ISOLDE
Isotope Separation On-Line
(ISOL)
Mats Lindroos
on
behalf of the CERN ISOLDE team
Summer students 2004
Mats Lindroos on behalf of the ISOLDE team
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Outline

• Overview of the ISOL technique
• ISOLDE-REX, post acceleration of radioactive ions
• Physics at ISOLDE
• Future plans
• Visit
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ISOLDE@CERN
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2004
Production of exotic ions

1 GeV p + \( ^{238}U \) → \( ^{201}Fr \) (spallation) + \( ^{11}Li \) (fragmentation) + \( ^{143}Cs \) (fission) + X + Y

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Production yields

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Thermochemical and physical principles
- Diffusion
- Effusion
The thermal shock of the proton’s dE/dx is transferred to the “cold” converter.

\begin{itemize}
  \item \textbf{UC target}
  \item \textbf{HT-oven electrical connections}
  \item \textbf{Ion-source}
  \item \textbf{PROTONS / NEUTRONS}
  \item \textbf{p+ beam-scan (\textsuperscript{95}Kr yield)}
\end{itemize}

\textbf{1 GeV p}\textbf{U}\textbf{Fr}\textbf{Li}\textbf{Cs}\textbf{Y}

\textbf{Spallation}\textbf{Fragmentation}\textbf{Fission}
**ISOECRIS**
- based on a ISOLDE unit
- coils
- consumable unit
- Running off-line

**MINIMONO ISOLDE**
- GANIL design [1,2]
- ‘standard’ ISOLDE unit
- permanent magnets
- consumable unit
- Running on-line

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F. Wenander, J. Lettry
Laser Ionization

- Laser beams
- atom
- ion
- continuum
- ionization energy < 9-10 eV
- excited states
- ground state
ISOLDE target change

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**Magnetic separation**

- "Isobaric" separation
- Separation limited by the beams transverse size
- Cooling at low energy with RFQ cooler
To get pure beams free from isobaric contamination:

- Target material
- Target and ion source chemistry
- Proton energy
- Ion source
- Magnetic separation
ISOL FACILITIES 1967

1967

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World Wide Radioactive Beam Facilities

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ISOL facilities 2003
Why bother?

• A few-body system of hadrons (neutrons and protons) with many remaining question marks
• “Largest” system where strong and weak interaction are manifested
• “Applications”
  – Astrophysics
  – Condensed matter
  – Energy
  – Medicine
“And why nuclear physics? My answer is the same as that of the young student who chose nuclear physics – it is a field of basic research with fascinating fundamental problems and applications to many other areas such as medicine and material science. I believe that nuclear physics is so broad that it is well on the way to becoming the most general natural science.”

Professor Paul Kienle, 1993
Physics at ISOLDE

- Solid state physics: 17%
- Particle and Astrophysics: 14%
- Biology/Medicine: 2%
- Atomic Physics: 18%
- Weak Interaction and Nuclear Physics: 49%

- 35 Experiments
- 270 Users
- 77 Institutes
- 22 Countries

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Astrophysics

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Halo Nuclei

$^{11}\text{Li}$: Borromean Halo Nucleus

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BEER is good for Nuclear Physics
Mass models

Constraints for nuclear mass models

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Mass measurements

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D. Lunney
Mass measurements

F. Herfurth, et al., NIM A 469, 264 (2001)

- Stable alkali ion reference source
- Cluster ion source
- Ion beam cooler and buncher
- Penning trap
- Removal of contaminant ions
- Isobaric separation
- Determination of cyclotron frequency
- Isomeric separation

\[ \omega_c = \frac{q}{m} \cdot B \]

Time-of-flight [\mu s]

Excitation frequency [Hz]

B = 6 T
B = 4.7 T

Nd:YAG 532 nm

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Solid state physics
Radioactive ions as “spies” (PAC) in high-Tc superconductors...

... or as dopants in semiconductors that change with time.

Time after annealing:
- 4 h
- 31 h
- 56 h
- 73 h
- 104 h
- 149 h
- 236 h
- 331 h
- 696 h

CdTe:^{71}As

(D, A_{As})

(D, A_{Ge})

(D, A_{Li,Na})

PL intensity [a.u.]

Energy [eV]
Example: samarium isotopes

“in vivo” dosimetry by positron emission tomography (PET)

142-Sm (e, T1/2 = 72m) -> 142-Pm (β, T1/2 = 40s)

Therapy: 153-Sm (β, T1/2 = 47h)

PET scan of a rabbit 60 min p.i. of ISOLDE produced 142-Sm in EDTMP solution
Principle of Radioimmunotherapy

DAUDI cells

Cell membrane

Proteins in healthy cells

Protein strand in cancer cells (CD20 antigens of B cells)

149Tb

Linker (CHX-A-DTPA)

MoAb (Rituximab) specific to CD20 antigens of B cells

Plasma

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Principle of Radioimmunotherapy
Post acceleration

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

2.2 MeV/u

Production and ionization

3.1 MeV/u

Time structure

Beam size

4.3 MeV/u

Acceleration

A < 145

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**ISOLDE**

- REX EBIS
- REXTRAP
- q/A-selector

**For A < 40:**
- Breeding time (A/q < 4.5) < 20 ms
- Repetition rate 50 Hz
- Beam intensities < 10^9/s

**Single charged ions from REXTRAP**
- Electron gun (0.5A/5kV)
- Solenoid (2T)
- Collector drift tubes
- Separation from residual gas ions

**For A > ?:**

**IS 397 team**

**Charge breeding of Uranium and**
- 96Sr^{15+}, 94Rb^{15+}

**Accumulation**

**Cooling**

**Ejection**
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Future Plans
More protons: Linac 4

From M. Vretenar
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600 ms cycling of the PS booster

- Present PSB cycle 1.2 s
- Increase PSB capacity to cope with increased demands for protons at CERN
- Major proton users to benefit: LHC, ISOLDE, CNGS

From M. Benedikt, AB, CERN
**FUTURE PLANS**

*Summer students 2004* Mats Lindroos on behalf of the ISOLDE team

**The SPL**

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- **Future Plans**
- **The SPL**
- **Summer students 2004** Mats Lindroos on behalf of the ISOLDE team
Future plans
A next generation RNB facility

Hall 1
Hall 2
Hall 3
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Target Development

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H.Ravn, U.Koester, J.Lettry, S.Gardoni, A.Fabich
AIM: provide beams of electron (anti) neutrinos by decay of beta active ions.

**The Beta-Beam**

- **Proton Driver**
  - SPL

- **Ion production**
  - ISOL target & Ion source

- **Beam preparation**
  - ECR pulsed

- **Ion acceleration**
  - Linac

- **Acceleration to medium energy**
  - Bunching ring and RCS

- **PS & SPS**

- **Experiment**
  - Decay ring
    - $B_r = 1500$ Tm
    - $B = 5$ T
    - $C = 7000$ m
    - $L_{ss} = 2500$ m

  - $^6\text{He}$: $g = 150$
  - $^{18}\text{Ne}$: $g = 60$

- **IF of RB?**

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CERN TO FREJUS

SPL @ CERN
2.2GeV, 50Hz, 2.3x10^{14}p/pulse à4MW
Now under R&D phase

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Water Cherenkov
Super KamioKande

MultiUSER detector: Astrophysics, Beta-beam, Super Beam, Proton Decay

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**Combination of beta beam with low energy super beam**

Unique to CERN:

combines CP and T violation tests

\[ \nu_e \rightarrow \nu_\mu \quad (\beta^+) \quad \leftrightarrow \quad T \quad \nu_\mu \rightarrow \nu_e \quad (\pi^+) \]

\[ \bar{\nu}_e \rightarrow \bar{\nu}_\mu \quad (\beta^-) \quad \leftrightarrow \quad T \quad \bar{\nu}_\mu \rightarrow \bar{\nu}_e \quad (\pi^-) \]

A. Blondel
Conclusions

• Nuclear physics and its applications:
  – are fascinating subjects
  – have an exciting future at new large scale facilities
  – holds exciting research opportunities for you; for a Ph.D. and a future research career

• Thank you for your attention!
ISOLDE visit

- Today at 15.00!
- Bring your filmbadge
- We are meeting outside the ISOLDE hall
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1. RILIS
2. Collections (medical physics, solid state physics)
3. Control room and targets
4. COLLAPS, COMPLIS and Tilted foil
5. ISOLDE Posters
6. ISOLTRAP
7. MISTRAL and NICOLE
8. MINI-BALL
9. ASPIC
10. REX