Nuclear physics at CERN

Lecture 1: Nuclear landscape and the ISOLDE facility

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on behalf of the CERN ISOLDE team
www.cern.ch/isolde

Outline

Aimed at both physics and non-physics students

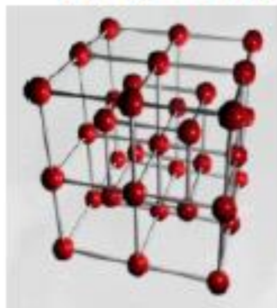
- **This lecture**: Nuclear landscape and the ISOLDE facility
  - Nuclear physics and nuclear scale
  - Nuclear physics at CERN
  - Chart of nuclei
  - Radioactive Ion Beam facilities
  - Beam production at ISOLDE
- Lecture 2: Science at ISOLDE

Nuclear physics and nuclear scale

Matter

Macroscopic

Crystal

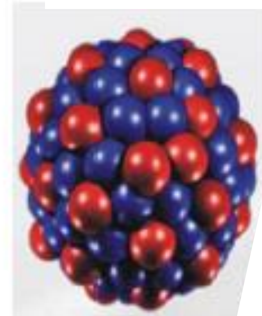


10^{-9} m

Atom

10^{-10} m

Atomic nucleus

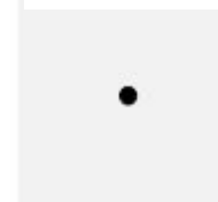


10^{-14} m
Angstrom

Nucleon

10^{-15} m
femtometer

Quark

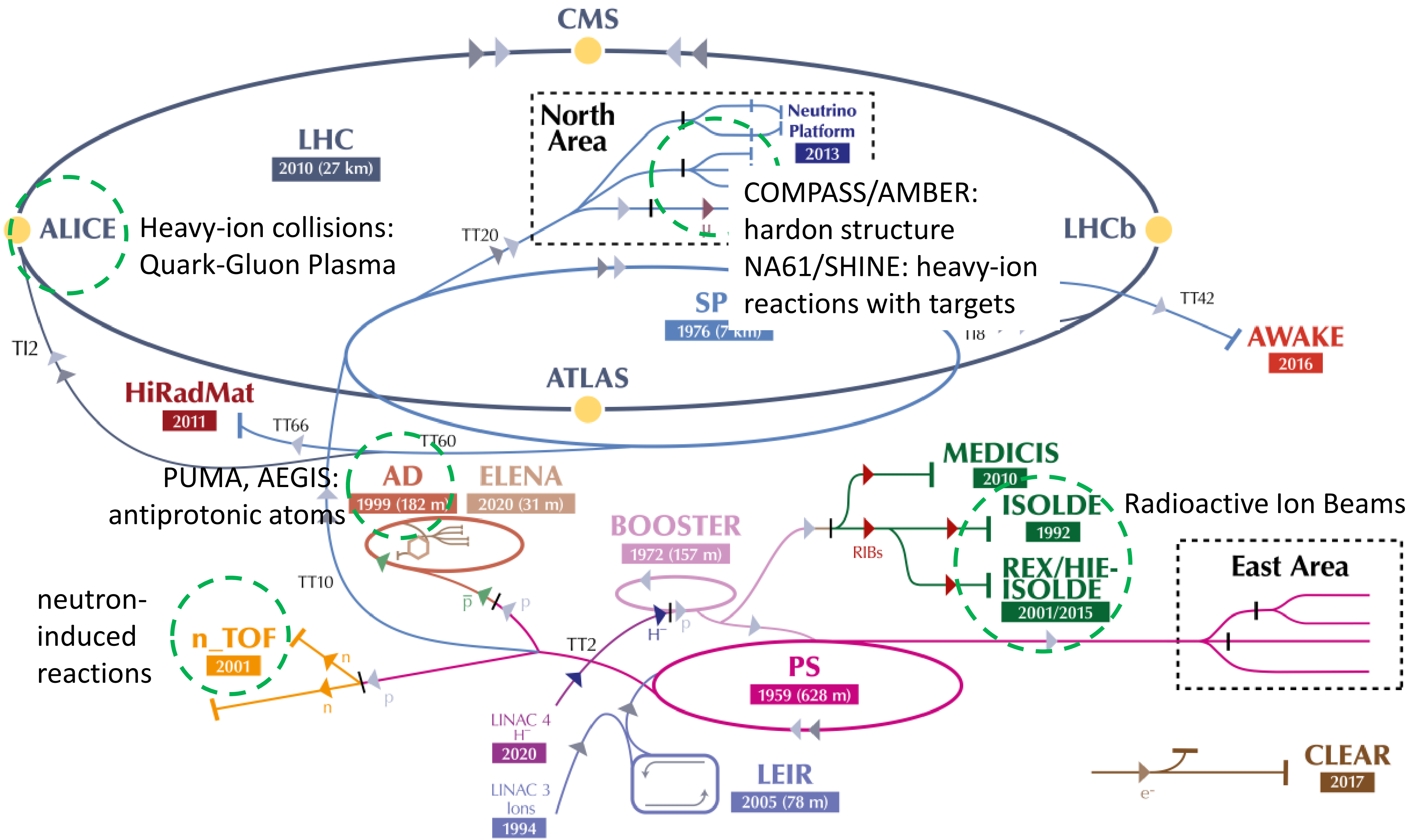


$< 10^{-18}$ m

Aim of nuclear physics:

- unravel fundamental properties of nuclei from their building blocks, protons and neutrons
- determine emergent complexity in realm of strong interaction from underlying quark and gluon degrees of freedom of Quantum Chromodynamics

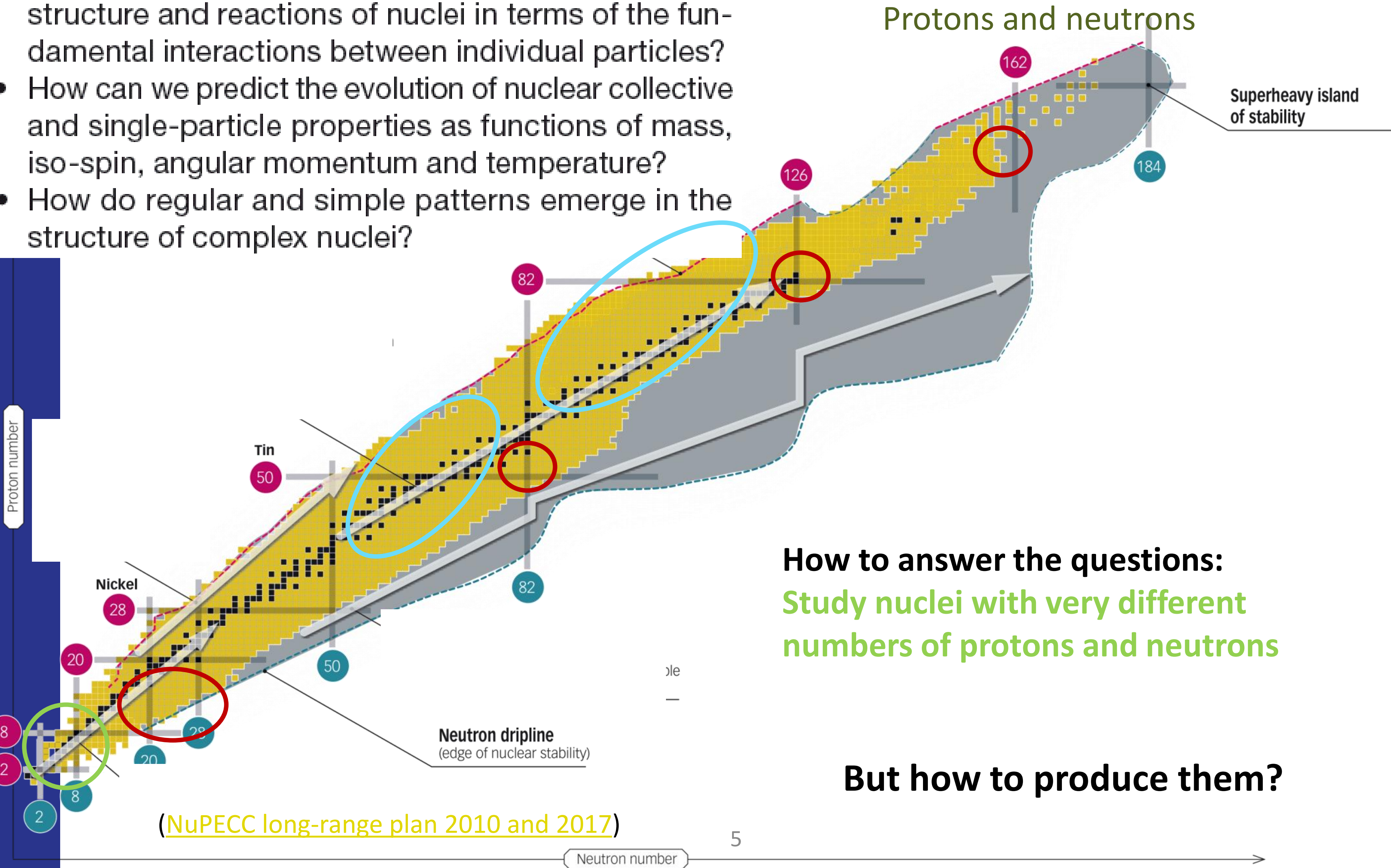
Nuclear physics at CERN



Open questions in low-energy 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:
Protons and neutrons



How to answer the questions:
Study nuclei with very different numbers of protons and neutrons

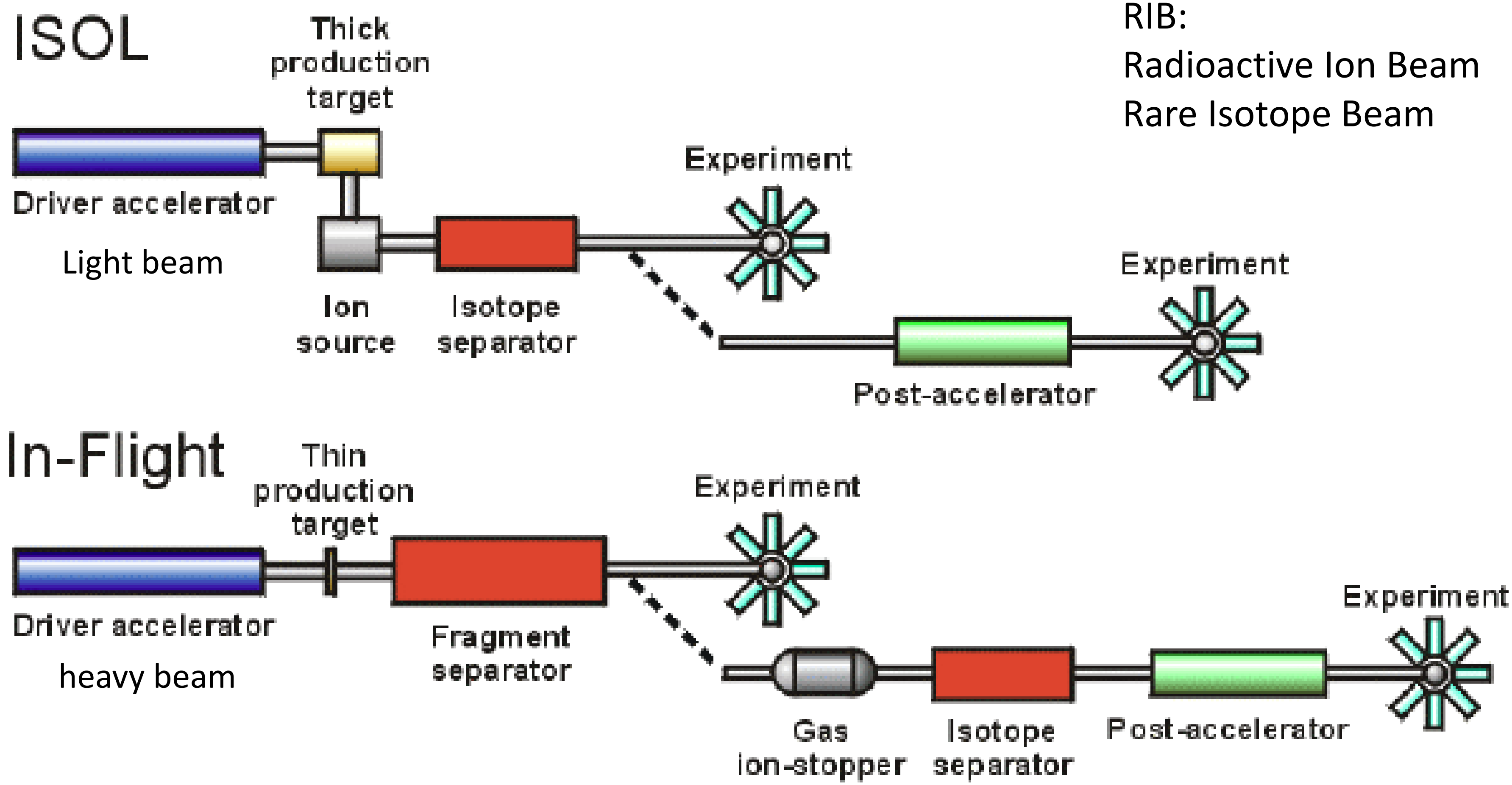
But how to produce them?

(NuPECC long-range plan 2010 and 2017)

RIB facilities

- Two main types of (complementary) RIB facilities:

RIB:
Radioactive Ion Beam
Rare Isotope Beam

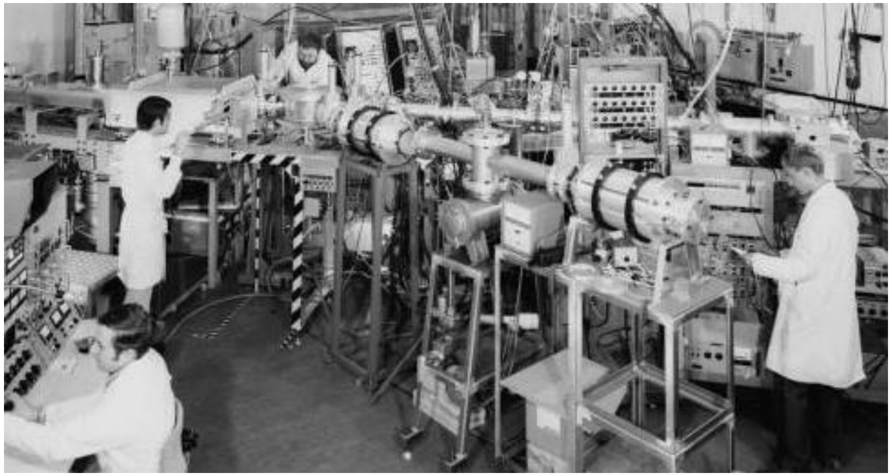


RIB facilities comparison

	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, SPIRAL2@GANIL, ISAAC@TRIUMF	GANIL, GSI/FAIR, RIBF@RIKEN, FRIB@MSU

ISOLDE at CERN

- Isotope Separator OnLine DEvice



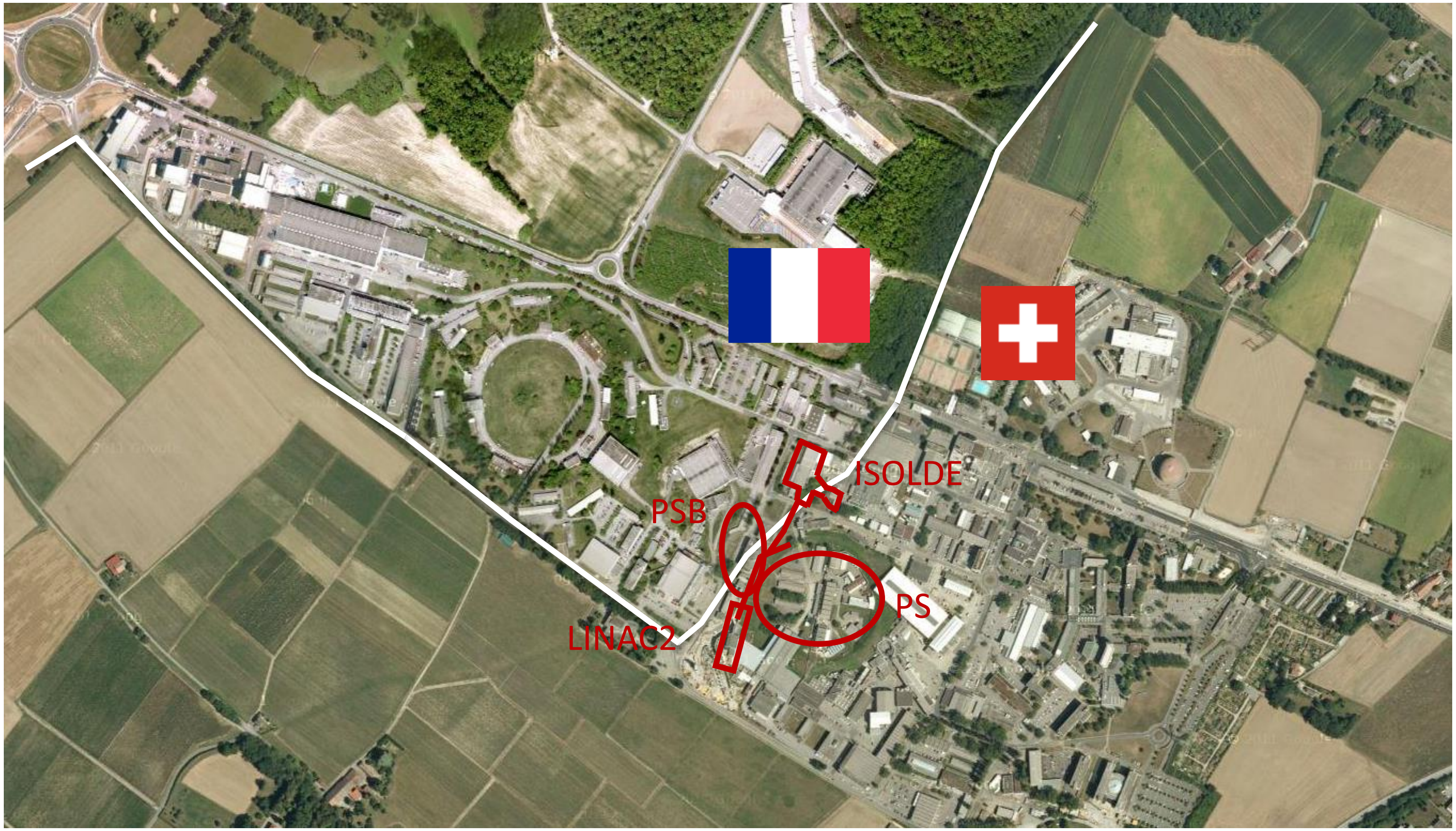
- First ISOL facility worldwide!

- Produces Radioactive Ion Beams (RIBs)
- Approved by the CERN council in 1964
  - 1st used 600 MeV protons from SC
  - Then used 1.0 GeV (later 1.4 GeV) protons from the PSB

- A small facility with a big impact!
  - 0.1% of CERN budget
  - 7% of CERN scientists
  - 50% of CERN proton pulses
  - 80% of CERN protons

http://timeline.web.cern.ch/timelines/ISOLDE

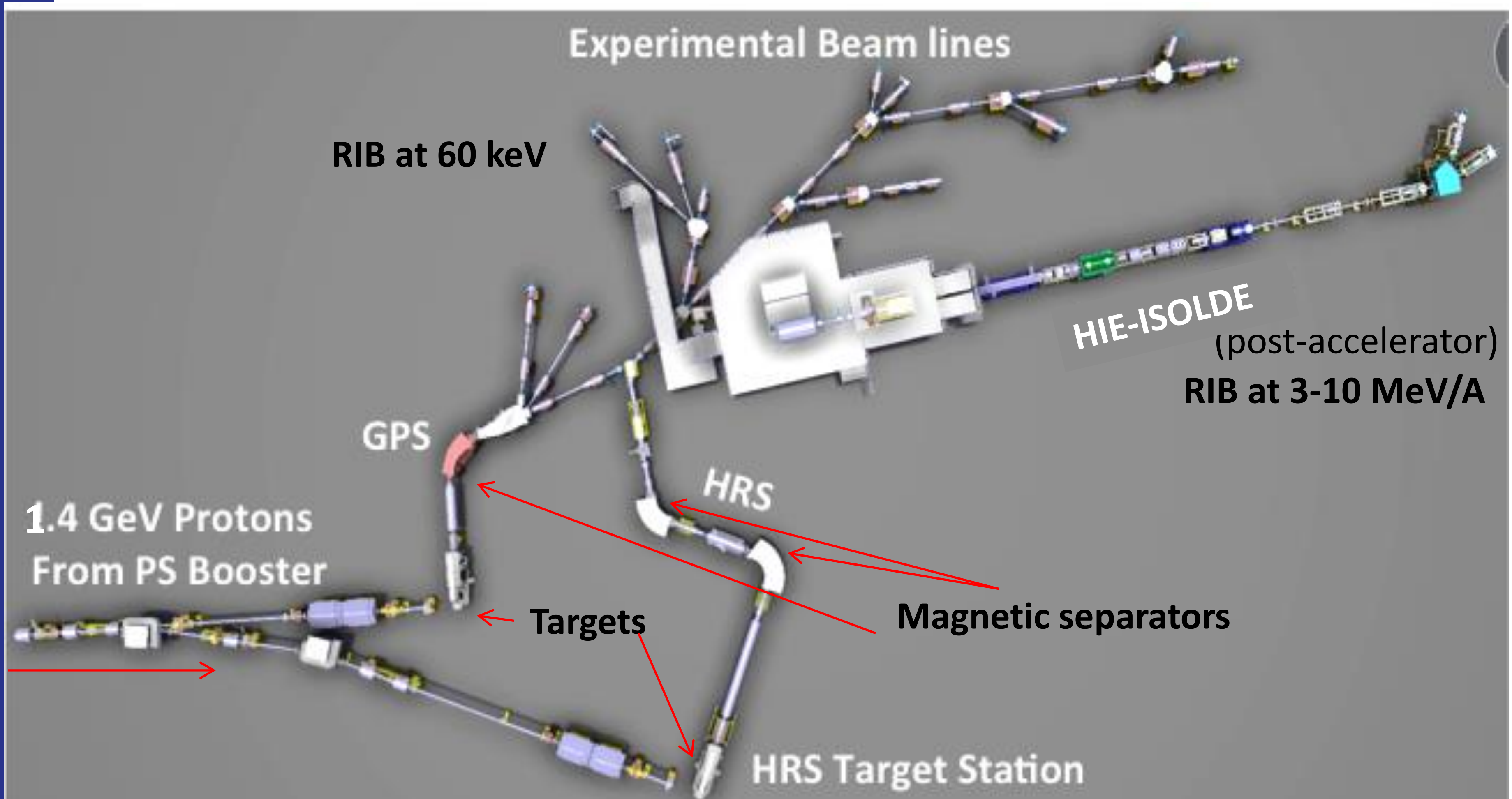
ISOLDE within CERN complex



- Operates ~8 months/year, 24/7
- ~50 staff/students/fellows
  - Maintain and operate the facility
- ~500 users for physics
  - More than 90 ongoing experiments

ISOLDE elements

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



Production – ionization – separation

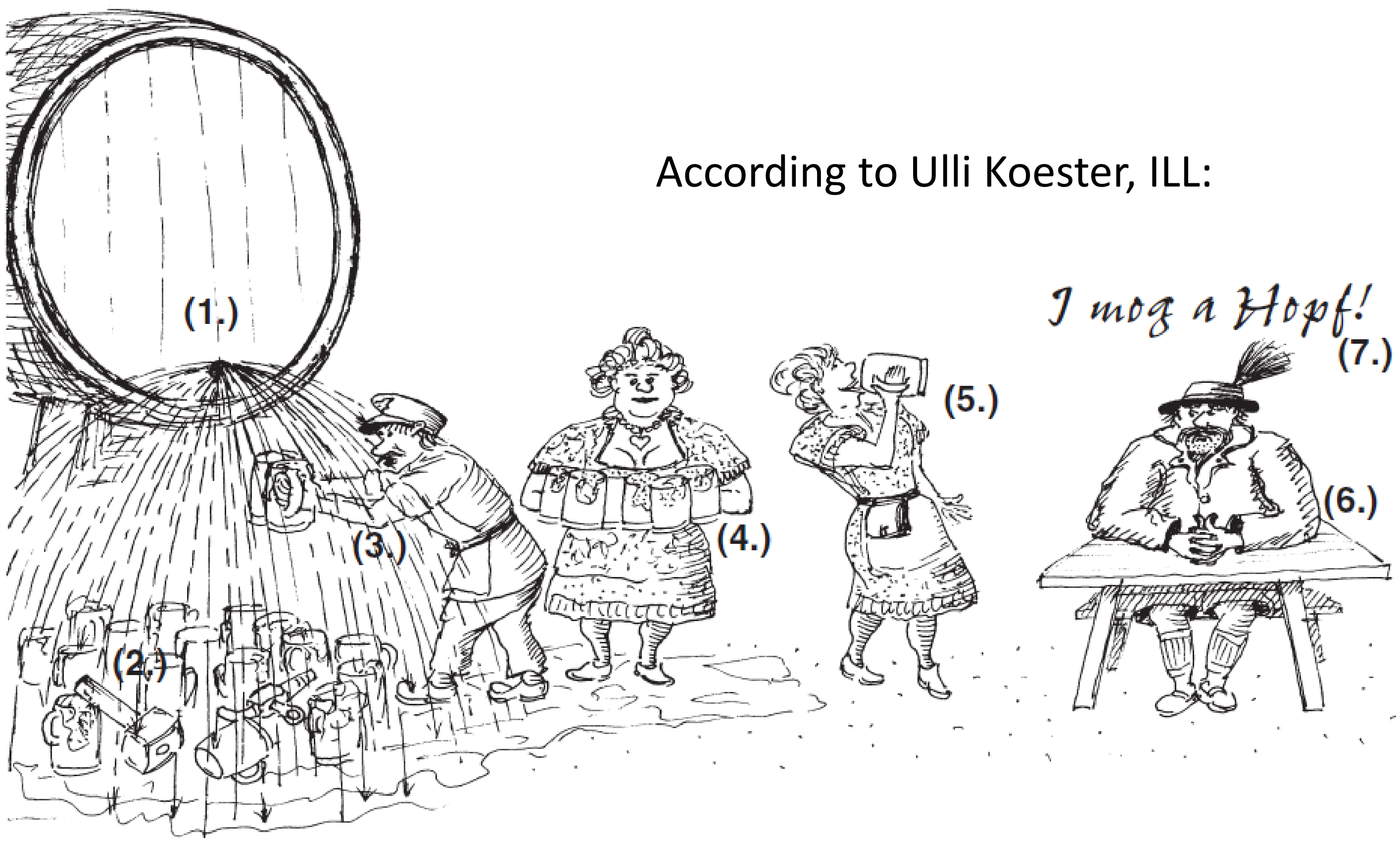
RIB beam intensity

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

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

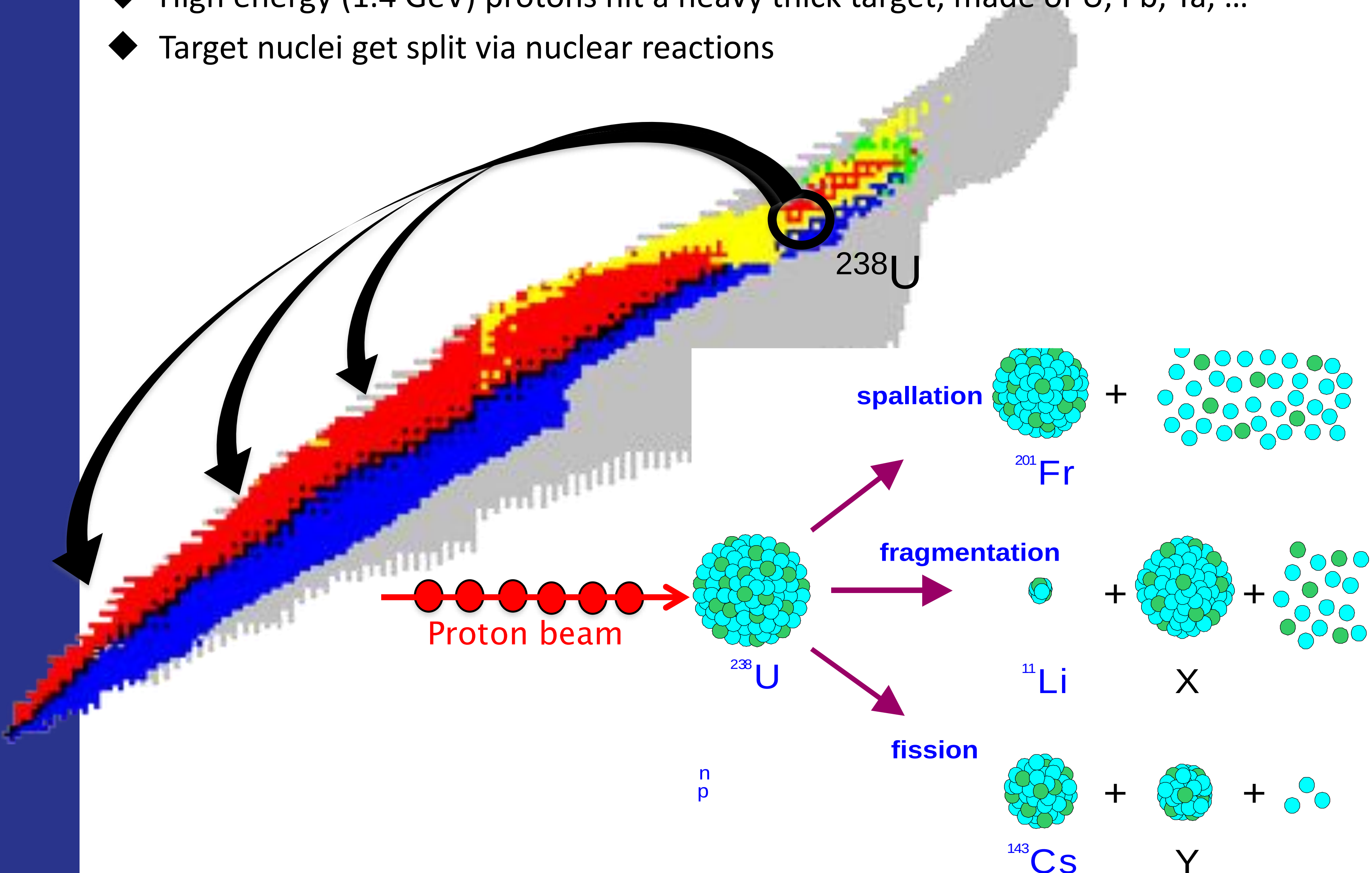
primary particle flux x reaction cross section x number of target particles x efficiencies

According to Ulli Koester, ILL:

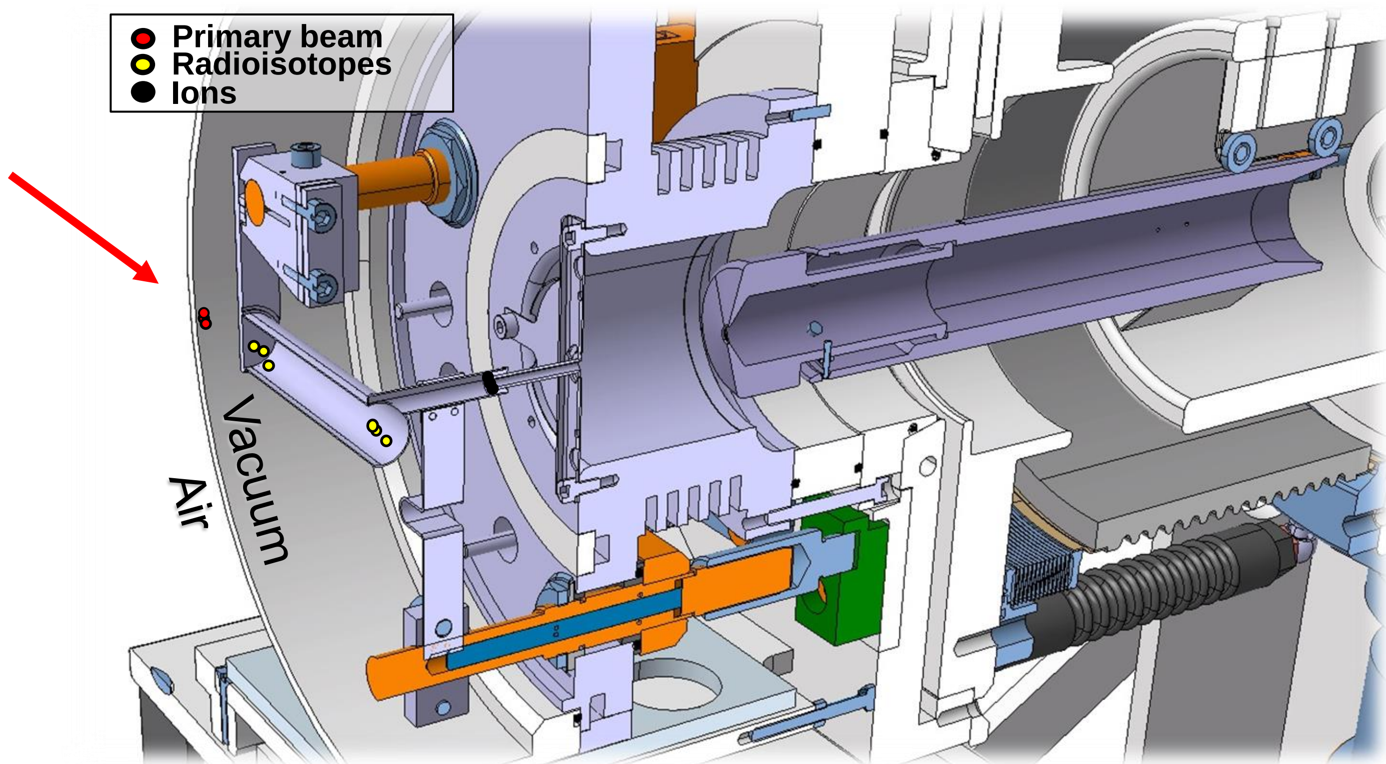


Production: Modern-day alchemy

- High energy (1.4 GeV) protons hit a heavy thick target, made of U, Pb, Ta, …
- Target nuclei get split via nuclear reactions



Production: Targets + ionisers

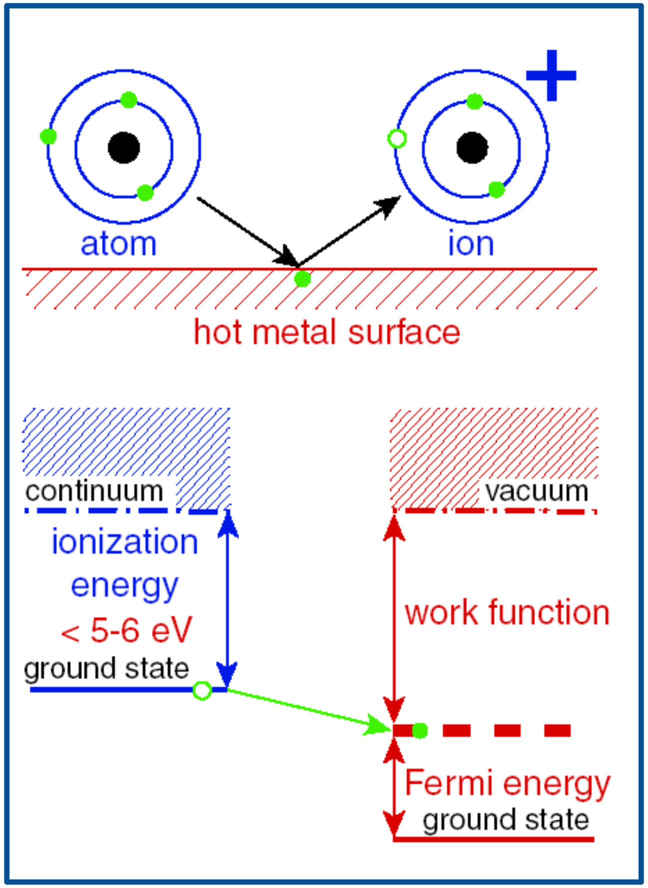


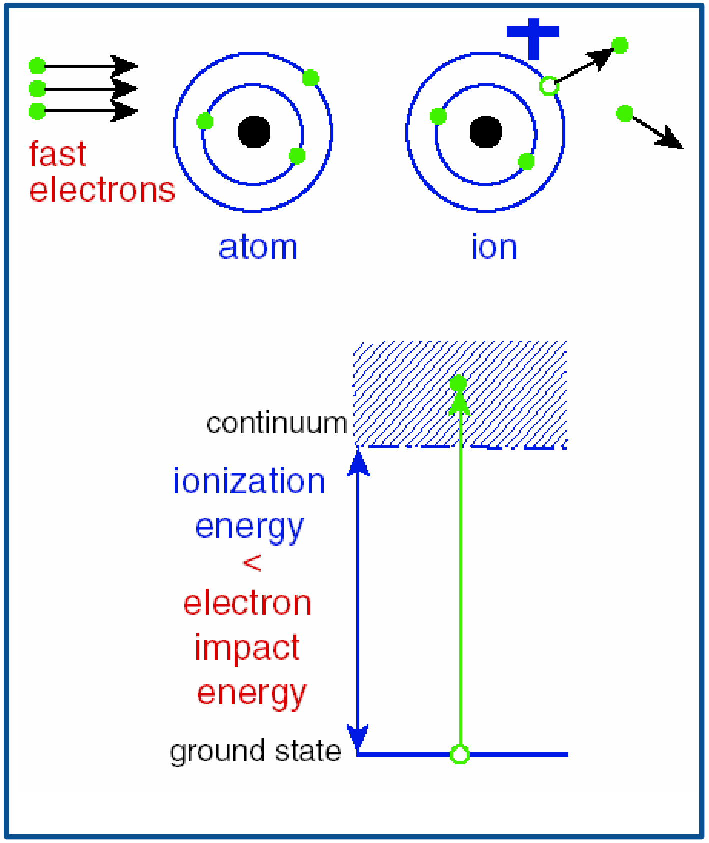
*picture and animation courtesy of M. Delonca

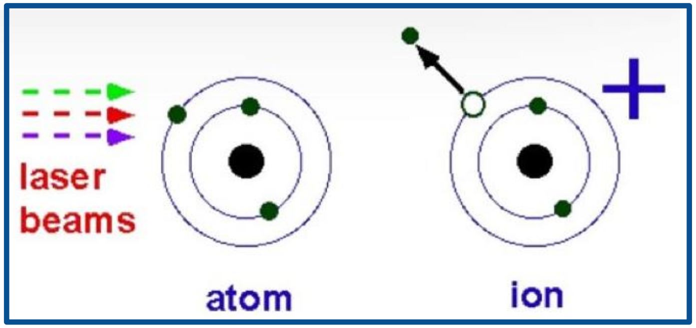
- Over 120 materials tested and/or used as ISOL targets
  - Examples: molten metals, nanomaterials
  - Choice given by RIB of interest
- Target material and transfer tube heated to 1500 – 2000 degrees
- Operated by robots due to radiation

Ionization

- Surface
- Plasma
- Lasers



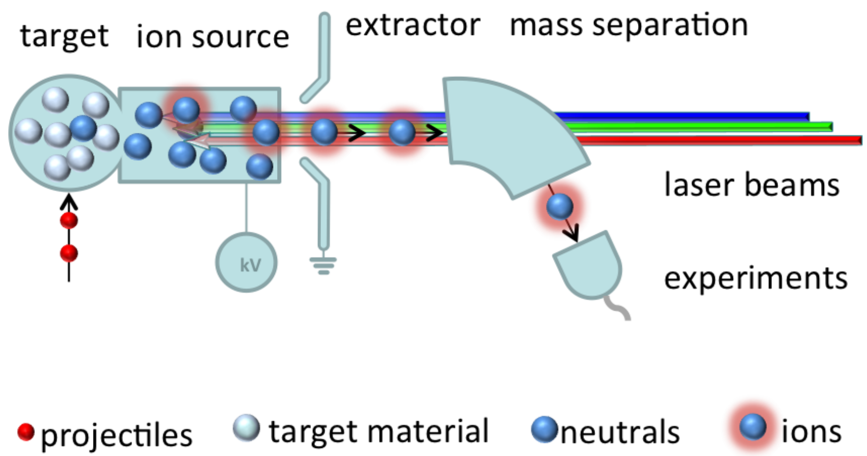


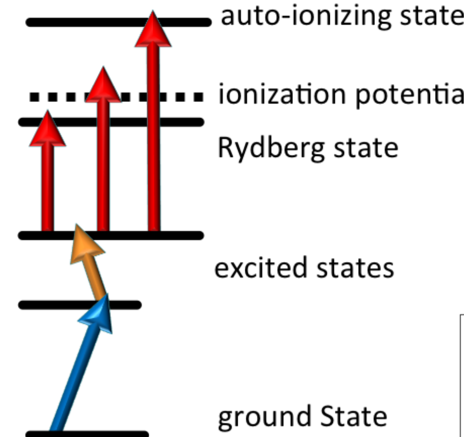


After U. Koester

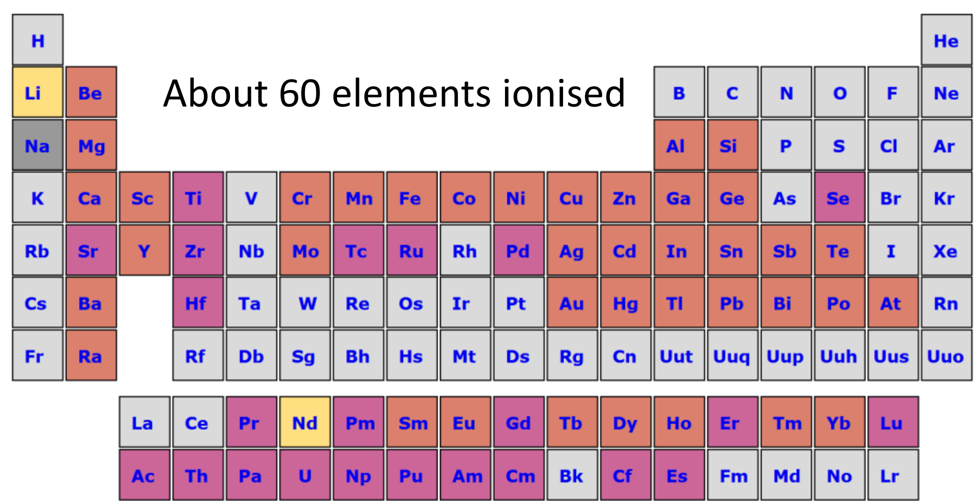
Ionization with lasers: RILIS

- Resonance Ionization Laser Ion Source
- Uses lasers to selectively ionize a particular element (isotope/isomer)



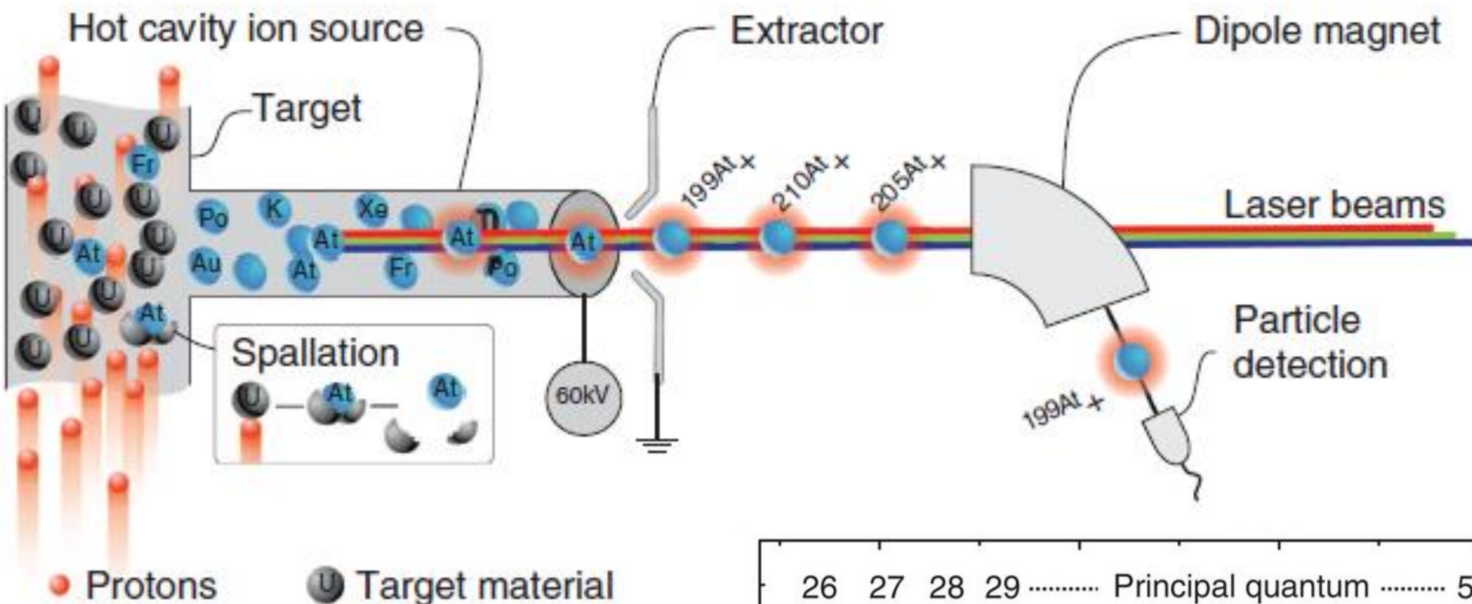


RILIS

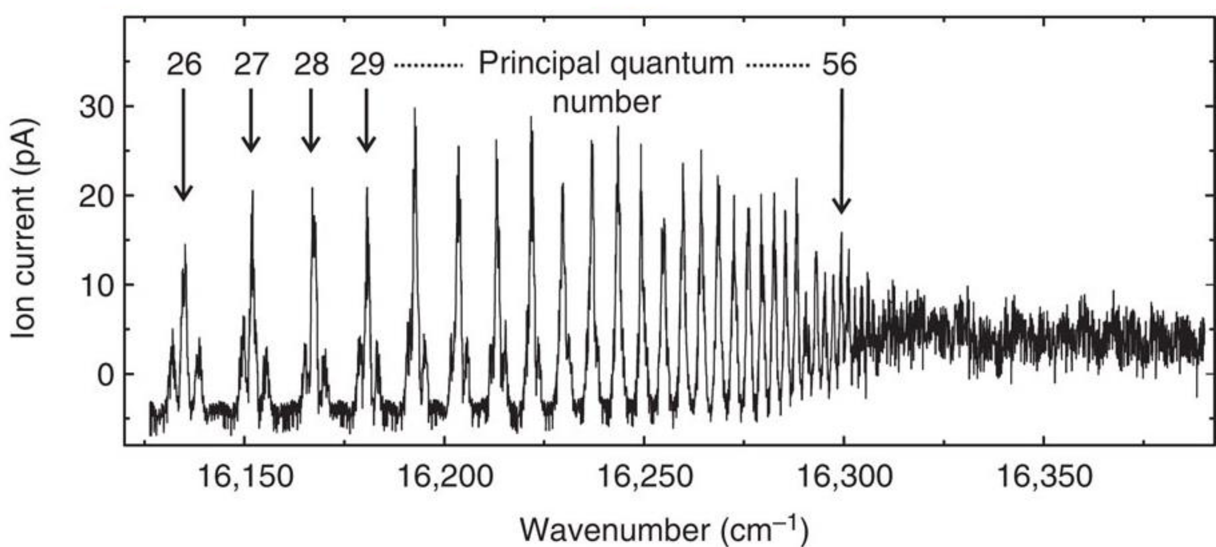


Example – astatine isotopes

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



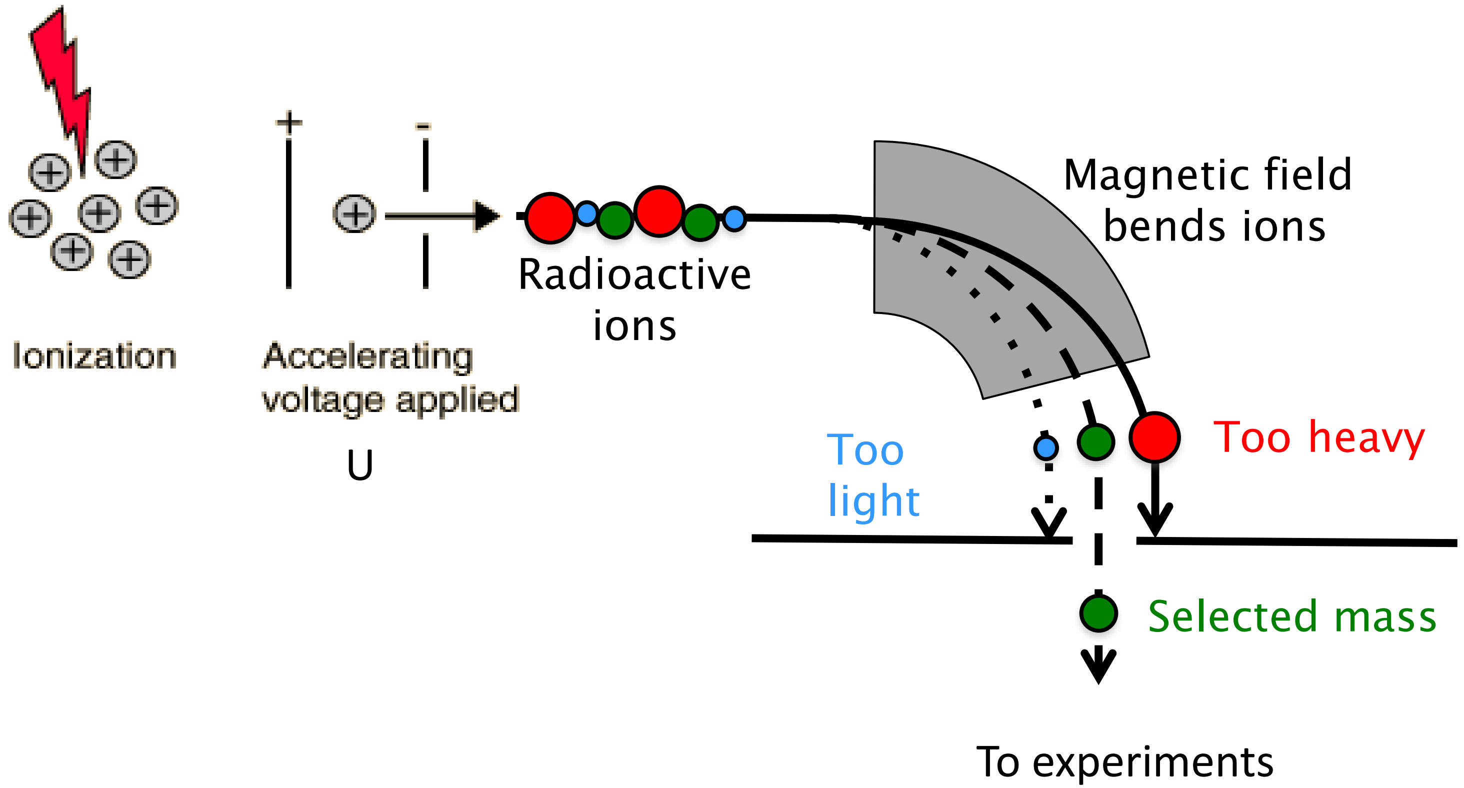
- And determine for the first time the At ionization potential



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

Beam extraction and separation

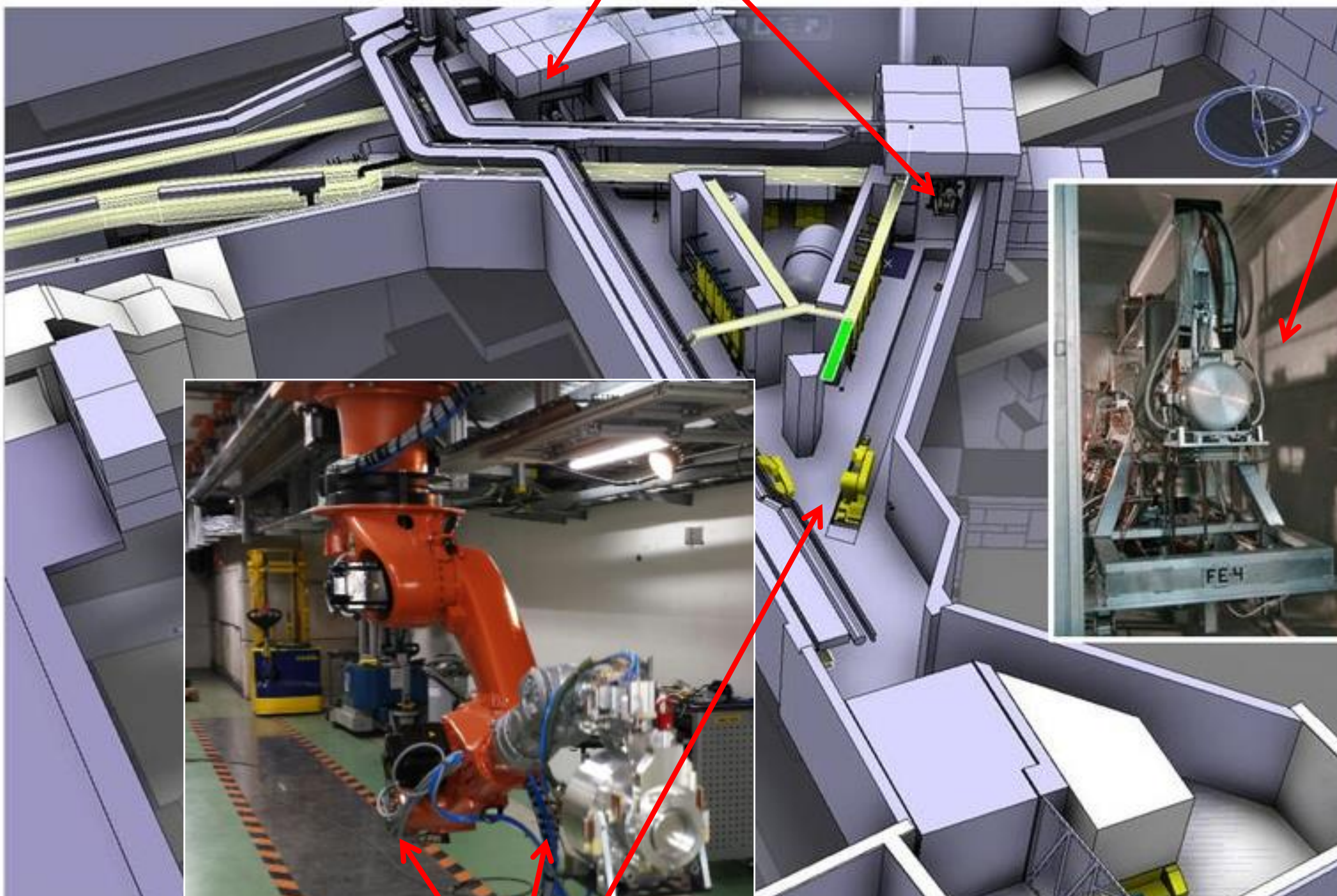
- All produced ions are extracted by electrostatic field (up to 60kV)
- The interesting nuclei are mass selected via magnetic field
  - Lorentz force: depends on velocity and mass
  - m/dm <5000, so many unwanted isobars also get to experiments



Production, ionization, extraction

target

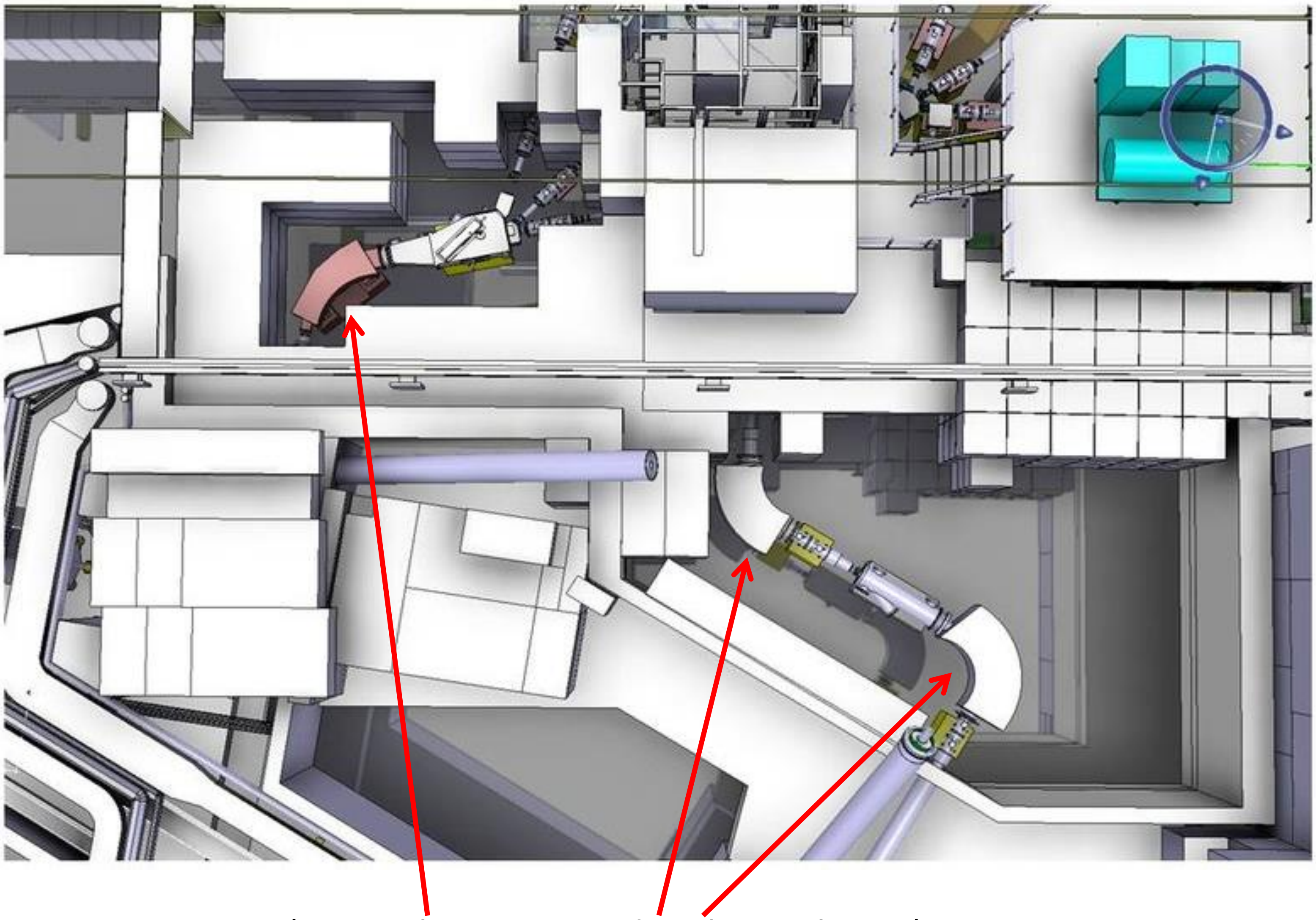
Target+ vacuum+ extraction



robots

Ion energy: 30-60keV

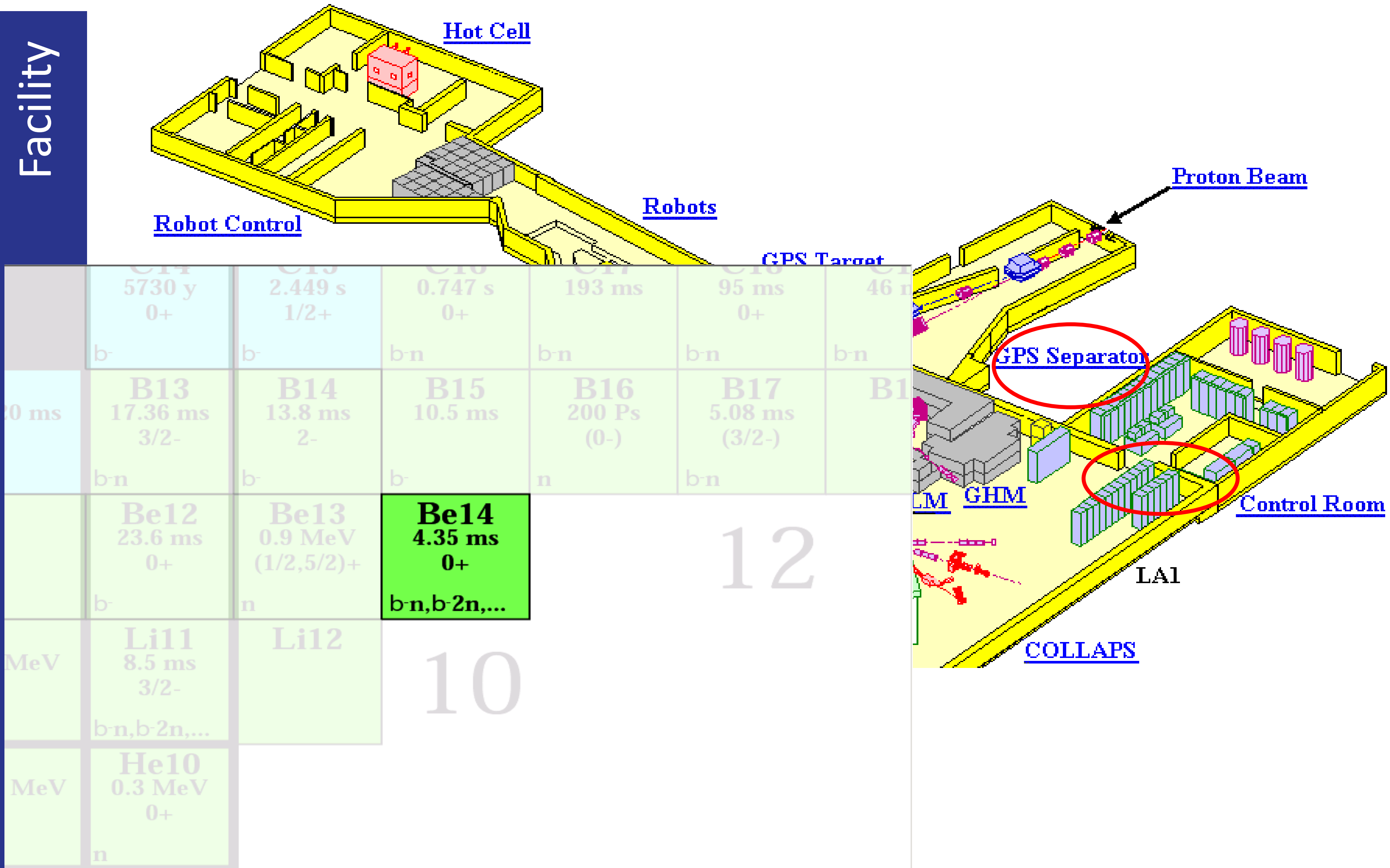
Separation



Magnet separators (General Purpose and High Resolution)

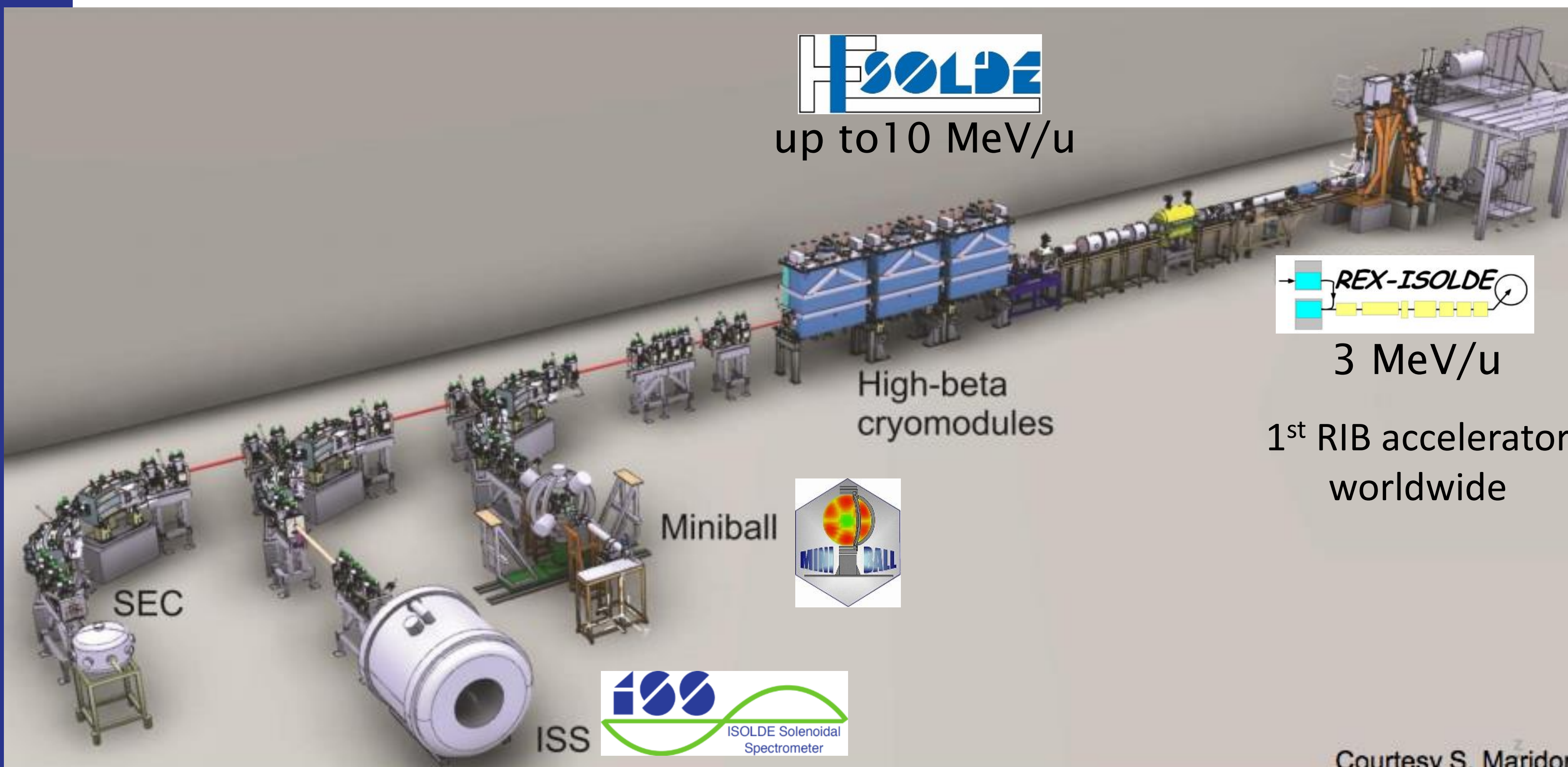
Production and selection - example

Facility



Post-acceleration

- Low energy (<60 kV) beams can be accelerated up to 10 MeV / nucleon (i.e. 1.3 GeV for 132Sn or 2 GeV energy for ^{208}Pb)

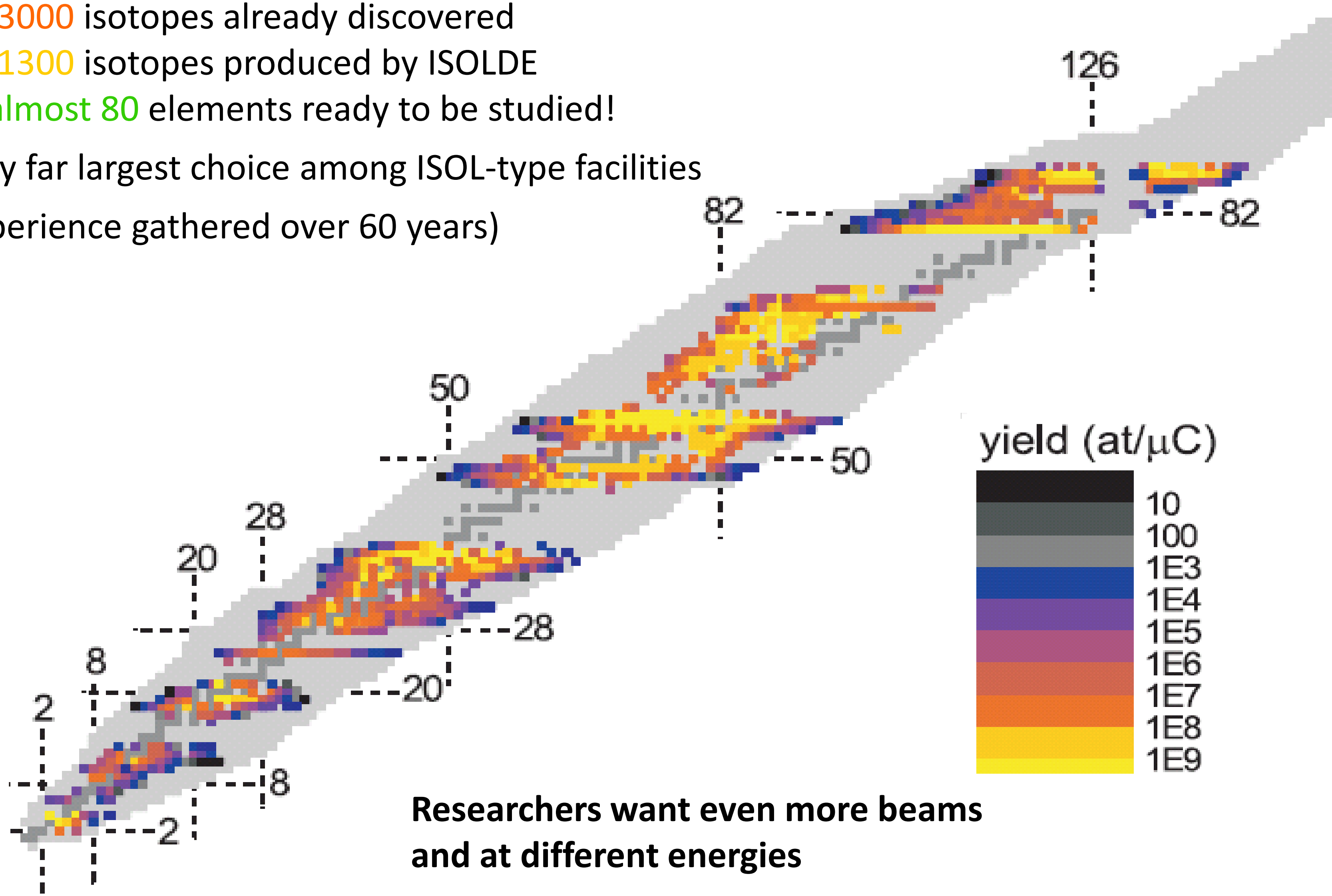


Extracted nuclides

- ~6000 isotopes predicted by theory
- ~3000 isotopes already discovered
- ~1300 isotopes produced by ISOLDE
- almost 80 elements ready to be studied!

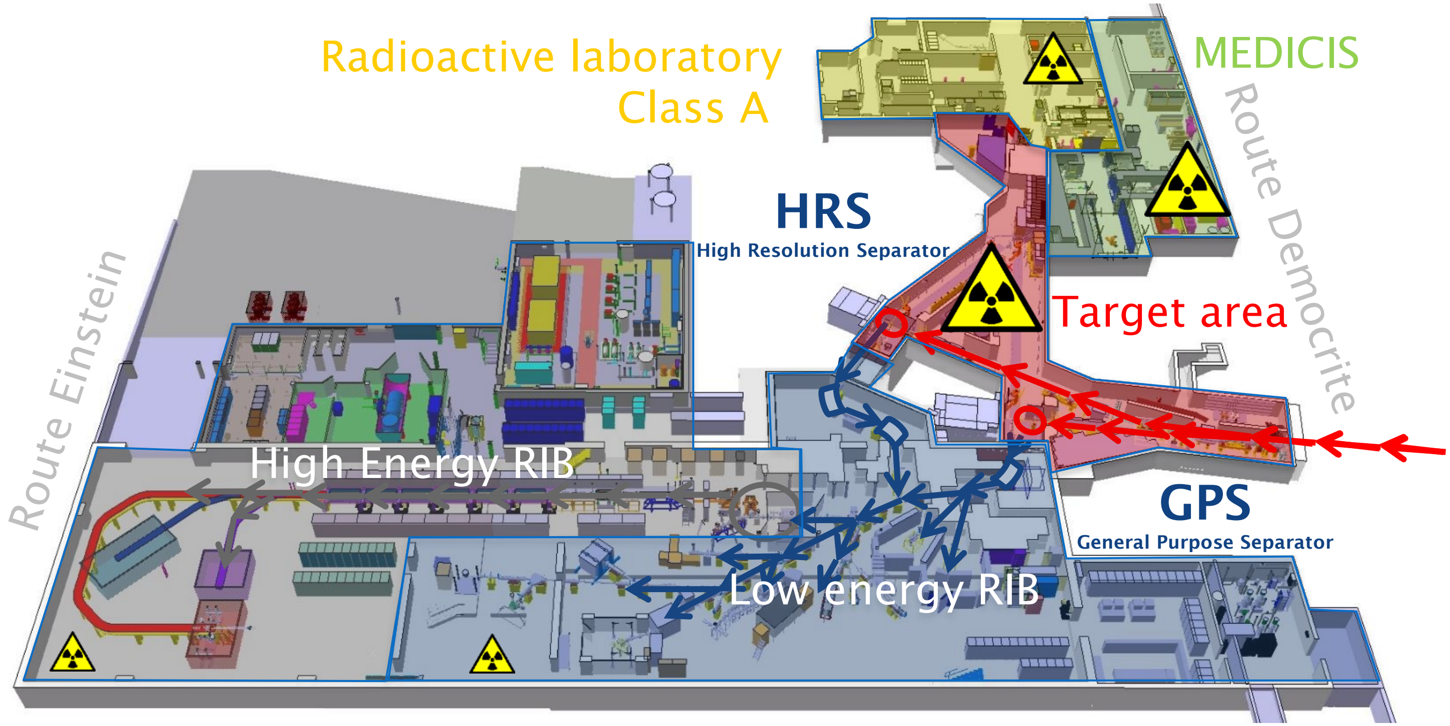
-> by far largest choice among ISOL-type facilities

(experience gathered over 60 years)



Researchers want even more beams and at different energies

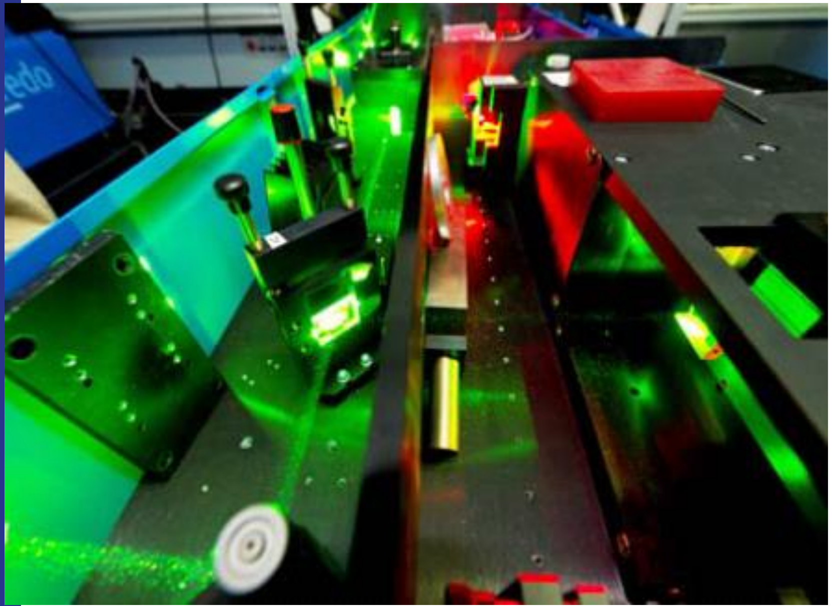
ISOLDE layout



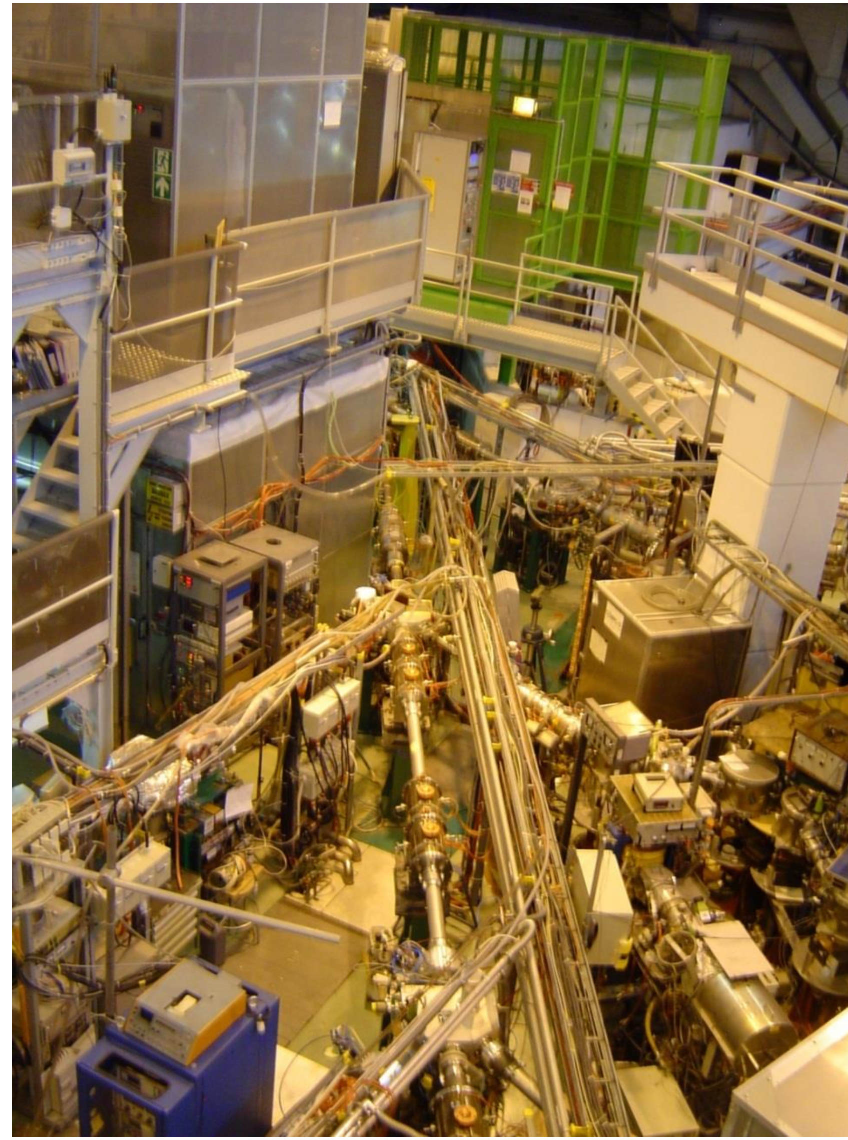
- Protons (1.4 GeV)
- Low energy RIBs (up tp 60 keV)
- High energy RIBs (up to 10 MeV/u)

- Pulse protons (1.2 s)
- 1.4 GeV
- 3.3 x 1013 protons per pulse

Facility photos



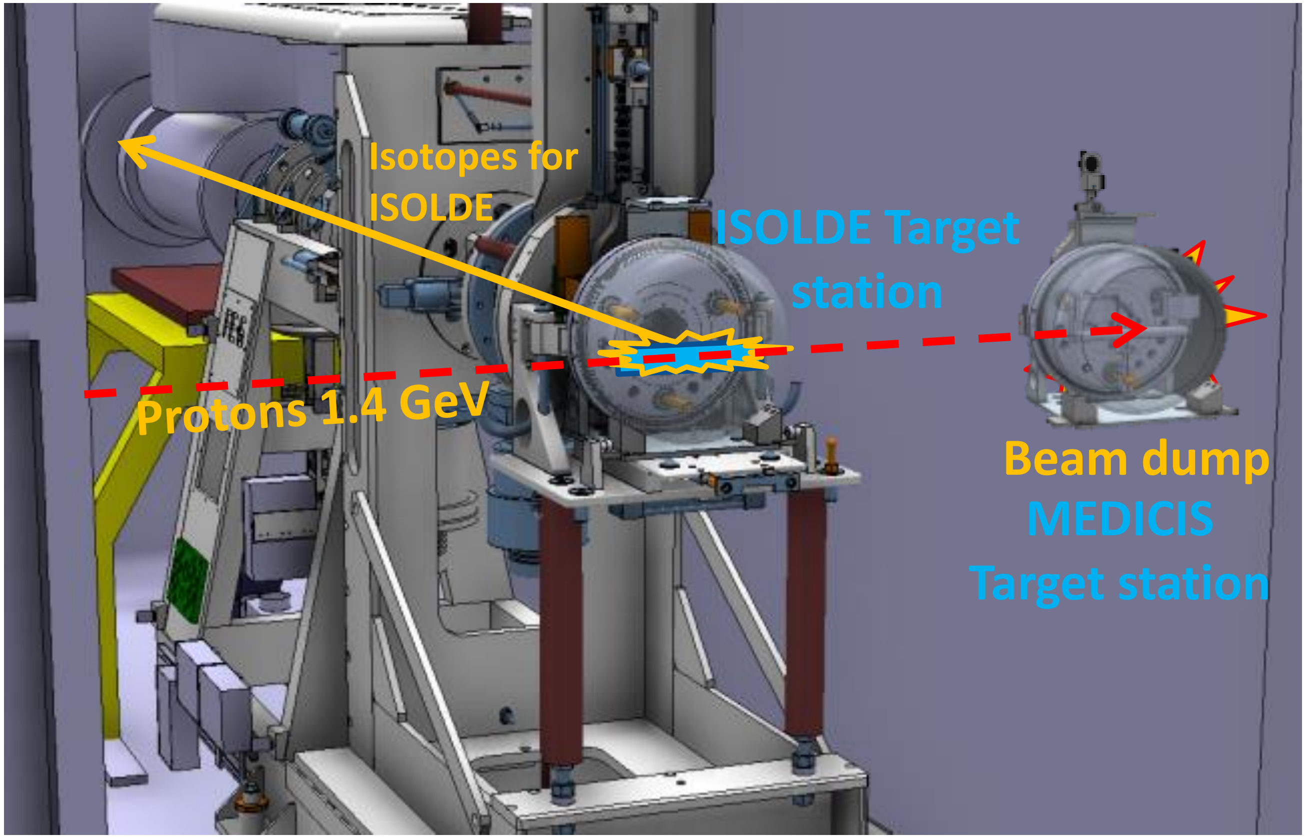
Experimental beamlines



Applications: MEDICIS at ISOLDE

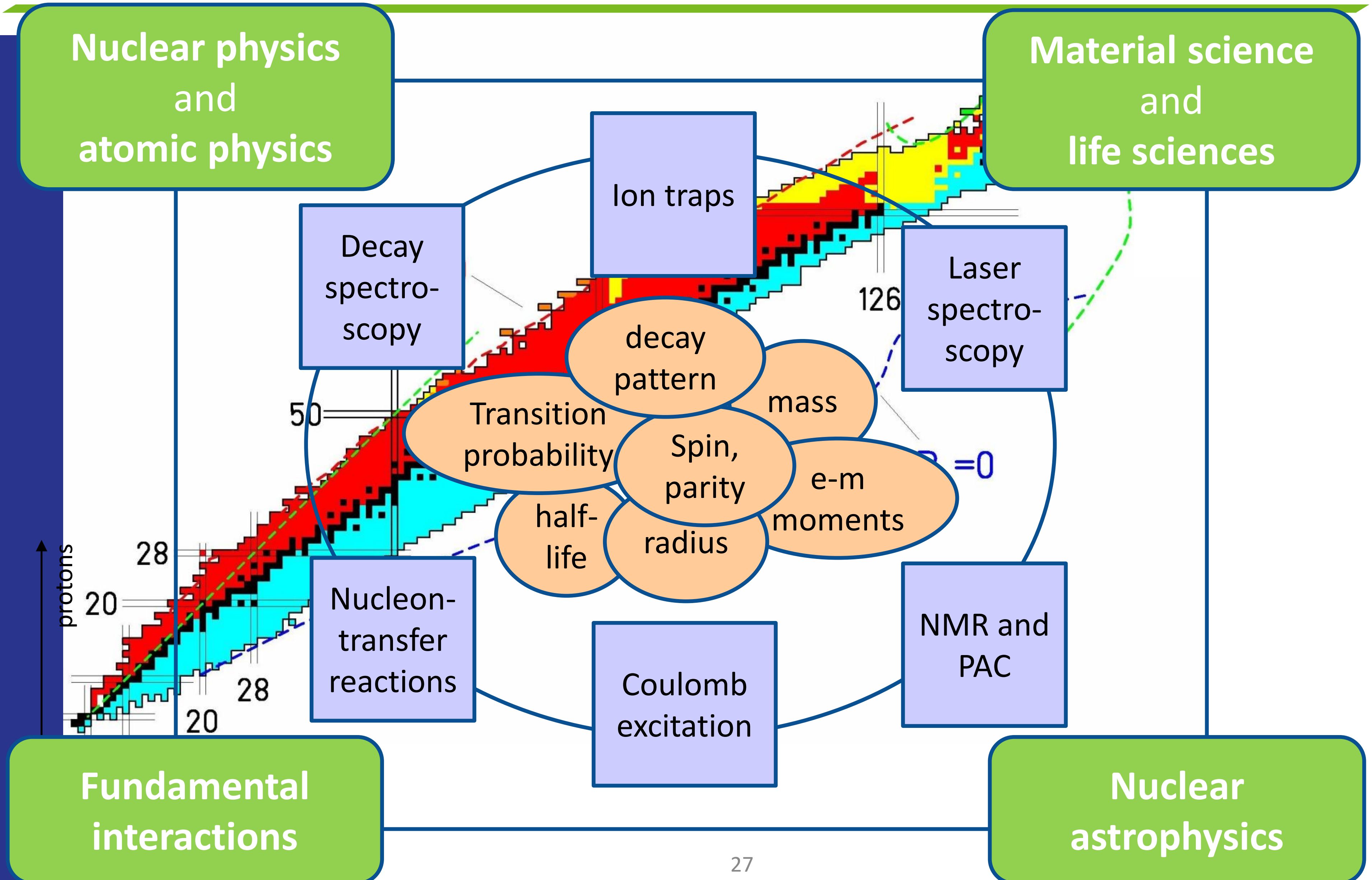
Production of medical isotopes for trials (not commercial use) via ISOLDE “dump” protons

-> little ISOLDE + chemical preparation



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

ISOLDE techniques and research topics



Summary

- Nuclear physics
  - deals with properties and interactions in and of atomic nuclei

- Addressed across CERN facilities

- Two complementary types of RIB facilities
  - ISOL and in-flight

- ISOLDE at CERN
  - ISOL-type facility which uses protons from PSB
  - Elements: production target, ionization, extraction, separation
  - Largest variety of beams worldwide
  - Post-accelerator HIE-ISOLDE
  - Medical isotopes with MEDICIS

  - **ISOLDE research topics => Lecture 2**