Laser-driven proton beam diagnostic: feasibility study of a novel technique and possible applications

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In the last years, significant developments have been made in the field of laser-driven proton (ion) acceleration, both in the improvement of the laser systems and in the design of innovative targets. However, the development of proper diagnostic instrumentation, capable of fully characterize the broad energy spectrum of laser-driven protons, is of equal importance and it still requires further developments in order to exploit these sources for several applications in material and nuclear science.

Ideal diagnostics for laser-driven proton (ion) acceleration experiments should be able to measure in real-time both the broad exponential energy spectrum and the directional distribution of particles on a shot-by-shot basis, also discriminating between the different ions and charge states. In this regard, the standard instrumentation is the Thomson parabola spectrometer (TPS) + microchannel plate (MCP) assembly [1]. Although it has proven to be effective, this system has some major limitations: *i)* the MCP needs a proper shielding against the very intense photon background, *ii)* the MCP/phosphor screen/CCD camera detection chain is somewhat difficult to be absolutely calibrated and *iii)* the TPS requires a high voltage supply, which can be subject to fluctuations that prevent the achievement of a stable proton trace, thus making the absolute calibration of the system less accurate.

In this work, a feasibility study of a reliable proton beam diagnostics is presented. The proposed technique is based on an alternative approach for the detection of laser-driven protons and the subsequent reconstruction of their energy spectrum. The proposed system consists in a magnetic spectrometer coupled to a pixelated strip semiconductor detector and a properly shaped aluminum filter for removing the heavy ion component of the radiation field, as represented in Figure 1.

In order to investigate the feasibility of the proposed detection system and to validate a solid theoretical basis for its possible future implementation, a theoretical study was carried out, by combining both analytical calculations and numerical simulations performed with the FLUKA code. A good agreement between results was obtained, showing that promising spectral capabilities and energy resolutions can be achieved within the proton energy range of interest.

A reliable detection system would allow the use of laser accelerators in a wide range of applications. For example, a well-characterized energy spectrum of laser-driven protons could be of interest in order to induce and study nuclear reactions characterized by a high cross section at low energies. As a case-study, this work will discuss the use of a laser-driven proton beam for the characterization of the proton-boron reaction ($p + {}_5B^{11} \rightarrow 3\alpha + 8.7\ MeV$), one of the most attractive aneutronic fusion process [2]. The reaction cross-section, as a function of the center of mass energy, shows two resonances at a proton energy of 148 keV and 614 keV. The exponential trend of laser-driven protons energy spectrum could be beneficial to maximize the reaction number thus allowing a more in-depth study of the reaction by using an appropriate diagnostic system to characterize the emitted alpha particles.

Disclaimer: It is worth highlighting that a similar proposal to the measurement of the laser-driven proton spectrum can be found in the literature [3]. However, instead of focusing on commercially available detectors, the present work aims at developing a new detection system, which is specifically tailored to the application of laser-driven proton spectrometry.

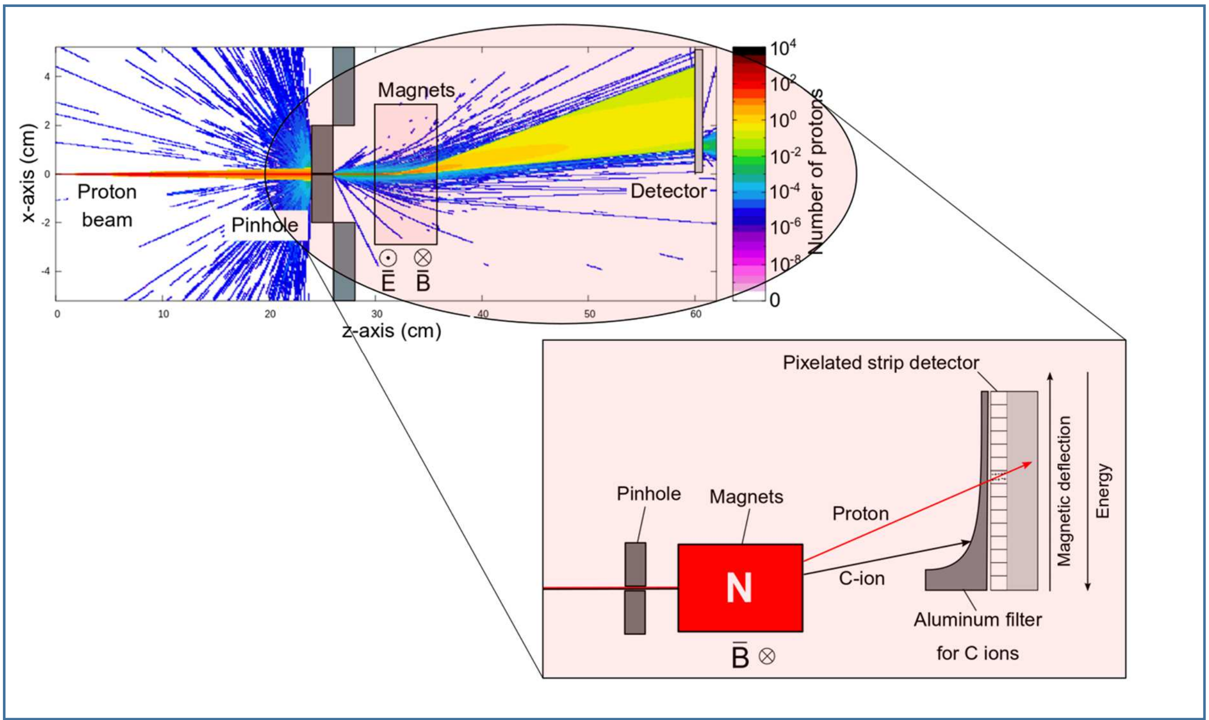

Figure 1: Tracking of the proton beam (FLUKA simulation) and schematics of the magnetic spectrometer coupled to the pixelated detector.

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[2] C. Labaune, *et al.*, Laser-initiated primary and secondary nuclear reactions in Boron-Nitride, *Sci .Rep.,* **6,** (2016), 21202.

[3] S. Reinhardt, *et al.,* A pixel detector system for laser-accelerated ion detection, *J. INSTRUM.,* **8**, (2013), P03008.