Detectors for laser-accelerated ion beams*

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The development of laser driven ion accelerators at LEX/CALA aims for high particle energies and improved energy resolution to allow their application as medical accelerators in future. Main difficulty in detection of laser-accelerated ions is the high instantaneous pulse flux, which requires any detector system to be able to handle more than 10^7 protons/cm^2 within a single ns-pulse. Other issues are the typically broad ion energy spread (several tens of %) as well as mixed radiation background due to by-products of the acceleration process. Diagnosis of the laser-accelerated ion spectrum is therefore a challenging task in particular for electronic detector systems where problems due to emission of an electromagnetic pulse (EMP) are expected in addition.

The Tandem accelerator allows to prepare single proton pulses of similar time structure and intensity as expected in laser-ion experiments. This offers unique possibilities to investigate suitable detector systems for future application in LEX/CALA under well-controlled beam conditions.

Even today, many laser-ion experiments still rely on non-electronic detectors such as Image Plates (IP), nuclear track detectors (e.g. CR39) or radiochromic film (RCF) which require a time consuming processing. Approaches for real time detection mainly focus on optical techniques, i.e. monitoring the output of a scintillator or phosphor screen coupled to a multi-channel plate. Our approach uses a pixel detector system based on the idea of fluence reduction per sensitive detection element (i.e. pixel). Different pixel detector systems were characterized with respect to single ion sensitivity, saturation level and radiation hardness [1, 2]. The final system is based on the RadEye CMOS imager and offers a large sensitive area of 25 x 50 mm^2 with 48 μm pixel pitch (fig. 1). The saturation level corresponds to approximately 10^7 protons/cm^2 (20 MeV energy) while the system also offers the possibility to detect single ions [2]. Although dynamic range and radiation hardness have shown to be sufficient for laser ion acceleration experiments so far, the strength of this approach is the sensitivity to the low energy tail of the ion spectrum. To enhance the saturation limit further, an ion beam profiler using this detector coupled to a stack of scintillators is under development and showed already an increase of the saturation level by 3 orders of magnitude during a first test at the Tandem accelerator. Further studies to fully characterize the new system at the Tandem are foreseen in the near future.

The possibility to deliver a dose of few Gy within a single laser-accelerated proton pulse has already be demonstrated experimentally [3]. The associated dose rate exceeds that of state of the art medical accelerators by several orders of magnitude and the dose rate dependent relative biological effectiveness (RBE) hast to be studied. RCF have been calibrated for dose determination in bio-medical applications in vitro [3] and in vivo [4]. RCF is known to show a significant dose under-response in the vicinity of the Bragg peak. The energy dependent film response was therefore investigated for various proton energies at the Tandem accelerator and compared to clinical proton and photon beams [5] to determine under-response corrections for future bio-medical experiments at LEX/CALA.

Figure 1: Detector system based on the RadEye1 imager which allows parallel read-out of up to 4 sensor elements.

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