Producción y uso de haces radioactivos en experimentos de desintegración

Master Interuniversitario de Fisica Nuclear

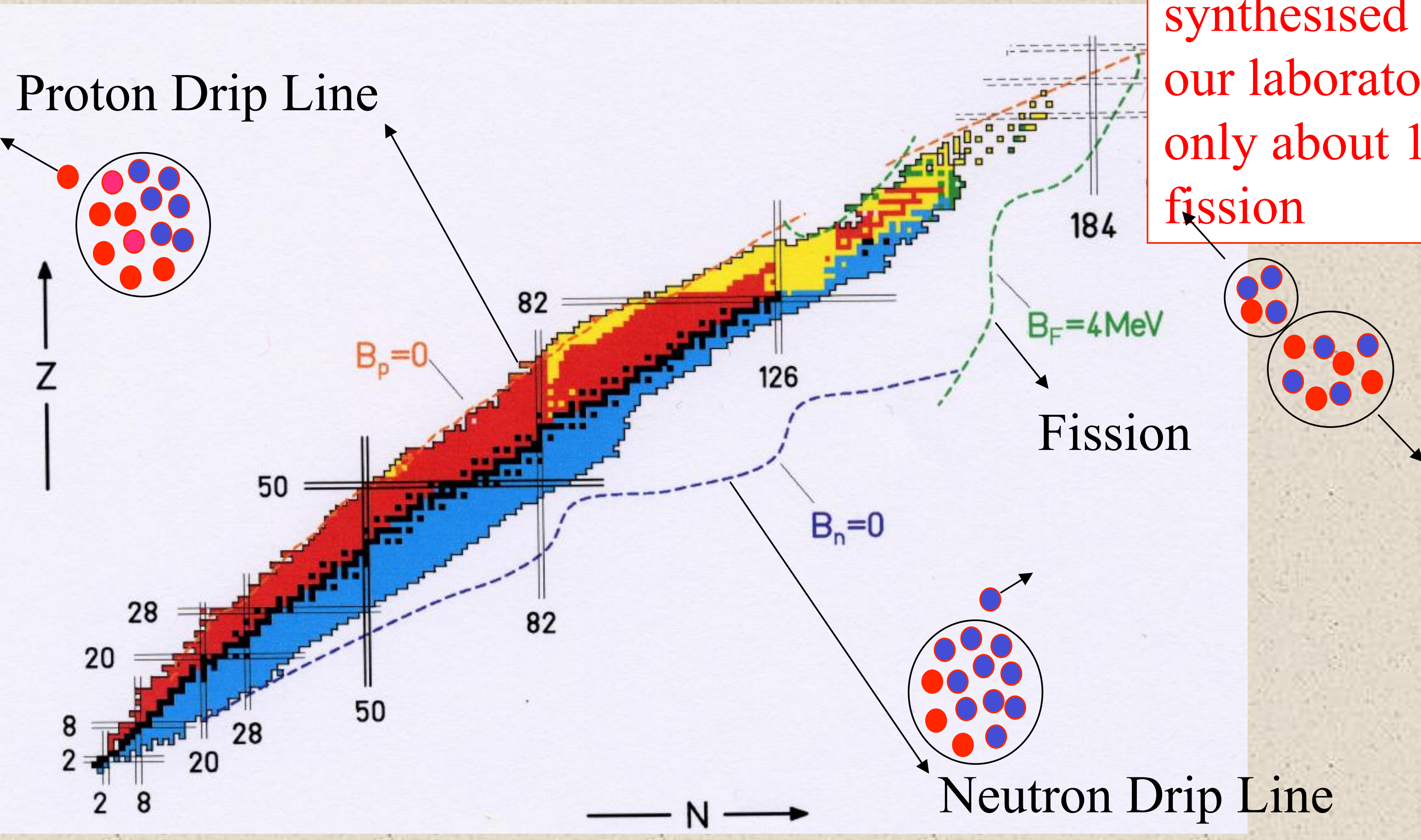
Berta Rubio IFIC (CSIC-Univ. Valencia)

Porqué son importantes las medidas de desintegración nuclear

265 stable

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

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



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

50 Protons

52

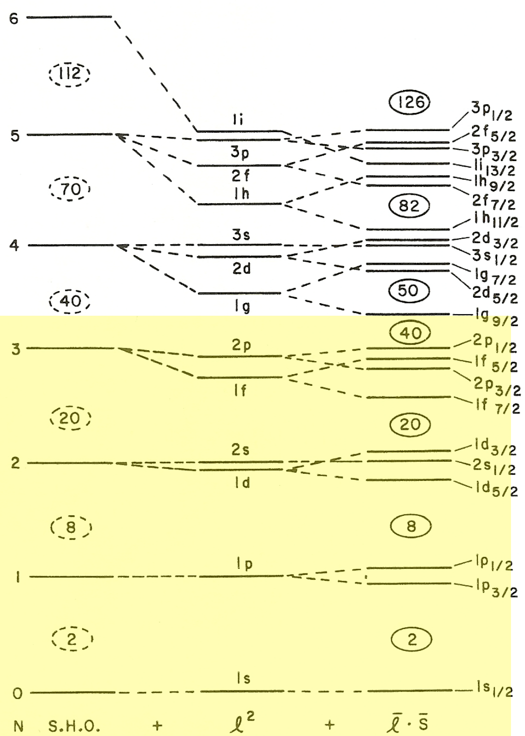


Fig. 3.2. Single-particle energies for a simple harmonic oscillator (S.H.O.), a modified harmonic oscillator with l^2 term, and a realistic shell model potential with l^2 and spin orbit ($l \cdot s$) terms.

82 Neutrones

52

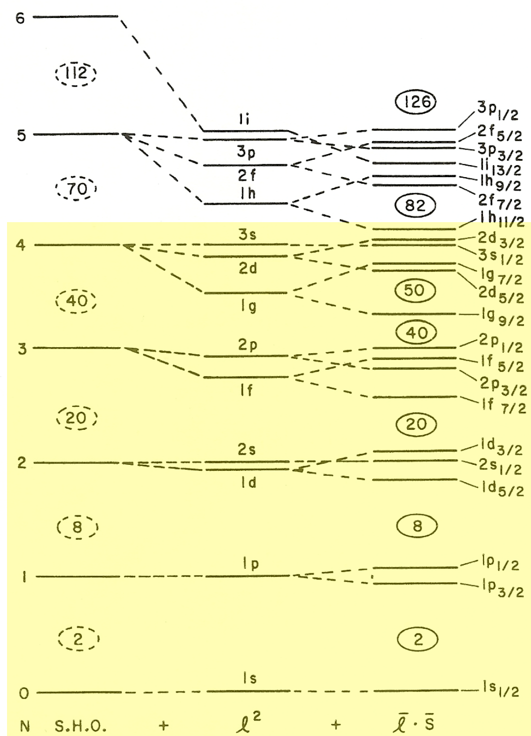


Fig. 3.2. Single-particle energies for a simple harmonic oscillator (S.H.O.), a modified harmonic oscillator with l^2 term, and a realistic shell model potential with l^2 and spin orbit ($l \cdot s$) terms.

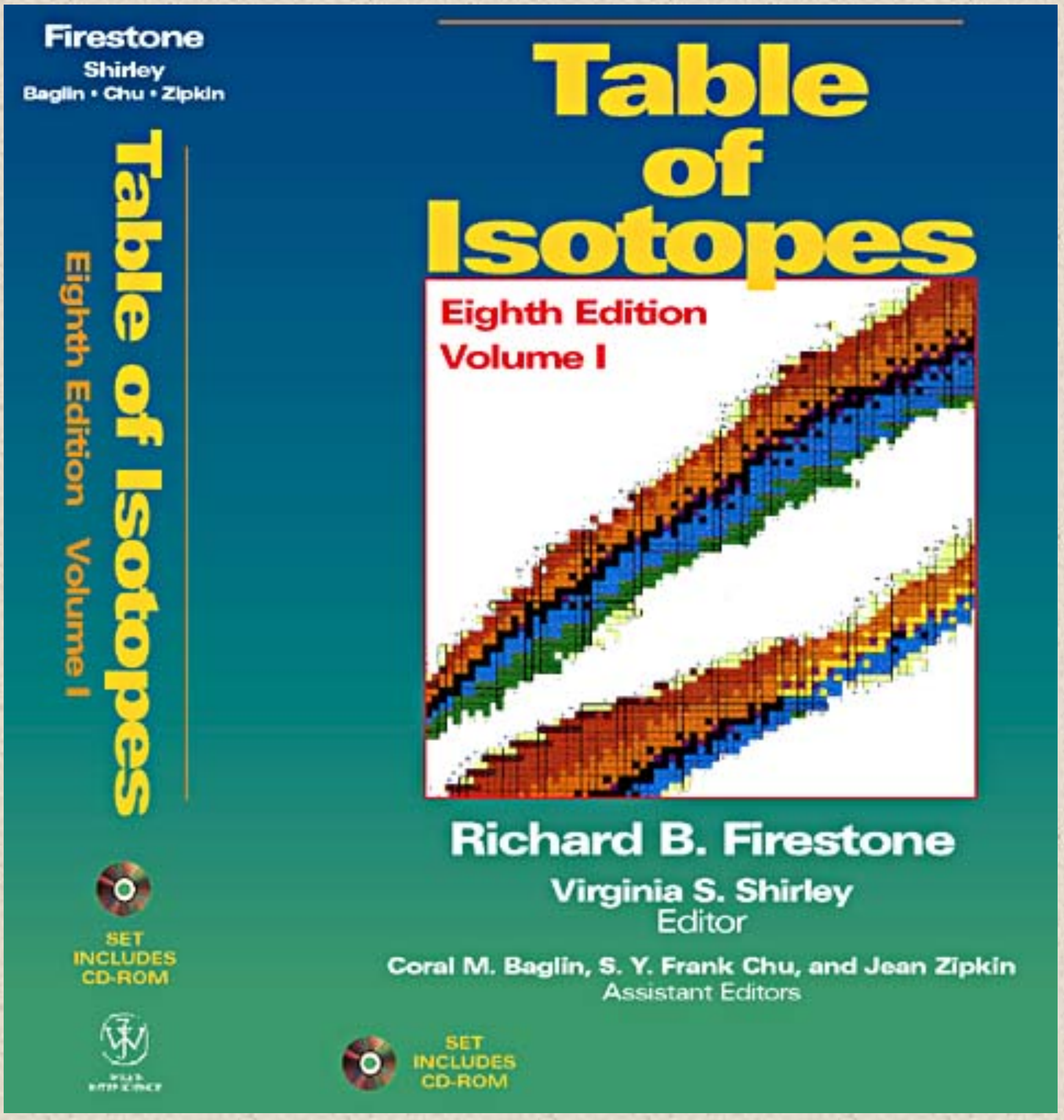

Firestone
Shirley
Baglin • Chu • Zipkin
Table of Isotopes
Eighth Edition Volume I
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Table of Isotopes
Eighth Edition
Volume I
Richard B. Firestone
Virginia S. Shirley
Editor
Coral M. Baglin, S. Y. Frank Chu, and Jean Zipkin
Assistant Editors
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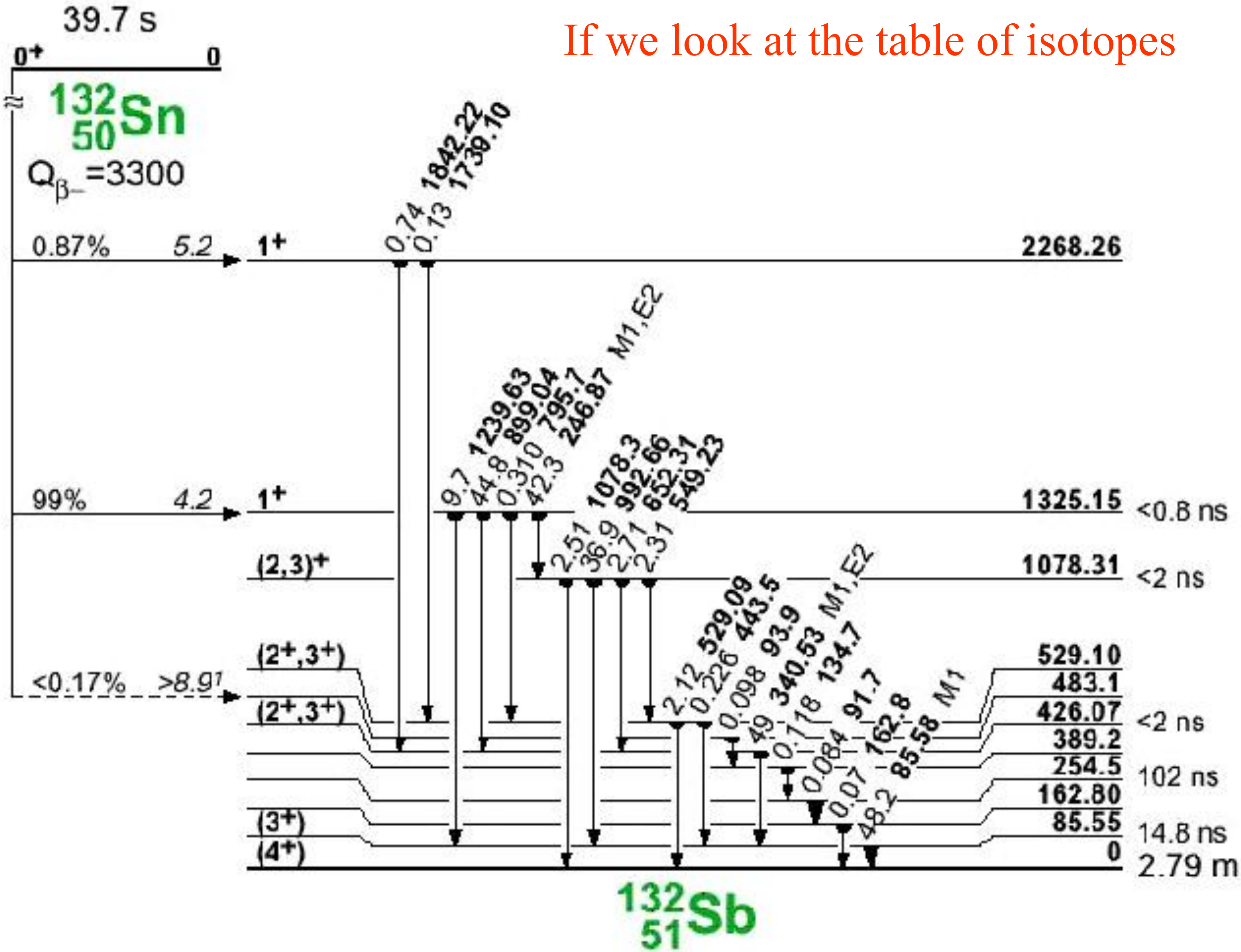
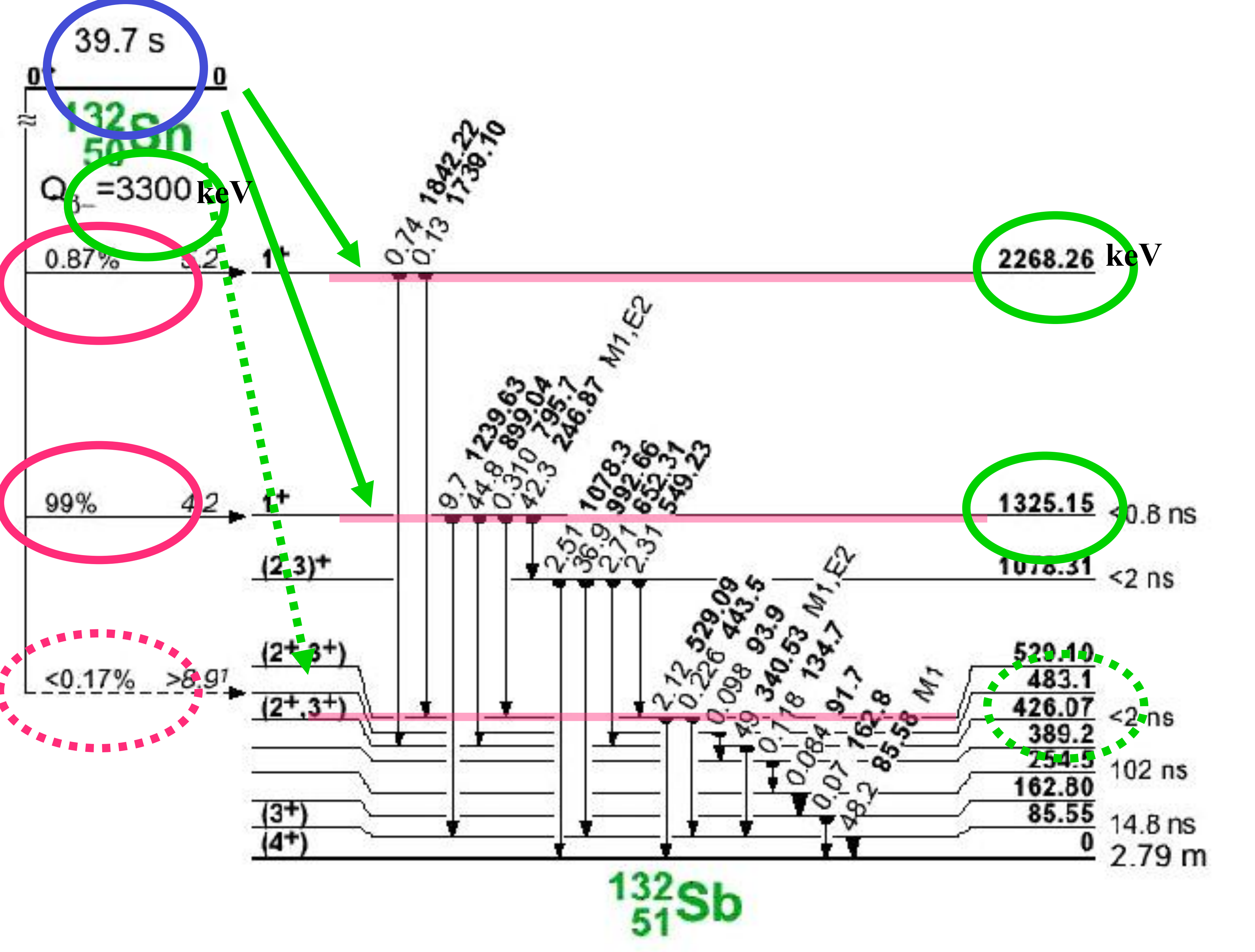
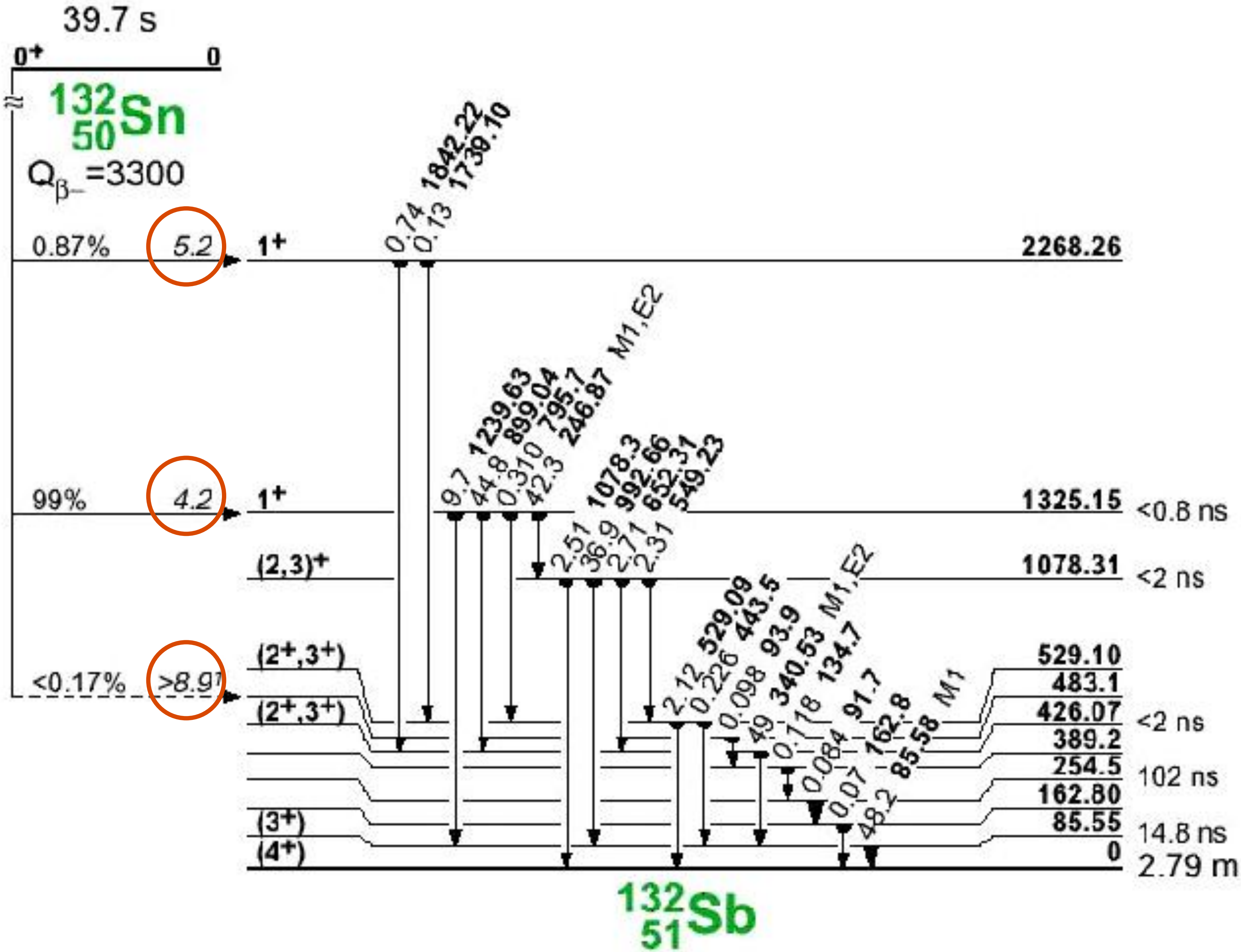
If we look at the table of isotopes





39.7 s
0
0
132
50
Sn
Q
β-
=3300 keV
0.87%
5.2
1+
99%
4.2
1+
(2,3)+
<0.17%
>8.91
(2+,3+)
(2+,3+)
(3+)
(4+)
0.74
0.13
1842.22
1739.10
2268.26 keV
M1,E2
9.7
44.8
0.310
42.3
1239.63
899.04
795.7
246.87
1078.3
992.66
652.31
549.23
1325.15
<0.8 ns
2.51
36.9
2.71
2.31
1078.31
<2 ns
2.12
0.226
0.098
49
0.118
0.084
0.07
48.2
529.09
443.5
93.9
340.53
134.7
M1,E2
91.7
162.8
85.58
M1
529.10
483.1
426.07
<2 ns
389.2
254.5
102 ns
162.80
85.55
14.8 ns
0
2.79 m
132
51
Sb


39.7 s
0+
0
132 50 Sn
Qβ- =3300
0.87%
5.2
1+
99%
4.2
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(2,3)+
<0.17%
>8.91
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(4+)
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42.3 246.87 M1,E2
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0.226 443.5
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49 340.53 M1,E2
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2268.26
1325.15 <0.8 ns
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529.10
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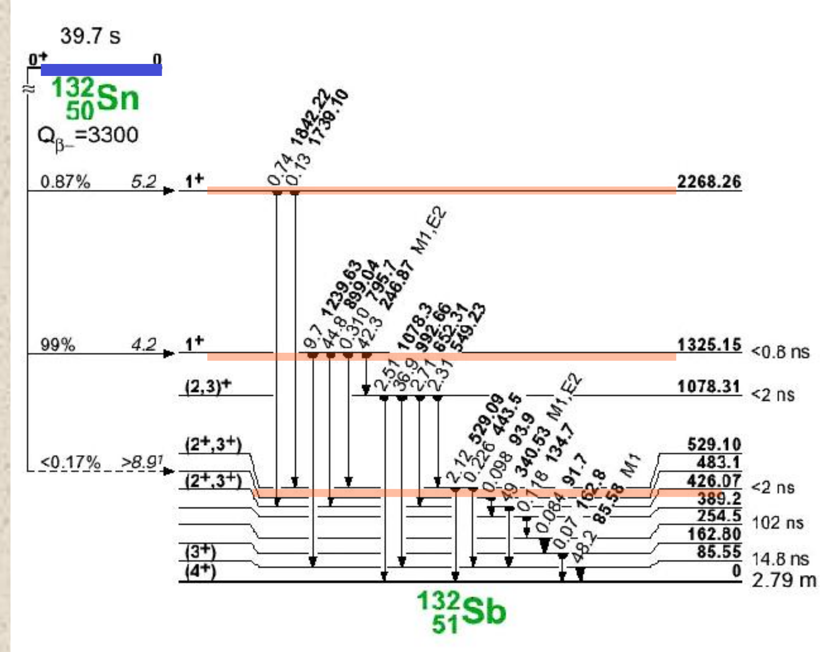
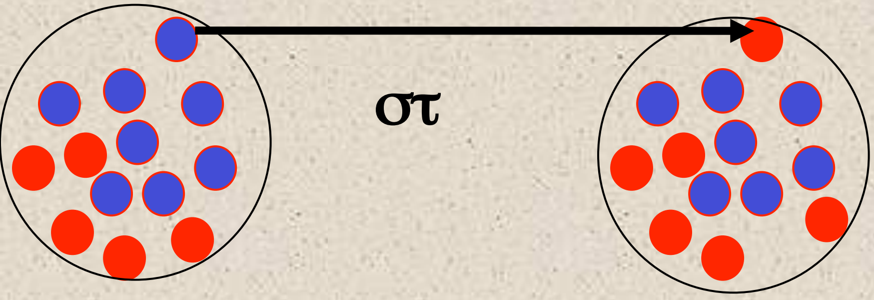
389.2
254.5 102 ns
162.80
85.55 14.8 ns
0 2.79 m
132 51 Sb

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

$\langle i|$



$|f\rangle$



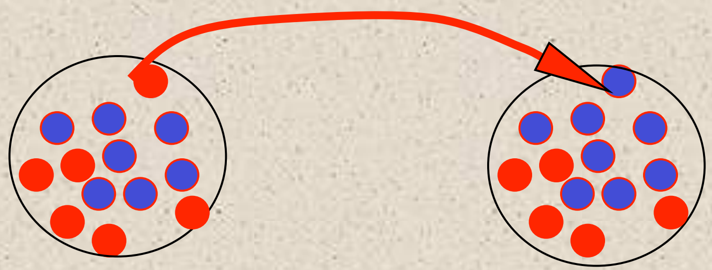
$\sigma\tau$

$\beta^-: n \rightarrow p + e^- + \nu$

neutron **proton**

Transition probability

$\langle i|$ **τ** **στ** $|f\rangle$



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

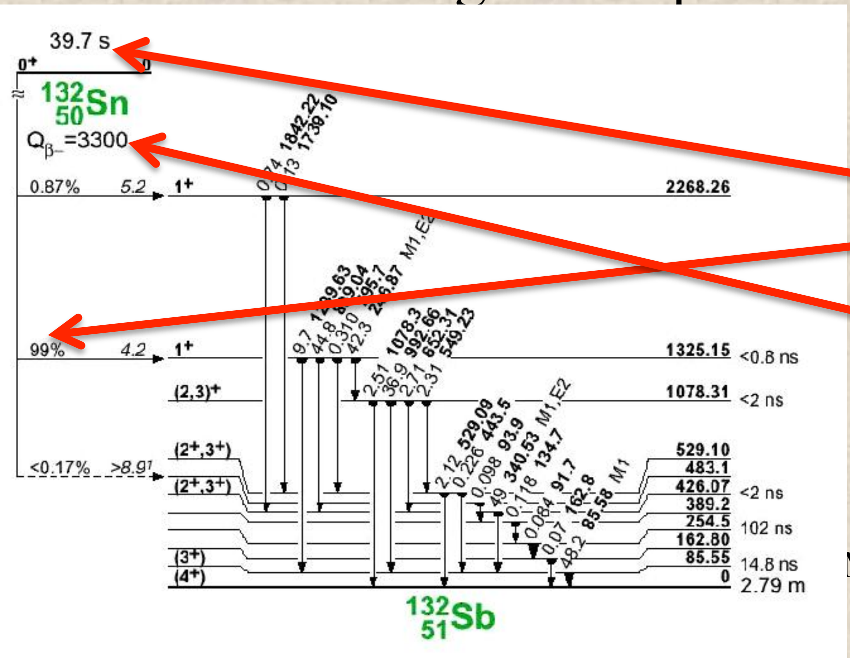
$$B_{GT} = \left|\frac{1}{\sqrt{2}}\left\langle \psi_f \mid \sum \sigma\tau^{\pm} \mid \psi_i \right\rangle\right|^2$$

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

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

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

Luego es importante medir $\frac{1}{f t_{1/2}}$



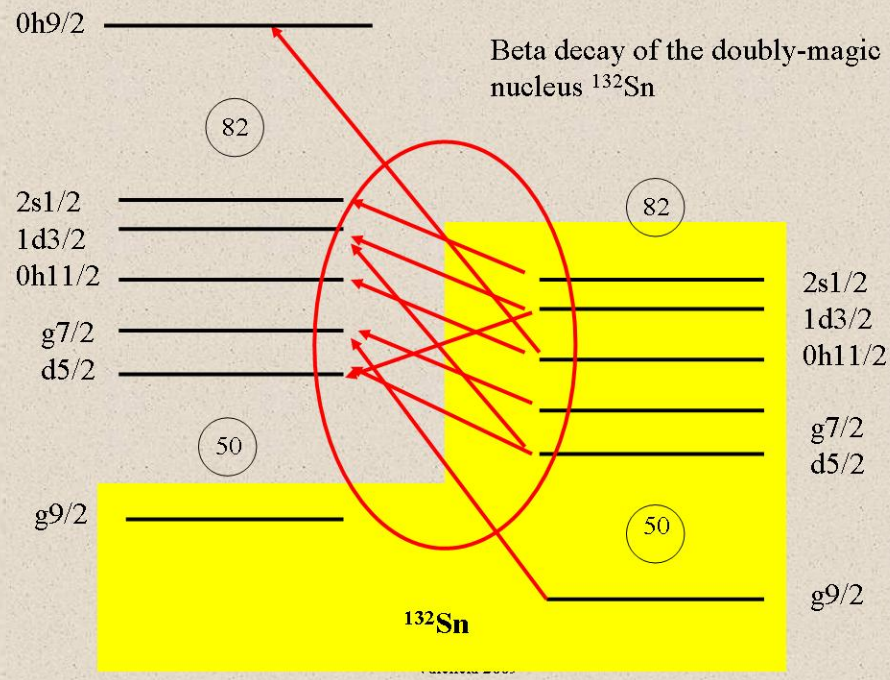
$$\frac{1}{ft} = \frac{I_\beta(E)}{f(Q_\beta - E, Z)\, T_{1/2}}$$

In our case the logft =4.2

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

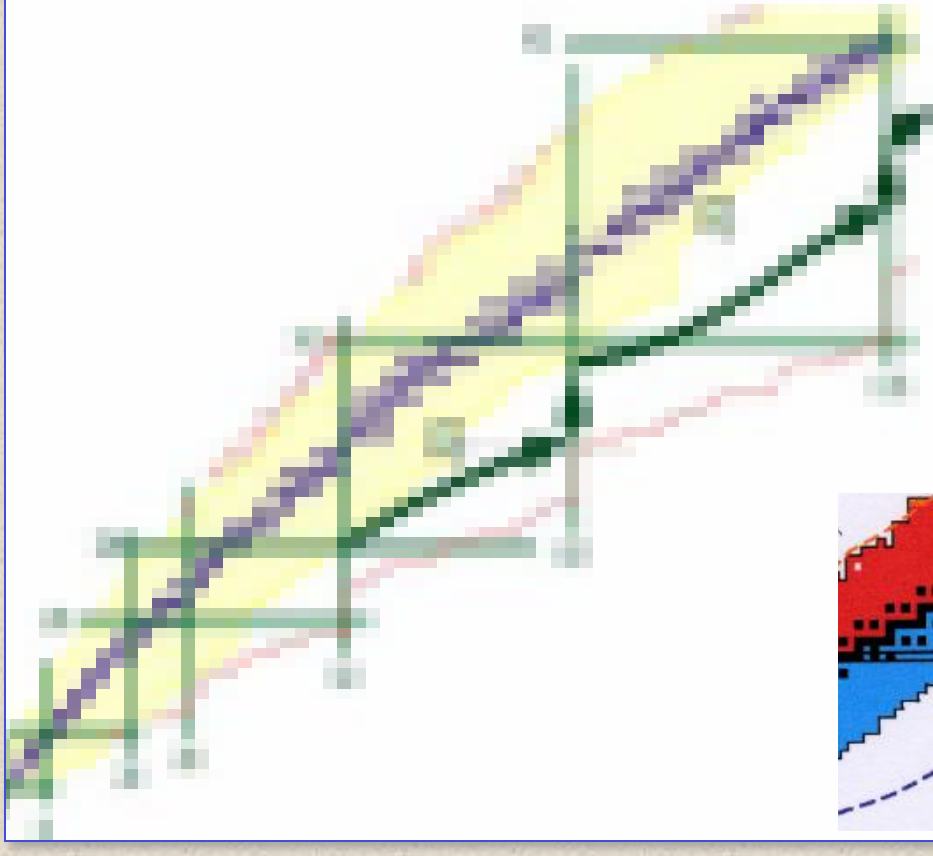
B_{GT}=0.24

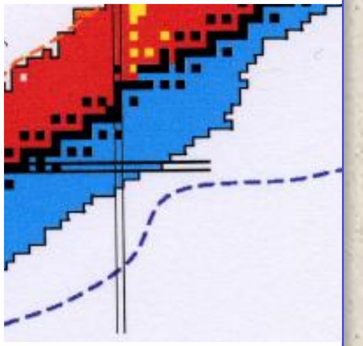
Expected
total BGT=96
units→
We see only a very
small fraction



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





In summary:

It is important to study the decay properties of radioactive nuclei

The first thing to worry about is how to produce them

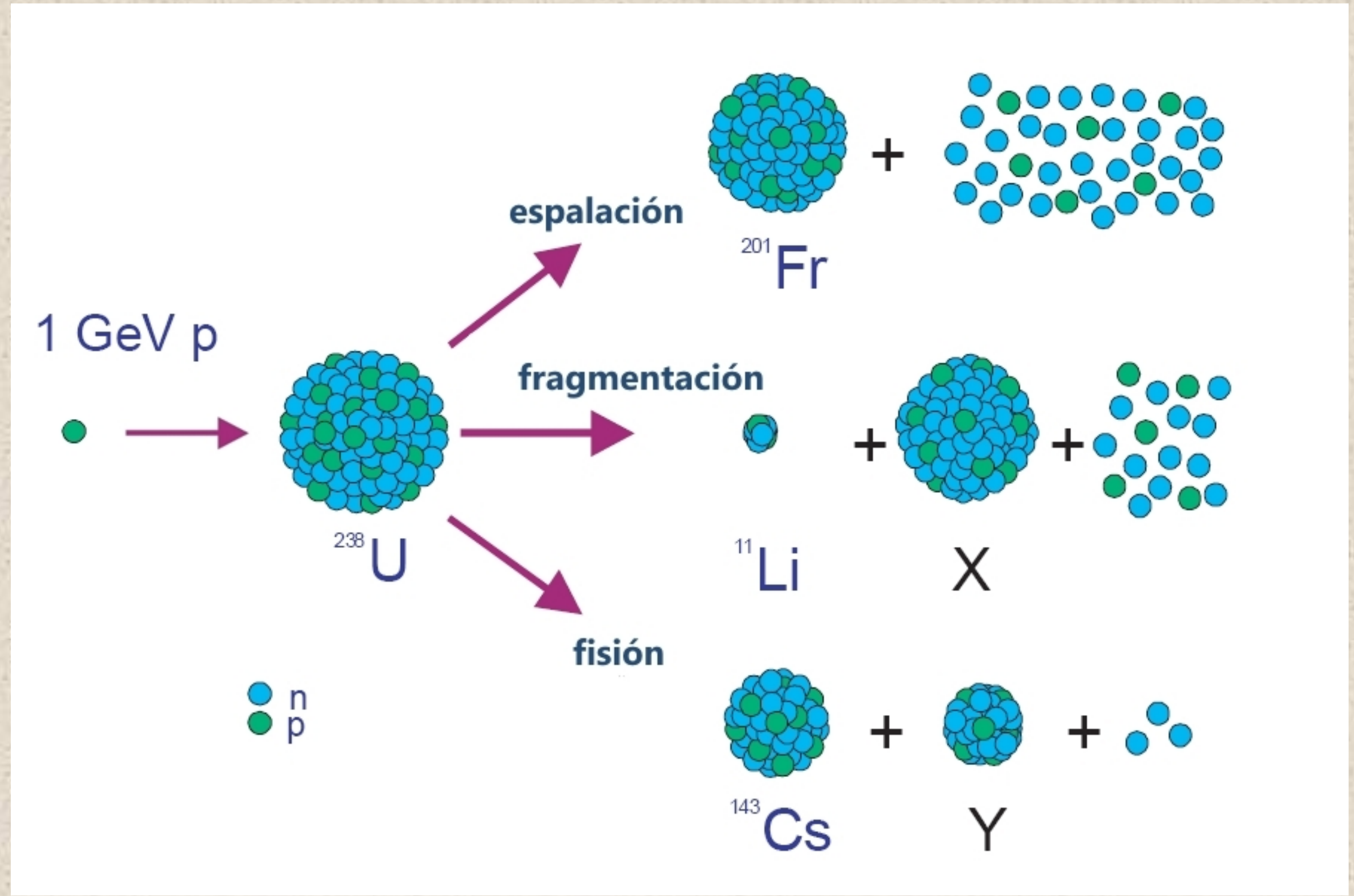
The second thing is to separate them from other radioactive products

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

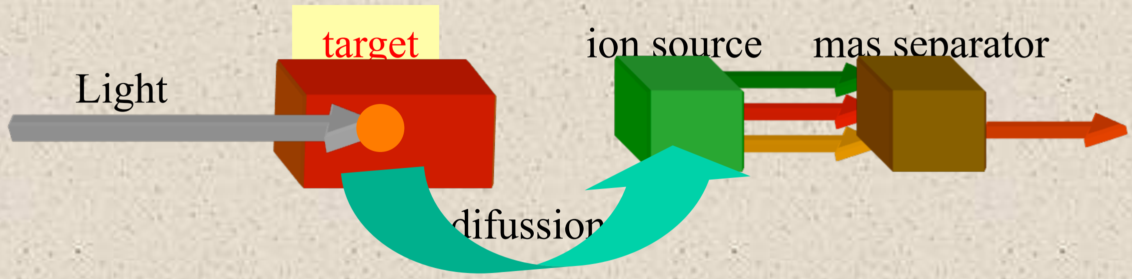
The first thing to worry about is how to produce them:
We need a reaction



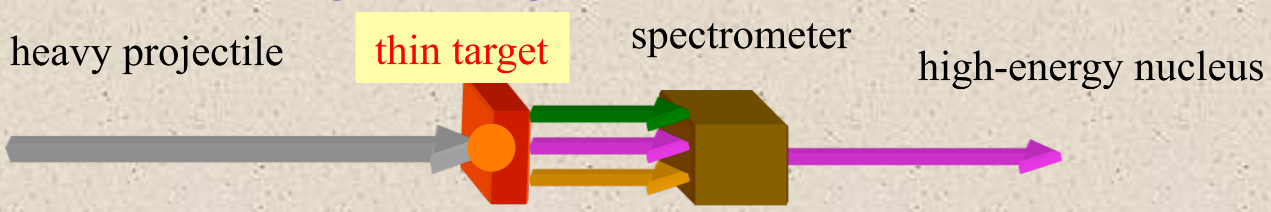
The second thing is to separate them from other radioactive products

Radioactive nuclei production techniques

Isotopic separation on-line (ISOL)

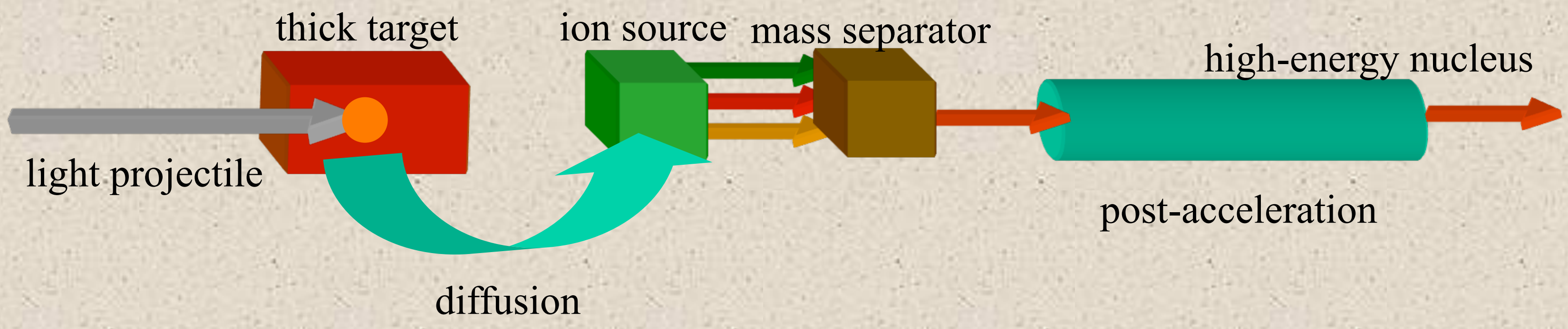


In-flight fragmentation

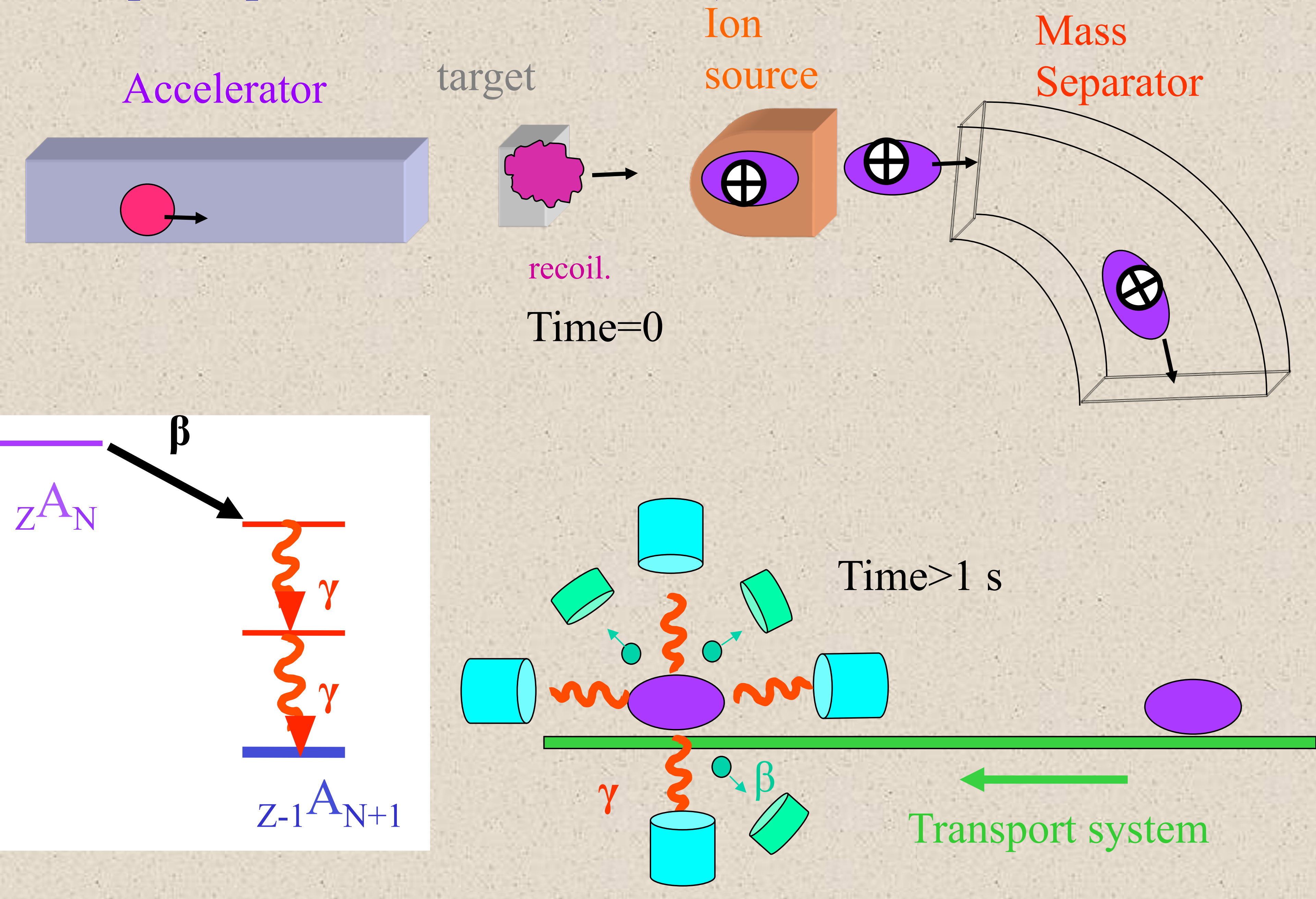


Production techniques Rad Beams: post acceleration

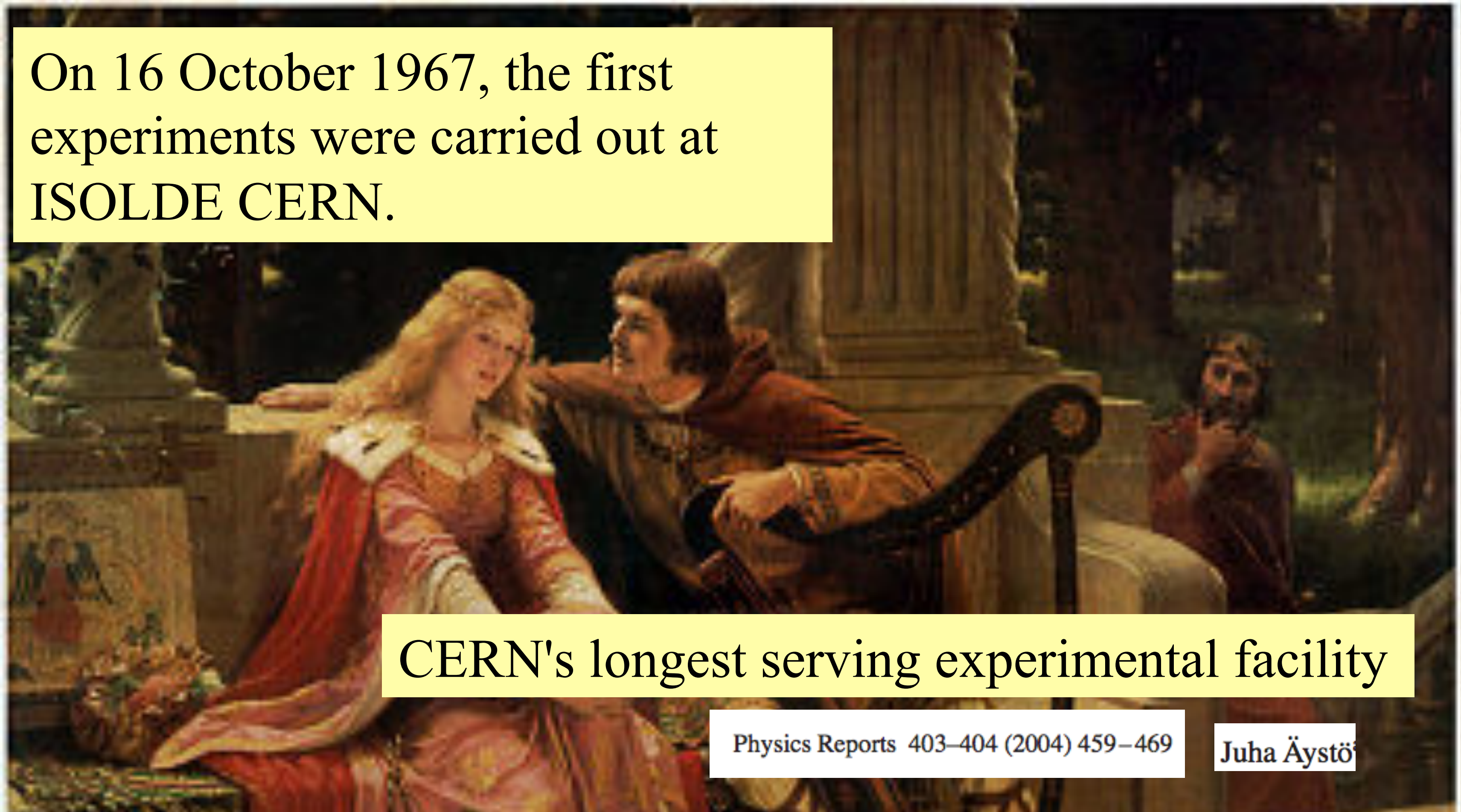
- Isotopic separation on-line (ISOL)



Isotopic separation on-line (ISOL)



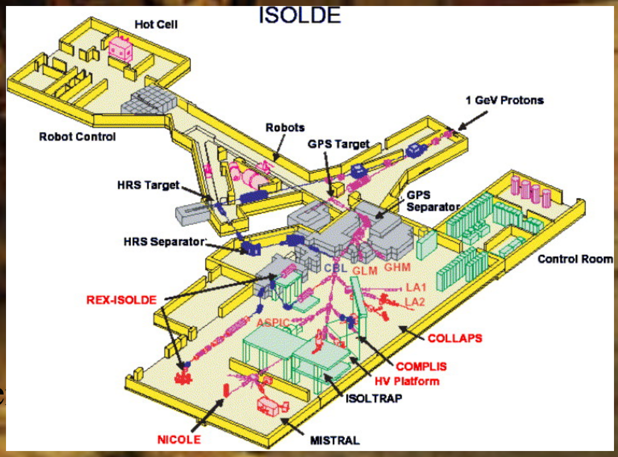
On 16 October 1967, the first experiments were carried out at ISOLDE CERN.

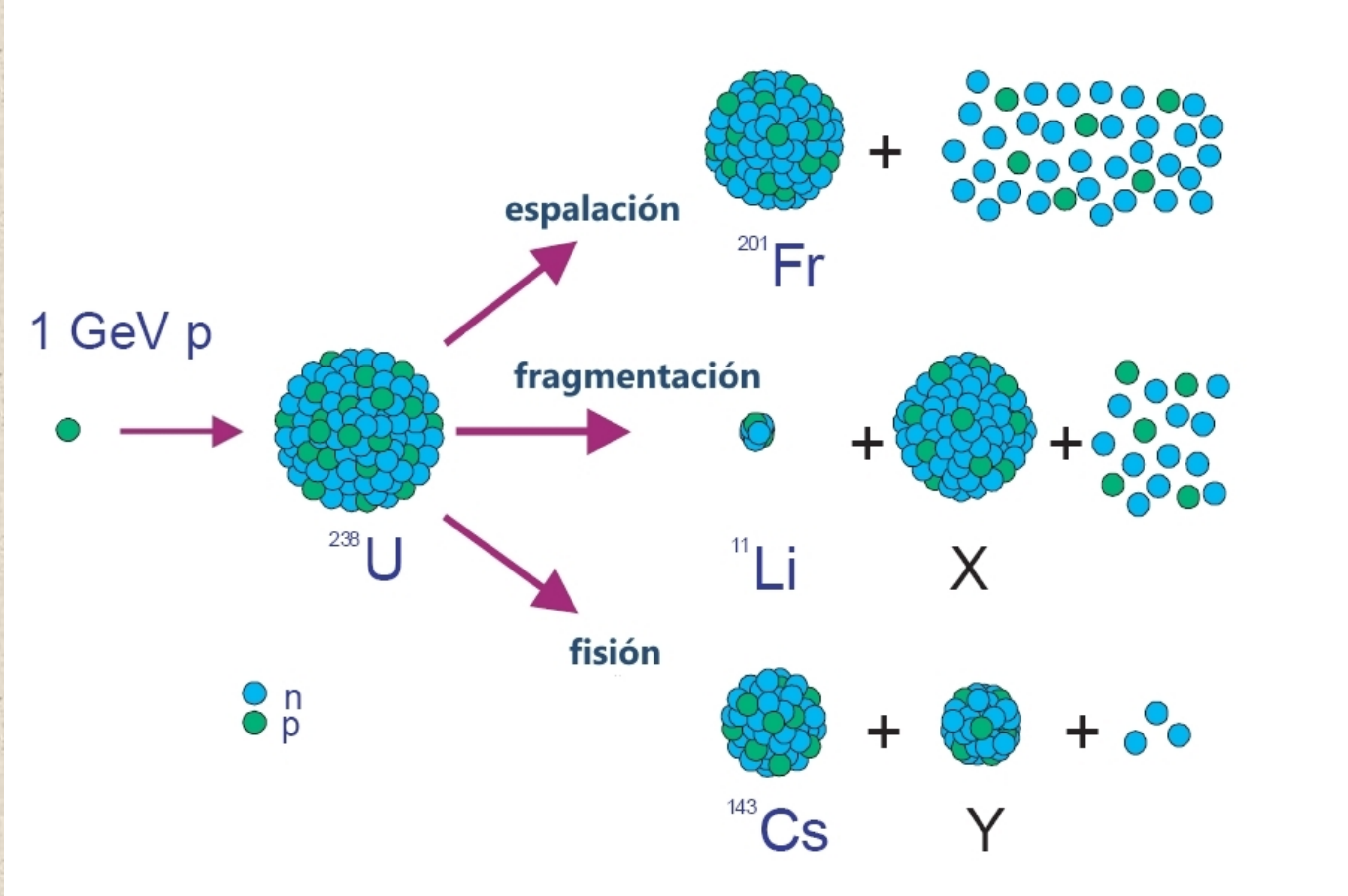


CERN's longest serving experimental facility

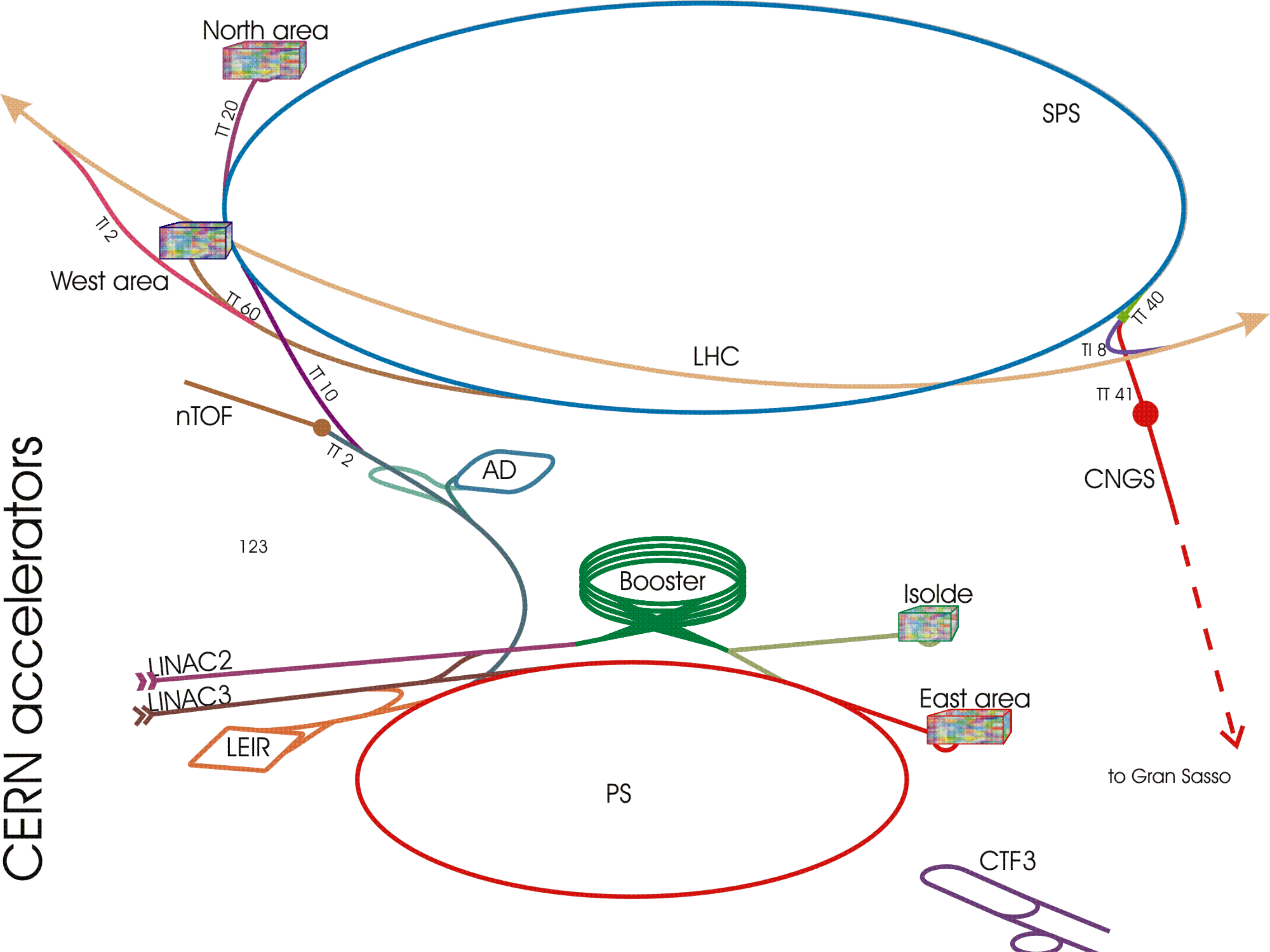
Physics Reports 403–404 (2004) 459–469

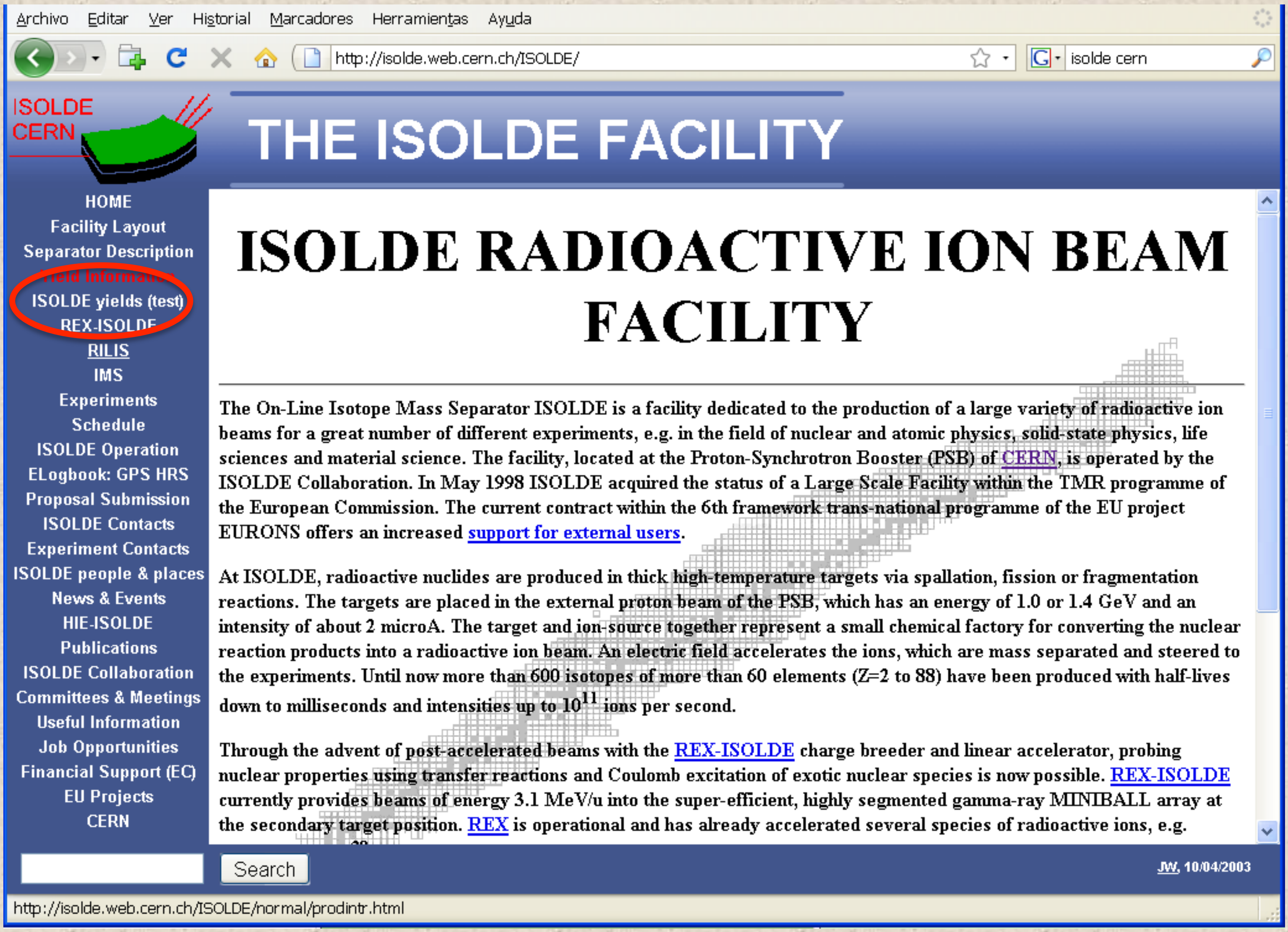
Juha Äystö





☺ thick target (100% of range) => high beam current (upto10^{16} s^{-1})
☹ long extraction and ionization time (ms)
☹ chemistry dependent


CERN accelerators
North area
SPS
TT 20
TI 2
West area
TT 60
TT 10
LHC
TT 40
TI 8
TT 41
nTOF
TT 2
AD
CNGS
123
Booster
Isolde
LINAC2
LINAC3
East area
LEIR
PS
to Gran Sasso
CTF3


Archivo Editar Ver Historial Marcadores Herramientas Ayuda
http://isolde.web.cern.ch/ISOLDE/
isolde cern
ISOLDE
CERN
THE ISOLDE FACILITY
HOME
Facility Layout
Separator Description
ISOLDE yields (test)
REX-ISOLDE
RILIS
IMS
Experiments
Schedule
ISOLDE Operation
ELogbook: GPS HRS
Proposal Submission
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Experiment Contacts
ISOLDE people & places
News & Events
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Publications
ISOLDE Collaboration
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Job Opportunities
Financial Support (EC)
EU Projects
CERN
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
http://isolde.web.cern.ch/ISOLDE/normal/prodintr.html

39.7 s

0^+ 0

$^{132}_{50}Sn$

$Q_{\beta-}=3300$

0.87%

99%

<0.17%

1842.22
1739.10

Archivo Editar Ver Historial Marcadores Herramientas Ayuda

http://isolde.web.cern.ch/ISOLDE/ isolde cern

ISOLDE CERN

THE ISOLDE FACILITY

Excelente Producción!!

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

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

Tin ISOLDE SC-Yields

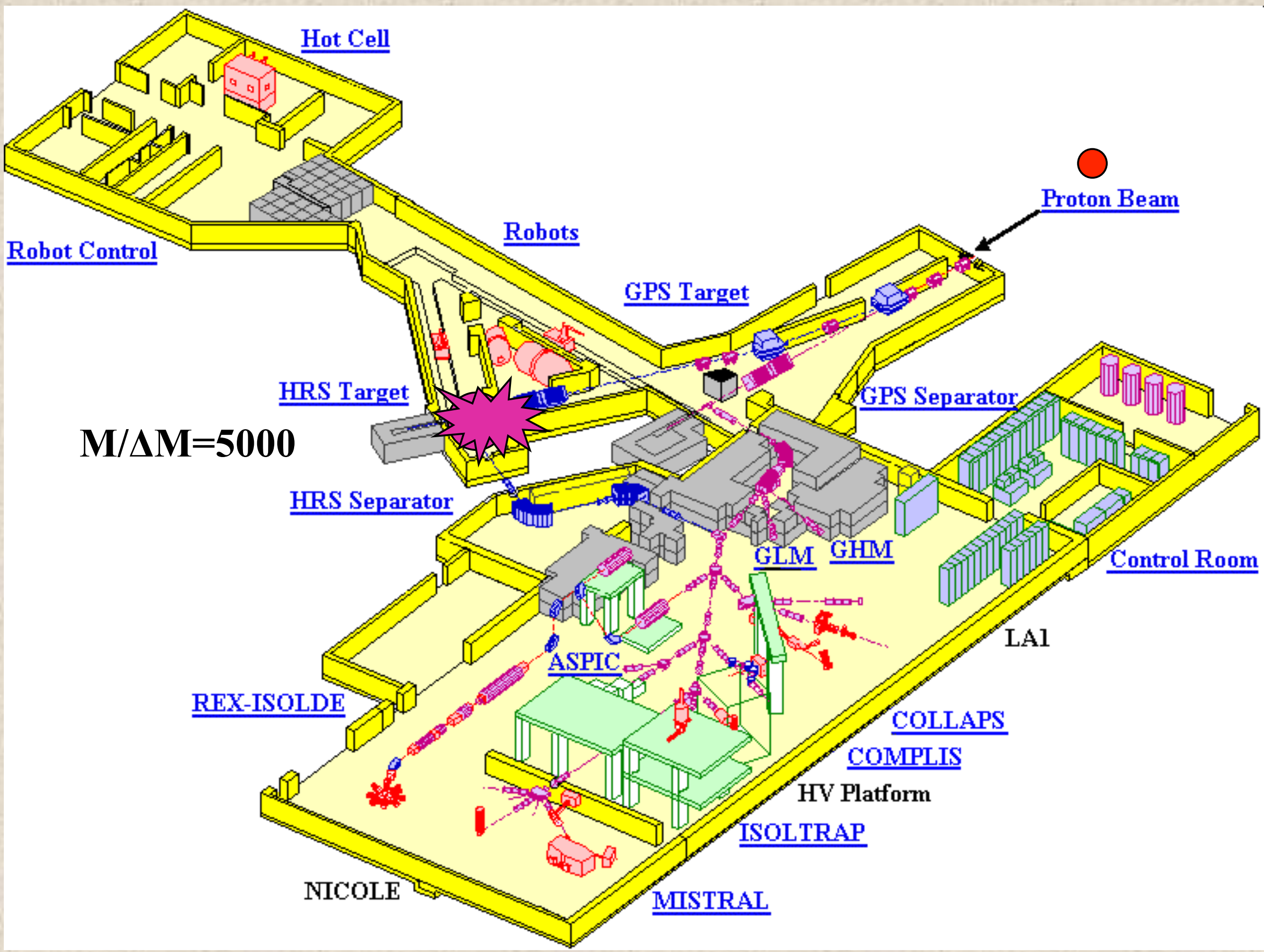
Element	Yield (atoms/uC)	Nucleus	Half Life	Target	Target density (g/cm2)	Ion Source
Sn	5.60E+04	108g	10.3 min	Ta Metal foil	122	Hot plasma
Sn	5.00E+04	108g	10.3 min	Ta Metal foil	122	Hot plasma
Sn	1.50E+05	109g	18 min	Ta Metal foil	122	Hot plasma
Sn	1.60E+05	111g	35.3 min	Ta Metal foil	122	Hot plasma
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

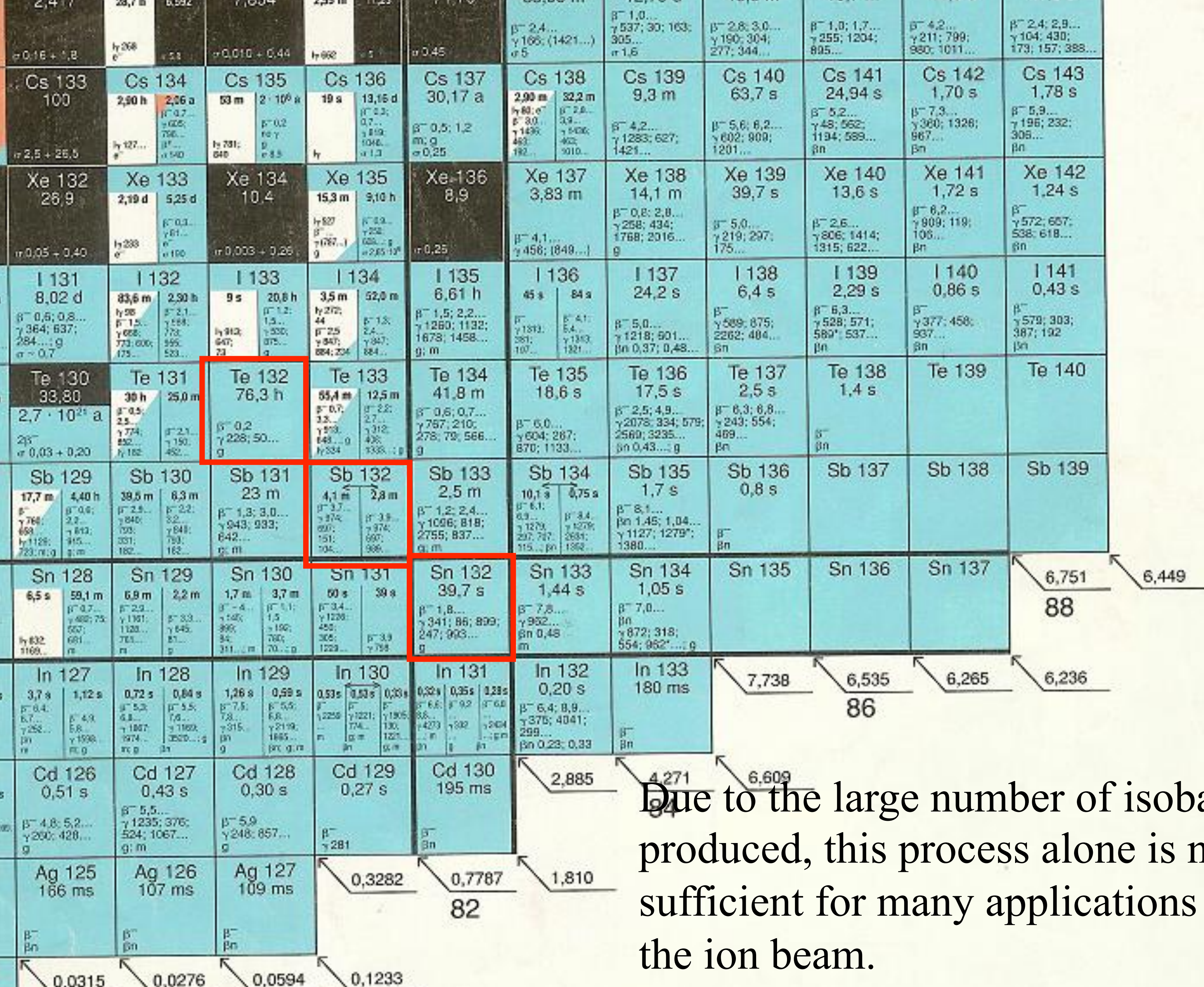
Search

JW, 10/04/2003

Sn	3.00E+07	132g	39.7	U Carbide	9.7g U /cm2	Hot plasma at 1950°C

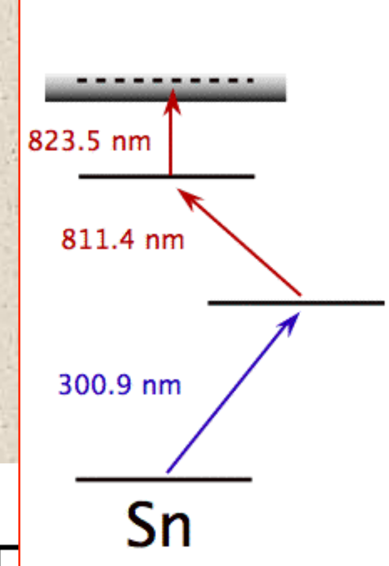
Reaction: 1.4 GeV protons on U 9.7 g/cm^2

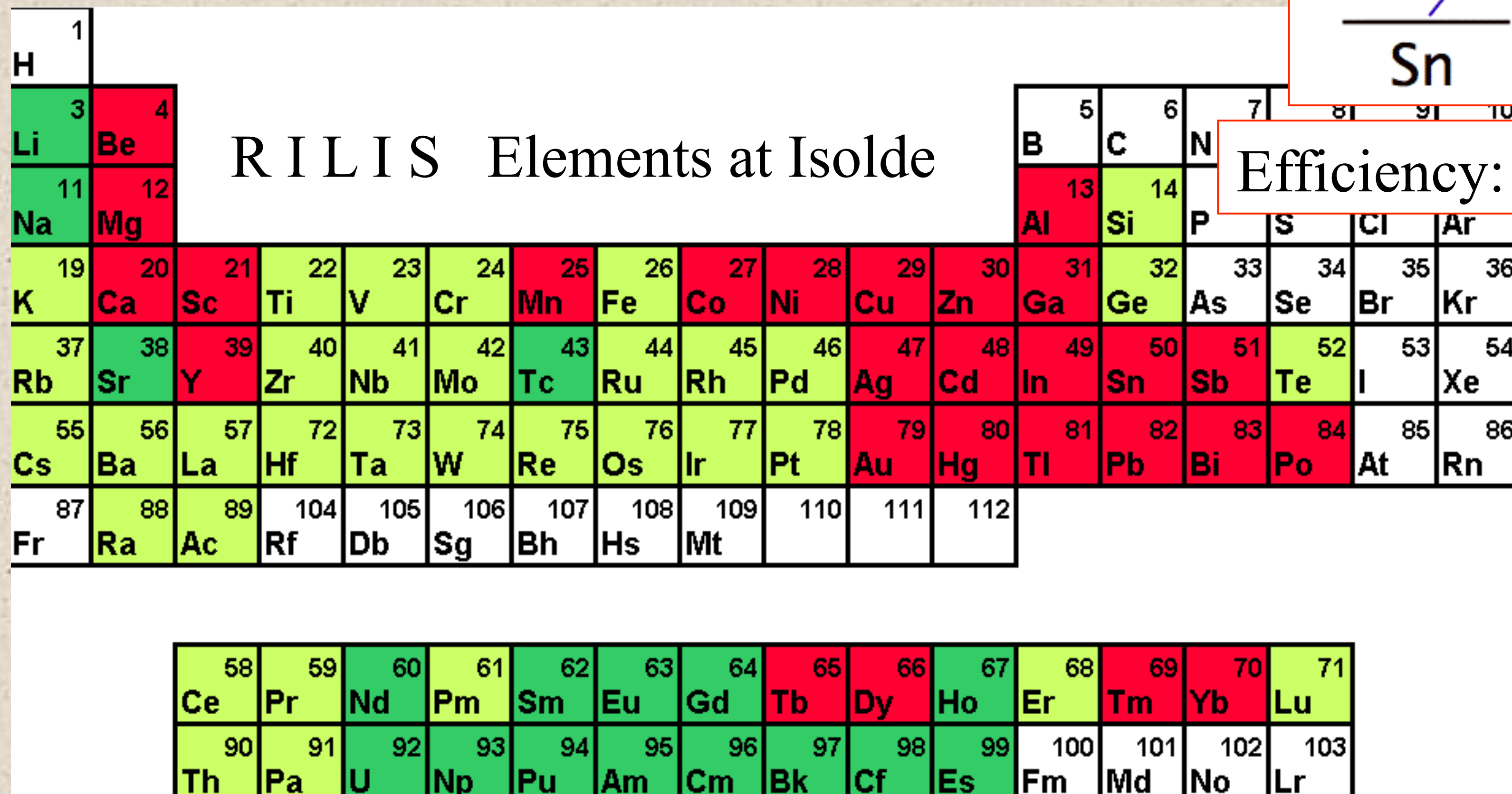




Due to the large number of isobars produced, this process alone is not sufficient for many applications of the ion beam.

Cómo obtener una fuente limpia de 132Sn?
Ionizar el átomo de interés, en este caso
Sn, de forma selectiva

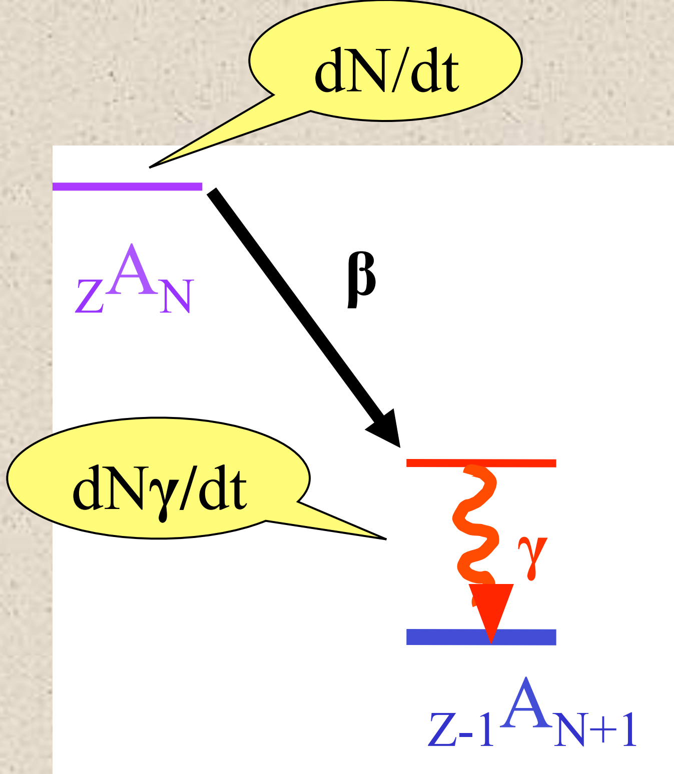




Efficiency: ≤9%

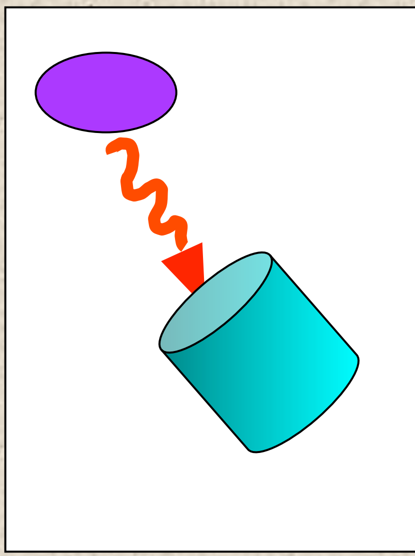
$$\frac{1}{ft} = \frac{I_\beta(E)}{f(Q_\beta - E, Z)T_{1/2}}$$

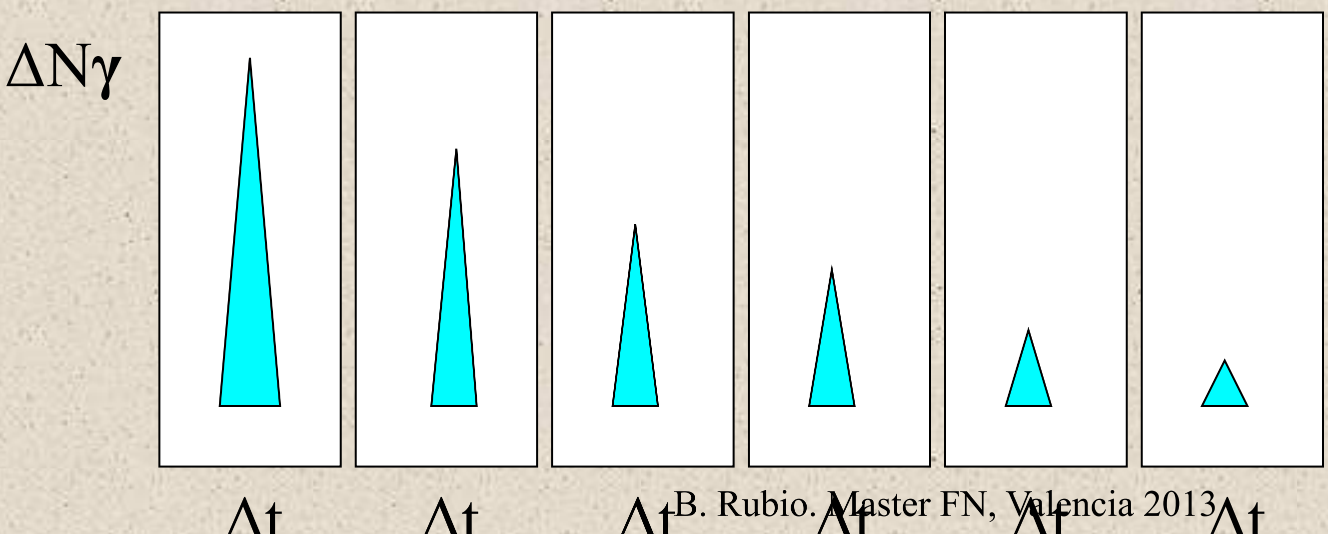
Half life measurement

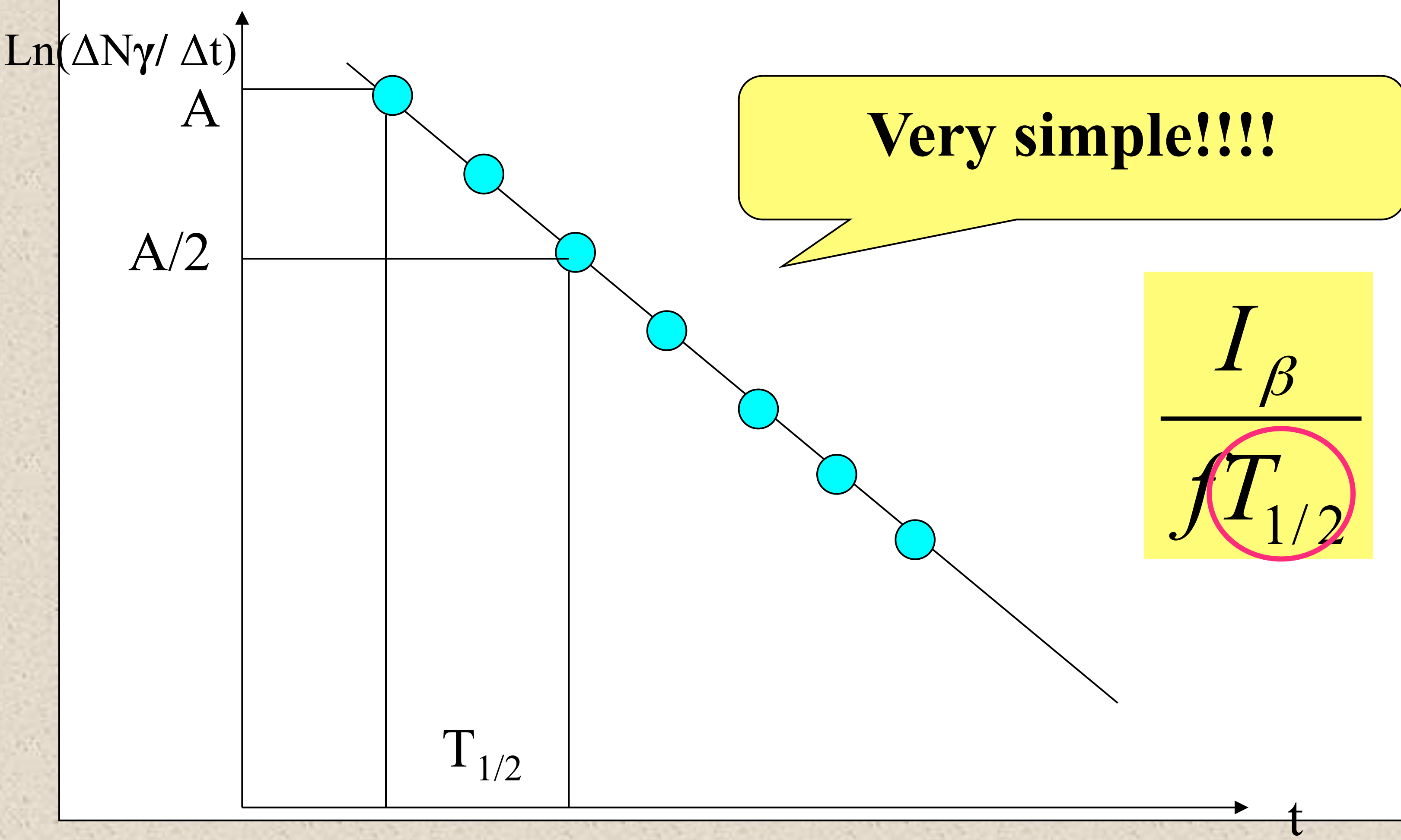


$$N(t) = N_0 e^{-\lambda t}$$

$$\lambda = \frac{1}{\tau} = \frac{Ln2}{T_{1/2}}$$

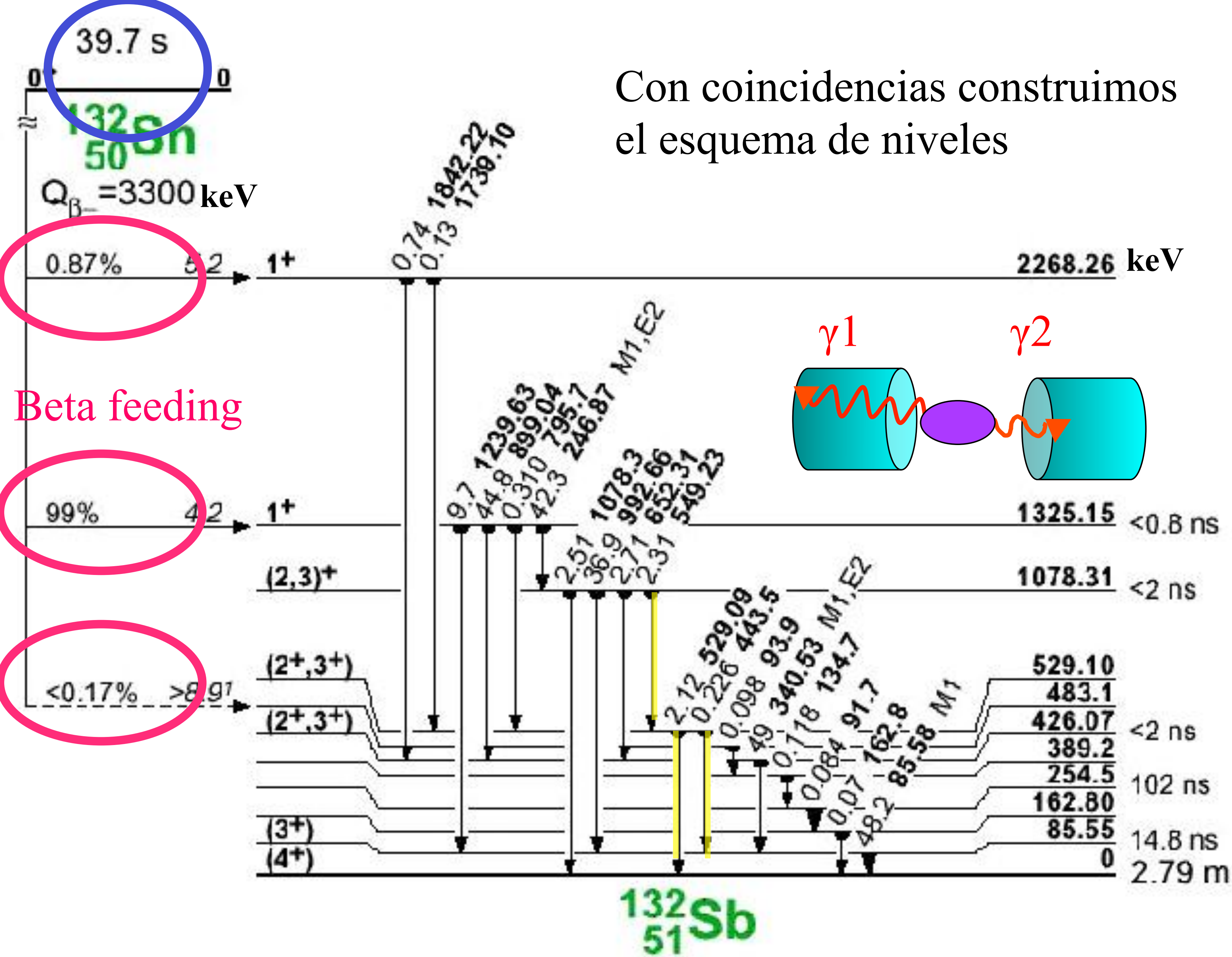






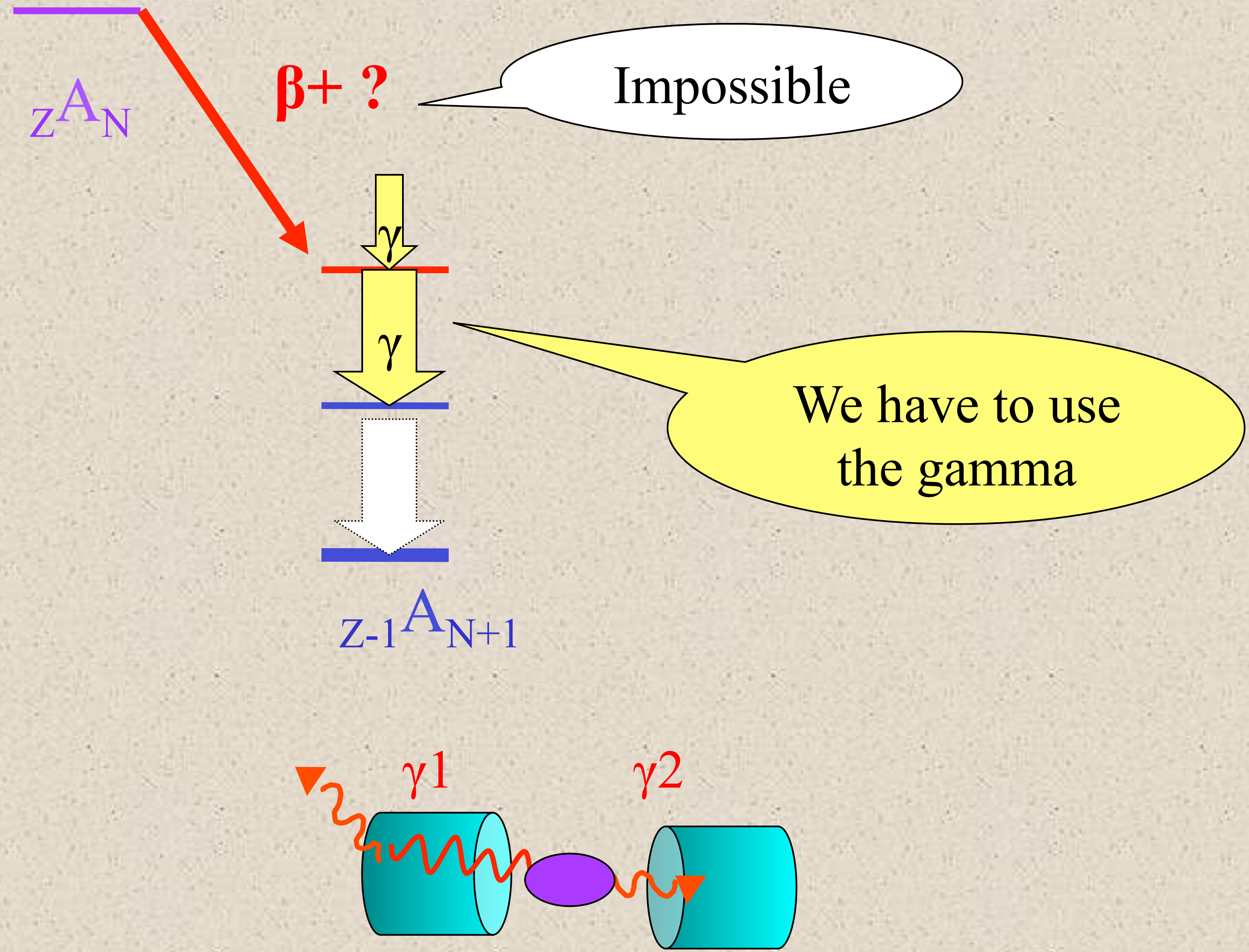
$$\frac{I_{\beta}}{f T_{1/2}}$$

Con coincidencias construimos el esquema de niveles

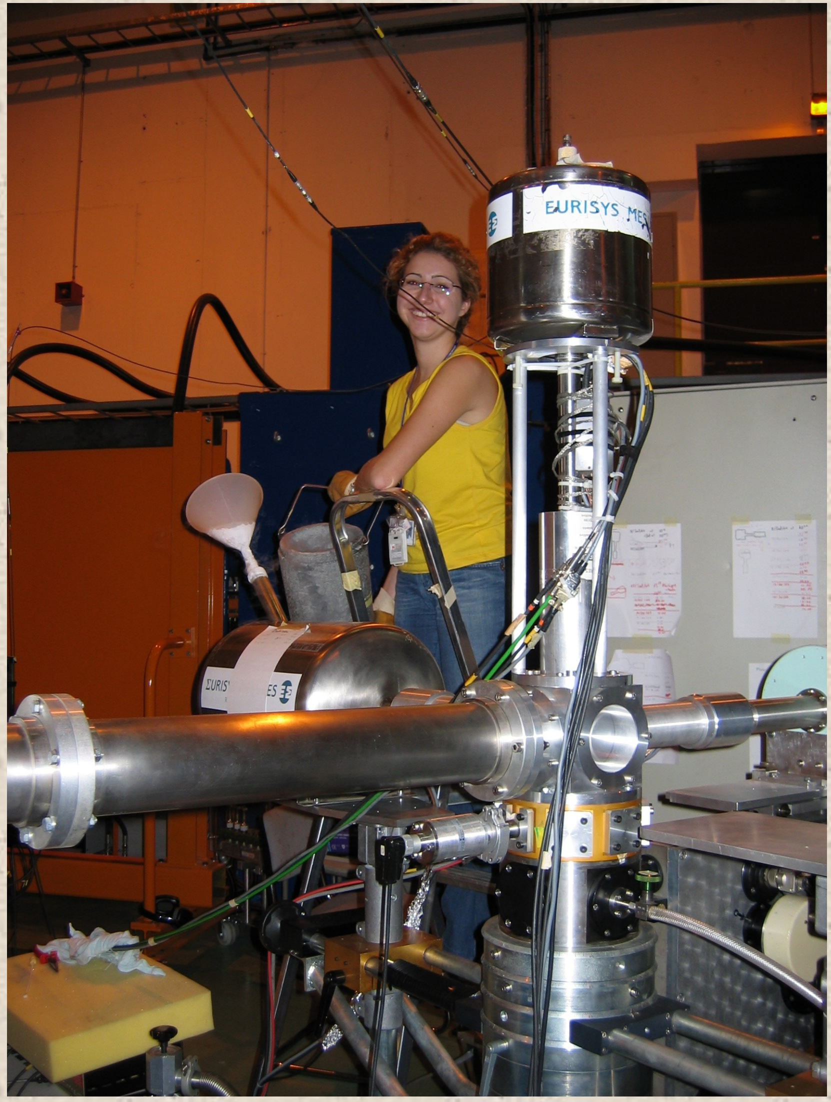


Beta-feeding

Iγ(in)- Iγ(out)



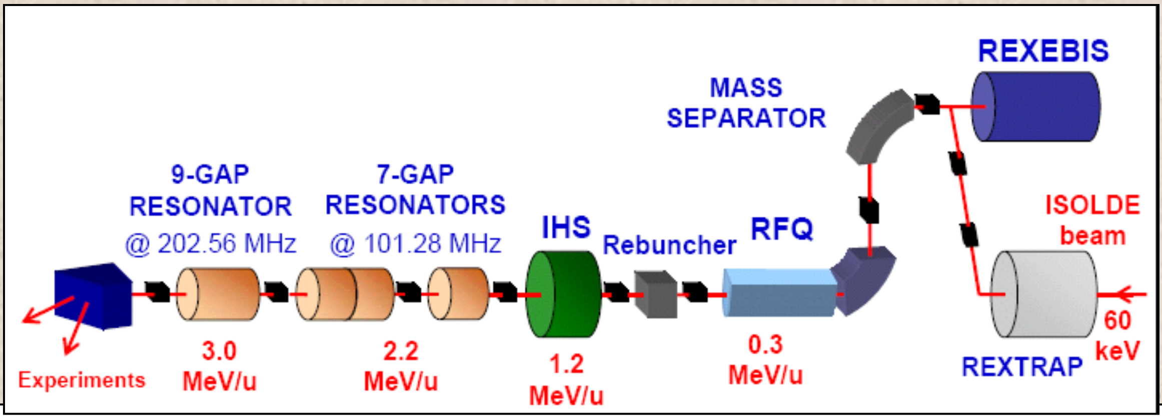
$$\frac{I_\beta}{fT_{1/2}}$$


EURISYS MES

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

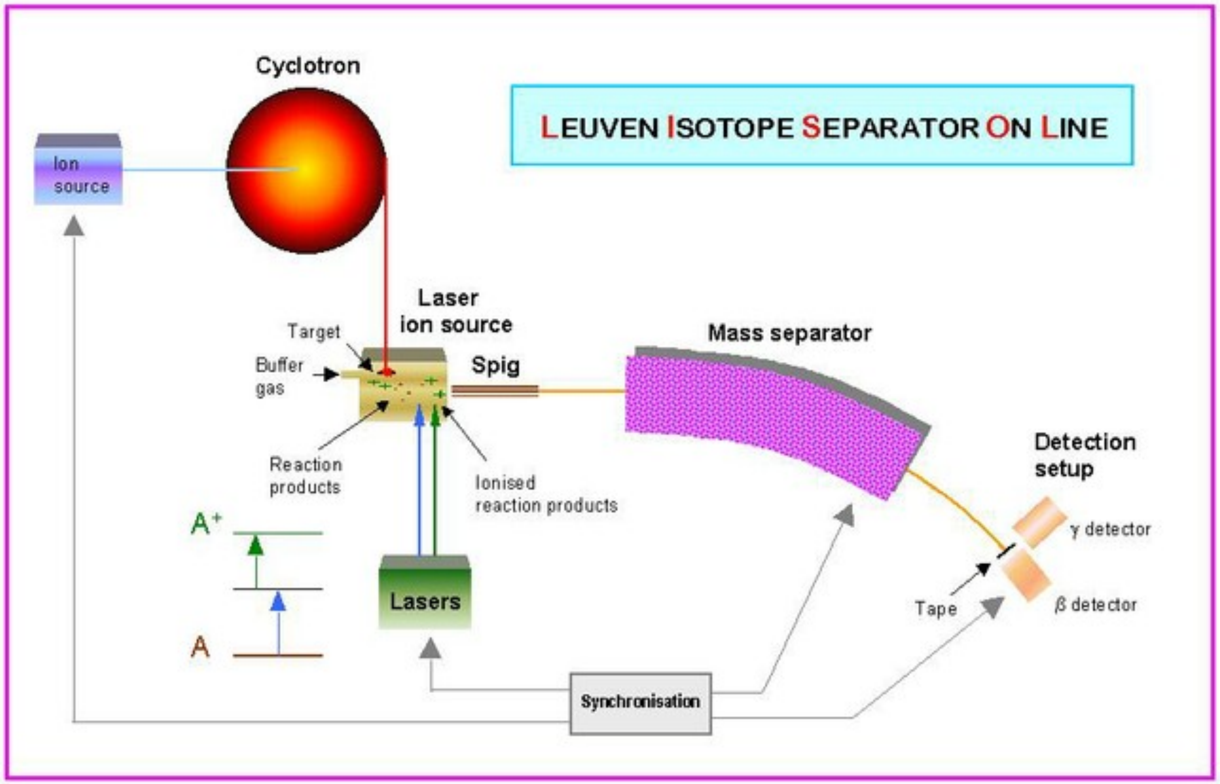
The measure of the mass of a nucleus deserves a separate talk

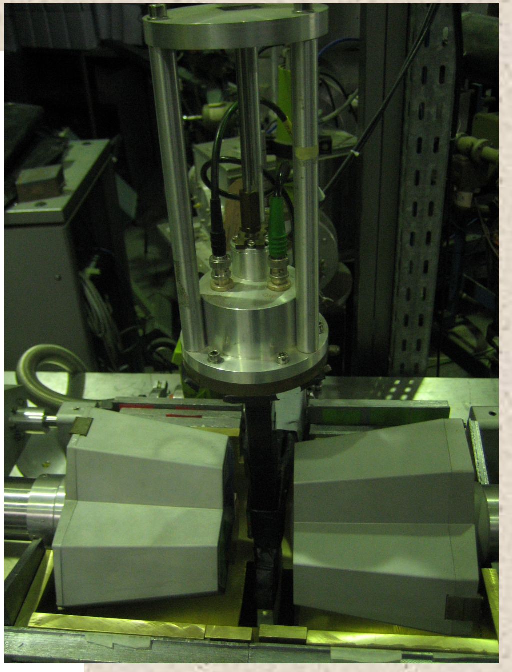
REX Isolde post-accelerator (Present)



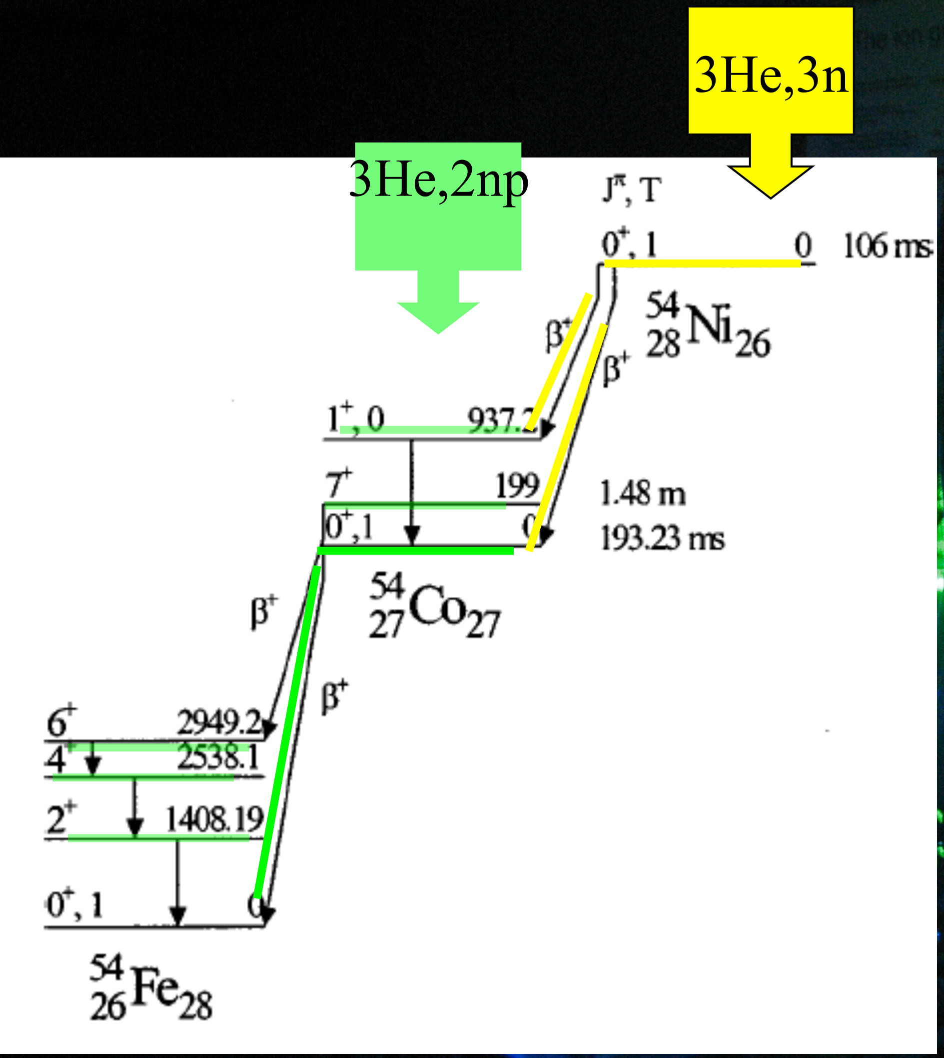
- REX has accelerated 43 different RIB
- Upgrade to 10 MeV/u is under construction: HIE-Isolde

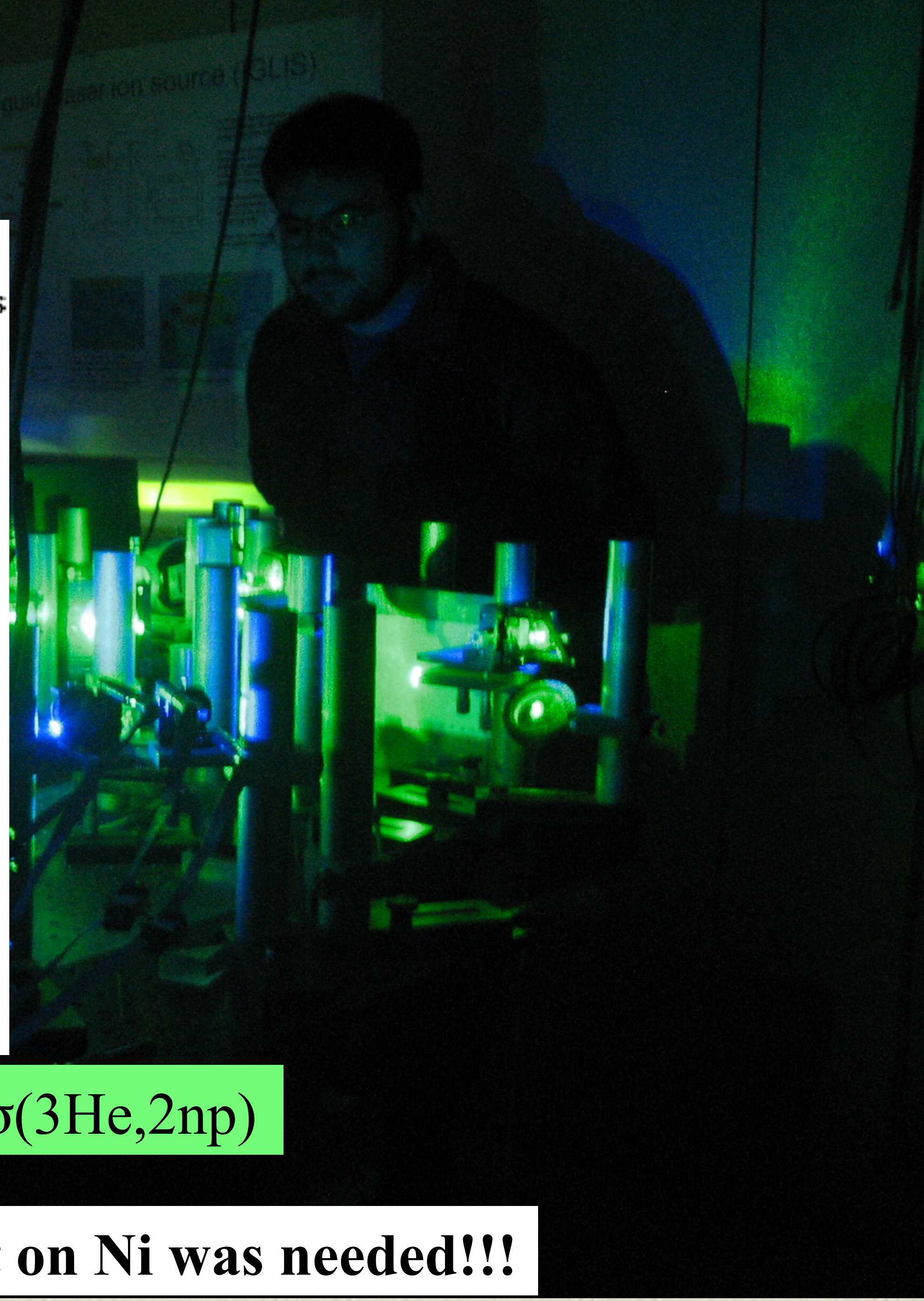
One can also use a simpler reaction, for instance, fusion evaporation





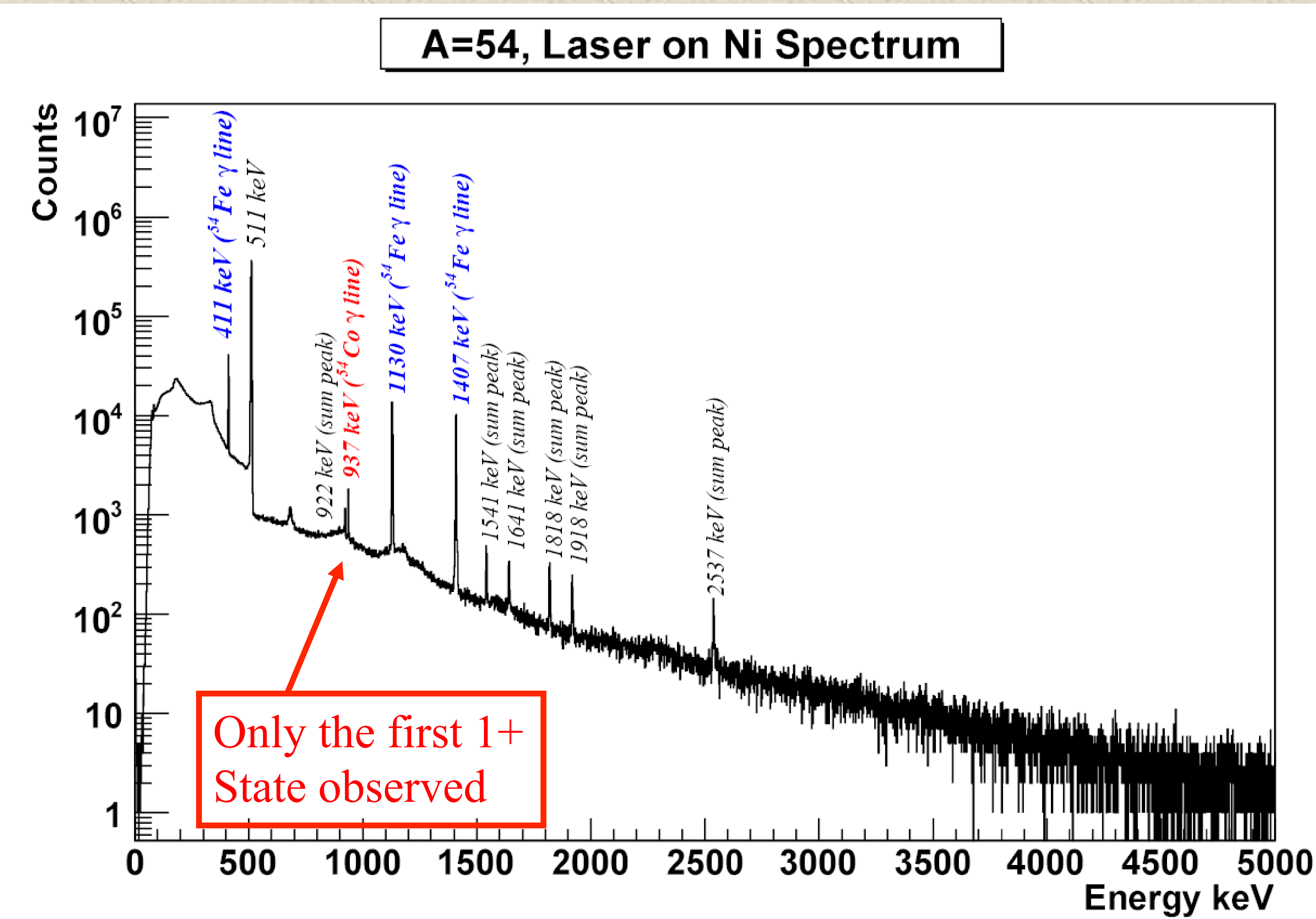
http://fys.kuleuven.be/iks/ns/lisol-leuven-isotope-separator-on-line





σ(3He,3n) << σ(3He,2np)

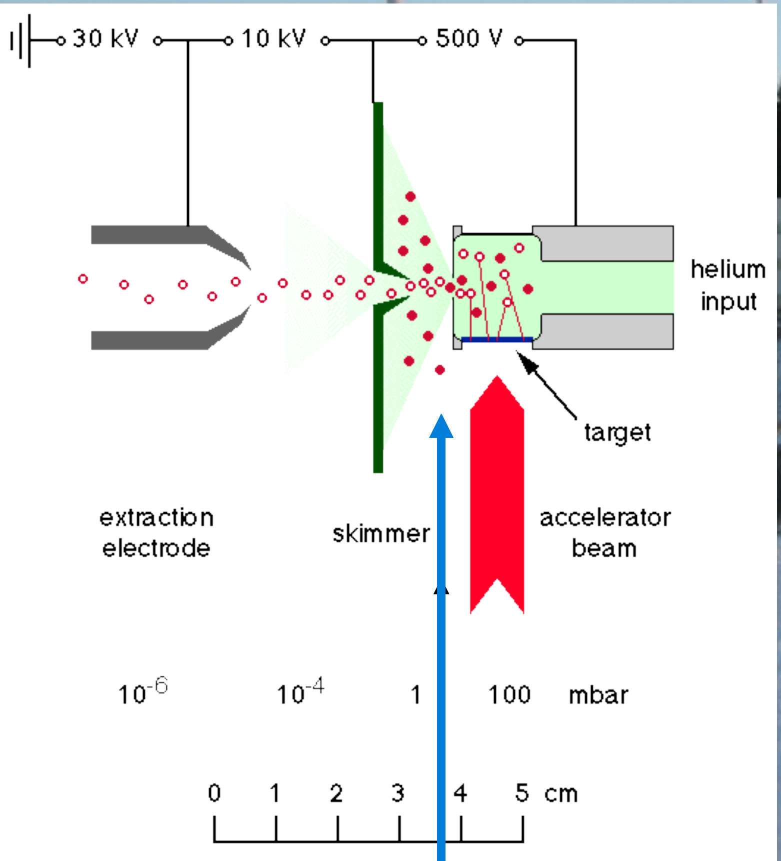
Laser ion souce resonant on Ni was needed!!!


A=54, Laser on Ni Spectrum
Counts
Energy keV
411 keV (54Fe γ line)
511 keV
922 keV (sum peak)
937 keV (54Co γ line)
1130 keV (54Fe γ line)
1407 keV (54Fe γ line)
1541 keV (sum peak)
1641 keV (sum peak)
1818 keV (sum peak)
1918 keV (sum peak)
2537 keV (sum peak)
Only the first 1+ State observed

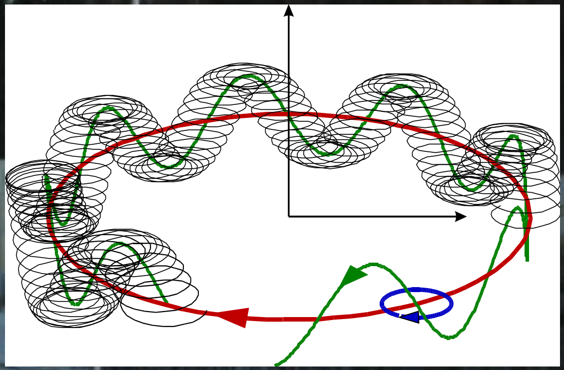
Almost all the ISOL separators suffer from one limitation:
They cannot produce refractory elements

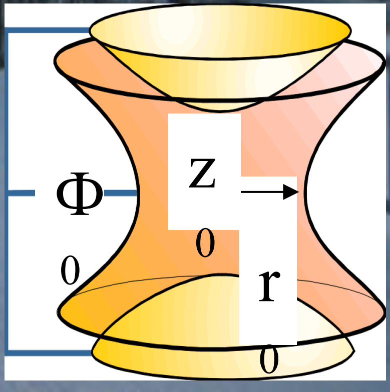
Ion Guide Isotope Separator On-Line (IGISOL) facility,

The ion gas guide
technique
mass separation



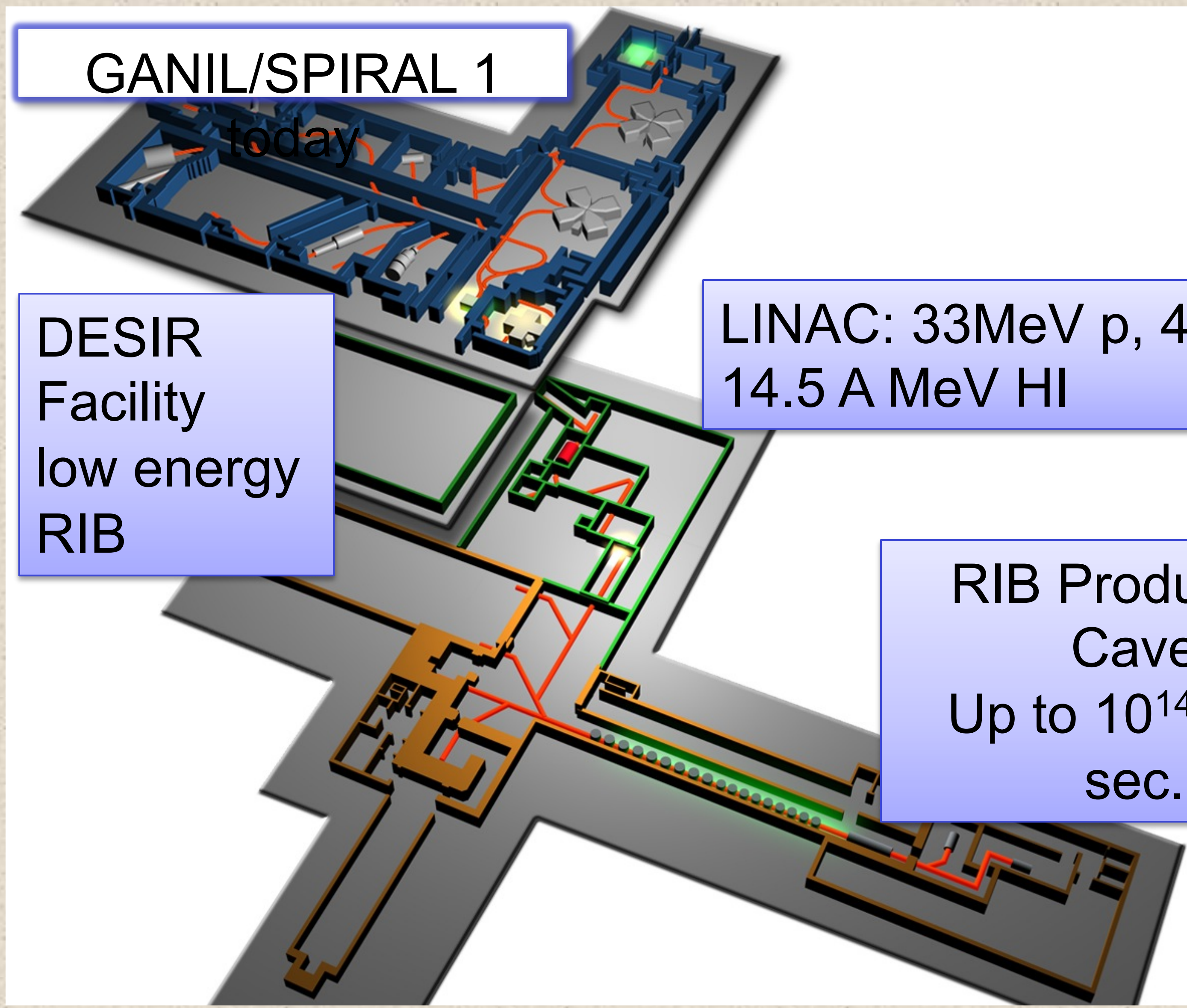
Isobar separation
using a trap
JYFLTRAP



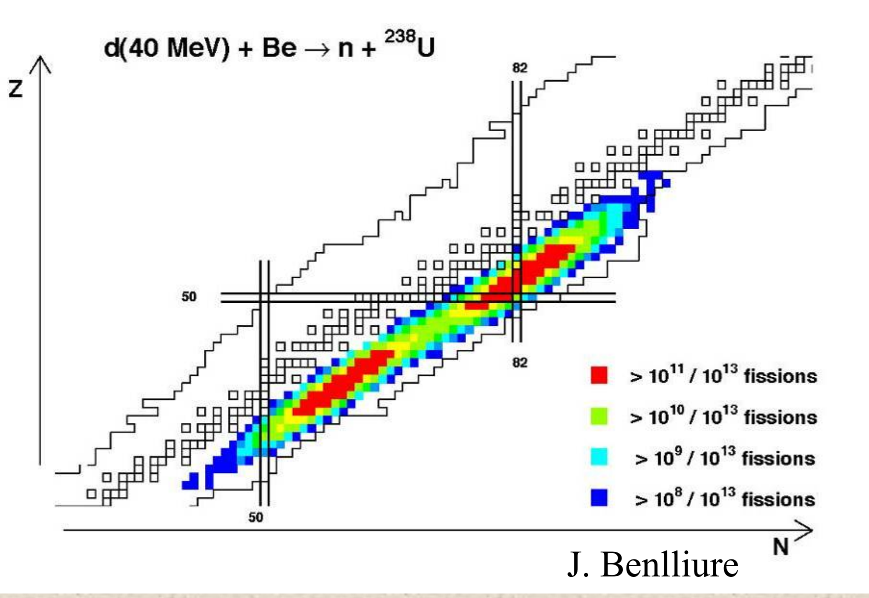


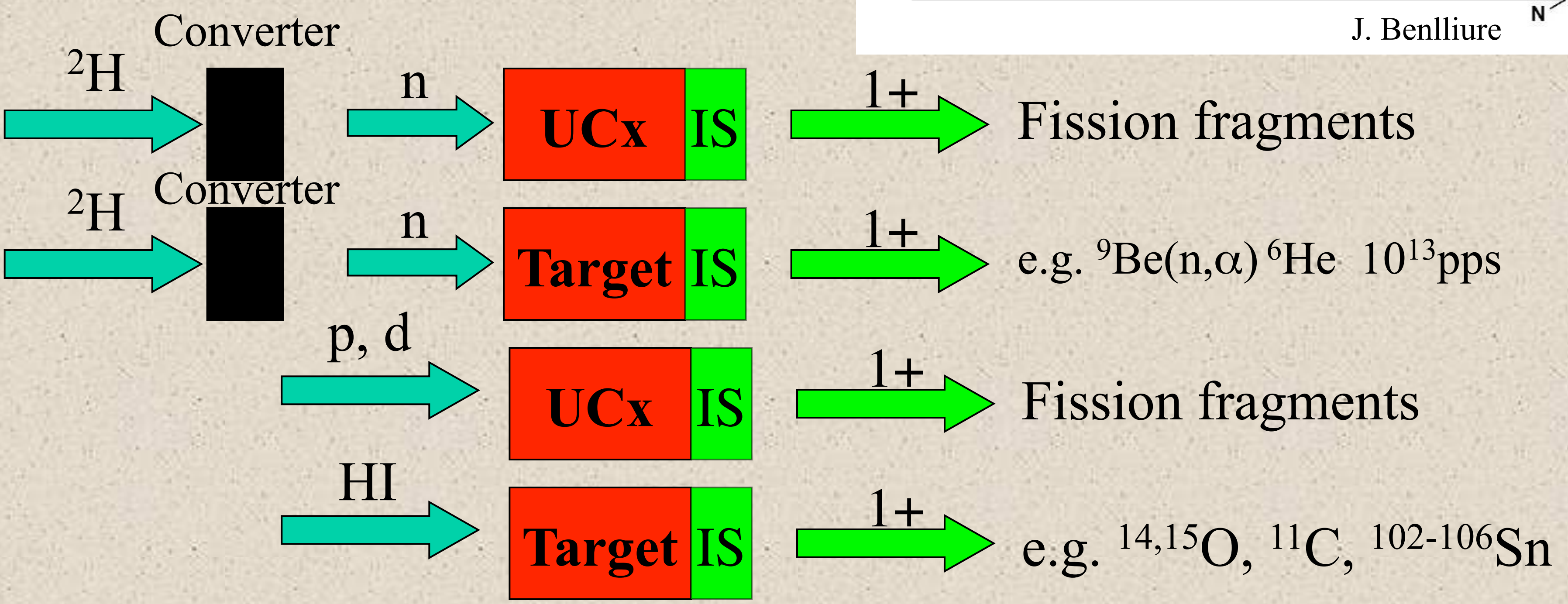
Future ISOL facilities

GANIL/SPIRAL1/SPIRAL2 facility layout



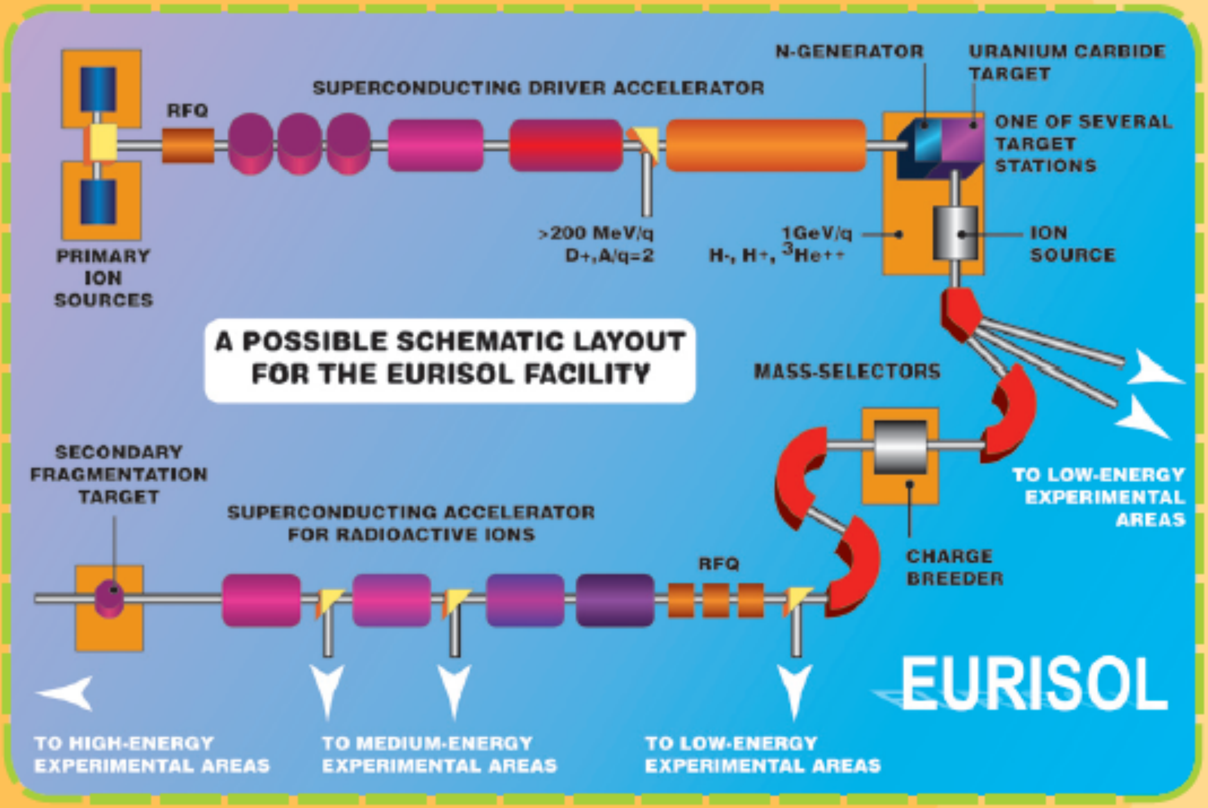
ISOL Rare Isotope Beams at SPIRAL 2





Far in the Future ISOL facility

Furthering target and accelerator technology



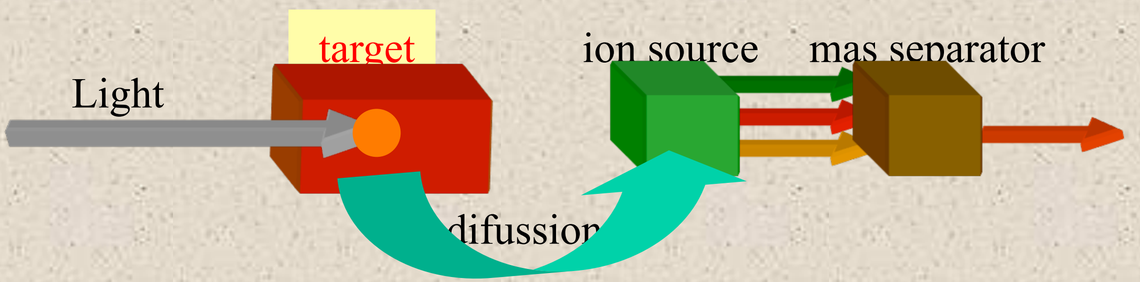
A 4-year Design Study began in 2005 in order to work on the technologically challenging aspects of the project, the instrumentation and the radiation safety issue. Synergy with other projects is being examined, including a feasibility study for the new 'beta-beam' neutrino proposal, forming an integral 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, ^{3}He 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)



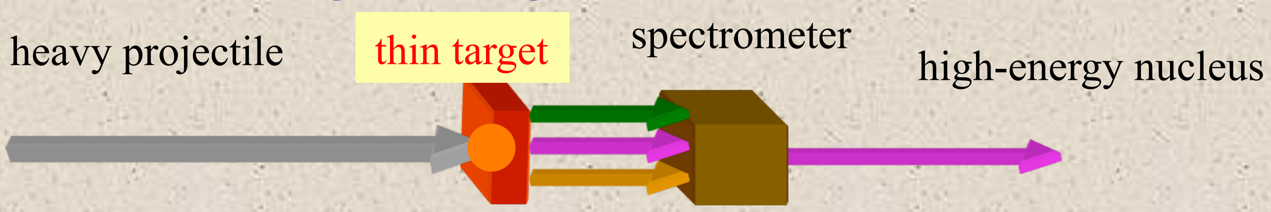
☺We can use thick targets (100% of range) =>

☺and high beam current (upto10^{16} s^{-1})

☹ long extraction and ionization time (ms)

☹ chemistry dependent

In-flight fragmentation

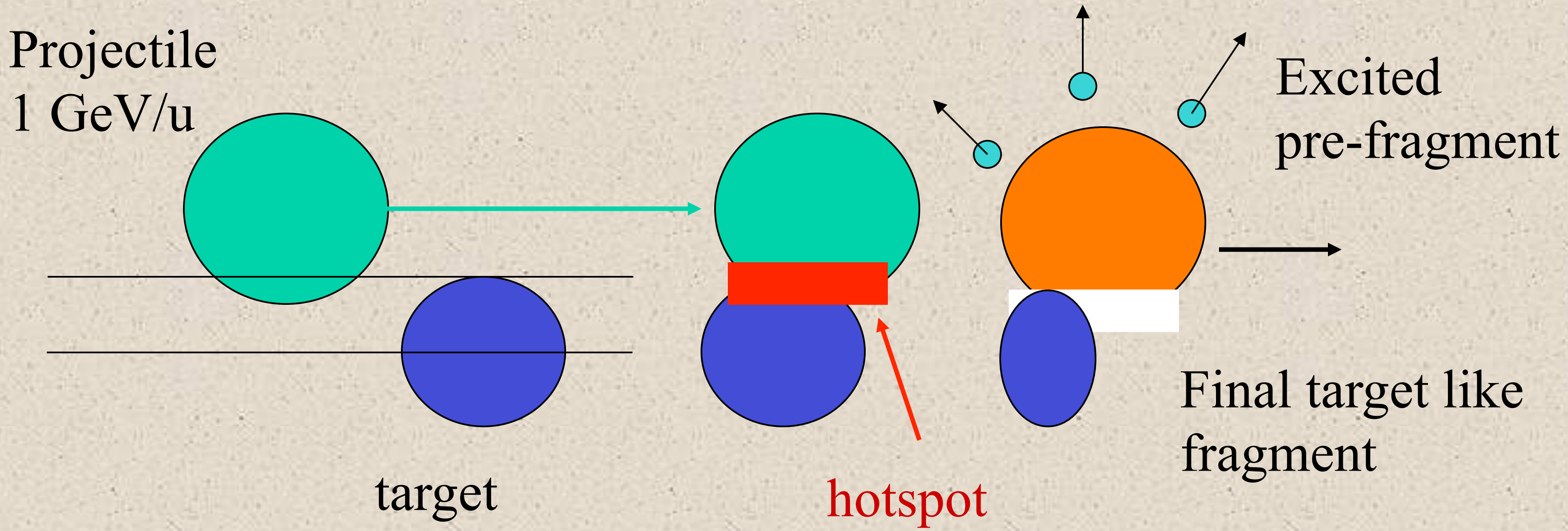


☺ short separation+identification time (100 ns)

☹ thinner targets (10% of range) =>lower beam currents (upto 10^{12} s^{-1})

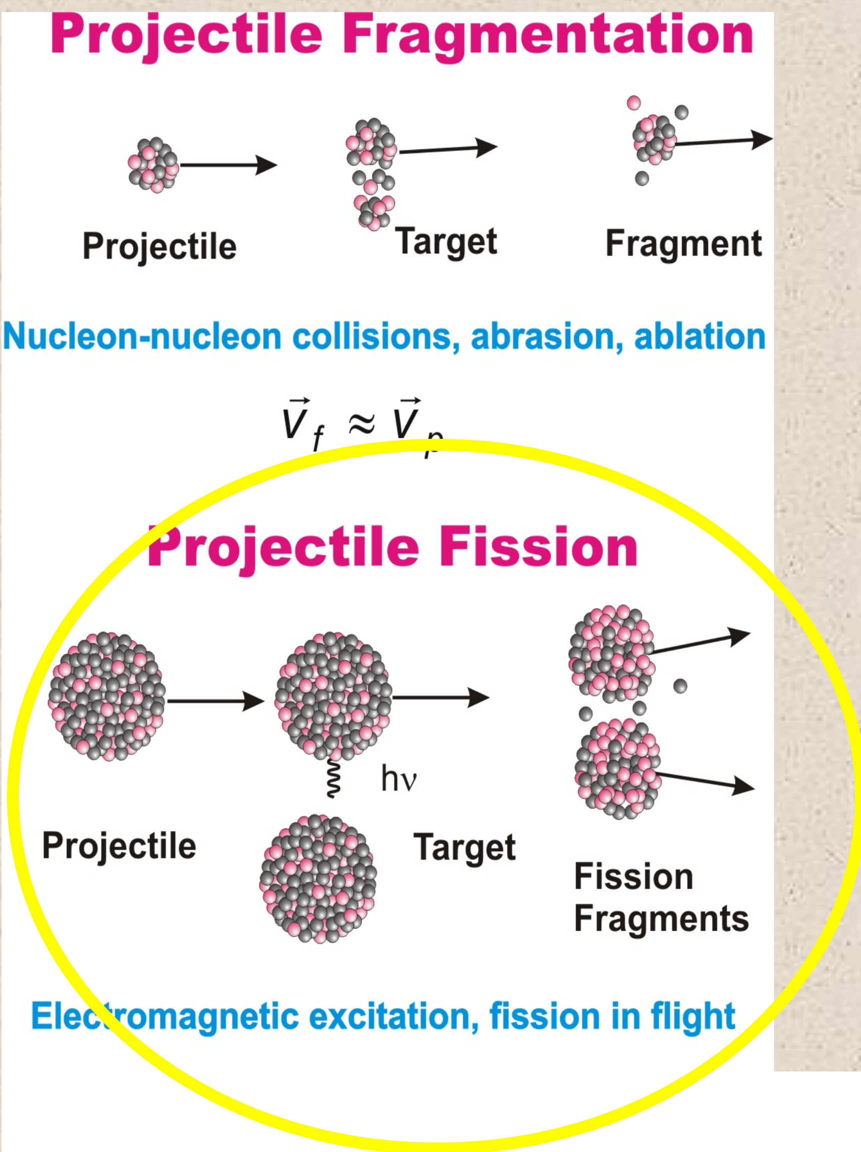
☺ chemistry independent

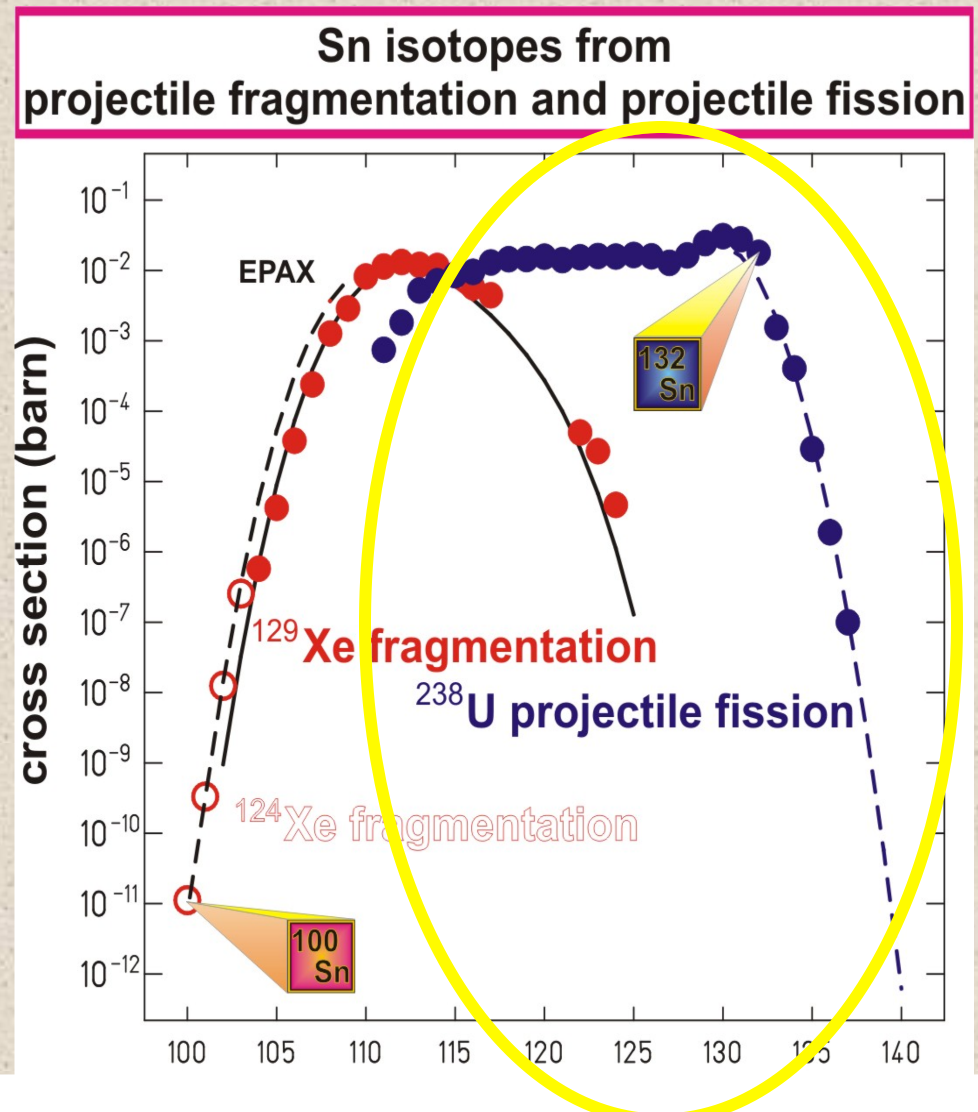
Projectile Fragmentation Reactions



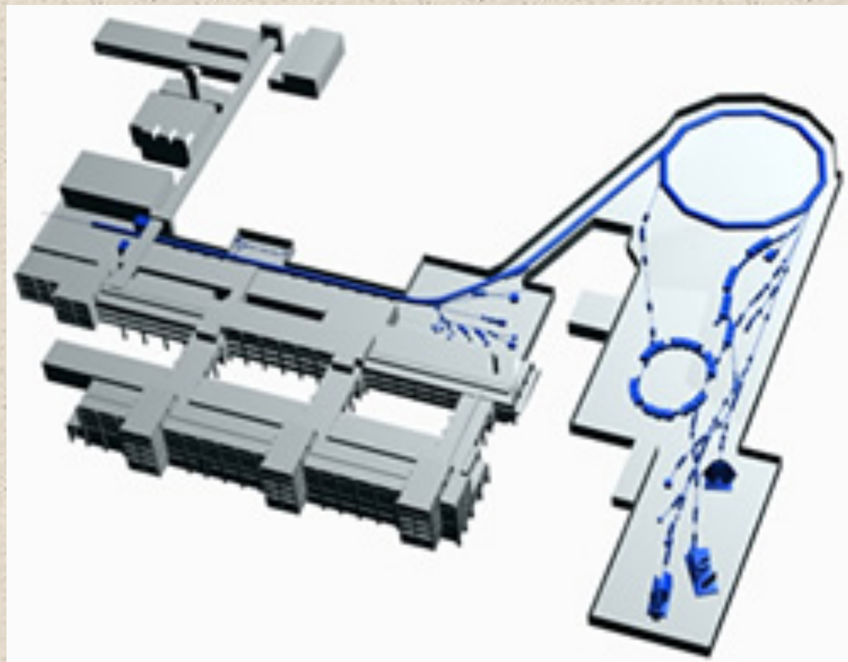
Energy (velocity) of beam > Fermi velocity inside nucleus ~30 MeV/u
Can ‘shear off’ different combinations of protons and neutrons.
Large variety of exotic nuclear species created, all at forward angles with ~beam velocity.

Proyectile Fission





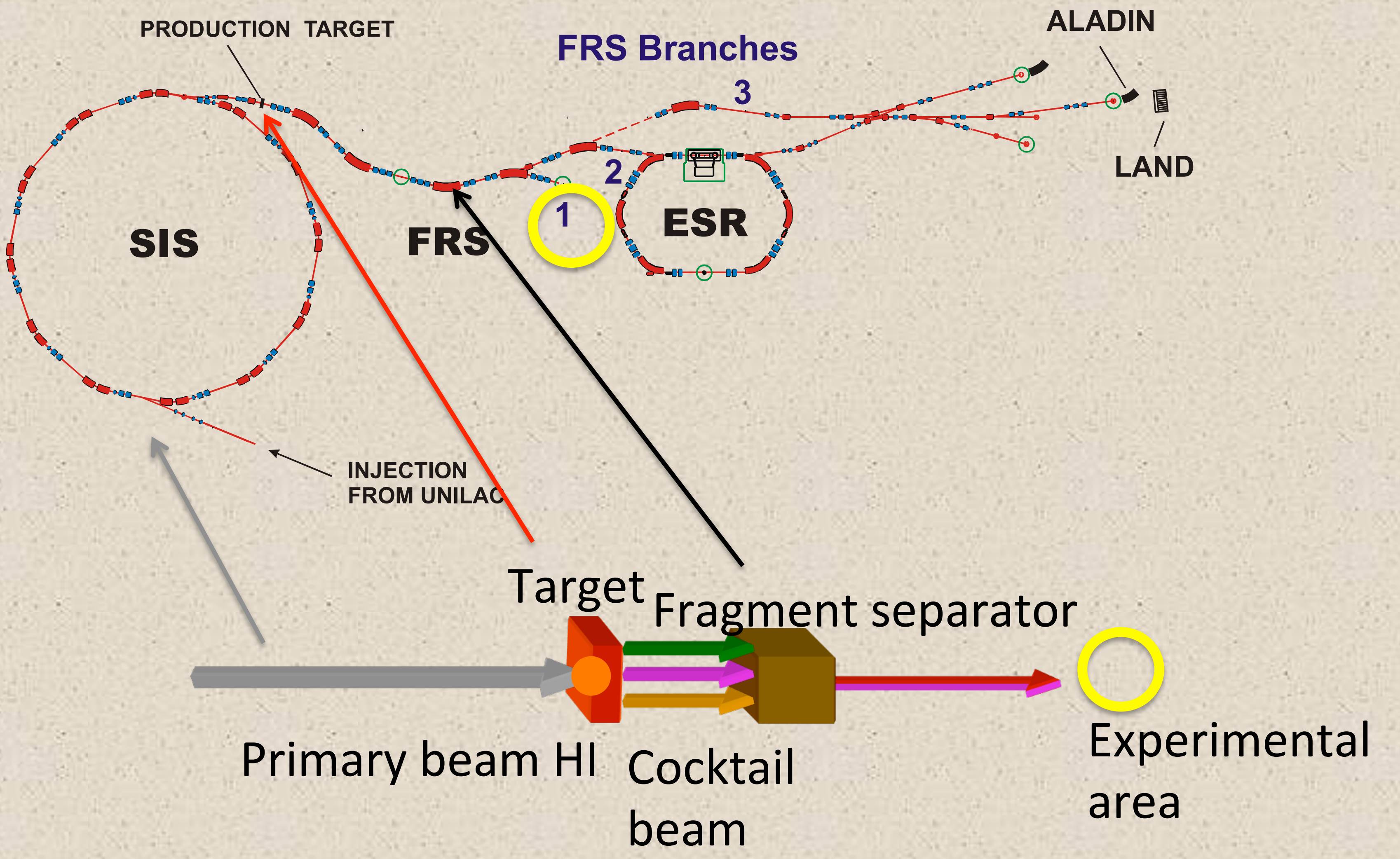
Beta decay experiment at the GSI fragmentation facility



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

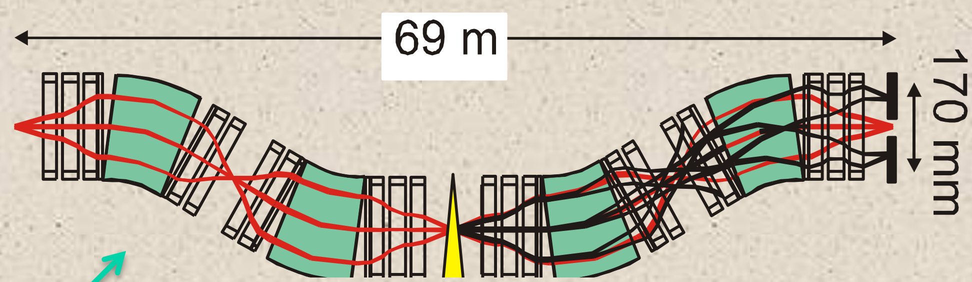
THE PRESENT RARE ISOTOPE FACILITY AT GSI



Bρ-ΔE-Bρ Separation Method

Optimised to separate very fast fragment or fission products

FRS →



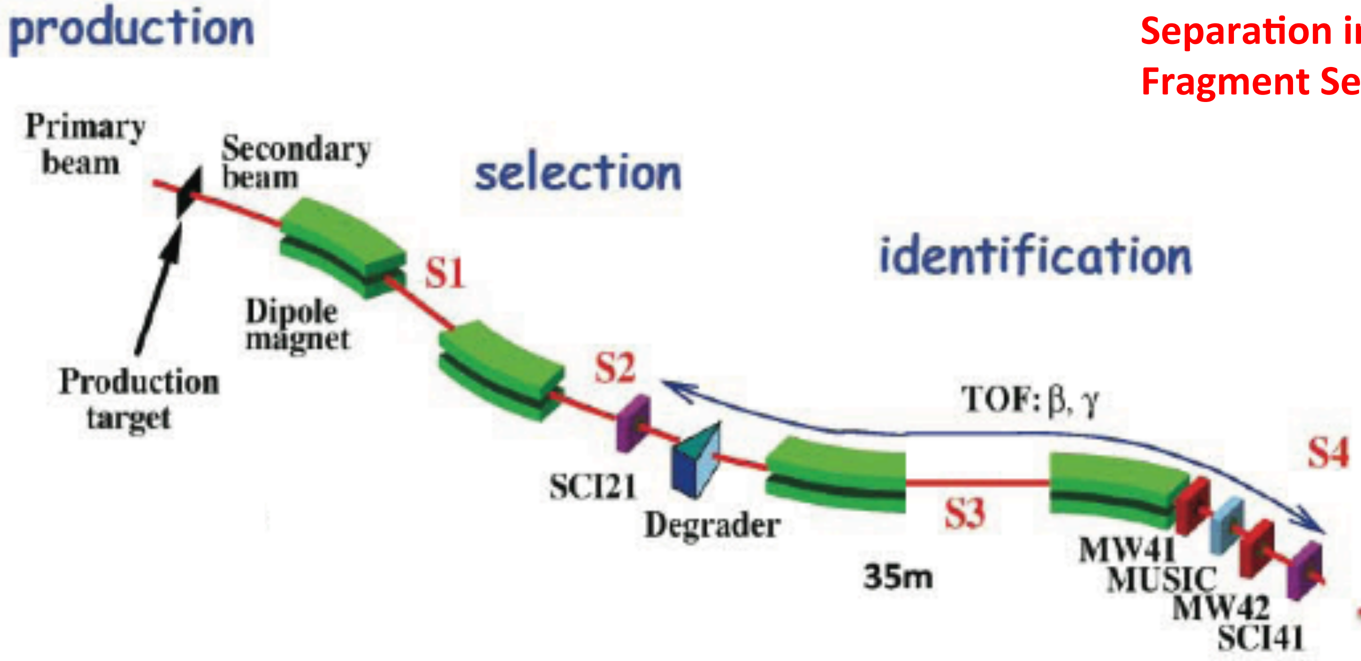
degrader

Ions are selected according
to the momentum to charge ratio
Mv/q=Mv/Z=Bρ. Primary beam is rejected.

Beta Decay Experiments @ RISING

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

Separation in flight with the Fragment Separator (FRS)



Event by event identification

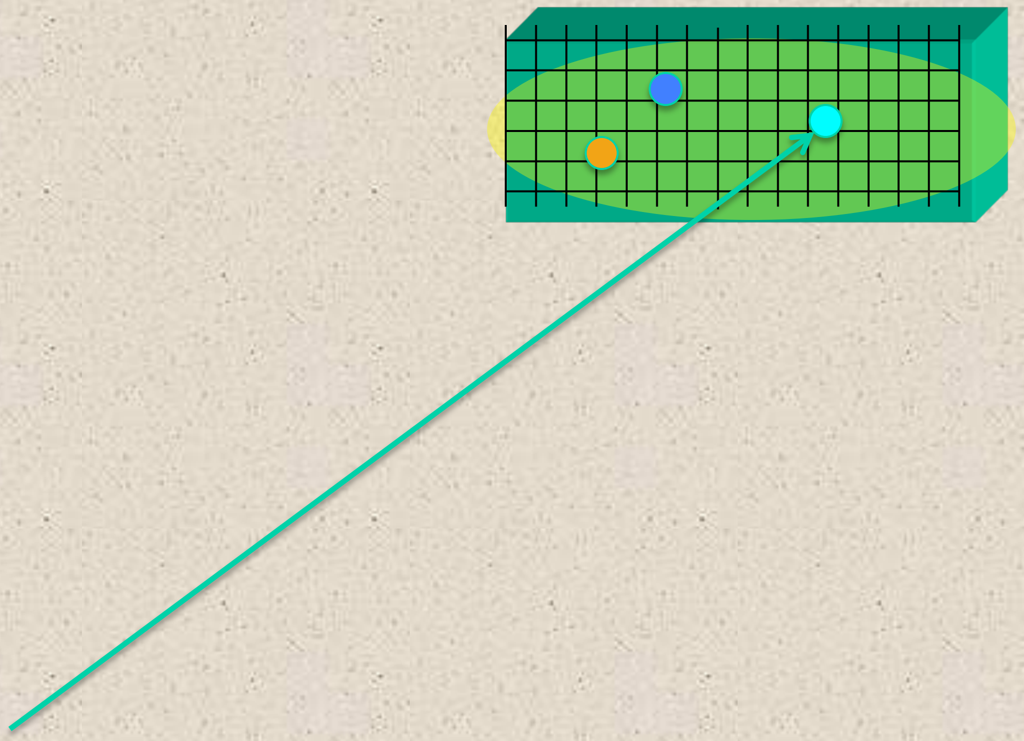
MW41, 42 x y --> Position --> Track of the beam

MUSIC --> dE } -->Z

SCI 21, 41 --> TOF -->β

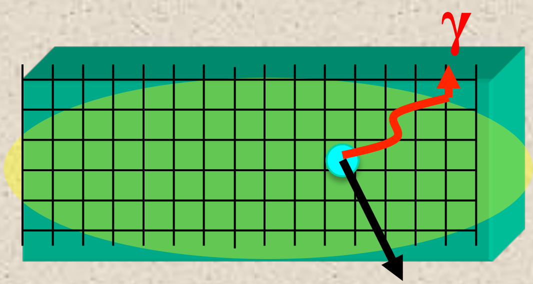
D. Magnet --> B ρ } -->A/Q $\frac{A}{Q} = \frac{B\rho e}{\beta \gamma c u}$

Active stopper and Gamma array



Implantation of heavy ion beam from the fragment separator

Some time later (related to the T1/2 of the nucleus of interest), in the same pixel we detect the **ß** signal (or the proton, alpha).



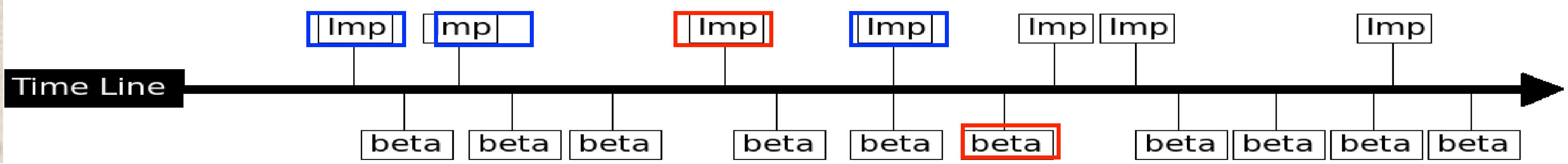
ß (ΔE signal)

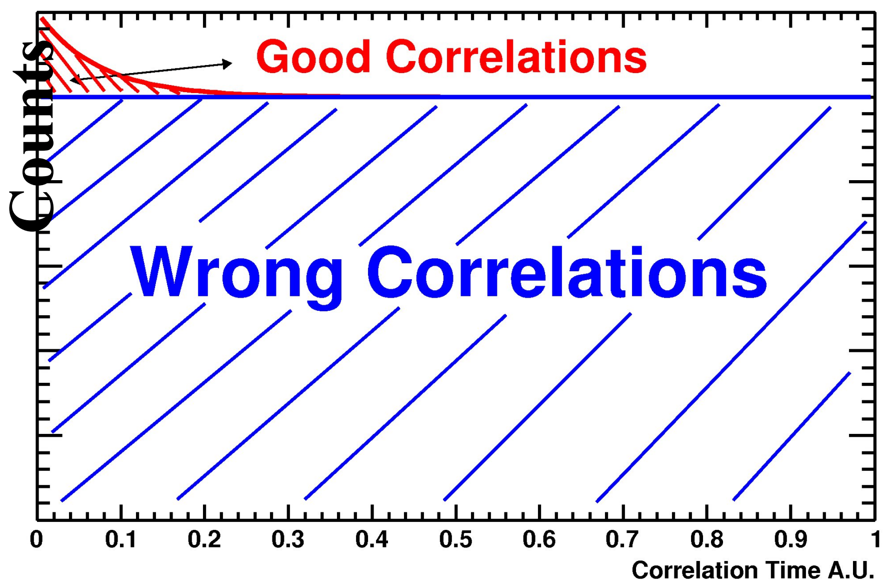
Around we can put gamma detectors or neutron detectors

All the data are recorded

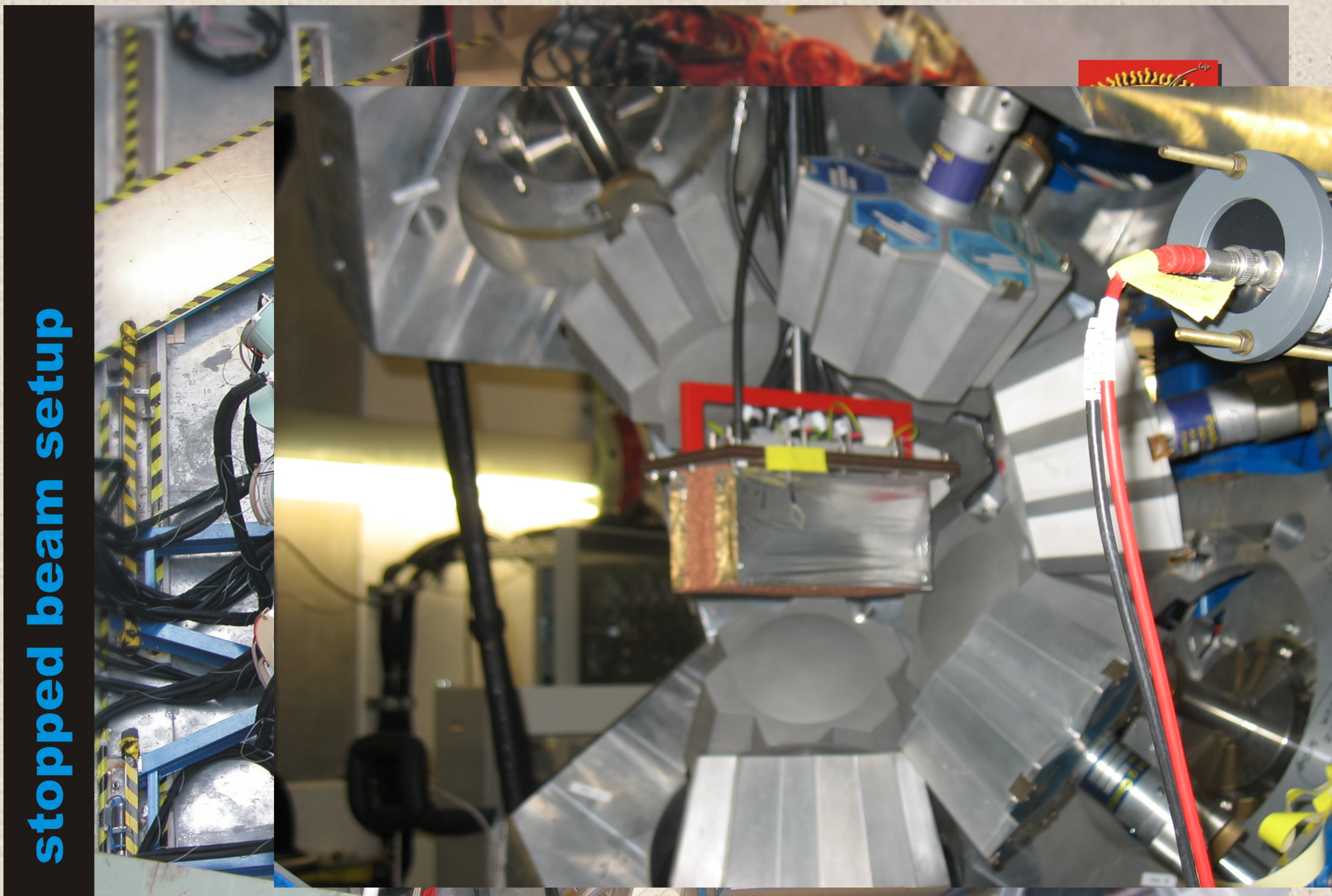
T=0, implant T=beta, gamma (proton, neutron signal)

One can correlate each beta decay with all previous implantation



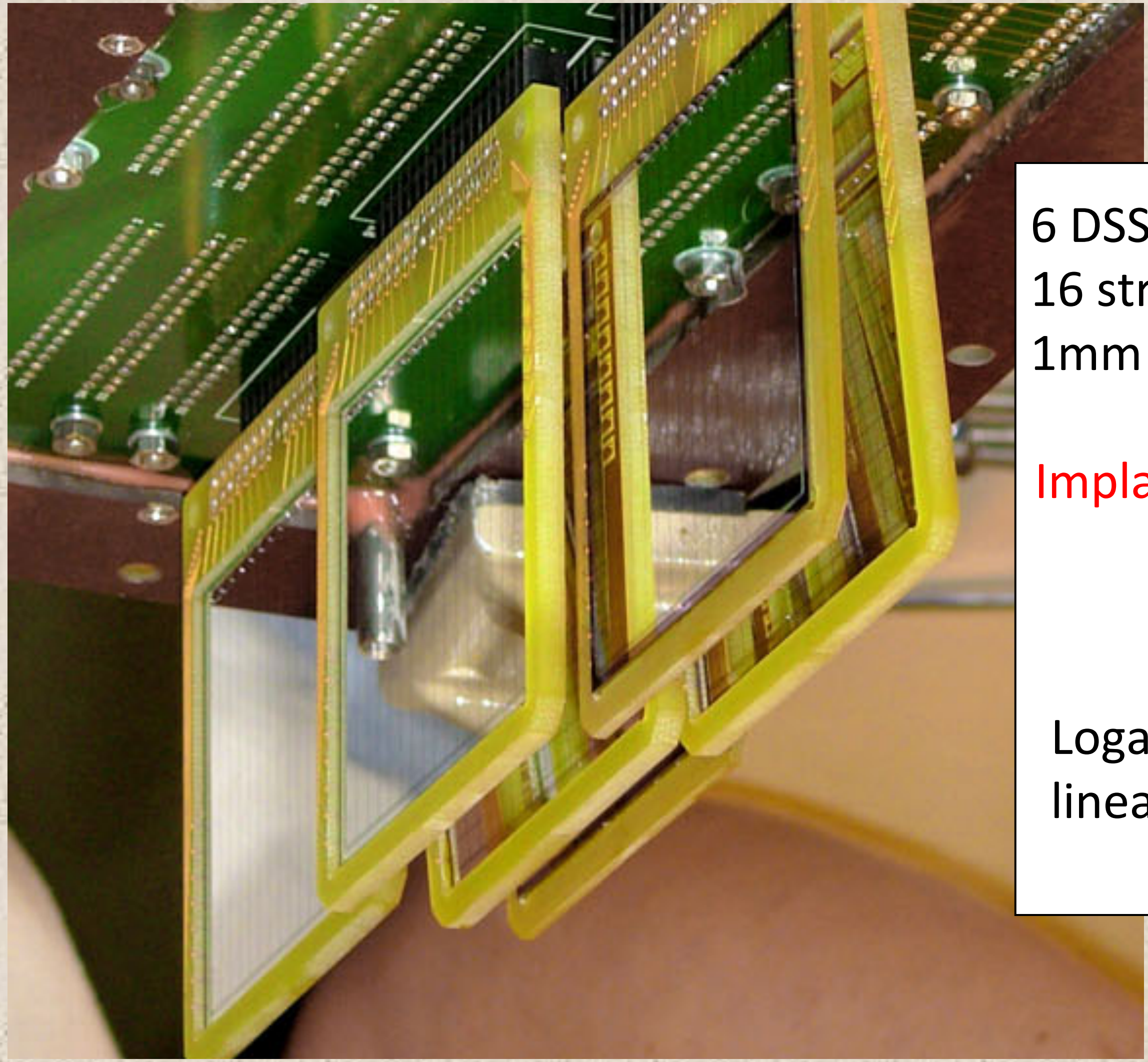


RISING (Ge Array)



55

Detector Setup (Rising and DSSSD)



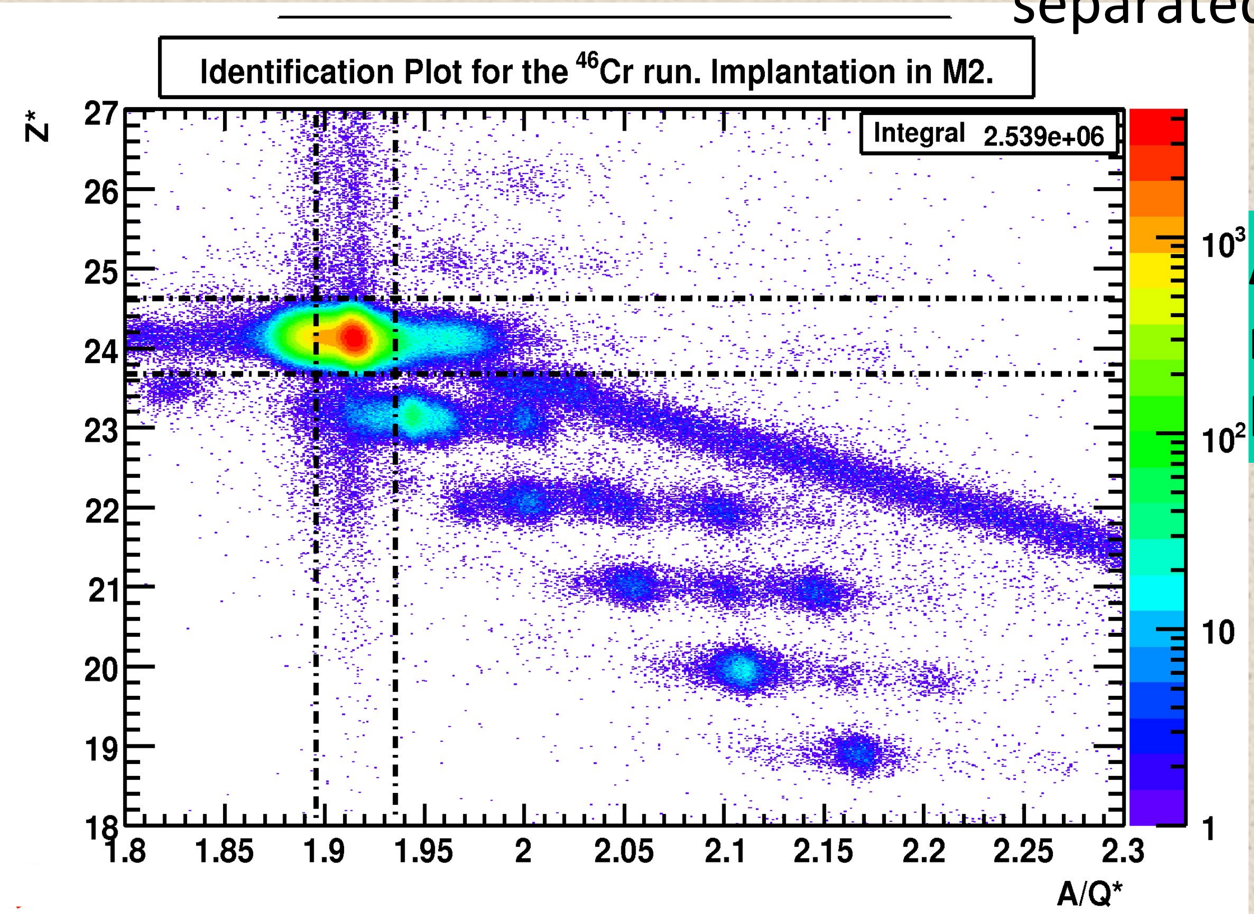
6 DSSSD detectors 1mm with 16 strips X and 16 strips Y, 1mm thick, 5 x 5 cm area

Implantations and Decay detectors

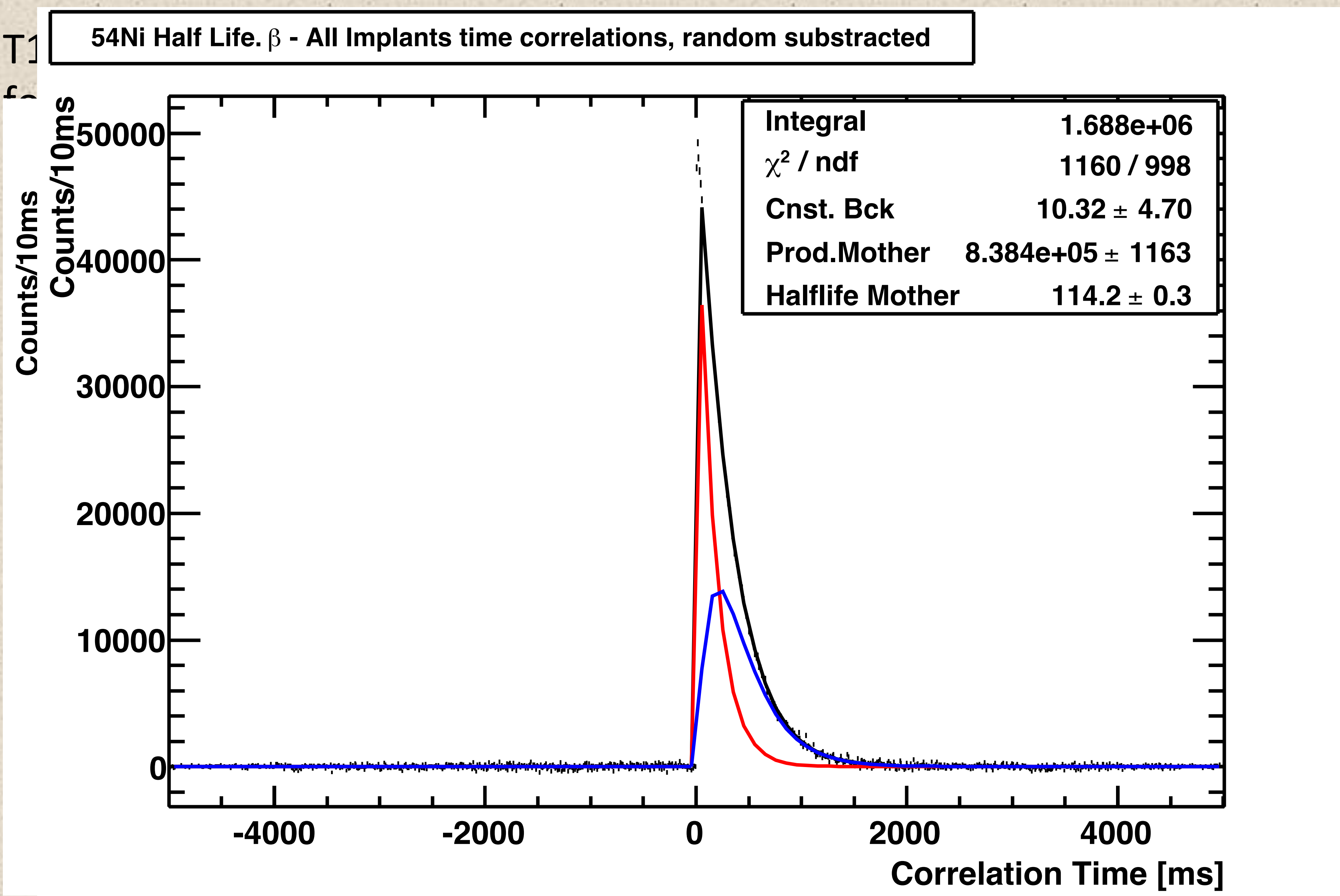
Logarithmic preamplifier linear up to 10 MeV.

46Cr Setting

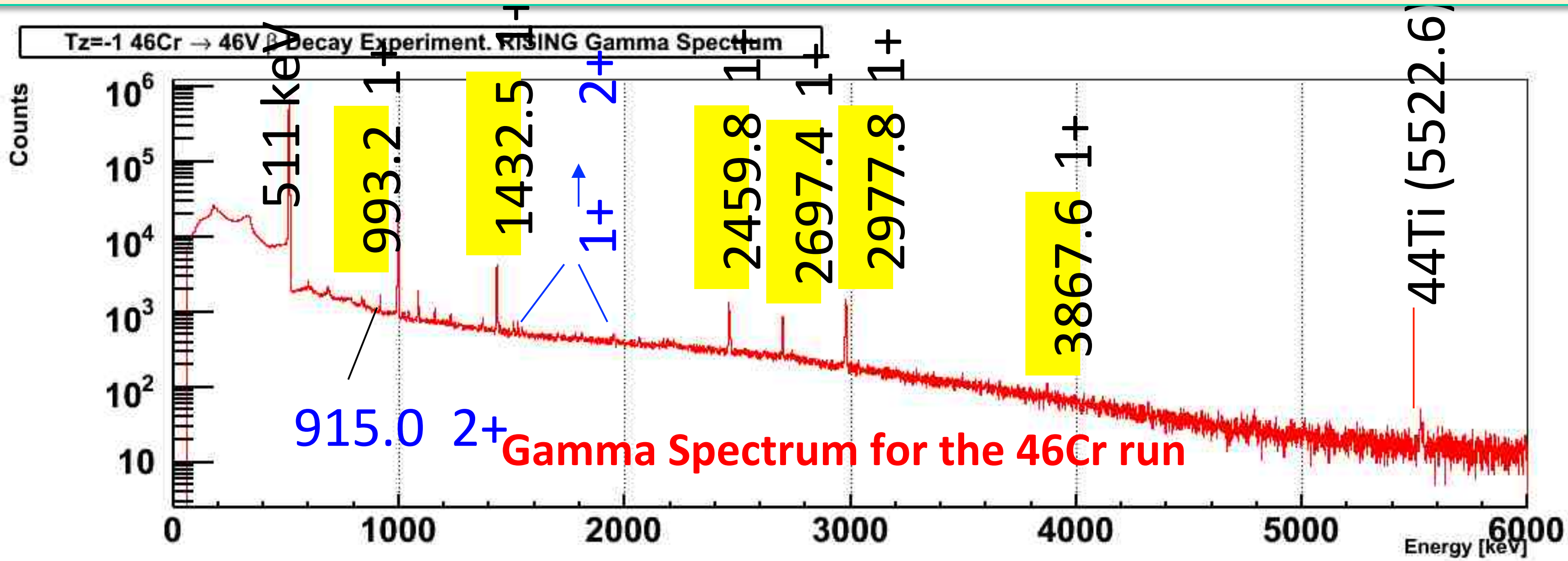
The most abundant nucleus produc
separated and identified up to sci41



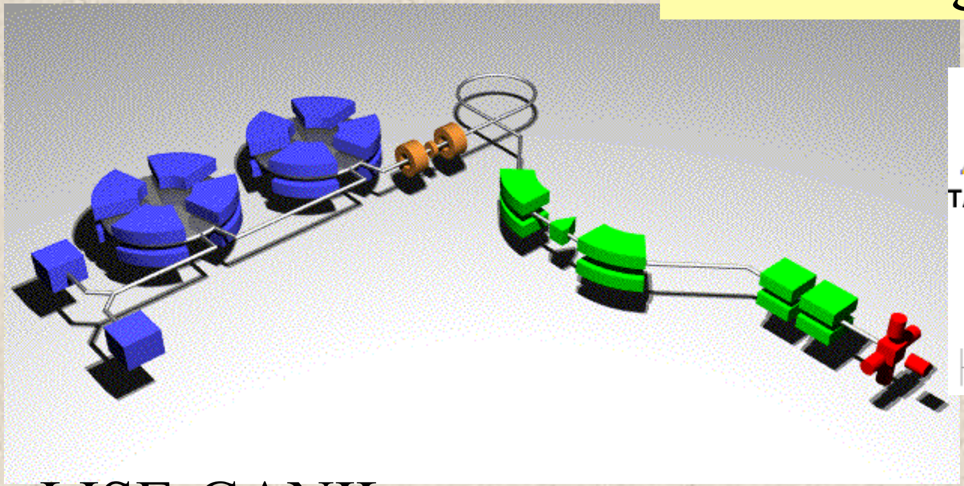
And the most abundant nucleus
Implanted in the DSSD.

T1

54Ni Half Life. β - All Implants time correlations, random substracted
Integral 1.688e+06
χ2 / ndf 1160 / 998
Cnst. Bck 10.32 ± 4.70
Prod.Mother 8.384e+05 ± 1163
Halflife Mother 114.2 ± 0.3
Counts/10ms
Counts/10ms
50000
40000
30000
20000
10000
0
-4000
-2000
0
2000
4000
Correlation Time [ms]

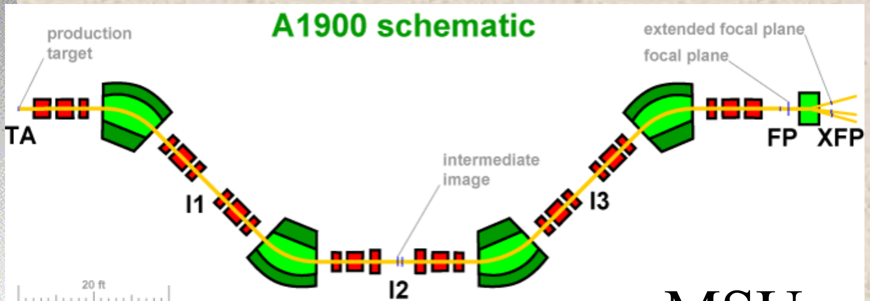
Gammas can be measured only in coincidence with the betas,
If so, the spectrum can be very clean



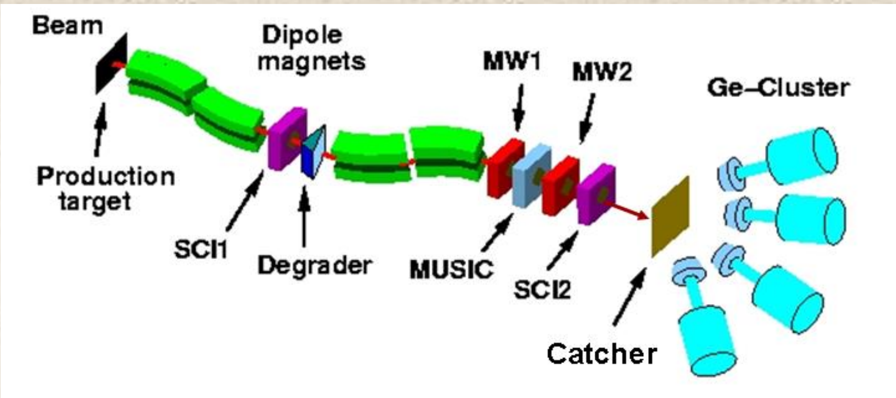
Actual Fragment Separators



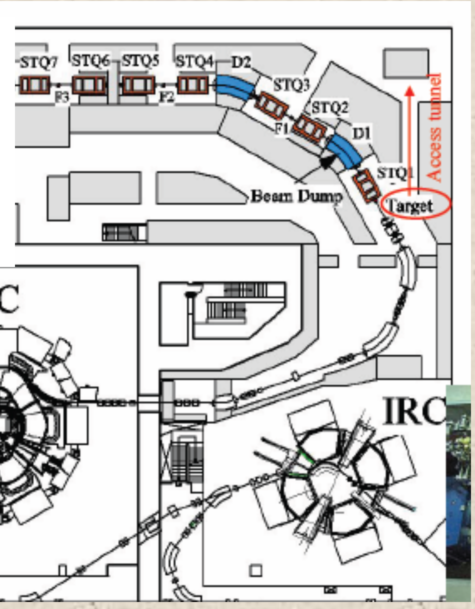
LISE-GANIL



MSU



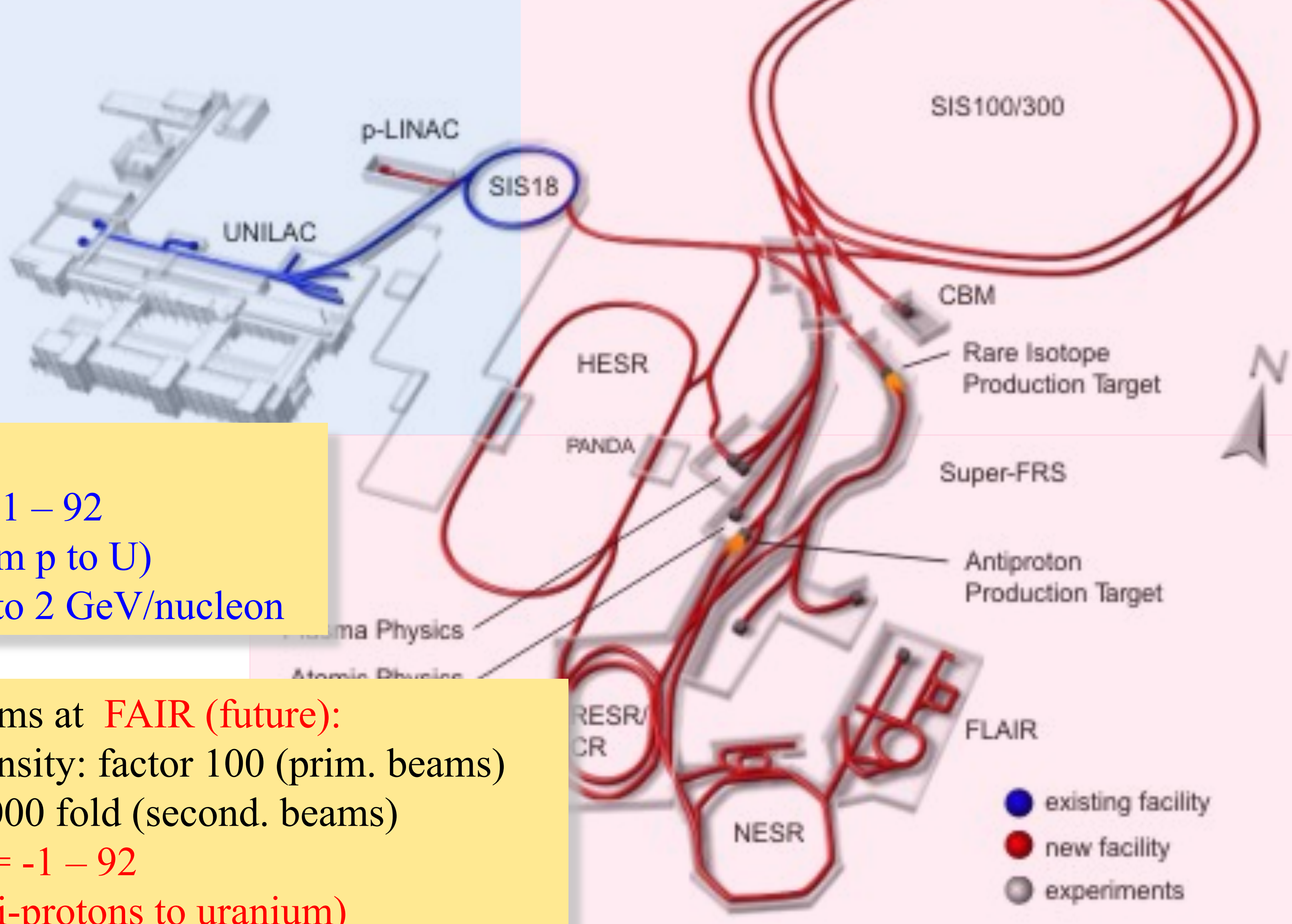
FRS GSI



RIKEN Big Rips

Future (in Europe)

Existing GSI facility　New facility

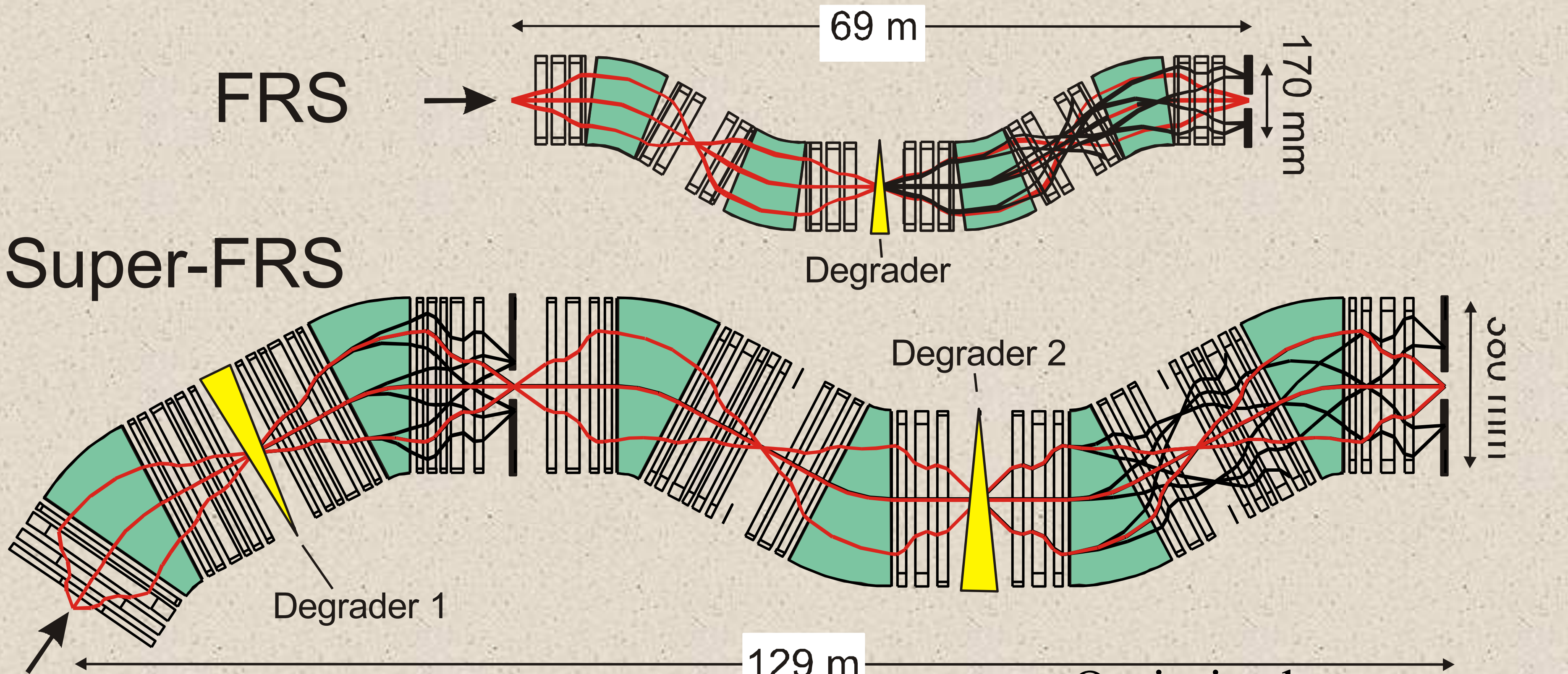


GSI
Z = 1 – 92
(from p to U)
Up to 2 GeV/nucleon

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

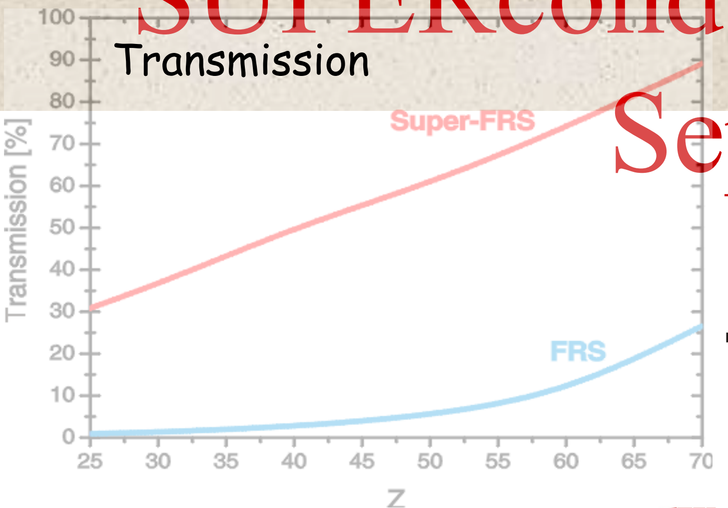
Bρ-ΔE-Bρ Separation Method

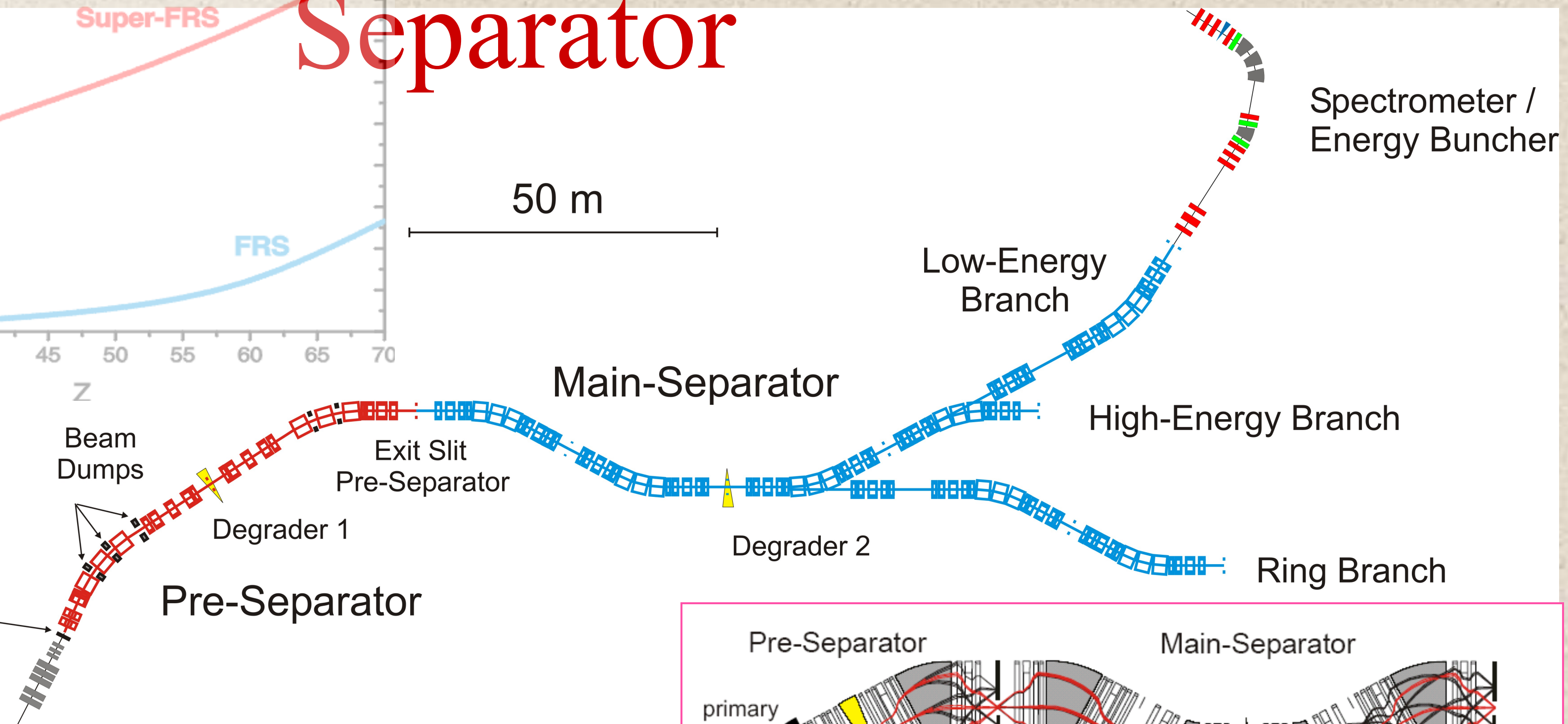


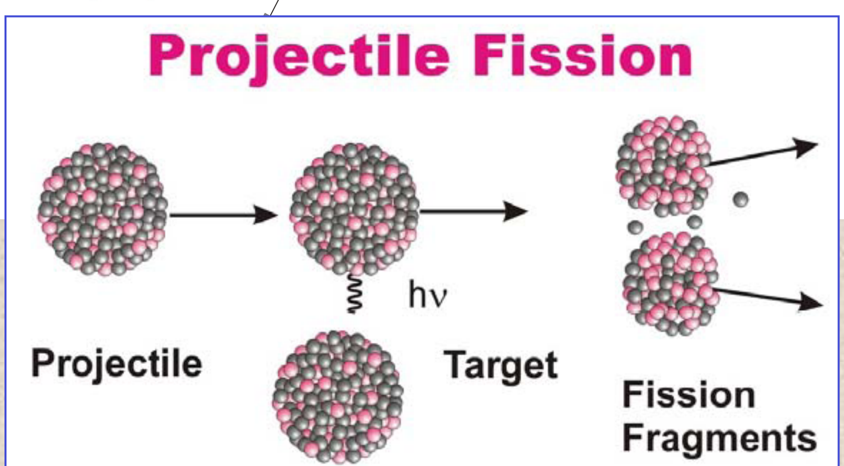
Optimised to separate very fast fragment or fission products

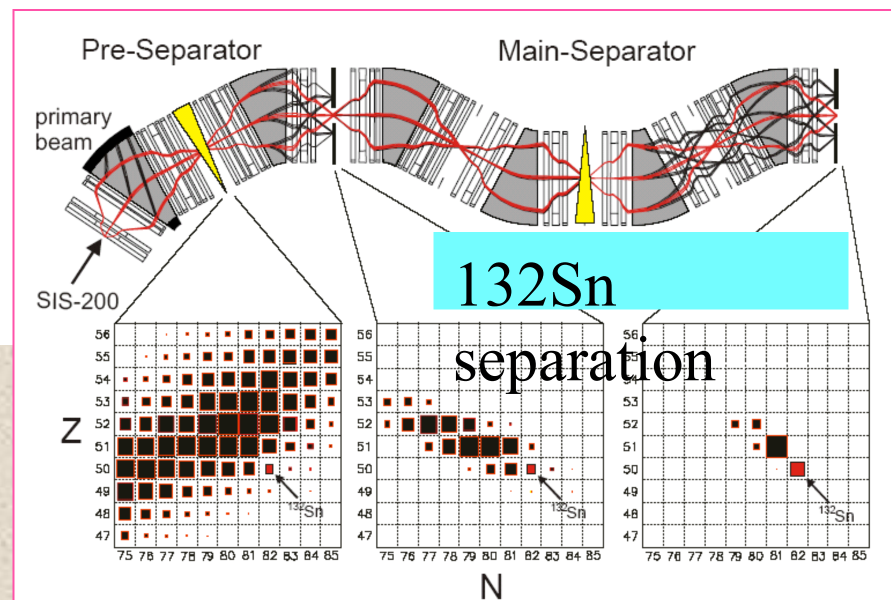
H. Geissel et al. NIM B 204 (2003) 71

SUPERconducting FRagment Separator









132Sn separation

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