High power targets for EURISOL and Beta ν-beams

H. L. Ravn/CERN, EP

Overview

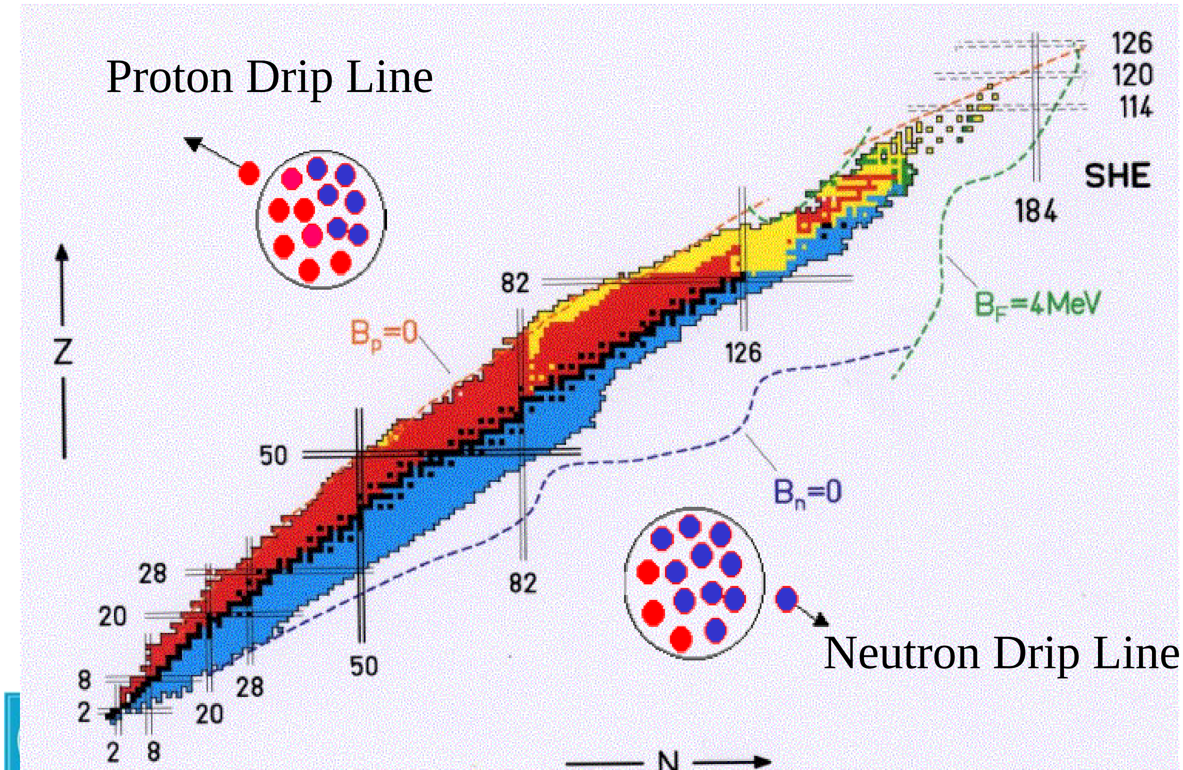
•Radioactive Ion Beam facilities (RIB) based on the Isotope Separator On-line principle (ISOL)
•The targets for RIB facilities
•The future extension of RIB facilities to MW driver beams like at EURISOL
•How the ISOL-RIB facility can be the injector for precursors of intense beams of
• ν_e and $\bar{\nu}_e$
•Conclusion and outlook

References and acknowledgements

- The ISOLDE Collaboration at CERN, Switzerland:
- http://isolde.web.cern.ch/ISOLDE/frames/isoframe.html
- The CERN Superconducting Proton LINAC (SPL) working group
- The beta ν-beam collaboration
- The European EURISOL project:
- http://www.ganil.fr/eurisol/index.html
- GANIL, Caen France:
- http://www.ganil.fr/research/developments/spiral/

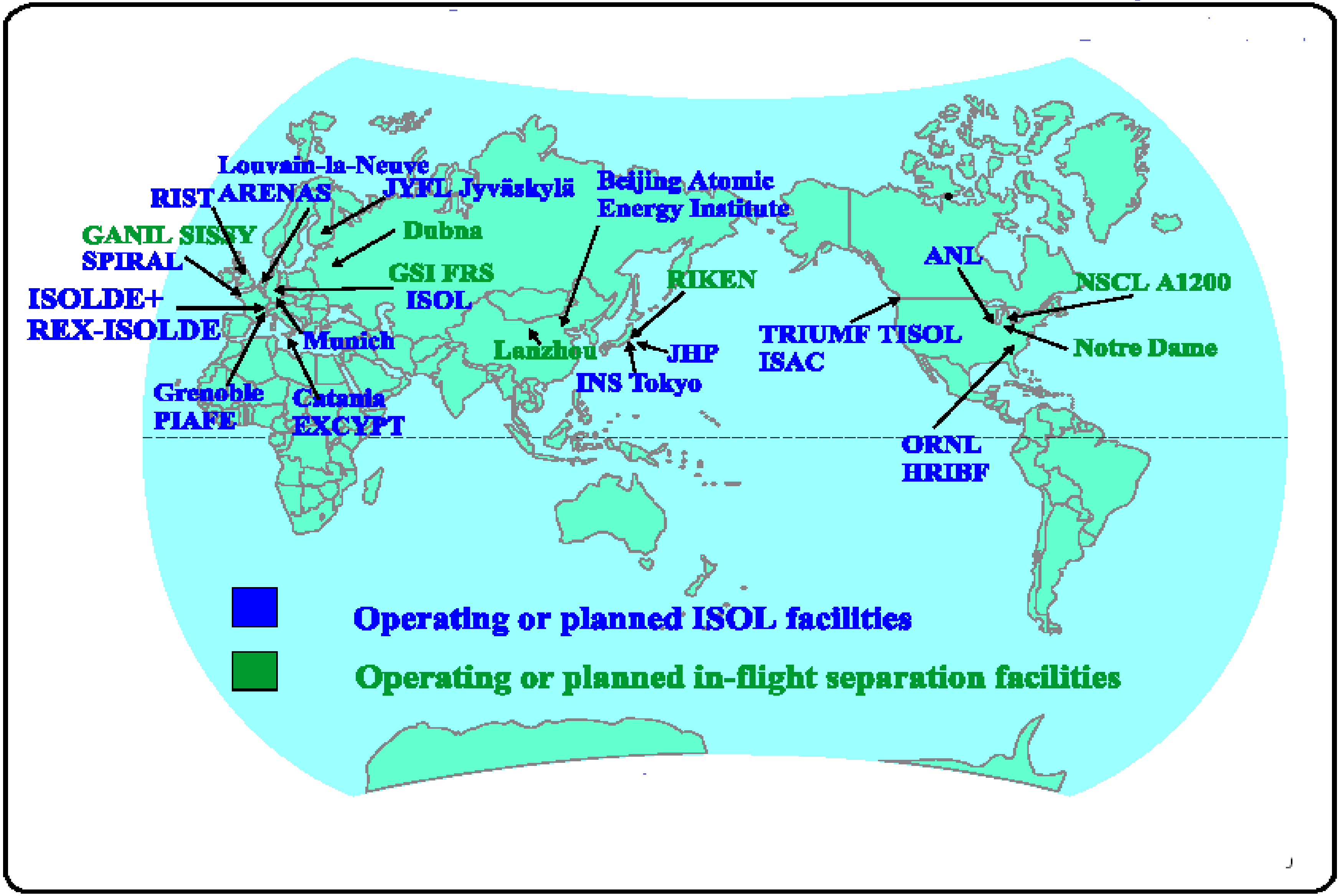
Radioactive ion beams (RIB)

Naturally found on our planet are 265 stable plus 60 radioactive nuclei which until now were the only ones accelerated.
However, there are about 6000 possible nuclei defined within the p- and n-driplines.
About 3000 isotopes are synthesised in our laboratories



Study nuclei under extreme conditions of spin and issopin
Astrophysics
Applications

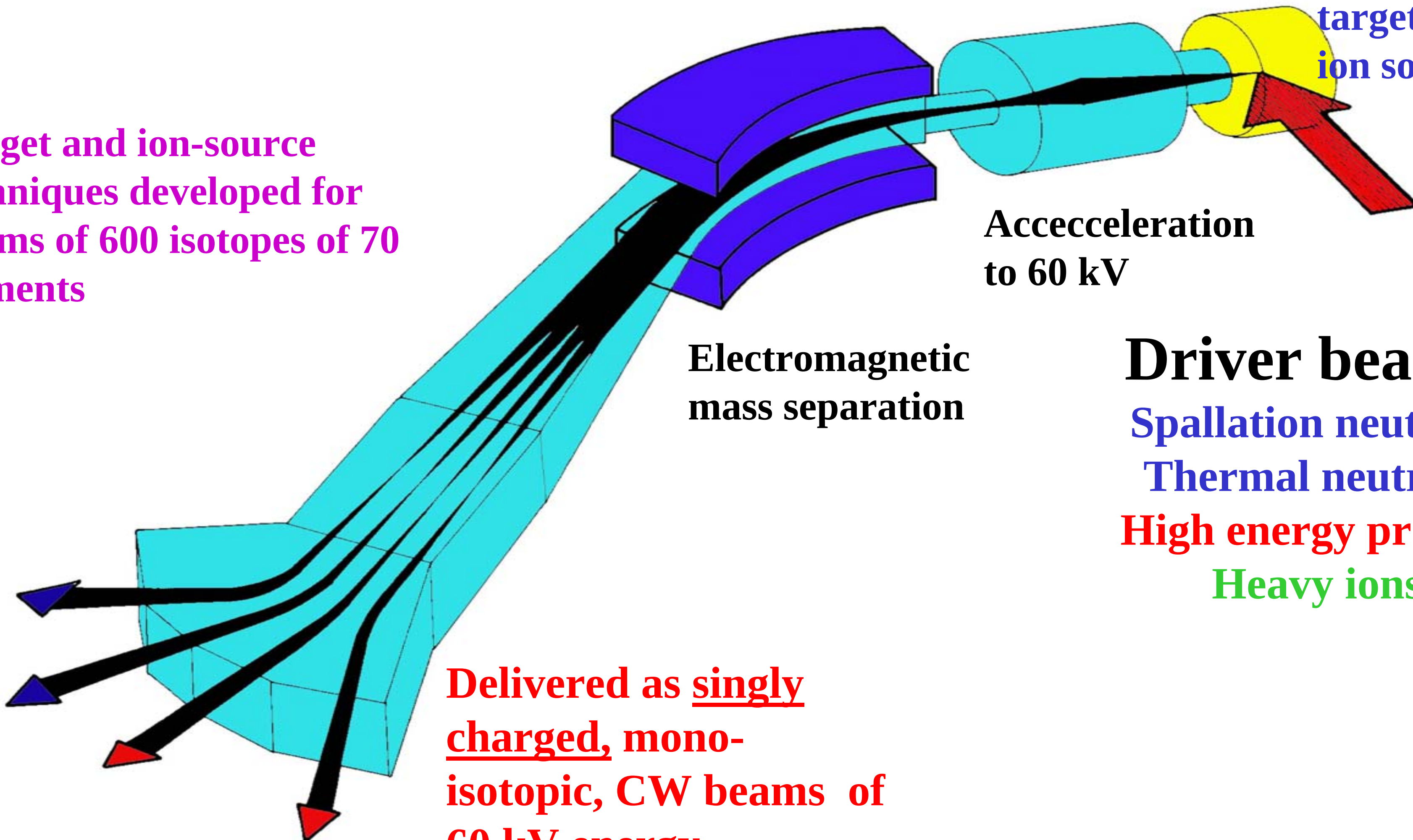
Radioactive beam facilities



The Isotope Separator On-Line (ISOL) as injector to post accelerators

Integrated target and ion source

Target and ion-source techniques developed for beams of 600 isotopes of 70 elements



Acceceleration to 60 kV

Electromagnetic mass separation

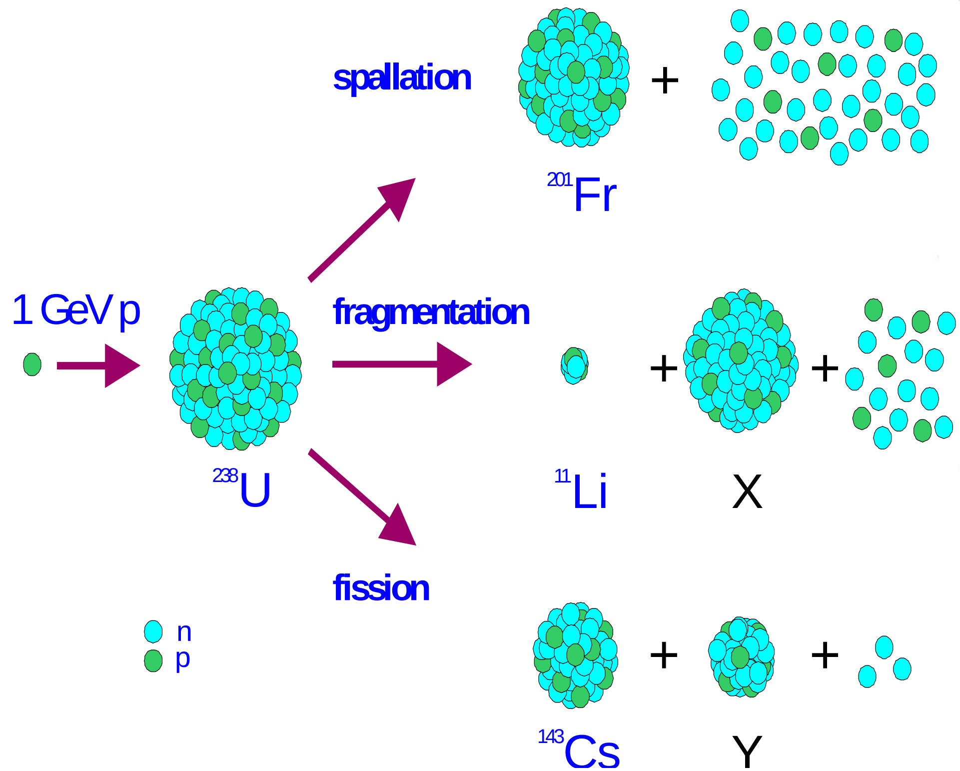
Driver beams:

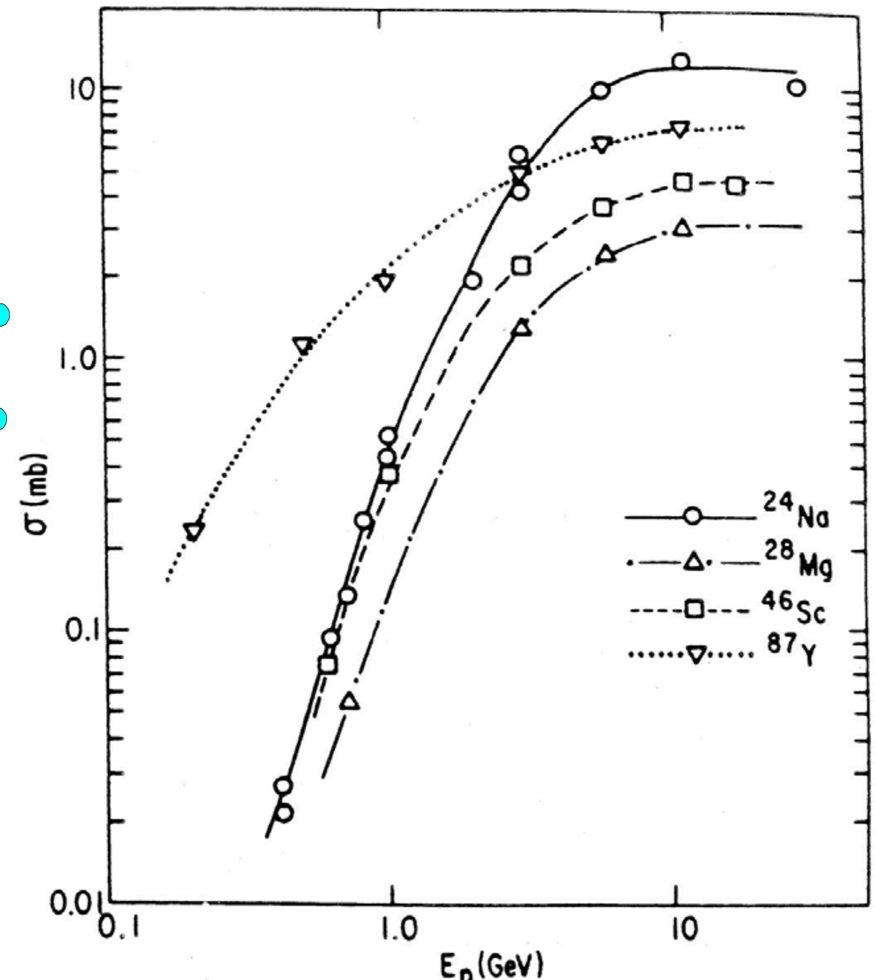
Spallation neutrons
Thermal neutrons
High energy protons
Heavy ions

Delivered as <u>singly charged,</u> mono-isotopic, CW beams of 60 kV energy

Reaction mechanisms

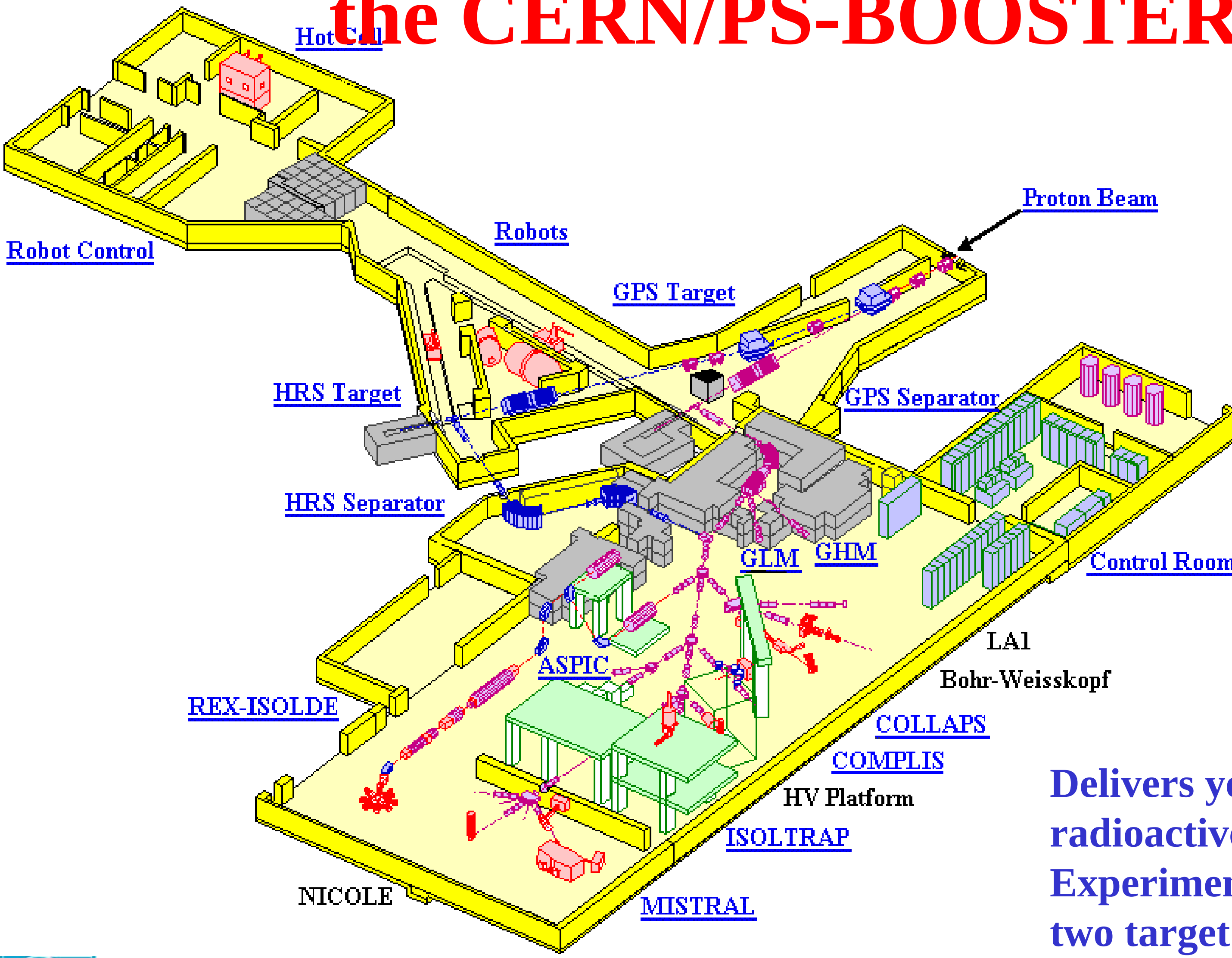
Ideal proton energy 1 to 5 GeV





The reaction products are brought to rest in thick ~ 100g/cm^2 targets

The Isotope Separator On-Line ISOLDE at the CERN/PS-BOOSTER

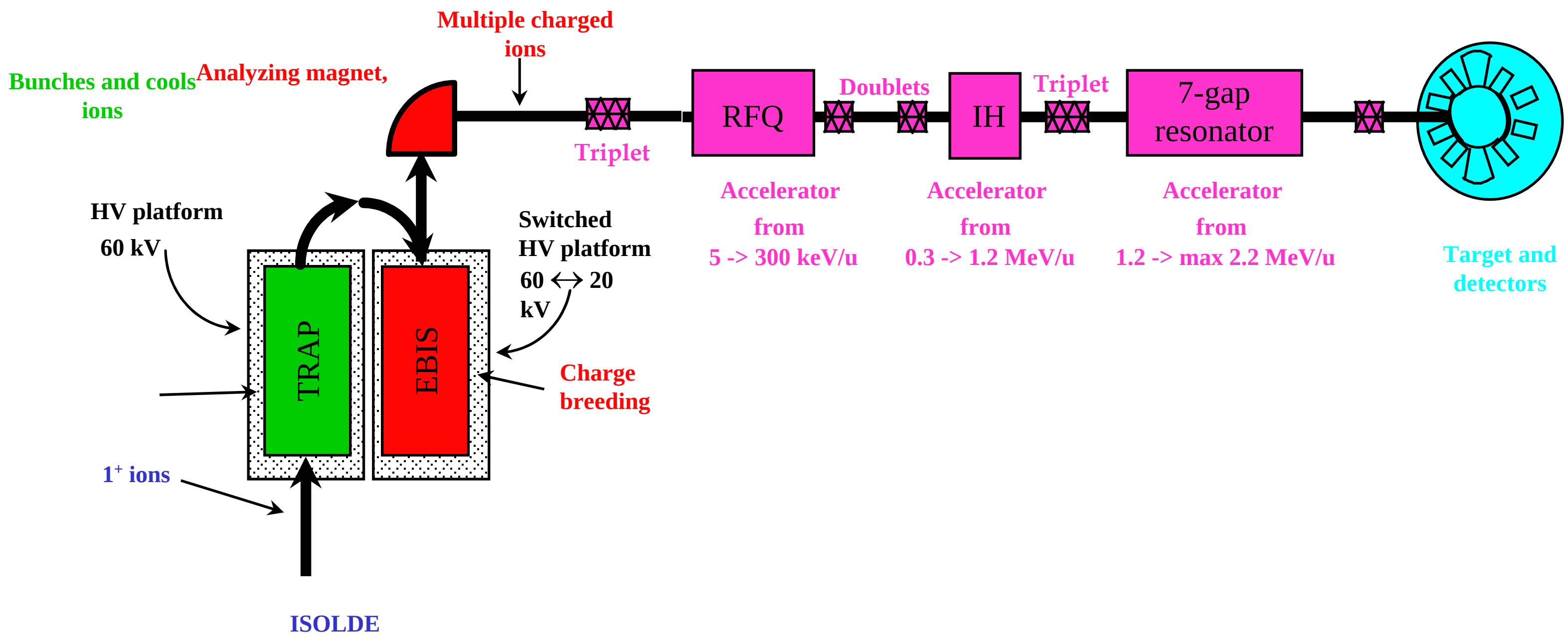


Proton beam:

1 -1.4 GeV
3E13 per pulse
2.4 μs pulse length
Rep. Rate 0.5 Hz
Max. current 4 μA
5.6 kW beam power

Delivers yearly 3200 h of radioactive ion-beam to 30 Experiments by means of two target stations

The REX ISOLDE post accelerator



Proton beam intensity limited !

The EURISOL Project

European Isotope Separation On-Line
Radioactive Nuclear Beam Facility

EURISOL index	*(This page)*
EURISOL project	*What is EURISOL? Find out here!*
EURISOL details	*The EURISOL contract and Participating Institutions.*
Meetings	*The 5 EURISOL Task Groups: Dates, notes and presentations*
1st Town Meeting	*Held in Orsay, France, in 2000*
2nd Town Meeting	*Held in Abano Terme, Italy, 2002*
3rd Town Meeting	*Held in Orsay, France, in May, 2003*
Mailing list	*Join our mailing list for regular updates*
Links	*Related sites and documents*
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http://www.ganil.fr/eurisol/index.html

Pre conceptual design study

3rd EURISOL TOWN MEETING: Orsay, France, 12 & 13 May 2003.
PRESENTATIONS

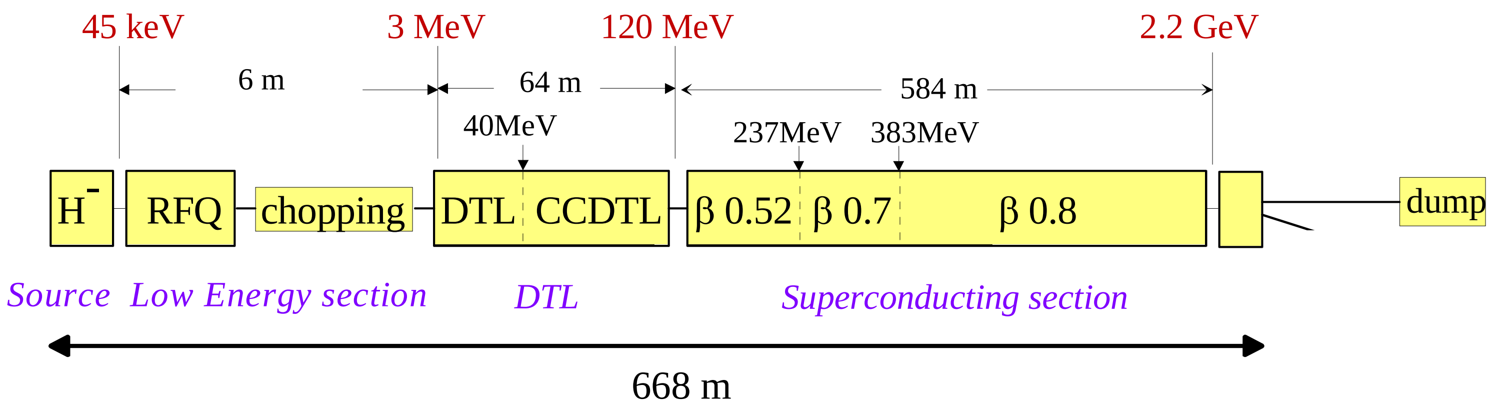
Note: if you did not receive the ANNOUNCEMENTS by e-mail, then you are probably not on the *EURISOL Mailing List*!

Draft Reports of the TASK GROUPS (still being revised):

- Key Experiments Task Group Draft Report (30 Mbytes)
- Driver Accelerator Task Group Draft Report (7.9 Mbytes)
- Target & Ion Source Task Group Draft Report (11 Mbytes)
- Post-Accelerator & Mass Spectrometer Task Group Draft Report (13 Mbytes)
- Instumentation Task Group Draft Report (4.5 Mbytes)

EURISOL

SPL design parameters



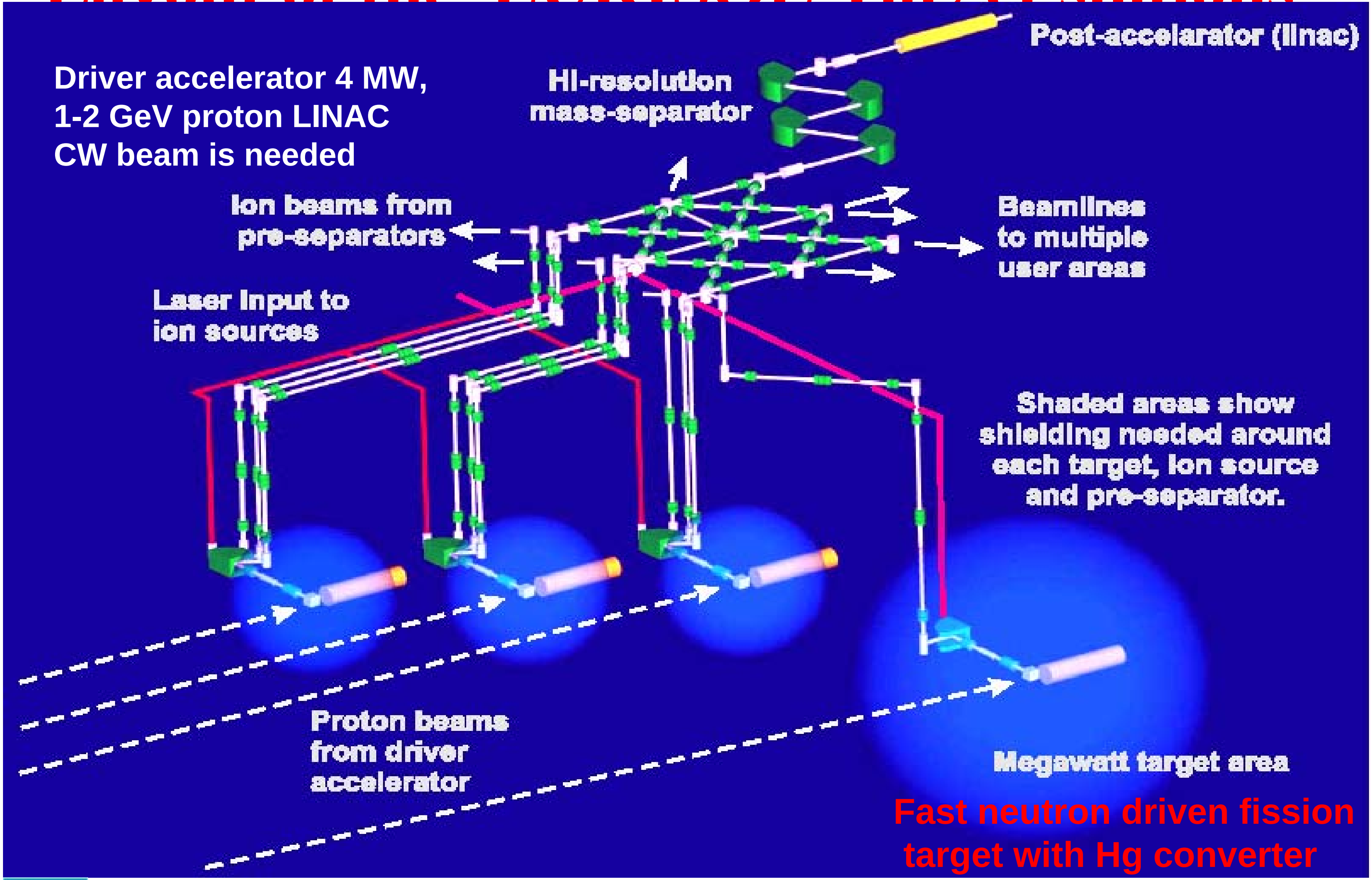
Ion species	**H-**	
Kinetic energy	**2.2**	**GeV**
Mean current during the pulse	**13**	**mA**
Duty cycle	**14.0**	**%**
Mean beam power	**4**	**MW**
Pulse frequency	**50**	**Hz**
Pulse duration	**2.80**	**ms**
Duty cycle during the beam pulse	**61.6**	**%**
Maximum bunch current	**22.7**	**mA**
Bunch length (total)	**0.5**	**ns**
Energy spread (total)	**0.5**	**MeV**
Normalised rms horizontal emittance	**0.4**	**π mm mrad**
Normalised rms vertical emittance	**0.4**	**π mm mrad**
Longitudinal rms emittance (352 MHz)	**0.3**	**π deg MeV**

Note that the beam requested by EURISOL is a CW beam

For neutrino physics, it has to be compressed with an Accumulator and a Compressor ring into 140 bunches, 3 ns long, forming a burst of 3.3 μs

Layout of the EURISOL Target stations

Driver accelerator 4 MW,
1-2 GeV proton LINAC
CW beam is needed



Fast neutron driven fission
target with Hg converter

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Production rate in the target

$$A = \Phi \; \sigma \; N$$

σ ***REACTION CROSS SECTIONS***

Spallation
Fission
Target fragmentation

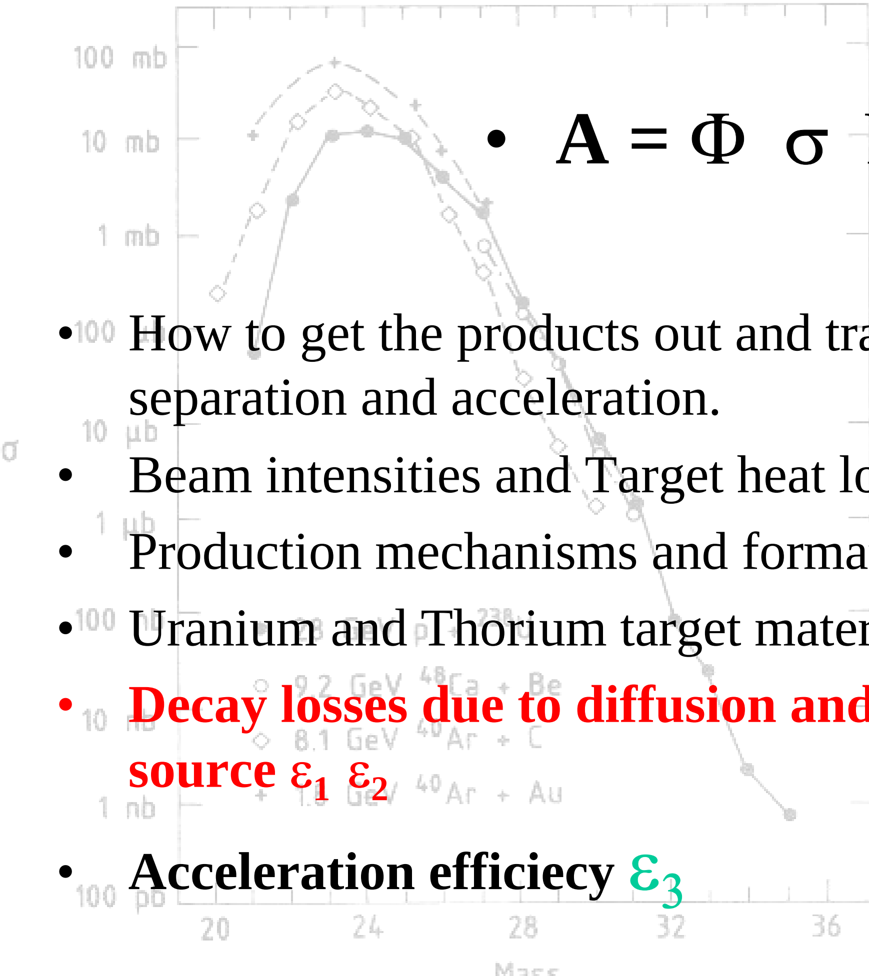
N ***TARGET THICKNESS***

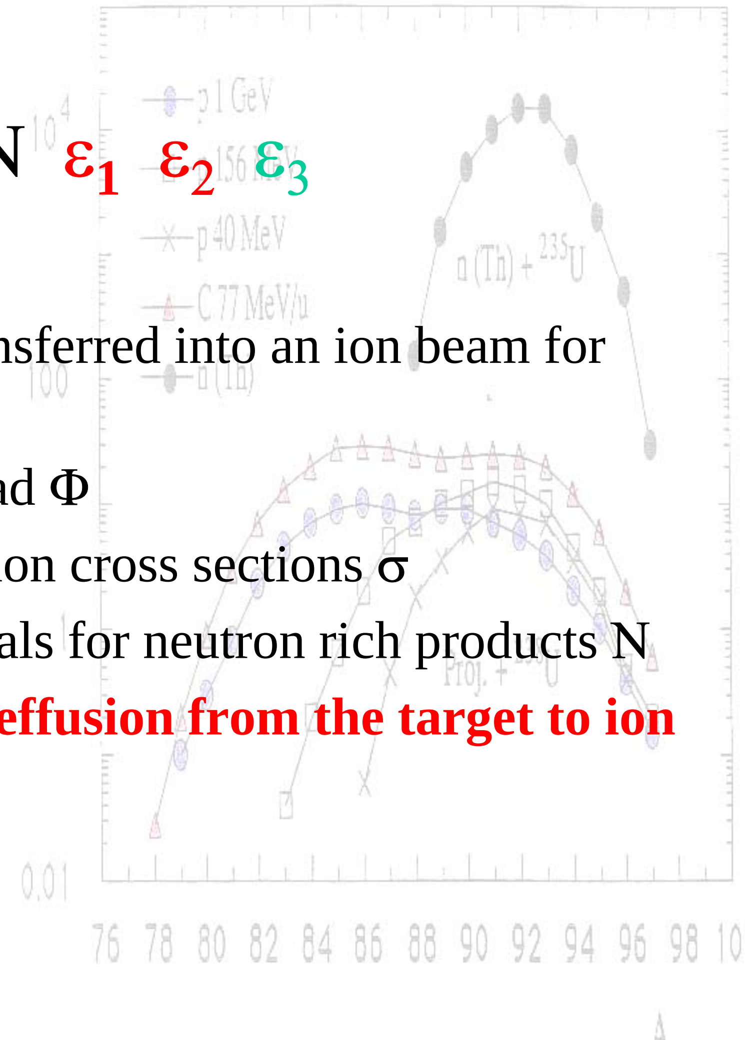
Very thick targets $>100 g/cm^2$

Φ ***DRIVER BEAM INTENSITY***

Driver beam intensity presently 1 to 100 µA

Mass transport





- $A = \Phi \ \sigma \ N \ \varepsilon_1 \ \varepsilon_2 \ \varepsilon_3$

- How to get the products out and transferred into an ion beam for separation and acceleration.
- Beam intensities and Target heat load Φ
- Production mechanisms and formation cross sections σ
- Uranium and Thorium target materials for neutron rich products N
- **Decay losses due to diffusion and effusion from the target to ion source $\varepsilon_1 \ \varepsilon_2$**
- **Acceleration efficiecy ε_3**

EURISOL

Diffusion effusion models

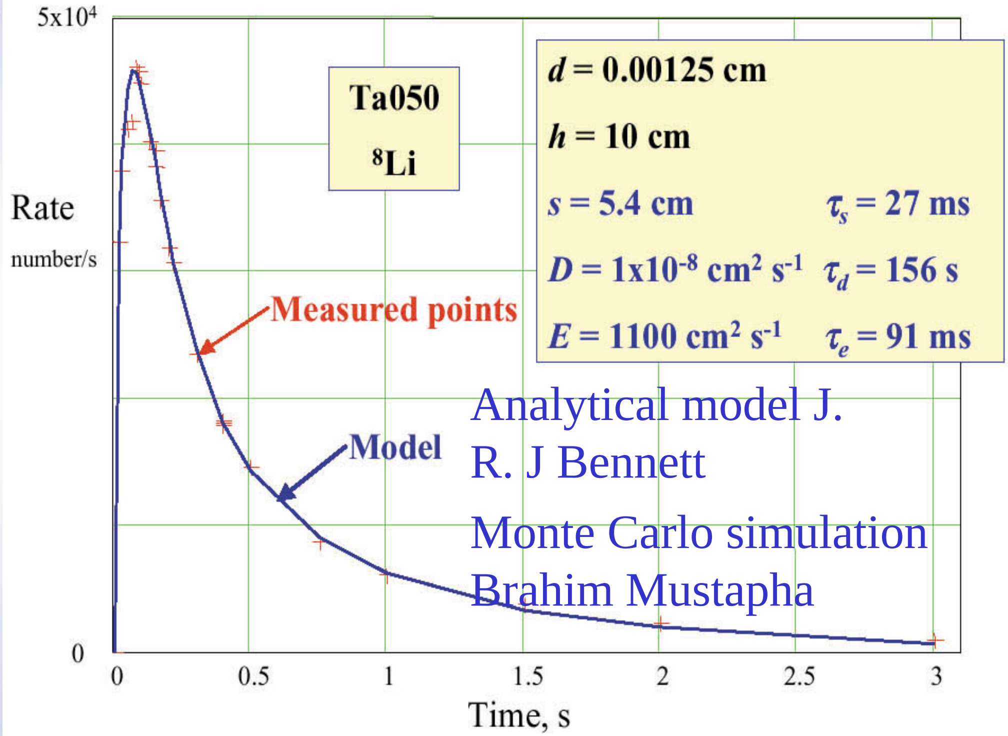
Assume that the target is bombarded by a very short pulse of protons, so that all the particles are produced in the target at one instant in time $t = 0$.

1. Solve Fick's law for diffusion from the foils. Diffusion coefficient D.

2. Solve Fick's Law for diffusion through the target and ioniser. Diffusion coefficient E.

3. Fold 1. into 2. This gives the release from the target for particles emerging from the foils at one instant in time.

4. Integrate over all times to give the resultant release.



$$p_{de}(t)=\int_0^t \sum_{n=-\infty}^{\infty}(-1)^n \frac{e^{-\frac{n^2\tau_d}{T}}}{\sqrt{\pi\tau_d T}} \sum_{m=-\infty}^{\infty}(-1)^n \frac{e^{-\frac{\left[m\sqrt{\tau_e}+\frac{(2m+1)}{2}\sqrt{\tau_s}\right]^2}{(t-T)}}}{\sqrt{\pi\tau_e(t-T)}}\,dT$$

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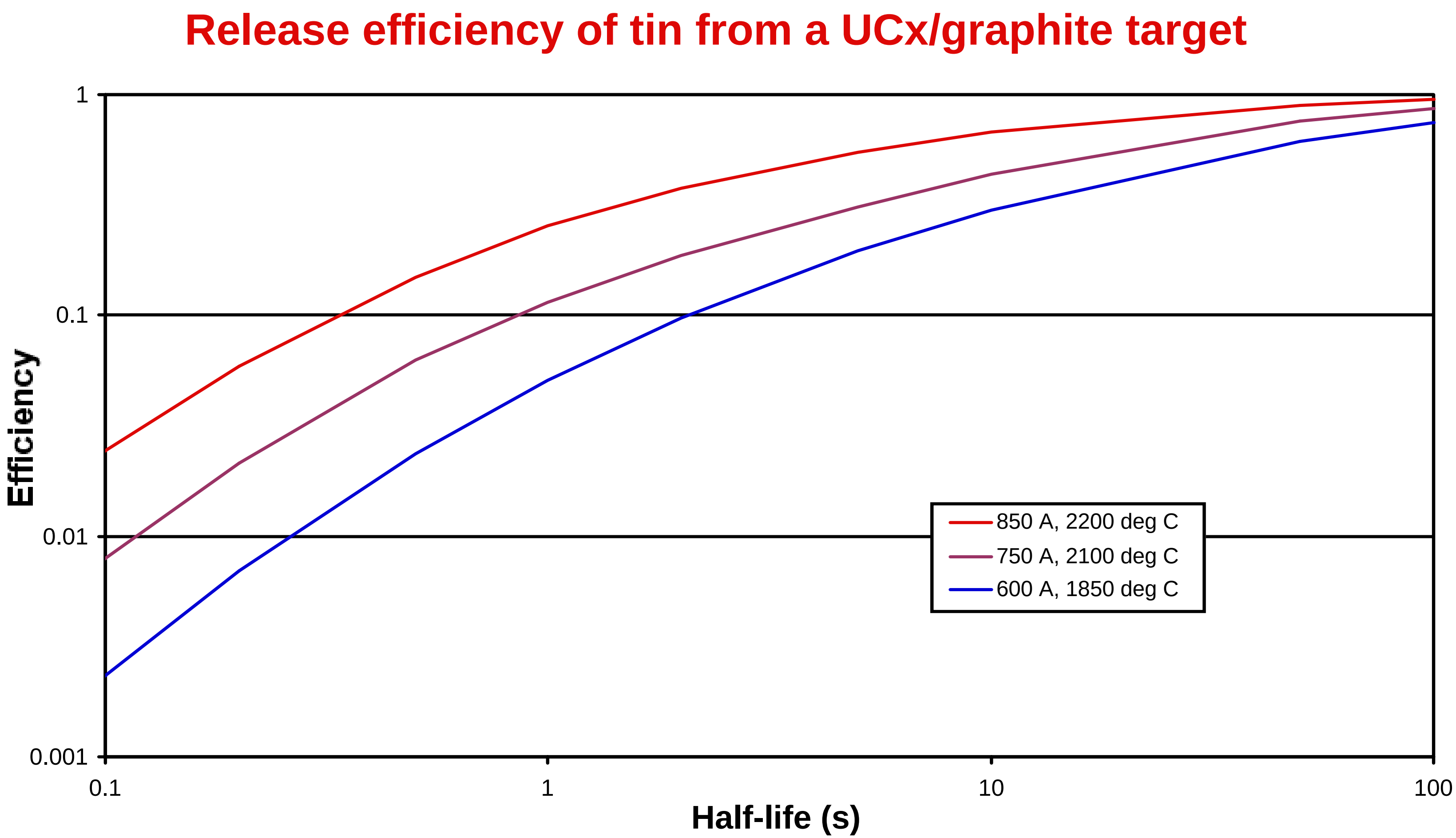
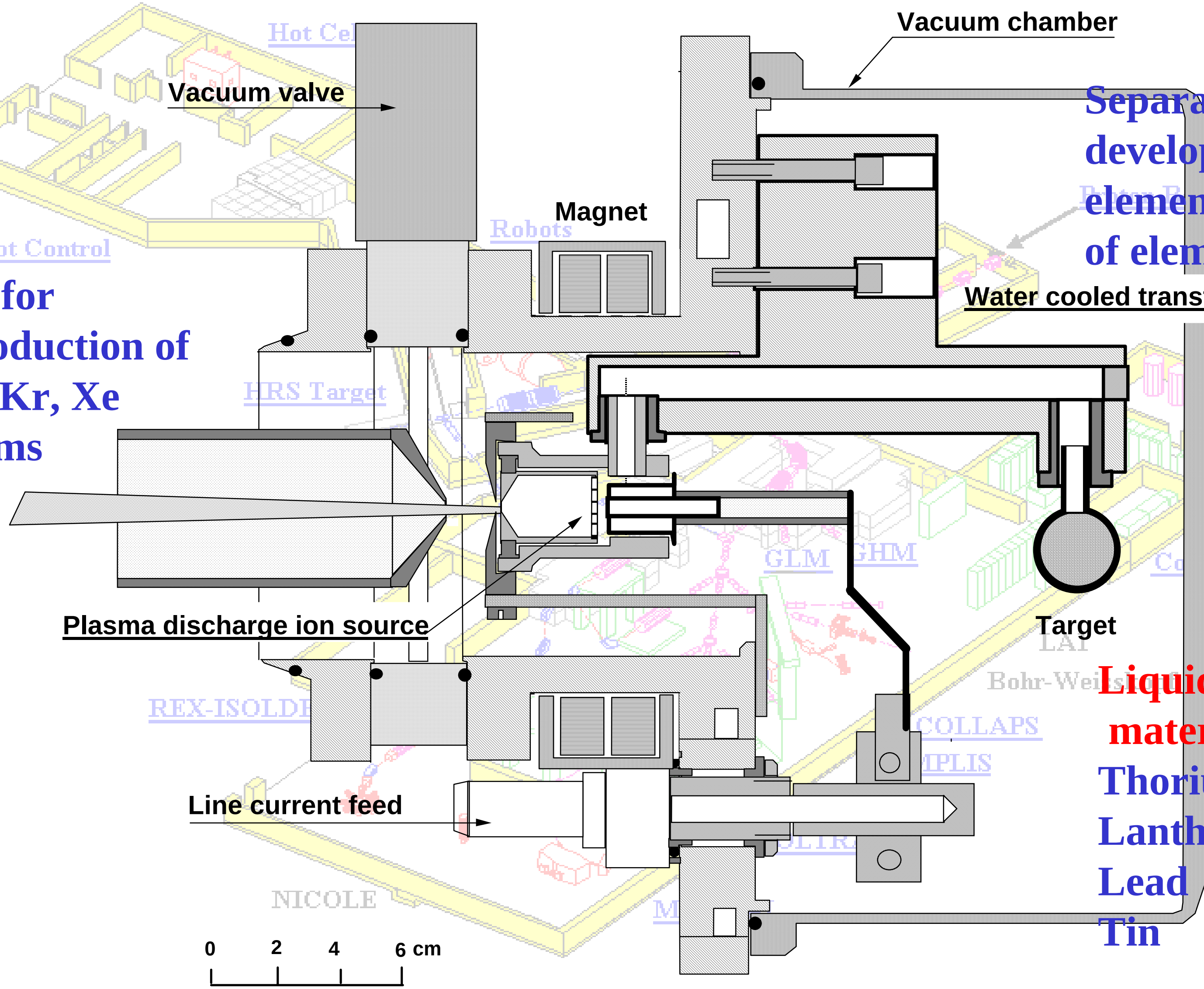
Release efficiency ε_1 ε_2 determined by the decay losses



The ISOLDE target and ion-source system

Target unit for selective production of He, Ne, Ar, Kr, Xe and Rn beams



Separate systems developed for each element or group of elements

Liquid metal target materials used:

Thorium alloys

Lanthanum

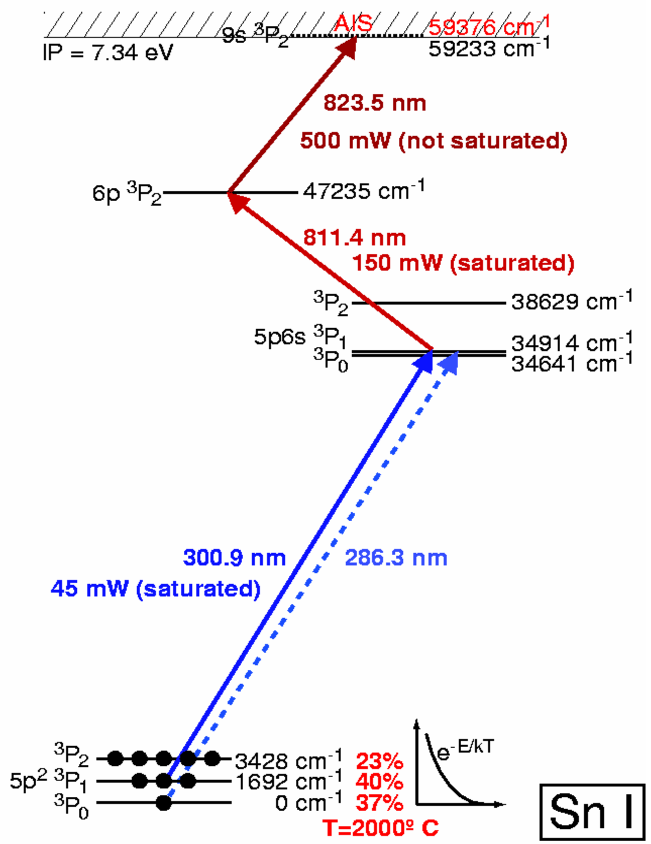
Lead

Tin

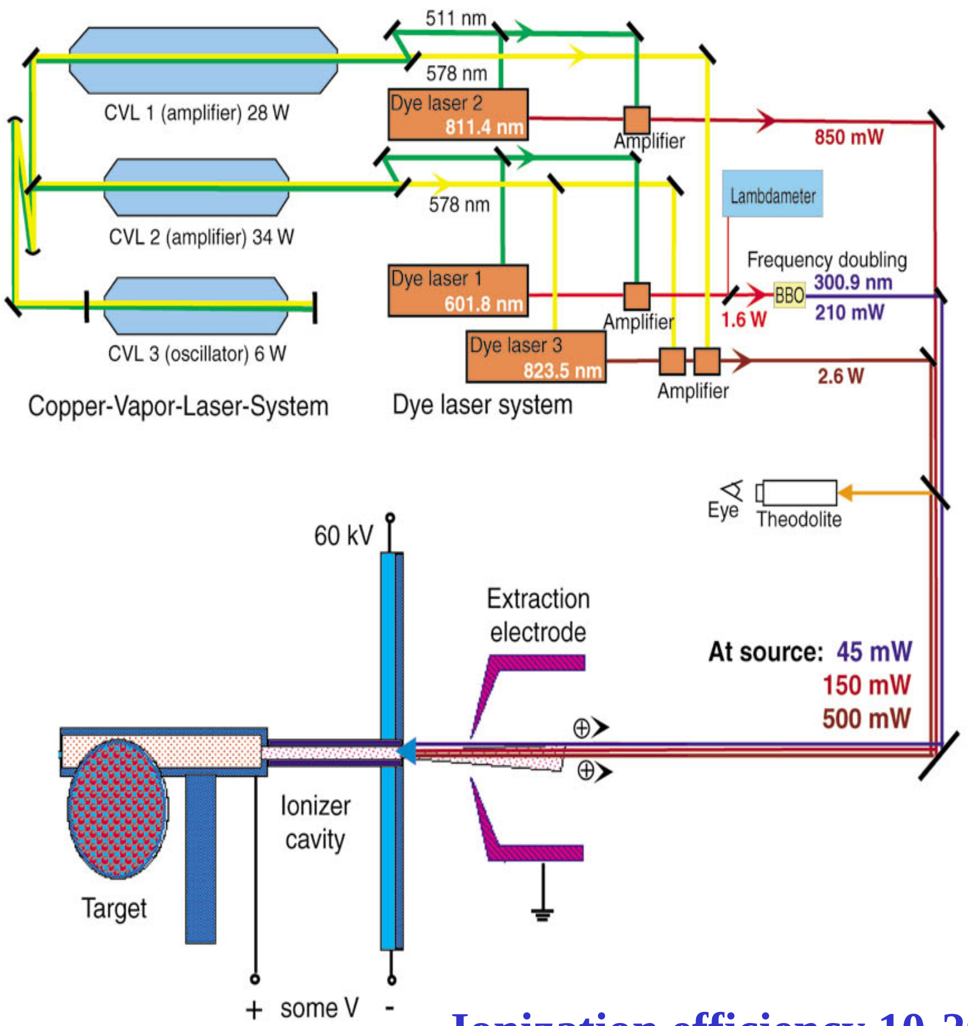
EURISOL

Stepwise resonant laser ionization of Tin

Ionization scheme for Tin



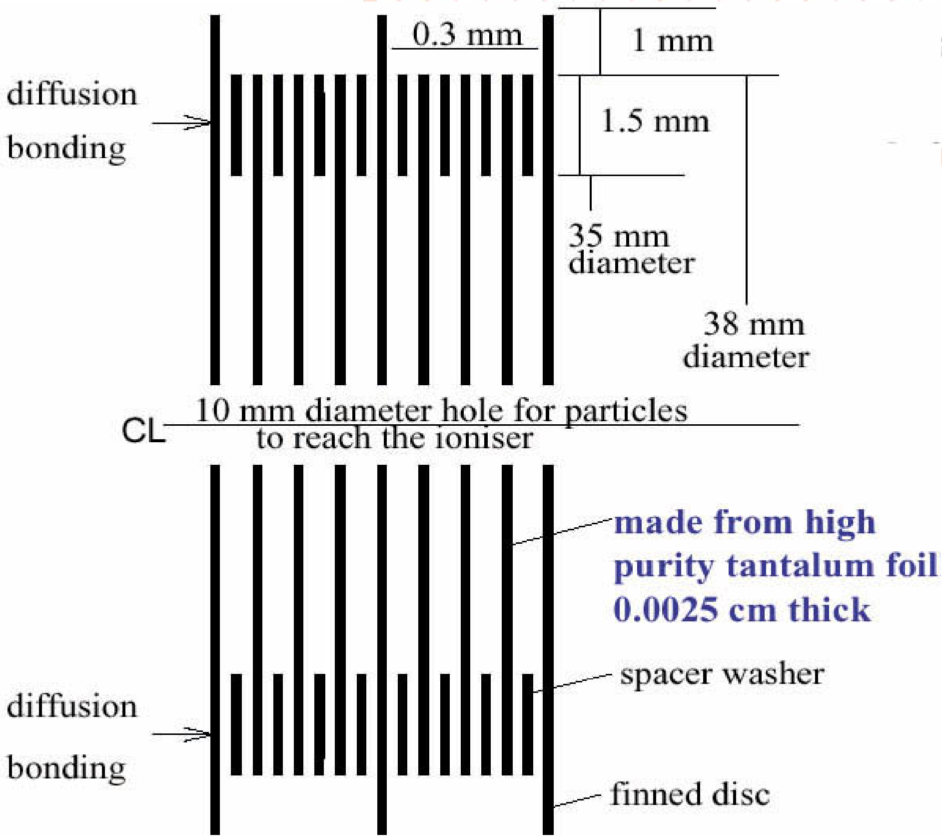
Three fine structure components of the ground state are thermally populated, but only one can be excited at a time. A second UV laser (dotted line) could roughly double the efficiency.



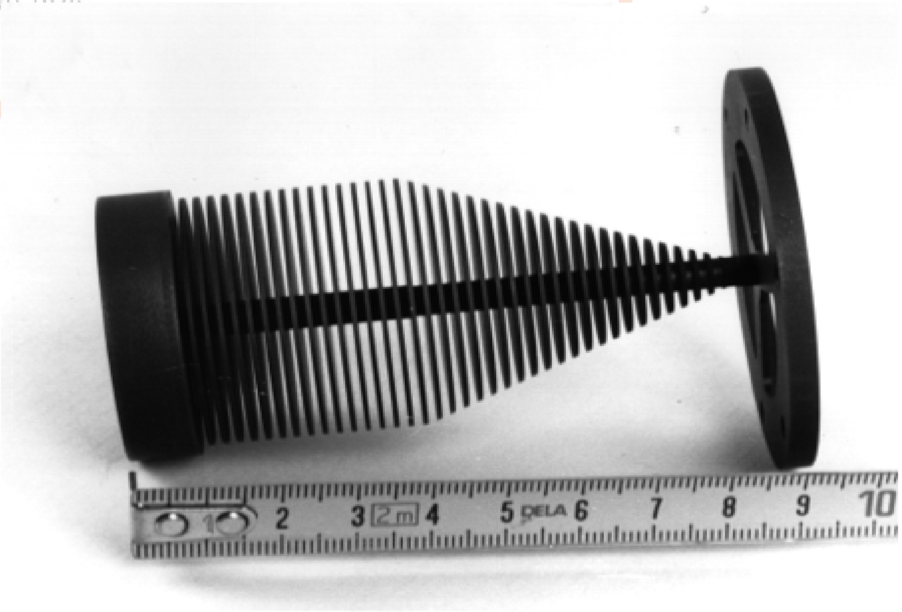
Ionization efficiency 10-20%

High power targets

30kW RIST Ta target



6kW GANIL C target



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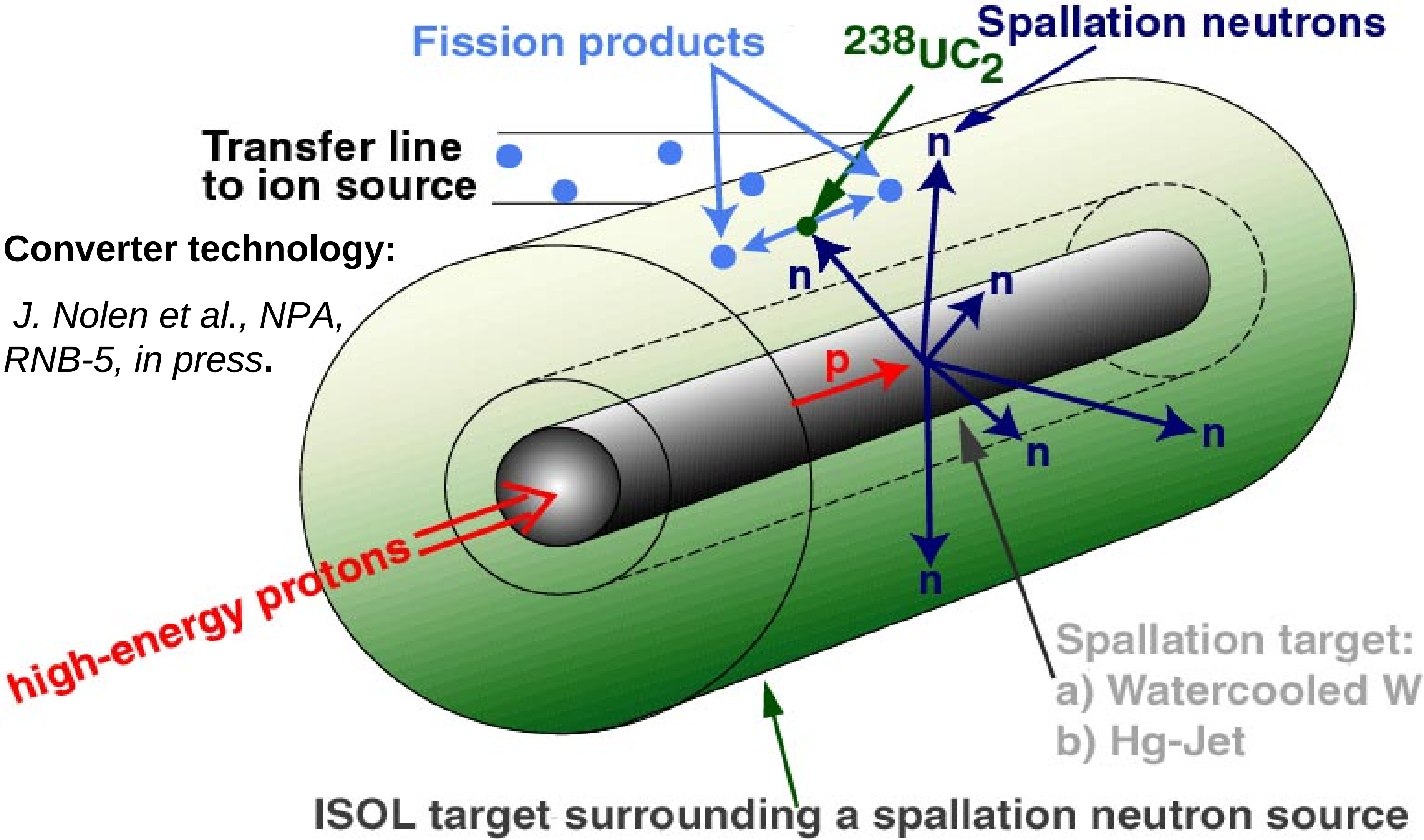
Power density ~5 MW/m^3

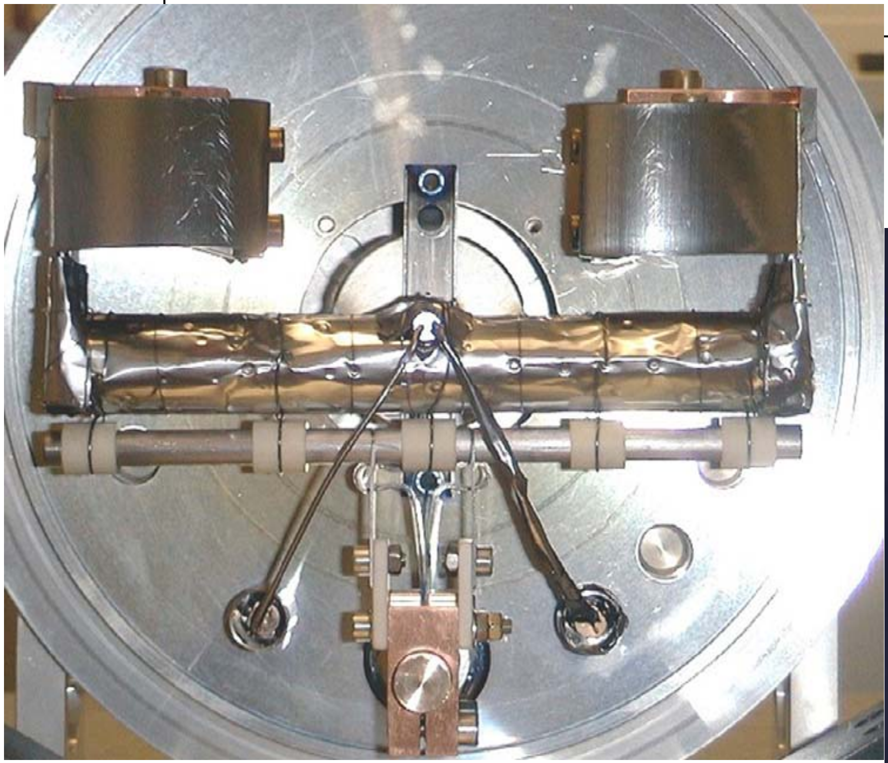
1 MW target for 10^{15} fissions per s

Converter technology:

J. Nolen et al., NPA, RNB-5, in press.



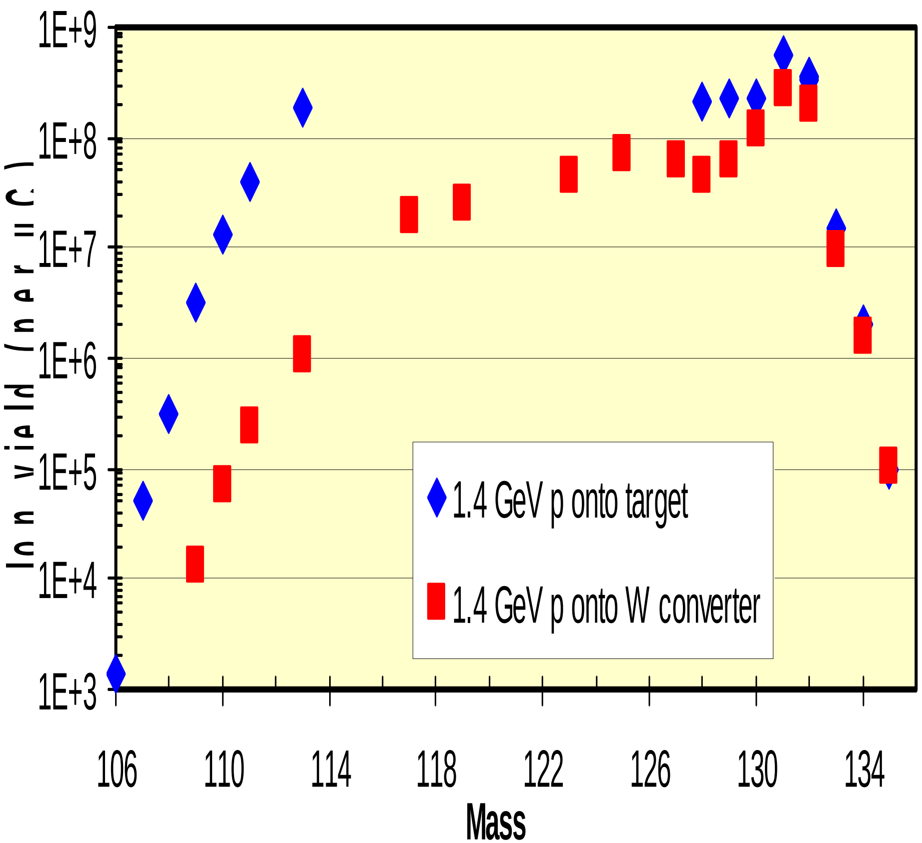
ISOLDE converter targets



Ta-converter mounted below the UC target before irradiation

Ta-rod after irradiation with 6E18 protons in 2.4 μs pulses of 3E13

Sn yields from a UC target



Today at ISOLDE:

$^{132}Sn^{+}$ intensity: 5.0E8 per s

with 2.5 μA of 1.4 GeV protons

onto 12.7 mm W converter

(release efficiency about 80%)

EURISOL:

1.0 GeV protons instead of 1.4 GeV	**0.7**
1 mA protons	**400**
cylindrical target	**10**
RILIS improvement	**5**
Total	**14000**

Expected intensity:

7E12 per s = 1 μA $^{132}Sn^{+}$

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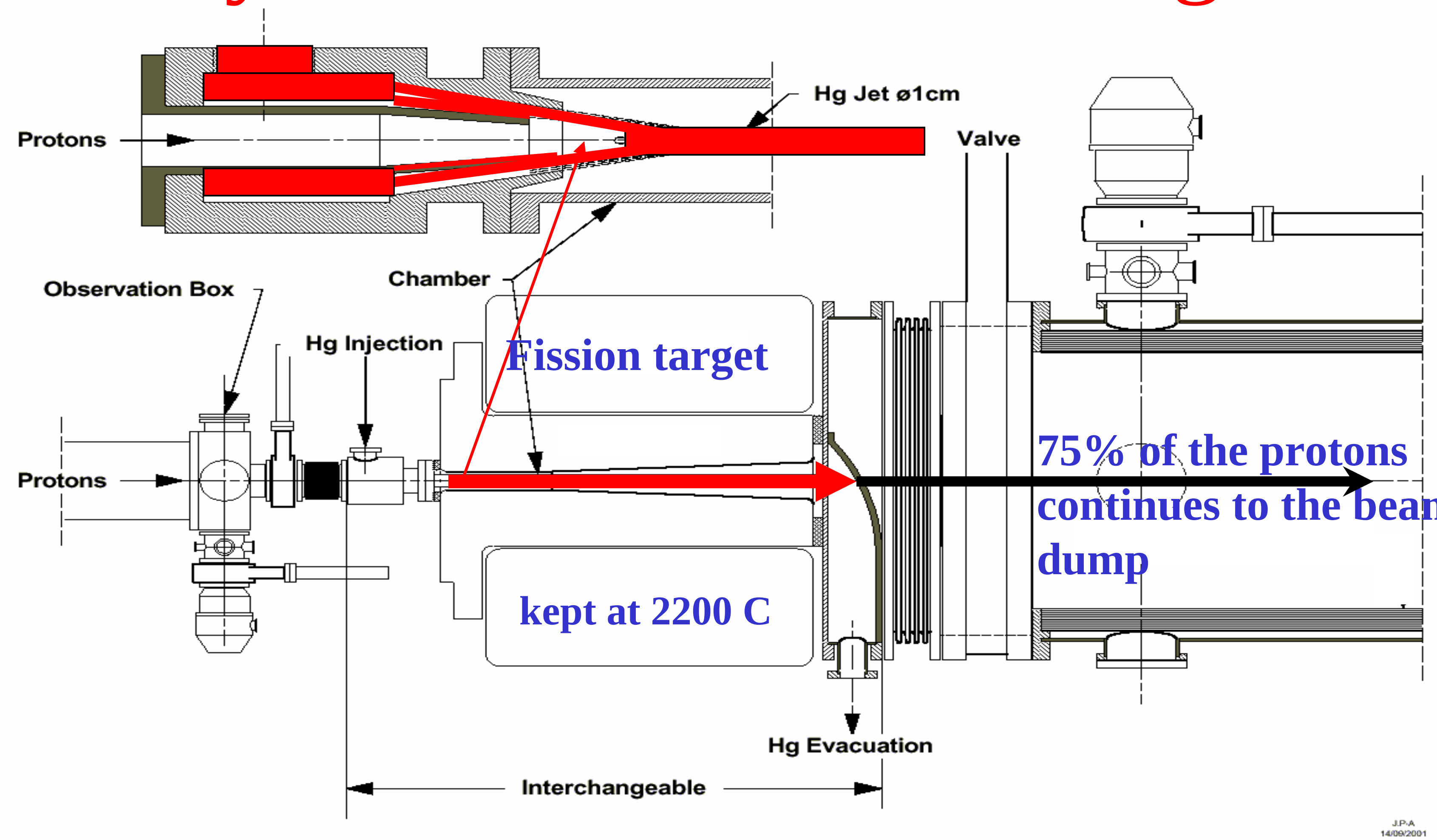
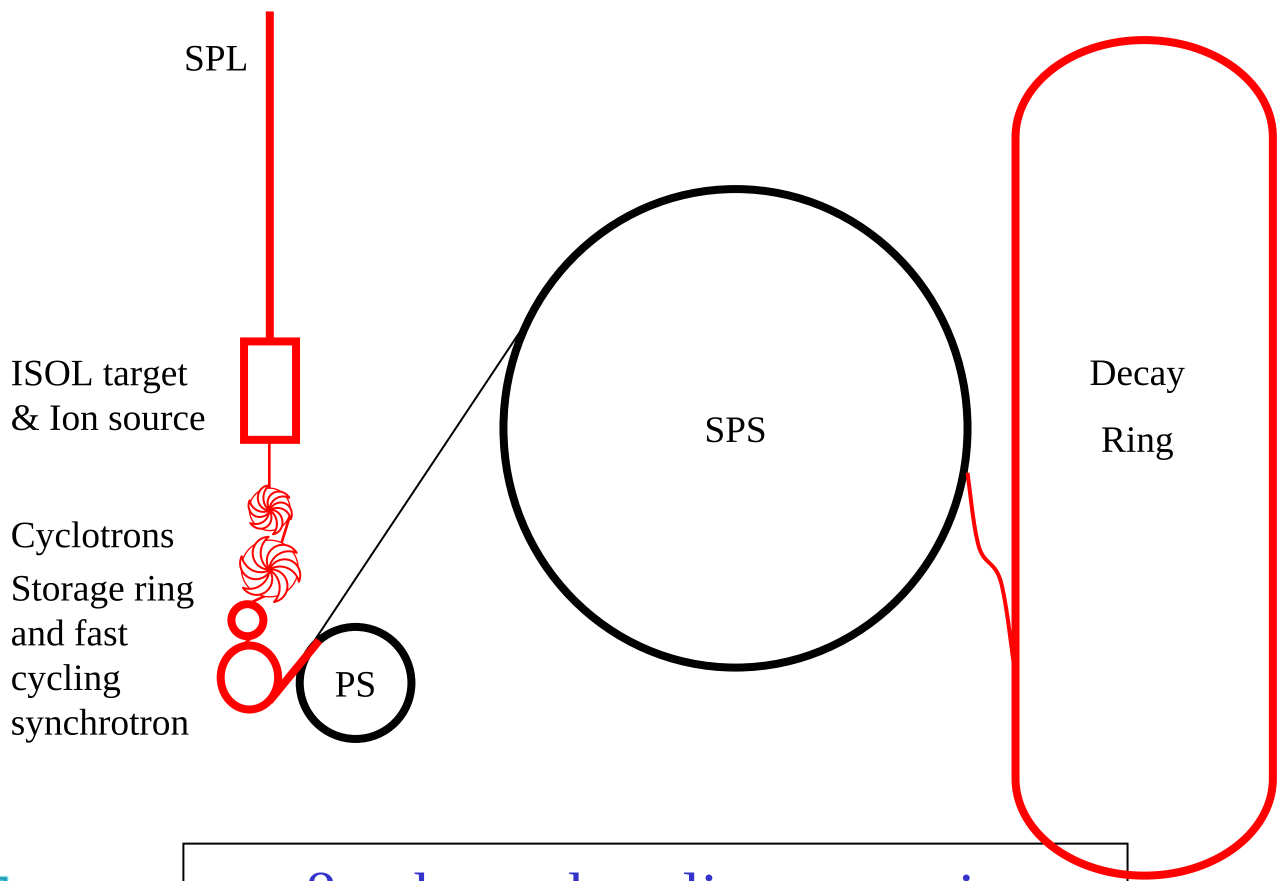
Mercury-jet p-n converter surrounded by a Uranium carbide target



Beta ν-beams

Why not solve the muon production and cooling problem by deriving neutrinos beams from stored short-lived beta emmitters (P. Zuchelli)



Decay ring

Brho = 1500 Tm

B = 5 T

L_{ss} = 2500 m

$^{6}_{2}He \to ^{6}_{3}Li\, e^{-} \overline{\nu}$

Average $E_{cms} = 1.937$ MeV

$^{18}_{10}Ne \to ^{18}_{9}Fe\, e^{+} \nu$

Average $E_{cms} = 1.86$ MeV

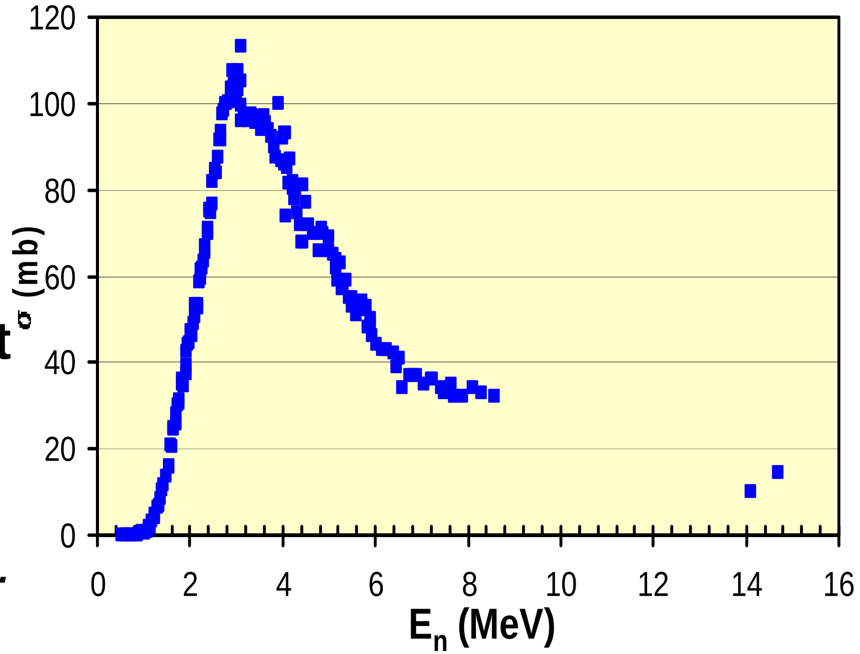
β-ν-beam baseline scenario

EURISOL

^{6}He production by ^{9}Be(n,α)

^{9}Be(n,α)^{6}He reaction favorable:

- **Threshold: 0.6 MeV**
- **Peak cross-section 105 mb**
- **Good overlap with evaporation part of spallation neutron spectrum: n(E)~√E*exp(-E/E$_e$)**
- **E$_e$: 2.06 MeV for 2 GeV p on Pb** *G.S. Bauer, NIM A463 (2001) 505*
- **BeO very refractory**



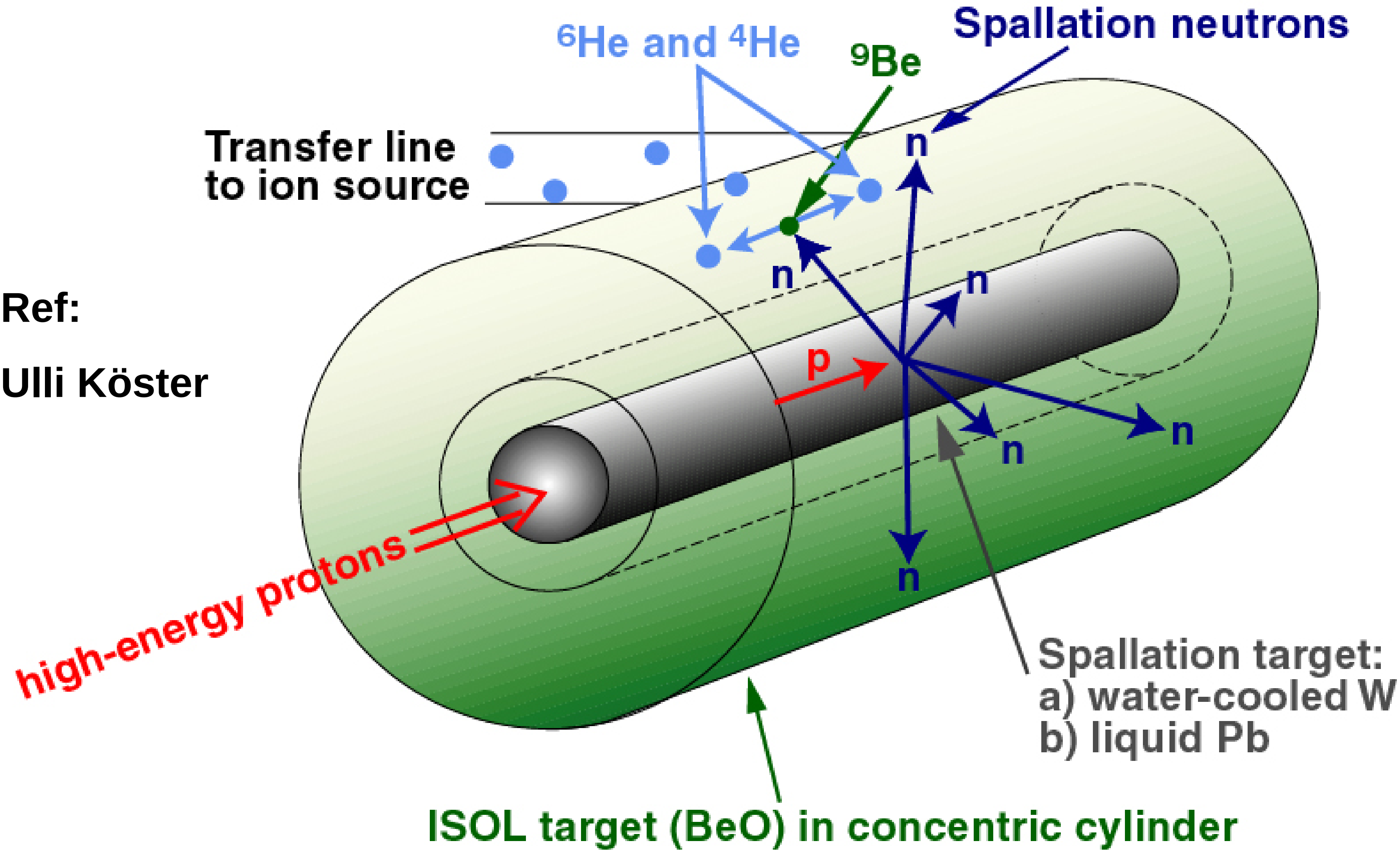
^{6}Li(n,p)^{6}He reaction less interesting:

- **Threshold: 2.7 MeV**
- **Peak cross-section 35 mb**
- **Li compounds rather volatile**

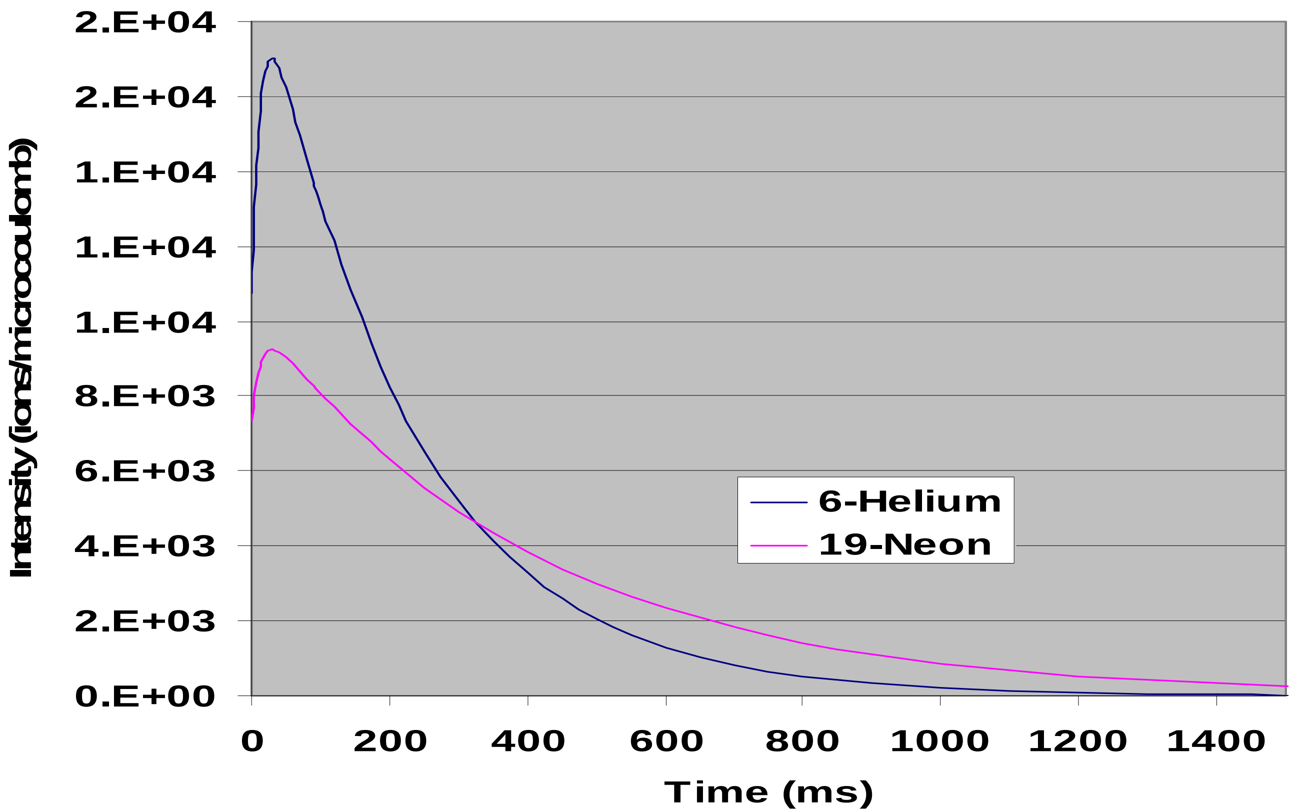
^{6}He production by $^{9}Be(n,\alpha)$

Ref:

Ulli Köster



He and Ne beam intensities



Target element and technique	Target thickness	Cross section	Proton driver beam		Rate in target	Transfer	6-He Beam
	g/cm2	cm2	Energy (GeV)	Intensity (mA)	atoms/s	efficiency	ions/s
MgO target technology presently operating	3	1.00E-27	1	0.004	1.86E+09	0.025	4.65E+07
BeO technology improved with known technique and SPL	30	1.00E-26	1	0.1	4.65E+12	0.25	1.16E+12
New BeO target technology to be developed for SPL	30	1.00E-26	2.2	2.5	3.14E+14	0.25	7.84E+13
Mercury-jet target technology to be developed for SPL	800	2.60E-26	2.2	2.5	9.75E+14	0.05	4.88E+13
			Spallation neutrons (n,α)				
BeO with converter technology under development and SPL	3	6.80E-25	2.2	2.5	2.13E+15	0.25	5.33E+14

GANIL/ISOLDE ECR ion-sources

Design principle

- Permanent magnets
- RF=2.45 GHz, <50 W
- Simple
- Radiation sensitive

ISOLDE construction team

+ **Jacques Lettry Fredrik Wenander**

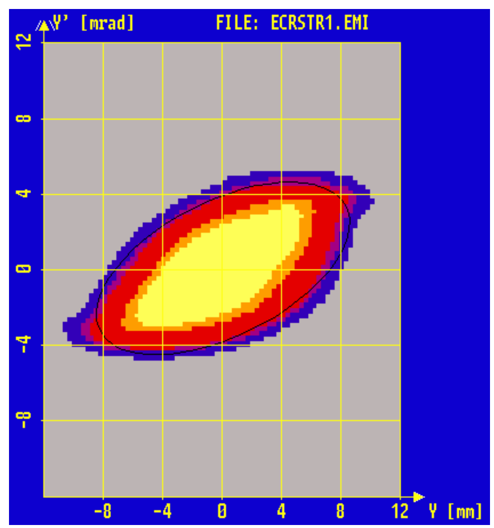
* Original design GANIL's MINIMONO, G. Gaubert, P. Jardin, R. Leroy

Expected performances

- **Aimed for noble gases and N_2 and S_2**

	Efficiency	**$T_{response}$(50%)**
He	**0.01% to 20%**	**20 ms**
Ne	**0.05% to 35%**	**30 ms**
Ar	**7.0% to 95%**	**40 ms**
Kr	**40% to 95%**	**40 ms**

Measured beam phase-space



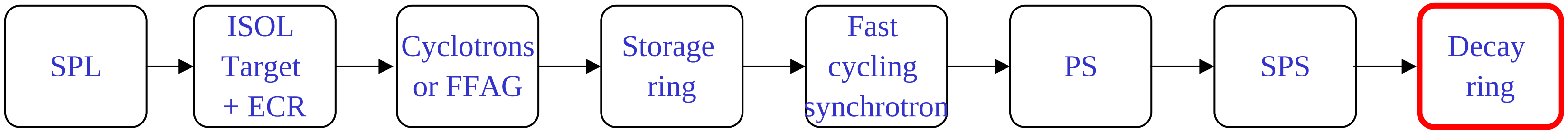
43 π mm mrad (95%) at 30 keV

Within standard target unit

Present status

- Plasma ignited
- Beam extracted
- Ar^+ efficiency of 25%
- Severe sparking problems!
- Upgrade power supplies
- Complicated puller design
- Off-line tests October
- On-line next year?

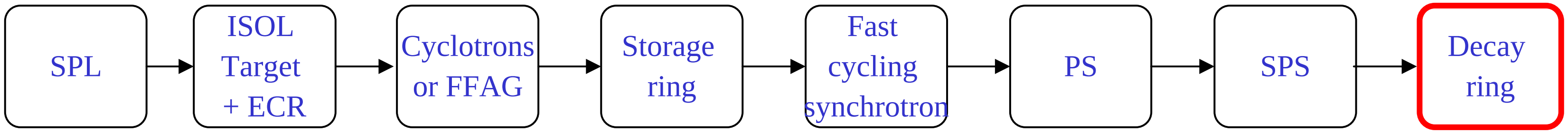
Intensities: ^{6}He



- From ECR source: $2.0\text{x}10^{13}$ ions per second
- Storage ring: $1.0\ \text{x}10^{12}$ ions per bunch
- Fast cycling synch: $1.0\ \text{x}10^{12}$ ion per bunch
- PS after acceleration: $1.0\ \text{x}10^{13}$ ions per batch
- SPS after acceleration: $0.9\text{x}10^{13}$ ions per batch
- Decay ring: $2.0\text{x}10^{14}$ ions in four 10 ns long bunch
  - Only β-decay losses accounted for, efficiency <50%

$$\bar{\nu}_e$$

Intensities: ^{18}Ne



- From ECR source: $0.8\mathrm{x}10^{11}$ ions per second
- Storage ring: $4.1\ \mathrm{x}10^{10}$ ions per bunch
- Fast cycling synch: $4.1\ \mathrm{x}10^{10}$ ion per bunch
- PS after acceleration: $5.2\ \mathrm{x}10^{11}$ ions per batch
- SPS after acceleration: $4.9\ \mathrm{x}10^{11}$ ions per batch
- Decay ring: $9.1\mathrm{x}10^{12}$ ions in four 10 ns long bunch
  - Only β-decay losses accounted for, efficiency <50%

ν_e

Subjects for Target R&D

- Optimization of the release from ISOL targets by determination of diffusion and desorption parameters (EU Project: TARGISOL)
- Participation in R&D of the liquid metal cooled p to n converter target.
- High power fission-target design and and cooling.
- Improvement of the bunching and charge breeding
- Layout and safety aspects of the target station and support laboratory.

Road map

- **Next 10 years RIB physics covered by the existing facilities or their possible upgrades**
- **Pre conceptual design study for EURISOL exists**
- **Next 4 years a design study of the facility is planned**
- **Next 4 years several joint R&D networks on ion-source developments are planned**
- **CERN, GANIL and Legnaro are possible sites for EURISOL**

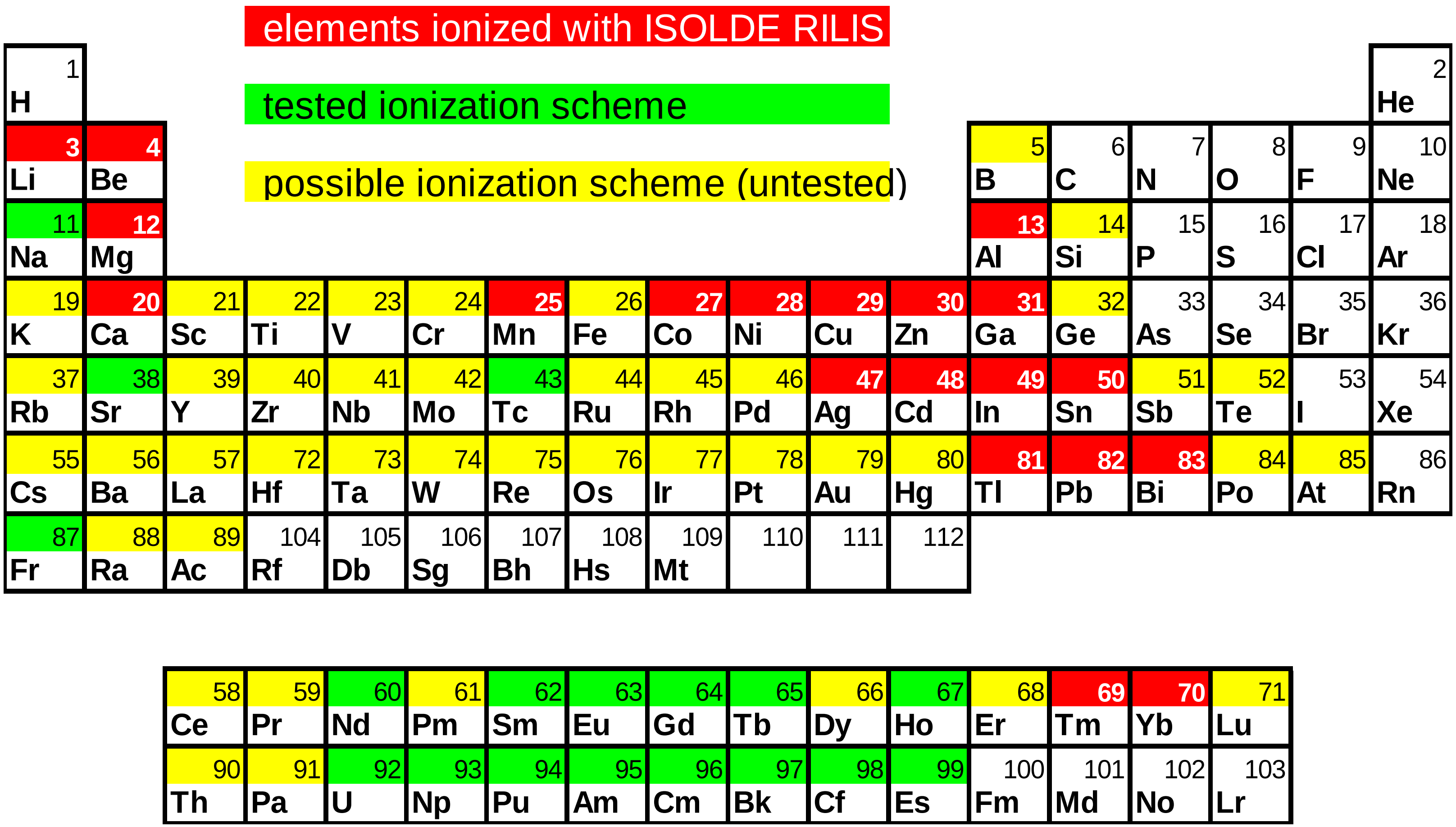
Conclusion and outlook

- **The ISOL methods has reached a stage where it may become the target and source in new high intensity RIB and beta-ν facilities.**
- **Optimization of the release from ISOL targets by determination of diffusion and desorption parameters will make further intensity increases.**
- **Proton driver beams in the 0.1-4 MW class may be used.**
- **Collaboration between high power target users needed in order to achieve the R&D on the liquid metal targets.**

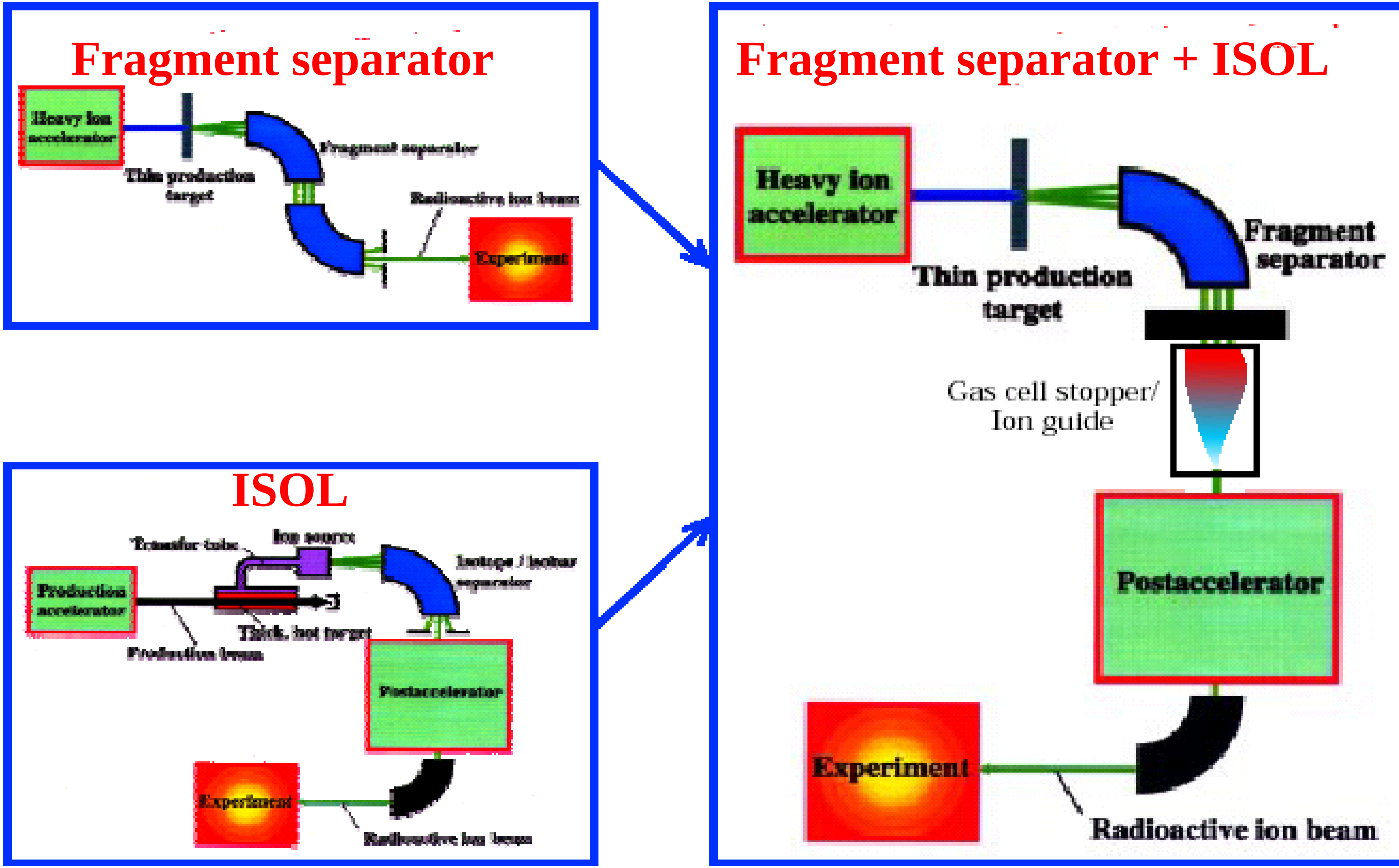
- **A baseline scenario for the beta-beam at CERN exists**
- **While, possible solutions have been proposed for all identified bottlenecks we still have problems to overcome and…**
- **…it is certainly possible to make major improvements!**
  - **Which could result in higher intensity in the decay ring!**
- **First results are so encouraging that the beta-beam option should be fully explored.**

RILIS elements

Resonance Ionization Laser Ion Source, using Copper Vapor Lasers

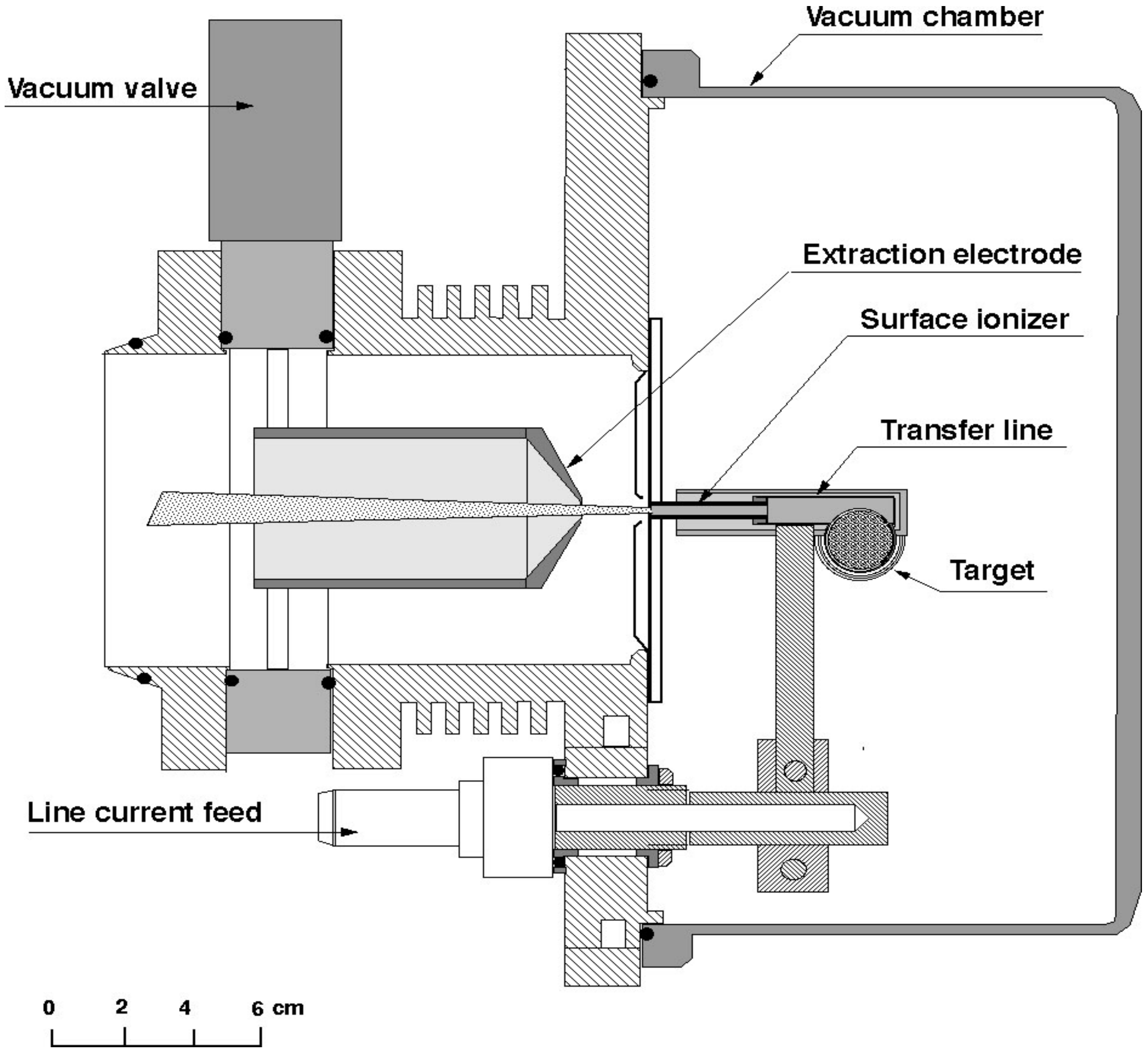


Principles of radioactive ion-accelerators



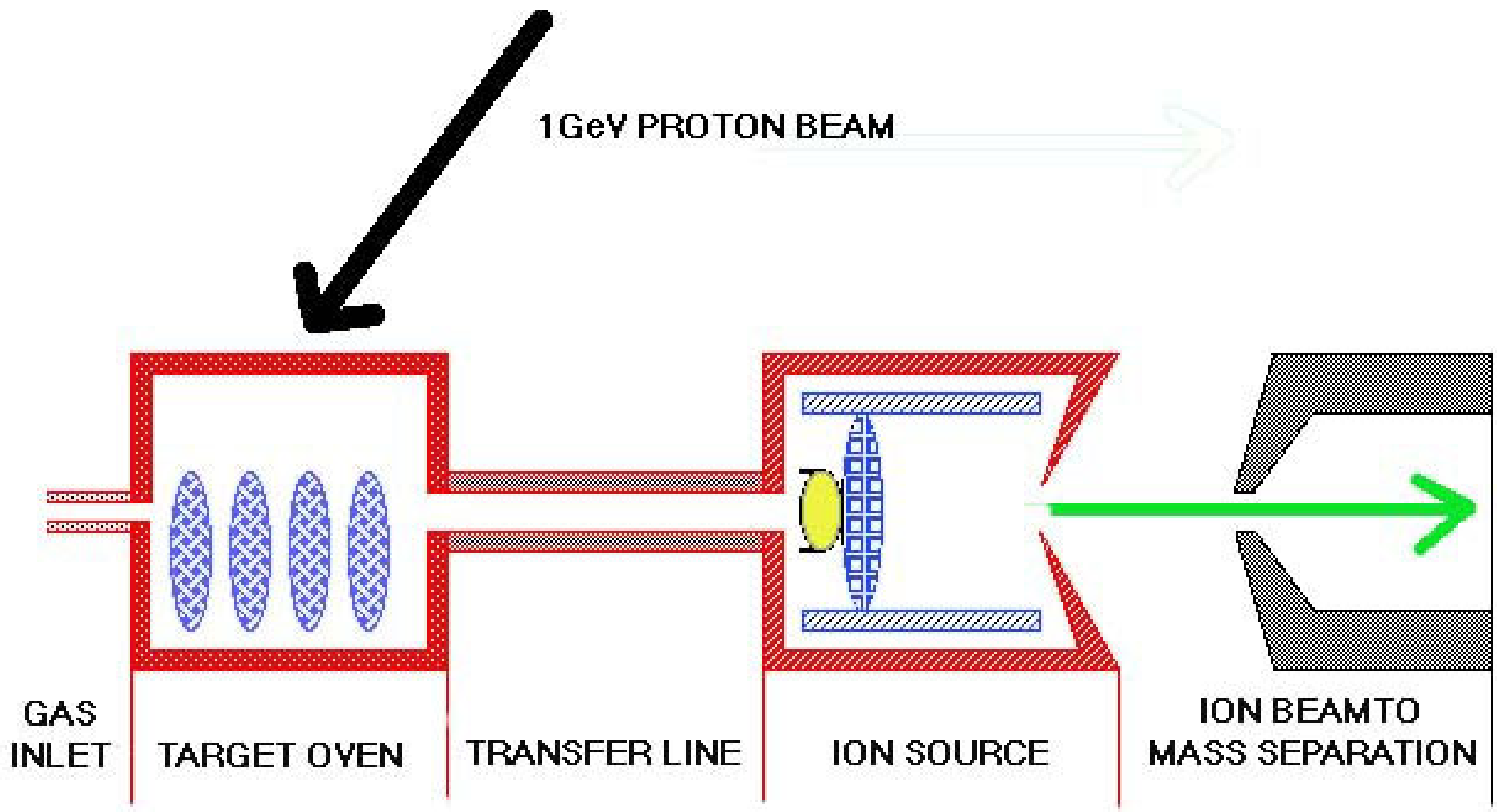
Result of CERN study

- A baseline scenario for the beta-beam at CERN exists
- While, possible solutions have been proposed for all identified bottlenecks we still have problems to overcome and…
- **…it is certainly possible to make major improvements!**
  - Which could result in higher intensity in the decay ring!
- First results are so encouraging that the beta-beam option should be fully explored
  - Investigate sites at other existing accelerator laboratories
  - Study a "Green field" scenario


Vacuum chamber
Vacuum valve
Extraction electrode
Surface ionizer
Transfer line
Target
Line current feed
0 2 4 6 cm

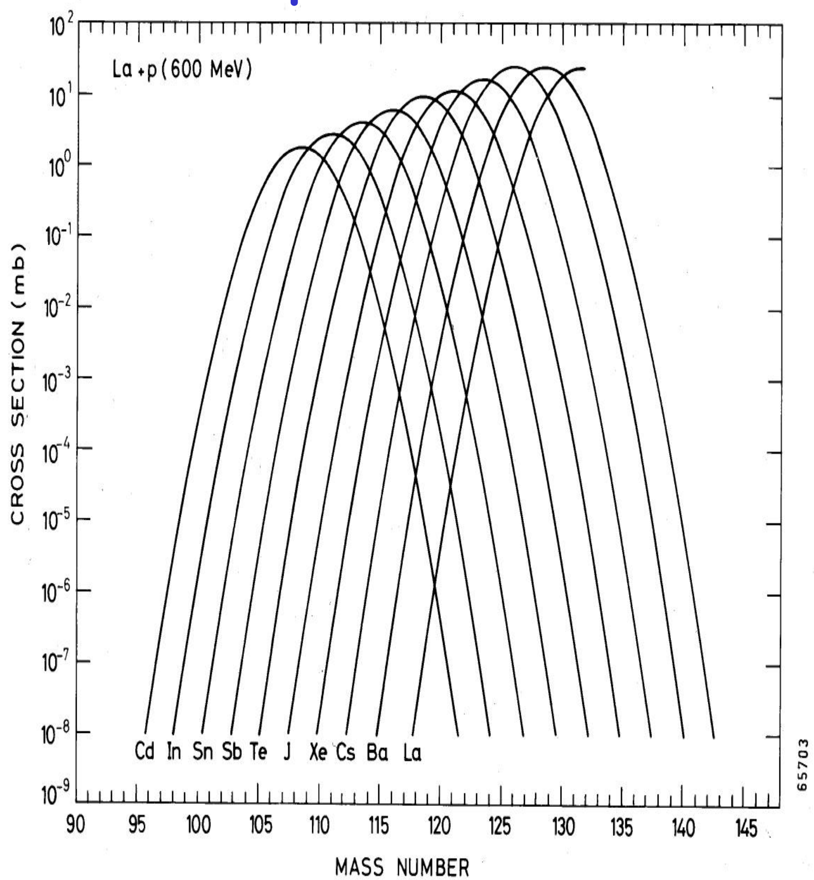
EURISOL

The principle of the integrated target and ion source



The need for selectivity

Spallation of La with 0.6 GeV protons



Fission of U with 1 Gev protons