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LARGE SOLID ANGLE TRACKING OF MONTE CARLO EVENTS OF HEAVY ION COLLISIONS IN TPC MAGNETIC SPECTROMETERS*

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INTRODUCTION

The BNL/CCNY collaboration has for some time had as its goal the development and use of ≈ 4π solid angle magnetic spectrometer tracking of charged particles produced in heavy ion collision experiments at AGS,[1] and eventually RHIC.[2] This program has led to the approved AGS Experiment 810 which includes collaborators from LBL† and Johns Hopkins.†† We are also participating in the NA36 experiment at CERN.

In Phase I of AGS experiment 810 (Fig. 1a) the collision of 15 GeV/nucleon sulfur and carbon or oxygen ions with various fixed targets such as carbon, sulfur and gold will be observed in the MPS magnetic spectrometer with a TPC chamber module based on the one being developed for the CERN NA36 experiment. However, modifications will be incorporated as needed to make it suitable for the AGS 810 environment. In the major arrangement of Phase I of AGS 810, this TPC will be placed just downstream of the target and be able to track ~ 50% of all charged particles. Figure 2 shows the Monte Carlo acceptance of this arrangement vs. rapidity for reconstructed tracks. The fall-off of efficiency

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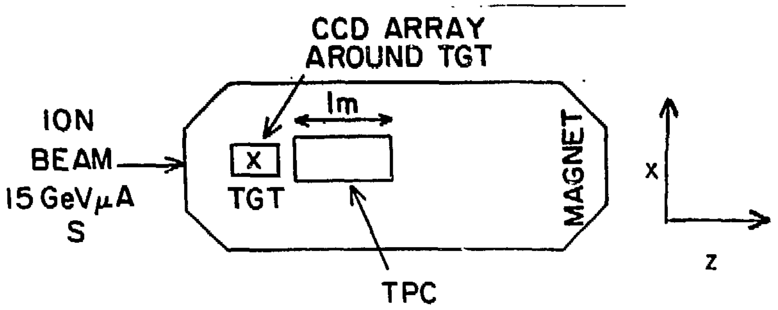

Figure 1a: Phase I of AGS 810. The cross section of the TPC module will be at least 50 cm x 50 cm but these dimensions may be increased by a factor ~ 1.5. The Monte Carlo calculations in the remainder of this paper assume the minimum cross section stated.

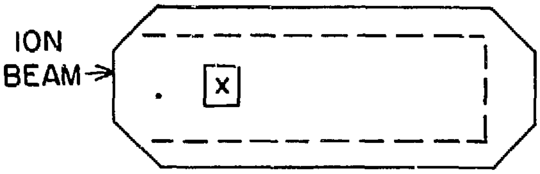

Figure 1b: Phase II of AGS 810. The dashed lines show the approximate cross section of the TPC in the magnetic bending plane. The drift space along the magnetic field will be increased to approximately 1 meter.

of track reconstruction at low rapidities is due to tracks leaving the TPC chamber module. In Phase II this is expected to occur only a small percentage of the time.* In Phase II of this program we intend to fill the MPS with TPC modules and thus have an ≈ 4π detector.

The design and construction of the NA36 TPC chamber is proceeding in CERN under the primary responsibility of the LBL group and will be described by Chuck Gruhn in his paper at this conference.[3] The BNL/CCNY group is primarily responsible for designing and constructing the TPC readout system and the data acquisition systems for NA36. The TPC readout system for NA36 is that developed for AGS 810, and is based on MPS II-style electronics.

A data acquisition system which can be used in NA36 and AGS 810 experiments is described in a paper by Eiseman et al.[4] The FASTBUS-based system will be capable of recording $\gtrsim$ 50 events per second from a variety of detectors including a TPC. Phase I of AGS experiment 810 is characterized by events that typically involve tracking of ≈ 100 or more charged particles.

Prototypes of the TPC readout system have been successfully tested and production devices are scheduled to be delivered soon.

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* Very slow short tracks will in general not be reconstructable.

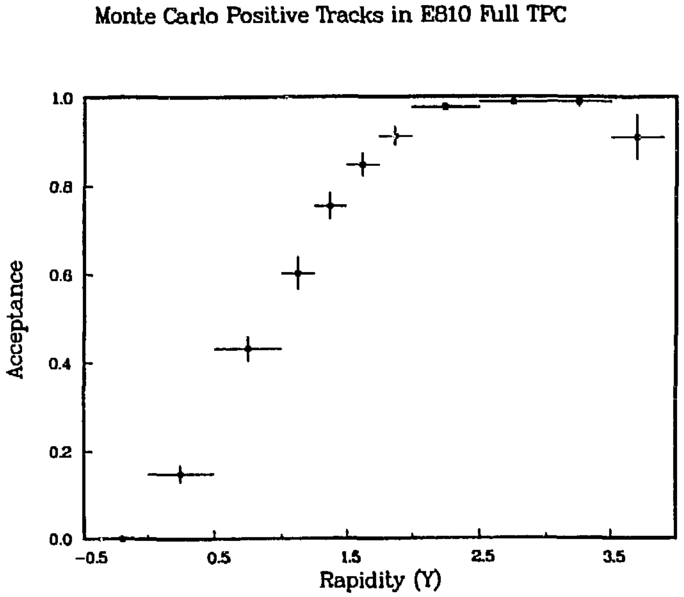

Figure 2a: Acceptance vs. rapidity for positive tracks in Phase I arrangement

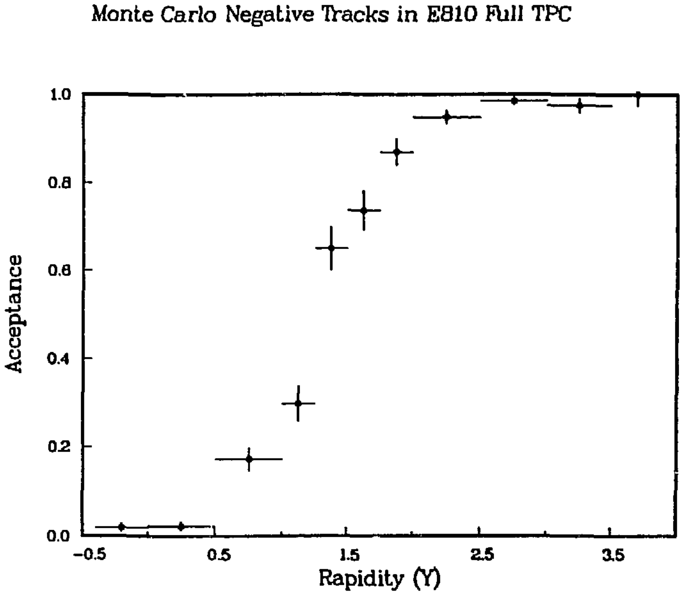

Figure 2b: Acceptance vs. rapidity for negative tracks in Phase I arrangement

PATTERN RECOGNITION OF TRACKS

We have also for AGS 810 developed a TPC track reconstruction program. The program was written by Tom Morris and is based in part on algorithms developed by Michael Mermikides for the ALEPH TPC. Bill Love and Ron Longacre generated the Monte Carlo events using HIJET. They were tracked through the apparatus by using GEANT-3. The track reconstruction program consists of three parts: a local pattern recognition which associates contiguous readouts on adjacent readout wires to form a single hit; a subroutine which positions the hits into slices in the yz-view (the vertical plane containing the beam and the vertical magnetic field) and the track reconstruction section.

The readout system consists of rows of wires parallel to the beam 1 cm long and separated by 1.27 mm. There are 40 such rows along the beam. The wires are assumed sensitive only in the middle 7 mm. The simulation apportioned the track length to the wires lying over the track as it passed through the 7 mm sensitive width. The track segment subtended by each wire then generated an amount of charge randomly distributed according to the Landau formula for that length. The charge under each wire was diffused in the y-direction with an rms half width of 4 mm for 1 meter of drift. Sinusoidal pickup noise corresponding to half the threshold signal was added. Five percent of the readout wires were considered dead and randomly distributed. Random hits equal to 20% of the track hits were distributed according to a 1/R algorithm where R is distance from the track, in order to attempt to simulate experimental operating conditions.

Figure 3 shows the tracks in the TPC from a HIJET generated central collision 15 GeV/nucleon sulphur ion incident on a gold target, when projected on a horizontal plane containing the beam and being perpendicular to the magnetic field.

The more than 100 tracks clearly leads to great confusion in any projective geometry pattern recognition approach and is clearly not practical.

However the three dimensional point detection feature of the TPC leads to a quite simplified pattern recognition problem. As shown in Figs. 3b and 3c (the xz view), when the TPC is partitioned into slices in the yz projection whose vertices are at the target, the pattern recognition appears quite

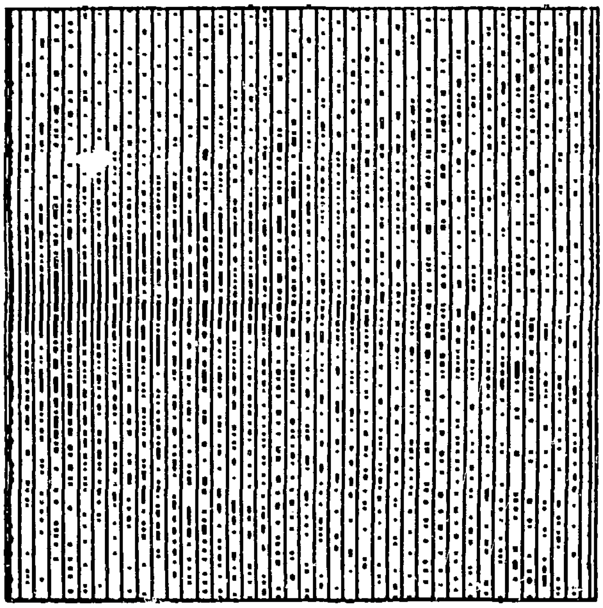

Figure 3a: HIJET 15 GeV × A sulphur on Au target central collisions projected on a horizontal plane containing the beam.

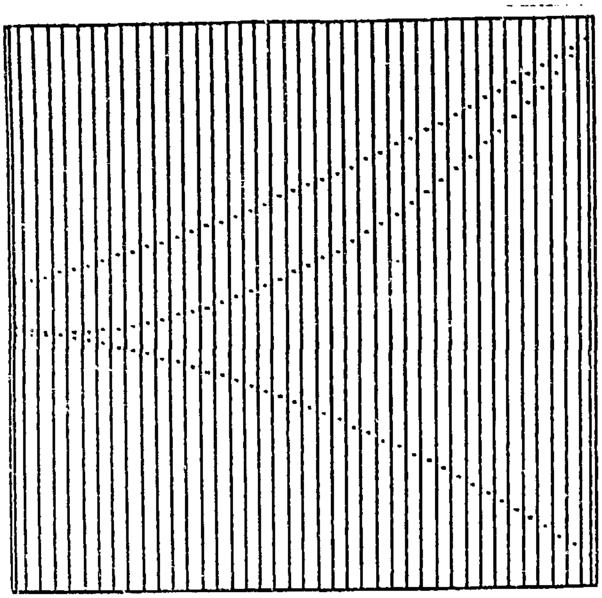

Figure 3b: Tracks in slice in yz projection $0 < y_L < 2$

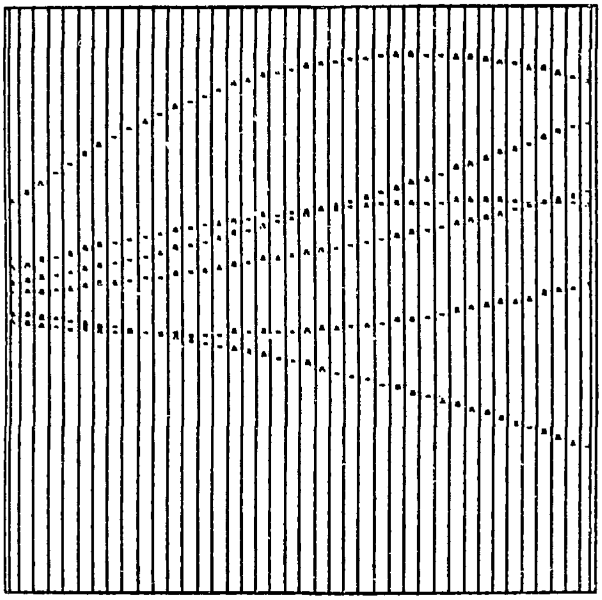

Figure 3c: Tracks in a slice in yz projection where $2 < y_L < 4$

manageable. The slices we are using are approximately 1 cm high near $y = 0$ (≈ the beam region) and approximately 5 cm high at the top and bottom. The hits in the readout pads are indexed by slice number in each wire row and the track recognition program normally searches hits only within a single slice thereby greatly speeding up the track finding.

The event generating program is interfaced to the CERN GEANT-3 simulation program which at present propagates HIJET-generated tracks through the apparatus and generates readouts at each TPC wire row. A front end for Monte Carlo data input has been written which simulates the effect of electron diffusion, charge multiplication and the response of the TPC readout electronics.

The track recognition starts at the downstream end of the TPC and works upstream. Only those hits within the working slice are searched; however if the track approaches a slice boundary, the hits in the adjacent slice are added to the search list. A track in the process of reconstruction is called a chain. There are forty rows of readout along the beam. When three hits on adjacent rows can be spacially associated in three dimensions, a chain is initialized.

The chain is developed upstream by local association from row to row in three dimensions. Absence of hits in two consecutive rows or two or more hit candidates in the same row terminates this stage of chain development.

In the next stage circle (linear) least square fits are performed in the x,z (y,z) views.

If the fits are successful, the fitted orbit is extended over missing wire rows and consistent hits are added to the chain. If the fitting fails there is provision for seeking out and discarding bad hits. The event shown in Fig. 3 had 206 charged tracks initially generated. Of these 113 charged tracks had $\gtrsim$ 10 hits in the TPC. 98 of the 113 were reconstructed. If we required $\geq$ 20 hits in the TPC, only 85 tracks of those generated met that requirement. 82 of these were reconstructed. 74 of these 82 had a percentage momentum error $\Delta p/p < 10\%$.

Preliminary results with Monte Carlo data simulating 15 GeV sulphur on gold events indicate that ≈ 93% of hits are assigned to tracks. Of these ≈ 96% are assigned correctly. Approximately 95% of tracks which span at least 20 wire rows (i.e. half the chamber length) are reconstructed. Of these ≈ 10% had reconstructed momentum that differed from the generated numbers by more than 10%. The reconstruction time on a VAX 8600 as a function of the number of tracks is shown in Fig. 4. Thus the reconstruction time appears to be approximately linear with track numbers.

The acceptance of the reconstructed tracks versus rapidity is shown in Figs. 2a and 2b. The fall-off of the efficiency of track reconstruction at low rapidities is due to tracks leaving the chamber module. In Phase II this is expected to occur a small percentage of the time.

In AGS 810 in addition to hardware triggers for central collisions we will have a CCD array around the target in which further software selection of desired events can be made rapidly, and multiplicities and angular distributions of the tracks emitted can be determined.

The Physics objectives in AGS 810 and later at RHIC are to look on an event-by-event basis for unusual events not expected from known processes. These events could be characterized by:

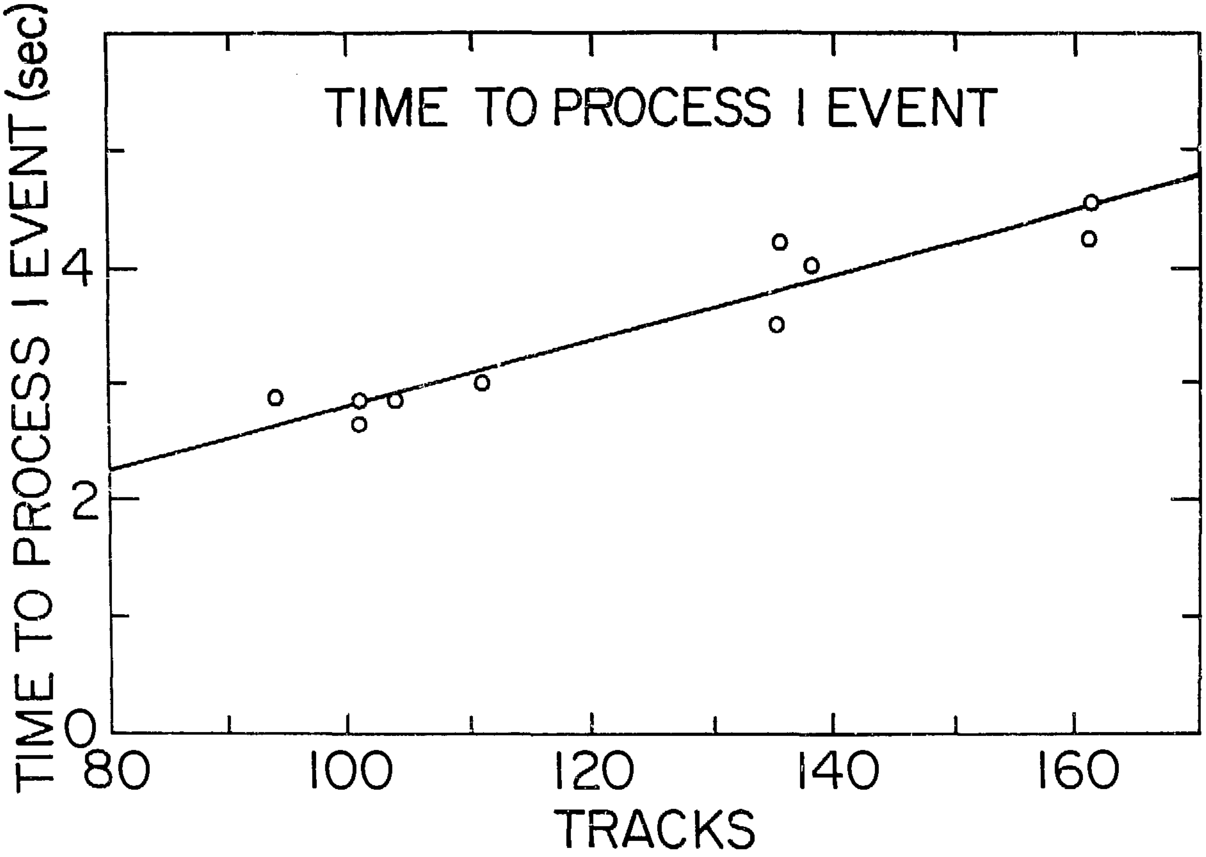

Figure 4:
Global pattern recognition time as a function of the number of tracks. To obtain the total processing time per event one should multiply the above times by ≈ 1.5 to allow for unpacking and local pattern recognition times.

1. Excessive local fluctuations (up or down) in pseudorapidity density (i.e., psuedorapidity bumps). In the case of negative particles which are momentum analyzed we can assume they are pions and look for rapidity bumps.

2. Excessive fluctuations in multiplicity.

3. Excessive local or global enhancement of strangeness.

4. Anomalous behavior in $P_\perp$ ($E_\perp$), or energy flow patterns.

5. Hanbury-Brown and Twiss effects.

6. Evidence for deflagrations (or detonations).

7. Special effects that correspond to the increase in entropy that may occur in the baryon dense region.

8. Something else which catches our eye.

9. Most important - the correlations between these -- For example we might find that pseudorapidity (or rapidity) bumps or dips or other anomalous behavior are associated with one or more of the above and may have similar pseudorapidity (or rapidity).

In summary the above illustrations are to be taken only as a guide. The important point is that we are planning to see a great deal of the characteristics of each event and their correlations on an event-by-event basis and therefore we shall see what if anything is anomalous, in a most favorable signal-to-background environment. We believe this approach is also important for RHIC.

This track recognition program has been translated into the tentative NA36 arrangement in the 3 Tesla EHS magnet. An approximate simulation of the magnet was used but E × B effects were neglected since their correction is a separate matter.

In the case of AGS 810, Phase I, the E × B effects are small enough so that neglecting them does not significantly affect the results.

Figure 5a shows a HIJET generated central collision event in the TPC module by a 200 GeV × A oxygen on Au event projected on the magnetic bending plane containing the beam. Figure 5b shows how this event looks in a slice near the beam. When we require $\geq$ 20 hits in the TPC, 77 of the originally generated 279 charged tracks remain. Of these 76 were reconstructed. When we require $\Delta p/p < 10\%$ for all tracks, 67 were reconstructed.

Figure 6 shows a 5 cm slice of a HIJET 100 GeV × A Gold + 100 GeV × A Gold colliding beam central collision in the SREL 5-meter-diameter magnet discussed in the RHIC Workshop (BNL, April 1985).[2] This event has ≈ 4,000 tracks. We had argued at that workshop and in various committees etc. that one could handle any number of tracks if the track hits/pixel were small enough. Secondly that the computer time would be approximately linear with track number if one used a reasonable approach to the problem.

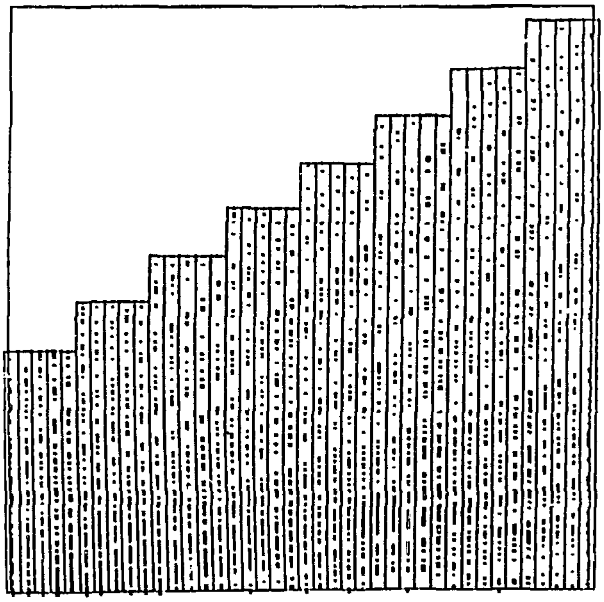

Figure 5a: A HIJET 200 GeV × A Oxygen ion on Au event in the tentative NA36 arrangement projected on the plane containing the beam and the magnetic field.

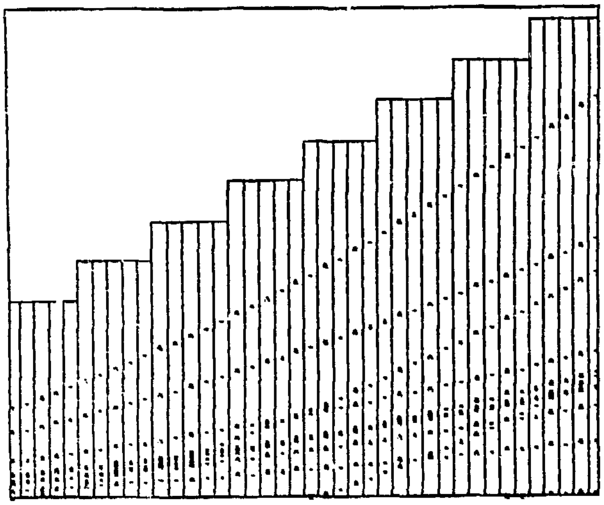

Figure 5b: A slice with 2 < y 4 in this event

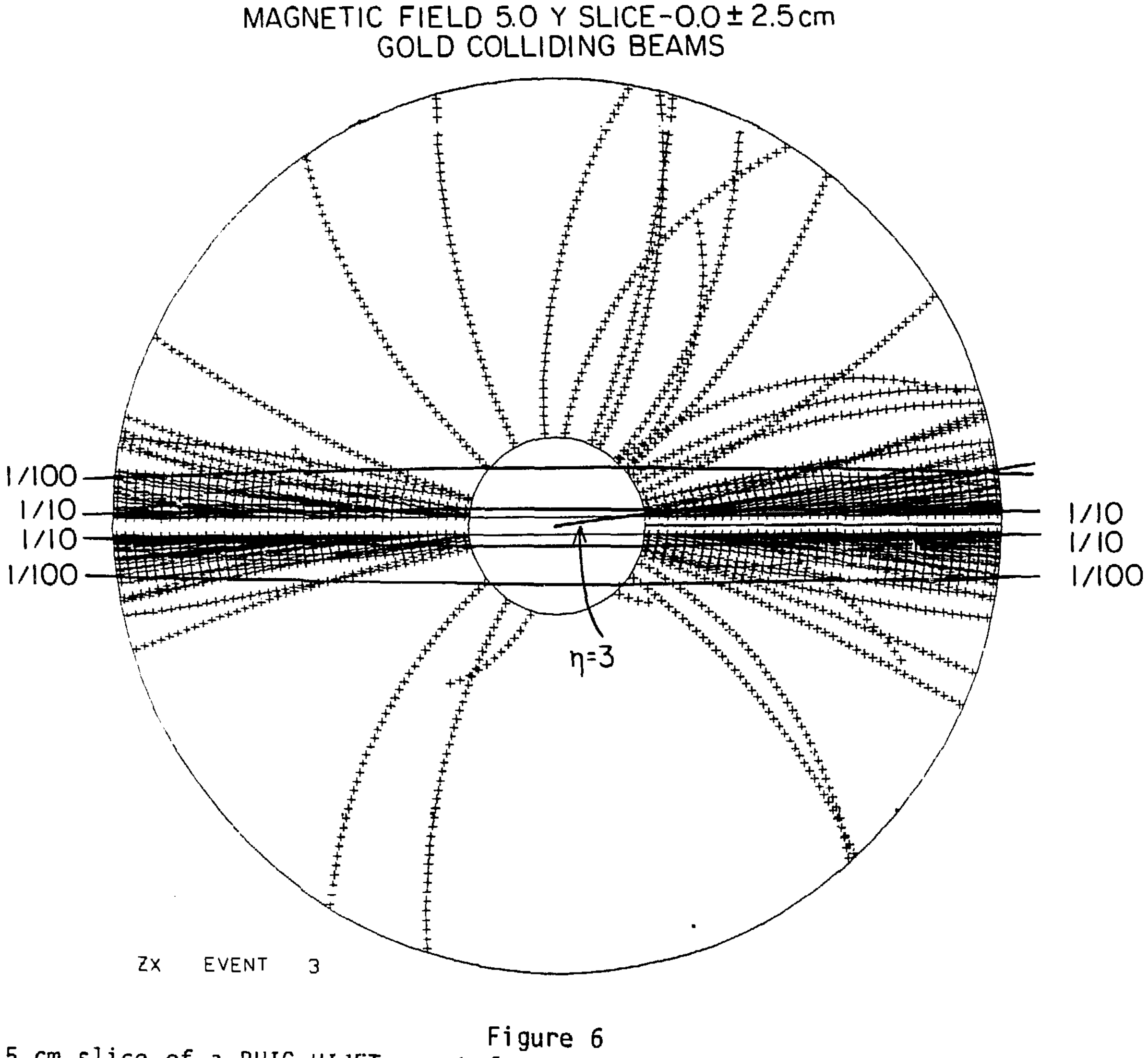

Figure 6
A 5 cm slice of a RHIC HIJET event for 100 GeV × A Au on 100 GeV × A Gold. The 1/10 and 1/100 lines refer to track hits/pixel ratio.

As you can see indicated in the diagram we had stated conservatively that if hits/pixel were $\leq$ 1/100 the problem of track recognition would be relatively easy. This corresponds to a distance of ≈ 30 cm from the beam.* We felt that even if hits per pixel approached ≈ 1/10 at the upstream end one could probably still do track recognition if one started from the downstream end with hits/pixel $\lesssim$ 1/100. In the AGS 810 Monte Carlo simulations discussed we find that the pixel size is ≈ 10 mm^2. This is approximately an order of magnitude less than other TPC's and is made possible by the compact AGS 810 readout electronics.

The track hits/pixel ratios vary from ≈ 1/250 at the downstream end to ≈ 1/3.5 at the upstream end. The efficiency for putting upstream hits on a track when hits/pixel ≈ 1/10 was found to be ≈ 99%. When hits/pixel ≈ 1/3.5 the efficiency for putting upstream hits on track drops to ≈ 63%.

Therefore Gold on Gold events can also be tracked if one merely increases the 25 cm distance of the upstream end of the chamber by a factor $\approx \sqrt{\text{multiplicity of Gold on Gold/multiplicity of sulphur on gold}} \approx 2.5$. In regard to the RHIC 100 GeV × A Au on Au events, preliminary investigations show that this program will perform track recognition satisfactorily on these types of events.

It should be noted that the readout geometry selected does introduce biases for tracks in certain directions. For example in the parallel row readout perpendicular to the beam chosen for AGS 810, tracks more or less perpendicular to the beam would be difficult to reconstruct. In the RHIC case, circular or elliplical row readouts were primarily envisioned. Here again tracks more or less parallel to the readout system would be difficult to reconstruct.

Combinations of directional arrays of readout geometries can of course be employed to solve these problems. The same electronics can be arranged in different readout configurations depending upon needs.

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* For higher event multiplicities (n), the distance from the beam (r) required to maintain the same hits/pixel ratio which corresponds to a distance r_0 and multiplicity n_0, scales approximately as $r_n \approx r_0 \sqrt{n/n_0}$ due to the approximate inverse square law reduction of track densities with distance.

CONCLUSIONS

HIJET + GEANT3 Monte Carlo simulations lead to the following conclusions:

1. High efficiency tracking of very high multiplicity events in a TPC (or other three-dimensional particle detectors) with good monentum resolution for tracks generated in heavy ion collisions is clearly feasible provided track hits/pixel ≈ 1/10 to 1/100.
2. If hits/pixel ≈ 1/100 the problem is relatively straightforward, even at RHIC.
3. The computer time for track reconstruction is ≈ proportional to the number of tracks.

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