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 $G_E$:

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

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.

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$^\circ$ so that the low-energy recoil protons from the electron scattering did not lose much energy. In order to measure the complete angular distribution simultaneously, seven Si detectors from 20$^\circ$ to 80$^\circ$ in steps of 10$^\circ$ 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

FIG. 1: A two-dimensional spectrum of time versus energy.
beam. In order to measure the beam shift on-
line, 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 un-
derstand various source of background. In or-
der 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 elec-
tronics are required. We have developed Si
surface barrier detectors from homogeneously
neutron-transmutation doped Si for PSD. As
we did a small test experiment in our de-
tector laboratory, where alphas from 241Am
source and electrons from the 207Bi were in-
duced from the rear side (reverse mount) in
the Si detectors. The difference between the
collection times of the two pulses was maxi-
imized and used for a rise time based discrim-
ination. 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 pro-
tons 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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References

(1980).