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Optimizing Tracking Software for a Time Projection Chamber

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Abstract

International research collaborations will be using accelerators in the U.S. and Europe to produce and detect the phase transition in high-density nuclear matter called the Quark-Gluon Plasma, formed in collisions between pairs of A≈200 nuclei, for projectiles with kinetic energies large compared to their rest mass energies. Each collaboration will use time projection chambers (TPC) to track thousands of secondary charged particles formed in the aftermath of each central primary collision. Creating and optimizing TPC tracking software is difficult in such a high multiplicity environment, particularly for particles with a low momentum (below 300 MeV/C). At high momenta, energy loss is low enough for particle-tracking to use unchanging helix parameters. However, at low momenta, tracking requires changing helix parameters as energy is lost along the path. Tracking software, written f0r particles of high momenta, may identify the track of a single low momentum particle as two or three separate tracks. This tracking problem was corrected by changing the main tracking algorithm to merge together these two-or-three fragmented, low-momentum particle tracks. Event displays were found exceedingly helpful in diagnosing the problems and optimizing the algorithms.

Introduction

Within the first microsecond after the big bang, the Standard Model predicts that mass-energy densities were so high, the dominant form of matter in the universe was the quark-gluon plasma or QGP (Schukraft, 1993). QGP is a state in which quarks and gluons move freely at a much higher mass-energy density than that of nuclear matter. At lower mass-energy density, quarks and gluons are usually bound together in particles such as protons, neutrons, pions, etc. Except, possibly, in the cores of neutron stars, densities and temperatures do not rise high enough to permit quarks and gluons to break free from protons and neutrons, so QGP is not readily observed in nature (Schukraft, 1993). Attempts to produce QGP have been made using the SPS (Super Proton Synchrotron) at CERN and using the AGS (Alternating Gradient Synchrotron) at Brookhaven National Laboratory. In each case relativistic nuclei collide with stationary nuclei in fixed targets. None of these experiments have reported the detection of the QGP (Schmidt, 1993).

Two distinct attempts are now being made to produce the phase transition from normal nuclear matter to QGP, using relativistic beams of heavy nuclei. One effort, which is underway, uses the SPS at CERN to provide lead (Pb) beams on a fixed lead target. The second effort is planned at Brookhaven National Laboratory using RHIC (the Relativistic Heavy Ion Collider), where heavy nuclei will collide in pairs. RHIC and its detectors are on schedule for completion by the end of the century (Schukraft, 1993).

RHIC is expected to provide the energy necessary to produce the QGP by colliding gold nuclei, where each is moving within 1 part in 20,000 light speed. At such speeds, the kinetic energy of each colliding gold nucleus is over 100 times its rest mass energy. The Standard Model predicts the QGP will be formed at these high energy densities, so even if the QGP is not formed, these efforts will provide a significant test of the Standard Model.

At RHIC, the effort to observe the QGP will be carried out by analyzing the particles emerging from the aftermath of central collisions between relativistic pairs of gold nuclei. Thousands of charged secondary particles, produced in each primary collision, will be used to investigate the physics of the primary collision. Detectors at RHIC are being built to track charged particles generated in the aftermath of each central primary collision. Several thousand charged secondary particles (called a high multiplicity environment) make tracking a difficult experimental problem.

The Solenoidal Tracker (STAR) is one of two large instruments located at RHIC at one of its six colliding-beam crossover points. Secondary charged particles produced at RHIC are observed using different sub-dectors of STAR, which is made up of a solenoidal magnet containing these sub-detectors. The solenoidal magnet surrounds the beam pipe of RHIC, creating a magnetic field (0.5 T) along the beam line. Charged particles will bend in this B-field, and the charge and momentum of these particles will be determined by measuring the curvature of their tracks. The STAR sub-detectors are being built to determine pixel-by-pixel coordinates of each particle's trajectory, so all can be tracked simultaneously.

The main sub-detector in STAR is the Time Projection Chamber (TPC), which measures the trajectories of charged particles in three spatial dimensions. The TPC is complemented by several other detectors; these include: a tracker near the collider vertex responsible for measuring all charged particle tracks, especially those with low transverse momentum (below 150 MeV / c) or short half-lives; trigger detectors for measuring when and where each gold on gold event occurs; and an Electromagnetic Calorimeter used to measure particle energies (STAR, 1992).

The TPC is a coaxial cylinder, 4.2 meters long, with an outside diameter of 4 meters and an inside diameter of 2 meters. The cylinder is located within the Solenoidal Magnet and around the vertex tracking detector. Particles with momenta greater than 125 MeV / c can make it through the TPC geometry, but tracking lower-momentum particles is left to the vertex detector. The TPC misses some high momentum particles due to its geometry, but overall it tracks about 50% of the secondary charged particles created in each central collider event (STAR, 1992). The TPC cylinder is divided in half by a high voltage membrane which creates an electric field (130 V / cm). The endcaps are made up of rows of pads at low potential (1265 V), where the signals for tracking particles are induced. The track density is great near the vertex; thus, pads close to the vertex are small (2.85 x 11.5 mm) providing good track separation. TPC pads farther from the vertex are larger (6.2 x 19.5 mm), providing better particle identification (STAR, 1992).

The TPC is designed to detect charged particles, identify them, and obtain the momentum and charge of each. The TPC can be viewed as electronically "taking a three-dimensional picture of the particle trajectories" as the particles ionize its gas, as seen in Fig. 1. The electric field causes the ionization electrons to drift toward the

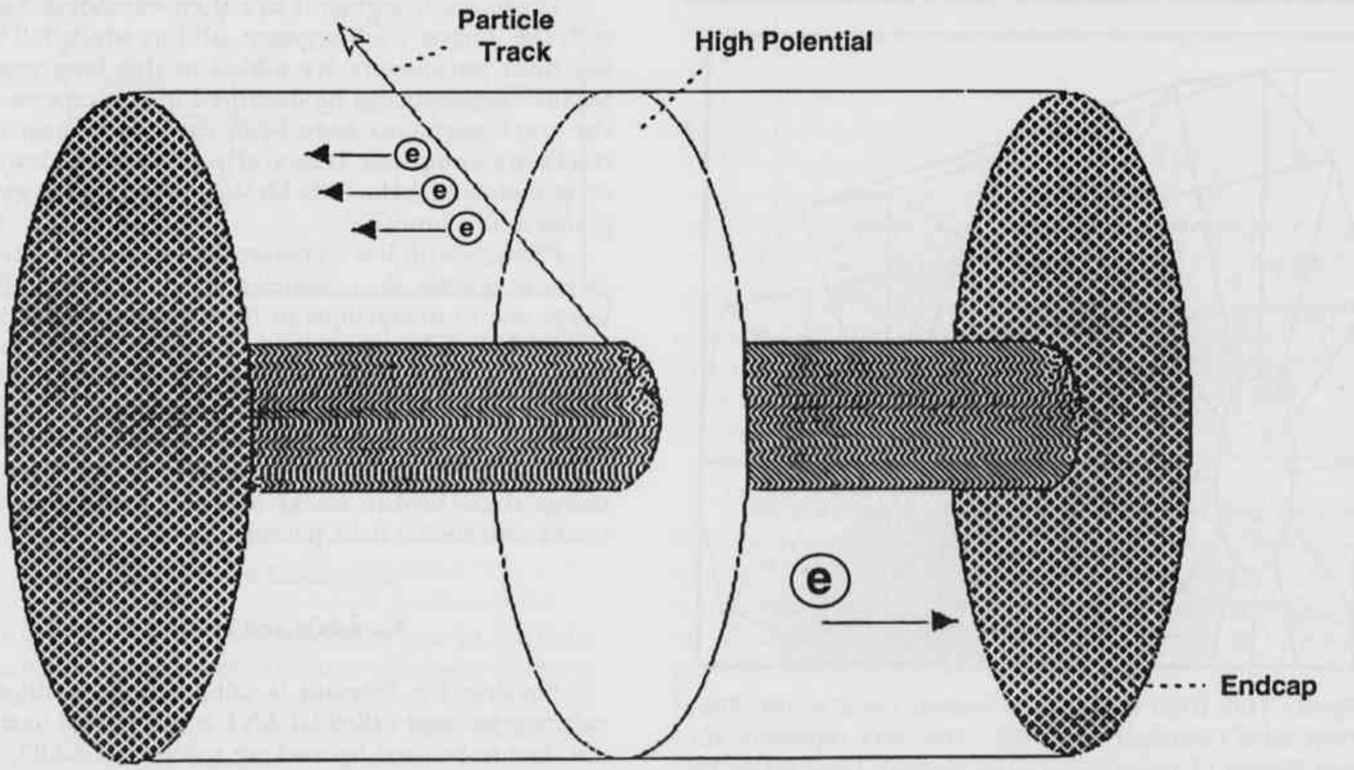

Fig. 1. Ionization electrons are shown drifting toward the endcaps of a Time Projection Chamber. The size of the beam pipe is exaggerated.

ends of the TPC chamber. There the signal from each electron is amplified at a thin anode wire; a signal is then induced on a pad under the wire. The placement of the signal on the pad gives two coordinates of the track, and the drift time gives the third coordinate. Up to 45 (x,y,z) pixel coordinates may be associated with a single track; tracking software groups these three-dimensional coordinates into particle tracks.

Measuring charged particle tracks is important because these tracks can be used to infer fundamental information about the primary central collision which created them. The curvature of each track can be used to calculate the charge and momentum of the particle, and the energy loss of a particle can be calculated by measuring the track density of ionized electrons as a function of this measured momentum. This energy loss may be used to determine the particle type. Measurements of what happens after each central gold on gold event are important to understanding the physical processes of these collisions.

Thousands of charged particles are created by each central gold on gold event. With such a large multiplicity, tracking is difficult (see Fig. 2). Particles decay as they leave the vertex creating other particles which must be tracked. These created particles make tracking even more difficult since their tracks can start anywhere in the TPC instead of starting at the vertex. All particle tracks do have common characteristics, and these characteristics are used in designing tracking software. For instance, charged particles follow helical paths in magnetic fields, so the tracking algorithm uses a helix to link hits into particle tracks.

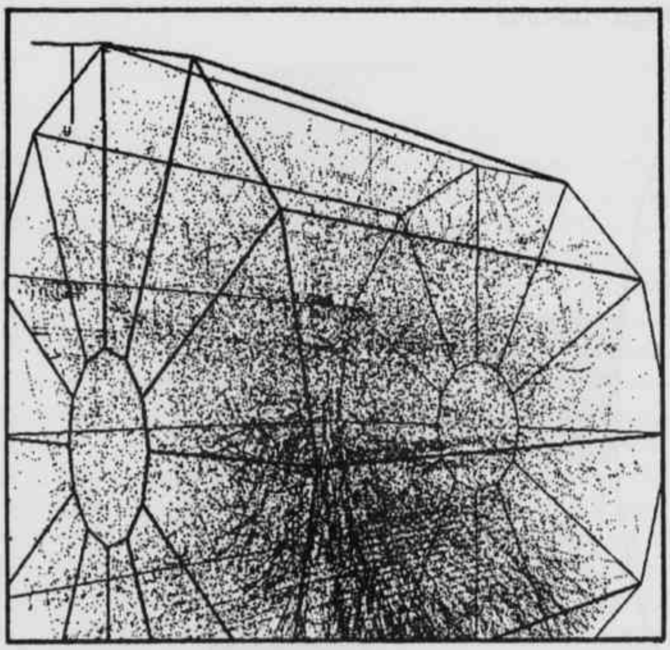

Fig. 2. Hits from a simulated Au+Au event in the Time Projection Chamber of STAR. The dots represent the coordinates of points along the particle trajectories for one gold on gold event. This display shows over 80% of the recorded points for a gold on gold event.

The tracking algorithm starts by making groups out of all the hits on the outside of the TPC. Because of the lower track density, this algorithm begins with the outermost hit and moves inward toward the vertex. When working on a given hit, nearby, unused hits which successfully form a helix fragment with the given hit are found. Then the possible groups for that hit are evaluated, and the group which most closely resembles a helix fragment is kept. The hits from this group are removed from the pool of unused hits, and the next unused hit is grouped (Mitchell and Sakrejda, 1994).

After all the initial groups are found, they are linked into longer tracks. Starting with a given group, all other unused groups with similar helix parameters to that of the first group are compared. The groups making the best helix are joined together into track segments. A single helix is then fit to the entire track segment, and any hits falling too far outside these helix parameters are removed from the track (Mitchell and Sakrejda, 1994).

These track segments are then extended. Starting with the longest track segment, all hits which fall within the helix parameters are added to this long segment. Smaller segments can be destroyed in this process. After the track segments have been extended, most of the tracks are complete. Tracks of particles with low transverse momenta (below 300 MeV /c) often do not get completed in this process.

Particles with low transverse momenta (pt) lose energy more quickly than particles with a higher pt. Energy losses due to interactions of these particles with the gas causes their helix parameters to change as they proceed through the TPC. The normal tracking algorithm breaks these tracks into two or three pieces interpreting each piece as a separate track. Since this track fragmentation is an error, the last step of the algorithm was changed to merge these broken tracks together, by joining low pt tracks with similar helix parameters.

Materials and Methods

Because the detector is not yet built, a simulation software package called GEANT is being used to provide test data to be used by tracking software (GEABT, 1994). GEANT is a Monte Carlo Program which provides data for simulating events expected to occur within the TPC. Pixel data made identical to data which will be produced by the TPC is constructed from the GEANT simulation. This pixel data is analyzed using a software package called the Physical Analysis Workstation (Paw, 1994), and the software which tracks each helix was written at the Lawrence Berkeley Laboratory (Mitchell and Sakrejda, 1994) for use with the TPC Analysis Shell.

GEANT provides all the information about each simulated particle, which then is used to test whether the tracking software correctly reconstructs each particle's type, speed and momentum. Thus, the efficiency of the tracking software is measured using known input data (Jones, 1994). Improvements in the tracking algorithm can be obtained by looking at the tracking efficiency of the software and by using event displays.

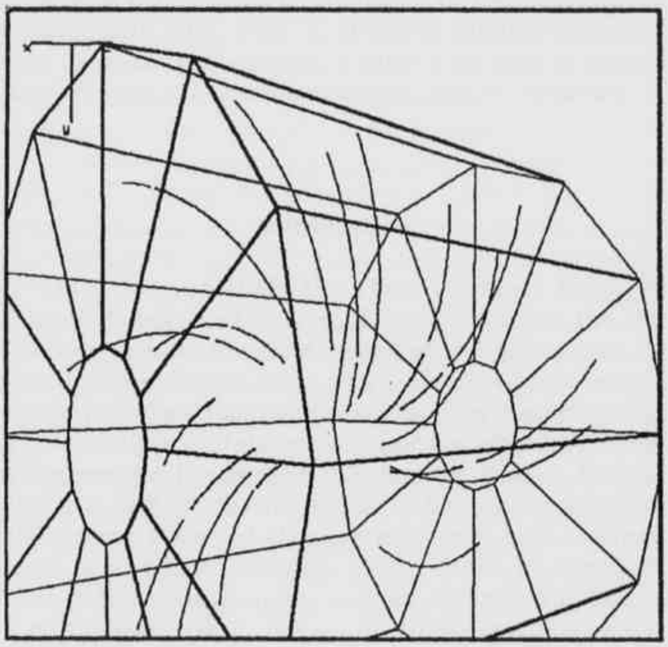

Fig. 3. Broken tracks from a simulated event containing only negative pinons. The information from this display was used to optimize tracking software so that broken tracks occurred less often.

Results and Discussion

Given the difficulty of associating low pt particles with fixed helix parameters, tracking efficiency drops at these lower pt values. Since particles of pt less than 125 MeV/c do not often make it into the TPC, efficiency drops dramatically at this low pt. Tracking efficiency is defined as the number of generated tracks in which all hits end up on one track divided by the total number of tracks. Partially or completely unrecorded tracks, broken tracks, and tracks with hits on two or more reconstructed tracks lowers tracking efficiency.

From the event displays, problems were found with the tracking code which lowered the tracking efficiency (see Fig. 3). Problems were solved by changing the algorithm which compared the helix parameters of the broken tracks.

An 8% improvement in efficiency was made for tracking low transverse momentum particles, i.e., particles having a transverse momentum around 150 MeV/c (see Fig. 4). This increase in tracking efficiency greatly improves the probability the TPC will successfully measure the trajectories of particles with a low transverse momentum.

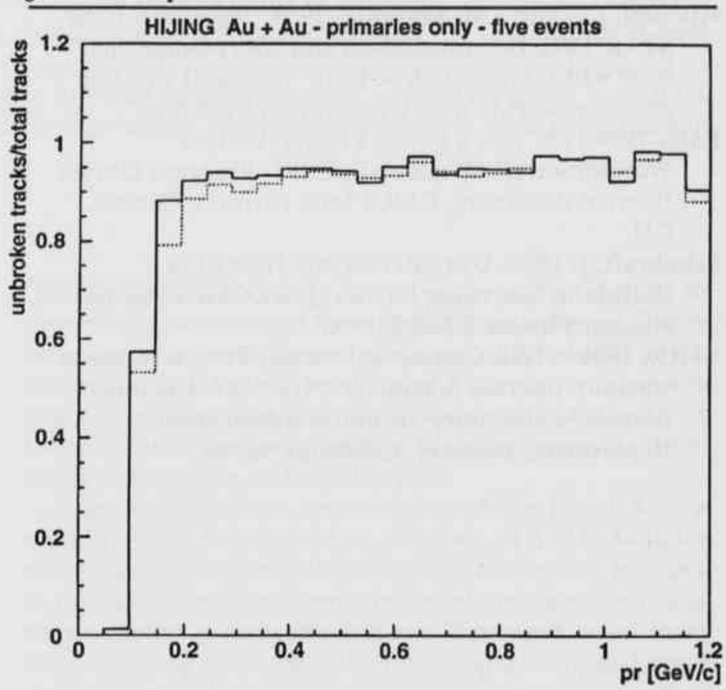

Fig. 4. The efficiency of tracking software as a function of transverse momentum. The dashed lines represent the efficiency before the software was optimized, and the solid lines represent efficiency after it was optimized.

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Literature Cited

GEANT. 1994. GEANT user's guide: Detector Description and Simulation Tool, CERN Program Library Internal document, CERN Data Division, Geneva, CH.

Jones, P.G. 1994. STAR TPC Tracking Capability in High Multiplicity Events. Star Note # 163. Available free from "ftp:rsgi01.rhic.bnl.gov/star/starlib/doc/www/sno/sn0163.html".

Mitchell, J.T. and I.M. Sakrejda. 1994. Tracking for the STAR TPC: Documentation and Users Guide. Star Note #190. Available free from "ftp:rsgi01.rhic.bnl.gov/star/starlib/doc/www/sno/sn0190.html".

PAW. 1994 PAW user's guide: Physics Analysis Workstation (PAW manual), CERN Program Library Internal document, CERN Data Division, Geneva, CH.

Schukraft, J. 1993. Ultra-Relativistic Heavy-Ion Collisions: Searching for the Quark-Gluon Plasma. Nuclear Physics A 553:31c-44c.

STAR. 1992. STAR Conceptual Design Review (original version). Internal document. PUB-5347. Lawrence Berkeley Laboratory Technical Information Department, Berkeley, California 94720.