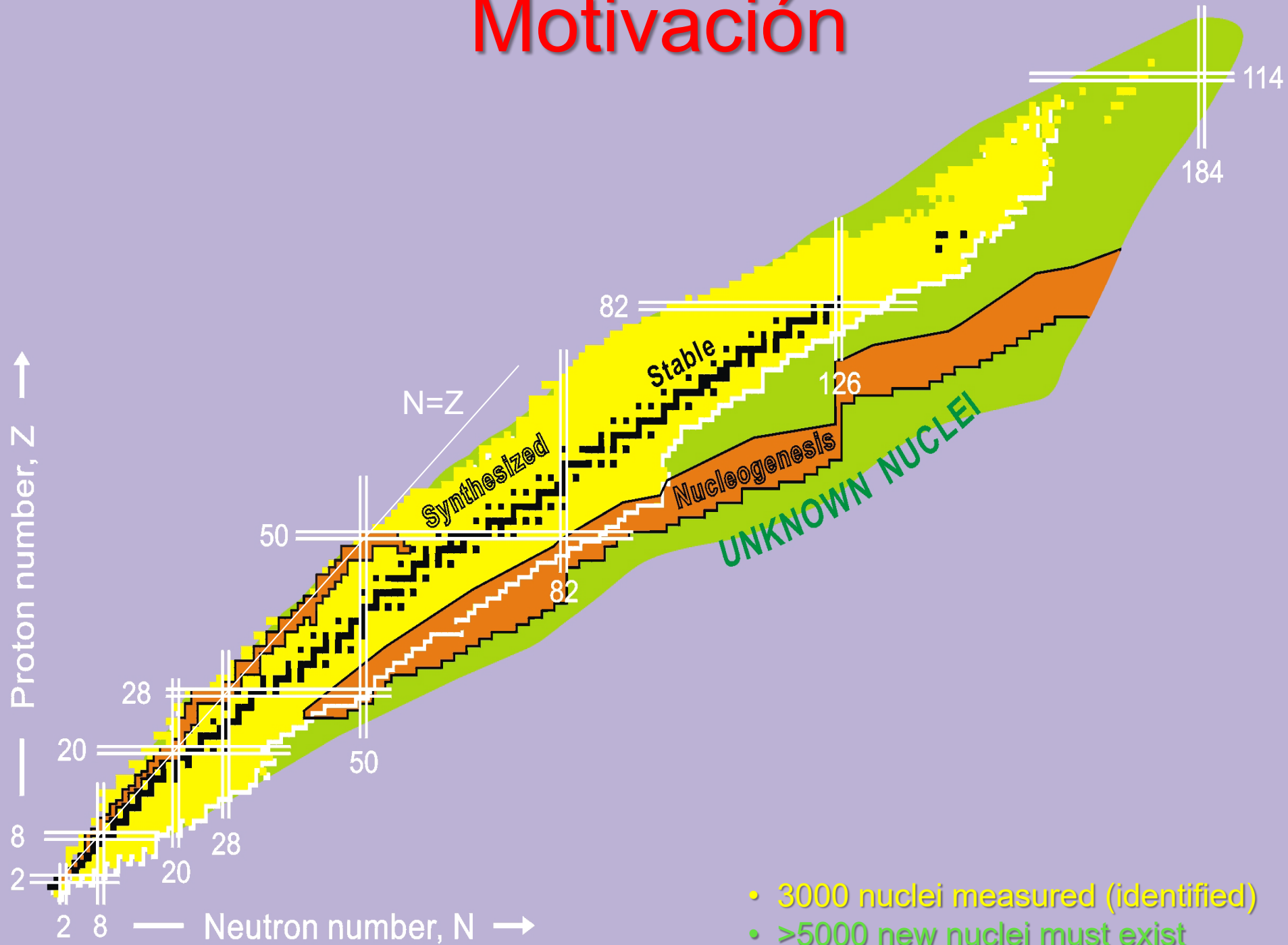


# Introducción a LISE++

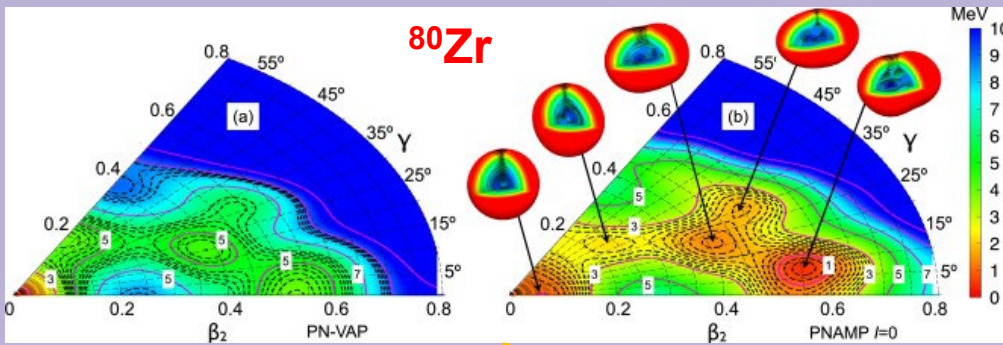
David Rodriguez  
Lola Cortina  
César Domingo

Instituto de Física Corpuscular  
(CSIC-Universidad de Valencia)

# Motivación

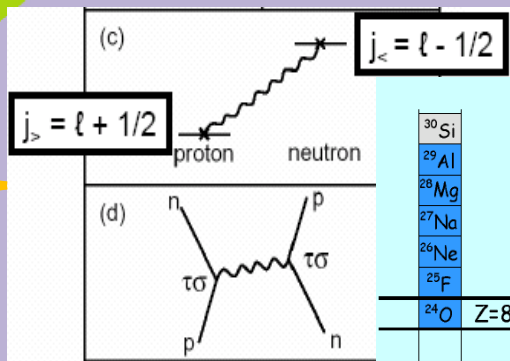
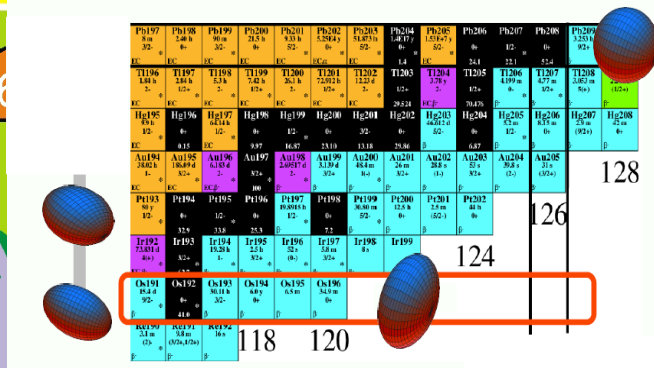
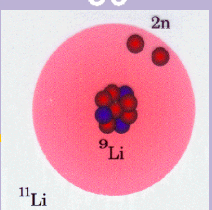
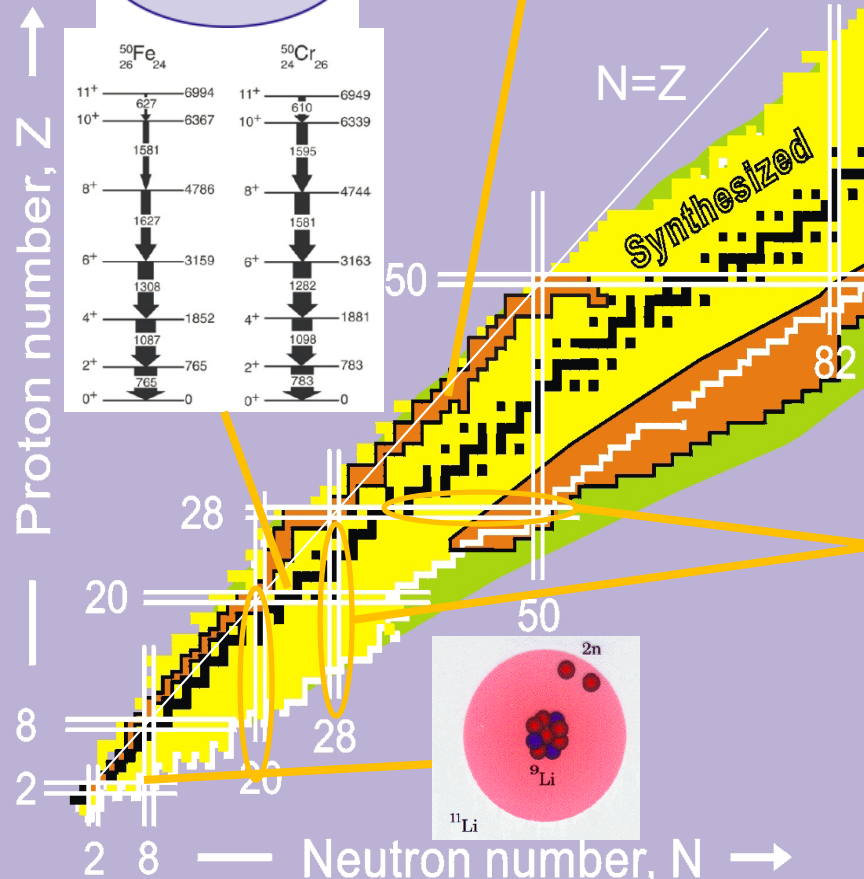
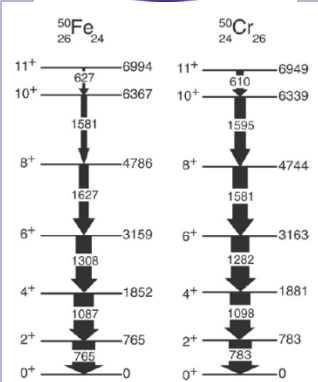
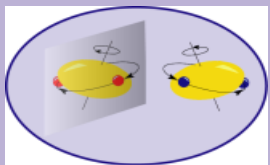


# Motivación



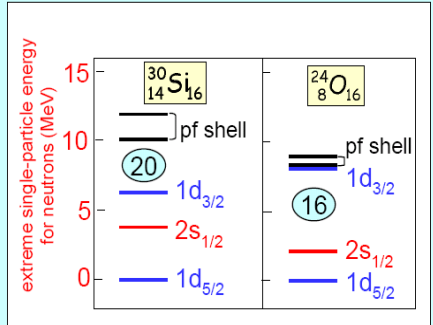
T.R.Rodriguez, PLB (2011)

<http://www.nupec.org/index.php?display=lrp2016/main>



30Si
29Al
28Mg
27Na
26Ne
25F
24O
Z=8
N=16

## New shell gaps



- 3000 nuclei measured (identified)
- >5000 new nuclei must exist

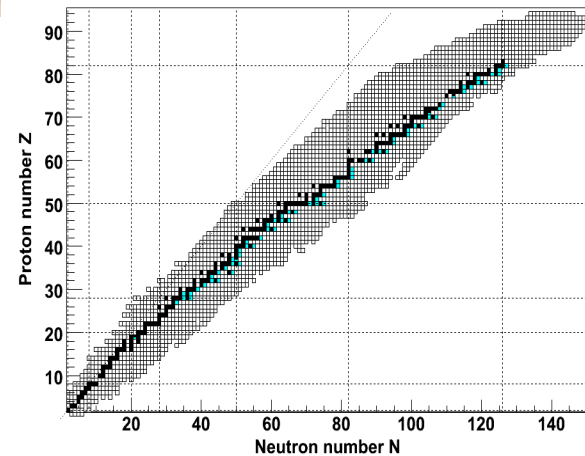
# Producción de haces de iones exóticos



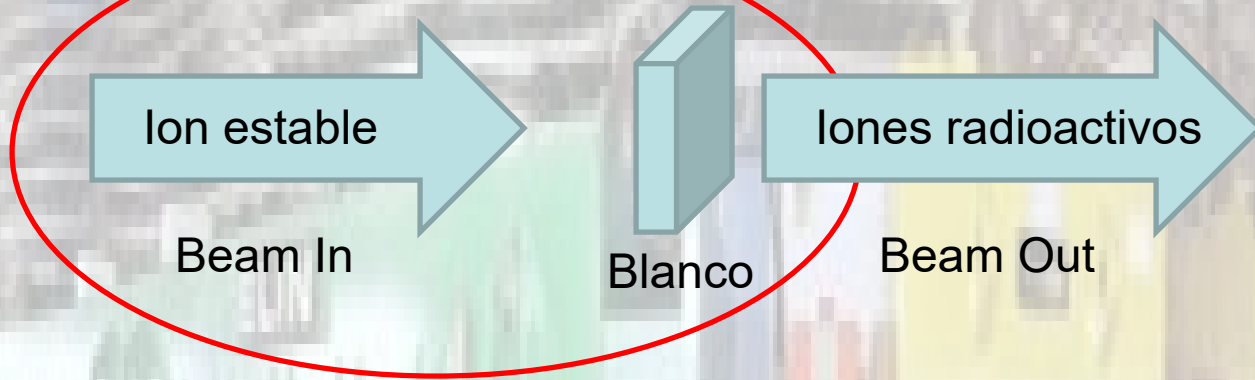
Es posible acelerar, cualquier isótopo estable, desde Hidrógeno hasta Uranio-238, para obtener un haz primario.

**Fuente  
iones  
estables**

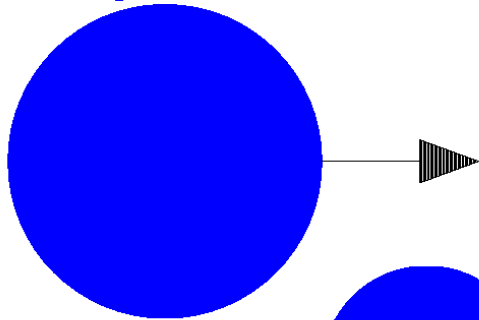
$^{238}\text{U}$ :	$2 \cdot 10^9$
$^{208}\text{Pb}$ :	$2 \cdot 10^9$
$^{144}\text{Sm}$ :	$2 \cdot 10^9$ (ns, used once)
$^{136}\text{Xe}$ :	$10^{10}$
$^{124}\text{Xe}$ :	$10^{10}$ (requires enriched material)
$^{112}\text{Sn}$ :	$\sim 10^8$ (requires enriched material)
$^{107}\text{Ag}$ :	$4 \cdot 10^9$
$^{86}\text{Kr}$ :	$2 \cdot 10^{10}$
$^{78}\text{Kr}$ :	$2 \cdot 10^{10}$ (requires enriched material)
$^{76}\text{Ge}$ :	$3 \cdot 10^8$ (no standard beam, needs to be developed)
$^{64}\text{Ni}$ :	$5 \cdot 10^9$ (requires enriched material)
$^{58}\text{Ni}$ :	$5 \cdot 10^9$
$^{48}\text{Ca}$ :	$3 \cdot 10^7$ (low intensity from the ECR source when used for pulsed beams for SIS. Or very very expensive ...)



# Producción de haces de iones exóticos

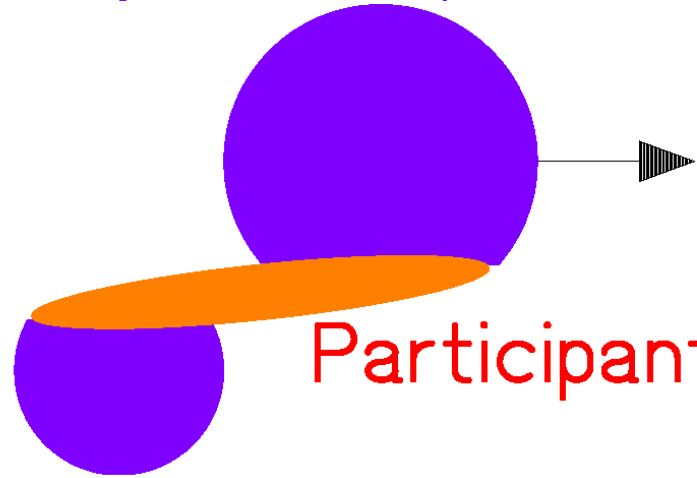


Projectile



Target

Projectile spectator

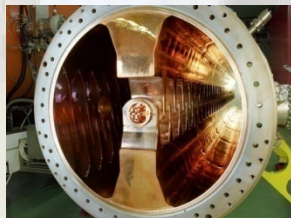
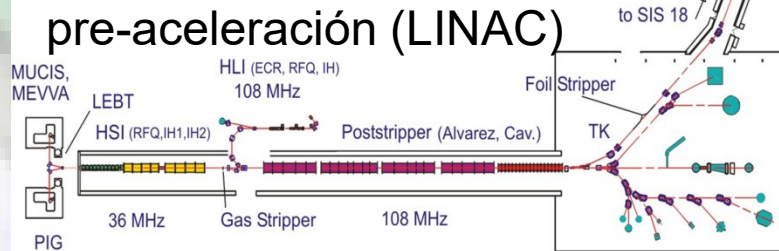


Target spectator

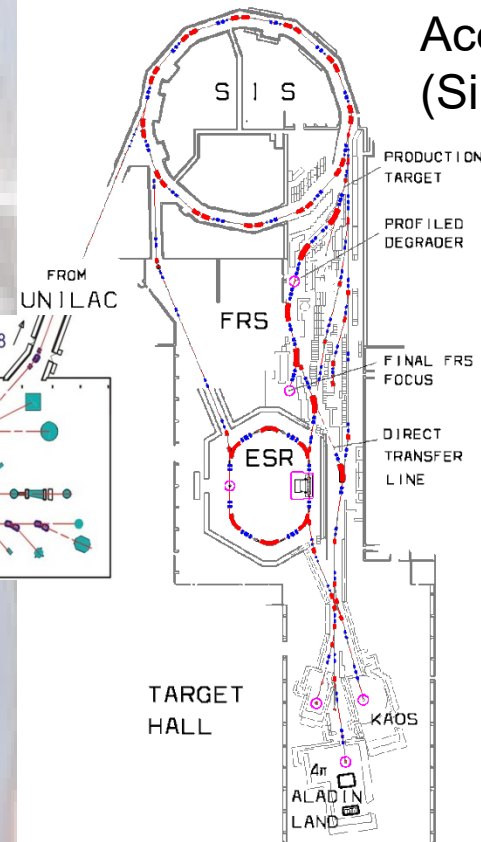
# Producción de haces de iones exóticos



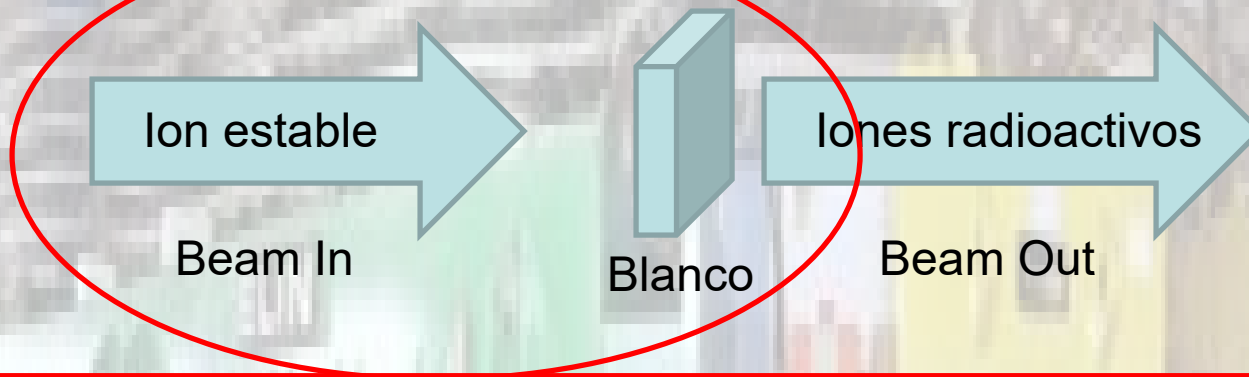
Fuente  
iones  
estables



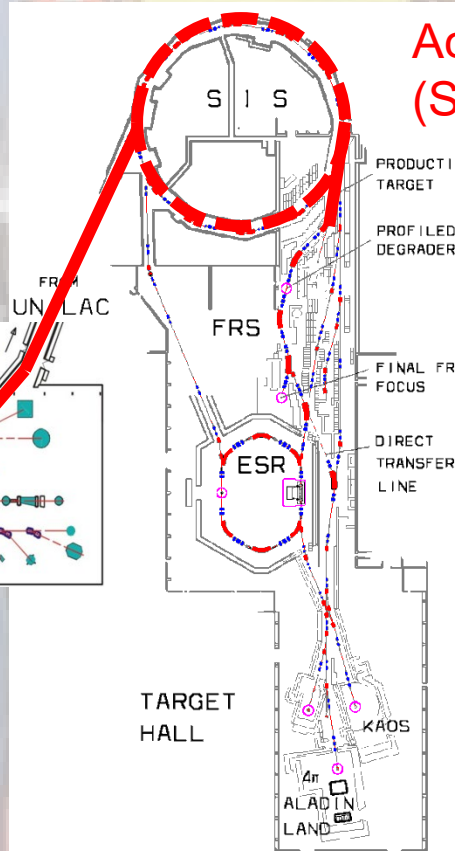
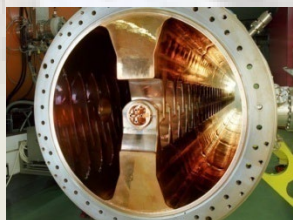
Aceleración  
(Sincrotrón)



# Producción de haces de iones exóticos



Fuente iones estables

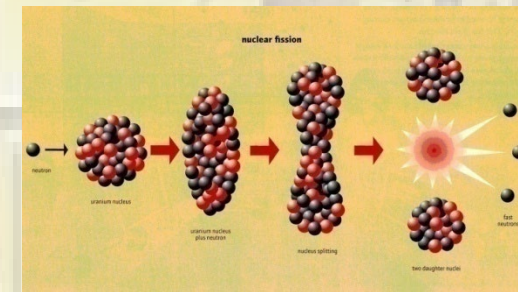
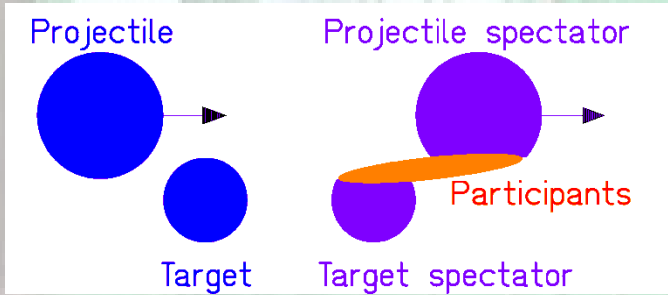


Aceleración (Sincrotrón)

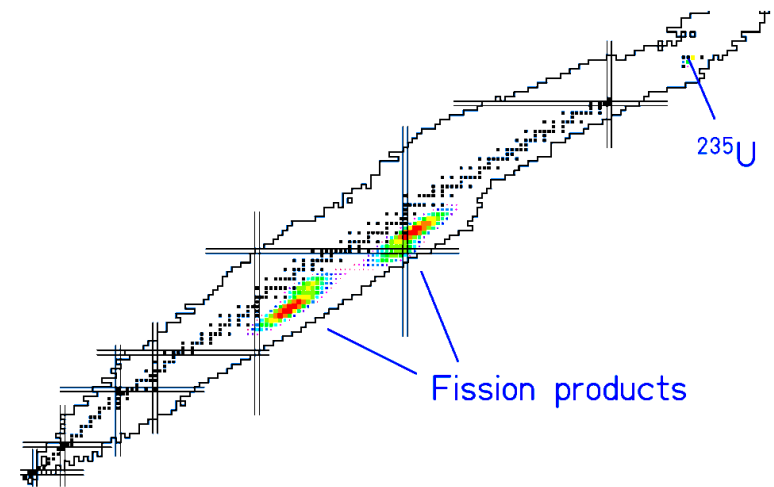
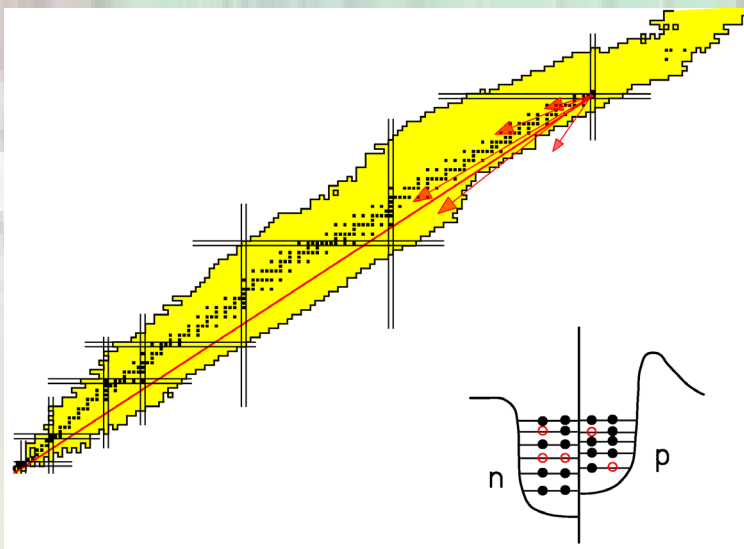
**SIS18:**  
0.1-1 GeV/u

**UNILAC:**  
11.4 MeV/u

# Producción de haces de iones exóticos



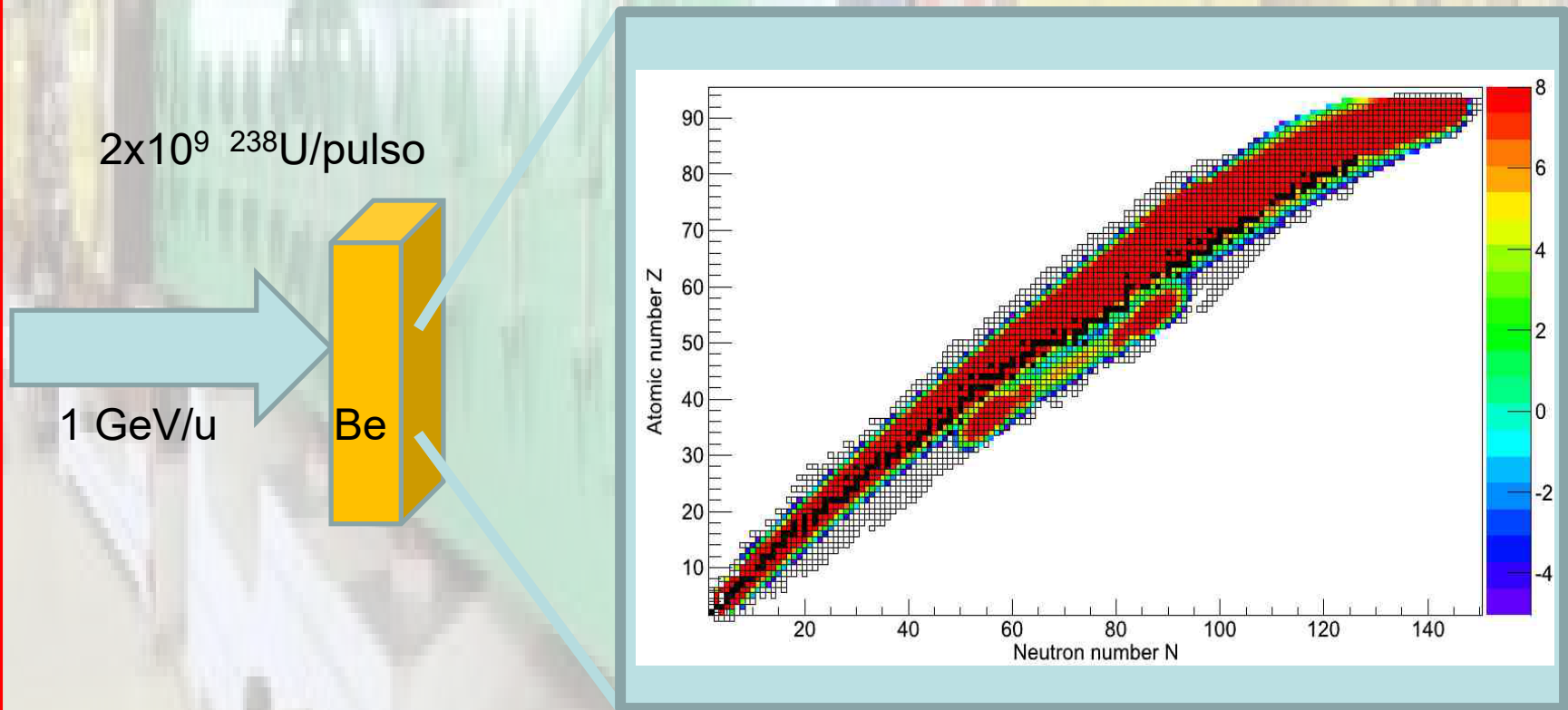
Fission induced by low-energy neutrons



# Producción de haces de iones exóticos

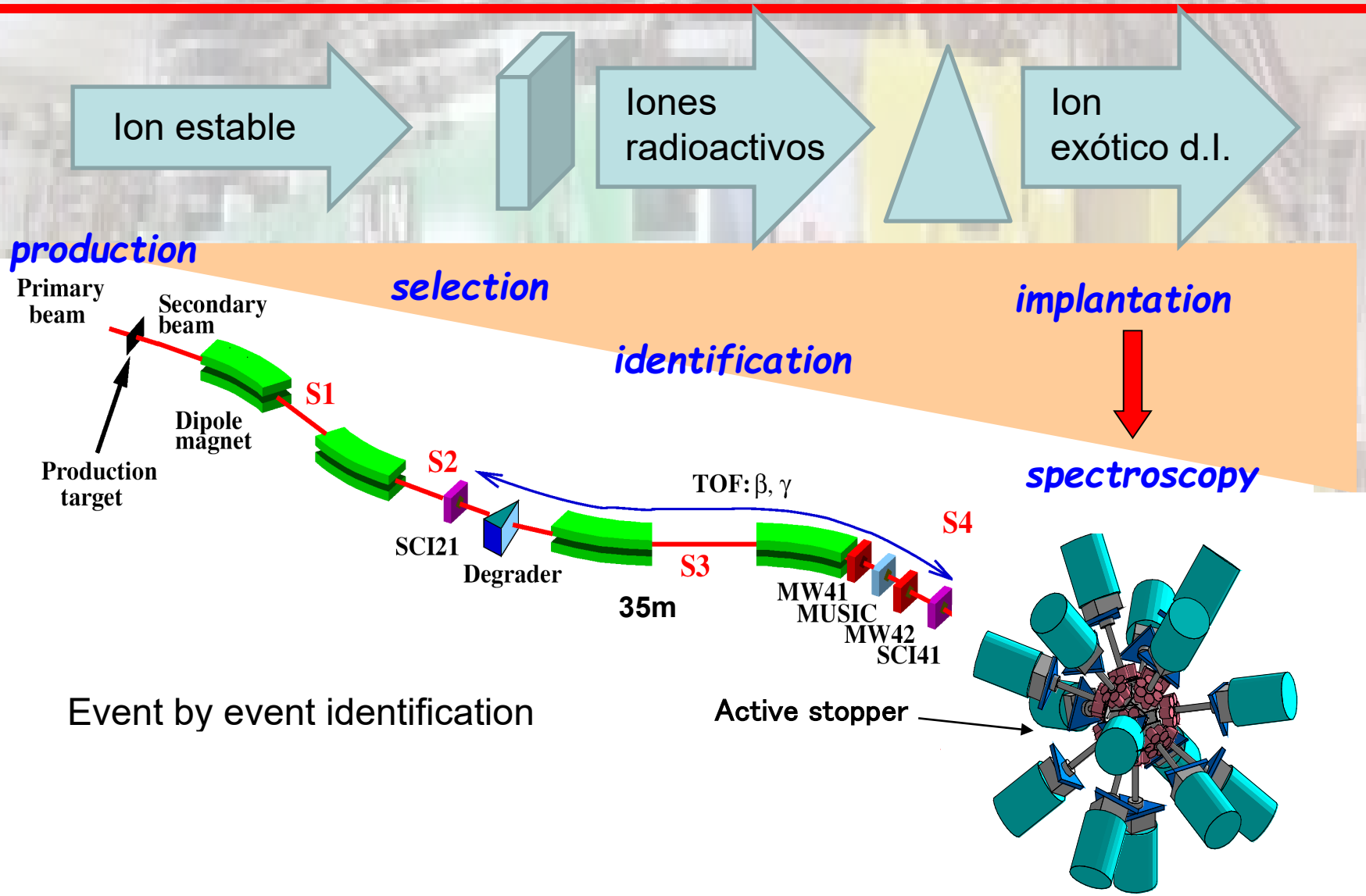


EJEMPLO:



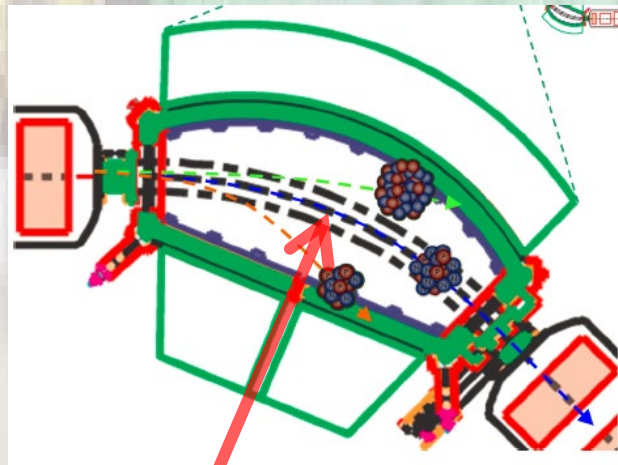
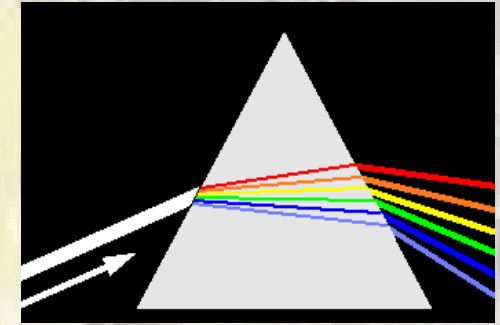
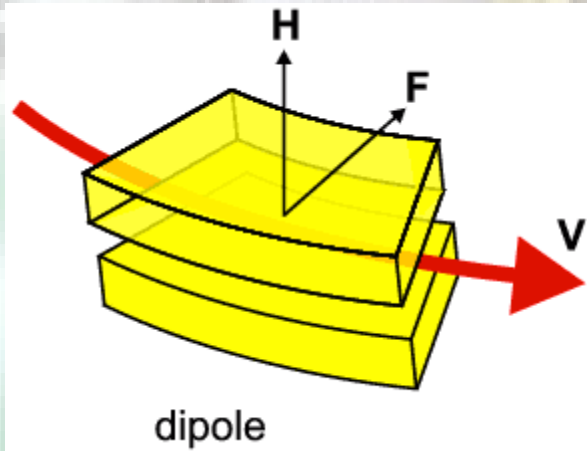
Tasas prohibitivamente altas para medirlos todos a la vez: hay que seleccionar una pequeña porción de todos ellos!

# Selección/identificación del isótopo de interés



# Selección del isótopo de interés

Dipolos magnéticos:

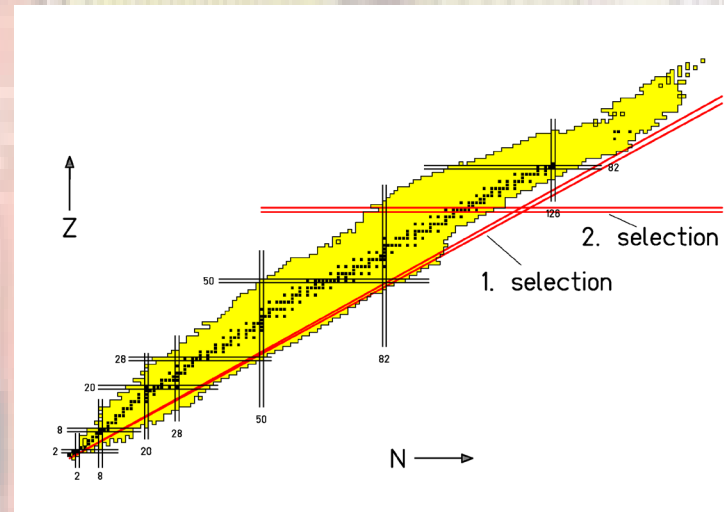


$$F_{\text{lorentz}} = F_{\text{centrípeta}}$$

$$q \cdot \mathbf{v} \times \mathbf{B} = m v^2 / \rho$$

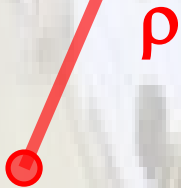
$$B \cdot \rho = \beta \gamma c m / q$$

$$B \cdot \rho = \beta \gamma c A / Z$$

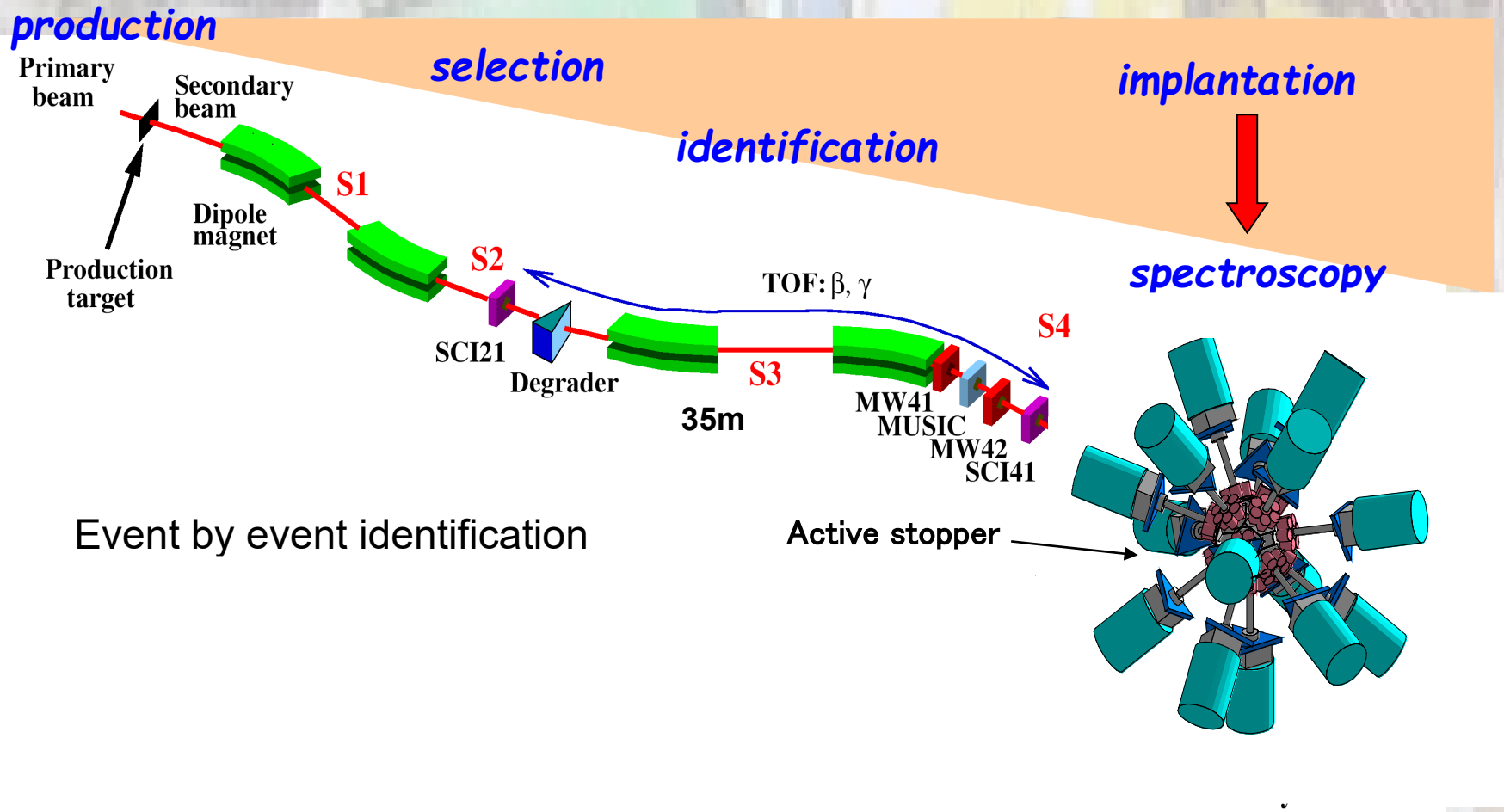


$B\rho$  proportional to mass over charge

Dipoles: 1<sup>st</sup> Selection in  $A/Z$

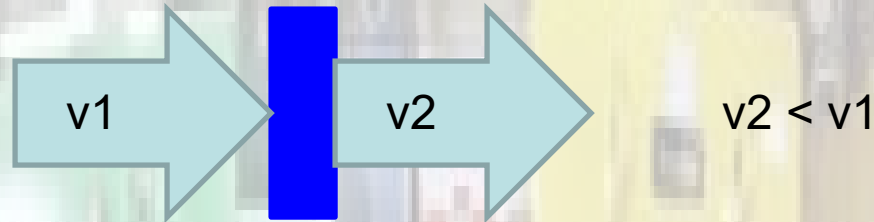
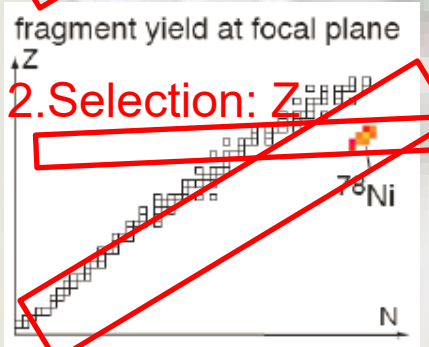
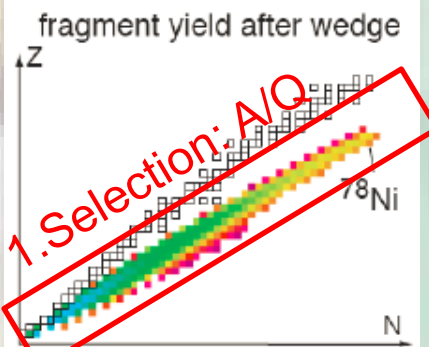
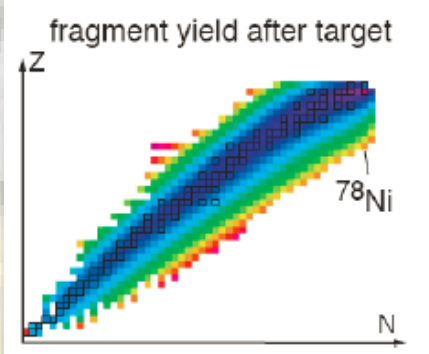


# Selección/identificación del isótopo de interés



# Selección del isótopo de interés

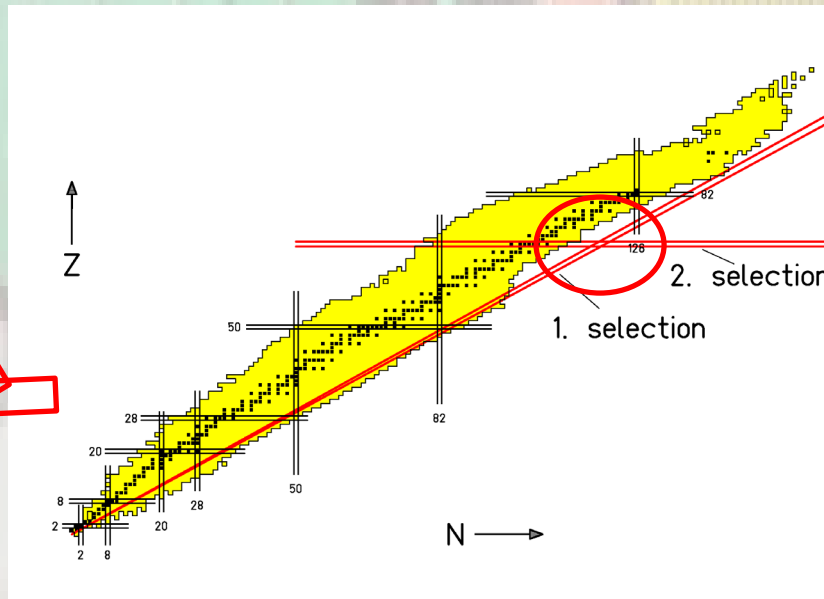
Degradadores:



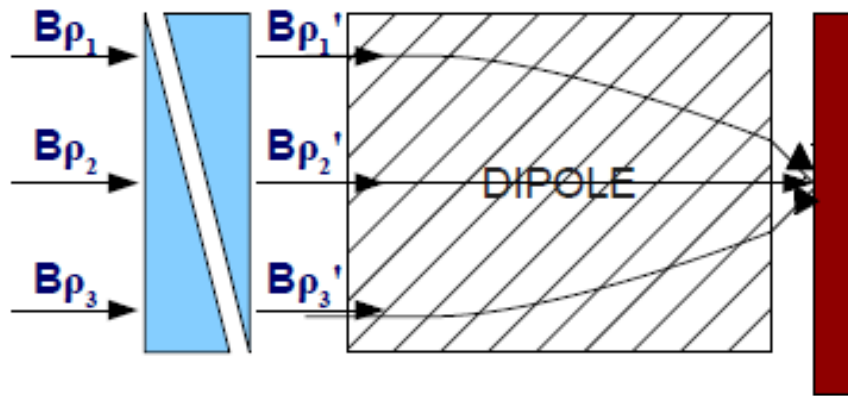
$$\frac{dE}{dx} = \frac{4\pi Z^2 e^4}{m_e v^2} N \left[ \ln\left(\frac{2m_e \gamma^2 v^2}{I}\right) - \frac{v^2}{c_0^2} \right]$$

Eloss proportional to  $Z^2$

Energy Degradar  $\rightarrow$  2<sup>nd</sup> Selection: in Z

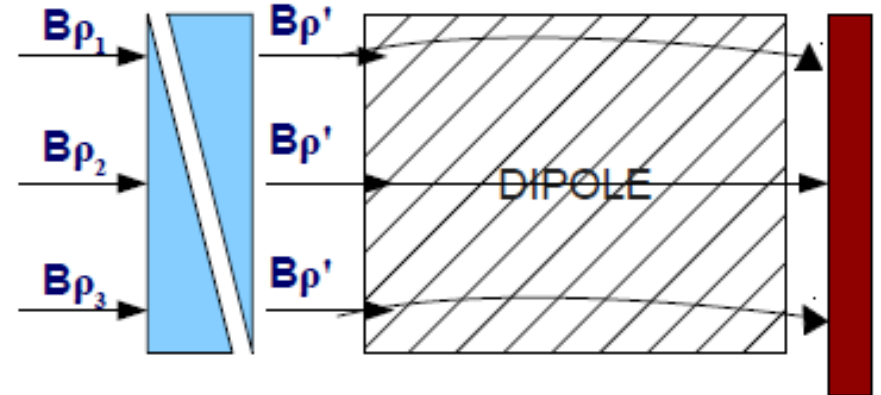


# Selección del isótopo de interés



## • ACHROMATIC MODE

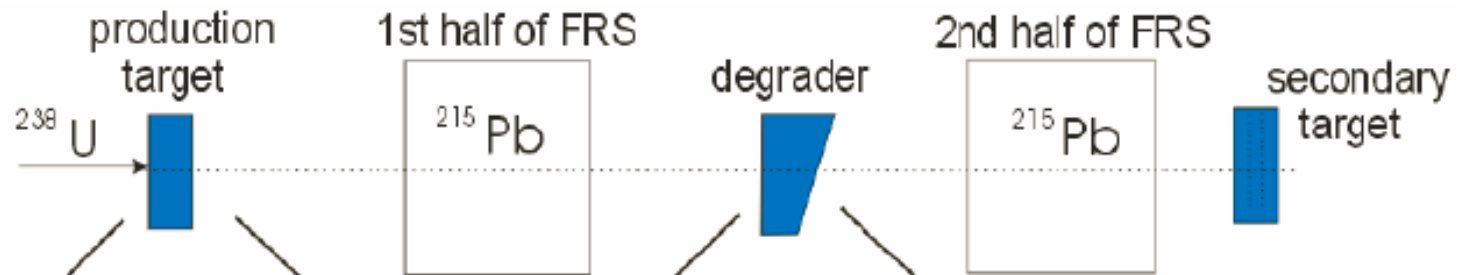
- Ions lose constant amount of energy in wedge
- All nuclei of same species arrive at same position on focal plane



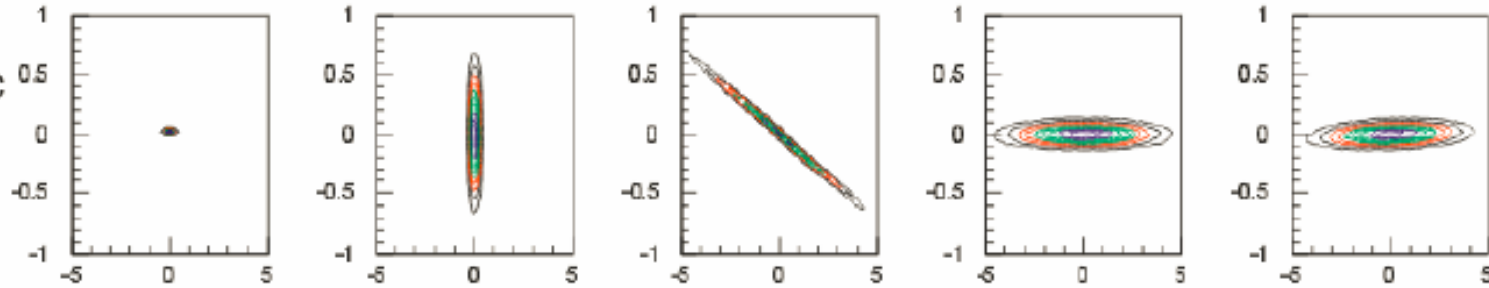
## • MONOENERGETIC MODE

- Momentum spread compensated by different path lengths in degrader
- All fragments of same species have same energy
- Fragments preserve their spacial distribution

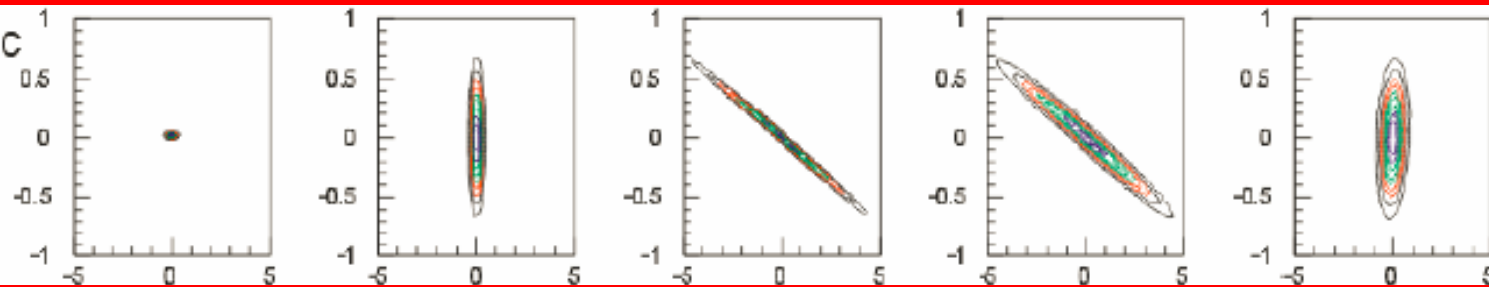
# Selección del isótopo de interés



mono-energetic  
 $\Delta p / p$   
(%)



achromatic  
 $\Delta p / p$   
(%)



X (cm)

MONO

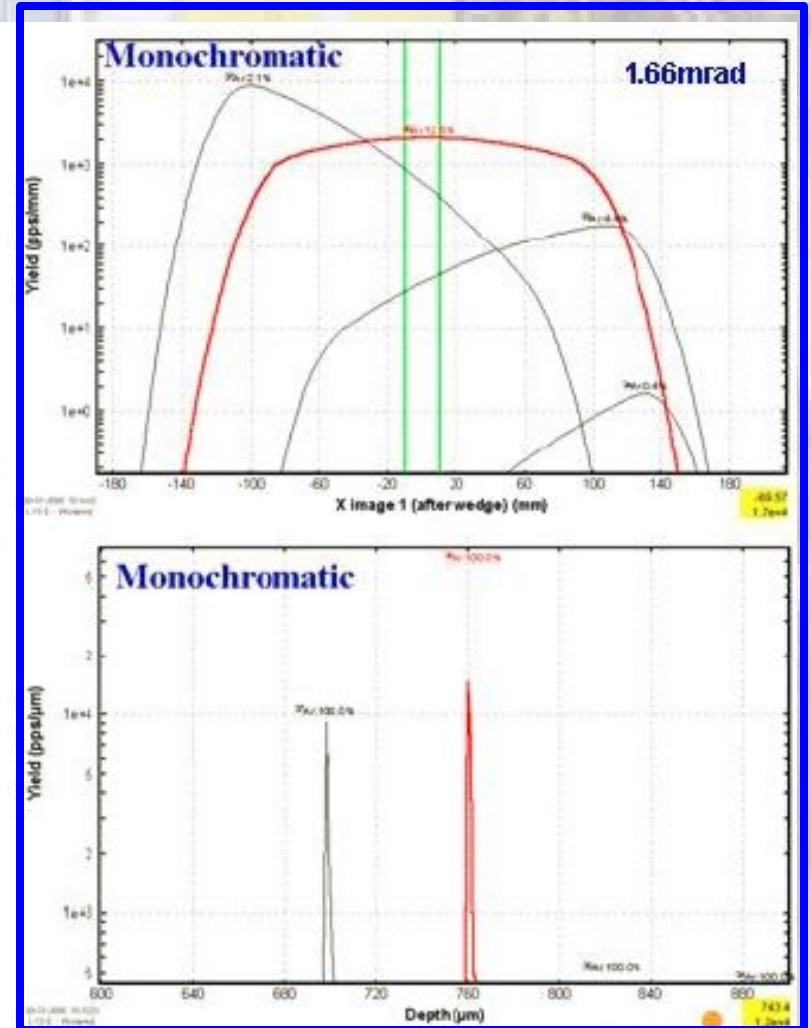
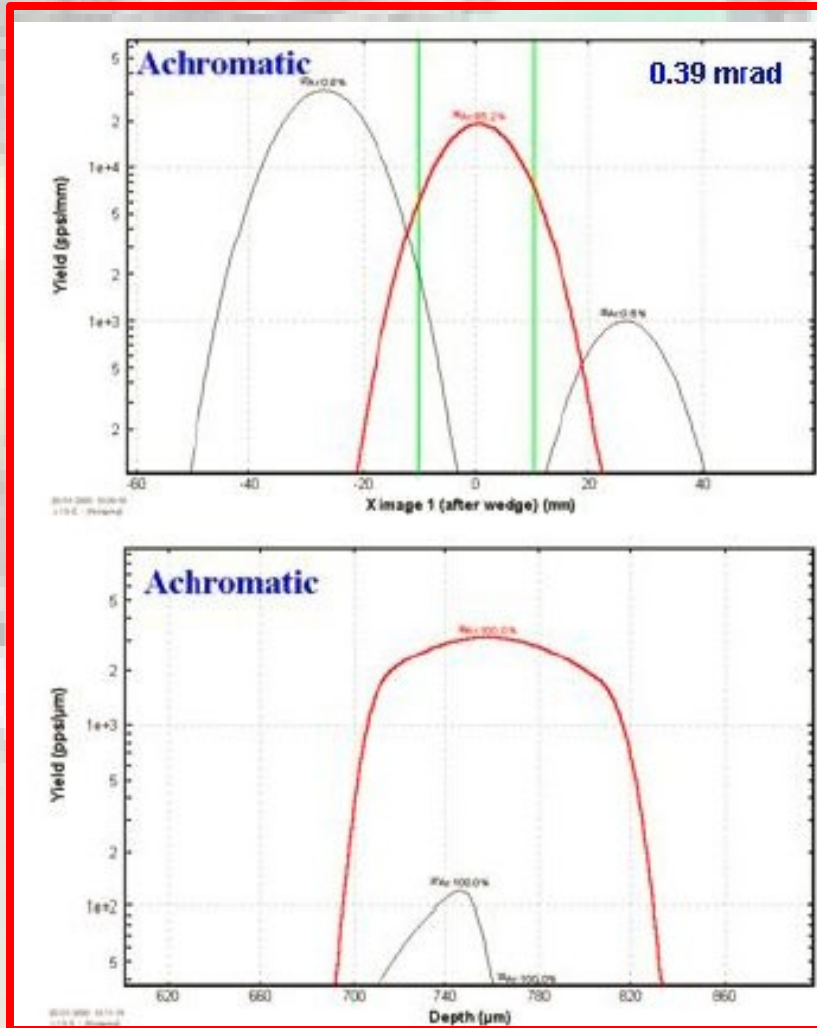
ACRO

# Separación acromática y monoenergética

## 40Ar@50MeV/u + Ta 100 um – Degradador 200 um Al

### ACRO

### MONO



# Selección del isótopo de interés

Selección final por medio de la técnica  $B\rho - \Delta E - B\rho$

*production*

Primary beam  
Secondary beam  
Dipole magnet  
Production target

*selection*

*identification*

*implantation*

*spectroscopy*

S1

S2

SCI21

Degrader

35m

S3

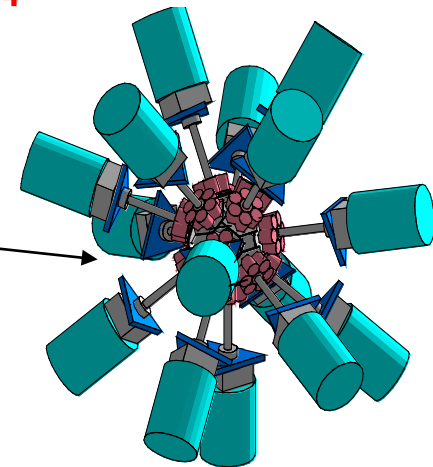
MW41  
MUSIC

MW42  
SCI41

S4

TOF:  $\beta, \gamma$

Active stopper



# Identificación del isótopo de interés

**Identificación** por medio de detectores de tracking

*production*

Primary beam  
Secondary beam  
Production target

Dipole magnet  
S1

*selection*

S2  
SCI21

Degrader

*identification*

35m  
S3

TOF:  $\beta, \gamma$

MW41  
MUSIC  
MW42  
SCI41

*implantation*

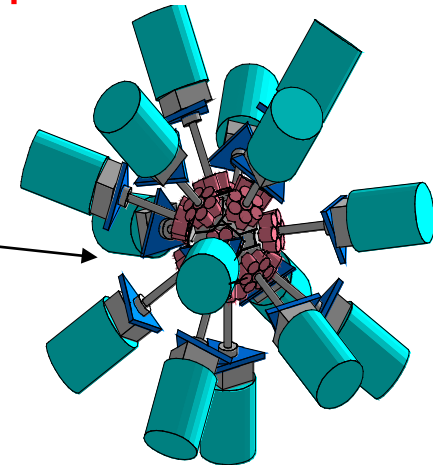


*spectroscopy*

**Event by event identification:**

Ionization Chambers  $\rightarrow \Delta E \rightarrow Z^2 \rightarrow Z$

Active stopper



Scintillators S2, S4  $\rightarrow$  ToF  $\rightarrow$  velocity =  $L/\Delta t$

$$A/Z = m/q = B \rho / (\gamma v)$$

# Identificación del isótopo de interés

Identificación por medio de detectores de tracking

*production*

Primary beam  
Secondary beam  
Dipole magnet  
Production target

*selection*

S1

S2

SCI21

Degrader

*identification*

S3

35m

TOF:  $\beta$ ,  $\gamma$

MW41  
MUSIC

MW42  
SCI41

S4

*implantation*

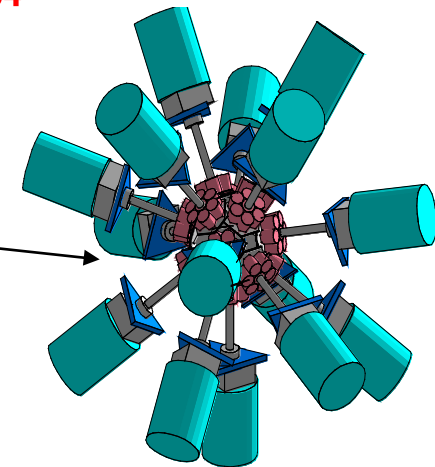
*spectroscopy*

**Tracking Detectors → Total Rate Limits:**

Total Rate Limit @ S2 = 3E6 Hz

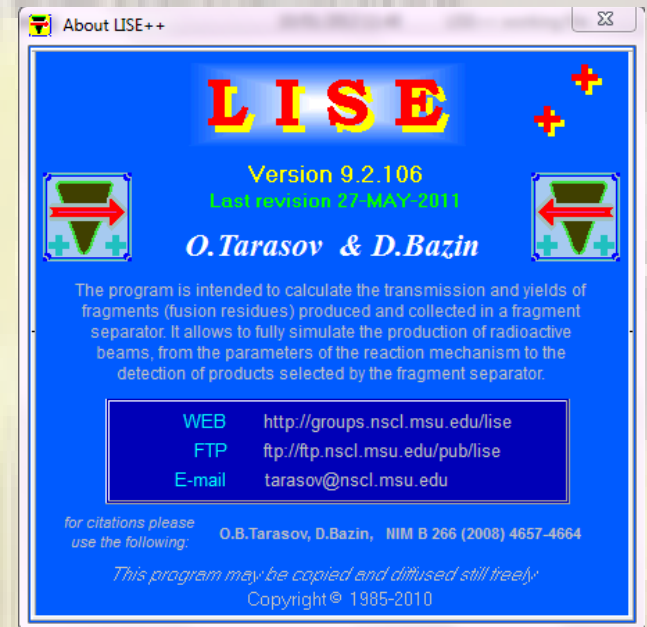
Total Rate Limit @ S4 = 1E4 Hz

Active stopper



# Aspectos prácticos del código:

0



- LISE++ es un código de libre uso, se puede descargar de internet y no necesita instalación.
- Creado por O.Tarasov y D.Bazin de MSU-NSCL (USA).
- Útil para calcular la producción y transmisión de fragmentos exóticos de interés en los experimentos de física nuclear.
- Muchas funcionalidades añadidas, como cálculo del rango y la pérdida de energía en materiales, y un largo etc.
- La mejor forma de aprender el código, es jugar/practicar con él.

# Aspectos prácticos del código:

1

- Definir las características del haz primario (proyector isótopo, energía e intensidad)
- Definir el haz secundario (setting fragment)

The screenshot displays the LISE++ software interface. The main window shows a list of components on the left and a central plot area. A red circle highlights the 'Projectile' and 'Fragment' settings in the component list. Two dialog boxes are overlaid on the interface:

**Beam Dialog:**

A	Element	q+
238	U	92
92		
Z		

Beam energy:

Energy	<input checked="" type="radio"/> 650 MeV/u
TKE	<input type="radio"/> 154733.01 MeV
Brho	<input type="radio"/> 11.0309 Tm
P	<input type="radio"/> 304.244 GeV/c
U	<input type="radio"/> 1.68e+6 KV

Beam intensity:

<input type="radio"/> 14.72 enA
<input type="radio"/> 0.16 pA
<input checked="" type="radio"/> 1e+9 pps
<input type="radio"/> 0.02475 KW

Emittance:

1. X mm	
2. T mrad	
3. Y mm	1
4. P mrad	3
5. L mm	
6. D %	0

Buttons: Ok, Cancel

**Setting Fragment Dialog:**

A	Element	Z
96	Cd	48

Charge states: 48+ D1

Buttons: Ok, Cancel

# Aspectos prácticos del código:

2

- Definir las características del blanco de producción (Target)

The screenshot shows the LISE++ software interface. The main window displays a list of components: Projectile (238U92+), Fragment (96Zr48+), Target (Pb, 1500 mg/cm2), Slits (S0\_slitY, S0\_slitX, S1\_slits), and Detectors (D1, D2). The Target component is highlighted with a red oval. A red arrow points from this oval to the Target dialog box, which is also highlighted with a red border. The dialog box contains the following information:

**Target**

Element: Pb, Density: 11.34 g/cm<sup>3</sup>

State:  Solid,  Gas

Dimension:  mg/cm<sup>2</sup> & micron,  g/cm<sup>2</sup> & mm

Angle: 0 degrees

Z	Element	Mass
<input checked="" type="checkbox"/>	82 Pb PT	207.19
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	

Thickness at 0 degrees:  1322.7513 micron,  1500 mg/cm<sup>2</sup>

Effective Thickness:  1322.7513 micron,  1500 mg/cm<sup>2</sup>

Thickness defect: [ ]

Absorbed Dose: [ ]

d / Range (beam): 0.161

Energy Loss in the target box [KW]: 0.00303

Atoms / cm<sup>2</sup>: 4.36e+21

Buttons: OK, Cancel, Compound dictionary, Cut (Slits)

<sup>94</sup>Sn

# Aspectos prácticos del código:

3

- Ajustar los campos magnéticos (Br) para el fragmento de interés (setting fragment)

The screenshot displays the LIS E ++ software interface. The title bar shows the file path: [C:\Users\domingo\Documents\work\MasterFisicaNuclear2013\Practica\_LISE\LISE\_beginning.lpp]. The menu bar includes File, Settings, Options, Calculations, Utilities, 1D-Plot, 2D-Plot, Databases, and Help. The toolbar contains various icons, with the 'Set-Up' icon circled in red. The main window is divided into several sections:

- Projectile:** 238U92+, 650 MeV/u, 1e+9 pps.
- Fragment:** 96Cd48+.
- Target:** Pb, 1500 mg/cm2.
- Stripper:** (empty).
- Slits:** S0\_slitY (s is), S0\_slitX (s is).
- Detector:** D1, Brho 7.9001 Tm.
- Slits:** S1\_slits (s is), with values -100 and +100.
- Degrader:** S1-degrader.
- Detector:** D2, Brho (partially visible).

The central plot area shows a 2D distribution of the projectile fragment, labeled 'PROJECTILE FRAGMENT', with red arrows indicating the direction of the fragment. To the right, a diagram shows the detector setup, including a green detector labeled  $^{94}\text{Sn}$ .

# Aspectos prácticos del código:

4

- Optimizar el target de producción (**cada vez que se modifiquen los parámetros del haz primario o del haz secundario**)

The screenshot displays the LISE++ software interface. The 'Calculations' menu is open, with 'Optimum Target' highlighted. The 'Optimal target calculation mode' dialog box is also visible, showing options for 'Keep value' (set to 'no keep value') and radio buttons for 'Thickness - varying, Inclination angle - const' (selected) and 'Inclination angle - varying, Thickness - const'. The 'OK' button is highlighted with a green checkmark.

LISE ++ [C:\Users\domingo\Documents\work\MasterFisicaNuclear2013\Practica\_LISE\LISE\_beginning.lpp]

File Settings Options **Calculations** Utilities 1D-Plot 2D-Plot Databases Help

Set-Up

Projectile 238U92+  
650 MeV/u 1e+9 pps

Fragment 96Cd48+

Target

Stripper

S0\_slitY

S0\_slitX

D1 7.80

S1\_slits  
-100 H +100

S1-degrader

D2

Calculations

- Goodies
- Calibrations
- Transmission and rate
- Optimum Target**
- Optimum Target-Wedge and Wedge-Wedge configurations
- Brho scanning
- Optimum charge state combination
- Monte Carlo calculation of transmission
- Physical Calculator
- Kinematics Calculator
- Mathematical Calculator
- Evaporation Calculator
- Fusion-Residue Calculator
- Matrix Calculator

Optimal target calculation mode

Keep value no keep value

Thickness - varying, Inclination angle - const

Inclination angle - varying, Thickness - const

OK Quit

# Aspectos prácticos del código:

5

- Calcular la producción del fragmento de interés (en primera aproximación):

The screenshot displays the LIS E++ software interface for nuclear fragmentation calculations. The window title is "LIS E ++ [C:\Users\domingo\Documents\work\MasterFisicaNuclear2013\Practica\_USE\LISE\_beginning.lpp]". The menu bar includes "File", "Settings", "Options", "Calculations", "Utilities", "1D-Plot", "2D-Plot", "Databases", and "Help".

**Parameter List (Left Panel):**

- P**rojectile: 238U92+, 650 MeV/u, 1e+9 pps
- F**ragment: 96Cd48+
- T**arget: Pb, 1500  $\pi$  cm<sup>2</sup>
- Str**ipper
- S**0\_slitY: s fs
- S**0\_slitX: s fs
- D**1: Brho, 7.8001 Tm
- S**1\_slits: s fs
- S**1\_degrader
- D**2: Brho, 7.8001 Tm
- S**2\_slits: s fs
- M**Scint21: H10C9, 3.2 nm
- S**2\_wedge
- D**3: Brho

**Central Plot Area:**

- PROJECTILE FRAGMENT:** A 2D plot showing the distribution of fragments.
- Nuclear Chart:** A grid of isotopes where the cell for <sup>96</sup>Cd is highlighted in red. The values for <sup>96</sup>Cd are 1.13e-5 and 48.061.

**Status Bar (Bottom):**

- Ncalc=1
- Sum=1.1e-05
- No charge states

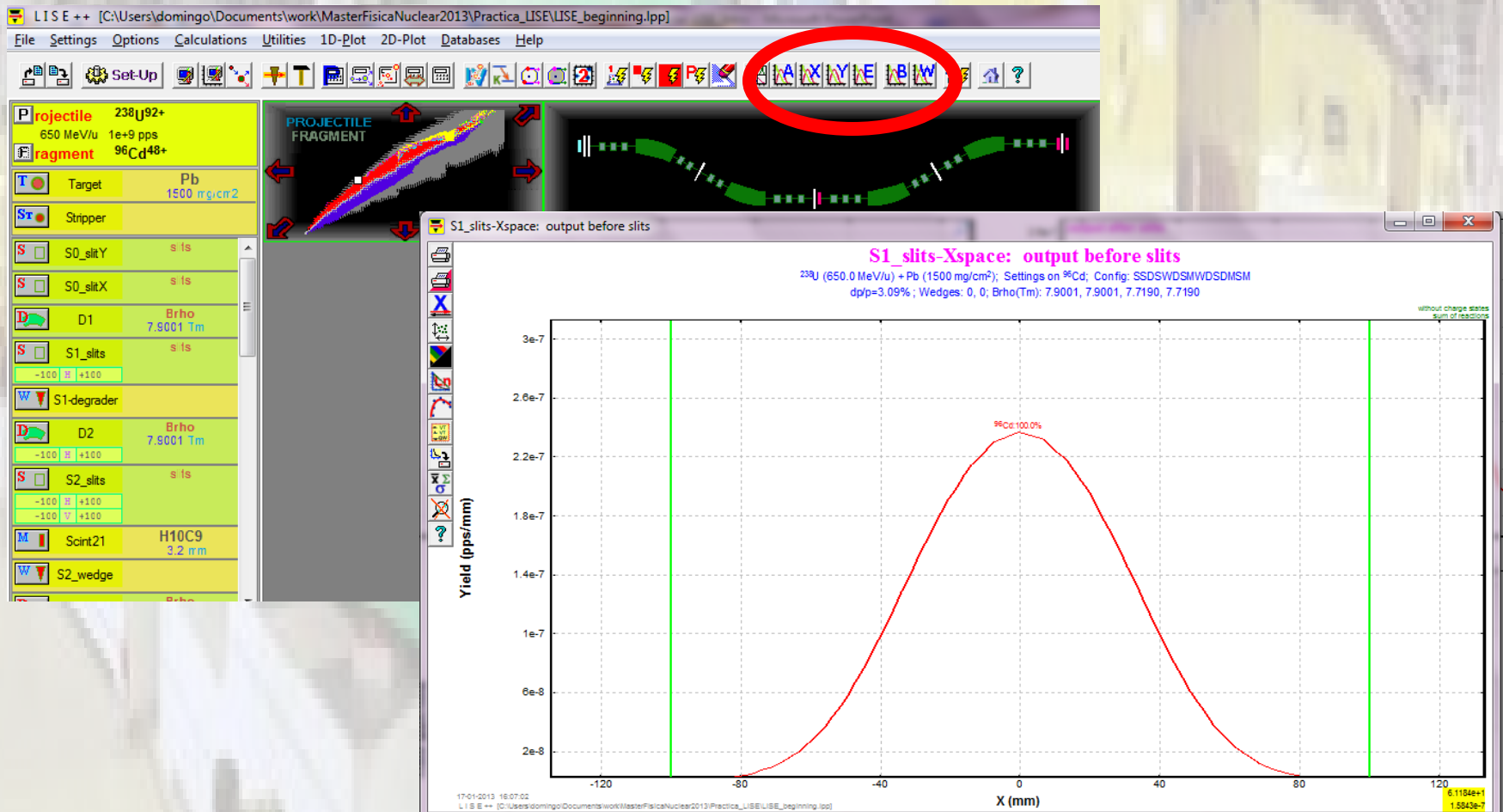
**Mouse Instruction:** A mouse icon with a red arrow pointing to it, labeled "Right Mouse Button".

# Aspectos prácticos del código:

6

- Menús de uso frecuente:

Distribución del RIB en posiciones (X) y en energía (E)



# Aspectos prácticos del código:

6

• Menús de uso frecuente:

Diseño del espectrómetro: desactivar elementos, ajustar S2-wedge, añadir una Faraday Cup, etc

The screenshot shows the LIS E++ software interface for spectrometer design. The 'Set-Up' menu is circled in red. The main window displays a list of components with columns for Block, Given Name, Z-Q, Length, m, and Enable. The 'Selected block' panel shows configuration for 'Drift (space)' with 'Block Length [m]' set to 0 and 'Length after this block [m]' set to 17.458. The 'Insert block' panel lists various components like Target, Stripper, Wedge, Material, Faraday cup, etc.

Block	Given Name	Z-Q	Length, m	Enable
T	Target			+
St	Stripper			+
S	Drift		0	+
S	Drift		0	+
D	Dipole	0	17.46	+
S	Drift		0	+
W	Wedge			+
M	Material			NO
M	Material			NO
M	Material			NO
M	Material			NO
D	Dipole	0	18.11	+
M	Material			NO
S	Drift		0	+
M	Material			+

Selected block: Drift (space)

Enable:

Let call automatically:

Block name = S1\_slits

Block Length [m]: 0

Length after this block [m]: 17.458

Sequence number: 6

Total: Number of Blocks: 86, Length [m]: 73.148

Insert block options: Target, Stripper after Target, Wedge, Material(Detector), Faraday cup, Dispersive (Dipole), Wien velocity filter, Drift (space), Beam Rotation, Electric dipole, Gas-filled separator, Compensating Dipole, RF separator, Solenoid, Delay (efficiency) block.

# Aspectos prácticos del código:

6

• Menús de uso frecuente:

Diseño del espectrómetro: desactivar elementos, ajustar S2-wedge, añadir una Faraday Cup, etc

The screenshot shows the LIS E++ software interface for spectrometer design. The 'Set-Up' menu is circled in red. The main window displays a list of components with columns for Block, Given Name, Z-Q, Length, and Enable. The 'Selected block' panel shows configuration for 'Drift (space)' with 'S1\_slits' selected. The 'Insert block' panel lists various components like Target, Stripper, Wedge, Material, Faraday cup, etc.

Block	Given Name	Z-Q	Length, m	Enable
T	Target			+
St	Stripper			+
S	Drift		0	+
S	Drift		0	+
D	Dipole	0	17.46	+
S	Drift		0	+
W	Wedge			+
M	Material			NO
M	Material			NO
M	Material			NO
M	Material			NO
D	Dipole	0	18.11	+
M	Material			NO
S	Drift		0	+
M	Material			+

**Selected block**

Enable  Drift (space)

Let call automatically  Block Length [m] 0

Block name = S1\_slits Length after this block [m] 17.458

Sequence number 6

**Total**

Number of Blocks 86

Length [m] 73.148

**Insert block**

- Target
- Stripper after Target
- Wedge
- Material(Detector)
- Faraday cup
- Dispersive (Dipole)
- Wien velocity filter
- Drift (space)
- Beam Rotation
- Electric dipole
- Gas-filled separator
- Compensating Dipole
- RF separator
- Solenoid
- Delay (efficiency) block

# Resultados practica

Target material effect:

Al 8.3 g/cm<sup>2</sup> 1.8E-3pps

Be 5.7 g/cm<sup>2</sup> 1.73E-3 pps → largest fragmentation CS

C 6.3 g/cm<sup>2</sup> 1.51E-1 pps

Cu 8.3 g/cm<sup>2</sup> 4.96E-2 pps

Ta 10.75 g/cm<sup>2</sup> 1.99E-2 pps

Pb 10.23 g/cm<sup>2</sup> 1.78E-2 pps → Magic → lowest CS

# Best target material

- Be / 7.9 g/cm<sup>2</sup> 1.73E-1 pps
- Pb / 10.23 g/cm<sup>2</sup> 1.78E-2 pps

238U 1.82 g/cm<sup>2</sup> 8.5E-4 pps

208Pb 2.28 g/cm<sup>2</sup> 6.42E-4 pps

144Sm 3.619 g/cm<sup>2</sup> 5.21E-2 pps

136Xe 3.8 g/cm<sup>2</sup> 2.85E-1 pps

124Xe 5.7 g/cm<sup>2</sup> 3.44E-1 pps

112Sn 4.7 g/cm<sup>2</sup> 3.64E-3 pps