CERN's Radioactive Ion Beam Facility

The nuclear playground

 ISOLDE is a radioactive isotope facility where the nuclear chart is our playground!







Production: Modern-day alchemy



- The protons split up the heavy nucleus to produce a wide variety of nuclei simultaneously!
- Requirements for experiment:
 - High production
 - Pure radioactive beams: 1 kind of isotope
- Different stages of preparation
 - Production
 - Ionization
 - Separation

Gold is one of the chemical elements produced at ISOLDE, both stable as well as radioactive isotopes

Production: Targets





Separation: where is the ion of interest?

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Ionization: RILIS

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



ISOLDE Robots





What is produced at ISOLDE?



ISOLDE can produce isotopes that live between 1 ms and 10¹² years

Production rates range from < a few per hour to >10⁹ a second



Radioactive decay







Simple nuclear reactions

- Scattering reactions can be used to determine the shape of nuclei.
 - Just like **Rutherford scattering**!
 - But the nucleus can get excited and gain angular momentum.

Accelerated at 10% speed of light











How does ISS work?

Bean

- Radioactive ion hits the target at 10-15% of the speed of light.
- Proton emitted during the reaction is bent back to the axis by the magnetic field.
- Energy and position of proton let's you "see" the reaction happen.





~0.9 m

Up to 4 T superconducting solenoidal

~2.5 m

e.g. proto

Si array

Empty slide



Recycling an MRI magnet





Research with radioactive beams

- How much do nuclei weigh? How big are they? What shape do they have?
- How and where in the universe are chemical elements produced?
- Why can protons and neutrons be bound together in many 1000 combinations? What are the limits of nuclear existence?
- How can we use the unique properties of radioactive nuclei for diagnosing and treating cancer?
- What's the location of impurities in crystals and biological samples?







Research with radioactive beams





The rich physics in an atomic nucleus

Coulomb force repels protons



 Strong interaction ("nuclear force") causes binding between nucleons (= attractive).

• Weak interaction causes β-decay



The rich physics in an atomic nucleus

20

- The atomic nucleus consists of a few 100 nucleons (protons and neutrons)
 - **Too few to apply statistical methods to describe its properties**
 - Too much to allow for 'ab-initio' calculations starting from the 'nucleon-nucleon interaction' between individual nucleons
- the 'nuclear' force between protons and neutrons is not a 'fundamental' force
 - Use 'empirical' or 'effective' nucleon-nucleon interactions
 - Recent progress: interaction derived from QCD via chiral effective field theory
- Use experimental data to test predictive power of nuclear models when going to 'extremes'...



Experiments to probe nuclear structure

21



ISOLDE at CERN

Isotope Separator OnLine Device

- Approved by the CERN council in 1964, first beams in 1967
 - Initially 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 the CERN budget
- ~7% of the CERN scientists
- ~50% of the CERN protons

Run by international collaboration

- CERN, BE, DE, DK, FI, FR, GR, IT, NO, PL, RO, SK, ZA, ES, SE, UK
- ~50 staff/students/fellows
- ~1500 users







The ISOLDE facility



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



Daily life at ISOLDE

- 1. Propose experiment for board of experts
- 2. Experiment gets scheduled
 - Winter: shutdown
 - April November: beam times
 - \square ~8 months/year, 24/7
- 4. Prepare set-up
- 5. Do experiment
 - ~1 week continuously
- 6. Analysis, discussion, publication, conferences



MEDICIS: recycling protons for

society

 Production of non-conventional radioisotopes for medical research

Acous

- 80-90% of the proton beam goes through the ISOLDE target unaffected
- Use these (free!) protons to





Theranostics

DiagNOSTICS



THERApy



β^+ -emissions

PET $E(\gamma) = 511 \text{ keV}$

γ -emissions

SPECT 100keV<E(γ)<200keV

α -emitter

High LET, short distance in human tissue

β-emitter

Low LET, long distance in human tissue









Medical isotope production







