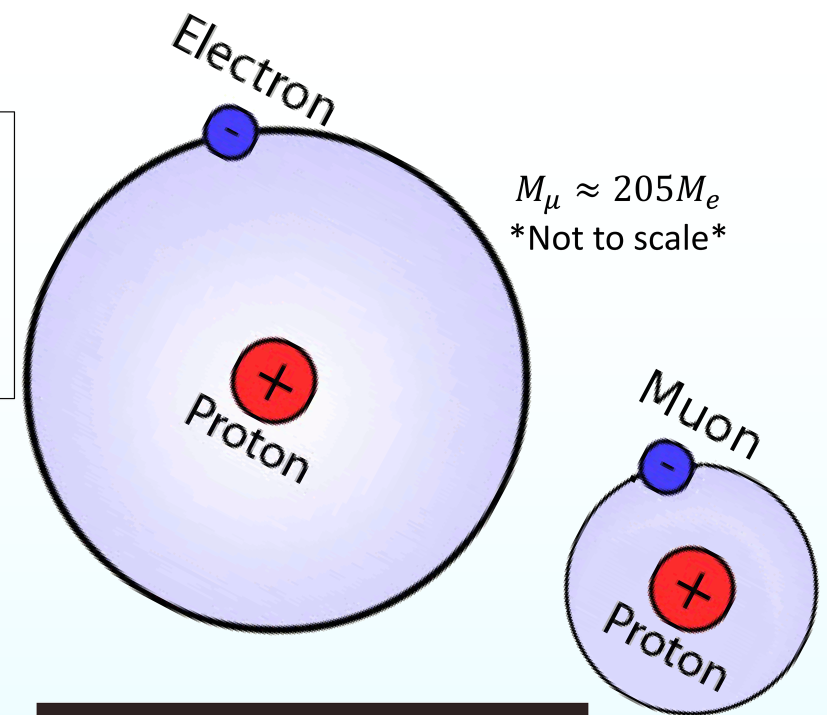
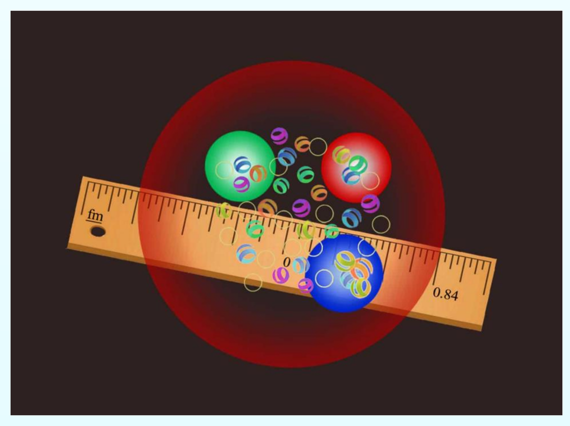
The Proton Radius (PRad) Experiment

Thomas Jefferson National Accelerator Facility

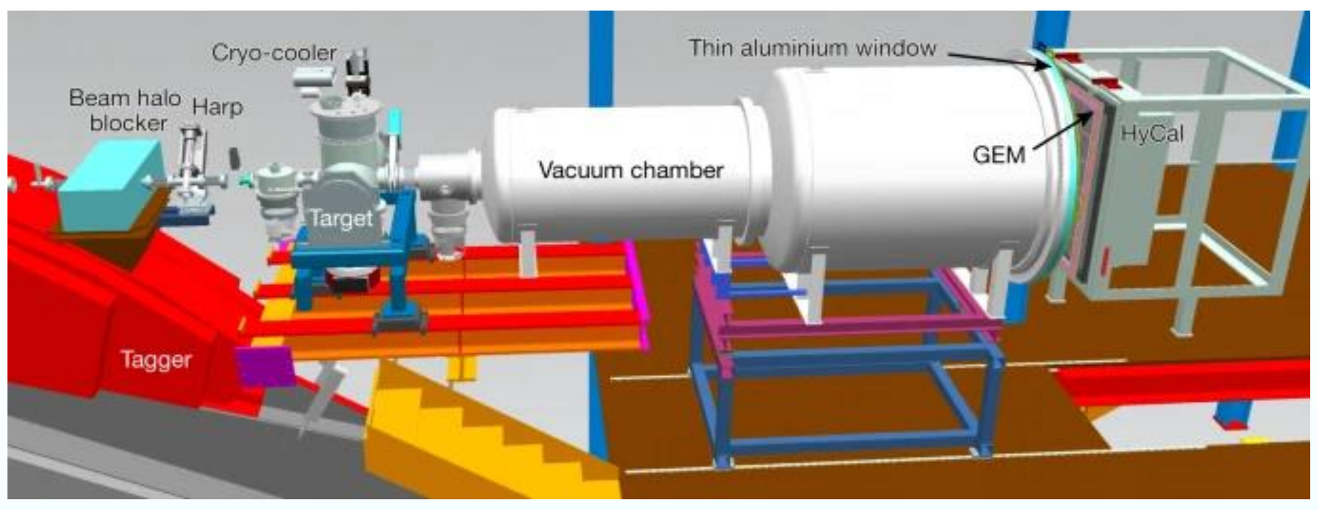
The Proton Radius Puzzle

In 2010, an experiment found the proton radius from measuring the energy levels of muonic hydrogen and found a value lower than any other measurement of the proton radius from normal hydrogen. This measurement had only a 1 in 100 billion chance to be a random chance.

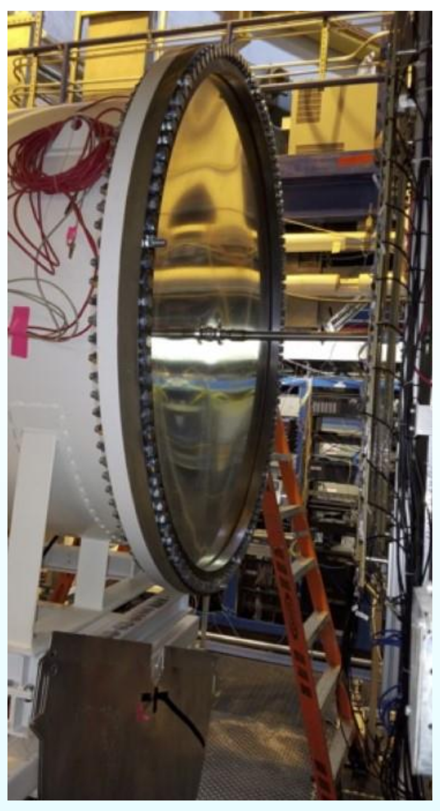


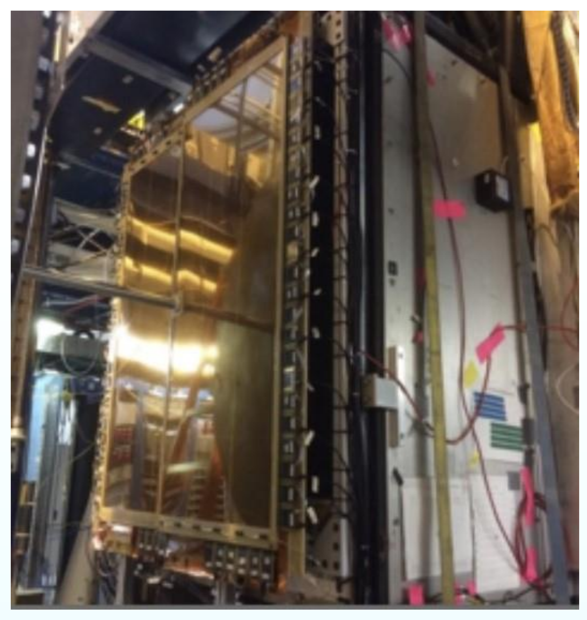


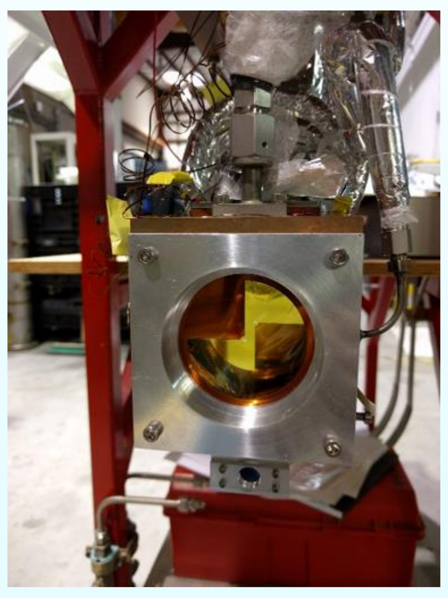
The Novel PRad Experiment at JLab

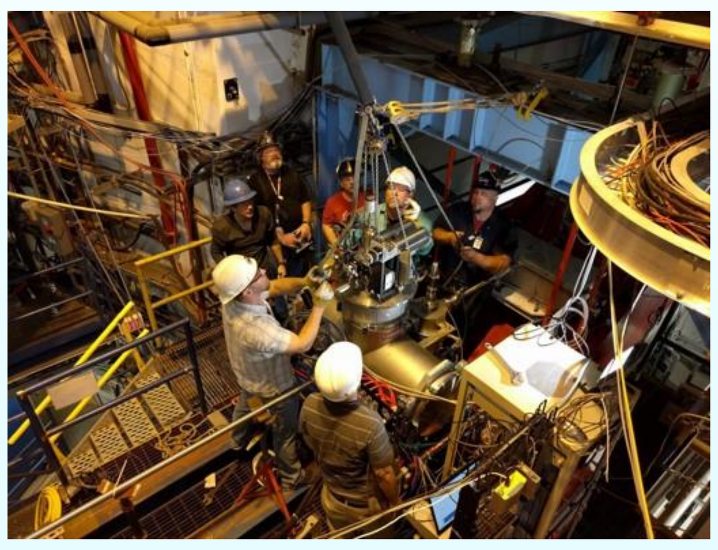


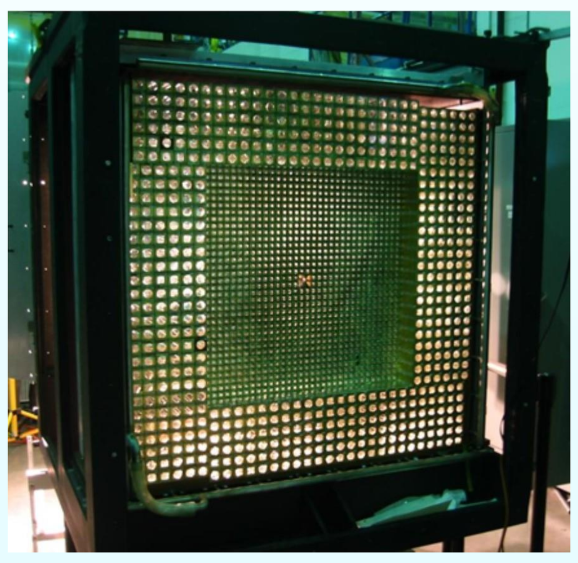
To solve this puzzle a new high precision electron scattering experiment on hydrogen was performed in Hall B at JLab. It used a completely unique target design along with covering a large angular range using a magnetic spectrometer free electromagnetic calorimeter.

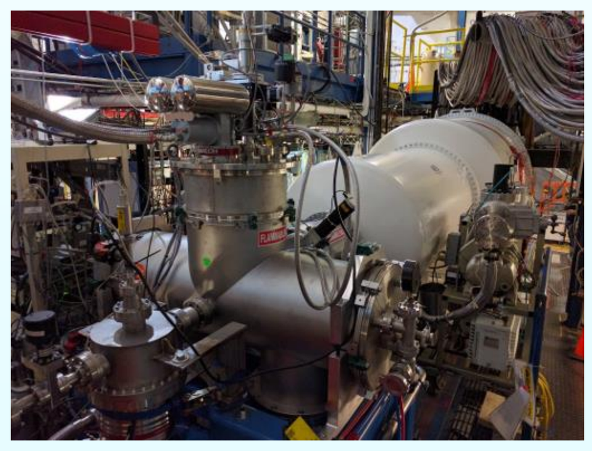






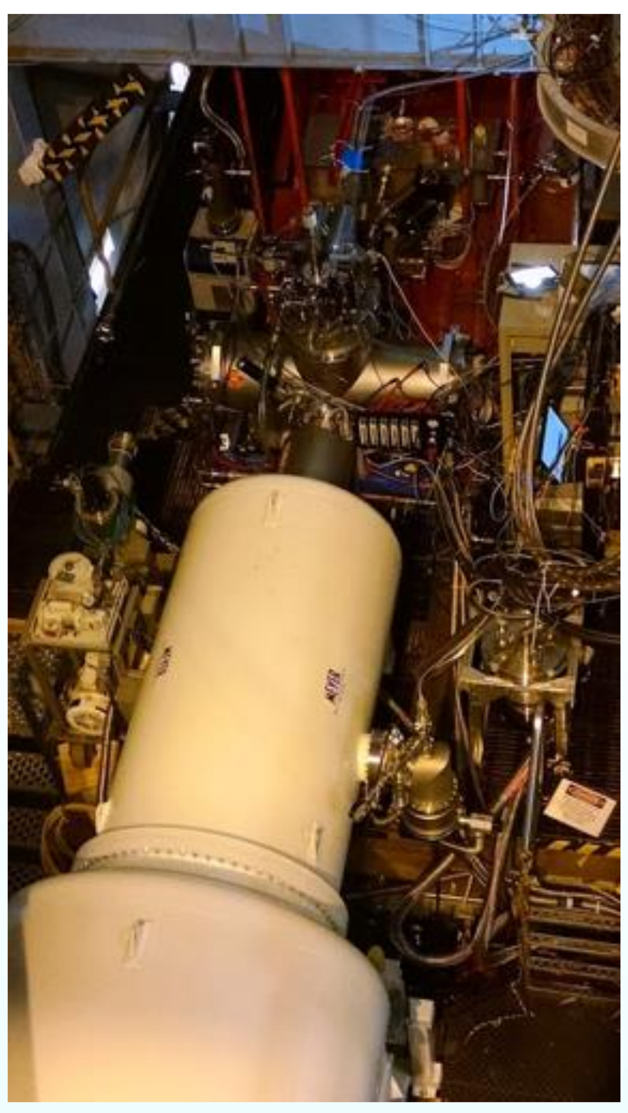


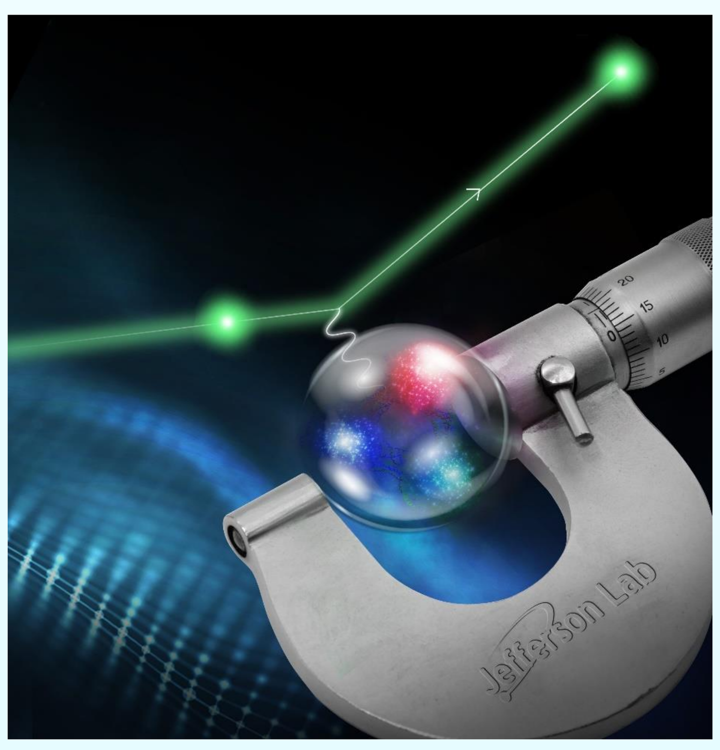




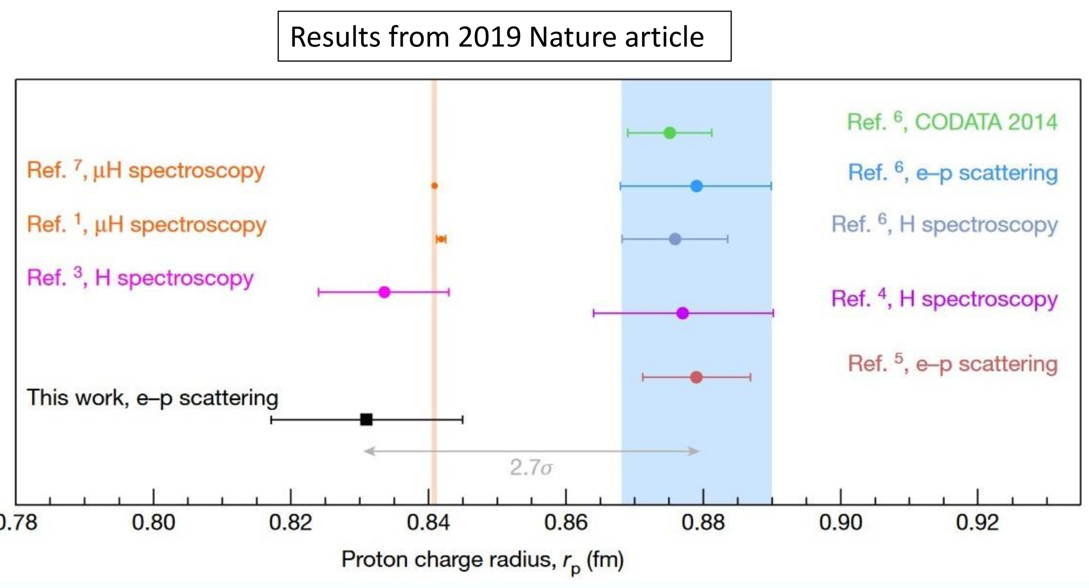
Target pictures contributed by the JLab Target Group

JLab Electron Scattering Results





Results from 2019 Nature article



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A small proton charge radius from an electron–proton scattering experiment

W. Xiong, A. Gasparian, H. Gao, D. Dutta, M. Khandaker, N. Liyanage, E. Pasyuk, C. Peng, X. Bai, L. Ye, K. Gnanvo, C. Gu, M. Levillain, X. Yan, D. W. Higinbotham, M. Meziane, Z. Ye, K. Adhikari, B. Aljawrneh, H. Bhatt, D. Bhetuwal, J. Brock, V. Burkert, C. Carlin, … Z. W. Zhao + Show authors

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Abstract

Elastic electron–proton scattering (e–p) and the spectroscopy of hydrogen atoms are the two methods traditionally used to determine the proton charge radius, r_p. In 2010, a new method using muonic hydrogen atoms[1] found a substantial discrepancy compared with previous results[2], which became known as the 'proton radius puzzle'. Despite experimental and theoretical efforts, the puzzle remains unresolved. In fact, there is a discrepancy between the two most recent spectroscopic measurements conducted on ordinary hydrogen[3,4]. Here we report on the proton charge radius experiment at Jefferson Laboratory (PRad), a high-precision e–p experiment that was established after the discrepancy was identified. We used a magnetic-spectrometer-free method along with a windowless hydrogen gas target, which overcame several limitations of previous e–p experiments and enabled measurements at very small forward-scattering angles. Our result, $r_p = 0.831 \pm 0.007_{stat} \pm 0.012_{syst}$ femtometres, is smaller than the most recent high-precision e–p measurement[5] and 2.7 standard deviations smaller than the average of all e–p experimental results[6]. The smaller r_p we have now measured supports the value found by two previous muonic hydrogen experiments[1,7]. In addition, our finding agrees with the revised value (announced in 2019) for the Rydberg

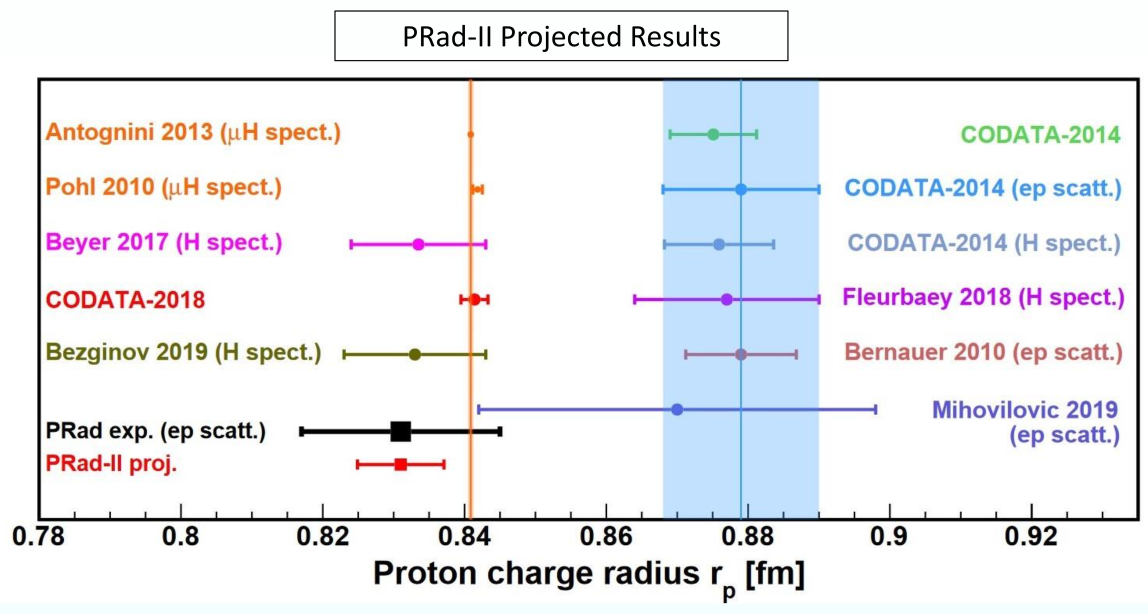
The smaller proton radius was confirmed with the new measurement by the PRad group. This suggested that some new force was not the cause of the puzzle. This has now been corroborated by 2 of 3 energy level measurements in recent years.

Future Experiments

Three more experiments utilizing the PRad apparatus are on the way here at JLab.

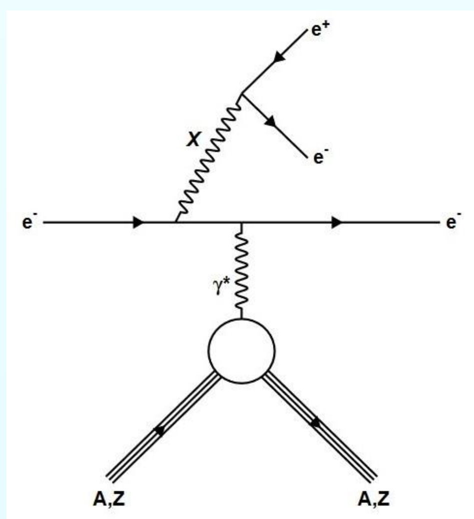
- **PRad II:**
  - After the original PRad experiment found such novel results and is giving answers pointing in the direction of the true size of the proton, there is an approved experiment to repeat this measurement with many improvements. This new measurement will use more beam time, with better position information, with a better understanding of and ability to control any uncertainties, and some new electronics. This is expected to be the highest precision measurement of the proton radius using the electron scattering method.

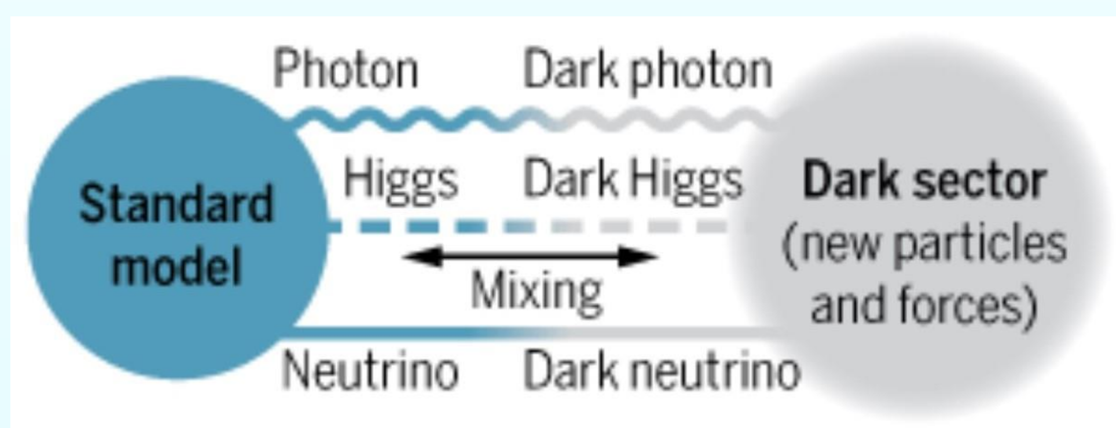
PRad-II Projected Results



Direct Detection Search for Dark Matter:

- A search for "Dark Light", or a dark matter equivalent of a photon called A' or X. This search will cover sweep over a mass region from 3-60 MeV and make use of the highly precise central crystal region of HyCal. This will be able to cover the entire phase space region of a potential 17 MeV particle (X17) that has been observed in other experiments in recent years. The target will be a thin Tantalum sheet. PRad's magnet-less setup is perfect for high precision measurements of small likelihood processes like Dark Matter interactions.





π^0 TFF:

- Using higher energy beams with the PRad setup a new experiment will make a high precision measurement of how the π^0 particle decays into 2-gamma rays.