PR12-20-004
Scientific Rating: A
Recommendation: C1
Title: PRad-II: A New Upgraded High Precision Measurement of the Proton Charge Radius

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Motivation: Precision information on the size of hadrons can be obtained both from electron scattering and from atomic spectroscopy. It came as a big surprise that the extraction of the proton charge radius from muonic hydrogen Lamb shift measurements is in strong contradiction with the values obtained from electron-proton scattering. This 'proton radius puzzle' has triggered a large activity worldwide.
In this context, the PRad Experiment has pioneered a new technique to extract the proton radius in elastic electron scattering. Instead of using the traditional experimental technique based on magnetic spectrometry, the experiment has adopted a new calorimetric method for low Q2 elastic scattering, using a windowless target and simultaneously recording Møller scattering for normalization of the measured cross-sections. In principle, this avoids individual point to point normalization uncertainties, which would impact the measured Q2 spectrum.
The results obtained by this pioneering experiment (recently published in Nature) are in apparent conflict with all previous modern electron scattering experiments, especially at high values of Q2 . A new experiment with a much improved control of radiative corrections (which at the moment account for the largest part of the systematic uncertainty), with larger data sets, and which makes use of a blind analysis, is imperative to clarify the current status and to reach for the ultimate precision in ep scattering.

The proposed experiment aims at reducing the total uncertainty down to 0.54%, which is 3.8 times smaller than what PRad achieved, by upgrading the experimental setup.

Measurement and Feasibility: The experiment relies on the PRad setup undergoing a variety of upgrades, in particular:
1. improving the overall tracking capabilities of the setup by adding a second plane to the tracking detector,
2. adding new rectangular cross-shaped scintillator detectors to separate Møller events in the angular range 0.5^{o} to 0.8^{o} ,
3. upgrading the HyCal by replacing the lead glass blocks by PbWO4 and converting its readout to FADC based one,
4. improving radiative correction calculations by going to NNLO.

Three beam energies are requested, namely 0.7, 1.4 and 2.1 GeV. The lowest and highest beam energies will allow to cover the Q2 range from 4 × 10-5 to 0.06 GeV2 . The 1.4 GeV run will serve as an important cross-check for possibly unaccounted systematics.

Issues:

- The μRWell technology (point 1 above) has never been used in a running experiment, and its reliability and radiation hardness have not been fully demonstrated. Since the main reduction on the total uncertainty arises from the addition of a second tracking station, the PAC recommends considering a second GEM station instead, further relying on the present GEM technology to reduce the risks of jeopardizing the final physics goal.
- The upgrade of HyCal (point 3 above) implies 1500 additional PbWO4 crystals and a new electronic readout. The cost estimate is about $5M. While it is clear that the new readout based on FADC will strongly increase the rate of data taking (and thus reduce the statistical uncertainty), the PAC could not be convinced on the necessity of the costly replacement of the crystals for reaching the final uncertainty on the proton radius.
- The PAC strongly suggests the planning of a blind analysis to convincingly reduce possible bias stemming from the normalization and the Q2 -dependence of the form factor. In particular, all radiative correction calculations and their implementation in the Monte Carlo simulation should be fixed before the fit for the proton radius.

Summary: Given the compelling physics case and the current tension between the form factor data of PRad and all previous ep scattering experiments, the PAC strongly supports the request for 40 days of beam time, pending a thorough technical investigation of the actual benefits or necessity of the HyCal upgrade and the adoption of the μRWell technology