ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME191

SIMULATION RESULTS OF THE FETS LASERWIRE EMITTANCE SCANNER

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Abstract

The Front End Test Stand (FETS) at Rutherford Appleton Laboratory (RAL) has been developed to demonstrate a high current (60 mA) H^- beam with the energy of 3 MeV that will be required for future proton drivers. At such high power beam machine a non-invasive diagnostics is required. To measure the emittance of the ion beam a laserwire scanner is being developed. A low power laser will scan across the H^- ion beam. The H^-particles will be neutralized via a photo-detachment process producing a stream of fast neutral hydrogen atoms bearing information about the phase space distribution of the initial H^- beam. To design an effective detection system and optimize its parameters a simulation of the processes at the interaction point is required. We present recent simulation results of the FETS laserwire system. Simulations were performed using measured data of the laser propagation and ion beam distribution, obtained with General Particle Tracer code.

INTRODUCTION

The Front End Test Stand built in collaboration between ISIS, ASTeC, Imperial College London, University of Warwick, University College London and John Adams Institute at Royal Holloway, University of London is designed to create a high quality, low emittance, high current, high duty factor H^- beam required for wide variety of future proton-accelerator projects such as ISIS upgrades, future Spallation Neutron Sources, a Neutrino Factory, Muon Collider, Accelerator Driven Sub-critical Systems and Waste Transmuters [1, 2]

Setup

The FETS consists of a caesium-enhanced penning surface plasma H^- ion source [3], a three-solenoid magnetic low energy beam transport (LEBT) [4], a 324 MHz, 4 metre radio frequency quadrupole (RFQ) [5], an electromagnetic quadrupole and rebunching cavity medium energy beam transport (MEBT) [6] and laser diagnostics section. The schematic layout of the main elements presented in Fig. 1.

Laser Diagnostics Concept

To measure the transverse emittance a laser system, based on photodetachment of the electrons from the H^- ions has been proposed. The basic concept the following: a low power (~8 kW peak power), infrared (1080 nm) fibre coupled laser focuses in the interaction point down to ~ 150 μm and collides with the ion beam neutralizing negative ions. Measuring the angular distribution of the neutral particles by the detector while the laser scanning across the ion beam one can measure the transverse phase space and subsequently reconstruct the transverse beam emittance.

In order to reduce the background of the neutral particles generated by stripping the residual gas, the interaction point is located inside the dipole magnet. Such geometry allows to separate neutrals coming from laser stripping and from the background.

The laser system has been already assembled and tested on 3 MeV H^- beam at Linac 4 (CERN). Description of the laser system as well as the results of the measurements can be found in [7].

Table 1: Parameters Used for Simulation

Parameter	Value
Laser wavelength	1080 nm
Laser micropulse width	110 ns
Laser macropulse width	2 ms
Laser peak power	~8 kW
Laser pulse repetition rate	30 kHz
Laser beam waist (σ_{lx}=σ_{lz})	~150 μm
Ion beam energy	3 MeV
Ion beam current	60 mA
Ion beam micropulse width	~3 ns
Ion beam macropulse width	2 ms
Ion beam waist:	
σ_{by}	3.87 mm
σ_{bz}	4.38 mm
Photo-ionization cross-section	3.613056×10^{-17} cm^2

SIMULATION RESULTS

To estimate the number of neutralized particles produced due to interaction of laser and ion beam one can use the following formula [8]:

$$N_{det} = c\Sigma_0 \int dt \int d^3x \quad n_l(x,y,z,t) n_b(x,y,z,t), \quad (1)$$

where c - speed of light, Σ_0 - photo-detachment cross-section, n_l and n_b - number of photons and ions per pulse per unit of volume respectively. Assume that both laser and ion beams have 3D gaussian distribution:

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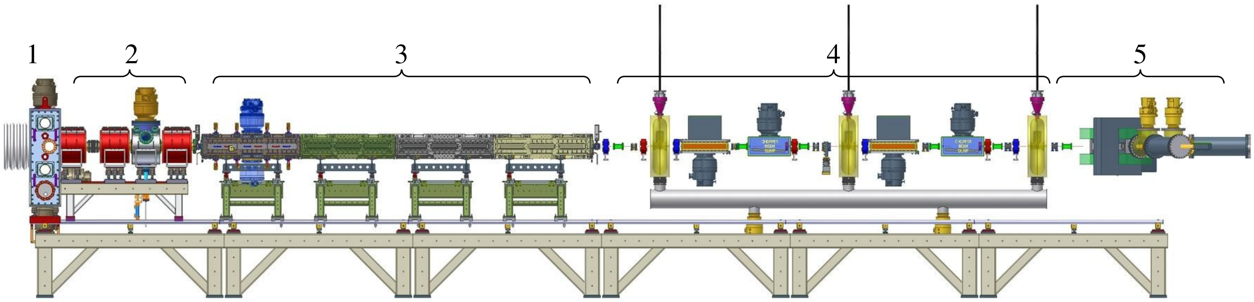

Figure 1: Schematic layout of the FETS (1 - ion source, 2 - LEBT, 3 - RFQ, 4 - MEBT, 5 - Laser diagnostics).

$$n_l(x,y,z,t) = \frac{N_l}{(2\pi)^{3/2}\sigma_{lx}\sigma_{ly}\sigma_{lz}} \times \times \exp\left(-\frac{x^2}{2\sigma_{lx}^2} - \frac{(y-ct)^2}{2\sigma_{ly}^2} - \frac{(z-\delta)^2}{2\sigma_{lz}^2}\right). \quad (2)$$

$$n_b(x,y,z,t) = \frac{N_b}{(2\pi)^{3/2}\sigma_{bx}\sigma_{by}\sigma_{bz}} \times \times \exp\left(-\frac{(x-\beta ct)^2}{2\sigma_{bx}^2} - \frac{y^2}{2\sigma_{by}^2} - \frac{z^2}{2\sigma_{bz}^2}\right). \quad (3)$$

Here $N_l(N_b)$ - total number of photons (ions), $\sigma_l(\sigma_b)$ - RMS beam size of the laser (ion beam) and δ - vertical position difference between ion and laser beam centres. Coordinate system has been chosen in such a way that the ion beam moving along x - axis and the laser beam moving along y - axis. Substituting (2) and (3) into (1) one can get the total number of neutralized particles:

$$N_{det} = \frac{N_b N_l \Sigma_0}{2\pi} \exp\left(-\frac{\delta^2}{2\left(\sigma_{lz}^2+\sigma_{bz}^2\right)}\right) \times \times \left(\frac{\left(\sigma_{lz}^2+\sigma_{bz}^2\right)\left(\sigma_{bx}^2+\beta^2\sigma_{ly}^2\right)\left(\sigma_{lx}^2+\sigma_{bx}^2+\beta^2\sigma_{ly}^2\right)}{\left(\sigma_{bx}^2+\beta^2\sigma_{ly}^2\right)} \times \times \frac{\left(\sigma_{bx}^2+\sigma_{lx}^2+\beta^2(\sigma_{ly}^2+\sigma_{by}^2)\right)}{\left(\sigma_{bx}^2+\sigma_{lx}^2+\beta^2\sigma_{ly}^2\right)}\right)^{-1/2}. \quad (4)$$

The exponential term in Eq. 4 demonstrates that the resultant beam size measured in an experiment is a combination of laser size and ion beam size: $\sigma^2 = \sqrt{\sigma_{lz}^2+\sigma_{bz}^2}$.

To estimate the number of neutralized particles one can use Eq. 4. Parameters for the FETS laserwire system are presented in Table 1. The cross-section of the photodetachment process can be obtained using data from [9]. Σ_0 was computed using the following fit function (see Fig. 2):

$$f(x) = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4. \quad (5)$$

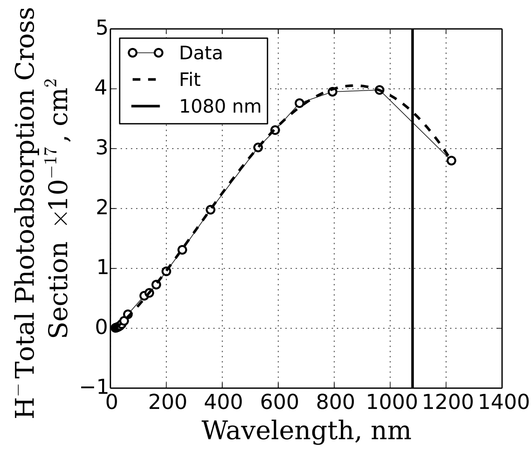

Figure 2: Total photodetachment cross-section (data from Table IV in [9])

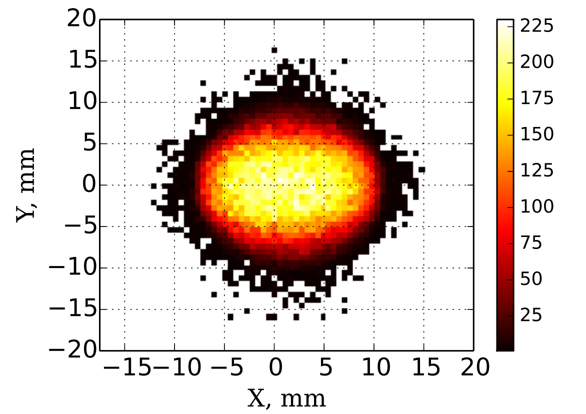

Figure 3: Distribution of the H^-ions at the laserwire interaction point.

Here a_0,...,a_4 are free fit parameters. Substituting these parameters in Eq. 4 one can obtain 1.83×10^5 neutral particles produced in one interaction. To calculate the total number of neutralized particles per laser macropulse per ion beam macrobunch let's take into account that one laser macropulse consists of $\sim$ 66 micropulses. Each of them interacts with $\sim$ 36 ion beam microbunches. Thereby, total number of neutral

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particles per laser macropulse per ion beam macropulse $\sim 4.37\times10^8$.

In order obtain a distribution of the neutralized particles at the detector plane one can calculate a stripping probability for each particle in the initial distribution at the interaction point [10]:

$$p_{strip} = 1 - \exp\left(\sigma(E)\rho t\right). \tag{6}$$

Here $\sigma(E)$ - photodetachment cross-section, ρ - laser photon flux, t - interaction time of the ion with the laser beam. The distribution of the H^- ions at the laser interaction point (Fig. 3) was obtained using a General Particle Tracer [11] code, that simulates the propagation of the ions trough the lattice with real parameters. Each particle of the initial distribution was weighted with its stripping probability. After a drift of about 0.5 m from the IP towards detector the weighted particles were integrated. The resultant distribution of the neutralized particles at the detector for different vertical laser centre positions in range from -10 mm to 10 mm with step of 2.5 mm is presented in Fig. 4. The laserwire scan (number of neutralized particles as a function of the laser centre position) is presented in Fig. 5.

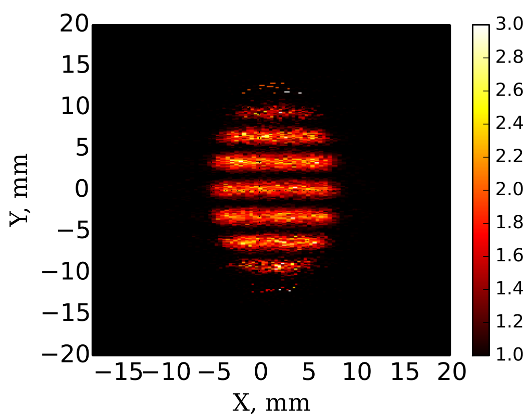

Figure 4: Distribution of the neutral particles at the laserwire detector plane (0.5 m behind the IP) for different laser positions (δ).

SUMMARY

In this paper we presented recent simulation results of the FETS laserwire emittance scanner. An algorithm that takes into account real laser and ion beam parameters for the estimation of the yield of H^0 particles produced in the laserwire interaction has been developed. Total yield of the neutralized particles arriving at the detector has been estimated as $\sim 10^8$ neutral particles per ion beam pulse. The distribution of the neutral particle density on the detector has also been simulated. Presented results should be taken into account in order to choose a correct detector type as well as its size and position from the IP.

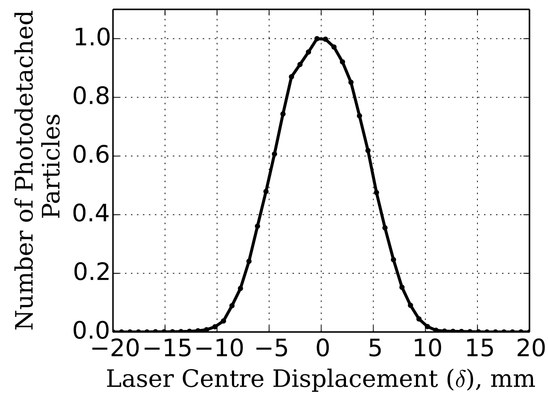

Figure 5: Number of neutralized particles (normalized) as a function of laser beam center displacement

ACKNOWLEDGEMENTS

This research was partially supported by the oPAC: FP7 Marie Curie Initial Training Network under contract PITN-GA-2011-289485

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