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CMS Endcap Muon System Long Term Resolution Tests of Max Planck Institute Transparent Amorphous Silicon Optical Beam Position Sensors in a Multi Sensor Straight Line Monitor

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Abstract

Prototype ATLAS muon system transparent Si optical sensors (ALMY) have undergone further testing at Fermilab. A detailed study of the long term behavior of a multi sensor straight line monitor (SLM) has been made.

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I. Introduction

Our initial studies of the ATLAS Muon system transparent amorphous Si sensors [1] during the summer of 1996 were restricted to measurements of the short term performance, resolution, refraction, and absorption effects. More recent studies, in the summer and fall of 1997, have made detailed measurements of the sensor performance, stability, and resolution over extended periods of time (> 9 days). We also studied thermal effects on the simple (non thermocooled) laser diode module sources.

In the CMS Endcap muon position monitoring system (EMPMS), critical phi reference planes will be transferred to the Endcaps at the CMS outer radial boundaries from the tracking/barrel muon systems. See references [2, 3]. This is to be achieved by the LINK laser beam tracker coordinate system transfer to the Barrel end MABs. Endcap Rasnik lines across the Barrel/Endcaps are defined by these MABs in Endcap Rasnik reference plates, and by local Endcap straight line monitors (SLMs). We plan to use transparent amorphous Si sensors in these straight line monitors (SLMs) to define radially opposite link points for Endcap cathode strip chamber (CSC) layers. An Endcap Rasnik reference plate on the Z+ end MAB is shown in Reference [3]. Across each of the cathode strip chamber (CSC) planes of the Endcap system, there will be laser diode beamlines located by the radially opposite link points. These are the layer reference phi plane SLMs. There are three or six of these lines across a detector plane. One linkpoint transparent amorphous Si sensor on a Link transfer plate with precision inclinometers defines the laser diode source position while the opposite radial end linkpoint/linkplate defines the position of a transparent amorphous Si sensor used to monitor the optical beam motions (i. e., defines the instantaneous optical straight line within short term sensor resolution).

Two transparent amorphous Si sensors mounted on each phi plane reference cathode strip chamber (CSC) will define their chamber positions (Rphi, z) relative to these crossed laser beams. This requires eight chamber position sensors and an endpoint definition sensor along each local phi straight line monitor (SLM) for a total of eight independent measurements. The laser beam must pass through all the detectors. The resolution requirement for the position measurements is 50-100 μm. A schematic of the ME1/2, ME1/3 cathode strip chamber layer (inner and outer rings) and phi boundary straight line monitors is shown in Reference [3].

II. Methodology

The transparent amorphous Si sensors were mounted on a heavy steel magnet assembly stand in a ‘half CSC layer’ arrangement. That is, sensors were positioned at distances and orientations mimicking their positions on chambers in one half of a CSC layer of inner and outer ring chambers. Available undisturbed laboratory space precluded a 13.5m setup. The full layer setup is to be implemented in future integrated system tests in the CERN ISR tunnel. The steel magnet stand was found to move slightly with the shifts in temperature in the laboratory (>±2C°) as well as transmit small vibrations from outside the immediate area.

The COHERENT systems (THOR) 3 mW, laser diode fixed optics module (LDM) used in most tests had a nearly constant beam profile and size (5 mm) over our test length to 13m. The module provided a stable, but non-Gaussian, beam shape which was measured with a simple photodiode and pinhole aperture. Beam profiles at Z = 1.52m and 8.85m are shown in Figures 1, 2. We did not observe significant diffraction secondary peaks and the short term output was stable. The module was held in a fixed mount. We did establish that the source and transparent amorphous Si sensors are adequate for a 13m path.

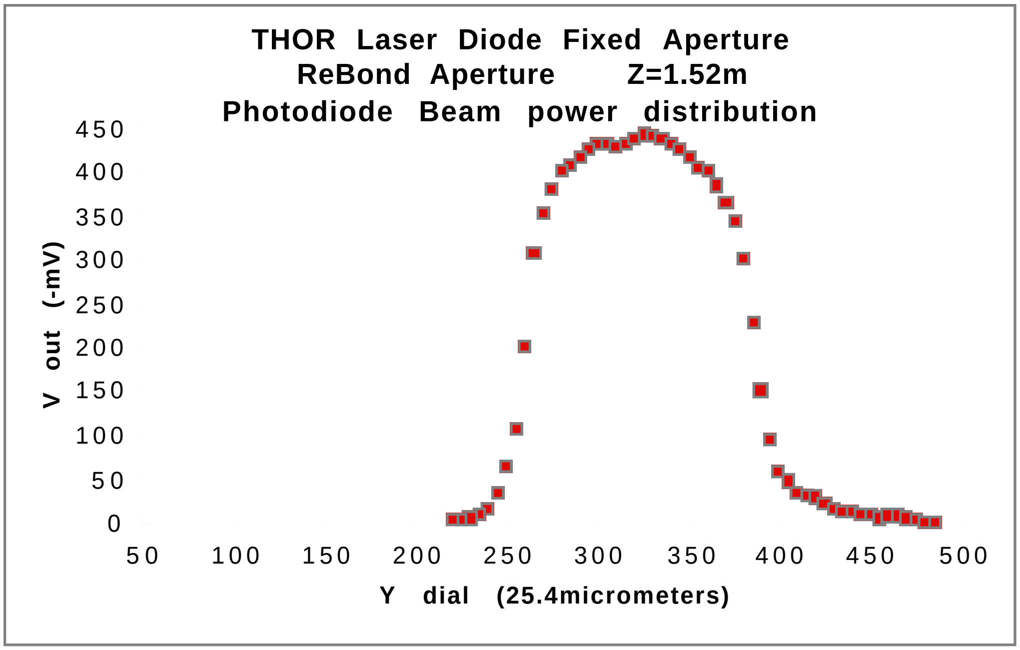

Figure 1. The measured Y beam power profile of the COHERENT Module VLM2-10RL at 1.52m.

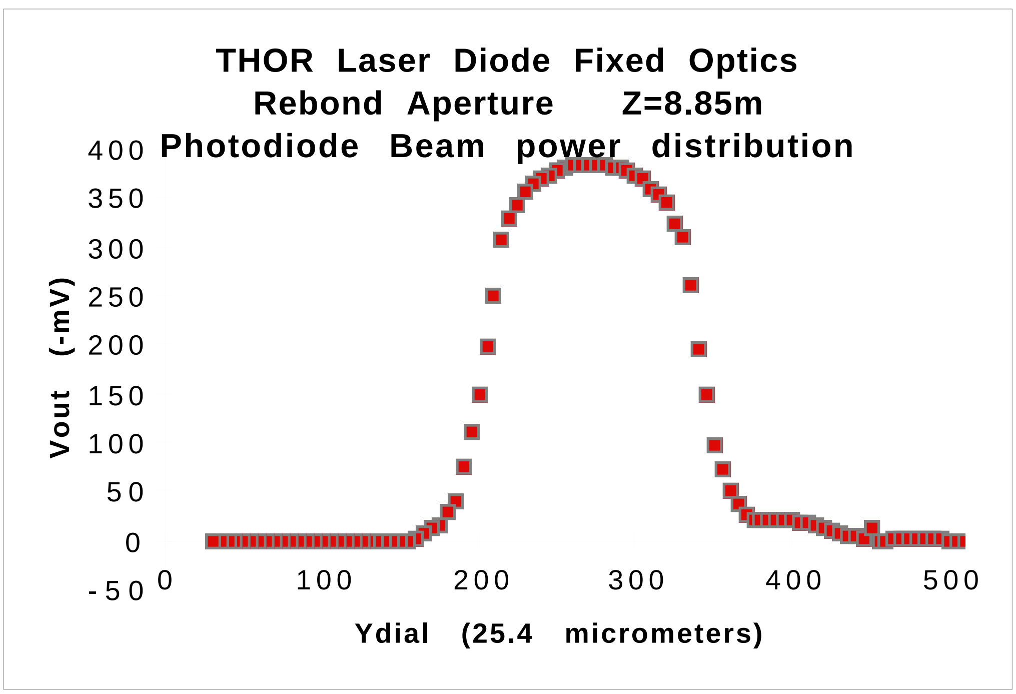

Figure 2. The measured Y beam power profile of the COHERENT Module VLM2-10RL at 8.85m.

Measurements of the fixed laser beam position were made in a manner consistent with the summer of 1996 measurements [1]. The sensors were first readout with the laser diode off to make a baseline background measurement and then again with the laser diode pulsed on to obtain a beam position measurement. The two measurements were subtracted from each other to produce a beam profile free from background distributions. The resulting profile was cut with a .1V threshold (about 2% of the maximum possible voltage) to eliminate tails outside the main distribution. The spectrum was then fit with a Gaussian curve, from which the mean and chisqr were determined (cycle). Datapoints of beam position spectra on the sensors were not determined from the averaging of several events (no stochastic averaging improvement) but rather taken as the mean of the fit Gaussian distribution of single cycles. Estimations of sensor resolution and performance were done by taking the standard deviations of large samples of **individual** measurements of beam position over time. These represent the worst case resolutions that can be improved by averaging a group of repeated measurements.

The laser diode source of the SLM included a filter so as to fully saturate the beam center strips of the first transparent amorphous Si sensor (ALMY S2, .40m downstream of LDM). Full saturation yielded a beam peak which overflowed near the center and corresponded to a maximum ADC value (Vmax) of +5V in both the X and Y strips. During most of the trials, the laser diode module was powerful enough to just about saturate the second sensor in the SLM line as well (ALMY S3, 2.55m from LDM). There appeared to be no degradation in the performance of transparent amorphous Si sensors ALMY S2 and S3 due to operation in these conditions. Furthermore, Gaussian curves placed on distributions of the resulting, if somewhat attenuated peaks, did not at any time yield results inconsistent with previous measurements of unattenuated peaks in sensors below saturation. Any potential damage to the sensor from operating in saturated conditions was most likely precluded by the quick OFF/ON cycling in a low duty cycle of the LDM during position measurements. We will treat the laser and transparent amorphous Si sensor optical stability issue in detail further on in the paper.

III. Long Term Resolutions

With the transparent amorphous Si sensors placed on the magnet assembly stand in their half-CSC layer positions, we took several long series of repeated **single** measurements for 9-10 days (approx. 900 single sample measurements at 12-15 minute intervals established by the computer clock). Optical tube shields were employed during the run to minimize external fluctuations in the ambient lighting. However, the system was subject to electrical, thermal, and vibrational disturbances in a normal simple concrete slab building. Measured **RAW** resolutions (including optical beam, thermal, and mechanical motions) varied from 15-100 μm in the different ALMY sensors along the 6m SLM. For two 9 day trials (RData 27 & 47) and one 10 day trial (RData 43); the average, **RAW** position resolutions are summarized below in Table 1:

Table 1: Average Long Term Resolution of Uncorrected Data
(RData 27, 43, & 47)

Sensor #	Distance (m)	σXmean (μm)	σYmean (μm)
2	0.40	10.84	19.98
3	2.55	46.57	41.29
4	3.34	56.47	42.51
5	4.74	78.66	74.62
6	5.70	95.87	56.65

The structure of the observed beam position fluctuations in all sensors was very similar in all long term runs. All sensor measurement spectra showed some long term drift (different in the runs) and several characteristic oscillation peaks of varying magnitude increasing with distance from the laser source. These peaks contained a single maximum and minimum for each day that data was acquired (diurnal cycles generally reflecting the temperature variation). Furthermore, each set of X or Y measurement beam position oscillation peaks occurred in phase for all transparent amorphous Si sensors. Although both axes (X horizontal, Y vertical) on all sensors displayed these periodic oscillations in beam position measurement, the two axes (X, Y) differed by a phase constant indicating different mechanical and vibrational contributions in the horizontal and vertical planes. Each plane was also out of phase with direct ambient temperature fluctuations.

Close inspection of the transparent amorphous Si sensor raw data distributions in the different long term stability runs (Rdata 27, 43, 47) revealed that the long term drifts in the sensor measured laser beam positions were reasonably linearly related; the drift was proportional to the distance between individual sensors and the laser diode module. In the RData47 run, the long term drifts were much smaller and the derived drift corrections (linear fits of the raw data spectra) were somewhat more variable reflecting minor differences in the diurnal fluctuations. Also, individual X, Y beam position measurements in the different transparent amorphous Si sensors, after the long term drift correction described above, were typically related by the same distance relationship. This indicated that the dominant variation of the beam position measurements was generated by long and short term variation of the position and pointing of the laser diode source. In the CMS Endcap SLMs, the final sensor beam position measurement (at the opposite linkpoint) is combined with the laser diode module source to define the instantaneous reference line.

To evaluate the effective long term resolution of the sensors in such a SLM, the final sensor 6 in the test SLM setup was taken as the endpoint reference sensor. Preceding sensors (2,3,4,5) had their position measurements (point by point) corrected by the fractional ratio of distance to the laser diode times the Sensor 6 fluctuation of the beam position measurement. For example, a transparent amorphous Si sensor 4 (S4) measurement of position was modified in the following manner: $(S4)_{corrected}=(S4)_{raw}$ - [(S4 distance to LDM)/(S6 distance to LDM)]*$(S6)_{raw}$

Figures 3,4 illustrate the horizontal (X) and vertical (Y) transparent amorphous Si sensors 2, 3, 3, 5, 6 beam position measurement oscillations (after correction for long term drifts) compared to the T3 measured temperature fluctuations.

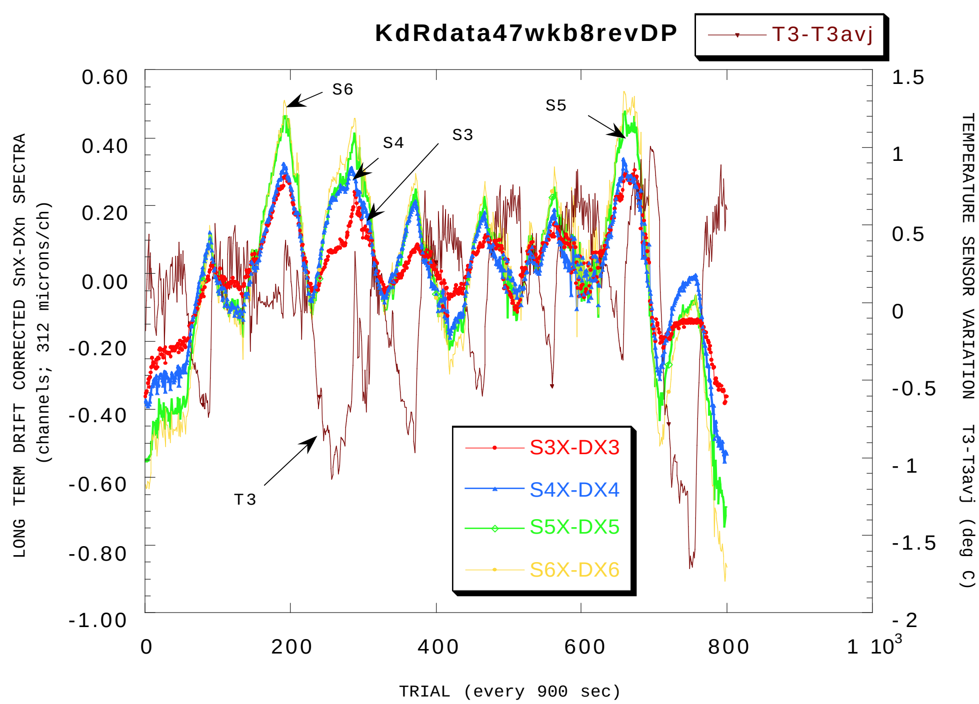

Figure 3. Sensor 3, 4, 5, 6 long term drift corrected X Beam Position Measurement spectra vs temperature.

Changes in the temperature of the magnet stands, sensor mounting plates, Z coordinate transfer structures, and sensor casings were recorded. Limited correlation between shifts in the aSi sensor beam position and the variation in temperature was observed. The beam position measurements in the long term runs show variable and generally weak **statistical** correlation to simultaneous measurements of temperature variation in the sensor environment. A good correlation (narrow linear distribution) is shown in Figure 5 while a poor correlation (broad distribution only showing a weak correlation of the major axis) is shown in Figure 6. Good correlations are observed mostly in the distant aSi sensors 5, 6 in both the horizontal and vertical planes. Our conclusion was that a direct beam position measurement correction using temperature sensor data would not improve the results. Test trials on RData 27 proved this to be the case.

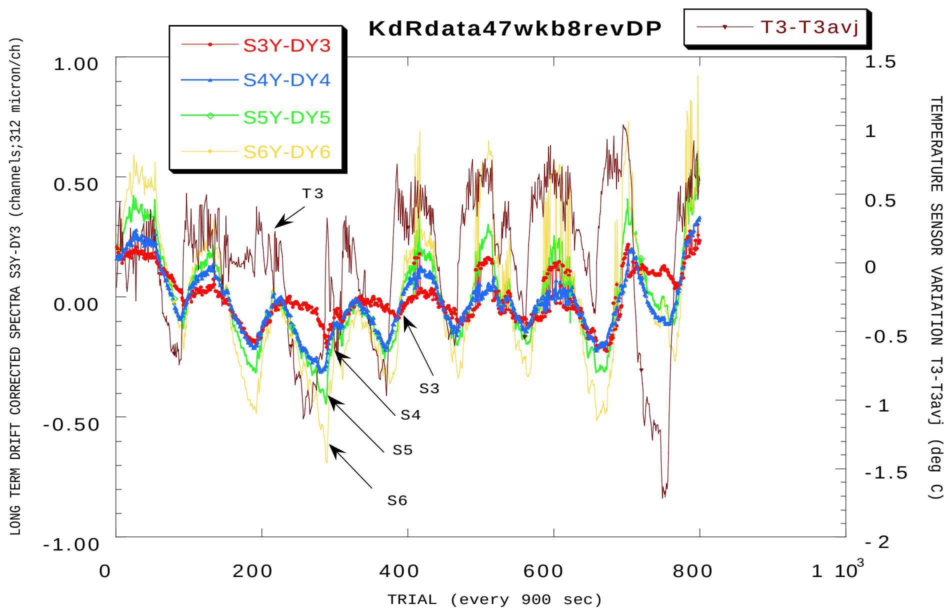

Figure 4. Sensor 3, 4, 5, 6 Long term drift corrected Y Beam Position Measurement spectra vs temperature.

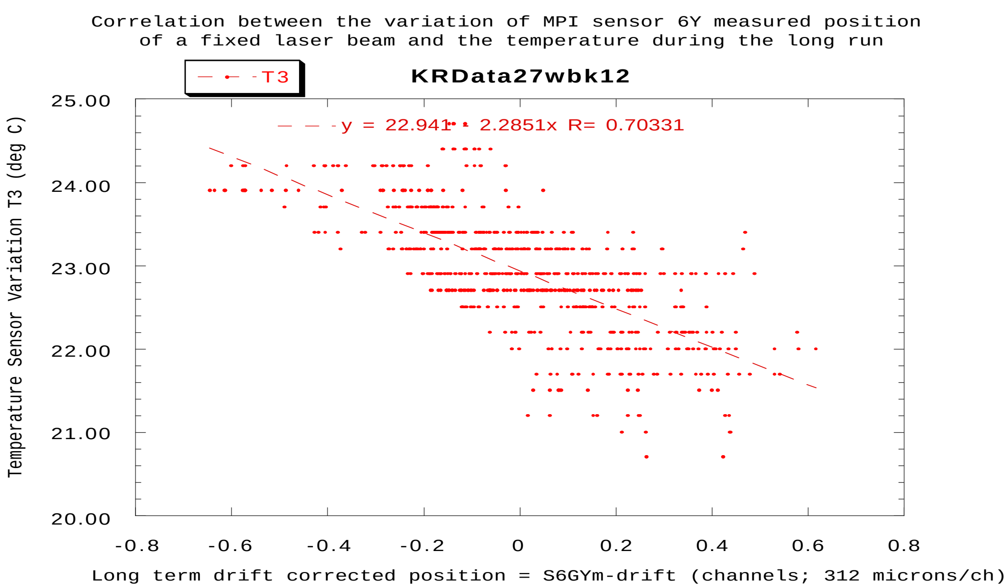

Figure 5. Drift corrected aSi sensor 6 Y beam position measurement data points vs temperature.

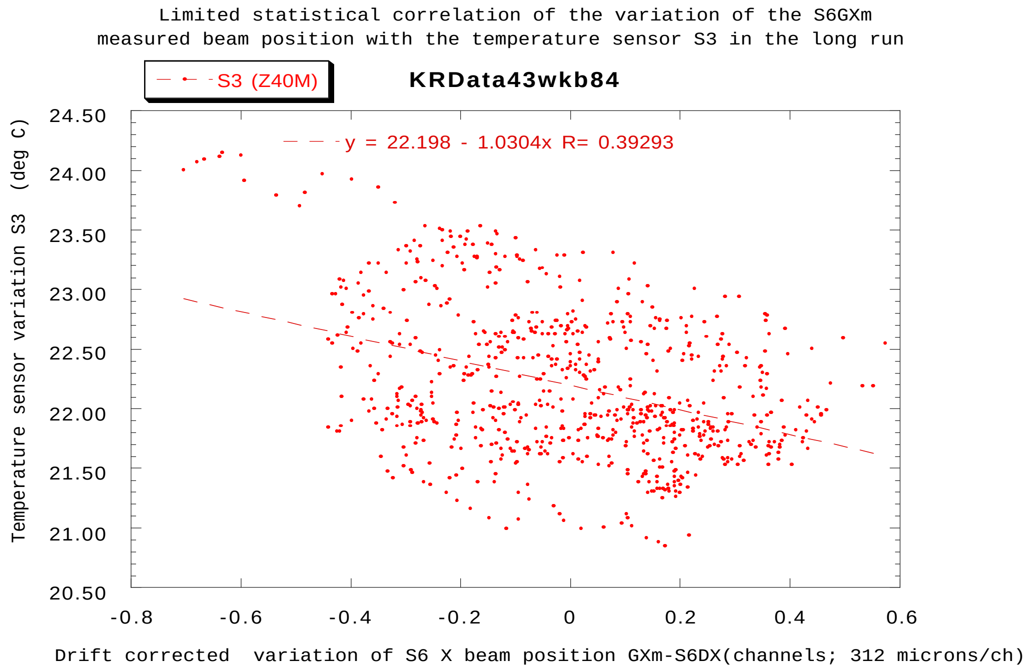

Figure 6. Distribution of the drift corrected aSi sensor 6 X beam position measurement data points in the long run RData43 plotted against temperature measurement values of the same data points.

Figure 7(a), (b) shows the independence of position measurements of the closest transparent amorphous Si sensor 2 to the laser diode (separation of .40 m) with respect to the temperature on the sensor's casing. This indicates that substantial variations in position measurements are dominated by laser beam motion and external mechanical effects.

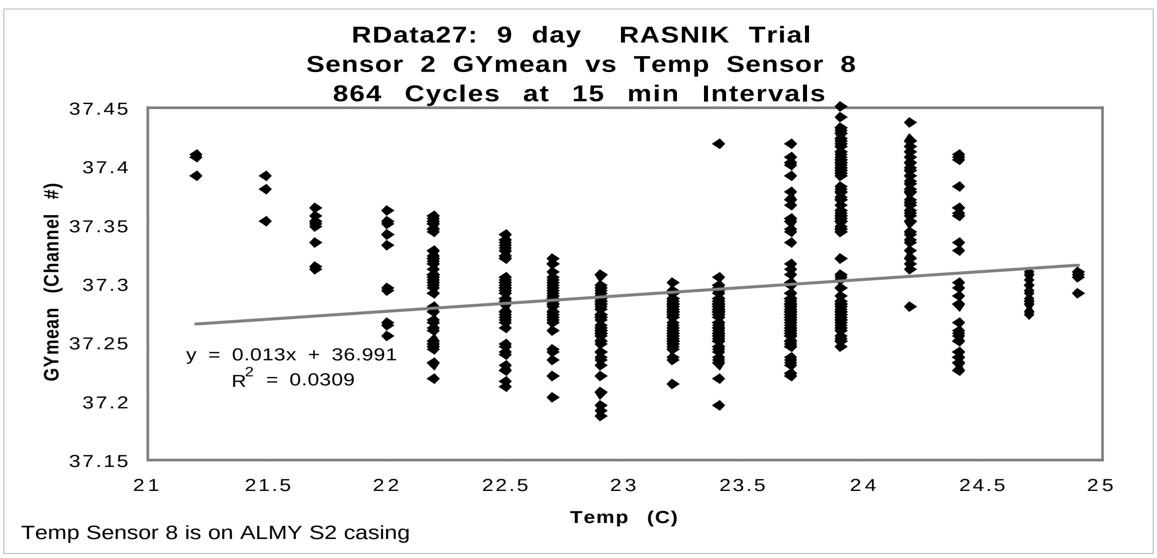

Figure 7(a) Raw data Y Gaussian Mean from aSi Sensor 2 versus Temperature

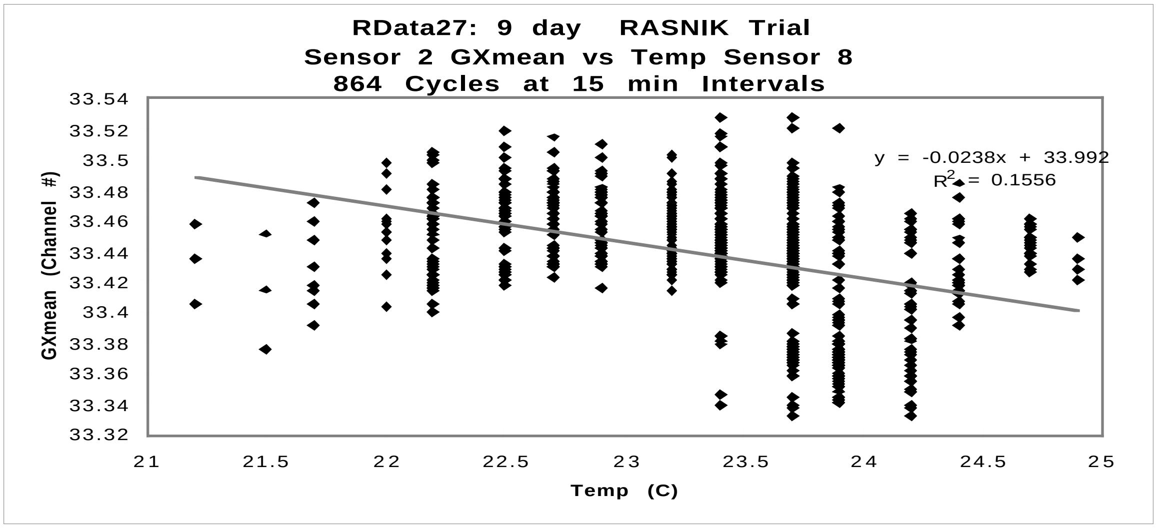

Figure 7(b). Raw data X Gaussian Mean from aSi Sensor 2 versus Temperature

After the long term drift and short term oscillation corrections, all the transparent amorphous Si sensors consistently exhibited resolutions between 10-25 μm over the extended trials. The corrected results of the two 9 day trials (RData 27 & 47) and one 10 day trial (RData 43) are shown below in Table 2.

Table 2: Average Long Term Resolution of Corrected Data

(RData 27, 43, & 47)

		transparent amorphous	silicon sensors
ALMY sensor #	LDM distance (m)	σXmean (μm)	σYmean (μm)
2	0.40	10.17	14.55
3	2.55	16.60	15.19
4	3.34	10.56	21.56
5	4.74	11.39	24.15
6	5.70	N/A	N/A

The averaged data sets (in all extended trials) were very similar, with all resolutions within 10% of the calculated averages shown in Table 2. The vertical plane contains more mechanical, thermal, and vibrational effects of the support beam that are not corrected by beam position tracking (using the endpoint reference sensor 6 correction). These resolutions **do not** include any geometrical X, Y refraction or optical gain variation corrections. Here, the transparent amorphous Si sensors are treated as simple, uniform detectors.

IV. Laser Diode Module (LDM) Warm-up Effects and transparent a Si sensor Short Term Resolution

Short term resolution was determined by making a series of 100 complete measurements (cycles) and finding the standard deviations of the resulting set of measurements. The readout cycles were spaced without any time delay and typically took about 20 seconds to record a single measurement, analyze, and reset the system. The resulting set of beam position measurements showed an initial smooth change in both the x and y beam axis positions. Figures 8 and 9 illustrate these drifts.

Investigations with a pinhole photodiode detector (pinhole aperture << LDM beam diameter) at the end of the SLM line revealed that the intensity of the LDM did not change through the measurements. So the initial shifts in the sensor positions are caused by small shifts in the LDM junction-optics (as the LDM is warmed up) rather than an initial warm-up (photocurrent) effect in the transparent amorphous Si sensors.

The sensors have been powered over a period of months. This warm-up effect of the LDM can also be seen as a rapid drift in the first 20-40 aSi X, Y beam position measurements in the long term runs; after which beam position measurement spectra drifts taper off and the periodic diurnal oscillation structure dominates.

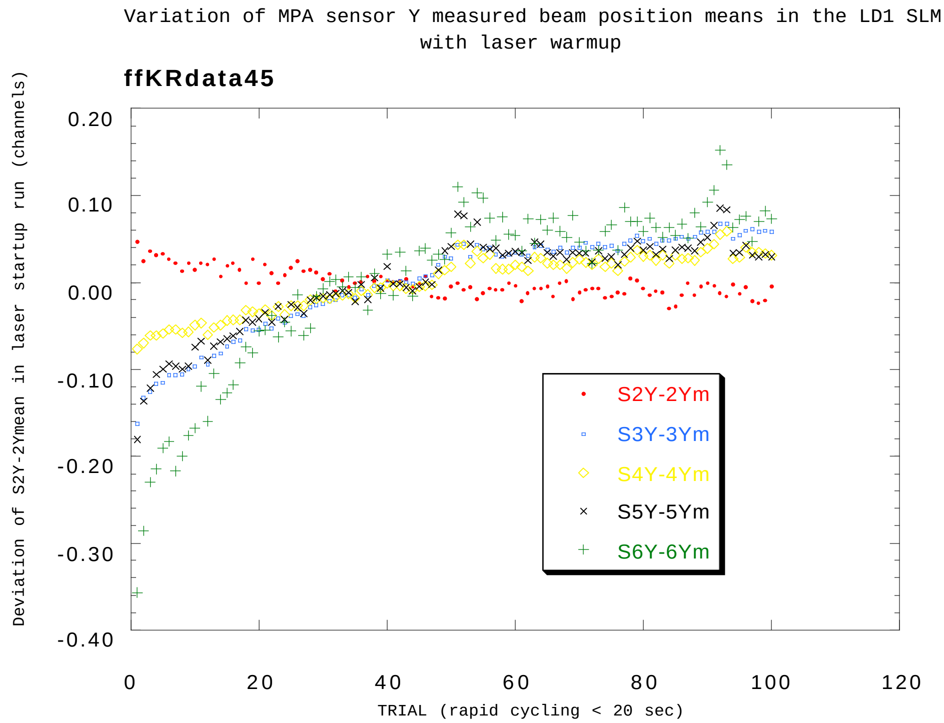

Figure 8. Variation of the aSi sensor Y measured beam positions with the warm-up of the LDM.

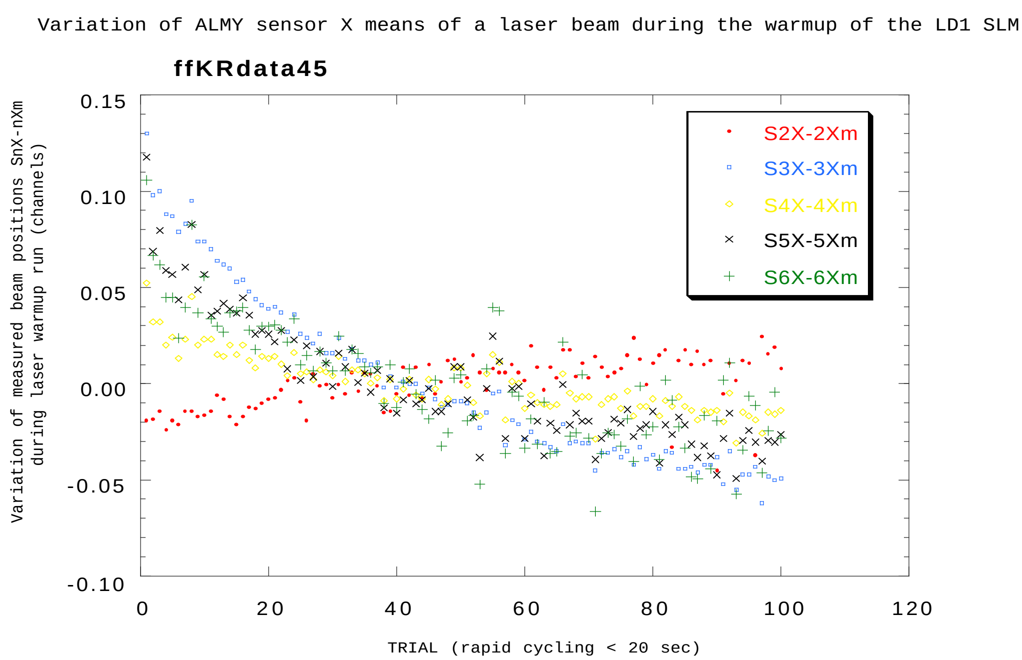

Figure 9. Variation of the aSi sensor X measured beam positions with the warm-up of the LDM.

The corrected short term resolutions on the steel magnet stand were found to be slightly higher than the resolutions recorded on the more stable granite table during the summer of 1996; but no sensor was found to show substantial deviations from the previous measurements. The resultant transparent amorphous Si sensor resolutions for two separate 100 short cycle runs is presented in average in Table 3. All transparent amorphous Si sensors (X, Y) yielded resolutions of ≤13 μm without geometric refraction or optical gain variation corrections of the individual transparent amorphous Si sensors.

Table 3: Average Short Term Resolution of Corrected Data

(RData 30 & 45)

		transparent amorphous	silicon sensors
ALMY Sensor #	LDM Distance (m)	σXmean (μm)	σYmean (μm)
2	0.40	3.97	5.83
3	2.55	11.31	3.69
4	3.34	5.07	12.93
5	4.74	5.53	9.17
6	5.70	N/A	N/A

V. Optical Long term stability of the Laser Diode Modules and the transparent aSi sensors.

In our mode of operation, we pulse the laser on only briefly (<20 sec) in a low duty cycle (10-15 minute for long runs). While there is a warm-up effect to thermal equilibrium, our measurement experience over a several month period indicates that the output of the simple Laser diode module is very stable. We conclude this from the stability of the signal level in the transparent amorphous Si sensors throughout and across the different long term runs which began in June and ended in October. The manufacturer suggests that the source output should be stable for several thousands of hours of operation.

In each of the long term stability runs, the peak signal amplitude spectra in all the non-saturated transparent amorphous Si sensors show the same general fluctuation structure. Comparing this structure with the diurnal temperature fluctuation (see Figure 10 comparing aSi sensors 5, 6 and the S3 temperature sensor) suggests some correlation. However, as for the beam position measurement spectra, the correlation varies greatly. A few amplitude spectra correlate very well. Most of the signal amplitudes show variable and sometimes weak **statistical** correlation to simultaneous measurements of temperature variation in the sensors environment.

Looking at the variations in the transparent amorphous Si sensor measured beam positions X, Y and the variations in the transparent amorphous Si sensor signal amplitudes, we do not observe significant correlation except for sensors 5, 6 in the vertical plane (Y). Like for the beam position measurement distributions, it is a **statistical** correlation of a broad distribution (band) of values and the quality of the correlation varies significantly. There does not seem to be any correlation in the horizontal plane (X).

We recorded the signal amplitude of all transparent amorphous Si sensors over the long term runs RData27 (June 27-July 6), RData43 (Aug 21-Sept 2), and RData47 (Sept 26-Oct 6). The source, fliter, and sensor positions were essentially unchanged. The signal amplitudes (ADC) are given in Table 4.

Table 4: Average aSi sensor signal amplitude (volts) in the Runs (RData 27, 43, 47)			
aSi Sensor #	RData27	RData43	RData47
2Y, 2X	4.98, 4.97	5.00, 4.97	5.02, 4.97
3Y, 3X	4.96, 4.92	4.99, 4.79	5.02, 4.84
4Y, 4X	4.22, 3.95	4.32, 3.84	4.62, 4.11
5Y, 5X	1.92, 1.98	1.95, 2.02	2.31, 2.43
6Y, 6X	1.42, 1.33	1.39, 1.34	1.68, 1.60

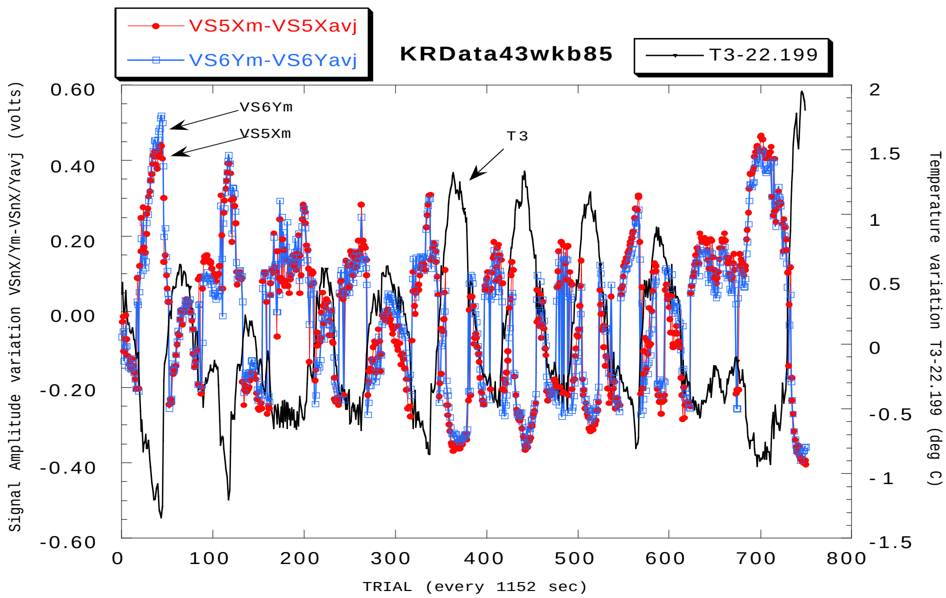

Figure 10. Comparison of the transparent amorphous Si sensors 5 X, 6Y signal amplitude variation and the S3 temperature variation during the long term run RData43.

VI. Conclusions

A. Transparent amorphous Si Sensor Performance

Our evaluations suggest that our SLM configuration of multi point alignment (MPA) transparent amorphous Si sensors, laser diode source, and fitting methodology provide adequate beam profiles, sensor resolution, Gaussian fits, and stability to make consistent **local** sensor position measurements well within a 25 µm error over periods of 10 days. Errors in position measurements are dominated by external mechanical/thermal factors and the 'wiggling' of the laser diode optics and not by the transparent amorphous Si sensors. Averaging a group of repeated measurements would improve the resolution.

As noted in our initial evaluation of the sensors [1], there are still several problems with the sensors including optical reflections and electrical termination problems for extremely short and long cable connections, hot channels in the readout (single channels spontaneously reading +5V; these were corrected by software control), variations in the thickness of the glass substrate which affect downstream beam profiles and positions, variation in the aSi layer which give the sensors a non-uniform optical response and transmission affecting the given sensor resolution and those downstream.

B. Transparent amorphous Si sensor Stability

The six transparent amorphous Si sensors were extensively tested at Fermilab over approximately 18 months and during that time did not show any apparent degradation in performance or resolution in the low duty cycle, pulsed low level laser beam operation. In particular, the sensors operated in the SLM configuration for 3 months. Position measurements obtained in that particular span of time were consistent with each other as well as with results obtained during initial evaluations in 1996. Possible degradation of the sensors' performance was perhaps mitigated by the short, pulsed LDM exposure (< 20sec) and the low duty cycle (10-15 minute cycle for the 9-10 day trials). This is in contrast to some ATLAS tests (4).

References

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