DIAMOND SENSOR RESOLUTION IN SIMULTANEOUS DETECTION OF 1,2,3 ELECTRONS AT THE PHIL PHOTOINJECTOR FACILITY AT LAL

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Abstract

In this paper, we present experimental and numerical studies of the signals from the Poisson-like distributions resulting from electrons incident on a diamond sensor placed near the exit of the PHIL photoinjector facility at LAL. The experiments were performed at the newly commissioned Low Energy Electron TECHnology (LEETECH) platform at PHIL. Bunches of 109 electrons are first generated and accelerated to 3.5 MeV by PHIL. The electrons are then filtered in LEETECH by a system of collimators, using a dipole magnet for momentum selection. The diamond sensor is located immediately after the output collimator to collect electrons in the range 2.5-3 MeV. We show that with standard scCVD diamonds of 500 micrometers thickness, the energy losses from the first three MIP (minimum ionizing particle) electrons are clearly resolved. We did not observe distinguishable peaks in cases when a significant fraction of the incident electrons had energies below a MIP. The described technique can be used as complementary approach for calibration of diamond detectors as well as to diagnose and help control accelerated beams in a regime down to a few particles.

INTRODUCTION

LEETECH (Low Energy Electron TECHnique) is a versatile source of electrons with adjustable bunch intensity and particles energy [1]. At the entrance it uses the beam from photoinjector PHIL with intensity of 10^8-10^9 electrons per bunch and energy of 3.5 MeV with 5 Hz repetition rate [2].

The entrance collimators system selects a direction of electrons sent to the spectrometer also adjusting the intensity. Thus obtained narrow secondary beam passes the magnetic field region inside the vacuum chamber. At the exit the electrons are again filtered by exit collimators system and through the thin ($100\mu m$) exit window impinged out to the detector.

Similar facilities are usually designed for wide-purpose range including high energies applications up to several GeV. The main difference of LEETECH that it provides energies from few 100 keV up to 5 MeV, using PHIL electrons as a primary source rather than large accelerators, this way significantly reducing the cost of beamtime. This regime is normally sufficient for calibration and testing of thin semiconductor detectors, gaseous tracking detectors and number of others detector related R&D. Ideologically our facility is similar to DAFNE Beam Test Facility (BTF) [3], but operating in lower energies and much more compact. It can be adjusted to operate in the single particle mode and it can reach high multiplicity of to 10^4.

We use the Diamond sensor (DS) as an instrument for the detection of electrons provided by LEETECH. Physical properties and the ability to detect the single MIP electron by diamond has been widely discussed in the literature [4–7]. However, to our knowledge the capability of the diamond sensor to distinguish between 1,2, and 3 electrons was not profoundly studied. One of the possible reasons is due to the need of the specific electron source. Nevertheless the knowledge of DS behaviour in the limit of few electron Poisson distribution is crucial. Such conditions are often met in the experiments, where the detector is located in the place, such as for example beam pipe (beam loss monitors), near the target, etc. where the shower from the high energy particle is almost completely absorbed leading to only few interactions with DS. The source of electrons of low multicity is of great importance in the detailed characterisation of the linearity of the detector response.

EXPECTED SIGNAL FROM THE DIAMOND SENSOR

In order to investigate and characterise the LEETECH system Geant4 model was developed Fig.1. The nominal parameters values of existent PHIL and LEETECH facilities are presented in the Table 1.

Table 1: PHIL and LEETECH Parameters

PHIL parameters	Number of electrons	10^9
	Beam energy	3.5 MeV
	Emittance	$4\,\pi \cdot mm \cdot mrad$
	Bunch length	5 ps
	Repetition frequency	5 Hz
LEETECH parameters	Target thickness	$100\mu m$; $2mm$; $4mm$
	Input collimators	up to 20x20mm
	Output Collimators	up to 20x20mm
	Magnetic Field	up to 900 Gauss

We introduced to Geant4 model a detector, which represents diamond sensor with lateral dimensions of 4x4mm and 0.5mm of thickness. DS is placed at the distance of 1 cm after the LEETECH exit window Fig. 1 (d6). The full scale Geant4 simulation for the statistics comparable with one that we can obtain in the experiment (thousands of bunches) is

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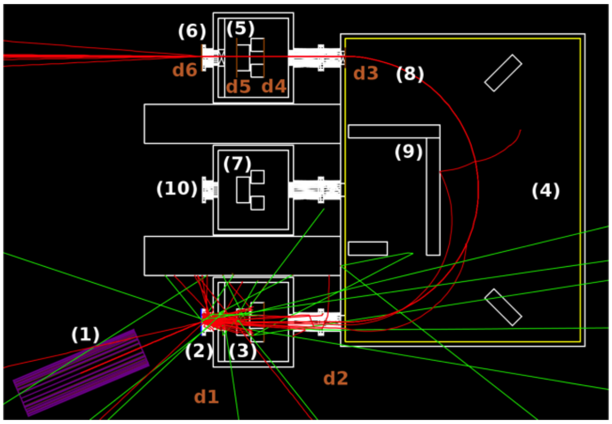

Figure 1: Geometry implemented in Geant4 simulation. Exit of the PHIL beam pipe (1), target (2), vacuum chamber with magnetic field (4), entrance and two exits collimator systems (3, 5, 7) and lead shielding (9) are shown. Red curves represent the electrons trajectories, green - photons.

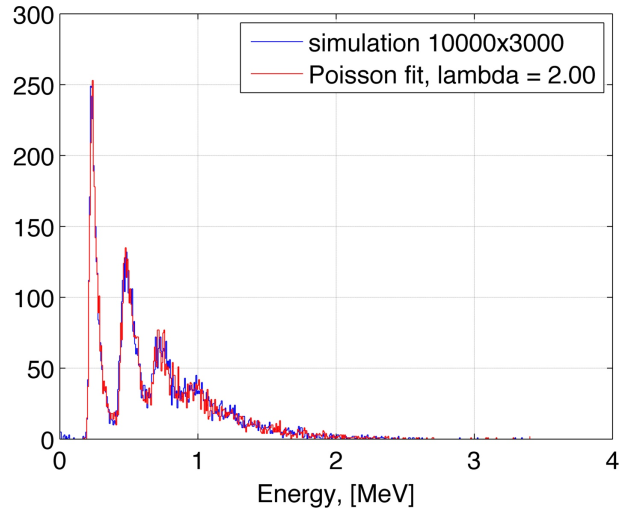

Figure 2: Histogram of energy deposition in the DS by 10000 events. Each event contain 3000 primary electrons generated by GPS. Red curve: Poisson fit of the result.

not realistic due to the need of huge computational power. Each bunch initially contains 10^9 particles (nominal PHIL parameters), which then are filtered by LEETECH collimators and magnetic field up to few tens/hundreds of electrons. To make our model computationally effective and to overcome the difficulty of long computation times we divided the full simulation on the several parts. Firstly, from the distribution after the entrance collimators (3) we construct a new particle source located immediately after entrance collimators with the generalised parameters of the particles of given bunch. It includes distributions of energy, angle, and position distributions of electrons. Entrance collimators of 0.5*0.5mm opening decreases the intensity of the initial bunch from 10^9 to 10^5. With this new general particle source (GPS) we obtain the same results after the exit collimators as with the initial electron bunch. For different configuration of the entrance collimators such procedure must be repeated.

We then use GPS in the following manner. For example, in one event from GPS containing 1000 electrons in average only 1 electron reaches the DS. Then in order to obtain 10000 of such events on the DS (which is typical number of events in our experiments) the GPS generates $N_{electrons} = 1000$ electrons in each of $N_{events} = 10000$ events. Therefore, one can consider that the number of events N_{events} represents the statistics, while $N_{electrons}$ represents the bunch charge.

In Fig. 2 we present the energy deposition in the diamond sensor by 10000 bunches containing $N_{electrons}$=3000 primary electrons from GPS; entrance and exit collimators openings were set to be the same 0.5x0.5mm. One can visually discriminate three clear peaks (Fig 2). These peaks are representing the contributions from one, two, or three electrons traversing the diamond simultaneously. Note that zeros are not represented in the histogram, but since the total number of events in the DS is 8762, the number of zeros is $10000 - 8762 = 1238$. Our simulation represents an independent events occurring in the fixed interval of time and with the fixed intensity $N_{electrons}$, the random nature of this phenomena, can be described by Poisson distribution: $P(\lambda, k) = \lambda^k e^{-\lambda}/k!$, where λ is the Poisson parameter (rate parameter), and k is a number of electrons leaving exit collimators. From the separate Geant4 simulation [8] we calculated the energy depositions (PDFs) in the DS by bunches consisting of only of 1,2,3,.. ,100 electrons (MIP), giving us the basis for the fitting. One can see a good agreement between the Poisson fit (red curve in Fig. 2) and the simulation data at the exit of LEETECH. The rate parameter of Poisson distribution in this case is equal to two.

MEASUREMENTS

In order to accumulate 10000 events one need to run experiment for approximately 30 minutes, since the repetition rate of PHIL is 5Hz. The largest statistics in our results is of about 25000, while the mean value of number of accumulated events in different runs is of about 10000.

Experimental setup is presented in Fig. 3. DS together with low noise charge amplifier from CIVIDEC were fixed on the XZ translation stage which can be remotely operated by WAGO controllers. The gain of CIVIDEC charge amplifier is 4mV/fC. The most probable value of charge collected by the diamond due to 1 MIP is 12mV. The signal acquisition was made by USB-Wavecatcher (12-bit 500-MHz bandwidth digitiser, sampling between 400 MS/s and 3.2 GS/s) which was installed near the LEETECH and protected from the radiation.

Diamond sensor used in the experiment was prototyped and fabricated at LAL (see inset in Fig 3). The single crystal CVD diamond from Element Six with TiPtAu metallisation on the top and bottom surfaces is glued by the conducting glue on the PCB. The top surface of the diamond is bonded to the signal line on the PCB by four bonding wires. Such design of DS allowed us to avoid the electron scattering

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before it reaches the active area of the diamond. High voltage is applied trough the conductive area on PCB underneath of the diamond. The standard calibration procedures of the DS with radioactive alpha and beta sources were performed prior to the experiment.

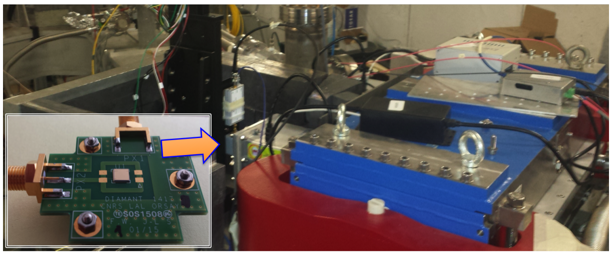

Figure 3: Photo of the experimental setup: LEETECH magnet with the collimators; XZ translation stage with DS and charge amplifier mounted on it. Inset: photo of DS developed at LAL.

The absolute positions of the collimators box were aligned at the fabrication stage with precision of 0.05 mm in such way that the centres of the collimators coincide with the centre of the magnet. During the experiment the alignment procedure was done in the following steps:

- Entrance and exit collimators are opened by 10x10mm. DS is placed approximately to the location of the geometrical centre of exit collimators. By tuning the magnetic field we maximize the signal on the DS. In such way we found the value of magnetic field corresponding to the maximum beam intensity. Reduce horizontal opening of input collimators settings to 2x10 mm to form the rectangular window. Scan by horizontal displacement of this window in the range of 20mm and maximize the signal on DS. Fix horizontal position at max. Do the same scan with the exit collimators. In such way we found the start point and the end point of the electron trajectories before and after the magnetic field.

- Reduce vertical opening of entrance and exit collimators to 2x2mm and now displace the DS in XY plane to maximise the signal. After this procedure the trajectories passing through the entrance, magnetic field, exit and the DS are in the same plane.

In Fig. 4 we present the results from one continuous run of ≈ 16000 events.

DISCUSSION AND CONCLUSIONS

We demonstrated that the number of electrons leaving LEETECH is forming the Poisson distribution. Geant4 simulation of LEETECH facility was performed. The optimal parameters of the collimation system and magnetic field for the selection of quasi mono-energetic electrons with low multicity were obtained. The results of this study were extremely helpful in the setting up of the experiment and in the formulation of the alignment procedure.

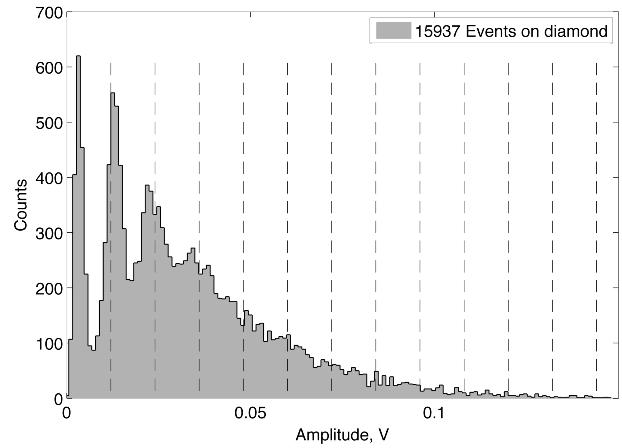

Figure 4: Histogram of measured energy deposition in the DS. Vertical lines are separated by 12mV and indicate the expected positions of 1,2, 3 etc. electrons. Note that the first peak is corresponding to the events with zero of electrons.

We demonstrated that the Poisson parameter of the outgoing distribution can be measured with diamond sensor. Even the resolution of the peaks is worser than one predicted by the simulation, one can clearly discriminate the peaks corresponding to 0,1,2 electrons in the distribution. We expect that with larger statistics the peak resolution can be improved. To the extent of our knowledge the experimental confirmation of the capabliity of DS to discriminate one and two electrons has been demonstrated for the first time.

Our future plans is to perform an XZ scan with DS of the $10x10$cm area in order to construct the maps of the outgoing distributions for different collimator openings. After that, several DSs (thanks to the small size) can be placed off-axis at the exit of LEETECH in order to control/monitor the Poisson parameter. This information is crucial for calibration of different detectors.

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