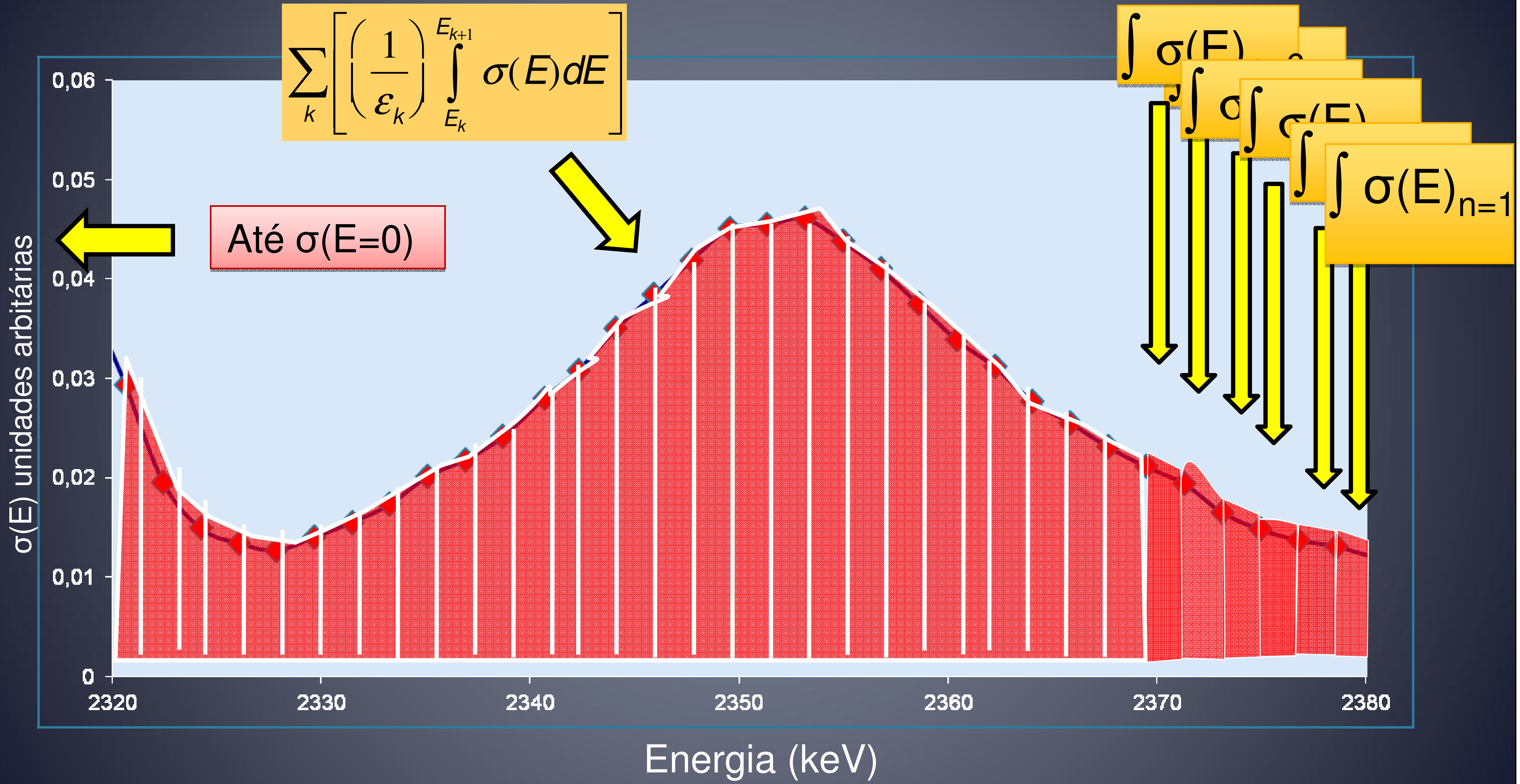
Análise ^{9}Be

Energia (keV)	Amostra	Razão Yexp/Ycal
1708	BeO	0,96
1610	BeO	0,96
1414	BeO	0,97
1218	BeO	0,94

Análise ^{19}F – 110 keV

Energia (keV)	Razão Yexp/Ycal Tandem + Jesus et al.	Razão Yexp/Ycal Cacciolli et al.+ Jesus et al.
3962	0,65	0,93
3913	0,57	0,81
3815	0,52	0,74
3619	0,62	0,86

Código ERYA-Subcamadas



FCT

Análise de PIGE do Be

- Função de excitação do $^{9}Be(p,\gamma)^{10}B$

Neutrões: ~~$^{9}Be(\alpha,n\gamma)^{12}C$~~ $^{9}Be(p,n)^{9}B$ Q= -1.851 MeV

$^{9}Be(p,\gamma)^{10}B$

E_{inc}< 1700 keV

E_{γ} = 718 keV

Pó de Be é muito tóxico

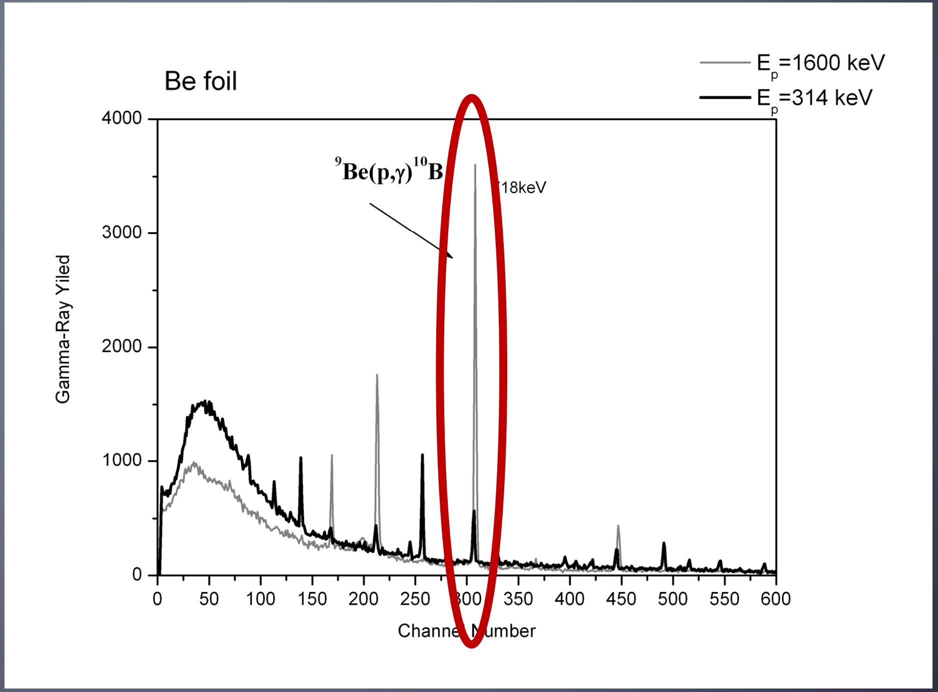
1ª Opção

↓

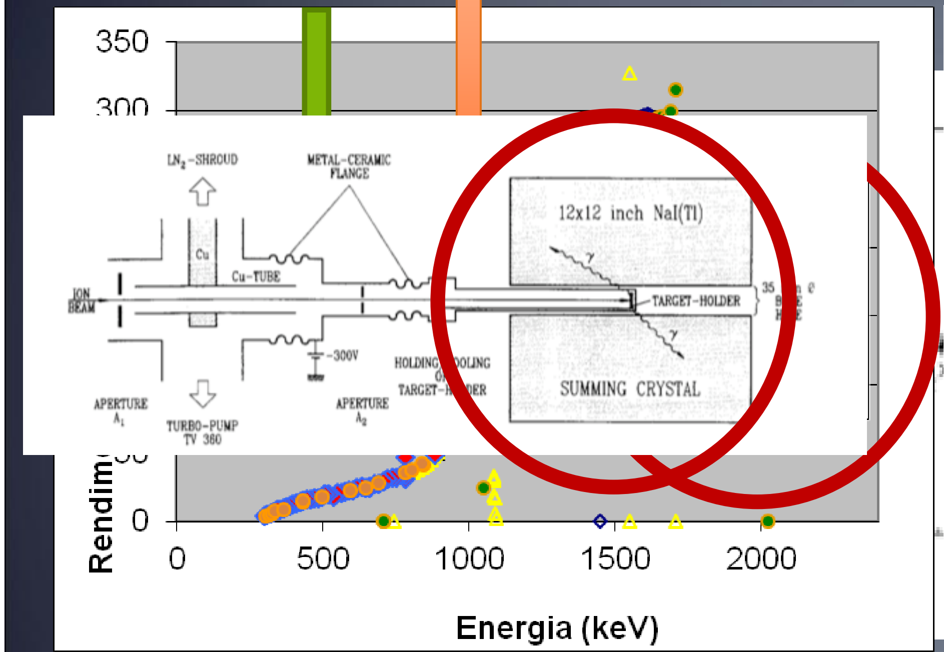
Alvo espesso

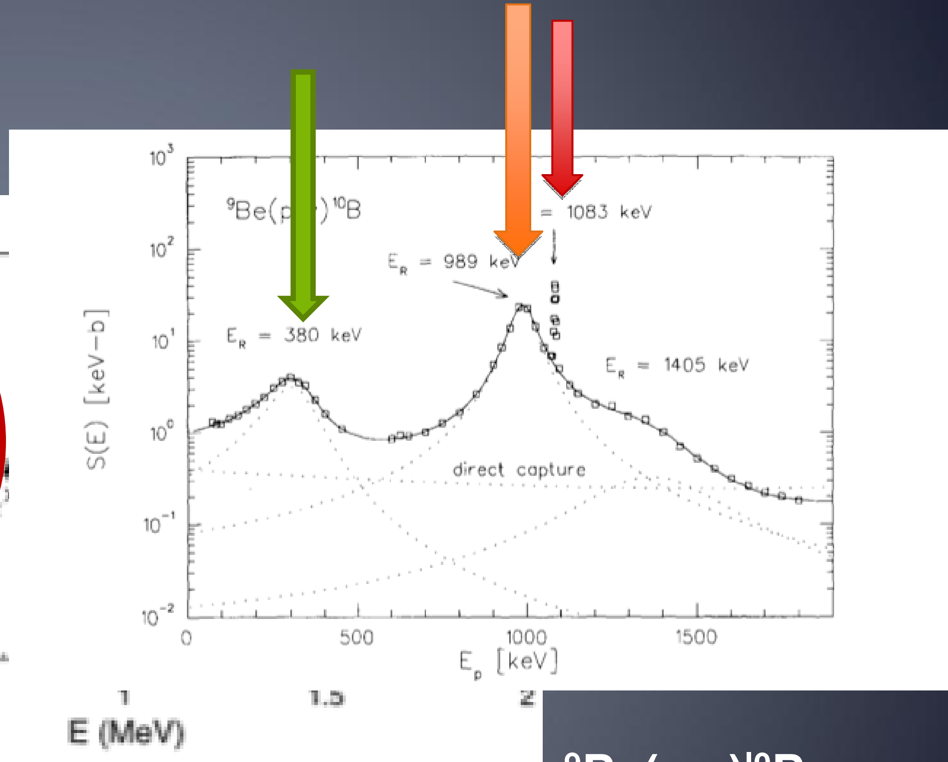
↓

Método de Secção eficaz diferencial



Análise de PIGE do Be





Medidas experimentais do γ=718 keV de Be metálico

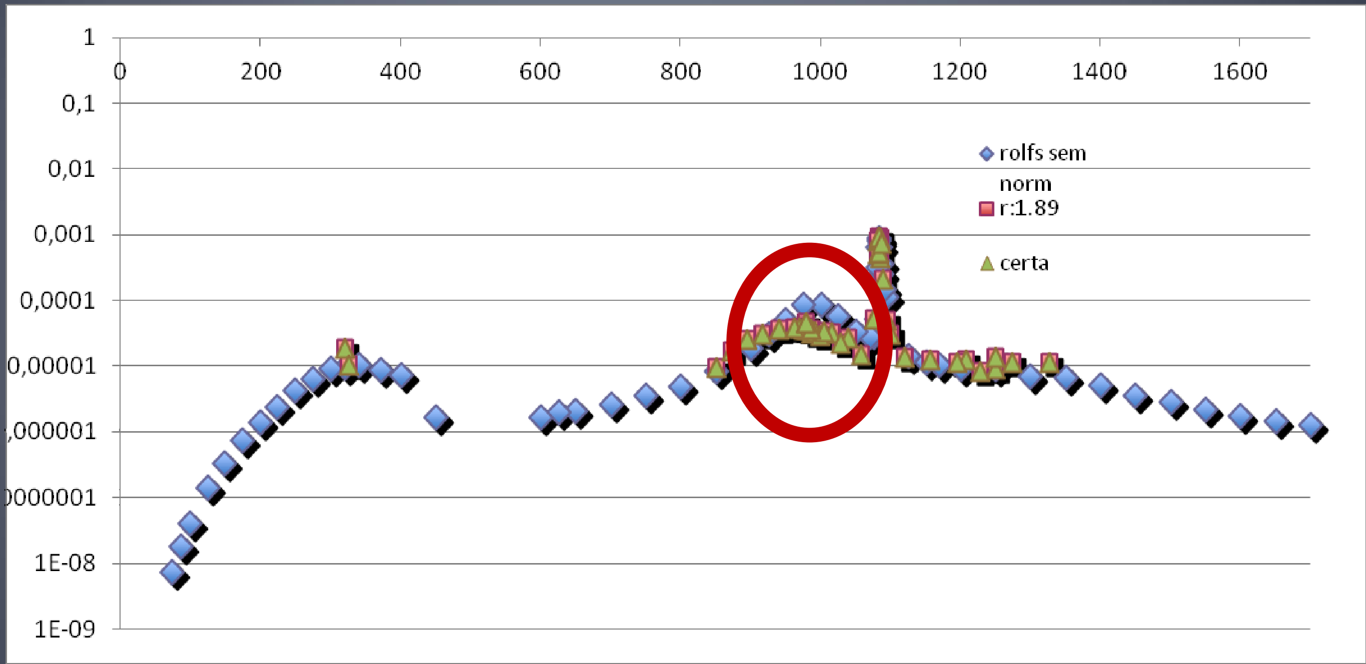
Interesse astrofísico

Função de excitação da $^9Be(p,\gamma)^{10}B$, em forma de facor astrofísico, obtida por um dtectr soma 4π

~~Método de Secção eficaz diferencial~~

Análise de PIGE do Be

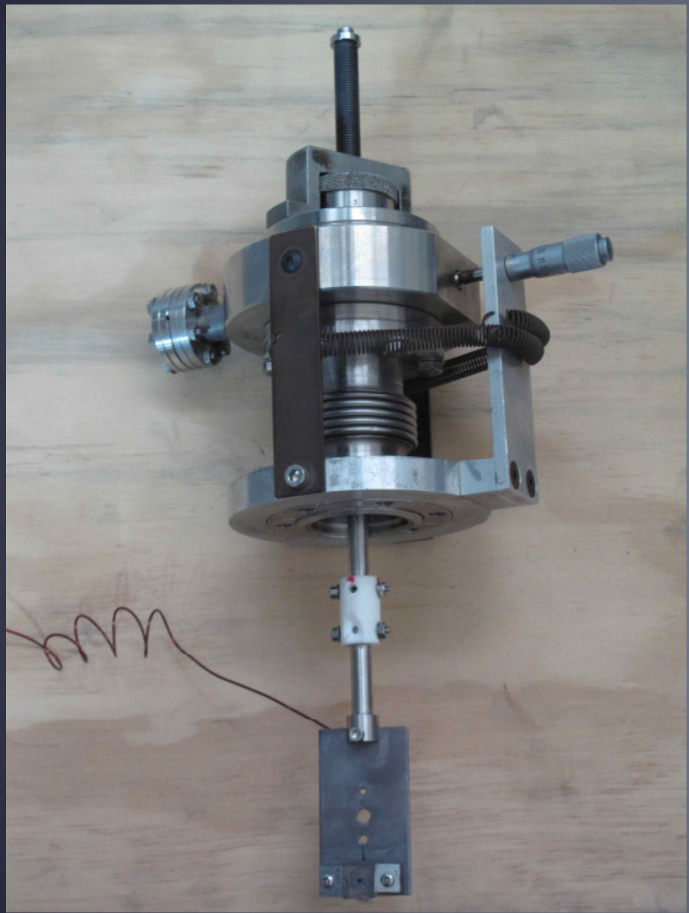
2ª Opção → Alvo fino → Be evaporado sobre Ag auto-suportada



Secção eficaz do detector Soma 4π corrigida pelos “branching ratios”

Necessário corrigir a distribuição angular

Setup Experimental: Nova Linha de Reacções Nucleares

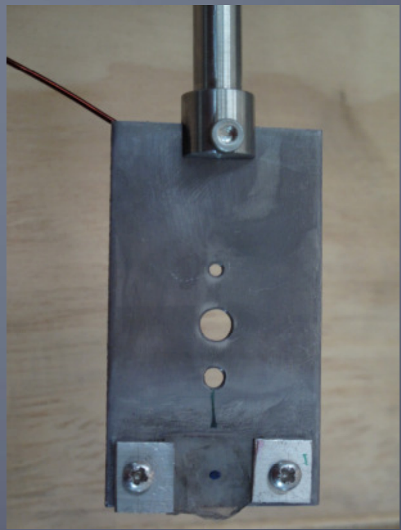


Colimadores à entrada da linha:

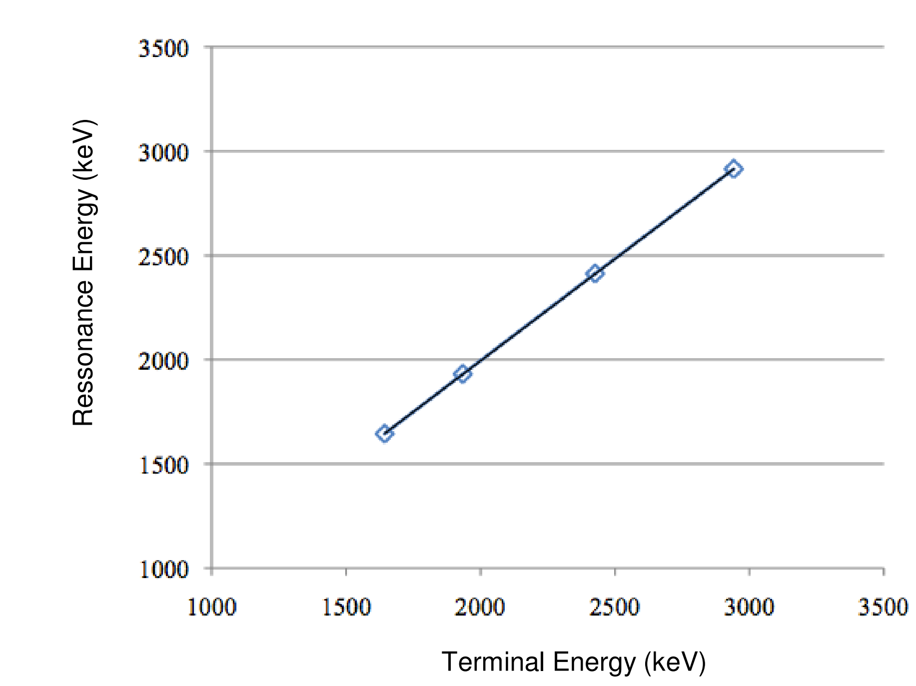
diâmetro=2, 3, 5 mm

quartzo

Permite medir a corrente



Energy Calibration



$$E = 0{,}976(TV_{nominal} \times 2) + 41{,}45 \quad [\text{keV}]$$

Protons: (1 + □)V

Applications

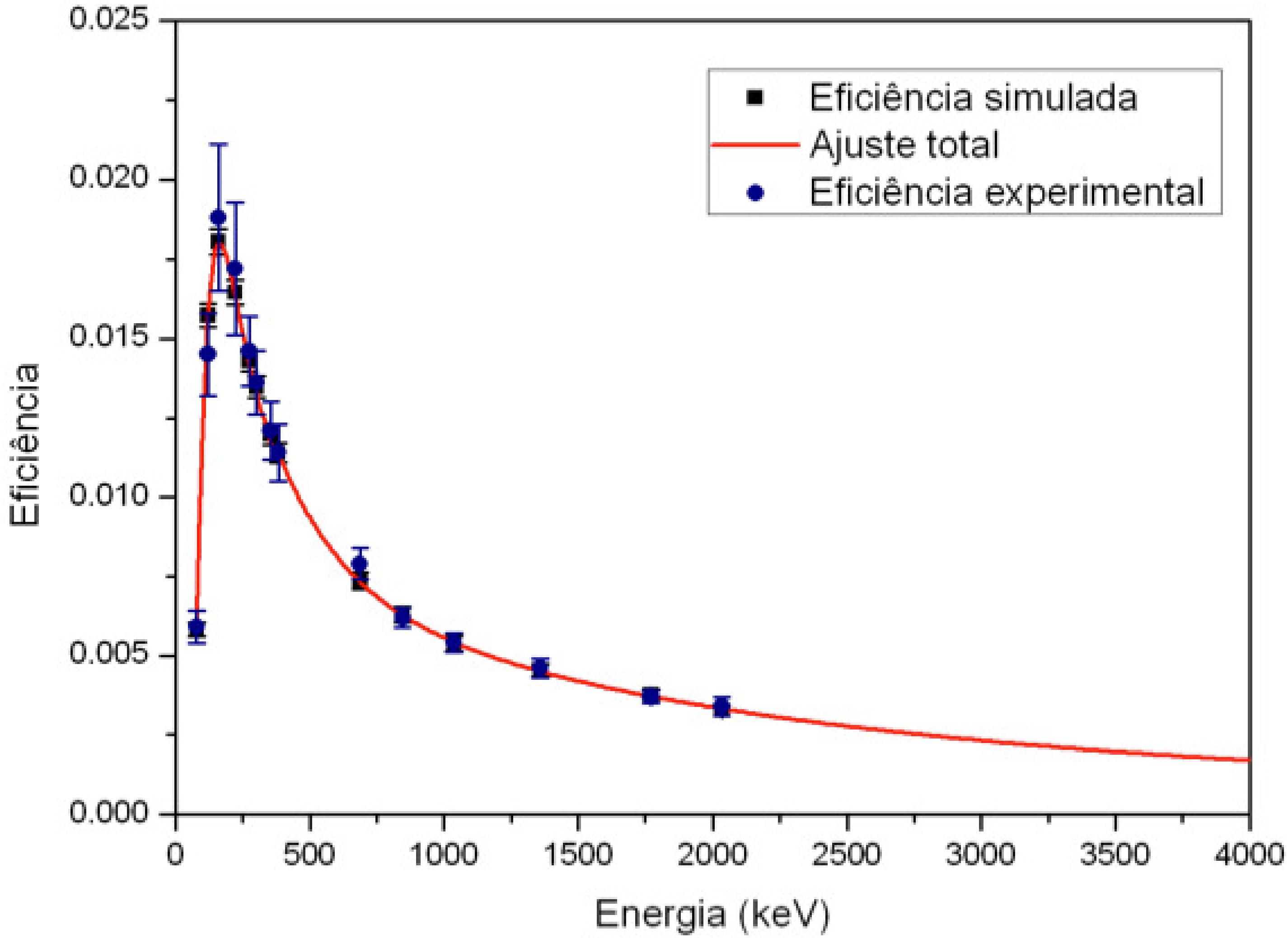
Frits: sodium oxide
lead bisilicate

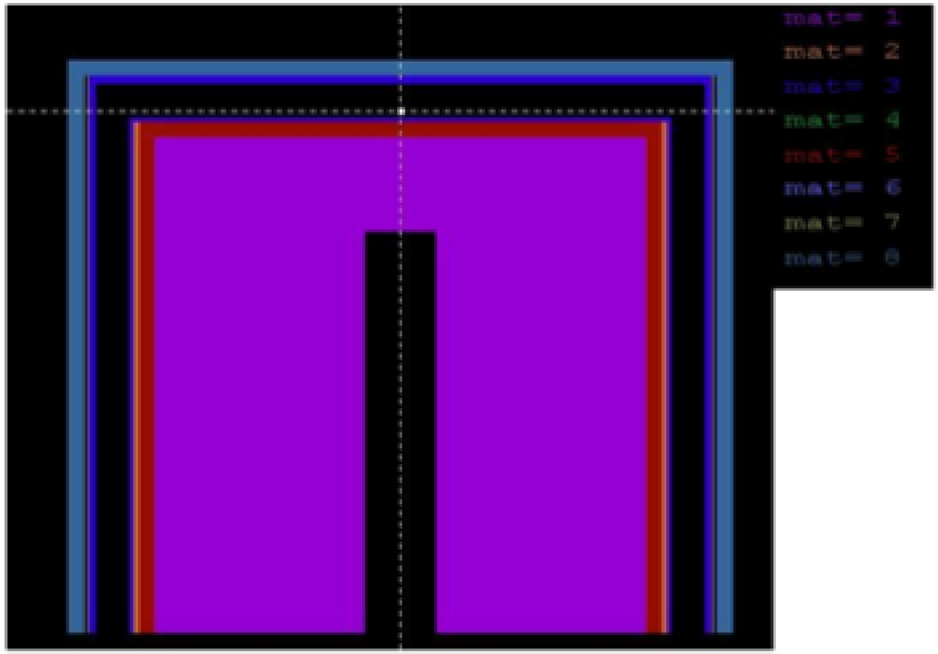
Mass Fraction Na: 34 %

Mass Fraction Pb: 18 %

Frits 1+ Frits 2

Elemento	Frita 1 f_m (%)	Frita 2 f_m (%)	Frita 3 f_m (%)	Frita 4 f_m (%)	Frita 5 f_m (%)	Frita 6 f_m (%)
Na	**3,2**	33.7	**18.2**	**7.5**	**6.2**	**38.5**
Mg	1.47	0.03	-	-	0.275	-
Al	8.3	5.80	5.97	7.9	8.5	3.54
Si	24.4	30.0	30.1	37.6	37.8	36.2
K	0.99	2.77	8.51	3.83	0.98	2.66
Ca	4.05	7.4	1.05	2.57	4.87	2.46
Ti	0.026	0.014	0.046	0.062	0.041	0.0135
Fe	0.084	0.092	0.084	0.125	0.123	0.057
Ni	0.010	-	-	-	-	-
Zn	19.9	19.9	0.041	1.32	0.78	7.5
Ba	0.064	0.094	0.057	0.85	0.091	0.056
Pb	19.5	-	0.37	1.43	2.46	-

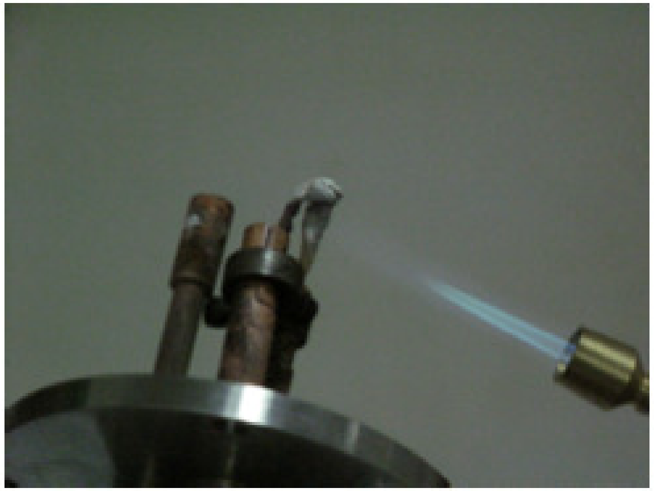

0.025
0.020
0.015
0.010
0.005
0.000
Eficiência
Eficiência simulada
Ajuste total
Eficiência experimental
0
500
1000
1500
2000
2500
3000
3500
4000
Energia (keV)



mat= 1
mat= 2
mat= 3
mat= 4
mat= 5
mat= 6
mat= 7
mat= 8

Tabela 6.II– Fontes de ^{152}Eu, ^{133}Ba e ^{56}Co: riscas e intensidades relativas

^{152}Eu ($t_{1/2}$ = 13,506 y) Energia (keV)	Intensidade relativa.	^{133}Ba ($t_{1/2}$ = 10,47 y) Energia (keV)	Intensidade Relativa
		80,999	512
121,784	1362	160,609	10,5
244,692	358	223,116	7,1
295,939	21,1	276,404	113
344,275	1275	302,858	292
367,789	40,5	356,014	1000
411,115	107	383,859	145
443,976	148	**^{56}Co ($t_{1/2}$ = 77,31 d)**	
488,661	19,5	**Energia**	**Intensidade**
564,021	23,6	**(keV)**	**Relativa**
586,294	22,0	846,772	100000
678,623	22,1	1037,840	14000
688,678	40,0	1175,102	2280
778,903	619	1238,282	67600
867,388	199	1360,25	4330
919,401	20,9	1771,351	15700
964,131	692	2015,181	3080
1005,279	31	2034,755	7890
1085,914	465	2598,458	16900
1089,700	82	3201,962	3040
1112,116	649	3253,416	7410
1299,124	78	3272,990	1750
1408,011	1000	3451,152	875
1457,628	23,3	3547,925	180



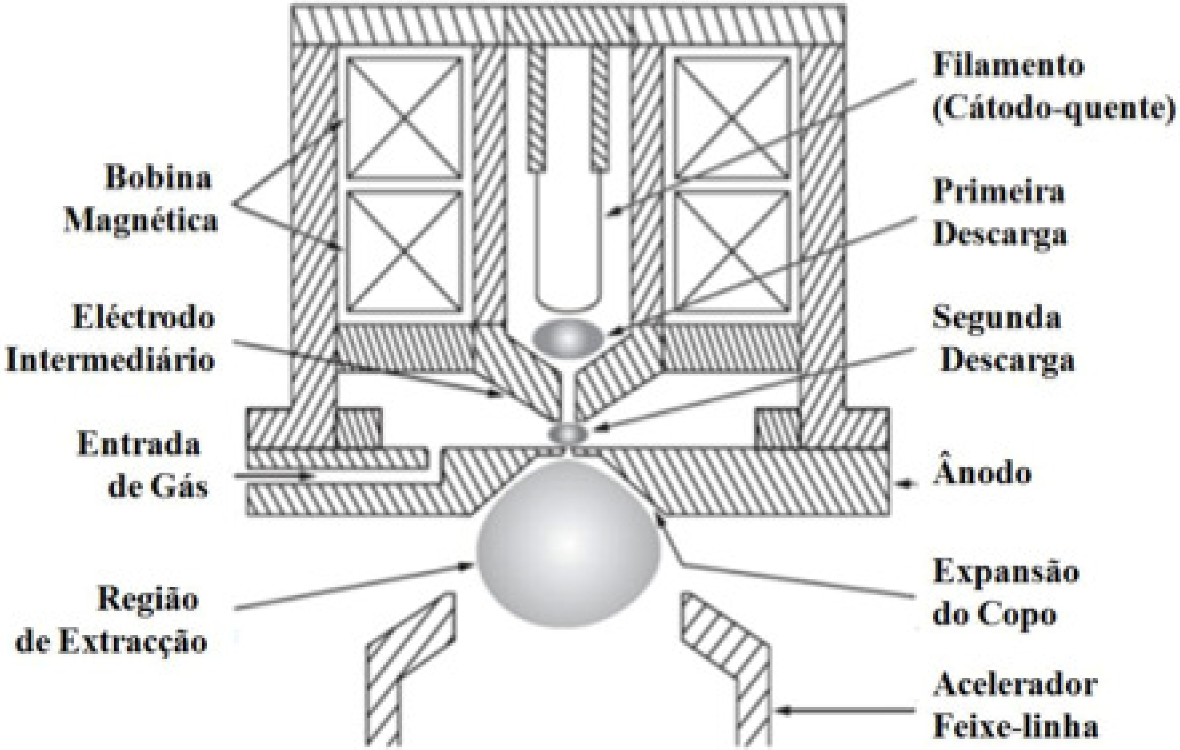
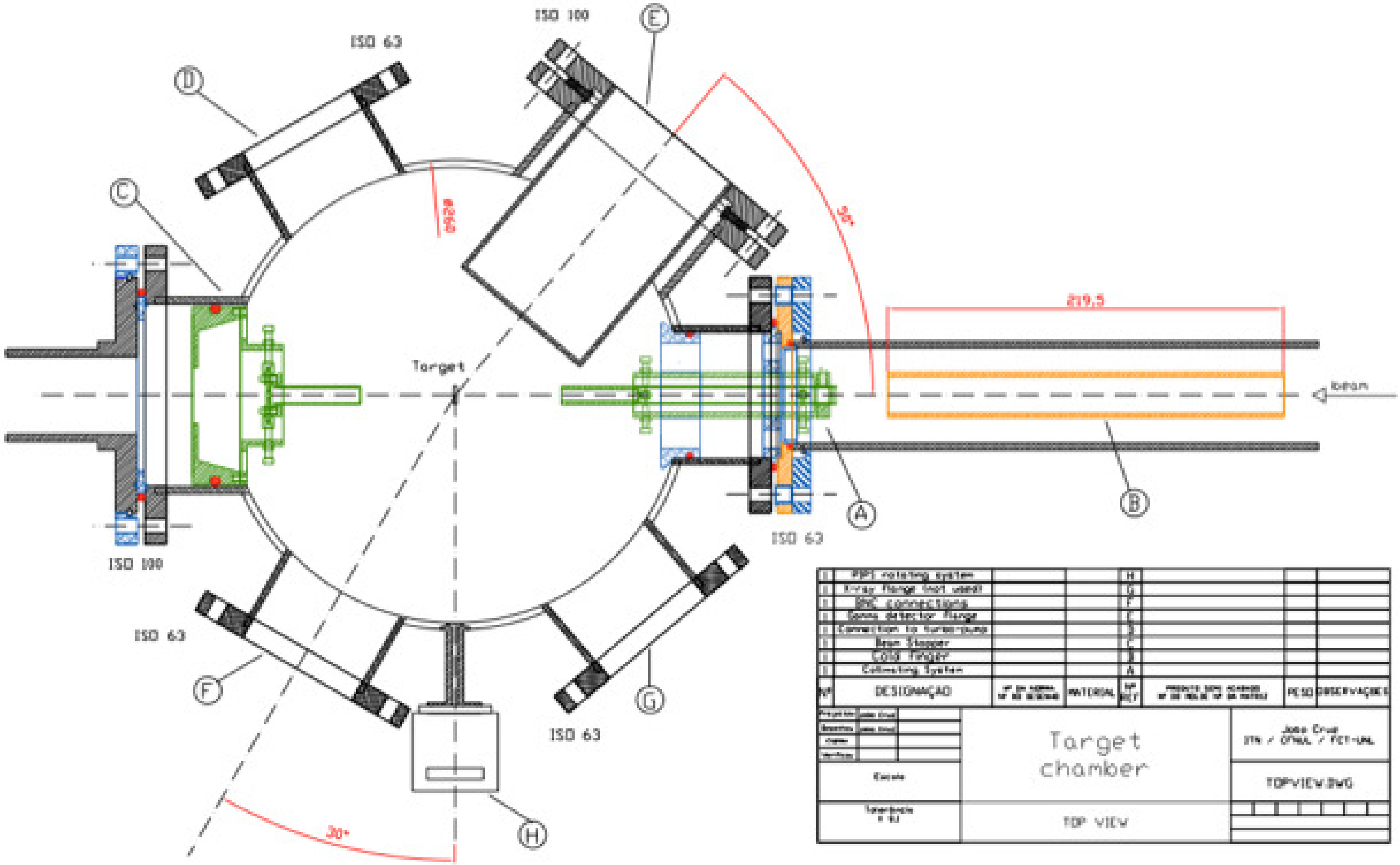


Figura 4.3: Esquema da fonte de iões Duoplasmatrão 358 [12].


ISO 100
ISO 63
ISO 100
ISO 63
ISO 63
ISO 63
Target
beam
219,5
90°
30°
Ø260
A
B
C
D
E
F
G
H
PIPS rotating system
X-ray flange (not used)
BNC connections
Gamma detector flange
Connection to turbo-pump
Beam Stopper
Cold finger
Collimating System
Nº
DESIGNAÇÃO
MATERIAL
PESO
OBSERVAÇÕES
Target chamber
TOP VIEW
TOPVIEW.DWG