

Producción y uso de haces radioactivos en experimentos de desintegración

Master Interuniversitario de Fisica Nuclear

Berta Rubio IFIC (CSIC-Univ. Valencia)

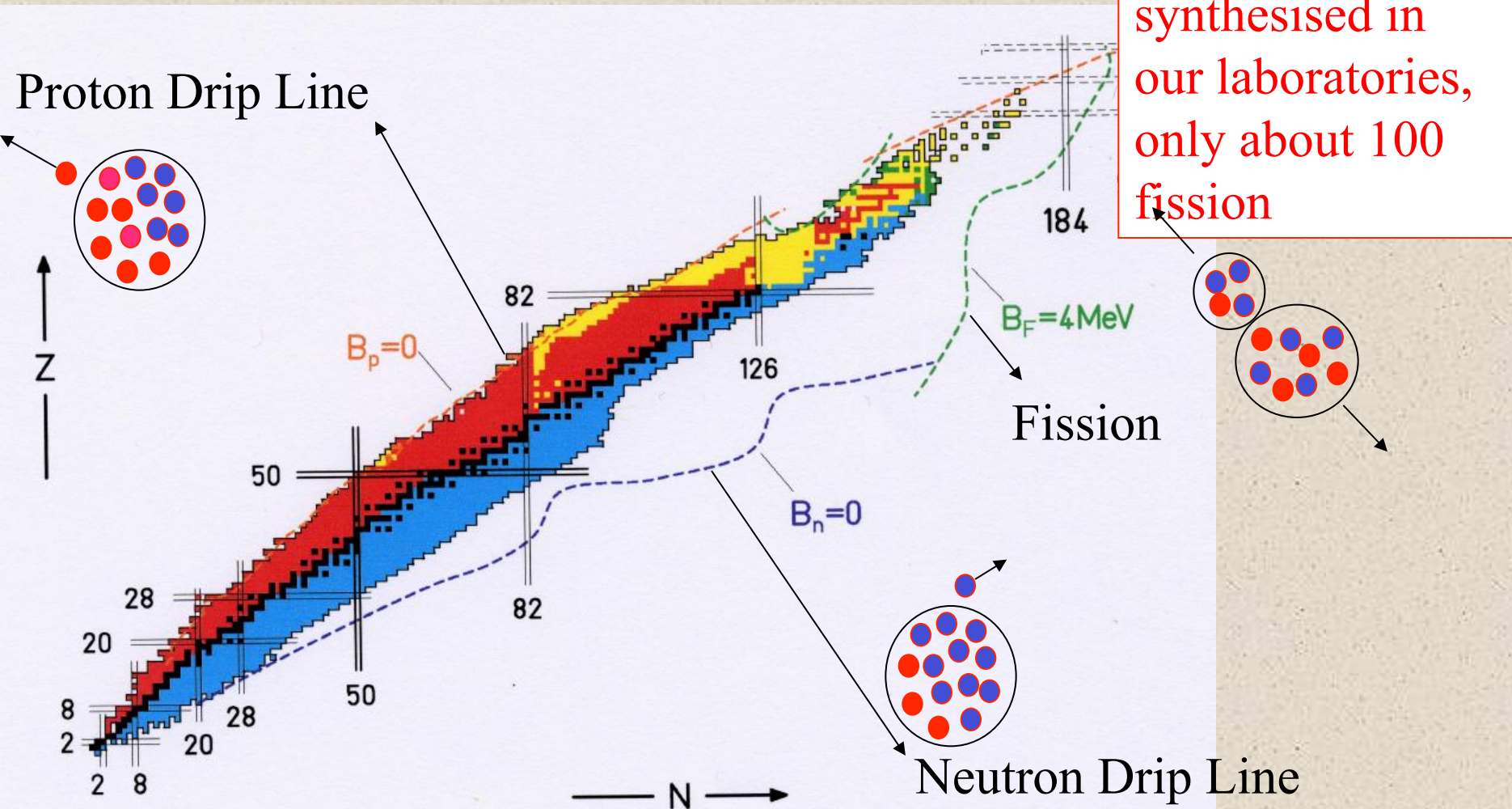
B. Rubio. Master FN, Valencia 2013

Porqué son importantes las medidas de desintegración nuclear

Most unstable nuclei decay
by either β^+ or β^- decay

265 stable

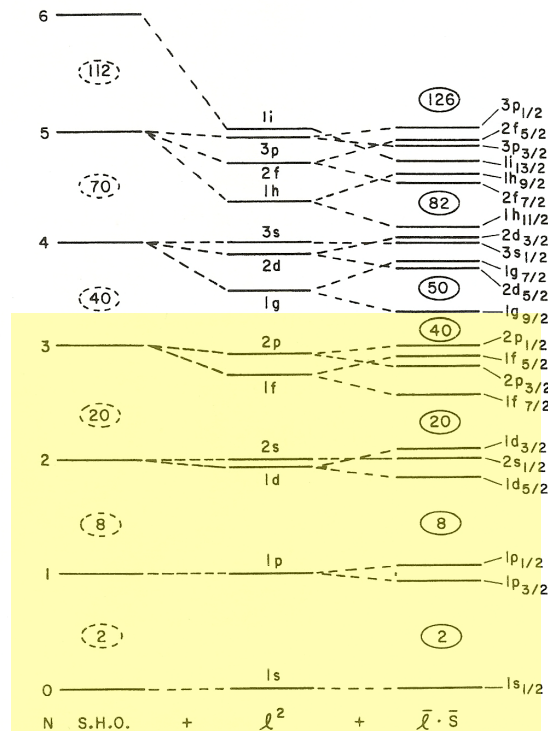
About 3000 out
of 6000
synthesised in
our laboratories,
only about 100
fission



Our first example will be the doubly magic nucleus $^{132}_{50}\text{Sn}_{82}$

52

50 Protons



Firestone
Shirley
Baglin • Chu • Zipkin

Table of Isotopes
Eighth Edition Volume I



SET
INCLUDES
CD-ROM



Table of Isotopes

**Eighth Edition
Volume I**



Richard B. Firestone

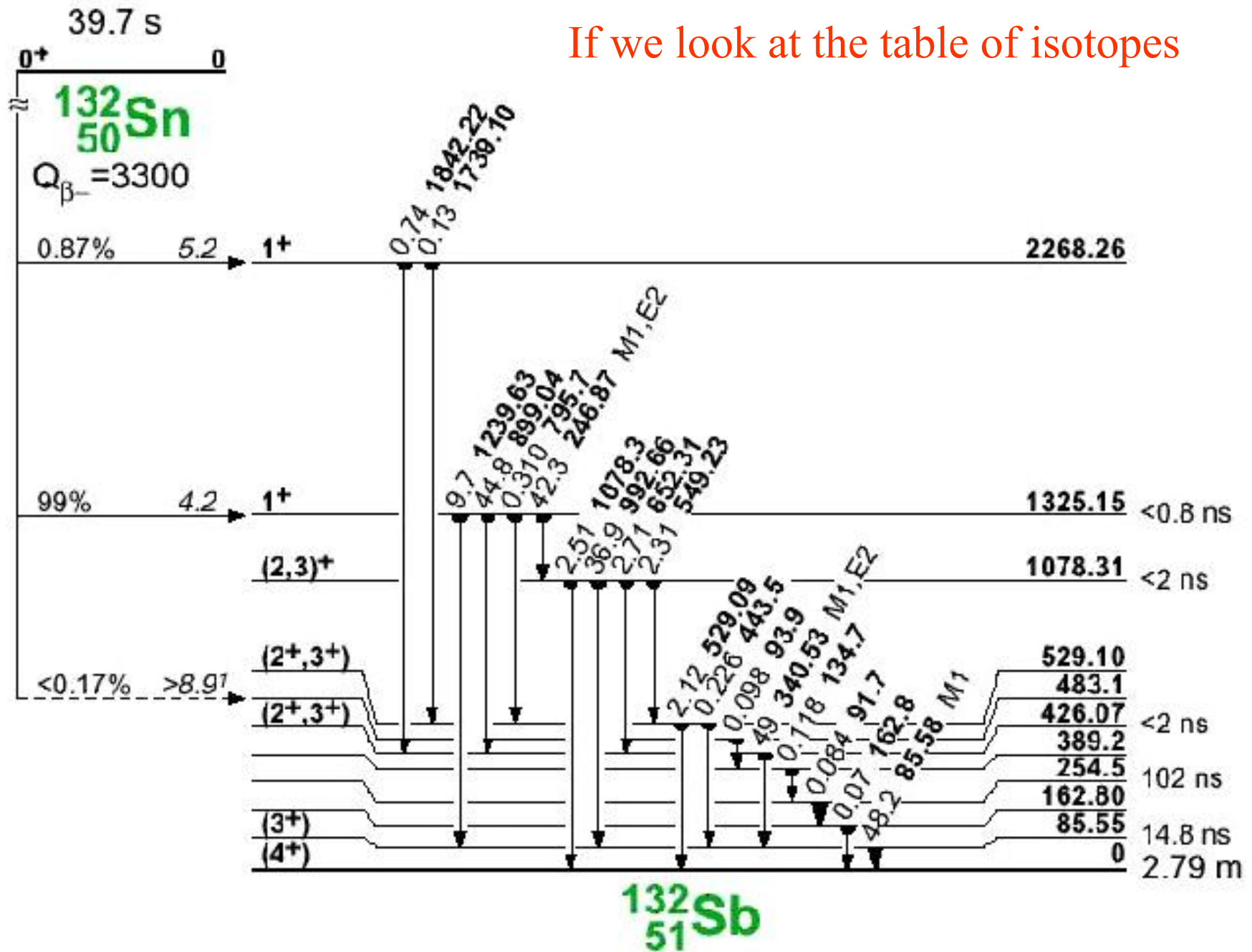
Virginia S. Shirley
Editor

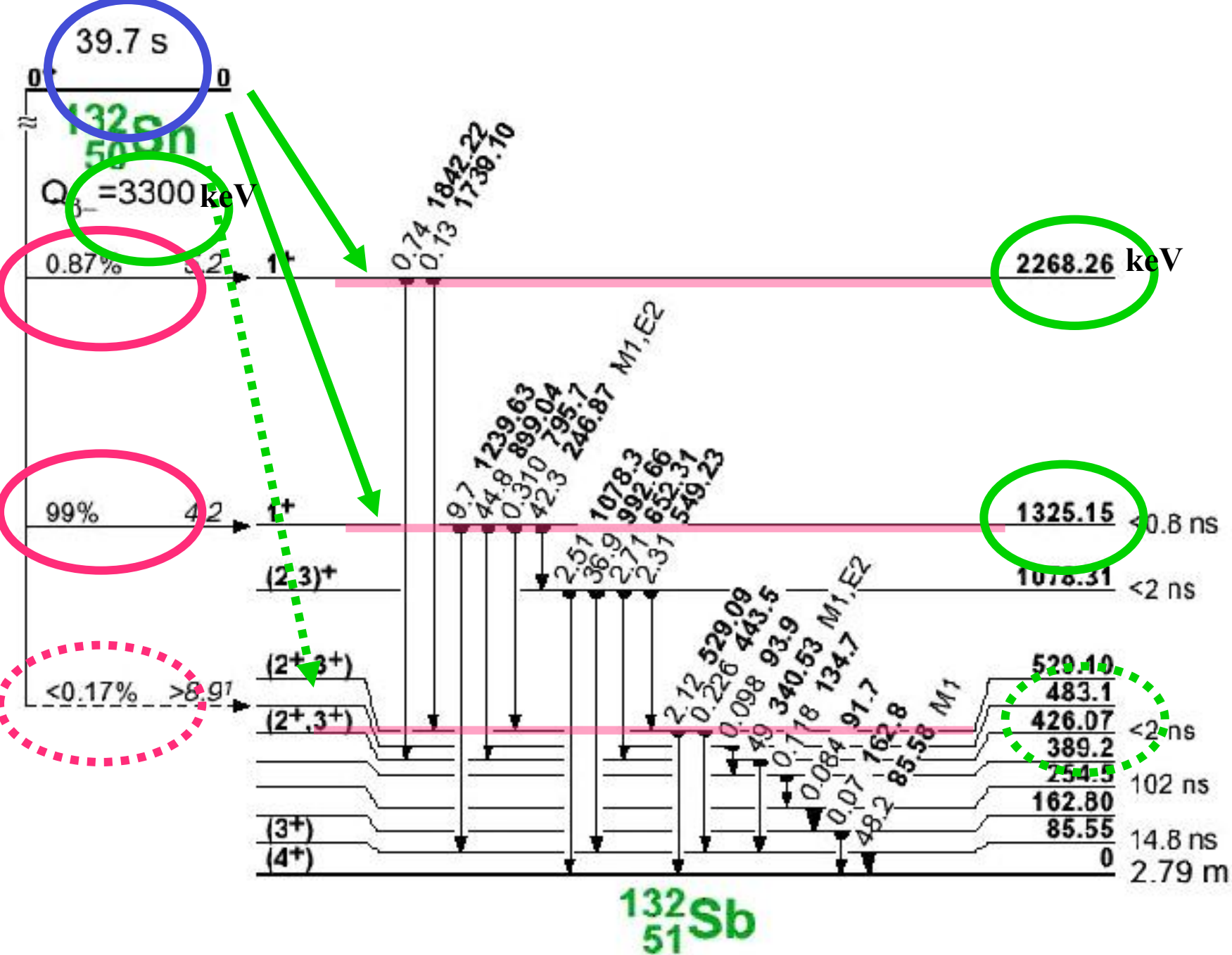
Coral M. Baglin, S. Y. Frank Chu, and Jean Zipkin
Assistant Editors

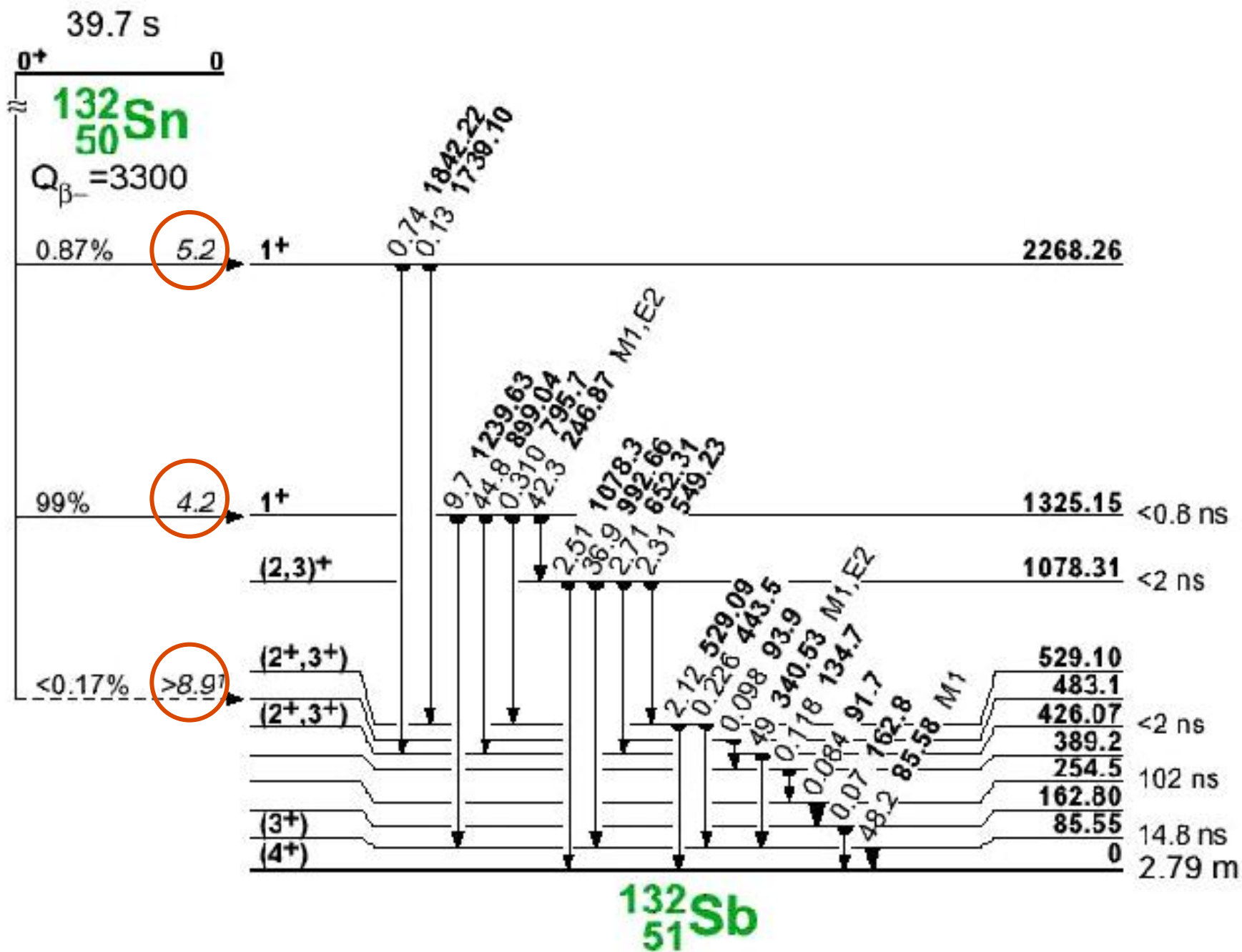


SET
INCLUDES
CD-ROM

If we look at the table of isotopes

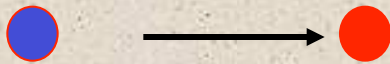
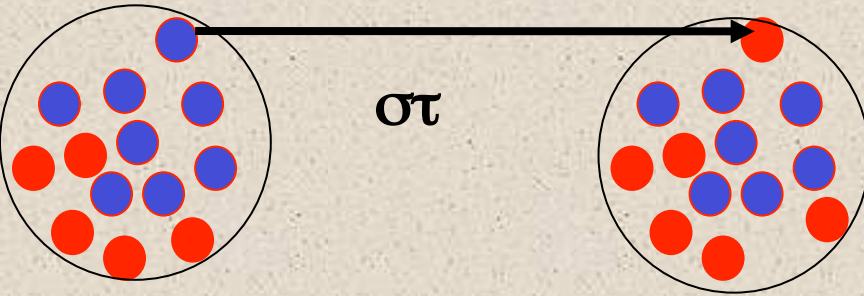






$$\langle i | \sigma \tau | f \rangle$$

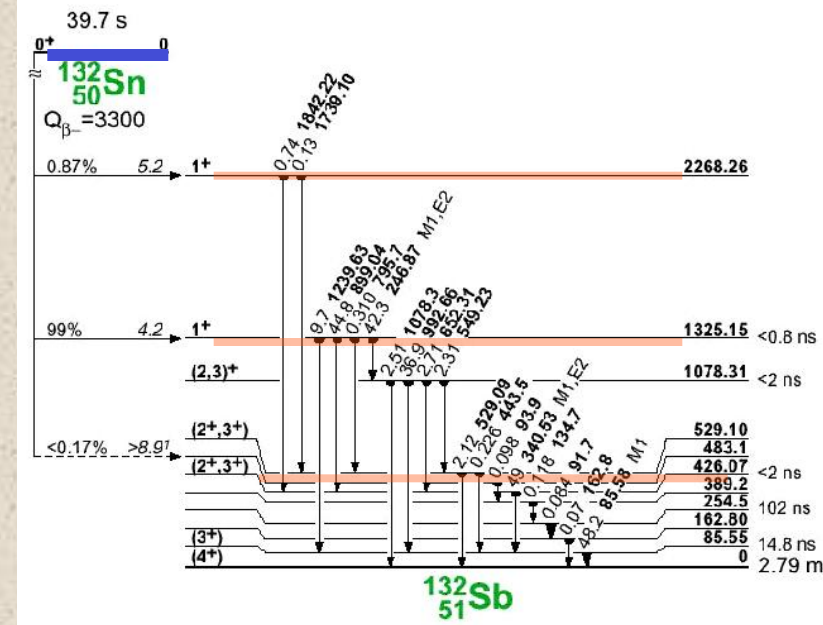
$$\langle i |$$



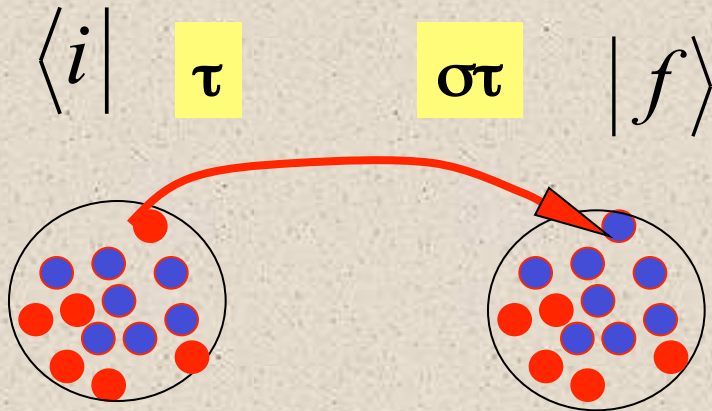
neutron

proton

$$| f \rangle$$



Transition probability



$$B_F = \left| \frac{1}{\sqrt{2}} \langle \psi_f | \sum \tau^\pm | \psi_i \rangle \right|^2$$

$$B_{GT} = \left| \langle \psi_f | \sum \sigma\tau^\pm | \psi_i \rangle \right|^2$$

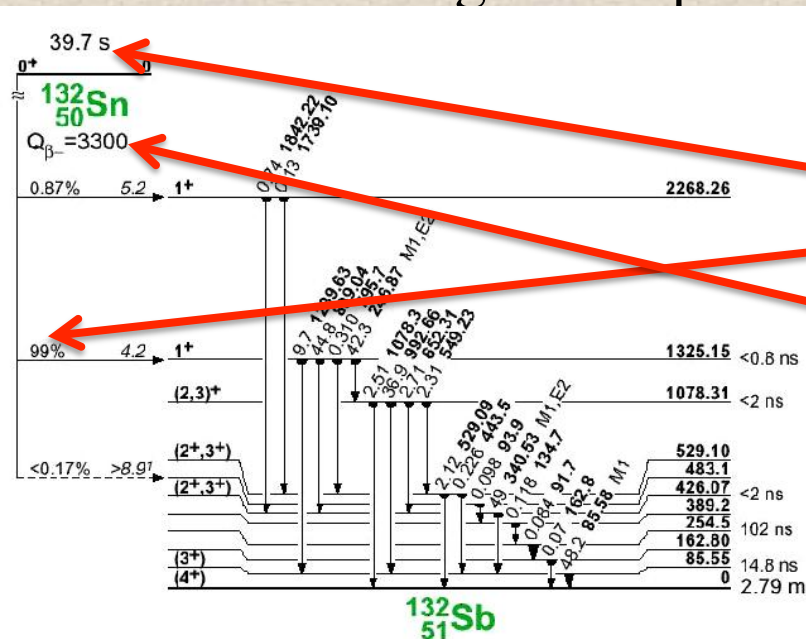
**B_{GT} and B_F can be calculated using microscopic models!!!
This is the main message of this talk!!!!**

$$B_{GT} = \left| \frac{1}{\sqrt{2}} \langle f | \sum \sigma \tau^\pm | i \rangle \right|^2$$

$$B_{GT} = 6147 \left(\frac{g_v}{g_A} \right)^2 \frac{I_\beta}{f T_{1/2}} = 6147 \left(\frac{g_v}{g_A} \right)^2 \frac{1}{f t_{1/2}}$$

Luego es importante medir

$$\frac{1}{f t_{1/2}}$$



$$\frac{1}{f t} = \frac{I_\beta(E)}{f(Q_\beta - E, Z) T_{1/2}}$$

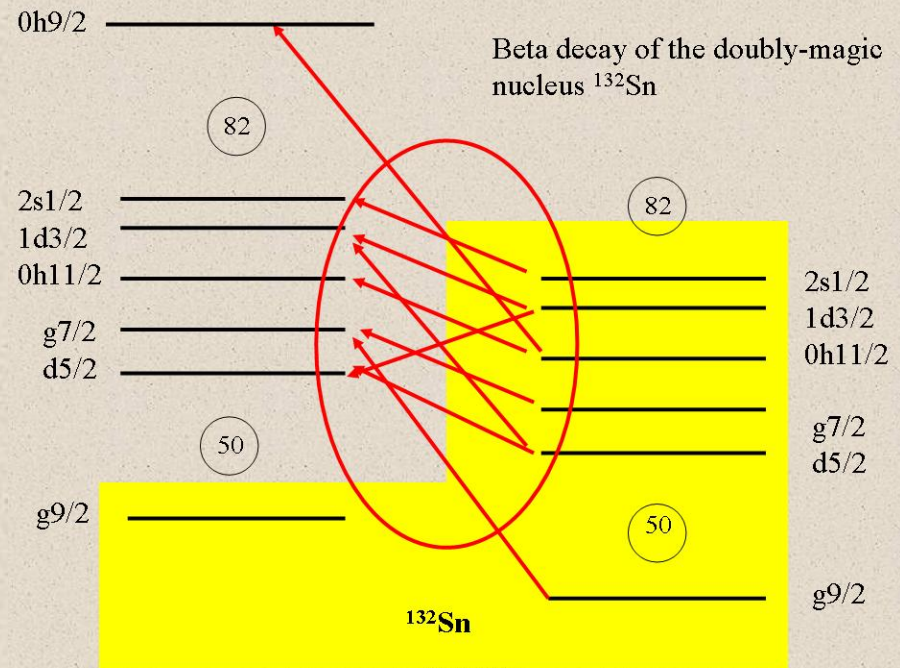
In our case the $\log ft = 4.2$

What does it mean in terms of B_{GT} ?

$$B_{GT} = 0.24$$

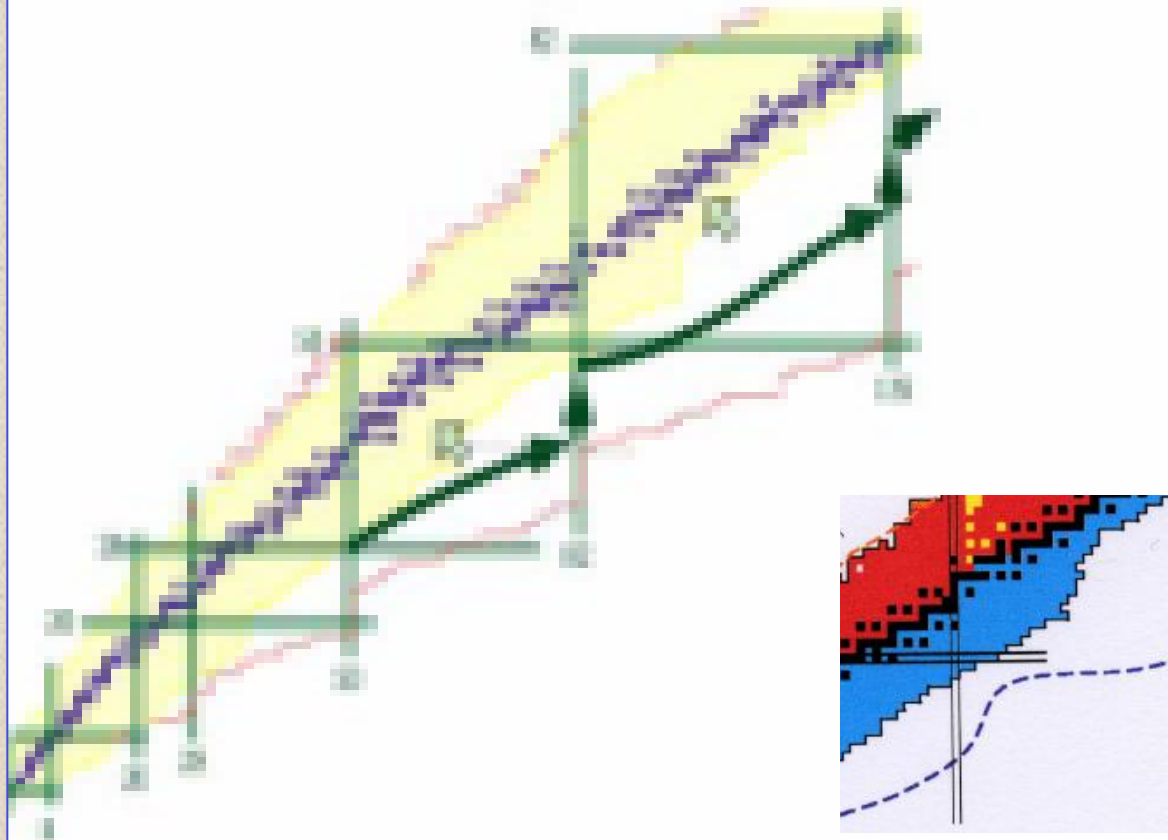
Expected
total $B_{GT} = 96$
units $\rightarrow$

We see only a very
small fraction



What we learn in our example is that we see only a very small portion of the expected strength inside the the Q window

We might want to go further away
Towards more exotic nuclei



Conclusion of this part

It is important to study the decay properties of radioactive nuclei

The first thing to worry about is how to produce them

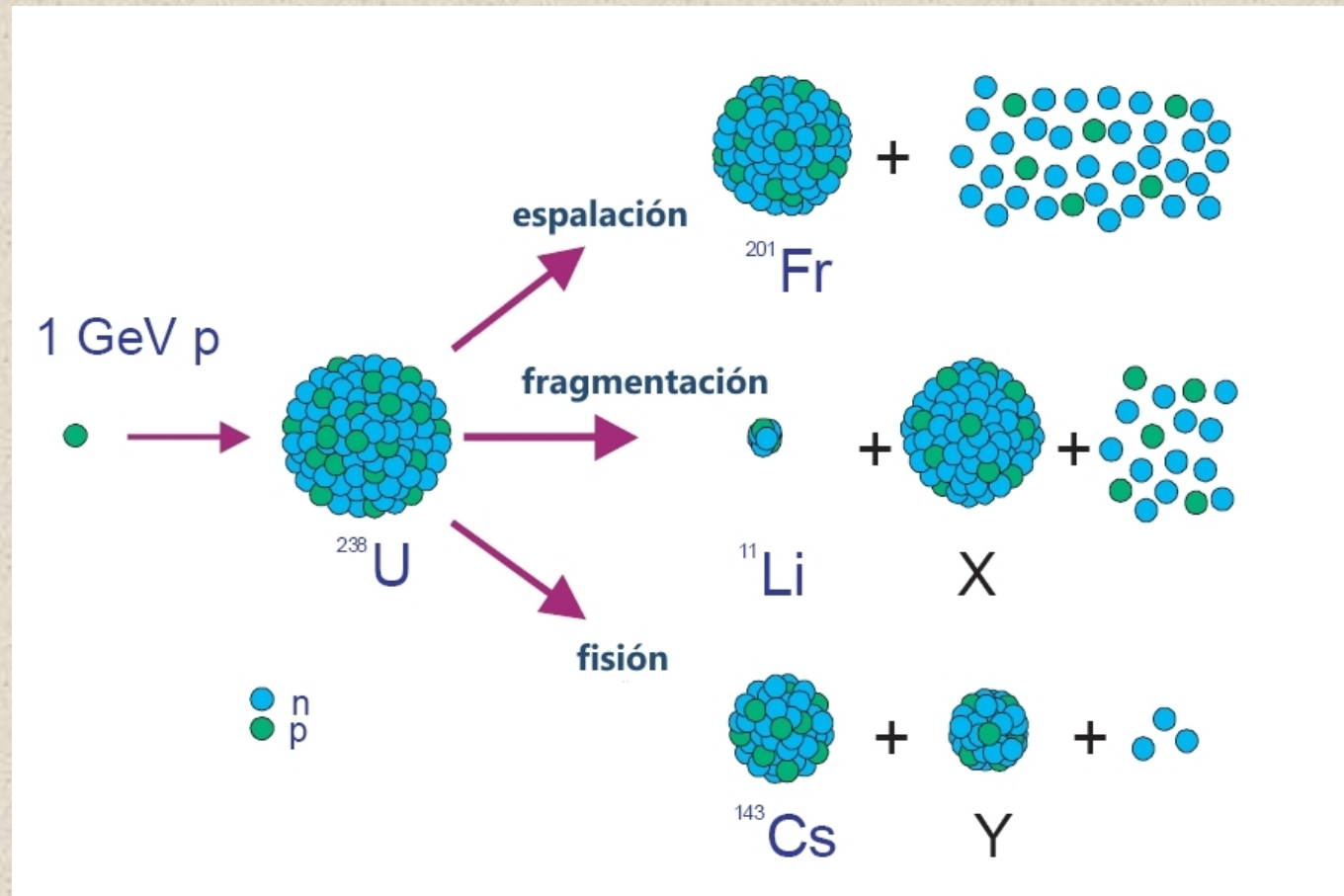
The second thing is to separate them from other radioactive products

There are two main ways: the Isol method and the fragmentation method

The first one is known since many years ago

Both methods have been improved recently with the aim to produce radioactive beams

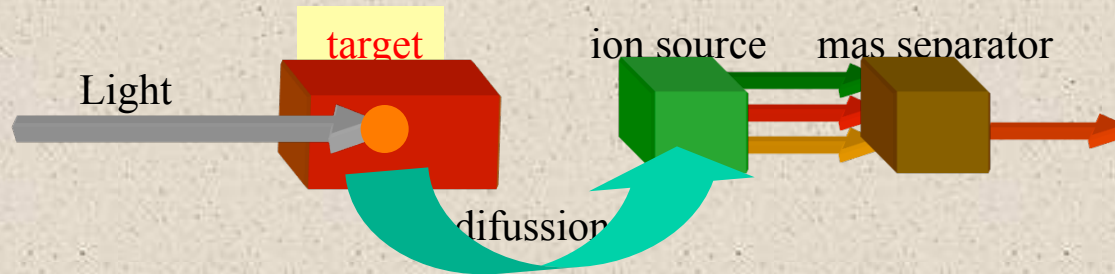
The first thing to worry about is how to produce them:
We need a reaction



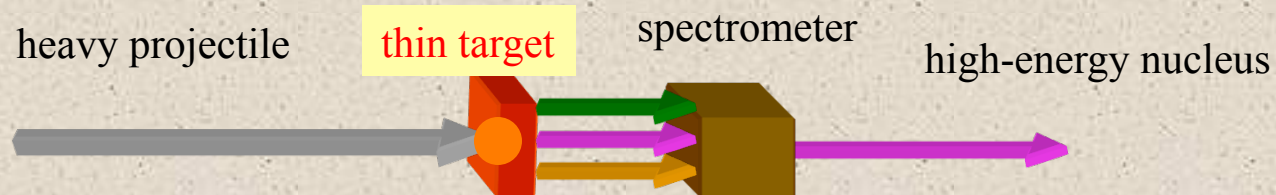
The second thing is to separate them from other radioactive products

Radioactive nuclei production techniques

Isotopic separation on-line (ISOL)

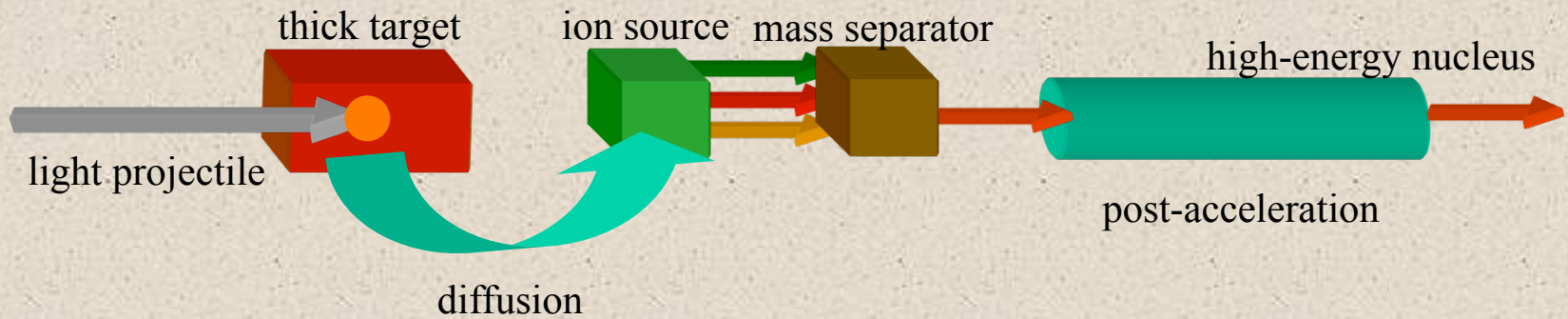


In-flight fragmentation

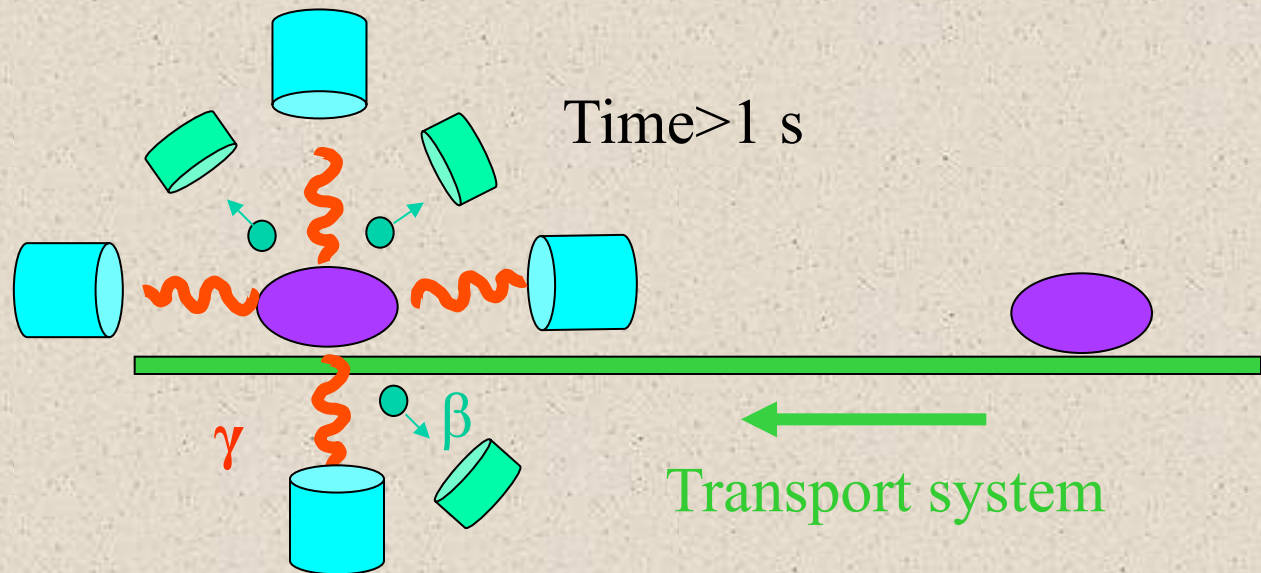
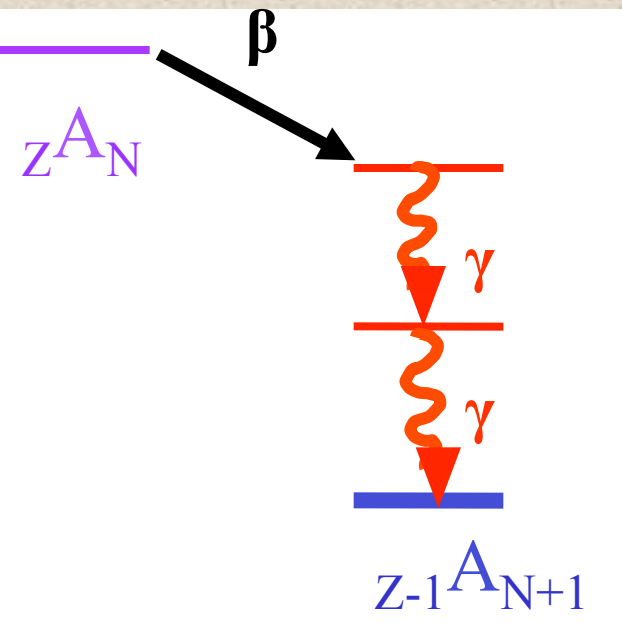
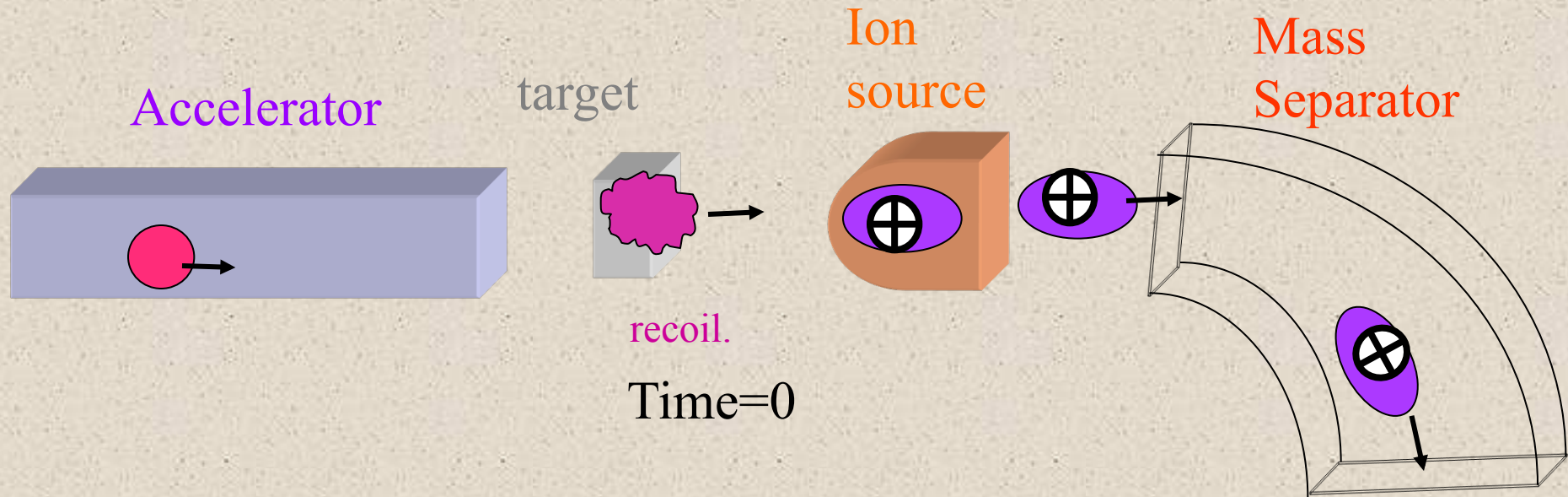


Production techniques Rad Beams: post acceleration

➤ Isotopic separation on-line (ISOL)



Isotopic separation on-line (ISOL)

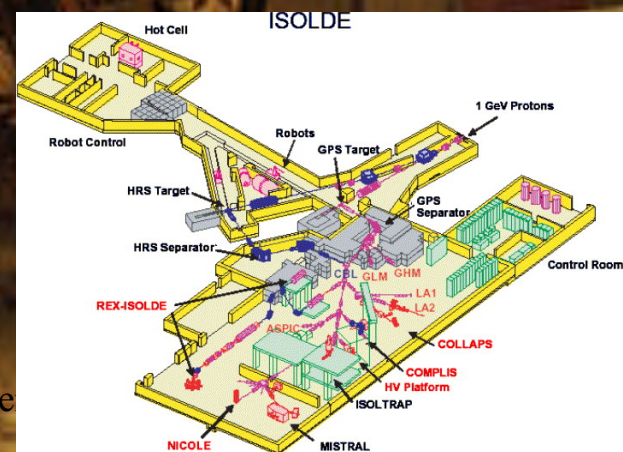


On 16 October 1967, the first experiments were carried out at ISOLDE CERN.

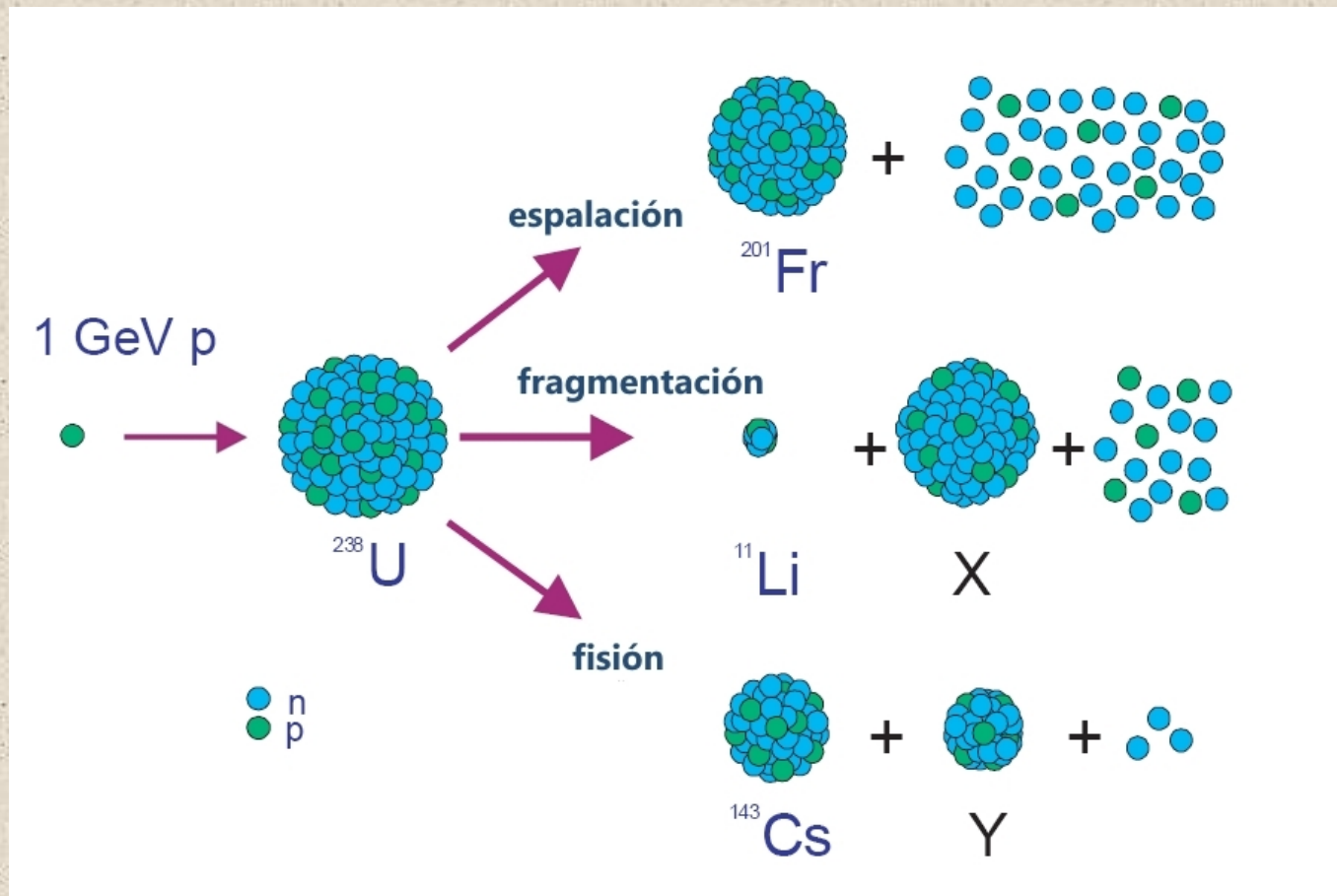
CERN's longest serving experimental facility

Physics Reports 403–404 (2004) 459–469

Juha Äystö

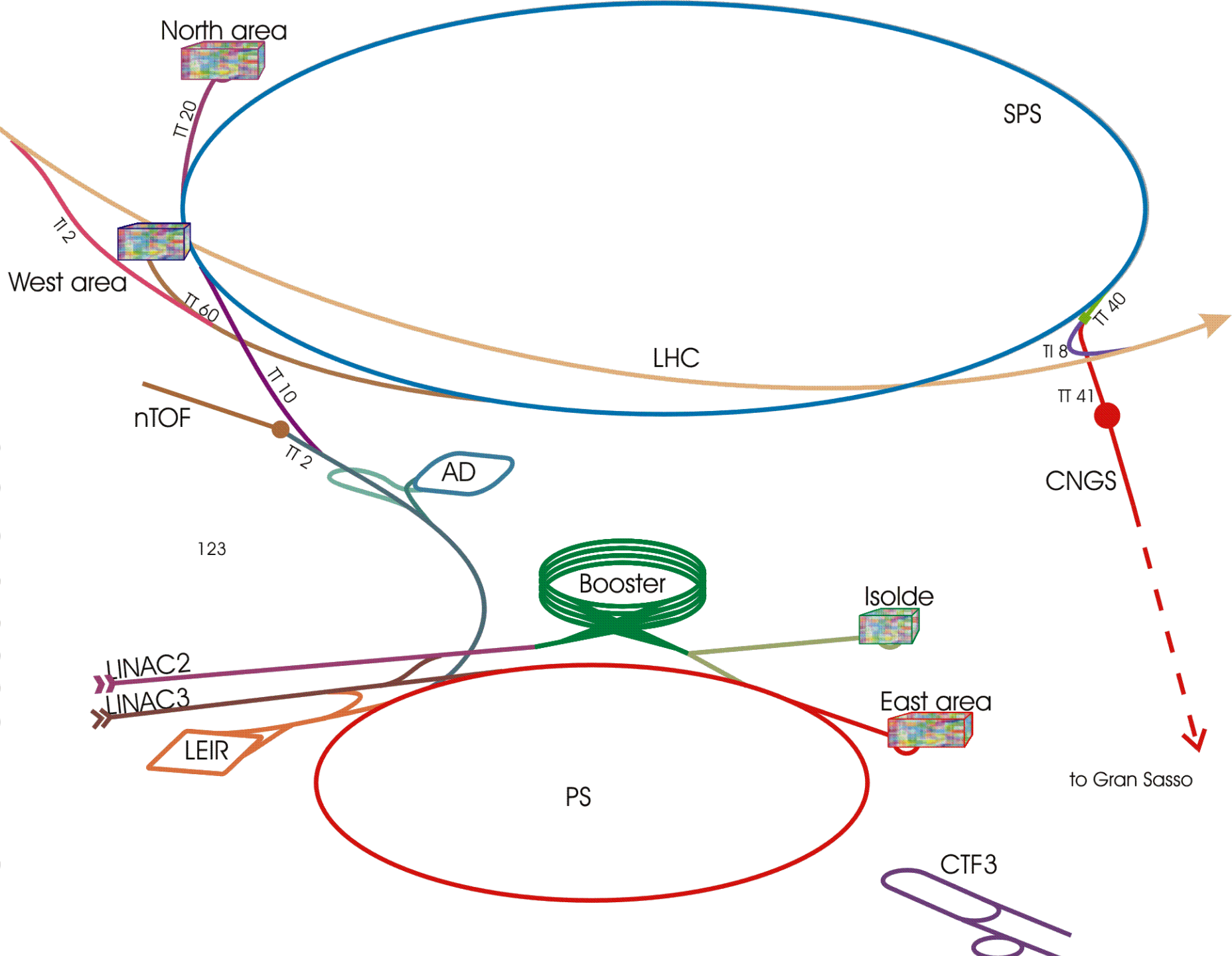


B. Rubio. Master FN, Vale

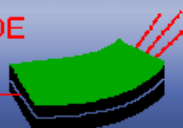


- ☺ thick target (100% of range) $\Rightarrow$ high beam current (upto 10^{16} s^{-1})
- ☹ long extraction and ionization time (ms)
- ☹ chemistry dependent

CERN accelerators



ISOLDE
CERN



HOME

Facility Layout

Separator Description

Yield Information

ISOLDE yields (test)

REX-ISOLDE

RILIS

IMS

Experiments

Schedule

ISOLDE Operation

ELogbook: GPS HRS

Proposal Submission

ISOLDE Contacts

Experiment Contacts

ISOLDE people & places

News & Events

HIE-ISOLDE

Publications

ISOLDE Collaboration

Committees & Meetings

Useful Information

Job Opportunities

Financial Support (EC)

EU Projects

CERN

THE ISOLDE FACILITY

ISOLDE RADIOACTIVE ION BEAM FACILITY

The On-Line Isotope Mass Separator ISOLDE is a facility dedicated to the production of a large variety of radioactive ion beams for a great number of different experiments, e.g. in the field of nuclear and atomic physics, solid-state physics, life sciences and material science. The facility, located at the Proton-Synchrotron Booster (PSB) of [CERN](#), is operated by the ISOLDE Collaboration. In May 1998 ISOLDE acquired the status of a Large Scale Facility within the TMR programme of the European Commission. The current contract within the 6th framework trans-national programme of the EU project EURONS offers an increased [support for external users](#).

At ISOLDE, radioactive nuclides are produced in thick high-temperature targets via spallation, fission or fragmentation reactions. The targets are placed in the external proton beam of the PSB, which has an energy of 1.0 or 1.4 GeV and an intensity of about 2 microA. The target and ion-source together represent a small chemical factory for converting the nuclear reaction products into a radioactive ion beam. An electric field accelerates the ions, which are mass separated and steered to the experiments. Until now more than 600 isotopes of more than 60 elements ($Z=2$ to 88) have been produced with half-lives down to milliseconds and intensities up to 10^{11} ions per second.

Through the advent of post-accelerated beams with the [REX-ISOLDE](#) charge breeder and linear accelerator, probing nuclear properties using transfer reactions and Coulomb excitation of exotic nuclear species is now possible. [REX-ISOLDE](#) currently provides beams of energy 3.1 MeV/u into the super-efficient, highly segmented gamma-ray MINIBALL array at the secondary target position. [REX](#) is operational and has already accelerated several species of radioactive ions, e.g.

Search

JW, 10/04/2003

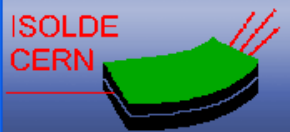
39.7 s
 $^{132}_{50}\text{Sn}$
 $Q_{\beta^-} = 3300$

1842.22
 1739.10

0.87%

99%

<0.17%



THE ISOLDE FACILITY

Excelente Producción!!

by an order of magnitude far off stability!!!!

- HOME
- Facility Layout
- Separator Description
- Yield Information
- ISOLDE yields (test)
- REX-ISOLDE
- [RILIS](#)
- IMS
- Experiments
- Schedule
- ISOLDE Operation
- ELogbook: GPS HRS
- Proposal Submission
- ISOLDE Contacts
- Experiment Contacts
- ISOLDE people & places
- News & Events
- HIE-ISOLDE
- Publications
- ISOLDE Collaboration
- Committees & Meetings
- Useful Information
- Job Opportunities
- Financial Support (EC)
- EU Projects
- CERN

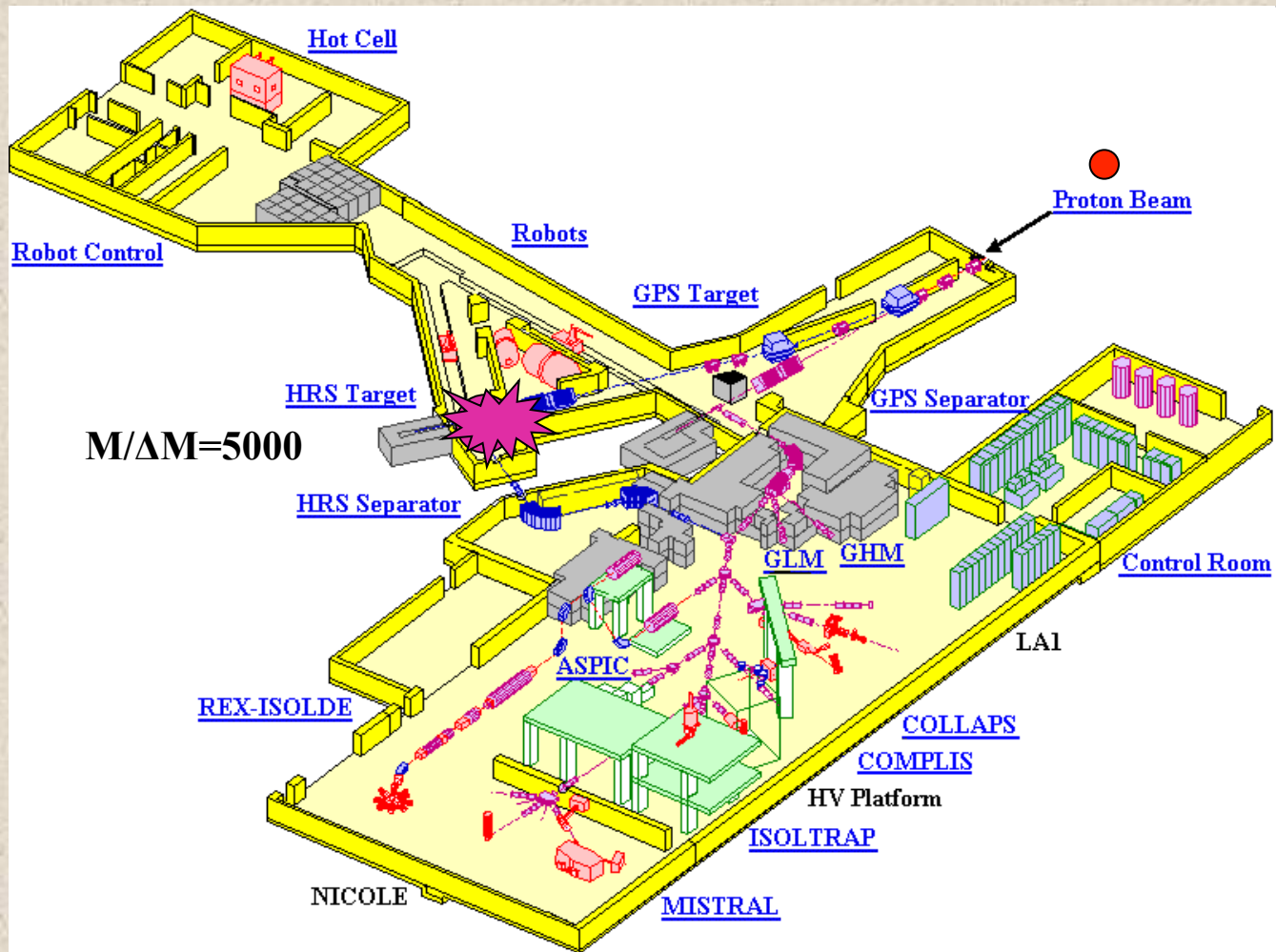
Tin ISOLDE SC-Yields

Element	Yield (atoms/uC)	Nucleus	Half Life	Target	Target density (g/cm2)	Ion Source
Sn	5.60E+04	108g	10.3 min	Ta Metal foil	122	Hot plasma
Sn	5.00E+04	108g	10.3 min	Ta Metal foil	122	Hot plasma
Sn	1.50E+05	109g	18 min	Ta Metal foil	122	Hot plasma
Sn	1.60E+05	111g	35.3 min	Ta Metal foil	122	Hot plasma
Sn	2.00E+07	107g	2.9 min	Te Chloride	6	Plasma heated line
Sn	5.00E+06	108m		Te Chloride	6	Plasma heated line
Sn	3.00E+07	109m		Te Chloride	6	Plasma heated line
Sn	3.00E+08	110g	4.11 hrs	Te Chloride	6	Plasma heated line
Sn	7.00E+08	111g	35.3 min	Te Chloride	6	Plasma heated line
Sn	2.00E+09	113g	115.09 days	Te Chloride	6	Plasma heated line
Sn	5.00E+08	123g	129.2	U Carbide	9.7g U /cm2	Hot plasma at 1950°C
Sn	1.30E+08	125g	9.64	U Carbide	9.7g U /cm2	Hot plasma at 1950°C
Sn	6.00E+07	127g	2.1	U Carbide	9.7g U /cm2	Hot plasma at 1950°C
Sn	5.00E+07	129g	2.16	U Carbide	9.7g U /cm2	Hot plasma at 1950°C
Sn	1.50E+07	131m	1.02	U Carbide	9.7g U /cm2	Hot plasma at 1950°C
Sn	3.00E+07	132g	39.7	U Carbide	9.7g U /cm2	Hot plasma at 1950°C

Search

Sn	3.00E+07	132g	39.7	U Carbide	9.7g U /cm ²	Hot plasma at 1950°C
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Reaction: 1.4 GeV protons on U 9.7 g/cm²



$\alpha 0.16 + 0.8$ Cs 133 100 $\alpha 2.5 + 25.5$	$\alpha 0.16 + 0.8$ Cs 134 2,90 h $\alpha 2.5 + 25.5$	$\alpha 0.010 + 0.44$ Cs 135 59 m $\alpha 2.5 + 25.5$	$\alpha 0.010 + 0.44$ Cs 136 19 s $\alpha 2.5 + 25.5$	$\alpha 0.45$ Cs 137 30,17 a $\alpha 2.5 + 25.5$	$\beta^- 2.4...537; 30; 163;305...1.6$ Cs 138 2,90 m $\alpha 2.5 + 25.5$	$\beta^- 1.0...537; 30; 163;305...1.6$ Cs 139 9,3 m $\alpha 2.5 + 25.5$	$\beta^- 2.8; 3.0...190; 304;277; 344...1.6$ Cs 140 63,7 s $\alpha 2.5 + 25.5$	$\beta^- 1.0; 1.7...255; 1204;895...1.6$ Cs 141 24,94 s $\alpha 2.5 + 25.5$	$\beta^- 4.2...211; 799;980; 1011...1.6$ Cs 142 1,70 s $\alpha 2.5 + 25.5$	$\beta^- 2.4; 2.9...104; 430;173; 157; 388...1.6$ Cs 143 1,78 s $\alpha 2.5 + 25.5$	
$\alpha 0.05 + 0.40$ Xe 132 28,9 $\alpha 0.05 + 0.40$	$\alpha 0.05 + 0.40$ Xe 133 2,19 d $\alpha 0.05 + 0.40$	$\alpha 0.05 + 0.40$ Xe 134 10,4 $\alpha 0.05 + 0.40$	$\alpha 0.05 + 0.40$ Xe 135 15,3 m $\alpha 0.05 + 0.40$	$\alpha 0.25$ Xe-136 8,9 $\alpha 0.25$	$\beta^- 4.1...456; [849...]g$ Xe 137 3,83 m $\alpha 0.25$	$\beta^- 0.8; 2.8...258; 434;1768; 2016...g$ Xe 138 14,1 m $\alpha 0.25$	$\beta^- 5.0...219; 297;175...g$ Xe 139 39,7 s $\alpha 0.25$	$\beta^- 2.6...48; 562;1194; 589...βn$ Xe 140 13,6 s $\alpha 0.25$	$\beta^- 6.2...809; 119;106...βn$ Xe 141 1,72 s $\alpha 0.25$	$\beta^- 5.9...196; 232;305...βn$ Xe 142 1,24 s $\alpha 0.25$	
$\beta^- 0.6; 0.8...364; 637;284...; gα ~ 0.7$ I 131 8,02 d $\alpha ~ 0.7$	$\beta^- 1.5...588;773; 606;175...α ~ 0.7$ I 132 83,6 m $\alpha ~ 0.7$	$\beta^- 2.1...588;773; 606;175...α ~ 0.7$ I 133 9 s $\alpha ~ 0.7$	$\beta^- 1.2...588;773; 606;175...α ~ 0.7$ I 134 3,5 m $\alpha ~ 0.7$	$\beta^- 1.5; 2.2...1260; 1132;1678; 1458...g; m$ I 135 6,61 h $\alpha ~ 0.7$	$\beta^- 5.0...1218; 901...βn 0.37; 0.48...g$ I 136 45 s $\alpha ~ 0.7$	$\beta^- 5.0...1218; 901...βn 0.37; 0.48...g$ I 137 24,2 s $\alpha ~ 0.7$	$\beta^- 5.0...1218; 901...βn 0.37; 0.48...g$ I 138 6,4 s $\alpha ~ 0.7$	$\beta^- 6.3...528; 571;580; 537...βn$ I 139 2,29 s $\alpha ~ 0.7$	$\beta^- 3.77; 458;937...βn$ I 140 0,86 s $\alpha ~ 0.7$	$\beta^- 5.79; 303;387; 192βn$ I 141 0,43 s $\alpha ~ 0.7$	
$\beta^- 0.5; 0.8...364; 637;284...; gα ~ 0.7$ Te 130 33,80 $\alpha 2.7 \cdot 10^{21}$ a $\alpha 0.03 + 0.20$	$\beta^- 0.5; 0.8...364; 637;284...; gα ~ 0.7$ Te 131 30 h $\alpha 0.03 + 0.20$	$\beta^- 0.2...228; 50...g$ Te 132 76,3 h $\alpha 0.03 + 0.20$	$\beta^- 0.7...228; 50...g$ Te 133 55,4 m $\alpha 0.03 + 0.20$	$\beta^- 0.6; 0.7...767; 210;278; 79; 566...g$ Te 134 41,8 m $\alpha 0.03 + 0.20$	$\beta^- 6.0...604; 287;870; 1133...g$ Te 135 18,6 s $\alpha 0.03 + 0.20$	$\beta^- 2.5; 4.9...2078; 334; 579;2560; 3235...βn 0.43...; g$ Te 136 17,5 s $\alpha 0.03 + 0.20$	$\beta^- 6.3; 6.8...243; 554;469...βn$ Te 137 2,5 s $\alpha 0.03 + 0.20$	$\beta^- 1.4; 1.04...1127; 1279...1380...βn$ Te 138 1,4 s $\alpha 0.03 + 0.20$	$\beta^- 1.4; 1.04...1127; 1279...1380...βn$ Te 139 1,4 s $\alpha 0.03 + 0.20$	Te 140 1,4 s $\alpha 0.03 + 0.20$	
$\beta^- 1.76...2.2...588;773; 606;175...α ~ 0.7$ Sb 129 17,7 m $\alpha ~ 0.7$	$\beta^- 1.76...2.2...588;773; 606;175...α ~ 0.7$ Sb 130 38,5 m $\alpha ~ 0.7$	$\beta^- 1.3; 3.0...543; 933;642...g; m$ Sb 131 23 m $\alpha ~ 0.7$	$\beta^- 1.2...543; 933;642...g; m$ Sb 132 4,1 m $\alpha ~ 0.7$	$\beta^- 1.2; 2.4...1096; 818;2755; 837...α; m$ Sb 133 2,5 m $\alpha ~ 0.7$	$\beta^- 6.1...1279; 1380...βn 0.43...; g$ Sb 134 10,1 s $\alpha ~ 0.7$	$\beta^- 8.1...145; 1,04...1127; 1279...1380...βn$ Sb 135 1,7 s $\alpha ~ 0.7$	$\beta^- 1.4; 1.04...1127; 1279...1380...βn$ Sb 136 0,8 s $\alpha ~ 0.7$	Sb 137 1,7 s $\alpha ~ 0.7$	Sb 138 1,7 s $\alpha ~ 0.7$	Sb 139 1,7 s $\alpha ~ 0.7$	
$\beta^- 0.7...588;773; 606;175...α ~ 0.7$ Sn 128 6,5 s $\alpha ~ 0.7$	$\beta^- 0.7...588;773; 606;175...α ~ 0.7$ Sn 129 6,8 m $\alpha ~ 0.7$	$\beta^- 0.7...588;773; 606;175...α ~ 0.7$ Sn 130 1,7 m $\alpha ~ 0.7$	$\beta^- 0.7...588;773; 606;175...α ~ 0.7$ Sn 131 60 s $\alpha ~ 0.7$	$\beta^- 1.8...341; 86; 899;247; 903...g$ Sn 132 39,7 s $\alpha ~ 0.7$	$\beta^- 7.8...952...βn 0.48m$ Sn 133 1,44 s $\alpha ~ 0.7$	$\beta^- 7.8...952...βn 0.48m$ Sn 134 1,05 s $\alpha ~ 0.7$	Sn 135 1,05 s $\alpha ~ 0.7$	Sn 136 1,05 s $\alpha ~ 0.7$	Sn 137 1,05 s $\alpha ~ 0.7$	Sn 138 1,05 s $\alpha ~ 0.7$	
$\beta^- 0.4...6.7...252...βnα ~ 0.7$ In 127 3,7 s $\alpha ~ 0.7$	$\beta^- 0.4...6.7...252...βnα ~ 0.7$ In 128 0,72 s $\alpha ~ 0.7$	$\beta^- 0.4...6.7...252...βnα ~ 0.7$ In 129 0,84 s $\alpha ~ 0.7$	$\beta^- 0.4...6.7...252...βnα ~ 0.7$ In 130 0,33 s $\alpha ~ 0.7$	$\beta^- 0.4...6.7...252...βnα ~ 0.7$ In 131 0,33 s $\alpha ~ 0.7$	$\beta^- 0.4...6.7...252...βnα ~ 0.7$ In 132 0,20 s $\alpha ~ 0.7$	$\beta^- 6.4; 8.9...376; 4041;299...βn 0.23; 0.33βn$ In 133 180 ms $\alpha ~ 0.7$	In 134 180 ms $\alpha ~ 0.7$	In 135 180 ms $\alpha ~ 0.7$	In 136 180 ms $\alpha ~ 0.7$	In 137 180 ms $\alpha ~ 0.7$	
$\beta^- 4.8; 5.2...200; 428...g$ Cd 126 0,51 s $\alpha ~ 0.7$	$\beta^- 4.8; 5.2...200; 428...g$ Cd 127 0,43 s $\alpha ~ 0.7$	$\beta^- 4.8; 5.2...200; 428...g$ Cd 128 0,30 s $\alpha ~ 0.7$	$\beta^- 4.8; 5.2...200; 428...g$ Cd 129 0,27 s $\alpha ~ 0.7$	$\beta^- 4.8; 5.2...200; 428...g$ Cd 130 195 ms $\alpha ~ 0.7$	$\beta^- 4.8; 5.2...200; 428...g$ Cd 131 195 ms $\alpha ~ 0.7$	$\beta^- 4.8; 5.2...200; 428...g$ Cd 132 195 ms $\alpha ~ 0.7$	$\beta^- 4.8; 5.2...200; 428...g$ Cd 133 195 ms $\alpha ~ 0.7$	$\beta^- 4.8; 5.2...200; 428...g$ Cd 134 195 ms $\alpha ~ 0.7$	$\beta^- 4.8; 5.2...200; 428...g$ Cd 135 195 ms $\alpha ~ 0.7$	$\beta^- 4.8; 5.2...200; 428...g$ Cd 136 195 ms $\alpha ~ 0.7$	
$\beta^- 0.3282$ Ag 125 166 ms $\alpha ~ 0.7$	$\beta^- 0.3282$ Ag 126 107 ms $\alpha ~ 0.7$	$\beta^- 0.3282$ Ag 127 109 ms $\alpha ~ 0.7$	$\beta^- 0.3282$ Ag 128 109 ms $\alpha ~ 0.7$	$\beta^- 0.3282$ Ag 129 109 ms $\alpha ~ 0.7$	$\beta^- 0.3282$ Ag 130 109 ms $\alpha ~ 0.7$	$\beta^- 0.3282$ Ag 131 109 ms $\alpha ~ 0.7$	$\beta^- 0.3282$ Ag 132 109 ms $\alpha ~ 0.7$	$\beta^- 0.3282$ Ag 133 109 ms $\alpha ~ 0.7$	$\beta^- 0.3282$ Ag 134 109 ms $\alpha ~ 0.7$	$\beta^- 0.3282$ Ag 135 109 ms $\alpha ~ 0.7$	$\beta^- 0.3282$ Ag 136 109 ms $\alpha ~ 0.7$
$\beta^- 0.0315$ Ag 125 166 ms $\alpha ~ 0.7$	$\beta^- 0.0276$ Ag 126 107 ms $\alpha ~ 0.7$	$\beta^- 0.0594$ Ag 127 109 ms $\alpha ~ 0.7$	$\beta^- 0.1233$ Ag 128 109 ms $\alpha ~ 0.7$	$\beta^- 0.1233$ Ag 129 109 ms $\alpha ~ 0.7$	$\beta^- 0.1233$ Ag 130 109 ms $\alpha ~ 0.7$	$\beta^- 0.1233$ Ag 131 109 ms $\alpha ~ 0.7$	$\beta^- 0.1233$ Ag 132 109 ms $\alpha ~ 0.7$	$\beta^- 0.1233$ Ag 133 109 ms $\alpha ~ 0.7$	$\beta^- 0.1233$ Ag 134 109 ms $\alpha ~ 0.7$	$\beta^- 0.1233$ Ag 135 109 ms $\alpha ~ 0.7$	$\beta^- 0.1233$ Ag 136 109 ms $\alpha ~ 0.7$

Due to the large number of isobars produced, this process alone is not sufficient for many applications of the ion beam.

Energy level diagram for Sn (Tin) showing three energy levels and three transitions:

- Top energy level (dashed line):
- Middle energy level (solid line):
- Bottom energy level (solid line):

Transitions and corresponding wavelengths:

- Transition from the bottom level to the top level: 823.5 nm (red arrow)
- Transition from the middle level to the top level: 811.4 nm (red arrow)
- Transition from the bottom level to the middle level: 300.9 nm (blue arrow)

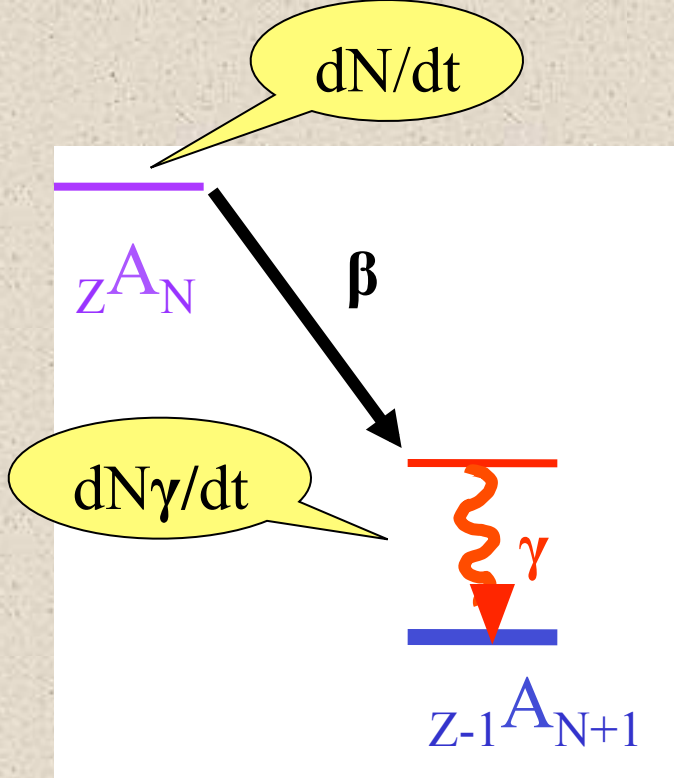
The label "Sn" is positioned below the bottom energy level.

Efficiency: $\leq 9\%$

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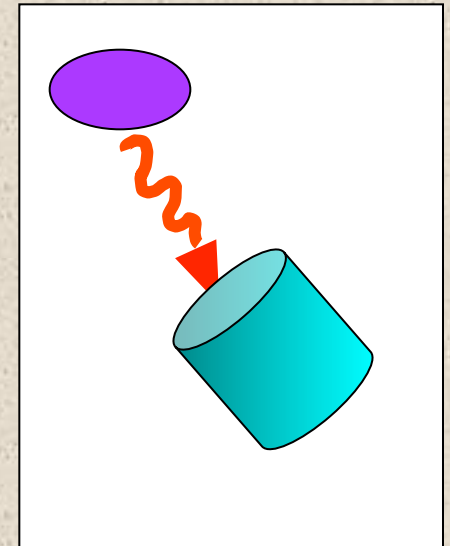
$$\frac{1}{ft} = \frac{I_{\beta}(E)}{f(Q_{\beta} - E, Z)T_{1/2}}$$

Half life measurement

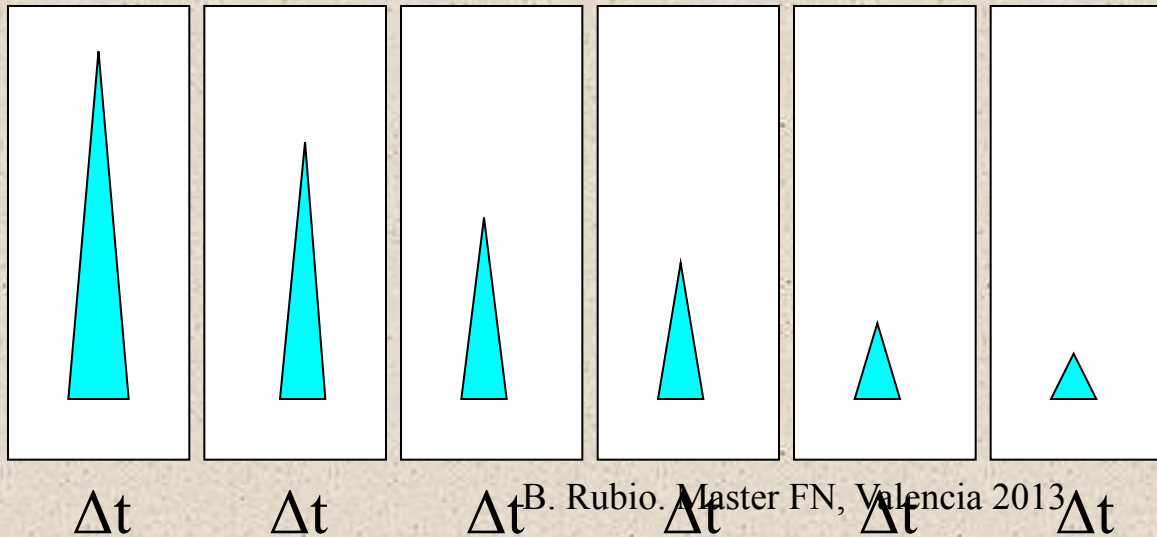


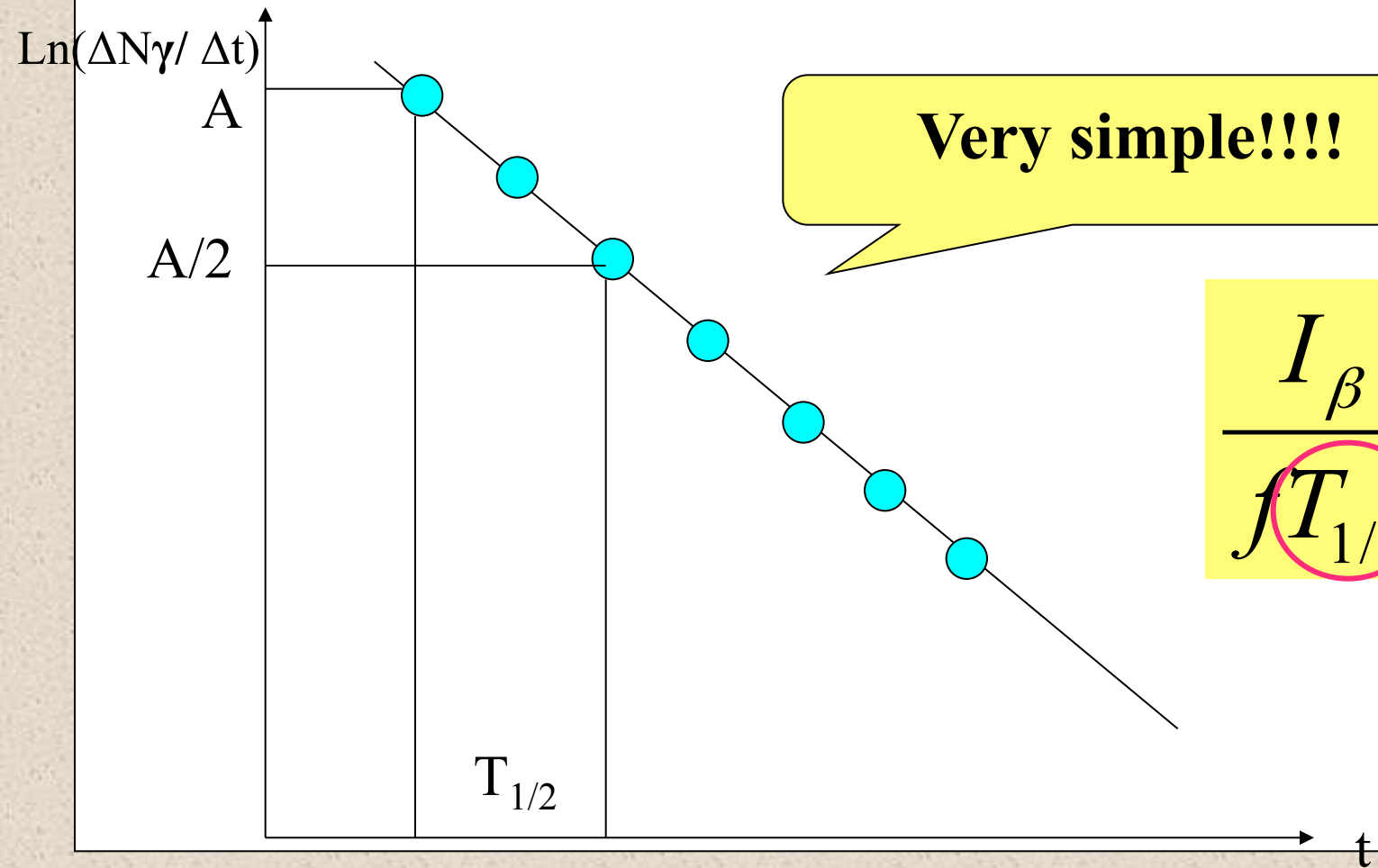
$$N(t) = N_0 e^{-\lambda t}$$

$$\lambda = \frac{1}{\tau} = \frac{\ln 2}{T_{1/2}}$$



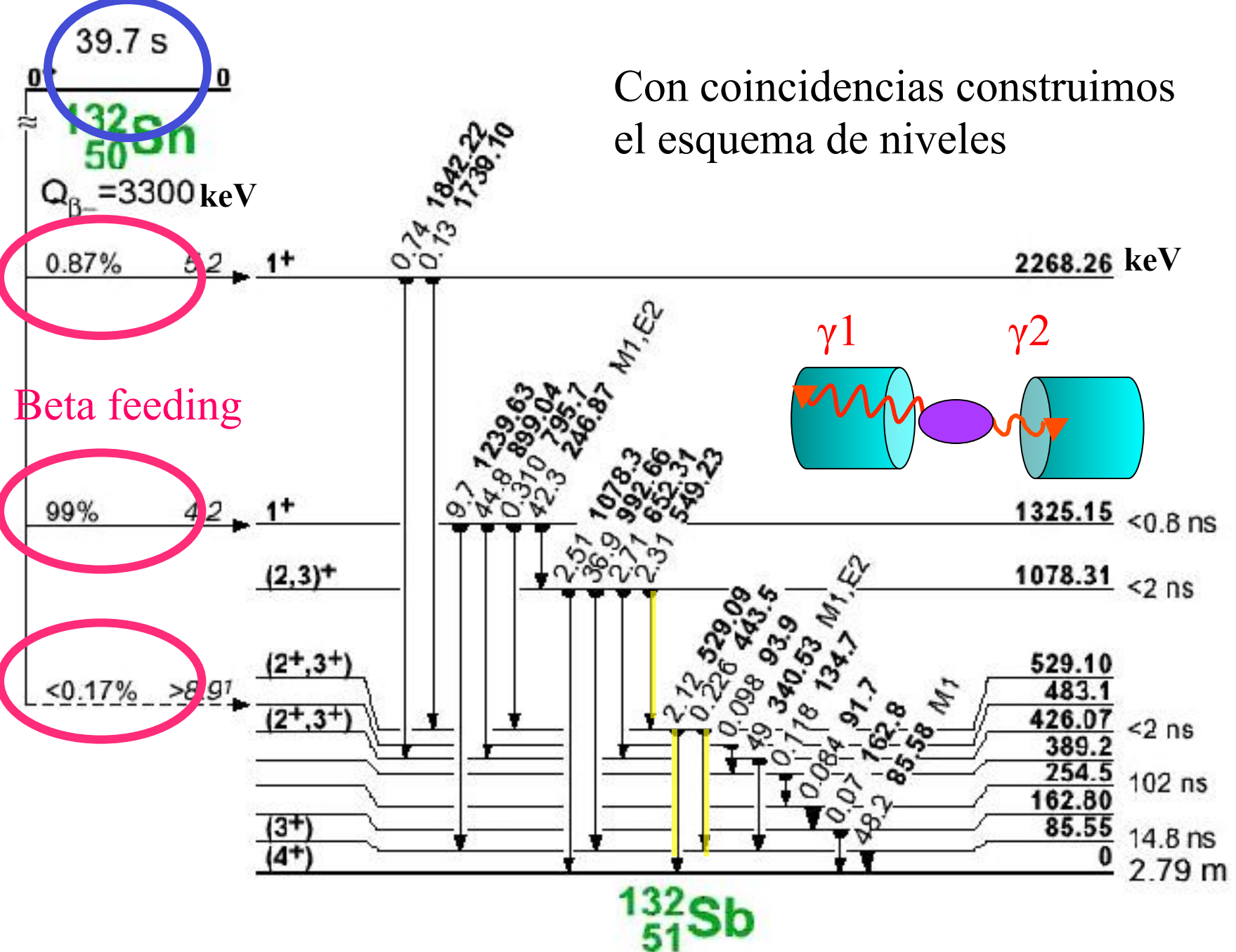
$\Delta N\gamma$





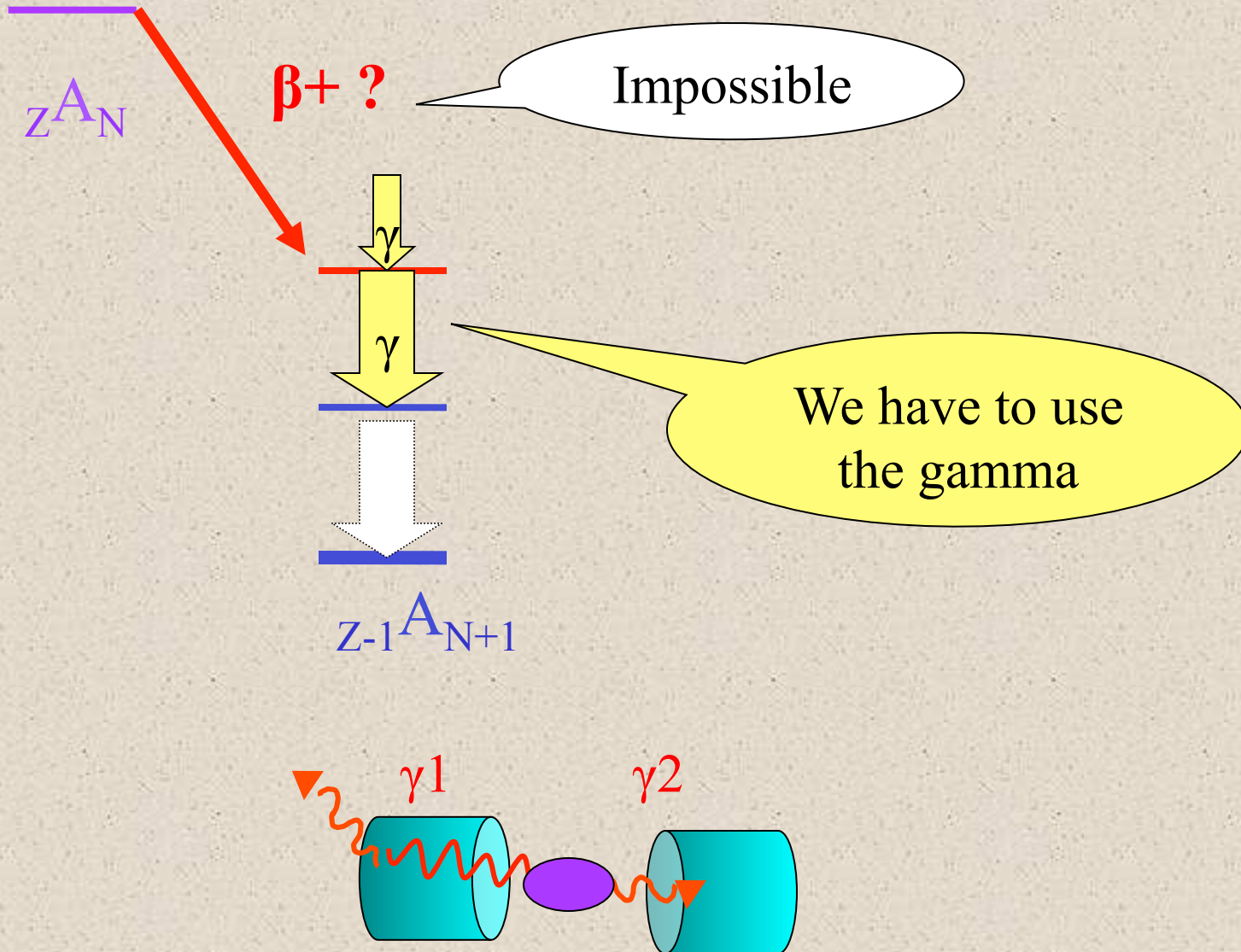
$$\frac{I_{\beta}}{fT_{1/2}}$$

Con coincidencias construimos el esquema de niveles

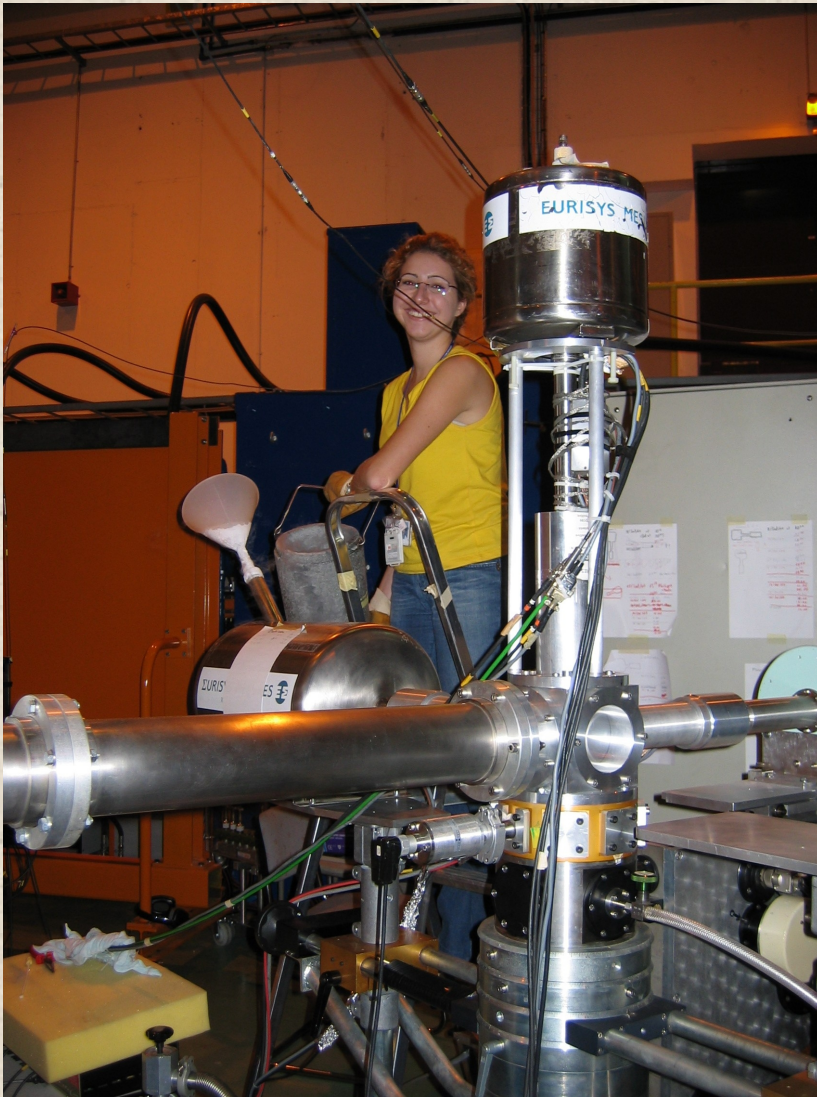


Beta-feeding

$$I_{\gamma}(\text{in}) - I_{\gamma}(\text{out})$$



$$\frac{I_{\beta}}{fT_{1/2}}$$



B. Rubio. Master FN, Valencia 2013

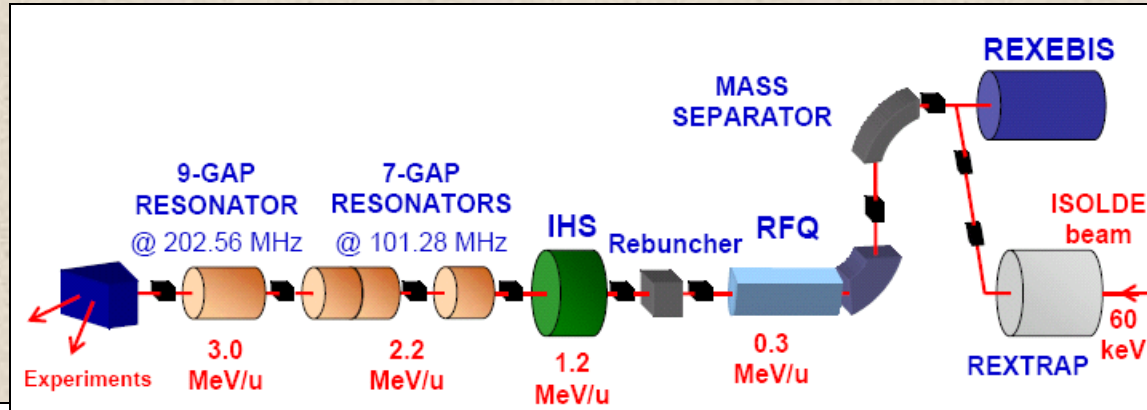
$$\frac{1}{ft} = \frac{I_{\beta}(E)}{f(Q_{\beta} - E, Z)T_{1/2}}$$

High-Precision Mass Measurements of Atomic (Exotic) Nuclei

Daniel Rodríguez
Departamento de Física Atómica Molecular y Nuclear
Universidad de Granada
danielrodriguez@ugr.es

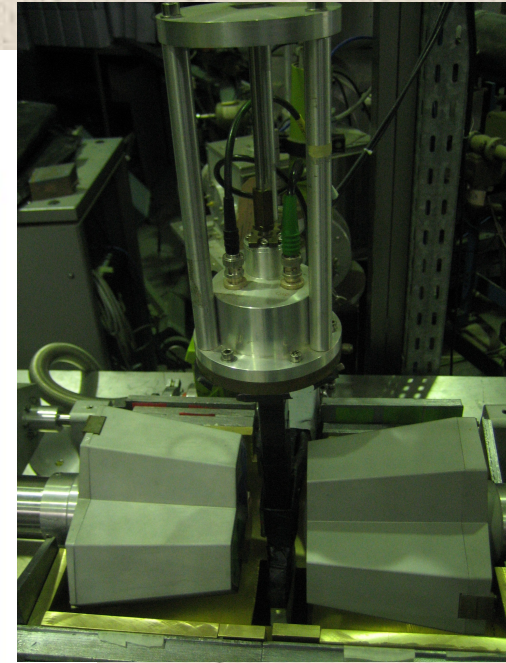
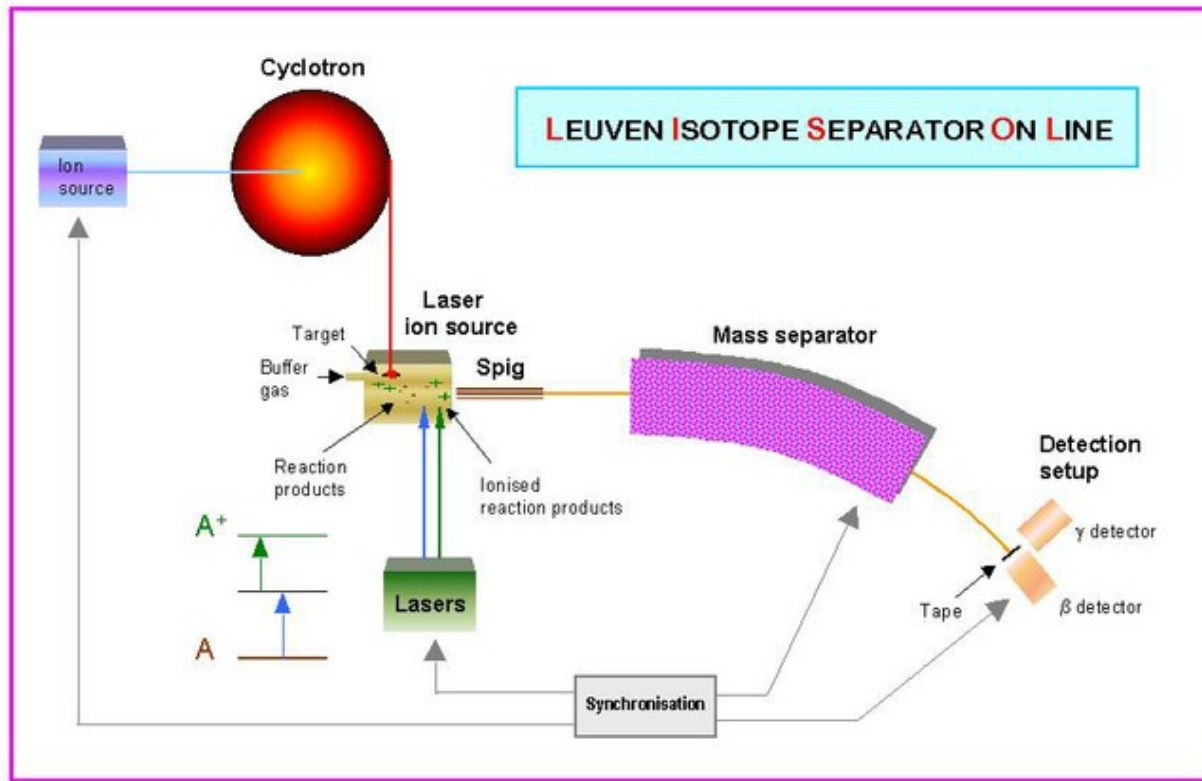
Master Interuniversitario de Física Nuclear
Valencia, Spain, January 2013

REX Isolde post-accelerator (Present)

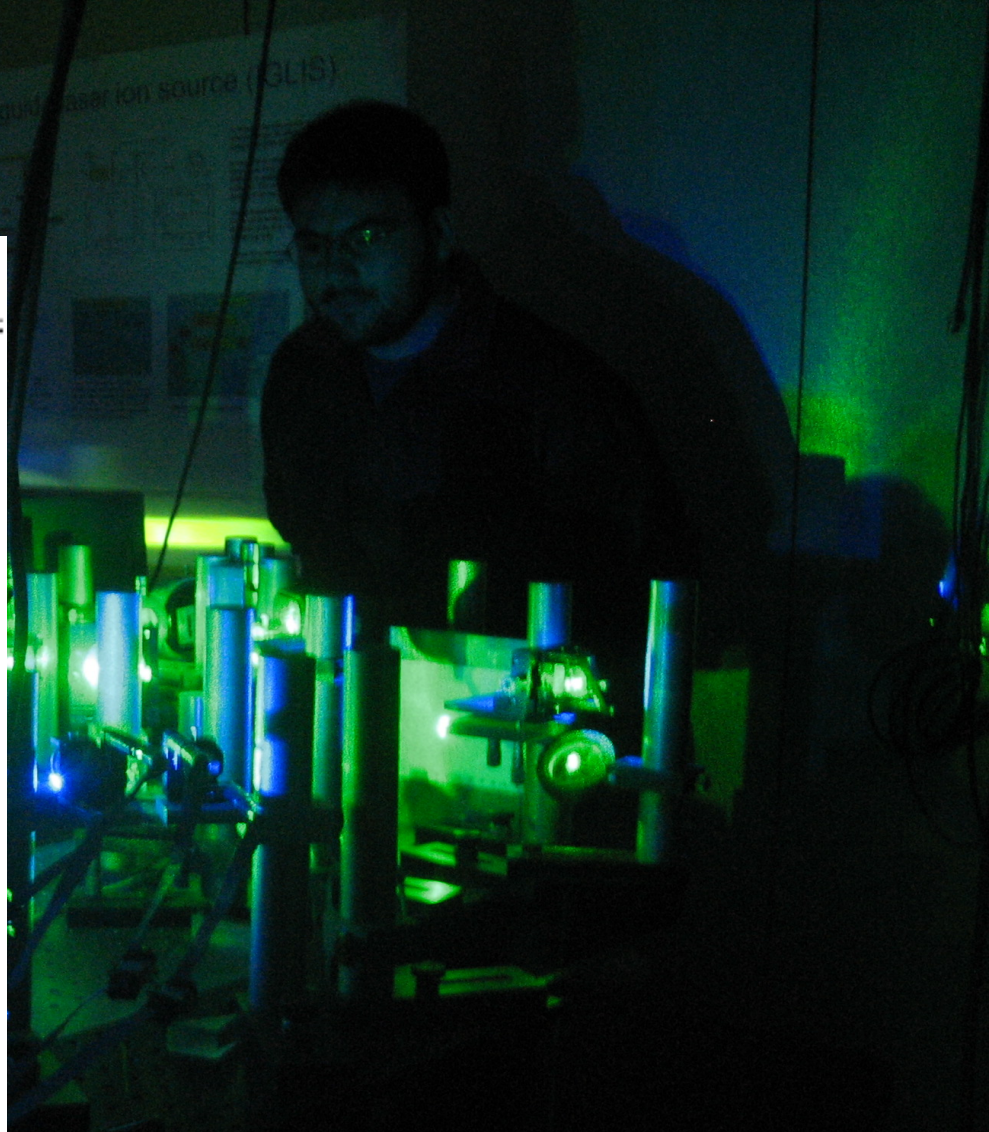
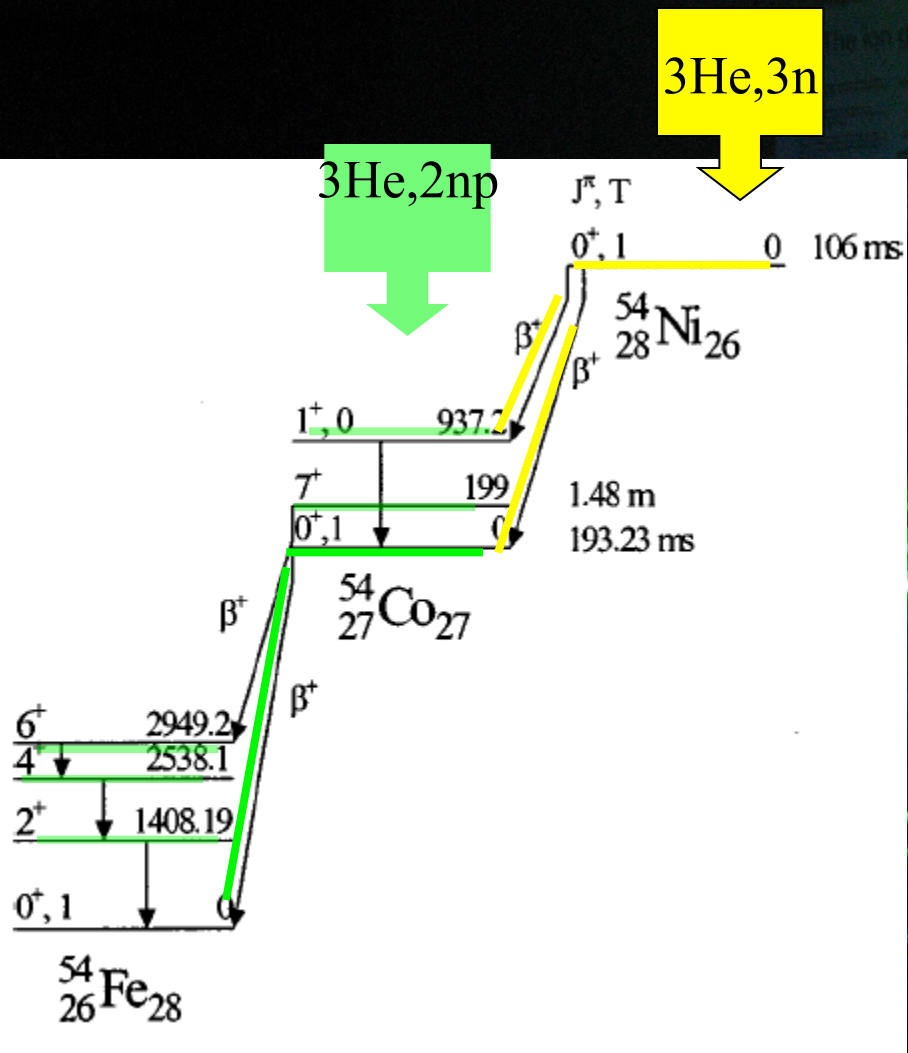


- REX has accelerated 43 different RIB
- Upgrade to 10 MeV/u is under construction: HIE-Isolde

One can also use a simpler reaction, for instance, fusion evaporation



<http://fys.kuleuven.be/iks/ns/lisol-leuven-isotope-separator-on-line>



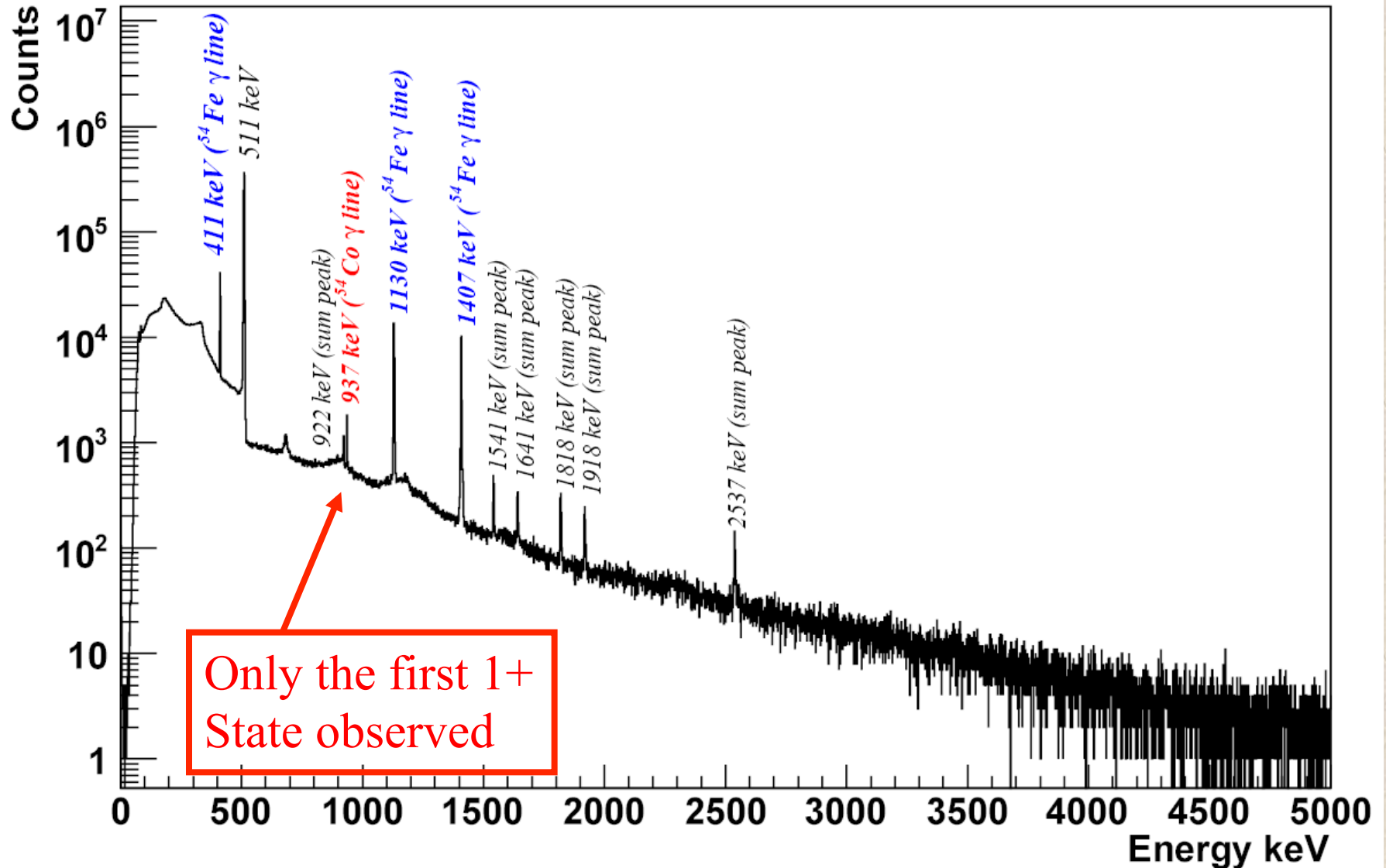
$\sigma(3\text{He}, 3n)$

$\ll$

$\sigma(3\text{He}, 2np)$

Laser ion source resonant on Ni was needed!!!

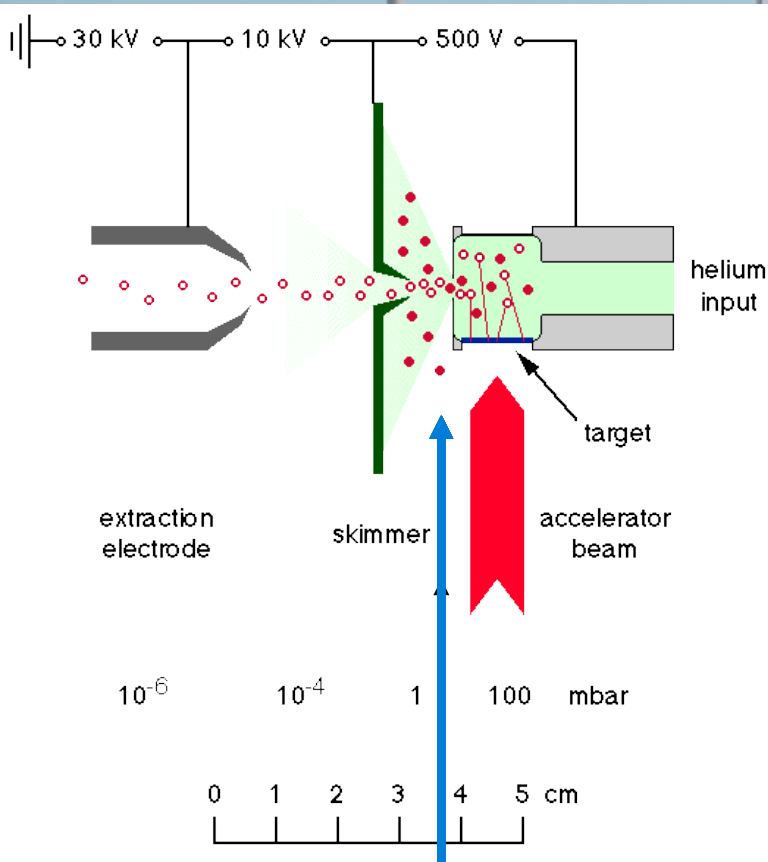
A=54, Laser on Ni Spectrum



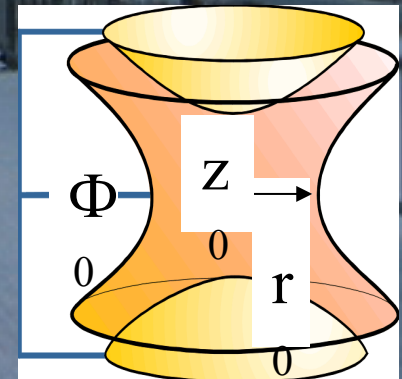
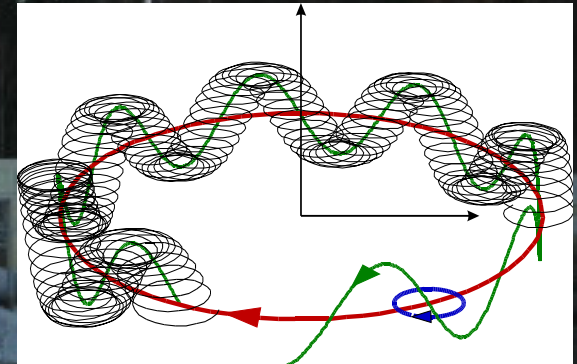
**Almost all the ISOL separators suffer from one limitation:
They cannot produce refractory elements**

Ion Guide Isotope Separator On-Line (IGISOL) facility,

The ion gas guide
technique
mass separation



Isobar separation
using a trap
JYFLTRAP



Future ISOL facilities

GANIL/SPIRAL1/SPIRAL2 facility layout

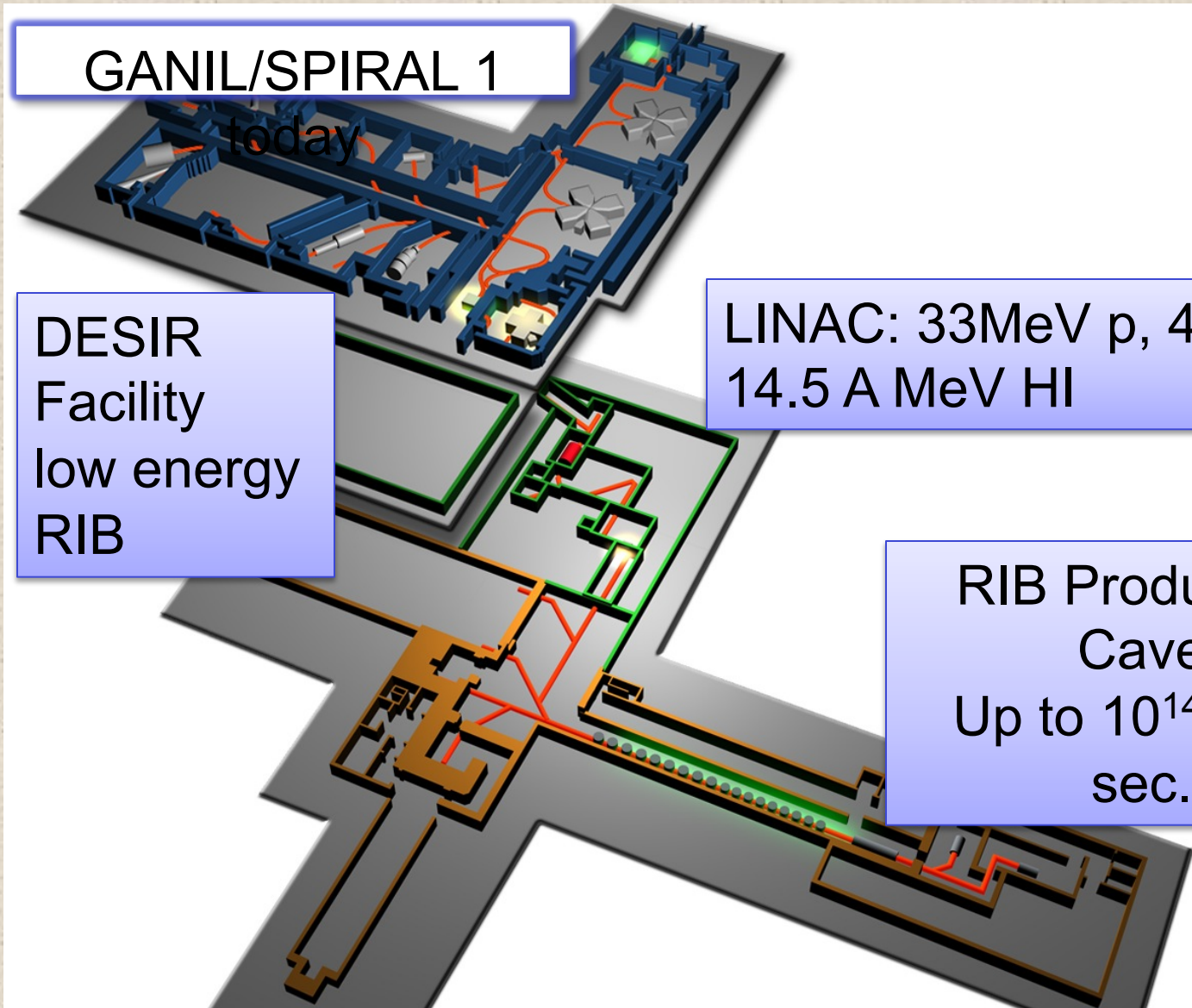
GANIL/SPIRAL 1

today

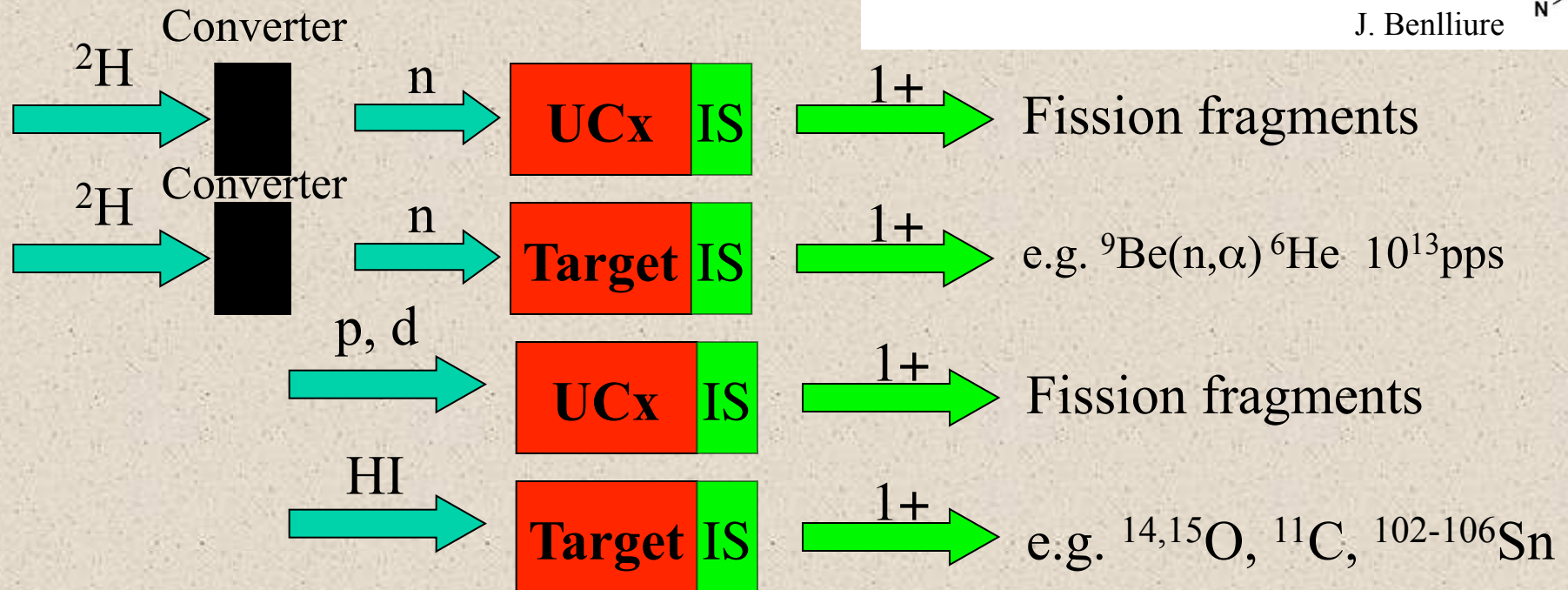
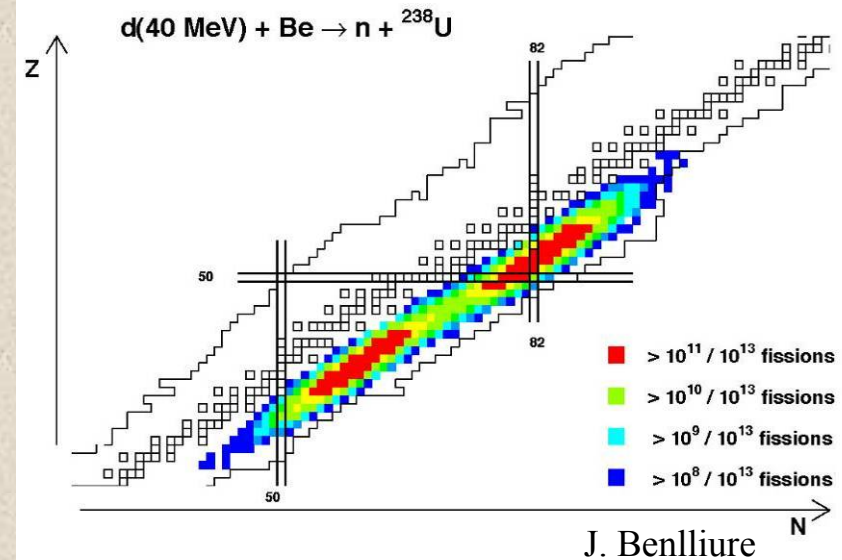
DESIR
Facility
low energy
RIB

LINAC: 33MeV p, 40 MeV d,
14.5 A MeV HI

RIB Production
Cave
Up to 10^{14} fiss./
sec.

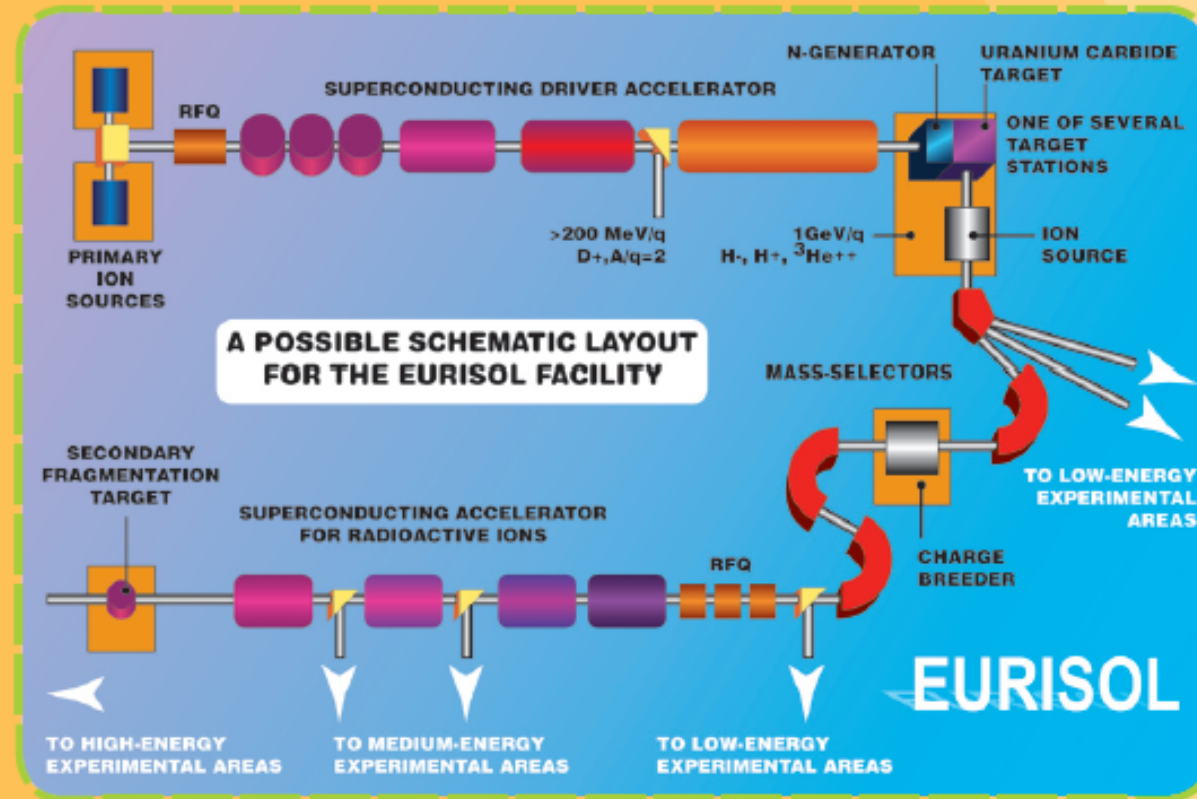


ISOL Rare Isotope Beams at SPIRAL 2



Far in the Future ISOL facility

Furthering target and accelerator technology



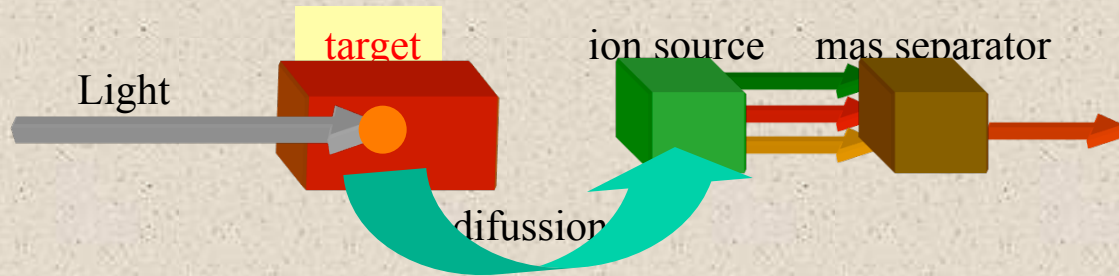
A 4-year Design Study began in 2005 in order to work on the technologically challenging aspects of the project, the instrumentation and the radiation safety issue. Synergy with other projects is being examined, including a feasibility study for the new 'beta-beam' neutrino proposal, forming an integral part of the Design Study. After this, possible sites will be evaluated, and the community will be ready for a full Engineering Design, to be followed by construction of the facility.

Researchers and engineers of several European laboratories are collaborating in twelve tasks to further the EURISOL design.

The EURISOL layout consists of a superconducting linear accelerator providing protons of energy 1 GeV and an impressive power of 5 MW, but also capable of accelerating deuterons, ^3He and ions up to mass 40. The beams will impinge simultaneously on two types of targets, either directly or after conversion of the protons into neutrons through a loop containing 1 ton of mercury surrounded by kilograms of fissile material. The unstable nuclei produced diffuse out of the target, are ionized and selected, and can be used directly at low energy or reaccelerated by another linear accelerator to energies up to 150 MeV per nucleon in order to induce nuclear reactions.

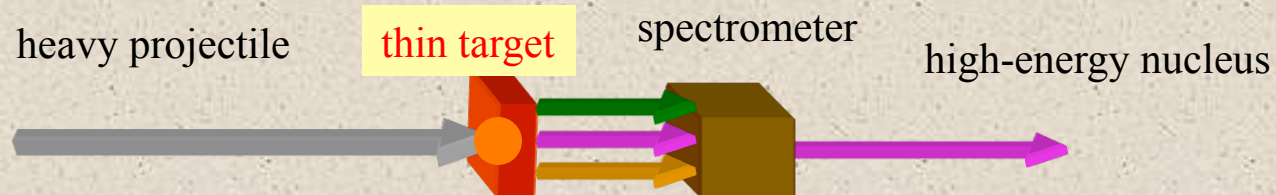
Radioactive nuclei production techniques

Isotopic separation on-line (ISOL)



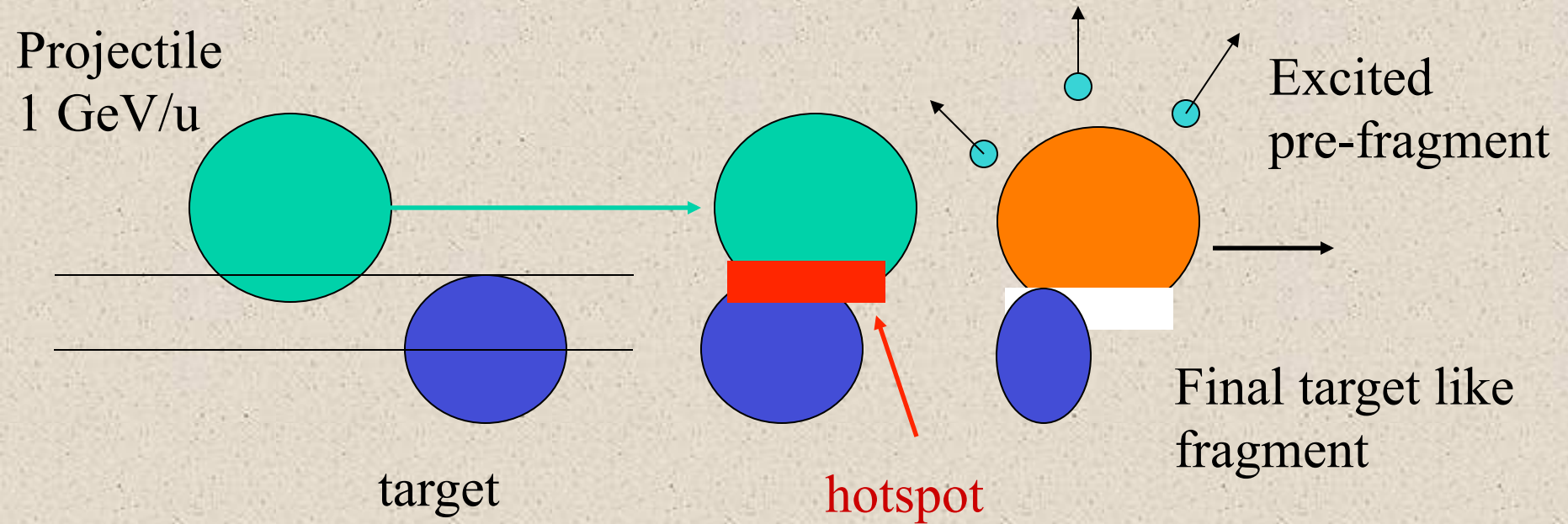
- ☺ We can use thick targets (100% of range) =>
- ☺ and high beam current (upto 10^{16} s^{-1})
- ☹ long extraction and ionization time (ms)
- ☹ chemistry dependent

In-flight fragmentation



- ☺ short separation+identification time (100 ns)
- ☹ thinner targets (10% of range) => lower beam currents (upto 10^{12} s^{-1})
- ☺ chemistry independent

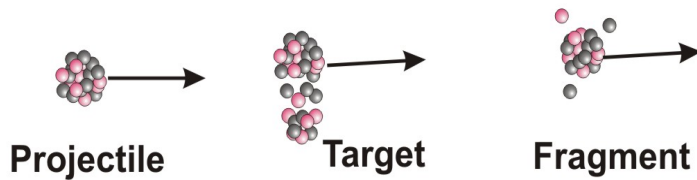
Projectile Fragmentation Reactions



Energy (velocity) of beam > Fermi velocity inside nucleus ~ 30 MeV/u
Can 'shear off' different combinations of protons and neutrons.
Large variety of exotic nuclear species created, all at forward angles with $\sim$ beam velocity.

Projectile Fission

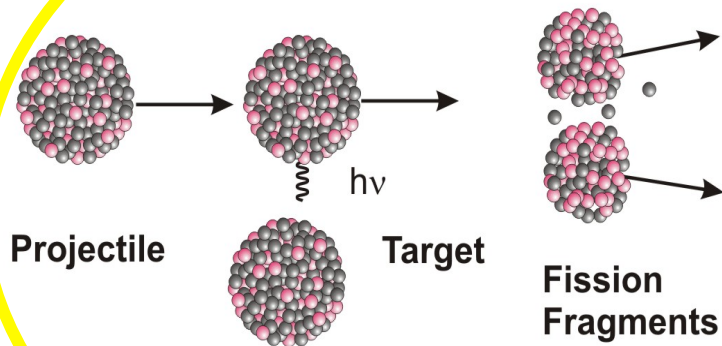
Projectile Fragmentation



Nucleon-nucleon collisions, abrasion, ablation

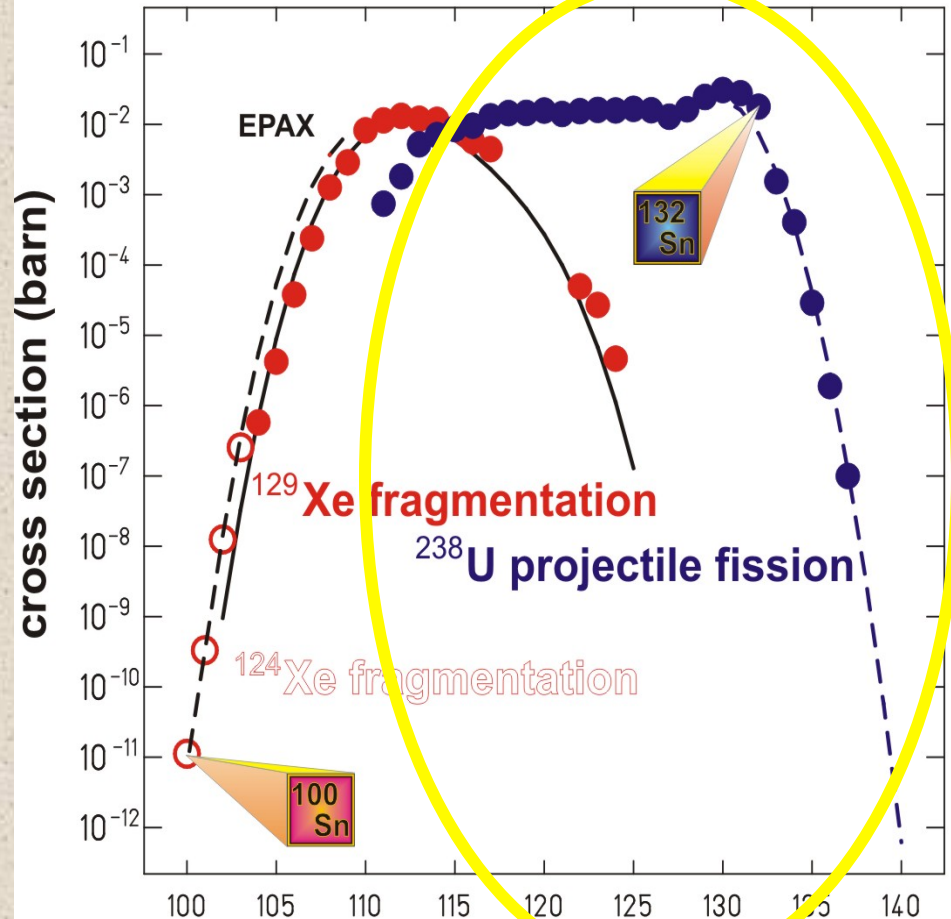
$$\vec{V}_f \approx \vec{V}_p$$

Projectile Fission

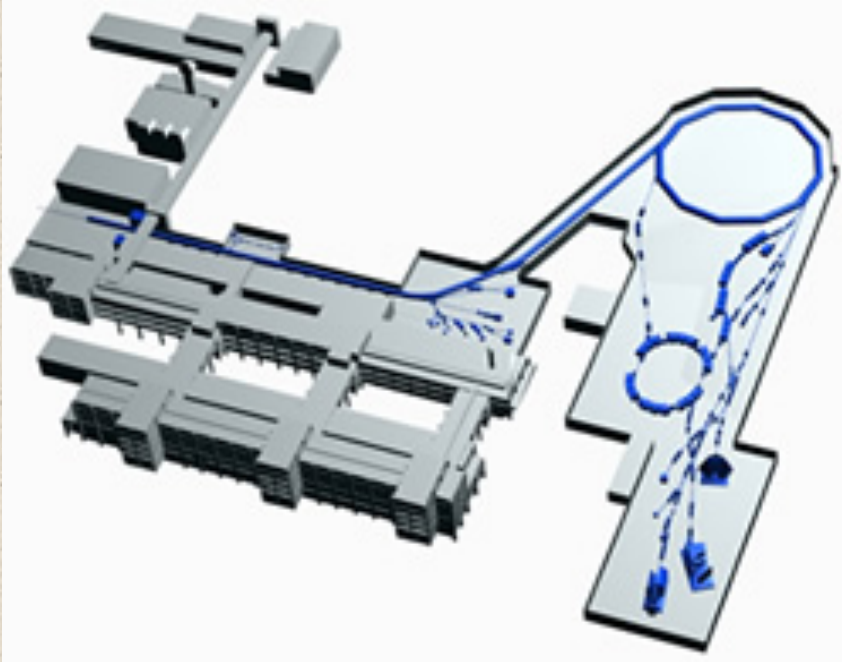


Electromagnetic excitation, fission in flight

Sn isotopes from projectile fragmentation and projectile fission



Beta decay experiment at the GSI fragmentation facility

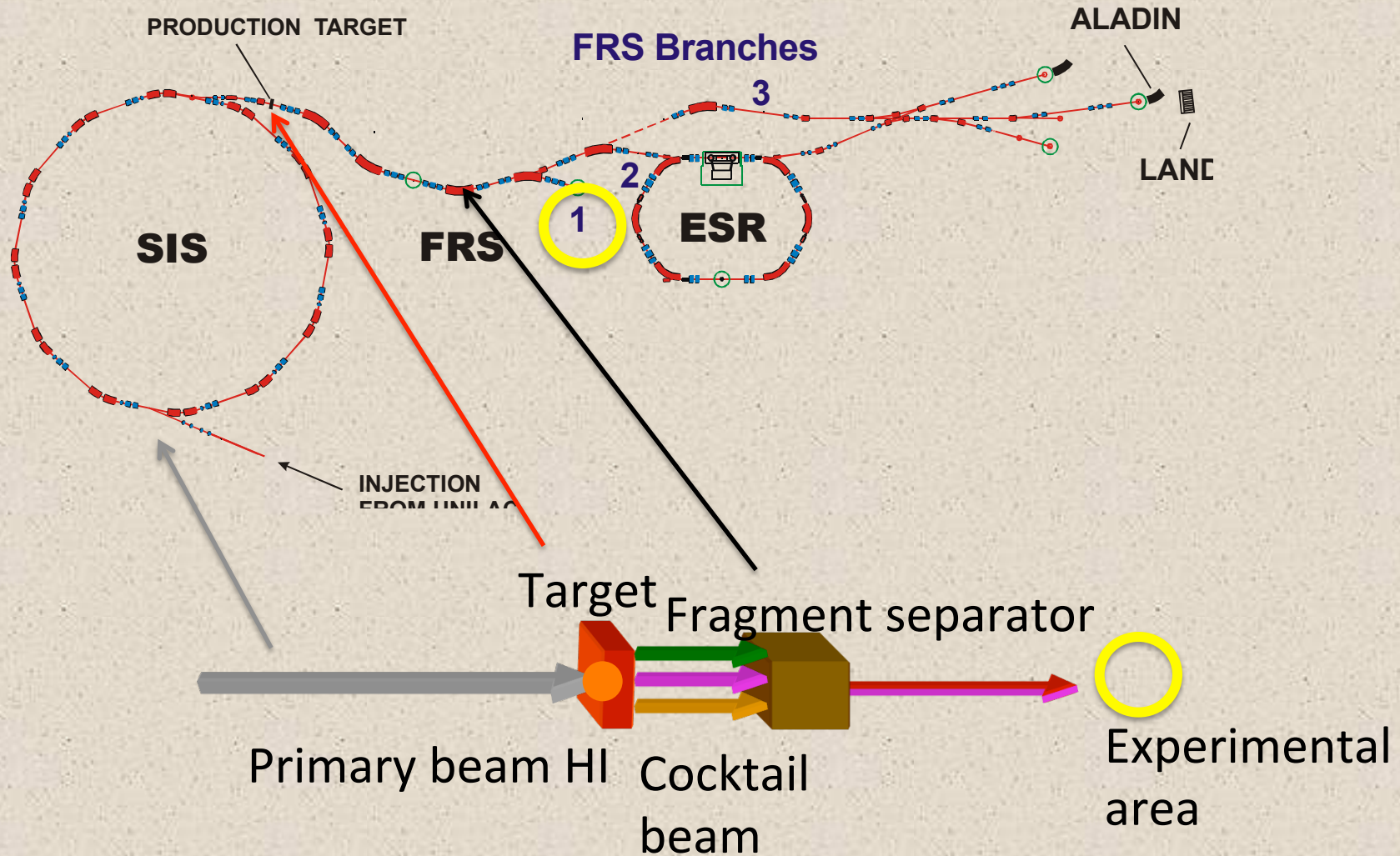


It is possible to accelerate stable Nuclei from H ($Z=1$) to U ($Z=92$), in the UNILAC + Synchrotron.

**Fragmentation of the primary ion beam:
“cocktail” of ions**

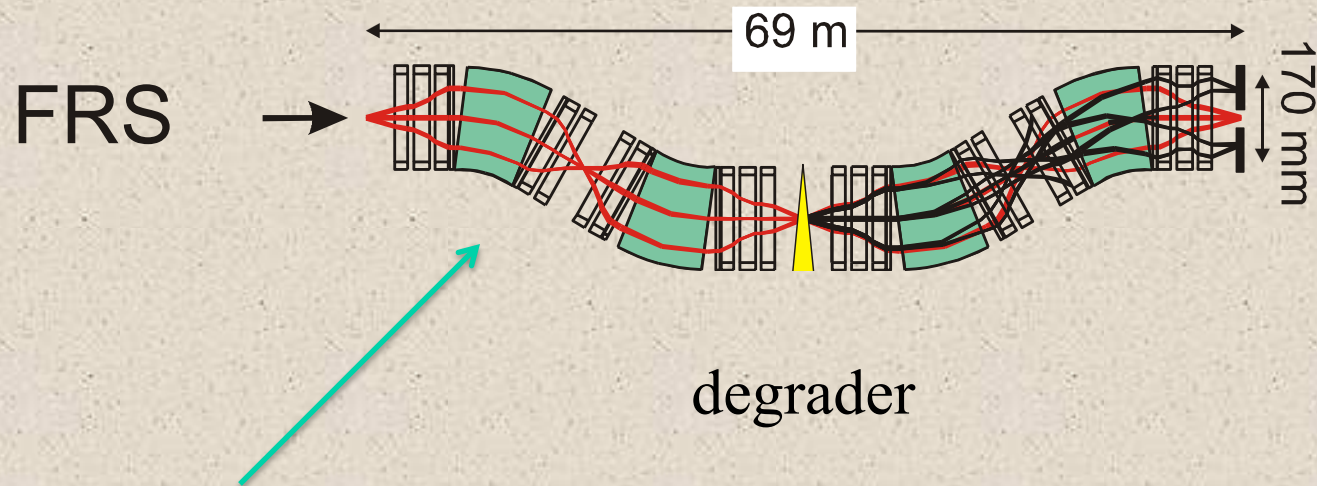


THE PRESENT RARE ISOTOPE FACILITY AT GSI



$B\rho$ - ΔE - $B\rho$ Separation Method

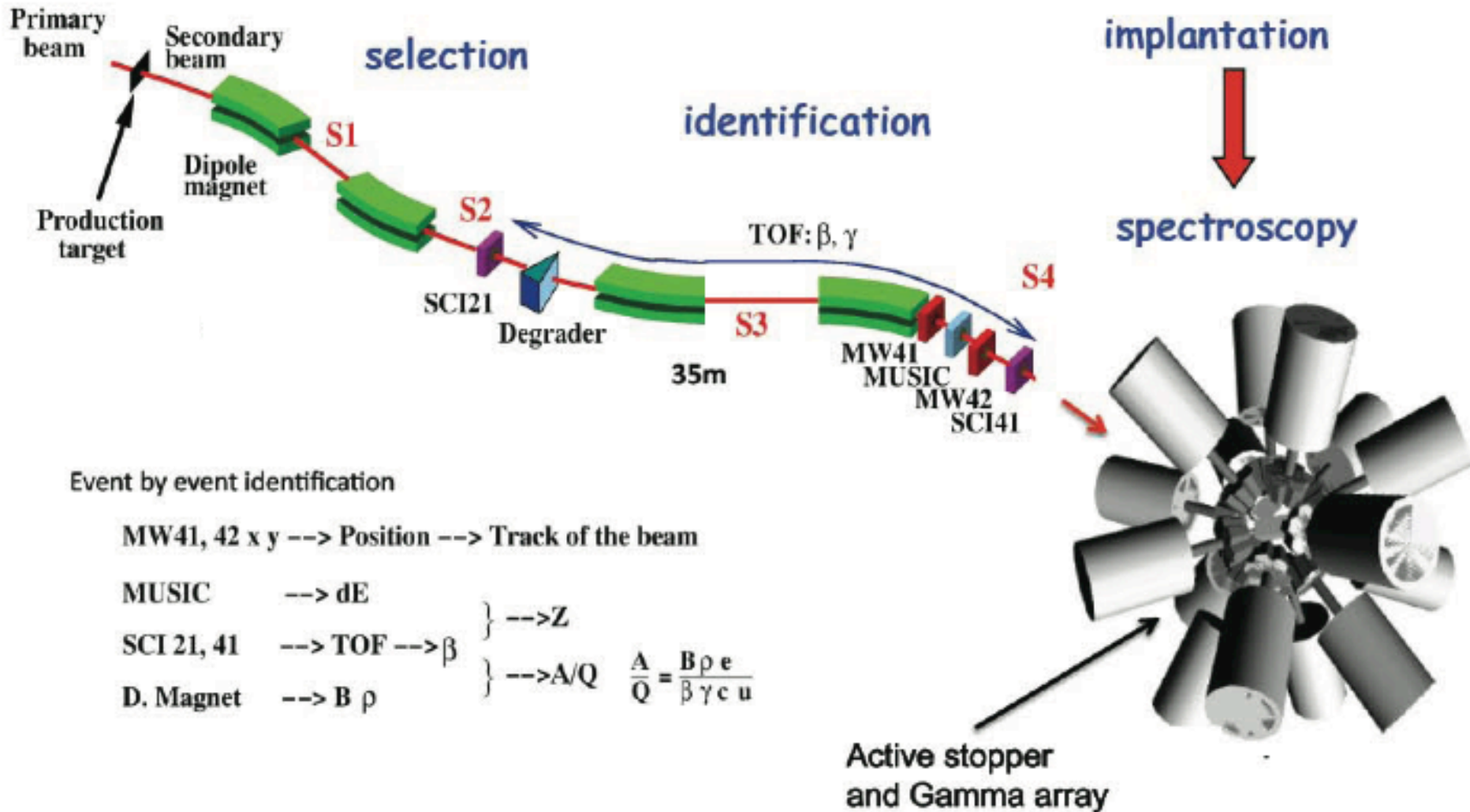
Optimised to separate very fast fragment or fission products

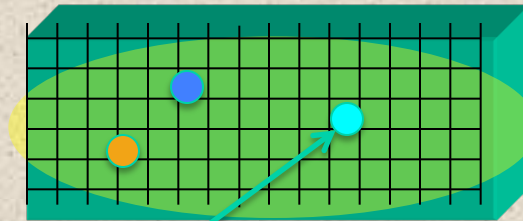


Ions are selected according to the momentum to charge ratio
 $Mv/q = Mv/Z = B\rho$. Primary beam is rejected.

Beam ^{58}Ni @680 MeV/u 10^9 pps (part per spill) Target Be 4g/cm²

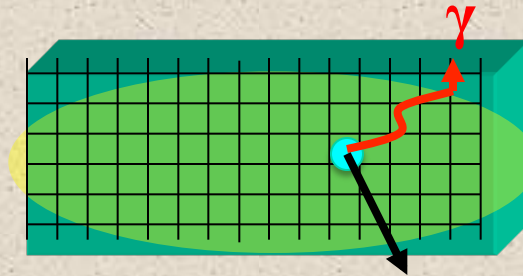
production





Implantation of heavy ion beam from the fragment separator

Some time later (related to the $T_{1/2}$ of the nucleus of interest), in the same pixel we detect the β signal (or the proton, alpha).



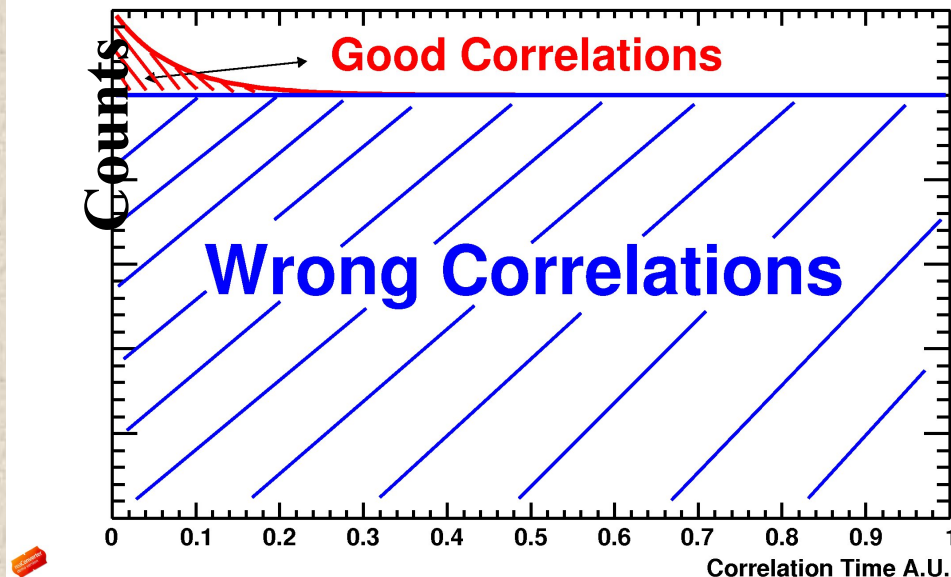
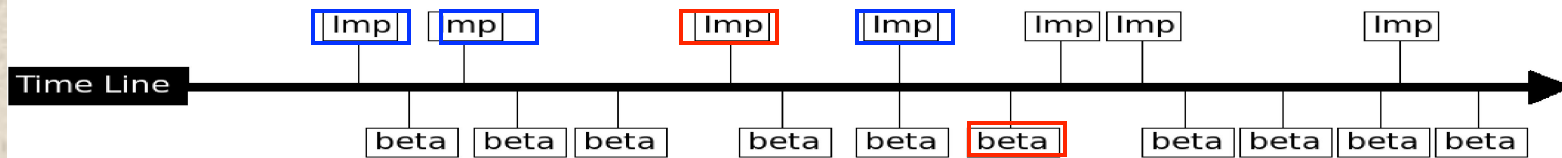
β (ΔE signal)

Around we can put gamma detectors or neutron detectors

All the data are recorded

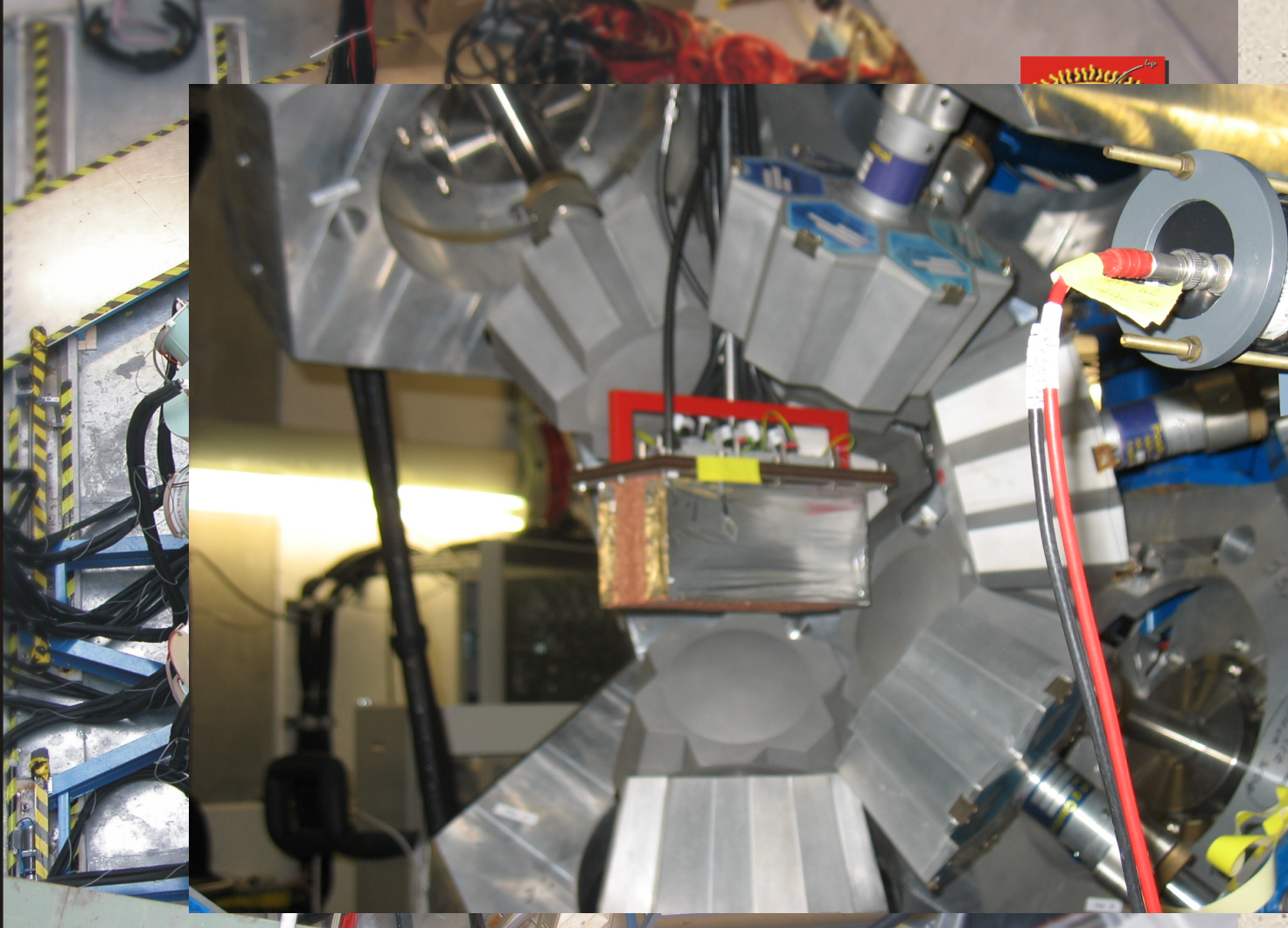
$T=0$, implant $T=\text{beta}$, gamma (proton, neutron signal)

One can correlate each beta decay with **all** previous implantation

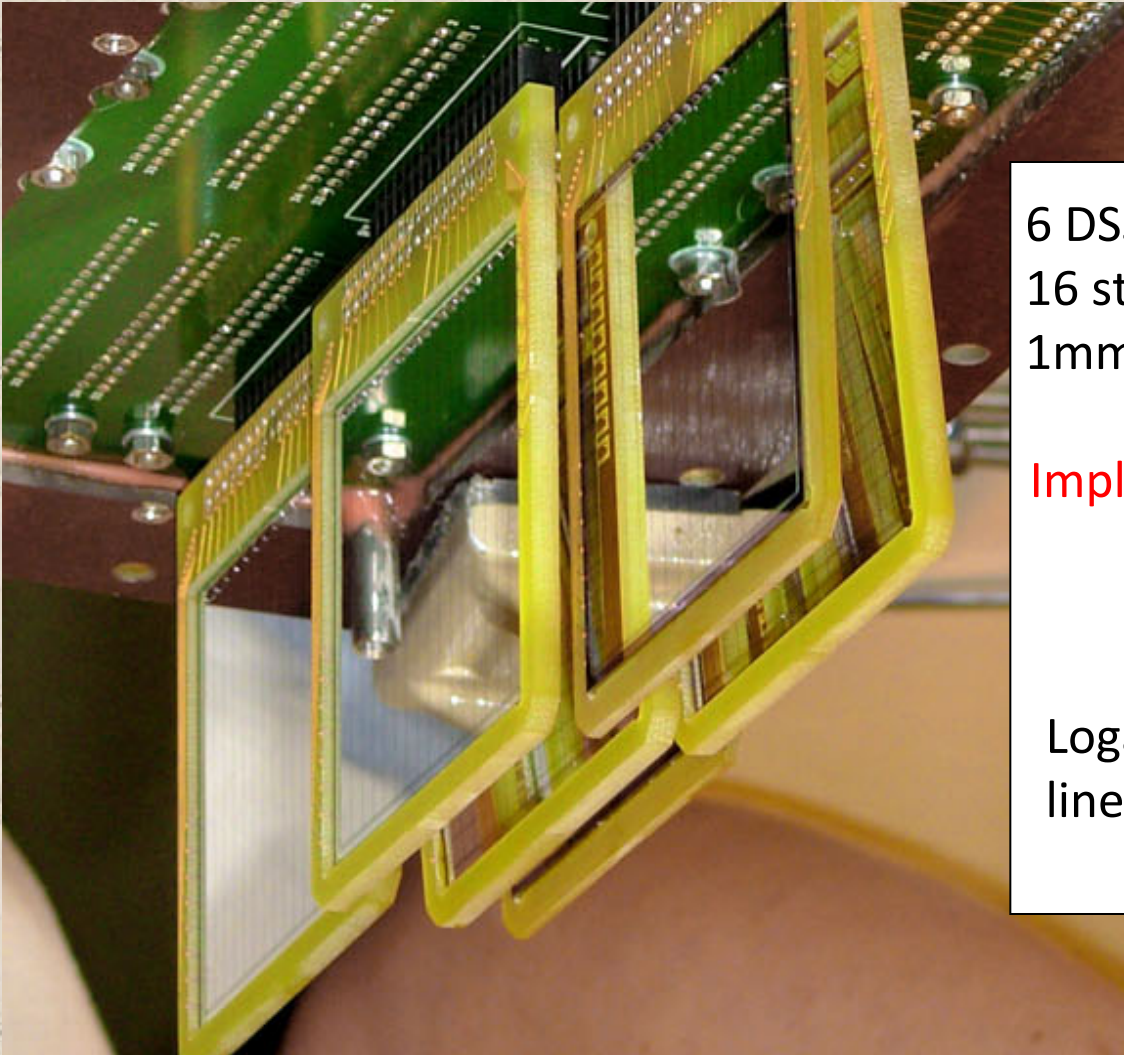


RISING (Ge Array)

stopped beam setup



Detector Setup (Rising and DSSSD)



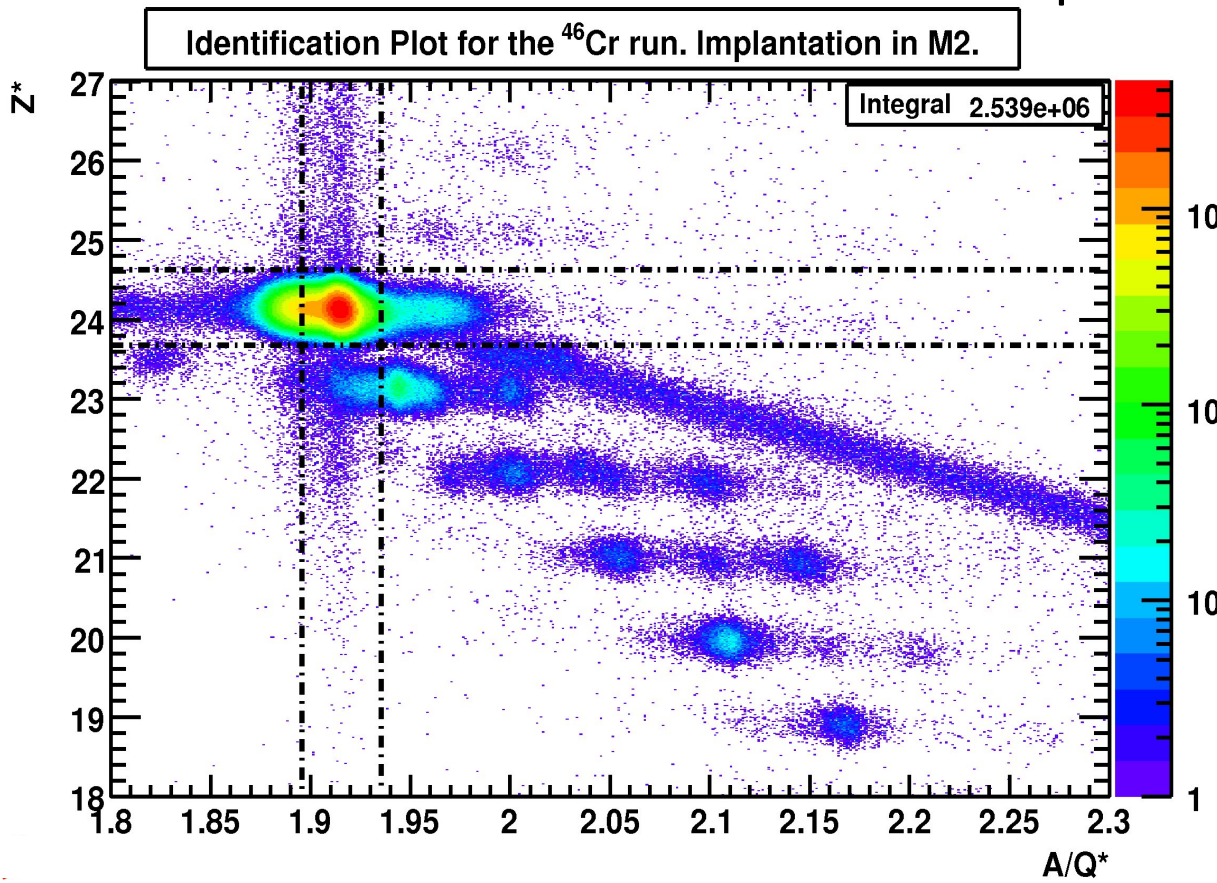
6 DSSSD detectors 1mm with
16 strips X and 16 strips Y,
1mm thick, 5 x 5 cm area

Implantations and Decay
detectors

Logarithmic preamplifier
linear up to 10 MeV.

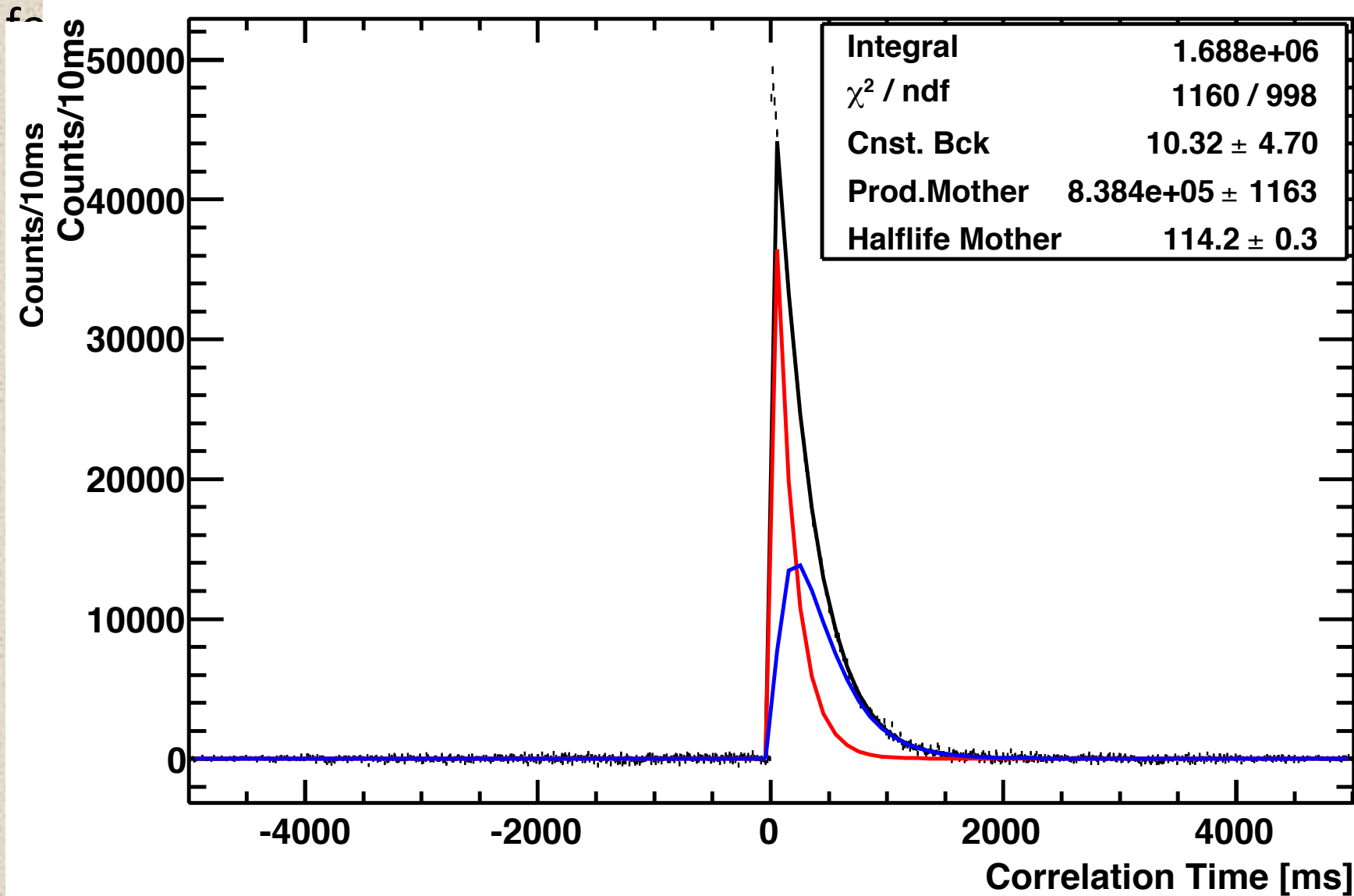
46Cr Setting

The most abundant nucleus produced
separated and identified up to sci4.

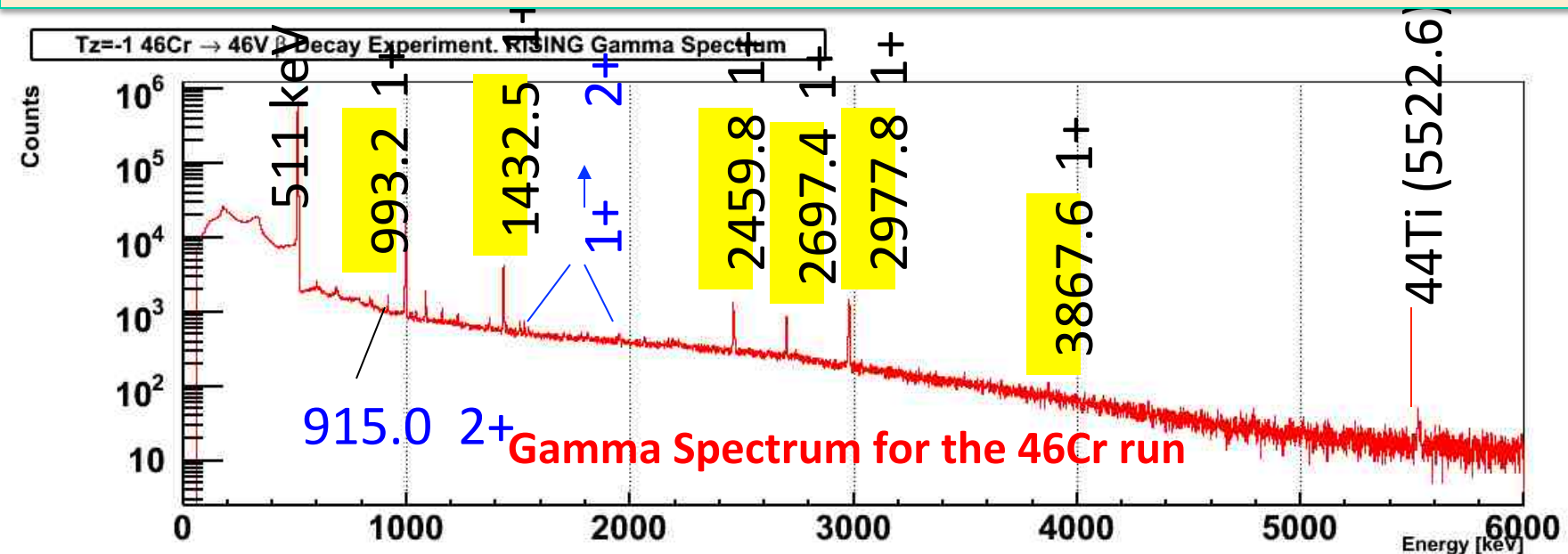


And the most abundant nucleus
Implanted in the DSSD.

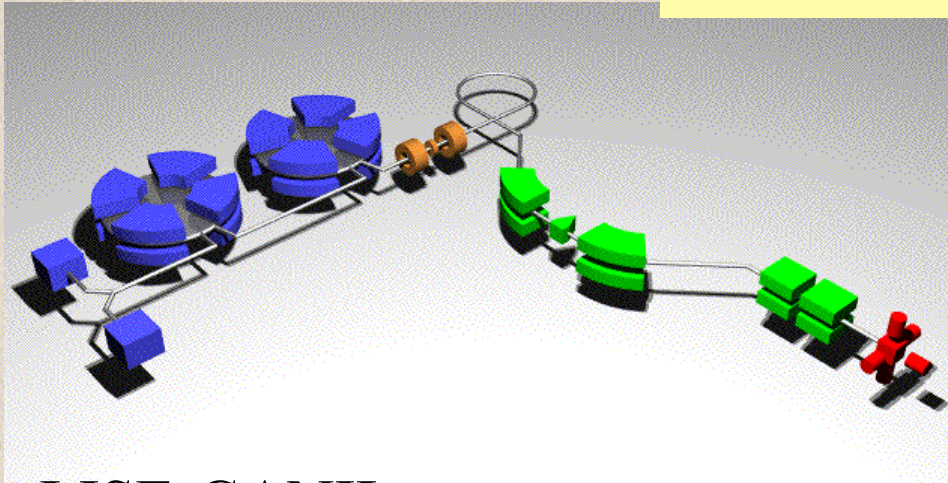
^{54}Ni Half Life. β - All Implants time correlations, random subtracted



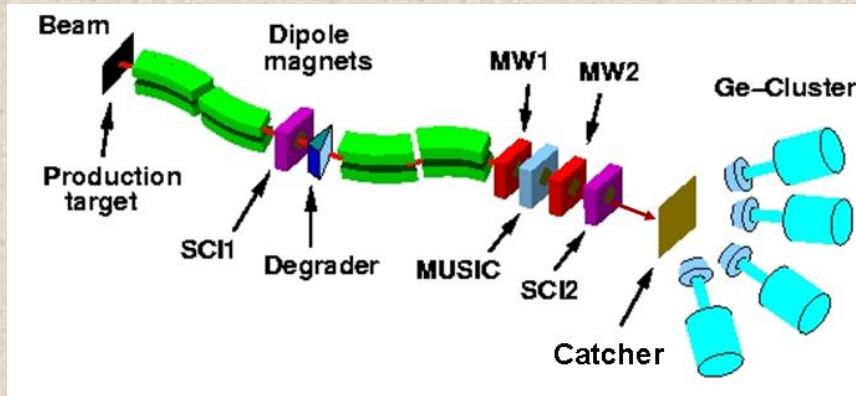
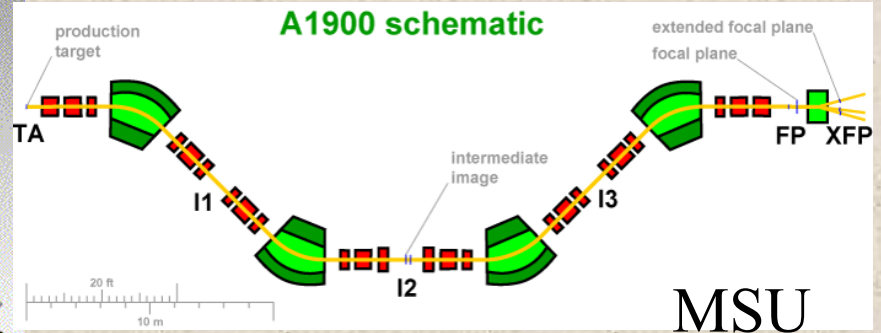
Gammas can be measured only in coincidence with the betas,
If so, the spectrum can be very clean



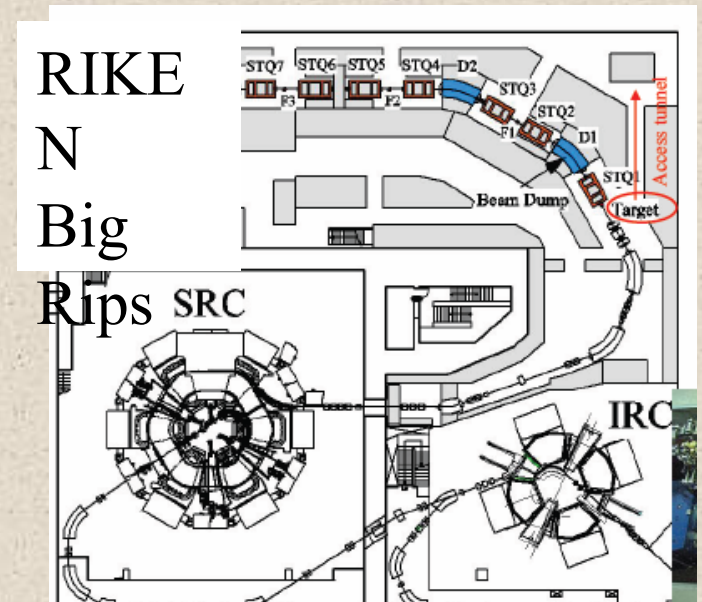
Actual Fragment Separators



LISE-GANIL



FRS GSI

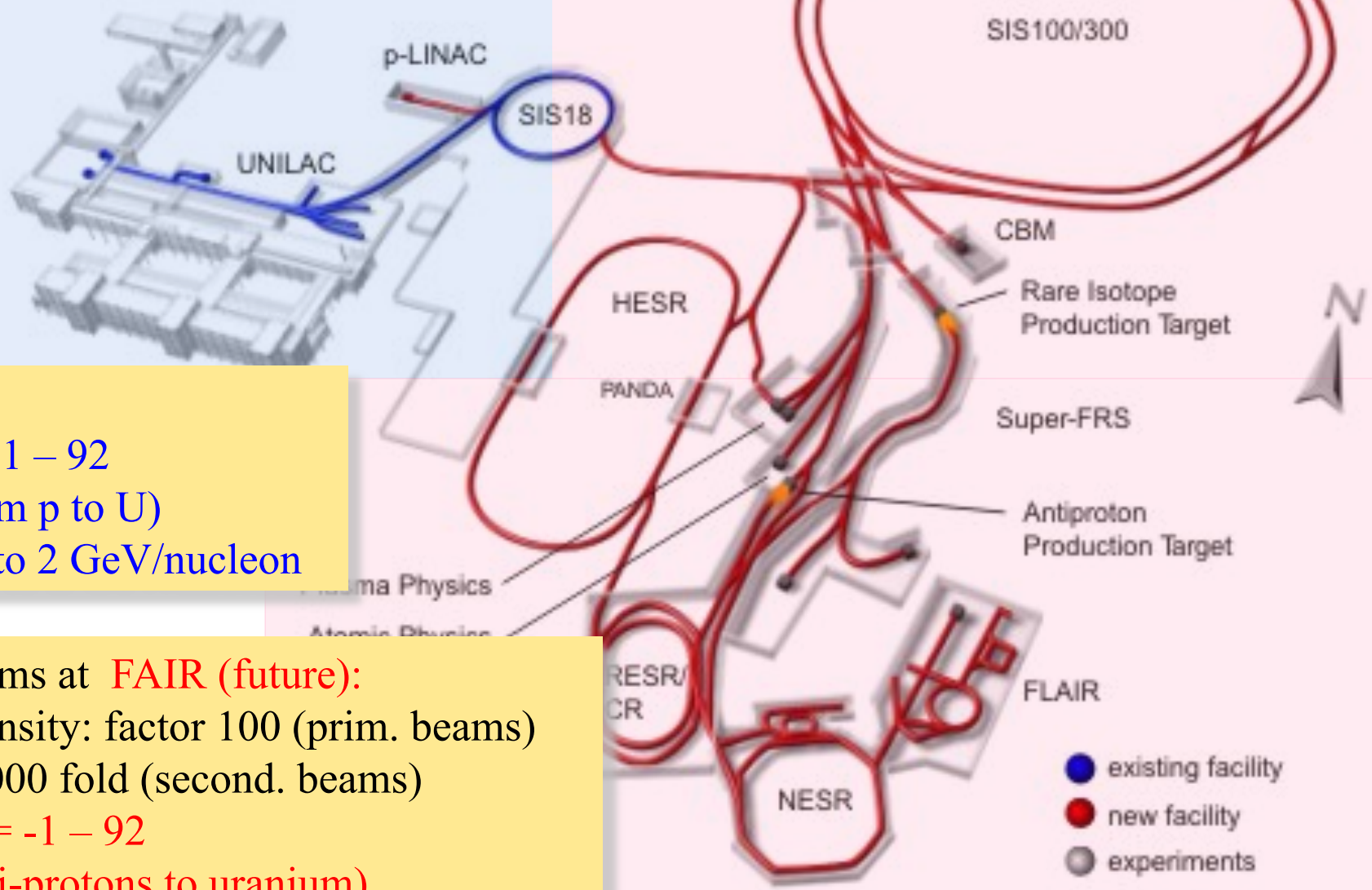


Future (in Europe)



Existing GSI facility

New facility



GSI

$Z = 1 - 92$

(from p to U)

Up to 2 GeV/nucleon

Beams at FAIR (future):

Intensity: factor 100 (prim. beams)

10 000 fold (second. beams)

$Z = -1 - 92$

(anti-protons to uranium)

Up to 35 - 45 GeV/u

„full beam cooling“

FRS to Super-FRS

$B\rho$ - ΔE - $B\rho$ Separation Method

FRS

69 m

170 mm

Degradar

Super-FRS

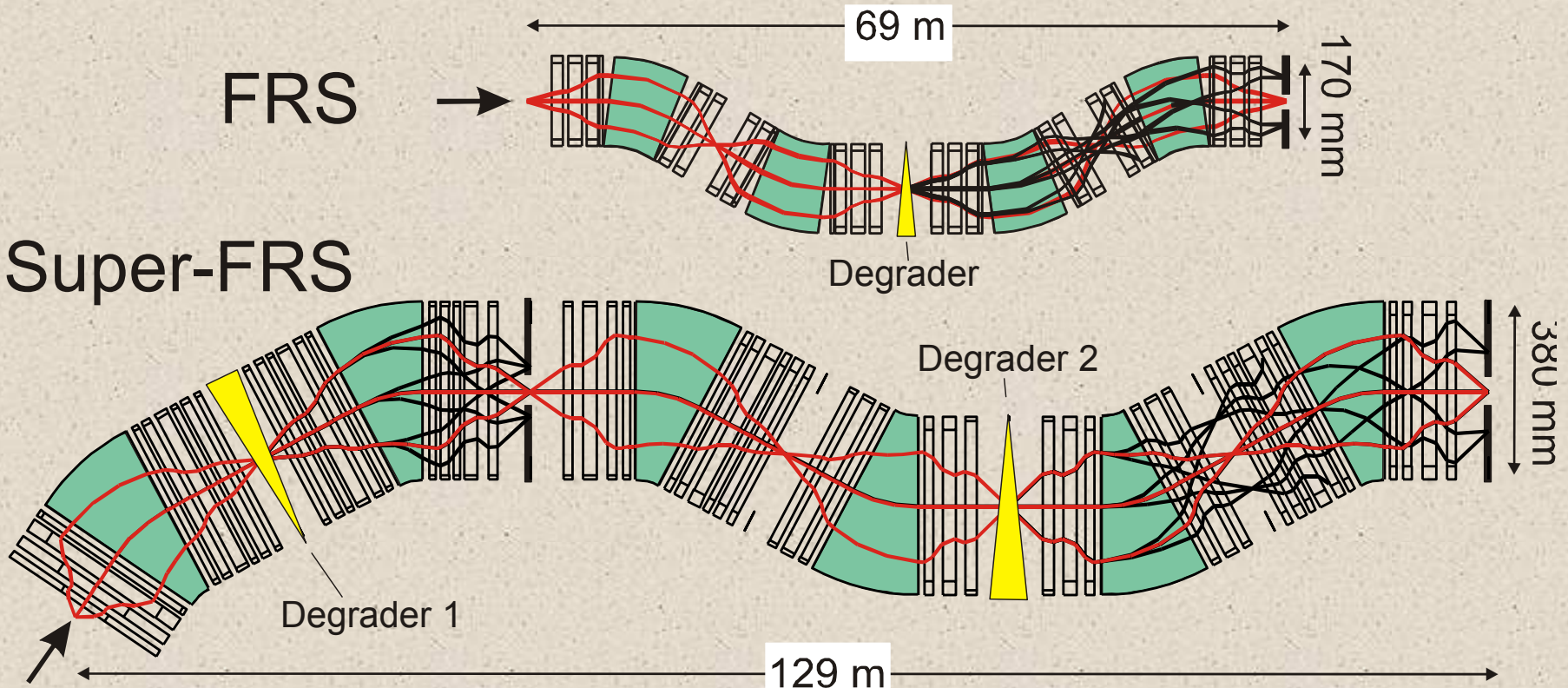
Degradar 2

380 mm

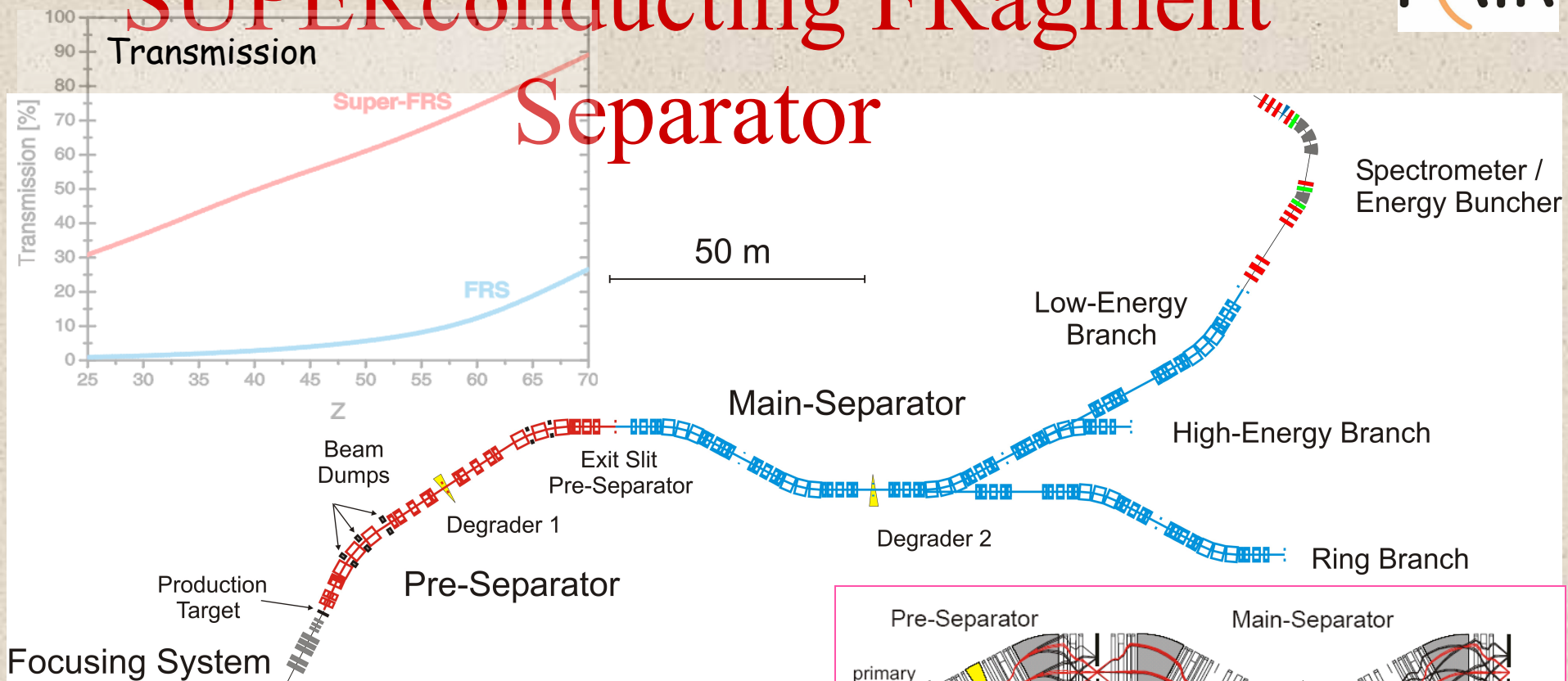
Degradar 1

129 m

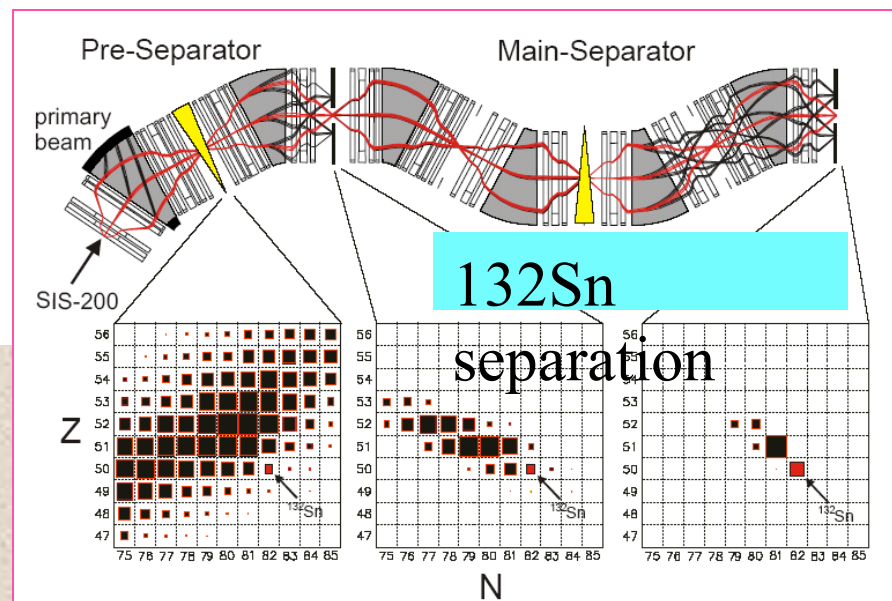
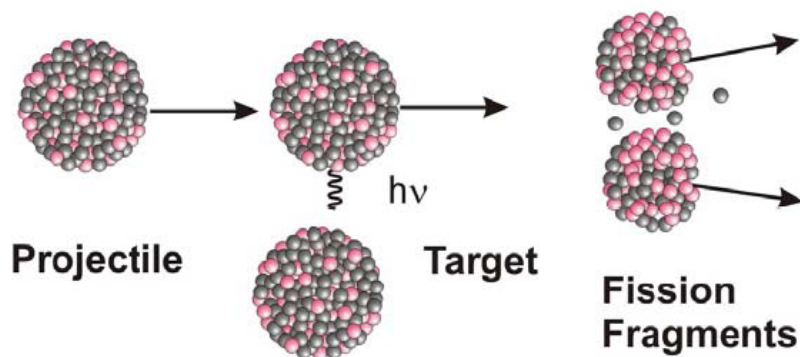
Optimised to separate
very fast fragment or
fission products



SUPERconducting FRagment Separator



Projectile Fission



ISOL and In-Flight facilities-Partners

It is probably true to say that if we worked at it virtually all experiments could be done with both types of facility but they are complementary.

In-Flight

- Relativistic beams
- Universal in Z
- Down to very short $T_{1/2}$
- Easily injected into storage rings
- Leads readily to colliding beam experiments

ISOL

- High intensity beams with ion optics comparable to stable beams
- Easy to manipulate beam energies from keV to 10s of MeV
- High quality beams ideally suited to produce pencil-like beams and point sources for materials and other applied studies

END