MPGD2015: Low-energy electron source to characterize Micromegas/InGrid and study of dE/dx for low energy electrons

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Abstract. Insert your english abstract here.A new versatile facility LEETECH for detector R&D, tests and calibration is designed and constructed. It uses electrons produced by the photoinjector PHIL at LAL, Orsay and provides a powerful tool for wide range R&D studies of different detector concepts delivering "mono-chromatic" samples of low energy electrons with adjustable energy and intensity. Among other innovative instrumentation techniques, LEETECH will be used for testing various gaseous tracking detectors and studying new Micromegas/InGrid concept which has very promising characteristics of spatial resolution and can be a good candidate for particle tracking and identification. In this paper the importance and expected characteristics of such facility based on detailed simulation studies are addressed.

1 Introduction

Development of new high-energy physics collider experiments calls for a rapid evolution of already established and development of new innovative detector techniques. To characterize new types of detector systems and ensure quality of the already developed instruments high accuracy tests need to be performed. Test beam facilities play a key role in such tests.

In this article we describe the design and simulation of versatile source of electrons with adjustable bunch intensity and particles energy, LEETECH (Low Energy Electron TECHnique). The facility is designed to deliver electron samples with energy spread of about 2% and sub-nanosecond time spread within a sample. A LEETECH like facilities are particularly required for a wide range of tests where the energy needs to be changed continuously and detector response to low intensity particle flows (down to 1 particle) needs to be studied. LEETECH will be particularly useful for the tests of Micromegas/InGrid technique [1] – the micro-pattern gaseous detector with pixel readout electronics, which provides 3D coordinate measurement and has a performance approaching that of silicon detectors. The counting of individual primary ionization clusters, using InGrid detector with 55x55 μm^2 pixels, could allow to achieve an ultimate energy loss (dE/dx) measurement [2].

The LEETECH source uses electrons from the PHIL facility [3] at LAL, Orsay. The PHIL is a photoinjector and a linear accelerator delivering electron bunches with energy up to 5 MeV with 5 Hz repetition rate and intensity of 10^8 to 10^{10} particles per bunch.

Test beams are usually obtained from big and expensive accelerator facilities with high energies between tens of MeV and 800 GeV [4–8]. Operational cost of these test platforms are quite high and user time is deficient. Such an important combination of beam characteristics as small time (tens of picoseconds) and energy spread (down to 1%), possibility to precisely adjust energy and reduced operational costs is highly required. Precise testing of timing characteristics of modern detectors requires test beams with short bunches in picoseconds range. Therefore LEETECH facility delivering electron samples of low and adjustable energy, variable intensity in the sample, with precise timing and small energy spread, accessible and having reduced operational costs, finds its place as a test facility for large variety of detector techniques.

2 Photoinjector PHIL

The PHIL (PHotoInjector at LAL) is an electron beam accelerator at LAL. This accelerator is dedicated to tests and characterization of the electron photoguns and high frequency structures for future accelerator projects (lepton colliders of next generation — CLIC, ILC). This machine has been designed to produce electron bunches of low energy (E < 10 MeV), small emittance ($\epsilon = 10\pi \cdot mm \cdot$ rad), high current (charge nearly 2 nC/bunch) electron bunch at

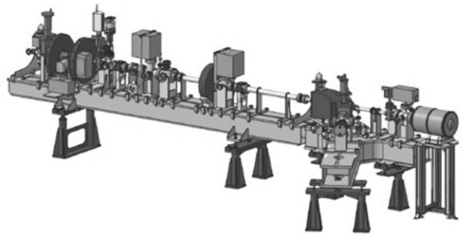

Figure 1. General view of PHIL photoinjector.

low repetition frequency (<10 Hz) [3]. At the end of the accelerator, the normalized emittance is about $4\pi \cdot mm \cdot$ rad. Bunch length is short and determined by laser pulses having FWHM duration of 5 ps. PHIL is currently the 6-meters long accelerator with two extracted beam lines (see Fig. 1).

The direct beam line is mainly dedicated to the 2D transverse emittance and bunch length measurement. The deviated line is devoted to the measurements of the beam parameters (mean and dispersion energy measurement of the beam). The injection in the deviated line is performed by the Tesla Test Facility injector dipole. The direct beam line is equipped with:

- 2 Beam Position Monitors.
- 1 phosphorescent transverse beam profile monitor.
- 1 Faraday Cup.

The beam profile monitor is the phosphorescent screen oriented at 45° relative to the beam axis. The screen is a ceriumdoped yttrium:aluminum:garnet (YAG:Ce) crystal scintillator of 300 μm thickness and 40 mm of diameter.

In 2010, three other phosphorescent YAG:Ce screen monitors were installed on PHIL. The first one is mounted at the entrance of the dipole. It provides important information on the beam behavior just before the dipole magnet, which is used to adjust the beam for the mean and energy spread measurement on the deviate line. Each phosphorescent screen is complemented with a versatile optical system (made of one or more achromatic lens) and a Gigaethernet CCD camera (2 with 1/3" sensor format with 7.4 μm pixel size and 2 with 1/2" sensor format with 4.65 μm pixel size). The CCD dynamic range is 8 bit. In order to avoid pixel saturation during the measurement a remote control optical density wheel is mounted in front of each camera.

One very important feature of the PHIL electron bunches that duration of one pulse is a few of picoseconds and signals from different bunches are very well separated in time which enables us to obtain good time resolution for investigating of detector timing characteristics. A two meters extension of the direct beam line has been constructed to accommodate the LEETECH facility.

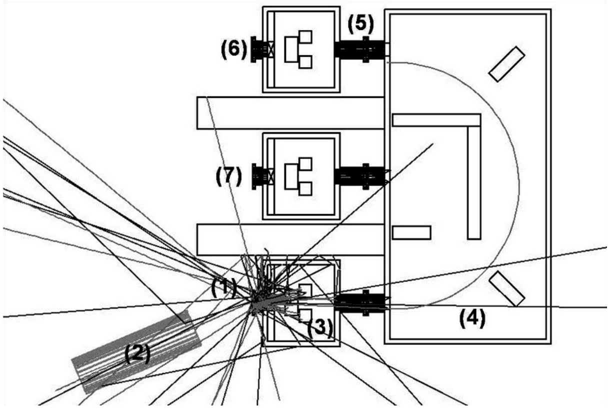

Figure 2. Geometry implemented into full Geant4 simulation. End of the PHIL beam pipe (2), target (1), vacuum chamber with magnetic field (4), entrance and exit collimator systems (3, 5) and lead shielding are shown.

3 Principle of the setup

The LEETECH platform uses electrons from PHIL to provide electron samples with adjustable energy and intensity. Schematic view of the setup is shown in Fig. 2:

The principle of setup is described below. An Al attenuator (1) is installed at the exit window of PHIL beam pipe (2). After the attenuator the electrons form a wide energy spectrum and solid angle distribution. The entrance collimators system (3) selects a direction of electrons sent to the spectrometer also adjusting the intensity. Thus obtained narrow secondary beam passes the magnetic field region (4) inside the vacuum chamber. At the exit (5) the electrons are again filtered by exit collimators system and through the thin exit window impinged in the tested detector (6). The second exit window (7) with collimators system is dedicated to the training and monitoring purposes.

The electrons of a desired energy are selected by choosing the magnetic field controlled by the current in the dipole magnet. Output intensity can be complementarily adjusted by changing the attenuator thickness and magnetic field. Remote control and monitoring of the collimator systems and dipole current is provided via user friendly interface from the PHIL control room.

4 Simulations

The full Geant4 simulation of LEETECH platform was performed [9]. Geometry of the setup used in the simulation is shown on Fig. 2. A dedicated shielding in the vacuum chamber suppresses contribution from reflected particles and increases signal to noise ratio.

For all particles entering this volume information about their type, position, momentum and time is stored to the ROOT [10] file. If required this information is used as an input to further simulation. For example this technique is used to simulate the response of diamond detector [12] installed at the exit of the LEETECH spectrometer.

A typical simulation spectrum of electron energy at the exit of LEETECH is shown in Fig. 3. A small collimator

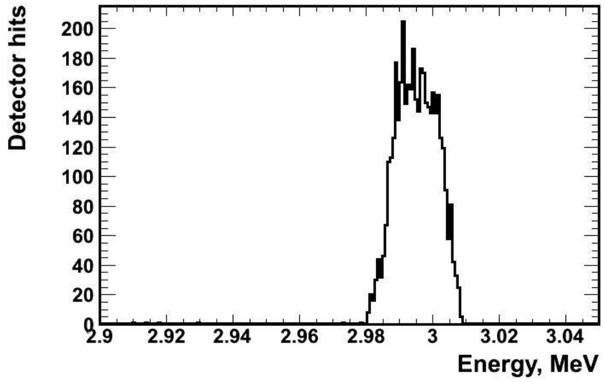

Figure 3. Spectrum of electrons at the exit of LEETECH facility.

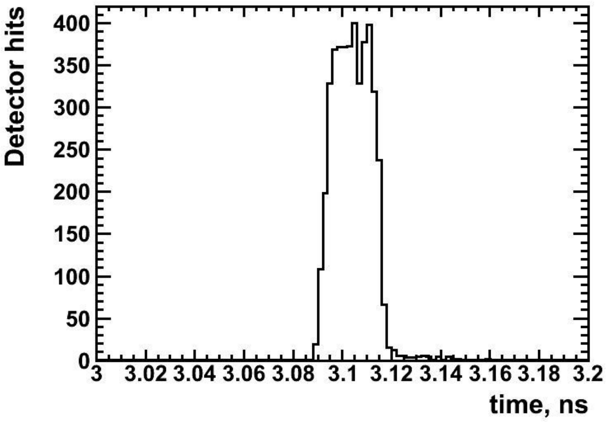

Figure 4. LEETECH timing characteristics for "narrow" mode of collimator system.

window was used to study how good energy resolution can we obtain in experiments.

The timing distribution obtained with the simulation is shown in Fig. 4. Both distributions correspond to the "narrow" collimators mode – collimators opening is 0.5x0.5 mm at the entrance and 1x1 mm at the exit. As we can see from Fig. 3 and Fig. 4 the energy resolution of 1% and time resolution of 40 ps can be achieved.

5 Attenuator thickness role

Dependence of angular and momentum spectra on the thickness of attenuator was studied. This simulation was performed with the detector positioned behind the attenuator. Momentum spectra of electrons after passing the Aluminum attenuators of different thickness are shown on Fig. 5. The obtained spectra show that different attenuator thickness favours different energy samples, so that attenuators of different thickness are foreseen to be produced.

The angular distribution of electrons' flight direction after the attenuator is shown on Fig. 6. In agreement to naive expectations, for thin attenuators the flight direction is smeared around the original flight direction. For thicker attenuators wider distribution of deviation angles

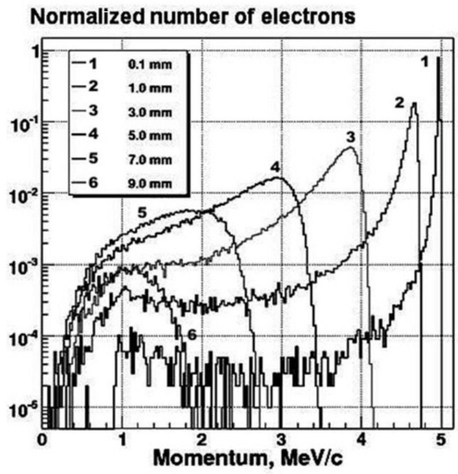

Figure 5. Momentum spectra of electrons after passing the Aluminum attenuators of different thickness. Momentum of primary electrons is 5 MeV/c

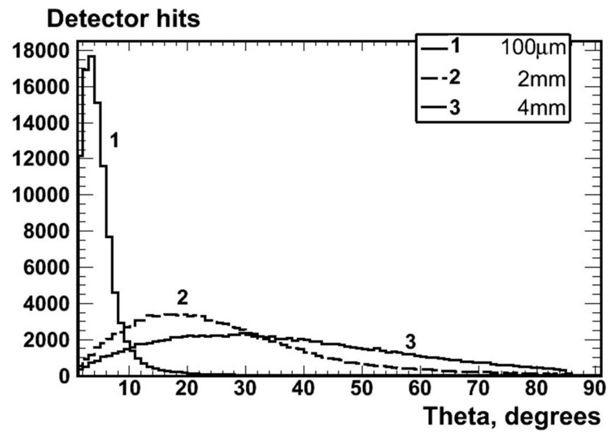

Figure 6. Angular distribution of electrons' direction after the attenuator.

is observed. This fact has to also be taken into account for calculations of the intensity of the delivered samples.

6 Variation of magnetic field

In this section we study the intensity of the delivered samples as a function of applied magnetic field. This dependence for different thickness of the attenuator is particularly important since it can be directly measured in the experiment and confronted to the simulation results. Simulation was performed using primary electrons of 3.5 MeV/c momenta for aluminum targets of 100 μm, 2 mm and 4 mm. The obtained intensities of delivered sample depending on the applied magnetic field are shown on Fig. 7.

These distributions are in agreement with the spectra shown on Fig. 5. Note that the magnetic field shown on the horizontal axis of Fig. 7 is proportional to the electron momentum shown on the horizontal axis of Fig. 5. For each attenuator, a maximum corresponding to the maximum energy of electrons after the attenuator and slow ris-

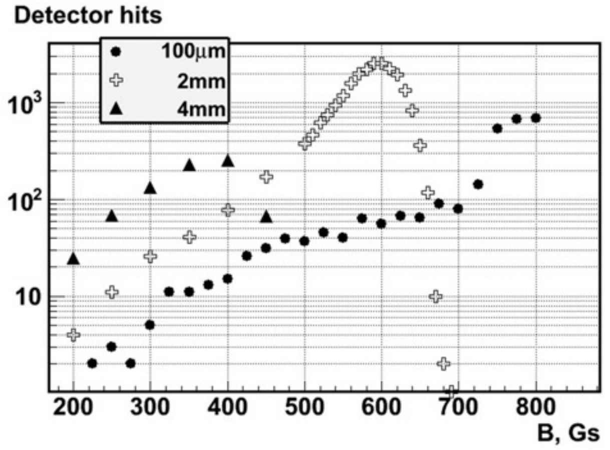

Figure 7. Magnetic field scans for different attenuator thickness.

ing edge, are observed. However, maximum intensity for the attenuator of 100 μm on Fig. 7 is lower than that for the attenuator of 2 mm. This can be explained by the inclination of the beam pipe with respect to the vacuum chamber by angle of 23°. In case of the 100 μm attenuator the beam solid angle after the attenuator is narrow and the main part of the beam goes aside and hits the collimators. Therefore the number of electrons accessing the vacuum chamber becomes significantly smaller than the total number of electrons after passing the attenuator. In case of the 4 mm attenuator the beam solid angle is wider so bigger part of electrons accesses the chamber.

7 Summary

A new facility LEETECH delivering low-energy electron samples with adjustable energy and intensity of the delivered samples was designed. The R&D, calibration and quality control programs with LEETECH are identified for a wide range of instrumentation techniques. The intensity of delivered samples ranges between few and 10^3 electrons. Bunches with a duration of hundreds (tens for further studies) of picoseconds are delivered at a frequency of 5 Hz. Samples energy is chosen in the range between hundreds of keV and the maximum PHIL energy of 5 MeV, with resolution of a few percents (down to 1% for further studies). Remote control of the entire setup has been developed.

The full Geant4 simulation of the facility has been performed. Desired parameters of the simulated samples were obtained by adjusting the dipole current and collimators position and by choosing the attenuator thickness. Time of the simulation was significantly reduced using tools for parallel computing. Further improvement of timing characteristics of the delivered samples will be studied.

Research was conducted in the scope of the IDEATE International Associated Laboratory (LIA).

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