THE GENERAL ELECTRON INDUCED EMISSION (GENIE) SYSTEM *

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Abstract

A real time beam diagnostic system is proposed for the Jefferson lab injector region. The Genuine ElectroN Induced Emulator (GENIE) consists of a package that includes both hardware (beam monitoring devices) and software (for 3D or 4D visualization of the beam transport). This beam diagnostic tool uses (very small) scintillating fibers placed in different planes to extract the beam profile, beam position, beam current, and beam emittance in real time. Accuracies in position and angle could be at the sub- µm and µrad levels, respectively. The beam current could be reconstructed within a few percent. A combined Geant4/Parmela simulation will be developed for beam optic studies. While Parmela offers the power of beam transport with phase matching capabilities (among others), Geant4 provides secondary particles tracking, as well as 3D & 4D visualization, to name a few. A phase I investigation of GENIE using a 100 keV line in the test lab is discussed in this document.

CONCEPT

The basic idea behind GENIE is the use of three consecutive (negligibly) invasive fiber array monitors to record the beam position and profile. The information gathered from the three detectors allows reconstruction of the beam emittance; and from the energy lost inside the fibers the beam current. These fibers consist of a polystyrene based material that can be blue, green or yellow shifted. They are commercially available from Saint-Gobin. At present, the smallest thickness available is 250 µm; however, thicknesses down to 150 µm could be produced within a year (information obtained from a private discussion with experts of the company).

Because they have a much lower density and smaller thickness than the currently used superharp tungsten wires, these fibers are practically non-invasive for high energetic electrons. They can be use continuously during beam delivery even at low injector energies (100 keV to 60 MeV). Previous tests with similar fibers show their capability for detecting electrons up to 70 MeV.

GEANT4 is the newest release of the well-know GEANT toolkit package used for high energy Monte Carlo simulation. The 4th version includes the low energy component (down to 1 eV). Consequently, once can span a study of particle transport into any given material and geometry from 1 eV to TeV! The power of GEANT is that it includes all electromagnetic and hadronic processes known to date. Additional non-standard reaction mechanisms can be inserted by the user. This code also has the ability to track every particle produced along by the primary beam, i.e., secondaries (charged or neutrals). Hence, it is a standard for estimating contribution from background particle effect. 1, 2, 3 and 4D visualization tools are available.

We present here calibration data obtained from an array of 12 scintillating fibers (1 mm thick) that will be used in GENIE. This test was done with a disk-shaped 25 µCi Sr-90 source, 8 mm in diameter. Preliminary Geant4 coding is discussed. A Parmela simulation is being done and results between the two codes will be compared in the near future.

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PROOF OF PRINCIPLE

To verify the possibility of using such a device in the injector region, we performed several experimental tests using a β-emitting radioactive source (^{90}Sr/^{90}Y, 25 µCi) and a permanent dipole magnet (with a highly non-uniform magnetic field distribution: Gaussian shape with Bmax = 5.5 kG at the center).

Detector Calibration Experimental Setup

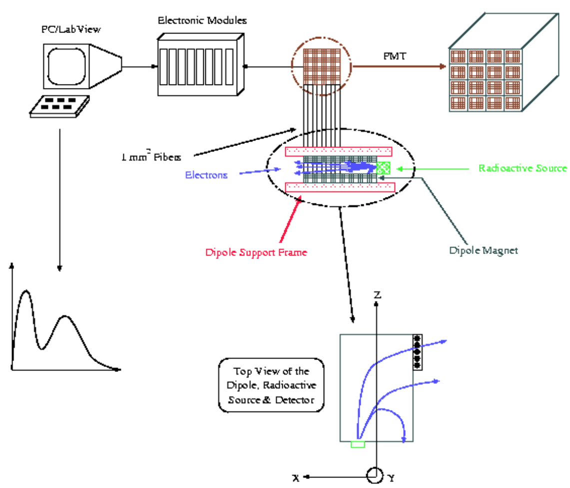

Figure 1: Schematic layout of the experimental setup.

The experimental setup consisted of an array of 12 fibers placed perpendicular to the exit of the dispersive plane of the dipole magnet as shown in Figure 1. The fibers were 31 cm long with a rectangular cross section of 1 mm^2 and were connected to one of the 16 available channels of a multi-anode photomultiplier tube (PMT - Hamamatsu H6568). The active area of each channel is 3 mm^2. The PMTs were connected to a CAMAC based data acquisition system and remotely controlled using dedicated LabView software.

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The radioactive source generates electrons with a maximum energy of 2.28 MeV and an average energy of 930 keV from a disk about 8 mm in diameter and 1 cm thick. The angular acceptance is: (Θ-horizontal, Φ-vertical) = (180º, 360º). The reference frame was selected as follows (see Figure1): X is the horizontal axis parallel to the entrance window of the dipole; Y is the vertical axis perpendicular to the entrance window of the dipole; and Z is the axis along the beam direction. The center of the source was moved to 40 different positions: (X, Z) = {-2.54, -1.27, 0, 1,27, 2.54} x {-4, -3, -2, -1, 1, 2, 3, 4}. For each fiber, we recorded the corresponding ADC spectrum. We estimated the uncertainty in the source location to be 250 µm. The fibers being 1 mm thick, the entire array covers a length 12 mm. The respective positions were assigned to be: -5.5, -4.5, -3.5, -2.5, -1.5, -0.5, 0.5, 1.5, 2.5, 3.5, 4.5, and 5.5 mm.

To have a good understanding of the collected data, we performed Geant4 simulations of the experimental setup. The simulation includes the magnetic field map as well as realistic models of the radioactive source energy distribution functions. The primary kinetic energies of the electrons were randomly generated between 0 and the maximum energies of the ^{90}Sr (2.28 MeV) and ^{90}Y (195 keV). A random generation between the two decay modes was also used to ensure that they were both present in the final simulated spectra. The focus of these simulations was not on the comparison of the ADC spectra but more on the electron energy distribution versus dipole exit position for a given experimental setting and used for qualitative information.

Preliminary Results

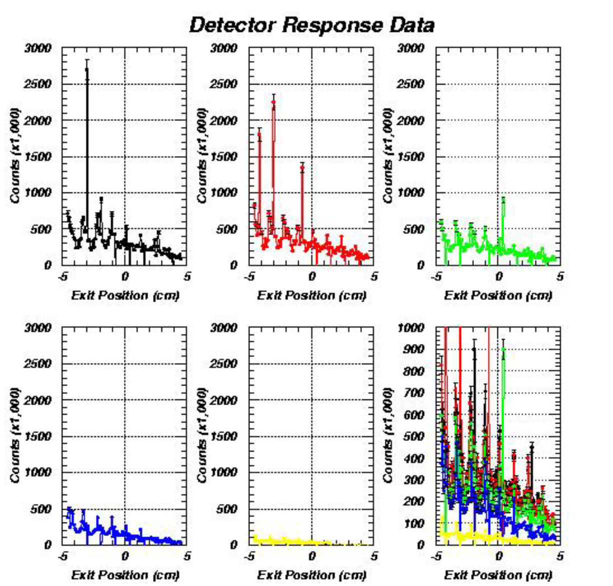

Figure 2: Detector response along the dipole exit face when the source was placed at different X positions: –2.54 cm (black), -1.27 cm (red), 0 cm (green), 1.27 cm (blue), and 2.54 cm (yellow). Also shown is the superposition of all signals on the bottom right panel.

Figure 2 shows the Z-dependence for the five different X locations of the radioactive source. We stress that the signals are not absolutely calibrated which explains why there are no smooth curves. First, the overall decrease of the signal is clearly visible when the source is moved away from the dipole exit face (i.e., from the black curve to the yellow curve). Second, there is a striking linear dependence of all signals on the position of the detector as it is moved along the dipole exit face.

Source Characteristic

Linear functions can be fitted globally on the data to represent the average of the observed linear dependencies.

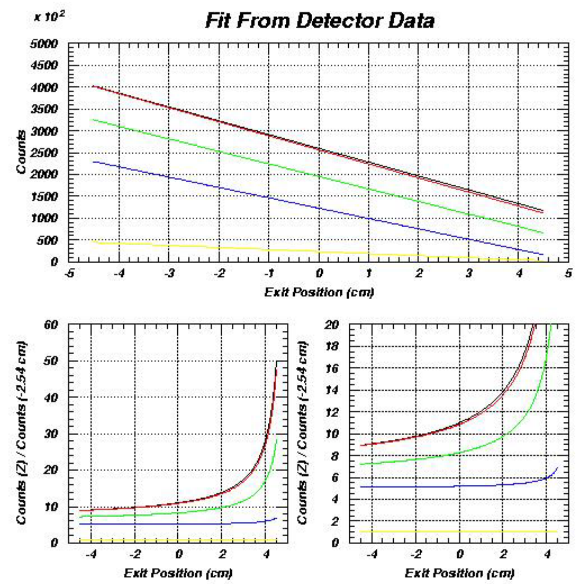

Figure 3: Top panel: Linear fits of the Z-dependence data. (Same legend as in Figure 2 for the color code). Bottom left panel: Ratio between each line to the yellow line representing the calibration curve. Bottom right panel: Zoom of the signal ratios.

From the fit (or data) we can make the following conclusions: (1) the radioactive source has an isotropic (uniform) distribution: the energy distribution of the source is identical at any given point on the source (i.e., the number of electrons with a given energy is constant). If this were not the case, i.e., higher energetic electrons at the center and lower energy electrons on the outer (for example), then the data curves (and incidentally the fits) would show some structure. In other words, one will get some enhancements (Gaussian-like peaks) at particular locations, since the contributions from these electrons will be enhanced differently when the radioactive source is moved towards X= -2.54 cm; (2) the fit ratios indicate more clearly that the slopes of the linear functions are different. This is an anticipated result since the contribution from low energy electrons varies with the source position.

Electron Energy Distribution

From these linear fits, the electron energy distribution can be generated (Figure 4): the red curves are the uncorrected spectra corresponding to the linear fits from Figure 3. The yellow curve in the bottom left panel of Figure 3 is our calibration curve. This is where the radioactive source was the farthest away from our detector (X = 2.54 cm). We are 100% confident that no electrons are seen at Z = 4 cm. However, there is an increased contribution of the low energy electrons when moving towards Z = –4 cm. One can therefore construct a cumulative probability distribution that indicates these features. The corresponding function is shown on the bottom right panel of Figure 4. This probability distribution is conserved for all settings. The reconstructed energy distribution spectra can be obtained by multiplying the linear functions by the cumulative probability distribution function (green curves).

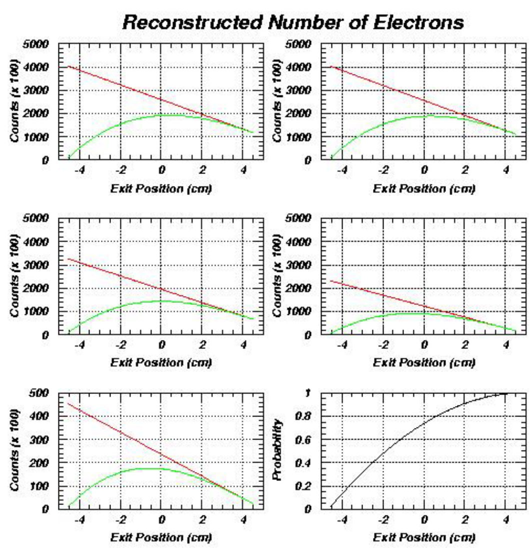

Figure 4: Red curves are the Z-distribution when the source X-location was at –2.54 cm (top left), -1.27 cm (top right), 0 cm (middle left), 1.27 cm (middle right) and 2.54 cm (bottom left). Green curves are the reconstructed energy distribution spectra. Bottom right: cumulative probability from the X = 2.54 cm data set.

The following conclusions can be drawn: (1) Comparison of the integral of the reconstructed energy spectrum to the projected number of electrons can be achieved by taking into account the acceptance of the spectrometer (see Table 1). Note that a simple acceptance correction was made: source collimation by the dipole physical geometry and only one side of the dipole is "active" (where the detector is located). In addition, no correction from multiple scattering in air was taken into account, as well as the production of secondary particles, or phase space. (2) The big discrepancy at Z = 4 cm is due to the low counts seen in some fibers which were not removed.

Table 1: Comparison between projected and reconstructed number of electrons

Z	-4 cm	-1.27 cm	0 cm	1.27 cm	4 cm
Proj./Recon.	2.465	2.511	3.390	5.757	30.214

Electron Energy Range

The position/energy correlation is trivial (Table 2): the peak of all distributions is about 1.15 MeV. The corresponding peak for the $^{90}Sr/^{90}Y$ is at 930 keV (about 24% lower). Although the final data analysis is not completed, this result is a definite proof of the possibility to reconstruct the individual energy lines of a 100% energy spread source using the method described in this document.

The lower and upper values of the energy range for each setting is listed in Table 2, in addition to the energy acceptance of the spectrometer. The energy acceptance is a function of the source location: slightly lower than 30% when closer to the detector and below 10% when away from it. This results from a combination of the spectrometer acceptance and the relativistic aspect of the electrons (i.e., β = v/c values).

The fibers were 1 mm thick and cover a total length of 1.2 mm. Consequently; the energy resolution is 1.376% (calculated using the 96 data points of the entire Z-dependence).

Table 2: Reconstructed lower and upper electron energy limits

Z	-4 cm	-1.27 cm	0 cm	1.27 cm	4 cm
E_{min} (MeV)	0.532	0.511	0.39	0.147	0.107
E_{max} (MeV)	1.853	1.874	1.989	2.239	2.278
E_{max}/E_{min} (%)	28.713	27.282	19.955	6.553	4.703

GEANT4 Simulation

GENIE will combine Parmela and GEANT4 to provide 3D and 4D visualization of the beam as shown in Figure 5. This "*sandwich*" tool will also be used for beam physics studies.

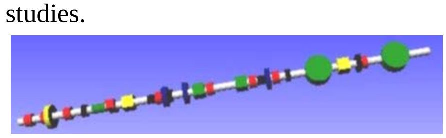

Figure 5: GEANT4 Simulation.

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