

Yield of D-D and D-³He fusion reactions produced by the interaction of intense ultrafast laser pulses with molecular clusters

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The interaction of intense ultrafast laser pulses with molecular clusters produces a Coulomb explosion of the clusters. In this process, the positive ions from the clusters might gain enough kinetic energy to drive nuclear reactions [1-3]. The ratio of the yields of two reactions, with different cross section, occurring simultaneously can be used to determine the average temperature of the ions at the time when the reactions occurred.

A first experiment to measure the yield of D-D and D-³He fusion reactions was performed at University of Texas Center for High Intensity Laser Science. Laser pulses of energy ranging from 100 to 180 J and duration 150fs were delivered by the Petawatt laser. A layout of the experimental setup is given in Fig. 1.

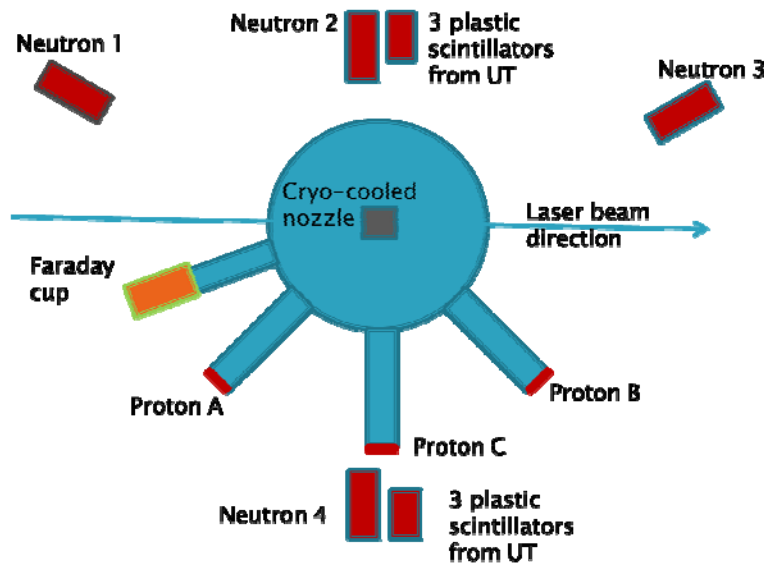


FIG. 1. Diagram of the experimental setup.

The experiment was divided in two parts. In the first part, pure D₂ clusters were used to optimize the yield of the D(D,n)³He and D(D,p)T fusion reactions. The temperature of the energetic deuterium ions was measured using a Faraday cup placed at 160° relative to the laser direction at a distance of about 1 m from the target. The yields of the D-D reactions were determined by detecting the characteristic 2.45 MeV neutrons and 3.02

MeV protons. In order to measure the 2.45 MeV neutrons, six plastic scintillators provided by the UT group were placed at 90° and -90° at distances of 2 m and 4 m from the target position. Four NE213 liquid scintillators of cylindrical shape (radius 7 cm and thickness 14 cm) were also placed at 36° , 90° , -90° , 151° and distances larger than 2 m.

The 3.02 MeV protons were detected using thin plastic scintillators (BC400) of thicknesses 254 μm ($\rho=1.03 \text{ g/cm}^3$) placed at 45° , 90° , 135° . Those detectors were placed at a distance of 106 cm from the target position. A 25.4 μm Al foil was placed in front of the detectors at a distance of about 5 cm in order to shield the detectors from the light and stop electrons of energy up to 50 keV.

Two Hamamatsu R1355 photo-multiplier tubes (PMT) were used to collect the scintillation light on both sides of the plastic scintillator. Home-made active bases were used to provide the high voltage to the PMTs and to derive the signal. The signals were recorded using three Tektronix TDS 3052 oscilloscopes. The time duration of a pulse signal was about 10 ns FWHM. The time difference between the signals produced by x-rays and by the proton was about 40 ns.

In the second part of the experiment, different concentrations of D_2 and ^3He or CD_4 and ^3He were mixed in the gas jet target to allow the simultaneous measurement of $^3\text{He}(\text{D},\text{p})^4\text{He}$ and D-D reactions. The 2.45 MeV neutrons from the $\text{D}(\text{D},\text{n})^3\text{He}$ reaction were measured as well as the 14.7 MeV protons from the $^3\text{He}(\text{D},\text{p})^4\text{He}$ reaction. The 14.7 MeV protons were detected using the same plastic scintillators used for the 3.02 MeV protons, but with a different degrader. The thin degrader was removed and replaced with a 1.1 mm thick Al degrader placed about 50 cm in front of the plastic scintillator. The energy of the protons was degraded to 4 MeV so that the time difference between the x-ray signal and the proton signal was about 25 ns. The detectors were calibrated using a 14 MeV proton beam delivered by the K500 superconducting Cyclotron at Texas A&M. Fig. 2 shows the typical signals produced by 3 MeV and 14.7 MeV protons.

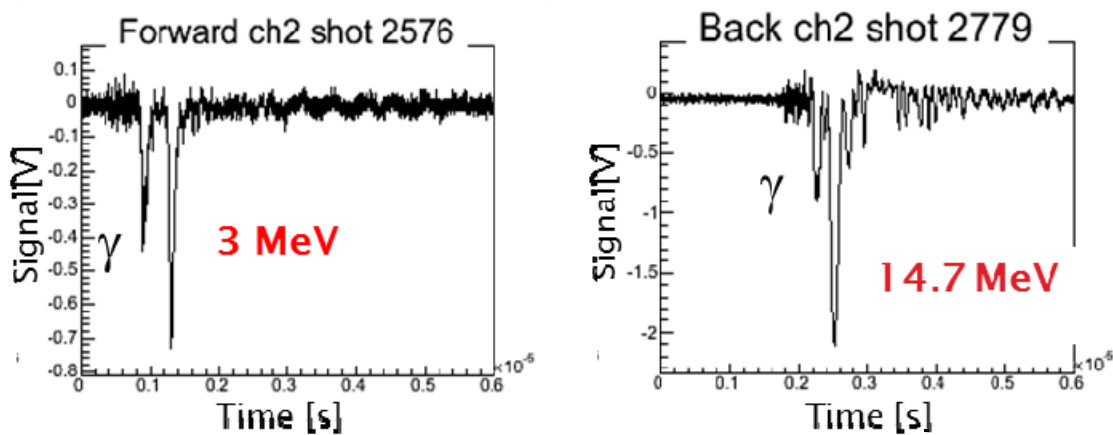


FIG. 2. Typical signals from the proton detectors. Left panel: 3 MeV protons from D-D fusion. Right panel: 14.7 MeV protons from D- ^3He fusion.

When ^3He was mixed with deuterium, the Faraday cup measurement showed no evidence of energetic ^3He ions, suggesting that the clusters were made of D_2 molecules and the ^3He was in the surrounding gas.

The preliminary results showing the ratio of the experimental yields as a function of the measured temperature are reported in Fig. 3. Within the experimental errors the temperature obtained from the yield ratio agrees with the temperature measured by the faraday cup.

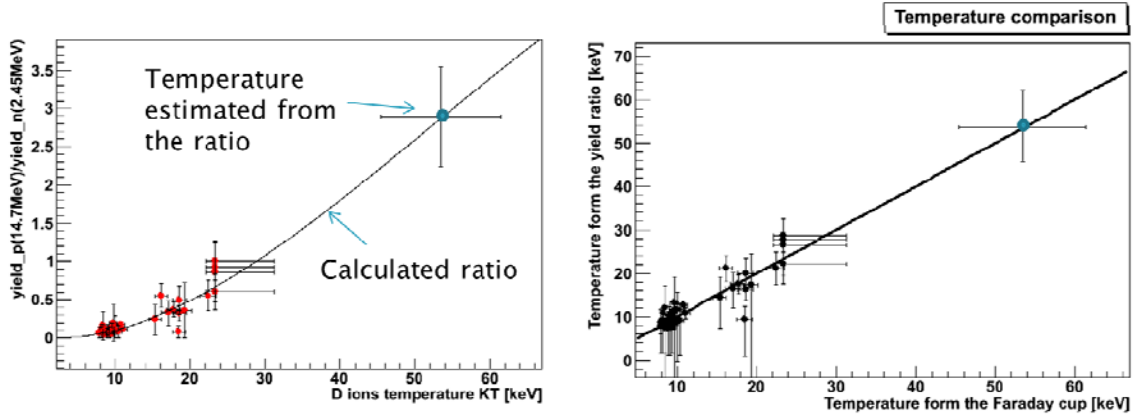


FIG. 3. Left panel: Ratio of the experimental yields as a function of the measured D ion temperature. The line shows the calculated ratio obtained using the cross-section parameterization from Bosch and Hale [4]. Right panel: D ion temperature estimated from the yield ratio plotted versus the D ion temperature measured using the faraday cup.

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