CLAS–NOTE 95-012

Region I Trial Installation

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ABSTRACT

Using a full scale prototype of the Region I mechanical structure, we have tested many of the critical steps needed to install the detector into CLAS. In this note, we describe our experiences with transportation from Pittsburgh to Hall B and docking of the device with the mounting supports, including active monitoring of endplate deflections throughout. A secondary benefit of our activities was to gain a better understanding of certain issues concerning cabling and alignment of the final detector when it is installed in CLAS.

1. Introduction

The completion of the Region I drift chamber will not occur when it has been strung and assembled into a complete six-sector structure in Pittsburgh. It will still be necessary to take the chamber to CEBAF and to install it in CLAS, without seriously affecting the wires or electronics. Because so much of the structural integrity of the device relies on the interdependence of many parts, we felt that the only realistic test of whether we would be able to do this was a full-scale transportation and installation study.

On June 11 - 17, 1995, we used the Region I prototype to conduct just such a study. Our test simulated transportation of the detector between CEBAF and Pittsburgh (twice), insertion into the central part of the spectrometer, and removal of the detector afterward. We succeeded in clearing up many of the uncertainties in our procedures, and have a much better idea now of how to improve them in some places.

2. Transportation of the prototype

In January 1993, we strung the sectors with sixty-four gold-plated aluminum and twenty-six gold-plated tungsten wires for the purpose of tension measurement. Both sets of wires were produced by California Fine Wire near the end of 1988 and were left over from another project. The aluminum wires were 4 mil (100 micron) diameter, 5056 alloy, the tungsten wires 0.8 mil (20 micron) in diameter. Linear mass densities were 26.6 and 6.6 mg/m respectively. Initial tensions applied to the wires were 100 and 50 grams force. To simulate the net force exerted on the sectors by the wires, we also installed twenty steel music wires, 31 mil (0.8 mm) in diameter at 45 pounds of force (axial) and 30 pounds (stereo). Twenty-two aluminum posts connecting the half-struts on either endplate supported the force of the wires throughout our installation exercises. We made transparent Lexan covers for the area corresponding to the inner and outer gas windows to protect the wires against casual contact. Although six pairs of prototype endplates exist, three sectors had already been taken apart so that pieces could go into the final drift chamber sectors under production.

We attached the three sectors to the large boss ring at their upstream ends every 120 degrees, leaving three gaps corresponding to the three missing sectors. To compensate in part for the loss in rigidity this represents as compared to the complete six-sector structure, we interconnected the sectors using seven sets of struts and posts, along the outer curved portion of the endplate. The downstream ends of the sectors were connected in the usual fashion to the sides of the six-sided aluminum pipe support. We decided not to make any further attempt to simulate the configuration of the final detector, such as weights to simulate missing sectors and cable bundles.

We constructed a pallet prototype with a suspension system to cushion the detector as much as possible during its journey from Pittsburgh to CEBAF. At the six outer corners of the boss ring we attached a set of compression springs to resist both upward and downward displacement of the device. The weight-bearing springs each had a spring constant of 59 pounds per inch, while the springs resisting upward displacements had spring constants of 24.6 pounds per inch. At three corners, we installed automotive-style heavy-duty shock absorbers to dampen oscillations. The total amount of vertical displacement allowed was approximately ±3 inches, corresponding to maximum restoring forces of about three times the weight of the prototype. Wooden walls and a roof completed the box. A number of the wire tensions were measured just before closing up the box. (Refer to Tables I–III). We used adjustable straps to constrain the range of motion at the downstream end of the device; these were attached to the walls of the box. We took no particular care to waterproof the joints at the time we built the box. After lifting the box onto a stake-bed truck using a forklift, we secured it using nylon strapping and metal turnbuckles.

The overall height of the box on the truck was 13.0 feet, sufficiently low to clear the overhead obstructions to be encountered on the road. (Nominal highway bridge overpass and tunnel clearances are generally a minimum of 13.5 feet.) The drive from Pittsburgh to Newport News took approximately ten hours on the interstates. On the way down, we encountered a thunderstorm with heavy rain and strong winds.

At Hall B, the box was taken off of the truck by forklift and placed on the floor. Shortly after unpacking the prototype, we found six broken aluminum wires. Two others broke in the following 24 hours (plus one more which we broke by accident). In each case, the wire broke at a random location along its length, not at the point of greatest stress as had always been our experience when we tested wires in the past. There was also evidence of corrosion of the wires and the support hardware, presumably due to water entering the box during the storm. We found that two of the adjustable straps between the six-sided pipe and the walls of the box had worked loose, and believe that this would have allowed large sideways motion during transit. None of the tungsten wires broke. Immediately after removing two of the sides of the box we measured many of the remaining wire tensions using a manual tension measuring device (Tables I–III).

We attached a lifting fixture to the downstream end of the prototype so that we could use the Hall B crane and a forklift to bring the prototype detector to a horizontal orientation on the floor of Hall B. Using the Hall B crane for support, one person could maneuver the the spider pipe to its position at the center of the prototype, so that the device could then rest on two supports. We attached a set of ribbon cables to a selection of tension-measuring wires (limited to a maximum of 60 by the number of computer channels we had available). These connections were made by clipping the ends of the wires onto the metal crimp pins, being careful not to put force on the pin itself. We then remeasured tensions, (Tables I–III) using our computer-controlled system. [1].

3. Installation into CLAS

Again using the crane we lifted the prototype by its spider pipe from the floor of the Hall to the first level platform, in a horizontal orientation. The only tricky parts of this maneuver were when the device had to pass over the uppermost level of the space frame, ensuring adequate clearance (strap length turned out to be critical), and when it passed through the cutout portion of the Level 2 platform (we had to reposition a set of temporary cables installed for the safety system so that they were out of the way). After we negotiated these obstacles, we were able to connect the upstream spider flange to downstream flange of the installation cart.

After removing the downstream lifting fixture, we prepared for docking into CLAS by attaching the forward docking fixture to the prototype and by attaching the fixed docking mount to the front fixing plate of the cryostats. The forward docking fixture holds two steel pins which dock into 1 inch bushings on the fixed docking mount. To align the the bushings vertically, we levelled the top edge of the docking fixture. At the upstream end of the prototype, we attached three upstream docking legs at the 2:00, 6:00, and 10:00 positions corresponding to the locations of fixed saddles on the aft cryostat ring. Finally, we corrected the settings of the installation cart to adjust the vertical height of the downstream end of the prototype to agree with the height of the beamline.

3.1. Clocking and insertion

To put Region I into CLAS, the endplates and circuit boards need to be rotated past the protruding parts of the six cryostats. Potential spatial conflicts near the midplane of each sector include the space between the outer gas windows and the cryostat protrusions. In the coil plane region of the detector we also need to make sure the outer edge of the signal translator boards stays away from the hardware attached to the aft cryostat ring and the Region II inner gas windows.

Ordinarily, during installation of the actual detector, the posts which connect the endplates making up each sector would have been removed before clocking. Because the prototype lacked three of the final sectors, this was not possible in our test, so we left these posts in place. This increased the possibility of interference between the prototype and the cryostat protrusions, in the area near sector midplanes, compared to what we would normally encounter.

Clocking was a simple matter of advancing the screw adjustment of the installation cart so as to turn the device around its axis. We rotated a full thirty degrees counterclockwise (seen from the upstream end) as measured by a clinometer on the boss ring. This is not the minimum rotation angle needed to avoid the obstructions in the midplane and on the aft ring. We found no change in the height of the downstream end of the prototype after clocking.

While inserting the device through the upstream end of the main magnet, we found that additional adjustment of the "pitch" angle of the device was needed, since the center of the upstream end was above the beamline by a few inches. This was a combination of a misalignment of the axis of the installation cart and the overall droop of the detector considered as a cantilever attached at its upstream flange. To bring the two ends of the prototype into alignment, we lowered the upstream end by about two inches while leaving the downstream end at the same height as before. When the upstream end was lowered in this fashion, the clearance between the prototype and the cryostat protrusions was a few inches at all six locations.

The initial setting of the stops on the rails for the installation cart did not give us enough room to engage the forward docking fixtures. Because the stops were already set at their extreme positions, we had to remove them entirely for the test. Thus, the forward travel of the cart plus prototype assembly was limited only by the footrails at the edge of the Level 1 platform. A few inches from the position where the downstream docking fixtures would start to make contact, we rotated the device back to the unclocked position.

3.2. Docking

It was impractical to dock the prototype in exactly the way we plan to do the final detector, because lines of sight to the forward docking pins were blocked by the support structure itself. Although sighting down the spider tube to check whether the central axis was close to that of the fixed docking plate was useful for gross alignment, we had no provision for precise positioning solely from information available at the Level 1 platform. By positioning a hydraulic lift on the floor of Hall B, we were able to place a person close enough to this area for visual inspection of the alignment between the docking pins and the bushings. A few adjustments to the installation cart settings allowed us to engage the docking pins.

The z position of the entire detector is defined by the dowel pins linking the upstream docking legs and the saddles attached to the upstream cryostat ring. Our design accomodates changes in overall length of Region I due to thermal expansion by allowing the forward docking pins to slide within their bushings. We designed in a 0.100 inch gap between the forward docking plate and the fixed docking plate so that we would be able to accomodate dimensional changes in both directions. In our initial docking attempt we found that we could not push the installation cart far enough forward to put the upstream dowel pins into place easily. We had to apply enough force to compress the rubber O-rings on the forward docking pins, squeezing down the gap between the forward docking plate and the fixed docking plate, to be able to drive home the upstream dowel pin at the 2:00 position. We could not insert the other two dowel pins without applying an unreasonable amount of force; in fact, we had some problems in inserting one of the screws at the 6:00 position which connected the upstream docking legs to the saddles on the aft cryostat ring.

After the prototype was attached at both ends, we were able to make adjustments to the position of the installation cart so as to remove all stress from the spider pipe. By turning the long screws which connect the spider pipe to the forward end of the prototype at the upstream end of the six-sided pipe and removing the legs between the spider and the boss ring we could then disconnect the spider and the prototype completely.

We remeasured as many of the wire tensions as possible with the device in its installed position. Since this location does not allow us to use a simple permanent magnet needed to drive the wires to resonance, we rigged up a pair of large coils to set up a field centered on the axis of the detector. Each coil has 181 turns of magnet wire wound on a circular form 25 inches in diameter. We operated the two coils in series, at 20 amperes. A couple of the positions where we ordinarily measure tensions were not available to us in this setup because the magnetic field was too weak to excite the wire to resonance. The results of the wire tension measurements we were able to make are included in Tables I–III.

To reverse the docking procedure, we reconnected the spider at both ends and removed the screws holding the upstream docking legs to the cryostat saddles. Using the screw adjustments on the installation pipe, we took up the weight of the detector so that the forward docking pins could slide out of the bushings, without binding. The detector was then clocked thirty degrees so that it could once again pass the protruding parts of the cryostats.

After we had finished our tests inside CLAS, we remeasured the wire tensions, repacked the prototype, transported it back to Pittsburgh, and measured the tensions one last time. We have now disassembled the full scale prototype in order to incorporate its parts into final Region I sectors.

4. Space allocations

The amount of clearance between the detectors and the cryostats was acceptable throughout the clocking and docking maneuvers. Figure 1 shows the amount of space between the outer edges of the endplate in the 6:00 position and the nearest edge of the cryostat, measured at a number of locations. The measurements are indicated by the heavy lines; the signal translator boards are shown only for reference. We found that the agreement between the measured distances and the expected distances was within 1 centimeter.

We feel that the best way to make the cable connections between the detector and the front end electronics would be to have a number of disconnect panels mounted on the upstream end of the boss ring. Relatively short signal and high voltage cables would be attached to the the drift chamber at an early stage (most likely before transportation to CEBAF) and would end at the disconnect panels. Then, when the detector is docked in place, we would plug in the long cables running from the front end boards and from the high voltage distribution sites to the panels. This avoids the mechanical load of heavy cable bundles, places the connection points at a place where there is relatively easy access, and makes it relatively simple to read out the detector from a standalone monitoring system independent of CLAS (for testing and troubleshooting). There seems to be sufficient space near the boss ring to place these panels in such a way as to leave enough room for cable bundles, supports for Region I and the minitoroid magnet, and gas tubing. It may also lead to a natural place to fan out the high voltage channels to individual segments on the detector.

5. Recommendations for the final installation

The most serious signs of trouble we encountered during our tests was the numerous aluminum wires which snapped either during the drive down to CEBAF or shortly after. If this had been due to the means of transport we used, the actual detector would be in serious jeopardy if we were to bring it by the same procedure we followed for the test. If, on the other hand, the wires broke for reasons unrelated to the structure of the detector, the box used for its transportation, or the way in which we handled the device, the danger would not be as large as one would estimate at first.

These are the indications we had that the wire breakage was caused by the particular combination of aluminum wire and wet conditions:

- We noticed a loss of elasticity on the part of the aluminum wires when we tried to bend the broken pieces by hand. Instead of returning to their original shape, or acquiring a permanent kink the way normal aluminum wire does when taken into the plastic regime, these wires were so embrittled they would shatter easily.

- We saw unusual signs of corrosion on the wires both as seen by the unaided eye and by the scanning electron microscope. Large deposits, approximately the same size as the wire diameter itself, appeared at frequent intervals, and refused to come off easily when we tried scraping the wire surface.

- Other exposed aluminum and steel surfaces in the prototype showed signs of water damage as well.

- Despite the wire breakage, we saw essentially no change in tensions in the surviving tension measurement wires. We have no reason to believe that the wires which broke after we unpacked the prototype were subject to any stresses or shocks at the time they broke.

- We conducted tests at CMU in which we exposed pieces of gold-plated aluminum wire to water spray periodically over two to three days and watched for changes. Just as in the case of the tension measuring wires, we saw extensive signs of corrosion on these wires, large enough to be easily visible to the unaided eye. We did these tests twice, once with wire from the same batch we used on the prototype, once with samples of the 140 micron field wire used in the final detector. Both trials showed identical signs of corrosion.

We may draw several lessons from the tension measurements displayed in the tables. The first is that the structure we are using seems to do a good job of maintaining wire tensions through all of the maneuvers we must put it through. The final tensions measured in Pittsburgh almost all seem to agree with the initial tensions, often to within a gram, indicating that the endplates were returning to their original positions. The size of the tension changes associated with turning the detector from a vertical axis to a horizontal one is consistent with our tests at Carnegie Mellon. [2] We also note one anomalous set of readings which were taken just after the prototype had been lowered from the platform to the floor of Hall B. We can account for no unusual conditions which might have caused actual tension changes so large and widespread, and are forced to ascribe the strange readings to some problem in the measurement technique.

Along with the measures we plan to take to improve the waterproofing of the box, we are thinking of ways to improve or modify the suspension for the detector. The road conditions were somewhat harsher than we expected both times we took the prototype on the road, and so an additional margin of safety cushioning the chamber against the shocks of the journey would be welcome.

The only major troubles we had with the setup for installation had to do with the amount of travel we had to work with during docking. We found that there was too little room to maneuver the installation cart in both the longitudinal ($+z$) and vertical ($-y$) directions. Accordingly, we recommend that CEBAF find some way to extend rails for the installation cart another six inches, at least. This might have a side benefit when it is time to use that cart for installation of the minitoroid magnet, and for support of the cryogenic target in real photon experiments. Also, we are already making changes to the Region I fixed docking plate to avoid the problem we had in the last millimeter of travel needed to engage the upstream docking pins with their bushings. The downward screw adjustments of the cart were much too close to the end of their travel to be certain that one would always be able to accomodate vertical height and angle requirements of the final Region I detector, the minitoroid, the cryogenic target, and so forth. Thus, we recommend that CEBAF modify the cart to increase the downward adjustment range by at least one-half inch at each screw position.

We were heartened by the rather short amount of time needed to install remove the prototype in CLAS. It took only a couple of hours of work to bring the device from the floor of Hall B to its docked position inside the magnet, and an even shorter time to reverse the process. We expect the actual detector would take longer to install because of the need to attach signal cables, gas lines, and high voltage connections. An even more significant cause for this increase will be the limited access we will have to the critical forward docking area at that time. We were able to encroach on the space which will be occupied by Regions II and III when it was time to install our fixed docking plate and when we docked the prototype fully into place. To compensate for the loss of this space, we hope to install small video cameras to view the docking area from different angles, along with position transducers (depth gauges, microswitches, etc.) as substitutes. Due to the inaccessibility of this part of CLAS, these will probably have to be semi-permanently installed along the edges of the cryostats, in the shadow of the magnets. As for alignment of the forward docking fixture when it is attached to magnet, there is probably no substitute for having a personnel access to that part of the spectrometer, which requires that the fixture be put into its final position before the lower Region II sectors are installed.

We found that optical alignment of the detector and installation carriage will be important to avoid guesswork in the installation process. We strongly recommend that CEBAF establish suitable surveying sites and instruments for Region I and other devices that go into CLAS. For our part, we are already making provisions for survey marks on both ends of the final detector which we shall use to locate its true position when it is installed.

1. S. A. Roth and R. A. Schumacher, "A Many-Wire Computer-Controlled Tension Monitoring System for Drift Chambers," submitted to Nuclear Instruments and Methods.
2. S. A. Roth, "CMU Tension Transfer Tests for the Region 1 Drift Chamber Prototype," internal memorandum.

FIGURES

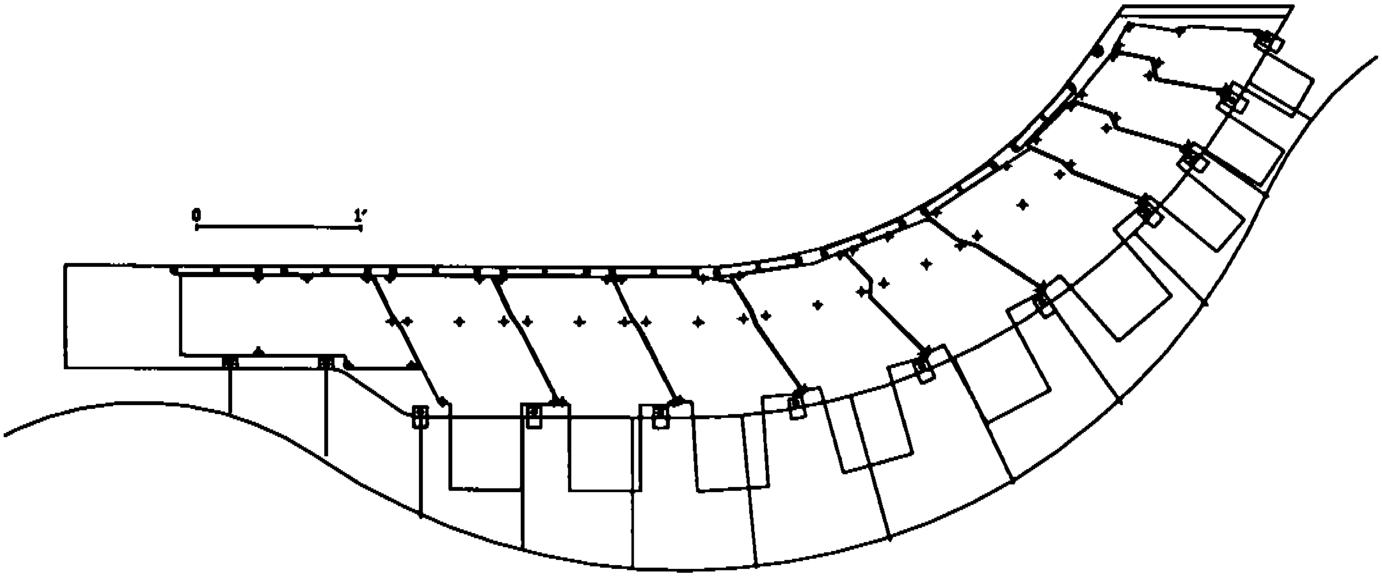

Fig. 1. Measured position of the 6:00 endplate in relation to cryostat. The lines show where measurements were taken the prototype. Final STB board outlines are shown for reference only.

Sector 3

Chan	Wire		L (cm)		Pitt Box #1 Vert 9 June period	CEBAF Box #1 Vert 12 June period	CEBAF Computer Horiz 13 June period	CLAS Box #2 Horiz 15 June period	CEBAF Computer Horiz 15 June period	Pitt Box #1 Vert 21 June period	Pitt Box #1 Vert 9 June tension	CEBAF Box #1 Vert 12 June tension	CEBAF Computer Horiz 13 June tension	CLAS Box #2 Horiz 15 June tension	CEBAF Computer Horiz 15 June tension	Pitt Box #1 Vert 21 June tension
10	I	3	12.69	Al	2050	2020			**1663**	2078	41.58	42.83			**63.19**	40.47
	I	5	25.16	Al	2595	2640					102.05	98.60				
11	I	7	38.30	Al	5708	5888	5464	5425	**7194**	5588	48.88	45.94	53.34	54.11	**30.77**	51.00
	I	9	47.98	Al	5420	5580					85.06	80.26				
12	I	11	54.38	W	4078	4095	3922	3909	**4608**	4098	47.90	47.50	51.79	52.13	**37.52**	47.43
	I	13	55.76	Al	6185	broken					88.24	broken				
13	I	15	55.76	W	4210	4236	4274	4208	**5128**	4236	47.25	46.67	45.85	47.30	**31.85**	46.67
	I	17	55.76	Al	5982	6280					94.33	85.59				
14	I	19	55.76	W	6192	6250	5952	5823	**7299**	6278	21.84	21.44	23.64	24.70	**15.72**	21.25
16	O	4	7.45	W	568		550		555	537	46.30		49.38		48.50	51.80
	O	8	20.78	Al	2450	2490					78.09	75.60				
17	O	12	37.98	W	3162	3190	3509	3178	**3597**	3162	38.87	38.19	31.57	38.48	**30.04**	38.87
	O	16	51.39	Al	6283	6550	broken				72.63	66.83	broken			
18	O	20	62.83	W	5080	5090	5587	5450	**5882**	5074	41.21	41.05	34.07	35.81	**30.74**	41.31
	O	24	70.30	Al	7880	8050					86.42	82.81				
19	O	28	75.12	W	5788	5830	5817	5742	**7246**	5804	45.38	44.73	44.93	46.11	**28.96**	45.13
	O	32	75.83	Al	8415	8790					88.15	80.79				
15	O	36	75.82	W	5840	5840	5921	5838	**7407**	5872	45.40	45.40	44.17	45.44	**28.23**	44.91
	O	40	75.82	Al	8235	8630					92.03	83.80				
	O	42	68.89	W	5179	5198					47.66	47.32				
	O	46	68.89	Al	8100	broken					78.53	broken				

Bold entries are outlying values for a wire. Periods are in microseconds, tensions in grams.

TABLE I. Tension measurements, Sector 3

Sector 4

					Pitt	CEBAF	CEBAF	CLAS	CEBAF	Pitt	Pitt	CEBAF	CEBAF	CLAS	CEBAF	Pitt
					Box #1	Box #1	Computer	Box #2	Computer	Box #1	Box #1	Box #1	Computer	Box #2	Computer	Box #1
					Vert	Vert	Horiz	Horiz	Horiz	Vert	Vert	Vert	Horiz	Horiz	Horiz	Vert
					9 June	12 June	13 June	15 June	15 June	21 June	9 June	12 June	13 June	15 June	15 June	21 June
Chan	Wire		L (cm)		period	period	period	period	period	period	tension	tension	tension	tension	tension	tension
30	I	3	12.69	Al	1550	1430		**1399**	1468	1406	72.74	85.46		**89.29**	81.09	88.40
	I	5	25.16	Al	2820	2880					86.42	82.85				
31	I	7	38.30	Al	4445	4480		4348	**5376**	4468	80.61	79.35		84.24	**55.10**	79.78
	I	9	47.98	Al	6525	6500					58.69	59.15				
32	I	11	54.38	Al	6040	6080		6070	**8130**	6143	88.00	86.85		87.13	**48.57**	85.08
	I	14	55.76	Al	7835	7678					54.99	57.26				
33	I	17	55.76	Al	6320	6400		6330	**8547**	6399	84.51	82.41		84.24	**46.21**	82.43
	I	19	55.76	Al	6410	6630	accidentally broken				82.15	76.79	accidentally broken			
	I	20	55.76	Al		broken						broken				
36	O	4	7.45	Al	850	830			**1224**	818	83.33	87.39			**40.19**	89.98
	O	8	20.78	Al	2310	2230					87.84	94.26				
37	O	12	37.98	Al	4080	4150		**3908**	4327	4172	94.10	90.95		**102.57**	83.66	90.00
	O	16	51.39	Al	5910	6040					82.09	78.59				
	O	19		Al		broken						broken				
38	O	20	62.83	Al	7020	7140			**8849**	7124	86.98	84.08			**54.74**	84.46
	O	24	70.30	Al	8180	8390					80.20	76.23				
39	O	28	75.12	Al	8600	8888		8758	**11235**	8763	82.84	77.56		79.88	**48.54**	79.79
	O	32	75.83	Al	8780	8990					80.98	77.24				
35	O	36	75.82	Al	8400	8888		8120	**4444**	8560	88.45	79.00		94.66	**316.02**	85.18
	O	40	75.82	Al	8160	broken					93.73	broken				
	O	42	68.89	W	5240	5280					46.56	45.86				
	O	44	75.82	Al		broken						broken				
	O	46	68.89	W	5283	5300	broken				45.81	45.51	broken			

Bold entries are outlying values for a wire. Periods are in microseconds, tensions in grams.

TABLE II. Tension measurements, sector 4

Sector 5

Chan	Wire		L (cm)		Pitt Box #1 Vert 9 June period	CEBAF Box #1 Vert 12 June period	CEBAF Computer Horiz 13 June period	CLAS Box #2 Horiz 15 June period	CEBAF Computer Horiz 15 June period	Pitt Box #1 Vert 21 June period	Pitt Box #1 Vert 9 June tension	CEBAF Box #1 Vert 12 June tension	CEBAF Computer Horiz 13 June tension	CLAS Box #2 Horiz 15 June tension	CEBAF Computer Horiz 15 June tension	Pitt Box #1 Vert 21 June tension
20	I	3	12.69	W	1020	1020		**989**	1004	1018	41.68	41.68		**44.33**	43.02	41.84
	I	5	25.16	Al	2728	2740					92.35	91.54				
21	I	7	38.30	W	3025	3040	3005	3028	**3425**	3040	43.18	42.76	43.76	43.10	**33.69**	42.76
	I	9	47.98	Al	5168	5270					93.56	89.98				
22	I	11	54.38	W	4480	4470	4545	4463	**5495**	4478	39.69	39.87	38.56	39.99	**26.38**	39.72
	I	13	55.76	Al	6005	broken					93.61	broken				
23	I	15	55.76	W	4928	4936	5033	4899	**6211**	4937	34.49	34.37	33.06	34.90	**21.71**	34.36
	I	17	55.76	Al	6235	6465					86.83	80.76				
24	I	19	55.76	W	4310	4300	4310	4288	**5208**	4309	45.09	45.30	45.09	45.55	**30.88**	45.11
25	O	4	7.45	Al	1205	1170			1244	1186	41.46	43.98			38.90	42.80
	O	8	20.78	Al	2360	2380					84.16	82.75				
26	O	12	37.98	W	3060	3050			3268	3078	41.51	41.78			36.39	41.02
	O	16	51.39	Al	5885	5990	broken				82.79	79.91	broken			
27	O	20	62.83	W	4850	4890		4838	**5952**	4872	45.21	44.48		45.44	**30.02**	44.81
	O	24	70.30	Al	7950	7740					84.90	89.57				
28	O	28	75.12	W	5860	5880		5793	**7462**	5883	44.27	43.97		45.30	**27.30**	43.93
	O	32	75.83	Al	11080	11140					50.85	50.30				
29	O	36	75.82	Al	11350	11380			11904	11389	48.45	48.19			44.04	48.12
	O	40	75.82	Al	11198	11200					49.77	49.75				
	O	42	68.89	W	5960	5980					35.99	35.75				
	O	46	68.89	Al	9840	9880					53.22	52.78				

Bold entries are outlying values for a wire. Periods are in microseconds, tensions in grams.

TABLE III. Tension measurements, sector 5