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Abstract

A simulation and analysis code for an SSC scintillating fiber tracking system is described. Initial results regarding occupancy, pattern recognition and momentum resolution are presented.

Introduction

The development of a tracking system is a difficult but essential task in the construction of a general purpose SSC detector. An ideal tracker provides imaging, measures global and jet multiplicities, flags charged tracks and associates each track with the correct primary or secondary vertex. The system becomes even more powerful with the addition of a solenoidal magnetic field providing measurement of the momentum and charge sign. All of the above are useful for both off-line analysis and on-line triggering.

Approaching this ideal is difficult because of the high multiplicities expected in the SSC environment. One expects hundreds of charged tracks in a single crossing at the design luminosity and would like the detector to continue to function as the luminosity is increased by a factor of ten or more. On the order of a million channels are required to sample in tens of layers and keep the occupancy around or below one percent. The tracking system must also have a very fast recovery time to minimize the pileup of events from other crossings.

We belive that a scintillating fiber tracking system is the best way to address these issues. With submillimeter fibers, one can obtain low occupancy and good precision (100 μm in a superlayer) along with time response and recovery within a single crossing period (16 ns). The important and difficult issues of readout and radiation damage are being actively studied and we are optimistic they can be resolved. Once these and other generic issues are settled, there are two major tasks required to confidently design a system. The first is the the construction of a series of increasingly complex prototypes to demonstrate feasibility and measure the efficiency, precision and other properties of single fibers, layers and superlayers. The second is the development of detailed simulation and analysis programs in which the design is varied to evaluate the capabilities of the system in the SSC environment.

SFTSIM is intended to address the latter. It provides a detailed description of the response of a scintillating fiber tracking system to events at the SSC. Routines for clustering hits, reconstructing tracks and simulating trigger response are also included. Here we describe the inner workings of the code and the user interface and give some initial results.

Inner Workings

After initialization, physics events are assumed to be provided by an external event generator and then tracked in the usual way by GEANT. An SFTSIM routine is called each time a track ends a step inside a tracking volume. The particle type, the position of the particle, its energy loss in the last step, and some GEANT flags are recorded in the GEANT hit bank. After the GEANT tracking is completed for all tracks, the hits are digitized and clustered. Next, tracks are reconstructed and trigger simulation is performed. Most of the features can be switched on or off at run time using an FFREAD control card. For instance, if the user is only interested in looking at cluster multiplicities, he can turn off the track reconstruction and triggering.

The bulk of the initialization involves determining the geometry of the detector which is defined at run time using an input file. The user defines volumes which GEANT assumes are filled with scintillator material (CH with density 1.0 g/cm^3). The user also defines the size, shape and positions of fibers within these volumes. Three types of volumes are available and all of them are described by the GEANT cylindrical shell shape TUBE. The difference lies in the arrangement of fibers. For the cylinder, the fibers are at constant radius and for the disk and spiral, the fibers are at constant z. In the disk, the fibers are straight and all run in the same direction (x, y, u, ...). In the spiral, the fibers run

*See paper by R. Lewis in these proceedings

from inner to outer radius with increasing curvature so that their spacing remains constant. Each volume may contain zero, one or more layers of fibers. The user can also define inactive silicon volumes to include material effects of an inner tracker.

The SFTSIM digitization routines extract adjacent pairs of hits from the GEANT hit bank and do a linear interpolation to calculate the path length overlap with individual fibers. This overlap is used to estimate the amount of energy deposited in the fiber which is used to calculate the number of photons produced. This number is then attenuated to account for the fiber acceptance, losses in the scintillating fiber, optical fiber and couplings and the quantum efficiency of the photodetector. The detected number of photons is then chosen from a Poisson distribution and if this number is greater than zero, a signal of fixed width is produced. The signal is sampled at specified intervals and if present, a bit is set. The parameters defining the fiber and readout characteristics can all be set in the geometry input file. In our present runs, we sample once and assign the signal a width of 16 ns.

Instructions for assigning layers to superlayers are contained in another file. This file also contains the map for combining the superclusters from each superlayer to reconstruct tracks.

The clustering algorithms are fairly simple. Adjacent hits in a layer are assigned to the same cluster and then overlapping clusters within a superlayer are grouped into a supercluster. The position, direction and corresponding uncertainties for each supercluster are calculated using a least squares fit treating each fiber as an independent measurement. Clearly this is not an ideal solution for large clusters or those coming from overlapping tracks and it is intended these algorithms will eventually be improved. One avenue is to develop a lookup table possibly using experimental data as input. The assignment of layers to superlayers is taken from another input file.

This input file also contains instructions for the track reconstruction. The reconstruction begins by starting tracks in a specified superlayer (one track/supercluster) and then extrapolating them to a second superlayer where an attempt is made to add each nearby supercluster to the track assuming it came from the origin. All tracks with reasonable fits are kept and the extrapolation is repeated for each of the superlayers listed in the map. To date, only the code for dealing with cylindrical fibers parallel to the axis has been developed. Stereo layers and disk and spiral volumes are important areas for future development. .

The code for the trigger simulation has not yet been completed although the framework has been defined and simple examples written. This is another high priority area for future work. We would like to implement trigger strategies like those under hardware development.

User Interface

SFTSIM is intended to be inserted in a GEANT-ba simulation program and is also available as a stand-alone code imbedded in a old version of the Argonne SSC simulation package ANLSIM. Here we describe the user interface to that version. It is currently running under VAX/VMS and on an IBM R6000. This version is a batch program in the sense that the input and output are all through files except for some messages that are repeated on the screen and the option of directing graphical output to the screen.

There are five input files. The first two are the geometry and track reconstruction files described above. Another contains instructions for graphics. Many different views can be defined and each can be directed to the screen, a metafile or to a ZEBRA bank for later plotting with PAW. Each view can contain different components including the detector, GEANT tracks, superclusters, reconstructed tracks or any combination of these. The fourth input file is read using FFREAD and contains cards used by GEANT and ANLSIM as well SFTSIM. The last contains the trigger map. The logical unit numbers and our local file names are:

```
81  sf.dat
82  trf.dat
83  drw.dat
84  anlsim.dat
85  trg.dat
```

There are 17 output files containing errors, output from the GEANT routines GPXXXX, histograms and lists of tracks, hits, digitizations, clusters, etc. The logical unit numbers and contents of each file are listed below:

```
61  SFTSIM error messages
62  GEANT geometry and other setup output
63  Pythia messages
64  SFTSIM listing of each GEANT track
65  GEANT hit listing
66  GEANT vertex listing
67  histograms filled each event (event.hst)
68  histograms filled each track (track.hst)
69  SFTSIM listing of the GEANT hits
70  GEANT digitization listing
71  SFTSIM listing of GEANT digitizations
72  SFTSIM list of clusters
73  SFTSIM list of superclusters
74  SFTSIM list of all reconstructed tracks
75  SFTSIM list of final reconstructed tracks
76  SFTSIM triggering output
77  not yet used
78  graphics ZEBRA file -- picture.dat
79  not used
80  not used (often the graphics metafile)
```

An FFREAD card can be used to limit the number of events for which most of these files are written. Typi-

superlayer numbers	radius (cm)	# fibers/ superlayer	mean # hit fibers 1 bg	int bg	$H \to ZZ$	total occupancy 10^{33}	10^{34}
1 - 4	70	36k	125	400	240	1.8 %	12 %
5 - 8	100	51k	80	260	180	0.9	5
9 - 12	130	66k	55	180	130	0.5	3
13 - 16	160	81k	32	80	100	0.22	1.4

Table 1. Radius, fiber count, number of hit fibers per superlayer and total occupancy for each superlayer. The number of hit fibers includes columns for a single minimum bias event, 1.6 minimum bias events/crossing integrated over all crossings and one $H \to ZZ \to 4\mu$ event. The total occupancy is given for luminosities of 10^{33} and $10^{34}/cm^2/sec$.

cally only the first one or few events are written to most of the files.

For our current production runs, the most interesting information is in four n-tuples. The first (501) is intended for studying our track reconstruction capability. It is filled for the subset of tracks that reach the outer layer of the tracker and contains the initial kinematics and the reconstructed track parameters. The second (502) contains the kinematics for each event generated by Pythia. The third n-tuple (503) is filled as often as every step and is intended for looking at track multiplicities. The last (504) is intended for studying occupancy and is filled each event for each superlayer. The number of superclusters, hit fibers, and entering tracks are recorded. Each of the n-tuples may be independently activated or deactivated with an FFREAD card.

Results

In parallel with the development of SFTSIM, we have used the program to study some of the issues relevant to a scintillating fiber tracking system. Here we present results in the areas of occupancy, pattern recognition and momentum and vertex resolution.

Occupancy was studied by generating mininum bias (low p_T) events with Pythia. Figure 1 shows the pseudorapidity and transverse momentum (p_T) distributions calculated from 100 such events. There were an average of 150 particles per event most of which were pions distributed evenly between the three charge states. The detector used for these studies is split along a plane perpendicular to the beam axis at the intersection point and contains eight superlayers in each half. Each superlayer contains four layers of fibers all parallel to the beam axis. The superlayers are in pairs separated by 2 cm at inner radii of 70, 100, 130 and 160 cm. The fibers are 0.5 mm wide and 4 m long. The total fiber count is 930,000. The detector is shown in figure 2.

To look a the contributions of out-of-time crossings we moved our digitization interval in 16 ns increments. We found that the out-of-time crossings increase the multiplicity by a factor of 2.0 at 70, 100 and 130 cm and by 1.5 at 160 cm.

The total occupancy at design luminosity is calculated by assuming 1.6 minimum bias interac-

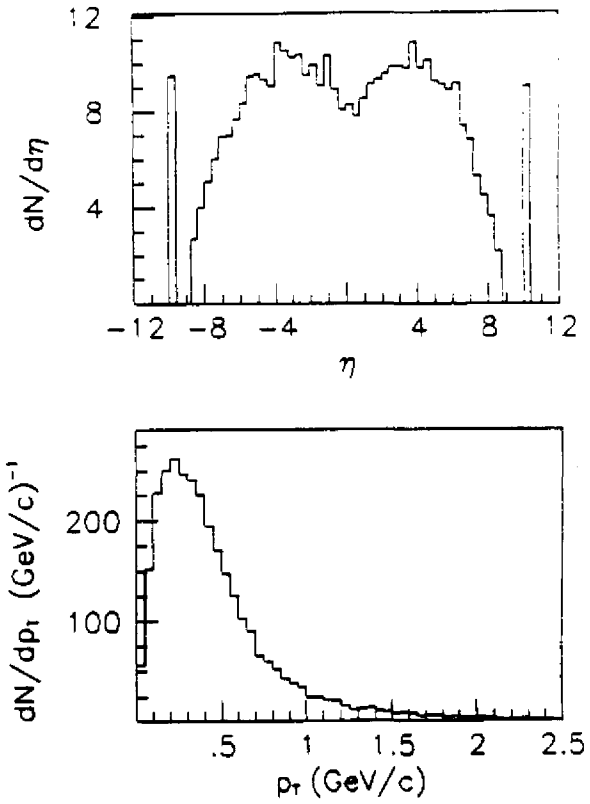

Figure 1: Pseudorapidity and transverse momentum distributions for Pythia mininum bias events normalized to one event.

tions/crossing and tossing in one "interesting" event. The latter is a 500 GeV $H \to ZZ \to 4\mu$ with Q_{Tmin} set to 200 GeV in Pythia. Occupancy at ten times design luminosity is calculated by including 16 minimum bias events/crossing. The results are shown in table 1. The design is not intended to be a final one but the results are quite encouraging. One would probably like to break up (or give up) the inner layer at least to run at the higher luminosities.

We have just begun to assess our pattern recognition capabilities. Using single mininum bias events and the tracker described above, we attempted to reconstruct all the tracks which reached the outer layer of the detector. This corresponds to a p_T threshold of

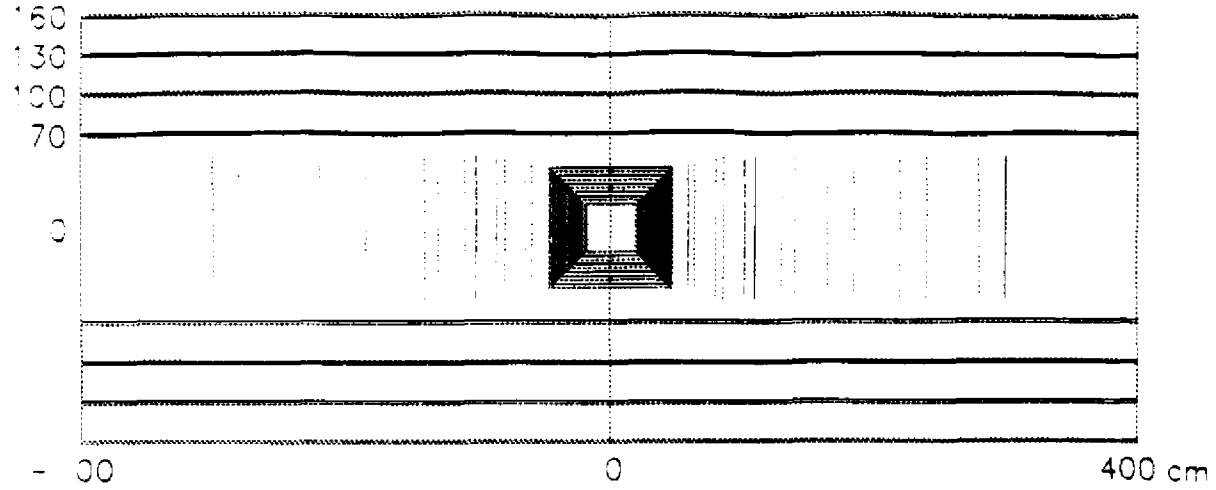

Figure 2: Side view of the detector used in the occupancy and pattern recognition studies. The outer four double superlayers are scintillating fibers. The inner cylinders and disks are silicon.

true	type I			type II		
p_T	p_T	σ	σ/p_T^2	p_T	σ	σ/p_T^2
20	20.0	0.31	0.78	20.0	0.16	0.41
50	50.1	1.81	0.72	50.1	0.81	0.32
100	100.	7.8	0.78	100.	3.5	0.35
200	204.	34.	0.83	201.	14.6	0.37
500				520.	131.	0.53

Table 2. Mean reconstructed momenta and root-mean-square deviations for type I and type II trackers for a variety of momenta.

0.5 GeV/c. We compared the reconstructed and initial transverse momenta and found that 98% of the tracks were within 0.1 GeV/c and 95% within 0.03 GeV/c.

Finally we present some early results in the areas of momentum and vertex resolution. These studies were done using a different tracker with double layers at 50, 100 and 150 cm. In the standard configuration, two of the four layers in a superlayer are offset by 0.5 fiber spacings to improve efficiency and spatial resolution. We refer to this as the type I arrangement. In the type II configuration, the fibers have quarter spacing offsets in the following sequence: 0.0, 0.5, 0.25, 0.75. Results obtained with single muon tracks at zero rapidity and a variety of momenta are presented in table 2. We find that the resolution is a factor of two better for the type II tracker. We also found that the type I tracker gave the wrong charge sign for 0.4% of the 500 GeV/c events while type II was always correct. The radial vertex reconstruction showed similar behavior and had a root-mean-square deviation of 0.02 cm for the type I tracker.

Future

It is clear that we have just begun to address the simulation issues facing a scintillating fiber tracking system. These occupancy results are encouraging but we need to demonstrate the pattern recognition and momentum resolution capabilities in an environment including both interesting and background events. The geometry of the detector needs to be considered very seriously to minimize the channel count (proportional to cost) without seriously compromising the physics capabilities.

The problem of forward tracking, i.e., for rapidities above 1.6 needs serious attention. It is not clear whether this can be carried out with barrel detectors of the type described here or if one must orient the fibers perpendicular to the beam. If so, one is probably forced to put in full stereo as part of the pattern recognition increasing the channel count and the complexity of the algorithms. In the simple trackers described above we did not include any stereo in our barrel detectors. We need to evaluate the physics gain as a function of channel count increase in both cases.

Another important issue is the integration of this simulation into a full detector package. Perhaps most important is the addition of active inner silicon layers so that the problems of pattern recognition, momentum resolution, etc. can be addressed from an integrated point of view. To do full physics capability simulations one will also have to include descriptions of the calorimeter and muon detector.

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