ISOLDE Decay Station: Year one and near future physics program

M. Madurga
A multipurpose Decay spectroscopy for ISOLDE

The ISOLDE Decay Station (IDS) project aimed to provide:

- **Permanent** Setup for decay studies using the RIB from ISOLDE
- **Flexible** (for several decay types or studies)
  
  **Basic approach:**
  
  - High Pure Ge-detector (4 clovers and up to 3 MiniBall detectors)
  - Ancillary detectors (LaBr₃, plastic scintillator, silicon, neutron detectors, ...)
  - Tape station/Windmill implantation chamber

- **Form a collaboration** to support and perform decay studies at ISOLDE
The IDS workhorses: 4 HPGe clovers (+ 1 Miniball Cluster)

- Leuven Tape collection
- 4 Ge Clovers at Backward angles
- 1 Miniball Detector (triple cluster)
- 3 plastic scintillators: 30%

(Avg Distance to center 74mm)
Spokesperson: Zsolt Podolyák (Univ. Surrey)

Physics:
- **Low-spin level structure** of the $^{207}$Tl by $\beta$-decay of $^{207}$Hg
- Breaking of the neutron or proton core
- Collective octupole phonon coupled to the single proton hole

Courtesy of R. Caroll
Gamma lifetime measurements @ IDS

Life Time Measurements

- Implantation on Tape
- 4 Ge Clovers at Backward angles
- 1-3 LaBr₃
- 1-3 beta plastic scintillator

2014: -Fast-timing commissioning experiment (C. Sotty, L.M. Fraile)
-Study of octupole deformation in neutron-rich Ba isotopes populated via β-decay (G. Benzoni, H. Mach)
Study of the $^{129}\text{Sn}$ structure populated in the beta decay of $^{129}\text{In}$

**Physics:**
- $3s_{1/2} \rightarrow 2d_{3/2}$ \(\text{M1 I-forbidden}\)
- Test for \textit{M1 effective operators} near shell closure

![Diagram of nuclear levels and transitions](image)

$^{129}\text{In}$ (1.23s, 459 keV)

- $\beta^-$
- 0.6%
- 1.5%
- 907
- 973
- 15.1%
- 315
- 3/2$^+$

$^{129}\text{Sn}$

- 1/2$^-$
- 3/2$^+$
- 1/2$^-$

Count rates vs energy for $^{129}\text{Sn}$ with a 315 keV gate, showing a Gaussian fit with FWHM = 271 ps and $T_{1/2}^{\text{exp.}} < 40$ ps.

Courtesy of R. Lica

Shell Model: A. Gargano Private communication
Delayed charged particle emission

P1: PAD 505 µm
U3: PAD 500 µm

Charged Particle Spectroscopy

- Implantation on C foil
- 4 Ge Clovers at Forward angles
- Si box: 6 DE-E telescopes (70%)

2014: -β-3p spectroscopy and p-γ width determination in the decay of $^{31}$A (H.O.Y Fynbo, G.T. Koldste, B. Blank)

- Experimental investigation of decay properties of neutron deficient $^{116-118}$Ba isotopes and test of $^{112-115}$Ba yields. (U.D. Pramanik O. Tengblad)
\( \beta\text{-}3p \) spectroscopy and \( p\text{-}\gamma \) width determination in the decay of \(^{31}\text{Ar} \)

- **Spokesperson:** H. O. U. Fynbo (Univ. Aarhus), G.T. Koldste (Univ. Aarhus), Bertram Blank (CENBG)

- **Physics:**
  - \( \beta\text{-}\text{delayed 3p-decay branch} \)
  - Information on the resonances of \(^{30}\text{S} \) and \(^{29}\text{P} \), in particular the ratio between the proton and \( \gamma \) partial widths relevant for astrophysics

Proton energy spectrum
Beta delayed neutron spectroscopy at the ISOLDE decay station

- 4 clovers, 4% efficient @ 1MeV
- Newly developed ISOLDE neutron detector
  - 45% efficiency/bar @ 1MeV
  - $\Omega = 21.7\%$ of $4\pi$
  - 60% $\beta$-trigger efficiency
  - 5.9% total efficiency @ 1MeV
Beta-decay of Cd isotopes beyond N=82 -- $^{132}\text{Cd}$

spokespersons: MM, R. Grzywacz

- FF and GT strength separated by N=82 shell gap
- Neutron distribution $\rightarrow v$-gdh single particle states

$P_n(^{132}\text{Cd}) \geq 60\%$

M. Hannawald et al., PRC 62, 054301 (2000)
$^{132}\text{Cd} @ \text{ISOLDE}$

I.N. Borzov, Private communication

**Neutron Energy (MeV)**

- **DF3$_a$ + cQRPA**

- **Nushell**

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**B(GT)**

- $S_n$
- $S_{2n}$
- $Q_\beta$

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**ToF$_n$ (ns)**

- Counts/1ns

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**ToF$_n$ (ns)**

- Counts/1ns

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**$E_n$ (MeV)**

- Counts/1ns

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Study of neutron-rich $^{51-53}$Ca isotopes via beta-decay
Spokespersons: A. Gottardo, MM

Different prediction going towards the $N=34$ for the $f_{7/2}$ gap (different 3N forces + coupling to continuum)

J. D. Holt et al., PRC 90, 024312 (2014)

The N=34 closure and $^{53,54}\text{Ca}$


$^{54}\text{Ca}$ : the $2^+$ energy and the mass indicate a subshell closure

$^{53}\text{Ca}$ : understanding single-particle energies going towards $\text{N}=34$: $\nu p_{1/2} - \nu f_{5/2}$ gap
Past $^{53}$Ca measurement

- The GT decay should populate the $\pi f_{7/2}$ shell -> we expect $\nu f_{7/2}^{-1} \pi f_{7/2}^{-1}$ states at 8-10 MeV: 2n emission
- FF could also lead to $\nu p_{1/2}^{-1} \nu p_{3/2}^{-1} \nu f_{7/2}^{-1}$ states (closed Z=20)


Not enough statistics to reconstruct the level scheme
Summary

- Nuclear structure from radioactive nuclei:
  - Decay properties: nuclear astrophysics/reactor physics
  - Properties of the daughter: Selective/clean probe of excited states

- IDS provides minimum infrastructure for decay experiments at ISOLDE:
  - 4 (+1) HPGe clovers
  - Beta triggers
  - Tape station
  - Digital data acquisition

- Flexible design for specialized setups:
  - Gamma lifetime measurements
  - delayed charged particle/neutron emission
Acknowledgements

The IDS Collaboration

Thanks for your attention
Experimental setup: Electronics and DAQ

- **TDR - DAQ for IDS:**
  - **TDR** – Total Data Readout (Daresbury, UK), widely used at JYFL, chosen for **ISOLDE IDS - phase I**.
  - Channels are **read out asynchronously** in singles mode and each data item is **time-stamped with an external clock**.
  - **3 x VHS-ADC**: 16 ch, 105 MSPS, 14-bit ADC (virtex4 FPGA) - could be available on loan from JYFL.
  - Capable to handle rates ~**30kHz/ch** (DC beam)
  - **Event building and analysis** has to be done entirely in the software **post-processing** the data stream.
  - Data recording framework: **MIDAS**

- **GRAIN – data analysis software (ONLINE):**
  - Developed at JYU to be used with the novel Total Data Readout (TDR) data acquisition system.
  - A flexible and efficient event parser and the accompanying software framework written entirely in **Java**.
    - [https://trac.cc.jyu.fi/projects/grain](https://trac.cc.jyu.fi/projects/grain)
  - P. Rahkila, NIM A 595, 637 (2008)

- **N4ids - data analysis software (ONLINE/OFFLINE):**
  - Conversion code developed at CERN written in **C++**
  - Analysis with **GASPWARE** or **ROOT**

+ **HPGe**: 19 ch (max 25, phase II)
+ **LaBr3**: 6 ch
+ **Plastic**: 3 ch
+ **TAC**: 15 ch

**Total: 43 ch** (48 ch available)

+ **ISOLDE status** (T1, T2, tape, laser...)

[https://github.com/rlica/nutaq4ids](https://github.com/rlica/nutaq4ids)

Courtesy of R. Lica
A factor 100 difference between theory and measurement

\[ T_{1/2}^{\text{theor.}} \sim 4\text{ns} \quad \gg \quad T_{1/2}^{\text{exp.}} < 40 \text{ps} \]

What are the implications?

A major change in the shell structure might not reproduce well the energy levels.

A slightly different from zero M1 effective operator for neutron holes greatly improves the agreement without changing any other matrix elements.

\[ <d3/2|\text{M1}|s1/2> \sim 0.1 \]

- already known for proton particles ( = 0.14 )
- unknown for neutron holes in the $^{132}\text{Sn}$ region

Our measurement can provide the first estimation for the value of the M1 effective operator.

\[ E^{\text{theor.}} (1/2+) = 294 \text{keV} \approx E^{\text{exp.}} (1/2+) = 315 \text{keV} \]

\[ T_{1/2}^{\text{theor.}} \sim 120 \text{ps} \]
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**Lyrtech VHS-ADC**

**Grain**

P. Rahkila, NIM A 595, 637 (2008)

**GASPWARE**

[Link](https://github.com/rlica/nutaq4ids)

**N4ids**

[Link](https://github.com/rlica/nutaq4ids)

Courtesy of R. Lica
IS545: Experimental investigation of decay properties of neutron deficient $^{116-118}$Ba isotopes and test of $^{112-115}$Ba beam counts

- **Spokesperson:** U.D. Pramanik (Saha INP), O. Tengblad (CSIC)
- **Physics:**
  - Study of n-deficient $^{116-118}$Ba on the vicinity to proton dripline
  - Proton emission, width of the resonant state
  - **Beam development for neutron-deficient $^{112-115}$Ba nuclei**
- **Set-up and Methodology:**
  - LaC target (nano-structured)
  - 4 HPGe Clover detectors at forward angles + Si box (5 DSSSD’s, 4 Pad’s)
  - ISOLDE MBS and IDS Nutaq use in parallel
  - 165 ch: Mesytec preamplifiers (2xMPR64, 2xMPR32)
  - Mesytec STMR16+ shapers
- **Preliminary Results:**
  - LaC target (nano-structured) led to **better release** specially for Ba
  - Injection of CF4 gave pure Ba (free from Cs)
  - **Estimated production 31 $^{115}$Cs/s**
  - Further data taken (not analyzed): $A=138(^{119}$Ba+$^{19}$F), $A=136(^{117}$Ba+$^{19}$F) and $A=133(^{114}$Ba+$^{19}$F).
IS590: Characterization of the low-lying $0^+$ and $2^+$ states of $^{68}\text{Ni}$

- **Spokesperson:** C. Sotty (KU Leuven-IKS), L. Fraile (Univ. Madrid)
- **Physics:**
  - Detailed spectroscopy data of the low-spin states of $^{68}\text{Ni}$ (triple pairs of $0^+/2^+$ states)
  - Gamma branching ratios of the $0^+$ and $2^+$ states and E0 transition strength

- **Low $^{68}\text{Mn}$ yields (<1pps) → Cancelled**

- **Yield tests to identify the origins of such low production rate:**
  - $^{64,66}\text{Mn}$ isotopes
  - Two different UCx targets (#509 and #512)
  - With/without neutron converter
  - **Target lower performing**
    → requested 5pps for the production of $^{68}\text{Mn}$

- **Commissioning of the fast timing configuration with the $^{129}\text{In}$ decay**
IS579: Study of octupole deformation in neutron-rich Ba isotopes populated via $\beta$-decay

- **Spokesperson:** G. Benzoni (INFN Milano), H. Mach (NCBJ)
- **Physics:**
  - $\beta$-decay of $^{150,151,152}$Cs to study Ba daughter nuclei
  - **Evolution of the octupole deformation** across the isotopic chain
    Insight via the B(E1), B(E3) transition strength
  - **Astrophysical process:**
    - Halflives necessary to determine the correct timescale and waiting points
    - $P_n$ values determine the $r$-process path and influence on the fission rates
- **Preliminary Results:**
  - $^{148,149}$Cs $\rightarrow$ $^{148,149}$Ba decay chains used as references
  - **Half of the shifts dedicated to study the $^{150}$Cs**
  - Yields lower than expected (~1.2 $^{150}$Cs /$\mu$C)
  - Lifetimes, delayed n-emission probabilities will be extracted thanks to:
    detailed spectroscopy and $\gamma$-$\gamma$ coincidences and fast-timing technique
Beta-decay of Cd isotopes around N=82

$^{130}_{82}$Cd

Low energy states in In driven by SPEs

$P_n(^{131}\text{Cd})=3.5\%$

IDS Status Report Campaign 2014 and future

- **Campaign 2014 (Phase-I.0):**
  - **Setup:**
    - Phase-I: 3 configurations operational
    - RC4 beamline operational
  - **Experiments:**
    - 6 proposals approved, 5 experiment performed,
    - Data analysis on going but already promising results

- **Campaign 2015 (Phase-I.1):**
  - **Setup:**
    - Same configurations available
    - Same electronics and DAQ
    - Upgrade beam diagnostics
    - Upgrade of the tape station (new motor and controller)
    - Coupling to VANDLE (run with its own electronics/DAQ)
  - **Experiments:**
    - INTC (October 2014): 1 proposal approved ($^{51-53}$Ca) 1 proposal under clarification ($^{130-132}$Cd)
    - **G4IDS:** Geant4 code to support the proposals and analysis
  - **Phase-II (from 2016 onwards)**
    - **Setup upgrades:**
      - New implantation chambers (for $\alpha$-decay, $\beta$-delayed fission, high-resolution electron spectroscopy studies)
      - New holding structure
      - Different DAQ system allowing a larger number of channels