LBL-27620

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Presented at the NATO Advanced Study Institute on the
Nuclear Equation of State, Peñíscola, Spain, May 21–June 3, 1989

The HISS TPC

G. Rai, F. Bieser, H.S. Matis, C. McParland, G. Odyniec, D.L. Olson,
H.G. Pugh, H.G. Ritter, T.J.M. Symons, and H. Wieman

August 1989

NUCLEAR SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

THE HISS TPC

G. Rai, F. Bieser, H.S. Matis, C. McParland, G. Odyniec, D.L. Olson, H.G. Pugh, H.G. Ritter, T.J.M. Symons, and H. Wieman

Nuclear Science Division, Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720, USA

INTRODUCTION AND PHYSICS MOTIVATION

Studies with 4π detectors at the Bevalac (the Streamer Chamber [1] and the Plastic Ball [2]) have opened a major new field of nuclear physics - the study of the dynamics of nuclear matter under extreme conditions, where baryon and meson degrees of freedom are excited. The first indications of the behavior of the nuclear matter equation of state under such conditions have been obtained. The energy regime of the Bevalac is optimally suited to such studies, yielding nuclear densities 2-4 times that of ground-state nuclear matter, with substantial excitation of low-lying hadronic states such as the Δ-resonance. However, only a modest number of such states are excited, so that microscopic analyses of the reaction dynamics can be attempted in parallel with the macroscopic analyses most directly related to questions of the equation of state. A complete understanding of the dynamics will require a consistent treatment of relativistic effects and of density-dependent and velocity-dependent forces, as well as an understanding of the time dependence of quasi-equilibrium processes. Such investigations are of fundamental interest, and are also essential for an understanding of supernova explosions and of neutron star structure. For the last several years one of the crucial questions for supernova calculations has been whether the nuclear equation of state is "soft" as predicted by most extrapolations from low energy nuclear structure physics, or "hard" as implied by observations made so far at the Bevalac.

In order to reach a unique description of the collision dynamics, experience has shown that it is necessary to make the simultaneous observation of a variety of nuclear processes and to apply a consistent theoretical formalism to fitting the data. Thus a comprehensive 4π detector system covering a large solid angle, with particle identification and momentum measurement for all the charged particles is needed. Such a detector will enable the extraction of source temperatures from the energy spectra, source pressures from collective momentum flow, source entropies from a study of the particle mix in the secondary particle spectra, and source sizes from Hanbury Brown, Twiss measurements on pairs of identical particles. Much work has already been done in this direction using the Streamer Chamber and the Plastic Ball, but the capabilities of those detectors are limited. The HISS TPC will allow this research to continue and to broaden.

Production of strange particles represents a distinctly different probe of the collision dynamics and of the properties of the hot nuclear matter produced. The study of neutral strange particle production (Λ^0 and K^0) is a natural candidate for experiments using any 4π detector that can resolve secondary decay vertices and identify the charged particles emerging from them. Such studies have been carried out for central collisions using streamer chambers, but statistical accuracy has been limited. Furthermore, for the lower yield peripheral collisions and for the important calibrations needed from nucleon-nucleon and nucleon-nucleus collisions, almost no measurements exist. The HISS TPC will permit a comprehensive study to be made of these processes.

Multifragmentation processes are presently of great interest. A highly excited system produced in heavy ion collisions decays into a large number of fragments of various sizes. It has been pointed out that this process might be similar to a transition from the liquid to the gas phase [3]. In spite of considerable experimental and theoretical efforts this process is not yet understood. In particular, more complete experimental information is needed. It is planned to perform experiments where the HISS TPC is combined with the MUSIC chamber [4] so that the charge of the emitted fragments can be determined and a complete experiment in charge space can be performed.

In 1986 a conceptual design report for a 4π TPC detector for the Bevalac (EOS) was presented [5]. The EOS TPC was a cylinder two meters long by two meters in diameter in a solenoidal magnet. The detector was designed to study central collisions with the most energetic and heaviest beams available at the Bevalac. In that study it was pointed out that in order to cope with the high multiplicity and high particle density typical for heavy ion reactions it would be necessary to abandon the conventional wire read out of the TPC and to read out a very high number of individual pads, making the TPC a truly three-dimensional detector.

The HISS-TPC is based on this concept, but an alternative design was chosen for the magnetic field which, by using the HISS dipole and other already existing HISS facilities, greatly reduces the cost while preserving as much as possible the capabilities envisioned for the original EOS design. Such a configuration also has the advantage of being able to make use of the existing array of detectors at the HISS facility.

Two classes of experiments are considered. One class concerns flow analysis and triple differential cross sections (cross sections relative to the reaction plane). For these studies it is important to have uniform acceptance, particularly in the azimuthal (ϕ) angle about the beam axis. Large beam currents are not required, however, since cross sections are large. The other class concerns study of rare events requiring large solid angles but not necessarily completely uniform coverage.

For the first class of experiments the TPC will be operated with the beam, at an intensity of $\leq 10^3$ particles per spill, passing through the active region. This minimizes problems with non-uniform azimuthal coverage normally associated with a dipole geometry and permits excellent momentum resolution in the forward direction. The beam current must however be limited to avoid excessive distortions of the drift field due to the slowly drifting positive ions created in the primary ionization. This operation will require a very efficient gating grid to prevent leakage of the non-interacting beam tracks into the gas amplification region where they generate additional positive ions. Prototype TPC tests in the HISS magnetic field have demonstrated that a low intensity Au beam does not cause serious problems even when there is no gate to exclude the electrons. The second class of experiments, those requiring large beam intensities, will need a beam pipe inside the TPC to isolate the heavily ionizing beam particles from the active gas volume. In this mode large solid angles will still be available for studying kaons or for other low cross section measurements such as momentum distributions far out on the tails.

The specific design parameters and performance of the TPC were checked in simulations. Special attention was given to those areas where the application of TPC techniques in a high multiplicity environment are more demanding or difficult than previously encountered in existing TPC's. The pad size and layout were optimized for two-track, momentum and dE/dx (charged particle identification) resolutions, using the simulations and the measurements made with the prototype TPC.

MECHANICAL DESIGN

The HISS TPC, sketched in Figure 1, is a single rectangular box centered in the HISS dipole. The detector is configured as a drift volume enclosed with field cage panels on the sides and a single proportional wire chamber - pad plane on the bottom. The active drift volume is 150 cm long in the beam direction, 96 cm wide in the bending direction and 75 cm high in the drift direction. The detector is encased in a relatively light weight skin for gas containment and thermal isolation.

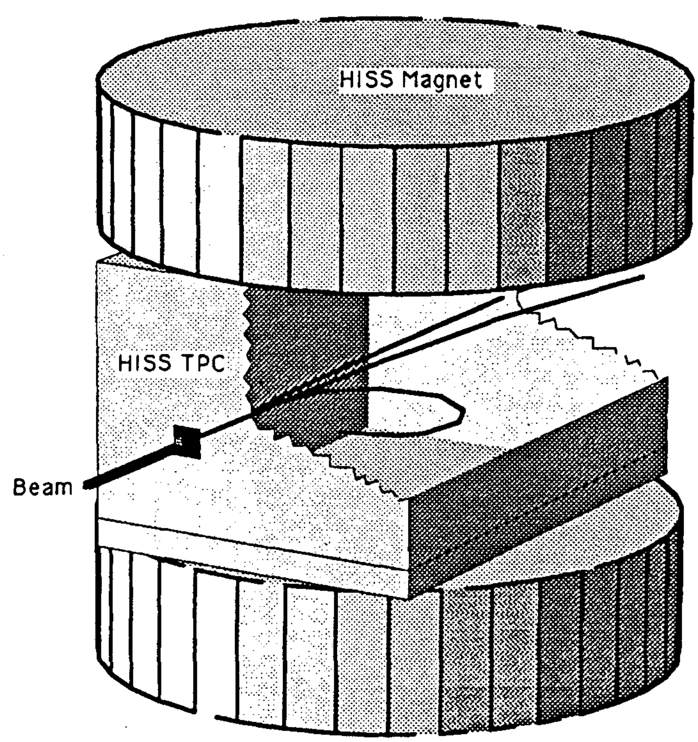

Figure 1: HISS TPC diagram. The E and B fields run vertically such that the primary ionization electrons drift down to the pad plane.

The pad plane is a single panel with an array of 1.2 cm × 0.8 cm pads covering a 96 cm by 150 cm rectangle (15,360 pads total) as depicted in Figure 2. The geometry of the wire planes over these pads will be essentially the same as used in the PEP4 and TOPAZ detectors: the first plane consists of alternating field and anode wires, the next plane is an isolation grid, and the third plane is a gating grid. The latter passes drifting electrons for the accepted events only and thereby limits positive ion build up in the drift volume. The anode wires will normally be operated at around 1170 volts to give a gas gain of 3000, but they will be divided among 16 separate power supplies to permit sections to be operated at reduced gas gain for analysis of tracks from heavier, more strongly ionizing particles.

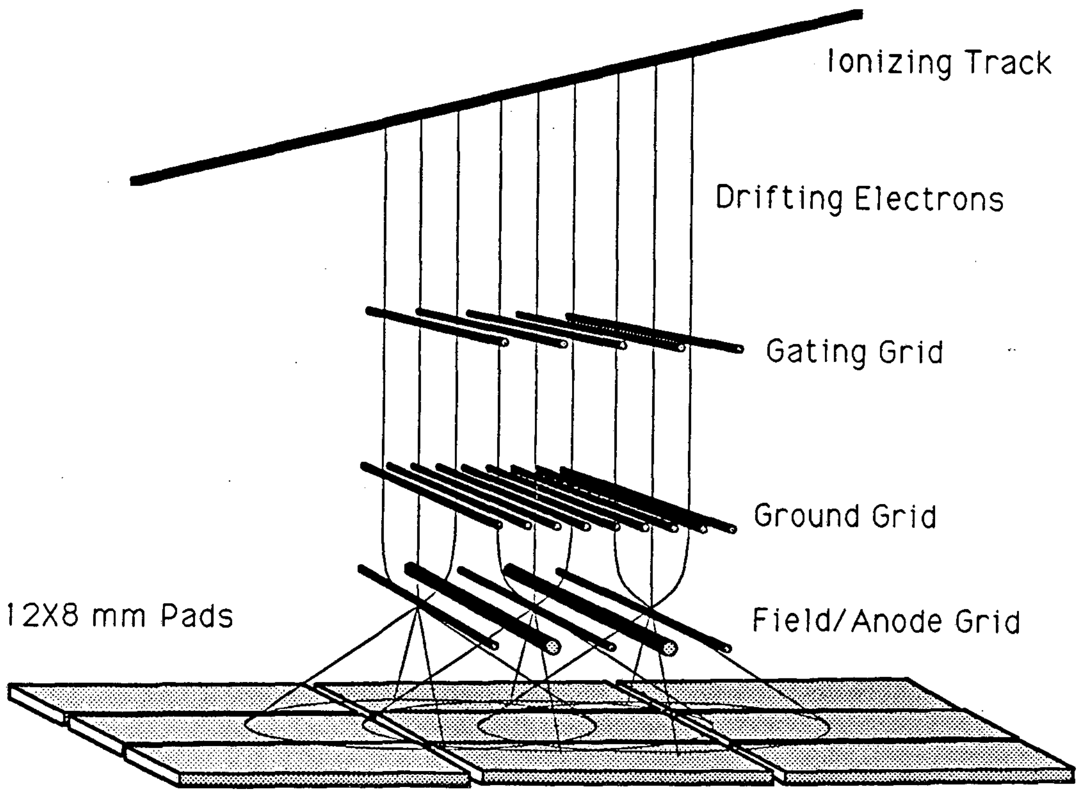

Figure 2: HISS TPC Wire and Pad plane layout.

The design of the field cage is derived from that of the ALEPH detector. It will be fabricated using kapton clad on both sides with copper strips. The copper strips alternate such that the thin exposed bands of kapton are backed on the opposite side with copper. Tests are in progress exploring the possibility of forming panels from two of these kapton/copper sheets with a Rohacell core. The cage will be constructed from four of these light weight panels set back about 5 cm from the active pad region, thus avoiding the local field distortions near the surfaces of the cage. In the low beam intensity configuration thin entrance and exit windows will be provided for the beam. In the high beam intensity configuration the field cage-box will be divided into two separate cages on either side of the beam.

The drift field for 90% Ar plus 10% CH_4 (P10) at atmospheric pressure is 130 V/cm. Thus a total bias of 9 KV will be required for the field cage.

ELECTRONICS CONFIGURATION

It is quite obvious that an electronic system for 15,360 pads cannot be constructed in the traditional way, where the preamplifier resides on the detector and the signals are transferred individually by cable off the detector for further processing. Recent progress in analog VLSI electronics encouraged us to choose a different design for the HISS TPC that would have a number of significant advantages. The most important advantage in the VLSI approach is the ability to accomplish amplification, shaping, analog storage, a high degree of multiplexing and digitization immediately on the pad plane. The resulting cabling reduction saves valuable vertical space between the pole tips. The remainder of the electronics can be contained in one or two racks, thus avoiding the need for additional housing and greatly reducing installation and maintenance problems and overall cost. Figure 3 shows a block diagram of the electronic system that will read out and process the data from 15,360 pads.

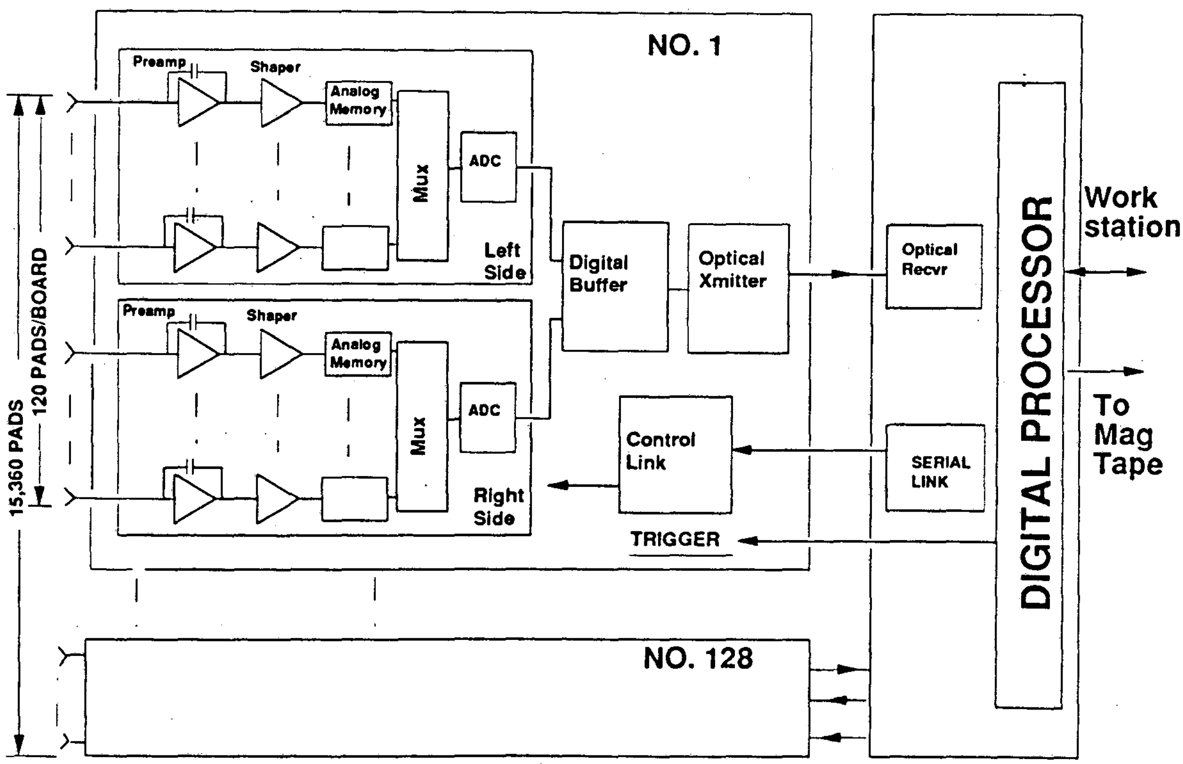

Figure 3: Block diagram of the complete HISS TPC electronics that will read out and process the data from 15,360 pads.

Great care has been taken to keep the connections between the pads and the preamplifiers as short as possible in order to obtain an optimal signal to noise ratio. This is achieved by mounting the electronic components on a "stick" that is inserted into card edge connectors (zero insertion force) directly connected to the individual pads. Each stick services two rows of pads (a total of 120 pads) across half of the width of the chamber. 15 hybrid circuits are mounted on each side. A hybrid contains an integrated 4-channel preamplifier and four discrete shaper-amplifiers. The shapers are designed to restore the baseline of the signals with a time constant of about 250 ns and to compensate for the tails generated by the slow drift of the positive ions. The hybrid occupies a height of about 10 cm between the pad plane and the pole face of the HISS magnet. In a multi-layered printed circuit board structure the output signals of the shapers are guided to the end of the stick where they are written into a 256-cell deep analog store (CCD) at a rate of 10 MHz. Thus each cell contains information about a drift space of 5 mm (100 ns). All 256 cells of the 60 CCD's on each side of the stick are multiplexed and digitized by a common ADC with a frequency of 1.25 MHz. The digital information from the two ADC's is sent off the detector via an optical link for further processing.

Two requirements drive the specification for noise and dynamic range of the pad read out electronics. Good position resolution for minimum ionizing particles is the first requirement. Position measurement is achieved by fitting a pad response function to the signals from two or more pads. This procedure places demands on both noise and digital resolution. The second requirement is a large dynamic range in dE/dx to include measurements of highly ionizing particles. To accommodate these two requirements the system has been designed with the maximum practical dynamic range and the TPC will be operated with the minimum gas gain required to achieve the desired position resolution.

The signal on a pad for a minimum ionizing track passing directly over the pad center is 11000 electrons. This number corresponds to the most probable value in the dE/dx distribution when a gas gain of 3000 is used. The expected noise on the preamp is 600 electrons rms and the final system noise is 700 electrons. This yields a most probable minimum ionizing signal/noise of 16:1 which is more than adequate to achieve 300 micron position resolution.

The dynamic range (maximum signal/noise) of the complete electronics system is 1400:1, that is the maximum signal is 90 $\times$ the most probable minimum ionizing signal. This dynamic range will allow dE/dx measurements for ions with charges as high as oxygen. By running sections of the chamber at a gas gain of 33 it will be possible to span a range in dE/dx from minimum ionizing to Au ions at 1 GeV per nucleon as demonstrated in Figure 4.

DATA ACQUISITION

Data rates are a major concern when implementing a data acquisition system for a detector of this size. Simulations with events with 200 tracks (central collisions of 1 GeV Au on Au) show that between 10-20 % of the pixels in the TPC volume will contain signals above threshold. Allowing two bytes per recorded pixel and including required addressing information, these events will be approximately 0.5-1.0 Mbytes in length. Combining the expected data rate of 10 events per spill with the expected spill rate of one spill per 5 seconds, we reach an aggregate recorded data rate of 1-2 Mbytes per second. Current large volume storage media (e.g. 8mm digital tape) will operate at sustained rates of approximately 250 Kbytes/second. Operating a number of these devices in parallel (5-10 units) will yield the desired recording speeds.

The design of a data acquisition system to achieve the above recording rates will require careful placement of processing, memory and recording elements. In order to achieve the necessary throughput we will use a VME-based system to read out, format and record events onto 8mm digital tape. With few exceptions, the system will utilize commercial components arranged in six interconnected VME crates. Four of these

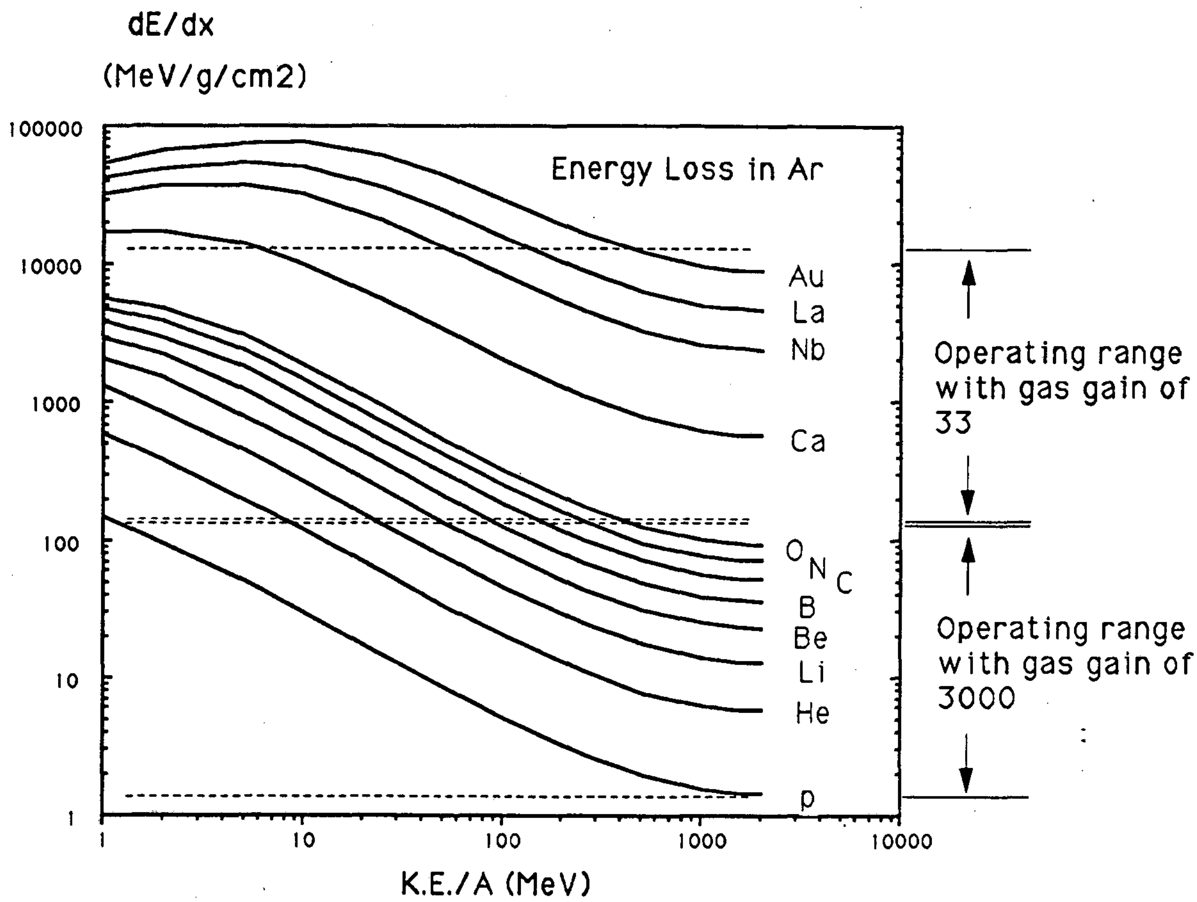

Figure 4: dE/dx versus kinetic energy per nucleon for a variety of ions. The dynamic range of the TPC electronics is shown for two different gas gains

VME crates will operate in parallel - each receiving and processing data from a different portion of the chamber. The remaining two VME systems will collect resulting data from these four systems and record it onto tape.

The progression of data from pad plane to tape is, roughly, as follows: Pad signals are amplified, shaped, stored and digitized by hybrid circuits located near the pad plane. The resulting data are then transmitted over optical fiber to off-chamber electronics located in an adjacent experimental area. Custom designed VME interfaces receive these digitized signals and store them in local memory buffers. A dedicated digital signal processor (DSP) applies pedestal and gain corrections to these signals and, after possible digital filtering and suitable data compression, moves them into dual-ported memory buffers connected to a VME bus interface. Data is read out of these buffers using a commercial VME processor and collected into one of a set of larger spill buffers. As their name implies, these large dedicated buffers will contain all the data associated with events of a single spill. Data from each of these buffers is written to an individual tape unit, thus achieving the required degree of parallelism.

Since scientific workstations currently offer substantially better computational performance than larger mini-computer systems, we plan to use workstations to perform on-line analysis. The high quality video subsystems on these systems will provide the required data display capabilities. On-line analysis programs will obtain events or, more typically, selected portions of events, via an ethernet link that interconnects all of the processors in the system. During data taking, events waiting to be taped will be available for selection and analysis by a number of workstations.

PROTOTYPE TPC

A small TPC borrowed from the PEP-4 group [6] has been modified to test the TPC design which utilizes complete pad coverage. The immediate goal was to demonstrate tracking and particle identification using only pad information. This test TPC, originally developed to study electrostatic field cage distortions, has a rectangular geometry (approximately 40 × 40 × 40 cm) with a drift length of 30 cm. Tracks drift down to the avalanche region which consists of two wire planes and a pad plane. The top wire plane, which is at ground potential, is a grid of 75 μm wires on a 2 mm pitch. This grid separates the drift and amplification region. The second plane, the avalanche plane, is located 4 mm below the grid and is composed of alternate field wires (75 μm) and sense wires (20 μm) set on a 2 mm pitch. The pad plane is located 4 mm beneath the field/sense wire plane and completes the confinement of the avalanche cells.

The pad plane consists of 256 pads arranged in two different ways. In the first set there are 8 rows of 16 pads whose size is 8 mm x 8 mm. Each row is displaced 4 mm from an adjacent pad to study a staggered pad geometry. The second group of pads consists of 12 mm x 6 mm pads.

The electronics for this test system are 256 channels of PEP-4 electronics. Each pad signal is recorded into CCD's at 10 MHz and read out into ADC's at 20 KHz. The read-out electronics can at most store 4000 words per events. As a result, in order to store data from a trigger, it is first necessary to do a threshold cut on the data in the electronics. As the pedestals from the CCD's are not constant with time, the threshold cut removes useful data. A more sophisticated cut will be made in the HISS TPC so that results from the HISS TPC should be better than the prototype.

The prototype has been studied at the Bevalac using He and Au beams. The chamber performed as expected during each of the tests. Resolution studies have shown that the measured standard deviation for a track can be as low as 0.250 mm depending on the signal to noise ratio and the track angle. Tracks were studied from 0 degrees to 90 degrees over a variety of signal to noise ratios and analysis is in progress.

Tests with a low intensity 600 MeV per nucleon Au beam have demonstrated that the chamber does not experience electrical breakdown when a highly ionizing particle passes through the active volume. This test was performed without a gating grid. From analyzing the Au tracks, we conclude that tracks which are more than a few cm away from the beam particle should be fully reconstructible.

SUMMARY

The HISS TPC will greatly expand detector capabilities at the Bevalac. It will provide the ability to completely measure most of the charged particles emitted from central collisions with the heaviest and highest energy beams at the Bevalac. Three dimensional tracking makes possible the unfolding of high multiplicity events with as many as 200 charged particles. Good tracking resolution in the HISS dipole and dE/dx information provide momenta and particle identification for most of the p, d, t, ^{3}He and ^{4}He ions emitted. A substantial fraction of the charged pions will also be measured. These capabilities can extend flow and entropy studies to full energy Au + Au collisions. They will also permit analysis of two particle correlations and make possible measurements of triple differential cross sections into the tails of the momentum distributions. In addition the system can be used to study a great variety of other interesting processes, like *e.g.* multifragmentation.

This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Division of Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

References

[1] A. Sandoval, R. Bock, R. Brockmann, A. Dacal, J.W. Harris, M. Maier, M.E. Ortiz, H.G. Pugh, W. Rauch, R.E. Renfordt, F. Riess, L.S. Schroeder, R. Stock, H. Ströbele, and K.L. Wolf, Nucl. Phys. **A400**, 365c (1983).

[2] H.H. Gutbrod, A.M. Poskanzer, and H.G. Ritter, LBL-Preprint LBL-26922, to be published in Rep. on Prog. in Physics.

[3] R.W. Minich, S. Agarwal, A. Bujak, J. Chuang, J.E. Finn, L.J. Gutay, A.S. Hirsch, N.T. Porile, R.P. Scharenberg, B.C. Stringfellow, and F. Turkot, Phys. Lett. **B118**, 458 (1982).

[4] W.F.J. Müller, G. Bauer, H. Beeskow, F. Bieser, W. Christie, U. Lynen, H. Sann, and C. Tull, 8th High Energy Heavy Ion Study, LBL-24580 (1987).

[5] H.G. Pugh, G. Odyniec, G. Rai and P. Seidl, **LBL-22314** (1986).

[6] M. Iwasaki, R.J. Madaras, D.R. Nygren, G.T. Przybylski and R.R. Sauerwein, Time Projection Chamber Workshop, TRIUMPF, Vancouver, B.C., Canada, AIP Conference Proceedings **108**, 214 (1983).

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
1 CYCLOTRON ROAD
BERKELEY, CALIFORNIA 94720