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Monte Carlo Detector Modeling and Display, Using the Cern Library

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Abstract

Detectors for high energy nuclear physics experiments are being modeled using programs developed and maintained at CERN, the European Organization for Nuclear Research. These programs include data handling and display routines, as well as those using random-sampling Monte Carlo techniques to calculate energy depositions for high energy particles as they pass through the various parts of the detector system. The complete CERN library has been imported for use with our Workstation computers in a multiple user environment. The enormous CERN Monte Carlo program GEANT (French for GIANT) tracks the progress of a particle through a detector on a simulated event-by-event basis. GEANT is being used to predict energy loss in materials using several different energy-loss assumptions. The energy loss in a silicon slab is calculated for charged particles at moderately relativistic momenta. The response of these calculations is known to result in an asymmetric energy deposition in silicon. Predicted responses are scheduled for examination using test beams at two different accelerator facilities.

Introduction

Some members of the High Energy Nuclear Physics Cluster at the University of Arkansas at Little Rock (UALR) are participating in Experiment Number 35 and Experiment Number 49 in the experimental North Area at CERN, the European Organization for Nuclear Research in Geneva, Switzerland. These experiments are referred to as NA35 and NA49, respectively. In addition, UALR has been granted independent institutional status in the approved Solenoidal Tracking experiment (STAR) at the Relativistic Heavy Ion Collider (RHIC) located at Brookhaven National Laboratory.

Researchers at UALR are eligible to use the CERN program library, developed and supported by CERN staff, due to their involvement with experiments NA35 and NA49 at CERN.

During the last year, UALR has imported the complete CERN library for use with our Digital Equipment Model 5000 (DEC-5000) Workstation computers. To assure backward compatibility, we maintain, as does CERN, old, new and production versions of each program on a common platform for simultaneous access by a variety of users. The principal UALR efforts are concentrated on two CERN programs: the Monte Carlo detector-modeling program, GEANT, and the display and data manipulation program PAW [Physics Analysis Workstation].

GEANT tracks the progress of a particle through a detector on an event-by-event basis (Geant, 1992). Each step uses known interaction probabilities and random choices to determine subsequent events.

Each subsequent event is individually tracked until its energy is depleted or it leaves the active region of the detector being modeled. Energy loss spectra in semiconductor silicon detectors are being calculated for a variety of momenta and for a variety of charged particles.

Silicon detector response predicted in these calculations will be tested at several different momenta with pions from the TRIUMF accelerator in Vancouver, British Columbia, and with protons from the Alternating Gradient Synchrotron (AGS) accelerator at Brookhaven National Laboratory. These efforts will test the predictions of GEANT under varying energy-loss assumptions.

Materials and Methods

For our work with the NA35 and NA49 experiments at CERN, as well as with the STAR collaboration, we are utilizing software packages from the CERN-program library on our DEC-5000 workstations to simulate the progress of charged particles on an event-by-event basis as they pass through semiconductor silicon detectors.

GEANT is one of the general purpose Monte Carlo codes for modeling the response of detectors to individual charged particles and, subsequently, to each charged particle's spallation products. This versatility accounts for its popularity in the High Energy Physics community.

UALR is using the Monte Carlo program GEANT to model pion and proton energy deposition in slab silicon at several different momenta to test the accuracy of GEANT predictions for these charged particles. This effort is assessing the accuracy of quantitative predictions of energy loss within semiconductor silicon detectors, which is relevant to identifying particle types using semiconductor silicon.

In addition, we are using GEANT to predict energy losses for electrons, pions, kaons, and protons passing through multiple slabs of active silicon detector material with thicknesses between 250 and 300 µm. Then we calculate the expected energy-loss separation between these particles passing through the multiple layers of silicon using two different methods.

Results and Discussion

The STAR instrument at RHIC, like most high energy detectors, uses a known magnetic field to bend charged particles in order to compute the momentum of each from the curvature of each measured path. Thus, separation of charged particle types into distinct groups involves identifying some distinguishing property at fixed momentum. One candidate for this distinguishing property is dE/dx, the rate of energy loss per unit distance in a detector (Bichsel, 1988). This rate is proportional to the amount of energy loss in a thin detector.

PAW is used to produce Fig. 1, which shows an energy loss distribution for charged pions incident on a 300-micrometer silicon detector, where each pion has a momentum of 300 MeV/c (where 1 MeV = 1.6×10^{-13} Joules and the speed of light c = 3×10^{8} meters/sec). The distribution shown in Fig. 1 is asymmetric, slightly favoring higher energy losses, which are induced by nearly head-on collisions of incident pions with electrons in the silicon. Asymmetric "tailing" in the energy loss distribution makes it difficult to separate different particle types, at fixed momenta, on the basis of their energy losses in a thin silicon detector.

However, since a head-on collision with an electron is an improbable event, a charged particle passing through multiple detectors is unlikely to have a nearly head-on collision in more than one of the detectors. To facilitate separation of particle types, two methods have been reported for reducing the asymmetry in the energy loss for the same charged particle. One method of particle-type separation employs a 'truncated mean method' (Schukraft, 1992), where, in multiple measurements, he throws away the most energetic events and averages the remainder. The other employs a "maximum-likelihood method" (Cramer, 1992) which makes use of all the data, but is most time consuming.

Detector design is carried out using codes like GEANT, which compute energy losses in a detector on a Monte Carlo basis, from probability distributions for the rate of energy loss, dE/dx. Options within GEANT use different strategies to calculate dE/dx for charged particles. The two most commonly used options are based on the Landau distribution (Landau, 1956), originally developed for collisions of fairly relativistic electrons with electrons. A more complicated approach is still being developed at CERN for the GEANT source code based on the Vavilov distribution (Vavilov, 1957; Schorr, 1974). Our present efforts are aimed at calculating the energy loss for pions and protons at fixed momenta using the various energy loss assumptions available in GEANT, so these predictions can be compared with data taken with test beams at the TRIUMF accelerator in Vancouver and the AGS accelerator at Brookhaven National Laboratory.

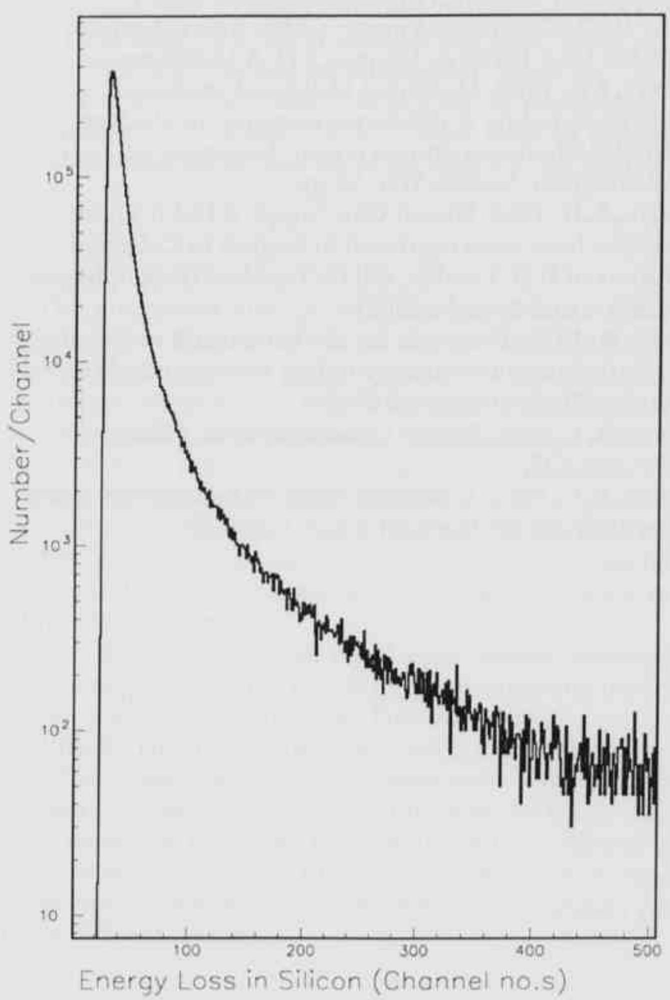

Fig. 1. Semi-logarithmic plot of the frequency distribution of 5 million 300-MeV/c pions, incident on a 300-micrometer slab of silicon, simulated using a Landau-distribution energy loss option in GEANT.

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