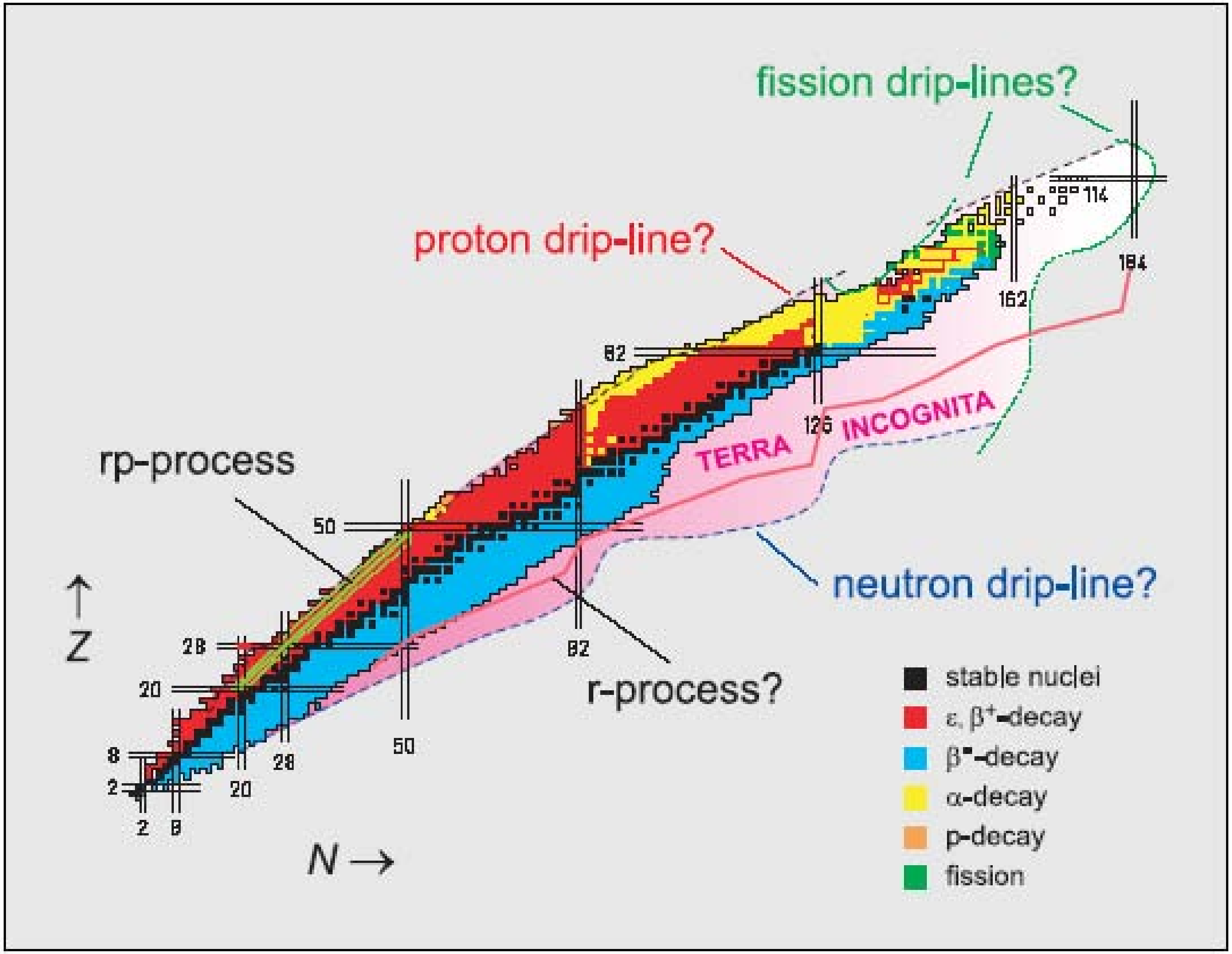
Review of ISOL-type Radioactive Beam Facilities

Mats Lindroos, CERN

Map of the nuclear landscape



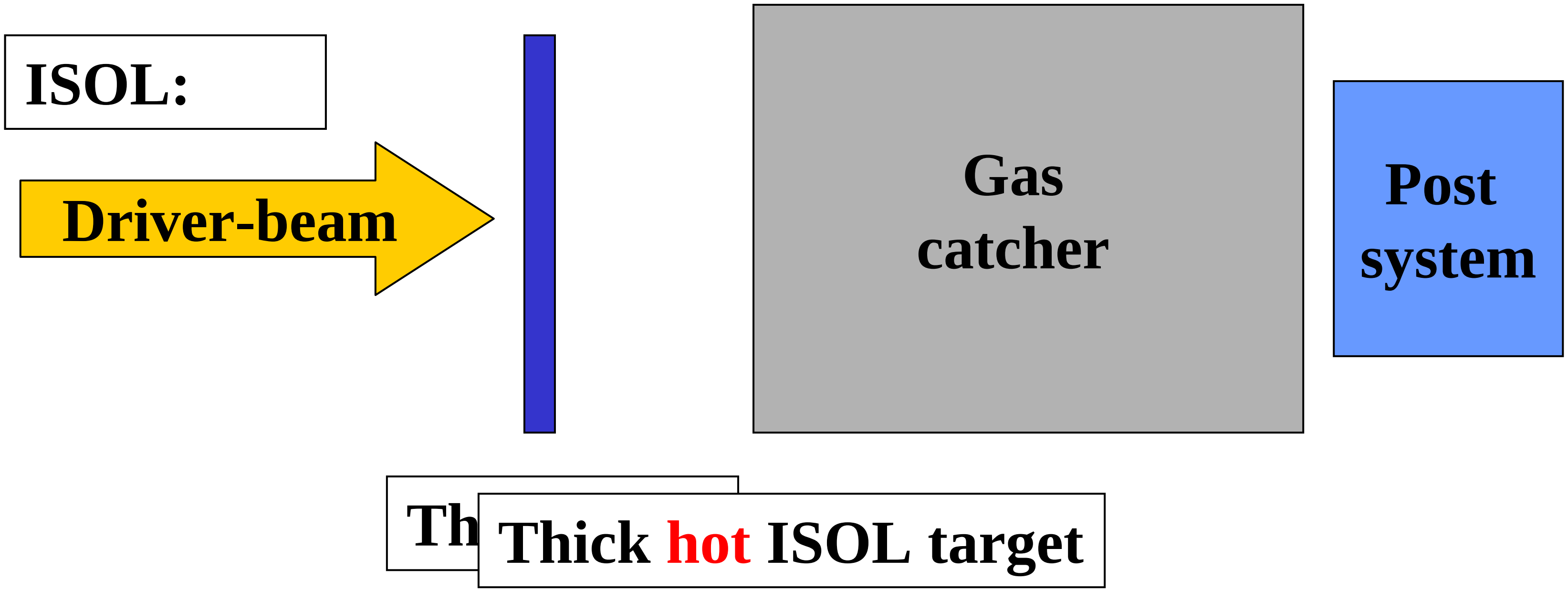
Outline

- The ISOL technique
  - History and Geography
  - Isotope Separation On-Line
- Existing facilities
  - First generation facilities
  - High beam power facility
- Future facilities and how we plan to get there!
- The beta-beam

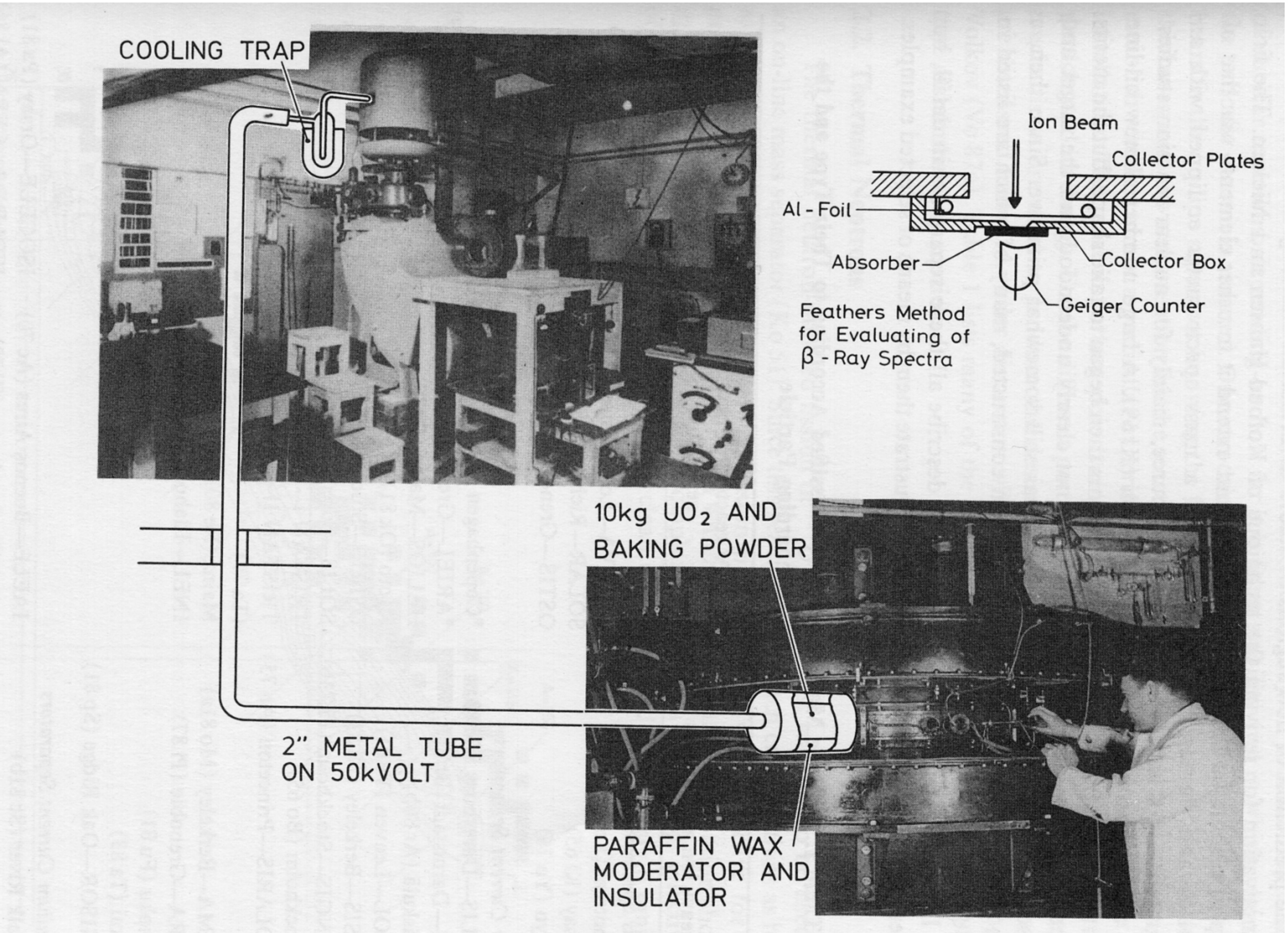
In-flight and ISOL

"ISOL: Such an instrument is essentially a target, ion source and an electromagnetic mass analyzer coupled in series. The apparatus is aid to be on-line when the material analyzed is directly the target of a nuclear bombardment, where reaction products of interest formed during the irradiation are slowed down and stopped in the system.

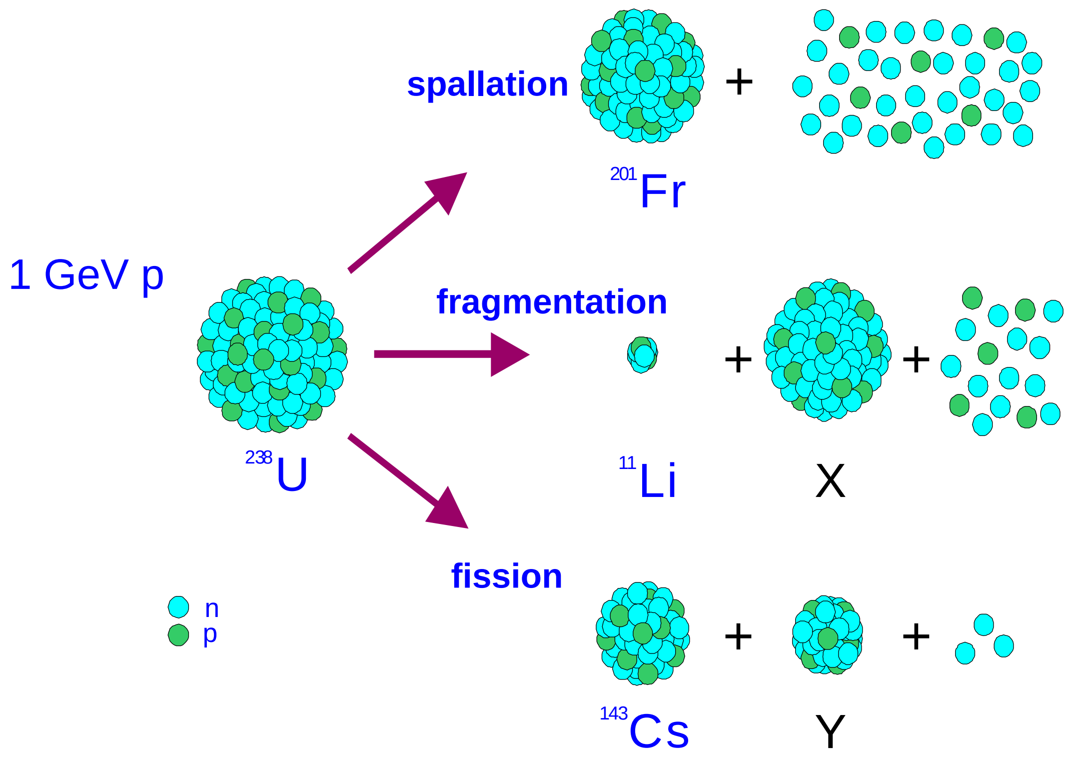
H. Ravn and B.Allardyce, 1989, Treatise on heavy ion science



ISOL: History



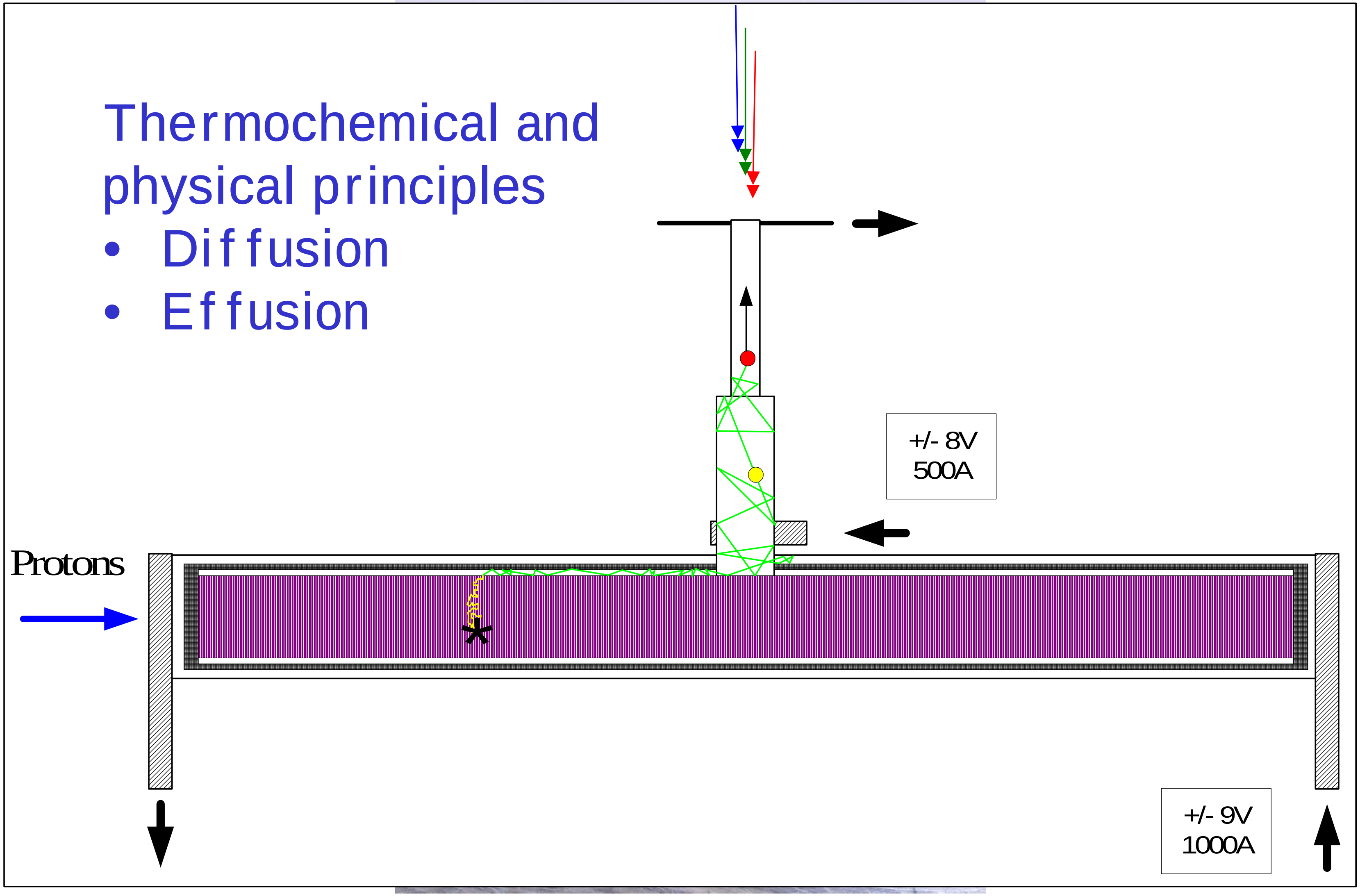
ISOL: The reaction products



The ISOL target

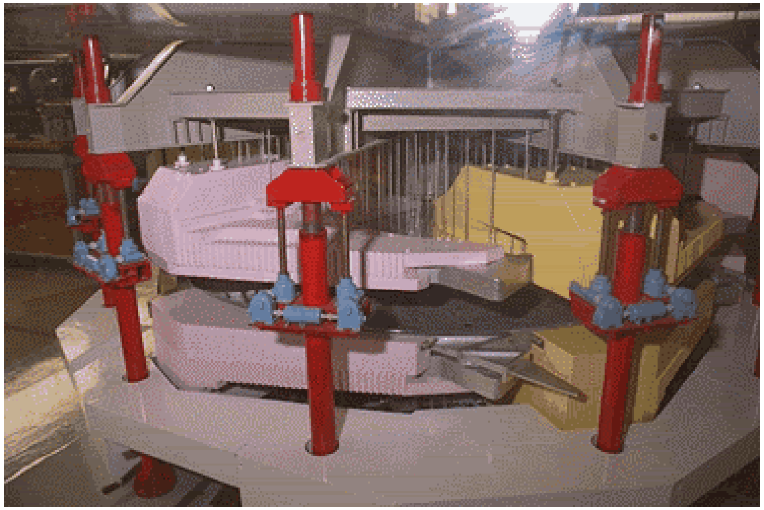
Thermochemical and physical principles

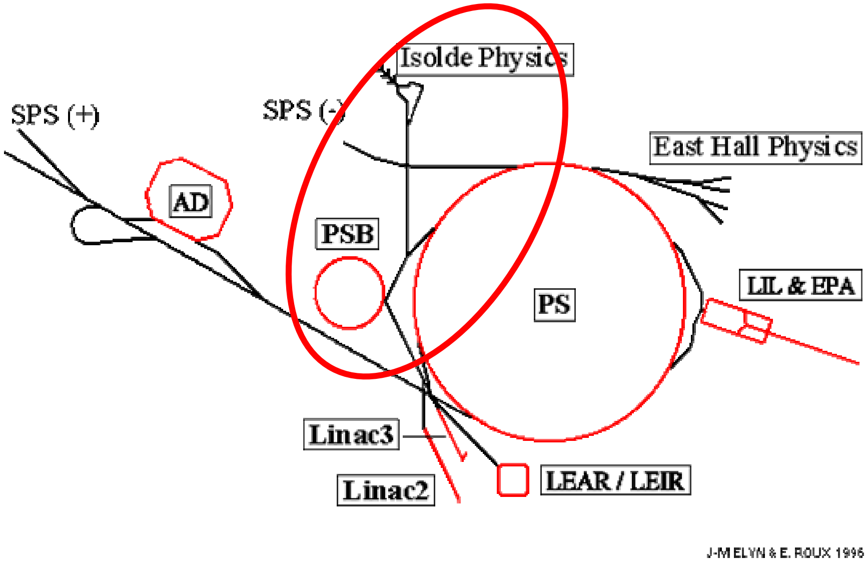
- Diffusion
- Effusion



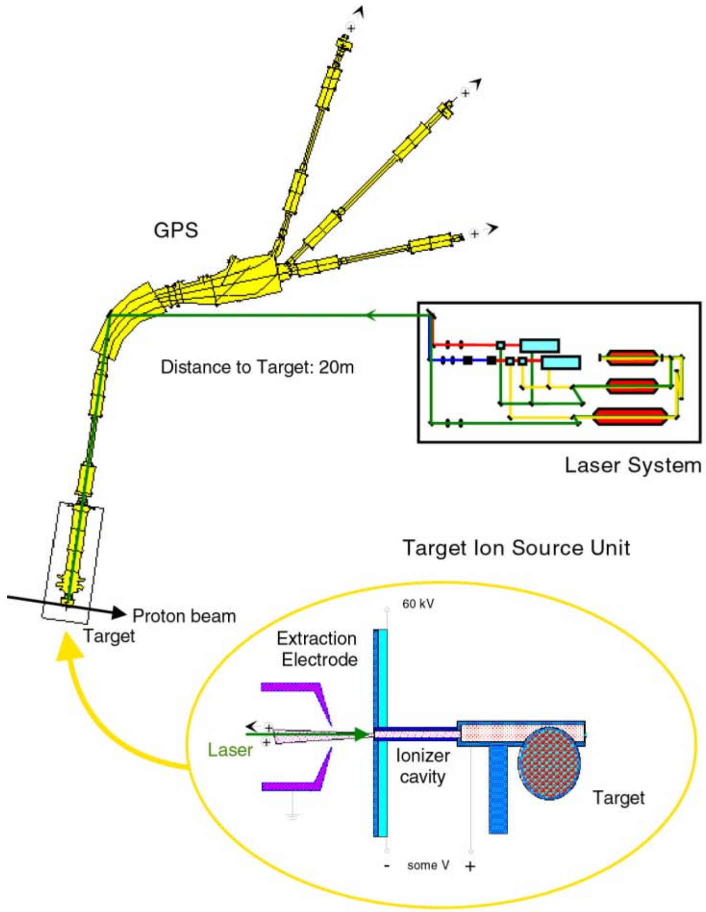
The ISOL driver

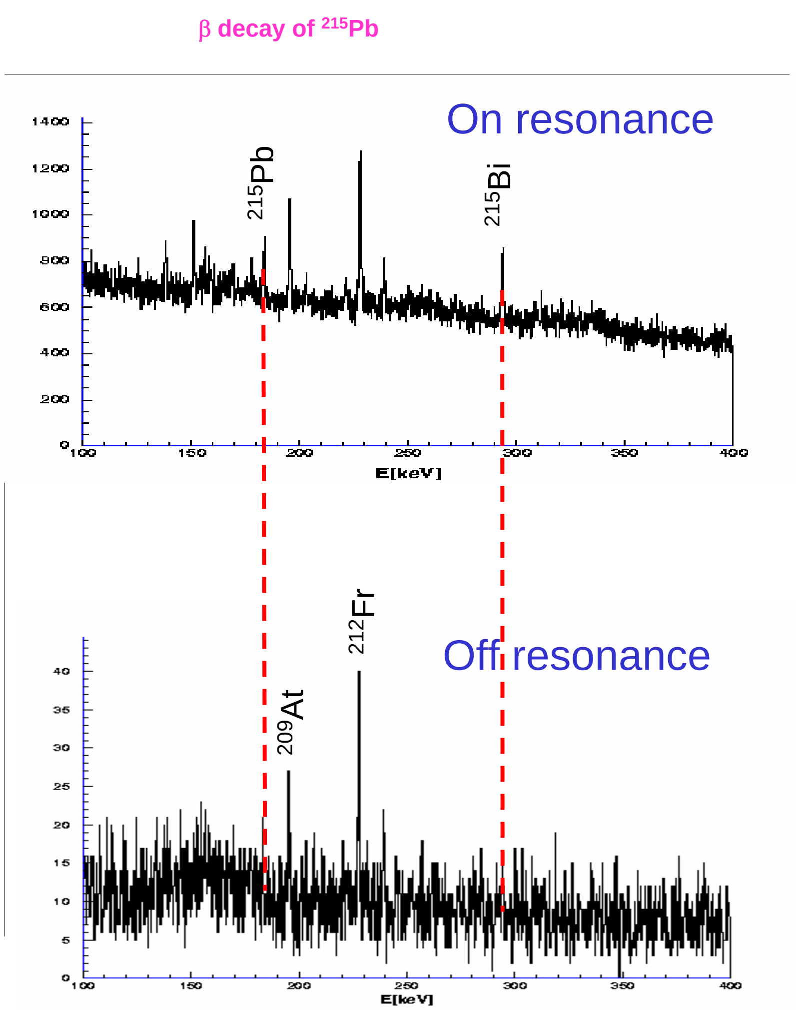
- Proton or ion machine
  - **Cyclotron**
  - **Synchrotron**
  - **Linac**
  - Tandem
  - **Reactor**
- Critical parameters
  - Cross section for reaction products and “good use” of proton beam
    - <2 GeV total energy
    - High intensity



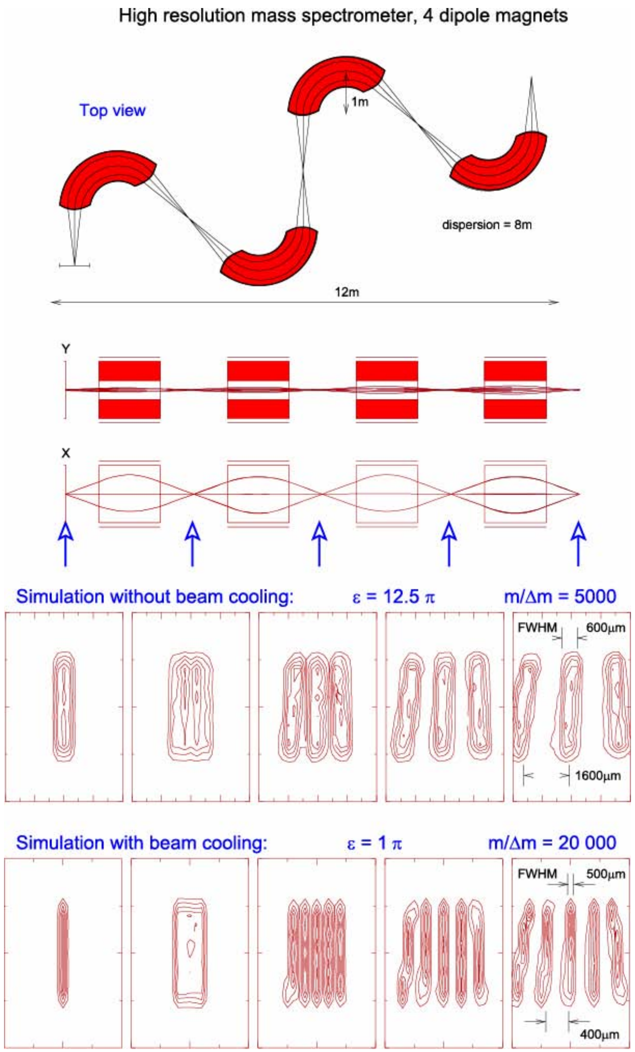


The ISOL ion source

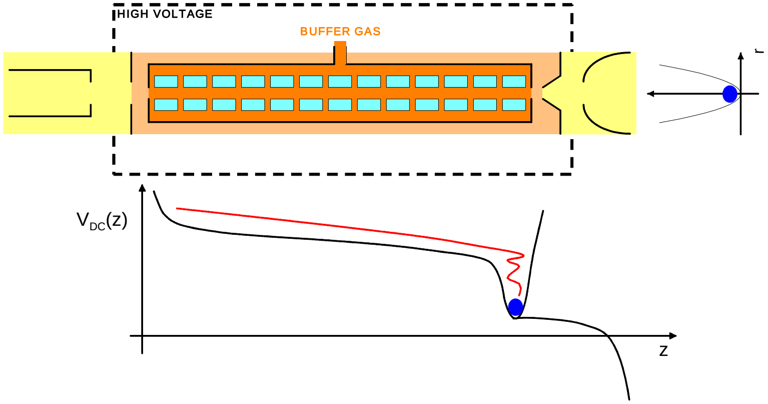




The ISOL separator

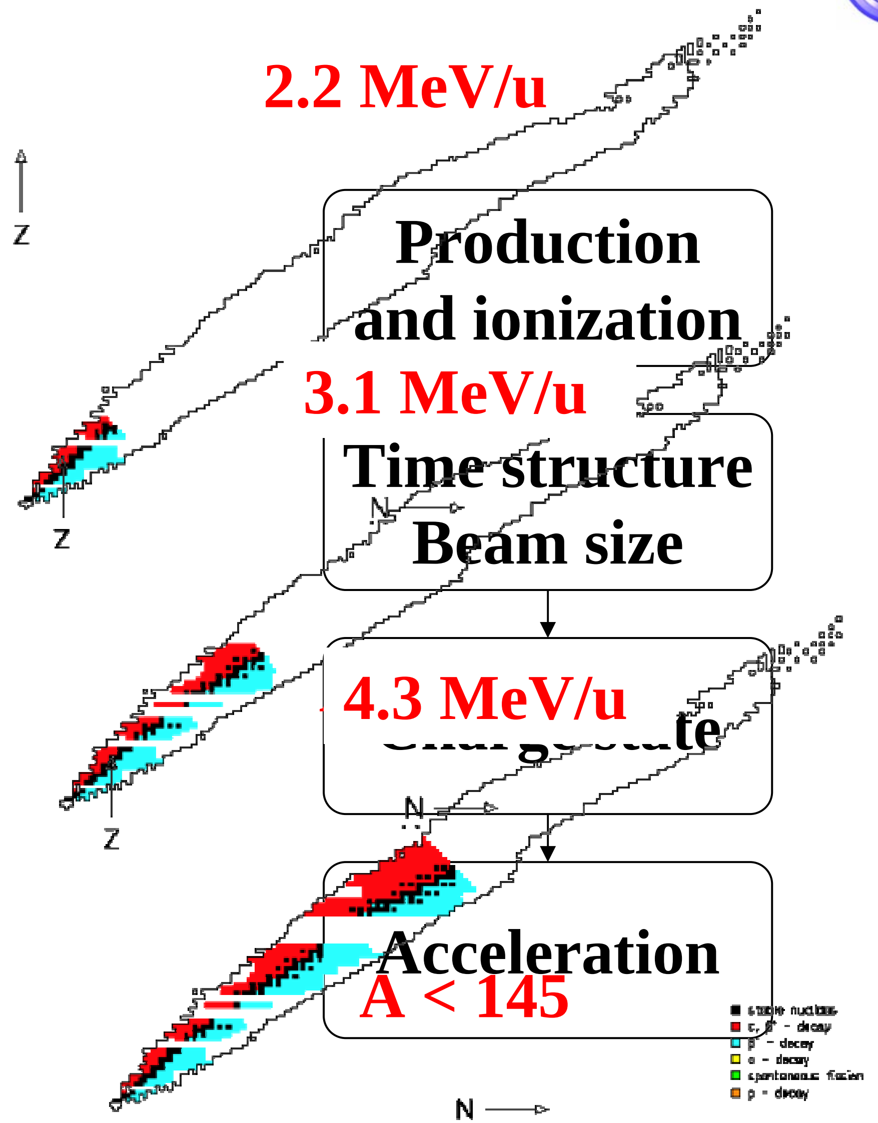


- “Isobaric” separation
- Separation limited by the beams transverse size
- Cooling at low energy with RFQ cooler

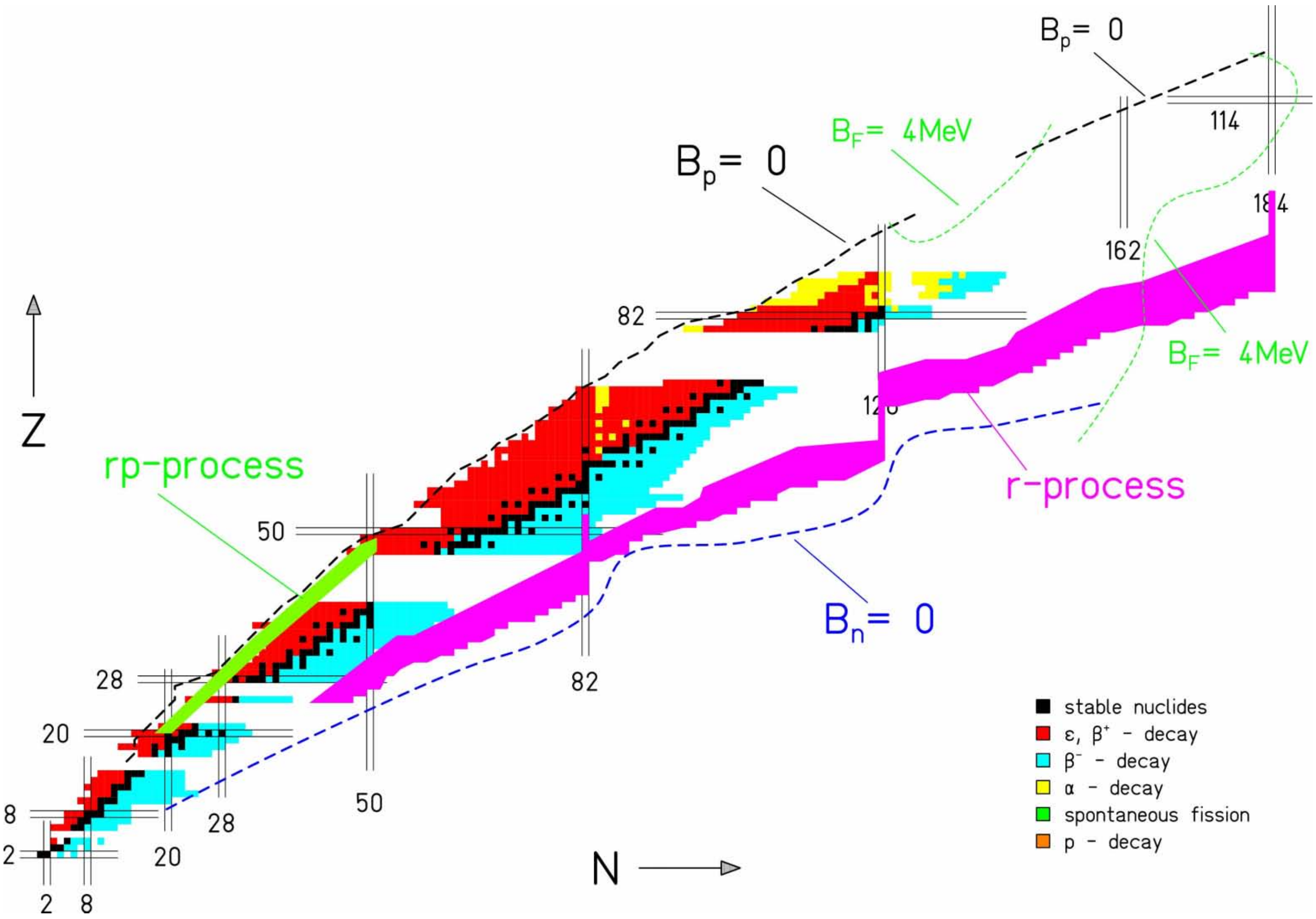


The ISOL Post-Accelerator

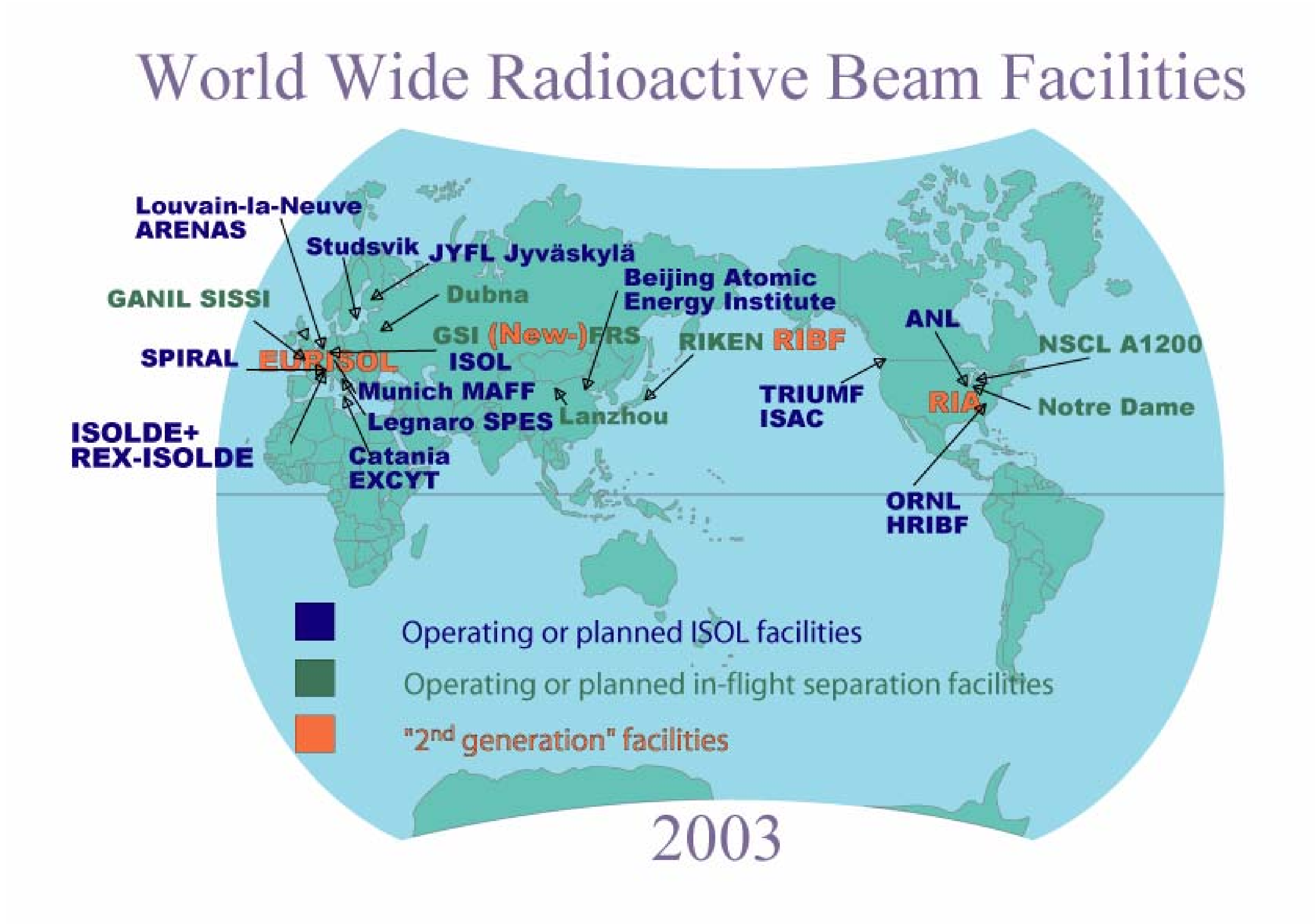
- Challenges when accelerating radioactive ions:
  - Low intensity
  - Short half lives
  - Charge state



The Nuclear chart according to ISOL(DE)



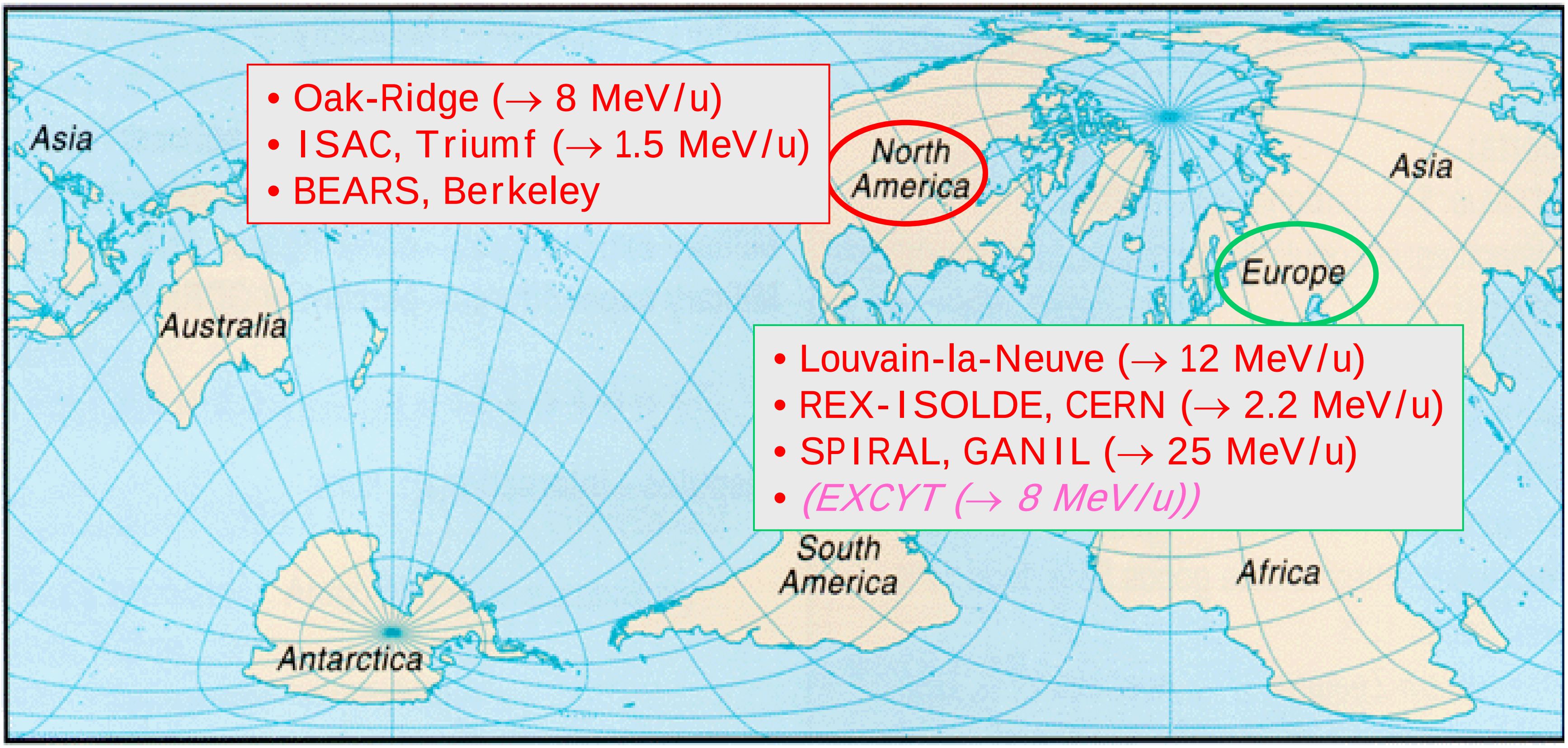
ISOL: Geography



First generation ISOL RNB facilities

Location	RIB Starting Date	Driver	Post-accelerator
Louvain-la-Neuve Belgium	1989	Cyclotron p, 30 MeV, 200 μA	Cyclotrons *K* = 110, 44
SPIRAL: GANIL Caen, France	2001	2 cyclotrons heavy ions up to 95 *A* MeV, 6 kW	cyclotron CIME *K* = 265, 2–25 *A* MeV
REX ISOLDE: CERN Genève, Switzerland	2001	PS booster p, 1.4 GeV, 2 μA	Linac 0.8-3.1 *A* MeV
EXCYT Catania, Italy	2004	K=800 cyclotron heavy ions	15-MV tandem 0.2–8 *A* MeV
HRIBF Oak Ridge, USA	1997	Cyclotron p, d, α, 50-100 MeV, 10-20 μA	25-MV tandem
ISAC-I: TRIUMF Vancouver, Canada	2000	Cyclotron p, 500 MeV, 100 μA	Linac up to 1.5 *A* MeV

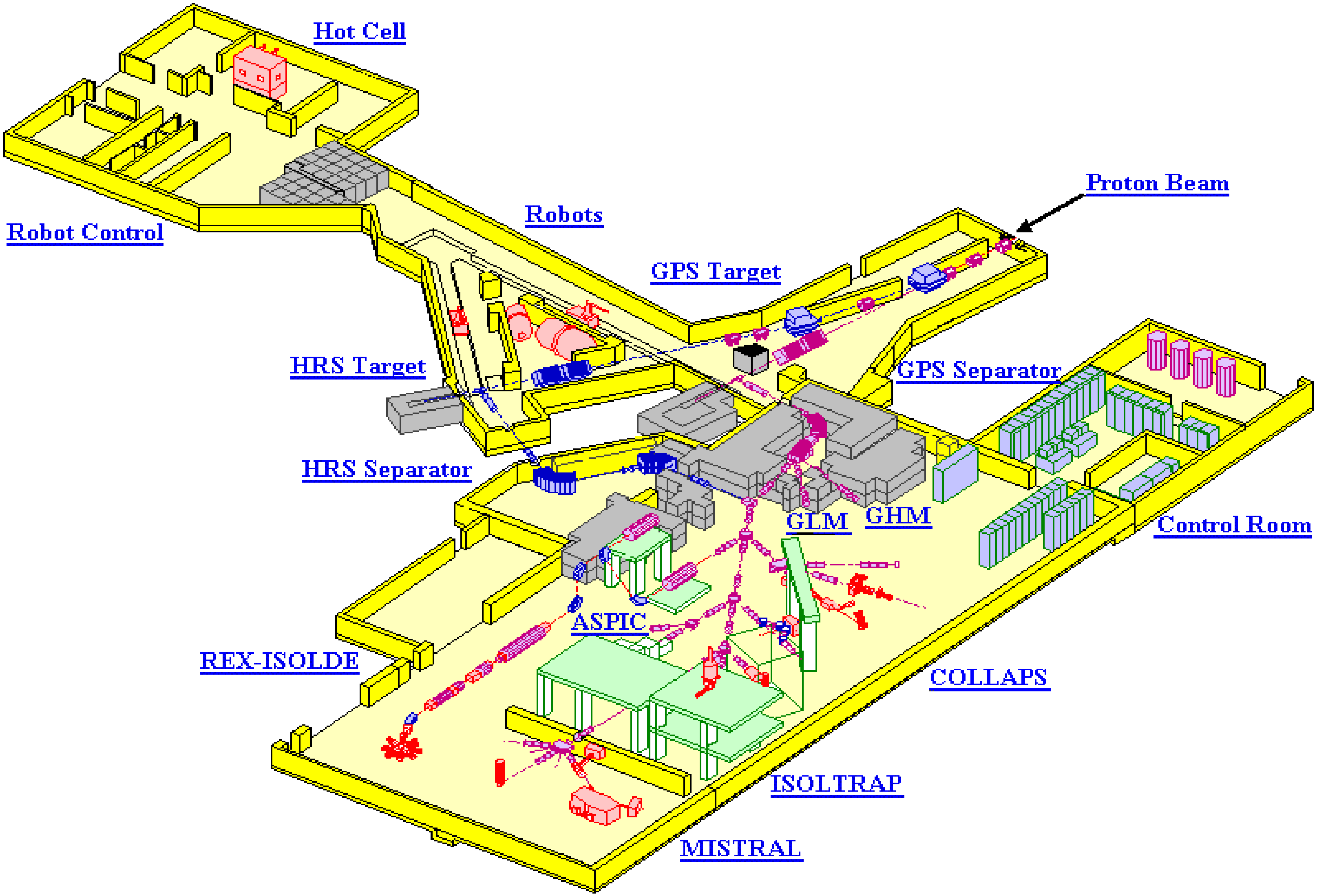
First generation ISOL facilities



- Oak-Ridge (→ 8 MeV/u)
- ISAC, Triumf (→ 1.5 MeV/u)
- BEARS, Berkeley

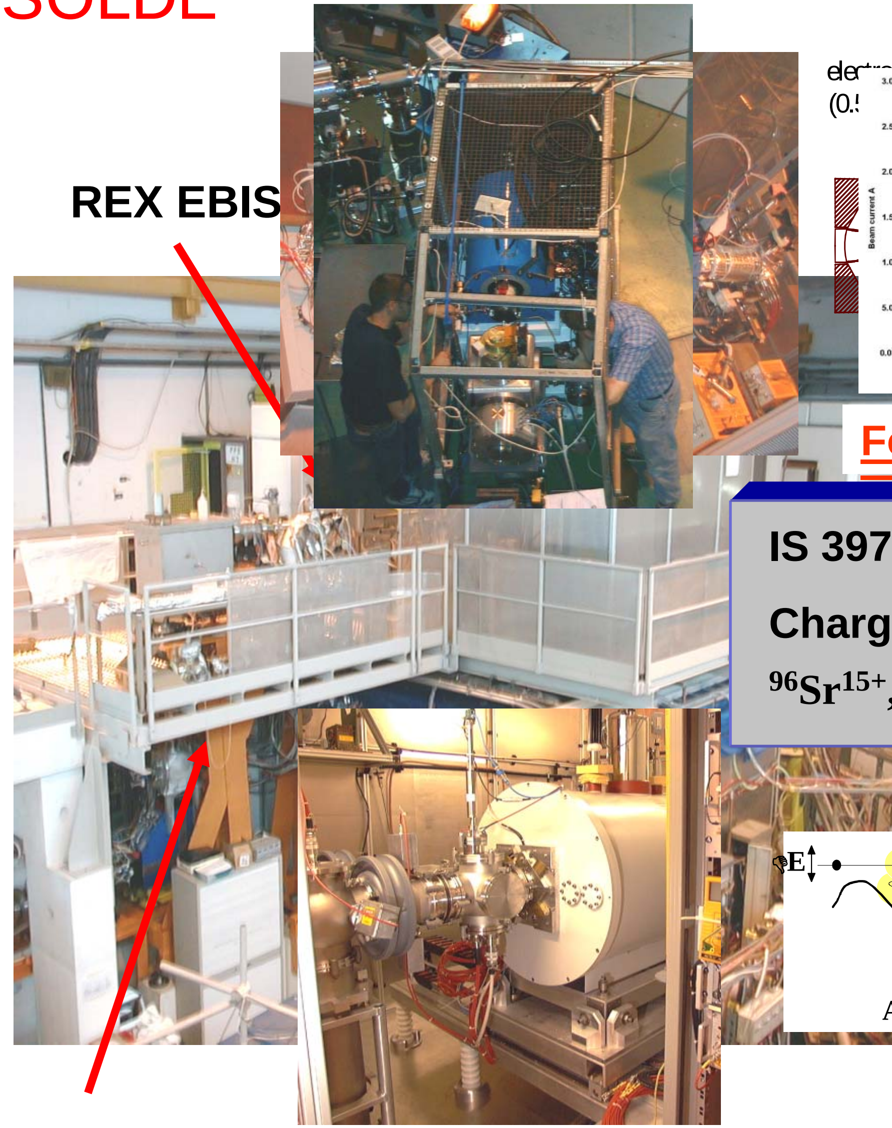
- Louvain-la-Neuve (→ 12 MeV/u)
- REX-ISOLDE, CERN (→ 2.2 MeV/u)
- SPIRAL, GANIL (→ 25 MeV/u)
- *(EXCYT (→ 8 MeV/u))*

ISOLDE


Hot Cell
Robot Control
Robots
GPS Target
Proton Beam
HRS Target
GPS Separator
HRS Separator
GLM
GHM
Control Room
ASPIC
REX-ISOLDE
COLLAPS
ISOLTRAP
MISTRAL

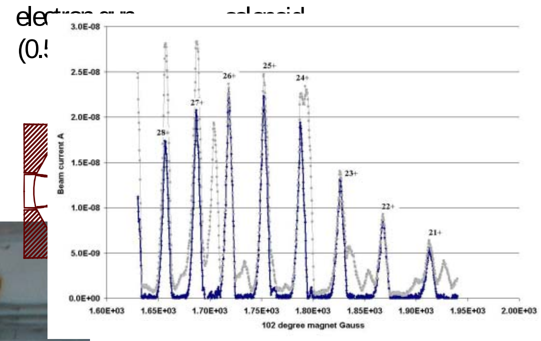
ISOLDE

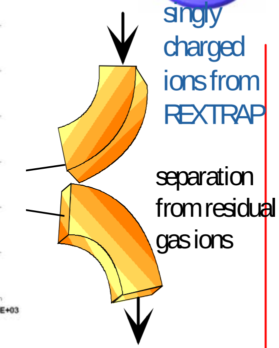
REX EBIS



q/A-selector

REXTRAP



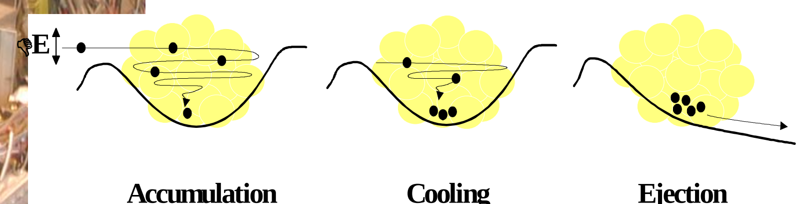


For A > ?:

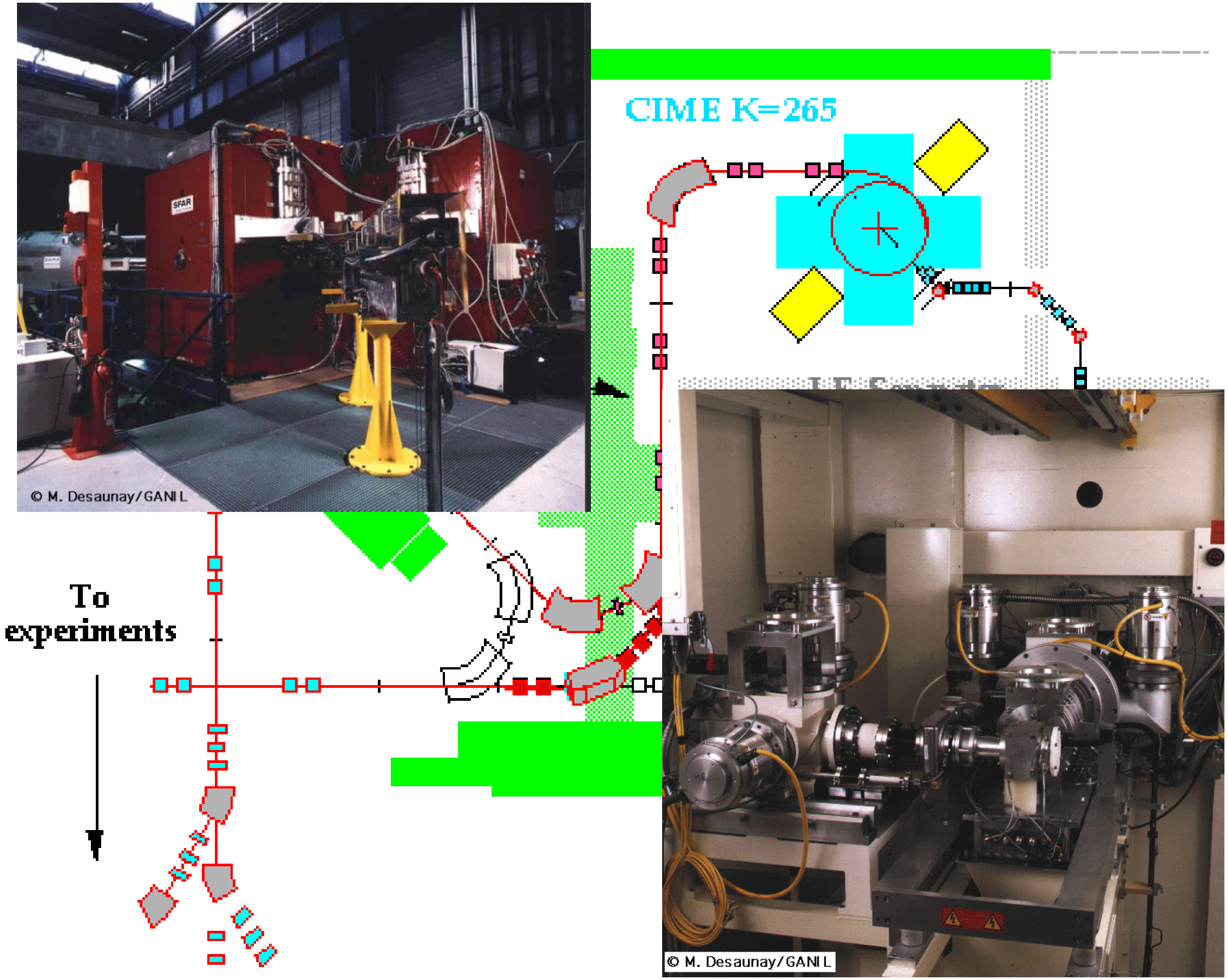
IS 397 team

Charge breeding of Uranium and

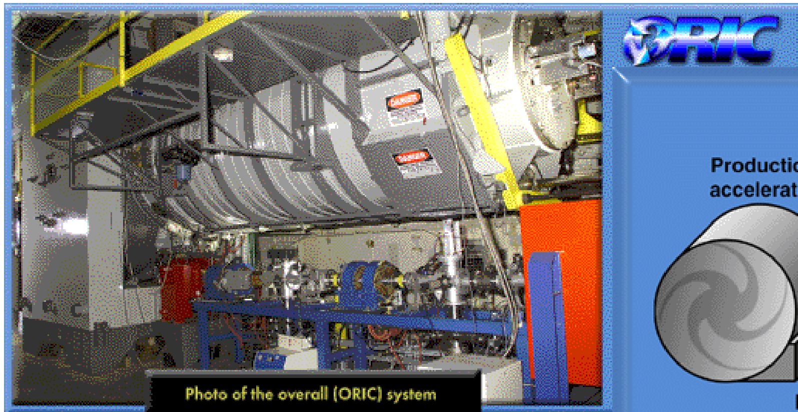
$^{96}Sr^{15+}$, $^{94}Rb^{15+}$

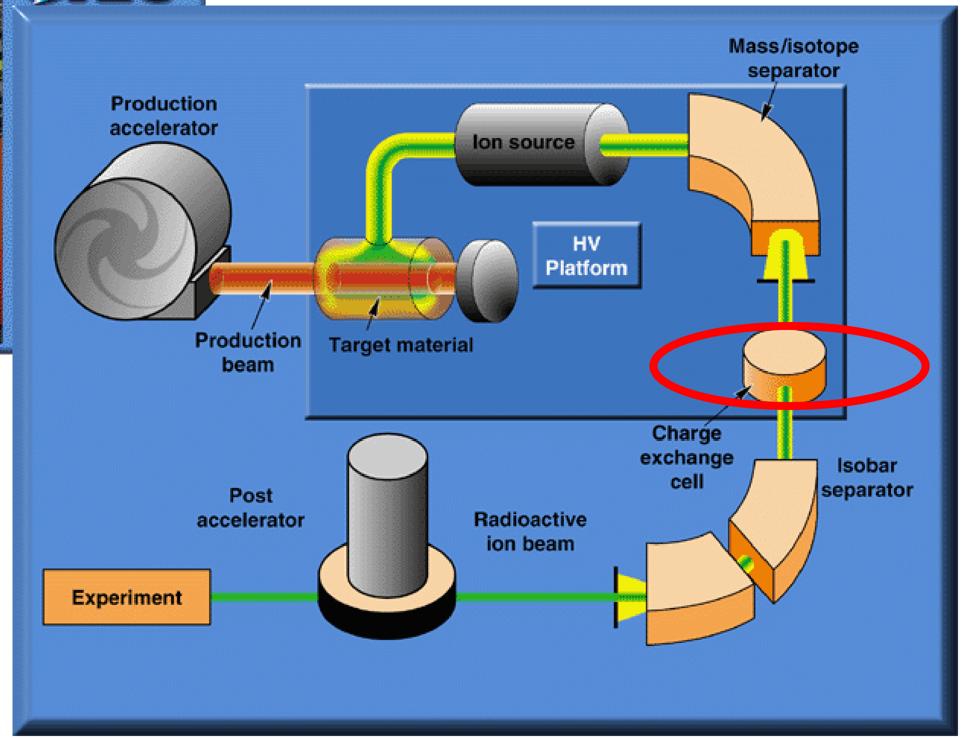


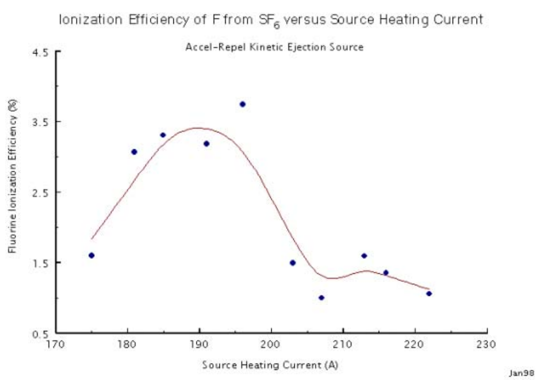
SPIRAL



HRIBF Oak Ridage





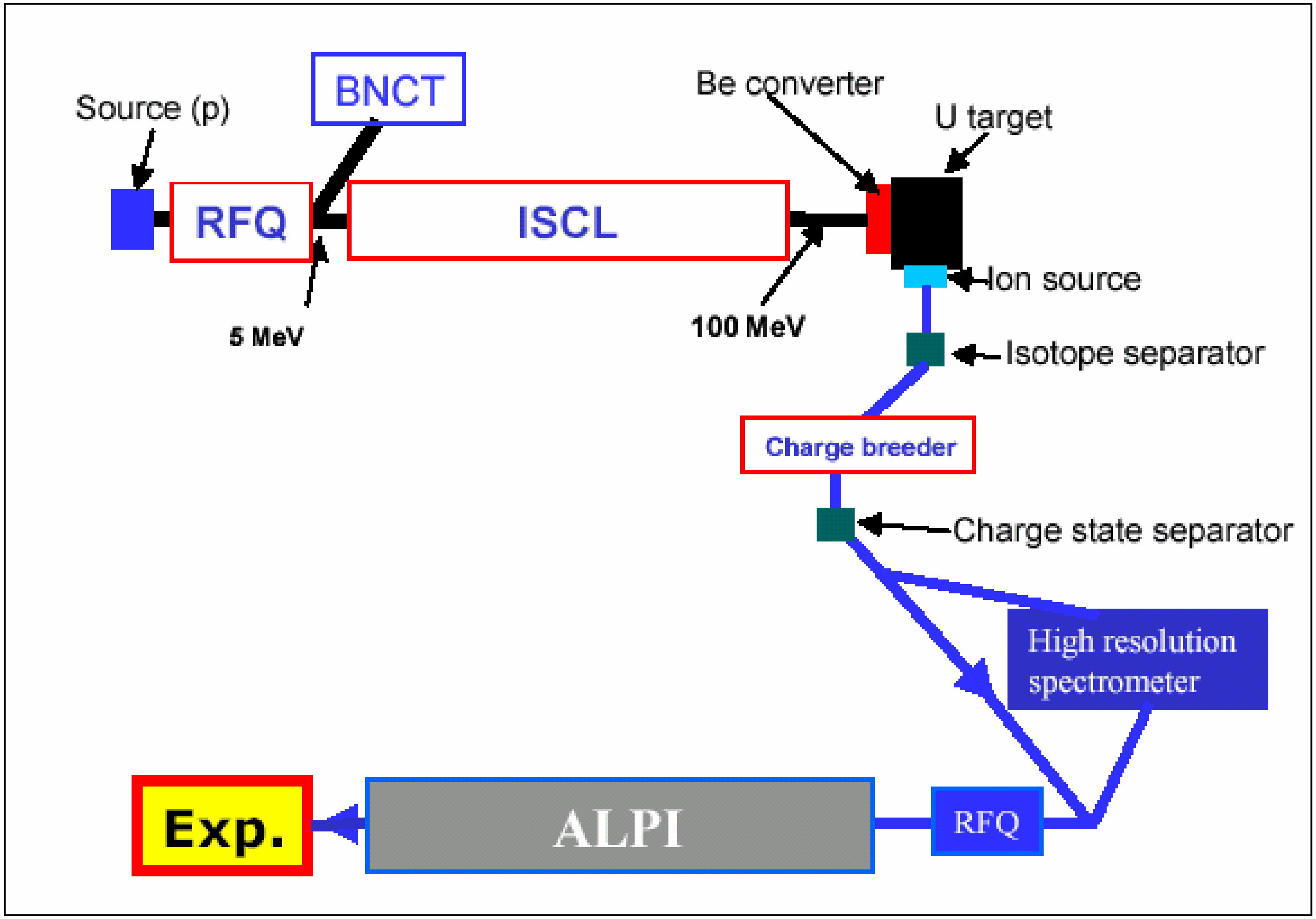


ISAC at TRIUMF: First high power facility!

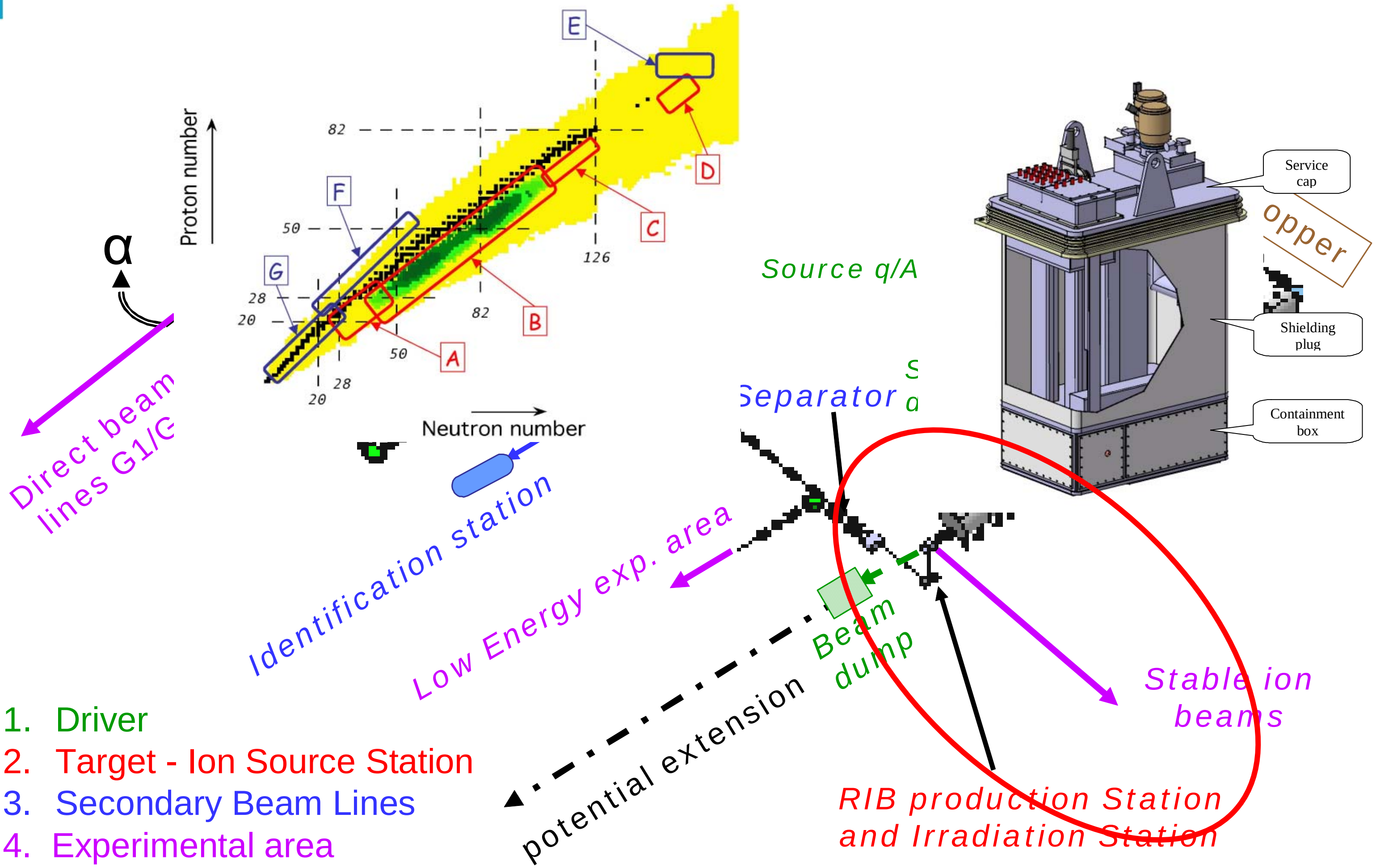
ISOL RNB: Intermediate facilities

Location	RIB Starting Date	Driver	Post-accelerator
SPIRAL-II: GANIL Caen, France	2008	SC linear accelerator LINAG deuterons up to 40 MeV heavy ions up to 15 *A* MeV	cyclotron CIME *K* = 265, 2–25 *A* MeV
MAFF Munich, Germany	2008	Reactor 10^{14} n/cm^2.sec	Linac up to 7 *A* MeV
SPES Legnaro, Italy	2008 (Initial phase)	SC proton linac	ALPI linac
ISAC-II TRIUMF	2007	Cyclotron p, 500 MeV, 100 μA	Linac up to 6.5 *A* MeV
ISOLDE upgrade CERN	2008	PS booster p, 1.4 GeV, 10 μA	Linac up to 5 *A* MeV

SPES


BNCT
Source (p)
RFQ
ISCL
Be converter
U target
Ion source
5 MeV
100 MeV
Isotope separator
Charge breeder
Charge state separator
High resolution spectrometer
Exp.
ALPI
RFQ

SPIRAL-2



1. Driver
2. Target - Ion Source Station
3. Secondary Beam Lines
4. Experimental area

MAFF

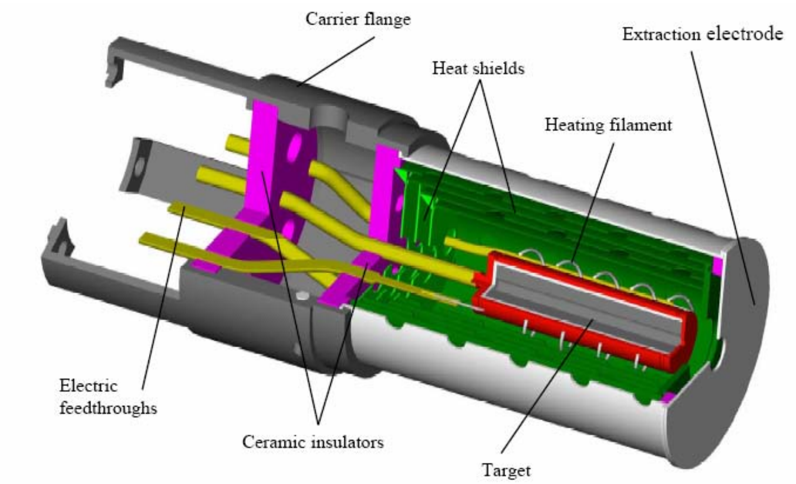
power in target: 3 kW = 200 MeV · 10^{14} fissions/s

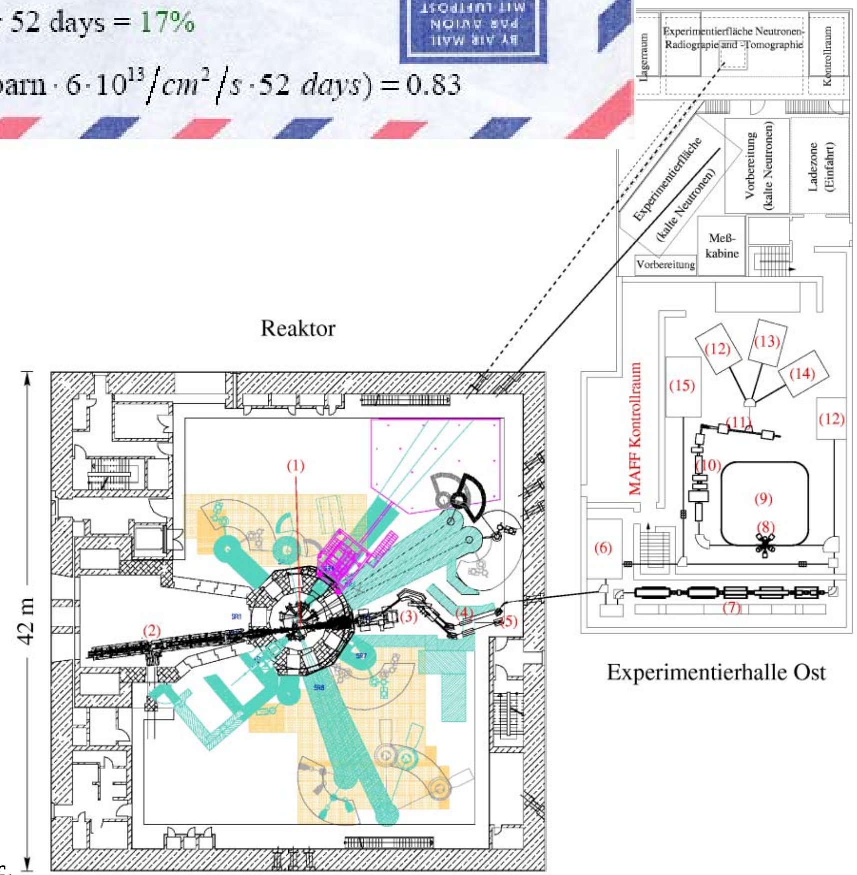
for 10^{14} fissions/s and 1g ^{235}U

I need $10^{14}/s = 600\ \text{barn} \cdot 6 \cdot 10^{23}/235 \cdot 6 \cdot 10^{13}/cm^2/s$ neutron flux

burnup of ^{235}U after 52 days = 17%

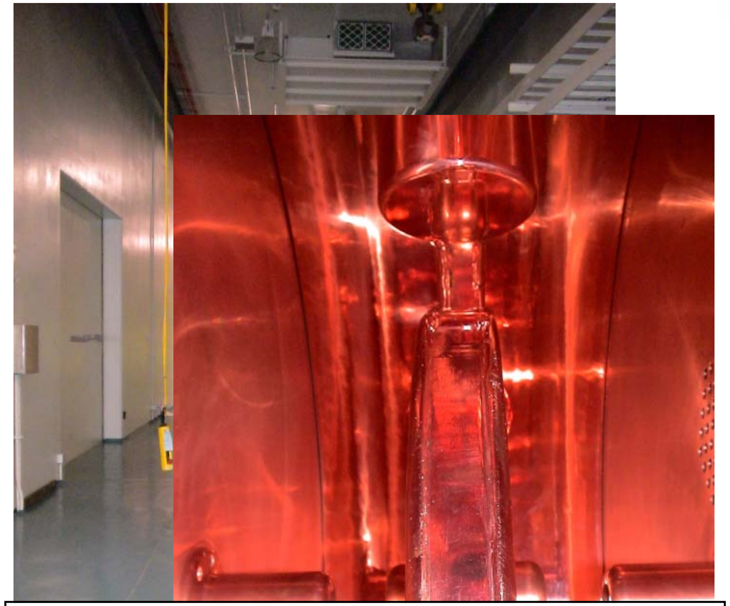
$$N/N_0 = \exp(-700\ \text{barn} \cdot 6 \cdot 10^{13}/cm^2/s \cdot 52\ days) = 0.83$$

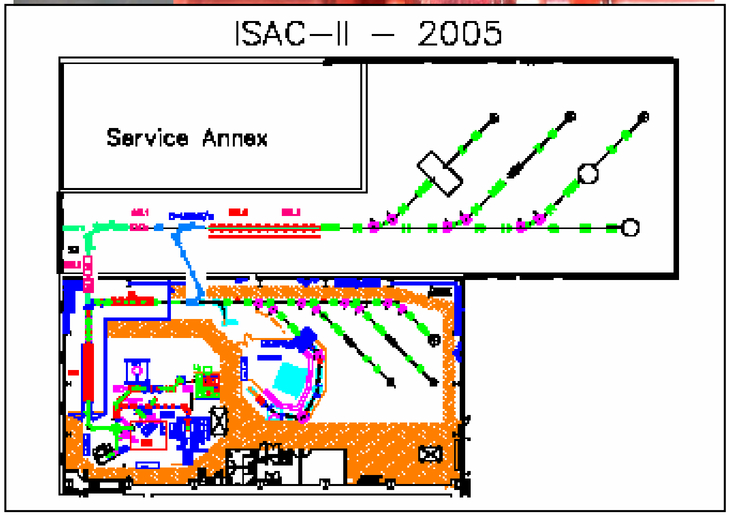




ISAC-2

- End of 2005: Beam to experimental hall
- April 2006, 5.3 MeV/u for most masses
  - Phoenix chargebreeder
  - Any mass that can be stripped to A/q=3 to 10 MeV/u
- 2007, 6.5 MeV/u
- Next five year plan:
  - 2 new target stations
  - One high power target station (shielded for 100 kW)

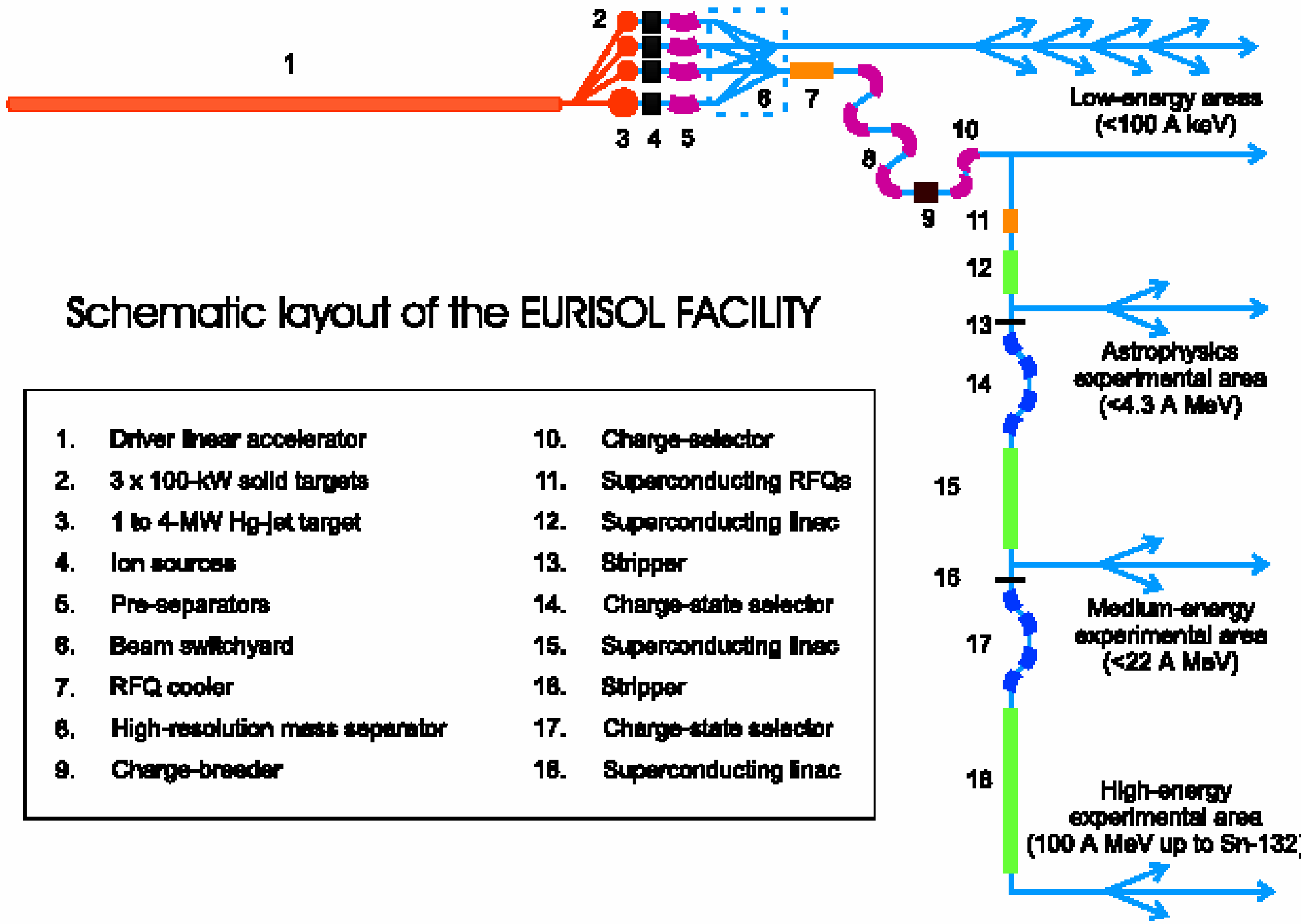




Future RNB facilities

Location	**Driver**	**Post-accelerator**	**Fragment separator**	**Type of facility**
Europe: GSI (Germany)	synchrotron, heavy ions: 1.5 A GeV	-	'Super-FRS'	In-Flight
Europe: EURISOL	protons, 1 GeV, 1-5 MW	CW Linac, up to 100 *A* MeV	-	ISOL
USA: RIA Rare Isotope Accelerator	900 MeV protons heavy ions: 400 *A* MeV, 100 kW	Linac up to 8–15 A MeV	4-dipole Separator	ISOL, In-Flight
JAPAN: RIKEN RIB Factory	Ring-cyclotrons up to 400 *A* MeV (light ions); up to 150 *A* MeV (heavy ions)	-	3 fragment Separators storage & cooler rings	In-Flight

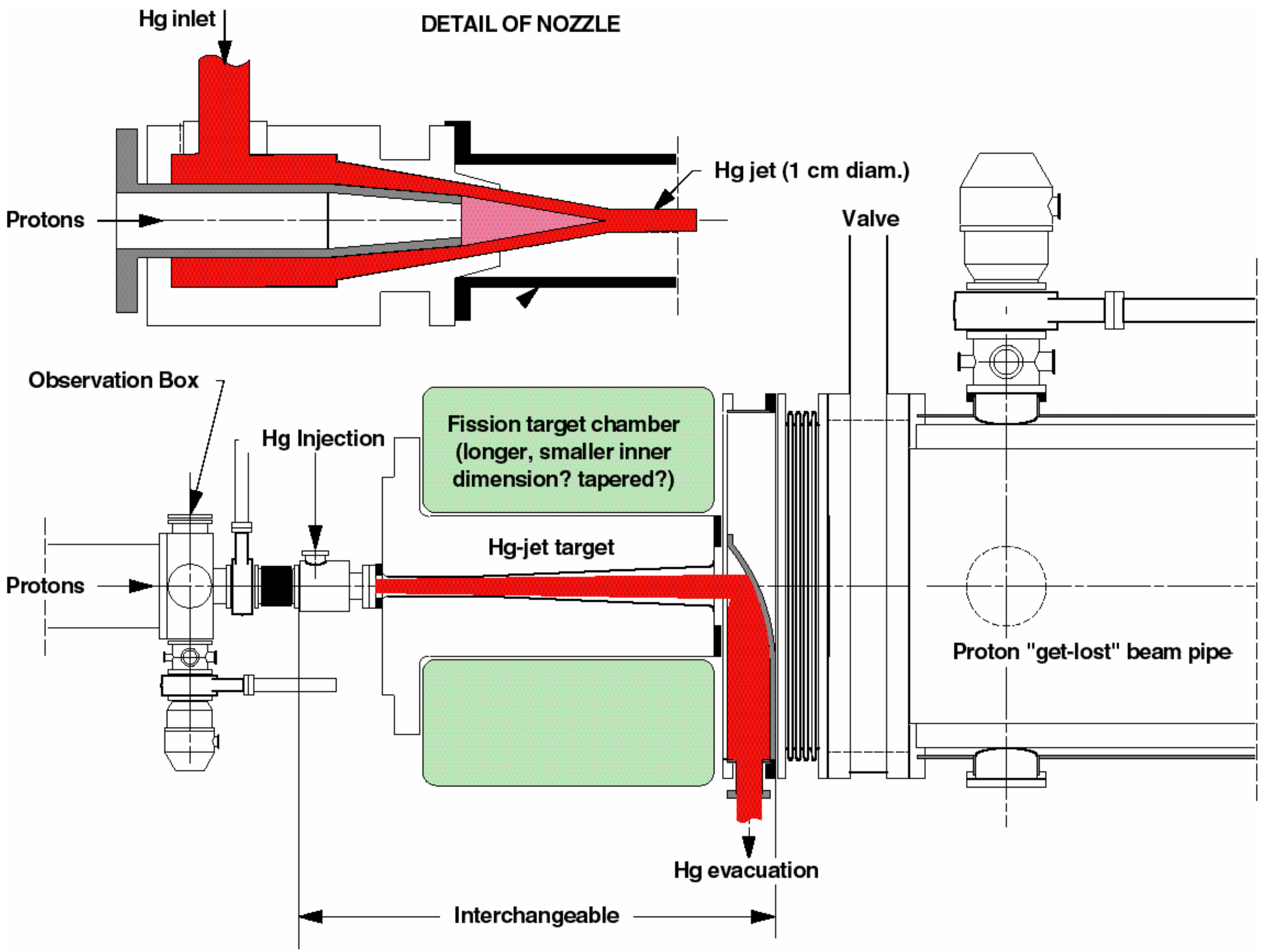
EURISOL DESIGN STUDY PROPOSAL



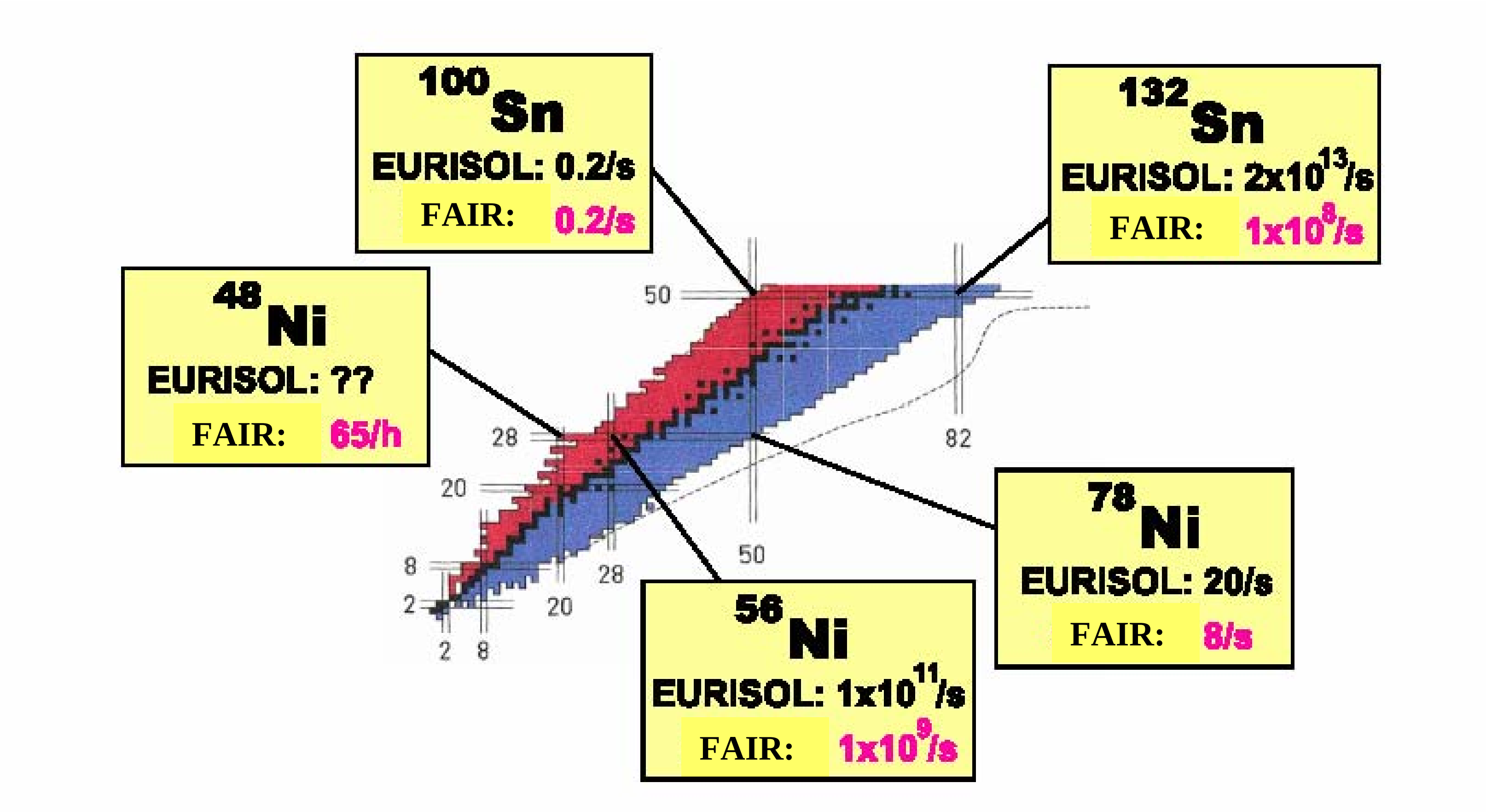
Schematic layout of the EURISOL FACILITY

1. Driver linear accelerator
2. 3 x 100-kW solid targets
3. 1 to 4-MW Hg-jet target
4. Ion sources
5. Pre-separators
6. Beam switchyard
7. RFQ cooler
8. High-resolution mass separator
9. Charge-breeder
10. Charge-selector
11. Superconducting RFQs
12. Superconducting linac
13. Stripper
14. Charge-state selector
15. Superconducting linac
16. Stripper
17. Charge-state selector
18. Superconducting linac

EURISOL : The ultimate neutron converter 5 MW



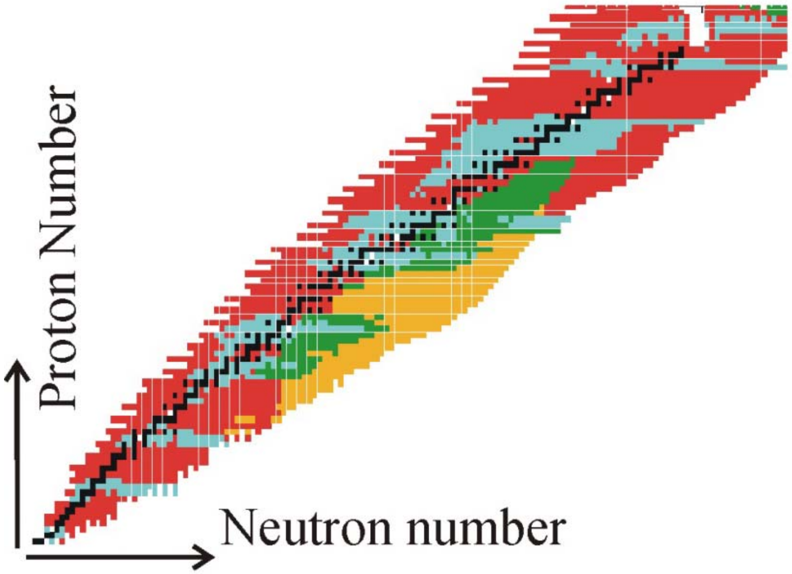
The EURISOL yields



RIA – Optimum Mechanism for Each Isotope

Optimum production method for low-energy beams

- Standard ISOL technique
- Two-step fission ISOL
- In-flight fission + gas cell
- Fragmentation + gas cell

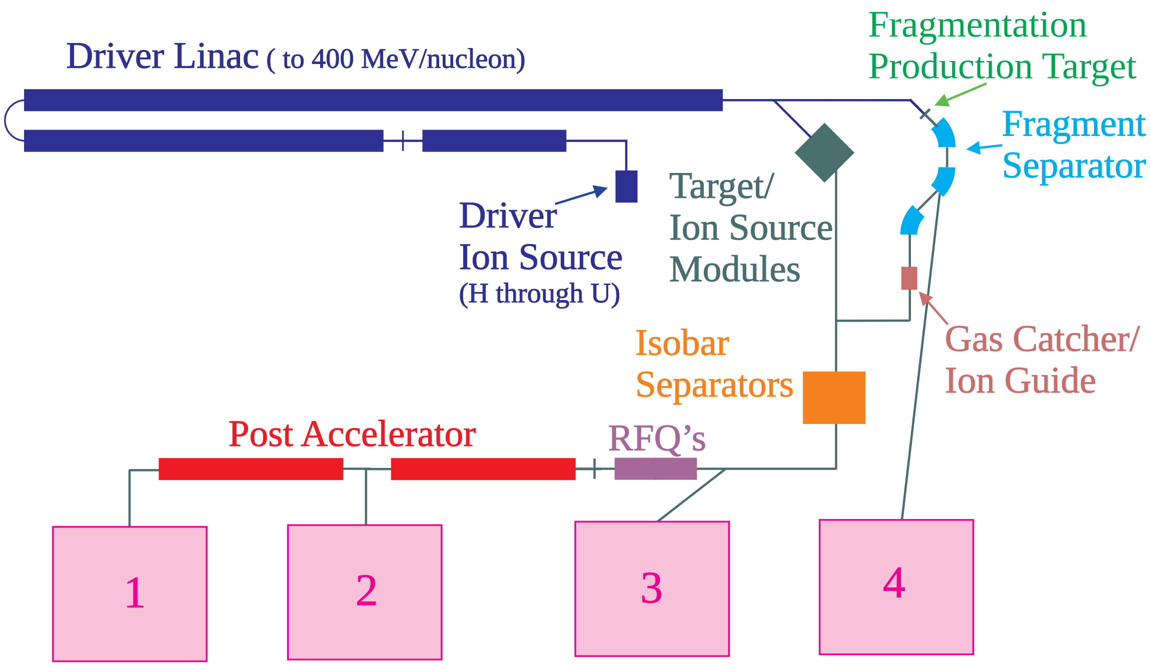


Both IF and ISOL

(Beam power compromise)

RIA Layout

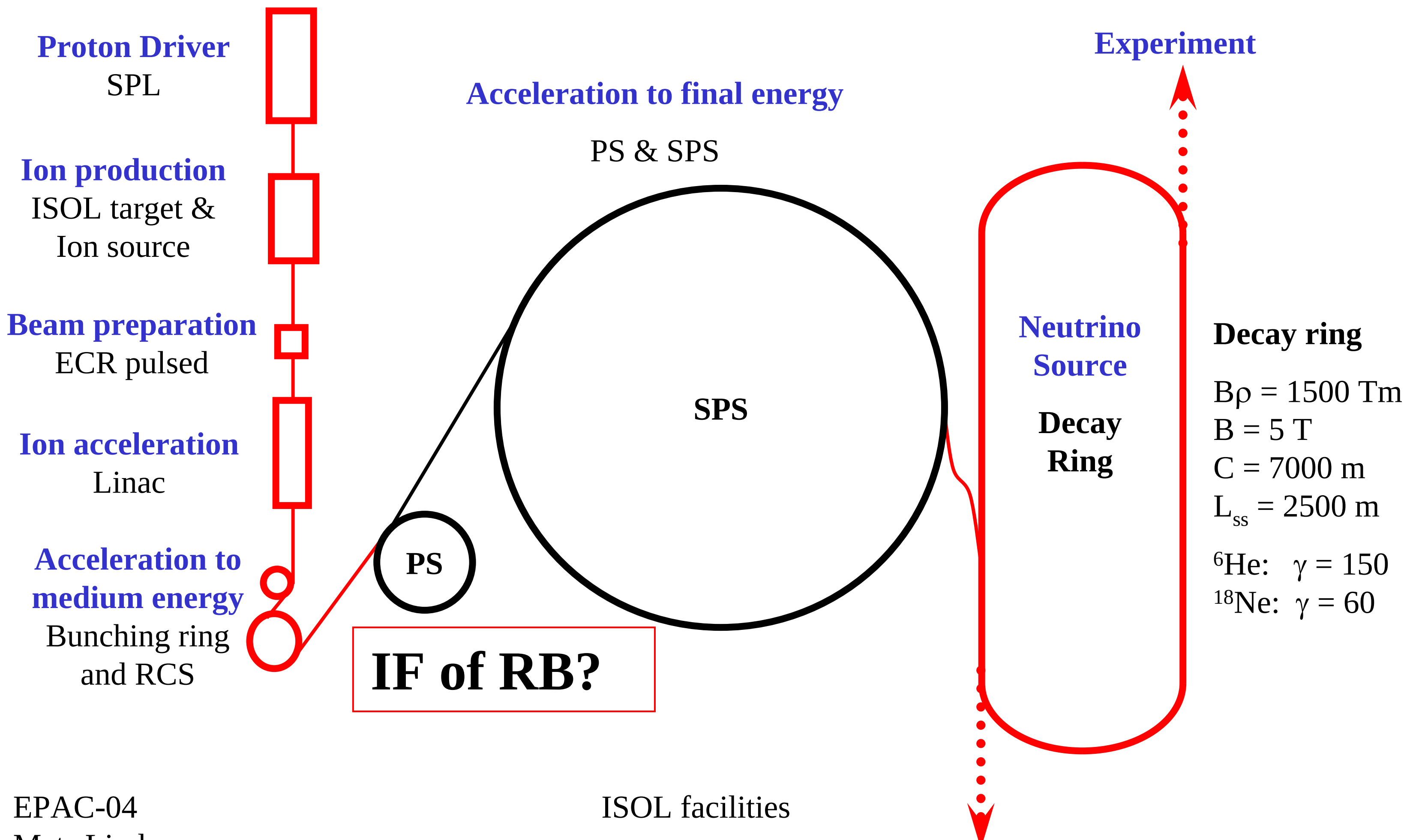
- Intense source of rare isotopes
  - ➢ **High power primary beams** protons to U at 100 kW and E > 400 MeV/nucleon.
  - ➢ Possibility to **optimize the production method** for a given nuclide.
- Four Experimental Areas (simultaneous users)



Experimental Areas:
1: < 12 MeV/u 2: < 1.5 MeV/u 3: Nonaccelerated 4: In-flight fragments

The beta-beam, see Poster MOPLT007

AIM: provide beams of electron (anti) neutrinos by decay of beta active ions.



Conclusions

- **First generation ISOL and IF facilities are absolutely needed**:
  - feasibility test
  - develop new detectors
  - perform physics experiments
  - complementary aspects

- **Push for the most exotic, short-lived, species:**
  - ISAC 2
  - RIA
  - FAIR
  - EURISOL

- **Towards even more exotic nuclei**

ISOL (high intense easy beam (e.g. ^{132}Sn)
+ post-acceleration up to 50 MeV/u (and higher)
+ IF
versus
direct IF

Acknowledgments

- Profound thank-you to all my colleagues in the Worldwide ISOL community