Spectroscopy of ^{23}F Following a One-Neutron Removal Reaction

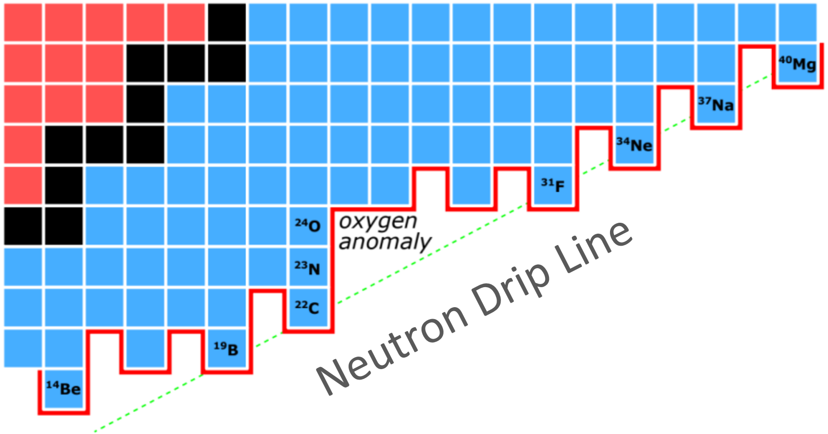
IOP Joint APP, HPP and NP Conference - 2024

Luke Tetley

10/04/2024

Light Neutron-Rich Nuclei

- Rich experimental testing grounds for nuclear models
  - Appearance of non-standard magic numbers (N=14 & N = 16)
  - Halo nuclei (^{11}Li & ^{11}Be)
  - Exotic decay modes (^{26}O 2n emission)



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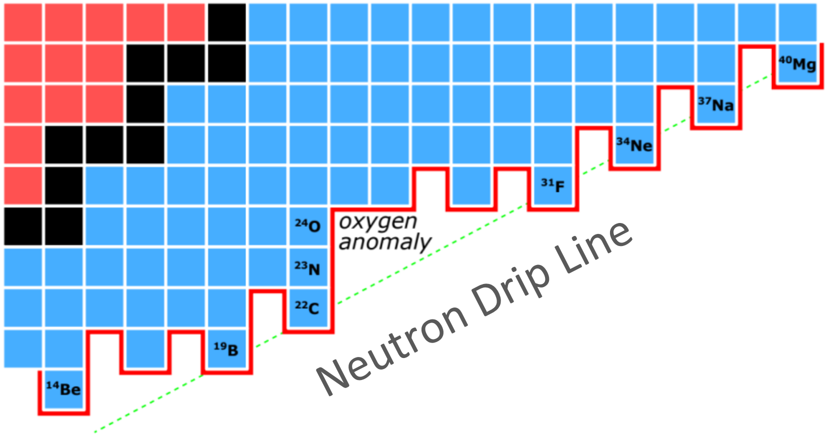

- ➢ Oxygen isotopic chain has had a notable role
  - Correct description of "oxygen anomaly" with inclusion of 3N forces

T. Otsuka *et al.* / Phys. Rev. Lett. **105** (2010)
H. Hergert *et al.* / Phys. Rev. Lett. **110** (2013)

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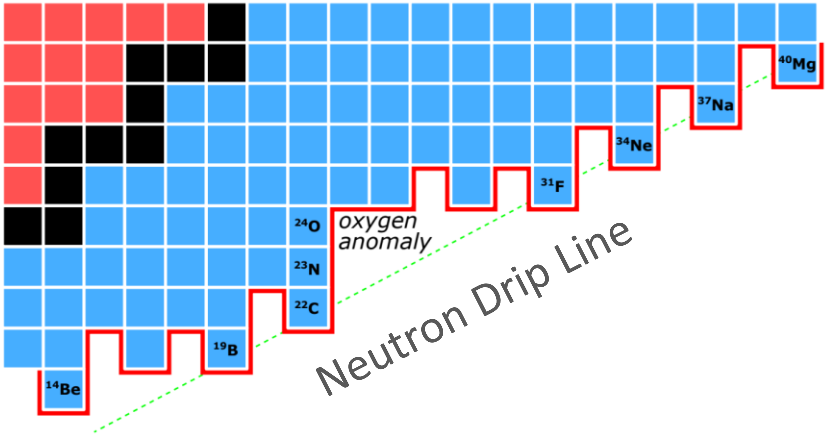
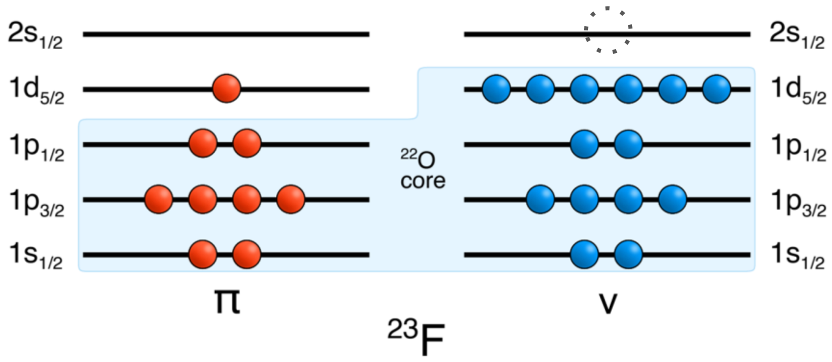


- ➢ Region has proven critical for benchmarking nuclear interactions
  - Observables sensitive to the details of the nuclear interactions

Nuclear Structure of ^{23}F

- Structure of a single valence proton outside of ^{22}O core (Z=8, N=14)
  - Study of S.P. degrees of freedom on top of closed shell



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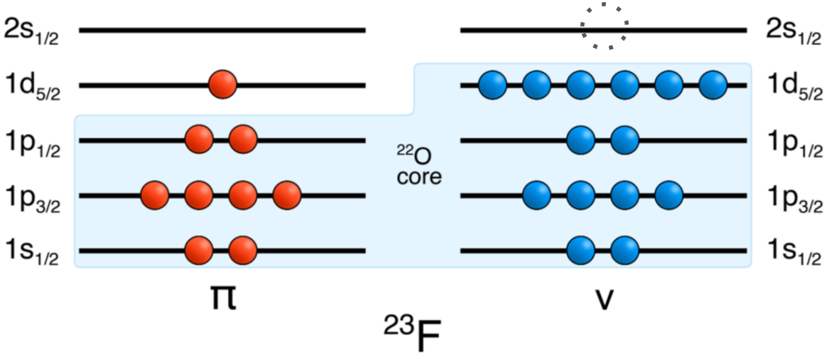
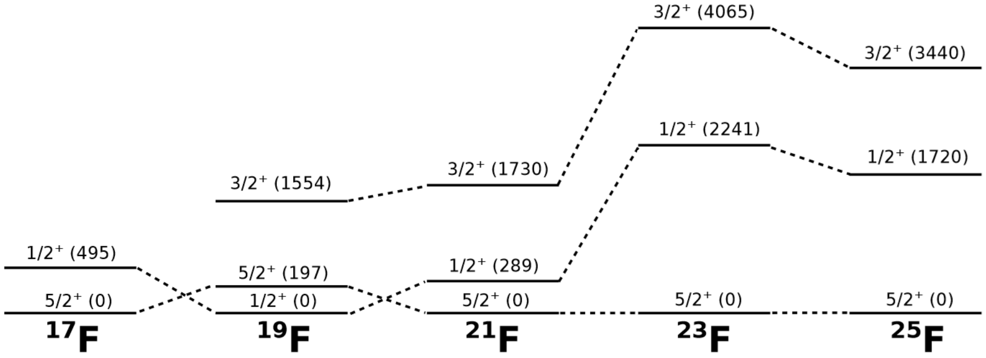
- ➢ Probe the role of the tensor force
  - Splitting the $\pi 1d_{5/2}$ - $\pi 2s_{1/2}$ via occupancy of neutron shells
  - Changes in S.P. structure linked to tensor force





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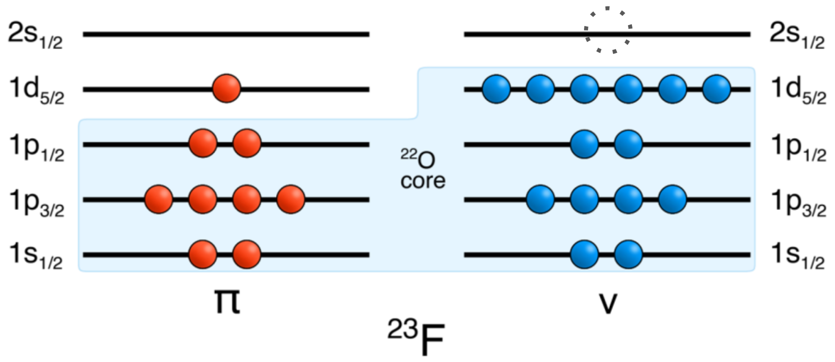

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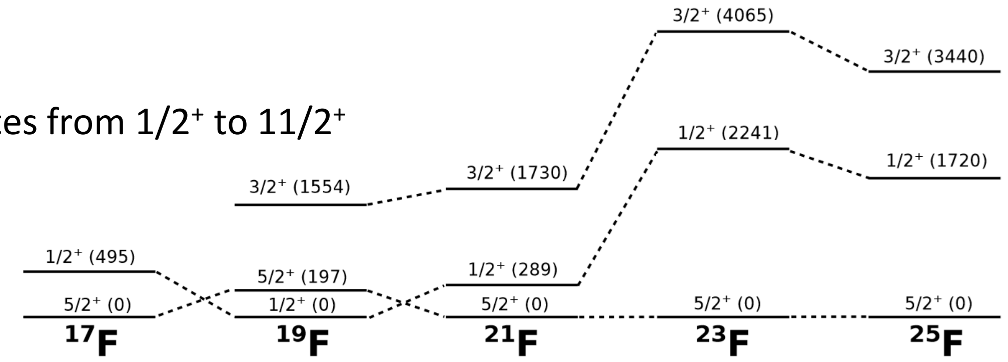
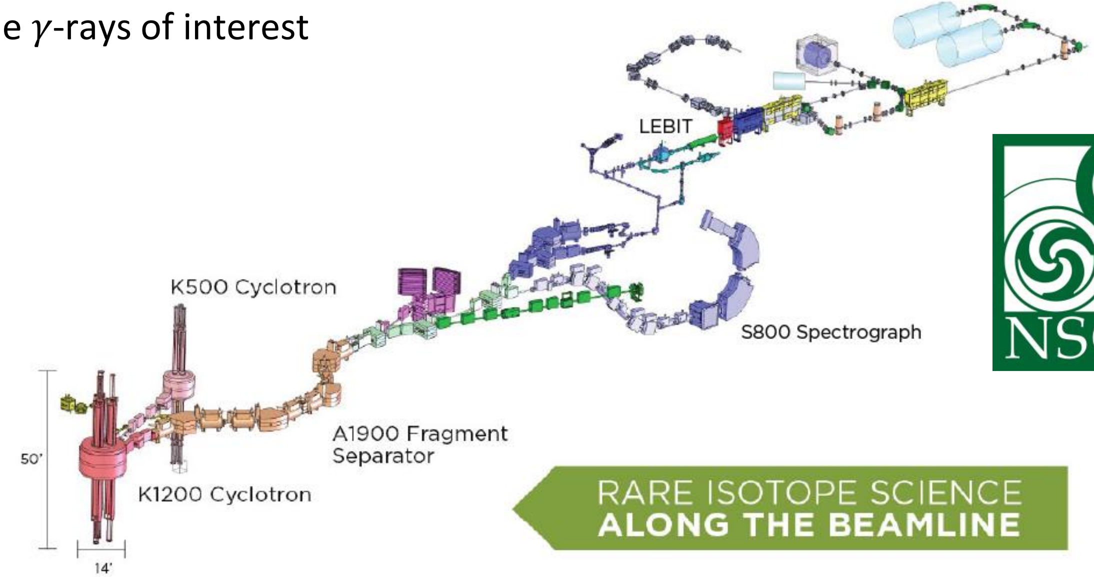
- ➢ One-neutron KO of ^{24}F should populate states from $1/2^+$ to $11/2^+$
  - From ^{24}F g.s. 3^+ coupled to $\nu 1d_{5/2}$



Experiment Overview

- Nuclear excited states of ^{23}F investigated via in-beam γ-ray spectroscopy following 1n removal of a ^{24}F beam

- Measurement was carried out at NSCL, using GRETINA coupled to the S800 spectrograph to measure the γ-rays of interest



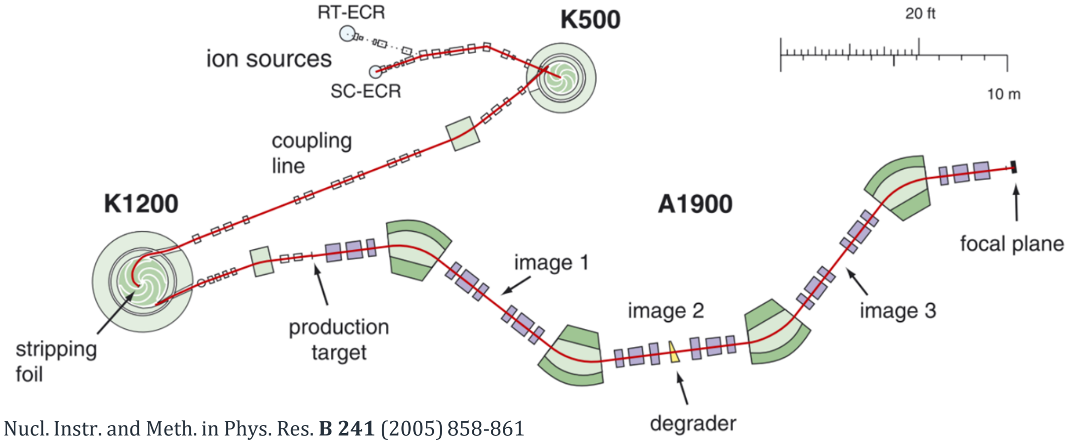
NSCL

RARE ISOTOPE SCIENCE
ALONG THE BEAMLINE

Experiment Details - Beam Delivery

- 95 AMeV ^{24}F beam (95% purity) delivered by A1900
  - Via ^{48}Ca primary beam fragmentation on a 893 mg/cm^2 ^9Be primary target
  - Accelerated by K500 and K1200 coupled cyclotrons

- ^{24}F fragments directed at 370 mg/cm^2 ^9Be secondary target
  - Wherein the 1 neutron removal reactions took place
  - Target shifted 13 cm upstream from nominal position



A. Stolz *et al.* / Nucl. Instr. and Meth. in Phys. Res. **B 241** (2005) 858-861

To the secondary ^9Be target and GRETINA and the S800

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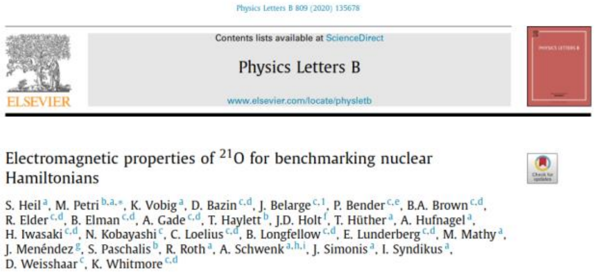
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Electromagnetic properties of ^{21}O for benchmarking nuclear Hamiltonians

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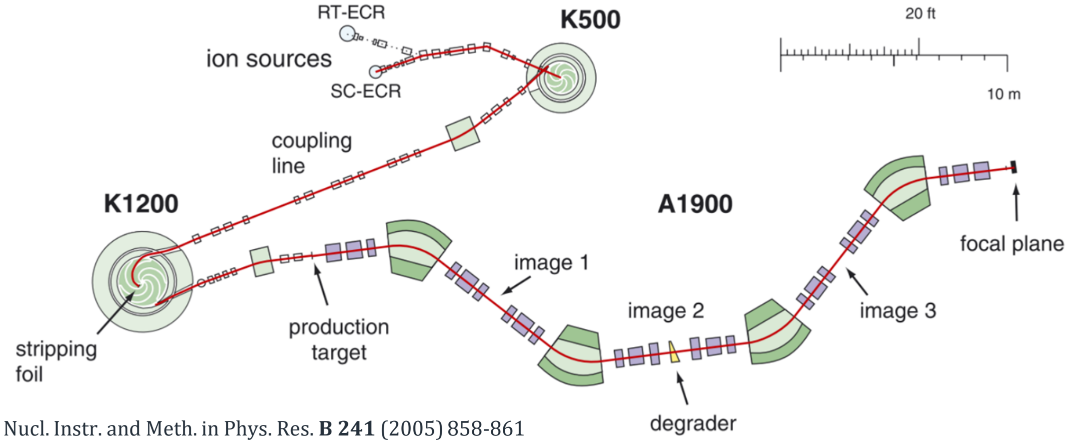

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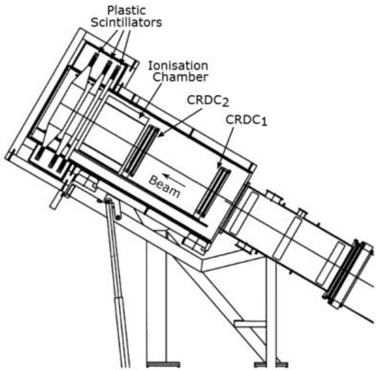
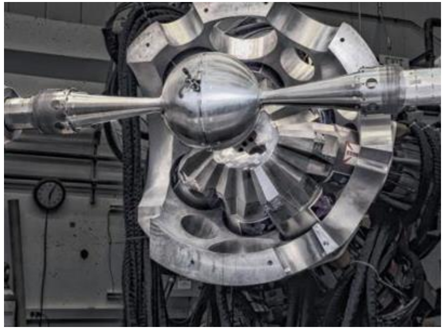
To the secondary ^{9}Be target and GRETINA and the S800

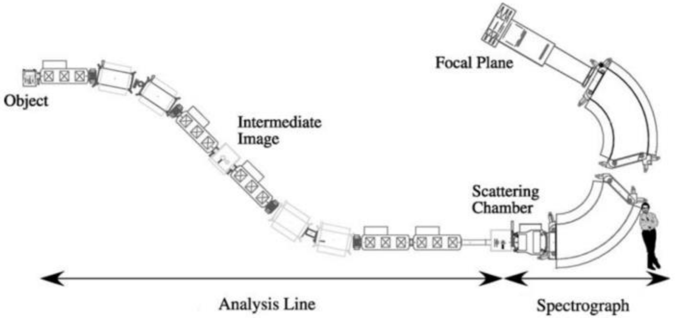
Experiment Details - GRETINA & S800

- ➢ γ-rays emitted in flight were detected by GRETINA
  - 9 modules available for this experiment, 1.2π solid angle coverage
  - Covering ~25^{o} to ~80^{o} w.r.t. target position
  - State-of-the-art tracking, enables good Doppler reconstruction



- ➢ The S800 used for the identification and tracking of outgoing fragments
  - Timing scintillators, CRDCs and IC at the focal plane

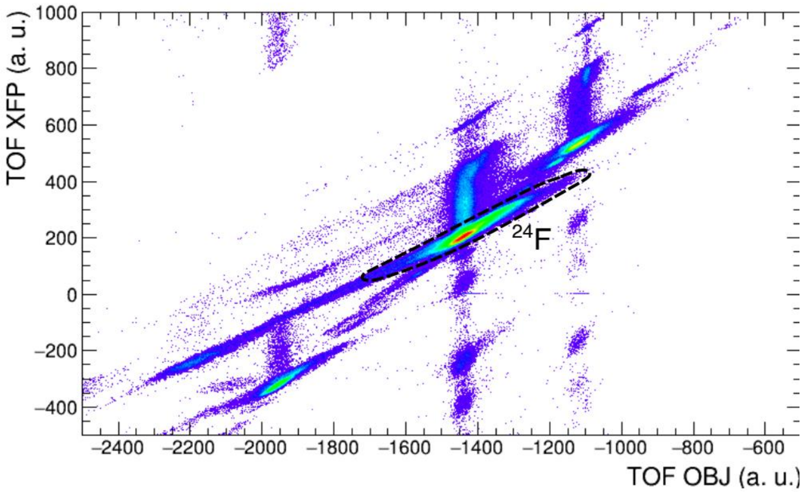


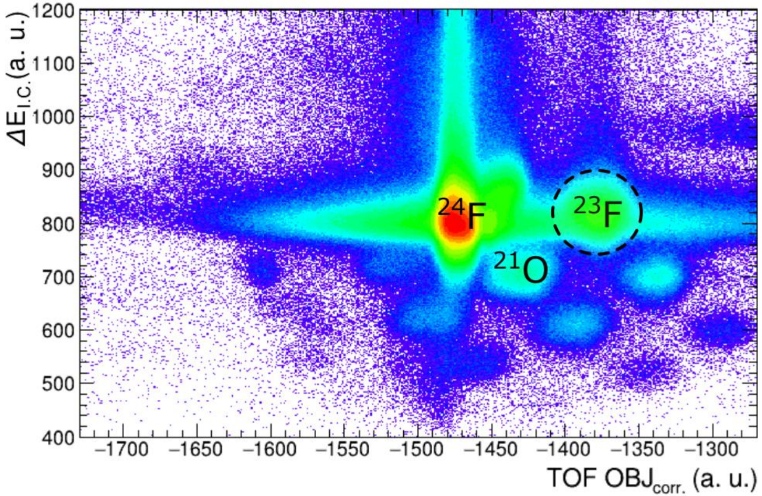


Particle Identification (PID)

- Incoming PID, TOFs between timing scintillators
  - Plastic scintillators at (OBJ) station, A1900 (Xfp) and S800 (E1) focal planes
  - Diagonal lines denote incoming fragments with same velocities

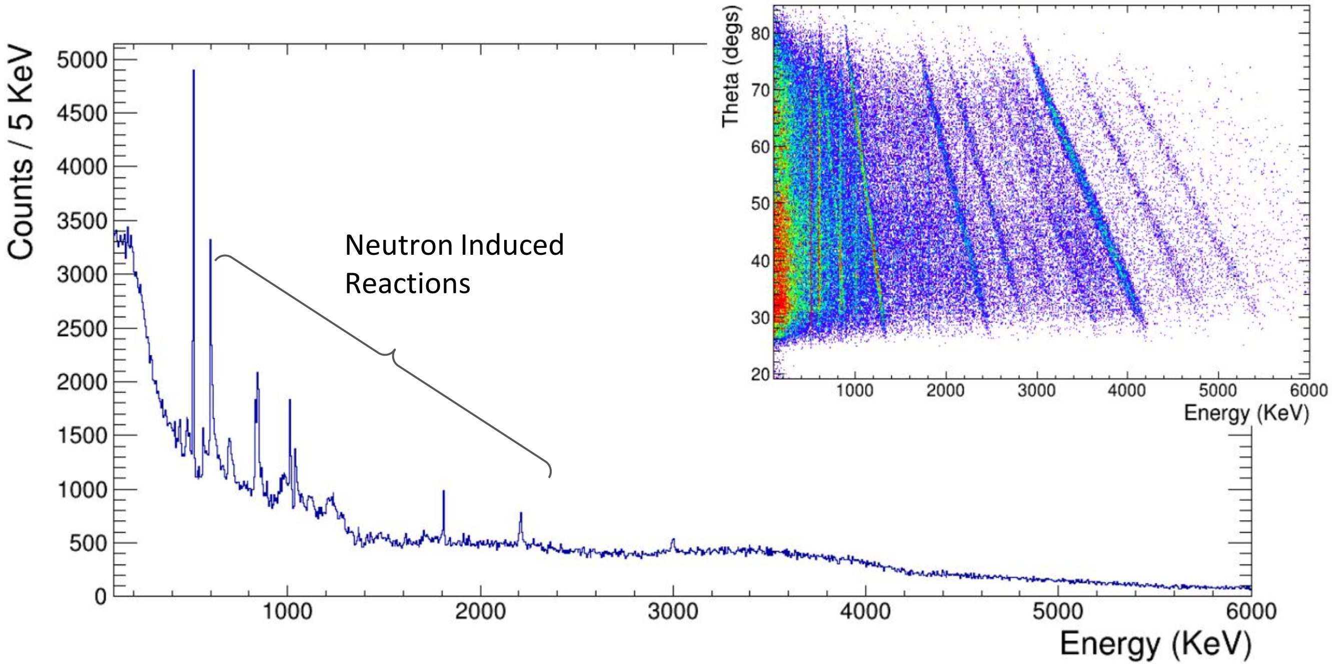
- Outgoing PID, energy loss in IC against TOF between OBJ and E1
  - TOF corrected for fragment trajectories through S800





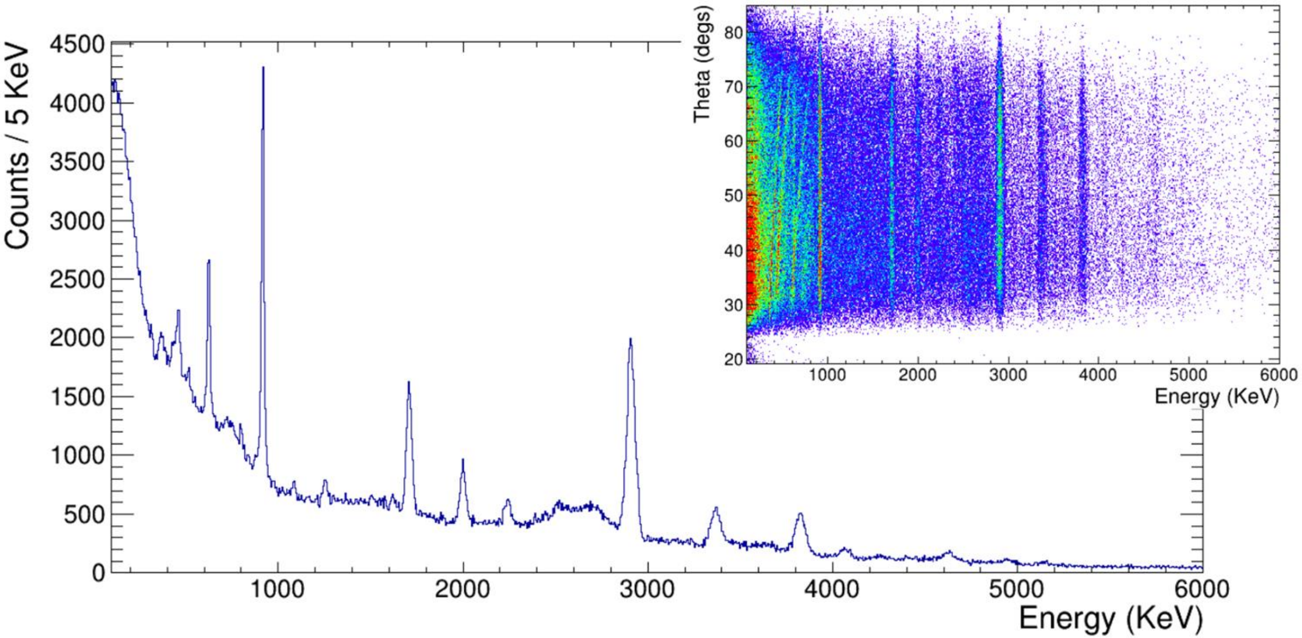
γ-ray Spectrum

- γ-rays decay in-flight at significant fraction of the speed of light
  - Angular dependence on γ-ray energy smears peaks



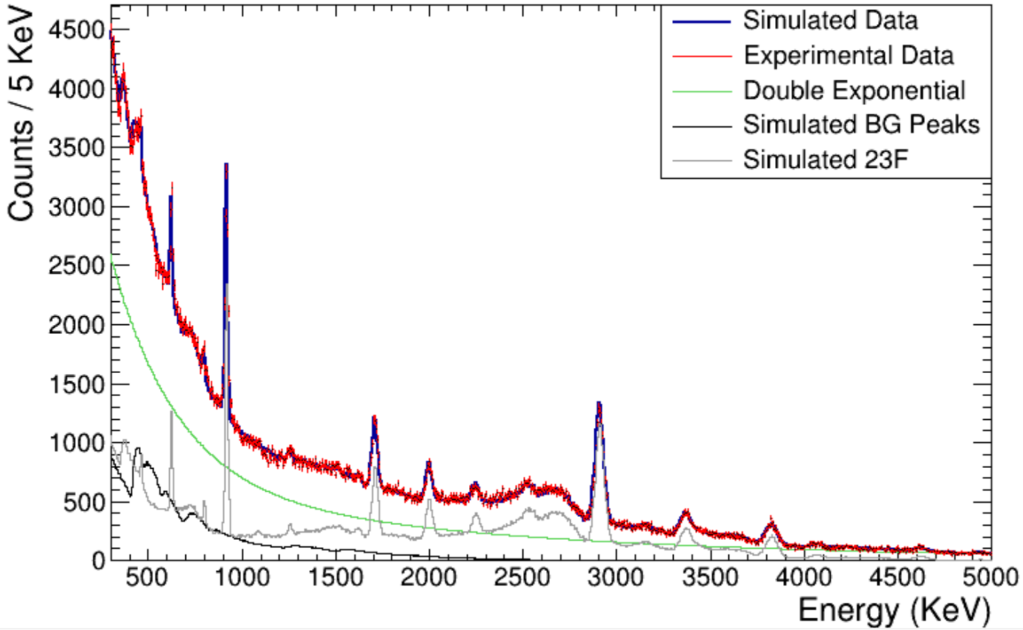
Doppler Corrected γ-ray Spectrum

- ➢ Doppler correction performed event-by-event
  - Average Doppler correction β = 0.4175, to remove energy-angle correlation
  - Beam direction from CRDCs at the S800 focal plane



GEANT4 Simulation Analysis

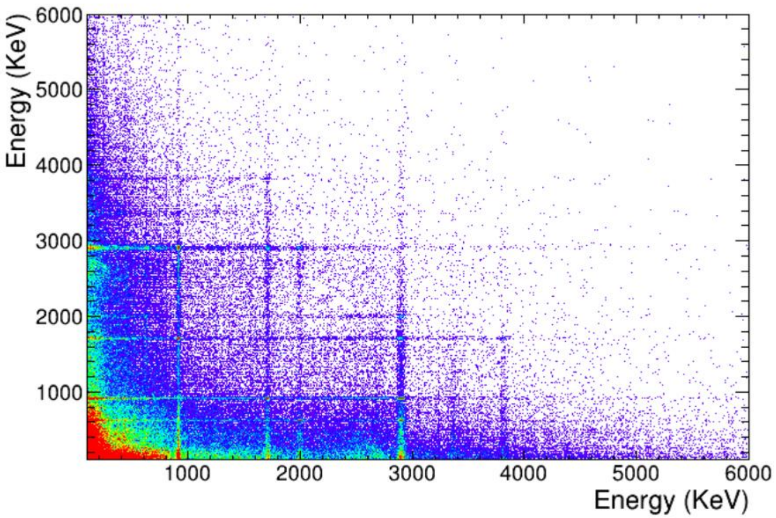
- ➢ Utilized detailed GEANT4 simulations to fully describe the spectrum
  - Correct detector response functions, materials and geometries
  - Simulated several background components, i.e neutron inelastic peaks, and a double exponential background function

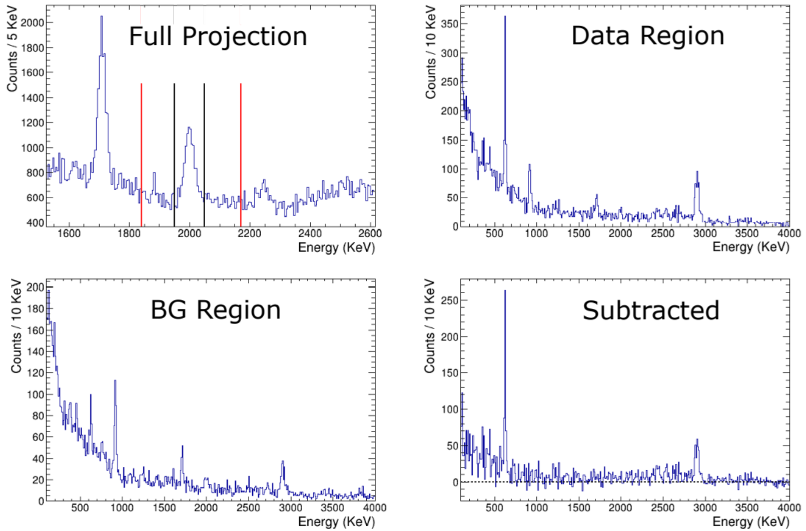


γ-γ Coincidence Analysis

- γ - γ coincidence matrix constructed to analyse the cascades
  - Background subtraction taken from gates adjacent to data gates

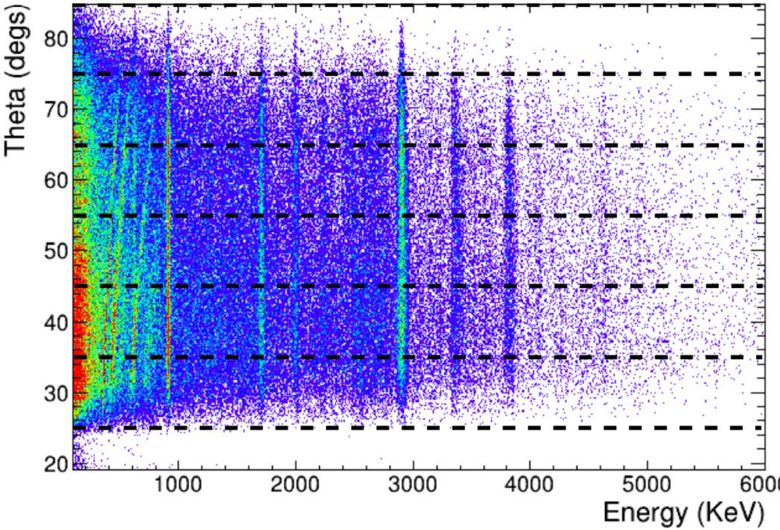
- Limited angular coverage of GRETINA (1.2π) impacts γ - γ efficiency
  - Only applicable to the most intense transitions

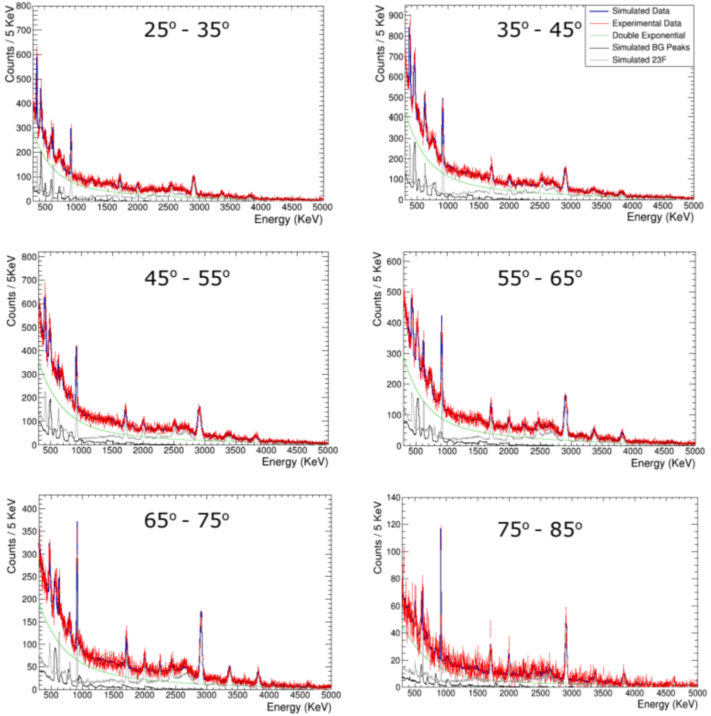




γ-ray Angular Distributions

- Slicing angular detection range and fitting spectra
  - Extraction of the experimental γ-ray angular distributions, in lab frame

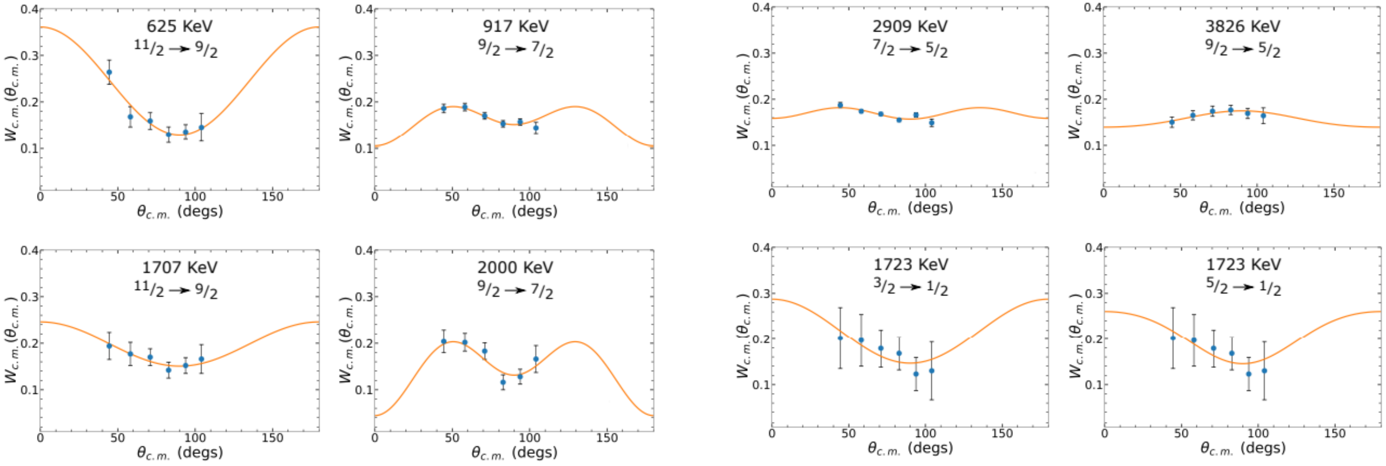




γ-ray Angular Distributions

- Calculated γ-ray angular distributions were fitted to the data
  - Converted to the C.M. frame
  - A range of distributions for M1 and E2 transition between spins of 1/2 and 11/2

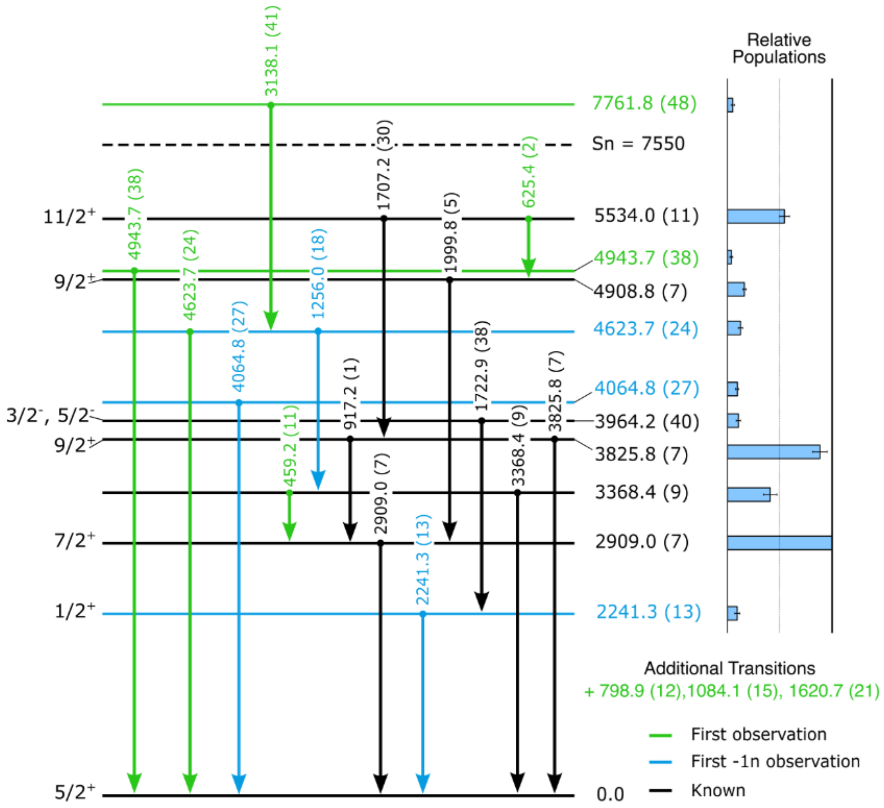
- Enabled spin assignments to the states
  - Only for the most intense transitions



Thank you to Jeff Tostevin for the Angular Distribution calculations

Results

- ➢ First observation of several transitions predicted by theory
  - New BR data



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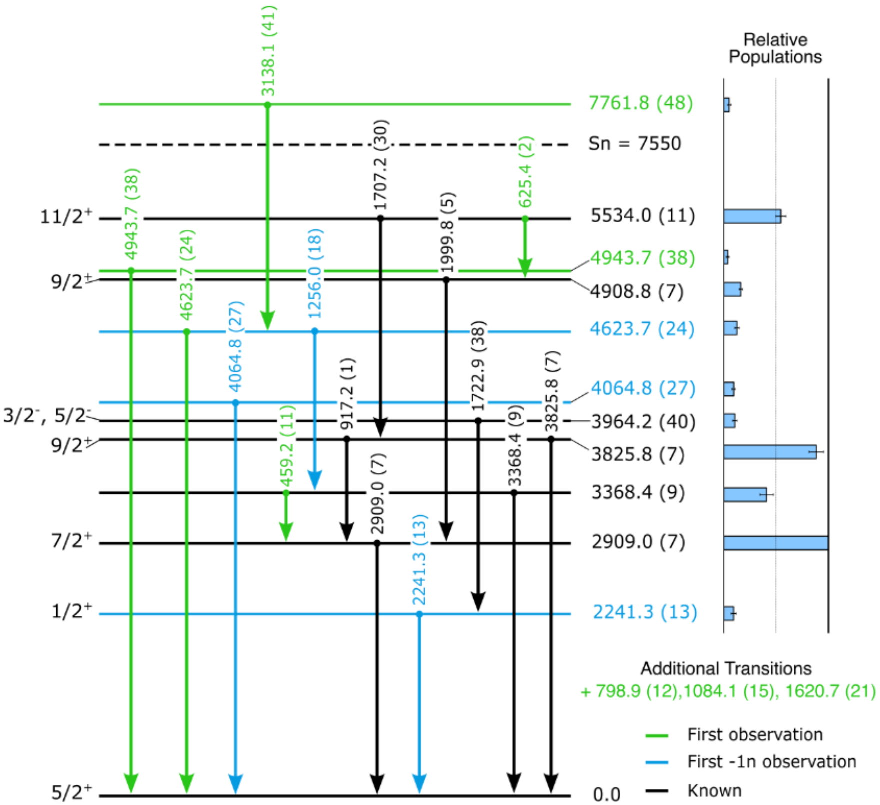
➢ γ-ray angular distribution confirms spin assignments from;
  - Shell model (USD-type)
  - Previous assignments from fragment ang. dist.



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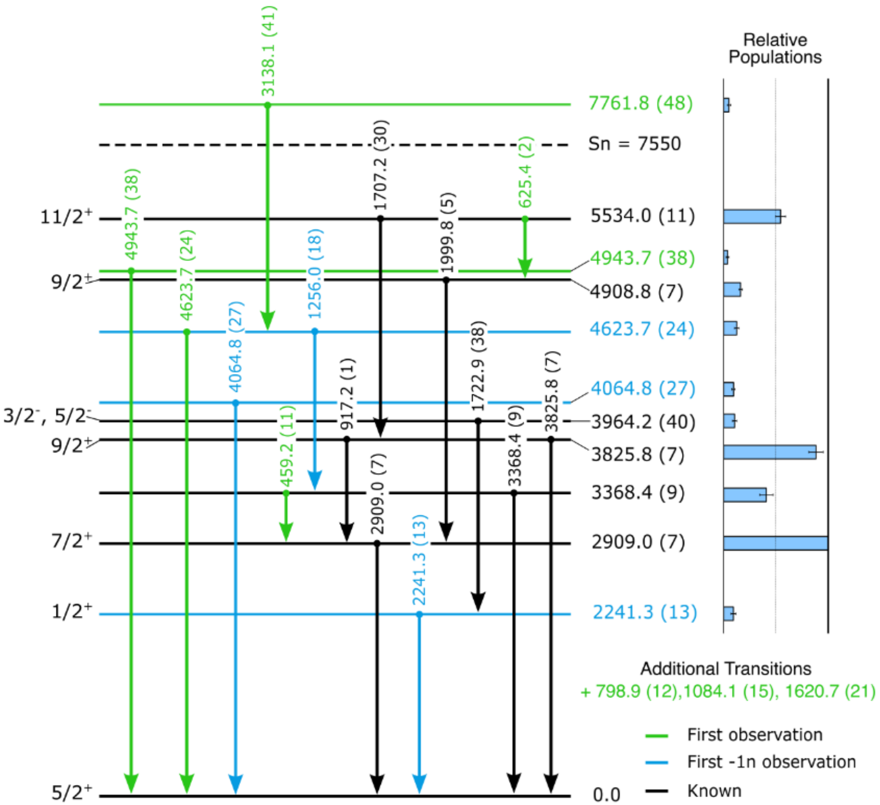
- ➢ Apparent direct population to s.p proton states
  - 2241 keV ($\pi 2s_{1/2}$) and 4065 KeV ($\pi 1d_{5/2}$)
  - Observed feeding can't account for measured intensities
  - Mixed nature or unobserved feeding?

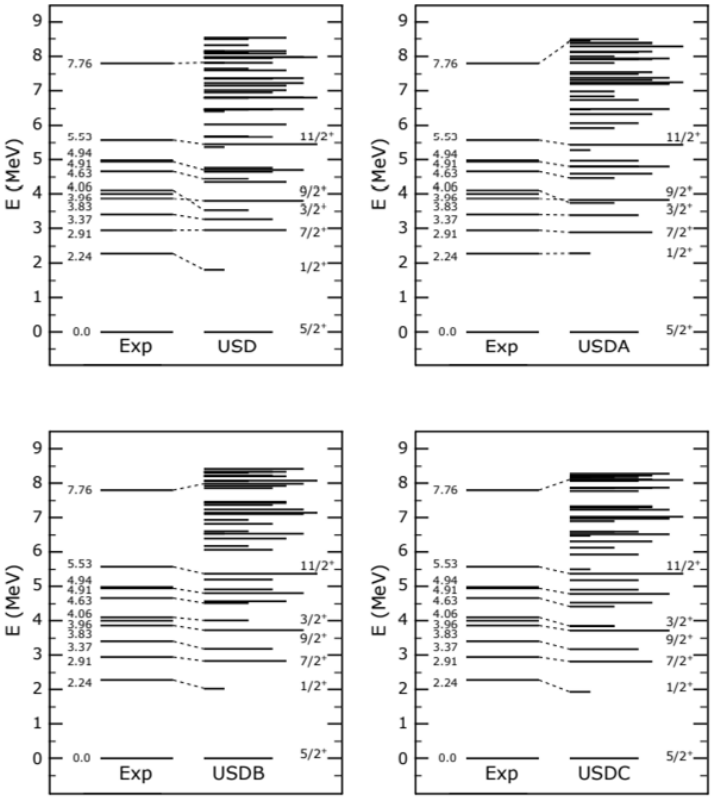


Shell-Model Calculations

- ➢ Compared data to phenomenological USD-type calculations

- ➢ Associated experimental levels via energies, spins, BRs

- ➢ USDA and USDB calculations are in best agreement with data
  - Not particularly surprising since they are fit with neutron-rich data



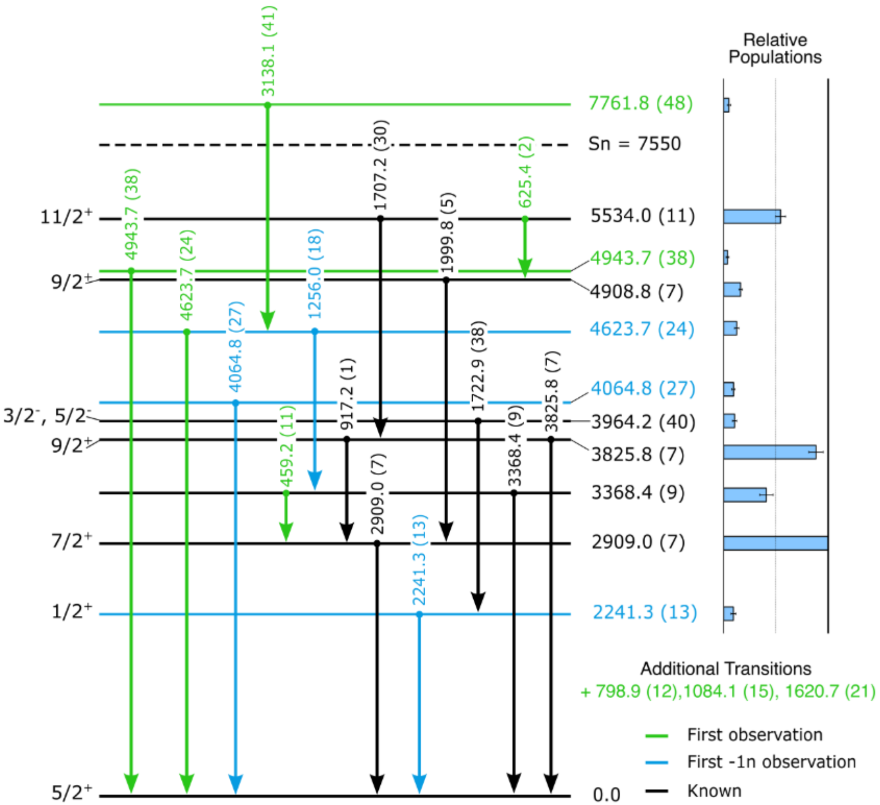
Thank you to Alex Brown for the Shell Model

Summary

- In-beam γ-ray spectroscopy measurement on ^{23}F following 1n removal reactions

- First observation of several transitions and excited states predicted by theory

- Observed an apparent direct population to what was previous assigned S.P. proton states



Collaboration

DFG Deutsche Forschungsgemeinschaft

THE ROYAL SOCIETY

SFB 1245

U.S. DEPARTMENT OF ENERGY | Office of Science

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