March 6, 2009

PROPOSAL

for an International Workshop at the ECT* on

1. Title: **"The Lead Radius Experiment and Neutron Rich Matter in Astrophysics and in the Laboratory"**

2. *Organized by:*

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3. *Tentative date of the workshop:* One week between July 17 and Aug. 9, 2009, preferably Aug. 3-8, 2009. A meeting in summer 2009 will build on the successful 2008 JLAB workshop and allow a final discussion of issues before the full PREX experiment is mounted in early 2010.

4. **Scientific Proposal**

The Lead Radius Experiment (PREX) uses parity violation to accurately determine the radius of the neutron distribution in ^{208}Pb. This fascinating measurement has remarkably broad implications for nuclear structure, astrophysics, atomic parity violation and low energy tests of the Standard Model. We propose a week-long program to review final plans for PREX and discuss the experiment's many implications. In addition, we hope to improve communication between electron scattering, nuclear structure, astrophysics, and atomic parity communities and between North American and European

researchers. The program will involve many experimentalists, in addition to theorists, and emphasize the close interplay between theory and experiment.

The nucleus ^{208}Pb has $Z = 82$ protons and $N = 126$ neutrons. Where do the $N - Z = 44$ extra neutrons go? Are they at the center or are some of them at the surface forming a neutron rich skin? This simple question involves many important issues. Historically, neutron densities have been measured with a variety of hadronic probes. Unfortunately, these measurements all have systematic errors associated with strong interaction uncertainties. These errors are difficult to quantify. They can be avoided with a purely electroweak probe. In the Standard Model the weak charge of the neutron is large, while the weak charge of the proton involves the small combination $1 - 4\sin^2\Theta_W$. Therefore parity violation provides a very clean electroweak probe of neutron densities. PREX will measure the parity violating asymmetry for longitudinally polarized 1050 MeV electrons elastically scattered from ^{208}Pb at 5 degrees to an accuracy of 3%. This allows one to determine the neutron radius to 1% (± 0.05 fm).

The pressure of neutron rich matter forces neutrons out against surface tension. The higher the pressure, the larger the neutron radius. Therefore PREX will constrain the pressure of neutron matter at slightly sub-nuclear densities. This has important implications for the radius, crust properties, and cooling of neutron stars. PREX will provide information on neutron rich matter that is complimentary to neutron star observations involving X-ray, neutrino, and gravitational wave probes.

The equation of state (pressure versus density) of neutron matter is an important testing ground for microscopic many-body calculations. Here, three neutron forces are important ingredients. These can also be probed with calculations and measurements in neutron rich few nucleon systems. In the realm of self-consistent mean-field models, one can use the neutron density in Pb to constrain energy functionals. The isovector effective interactions in these functionals are related to isovector response (polarizability, giant dipole resonance), in particular to the symmetry energy. This describes how the energy rises as one goes away from equal numbers of neutrons and protons. These functionals can then be used to predict properties of a neutron rich nuclei that are important for nucleosynthesis or that can be studied with radioactive beams. Measurements of neutron skins in very neutron rich unstable systems are complimentary, although in general less precise, than the PREX measurement for ^{208}Pb.

Atomic Parity Nonconservation (PNC) provides an important low energy test of the Standard Model. Parity violation arises from weak interactions between atomic electrons and the nucleus. Since the weak charge of a nucleus is carried predominately by the neutrons, atomic PNC is sensitive to the neutron radius. This sensitivity will be increased in future experiments involving ratios of measurements in different Yb isotopes or for measurements in heavier atoms such as Francium. Therefore, it is important to accurately predict the neutron skins of nuclei involved in atomic PNC experiments. The PREX measurement, coupled with appropriate advances in nuclear theory, may greatly constrain these neutron skins.

5. **Outline of the programme**

    1. PREX Experiment
        (a) Overview of parity violation program
        (b) PREX overview

   (c) Systematic errors
   (d) Polarimetry
   (e) Radiative corrections, Coulomb distortions, Analyzing power
2. Neutron densities and nuclear structure
   (a) Overview of present-days nuclear structure models
   (b) Relation between neutron radii and isovector observables
   (c) Neutron radii, neutron-rich nuclei and neutron matter
   (d) The systematics of neutron skin over the chart of isotopes
3. Atomic parity nonconservation and neutron densities
   (a) PNC in Yb
   (b) PNC in Francium
   (c) Low energy tests of standard model
   (d) Calculations of neutron densities for atomic PNC
4. Heavy ions, radioactive beams and neutron densities
   (a) Measuring symmetry energy at low densities with HI collisions
   (b) Measuring symmetry energy at high densities
   (c) Measuring neutron densities of exotic nuclei in radioactive beams
5. Neutron rich matter in astrophysics
   (a) Radii of neutron stars and equation of state
   (b) Measuring neutron star radii with X-ray observations
   (c) Neutron star cooling and dense matter
   (d) Gravitational waves and dense matter
6. Discussion