depths beneath the Appennines and in front of the Ionian slab could cause inefficient wave propation paths [15], from the earthquake hypocenter to the used stations.
Our solution is characterized by a good match between synthetic and observed seismograms and, with respect to the other solution reported in the literature, it also shows a good agreement with the regional geologic contest.

Future steps

Working with historical seismograms is a very challenging task and there are several aspects to take into account. To recover and analyze by means of modern waveform inversion techniques the past earthquakes is very important for the knowledge improvement because they allow to recover an irreplaceable data amount and to obtain information actually not available from recent seismicity. This study allowed to test the above described modern-standard time-domain analysis technique for the frist time on an italian historical seismic event and re-evaluate the source parameters of the *Ferruzzano* eartquake. Further efforts will be done to collect other original seismograms from different archives in order to have a greater number of data suitable for the inversion procedure and a better azimuthal coverage. Moreover additional tests will be performed to investigate the wave propagation paths along the Appennines that could have influenced the magnitude estimate. The good results obtain in this study demonstrate the value of the preservation of historical seismic data and the capability of modern-standard time-domain technique to properly analyze them. Following this first study other investigations will be carry out to analyze italian earthquakes of the early XX century.

References

[1] *DBMI15, the 2015 version of the Italian Macroseismic Database*. 2016, http://istituto.ingv.it/it/archivi-e-banche-dati.html

[2] Presti, D., Neri, G., Orecchio, B., Scolaro, S., Totaro, C.: *The 1905 Calabria, Southern Italy, Earthquake: Hypocenter Location, Causative Process, and Stress Changes Induced in the Area of the 1908 Messina Straits Earthquake. The 1905 Calabria, Southern Italy, Earthquake*. Bull. Seismol. Soc. Am., (1–11), 2017. doi:10.1785/0120170094

[3] *CPTI15, the 2015 version of the Parametric Catalogue of Italian Earthquakes*. 2016, http://istituto.ingv.it/it/archivi-e-banche-dati.html

[4] Stich, D., Batllò, J., Morales, J., Macià, R., Dineva, S.: *Source parameters of the Mw= 6.1 1910 Adra earthquake (southern Spain)*. Geophys. J. Inter., 155(2) (539–546), 2003.

[5] Stich, D., Batllò, J., Macià, R., Teves-Costa, P., Morales, J.: *Moment tensor inversion with single-component historical seismograms: The 1909 Benavente (Portugal) and Lambesc (France) earthquakes*. Geophys. J. Inter., 162(3) (850–858), 2005.

[6] Batllò, J., Stich, D., Macià, R., Morales, J.: *Moment tensor inversion for the 5 July 1930 Montilla earthquake (Southern Spain)*. Seismol. Res. Lett., 81(5) (724–731), 2010.

[7] Gasparini, C., Iannaccone, G., Scarpa, R.: *SFault-plane solutions and seismicity of the Italian peninsula*, Tectonophysics, 117(1–2) (59–78), 1985.

[8] Dziewonski, A. M., Ekström, G., Franzen, J. E., Woodhouse, J. H.: *Global seismicity of 1978: centroid-moment tensor solutions for 512 earthquakes*. Phys. Earth Planet. In., 46(4) (316–342), 1987.

[9] http://www.isc.ac.uk/

[10] Michelini, A., De Simoni, B., Amato, A., Boschi, E.: *Collecting, digitizing, and distributing historical seismological data.*. Eos, Transactions Am. Geophys. Un., 86(28), (261–266), 2005.

[11] Ferrari, G., and Pino, N., A.: *Euroseismos 2002-2003, a project for saving and studying historical seismograms in the Euro-Mediterranean area*. Geophys. Res. Abstr., 5, 05274.

[12] Pintore, S., Quintiliani, M., Franceschi, D.: *Teseo: A vectoriser of historical seismograms.*. Computers & Geosciences, 31(10), (1277–128), 2005.

[13] Batllò, J., Stich, D., Palombo, B., Macia, R., Morales, J.: *The 1951 Mw 5.2 and Mw 5.3 Jaén, southern Spain, earthquake doublet revisited.*. Bull. Seismol. Soc. Am., 98(3), (1535–1545), 2008.

[14] Batllò, J., Bormann, P.: *A catalog of old Spanish seismographs*. Seismol. Res. Lett., 71(5), (570–582), 2000.

[15] Mele, G., Rovelli, A., Seber, D., Barazangi, M.: *Lateral variations of P_n propagation in Italy: Evidence for a high-attenuation zone beneath the Apennines*. Geophys. Res. Lett., 23(7), (709–712), 1996.

REPORTS
PH.D. STUDENTS
CYCLE XXXII

Design of an Electromagnet for Laser-generated Plasma diagnostics

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Abstract

In this paper, we propose a plasma diagnostic method with magnetic fields perpendicular to the direction of propagation of the particles in a laser-generated plasma. The design of the electromagnet requires accurate simulations, conducted with COMSOL Multiphysics simulation software. Here are illustrated the advantages of using magnetic fields that are adjustable from the outside, compared to fixed ones, and a careful study of their realization. The ultimate aim is to obtain a useful device for the characterization of plasmas generated by low-intensity laser pulses, of the order of 10^{10} W/cm^2, and its subsequent application for the characterization of plasmas at higher temperatures, generated by higher laser intensity.

Keywords: Laser-generated Plasma, Magnetic Field, Electromagnet, Plasma Diagnostics.

Introduction

When a laser with a very high intensity ($\geq 10^{18}$ W/cm^2) is focused on a solid target, photons, electrons, protons and ions emerge from the irradiated material with very high energy. High ion accelerations are possible under Target Normal Sheath Acceleration (TNSA) or Radiation Pressure Acceleration (RPA) [1], and to date the highest energies observed for protons are in the order of dozens of MeVs [2]. Ion acceleration by laser-generated plasmas has become relevant scientifically in recent decades, due to the high number of application fields, such as Laser Ion Source, medical applications, hadron research, and more [3].

Plasma diagnosis is therefore important for knowing the properties of the ion beams generated in the laser-matter interaction. In this paper, we propose the design of an electromagnet for the study of a low-intensity laser plasma of about 10^{10} W/cm^2. Recent studies on the application of magnetic and/or electrical fields have been conducted for the characterization of non-equilibrium plasmas generated by low intensity lasers [4, 5].

Magnetic Field can be applied to charged particles of a laser-generated plasma with axial symmetry to the latter, obtaining increments in the detection yield and in the particles energy like reported in literature [6]. If the magnetic field have a transversal symmetry to ions beam of non-equilibrium plasma, charged particles are separated in accordance with Lorentz's Force, and circulate with a radius:

$$r = \frac{mv}{zeB} \tag{1}$$

where m is the mass, v is the velocity, z is the charge state of ion investigate, e is the elementary charge and B is the magnetic field module applied. Therefore heavier ions, but with the same charge state, will have higher radius, and thus will be less deflected. At the same time, ions with higher charge state, but with the same mass, will be deflected more. It is clear that a device is based on this physical principle will separate the same ion, with the same charge state, according its own velocity.

By positioning a high-resolution detector at a given angle, for example 30°, if we change the magnetic field applied by the electromagnet, it is possible to have a device that works as a filter for the ratio linear momentum to charge state, from the eq. (1):

$$\frac{\mathbf{p}}{z} = re\mathbf{B} \tag{2}$$

where $\mathbf{p} = m\mathbf{v}$ is the linear momentum. The product $r \cdot e$ is fixed and $\mathbf{B}$ is controlled by the user. By using Time Of Flight technique (TOF), it is possible to evaluate the velocity of the ions that travel a known distance:

$$v = \frac{L}{TOF} \tag{3}$$

where L is the distance between the target and the detector, and TOF is the time of flight, measured with a fast storage oscilloscope. Thus, it is possible from eq. (2) and (3) to have information on charge-to-mass ratio, and by varying the magnetic field we can reconstructed the distribution of the charged particles velocity in non-equilibrium plasma, as will be presented.

Material and Methods

A Nd:YAG laser was employed to generate a non-equilibrium plasma in vacuum chamber at low pressure of about 10^{-6} mbar. The laser beam, with fundamental wavelength of 1064 nm, pulse duration of 3 ns, and variable energy from 1 to 300 mJ, was focussed with optical lens on a target. The product plasma travel in vacuum for 90 cm before to be detected. Charged particles of plasma, in their flight, pass through a system of two pinholes (with a respectively dimeter of 3 and 1 mm) to generate a tight and collimated ions beam [7]. The collimated ions beam is detected by 32 faraday cups, distributed with an angle of 90°, each distant 2.9° from the other. They are placed on a mobile sleigh, in the horizontal plane on the ion trajectory, that permits to investigate different angle from 0° to 180°, (Figure 1). The faraday cup signal is sent to a fast storage oscilloscope; however, since collimators cut down ionic current, it is necessary to work with high input impedances of the megaOhm order. In this way we get a signal amplification, but a slow discharge of the RC circuit.

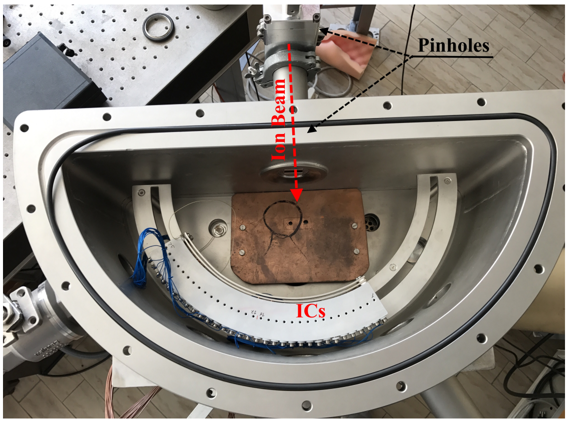

Figure 1: *Picture of chamber where are placed the 32 faraday cups.*

This device can be used to evaluate the angular distribution of ions beam emitted from the target that cross the collimators system. Fixed magnetic fields can be inserted after the pinholes system, so that the plasma ions deflection can be studied between 0° and 90°. However, if greater resolution is required, faraday cups may be replaced by an electron multiplier, scintillator, or more other; thus positioning the high-resolution detector at a fixed angle, we can operate by changing the magnetic field module. Therefore, if a suitable magnetic field is introduced after the pinholes system, positive ions will be deflected at a certain angle, based on their mass and velocity, according to eq. (1). In this way, we obtain a mass spectrometer that provides information about the plasma properties.

Results and Discussion

As previously reported, if there is not a magnetic field in the system we can study the angular distribution of particle emitted from target, when the laser beam shoot it. In Figure 2 is shown the angular distribution for Aluminium ions.

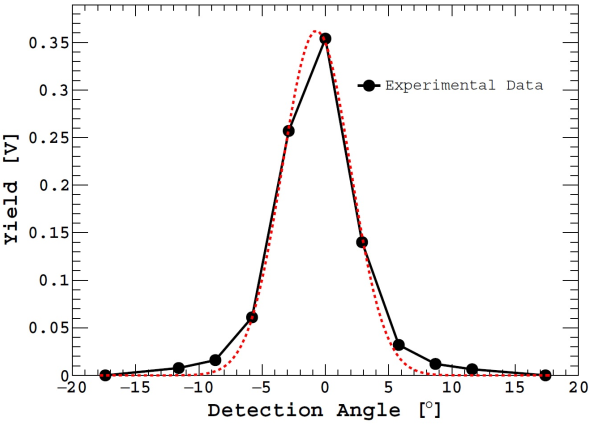

Figure 2: *Experimental data (in black) and fit (in red) of the angular distribution for Al-ions, emitted from a target of pure Aluminium.*

The angular distribution reported in Fig. 2 shown the profile of the ions beam after it passes through the collimation system. The data was obtained evaluating the maximum yield detected with a faraday cups placed at a certain angle vs. the angle of detection. Fit of experimental data was done using a Normal Distribution:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{4}$$

where μ is the mean or expectation of the distribution, and σ is the standard deviation. The correlation between the Full Width at Half Maximum (FWHM), Γ, and the standard deviation is $\Gamma = 2\sqrt{2\ln 2} \cdot \sigma$, so we obtain from the fit $\Gamma \approx 6.33°$. This means that the two pinholes generate an ions beam of Gaussian-shaped, which have very narrow angular aperture, but also with low currents. For more heavy ions we aspect smaller angular distributions, according to literature [8].

When a Magnetic Field, orthogonal to particle direction, is applied to plasma plume, the ions are deflected according to Lorentz' force, shown in eq. (1). In this way, it is possible to evaluate some of important features about the charged particles that constitute the non-equilibrium plasma, such us velocity, energy, charge state, and more. Figure 3 shown the simulation, performed with COMSOL Multiphysics simulation software [9], for first charge state of Aluminium and Tantalum, in the interest system.