

Study of light neutron-deficient nuclei

Progress report

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Outline

- 1 Motivation
- 2 New opportunities at MSU
- 3 Experiment at IGISOL, Aug.-Sep. 2020
- 4 Development and maintenance of software
- 5 Analysis of the decay of ^{21}Mg
- 6 Outlook

Theme

Preparations and training for experiments at MSU
– rescheduling of plans

Motivation

New opportunities
at MSU

Experiment at
IGISOL, Aug.-Sep.
2020

Development and
maintenance of
software

Analysis of the
decay of ^{21}Mg

Outlook

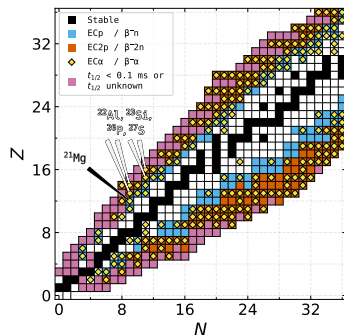
Motivation

Rich and complex array of decays along drip lines

Consolidation

Exploit **β -delayed particle emission** in order to study:

- 1 Mechanisms of multi-proton and α emission
- 2 β strength in decays with large open energy windows
- 3 Properties of resonances above proton separation energies



Limited knowledge on
neutron-deficient nuclei with
 $A \sim 20 \dots 30$

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Outlook

β -delayed particle emission

Motivation

New opportunities at MSU

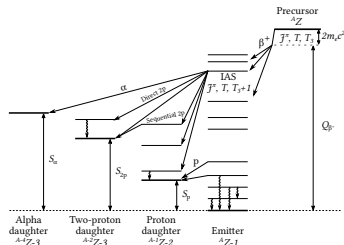
Experiment at IGISOL, Aug.-Sep. 2020

Development and maintenance of software

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Outlook

- 1 Mechanisms of multi-proton and α emission
- 2 β strength in decays with large open energy windows
- 3 Properties of resonances above proton separation energies



Slowness of β -decay makes these observations possible

$$ft = \frac{K}{g_V^2 B_F + g_A^2 B_{GT}}$$

$$K = \frac{2\pi^3 \hbar^7 \ln 2}{m_e^5 c^4}$$

New opportunities at MSU

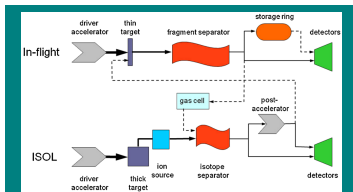
Beam production

In-flight advantages:

- Short separation times
- Large separation efficiencies

ISOL advantages:

- High purity, low energy beams
- Large yields



M. Pfützner *et al.*, *Rev. Mod. Phys.* **84**, 567 (2012).

Beam production at MSU

Combination of ISOL and
in-flight methods

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Outlook

NSCL → FRIB: Even greater yields

Low Energy Community Meeting August 9th-11th 2021

Motivation

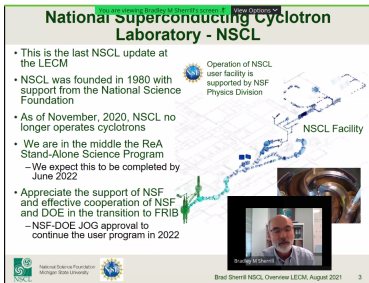
New opportunities at MSU

Experiment at IGISOL, Aug.-Sep. 2020

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Outlook



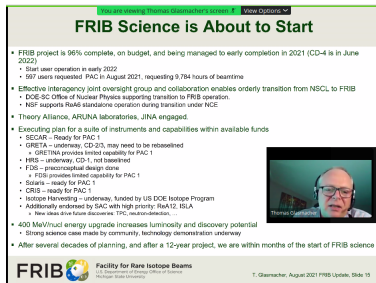
National Superconducting Cyclotron Laboratory - NSCL

- This is the last NSCL update at the LECM
- NSCL was founded in 1980 with support from the National Science Foundation
- As of November, 2020, NSCL no longer operates cyclotrons
- We are in the middle the ReA Stand-Alone Science Program
 - We expect this to be completed by June 2022
- Appreciate the support of NSF and effective cooperation of NSF and DOE in the transition to FRIB
 - NSF-DOE JOG approval to continue the user program in 2022

Operation of NSCL user facility is supported by NSF Physics Division

NSCL Facility

Brad Sherril NSCL Overview LECM, August 2021 3



FRIB Science is About to Start

- FRIB project is 96% complete, on budget, and being managed to early completion in 2021 (CD-4 is in June 2022)
- Start user operation in early 2022
- 597 users requested PAC in August 2021, requesting 9,784 hours of beamtime
- Effective interagency joint oversight group and collaboration enables orderly transition from NSCL to FRIB
 - DOE-SC Office of Nuclear Physics supporting transition to FRIB operation.
 - NSF supports ReA6 standalone operation during transition under NCE
- Theory Alliance, ARUNA laboratories, JINA enabled.
- Executing plan for a suite of instruments and capabilities within available funds
 - SECAR – Ready for PAC 1
 - GRETA – underway, CD-2/3, may need to be rebaselined
 - GREINA provides limited capability for PAC 1
 - HRIS – underway, CD-1, not baselined
 - FDS – pre-conceptual design done
 - FDS provides limited capability for PAC 1
 - SoLaris – ready for PAC 1
 - CRIS – ready for PAC 1
 - Isotope Harvesting – underway, funded by US DOE Isotope Program
 - Additionally endorsed by SAC with high priority: ReA12, ISLA
 - New ideas drive future discovery: TRIP, muon-electricity
- 400 MeV/nucleon energy upgrade increases luminosity and discovery potential
 - Strong science case made by community, technology demonstration underway
- After several decades of planning, and after a 12-year project, we are within months of the start of FRIB science

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

T. Glasmacher, August 2021 FRIB Update, Slide 15

Good news!

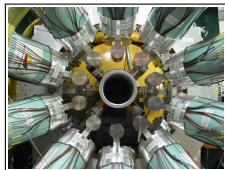
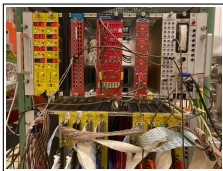
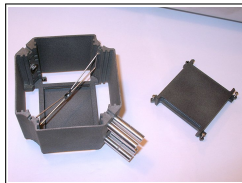
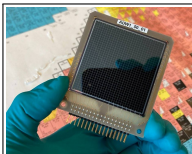
The experiments originally planned at NSCL would have had much greater statistics compared to any previous study

The upgrade to FRIB further enhances the yield by an order of 10^3 !

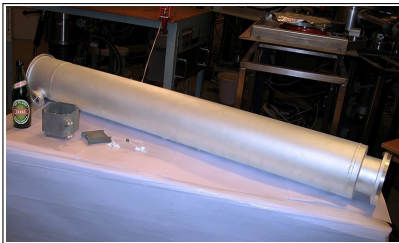
Beam time next summer would grant one whole year for analysing the data

Detection setup

- DSSSDs and SSSDs
- Specially designed cube
- Stopping foil
- Custom-made aluminium tube
- SeGA at MSU
- Our DAQ



A. Gade, NSCL (2016).



Motivation

New opportunities
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Experiment at
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2020

Development and
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Analysis of the
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Outlook

Experiment at IGISOL, Aug.-Sep. 2020



Jyväskylä, Finland

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Outlook

Andreas Gad's PhD project

Studying resonances above the *Hoyle state* in ^{12}C
through the decay of ^{12}B

Brief relaxation of travel restrictions meant only Andreas and I could participate

*Completion would not have been possible without the tremendous assistance and effort
of the people at IGISOL*

Outcome of experiment at IGISOL

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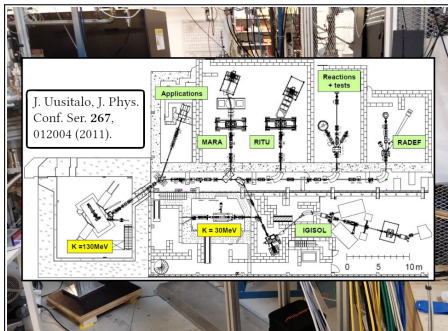
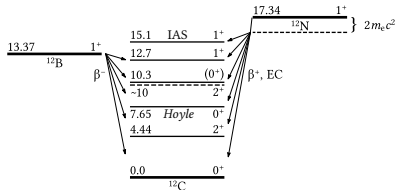
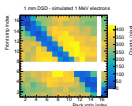
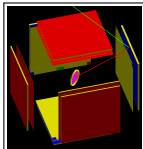
Outlook

Much greater statistics than previously on the decay of ^{12}B

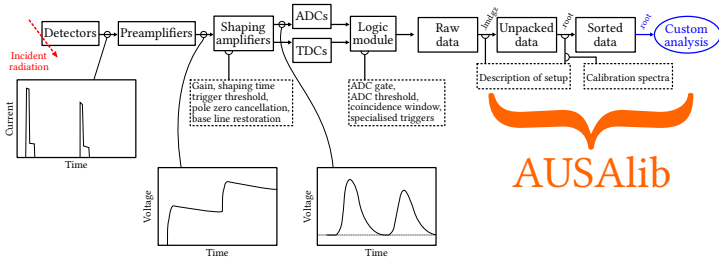
- Andreas is currently analysing the data

From *my* PhD project's point of view:

- Pilot experiment for the MSU experiment
- Training in carrying out long experiments at accelerator facilities
- Lessons learned
- Geant4 simulations



Development and maintenance of software



AUSAlib based on ROOT from CERN

My work

Expansion of AUSAlib

Future-proofing AUSAlib:

- ROOT v. 6 (C++11) → ROOT v. 7 (C++14)
- New CMake standards

Motivation

New opportunities at MSU

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Outlook

CMake – a Build System Generator

The file CMakeLists.txt is the entry point for building the library

CMake version 2.8

```
erik@susics:~/devel/resources/ausalb/build> cmake ../
CMake Deprecation Warning at CMakeLists.txt:1 (cmake_minimum_required):
Compatibility with CMake < 2.8.12 will be removed from a future version of
CMake.
# ...
# ...
-- Configuring done
-- Generating done
-- Build files have been written to: /home/erik/devel/resources/ausalb/build
erik@susics:~/devel/resources/ausalb/build> █
```

CMake version 3.15

```
erik@susics:~/devel/resources/ausalb2021/build> cmake ../
-- Build type set to Release
-- Build shared libraries set to OFF
-- Build AUSALIB python bindings set to OFF
# ...
# ...
-- Configuring done
-- Generating done
-- Build files have been written to: /home/erik/devel/resources/ausalb2021/build
erik@susics:~/devel/resources/ausalb2021/build> █
```

```
CMakeLists.txt (Home/erik/devel/resources/ausalb)
1 cmake_minimum_required(VERSION 2.8)
2 project(AUSALIB)
3
4 # Full cmake where to look for cmake modules.
5 set(CMAKE_MODULE_PATH "${CMAKE_MODULE_PATH};${CMAKE_SOURCE_DIR}/cmake")
6
7 # Make it possible to configure shared/static
8 if(NOT DEFINED LIB_TYPE)
9   set(LIB_TYPE SHARED)
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15 # Set build type to "Release" per default, but allow user-specification.
16 set(BUILD_TYPE Release)
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Analysis of the decay of ^{21}Mg

Motivation

New opportunities at MSU

Experiment at IGISOL, Aug.-Sep. 2020

Development and maintenance of software

Analysis of the decay of ^{21}Mg

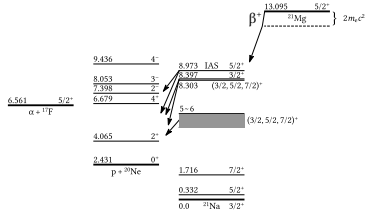
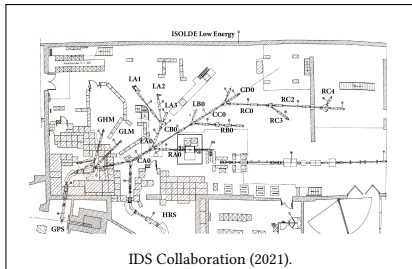
Outlook

Experiment on ^{20}Mg at IDS at CERN in 2015:

Measurements on ^{21}Mg for calibration purposes (5~6 hours)

Large amount of statistics on ^{21}Mg , nevertheless

New analysis; new insights

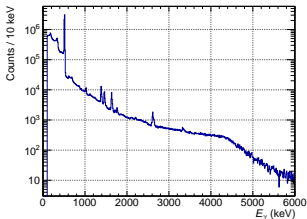


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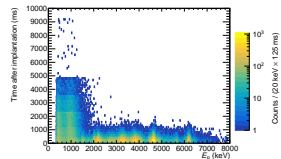
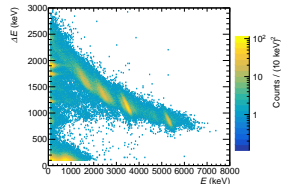
IDS setup shares characteristics with the MSU setup

Can utilise (and combine):

- Telescopes
- Time after production
- Clovers



M. V. Lund, PhD thesis, Aarhus University (2016).



Motivation

New opportunities at MSU

Experiment at IGISOL, Aug.-Sep. 2020

Development and maintenance of software

Analysis of the decay of ^{21}Mg

Outlook

Proton spectrum

Motivation

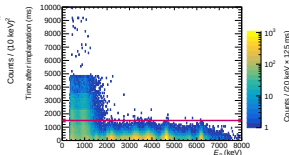
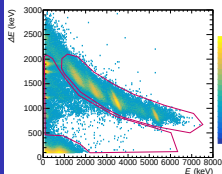
New opportunities at MSU

Experiment at IGISOL, Aug.-Sep. 2020

Development and maintenance of software

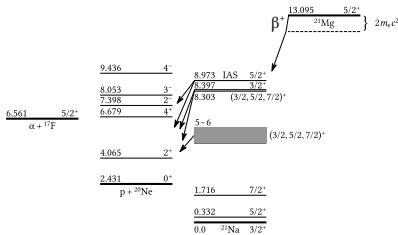
Analysis of the decay of ^{21}Mg

Outlook

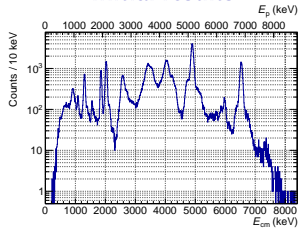


Erratum

Conservation of energy no longer violated



Initial results



Gating on transitions

Motivation

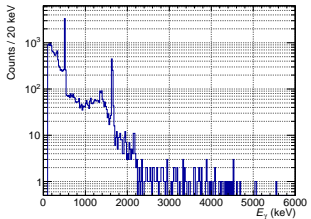
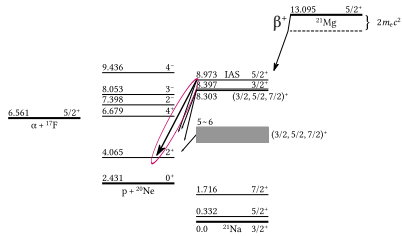
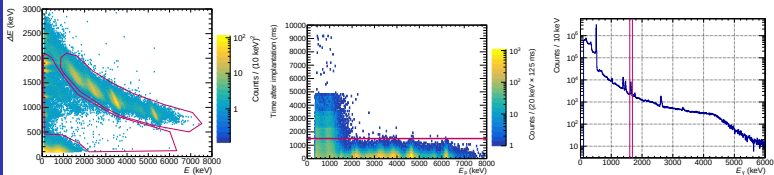
New opportunities at MSU

Experiment at IGISOL, Aug.-Sep. 2020

Development and maintenance of software

Analysis of the decay of ^{21}Mg

Outlook



Outlook

Motivation

New opportunities
at MSU

Experiment at
IGISOL, Aug.-Sep.
2020

Development and
maintenance of
software

Analysis of the
decay of ^{21}Mg

Outlook

All preparations complete – ready for the experiment(s)
at MSU!

In the meantime:

- Continuation of analysis of ^{21}Mg
 - R-matrix theory
 - Extension to data on ^{17}Ne , ^{31}Ar
- Backup experiments?
 - Experiments at ISOLDE or IGISOL
 - Experiments at 5 MeV accelerator in Århus

Thank you for your attention!

(we apologise for any inconvenience caused)