Title: Collaborative Research: Equipment for and Running of the PSI MUSE Experiment

Institution: Rutgers University New Brunswick

NSF Program: Hadrons and Light Nuclei

Principal Investigator: Gilman, Ronald

Rating: Excellent

Review:

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.

This is an excellent proposal which might clarify one of the outstanding
issues in nuclear physics. It uses a novel innovative method be combining electron and muon scattering and their antiparticles off the proton. The only weakness I see is that from the proposal it is difficult to judge whether the attempted precision can be reached.

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to broader impacts.

If successful, this proposal will have a far-reaching impact as it might solve an outstanding problem. Further, the educational impact on the hired graduate students and post-docs will be large as they will have to work quite independently. If the experiment can not achieve its
goals, it will have no broad impact.

Please evaluate the strengths and
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if applicable

Not applicable

Summary Statement

Executive summary:

This is an ambitious proposal that should be funded. Before doing so,
however, the collaboration has to lay out a more detailed time line and should provide simulations that show that the expected precision of the radius extraction can indeed be achieved.

Detailed review:

1. What is the potential for the proposed activity?

The applicants intend to measure low-energy cross section of electron/positron and

positively/negatively charged muon scattering off the proton. The aim is to extract the proton charge radius from the two scattering processes including an unfolding of the two-photon corrections from the two different lepton charges. To my knowledge, such a measurement has not been attempted before and it is
timely in view of the conflicting data/analyses that lead to the so-called proton radius puzzle. There have been speculations that the smaller radius seen in muonic hydrogen is a signal of BSM physics, however, sophisticated analysis of the Mainz electron scattering data based on dispersion relations also favor a small radius.
Still an independent extraction of the radius from muon scattering would be very valuable and it is clear that given the importance of such a crucial quantity, any effort should be made to clean up the messy situation. If successful, this measurement will have a major impact. Furthermore, such an experiment offers excellent opportunities for students and young researchers to make a major impact and also will qualify them very well for a career
outside of fundamental physics.

2. To what extent do the proposed activities suggest and explore creative, original, or potentially transformative concepts?

The proposed experiment is original in two respects - it not only wants to extract the proton radius from electron and muon scattering off protons, but by using the corresponding antiparticles, one will furthermore obtain a handle on the two-photon corrections. These have
turned out to be important if one is after a precision extraction. They are presently measured for electrons and positrons with the OLYMPUS experiment at DESY. This experiment,however, has a lowest photon virtuality of about 0.4 GeV^2 and thus will not contribute
to the radius puzzle. With a simultaneous measurement of electron and muon scattering, many systematical uncertainties are expected to cancel, which is also quite original. MUSE is a novel approach to a fundamental question in nuclear physics and thus should be funded.

3. Is the plan for carrying out the proposed activities well-reasoned, well-organized, and based on a sound rationale? Does the plan incorporate a mechanism to assess success?

The MUSE experiment can, and will, go in steps. Some of the initial steps like investigating the properties of the beam line have been done. The proposal offers a short description of the various detector parts and analysis methods to be implemented plus a schedule how to set up the experiment in various stages in the following years with clear responsibilities assigned to the various groups. All that looks fine. What I am missing at this stage are simulation details,
for me it is not possible to judge based on the given material whether the ambitious aim of achieving a percent accuracy on the various cross sections is feasible?

How well qualified is the individual, team, or institution to conduct the proposed activities?

To my opinion, the team is very well qualified to conduct the experiment. All of the PIs and groups have a very good experience in electron scattering, leading various experiments at JLab to unravel the nucleon form factors and sizes. In addition, Prof. Koehl is

one of the main players in the OLYMPUS experiment. With the excellent support from the laboratory, I see no obvious stumbling stone for the experiment.

5. Are there adequate resources available to the PI (either at the home institution or through collaborations) to carry out the proposed activities?

As it appears, the experiment will be set-up and run at PSI but the PIs will mostly work at their home institutions. Thus, a careful search of very independent and creative post-docs is required. The PIs have been successful in finding good post-docs in the past, and certainly have a strong support and good infrastructure at their home institutions. Most of them are also integral part of other successful collaborations.