ENERGY ANALYSIS OF NEGATIVE HYDROGEN IONS USING PHOTODETACHED ELECTRONS

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Abstract

An electron of a negative hydrogen ion (H^-) can be easily photodetached by collisions with a laser beam (λ =514.4 nm, 2.4 eV), because its electron affinity is small (0.754 eV). The photodetached electrons have been observed by the laser beam method at the H^- beam energies of 700, 650 and 600 keV, respectively. A preliminary experimental result of an energy analysis of a H^- beam using photodetached electrons is presented.

1 Introduction

In the KEK 12 GeV proton synchrotron (KEK-PS), charge-exchange multiturn injection with a negative hydrogen-ion beam has been used. Good matching between the longitudinal emittance of the injected beam and the longitudinal acceptance of the synchrotron is required to make efficient beam acceleration. For longitudinal matching, the central value of the energy and the energy distribution of the injected beam must be carefully measured. For this purpose, a magnetic energy analyzer at the injection beam line has been used in normal operation. However, during the measurement the beam cannot be injected into the synchrotron.

Recently, measurement of photodetached electrons by laser light has been reported[1]-[3]. By introducing photons corresponding to the binding energy between the atoms and the additional electron, the electron of the negative hydrogen ion is easily detached. To obtain information about the original negative ion beam, the photodetached electron or the atomic hydrogen (H^0) should be measured. If external laser light has a short time width compared with that of a bunched beam from the injector linac, the energy distribution of the beam in each longitudinal position of the bunches can be measured.

We have developed a compact and simple arrangement for measuring the energy and an energy-distribution measurement of a H^- beam using photodetached electrons.

2 Experimental Apparatus

A negative hydrogen ion is an ion with one electron attached to a hydrogen atom with an electron affinity of 0.754 eV. An electron can be easily detached from a negative hydrogen ion by a collision with an laser beam. This photodetached electron has the same velocity as the original negative hydrogen ion, if the energy transfer in the collision is negligibly small. The photodetached electron's energy is much smaller than the energy of the negative hydrogen ion by 1/1838. Since the magnetic field strength needed to analyze this low-energy electron distribution is so small, there is no significant disturbance to the original negative ion beam.

An energy analysing system using a laser beam is shown in Fig. 1. A preliminary experiment was made using the 750 kV preinjector beam line. The preinjector ion source was operated in a pulsed mode with the

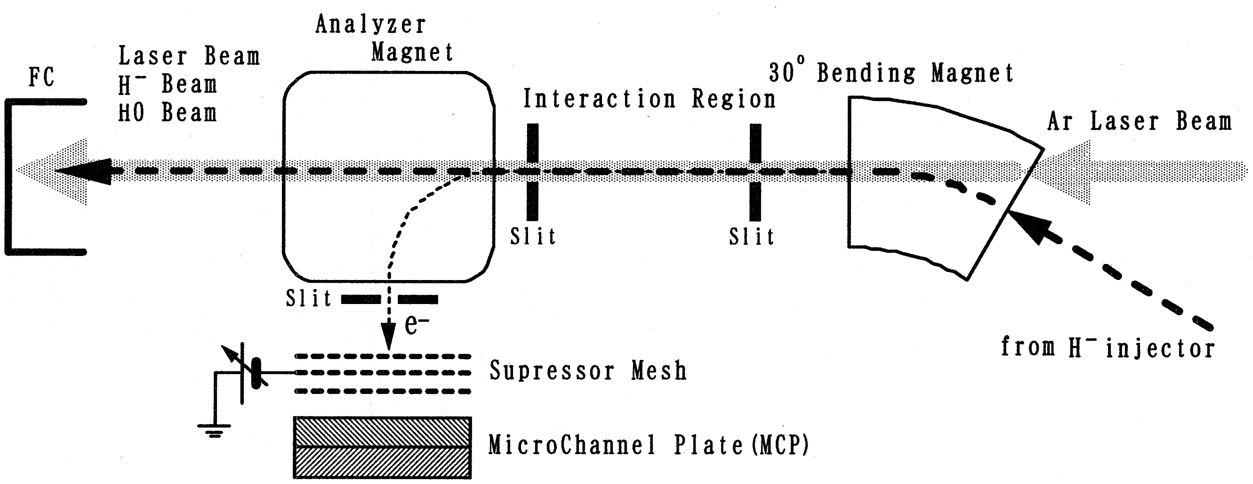

Figure 1: Schematic diagram of the energy analysing system for electrons photodetached from a H^- beam using an Ar laser beam.

pulsed H^- beam width of 200 μsec and a repetition rate of 20 Hz. Three acceleration energies of 700, 650, 600 keV were chosen at this experiment. The beam intensity was kept at about 1 μA during the experiment. After a 30° bending magnet, an analyzer magnet was installed inside the vacuum chamber. Electrons coming from upstream of the beam line could be eliminated with the 30° bending magnet. An Ar laser (λ=514.4 nm, 5W) was used for photodetached. The laser power was 0.3W (6W/cm^2) measured at the FC. The Ar laser beam intercepts a H^- beam at 0° .

This electrons photodetached from H^- ions were deflected by the analyzer magnet. The photodetached electrons were measured by a micro-channel plate (MCP). A suppressor mesh electrode system in front of MCP was installed. By changing a negative voltage to this mesh, the energy distribution of the photodetached electrons can be measured. A small Faraday cup was installed down stream of the chamber to monitor the intensity of H^- beam current during the experiment. Figure 2 shows the energy analysing system placed in the vacuum chamber.

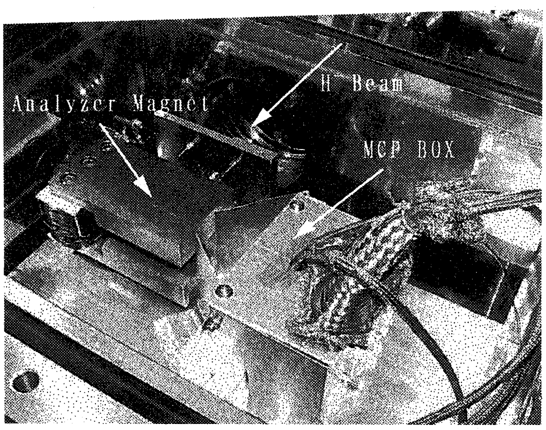

Figure 2: Photograph of the energy analyzing system in the vacuum chamber.

3 Experimental Results and Discussions

In this preliminary experiment, the output voltage from the MCP was measured as a function of the H^- beam energy by changing coil current of the analyzer magnet from 0 to 1000 mA. The suppressor voltage for the low-velocity electrons in front of the MCP was set to −100 V. When an Ar laser beam was injected in to the H^- beam, an increase of the photodetached electrons was observed, as shown in Fig. 3. The position of this peak depended on the energy of the H^- beam. An energy measurement of the photodetached electron was achieved by this retarding method. During this measurement, the current of the analyzer magnet was fixed to obtain a peak of the photodetached electron, as shown in Fig. 3. The suppressor voltage was swept from 0 to −500 V to

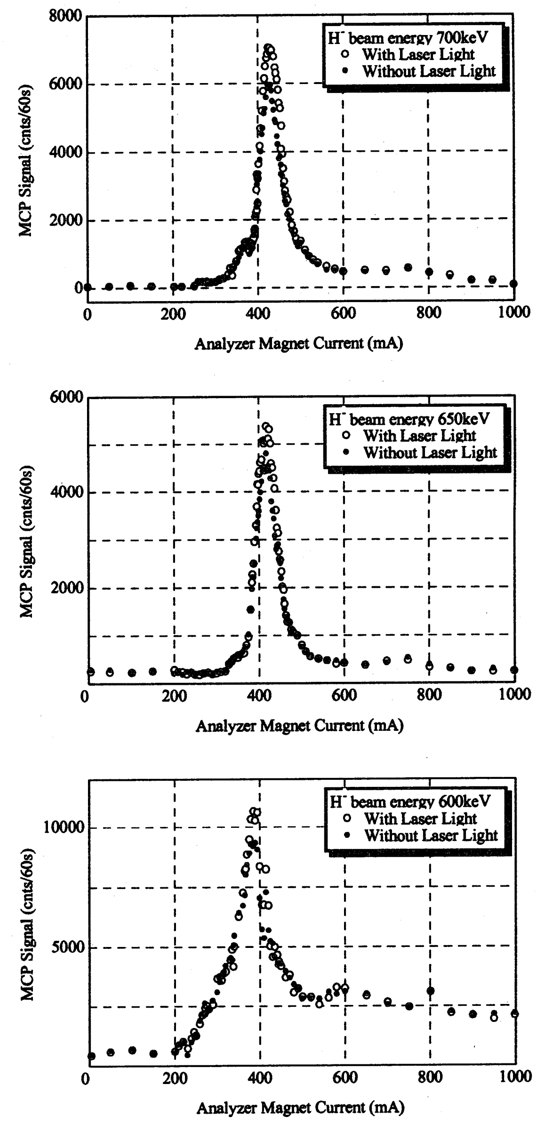

Figure 3: Characteristics of the MCP signal by changing the coil current of the analyzer magnet. The position of this peaks depended on the energy of the H^- beam. During these measurement, the retarding voltage was set to −100 V to reject the low-velocity electron component.

observe the energy distribution of photodetached electrons. Figure 4 shows the example of MCP signals with/without laser light at the H^- beam energy of 700 keV. Figure 5 shows the difference of MCP signals between data with/without laser beam, when the H^- beam energies were set to 700, 650, and 600 keV, respectively, by changing the preinjector accelerating voltage. As the case of a H^- beam energy of 700 keV, the MCP signal decreased rapidly near a retarding voltage of −380 V as shown in figure 5(a). The same tendency appeared for the other two cases. Figure 6 shows the differentiated values of the data of Fig. 5. The peaks of the differential curves appeared at a retarding voltage of 381 eV (FWHM 24 eV) for 700 keV, 352 eV (FWHM 26 eV) for 650 keV, and 332 eV (FWHM 44 eV) for 600 keV, respectively. Figure 7 shows the photodetached electron energies measured by the retarding method versus H^- beam

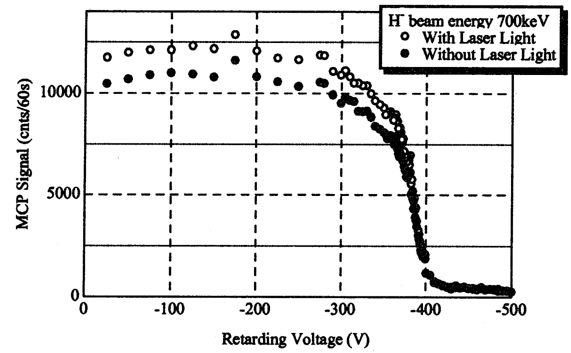

Figure 4: Characteristics of the MCP signal by changing the retarding voltage, when the H^- beam energy was kept to 700 keV.

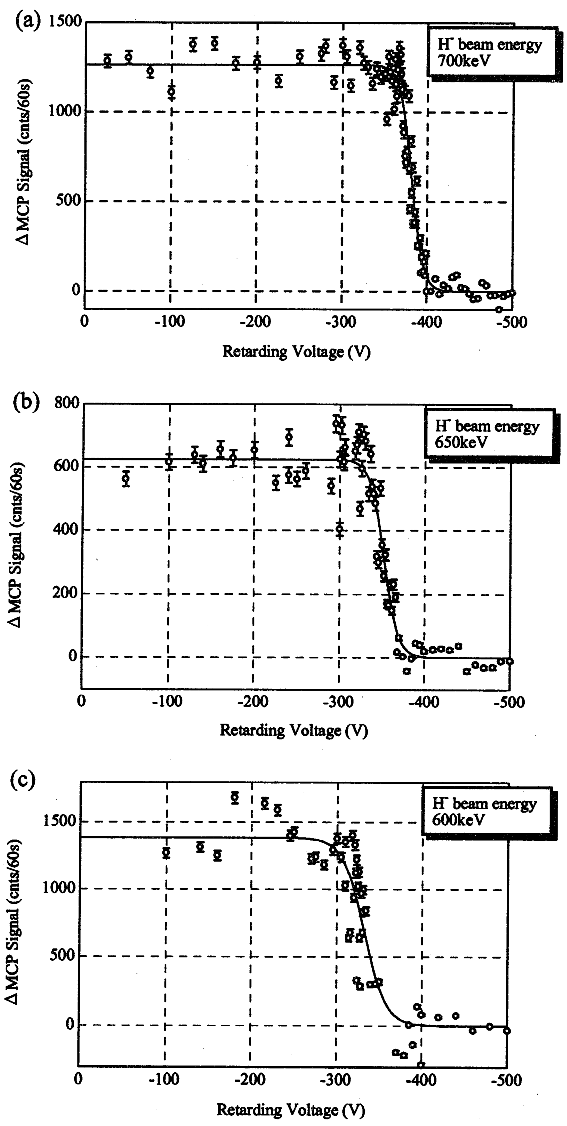

Figure 5: The difference between data with/without laser beam versus retarding voltage. H^- beam energies were set to (a) 700 keV, (b) 650 keV and (c) 600 keV, respectively.

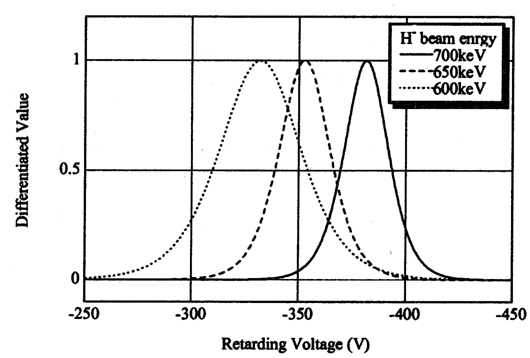

Figure 6: Differentiated value of the data in Fig. 5.

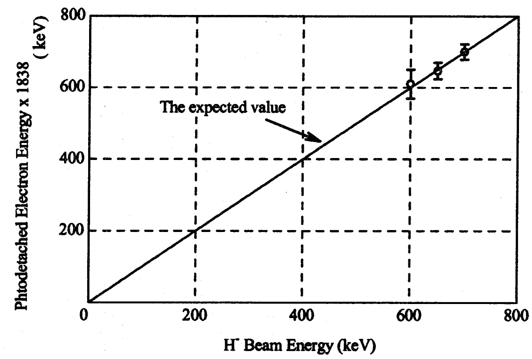

Figure 7: Correlation between the H^- beam energy and the photodetached electron energy by retarding method. The plotted points are the data obtained from Fig. 6.

energies. The plotted points are the data obtained from Fig. 6. The linearity between the measured energies of the photodetached electrons and the given energies of H^- ions seems to be well with the errors of less than 8%. In this analysis, the energy-transfer effects at collisions between a H^- ion and a photon is negligible in this experiment. This may be supported because we have measured very forward-direction electrons.

4 Conclusion

A simple apparatus enabled the use of a photodetached electron to perform an energy analysis with an error of less than 8% in this experiment. With this device, we could easily observed photodetached electrons from a H^- beam by the laser light method. Farther improvement of the energy analysis by use of the retarding method is expected to provide better measurements.

6 References

[1] P. G. Harris *et al.*, Nucl. Instrum. Methods Phys. Res. A 292, 254 (1990)

[2] D. P. Sandoval, AIP conference proceedings 333, 445 (1995)

[3] R. E. Shafer, AIP conference proceedings 451, 191 (1998)