Precision measurement of the proton charge radius at the S-DALINAC

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The proton charge radius (r_p), which is one of the fundamental quantities in physics, its precise determination is very important for high-precision QED tests using Lamb shift measurements [1] and for understanding its structure in terms of quark and gluon degrees of freedom of QCD. Using electron proton (ep) scattering experiments, and detecting electrons, there are several measurements existing in the literature for r_p. The two most precise and mostly cited values for r_p are 0.805(11) fm [2] and 0.862(12) fm [3] which differ from each other by more than 7 %. There is a reanalysis of all the existing data on elastic ep scattering by Sick [4] which yields a value of 0.895(18) fm, which is significantly large.

At the S-DALINAC facility of TU darmstadt, we have used a new experimental method to determine r_p with elastic ep scattering at low momentum transfer, where instead of detecting the scattered electrons, the recoil protons are detected in a set of Si detectors. This measurement is based on the direct relation between elastic scattering cross section and the electric form factor at low momentum transfers. For very low momentum transfer, the mean square charge radius is proportional to the electric form factor G_E

$$\frac{< r_p >^2}{6} = \frac{dG_E(q^2)}{dq^2} \quad (1)$$

where q is the three momentum transfer. This new technique offers a number of advantages over measuring the electrons: the detection for protons with the Si detectors is 100% and the solid angle is exactly defined by a collimator. Most importantly, the complete angular distribution or in other words the q-dependence is measured simultaneously.

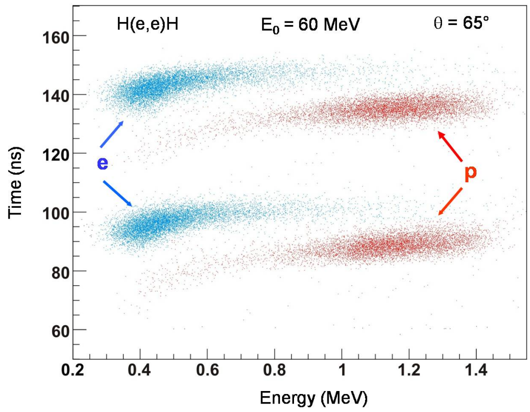

FIG. 1: A two-dimensional spectrum of time versus energy.

A test measurement [5] was carried out using a 60 MeV electron beam, which was scattered on a polyethylene (CH_2) target of thickness 0.356 mg/cm^2. The target was rotated to 60° so that the low-energy recoil protons from the electron scattering did not loose much energy. In order to measure the complete angular distribution simultaneously, seven Si detectors from 20° to 80° in steps of 10° each were positioned in plane at a distance of 19.5 cm. The corresponding momentum transfer covered was in the range of 0.1 to 0.55 fm^{-1}.The Si detectors of 2.5 x 2.5 cm^2 used were built in-house in the detector laboratory. The detectors were calibrated using ^{241}Am source. The effective q measured during the experiment is sensitive to the horizontal shift in the

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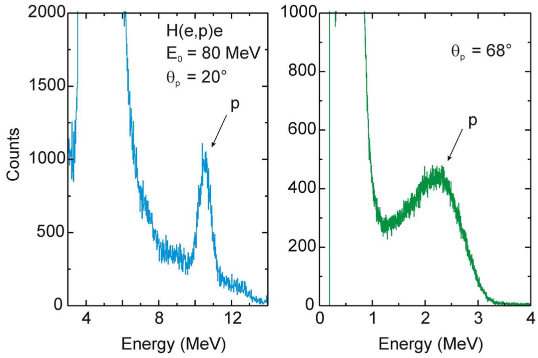

FIG. 2: Measured energy spectra.

beam. In order to measure the beam shift online, a symmetric Si detector was placed at an angle of -50° w.r.t. the beam. In order to detect the scattered electrons, the QCLAM Spectrometer [6] was kept at -75°, covering a solid angle of 35 msr. The elastic peak from the carbon content in the target was used for normalisation. Measurements were also made using carbon and blank target, in order to understand various source of background. In order to separate electron induced background, a halo free, pulsed beam of 3 ns width with repetition rate of 20 MHz was imprinted on 3 GHz time structure.

Fig. 1 shows a two-dimensional spectra of energy versus time-of-flight. As can be seen from figure, at backward angles, the protons are very well separated from the electrons. However at forward angles, the protons are not very well separated from the electrons. An alternative method could be, to use pulse shape discrimination (PSD) between electrons and protons. PSD is a very powerful tool for particle identification. Fazzi *et al.* [7], has shown that for a one MeV deposited energy, protons and electrons are very well separated using PSD method, if they are injected from the rear side of the Si detectors. For good PSD using Si detectors, high homogenity of Si material and fast low-noise front-end electronics are required. We have developed Si surface barrier detectors from homogeneously neutron-transmutation doped Si for PSD. As there is no source which could give protons, we did a small test experiment in our detector laboratory, where alphas from ^{241}Am source and electrons from the ^{207}Bi were induced from the rear side (reverse mount) in the Si detectors. The difference between the collection times of the two pulses was maximized and used for a rise time based discrimination. Using PSD method, we could very well separate the alphas from electrons. The time resolutions we got was around 2.5 ns.

Recently, we did a production run at a higher electron beam energy of 80 MeV. The experimental details are same as that from 60 MeV beam energy, except the following: the symmetric detector was placed at -40°, the QCLAM spectrometer was placed at -52°. We applied pulse shape discrimination method at forward angles and time-of-flight method at backward angles, in order to separate the protons from the electrons. Fig. 2 shows a raw measured energy spectra at two angles, 20° and 68° respectively. Further data analysis is in progress.

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