Proposal for workshop “Soft photons and light nuclei”

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A new generation of photon machines has recently come, or will soon come, online. These machines provide high-intensity beams of quasi-monoenergetic photons with energies of order, or less than, the pion mass. Prominent among these are the HIγS(E_γ of a few MeV to about 200 MeV) facility in the US, the MAX-lab tagged photon(E_γ =10–180 MeV) facilty in Lund Sweden, the SLEGS(photon energies of several tens of MeV) facility at the Shanghai light source in China, and the New SUBARA(E_γ ~ 10MeV) project in Japan. (There is also a plan at Spring-8 in Japan for the production of 10MeV γ-rays via Laser Compton Scattering using a Far Infrared Laser.) All these machines except MAX-lab can produce beams of linearly or circularly polarized photons with a high degree of polarization. While the facilities in Asia that probe the lower-energy region will be operational in the near future, the Lund and HIγS facilities already exist with known capabilities. Therefore, the planned physics program at these two facilities will be the focus of this workshop. But our proposed workshop will also provide the opportunity to draw out physics issues that the lower-energy machines can address.

At the same time, exciting theoretical developments involving effective field theories (EFTs) are providing new insights into the reactions measured at these machines. This is possible because EFT’s character as a systematic expansion in ratios of physical scales provides a means to progressively improve the treatment of both nuclear forces and the currents through which nuclear degrees of freedom interact with photons. Two EFTs are relevant for the energy domain covered by these facilities. At lower energies the so-called “pionless” EFT is applicable. Once the energy is high enough that pionic degrees of freedom are specifically probed (~ 30–50 MeV), chiral EFTs can be used to describe the interaction of nuclei with photons. In both cases, EFT’s description of nuclear structure and reactions involves progressively smaller effects in the nuclear force, e.g. two-and three-pion exchange and consistent three-nucleon forces. In particular, the chiral EFT forces have now been worked out to several orders in the expansion. The resulting description of NN scattering data below laboratory energies of 200 MeV is as good as in sophisticated NN potential models. When the consistent three-nucleon forces predicted by the chiral EFT are included in the calculations, the binding energy of the alphaparticle is successfully predicted and three-nucleon scattering data can be predicted up to energies of about 100 MeV. Further improvement in this description can be expected too, as new three-and four-nucleon forces at higher orders in the expansion are currently under development. While much is known about the electromagnetic properties of the nucleon itself in these chiral EFTs, work on building up the current operators for light nuclei is at a relatively early stage. But such calculations hold the promise of operators for electromagnetic reactions that are derived using techniques analogous to those employed for the nuclear force, and describe data at a concomitant level of accuracy.

Furthermore, for A ≤ 4 modern nuclear Hamiltonians can now be solved essentially exactly for observables involving both bound and scattering states using, e.g. Faddeev-Yakubovsky or

Correlated Hyperspherical Harmonics techniques. These theoretical advances give us access to theoretical descriptions of reactions on light nuclei which are systematically improvable, and whose consequences can be reliably computed. Used in concert with accurate experiments, such calculations provide a powerful tool to elucidate critical details of the strong nuclear force.

The combination of theoretical and experimental advances will facilitate the re-examination of two topics which have a significant history in the few-nucleon community, as well as detailed investigation of a new sphere of inquiry which provides exciting access to chiral dynamics in light nuclei. These areas are:

1. Examination of three-body forces through photo-induced processes on ^{3}He: ^{3}He(*γ,n)pp*, ^{3}He(*γ,p)d*, ^{3}He(*γ,p)pn*. In each case the consequences of a particular nuclear Hamiltonian for differential cross sections (including cases with polarized photons and a polarized ^{3}He nucleus) can be computed essentially exactly. This allows for detailed predictions for three-body force effects, which are especially pronounced and promising in the three-nucleon break-up of ^{3}He. Calculations for the complete 3N breakup indicate strong three-body effects at energies of 120 MeV. At lower energies the effects are smaller depending also on how exclusive the observables are, but the ability to compute reliably in chiral EFTs at these energies make them an ideal place to test three-nucleon forces and currents based on chiral EFTs [1].

2. The spin structure of the polarized ^{3}He nucleus. Contemporary studies of the spin structure of light nuclei focus on measurements of the Gerasimov-Drell-Hearn(GDH) integrand from the nuclear breakup threshold to the pion-production threshold. The GDH integrand is the difference of the cross sections for the absorption of photons with polarization aligned parallel and anti-parallel to the spin of the target, divided by the photon energy. As such, the integrand is largest near the threshold for the photodisintegration reaction. Chiral EFTs are definitely applicable in this energy domain and the pionless EFT can even be used at its lower end. Over this range of energies the nuclear GDH integrand is governed solely by the nuclear dynamics and is a sensitive probe of the spin dependence of the dynamics.

At the HI*γ*S facility experiments are proposed, under way, or completed, that will measure this integrand for both deuterium and ^{3}He over a range of energies. The HI*γ*S facility is an ideal place to measure the GDH integrand on the ^{3}He nucleus, and this will be done using a high-pressure polarized ^{3}He gas target, and a circularly polarized photon beam. In the case of this nucleus, the ability of EFTs to capture the spin dependence measured in these experiments will reflect on their ability to encode the nuclear corrections to the GDH sum rule for the neutron once energies above pion threshold are considered. An accurate understanding of these corrections is essential in order for detailed comparisons to the wealth of data on the proton GDH integrand to be meaningful.

More generally, further experimental and theoretical work on these issues will illuminate the extent to which a polarized ^{3}He nucleus can be used as a polarized neutron target. This technique is widespread, but understanding its limitations is increasingly important as data on the proton become more and more precise, and the issue of charge-symmetry breaking in nucleon structure becomes increasingly relevant.

[1] In these EFTs three-nucleon forces are well-defined, since they are specified with respect to a particular, EFT-based, two-nucleon force.

3. Compton scattering on light nuclei. Compton scattering experiments on weakly-bound systems require accurate knowledge of the incoming beam energy and photon detectors with good energy resolution. The new generation of photon machines is providing access to these conditions. Meanwhile, chiral effective theories show that the coupling of two photons to hadronic systems makes Compton scattering a process that is particularly sensitive to their long-distance physics, and so an excellent place to test and use these approaches for light nuclei. A series of accurate measurements of the γd cross section between 50 and 120 MeV over a broad range of angles will be taken over the next two years at Lund. This data set has excellent potential for enabling an extraction of neutron electromagnetic polarizabilities, thereby providing a key test of chiral effective theory predictions for the internal structure of the neutron. At the HIγS facility, an extensive program on Compton scattering from both polarized and unpolarized nucleon and nuclear targets is planned. These studies have the potential for improved extractions of the neutron electromagnetic polarizabilities, and will provide the first data on some of the "spin polarizabilities" of the neutron and the proton— quantities which are at present only partly constrained by data. Meanwhile, Compton scattering from the helium isotopes will allow for a determination of the ^{3}He and ^{4}He nuclear polarizabilities. Therefore this new generation of Compton scattering experiments will provide constraints on and tests of effective field theories and emerging lattice QCD calculations of nucleon polarizabilities, as well as testing the predictions for nuclear polarizabilities made by state-of-the-art few-body calculations.

These are a few key examples of the sizable physics potential of photo nuclear facilities examining light nuclei with photons at energies up to 200 MeV. Experiments at the new facilities that are interpreted using EFT techniques will probe important issues of hadron dynamics.

Therefore we propose a two-week workshop at the INT in the spring or June of 2008 that will bring together leading theorists involved in calculations in the three areas listed above and experimentalists doing experiments at some of the aforementioned photon facilities. The goal of the workshop will be to identify the most promising experiments for access to these three physics goals. This will include detailed collaborative work and discussions between theorists and experimentalists on which particular experiments and kinematics/observables are optimal with respect to both theoretical control and experimental viability.

Because this goal is quite focused it is essential that we draw to the meeting theoretical practitioners who are deeply involved with the details of calculations of the relevant reactions. However, we also want to attract physicists who understand the larger picture of the strengths and limitations of the theoretical approaches that will be under discussion. Therefore we have (somewhat arbitrarily) divided our list of key theoretical participants along these lines. Ideally we would like a good mix of people from both groups. (Note that we have listed people together with their usual collaborators, even when they are not from the same institution.)

Structure of workshop

We want to expose theorists to the experimental issues involved in these measurements, and give experimentalists an appreciation for the appropriate and effective uses of these theoretical tools. This goal will be served in two ways. The mornings of the meeting will consist of four talks, each of 50 minutes. Speakers will be asked to prepare only 35 minutes of material, allowing significant time for questions and responses. The afternoons will be free for further discussions, for collaborative work, and to go away and perform theoretical calculations or experimental simulations in order to respond to questions posed in the morning's talks. The INT is therefore the best—and possibly the only feasible—place in the US to host such a meeting. Its combination of meeting rooms, discussion space, and office facilities for the many workshop participants will allow all of the different but important aspects of the workshop to occur.

Summary

We will make significant efforts to include a number of younger, not-as-well-known, theorists as workshop participants, since, in many cases, they are the ones who are intimately familiar with the details of the calculations. This means that all of those on the first list above are "key" participants, even if not all of them will give talks at the meeting.

Suggested Participants (list of names)

In view of the exciting experimental capabilities of a new generation of low-energy photon facilities–especially the ability to make polarized beams and targets–as well as the recent theoretical advances in effective field theories, the time is right for an INT workshop to explore how best to utilize the new facilities to further our understanding of hadron dynamics. Specifically, we propose an INT workshop that focuses on three areas of hadron dynamics that can be addressed with the new facilities: three-body forces through the photodisintegration of ^{3}He; spin structure of ^{3}He; and Compton scattering on light nuclei. The workshop would involve strong overlap between theorists and experimentalists with the goal of identifying the most promising experiments at the new facilities for making significant progresss in each of the three areas. Ideally the workshop would be two weeks long and take place during the Spring or early Summer of 2008.