Nuclear structure with exotic beams

Lecture 4:
Techniques
Production and Detection
RIB facilities

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

RIB:
- Radioactive Ion Beam
- Rare Isotope Beam
Facility for Rare Isotope Beams in the world

- TRIUMF-ISAC
  500 MeV – 100 µA
- EURISOL
  1 GeV – 100 µA
- SPES
  40 MeV – 20 µA
- IGISOL
  30 MeV – 100 µA
- IBS RISP
  78 MeV – 1 mA
- ISOL@MYRRHA
  600 MeV – 4 mA
- ISOLDE
  1.4 GeV – 2 µA
- HIE-ISOLDE
  1.4 GeV – 6 µA
- SARAF
  40 MeV – 6 mA

- In-flight production
- ISOL production
- ISOL production using proton beam (In operation – upgrade or construction – project)

F. Pellamoine, February 29 2016 Proton Driver Efficacy Workshop, Slide 6
ISOTOPE production in ISOL method

High intensity, high quality, energy tunable

Chemically selective, not all beams are possible
Short-Lived Krypton Isotopes and Their Daughter Substances

O. KOFOD-HANSEN and K. O. NIELSEN
Institute for Theoretical Physics, University of Copenhagen,
Copenhagen, Denmark
(Received February 9, 1951)

The isotopes Kr$^{85}$, Kr$^{84}$, Kr$^{83}$; and their daughter substances have been investigated. Krypton formed in fission of uranium was pumped through a 10-m long tube directly from the cyclotron into the ion source of the isotope separator. The cyclotron and the isotope separator were operated simultaneously, and the counting could begin immediately after the interruption of the separation. The rubidium and strontium daughter substances were separated chemically; strontium was precipitated as carbonate. Half-lives were measured and an absorption analysis of the radiations was carried out. The results are given in Table I.
Re-accelerated ISOL Beams

Pioneering work done at Louvain-La-Neuve

Prompt γ-ray spectrum
Time-coincidence spectrum
Charged-particle spectrum

D. De Roeck, O. Thirion, M. Lefebvre, O. M. J. Kiewi, P. Van Deren, O. S. V. Van Den Abbeele, and O. S. V. Van Den Abbeele.
Produced Nuclei: ISOLDE 45 y Experience

- Over 20 target materials and ionizers, depending on beam of interest operated at high temperature
- U, Ta, Zr, Y, Ti, Si, ...
- 3 types of ion-sources: Surface, Plasma, Laser
- > 700 nuclides of over 70 chemical elements produced

ISOLDE today offers the largest range of available isotopes of any ISOL facility worldwide.
HIE-ISOLDE: Upgraded to accelerate to 10 AMeV
Production of Rare Isotopes in Flight

1. Accelerate heavy ion beam to high energy and pass through a thin target to achieve random removal of protons and neutrons in flight.

   - Projectile
   - Target
   - Hot participant zone
   - Projectile fragment

2. Cooling by evaporation

   - Projectile fragment
   - Rare isotope beam

Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science
Michigan State University

(M. Thoennesen)
All species possible, Can go far from stability, high (100s of AMeV) energies

Poorer emittance and beam quality, high energies

FIG. 1. Scatter plot of data obtained from the reaction of 205-MeV/nucleon $^{40}$Ar ions on a carbon target. The line running through the figure indicates the previously known limit of stability.
Many many nuclei are produced!
(BIGRIPS, $^{238}\text{U}+^{9}\text{Be}$)

T. Ohnishi et al.,
Re-accelerating Fast Fragmentation beams

CARIBU Gas Catcher at ANL
Expected FRIB/ReA beam yields

Probable minimum – few $\times 10^3$ pps

Adequate for direct reactions
Detecting charged Particles: Silicon-detector arrays
Silicon-array CP detection

Resolution challenged in Inverse kinematics

$^{30}\text{Mg}(t,p)^{32}\text{Mg}$

$^{8}\text{Li}(d,p)^{9}\text{Li}$

$^{132}\text{Sn}(d,p)^{133}\text{Sn}$
Detecting Photons

GAMMASPHERE
~100 Compton-suppressed Ge detectors

GRETINA/GRETA – Gamma-ray tracking

AGATA – Gamma-ray tracking
Detecting charged particles and gamma rays together

$^{30}\text{Mg}(t,\gamma)^{32}\text{Mg}$

MINIBall @ CERN-ISOLDE

ORRUBA/GODESS
ORNL/ANL
Tracking and Active Targets

Excellent for low-rate experiments
Intrinsic resolution not quite as good as Si

Sπrit TPC
(SAMURAI @ RIKEN)

ATTPC @ NSCL

MAYA TPC
@ GANIL
Magnetic Spectrometers

SAMURAI @ RIKEN

S800 @NSCL

Reaction product identification
S800 spectrograph

Energy loss (arb. units)

Time of flight (arb. units)
HELical Orbit Spectrometer - HELIOS

\[ B_{\text{MAX}} = 2.85 \text{ T} \]

2.35 m

0.9 m

Solenoid Spectrometer

Beam

Silicon Array

Target

Laser rangefinder

X-Y-\(\theta\) positioning stage

J. P. Schiffer, RIA equipment workshop 1999
J. C. Lighthall et al., NIMPRA 622, 97 (2010)
Kinematics in a solenoid

\[ ^8\text{Li}(t,p)^{10}\text{Li} \]

\[ ^8\text{Li}(d,^3\text{He})^7\text{He} \]

- \( E_p \) vs. \( \theta \)
  - \( \theta_{CM}(p) = 90^\circ \)
  - \( \theta_{CM}(p) = 0^\circ \)

- \( E_{^3\text{He}} \) vs. \( \theta \)
  - \( \theta_{CM}(^3\text{He}) = 80^\circ \)
  - \( \theta_{CM}(^3\text{He}) = 5^\circ \)

- \( E_p \) vs. \( Z \)
  - \( ^8\text{Li}(t,p)^{10}\text{Li} \)

- \( E_{^3\text{He}} \) vs. \( Z \)
  - \( ^8\text{Li}(d,^3\text{He})^7\text{He} \)

“backward”

“forward”
A highly versatile instrument

- Major research programs from UConn, LANL, LSU, etc. Others include Berkeley, Lowell, CMU, Manchester, ...
- Apollo, gas target, ion chamber, backwards / forwards / all routine
- Use of tritium target
Preaching and Conclusion

• Remember history – basic understanding embedded in early work, often obscured by nuance and details accumulated over the years

• Put results in context – nuclear physics progresses by the assembly of a puzzle with many parts, individual measurements are pieces but don’t lose sight of the Big Picture

• Technical advances can help provide better data, but equally important are imagination and insight in the design of experiments and the interpretation of data.

• There is a lot that I did not cover. Take this and run with it!