Time Projection Chamber's Efficiency, Obtained Using CERN's GEANT Code

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Abstract

Geometrical acceptance and reconstruction of tracks have been carried out for a Time Projection Chamber (TPC) used in Experiment NA35: the 35th experiment in the North Area of the Super Proton Synchrotron (SPS), located at the European Organization for Nuclear Research (CERN). NA35 used the SPS at CERN to produce 6.4 TeV beams of ^{32}S for central collisions with Au nuclei. The TPC modeling effort used a modified version of CERN's Monte Carlo program GEANT, which simulates the response of the NA35 TPC to output from CERN's primary event generators. GEANT was used to simulate three-dimensional pixel data in the same format as data taken by direct readout of the TPC. These simulated data were stored on magnetic tape and processed using the TPC analysis and reconstruction program TRAC. Analysis of these simulated data allowed a calculation of the efficiency of the TPC, to within about 1%, by comparing the output of TRAC with the known input from GEANT. Also, reconstructed events from GEANT were used to eliminate false tracks and to determine systematic errors in track position and momentum in data taken by NA35 in the Spring of 1992.

Introduction

If we could travel back in time to fractions of microseconds after the Big-Bang, we would find the universe to be extremely hot and dense. At these high energy densities (>3 GeV/fm^3 or >4.8 x 10^{35} Joules/m^3), quarks and gluons, normally trapped inside hadrons, escape and move freely within this high energy density region. This deconfinement of the quarks is predicted to occur as a Quark-Gluon Plasma. An experimental group at the University of Arkansas at Little Rock is investigating matter at energy densities where a Quark-Gluon Plasma is expected to form.

Ultra-relativistic nucleus-nucleus collisions produce similar energy densities as those calculated for a fraction of a microsecond after the Big-Bang. Nuclei accelerated to kinetic energies about 100 times their rest mass are moving at nearly the speed of light, with their length contracted by a factor of 100 in their direction of motion. The high energy densities following each central collision results in the possibility of exciting a Quark-Gluon Plasma.

It would be very interesting to "observe" the Quark-Gluon Plasma as it expands and cools, first creating kaons, then pions, as the temperature progressively cools. Similar interferometric techniques to those used by astronomers for measuring the sizes of nearby stars are applied to the nuclear domain to measure the size and duration of quark-gluon "hot spots" produced in the aftermath of each central ultra-relativistic nucleus-nucleus collision, where each "hot spot" decays into hundreds of charged pions (Cramer, 1991).

The enormous energy densities required to form a Quark-Gluon Plasma necessitate the use of huge particle accelerators and very large detectors weighing several thousands of tons. The Time Projection Chamber (TPC) is indispensable in determining, simultaneously, momenta of each of the hundreds of secondary particles. The TPC provides excellent geometrical acceptance, good resolution and "automatic" digital data representing the x, y, and z coordinates of each individual secondary particle track produced following a central collision between two ultra-relativistic nuclei.

Even if a TPC meets all the design criteria, systematic errors may occur in the process of reconstructing particle tracks from experiment data. This makes it necessary to determine the TPC's track reconstruction efficiency in order to make corresponding corrections. Furthermore, since we are primarily interested in hadrons which originate from the hot spots located around the vertex, we must determine criteria to eliminate tracks which result from either track reconstruction errors or secondary particles (Roland, 1922b).

Materials and Methods

The TPC uses collections of instrumented cathodes (called Pads) to collect ionization left by the passage of charged particles through the gas-filled TPC volume. A 100-200 V/cm field is used to sweep the electrons to anode chains where they are accelerated, causing an

avalanche multiplication of electrons. The x and y coordinates of each particle trajectory are given by the pad locations, while the z coordinate is determined from the electron drift time. The pad charge is amplified and enters the digital sampling process through one of several hundred thousand detector channels. The data are then stored on magnetic tapes for later analysis.

Although the intrinsic sensitivity of a TPC is ultimately determined by the instrument's physical design parameters and data acquisition electronics, the response of the detector depends on the data analysis software. Such physical characteristics as pad plane design determine the optimal performance of the detector, while the effectiveness of the design depends on the processing and interpretation of detector signals (Jones and Rai, 1991). The usefulness of the information provided by the acquisition electronics will depend on the ability of the analysis software to reconstruct tracks from hits, identify particles, determine momentum and other particle characteristics (Roland, 1992a).

The response of the TPC is determined using simulated events produced by FRITIOF, which generates particles using the Lund model (Anderson et al., 1982) for string fragments. These events are then used by the GEANT detector simulation program to create input for the data analysis software (Geant, 1992). The efficiency of the TPC is determined by comparing the track analysis from the reconstruction software to the original tracks produced by the GEANT simulation code (Bloomer et al., 1992). In addition to improving the efficiency and accuracy of the TPC track reconstruction algorithms, the simulation chain produces the necessary data required to determine selection criteria for tracks, further reducing error by allowing a prefiltering of tracks which were produced outside of the collision vertex region.

Results and Discussion

The determination of track reconstruction efficiency and the setting of vertex selection criteria are important to the correlation analysis. This effort reduces the number of specious tracks generated outside the collision vertex by decays or by secondary particle production without appreciably reducing the efficiency of primary tracks needed to extract particle source sizes. Also, two particle correlation analysis (Gyulassy and Harlander, 1991) requires excellent momentum resolution and particle identification, established by the present work on TPC track reconstruction efficiency.

The NA35 TPC TRAC algorithms were found to have reconstruction efficiencies of better than 95% for charged particles at normal track density. When track density was increased by a factor of 3 in the simulated data sets, the efficiency was found to drop less than 5%. In addition, rejection of events more than 6.0 mm from the collision vertex resulted in less than a 4% reduction in reconstruction efficiency, while reducing background events by over 35%. These results were found by comparing simulated data with the experimental NA35 data taken in the Spring of 1992.

The same simulation tools used in detector design are being used in refining the data analysis software, an application of equal importance.

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