Neutron yield from d-d reaction in laser induced gas cluster explosions

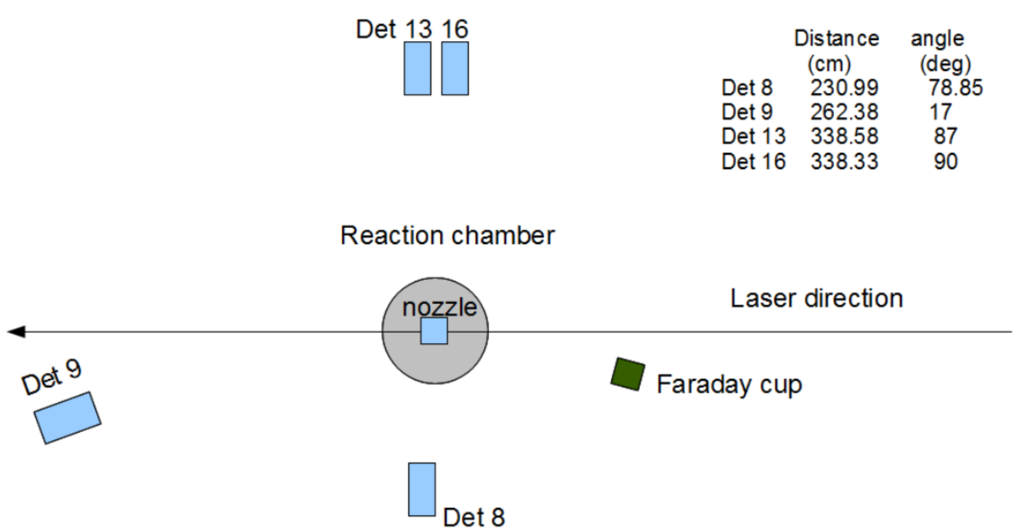
M. Barbui, A.Bonasera,[1] K. Hagel, J. B. Natowitz, M. R. D. Rodrigues, K. Schmidt, R. Wada, H. Zheng, M. Barbarino, W. Bang,[2] T. Ditmire,[2] G. Dyer,[2] H. Quevedo,[2] and A. Bernstein[2]
[1]*INFN Laboratorio Nazionale del Sud, Catania, Italy*
[2]*University of Texas, Austin, Texas*

Several experiments in the last years have shown that the interaction of intense ultrafast laser pulses with molecular clusters produces the explosion of the clusters with enough kinetic energy to drive nuclear reactions. In case of few nm diameter deuterium clusters, laser pulses with intensities of the order of 10^{16}-10^{18} W/cm^2 can remove the field ionized electrons from the cluster. Consequently the clusters explode due to the Coulomb repulsion of the closely spaced positive ions.

The gas clusters are formed in the expansion in the vacuum of cryogenically pre-cooled and compressed (about 800 psi) D_2 gas. The expansion is regulated by a supersonic nozzle valve.

The d(d,p)T and d(d,n)He^3 nuclear reactions can occur with the same cross-section. The reaction d(d,n)He^3 has been extensively studied, by detecting the characteristic 2.45 MeV neutrons [1] [2]. The study of the reaction d(d,p)T is more difficult because it requires the detection of the 3.02 MeV protons. Thin fast plastic scintillators placed at a proper distance from the reaction point have been used in the past to detect the charged particles produced in laser induced nuclear reactions [3] [4]. CR-39 plastic films [5] or micro-channel plates detectors [6] both coupled to magnetic separators can also serve this purpose.

A first test was performed in March 2011 at University of Texas Petawatt Laser to confirm our capability of measuring the neutrons from the d(d,n)He^3. Four NE213 neutron detectors were placed at different angles with respect to the laser direction as shown in Figure 1. The average energy of the deuterium ions was measured using a Faraday cup.



	Distance (cm)	angle (deg)
Det 8	230.99	78.85
Det 9	262.38	17
Det 13	338.58	87
Det 16	338.33	90

FIG. 1. Experimental setup used for the test at UT petawatt laser. The neutron detectors # 8, 9, 16, 13 are liquid scintillators NE213 of cylindrical shape with radius 7 cm and thickness 14 cm. HV=-1800V. The distance from the nozzle and the angle with respect to the laser direction are shown in the picture.

The neutron detectors were calibrated using a ^{252}Cf source. For the calibration, the signals were amplified by a factor 200 using a fast amplifier (ORTEC FTA820) and recorded using the same flash ADCs used in the experiment (10 ns sampling interval). The time of flight of the neutrons was also measured. In this case the start the signal was given by a silicon detector placed very close to the source and the stop signal by the neutron detector. With a proper window on the time of flight we selected the neutrons in the energy range around 2.45 MeV and plotted the distribution of the amplitudes of the signals, as shown in Figure 2. For every neutron detector, the average of this distribution is used to count how many 2.45 neutrons hit the detector in the real experiment.

Given the thickness of the detectors, we assume a detection efficiency of about 90% for 2.45 MeV neutrons.

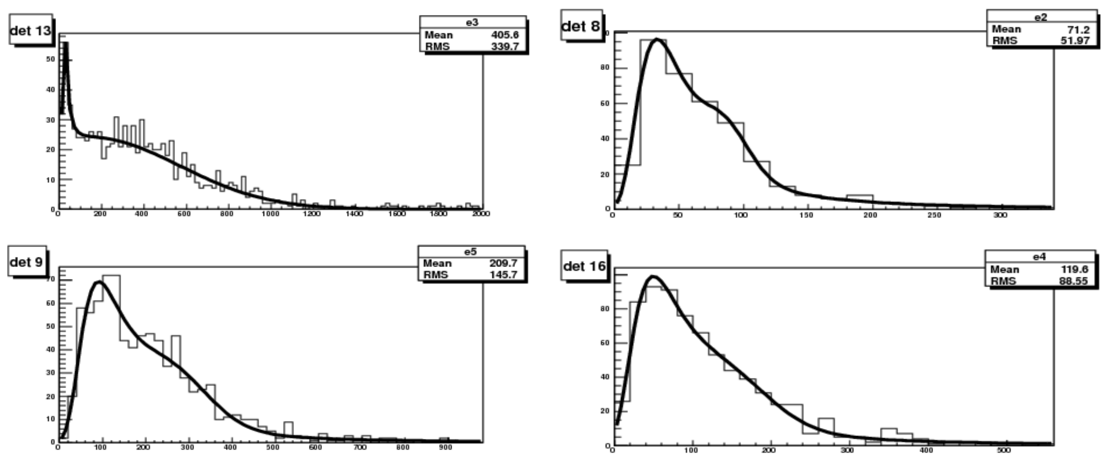


FIG. 2. Distribution of the signal amplitudes given by 2.45MeV neutrons in the detectors. The shape of the distribution can be fitted by a Landau + Gauss function.

In the test at UT Petawatt we employed system shots of energy 115 J and duration time 170 fs. A plasma mirror was used in order to reduce the pre-pulse resulting from non-linearities of the laser amplification process. In order to find the best conditions for inducing the nuclear reactions, several positions of the nozzle different from the optimal focus position were tested. The results are reported in Figure 3.

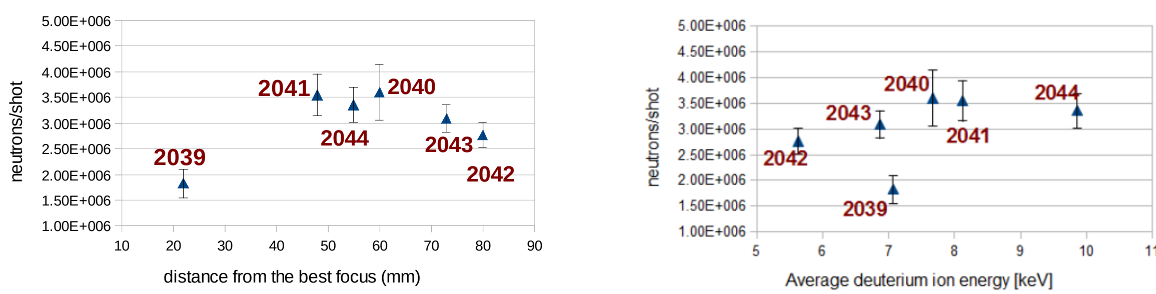


FIG. 3. Left panel: neutron yield as a function of the distance of the nozzle from the best focus position. Right panel: neutron yield as a function of the deuterium ions temperature measured with a faraday cup.

The optimal nozzle position was found at about 5-6 cm from the best focus. In this setting we measured a neutron yield of about 3.5×10^6 neutrons/shot over 4π and an average deuterium ion energy ranging from 7 to 10 keV. Our results are in fair agreement with those obtained in the same experiment by the UT group using plastic scintillator detectors. Comparing the results obtained from detectors 8, 13 and 16 placed at about 90° with respect to the laser direction with the result from detector 9 placed in forward direction we did not observe any anisotropy of the neutron distribution. Figure 4 shows an estimate of the reaction rate (obtained dividing the number of measured neutrons by the number of energetic ions in the Faraday cup) as a function of the average energy of the ions. It is interesting to note that rate is almost constant as the average energy of the ions increases from 7 to about 10 keV.

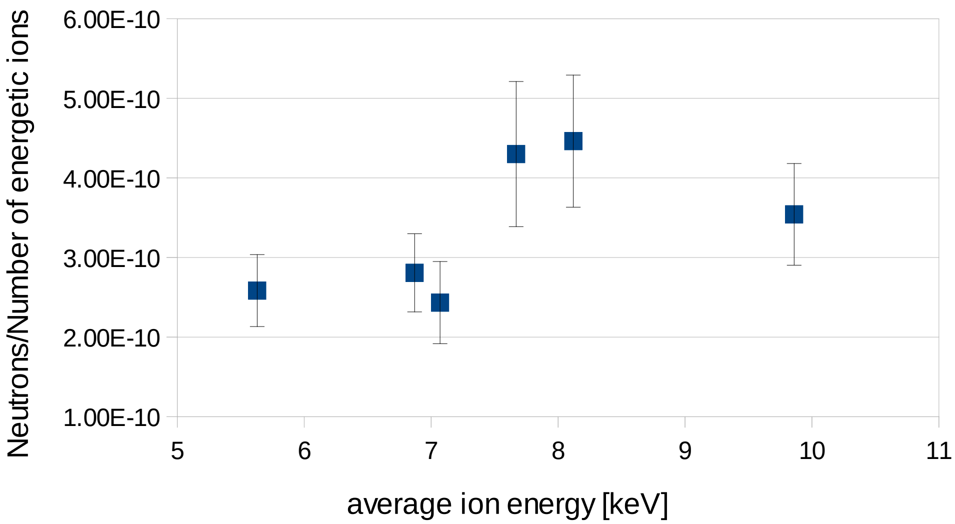


FIG. 4. Reaction rate as a function of the average ion energy. To calculate the error bars we assumed an uncertainty of about 15% on the measured number of energetic ions.

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