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Inverse-Kinematics Proton Scattering on 44S

Max A. Liggett
Ursinus College, maxliggett1@gmail.com

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Inverse-Kinematic Proton Scattering on ^{44}S

Max Liggett

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Abstract

Using data from a 2016 experiment that took place at the National Superconducting Cyclotron Laboratory(NSCL) in Michigan State University we study the excited states of ^{44}S using the NSCL/Ursinus College liquid hydrogen target and the Gretina gamma-ray tracking array. I will discuss the results in the context of similar experiments on neutron-rich sulfur isotopes.

Introduction

A number of experiments have been performed focusing on the shell structure and excited states of ^{44}S. Reliable information on the first excited state exists collected via experiments done by T. Glasmacher et al. [1] and S. Grevy et al. [2] while other experiments have proposed a number of other existing gamma-rays and corresponding energy levels [3]. The data from these experiments will help in further study of ^{44}S and the identification of gamma-rays in observed gamma-ray spectrum. A large unsolved mystery and center of focus surrounding exotic nuclei at N=28 is the loss of magicity in ^{42}Si, and the the purpose of this experiment is to gain insight into this inconsistency in the pattern of magic numbers and nuclear shell structure by learning more about exotic nuclei near ^{42}S.

Experiment

The experiment was performed at the National Superconducting Cyclotron laboratory(NSCL). The fragmentation reaction of a 140 Mev ^{48}Ca beam on a 1222 mg/cm^2 ^{9}Be target produced a secondary beam consisting of 8.4% ^{43}P, 45.1% ^{44}S, and 45.2% ^{46}Cl. The fragments then traveled through the A1900[4] fragment separator where the secondary beam passed through two scintillators that identified the nuclei by time of flight. After initial identification,Shown in Figure 1, the nuclei collided with the Ursinus College liquid hydrogen target [5] where gamma rays from the resulting excited states were detected by the GRETINA gamma-ray tracking array [6] which surrounded the target. After leaving the

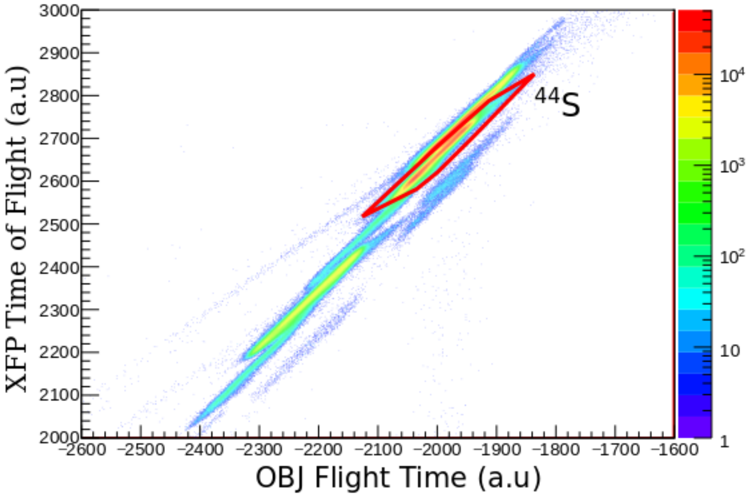

Figure 1: Incoming particle identification spectrum with the time of flight from the S800 object scintillator (OBJ) on the horizontal axis and that from the A1900 extended focal plane scintillator (XFP) on the vertical axis. The Scintillator in the S800 focal plane was used to stop both timing measurements. The red outline shows ^{44}S.

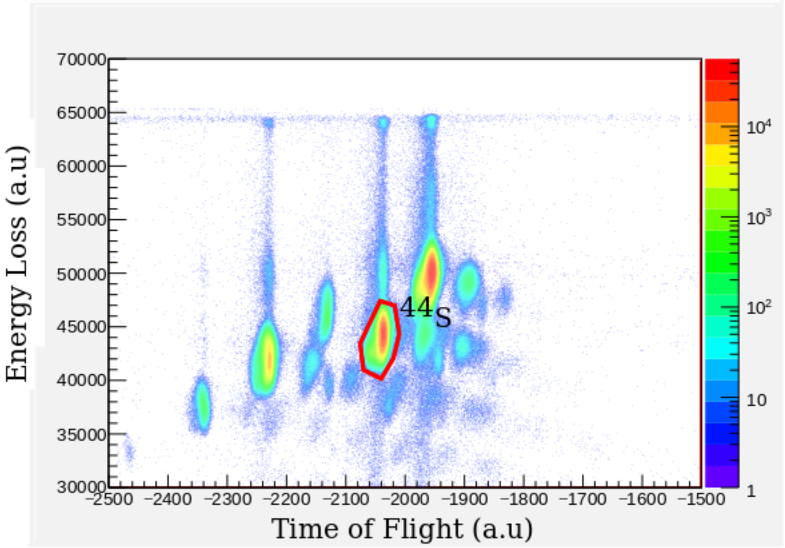

Figure 2: Outgoing particle identification spectrum using energy loss from the ion chamber on the vertical axis and time of flight from the S800 Object scintillator and S800 focal plane scintillator on the horizontal axis. The red outline shows 44S.

target, the scattered particles entered the S800 magnetic spectograph [7] and a final set of scintillators, one at the S800 object position and another on the S800 focal plane, were used to identify the outgoing nuclei based on time of flight and the energy loss data from the ion chamber depicted in Figure 2.

Analysis and Results

The simulation code UCGretina built with the GEANT4 toolkit [8] is used to simulate the emission and detection of gamma-rays as the particle beam passes through the target. Simulations were fitted to the measured outgoing kinetic energy spectrum in order to determine the target thickness. Doppler corrections could be made, gaining reliable simulations of emitted gamma-rays from particles that decrease in speed as they pass through the target. The liquid hydrogen target is contained in a 30 mm long cylindrical aluminum cell with 125 μ kapton entrance and exit windows. There is an additional window bulge caused by the pressure difference between the aluminum cell and vacuum of the beam chamber. Simulations of various thicknesses were fitted to the kinetic energy spectrum of the outgoing beam particles in order to optimize the window bulge thickness as seen in Figure 3.

The gamma-ray spectrum in Figure 5 is the Doppler-corrected spectrum with the optimized bulge thickness. After identifying energies in the gamma-ray

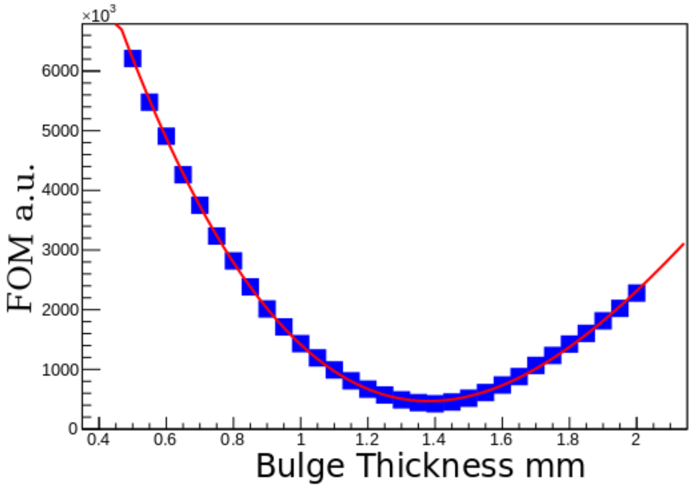

Figure 3: Simulated values for target bulge thickness caused by pressure difference between beam chamber and windows of liquid hydrogen. Minimum shows the optimized value for the bulge thickness. Vertical axis is an arbitrary unit representing margin of error, while the horizontal axis is the window bulge.

spectrum seen in Figure 5, known energies 950, 1128, 1889, and 1929 correspond to gamma-rays observed by D.Santiago-Gonazale et al.[3]. The strongest and least ambiguous of energies of gamma-rays in ^{44}S , the first excited state at 1329 keV, was taken from an experiment performed at the GANIL institute in France by S.Grevy et al [9]. Grevy's experiment very reliably pinpointed the first excited state with made it possible to use the 1329 keV gamma-ray to determine the target position along the beam axis [10]. Adjustments were made to the optimization simulations for the 1154 keV gamma-ray to accommodate a 110ps half-life established by Parker et al. [11]. After Considering the gated spectrum for the 1329 keV energy shown in Figure 4, known energies 288, 988, and 2632 seen in a separate experiment performed at GANIL by C.J Moore and M.J Taylor[12] were dismissed as not being observed in the gamma-ray spectrum. The gated spectrum did support the 2691 keV gamma ray as feeding the first excited state. In Addition, we observed a new gamma ray at 3081 keV that can be seen in Figure 1. The last step of the analysis was finding the cross-sections for exciting the ^{44}S nucleus to the first excited state. We used the cross-section of 16(3) and calculated the amplitude of the quadrupole deformation, δ_2.

Discussion

After finding the deformation length for N = 28 we plot it with deformation lengths from previous work [13]. The plot in Figure 7 shows there is still evidence

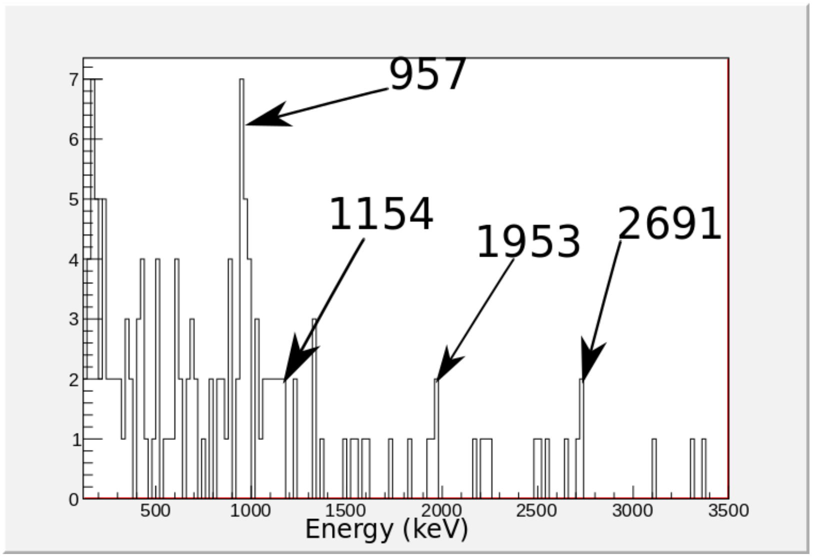

Figure 4: Gated spectrum for gamma-ray energy 1329. Shows emitted gamma-rays that are detected in coincidence with the 1329 keV gamma-ray energy.

E_{level} (keV)	J^π	E_γ (keV)
1329(2)	2_1^+	1329(2)
2286(5)	2_3^+	957(4)
2481(20)	4_1^+	1154(19)
3282(21)	2_3^+	1899(7)
3282(28)	2_4^+	1953(18)
4020(30)	—	2691(10)
4410(31)	—	3081(9)

Table 1: This table shows the energy levels in the γ-ray spectrum, the gamma-ray energies that were optimized, the error, and their spin and parity.

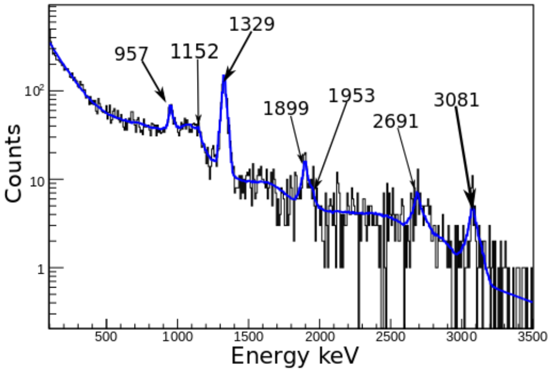

Figure 5: Gamma-ray spectrum with energy measured in keV on the horizontal axis and the number of times they were detected by the GRETINA gamma-ray tracking array on the vertical axis

of the closed spherical shell based on the smaller amplitude. Based on proton-scattering deformation lengths for sulfur nuclei near ^{42}Si[13] and those from this experiment, we can see that the amplitude for the quadrupole deformation of exotic sulfur isotopes in Figure 7 do not show the same inconsistencies of ^{42}Si. ^{44}S behaves according to the observed pattern attributed to nuclei with magic numbers of neutrons. Evidence of the complete spherical shell is still present in ^{44}S just as it is in ^{36}S. This supports the idea that there is no loss of magicity in ^{44}S.

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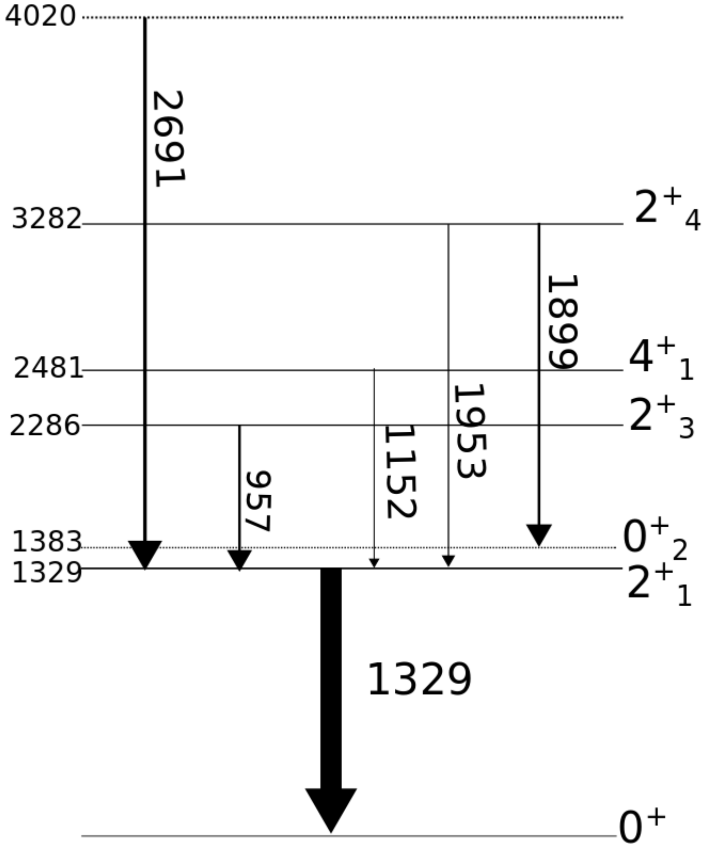

Figure 6: Proposed partial level scheme for ^{44}S including levels populated in the present work.

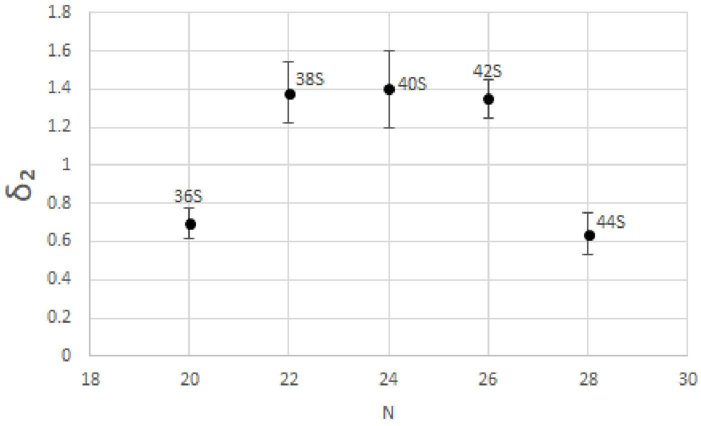

Figure 7: Graph showing the amplitude of quadrupole deformation of the 2_1^+ excitations in the sulfur isotopes from the work performed by Marechal et al. [14] and present work.

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