A Freon Filled Bubble Chamber Used for the Spectra Measurement of Ultrashort Gamma Ray Bursts

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Introduction

Recently, many experiments demonstrated that bright ultrashort gamma-ray bursts can be generated from the interaction of high-power lasers with plasma [1-3]. These bursts, typically with sub-picosecond duration, are very promising light sources for ultrafast gamma-ray radiography. However, their short pulse duration also poses challenges on the measurement of the spectra. Conventional solid-state spectrally-resolved detectors are unsuitable because the pulse durations of these bursts are orders of magnitude shorter than the response time of the detectors [4]. Signals from the photons just pile up in each channel and cannot be counted one by one. To overcome this problem, two kinds of indirect spectral measurement method have been developed. Both of them exploit Compton scattering of gamma-rays with low-Z material. One is to measure the large-angle scattered X-rays with a pixel X-ray detector [3]. Another is to measure the forward scattered electrons with a Thomson Parabola (TP) spectrometer [6]. The spectra of the incoming gamma-rays can be convoluted from the measured X-ray or electron spectra. The measurement ranges of these two methods are 50keV-1MeV and 3MeV-20MeV correspondingly. However, there is an unfilled gap between 1MeV-3MeV because the energy of scattered photons or electrons in this range strongly depends on the scattering angle. In order to get the spectra, one must measure the energy of scattered photons/electrons and scattering angle at the same time, which is hard to achieve with either of the two methods.

Here we report a novel Freon filled bubble chamber detector for the spectral measurement of ultrashort gamma-ray bursts in the range of 0.4MeV-4MeV. This detector was used in the Gemini campaign in January 2015. It simultaneously records thousands of bubble traces created by scattered Compton electrons. By analyzing the length and angle of the traces, the gamma-ray spectra can be convoluted in the range of 0.4 MeV-4 MeV with high efficiency and resolution.

Working principle of a bubble chamber as gamma-ray detector

Bubble chambers have been used as particles detectors for many years [7]. They work when the liquids in the chamber are in a superheated state. This superheated state is created by rapidly expanding the liquid at a pressure above its vapor pressure, resulting in a fast pressure drop, at constant temperature, to below the vapor pressure. The energy loss of an energetic particle traveling through the superheated liquid locally triggers the transition from liquid to vapor (boiling): bubbles are formed along the particle's path. Photographing these bubble tracks allows one to deduce the energy and incident angle of the particles.

When a gamma photon, instead of a charged particle, enters the chamber, it has a chance to generate secondary electrons in the liquid via Compton scattering. The energy of the incident gamma photon can be calculated from the energy and angle of Compton electrons as:

$$E_e = \frac{E_\gamma^2(1-cos\varphi)}{m_e c^2 + E_\gamma(1-cos\varphi)} \qquad (1)$$

Here E_e is the energy of the Compton electron, φ is the scattering angle, which can be obtained by analyzing the bubble track of the electron.

In our experiment, the bubble chamber detector is specially designed for short-pulse laser-plasma experiments. Figure 1(a) shows a photograph of the detector. The detector [5, 6] was composed of a windowed chamber filled with Freon, a pneumatic piston below the chamber controlling the pressure, and a closed loop water heating system controlling the temperature. A collimated light source was used to illuminate the chamber through one of the windows. 3-4 CCD cameras were placed on the other side to take photos of the bubbles. Figure 1(b) shows the time chart. First, the piston was triggered 40 ms before the laser pulse. The pressure of the chamber drops quickly thereafter and the Freon turns into superheated state 10 ms before the arrival of main pulse and will last for 20 ms~40 ms. When the gamma burst arrives, thousands of bubbles are generated and photographed by the cameras with exposure time of 1-3 ms.

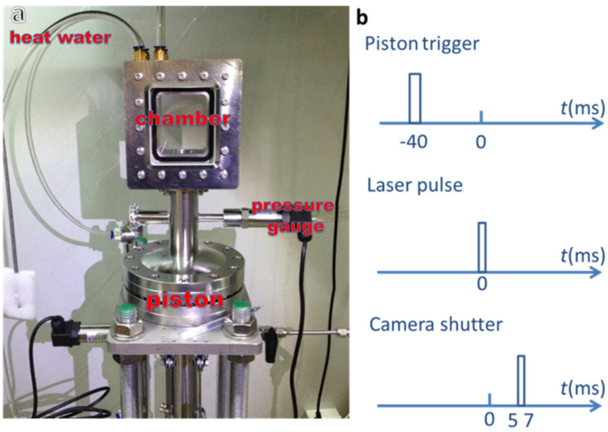

Figure 1. a) A photograph of the detector, where the components are shown with red labels. b) The time chart of the system.

Experimental Setup

The experiment was performed at the Gemini Laser Facility. 50 femtosecond, Ti:Sapphire laser pulses with a peak intensity of 2×10^{20} W cm^{-2} were shed on near-critical-density targets with linear and circular polarization. A schematic drawing of the experimental setup is presented in Figure 2.

The experiment is designed to measure the X/Gamma ray radiation from the interaction of ultra-intense laser pulses with near critical density plasma [8]. The laser pulses are focused by an *f*/2 off-axis parabola on targets made of carbon nanotubes (CNT). The generated wide-angle energetic electrons were deflected sideward by strong magnets placed behind the target. We built a 30 cm thick lead wall to shield the detectors, and a 2cm×4cm channel in the wall was used collimate the X/Gamma ray beam for spectra measurements. A X-ray pixel detector was positioned at 0° to obtain the low energy (50keV—1MeV) spectra. At the same time, the bubble chamber measured the high energy (0.4MeV—5MeV) spectra at 7.5°. As shown in Figure 3, the collimating illumination light is incident from the back window. 4 CCD cameras were positioned at different angles to take photos of the bubbles when laser pulses come.

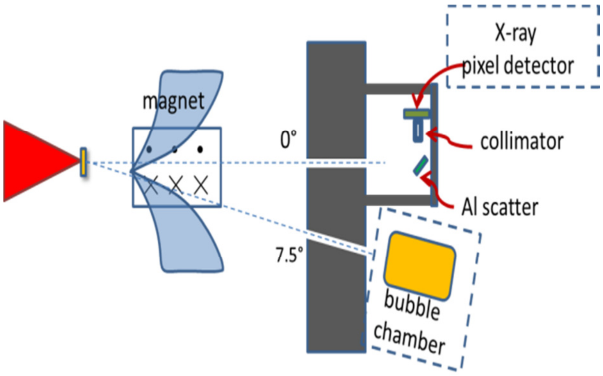

Figure 2. A schematic drawing of the experimental setup.

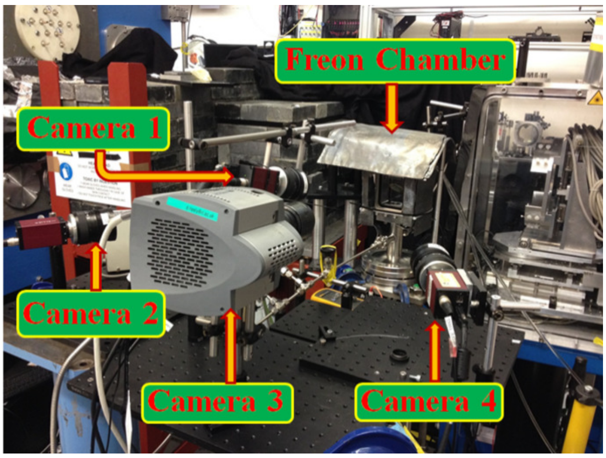

Figure 3. On-site setup of the bubble chamber in the experiment.

Experimental Results

A large number of gamma-ray signals were obtained in the experiment. Figure 4 shows a picture from one of the 4 cameras. One can clearly identify bubble tracks resulting from Compton electrons. The longest track consists of 11 bubbles as shown in the inset figure. The 3D coordinates of the bubbles could be reconstructed by combining the results with the other 3 cameras. And then, we will get the scattering angle and energy of the Compton electrons at the same time, which would tell us the energy of the gamma photon according to formula (1). We calibrated the bubble chamber using a ^{22}Na (activity 300kBq) source in the experiment for later analysis.

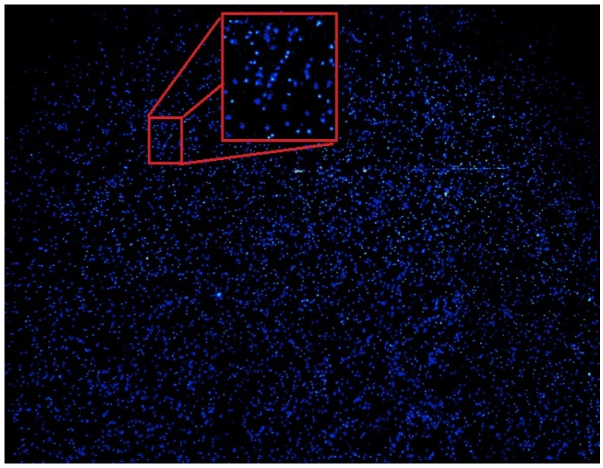

Figure 4. The photograph of the bubbles taken by a CCD camera.

Conclusions

A Freon-filled bubble chamber was successfully used in the experiment performed at the Gemini laser facility as a spectrally-resolved ultrashort gamma-ray detector. Significant signal was obtained from the interaction of 500 TW class laser pulses and near-critical-density plasma. Gamma-rays with a highest energy of 3MeV were observed. The data analysis on the convolution of spectra is ongoing.

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