TRANSFORMATIONS FOR CRIS AND SIS COORDINATES

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inre: Coordinate systems and the transformations between them are reviewed for both the CRIS and SIS arrays. The adjustments needed for non-ideal geometries are also described.

INTRODUCTION

Two coordinate systems are defined on each CRIS or SIS detector. The first is "hodo space" and is placed on a complete array of hodoscope and silicon detector elements. The second is "map space", placed on each individual detector. Hodo space is used to specify the trajectory of a particle through a CRIS or SIS array. Such a trajectory is projected from hodoscope coordinates alone. Map space is used to specify the dead layer and total thickness of each detector at that point where a particle penetrates. Separate data bases of interferometry, alpha-particle, and nuclear-beam measurements are recorded in this space. ACE memos concerning these coordinate systems can be found in [1], [2], and [3].

Transformations between hodo and map space are needed. Such relationships can be quite complicated depending on how many adjustments are required to correct for deviations from the ideal goemetry. (The nominal hodoscope-stack geometry is characterized by parameters like stack-detector positions, and global offsets and rotations. For an ideal array, all detectors are flat, parallel, coaxial and oriented alike. Deviations occur via machining inaccuracies and tolerances.) In general, details of the hodo/map transformations depend on trajectory projection uncertainties and thickness gradients across the stack detectors.

In the following, hodo-space coordinates are distinguished by using capitol letters, with primed/unprimed letters denoting hodoscope/stack detectors respectively. Map-space coordinates are in lower case. Cartesian systems are used throughout.

COORDINATE SYSTEM TRANSFORMATIONS FOR IDEAL ARRAY GEOMETRIES

Recall that for both CRIS and SIS the global coordinate system is arranged with the positive Z axis pointing out of the array through the hodoscope. The Z = 0 origin is taken at the lower-most hodoscope plane; i.e. $Z_3' = 0$ for CRIS, with the other scintillating fiber planes lying at Z_2' and Z_1' (whereas $Z_2' = 0$ for SIS, with the top-most matrix detector lying at Z_1'), and below these lie 15 silicon stack detectors whose top-most surfaces are at Z_1, Z_2, Z_3, ... successively. The Z axis, which runs normal through the detector planes [where $(X_i',Y_i') = (X_i,Y_i) = (0,0)$ for all i] is centered on a post in CRIS which is beyond the edge of the hodoscope, but for SIS it passes up through the center of each stack.

Suppose a particle enters an array along a trajectory defined by the coordinates (X_1',Y_1',Z_1') and (X_2',Y_2',Z_2') derived from two hodoscope planes. This trajectory extrapolates through each stack detector's top-most surface at coordinates (X_i,Y_i,Z_i), with

$$X_i = [X_1'(Z_i - Z_2') - X_2'(Z_i - Z_1')]/(Z_1' - Z_2')$$

$$Y_i = [Y_1'(Z_i - Z_2') - Y_2'(Z_i - Z_1')]/(Z_1' - Z_2')$$

and where Z_i goes to Z_i - (detector thickness) for extrapolations through the bottom-most detector surface. The depth of material traversed in each silicon detector is a factor

$$\sec\Theta = [(X_1' - X_2')^2 + (Y_1' - Y_2')^2 + (Z_1' - Z_2')^2]^{1/2}/(Z_1' - Z_2')$$

more than the thickness of that detector at that (X_i,Y_i). This same factor applies to dead layer corrections.

Look-up data tables must then be incorporated that describe maps of the total thickness and dead layers on the upper and lower faces of each silicon detector. In order to interpolate this data at the correct position in map-space (x,y), a transformation must be made from stack coordinates (X,Y). For an ideal array the transformation is given by

$$x_i = I_i[(X_i - X_o)\cos\Phi_o + (Y_i - Y_o)\sin\Phi_o]$$

$$y_i = -(X_i - X_o)\sin\Phi_o + (Y_i - Y_o)\cos\Phi_o$$

Here (X_o,Y_o) and Φ_o are global parameters (valid throughout the stack), and I_i is a sign that indicates whether a particular detector is "upside down" in hodo-space with respect to map-space. (X_o,Y_o) are offsets needed to register the map-space origin with the stack origin defined by the hodoscope. The angle Φ_o is the amount by which every detector is rotated asymuthally about the stack axis: and we know that $\Phi_o = 0$ for CRIS, whereas $\Phi_o = \pi/4$ for SIS. A list of nominal parameters are reproduced from [1] and [2] below.

NOMINAL PARAMETERS FOR CRIS AND SIS GEOMETRY

	CRIS-A	CRIS-B	CRIS-C	CRIS-D	SIS
X_o	+7.57 cm	+7.57 cm	+19.63 cm	+19.63 cm	0 cm
Y_o	+19.63 cm	+7.57 cm	+19.63 cm	+7.57 cm	0 cm

	CRIS-ID	Z	I_i
Z_{1X}'	H1X	+7.31 cm	*
Z_{1Y}'	H1Y	+7.29	*
Z_{2X}'	H2X	+3.37	*
Z_{2Y}'	H2Y	+3.35	*
Z_{3X}'	H3X	+0.03	*
Z_{3Y}'	H3Y	+0.01	*
Z_1	E1	-1.59	+
Z_2	E2	-2.00	-
Z_3	E3-1	-2.64	+
Z_4	E3-2	-2.99	-
Z_5	E4-1	-3.47	+
Z_6	E4-2	-3.81	-
Z_7	E5-1	-4.57	+
Z_8	E5-2	-4.92	-
Z_9	E6-1	-5.40	+
Z_{10}	E6-2	-5.74	-
Z_{11}	E7-1	-6.44	+
Z_{12}	E7-2	-6.79	-
Z_{13}	E8-1	-7.27	+
Z_{14}	E8-2	-7.61	-
Z_{15}	E9	-8.03	-

Z-positions in the SOFT hodoscope are given at the middle of each fiber plane. Fibers are 0.020 cm thick.

E2, E3-2, E4-2, E5-2, E6-2, E7-2, E8-2, and E9 are oriented with their junction sides facing downward.

For CRIS, we have the ideal relation ...

$x_i = I_i(X_i - X_o)$

$y_i = \quad (Y_i - Y_o)$

	SIS-ID	Z	I_i
Z_1'	M1	+6.00 cm	-
Z_2'	M2	+0.00	+
Z_1	T1	-0.64	-
Z_2	T2	-0.96	-
Z_3	T3	-1.59	-
Z_4	T4	-1.91	-
Z_5	T5	-2.48	-
Z_6	T6-1	-2.80	-
Z_7	T6-2	-3.11	-
Z_8	T6-3	-3.43	-
Z_9	T7-1	-4.03	-
Z_{10}	T7-2	-4.35	-
Z_{11}	T7-3	-4.67	-
Z_{12}	T7-4	-4.99	-
Z_{13}	T7-5	-5.43	-
Z_{14}	T7-6	-5.74	-
Z_{15}	T8	-6.06	-

All except M2 are oriented with their junction sides facing downward.

For SIS, we have the ideal relation ...

$x_i = I_i(X_i + Y_i)/\sqrt{2}$

$y_i = \quad (Y_i - X_i)/\sqrt{2}$

ADJUSTMENTS FOR NON-IDEAL DEVIATIONS ON INDIVIDUAL DETECTORS

There are many small adjustments that may be needed for each individual detector, and that fix the exact relationship between hodo space and map space. A detector could be offset from its nominal position in all three dimensions, and it could be rotated a bit more or less beyond Φ_o. It may also be tilted out of normal with respect to the stack axis. Finally, a detector may not be flat, but bowed or warped. There are two kinds of deviations that play a role here: (1) fixed differences from the ideal, due to vagaries of detector positioning in mounts, module machining inaccuracies, etc., and (2) random uncertainties due to sloppiness in fixtures which affects the reproducibility when arrays are reassembled. In the following, no distinction is made between these kinds of deviations since only after-the-fact knowledge of actual geometries are of concern, when the arrays are reassembled for the last time.

Given the mechanical precision and tolerances that characterize the construction of CRIS and SIS, estimates can be made of the level of adjustment likely for each of these parameters. Sandy Shuman's estimates of extreme values for deviations are listed here...

		CRIS	SIS		CRIS	SIS
twist:	$\Delta\Phi_i$	< 0.1°	< 0.1°	ΔX_i	< 0.5 mm	< 0.25 mm
tilt:	$\Delta\Theta_i$	< 0.1	< 0.1°	ΔY_i	< 0.5 mm	< 0.25 mm
warp:	$\Delta\Theta_i$	< 0.02°	< 0.5°	ΔZ_i	< 0.25 mm	< 0.25 mm

These are to be incorporated with the following extreme values of dead layer and total thickness gradients measured on the actual flight detectors:

		CRIS	SIS
dead layer:	∇D (µm/mm)	1.1	0.03
total thickness:	∇T (µm/mm)	1.8	0.25

(SIS gradients refer to the thinnest detectors.) For both CRIS and SIS, total thickness gradients dominate.

To determine whether any particular deviation must be accounted for, use is made of the relationship between isotope mass, detector thickness, and angle of incidence with respect to the local normal noted in Mewaldt's memo [4]: $M \propto (T\sec\Theta)^{-4/3}$. For errors in thickness $\Delta M \approx 4M\Delta T/3T$, and for errors in angle $\Delta M \approx 4M\Delta\Theta\tan\Theta/3$. The goal is to keep mass uncertainties resulting from these errors below about 0.05 amu for 70 amu particles. For the CRIS detectors (or the thinnest SIS detectors) thickness variations above 1.6 µm (0.05 µm), equivalent to displacements of 0.9 mm (0.2 mm) need to be followed. For CRIS (SIS) the maximum angle of incidence is 60° (50°), so corrections for Θ variations above 0.02° (0.03°) must be made, especially for the top-most detectors in each array.

Tilt angles of $\Delta\Theta_i = 0.1°$ clearly cannot be ignored. Let Ψ_i be the angle about the stack axis where the tilt is at its maximum; i.e. where the detector edge dips the most below its nominal plane at Z_i. Suppose particles penetrate this detector along a trajectory defined by the angles (Θ,Φ) where $\tan\Phi = (Y_1' - Y_2')/(X_1' - X_2')$ and $\sec\Theta$ is as defined above. To make a general first-order correction for the tilt, the thickness scale, $\sec\Theta$ must be multiplied by $[1 - (\Delta\Theta_i) \tan\Theta \cos(\Phi - \Psi_i)]$. (See Appendix 1.)

A bowed or warped detector is treated much like a tilted one. Instead of a constant tilt specified by $\Delta\Theta_i$ and Ψ_i, however, a map of $(\Delta\Theta_i,\Psi_i)$ across the detector is needed. CRIS detectors are so rigid that any bow or warp would have to be ground in place. The thinnest SIS detectors are quite flexible, however, so their flatness must be checked.

Deviations perpendicular to the Z axis include the displacements ΔX_i and ΔY_i, as well as $(\Delta Z_i)\tan\Theta$, $R_o(\Delta\Phi_i)$, and $R_o(\Delta\Theta_i)\tan\Theta$ where R_o is the detector radius (~50 mm in all cases). These do not warrant concern in CRIS. In SIS, the terms involving R_o are within ignorable tolerances, while the ΔX_i and ΔY_i terms are potentially sizable. (The ΔZ_i terms are treated differently; any such deviations found are absorbed back into the nominal Z_i values, so transformations between hodo and map spaces do not incorporate ΔZ_i offsets.) SIS transformations should then (provisionally) take the form:

$$x_i = I_i[(X_i - \Delta X_i) + (Y_i - \Delta Y_i)]/\sqrt{2}$$
$$y_i = \quad [(Y_i - \Delta Y_i) - (X_i - \Delta X_i)]/\sqrt{2}$$

GENERAL PROCEEDURES FOR FINDING ADJUSTMENTS

A direct, empirical method of determining the level of adjustment required for X_i, say, is first to define a measure of the mass resolution ∂M, then slowly vary ΔX_i until ∂M reaches its minimum. Do the same for Y_i, Z_i, Φ_i, and $(\Delta\Theta_i,\Psi_i)$, then iterate on the results.

HODOSCOPE MISALIGNMENTS AND STACK ADJUSTMENTS

If one hodoscope plane is displaced in X, Y, or Z with respect to its nominal position, then progressively larger ΔX_i and/or ΔY_i will appear in the stack adjustments. If one hodoscope is rotated out of alignment, then progressively larger $\Delta\Phi_i$ will appear. If all of the hodoscope planes are uniformly non-normal to the stack axis, then a common tilt will appear as well as progressive ΔX_i and/or ΔY_i adjustments. If however the hodoscope planes are not parallel with each other, then Φ-dependent adjustments will appear.

REFERENCES

[1] CRIS geometry and global coordinate system
1997.01.10.BLD.a (JPL/CRIS/geometry,coordinate system)
[2] SIS geometry and global coordinate system
1997.01.10.BLD.a (JPL/SIS/geometry,coordinate system)
[3] Clarification of CRIS/SIS "BS Detector Coordinates"
1996.12.22.BRS.1 (CIT/C+S/detector coordinates)
[4] Tolerances on Detector Alignment - Revised
20 October 1992 (SIS-#RAM92-002)

APPENDIX 1: General Approach to Tilt Adjustments

A plane may be defined via the parameters a, b, and c in the Cartesian equation

$$aX + bY + cZ = 1$$

or by specifying the angles (Θ_o,Φ_o) in polar coordinates which point in a direction normal to the plane, and adding R_o, the distance of closest approach of the plane to the origin. Since

$$X = R \sin\Theta \cos\Phi,$$

$$Y = R \sin\Theta \sin\Phi,$$

and

$$Z = R \cos\Theta,$$

we can convert between these specifications. The minimum of R is found by simultaneously solving both

$$\partial R/\partial\Phi = 0$$

and

$$\partial R/\partial\Theta = 0,$$

giving

$$\tan\Phi_o = b/a$$

and

$$\tan\Theta_o = (a^2+b^2)^{1/2}/c.$$

Thus

$$R[\sin\Theta_o \sin\Theta \cos(\Phi_o - \Phi) + \cos\Theta_o \cos\Theta] = R_o$$

Suppose we have a plane defined by $Z = H$; i.e. $(\Theta_o,\Phi_o) = (0,0)$ and $R_o = H$. Then the distance from the origin to any point on that plane is $R = H \sec\Theta$. Now let us tilt the plane about the origin to $(\Delta\Theta,\Psi)$ where $\Delta\Theta_i \approx 0$. The distance to the new plane, along the same (Θ,Φ) as previously followed, is now given by

$$R = H/[\sin(\Delta\Theta) \sin\Theta \cos(\Psi - \Phi) + \cos(\Delta\Theta_i) \cos\Theta]$$

i.e. to first order, it is a factor of $[1 - \Delta\Theta \tan\Theta \cos(\Psi - \Phi)]$ different than before.

APPENDIX 2: General ΔX_i, ΔY_i, ΔZ_i, $\Delta\Phi_i$, and $(\Delta\Theta_i,\Psi_i)$ Deviations

If all deviations were relevant, the transformations would vary with each event:

$$x_i = I_i[\ (X_i - X_o - \Delta x_i)\cos(\Phi_o - \Delta\Phi_i) + (Y_i - Y_o - \Delta y_i)\sin(\Phi_o - \Delta\Phi_i)]$$

and $$y_i = [-(X_i - X_o - \Delta x_i)\sin(\Phi_o - \Delta\Phi_i) + (Y_i - Y_o - \Delta y_i)\cos(\Phi_o - \Delta\Phi_i)],$$

where $$\Delta x_i = \Delta X_i + [\Delta Z_i + R_i\,(\Delta\Theta_i)\cos\Psi_i]\tan\Theta\cos\Phi$$

and $$\Delta y_i = \Delta Y_i + [\Delta Z_i + R_i\,(\Delta\Theta_i)\sin\Psi_i]\tan\Theta\sin\Phi,$$

with $$R_i = (x_i^2 + y_i^2)^{1/2} \approx [(X_i - X_o)^2 + (Y_i - Y_o)^2]^{1/2},$$

$$X_i = [X_1'(Z_i - Z_2') - X_2'(Z_i - Z_1')]/(Z_1' - Z_2'),$$

$$Y_i = [Y_1'(Z_i - Z_2') - Y_2'(Z_i - Z_1')]/(Z_1' - Z_2'),$$

$$\sec\Theta = [(X_1' - X_2')^2 + (Y_1' - Y_2')^2 + (Z_1' - Z_2')^2]^{1/2}/(Z_1' - Z_2'),$$

and $$\tan\Phi = (Y_1' - Y_2')/(X_1' - X_2').$$