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CLAS TOF SCINTILLATOR POSITIONS

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This note details the calculation of the CLAS TOF scintillator positions using the JLAB Survey Group surveys. The "as built" positions within the support structures (Forward Carriage, North Clamshell, South Clamshell, and Space Frame) are determined. The positions of the scintillators with respect to the CLAS target are then determined from these positions and the survey of the movable support structures.

1. Introduction

The CEBAF Large Angle Spectrometer (CLAS) TOF system consists of 342 scintillators arranged in six sectors to match the six fold azimuthal symmetry of the CLAS. Each sector is subdivided into four panels. These 24 planes of scintillators are rigidly mounted on nine structures, the Forward Carriage (FC), the North Clamshell (NC), the South Clamshell (SC), and the six Space Frames (SF). These nine structures can be moved independently and frequently are during maintenance of the CLAS. The six sectors of the SF, unlike the other structures, can pivot independently but cannot move otherwise. Figures 1 and 2 show the details of these arrangements. There are two exceptions to these

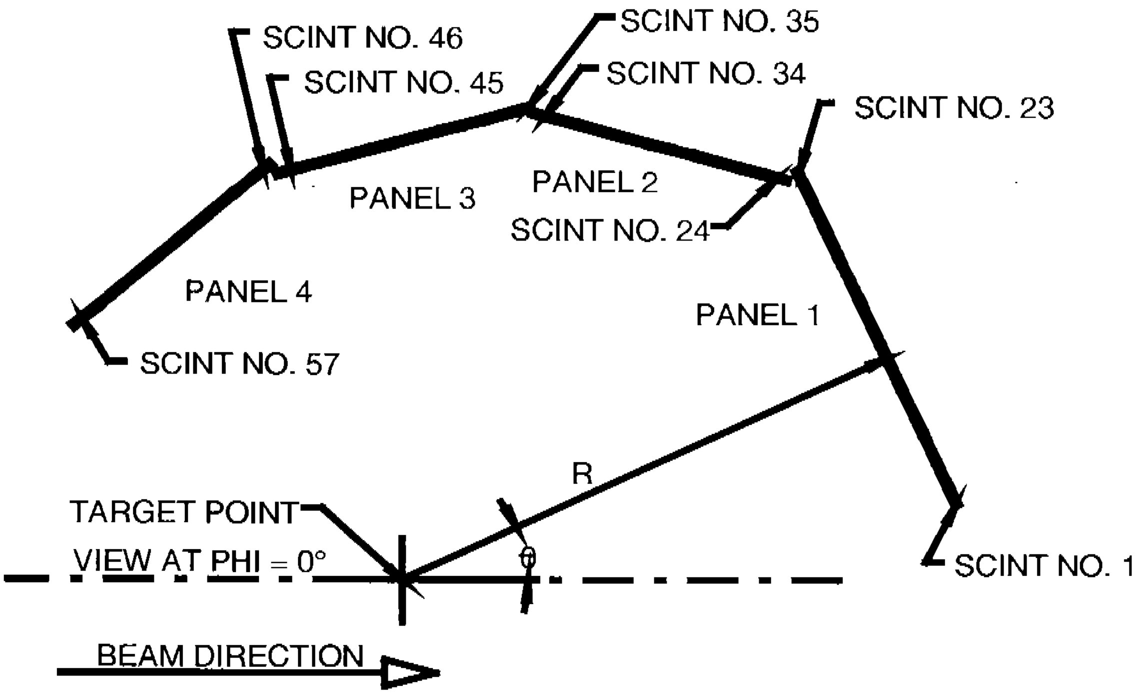

Figure 1. Arrangement of TOF panels in CLAS.

statements. The six SF panels can be adjusted by approximately one cm in X, Y, or Z, but this will be done only once, and then the attachments will be welded in position. This has not been done at the time of this document. Also the bottom sectors of panel 2 (sector 6 in the SC and sector 5 in the NC) can be pivoted about their attachment point to the Clamshells near scintillator #24. However the screw jacks driving this motion are marked so that the position of these planes should be reproducible. We will assume that this is so and ignore this degree of freedom.

The FC contains all six sectors of panel 1. Each sector contains scintillators #1 - #23. The NC contains sectors 3, 4, and 5 of panels 2 and 3. The SC contains sectors 1, 2 and 6 of panels 2 and 3. Each sector of panel 2 contains scintillators #24 - #34. Each sector of panel 3 contains scintillators #35 - #45. Finally, the SF contains all six sectors of panel 4, comprising scintillators #46 - #57. In order to reduce the number of electronics channels, some of the scintillators have been ganged together electronically. Since there is no way to tell which of the two scintillators were struck by looking solely at TDC and ADC data, these counters are treated as single double width units. This occurs for the last four scintillators in panel 3 and all of the scintillators in panel 4. Thus the SCG BOS bank contains the positions of TOF paddles #40 - #42 in panel 3 which are the ganged scintillators #40-#41, #42-#43 and #44-#45. In panel 4, all scintillators are ganged together in pairs to form paddles #43 - #48. Further details about the scintillators are given in Appendix A.

The position of the scintillators can be determined by the following procedures. (Since the SF presents unique problems, it will be discussed separately). Paper surveying foils are pasted on the surface of the scintillator planes facing the center of CLAS. There are 4 –7 such foils on the various planes. There are also precision optical positioning targets attached to the FC, NC, and SC. The Jefferson Laboratory Alignment Group (JLAG) surveys these foils and targets when the CLAS is open. The targets on the support structures are also surveyed when the CLAS is assembled for running, at which time the foils on the scintillators cannot be seen. From this data, the JLAG calculates the position of the foils on the face of the scintillator panels in the assembled position. These numbers are assumed to be accurate to better than 2 mm in Z and 1 mm in X or Y. A survey of any structure that has been moved is made each time the CLAS is reassembled. The nomenclature and coordinates of these foils with respect to the panel is given in Appendix B.

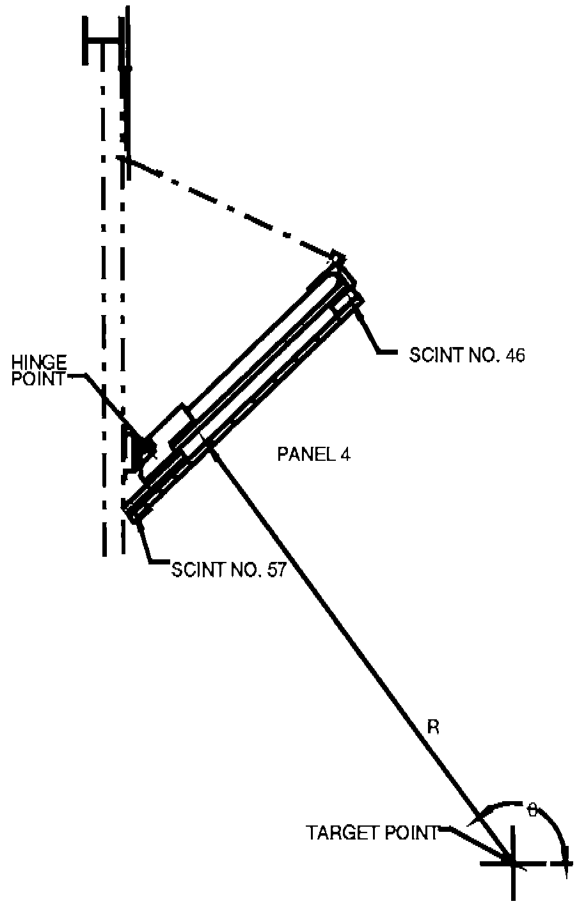

Figure 2. Details of panel 4 support structure.

The purpose of this note is to detail how these survey numbers are converted into the positions of the individual scintillators for use in the data analysis. The problem is twofold. First the position of each scintillator on its support structure must be determined, and secondly the position of the support structure must be determined. The first task need only be done once, while the second must be done for each setup. The coordinates of the scintillators with respect to their support structures is given in terms of their positions in the CLAS coordinate system assuming that the support structures are perfectly aligned on the beam axis and at the desired position along the beam line. This is will be called the "nominal" position or the "body coordinates". Then the coordinates of the support structures, which vary each time the CLAS detector is reassembled, are used to calculate the "actual" or "space coordinates" of the scintillators. These positions were derived from the December 3, 1997, March 10, 1998, and March 31, 1998 survey data (Kelly Tremblay x7282 Data Transmittals #391, #418 and #426), and are given in mm.

2. Co-ordinate systems

The foil survey data and the position of the scintillators are given in terms of the Hall B coordinate system. This system has it's origin at the incoming beam's X and Y location, and a Z at the center of the CLAS Torus magnet. This is a right handed coordinate system with positive Z pointing downstream, positive Y pointing up, and positive X pointing in the horizontal plane, beam left.

The position of the scintillator planes with respect to the CLAS coordinate system is given in terms of the normal vector, **R**. **R** is specified by the coordinates R, θ, and ϕ, where R is the normal distance from the CLAS origin to the plane, θ is the polar angle and ϕ is the azimuthal angle. (See Fig 1.)

The coordinates of a foil (or scintillator) in a given scintillator plane is given by X', the distance from the downstream edge of the lowest numbered scintillator and Y', the distance from the centerline of the scintillator plane. X' and Y' are defined and tabulated for the foils in Appendix B. We assume that all scintillators are aligned to the centerline of a given plane. The position of this plane with respect to the CLAS Coordinate system is given by the coordinates X_{off}, ΔY and ϕ'. X_{off} measures the distance from the leading edge of the plane (downstream edge of lowest numbered scintillator), to the intersection of the normal vector. ΔY measures the distance from the centerline of the scintillators to the intersection of the normal vector. The angle ϕ' measures the rotation of the scintillator plane about the intersection of the normal vector. These last three parameters can vary each time the CLAS detector is reassembled.

The coordinates of each scintillator, which are stored in the SCG BOS bank, are given in terms of the coordinates defined in CLAS-Note #96-014 [1]. Basically the center of each end of a scintillator is stored and labeled as XCW, YCW, ZCW, and XCCW, YCCW, and ZCCW. These coordinates are in the CLAS coordinate system and are given in units of centimeters. CW and CCW refer to clockwise and counterclockwise. This bank gives the coordinates of the center of a double width paddle, rather than the coordinates of the individual scintillators. See CLAS-Note #96-014 for details.

3. Position Calculations

The normal vector from the center of CLAS to a given scintillator plane is found by fitting a plane given by the equation

$$X/a + Y/b + Z/c = 1,$$

to the coordinates of the survey foils. The set of m simultaneous linear equations

$$a_{11}x_1 + a_{12}x_2 + a_{13}x_3 = 1$$
$$\ldots\ldots$$
$$a_{m1}x_1 + a_{m2}x_2 + a_{m3}x_3 = 1$$

can be written as the matrix equation

$$A \bullet x = b$$

where $a_{i1} = x_i$, $a_{i2} = y_i$ and $a_{i3} = z_i$ are the coordinates of survey foils and $x_1 = 1/a$, $x_2 = 1/b$ and $x_3 = 1/c$. These equations are solved using standard matrix inversion techniques [2]. The least squares fit to the m simultaneous equations is given by

$$(A^T \bullet A) \bullet x = A^T \bullet b$$

where A^T is the transpose of the matrix A. The normal vector is then calculated from the equations

$$a = R/\sin\theta\sin\phi$$
$$b = R/\sin\theta\cos\phi$$
$$c = R/\cos\theta$$

and the coordinates of the intersection of the normal vector with the scintillator plane is given by the equations

$$X = a\,\sin^2\theta\sin^2\phi$$
$$Y = b\,\sin^2\theta\cos^2\phi$$
$$Z = c\,\cos^2\theta.$$

The above procedure gives the distance to the face of the scintillators. To find the coordinate of the center of a scintillator we must increase R by 2.62 cm. Typical values of R_C, θ and ϕ are given in Table 1, where R_C is the distance to plane through the center of the scintillators.

Using the measured positions, X′ and Y′, of the survey foils, we then calculate the quantities X_{off}, ΔY, and ϕ'. We can also calculate W, the distance between the centers of adjacent scintillators. In general W = 151.5 mm for panel 1 and 221.5 mm for panels 2, 3 and 4. (The details about the widths are given in Appendix A). The extra 1.5 mm corresponds to the scintillator wrapping thickness. The positions of the survey foils are then given by the following equations

$$X'' = X'\cos\phi' - (Y' - \Delta Y)\sin\phi' + Xoff$$
$$Y'' = X'\sin\phi' + (Y' - \Delta Y)\cos\phi'$$
$$X = R\,\sin\theta\,\cos\phi + X''\cos\theta\,\cos\phi - Y''\sin\phi$$

$$Y = R \sin\theta \sin\phi + X'' \cos\theta \sin\phi + Y'' \cos\phi$$
$$Z = R \cos\theta - X'' \sin\theta$$

Table 1. Normal vector, $\mathbf{R_C}$, to the 24 planes of scintillators

Panel	Sector	R (cm)	θ	φ	Panel	Sector	R (cm)	θ	φ
1	1	493.6	24.70	0.16	3	1	398.3	105.09	-0.02
1	2	493.4	24.79	60.50	3	2	397.6	105.19	60.02
1	3	493.1	24.86	119.04	3	3	398.3	104.86	119.89
1	4	493.5	24.67	179.81	3	4	399.3	104.48	179.90
1	5	493.3	24.74	240.30	3	5	395.9	105.29	240.22
1	6	492.8	24.80	299.93	3	6	399.0	104.89	300.35
	Av	494.4	24.76	-0.04			398.1	104.97	0.06
2	1	456.4	75.04	-0.07	4	1	377.3	129.09	-0.08
2	2	456.0	75.08	59.88	4	2	377.3	129.72	60.36
2	3	455.0	74.93	119.75	4	3	377.1	130.28	119.60
2	4	455.7	74.94	180.17	4	4	377.5	130.37	180.03
2	5	453.8	75.15	240.24	4	5	377.8	130.59	139.73
2	6	456.0	74.60	300.54	4	6	378.1	129.97	300.08
	Av	455.7	74.96	0.09			377.5	130	-0.05

These coordinates are calculated for each of the survey foils and compared to the survey numbers. The parameters ΔY and φ′ are varied to minimize the difference. This set of parameters is then used to calculate the positions of each scintillator.

AS was stated earlier, the foil survey numbers are accurate to better than 2 mm in Z and 1 mm in X or Y. The foils are assumed to lie in a flat plane and are placed to about 1/16" (1.6 mm) accuracy in X' and Y'. Thus we would expect that the foil positions from the survey and those calculated from the R, θ,φ, X' and Y' coordinates would agree to better than 1.8 mm in X and Y and 2.5 mm in Z. The corresponding mean and rms of this difference are given in Table 2. The rms values are best for the FC and in fact are better than the estimates just given. The NC and SC have worse agreement, presumably because the survey targets were added after the scintillator panels had been mounted on the CLAS detector. In this case it was difficult to place them to an accuracy of 1/16". The positions of the individual scintillators with respect to the foils should be accurate to about 1/16".

Table 2. Fitting errors

Structure	Panel	ΔX	σ	ΔY	σ	ΔZ	σ
FC	1	-0.02	1.5	0.02	1.5	-0.01	1.7
NC	2	0.07	2.8	0.08	2.7	0.20	2.7
SC	2	0.04	1.6	-0.16	2.6	0.01	2.6
NC	3	-0.02	2.3	-0.24	1.5	-0.02	2.3
SC	3	0.04	1.0	-0.09	3.0	0.00	3.0
SF	4	-0.08	5.2	-0.25	7.2	-0.01	7.7

4. Nominal Positions.

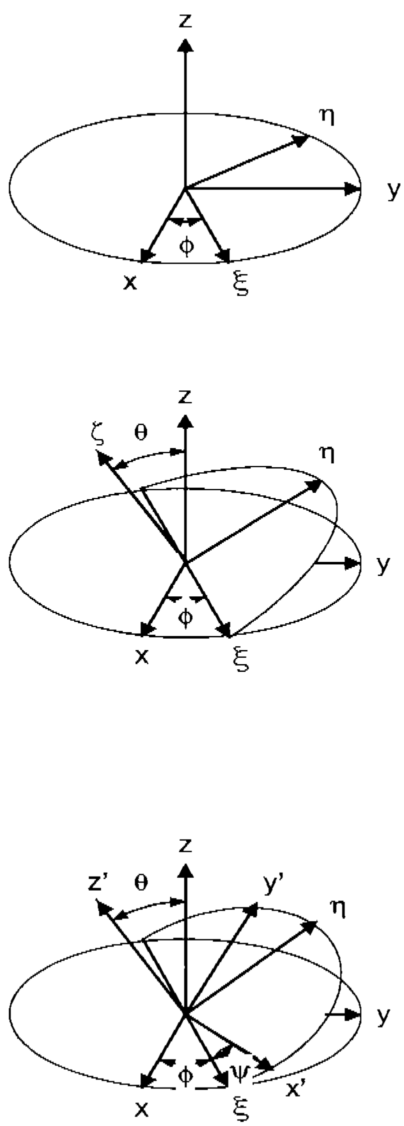

Figure 3. The rotations defining the Eulerian angles.

The above procedure gives the coordinates of each scintillator for a given survey. In order to reduce the number of data entries into the BOS banks, we have derived a set of positions for each scintillator assuming that the structure, the scintillator is mounted on, is at its optimum position. These are called the "nominal" positions. Then for each survey, the deviation of the support structure from this nominal position is calculated. These deviations can then be used to calculate the actual positions of the scintillators from the nominal positions. To do this we use the Euler angles, θ, ϕ, and ψ to describe the position of the rigid body supporting the panels [3]. (See figure 3). The deviation of the structure is then calculated in terms of the Euler angles and the deviations ΔX, ΔY, and ΔZ of the axis of this body from the center of the CLAS detector. The position of the scintillators with respect to the CLAS target is then given by the equations

$$X = X_{rot} - \Delta X$$
$$Y = Y_{rot} - \Delta Y$$
$$Z = Z_{rot} - \Delta Z$$

The rotated positions are given by

$$X_{rot} = A^{-1} X_{nom}$$

where X_{nom} are the nominal coordinates of a scintillator and A^{-1} is the inverse of the Euler transformation matrix. A^{-1} is given by

$$X_{rot} = X_{nom}(\cos\psi\cos\phi - \cos\theta\sin\phi\sin\psi) + Y_{nom}(-\sin\psi\cos\phi - \cos\theta\sin\phi\cos\psi) + Z_{nom}\sin\theta\sin\phi$$
$$Y_{rot} = X_{nom}(\cos\psi\sin\phi + \cos\theta\cos\phi\sin\psi) + Y_{nom}(-\sin\psi\sin\phi + \cos\theta\cos\phi\cos\psi) - Z_{nom}\sin\theta\cos\phi$$
$$Z_{rot} = X_{nom}\sin\theta\sin\psi + Y_{nom}\sin\theta\cos\psi + Z_{nom}\cos\theta$$

The rigid body is defined differently for each structure. For the FC the two planes passing through the middle of scintillators #1 and #23 define the body. These coordinates are fitted to a plane using the procedures described above. The normal vectors to these two planes are rotated to be parallel to the beam axis. Then the offset of this axis from the beam line is calculated giving ΔX and ΔY. ΔZ is chosen to place scintillators #23 at a

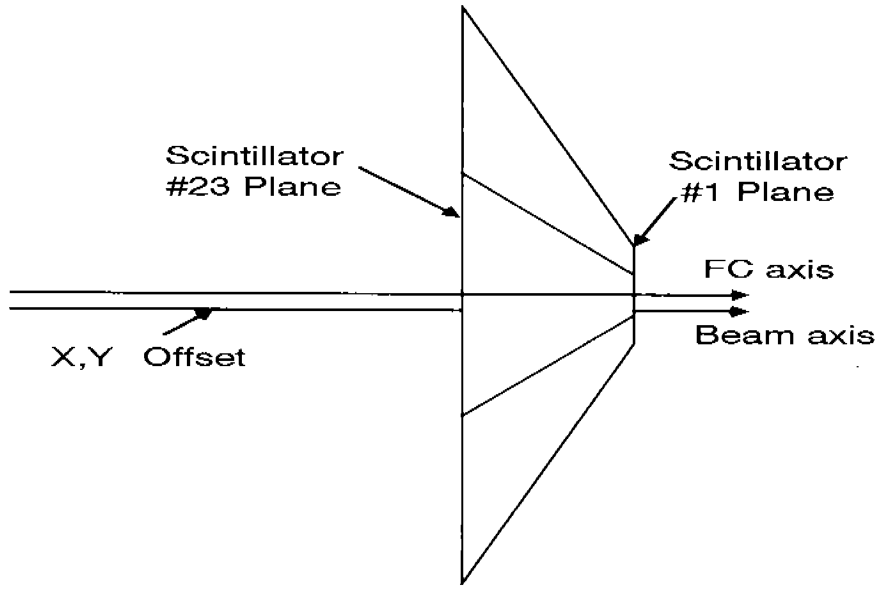

Figure 4. FC alignment

nominal distance of Z = 368.0 cm from the CLAS target. See figure 4.

For the NC and SC, the ends of scintillators #24, #34, #35 and #45 define four planes. These are then rotated and the offsets calculated. ΔZ is chosen to place scintillators #35 at

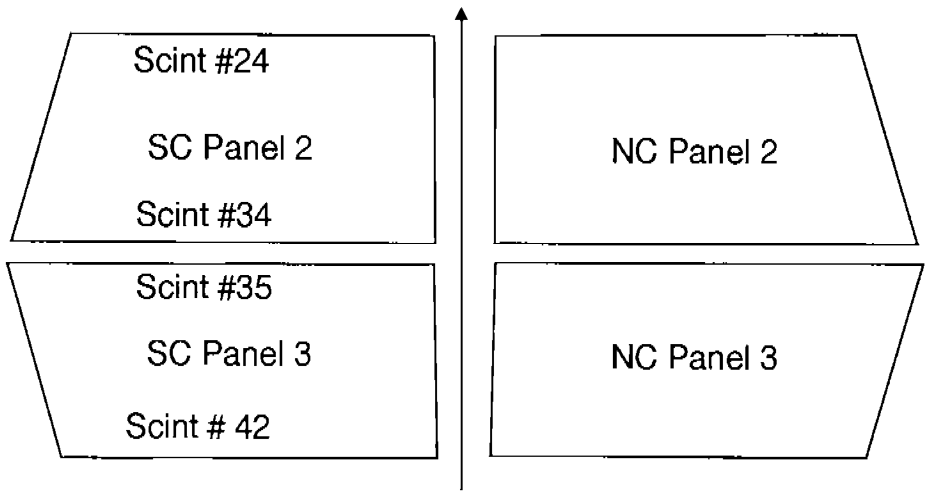

Figure 5. Alignment of NC and SC

a nominal distance of Z = 345.8 cm from the CLAS target. See figure 5.

5. Space Frame

The SF panels have to be treated slightly differently since each of the six panels can move independently, but only about an axle attached to the immobile Space Frame structure. See figure 2 for details. The design values of the axle coordinates are given by

$$\phi_p = 60°(\text{Sec\#} - 1)$$
$$X_{axle} = 302.7 \cos\phi_p \text{ cm}$$
$$Y_{axle} = 302.7 \sin\phi_p \text{ cm}$$
$$Z_{axle} = -272.5 \text{ cm}$$

These values were used in the analysis, since the axle positions have not been surveyed. The positions of the survey foils are fitted to find R, θ, and ϕ as described above. Then the coordinates X_{off}, ΔY and ϕ' are determined. For panel 4, X_{off} measures the distance from the downstream edge of the plane (downstream edge of scintillator # 57), to the intersection of the normal vector. These last three parameters cannot vary since the pivot point is rigidly mounted to the Space frame. (See, however, the comment in the first paragraph). Rotating the structure to the nominal position must be handled differently than the procedure given earlier. The procedure consists of translating the axle of a given scintillator plane to the CLAS origin and rotating the plane to the nominal angles of $\theta = 130°$ and $\phi = 60°(\#\text{Sec} - 1)$. The ΔZ is chosen so that the actual pivot point is at the design value. The axle of the plane is then translated back to the nominal position.

In this case the survey numbers are not accurate to 1mm in X and Y and 2 mm in Z. The JLAG had to set up their equipment on the Space Frame which vibrates from the mechanical equipment installed. As can be seen from table 2, the rms for the fits to the foils was about 7 mm. Also they could not survey foils placed on the surface of the scintillators as in the other cases. Instead foils were placed on the aluminum frames that support each scintillator and the positions of the scintillators were calculated from these points. This introduced an additional several mm of error in the nominal positions of the scintillators. As a result we estimate that the panel 4 scintillators positions are known to about one cm.

6. Results

The nominal geometry for the TOF array is stored in a fpack format file in $CLAS_PARMS. The differences between the nominal geometry and the actual geometry for each carriage and the spaceframe are stored in a run-indexed database called GEOMETRY.map in $CLAS_PARMS/Maps as the following variables;

FC: fwd_carr_pos, fwd_carr_ang
NC: n_clam_pos, n_clam_ang
SC: s_clam_pos, s_clam_ang
SF: space_f1_pos, space_f2_ang,

space_f2_pos, space_f2_ang,
etc.

The above rotation and translation parameters for each running period are inserted into the map at a run number before the beginning of each running period. During the initialization of the Scintillator package in recsis [4], the positions and rotations of the various carriages and the space frame are read from the map and the nominal geometry values are manipulated in software to remake the SCG BOS bank. Thus this bank then contains the actual TOF geometry to be used for that running period.

The results for the FC, NC and SC for the Dec. 1997 survey, the FC and SC for the March 1998 survey and for the FC and SF for the April 1998 survey are given in Table 3. The SF was not surveyed before April 1998. The NC was not moved after the Dec. 1997 survey, while the SC was not moved after the March 1998 survey. The units are centimeters and degrees. The parameters given in the table have been entered into the GEOMETRY_map bank. The Dec. 1997 survey data was used to derive the FC and NC nominal positions. The March 1998 survey data was used to derive the SC nominal positions. And, finally, the April 1998 survey data was used to derive the SF nominal positions. Comparison of the scintillator positions calculated from the nominal positions and the parameters in Table 3 with the actual positions of the scintillators derived from the individual surveys, agree to better than 2 mm. The nominal positions are estimated to be accurate to about 2 to 3 mm for the FC, NC and SC and about 1 cm for the SF.

The "as built" positions are in reasonably good agreement with the design goals. From Table 1 we see that the design goals of θ=25°, 75°, 105° and 130° and ϕ = 60°(Sec# - 1)

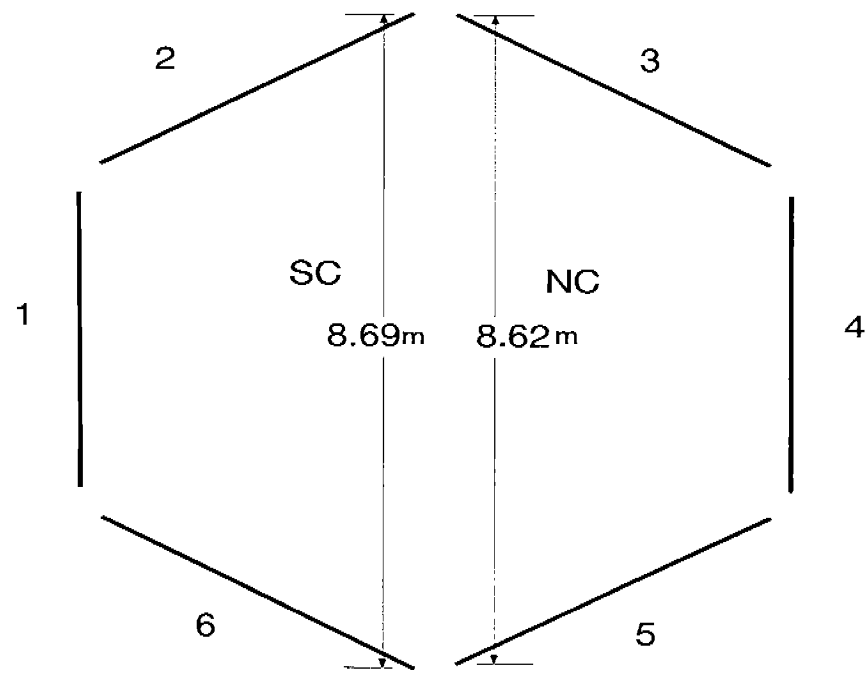

Figure 6. Upstream End of TOF Panel 3

were met to better than 0.5°, except for panel 1 sector 3 where ϕ is low by 1°. The value of R is also in good agreement with the design goals of 494.4, 455.7, 398.3 and 377.0 cm. The major disagreement occurs in panel 3 in the spacing between the ends of the scintillators, #35, in sectors 1 and 6 and sectors 2 and 5. This is larger by about 7 cm for the SC than in the NC. This is shown in figure 6. From the values of R given in Table 1, it appears that sector 5 of panel 3 is the primary cause of this misalignment.

Table 3. Geometry_map parameters

These parameters give the offset and rotations of the FC, SC, NC, and SF for the Dec. 1997, March 1998 and April 1998 surveys.

Date	Structure	ΔX (cm)	ΔY (cm)	ΔZ (cm)	θ (deg)	φ (deg)	ψ (deg)
Dec-97	FC	0.40	-0.65	-0.60	0.03	-79.22	79.15
	NC	1.00	0.70	-2.52	0.00	0.00	0.22
	SC	1.40	1.55	-7.27	0.51	-78.50	78.33
Mar-98	FC	0.61	-0.86	-0.90	0.07	251.80	-251.86
	SC	0.50	1.00	-1.67	0.34	-86.00	86.00
	SF1	-1.36	-1.17	-1.64	0.913	-90.081	90.00
	SF2	-2.00	0.00	-1.03	0.279	-29.639	30.00
	SF3	1.57	-1.79	-1.96	0.281	-150.400	150.00
	SF4	1.11	0.14	-1.02	0.371	-89.970	90.00
	SF5	0.38	0.78	-1.19	0.588	-30.267	30.00
	SF6	-1.58	-0.02	-1.84	0.030	210.080	-210.00
Apr-98	FC	0.29	-0.46	-0.35	0.02	-66.60	66.50

7. References:

1. CLAS note 96-014 Sc 2.2 "Time of flight Scintillator Reconstruction Software"
2. Press, W.H. et. al., Numerical Recipes. Cambridge, Cambridge University Press (Chap. 14)
3. Goldstein, Herbert, Classical Mechanics. Reading Mass, Addison-Wesley (pg. 107-9)
4. RECSIS, http::/www.cebaf.gov/clas/recsis/recsis.html

Appendix A. Scintillator Details

The length and width of each scintillator is given in Table 4. All scintillators are 5.08 cm thick (2"). The arrangement of the scintillators in each panel is shown in figure 7. The last four scintillators in panel 3 and all of the scintillators in panel 4 are ganged together to form double width paddles. Thus in panel 3 the TOF scintillators #40-#41, #42-#43 and #44-#45 are ganged together to form the paddles #40 - #42. In panel 4, all the TOF scintillators, #46-#57 are ganged together in pairs to form paddles #43 - #48. Table 5 lists the angle and Table 6 the distance of the center of each scintillator with respect to the CLAS coordinate system. These numbers vary from run to run depending on the positioning of the support structures. The values given in the table are for the Dec. 1997 survey.

Table 4. Scintillator Dimensions

Panel #	Scint #	Width (mm)	Length (mm)	Panel #	Scint #	Width (mm)	Length (mm)
1	1	150	322.9	2	31	220	4193.3
1	2	150	481.4	2	32	220	4261.9
1	3	150	640.0	2	33	220	4330.5
1	4	150	798.5	2	34	220	4399.0
1	5	150	957.1	3	35	220	4450.6
1	6	150	1065.6	3	36	220	4393.2
1	7	150	1224.2	3	37	220	4335.5
1	8	150	1382.7	3	38	220	4278.1
1	9	150	1541.3	3	39	220	4220.5
1	10	150	1699.8	3	40	220	4163.1
1	11	150	1858.4	3	41	220	4105.4
1	12	150	2016.9	3	42	220	4047.7
1	13	150	2175.5	3	43	220	3990.3
1	14	150	2334.0	3	44	220	3932.7
1	15	150	2492.6	3	45	220	3875.3
1	16	150	2651.1	4	46	220	3800.6
1	17	150	2809.7	4	47	220	3635.2
1	18	150	2968.2	4	48	220	3469.6
1	19	150	3126.7	4	49	220	3304.3
1	20	150	3285.3	4	50	220	3138.7
1	21	150	3443.8	4	51	220	2973.1
1	22	150	3602.4	4	52	220	2807.7
1	23	150	3761.0	4	53	220	2642.1
2	24	220	3713.0	4	54	150	2467.9
2	25	220	3781.6	4	55	150	2354.1
2	26	220	3850.1	4	56	150	2240.5
2	27	220	3918.7	4	57	150	2126.7
2	28	220	3987.3				
2	29	220	4056.1				
2	30	220	4124.7				

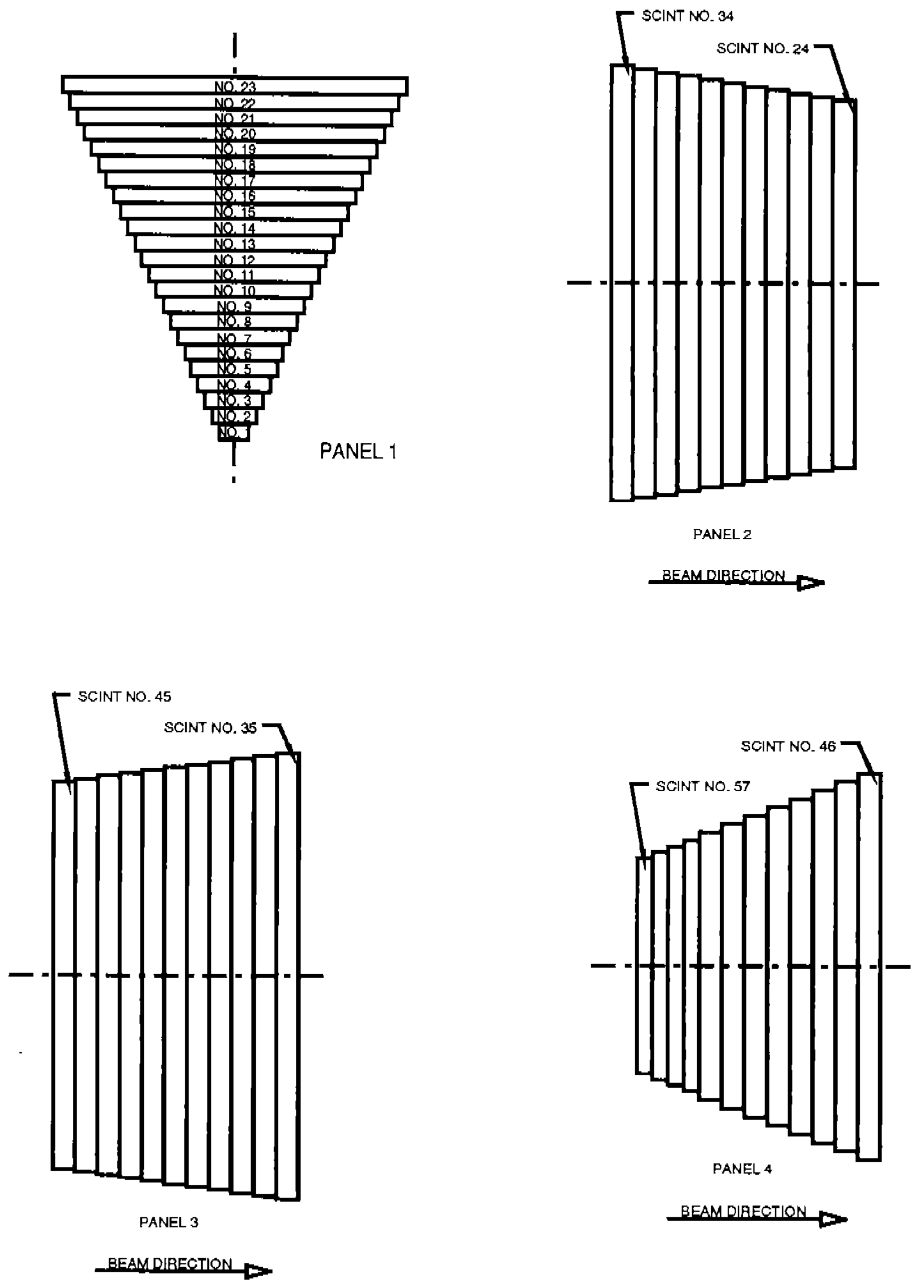

Figure 7. Arrangement of Scintillators in panels 1-4.

Table 5. Scintillator angle versus sector number

Panel	Scint #	1	2	3	4	5	6
1	1	8.62	8.58	8.62	8.55	8.62	8.59
1	2	10.26	10.22	10.26	10.20	10.26	10.23
1	3	11.92	11.89	11.92	11.86	11.93	11.89
1	4	13.61	13.57	13.60	13.55	13.62	13.58
1	5	15.32	15.28	15.31	15.26	15.33	15.29
1	6	17.04	17.00	17.03	16.98	17.05	17.02
1	7	18.78	18.74	18.76	18.72	18.79	18.76
1	8	20.53	20.49	20.51	20.48	20.54	20.51
1	9	22.29	22.24	22.27	22.23	22.30	22.26
1	10	24.05	24.00	24.03	24.00	24.06	24.03
1	11	25.81	25.77	25.79	25.76	25.83	25.79
1	12	27.57	27.53	27.55	27.53	27.59	27.56
1	13	29.33	29.28	29.31	29.28	29.35	29.32
1	14	31.07	31.03	31.05	31.03	31.10	31.06
1	15	32.81	32.77	32.79	32.77	32.83	32.80
1	16	34.53	34.49	34.51	34.49	34.56	34.53
1	17	36.23	36.19	36.21	36.20	36.26	36.23
1	18	37.91	37.87	37.90	37.88	37.95	37.92
1	19	39.57	39.53	39.56	39.54	39.61	39.58
1	20	41.20	41.17	41.19	41.18	41.24	41.22
1	21	42.81	42.78	42.80	42.79	42.85	42.83
1	22	44.39	44.36	44.38	44.37	44.43	44.41
1	23	45.93	45.91	45.94	45.92	45.98	45.96
2	24	47.36	47.71	47.82	47.77	47.60	47.49
2	25	49.60	49.96	50.08	50.03	49.85	49.75
2	26	51.92	52.28	52.42	52.37	52.20	52.09
2	27	54.33	54.69	54.84	54.79	54.62	54.52
2	28	56.82	57.17	57.34	57.30	57.13	57.02
2	29	59.38	59.72	59.91	59.87	59.71	59.60
2	30	62.00	62.34	62.55	62.51	62.35	62.24
2	31	64.68	65.01	65.24	65.20	65.05	64.93
2	32	67.40	67.73	67.97	67.94	67.79	67.66
2	33	70.15	70.48	70.74	70.71	70.57	70.42
2	34	72.93	73.25	73.52	73.50	73.37	73.21
3	35	75.73	75.94	76.36	76.37	76.22	76.02
3	36	78.22	78.42	78.88	78.90	78.73	78.52
3	37	80.82	81.02	81.50	81.54	81.35	81.14
3	38	83.53	83.72	84.23	84.30	84.08	83.86
3	39	86.35	86.52	87.07	87.15	86.92	86.69
3	40	89.26	89.42	89.99	90.09	89.86	89.61
3	41	92.25	92.40	93.00	93.11	92.88	92.62
3	42	95.31	95.45	96.08	96.20	95.97	95.69
3	43	98.43	98.65	99.21	99.34	99.12	98.82
3	44	101.59	101.71	102.37	102.51	102.30	101.98
3	45	104.77	104.88	105.55	105.69	105.51	105.16
4	46	108.75	108.78	108.93	108.76	108.79	108.82
4	47	111.77	111.76	111.91	111.72	111.74	111.79
4	48	114.88	114.86	114.99	114.79	114.80	114.87
4	49	118.09	118.05	118.17	117.95	117.96	118.05
4	50	121.36	121.31	121.42	121.20	121.19	121.30
4	51	124.69	124.62	124.73	124.50	124.49	124.60
4	52	128.04	127.97	128.08	127.85	127.83	127.94
4	53	131.40	131.34	131.45	131.21	131.19	131.30
4	54	134.22	134.16	134.27	134.03	134.01	134.12
4	55	136.50	136.44	136.56	136.32	136.29	136.39
4	56	138.75	138.70	138.82	138.58	138.56	138.65
4	57	140.97	140.93	141.06	140.82	140.80	140.88

Table 6. Scintillator radius (cm) versus sector number

Panel	Scint #	1	2	3	4	5	6
1	1	513.4	513.4	513.1	513.3	513.4	513.1
1	2	509.4	509.4	509.1	509.3	509.3	509.1
1	3	505.9	505.8	505.5	505.7	505.8	505.5
1	4	502.7	502.6	502.3	502.6	502.6	502.3
1	5	500.0	499.9	499.5	499.8	499.9	499.6
1	6	497.8	497.6	497.3	497.6	497.6	497.3
1	7	496.0	495.8	495.4	495.8	495.8	495.4
1	8	494.7	494.5	494.0	494.4	494.5	494.1
1	9	493.8	493.6	493.1	493.5	493.6	493.2
1	10	493.4	493.1	492.6	493.1	493.1	492.7
1	11	493.5	493.2	492.6	493.2	493.2	492.8
1	12	494.0	493.7	493.1	493.7	493.7	493.2
1	13	495.0	494.6	494.0	494.7	494.7	494.2
1	14	496.5	496.0	495.4	496.1	496.1	495.6
1	15	498.4	497.9	497.3	498.0	498.0	497.5
1	16	500.8	500.3	499.6	500.4	500.4	499.8
1	17	503.6	503.0	502.4	503.2	503.2	502.6
1	18	506.8	506.3	505.6	506.5	506.5	505.9
1	19	510.5	509.9	509.2	510.1	510.1	509.5
1	20	514.6	514.0	513.2	514.2	514.2	513.6
1	21	519.2	518.5	517.7	518.8	518.7	518.1
1	22	524.1	523.4	522.5	523.7	523.7	523.0
1	23	529.4	528.7	527.8	529.0	529.0	528.3
2	24	513.8	513.0	510.5	510.4	509.9	510.5
2	25	504.0	503.5	500.8	500.6	500.1	500.9
2	26	495.0	494.6	491.9	491.7	491.0	492.0
2	27	486.9	486.5	483.9	483.6	482.9	484.0
2	28	479.6	479.3	476.7	476.5	475.6	476.9
2	29	473.2	473.1	470.5	470.2	469.2	470.8
2	30	467.9	467.8	465.3	465.0	463.9	465.6
2	31	463.5	463.5	461.0	460.7	459.5	461.4
2	32	460.2	460.2	457.8	457.5	456.2	458.2
2	33	457.9	458.0	455.7	455.3	453.9	456.2
2	34	456.6	456.8	454.6	454.2	452.7	455.1
3	35	456.6	456.6	454.1	452.4	452.5	454.8
3	36	446.2	446.3	443.9	442.4	442.2	444.6
3	37	436.8	436.8	434.7	433.3	432.8	435.2
3	38	428.3	428.3	426.4	425.1	424.3	426.9
3	39	420.8	420.8	419.1	418.0	416.8	419.5
3	40	414.3	414.4	412.9	411.9	410.3	413.1
3	41	408.9	409.0	497.7	407.0	405.0	407.9
3	42	404.7	404.7	403.8	403.2	400.8	403.9
3	43	401.7	401.7	401.0	400.6	397.8	401.0
3	44	399.9	399.8	399.4	399.3	396.1	399.3
3	45	399.2	399.1	399.1	399.1	395.5	398.8
4	46	402.3	404.0	404.8	406.0	406.9	405.4
4	47	395.1	396.6	397.3	398.3	399.2	398.0
4	48	389.1	390.3	390.9	391.8	392.6	391.6
4	49	384.3	385.2	385.7	386.5	387.1	386.4
4	50	380.7	381.4	381.6	382.3	382.9	382.5
4	51	378.3	378.8	378.8	379.4	379.9	379.8
4	52	377.3	377.5	377.3	377.8	378.2	378.3
4	53	377.5	377.4	377.1	377.5	377.8	378.2
4	54	378.7	378.4	378.0	378.2	378.4	379.1
4	55	380.4	379.9	379.3	379.5	379.6	380.5
4	56	382.6	382.0	381.3	381.3	381.4	382.5
4	57	385.5	384.6	383.8	383.8	383.8	385.1

Appendix B. Survey Foils

The arrangement and position of the survey foils within a given panel are given in Tables 7-10. The target nomenclature used by the JLAG is; Sector 1 is at 9 O'clock, 2 is at 11 O'clock, 3 is at 1 O'clock, 4 is at 3 O'clock, 5 is at 5 O'clock and 6 is at 7 O'clock. A schematic of the relative position of each target is given in figures 8-11. The variable Y" is the distance from the centerline of the panel to the survey target. The variable X' is determined from the equation

$$X' = (n-1) W$$

Where W is the center to center spacing of the scintillators and n is measured from the downstream edge of a scintillator. For example, n = 1 for the downstream edge of scintillator #1 and is at X' = 0. All dimensions are in mm.

Table 7. Panel 1 (FC) Survey Foils

Y' is the distance of the survey foil from the center of the panel. N is the distance from the front edge of the panel to the survey foil in units of the scintillator width. (W =151.5 mm).

Target	n	Y' (mm)	Target	n	Y' (mm)	Target	n	Y' (mm)
1A	23	-1696	3A	23	-1696	5A	22	-1696
1B	23	1696	3B	23	1696	5B	22	1696
1C	13	0	3C	13	0	5C	13	0
1D	2	-140	3D	2	-140	5D	2	-140
1E	2	140	3E	2	140	5E	2	140
7A	22	-1696	9A	23	-1696	11A	23	-1696
7B	22	1696	9B	23	1696	11B	23	1696
7C	13	0	9C	13	0	11C	13	0
7D	2	-140	9D	2	-140	11D	2	-140
7E	2	140	9E	2	140	11E	2	140

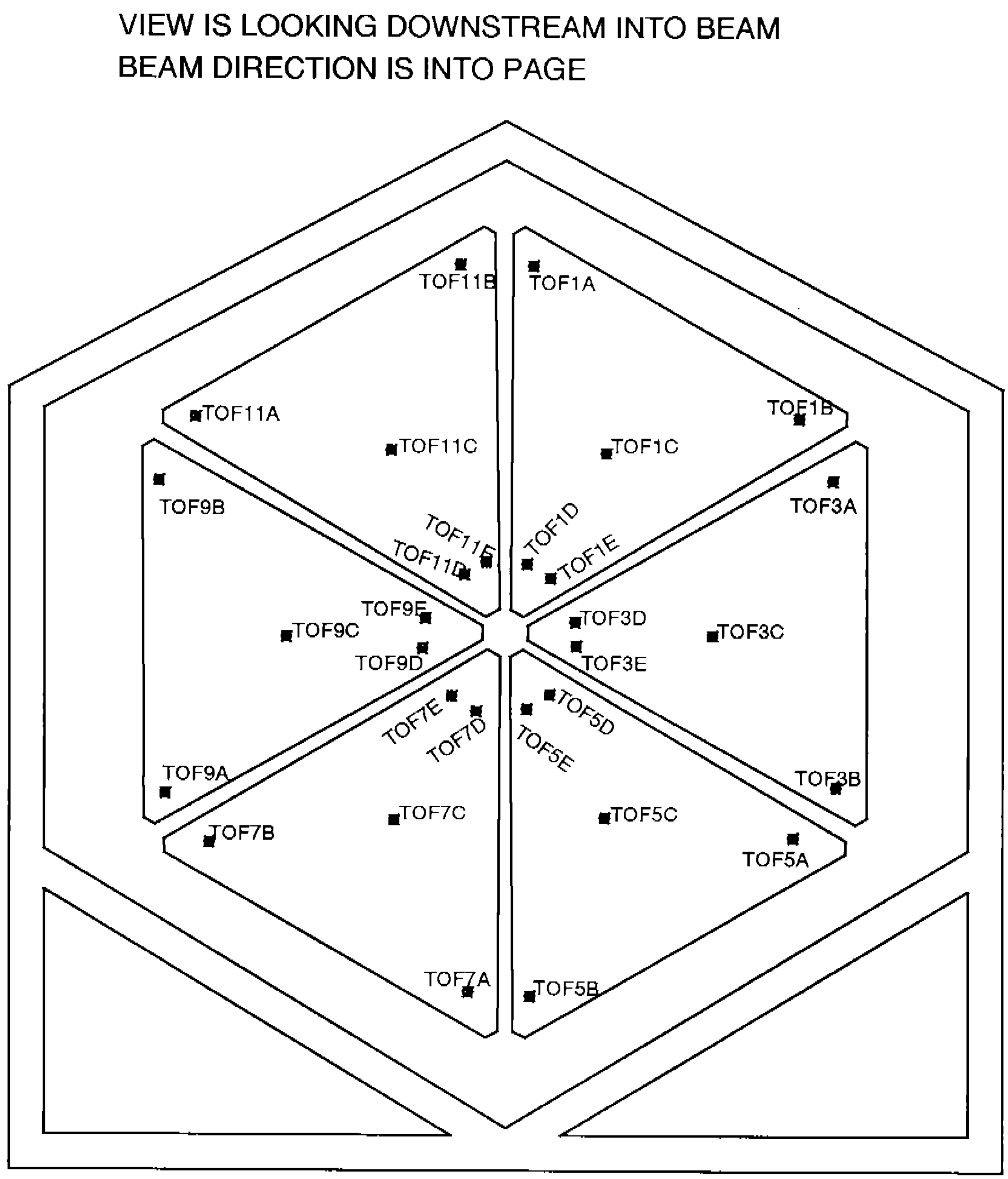

Figure 8. FC survey foil positions

Table 8. Panel 2 & 3 (NC) Survey Foils

See Table 7. In this case D refers to panel 2 and U refers to panel 3. The units for n are; W = 221.5 mm. N is measured from the upstream edge of panel 2, (n = 24) and the upstream edge of panel 3 (n = 35).

Target	n	Y' (mm)	Target	n	Y' (mm)	Target	n	Y' (mm)
B1U	45.00	-1829	A3U	40.50	-2032	A5U	36.00	-1829
C1U	45.00	0	B3U	45.00	0	B5U	45.00	-1829
D1U	45.00	1829	C3U	40.50	2007	C5U	45.00	0
E1U	36.00	1829	D3U	39.50	2083	D5U	45.00	1829
F1U	36.00	0	E3U	36.00	0	E5U	36.00	1829
G1U	40.50	0	F3U	40.50	0	F5U	36.00	0
						G5U	40.00	0
C1D	34.00	0	A3D	29.50	-1981	A5D	25.00	-1829
D1D	34.00	1829	B3D	34.00	0	B5D	34.00	-1829
E1D	25.00	1829	C3D	30.50	2007	C5D	34.00	0
F1D	25.00	0	D3D	29.50	1956	D5D	34.00	1829
G1D	29.50	0	E3D	25.00	0	E5D	25.00	1803
			F3D	29.50	0	F5D	25.00	0
						G5D	30.00	0

Table 9. Panel 2 & 3 (SC) Survey Foils

See Table 7. The foils for panel 2 are shown on the right of figure 9 and the foils for panel 3 are shown on the left side of figure 9.

Target	n	Y' (mm)	Target	n	Y' (mm)	Target	n	Y' (mm)
7A	45	1829	9A	40.5	2032	11B	36	1829
7B	36	1829	9D	45	0	11E	45	0
7E	45	0	9E	36	0	11F	36	0
7F	36	0	9H	40.5	-2032	11K	45	-1829
7J	45	-1829				11L	36	-1829
7K	36	-1829						
7C	34	1829	9B	34	1829	11C	34	1829
7D	25	1829	9C	25	1829	11D	25	1829
7G	34	0	9F	34	0	11G	34	0
7H	25	0	9G	25	0	11H	29.5	0
7L	34	-1829	9J	34	-1829	11J	25	0
7M	25	-1829	9K	25	-1829	11M	34	-1829
						11N	25	-1829

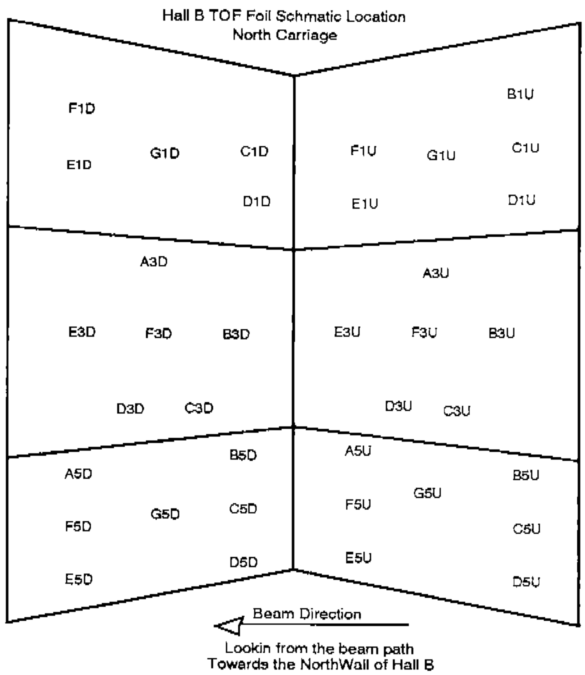

Figure 9. NC survey foil positions

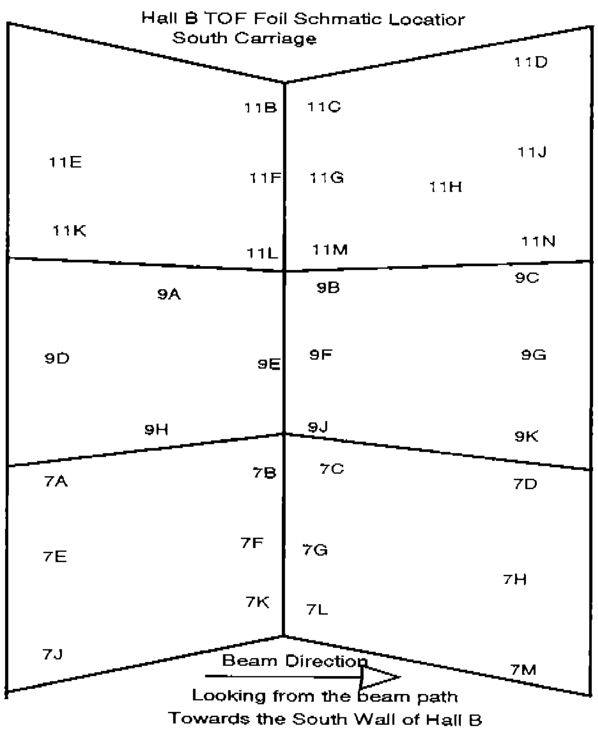

Figure 10. SC survey foil positions

Table 10. Panel 4 (SF) Survey Foils

See Table 6. All foils are attached to the 220 mm wide scintillators.

Target	n	Y' (mm)	Target	n	Y' (mm)	Target	n	Y' (mm)
1A	46.49	-1330	2A	46.53	-1499	3A	47.55	-1318
1B	51.46	-1095	2B	52.47	-572	3B	52.55	-595
1C	49.48	0	2C	50.58	0	3C	50.79	0
1D	46.59	1442	2D	46.19	1627	3D	47.56	1218
1E	52.58	562	2E	52.52	649	3E	53.46	778
4A	47.55	-1359	5A	46.61	-1467	6A	46.56	-1440
4B	52.63	-676	5B	51.55	-421	6B	53.49	-980
4C	51.27	0	5C	50.52	0	6C	50.51	0
4D	46.72	1438	5D	46.56	1507	6D	46.51	1529
4E	53.46	868	5E	52.50	808	6E	52.51	352

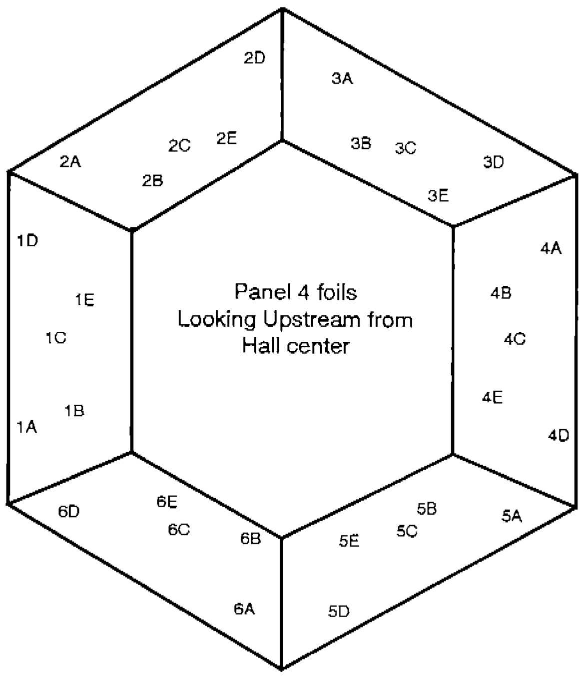

Figure 11. SF survey foil positions.