Setup of Longpulse Laser System for E158

April 11, 2001

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Introduction

This document is meant to explain the setup of the CID E158 optics and cable plant. It should explain the various features of the system and list all the operating parameters relevant for setup and routine operation. It is intended to provide an overview of the system for nonexperts, while also containing all the relevant running parameters needed by experts.

Overview of Optics Setup

Figure 1 is a diagram of the optics layout from the Flash:Ti cavity to the cathode. The following subsections describe the optics on each bench in more detail.

Flash:Ti Bench

The Flash:Ti cavity is defined by a 100% reflective back mirror and a 85% (80%?) reflective output mirror. A Brewster tuner and a half-wave plate are used to select the wavelength of the laser, currently at 854nm, and keep it reasonably narrow-band; FWHM is about 4nm. The output pulse is approximately 12μs long and typically has 1.0-1.1W at 60Hz. The Longpulse photodiode is used to monitor the laser power.

The linear polarizer shown just upstream of the SLICE Pockels cell defines the polarization at that point to be horizontal; a half-wave plate just upstream of it rotates the cavity output polarization to horizontal. The linear polarizer downstream of SLICE is vertical. The SLICE Pockels cell is used to select out the portion of the longpulse beam we want to use: it can be driven between zero and 3000V, its approximate half-wave voltage (because it is a double crystal Pockels cell), and can pulse for a duration of between 70 and 400ns. The timeslice chosen out of the longpulse is determined by a tradeoff between intensity and jitter: the earlier part of the longpulse has greater intensity but also greater jitter. A compromise is typically found that provides $\leq$1.5% intensity jitter. Setting the SLICE Pockels cell to zero volts gives an extinction factor of 500; this will be used to reduce the beam intensity for the low-current part of the E158 commissioning run. The TOPS Pockels cell is pulsed by an arbitrary function generator and is used to shape the laser pulse's temporal profile to compensate for cathode saturation or accelerator beam loading effects. The linear polarizer downstream of it is also oriented to transmit vertical polarization, so increasing the voltage on TOPS in a given timeslice reduces the laser beam intensity for that slice.

Combining Bench

The Combining Bench contains a remotely controllable wavelength diagnostic and a photodiode that monitors the laser power in the SLICEd beam. The Harmonic Beam Sampler

(HBS) sends approximately 1% of the laser intensity to each of those diagnostics. In addition, there is a remotely-insertable mirror that merges an 833nm diode laser onto the Flash:Ti path while extinguishing the Flash:Ti beam (by an unmeasured amount, but "pretty good"). The diode laser has a separate shutter controlled through the SCP. To switch from Flash:Ti operation to diode operation, insert the remote mirror and then remove the diode laser shutter.

Wall Bench

The goals of the Wall Bench optics are to control the polarization of the laser beam and to control helicity-correlated systematics on the beam. The heart of the system is the combination of the CP and PS Pockels cells. The CP (Circular Polarization) cell has its fast axis at 45deg and is pulsed at ± quarter-wave voltages. It converts incoming vertically polarized light into nearly circularly polarized light. Its voltages can be tweaked from quarter-wave to correct for any phase shifts on the x,y axes downstream. The PS (Phase Shift) cell has its fast axis vertical and is typically run at low voltages. Adjusting the PS cell voltage corrects for phase shifts on the u,v axes. In principle, it should be possible to create almost perfectly circularly polarized light on the photocathode by adjusting the CP and PS cell voltages from their nominal values (±quarter-wave and 0, respectively). Note that switching the fast and slow axes of either Pockels cell reverses the sign of the phase shift it applies to the beam, and as of April 11, 2001we're not sure which is which.

Immediately upstream of the CP cell is the Cleanup Polarizer, a linear polarizer oriented vertically and used for two purposes: to "clean up" the polarization of the Flash:Ti beam; and to merge the YLF:Ti beam onto the same path.

Behind the first mirror is the Intensity 1 photodiode, a beam diagnostic whose signal will be nearly identical to the SLICE photodiode because there is so little between them. However, the SLICE photodiode is upstream of the diode combiner (which blocks the Flash:Ti), and Intensity 1 photodiode is downstream.

The IA (Intensity Asymmetry) Pockels cell is pulsed in a helicity-correlated way and in combination with the Cleanup Polarizer can be used to introduce a helicity-correlated intensity asymmetry on the laser beam (hence the name). By default, the IA cell pulses to yield 99% transmission through the Cleanup Polarizer for both states. The IA cell is part of the helicity-correlated intensity feedback system. The Intensity 2 photodiode looks at the leakage light coming out of the Cleanup Polarizer, which will typically be roughly 1% of the beam intensity. When the IA feedback is running, this photodiode will presumably see a large asymmetry on the leakage light that is proportional to the asymmetry induced on the primary beam, but as of April 11, 2001this diagnostic has not been commissioned.

The second mirror is mounted on a piezo stack that can also be pulsed in a helicity-correlated way. This mirror can change the angle of the laser beam through the remainder of the optical system, and typically can produce helicity-correlated displacements on the cathode of tens of microns. We refer to this mirror as the "piezomirror" and use it in as part of the helicity-correlated position feedback system. Immediately after the last mirror is a glass plate mounted on an identical piezo stack. Tilting the glass plate induces a displacement of the beam, rather than an angle change. This mirror is the "piezo tilt plate," and though it hasn't been commissioned as of $April 11, 2001$ it is a second option for helicity-correlated position feedback, probably having a dynamic range on the order of one micron. The key difference between the piezo mirror and the piezo tilt plate is that the former affects the angle of the laser beam, while the latter affects its position. Whether that difference will translate to different behavior on the electron beam remains to be seen.

Just downstream of the PS cell is the Asymmetry Inverter. The Asymmetry Inverter is a translation stage carrying two sets of lenses: a doublet that provides a magnification of roughly -2.25 and a quadruplet that provides a magnification of roughly +2.25. Both sets have an effective lever arm close to zero; i.e. they put a transformation on the laser beam of $\pm 2I$. Switching between the two states of the Asymmetry Inverter should invert the spatial distribution of the laser beam's intensity profile, as well as reversing whatever angle it may have. The idea is to use this Asymmetry Inverter to gain a cancellation of helicity-correlated position and angle effects on the electron beam. A single test of it during T-437 indicated that it does provide some cancellation.

Past the Asymmetry Inverter are two insertable optics mounts, the first containing a half-wave plate (for 850nm) and the second containing a helicity filter (a quarter-wave plate glued to a linear polarizer such that one circular polarization is transmitted and the other extinguished). The half-wave plate can be used to provide a slow reversal of the physics asymmetry, while (hopefully) leaving untouched any helicity-correlated systematics. There is a second half-wave plate on the Gun Bench for the same purpose, and during T-437 it did provide some degree of cancellation of systematics. The half-wave plate on the Wall Bench hasn't been tested as of $April 11, 2001$ for this purpose. The helicity filter (HF) is used while scanning the CP and PS cell voltages and measuring the laser intensity on the Gun Bench photodiode in order to set their initial operating voltages (which may then need small adjustments to compensate for phase shifts in the optics between the Pockels cells and the cathode). Running with the HF inserted and the CP cell pulsing for extinction should give an extinction ratio of $\geq$1000:1; this mode of running will be used during part of the low-current commissioning period.

The last item on the Wall Bench is the PES Shutter, which can be inserted to prevent laser light from leaving the Laser Room. This shutter is used in the machine protection system (MPS) and is interlocked to the gun HV, the lens and corrector bulk supply, solenoids 396 and 400, bend magnet 405, valves 406 and 409, the CID Faraday cup, and some additional valves in the electron beam.

Optical Transport System

The Optical Transport System (OTS) consists of a long tube (about 20m) filled with nitrogen at atmospheric pressure and containing a minimal set of optics: a 5m focal length relay lens on a remotely-controlled x-y stage, a Mirror Box containing 4 helicity-compensated mirrors that bring the beam onto the Gun Bench with an essentially straight path to the cathode, and a 3/8" thick window on each end. The 4 helicity-compensated mirrors are mounted in two helicity-compensated pairs, for which the bounces within each pair interchange 's' and 'p' polarizations. Care was taken to make sure that the mirrors came from the same coating run. In the past the OTS has run at vacuum, but for E158 we are running it at atmosphere to reduce the strain-induced birefringence on the end windows. The OTS also contains the Laser Safety Stopper (LSS), a personnel protection system (PPS) / beam containment system (BCS) device, as well as two insertable screens for checking the beam position, the first about 1m downstream of the 5m lens and the second between the Mirror Box and the Gun Bench.

Gun Bench

The primary laser beam has a straight shot across the Gun Bench to the photocathode. Along the way, it goes through the All Beam Telescope and a single vacuum window. The All Beam Telescope consists of a -75mm focal length lens on a remotely controlled x-y-z stage and a +100mm lens fixed in position. There is also an insertable half-wave plate that is used for a slow helicity reversal just like the one on the Wall Bench; the virtue of this half-wave plate is that it is located downstream of every optical element except for the vacuum window. Finally, there is an insertable 80% mirror immediately before the Gun Bench exit that will dump the bulk of the beam into a diagnostic line.

The diagnostic line has a length identical (to within a couple inches) to the distance between the pickoff and the photocathode; at the end of the diagnostic line is a paper target that represents the photocathode. The Big Sky camera looks at that paper target. Behind one of the mirrors in the diagnostic line is the Cathode Photodiode. This photodiode is only useful for checkout and calibration runs, times when the pickoff will be inserted.

Pockels Cell Alignment

This section summarizes the information we have on the locations and alignment of the IA, CP, and PS Pockels cells on the Wall Bench as of the time we were kicked out of the CID Laser Room (Jan 8, 2001). Table 1 below summarizes the readings of the translation and rotation micrometers on each of the Pockels cells. The translations were chosen to center the Pockels cells as best as possible by eye on the laser beam. Figures 4 through 11 at the end of the paper summarize the translation scan data taken in late October, 2000. This data was taken with the Spotsize Detector (a 1-d array photodiode with 6-8 channels read out). A linear polarizer was placed just downstream of the PS cell to provide a large analyzing power. Table 2 below summarizes the measured PITA slopes for these studies.

The laser beam path has shifted horizontally by about 1.5-2mm, so that the micrometers must be at larger values now for the beam to be centered than in October-November, 2000. So when referencing the translation studies, keep this offset in mind: a horizontal setting of 14.0mm on the translation plots would probably translate to a setting now of about 16.0mm.

Asymmetry Inverter Design

As explained in an earlier section, the Asymmetry Inverter is a translation stage carrying two sets of lenses: a doublet that provides a -2.25I transformation and a quadruplet that provides a +2.25I transformation. Table below summarizes the focal lengths and separations

micrometer	IA Cell	CP Cell	PS Cell
Horz	11.65	15.50	16.0
Vert	11.73	8.0	8.0
Pitch	7.327	7.173	7.78??
Yaw	5.59	4.413	8.677
Roll	12.675	8.23	-0.295
Roll Angle	332deg	2deg	4.5deg

Table 1: Summary of Pockels Cell alignment information

	CP Cell Scans	PS Cell Scans
CP PITA slope	-1050ppm/V	-20ppm/V
PS PITA slope	-5ppm/V	1050ppm/V

Table 2: Summary of PITA slopes measured during translation studies.

of the lenses; the actual separations should be close to these values but not exact. To recover the beam alignment when switching from one state to the other, it is important to translate the stage to the proper setting: for the -2I doublet, the stage should be translated away from the wall until the dial on the hand-crank is at the last 0.49 that can be reached; for the +2I quadruplet, the stage should be translated towards the wall until the dial on the hand-crank is at the last 1.36 that can be reached. If there's any doubt about these numbers, go by the ones written on the paper taped on the wall (or written in the CID Laser Log 4).

	-2I Doublet		+2I Quadruplet	
Lens Number	Focal Length	Z dist from prev.	Focal Length	Z dist from prev.
1	88	123.4	50	75.5
2	200	286.3	75	117.1
3	—	—	50	75.5
4	—	—	75	117.1

Table 3: Summary of Asymmetry Inverter Design (all unit in mm)

Beam Size and Imaging

The beam sigma is about 1mm at the CP cell. The Asymmetry Inverter is designed to provide a magnification of about 2.25 in either state and the All Beam Telescope provides a magnification of roughly 2. The laser spot slightly underfills the cathode; the camera image has a diameter of roughly 16mm. If the visible laser spot represents roughly plus/minus two sigma on the beam, then the beam sigma is about 4mm on the cathode, consistent with the design magnifications and the beam size at the Pockels cells.

The plan was to image the laser beam from the face of the CP cell to the cathode. This would minimize the contribution of any helicity-correlated steering from the CP cell, and would still leave a lever arm of approximately 0.5m for the piezomirror. In practice, the best we can do is to put the image point at the face of the PS cell, approximately 6 inches downstream of the CP cell (same within measurement ability, a couple inches, for both Asymmetry Inverter states). This happens because the first step is to use the All Beam Telescope to set the beam size on the cathode, and the second step is to locate the image point on the Wall Bench and place the CP cell there. However, constraints on the locations of the Asymmetry Inverter and the PS cell prevent the CP cell from going right at the image point.

Brief Overview of Electronics and Cable Plant

This section gives a brief description of the cable plant at CID relevant to E158. Figures 2 and 3 document the E158 cable plant in the CID Control Room and Laser Room.

PMON and Feedback Control Hardware

PMON (Polarization Monitoring) is the system we use to generate a pseudorandom quadruplet-based helicity sequence, and to control helicity-correlated devices. The PMON Controller uses a 33-bit algorithm as described in Horowitz and Hill to generate the pseudorandom sequence. It transmits the polarization information for the current event to the PMON Interface module, which is used to control all of our helicity-correlated devices: the IA, CP, and PS Pockels cells and the piezo mirror and tilt plate. The PMON Interface module takes as input a DAC bus that tells it what signal levels should be output for each helicity-correlated device for each helicity. The module then looks at the helicity of the current event and chooses the appropriate voltage levels for its outputs.

SCP Controls and Readout

The following signals of interest read out on SCP:

ARRY LI00 251	Channel	Signal
	1	Spontaneous Emission
	2	Longpulse PD (W)
	3	SLICE PD (μJ)
	4	open
	5	Cathode PD (μJ)
	6	open
	7	SLICE HV MON (V)
	8	open
	9	open
	10	open
	11	Intensity 1 PD (μJ)
	12	Intensity 2 PD (counts)

E158 Controls and Readout

The following signals of interest read out through the E158 ADCs at CID:

Channel	PMT 1	PMT 2
5	Gate Gen 1 (Rack 29)	SLICE HV MON
4	open	Gate Gen 2 (Rack 15)
3	BES 2 PD	Intensity 2 PD
2	Intensity 1 PD	Cathode PD
1	SLICE PD	Remote Spectrometer
0	Longpulse PD	open

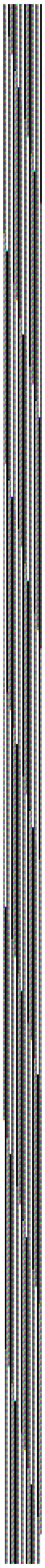

Figure 1: Diagram of optics setup in CID Laser Room.

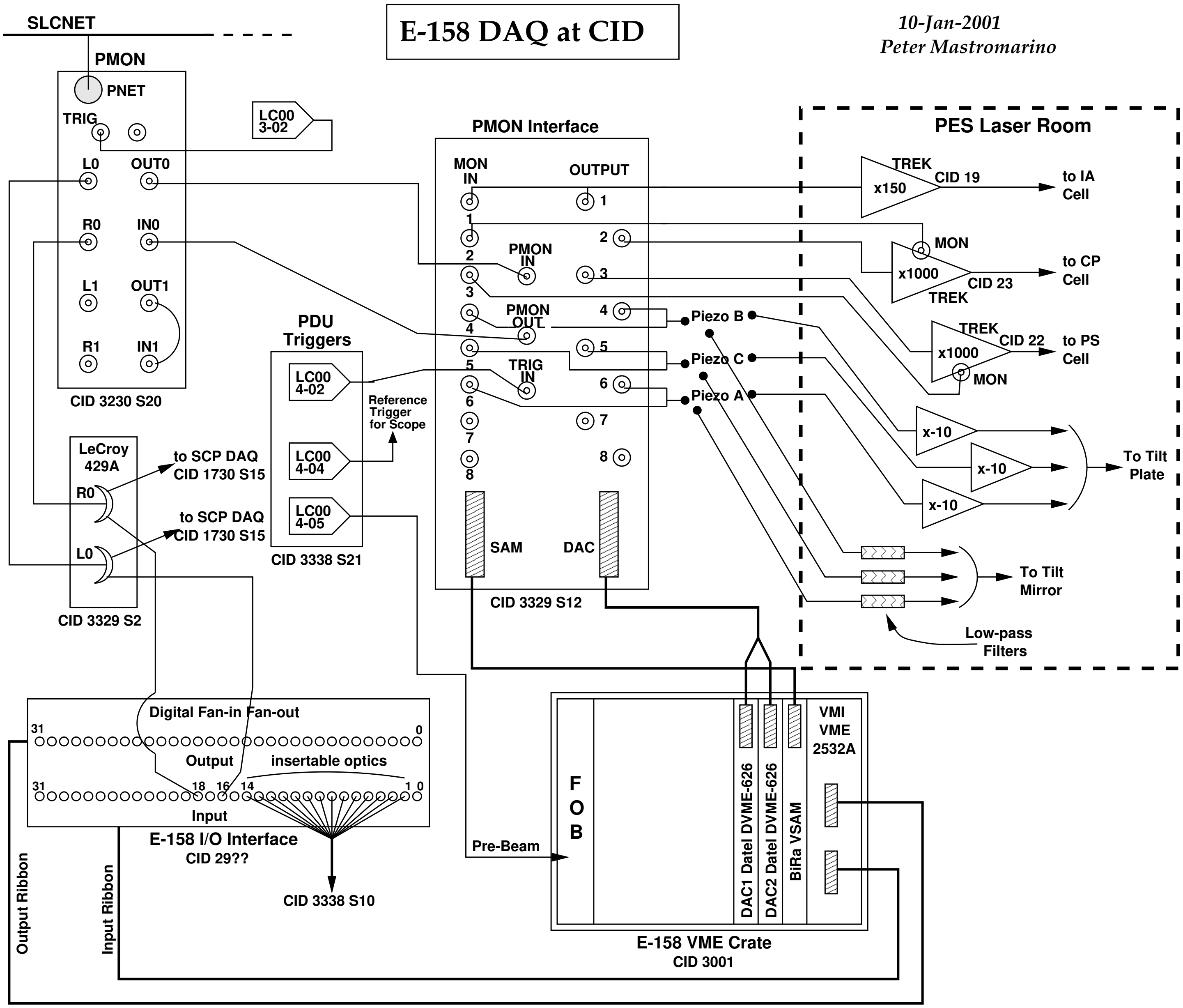

Figure 2: CID Control Room Cable Plant.

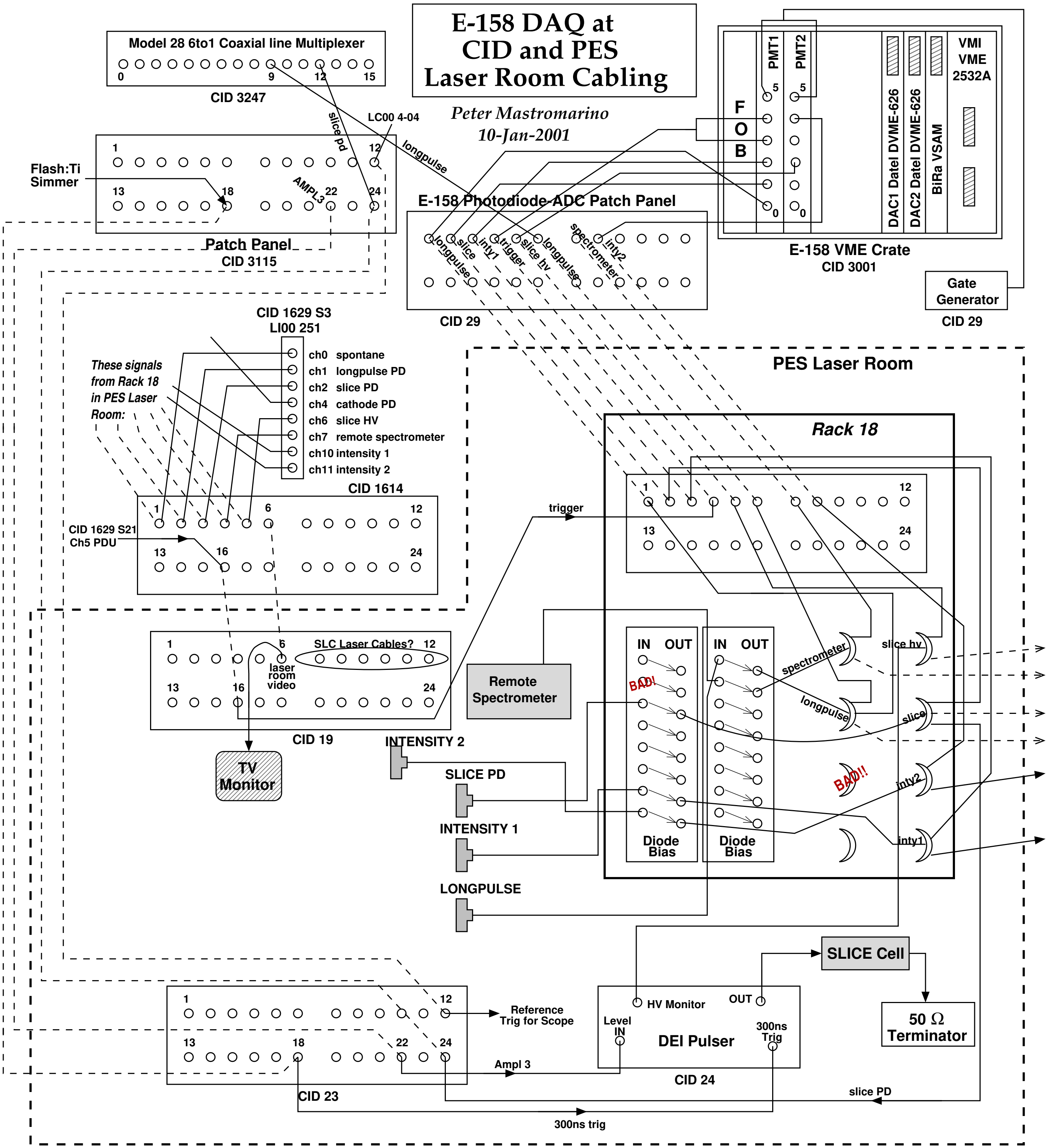

Figure 3: CID Laser Room Cable Plant.

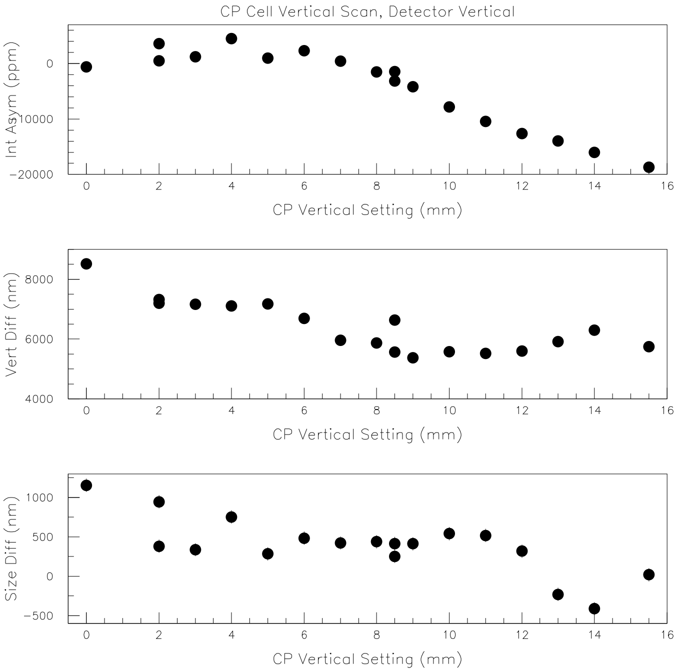

Figure 4: CP Cell Vertical Scan, Detector Vertical.

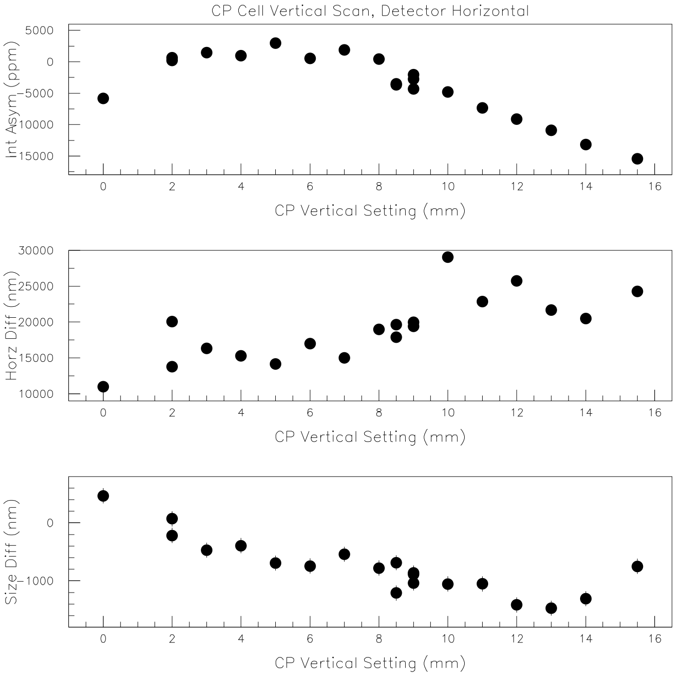

Figure 5: CP Cell Vertical Scan, Detector Horizontal.

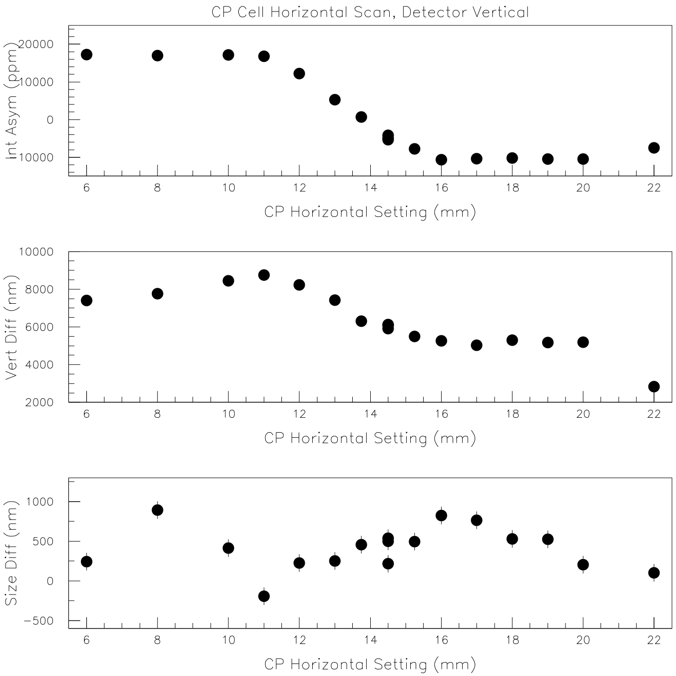

Figure 6: CP Cell Horizontal Scan, Detector Vertical.

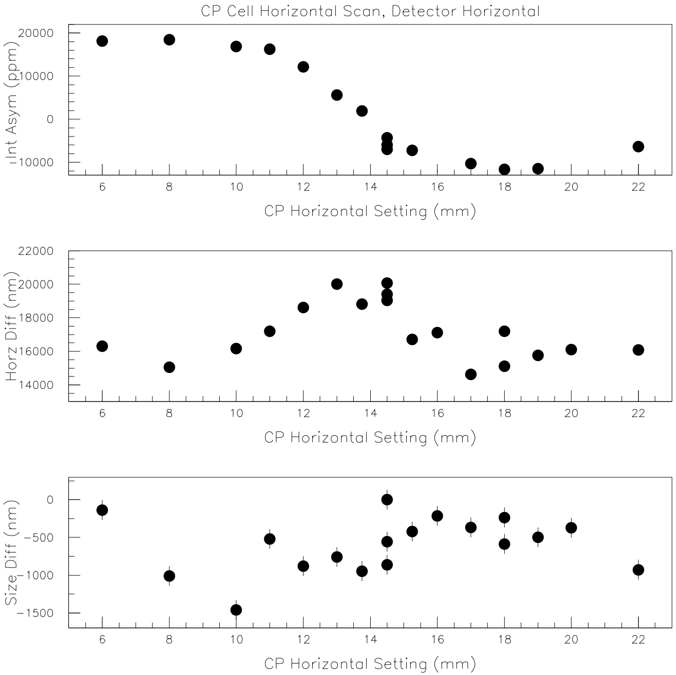

Figure 7: CP Cell Horizontal Scan, Detector Horizontal.

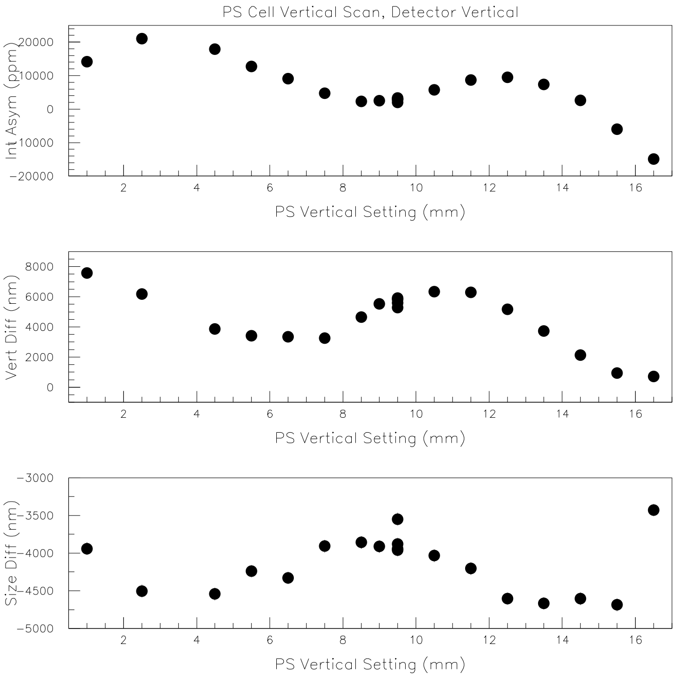

Figure 8: PS Cell Vertical Scan, Detector Vertical.

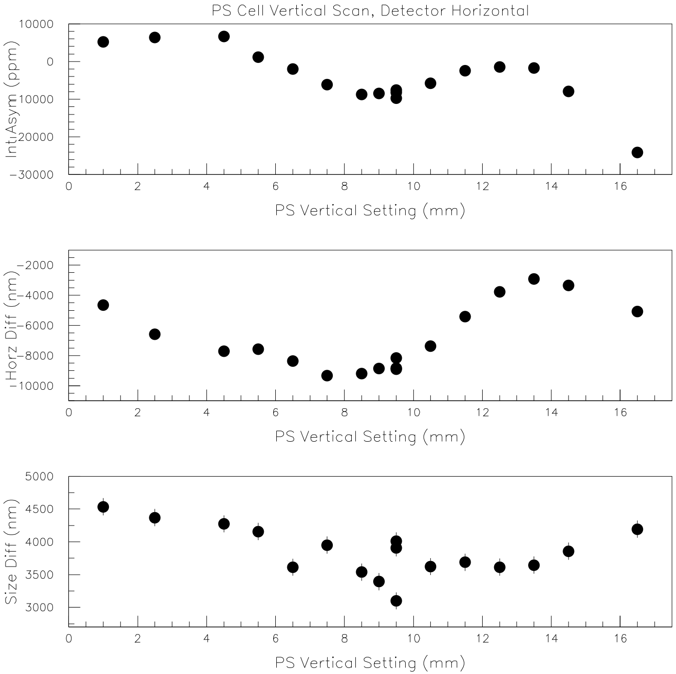

Figure 9: PS Cell Vertical Scan, Detector Horizontal.

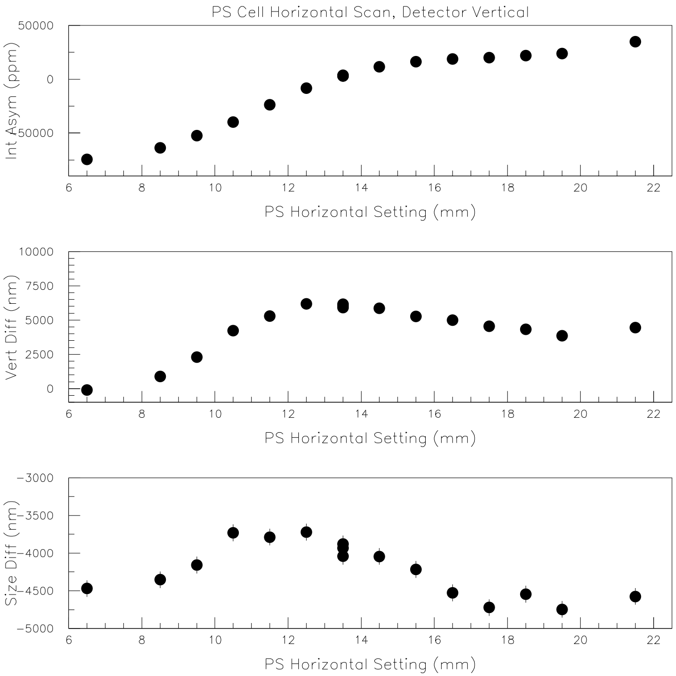

Figure 10: PS Cell Horizontal Scan, Detector Vertical.

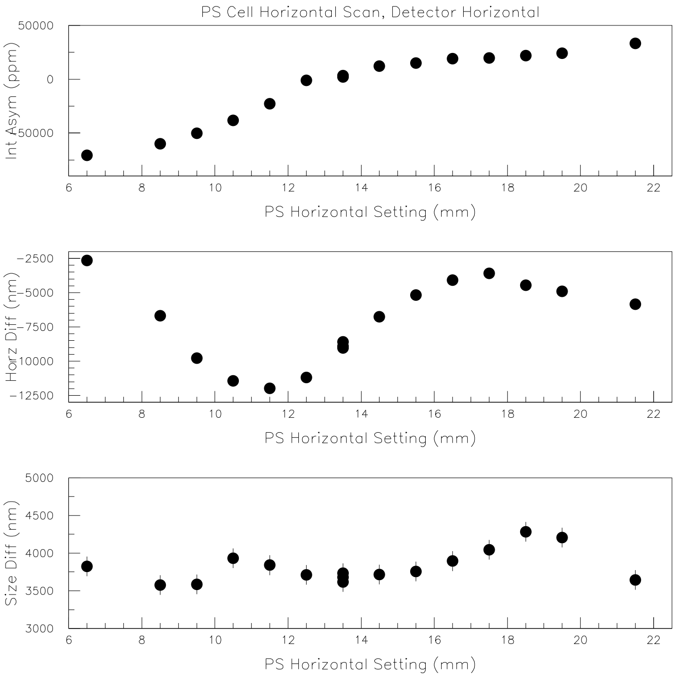

Figure 11: PS Cell Horizontal Scan, Detector Horizontal.