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High Precision Measurement of the Proton Charge Radius

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The PRad experiment aims to measure the charge weighted size of the proton with high precision. This size of the proton, also known as its charge radius, is a fundamental quantity in physics. The precise knowledge of the size of the proton has a wide variety of impact ranging from the understanding of the strong force that holds atomic nuclei together to our knowledge of fundamental constants of nature.

For nearly half a century the charge radius of the proton had been obtained from high precision measurement of the energy levels of the hydrogen atom or by scattering electrons from a hydrogen atom and measuring how the probability of scattering varied with the scattering angle and then extrapolating it to zero angle (one cannot measure at zero scattering angle since we run into the incoming beam). Until recently the proton charge radius obtained from these two methods agreed with one another within experimental uncertainties. In 2010 the proton charge radius was obtained for the first time by precisely measuring the energy levels of an unusual kind of hydrogen atom. In these specially prepared hydrogen atoms the electron is replaced by its heavier cousin known as the muon. The muon being about 200 times heavier than the electron, is held much closer to the proton in the special hydrogen atom, also known as muonic hydrogen. This means that the energy levels of the muonic hydrogen are more sensitive to the size of the proton and hence allow a more precise measurement of its size. The charge radius of the proton obtained from muonic hydrogen was significantly smaller than those obtained from regular hydrogen atoms. Around the same time an electron scattering experiment was also performed which measured the change of the scattering probability with angle over a large range of angles with very small steps between the angles. Although the new electron scattering result was more precise than previous scattering measurements, it was consistent with them. This meant that the muonic hydrogen and regular hydrogen results being this different just by chance was less than about 1 in a 100 billion.

This was called the “proton charge radius puzzle” and led to a rush of experimental as well as theoretical efforts to understand why the size of the proton appears to be different when measured in regular hydrogen vs. muonic hydrogen. Our experiment is one such effort which will use electron scattering from a regular hydrogen atom, but with several innovations that will make it the highest precision electron scattering measurement. One of the innovations involves using a special high resolution detector called a calorimeter that allows us to reach the smallest angles ever, but at the same time measure over a wide enough range of angles such that the extrapolation to zero angle is robust. The second innovation is to continuously flow hydrogen atoms as they interact with electron beam by holding the atoms inside a tube with no end-caps and using powerful pumps to remove the hydrogen that spills out of the tube. This eliminates the scattering from the end caps of the tube that tend to hide the electrons that scatter from the hydrogen inside the tube, a common problem with all previous electron scattering experiments. The third innovation is to simultaneously detect the electrons that scatter from the proton in the hydrogen atom as well as the electrons that scatter from the electron in the hydrogen atom. Doing so eliminates the need to know exactly how many hydrogen atoms were hit by the electron beam. In all previous electron scattering experiments knowing exactly how many hydrogen atoms were hit by the electron beam was one of the largest source of uncertainty.

These innovative methods will allow us to measure the size of the proton more precisely than it has been measured before using electron scattering. It will provide an independent check on previous electron scattering experiments. If the difference in the size of the proton measured in regular vs. muonic hydrogen is confirmed it could indicate the possible existence of a new force beyond the four forces that are currently known.