# Photonuclear effects during filamentation of ultrashort laser pulses in deutereted clusters - application to compact magnetic fusion devices

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**Abstract**

We investigate for the first time the filamentation effects during the propagation of an ultrashort high intensity laser beam with deutereted clusters and its potential application to compact magnetic fusion devices. The interaction of laser pulses with deutereted clusters allows to accelerate ions to kinetic energy up to tens of keV capable to initiate nuclear fusion reactions. Experimental measurements of ion kinetic energy, gamma-ray emission and neutron production during the laser beam propagation in deutereted clusters allows the optimization of the conditions for filamentation effects and improves the coupling for energy transfer from the laser pulse to the deuterium (or hydrogen) plasma. A 2-D MHD resistive code in axisymmetric cylindrical geometry is used to calculate the spatio-temporal evolution of the state parameters of the plasma produced by filamentation. The code can handle high external applied magnetic field strengths in mirror like topology. The results from both the experiments and the numerical simulations enable us to investigate an improved configuration, based on filamentation effects, for application to compact magnetic fusion devices.

## Introduction

The main aim of our investigation is to develop a compact fusion device in open magnetic topology for high neutron flux production. Experimental studies[1, 2] confirm that high intensity ultrashort laser beam interaction with deutereted clusters could be a potential monoenergetic neutron source. The laser-cluster interaction produces a high density and high temperature plasma capable to initiate D-D ion fusion nuclear reactions, this plasma expand rapidly in the vacuum decreasing the plasma density and consequently the neutron production. In our previous numerical investigation we study the spatio-tempral evolution of a high density and temperature plasma with a high external applied magnetic field in mirror-like topology using a 2-D MHD resistive code [3, 4, 5]. The results show that in such a configuration the trapping time of the plasma increases with a production of $10^9$ neutrons per laser shot when external magnetic field up to 150 Tesla was applied. Such an alternative table-top, pulsed and monoenergetic laser based neutron source, can be used: to study the dynamical properties of materials or for biomedical investigations for cancer therapy like the BNCT method if there are improvements on the neutron production. The total number of neutron is a function of the value of the local density and temperature of the plasma, the trapping time and the total volume of the laser-plasma interaction. The laser cluster interaction volume is limited by the optical focusing system in the most of the experiments. A new idea is based on the effect of the self-guided properties of the ultrashort laser beam during the propagation in the cluster volume[6]. Under these conditions of propagation the interaction volume increase preserving all the plasma parameters as in the case of single focus.

**Experimental verification**

A Thomson parabola mass spectrometer and a neutron detector enables to find the optimum experimental condition for self guiding propagation with high energy D-ions production up to 45 keV and the neutron production. For the purpose of the experiment a supersonic pulsed nozzle produces deutereted clusters interacting with a laser beam of up to $5.10^{16}$ W/cm$^2$ and pulse duration of 30 fs. Fig 1 shows the output of the Thomson parabola mass spectrometer which presents a number of hot spots corresponding to the self-guiding propagation and filamentation formation of the laser beam. Each parabola in fig.1 corresponds to the D-ion energy distribution of the successive multi-plasma spots formed the one after the other during, the laser beam propagation. The multi-plasma spots preserves the same density and temperature values as was for the case of the single focus spot. This new experimental configuration confirms the volume increases of the high density and temperature plasma during the laser beam propagation in the clusters volume.

**Numerical Simulation and Results**

In the next step of our investigation we study the spatio-temporal evolution of the multi-plasma spot production due to the laser self-guiding in the cluster volume. A 2-D resistive MHD code[4, 5] in axisymmetric cylindrical geometry, which solves the conservation equations for mass, momentum and energy of the plasma, coupled with the magnetic field equations has been used.

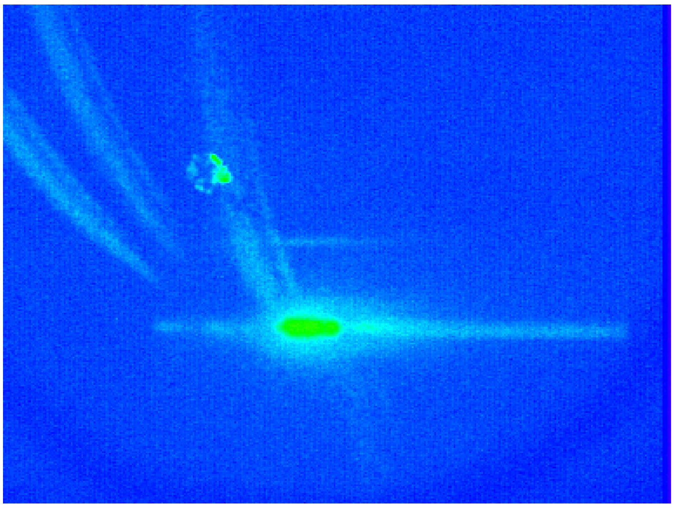

Fig_1. Multi-plasma spots and multi acceleration regions due to the self-guiding propagation of the laser beam in the cluster volume.

The code can handle very large magnetic fields and very steep gradients of the plasma parameters; the code is applied to study very high density plasmas in a compact fusion device with mirror-like magnetic field. A double-plasma spot was consider, describing the initial plasma distribution with a plasma density up to $10^{19}$ $cm^{-3}$ and temperature of 20 keV for the self-guided region and a plasma density of $10^{17}$ $cm^{-3}$ for the surrounding the multi-plasma spot region. We investigate the trapping time and the plasma spatio-temporal evolution of the plasma density for two cases. The first correspond to the double-plasma spot and the second to the single focus case. For both cases an external mirror like magnetic field up to 150 Tesla was consider with a ratio of $B_{max}/B_{min} \approx 2$. Fig.2a and fig.2b represent a comparison of the spatio-temporal evolution of the plasma density for the double-plasma spot and the single focus respectively. The time scale corresponds to an interval of 10 ns. The horizontal axes in fig.2 represent the plasma dimensions in cylindrical (r, z) coordinates and the vertical axe represent the value of the plasma density.

**Conclusion**

The comparison between the two cases was performed using the same initial physical and geometrical plasma parameters and external magnetic field. The main result is that the plasma density in the double-plasma spot case corresponds to a higher density by an order of magnitude compared to the single focus case. For the double-plasma spot case we observe an oscillation of the plasma density producing 2.5 times longer trapping time with relatively high density compare to the single focus case, confirming both the efficiency of the proposed self-guiding propagation configuration and the magnetic field mirror-like topology. Under these conditions we expect experimental improvements on neutron production by three orders of magnitude compare to the single focus case.

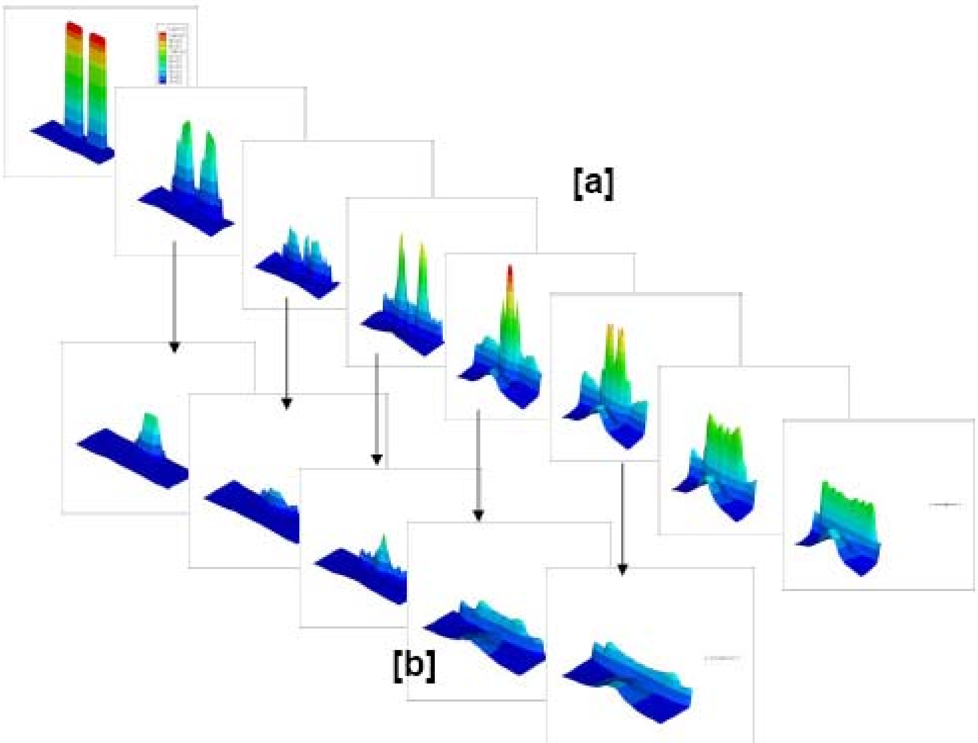


Fig. 2 The spatio-temporal evolution of the plasma density for the [a] double-plasma spot and [b] single focus. Both correspond to a time interval of 10 ns.

**References**

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