Nuclear Instruments and Methods in Physics Research A 830 (2016) 391–396

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Operation of a fast diamond γ-ray detector at the HIγS facility

T. Williams [a], C. N'Diaye [a], D. Breton [a], K. Cassou [a], K. Dupraz [a], P. Favier [a], D. Jehanno [a], V. Kubytskyi [a], X. Liu [a], J. Maalmi [a], A. Martens [a,*], Y. Peinaud [a], A. Stocchi [a], F. Zomer [a], E. Griesmayer [b], P. Kavrigin [b], M.W. Ahmed [c,d,e], M. Sikora [c,d], H.R. Weller [c,d]

[a] LAL, Univ Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France
[b] Vienna University of Technology, Austria
[c] Triangle Universities Nuclear Laboratory, Durham, NC 27708, USA
[d] Physics Department, Duke University, Durham, NC 27708, USA
[e] Department of Mathematics and Physics, North Carolina Central University, Durham, NC 27707, USA

ARTICLE INFO

Article history:
Received 23 January 2016
Received in revised form
1 June 2016
Accepted 3 June 2016
Available online 7 June 2016

Keywords:
Diamond sensor
Gamma-ray detector
Fast detector
Flux measurement

ABSTRACT

Operations of a diamond sensor placed in a high average-intensity beam of photons with energies of a few MeV are reported. Data was taken at the HIγS facility of TUNL in parasitic mode while nuclear-physics experiments were taking place. The energies of the photons during data taking were 2, 3 and 7 MeV with circular and linear polarisations of the photon beam. The collected charge appears to be constant at these energies, which is consistent with simulations. A dedicated run with bunches of photons separated by 16 ns shows that they are unambiguously distinguished. This is possible thanks to a FWHM of the pulses measured to be about 6 ns. The results indicate that the tested apparatus fulfils the requirements for a fast monitoring detector for the ELI-NP source currently under construction, which motivates this work, and demonstrates for the first time the capabilities of such detectors in high average-intensity photon beams.

1. Introduction

The Extreme Light Infrastructure Nuclear Physics Gamma Beam System (ELI-NP GBS) [1] is a novel source of photons with unprecedented spectral density, under construction in Magurele, Romania. Photons in the range 200 keV to 20 MeV will be produced by Compton scattering off electrons. Electrons are produced by a high-quality LINAC to ensure low transverse emittance and reduced energy spread at the interaction point where they are colliding with a high intensity laser. The expected number of backscattered photons per bunch is estimated to be of the order of 10^7 in a solid angle of 4π. A new optical system is implemented in order to reach a spectral density greater than 5000 photons/(s eV). In this system the laser is recirculating 32-times at a repetition rate of 100 Hz. The synchronous and aligned collisions of the 32 pulses of the laser at the interaction point with the 32 bunches of electrons require a thorough optimisation procedure described in Ref. [2]. The individual time separation between each of the 32 successive collisions is approximately 16 ns. Since the tuning of this new apparatus is complicated, a fast monitoring tool of the number of photons of each bunch is of interest. This tool will be required to measure the relative flux of the 32 bunches every 10 ms with a precision of a few percent. It is expected to provide a precise-enough understanding of the synchronicity and overlapping of the electron beam and laser pulses of the 31 subsequent collisions with respect to the first one. It thus may prove useful for monitoring the stability of the apparatus in time. The ability to evaluate the transverse shape of the beam would be an additional asset for such a detector.

Since bunches separated by 16 ns must be clearly distinguished by the foreseen detector, calorimetric measurements, usually performed for flux measurements of photons with energy of several MeV, are not well suited as they involve scintillating plates with pulse durations of several nanoseconds in the best cases [3]. Indeed, if fast scintillation components exhibit pulse durations this short, they are only a small part of the scintillation light. They always lie on a large background with slow response of several tens of nanoseconds. This makes the analysis of the signal difficult, even when the low spectral component is filtered out.

In this paper we exploit the fast response of diamond sensors which arises from their large saturated drift velocities [4,5]. To the best of our knowledge, they have never been used in the context of the monitoring of bunches of photons in the few MeV range. However, they have been extensively studied in the context of

---

[*] Corresponding author at: LAL, University Paris-Sud, CNRS/IN2P3, Orsay, France.

http://dx.doi.org/10.1016/j.nima.2016.06.014

hadron and electron detection in the high-energy physics community [4,5] and used for the detection of few keV X-rays [6–8]. The principle of detection is similar to that of semiconductor-based detectors. Photons of a few MeV are expected to interact in the diamond sensor predominantly by the Compton process thus creating secondary electrons which in turn create electron-hole pairs. These charge carriers are separated and drift if an external electric field is applied. Since the energy spectrum of the secondary electrons is broad the collected charge is expected to fluctuate more than in the case of the detection of Minimum Ionising Particles (MIPs). The depth at which the secondary electrons are generated also plays an important aspect in the variation of deposited charge. The expected charge collection efficiency is close to 100%, at 400 V bias for a 500 μm thick single-crystal chemical vapour deposited (sCVD) diamond sensor. The conversion efficiency of photons into secondary electrons in this sensor is a fraction of percent for MeV photons.

The purpose of this article is to monitor the relative number of photons of bunches separated by 16 ns. Investigations to use this detector as a tool for precise alignment and to measure absolute fluxes are also targetted. The results presented in this paper were obtained at the HIγS facility.

The article is organised as follows. The relevant machine parameters and the experiment are described in Section 2. The results are given in Section 3. Prospects for the implementation of such a device for the ELI-NP photon source are given in Section 4 along with plans for further tests before commissioning in Romania.

2. Experimental set-up and data

The HIγS facility [9–11] is at present the most intense source of photons in the energy range of 1–100 MeV. They are produced by Compton scattering off electrons. The photon beam is obtained from a free electron laser (FEL). Tuning of the photon energy is accomplished by changing the electron energy and the FEL wavelength, which can involve changing optical mirrors. Both linear and circular laser polarisations can be obtained by using either a planar or a helical wiggler. The photon beam polarisation is expected to be given by the laser polarisation, provided that on-axis photons are selected and that smearing due to the finite size and emittance of the beams is negligible. This has been verified by measurements performed at HIγS [9]. The optical cavity at the Duke FEL Laboratory (DFELL) is 53.7 m long allowing Compton interactions at a rate of 5.58 MHz. The number of produced photons reaches 10^9 per second over the full solid angle but the exact intensity depends upon the desired photon beam energy. The monochromaticity of the beam is improved by means of circular apertures centred on the beam that allow the selection of on-axis photons[1]. The drawback is a reduction of the photon flux.

In the experiment described in this paper, a diamond sensor was placed at 63.47 metres from the Compton interaction point and 10.51 m downstream of an 18 mm aperture. The transverse diameter of the photon beam where the diamond sensor is located is thus about 20 mm.

The apparatus installed in the beam consists of a sCVD diamond sensor from the CIVIDEC company [12] of transverse size $4.5 \times 4.5\ \text{mm}^2$ and 500 μm thickness. The Ti-Pt-Au electrode metallisation has an active area of $4 \times 4\ \text{mm}^2$ and a thickness of 500 nm. With a 400 V bias voltage used in the subsequent experiment the expected FWHM of the pulse is approximately 5 ns for MIPs. In order to observe the small signal provided by the diamond sensor, a low noise, broadband amplifier also provided by CIVIDEC [12] is employed. The amplitude of the amplified signal from a MIP amounts to about 7 mV. This level of signal is very close to the electronic noise which has an RMS value of 1.4 mV, dubbed σ_{noise}. This noise was found to be stable over the two days of data taking with the variation of this figure being approximately 0.03 mV peak to peak. The diamond sensor and the preamplifier are mounted on two translational stages along the horizontal and vertical axes in order to precisely position the diamond sensor in the γ beam. A pre-alignment of the system within 1 cm is made with a He–Ne laser tracker. The output signal of the amplifier is read out by a USB WaveCatcher [13]. This DAQ allows 1024 points to be registered with a sampling frequency of 3.2 GHz. Waveforms are sent to a PC connected via USB whenever a new trigger is received and the reception of the previous event has been made by the PC. The trigger signals are obtained from the passage of electrons through Beam Position Monitors (BPMs) of the accelerator [14]. Coincidences of this trigger with the detector signal allows events to be registered at rates of a few hundreds of Hertz. A threshold of 7 mV is applied to the detector signal. Indeed, triggering with the BPM alone would lead to a large fraction of trigger with no signal in the sensor, since the number of incident photons is only a few units and the detection efficiency about a fraction of a percent. The number of events recorded per unit of time is limited by the bandwidth of the communication between the PC and the WaveCatcher. Nevertheless, the actual equivalent rate between two consecutive events is computed, thanks to counters embedded in the DAQ, and stored with the waveforms allowing the actual rate of events seen by the DAQ to be reconstructed. This system was mounted within a couple of hours and operated without any manual intervention for three days.

The photon beam energies used were 2, 3 and 7 MeV corresponding to electron energies of 280, 335 and 511 MeV, respectively. The photon production rate was approximately 10^6–10^7 photons/s. Two different settings of the DFELL were used during this experiment. They are dubbed *regular* and *bunched*. In *regular* mode, two electron bunches are circulating in the storage ring. They are both lasing and producing photons by Compton backscattering. They are separated by 179 ns, which corresponds to twice the revolution frequency of 2.79 MHz. In the *bunched* mode, a first electron bunch serves as the lasing material. This created laser beam collides with three other electron bunches separated in time by 16.8 ns, which were injected into every third RF bucket for the first nine (out of a total of 64). This mode is of particular interest as it presents a similar temporal configuration as the one that will exist at the ELI-NP-GBS. Data related to the machine is also stored in an EPICS [15] database provided on site. This information allows matching the data taken with the WaveCatcher to precise running conditions, namely, the electron beam energy, the FEL laser polarisation and the relative flux measured using a 5-paddle monitor [16], placed a few metres upstream from the diamond sensor. The 5-paddle allows determining the flux with a systematic uncertainty of 2% but this performance has never been proven experimentally at the energies used in the present analysis [16].

The 5-paddle flux measurements are updated in the database approximately once a minute. The acquisition of a run of 10,000 events lasts about one to two minutes. Moreover, a constant shift of a few seconds between the data taken and the database information is present and cannot be corrected for offline. These facts render the run by run normalisation of the rate of observed events by the 5-paddle reference difficult. Only average measurements over tens of minutes can be corrected with the information from the EPICS database.

---

[1] The Compton process induces a correlation between the energy of the emitted photon and its angle with respect to the reference electron beam axis.