New Instruments And Devices At The Wright Nuclear Structure Laboratory

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Abstract. Some of the new instruments and devices recently commissioned at the Wright Nuclear Structure Laboratory (WNSL) are described and the physics programs carried out using them are outlined.

INTRODUCTION

The Wright Nuclear Structure Laboratory (WNSL) located on the campus of Yale University carries out active in-house research programs in Nuclear Astrophysics and Nuclear Structure Physics, together with off-site programs using radioactive beams at TRIUMF, ANL and ORNL. In addition, our Relativistic Heavy Ion Group carries out a program at Brookhaven National Laboratory to search for and investigate the properties of the quark-gluon plasma.

The in-house programs utilize the wide variety of heavy-ion beams provided by the ESTU tandem Van Der Graaff generator. More details about the accelerator and the physics programs can be found at our web-site, www.wnsl.physics.yale.edu. In this presentation I will briefly describe the status of some of the new instrumentation at the laboratory which enables these physics programs.

THE NUCLEAR ASTROPHYSICS AND NUCLEAR STRUCTURE PROGRAMS

The Nuclear Astrophysics program, staffed by Peter Parker, Jac Caggiano and their students, is chiefly concerned with investigating the properties of states important as resonances in explosive hydrogen burning sites, such as novae, supernovae and x-ray bursters. Their investigations utilize the Enge split-pole spectrometer which is equipped with a gas filled ionization counter at its focal plane to measure the position, energy and energy loss of incident charged particles.

A multiple element silicon detector array, the Yale Lamp Shade Array, or YLSA, has recently been commissioned by this group. The array is placed at backward angles at the target position of the split-pole. YLSA consists of 5 segmented Si detectors, each with 16 strips. Each strip is 3 mm wide while the active depth of the detector is 500 µm. YLSA has a total geometric efficiency of 15% of 4π. Measurement of backward going light charge particles (e.g. protons and alphas) in YLSA in coincidence with the forward going transfer product in the split pole allow an unambiguous measurement of the reaction product and the partial decay widths of their resonances. These determine the energy generation rates and nucleosynthesis scenarios in exploding stellar environments.

The Nuclear Structure Program is carried out by Rick Casten, Victor Zamfir, Jo Ressler, Hanan Amro and myself, together with our students. The research program focuses on a number of broad themes, namely structural evolution, collective modes, proton-neutron correlations and exotic nuclei.
A suite of new instruments has been implemented over the past few years to enable this research. These instruments include

YRAST Ball: The Yale Rochester Array for SpecTrosopy. YRAST Ball, with a total photopeak efficiency, $\varepsilon_{\text{ph}} \sim 3.5\%$, is the largest university based Ge detector array in the U.S. [1]. In standalone mode YRAST Ball currently consists of 9 segmented clover Ge detectors (each $\sim 150\%$ relative efficiency) and 19 smaller $25\%$ coaxial Ge detectors.

NYPD: The New Yale Plunger Device. The NYPD is a state of the art recoil distance plunger device [2]. When utilized with YRAST Ball the NYPD is capable of measuring lifetimes from ns down to several ps.

ICEY Ball: The Internal Conversion Electron array at Yale. ICE Ball, which consists of six mini-orange electron spectrometers, is a Gammasphere auxiliary detector, designed and built by Juerg Saladin at the University of Pittsburgh [3]. Following Juerg’s retirement WNSL has become the host institution for ICE Ball. The combination of the high efficiency YRAST Ball and ICE Ball arrays is a powerful tool for gamma and internal conversion measurements.

MTC: The Moving Tape Collector. Two Moving Tale Collector systems are available at WNSL. Each uses aluminized Mylar tape to transport nuclei of interest to remote counting stations. One of these MTC systems is instrumented with up to four clover Ge detectors arranged in a very compact geometry together with a plastic scintillator to measure $\beta$ particles and a fast BaF detector to implement the FEST (Fast Electronic Scintillator Timing) method. The second MTC system transports the activity to a 6 T superconducting solenoid magnet for perturbed angular correlation measurements.

SASSYER: The Small Angle Separator System at Yale for Evaporation Residues. SASSYER is our newest instrument. SASSYER is a high transmission efficiency gas-filled recoil separator and will be described in more detail below.

THE SASSYER RECOIL SEPARATOR

Over the last several years the coupling of powerful germanium detector arrays to recoil separators had lead to tremendous advances in nuclear structure physics, enabling exquisitely sensitive experiments to be carried out at, and perhaps beyond, the limits of nuclear stability. Examples of such coupled devices include the RITU/Jurosphere array at the University of Jyvaskyla, Finland [4] and the Argonne FMA/Gammasphere combination in the U.S. [5].

SASSYER consists of three magnets, a vertically focusing gradient field dipole, followed by a horizontally focusing quadrupole lens and finally a second gradient field vertically focusing dipole. The overall length of the separator is 2.4 m while the acceptance is approximately 5 msr. The maximum $B\rho$ is 2.2 Tm. The entire magnet volume and the target chamber can be filled with $\sim 1$ Torr of He gas which is isolated from the beam line vacuum by means of a 50 $\mu$g/cm$^2$ carbon window. The use of gas offers several advantages over vacuum devices. The primary advantage is a large increase in the transmission efficiency since, due to charge exchange interactions, the recoils acquire an average charge state that can be focused onto a sensibly sized focal plane detector. The transmission efficiency of SASSYER was measured to be $\sim 16\%$ in our commissioning experiments, although clearly this changes from experiment to experiment. A second advantage is the convective cooling of the target by the gas which allows the use of much larger...
beam currents with a consequent increase in reaction rate.

SASSYER has a long and distinguished history. Designed and built by Al Ghiorso at Lawrence Berkeley National Laboratory, SASSY I and SASSY II were used in the synthesis of element 110 at the HILAC in Berkeley [6]. We gratefully acknowledge the generosity and help of our many friends and colleagues at Berkeley who made the separator available to us and whose advice and expertise was invaluable in understanding and commissioning the device.

The YRAST Ball multi-germanium detector array [3] can be mounted at the target position of SASSYER. In this location, YRAST Ball is currently configured with 5 clover detectors at 90° and four at 41° with respect to the beam axis, giving a total photopeak efficiency of ε_ph ~ 2.7%. A maximum of 13 clover Ge detectors can be accommodated.

The SASSYER focal plane instrumentation currently consists of a 30-element solar cell array to detect fusion evaporation recoils and their subsequent alpha decay. These are arranged in a 3 cell high by 10 cell wide configuration. Each solar cell has an active area of 1 cm². In addition, a DSSD detector and parallel plate avalanche counter are also available.

To search for isomeric gamma decays six or more ~25% coaxial Ge detectors from the YRSA ST Ball array are also arranged in a close geometry around the focal plane chamber.

Early physics experiments using the SASSYER/YRAST Ball combination have focused on the structure of light Rn and Ra nuclei in particular on the structure of ²⁰²,²⁰³Rn and ²⁰⁹,²¹⁰,²¹¹Ra. These nuclei are interesting for a variety of structure reasons, including predictions of coexisting prolate and oblate shapes, similar to those found in Pt/Hg nuclei below the Z = 82 shell closure. Indeed, for the ground state a change from a slightly oblate deformed shape to a well-deformed prolate shape has long been predicted for neutron number around 110. In addition, more exotic phenomena, including shears bands and superdeformation may also be found in this region.

Little experimental information is available for these nuclei, particularly for the odd Rn and Ra isotopes, primarily due to the low fusion cross section and very large fission background encountered in such heavy systems. Such systems provide an ideal testing ground for SASSYER as the fusion cross section, while low is still on the order of several hundred microbarns. In addition, the Rn nuclei have previously been studied at Yale using YRAST Ball as a standalone device and these previous results can be directly compared to the SASSYER/YRAST Ball data.

That the comparison is indeed dramatic is illustrated in figure 1 the top portion of which shows a total projection of a gamma-gamma matrix previously measured with YRAST Ball following the ³²S + ¹⁷⁶Yb → ²⁰³Rn + 5n reaction. The spectrum is dominated by a very large, essentially smooth background originating from fission fragment gamma-rays and by several very intense Coulomb excitation gamma-rays. The largest fusion evaporation peak, the 498 keV (17/2⁺) → (13/2⁺) transition in ²⁰³Rn is just barely visible to the left of the 511 keV annihilation peak. On the other hand, the lower portion of figure 1 shows a similar projection of a gamma-gamma matrix, now selected by Rn recoils detected at the focal plane of SASSYER. The difference is dramatic, the spectrum now being dominated by transitions from fusion-evaporation residues (mostly ²⁰²,²⁰³Rn) while the 498 keV peak is now the largest in the spectrum. A total of ~6 x 10⁶ recoil gated gamma-gamma coincidence events were recorded in around one week of beam time. Preliminary analysis of these data confirm most of our previous results [7] while adding several new transitions to both ²⁰²Rn and ²⁰³Rn.

The isomer decay tagging method, whereby a delayed gamma-ray, correlated with an implantation event in the solar cell array is used to tag prompt gamma-rays detected using YRAST Ball, has been utilized in a very recent experiment to investigate the structure of the Z = 88 Ra nuclei ²⁰⁹,²¹⁰,²¹¹Ra. Prior to this experiment no information at all was available for excited states in these odd mass Ra nuclei, while the level structure, without transition energies, of ²¹⁰Ra...
has been reported up to the $8^+$ state [8]. Furthermore, the $8^+$ state is isomeric with a lifetime of 2.2 $\mu$s. Figure 2 shows the gamma-ray spectrum recorded at the focal plane of SASSYER within 1 $\mu$s of a recoil implantation (the flight time was $\sim 400$ ns).

Figure 3. The total recoil gated gamma-ray projection showing transitions in $^{209,210,211}$Ra (top). The lower spectrum, tagged both by recoils and a valid isomer event, is dominated by transitions that feed the $8^+$ isomeric state in $^{210}$Ra.

As can be seen, the spectrum is dominated by $^{210}$Ra transitions that lie below the $8^+$ isomeric state. The resulting isomer tagged spectrum of prompt gammarays (which clearly feed the isomeric state) is shown in the lower part of figure 3 where it can be compared to the total recoil gated gamma-ray spectrum (top). While analysis is still underway it is clear that a wealth of new information will be available on both higher lying states in $^{210}$Ra and for the first time, on the odd $^{209,211}$Ra nuclei.

Looking to the future we anticipate placing the New Yale Plunger Device (NYPD) our state of the art recoil plunger device at the target position of SASSYER. By use of a retardation foil instead of a stopper foil, recoils can still be focused through SASSYER. Hence, with the extremely clean channel selection provided by SASSYER this should allow the measurement via the recoil distance method of lifetimes in extremely weak reaction channels or in regions dominated by fission events.

**CONCLUSION**

Some of the new instruments and devices available at the Wright Nuclear Structure Laboratory have been described and the physics program enabled by these devices outlined. Many people are responsible for the data and work presented in this paper. In particular I wish to acknowledge the efforts of Jo Ressler and Reiner Kruecken and the technical staff at WNSL for their efforts in the successful commissioning of SASSYER. This work is supported by the U.S. D.O.E. under grant number DE-FG02-91ER-40609.

**REFERENCES**