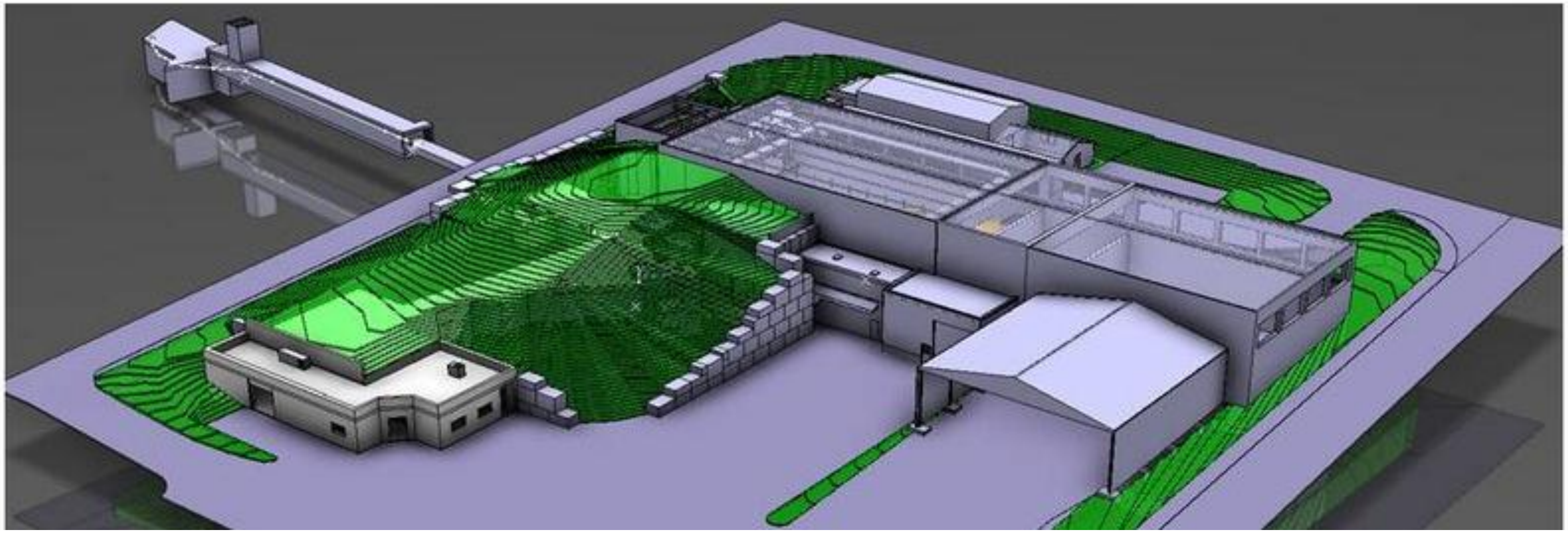
The ISOLDE Facility



Outline:

ISOLDE within CERN

ISOLDE as facility

Science and users

Examples of experimental setups

Magdalena Kowalska
ISOLDE Physics Coordinator,
CERN, PH-SME-IS

Facility

Very short history

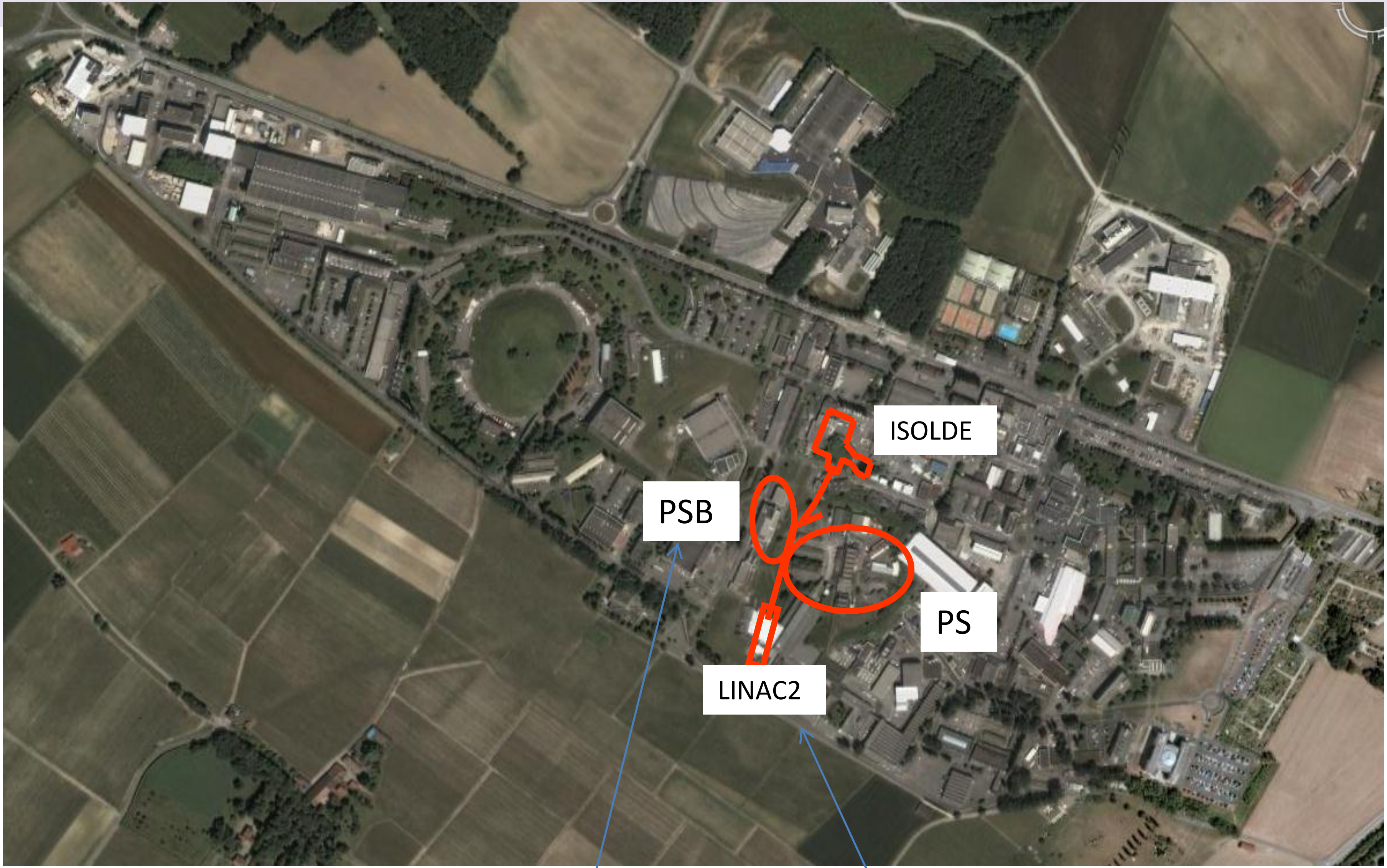
First beam October 1967

Upgrades 1974 and 1988

New facility June 1992

First ISOL-type facility worldwide

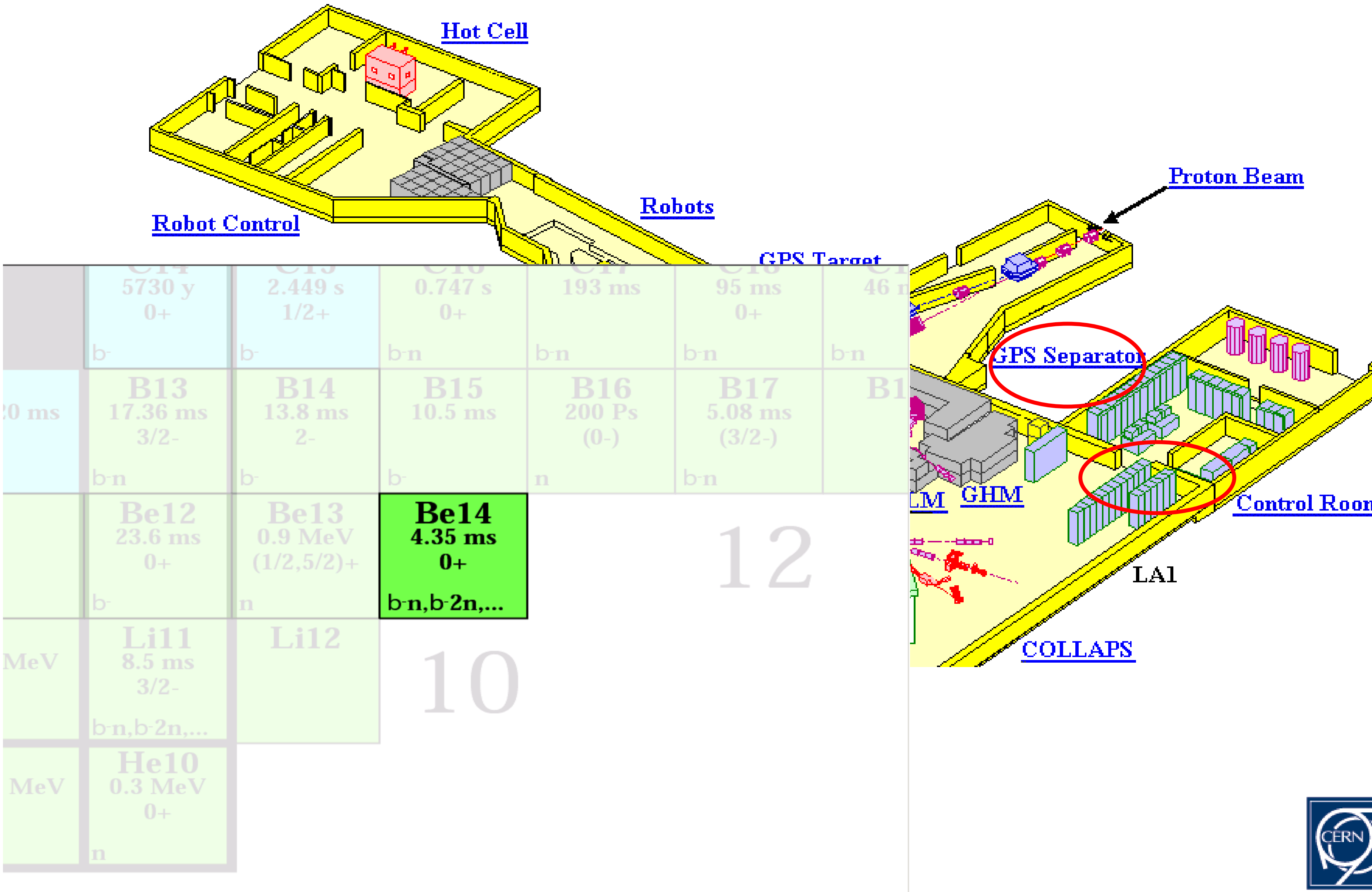
ISOLDE within CERN accelerators



To be upgraded in intensity (2uA->6uA p to ISOLDE) and energy (1.4->2GeV)

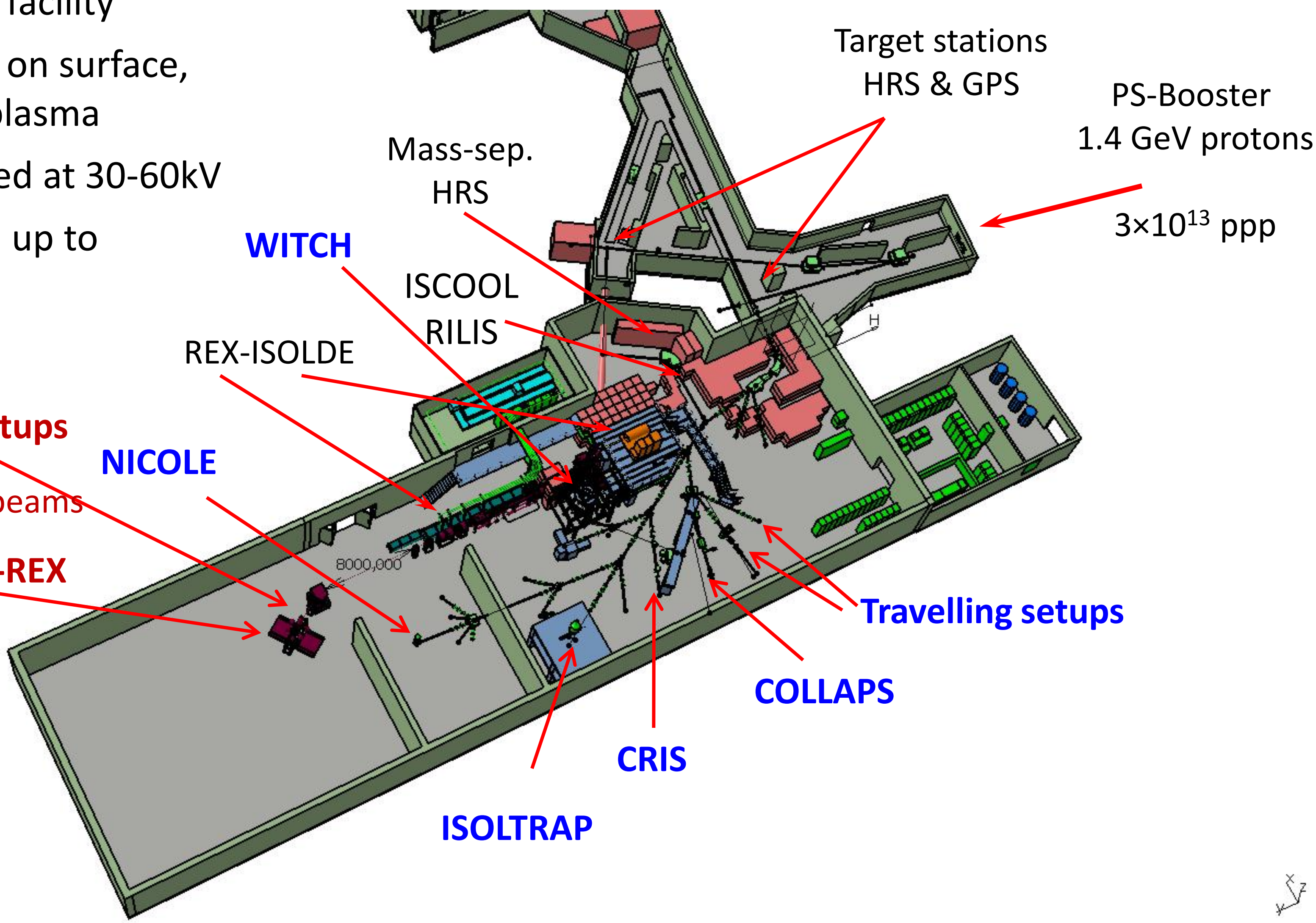
To be exchanged by LINAC4

Nuclei production and selection

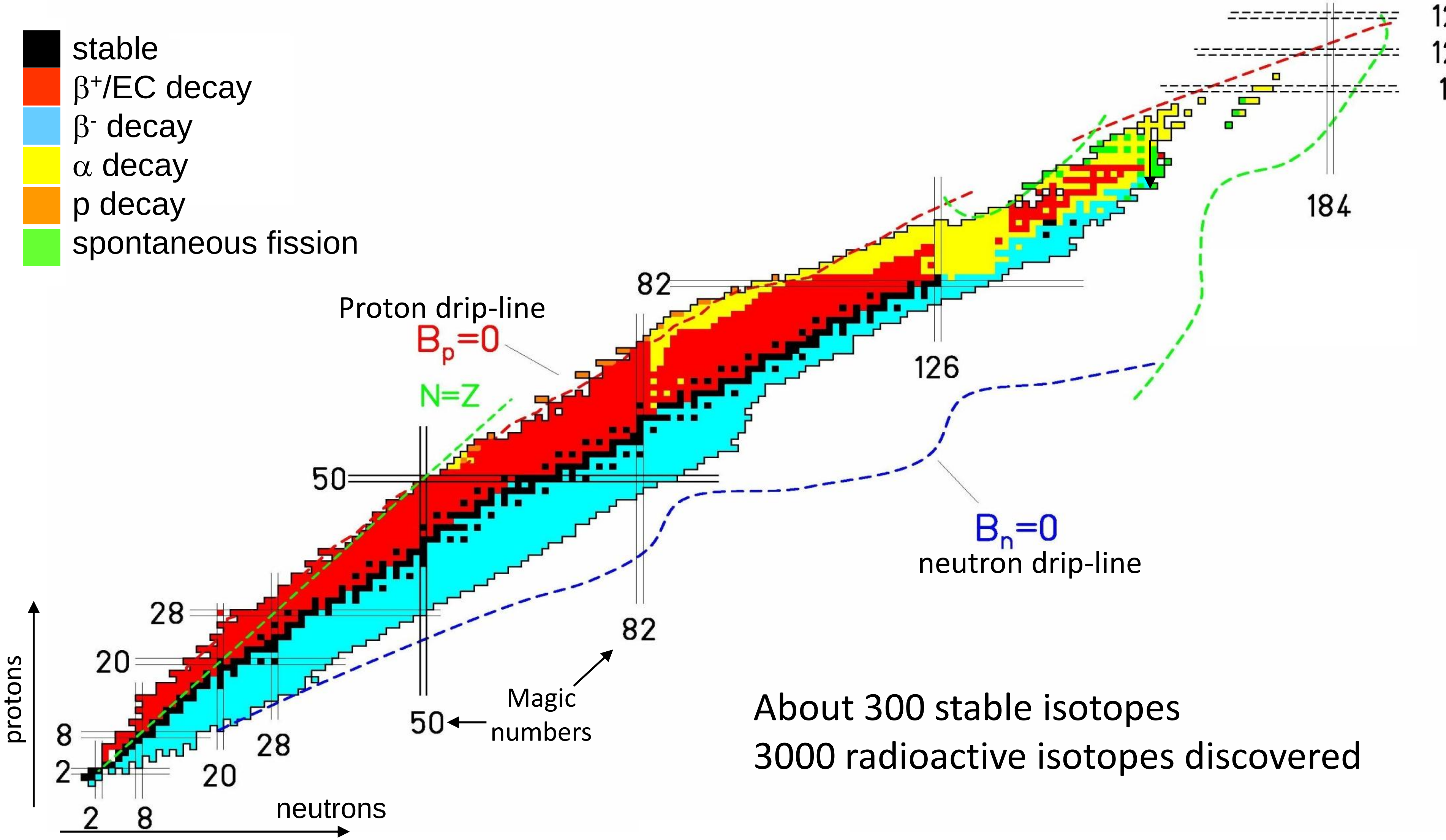


Experimental setups

- First ISOL-type facility
- Beams ionised on surface, by lasers, or in plasma
- Beams extracted at 30-60kV
- Reacceleration up to 3.5MeV/u



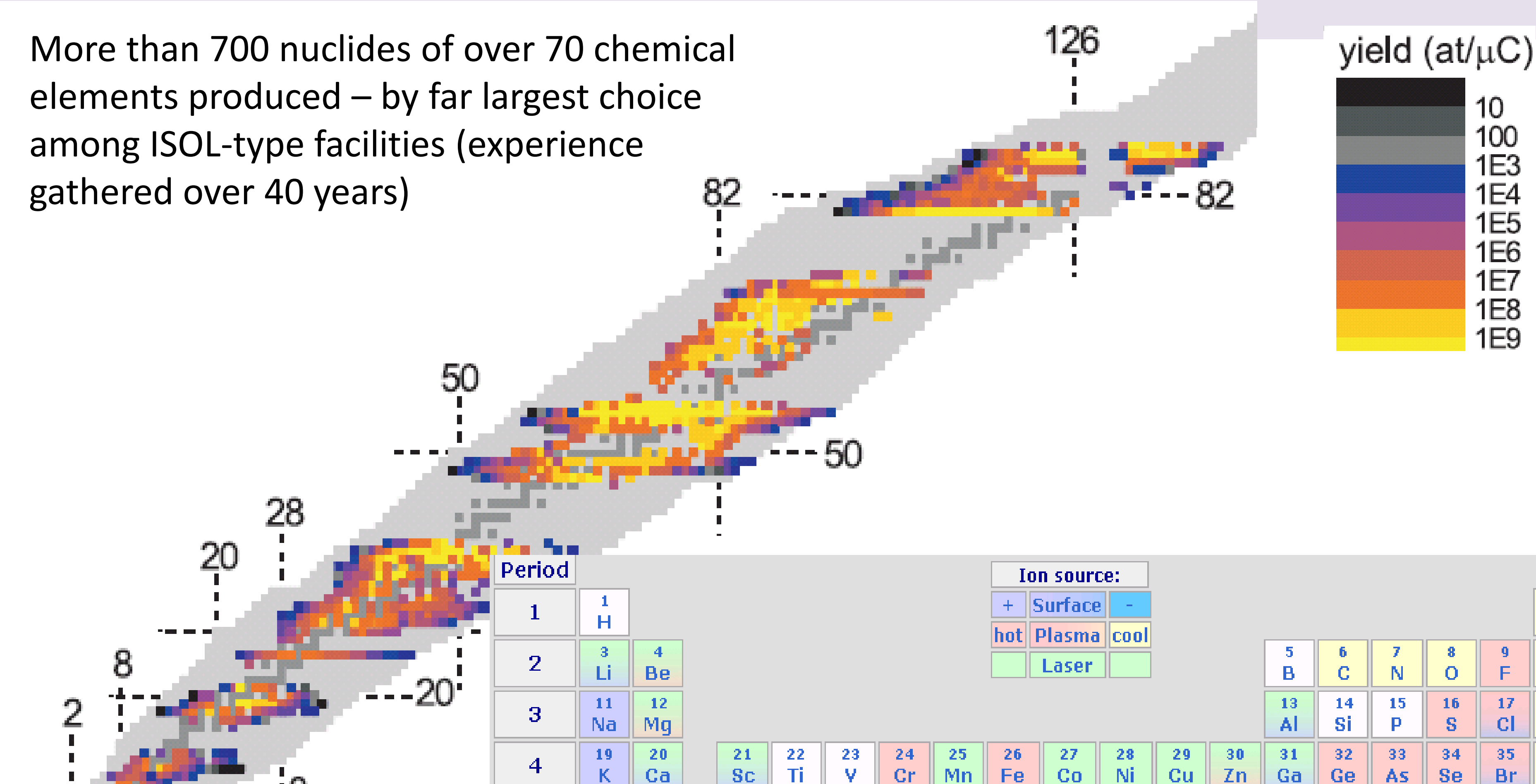
Nuclear landscape

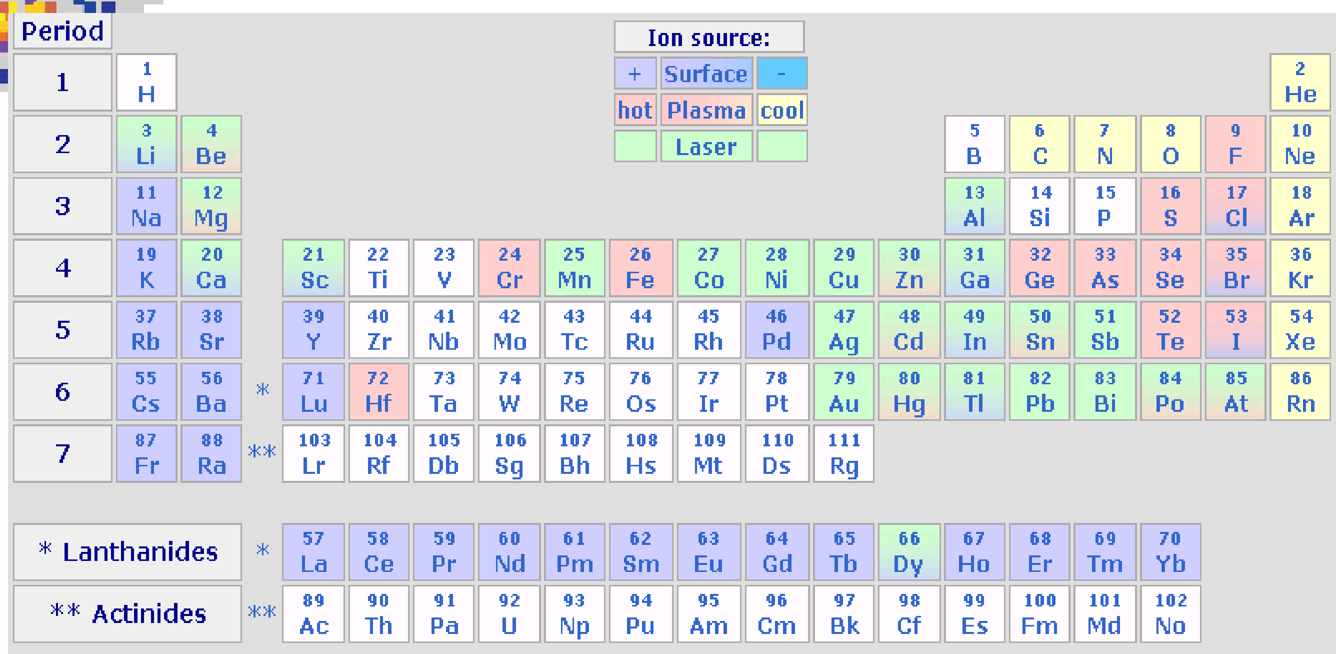


About 300 stable isotopes
3000 radioactive isotopes discovered

Produced nuclides

More than 700 nuclides of over 70 chemical elements produced – by far largest choice among ISOL-type facilities (experience gathered over 40 years)





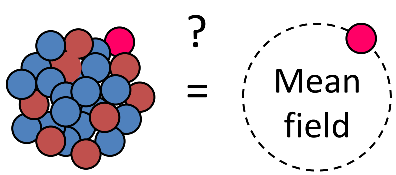
Physics

Physics topics

Nuclear physics

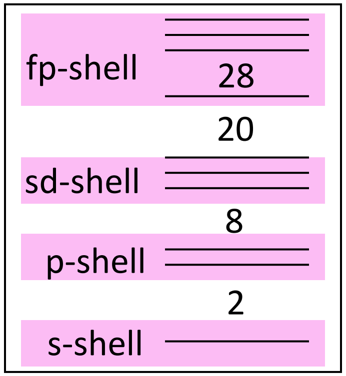
Strong interaction in many-nucleon systems

Nuclear driplines



34Ne:
10 protons + 24 neutrons

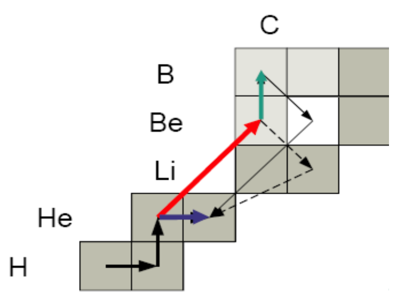
Does it exist?

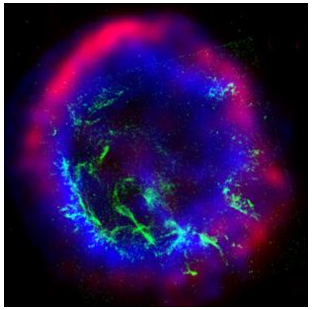


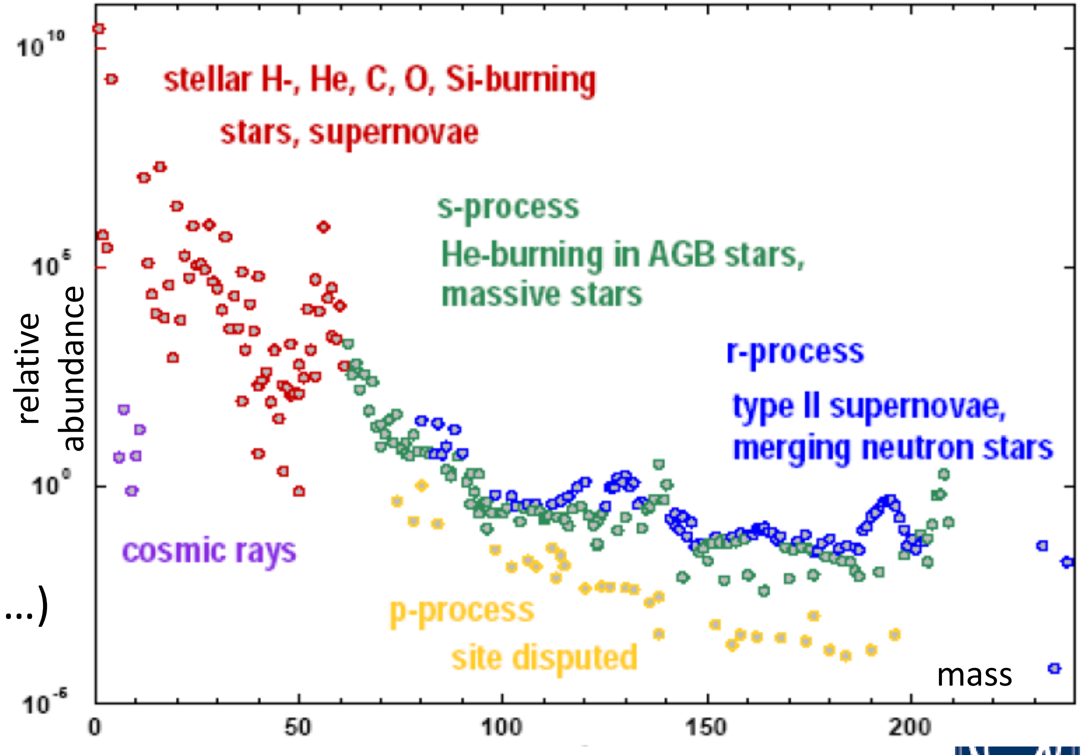
Astrophysics

Nucleo-synthesis, star evolution

Abundances of elements







Fundamental studies

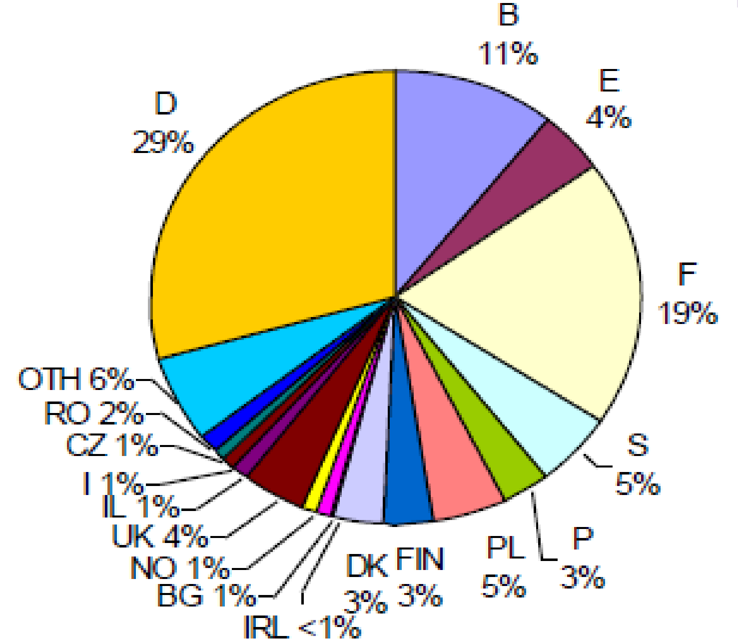
Beyond standard model (neutrino mass, …)

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

Solid state physics, life sciences

Physics and users

Physics interest:
- Nuclear structure from decay and reactions
- Nuclear structure via atomic techniques
- Nuclear astrophysics
- Fundamental interactions
- Solid-state physics
- Bio- and medical physics



Around 450 users (7% of CERN's total)
25 countries; 100 institutions
175 experiments (in 4 years)
90 active experiments in 2011

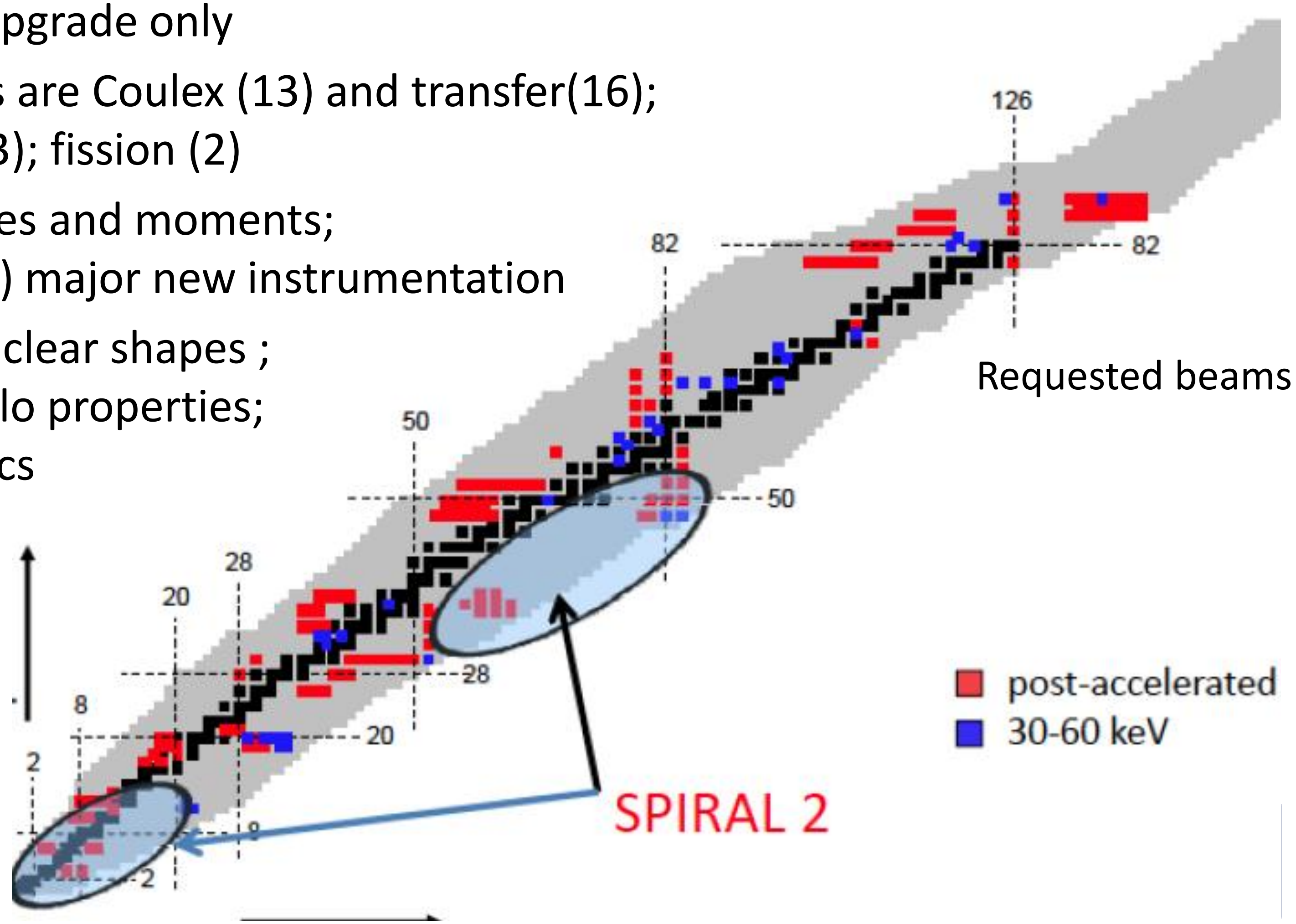
User requirements:
- Higher energy for the post-accelerated beam
- More beams (intensity wise and different species)
- Better beams (High purity beams, low emittances, more flexibility in the beam parameters)

=> Need upgraded facility : **HIE-ISOLDE proposal**

Letters of Intent for HIE-ISOLDE

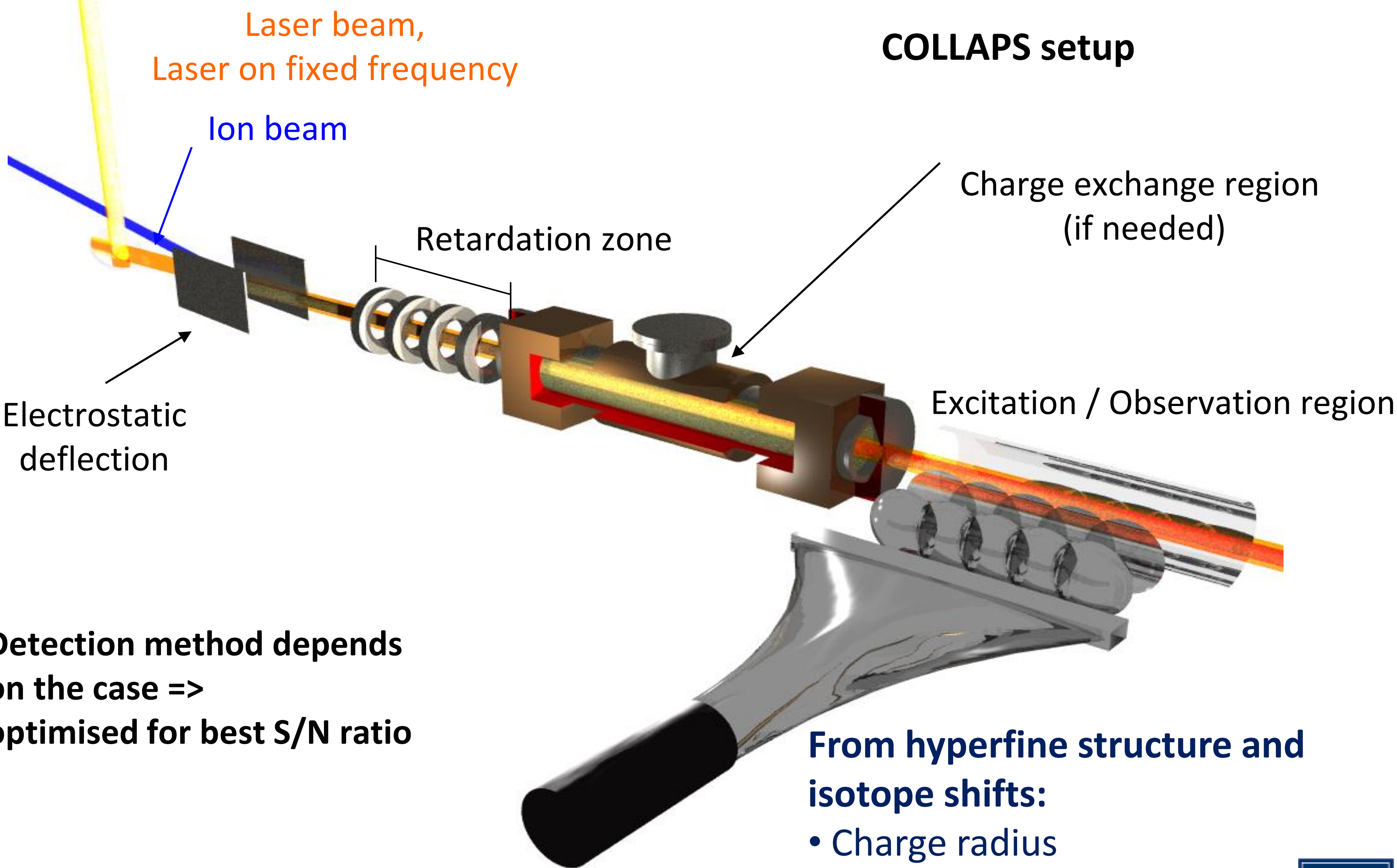
First call in May 2011

- 34 Letters submitted
- 284 Participants from 76 Laboratories in 22 Countries
- 30 LOIs make use of the Energy and Intensity increases; 4 of the intensity upgrade only
- Major mechanisms are Coulex (13) and transfer(16); elastic scattering (3); fission (2)
- (3) letters on masses and moments; (4) astrophysics, (5) major new instrumentation
- Major subjects: Nuclear shapes ; Shell evolution; Halo properties; Nuclear astrophysics



Experimental techniques

Collinear laser spectroscopy



Detection method depends on the case => optimised for best S/N ratio

From hyperfine structure and isotope shifts:

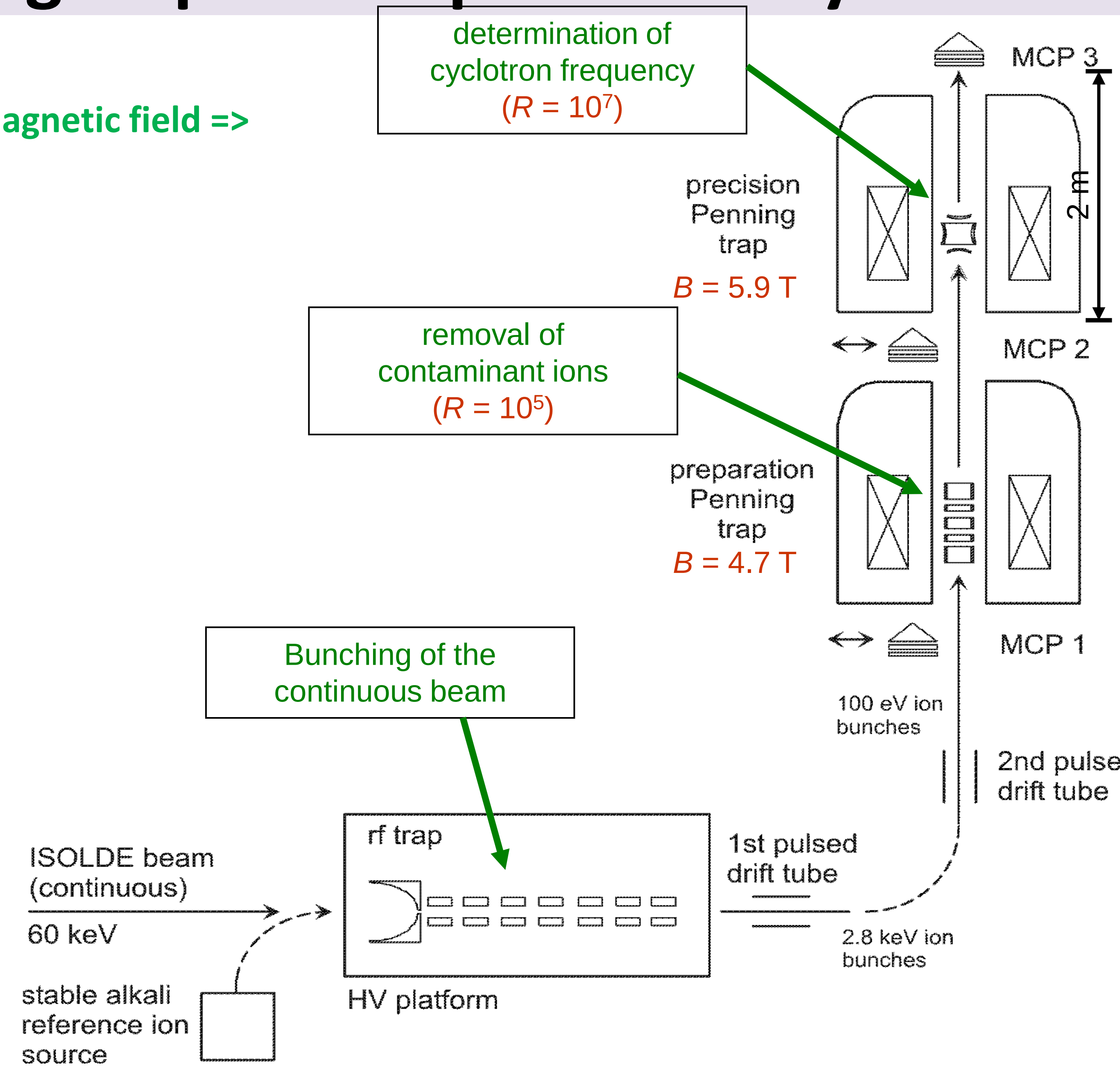
- Charge radius
- Spin, magnetic dipole and quadrupole electric moment

Penning trap mass spectrometry

Cyclotron frequency in magnetic field => atomic mass

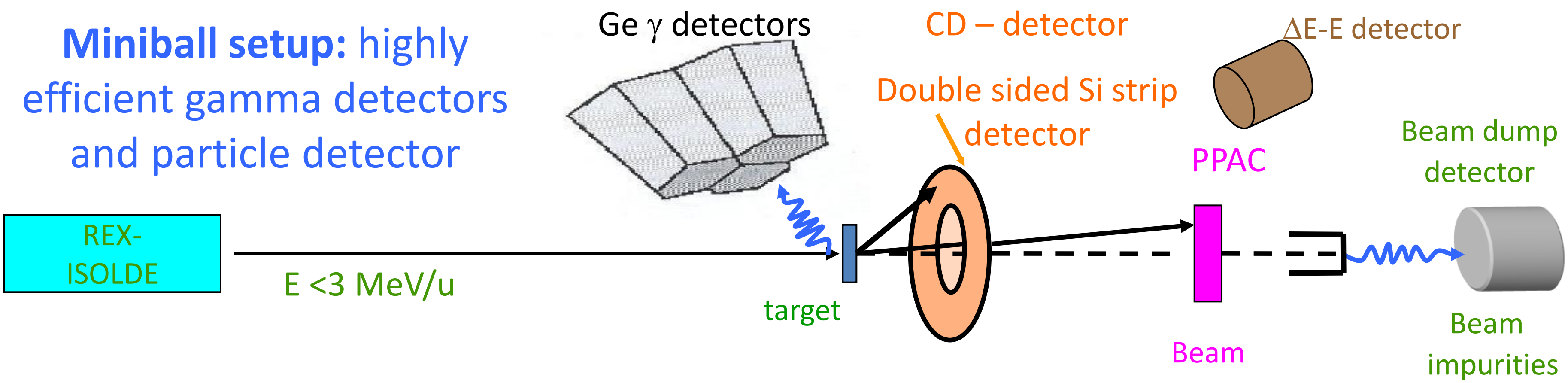
$$\nu_c = \frac{1}{2\pi}\frac{q}{m}B$$

ISOLTRAP setup

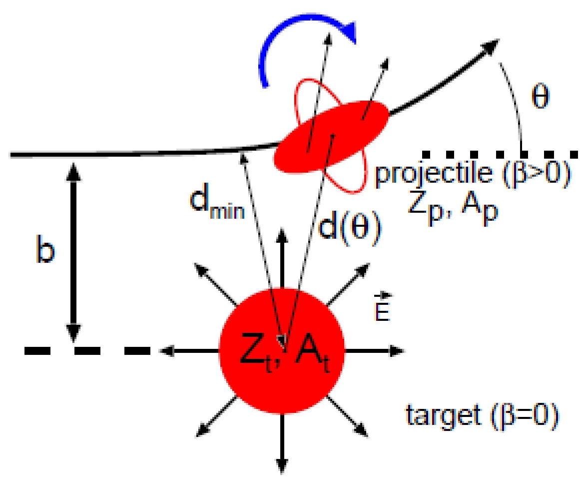


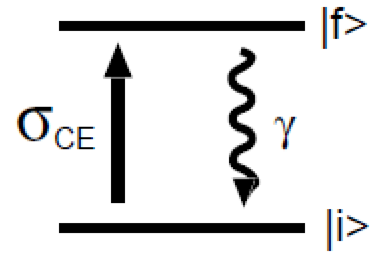
Coulomb excitation (behind REX)

Miniball setup: highly efficient gamma detectors and particle detector



Excitation of a projectile nucleus (radioactive) by the electromagnetic field of the target (made of stable nuclei)





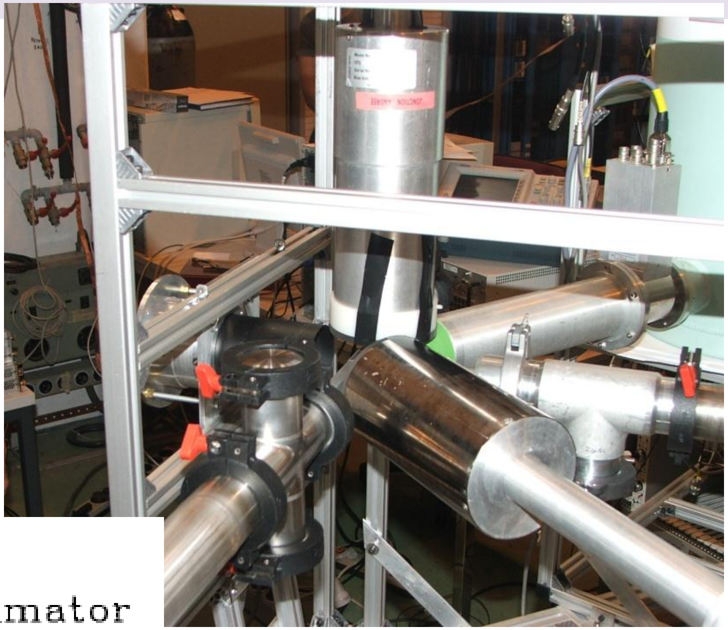
Observables: Transition energies and intensities

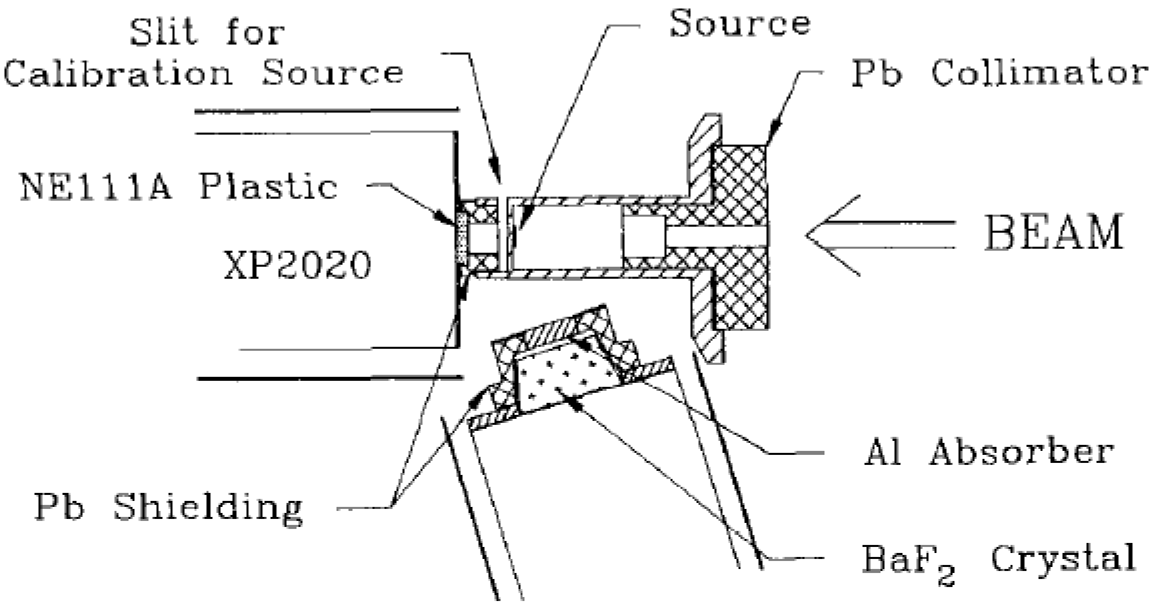
=> Study collective properties and deformations of nuclei

Fast timing decay studies

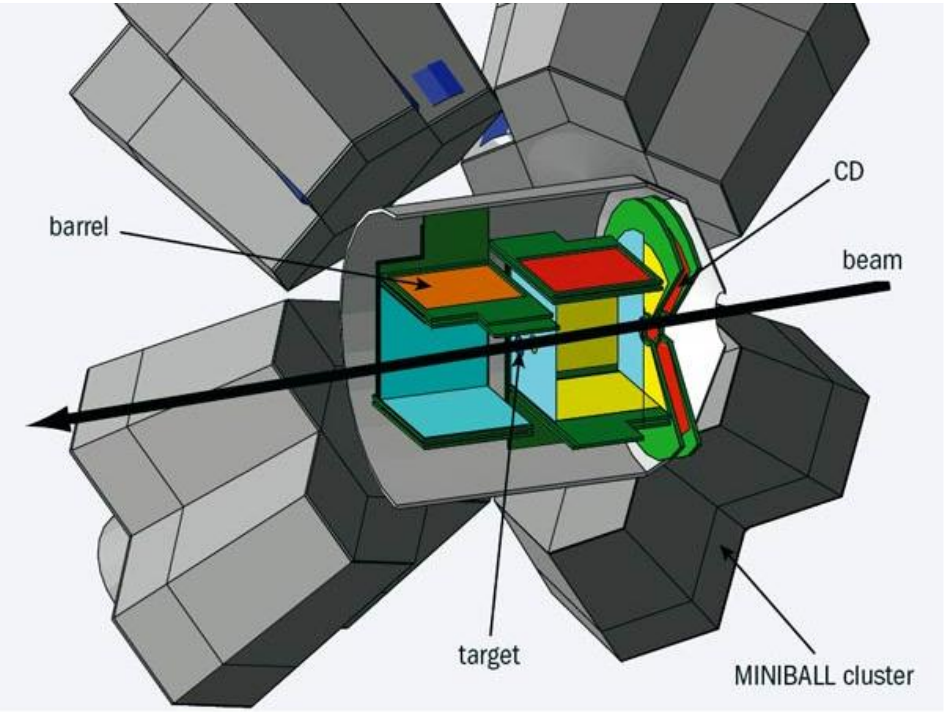
Gamma spectroscopy with BaF2 crystals
(very fast response, <ps lifetime studies)

=> Transition energies and probabilities, deformations

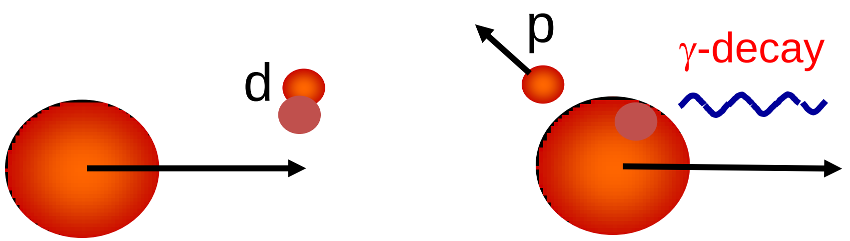




Transfer reactions (behind REX)



Miniball + T-REX setup (Si detector barrel):
gamma detectors and particle identification



<u>Observables</u>

- energies of protons (+ E_g) — (single-particle) level energies
- angular distributions of protons (+ γ-rays) — spin/parity assignments
- (relative) spectroscopic factors — particle configurations

Solid-state physics

Why radioactive isotopes?

Nothing is more easy to detect with high sensitivity than nuclear radiation, i.e. very low concentrations of radioactive impurity atoms in a material can be detected.

The radioactive isotopes ("probes") act as "spies" transmitting information with atomic resolution via their decay. They add "chemical sensitivity" to spectroscopic techniques sensitive only to electrical or optical properties of a defect.

From K. Johnston

Solid-state physics

Wide range: from traditional semiconductors to exotic High Tc Superconductors

Semiconductors:	ZnO, GaN, ZnTe, Si, Ge
Superconductors:	HgBa CuO
Proteins:	*de-novo* designed peptides
Surfaces:	Ni crystals
Manganites:	LaMnO3

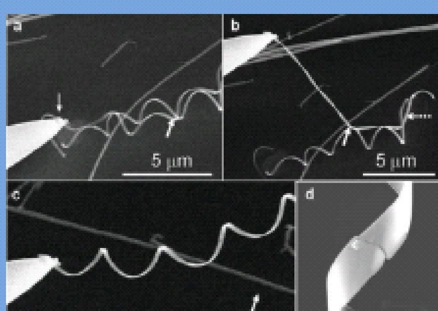
From K. Johnston

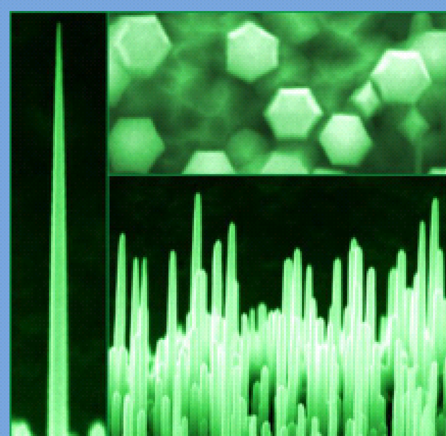
Solid-state physics

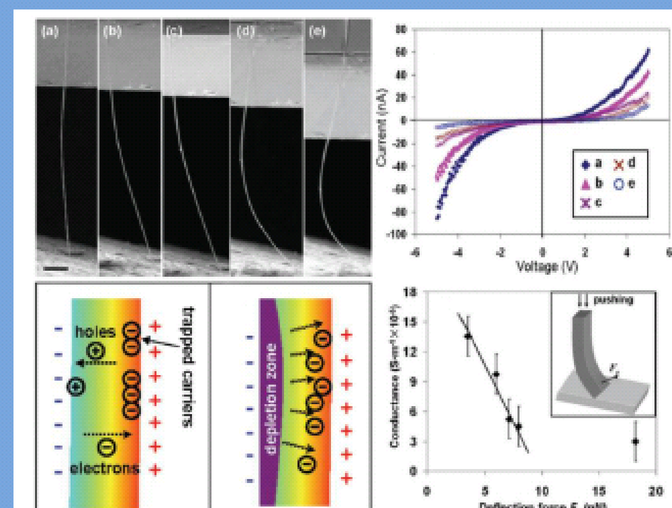
Current "hot material": ZnO (> 1200 papers already in 2007)

Proposed uses:

- Optoelectronics (3.4eV band-gap)
  - Beyond Blu-ray etc (405nm); ---DVDs = 650nm; CDS=780nm; white LEDS
- Spintronics
  - "Predicted" room temp magnetism
- Sensor material
- Very nano-friendly
- BUT!!!!!!!!! Many fundamental properties unknown







From K. Johnston

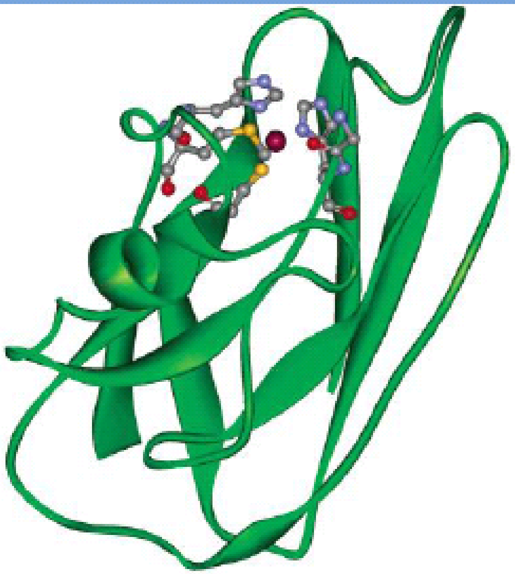
Bio-physics

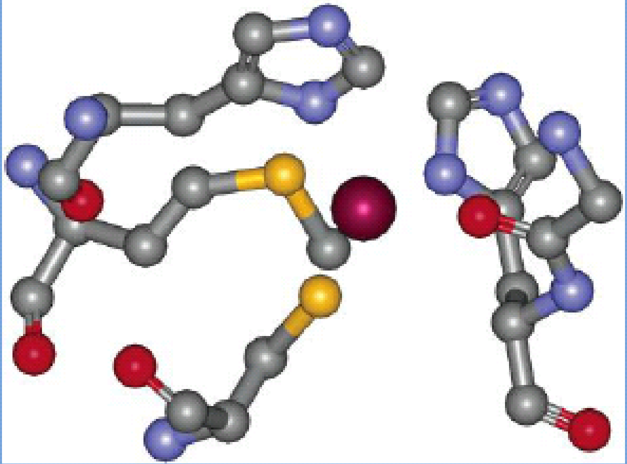
Biophysics: Toxicity in Proteins

Toxicity caused by minute quantities of Hg, Pb and Cd

These are also good nuclear probes (produced at ISOLDE): ^{199}Hg; ^{204}Pb; ^{117}Cd

Collections are done in ice and then this "radioactive ice" is used to do some biochemistry and afterwards measurements to get info on the binding of the metals in the proteins

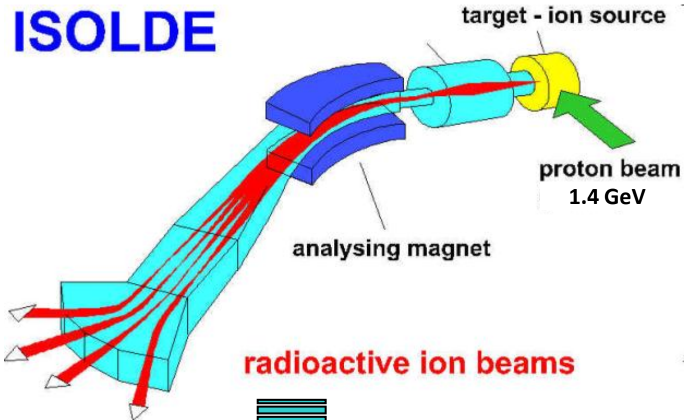




From K. Johnston

Medical applications

i. Collection at ISOLDE

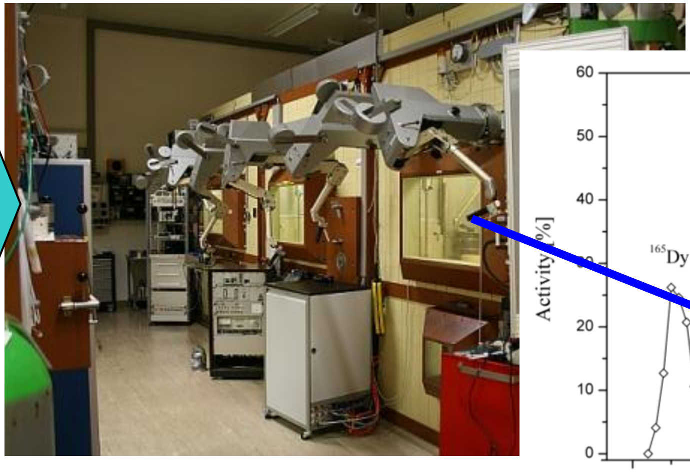


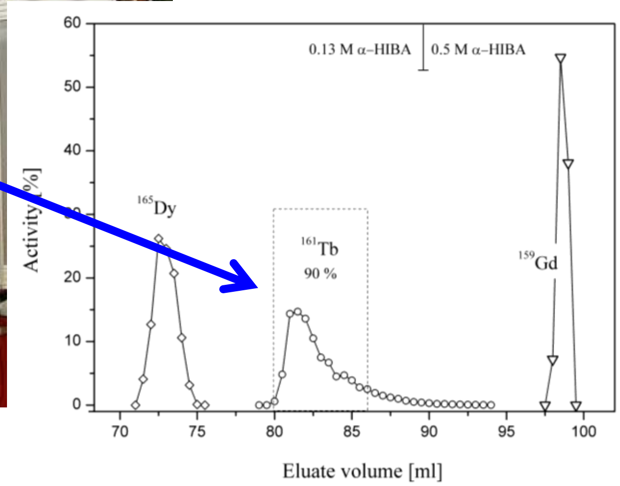
iv. Injection into mouse

v. PET/SPECT imaging and tumor treatment

ii. Shipping to PSI

iii. Radiochemical purification and labeling





Summary

- ISOLDE is the 1st ISOL-type facility and can provide over 700 radioactive nuclides to 90 open projects
- Physics interest: nuclear physics, via astrophysics and fundamental studies to applications
- A dozen fixed setups cover above topics (and many travelling experiments)
- HIE-ISOLDE will give users higher intensity and quality of beams, and higher energy of postaccelerated beams

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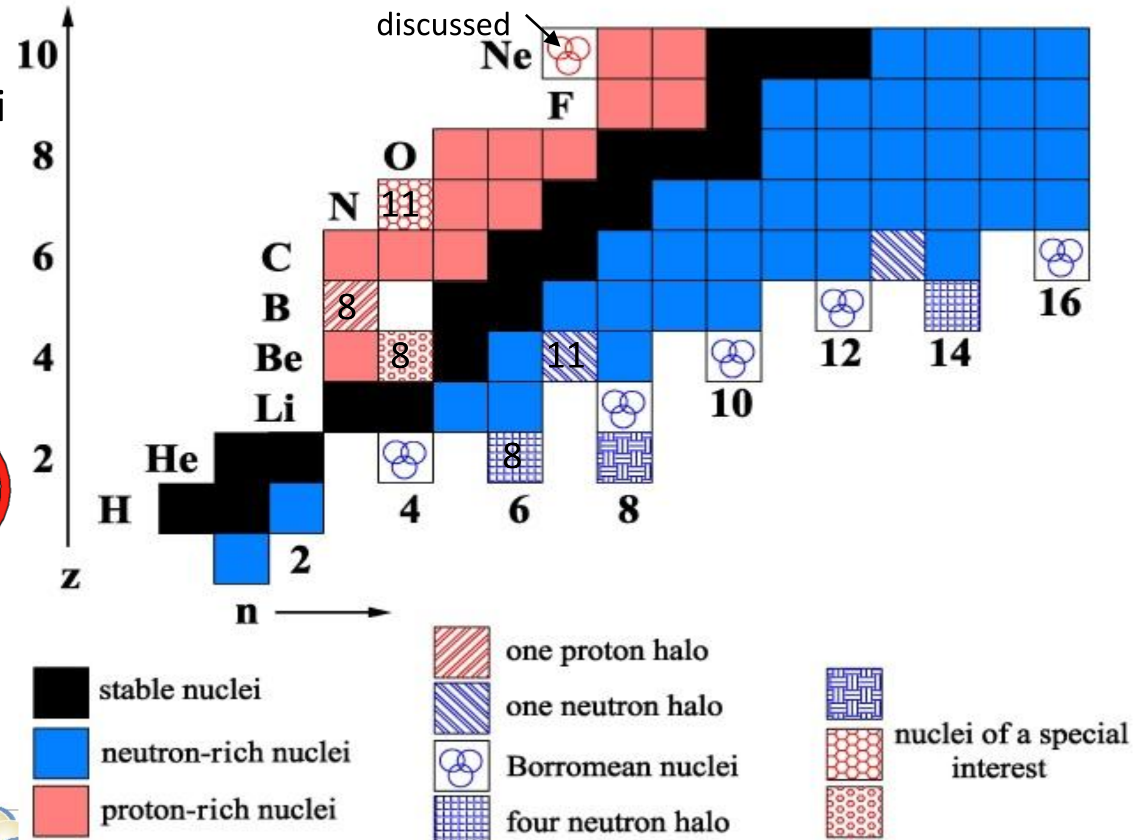
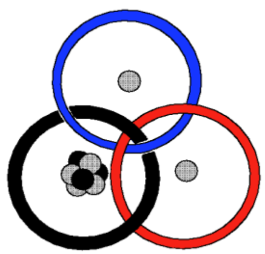
Halo nuclei

Halo: nucleus built from a core and at least one neutron/proton with spatial distribution much larger than that of the core

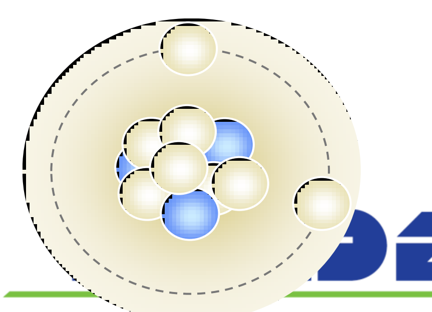
- 1985: first halo system identified: ^{11}Li
- 2005: half-dozen other halos known
- Nuclear structure and core-halo interaction still not well understood

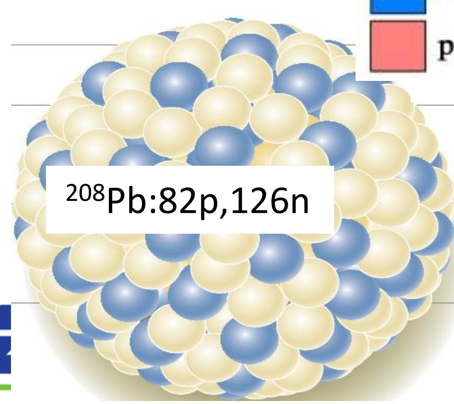


=> Crucial information:
Mass/binding energy
Spin-parity
Magnetic moment
Mass and charge radius
Quadrupole moment
Energy level scheme



^{11}Li:3p,8n

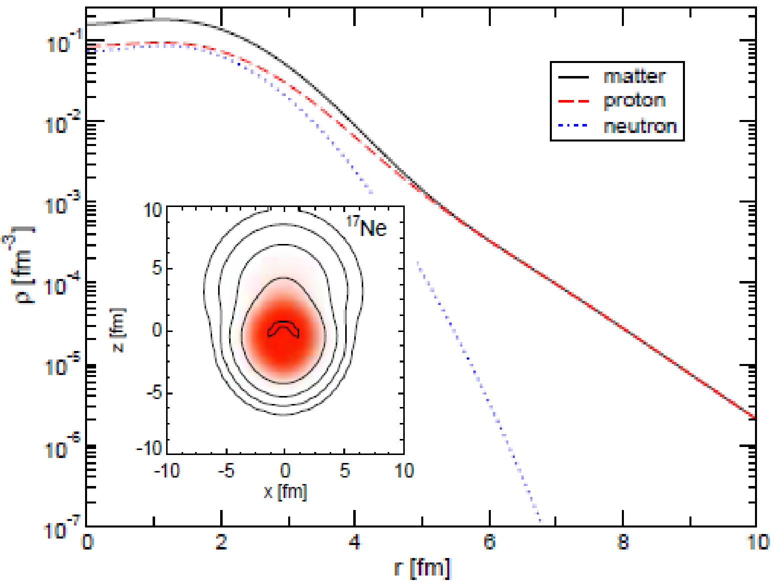


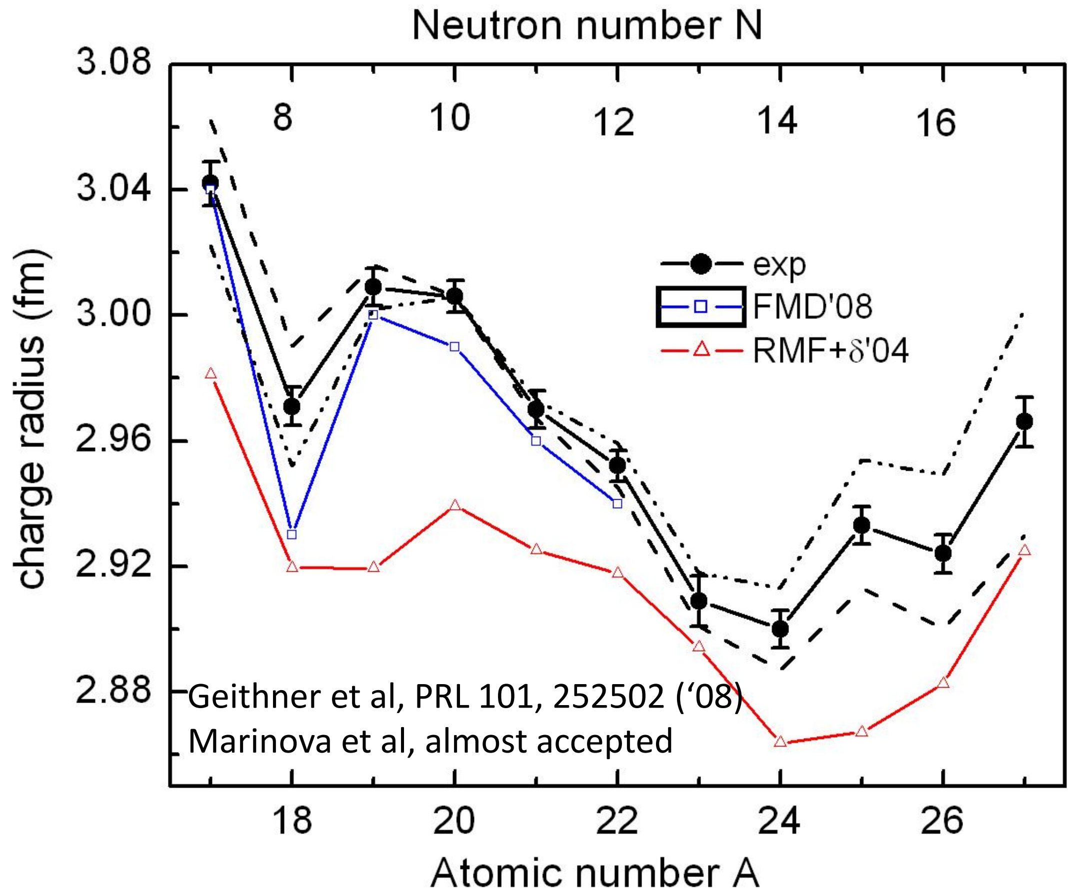


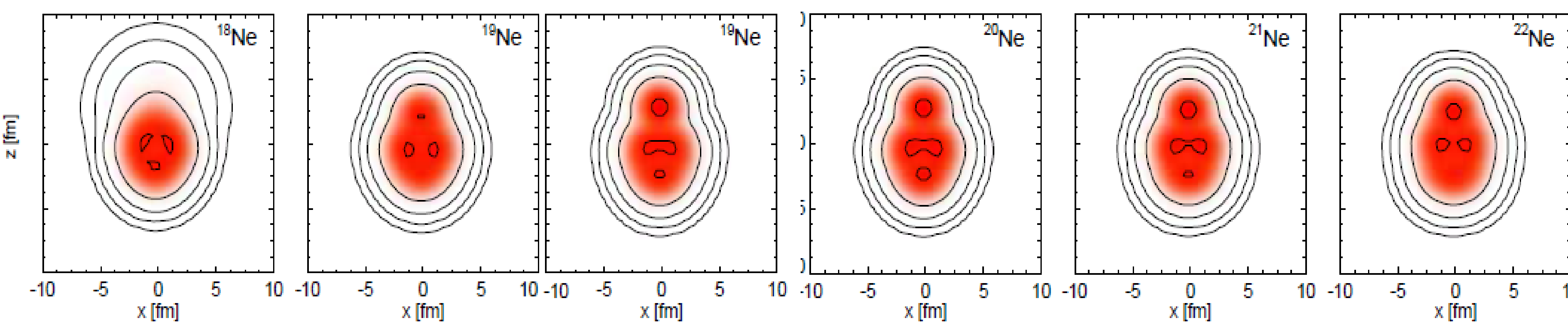
Charge radii of Ne isotopes

Laser spectroscopy

Intrinsic density distributions of dominant proton FMD configurations

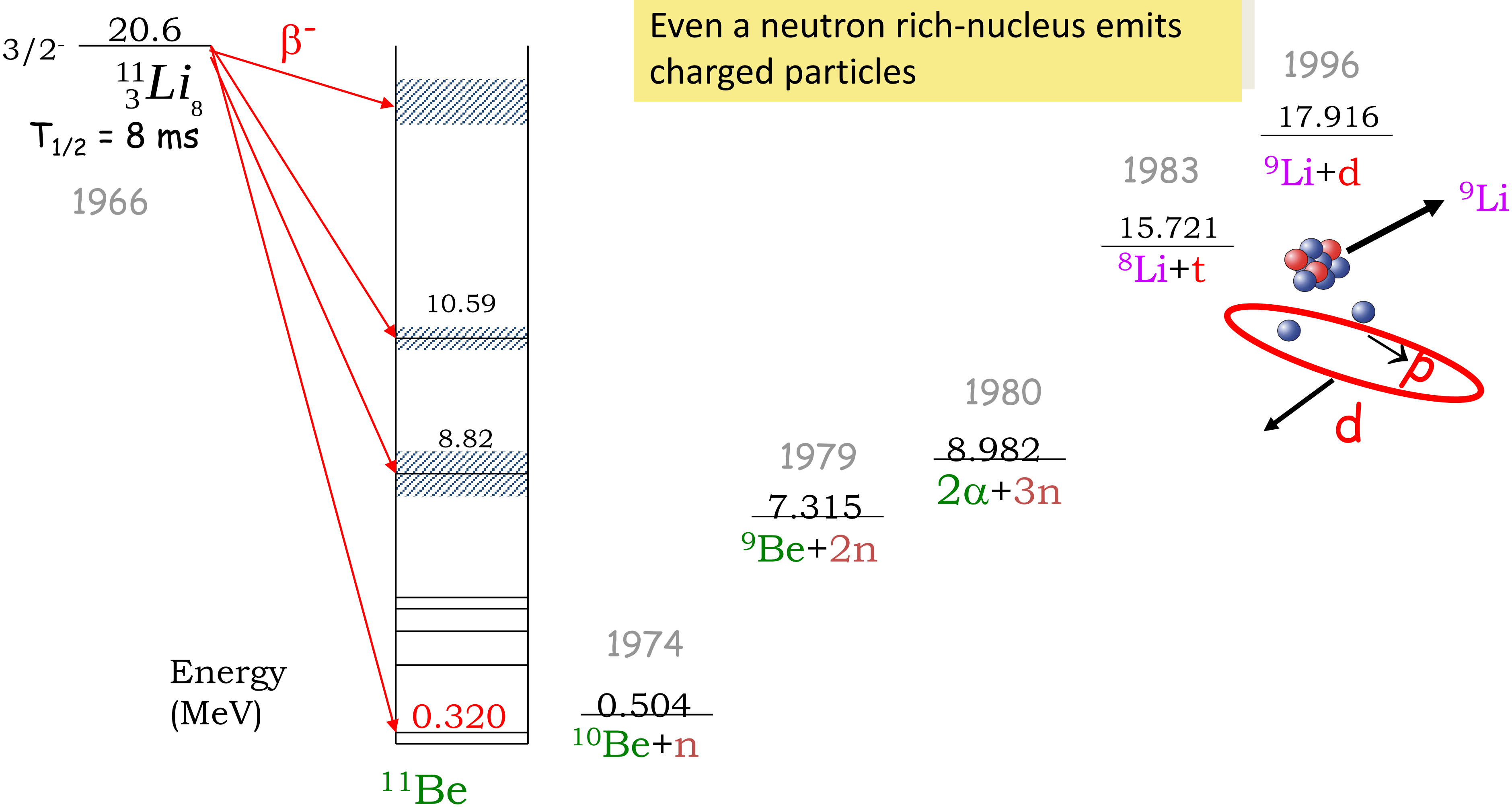






Exotic decays

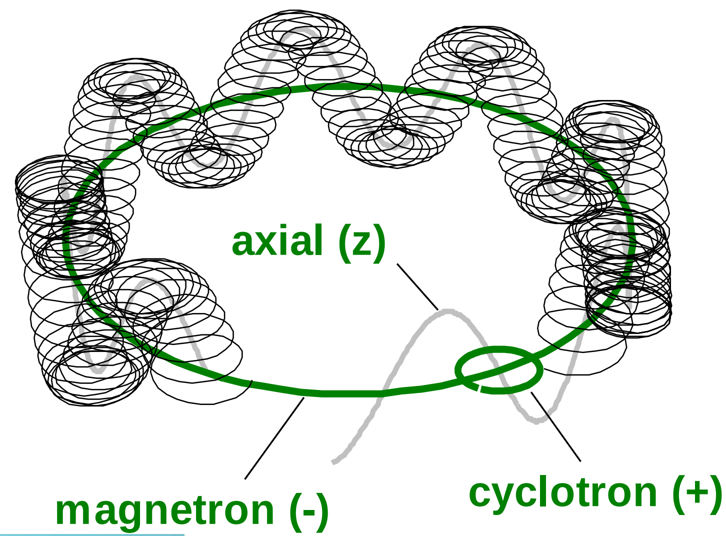
Even a neutron rich-nucleus emits charged particles

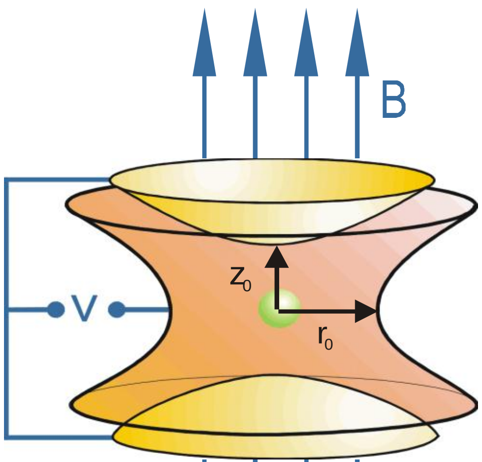


Penning traps and masses

- Mass determined from ion cyclotron frequency in magnetic field
- Penning trap used to confine ions during measurement

$$\nu_c = \frac{1}{2\pi}\frac{q}{m}B$$



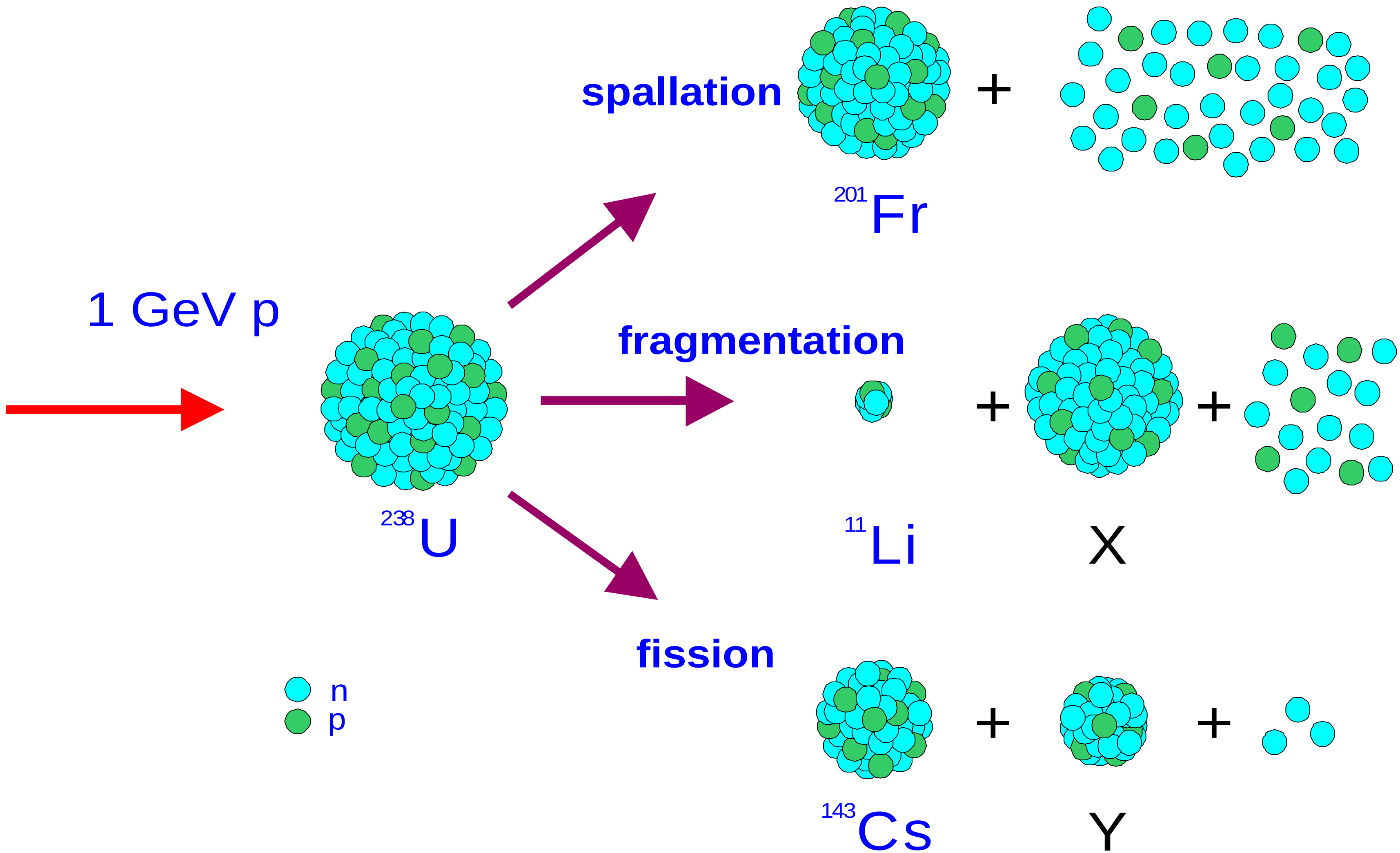


$$\nu_c = \nu_+ + \nu_-$$

A=100, B=6T

- $\nu_+ \approx 1$ MHz
- $\nu_- \approx 1$ kHz
- $\nu_z \approx 44$ kHz

ISOTOPE production



Physics topics

Nuclear Physics

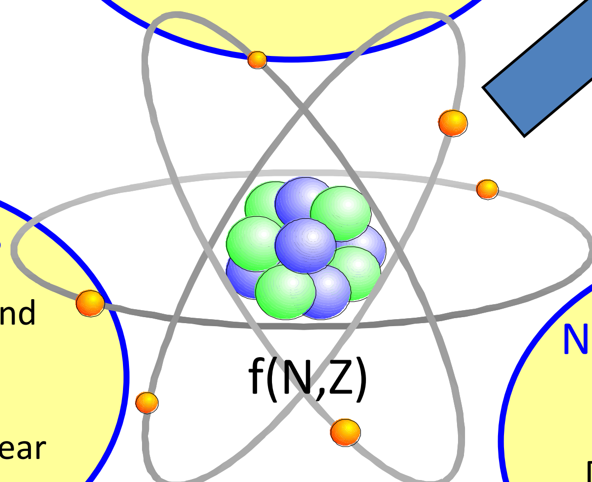
Nuclear Decay Spectroscopy and Reactions
Structure of Nuclei
Exotic Decay Modes

Applied Physics

Implanted Radioactive Probes,
Tailored Isotopes for Diagnosis and Therapy
Condensed matter physics and Life sciences

Fundamental Physics

Direct Mass Measurements,
Dedicated Decay Studies - WI
CKM unitarity tests, search for b-n correlations, right-handed currents



Atomic Physics

Laser Spectroscopy and Direct Mass Measurements
Radii, Moments, Nuclear Binding Energies

Nuclear Astrophysics

Dedicated Nuclear Decay/Reaction Studies
Element Synthesis,
Solar Processes

Examples of physics topics

- Nuclear Physics
  - shell closures, shape evolution shape coexistence, halo nuclei …
- Fundamental interactions
  - P, T violation, neutrinos, Vud matrix element
- Solid state physics
  - semiconductors spintronics, nano…
- Biophysics, medical physics
  - Radioisotopes, heavy metal toxicity

ISOLDE

CERN

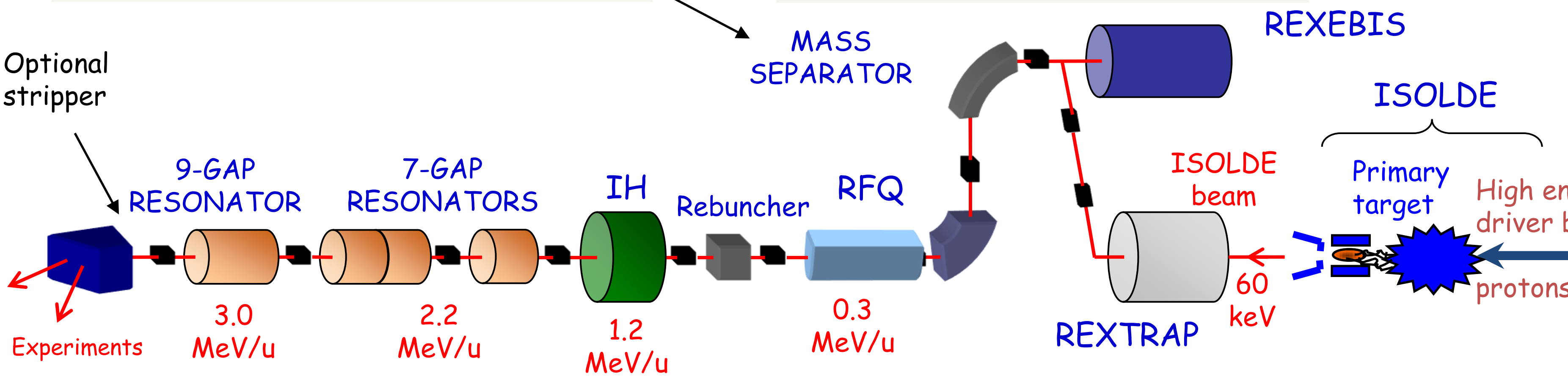
REX

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 %