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eli nuclear physics

Research projects for future experiments at ELI-NP

2014 - 2016

Bucharest-Măgurele, ROMANIA
2016

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Method to characterize propagation effects on ELI laser pulse (PULSE-PROPAG)

Project Leader: Valer TOȘA
Project Coordinator: INCDTIM
Project web page: *http://www.itim-cj.ro/eli/index.htm*

The purpose of the present project is to offer a reliable numerical calculation **tool for ELI beam characterization and diagnostics** throughout all the stages of beam shaping and transport, especially at points where experimental measurements are difficult or impossible to be performed. As project was planned, two types of methods were developed to characterize the laser pulse. First, using the measured data at the diagnostic points one can calculate the laser field in any given plane along the laser **beam transport** lines from the compressor to the interaction chamber; second, in the regions of very high intensities we calculated the perturbations suffered as a result of **pulse propagation** in an ionizing medium.

Beam transport method

Using the measured data at the diagnostic points one can calculate the laser field in any given plane along the laser beam transport lines from the compressor to the interaction chamber. We assume that the field in a given location is measured using an experimental method. ELI-NP White book specifies the main diagnostic point after the compressor and the methods to be used. From these data one can obtain the field $E(r_1, z_1, \varphi_1, \omega)$ at measurement point 1. In the measurement point 2, we need to calculate the field $E(r,z,\varphi,\omega)$ that arrives after being transported through an optical system characterized by a known ABCD matrix. For example, if the propagation is through a medium of length d and of a frequency dependent refractive index $n(\omega)$ the matrix elements are: $A=D=1$, $B=d/n(\omega)$, $C=0$. Calculation is performed in frequency domain and is done for each spectral component of the pulse so that one can take into account the dispersion of the pulse during propagation. After calculation one can perform an inverse Fourier transform to find the temporal characteristics of the pulse. Input field can be in time of frequency domain so one can account for amplitude and phase variation of the input field due to mirror irregularities or due to the amplification process. In Fig 1.a we can see such irregularities.

We built and tested a computer program for the calculation of pulse transport and pulse focusing. In its present form it can be used independently in executable form with an input file, but in ELI-NP environment it will be integrated as a callable routine in a larger application which controls or diagnose the beam. The results shown in Fig. 1.a represent the data measured at the PW laser system in GIST, Korea, before focusing. A pierced mirror is used so that the field in the central part is missing. The field calculated in the focus is shown in Fig. 1.b and shows the capabilities offered by our software, to model beams with a high deviation from axial symmetry. We emphasize that developing the non-axial symmetry calculation was additional to the initial proposal which was limited to cylindrical geometry, as a result of discussions and requests from ELI-beam experimentalists.

Pulse propagation method

In the regions of very high intensities we can calculate the field perturbations due to propagation in an ionizing medium. The space-time dependent refractive index of the medium is build-up during calculation takes into account the dispersion by neutrals and by plasma as well as the nonlinear Kerr effect. We start from a non-adiabatic propagation equation, solve it in frequency domain by a finite difference method assuming a cylindrical symmetry of the field, and working in the moving frame. At low intensities (<0.5 PW/cm^2) the electron concentration in the medium originates from single (usually multiphoton or tunel) ionization of atoms/molecules. In a very intense laser field an atom/molecule experience multiple stripping of electrons, starting from the outer shell ones. To calculate the electron concentration we considered sequential ionizations and developed a system of rate equations which allows the calculation of fractions of ionic species. For ionization rates we used Ammosov-Delone-Krainov (ADK) model for all ionic species. We also needed to implement the calculation of the ionization rates for N_2 and O_2 by using the molecular version of ADK model. In the present form the model is able to deal with intensities which depend on the ionizing medium but can reach 10^{16} - 10^{17} W/cm^2. This range of intensities are of interest in the regions just before the focus and in the temporal and spatial pedestals of the focused ELI beam. In Fig. 2 we give an example of how propagation effects affect the pulse intensity, plasma defocusing being the main effect. We plotted in Fig. 3 the spectral structure on axis of the focused beam in 85 torr of Ne, before and after propagation [1].

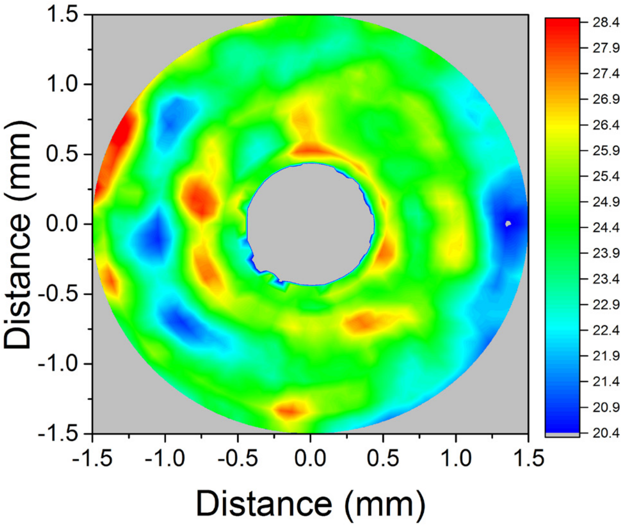


Fig. 1a: Peak amplitude of the beam measured at 205 mm before focusing

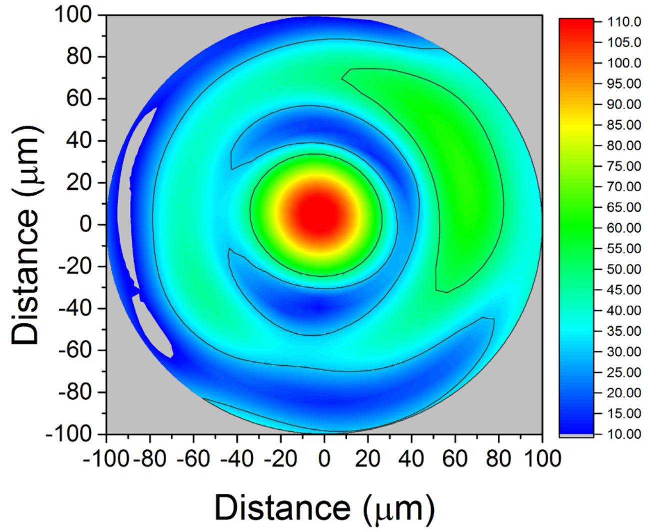


Fig. 1b: Peak amplitude in the focus calculated by the beam transport method

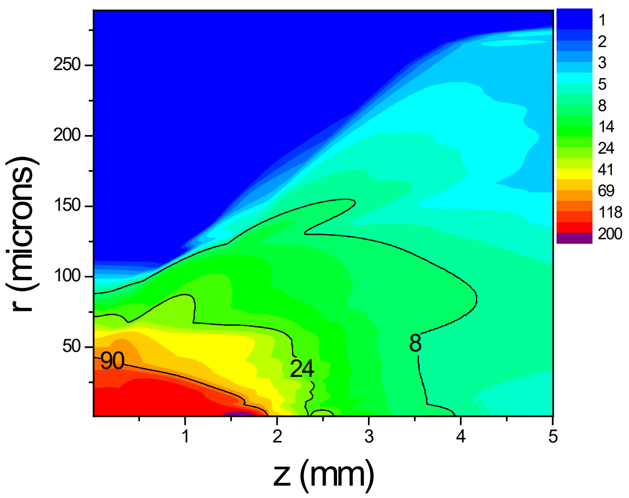


Fig. 2 Spatial structure of the peak intensity of the beam propagating in 5 mm of Ne at 85 torr

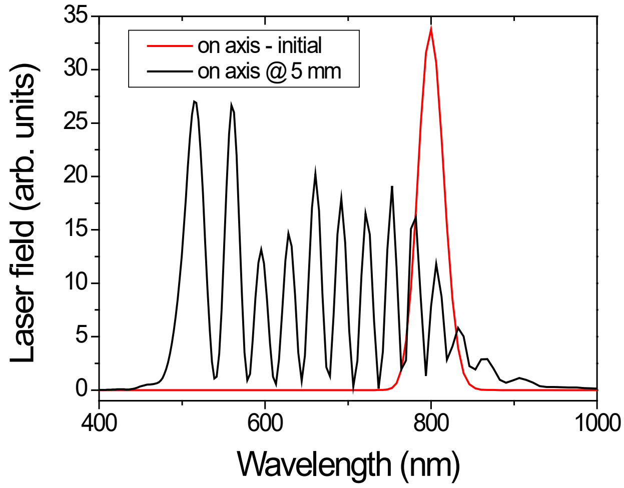


Fig. 3 On-axis spectra of the pulse at medium entrance and after propagation in 5 mm of Ne at 85 torr

In conclusion we developed numerical tools to calculate the laser field configuration starting from measured quantities. The aim is to characterize the field, in space, time and frequency domains, an positions and/or situations along the ELI beam path where measurement is difficult or impossible to perform. Both methods are developed and tested and are available to be implemented in the diagnostic system of ELI-NP. They can be used also as independent tools for beam characterization.

[1] V. Tosa, K. Kovacs, B. Major, E. Balogh, K. Varju, Quantum Electronics **46**, 321-326 (2016)

Extreme Light Induced Ablation Plasma Jet and Nanopatterning (ELIAN)

Project Leader: Silviu GURLUI
Project Coordinator: UAIC
Partner: INFLPR
Project webpage: *http://spectroscopy.phys.uaic.ro/ELIAN.html*

The present project is based on two main directions: a) to study the fundamental aspects that characterize the interaction between the high fluency laser ablation and solid state material via experimental methods and to develop a new theoretical model that describes all the implicated processes (solid state changes after irradiation, plasma generation and expansion behavior, etc.); b) to improve the properties of the studied solid state by means of laser irradiation, to reduce the contamination of the plasma, to increase the lifetime of the plasma, to obtain low absorption rate of D and T and a high melting temperature.

The goal of this project is twofold: firstly is to provide the answers to a complex scientific problem, with high technological impact, and secondly to develop, around an already existing scientific nucleus, a highly collaborative network joining both theorists and experimentalists for fundamental studies and applications possibilities. This feature is structured in two training components: via research and via teaching. Various sub-disciplines are considered (from both physics and chemistry fields) while the societal implications are not ignored: **Physics**: atomic physics in plasmas, laser-matter interaction physics, laser-driven charged particles acceleration; **Experiment:** experiments towards high-efficiency high-power plasma amplification, radiation pressure assisted acceleration of heavy ions, (ns, ps, fs) transitory plasma behavior, PW laser interaction and plasma physics, nanosecond pulsed high repetition rate laser systems plasma dynamics and surface wall cleaning, space-time resolved optical emission spectroscopy etc; **Chemistry**: multiphase reactivity; investigation of selected reactions or of complete reaction sequences.

Summary of accomplishments

- Research activity: Plasma plume dynamics of both pure (W, Ni, Al, etc) and chemically complex materials, influence of the wall physical parameters, obtained nanoparticle and studies by laser ablation in different conditions, Deposition of ternary W containing layers - W/Fe/Ni and W/Be/C.
- Results: 2 ISI paper, 1 ISI submitted paper, 18 conferences: *http://spectroscopy.phys.uaic.ro/ELIAN.html*

A. In order to study the influence of the substrate wall to the dynamics of the transient laser ablation plasma plume, a cylindrical metallic wall has been used. Set as a coupled mechanical system, both the target and substrate wall have been electrical isolated, and placed at different distances from each other. Typical recorded ICCD images (20 ns gate time) of the expanding plasma plume at different delays after the laser pulse are given in Fig. 1. The images of these structures reveal a splitting process of the plasma blobs into three plasma structures. These preliminary results seem to be interesting wile only two plasma formations have been previously evidenced using chalcogenide targets. Nevertheless, a third plume component close to the target with well defined interface and large contact area with the surface has been also observed in the ablation of the $LiMn_2O_4$ in an oxygen atmosphere. Therefore, our preliminary results underlined that the three plasma formations behavior seem as depending of the concentration of each used bulk target and the splitting of the plasma plume expansion could be linked to multiple scattering interactions between the background gas molecules and the fast expanding plasma plume. The interaction of the backscattered particles with the incoming particles gives rise to the third plume clustered component. The obtained clusters created by collisions with a background gas in the third component plasma plume can be useful in PLD applications to obtaining films with well different electronic properties. Moreover, the collision between different plasma species may contribute to the slight deceleration of the third plasma plume velocity.

To understand the plume expansion mechanism and its evolution with the dopant, the velocities of the three plasma formations have been calculated by measuring the position of the maximum emissivity at different delays. Indeed, the dopant concentration may induce interesting physical phenomenon since the expansion velocity profiles are clearly influenced.

B. Using thermionic vacuum arc (TVA) method mixed layers (W, Fe, Ni) in fixed and rotated deposition geometries were produced. X-ray micro-beam fluorescence (µXRF) method was used as non-invasive solution in order to quantify film composition on specific position on a disc holder of 300 mm in diameter. The geometrical dependence on a planar substrate using three independent evaporators was studied comparing 2D µXRF mapping with theoretical

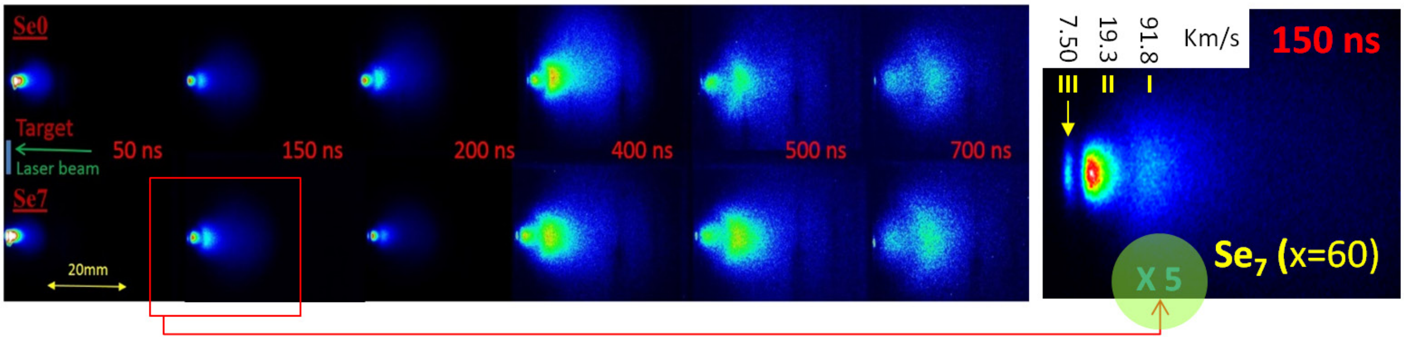


Figure 1. ICCD images of laser produced plasmas

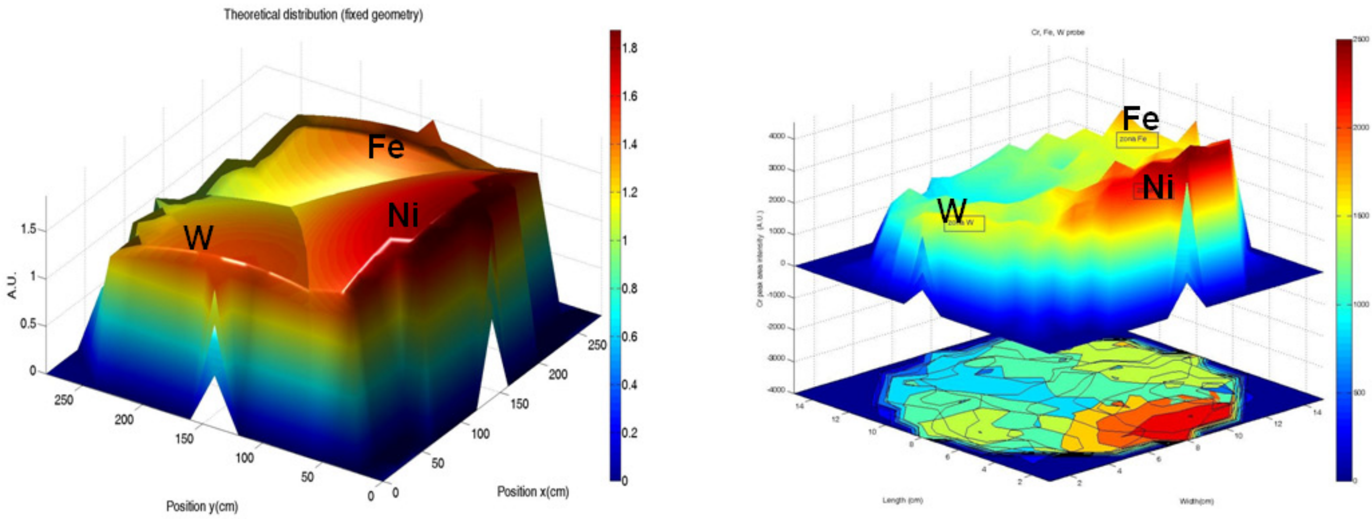


Figure 2. Color map 3D surface plot of fixed geometry of W, Fe, Ni deposition (Experimental./Theoretical)

results. For fixed deposition setup, within elemental combinations of W-Fe-Ni, a surface mapping campaign was conducted. A total of 148 samples (silicon substrate with 10 mm x 10 mm) were measured, with a measuring point step of 20 mm (each sample measured once).

The recombined result of the 4 zones is shown by a 3D color map surface plot with a contour profile (Fig.2). In the color map, the Z axis represents the intensity of the integrated area value of different characteristic energetic K or L lines corresponding to W, Fe and Ni elements. Contour plot shows that the highest deposition thickness is situated above Ni anode area (marked with the red area) suggesting a higher evaporation rate while the thinnest deposition area is situated in a line profile from the central to periphery opposite to the Ni anode (marked by cyan area). TVA method is used to produce functional materials applied as thermal barrier coatings in industry. XRF method was used as a non-invasive solution adapted for thin functional coatings layers.

Further investigations

- In order to obtaining a better understanding of the wall thermal and mechanical effects during the laser ablation process and TVA but also the fundamental of high kinetics charged species behavior ejected from irradiated wall, complementary models in the COMSOLE platform will be furthermore developed.
- A theoretical model will be elaborated in order to explain the obtained experimental data and to improve the environmental conditions. Both laser surface matter and plasma wall interactions in different time scale (ns, ps and fs regimes) will be modeling based on fractal theory that has already proposed.

High Power Laser System (HPLS): High Harmonic Generation and Dosimetric - Estimates of Induced Radiation (HHGDE)

Project Leader: Niculae Tiberiu N. PUȘCAȘ
Project Coordinator: UPB
Project webpage: *http://www.physics.pub.ro/Departament_Fizica/Proiecte_cercetare/HHGDE/index.html*

The ***objectives*** of the project are related to the theoretical and experimental study of several high order harmonic generation in gases, plasma ablation and the dosimetric estimates of the induced radiation.

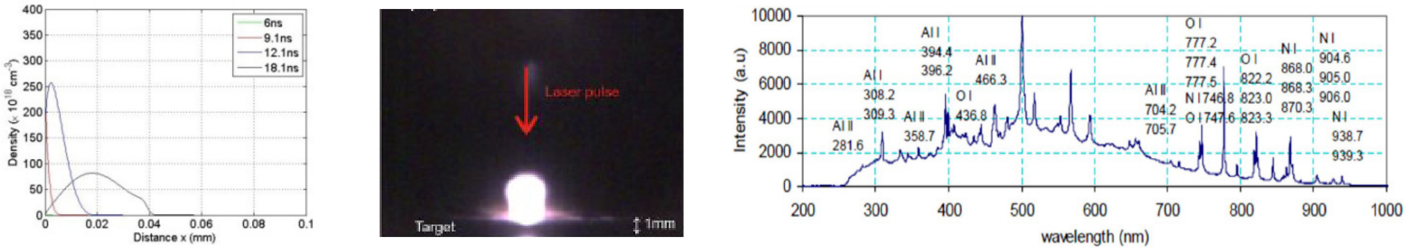
Between 2014-2015 we performed a theoretical analysis of high order harmonic generation (HHG) in gas mixtures with high intensity laser pulses. Based on the models existing in literature and considering a driving laser beam with a Gaussian intensity profile in the radial direction, we estimated several laser and target parameters (i.e. focusing parameters-focus length, *b*, beam radius at the waist, length of the nonlinear medium, *L*, wave vector mismatch, Δ and concentration of the gas) involved in efficient conversion of a Nd:YAG ns laser radiation to higher frequencies [1]. Also, we evaluated the wave vector mismatches, length of the nonlinear medium and focusing parameters for efficient generation of (FHG) and seventh (SHG) order harmonics generated in mixtures of sodium vapors and xenon. For example in the case of a long focus the intensity of SHG reaches its maximum for: $b/L=1/2$ if the wave vector mismatch for the direct SHG and FHG processes, respectively are: $\Delta 17 = \Delta 15 = 0$. In the case of tight-focusing of the laser beam considering that the beam is focused in the center of the nonlinear medium $\Delta 15=10/b$ for the direct SHG process and $\Delta 17=4/b$ for that corresponding to the step processes involving FHG process.

In the case where the gas jet is produced by laser ablation, the condition for obtaining optimum gas density/pressure profile for HHG was evaluated theoretically by solving numerically the hydrodynamics of the ablation plume produced by a nanosecond laser pulse (4.5 ns, 1064 nm). The equations concerning the mass, momentum and energy conservation in the laser-target interaction were solved by using numerical FEM method implemented in MATLAB in order to estimate the ablation gas jet properties as a functions of the target, laser and ambient conditions. The fluence of the focused laser pulse was set to 15 J/cm^2, which gives a peak intensity of ~3GW/cm^2 at the Al target surface. These parameters determine a high density ablation plume, above 10^{19}cm^{-3} as needed in most HHG in gas jets where backing pressure of several bars are used, and low ionization degree. The spatial distribution of the ablation plume density at different times relative to the onset of laser pulse is presented in Fig. 1a. which indicates that a density of several 10^{19} cm^{-3}, which is suitable for efficient HG, can be obtained after the peak of the laser pulse at heights of several tens of microns above the target surface.

In 2015 we performed an experimental analysis of THG in Ne with high intensity laser pulses [2]. Using a 150 kW input pump power of the Nd:YAG laser (λp=1060 nm) we obtained about 0.0001 conversion efficiency of the fundamental radiation into the TH radiation.

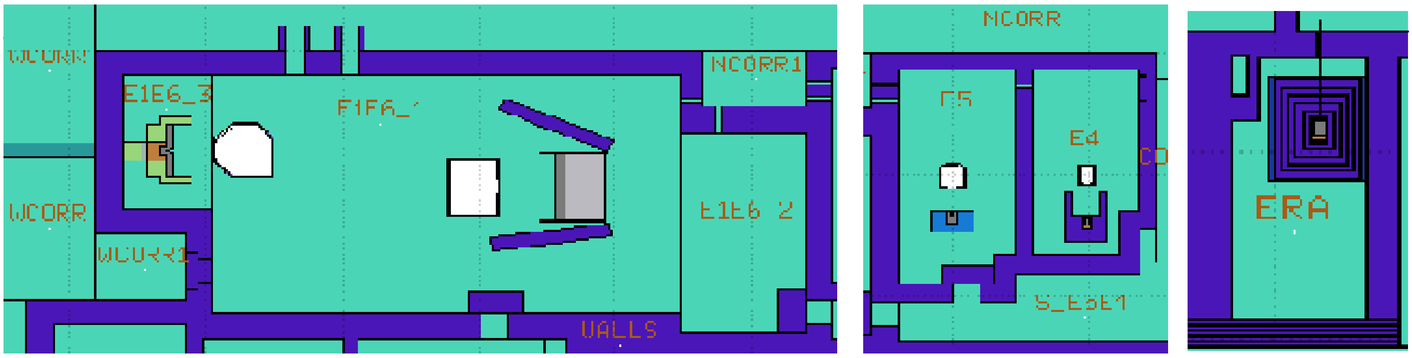
We also analyzed experimentally the dynamics in ambient air of the ablation plume considered as a non-linear mediums for HHG by imaging the ablation plasma produced on an Al target. The experimental set-up consists of a Nd-YAG Q-switched laser system generating 4.5 ns pulses at 1064nm wavelength which are focused at normal incidence on the aluminium target to obtain a spot of ~100 micron diameter and, accordingly, an intensity of ~100 GW/cm^2. Fig. 1b indicates that the maximum length of the plasma plume produced by the first pulses is ~3 mm while its transversal dimension near the target is ~2mm. A typical spectrum of the radiation emission from the ablation plume produced on the Al target in air, is presented in Fig. 1c.

In 2014, a survey of the scientific literature was performed, source terms were selected, and scaling laws were used in order to obtain parameter values at 10 PW. In FLUKA, a set of Fortran SOURCE subroutines were written to generate particles with typical energy and spatial distributions; in GEANT4 the same task was performed by writing a program DOSE which uses the General Particle Source module. Parallel computations of the deposited doses in a simplified geometry setup were carried out and results were reported in [3,4]. In 2015-2016, the geometry of the most difficult experimental areas of the ELI-NP building was written according to the drawing files of the ELI-NP project (Fig. 2). Initially it comprised the walls with penetrations (doors, laser transport beamlines, beamline at ERA, etc), and the interaction chambers. A shielding assessment of the individual experiments at E1/E6, E4, E5 of the HPLS and ERA of the GBS was conducted. We used updated source terms in order to compute ambient dose equivalent rates throughout the experimental areas, and we checked the compliance of the results with legal dose constraints. Fluences of secondary photons, neutrons, protons, electrons and positrons, muons were scored in order to facilitate an optimum selection of the material and geometrical layout of



(a) (b) (c)

Fig. 1. a), b), c). Spatial distribution of the ablation plume density at different times.



a) b) c)

Figs. 2 a), b), c). FLUKA geometry for the following experimental areas: a) E1/E6 (HPLS); b) E4, E5; c) ERA (GBS)

the local shielding. In each case a beamdump was designed to stop the ionizing radiation with a minimum cost in activation. For those sources characterized by high current and high divergence, local shielding was added in order to get the predicted equivalent dose rates below the admitted values.

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1. *Analysis of optimum conditions for high order harmonic generation in gaseous medias*, M. Stafe, C. Negutu, G. C. Vasile, N. N. Puscas, U. "Politehnica" Bucharest, Sci. Bull, Series A, Vol. **77**, No. 1, p. 187-202, (2015).
2. *Analysis of optimum conditions for third order harmonic generation*, M. Stafe, C. Negutu, G. C. Vasile, N. N. Puscas, Univ. "Politehnica" of Bucharest, Sci. Bull, Series A, Vol. **77**, No. 4, p. 303-306, (2015).
3. *Preliminary dosimetric evaluation of electron source terms at PW laser systems*, M. A. Popovici, R. Ionica, Gh. Cata - Danil, U.P.B. Sci. Bull. A, Vol. 77, no.1, p. 249-263, (2015).
4. *Dosimetric studies of proton source terms at PW laser systems,* M. A. Popovici, R. Ionica, Gh. Cata - Danil, U.P.B. Sci. Bull. A, Vol. 77, no.4, p. 319 – 331, (2015).

Advanced technological platform for preclinical studies on radiopharmaceuticals (RADIOMED)

Project Leader: Mihail Eugen HINESCU
Project Coordinator: IVB
Partners: IFIN-HH; IOB
Project webpage:
http://www.ivb.ro/v2/index.php/ro/2012-11-30-13-03-01/34-default/389-ro-cern

Main objective: setup of a functional and ready-to-use technological platform for advanced preclinical investigation of radiopharmaceuticals (imaging tracers and therapeutic agents), as preparatory phase for ELI-NP experiments on radiopharmaceuticals development.

Scientific focus and medical impact:
1) Development of new targeted radiopharmaceuticals for advanced imagistic diagnosis and therapy of cancer in the frame of precision medicine;
2) Application of advanced redox biology concepts and tools for improving the efficacy of radiotherapeuticals.

Secondary objectives:
a) training and career development of young scientists within a competitive multidisciplinary team;
b) knowledge and technology transfer within the consortium.
Connection to ELI-NP domains: 5.6.4 "Producing of medical isotopes via the (γ, n) reaction", 5.6.5 "Medical radioisotopes produced by γ beams"; 5.6.15 "Materials research in high intensity radiation fields".

The multidisciplinary RADIOMED team

RESULTS
Technological bio-platform for preclinical investigation of radiopharmaceuticals

***In vitro* platform**
- standardized tumor and normal cell lines
- characterized primary immune cells
- real-time investigation of cellular uptake of radiopharmaceuticals (LigandTracer)
- advanced *in vitro* methods: flow cytometry - cell phenotype and functions, real-time impedance measurements - cell adhesion and proliferation, pathway-focused gene

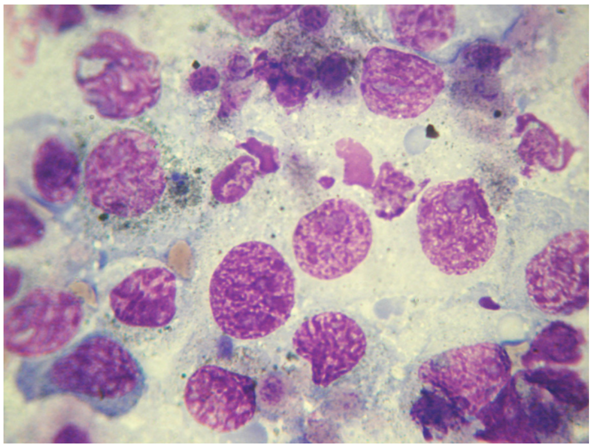
***In vivo* platform**
- standardized normal and transgenic mice
- small laboratoryanimal models of solid tumors of human and mouse origin - histologically defined experimental tumors; *in vivo* monitoring of tumor progression by echography and PET
- characterization of the anti-tumor immune

Ready to use biobank and experimental biomedical facilities *for future ELI-NP experiments*

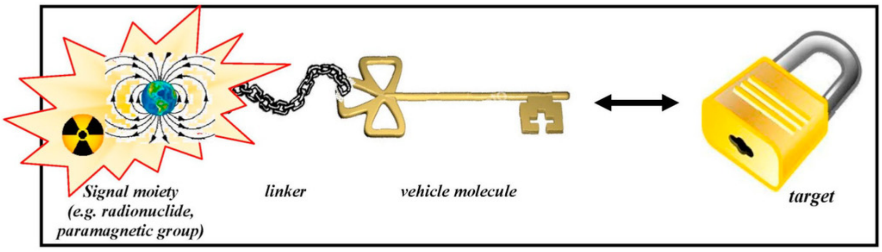
Demonstration of the bio-platform functionality

- Uptake and biodistribution of targeted radiotracers for tumor imaging through $\alpha_v\beta_3$ integrin receptors using RGD peptides (^{68}Ga-NOTA/DOTA - ciclo RGD dimers)

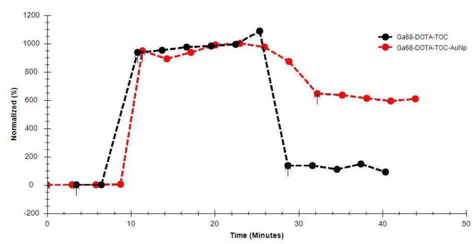
a) Production of targeted radiopharmaceuticals



b) Testing in cells and animal models

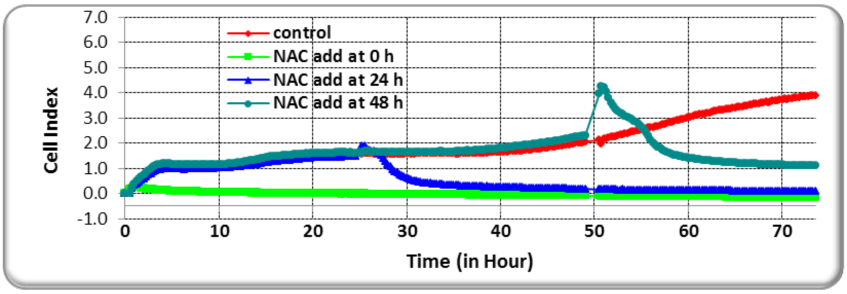


a) Targeted radiotracers



b) The promise of nano-radiotracers

- Exploration of new co-therapies for improving the efficacy of radiotherapeuticals:
  a. limitation of tumor growth by modulating the intrinsic oxidative stress of cancer cells through up-regulation of the endogenous antioxidant system (repeated exposure to N-acetyl cysteine-NAC)
  b. up-regulation of the anti-tumor immune response mediated by NK cells with cytokines.



Perspectives:

1) development of nano-targeted radiotherapeuticals for improving their specific uptake into solid tumors;
2) down-regulation of the endogenous antioxidant system through pharmacologic intervention on the Nrf2 transcription factor for improving the efficacy of radiotherapeuticals.

International collaboration:

1) the EU-ROS consortium (COST Action BM1203) – particularities of redox signaling in irradiated biological samples;
2) Prof. Antonio Cuadrado (Autonomous University of Madrid, Spain) - new radiotracers for non-invasive diagnosis of redox-mediated diseases.

Publications:

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3) Grigorescu R, Maria Gruia MI, Nacea V, Nitu C, Negoita V, Glavan D. Role of non-enzymatic antioxidants in limiting the oxidative stress associated to tumor development, Oncolog-Hematolog.ro, 31(2): 8-12, 2015.

Laser plasma acceleration of electrons in the GeV range (LAPLACE)

Project Leader: Cătălin TICOȘ
Project Coordinator: INFLPR
Partner: UB
Project webpage: *http://laplacee06.inflpr.ro/*

The main objectives of the project are:

- to realize the experimental setup for producing electron beams using gaseous targets;
- to accelerate electrons at an intermediate level of energies of 10 to 100 MeV in a laser produced plasma by using a gas jet and at energies beyond 100 MeV and up to1 GeV in a gas cell in a controlled gas flow environment and the characterization of the electron beam.

The main scientific results obtained within the project are:

- The realization of the experimental configuration with the gas jet to produce electron beams;
- The achievement of a large number of interactions between the PW laser with the gas target (over 50 shots) at different laser energies of up to 5J, as shown in Fig. 1. The pulse duration was about 40 fs;
- The operation of the gas valve in He at pressures up to 80 bar and its synchronization with the laser pulse at 10 Hz. The valve had a diameter of 0.6 mm. We used two nozzles: one with a diameter of 1 mm and a length of 1 mm and the second having a diameter of 1 mm and a length of 8 mm;
- The alignment of the PW laser beam in the gas jet target with micrometer precision, the central spot diameter of the laser having about 60 microns;

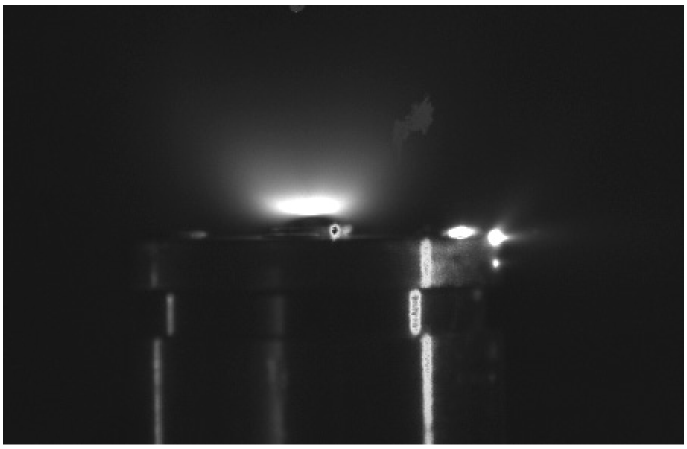
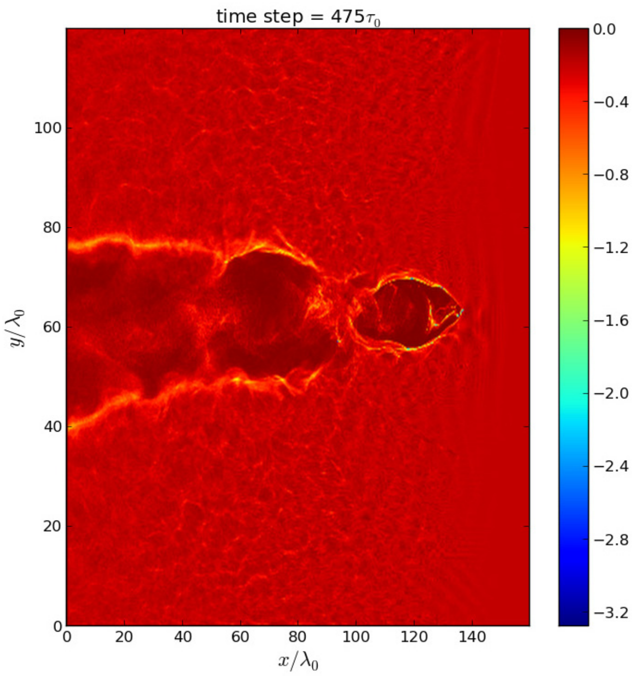


Fig. 1 Laser-plasma produced in He at a pressure of 40 bar and laser energy of 2.75 J.

- The building of an electron spectrometer to measure electron energies up to 100 MeV and its testing at the electron linear accelerator ALID using radiochromic film (RCF) and LANEX screens in order to visualise the electron trajectories;
- The detection of 6 MeV electrons with Lanex and RCF screens;
- The simulation of electron trajectories in the magnetic field of the spectrometer and their fit with the experimentally measured trajectories;
- The simulations using a „particle in cell" (PIC) algorithm of the interaction between the laser pulse and the gas jet target using the supercomputer BlueGene/P located at the West University of Timisoara which comprises 1024 quadcore CPUs and 4TB of RAM memory (at 11.7 Tflops).



In Fig. 2 a PIC simulation of the laser pulse interacting with the gas is shown. The laser pulse has an intensity $I=10^{21}$ W/cm^2, while the electron density in the laser produced plasma is $n_e=0.05\ n_c$, where n_c is the critical electron density. The electron maximum energy E_{max} = 300.5 MeV, while the simulation time is 1.3 ps. In the color bar a value of 0.225 corresponds to 0.05 n_c.

The obtaining of relativistic electrons with the PW laser will subsequently be pursued in all ranges of experimental parameters to better understand the acceleration regime and to optimize the acceleration mechanism. Short bunches of accelerated electrons of tens of femtoseconds and a few picoseconds at energies in the 100's MeV and GeV have many potential applications, from astrophysical and fusion technology to material science. As an example, the environment of the Jupiter radiation belt can be simulated with accelerated electrons obtained by laser-plasma interactions. Thus, the electronics used in space probes for future missions to Jupiter can be tested and evaluated for radiation effects. The processes in fusion tokamaks can be partially recreated by producing highly energetic plasmas with the focused laser beam in specific gases such as deuterium. Materials used in fusion technology which are in contact with the hot plasma can therefore be tested at the PW laser facility.

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Nuclear Spectroscopy Developments for experiments at the ELI-NP Gamma Beam System (ELINUS)

Project Leader: Nicolae Marius MĂRGINEAN
Project Coordinator: IFIN-HH
Project webpage: *http://proiecte.nipne.ro/pn2/158-proiecte.html*

The study of the structure of atomic nuclei is expected to get a boost from the major investment projects in the field like FAIR in Germany, SPIRAL2 in France or, more recent, ELI-NP in Romania. Many members of the ELINUS project group are also partially involved in the NUSTAR (Nuclear Structure and Astrophysics) experiment at FAIR, have a consistent involvement in ISOLDE and contribute to the definition of the experimental part of ELI-NP. This follows our main idea to study different aspects of nuclear structure at the facility that offers the best experimental conditions for the problem to be investigated and on the same time to insure a very solid experimental basis in the local laboratory as training basis for the students and to work on isotopes not very far of the stability line.

The involvement in ELI-NP is particularly important since the new facility will provide a new tool presently not available in Europe, namely a high-resolution gamma beam. There is an obvious complementarity with other facilities regarding the experimental thematic, which combined with the non-negligible factor of the geographical location gives us strong a strong motivation to contribute, within the present project, to the successful building of the new facility.

The project's main objectives are:

- Study the impact and advantages of using Compton shielded segmented clover detectors for level widths measurements at ELI-NP.
- Development of dedicated prototype digital data acquisition and novel read-out systems for the detector arrays foreseen to be used at the GBS of ELI-NP.
- Study of response of the different neutron detectors used in the photo-neutron induced reactions.

During 2015, we focused our activity on a major objective, namely **Development of dedicated prototype digital acquisition and novel read-out systems for the detector arrays foreseen to be used at the GBS of ELI-NP correction**, with two directions envisaged:

- o Test stand for digital sampling of gamma–ray detector signals
- o Development of a SiPMT based readout system and realistic test with BGO and plastic scintillators

Scientific accomplishments – Results obtained in the last year.

The two research directions of the present project for this year were related to ELIADE array, a HPGe high-resolution, high-efficiency gamma detectors array for the study of nuclear resonance fluorescence processes in stable targets using the Gamma Beam System. The ELIADE detectors will be segmented CLOVER-type detectors commercially available, namely the EXOGAM-like clovers produced by Canberra. Each detector was provided with a three pieces anti-Compton shield: a CsI back-catcher, BGO side-catchers on the laterals and BGO side-shields covering the tilted side of the capsule. In addition to the CLOVER detectors that provides 36 output signals/detector, one has to of high efficiency LaBr3 scintillators. Moreover, the time structure of the beam, 32 micro-pulses ~1 ns wide, repeated each 16 ns and grouped in 100 Hz macro-pulses, introduce an additional difficulty. As a result, a digital data acquisition system was chosen as the solution for the read-out of the ELIADE detectors.

- *Test stand for digital sampling of gamma–ray detector signals*: An electronics test stand for the data acquisition system at ELI-NP is required for both the acceptance testing of the detectors as well as the development of the final data acquistion system. The requirements for the digital electronics to be purchased were discussed and decided in the NRF working group and the first components were delivered October 2015. The main goal of the test stand was to test the performance of the digitisers while maintaining a high degree of flexibility. All the possible trigger modes were discussed and tested: the electronics should allow both the triggerless and triggered runs, with many types of trigger configurations. The triggered runs are necesarry to allow the data acquistiion to be sincronized with the incoming photon beam, while the trigerless operation is required for the calibration runs and other type of experiments. A very challenging experiment proposed for the ELI-

NP project is the ELIADE array, which will be used for NRF experiments and which will comprise 8 segmented clover detectors, which will require a high density of channels, with very good energy resolution, and precise timing. The high number of channels for this array forced us to consider a complex data aquisition system, distributed over a few powered crates (VME) and a matching data aquisition system. The associated computer configuration needs to be tailored to match the flow of data from this high number of detector channels, with special care being given to maintain the time sincronisation between boards running in different power crates. Since October 2015, the test stand was used to study the performance of the digitisers using signals from pulsers, $LaBr_3$(Ce) scintillators and HPGe detectors. Currently, the DAQ is coupled to the ELIADE CLOVER detectors.

- *Development of a SiPMT based readout system and realistic test with BGO and plastic scintillators:* A readout system based on SiPMT was required as part of the effort to develop a compact and efficient back-catcher for the ELIADE CLOVER detectors. The commercially available solution is a CsI scintillator read-out by Hamamamtsu short PMT's which occupy roughly 50% of the volume available. A SiPMT will allow to use more efficiently the space available and by using a LaBr3 crystal one can also try to recover the energy of the scattered photons. Recently, SiPMT cells sensitive in the 200-400 nm wavelengths interval became available. We tested such a single 6x6 mm cell with a LaBr3 crystal and the preliminary results were encouraging. The following step was to acquire an 8x8 matrix of SiPMT's each 6x6 mm, thus allowing to readout a 2x2 inch LaBr3 crystal. However, connecting in parallel such a high number of cells will result in a high capacitance and a poor signal/noise ratio. Thus, we developed a multiplexed readout solution with improved timing properties based on Schottky diodes. Currently, the SiPM cells are tested with $LaBr_3$(Ce) scintillators of various sizes to test the energy and timing properties. Preliminary results show that the SiPM cells offers the same energy resolution as the Hamamatsu R9779 PMT, while the timing resolution is around 5-10% worse.

Short-lived nuclear isomers produced by high-power laser accelerated ions (LDISOM)

Project Leader: Florin NEGOIȚĂ
Project Coordinator: IFIN-HH
Project webpage: *www.nipne.ro*

Understanding the way protons are accelerated by the laser-matter interaction is critical for planning the future experiments at ELI-NP. The LDISOIM project aims at developing new techniques to characterize the flux and energy of protons accelerated from the interaction between a solid target and a very intense, short duration and tightly focused laser pulse. The use of *in situ* gamma detectors will offer the possibility to obtain real time information, not achievable with the standard methods used to detect protons accelerated in laser driven experiments (RCF, image plates etc.) over full emission angle. In the same time, the development of in-situ gamma spectroscopy will open up new possibilities of performing laser-driven nuclear physics experiments.

The efforts in the project were directed mainly in solving the following aspects:

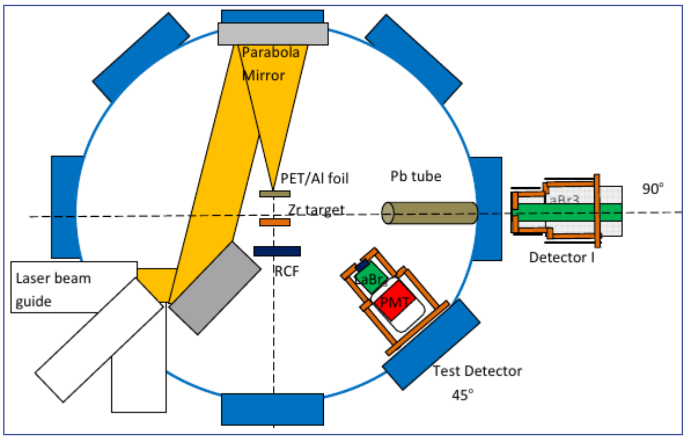
- analysis of experimental data acquired in an experiment performed at 100 TW ELFIE laser facility from LULI/Ecole Polytechnicque (France) where the measurement of the decay of isomeric states with life time down to 1 ms has been first demonstrated
- calculation of isomeric yield based on cross section calculation and various target combinations that will allow to extract the information of energy distribution of produced nuclei
- preparing and performing new experiments with improved experimental tools aiming to prove the advantages of the proposed method in comparison with other well-established methods as well as to push its limits toward shorter lived isomeric states observation and enlarge therefore its capabilities.

A schematic representation of experimental set-up used at ELFIE facility is shown in Figure 1 together the acquired bi-dimensional spectra of gamma energies versus time relative to laser pulse arrival on target. The decay of several nuclear states was observed [1] through their characteristic γ-ray lines: 122 keV – $T_{1/2}$=18.8 s and 257 keV – $T_{1/2}$=6 ms of ^{90}Nb, the 1436 keV originating from internal contamination of the $LaBr_3$ crystal, and a line at 208 keV line identified as 5.1 s isomer of ^{79}Br produced by photoexcitation inside the detector.

The observed yields are of more than 100 counts per laser pulse and deviate in most case by less than 20% compared with estimations based on cross sections calculated using TALYS code, stopping powers calculated with TRIM code and the proton energy spectra measured using radiochromic films (RCF). The proposed method of determination of proton energy from measured isomeric yield implies the use of various target materials and population of various isomers. Therefore, the cross sections for population of many isomeric states have been calculated, some of them shown in figure 2, as function of proton energies allowing to define the combination of materials and their thickness sequence. On the technical side, the reduction of the recovery time of the detector after the saturation due to gamma flash associated to laser pulse interaction will give the possibility to measure large number of isomers with shorter lifetimes (down to microsecond) and it is approached with new gated photomultipliers, modification of their polarization scheme (such as the suppression of last electron amplification stages – see Figure 2) as well as with other means to readout the optical photons produced in the scintillating process while preserving the energy resolution.

In order to test of the new technical developments two experiments have been prepared and performed at 1PW CETAL facility of INFLPR. The calibration of a new Thomson parabola spectrometer that can provide the proton spectrum (in a very small acceptance angle) simultaneously with isomeric decay measurement, has been performed at Tandem accelerator of IFIN-HH. A new experiment has been proposed and accepted by Programme Committee at ELFIE facility.

[1] F. Negoita et al., "Perspectives for neutron and gamma spectroscopy in high power laser driven experiments at ELI-NP", AIP Conference Proceedings 1645, 228 (2015)



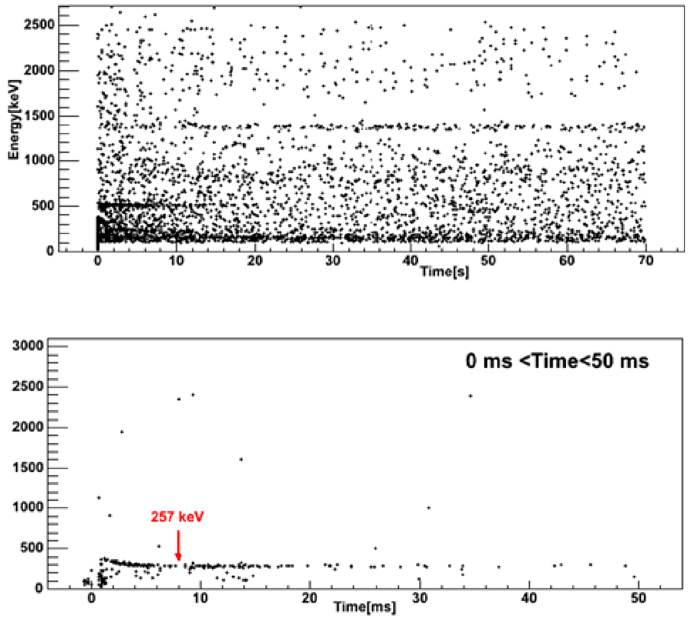
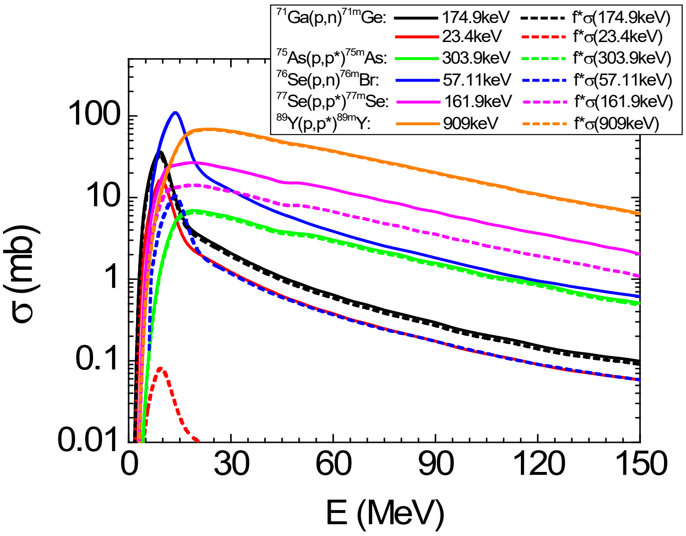


Figure 1. Experimental arrangement and results demonstrating short-lived isomer gamma decay measured with a $LaBr_3$ scintillator detector placed in an air-bubble inside the vacuum chamber



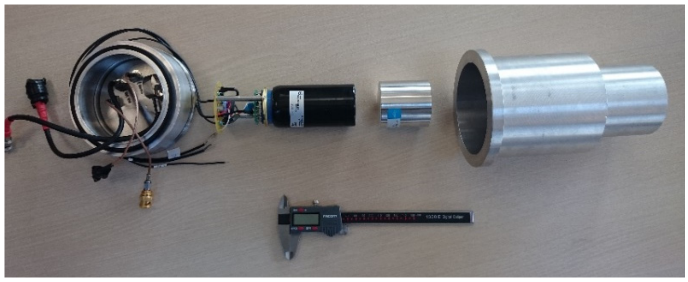


Figure 2. Left: calculated cross section for various isomeric state production multiplied by the factor f corresponding to gamma emission from the total decay modes; Right: exploded view of a new LaBr3 detector assembly to be used of in-situ gamma measurements.

High Temperature Superconducting Magnet for Nuclear Magnetic Moments (MSMMN)

Project Leader: Ion DOBRIN
Project Coordinator: ICPE-CA
Partner: IFIN-HH
Project webpage: *www.icpe-ca.ro*

Project objectives

- The overall objective of the project consists in the realization of a superconducting dipole magnet for the measurement of nuclear magnetic moments. This prototype will produce a magnetic field of > 2T with a high uniformity of $10^{-3} – 10^{-4}$ over the active area of the magnet and in the "hot" channel of the magnet, using HTS superconducting materials and a cryocooler for the low temperature regim needed (<30K).
- The second objective is the realization of a magnetic field measurement system, destinated to map the values measured into the „good field zone" generated by a magnet.

Main stages

1st stage: 2014

- Elaboration of the technical theme with the setting of the necessary parameters to be obtained by the superconducting magnet (field intensity, uniformity, main dimensions, etc).
- Elaboration of conceptual model of HTS superconducting magnet.
- Numerical simulations of the generated magnetic field, of the thermal field and of the Lorentz forces in the windings.
- Elaboration of the conceptual model for the magnetic field measuring system.

2nd stage: 2015 - Design of the experimental model of HTS superconducting magnet and of the magnetic field measuring system.

- Design of the experimental model of HTS superconducting magnet and of the related parts (the HTS coils, the Cryostat, HTS current leads and normal current leads, thermal shields, the cryogenic cooling System)
- Design of the measurement system of the magnetic field generated by the HTS superconducting magnet (3 axes mechanical movement system, Hall probe measuring device)

3rd stage: 2016

- Realization and testing of the HTS magnet system
- Realization and testing of the magnetic field measurement system

RESULTS

I. HTS magnet realization

Fig.1. The HTS magnet ensemble.

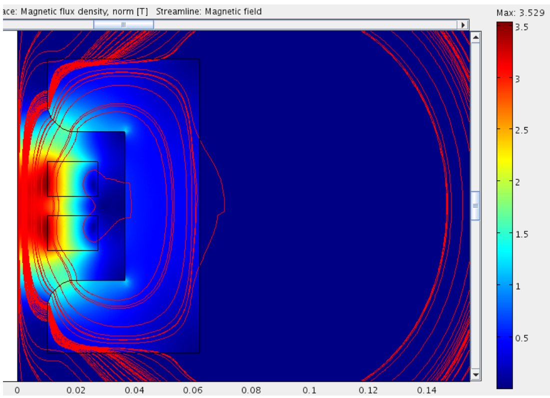


Fig. 2. The generated magnetic field and the magnetic field lines

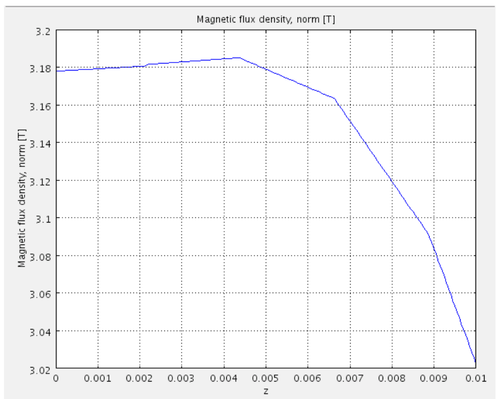


Fig. 3. Magnetic field density B(x) in the centre

II. The magnetic field measurement system

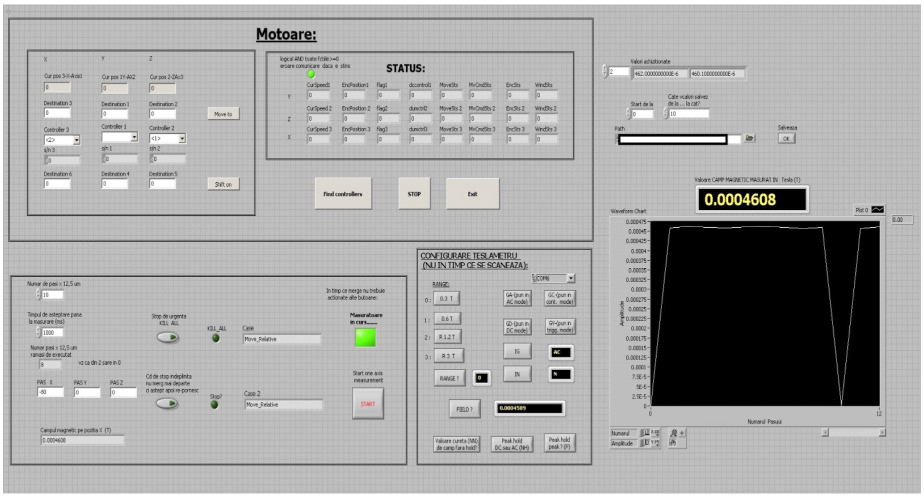


Fig.4. The 3D movement system for the magnetic field measurement.

Fig.5. Screen capture of the LabVIEW application performed for the magnetic field measuring system.

Applications

Nuclear Physics (nuclear excited states magnetic moments measurements, other properties,etc.)

Impact

New results in nuclear physics excited states measurements, physics of materials properties research, etc.

Perspectives

Higher magnetic fields (>3T) can be obtained, with more powerful HTS magnets for advanced studies on nuclear excited states properties.

Publications

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3. I. Dobrin, T.B. Sava, B. Savu, M. Popa, *"Conceptual model of a Hall sensor based system for magnetic field mapping"*, 10th International Conference and Exhibition on Electromechanical and Power Systems, 8-9 October, Chisinau, Republic of Moldova. *http://sielmen.ucv.ro/data/_uploaded/file/Program_V4%20final%202.pdf, pag. 11*.
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5. D. Balabanski, I. Dobrin, et al,- ed., *TDR of Photo-fission Experiments at ELI-NP,* (ELI-NP/TDR/PHF/3/Ian.2015). *ch. 3.4.1 Assembly for g- factor measurement*, pp. 39-41.

Advanced Target Engineering for Studying Ion Beams Generated by Petawatt-Class Lasers (AdvTargetPW)

Project Leader: Victor KUNCSER
Project Coordinator: INFM
Project webpage: *http://www.infim.ro/ro/projects/tinte-avansate-pentru-studiul-fasciculelor-ionice-generate-cu-laseri-de-clasa-petawatt*

The well localized production of ion beams of MeV energy, of high degree of collimation and laminarity, is highly desired due to applicative perspectives (e.g. production of warm dense matter, fast ignition of fusion targets, bio-medicine, nuclear physics, etc.). At variance to the classical ion sources and accelerators, laser-plasma particle accelerators represent compact and high quality sources for energetic particles, the ion acceleration driven by super-intense laser pulses being under intensive and continuous investigation over the last decade. Definitely, there is an unusual physics taking place during the interaction of extreme high intensity and very short laser pulses with the matter, giving rise to peculiar phenomena depending on both the pulse characteristics and the target material properties and geometrical configuration. Engineering of advanced solid targets for the study of intense radiation - matter interactions is a top necessity for an adequate generation of high energy ion beams experiments using petawatt-class lasers, being also the aim of this project. By considering simplified models based on the problematic of hot electrons generation and distribution and on the Target Normal Sheath Acceleration (TNSA) mechanism, three objectives have been proposed and accomplished along the 3 stages of the projects as follows: (i) engineering and characterization of multi-layer targets based on light elements LE (e.g. Fe) and heavy elements HE, (e.g. Au) (ii) engineering and characterization of targets made as nanoglobular thin films and ribbons based on the formation of light elements LE (e.g. Fe) clusters in heavy elements HE matrices (e.g. Au) and (iii) engineering and characterization of targets made as supports of heavy elements HE (e.g. Au) on top of which nanowires of light elements LE (e.g. Fe or Ni) are grown. It is worth to mention that the reason for choosing such systems was related to the expectation that in the multi-element samples, the mass ratio, the relative concentration and the geometry of the sample can be properly engineered in order to obtain well defined ion beams due to only LE ions (the theoretical proof of such expectation was also obtained by a simple modelling of plasma expansion in vacuum and using plan parallel initial static configuration of ions, e.g. thin films of either LE or superposed LE+HE, as can be observed in Fig.1).

According to Fig 1, it may be observed a much faster displacement of the LE ions as compared to HE ions, in conditions of increasead ratio $\alpha = \dfrac{A_{HE} / Z_{HE}}{A_{LE} / Z_{LE}}$ (e.g 5/3 in case of Fe+Ag and 10/3 in case of Fe+Au).

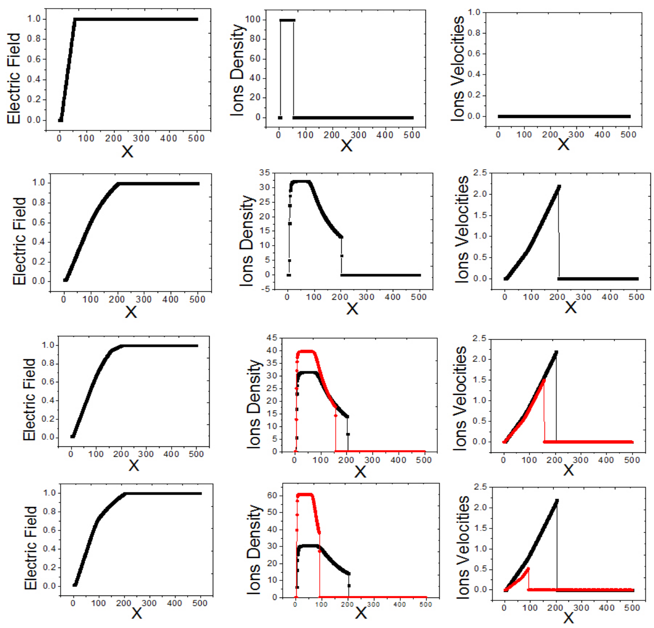

Fig.1. Initial distribution of the electric field, ion density and ion velocity (first line) and corresponding distributions after a same time (fs order) for an initial Fe layer (second line), Fe-Ag layer (third line) and Fe-Au layer (forth line) of identical thickness of order of tenths of nm.

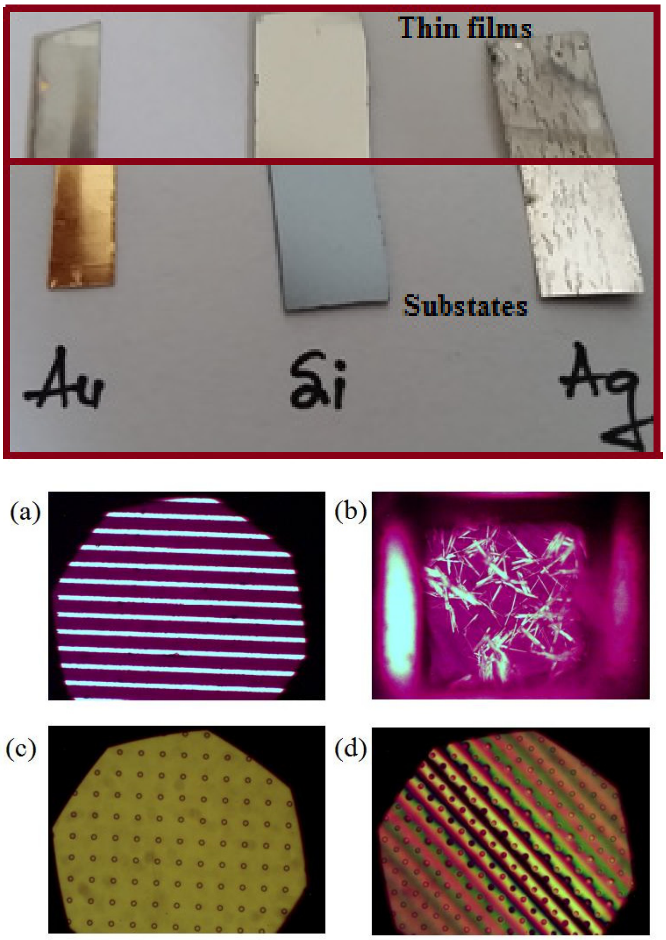

Fig.2. Thin films of metallic Fe (50 nm) deposited on different substrates (up) and Ni NWs (100 nm diameter) on Cu sieve (b) and Au/Fe micrometric wires (c and d); In a) is the optical microscopy image (1000x) of the 0.01 mm unit.

After considering various aspects related to target engineering (including the design and preparation of multilayered structures of type Ag(cap layer)/Fe(20-50 nm) /Ag (ribbons of 100 μm, and codeposition of Fe-Mo thin films and respectively Fe-Ni thin films for investigation the elemental density profile in depths of materials), the activities related to preparation of various targets have been extended to systems of type thin films of Fe (different thicknesses in the range of tenths on nm) enriched in the ^{57}Fe isotope and covered by 5 nm Au cap layer, as deposited on thin foils (70 μm) of Au (deposition on Ag ribbons and Si substrates wit 5 nm Ah buffer layers were also considered for a proper characterization and comparisons of the systems; the metallic state-lack of oxidation- has been always proven by Mossbauer spectroscopy). Thin films of Au-Fe and Ag-Fe (50 nm thickness) have been also deposited on Au foils as well as on Si substrates. Finally, Au wires with diameters of 1 μm with Fe films (50 nm thickness) on top were prepared as micrometer(HE)/nm(LE) size systems whereas Ni nanowires (NWs) of 100 nm diameter were transversally deposited on Cu sieve (100 μm holes) specific to TM holder, as the thinnest auto-supported target achieved in this study.

All the prepared systems have been intensively investigated with respect to geometrical, structural and morphological aspects as well as with respect to phase composition and local interactions (e.g. magnetic aspects are dependent on structural ones) by X ray reflectometry (XRR), X ray diffraction (XRD), Transmission Electron Microscopy (TEM), Scanning Electron Microscopy (SEM) coupled with EDXS for describing the depth dependent elemental profile. Simulations via TRIM/SRIM code of Fe ion paths in W foils (sensors) have been performed for various incident energies (between 5 MeV and 40 MeV). A new methodology for the estimation of both the average energy and the energy distribution of the incident ions from the experimentally obtainable elemental density distribution of Fe ions in the W foils (via EDXS) has been proposed. At the present moment different targets are ready to be used for real laser-plasma experiments deserving the formation of controllable ion sources and the methodology for the characterization of the ion beam via the elemental profiles in solid targets is partially established.

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2. A. Kuncser, V. Kuncser, Magnetization reversal via a Stoner-Wohlfarth model with bi-dimmensional angular distribution of easy axis, J. Magn. Magn. Mat. 395 (2015) 34-40
3. Pintilie, P. Badica, M. Bulinski, V. Kuncser, Shapes and Patterns in matter and fields: inter-related microscopic and macroscopic physical properties, book chapter (On Form and Pattern, ed. C. Vasilescu, M.L. Flonta, I. Craciun) Ed. Academiei Romane, 2015 (101-137)
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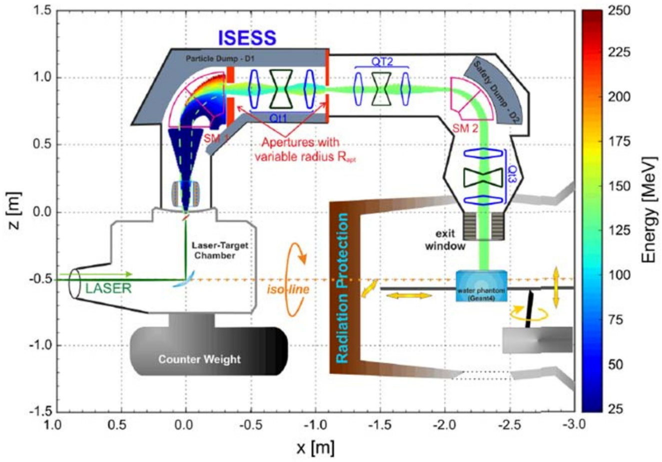
Preliminary Studies for Implementation of Bio-Medical Experiments at ELI-NP (ELI-BIOMED)

Project Leader: Dan Constantin DUMITRAȘ
Project Coordinator: INFLPR
Partners: IFIN-HH, UMF, Canberra
Project webpage: *http://www.eli-biomed.inflpr.ro/*

OBJECTIVES: The **main objective** of the project consists in the elaboration of a feasibility study for establishing a branch of bio-medical applications at ELI-NP, preparing the technical solutions, evaluating the chart of bio-medical options and assessing the financial effort implied by the start-up of the targeted experiments. The project was based on a several **specific objectives**:

- Assessing the best solution for particle beam production with respect to the particle type: electrons, protons, heavy ions
- Optimizing the particle beam characteristics in relation with the envisaged applications
- Establishing the dedicated detection chain, taking into consideration the constraints of in-vivo experiments and possible a restrictive geometry of the space
- Developing an extensive software database for simulations
- Establishing the chart of targeted bio-medical applications and corroborating these with the parameters delivered
- An intensive dissemination with the goal to focus the scientific community on the problems of bio-medical applications developed at the future infrastructure ELI-NP.

WORK: The project was structured on five work packages with parallel deployment on three main activities plus a secondary one. All the work packages and activities involved the partners in a balanced way, according to their main expertise. Starting with a thorough documentation on the design of different experimental setups dedicated to particle acceleration (electrons, protons, heavy ions) and an evaluation of the possible use of those particle beams, we have selected the proton solution. Then we considered the option range of our applications and we decided to focus on bio-medical applications, regarding both cell cultures and tumor bearing small animals, and the feasability of an explorative experiment for the production of 99mTc (used in nuclear medicine imaging) from molybdenum targets irradiated with protons beams obtained by the interaction of ultrashort intense laser pulses with plasma. Once that the parameters required by the bio-medical specificity of our intended experiments were established, we could work on finding the most appropriate technical choice for the production, transport and control of obtained beams (beam focusing, energy selection, etc). A compact solution for the proton accelerator was considered to be the one proposed by Masood et al., with the size of only 3x4 m.



From a series of detection solutions which have been identified for the geometric characterization and the dosimetry of the delivered proton beam, the best solution was considered the use of RCF films, namely the Gafchromic EBT3, correlated with a high resolution scanner and proper beam analysis software, like the Mephysto Mcc. For the required simulations we focused on building a software library (GEANT, FLUKA, Comsol, etc) and the construction of a full set of parameters implied in the laser beam propagation, particle production and transport, delivery and detection. During our work, we continuously took into consideration the science progress up-to-date, including the techniques developed during the project duration. An intensive dissemination activity included 5 papers, more than 20 participations in conferences, workshops and round tables, with the major dissemination action represented by the 2nd International Conference of the Romanian Society of Hadrontherapy, organized by the consortium at Sinaia, 25-28 Feb. 2015.

RESULTS: The short list of our accomplishments:

- Schematic design of a chain for production and acceleration of protons with high intensity laser pulses for biological studies
- Establishing of the objectives for radiobiology and experiments in vitro
- Identification of clinical requirements imposed by in-vitro experiments for proton-therapy
- Development of new route for technetium-99m radioisotope production
- Identification of detection solutions for the beam characterization and the dosimetry of the delivered beam.
- Choice of optimal solutions, necessary equipment, software solutions, human resources evaluation and cost estimation.
- Building of a multidisciplinary team, both with complementary and disjunct skills, able to propose concepts and experiments in the field of bio-medical applications of high power lasers.

Selected paper: V. Jinga et al., "Compositional, morphological and mechanical investigations of monolayer type coatings obtained by standard and reactive magnetron sputtering from Ti, TiB2 and WC", Applied Surface Science, Vol. 358, Part B, pages 579–585 (2015)

APPLICATIONS/IMPACT: The scientific impact of the project consists in giving the opportunity to the Romanian scientific community to rapidly start the exploitation of the ELI-NP, allowing consistent preparation of the experiments and establishing pre-collaborations with international partners, or training of young specialists. Another major impact of the project is considered to be the fact that a preparation phase of the implementation of bio-medical experiments at ELI-NP reduces the implementation time and the financial effort when the facility will be operational. A period of two years of searching technical solutions and planning further development prior to establish the first experiments was highly contributing to the quality of the full implementation, reducing the implementation time, assessing the future financial effort, and partially ensure the success of the first trials.

PROSPECTS: Based on the expertise acquired in this project and on the existence of a multidisciplinary new team, as well discovering the synergies with other projects from the actual program, we already identified two future directions of development, partially continuing our studies and simulations, but with the further aim of implementing experiments with the high power laser beam available at the CETAL facility.

High energy radiation effects on some fluoride and semiconducting crystals (ELICRYS)

Project Leader: Daniel VIZMAN
Project Coordinator: UVT
Project webpage: *http://www.physics.uvt.ro/~vizman/ELICRYS/*

The laser plasma accelerated particles represent an interesting case study due to their similarity with cosmic radiation, which might be useful for testing electro-optical devices bound for outer space applications. The objective of this project is to prepare physical and numerical experiments in order to study the laser accelerated particle radiation (LPA) generation and its interaction with fluoride crystals and solar cells. The experience gained from the development of these experiments could then be used for LPA irradiation at the future ELI-NP infrastructure. The specific objectives are listed below:

O1: Design and execution of crystal irradiation experiments

O2: Investigation of radiation effects on the rare earth doped fluoride crystals

O3: Investigation of radiation effects on some semiconductor crystals

O4: Numerical modeling of the laser accelerated proton and electron radiation through

As a main result of the project, two proposals for the Technical Design Report „Materials in extreme environments for energy, accelerators and Space applications at ELI-NP" [Romanian Reports in Physics, Vol. 68, Supplement, P. S275–S347, 2016]:

1. *Degradation of optical crystals and solar cells in space*. High power lasers could be a better alternative for reproducing cosmic ray interaction with condensed matter. The energy spectrum of laser accelerated particles is similar to the broad, multi-MeV-scale spectra of natural cosmic radiation, as opposed to the quasi-monoenergetic spectrum of particle beams in classical accelerators. At ELI-NP the highest fluence of LPA radiation in the world will be obtained. Therefore, we propose to use ELI-NP facilities for accelerated testing of the degradation of optical crystals and solar cells performance in space-like irradiation conditions. Beyond the scientific experiments, it can be thought as a testing service that ELI-NP can provide to manufactures of space solar cells or optical components designed to be used for satellites.

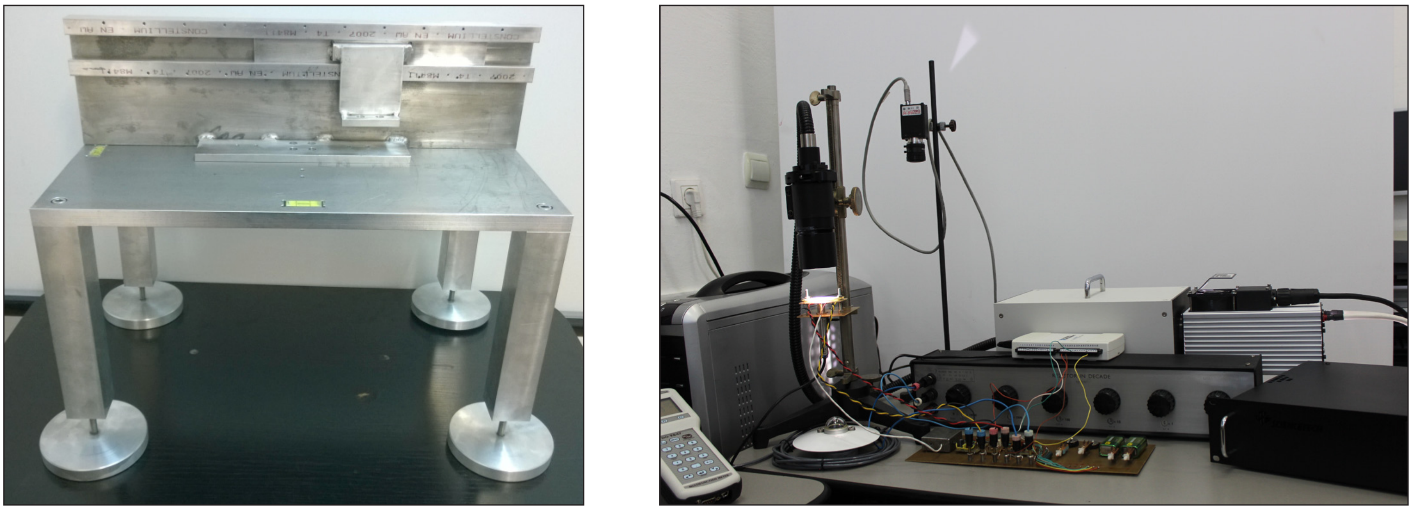
2. *Doped fluoride crystals irradiation for fundamental studies of optical proprieties modification.* The aim is to use LPA radiation from ELI-NP in order to study the change in optical and dielectric properties of irradiated crystalline materials with perspective novel laser applications. A very important aspect of LPA usage for radiation induced optical defects in crystals concerns the availability of an easily tunable and cheap proton source, compared to the high costs involved with classical proton accelerators. Also, charge conversions from Yb^{3+} to Yb^{2+} could be rapidly reached with the high dose per pulse of the LPA radiation obtained at ELI-NP, for the improvement of the UV emission intensity of Yb^{2+}.

In the frame of first objective, there have been made the devices essential to running the test experiments for accelerated degradation of the efficiency of solar cells in irradiation conditions similar to those of the space: (1) a mechanical device for positioning the samples (samples crystalline solar cells) into the interaction chamber (fig1.a) and (2) the experimental stand for testing the performance of solar cells before and after irradiation ((fig1.b).

In order to investigate the effects of space-like radiation on the Ytterbium doped Barium fluoride crystals, 9 crystal growth experiments have been conducted using the Bridgman technique. The experiments have consisted in the identification of the optimal BaF_2 crystal growth conditions: a temperature gradient in the hot region between 10-15 K/cm, with an adiabatic region around the solidification temperature of 1654 K and in the cold region a temperature gradient around 16 K/cm.

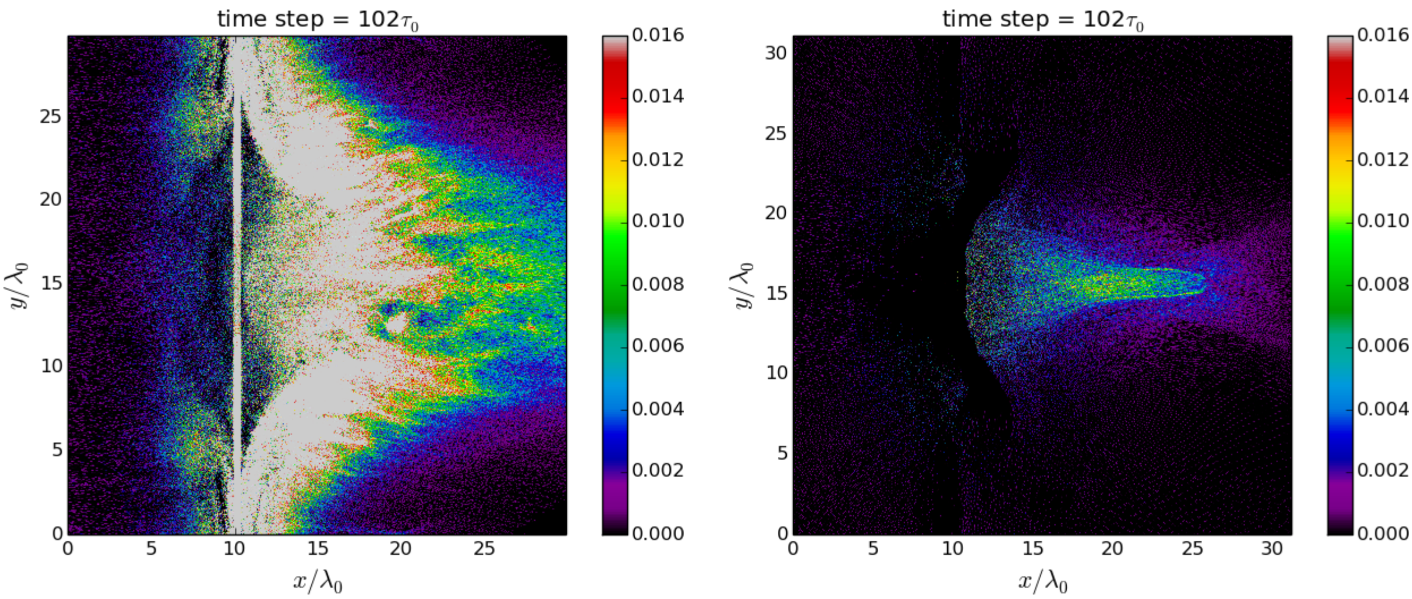
The probes considered (fluoride crystals and solar cells) have been irradiated with protons (at TANDEM accelerator – IFIN-HH institute) and electrons (at Center for radiotherapy in Timisoara). The probes have been analyzed before and after irradiation. It was concluded that the ELI irradiation experiments are strongly recommended in order to obtain realistic conditions close to the space environment.

In the frame of 4th objective, an expertise in the field of numerical modelling of interactions between high intensity lasers with high density plasmas using the Particle-in-Cell (PIC) method have been developed. The method is widely used to model systems with a large number of charged particles in their self-consistent electromagnetic field. The modeling of laser-plasma interaction at high laser intensities using PIC codes is done by describing the



a) *b)*

Fig.1 a) device for positioning the probes inside the interaction chamber; b)solar simulator.



a) plain target - 100 nm *b) curved target - 320 nm*

Fig. 2. Collimating effect of the curved target

plasma system through the Vlasov equation for different charged particle species.

To validate the accuracy of the chosen code for laser-plasma acceleration process, a parametric study was designed to estimate the energy protons accelerated by the interaction of a laser pulse with an over-dense thin film. It was shown that microstructured targets and curved foils have a collimating effect on the beam of accelerated particles.

Publications:

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