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NEW VERSATILE PLATFORM BASED ON THE LOW ENERGY ELECTRON BEAM DELIVERED BY THE PHIL PHOTOINJECTOR

New flexible facility is proposed to be constructed at the photoinjector PHIL at LAL, Orsay. The proposed setup will provide a powerful tool for wide range R&D studies of different detector concepts using “mono-chromatic” samples of low energy electrons with adjustable energy and intensity. Main detector concepts to be studied with the new platform range from large area radiation resistant precision tracking, Micromegas/InGrid concept, and particle identification, to the beam monitoring using bent crystal technique. Other immediate platform applications are scintillator measurements for the neutrinoless double-beta decay experiments (SuperNEMO), diamond sensor tests as profile monitors and as tracking devices for the ATF2 project. In the framework of by-product physics studies, dE/dx for non-relativistic electrons will be measured using Micromegas/InGrid detector for single primary electron cluster reconstruction. Main characteristics of the setup and simulation results are addressed by this paper.

Keywords: Micromegas/InGrid, photoinjector PHIL, beam monitoring, precision tracking.

Introduction

Development of high-granularity detectors with utmost spatial and time resolution is a key requirement for modern High Energy Physics (HEP) projects, such as Large Hadron Collider (LHC) experimental setups and their future upgrades or the International Linear Collider (ILC) project. Development and tests of new detector concepts, prototypes and large detector systems require particle sources with precisely known characteristics: particle type, energy, arrival time and position.

We propose to construct the new facility at the photoinjector PHIL that will yield samples of low energy electrons with adjustable energy and intensity. It will provide a powerful tool for wide range R&D studies of different detector concepts. It will serve a unique flexible source of low energy electrons with precise timing and adjustable multiplicity and energy parameters. This facility will complement the conventional test beam facilities, where availability is often compromised between many competing groups, higher electron energies are preferred and no easy energy change/adjustment is often possible, and ultimately intensive radioactive sources, Ru^{106} or Fe^{55}, with limited range of accessible energies and in the case of Ru^{106} limited lifetime. This approach thus provides a unique place to comprehensively characterize the newly developed technologies. Along with the Micromegas/InGrid [3, 4] R&D, and development of other tracking detector technologies, the demand comes as well from the prototype studies for beam monitoring, novel particle identification approaches and extended energy range measurements of the scintillator materials.

The full Geant4 simulation of the facility is being performed.

Proposed setup aims at providing samples of “monochromatic” electrons with adjustable energy between few 100 keV and 5 MeV, and intensity (number of electrons in a sample) varying from few electrons per sample to a large number of electrons comparable to that in the initial PHIL bunches. Energy spread is adjusted by the collimator openings, and spreads better than 1% will be achieved for the samples aimed at 1 MeV energy with sample intensities of few 10^3 electrons or below.

The photoinjector PHIL produces bunches of electrons with energy of 3 MeV (will be 5 MeV, and then 8 MeV) of 10^8 (will be 10^{10}) electrons per bunch. Al beam plug will be installed at the end of beam pipe on the way of the PHIL electrons in order to smear the initial beam energy. Full Geant4 simulation shows that for inclination angle of ~0.5 rad, possible sample intensity reaches the plateau for different sample energies as well as for different plug thickness values. First set of collimators (at the entrance to the magnetic field area) selects unique direction of the electrons entering the magnetic field area. Electrons make a half-turn in the magnetic field, inside the vacuum chamber. This way the field value (or the position of the detector) will define the energy of the electron sample. Both collimator sets (at the entrance and at the exit from the magnetic field area) will adjust the intensity and the electron energy spread. Simulation shows primary vacuum of 10^{-3} bar to be sufficient in order that the effect of multiple scattering is smaller than that caused by the initial spread in the direction of electrons. The entrance and exit windows of the vacuum chamber are produced from 20 μm thick aluminum. Geometry of the collimator system and 20 μm aluminum windows is shown on Fig. 5.

Lead shield protects detector test area from the background dominated by scattered electrons and Bremsstrahlung photons.

The new test platform meets the need of many detector developments within HEP or nuclear physics.

Main detector concepts to be studied with the new platform range from large area radiation resistant precision tracking, Micromegas/InGrid concept (proposed R&D program in the framework of the RD51 [2] collaboration at CERN), and particle identification, e.g. studies of TOF-Cherenkov detectors [6], to the beam monitoring using bent crystal technique within the UA9 [5] project. Other immediate platform applications are scintillator measurements for the neutrinoless double-beta decay experiments (Super-NEMO [7]), diamond sensor tests as profile monitors and as tracking devices for the ATF2 project [8], SiPM characterization and SIPMED project. In the framework of by-product physics studies, dE/dx for non-relativistic electrons will be measured using Micromegas/InGrid detector for single primary electron cluster reconstruction [9].

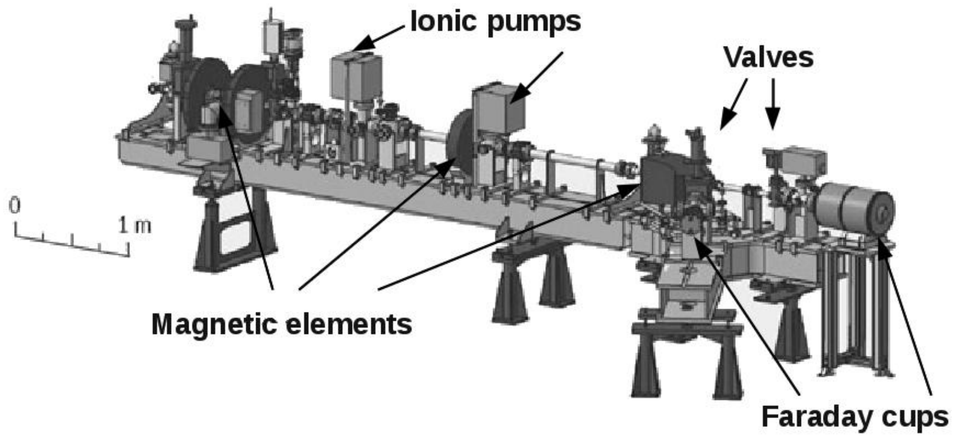

Fig. 1. General view of PHIL (with diagnostics).

Photoinjector PHIL

The “PhotoInjector at LAL” (PHIL: http://phil.lal.in2p3.fr/) is a new 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 (next generation lepton colliders, CLIC, ILC). This machine has been designed to produce low energy (E<10 MeV), small emittance ($\varepsilon \approx 10\,\pi$ mm mrad), high current (charge nearly 2 nC per bunch) electrons bunch at low repetition frequency (<10Hz) [1]. At the end of the accelerator, the normalized emittance is about 4 π·mm·mrad. The bunches are well timed (laser pulse FWHM duration of 5 ps). PHIL is currently a 6 meters long accelerator with 2 diagnostics beam lines (see Fig. 1).

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

– 2 Beam Position Monitor (BPM).

– 1 phosphorescent transverse beam profile monitor.

– 1 Faraday Cup (FC).

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

In 2010, three others phosphorescent YAG:Ce screen monitors was installed on PHIL. The first one was mounted at the entrance of the dipole. It gives important information on the beam behaviour just before the dipole, which is used to correctly prepare the beam for mean and energy spread measurement on the deviate line. Each phosphorescent screen is associated 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 is coded on 8 bit. In front of each camera a remote control optical density wheel is mounted in order to avoid pixel saturation during measurement.

GEANT4 simulation of the facility principle

The full Geant4 [10] simulation of the setup provided a proof of principle and is used to optimize the design of collimator systems, vacuum chamber, magnet and detector area shielding, as well as the beam plug thickness. The ultimate goal is to provide best possible energy resolution and flexibility in terms of energy and multiplicity of the samples.

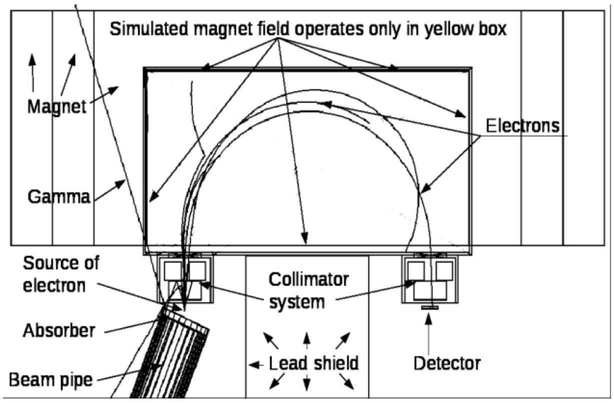

Fig. 2. Top view of geometry simulations.

Figure 2 shows geometry (top view) of the setup. Magnetic field is simulated only in the central box located in the central part of the Figure 2. Magnetic field area is surrounded by the vacuum chamber with 3mm aluminum wall thickness. Two sets of collimators are located at the entrance and exit of the vacuum chamber. The chamber is located inside the dipole magnet (see Fig. 2 and 3). The 5 MeV electrons from PHIL are scattered by the absorber (beam plug). Resulting momentum and direction spread is shown on Figure 4 depending on the absorber thickness.

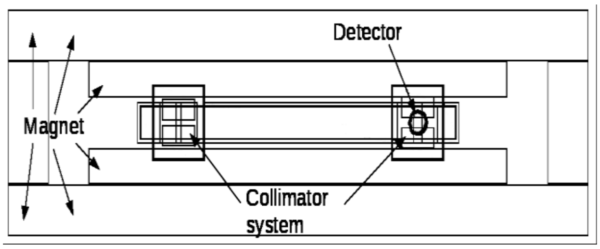

Fig. 3. Side view of geometry simulations.

Different plug thickness favours different energy samples, so that it is advantageous to produce several plugs of different thickness. For example, highest multiplicity of 1 MeV/c momentum electrons is obtained using 7 mm thick absorber (see Fig. 4).

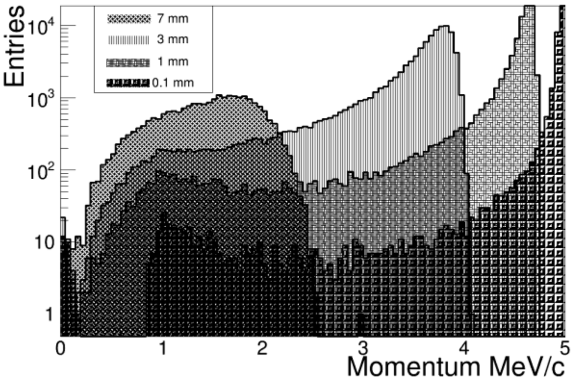

Fig. 4. Momentum spectra for different thickness of absorber.

Simulation of samples of 10^8 electrons requires big computing time. In order to provide a reasonable approximation for 1 MeV electron samples, the electrons were emitted after the absorber in the 15 degrees solid angle with energy uniformly distributed between 0.5 and 1.5 MeV.

Table 1

Dependences: RMS, sigma, entries on first and second distance between collimators

1-st, cm	2-st, cm	RMS	Sigma, MeV	Total Entries
0,2	0,6	0,158	8,24E-03	30
0,3	0,8	0,104	1,06E-02	159
0,3	1	0,111	1,17E-02	220
0,3	1,4	0,128	1,52E-02	435
0,4	0,8	0,14	1,31E-02	175
0,4	1	0,09	1,46E-02	339
0,4	1,2	0,083	1,62E-02	459
0,4	1,4	0,086	1,93E-02	633
0,4	1,6	0,099	1,93E-02	748
0,6	1	0,123	1,65E-02	464
0,6	1,2	0,104	1,74E-02	694
0,8	1	0,116	1,82E-02	677
0,8	1,2	0,107	2,05E-02	912
1	1	0,11	2,10E-02	734
1	1,2	0,118	2,25E-02	1131
1	1,4	0,097	2,31E-02	1506
1	1,6	0,105	2,75E-02	2020
1	1,8	0,119	2,80E-02	2257
1,2	1,4	0,102	2,84E-02	1694
1,2	1,6	0,107	3,11E-02	2191
1,2	1,8	0,116	3,20E-02	2557
1,4	0,4	0,137	2,33E-02	117

These simplified settings reduce the needed computation time and give possibility to quickly test geometry modifications and obtain estimated (momentum) spectrum. One of spectra with described settings is shown on figure 6. The openings are 1 cm and 1.4 cm for the first and second system of collimators respectively. Table 1 shows the intensity, RMS and Gaussian sigma for different collimator openings_in the first and second collimator systems. As expected, intensity and energy spread depend on the collimator openings.

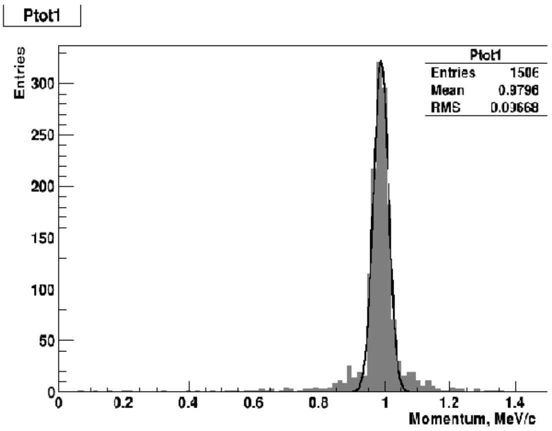

Fig. 6. Spectrum for simplified settings with distance between collimators in first and second systems is 1 and 1.4 cm respectively.

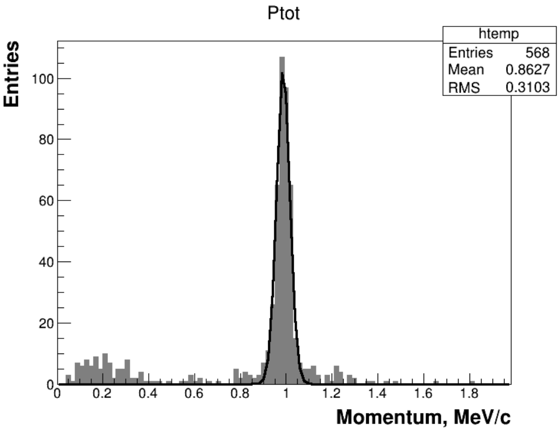

Fig. 7. Spectrum for real settings with distance between collimators in first and second systems is 1 and 1.4 cm respectively.

Full Geant4 simulation was performed for the collimator openings of 1 cm in the first collimator system and 1.4 cm openings in the second collimator system (see Fig. 7). Significantly higher background from Bremsstrahlung photons at the low momentum part of the spectrum is observed with respect to the simplified settings. Origin of these photons should be understood.

In addition background electrons have been observed, and attributed to the residual Bremsstrahlung rays.

Summary

New versatile platform will be constructed at the photoinjector PHIL at LAL, Orsay. It will provide a powerful tool to test particle detectors using "monochromatic" samples of low energy electrons with djustable energy and intensity. The main principle is the selection of the "mono-chromatic" samples from the half-turn of electrons in the magnetic field.

The Geant4 simulation of the facility is performed. Samples of 1 MeV/c momentum have been studied. The required energy spread is obtained with estimated multiplicity of the samples from the few tenths to the few thousand with initial intensity of 108 electrons per bunch and sigma varied from 10 to 30 keV depending on the collimator adjustments.

The obtained spectra have small contribution from the electron background in wide range of momentum and Bremsstrahlung photon background in the low momentum part of the spectra. The design will be further optimized in order to suppress the observed background level.

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НОВА УНІВЕРСАЛЬНА ПЛАТФОРМА НА ОСНОВІ ЕЛЕКТРОННОГО ПУЧКА НИЗЬКИХ ЕНЕРГІЙ З ФОТОІНЖЕКТОРА PHIL

Пропонується нова розробка додаткового пристрою для фотоінжектора PHIL (ЛАЛ, Орсе). Запропонована розробка стане ефективним інструментом для широкого кола R&D стадій для різних детекторів, яка забезпечить “монохроматичні” пучки низькоенергетичних електронів зі змінною енергією та інтенсивністю. Головний напрямок використання цього пристрою це радіаційно стійкі трекові детектори, системи розпізнавання типу частинок з використанням Micromegas/InGrid та методики моніторування пучка за допомогою зігнутих кристалів. Інше безпосереднє використання цього пристрою це калібрування сцинтиляційних кристалів для експерименту SuperNEMO, тестування діамантових детекторів як монітори профілю та трекові детектори в проекті ATF2. Такі важливі величини як dE/dx для нерелятивістських електронів будуть виміряні за допоїмогою Micromegas/InGrid детекторів при реконструюванні одиночних електронів. В цій роботі представлені основні характеристики пристрою та результати симуляції.

Ключові слова: Micromegas/InGrid, фотоінжектор PHIL, моніторування пучка, точна реконструкція треків.

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НОВАЯ УНИВЕРСАЛЬНАЯ ПЛАТФОРМА НА ОСНОВЕ ЭЛЕКТРОННОГО ПУЧКА НИЗКИХ ЭНЕРГИЙ ИЗ ФОТОИНЖЕКТОРА PHIL

Предлагается создать новую установку для фотоинжектора PHIL в ЛАЛ, Орсе. Предлагаемая разработка станет эффективным инструментом для широкого круга исследований разных детекторов с использованием “монохроматических” пучков низкоэнергетических электронов с варьируемой энергией и интенсивностью. Главное направление использования этого устройства - это реконструкция треков радиационно устойчивыми детекторами, распознавание типа частицы детекторами, основанными на системе Micromegas/InGrid, и мониторинг пучка с использованием техники согнутых кристаллов. Другой важной областью применения является калибровка сцинтилляционных кристаллов для эксперимента SuperNEMO, тестирование алмазных детекторов и трековых детекторов в проекте ATF2. Такие важные параметры как dE/dx для нерелятивистских электронов будут измерены с помощью Micromegas/InGrid детекторов при реконструкции треков одиночных электронов. В этой работе представлены главные характеристики этой установки и результаты симуляций.

Ключевые слова: Micromegas/InGrid, фотоинжектор PHIL, мониторинг пучка, точная реконструкция треков.