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A 4π TRACKING TPC MAGNETIC SPECTROMETER FOR RHIC*

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PHYSICS OBJECTIVES

The primary physics objective of the 4π TPC magnetic spectrometer proposal[1-3] is to search for the Quark-Gluon Plasma. In previous workshops we have discussed what the possible hadronic signatures of such a state of matter would be. Succinctly, the QGP is a direct prediction of non-perturbative QCD. Therefore the question of the existence of this new state of matter bears directly on the validity of non-perturbative QCD. However, since non-perturbative QCD has never been established, it is apparent that what may await us is a host of new phenomena that will go beyond the standard model.

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In order to maximize the probability of observing new phenomena, the apparatus is designed to cover nearly 4π solid angle and to track and measure the momentum of individual particles produced in the collision. In addition the spectrometer will incorporate particle identification by measuring dE/dx and time-of-flight for the tracked particles. These capabilities should enable us to recognize the hadronic signals associated with the formation of a QGP, and to very likely establish its properties if it is produced at a sufficient rate.

The following list of what we hope to measure summarizes our physics objectives.

1. We will track and measure the momentum over nearly 4π of the charged particles emanating from $A+A$ and $A+A'$ collisions where A, A' range from protons to Gold.
2. We will identify charged particles by time-of-flight and dE/dx in a TPC Magnetic Spectrometer. We will be able to separate π/K/p up to ≈ 2.7 GeV/c and $(\pi+K)/p$ or $\bar{p}$ up to 4.5 GeV around the central region ($|\Delta Y| \approx 2$ for $p, \bar{p}$, $|\Delta Y| \approx 2.5$ for K^+, K^- and $|\Delta y| \approx 3$ for $\pi^+\pi^-$.
3. If strange and antistrange quark production is enhanced at higher momenta, we will be able to identify fast Λ, $\bar{\Lambda}$, and K^0's in each event. Future vertex detectors could allow the identification of slower $\Lambda\bar{\Lambda}, K^0$ and possibly other long lived particles.
4. The proposed techniques will allow the search for correlations of various signals from any unusual events to indicate the properties of the mechanisms involved. It is important to note that the enormous amount of information we obtain from each event will act as powerful constraints on its interpretation. In parallel we will generate predictions of what to expect from conventional effects by extensive simulations with cascade and other conventional models.

This program of physics goals can be most efficiently met by the type of spectrometer being proposed here.

WORKSHOP OBJECTIVES AND ACTIVITIES

The collaboration plans to submit a Letter of Intent this fall for a first round RHIC experimental program. Therefore the group's activities during this workshop were concentrated on expanding and improving the existing proposal.

A 4π tracking TPC magnetic spectrometer for RHIC was proposed by various members of this collaboration in all three prior RHIC workshops.[1–3] Figure 1 shows the configuration primarily considered in the prior two workshops with the addition of the time-of-flight walls described later. It consists of a central TPC, 5 meters along the beam by 5 meters wide by 2.8 meters high located inside a 5KG window frame dipole magnet. A 40 cm high by 40 cm wide region* around the beam was omitted from the TPC since track densities in some cases were considered too high to be handled at smaller distances. This central TPC will have dE/dx capability. The two end TPC's shown will track but not measure dE/dx since it is not considered useful for the generally higher momentum tracks entering there.

* This 40 cm region may be extended in the vertical direction into a slab over the beam interaction region at the height of the TPC for various practical purposes.

A dipole magnet was selected as the most practical and economical way of covering a large solid angle while maintaining good momentum resolution for forward and backward going particles.

The AGS BNL, CCNY and RICE E-810 experimental program at the AGS has provided valuable experience in TPC construction, operation, pattern recognition and data analysis. In many respects AGS E-810 serves as a valuable prototype program for this RHIC proposal. In addition, BNL/CCNY/LBL/Rice have engaged in a RHIC TPC R&D program. A Notre Dame group joined the collaboration so that the collaboration now consists of the BNL/CCNY/Notre Dame/Rice personnel listed on the first page.

THE MAIN TOPICS CONSIDERED IN THIS WORKSHOP

1. Time-of-flight walls to extend the particle identification range and there-by enhance the rapidity coverage of the TPC system.
2. Consideration of various dipole configurations to best accommodate experimental arrangements and time-of-flight.
3. Methods of incorporating the dipole in the RHIC accelerator ring with the generous assistance of S.Y. Lee.
4. Monte Carlo simulations to evaluate detector performance and optimize its design.
5. Consideration of which experimental halls can be used to house this detector system and some practical considerations in regard to its assembly and maintenance.
6. Finally, we considered what questions remain to be worked on.

TIME-OF-FLIGHT SYSTEM FOR PARTICLE IDENTIFICATION

It was felt that $\sigma \approx 75$ picoseconds time resolution although somewhat optimistic at present should be realizable for RHIC. This opinion was presented by others at the workshop.[4]

Figure 2 shows β vs. momentum in GeV/c for π, K, and p for a length of 9M and $\sigma = 75ps$. Each particle curve is accompanied by $\pm 3\sigma$ bands. It is then assumed that when these bands overlap for two particles they are no longer effectively identifiable.

With this criterion we find π, K and p are individually separable up to about 2.7 GeV/c. Protons and anti-protons are separable from the other two particles up to about 4.5 GeV/c. When combined with our dE/dx particle identification in the central TPC we cover rapidity ranges of $\Delta Y \approx \pm 3$ for pions, $\Delta y \approx \pm 2.5$ for kaons and $\Delta y \approx \pm 2$ for protons and antiprotons. Only pseudorapidities can be determined for particles with larger rapidities. The particle separations quoted above can be achieved with a time resolution of $\sigma = 105$ps if the requirement is relaxed to 2σ (95% C.L.). The final choice of design will probably be driven by cost rather than ultimate time resolution technically feasible.

CONSIDERATION OF VARIOUS DIPOLE CONFIGURATIONS

Figures 3a and 3b show the configuration of the time-of-flight walls with the additional open dipole magnet options considered. The configurations considered attempt to optimize their general usefulness and extend particle ID and thus rapidity coverage for individual particles. At the same time the TOF system should contain $\approx 20,000$ channels to keep the occupancy at $\lesssim 10\%$ and also contain costs. The time-of-flight walls will be placed around the beam in sections. These new magnet options will be further investigated. Their advantage is that openness is preserved for future use. Their disadvantage is that the better uniformity and probably lower cost of a window frame dipole will be compromised.

In any event the magnet should be built in a symmetrical manner so that RHIC accelerator correcting magnets can be designed simply. In this regard the dipole may be the simplest for the RHIC designers. It should be noted that the time-of-flight walls are positioned to measure the particles going out the forward and back ends of the dipoles. Our Monte Carlo simulations indicate that this is where they will be most necessary to extend the rapidity range coverage. However we can of course in principle redeploy some of them in the open arrangements in the wide angle region if for any reason we decide to identify faster charged particles in these regions.

MATCHING THE DIPOLE TO RHIC

S.Y. Lee has designed a system for matching our 2.5 Tesla meter dipole magnet into RHIC. This system and some of its characteristics are shown in Fig. 4. S.Y. Lee is of the opinion that this procedure is feasible and forsees no problems.

MONTE CARLO SIMULATIONS

For our Monte Carlo simulations we have developed two new event generators. The first is a cascade generator called RHIC EVENT. We use the HIJET approach with the following important modifications:

1. We included all relevant conservation laws, and conserved quantum numbers (energy, momentum, charge, baryon number, and strangeness).
2. In order to attain the generally expected flat central plateau and proton fragmentation peaks the stopping power was reduced phenomenologically by allowing each colliding nucleon to fragment each time it hits by losing ≈ 3 units of rapidity (the width of the fragmentation region) which then goes into fragmentation. The remainder proceeds as a particle for additional collisions. This led to flat central plateaus and proton fragmentation peaks.

Thus we simulate what is generally expected at RHIC. When we get RHIC data this approach will be modified as indicated. At RHIC energies the effects of secondary interactions is being worked on in a program called HADGAS.

We have also developed a program called RHIC PLASMA EVENT. We considered the case of 100 GeV per nucleon gold on 100 GeV per nucleon gold. We tag a region of impact parameter $\pm$ 1.25 fermis and allow the nucleons in this tagged region to produce a QGP bubble of the Van Hove type, around $y = 0$ in the cms, and allow it to break up according to the model described below. This program models as plasma bubble breakup according to the work of P. Koch, M. Mueller and J. Rafaelski.[5] The particle production probabilities depend on the critical temperature and the gluon fragmentation function. Simple combinatoric weights are used to produce particles according to these probabilities with a momentum distribution of that of the critical temperature (chosen as $\approx$ 170 MeV). About 6% of the available energy was thus allowed to go into plasma. This is a reasonably conservative guess. However the changes in RHIC EVENT behavior the plasma bubble introduces can of course be scaled up or down according to the percentage of plasma selected. The results of RHIC EVENT (cascade without plasma) and RHIC PLASMA EVENTS (RHIC EVENT + 6% plasma) are shown for π^- or π^+ in Figs. 5a and 5b.

Figure 5b shows dN/dy for an average over 10 RHIC EVENTS to show the nature of the cascade plateau with good statistics. Figure 5a shows a single RHIC PLASMA EVENT with actual counts on the left scale and dN/dy on the right scale.

Our TPC system with the time-of-flight wall would allow a rapidity range of $\Delta y \approx \pm 3$ for pions to be detected and thus this phenomena would be clearly observed. Figure 6a shows one RHIC PLASMA EVENT for K^+ or K^-. Figure 6b shows an average of ten RHIC EVENTS (cascade), revealing an even more striking rapidity peak for the plasma over the cascade. Our TPC system with the time-of-flight wall would allow a rapidity range of $\Delta y \approx \pm$ 2.5 for kaons to be detected.

Figure 7a shows one RHIC PLASMA EVENT for $\bar{p}$. Figure 7b shows an average of ten RHIC EVENTS (cascade) for $\bar{p}$, again revealing a striking rapidity peak for the plasma over the cascade. For $\bar{p}$ and p we can detect the rapidity range $\Delta y \approx \pm 2$. Figure 8a shows one RHIC PLASMA EVENT for p. Figure 8b shows an average of ten RHIC EVENTS (cascade) for p. The upper event clearly shows a central peak accompanied by two fragmentation peaks. Although we could detect the central peak with $\Delta y \approx \pm 2$ we would not see the fragmentation peaks.

Of course moving multi-bubbles would spread these peaks but the total number of extra particles would tend to remain about the same. There could be fluctuations in which considerably more or considerably less plasma is created. However, one should note that assuming that signals of this nature survive in a sufficient number of events we expect it would be very difficult to explain them without a Quark-Gluon Plasma.

The ability of our apparatus to see a great deal of detail is an advantage in a new field, since no one can be sure what will occur when the experiments are performed. If there are fast enough $\Lambda, \bar{\Lambda}$ or K^0's we should be able to observe them. However one of our planned future projects, a close in vertex detector should if it materializes allow the detection of slow $\Lambda, \bar{\Lambda}$ and K^0's. It also possible in that case that we may see $\Xi^- \to \Lambda\pi^-$ and $\Omega^- \to \Lambda K^-$. Our proposed apparatus has great potential for observing the unexpected which may well in the end be its greatest virtue.

Simulation of RHIC 100 GeV Per Nucleon Au on Au

During the workshop we addressed the question of helical tracks which spiral in the 5 KG magnet for momenta of $p \leq 0.25 GeV/c$. The result is shown for 10% of the tracks in Fig. 9. Since the TPC essentially sees in 3D, we found the helical spiraling did not cause a problem. In fact with the 500,000 channels of readout we plan we estimated that only $\approx$ 1% of the available pixels were occupied.

Before discussing other prior simulations a description of the TPC's is in order.

THE TPC'S

The magnet is filled with TPC modules at atmospheric pressure, occupying the entire volume except for a region 80 cm wide by 80 (or more) cm high centered around the beam pipe.* This TPC (TPC1) is read out by a conventional anode wire and cathode pad system like that used for the original PEP-4 TPC. In this case, however, the readout is located over the two pole faces of the dipole. A full meter of track is measured for polar angles

* A vertex detector of suitable resolution is anticipated to be placed within this region.

greater than 15° from the beam axis. The pseudorapidity interval covered is $-2 < \eta < 2$. For most of the volume at least 100 energy loss samples will be made for each track. For tracks at small angles to the field lines momentum is not well measured.

Two other TPC's (TPC2) are located outside the magnet at each end to measure the small angle tracks. They cover the angular range from about 4° to the beam out to 24° (pseudorapidity from 1.5 to 3.5 and -1.5 to -3.5). These detectors use the short anode wire readout scheme developed for AGS Experiment 810, which gives better two-track separation but yields no usable dE/dx information. Anode wire spacing of 2.5 mm is used arranged in rows 5 cm apart. The angle and position measurements in TPC2 will enable the reconstruction of the track, measurement of momentum and assignment to the primary vertex of these tracks.

TPC READOUT ELECTRONICS

TPC1 has a $50m^2$ readout area (read out top and bottom for speed) covered with closely spaced anode wires and cathode pads underneath arranged in rows locally roughly perpendicular to the average track direction with 0.5 cm pads on 0.5 cm centers.* TPC1 requires about a half million channels of readout electronics each capable of recording multiple sets of measurements of time and pulse height (up to 16 segments of 8 amplitude samples each). The device should separate hits in the time dimension which are 0.2 cm apart so the bin size should correspond to 1 mm. This requires 10 or 11 bits of time resolution. The result is to divide the volume of the TPC into about a billion cells and to present each track with the equivalent of 150 detector planes each with pixels $0.2cm \times 1.5cm$ (assuming 3 pads corresponds to the pixel length).

The track density $d\sigma/d\Omega$ is estimated to be ≈ 400 in the central region at RHIC even for the 6% plasma events. As shown in Fig. 10 we have successfully handled track density twice this at 40 cm from the target in AGS E-810 where the pixel size is approximately the same. For an approximately constant dN/dy the hits per pixel are approximately constant at a constant distance from the RHIC beam pipe. Therefore we believe we can handle the rates at 40 cm from the RHIC beam.

We have estimated that in the very unlikely event that all the available energy in a 100 GeV Au and Au collision goes into plasma, track densities $\approx$ a factor of six higher than we have considered could occur. Thus we could in these events separate tracks at distances ~ 1 meter and still have sufficient path length to do dE/dx. A similar statement applies to other possible high density fluctuations.

In order to implement such a large fast sampling analog and time measuring system, work is under way to develop large scale integration elec tronics utilizing the concept of the segmentable analog memory. At the 1987 RHIC Workshop the basic design of a chip set was acheived.[2] It was based on a low noise, low power amplifier shaper chip and a segmented analog memory chip each having 8 channels per IC (Fig. 11). The amplifier design is straight-forward and should not require high priority for prototyping. The analog memory was based on an adaptation of an LBL development by Nygren and Kleinfelder. Design changes were made to implement the segmented memory function. This is important because desparisfying or compacting the data on the fly is mandatory

* The arrangement of the cathode pads can be customized as desired.

in a system of 5×10^5 channels. It is also important to reduce memory size to minimize power consumption and silicon cost. This design reached the point that prototype chips could have been produced. Subsequently the process used in this design has been replaced by a more advancéd process so a redesign is required. In order to verify the efficacy of this concept it is important to proceed with prototype production, test and evaluation. Most likely several iterations of the chip will be required for debugging and optimization.

A prototype chip run through MOSIS costs about $10,000. A conservatve estimate of the manpower and equipment to successfully develop such a chip is 5 or more man years and several hundred thousand dollars for computer and software systems, test facilities, interfaces etc. At the end of this effort, however, is the prospect of very low production costs estimated to lead to ≈ $10.00 per channel for the readout electronics.

The two modules of TPC2 each have $5m \times 1m$ area readout on top and bottom for a total of $20m^2$. Since no dE/dx measurement is contemplated in TPC2, 20 rows each with elements on 2.5 mm spacing should suffice (equivalent pixel figured at $2 \times 7.5mm$). This requires an additional 160,000 channels of electronics which needs to record only the drift time.

DATA ACQUISITION FROM THE TPC

Organizing and compressing time and amplitude sampling information from a half million pads raises some challenging issues. The raw uncompacted data from TPC1 produces $> 10^9$ bytes of information, $> 99\%$ of which are samples empty of relevant information. Therefore the first strategy is to record, even temporarily, as little of the empty samples as possible at the front end of the electronics chain. It is proposed at this level, to reduce the empty samples by a factor of 100-200 using the concept of the segmentable analog memory. This will leave analog data encompassing the time samples that have been triggered by an analog threshold detection.

The next level of compaction is to fit the analog samples in time yielding another factor of two or three. These two levels of compaction can be accomplished with electronics mounted on the TPC, reducing the event size to 2 - 5 MB for further processing. Higher levels of organization would be done remotely from the TPC. Electronic systems for these first two levels of compaction would be organized in 1000-2000 serial links to this external processing system.

TPC TRACK RECOGNITION

Track reconstruction efficiency for the proposed RHIC TPC was estimated by analyzing the plasma events using an existing TPC reconstruction program from AGS E-810. GEANT was used to convert the HIJET events into hits in the TPC padrows. Each hit was then converted into a simulated TPC readout taking into account Landau fluctuations, ion drift time and diffusion, and readout electronics characteristics. Background noise was added, and a randomly distributed. 5% of the readout channels were assumed dead. A readout signal was generated based on the expected amplifier characteristics. The resulting detection efficiency for individual hits was ≈ 90%.

The simulated readouts were then analysed by the track reconstruction program developed for AGS E-810. The E-810 TPC is rectangular with parallel readout pad rows. The proposed RHIC TPC1 will have segments whose padrows are oriented in different directions to optimize track reconstruction. In order to use the existing program to investigate the track recognition efficiency for a segmented TPC system, the proposed RHIC TPC was simulated with three different configurations.

90° Chamber:	100 cm by 140 cm by 200 cm TPC centered at $(X, Y, Z) = 90, 70, 0$ cm relative to the beam intersection point; readout plane normal to X (beam along Z).
0° Chamber:	100 by 140 by 200 at 90, 70, 150 cm; readout plane normal to Z.
30° Chamber:	similar to 0° chamber, but with readout planes rotated 30 degrees

Efficiencies were computed for correctly reconstructing tracks which spanned ten or more padrows. Overall efficencies achieved in the 0, 30, and 90 degree chambers were, respectively, 94%, 98%, and 95% for positive tracks; 97%, 81%, and 90% for negative tracks.

Using the configuration which gave the highest efficiency for a given pseudorapidity region, the efficiency for tracks with at least ten hits is greater than 95% in the pseudorapidity range $|\eta| < 2$.

MOMENTUM RESOLUTION

The momentum resolution in the TPC1 detector will be dominated by multiple scattering and can be estimated by comparing the momentum of the reconstructed track with the generated momentum. For this comparison only tracks that spanned 25 or more padrows were used. The fraction of tracks with $\Delta P/P < 5\%$ was 74%, 83%, and 85% for the 0, 30, and 90 degree chambers, respectively. The fraction with $\Delta P/P < 10\%$ was 87%, 95%, and 94%. The average momentum resolution was about 2%. It is anticipated that the cathode pad readout in TPC1 will give better momentum resolution than this present simulation predicts. The average angular resolution is about 10 mrad.

Due to the generally higher momentum of the tracks the momentum resolution of TPC2 will be dominated by measurement accuracy. An estimated position resolution of 1 mm leads to an angle resolution in TPC2 of about 3 mrad and a momentum resolution $\Delta p/p = .01P(GeV/c)$.

TPC ACCEPTANCE

The GEANT program tracked all charged particles (assuming their identity was known) through the detector shown in Fig. 12. Hits were recorded as the tracks passed over pad rows. If a particle decayed, no further hits were recorded. Figure 12 is a GEANT plot of the hits from a small fraction ($\approx 2\%$) of the tracks from one central event in the proposed TPC. Because of the larger number of tracks involved it is difficult to produce a presentable figure of a full RHIC event. The pattern recognition results are based on complete events, of course. The track was defined as "accepted" for momentum measurement if there were 10 separate hits recorded.The particle was "accepted" for particle identification if there were 80 cm or more of track samples recorded. The resultant acceptance is indicated in the following table.

CENTRAL EVENT ACCEPTANCES

$\|Y\|$ Range	Tracks	TPC1 > 10 hits	TPC1 Particle I.D.	TPC2 > 10 hits
0 to 1	445	95.0%	81.8%	3.9%
1 to 2	513	88.3	81.7	33.7
2 to 3	497	35.8	19.7	84.1
3 to 4	384	0	0	70.6
above 4	266	0	0	16.9
PLASMA EVENT ACCEPTANCES				
0 to 1	1284	88.6	74.1	4.3
1 to 2	556	86.4	80.1	29.4
2 to 3	433	35.9	20.6	85.9
3 to 4	335	0	0	72.0
above 4	279	0	0	16.1

TPC1 is quite efficient for $\mid Y \mid < 2$ and TPC2 complements the acceptance for larger Y where it is quite efficient. It should be noted that the above simulations assume particles are identified. In reality when we combine dE/dx and time-of-flight particle identification the rapidity ranges the TPC detector system can effectively cover are $\Delta y \approx \pm 3$ for pions, $\Delta y \approx \pm 2.5$ for kaons, and $\Delta y \approx \pm 2$ for $\bar{p}$ and p. At rapidities of larger magnitude only the pseudorapidities can be determined.

PARTICLE IDENTIFICATION

Particle identification is of particular importance for the aforementioned physics goals. In Fig. 13 is plotted the momentum spectrum for π's, K's and protons in the central rapidity region. As has been demonstrated by PEP4, the TPC is particularly effective in separating particles by ionization loss in the region between 100 and 700-1500 MeV/c depending on the particle species; see Fig. 14. It should be noted that clear π/μ separation is possible below 100 MeV/c. π/K/p separation is obtained between 100 MeV/c and 700 MeV/c, $p/(K^+ + \pi^+)$ to > 1000 MeV/c and deuterons to 1500 MeV/c. There are narrow bands of electron contamination (see Fig. 14). One should note that PEP-4 operates at a pressure of $\approx$ 5 atmospheres but we have a length of about 2.5 times greater so that the particle identification capabilities should be approximately comparable. Extending π/K/p separation to as low a momentum as possible imposes difficult requirements on electronics dynamic range. A dynamic range of 50:1 is required to distinguish K's from p's down to 100 MeV/c although π/K separation should work to 50 MeV/c. With a nominal 100 cm of sampled track (100 cm of gas) the sigma of truncated mean samples at minimum ionization is 5-6%. In order that the sampling granularity does not materially reduce this resolution, minimum ionization should be more than 5 times the least significant bit of the digitizer.

Thus to cover 50 times minimum, 8 bits of dynamic range is essential (10 bits would be more comfortable). The effort in progress mentioned in "readout electronics" has as a goal a dynamic range of 10 bits. dE/dx is the major element in our particle ID since it covers the high track density low momentum central region where prominant hadronic plasma signals are expected. However in order to extend our rapidity coverage in the non-central regions with higher momentum cascade particles we have in this workshop added $\approx 20,000$ channels of time-of-flight as discussed previously.

QED ELECTRONS

Before and during the workshop Mark Rhoades Brown[6] reported on e^+e^- pairs produced by heavy ion beams in the crossing region is proportional to the production cross section σ = constant $\times(Z_1\alpha)^2(Z_2\alpha)^2$. Obviously Au and Au is the worst case. For $\gamma = 100$ Gold on Gold he obtained $\sigma_{e^+e^-} = 3.36 \times 10^4$ barns. This now seems to be about the consensus cross section for perturbative calculations. $L = 2 \times 10^{26} cm^{-2} sec^{-1}$ for Au on Au beams in RHIC. The event rate is $L\sigma_{e^+e^-} \approx 7 \times 10^6$ events per second for $L = 2 \times 10^{26} cm^{-2} sec^{-1}$. For 28μ sec "on time" of our TPC the event rate $\rightarrow\approx 200$ events per second. However from his distribution curves for $P_{||}$, approximately 14 slow single electrons would, he calculated,[7] enter our TPC. Allowing for non-unitary effects this could be ~ 50. They would be concentrated near the 40 cm distance from the beam pipe and due to drift they would be uniformly distributed in the vertical direction. Therefore we consider this to be a manageable problem. However we will keep an eye on this effect.

THE TRIGGERING SYSTEM AND OTHER DETECTORS

A small calorimeter surrounding the beam pipe and subtending a pseudorapidity range from 4 to 5 will measure an energy that depends on the impact parameter of the collision. A large plane device located just behind the central TPC which measures multiplicity will give a more direct measurement of the interest of the event as far as TPC response is concerned. Count information from the TOF counters can also be used as a trigger element. Note that the region 80cm wide by 80cm (or more) high immediately around the interaction region is available for insertion of a special device capable of dealing with the very large track densities. Such a device would have to have very low mass, of course, to avoid compromising the TPC.

COMPUTATION AFTER TRIGGERING

For 100 GeV $\times$ A Au on 100 GeV $\times$ A Au, the inelastic event rate $\approx \sigma L \approx 6.8 \times 10^{-24} \times 2 \times 10^{26} \approx 1400$ per sec. The trigger reduces the rate by $\approx$ a factor of 100. Pattern recognition would take about 0.5 sec per track on VAX780 based on AGS 810 experience.

Thus $\approx 14 \times 4,000 \times 0.5 \rightarrow\approx 28$ KiloVAX780 to process as we run. Approximately 20 KiloVAX780 should be sufficient when allowing for percentage on time. We now can get one 780 equivalent for < \$1,000. We expect to gain a factor ~ 5 or better when RHIC is available, so $\approx$ \$4M is sufficient. We plan to improve the trigger, and all run time will not be analyzed so allowing $\approx$ \$3M - \$4M for computing should be reasonable.

COST ESTIMATES

Cost estimates were made for the TPC Magnetic Spectrometer system and published in the LBL Workshop.[2] Salaries of the collaboration, EDIA and contingency were not included. The total cost estimated for the window frame magnet, TPC system, trigger system, and computer system was 18.5 million dollars. The time-of- flight wall we have added at this workshop is expected to increase the costs by about 5 million dollars.

A cost estimate will be included with the Letter of Intent.

EXPERIMENTAL HALLS

This detector can be installed in either the wide angle (Fig. 15) or the major facility hall (Fig. 16) without significant modification to the halls. Use of the narrow angle hall or the open region would require major reconstruction and will not be pursued. A preliminary look at the possibility of moving the magnet and attached detectors in order to simplify assembly and maintenance of the system indicates that it will not be a major difficulty, and is being studied further.

AGS E-810 PROGRESS ON TPC SYSTEM

The success of the AGS E-810 TPC Program is a clear indication that we have the appropriate expertise for this project.

The experimental arrangement for AGS E-810 is shown in Fig. 17. The AGS E-810 TPC system consists of three modules of twelve anode rows each. They are placed along the beam in the MPS 5KG magnet (Fig. 17) with the Si ion beams passing through the TPC to provide large solid angle coverage. We have been able to handle 5,000 to 10,000 Si ions per AGS pulse passing directly through the center of the TPC. When the booster becomes available at AGS to accelerate Au ions it will become necessary to deaden the beam area unless one chooses to run at rates of a few hundred incident Au ions per pulse. The anode readout wires are 25μ gold-plated tungsten 1 cm long rows parallel to the beam direction. There are 10 wires to the inch between cathode structures. A gate which opens only when events of interest occur is included for operation at high ion beam rates ($\sim 1/2\ \ 10^4$/pulse).

14.5 GeV/c $\times$ A Si on Au events with up to 90 tracks were reconstructed with good pattern recognition efficiencies. The event shown in Fig. 18 contains 68 tracks including a Λ. Clear Λ and K^0 peaks were obtained. About 700 single Λ events were obtained for 14.5 GeV/c Si $\times$ A on Au events during a running period of about one day. Over 50 double Λ events were observed, and 2 triple Λ events were observed (see Fig. 19). These experiments were described in references 8-10.

dN/dy distributions for negative tracks assuming they were pions were obtained and dN/dy for protons was obtained approximately by subtracting negatives from positives (see Fig. 20). Temperatures were estimated for the various particles.[9] About an order of magnitude more data was obtained for various targets ranging from Si to Tungsten in the most recent Heavy Ion run. This data is currently under analysis. A Physics Letters B on the Λ and K_s^0 data is in press.[10]

SUMMARY

1. A 4π tracking TPC magnetic spectrometer for RHIC has been proposed by members of this collaboration in all four RHIC Workshops.
2. During this workshop the only basic change was the addition of time-of-flight walls to enhance particle ID and thus increase the rapidity ranges covered. We also considered various open dipole options.
3. S.Y. Lee designed a system to match our dipole into the RHIC ring.
4. The BNL/CCNY/Notre Dame/Rice collaboration believes this proposal will allow a sensitive search for a Quark-Gluon Plasma and possibly other new phenomena which go beyond the standard model.
5. Recent successes with the BNL/CCNY/Rice experimental program in AGS E-810 has demonstrated that the collaboration has the expertise required for such a project. This has been further enhanced by a successful RHIC R&D program for developing a TPC at RHIC.[11] A summary of this is given in Table I.
6. The BNL/CCNY/Notre Dame/Rice collaboration plans to submit a Letter of Intent this fall for a first round RHIC experimental program with a device of this type. Therefore at the Workshop we concentrated on preparing for this.

REFERENCES

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2. S.J. Lindenbaum. An Approximately 4π Tracking Magnetic Spectrometer for RHIC. *Proc. of the Second Workshop on Experiments and Detectors for a Relativistic Heavy Ion Collider (RHIC), Lawrence Berkeley Laboratory, Berkeley, California, May 25-29, 1987*, Editors, Hans George Ritter and Asher Shor, pp. 146-165 (Lawrence Berkeley Laboratory, 1988).
3. S.J. Lindenbaum. A 4, Tracking Magnetic Spectrometer for RHIC. *Proc. of the Third Workshop on Experiments and Detectors for a Relativistic Heavy Ion Collider (RHIC), Brookhaven National Laboratory, July 11-22, 1988*, B. Shivakumar and P. Vincent, Editors, pp. 82-96 (Brookhaven National Laboratory, BNL 52185).
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7. Mark Rhoades Brown, private communication.
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9. W.A. Love (for the E-810 Collaboration). Silicon Ion Interactions Measured in the E-810 TPC at the AGS. *Proc. of Quark Matter 90, Menton, France, 7-11 May 1990*, (to be published in a special issue of Nuclear Physics A).
10. S.E. Eiseman et al. Neutral V Production with $14.6 \times A$ GeV/c Silicon Beams. Phys. Lett. B (in press).
11. E.D. Platner, talk presented at this conference.

FIGURE CAPTIONS

Fig. 1 Horizontal section (containing the beam) of the previous[2,3] experimental arrangement. The central TPC (TPC1) is in the 5KG window frame magnet (field vertical). The external TPC's (TPC2) is only shown on the right side, but the left side contains these also. Trigger calorimeters (between $| n |= 4 - 5$) and trigger multiplicity counters (beyond TPC near yoke) are not shown. The time-of-flight arrays have been added in this workshop.

Fig. 2 Beta vs. momentum in GeV/c for π, K, p for a length of 9mm with TOF $\sigma = 75ps$. Each curve is accompanied by 3σ bands.

Fig. 3a Horizontal section (contining the beam) of an open dipole option with time-of-flight walls. The left side external TPC (TPC2) and trigger elements are not shown.

Fig. 3b Open dipole option with time-of-flight walls. The opening is in the central region. The left side external TPC (TPC2) and trigger elements are not shown.

Fig. 4 Design by S.Y. Lee for matching our 2.5 Tesla meter magnet into the RHIC ring.

Fig. 5a π^+ or π^- counts and dN/dy vs. Y for one central RHIC PLASMA EVENT.

Fig. 5b The average π^+ or $\pi^- dN/dy$ vs. Y for 10 central RHIC EVENTS.

Fig. 6a K^+ and K^- counts and dN/dy vs. Y for one central RHIC PLASMA EVENT.

Fig. 6b The average K^+ or $K^- dN/dy$ vs. Y for 10 central RHIC EVENTS.

Fig. 7a $\bar{p}$ counts and dN/dy vs. Y for one central RHIC PLASMA EVENT.

Fig. 7b The average $\bar{p} dN/dy$ for 10 central RHIC EVENTS.

Fig. 8a p counts and dN/dy vs. Y for one central RHIC PLASMA EVENT.

Fig. 8b The average $p\ dN/dy$ for 10 central RHIC EVENTS.

Fig. 9 10% of the spiraling tracks with $p < 0.25 GeV/c$ are shown for clarity. The simulation used 100% of the tracks. Since the TPC detects 3-dimensional points, there is no significant confusion.

Fig. 10 $dN/d\Omega$ vs. θ measurements obtained in AGS E-810.

Fig. 11 RHIC TPC on chamber electronics. There are 256 channels per hybrid.

Fig. 12 2% of the tracks generated in a $100 GeV \times A$ Au on a $100 GeV \times A$ Au central collision. Since the TPC detects in 3D it can handle the actual track density.

Fig. 13 Calculated momentum spectrum for $\pi^{\pm}, K^{\pm}$ and p in the central region.

Fig. 14 dE/dx(KeV/cm) vs. momentum (GeV/c). This data was obtained in the PEP4/9 TPC.

Fig. 15 The TPC detector is shown in the wide angle hall. The time-of-flight walls are not shown.

Fig. 16 The TPC detectors is shown in the major facility hall. The time-of-flight walls are not shown.

Fig. 17 The experimental arrangement for AGS E-810 showing the TPC system in the MPS 5-meter-long 5KG magnet.

Fig. 18 A 68 track 14.5 GeV/c × A Si on Au track event containing a Λ. (a) With all tracks shown; (b) with Λ only.

Fig. 19 A triple Λ event.

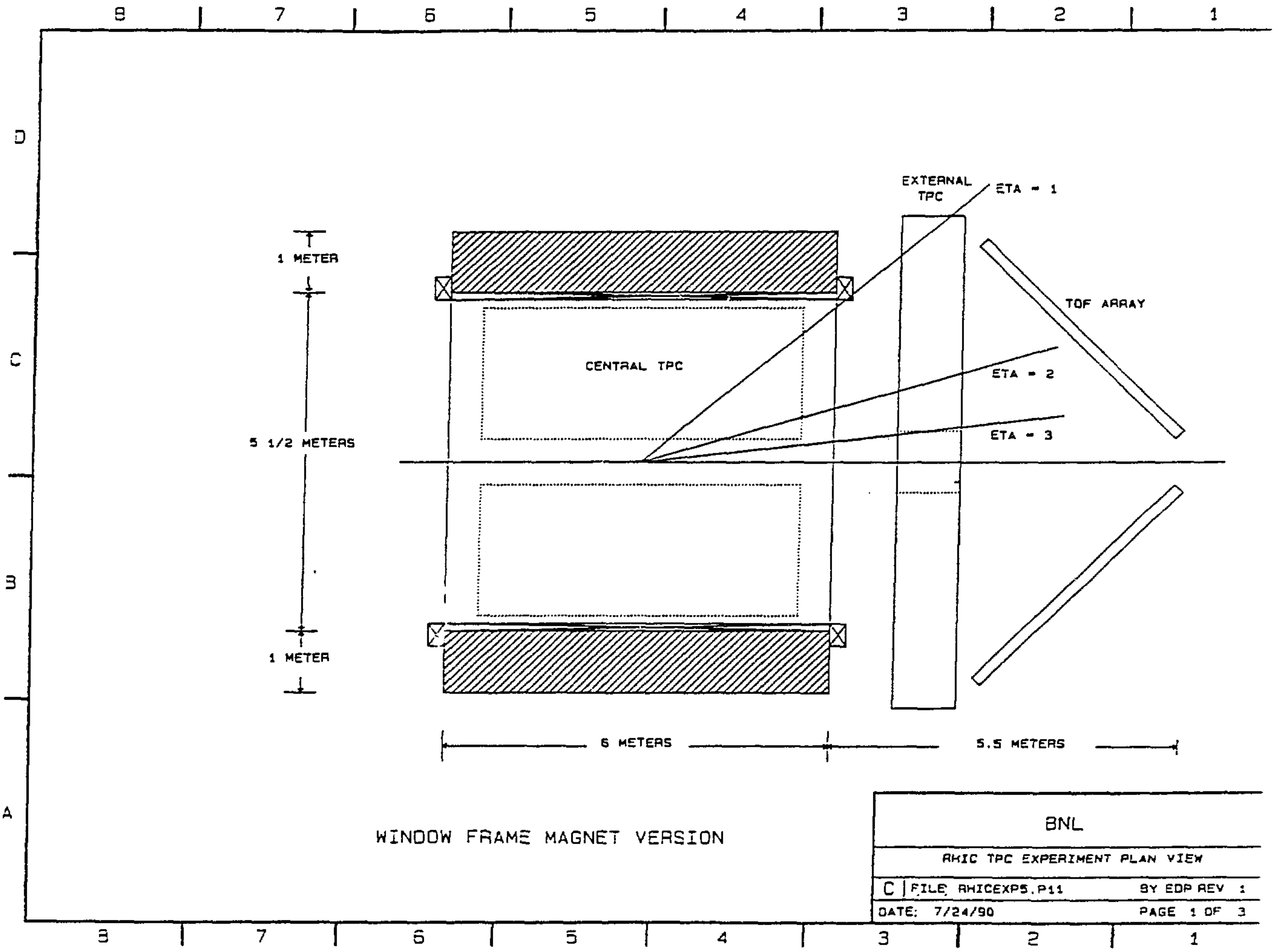
Fig. 20 Pseudorapidity distribution of charged tracks from central collsions.

Fig. 21 Rapidity distribution of pions (circles) and protons (triangles) from central collisions. Proton data are scaled one decade for clarity.

Table I

TPC R & D PROGRAM
1990 PROGRESS AND FUTURE GOALS

Progress	Goals
Electronics assembly method found and tested (260 contacts). Developed elastic interconnect devices.	Develop multilayer circuit boards for chips under development.
Constructed cathode pad endcap assembly for test chamber	Fully assembled test TPC.
Gas system designed for accurately mixing a variety if gases.	Completion of gas system.
Three-dimensional field mapping program development including acquisition of 387SX computer and MATHCAD software.	Completion of field mapping program and testing against actual chamber configuration.
Laser system review of existing lasers and multipliers.	Purchase of laser system and integration with test chamber.
Review of amplifier-shapers suitable for a RHIC TPC.	Acquisition of chips and test and evaluation. Installation of chips on assembly PC's. Test on TPC.
Review of existing memory chip properties as tested by others.	Acquisition of memory chips and test and evaluation. Installation of memories on assembly PC's. Test on TPC. Design of segmented memory version. Prototype production. Test and evaluation at BNL. Installation on assembly PC's.
Design IC test facility.	Acquire test electronics - includes waveform generator, digital oscilloscope and appropriate computer interfaces. Acquire computer suitable as driver and data acquisition for these instruments and TPC tests.



EXTERNAL TPC
ETA = 1
1 METER
TOF ARRAY
CENTRAL TPC
ETA = 2
5 1/2 METERS
ETA = 3
1 METER
6 METERS
5.5 METERS
WINDOW FRAME MAGNET VERSION
BNL
RHIC TPC EXPERIMENT PLAN VIEW
C
FILE RHICEXP5.P11
BY EDP REV 1
DATE: 7/24/90
PAGE 1 OF 3

Figure 1

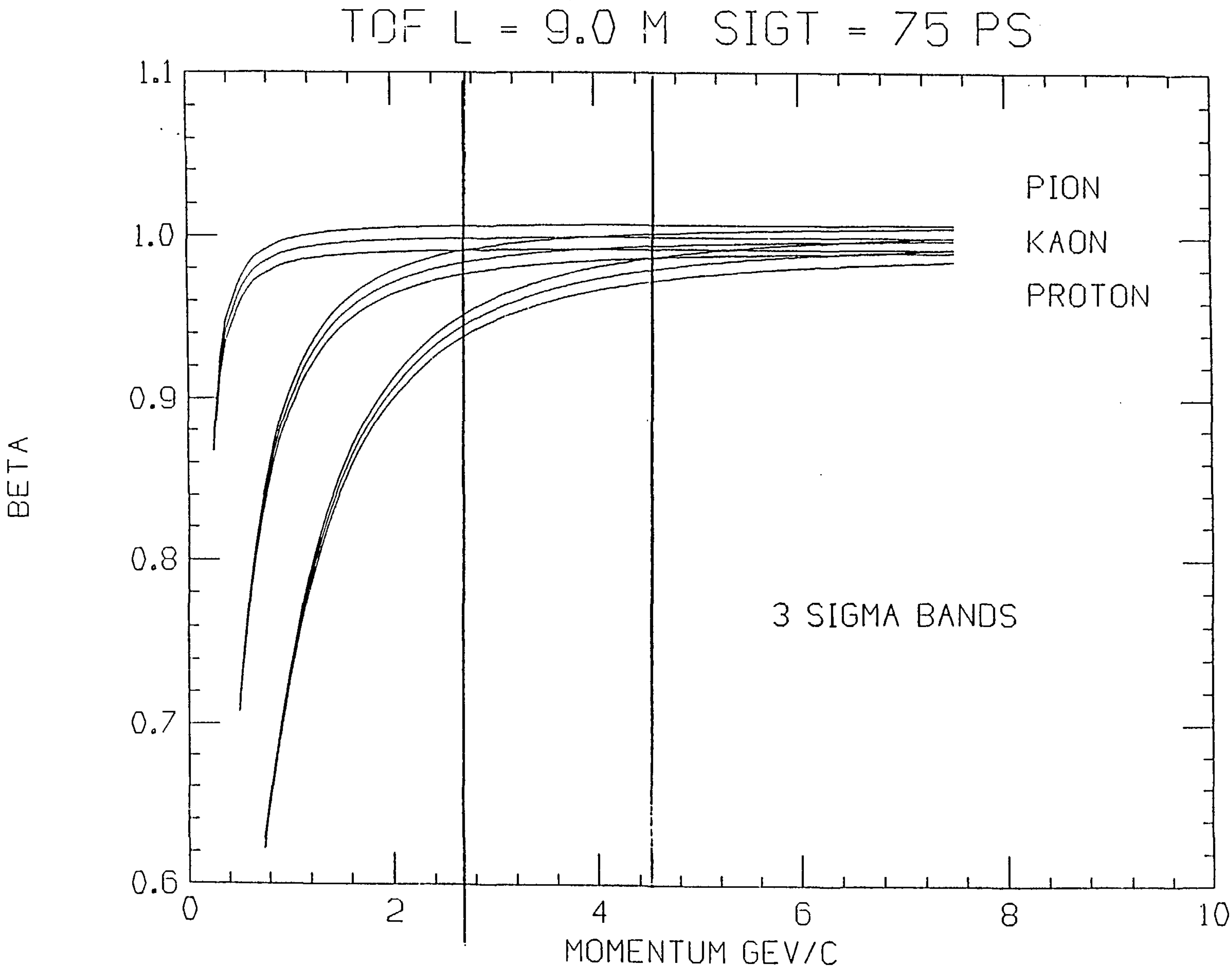
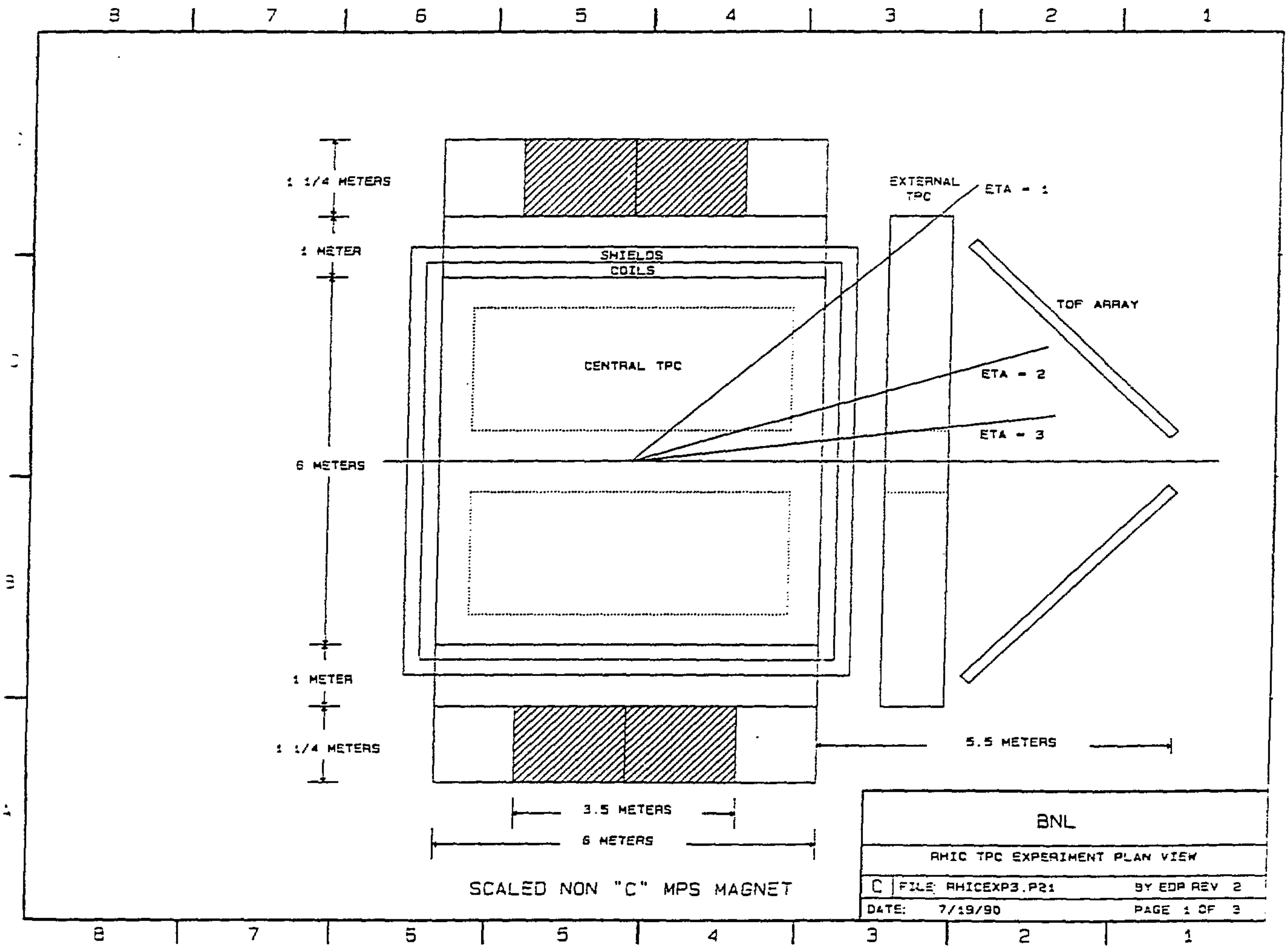
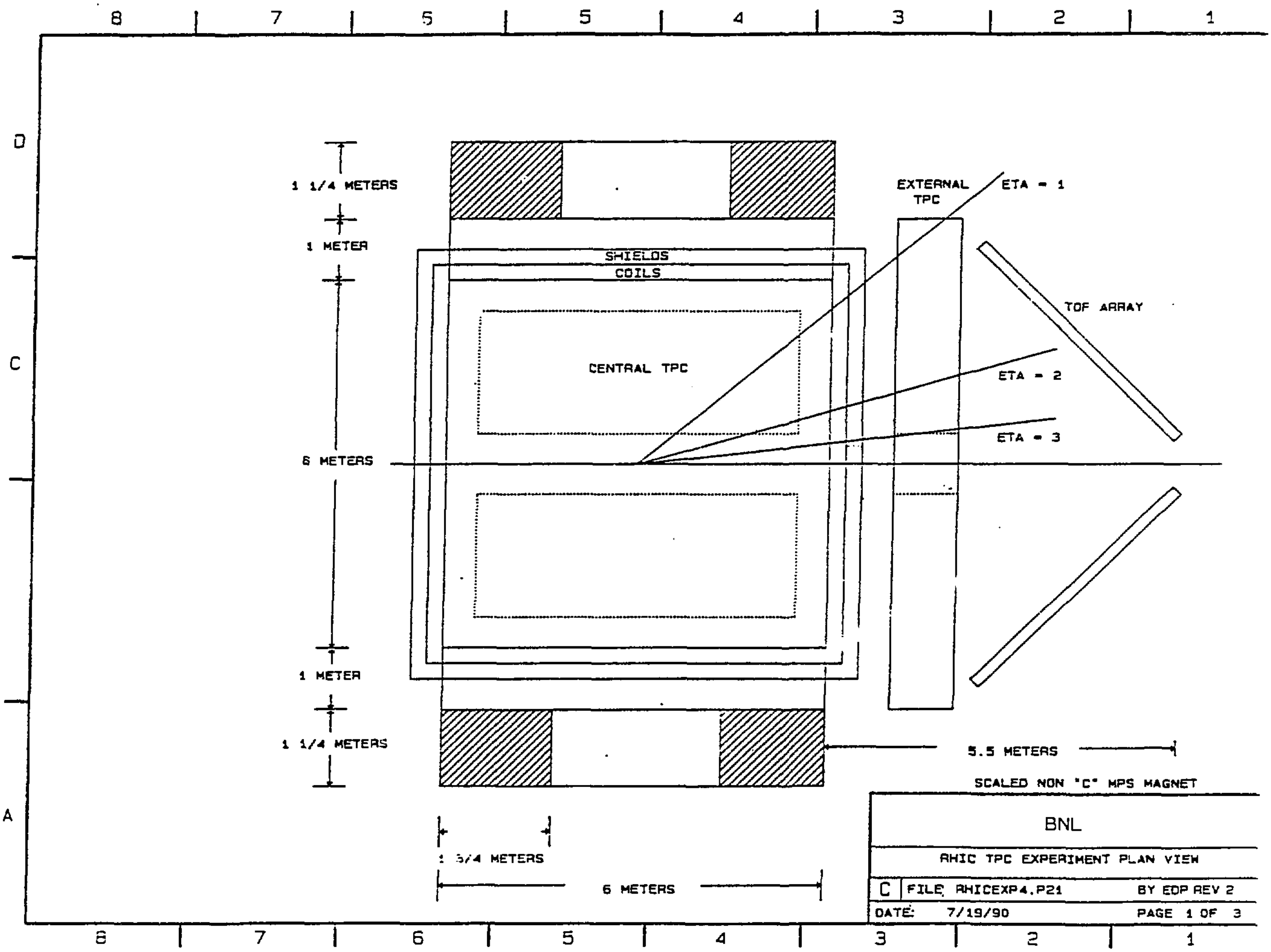

TOF L = 9.0 M SIGT = 75 PS
1.1
1.0
0.9
0.8
0.7
0.6
BETA
0
2
4
6
8
10
MOMENTUM GEV/C
PION
KAON
PROTON
3 SIGMA BANDS

Figure 2



1 1/4 METERS
1 METER
6 METERS
1 METER
1 1/4 METERS
SHIELDS
COILS
CENTRAL TPC
EXTERNAL TPC
ETA = 1
ETA = 2
ETA = 3
TOF ARRAY
5.5 METERS
3.5 METERS
6 METERS
SCALED NON "C" MPS MAGNET
BNL
RHIC TPC EXPERIMENT PLAN VIEW
C FILE: RHICEXP3.P21
BY EDP REV 2
DATE: 7/19/90
PAGE 1 OF 3

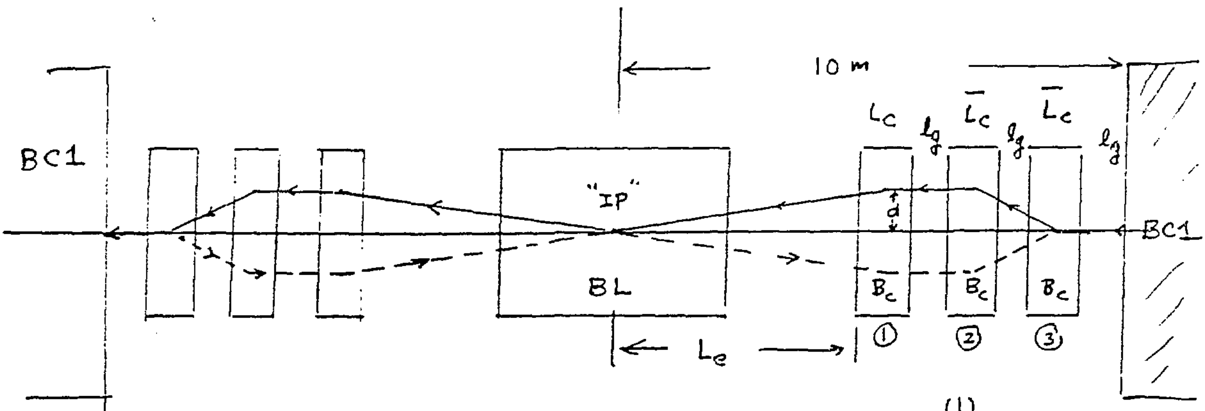
Figure 3a



1 1/4 METERS
1 METER
6 METERS
1 METER
1 1/4 METERS
SHIELDS
COILS
CENTRAL TPC
EXTERNAL TPC
ETA = 1
ETA = 2
ETA = 3
TOF ARRAY
5.5 METERS
1 3/4 METERS
6 METERS
SCALED NON "C" MPS MAGNET
BNL
RHIC TPC EXPERIMENT PLAN VIEW
C
FILE RHICEXP4.P21
BY EDP REV 2
DATE: 7/19/90
PAGE 1 OF 3

Figure 3b

Available space for Transverse field detectors



$$B_c L_c = \frac{1}{2} BL \qquad (1)$$

$$d = \frac{1}{2} \frac{BL}{B\rho} * \left(L_e + \frac{1}{2} L_c \right) \qquad (2)$$

$$\frac{B\bar{L}_c}{B\rho} \left(\bar{L}_c + l_g \right) = \frac{1}{2} \frac{BL}{B\rho} \left(L_e + \frac{1}{2} L_c \right) \qquad (3)$$

$$L_e = 10 - 3 l_g - L_c - 2 \bar{L}_c \qquad (4)$$

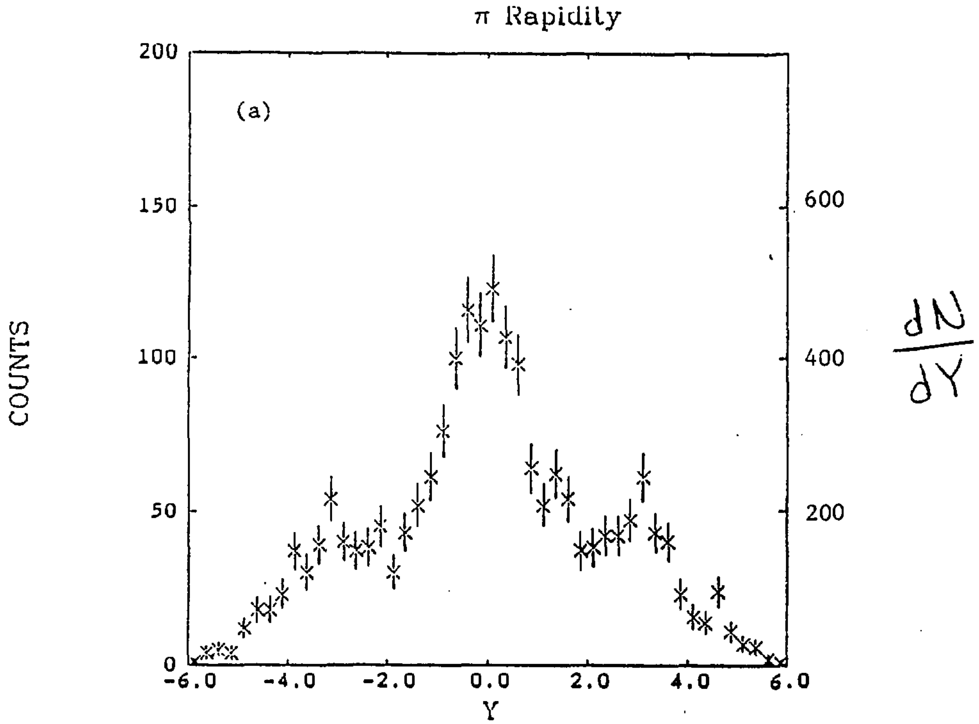
$l_g = 0.75$ m $\qquad B_c = 3.5$ T $\qquad$ @ $B\rho = 840.5$ Tm

BL (Tm)	1	1.5	2.0	2.5	3.0
d (mm)	3.8	5.4	6.8	8.1	9.3
L_c (m)	0.142	0.214	0.286	0.357	0.429
$\bar{L}_c$ (m)	0.651	0.82	0.95	1.07	1.19
L_e (m)	6.31	5.90	5.55	5.26	4.99

$$\bar{L}_c^{\,2} + l_g \bar{L}_c = \frac{1}{2} \frac{BL}{B_c} \left(10 - 3 l_g - L_c + \frac{1}{2} L_c \right) - \frac{BL}{B_c} \bar{L}_c$$

Figure 4

ONE RHIC PLASMA EVENT π
6% PLASMA



RHIC EVENT

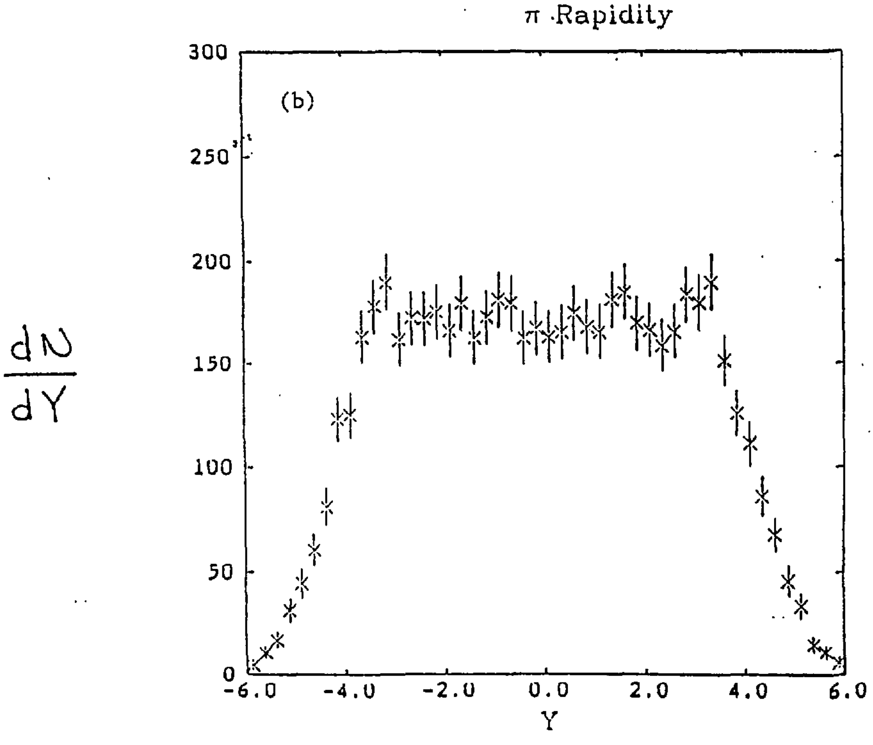
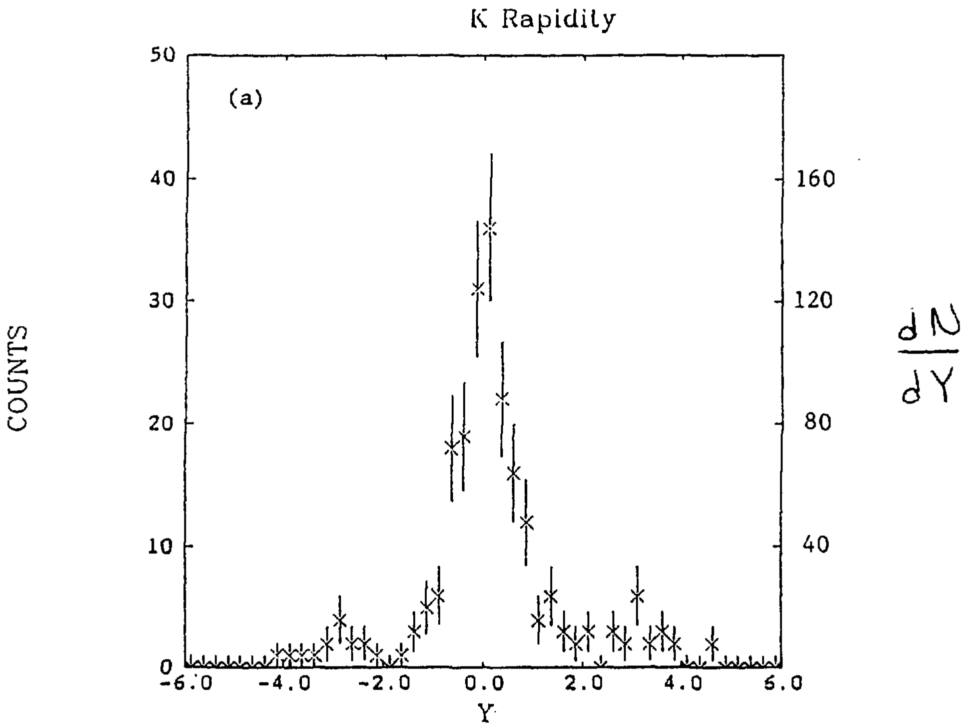


Figure 5

ONE RHIC PLASMA EVENT



RHIC EVENT

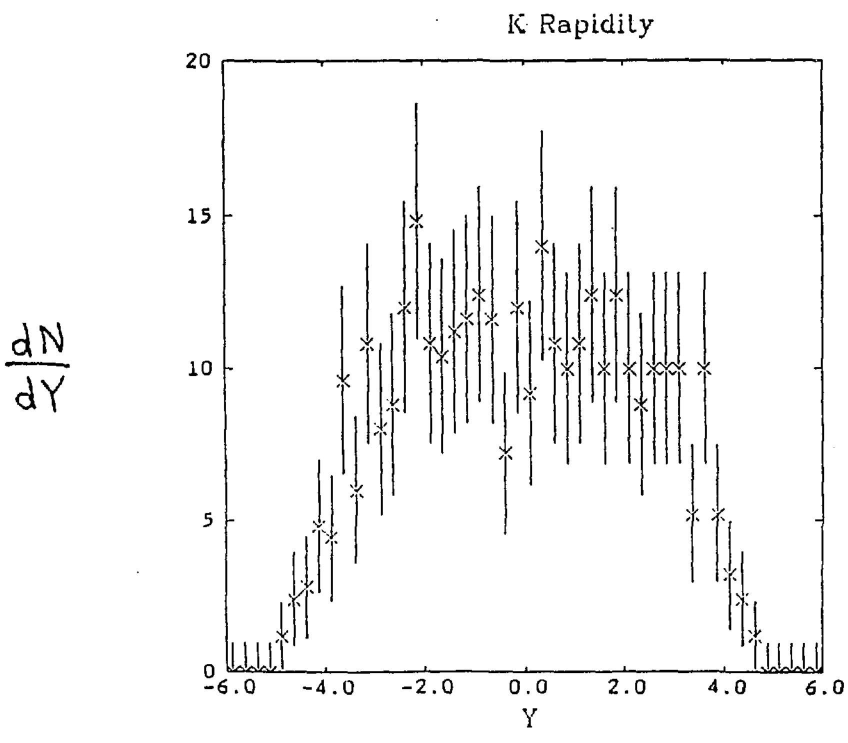
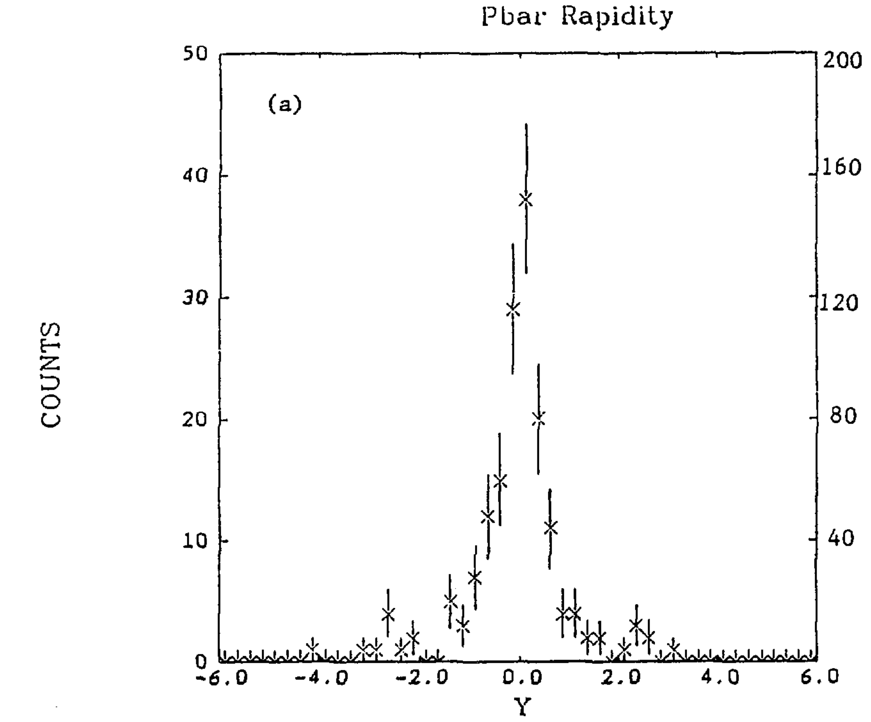


Figure 6

ONE RHIC PLASMA EVENT



RHIC EVENT

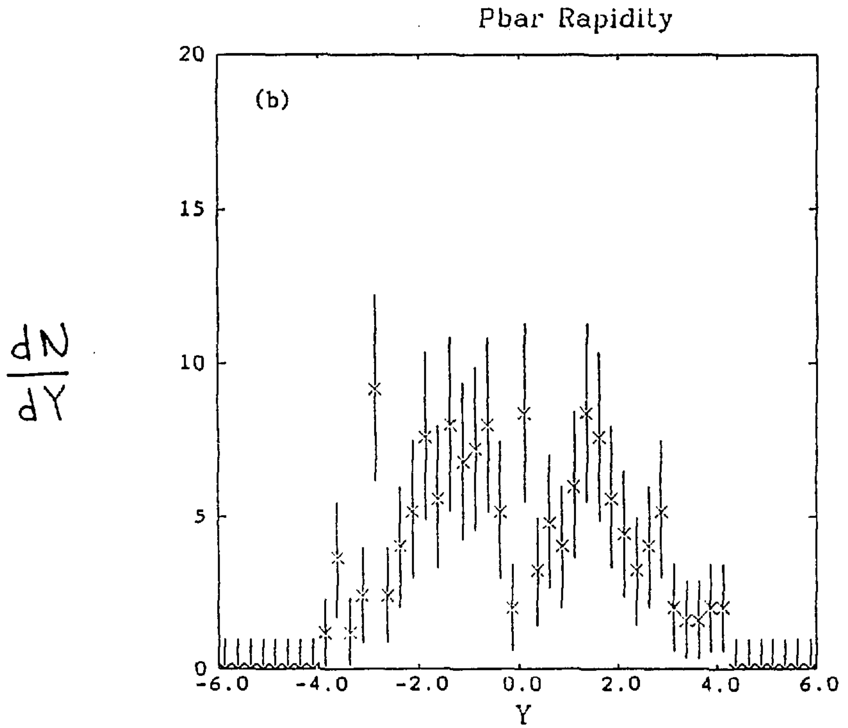
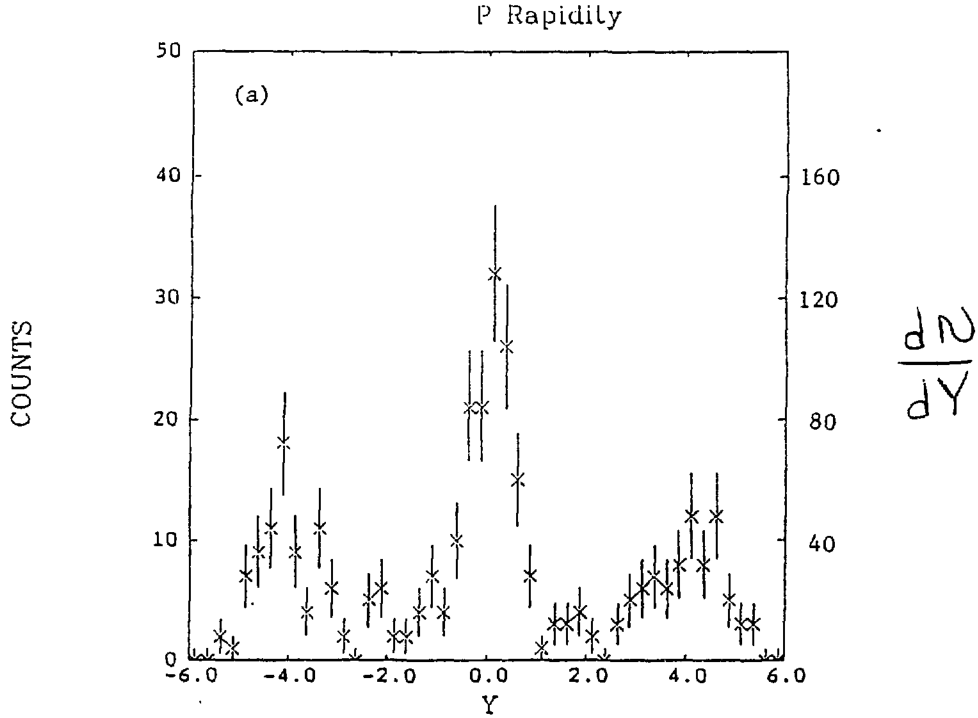


Figure 7

ONE RHIC PLASMA EVENT



RHIC EVENT

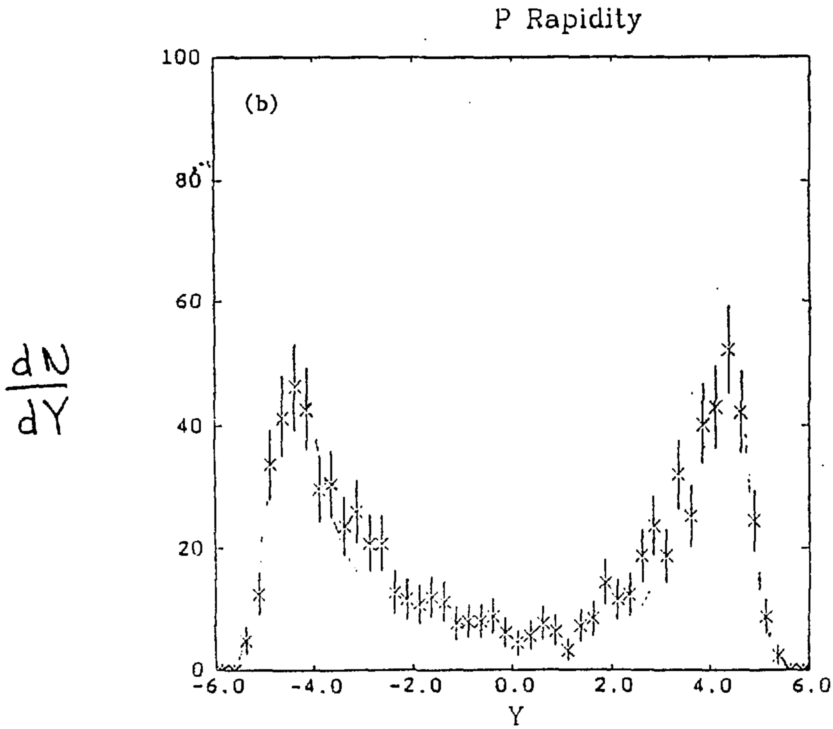


Figure 8

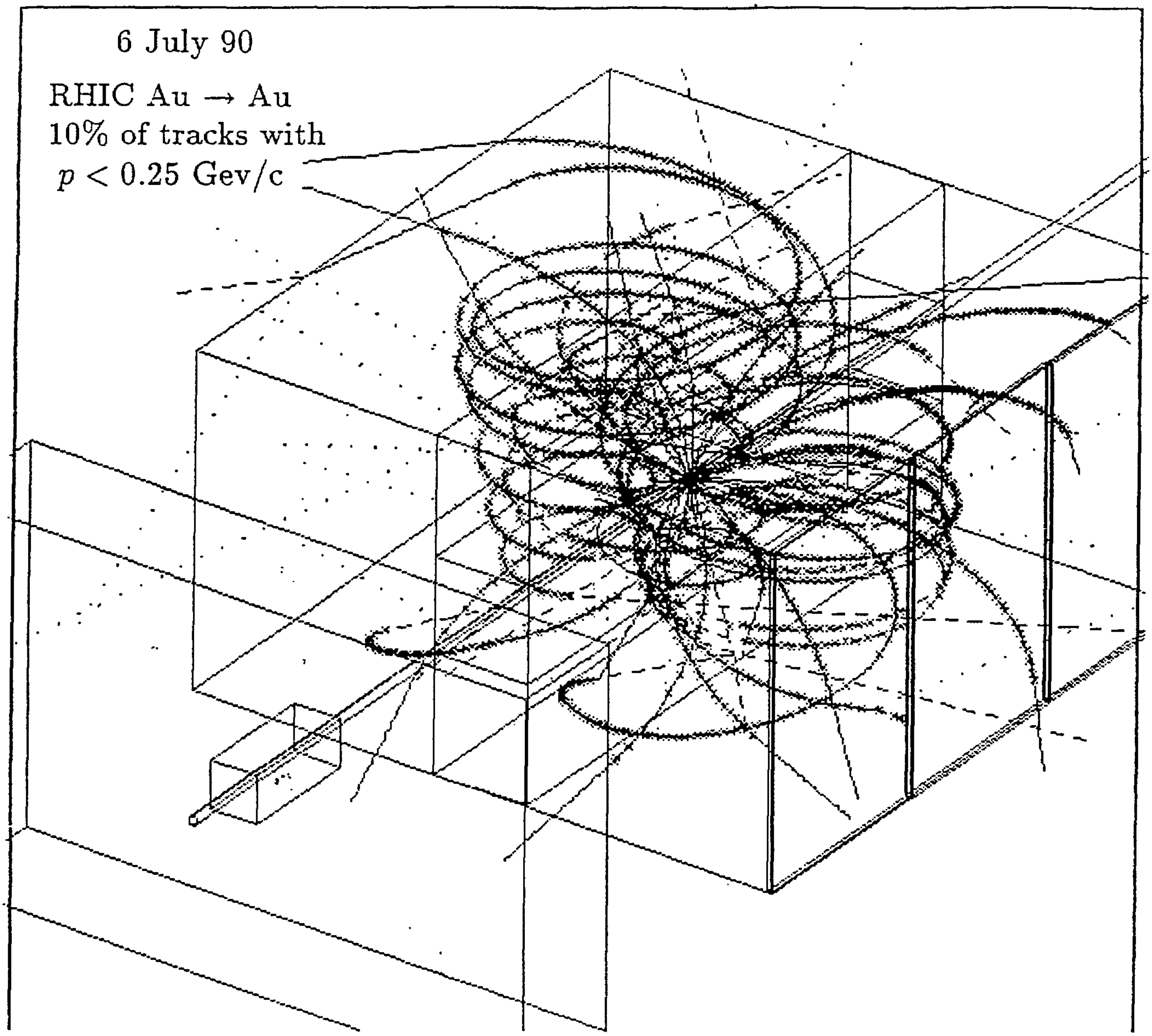


Figure 9

Track density 86 Si-Pb Central Events

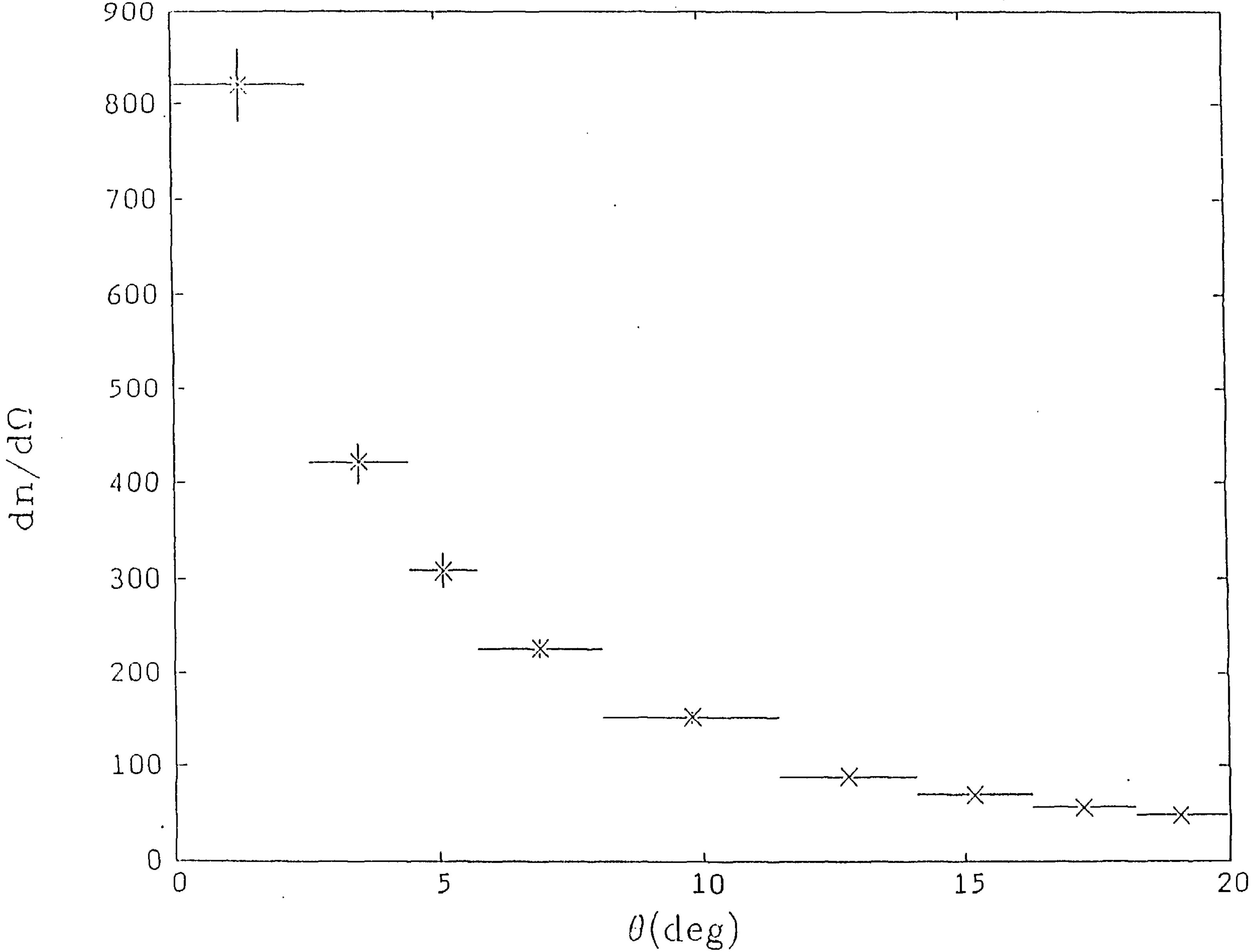


Figure 10

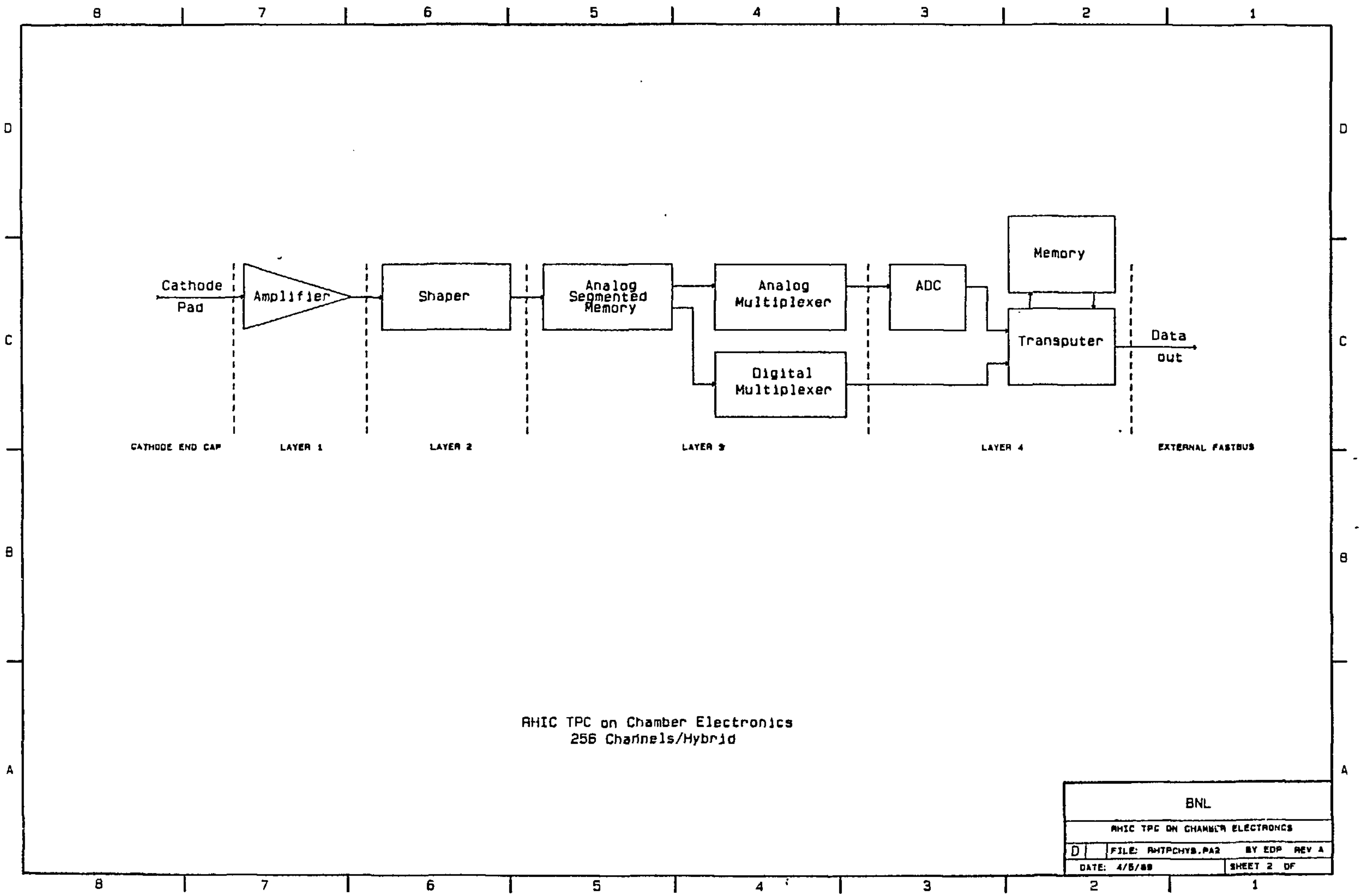

Cathode
Pad
Amplifier
Shaper
Analog
Segmented
Memory
Analog
Multiplexer
Digital
Multiplexer
ADC
Memory
Transputer
Data
out
CATHODE END CAP
LAYER 1
LAYER 2
LAYER 3
LAYER 4
EXTERNAL FASTBUS
RHIC TPC on Chamber Electronics
256 Channels/Hybrid
BNL
RHIC TPC ON CHAMBER ELECTRONICS
D
FILE: RHTPCHYB.PA2
BY EDP
REV A
DATE: 4/5/89
SHEET 2 OF

Figure 11

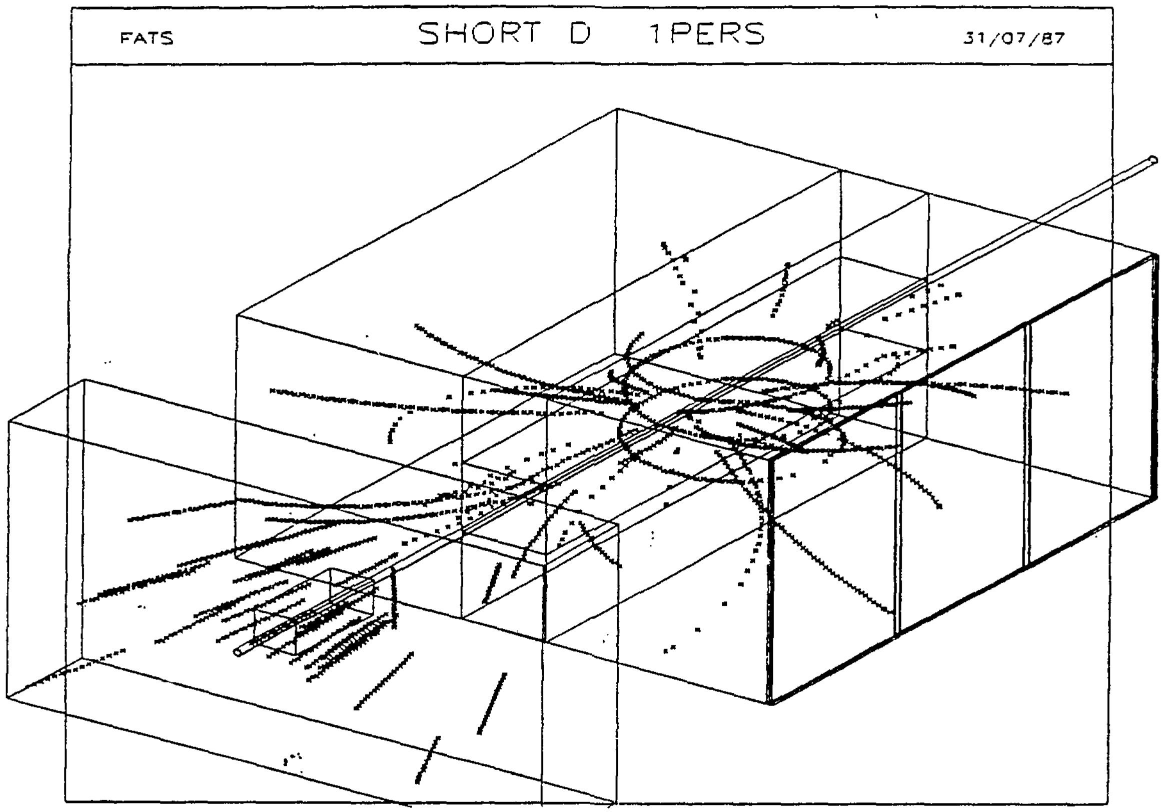
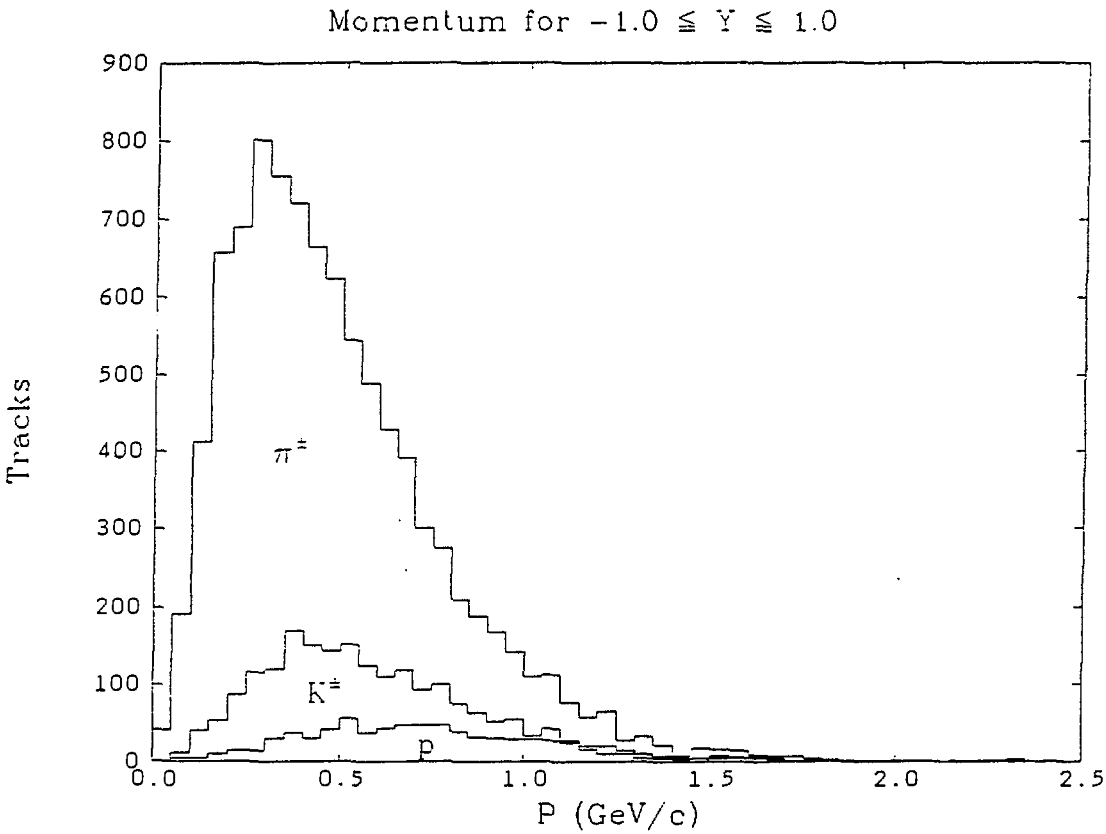


Figure 12



Momentum for −1.0 ≦ Y ≦ 1.0
Tracks
900
800
700
600
500
400
300
200
100
0
0.0
0.5
1.0
1.5
2.0
2.5
P (GeV/c)
π±
K±
p

Figure 13

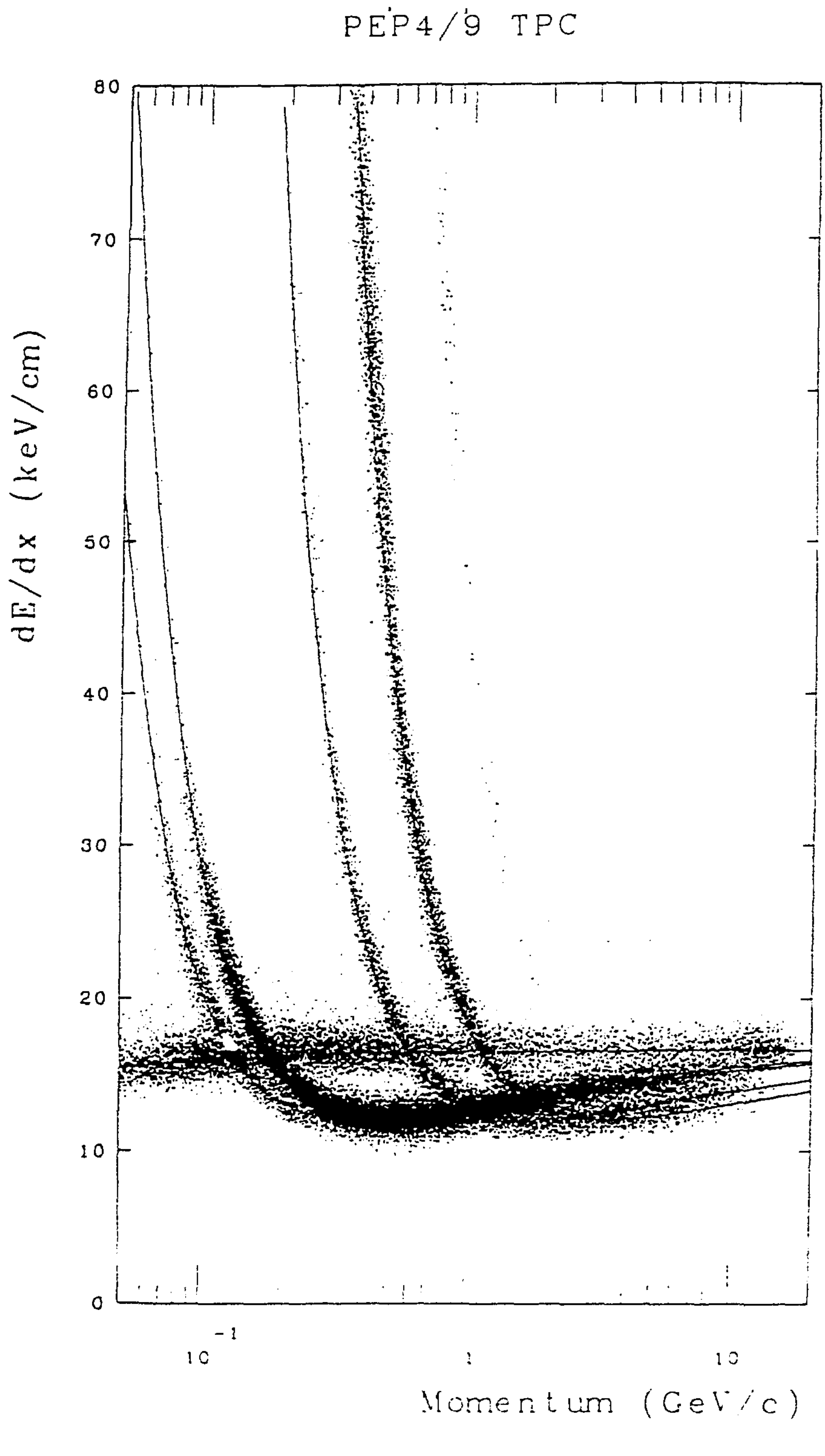
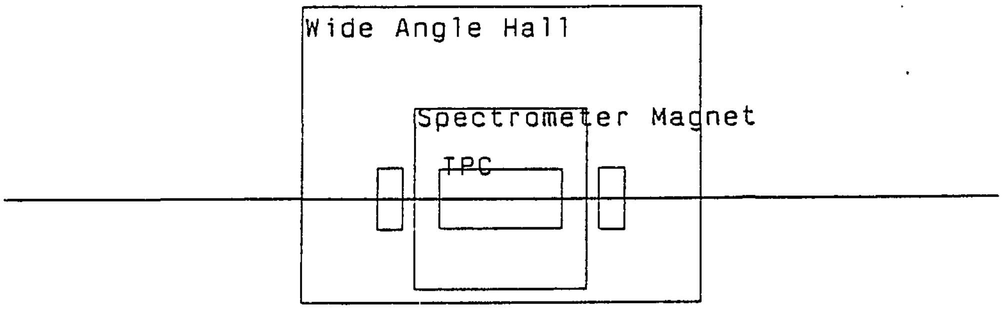
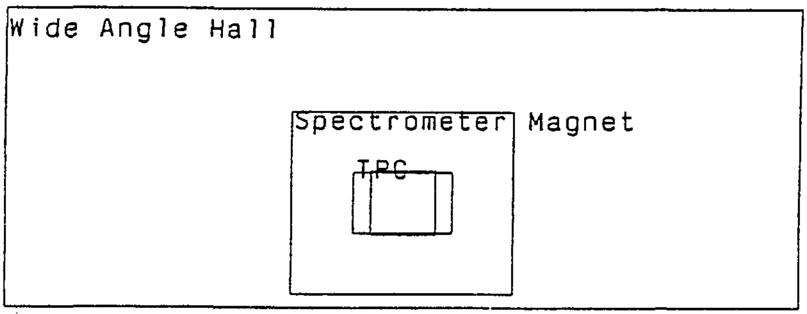

PEP4/9 TPC
80
70
60
50
40
30
20
10
0
dE/dx (keV/cm)
10^{-1}
1
10
Momentum (GeV/c)

Figure 14

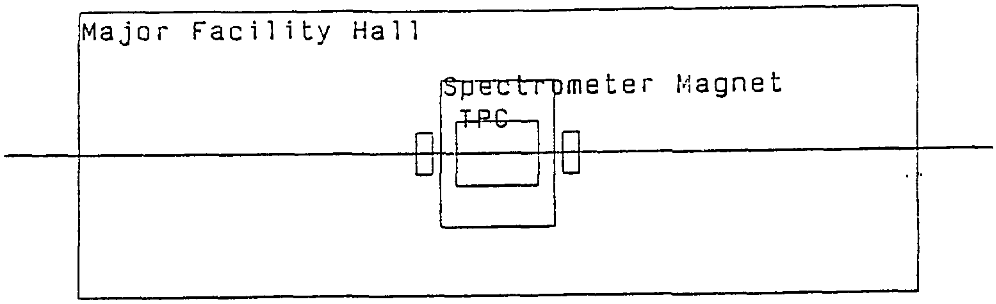


RHIC VIEW YZ

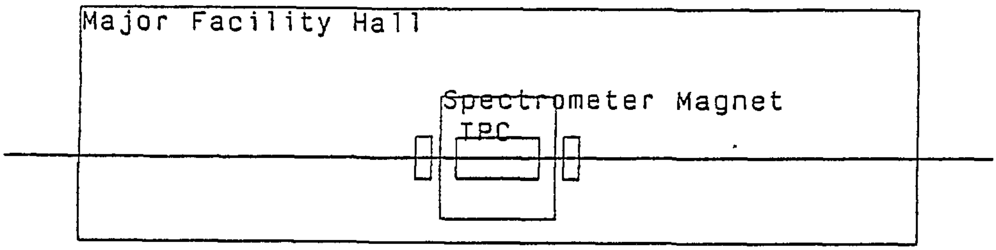


RHIC VIEW XY

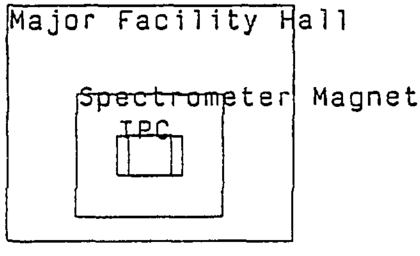
Figure 15



RHIC VIEW XZ



RHIC VIEW YZ



RHIC VIEW XY

Figure 16

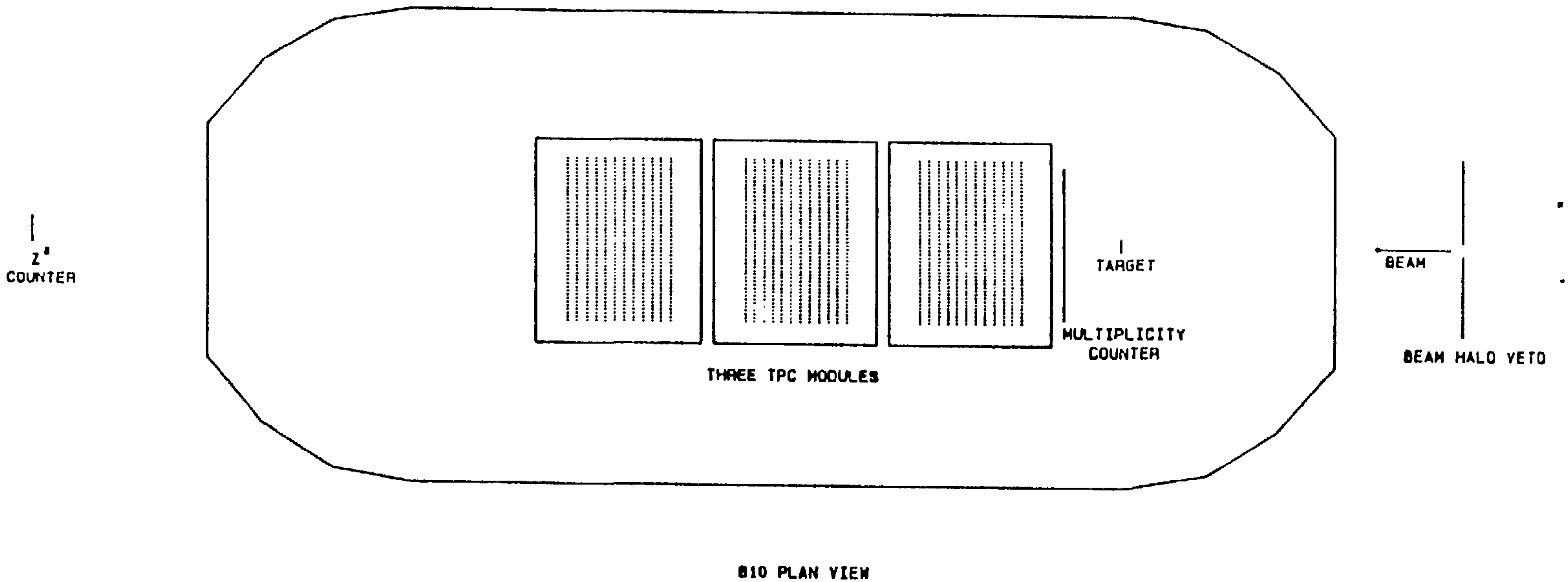

Z'
COUNTER
TARGET
BEAM
MULTIPLICITY
COUNTER
BEAM HALO VETO
THREE TPC MODULES
810 PLAN VIEW

Figure 17

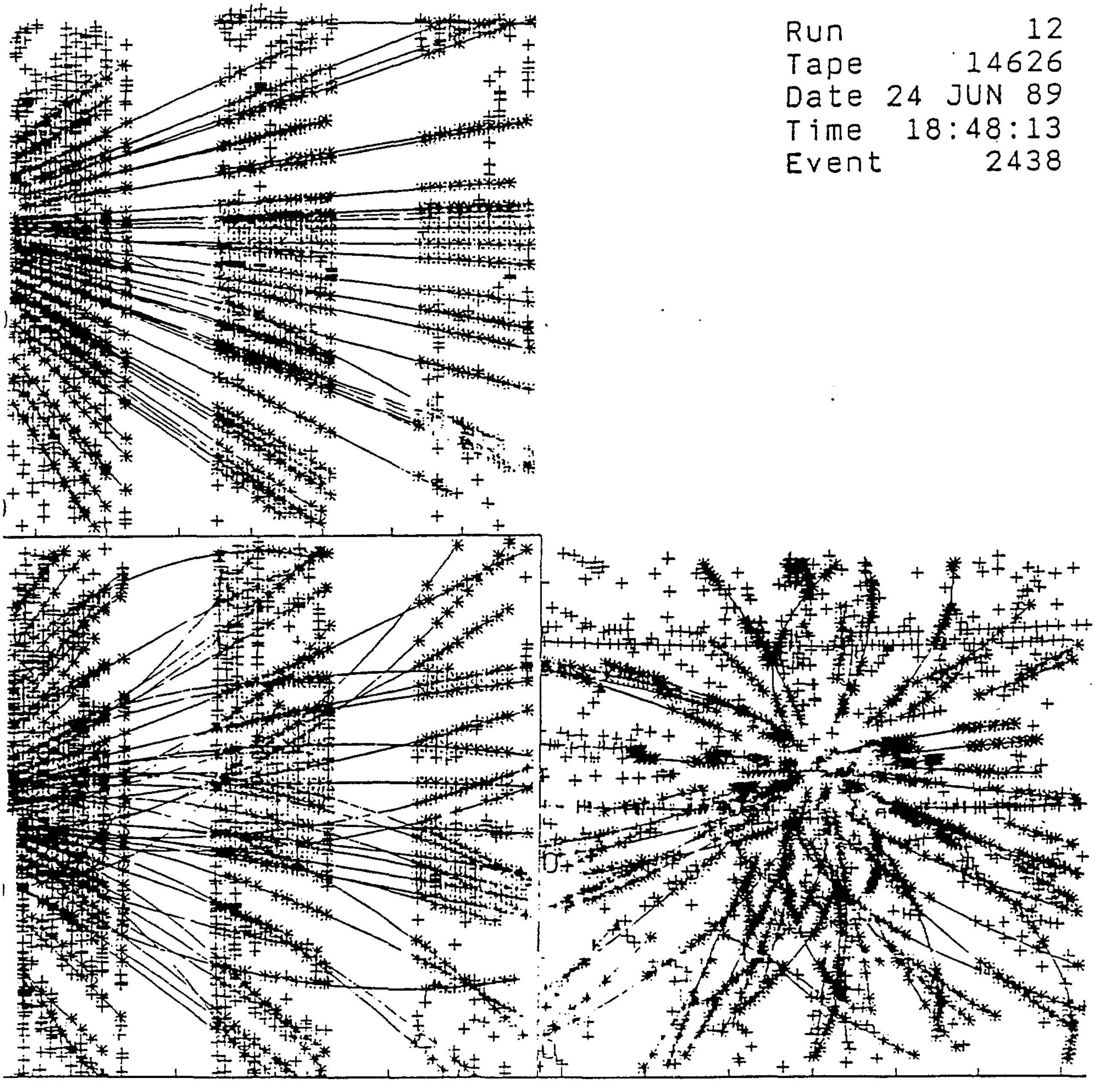


Figure 18a

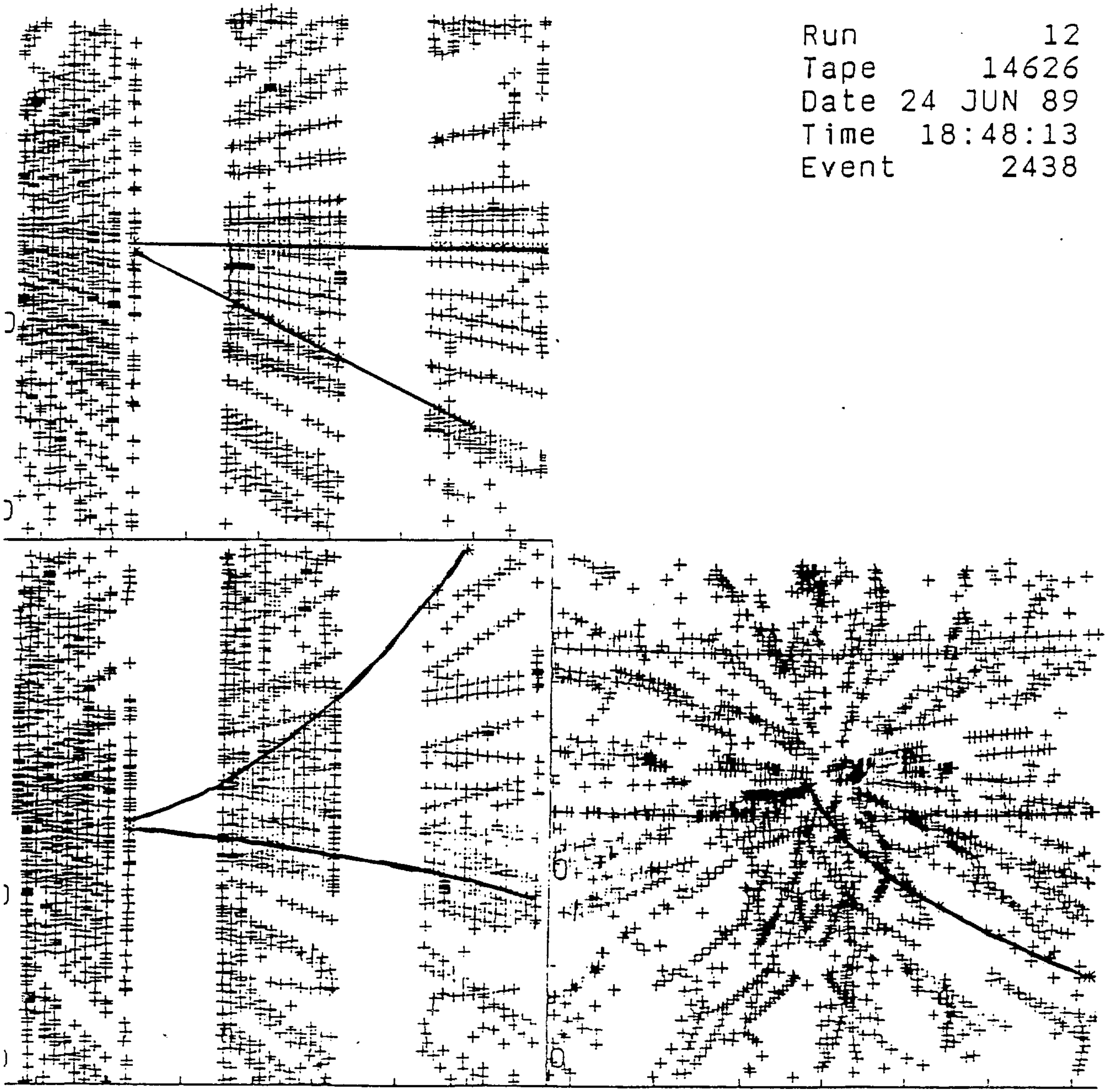
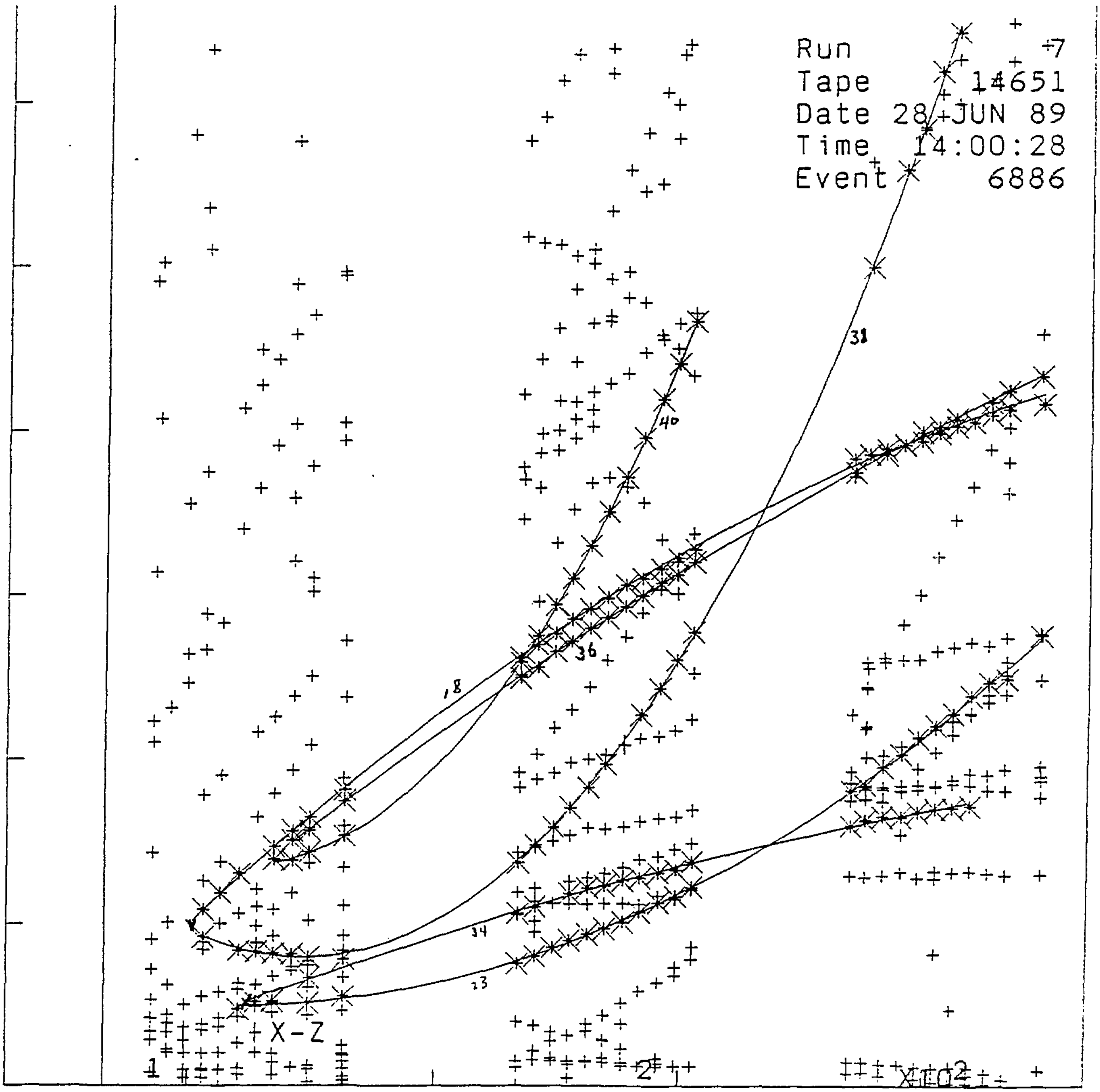


Figure 18b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Tape 14651
Date 28-JUN 89
Time 14:00:28
Event 6886
X-Z
1
2
X10 2
18
36
31
40
34
23

Figure 19

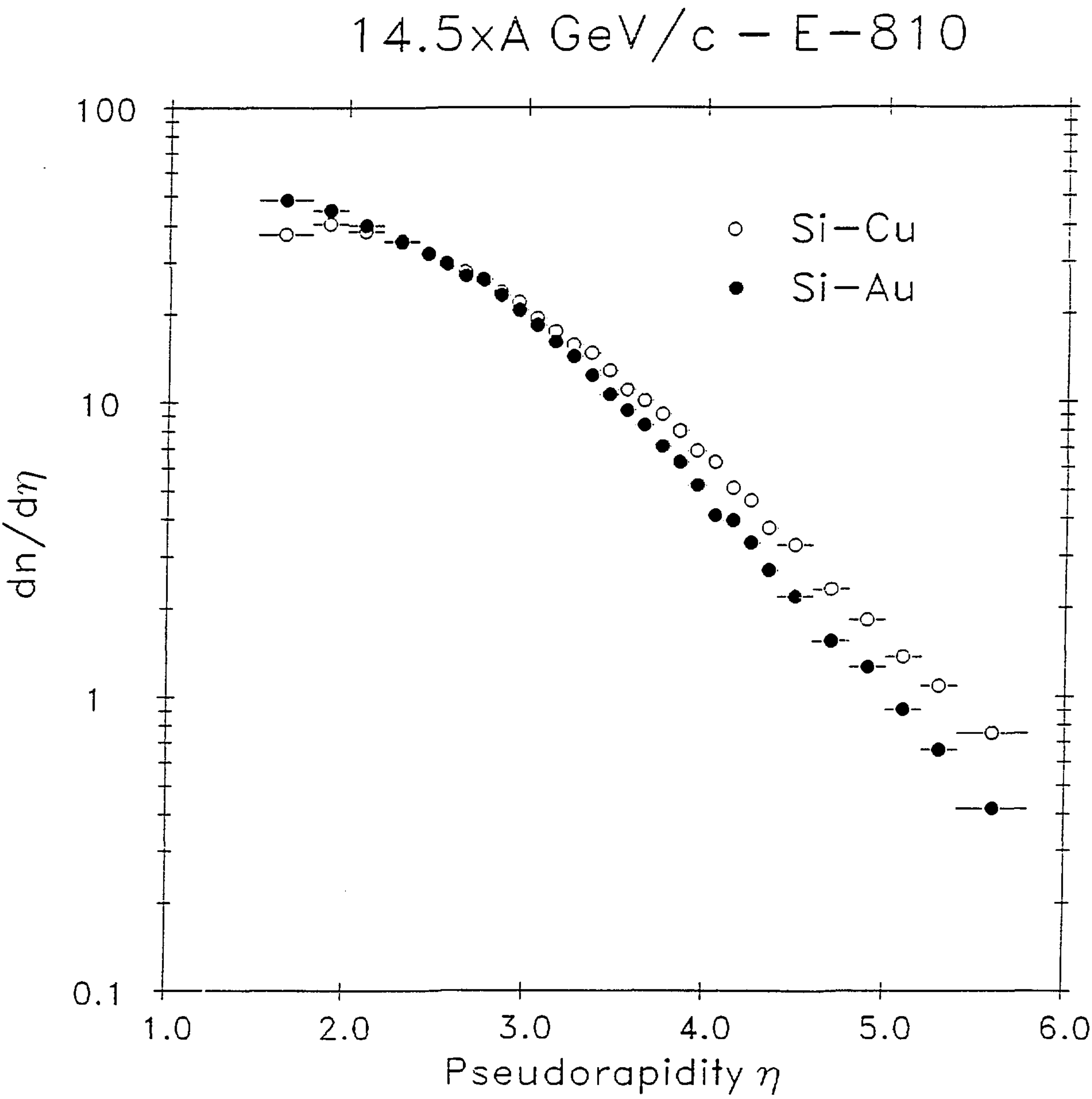
14.5xA GeV/c - E-810
Si-Cu
Si-Au
dn/dη
Pseudorapidity η
100
10
1
0.1
1.0
2.0
3.0
4.0
5.0
6.0

Figure 20

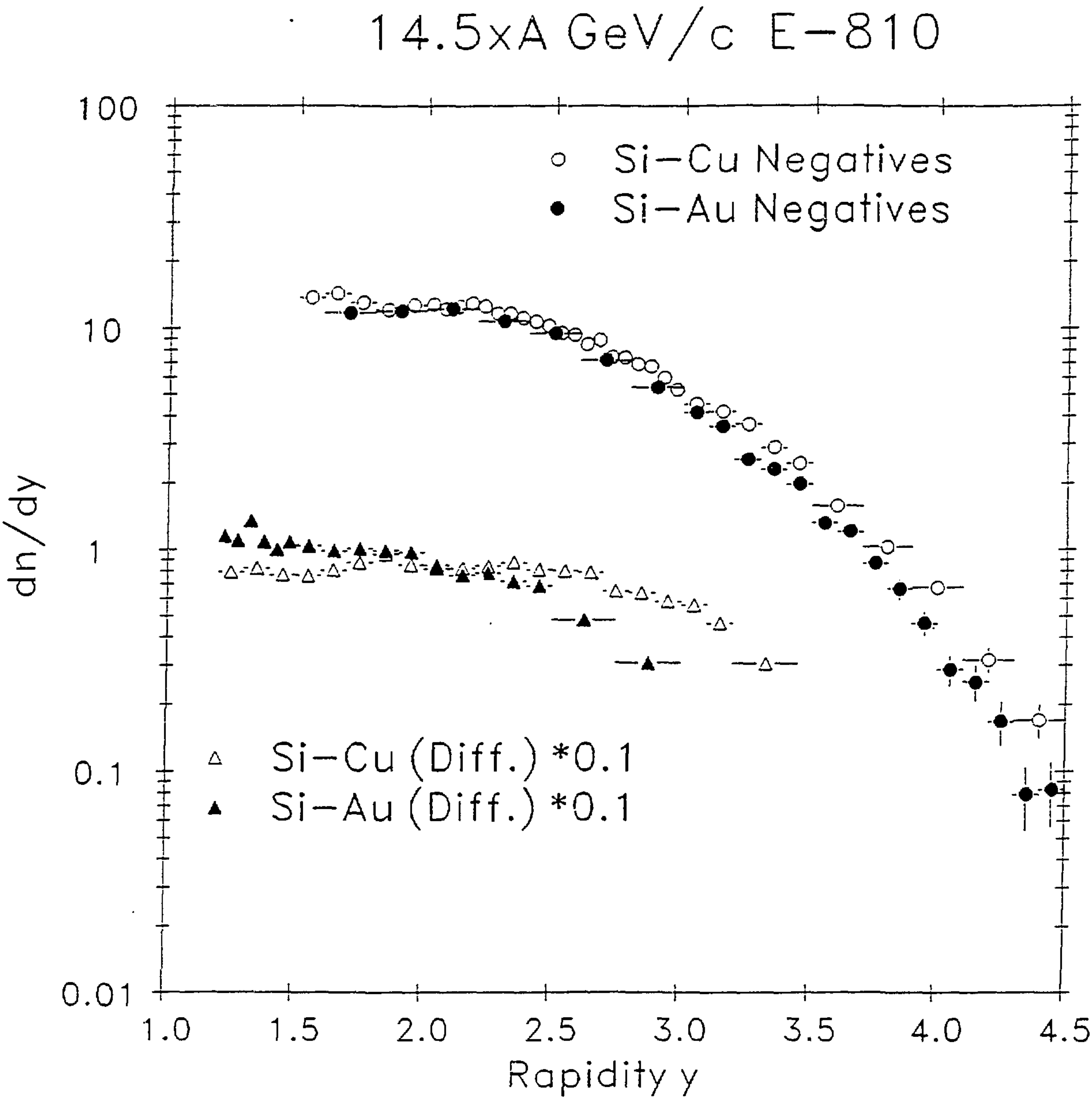
14.5xA GeV/c E-810
Si-Cu Negatives
Si-Au Negatives
Si-Cu (Diff.) *0.1
Si-Au (Diff.) *0.1
dn/dy
100
10
1
0.1
0.01
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Rapidity y

Figure 21