Calibration and study of an high dispersive power, high energy resolution Thomson Parabola Spectrometer

F. Schillaci[1], G. A. P. Cirrone [1,4], G. Cuttone[1], M. Maggiore[3], D. Margarone[4], G. Parasiliti Palumbo[2], P. Pisciotta[1], D. Rifuggiato[1], F. Romano[1], G. Russo[2], V. Scuderi[1,4], C. Stancampiano[1], A. Tramontana[1,2], A. Velyhan[4], A. Amato[1], G. F. Caruso[1], S. Salamone[1]

[1] *INFN LNS, Catania, Italy*

[2] *University of Catania, Physics Department, Catania, Italy*

[3] *INFN LNL, Legnaro, Italy*

[4] *Institute of Physics of the ASCR, ELI Beamlines Project, Prague. Czech Republic*

Abstract

Thomson Parabola is very useful diagnostic device for characterization of laser-driven beams but it suffers some limitations as data analysis is not straight forward and it strongly depends on energy resolution and on the Q/A resolving power. At INFN-LNS in Catania (It) a Thomson Parabola with high dispersive power and high energy resolution ($40\,\mathrm{MeV} \pm 1\,\mathrm{MeV}$ for protons) has been developed and successfully tested in an experimental campaign at PALS laboratory, Prague (Cz). Experiments with laser-accelerated beams are useful for a preliminary characterization of the device, but a calibration with monochromatic beams is crucial for understanding all the device characteristics and improve data analysis as well. The calibration of the deflection sector of the device has been performed at INFN-LNS using a monochromatic proton beam delivered by a Tandem accelerator in the energy rangy between 6 and 12.5 MeV. The data analysis allows to evaluate the real energy limit of the spectrometer, its resolving power in terms of energy and charge state separation. Results of the experiment and the related study will be reported in this contribution.

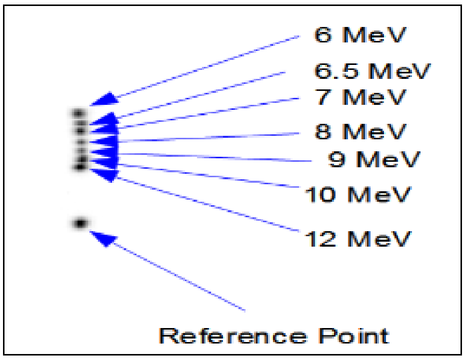
Introduction

Thomson Parabola Spectrometers (TPS) is a device used to measure charge-to-mass and energy of charged ions. In recent years it has found applications in the diagnostics of laser accelerated ions [1]. In the TPS set-up, the particles are dispersed in the direction perpendicular to the magnetic field according to their charge-to-momentum ratio and the electric field deflects the particles in its direction and the deflection is proportional to the charge-to-energy ratio. The distances of the deflected beam spot form the reference point, usually due to neutral radiation produced in laser-target interaction, can be used to characterize the beam in terms of energy, momentum and q-over-m ratio, which allows the analysis of the ion source properties as well.

An efficient TPS have been realized at INFN-LNS within the ELIMED project. In this paper we report the results obtained during the TPS calibration with INFN-LNS Tandem proton beams in the energy range between 6 and 12.5 MeV. Tandem allows to vary the energy of accelerated particles with a great precision and in a very narrow energy spread ($\Delta E/E < 0,1\,\%$). During the experiment the deflection sector have been calibrated and also the energy resolution and the energy limit of the device have been evaluated.

TPS description and experimental procedure

A TPS[4] has been designed and realized at INFN-LNS for the characterization of ion beams up to 40 MeV protons with an high energy resolution (some percent for higher energy). The device has been tested in different experimental runs at PALS laboratory and some results have been already reported. The TPS consists of four parts: the collimation system, the deflection section, the magnification drift and the imaging system. The magnetic field is produced by an electromagnet made of two resistive coils and a H-shaped iron yoke ensuring good field uniformity along the particles trajectories. The field can be tuned up to $0,25\,$T. The technical choice of resistive coils is crucial to increase the dynamic range. In fact tuning the magnetic field it is possible to stretch the parabolic traces in order to increase energy resolution and to reduce errors in energy evaluation. The electric field is generated by two copper electrodes, 7.0 cm long with a gap of 18 mm. A map of the electric field has been simulated and it can be assumed uniform along particles trajectory. It can be tuned up to $30\,rmkV$ of electrical potential difference over the electrodes gap. After passing the deflection and drift region, which allows to increase both particles deflections and separation among different traces, an imaging system is used as a detector. In this case it is a 2 mm thick BC408 squared plastic scintillator with a side of 50 mm. It was set outside the spectrometer and the produced light was acquired with a CCD camera CHROMA C4-DSP, exposition time have been set to 10 sec. The vacuum chamber has been closed with a 50 nm thick kapton window. The electric and magnetic dispersion of the spectrometer have been calibrated using monochromatic proton beams produced by the INFN-LNS Tandem. The TPS has been set at the 80 deg experimental hall of LNS laboratory. Two different values of the magnetic field ($0,09\,$T and $0,07\,$T) in order to not lose the low energy spot outside the detector surface. For the electric field we have selected the following values of potentials: 12 kV, 20 kV and 24 kV. For each beam energy the deflection section has been mapped combining all the acquired spots in a single image. The beam spot size have been evaluated to be $4\,\text{pixel} = 340\,\mu$m, which means that the beam divergence is less than $0,18\,$mrad. This values have been evaluated from geometric consideration and without taking in account scattering effects on the pinholes and on the kapton window and scintillator. The procedure



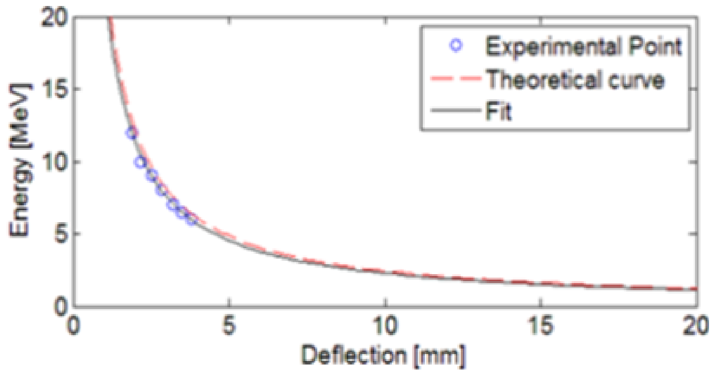


Figure 1: *Experimental data and alanysis for* $V = 24\,\mathrm{kV}$

for carrying out the calibration of the deflection sector follows what reported in [3, 2] and it is briefly described below. The ion beam profile on the quartz was inspected visually using a camera mounted on a view port perpendicular to the quartz viewer. The electric field calibration measurements are performed without magnetic field and viceversa. An example is in Figure 1.

The equation describing the electric calibration hiperbola is:

$$E_{\mathrm{kin}} = \frac{A_e}{y} \tag{1}$$

where A_e is a factor taking in account the geometry of the system and the characteristic of the ion species. A similar equation can be evaluated for the magnetic field. The agreement between experimental calibration hyperbolas and theoretical equation is within the $7\,\%$. Combining the equation of an electric and a magnetic hyperbolas it is possible to have the equation of a parabolic trace on the detector screen. For different combinations of electric and magnetic fields, it was observed that the theoretical coefficient andthe experimental coefficient result to be in agreement within the 10The energy resolution can be expressed as a function of the energy and of the field (electric or magnetic) by the derivative of the calibration hyperbolas. Data analysis shows that protons with an energy of $40\,\mathrm{MeV}$ can be resolved; the same resolution can be obtained for other ion species with maximum energy of $(4 * Q)\,\mathrm{AMeV}$. However, energy resolution is strictly related to the Q/A resolving power strongly dependent on the electric deflection and on the beam spot size on the detector screen, which is $\delta = 340\,\mu\mathrm{m}$ for the in exam. It can be evaluated calculating the smaller distance from the spectrogram center at which it is necessary to set two energy point of ions with close Q/A ratio in order to have them resolved. Hence their distance, in the vertical, or y axes, direction have to be bigger than δ. Calculations show that the energy limit for carbon ions is actually $(1,2 * Q)\,\mathrm{AMeV}$ and all six charge states are fully resolved at distance of $23,2\,\mathrm{mm}$ from the spectrogram origin. In this conditions protons are not affected and their energy limit remains of $40\,\mathrm{MeV}$.

Conclusion

Thomson parabola ion spectrometer has been designed to study ions accelerated from the rear side of laser illuminated targets. The magnetic and electric deflection of the device has been calibrated using ions of well-known energy from the LNS Tandem accelerator in Catania, allowing the absolute energy of studied ions to be determined. Furthermore, the energy limit and the energy and Q/A resolutions have been determined. Calibration of the deflection sector is crucial for this kind of device, as it is affected by several error source such as the position of the spectrogram origin, presence of parasitic field etc. Once the deflection sector is calibrated data analysis of laser-accelerated ions can be performed in a more precise and robust way. Moreover the proposed model, results useful for setting up the TPS and to study its scalability for realize devices suitable for higher energy. The proposed study on energy limit and energy resolution is also crucial for the scalability of the system and the realization of a more performing device with very high-energy resolution suitable for the ion beams that will be produced at ELI-beamlines.

References

[1] W. Mroz, Rev. Sci. Strum. 67 1272 (1996)

[2] Schillaci et al, Rev. Sci. Instrum, submitted

[3] Freeman et al, Rev. Sci. Instrum. 82, 073301 (2011)

[4] M. Maggiore, et al, Nejaka Hlavicka 123(2010), 123-456