STATUS REPORT OF THE RAL PHOTO–DETACHMENT BEAM PROFILE MONITOR*

C. Gabor†, STFC, ASTeC, Rutherford Appleton Laboratory (RAL), Oxfordshire, UK,
G.E. Boorman, A. Bosco, Royal Holloway, University of London, UK
J.K. Pozimski, P. Savage, Imperial College London of Science and Technology, Blackett Laboratory, UK
A.P. Letchford, STFC, RAL Isis Neutron Source, Oxfordshire, UK

Abstract

The Rutherford Appleton Laboratory (RAL) is developing a front end suitable for High Power Proton Applications HPPA. The main components are an H^- ion source with up to 60 mA current at 65 keV, a transport section to match the beam to an RFQ with 3 MeV output energy and a LEBT comprising a chopper system with several buncher cavities. Photo detachment can be used as a non-destructive diagnostics method. The paper reports on progress with a beam profile monitor that is placed in a pumping vessel right after the ion source at the intersection to the Low Energy Beam Transport (LEBT). This diagnostics tool consists of mirrors inside the vacuum to scan the laser beam through the beam, the actual detector to measure photo detached electrons, laser and optics outside the vacuum and electronics to amplify and read out the signal. The paper summarizes the experimental set-up and status, discusses problems and presents recent measurements.

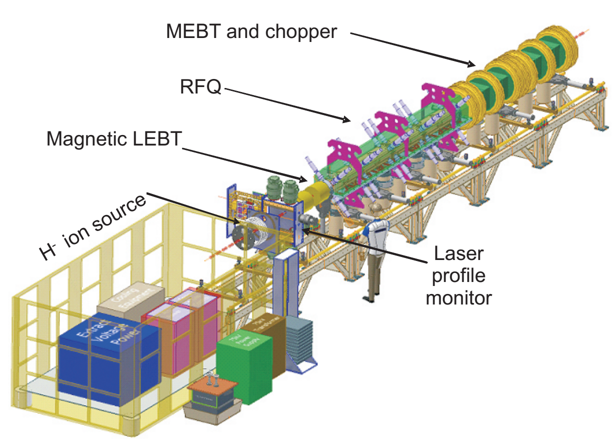

Figure 1: Overview of the FETS set up. The main elements are a Penning type ion source, 3 solenoid LEBT, RFQ and the MEBT consisting of quadrupoles, four buncher cavities and a combined slow/ fast chopper. It is intended to use photo–detachment as a non–destructive diagnostics method applying to a beam profile monitor and an emittance scanner at 3 MeV beam energy.

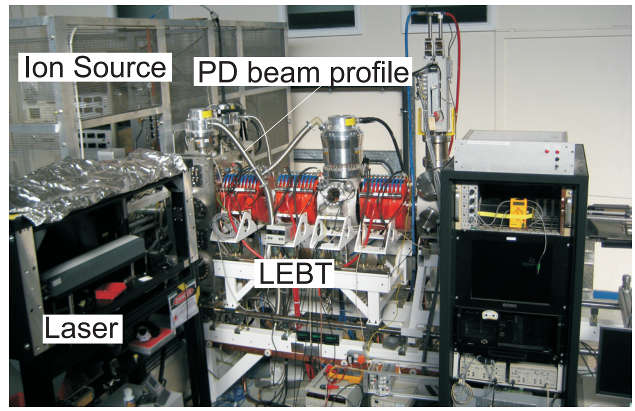

Figure 2: Recent set-up of ion source, differential pumping vessel which hosts also the beam profile monitor.

INTRODUCTION

High Power Proton Particle Accelerators in the megawatt range have many applications including drivers for spallation neutron sources, neutrino factories, transmuters (for transmuting long-lived nuclear waste products), and energy amplifiers[2, 3]. FETS is RALs contribute to the development of HPPAs but also to prepare the way for an upgrade to the Isis accelerator and to contribute to the U.K. design effort on neutrino factories.

The Front End Test Stand FETS project[1], located at RAL, is to demonstrate that chopped low energy beams of high quality can be produced. FETS (see Fig. 1) consists of a 60 mA Penning Surface Plasma Ion Source, a

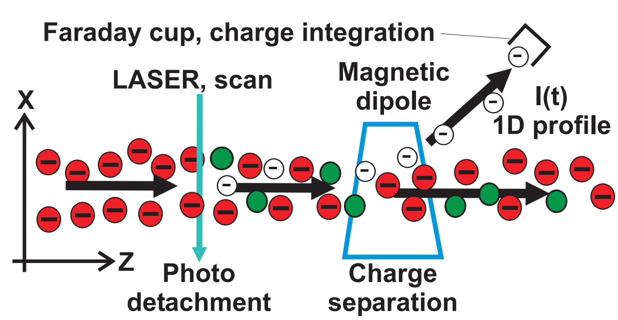

Figure 3: Basic principle of photo detachment ion beam diagnostics The H^- ions get neutralized by laser light. The diagnostics is in general a three stage process: detachment, charge separation and detection.

* work supported by Institute of Applied Physics with a laser loan
† christoph.gabor@stfc.ac.uk

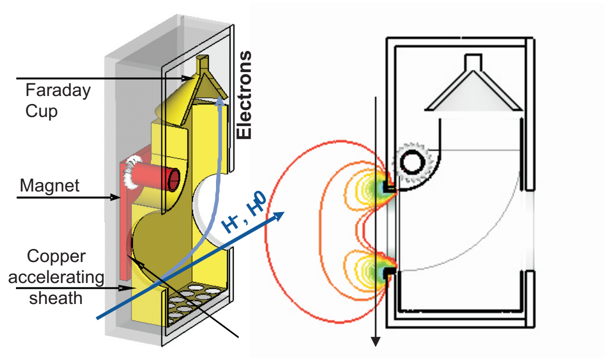

Figure 4: Schematics of the detector with simulations of the electrostatic suppression ring.

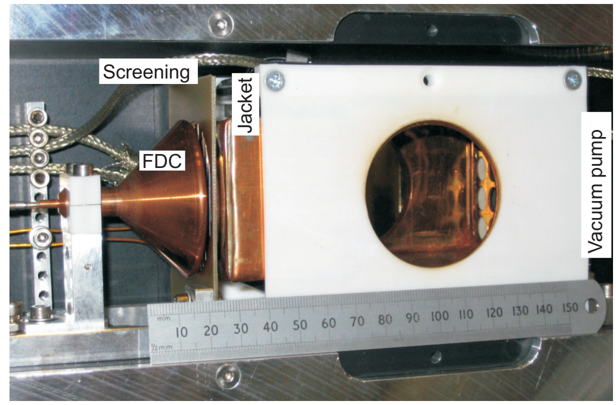

Figure 5: Photograph of the electron detector, view from the back. The opening for the ion beam is 50 mm in diameter.

three solenoid low energy beam transport, a 3 MeV four-vane radio frequency quadrupole RFQ, a combined a fast/ slow electrostatic chopper, and a comprehensive suite of diagnostics. This paper details the status of the beam profile monitor and reports some of the first measurements to proof photo–detachment experiments on the FETS beamline.

At the time of writing the ion source, LEBT and a diagnostics vessel with pepperpot and two slit–slit scanners are operational. Design of the chopper and RFQ are well progressed and the RF system for the RFQ has been commissioned to 1 MW. The latest status and overview can be found in [4].

Photo–Detachment is a common way to replace traditional, destructive beam diagnostics, having the advantage not to penetrate the beam with any mechanical part. Motivations can be either of technical (avoiding heat load on slits, wires, etc.) or physical nature (reducing beam perturbation to a minimum). This as motivation Imperial College launched with a Ph.D. activities on that field with the aim of a 2D beam profile monitor applying a tomographic method and an emittance instrument [5]. Whereas the "proof or principle" for the emittance scanner has been demonstrated [6] and developed further to a 4D emittance scanner ([7, 8] a concept and technical design of a 2D scanner has been worked out and built [9], supervised by Imperial College. In the more recent past RAL/ RHUL took care about all changes and measurements presented here, that includes especially an improved version of the electronics and laser (optics) related issues.

Photo–Detachment Beam Diagnostics

Photo–Detachment means that the energy of photons is sufficient that a (weakly) bonded electron of negative ions can be dissociated. For H^- the binding energy of the 2nd is about 0.75 eV thus photons beyond this threshold are able to neutralize ions $H^- + \gamma \longrightarrow H^o + e^-$ and a maximum of $\sigma = 4.0 \times 10^{-17}\, cm^2$ can be found [10].

The basic principle of utilizing photo–detachment for beam diagnostics is illustrated in Fig. 3. Compared to more common devices like a (wire) profile monitor or an emittance scanner the laser neutralizes only a small portion of the beam without interfering with the beam elsewhere. The charge separation can be carried out either electrostatic or magnetically in a way that most of the beam should be transported through the instrument without influence. The actual diagnostics is then carried out with the detached electrons done with a Faraday cup and suitable electronics[1].

EXPERIMENTAL DESIGN

The detector is installed in the differential pumping tank between ion source and LEBT (see Fig. 1). It is extensively described in David Lee thesis [11] and more recent changes relevant for the measurements here are discussed in [12].

The actual particle detector is shown in Fig. 4 and 5 and uses a small dipole I to separate the detached electrons from the rest of the beam.

Since the energy of the detached electrons is not more that 40 eV it was thought that a post acceleration ("jacket" J) up to a level of 2 keV is necessary. A suppression ring S is placed at the entrance of the dipole creating a potential wall for negative particles produced due to residual gas stripping further upstream. The detachment region is where the two superimposed potentials of opposite polarity S and J create a dip. Further parameters are the biased voltage B of the Faraday cup and the grid G in front of the cup hole acting as a secondary suppression. Comprehensive simulations performed by D. Lee have shown best electron acceptance with I =1 A, S =-500 V, J =2000 V, G =250...400 V and B =500 V.

Paying tribute to the space restrictions given by the position between ion source and first solenoid the design had to be very compact consequently, the clearance for the beam is of not more that 50 mm across the opening.

[1] other principles might be common, e.g. to measure the emittance

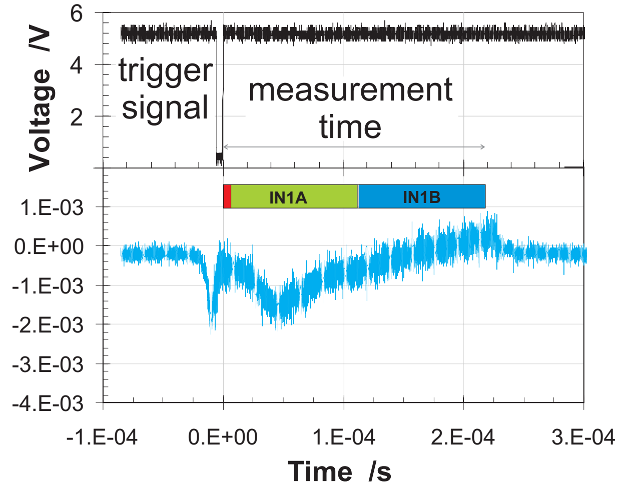

Figure 6: Triggering of the electronics and integration cycles of the ADC. Between the rising edge of the trigger and the start of the integration is a delay of 6.3µs. The lower scope trace shows a typical background signal (∝ voltage drop on 50Ω).

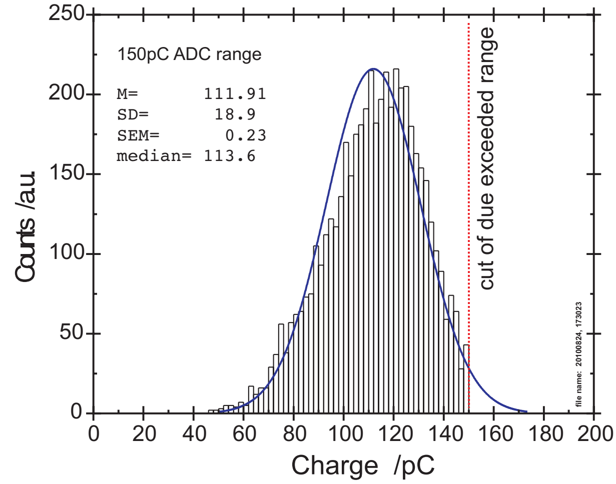

Figure 7: A typical distribution of measured charge, here shown as background (no laser, $I = .335\,A$, $B = 89\,V$, $G = 155\,V$, total measurement time $t = 203$ sec,"B–cycle").

Since the laser originally bought for the diagnostics is not powerful enough and the time jitter is far to high RAL appreciates the Institute of Applied Physics IAP, Goethe–University Frankfurt, made kindly a more suitable laser available. This is a *cw* laser and boosts the power from 500 mW up to a maximum of 10 W, the optics was adopted to $\lambda = 1030$ nm and keeps the laser on a fixed, central position.

MEASURED RESULTS

Charge Integrator The electronics is capable to run with up to 25 Hz, the actual measurement range is determined with 7 different capacitors between 50. . . 350 pC. This range is then digitized with a resolution of 20 bit. The ADC has two integration cycle *A* and *B* each 103 µs long (see Fig. 6, in between is a negligible gap to switch from one to the other cycle. The whole integration period can be moved throughout the whole signal by varying a trigger pulse, also shown in Fig. 6. Since there is always more ringing at the beginning of the pulse the integrations covers only the last 200 µs. Shape and height of the signal depend strongly of all detector settings and the signal would exceed drastically digestible charge of the ADC for nominal design values ([12]. Therefore the background should always close to zero and should be checked for every measurement and settings.

Reason for this behaviour is the change in compensation level, hence beam expanding follows and this leads in combination with the small opening to high beam losses of up to 50% [13].

The only way to operate the detector with amplifier is to find experimentally settings for *J*, *S*, *G*, *B*, *I* with reasonable small background on the one hand and on the other hand just enough "guidance" for the detached electrons to be trapped with the FDC without interfering with the H^- beam to much.

Noise A typical distribution is shown in Fig. 7 which has taken just the background PD_{bck} without laser. The distribution consists of about 5000 measurements, the broken symmetry is down to the capacitance of 150 pC. The width of the bell curve represents the noise of the detector FDC and is rather large. Qualitatively, several reasons can be identified:

- rise time of the extraction power supply changes plasma meniscus and hence current and emittance
- plasma instabilities produce a source noise which is expressed by current fluctuations of ≈10 %
- high–voltage breakdowns happen regularly; recovery takes a few pulses
- beam loss causes secondary particles by interacting with the surfaces and amplifies the noise already existing
- it is possible that the power supplies used for the detector electrodes add another layer of noise but is hardly possible to quantify
- over longer periods (e.g. minutes & hours) and from day to day and from source to source the level (mean) of the background PD_{bck} can vary a lot

It should be noted that the noise discussed here is not necessarily the H^- ion beam noise because of the secondary effects produced by the beam loss.

Sparking Despite beam loss and a signal well beyond the ADC's measurement range Fig. 8 shows the most strongest argument to move away from nominal design settings. It is shown voltage which builds up if the jacket *J* or the suppression ring *S* exceed a voltage of about $J \geq 80\,V$ and $S > 110\,V$. The high voltage pulse is measured with a probe 1000:1 on a scope between the FDC

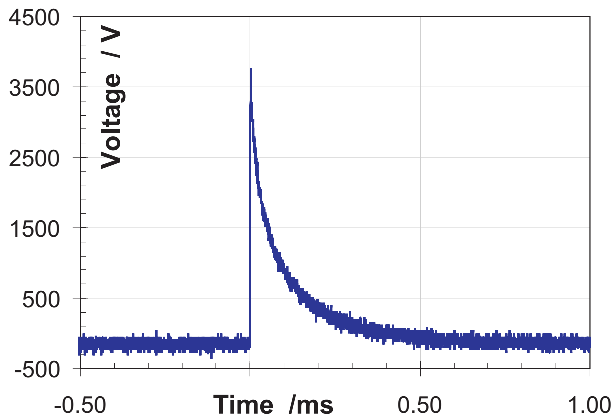

Figure 8: High voltage pulse, measured with a 1000:1 probe between BNC vacuum feed through coming from the FDC and ground outside the vessel.

output and ground. The HV–pulse varies depending on J and S but it is repeatable within roughly a few seconds and will destroy in any way the amplifier. The time dependence may imply a charge effect. It should be mentioned that no burn marks can be encountered and without beam the whole system can hold far higher voltages, e.g. $J > 2500\,V$, $S > 800\,V$, $G > 600\,V$.

Photo–Detachment Results If you compare the background measurements PD_{bck} with the number theoretical possible photo–detached electrons you would need 20. . . 30 W laser power minimum to produce ≈20 pC. Since the starting distribution of the electrons is not known and their birth potential is only 40 eV it is very difficult to make predictions about the number of collected electrons in practice.

In Table 1 the PD_{bck} is subtracted from the laser measurements PD_{laser} and the difference Δ_{mean} and its standard deviation error SDE_{mean} are compared. Advantage here is reasonable high number of observations to keep the SDE_{mean} small. But the different measurements (1 + 2 and 3 . . . 5 at different days but with same source settings) show also the problem of not constant background and (non–linear) behaviour of the detector ($1+2$ vs. $3+4$). Especially the combination of bias and grid show a significant influence. It might be counter-intuitive to measure more charge than with a 6 W laser actually is possible but some electrode/ detector settings work apparently in a way that additional secondary particles will contribute to the signal. This has to be chosen very careful otherwise the accumulated charge may cause problems with the ADC.

SUMMARY & OUTLOOK

The paper presents the experimental status of the tomographic beam profile monitor. The primary focus was on measuring photo–detached electrons with the existing detector design (“proof–of–principle”). A small but repeatable effect between PD_{bck} and PD_{laser} can be verified but all measurements suffer heavily under large (moving) background and not neglectable standard deviation.

Table 1: Summary of Some Measurements. Shown the difference $\Delta = PD_{bck} - PD_{laser}$ and some numbers computed with descriptive statistics. Due to high voltage sparking J and S were not in use if the amplifier was connected.

	No. 1	No. 2	No. 3	No. 4	No. 5
Range /pC	150	100	350	150	150
P_{laser} /W	6.62	6.62	6.4	6.5	3.55
Δ_{mean}	1.84	2.17	46.0	56.9	16.88
Dipole I /A	0.62	0.62	0.41	0.34	0.34
Grid G/V	109	109	159	155	155
Bias B/V	0	0	89	94	94

There might be a few more possibilities like improving the statistics and testing more detector settings but it is believed that just a more powerful laser is not a sustainable path because its actual the detector which is driven to its limits. It has been turned out that the idea of post–acceleration in combination with a rather limited acceptance for the H^- beam is very challenging to run reasonable. If the aim is to build non–destructive beam diagnostics then significant beam losses are not acceptable, and therefore a redesign is necessary.

The present campaign will come to an end shortly because of the termination of the laser loan. The remaining time will be used to carry on with measurements varying different parameters (laser, detector, beam) to improve the statistics.

In future it looks advisable to appreciate the experience and move the diagnostics to a more convenient place with less geometric restrictions. It is also wishful to develop new design of the detector to reduce the influence onto the beam. Ideally, the new detector should cover the full energy range of the FETS beamline from 70 keV till 3 MeV.

Regarding the original aim of having a beam profile monitor a more powerful laser (pulsed) would also help to overcome the background problems.

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