

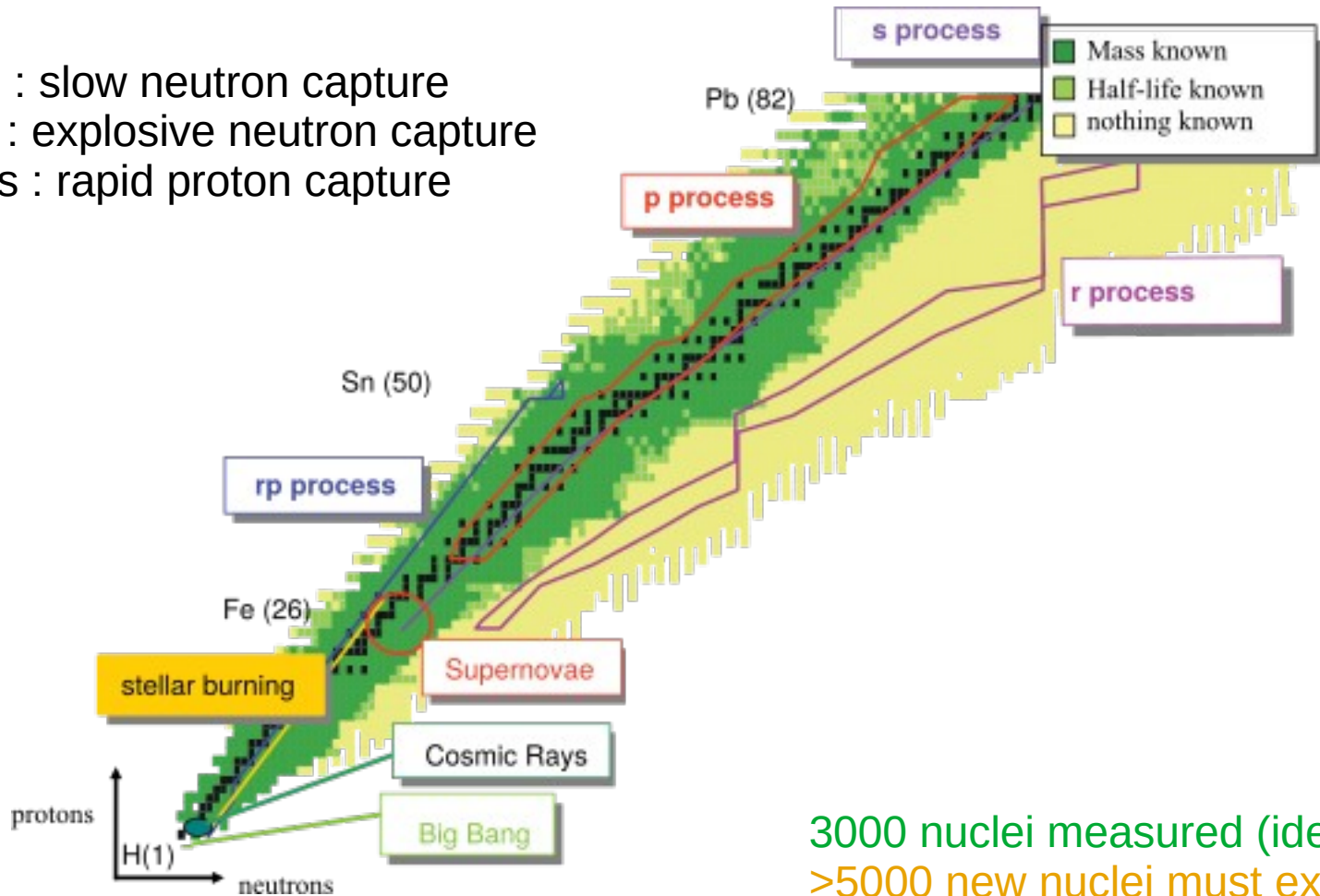
Introduction to LISE++

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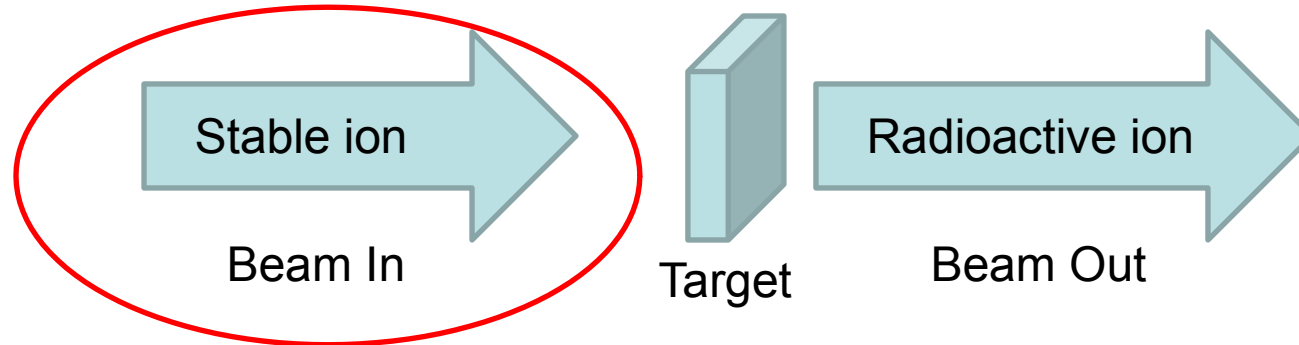
Motivation

s-process : slow neutron capture
r-process : explosive neutron capture
rp-process : rapid proton capture



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

Production of radioactive ion beams



It is possible to accelerate every stable isotope, from hydrogen to uranium-238, in order to obtain the primary beam.

Stable ion sources

^{238}U : $2 \cdot 10^9$

^{208}Pb : $2 \cdot 10^9$

^{144}Sm : $2 \cdot 10^9$ (ns, used once)

^{136}Xe : 10^{10}

^{124}Xe : 10^{10} (requires enriched material)

^{112}Sn : $\sim 10^8$ (requires enriched material)

^{107}Ag : $4 \cdot 10^9$

^{86}Kr : $2 \cdot 10^{10}$

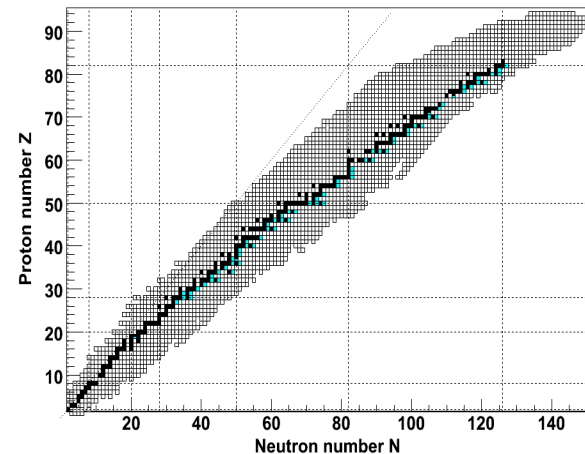
^{78}Kr : $2 \cdot 10^{10}$ (requires enriched material)

^{76}Ge : $3 \cdot 10^8$ (no standard beam, needs to be developed)

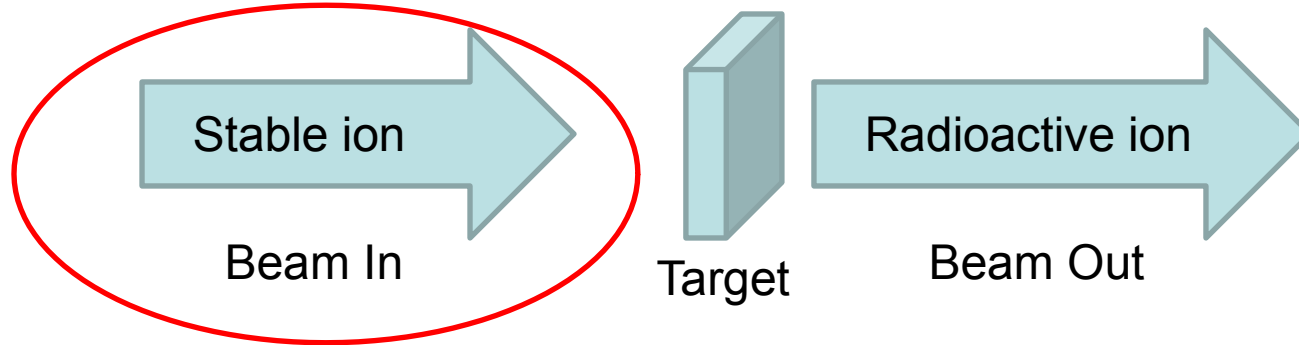
^{64}Ni : $5 \cdot 10^9$ (requires enriched material)

^{58}Ni : $5 \cdot 10^9$

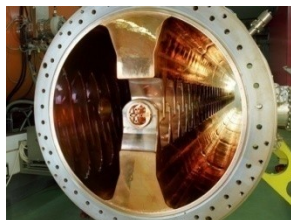
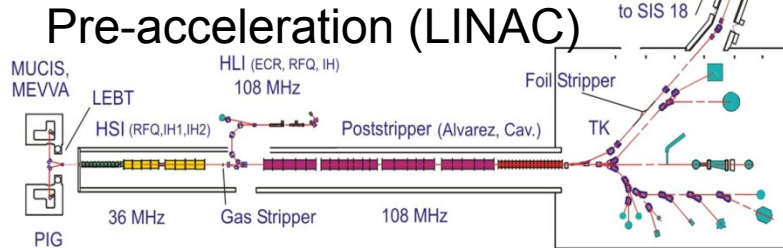
^{48}Ca : $3 \cdot 10^7$ (low intensity from the ECR source when used for pulsed beams for SIS. Or very very expensive ...)



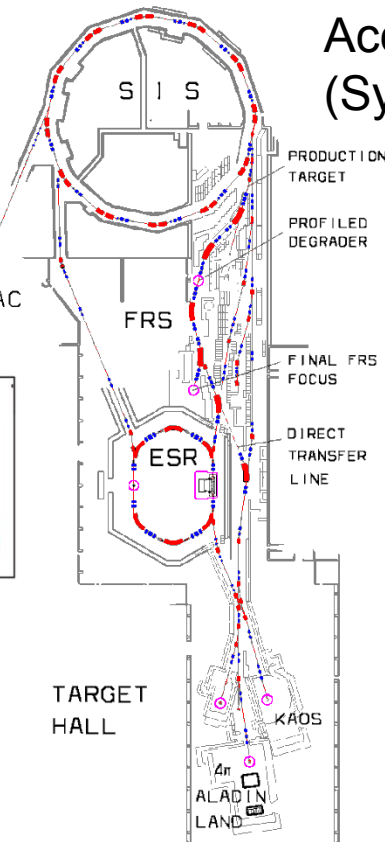
Production of radioactive ion beams



Stable ion sources



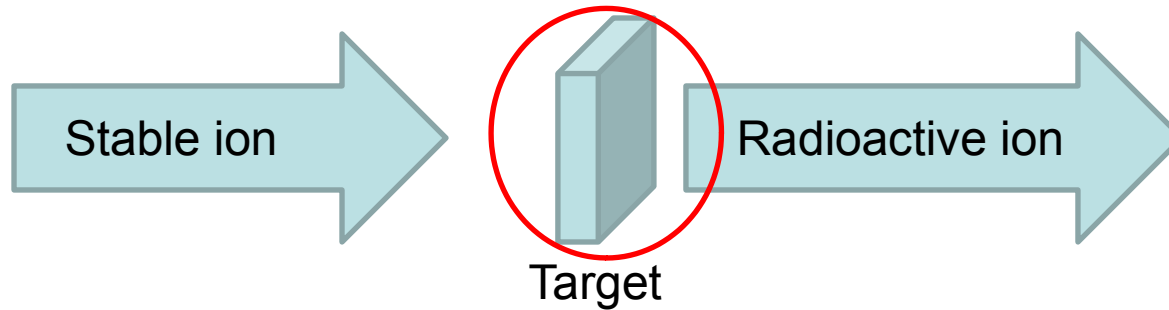
Acceleration (Synchrotron)



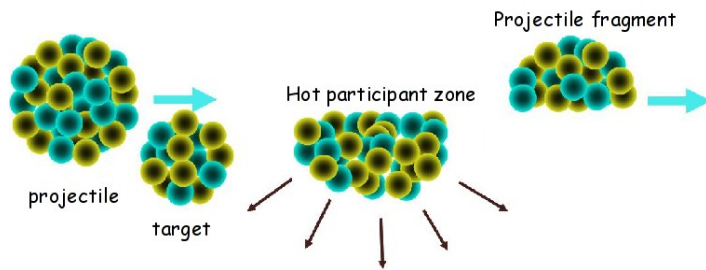
SIS18:
0.1-1 GeV/u

UNILAC:
11.4 MeV/u

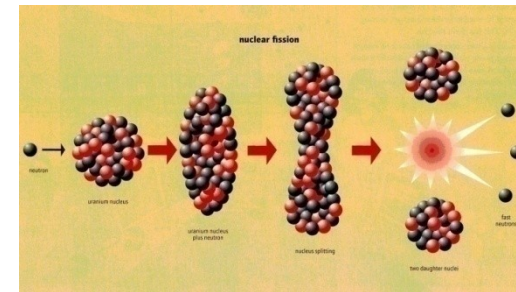
Production of radioactive ion beams



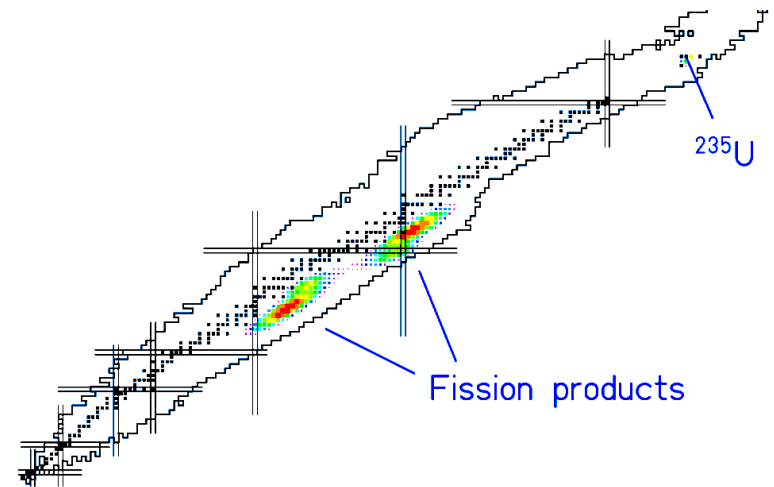
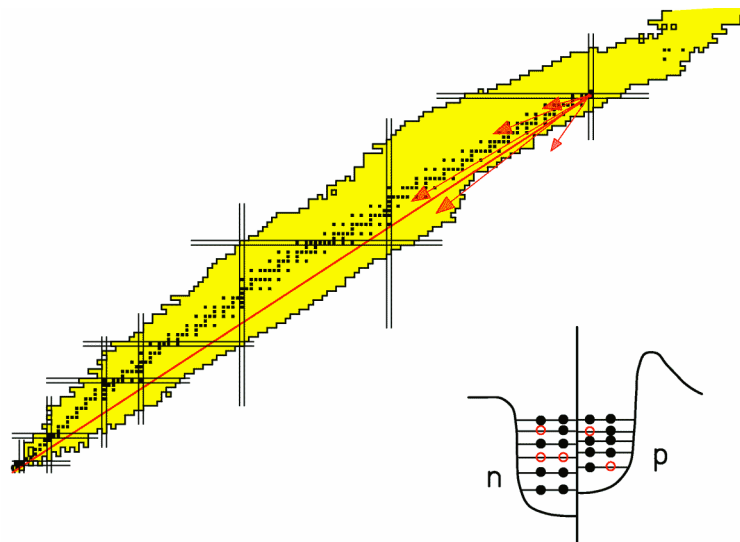
FRAGMENTATION



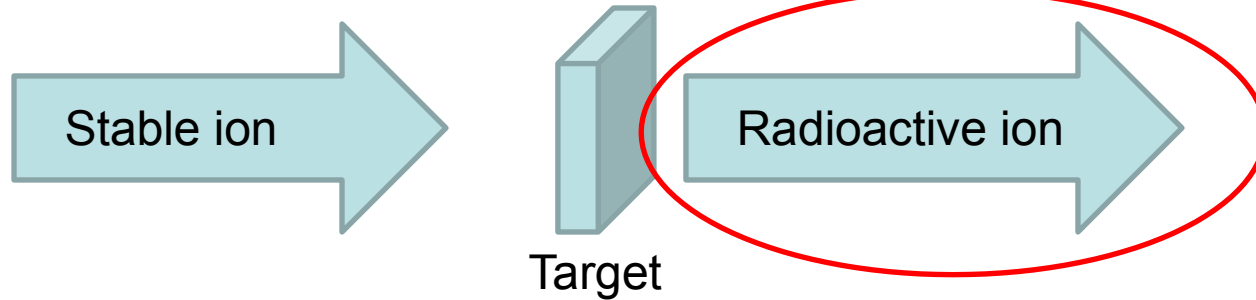
FUSION - FISSION



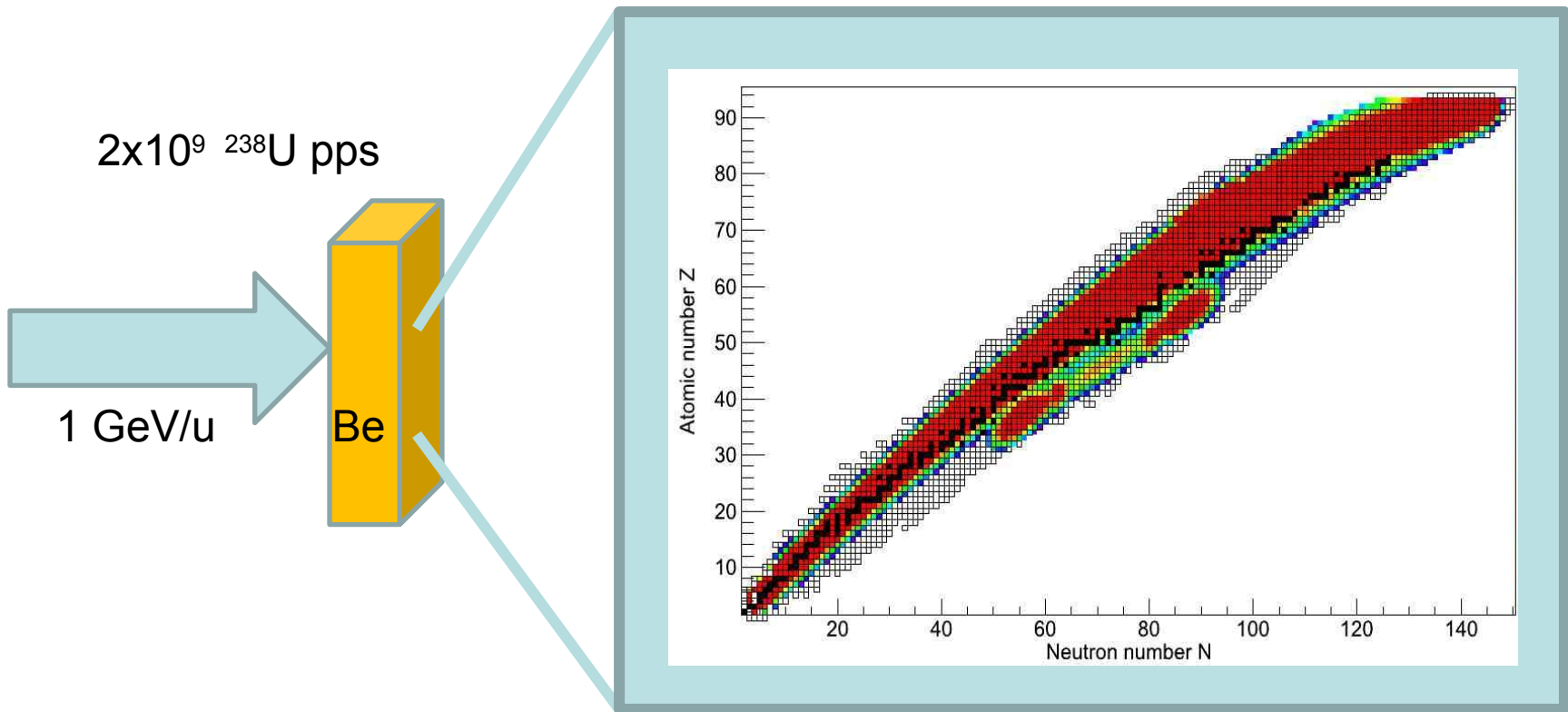
Fission induced by low-energy neutrons



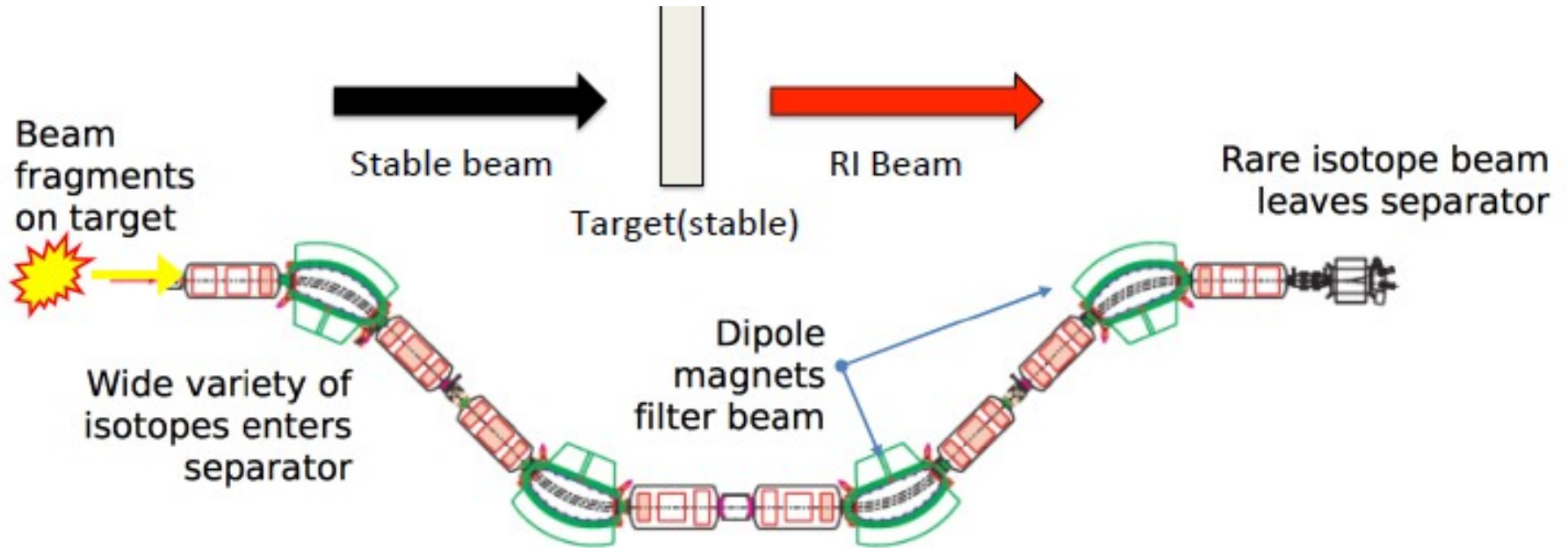
Production of radioactive ion beams



EXAMPLE:

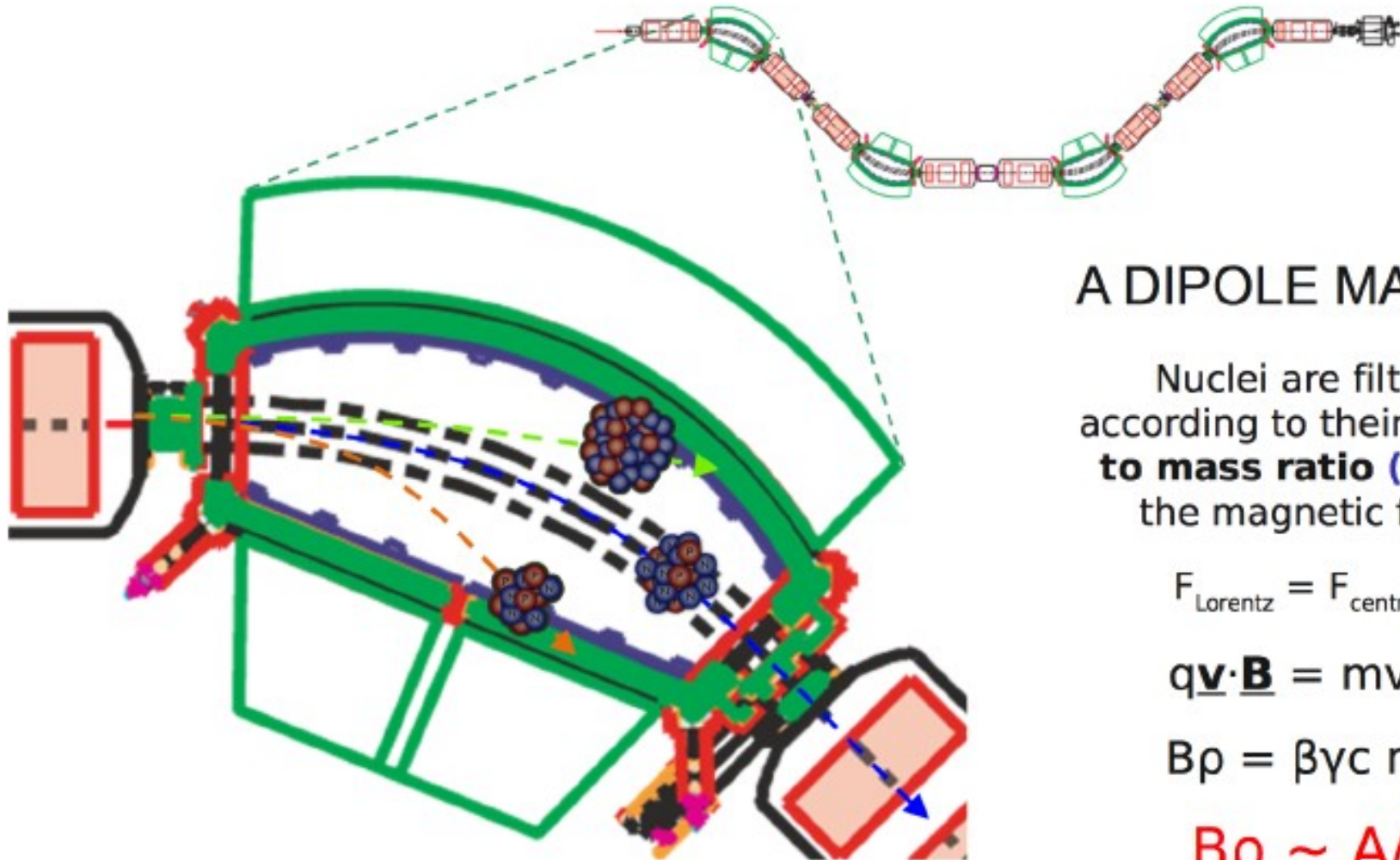


In-flight separation



The *dipole magnets* affect different isotopes "like prisms affect light", separating the unwanted nuclei (of any isotope not currently being studied) out of the beam

In-flight separation



A DIPOLE MAGNET

Nuclei are filtered according to their **charge to mass ratio (Q/A)** in the magnetic field.

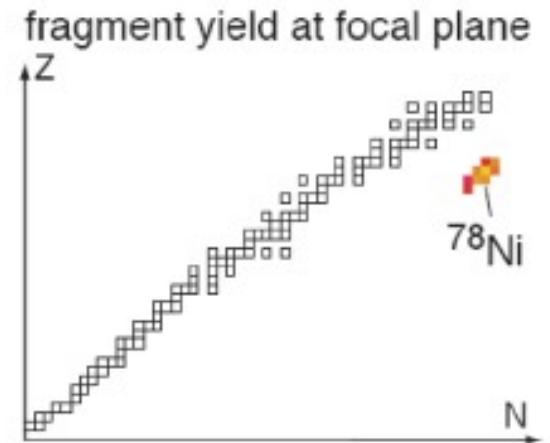
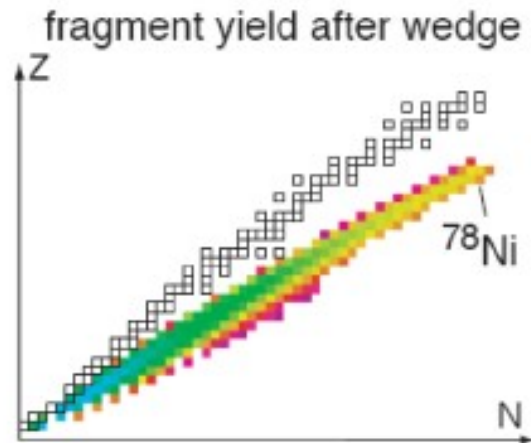
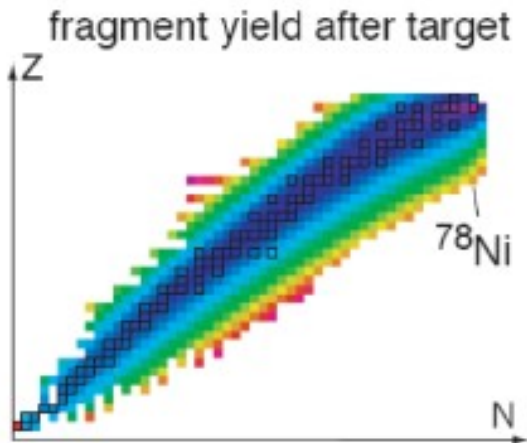
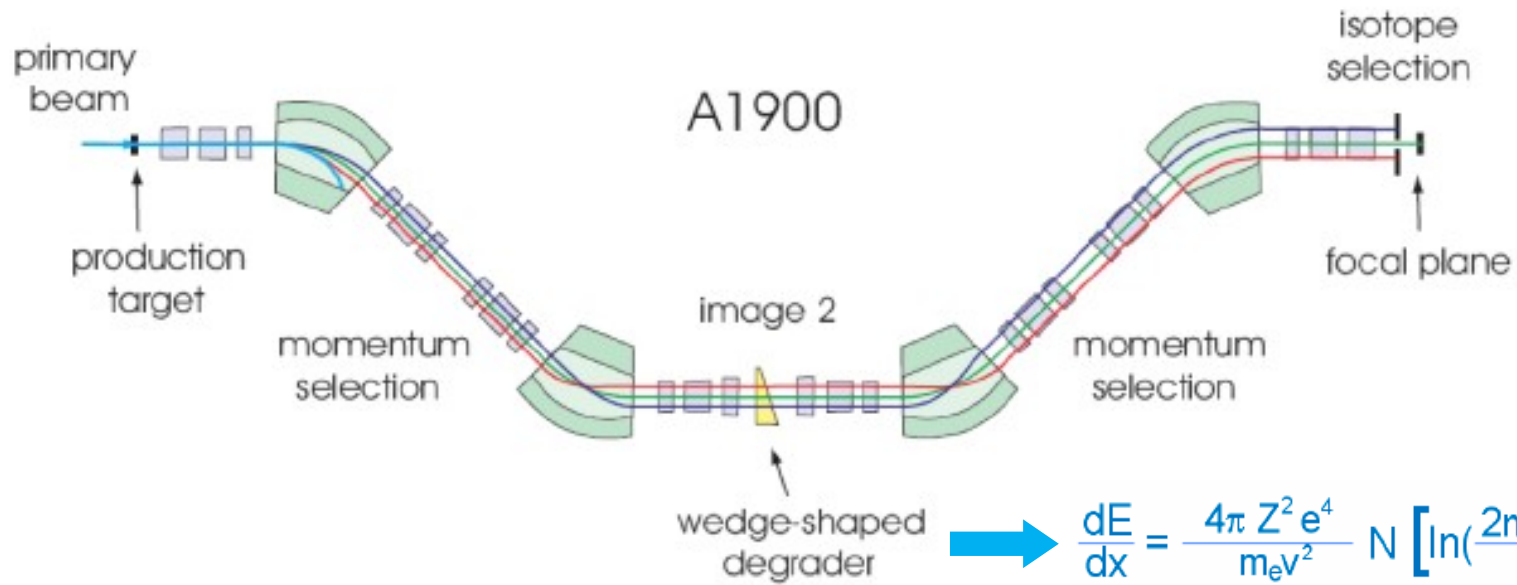
$$F_{\text{Lorentz}} = F_{\text{centripetal}}$$

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

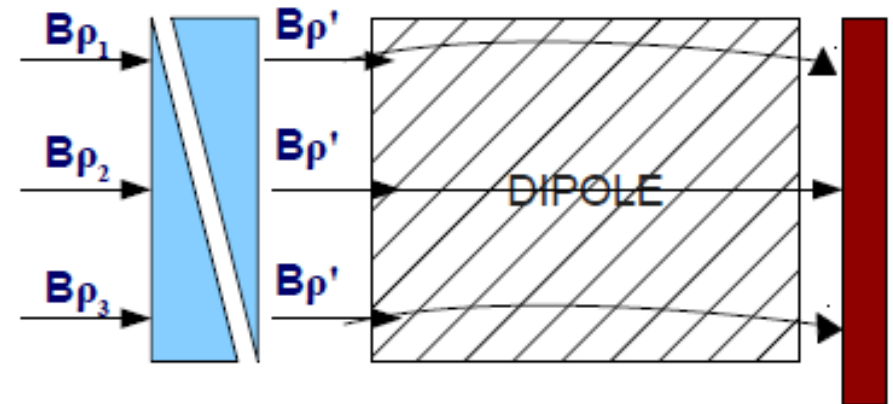
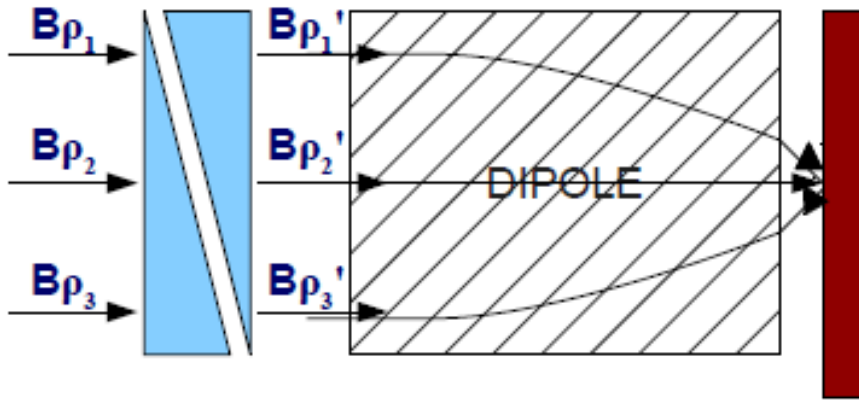
$$B\rho = \beta\gamma c m/q$$

$$B\rho \sim A/Z$$

In-flight separation



In-flight separation



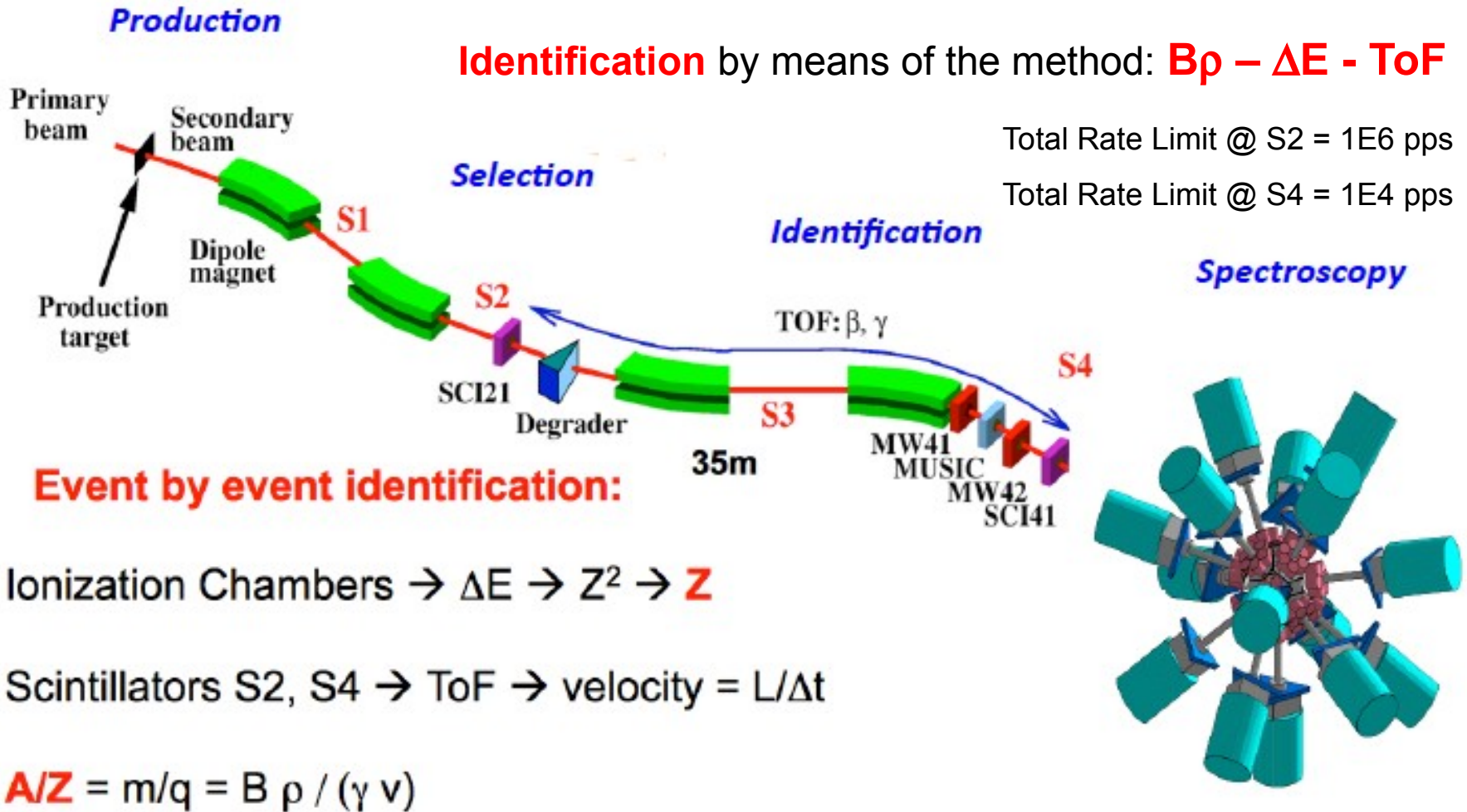
• ACHROMATIC MODE

- 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

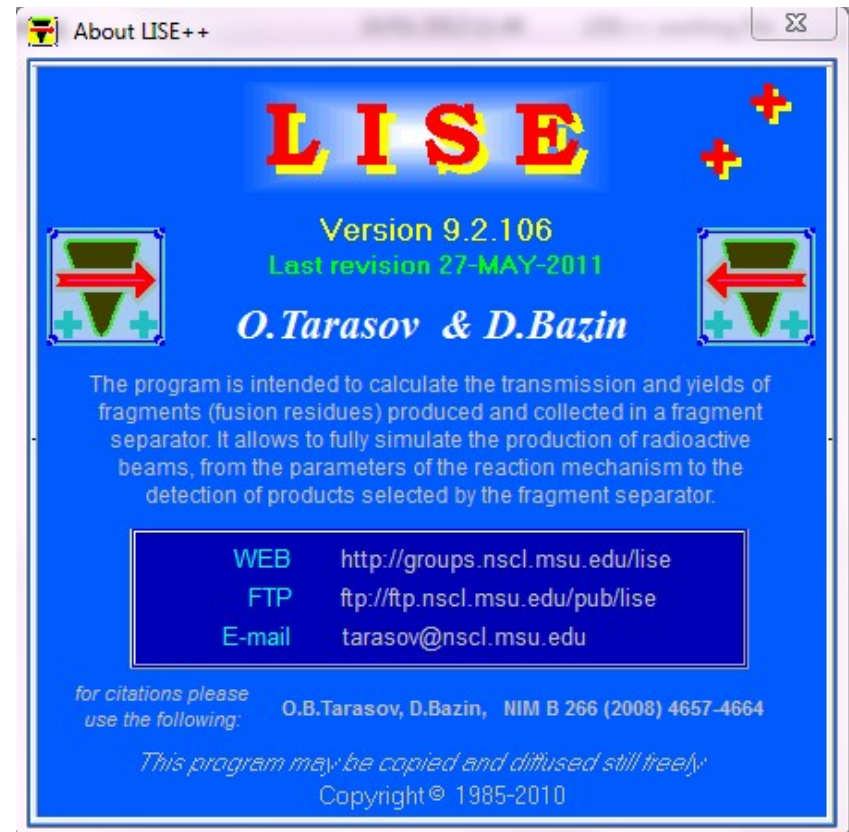
In-flight identification



Practical aspects about the program:

0

- LISE++ is a free software, it can be downloaded online.
- Created by O.Tarasov y D.Bazin of MSU-NSCL (USA).
- Useful for calculating the production and transmission of exotic fragments for nuclear physics experiments.
- Several utilities, as range calculation and energy loss in materials, and a long etc.
- The best way to learn about LISE++ is playing/practising with it



Practical aspects about the program:

1

- Set the primary beam characteristics (isotope, energy and intensity)
- Set the fragment of interest

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

Beam Dialog: This dialog is used to set primary beam characteristics. It includes fields for:

- Beam energy:** Energy (650 MeV/u), TKE (154733.01 MeV), Brho (11.0309 Tm), P (304.244 GeV/c), U (1.68e+6 KV).
- Beam intensity:** 14.72 enA, 0.16 pnA, 1e+9 pps (selected), 0.02475 KW.
- Emittance:** Fields for X, T, Y, P, L, and D.
- Table of Nuclides:** A, Element, q+ (238, U, 92).

Setting Fragment Dialog: This dialog is used to set the fragment of interest. It includes fields for:

- Fragment:** A, Element, Z (96, Cd, 48).
- Charge states:** 48+ D1.
- Table of Nuclides:** A, Element, Z (96, Cd, 48).
- Beta+ decay:** A checkbox.

Practical aspects about the program:

2

- Set the production target characteristics (element and thickness)

The screenshot displays the LISE++ software interface. The main window shows a list of components in a table:

Component	Element	Mass
Projectile	$^{238}\text{U}^{92+}$	
Fragment	$^{96}\text{Zr}^{48+}$	
Target	Pb	1500 mg/cm ²
S0_slitY	s	1s
S0_slitX	s	1s
D1	Brho	7.9001 Tm
S1_slits	s	1s
S1-degrader		
D2	Brho	

The 'Target' dialog box is open, showing the following settings:

- Element: Pb, Density: 11.34 g/cm³
- State: Solid, Gas
- Dimension: mg/cm² & micron, g/cm² & mm
- Angle: 0 degrees
- Thickness at 0 degrees: 1322.7513 micron, 1500 mg/cm²
- Effective Thickness: 1322.7513 micron, 1500 mg/cm²
- Buttons: Thickness defect, Absorbed Dose, d / Range (beam) 0.161, Energy Loss in the target box [KW] 0.00303, Atoms / cm² 4.36e+21, OK, Cancel

Practical aspects about the program:

3

- Tune the magnetic fields (B) for the fragment of interest, depending on the spectrometer design

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 'Utilities' icon (a wrench and screwdriver) circled in red. The main window is divided into a left sidebar and a central plot area.

Left Sidebar:

- P**rojectile: 238U92+, 650 MeV/u, 1e+9 pps
- F**ragment: 96Cd48+
- T**arget: Pb, 1500 mg/cm2
- St**ripper
- S**0_slitY: s is
- S**0_slitX: s is
- D**1: Brho, 7.9001 Tm
- S**1_slits: s is, -100 | +100
- W** S1-degrader
- D**2: Brho

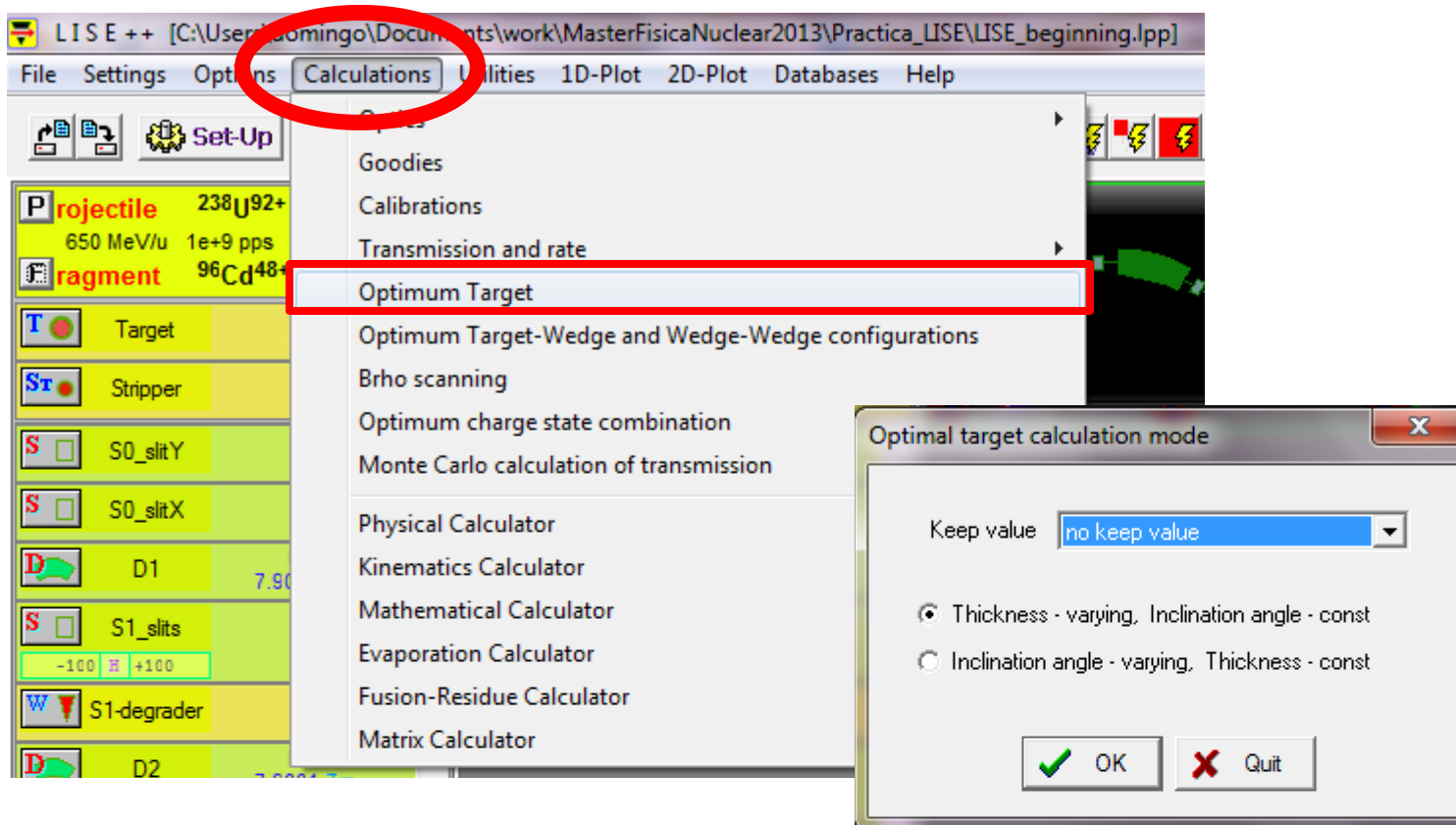
Central Plot Area:

- 3D plot titled "PROJECTILE FRAGMENT" showing a distribution of particles in a 3D space, with red arrows indicating movement directions.
- A schematic diagram on the right shows a particle trajectory through a series of slits and a detector labeled ^{94}Sn .

Practical aspects about the program:

4

- Optimize the production target thickness (**each single time that primary or secondary beam parameters are modified**)



Practical aspects about the program:

5

- Obtain more details about the production and transmission of a specific fragment

The screenshot shows the LIS E++ software interface. On the left, a parameter panel is visible with the following settings:

- Projectile: 238U92+, 650 MeV/u, 1e+9 pps
- Fragment: 96Cd48+
- Target: Pb, 1500 $\mu\text{g/cm}^2$
- Stripper: S0_slitY, S0_slitX (both s/s)
- D1: Brho, 7.8001 Tm
- S1_slits: s/s
- S1-degrader: S1-degrader
- D2: Brho, 7.8001 Tm
- S2_slits: s/s
- Scint21: H10C9, 3.2 mm
- S2_wedge: S2_wedge
- D3: Brho

The central plot area shows a 2D distribution of fragments (left) and a 3D trajectory of the projectile (right). The right side of the interface features a periodic table where the 96Cd cell is highlighted in red and contains the following data:

94Sn	95Sn	96Sn	97Sn	98Sn	99Sn	100Sn	101Sn	102Sn	103Sn	104Sn	105Sn	106Sn					
			96In	97In	98In	99In	100In	101In	102In	103In	104In	105In					
90Cd	91Cd	92Cd	93Cd	94Cd	95Cd	96Cd	97Cd	98Cd	99Cd	100Cd	101Cd	102Cd	103Cd	104Cd			
				93Ag	94Ag	95Ag	96Ag	97Ag	98Ag	99Ag	100Ag	101Ag	102Ag	103Ag			
86Pd	87Pd	88Pd	89Pd	90Pd	91Pd	92Pd	93Pd	94Pd	95Pd	96Pd	97Pd	98Pd	99Pd	100Pd	101Pd	102Pd	
			88Rh	89Rh	90Rh	91Rh	92Rh	93Rh	94Rh	95Rh	96Rh	97Rh	98Rh	99Rh	100Rh	101Rh	
83Ru	84Ru	85Ru	86Ru	87Ru	88Ru	89Ru	90Ru	91Ru	92Ru	93Ru	94Ru	95Ru	96Ru	97Ru	98Ru	99Ru	100Ru

The 96Cd cell contains the values: 1.13e-5 and 48.061%. A mouse cursor is pointing at this cell, and a red mouse icon is overlaid on the bottom right of the table.

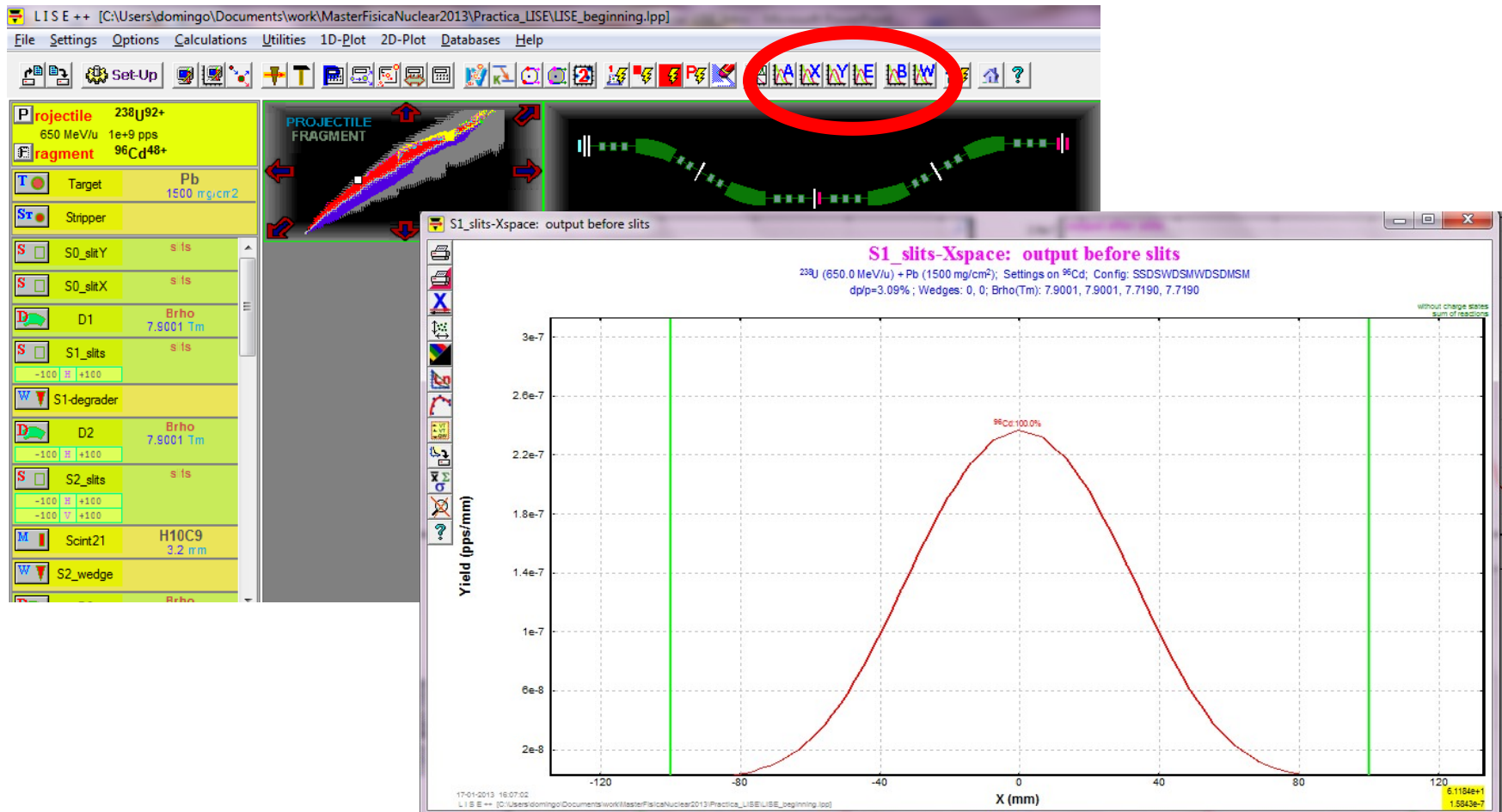
Right click

Practical aspects about the program:

6

- Useful options:

RIB distributions in position (X) and in energy (E)



Practical aspects about the program:

6

- Useful options: Spectrometer design: turn off elements, modify S2-wedge, insert a Faraday Cup, etc

The screenshot displays the LIS E++ software interface for spectrometer design. The 'Set-Up' button in the top-left corner is circled in red. The main window shows a list of blocks with columns for Block, Given Name, Z-Q, Length, and Enable. A 'Selected block' dialog is open for 'S1_slits', showing options to enable/disable, set length, and name. An 'Insert block' panel on the right lists various components like Target, Stripper, Wedge, Material, Faraday cup, etc.

Block	Given Name	Z-Q	Length, m	Enable
T	Target			+
Str	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: S1_slits

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