Nuclear physics: the ISOLDE facility

Lecture 2: CERN-ISOLDE facility

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on behalf of the CERN ISOLDE team
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Small quiz 2

- Who are the two biggest VIPs in this photo (excluding the lecturer ;))?

Note: all ladies in this photo are real ISOLDE physicists!

Replies should be sent to Kowalska@cern.ch

Outline

Aimed at both physics and non-physics students

- Lecture 1: Introduction to nuclear physics

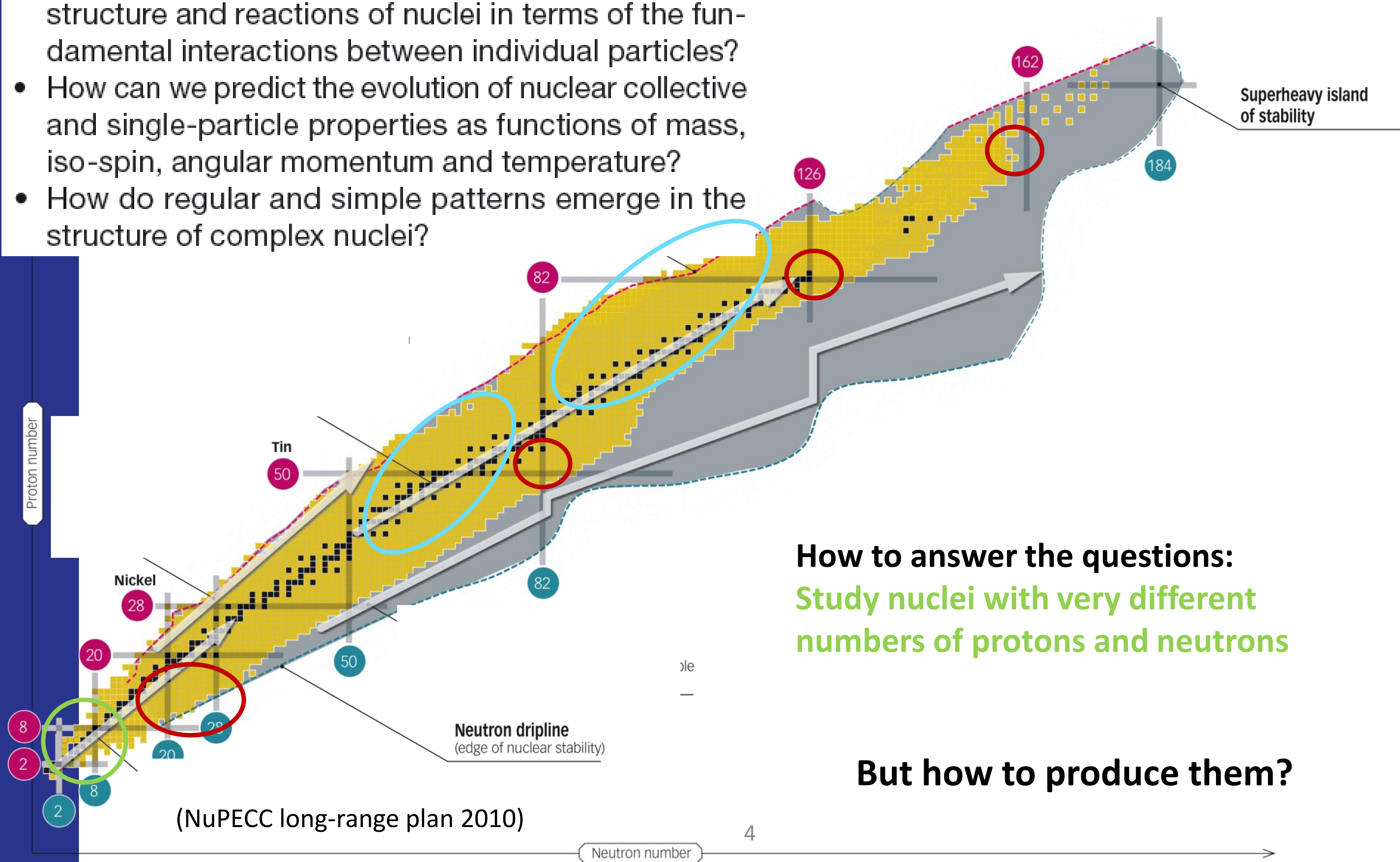
- **This lecture**: CERN-ISOLDE facility
  - Types of radioactive ion beam facilities
  - ISOLDE within CERN
  - Beam production at ISOLDE

- Lecture 3: Physics of ISOLDE

Open questions in nuclear physics

- How can we describe the rich variety of low-energy structure and reactions of nuclei in terms of the fundamental interactions between individual particles?
- How can we predict the evolution of nuclear collective and single-particle properties as functions of mass, iso-spin, angular momentum and temperature?
- How do regular and simple patterns emerge in the structure of complex nuclei?

2 kinds of interacting fermions



How to answer the questions:

Study nuclei with very different numbers of protons and neutrons

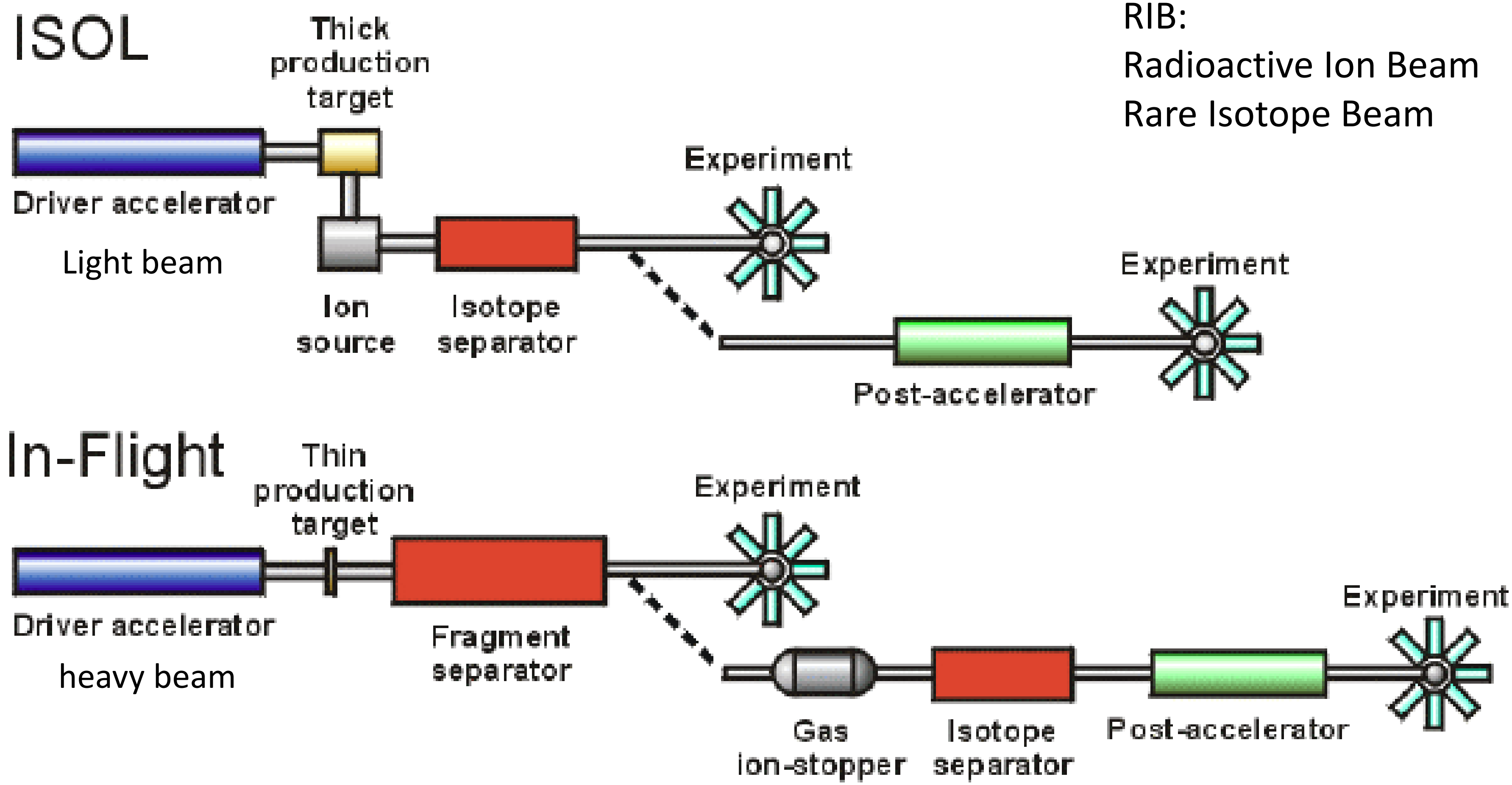
But how to produce them?

(NuPECC long-range plan 2010)

RIB facilities

- Two main types of (complementary) RIB facilities:
  - ISOL (Isotope Separation On-Line) and In-Flight

RIB:
Radioactive Ion Beam
Rare Isotope Beam

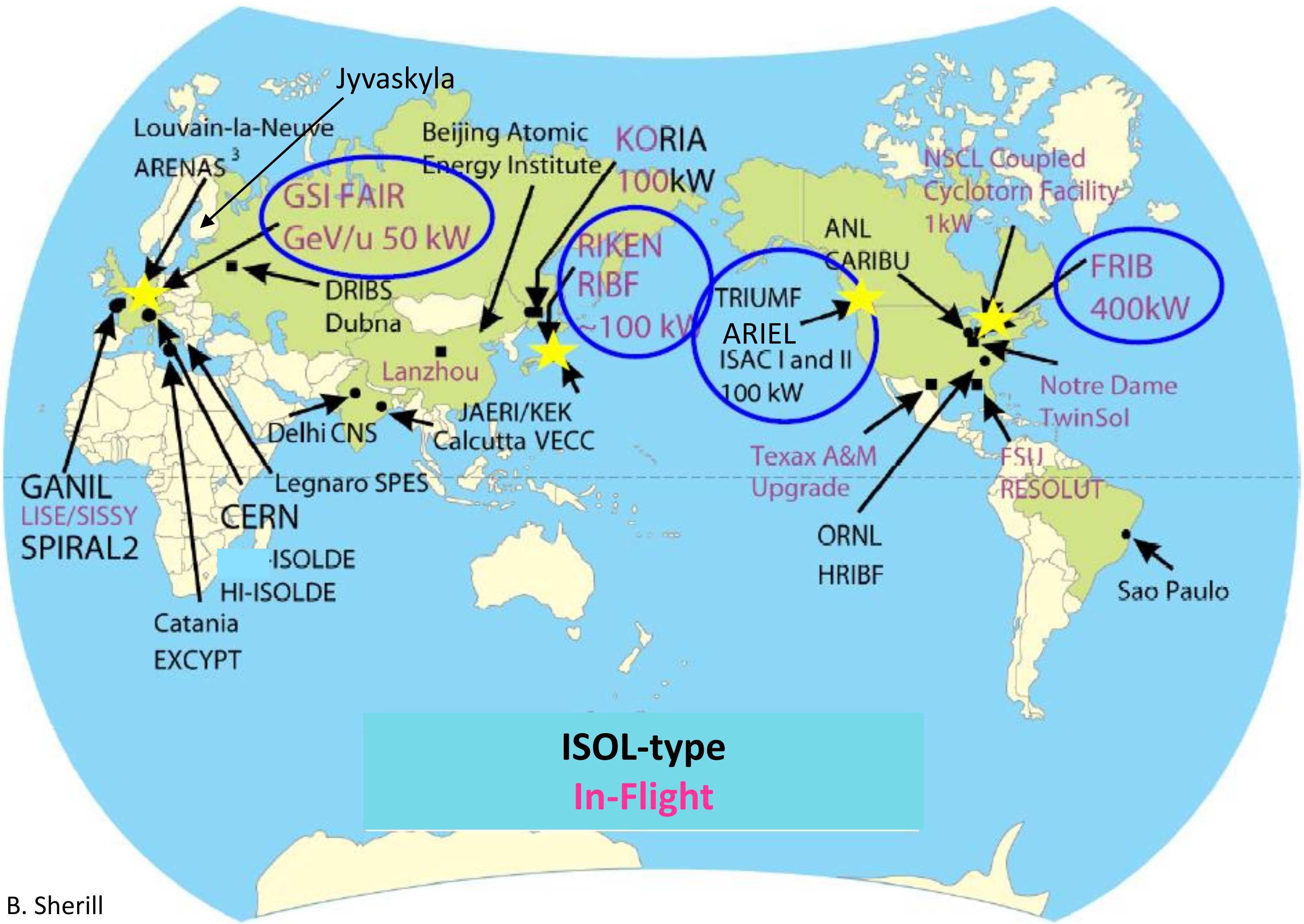


RIB facilities comparison

	ISOL	In-Flight
Projectile	light	heavy
Target	thick	thin
Ion beam energy		
Beam intensity		
Variety of nuclides		
Release from target		
Beam quality		
Examples	ISOLDE@CERN, SPIRAL@GANIL, ISAAC@TRIUMF	GANIL, GSI, RIKEN, NSCL/MSU

RIB facilities worldwide

- Existing and in preparation



After B. Sherill

ISOLDE – short history

ISOLDE = Isotope Separator OnLine DEvice

CERN facility for production and studies of RIBs

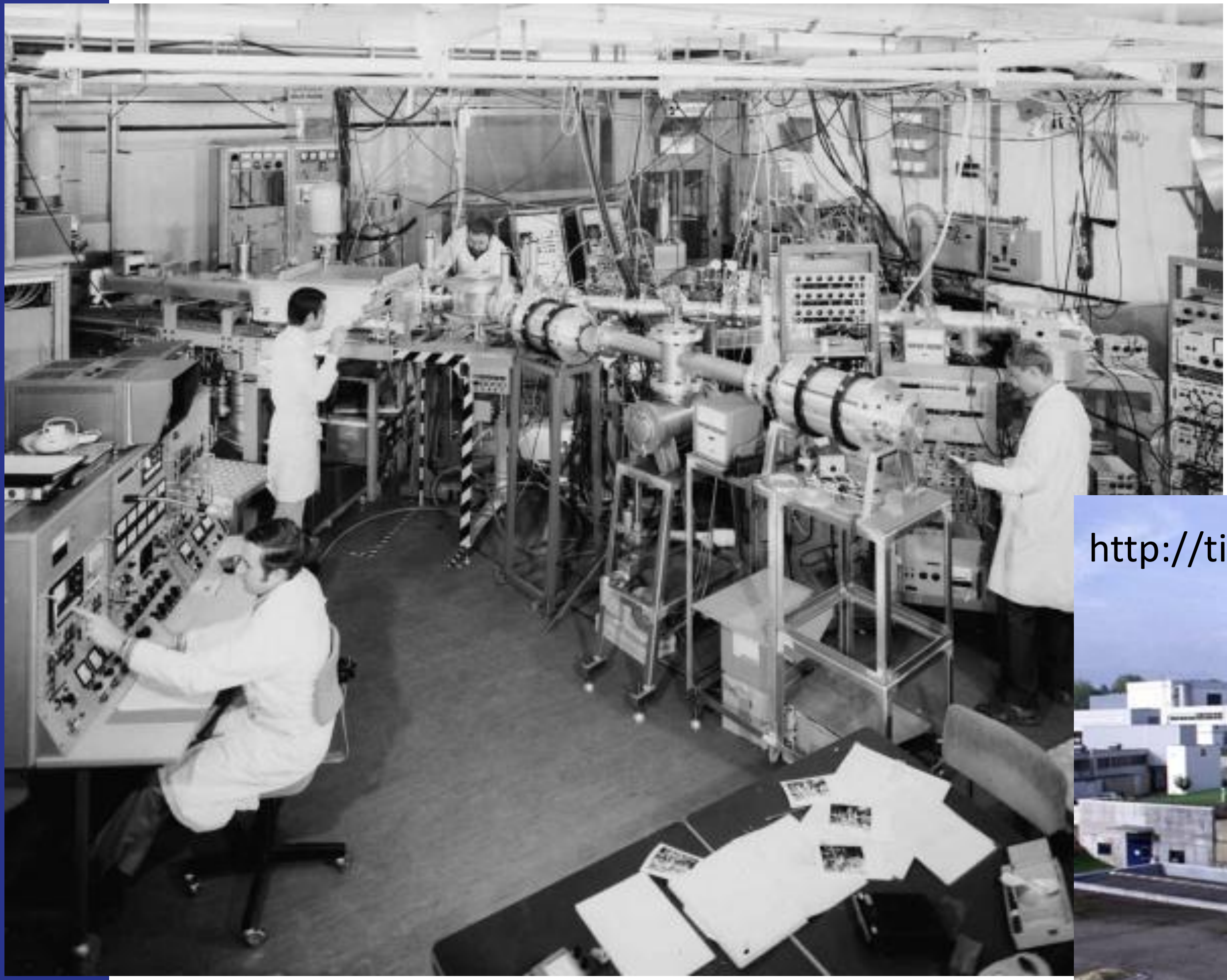
Accepted: December 1964

First beam: October 1967

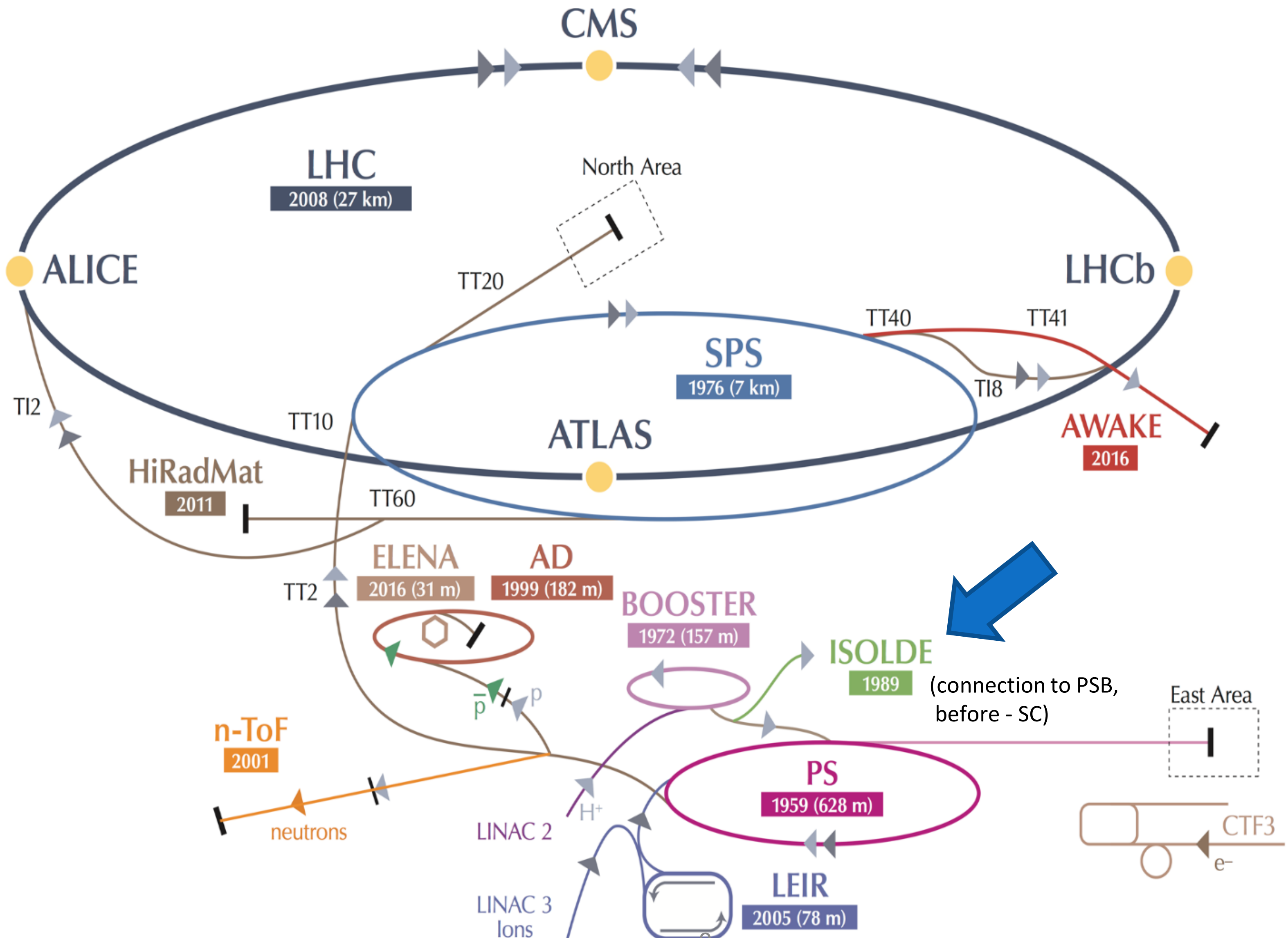
Upgrades: 1974 and 1988

New facility: June 1992

HIE-ISOLDE: October 2015

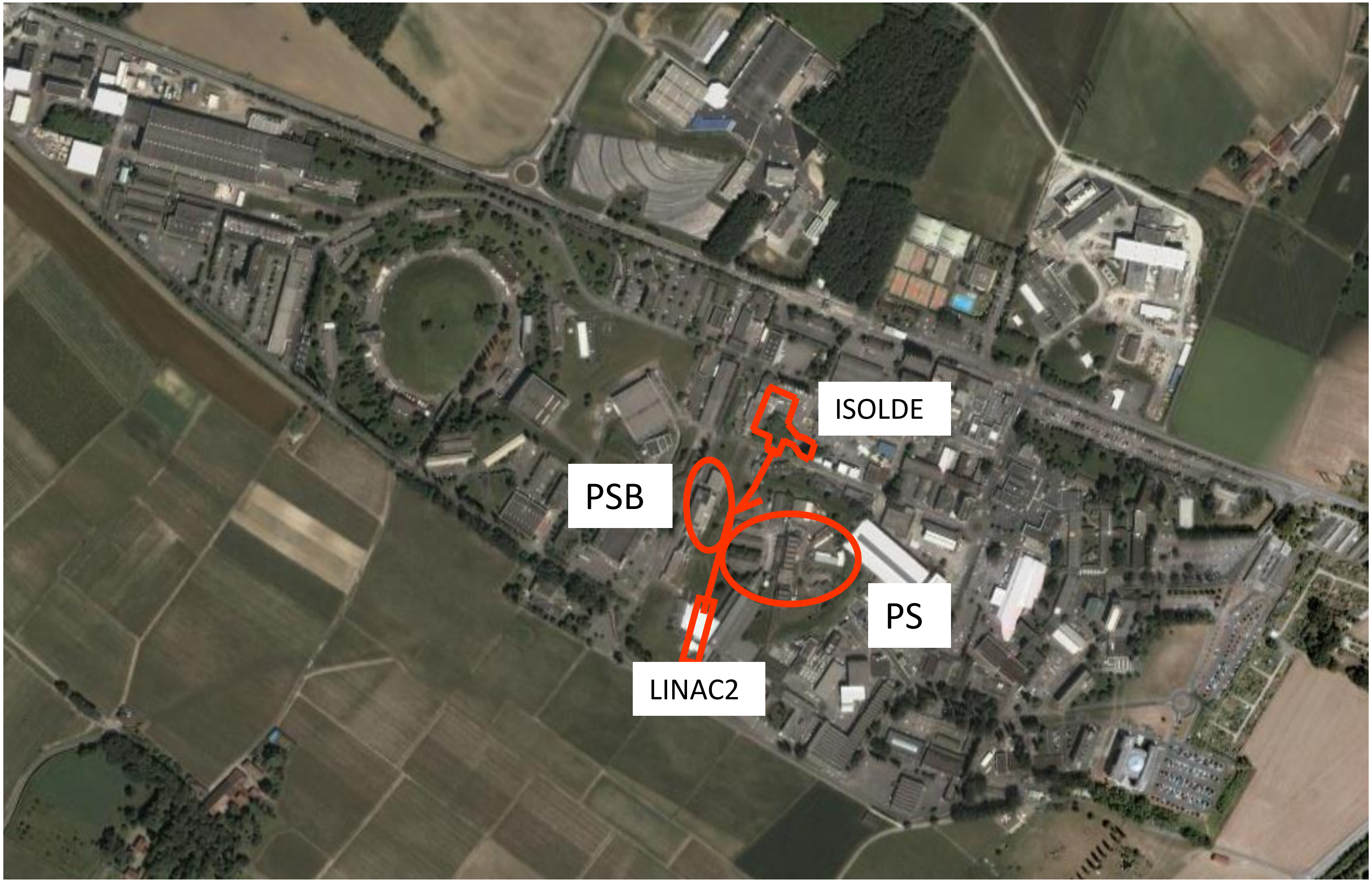


ISOLDE at CERN



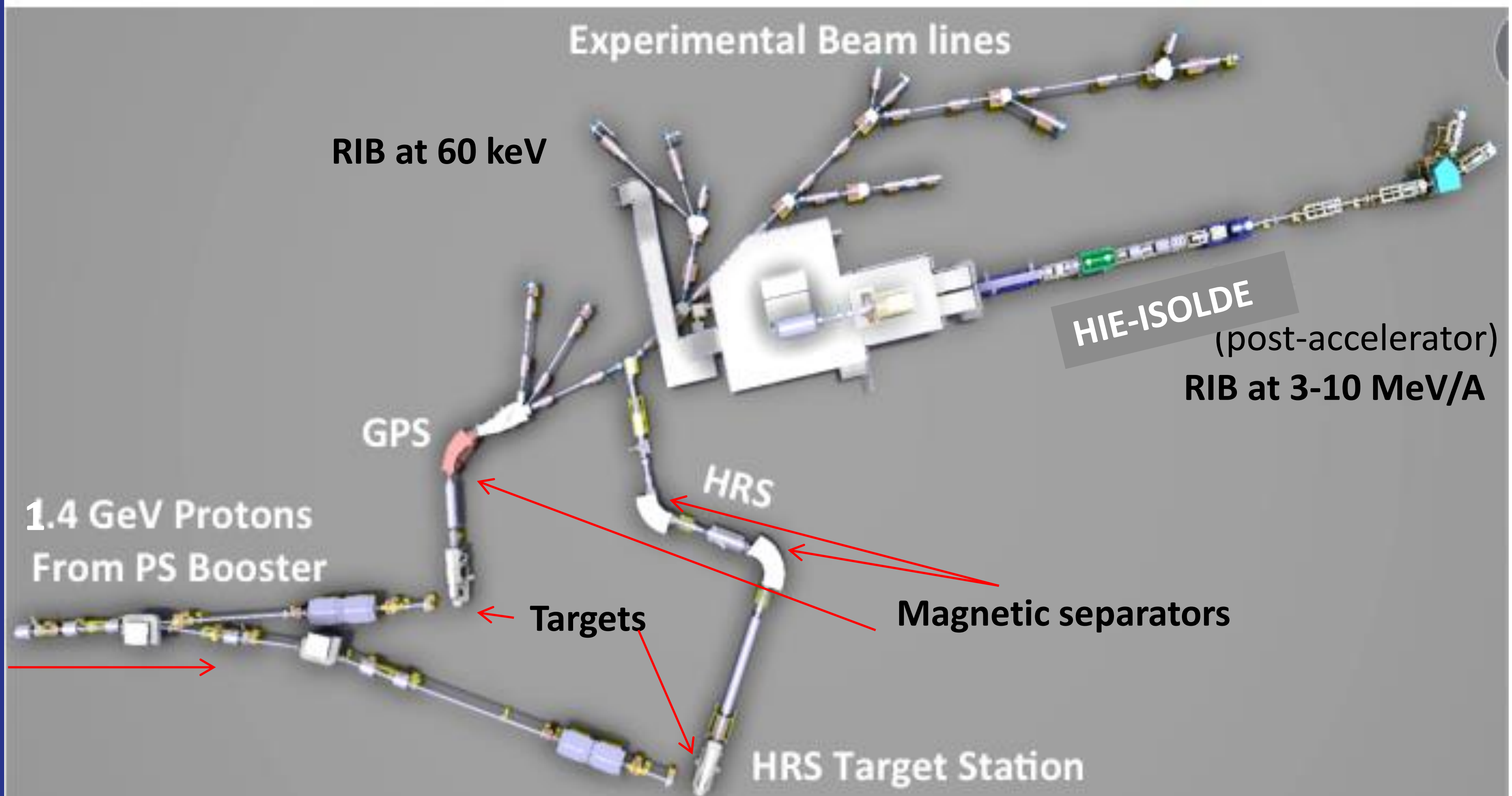
(connection to PSB, before - SC)

ISOLDE within CERN accelerators



ISOLDE elements

Isotope production via reactions of light beam with thick and heavy target



Production – ionization – separation

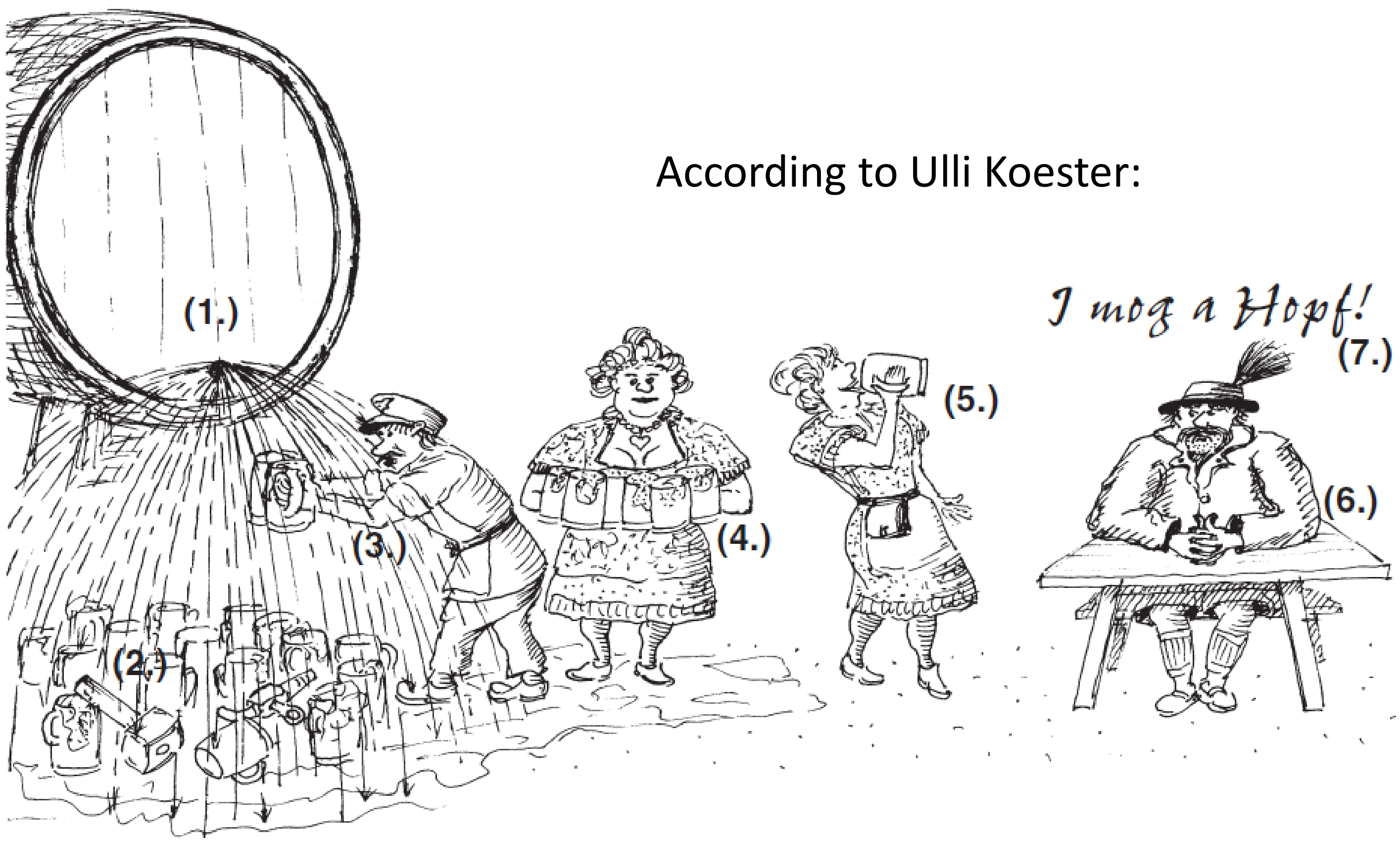
Ion beam intensity

- Number of extracted ions (yield) is governed by:

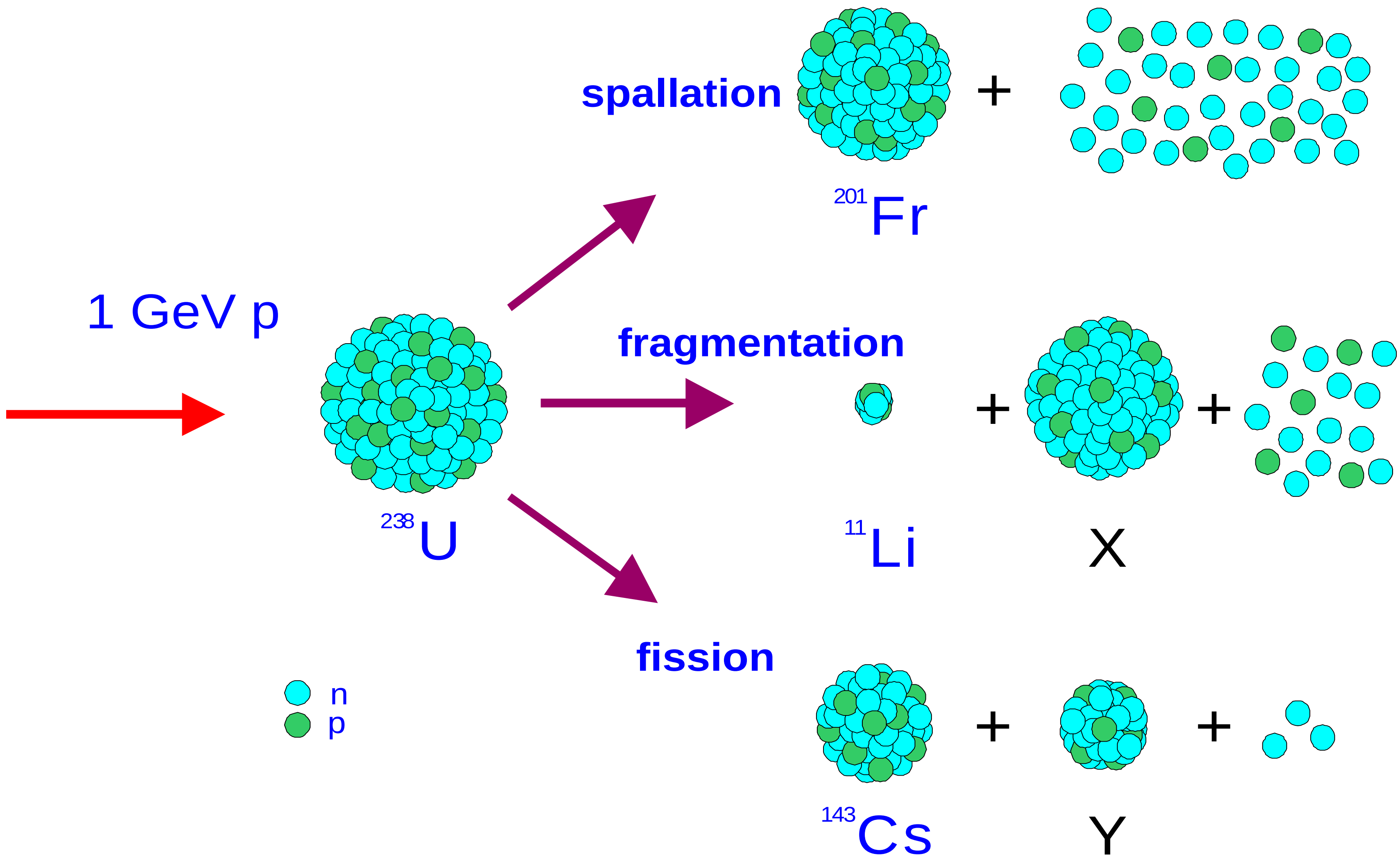
$$r = \Phi \cdot \sigma \cdot N \cdot \varepsilon_{\text{target}} \cdot \varepsilon_{\text{source}} \cdot \varepsilon_{\text{sep}} \cdot \varepsilon_{\text{transp}} \cdot \varepsilon_{\text{det}} \cdot$$

primary particle flux x reaction cross section x number of target particles x efficiencies

According to Ulli Koester:

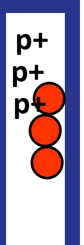


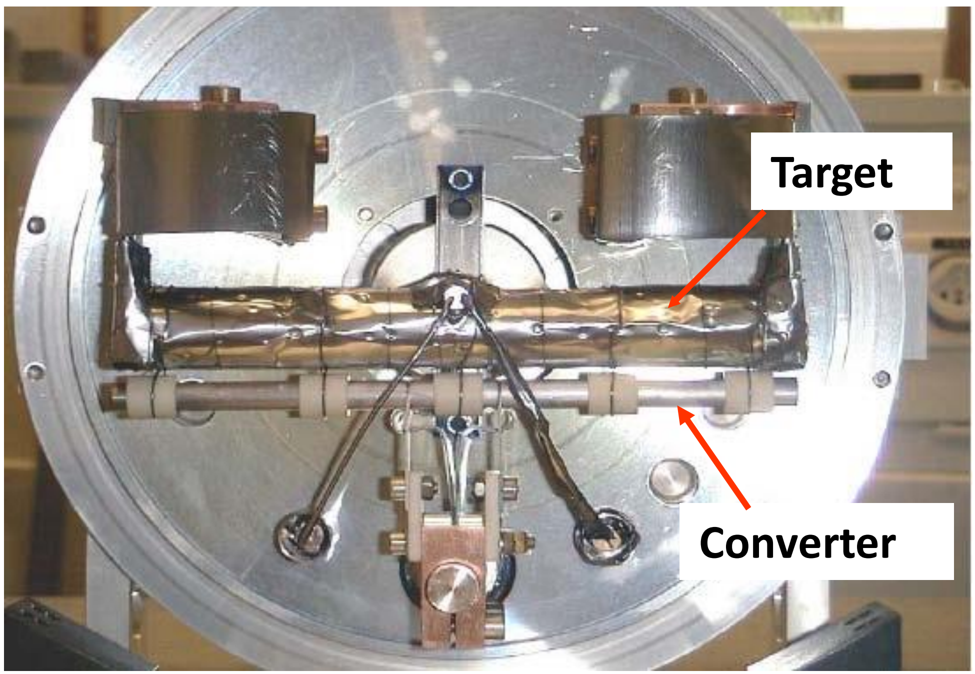
Production channels



Production targets

- Over 20 target materials and ionizers, depending on beam of interest
- U, Ta, Zr, Y, Ti, Si, …
- Target material and transfer tube heated to 1500 – 2000 degrees
- Operated by robots due to radiation



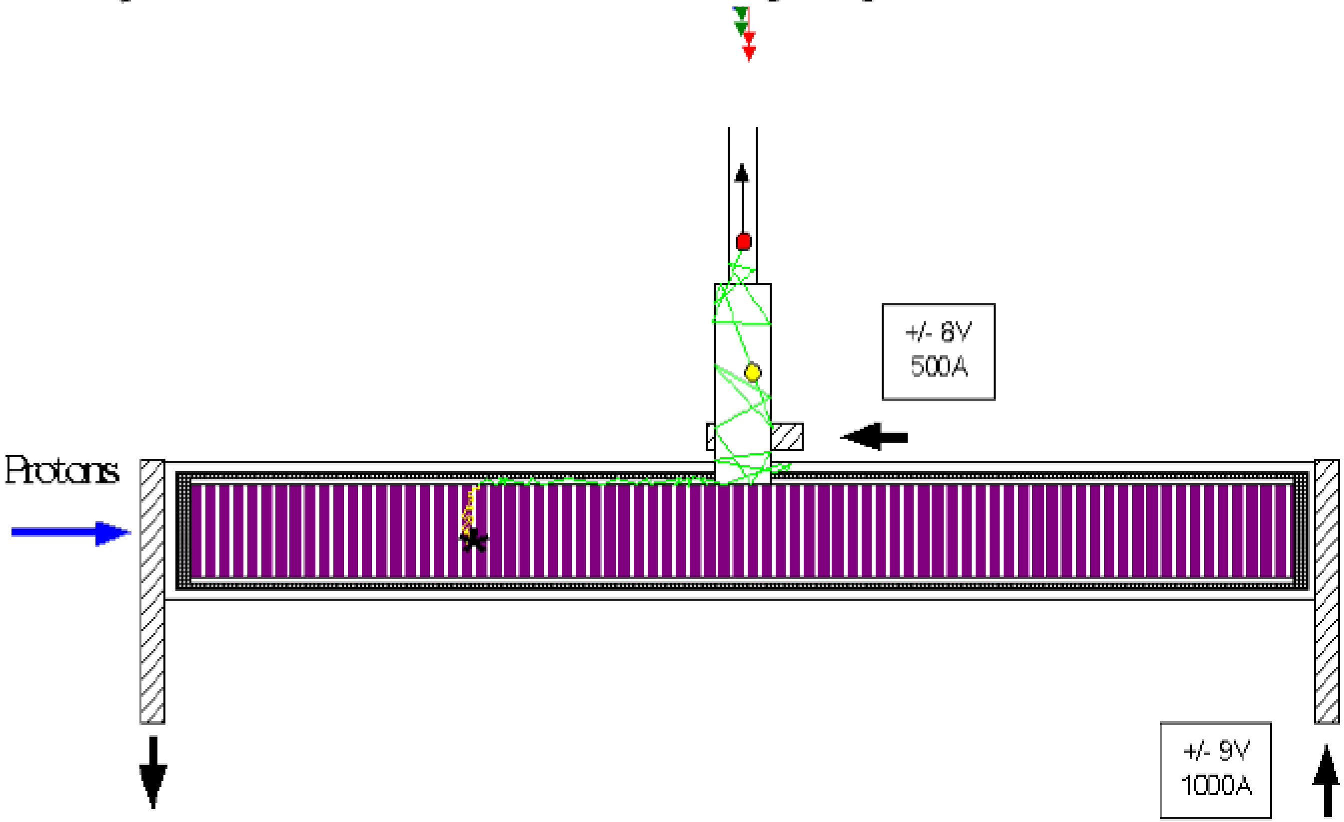


Converter Target

Standard

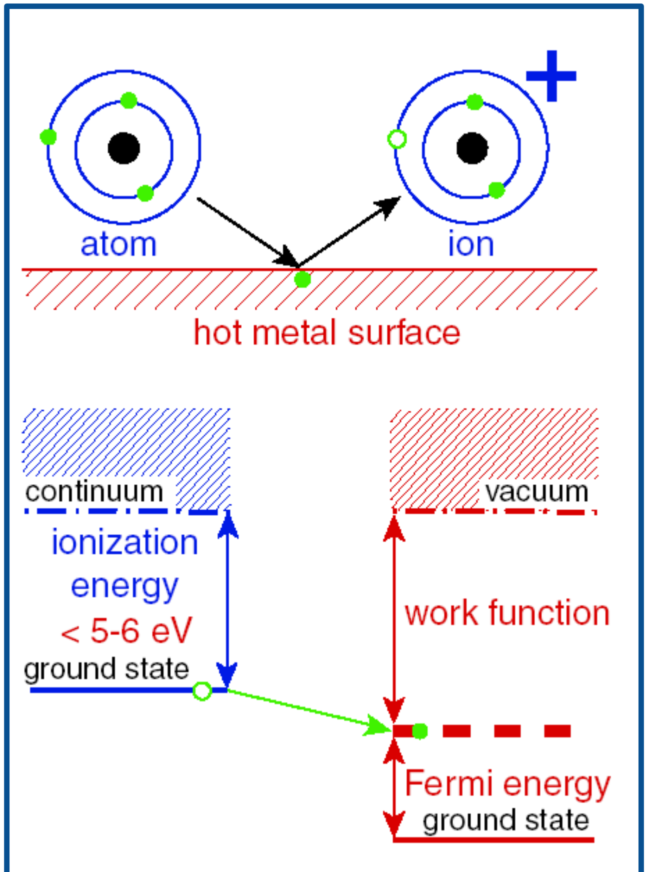
Inside a standard target

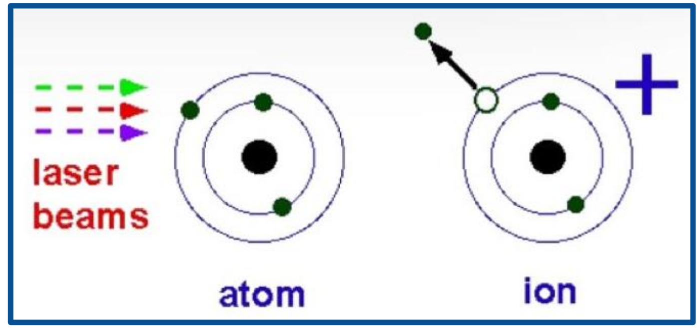
In the early Copenhagen experiments a ten kilo target consisting of a mixture of baking powder [essentially $(NH_4)_2CO_3$] and uranium oxide was used. Fast neutrons from an internal beryllium target in the cyclotron were used to irradiate the external target, and the radioactive isotopes were produced by fission reactions in the uranium. The radioactive noble gases were then diffused out of the target and swept into the ion source of the isotope separator.

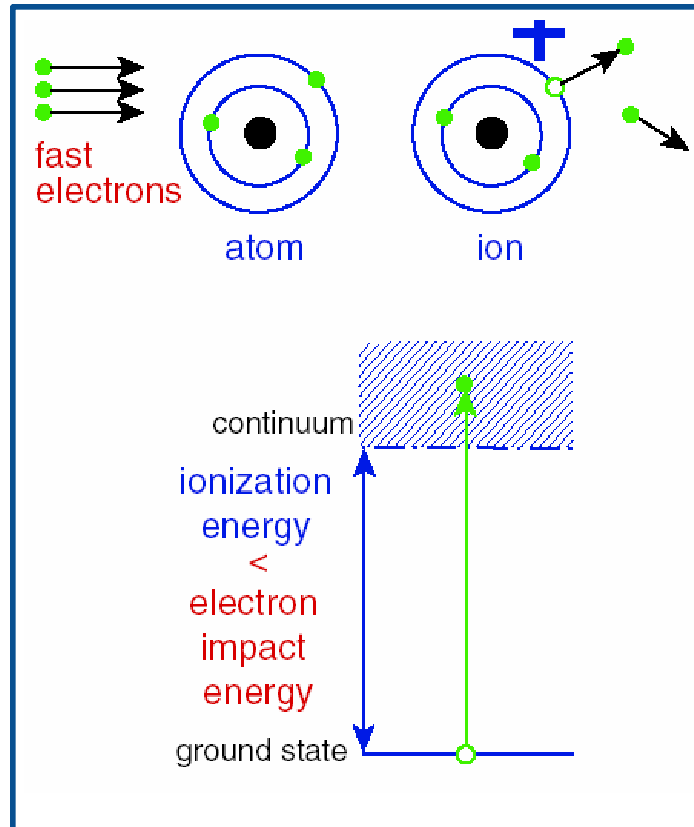


Ionization

- Surface
- Plasma
- Lasers



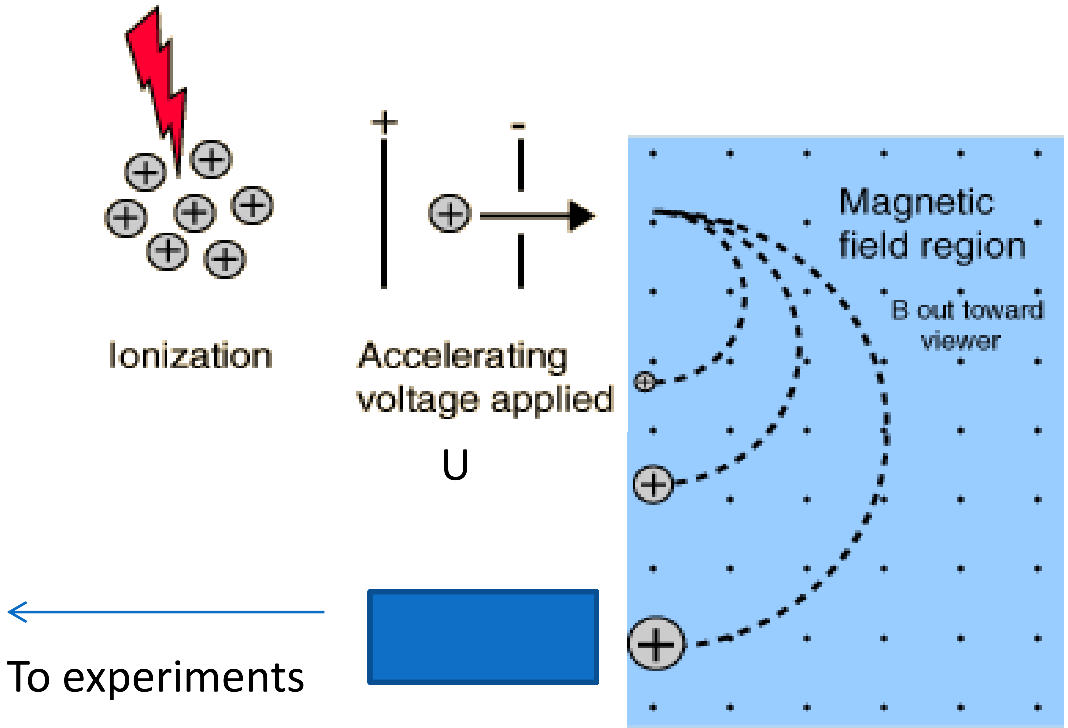




After U. Koester

Beam extraction and separation

- All produced ions are extracted by electrostatic field (up to 60kV)
- The interesting nuclei are mass selected via magnetic field
  - Lorentz force: depends on velocity and mass
  - m/dm <5000, so many unwanted isobars also get to experiments

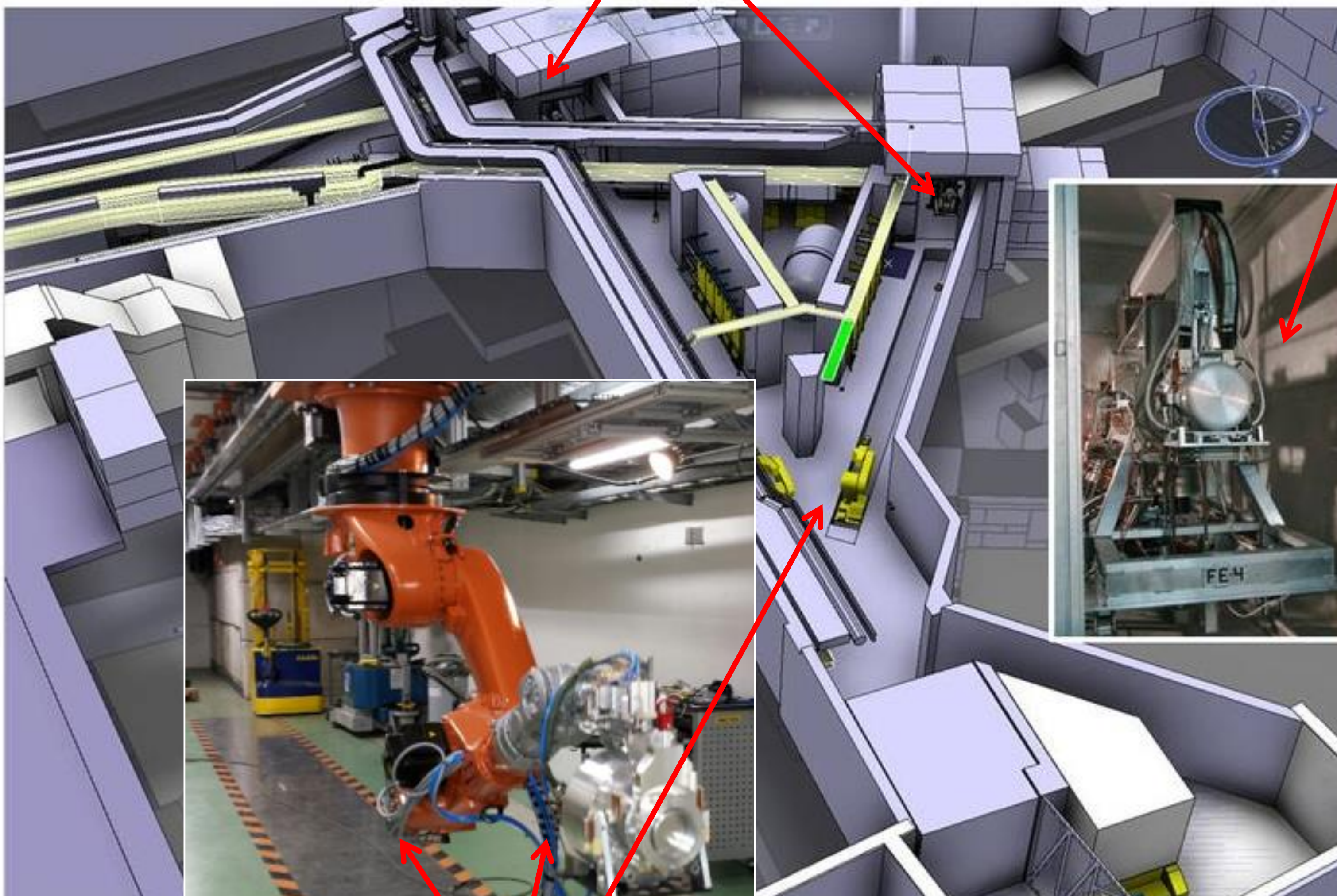


$$r = \frac{mv}{qB} = \sqrt{2mU}/(qB)$$

Production, ionization, extraction

target

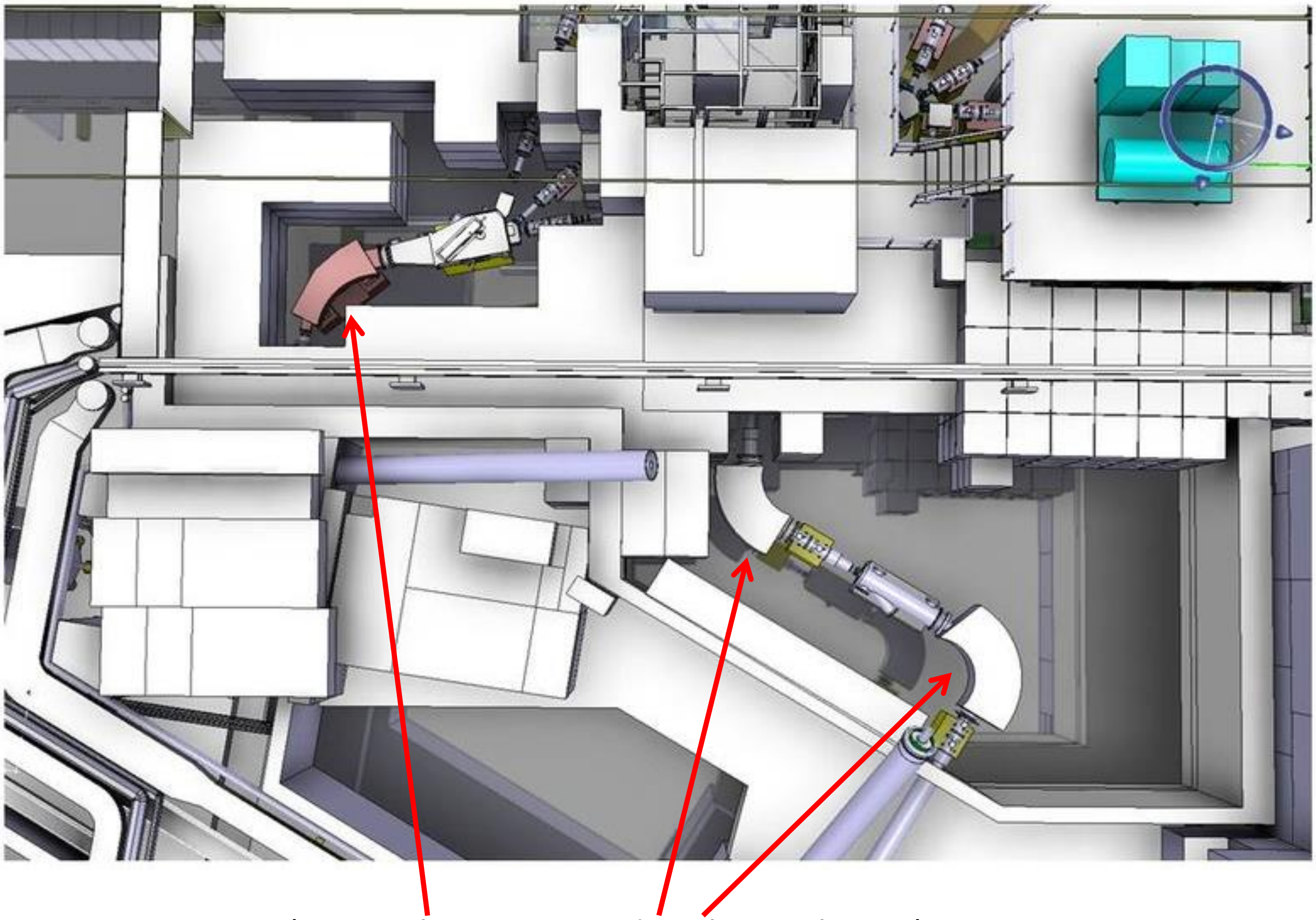
Target+ vacuum+ extraction



robots

Ion energy: 30-60keV

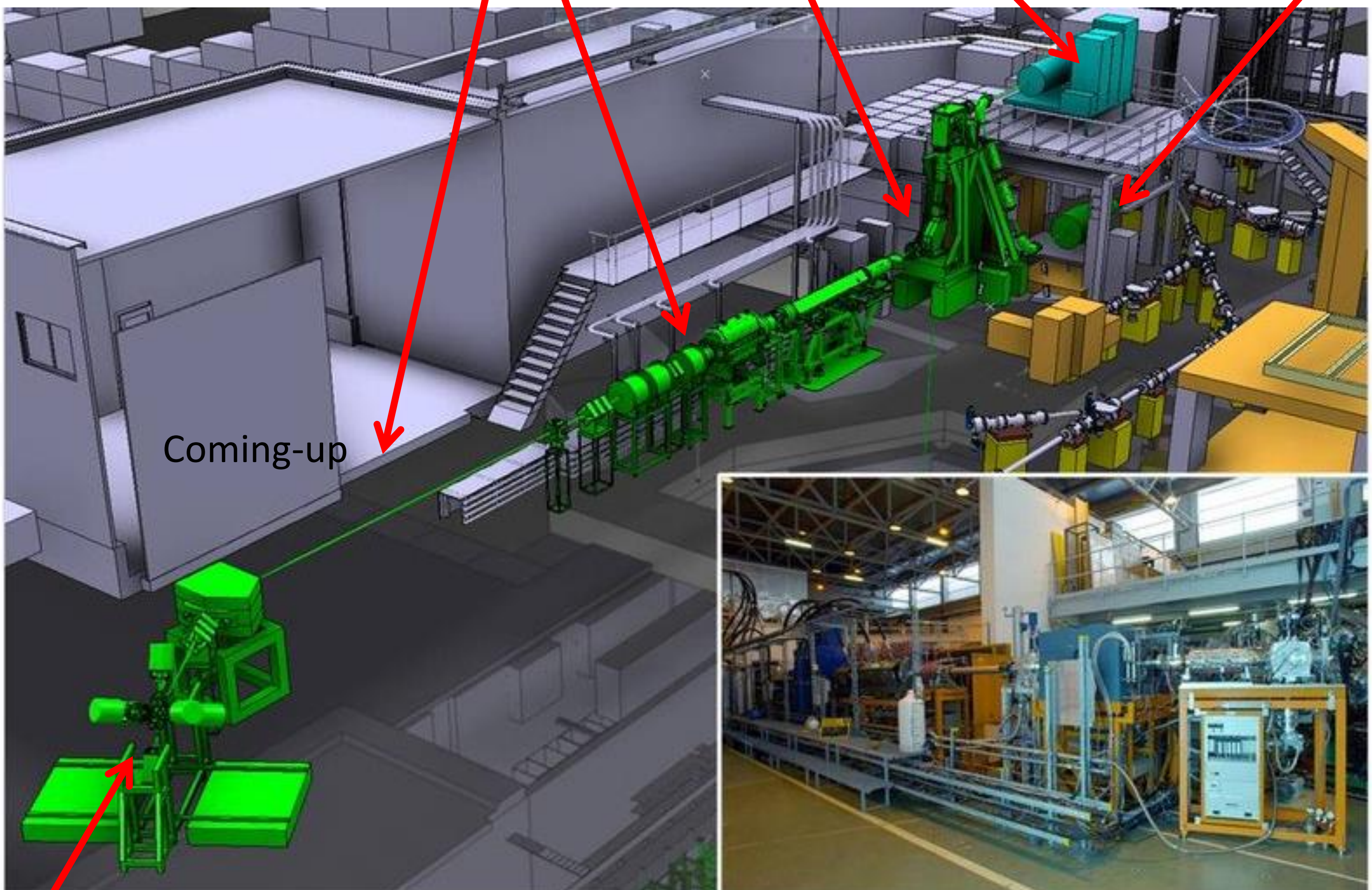
Separation



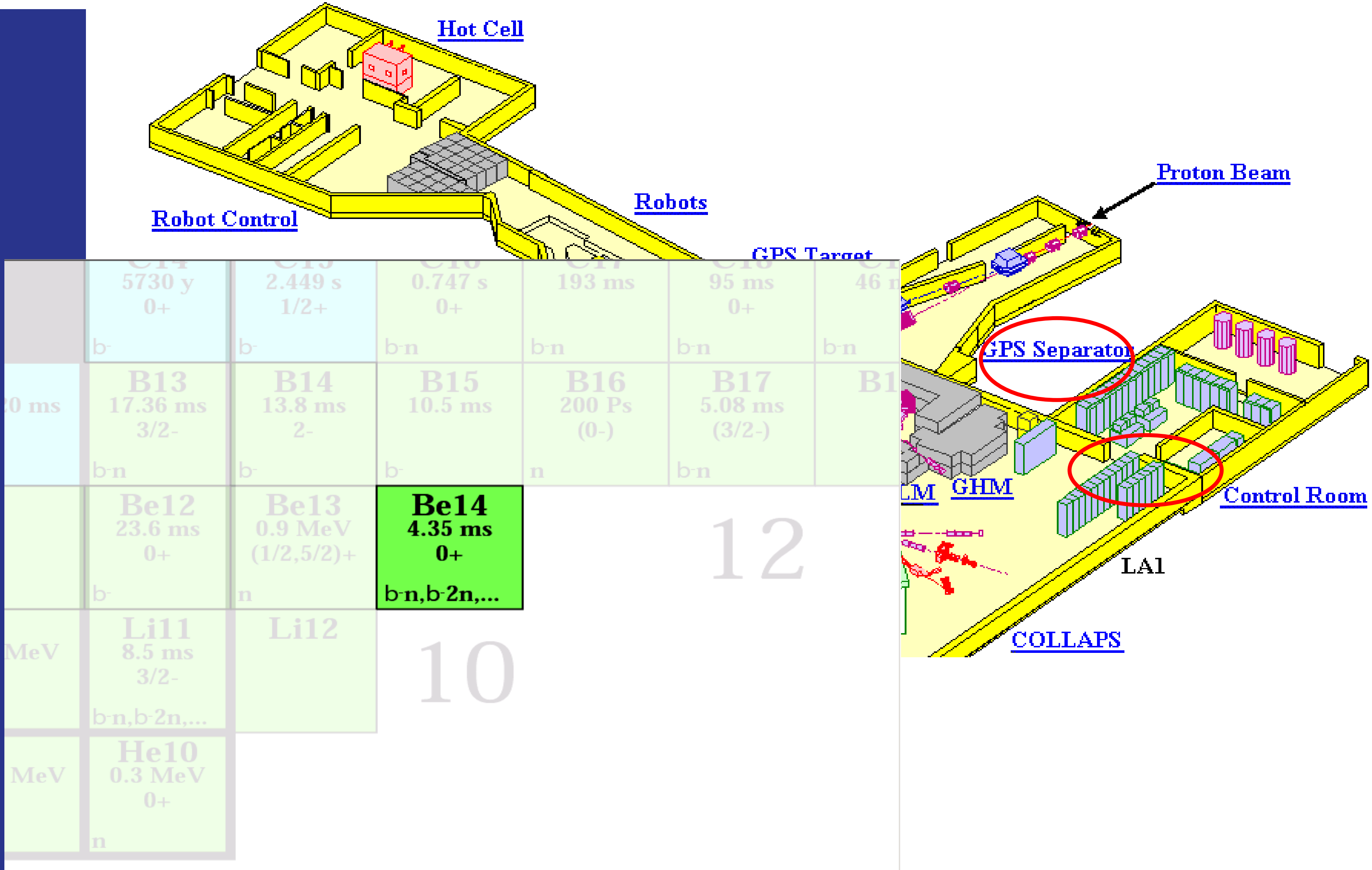
Magnet separators (General Purpose and High Resolution)

Post-acceleration

REX and HIE-ISOLDE accelerators

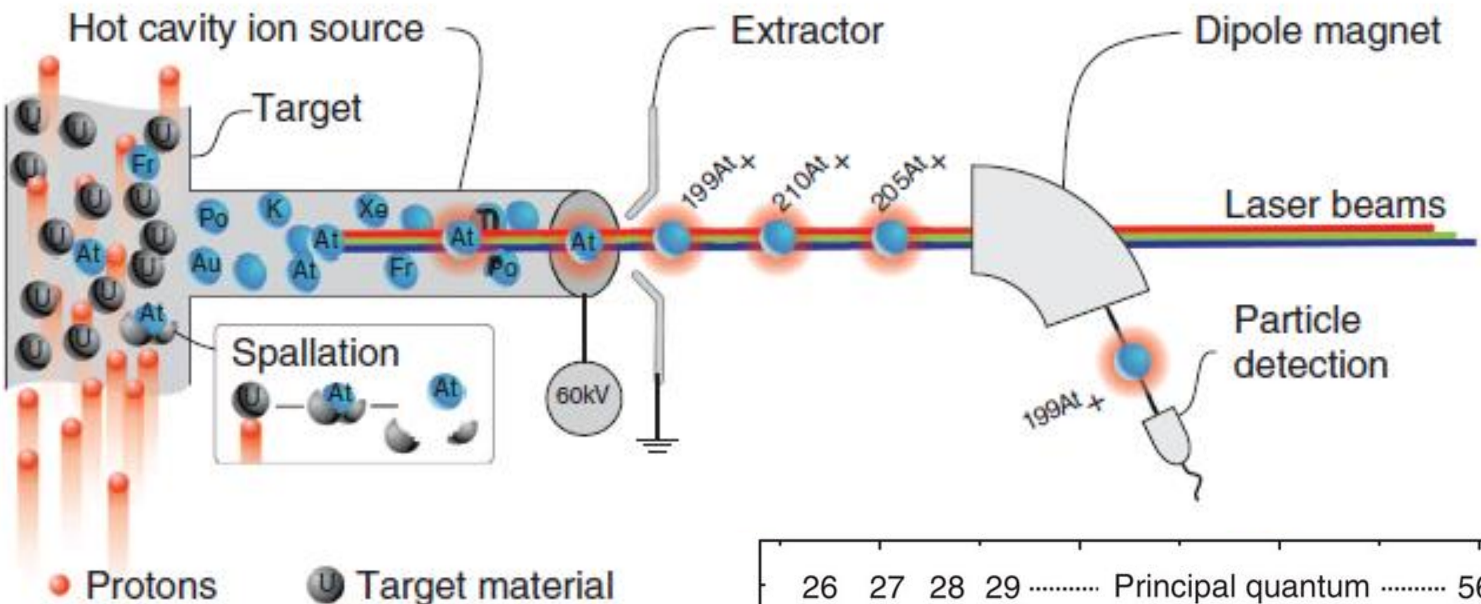


Production and selection - example

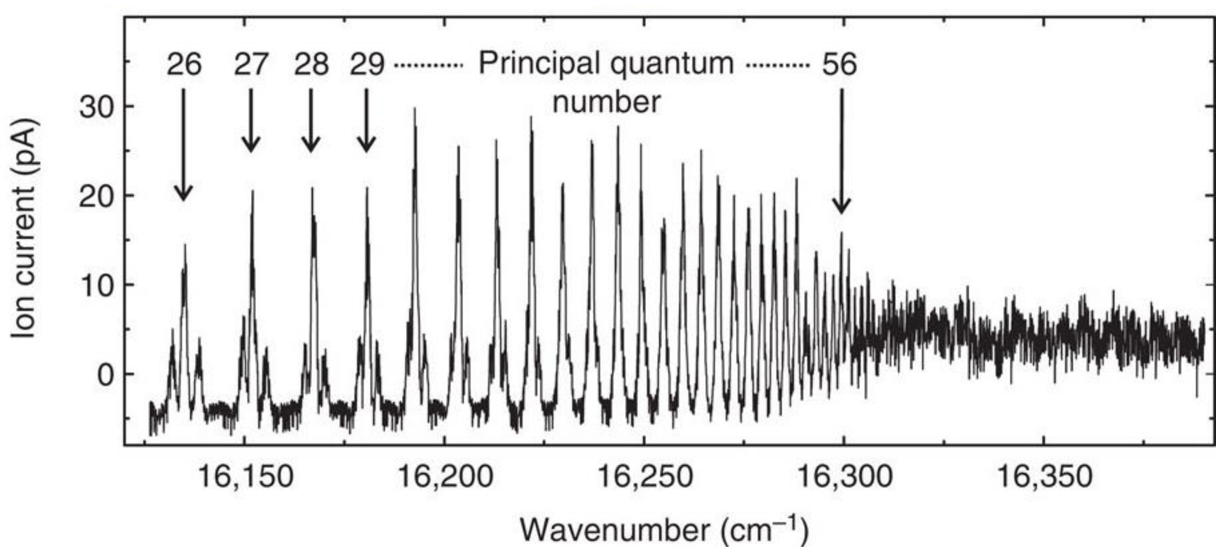


Example – astatine isotopes

- How to produce pure beams of astatine isotopes (all are radioactive)?
  - Use lasers to ionize them



- And determine for the first time the At ionization potential



S. Rothe et al,
Nature Communications 4 (2013), 1835

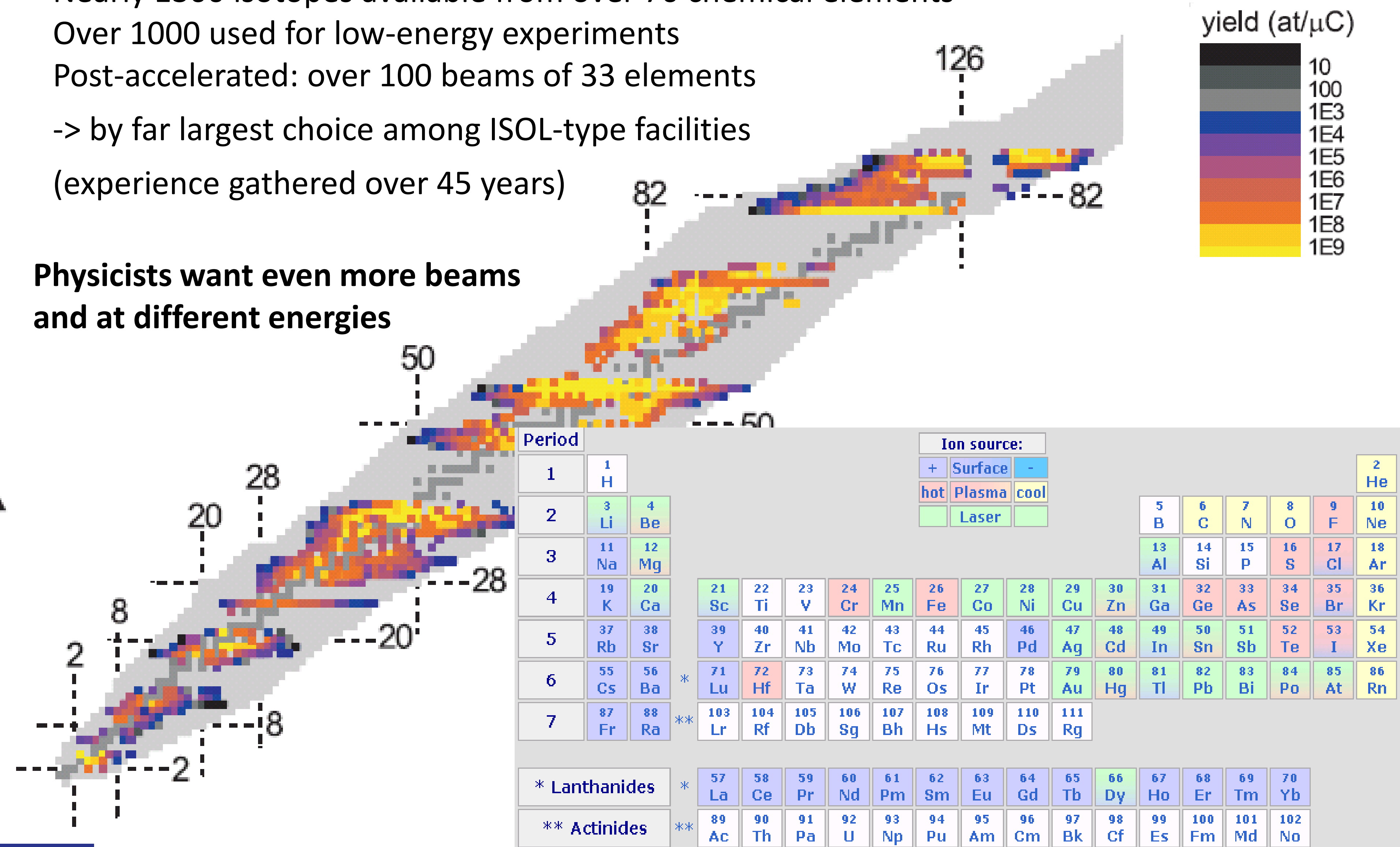
Extracted nuclides

Nearly 1300 isotopes available from over 70 chemical elements
Over 1000 used for low-energy experiments
Post-accelerated: over 100 beams of 33 elements

-> by far largest choice among ISOL-type facilities

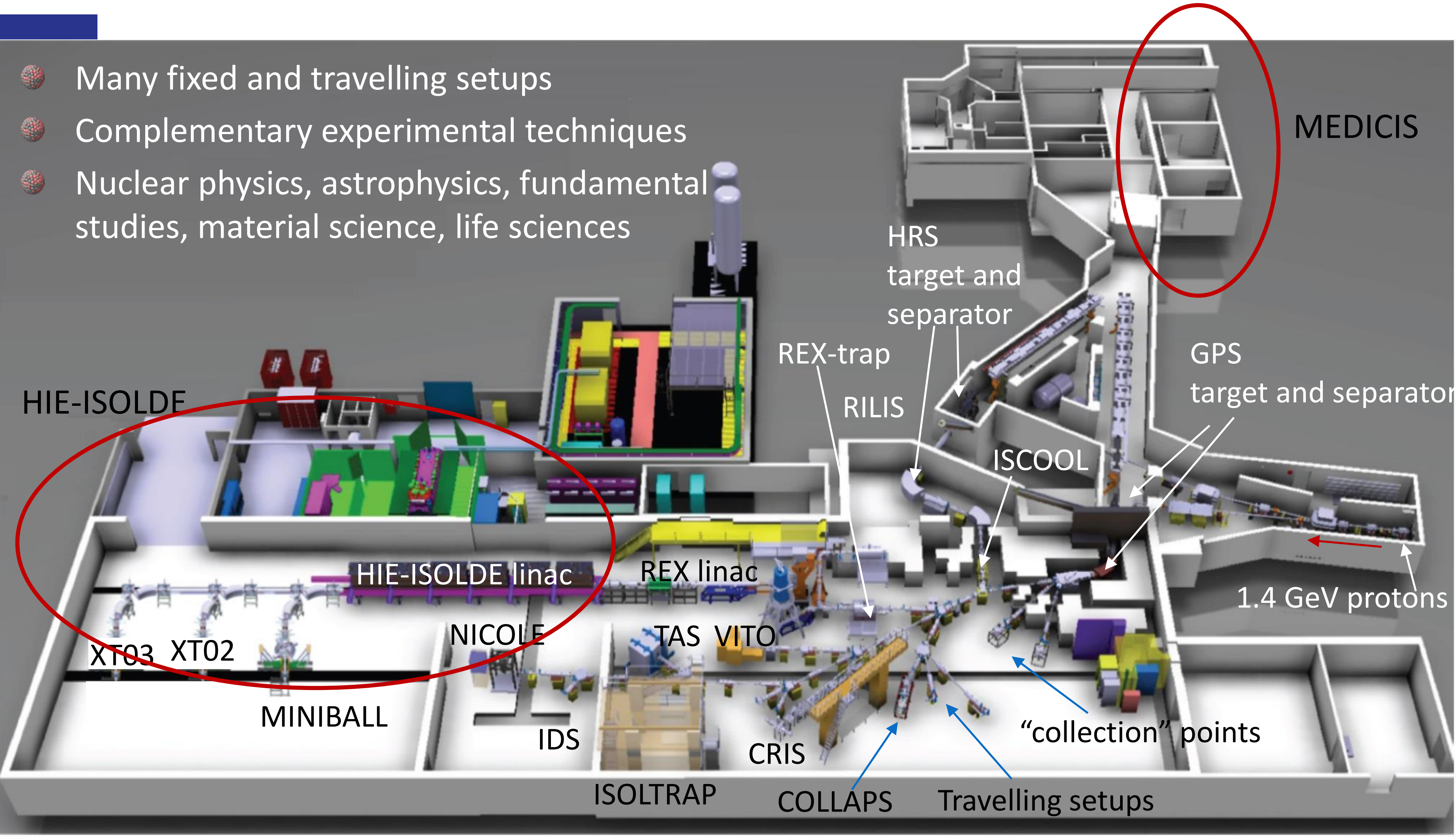
(experience gathered over 45 years)

Physicists want even more beams and at different energies

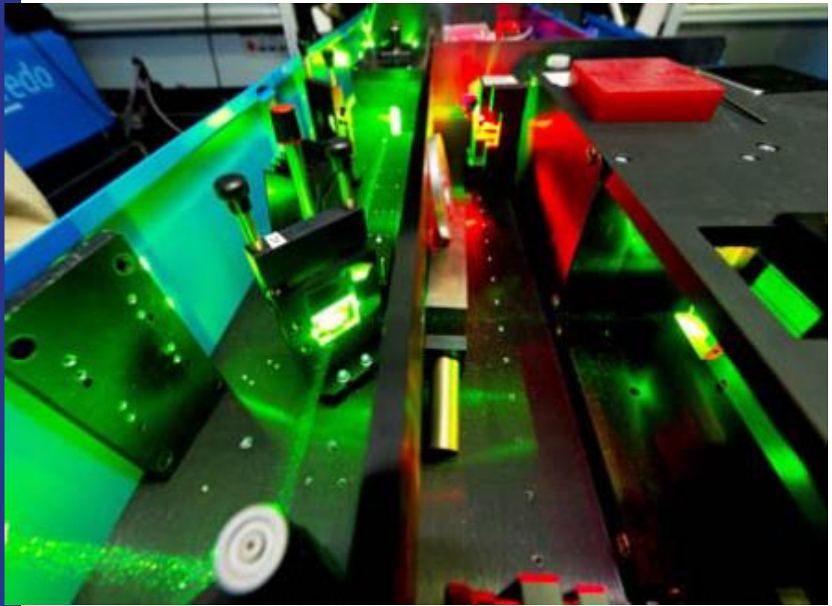


ISOLDE present layout

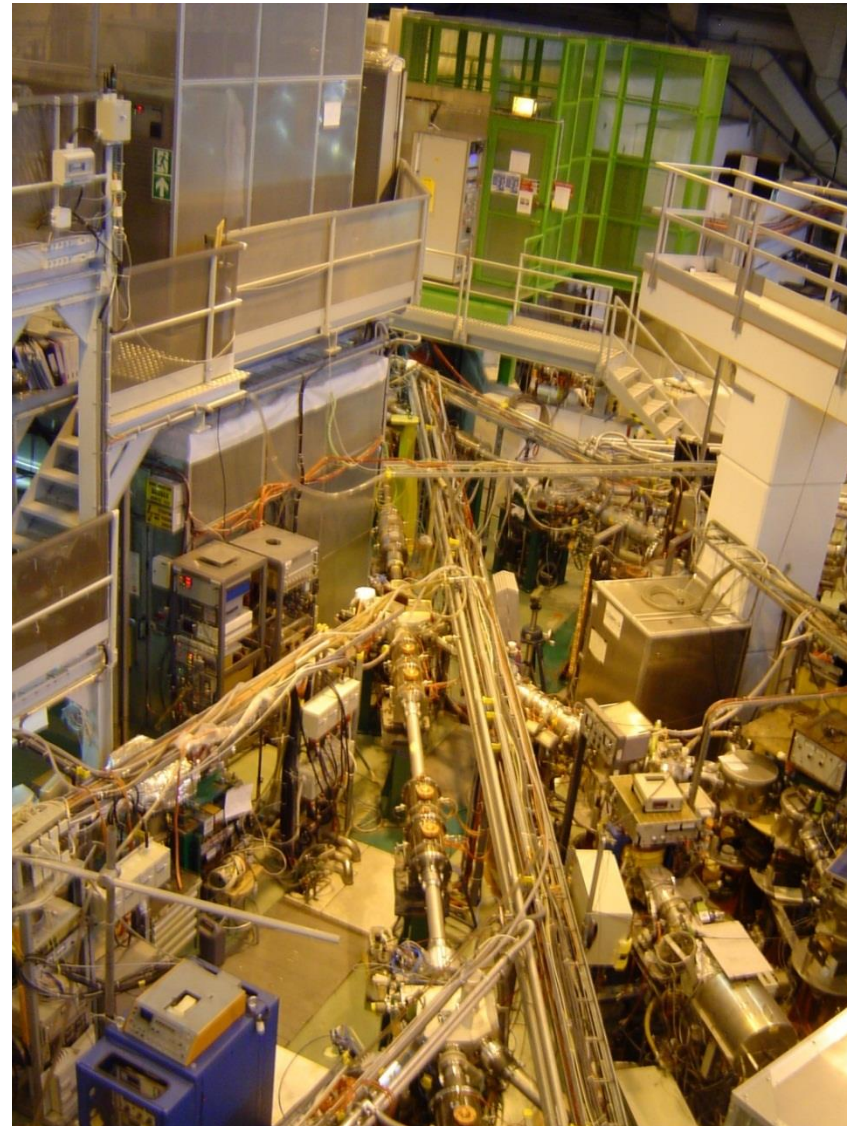
- Many fixed and travelling setups
- Complementary experimental techniques
- Nuclear physics, astrophysics, fundamental studies, material science, life sciences



Facility photos



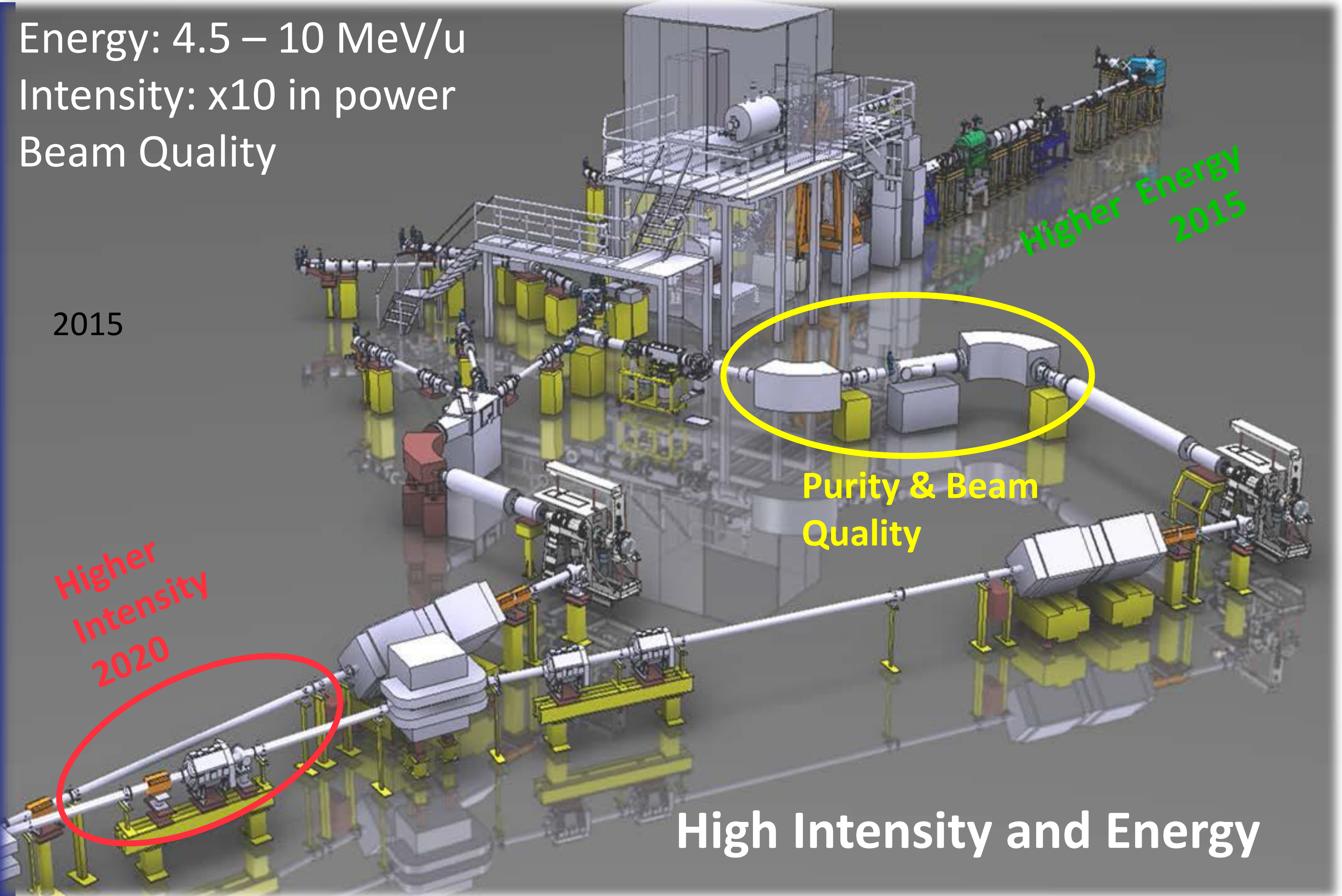
Experimental beamlines



Upgrades: HIE-ISOLDE project

Energy: 4.5 – 10 MeV/u
Intensity: x10 in power
Beam Quality

2015

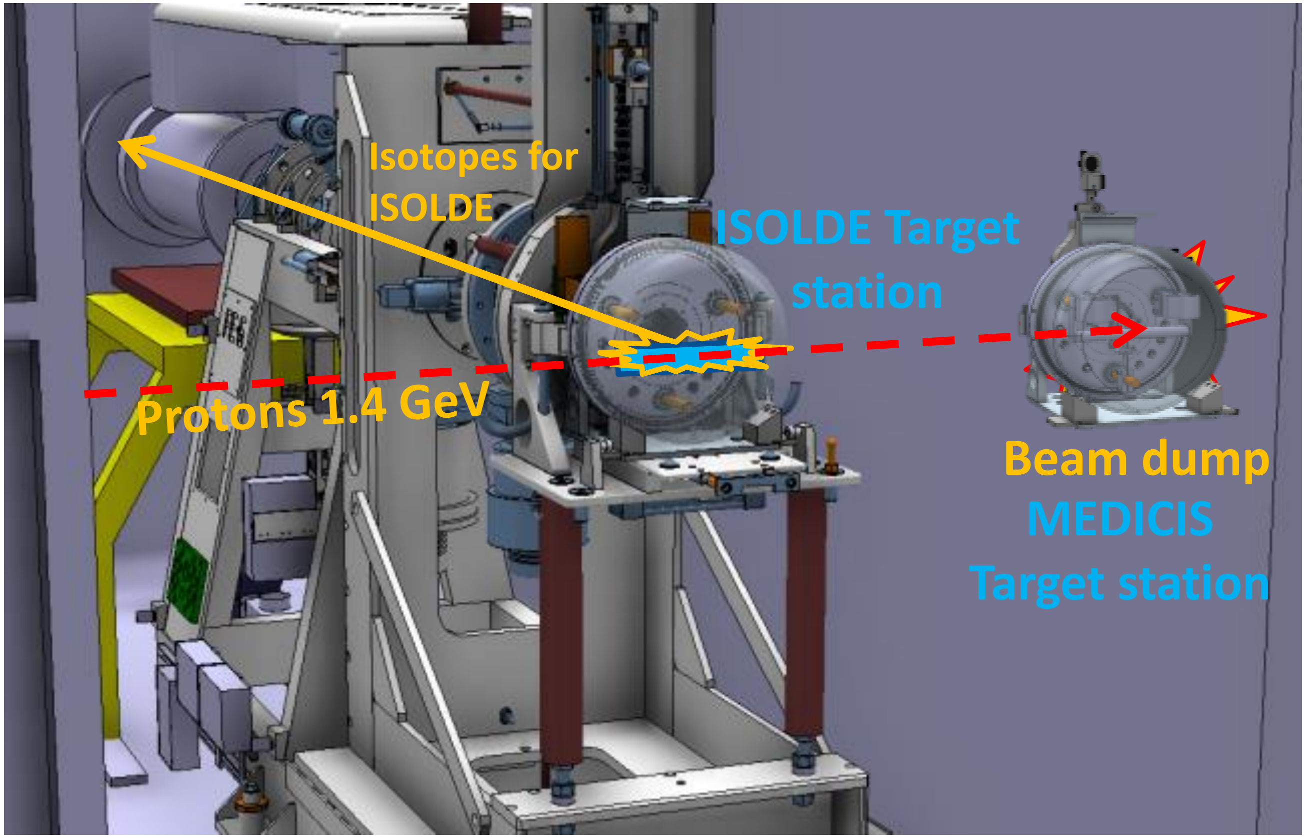


High Intensity and Energy

Applications: MEDICIS at ISOLDE

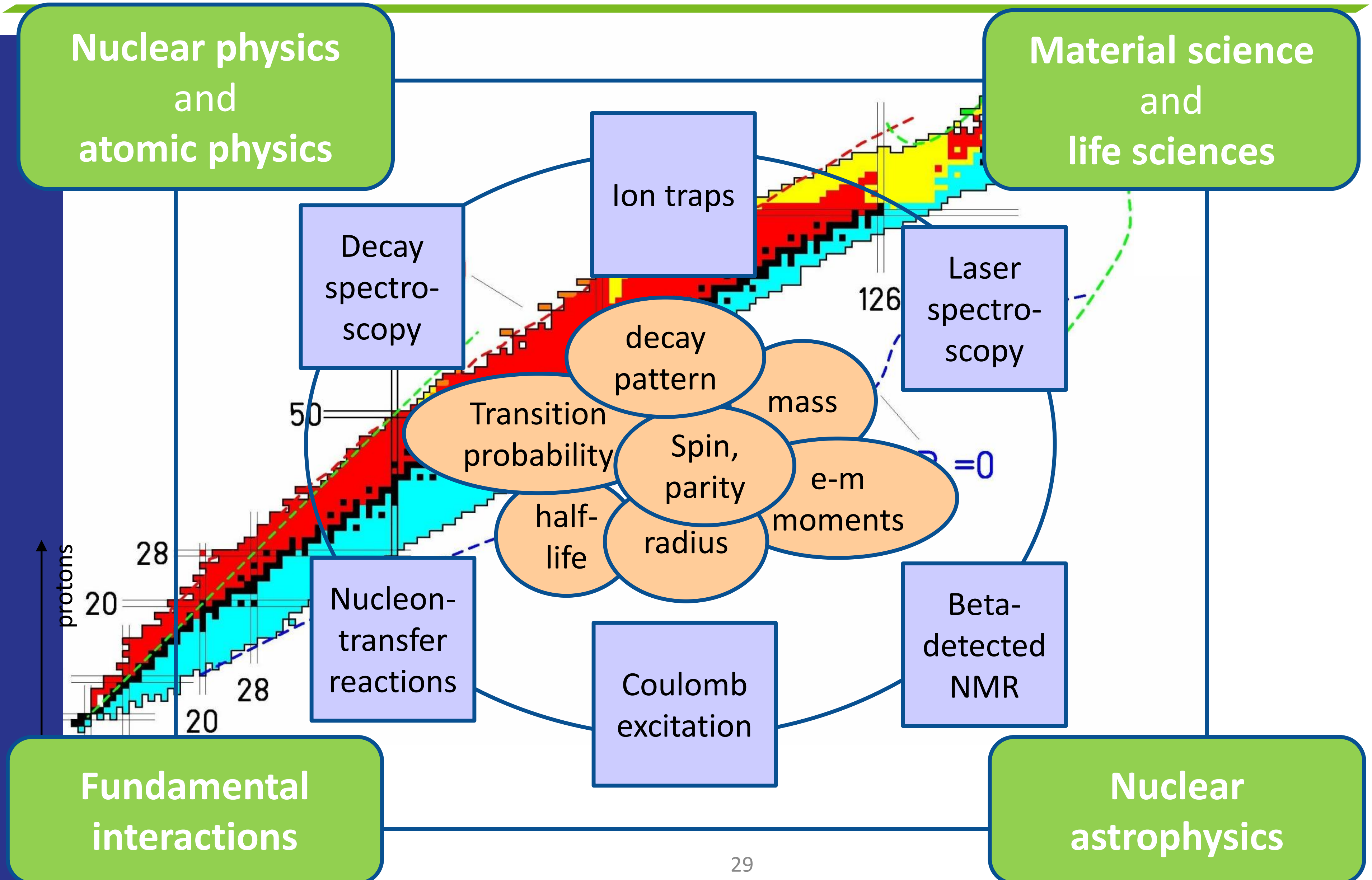
Production of medical isotopes for trials (not commercial use) via ISOLDE “dump” protons

-> little ISOLDE + chemical preparation



Use protons (~90%) normally lost into the **Beam Dump**

ISOLDE techniques and physics topics



Summary

- Two complementary types of RIB facilities
  - ISOL and in-flight
  - Several dozen facilities worldwide and new ones coming

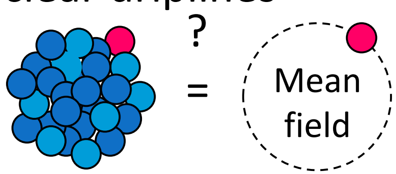
- ISOLDE at CERN
  - ISOL-type facility which uses protons from PSB
  - Elements: production target, ionization, extraction, separation, (post-acceleration)
  - Largest variety of beams worldwide
  - Upgrade project: HIE-ISOLDE
- ISOLDE research topics:
  - Nuclear physics
  - Atomic physics
  - Nuclear astrophysics
  - Fundamental studies
  - Applications
  - **=> Lecture 3**

Research with radionuclides

Nuclear physics

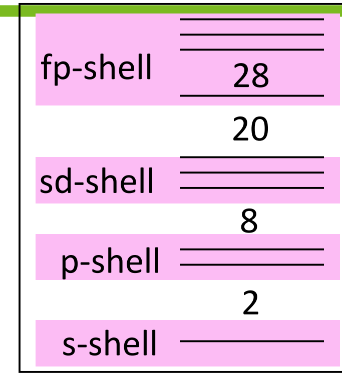
Strong interaction in many-nucleon systems

Nuclear driplines



34Ne:
10 protons + 24 neutrons

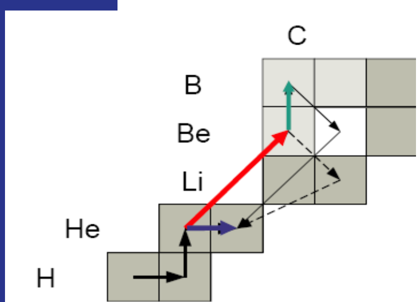
Does it exist?

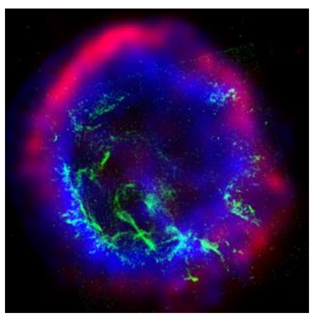


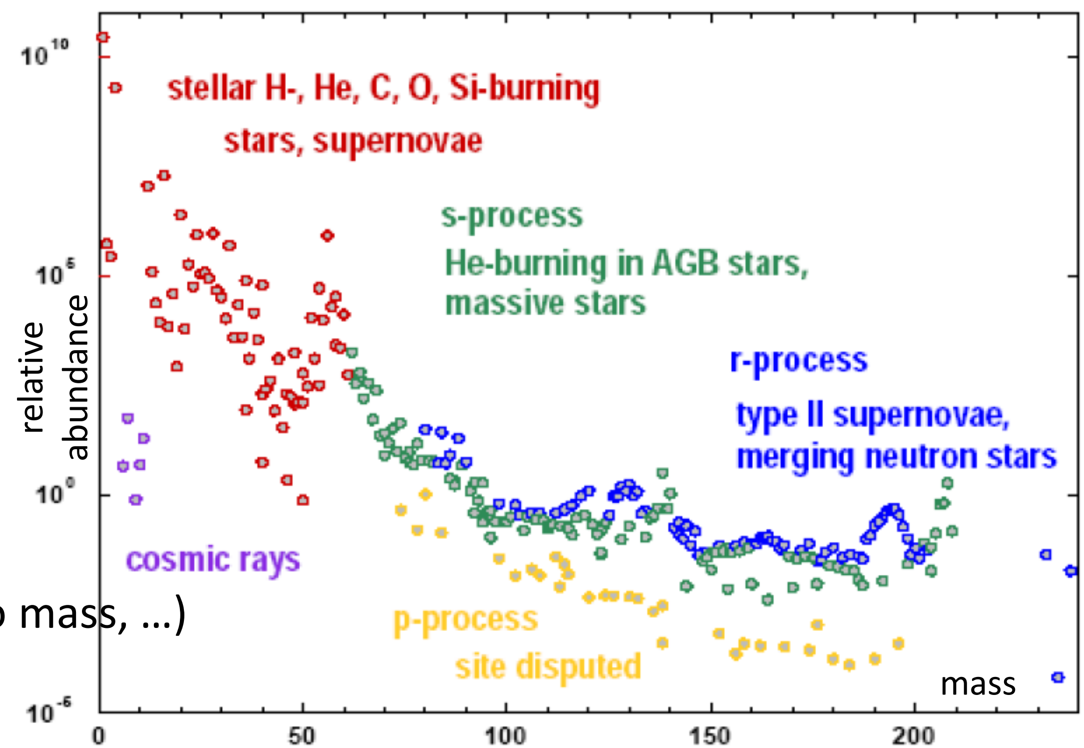
Astrophysics

Nucleo-synthesis, star evolution

Abundances of elements







Fundamental studies

Beyond standard model (neutrino mass, …)

Applications, ***e.g.***

Solid state physics, life sciences

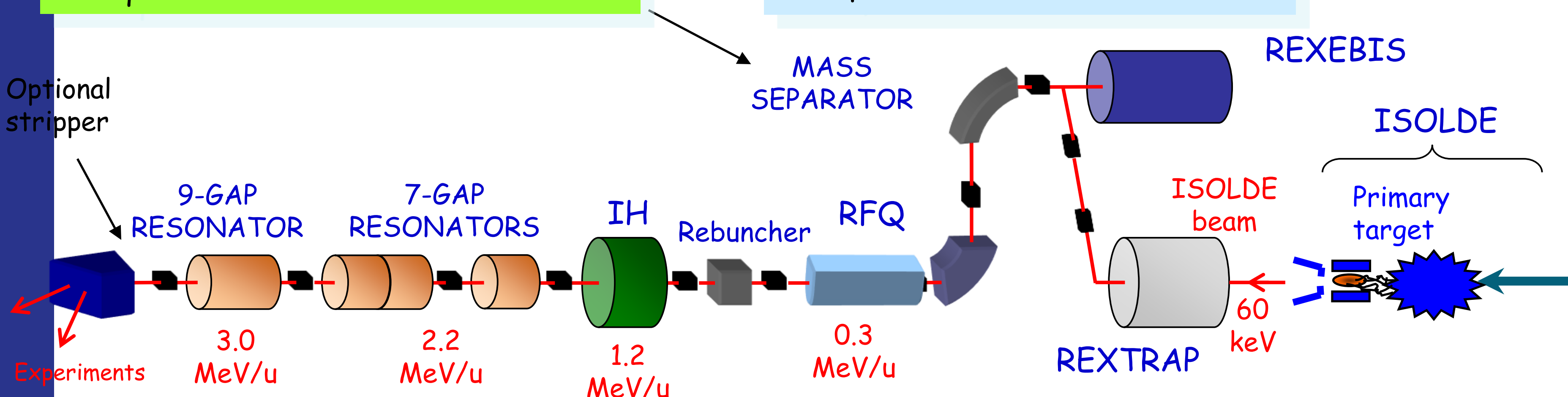
REX post-accelerator

EBIS

- Super conducting solenoid, 2 T
- Electron beam < 0.4A 3-6 keV
- Breeding time 3 to >200 ms
- Total capacity $6 \cdot 10^{10}$ charges
- A/q < 4.5

Nier-spectrometer

- Select the correct A/q and separate the radioactive ions from the residual gases.
- A/q resolution ~150



Linac

Length	11 m
Freq.	101MHz (202MHz for the 9GP)
Duty cycle	1ms 100Hz (10%)
Energy	300keV/u, 1.2-3MeV/u
A/q max.	4.5 (2.2MeV/u), 3.5 (3MeV/u)

REX-trap

- Cooling (10-20 ms)
  Buffer gas + RF
- (He), Li,...,U
- 10^8 ions/pulse

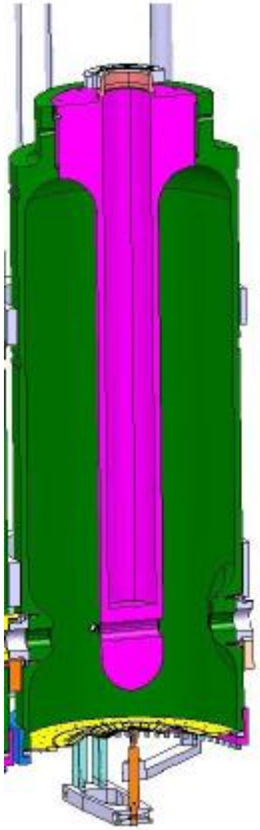
(Space charge effects $>10^5$)

Total efficiency : 1 -10 %

HIE-ISOLDE

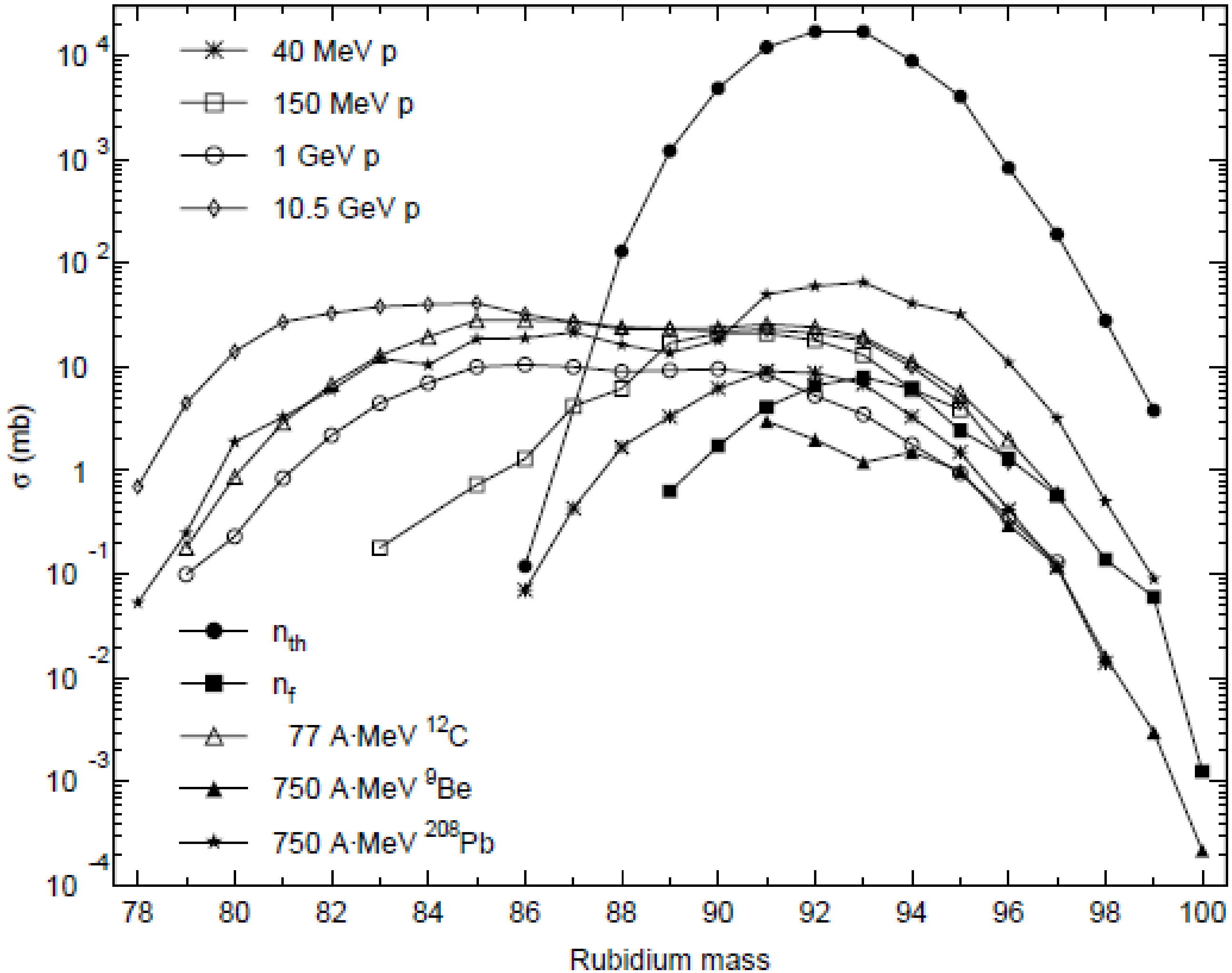
- SC-linac between 1.2 and 10 MeV/u
- 32 SC QWR (20 @ β_0=10.3% and 12@ β_0=6.3%)
- Energy fully variable; energy spread and bunch length are tunable. Average synchronous phase fs= -20 deg
- 2.5<A/q<4.5 limited by the room temperature cavity
- 16.02 m length (without matching section)
- No ad-hoc longitudinal matching section (incorporated in the lattice)
- New beam transfer line to the experimental stations

Quarter-wave resonators (Nb sputtered)



Reaction probability

- Primary beam type and energy are important



Reaction probability