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.

The MUSE collaboration is requesting approximately 6.0M$ in funding to both construct the experimental setup and install, commission and run the experiment. The MUSE collaboration (Rutgers, George Washington, Hampton, South Carolina + overseas institutions) proposes simultaneous measurements of mu-p and e-p scattering (both positive and negative polarity) at low incident momenta (115 - 210 MeV/c) to determine mu-p / e-p relative cross sections to a few tenths of one percent. The proposed measurements will surpass the precision of earlier mu-p scattering experiments conducted by more than two orders of magnitude.

The intellectual merit of the proposal is excellent. The proton radius is an important quantity in nuclear science. The 7-sigma discrepancy between the proton radius extracted from muonic hydrogen lamb shift measurement r_p = 0.8409 +/- 0.0004 fm compared to electron scattering data and ordinary hydrogen spectroscopy (0.87 - 0.88 fm and 0.87 +/- 0.01 fm) is an important, intriguing puzzle. To date, attempts to explain the puzzle by measurement errors, extraction errors or new physics have not succeeded. The proposed mu-p cross section measurements would permit a determination of r_p to +/-0.01 fm, offering interesting sensitivity to two-photon exchange effects and testing some models involving new / novel
physics. No matter the final resolution of the proton puzzle - the
MUSE experiment appears of long-lasting value.

I rate the qualification of the collaboration as excellent. The various groups / members of MUSE have outstanding reputations and
are well qualified to carry out the experiment (many have long histories of involvement in electron scattering experiments). The various groups bring valuable expertise to the project, e.g.
GEM detectors, cryogenic targets, scintillator / fiber arrays
as well as demonstrated leadership. My only reservation on the personnel, is whether the current team has sufficient manpower to cover the construction, installation, lengthy running, data analysis and systematics studies of this challenging precision measurement.
Although the collaboration responsibilities for detector components
are listed - the details of plans (manpower, schedules and milestones) for developing the instrumentation seem somewhat vague for a 6.0M$ project investment.

The proposal indicates the collaboration has conducted several

test measurements at PSI to demonstrate the project's feasibility including (i) measurements of the beam characteristics of the piM1 secondary beamline and (ii) prototyping the Cerenkov counters, GEM chambers and scintillating fiber array. Such activities convey the collaborations commitment to the development of the experiment.

Obviously, the low intensity, large emittance, secondary muon/electron beams presents major challenges for precision cross section measurements. A detailed understanding of the electron/muon beam characteristics (spatial/momentum distributions) as well as how these properties will impact the relative cross section determinations is important (could differences in the e/mu sources at the production target generate significantly different e/mu beam distributions?). Also important are presumably the differences between electron/muon energy loss, multiple scattering, etc., in entrance/exit counters and target assembly, and how such effects impact the determination of scattering angles and cross sections for electrons/muons. Given the impact of the muon/electron mass on scattering kinematics, the knowledge/determination of detector efficiencies is presumably also important. In short, I think there's no short-cut to demonstrating the projects technical feasibility, it requiring a thorough simulation using measured beam properties and complete detector geometry to understand the experimental precision and key design factors. Since the proposal only contains a brief description of the experimental setup and lacks a detailed simulation, I didn't think the proposal itself demonstrated technical feasibility.

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

The broader impact is very good. The various collaborators have excellent records of suitably involving post-docs, graduate students, undergraduate students and high school students in their research activities. Prof. Briscoe has a strong record of involving undergraduate in research through both NSF REU and IRES funding. Hampton collaborators have unique opportunities to involve under-represented groups in research and other collaborators have good records of involving women in research. The list of USC undergraduates and graduate students they've involved in research is very impressive. Moreover, the "radius puzzle" itself has broad interest spanning atomic, nuclear and particle physics and the experiment involves some interesting, emerging technologies. The radius puzzle has also attracted attention in the popular media.

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

The Rutgers group and George Washington groups both request post-doc support. Both groups have included suitable post-doc mentoring plans

Summary Statement

In summary, contingent on a thorough demonstration of the technical feasibility of the experiment, I rate the project as excellent and

strongly encourage is full support. The physics is excellent and unique, the collaboration is strong and qualified, and I've every confidence that the technical feasibility can be demonstrated by the collaboration.