HIGS2: The Next Generation Compton γ-ray Source

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31 August 2012

This document provides a prospectus of research opportunities created by an intensity upgrade to the High Intensity Gamma-ray Source (HIGS) at the Triangle Universities Nuclear Laboratory (TUNL). The current maximum gamma-ray intensity on target at the HIGS is more than 10^8 γ/s in the energy range between 9 and 12 MeV. An increase of total intensity of about two orders of magnitude will be achieved using a high average-power Fabry-Perot resonator driven by an external laser. This next generation Compton γ-ray source, the HIGS2, with fast helicity reversal capability and low beam-energy spread, will open opportunities for experiments in hadronic parity violation, nuclear astrophysics and nuclear structure, and will make possible long-baseline searches for dark-matter particles. The upgrade is based on well established technologies, and will interrupt operation of the HIGS for less than one year for implementation. This document outlines the research opportunities and describes the HIGS2 facility.

1.1 Introduction

The High Intensity Gamma-ray Source (HIGS) at TUNL is the most intense accelerator-driven γ-ray source in the world in terms of average spectral intensity in units of gammas/s/keV. The layout of the HIGS facility is shown in Figure 1.1. The γ-ray beam is produced by Compton backscattering of the photons inside the optical cavity of a storage-ring based Free-Electron Laser (FEL) from circulating electron bunches. The HIGS can delivery a beam on target in the energy of 1 to 100 MeV with beam energy spread selected with collimation as low as about 1% FWHM. The beam intensity on target with 5% energy spread at energies less than 10 MeV is as high as 10^9 gammas/s. The high intensity of this source relative to other Compton-scattering γ-ray sources is due mostly to the combination of high intracavity optical power relative to external laser light sources and high average beam current in the storage ring (about 100 mA).

As shown in Figure 1.1, the electron accelerator drivers consist of a 180-MeV linac pre-injector, a booster injector operating in the energy range of 180 MeV to 1.2 GeV and a race-track shaped storage ring that has an energy range of 250 MeV to 1.2 GeV. The circumference of the storage ring is about 108 m, and the length of the two-mirror FEL optical cavity is about 54 m. The facility is capable of providing either linearly or circularly polarized gamma ray beams by using either the Optical Klystron # 4 (OK-4, with planar undulators) or the OK-5 (with helical undulators) FEL.

About 135 scientists from 35 institutions conduct nuclear physics research at the HIGS in areas of nuclear structure, nuclear astrophysics, and low-energy QCD. Over the last four years 18 Ph.D. degree recipients conducted their thesis research at the HIGS. In addition to basic nuclear physics research, several groups conduct research in applied nuclear physics with an emphasis on homeland security and national nuclear security. The facility operates for about 1800 hours of beam on target each year, of which about 75% is for the basic nuclear physics program.

The beams at the HIGS enable experiments that study a broad range of phenomena, including collective properties of nuclei, reactions relevant to astrophysics, and the structure of nucleons. The hierarchal structure of nuclear matter in terms of the main effective degrees of freedom is shown schematically in Figure 1.2. The regions bracketed by the arrows indicate the types of experiments at the HIGS that probe particular degrees of freedom. Nuclear resonance fluorescence (NRF) is used to study collective modes of excitation at energies below the Giant Dipole Resonance (GDR) and

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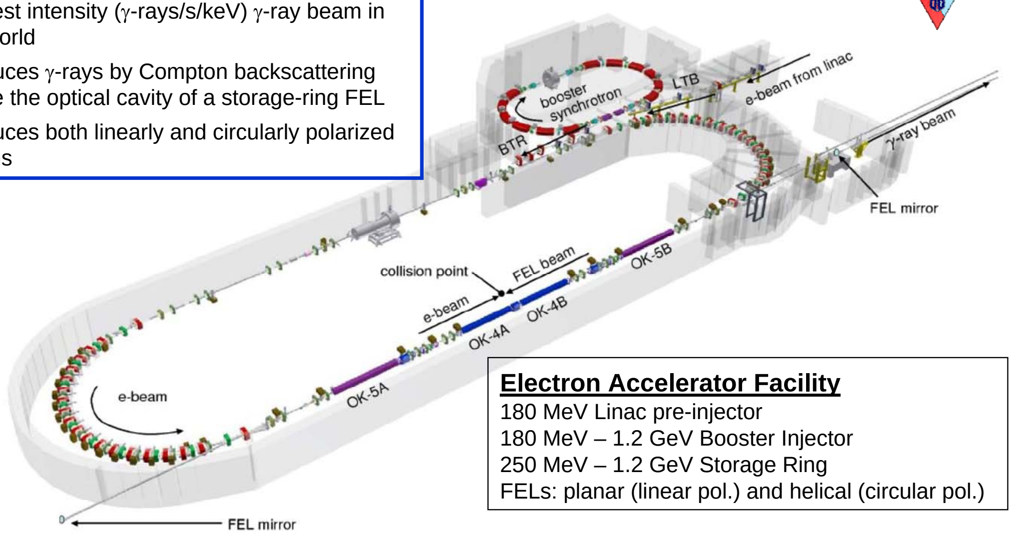
High Intensity Gamma-ray Source (HIGS) at TUNL

- Highest intensity (γ-rays/s/keV) γ-ray beam in the world
- Produces γ-rays by Compton backscattering inside the optical cavity of a storage-ring FEL
- Produces both linearly and circularly polarized beams



Electron Accelerator Facility
180 MeV Linac pre-injector
180 MeV – 1.2 GeV Booster Injector
250 MeV – 1.2 GeV Storage Ring
FELs: planar (linear pol.) and helical (circular pol.)

γ-ray beam parameters	Values
Energy	1 – 100 MeV
Linear & circular polarization	> 95%
Intensity with 5% $\Delta E_\gamma/E_\gamma$	> 10^7 γ/s

For more details see:
http://www.tunl.duke.edu/higs/

Figure 1.1: Schematic diagram of the HIGS.

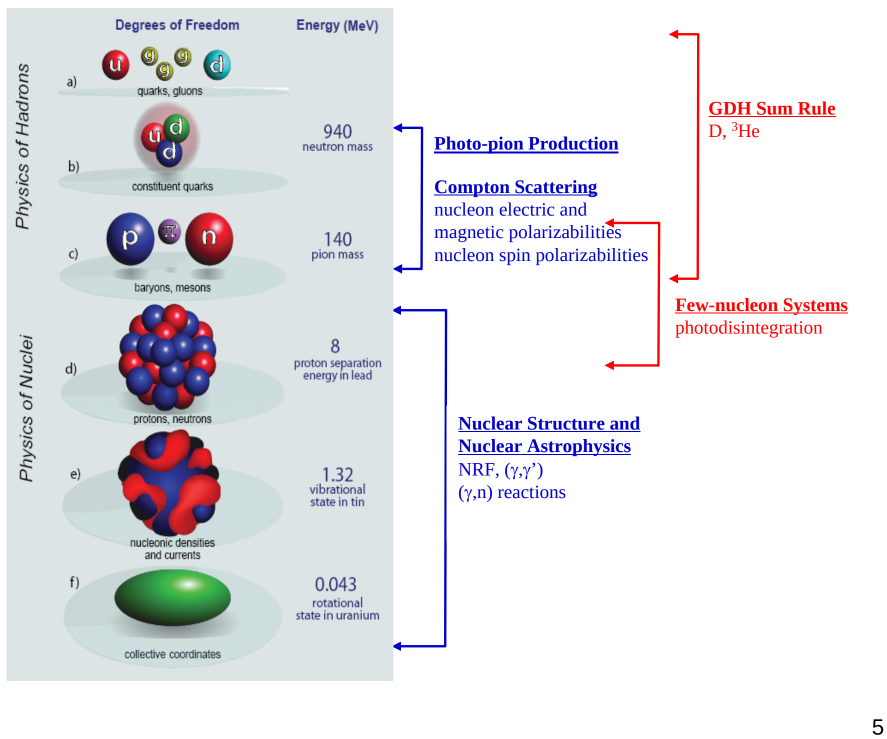


Figure 1.2: Schematic diagram of the effective degrees of freedom of nuclear matter at different excitation energy scales. This figure was taken from the 2007 Long-Range Plan for Nuclear Science in the USA by the DOE/NSF Nuclear Science Advisory Committee. The regions bracketed by the arrows indicate the degrees of freedom probed by different types of measurements made at the HIGS.

polarized Compton scattering measurements map out coherent nuclear responses above the GDR, e.g., the isovector giant quadrupole resonance. Compton scattering from unpolarized and polarized targets at energies above 60 MeV reveal information about the collective electromagnetic response of the internal degrees of freedom of nucleons.

Over the next five years the main goals of the nuclear physics program at the HIGS include:

- Measuring the astrophysical S-factor for the ^{12}C(α,γ)^{16}O reaction at low enough energy and with sufficient accuracy to determine the reaction mechanism
- Determining the electric and magnetic polarizabilities of the nucleons
- Measuring the spin polarizabilities of the nucleons
- Studying collective nuclear excitations using NRF and Compton scattering

Beyond the next five years a research emphasis at the HIGS will be symmetry breaking in systems of strongly interacting particles. This plan includes studying hadronic parity violation in few-nucleon systems at energies below 15 MeV where effective field theory calculations can be made and measurement of the πN scattering length near the photopion production threshold (around 150 MeV) as a means for probing the mechanism for chiral symmetry breaking in QCD. Both programs require the development of enhanced γ-ray beam capabilities at the HIGS. An upgrade that increases the beam intensity by about two orders of magnitude is needed to pursue parity-violation measurements at low energies, and an extension of the maximum energy reach above 150 MeV will enable photopion production experiments. The accelerator group at the HIGS is working with a research partner in Germany (Laser Zentrum Hannover e.V.) to develop durable mirrors for the FEL optical cavity that will enable production of γ-rays with energies above the photopion production threshold. However, the focus of this prospectus is on the path that involves high precision measurements at low energies using the high intensity polarized γ-ray beam provided by the HIGS2. The HIGS2 would use advanced laser and accelerator technologies established in recent years to obtain the required performance while keeping the technical risks low.

A community interested in the research that can be done at the HIGS2 is forming. In the coming year working groups will explore the research opportunities at the HIGS2. A workshop is planned for 2013 where members of the various working groups will gather to develop a collective vision for the HIGS2 and to identify the most compelling questions that can be pursued at this advanced γ-ray beam facility. An outcome of these interactions will be a whitepaper that describes the research opportunities and provides technical details about the HIGS2. This document describes the essential technical aspects of the HIGS2 and gives an overview of the research in hadronic parity violation, nuclear astrophysics and nuclear structure made possible by the HIGS2.

1.2 Technical Overview of the HIGS2

The HIGS2 is designed to meet the beam requirements to carry out hadronic parity violation measurements on few-nucleon systems. In meeting these requirements, the capabilities of the HIGS2 will open research opportunities in nuclear astrophysics, nuclear structure, and long-base line searches for dark-matter particles.

The HIGS2, an ultra-high intensity, highly polarized Compton gamma-source in the energy range of 2 to 12 MeV, will be developed as a complementary source to the existing HIGS (1 to 100 MeV) at a cost for accelerator and laser development estimated to be about \$5M. To allow the use of the same gamma-ray beamline and experimental nuclear physics facility downstream from the collision point, the HIGS2 will be hosted in the same long straight section of the storage ring where the FEL wiggler magnets are located (see the schematic layout of the HIGS2 in Figure 1.3). When operating the HIGS2, the FEL wigglers will be moved out to the side; this physical arrangement was made possible as the result of installing a wiggler switchyard system in Spring 2012.

The HIGS2 gamma-ray beam is produced by colliding a high current electron beam with a high power photon beam. The electron beam is provided by the storage ring which will be operated with 32 electron bunches with a beam rate of 89.3 MHz and with a total current between 300 and 500

Parameters	Value Range
Gamma-ray beam energy	2–12 MeV
Gamma-ray beam pulse rate	89.3 MHz
Polarization (switchable)	Linear and Circular (90 to 99%) (Degree of polarization depends on collimation, photon beam polarization, electron beam energy, etc.
Total gamma-ray intensity	10^{11}– $10^{12}\gamma$/s Collimated intensity = 0.015×(total flux)× (FWHM energy resolution in %)
Best energy resolution	FWHM < 0.5% (Tight collimation and at a low flux)
Gamma-ray beam angular spread (full opening)	Typical $D/L = 0.19 - 0.60$ mrad $D_{\text{min}} = 10$ mm, $D_{\text{max}} = 32$ mm, $L = 53$ m
Full beam "without" collimation	$D \sim 32$ mm (effective collimation) FWHM energy spread: 7% (2 MeV) to 30% (12 MeV)

Table 1.1: The projected performance parameters for the HIGS2 with a high power Fabry-Perot optical resonator driven by a 2 micron external laser.

mA. The photon beam will be a high power CW laser beam (10 to 20 kW average power) built-up inside a high-finesse Fabry-Perot resonator driven by an external infrared laser. Compared with the FEL driven HIGS, a higher average intracavity laser power and significantly reduced beam sizes at the collision point make it possible for the HIGS2 to achieve a total gamma-flux of $10^{11} - 10^{12}$ γ/s in the energy range of 2 – 12 MeV, an intensity increase of two to three orders of magnitude compared with the HIGS in the same energy range. In addition to the substantial intensity increase, the HIGS2 facility will produce gamma-ray beams with a better monochromaticity, choices of linear polarization in any direction and left- or right-circular polarization, and the ability to rapidly switch the gamma-ray helicity at a rate of tens of Hz or higher. The fast helicity switch of the gamma-ray beam will be realized by changing the polarization of the laser beam outside the Fabry-Perot resonator using polarizing optics such as Pockels cells and wave-plates. The projected gamma-ray beam parameters of the HIGS2 are listed in Table 1.1.

1.3 Hadronic Parity Violation

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Introduction

In this section we discuss the possibility of performing photonuclear reactions at the HIGS2 that can observe parity violation (PV) induced from the weak interaction between nucleons. The physics considered here addresses Performance Measure F18, "Perform independent measurements of parity violation in few-body systems to constrain the non-leptonic weak interaction" from the 2007 NSAC Performance Measures document.

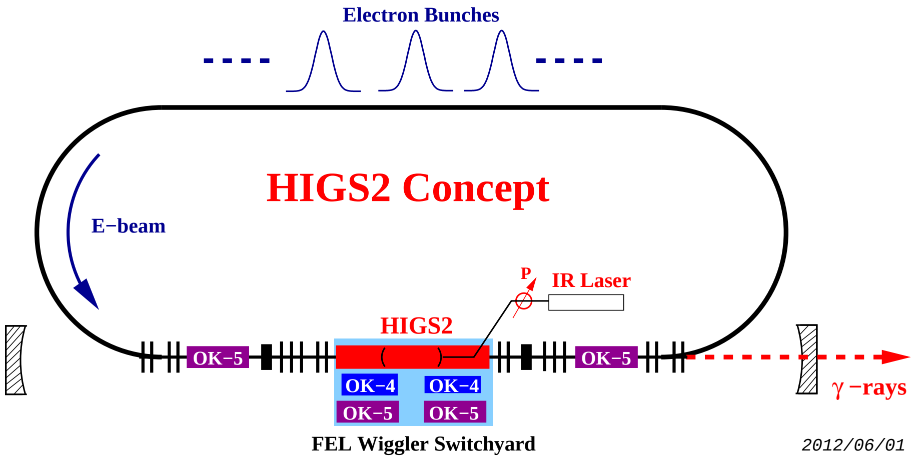

Figure 1.3: The schematic layout of the HIGS2 Compton gamma-ray source. The HIGS2 is located in one of the two long straight sections of the Duke storage ring. Guided by a set of deflection magnets, the electron beam enters and exits the high power Fabry-Perot resonator to collide with the photon beam in the center of the resonator. The polarization of the gamma-ray beam is switchable by changing the polarization of the laser beam from an external infrared drive laser using polarizing optics.

At the present time, it is unclear whether currently available measurements involving low energy nucleons are consistent with the Standard Model, or indeed with each other. The reason for this is that most such measurements involve heavy nuclei whose strong interactions, binding mechanism, etc., are not understood in terms of QCD. While it is likely that the PV observables in heavy nuclei are the result of weak interactions among only two or three constituent nucleons, that physics is not presently extractable from the complicated strong interaction physics involved.

To unambiguously extract the weak interactions among nucleons requires PV measurements in very light nuclei: the deuteron, tritium, He-3, and now perhaps even up to four nucleons, because the strong interactions in these very light systems are understood in terms of effective field theories (EFTs) that systematically incorporate the symmetries of QCD in a consistent fashion. At leading order, and at very low energies (e.g., photon energies below 10 MeV), there are five low energy PV constants (LECs) that parameterize the physics [1, 2, 3]. Before we know whether the Standard Model as encoded in the relevant EFT, i.e. EFT($\not\pi$), is correct, all five will have to be determined. These LECs are the PV version of the parity conserving LECs (which include scattering lengths, effective ranges, etc.) in that they must be fixed by experiment in the absence of a lattice, for example, determination. A complementary point of view is that utilizing weak interactions in few nucleon systems provides a unique probe of QCD in these systems, as the observables in question come from interference between weak and strong effects.

One constraint on the PV LECs is available from the low energy (13.6 MeV) PV longitudinal asymmetry from polarized protons scattering off unpolarized protons [4, 5], $A_L = (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-)$ where $\sigma_\pm$ indicates the cross section from protons polarized along/against the incoming proton's direction of motion. A second independent measurement is underway at the Oak Ridge SNS, NPDGamma [6], an experiment that will measure the angular distribution of the exiting photon after polarized neutron capture on a proton, $\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta} = 1 + A_\gamma \cos\theta$, where A_γ is the PV-dependent quantity and θ is the angle between the direction of polarization of the neutron and the photon momentum.

We discuss in this paper the possibility of a third independent measurement: $\vec{\gamma} d \to np$. Note that this is *not* the same as an NPDGamma back reaction. Instead it is related to the time reversal of $np \to d\vec{\gamma}$ and constitutes a completely orthogonal observable to A_γ. Limits from previous attempts exist from Chalk River[7], and the reverse reaction [8, 9]. Experiments to measure this observable have been proposed at JLAB [10, 11], SPRING-8, and the Shanghai Synchroton, but have not been seen as feasible there.

What we propose here is an upgrade of the High Intensity Gamma Source (HIGS) at the Triangle Universities Nuclear Laboratory (TUNL). The HIGS2 would provide unprecedented photon luminosity, polarization control, and energy resolution. The expected capabilities of the HIGS2 are: E_γ = 2 - 12 MeV; rapid switch linear and circular polarization at 90-99%; $10^{11} - 10^{12}$ photons per second in total intensity; minimum energy resolution of less than 0.5% (with a tight collimation and a reduced gamma-ray beam intensity on target).

PV in circularly polarized photon breakup of the deuteron

Naive dimensional analysis suggests that the PV asymmetry involved in $\vec{\gamma} d \to np$ is on the order of 10^{-7}. The relation between this asymmetry and weak couplings has been calculated by several authors, both as a function of gamma energy in hybrid calculations [12, 13, 14, 15, 16, 17, 18] and at threshold, where it is related by time reversal symmetry to the circular polarization of the photon in unpolarized neutron-proton capture [20, 19].

The desired statistical uncertainty of the measurement is 10^{-8}, which means about 10^{16} detected neutrons. About 4×10^{18} gammas are needed on target to achieve this statistical accuracy assuming a cross section of 1.0 mbarn at $E_\gamma = 2.5$ MeV[21] and a liquid deuterium target of thickness 5×10^{24} deuterons/cm^2 and a product of solid angle and detection efficiency for the neutron counter of 0.5. Even with a flux of 10^{11} γs per second, about 450 days of running are required just to achieve the statistical accuracy.

While all the laser and accelerator components involved in the creation of the HIGS2 are known technology, putting them together to create such a high performance machine has not yet been attempted. The technical requirements for an upgraded HIGS facility to be able to perform this measurement are quite stringent. They include the following: (1) The flux of 2.5 MeV circularly polarized photons should provide at least 10^{16} total photodisintegration reactions in the liquid deuterium (or perhaps D2O) target for the experiment in a calendar year of operation; (2) The helicity of the photons must be reversible at high frequencies ($1 - 100$ Hz) in a controllable pattern to be able to make the asymmetry measurement insensitive to slow drifts in detector efficiencies. A capability to insert unpolarized bursts of photons into the sequence may also be very important as a null test for certain false asymmetries; (3) Since this measurement almost certainly must be performed in current mode, the beam intensity noise within the frequency bandwidth of the helicity flip must be negligible compared to the noise from gamma counting statistics; (4) The variation of circular polarization and contamination with linear polarization components under changing gamma-ray beam conditions such as intensity, beam divergence, beam direction, mean energy, energy distribution, etc. must be measured and minimized. Laser technology developed for polarized electron production in the very successful parity violation measurements in electron scattering at Jefferson Lab may already be capable of satisfying conditions (2), (3), (4). Analysis of how these phase space properties get modified through laser backscattering is needed, and for a real experiment one must prove that these conditions are met.

We plan to detect both the neutrons (which can escape the target and be moderated in the deuterium target to slow neutron energies where they are easy to detect), the gammas transmitted through the target, and the gammas scattered into 4π. The liquid deuterium target can be surrounded by a graphite moderator to slow down the neutrons to thermal energies if needed, by an ion chamber for slow neutron detection, and by a current mode gamma detector array. The current-mode gamma detectors could be very similar to those presently being used in the NPDGamma experiment, which are known to be free of systematic errors at the 1 ppb level [22, 23]. One can construct a current-mode ion chamber for the neutron detection which is quite insensitive to the intense gamma field around the target by using a chamber with a ^{4}He gas layer in front of a ^{3}He gas layer since the gamma interactions are almost identical whereas the neutrons absorb strongly in ^{3}He [24]. The signal could be formed as the helicity dependence of the ratio of the neutron to gamma signal. A transmission detector for the gammas through the target can be used to monitor some of the gamma beam properties.

There are several potential sources of systematic error that must be considered. For example, possible systematic effects which can come from the laser beam include, but are not limited to: degree of polarization in the beam; stability of photon flux upon helicity flip; and effect on polarization due to laser optics. We have identified the scalar invariants that can be present in photon reactions in the deuteron target that could pollute the desired signal. Many of these quantities have been measured in deuteron photodisintegration, and the system is simple enough that theoretical calculations can be conducted if necessary. The HIGS2 may need to possess apparatus to measure or constrain such asymmetries in subsidiary measurements.

Conclusions and Outlook

We are not aware of any other facility in the world that has the potential to reach the desired photon luminosity and energy resolution as described here for the HIGS2. All of the elements of the machine described above utilize proven technology. Even if additional experiments with slow neutrons are conducted after the NPDGamma experiment, the full complement of leading order low energy PV LECs cannot be obtained without measurements involving photons. In order to resolve the question of whether we understand PV in nuclei depends upon our understanding of PV in few nucleon systems, which requires the measurements of $\vec{\gamma}d \to np$.

If the PV asymmetry in $\vec{\gamma}d \to np$ is successfully measured at the HIGS2, it will provide, along with the results from NPDGamma and the earlier proton asymmetry, three of the necessary five measurements needed to resolve the question of low energy PV in nuclei. At that point there is no barrier to obtaining other PV photo-induced asymmetries by using tritium or He-3 targets at the HIGS2. These may provide further independent measurements of the low energy PV LECs. Further energy upgrades to the HIGS2 may allow access to He-4, for example, but in that case the experiment will need to be analyzed using an EFT that includes dynamical pions.

1.4 Nuclear Astrophysics and Nuclear Structure

The ^{12}C(α,γ)^{16}O Reaction

The high γ-ray beam intensity at HIGS2 will make it possible to measure cross sections for photon-induced reactions at astrophysical-interesting energies and with much-improved sensitivity. This permits, for example, measurements of the inverse of charged-particle capture reactions, which could offer significant advantages over traditional approaches. In addition, HIGS2 will offer improved sensitivity for extending nuclear structure studies that have an astrophysical context.

A central theme in nuclear astrophysics research at HIGS2 will be the structure, evolution and nucleosynthesis of evolved stars that give rise to supernova explosions. In particular, the main goal of this program will be to push measurements of the ^{12}C(α,γ)^{16}O reaction to energies lower than currently achieved by measuring the inverse ^{16}O(γ,α)^{12}C reaction.

Late-stage red giant stars produce energy in their interiors via helium burning. In first-generation stars, helium burning proceeds through the 3α process to ^{12}C(α,γ)^{16}O and in later generations, α-captures also involve the various CNO seed nuclei. In both cases, the^{12}C(α,γ)^{16}O reaction helps to regulate the efficiency of helium burning. If the rate of this reaction is high, then helium is more effectively converted into heavy elements than would be the case for a low rate. The mass of the helium-burning "ash" governs the subsequent evolution of the star and for massive stars, this includes the (Type II) supernova stage where the majority of the heavy elements in our galaxy originate. The ^{12}C(α,γ)^{16}O reaction determines core mass, temperature and density during the latter stages of stellar evolution, and ultimately, the mass of the iron core in the incipient supernova. In addition, the C/O ratio influences the abundances of elements produced in the ensuing explosion. The current uncertainty in the rate of this reaction is still significant, despite about 50 years of concerted effort, and directly limits our understanding of the latter stages of stellar evolution, core collapse supernovae (see e.g. [25]), hypernovae, collapsars, magnetars and their connection with gamma ray bursts [26]. It has also been pointed out that the light curves of Type Ia supernovae, which are used as standard candles in mapping out the cosmic distance scale, might be influenced by the ^{12}C(α,γ)^{16}O reaction [27, 28].

Two collaborations have pursued complementary approaches to measuring the ^{16}O(γ,α)^{12}C reaction at HIGS and plan to continue their efforts at HIGS2, where a definitive measurement is possible. The STAR collaboration is developing a measurement of the total cross section using a water bubble chamber as an active target. The main advantage of the new target-detector system is a density as high as a factor of 10,000 over conventional gas targets. Also, the detector would be virtually insensitive to the γ-ray beam itself, thus allowing detection of only the products of the nuclear reaction of interest. The aim here is to achieve a level of sensitivity as low as 10^{-12} barn, which is almost two orders of magnitude lower than what has been achieved to date in (α,γ) studies.

The other approach is based on a gas-target Optical Time Projection Chamber (OTPC). This target is less dense than the bubble chamber and thus this measurement can not extend to as low an energy ($E_{cm} \approx 1$ MeV for the OTPC vs. ≈ 675 keV for the bubble chamber for the anticipated γ intensity). However, the advantage here is ability to measure complete angular distributions in order to cleanly separate the E1 and E2 contributions and to measure their phase difference, information that is needed for R-matrix fits of the total cross section. In addition, there are considerable ambiguities in the R-matrix fits to the existing (α,γ) data that lead to drastically different reaction rates at stellar energies. The sensitivity of the OTPC is sufficient to eliminate these ambiguities and should provide the most precise E1 and E2 measurements available for $E_{cm} < 1.5$ MeV.

Both approaches have advantages and challenges that are distinct to the methods employed. Having two experiments with clearly distinguishable sources of systematic errors provides a check on the absolute uncertainties of each measurement while also providing a more complete data set than either measurement alone.

Measurements of (γ,n) Reactions

Photonuclear reactions play a central role in the nucleosynthesis of the so-called p-nuclei, neutron-deficient stable nuclei with A $\geq$ 74. These nuclei are bypassed by both the r- and s-processes and it is thought that they are formed in supernovae by a sequence of photodisintegrations and β^+ decays known as the γ-process (see e.g. [29]). Although calculations of the γ-process concept can produce the bulk of the p-nuclei within a factor of about 3, the most abundant p-isotopes, ^{92,94}Mo and ^{96,98}Ru are rather underproduced and it is not clear if this situation is the result of deficiencies in the astrophysical models or in the nuclear physics input. Recent calculations [30] of Type Ia supernovae have been shown to reproduce the solar abundances of both light and heavy p-nuclei, including ^{92}Mo and ^{96,98}Ru, but not ^{94}Mo. This may imply a deficiency in the nuclear input and seems to be related to the rate of the ^{94}Mo(γ,n)^{934}Mo reaction. A precision measurement of this reaction is within the capabilities of HIGS2.

Nuclear Structure Studies

HIGS2 will also be useful for studies of nuclear structure, some of which also have an astrophysical context. For example, detection of charged- and neutral-current interactions of supernova neutrinos can tell us about neutrino flavor transformation in the explosion. With HIGS2 it will be possible to map out the M1 strength distributions for isotopes such as ^{40}Ar and the isotopes of Mo, both of which have been proposed for neutral-current detectors. The latter is of particular interest because recent calculations suggest that the stable isotopes of Mo are sensitive to both ν_e and $\bar{\nu_e}$ interactions [31].

The electric dipole (E1) response is a fundamental property of atomic nuclei. As with other collective multipole responses it is directly connected to the bulk properties of nuclei and nuclear matter. Recently, the E1 response (especially its low-lying part) has been shown [32, 33, 34] to provide a constraint on the isovector properties of nuclear matter, e.g., the symmetry energy, which are key ingredients in the description of exotic astrophysical objects like neutron stars [35]. Furthermore, the E1 response builds up the major part of the photo-absorption cross section and represents the dominant γ-ray strength function, an important quantity in determining reaction rates in different astrophysical scenarios (see e.g. [36, 37] and references therein). Photon induced reactions are an ideal tool to investigate the dipole strength below and above thresholds in a model independent way. However, data are so far available only for a few nuclei mainly at or close to the magic shell closures. Measurements of (γ,γ') reactions at HIGS2 will extend these studies to a wider range of masses including highly deformed nuclei.

Dipole excited states, particularly, the pygmy dipole resonance (PDR) are at the intersection of nuclear structure and nuclear astrophysics. They are of interest to nuclear structure because they represent a weak collective mode that remains to be understood in a systematic way. The astrophysics context is more clear since these states directly influence the rates for stellar photodisintegration reactions. Nuclear resonance fluorescence studies of the PDR at HIGS show that we are missing significant (maybe most) of its excitation strength because cascades through lower-lying excited states have thus far escaped detection. Coincidence measurements, which will isolate cascades require the intensity and energy resolution of HIGS2

High-resolution charge particle spectroscopy has been used to map out the fission barrier landscape of many of the light actinides [38, 39]. As a result, a new picture of the triple-humped fission barrier was established with an unexpected, rather deep, third hyperdeformed minimum. New photofission experiments could significantly improve our present knowledge on the fission resonance structure and on the potential energy landscape of the actinides, which has very important astrophysical relevance as well: the fission barrier controls the fission losses at the end of the r-process path and also the population of long-lived Uranium and Thorium nuclei. The improved beam energy resolution of the HIGS2 will allow for the search and study of narrow fission resonances near the barrier.

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