SSC-PC-024
119 PAGES

SSC Detector Subsystem Proposal
Central and Forward Tracking with Wire Chambers

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Outline of Proposal

1. SUMMARY OF PROPOSAL

Hardware

We are proposing to carry out detailed studies of a wire chamber tracking system for the SSC. The system will include a complete design for both the central tracking system and the intermediate tracking region, as shown schematically in Fig. 5.1. The design will include the drift cell designs, envisioned at the onset to be small cells for the central tracking and possibly radial wire chambers for the intermediate region. In the central region small cells will be grouped in superlayers in order to give track segments. We will investigate the support structure and develop techniques for precise mechanical alignment of the complete tracking system. Mechanical design studies will also include evaluation of materials, thermal studies, and engineering studies of fabrication processes.

The geometry of radial wire chambers may make them a good choice for tracking in the intermediate region. In addition, as exemplified by those for the H1 experiment at HERA, they offer the possibility of electron identification by transition radiation detection within the same tracking volume. We propose to investigate the possibility of using radial wire chambers for intermediate tracking at the SSC. Straw tube chambers offer yet another possibility for transition radiation detection as part of an SSC tracking system.

Front end electronics for wire chambers at the SSC must be fast and have low noise and power dissipation. We will develop front end electronics for wire chamber tracking systems at the SSC. A great deal of R&D along these lines has already been carried out by some of the proponents. We will test prototypes of front end electronics on prototype wire chambers. We will investigate the layout of the electronics for the chamber system, including on-chamber signal processing and segment finding. We will include a system for determining the axial position of each hit and the bunch number using superlayers of small-angle stereo wires.

We propose to fabricate full-scale modules of chambers for both the central and intermediate tracking systems, concentrating on fabrication techniques that will be required for assembly of the complete system. The full-scale modules will be used to test alignment and support systems. We will also carry out investigations of gas properties in a 2 Tesla magnetic field. The overall tracking system design will be closely coordinated and studied using tracking simulation programs to evaluate and predict performance.

Software

We will continue the studies of tracking systems for the SSC using and improving the computer simulation software developed by some of the proponents. The work will include:

- More realistic effects in the simulation, such as the effects of $\mathbf{E} \times \mathbf{B}$ on electron drift in straw tube drift chambers and time of flight for looping tracks in the magnetic field.
- Continued studies of pattern recognition and track finding, including the intermediate tracking region, measurement of the coordinate along the wires, and possibilities for triggering.
- Tracking simulation of radial wire chambers, with particular attention to the measurement of the coordinate along the radial wire and finding high-p_T track segments for the trigger.
- Detailed studies to optimize the overall tracking system, including varying the tracking system parameters such as cell radius and number of layers in a superlayer, effects of dead areas at cell and module boundaries, need for pad readout, boundary between central and intermediate tracking, integration with silicon detectors, and value of the magnetic field.
- Determination of tracking efficiency and momentum resolution for the overall tracking system for various physics processes: isolated high-p_T tracks in complex events, high-p_T jets, new heavy quarks, etc.
- Putting together several components of a detector, such as calorimetry and muon system, in a single simulation to determine how well events from

interesting physics can be identified and measured.

2. CENTRAL TRACKING HARDWARE R&D

2.1. Straw Chambers

The central tracking group at SNOWMASS 86 considered many aspects of tracking at SSC. [1] They looked at several drift chamber designs. In particular , they compared a cell defined by cathode wires and an enclosed cell, 'straw chamber'. It was found that a continuous cathode chamber made from mylar straws would introduce no more absorber than an open wire chamber and could have less material than the conventional design. They also considered the safety features of enclosed cathode systems for large wire systems, such as isolation of wire breakage, and immunity to noise and concluded that they were superior. We are proposing to do a detailed study of an enclosed cell tracking system for the central tracking region. In the intermediate region we will develop a design based both on radial chamber design similar to a H1 design and straw tubes .

Cells

The heart of the tracking chamber is the drift cell. We will concentrate in this proposal on a continuous cathode design. The continuous cathode design should guarantee that chamber ageing be slow, assuming a wise choice for the gas has been made. There are other practical advantageous to a tubular design. The tubes are physically and electrically isolated from one another. This isolation is especially important for 350,000 cells ,where in an open design one broken wire could put the entire chamber out of service. The cathode arrangement will also allow wire supports along the length of the straw. These will reduce the wire tension requirements. In this design each module can support its own wire tension, so that the superlayer support and end plate requirements are reduced considerably from a conventional design.

The optimum size of a drift cell at the SSC has been discussed in the SNOWMASS meetings and at the Vancouver Tracking Workshop. For wires to survive at distances of 0.5 meters from the SSC beampipe the cells must be no larger than 4 mm. On the other hand the cells much smaller than 4 mm will suffer from poor efficiency due to limited track ionization length and from electrostatic stability problems. We have studied these SSC requirements. The results are given in the next section.

2.2. Rates and Occupancies at SSC

Assuming the design luminosity of SSC to be 10^{33} cm^{-2} sec^{-1}
and using an interaction cross section of 100 mb, the charged particle rate per unit area can be expressed as

$$\frac{\partial N_{ch}}{\partial A} = \frac{120 \text{ MHz}}{R_\perp^2}$$

where $R^2{}_\perp$ is the distance from the beam line in centimeters.

The particle rates, occupancy and current can then be calculated for drift cells parallel to the beam. This was done assuming that a drift cell subtends a fixed polar angle, taken to correspond to a pseudorapidity , η_{max} , of 2.

Counting rates in each wire

The particle rate for a fixed rapidity straw is given by

$$N = \frac{2*D*\eta_{max}*1.2*10^8}{R_\perp}$$

where D is the cell diameter. The plot of this is shown in Figure 2.1.

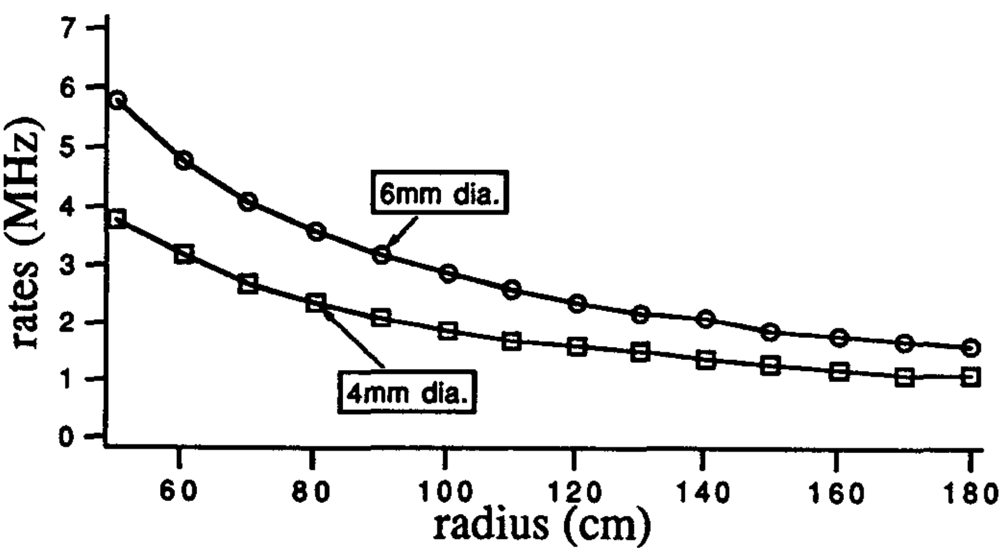


Fig. 2.1

The rate is about 4 MHz at 50 cm from the beam for a 4mm cell spanning to $\eta_{max} = 2.0$.

Occupancy

The occupancy of the cell can then be calculated from the ratio

O= Drift time/ ave time between hits = Drift time* rate of hits

This is shown in Figure 2.2 . A total drift time plus recovery time of 61 ns was used for the 6 mm straw and 42 ns for the 4 mm straw.

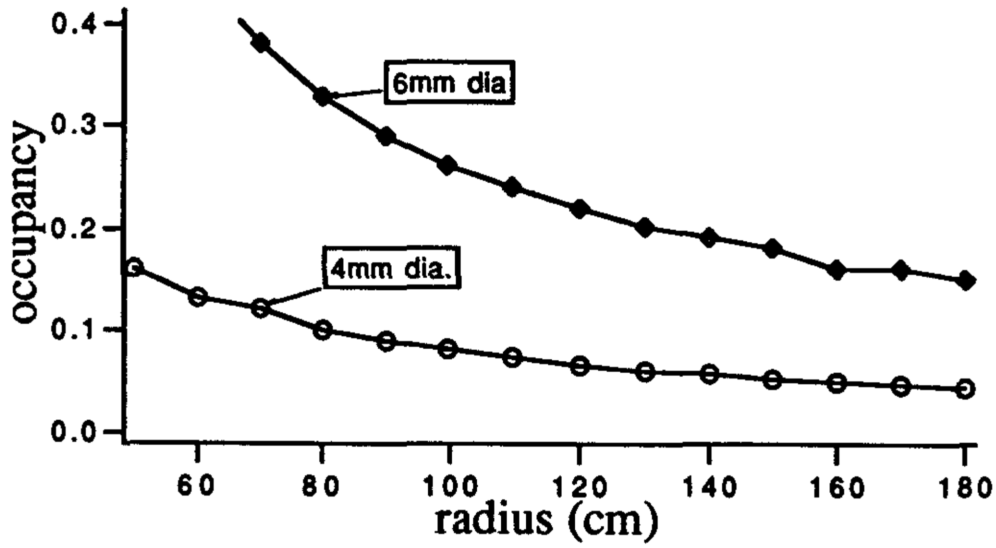


Fig. 2.2

We now begin to see some of the constraints on cell size at SSC. At 50 cm from the beam the 4mm full length cell will have a 16% occupancy. This is too high to allow efficient tracking. A simple way to remedy the situation is to cut the cell length in two, ie., use two cells to span the full length. Each cell then spans half the detector, or $\Delta\eta$ of 2. It is also clear that cell sizes greater than 4mm will cause occupancy problems at all radii.

Current draw

The current draw for each cell can be easily calculated, also, once the rate in each cell is known.

I = N * e* 100 ion pairs/cm * track length* gain

This assumes a ionization of 100 electrons / cm. The track length is calculated for particles coming from the intersection point averaged over the entire cell. This is plotted vs distance from the beam in Figure 2.3.

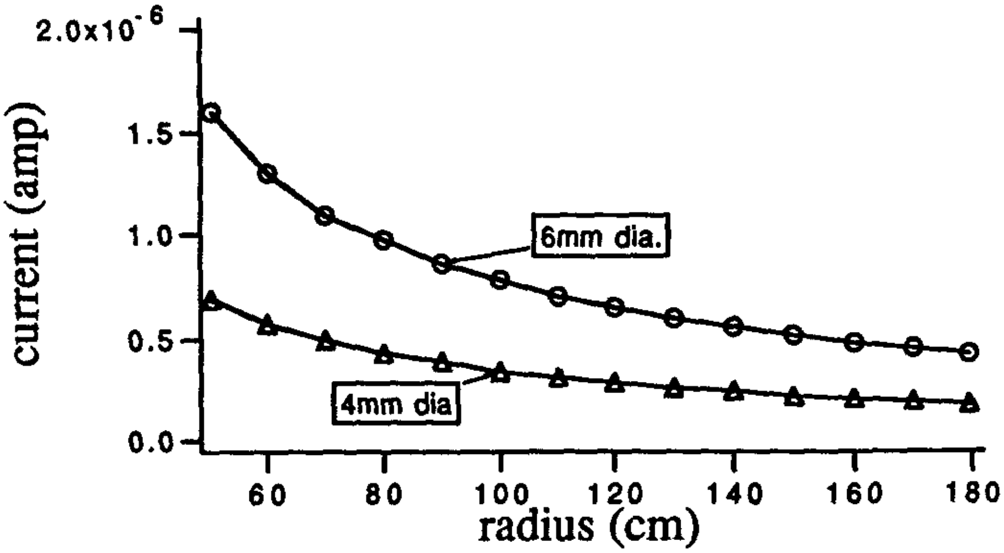


Fig. 2.3

The gain in this plot was assumed to be 2×10^4. It is assumed that current draw in any straw much above 0.5 microamps will be unacceptable, so current draw again presents a cell size limitation at SSC and the cell length may have to be divided in two to keep the currents manageable. As we will discuss later, this current draw also has the unfortunate property of heating the gas; at typical voltages of 2000 V we expect about 1mW of power delivered to each cell.

Chamber lifetime

A constant source of concern at SSC is radiation damage to detector components. One aspect of this problem for design of a drift cell is the total charge/cm for the lifetime of the chamber. There have been extensive studies of this problem for both MWPCs and drift chambers. In particular there have been some studies of fast gas mixtures such as CF_4 and isobutane.[2] These studies show that chamber lifetimes above 0.2 C/cm can be expected. The current draw calculated in the previous plot can be used to determine the charge/cm as a function of the radius for a 5 year running period (5×10^7 sec). This is shown in Figure 2.4.

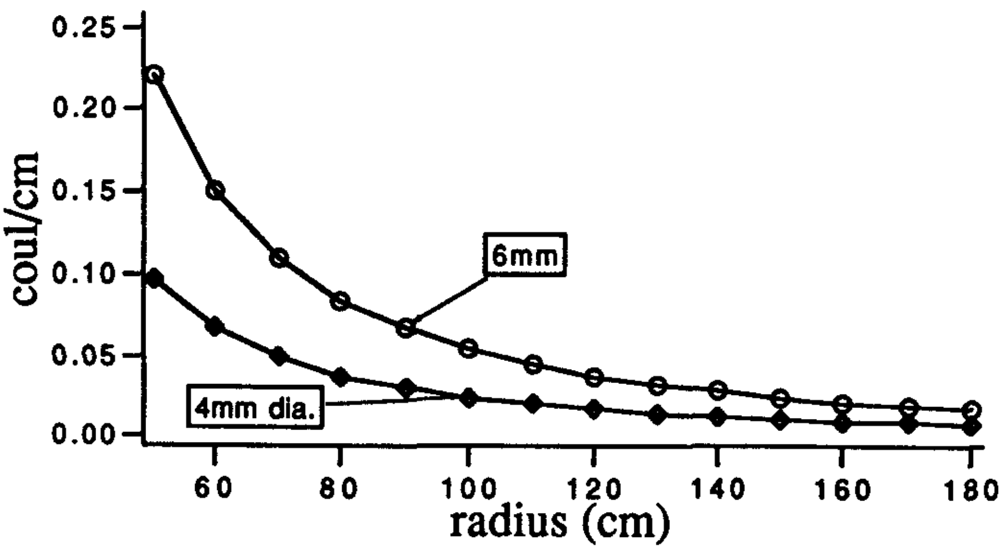


Fig. 2.4

As can be seen, the lifetime of the wires should not be a problem if 4mm cells are used at small radii.

2.3) Gas Studies

As part of an ongoing SSC R&D effort at Indiana University we are studying the properties of 4mm straw tubes. The ionization and drift properties of the various gases, which might be used in the tracking drift chambers of SSC detectors, needs further study. The reason for this is that the short time between beam crossings dictates a short ionization collection time which in turn suggests that gases with high drift velocity be used as well as very short drift cells.

The fastest gas we have tested to date is CF_4 . The full drift time of a 2 mm radius is about 18 ns. The raw tdc time distribution is shown in Figure 2.5.

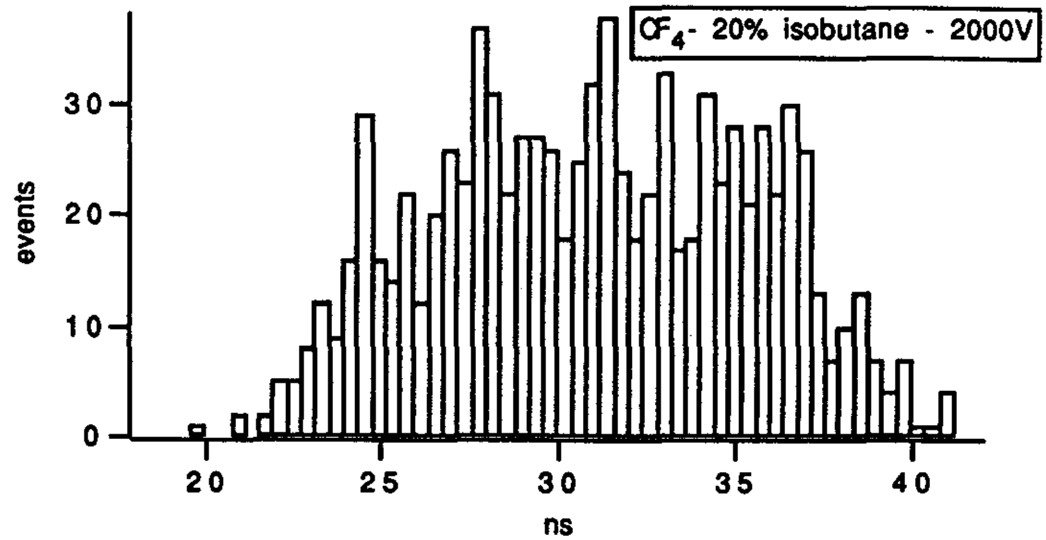


Fig. 2.5

CF4 however has well known problems with electron attachment. For that reason we have followed the example of others [2] and used a 20% isobutane mix. The optimum quenching agent and percentage is one of the objects of our study. The efficiency for the unmixed and mixed gases are shown in Figure 2.6.

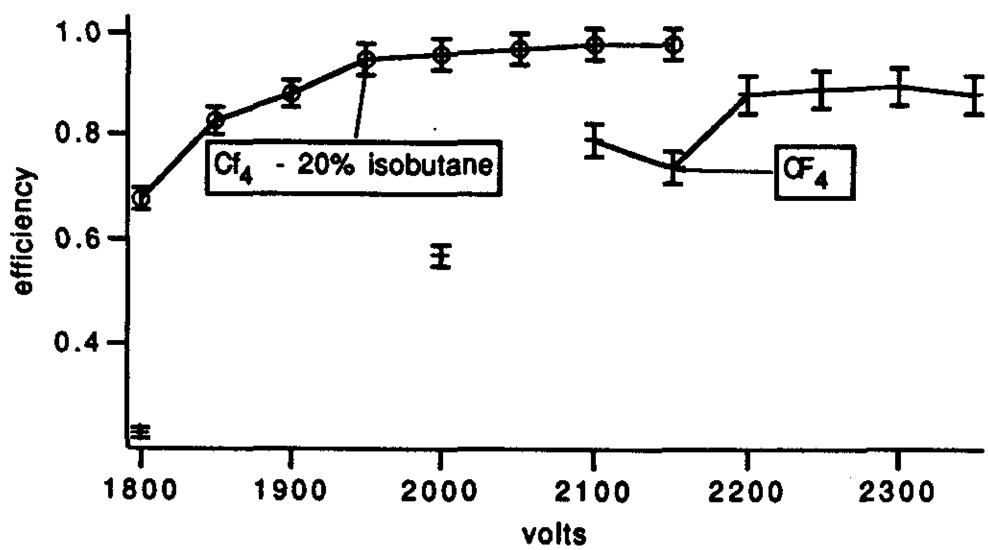


Fig. 2.6

The 4 mm straws plateau at about 96% efficiency. This corresponds to the wall thickness of 40 microns and a 40 micron inefficient region where the path length is less than 300 microns and the cluster statistics is poor.

The tubes were constructed in a triangle of six straws. The average resolution was measured by fitting a comic ray through three tubes. This resolution is shown in Figure 2.7. The average resolution for the entire straw is 105 microns at 2100 Volts at atmospheric pressure.

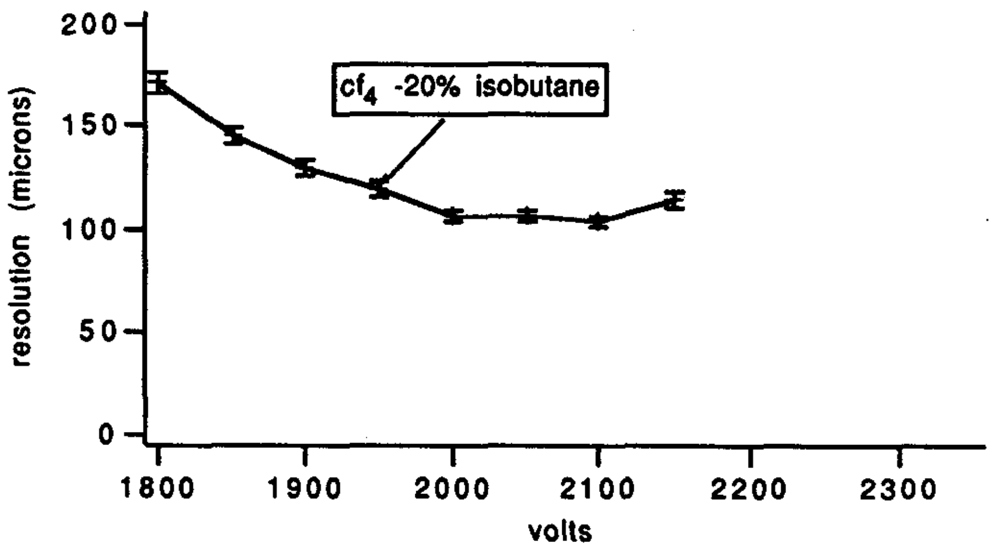


Fig. 2.7

For this measurement the tubes were operated with a gain approximately 5 x 10^4 and an amplifier threshold of .7 mv into 500 ohms. This resolution number also includes possible misalignment errors of the straws, which were self centered in a triangular wedge.

Magnetic Field tests

The drift in a high magnetic field is slower than when a magnetic field is absent.The Lorentz angle, however, depends on the gas, as well as the electric and magnetic fields, so there might be an optimum gas mixture that would minimize the drift time. The requirements of SSC detectors are consequently sufficiently different from the usual requirements of small diffusion and slow drift that it is necessary to re-evaluate the properties of known gas mixtures and search for even more suitable gas mixtures. As part of an SSC R&D project we are making a systematic study of the properties of many gas mixtures, some which have already been studied fairly well but not at magnetic fields as high as 2 T, some which have recently been suggested and some new ones as seems appropriate.

We are measuring the drift velocity and angle of drift at various electric and magnetic fields up to at least 2 T. The basic gas parameters, such as the electron mean free path, can be extracted from these measurements. The method is similar to that of a recent FNAL measurement. [3]

A test drift cell with uniform electric field is being constructed . It will be placed in a uniform magnetic field using a research magnet in operation at Indiana University. The research magnet has been tested at fields up to 2.3 T . It appears that the field uniformity will be adequate for this test. The source of ionization will be an UV laser. This is very convenient because the timing of the light pulse is easily detected and the ionization path is well collimated. The laser has been ordered and the necessary test setups are being designed.

2.4. Mechanical tests on straws

Wire stability studies

The electrostatic stability of a wire in a straw is a function of the tension on the wire. The linear term in electrostatic force due to the attraction of the wire to the cathode when the wire is off center is given by

$$F=\frac{2\Pi\varepsilon_0 V^2\delta}{[\ln(\frac{R}{r_0})]^2 R^2}$$

where V= Voltage, R= cathode radius, r = wire radius, δ= displacement from center. Assuming that the wire will have a sinusoidal shape, and imposing the boundary conditions that the wire is fixed at both ends gives the condition on the wire tension for stability:

$$T > \frac{2\varepsilon_0 V^2 L^2}{\pi R^2 \ln(R/r)^2}$$

where L is the wire length.

For a 2 mm radius tube and a 12.5 μ wire this condition is

$$T > 5.6 \times 10^{-6} V^2 L^2 \text{ gm}$$

This is the minimum theoretical tension (in grams of force) required for stability and is plotted vs length in Figure 2.8 for a 2 mm radius tube,

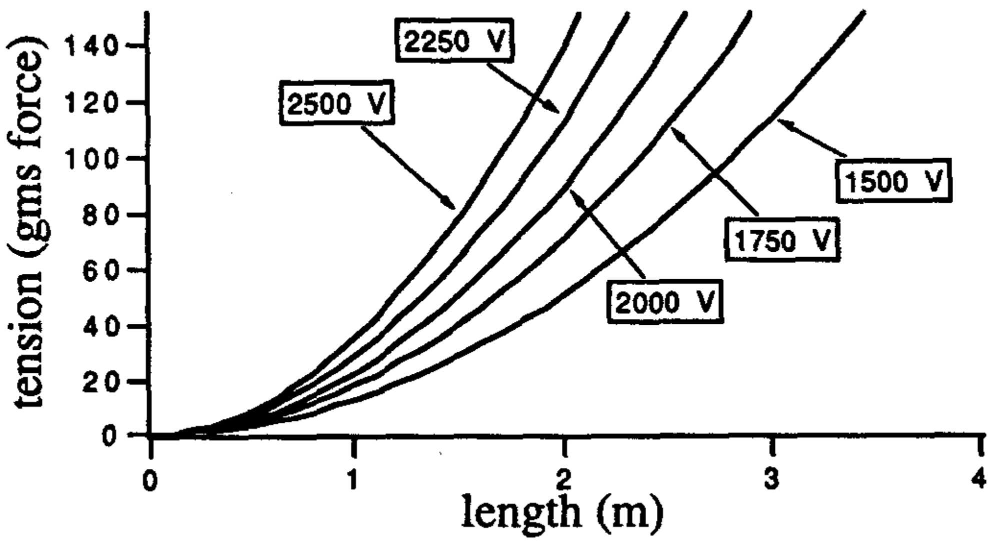


Fig. 2.8

We have measured the onset on wire instability in a 4 mm straw. The results are shown in Fig. 2.9.

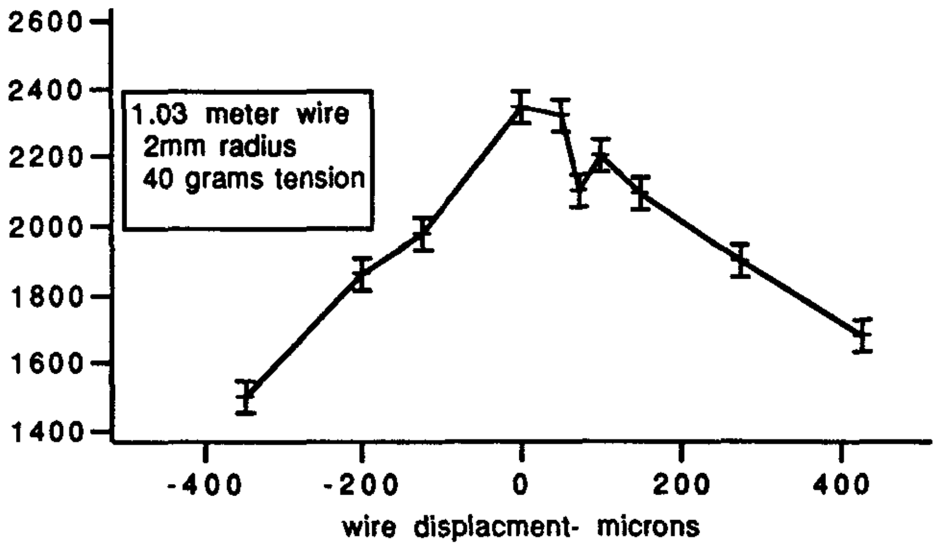


Fig. 2.9

This measurement has been performed on a 1 meter straw in our laboratory. The straw was held rigidly in a horizontal position, while the central wire could be moved at either end by means of precision XY translators. Figure 2.9 shows the onset of wire instability (Voltage) versus the vertical displacements of the wire. We calculate that the wire sag is about 30 microns at 40 grams. This may be partially responsible for our inability to reach the calculated instability point: however, it indicates that by holding position tolerances to about 50 microns, we can safely plan on 1 meter suspension points for tensions of 60 grams. These measurements will be repeated for longer tubes and more realistic structures.

We will also begin an active design and testing program for wire spacing devices. We anticipate that during the first year of the proposal we will have several designs fabricated by a local extrusion molding company for evaluation .

Straw dimensional studies

Since the individual straws are quite flexible, they must be glued together to form a rigid, self supporting structure, or some other technique must be devised to provide an equivalent structure.

We have begun some tests to determine the rigidity of straw tube structures. At UCD a few sample beams have been made from 4.3 mm diameter straws. (UDC- internal Report-Dye,Lander). The straws were wound from two layers of 1 mil mylar. They were glued in a jig to form a beam. The beams were of a rectangular cross section, 3 straws wide and either 8 or 16 inches high, in an hexagonal array. The deflection of such a beam, supported a distance L apart, when loaded by a weight suspended at the midpoint is given by

$$Y = L\,(\text{load}/48 + W/76.8)/K$$

where W is the weight of the beam, and K is a constant depending on the material and the geometry of the beam. The change in Y with load determines the value of K, from which the sag of the beam under its own weight can be determined. The initial measurements found that a 3x8 straw beam with a 60 cm length would sag by about 100 microns. Increasing the section to 12 or 16 tubes vertically would reduce this, but free spans of more than a meter are probably not possible with simple glued straw structures. This work will continue and be coordinated with the mechanical design engineers at Westinghouse.Many of these same areas of development will be discussed in section 5 .

2.5. Signal Attenuation studies

We have measured the attenuation of signals in a 2 meter straw and compared it to a calculation based on an straw impedance of 300 Ω, a wire resistance of 90 Ω/meter, and a cathode resistance of 100 Ω/meter. This is shown in Fig. 2.10.

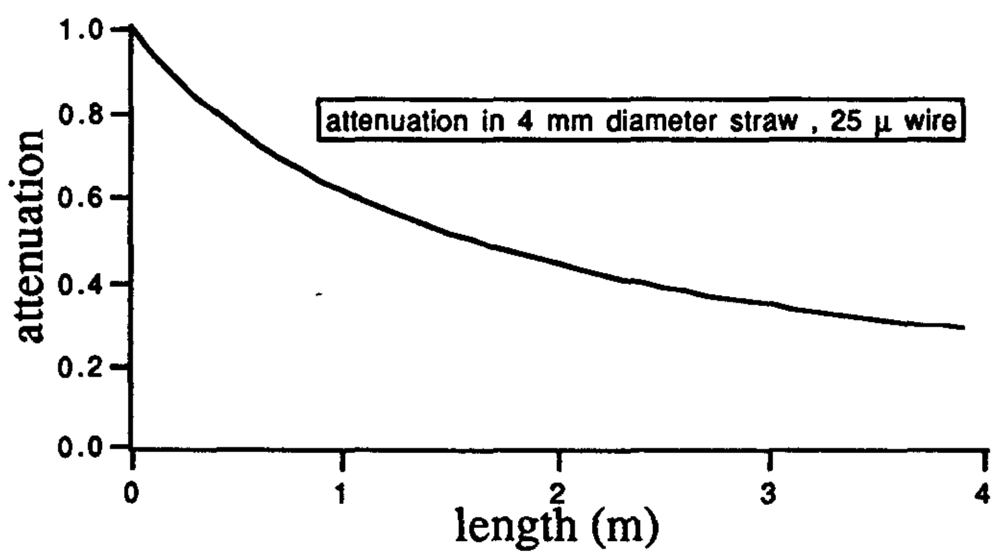


Fig. 2.10

We will work on the attenuation measurements during the course of this proposal. With increased wire size and with alternative cathode materials we hope to be able to reduce this somewhat. Measurements with straws up to 4 meters in length will clarify whether this is a problem.

2.6) Z Reconstruction

We have also been studying the methods of obtaining a Z coordinate on individual straws. This is important for both track pattern recognition and track reconstruction resolution. For the former, the Z readout is much more useful if it can be done on individual straws, for then it provides a space point on the track. This may be particularly useful in the forward direction. The effect of the Z readout design on the overall track recognition at SSC will be one of the topics covered in computer simulation.

One method to obtain a Z coordinate uses the spiral winding of the cathode as a delay line (UCD report 9-89). A 60 cm long test array of 36 straws at UCD gave a Z resolution of a few centimeters. Further studies will be done to improve this resolution and to determine cross talk characteristics of the array. A second technique under study is the use of vernier charge division cathode pads. These offer the possibility for good space resolution and fast readout. A major hurdle is the method of applying the aluminized pad patterns to the straws. Spirally wound straws do not readily lend themselves to techniques involving pre-printing patterns on the strips that form the straws. If tubular arrays could be formed from two layers of sheets, a technique that Los Alamos will investigate as part of this proposal, then a pad design for several selected super layers might be possible. Even a relatively crude Z coordinate could be of great help in triggering and track finding, so the feasibility of these approaches (and others) will be thoroughly examined.

2.7. Module and Superlayer construction

The major thrust of this subsystem proposal is to develop a tracking system for an SSC detector. This will require defining the drift chamber specifications by means of small module tests and then working with the engineering group at Westinghouse to develop a design for a module, superlayer, and support structure.

During the first year of this proposal we will extend the tests mentioned above to 2 meter and 4 meter modules. These tests will include mechanical tests on multitube arrays to estimate the structural rigidity of a module , measurements of cross talk in multitube systems, determination of gas flows, and power dissipation in the straws. This will identify areas for future development and allow a full scale design to be worked out. The details of the mechanical development will be discussed in section 5.

3. INTERMEDIATE TRACKING HARDWARE

3.1. Radial Wire Drift Chambers

Introduction

Track reconstruction at SSC is dominated by the problems of high multiplicity. Any meaningful consideration of how one would use track detectors for physics quickly leads to the conclusion that the major aims are identification of jets and leptons. At 1 TeV Burrows and Ingelmann[4] have shown that jet fragments are separated spatially by at least 2 mm when about 0.5 m from their production vertex. Gaseous drift chambers with flash digitisation have already achieved such two track separation.[5] Lepton measurement requires reliable and accurate spatial reconstruction and association of individual tracks with energy deposition in electromagnetic calorimeters and with hits in external muon filters. Electron/hadron discrimination can be enhanced in gaseous drift chambers if transition radiation (TR) is detected.[6]

One possible approach to achieve these aims in the intermediate tracking region of an SSC experiment is to use drift wires which are transverse to the beam axis. Each drift cell is optimised for the best possible spatial precision and the most uniform track and X-ray response. The combination of these distinguishing features plus multi-hit read-out in the form of flash digitisation or equivalent is essential if the power of such a detector is to be fully realised.

Such a system involves precision drift cells with both a linear drift time *vs.* distance relationship and a uniform track length throughout the drift cell. Operating, and thus proven, examples are many and varied, ranging from well established planar drift chambers to jet chambers used as central detectors in many contemporary collider experiments at LEP, CDF, SLC and HERA.[5,7] They all contrast with the much simpler cylindrical cells of straw chambers and such like in which the benefits of ruggedness and individual sense wire isolation are considered to override the disadvantages of non-linearity and less uniform response (see Sections 2 and 3.2).

Radial wire drift chambers provide the most efficient way of achieving such a transverse wire system in the intermediate tracking region of an SSC detector.

Principle Features of Radial Wire Drift Chambers

Radial wire drift chamber systems have been constructed for CDF[8] and are under construction for H1[9–11] (Fig. 3.1). The H1 chambers will operate in the solenoid magnetic field of 1.2 T. They have been designed to include the possibility of enhanced e/π discrimination by means of TR in an attempt to isolate electrons in the hostile multi-track environment of the forward proton region at HERA.[5] The latter provides an environment similar to that expected at SSC.

In a radial configuration of transverse sense wires, wires are strung along radii between an inner cylinder, or hub, and an outer cylinder, or frame, to form drift cells of variable maximum drift length (Fig. 3.2). Cathode planes consisting of voltage graded conducting strips maintain the constant drift field in the r-phi direction. Each drift "wedge" includes a number of such sense and field wires thereby providing vector track segments for efficient multi-track pattern recognition. Read-out is at the outer radius as far as possible from the interaction region. Like the (perhaps) more familiar jet chamber superlayers of central vector drift chambers, each sense wire with the cathode planes defines isochronous drift cells with uniform acceptance for primary ionisation.

The use of a radial wire configuration has many advantages:

- It fills the available space most efficiently, providing drift cells of smaller dimension at smaller radial distance from the beam pipe where track illumination is higher.
- It has azimuthal symmetry (barring small stereo modifications) which makes for balanced stresses in mechanical construction.

- In systems contemplated for SSC it will not involve supporting wires of length greater than about 1 m.
- The drift time measurement is an accurate determination of the track sagitta in the r-phi projection of a solenoidal magnetic field so that optimum track momentum resolution is achieved.
- Space point measurements are in principle possible by means of charge division or by including a small stereo angle by tilting the wire in the r-phi plane away from exact radii.
- Multi-track pattern recognition is optimised because track segments are related linearly in the measured space points as a function of z (the beam axis co-ordinate) in a constant solenoidal magnetic field.
- When combined with flash digitisation of pulse profile, the isochronicity and uniform ionisation acceptance of the drift cells make for the best two track resolution and particle identification.

Like all drift chambers, measurement of the co-ordinate along the sense wire direction (radially) relies on charge division or time difference. The H1 radial chambers operate with read-out at both outer ends of a pair of sense wires coupled round the inner hub. The precision of this measurement is dominated by signal to noise, i.e. gas gain, and so is complemented by additional drift chambers with parallel sense wires. This has the additional advantage of then resolving the other "classic" ambiguity of any sense wire, namely two hits at the same drift distance but at very different co-ordinate along the wire direction.

The H1 configuration is conservative, designed at a time when the concept of radial wires was not proven. The inclusion of a small stereo tilt of some planes of radial wires away from the true radii is now foreseen as an equally valid way of solving this problem. This avoids the need for a different (second) design of drift chamber in this intermediate tracking region, and resolves the ambiguities in a way closely analogous to stereo wires in central drift chambers.

The uniform ionisation deposition of measured tracks independent of drift distance in the radial wire drift cell is exploited for enhanced electron identification by TR X-ray deposition in the H1 experiment (Fig. 3.3).[12] The technique involves careful design of the upstream wall of the chamber for optimal X-ray transparency plus operation of the drift wedge with a dilute X-ray sensitive gas, $Xe/He/C_2H_6$, such that the spatial resolution of each sense wire is maintained at $\sim 150\ \mu m$ but with 100% X-ray detection efficiency. The multiwire sampling of both the dE/dx and X-ray photon ionisation leads to the discrimination shown in Fig. 3.3. Furthermore, the precise spatial determination of the reconstructed track segment, the hits of which are used in the e/π discrimination, means that much of the usual knock-on background which is present in many other TR detectors can be identified and eliminated. The final establishment for this technique and the degree to which it will facilitate electron identification in or near high-multiplicity jets will come with data from H1 in 1991.

Feasibility of Radial Sense Wires at SSC

The feasibility of different transverse wire configurations in the intermediate region ($1.2 < |\eta| < 2.3$) of a magnetic detector like the Large Solenoid Detector[13] were recently considered in some detail at the Vancouver SSC workshop.[10,14] Beyond a radial distance of 0.5 m from the beam, a radial sense wire configuration was found to be a realistic possibility as a track detector.

In a magnetic detector at SSC, the requirement of charge sign determination at 1 TeV specifies the necessary precision of momentum measurement to be 0.3 at 1 TeV. Given a 2 T solenoidal magnetic field it is possible to achieve this precision (Fig. 3.4) with an array of radial wires occupying the intermediate tracking region of Fig. 5.1 with a realistic density ($\sim$ 1 cm spacing) in z.[10,11,15]

As with any gaseous proportional wires at a supercollider, the over-riding criterion is survival in the high radiation environment. In all the estimates which we have made and which are here summarised no account has been made of radiation exposure other than due to the 100 mb of inelastic pp interactions in each bunch crossing. Beam-gas, beam-wall and beam halo are hard to estimate at this stage.

Table 3.1. SSC machine parameters used in operational estimates

Luminosity	10^{33} cm^{-2} s^{-1}
Bunch crossing interval	15 ns
Inelastic *pp* cross section	100 mb
Charged particle multiplicity	7 per unit rapidity
No. (*pp*) interactions per bunch crossing	1.6
Total interaction rate	100 MHz

Calculations for radial wires in an FTD like that of Fig. 5.1, in which each wire has an acceptance of ~ 1 unit of rapidity and is operated with a gas gain of 2×10^4 are summarised in Tables 3.1 and 3.2. A fast gas (~ 120 μm/ns), such as Ar/CF_4 or Xe/CF_4 mixture, is assumed with a primary ionisation of 100 ion pairs per wire. Then an SSC luminosity of 10^{33} cm^{-2} s^{-1} with a maximum drift length at the outer radius (1.5 m) of 1.4 cm means an operating sense wire current of 0.66 μA, which is tolerable. Such a current is not prohibitive and gives rise to ~ 15 years operational exposure at a maximum dose of 1 C/cm before sense wires will die at an inner radius of 0.5 m. It should also be stressed that looping tracks in a magnetic field do not increase the currents and rates in a radial wire chamber as they do for a central tracking system with axial wires.

The pattern recognition of multi-track events requires the smallest possible hit occupancy of each drift cell when in operation. With a fast gas mixture in the system discussed above, assuming 7 charged particles per unit of rapidity, and with the SSC bunch crossing interval of 15 ns, each radial wire has a mean total occupancy of 26%. The density of wires is thus sufficient to provide the hit redundancy necessary to overcome the complications of large SSC event multiplicity and of multi-bunch sensitivity. In fact in this system the maximum memory time

Table 3.2. Radial chamber sense wire operating characteristics and data occupancy

Rapidity acceptance of sense wire	1
Maximum drift length of radial wedge	1.4 cm
Number of radial wires at fixed z	336
Sense wire gas gain	2×10^4
No. ion pairs per track per sense wire	100
Sense wire operating current	0.66 μA
Experimental year	10^7 s
Sense wire charge collection (r is radial co-ordinate along wire $50 < r < 150$ cm)	$3.3/r$(cm) C/cm/year
Average drift cell occupancy per interaction	0.021
Drift velocity (CF_4 doped Ar/Xe)	120 μm/ns
Drift cell memory time (at $r = 150$ cm)	117 ns 8 bunch crossings
Average no. interactions in cell memory time	12.4
Average total drift cell occupancy	0.26

of a radial wire is only 9 bunch crossings at its outer radius, which is small in comparison with 15 for the H1 radial chambers at HERA.

The above considerations mean that an array of radial wires for the intermediate tracking region of Fig. 5.1 will be considerably more ambitious than in the H1 FTD at HERA. The configuration, calculations for which are shown in Tables 3.1 and 3.2, implies that in each wire plane at fixed z there will be 336 sense wires separated by 336 cathode planes . The total number of sense wires in the FTD is thus $\sim$ 33600 and their spatial density is at least four times greater in azimuth than for the (proven) H1 chambers. To this must also be added $\sim$ 33000 field wires.

Given that the considerable mechanical problems of such an array of wires can be overcome, many questions concerning operational feasibility arise. Chamber operation at the low gas gain of 2×10^4 means that charge division precision will depreciate so that stereo (tilted) planes of wires will be necessary for the "other" co-ordinate, introducing further complications in mechanical construction. Furthermore, at such a low gas gain, it is not clear how effective will be the sampling and pulse profile analysis for electron id using the integrated TR. The use of CF_4-based fast gas with the lightweight materials needed for fabrication is not yet proven. If flash digitisation, or its equivalent, is to be used, clock frequency must be increased to at least 200 MHz.

All the above problems can be addressed in a detailed program of R & D. Then and only then will it be possible to evaluate fully the feasibility of using radial wire chambers at the SSC and set about a detailed design for a detector.

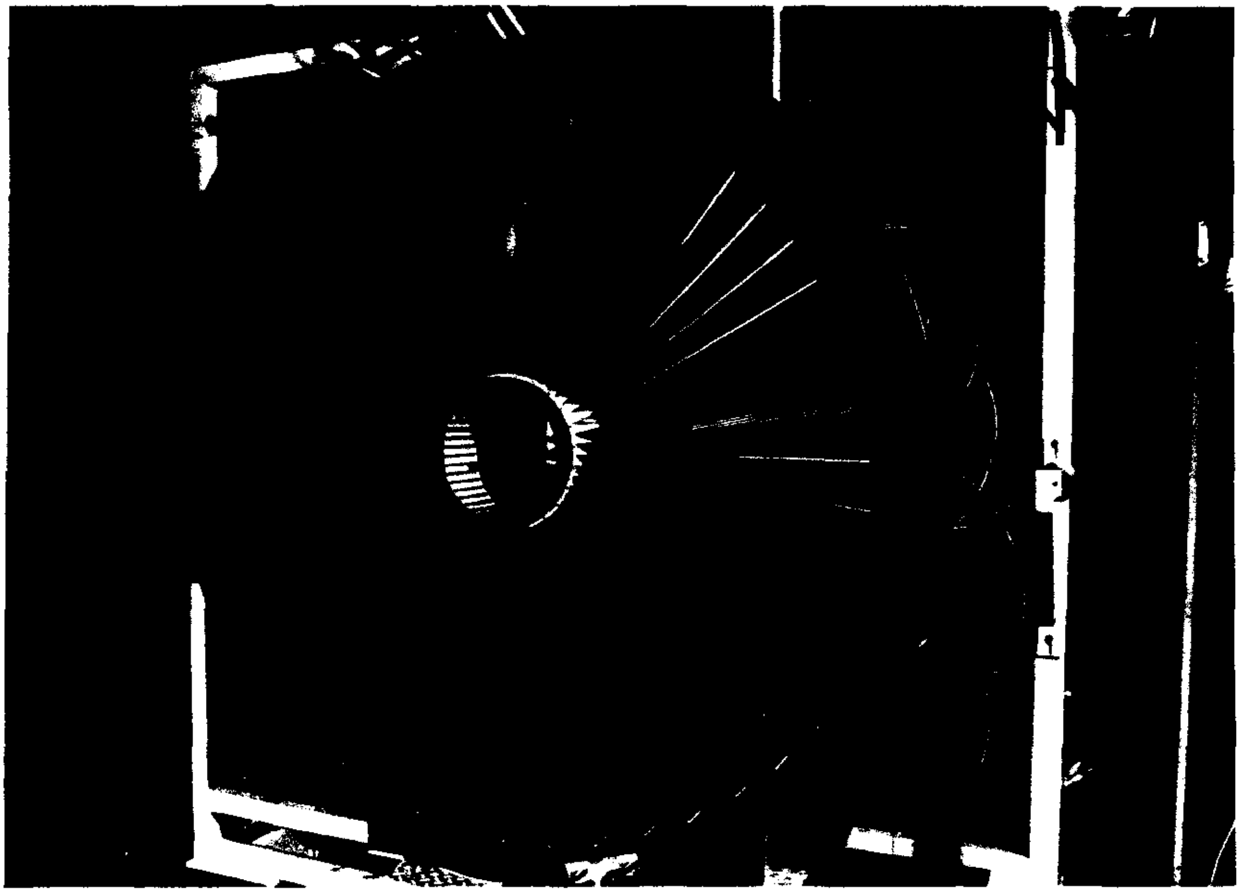


Fig. 3.1. Nearly beam's eye view of a radial wire drift chamber (without its TR front window) to be used in the H1 experiment at HERA. Light reflected from the radial wires in certain wedges can be seen. Cathode planes and field former pc strips are also visible supported in the the "dish-like" composite frame.

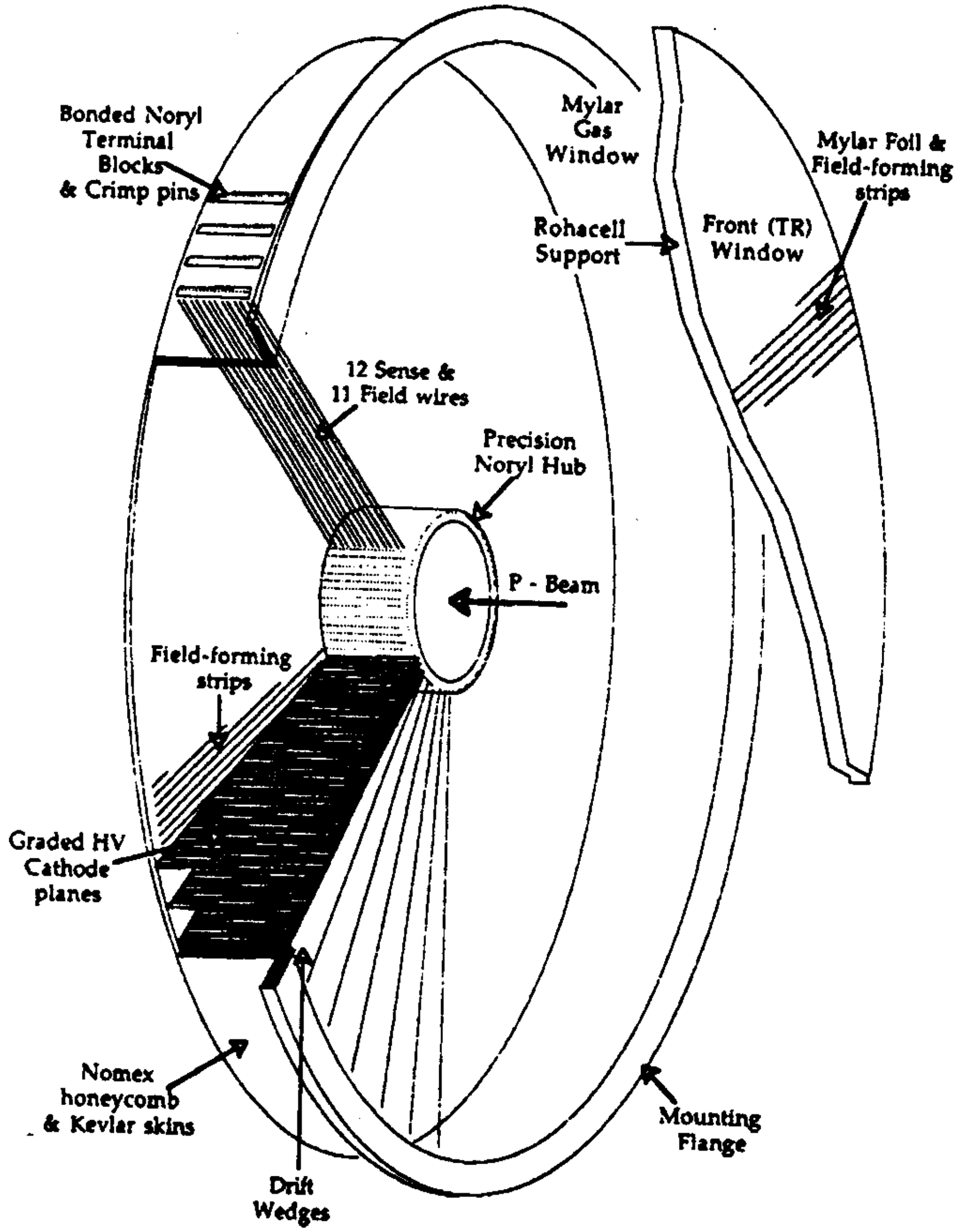


Fig. 3.2. Schematic "blow-up" of a radial wire drift chamber indicating the principles of construction and function.

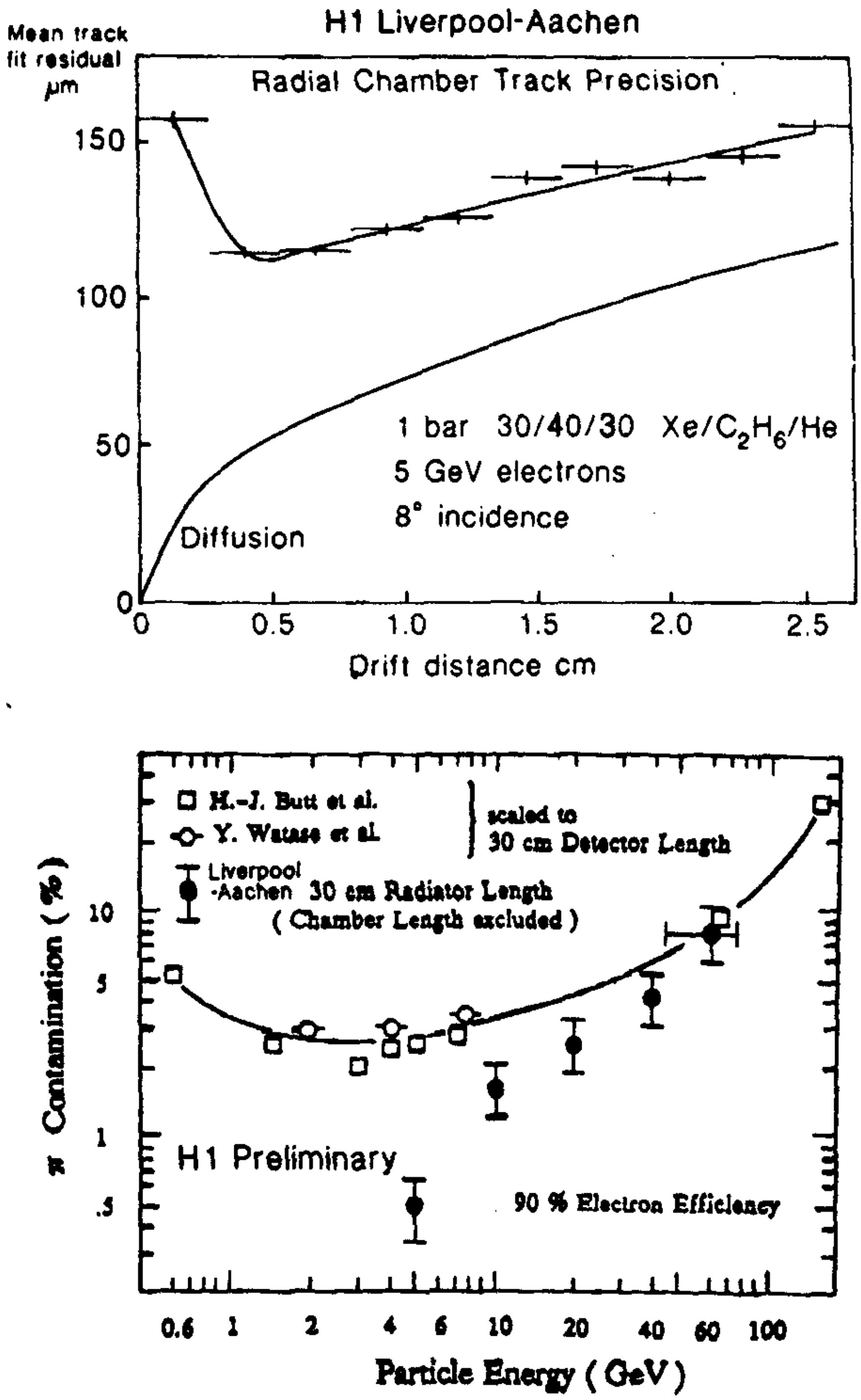


Fig. 3.3. a) Spatial resolution using an X-ray sensitive gas in the drift co-ordinate of a radial wedge, and b) pion contamination keeping 90% electrons as a function of momentum after a pulse integral analysis exploiting the multi-wire sampling of both dE/dx and X-ray (TR) energy deposition in the radial wedge.

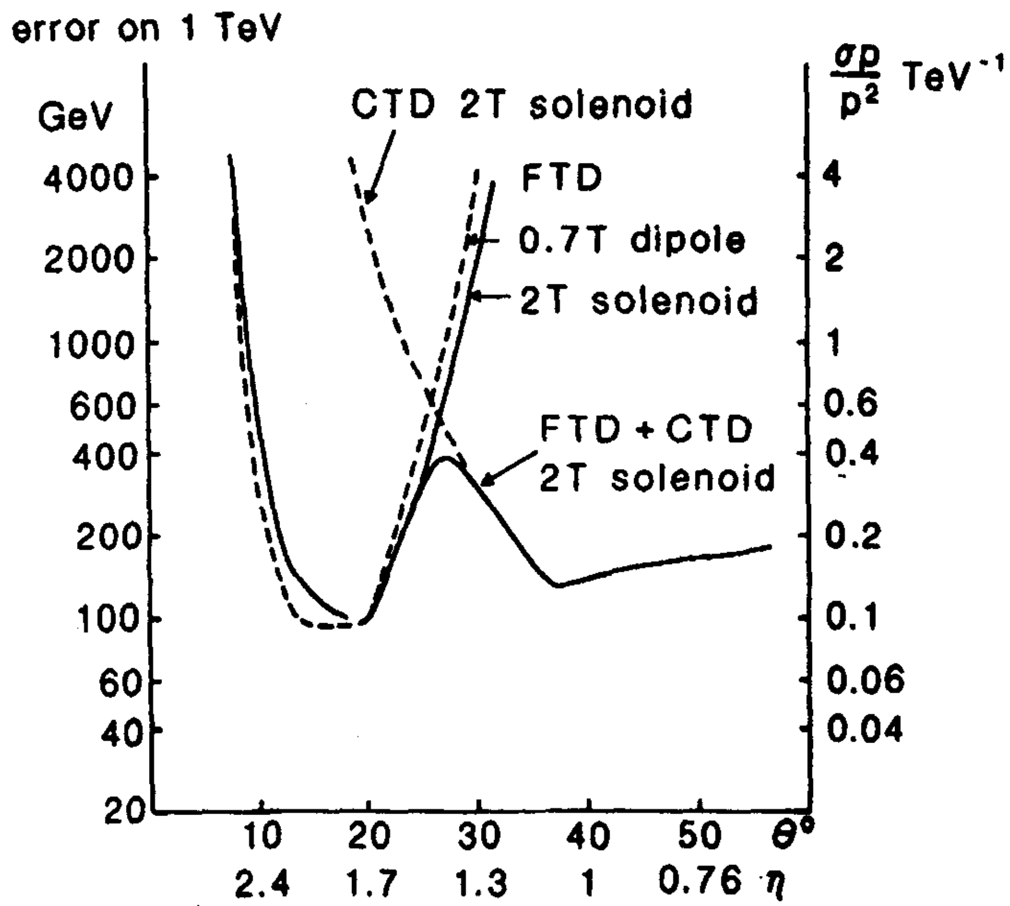


Fig. 3.4. Track momentum resolution in a 2T solenoidal magnetic field as a function of track polar angle; individual contributions due to a realistic central track detector (CTD) and a forward track detector (FTD) plus a combined detector (CTD+FTD) are shown. 20% of available track points are dropped to allow for multi-track overlap.

3.2. Intermediate Tracking using Straw Chambers

We will also use our central straw chamber development to confront the requirements of an intermediate tracking system. The study could be useful to establish alternative triggering schemes with straws and to focus these issues in comparison to the radial design. The type of layout we will first consider is shown in Figure 3.5. The forward system is composed of a multilayer system with the straws transverse to the magnetic field.

The wire rates, current draw , occupancy , and total charge for 5 years are shown in the Figures 3.6-3.9 Notice that each figure shows the relevant quantity plotted for a continuous disk extending through the beam line and for the case where a 30 cm hole has been removed from the disk.

Most of the design details for the straws can be directly applied to the radial chambers. We will study the operation of the straw chambers in a transverse magnetic field, in order to assess their resolution in this configuration. Support systems for the intermediate region will have many of the same alignment criteria as for the central system. We anticipate that the support systems developed for the radial wire chambers will have many aspects in common with straw design. Much of the mechanical design work will be integrated for the two systems.

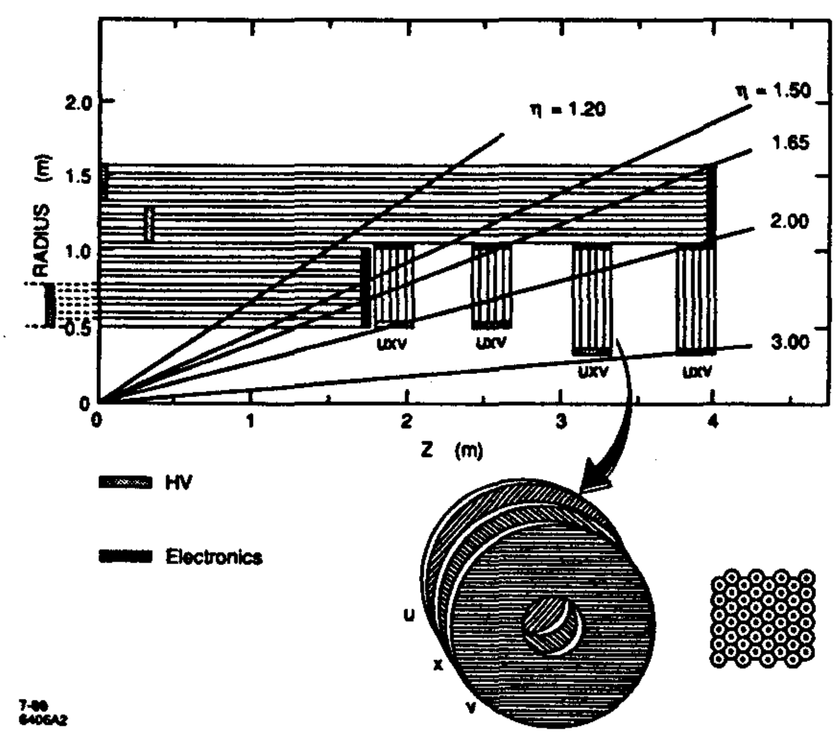
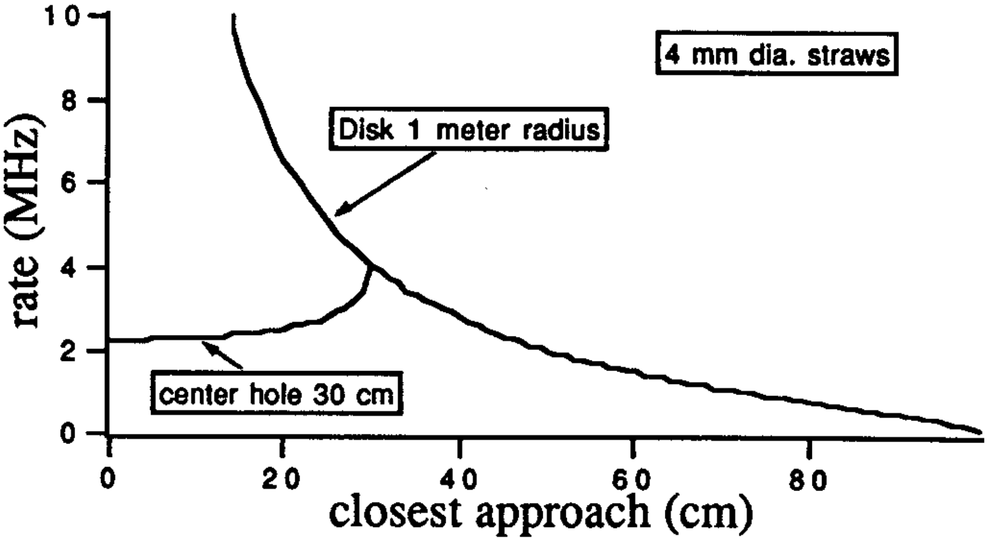
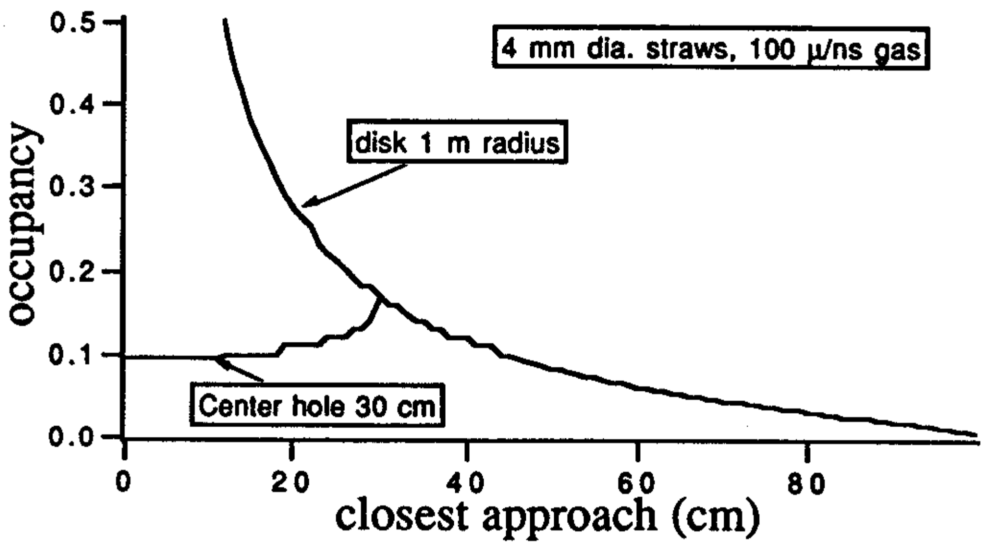


Fig.3.5



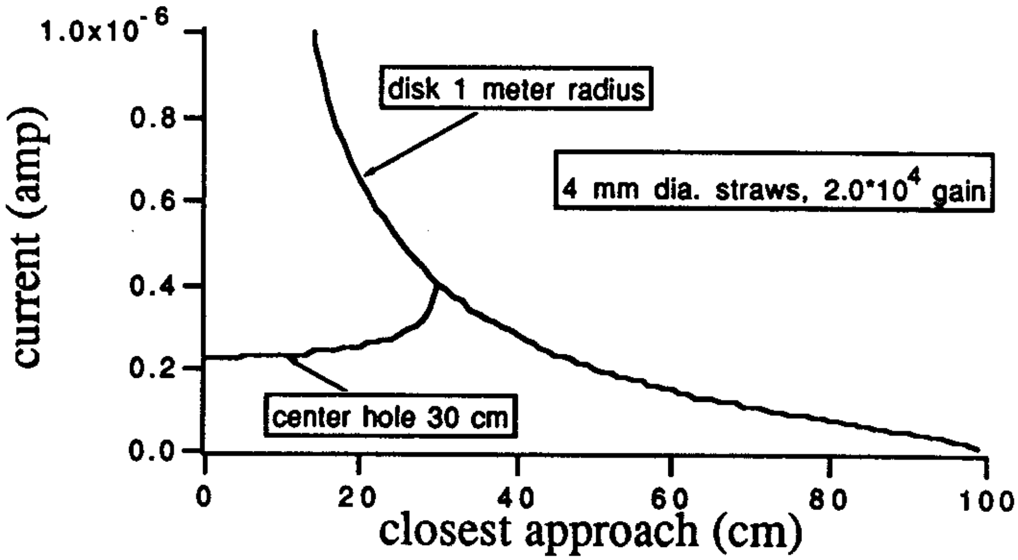
4 mm dia. straws
Disk 1 meter radius
center hole 30 cm
rate (MHz)
closest approach (cm)
0
2
4
6
8
10
0
20
40
60
80

Fig. 3.6



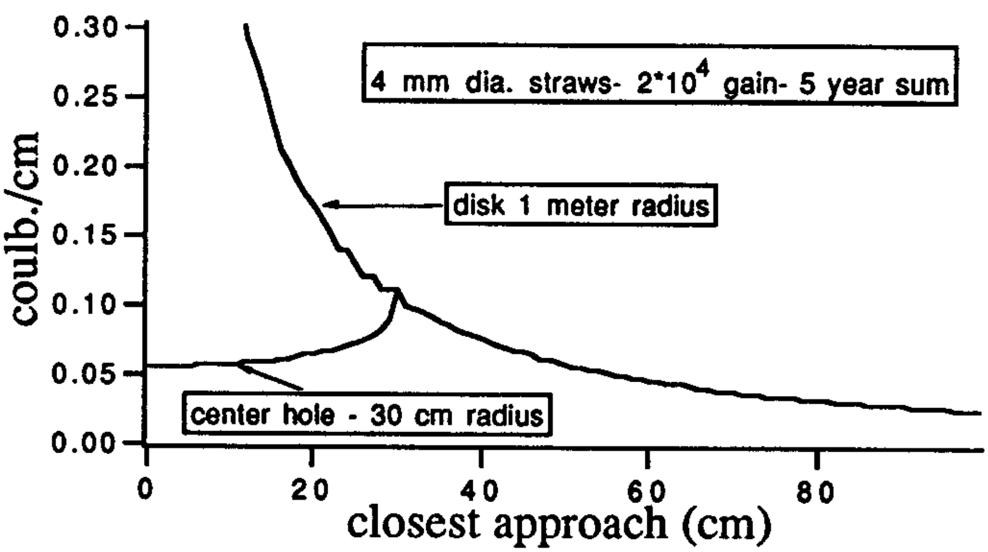
4 mm dia. straws, 100 μ/ns gas
disk 1 m radius
Center hole 30 cm
occupancy
closest approach (cm)
0.0
0.1
0.2
0.3
0.4
0.5
0
20
40
60
80

Fig. 3.7



1.0x10^-6
0.8
0.6
0.4
0.2
0.0
current (amp)
disk 1 meter radius
4 mm dia. straws, 2.0*10^4 gain
center hole 30 cm
0
20
40
60
80
100
closest approach (cm)

Fig. 3.8



0.30
0.25
0.20
0.15
0.10
0.05
0.00
coulb./cm
4 mm dia. straws- 2*10^4 gain- 5 year sum
disk 1 meter radius
center hole - 30 cm radius
0
20
40
60
80
closest approach (cm)

Fig. 3.9

4. ELECTRON IDENTIFICATION

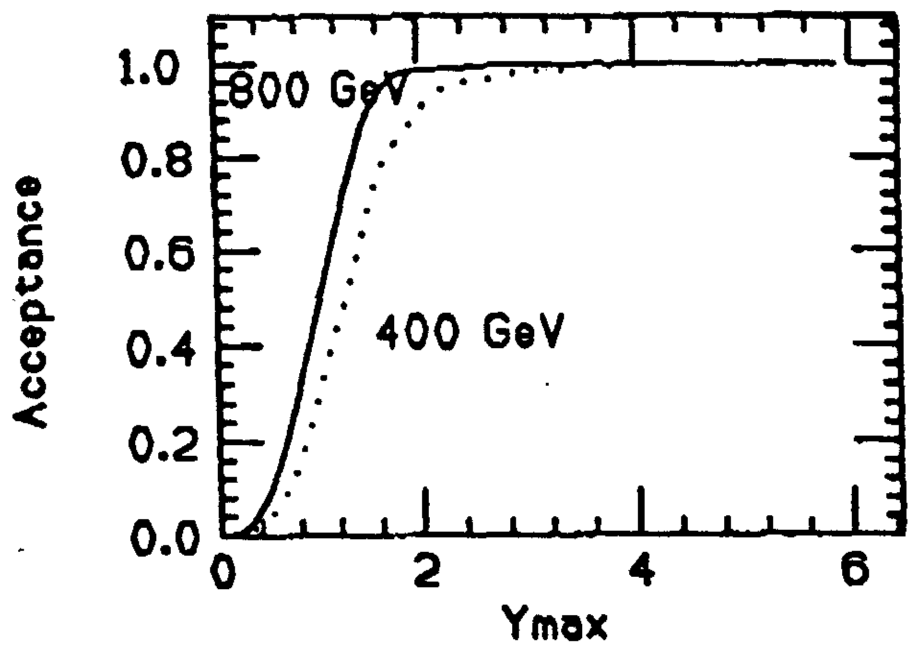
The importance of finding and then reconstructing leptons with precision at the SSC cannot be overemphasised. Figure 4.1, taken from a recent SSC study, shows acceptance for Higgs detection by means of its four lepton decay mode. It emphasises the need for as complete angular coverage as possible. The implications for charged track detection are that any tracking system must reconstruct accurately the lepton track vectors so that correlation with external shower and muon filter detectors can be made over the complete angular range.

At the SSC the problem of such reconstruction is compounded by the confusion due to the high multiplicity of hits associated with the large pp interaction cross section and the sensitive time of the maximum drift length. Efficient recognition of electron candidates within such a confused environment is possible if candidate hits, or even track vector segments, can be flagged as early as possible in software processing as being attributable to electrons. A way of achieving this is to interleave suitable material as a source of transition radiator between the drift cells. Then, provided the cells have good X-ray detection efficiency, i. e. they are thin-walled and use a suitable gas, electrons can be flagged and identified by means of pulse height/integral. In addition, (multi) electron triggers from the tracking system become conceivable.

As already mentioned in Sections 2 and 3, we intend to pursue the possibility of a hybrid detector for accurate charged track reconstruction with integrated electron identification. Such a technique can be applied in the context of both straw tube and radial wire drift chambers.

In the central tracking region a suitable TR foam can be used as a rigid support of modules or supermodules of straw tubes, somewhat along the lines suggested by Chernyatin *et al.*[17] and Dolgoshein.[18] These authors have estimated that such a system may provide better than 1% pion contamination (90% electron acceptance) at SSC momenta. The thin-wall structure of the straws (Section 2) means that the X-ray transparency is good. The operation with fast gas which is also X-ray sensitive (Xe/CF_4 mixture) remains to be investigated.

For the intermediate tracking region, the radial wire drift chamber choice will also employ enhanced electron energy deposition using TR material preceding groups of sense wires. As mentioned in Section 3, such a technique has already been implemented in prototype form for the H1 experiment at HERA (Fig. 3.3).[12] We propose to build on experience of this newer TR technique at H1 by integrating further suitable transition radiator material into the construction of the radial wire chambers.



The four-lepton acceptance vs lepton rapidity coverage.

Fig. 4.1. Detection efficiency for reconstructing a Higgs in its four-lepton decay mode as a function of rapidity range of the detector (from Ref. 16).

5. TRACKING SYSTEM DEVELOPMENT

5.1. System considerations

In order to provide the momentum resolution discussed earlier, the tracking system must maintain a position resolution better than 100 μm over the whole volume of the system shown in figure 5.1. The outer surface of this volume is a cylinder of diameter 3.6-4.0 m and length 11 m, and the complete system consists of 350,000 individual cells. Therefore, the mechanical structure must be designed and constructed with a cell location accuracy and stability of roughly 50 μm over an enormous volume. In addition, the parameters of the gas mixture in the cells must be kept within acceptable limits throughout the whole system. There will be an extensive list of electro-mechanical design consideration to ensure absolutely every aspect of the physical stability and environment of the system maintain the necessary standards. In order that an integrated approach is taken to achieve this in the university groups will work with Westinghouse Science and Technology Center.

5.2. Modularity

The first step in the design of the mechanical structure will be to decide the scale of the system modularity. A major consideration in this decision will be service access to all parts of the detector. In our design there will most likely be three levels of modularity. The first modules will be the straws. The enclosed cathode idea has been chosen as the best solution to the high-rate SSC environment. The next section will discuss our development program to invent straw modules with larger scales than the classical mandrel-wound individual straw. The next level of modularity will be that of the superlayers. The straw modules will be packed into rigid mechanical structures containing suitable end-plates with integral alignment fixtures. The alignment system is considered later. The rigid superlayer modules will then be arranged in larger modules. In the barrel region these modules will be wedges, such that a single track stays within a single wedge module, so the wedge to wedge location is less crtical than the location within a wedge. In the forward region the solution for large scale modules will probably be split cylinder. Forward tracks will pass through barrel wedge modules as well as the split cylinder modules, so the relative location of these two different sorts of module will present a special challenge.

5.3. Development of alternative straw modules

The Los Alamos Materials Science division will investigate novel methods of producing enclosed cathode structures for drift chambers. Several different ideas will be investigated. In one scheme, the tubes would be constructed of a formable, thin, metallized plastic sheet. Fig. 5.2 illustrates a technique based upon the one used commercially to make honeycomb for sandwich construction. It is made by stacking resin impregnated kraft paper with longitudinal strips of thermally activated adhesive. The upper view in the figure is down the long axis of the honeycomb. The other lines are the kraft paper, or in the case of straw modules, a thin polymer film vapor deposited with a metal coating. Assembly is by sheet placement, followed by heat activation of the adhesive strip. Once a stack is assembled, the stack is expanded, creating the hexagonal cell honeycomb shown. In the case of commercial structural honeycomb, the assembly is then oven cured to harden the resin impregnated in the paper, giving a structural honeycomb. In the case of a drift chamber module, the expanding support would be provided by an external frame, made of carbon composite having low atomic number and low mass. The anode wires would then have to be threaded through the cells (or placed there, loose, during layup) and stretched between end plates, which would provide the alignment. Development is needed to learn whether precisely shaped hex cells can be created this way.

Another approach would be to thermoform sheets of connected half cells from a metallized plastic film, as shown in Fig. 5.3. A sheet of cell "lowers" can be laid out and anode wires laid in place to avoid subsequent threading. A sheet of cell "uppers" can then be positioned by means of a vacuum mandrel, which provides both alignment and a thermal impulse, which welds the uppers and lowers along the intersection. Center wires would again have to be positioned by stretching between end alignment plates. Or the lowers could be filled with a temporary filler on which the wire might be laid down, along with periodic support fibers. The temporary filler would support the wire until it could be attached to supports on each end. Subsequent hex layers would be fabricated in a similar manner. Finally, the temporary filler would be leached from the assembly after permanent supporting connections were made. As noted above, it may be possible to assemble these components without the use of a temporary filler, thus simplifying the process.

A variation on the above theme would utilize a conductive plastic as the formable layer. The conductive plastic would allow discharge to the tube wall from the wire. It would still need to be metallized, but now exterior metallization would be sufficient to increase the current carrying capacity to that required. Extrusion of a continuous length of the conductive polymer followed by metallizing on the exterior surface would be much simpler than metallizing an interior surface.

Another possibility would be to explore liquid crystal and other ultra high strength polymers as the tube formers. These might give extra rigidity and permit more stable structures. Thin composite sheets would be examined if they could be made to meet the low mass requirements.

Yet another variation would entail the use of a low density, structural foam as a filler material between cylindrical straw tubes. Cylinders could be fabricated by extruding a mandrel over the central wire and coating or wrapping the mandrel to give a metallized surface either on a thin plastic film or on the surface itself. The cylinders would then be built into a structure, aligned, and tied to end plates. The foam would then be pumped into the spaces between the cylinders to make a unitized, rigid structure. Finally, the mandrels would be leached out of the cylinders to create an array of tubes with wires along their axes.

The Los Alamos and Colorado groups will collaborate on these investigations, with Los Alamos responsible mainly for cathode structure development, and Colorado mainly for assembling these into prototype drift chambers and testing them.

5.4. Dynamical alignment strategies

To avoid the momentum resolution of the finished system being dominated by systematics arising from the relative module alignment, we will start developing a comprehensive opto-mechanical alignment system, in parallel with the tracking component development. Only by developing the alignment as an integral part of the tracking system can the systematic errors be minimised.

In developing the alignment system we will start by considering the existing L3 survey system[19] which uses laser beams, LEDs and photodiode sensors to monitor the relative chamber positions in the detector. This L3 system employs, straight-line monitors, each consisting of an LED, a lens and a quad photodiode, and also, coplanarity monitors, each consisting of a ' laser beacon ', produced by a rotating mirror, and arrays of photodiode sensors. Initially, we will construct similar straight-line monitors, but will attempt to develop a coplanarity monitor with no moving parts. For this later purpose we will investigate whether an adequately uniform plane of laser light can be made using accurate diffraction gratings or other passive optical components.

In addition to the position monitoring in the experiment, a comprehensive alignment system must include the fixtures and instruments to ensure the tracking component parts are accurately constructed and measured. Using our experience working with the SLAC alignment group on the survey of the SLD drift chambers, we propose to purchase and set up at Colorado a Laser Interferometry measurement system. Initially, this would enable us to evaluate prototype straw chamber modules in conjunction with our proposed cosmic ray telescope and so choose suitable construction techniques. Later, we would be able continually to provide quality control for the chamber module production.

5.5. Coordinated mechanical design

The Westinghouse Science and Technology Center will undertake a 24-month program to perform the preliminary mechanical design of the tracking system. The program will investigate the areas of mechanical design, material science , thermal management, and manufacturability of the detector/components. This program will culminate in the costing and manufacturing requirements for the fabrication of a full length section of the proposed tracker which will demonstrate all of the design features and manufacturing procedures. The first phase of the program will result in a functional specifications document for the tracker which will delineate all pertinent design requirements, alignment specification, and material characteristics/properties necessary for a rugged, reliable tracker design.

Upon review of all of the tracker design options by the group, a lead concept will be identified for initial analysis. Detailed structural and thermal models of the tracker will be generated and analyzed for various loading scenarios expected during typical operating regimes. The models will be used to verify the adequacy of the support system to maintain proper operating temperatures and minimize temperature gradients along the axis of the chamber.

Layout drawings of various tracker components will be generated throughout the program in sufficient detail for analytical modelling and cost estimating purposes. Upon selection of a lead concept, manufacturing and assembly layouts will be created, when appropriate, in order to construct and assemble a partial section of the prototype tracker.

The fabrication and assembly processes will be specified in detail. A complete study will be made of the QA/AC testing necessary. The layout for the electrical cables and fluid hoses will be produced. A thermal management strategy will be developed to remove heat from the electronics and maintain the temperature gradients in the drift gas to a level where the position resolution will not be degraded. System integration with the rest of the detector will be investigated.

Westinghouse, with input from the rest of the group, will estimate the cost and schedule for the overall fabrication and delivery of a completed device to the SSC detector location.

5.6. Test facilities

There will a number of small module prototypes built by this collaboration. T he major prototype assembly will be a multisuperlayer system containing atleast 1000 cells. We anticipate that there will be three superlayers and a complete support system.

To evaluate the position resolution of prototype straw chamber modules developed in this program we propose using a cosmic ray telescope at the University of Colorado. For the SSC studies we would improve an existing system built for the studies of SLD prototype[20] and production[21] drift chambers. The improvements on the SLD system consist of better segmentation in the scintillation counter triggers and increased numbers of drift chamber readout channels to cope with the smaller cell size of the SSC plans. Figure 5.4 shows the envisioned system.

The trigger requires the particles to pass through 26cms of lead and so selects muons with momenta greater than 0.5 Gev/c by range. Typically we would have an active area of 10 x 200 cm^2, and with the above momentum cut we would collect about 30k tracks overnight, with the system. In general, we would have many layers of straw chambers and measure the resolution of some layers using other layers as the reference points.

POSSIBLE TRACKING SYSTEM CONFIGURATIONS

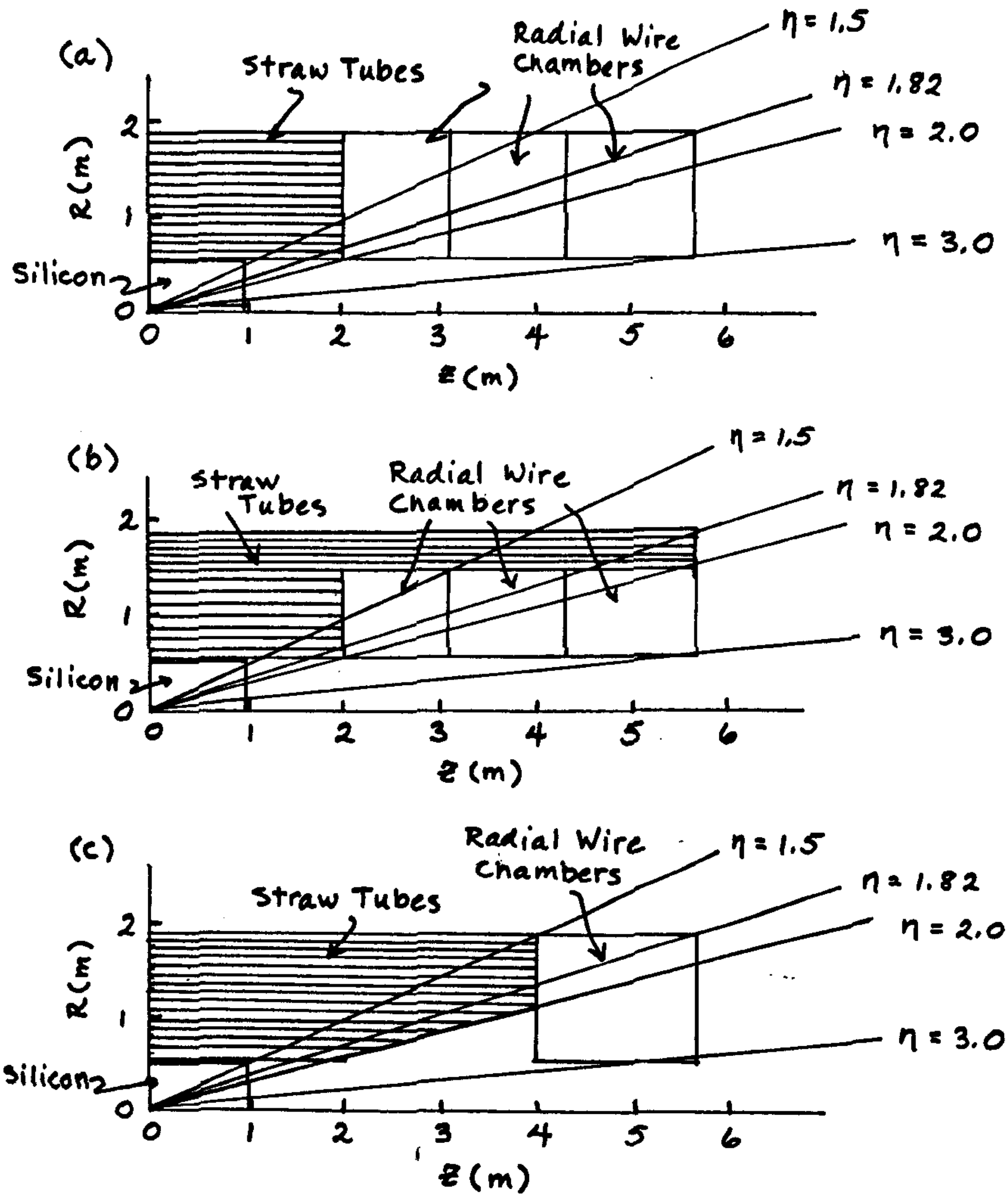


Fig. 5.1

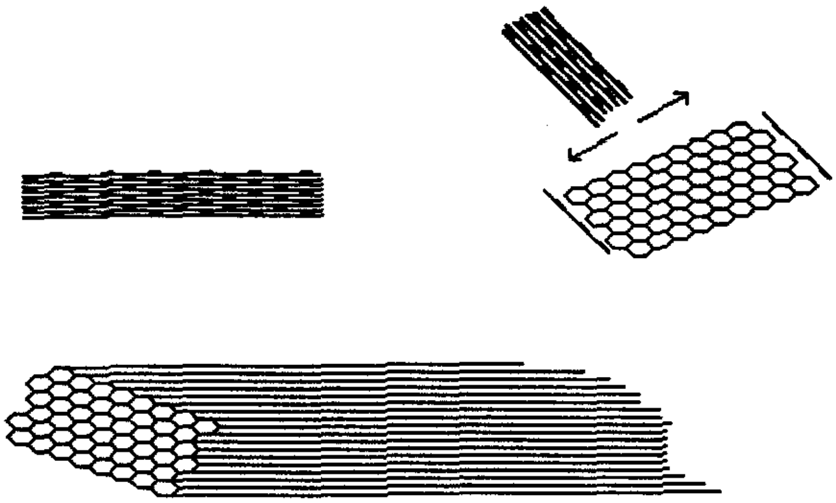


Fig. 5.2 Hexagonal Array construction using layered construction

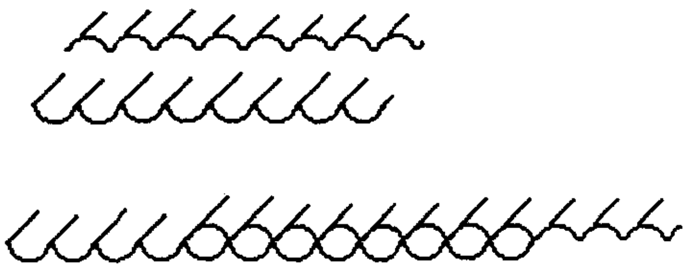


Fig. 5.3 Formation of hexagonal or tubular arrays with upper and lower forms. Leachable plastic could be used for machining strength.

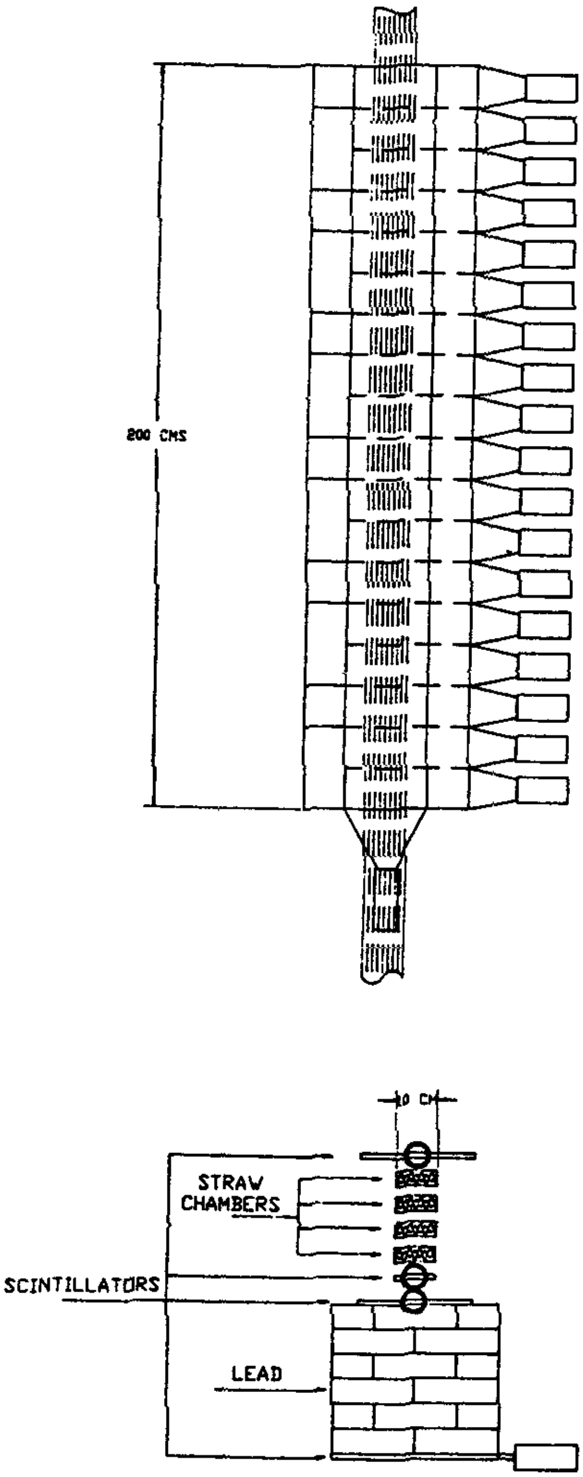


Fig. 5.4 Cosmic Ray testing facility

6. FRONT END AND TRIGGERING ELECTRONICS

Introduction

We propose to develop, test and install front end electronics for signal processing and sparsified readout of the central tracking detector based principally on a data driven architecture that has been under development at the University of Pennsylvania for the past two years. This design depends heavily on custom integrated circuits mounted at the ends of the detector. Each channel will be self-gating and have a multi-hit capability. Data will be "stored" based on the status of system "triggers" and digitized only after qualification by several levels of acceptance. Sparsification and the inclusion of local memory will allow the implementation of a highly multiplexed readout. Figure 6.1 gives an illustrative overview of the front end readout system.

The development of these ASICs (Application Specific Integrated Circuits) is being addressed by other proposals, but it is expected that we will want to customize the behavior of the signal processing chip and take full responsibility for the procurement of production quantities of these chips. Prototyping efforts will proceed in parallel with the development of finalized electronics with each step integrating more of the system.

Detector Constraints on Electronics

To set timing and double pulse resolution required by the electronics we estimate a saturated electron velocity of about 70–100 μm/ns. For position resolution of better than 100 μm we require a time resolution of less than one nanosecond. The longest signals will arise from tracks passing through the center of the straw where the trail of ionization will extend to the full diameter of the tube. Negative ions produced near the cathode will take as long as 30 ns to drift in giving rise to a pulse of at least this width in time. For this reason we do not expect to resolve double tracks in the same sensor or all hits in events occurring in sequential crossings. The electronics will be designed to have a double pulse resolution of about 16 ns since there may be several sources of noise triggers in addition to ionizations that do not have long signal duration.

The bulk of the induced charge arising as a "tail" following the arrival of the last ionizing electrons is moderated by the motion of positive ions towards the cathode. Positive ion mobilities on order of about 2×10^{-4} m^2/Vs combined with the logarithmic potential will produce a signal that decays with a $1/t$ dependence and will last as long as several hundred μs. These tails are commonly truncated to improve double pulse resolution.[22] In order to accommodate the instrumentation of large numbers of channels, it will be necessary to develop integrated versions of cancellation circuits such as those cited in the reference above.

There are several physical requirements that will drive the design of instrumentation for the central tracking system. As has been discussed in several SSC workshops, multiple scattering and the need to limit "cracks" in the calorimeter will make it impossible to bring all signals out from the detector. Data will have to be selectively processed and held for readout onto highly multiplexed bus structures. The 4 mm straw will severely limit the footprint available for instrumentation at the ends of the chamber and there will be a high premium put on the space that extends beyond the straw, especially if a split at $z = 0$ is implemented.

In addition, the power budget will be severely limited due to the difficulties of providing cooling inside a tightly closed calorimeter. Temperature dependence of the gas gain will present a further constraint. Neutron albedo from the large number of interactions in the calorimeter will result in the need to provide radiation hardened chamber electronics.

Feasibility

A large amount of work has already been carried out on the development of specialized integrated circuits for signal processing and readout at the SSC[23] as was mentioned in the introductory paragraph. A fast, low power, low noise, prototype ASIC suitable for gas ionization detectors has already been designed, fabricated[24] and tested. Figure 6.2 shows the pulse response of this circuit averaged over forty events for a 6000 electron input. The base-to-base time is less than the 16 ns design goal and the measurement time is close to the 5 ns expected. Figure 6.3 shows a comparison between predicted and measured noise performance. Good agreement between simulation and measured results in this and other designs[25] leads us to believe that virtually all signal processing can be performed on chip. The power requirement will be a factor of nearly fifty lower than conventional designs due to reduced stray and interconnect capacitance. A second benefit of this scaling is the reduced transmission and pickup of "system" noise. External signals will be treated using the following algorithm:

> Fast signals carrying timing information will be transmitted differentially and shielded where possible. Voltage excursion will be limited to a few hundred millivolts. Data lines which may need to be single-ended due to pinout limitations will be shielded and adjusted for the minimum dV/dt consistent with reliable operation.

The parts count of these systems will be so low that novel mounting techniques may be possible, integrating the signal processing electronics and readout into gas manifolds or other structures. A good set of simulation tools and a carefully planned prototyping agenda will keep the total cost of development and production far below that of hybrid or discrete designs.

Systematic calibration and integrity tests for each part of the readout will need to be "built in" to assess changes and failures. Critical data paths will need to be redundant and implemented with components that have predictable failure modes. These needs are addressed in an electronics subsystem proposal and developments from that work are expected to be implemented wherever possible.

Position resolution depends critically on the characteristics of the detector and electronics. As stated earlier 100 μm position resolution will require at least 1 ns timing resolution given the expected electron velocities. A prototype time-to-voltage converter TVC has been built[26] and has demonstrated the capacity to easily measure and hold multiple timing samples with a precision of much better than one nanosecond.

The capacity of the front end signal processing electronics to accurately provide this timing information to the TVC without requiring an unacceptable gas gain can be demonstrated as follows. The time development of the charge induced by positive ion motion can be written:

$$Q(t)/Q_{max} = \frac{ln(1 + t/T)}{2\,ln(b/a)} \,.$$

T is a characteristic detector tail time, depending on positive ion motion, wire potential and inner and outer chamber radii a and b. (T is about 2 ns for the straws being considered.) Q_{max} is the gas gain when $Q(t)$ is the signal due to a single primary electron. It can be seen that the signal increases rapidly with t when t/T is near unity. Therefore the useful part of the total gain increases rapidly with t when it is of the same order as T. In addition, a small contribution of about 1–2% of the total signal will arise almost instantly from the motion of avalanche electrons towards the wire.[27]

Thermal and shot noise which set the design limit for minimum noise are determined by circuit design and available technology. A fair estimate for the final electronic performance would be an equivalent noise charge of 1000 rms electrons for a 10 pF detector capacitance, 5 ns measurement time, and total power dissipation of less than 25 mW including the TVC and readout.

Having defined the signal and carefully estimated noise, we can next address the minimum acceptable signal to noise ratio (S/N) by examination of the limits on discriminator threshold. In order to limit dead time due to triggers caused by thermal and shot noise in the preamplifier, we will need to set the threshold at least three times higher than the rms preamplifier noise. Considering the fast shaping amplifiers being developed for use at SSC, this will result in a trigger rate of 1–2 hundred kilohertz. To achieve high triggering efficiency (99.7%) we require the discriminator threshold setting to be at least three times the rms preamplifier noise below the minimum signal. These two constraints combine to set a lower limit of 6:1 for S/N.

To find the effect of this S/N on the timing resolution we write the transfer characteristic of the multiple pole shaping amplifier we expect to use:

$$V(t)/V_{max} = (e/n)^n \, (t/T_i)^n \, e^{-(t/T_i)} \; ,$$

where there are $n-1$ shaping stages with integration times T_i. The time resolution for triggering on the first electron can now be obtained by setting a threshold as prescribed above, superimposing a gaussian noise distribution and plotting the expected trigger time. Figure 6.4 shows the result for three shaping stages with a measurement time of 5 ns (the values that apply to ATT prototype amplifier referred to above). The half nanosecond rms value for this distribution gives encouragement that the present state of amplifier development is sufficient to satisfy the timing requirements. Plugging the 5 ns measurement time into the charge equation given above and adding a 2% contribution for the electron component, we find that about 14% of the total charge will be collected. Since the minimum signal must be 6000e during this time it can be estimated that the total gas gain required is about 4×10^4 for a S/N of 6:1.

Electronics Under Development for SSC Detector Systems

As mentioned in the introduction, this project will make use of generalized electronics being developed to meet signal processing, rate, occupancy and radiation hardness constraints set by the SSC. We expect to have access to and use prototypes of the following ASICs:

- Preamplifier/shaper
- Preamplifier/shaper with detector tail cancellation

- Low power differential discriminator
- TVC and Analog Memory unit with some trigger control
- Radiation hardened TVC/Analog Memory unit
- Data collection chip

The parts appear in roughly the required sequence. We assume that the majority of the burden of development will be with the electronics R&D proposal.

We would also like to pursue making use of the digital time measurement system called TMC (Time Memory Cell).[28] TMC uses 0.8 micron CMOS technology to measure time digitally with an accuracy of 0.8 to 1 ns. Contrary to TVC, TMC uses standard CMOS memory technology with no analog processes involved for timing measurement. TMC has been actively developed in Japan under the collaboration between KEK and NTT. A prototype chip achieved 0.8 ns time resolution. It is expected to have a second version of TMC by Spring 1990. The preamplifier-shaper-discriminator system being developed for silicon strip readout using super high speed bipolar technology[29] will be used for the present wire chamber readout. The system has been developed in Japan under the same technical collaboration between KEK and NTT. The prototype of the preamplifier and shaper circuit has demonstrated pulse amplification with a shaping time of 15 ns.

Detector Specific Issues for This Proposal

Although circuit design and shaping issues will largely be solved with the existing prototype work, it will likely be necessary to make performance modifications to adjust input impedance, add system noise compensation or some form of fast output for triggering processors. This will require some additional prototyping that is expected to be the responsibility of this group. These customized ASICs will be for the front end signal processor and discriminator but probably not for the TVC or readout processor.

It is expected that after the ASIC designs are finalized that most of the burden of ASIC production and the related specialized development of boards and readout systems will be the responsibility of this collaboration.

Radial Drift Chambers

The forward detector may be realized as a radial drift chamber rather than a straw tube chamber. The readout of this kind of detector has traditionally been with Flash ADCs. As a result of discussion at the Vancouver Tracking Workshop we concluded that the signal processing and readout system being developed for the central tracker would probably also work well for radial drift chambers. Some modifications might be necessary to handle longer drift times and a possible additional feature of dual threshold triggering to allow a TRD mode of operation. These ideas will require additional discussion before specific R&D goals can be stated.

Extraction of Important Tracking Parameters from Superlayers

Two ideas have been discussed at recent tracking workshops that would take advantage of information available from adjacent layers within a superlayer to present the Level 1 or Level 2 trigger system with critical tracking information. These ideas could be implemented with simple additions to planned circuitry.

Stiff track segments may be easy to identify and match in a solenoidal field. Taking advantage of the half cell offset between layers and the nearly constant time across any two layers, J. Chapman has suggested an "electronic" version of a simple segment finder.[30] In offline analysis the position along the wire will be found by matching stereo views and then using tracking information to get good precision. At the suggestion of G. Hanson simple circuit schematics have been developed to use coincidence information between superlayers to find a crude z position within less than 100 ns after the beam crossing. This might allow the central tracker to point into the calorimeter to the expected location of stiff tracks. The solid angle for taking energy sums might in turn be limited to exclude uninteresting regions and calorimeter "noise" might be substantially reduced.

While these ideas are still in their infancy it is clear that some type of "smart" electronics is possible. Prototyping of several layers will help provide a testbed for examining the accuracy and survivability of these schemes.

System Level Tests

It will be necessary to submit the electronics, as well as the straw tubes themselves to a realistic system level test in a charged particle beam. Rate effects, bottlenecks and system noise will need careful study. The present plan is to develop and test single and multiple channel prototypes of the front end signal processor in the first year, allowing the TVC development to be completed elsewhere. The second and third years would include full system tests with all available electronics. This will require the development of specialized readout boards and a full data acquisition system. In addition, it will be necessary to simulate control, test and calibration signals in the electronics before it is installed on the prototype detector. This will require the development of specialized "test" stations.

Triggering Electronics for Drift Tubes

For data from drift tubes to be used in the first level trigger at the SSC fast tracks must be found quickly and the background from the high occupancy of hits must be suppressed greatly. Since the drift times in straw tubes is considerably less than the pipeline storage time being considered for the SSC, the information about which wires are hit is available in time for a fast decision. Two problems must be overcome if the tracking signals are to be most effective as a component of the trigger. First, the presence of a high momentum track must be sensed and second, the particular beam crossing of the triggering track needs to be determined. One would also like to know a rough z coordinate for the track.

A technique to obtain these pieces of information has been devised and simulated – the synchronizer. The basic approach has been documented in a preprint and a publication has been submitted to IEEE, Nuclear Instruments and Methods.[30] We propose to implement the scheme in custom integrated circuits. The circuit will accept as input the signals from the front end discriminators of three tubes arranged in the staggered cell pattern of the straw tube superlayer. It will output a pulse at the maximum drift time of the cell if the track is within a preset angle with respect to the normal to the superlayer. The angle restriction is one-to-one related to a momentum threshold for the track. A coincidence of signals from axial and stereo layers of straws then defines a z coordinate range for the stiff track. A fixed time delay of the coincidence can be arranged so that the output is always a fixed time after the particle passage as though there were no variable drift or propagation delay, just a fixed cable delay.

A program to construct a chip containing the synchronizer, the momentum selection, the coincidence, and program settable delay has been submitted as part of a trigger subsystem proposal from the University of Michigan, the University of Chicago, and Fermilab. One member of that proposal is also part of this proposal as a means of coordinating the work of chamber design with trigger design.

GENERALIZED FRONT END ELECTRONICS

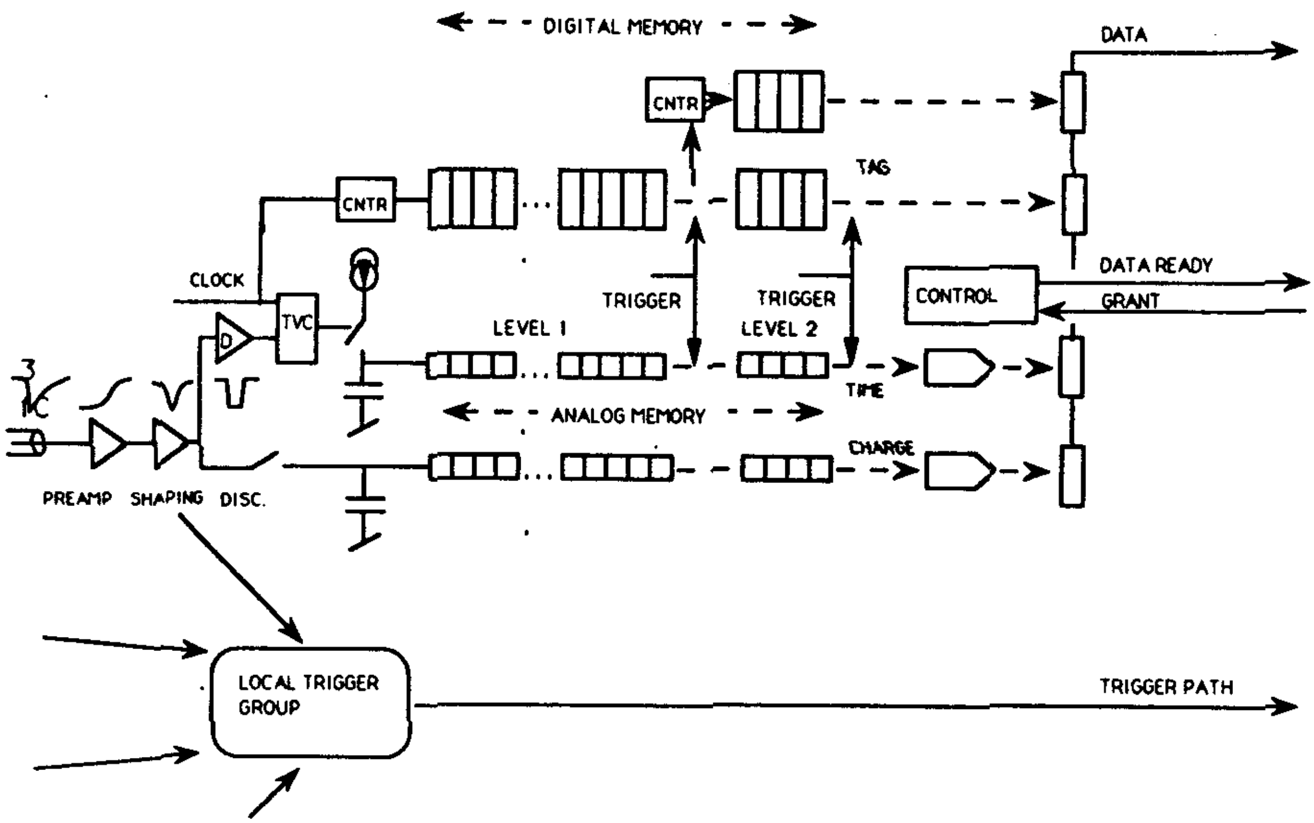
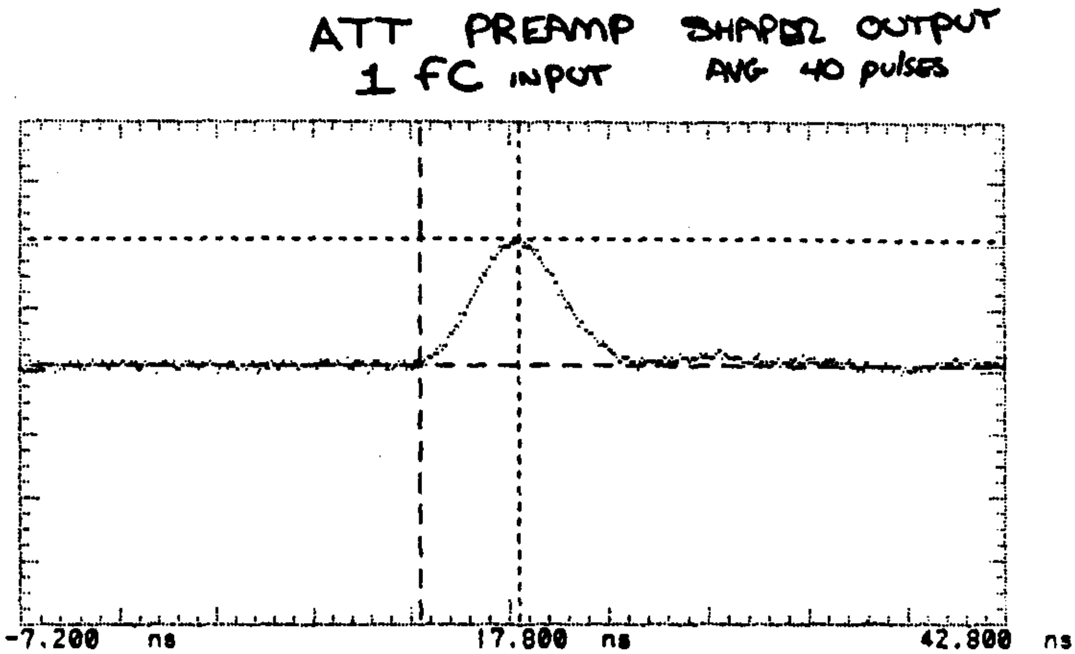


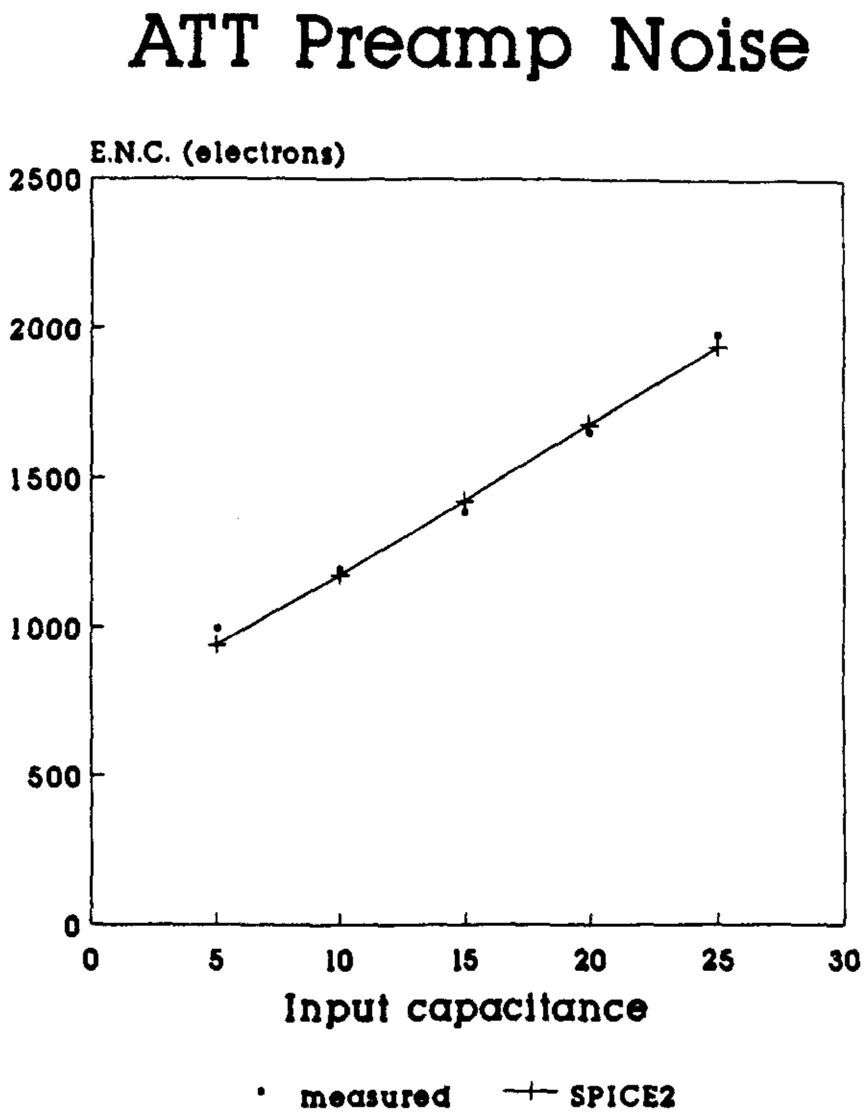
Fig. 6.1.



Function1 =	5.000 mVolts/div	Offset =	-312.5 uVolts
Timebase =	5.00 ns/div	Delay =	17.800 ns
Delta V =	10.00 mVolts		
Vmarker1 =	200.0 uVolts	Vmarker2 =	10.20 mVolts
Delta T =	5.000 ns		
Start =	13.300 ns	Stop =	18.300 ns

Trigger mode : Edge
On Pos. Edge on Trig4
Trigger Levels
Trig4 = 705.0 mVolts
Holdoff = 70.000 ns

Fig. 6.2.



measured slope 39electrons/pF up to 15p

Fig. 6.3.

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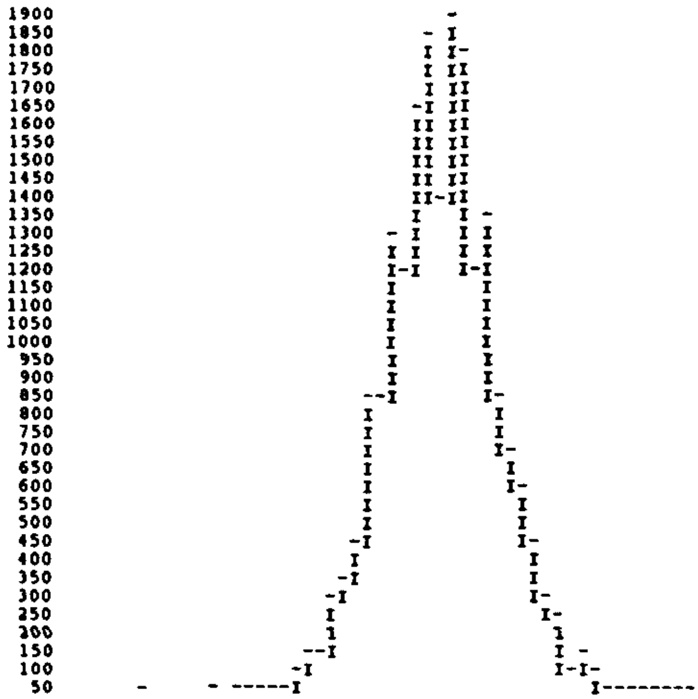
TIME DISTRBUTION FOR S/N=6 TM=5NS

HBOOK      ID =          3                                    DATE  892109??          NO =  2
```



```
CHANNELS  10   0        1         2         3         4         5
           1   12345678901234567890123456789012345678901234567890

CONTENTS1000                        111111111
         100                 112348821683871386542211
          10            122453260400974575992385272015313
          1.   6     7 907198442288206306798631646504284479246

LOW-EDGE  1.             1111111111222222222233333333334444444444
           0   01234567890123456789012345678901234567890123456789

* ENTRIES =        19957     * ALL CHANNELS = 0.1996E+05     * UNDERFLOW = 0.0000E+00     * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E+00       * MEAN VALUE   = 0.2568E+01     * R . M . S = 0.4851E+00     * ABNOR CHA=  0.0000E+00
```

Fig. 6.4.

7. COMPUTER SIMULATION STUDIES

Introduction

One of the members of this collaboration (G. Hanson) began work on computer simulation of tracking systems for the SSC as part of the effort of the Central Tracking Group during the 1986 Snowmass Workshop[1] and has been working on this project with co-workers under DOE support since October, 1987. During the past two years we have made substantial progress in computer simulation of a central tracking system similar to that for the Large Solenoid Detector described in Ref. 13. We have used the general detector simulation package GEANT3.[31] Results from this simulation are summarized here and have been reported in detail at several conferences and workshops.[32–35] As part of the effort described in this proposal we will continue the tracking system studies with the goal of designing an SSC tracking system, including tracking in the intermediate region ($1.2 < |\eta| < 3.0$) and possible integration of a wire chamber (could be scintillating fiber) tracking system at radius > 50 cm with high-precision silicon tracking systems at smaller radius. In addition, the results of the simulations will be useful for studies of charged particle triggers.

Summary of Tracking Simulation Studies

The SSC tracking system design used in the simulation studies was based on that discussed in the Large Solenoid Detector Group Report from the 1987 Berkeley Workshop,[13] although it is quite general and can be used for any system of cylindrically oriented sensing elements. The simulated tracking system consisted of cylinders of sense wires with azimuthal spacings of 4–7 mm. These wires could be in straw tubes, small-cell wire chambers, or even jet cells. The central tracking system extended from 50 to 160 cm radially and covered $|\eta| <$ 1.2–1.5. The tracking system is shown in Fig. 7.1. The layers of wires were grouped into 13 superlayers with 8 layers each. Within each superlayer the layers were staggered by half the cell width in order to resolve left-right ambiguities and allow the hits from out-of-time bunch crossings to be rejected, as shown in Fig. 7.2. The design is based on a pattern recognition strategy of finding track segments in superlayers and then linking the segments to form tracks. Track segments in outer superlayers can also be used in the trigger. The calculated momentum resolution of such a system would be $0.54p_T$ (TeV/c) for 150 μm spatial resolution and a 2 Tesla solenoidal magnetic field, although real tracking systems would be expected to have somewhat worse momentum resolution due to pattern recognition problems in complicated events and systematic alignment errors for a large tracking system. The momentum resolution would improve with the constraint that the particles come from the interaction region.

We used ISAJET to generate events, both from interesting physics processes and from inelastic scattering background. We used the GEANT3[31] general-purpose detector simulation package to simulate the interactions of the particles with the detector. The reasons for using GEANT3 were that so much effort had already gone into it over many years, it seemed that such a package might be more suitable for use by physicists working on simulation of various parts of the detector and later putting together the various subroutines within a consistent framework, and we wanted to gain experience and hopefully contribute software which could be used by others. We have already realized some of the advantages of using a general-purpose detector simulation package since the SLD Group at SLAC is using GEANT3 to simulate their detector and we were able to make use of their efforts in getting GEANT running on the SLAC IBM 3081 computer, particularly their implementation of GEANT graphics.

We included curling tracks in the 2 T magnetic field and photon conversions in the 8% of a radiation length of material (this was the estimate given in the Large Solenoid Detector Group Report for a central tracking system built of straw tubes). We superimposed the background from minimum bias events in the same and out-of-time bunch crossings by including the number of bunch crossings before and after the bunch crossing of interest given by the resolving time of the drift chamber cells (we used a 50 μm/ns drift velocity) and generating at each bunch crossing a number of events given by a Poisson distribution with a mean of 1.6 interactions per bunch crossing. For each track crossing a cylinder of wires a hit was produced representing the distance of closest approach of the track to a wire converted to drift time and the wire number of the closest wire. For the minimum bias events, the drift time was corrected for the difference in time between bunch crossings. To simulate double-hit resolution, we kept only the earliest hit on each wire. Also, hits within the tails (the width of the pulse was equal to half the sense wire spacing) of hits from previous bunch crossings were removed. The double-hit resolution is the mechanism by which information is lost in these complex events. We also included a spatial resolution of 150 μm and multiple Coulomb scattering in the material. To date we have simulated only axial wires. The simulation program is described in more detail in Ref. 36.

Using this simulation, we have been studying tracking in events from interesting physics processes. So far, we have looked at high-p_T ($p_T > 1$ TeV/c) two-jet events and heavy Higgs boson production and decay into Z^0Z^0 with both Z^0's decaying into e^+e^- or $\mu^+\mu^-$. An example of a high-p_T two-jet event in the simulated tracking system is shown in Fig. 7.3, and an example of a Higgs event is shown in Fig. 7.4. We have studied the total number of hits in events, including hits from background from out-of-time bunch crossings, and the fraction of hits lost because of the double-hit resolution, and began working on pattern recognition algorithms in order to examine our original design goals of finding track segments in superlayers and removing hits from out-of-time bunch crossings. As an example, Fig. 7.5(a) shows all of the hits for the Higgs event shown in Fig. 7.4, including those from minimum bias background events. Figure 7.5(b) shows only those hits which are included in the track segments. Figure 7.5(c) shows the tracks from the original event in the outer five superlayers in the region around the muon at the lower right. Figure 7.5(d) shows all of the hits in the event in the enlarged region (the locations of the hit wires are displayed), and Fig. 7.5(e) shows only the hits in the enlarged region which form track segments (here, the left-right ambiguities have been resolved, the drift times have been converted to distances, and the hits are displayed at the positions of closest approach of the tracks to the wires). One can see that keeping only the hits which form track segments cleans up the events considerably. The results from this tracking simulation have been reported at several workshops and conferences.[32–35]

Ongoing and Future Tracking Simulation Studies

The simulation reported above did not include measurement of the coordinate along the wire nor did it include tracking in the region of pseudorapidity $1.2 < |\eta| < 3.0$, the intermediate region. For central tracking, the coordinate along the wire can be measured using small-angle stereo wires. The conceptual design for a central tracking system includes alternate superlayers of axial and small-angle stereo wires. Cathode pads or strips may be needed to help match the axial and stereo track segments. The propagation time along the longest wires is about 16 ns, about the same as the time between bunch crossings. The need for information about the position along the wire as input to the segment finding is being examined. At the Vancouver Workshop[14] a scheme was worked out for determining the bunch number from the displacement of segments in outer axial and stereo superlayers. Simulation studies can help determine whether the method works for complicated events.

We are also including simulation of intermediate tracking ($1.2 < |\eta| < 3.0$). One promising configuration for wire chambers for the intermediate region is radial wire chambers.[9,10] So far, no tracking simulations for radial wire chambers at the SSC have been carried out, and there are many areas for study. Two of these are how to measure the coordinate along the radial wire and how to use radial wire chambers to find a high-p_T track segment for the trigger. Another possibility for the intermediate region is crossed planes of wires or straw tubes. These might also be used in conjunction with radial wire chambers. We may also find that we need cathode pads in the intermediate region.

We are continuing work on pattern recognition algorithms for both the central and intermediate tracking regions since they are integral to the design. In particular, experience with pattern recognition in the intermediate region will help determine the optimal tracking system design for this region.

A track fitting algorithm will be set up that will properly integrate information from both the silicon and wire chamber components of the tracking system. It should include the effects of multiple Coulomb scattering as well as proper weighting of the data from the different types of devices.

We will use the tracking simulation software to evaluate various configurations and numbers of layers in order to optimize the overall tracking system design.

In the technical computing area, we encountered difficulties in carrying out this simulation work on the IBM 3081 because of the limited address space for virtual memory. In order to carry out a complete simulation, we had to run five separate jobs in order to generate the four-vectors for interesting physics and backgrounds, simulate the detector response for each, and merge the results. While this problem may be somewhat alleviated with the new operating system on the present IBM 3090 at SLAC, we are in the process of converting the code to run on a VAX computer so that we can carry out the entire simulation in one process. Another effort in this area is implementing the GEANT graphics in GKS.

Summary of Tracking Simulation Proposal and Personnel

During the next three years we will continue our studies of tracking systems for the SSC using and improving the computer simulation software we have developed. The computer simulation will be carried out on the High Energy Physics Group VAX 6340 at Indiana University, the VAX 8800 at the University of Colorado, and the VAX cluster at the Lawrence Berkeley Laboratory. The work will include:

1. Including more realistic effects in the simulation, such as electron drift in small-cell or straw tube drift chambers, including the effects of $\mathbf{E} \times \mathbf{B}$. We have so far used only the geometric distance of closest approach. We

also should be keeping track of the time of flight for looping tracks in the magnetic field since a drift chamber cell can be sensitive to a track from a much earlier bunch crossing.

2. Continued studies of pattern recognition and track finding along the lines described above, including the intermediate tracking region, effects of the measurement of the coordinate along the wires, and possibilities for triggering.

3. Detailed studies to optimize the overall tracking system, including varying the tracking system parameters such as cell radius and number of layers in a superlayer, effects of dead areas at cell and module boundaries, need for cathode pads, boundary between central and intermediate tracking, integration with silicon detectors, and value of the magnetic field.

4. Put together several components of a detector, including calorimeter, muon system, etc., in a single simulation to determine how well events from interesting physics can be identified and measured.

The institutions involved in the tracking simulation effort are the University of Colorado, Indiana University, the Lawrence Berkeley Laboratory, and the University of California at Davis. The personnel are listed in Section 8.

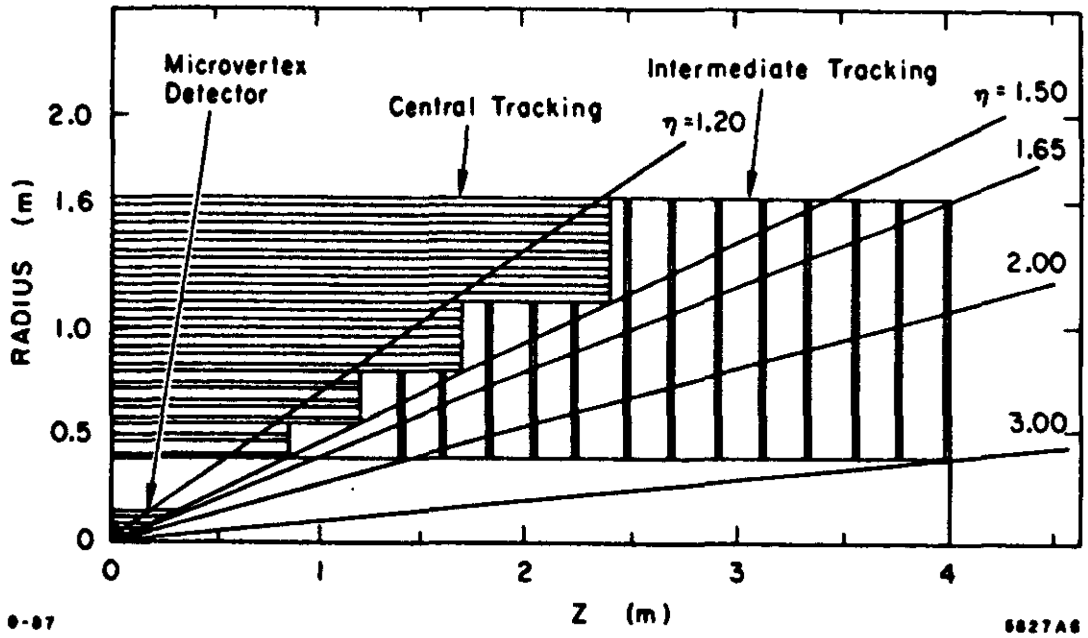


Fig. 7.1. Schematic view of central and intermediate tracking systems in the Large Solenoid Detector (from Ref. 13).

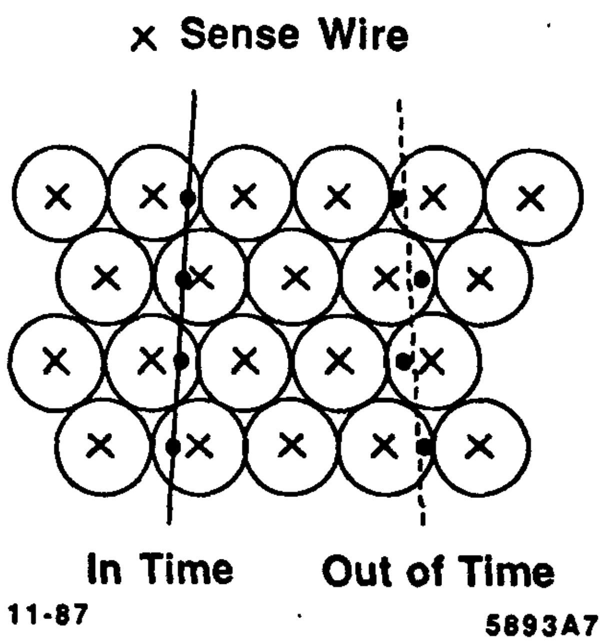


Fig. 7.2. Layers of straw tubes in a superlayer with every other layer staggered by the straw tube radius. A single in-time track will appear as a series of hits on the wires on alternate sides of the track. The left-right ambiguity is easily resolved locally. A track from an out-of-time bunch crossing will produce hits which are displaced from possible tracks by at least 16 ns in drift time.

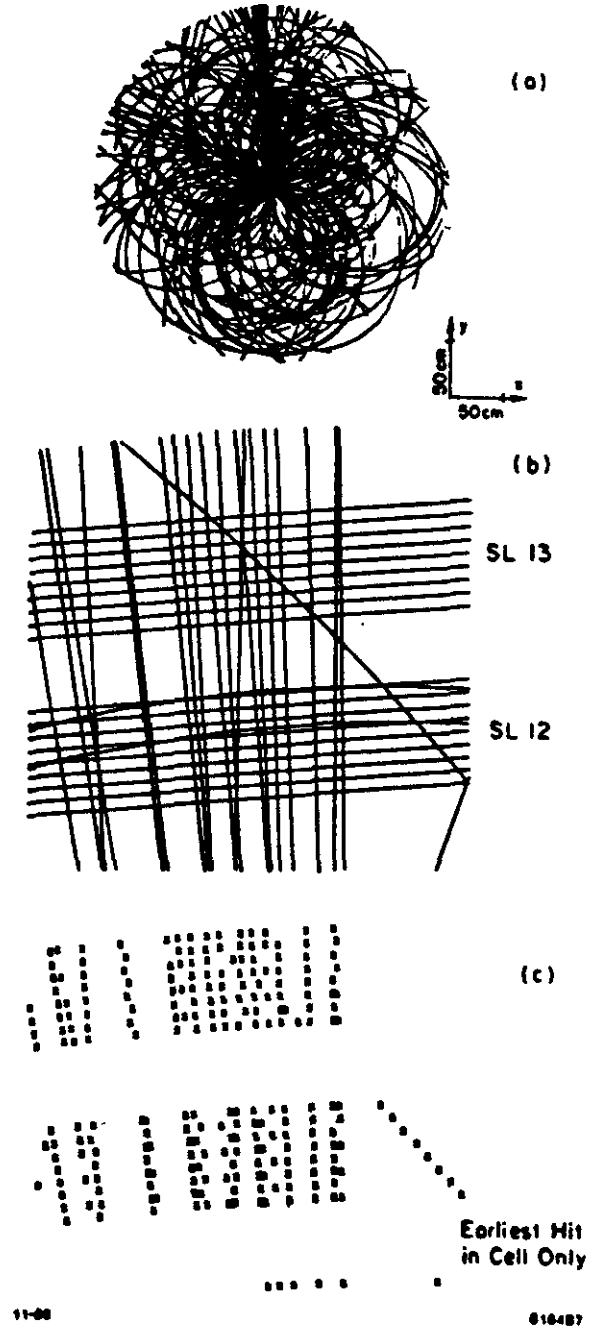


Fig. 7.3. (a) Two-jet event from ISAJET with $p_T > 1$ TeV/c in a 2 Tesla magnetic field in a detector of the geometry of the Large Solenoid Detector. There are 223 particles with $p_T > 200$ MeV/c and $|\eta| < 1.5$. Converted photons and background from minimum bias events are not shown. (b) Enlargement of the event in the outer two superlayers in the area of the dense jet at the top of the detector. (c) Earliest hit in each cell for the tracks shown in (b).

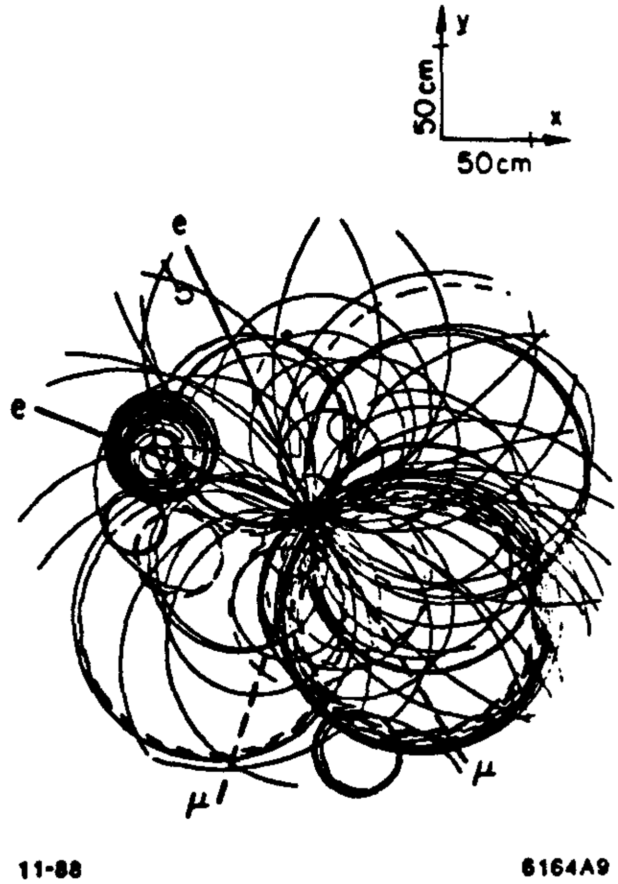


Fig. 7.4. Example of a Higgs event in the simulated central tracking system. The leptons from the Higgs decay are indicated by the heavier lines. Converted photons and other interactions with the material are included.

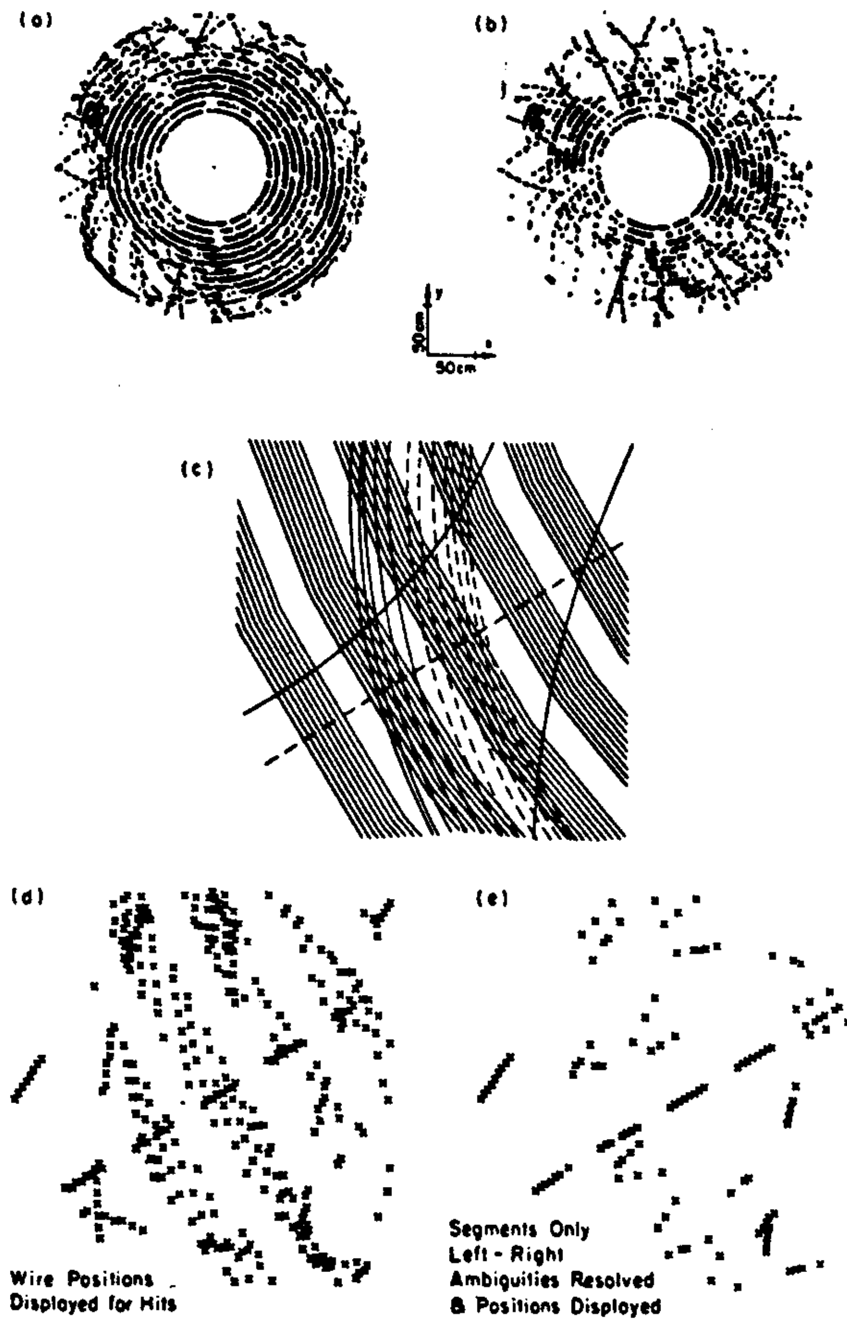


Fig. 7.5. (a) All of the digitizations for the Higgs event shown in Fig. 7.4, including those from minimum bias background events. (b) Digitizations for this event which are included in track segments, as defined in the text. (c) Tracks from the original event in an enlarged region in the outer five superlayers in the region around the muon at the lower right. (d) All of the digitizations in the event in the enlarged region of (c) (the digitizations are displayed at the locations of the hit wires). (e) Only those digitizations which form track segments in the enlarged region. Here, the left-right ambiguities have been resolved, the drift times have been converted to distances, and the digitizations are displayed at the positions of closest approach of the tracks to the wires.

8. PROJECT ORGANIZATION

Contact person: G. Hanson

The proposal can be broken down into the following major areas. We list each area and the personnel from each institution who will be responsible.

Straw Chamber Development

H. Ogren, R. Foster, G. Hanson, X. Lou, C. Neyman, D. Rust (Indiana University)

U. Nauenberg, P. Rankin, J. G. Smith, G. Schultz, plus 1 FTE undergraduate (University of Colorado)

R. Lander, R. Breedon, K. Maeshima, plus 0.5 FTE electrical engineer, 0.5 FTE mechanical engineer and 3 FTE graduate students (University of California, Davis)

Radial Wire Chambers

J. B. Dainton, P. S. L. Booth, E. Gabathuler, plus 1 FTE design engineer, 1 FTE physicist, 1 FTE graduate student and technical support (University of Liverpool)

D. H. Saxon, P. Sharp, J. C. Hart, N. A. McCubbin, plus 2 FTE electronics engineers, 1 FTE physicist, 1 FTE graduate student and technical support (Rutherford Appleton Laboratory)

Alternative Cell Structures

J. Carr, P. Rankin, E. Erdos, plus 0.5 FTE physicist (University of Colorado)

D. Duchane, S. Newfield, plus technical support (Los Alamos National Laboratory)

Mechanical Integration

H. Ogren, G. Hanson, C. Neyman, D. Rust (Indiana University)

W. T. Ford, J. Carr, G. Schultz, E. Erdos, plus 1 FTE graduate student, 1 FTE undergraduate (University of Colorado)

D. Hackworth, J. Hendrickson, J. W. Barkell, plus engineering support (Westinghouse Science and Technology Center)

R. Lander, R. Breedon, K. Maeshima, plus 0.5 FTE electrical engineer, 0.5 FTE mechanical engineer and 3 FTE graduate students (University of California, Davis)

Front End Electronics

F. M. Newcomer, R. Van Berg, H. H. Williams, plus 0.4 FTE designer, 0.5 FTE CAD/CAE systems manager and technical support (University of Pennsylvania)

Y. Arai plus technical support (KEK)

R. Crittenden, D. Rust, P. Smith, plus engineer and 0.5 FTE data acquisition programmer (Indiana University)

Triggering Electronics

J. Chapman (University of Michigan)

Computer Simulation

G. Hanson, B. Brabson, A. Dzierba, X. Lou, D. Zieminska, 2 FTE physicists/programmers, 1 FTE graduate student (Indiana University)

W. T. Ford, J. G. Smith, plus 0.5 FTE physicist, 1 FTE graduate student (University of Colorado)

A. P. T. Palounek (Lawrence Berkeley Laboratory)

W. Ko, J. Smith (University of California, Davis)

9. Milestones

Milestones for the central tracking

Year 1:

a) Determine spatial resolution, drift time, efficiency for straw chambers .

This will be done for a wide range of gas mixtures and in magnetic fields up about 2T. The dependence on threshold and amplifier designs will also be studied.High rate tests with both sources and beams will be made to study effects of high current draw, such as heat build up in the gas, and wire lifetimes.
(Indiana, Colorado)

b) Develop a wire support system.

The tension vs voltage characteristics for wire stability will be studied. This will determine the maximum free wire span. We will study a number of test designs in active chambers. Finally the large scale fabrication of wire centering devices will be developed.
(Indiana, Westinghouse)

c) Determine the maximum length of straw systems.

We will construct a 2 meter test array to measure resolution, efficiency, stability questions. This will be followed by the construction of a 4 meter test array. Basic questions concerning resolution, wire stability, signal attenuation for long systems should be answered.
Mechanical studies of bonded straws will be studied. This will include sag measurements on straw beams, the fabrication of pre-stressed beams, and the design of support structures.
(Indiana, UC,Davis, Colorado, Westinghouse)

d) Z Reconstruction techniques
Develop straw tube arrays with lengths up to a few meter, using several different winding ratios. Measure the signal propagation, position resolution, and cross talk.

e) Study fabrication techniques for enclosed cathode systems.

Construction techniques must be studied for mylar straw designs. Alternative designs using hexagonal or layered construction will be studied and compared to straw systems. All systems will be evaluated for efficient wire stringing techniques. We will develop testing techniques for maintaining quality control of wire tension, cell spacing and cell size. The radiation resistance of materials will be studied. (Indiana, Colorado, UC-Davis, Los Alamos, Westinghouse)

f) Develop alignment criteria for a multitube module and superlayer support system.
This will include developing laboratory testing methods and techniques.
(Westinghouse, Indiana, Colorado)

g) Develop a design for a multitube module and the conceptual design of a superlayer support system. We will determine the support criteria, make materials selections, and set up alignment test procedures.
(Westinghouse, Indiana, Colorado)

h) Develop a design for a module end cap.
This will include gas, HV, signal wires design with integration of the end support system.
(Pennsylvania, Indiana, Westinghouse)

i) Establish a first cost estimate of the entire project for the complete straw chamber system. Estimate the construction schedule for such a system.
(Westinghouse)

Year 2

Many of the first year projects will continue into the following years. In addition we will specifically focus on the following:

a) Fabricate 2 meter superlayer modules for testing.

Some of the areas to be studied are: alignment, support system,gas flow, electronics interface, high rate beam tests.
(Westinghouse, Indiana, Colorado, UC-Davis)

b)Tests of realistic SSC front end electronics on a module.
As electronics designs are prototyped we will measure resolution, noise, power requirement. This will be done with cosmic rays, sources and in high rate beam tests.
(Pennsylvania, Indiana)

c) Fabricate a 4 meter superlayer module for testing.

From the results of the 2 meter studies a full length system will be constructed to repeat the above studies on a realistic multi layer system. Particular emphasis will be placed on mechanical stability and alignment
(Westinghouse, Indiana, Colorado)

d) Design the complete superlayer support system.

(Westinghouse)

e) Develop a construction and cost schedule for fabrication of all modules and the support system for a complete system.
(Westinghouse)

Year 3

Many of the second year projects will continue into the third year. In addition we will focus on the following:

a) Fabricate a multisuperlayer system for final system check out.

This will include at least three superlayers with several modules in each layer. The support system will of the final design and will be studied for alignment and stability.This will be used to measure alignment and chamber stability using cosmic ray tests and beam tests. Beam tests will evaluate high rate- cross talk, heat build up, and electronics integration.

(Westinghouse, Indiana, Colorado, UC-Davis)

Milestones: Intermediate Tracking Hardware

In a program of R & D lasting over three years we foresee the following as milestones (time ordering by number):

1. Detailed drift cell design (wire diameter, spacing, etc.) to meet specifications of cell dimension and operating conditions (including TR).

   Choice of radiator material to optimise TR X-ray yield for SSC momentum spectrum and for mechanical construction.

2. Manufacture and test single or triple wedge prototype using conventional materials and convenient mechanical techniques to establish operating characteristics and performance (including magnetic field and transition radiation) with right gas mixture (conventional 200 MHz flash digitisation readout).

   Mechanical R & D to establish

   (a) Choice of lightweight materials (with industry) bearing in mind their suitability for the (gaseous) environment and the need to include transition radiator.

   (b) Manufacture (in industry) of items in lightweight materials with acceptable precision over full scale of detector;

   (c) Exploitation of electrical properties of new lightweight materials (such as carbon fibre) in the design.

3. Mechanical design of full scale radial modules with necessary stereo.
4. Fabrication of components in industry to required tolerances.
5. Assembly of full scale modules.
6. Detailed beam test (electron and pion) of full scale modules.

In parallel with this program we foresee the development of suitable read-out electronics. The test program in 2, and ultimately in 6, above will drive the design of cheap amplification and processing cards capable of providing all the data necessary to exploit fully the reconstruction and electron identification possibilities of the chambers. Initially this will build on off-line software analysis of straightforward 200 (or greater) MHz flash digistisation. As prototype cards become available we will expect to test them on the prototype chambers in stage 2 or 6 above, whichever is available.

Milestones for mechanical integration

a) Year 1

Specify the functional design requirements of the mechanical system in detail, decide on suitable materials for the components, and develop preliminary cost estimate (Westinghouse). Develop preliminary design of dynamical alignment scheme, set up laboratory alignment bench (Colorado).

b) Year 2

Complete a preliminary mechanical design and produce the necessary drawings to assist in fabrication and assembly planning; evaluate the design with structural and thermal analysis codes (Westinghouse). Build optomechanical alignment prototype and evaluate it in the laboratory; complete construction of cosmic ray tracking array (Colorado).

c) Year 3

Complete design of the thermal management issues, and the integration of the straw chamber system with the rest of the experiment; make plans for production and quality control; produce a final subsystem cost estimate and production schedule (Westinghouse). Measure resolution of multi-layer tracking prototype with cosmic rays and/or in a test beam; evaluate mechanical support system and dynamical alignment (Colorado).

Milestones for alternative cell R and D.

a) Year 1

Produce small sample cathodes for each of several alternative cell ideas (Los Alamos). Build prototype chambers from these, and test the prototypes with cosmic rays (Colorado).

b) Year 2

Decide on one preferred cell type and make a 2 m long prototype module. Evaluate this prototype for accurate alignment and for adequate postion resolution (Los Alamos, Colorado).

c) Year 3

Produce a full length prototype using the planned industrial production method (Los Alamos, Westinghouse, Colorado).

Winter 1992	**Submit for masks for production runs of ASICs**
	Finalize board design

Milestones: Computer Simulation and Conceptual Design

Year 1 (FY 90)

Central Tracking

1. Include stereo wires and match axial and stereo segments. Determine need for cathode pads or strips.
2. Determine feasibility of determining bunch number and coordinate along wire by displacement of stereo roads.
3. Determine feasibility of high-p_T track segments for trigger.

Intermediate Tracking

1. Determine method of measuring coordinate along wires for radial wire chambers and crossed planes of wires or combination of both.
2. Determine need for cathode pads.
3. Determine possibility of finding high-p_T track segment for trigger with radial wire chambers and crossed planes of wires.

Both Central and Intermediate Tracking

1. Set up pattern recognition and track finding algorithms to integrate silicon and wire chamber components (both central and intermediate) of tracking system.
2. Include more realistic effects, such as $\mathbf{E} \times \mathbf{B}$, time-of-flight for looping tracks, cracks, etc., in order to determine realistic current draw, occupancies, efficiencies, and momentum resolution.

Year 2 (FY 91)

1. Determine best overall tracking system: central/forward integration, radial wire chambers *vs.* crossed planes of wires, wires/silicon/scintillating fibers mix.
2. Specify tracking system design parameters: radii, lengths, cell sizes.
3. Continue study of pattern recognition and track fitting algorithms.
4. Study charged particle triggering (high-p_T track segments) with overall system.
5. Study tracking for various physics processes, such as isolated high-p_T tracks (in complex events), high-p_T jets, and very heavy quark decays.

Year 3 (FY 92)

1. Continue study of pattern recognition and track fitting algorithms.
2. Continue study of physics processes. Determine tracking efficiency and momentum resolution for overall system for various physics processes: isolated high-p_T tracks (in complex events), high-p_T jets, very heavy quark decays, etc.
3. Study feasibility of using secondary vertices to identify heavy quark decays, τ lepton production, etc.

10. BUDGET

project	institution	1990	1991	1992
		$ (K)	$ (K)	$ (K)
Straws	Indiana	120	125	123
	Colorado	72	140	82
	UC,Davis	10	12	15
Alternative Cells	Colorado	72	140	82
	Los Alamos	250	400	250
Radial Ch.	Liverpool-RAL	340	320	320
Mechanical Integration	Indiana	70	85	85
	Colorado	157	97	68
	Davis	8	8	8
	Westinghouse	194	461	300
Electronics	Pennsylvania	222	229	235
	Indiana	165	159	157
Simulation	Indiana	55	62	62
	Colorado	99	70	68
	LBL	10	15	15
Total		$1,844 K	$2,323 K	$1,870 K

Detailed budgets for each institution are included in the appendix.

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Year 2)

Personnel

Electronics Engineer	$37,000
Programmer	$33,000
DAQ Programmer (50%)	$25,000
Hourly help (student)	$ 7,000
Graduate student	$12,000

Supplies

Endcap electronics Fabrication	$20,000
Testing Modules,Test beam supplies	$40,000

Equipment

Test equipment Computer terminals Data Acquisition for remote testing Software	$100,000

Travel

	$ 40,000
University Overhead and Fringe	$ 110,000
Total	$429,000

Year 3)

Personnel

Electronics Engineer	$39,000
Programmer	$35,000
DAQ Programmer (50%)	$25,000
Hourly help (student)	$ 9,000
Graduate student	$14,000

Supplies

Testing Modules,Test beam supplies Endcap electronics	$60,000

Equipment

Test equipment Computer terminals Data Acquisition for remote testing	$85,000

Travel

	$ 45,000
University Overhead and Fringe	$115,000
Total	$427,000

Personnel at Indiana University

Ray Crittenden	20% of time
Alex Dzierba	20%
G. Hanson,	40%
Harold Ogren	20%
Dave Rust	20%
D. Zieminska	10%

Chris Neyman Research support scientist	100%
R. Foster Programmer/designer	100%
Electronics Engineer (to be hired)	100%
2 physicist/programmer (1 to be hired)	100%
Data Acquisition Programmer (to be hired)	50%

Indiana University contributes to this project at many levels. All of the principal investigators are employed by the university. In addition the present systems manager (T. Sulanke) and two technical level employees (B. Martin and K. Welsh) are paid by the university. Both graduate and undergraduate students will be involved in this work. The Physics Department offers free machine shop time for all research work, we will make extensive use of this for prototype construction.The High Energy Physics Group at Indiana University has played a strong technical role in experiments in which we are been collaborators at Fermilab and SLAC. The group also includes a DOE supported electronics engineer (Paul Smith)

Appendix II - University of Colorado

Research and Development of a Wire Chamber Tracking System for an SSC Solenoidal Detector

G. BARANKO, H. CHEUNG, J. CARR, J. P. CUMALAT,
E. ERDOS, W. T. FORD, J. GINKEL U. NAUENBERG,
P. RANKIN, G. SCHULTZ, AND J. G. SMITH

University of Colorado
Department of Physics
Boulder, CO 80309-0390

We propose a program of research and development leading to the design of a large wire drift chamber. This would be one component of the magnetic charged particle tracking system of a detector for the Superconducting Supercollider (SSC). For reference we take the Solenoid Detector Experiment design, described below.

This proposal is part of a multi-institutional collaborative proposal, a copy of which accompanies this document. Both university high energy physics research groups and industrial firms are represented in this program. We present here the part of the program to be carried out at the University of Colorado.

01 Solenoid Detector Experiment for the SSC

The Solenoid Detector Experiment (SDE) study group emerged as an extension of efforts at the 1987 Berkeley workshop on experiments and detectors for the supercollider.[1] The concept of this detector puts emphasis upon high quality charged particle tracking in a strong magnetic field coupled with hermetic calorimetry of high resolution.

02 Charged Particle Tracking for SDE

Earlier work at the Snowmass summer studies (see, e.g., Ref. 2) studied the problem of the segmentation required for a wire chamber in the dense SSC environment. (The reference design for the collider calls for a luminosity of 10^{33} cm^{-2}s^{-1}, 1.6 interactions per bunch crossing on average, and 16 ns intervals between crossings.) The conclusion is that the drift chambers should be made of small cells (about 2 mm maximum drift distance) and should use a gas with fast electron drift, to minimize the time overlap of hits. In the work done to date, a thin-tube cathode (straw) geometry is favored. Silicon strips have promise for the region inside a radius of about 50 cm, and CCD pixel devices in the region nearest the vertex.

The acceptance of the trackers should reach 2 or more units of rapidity with good momentum resolution. Taking a magnetic field of 2 T, point measurement precision of 200 , and a desired resolution of $\Delta p_{\perp}/p_{\perp} \simeq .6\frac{p_{\perp}}{1\ \mathrm{TeV}}$ (sign determination to 1 TeV), we find we need to cover the radial range 0.5 to 1.8 m, at a half length of 5.4 m. This is a large array. Some of the physics of interest at the SSC may call for even more stringent requirements on the tracking resolution. Conversely, the space available for tracking detectors is constrained by the needs and cost of the extensive calorimeter, coil, flux return, and muon detection systems which surround them.

It is clear we have a strong incentive to optimize the tracking system with respect to both the intrinsic and the system resolution. Straw tube arrays have been operated at one atmosphere that achieve better than 100 point measurement resolution. It is, however, not uncommon for large devices to end up with somewhat poorer system resolution, presumably because of the difficulty of maintaining location tolerances on a large scale. Such problems may be compounded with a multi-stage design such as the one presently envisioned for SDE, incorporating both wire chambers and silicon devices.

The research and development effort we propose here covers the areas discussed in the following sections:

- Computations and software development to establish performance specifications for the tracking system.
- Research and prototype evaluation on wire chamber structures.
- Engineering and development of techniques for mechanical alignment.

Following these sections is a description of our plans to study the performance of the candidate systems.

03 Computational studies and software development

Some simulation work for an SDE straw chamber array has been done[1,2] under previous generic detector R & D contracts. The GEANT detector Monte Carlo and ISAJET event generator were used to study the response of the model detector. These programs are now operational also on the VAX 8800 at Colorado. Our proposed extensions of these studies include

- Setting up a track fitting algorithm. This should properly integrate information from both the silicon and wire drift chamber components of the tracking system. It should include the effects of multiple Coulomb scattering as well as proper weighting of the data from the different types of devices.
- Exploring pattern recognition algorithms. These need to be tuned to work efficiently in the anticipated very busy environment of an SSC collision region. This requires detailed simulation of all the particle interactions that tend to degrade the raw data, and evaluation of their effect on the fitted tracks.
- Evaluation of the number and configuration of the tracking layers, to be sure a design is chosen that is adequate to the task.
- Application of these software tools to evaluate or motivate alternative designs. For example, if we can find a scheme to measure directly the third dimension (along the wire) coordinate of each measurement, how much would that improve the results. How adequate is the (technically straightforward) stereo wire approach.
- Examination of the choices for chambers to cover the smaller polar angle regions, beyond the central barrel. Should there be 60° stereo rafts of straws, cathode strips, radial sense wires, etc.?

an adequately uniform plane of laser light can be made using accurate diffraction gratings or other passive optical components.

In addition to the position monitoring in the experiment, a comprehensive alignment system must include the fixtures and instruments to ensure the tracking component parts are accurately constructed and measured. Using our experience working with the SLAC alignment group on the survey of the SLD drift chambers, we propose to purchase and set up at Colorado a Laser Interferometry measurement system. Initially, this would enable us to properly evaluate prototype straw chamber modules in conjunction with our proposed cosmic ray telescope and so choose suitable construction techniques. Later, we would be able to continually provide quality control for the chamber module production.

06 PROTOTYPE EVALUATION

By the time we have a scheme for mounting supercell modules into precisely aligned structures and (if necessary) for dynamically measuring and maintaining alignment, we will want to have in place a tracking array large enough to determine the system performance.

Cosmic ray telescope

To study the position resolution of prototype chambers we propose using a cosmic ray telescope at Colorado. For the SSC studies we would improve an existing system built for the studies of SLD prototype[4] and production[5] drift chambers. The improvements on the SLD system consist of better segmentation in the scintillation counter triggers and increased numbers of drift chamber readout channels to cope with the smaller cell size of the SSC plans. Figure 1 shows the envisioned system, and Table 1 itemizes its costs.

The trigger requires the particles to pass through 26 cms of lead and so selects muons with momenta greater than 0.5 Gev/c by range. Typically we would have an active area of 10 x 200 cm^2, and with the above momentum cut we would collect about 30k tracks overnight.

Prototype fabrication To provide enough measurements for overdetermined tracking in prototype devices we plan for four superlayers each of about 10 cm width and the full length (4 or 5 meters) of an actual SSC device, as shown in Fig. 1. To estimate the cost of such an array we assume the current Indiana design with 4 mm diameter by 1 meter long straws. Long cathodes are created by joining straws end-to-end with molded plastic unions and conducting sleeves. Supercells of 8 to 10 layers in triangular boxes are combined to form the superlayers. The proposed readout system will accommodate enough cells so that we can determine with the outer layers a track location against which to measure the performance, in the context of fully reconstructed tracks, of a module under test that is placed between them. Several such test modules of different designs will be explored, as will the schemes for establishing and maintaining large scale alignment. The cost estimate for such a system is given in Table 2 for the readout electronics, and in Table 3 for the fabrication.

With the redundant tracking system we will be testing both the intrinsic resolution of the superlayers and the alignment of the layers with respect to one another. The goal is to be able to prove our ability to achieve a resolution of 100 microns or better that will propagate, undegraded, to the momentum resolution over a large tracking length.

07 RESOURCES OF THE COLORADO HEP GROUP, PARTICIPATION LEVELS

The contact person at Colorado for this effort will be William Ford, who expects to contribute 30% of his research time initially, increasing to 60% in the third year. Levels for the other faculty associates on this project averaged over the three years are 20% each for John Carr, Patricia Rankin, and James Smith, and 10% for John Cumalat and Uriel Nauenberg. Engineer Gerhard Schultz and Instrument Maker Eric Erdos have worked with the Colorado HEP group for many years, and will each devote 50% time to this program, and 50% to other HEP efforts. Erdos receives half of his support from the University of Colorado. Participation of the research associates (Baranko, Cheung, and Ginkel) will be encouraged as approprate in view of existing commitments. We are requesting 50% of the support of one additional research associate, as well as two graduate research assistants and two FTE undergraduate helpers to work in the laboratory and with the computations.

Current commitments of the group are to Fermilab Experiment 687 (charm and beauty photoproduction) and SLAC/SLC experiments Mark II and SLD (Z^0 production and decays). The E687 and Mark II efforts are expected to continue, including data analysis, through 1991; SLD will run considerably farther into the future.

Proposed commitments include, besides this proposal, a collaborative program to study the properties of amorphous silicon for use in tracking detectors. Some apparatus would be shared between that effort and this one, including the permanent equipment listed in Tables 1 and 2 of this proposal (about $60,000), and probably some of the in-house manufactured drift chambers ($10,000-15,000). Effort expended in setting up the FASTBUS readout system and programming it will also be largely shared. The two proposals plan for engineer G. Schultz and instrument maker E. Erdos to divide 100% of their time equally between these projects.

Previous experience of the participants in this proposal pertinent to the proposed effort includes:

- Ford, Smith, and Schultz built the central drift chamber for the MAC detector at PEP and a straw trigger chamber for Mark II used in its PEP run; Ford and Smith are involved with the vertex drift chamber built at SLAC/LBL for Mark II at SLC.
- Carr, Nauenberg, Erdos, and Schultz have built and are installing the endcap drift chambers of the SLD.
- Baranko, Carr, Cumalat, Ford, and Smith have extensive experience with pattern recognition, fitting, and calibration of drift systems, with E687 and its predecessor experiments, MAC, Mark II, SLD, etc.

- Rankin and Smith have a great deal of experience with online software; Rankin has done much of the FASTBUS programming for Mark II.

The University of Colorado provides a quality machine shop in the physics building. The group have recently acquired a computer aided design system which will be used in the design work. We have a VAX 8800 (about two-thirds devoted to HEP), for which the lease- purchase agreement will be fully paid off after 1990. The core of a FASTBUS system will be in place for use in this research, along with a drift chamber gas system, part of the cosmic ray telescope, some of the fast electronics, etc.

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Appendix III – University of Pennsylvania

The University of Pennsylvania has been involved, through its generic SSC electronics R&D grant, in the development of custom integrated circuits for gas ionization chamber readout. As members of a separate electronics subsystem proposal, we intend to extend this work to include the development of radiation hardend front end electronics and system integration.

As members of this proposal it is our intention to help with the implementation of custom ASICs developed by the electronics design group in the prototyping and system test stages, to modify the front end signal processing electronics to include detector specific enhancements and help to arrange the manufacture of production quanities of custom ASICs.

(Note: Indiana University will contribute engineering and technical expertise for board level designs, system integration and data aquisition software. For the sake of a complete description of the front end electronics effort, they will be included here, appropriately denoted. It is clear that there is room for other institutions to share in the responsibility for the development of this complex system.)

Preliminary Budget and Personnel

Legend	P Penn based	X	Fully funded by this proposal
	I Indiana based	E	Anticipated funding by other work
		C	Funding source needs clarification

<u>Personnel</u>

				89	90				91				92	
				F	W	S	S	F	W	S	S	F	W	S
F. M. Newcomer	35%	X	P	*	—	—	—	—	—	—	—	—	—	→
H. H. Williams	10%	X	P	*	—	—	—	—	—	—	—	—	—	→
R. Van Berg	25%	X	P		*	—	—	—	—	—	—	—	—	→
	+ 5% travel													

EE CMOS Designer	40%	X	P	*————————————→	
CAD/CAE Systems Manager	50%	X	P	*————————————→	
DAQ Programmer	50%	X	I		*——————→
Experienced tech	50%	X	I	*——————→	
or graduating EE	100%	X	I		*——————→
Staff Tech Support	20%	X	P	*——————→	
	50%	X	P		*——————→

<u>Travel</u> (Front end electronics related)

(Estimate)	X	P	$20K annual
	X	I	10K annual

<u>Fabrication Costs</u>

			(contingency)
Multi ch. bipolar prototype	C	P	35K (50%) assumes wafer brokerage
Full design bipolar prototype	X	P	35K (50%)
CMOS TVC/An. Memory prototype	E	P	5K (50%) MOSIS run
Final Bipolar ASIC prototype	X	P	35K (50%) chips for 1000 ch test
CMOS ASIC final prototype (rad hard version)	E	P	50K (50%) chips for 1000 ch test
Production runs of ASICS	X	P	To be determined

⋆ Fabrication costs depend critically on the chosen technology. These estimates are based on the expected cooperation of the vendors and the likelihood that designs for multiple projects may be submitted for the same run. Some masking techniques depend on a highly repetitive structure and may not allow more than a few designs to be submitted on the same run.

Equipment Costs

Dedicated design station	X	P	15K (25%)
Automated test equipment	X	P	20K (25%)
Computer driven test station (Home institution)	X	P	15K (20%)
Computer driven test station (Second institution or beam)	X	I	15K (20%)
VME standard or equivalent data acquisition computer	X	I	12K (20%)

Software Costs

Layout software	E	P	20K (20%)
Maintenance agreements	E	P	10K (20%)
Data acquisition OS	X	I	3K

Board Manufacturing Costs

Prototyping boards			
Layout	X	I	10K (25%) 5 small multilayer boards
Manufacture	X	I	7K (25%)
Detector electronics board for prototype run			
Layout	X	I	5K (?)
Manufacture	X	I	3K (?)

Surface Mount Technology

Solder/Desolder station	X	I	5K

Appendix IV- University of California, Davis

Personnel

R. Breedon	Mechanical structure an Z coordinate
R. Lander	"
K. Maeshima	"
Electrical Engineer (50%)	"
Mechanical Engineer (50%)	"
Graduate student (3)	"
W. Ko	Simulation
J. Smith	

Appendix V – University of Liverpool and Rutherford Appleton Laboratory

Manpower and Resources

1 or 2 senior physicists

2 post doctoral physicists

1 design engineer (including CAD)

2 mechanical technicians with access to well equipped mechanical workshop

> 1 graduate students

1 senior electronic engineer with access to well equipped electronic workshop (possibly at RAL).

1 junior electronic engineer under supervision of senior

Electronic technical effort (possibly at RAL).

An in-house minimum ionising test beam is available at RAL for chamber development and access to an e^- beam.

Finance

It is anticipated that the total funding for R & D work on radial chambers will come from both US and UK sources. We list below items which we request to be funded from US sources.

Consumable items for chamber construction (*e.g.* composite manufacture, pc boards, TR material)	$200,000
Consumable items for chamber testing	60,000
2 fixed term physicist appointments	100,000 per year
1 senior electronics engineer (possibly at RAL)	60,000 per year

1 junior electronics engineer (possibly at RAL)	50,000 per year
Travel (to/from US, to/from test beams)	30,000

We plan to bid for UK funding to cover the following items:

Consumable items for chamber construction and testing (e.g. gas, mechanical construction jigs, test facility computers and electronics, general lab infrastructure)

Consumable items for electronics development (partly at RAL).

Note that should the R & D program lead to the conclusion that a radial wire array be designed for the intermediate tracking region, then considerable additional manpower and funding will be necessary for construction and commissioning.

Appendix VI-Westinghouse Science and Technology Center

89M844-2

Proposal to

Physics Department
Indiana University at Bloomington
Bloomington, Indiana

Mechanical Design and Analysis of a Straw Tube Drift Chamber

STATEMENT OF WORK AND COST PROPOSAL

September 1989

Approved:

F. T. Thompson

F. T. Thompson, General Manager
Engineering Technology Division
Westinghouse Science and Technology Center

MECHANICAL DESIGN AND ANALYIS FOR A STRAW TUBE DRIFT CHAMBER

— STATEMENT OF WORK —

The Westinghouse Electric Corporation proposes to undertake a 24-month program to perform the preliminary mechanical design and analysis of a straw tube drift chamber for the SSC large solenoid detector. The work will be carried out at the Westinghouse Science and Technology Center in Pittsburgh, Pa. Upon completion of the proposed program, the following items will be delivered to Indiana University in Bloomington, Indiana: concept drawings and estimated costs and schedule for the procurement, fabrication, assembly, and testing of the proposed straw tube drift chamber.

The program is divided into four areas of performance:

- Mechanical Design
- Material Science
- Thermal Management
- Manufacturability

These areas have been divided into nine tasks. Each task is described in the following pages, and a task schedule is shown in Figure 1.

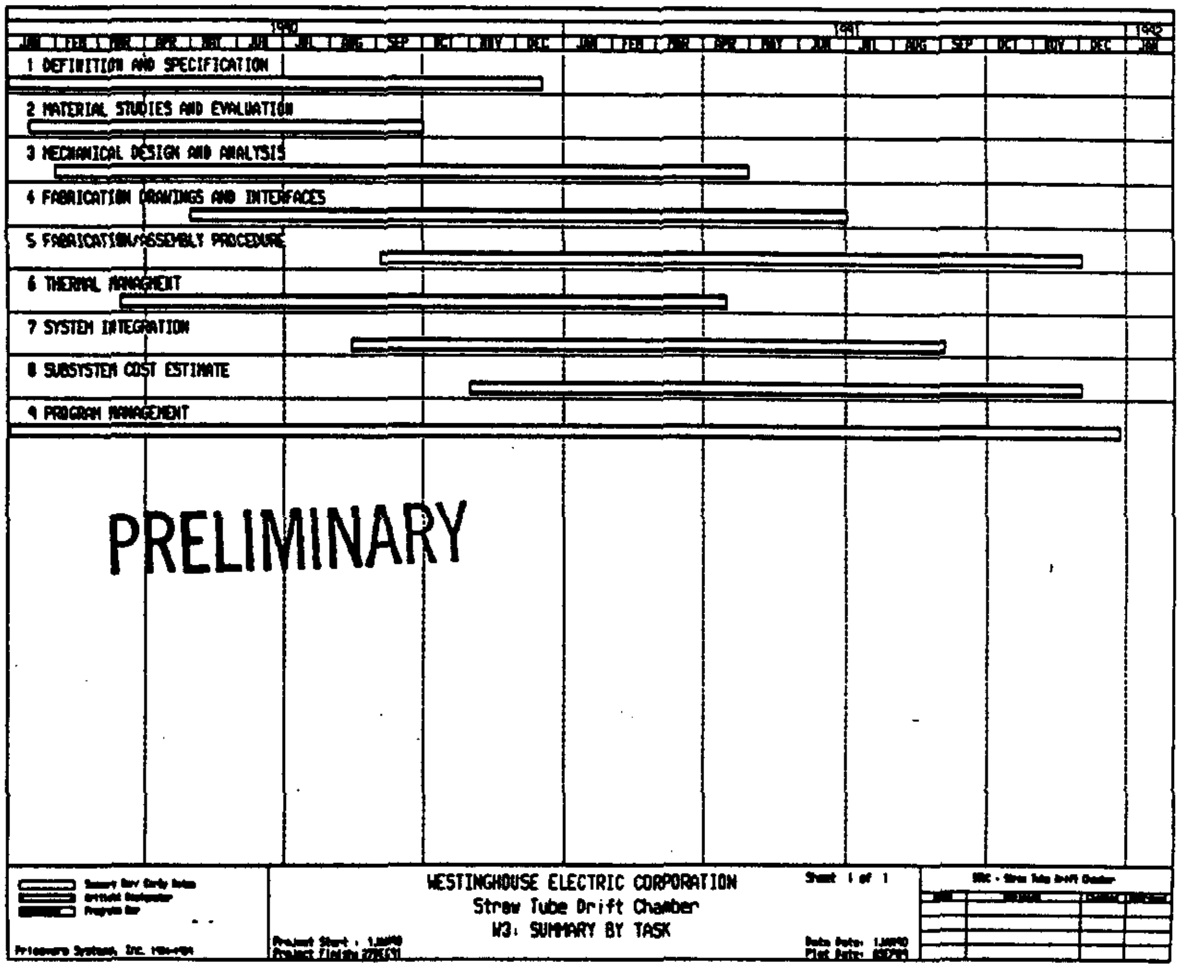

Figure 1 — Program Schedule

TASK 1. STRAW TUBE DRIFT CHAMBER DEFINITION AND SPECIFICATION

In Task 1, Westinghouse STC will work with the Straw Tube Drift Chamber Group to specify the functional design requirements for the detector. Physical constraints, such as size, weight, length, and detector geometry, will be identified as well as electrical leads and cooling requirements. Figure 1 shows this effort lasting most of the first year of the program. This amount of time will be required in order to make specification modifications as the concept progresses over the first year.

TASK 2. MATERIALS STUDIES AND EVALUATION

Material property requirements for the support structure and auxiliary system will be specified in this task. Candidate materials will be reviewed for use based on work performed by the national laboratories concerning radiation length and susceptibility to radiation damage. The major effort on materials will be performed by the national labs, with Westinghouse relating the data to the particular component or structure.

TASK 3. MECHANICAL DESIGN AND ANALYSIS

In this task, the preliminary design of the straw tube drift chamber assembly will be performed. Concepts proposed by the working group will be reviewed and evaluated in order to identify the most promising one for overall detector operation. The concept selected will be analyzed for structural support to ensure that stability and rigidity will be sufficient to maintain critical alignment requirements over the design life of the device. All routing and connections of power, cooling, and instrumentation cabling and hoses will be conceptualized. In addition to the design and analysis work, general requirements for assembly and alignment will be specified during this task.

TASK 4. FABRICATION DRAWINGS AND INTERFACES

Layout drawings will be prepared of various concepts proposed and studied in Task 3. A concept drawing of the selected silicon strip detector configuration will be prepared in sufficient detail to obtain costing and scheduling information. Assembly drawings will be developed as necessary to assist in the fabrication and assembly procedure as well as interfaces with adjacent structures.

Three-dimensional solid modeling will be utilized as needed in the design process to verify spatial relationships among components and to ensure proper assembly and system integration.

TASK 5. FABRICATION/ASSEMBLY PROCEDURES

The purpose of this task is to specify in sufficient detail the fabrication processes and assembly procedures required of the concept selected. These procedures will include such items as the following:

- Straw tube mounting procedure
- Structural support fabrication method
- Special tooling
- QA/QC testing
- Modular assembly sequence
- Electrical cable routing procedure
- Cooling hoses routing procedures

These procedures will be prepared in a form to match the concept detail and costing estimate requirements for construction of a device. Prior to any device construction, a detailed procedure write-up will be required and prepared at that time.

TASK 6. THERMAL MANAGEMENT

Thermal management will address cooling methodologies for removing the heat generated within the modules. All known sources of heat, both internal and external to the straw tube drift chamber, will be determined and evaluated according to their effect on the detector concept. A scheme will be proposed for maintaining the detector modules at a reasonable operating temperature with minimum compromise on the overall performance of the straw tube drift chamber. Upon completion of this task, a listing of the cooling system equipment will be prepared.

TASK 7. SYSTEM INTEGRATION

Integration of the straw tube drift chamber with the surrounding equipment in the overall SSC detector system will be investigated. Included in this effort will be the assembly and disassembly of the straw tube drift chamber within the system as well as the mounting requirement and constraints of the device. In addition, a survey of the known external forces and loading conditions affecting the straw tube drift chamber will be prepared.

TASK 8. SUBSYSTEM COST ESTIMATE

The cost and schedule will be estimated for the overall fabrication and delivery of a completed device to the SSC detector location. Included in this task will be the cost and schedule for the following items:

- Materials procurement
- Component fabrication
- Module assembly
- Module QA/QC testing
- Module shipping to SSC site
- System assembly at site
- System testing
- System installation

This effort will require input from all areas within the group in order to establish reasonable and accurate costs and schedule.

TASK 9. PROGRAM MANAGEMENT

The program management task consists of the preparation of reports, design reviews, general meetings, and cost reporting to the program manager. Estimates of the Westinghouse effort are based on the following activities:

- Monthly progress and cost letter reports for 24 months
- Group meetings at Indiana University every six weeks
- Two DOE design reviews, one of each at the end of each year
- Yearly reports to DOE describing technical progress

Westinghouse

D. T. Hackworth, Manager, Electromechanics
Westinghouse Science & Technoogy Center

B.S., M.S. course work, mechanical engineering, University of Pittsburgh.

Mr. Hackworth is working in the area of high current systems. This covers all aspects of high current systems: the development, design, analysis, specifications, and testing as well as the development of specialized mechanical equipment. He has lead responsibility for the Westinghouse effort in Superconducting Magnetic Energy Storage (SMES). On this project, he has overall responsibility for all systems of the superconductor and coil cold pack design, analysis, component fabrication and testing as well as the system coil manufacturing plan.

From 1976 to 1981 Mr. Hackworth had responsibility for the design of superconducting apparatus in the design and structural engineering role for the Westinghouse effort on the Large Coil Program with Oak Ridge National Laboratory. On this project, he was responsible for all aspects of the mechanical systems, including design, analysis, drafting, and materials.

Mr. Hackworth had responsibility for the structural design in a DOE-sponsored conceptual study of toroidal field magnets for the Experimental Power Reactor study. In addition, he was Lead Mechanical Engineer on the 400 kJ coil program for LASL. He also completed a conceptual structural design of the toroidal-field coils for the High Field Compact Tokamak Reactor for MIT. This assignment required the integration of a conductor design and a viable structural design based on material and manufacturing capabilities.

From 1973 to 1976, Mr. Hackworth served as a Mechanical Engineer in the Development Group of the Generation Systems Department, where he contributed mechanical development expertise to programs for system design. He has performed stress and dynamic analysis to alleviate vibration and structural problems and has developed testing procedures for structural analysis. Central to his contribution was the development of a Westinghouse computer program to facilitate steady state thermal analysis for internal non-rotating windings of turbine generators.

Mr. Hackworth has nine disclosures in the area of high current systems and robotic systems, and holds two patents dealing with large motor control and robotic vision systems.

Publications:

"Design of Pulsed Power Cryogenic Transformers," Tenth International Conference on Magnet Technology, September 1987.

D. T. Hackworth (Continued)

"Design of Pulsed Power Cryogenic transformers for Electromagnetic Launchers," 1987 Strategic Defense Initiative Technical Achievements Symposium, March 1987.

"Advantages of the Distributed Structure Concept of the Westinghouse LCP Coil Design," Applied S/C Conference, October 1986.

"A 10 MJ Cryogenic Inductor," 3rd Symposium on Electromagnetic Launch Technology, April 1986.

"Advanced Techniques in the Design of Electromagnetic Stirrers for Continuous Casting," 1985 AISE Annual Convention, September 1985.

"Quiet Cooling System Development for a Traction Motor," ASME Vibration Conference, September 1985.

"Manufacturing Plan for the Westinghouse Nb_3Sn Large Coil," 9th Symposium on Engineering Problems of Fusion Research, October 1981.

"Structural Design of the Westinghouse Superconducting Magnet for the Large Coil Program," IEEE Transactions on Magnetics, Volume MAG-15, January 1979.

"Design of a Low-Loss Fast-Pulsed Superconducting Energy Storage Coil," 8th Symposium on Engineering Problems of Fusion Research, 1978.

"Westinghouse Conceptual Design of a Test Coil for the Large Coil Program," Proceedings of the Seventh Symposium on Engineering Problems on Fusion Research, 1977.

Westinghouse

J. W. Barkell, Jr., Engineer
Westinghouse Science & Technology Center

B.S., mechanical engineering, Wichita State University; M.S., mechanical engineering, Carnegie Mellon University.

Member, ASME; Registered Professional Engineer (Pennsylvania).

Mr. Barkell has ten years of experience devoted to product design and development of electromechanical devices. Projects have included medium and low voltage switchgear, watt-hour meters, and low voltage switches. His most recent assignment was design engineer on the 6400 A Naval Insulated Case Power Circuit Breaker. His duties included design of the drawout mechanism and interface, and various aspects of the circuit breaker and nonremovable element. He also performed analytic studies of current distribution and associated effects in large ac conductors using a Westinghouse electromagnetic field analysis program.

In the last two years, Mr. Barkell has used PATRAN & ANSYS for structural analyses of electro-mechanical equipment. His most recent analysis is a 2D axisymetric analysis of a cryogenic stator body for the Air Force. This model includes non-axisymetric loads and cooldown stresses applied to an orthotropic composite structure.

Mr. Barkell is a Captain in the U.S. Army Reserve and completed his four years in the U.S. Army Corps of Engineering as a Lieutenant.

Westinghouse

J. A. Hendrickson, Senior Engineer
<u>Westinghouse Science and Technology Center</u>

B.S., mechanical engineering, Pennsylvania State University; M.S., mechanical engineering, University of Pittsburgh; additional graduate study, University of Pittsburgh.

Registered Professional Engineer (Pennsylvania); Member, American Society of Mechanical Engineers; Society of Automotive Engineers; Society of Manufacturing Engineers; Certified Manufacturing Engineer (Tool Engineering Specialty).

Mr. Hendrickson has more than seven years of experience in the field of mechanical tooling systems design and implementation. He joined the Westinghouse Electric Corporation in 1982 as a field service engineer in the Power Generation Service Division. His work history has included maintenance and troubleshooting efforts on steam turbines, electric generators, heat transfer equipment, turbine-generator control systems, and all phases of nondestructive testing and examination of related components. Typical test experience includes rotor bore examinations, fluorescent penetrant inspections of steam turbine components, UT inspection of foundation bolting, and generator thermovision examinations.

In 1983, Mr. Hendrickson transferred into the Nuclear Service Division, where he developed an expertise in the area of design and development of remote operated tooling systems to address the needs of the nuclear power industry. The majority of the tooling had special requirements for underwater operation in high radiation fields. Mr. Hendrickson has designed and fabricated several precision positioning systems to support underwater machining and repair programs as well as various end effectors for remote manipulator applications.

Since joining the Science & Technology Center in 1986, Mr. Hendrickson has been involved with the design of light gas pre-acceleration systems and electromagnetic launchers, "rail-guns," to support various SDI programs. He was responsible for the complete design, erection, and commissioning of the SUVAC II pre-accelerator, the first to be built and operated in the corporation. The SUVAC II pre-accelerator is capable of accelerating a 10 gram projectile to an injection velocity of 1 km/sec.

Most recently, Mr. Hendrickson has been involved in the design of a supercritical hydrogen cooled hyper-conducting alternator stator for the Aero Propulsion Lab at Wright-Patterson Air Force Base. The high voltage stator design incorporates state-of-the-art structural composites technology in order to increase stator power density an order of magnitude over conventional designs. He has also been involved in the design of the plasma accelerator for the space power experiment, SPEAR II.

J. A. Hendrickson (Continued)

Mr. Hendrickson has been active in the patent area with over 28 disclosures.

Publication:

"The Design and Testing of a Single-Stage Light Gas Gun as a Projectile Pre-Accelerator for an Electromagnetic Launcher," 4th Symposium on Electromagnetic Launch Technology, April 1988, University of Texas at Austin.

COST SUMMARY BY YEAR

WESTINGHOUSE ELECTRIC CORPORATION
SCIENCE AND TECHNOLOGY CENTER
1310 BEULAH ROAD
PITTSBURGH, PA 15235

STC NO: 89M844-2
RFP NO:
AGENCY: INDIANA UNIV.
DOE
TITLE: STRAW TUBE DRIFT CHAMBER

FISCAL YEAR 1990 COSTS

			FY1990
A.	MATERIAL/EQUIPMENT		-
B.	LABOR		
	1. ENGINEERING	HRS	2,104
		($)	64,170
	2. SUPPORT	HRS	240
		($)	5,158
	3. TOTAL LABOR	HRS	2,344
		($)	69,328
C.	OVERHEAD (*)		83,471
D.	OTHER		
	4. CONSULTANTS		-
	5. COMPUTER		3,000
	6. SUBCONTRACTORS		-
	7. OTHER		4,310
E.	IWR		-
F.	TOTAL DIRECT COST		160,109
G.	G&A (16.870%)		27,010
H.	P. O. T. COSTS		-
I.	COC-STC (9.797%) OF B3		6,792
J.	COC-CORP (0.241%) OF F		386
K.	TOTAL COSTS		194,297
L.	FEE		-
M.	TOTAL COSTS & FEE		194,297

*VARIOUS OVERHEAD RATES USED

THIS IS TO CERTIFY THAT THIS COST DATA IS BASED UPON OR COMPILED FROM THE BOOKS AND RECORDS OF THE COMPANY. TO THE BEST OF OUR KNOWLEDGE AND BELIEF, THE COST DATA PRESENTED IS IN CONFORMANCE WITH PROVISIONAL COSTING RATES.

(W) STC REFERENCE 89M844-2

Straw Tube Draft Chamber

COSTS BY FISCAL YEAR

Fiscal Year 1990	$194,297
Fiscal Year 1991	461,511
Fiscal Year 1992	49,010
TOTAL . . .	**704,818**

(W) STC REFERENCE 89M844-2

Straw Tube Draft Chamber

TASK BREAKDOWN

	FY 1990	FY 1991	FY 1992	TOTAL
Task 1	17,227	1,969	---	$ 19,196
Task 2	10,528	---	---	10,528
Task 3	60,762	63,944	---	124,706
Task 4	14,809	30,500	---	45,309
Task 5	7,093	158,604	31,553	197,250
Task 6	40,992	57,157	---	98,149
Task 7	8,612	67,781	---	76,393
Task 8	---	35,047	5,105	40,152
Task 9	34,274	46,509	12,352	93,135
TOTAL . . .	**194,297**	**461,511**	**49,010**	**$704,818**

Appendix VII - Los Alamos National Laboratory

The various concepts of using specialized materials tecnology in the fabrication of straw tube modules all rely on hte fabrication of precision fixturing and molds. A faily large portion of the cost will be for machining. The development effor would involve 1-2 persons full time. The following is an estimate of the yearly costs associated with the materials development portion of the novel fabrication methods likely to be necesary for the straw tube fabrication for SSC.

Effort Estimate in $K

Year	Manpower	machining and materials	total
1	175	75	250
2	250	150	400
3	150	100	250
total			900

It should be noted that formal proposals from Los Alamos must be submitted through the standard procedure, and that DOE must formally accept any proposal submitted by us. Thus, our input to this proposal must be considered informal, and cannot be considered binding unless and until the formal proposal and approvals have been obtained.