Spectral and angular characterization of laser-produced proton beams from dosimetric measurements

E Breschi

Dipartimento di Fisica, Università degli studi di Siena, via Roma 56, 53100 Siena, Italy

M Galimberti†, D Giulietti†, L A Gizzi

Istituto per i Processi Chimico-Fisici, via G. Moruzzi 1, 56124 Pisa, Italy

†also at Dipartimento di Fisica, Università degli studi di Pisa, Pisa, Italy

M Borghesi, L Romagnani, S Kar

Queen's University of Belfast, Belfast, BT7 1NN, UK

A Schiavi

Dipartimento di Energetica, Università "La Sapienza„ di Roma, via A. Scarpa 14, 00161 Roma, Italy

O Willi

Heinrich-Heine-Universität Düsseldorf, 40225 Germany

Main contact email address: *m.galimberti@ipcf.cnr.it*

Introduction

When an ultra-intense laser pulse is focused on a solid target a sizeable fraction of the laser energy is transferred to charged particles1). In particular, the generation of multi-MeV proton beams has been observed. Such proton beams are now under consideration for application in radiotherapy as well as medical diagnostic. In spite of the growing interest on laser produced proton beams, the physical mechanisms of generation and acceleration of such protons is only partially understood.

During a series of experiments at the CLF, the Vulcan Nd: glass laser operating in the Chirped Pulse Amplification mode was used to investigate this mechanism. The targets used for the production of the proton beams were 1 mm wide and about 1 cm long Al foils. The target thickness was 25, 100 or 250 µm. The energy of the laser pulse was about 100 J. The diameter of the focal spot on target was about 10 µm (FWHM) containing almost 40% of the energy. The duration of pulse was 1 ps allowing intensities up to 10^{19} Wcm^{-2}. The protons were detected using several layers of Radio-Chromic Films (RCF). A schematic experimental setup is shown in Figure 1.

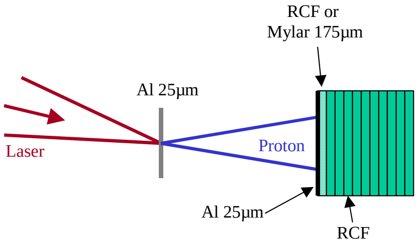

Figure 1. Experimental setup for the detection and characterization of proton beams.

Proton detection

A fundamental step towards the experimental characterization of laser produced proton beams is the use of a detection technique capable of providing good spatial and spectral resolution in single shot measurements and in the presence of the large electromagnetic noise typical of high power, ultrashort laser interaction experiments.

The detection technique based on RCF exploits the proportionality between the optical density (OD) variation of active layers and the energy deposited locally by the impinging particle beam (absorbed dose). The main disadvantage in the use of RCF is that from the signal recorded it is not possible to discriminate between different types of ionizing particles (electrons, protons or other kind of ions). Therefore, additional measurements, possibly based upon track particle detectors (e.g. CR39) are used to identify the nature of particles.

A straightforward interpretation of data from RCF does not immediately provide complete spectral information. A numerical analysis is required in order to reconstruct the proton beam spectrum. An algorithm was developed2) to reconstruct the energy-dependent proton density. The main idea behind the algorithm is to reconstruct the proton angular distribution and spectrum at a particular sampling energy. The choice of this energy value is obtained by comparison with the response of the detector to monochromatic and mono-directional protons beams. The numerical expression of the detector response is calculated by means of a Montecarlo simulation. The algorithm has been tested on simulated data and preliminary application to real data has been performed3). From the preliminary analysis of the performance of the algorithm we found that the main source of error in the numerical reconstruction of the proton beam spectrum is due to the digitization of the RCFs (scanned image). In the preliminary tests the scan was done with an 8 bit commercial scanner. In order to reduce the noise due to the digitization process and to increase the accuracy of the measured dose from the RC films a CCD-based home-made scanner has been developed.

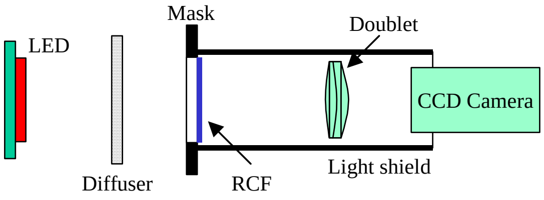

Figure 2. Setup of the scanner used to digitize the RCF.

The scheme of the scanner is shown in Figure 2. The light source used was a red LED (λ_c=625nm and width $\Delta\lambda_{1/2}$=45nm) chosen to maximize light absorption by the RCFs. The light transmitted by the RCF was collected by a high quality digital CCD camera (with 16 bit nominal dynamic range). Particular attention was taken to shield the camera from diffused light. The spatial calibration of the detector was done by scanning a calibrated grid. An image of an unexposed RCF was recorded and used as a reference in order to isolate the film background from the ionizing radiation signal deposited on the RCFs.

Experimental data

In this report we consider data from two shots taken under similar experimental conditions (shot nos. 190206 and 190208). In both cases the target was a 25 µm thick piece of Al foil. The

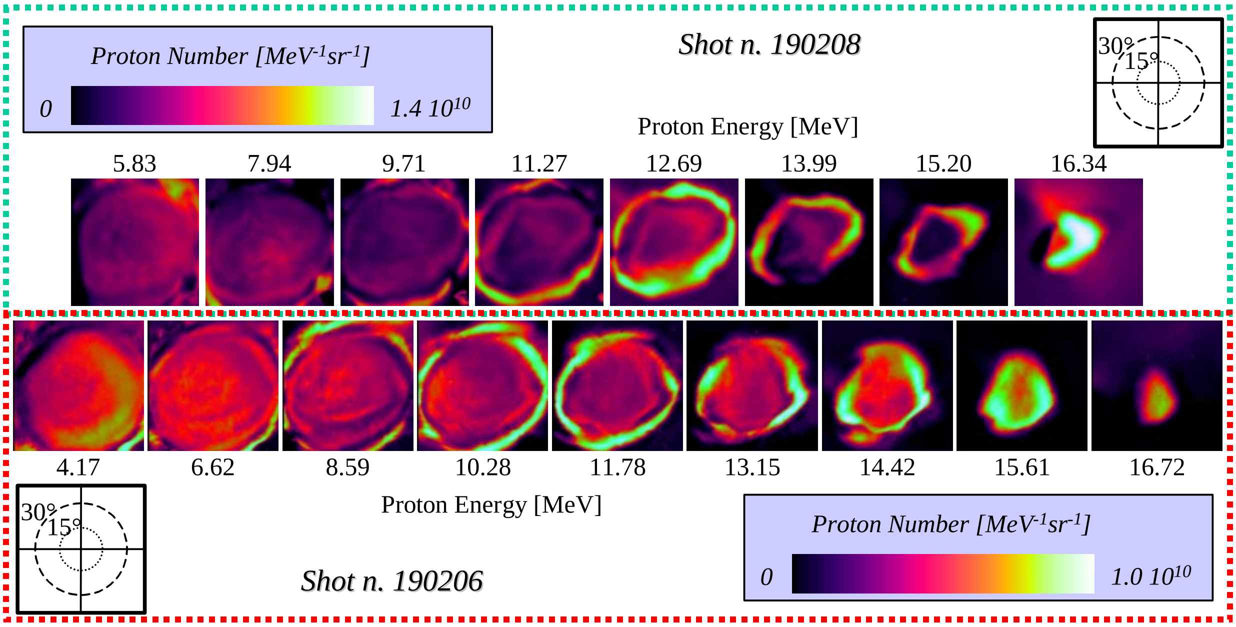

Figure 3. Angular distribution at different proton energies for the two shots.

generated proton beams were detected using a stack of RCF type MD-55 by Gafchromic. The only difference between the two shots is that in shot no. 190208 the first layer of RCF was replaced by a foil of Mylar 175 µm thick (see Figure 1). The effect of the Mylar layer on the analysis is to increase the energy values chosen for the sampling. In both cases, a layer of Al (25µm thick) was placed in front of the detector stack in order to protect the RCF from the laser light.

The numerical reconstruction of the proton beam profile is reported in Figure 3 where the angular distributions of the protons at the sampling energies for both shots are shown. These maps show clear evidence of a ring where the proton density is enhanced, with a decreasing radius for increasing proton energy, as previously observed with CR39 detectors[4)].

Integrating the angular distribution over the whole beam yields the total spectra of the proton beams, as shown in Figure 4a. A comparison of the two spectra shows that the spectrum of the shot no. 190208 exhibits two peaks roughly at 13MeV and 16MeV. By selecting the angular region in which the most energetic protons are found, (see Figure 5), we obtain the spectra reported in Figure 4b. Shot no. 190208 clearly shows a peak at about 16 MeV. The protons in the central part of the beam have a well- defined quasi-monochromatic component, close to the maximum proton energy of the beam, with a roughly constant low energy tail.

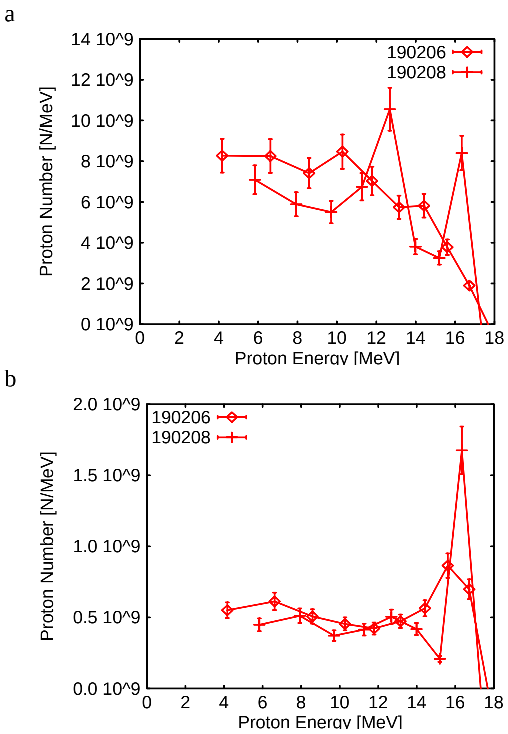

Figure 4. Integrated spectra of protons for both selected shots: a – integrated on the observed area; b – selected region.

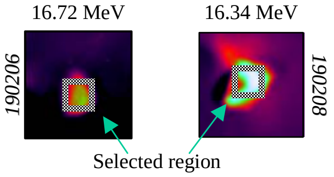

Figure 5. Selected angular region.

Shot no. 190206 shows a similar spectrum for energies up to 14 MeV. A broad peak at 16 MeV, although less pronounced than in the previous shot, is also observed. The broadening could also be explained by the limited number of sampling points that did not enable an accurate reconstruction of the spectrum around the 16 MeV energy.

Conclusion

A set of RCF data on proton beam generation acquired during a series of experiments at Vulcan has been analysed using a custom-developed scanner and a numerical code. The spectra and the angular distribution obtained from the data show that protons are emitted with a quasi-monochromatic component localised at the center of the beam. The detection of this component, however, depends critically on the position of the energy sampling points, fixed by the setup of the RCF stack.

References

1. S.J. Gitomer *et al.*, Phys. Fluids, 29, p. 2679 (1986)

2. E. Breschi *et al.*, Nuclear Instr. and Methods A, 522, p. 190 (2004)

3. E. Breschi *et al.*, Laser and Part. Beams, 22, p. 393 (2004)

4. E.Clark *et al.*, Phys. Rev. Lett., 84, p. 670 (2000)