β-Decay Studies of r-Process Nuclei Using AIDA

The Advanced Implantation Detector Array

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In order to test our theoretical understanding we want to compare to experimental data.

The best experimental data for this is observations of the abundances of nuclei throughout the solar system.

Further from stability there are less measurements to base models on.
As the nuclei shift to becoming more exotic theoretical models begin to diverge

It is important to have experimentally measured values to base the theory of

Sensitivity studies can highlight nuclei and parameters of importance
Experimental Challenges

- Environments in which these elements are created cannot be replicated in labs

- Instead have to produce nuclei through other methods

- Half-lives involved are short
  - Decay’s must be measured immediately following an isotopes creation
The Advanced Implantation Detector Array

Requirements of the system:
• Sensitive to energy ranges of decays, 100s keV, to implantation, GeV.
• Fast timing response of the electronics
• Support a high implantation rate
DSSDs

• Stack of 6 BB18 DSSDs by Micron Semiconductors

• Each detector is 1mm thick

• 128x128 channels on a 7.163cmx7.163cm face giving a pitch of 560µm

• 1536 independent strips over six detectors with a total of 16384 pixels per detector
DSSD Signal Handling

- Each strip is individually read out as it’s own independent channel

- Front and back strips provide position information of the events that are measured

- 1536 strips within a 1/3L volume (Large glass of wine) requires high density electronics to read out all strips
Front End Electronics and ASICs

- 1536 strips within a 1/3L volume requires high density electronics to read out all strips
- ASICs are the answer
- Need a short recovery time from large implant signals (\(\sim\)GeV) to detect subsequent decays (\(\sim\)10s-100s keV)
Front End Electronics and ASICS

- 1536 strips within a 1/3L volume requires high density electronics to read out all strips

- ASICS are the answer

- Need a short recovery time from large implant signals (~GeV) to detect subsequent decays (~10s-100s keV)
Localising Events

• Position is obtained by matching energy of front signals to back signals

• Implant and beta-signals may be spread over multiple strips

• Need to form clusters which can then be matched

• Gives us an area in which the implant or beta stops
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Implant-Decay Correlations

- End up with a distribution of events across the detector
- Use the spatial information of the positions of the implants and betas
- Look for overlaps in areas of decay signals with an implant
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- Use the spatial information of the positions of the implants and betas
- Look for overlaps in areas of decay signals with an implant
- Taking the time difference between implants and decays produces a decay curve
Implantation within the Detector

- Large range of ions implanted within the detector
- Differing Z values result in different stopping power of ions

\[ ^{141}\text{Te} \quad ^{122}\text{Rh} \]

Implant Distributions Through Detectors

- Make full use of the detector stack
- Implantations spread throughout the stack
Studies of the N=82 Region

• N=82 Relates to a closed neutron shell
  • Increased stability of nuclei with N=82
  • Forms a ladder in the r-process where neutron capture is less efficient
• Also have nuclei with Z=50 a closed proton shell
• Spectra generated from one hour of data

$^{132}\text{In Decay Curve}$
$^{132}$In Decay Curve

<table>
<thead>
<tr>
<th>In132ImplantBeta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Std Dev</td>
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</tbody>
</table>
$^{132}$In Decay Curve

$^{132}$In $\xrightarrow{\beta} ^{132}$Sn $\xrightarrow{\beta} ^{132}$Sb $\xrightarrow{\beta} ^{132}$Te

$^{131}$Sn $\xrightarrow{\beta} ^{131}$Sb $\xrightarrow{\beta} ^{131}$Te
Bateman Equations and a Generic Fit Program

• A mathematical model to describe the abundances and activity of nuclei in a decay chain

\[ f_\beta = \sum_{i \in \beta} e^{\beta} \lambda_i N_i(t) \]

\[ N_k(t) = N_1 \prod_{i=1}^{k-1} (b_{i,i_1} \lambda_i) \times \sum_{i=1}^{k} \frac{e^{-\lambda_i t}}{\prod_{j=1 \neq i}^{k} (\lambda_j - \lambda_i)} \]

\[ b_{i,i+1} = P_{1n}^i, P_{2n}^i \text{ or } 1 - P_{2n}^i - P_{1n}^i \]

• Can be computationally calculated and used as a fit function
In Decay Curve Fit

- Entries: 1187366
- Mean: 1.439
- Std Dev: 1.434
The BRIKEN Collaboration

- **BRIKEN**
  - 140 $^3$He Tubes
  - Arranged in a plastic moderator surrounding the AIDA detector stack
  - High efficiency detection of β-delayed neutrons ~70%

- **HPGe Clover Detectors**
  - Detect the prompt gamma rays from the decay of nuclei
  - Ions are implanted on the DSSSD stack
    - Subsequent decays are then measured using the positional information
    - Half-lives can be determined
  - Detection of β-delayed neutrons allow a $P_n$ value to be calculated


Image from: BRIKEN Collaboration Rare Earth Metals PAC Proposal
**P_n Measurements and Isomer Studies**

- Neutrons can be correlated with beta signals.
- Can produce $i\beta 1n$ and $i\beta 2n$ curves using these correlations.
- Have to account for randoms and detection efficiencies but $P_n$ and $P_{2n}$ values can be calculated.
Measurements and Isomer Studies

Fits of $^{134}$In

- N0 = 27293
- $T_{1/2} = 128(2)$ ms
- $P_n \approx 80\%$
- $P_{2n} \approx 10\%$

- Just statistical errors so far.

- Systematic errors will come from a full Monte-Carlo based study on the effect of different parameters on the fit.

Histograms provided by V. Phong. Fits calculated using generic Bateman fit program discussed.
Summary and Outlook

• Summary
  • Custom FEEs and ASICs allow a fast recovery time from high energy implant signals to allow measurement of decays
  • High segmentation of DSSDs supports a high implantation rate of exotic nuclei
  • AIDA has been used to carry out beta-decay studies of exotic nuclei at RIKEN

• Outlook
  • Analysis is progressing on the decay properties of r-process nuclei
  • More experiments using AIDA are approved and will run over the coming years

Image from: BRIKEN Collaboration Workshop
Acknowledgements

• University of Edinburgh
  • C. Bruno, T. Davinson, C. Griffin, D. Kahl & P. Woods

• IFIC-CSIC, Spain
  • J. Agramunt, A. Algora, C. Domingo Pardo, A. I. L Morales, J. L. Tain & A. Tolosa

• RIKEN
  • H. Baba, J. Liu, K. Matsui, S. Nishimura, H. Sakurai & P. Vi

• NPL
  • G. Lorusso

• Central Michigan University
  • A. Estrade & N. Nepal

• Michigan State University
  • F. Montes

• University of Liverpool
  • L. Harkness-Brennan, T. Grahn, P. Nolan, R. Page, S. Rinta-Antila & D. Seddon

• STFC DL