5. The Scintillating Fiber Tracker

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A high resolution scintillating fiber detector is used in conjunction with the changeable emulsion sheets to predict the position of charged particle tracks in the emulsion [ref]. The track predictions must be made with sufficient precision to allow the automated scanning algorithms to find the tracks in the emulsion stacks. A system similar to that used for E872 was employed for this purpose in the CHORUS experiment at CERN [1]. The scintillating fiber detector consists of a series of planes of fibers interspersed with the target modules inside the target box, see Figure 1. The following sections describe the major elements of the scintillating fiber tracker.

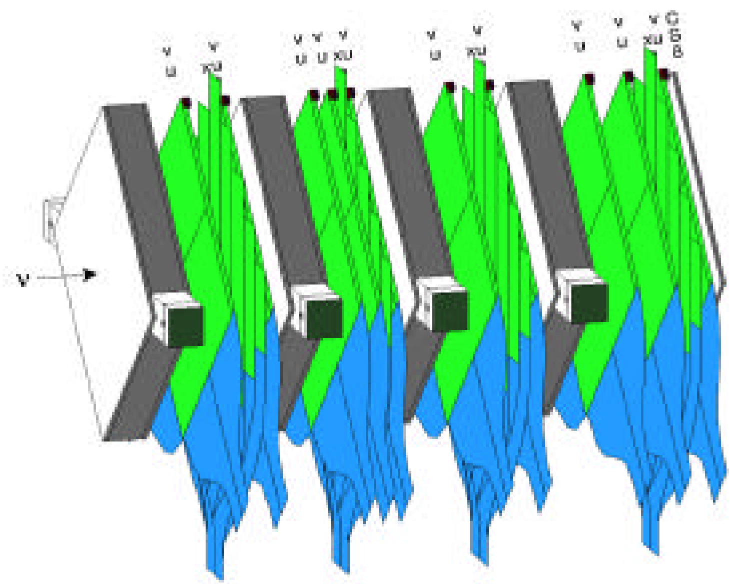

Figure 1: Emulsion target and scintillating fiber tracker configuration. The fiber planes are arranged in three views, the six image intensifiers and readout CCD cameras are not shown.

6.1 Scintillating Fiber Planes

There are 60000 scintillating fibers in the scintillating fiber tracker. Each fiber has a polystyrene center (core) doped with 1% butyl-PBD[1] and 0.1% BDB[2]. The outer layer (cladding) of the fiber is made of PMMA[3], which has a smaller index of refraction to produce total internal reflection of the scintillation light.

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Each fiber has a diameter of 0.5 mm. The fiber length varies between 0.7m and 1.2m. An aluminum mirror with 85% reflectivity is put on one end of the fiber to increase the light output at the other end. The pulseheight response variation is less than 15% along the 0.56m of fiber that is glued into the plane (Figure 2).

The fibers are arranged to read out coordinates in *u*, *v*, and *x*. The *u*-*v* axes are oriented at 45° to the *x*-*y* axes, where the *y* axis is vertical. The fibers are placed side-by-side in layers, with 1200 fibers per layer. Each layer is coated with highly reflective TiO_2 - based paint that also serves as glue. The *u* and *v* planes each have two layers of fibers; the *x* planes have four layers. The plane configurations are illustrated in Figure 2 and Figure 3. Since the *u* and *v* planes are identical in their construction they are called *uv* planes. There are 44 planes of fibers altogether: 4 *x* planes, 20 *u* planes, and 20 *v* planes. Five planes of scintillating fibers are mounted downstream of emulsion modules one and three, four planes are mounted downstream of modules two and four.

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[1]butyl-2-phenyl-5(4-biphenylyl)-1-3-5-oxadiazole

[2]4,4'-bis-(2,5-dimethylstyryl)-diphenyl

[3]polymethyl methacrylate

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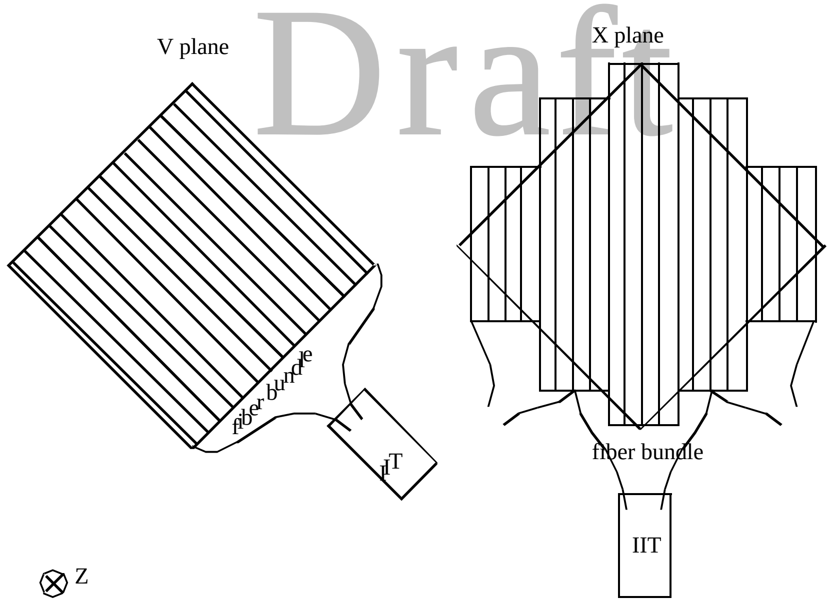

Figure 2. Front view of the fiber layout on a V and an X plane. Each plane has dimensions of 0.56m by 0.56m. Different sections of the X plane are connected to different IITs. The Z-axis points into the paper.

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other types of printers.

Figure 3: Fiber-on view of a scintillating fiber plane. The left-hand side shows the two layers of an UV plane, the right-hand side the four layers of an X plane.

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Each plane has an area of 0.56m by 0.56m. In a *uv* plane, the fibers run parallel to a side; in an *x* plane they run diagonally, as shown in Figure 2. The average distance between a fiber plane and the readout system is 0.5m.

Image Intensifier (IIT) Modules

Six image intensifier (IIT) modules [4] read out the fiber planes. Light from the fibers enters the IIT module and produces electrons in the photocathode of the entrance window, as shown in Figure 4. The electrons are focussed and accelerated in the first image intensifier stage.

At the output window of the first stage is a phosphor screen that converts the electrons into photons. The screen is connected to the photocathode of the next stage through a fiber-optic plate. This plate is made of millions of small diameter clear fibers that guide the light in a straight path. The fiber-optic plate is used to focus the light instead of a conventional lens system, which would take up much more space. There are four image intensifier stages. Each has a photocathode to produce electrons, electrostatic tubes to multiply the electrons, and a phosphor screen to convert the electrons into photons.

The IIT modules are shielded from the magnetic field of the analysis magnet with large soft iron canisters. The canisters reduce the fringe field, which reaches

[4] Image Intensifier type IC-5502X made by Hamamatsu Photonics, Japan.

150 G at the most upstream IIT, to an acceptable level below 0.2 G. The canisters are depicted in

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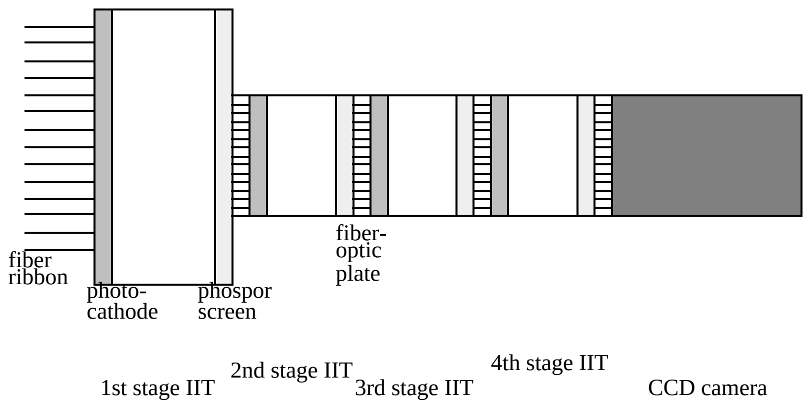

Figure 4: Layout of the IIT-CCD system.

The performance of the IIT module is determined by two parameters:

1. The quantum efficiency of the first stage. This is the probability that an electron will be emitted when a photon strikes the photocathode. When only a few photons reach the photocathode, this number determines the probability that a signal will be produced. The quantum efficiency is 20%.

2. The overall light multiplication factor or gain. This is the number of photons that exit the phosphor screen of the fourth stage when one photon strikes the photocathode of the first stage. This factor is 3-4 $\times 10^6$ for the IIT modules.

The phosphor screen of the fourth IIT stage is mounted on a charged coupled device (CCD) video camera module through a fiber-optic plate. The camera has a sensitive area of 8.8mm by 6.6mm that is divided into 768 by 493 pixel[5]. About half of the CCD image area is occupied by fibers.

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An eight-bit flash ADC that was custom-built for this experiment digitizes the pulseheight from the CCD camera. The pixels are read out at a rate of 14MHz.

The image intensifier stages map each scintillating fiber onto a circle with a diameter of about three pixels on the CCD camera, which corresponds to a demagnification factor of 0.034. The diameter is slightly larger (~20%) at the edge of the image due to non-uniformity of the IIT. The CCD is read out into a VME-based FIFO memory buffer. The mean readout time for a single event is 24ms and this is the dominant factor in the deadtime for data acquisition.

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[5] CCD video camera XC-77RR made by Sony, Japan.

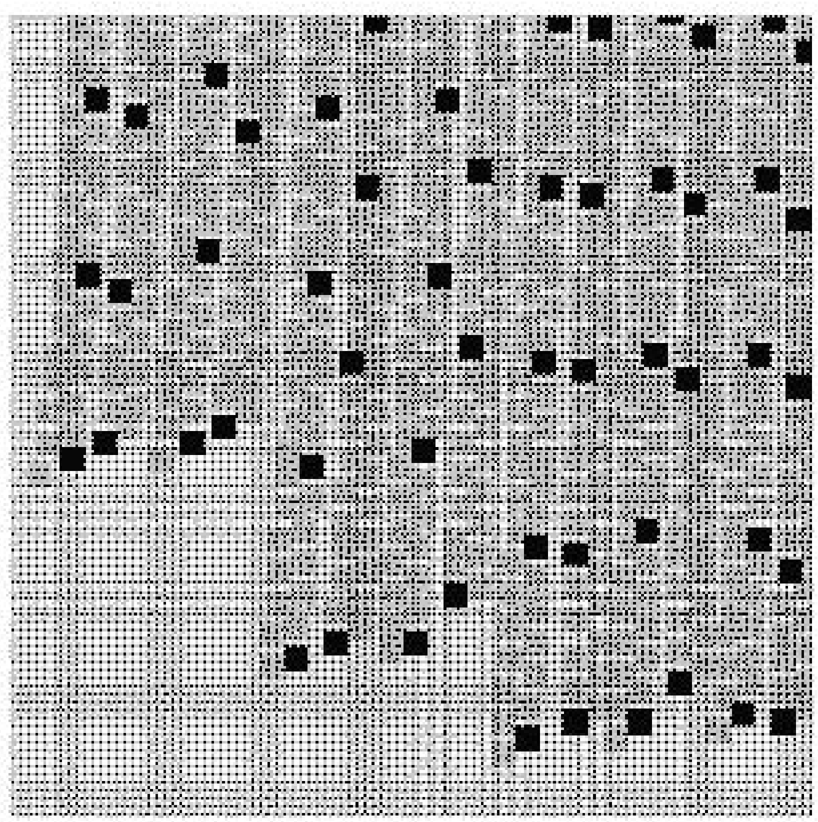

Figure 5: Small section of a CCD image. Each small box is one pixel. A gray box indicates the location of a fiber; a black box indicates the location of a fiducial fiber.

Alignment

Aligning the scintillating fibers is a critical task in the experiment. To locate a vertex in the emulsion successfully, the vertex position has to be predicted with an accuracy of about $1mm^2$ in the *uv* plane and about 10mm in Z.

To align the fibers with respect to the global E872 coordinate system, each SF plane is surveyed before it is mounted in the target stand. Fiber location, offset and angles between fibers are recorded in the survey. Also, the exact position of the stand itself is determined.

Once the plane is in place, cosmic ray muons and muons produced by proton beam losses upstream are used to align the fiber plane with respect to each other and with respect to the other detector components. Alignment of the fiber planes is periodically monitored with single muons that pass through the detector. A special trigger allows the muons to be added to the data stream. More detailed alignment information is also gathered in dedicated muon calibration runs.

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The result of the fiber alignment is shown in the form of a histogram of "residuals". A muon track that passes through all 44 SF planes is fitted with points from 43 planes and the projection to the remaining plane is calculated. The residual is defined as the distance between the track position and the hit that would have been used in the track. The histogram of residuals is shown in figure 5. The distribution has a standard deviation of about 0.17mm.

The maximum distance between fiber planes along the *z* axis behind a single emulsion module is 0.1m (except for module 4). That means the angle of a track can be determined to an accuracy of 3.3 mrad, as shown in Figure 7. As Figure 7 also shows, the track location projected to the changeable sheet can be determined to within a distance of about 0.35mm. Projected to the center of the emulsion module, this translates to within a distance of about 0.5mm.

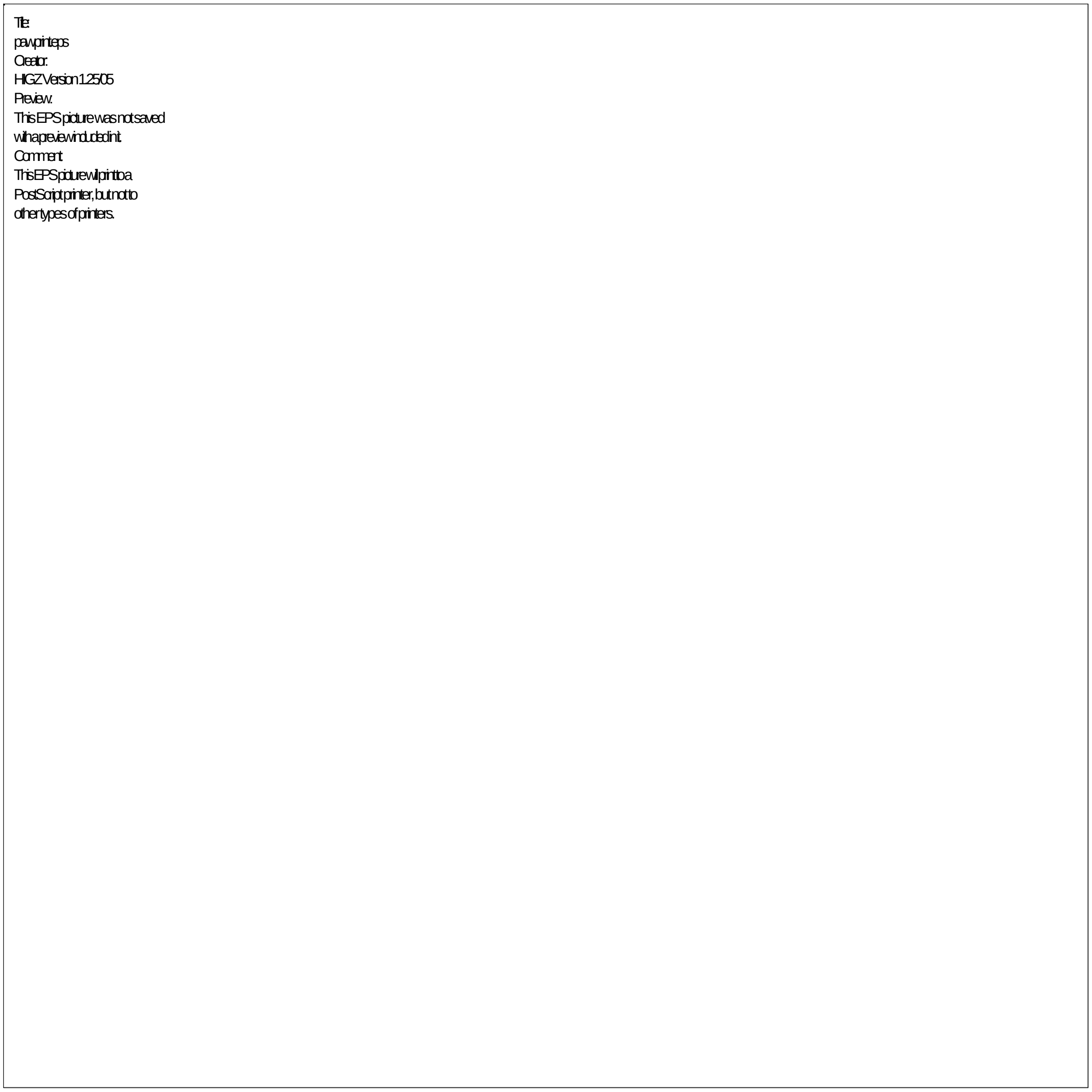

Figure 6: Histogram of the distance between track projection and hit position for SF hits in events from a muon run.

Figure 7: Histogram of the projection error from the SF system to changeable sheet CS5. The upper row shows the angle deviation for U and V planes, the lower row shows the position deviation for U and V planes. The solid line is a Gaussian fit to the histogram.

The fibers also have to be aligned on the face of the CCD camera. Mapping the fibers to CCD coordinates cannot be done at assembly time because of the IIT system and the size of the fiber image. An optical calibration system monitors the location of a few fibers on the CCD image. In each SF plane, some of the fibers are connected to an electroluminesence (ELP) plate. Light from these “fiducial fibers” is easily found on the CCD image. The fiducial image is taken in between runs; the light is turned off during data acquisition. A map is created from the fiducial information that contains the location in space and on the CCD image for each fiber.

Figure 5 shows a small section of a CCD image with the location of the fiducial fibers. There is a fiducial mark for every twelve fibers in the *uv* planes.

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The location of each fiducial fiber can be determined to better than a fraction of a pixel. A typical fiber hit deposits a pulseheight in an area larger than 3x3 pixel. The location of each fiber on the CCD image is therefore very well known, but the pulseheight from a single fiber spreads to several fibers on the IIT image.

The fiber plane efficiency is was measured to be 96% for a *uv* plane using cosmic rays. The efficiency for an *x* plane is estimated to be 99.8%.

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1 E. Eskut et al., Nucl. Inst. and Meth. A 401 (1997) 7.