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SOLENOIDAL DETECTOR NOTES

REPORT OF THE TASK FORCE ON R&D DIRECTIONS FOR TRACKING

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1. Executive Summary and Recommendations

The Task Force organized working groups in the following areas:

1. Estimate the schedule for R&D, design, construction, and testing of the tracking system in each of its options. Assume a target completion date of Oct., 1998 (one year earlier than nominal plan, to allow for contingency).
2. Unified pattern recognition
3. Intermediate angle tracking and triggering
4. Central triggering
5. Mechanical support and alignment
6. Readout electronics
7. Background radiation fluxes and survivability

Extensive discussions were held during the January collaboration meeting at SSCL, during a dedicated three-day workshop at Oak Ridge National Lab on February 11-13, and during the March collaboration meeting at ANL. Task force executive deliberation sessions at ORNL and at ANL led to the plans and recommendations discussed below.

Task force members are: Amendolia, Chapman, Dainton, Edwards, Elias, Ford, Goshaw, Hanson, Kim, T. Kondo, Matthews, Miller, Nygren, Ohsugi, Ruchti, Ryan, Seiden, Stone, Strovink, Swensrud, Williams. Very broad participation by tracking experts throughout the collaboration has been essential to this continuing effort.

Detailed schedules drawn up by the subsystem mechanical and electronics engineering teams may be summarized by stating that around the middle of calendar year 1992, significant costs for engineering design begin to be incurred (earlier for the silicon system). Thus we see that in most areas conceptual R&D will need to be completed and technology choices made before the end of FY92, and some expenditures for engineering design incurred in that fiscal year.

In the recommendations we designate priorities for R&D in four categories: directed toward proof of principle, performance, conceptual engineering design, and

costing. The priority levels are:

1) Must proceed to meet schedule requirements and permit a credible design for the initiation of construction

2) Should proceed but may not be on the critical path

3) Should proceed, if funds are available

Silicon pixels have strong potential to enhance the pattern recognition and vertexing capability of the detector. R&D toward proof of principle should proceed at priority 1, to address issues including the continuously active analog/digital circuitry and noise suppression, "smart pixel" architecture, and radiation damage. While it is recognized that the time scale for most of the hardware R&D results is early 1992 or later, the pixel group are asked to produce by the time of the September collaboration meeting at Oak Ridge a detailed layout (priority 2) to demonstrate just how the detectors would be used in the the experiment, to facilitate simulation, integration, costing etc. Preliminary costing should proceed at priority 2.

Silicon strips carry a major role in the tracking system for pattern recognition, vertexing, and high-eta momentum measurement. Priority 1 R&D is needed on support structures, alignment, and cooling directed toward proof of principle, performance, conceptual design, and costing. Priority 1 R&D on proof of principle for radiation hard detectors and readout, detector performance, and readout conceptual engineering are also needed, with work at priority 2 on readout performance, detector engineering and costing for both. Decisions are to be made by September 1991 on strip lengths, single or double sided detectors and module structure.

The outer tracker contributes to the pattern recognition and is essential for the stiff-track component of the trigger and for the long lever arm needed for precision momentum measurement, for extrapolation outward to the outer calorimeters and muon detectors, and for extrapolation inward to the vertex region. Candidate technologies for the barrel are straws and scintillating fibers. The straw technology is "mature". Fiber work has recently achieved a proof of principle at the single detector level, and fibers have a clear advantage in high-occupancy regions. Both must

be pursued at priority 1 with R&D on performance, conceptual engineering, and costing.

For readout of scintillating fibers, VLPC development (performance, design, and cost) should proceed with priority 1. Avalanche photodiodes (APD's) represent an option that could prove more cost effective, and should receive priority 1 research for proof of principle (fast quenching) and costing, with priority 2 for performance and conceptual design.

Readout electronics for straws (some of which may serve also for VLPC's and/or muon chambers) are under development at KEK (TMC) and Penn (TVC/AMU). The TMC already exists as a multi-channel custom IC. Work is needed (priority 1) on proof of principle for high-density amplifier-shaper-discriminator and TVC/AMU ASIC's, and on performance, circuit develpment (including power-on radiation hardness), and costing for both options.

The outer tracker mechanical support structure is to be developed in a unified effort encompassing both wires and fibers. A draft baseline layout for mechanical engineering purposes has been specified. Work on this layout will seek to establish the concept for straw packaging (e.g., in modules or attached directly to precision cylinders) by May/June 1991. This conceptual engineering and associated costing are priority 1. The engineering baseline layout is not construed as the choice for optimum performance; a set of options is proposed that allow for performance optimization.

Development of concept and costing of triggering strategies and circuitry for barrel wires and fibers should proceed with priority 1. Detailed performance evaluation is recommended at priority 2.

The intermediate angle outer system is the least developed at this time. Options under consideration include radial wires, straw disks, space-filling spiral fiber disks, and microstrip gas devices in varous configurations.

For radial chambers the biggest concern has been with current draw (about .5 microamp at luminosity of 10^{33}) and its effect on the cathode voltage divider. Present thinking is that this can be handled with multiple external power sources.

A stereo scheme to be developed will provide the r measurement, in place of the previously proposed anode current divison which would have doubled the occupancy.

The space-filling fiber spirals and radial straws suggested for this region have a limited range of (rmin,rmax). This leads to preference for a long barrel plus end plug configuration. Conversely, radial wires require short (3m) barrel plus end caps (because of massive attachments at rmax). Both fibers and straws have been shown now to have attenuation lengths of 6 m or more which appears to establish the feasibility of a 4 meter long barrel for both technologies.

The gas microstrip technology needs at least a year of R&D to become a credible option. Work on this will proceed at Rutherford Lab, among other institutions, independent of SDC plans. A microstrip group within SDC involving Canadian and UK groups, Rochester, and Texas A&M is forming to coordinate hardware R&D and simulation efforts.

Our conclusion is that among the radial wire, straw, and scifi options we have at present no solution that is clearly affordable AND clearly provides trigger functionality. For this reason the microstrip gas option should not be ignored. The draft baseline layout we have chosen reflects a preference for a long barrel to take maximum advantage of our best-established technologies for tracking and triggering.

We recommend priority 1 effort on intermediate angle triggering proof of principle for straw and fiber disks. The trigger concept for radial wire chambers should be developed (priority 2), along with performance and conceptual engineering (priority 3).

Gas microstrip R&D should be pursued toward proof of principle with priority 3.

These recommendations are summarized in Table 1.

Table 1. R&D priority summary.
PoP: Proof of principle
Perf: Performance development
ConcDes: Conceptual engineering design
Cost: Cost assessment
x means "completed"
(x) means at individual detector level, not yet system.
Priority levels are defined in the main text.

	PoP	Perf	ConcDesn	Cost
Si Pixel	1	2	2	
Si Strips				
structure/alignment/cooling	1	1	1	1
rad hard detectors	1	1	2	2
rad hard readout	1	2	1	2
Straws				
detector R&D	x	1	1	1
rad hard readout electronics	1	1	1	1
Scifi				
rad hard scintillator detectors	1	1	1	1
VLPCs	(x)	1	1	1
APDs	1	2	3	1
Outer structure	x		1	1
Barrel trigger				
straws	x	2	1	1
scifi	x	2	1	1
Radial wire chambers trigger concept	2			
Radial wire chambers device R&D		3	3	
Scifi disk trigger concept	1			
Straw disk trigger concept	1			
Gas microstrip	3			

2. Silicon Strip Tracker

The task team for the silicon tracking system was assigned responsibility for establishing a first cut at the silicon tracking system R&D program schedule and cost. To this end, we sub-divided the effort into five manageable technical areas and identified key institutions for each of these areas. Next, members from each technical area scoped out the basic R&D program activities. Guidance for the R&D planning session was established by first identifying timelines for long lead component fabrications, major construction items, assembly and checkout, and reassemble at the SSCL. Starting with the SSCL commissioning milestone date and working backwards only served to confirm our intuition that the schedule for the silicon

tracking system will be largely driven by R&D activities.

The five technical areas which formed the basis for our plan are:

- Detectors
- Electronics
- Mechanical and Cooling
- Physics/Simulations
- Trigger/DAQ

Preliminary schedules have been developed for each of these areas. Our current scheduling/costing activities address detailed planning of individual activities for each technical area. A proper and well thought-out program plan with accurate cost profiles is no small task, and must not be treated lightly. The planning activity will be an on-going effort that requires attention to detail and updating as more information becomes available. For the present, we have provided guidance to the overall scheduling effort by submitting information on detail tasks, however, that information should be treated as very preliminary.

Critical issues were identified in the subject technical areas. Those issues formed the basis of the R&D plan. In the process of focusing our thoughts on R&D issues, we also developed engineering plans for major activities e.g., component and system assembly, detector alignment, both internal and external, and utilities management. The plans were produced in an outline format and are not included herein. We will expand the outlines into actual published documents, which we will disseminate when they are completed. Our Environment, Safety, and Health (ES&H) documents will be derived from this material as well. For example, we are presently working on the safety plan for the silicon tracking butane cooling system.

2.1. Strip Configuration

The Silicon detector is built up in a modular fashion with detectors assembled into modules, mounted on structures, which are then held by a large space frame. We have made an initial schedule for the R&D and construction phase. Development work through 1994 will provide a final design with all prequalification tests required for mass production and assembly. The schedule is very tight and will require considerable discipline to avoid falling behind.

The first decision that will be made is the choice of detector length and detector module structure. This will define the basic units out of which the whole device is built up. The possible choices are short-strip detectors using single-sided silicon detectors with readout every 1 cm or long-strip detectors using double-sided silicon detectors with readouts spaced somewhere between 6 and 18 cm, to be optimized as part of the decision process. For the long-strip detectors the choice of stereo angle also needs to be finalized.

Groups have been set up to look at the issues for the strip length decision from the point of view of physics, electronics, mechanics, and detectors. A report from these groups will be assembled at the end of July and a final decision made at the end of September.

Although it would have been advantageous to include a final specification of the electronics in the strip length decision, we are not far enough to do so. At this point the open questions in the electronics system have little to do with general philosophy, but are directed towards determining the most efficient and economical scheme to achieve the required performance. The questions of DAQ and trigger will be looked at with high priority in parallel with the strip length issues. We expect in 1992 to decide many of the frontend design and fabrication issues. The discussions below will be addressing the R&D we are expecting to do over the next few years.

2.2. Readout Electronics

Front-end Electronics

LBL has been assigned primary responsibility in this area. Emphasis in FY91 will be on obtaining data critical to comparing systems of various strip lengths. We will review bipolar designs from KEK and UCSC, and the CMOS circuits developed at LBL. Measurements of radiation effects on radiation-hard CMOS test devices from UTMC and IBM will be completed. These data will be used as a basis for identifying circuit improvements for simulation of comparison systems. The comparison systems will be specified on the basis of functional requirements for the complete detector, i.e. the electronic specifications will be tailored to the occupancy, required S/N, and radiation susceptibility of the various options. These comparisons must also include reliability and manufacturability; in comparing designs one must consider the availability and maturity of the manufacturing processes required. The most important task is to assess the results of all these activities and complete a report for the Silicon Tracker Technical Board that compares the electronics aspects of the various detector options.

Design of the final electronic system will begin in early FY92. Roughly two years have been allocated to completing the design, including design iterations, interim fabrication runs and tests of radiation effects with detectors. In August, 1993 the final prototype design is to be submitted for a pre-production run. After extensive pre-qualification tests of complete module systems, and presumably only minor modifications, mass production should begin in mid-1994.

Milestones:

15 April 1991	complete evaluation of current CMOS ICs
15 April 1991	provide preliminary summary of heat-loads and cabling plan to Mechanical Design Group
31 May 1991	complete evaluation of radiation-hard CMOS test devices from UTMC and IBM, including noise measurements
31 July 1991	complete comparison of design alternatives and submit report
30 Sept 1991	complete evaluation of reports, supplementary studies, submit final report
Aug 1993	Submit final prototype for pre-production run
May 1994	Place order for mass-production run

Data Transmission

A conceptual design for the data readout system will be developed in FY91. A likely arrangement is a set of external busses serving sections of barrel layers or disks, respectively. Local busses would bring data to intermediate bus selection chips whose outputs feed into the external bus, which will probably be a fiber link. FY91 work will specify the required signals, the arrangement and number of signal sources, local data rates, and a preliminary bus layout. This will provide a basis for a more detailed engineering study in FY92 to compare implementations and develop a final design. The conceptual design is closely linked to the design of front-end electronics and the detector modules (see below). The schedule for completion of the data transmission system is rather loose since the schedule is determined by the front-end electronics.

Milestones:

Sept 1991	Complete conceptual design specification
Aug 1992	Complete preliminary system design
Sept 1993	Complete final system design and component tests
Oct 1994	Complete tests of system subset and begin production

Detector Module Design

To facilitate testing, assembly, and maintenance of the Silicon Tracker it is important to adopt a modular design based on subassemblies (i.e. sectors of barrels or disks) that combine detectors, readout chips, and local bussing. A key characteristic of these modules is that they can be assembled, tested, installed, and - if necessary - replaced as self- contained entities. One of the critical constraints in module design is cross-talk from either the digital electronics or the signal busses to the detector input. The design must also accommodate readout chips and decoupling circuitry without introducing excessive dead area or mass. We will assess various module types, e.g. configurations that place readout chips on cooling rings and others with distributed heat loads between cooling rings (for pixel devices and short strips). To obtain starting data for prototype designs we will assemble a module test structure that includes strip-detectors, front-end amplifiers, and a ribbon cable that approximates a practical design for the Silicon Tracker. The bus will be driven by pulse

trains that mimic bus activity at the SSC and we will measure the cross-talk to the electronics for various orientations and spacings of the bus relative to the detector-readout. This will provide crucial information for the final detector design. We have set up a consulting agreement with an experienced interconnect engineer to assist us in the design and procurement of the cable; he will also conduct a survey of available technology for high-density, low-mass connections and cabling.

Milestones:

15 Mar 1991	Identify test configurations and determine cable geometry
15 Jun 1991	Begin measurements on phase-1 test module
30 Jun 1991	Define phase-2 test module
31 Jul 1991	Complete measurements and preliminary report

Required Effort

Estimated effort per year FY92 ... FY94 (production begin) for Front-end Electronics, Data Transmission, and Module Design.

Physicists	4 FTE
Electronics Eng.	9 FTE
Mech Eng./Designers	3 FTE
Technicians	5 FTE

2.3. Mechanical Support, Alignment, and Cooling

The R&D technical issues which were identified are listed in Tables 1 through 4. The fiscal year breakdown of these technical accomplishments must be coordinated through the R&D planning activity now under development. Furthermore, interrelations exist between the various technical areas that have only been addressed in a cursory way. Those interconnects must be resolved through our program plan in its final form. There is evidence in our preliminary planning effort that there is no slack time in the R&D activities. We are concerned that this situation may be more acute than first envisioned.

It is important to realize that our subsystem R&D activities originally planned for FY91 encompassed substantially more work than could be supported with the limited funds. Our technical accomplishments planned for FY92 must address specific activities planned for FY91 as well. Demonstration tests planned for insuring

resolution of critical mechanical stability and cooling issues have now slipped into FY92. Our current estimated program R&D funding profile to achieve our objectives is given below. It is essential that a substantial increase in silicon tracking system R&D funds be programmed starting with FY92, otherwise, the entire tracking system program plan will be placed in jeopardy.

Total budget by fiscal year.

FY90	$ 350K
FY91	$ 600K
FY92	$2800K
FY93	$2500K
FY94	$2100K

Table III: FY93 PRIORITY ISSUES - MAJOR TOPICS

SILICON TRACKING SYSTEM KEY R&D MILESTONES: MECHANICAL, COOLING AND INTEGRATION

Mechanical structures
- o Conduct 5 micron stability test on forward region prototype-versus cooling and structural behavior.
- o Fabricate MMC forward region space frame. Verify assembly and disassembly techniques.

Materials
- o Final radiation tests on complete silicon ladder design concept with chips, cabling attachments.
- o Radiation tests of high-speed interconnects (fiber optics) with silicon ladder assembly and cooling ring/PC board interface.

Cooling
- o Prepare for prototype operation in radiation environment.

Cabling
- o Demonstrated, via prototype test, performance of internal main power feed network.
- o Radiation tests of cabling and connections.

Alignment
- o Continue optical alignment demonstration. Remote readout of stability measurements demonstrated.

System Integration
- o Mock-ups and tests of major external service connections, cables, fiber optic connectors.
- o Actual Beam Tests - ? Prototype silicon module system plus cooling.

Table I: FY91 PRIORITY ISSUES - MAJOR TOPICS
SILICON TRACKING SYSTEM KEY R&D MILESTONES: MECHANICAL, COOLING AND INTEGRATION

Mechanical Structures
- o Long strip vs short strip carrier and construction concept decision.
- o Allowable ladder structural mass established.
- o Demonstrated structural integrity of silicon shell sandwich and/or (central region) silicon wafer edge support concept.
- o Commence fabrication of prototype central region silicon shell assembly for FY92 prototype operation (preliminary work on kinematic mounts completed).

Materials
- o Demonstrate compatibility of adhesives and actual silicon strip detector in a radiation environment while exposed to butane.
- o Preliminary radiation tests of candidate wick materials.

Cooling
- o Demonstrated heat pipe wicking performance using butane.
- o Tacit approval from SSCL on butane acceptability question. (Requires presentation of operation concepts).
- o All safety issues handled by approved preliminary safety plan.

Cabling
- o Decision on cabling and electrical connection concepts for selected carrier design.
- o Conceptual definition of connectors/feedthroughs.

Alignment
- o Establish requirements for construction tolerances for wafer placement in silicon tracking system, and tracker relative to next assembly (absolute versus resolution).
- o Establish resolution requirements for alignment tasks.
- o Demonstrate IR laser alignment concept.

System Integration
- o Integration questions regarding electronics/readout provisions and the cooling ring bonding techniques answered.
  - Method of disassembly (de-bonding individual silicon detector ladder assembly from cooling ring demonstrated).
  - Method of employing fiber optics in high speed read-outs established.

2.3.1 FY92 R&D Program Description

One of our technical goals for FY92 will be to perform the critical mechanical stability and cooling tests utilizing a prototype of central region. We have placed emphasis on three specific technical tasks in FY91 to insure attainment of this goal. The tasks are: (1) wick development tests, (2) design and construction of a graphite composite cooling ring, and (3) development of a mechanical support method for

Table II: FY92 PRIORITY ISSUES - MAJOR TOPICS
SILICON TRACKING SYSTEM KEY R&D MILESTONES: MECHANICAL, COOLING AND INTEGRATION

Mechanical structures
- o Demonstrate 5 micron stability capability using central region prototype.
- o Prototype MMC space frame for central region structural tests.
- o Build and structurally test silicon "carrier" specimens for simulating forward region assembly concepts.
- o Double-wall sealed penetration design concepts - prototyping.

Cooling
- o Continue to work out all operational and safety issues. Submit final safety analysis report for approval.
- o Prototype testing of cooling ring with read-out chips and opto-electronic devices appropriately emulated.
  - Stable ultralightweight cooling ring/mounts demonstration.
  - Wicking performance/optimization test evaluation.

Cabling
- o Prototype of cabling for powering silicon wafer electronics
  - Reliable near-massless electrical connections demonstrated.

Alignment
- o Demonstrate optical alignment methods for central region.
  - Installation of silicon ladders.
  - Alignment concepts for kinematic mounts, etc.
  - Electronic Speckle Pattern Interferometer or holographic photography for large area stability measurements demonstrated.

System Integration
- o Be beam pipe design approach accepted by SSCL.
- o Double-wall penetration design concepts accepted by SSCL safety committee.
  - Prototype demonstration tests as required.

Materials
- o Preliminary radiation tests on complete silicon ladder design concepts with chips, cabling attachments (closed versus open vapor system decision).
- o Construct a G/E structural shell & test in radiation/butane environments.
- o Final radiation tests of selected wick candidate.
- o Closed versus open vapor system decision.
- o Radiation tests of MMC Frame members.

the silicon detectors. Activities involved with task (3) include evaluation of two separate concepts, one for the long strip edge-bonded detector and the second for an intermediate strip detector length. The intermediate strip detectors are individually supported on a carrier. The individual detector modules (complete strip detectors/electronics sub- assemblies) will be simulated by full scale replicas made

Table IV: FY94 PRIORITY ISSUES - MAJOR TOPICS
SILICON TRACKING SYSTEM KEY R&D MILESTONES: MECHANICAL, COOLING AND INTEGRATION

Mechanical Structures
- o Structural stiffness tests of entire MMC space frame.

Materials

Cooling
- o Full system tests demonstrating precise temperature control and uniform temperature distribution in multi-module assembly (see integration tests).

Cabling

Alignment
- o Demonstrate and prove alignment concepts for system components (i.e. forward region to central region, etc.)

System Integration
- o Conduct fully integrated system test of central and forward prototype. Verify operation and stability in a radiation environment. (Use active strip detectors in appropriate "ladder" construction arrangement.)
- o Make any modifications as required and retest for verification.
- o Update fabrication drawing and place orders for long lead mechanical items.

NOTE: Engineering is transferring into the final design and construction phase (hopefully); therefore R & D effort is on downward trend in FY94.

from engineering grade silicon and resistive heat loads. Overall detector power, performance, and structural mass are among the critical issues which must be studied to select the appropriate approach.

For conducting complete system operation tests of the central region prototype we will construct a full scale replica of two super-layers of the central region with associated graphite support structures, kinematic supports, and integral heat pipe cooling network. The stability will be monitored with an external optical set-up. This approach will provide confirmation of data extracted from an internal fiber-optic optical position monitoring system. The internal optical system will become a part of the overall detector assembly.

Demonstration of our alignment/assembly concepts will be required before we construct a full scale central region prototype. The precision by which we must accomplish those key steps are described later. Additionally, the FY92 work will

involve a demonstration of all steps essential to performing a highly repetitive, precision assembly operation. Development and demonstration of opto-mechanical work stations suited to performing important elements of this task are planned.

Operational tests of the prototype central region will instill confidence in the ES&H plans developed specifically for the silicon tracking system. We are concentrating on seeking early resolution of all issues in this area. In the final system design we are faced with the prospect of providing double walled sealing of key penetrations through the butane vapor space. In FY92 we plan to address these design areas, and conduct scale prototype tests as necessary.

Other critical areas of the central region which need to be undertaken in FY92 relate to material compatibility and system integration issues. Compatibility tests of materials in a combined radiation and hydrocarbon environment will be a subject of continuing study. Tests to date, although quite encouraging, have been limited in scope, e.g., did not include important elements of a fully active strip detector with associated cabling. Completing these planned tests will serve to resolve an important system issue, namely, an open versus closed butane vapor space environment.

In FY92 we will also concentrate on addressing design concepts for the remaining silicon tracking elements, e.g., forward region, space frame and composite structures. The flat planar arrays are a distinctly different structural arrangement from the central region and will require considerable development to achieve the highly stable platform requirements desired of the silicon system. Aspects associated with achieving kinematic strain free support of the forward region and the primary structural space frame will be investigated as well. Re-examination of the space frame material selection will be undertaken. Tubular frame members will be ordered and structural tests will be conducted. Demountable frame section concepts will be studied and a baseline approach will be selected to achieve the system assembly/disassembly approach.

2.3.2 Mechanical System Studies

Of the various issues studied by the mechanical support and alignment task team, by far the most productive result was the outcome of the alignment study.

Information generated for the mechanical support activities, maintenance, and assembly was important and beneficial to focussing our thoughts, however, the alignment study effort addressed extremely important aspects of the detector for the first time. Questions regarding initial assembly (placement) errors versus residual calibration errors were discussed. The first pass through this topic yielded insight into what assembly and alignment tasks will be crucial to silicon tracking system and the location of the silicon system relative to other elements of the central detector. Because of time constraints, the study of alignment requirements for the silicon subsystem was confined to the central region. This effort needs to be continued to encompass the forward region, and the interrelation between the two regions.

The subsequent sections deal with the alignment study results. As cited earlier the extensive material put together for the silicon tracking system mechanical study plans is not attached to this summary report, but rather will be used to form the basis of a continuing study effort.

2.3.3 Alignment Requirements

The alignment requirements for the tracking system have far reaching impacts on the system design and assembly procedure. Tolerances on certain dimensions are very tight (e.g. phi), but are quite relaxed on others (e.g. z in the barrel section). Results of work on alignment issues have already resulted in the redirection of some effort. The question of tolerances involve two independent issues:

A) How accurately must the positions and orientations of the detectors be known at all times relative to different internally and externally defined reference systems, and

B) How accurately must detector components be placed, regardless of how well the positions and orientations are later measured? For instance, a strip or straw which is supposed to be parallel to the zaxis and thus provide a measure of phi, will always give an inferior measurement if it is not parallel to the z-axis regardless of how well its orientation with respect to the z-axis is known.

The question of the tolerances must be answered at each level of the assembly procedure.

MEASURED POSITION ACCURACY

The following results concerning measured detector location item A) above are a summary of a note prepared by Abe Seiden. They deal with the barrel section of the detector.

For the statistical errors we assume a circumferential distance sigma = 12 microns for a double-sided silicon measurement and 80 microns for a superlayer of straws. We look at the beam constrained momentum measurement which is the most accurate quantity we want to measure. For p = 1 TeV, B = 2 Tesla, and using the statistical errors (DELTA) given above, the error in the track curvature (dK) is given by the sum over all 16 layers of the product of DELTA and a coefficient (ALPHA) for each layer. The values of the coefficients ALPHA for the 16 layers are given in Table 5.

TABLE 5. Radii and error coefficients of the barrel tracking elements

Silicon Layer#	Radius(cm)	ALPHA(m^-2)	Straw Superlayer#	Radius(cm)	ALPHA(m^-2)
1	18	-0.35	1	68.6	0.007
2	21	-0.38	2	82.5	0.021
3	24	-0.40	3	95.4	0.038
4	27	-0.41	4	109.3	0.060
5	30	-0.42	5	122.3	0.084
6	33	-0.41	6	136.0	0.114
7	36	-0.39	7	149.2	0.146
8	39	-0.37	8	162.7	0.183

The table indicates that:

a) The silicon layers all have roughly equal impact on the curvature and therefore momentum measurement,

b) The inner straw superlayers are only important for pattern recognition, and

c) The outer few straw layers have a large impact on the momentum measurement.

One will wish to keep any errors in the knowledge of detector position small (approximately 1/3 that of the statistical errors associated with the measuring accuracy

of the detector elements themselves). Thus taking as goals systematic errors < 5 microns for the silicon and < 35 microns for the straws one can derive the allowable error limits given in Table 6.

TABLE 6. Allowable errors in known detector location

Maximum uncorrelated position errors:

Silicon detector	Circumferential	5 microns
	Radial	80 microns
	Longitudinal	250 microns
Straw superlayer	Circumferential	35 microns
	Radial	400 microns
	Longitudinal	250 microns

Maximum correlated system error, silicon relative to straws:

Rotational alignment	10^-5	radians
Radial alignment	200	microns
Longitudinal coordinate	250	microns
Displacement of detector centroids	15	microns

Note: all the preceding values are standard deviations, not the edges of box shaped distributions which span a range of +- 1.73 times the values tabulated above. Furthermore, these are the precision to which the position of the detectors or assemblies must be known. The implications are that the positions must be monitored to the precision given above, and that there can be no vibrations whose magnitude exceed those limits and whose frequency is higher than the frequency of the position monitoring.

PLACEMENT TOLERANCES

As previously stated, the primary measurement responsibility of the silicon detector involves the measurement of the change in azimuthal angle (phi) from one plane of detectors to the next. Therefore, the azimuthal angle must be very precisely determined. That in turn implies that each strip must define the smallest range in phi possible, and therefore each strip must be parallel to the beam (z) axis. That parallelism can only be achieved through placement. A detector that is not parallel

to the z-axis will automatically give poor phi resolution. Below we will consider a number of different placement errors. For clarity we will consider a detector which has the following local coordinate system: The detector is nominally centered on the x-axis with the strips parallel to the z-axis. As one moves from one strip to the next, one moves vertically (in the y direction). Again, we deal with the barrel section of the detector.

Rotations

a) Rotation of the strips about the x-axis by an angle beta: That rotation makes a single strip cover a vertical height of

h = L x sin(beta) + P x cos(beta)

where L is the detector length and P is the detector pitch. Assuming that we want no more than an additional 5 microns systematic error linearly added to the original random error associated with the strip of approximately 12 microns, we will assume sigma = 17 microns. We further assume P = 50 microns. Using the equation for sin(beta) above, and solving for beta function of L, we find for L = 12 cm, beta = 259 microradians, and L x sin(beta) = 31 microns. Thus if one end of a detector is raised by 31 microns with respect to the other end, the total measurement error increases from 12 to 17 microns.

b) Rotation of the strips about the y-axis by an angle gamma: That rotation produces a change in radial distance as one moves along a single strip in z. Taking the maximum uncorrelated radial error of 80 microns given in Table 6, one finds one can tolerate a rotation gamma = 80 microns / 12 cm = 667 microrad for a 12 cm long detector.

c) Rotation of the strips about the z-axis by an angle lambda: That rotation has virtually no impact on the position resolution until it becomes very large, provided that one knows what lambda is. A 5 micron error in circumferential distance results from lambda = arctan (2x5 microns / 300 microns) = 33 mrad. (The detector thickness is assumed to be 300 microns.)

Translations

Errors in placement that are translational in nature (i.e. dr, dz, dphi) can be completely corrected for, provided their values are known. However, in order to avoid the use of large tables and computations to correct for tranlational errors, one would like to keep those errors comparable to those given in Table 6, wherever possible.

The results on placement tolerances are summarized in Table 7.

TABLE 7. Detector Placement Tolerances

{Detector is nominally parallel to the z-axis, centered on the x-axis, and provides a y measurement}.

Rotations:

about the x-axis	259 microrad	(assuming 12 cm detectors and no z information)
about the y-axis	667 microrad	(assuming 12 cm detectors and no z information)
about the z-axis	33,000 microrad	

Translations: Can be corrected for, but in practice one would like to limit them to the values given in Table 6.

2.3.4 Conclusion

The high precision needed in the entire central tracking system, and especially in the silicon subsystem thereof, requires a significant R&D effort. It is essential that this work is adequately funded to allow its timely completion. Lack of progress in the R&D effort negatively impacts the entire tracking system schedule, which is already extremely tight. Furthermore, progress is essential in our attempt to reduce the contingency values associated with the silicon system.

2.4. Radiation Hardness

Silicon microstrip detectors have been used for some time in HEP instrumentation. A more recent development is double-sided detectors, which we plan to use in the SDC tracker. Radiation hardness of the detectors has been the subject of intensive R&D.[1-4] The scope of the investigations has been to find out at what fluences the detectors become too damaged to be useful. The radiation damage can

be divided into three categories which have been studied to a different degree: (a) the bulk damage and (b) the properties of components of double-sided detectors are well understood, while (c) the AC characteristics and pulse generation are less well studied.

a) Bulk Effects

Bulk effects are proportional to the fluence Φ and often show simple annealing. A well-studied effect is the increase in leakage current, $\Delta I = \alpha \cdot \Phi \cdot Vol$ where $\alpha = 3-6 \cdot 10^{-17} A\ \mathrm{cm}^{-1}$, depending on energy and type of the particle. An annealing to 50% is observed and can be taken as a safety factor. The conventional wisdom is that the leakage current does not make an AC coupled detector useless, but that excess noise generation due to the leakage current will be the limiting factor. Short shaping times and small detectors (i.e., small volume Vol) are one way to increase the fluence limit to $10^{14}\ \mathrm{cm}^{-2}$.

A second bulk effect is the apparent increase in acceptor concentration, $\Delta N_A = \beta \cdot \Phi$ ($\beta = 0.03/\mathrm{cm}$ after annealing), which first lowers and then increases the depletion voltage. We observe type reversal: $N_A > N_D$ for the usually employed n-type detectors. Note that at very high fluences the detectors cannot be depleted anymore. This effect is independent of detector size. The detector lifetime could be increased by starting out with lower resistivity material. Again, fluence limits of $10^{14}\ \mathrm{cm}^{-2}$ seem possible.

There are a few tests left to perform: The bulk damage should be studied at the operating temperature (0°C) and in p-type and lower resistivity bulk material.

b) Components for AC coupled detectors

The resistors and capacitors needed for AC coupled detectors have been studied and will pose no problems up to fluences in excess of $10^{14}\ \mathrm{cm}^{-2}$. We would recommend using polysilicon resistors of a few 100 kΩ to allow for large leakage currents without large voltage across the resistors. Coupling capacitors have to be able to hold 300 V due to the increased depletion voltage mentioned above.

c) Surface effects & AC characteristics

Only recently have we started to look into the details of surface effects and the change of AC characteristics due to radiation. From the very well-documented sensitivity of MOS structures to radiation due to formation of oxide charges, we would expect that parameters depending on the surface would be affected by radiation. One parameter is the capacity (which is dominated by the inter-strip capacity) and especially the one on the ohmic side. Another parameter is the interstrip isolation which has to be much larger than the bias resistors even after bulk inversion from n-type to p-type. From our investigation, the isolation on the junction side looks OK. Another possible area of detector degradation is the charge collection. We will be testing the pulse shape (for short shaping times $\tau_{\text{Peaking}} \approx 20 - 30$ ps) on both the junction and ohmic side, and the charge trapping to evaluate the signal/noise ratio and time slewing.

3. Silicon Pixel Detector

The pixel vertex detector group has focussed in FY91 on the design and fabrication of Proof-of-Principle devices, on the refinement of pixel array architecture concepts to match the challenge of the SSC, on software development basic to the GEANT simulation of the pixel vertex detector in the SDC context, detector radiation damage studies, and on preparations for beam tests. In addition, a structural design compatible with the general framework of the silicon tracker has been completed.

In FY92, the effort will shift to test programs for the proof-of-principle devices, and the design of a complete SSC pixel array with all of the required functionality. Additional effort will be directed to the demonstration that the required radiation hardness exists for both detectors and readout IC's. The third major emphasis will be the exploitation of the SDC simulation software to reveal the physics and pattern-recognition impacts provided by a pixel vertex detector.

Architecture

In FY91, a complete architectural design, based on goals and specifications

established by the collaboration, was completed by our industrial partner, Hughes Aircraft Company. This design incorporates the following performance features:

1. x - y storage of smart pixel hits in 32-deep pattern registers;
2. Time stamping of hits in 32-deep content addressable memory;
3. Sparse readout of valid hits in selected time slice;
4. On-chip rejection of ghost hits;
5. On-pixel storage of analog information;
6. Non-redundant readout of neighbors option;
7. Programmable microcontroller.

Each major section of the design has been simulated and verified, but has not been laid out. The design, because of the programmable microcontroller, has considerable flexibility. The modelled behavior was instructive, and gave us confidence that the overall smart pixel array concept is feasible.

The design is data-driven, allowing a substantial reduction in trigger level I buffer size relative to a clock-driven scheme. However, the trigger level I latency has steadily grown, to more than 3 microseconds, and possibly as much as four. Adapting to this growth requires an unpleasant increase of the buffer size. Given additional uncertainty about background rates and ultimate luminosity levels, concern has arisen that pattern register depths will become unacceptably large. While this latency growth is a concern for other systems as well, for the pixel vertex detector there is an additional issue because the analog charge information resides on-pixel until the level I trigger. At four microseconds (plus readout time), the issue of hit pile-up on nearby pixels, with attendant corruption of information, may become a non-trivial issue.

This trigger level I latency concern has led to a reexamination of the basic concept of on-pixel storage of analog information. At the same time, the observed time-walk, discussed below in the prototype section, raised concern that an event

would be detected in a time span unavoidably larger than a single SSC beam crossing. The present architectural concept would use register space inefficiently in this circumstance, as several buffer time-stamps would become used in one event, or some hits may be lost because the buffers are full.

Both of these potentially serious issues appear to be solved in an exciting new architectural concept that is a radical departure from the above, and perhaps a simplification as well. The new design concept eliminates analog storage from the pixel, yet obtains charge information needed for spatial interpolation. An all-digital concept, with negligible pile-up or deadtime effects, the main structural feature is the incorporation of autonomous processes within the array to perform the detection, hit recording, data formatting, trigger sensing and data transmission functions. Here the role of a central microcontroller is minimal, and the various activities can occur simultaneously and asynchronously.

The basic idea is to exploit time-over-threshold information derived from the pixel cell comparator to provide both charge information of good quality and good timing information, by measuring both leading edge and trailing edge times of the comparator output signal. When the pixel cell detects a hit, simple signal shaping causes the comparator output, propagated on common *hit_row* and *hit_column* busses to the array periphery, to carry the required information. The width of the comparator signal will provide a good measure of the charge; at the same time, the time-walk can be inferred, and corrected for, using the charge information.

Each column and row independently records the leading and trailing edges of the buss signals. As soon as any row or column has recorded the leading and trailing edges of a hit, a primary register scan process transfers the time information to formatted data buffer, where data can be efficiently stored. Tests for valid level I trigger data can be performed on the formatted data using a CAM.

In this fashion, three major challenges are met:

1. Seamless registration of hits with negligible deadtime;

2. Good time resolution to match tracks to the proper beam crossing;

3. Good measurement of deposited charge, without implementing any analog circuitry on-pixel.

Prototype and Test Devices

Test IC's have been designed and fabricated by Hughes to determine behavior of single pixel cells and two-dimensional arrays of pixel cells. The pixel cell was designed with emphasis on smallest physical area (50 x 150 microns^2), consistent with SSC performance requirements, and employs CMOS switched capacitor design principles. The first test IC is a single pixel cell and the other is a 32 x 64 array of pixels with simple peripheral registers. Much has been learned with these devices.

The major lessons include the importance of extremely good substrate isolation to prevent coupling of digital transient noise to the sensitive analog section, and the unexpectedly large effects of the parasitic couplings that are not handled by available simulation software. Nevertheless, the "smart" pixel concept, allowing a sparse data scan was demonstrated and a noise figure of less than 200 electrons was measured.

A third test IC, designated Foresight 5. Foresight 5 chips have just been received from the foundry, - August 9. In this improved 32 x 64 array, a number of changes to eliminate the observed problems and improve performance have been included, and electrical tests will begin shortly at Hughes. The peripheral register structure has been redesigned to permit operation with an available VLSI test station.

The Foresight 5 IC can be bump-bonded to a detector for tests with ionizing radiation. LBL is fabricating detectors for these tests that have two different pixel shapes, 50 x 150 μ^2, and 25 x 300 μ^2. By cleverly arranging the pixel cell layout, the same IC can accommodate the two geometries with no penalty in area or design.

At LBL, an advanced pixel cell design has been pursued with encouraging results. This design incorporates RC-CR shaping, peak sample and hold, DC servos to stabilize operating points, and autonomous operation, requiring no resets or initialization. The design incorporates principles that maximize radiation hardness. Some of these features will be needed for the final pixel cell design, but not all can be included if the pixel cell area is to be kept near the current size.

Preliminary results indicate that the design meets specifications for noise and general functionality. Time-walk measurements show that a time span of about three beam crossings is needed to register signals from one to eight fC at the input. As the signal approaches threshold, a considerably greater time span is required. These results for time-walk suggest that it may be difficult in a low-power design to meet the time resolution requirement of 16 nsec over a wide range of input charge. This is partly due to charge sharing and charge collection time effects that are intrinsic to the P-I-N detector. This result is a significant part of the motivation for the new architectural time-over-threshold concept discussed above. An unexpected problem has also been observed, namely an unexpectedly large variation in V_t; this can be overcome by both circuit design changes and layout.

For FY92, the highest priority for prototype development will be the design of the blocks needed for a complete smart pixel array based on the concept of time-over-threshold measurement. The design approach can capitalize on the independence of the various autonomous processes, allowing separate design, verification, and prototyping.

The realization of truly radiation hard circuits involves both design principles and fabrication process. The circuit designer must incorporate design elements that can tolerate threshold shifts that come with high fluence. Due to junction leakage, voltage levels on capacitors may drift significantly. The appropriate design tactics generally increase circuit complexity due to the use of matched differential pairs, DC servos, etc. The challenge is to realize the needed functionality in the smallest possible area.

Radiation Damage Effects

Radiation damage studies using the UC Davis cyclotron showed that results obtained with this low-energy facility can be scaled accurately to represent SSC conditions. Further studies focussing on the type-inversion phenomenon will be undertaken using the familiar Hamamatsu photodiodes, and perhaps some LBL fabricated pixel detectors. Of particular interest is charge collection time degradation, which may be observable at the very highest expected fluences.

The working concept for the pixel vertex detector is that the dopant changes in the detector itself caused by radiation damage will lead to a very soft ultimate limit for the maximum fluence, after several years at maximum luminosity. The pixel arrays are configured as single-sided, with the diode at the pixellated side; when the detectors can no longer be completely depleted, the depletion depth will shrink as the square root of fluence, for constant applied voltage. Isolation will be maintained, and the very high intrinsic signal/noise ratio will provide headroom for a graceful deterioration. As we intend to use the LBL high-temperature process that utilizes phosphorus-doped polysilicon gettering on the n^+ side, we need to gather experience with regard to how sufficient isolation and gettering can be accomplished simultaneously. Obtaining signals from the n^+ side also changes the polarity of the input signal, affecting the circuit design beneficially.

Because the detector is effectively divided into such small volumes in a pixel detector, the leakage current is not expected to be a problem. AC coupling can be built-in to the detector with a polysilicon resistor and capacitor, but the resistors must be physically small, with good noise performance, and this would need to be tested. However, if the pixel cell has continuous time signal shaping with a carefully designed DC servo on the preamp, rather than a switched capacitor, the servo should be able to soak up the leakage current (a few nanoamperes/pixel). A design has already been made confirming this.

For the readout IC, much remains to be done to establish beyond doubt that noise, threshold and functionality of circuitry will be retained at dose levels exceeding five megarads. The preliminary results obtained with UTMC devices by the silicon tracker group are encouraging. The pixel vertex detector group will attempt to increase the available effort to address this fundamental issue. There is evidence that some processes can survive many tens of megarads, and we will be both following closely the silicon tracker group's work, and be performing additional tests, as we can manage. Our new collaborators may be able to contribute to this effort.

Beam Tests

The Space Sciences Laboratory at UC Berkeley, in collaboration with Hughes,

SLAC, and the University of Oklahoma have performed beam tests of high resolution non-smart 256 x 256 pixel arrays. Both the intrinsic performance of these small pixels and their use as beam defining elements for testing the new Foresight 5 pixel arrays motivated these efforts. A high precision telescope for more beam tests is being constructed. Plans call for initial beam tests in September and late fall/early winter for followup work.

Mechanical Systems

A modest effort to maintain mechanical system design will be needed to establish and maintain compatibility with the silicon tracker's progress. Few problems are expected here, but the challenge will always be to keep material at the minimum.

Data Acquisition

In a similar manner, effort will be focussed on the data acquisition system requirements to maintain compatibility with the silicon tracker's progress. The pixel system may be transmitting large quantities of data to the local data collection chips, but should not represent a much different load to an external data acquisition system. Buffering at the data collection chip could easily include both level I and level II, or just level I.

Physics Simulation

Currently, the pixel arrays are being incorporated into the SDC Monte Carlo shell in a manner compatible with the silicon strip arrays. This will be used to evaluate overall impact on patten recognition, impact parameter resolution, and efficiencies for tagging and reconstructing secondary vertices. Further studies must also be carried out on technical issues, such as pixel readout strategies in jets. These studies are pivotal in establishing the physics value of the pixel vertex detector within SDC.

4. Central Tracker

4.1. Baseline Layout with Options

Baseline layout

The baseline design is shown in Fig. 1. Numerical data associated with this layout drawing appear in the tables below.

Central outer barrel; fiber section:

superlr	layer	$\langle r \rangle$	Nfiber	half length	stereo
1	1	$0.700 - 0.0235$	22670	2.80	0°
	2	$0.700 + 0.0235$	24245	2.80	0°
2	1	$1.000 - 0.0235$	32723	3.15	0°
	2	$1.000 - 0.0205$	32823	3.15	−4.5°
	3	$1.000 + 0.0205$	34197	3.15	+3°
	4	$1.000 + 0.0235$	34298	3.15	0°
		total (both ends)	361912		

Straw section:

superlr	r_1	Nstr/lr	Nlr/sl	$z_{\min}$	$z_{\max}$	stereo
3	1.21722	1912	6	0.03	3.550	−3°
4	1.34963	2120	6	0.03	3.900	0°
5	1.48205	2328	6	0.03	3.950	+3°
6	1.61447	2536	9	0.03	3.950	0°
total (both ends)		121968				

Intermediate angle fiber tracker. Each superlayer (disk) is eight fibers thick, with four layers (each with two staggered rows), oriented uxyv. The spiral pattern of fibers in each layer is space-filling, which means that it is defined by the inner and outer radii of the disk, the fiber pitch, and the radius r_0 at which the fibers have a radial orientation. Layers labelled x or y have $r_0 = r_{\min}$, and are distinguished (x from y) by the sign of $d\phi/dr$ for the spirals. The u and v layers have $r_0 < r_{\min}$.

disk	downstream z	r_{inner}	r_{outer}	Nfiber
1	3.20	0.52	1.09	34851
2	3.60	0.585	1.22	39207
3	3.95	0.65	1.34	43563
		total (both ends)		235242

Notes:

1. The support cylinders are assumed to extend over the full eight meters of the tracking volume.
2. The barrel and intermediate trackers are to be supported separately, but must be aligned to each other.
3. The silicon tracker is assumed to be supported from the outer barrel.
4. Need to understand to what the outer supports are attached (coil/cryostat? calorimeter?)
5. We are leaving open at this time the question whether straws are laid on support cylinders individually, in bundles without wires, in pretested complete detector modules, etc. First priority is to understand the feasibility of precision cylinders.
6. The design is not required to allow for removable straw modules.
7. The problem of stereo straws is to be addressed in the baseline design effort. Cylinders with shim rings are a possible solution.
8. R&D is needed now to learn whether fiber light guides can be joined to fibers by removable couplers or must be permanently attached.
9. Need to understand how fiber layers can be laid down precisely, and whether they can be placed on the inside of the support cylinders.
10. A variation shown in an earlier layout has a large fiber disk at 4 m in z whose purpose is to provide the trigger for eta greater than 1.6, where the outermost barrel layer ends. However, it was felt that we don't yet understand how this would work, because the single disk is insufficient for a coincidence by itself, and would have to be combined with axial straw superlayers somehow. (It

has been suggested by Dave Adams[5] that this is not too difficult in principle, given a scheme[5] for combining the fiber disk layers to get (r, ϕ), which matches to (r, ϕ) from the straw superlayer.) For the present draft of the baseline design we omit the large disk, and enlarge the three forward disks to cover a larger η band. In the revised layout above, the coverage of the forward disks is $1.8 < \eta < 2.5$. The false trigger rates in these would be greater than the estimates for the smaller disks $(2.0 < \eta < 2.5)$ of Adams's memo. We defer until the next revision a complete understanding of how to cover the eta range between about 1.6 and 1.8. This range is now covered by three axial superlayers (scifi 1 and 2 and straw 4), so one possiblility is to trigger on a coincidence of these, using z information[5] to limit this trigger to the forward region.

Option 1: All scifi A feature of particular interest here is the evaluation of the scifi trigger. The layout is assumed to be as in the LoI. Some variations in detail from the LoI that are under consideration include the fiber diameters and alternative stereo superlayer configurations such as $(4x) - (4x)(4u)(4v)$ rather than the grouping indicated in the table. Trigger studies[5] have been performed assuming barrel fiber superlayers of a $(2u)(4x)(2v)$ configuration, with less emphasis on the vector character of the superlayer.

Option 2: All wires This includes as sub-options the LoI layout with barrel straws of 3 m length combined with radial wire chambers, and variations in which the radial chambers are replaced with straws or with gas microstrip devices. Oh and Chapman have recently developed a concept with radial straws that could provide a trigger whose $p_\perp$ threshold is approximately independent of eta. A substantial effort is being organized within SDC to explore the gas microstrip option.

Option 3 Here we combine wires with fibers to make 3-d vector superlayers.

```
                          SL STRUCTURE            FUNCTION

SL1     *************  x scifi (2 to 4)          3-d vector layer
         4cm gap
        *************  x-u-v scifi (6 to 12)
```

```
SL2    ************* x straws (6 to 8)      r-phi only layer

SL3    ************* u-v scifi (4 to 8)     3-d vector layer
       ************* x straws  (6 to 8)

SL4    ************* u-v scifi  (4 to 8)    3-d vector layer
       ************* x straws   (6 to 8)

SL5    ************* x straws   (8 or 9)    r-phi only layer (trigger)

SL6    ************* x straws   (8 or 9)    r-phi only layer (trigger)
```

Comments on option 3:

1. SL1 is scifi to take care of high occupancy.
2. All stereo is done with scfi (SL1, SL3, SL4). The x-u-v triplet layers are kept as close together as possible to simplify pattern recognition.
3. Straw tubes are used only in the axial(x) configuration. The support structure and fabrication of straw tubes would be as uniform and simple as possible.
4. The detector provides three 3-d vectors. If simulations show this to be unnecessary (or insufficient), one scfi u-v layer would be removed(or added).
5. The number of r-phi hits is tuneable from 38 to 50 depending on the results of simulations.
6. The superlayer lengths would be adjusted to match the intermediate tracker configuration.
7. Note that this design has considerable physics flexibility which does not require changes in the basic mechanical configuration.

<u>Option 4</u> Here we combine wires with fibers minimizing the number of fibers, placing them in regions of highest occupancy, and (as in option 3) using them for all stereo measurements.
SL1 $xu - vx$ or $x - xuv$ fibers
SL2 $xu - vx$ or $x - xuv$ fibers

SL3 6 x straws
SL4 6 x straws
SL5 9 x straws (trigger)

If more than one trigger straw layer is needed, SL3 and 4 might be replaced by one 9-layer superlayer.

Comments and considerations

1. For the final technology choice, the advantages of keeping both wires and fibers have to be convincing, and the extra cost understood.
2. We don't yet know the relative performance of straw and fiber for triggering. For wires the concept so far has been a one-superlayer $p_\perp$ sensitive trigger with the synchronizer circuit, whereas the scifi concept relies on coincidence between superlayers, rather than the pointing capability of one superlayer (which is minimal in some proposed layouts). But it's not yet clear these are being compared under the same conditions. In fact we don't know what level of false trigger rate is acceptable until we look at the tracking trigger in the context of the overall trigger.
3. The number of straw layers per superlayer should be (a) at least 8; (b) a power of 2; (c) could be 2 or 4 (i.e., just enough to resolve the right/left ambiguity, not provide pointing), for at least some of the superlayers, depending on whom you talk to. The choice of deployment of layers and superlayers depends in part on what pattern recognition strategy one has in mind.
4. Simulation of pattern recognition and triggering is urgently needed.

4.2. Mechanical Support and Alignment

There are several mechanical design options for arranging straw tubes into superlayers with the required alignment precision. Currently all options use full length (up to 8 m) support cylinders. There appear to be no fundamental problems. Options under consideration include placing straws directly onto precision cylinders, prepackaging straw tubes into carbon-fiber modules or possibly some intermediate approach which preassembles sections of straw tubes before attaching them to the

support cylinders. The choice of the best superlayer construction procedure will require some serious R&D work which will address placement precision, material thickness, ease of fabrication and assembly cost. Another mechanical issue is the fabrication of stereo straw tube superlayers. A solution using straw tube modules has been studied rather thoroughly and appears to be practical. Other options include the possibility of fabricating hyperbolic cylinders to allow a uniform support surface for the stereo straws. These issues will be addressed during the engineering study of the baseline design.

The mechanical design of the central tracking chamber (CTC) is being evaluated by engineers at the Oak Ridge National Laboratory (ORNL) and the Westinghouse Science and Technology Center (WSTC). A simulated fabrication/assembly method is used to evaluate the straw placement options. In this approach, each step of the fabrication/assembly process is outlined and drawn up. This step-by-step drawing includes representations of the final components as well as tooling and fixturing required to complete the process and expected assembly tolerances. Upon completion of the drawings, a data sheet is assembled that lists the equipment required to complete the process; the estimated cost for each piece of equipment used; the estimated cost for materials; and the time required for each step in the process. This is then compiled in a spreadsheet for overall evaluation of the various fabrication/assembly approaches.

Currently, we are preparing eleven different tracking element placement schemes and three different cylinder fabrication schemes for evaluation. The tracking element placement schemes have been broken down into three categories; one is the use of "precision" cylinders for support of tracking elements; two is the use of "imprecise" cylinders with rings for supporting tracking elements; and three is the use of "imprecise" cylinders with continuous support for the tracking elements. Within each category are several different methods for accomplishing the tracking element placement including individual element placement, "bundled" placement, ribbon placement, the use of modules and stiff-back for support. Each will be evaluated. In coordination with the placement methods being addressed, we are also pursuing the issue of overall system alignment. The positional location requirements imposed

by the physics requirements of the SSC demand special procedures for achieving the goals. An evaluation of current optical and laser alignment methods is being performed. This task will provide the design team with procedures required to meet prescribed tolerances and the cost associated with them. Its results will apply to both the placement of tracking elements and cylinder fabrication.

The final item that is being addressed in this evaluation is the fabrication of the carbon-based cylinders. There are presently three methods that have been proposed for fabricating the cylinders. The first method is to take a standard cylindrical mandrel and either wind or wrap the carbon material around it. This method has been used for years and is very well developed. The second method, used in some sectors of the industry, involves laying-up the carbon material on the inside of a mandrel shell. The final method involves producing thin, flat sheets of carbon material and rolling them up into a cylinder and supporting them with stiffening rings. Each of these methods will undergo an evaluation similar to that outlined for determination of tracking element placement.

The goal of this evaluation plan is to assist in choosing a method for fabricating a carbon-based cylinder and a method for placing tracking elements on that cylinder. The magnitude of this task appears to be large. However, once the basics have been completed, the final choice will be much clearer. The coordination of ORNL and WSTC will be essential in completing this task in a timely manner. The details of the overall project coordination have not been resolved, but we are pursuing a logical division of the design effort. Regardless of the division chosen, ORNL and WSTC will be required to work in close cooperation in order to produce a cost effective design that meets the physics and engineering requirements of the central tracking chamber.

4.3. Critical Issues for Scintillating Fibers

VLPC Development

The development of the Visible Light Photon Counter (VLPC) at Rockwell International Science Center has been one of the important and fundamental initiatives

undertaken by the Fiber Tracking Group, and this effort has been supported under the SSC Subsystem Program. The VLPC is a variant of the Solid State Photomultiplier (SSPM) but is an optimization based on the following characteristics: high quantum efficiency (> 80%) at the peak of the visible spectrum $500 < \lambda < 600$ nm; elimination of infrared response $\lambda > 1$ μm; improved rise time ~ 5 ns; and a layout appropriate for matching to fiber ribbons, with pixel size of order 900 microns.

To date VLPC pixels in linear arrays of the required size have been produced. A quantum efficiency of 85% at 550 nm has been established. A rise time of 8 ns has been measured using a room temperature preamplifier. These structures have been designated VLPC-I. By the end of FY91 it is intended that requirements of suppression of the infrared response and reduction in rise time will be satisfied. These developments are awaiting the availability of FY91 funds, and once completed, these structures will be designated VLPC-II.

Significant and essential further research and development steps are required to guarantee successful implementation of the VLPC for SDC and to provide a well-conceived system design for the proposal. These include the development of a readout cassette to properly house and interface fiber ribbons to the VLPC at 6.5 ± 0.5 K which is the optimal operating temperature range for these devices, the development of appropriate low thermal loss readout cables, and the optimization of a preamplifier for use with the VLPC. On this latter point, we are encouraged by the successful use of a candidate room temperature preamplifier. Cyrogenic preamplifier options are also under consideration.

Of the R and D items, the VLPC development contract and some resources for preamplifier development are available within the subsystem program. Resources for cassette conceptual design and cyrostat design are requested from FY91 LOI funds and are essential for a credible design and costing of the VLPC system for the proposal.

MILESTONES:

VLPC-I	DECEMBER 90
DELIVERY OF 128 CHAN. VLPC-I	JANUARY 91
PRELIMINARY COST ESTIMATE	FEBRUARY 91

QE > 80% MEASUREMENT	FEBRUARY 91
RAD. RES./NEUTRON DAMAGE	FEBRUARY 91
SOURCE TESTS WITH FIBERS	MARCH 91
BEAM TESTS WITH FIBERS	SUMMER 91
VLPC-II	SEPTEMBER 91
DELIVERY OF 256 CHAN VLPC-II	SEPTEMBER 91
CASSETTE DESIGN	SEPTEMBER 91
CRYOSTAT DESIGN	SEPTEMBER 91
CASSETTE PROTOTYPE	FY92
CRYOSTAT PROTOTYPE	FY92
DELIVERY OF 1K CHAIN VLPC-II	FY92
SYSTEMS TESTS	FY92

Avalanche Photodiode Development

4.3.1.0 Introduction

Recent measurements using green emitting fibers ($\lambda \sim$ 500nm) indicate that the avalanche photodiode operating at room temperature in the Geiger mode with single photon detection efficiency in the 40% to 60% range should constitute a satisfactory and less expensive alternative to the VLPC as readout device for the scintillating fibers used in tracking applications. The avalanche photodiode (APD) operating in the normal mode (below breakdown) may be the most suitable detector for scintillating fiber and scintillating strip readout for pre-shower, shower max and calorimetry applications. In this section we summarize the present status of APD's, indicate potential improvements and outline an R&D program aimed at assessing and achieving these improvements. A more detailed discussion is given in Ref. 6.

4.3.2.0 Geiger Mode Performance

4.3.2.1 Measurements on Modified C30921S Avalanche Photodiodes

The following measurements were made on modified EG&G C30921S detectors coupled to 500μm blue emitting fibers ($\lambda \sim$ 430nm). The modification included replacing the standard 250μm light-guide by a 500μm light-guide and A/R coating the diode for blue light.

- Single photon detection efficiency P_d ~40% at 10V above breakdown voltage (V_B).

(Note: $P_d = \eta_c \eta_d P_b$ where $\eta_c \sim 0.9$ is the light coupling efficiency, $\eta_d \sim 0.9$ is the detector quantum efficiency and $P_b \sim 50\%$ is the probability of a single photon induced breakdown pulse.)

- Response-time ~20ns; timing jitter ~5ns.
- Dead-time of at least 200ns required to prevent after-pulsing.
- Dark count rates ~1000-10000 per second at 22°C.

4.3.2.2 APD Array Experiment

This experiment was intended to demonstrate the feasibility of an APD array, designed for coupling to 500μm scintillating fibers. Results of the experiment on a prototype 4-APD array were:

- Optical and/or electrical cross-talk not a problem.
- Simple parallel reset circuit demonstrated. All other electrical components are inexpensive.
- Fiber alignment is critical.
- This design not suitable for larger fibers.

4.3.2.3 Fast Quench Operation

A model was developed, consistent with all C30921S results, that indicates that the breakdown pulse consists of a large number (~1000) of smaller, space-charge limited current pulses flowing in distinct filaments, each conducting a few μA current. A circuit which senses the first of these pulses should allow:

- Timing resolution of better than 300ps.
- Use of a fast-quench circuit which quenches the pulse and resets the diode in a time possibly as low as 10ns. This should also reduce the after-pulsing rate by about two orders of magnitude.

A proprietary circuit designed by C. Moir has been used with APD's similar to the C30921S to count at photon rates up to 35MHz. A time resolution of 320ps has been measured (for red light) by Ripamonti et al.

4.3.2.4 SLIK Development Work

Small area (< 200μm diameter) super-low-k (*Slik*) APD's have been developed within the past two years. Recent efforts have been directed at the fabrication of larger diameter *Slik*s. A 500μm device has been fabricated and tested. It showed uniform sensitivity in the Geiger mode, but the first lot of devices suffered from a rather low QE at 500nm (~50%) so that the overall measured detection efficiency was only ~30%. This should be a curable problem.

The *Slik* structure should allow P_d as high as 60% in the Geiger mode, possibly 70% with a fast-quench circuit, or should allow high detection efficiency (> 80% for a 5 photon pulse, for example) in sub-Geiger mode when used with existing GaAs integrated circuit transimpedance preamplifiers (rise-time of a few ns).

4.3.3.0 Some Results with Green Fibers

Fig. 2 shows the most recent result for a 4m long, 875μm diameter BICRON G2 green emitting fiber. A Ru^{106} source is located with two short 1.0 mm diameter trigger fibers at various positions along the test fiber length. The efficiency is defined by the ratio of APD pulses to source triggers. The lower points show raw data and the upper points show data corrected for the geometrical mismatch of 500 μm APD light-pipe and 875 μm fiber (correction factor = $(500/875)^2$). The upper curve is a plot of:

$$\text{Efficiency}=1\text{-}e^{-n_0 e^{-L/\lambda}}$$

with n_0=6 equivalent photoelectrons and λ=3m. Note that n_0 is the product of the photon detection efficiency P_d and the number of *detectable* photons at L=0.

4.3.4.0 Other Factors

- Reliability: Greater than 10^7 hours operation at room temperature.

- Cost projection: $20-30 per channel. The main contribution to the per channel cost comes from packaging and electronics. It is difficult to imagine a cryogenic device being less expensive than a room temperature device.

- Production capability: Present facilities are adequate.

4.3.5.0 Proposed Program

4.3.5.1 By September 1991:

- Evaluate present fast quench circuit.
- Evaluate ball-lens coupling approach.
- Evaluate sub-Geiger mode and linear mode with GaAs IC.
- Complete 500μm *Slik* development.

4.3.5.2 By January 1992:

- Optimise fast-quench circuit using an approach which lends itself to integration.
- Evaluate low-noise IC preamplifier approaches with the necessary low-noise sensitivity and low cost per channel.
- Continue *Slik* development work with emphasis on low dark count rate, high QE and low cost.

4.3.5.3 By September-December 1992:

- Develop and evaluate fast-quench IC.
- Develop and evaluate low-noise preamplifier for sub-Geiger and linear modes of operation.
- Evaluate light coupling techniques which can be integrated in an array.
- Evaluate problems of electrical cross-talk.
- Finalize design.

4.3.5.4 By September 1993:

- Design and acquire suitable packages.
- Assemble and evaluate prototypes.
- Establish yields and final pricing.

Scintillator and Waveguide Development

The successful implementation of fiber tracking for SDC requires the development and optimization of scintillation material having high efficiency, fast response, good radiation resistance, and minimal self-absorption, and the successful incorporation of such material in optical fiber waveguides of diameters less than 1 mm and in lengths $\leq$ 4 m. These detectors are then optically spliced to clear, non-scintillating

fiber waveguides having identical diameter and cladding thickness, to transport the scintillation signal outside the tracking volume and with minimal attenuation to VLPC detector arrays located at the periphery of the calorimitry. This location is ideally suited for in situ interfacing of fiber tracking information with calorimetry energy measurment for level 1 trigger definition. Additional benefits for VLPC operation include the low neutron and charged particle fluences in this locale and accessibility.

Candidate fiber waveguides based on polystyrene cores and acrylic cladding have been under study for some time. Several options for scintillation mixtures and waveguide materials have been considered. Key features of polystyrene include excellent optical transparency at visible wavelengths $\leq$ 500 nm for doses of $\leq$ 10 Mrad. Very recent measurments by the Fiber Tracking Group, and reported by M. Atac,[7] have demonstrated conclusively that detected photoelectron yields are excellent for 4 m of BCF99-05 scintillating fiber optically spliced to 4 m of BCF98 clear fiber with VLPC readout. Additionally the BCF99-05 material is known to be adequately rad hard for our intended applications in outer tracking. These results establish the viability of fiber tracking for SDC and represent a bench mark system around which we can now optimize.

System refinements include development of high purity core polymer and cladding acrylics, further developmental work on the flourescent dyes and the optimization of these for incorporation into fiber waveguides. Examples of optimization studies include variations in the mechanical and thermal parameters of fiber manufacture, variations in core and cladding refractive indicies, and studies of long-term material stability and radiation resistance of the scintillation fibers and waveguides in nitrogen and air environments.

Important new initiatives within the subsystem program include the manufacture of fiber ribbons in single and double layers, and for optical splicing techniques for ribbons as well as single fibers. Recent success of fiber-to-fiber coupling with optical grease (rather than reliance on thermal splicing) has led to substanial interest in the development of optical connectors between fiber ribbons based on this principle. Such a scheme has clear advantages for construction and maintenance of

the fiber tracking elements of the SDC detector.

MILESTONES:

INITIAL RIBBON STUDIES	DECEMBER 90
BCF99-05 FOR TESTS WITH VLPC-I	MARCH 91
RIBBONS FOR SOURCE TESTS	SPRING 91
STUDIES OF 3-HF, VARIANTS. ALTERNATIVES	FY91
LOW INDEX CLADDINGS	FY91
SPLICING CONNECTOR DEVELOPMENT	FY91
RIBBONS FOR BEAM TESTS	SUMMER 91
REFINED RIBBON MANUFACTURE	FY91
STUDIES OF LARGE SCALE MANUFACTURE	FY92

Radiation Hardness

Scintillating fibers represent one of the most rapidly developing new elements for the next generation of tracking systems due to their high rate capability and good position resolution. Still some critical issues are under investigation such as radiation hardness for operation in high flux environment, the intrinsic attenuation of photons for fine diameter and long fiber and the development of a reliable, high quantum efficiency multichannel photo-sensor. Here we summarize the review and discussion of critical issues in the area of radiation hardness of scintillating fiber by the task force member.

A scintillating fiber tracker of SDC detector is thought to be placed at radial distance more than 50 cm from the beam line where the radiation level is expected to be 0.05×10^4 Gy per year (50 kRad/year) for the standard SSC luminosity.[8] Recent experimental data with short term high-rate dose show that rad-hardness of new green scintillator does clear this radiation level if significant recovery due to annealing in oxygen environment is taken into account.

Many interesting investigations[9–14] are reported for a development of a radiation hard scintillator and its radiation damage. Remarkable progress are seen for a development of polystyrene base, two steps wave length shifted, green light scintillating fiber. Fig. 3 shows transmittance degradation as a function of wavelength for a polystyrene base scintillator with two wave length shifters of pT and 3HF when irradiated by gamma rays. On this figure the flourescence wave length distribution of

the 3HF is superimposed.[13] Severe degredation was observed in a short wave length region, while in the 3 HF flourescence region the degredation of transmittance is less severe and significant recovery with room temperature annealing is observed in oxygen gas. Unfortunately these data are not enough to guarantee the radiation hardness of this scintillator because of unclear radiation rate effects and unclear oxygen role for annealing.

The significant annealing was observed only in the case of high dose rate experiments. There are some conflicting reports concerning the role of oxygen whether it plays a beneficial or damaging role in the radiation induced damage and its anealing.[9,10] Clough and Wallace investigated the radiation damage of polymer-based scintillators[11] and the annealing effect. They discussed two types of color center: annealable and nonannealable. At dose of a few Mrad with high dose-rate an annealable color center accounts for a large fraction of the observed radiation induced absorption. Oxygen accelerates a recovery of annealable damage. In the absense of oxygen, annealing can occur but with very slow rate at room temperature compared with oxygen-mediated annealing. On the other hand, they pointed out that oxygen may have an undesirable degrading effects, possibly leading to higher concentration of permanent, nonannealable color centers and to oxidative degradation of dyes. This may give a interpretation for the phenomenon of low-rate dose effect in which we cannot expect any acceleration nor improvement effect for annealing by oxygen.[10]

One more unclear subject is particle species dependence of radiation damage. For the silicon case, non-ionizing energy loss contributes the bulk damage, so that the radiation damage heavily depends on an incident particle species. Why does not the scintillator behave like the silicon? A heavy particle can make a large damage cluster which may create a more nonannealable color center. So far most of the available radiation damage data are gamma irradiation and low energy electron irradiation.

We saw that an improvement of rad-hardness of scintillator was very impressive in recent few years. All data are supporting that new green flourescent scintillator can survive in the SDC outer tracker region. But this does not guarantee long term

stablity of good performance of the scintillating fiber. To attain definite confidence:

1. We have to make clear the low-rate long term irradiation damage effects and the oxygen role for the annealing of radiation damages.
2. Need a systematic studies for oxidative degradation of organic scintillator.
3. Need heavy particle irradiation data such as protons and neutrons to investigate particle dependence of radiation damage.

4.4. Critical Issues for Straw Tubes

At low gas gain ($\sim 2-5\times10^4$), the lifetime of straw tube drift chambers should not be a problem at distances greater than about 50 cm from the beam at the SSC. Operation with optimum resolution and efficiency at low gas gain requires the ability to set a low threshold in the front end electronics discriminator. Thus, low noise levels in the electronics and in the coupling to the environment are needed. Low threshold operation at this level has been achieved in other experiments but will need to be verified using the front end electronics being designed for straw tubes at the SSC. At low gas gain, current draw is at the level of tenths of microamps, and while the current draw must be taken into account in the design of the high voltage system, it does not appear to be a serious issue. Heating of the high density front end electronics is more of a problem and requires careful design of a cooling system.

One of the possible problems with straw tube chambers is occupancy. Calculations taking into account minimum bias and low-pt backgrounds from bunch crossings within the time measuring window, including loopers from much earlier bunch crossings, give numbers which range from about 12% in the inner superlayer to a few percent in the outer superlayers at the design luminosity of 10^{33} cm^{-2}s^{-1}. Tracking simulation studies have shown high segment finding efficiency at this level. At ten times the design luminosity the occupancy of the inner superlayers would be problematic, but the outer layers would still be able to provide useful information. The role of tracking will likely be different at ten times the design luminosity. Even a perfect tracking system will have to deal with an average of sixteen interactions per bunch crossing at ten times the design luminosity. The effects of occupancy at

the level of tens of percent on the pattern recognition, track finding efficiency, and fake trigger rate are under study.

The attenuation length of the straws is improved by applying an extra thick coating of aluminum to the cathode surface. This has been done successfully both on Kapton and carbon-loaded polycarbonate. The resistance per unit length is 30 ohms per meter in both cases. The anode wire then presents the larger proportion of the resistance. The attenuation length of the straw is about 6 m with the standard 25 μm wire. Although this is already good enough for a 4 m straw tube, there is also the possibility of increasing the anode wire diameter somewhat and increasing the attenuation length even more. Tests are in progress to optimize the mechanical and electrical properties of the straw tubes.

Milestone and goals	Date
Assembly of full-scale 4 m module	1/92
Complete construction of second 4 m module	4/92
Complete evaluation of efficiency, resolution, and attenuation of 4 m module with prototype of full electronics (preamp/shaper/discriminator/TVC or TMC)	12/92
Prototype support structure assembly of full-scale sector	10/92
Auto assembly and manufacturing design	10/92
Construction of full sector	5/93
Evaluation of first preamp/shaper/discriminator prototype	12/91
Build and test direct board mounting of Penn 4-channel preamp/shaper/discriminator chips into 16- or more channel board.	12/91
Develop HV distribution with failure confinement (e.g. fuses); establish cable and utilities plant requirements.	2/92
Produce readout boards with TVC/AMU and DCC chips.	3/92
Produce readout boards with TVC/AMU and DCC chips (direct board mnt)	6/92
First generation straw arrays with detachable readout board.	9/92

4.5. Straw Tube Readout Electronics

The R&D plan for readout electronics for straw tubes is based on the schedule presented in Fig. 4. During FY91 the primary goal has been demonstration that integrated electronics can be delivered which meets the performance specification for noise, risetime, double pulse resolution, and position resolution at an acceptable power dissipation. Prototype preamplifier/shaper circuits have been produced and tested which deliver the desired performance in tests of a small number of tubes.

Preamplifier/shaper circuits (single channel/chip) are now being delivered in sufficient quantitities (> 500 channels) to allow numerous tests of systems comprising several tens of channels (or more). For the balance of FY91 the emphasis is on delivering multiple channel versions which include the discriminator on chip. KEK expects 4 channel chips in March-April which include preamp/shaper/comparator and a University of Pennsylvania design which includes 4 channels of preamp, shaper, tail cancellation, and discriminator is about to be submitted.

Considerable progress has been made on the two complementary time measurement systems. The 4 channel/chip TMC developed at KEK has been demonstrated to deliver excellent time resolution (< 0.5 ns) over times up to 4 μs; it also is radiation resistant to doses of > 1 Mrad with power off. Measurements of the radiation resistance with power on will be carried out shortly. The primary issues outstanding for the TMC approach are the cost, area, and inclusion of Level 2 buffering and readout control. The current TMC (approximately 5.5 mm $\times$ 5.5 mm) includes 2 channels of 2 μs pipeline or 1 of 4 μs delay. At the present 2 μs pipeline delay, 256 channels thus require 128 5 mm $\times$ 5 mm chips just for L1 storage. Extension of pipelines to $3-4$ μs represents a fairly serious problem in terms of the amount of silicon required.

The time-to-voltage converter and analog memory (TVCAMU) approach being developed at the University of Pennsylvania promises significantly higher density of order 4 channels/chip for a 6 mm$\times$6 mm die including Level 2 storage and for a 2 μs pipeline. For slightly larger chips 8 channels/chip with 2 μs pipeline or 4 channels per chip with $3-4$ μs pipeline appear feasible. The basic TVC conversion has been shown to have resolution < 0.5 ns; this has not yet been demonstrated over the full $2-4$ μs range though there is no reason to expect it to be any different.

The critical issues for FY92 are

(1) demonstration of the time measurement system over the full pipeline time range and including L2 buffering and readout control

(2) Assembly and test of preamp/shaper/discriminator and time measurement system for 128 - 256 channels in nearly the correct geometry.

There is very little doubt that the electronics systems themselves will deliver the performance required. However, operation of several hundred channels in the nearly final geometry is a very critical test because of the potential crosstalk between the 60MHz digital logic and the sensitive preamplifiers.

At the moment the TMC approach appears more robust since it is all digital but faces significant issues of density and cost, especially if the pipeline is extended to $3-4$ μs. The TVCAMU promises significantly higher density and lower cost but has not yet demonstrated operation of the full system. Becuase (1) neither of these systems has yet demonstrated a solution, (2) they both show considerable promise, and (3) cost will ultimately be a significant factor, it is recommended that R&D be aggressively pursued on both of these systems.

A complete system test at the module level would include readout of the digital data from the TMC or TVC via a local data collection chip. A significant overall part of the module design includes questions of whether the communication between the front end chips and a data collection chip should be parallel or serial, the number of bits if parallel, single ended versus differential transmission, etc. These issues impact the readout control and number of buffers in the TVC/TMC as well as cross talk issues. It is therefore strongly recommended that prototype DCC's be included in the FY92 tests. It is probably not necessary that the DCC's for this test be radiation hard nor that they include the ultimate functionality or protocol with the rest of the DAQ system.

An important part of the module system test is selection of an appropriate substrate technique for mounting the bare dice (normal packaging such as surface mount is virtually excluded by the required ratio of silicon area to substrate area). The primary options include (1) bonding of bare dice to ceramic substrates (or printed circuit boards) directly and (2) packaging of the chips in multichip modules (using advanced techniques such as silcon on silicon) with the multichip modules then mounted on ceramic or printed circuit board substrates. While either technique could be used for the TVC or TMC it is currently planned that the Japanese effort will initially pursue multichip packaging while the US effort will initially pursue direct bonding of dice to ceramic substrates. Work on the design and test of appro-

priate substrates in the US is being done at Colorado, Oak Ridge, and Penn with each taking on different tasks to avoid redundancy.

4.6. Barrel Trigger Performance

Conceptual designs have been proposed and initial studies begun for both the straw and fiber based triggers in the central tracking region. No fundamental problem leads us to believe that triggers cannot be developed for both tracking approaches. The difficult issues for triggering with the two detector technologies are different and mirror the general differences of the sensors themselves.

For straws the drift time along with the minimum possible pulse separation must be handled optimally. The larger cell size is both a blessing and a curse. A "modest" channel count results along with higher occupancies. A full physics simulation of the straw tracker has been developed along with triggering. This simulation will be run extensively in the future to determine the effectiveness of two general approaches for straw tube triggering. These two approaches, one from KEK[15] and one from Michigan,[16,17] are converging and may become a single approach in the near future. The evolution will depend on the results of the simulation.

For fiber triggering the absence of timing considerations reduces the problem to one of coincidence logic alone. This simplification is countered by the need to handle nearly 1 million signals. A design has been proposed[18,19] and initially simulated for processing this large number of signals. Details of the processing steps, size, and characteristics of the data paths for this architecture must be defined as the tracking simulation is enhanced to include the pipeline processor that forms the trigger. The complication in the case of fiber triggering is that of magnitude.

A common input to the trigger simulation is important so that comparative evaluations can be made. A common set of comparitive plots has also been proposed. With full simulations we will examine the efficiency, false triggering rate, and P_t threshold behavior, at several collider luminosities for each proposed design.

Straws Trigger R&D

Triggering on straws in both the KEK 3/4 coincidence and synchronizers makes

use of the timing difference for radially aligned wires. The KEK approach and synchronizer approaches are converging and exact tuning between the approaches will depend on detailed simulation. The KEK design is based on 8 layers of straws per superlayer. The Michigan design most extensively studied is based on 9 layers per superlayer. Whether 9 straw layers are important for good triggering efficiency must await the simulations as well. Nine layers will give more redundancy and synchronizer timing will improve the crossing determination but the magnitude of the improvement is yet to be determined. The KEK design includes logic to associate high P_t tracks found in each of three single layers while the Michigan design proposes a single layer trigger that is replicated times 2 for redundancy. Again, questions of sufficiency and operational margin await full simulations. At least one "good" straw tube trigger appears likely for occupancies up to 10% and possibly up to 20%.

A detailed simulation including the effects of loopers and minimum bias events has been developed with the inclusion of the synchronizer trigger. That program is being run and will continue to be run for months to come since many computer hours will be needed to refine the trigger design. The KEK trigger algorithm will be incorporated along with the synchronizer simulation so that a detailed comparison can be developed. The number of trigger superlayers and number of layers per superlayer are important questions to address with this simulation.

The major issues for the straw tube trigger are:

1. The false triggering rate vs occupancy
2. The efficiency vs occupancy
3. Number of trigger signals exiting superlayers
4. Is intersuperlayer trigger processing needed
5. Frontend electronics questions
   (a) Clock pickup at the frontend chips
   (b) Power dissipation
   (c) Costs/channel estimates

Triggering on Fibers

A level 1 trigger based on tracking information from scintillating fiber superlayers in the barrel region has been proposed which, when incorporated in ASIC technology, can be incorporated directly in the readout/data acquisition path for fiber tracking. The trigger exploits the intrinsic speed of scintillator and the low occupancy in the fiber superlayers. Detected signals in a given fiber superlayer are interogated for slope information in ASIC-I. Information from separate superlayers is compared in ASIC-II and the result is reported in units of sagitta. Given the granularity of the fiber information, excellent resolution in transverse momentum ($.004P_T$) is available directly at level 1, rather than simply a threshold P_T cut. The momentum information can be interfaced in situ with calorimetry information, for estblishment of a powerful electron trigger. Simulation studies have shown that such a fiber trigger scheme can provide excellent rejection power to the highest available luminosities expected at the SSC.

A similar architecture is under consideration for triggering in the intermediate tracking region, in which ASICs are used to combine information from spiral fiber layers to determine change in azimuth with z coordinate.

As part of the Fiber Tracking Group Subsystem Program, a prototype based on discrete elements will be constructed and available in later summer for beam tests with fiber superlayer structures and VLPC. The prototype will be capable of 53MHz operation, a rate appropriate to the RF structure of the Tevatron, and which is close to the 63 MHz operation appropriateto to SSC.

Schedule/Milestones

All triggering designs imply custom integrated circuits. The work done on chips to date has been key in the development of the necessary expertise in chip development. The work just beginning on radiation hardness is applicable to the straw tube circuit development and the circuit design will move to this process in 1992. Test version in the UTMC process are anticipated in 1991. The KEK design has been implemented in a process that has received initial radiation testing and has proven excellent in resistance. As far as trigger testing is concerned the use of ac-

celerator test beams must be associated with the general detector prototype test. The basic trigger design performance can be evaluated in computer controlled test fixtures and cosmic ray test stands. The system tests will require large prototypes and many channels.

The R&D activites to date and through 1993 are below:

1. Synchronizers for straws
   (a) Hardware fabrication
      (i) First chips tested - 1990 (done)
      (ii) All digital chip prototype - May 1991
      (iii) Full unit with coincidence - Late 1991
      (iv) Radiation hardenend full design - Late 1992
   (b) Simulation
      (i) Coded - Mar 1991
      (ii) Preliminary evaluation - Aug 1991
      (iii) Evaluation with calorimeter and muon - Early 1992
   (c) Test fixtures
      (i) Individual chips - Late 1990 (done)
      (ii) Cosmic ray test stand - Jun 1991
      (iii) Cosmic ray synchronizer test - Dec 1991
      (iv) Full production test fixture - Early 1993
2. 3/4 coincidence for straws
   (a) Hardware fabrication
      (i) First chips - Late 1990
      (ii) Radiation tests - Early 1991
   (b) Simulation - Jun 1991
   (c) Preliminary evaluation - Sep 1991
3. Fiber trigger
   (a) Fabrication using discretes - Summer 91
   (b) Prototype ASIC - slope finder - FY 92
   (c) Prototype ASIC - linker - FY 92
   (d) Prototype ASIC - interm.trking - FY 92

4.7. Intermediate Angle Fiber Tracker

4.7.1. Layout and Deployment

The intermediate angle region of the outer tracker, in the case of scintillating fibers, is covered using fiber disc structures that are oriented perpendicular to the beam line. Arrangements which avoid an intermediate angle region by having all barrel layers the same, extending over the full 4-meter half length of the tracking volume, suffer from very high occupancies for the inner layers, large increases in material thickness as η approaches 2.5, and a difficult trigger problem for the region $1.6<\eta<2.5$. Changing the orientation from axial to transverse in the large η region ameliorates all three of these problems and allows for a transition along a constant-η line.

Due to the flexibility of scintillating fibers, many disc layouts and configurations are possible. These range from simple rectilinear arrays, through radial spoke arrangements, to space-filling spirals. Simulations of the simple rectilinear configurations[20] have uncovered occupancy/combinatoric limitations for triggering and pattern recognition at high luminosity, and attention has shifted to the more complex arrays which have significantly better pattern recognition capability.

Space-filling spiral arrays are a common ingredient in the newer design studies.[21–23] As can be seen from Fig. 5, the radial extent of a spiral is limited by practical considerations to a ratio of about 2:1 between outer and inner radii. This feature lends to a preference for a long outer barrel involving several superlayers which contains a fiber disc end plug as in Fig. 1. Considerations of the transition from a trigger based on $r-\phi$ measurements to one using $r-z$ measurements and the necessity for δr segmentation in the latter (as described in Section 4.7.3) also favor a long outer barrel section and a limited δr span for the plug.

4.7.2. Momentum Resolution

In the intermediate angle region, momentum resolution is provided by linking tracks from the silicon inner plug system to the fiber disc system. In an analysis of the plug region[24] for the momentum resolution, the simplifying approximation

was made of replacing the multilayer fiber disc structure by a single measurement station at a z of 4 meters. The space point accuracy of this station would be that provided by the combination of layers being approximated.

The curve in Fig. 6 shows the momentum resolution of the system as a function of the space point precision of the station at $z = 4$ meters for 1 TeV/c tracks at $\eta = 2.0$. A 20 micron beam constraint is used which is the same as having 2 layers of silicon pixels. Two features are apparent from the graph, the silicon system has a pointing accuracy at $z = 4$ meters of 100 to 200 microns in stand-alone mode, and the station at $z = 4$ meters should have a spacial precision of about 50 microns to match the silicon system and improve the resolution by a factor of 2. This is readily achievable, with 1 mm fibers and 8 layers of half diameter staggered pairs, for example.

Another aspect of momemtum resolution is mass resolution as in the width of reconstructed Z-bosons. For the momentum resolution result quoted above, special precision was only in the ϕ-direction; no r measurement was needed. For reconstruction of the Z^0 mass, however, there is significant error if the dip angle for leptons in the intermediate angle region is not measured. Fig. 7 shows a curve for the invariant mass resolution of Z^0's produced by an 800 GeV Higgs as a function of the η of the largest angle lepton. An r-resolution of a few mm was included to remove the dip angle effect. Again, the conclusion is that a ϕ spacial precision of about 50 microns is the appropriate area. It seems likely that triggering considerations will yield the most stringent performance criteria for intermediate fibers.

4.7.3. Trigger

Triggering in the intermediate angle region divides into two categories: an overlap region, where both barrel and planar tracking contribute, and a forward region of larger pseudo-rapidity where only planar tracking contributes. Of these, the overlap region is least studied and is possibly the most challenging. One proposal[5] for triggering in the overlap region attempts to compensate for the loss of the outermost barrel layer, which does not participate in this angular region, by adding a fiber disc layer at $|z| \simeq 4$ m and at larger radius. The station is then used in conjunction

with the inner barrel tracking layers to form the trigger. This proposal does add complexity to the problem by requiring the fiber disc hits to be decoded into $r - \phi$ coordinates and combined with the appropriate axial layer measurements to form the trigger. If trigger coverage is deemed essential over this overlap region, then evaluation of such a trigger layer, or alternate proposals, should be given high priority. At a minimum some R&D should be carried out to evaluate the difficulties of realizing a trigger which combines barrel and planar tracking. A good solution to this problem could have an impact on the design of the overall outer tracker as all of the proposed designs and layouts in the EoI, the LoI, and elsewhere exhibit such an overlap trigger region.

Intermediate angle region triggering using the planar tracking has been discussed by a number of authors.[20–22,23,5] In general, these studies assume a minimum desirable $P_\perp$ threshold of approximately 10 GeV/c, and consider that the forward tracking planes extend along the beam direction from z=3 to z=4 meters. Furthermore, the analyses assume that the planar tracking elements provide mainly azimuthal (ϕ) information, with some measurement of r (and thus pseudo-rapidity) provided to limit the range on the dip angle. These studies find that 1 mm diameter scintillating fibers provide adequate azimuthal segmentation for triggering. As the forward planes directly measure P_z, a measurement of the radial coordinates of the track must be made to convert this to a determination of $P_\perp$. Typically this implies that the azimuthal trigger roads must be divided into $3-4$ pseudo-rapidity bins (for $1.75 <| \eta |< 2.5$). The different approaches proposed range from using constant-radius fiber disc arrays, to large angle stereo through oppositely oriented spirals, to small angle stereo spirals with the same sense. One important characteristic which distinguishes between approaches is susceptability to false triggers from combinatorics (ghosts) in the minimum bias event background. All studies which have quantified this issue have concluded that at least three measuring stations that are distributed over approximately 1 m along the beam line, are required to minimize accidental triggers from combinatoric backgrounds.[5,25]

The preliminary studies are encouraging. However, simulations are needed to optimize the number, placement and the geometry of the fiber disc measuring sta-

tions and to evaluate trigger performance. The space point accuracy needed for triggering when combined with the redundancy needed to defeat the combinatoric background automatically satisfies the momemtum resolution requirement. Detailed studies of the trigger issues continue attempting to optimize performance with the lowest channel count. In addition, high priority should be given to the R&D efforts aimed at implementation schemes for the trigger electronics for the various ideas in the context of the digitally pipelined logic necessary for a deadtimeless Level 1 trigger.

4.8. Intermediate Angle Radial Wire Tracker

The details of the layout of an outer gaseous tracking detector for the intermediate angle region in conjunction with the inner silicon tracker have yet to be properly evaluated in simulation. We are investigating layouts which either use radial wire drift chambers, or gas microstrip detectors or a combination of the two to meet the specifications for track reconstruction, momentum resolution and triggering in this difficult region. It should be noted that because a radial wire drift chamber has all its structure for preamplifier mounting and wire support at its outer circumference, it is only a sensible choice if the short (3m) barrel tracking option is adopted.

The advantages of radial wire drift chambers are well documented in contributions to the Fort Worth R&D symposium[26] A "standard" design of radial wire drift chamber gives rise to two areas of concern for use in SDC at a luminosity of 10^{33}.

Current Draw

The current draw, which is expected to be 0.5 microamp per sense wire at a luminosity of 10^{33}, will induce a similar current in the voltage graded cathode plane which will cause voltage sag if a resistive divider is used. The consequences are intolerable drift velocity and gas gain variations as a function of radius. An alternative approach, which is now favoured, is to supply each cathode strip, via a distribution network, from a set of ganged power supplies, one for each different voltage in the chamber. Such a system introduces no new conceptual design problems other than the large number of voltage lines needed to supply the drift chamber. The

availability of thin high voltage lines is being investigated. This solution has the additional advantage of permitting the inner radius of sensitivity of the chamber to be increased to cope with unexpected background levels.

Occupancy

Occupancy, as presently used to evaluate the performance of straw tubes with single hit electronics, is misleading when mutlti-hit electronics are used. It is necessary to distinguish "memory time" and "busy time". Memory time is the maximum drift time, in this case 157 ns or 10 beam crossings. Busy time is twice the two hit resolution divided by the drift velocity, 2×2 mm divided by 100 μm/ps, or 40 ns. Using the busy time in the calculation, the effective occupancy is 12% at a luminosity of 10^{33}. This is comparable to the occupancy of straws in the barrel outer tracker, as expected when one considers that the rapidity range and phi segmentations are similar.

The operational characteristics of the radial wire drift chamber in SDC are usefully summarised by the following:

Hit losses due to busy time.

In simulation at a luminosity of 10^{33} the loss of hits due to the anticipated two hit resolution (2 mm) is only 7%.

Minimum bias background

The proposed inclusion of a "crossing tagger" with a time resolution conservatively estimated at 3 beam crossings has been demonstrated by simulation to reduce the fraction of minimum bias hits per trigger in the ITD from 79% to 27% of the total. This gives confidence that the pattern recognition problems will be manageable.

In Liverpool, design engineering work is underway which is concerned with the details of construction and assembly of small aperture SDC radial wire wedges. Many modifications to the H1 design are necessary. First layout drawings have been made. At the same time consideration is being given to modifications to standard wedge orientations which are more appropriate to the SDC environment. They

have the advantages of determining the individual beam crossings, of providing an accurate measurement of the radius, and maybe of providing a trigger. The provision of a useful trigger in Pt in the intermediate angle region demands high precision in both R and phi of any tracking device. These considerations are being pursued in the UK, and will be evaluated fully in the SDC simulation as soon as the relevant programs are running reliably in the UK.

The first radial wire drift chamber wedge with SDC dimensions has been built at Liverpool. It is being used in Liverpool to confirm the expected operational characteristics of the design, and, in the near future, will be taken to RAL to establish operation in a 2T magnetic field with fast drift gases. A test beam run at CERN using the spare H1 radial chamber is scheduled for summer 1991. Beam test of the next SDC wedge prototype will be included in this run.

By September 1991 we expect to have:

a) Understood and evaluated the modifications to the standard wedge orientations mentioned above.

b) A first design of an SDC radial wire drift chamber module.

c) Proven the expected operating characteristics.

d) Started an evaluation of the requirements for the read out electronics, having operated the prototype with fast drift gases.

4.9. Intermediate Angle Straw Tube Tracker

Another option of the gaseous intermediate tracking is using straw tubes. In this scheme, the straws are placed like bicycle spokes (ϕ straw). The radius of straws is 2 mm like the straws in the barrel tracking. Since the radius of straws cannot be changed, there is a gap between straws as r increases. In order to obtain a complete coverage, another radial straw which is offsetted by exactly half radius has to be placed behind. (This limits the radial size of the chamber such that the outer radius is twice of the inner radius). The typical inner radius of a chamber is about 65 cm and the outer radius is about 130 cm.

To make the r measurement, some layers are tilted by a small angle to obtain stereo information. The present scheme for the stereo straws is one stereo straw covers one ϕ straw (in this case, the stereo angle is about 0.01 radian, which translates to about 1 cm r resolution). It is not clear whether better resolution is necessary since silicon system can make much better measurement.

In order to reduce the occupancy, sense wire could be joined by an insulator at the middle of each tube (for ϕ straws only) and read out from both ends. This way, not only occupancy is reduced by a factor of 2, but also there are two η bins for the trigger. First estimation for the occupancy for one layer is about 5% at the design luminosity if a wire is read out from both ends. A more careful study is necessary. As already shown from the study of the straws in the barrel region, there is no problem with either the current draw or space charge.

The design being considered is (there are four chambers in each end-cap region)

$$zzuuzz \text{ (25 cm separation) } zzvvzz \text{ (25 cm) } zzvvzz \text{ (25 cm) } zzvvzz,$$

where z means the ϕ straws and $u(v)$ means the stereo straws. Each z layer consists of 2000 readout channels, and each u or v layers consists of 1000 readout channels. In overall there are 40000 channels for one end-cap chamber (80000 total for both end-caps). Here, the z straws are read out from both ends and u v straw are read out from one end. The exact geometry of the straw tubes and number of superlayers maybe changed according to the need of the trigger requirement.

There are several advantages for this system. It is fairly easy system to build. The straws are 60-70 cm long so wire support is not necessary. The system is small and compact so can be built without much support. The same electronics developed for the barrel system can be used. And moreover if the trigger scheme is similar to the barrel tracker, then again one does not have to develop the trigger electronics. The estimate weight of each module is about 10 kg, and the total radiation length of one end-cap chamber is less than 3%.

There are a few R&D areas.

1. The occupancy rate should be calculated accurately.

2. The trigger scheme should be worked out and tested. This should have the highest priority, since the main function of the intermediate tracking is providing the trigger. A preliminary study by Chapman[27] shows how a trigger with $P_\perp$ threshold nearly independent of polar angle could be derived if the disks are laid out as shallow cones.

3. Since the chambers are inside a magnetic field, the Lorentz angle should be measured. This measurment may affect the trigger design.

4. Although there is no obvious difficulty in building the proposed chamber, a prototype should be constructed soon.

4.10. Gas Microstrip System

Gas microstrip detectors, including knife edge chambers, offer the possibility of high rate operation (to a luminosity of 10^{34}), fast signals (30-40 ns), and sub-millimeter spatial resolution. However, they are only in the very early stages of development. A number of SDC collaborators, Carleton, Liverpool, Rochester, Rutherford, and Texas A&M, have expressed interest in their development. It is planned that this work be coordinated, and a first meeting to this end has been arranged to follow immediatly after the SDC meeting at ANL.

Some small working devices have been built at RAL and tested using Fe^{55} X-rays. So far the results confirm the expected pulse rise and fall times.

A second generation of electrode masks have been made using the RAL Electron Beam Lithography facility. These will be used to investigate:

a) Various substrate materials.

b) Metalisation thickness.

c) Technologies available to produce useful sized devices.

d) Bonding to preamplifiers.

e) Preamplifier design.

In Liverpool development work (in collaboration with LHC initiatives) is already well underway using silicon substrates.

Texas A&M have small knife edge chambers working.

No engineering design work has yet commenced for the layout of an intermediate angle tracker based on gas microstrip detectors.

It is difficult at this early stage to estimate the speed with which this development programme will proceed.

5. System Considerations

5.1. Milestones for Pattern Recognition, Resolution

Substantial progress has been made by many contributors to setting up a unified tracking system simulation package. GEANT models have been set up for each of the subsytems in one or more variants, and these have been embedded in the shell structure, at least for initial tests. Much discussion has served to develop a concensus on data structures which have now been defined. Work is in progress to complete the task of making the various contributions conform the these structure formats. The next step is to get this package disseminated among the various institutions, debugged, and brought into general use. Development of pattern recognition algorithms for the unified tracker(s) is a high priority; we plan to have this far enough along by the end of May so that comparative performance results can be generated during the summer.

5.2. Material in the Particle Path

The estimated total material of the tracking system as a function of η is shown by the upper solid curve in Fig. 8. Here is a brief summary of the model used for this calculation:

1. Vacuum pipe: 0.050 in beryllium.
2. Silicon pixel tracker: 3 axial and two disk layers, per layout provided by R. Stone (this should be 2 axial; on the other hand, the short barrel plus disk gives a considerably more favorable material load at large η than the two long

barrels once assumed). Each layer is 300 μm thick, with about half the true silicon radiation length, giving a factor of two to account for support.

3. Silicon strips: 8 axial and 22 disk layers, per layout in the LoI. Again, 300 μm thick with radiation length equal to half that of silicon.

4. Barrel scifi and light guides: Two superlayers as in the baseline above, the first having eight and the second 16 layers of 750 μm diameter polystyrene. Each is supported by a sandwich of two 0.010 in graphite epoxy skins bonded to 4.1 cm thick Rohacel 31 (acrylic foam).

5. Barrel straws: Three superlayers of six straw layers each (outermost straw layer is ignored). Each detector is 4 mm diameter, 37 μm wall mylar cathode, 25 μm diameter tungsten wire, and a filling of CF_4 gas. There are two module wrappers of 0.010 in graphite epoxy, and a 1 in thick sandwich support, constructed as for the scifi. The first superlayer's end fittings and electronics are included; the remaining layers run to the end of the tracker.

6. Intermediate angle scifi disks: Two superlayers (we ignore the third at the end of the tracker) of eight layers of fibers, each supported by a 1 in thick sandwich disk constructed as for the barrel.

7. Support: Four 1 in thick sandwich disks at $z = (\frac{1}{2} + n) \times 0.88$ m, $n = 0, 1, 2, 3$.

The outer tracker contribution is shown in Fig. 9, In general, a straw system has less material in the detectors, but more in the support, than does scifi in this model; the total is about the same for either. Light guides for scifi and electronics for wires cause about 20% of a radiation length over a narrow η range.

The total amount of material averages a bit over 20%, except for the region of width $\Delta\eta \simeq 0.2$ occupied by light guides. Work is needed to assess the impact of this on both the electron identification and the trigger.

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FIGURE CAPTIONS

1) Layout drawing of the draft baseline design.
2) Efficiency Plot for BICRON G2 Fiber.
3) Transmittance degradation from gamma irradiation as a function of wavelength for polystyrene based scintillator with pT and 3HF wave length shifters.
4) Schedule for R&D, design, fabrication, and installation of straw electronics.
5) Schematic layout of space-filling scinitillating fiber disk for the intermediate angle tracker.
6) Intermediate angle system momentum resolution as a function of point measurement precision.
7) Z^0 mass resolution vs rapidity for lepton in the intermediate angle system.
8) Number of radiation lengths of tracker material vs rapidity for the baseline layout. The lower solid curve is the contribution of the vacuum pipe; the dotted curve with silicon added; the dashed curve with scifi added.
9) Number of radiation lengths due to the outer central tracker in the baseline layout; dashed curve is the contribution from the support structures.

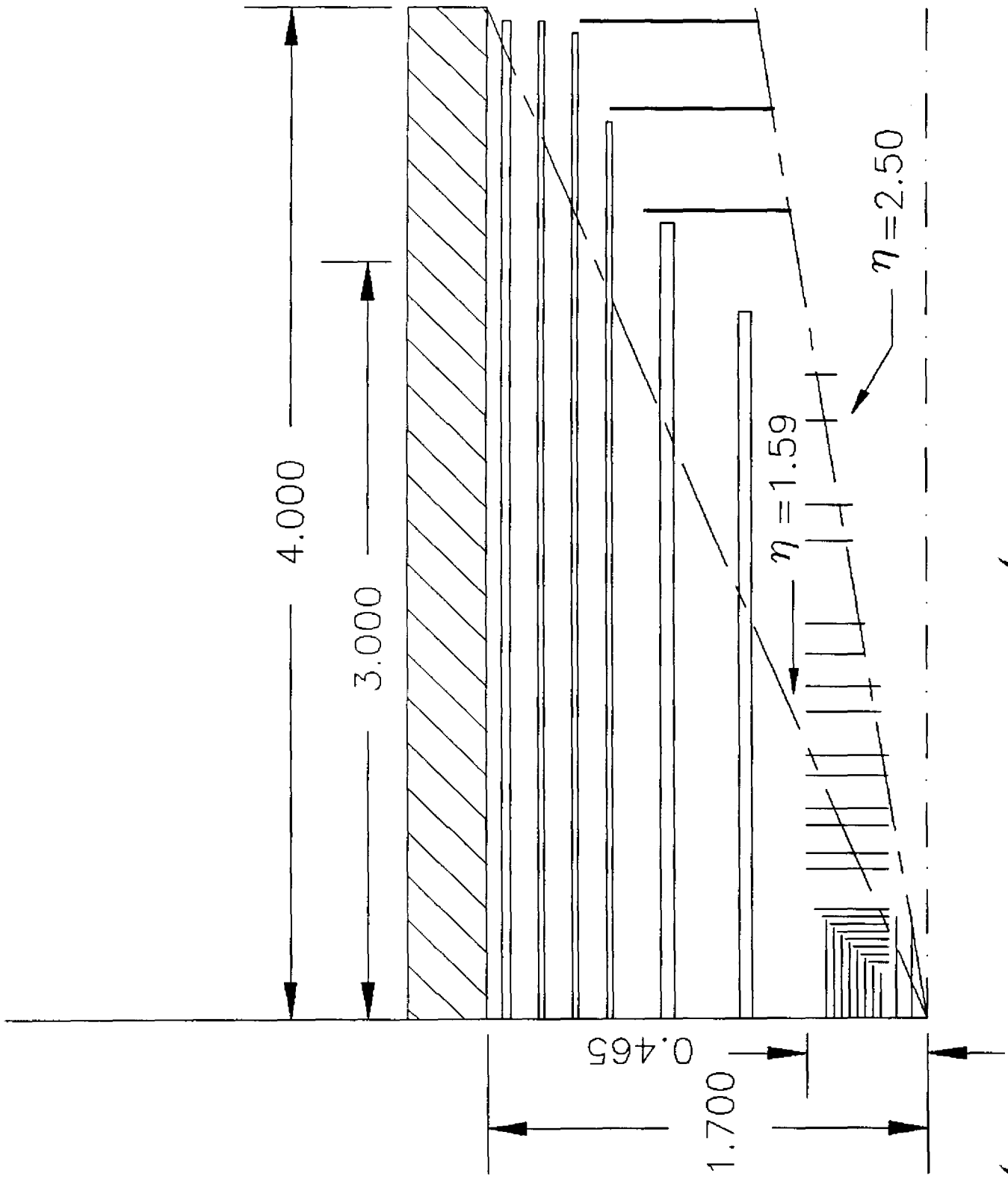

Fig. 1

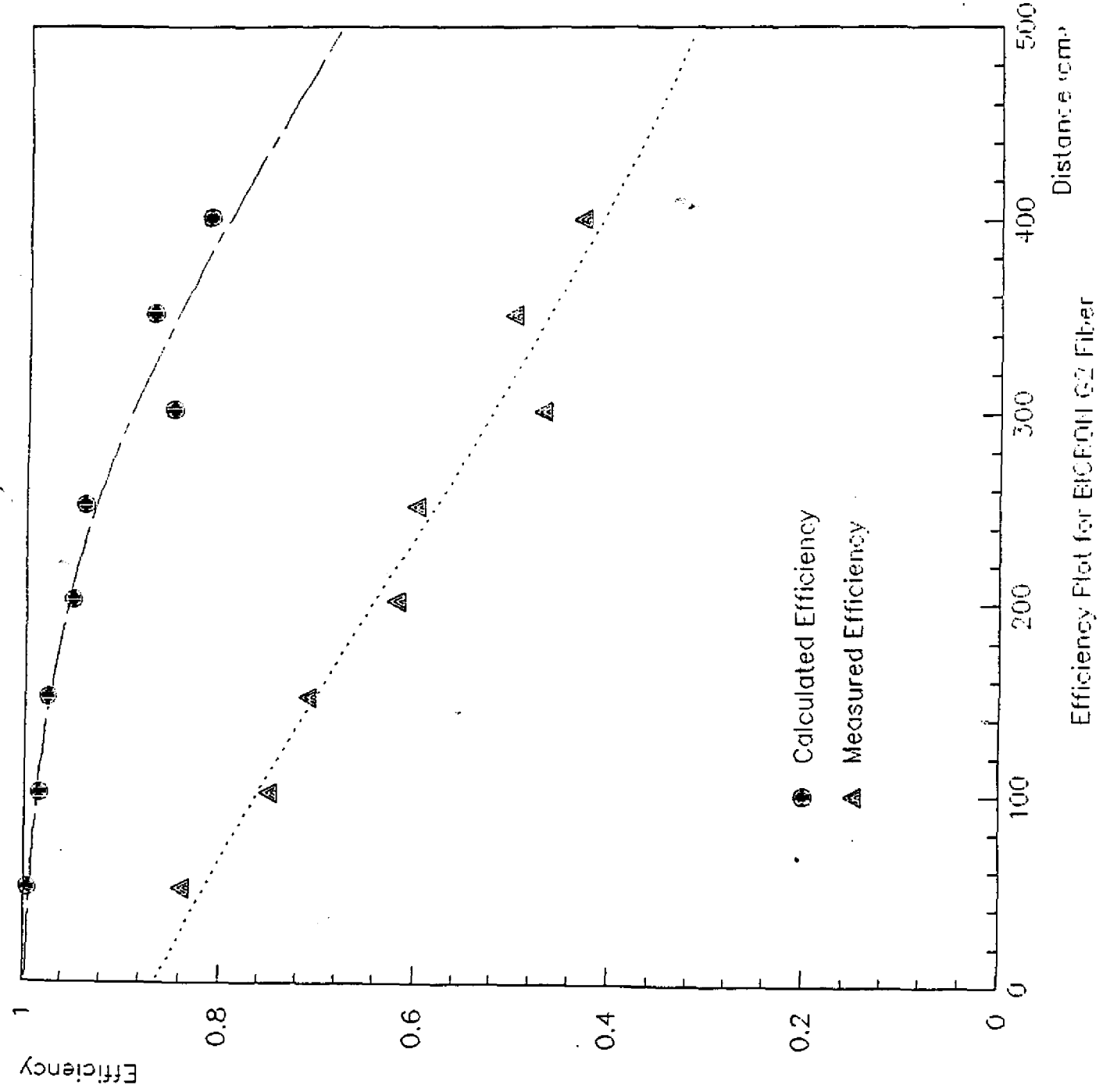
Efficiency
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
Distance (cm)
Calculated Efficiency
Measured Efficiency
Efficiency Plot for BICFOH G2 Fiber

Fig. 2

TRANSMITTANCE OF POLYSTYRENE + pT + 3HF

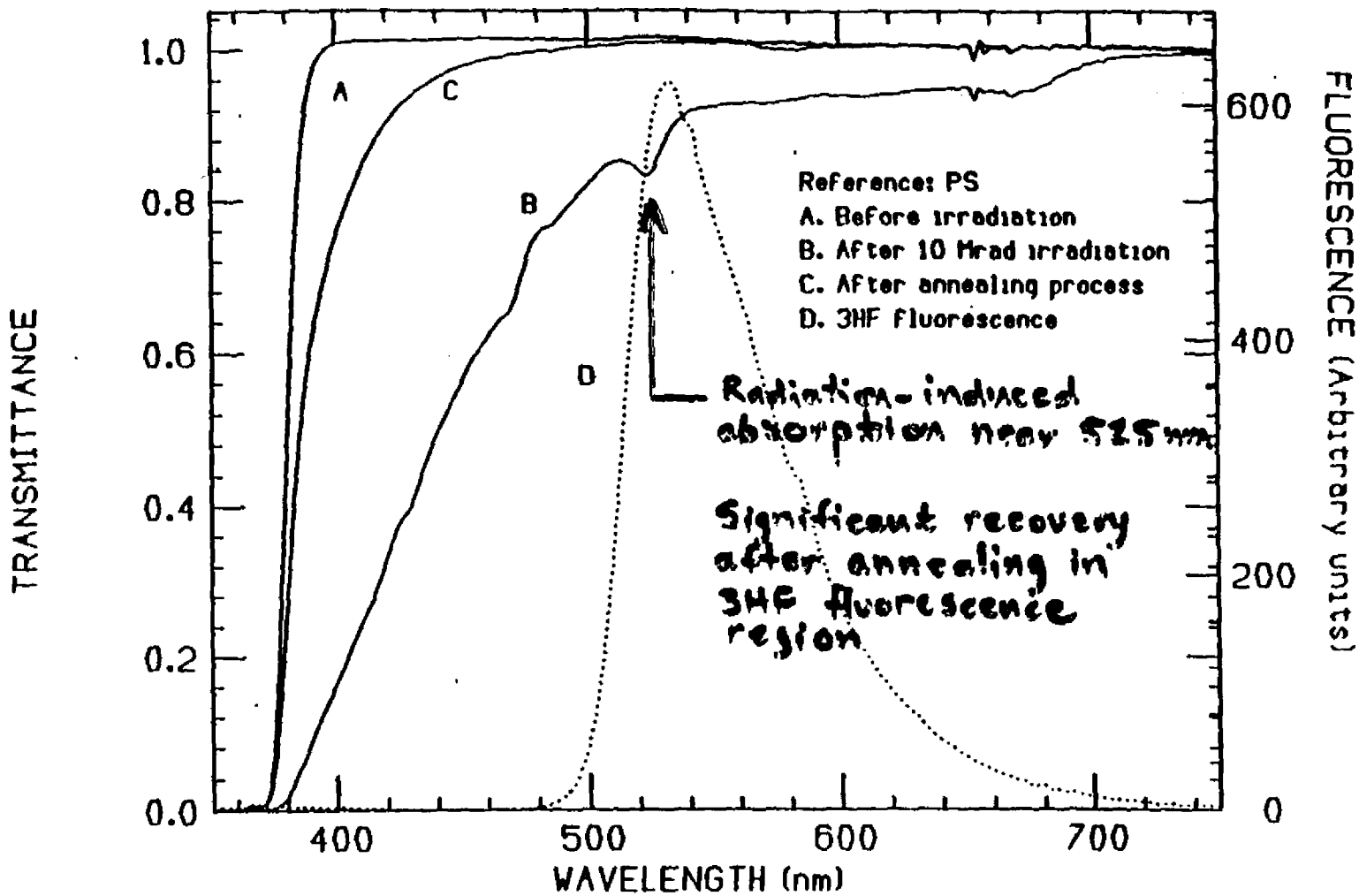

Fig. 3

SDC CTC Electronics Plan v1.3

WBS Code	Task Name	Durstn (Mths)
129/1	Front End Module	37
129/1.1	Input Connection	0
129/1.2	HV Distribution on Modules	8
129/1.2.1	HV Resistors - Init. spec.	8
129/1.2.2	HV Decoup Caps- Init. spec.	8
129/1.3	Preamp/Shaper/Discriminator	18
129/1.3.1	1 Chan AT&T	2
129/1.3.2	2/4 Chan Semi-Custom	6
129/1.3.3	4 Chan Full Custom	7
129/1.3.4	4-8 Chan. Improved	8
129/1.4	TVCAMU	24
129/1.4.1	1 Chan KUL V2 (MOSIS)	3
129/1.4.2	1 Chan KUL+ V3 (MOSIS)	5
129/1.4.3	4 Chan MOSIS	6
129/1.4.4	4 Chan IBM	8
129/1.4.5	8 Chan IBM (partial 0.5u)	8
129/1.5	DCC	28
129/1.5.1	Specification	0
129/1.5.2	Functional Design	4
129/1.5.3	Detailed Design/Layout	3
129/1.5.4	Fabrication & Test	6
129/1.5.5	Revised Spec & Design	8
129/1.5.6	Fabrication & Test	6
129/1.6	L1,L2,Clock Rcvr/Fan Out	10
129/1.6.1	Design	4
129/1.6.2	Fabricate & Test	6
129/1.7	Segment Finder	20
129/1.7.1	Proof of Principle	12
129/1.7.2	Integration with TVC	8
129/1.7.3	Signal Drive/Transmit to L1	2

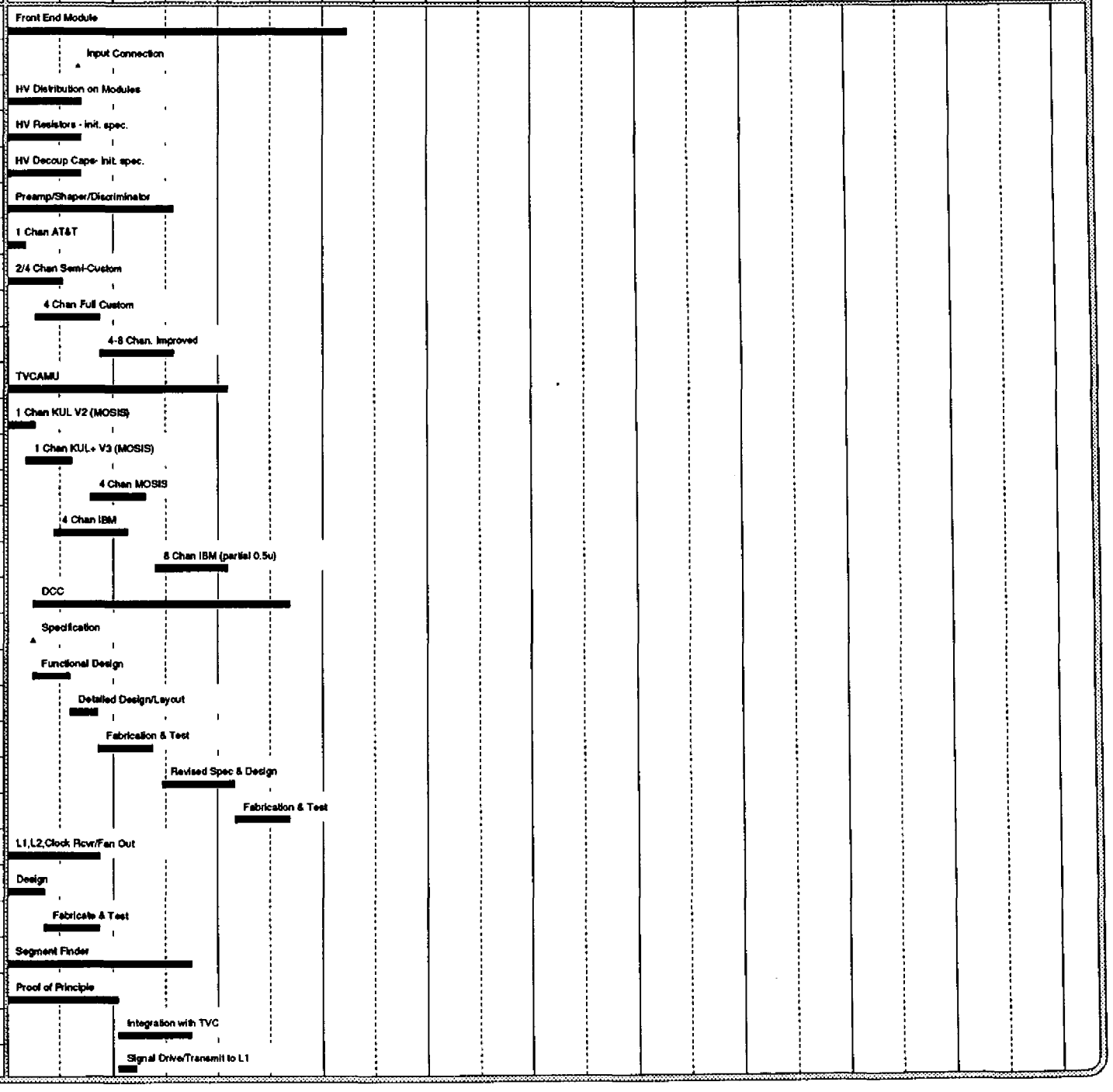

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Fig. 4

SDC CTC Draft Electronics Plan v1.3

WBS Code	Task Name	Durstn (Mths)
129/1.8	LV Caps/Filters (init. spec)	6
129/1.9	Substrate(s)	37
129/1.9.1	Test Version(s)	11
129/1.9.1.1	16 Channel "generic"	3
129/1.9.1.2	Multichannel w/TVC	4
129/1.9.2	"Final" Version(s)	30.2
129/1.9.2.1	HV Distribution (on Module)	8
129/1.9.2.2	Active Substrate	30.2
129/1.9.2.2.1	Test - wire bond	4
129/1.9.2.2.2	Test - flip chip	4
129/1.9.2.2.3	Test - tab	4
129/1.9.2.2.4	Second Generation	7
129/1.9.2.3	Cable to FIO Box	20
129/1.9.2.3.1	Conceptual Design	6
129/1.9.2.3.2	Test Version(s)	11
129/1.9.2.3.2.1	All Copper	11
129/1.9.2.3.2.2	Mixed Glass Copper	11
129/2	Fan In/Out Box	45.7
129/2.1	LV Supplies	34
129/2.1.1	Conceptual Design	11
129/2.1.2	Detailed Concept. Design	6
129/2.1.3	Final Design	4
129/2.2	HV Supplies	34
129/2.2.1	Conceptual Design	10
129/2.2.2	Detailed Concept. Design	6
129/2.2.3	Final Design	4
129/2.3	DAQ Interface	37
129/2.3.1	Receivers/Drivers	30
129/2.3.1.1	Conceptual Design	4
129/2.3.1.2	Initial Engineering	6

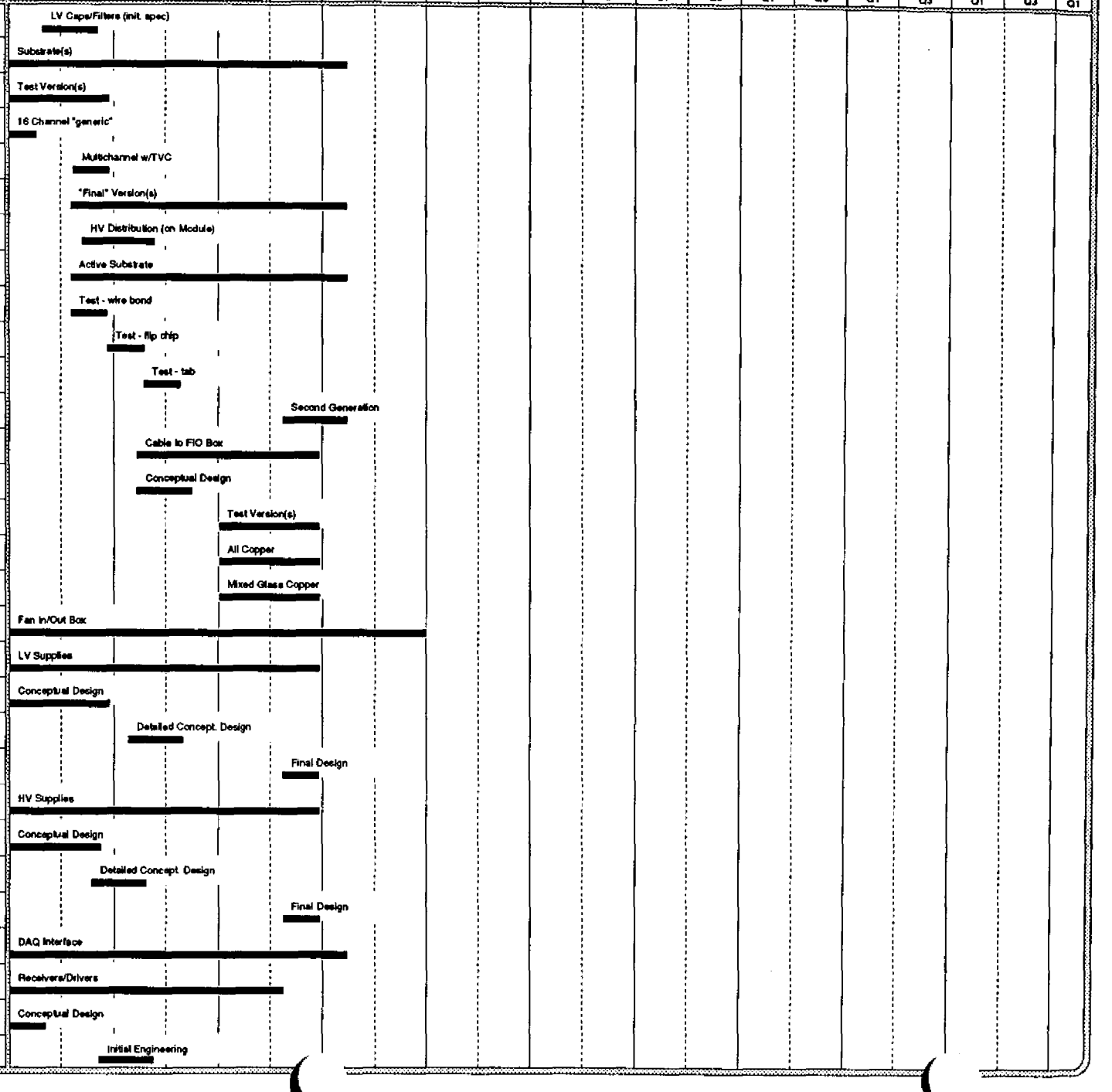

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Fig. 4 (out.)

SDC CTC D ctronics Plan v1.3

WBS Code	Task Name	Duratn (Mths)
129/2.3.1.3	Detailed Engineering	6
129/2.3.2	Upper Level DCC	17
129/2.3.2.1	Conceptual Design	4
129/2.3.2.2	Detailed Design	5
129/2.3.2.3	Fabricate & Test	8
129/2.3.3	Fiber (?) Interface	10
129/2.3.3.1	Conceptual Design	3
129/2.3.3.2	Detailed Design	4
129/2.3.3.3	Fabricate & Test	3
129/2.4	Trigger Interface	22
129/2.4.1	L1, L2 Fan Outs	6
129/2.4.2	Clock Fan Out	6
129/2.4.3	Segment Receivers	5
129/2.4.4	Segment Linker(s) (?)	12
129/2.4.5	Drive/Cable to L1 Trigger	3
129/2.5	Test/Calibration System	36
129/3	Proto System Test 500-1000 Ch.	0
129/4	Pre-Prod System Test 1-5000 Ch	11.4
129/5	Production Phase	38
129/5.1	Fab & Test 1/8 of Chips	8
129/5.2	Module Assembly	6
129/5.3	Module Test	3
129/5.4	FIO Box Fab & Test	9
129/5.5	1/8 System Test	4
129/5.6	7/8 Chip Production	9
129/5.7	Module Assembly	8
129/5.8	Module Test	3
129/6	Install & Test on Detector	6
129/7	Full Comissioning Tests	10

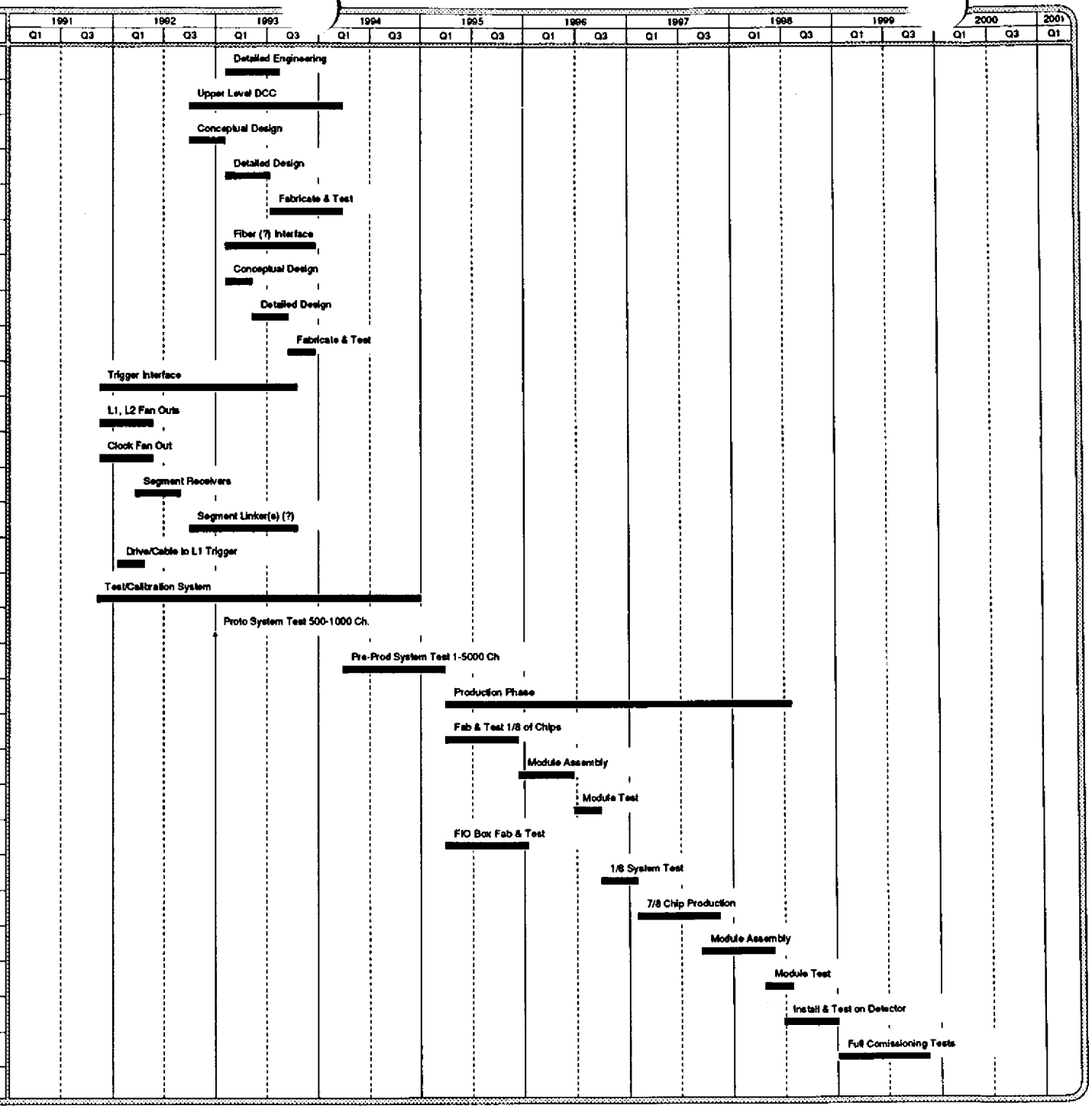

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Fig. 4 (cont.)

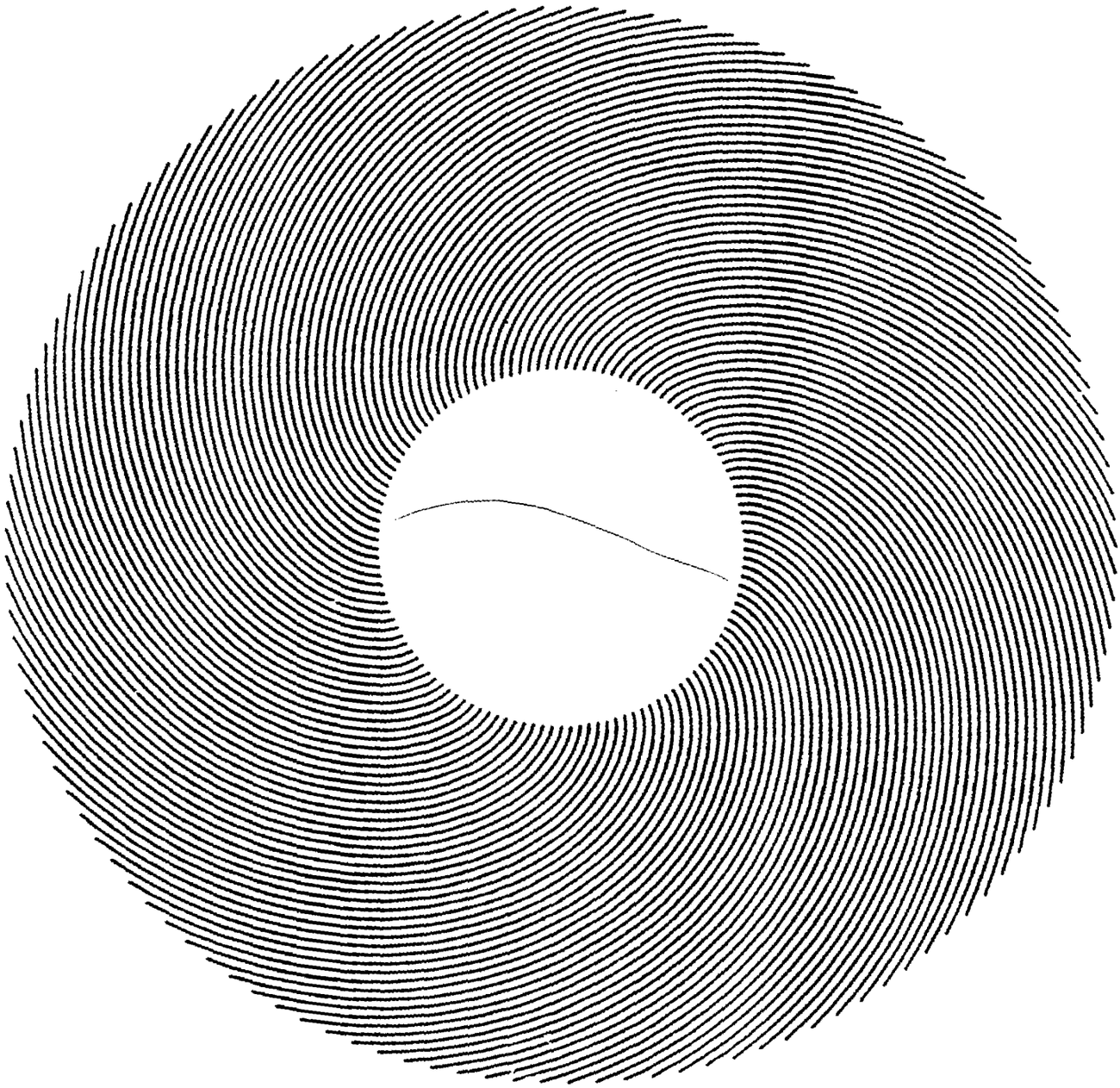


Fig. 5

Fig. 6

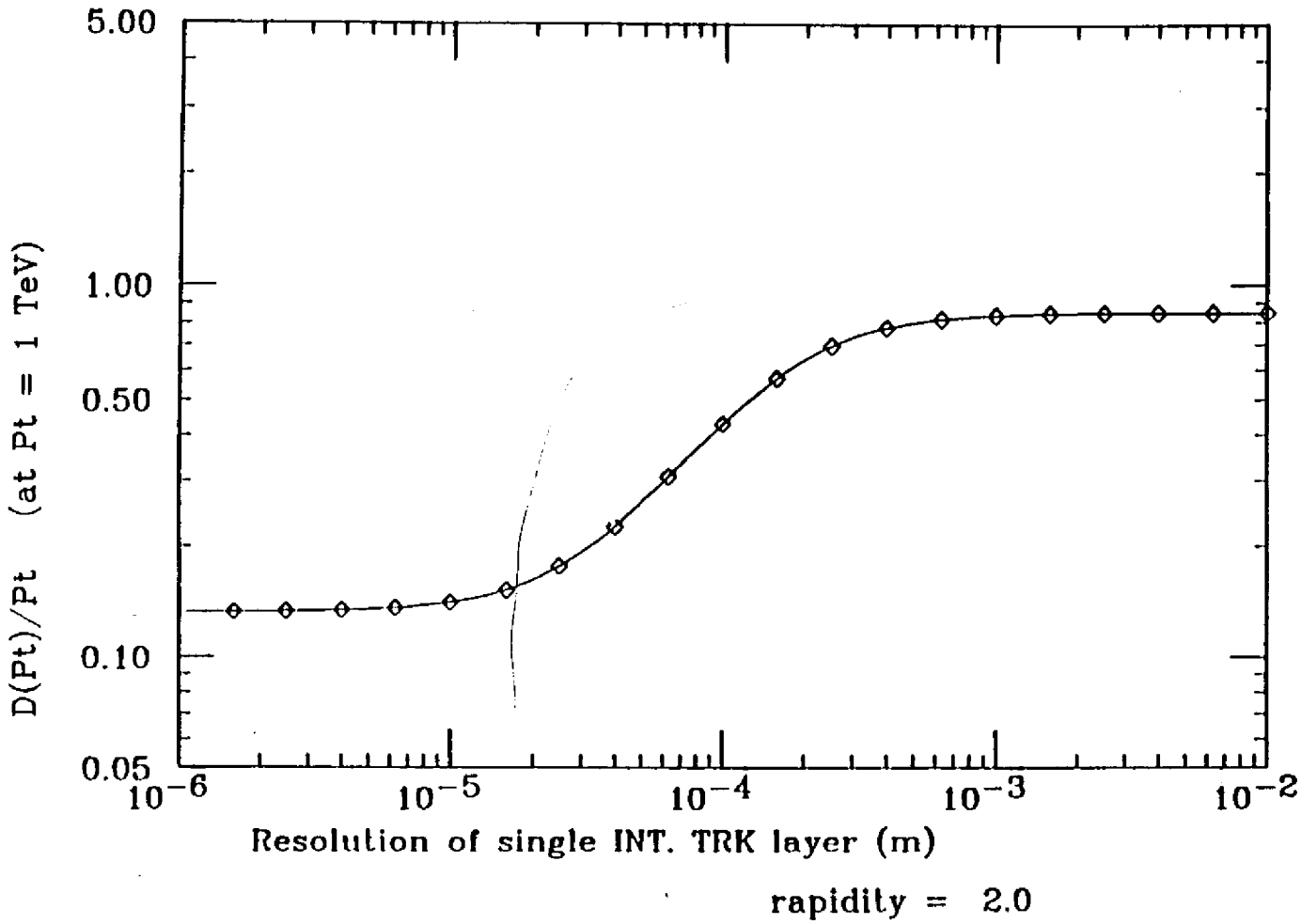
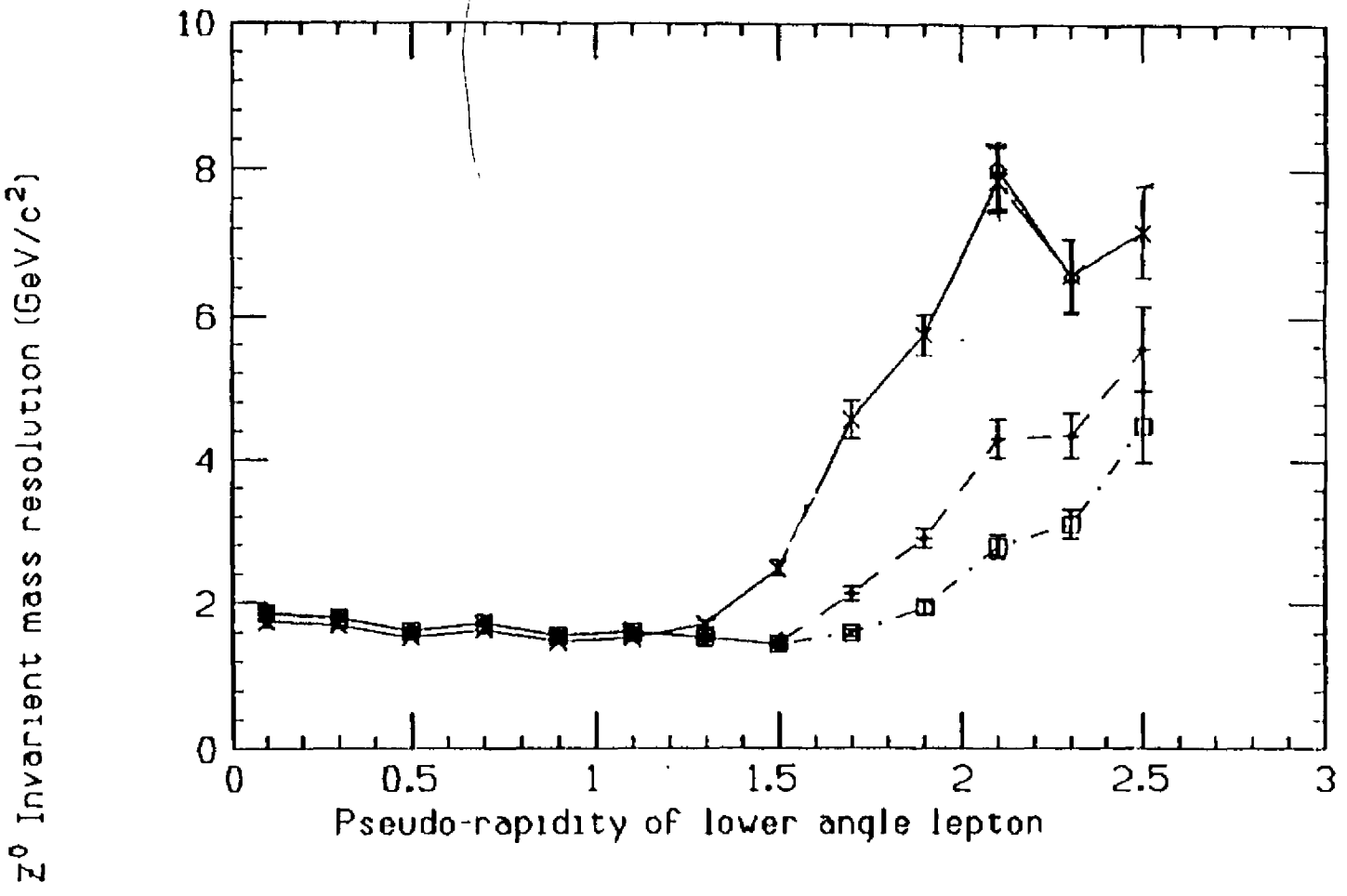

5.00
1.00
0.50
0.10
0.05
D(Pt)/Pt (at Pt = 1 TeV)
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
Resolution of single INT. TRK layer (m)
rapidity = 2.0

Fig. 7

Fig 4



——— no intermediate tracker

_ _ _ intermediate tracker position resolution = 100 microns

_._._ intermediate tracker position resolution = 50 microns

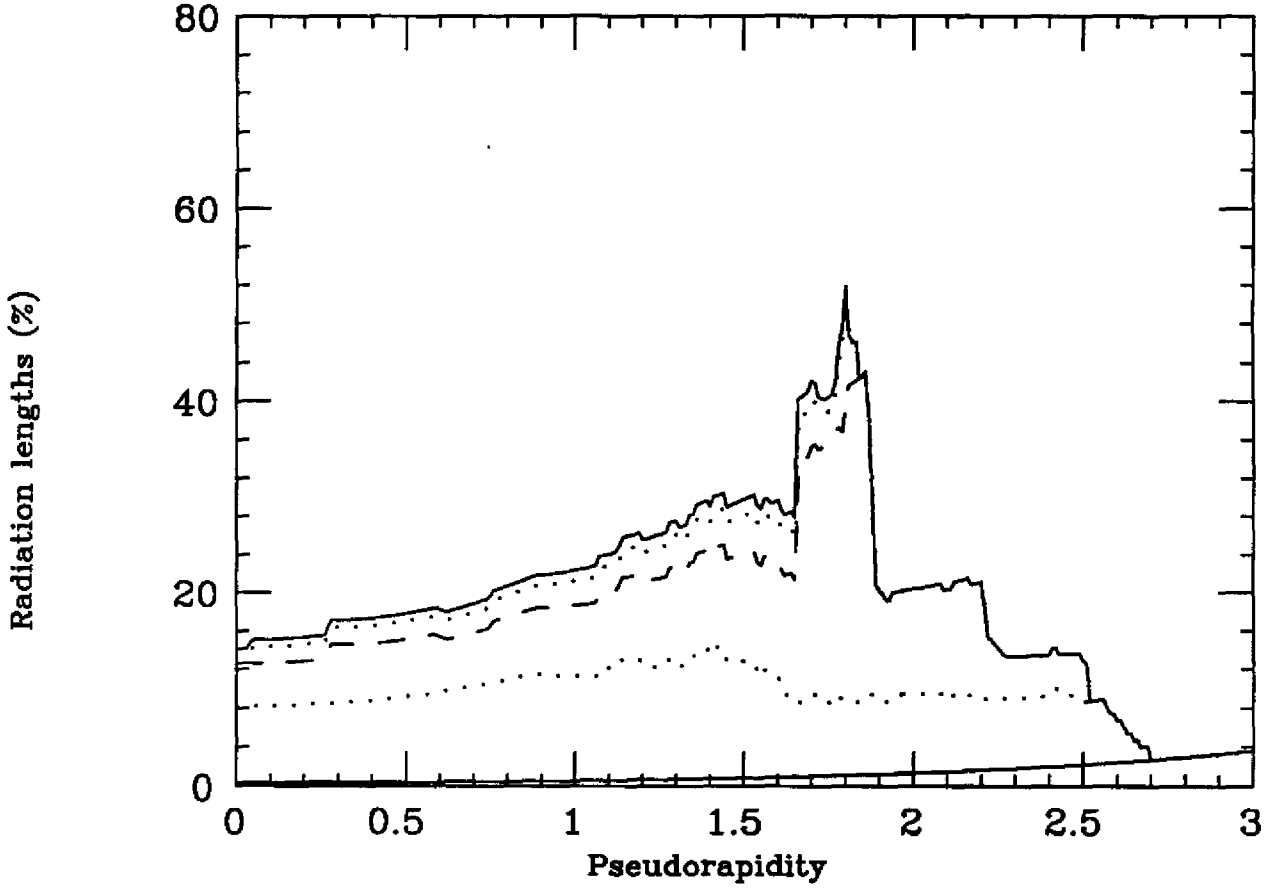


Fig. 8

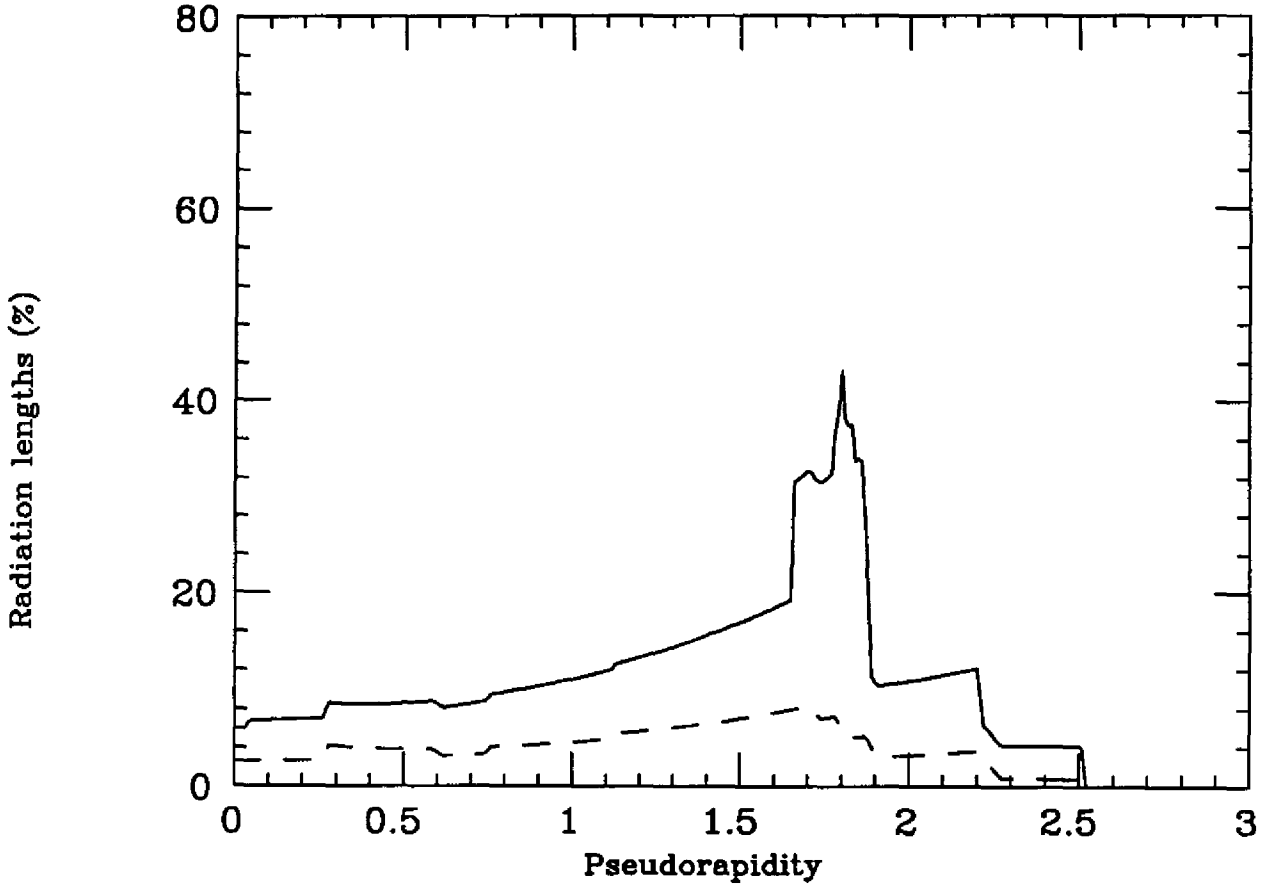


Fig. 9