GEM TN-93-467

Simulation of the GEM Silicon Central Tracker Using GEANT

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The GEANT Code The GEANT code that we have used to do simulations will generate an event using either PYTHIA, ISAJET, or single particle generation. The particles are tracked through the detector and whenever a detector volume is entered the "HIT" is stored in a bank. Following the tracking of an event through the volume, digitizations (detector responses determined by user code) are calculated and stored along with the corresponding coordinates. After calculation of the coordinates is completed, the set of all coordinates is available for pattern recognition, physics analysis code, etc.

Since the design of the silicon portion of the detector is evolving, care has been taken to allow expected geometric and digitization changes to be made easily, by changing appropriate data cards and then rerunning the code. A list of most of the data cards that are available is given in Appendix I. The data cards are used to select event type, geometry variables (e.g. the number of layers in each detector section, the radii at which they are located, etc.), detector resolutions where applicable, various digitization parameters, interaction processes to be activated, magnetic field magnitude, vertex smearing, and what parts of the detector are to be included in geometry setup, digitization, and pattern recognition. Appendix II shows an example of the data card values that were used for most of the work presented in this paper.

Detector Geometry The central tracker of the GEM detector is made of silicon strip wafers in the inner part with interpolating pad chambers (IPC's) surrounding the silicon. This paper will describe the geometry of the silicon portion of the tracker. There are two regions of silicon: a central region where the wafers are arranged in cylinders that are concentric to the beam axis, and forward regions where the wafers are arranged in discs that are perpendicular to the beam axis.

In the central (barrel) region there are six silicon layers (three superlayers, each having two closely spaced silicon layers) between 10 cm and 22 cm in radius and 36 cm long in z. Each silicon layer is made up of stereo pairs of silicon wafers that are bonded together, with strip angles of +/- 5 mrad. The barrel silicon ladder length is 18 cm, bonded together to form the 36 cm barrel. The silicon ladders in the barrel region currently are placed at 5 degrees, but will be changed to 0 degrees in the interest of having a simpler mechanical design. A study has been done to show that the charge distribution over the strips will still result in good position resolution even though the tilt is not quite equal to the Lorentz angle.

The forward regions are made up of fourteen silicon layers (also stereo pairs) extending from 20 cm to 87 cm The first ten forward silicon layers are 16 cm long radially, while the last four ladders are 14 cm. Fourteen layers were chosen so that the we could achieve our goal of having six or more silicon detector layers hit by straight tracks over the entire eta region of the detector.

The geometry of the silicon portion of the tracker is very detailed in the GEANT code. Each individual silicon ladder is represented, with the strip pitch, dead regions on the wafer edges, thickness of the wafer, strip angle for "stereo" and "non-stereo" wafers, the alignment resolution of the silicon tracker in r, phi and z, the percentage of strips that are dead due to manufacturing problems, and the threshold energy cut for the silicon strips all input via data cards. The variable values that we have used for the current studies are shown in Table I.

Region	Variable	Value used
Barrel:	Ladder dimensions (includes both stereo wafers)	600μm x 3.3cm x 18cm
	Alignment in phi	10 μm
	Alignment in r	50 μm
	Alignment in z	100 μm
Forward:	Ladder dimensions	600μm x 3.3cm x 16cm and 600μm x 3.3cm x 14cm
	Alignment in phi	10 μm
	Alignment in r	100 μm
	Alignment in z	50 μm
Barrel and Forward:	Strip pitch	50 μm
	Stereo angles	±50 mrad
	Fraction of Dead Strips	1.0%
	Width of Dead Regions	0.5 mm
	Threshold cut	20 KeV

Table I. The variable values that were used for the silicon wafers for the current tracker studies.

We also have an option to put a random amount of noise on wafer strips for threshold studies, as well as an option to record all hits from N events previous to the event of interest so that the dead time of the detectors can be included in studies.

Detailed geometry for the non-sensitive volumes in the silicon portion of the tracker has also been put in to try to understand the total amount of material that will be present in the silicon tracker. The non-sensitive volumes that have been included are: the silicon wafer electronics, the cabling for the full silicon tracker, the support structures, the beam pipe, and the silicon gas enclosure.

The silicon ladder electronics are represented by 400 μm thick silicon boxes (3.3 x 4.0 cm wide) that sit on each side of a given silicon ladder. Each superlayer has cooling rings which are positioned next to the ladder electronics.

An estimate of the cabling in the silicon portion of the tracker has also been included. It is represented by 1) aluminum disks in between the barrel and forward regions which represents cabling needed to transport signals from the barrel silicon to the outside of the tracker, 2) aluminum disks at the outer edges of each forward silicon disk that represent the cabling needed to transport the signals from the forward disks to the signal bus, and 3) aluminum tubes which surround the forward regions which are the signal buses.

The current support structure for the silicon as determined by the engineering has also been put into the GEANT code. The space frame that provides the support for all of the silicon wafers is made of aluminum metal matrix which is represented by a low density, high radiation length aluminum.

The other materials that are included in the tracker are a beryllium beam pipe and a butane enclosure which surrounds the entire silicon tracker and is comprised of an inner tube of beryllium and an outer tube and endcaps that are made of carbon composite. The carbon composite is represented by an equivalent radiation length thickness of pure carbon.

A quadrant of all of the material that is found in the silicon portion of the tracker is shown in Figure 1. In the barrel portion, the volumes shown (starting from the innermost radius and moving out radially) are: 1) the beam pipe, 2) the inner portion of the butane enclosure, 3) the first silicon layer with its electronics, 4) the cooling rings for the first superlayer, 5) the second silicon

layer with its electronics, and then the pattern repeats itself. Beyond the barrel portion of the silicon is shown the cabling disks, the support structure that goes between the barrel and forward regions, and then the forward silicon disks, with their cooling rings. Outside of the silicon is shown the rest of the support structure, the forward disk cabling, the cabling that goes from the forward region to the outside of the silicon, and the outer portion of the butane enclosure.

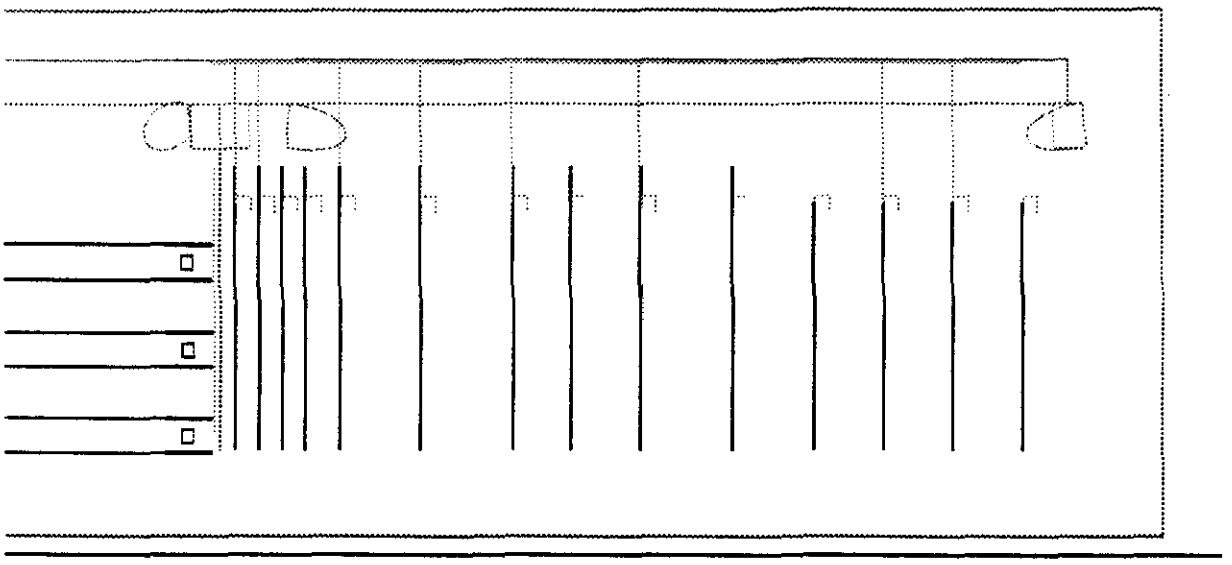


Figure 1. A quadrant of the full silicon tracker, showing the silicon detectors as well as the support structures, cabling, cooling rings and electronics, as represented in the GEANT code. Note that the r to z scaling in this picture is approximately 3:2 so that all of the tracker can be seen clearly.

The materials that were used for the silicon portion of the tracker, and the thicknesses used are shown in Table I.

Volume	Material Type	Density (g/cm^3)	Radiation Length (cm)	Thickness (cm)	Thickness (Rad. Lengths)
Si ladders	Si	2.33	14.0	.03	.0021
Si electronics	Si	2.33	14.0	.04	.0036
Butane Enclosure					
inner pipe	Be	1.848	35.3	.1	.0028
outer pipe, endcaps	C	2.265	18.8	.06	.0032
Space Frame:					
Al-MM tubes	Modified Al	.279	219.0	2.54	.01
Spoked disks	Modified Al	2.39	13.2	.17	.013
Cooling Ring Walls	C	2.265	18.8	.03	.0016
Cable disks between barrel and forward Si	Al	2.7	8.9	.018	.002
Forward cable disks	Al	2.7	8.9	.084	.0005
Forward cable tube	Al	2.7	8.9	.089	.01

Table II. The materials and thicknesses of materials that were used for the different parts of the silicon tracker in the GEANT code.

The radiation length contributions for the silicon tracker materials as produced by GEANT are shown in Figure 2.

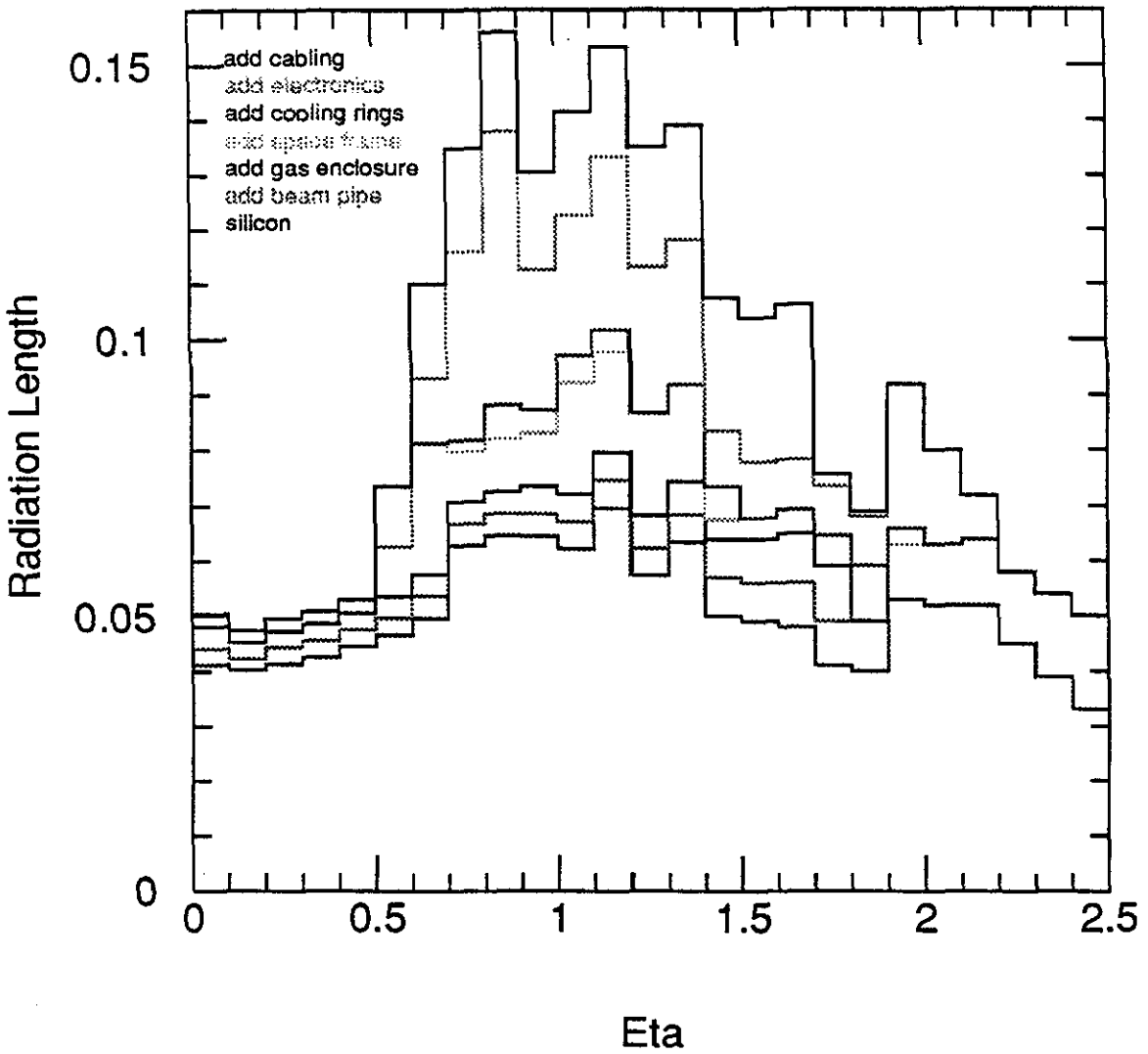


Figure 2. The radiation length contributions of the various materials in the central silicon tracker vs. eta produced by GEANT.

Detector Digitization In GEANT the detector response to a particle passing through it, which is called a digitization, is provided by the user. The response of the silicon strip detectors is simulated by first recording the position where a particle enters a wafer and where it exits the wafer, as well as the total energy deposited in the wafer and the time of flight from the interaction region to the wafer (these are the HITS).

The digitization is done separately for stereo and non-stereo wafers. The energy that was deposited in the wafer is distributed among the strips according to the path length that the particle traversed while in the vicinity of each strip. This is done for every "hit" on the wafer and the total energy deposited on each strip is accumulated in the case of overlapping hits. All strips that have energy deposited on them are then checked to see if they are a dead strip (with the fraction of strips that are dead set by a data card, and the actual strips that are considered dead are calculated at the

beginning of a run). If the strip is dead, the energy deposited is set to zero. The energy deposited on each strip is then compared to a threshold energy (currently 20 keV), and if the energy is greater than the cutoff energy, the strip is said to be on.

When the event type is a multiple crossing event (an event where hits in events previous to the crossing of interest are recorded so that the dead time of the detectors can be taken into account), all strips that are turned on are recorded along with the crossing time. Then, if a strip was turned on during a crossing that preceded the physics event, the strip is said to be dead during the physics event and the energy deposited on the strip is set to zero. If loopers from crossings prior to the physics event pass through a detector during the physics event time bucket, then they will be recorded in the physics event.

The typical number of strips turned on in a Higgs plus minimum bias background event in the barrel and forward regions is shown in Figure 3 along with the peak strip energy distribution and the cutoff energy. The average number of strips turned on in the barrel region is approximately 1.6 and the average energy of the peak strip is approximately 110 KeV. Note, that the average number of strips turned on by a high p_T track is less than the average for a full physics event because in a full physics event there are a large number of low energy tracks, some of which can become trapped in the silicon and turn on many strips, and also because of the secondary particles which pass through the silicon at large angles and traverse many strips.

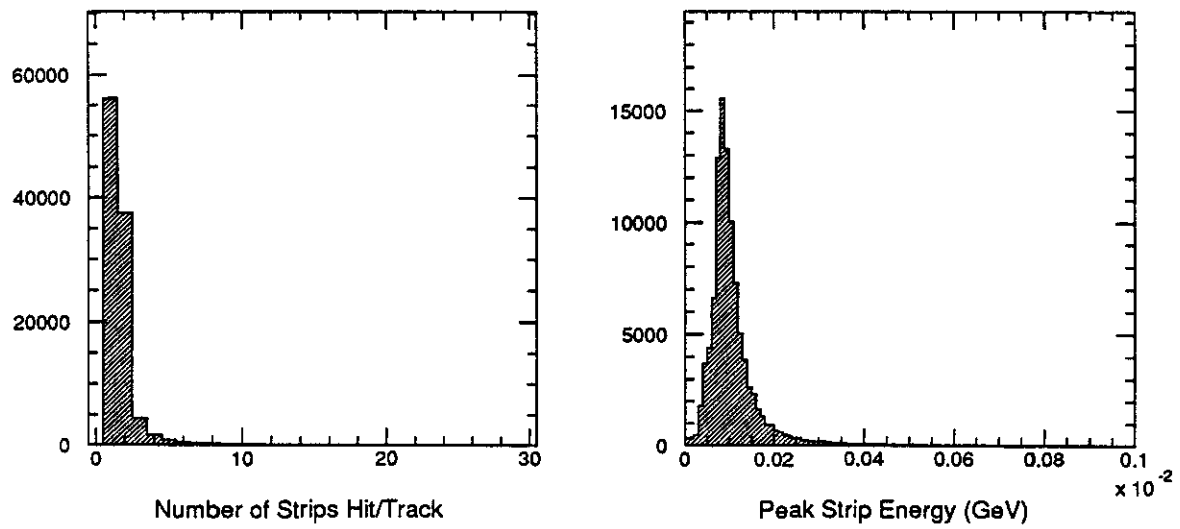


Figure 3. The distribution of the number of strips turned on per track and the distribution of the peak strip energy for tracks above 1 GeV/c in a full physics event with 10^{33} minimum bias background. The mean number of strips is 1.6 and the mean energy is 110 KeV

Coordinate Formation The digitizations are recorded as the number of strips in a row that are turned on (that pass the above cuts), the strip number of the first strip in the bunch and the time of flight from the interaction point. Space points are found by interpolating digitally between the bunches of hit strips and then finding all intersections of strip bunches that are turned on on the stereo side of the wafer with strip bunches on the non-stereo side of the wafer. Since all intersection points are calculated, "ghost" points (coordinates that are formed by a hit from one track on the "stereo" side of the wafer, and a hit from a different track on the "non-stereo" side of the wafer) as well as true points will form coordinates.

The space point resolutions that results from this digitization are shown in Figure 4 and are approximately 13 μm in the r/phi plane if the alignment resolution of the detector is set to 10 μm (in the barrel region) and 1.4 mm in the z coordinate (with +/- 5 mrad strip angles). The error in the

space point due to detector alignment capabilities is included by adding a gaussian error to each coordinate in r, phi and z that corresponds to the expected incorrectable misalignments of the detectors. The alignment resolutions used were the ones given in the geometry section. The forward silicon resolution is approximately the same as the barrel resolution if the strip pitch is set to 50 μm at the outer radial edge of the wafers. This pitch then decreases as you move inward radially.

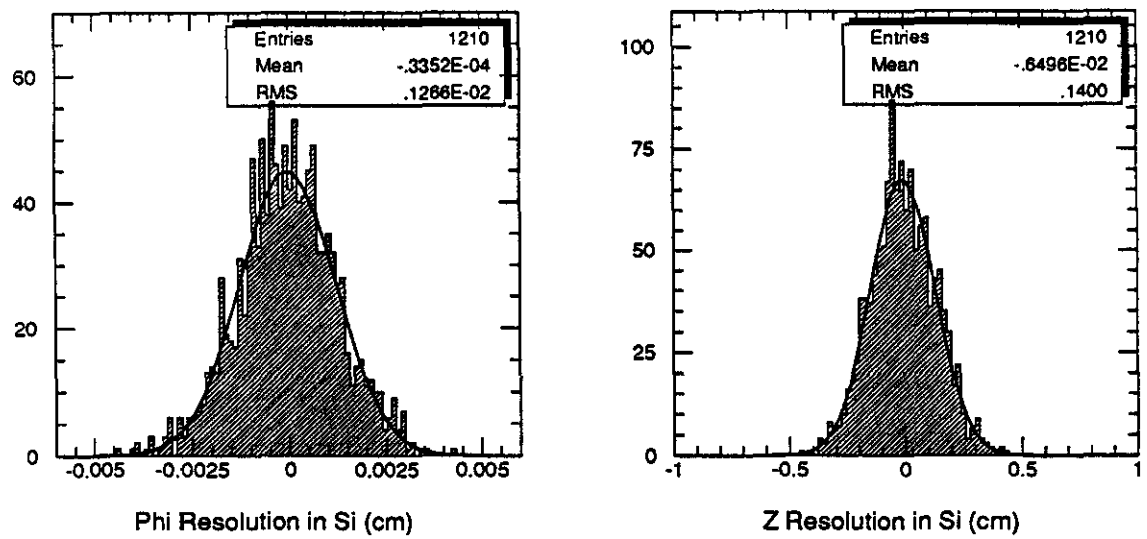


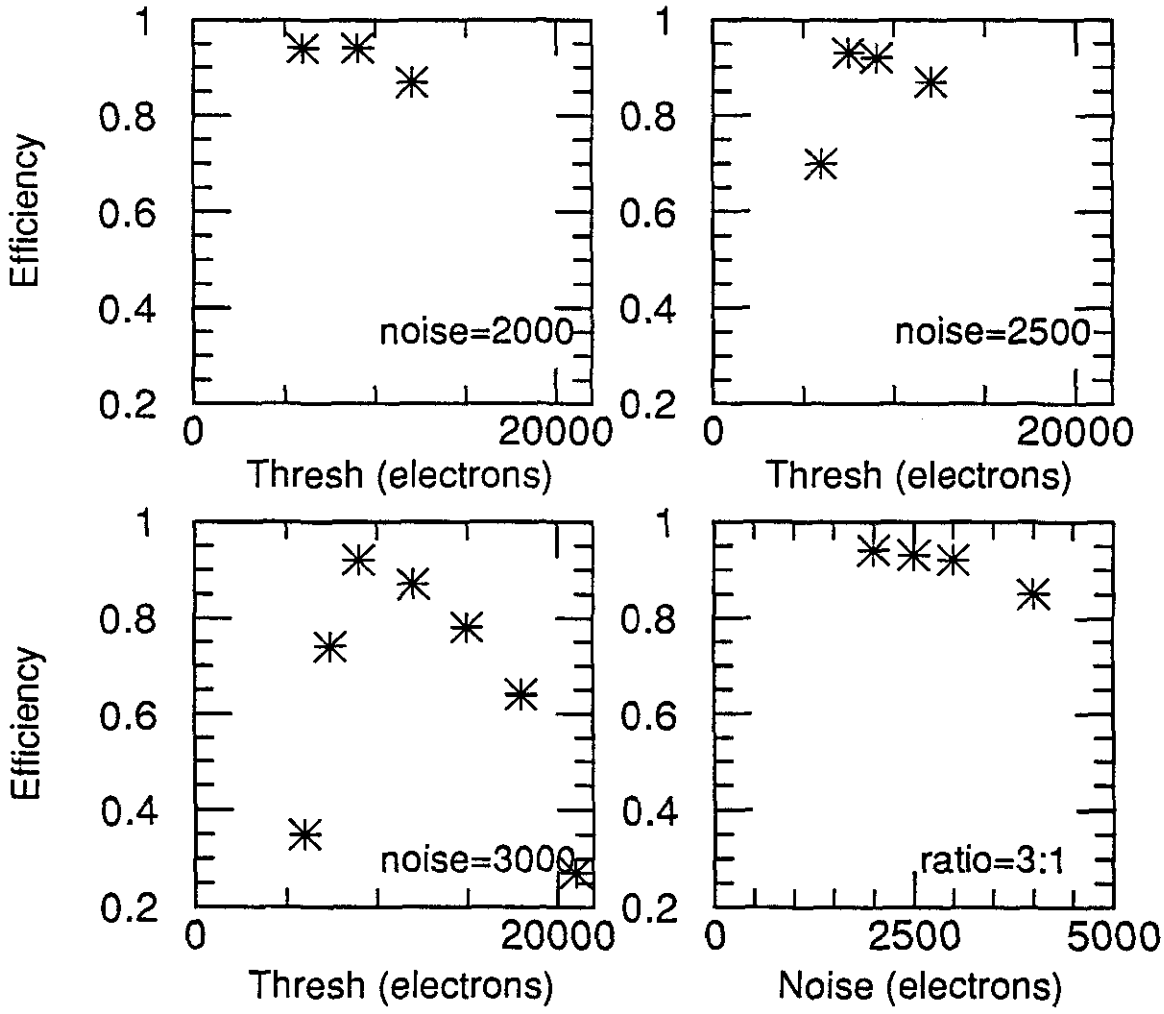
Figure 4. The phi and z resolutions in the barrel region as calculated by the GEANT code. The sigma of the phi resolution is approximately 13 μm when a 10 μm alignment resolution is included, and the sigma of the z resolution is approximately 1.4 mm when the stereo angles are ±5 mrad.

Pattern Recognition Study with Various Noise and Threshold Levels. The pattern recognition (described in GEM TN-93-468) capabilities of the silicon portion of the GEM tracker have been studied for Higgs events at 10^{33} $cm^{-2}s^{-2}$ luminosity with various levels of noise on the strips, various threshold cuts, and dead time from ten minimum bias crossings included in the digitizations. This has been done to try to determine what the maximum acceptable noise levels are for the silicon, and what the threshold to noise ratio should be.

For constant noise levels of 2000, 2500, and 3000 electrons, the threshold level of the strips was varied from 6000 electrons to 21000 electrons to see what threshold regions produce acceptable pattern recognition efficiencies. The results are shown in Figures 5, 6, and 7. As can be seen, when the threshold to noise ratio is below about three for each noise level, the pattern recognition efficiency drops because dead time from noise hits in previous crossings causes the number of coordinates formed in the crossing of interest to drop too low for the pattern recognition to be able to perform well. When the threshold level becomes too high (about 12000 electrons, regardless of noise level), the pattern recognition efficiency also drops because the threshold cut begins to cause a significant number of the hits in the event of interest to be thrown out. It can also be seen that the range of threshold levels which produce a high pattern recognition efficiency becomes smaller with increasing noise levels.

As can be seen in Figure 8, where the efficiency is plotted vs. noise level for a constant threshold to noise ratio of 3:1, the efficiency is constant up to about 3000 electrons, and above 3000 electrons the threshold level becomes too high for the pattern recognition. Therefore, the

pattern recognition can be expected to perform well as long as the threshold to noise level has a minimum ratio of 3:1 and the noise level does not exceed 3000 electrons.



Figures 5-8. The pattern recognition efficiency for constant noise levels of 2000, 2500, and 3000 electrons vs. threshold level, and the efficiency vs. noise level for a constant threshold to noise ratio of 3:1.

Conclusion: A simulation of the GEM silicon central tracker has been produced which accurately represents the expected material of the tracker as well as the geometric coverage of the detectors themselves, and the detector response to tracks passing through them. The digitization portion of the code produces a detector resolution of approximately 13 μm in the phi direction, per stereo pair layer, when a 10 μm alignment resolution is included. The z resolution is approximately 1.4 mm when the stereo angles are ± 5 mrad. The code has been set up to allow the geometry of the tracker to be somewhat flexible by having all of the geometric variables of the tracker input via

data cards. We have also included digitization options which allow the user to study the detector capabilities with various levels of dead strips, sizes of dead regions around the wafers, numbers of noisy strips, threshold cuts on the strips, and crossings that contribute to dead time in the detectors. The options to vary the noise levels on the wafers, the threshold cut on the strips, and to include the dead time in the detector digitizations has been used to determine what maximum noise levels and minimum threshold to noise ratios that can be tolerated while still maintaining an efficient tracker in terms of pattern recognition.

Appendix I

User Data Cards

CARD	N	T	Variable	Short Description
General Running Conditions:				
SWIT	2	I	ISWIT(1)	1. Store all products as new tracks. 2. Forget all secondaries. OTHERWISE - Store secondaries on the stack
			ISWIT(2)	1. Save track points for neutral particles
ETRC	1	R	ETRAT	Minimum total energy for tracking secondaries
EVNT	1	I	MULTCR	If=1, do multiple crossing event; If=0, normal event.
	1	I	PHYSEV	The physics event to be used in a multi-crossing event Currently, 1 = Higgs.
	1	I	BACKEV	The background event to be used in a multi-crossing event. Currently, 1 = minimum bias.
	1	I	NUMBEF	The number of background events before the physics event.
	1	I	NUMAFT	The number of background events after the physics event.
	1	I	NEWEVT	Set equal to 1, it initializes a new event.
VERT	3	R	GVERX	The x,y,z position of the interaction point
	3	R	SIGVTX	The sigma on the vertex position sx, sy, sz.
	1	R	SIGB	The error in the measured impact parameter/2, used to refit the track using a vertex point.
	1	R	SIGBZ	The z resolution that is used for vertex point.
KINE card, only relevant for PYTHIA compile option				
KINE	1	I	IKINE	1. generate only particles as defined by PKINE values 2. read event from ISAJET file, or generate with Pythia data cards. Selection between ISAJET and PYTHIA is done during compilation. 3. read previously generated Monte Carlo data. 4. generate the particles given in PKINE array and the data from the ISAJET file (or PYTHIA generation). 5. same as 1 only flat eta distribution rather than flat theta distribution. 6. same as 4 only eta dist'n rather than theta
	10	R	PKINE(1)	Minimum (or only) value of the momentum for particles whose ID in PKINE(5) - PKINE(10) is positive.
			PKINE(2)	If given and greater than PKINE(1), momenta are generated on a uniform distribution from PKINE(1) to PKINE(2) for all particles with ID greater than zero.
			PKINE(3)	Minimum theta angle of particles [only value of theta if PKINE(4) is not given or is less than PKINE(3)].

			PKINE(4)	If given and greater than PKINE(3), particles are generated with PKINE(3) <= Theta <= PKINE(4).
			PKINE(5)-PKINE(10)	If a value is given and the absolute value is greater than zero and less than 100, a particle with particle ID equal to the absolute value will be generated. If the number is positive, the particle will be generated with the kinematics given by PKINE(1) through PKINE(4). If the number PKINE(4+2) is less than zero, then PKINE(3) <= Theta <= PKINE(4) and the momenta come from histogram ID = i is the histogram 11PANC/PKINE for a particle ID = abs(PKINE(4+2)).
FIEL	1	R	FIELD	Set magnetic field
GET			'INIT'	Read geometry, etc.
			'CONT'	Same as 'INIT' plus skip previous events to continue generating data.
DIGI	20	I	LDIGI	The sets to digitize [implies both a GEOM and SETS for each SET given.]
TRIG	1	I	TRIG	The number of events to trigger
Selection of output to data file geant.out:				
DEBUG			DEBUG(1)	The first event to print information for
			DEBUG(2)	The last event to print information for
			DEBUG(3)	The step size between DEBUG(1) and DEBUG(2)
PRIN			'VERT'	If IDEBUG is on, print all vertices for the event.
			'KINE'	If IDEBUG is on, the track info for all tracks
			'HITS'	If IDEBUG is on, print all hits
			'DIGI'	If IDEBUG is on, print all digitizations
			'PSTP'	If IDEBUG is on, print individual steps on all tracks during the run.
			'MATE'	The materials as set up
			'TMED'	The tracking media as set up
			'PART'	Particle tables
			'VOLU'	The defined volumes
			'ROTM'	The rotation matrices
			'SETS'	All defined detector sets
SAVE			'TRIG'	Save data banks HEAD, KINE, JXYZ, HITS, and DIGI on each event
			other	Save the particular data bank
			'SXYZ'	Store data to JXYZ bank on the steps NOTE: Neutral particle track points are only saved if ISWIT(2) is equal to 1.
General Geometry Definitions				
AVOL	1	M	AVOLG	The type of volume used for the mother volume for the detector. NOTE: Only types 1 ('BOX') and 5 ('TUBE') are currently allowed.
	3	R	AVOLG	The three volume definition parameters
PIPE	1	R	RAPIPE	Radius of beryllium beam pipe
	1	R	PIPETH	Thickness of beam pipe
The Silicon Barrel Definitions:				
Card for electronics' dimensions				
ELN1	1	R	ELTHI	Thickness of each electronics card in cm
	1	R	ELWID	Width of electronics
	1	R	ELLEN	Z length of electronics
Card for cooling ring dimensions				
SCN1	1	R	CRNGHT	Radial height of cooling ring in silicon barrel

	1	R	CRNGWD	Z width of cooling ring
	2	R	CRNGZ	Z position of cooling rings in barrel
	1	R	CRRADL	Thickness of cooling ring walls in radiation lengths

Barrel silicon detector cards:

SDN1	1	I	LSUPSD	The number of superlayers
SDR1	1	R	ANGSD	The maximum angle covered by outermost layer of the superlayer
	1	R	STHKSD	Thickness of the detector wafer
	1	R	DEDZDS	Z extent of dead border region on each end of the detector wafer
	1	R	DEDWSD	Extent of dead border region on each side of the detector wafer
	1	R	SANGSD	Stereo angle (degrees)
	1	R	NSANSD	Strip angle of non-stereo wafer (degrees)
	1	R	DNSISD	Density factor for the silicon **(not used anymore)**
	1	R	NMATSD	Material number of the support material **(not used anymore)**
	1	R	DEADFR	The fraction of strips in the barrel silicon wafers that are dead because of manufacturing capabilities.
	1	R	SDNOIS	Sigma of noise on strips in GeV
	1	R	SSTEFF	Readout efficiency for silicon strips

nn for the following cards refer to the superlayer number.
Currently up to 10.

SDnn	1	R	RINSD	Inner radius of the superlayer
	1	R	TSUPSD	Thickness of the superlayer
	1	R	PHI0SD	Starting phi value of wafer 1 of the superlayer
	1	R	PTCHSD	Pitch of strips in the superlayer
	1	R	WZLNSD	Approximate Z length of the wafers in the superlayer
	1	R	WWWDSD	Approximate width of wafers in the superlayer
	1	R	RADLSD	Fraction of radiation length of support material used in the superlayer **(not used anymore)**
	1	R	ECUTSD	Energy threshold cutoff for silicon strip digitizations
	1	R	ZMAXSD	**(not used anymore)**
	1	R	ZLENSD	Half length in z of superlayer
	1	R	PHOVLP	Phi overlap of silicon wafers in barrel
SDRE	1	R	SIPRES	The alignment resolution of the silicon detector in phi (ds)
	1	R	SIRRES	The alignment resolution of the detector in r.
	1	R	SIZRES	The alignment resolution of the detector in z

(The following resolutions are used only for weighting of points in pattern recognition)

	1	R	SDPRES	Position resolution of silicon detector in phi (ds)
	1	R	SDRRES	Position resolution of silicon detector in r
	1	R	SDZRES	Position resolution of silicon detector in z
SCHI	1	R	WTPHI	phi weight in chi-square calculation in track fit **(not used anymore)**
	1	R	WTKAP	kappa weight in chi-square calculation in track fit **(not used anymore)**
	1	R	WTTHE	theta weight in chi-square calculation in track fit **(not used anymore)**
	1	R	CHICUT	cutoff for good chi-square in pattern recognition tree search
SDAN	20	I	LSDAN	List of analysis phases to process for the silicon barrel system to be performed for each event. [Currently, 'CORDS', 'PATR', and 'FIT ' are the only supported phases.]

The Forward Silicon Definitions:

Card for electronics' dimensions

SFEL	1	R	SFELTH	Thickness of forward silicon electronics (cm)
	1	R	SFELHT	Radial height of forward silicon electronics (cm)

Card for cooling ring dimensions

SFCR	1	R	SFCRHT	Radial height of forward cooling ring
	1	R	SFCRWD	Z width of forward cooling ring
	1	R	SFCRTH	Thickness of ring wall in rad. lengths
	1	R	SFRPOS	Distance from end of ladder to middle of cooling ring.

Forward silicon detector cards:

SFN1	1	I	LSUPSF	The number of superlayers
	1	I	LSUBSF	The number of layers/superlayer (**not used anymore**)
	1	I	NMATSF	Material number for the support structure (**not used anymore**)
SFR1	1	R	STHKSF	Thickness of single-sided detector wafer
	1	R	DEDRSF	Length of dead region at each radial end of wafer
	1	R	DEDWSF	Width of dead region at each phi boundary of wafer
	1	R	SANGSF	Stereo angle of the strips on the stereo wafer
	1	R	NSANSF	Stereo angle of the strips on the non-stereo wafer
	1	R	DNSISF	Density factor for forward silicon (**not used anymore**)
	1	R	DDFRSF	The fraction of silicon strips in the forward region that are dead because of manufacturing capabilities
	1	R	SFNOIS	Sigma of strip noise
SFRE	1	R	SFPRES	The alignment resolution of the silicon detector in phi (ds).
	1	R	SFRRES	The alignment resolution of the detector in r
	1	R	SFZRES	The alignment resolution of the detector in z

(The following resolutions are used only for weighting of points in pattern recognition)

	1	R	SFDPRE	Position resolution of silicon detector in phi (ds)
	1	R	SFDRRE	Position resolution of silicon detector in r
	1	R	SFDZRE	Position resolution of silicon detector in z
				nn for the following cards refers to the superlayer number.
SFnn	1	R	ZSTRSF	Starting z-position of the superlayer
	1	R	TSUPSF	Thickness of the superlayer
	1	R	PTCHSF	Pitch of strips on the superlayer
	1	R	WWWDSF	Approximate outer width of wafers in superlayer
	1	R	ECUTSF	Threshold energy cut for hit in superlayer
	1	R	RAD1SF	Inside radius of the superlayer
	1	R	RAD2SF	Outside radius of the superlayer
	1	R	NRNGSF	Number of rings in the superlayer
	1	R	RNGRSF	Inside radii of the rings of the superlayer
SFAN	20	I	LSFAN	List of analysis phases to process for the silicon barrel system to be performed for each event. [Currently, 'CORDS', 'PATR', and 'FIT ' are the only supported phases.]

General Silicon Structures:

Butane Enclosure:

SEN1	1	R	SERADI	Inner radius of butane enclosure
	1	R	SERADO	Outer radius of butane enclosure
	1	R	SEZLEN	Half length in z of enclosure
	1	R	SERADL	Thickness of enclosure in radiation lengths

Barrel silicon supports

SSN1	1	R	SSRADL	Thickness of cylinders in radiation lengths
SISP	1	R	SPROUT	Outer radius of space frame
	1	R	SPZLEN	Half length in z of space frame
	1	R	SPRIN	Inner radius of spoked disk in space frame

	1	R	SPTHI	Thickness of spoked disk
	1	R	SPKTHI	Thickness of spoke of disk
	1	R	SPDZ	Z position of forward support disk
	1	R	SPWHZ	Z positions of space frame "wheels"
Tracker cabling				
SDCA	1	I	NCAMAT	Material number for cabling
SCAB	1	R	SCABRA	Radii of cable tubes in barrel region
	1	R	SCABZL	Half length in z of cable tubes
	1	R	SCABZP	Beginning position of cable tubes in z
	1	R	SCABRL	Thickness of tubes in radiation lengths
SCAD	1	R	SCADRI	Inner radius of cable disk between forward and barrel regions
	1	R	SCADRO	Outer radius of cable disk
	1	R	SCADRL	Thickness of disk in radiation lengths
	1	R	SCADZP	Z position of disk
SCAF	1	R	SCAFRA	Radius of forward cable tube
	1	R	SCAFZL	Half length in z of tube
	1	R	SCAFZP	Beginning position of cable tube
	1	R	SCAFRL	Thickness of tube in radiation lengths
	1	R	SFRGRL	Thickness of forward cable disks in radiation lengths

Appendix II.

Sample Data Card Values

```
C Turn on various PHYSICS processes
PAIR 1
COMP 1
PHOT 1
PFIS 1
ANNI 1
BREM 1
HADR 1
MUNU 1
LOSS 3
MULS 2
SWIT 1 1 3
EVNT 0 1 1 0 0 1 110.
VERT 0.0 0.0 0.0 0.0005 0.0005 5.0 0.0015 0.05
KINE 5 1. 500. -.2 .2 5.
FIEL 8.0
GET 'INIT'
DIGI 'SISD' 'SISF' 'PADB' 'PADF'
TRIG 1
DEBUG 1 10 1
PRIN 'VERT' 'KINE' 'HITS' 'VOLU' 'TMED' 'SETS' 'DIGI' 'CORD' 'MATE' 'PART'
SAVE 'INIT'
PIPE 4.0 .1
ELN1 0.04 3.3 4.05
SCN1 .8 1.0 15.9 0. .0016
SDN1 6 1 12.
SDR1 60.5 0.03 0.05 0.05 0.2864788 -.2864788 1.33 6.0 0.01 0. 1.0
```

```
SD01 10.00 0.16 0.0 0.0050 18.0 3.3 0.003 0.00002 150. 18. .2
SD02 12.00 0.16 0.0 0.0050 18.0 3.3 0.003 0.00002 150. 18. .2
SD03 15.00 0.16 0.0 0.0050 18.0 3.3 0.003 0.00002 150. 18. .2
SD04 17.00 0.16 0.0 0.0050 18.0 3.3 0.003 0.00002 150. 18. .2
SD05 20.00 0.16 0.0 0.0050 18.0 3.3 0.003 0.00002 150. 18. .2
SD06 22.00 0.16 0.0 0.0050 18.0 3.3 0.003 0.00002 150. 18. .2
SDRE 0.001 0.005 0.01 0.001 0.00 0.14
SCHI 2.856E4 3.114E5 .7887 3.0E1
SDAN 'CORD' 'PATR' 'FIT '
SFEL .04 4.0
SFCR 1.0 1.3 0.0016 2.1
SFN1 14 1
SFR1 0.03 0.05 0.001 0.2864788 -.2864788 1.33 0.01 0.0 1.0
SFRE 0.001 0.01 0.005 0.001 0.14 0.0
SF01 20.  0.16 0.005 3.3 0.00002 10.0 26.0 1.0 10.0
SF02 22.  0.16 0.005 3.3 0.00002 10.0 26.0 1.0 10.0
SF03 24.  0.16 0.005 3.3 0.00002 10.0 26.0 1.0 10.0
SF04 26.  0.16 0.005 3.3 0.00002 10.0 26.0 1.0 10.0
SF05 29.  0.16 0.005 3.3 0.00002 10.0 26.0 1.0 10.0
SF06 36.  0.16 0.005 3.3 0.00002 10.0 26.0 1.0 10.0
SF07 44.  0.16 0.005 3.3 0.00002 10.0 26.0 1.0 10.0
SF08 49.  0.16 0.005 3.3 0.00002 10.0 26.0 1.0 10.0
SF09 55.  0.16 0.005 3.3 0.00002 10.0 26.0 1.0 10.0
SF10 63.  0.16 0.005 3.3 0.00002 10.0 26.0 1.0 10.0
SF11 70.  0.16 0.005 3.3 0.00002 10.0 24.0 1.0 10.0
SF12 76.  0.16 0.005 3.3 0.00002 10.0 24.0 1.0 10.0
SF13 82.  0.16 0.005 3.3 0.00002 10.0 24.0 1.0 10.0
SF14 88.  0.16 0.005 3.3 0.00002 10.0 24.0 1.0 10.0
SEN1 5. 35. 100. .0032
SSN1 0.003
SISP 29.6 92. 10. .169 5.3 18.725 17.455 19.995 91.995
SDCA 9
SCAB 11. 16. 21. 4.0 16. .0083 .0056 .0044
SCAD 11. 26. .002 18.13
SCAF 32. 35. 18. .01 .0005
SFAN 'CORD' 'PATR' 'FIT '
```