

Report of the Tracking Subgroup

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The charged particle tracking system is a key element of the SDC configuration. This system is expected to provide pattern recognition, momentum resolution, vertex information, a charged-particle p_t trigger, and electron/hadron separation. It is expected to interact strongly with the other detection elements: it will be the device that provides the momentum resolution for muons, which are identified in the muon system, and comparisons of results from the charged-particle tracker with the calorimeter response will be essential for electron identification. Moreover, electrons and charged hadrons will be used to maintain the calibration of the EM and Hadron calorimeters.

The current “baseline” system consists of a rather elaborate silicon-strip tracker, extending to $r \simeq 40\text{cm}$ and covering the pseudorapidity range $|\eta| \leq 2.5$, in conjunction with an outer tracker consisting of straw tubes in the central region ($|\eta| \leq 1.8$) and gas micro-strip detectors in the forward region ($1.8 \leq |\eta| \leq 2.8$). The silicon system provides the pattern recognition and vertex determination. The outer system provides the level-1 charged-particle p_t trigger and provides significant improvements over the capabilities of the silicon system alone for momentum resolution and the extrapolation of tracks to outer detector elements. A scintillating fiber system covering $|\eta| \leq 2.3$ is under consideration as an option to the baseline outer tracker.

Physics requirements

The tracking system has been optimized for the study of the decay Higgs to 4 leptons and meets this goal admirably in the mass region $130 \text{ GeV} < M_H < 800 \text{ GeV}$. Over much of this region the signal is unmistakable. The restrictions on the momentum resolution and

the rapidity coverage imposed by the SCD collaboration on the tracking system are largely driven by the desire to observe the Higgs in this mode in the mass range between around 160 GeV and 180 GeV , where the rate is small. It is not clear, however, that a Higgs existing in this small mass region could not be observed with a somewhat more restricted rapidity range.

A strongly interacting electroweak symmetry breaking scenario may manifest itself in the $W^+W^+ \rightarrow W^+W^+$ channel. In order to observe this signal, it is necessary to determine the particle charges at 1 TeV to 1 part in 1000. Even this may not be sufficient to observe the signal. It would be nice to see the necessary simulations in order to justify the need for this capability.

Another physics possibility that challenges the tracking system is the measurement of forward-backward charge asymmetries for new heavy Z bosons, should they be discovered. Measurements of these asymmetries, which will be needed to determine the couplings of the new Z , place a premium on charged particle tracking in the high η region. However, the value of the inner tracker for such measurements is not demonstrated in the TDR. For these measurements the forward muon system may be more important.

The Silicon Tracking System

Reconstructing tracks close to a collision point of the SSC will be a formidable task for which the SDC group places a heavy reliance on a rather elaborate silicon tracking system. A considerable amount of R&D has been carried out on double-sided silicon detectors, the associated front-end electronics and the mounting, alignment and heat removal schemes. The work in each of these areas is of extremely high quality and excellent progress has been made.

Double-sided Silicon Strip Detectors The prototype silicon microstrip detectors produced by Hamamatsu meet nearly all the specifications of the experimenters. The silicon detector structures seem optimized for performance and satisfy the radiation damage requirements. The break-down voltages should be increased to insure reliable operation; it was reported that this is being worked on by the manufacturer.

Front-end Electronics The overall systems concept for the Si-Tracker electronics is sound

and well documented. The signal from the silicon strips is conditioned by a analog bipolar amplifier/shaper/discriminator. The hit/no-hit information is then buffered and sparsified in a custom CMOS device. Signals are transmitted via low-mass Al/Kapton ribbon cables to fiber drivers located at the outer shell of the tracker.

Work on the preamplifier chip is very impressive and appears to be going very well. Key performance parameters as noise, time resolution and power dissipation meet or surpass the goals. Attention is given to improve the dead-time. Calibration circuitry still has to be incorporated. Radiation resistance is satisfactory through the choice of intrinsically hard bipolar processes. Several potential vendors with suitable processes were identified, so future production will not rely on a single source.

For the digital CMOS time-slice buffer, various schemes have been simulated and test circuits are in fabrication. A final complete circuit has still to be selected and needs to be prototyped by the end of this calendar year. The device has to be fabricated in special radiation hard technology.

The design of the module which combines detectors, electronics, and cabling looks promising and a lot of effort has gone into preventing digital crosstalk to the analog front-end. A critical test that remains to be done as soon as possible is the performance of an assembled module including cabling and cooling.

Technically the silicon tracker electronics seems well understood. The next crucial step is to use these detectors with prototype readout chips to test the operation of the proposed mounting scheme. A major concern is the schedule, which is very aggressive.

Mechanical structure, alignment, and heat removal The proposed silicon tracking system, which occupies a cylindrical volume that is approximately 80cm in diameter and 5m long, is nearly 10 times bigger than previous storage ring devices. A precise and stable mounting system that locates the detector elements with $25\mu\text{m}$ precision and maintains it at the $5\mu\text{m}$ level is proposed. The material in the tracking volume must be minimized; the proposed scheme corresponds to 3% of a radiation length. In addition, the detectors and front-end electronics, which dissipate about 6kW of power, are to be

maintained at a stable temperature of 0°C.

The proposed solution is to bond silicon wafers together into “ladders” and mounting the ladders on to a space frame made from a carbon fiber-metal matrix material. Cooling is provided by evaporating butane from styrene wicks in a channel mounted directly to the circuitry. A holographic alignment system is being developed. We think that the design is elegant and well conceived. However, the implementation will require considerable development. In light of this, we deem the schedule to be quite aggressive with little room for any set backs.

The Straw Tube Tracker

The straw-tube tracker covers the range $|\eta| \leq 1.8$, providing a level-1 charged-track p_t trigger and improvements in momentum and track extrapolation resolution. The proposed system is an extrapolation of previous detectors and we expect that the system would work approximately as planned and could be built within the costs and schedule presented.

A major concern for the straw tube system is the large occupancies, particularly for the inner layers. The calculated rates indicate that some layers may be marginal at the design luminosity and one can worry about the reliability of these calculations when the results are so close to the tolerance level. Another concern is the possibility of vendor-dependent aging characteristics of the straws.

The Intermediate Tracker

The Intermediate Tracking System (ITS) covers $1.8 \leq |\eta| \leq 2.8$; the $\eta = 2.8$ is chosen to cover the fiducial extent of the intermediate EM calorimeter. The ITS provides level-1 trigger with a sharp threshold turn-on at $p_t = 10\text{GeV}$. This increases the acceptance for $Higgs \rightarrow 4l$ by 15% for a single lepton trigger. It also improves the resolution for extrapolating tracks to the EM calorimeter from 4 mm (Silicon alone) to 0.4 mm, and improves the momentum resolution at 100GeV from 18% (Silicon alone) to 6%.

The proposed system, which is based on gas micro-strip detectors, meets the localization accuracy and rate capability requirements in the intermediate region: $100\mu\text{m}$ accuracy and rate capabilities in excess of $10^5/\text{mm}^2\text{s}$ (at 10 times the nominal SSC luminosity near the beam pipe). Lifetimes above 10 years at nominal Luminosity have been demonstrated, more

work is needed (and is in progress) to extend the limit. However, although several prototypes are under extensive testing in a dozen of laboratories, but only one medium-term (six months) operation in an experiment has been reported.

The electronics appears to be in hand, but is a critical path item. It depends largely on the development of amplifiers-discriminators for silicon or for the straw chambers, but may need some modifications to cope with the readout density, incorporation of spark protection and a Level 1 trigger structure.

There is a considerable amount of R&D effort still pending, particularly in the areas of long term stability and reliability tests, as well as for developing an optimized manufacturing technique. Several groups are working and cooperating on the effort, and the basic operating principles, which are very close to those for multiwire chambers, are well understood.

Other than silicon, gas multistrip chambers are the only type of detector that can satisfy the tracking requirements in the intermediate region, and the large area to be covered (close to 100 square meters) precludes the use of silicon. Since these devices are rather new developments and there is little solid operating experience with them, a large R&D effort is planned. The R&D program seems adequate and well organized. It should provide the necessary information within a year.

The Scintillating Fiber option

Scintillating fibers are being studied as an alternative to the baseline outer tracking system. In the system being studied, both the straw tube and gas micro-strip trackers are replaced by a single cylindrical scintillating fiber system covering the $|\eta| \leq 2.3$ region. The proposed system would provide all of the functions of the baseline system albeit over a somewhat more restricted η region. The fiber system are attractive because they have a major advantage over the straw tube system in terms of occupancy and speed.

The recent developments in infrared-blind Visible Light Photon Counters (VLPCs) have been very encouraging: it is reasonable to anticipate quantum efficiencies of 80% and a “reasonable” cost of \sim \$25/channel. However, these devices are rather new and there is limited experience with them; they have to run at cryogenic temperatures, which introduces operational complications; and there is only a potential vendor.

Although there is a considerable amount of R&D needed before the scintillating fiber option could be adopted by the group, the advantages are attractive and recent progress in the R&D program has been impressive. We support the continuation of this option for the outer tracking system.

Summary and Questions

1. The integration of the mechanical mounting systems for the various tracking subsystems (silicon, straws, and gas microstrips) is an important part of the tracking system design and as such may require an engineer-in-charge to coordinate this effort. Since the materials used for the mechanical structure of the various subsystems are similar, it is natural to have close communication between subgroups.
2. The designs of the intermediate tracker and the forward section of the silicon tracker do not appear to be integrated and optimized. We recommend further work in this area.
3. The adoption of the fiber option would eliminate outer tracker coverage of the $2.3 \leq |\eta| \leq 2.8$ region. The usefulness of this extra coverage should be studied and documented.
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