# High energy electron measurements in relativistic interactions with underdense plasmas

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## Introduction

In a previous experiment [1)] on the propagation of an intense short pulse (50J, 1ps) in a preformed channel created by a precursor pulse (25J, 1ps) clear evidence was found of a correlation between fast electrons generated by the interaction and the "age" of the channel, i.e. the delay between the channel forming pulse and the interaction pulse. An important issue to be addressed in that experiment was the correlation of those measurements with angular and spectral features of high energy electrons. To this purpose we have designed a multilayer radiochromic-based detector for energetic charged particles (SHEEBA). When exposed to such high energy particles, the active layers within the film absorb energy and change optical density. The exposure to high energy protons also results in nuclear activation of the film, which is monitored using a Geiger counter. The absence of activation in the results shown here is additional evidence that our signal was entirely due to electrons.

Here we report on the first SHEEBA measurements of the spectral and angular distribution of fast electrons generated in the case of interactions of intense CPA pulses with underdense plasmas. Our measurements demonstrate that this simple detector, in combination with appropriate numerical analysis tools, provides a powerful diagnostic technique for this class of experiments.

## Experimental setup

The plasma was generated by irradiating a 0.3 µm thick plastic foil (FORMAVAR) with two heating beams ( $\lambda$ = 527 nm, $\tau$ = 1 ns, 100J per beam) at I=5.10$^{14}$ W cm$^{-2}$. A CPA laser beam ($\lambda$ =1053 nm, $\Delta t$=1 ps, up to 120 J) was focused (off-axis parabola f/3.5) on this plasma 1.3 ns after the heating beams. The peak density at the time of interaction was estimated to be $n_C/10$. The density was characterized by Nomansky interferometry using a UV laser pulse ($\lambda$=267 nm, $\Delta t$=1 ps). Finally, the detector (SHEEBA) was placed at 2 cm from (behind) the target on the main laser pulse propagation axis. The layer set-up used for SHEEBA is shown in Figure 1.

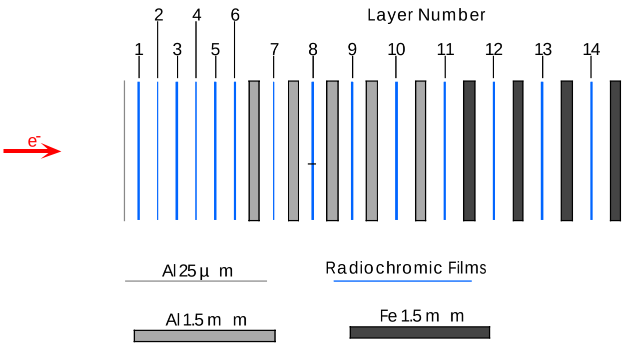


**Figure 1.** Set-up used for the fast electrons detectors SHEEBA.

## Experimental results and discussion

Figure 2 shows the optical density distribution for the various layers of the detector due to exposure to energetic electrons generated by the interaction of a 120 J CPA pulse focused on

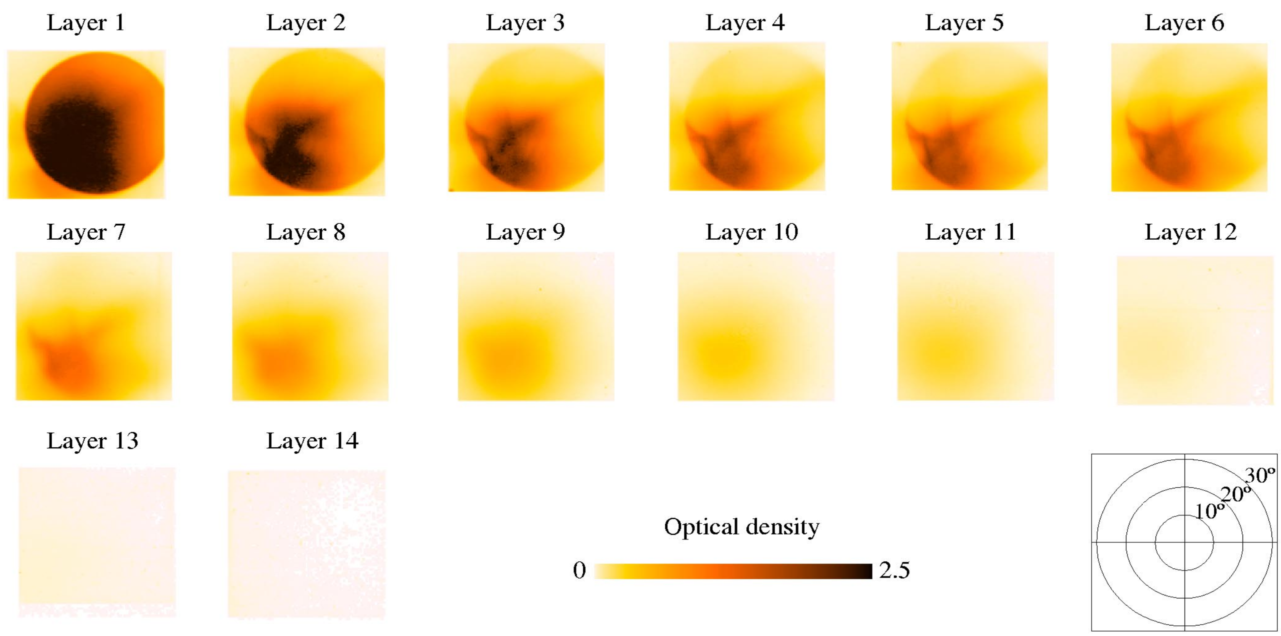


**Figure 2.** Optical density distribution for the various layers of the detector due to exposure to energetic electrons.

the preformed plasma.

These images clearly show that the electrons are confined in a cone of small aperture, less than 10 degrees. As we proceed from layer 1 to layer 14, the overall optical density decreases and the small scale structures are smoothed out as a result of electron propagation/diffusion through the layers.

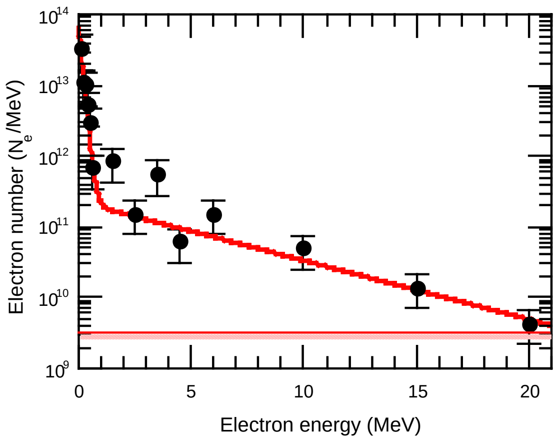


**Figure 3.** Overall reconstructed spectrum of the electrons from radiochromic films data.

A quantitative analysis of these images has been carried out using a Montecarlo simulation code based on the library GEANT 4.2.0 [(2)] in order to obtain the spectral distribution of the electrons. Our analysis shows that two populations of electrons exist, which are well characterised by two different temperatures of 133±23 keV and 5.23±0.84 MeV, respectively (see Figure 3). Several physical mechanisms can account for the generation of high energy electrons including direct laser acceleration [3)] and acceleration in the plasma waves generated by forward Raman scattering [4)]. In fact, many experiments have been reported in which high energy electrons have been observed where, depending on the interaction conditions, each of these mechanisms is claimed to play a dominant role.

It is interesting to observe that in one of these experiments [5)] a two-temperature hot-electron energy distribution was already observed in conditions similar to those of our experiment and was ultimately attributed to direct laser acceleration. In that experiment fast electrons were detected using a magnetic spectrometer with a small angular acceptance looking at 45° from the laser axis in the forward direction. In contrast, in our experiment most of the fast electrons were found to be emitted in a narrow cone in the forward direction. This measurement was possible thanks to the large angular acceptance and high angular resolution of our detector. Although the analysis of these data is still in progress, it is clear that our measurements provide basic information for the identification of the physical mechanisms at the origin of high energy electrons and, in particular, of the two-temperature distribution.

## Conclusions

We used a detector based on radiochromic film to measure the properties of high-energy electrons generated during ultra-intense laser-plasma interactions. The detector could be placed very close to the target and allowed the angular distribution of the electrons to be measured directly. The spectrum of the electrons was also obtained with the aid of simulations. Our results show that this detection system offers a good alternative to conventional high energy electron spectrometers, usually heavy and bulky and characterised by a small angular acceptance. Also, the angular distribution of high energy electrons can be measuresd directly in a single shot.


## Acknowledgements

The authors wish to thank the staff of the Central Laser Facility for their assistance and support throughout the experiment. The experiment was funded by an EPSRC grant. Support from the TMR European Network "Xray Probing Of the Structural Evolution of Matter", XPOSE (contract N. HPRN-CT-2000-00160) is also acknowledged.


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