4.d Converter / Tracker (24 pages)

4.d.1 Requirements (Bill 3pages)

4.d.2 Design & Layout (Bill 7pages)

4.d.2.1 Physical layout
4.d.2.2 Optimization
4.d.2.3 Expected performance
(direction, energy, efficiency, polarization?)

4.d.2.4 Silicon Strip Detectors as the tracker medium

An in-depth study has been performed [] to investigate alternatives to silicon strip detectors as the tracker medium. Possible alternatives are Micro Strip Gas Counters (MSGC's) and Scintillating Fibers. The performance properties are shown in Table 4.d.1

Table 4.d.1 Typical Performance Properties

As noted, the MSGC's have the disadvantage of very large angular dependence of the efficiency and relatively small signal/noise. The fiber trackers have worse resolution, two-track separation and low signal/noise. Given that there is no modularity in a fiber tracker, the question of background rejection of cosmic rays coinciding with signal of photons is a serious one. Even more revealing is a comparison of the operational properties shown in table 4.d.2.

Table 4.d.2 Typical Operational Properties

The MSGC's need gas of extremely high purity and in addition low noise high voltage supplies. It should be noted that up to now, no experiment has been able to get large MSGC panels working. The scintillation fibers have the problem of readout either by VLPC's which need He-temperature cryogenics or fairly slow CCD's and slow image intensifiers. In contrast, silicon microstrips are a mature technology with wide-spread use in High Energy Physics and Space Sciences, with excellent two-track resolution and high signal-to-noise ratio. The high modularity with on-chip data compression and fast read-out results in good background rejection.

4.d.3 Detectors (Hartmut)

The fact that the GLAST converter/tracker will use silicon strip detectors in unprecedented large numbers (of the order 100m^2 will be used), is reflected in the specifications of the detectors ("sensors"). While some of the geometrical dimensions like the pitch are dictated by the physics (see Sec. 4.d.1 above), many characteristics of the sensors are determined by two overriding criteria: reliability and cost. Here, past experience with development of sensors for High Energy Physics experimentation (LEP, HERA, SSC, LHC, Babar , CDF, CLEO, BELLE) has helped. The specifications have been reviewed by an international panel of experts. They are listed in the Appendix, Table A.4.d.1, and are discussed in the following. The bonding pads and details of the strips are shown in Fig. A.4.d.1-A.4.d.3 in the Appendix.

Because of the need for reliable operation, single-sided sensors have been chosen. Given that the total radiation dose will be small (less than 10kRad), detectors with p-implants in n-bulk offer sufficient radiation hardness and are the cheapest choice []. Yet the observed leakage currents for the anticipated dose are large enough that the detectors will be AC coupled to block the currents from the amplifier input []. This is shown in Fig. 4.d.1, where the currents extrapolated from gamma irradiation in the UC Santa Cruz ^{60}Co source are shown as a function of the operating temperature for the GLAST strip geometry. In addition, the total noise is shown increasing strongly at temperatures beyond about 10-15^{o}C. This shows the need for temperature control. The bias resistors have been chosen to be made from polysilicon, instead of punch-through resistors which have exhibited excess noise[]. The value of the bias resistors has been specified to be very large in order to keep their noise contribution small.

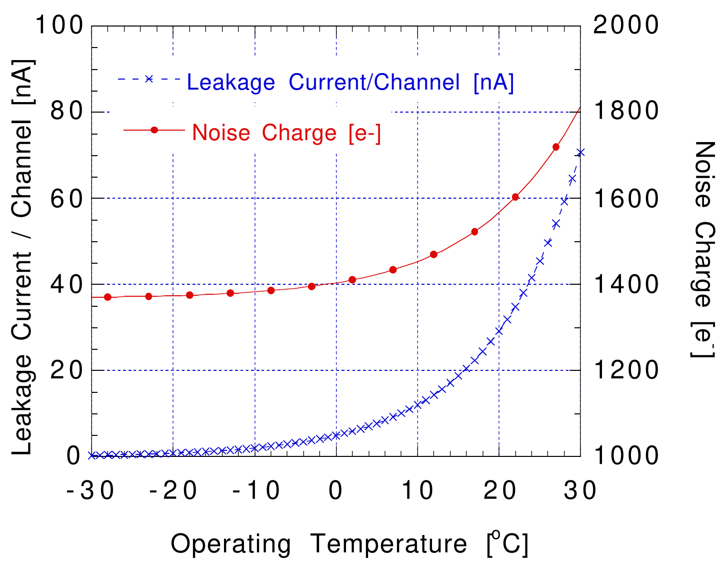

Fig. 4.d.1 Leakage currents/32cm long strip extrapolated from ^{60}Co irradiations and predicted noise as a function of the tracker operating temperature. []

The largest detector area (6.4cmx6.4cm) possible with 4" wafers is chosen. A future extension to 6"wafer production will be possible. Even if there will be no price advantage because of the smaller yield for larger detectors, larger detectors will offer reduced dead space. The detector thickness is a compromise between increasing the signal by having thicker detectors and minimizing the multiple scattering and the operating voltage. The signal increases linearly with the thickness, while the multiple scattering increases with the square root and the depletion voltage with the square of the thickness, respectively. The thickness of 400microns will yield about 32,000 electron-hole pairs, which gives comfortable head-room in the signal-to-noise ratio: at an anticipated noise level of 1500 electrons. This will allow very efficient discrimination at about 6000 electrons with very low noise occupancy.

The pitch of 195microns is given by the physics requirements and the need that a sensor is serviced by an integer number of 64 channel FEE chips. The implant width has been chosen to be fairly narrow to minimize the detector capacitance[]. which is the major noise source, yet wide enough to have good charge collection[]. Both implant and metal side of the integrated coupling capacitor are accessible to probing. In the GLAST trays, five detectors will be bonded together ("ganged") to produce readout strips of 32cm length. To eliminate the inefficiency due to one bad strip on one detector deaden the four others in the chain, a by-pass scheme of extra and split metal lines has been prototyped (Fig, A.4.d.2 and A.4.d.3). After experience in the prototype tower, one of the two schemes will be chosen .

4.d.4 Front-end Electronics (Robert 5pages)

4.d.4.1 Specifications
4.d.4.2 Design and Layout
4.d.4.3 Prototype Results
>

4.d.5 Hybrids (Robert 1page)

4.d.6 Read-out Control Chip (Robert 2page)

4.d.6.1 Specifications
4.d.6.2 Design and Layout
>

4.d.7 DAQ and Trigger (Robert/Roger 2pages)

>

4.d.8 Interconnects (Robert 1page)

4.d.8.1 Kapton interconnect
4.d.8.2 Kapton cables
>

4.d.9 Issues in Tray Engineering (Hartmut/Gary 1/2 page)

In the baseline design, planes of silicon sensors are mounted onto trays, which consist of low-mass material (e,g. foam, honeycom) with thin facings. Both sides of the trays carry Kapton sheets with silicon detectors. The thickness of the trays is 3cm, and the lower face contains also the converter, a Pb sheet of 3.5% X_O. Details of the tray engineering are given in Section xx. In the following, the mechanical tolerances for the assembly of the trays are discussed

In a large detector like GLAST with 20,000 silicon detectors, it is important to be able to treat as large an assembly as possible as a rigid body, which can then be described by 3 position and 2 angle variables. Thus the precision of the instrument becomes depends on the assembly, tolerances. The unit which is ideally suited for precision assembly is the tray which carries 25 detectors each on its two sides.

The mechanical scale is set by the resolution of the silicon strip detectors, which for a single plane is pitch/$\sqrt{12}$ = 56μm. Mechanical tolerances, which can introduce systematic errors, should, when related to the single plane resolution, be 1/3 of this, i.e. Δ = 20μm.

In the following different mechanical tolerances in the tray are discussed.

1) Placement of the detectors in a tray:

25 detectors of 6.4cm x 6.4 cm are placed on each face of the tray, and are wire bonded together in groups of 5 to be read out together. These groups of 5 have to be aligned, i.e. placed, to a tolerance of Δ = 20μm normal to the directions of the strips. In the directions along the strips, the maximum distance between detectors is 200μm. Thus the placement should be done to 50μm, which is anyway the tolerance of the detector outside dimensions. The tolerance on the rotation of the detectors has to be such that it produces an displacement over the length of the detectors (6.4cm) of less than Δ = 20μm , i.e. which means less than 0.3mrad. These tolerances ensure that wire bonding can proceed with identical maps for different detectors. In order to avoid error build-up, the placement device should be able to place detectors at random, i.e. independently from the location onto which the previous detector was placed.

2) Rotation of two x planes in a tray relative to the other:

A plane rotated by an angle ϕ appears as having a pitch scaled down by $\cos\phi$. For a track with inclination α relative to the normal, the effective error made over the length of the tray should again be less than Δ:

$$d(\tan\alpha) = x/z - x*\cos(\phi)\ /z=1/2*x/z*\phi^2 \leq \Delta/z \quad .$$

For x=32cm,this results in $\phi \leq \sqrt{2*\Delta/32\mathrm{cm}}$ =11mrad ≈ 2/3°   .

3) Distance of two planes in a tray:

The precision of measuring the projected angle in two adjacent planes of a single tray is angle dependent. Moreover, it depends on the energy of the track because of multiple scattering, pair creation angle and nuclear recoil. In order to have a reasonable stringent specification for high energy tracks, the pointing accuracy PAT in a single tray of thickness z is calculated for incident angle α:

$$PAT = \sqrt{2} * (\cos^2(\alpha) * \tan(\alpha)) * \sigma_x/z \quad .$$

The PAT is an essential ingredient for the determination of the point spreading function PSF, i.e. PSF ≈ 1/$\sqrt{n}$ * PAT, where n is the number of planes in the track. The PAT is shown for 20GeV photons as a function of the angle of incidence in Fig. 4.d.x. Note the strong angle dependence of the PAT, which becomes very small at large angles of incidence, because the effective pitch gets reduced with the cosine and the lever arm of the angle measurement increases with 1/cosine. Assuming that the precision in the tray thickness σ_Z should not exceed the projected PAT at every angle of incidence α, the required precision in the distance and planarity of the two faces of the tray is

$$\sigma_Z = z*PAT/\sqrt{2}/(\cos^2(\alpha)*\tan(\alpha)) \ .$$

This is shown in Fig. Fig. 4.d.x., indicating that at zero degree and close to 90degree, there is no sensitivity to the distance of the planes either from the steep angle or from multiple scattering, but that at angles in between, a tolerance of about 50 μm is required in the planarity and distance of detector planes in a tray.

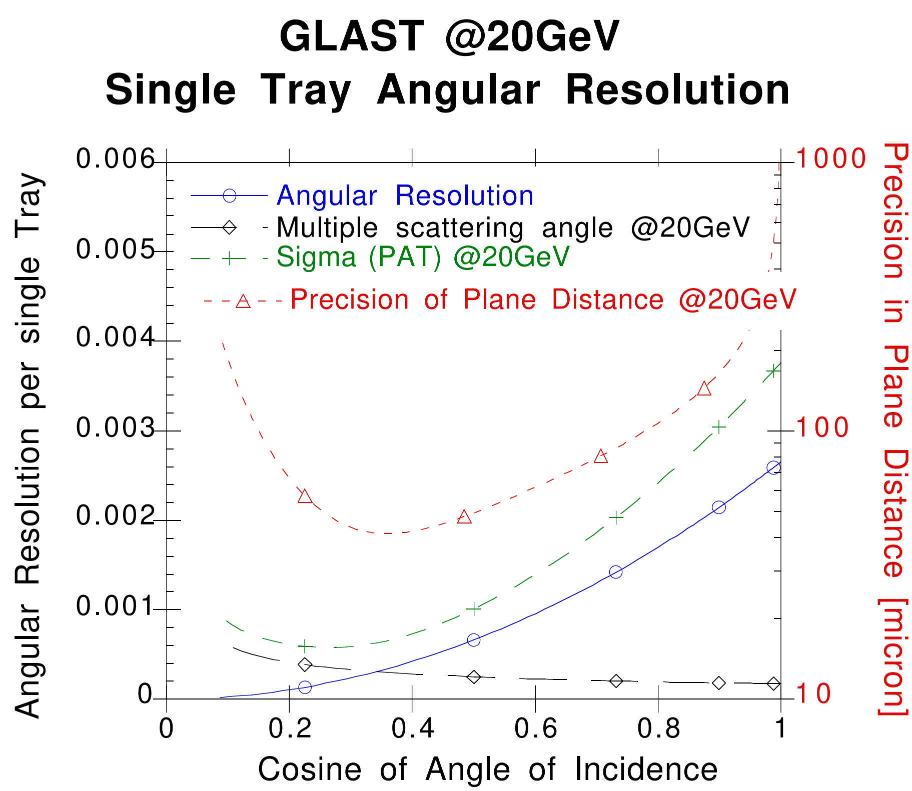

Fig. 4.d.x Angular resolution, multiple scattering angle and pointing accuracy for single tray PAT for 20GeV photons as a function of the angle of incidence. The required precision for the distance of two planes are shown too.

Another way of looking at the required precision in building the trays is to evaluate the pointing accuracy per tray PAT as a function of angle and adding in quadrature the error due to different levels of precision of the tray distances z. This is shown in Fig. 4.d.y for 20GeV photons and infinite precision, and tolerances of 50, 100, and 200 μm on the tray precision. As expected, the worsening of the resolution for 50micron is at most a factor 1.4, while it is a large effect at 100micron precision and above. One should note that this might lead to serious detoriation of the point spread function PSF because the increase appears in the region of large angle of incidence where the number of planes on a track is reduced. Thus the required precision of the separation of the detectors on a tray should be of the order 50microns or less. Clearly, the effect of precision of the tray assembly is the largest for the higher energy photons, while the measurement for the lower energy photons is multiple scattering limited at larger angles of incidence.

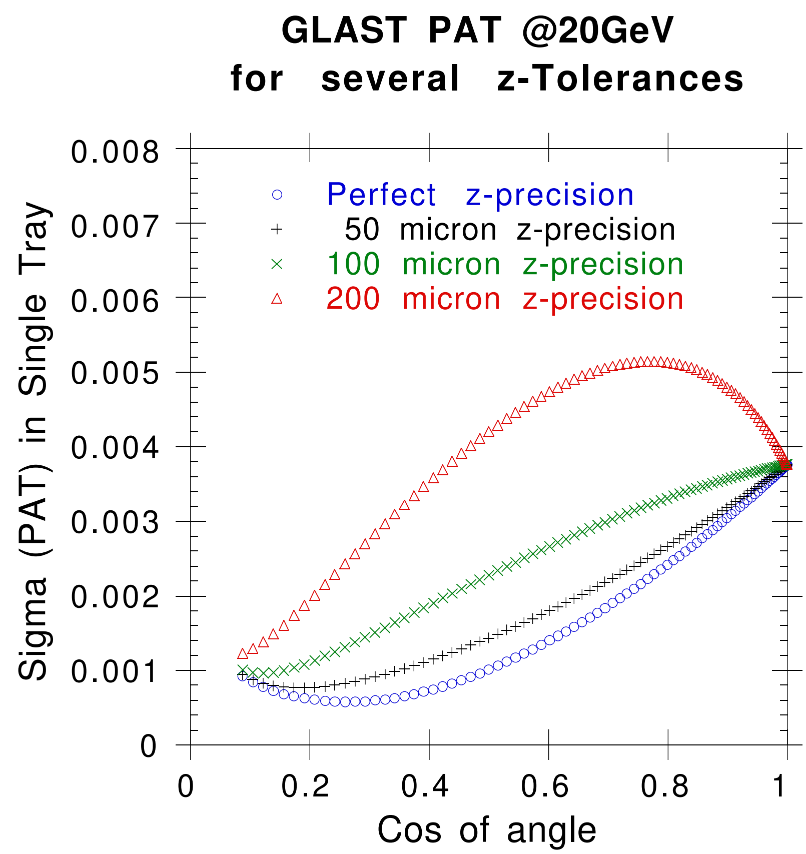

Fig. 4.d.y The point ing accuracy per tray PAT for 20GeV photons vs the angle of incidence for several tolerances for the distance of the faces in a tray.

The mechanical tolerances of the tray assembly are summarized in Table 4.d.x. They are quite exacting for a large instrument, and need to be checked with a MC simulation including angled tracks. If necessary, the positions need to be corrected for with the help of a survey. In addition, before and after launch cosmic ray data runs with high energy muons will help with the alignment of the trays.

Table 4.d.x Assembly Tolerances of the GLAST Tracker

Parameter	Tolerance
Placement of detectors in tray:	
normal to strip direction	20μm
in strip direction	50μm
rotation	0.3mrad
Rotation between pairs of planes	0.67°
Separation of pairs of planes	50μm

In the silicon tracker, the mechanics is tightly coupled with the electrical performance. There is a large list of R&D topics which are at the interface of electrical and mechanical engineering awaiting solution in the next years:

grounding and shielding
heat management
precision placing of sensors on the tray
glueing of sensors
wire bonding of about 8million bonds
redundancy and failure analysis of detectors
extend of rework and repairs needed.

APPENDIX

Table A.4.d.1 Specifications of the GLAST Silicon Sensors (Takashi 1page)

Fig. A.4.d.1 Layout of the GLAST silicon sensors: arrangement of pads. (Tune 1/2 page)

Fig. A.4.d.2 Layout of the GLAST silicon sensors: detail with redundancy scheme having two parallel metal strips per implanted strips. (Tune 1/4 page)

Fig. A.4.d.3 Layout of the GLAST silicon sensors: detail with redundancy scheme having an extra metal strip between implanted strips. (Tune 1/4 page)