Commissioning of the SLD 45-Degree Chambers

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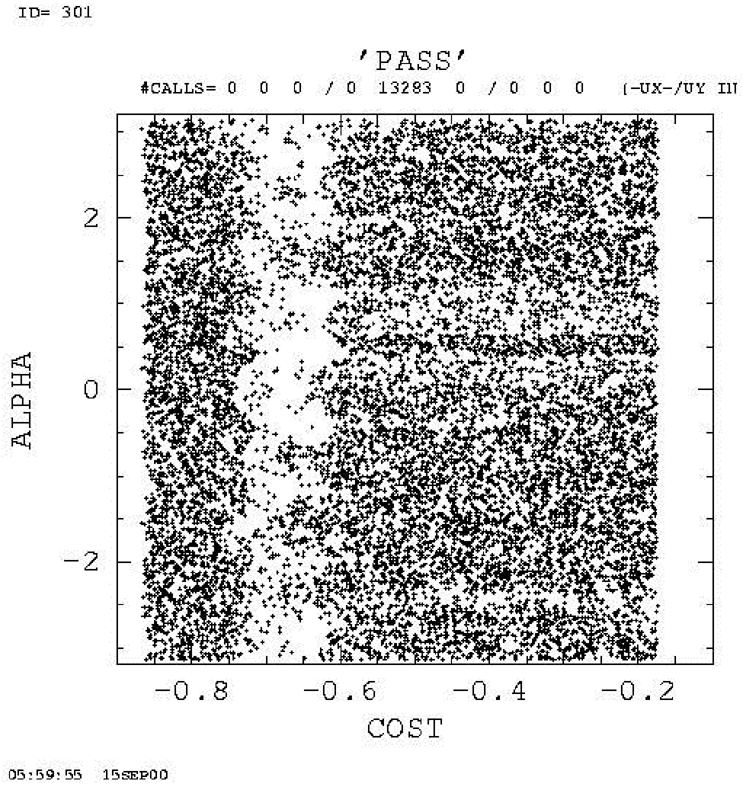
Abstract

The SLD detector has a significant gap in its muon tracking coverage resulting from the redesign of the detector to meet earthquake safety standards. The 45-degree chambers are supplemental chamber planes added to recover tracking efficiency for muons in this gap between 0.65£|cosθ|£0.85. This note describes the effort on the part of the University of Mississippi group to commission these chambers.

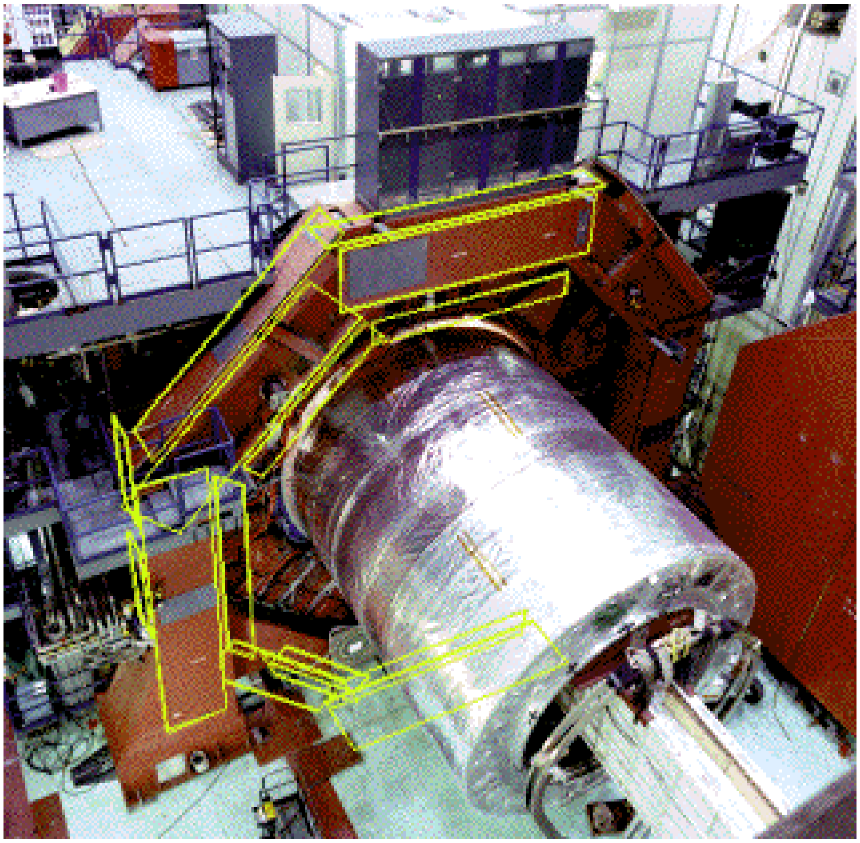
Introduction

Figure 1. shows the acceptance for single 45 GeV monte carlo muons in the south end of the SLD as a function of cosθ and ϕ.



Physical location

Figure 2. shows the locations of the chambers (outlined in yellow) in relation to the Warm Iron Calorimeter (WIC) and the steel arch support structure that holds the detector. Some of the chambers are attached to the endcap door, not shown.

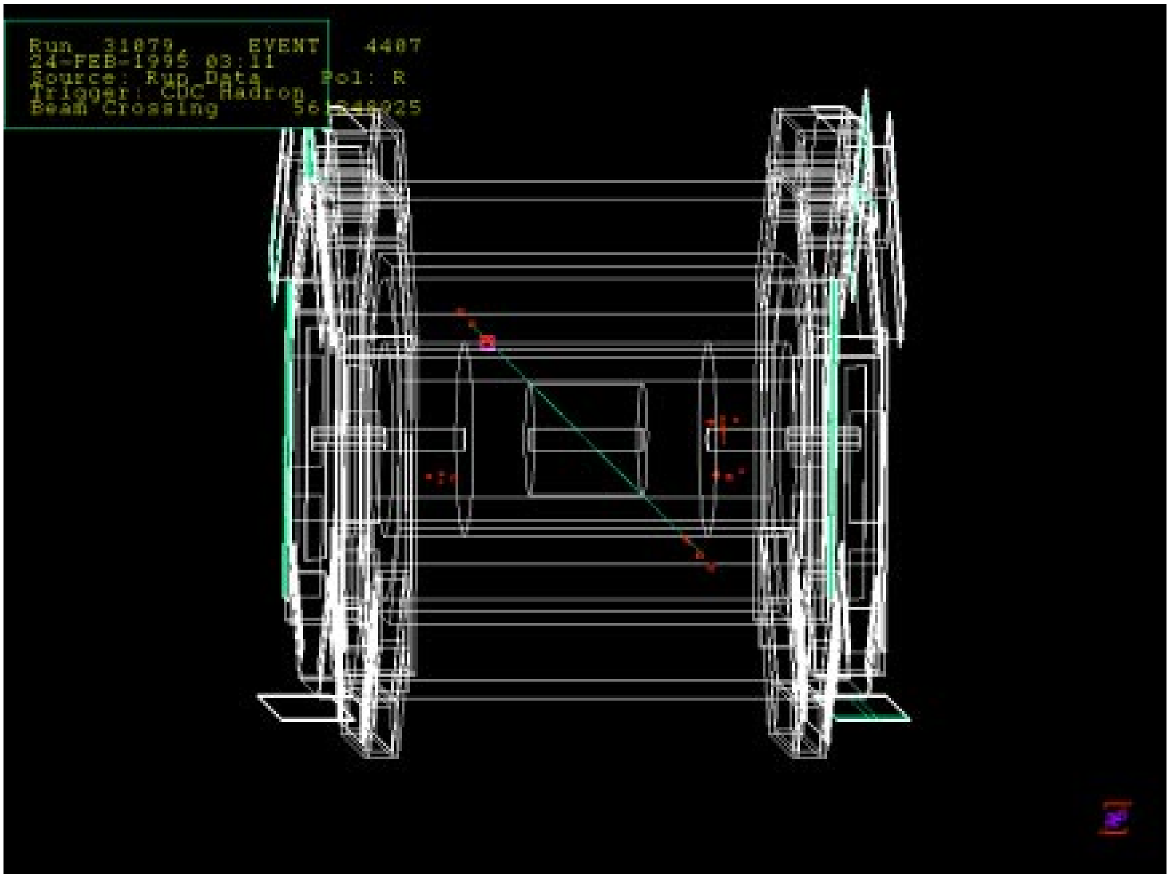


The chambers are constructed of Iarroci tubes (plastic limited-streamer tubes) of the same design, which has been employed in the Warm Iron Calorimeter (WIC). Figure 3. shows an event display with 45-degree chamber hits indicated in green in the lower right.

Challenges

The commissioning task presented many challenges. The reconstruction software for the Warm Iron Calorimeter sub-system is voluminous, ten man and woman years went into developing it. During this large effort very little thought was devoted to the eventual inclusion of the 45-degree chambers in the overall code scheme. The barrel and end cap portions of the WIC were treated in the track finding, the muon pair filter and WIC fitter as if they had been two separate fixed target muon spectrometers. The coordination of the two regions had, in some degree, been deferred to a subsequent implementation including the 45-degree chambers.

In the barrel and end cap, geometrical information was encoded into the subsystem number, layer number, and layer. In the 45-degree chambers these numbers were generally meaningless or conflicted in definition with their use in the barrel and endcap. Kludges had to be improvised in many places to attempt to incorporate the 45-degree chamber hits into an overall scheme to which they were not at all suited, frequently treating each of 50 chambers as a special case.



Much of the WIC code was developed with the assumption of octagonal symmetry, which the layout of the 45-degree chambers violates badly. The greatest difficulty associated with including the 45-degree chambers in the overall program of track fitting had to do with the fact that the WIC track fitter has its own geometrical description of the WIC geometry independent of the GEANT geometry. The fitter's locator routines assume that the detector geometry is a series of tessellating convex volumes, which have eightfold symmetry by octant. The 45-degree chambers violate these conditions, forcing drastic revisions to the geometry and associated code, which are described below.

In most cases the original experts who wrote the code were no longer available for consultation. We could not avoid reading most of this large and very complicated body of code in great detail. To add to the complications, no blueprint or other reliable record of the precise location of the chambers and their sense wires were transmitted from one subsystem commissioner to the next. There were three conflicting sources of information about the location and size of the detectors and surrounding steel. The geometry defining the 45-degree chambers for wire mapping etc. was performed separately from the WIC fitter geometry specification (because their required formats were different) and the GEANT Monte Carlo geometry derived from part of the wire map geometry. The various contributors to the wire mapping code and the WIC fitter code used different sources of information, resulting in multiple conflicting versions of the geometry.

First Steps

We spent an initial six months tracking down bugs in the wire map geometry, which derived from inaccurate information used in creating the GEANT geometry. After resolving these questions the pass 1 muon filter had to be rewritten because it was so inefficient for the 45-degree region. We attempted to create one within the scope of the existing filter which used WIC hits only, but eventually reached the conclusion that no combination of WIC and 45-degree information alone would make a pass 1 filter of sufficient purity and efficiency in the 45-degree region. Giampiero Mancinelli put together a new muon filter including calorimeter information, which was a good deal more efficient in the 45-degree region.

In the course of this work we discovered that the WIC dead and noisy channel management code had been disabled. The barrel and endcap WIC were so robust that the experts had simply decommissioned the dead channel management with no impact on the purity or efficiency of the sample. The 45-degree chambers had not been maintained with the same vigilance as the barrel and endcap and we resurrected this code.

The Pattern Recognition Stage

Hits that are close to the extrapolated drift chamber track are grouped together into subpatterns according to direction of their measurement axes.

If a hit is more that four-sigma away from the hit in any dimension of the extrapolated errors that hit is rejected. Each chamber layer is allowed only one hit per sub-pattern and successive hits must be within 3-sigma of each other based on simple multiple scatter criteria.

We added the 45-degree chamber information in the pattern recognition step by creating a new direction type for each 45 degree-chamber layer. This was the simplest work around to the problem that 45-degree chamber layer numbers would have otherwise conflicted with barrel and endcap layer numbers for strips in the same direction. Because the 45 degree-chambers violated all the symmetric numbering conventions of the other sections of the WIC, each of the 100 45-degree chambers layer planes had to be treated as a special case.

WIC Fitter Locator Routines for the 45 degree Region

The WIC track fitter originally required about three man-years of development and the retrofitting necessary to accommodate the 45-degree chambers has proved to be a project similar in scope. WIC track fitter has its own geometrical description of the WIC geometry independent of the GEANT geometry. It also has an independent track swimming algorithm that depends on the one in GEANT only to the degree that it uses the GEANT description of the magnetic field.

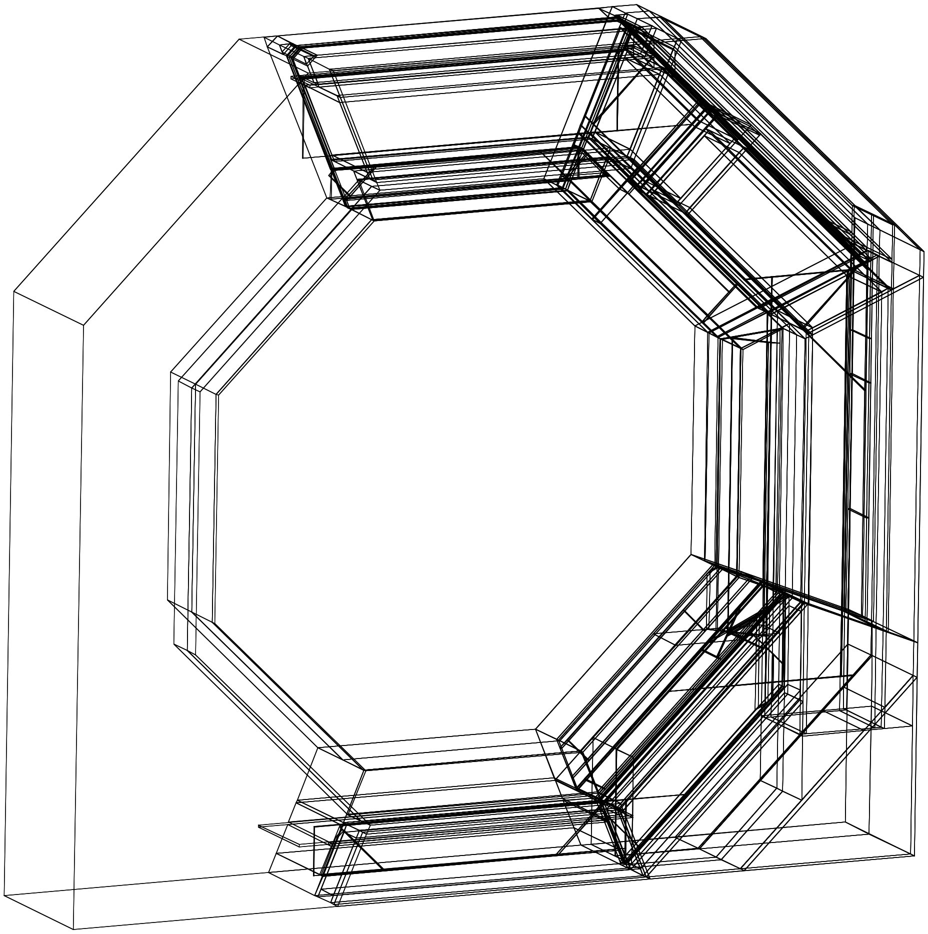
The fitter was designed so that its locator routines would execute much faster than the comparable GEANT locator routines. The scheme associates a space point with the correct volume by determining on which side of a series of planes the point falls. The fitter's locator routines assume that the detector geometry is a series of tessellating convex volumes, which have eightfold symmetry by octant. The 45-degree chambers violate these conditions, forcing drastic revisions to the geometry and associated code.

The Fitter Geometry

Robin Verdier of M.I.T., the original architect of the WIC fitter agreed to study the problem of a retrofit for the fitter code. The incompatibilities were so severe that Robin gave serious consideration to recommending that we throw away the existing fitter and start creating a new one from scratch. He eventually concluded that the best approach was to try to create a specification of the 45-degree chamber geometry to be incorporated into the existing fitter geometry and code.

This reduced the worst difficulties of including the 45-degree chamber information into the fitter to the problem of creating an exhaustive data file specifying the normal direction for each plane bounding each volume and its impact parameter to the interaction point. The geometry had to fill all the space in the region without voids or conflicts. In addition a pointer must be supplied for each volume face that specifies another volume (usually a neighbor) to be searched next if the space point being located is not in the current volume.

We inherited a highly preliminary version of this geometry, which turned out to have been based upon highly inaccurate information. Of the original 150 volumes, we deleted 65 and altered all but eight of the rest. We created 140 new volumes. The final geometry is pictured in figure 3. We went through three major revisions and expansions to arrive at the completed geometry definition amounting to almost 6000 data words. It was very labor intensive to specify, requiring us to devise a lot of specialized code to reduce the labor.



Specialized Code for Development of the WIC Fitter Geometry

First we created routines to display the detector geometry by unpacking the direction cosine and impact parameter for each face of a volume, finding the vertices and drawing the faces. Our graphics routines allowed for rotation of views to arbitrary orientations, perspective and red and blue stereo views. We included routines to discover cases in which a vertex fell inside another volume in order to locate conflicts between volumes, and we built an interactive editor function to alter the volumes on line in the display program. Using these tools we repaired the original 45-degree fitter geometry.

The layout did not seem to match the event display very well. To investigate, we interpolated supplemental code into the routines that build the GEANT description of the 45-degree region and the arch support structure. Whenever GEANT routines created a trapezoid or box, this code calculated the direction cosines and impact parameters as well for comparison to the fitter geometry. There proved to be very extensive differences between the two descriptions; and the revisions to the fitter geometry are described below.

Voids, small gaps, and conflicts are not readily discerned in the wire frame drawings we had relied on initially. For these reasons and in order to resolve a large class of conflicts in which two volumes cross but neither one has a vertex inside the other volume we had to develop a set of new diagnostic tools. Bauer and Eschenburg created programs to perform raster scans to discover such conflicts and voids. Points assigned to more than one volume were flagged as conflicts; those unassigned to any volume were histogrammed against each of the direction cosine axes so we could identify the outlines of missing volumes by direction cosine and approximate impact parameter. These routines were terribly CPU intensive. Since each impact parameters is specified as integer number of millimeters small voids and conflicts of less than millimeter dimension must be tolerated wherever two volumes from neighboring octants meet at a point not on a 45-degree diagonal. The WIC fitter software doesn't tolerate gaps larger than a millimeter in size. A raster scan of the full 45-degree region would take months at that scale so we also developed some fast and highly automated routines to survey the faces of a given volume for conflicts or adjacent voids without the long turnaround time.

A Point and click function was developed to survey the neighbors of faces interactively to check for conflicts and neighboring voids. The routine rotates the view to the necessary local coordinates to display a selected face at normal incidence, draws this face and presents a crosshair. The user clicks a given point of the face and the routine returns the number of the neighboring volume. Some faces bordered as many as 14 neighbors.

The point and click function was so useful we automated it via a triangulation scheme. We divide a face into triangles, then assume that if all the vertices in a triangle agree on a single neighboring volume then we don't have investigate that triangle further. If only two agree we split the triangle along the border between two volumes, as in fig 21, and retire the 4 sided piece with all four vertices in agreement. The we check the remaining triangle and so on. If no two agree we split the triangle at the midpoint of its longest leg and inspect the two longest leg of the triangle. The automated routine quickly locates any conflicting volumes and voids. The whole 45-degree fitter geometry can be surveyed in ten CPU minutes on a millimeter scale for most types of conflicts and voids, as compared with months for the raster scans.

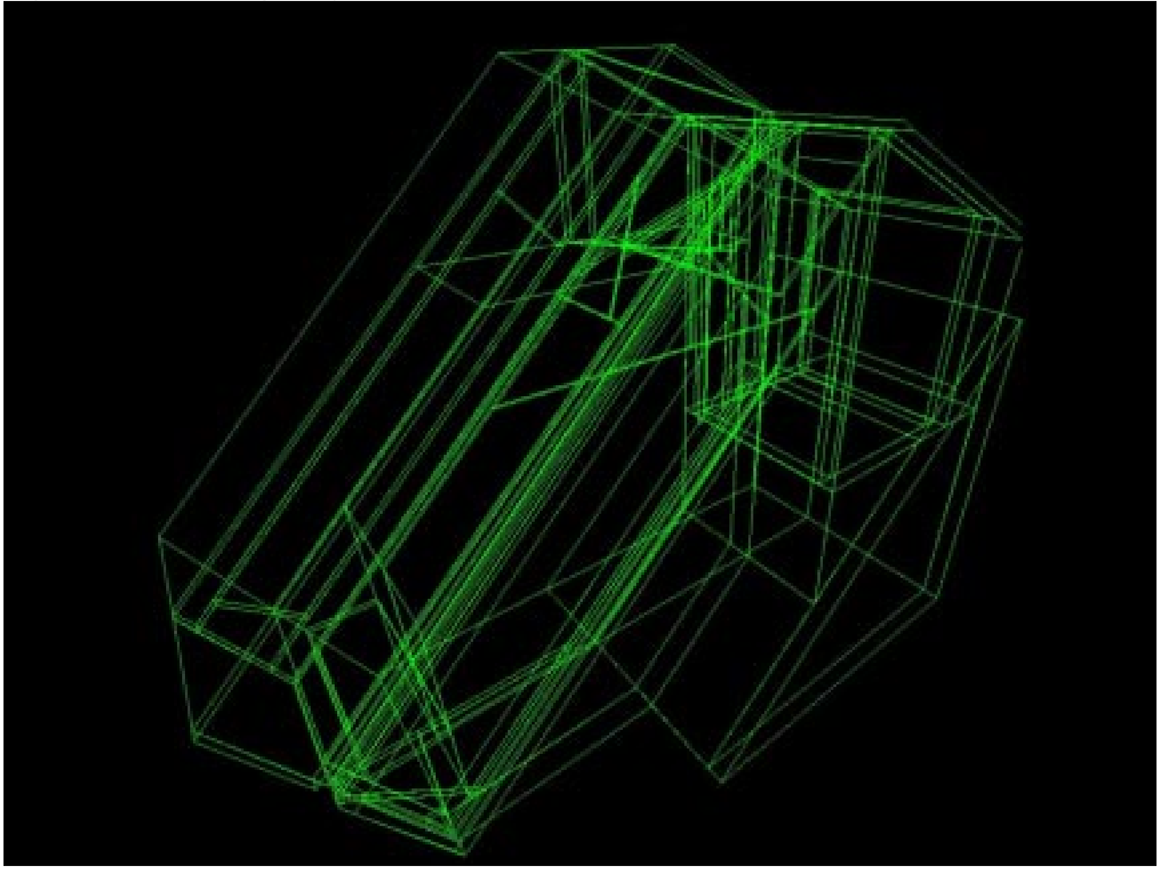
The routines described here are contained in the directories [rkroeger.wic.views], and in particular most of the functions described are in the executable nuwicshr.exe.

Stages of Development of the 45-degree Fitter Geometry

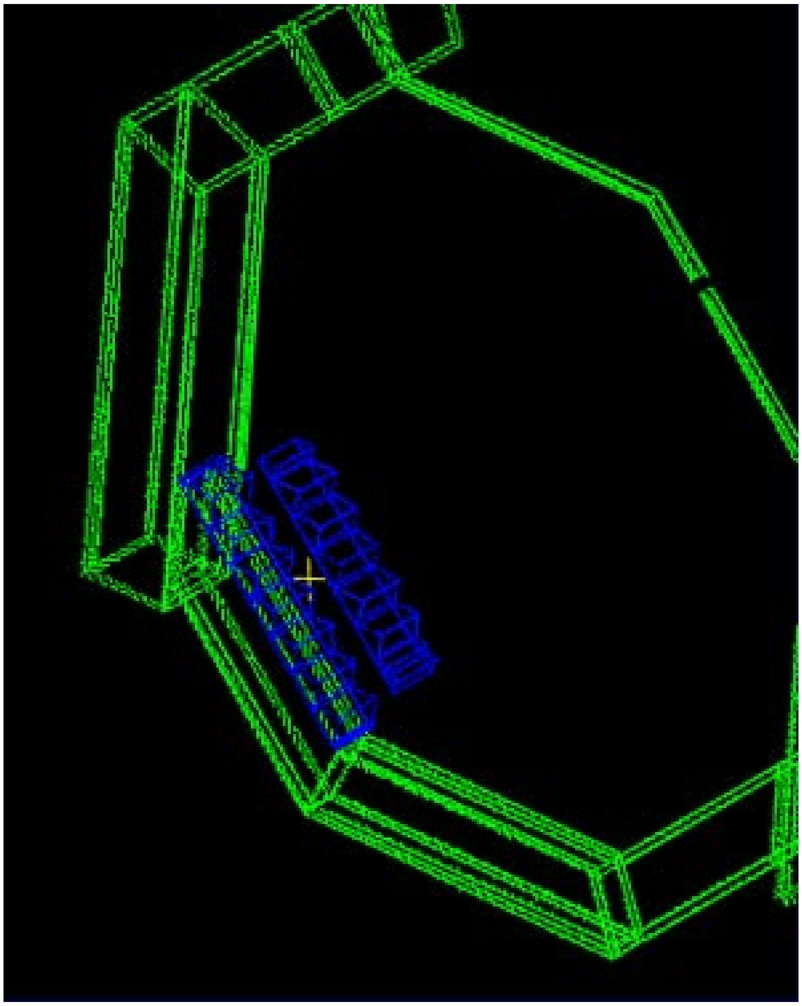
As described above, we discovered that the GEANT geometry and the original fitter geometry differed as to the location of the arch steel, as well as the location size and composition of the 45-degree chambers. The fitter geometry seemed to have better information about the chamber locations; the GEANT description described the steel better

The arch flanges were not represented in original geometry, and all arch steel in all octants was slightly dislocated (a few millimeters up to a centimeter here and there) relative to GEANT volumes. Since so many other alterations were required on the steel volumes, and because the arch flanges are very massive and fall between chambers and the I.P., we decided to move all steel to match GEANT precisely and implement the arch flanges. Surrounding volumes were altered accordingly to suture up the damage done by shifting the steel.

All the steel in octant 7 arch and leg structure had to be built over from scratch as the joint between arch and leg was built according to an inadequate drawing set showing only the beam axis view. This was very major surgery as the particular joint between octant 7 arch and legs includes an awkward intersection where chambers inside the end cap door legs (oriented at 48 degrees to the beam axis in the horizontal plane) meet vertical and 45-degree diagonally oriented steel. (Figure 5. shows a close-up of the region after the stair structure described below was removed and the whole region was rebuilt). This is a region with lots irregularly shaped volumes some seven sided.



We discovered that many of tons of steel were missing from the original endcap geometry of the WIC fitter. This missing steel was located between some of the 45-degree chambers and the interaction point, representing a problem for the WIC fitter in the 45-degree region, though it has no significant consequence for tracking with the barrel and end cap alone. In Figure 5 the octant 7 stair step structure is depicted; the green outline indicates a chamber and the red crosshairs indicate the interaction point. Such a staircase region was in octants 1,3, and 5 in the north and south. Due to misinterpretation of a drawing, these regions had been implemented as air volumes in the original description of the 45-degree region rather than interleaved steel and air volumes in the endcap. Consequently we had to remove the stair step air region in the 45-degree description and replace it 32-fold with air and steel volumes in the endcap. This implied a very extensive revision to the locator routines for the endcap.



The last stage, the fitter geometry for the arch/leg and 45-degree chamber region had to be entirely enclosed in a headstone shaped region (to join the "coffins" in the barrel region), which is the smallest convex volume that contains all the steel and chambers. We finished the geometry in June 1998

Pointer Specification

With the fitter geometry completed we turned to defining its pointers. The specification of the pointers for the 45-degree geometry posed a difficult "traveling salesman"-like problem because of the irregular shapes of the volumes. There can be up to ten sides, and in some cases, no two sides are parallel or no two orthogonal. Combined with the fact that a given face of a volume may meet as many as 14 faces of other volumes, but only one pointer can be defined for the face, this presented a challenge. It was problematic to insure that there are no regions unreachable by the search, and no regions that result in infinite loops. The point and click function to survey all the faces opposing any specified volume was invaluable in avoiding potential trouble spots in the 1200 pointers assigned.

Changes to the Fitter Algorithm

The 45-degree chambers were also afflicted by large fluxes of beam background muons and electronic noise. For these reasons we looked hard at improving the cooperation between the barrel end cap and 45-degree sections of the WIC, by reconstituting the fitting algorithm itself. The WIC fitter provides hope of improved purity over the pattern recognition stage based on fitter's careful treatment of correlations among successive wire hit residuals due to multiple scattering effects.

The fitter assigns a chi-squared to a hypothetical track trajectory through the Warm Iron Calorimeter as a function of a track parameters {P} and measured hit positions y^*_i:

$$\chi^2 = \sum_{i,j=1}^{N} \left(y_i^* - y_i(\{P\})\right) W_{ij} \left(y_j^* - y_j(\{P\})\right)$$

y_i^* is the i$^{\mathrm{th}}$ of the N measured coordinates that constitute the track,

$\mathrm{y}_\mathrm{i}(\{\mathrm{P}\})$ is the fitted function of the parameters corresponding to y_i^*,

The parameters set {P} consists of positions and slopes of the starting trajectory projected along two orthogonal directions on a specified reference plane, and the magnitude of the initial momentum,

W is the weight matrix. It has non-diagonal terms arising from the persistence of deflections due to multiple scattering. The correlation between the measurement residues at the ith and jth detector plane due to multiple scattering deviations is represented in the off diagonal elements of the weight matrix:

$$\mathrm{W}_{\mathrm{ij}}^{-1} = <(\mathrm{y}_\mathrm{i}^* - <\mathrm{y}_\mathrm{i}^*>)(\mathrm{y}_\mathrm{j}^* - <\mathrm{y}_\mathrm{j}^*>)> - <\mathrm{y}_\mathrm{i}^* - <\mathrm{y}_\mathrm{i}^*>><\mathrm{y}_\mathrm{j}^* - <\mathrm{y}_\mathrm{j}^*>>$$

$$= \delta_{ij}\sigma_i^2 + (14\mathrm{MeV}^2)\hat{m}_i \bullet \hat{m}_j \times$$

$$\int_0^{\min(s_i,s_j)} ds'(s_i - s')(s_j - s') / \left[\hat{t}(s_i)\cdot\hat{n}_i\hat{t}(s_j)\cdot\hat{n}_j X_{rad}(s')p(s')^2\right],$$

where the integral is taken over all the material in front of both detector planes i and j,

σ_i is the rms position resolution error assigned to the ith and measurement,

s_i, s_j are the path lengths to the points where the track crossed the ith and jth detector planes,

$\hat{m}_i, \hat{m}_j$ are unit vectors along the ith and jth measurement axes,

$\hat{n}_i, \hat{n}_j$ are unit vectors normal to me ith and jth detector planes,

$p(s')$ is the momentum times c, and

$X_{rad}(s')$ is the radiation length at path length s' along the trajectory.

The expression has an obliquity factor that is appropriate to a fixed target geometry with all the detector planes aligned along a common normal direction and with the track trajectory nearly normal to the detector planes in all cases.

The weight matrix as constituted doesn't correlate a significant fraction of 45-degree chamber hits with the relevant endcap and barrel hits. The figure below represents another 3.5 GeV muon in the WIC. The measurement axis for the inner endcap hits is vertical and the 45-degree chamber hit has a horizontal measurement axis; there is no correlation in the weight matrix because the obliquity factor is zero for two detector planes with orthogonal measurement axes.

We calculated a new obliquity factor with fewer simplifying assumptions:

$$\left[(\hat{\alpha}_1 \bullet \hat{m}_1)(\hat{\alpha}_2 \bullet \hat{m}_2)\cos\Delta\phi / \left((\hat{t} \bullet \hat{n}_1)(\hat{t} \bullet \hat{n}_2)\right)\right] +$$
$$\left[(\beta_1 \bullet \hat{m}_1)(\hat{\beta}_2 \bullet \hat{m}_2)\cos\Delta\phi\right] +$$
$$\left[(\hat{\alpha}_1 \bullet \hat{m}_1)(\hat{\beta}_2 \bullet \hat{m}_2)\sin\Delta\phi / (\hat{t} \bullet \hat{n}_1)\right] -$$
$$\left[(\hat{\alpha}_2 \bullet \hat{m}_2)(\hat{\beta}_1 \bullet \hat{m}_1)\sin\Delta\phi / (\hat{t} \bullet \hat{n}_2)\right]$$

with the following definitions:

$$\hat{\alpha}_1 = \frac{(\hat{n}_1 \bullet \hat{t})\hat{n}_1 - \hat{t}}{|\hat{t} \times \hat{n}_1|}$$

$$\hat{\alpha}_2 = \frac{(\hat{n}_2 \bullet \hat{t})\hat{n}_2 - \hat{t}}{|\hat{t} \times \hat{n}_2|}$$

$$\hat{\beta}_1 = \frac{(\hat{t} \times \hat{n}_1)}{|\hat{t} \times \hat{n}_1|}$$

$$\hat{\beta}_2 = \frac{(\hat{t} \times \hat{n}_2)}{|\hat{t} \times \hat{n}_2|}$$

$$\cos\Delta\phi = \frac{\hat{n}_1 \bullet \hat{n}_2 - (\hat{t} \bullet \hat{n}_1)(\hat{t} \bullet \hat{n}_2)}{|\hat{t} \times \hat{n}_1||\hat{t} \times \hat{n}_2|}$$

$$\sin\Delta\phi = \frac{\hat{t} \bullet (\hat{n}_2 \times \hat{n}_1)}{|\hat{t} \times \hat{n}_1||\hat{t} \times \hat{n}_2|}$$

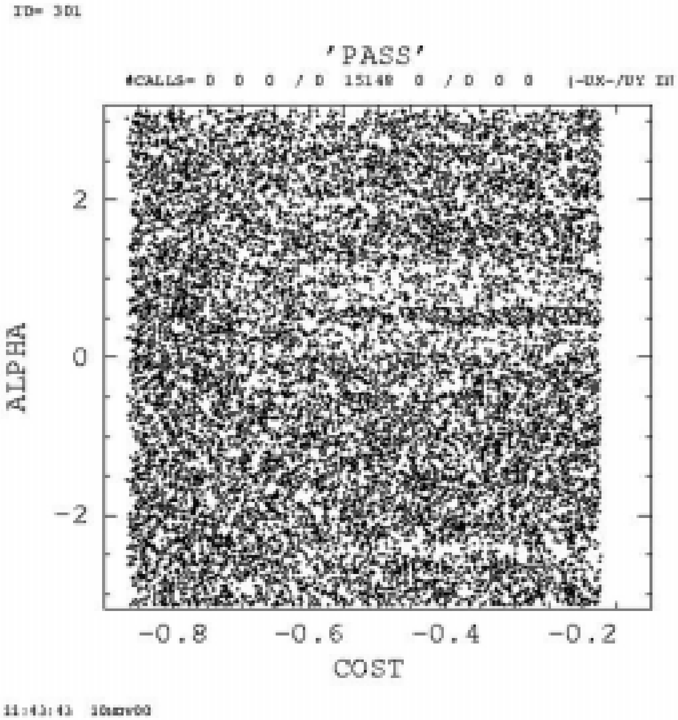
The calculation is described in an appendix to this note.

Track Matching

Because the fitter is instructed to use the momentum of the drift chamber track which is being matched, and since the fitter fits offsets and directions in two dimensions the number of fit parameters is usually equal to four. But if the fitter cannot resolve one or more of the fit parameters due to a lack of sufficient hits in the two orthogonal directions, one or more fit parmaters must be excluded, and $n<4$. The addition of 45-degree information in some regions of θ and ϕ makes it possible for the fitter to find all four fit parameters where only three would be possible with the barrel and endcap alone.

Penetration Analysis

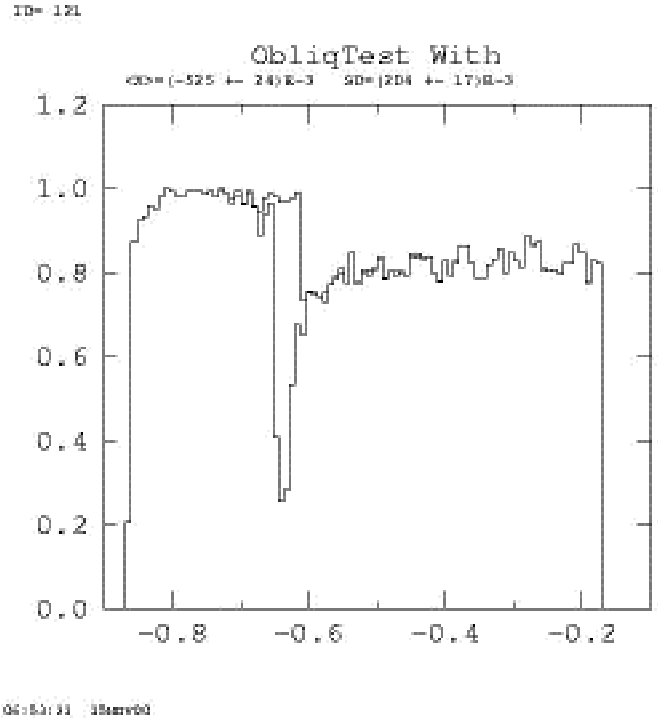
The penetration analysis flags a WIC track as fully penetrating if it has at least two hits in the last two layers chambers which are encountered as the track is extrapolated outward through the detector. The double layers of each 45-degree chamber automatically fulfill this requirement.



Results

Figure 4. shows (for comparison with figure 1.) the monte carlo acceptance without background in cosθ and ϕ for high energy muons after commissioning of the 45-degree region.

The monte carlo efficiency for single 45-Gev muons as a function of theta is shown in figure 5. for the south end of the detector; the plot overlays the efficiency after commissioning with the production version. Figures 5 and 6 do not include dead channels.



Conclusions

In 1994 at the time we undertook this task, the experiment was much more statistics limited than systematics limited. By the time the commissioning task was drawing to completion this was not longer quite as true. It became clear that the additional potential for physics provided by the 45-degree chambers was limited, because of the systematic uncertainties associated with the strange acceptance, background muons from the SLC, uncertainties in the magnetic field in the vicinity of the chambers, and skepticism about the quality of the WIC fitter swimmer which does the track extrapolation for the fitter.

Conclusions

About 15,000 lines of FORTRAN code have been written in connection with the 45-degree chamber commissioning since early 1995, including the revised subsystem code, programs to create and test the fitter geometry and its pointers, and to test the fitter locator routines. More than fifty routines and data files were written new or revised for the WIC code. About 25 of them were written or modified by the Mississippi group, and dozens more were written by us for the programs to build the fitter geometry.

The code updates for the WICSHR and SWIMSHR executables reside in [rkroeger.wic]. This is exclusive of code (25 routines and data files) that has already been put into prod by David Williams and Giampeiro including our geometry updates to the GEANT geometry.

SWEXTGP	Resides in SWEXTR.prepmort. Was altered to change some hardwired limits on how far tracks may propagate in the WIC fitter swimmer.
WFBDAT.prepmort	Block data expanded to include WFGC45 common.
WFCHID.prepmort	400 words of data added plus significant code changes to supply the association between fitter volumes in the locator routines and hit identifiers for the data.
WFCODAT.prepmort	300 words of data plus code supplying direction cosines for the measurement axis and normal direction of each plane
WFCONS.prepmort	Elaborate kludge added to allow for stair step steel to be restored to the endcap. Numerous other changes to allow for 45-degree code (e.g. more than six faces per volume are now allowed etc.)
WFCONS45.prepmort	New routine to construct 45-degree volumes in the same format as WFCONS. 6000 words of data created in WFGC45.common.
WFITC.common	Changes to some dimensions etc.
WFCVOL.comdat	Minor additions to allow for reflections in x and z in 45-degree locator routines and to accomodate kludge for missing endcap steel.
WFGC.comdat	New direction cosines were created for chambers inside endcap legs and others.
WFGC45.comdat	New file creating 6000 word description of WIC fitter geometry for the arch/leg/45 region
WFFSS.prepmort	Extesnsively rewritten to accomodate a whole new “the headstone” region including the arch, legs and 45 degree chambers.
WFLIKE.prepmort	Modified to allow for new obliquity factor.
WFLOC.prepmort	Modified to call the 45-degree versions of WFCONS, WFSSO when locator point is in the arch/leg/45 region
WFOBLIQ.prepmort	New routine which calculates the new obliquity factor in χ^2 appropriate to the barrel endcap joint.
WFSSO.prepmort	Altered so that tracks leaving the barrel or endcap are propogated into the arch/leg/45 region, and to accomodate kludge for stair step region.

WFSSO45.prepmort	New routine which sets the search order for 45 degree fitter volumes
WFSTEP.prepmort	Altered to create a work around for double layers in the 45-degree chambers which were not created separately in the fitter geometry to be able to use both the longitudinal and transverse strips.
WGPOSP	New routine, creates WIC fitter volume planes in parallel when GEANT routines creating trapezoids and boxes are called to created chambers or arch/leg structure. Resides in WGVOLA.prepmort
WGVOLA /WGVOLC WGVOLUB	reside in WGVOLA/prepmort. In these three routines some code was added to the routines WGVOLA,WGVOLUB, WGVOLC, to call WGPOSP in parallel when arch/leg/chamber volumes are being created in GEANT.
WUFFITH	Resides in WUFFIT.prepmort. code and 300 words of data added to supply measurement axis and direction cosines. Altered to allow 45-degree hits to retain subsystem information.
WUFHITS.prepmort	Altered to keep track of the number of 45-degree
WUFHDT	In WUFHITS.prepmort. Altered to create a new direction type for each 45-degree chamber layer.
WUFPAT.prepmort	Altered to reduce the number of hits required in endcap and 45 regions.
WUFPEND	In WUFPEN.prepmort was altered to exempt 45-degree hits from the calculation of subsystem information from geometry .
WFDREF.prepmort	Modified to allow 45-degree hits to be considered in and number number of track parameters to fit.
WFIT.prepmort	Altered to use 45 degree hits differently than others in finding the number of track parameters to fit.