Operating Instructions

for VPT Experiments

at UVa's HEP Laboratory

Written by

John Christopher Jones

Summer 2010

[DRAFT]

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1 Preamble

1.1 How This Document Was Written

This document was written in LaTeX, and was compiled with XeTeX 0.94 from MacTeX 2009 for Unicode support. The Lucida Grande font is used for sans-serif typefaces, available on Mac OS X. Anonymous Pro is used for the monospaced font, also available on Mac OS X.

A number of LaTeX packages were used. The document was typeset with the *Memoir* class. Graphics are provided with the TikZ package. The glossary was constructed with the `glossaries` package. Tables make use of the `booktabs` and `multirow` packages. Links are provided by the `hyperref` package. Several other packages are loaded for symbol support: `amsmath`, `textcomp`, `ucs`, `xunicode`, `xltxtra`.

1.2 Conventions Used in This Text

1.2.1 Font Conventions

The following conventions are used in this text:

Example	Description
File → Open	For menu items, a sans-serif font is used with → between the menu items.
keys	For short key sequences that sould be pressed, a sans-serif font is used.
`/foo/bar`	For directories, filenames, and paths, a mono-spaced font is used.
`command -o file.ext`	For commands that should be entered literally into a terminal, a bold mono-spaced font is used.
`--file` ⟨*named field*⟩	For options the user should supply, a brief description of the option is surrounded in angle brackets.
LabVIEW	For software, application names, and operating systems, a sans-serif font is used.
CAEN	The maker of a component is typeset this way.
CAEN `SY1527LC`	The make (manufacturer) and model number of a component are typeset this way.
`SY1527`	The model number of a component is typeset this way.

1.2.2 Advisories

⚠ **AVOID** hazards pointed out by the warning signs.

✓ **DO** read positive recommendations in boxes like this.

✗ **DO NOT** ignore negative recommendations without consulting with the experiment maintainer.

1.2.3 Symbols Used

For brevity and consistency, a number of standard symbols are used to represent keyboard keys. These conventions were largely adopted from Mac OS X.

Table 1: Keyboard Symbols

Symbol	Name	Also Known As
⇧	Shift	—
⌃	Control	—
⌥	Option	*Alt*
⌘	Command	*Windows Key*
⌦	Delete Right	—
⌫	Delete Left	—
⎋	Escape	—
↩	Return	*Enter*
←	Left	—
↑	Up	—
→	Right	—
↓	Down	—
⇥	Tab	—

Four of these keys are *modifiers*: ⌘, ⇧, ⌃, ⌥. These keys do nothing on their own (except for ⌘, which toggles the Start Menu in Windows), and have to be combined with another character. This is denoted by joining two keys, such as ⌘C (Copy, OS X) or ⌃C (Copy, Windows).

1.3 Links

If this document is viewed as a PDF, you'll be able to follow hyperlinks throughout the document. These links have different styles depending on their destination:

Example	Description
Google	External link to URI (hyperlink)
Manual.pdf	External link to local companion files
§1.3 Links	Internal link within the same document
LabVIEW	Internal link to glossary definition

2 Overview

2.1 Introduction

The University of Virginia is part of the CMS experiment at CERN. The CMS detector is a multistage general purpose detector. The first inner stage of the detector is the electromagnetic calorimeter (Ecal). The central cavity of CMS is cylindrical, with the beam coming in along its axis. The walls of the cylinder are formed by the Ecal detectors. The rounded walls are the barrel, and at either end are the endcaps. The detectors are made of two main components. The masses that react with the beam products are dense inorganic $PbWO_4$ (*"lead-tungstate"*) scintillator crystals. Behind those scintillators are the scintillation detectors. In the barrel, these detectors are avalanche photodiodes (APDs). In the endcap, these detectors are Vacuum Photo-Triodes (VPTs.)

Some of the main objectives of the CMS detector, such as the discovery of the Higgs boson, will be seen primarily in the Ecal. If a light (<140 GeV) Higgs boson is discovered, it will be from a $H^0 \rightarrow 2\gamma$ decay. Above 140 GeV and through 600 GeV the Higgs boson is predicted to decay into two Z bosons, which further decay into four leptops, such as electrons and muons. Electrons and photons will be detected by the Ecal.

Taken from K.W. Bell et al., "Vacuum Phototriodes for the CMS Electromagnetic Calorimeter Endcap," IEEE Transactions on Nuclear Science, vol. 51, no. 5, pp. 2284-2287, 2004.

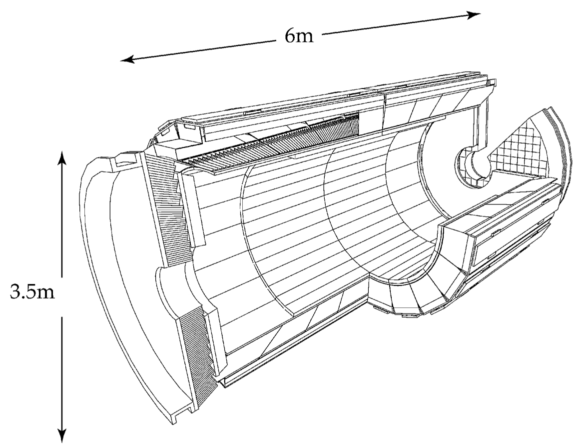


Figure 1: Schematic View of CMS Electromagnetic Calorimeter

As the beam comes in on-axis, the majority of the beam products are produced just off-axis. This means that the endcaps receive the highest radiation dosage, and the detectors need to be especially hardened against neutron radiation. The $PbWO_4$ crystals scintillate in the visible spectrum, near 420 nm. The faceplates of the VPTs are made of a radiation-hard UV-transmitting borosilicate glass. Glass tends to darken when exposed to neutron radiation. The glass used for the VPT faceplates is manufactured in small batches and is proven to have less than 10 % transmission loss after a dose of 20 kGy over a 48 hour period using a ^{60}Co source, prior to being accepted for use in VPT production.

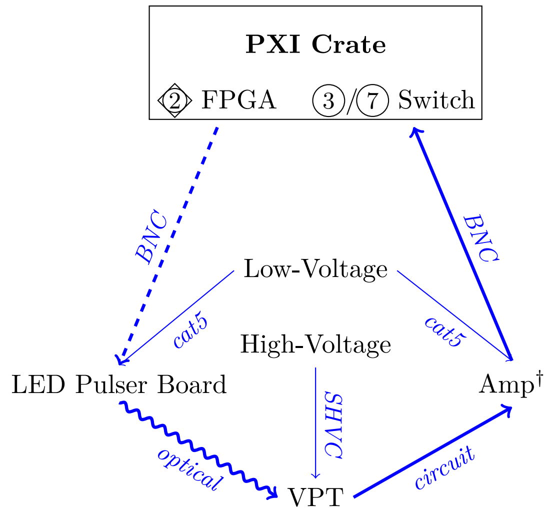
The exact performance characteristics of VPTs under extended optical loads in strong magnetic fields are still being studied. The University of Virginia has previously studied their performance under temperature variation, and also under a non-axial magnetic field (§4.3.1 Further Reading.) We are currently (Summer 2010) studying their long term response behavior, which has been shown to decay over time.

2.2 Experimental Setup

The experimental setup at UVa has two main sections: The PXI Crate and the Rig. The PXI Crate sends signals from its 2 Field Programmable Gate Array (FPGA) module to the rig's LED boards. The boards send a photon pulse to VPTs housed inside a 3.8 T magnetic field, and the VPT translates those photons into a charge on its anode. The anode signal is amplified by a Stephenson amplifier, and that amplified signal is sent back to the PXI Crate's 3 Switch. The PXI Crate then processes and records the signals.

Conceptually part of the rig, a high voltage supply provides a +800 V and +600 V potential difference to the VPT's anode and dynode, respectively. A low voltage supply provides power to the LED pulser boards and the Stephenson amplifier.

Figure 2 is a conceptual view of the conduits between the components of the rig. The "Amp" branch is a simplification. Only the VPT anode connects to the amp, which then connects to the 7 Switch. The VPT cathode bypasses the amp and connects to the 3 Switch. The PIN diode (§2.2.2 VPT Branch), part of the VPT node here, also bypasses the Amp to connect to the 7 Switch.



† Conceptual node; anode only

Figure 2: Rig Connections

2.2.1 LED Branch

The FPGA sends three TTL signals to a set of powered line driver chips (`74LS241N` and `74LS241PC`), which then drives the TTL signals over BNC cables to the powered LED board. Each TTL signal corresponds to a single LED. (§4.2 LED Pulser Boards [FIXME])

Load Signal is a simple simulated collider beam signal, intended to represent photon activity during beam events.

Soak Signal is a faux load between beam events to maintain the VPT's response curve.

Reference Signal is a measurement pulse inserted between the load and soak pulses to measure the VPT's response characteristics.

Each of the three optical signals that the LED board emits are multiplexed (muxed) into five different optical fibers, and terminate in light-sealed boxes containing a VPT and a PIN diode. The PIN diode's signal can be used to make adjustments do to variations in LED light output on a pulse-by-pulse basis. The light from each fiber is projected onto the entirety of the VPT's photocathode. So, in total, each VPT receives three fibers (one from each LED), and there are five PIN diodes (one for each VPT) acting as references for LED light output.

2.2.2 VPT Branch

A VPT (§4.3 Vacuum Photo-triodes) is a single stage photomultiplier. The VPT's photocathode, dynode, and anode accumulate charge as light impacts the photocathode, with the most charge accumulating on the anode. As photons strike the photocathode, electrons are liberated. A large potential of +600 V is driven from the photocathode to the dynode, The current from the VPT's anode and cathode are ultimately routed

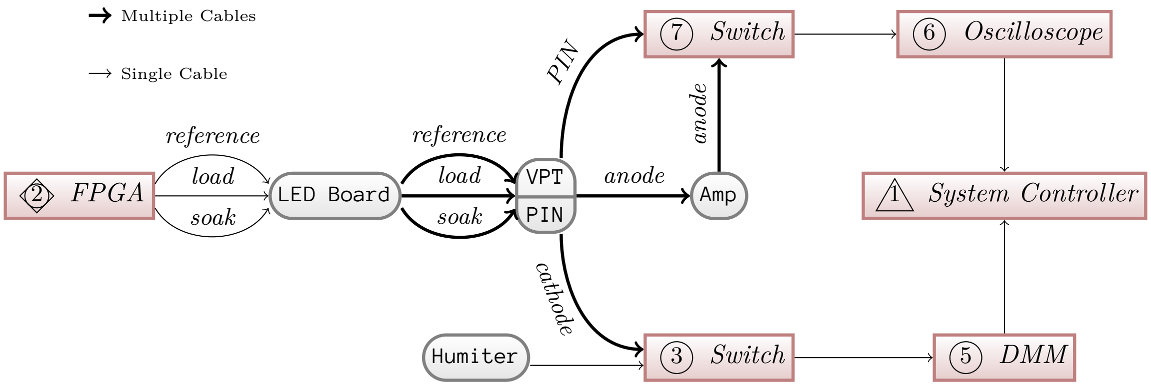


Figure 3: Signal Path in Teststand

to the PXI Crate's switches, and then on to the crate's DMM or oscilloscope. Before that, they go through an amplification stage.

The VPT's anode is connected directly to a Stephenson amplifier (§4.1 Amplifier Board [FIXME]), which connects to the 7 high-frequency switch. The PIN diode signal passes unmodified to that same 7 high-frequency switch. The cathode signal cables connect to a distribution box near the PXI Crate. The distribution box then routes their signals to the terminal block on the 3 low-frequency switch. All of these signals leave the rig over BNC cables before terminating at or adjacent to the PXI Crate.

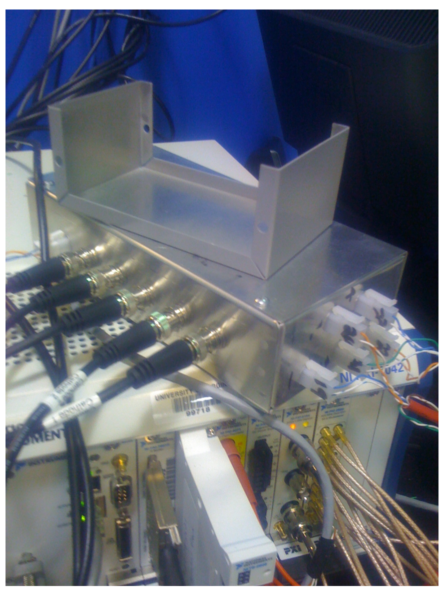


Figure 4: Distribution Box for Cathode Signal to Terminal Block

A temperature and humidity monitor is mounted next to the rig, and a single cat5 cable carries power to it and returns its readings to the 3 low-frequency switch via the distribution box. It connects via MOLEX connector next to the cathode signal BNC connectors.

Part I

Equipment

3 Superconducting Solenoidal Magnet

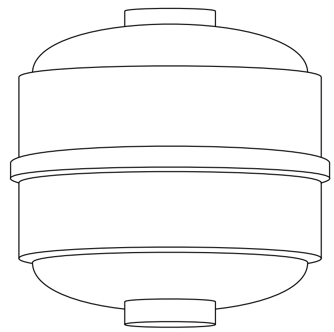


Figure 5: Top-down external view of Superconducting Solenoidal Magnet

The laboratory at HEP houses a Type-I superconducting solenoidal ("supersolenoid") electromagnet wired for persistent operation. Lacking the flux-resistive characteristics of Type-II superconductors, a Type-I superconducting electromagnet is able to maintain a constant field over the course of years, rather than the weeks to months of a higher temperature Type-II supersolenoid. However, like all known Type-I superconductors, its critical temperature lies just north of 4 K, necessitating that it be cooled with liquid helium (LHe).

Similar to other small LHe cryogen systems, the supersolenoid uses a three-chamber system. The outer chamber is under partial vaccum to insulate the interior chambers from ambient temperature. The middle chamber is filled with liquid nitrogen to cool the interior chambers to a maximum of 78 K. The innermost chamber, which houses the superconducting solenoid, is filled with liquid helium. Liquid helium comes into direct contact with the supersolenoid.

Superconducting magnets have a number of significant advantages over ferromagnetic solenoids. Operating at high currents, they can be relatively compact compared with their ferromagnetic cousins. Of practical benefit in the lab, their interior (where the field direction and magnitude is nearly uniform) can be empty and externally accessible, as in our lab. Ferromagnetic solenoids must house a ferromagnetic yoke along their axis to achieve the field strengths of supersolenoids. When wired in persistent mode, a supersolenoid requires no additional electrical power and may remain at full strength while disconnected from a power source indefinitely. While in persistent mode, a supersolenoid's field is more stable than a ferromagnetic solenoid, which is practically advantageous when measurements must be taken over extended periods.

3.1 Cryogen System

Maintenance of the superconductor's cryogen system is detailed in §13 Maintainence. The cryogens boil off, and need to be monitored regularly, as detailed in §13.2 Measuring Cryogen Levels.

3.1.1 Liquid Nitrogen

The liquid nitrogen boils off at a rate of 10 % per day when it is nearly full. The rate increases somewhat as the tank approaches empty. It's generally good policy to keep the LN2 level as high as possible, filling on Mondays and Fridays in case a fill must be missed for some reason.

The liquid nitrogen is usually delivered in 240 L dewars, such as the Taylor-Wharton XL-65 dewar. For filling instructions, see §13.3 Filling LN2 Cryogen.

3.1.2 Liquid Helium

The liquid helium boils off at a rate of 10 % per week. One full 250 L liquid helium dewar will fill the magnet's tank from 20 % to around 95 %. For filling instructions, see §13.5 Filling LHe Cryogen.

3.2 Warnings

⚠ **AVOID** proximity to the magnet if you carry medical equipment, including remote monitors and pacemakers.

⚠ **AVOID** contact with the outer casing while the high voltage is active. The central cavity of the magnet houses high voltage equipment. Although the outer casing of the magnet *should not* carry an electric potential, improper grounding, wiring, or cable failure may occur. The high voltage to this equipment should be powered down before touching the outer casing of the magnet or the rig.

⚠ **AVOID** bringing magnetic materials near the magnet. The strength of the magnetic field grows inversely to the *cube* of distance—that is, much faster than intuition may suggest. Screwdrivers, metallic watches, and even metal glasses have been known to be pulled off of individuals passing by the magnet. *Remember to remove your wallet before approaching the 10 000 gauss line near the magnet*, because it *will* erase your credit cards.

4 The Rig

The rig is a mounting system attached to the superconducting magnet. It includes mounts for the VPTs themselves, in addition to the LED pulser boards and the Stephenson amplifiers.

The current rig was assembled during the 2009–2010 school year by Michael Balazs, Brian Francis, and Benjamin H. "BH" Kent (Associate Machine Shop Foreman). It features a number of improvements over the previous rig:

It can accomodate up to five (5) VPTs at once, up from two. It also has a notched lever on the rear to rotate the VPTs from $-25° \to +25°$, up from $0 \to 23°$.

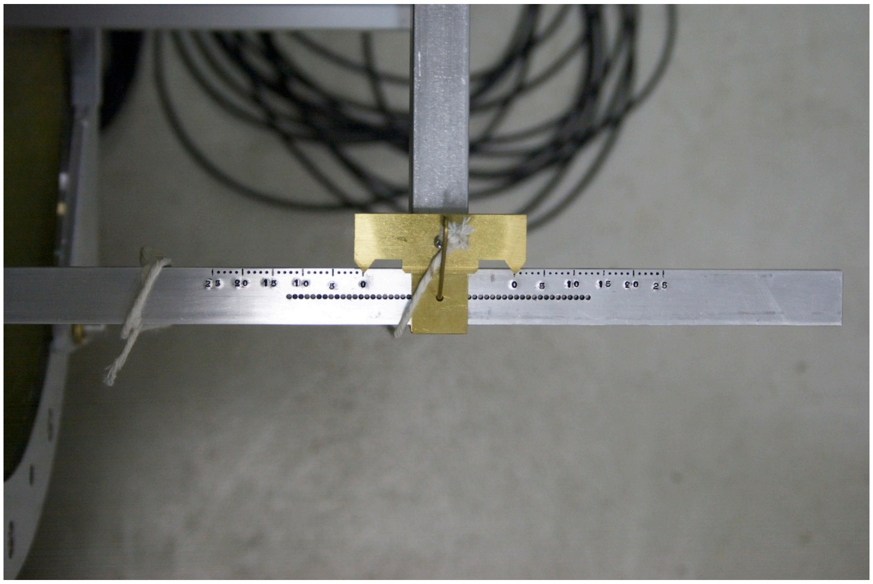


Figure 6: VPT Angle Adjustment Lever

The LED boards are now mounted inside the field near the VPTs, clearing a large amount of floorspace that was used for an articulating arm that protruded out of the field and limited the angle of rotation available for the VPTs. A new housing has been constructed for the LED boards, VPTs, and Stephenson amplifiers.

4.1 Amplifier Board [FIXME]

The **V**acuum **P**hoto-**T**riodess (VPTs) are connected directly to a high-speed low-noise charge amplifier. At the heart of the amplifier circuit is a National Semiconductor CLC428 (datasheet), which is the "Stephenson pre-amp chip." [FIXME] (Talk to Mike. Having trouble following paper trail.)

4.2 LED Pulser Boards [FIXME]

[FIXME] The LEDs in use are probably 5mm LED RL5-B5515. [David Phillips et al]

4.3 Vacuum Photo-triodes

The electromagic calorimeter (Ecal) is composed of scintillators and scintillator detectors. The scintilators are transparent $PbWO_4$ crystals. These crystals are relatively weak scintillators, producing only ~50 photons per MeV. [K.W. Bell, et al.] As such, to reach the energy resolutions needed by CMS the photodetectors must have a built-in gain mechanism with low noise production. In the barrel of CMS, Avalance Photo-Diodes (APDs) are used. However, in endcap, where radiation levels much higher, Vacuum Photo-Triodes (VPTs) are used.

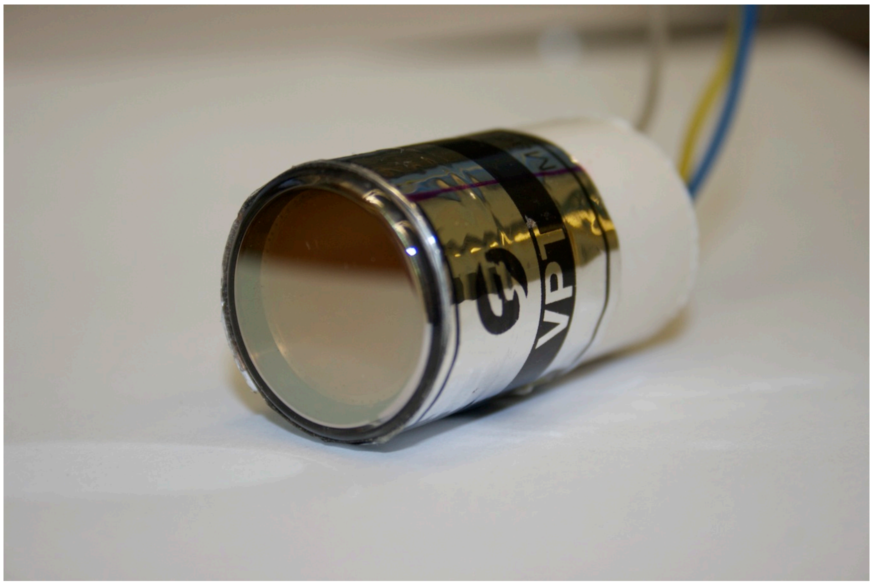


Figure 7: Photograph of Vacuum Photo-Triode

A Vacuum Photo-Triode (VPT) is a specific electronic light sensor with a built-in photo-electron multiplier effect. Like a photodiode, it exploits the photoelectric effect to liberate electrons with incoming photons. As photons strike the photocathode, electrons are ejected. (The photocathode has effectively infinite current to replenish its electrons.) In addition to the energy from the incident photon, the electrons are imparted with an additional 1400 eV of potential energy from the high voltage applied to the anode and dynode.

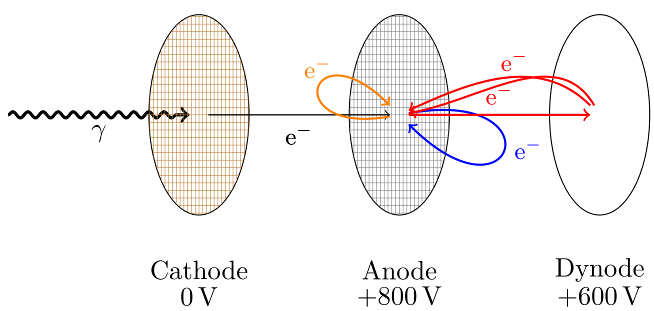


Figure 8: VPT Electron Action

The emitted photoelectron falls towards the anode and may miss the anode mesh and collide with the dynode, causing secondary electron emissions which will fall back towards the anode. If the initial photoelectron hits the anode mesh, it may also cause secondary emissions which will impact the dynode and cause tertiary emissions to fall back to the dynode. The electrons continue falling up and down the potential energy well causing secondary emissions until their kinetic energy at the anode is less than the work function, and so get absorbed without secondary emissions. This results in a rapid rise in output (anode) current followed by a slower fall off. This process is extremely fast, returning to zero current from a pulse of 420 nm light in around 200 ns.

The 200 ns response time of VPTs makes them acceptable for use in CMS, which operates at 40 MHz ($T = 25$ ns). The chance of beam products interacting with the same barrel crystal before complete recovery is small, and the occasional overlapping event can be detected accounted for.

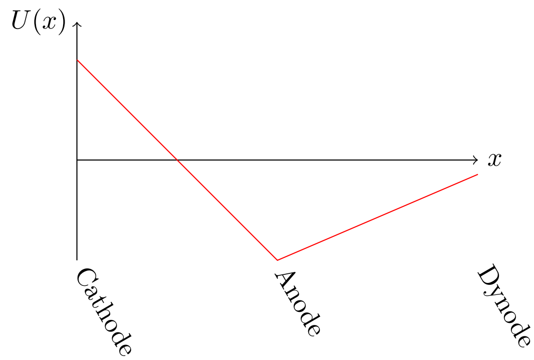


Figure 9: VPT Electron Potential Well (qualitative)

Taken from Christine Drown's PHY 393 Spring 2008 Paper

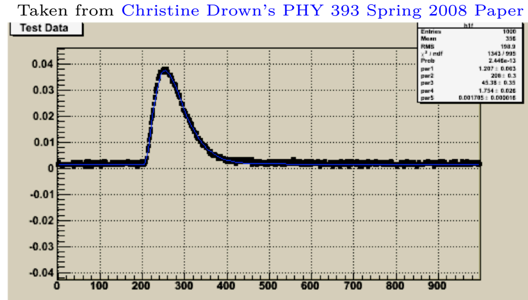


Figure 10: VPT Pulse Shape

When we test a VPT at HEP, we send a pulse of light from a single source (an LED) down at least two different fibers. One fiber illuminates the photocathode of the VPT, while the other illuminates a standardized PIN diode. We use the PIN diode's output as a reference for the light input to the VPT. We can then calculate the gain, or the amount of charge amplification the VPT provides.

VPTs have a number of interesting characteristics that need to be studied. One of the reasons VPTs were chosen is that they continue to function in strong non-axial magnetic fields, due to their single-stage photomultiplier design. However, they still exhibit varibility in their response within non-axial magnetic fields. The field in CMS is not entirely uniform between the beam axis and the outer edges of the endcap. Therefore, the relative gain of each VPT is affected by the direction of the magnetic field, which varies continuously depending on how far from the beam axis the VPT is placed.

VPTs also demonstrate a burn-in effect which can sometimes be quite pronounced. The amplification VPTs produce degrades over time, so that the same pulsed photocurrent will result in less output days later. The effect is not permanent, however. The self-correcting behavior of VPTs was being studied at UVA in 2009 when an electrical failure of the old NIM crate damaged several instruments and interrupted the experiment.

4.3.1 Further Reading

- D.C. Imrie. Long-Term Behaviour Of Three Prototype Vacuum Phototriodes Operated With High Photocurrents. January 2000.

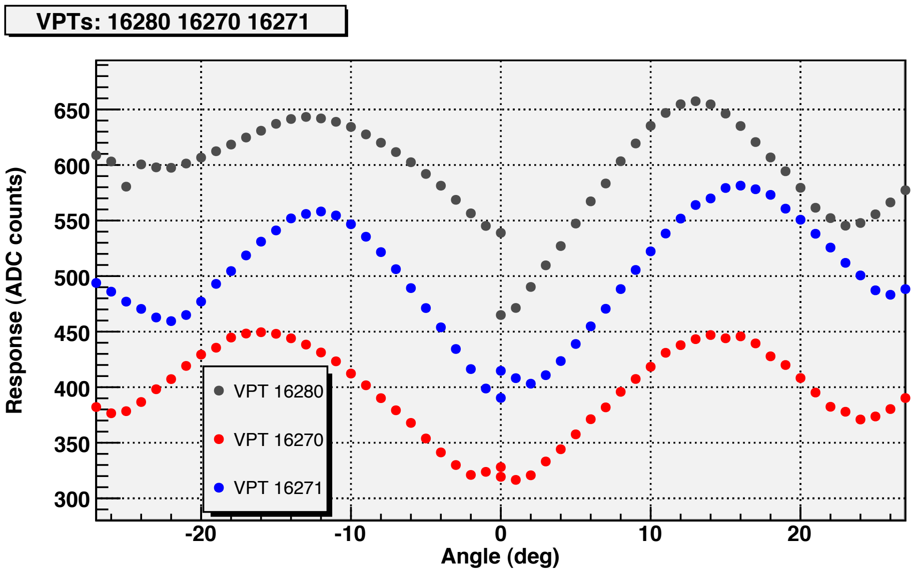


Figure 11: VPT Angle Repsponse Example

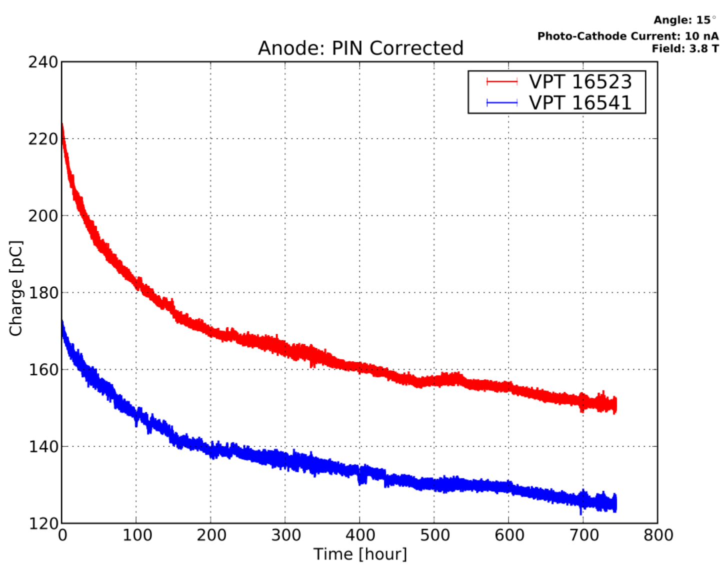


Figure 12: VPT Long Term Effect

- M.N. Achasov, et al. Compact Vacuum Phototriodes for operation in strong magnetic field. 26 February 2001.
- K.W. Bell, et al. Vacuum Phototriodes for the CMS Electromagnetic Calorimeter Endcap. October 2004.
- P.Adzic, et al. Intercalibration of the barrel electromagnetic calorimeter of the CMS experiment at start-up. October 2008.

At UVA

- C. Drown. Properties of Vacuum Photo-Triodes in a 4 T Magnetic Field. Spring 2008.
- D.G. Phillips II, et al. A Measurement of the Temperature Stability of Vacuum Phototriodes for the CMS ECAL.
- J.C. Jones. Long Term VPT Response of Vacuum Photo-Triodes. Fall 2008.

5 High Voltage Supply

Our high voltage supply is made by CAEN. *CAEN* is one of the main companies responsible for the design and manufacturing of components in ATLAS, CMS, ALICE, and LHCb. To date, *CAEN* has supplied the LHC with 6138 units. The modular *CAEN* high voltage supply replaced an aging power supply in 2009.

Our high voltage modules are housed in an 8U-high 19 inch-wide *CAEN* `SY1527LC` *Universal Multichannel Power Supply System*, which acts as a chasis and system controller for the various installed modules. The `SY1527` system has four main sections: On the front are the CPU and Front Panel section, and the Power Supply section. On the rear are the Board Section and the Fan Unit. The `LC` designation means "low cost," and refers to lack of a built-in LCD screen, compact switch, alphanumeric keyboard, and I/O Control section.

Taken from CAEN SY1527 User Manual, Figure 2.3

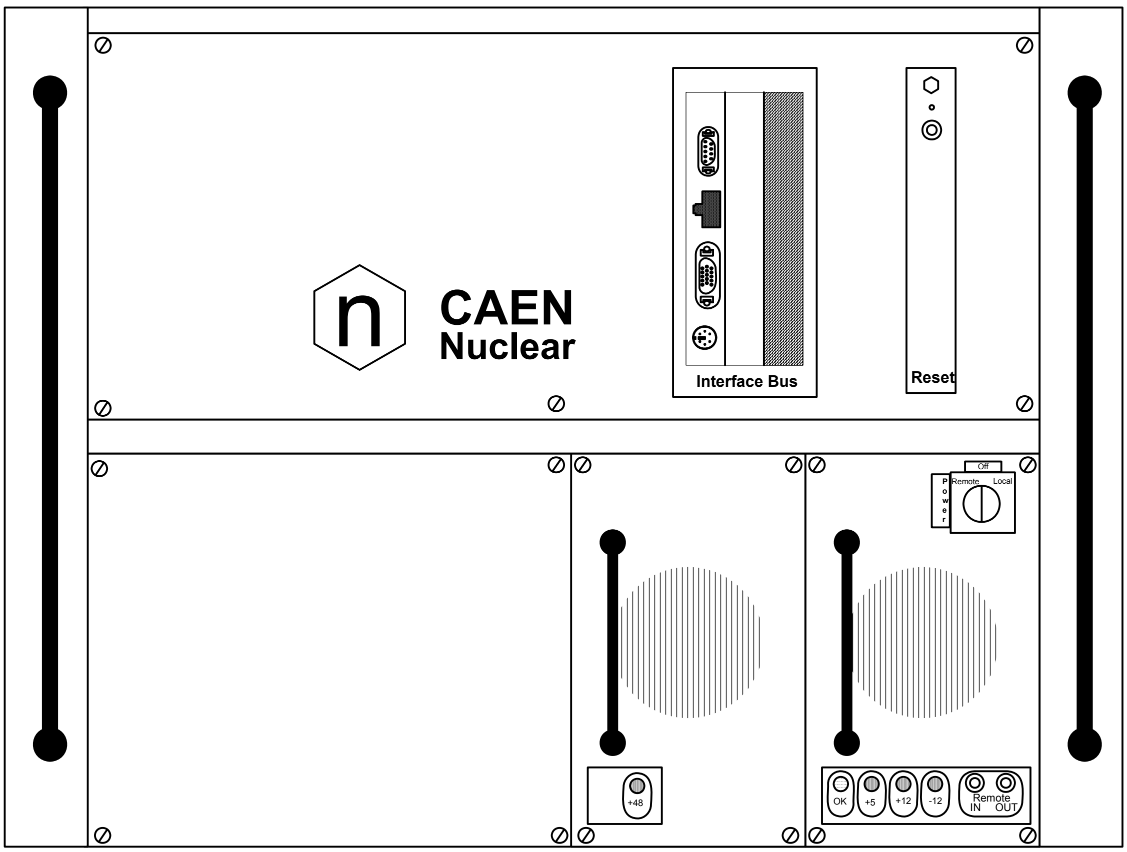


Figure 13: Front Panel of the SY1527LC System

The *Power Supply Section* houses up to four *power supply units*, which provide power to the whole system. We use one optional power supply in addition to the primary power supply. The *Board Section* houses up to 16 Channel Boards. We use two standard HV boards, which distribute high voltage to the experimental rig. However, the system is capable of housing other types of boards, including low voltage and generic I/O boards. (We do not use *CAEN* LV boards; for our needs they are cost prohibitive.)

The system may be controlled either locally or remotely. A small 7.7 inch color LCD and a standard PS/2 keyboard are attached to the system for local control. The system can be remotely controlled over RS232 (serial) or ethernet. Over ethernet, the system can be logged into via telnet. *CAEN* has also developed a C language library (CAEN HV Wrapper) for remotely monitoring and controlling system parameters over TCP/IP. (Currently, remote control is not set up.)

A key on the primary power supply (front, bottom-right module) may be set to *Off*, *Local*, or *Remote*. *Off* completely powers down the rig, and immediately kills any voltage supply channels without ramping down the voltage. *Local* powers on the system and provides local control via the LCD and keyboard. *Remote* sets the system to allow a remote power-on using NIM, RS232, or ethernet.

Model Number	Location	Description
`SY1527LC`	Chasis	Modular power supply chasis
`A1531`	Front	Primary chasis power supply
`A1532`	Front	Auxillary chasis power supply
`A1833D`	Rear	Positive high voltage supply
`A1833N`	Rear	Negative high voltage supply

Table 2: *CAEN Nuclear* Components

✗ **DO NOT** power down the system by turning the key on the primary power supply without first initiating a software-controlled ramp-down.

✓ **DO** power down the rig by first setting all of the channels to ramp down, and then turning off the system with the key.

For detailed information on the SY1527 system see the CAEN SY1527 User Manual.

At present, only the positive HV channel board is used to supply +800 V and +600 V to the five VPT anodes and dynodes, respectively. These ten cables run across the floor to the magnet and connect to the rig.

For further operating instructions, see §11 High Voltage Supply.

6 Low Voltage Supply

Most of the pieces of equipment in the rig have low voltage and current requirements. For our external power supply, we use two *BK Precision* `9130` Triple Output Programmable DC Power Supplies.

Taken from BK Precision 9130 Manual.

Figure 14: BK Precision 9130 Front View

The *BK Precision* `9130` Triple Output Programmable DC Power Supply has three independent outputs providing 0–30 V & 0–3 A on two channels, and 0–5 V & 0–3 A on a third. It can be remotely controlled over USB or RS232. It is also rack mountable, at 2 U×½ U.

Supply	Channel	Voltage	Current	Distributed to...
1	1	12.0 V	0.665 A	LCD Monitor Power
1	2	12.0 V	0.082 A	LED Pulser Board Power, Humiditer Power
1	3	5.0 V	0.045 A	LED Pulser Board Voltage Bias, Trigger's Pulse Generator Chip Power
2	1	10.0 V	0.421 A	Supply 2 is wired in series to provide a ±5 V supply
2	2	0.0 V	⟨`OFF`⟩	relative to the ground shared by the Stephenson
2	3	`Series`	`CH1+3`	Amp and FPGA, rather than a floating ground.

Table 3: DC Power Supply Channel Configuration

For detailed information on the external power supplies, see the BK Precision 9130 Manual.

Table 3 lists the voltage each channel is set to, and what it is currently connected to. Table 4 lists the cables which require low voltage supplies and where they're currently connected.

The FPGA is capable of meeting the voltage and current requirements for the LED boards, and directly connecting them would also allow the LED bias to be controlled directly by the FPGA. That would permit us to control the photocurrent automatically. They were removed from the FPGA while tracking down a source of signal noise, and may be safely re-attached to the FPGA at a later date.

The "Trigger Pulse Generator Chip" is a pair of a `74LS241N` and `74LS241PC` line drivers, chips designed to be able to drive signals over BNC cables. The trigger signals run from the FPGA to the generator chips and then on to the LED boards themselves. The FPGA isn't capable of driving the BNC cables directly.

Cable Name	Cable Pair	Voltage	Supply
LED Voltage	blue LED Bias	± 5 V	Supply 1, Ch 3
	green LED Bias	± 5 V	Supply 1, Ch 3
	orange LED Bias	± 5 V	Supply 1, Ch 3
	brown LED Power	± 12 V	Supply 1, Ch 2
Stephenson Amp	± 5 V to earth ground		Supply 2
Local Power	blue Trigger Pulse Gen	± 5 V	Supply 1, Ch 3
	brown Not used	± 12 V	Supply 1, Ch 2
Humiditer	green Power	± 12 V	Supply 1, Ch 2
LCD Panel	red & black Power	± 12 V	Supply 1, Ch 1

Table 4: DC Voltage Requirements

7 National Instruments

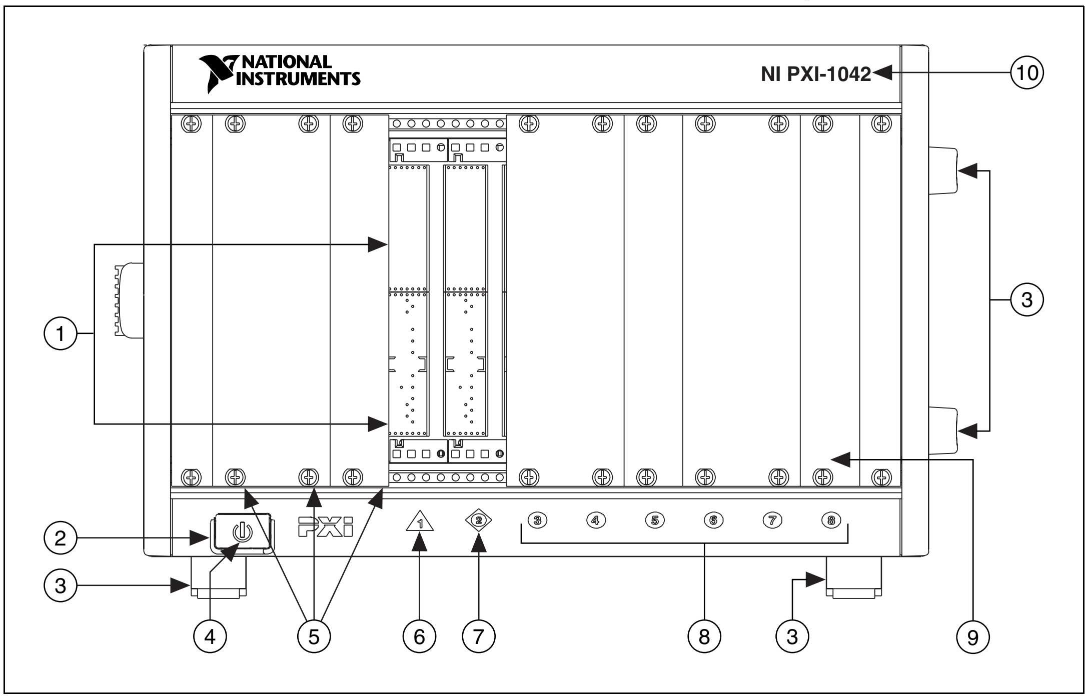
7.1 PXI Crate

The *National Instruments PXI Crate* is a programmable experimental test-stand capable of automating many aspects of an experiment. It can be configured to control the experiment, perform advanced analog and digital signalling and sampling, control power supplies, perform DAQ, process and export data, and more.

7.1.1 NI PXI-1042 Chasis

What we refer to as the "PXI Crate" or just "the crate" is a **N**ational **I**nstruments (NI) `NI PXI-1042` series chasis and the NI-designed modules it houses. The chasis itself is a Compact 3U rack-mountable chasis that provides Universal AC, a power overload breaker, air temperature regulation, and a removable modular power supply. In most cases, replacing a faulty component can take seconds.

Taken from National Instruments NI PXI-1042 Series User Manual and Specifications



1	Backplane Connectors (Located in Slots 1–8)	6	System Controller Slot
2	On/Off (Standby) Power Switch	7	Star Trigger Slot
3	Removable Feet	8	Peripheral Slots
4	Power LED	9	Filler Panel
5	Controller Expansion Slots	10	Chassis Model

Figure 15: Front View of the PXI-1042 Chasis

The chasis backplane supplies several busses to each slot. First, all modules share the 64-bit CompactPCI-compatible PXI bus. Second, a *Star Trigger Bus* originates from Slot 2, and connects to the other six peripheral slots. Third, a *Local Bus* connects all seven peripheral slots in a daisy chain; the left-local bus signals on Slot 2 are used for *Star Trigger*, and the right-local bus signals on Slot 8 are not routed. The *Local Bus* is 13-lines wide and can pass anything from high-speed TTL to analog signals up to 42 V. Fourth, the *Trigger Bus* provides eight shared trigger lines to all eight slots. Finally, the chasis supplies a 10 MHz system reference clock signal (PXI_CLK10) independently to each peripheral slot. The clock signal is also accessible externally via rear-mounted BNC connectors.

Taken from National Instruments NI PXI-1042 Series User Manual and Specifications

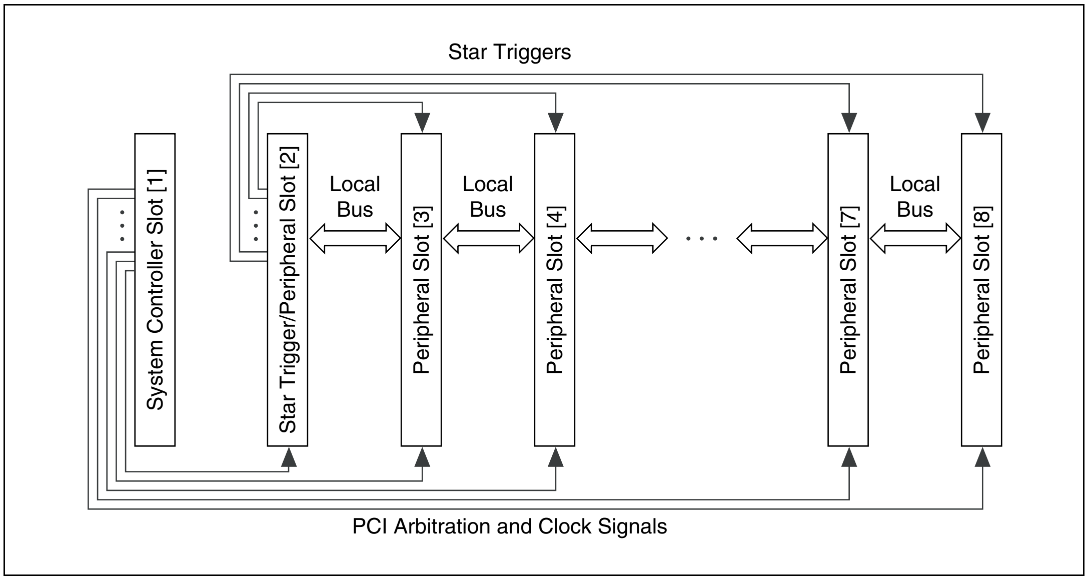


Figure 16: PXI Local Bus and Star Trigger Routing

7.1.2 Modules

The chasis at HEP is configured with the following modules, described in the following sections:

1 `PXI-8104` **Embedded Computer** A full-featured embedded computer running Windows XP (downgraded from Windows Vista Business by default by NI). This module ultimately controls all the other components in the crate. It hosts an RDP server for remote login. The maximum amount of RAM has been installed, 2 GiB, as two SO-DIMMs of PC2-5300 1 GiB, 128 MiB×64, CL 5, 1.18 inch max (NI part number 779302-1024). It also features a Celeron M 440 (1.86 GHz single-core), a 60 GB SATA hard drive, and gigabit ethernet. As it occupies the System Controller slot, it is generally referred to as the *system controller* in NI literature. For detailed information see the PXI-8104 User Manual. The internal hard drive is only used for system and experiment software. All experimental data is stored on the ReadyNAS.

2 `PXI-7851R` **FPGA** Essentially a reprogrammable integrated circuit, the FPGA controls all the real-time trigger signals. The module itself has a break-out box connector, and the break-out box houses the connections to devices which receive external trigger signals. (Namely, the LED pulser boards.) The break-out box is an *NI* `SCB-68`.

3 [FIXME] **24-Channel two-wire Multiplexer** Referred to as "the switch." Featuring a single large external port, the switch connects any of the 24 two-wire channels to the internal busses. The switching mechanism is software controlled. An `NI TB-2605` multiplexing terminal block is currently mounted directly on it. This switch receives the cathode current and humiter signals and routes them to the DMM.
[FIXME] This is either an `PXI-2501` or `PXI-2503` multiplexer.

4 `PXI-4110` **DC Power Supply** A software-controlled DC power supply, not currently in use.

5 `PXI-4071` **PXI Digital Multimeter** A software-controlled Digital Multimeter.

6 `PXI-5154` **Digitizer/Oscilloscope** A high frequency (2 GS/s) oscilloscope, optimized for automated testing.

7 `PXI-2593` **16-Channel Multiplexer** A 16-channel high frequency switching multiplexer, able to handle frequencies from DC to 500 MHz. This switch receives the anode and PIN diode signals and routes

them to the oscilloscope.

[FIXME] All signals requiring measurement are routed from this multiplexer to either the DMM or the Oscilloscope.

[FIXME] Wouldn't it make more sense for this multiplexer to be adjacent to the 24-channel multiplexer so that they could communicate directly over the local bus?

7.2 LabVIEW

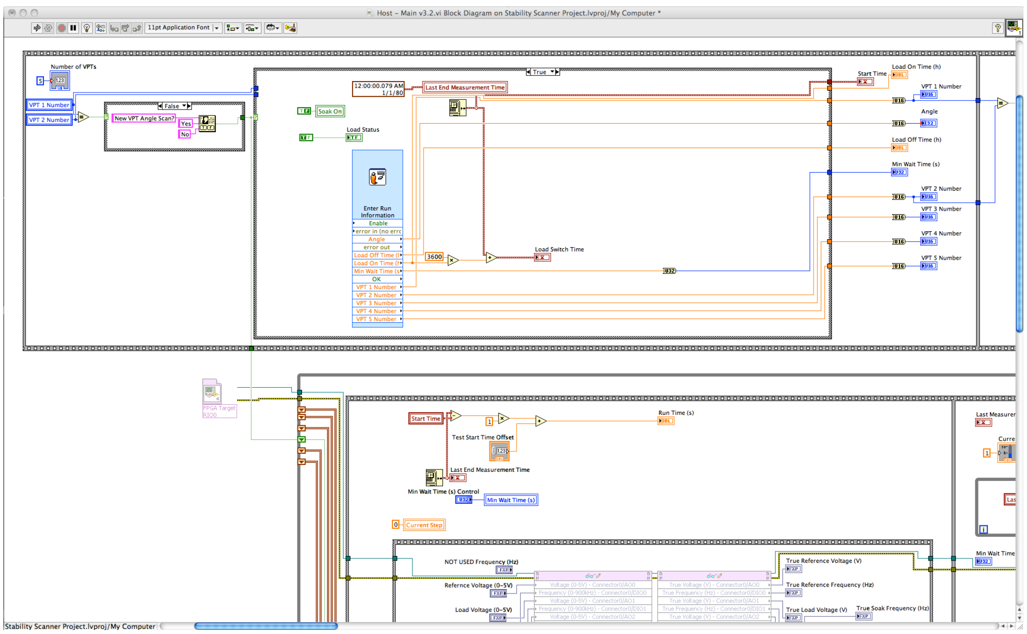


Figure 17: LabVIEW Block Diagram of `Host - Main.vi`

LabVIEW is a graphical programming environment used for developing programs called virtual instruments, or **V**irtual **I**nstruments (VIs), which imitate physical instruments. LabVIEW uses a visual programming language called "G" for building virtual instruments. "G" is a data-flow driven language, as opposed to a procedural like C or functional language like LISP or Haskell. [FIXME] (rephrase) In LabVIEW program execution is determined by the availability of data to the components inside a VI. As such, LabVIEW's programs are inherently parallel, meaning that different parts of the program can run simultaneously.

To get started with LabVIEW right away, read the manual Getting Started with LabVIEW. This manual is also available from within the LabVIEW 2009 "Getting Started" dialog when the application is launched, in the right-hand pane under "Help."

For historical background on LabVIEW, see the Wikipedia entry.

The remainder of this section is a conceptual crash-course in LabVIEW. For hands-on practice, ...[FIXME]

7.2.1 Block Diagram and Front Panel

A Virtual Instrument (VI) is a program in LabVIEW for which LabVIEW provides a visual programming interface. Every VI has a *front panel*, which is a visual representation of its inputs and outputs, and a *block diagram*, which is a functional diagram of how to process its inputs and to produce its outputs. The actual programming of a VI takes place in the block diagram. However, you generally start creating the VI from the front panel, much like how you generally start writing a function with its interface or signature.

A VI may be made of atomic logic units, like numbers, arithmetic, and control structures like loops and conditional branches. It will contain any widgets you created on the front panel. It may also contain any number of additional VIs. VIs referenced within another VI are called "sub-VIs," for the sake of discussion, but are otherwise the same as any other VI.

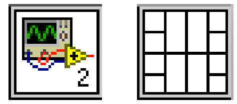


Figure 18: LabVIEW (default) Icon and Connection Panels

From the front panel, a small icon is visible in the upper right-hand corner of the window. This is how the VI appears when placed in another VI. If you right-click this icon from the front panel (only) and select "Show Connector" and then a component on the front panel, you'll reveal connection pins that you can assign to front panel components by clicking the pin and then a front panel component. If you use this VI as a sub-VI, you'll be able to fill in front panel inputs and read front panel outputs from another VI by using the pin connections.

The block diagram will automatically be populated with the required components for the front panel and the pin connections you've designated from the front panel. Connections between block diagram components can be made by clicking on the small pin-out location you wish to start from and the small pin-in location on the destination. A wire will be drawn from the source to the destination. The style (color, thickness, pattern) will indicate its type. LabVIEW will only allow you to complete connections between compatible types, but it will automatically insert conversion components for you, if possible. New components may be dragged onto the block diagram from the "Controls" palette.

The exact behavior produced by a left-click varies with the click's distance from an element. For instance, clicking adjacent to a wire splices a branching connection into the wire, while clicking exactly on the wire allows you to select the wire itself. The cursor will change to help you determine what will happen.

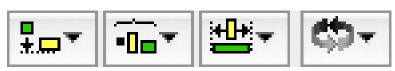


Figure 19: LabVIEW Arrangement Buttons

Because editing with the mouse can be a bit tedious, LabVIEW has a number of tools to automate a lot of large-scale housekeeping on block diagrams. Under the `Edit` menu, you can automatically `Remove Broken Wires` and `Clean Up Diagram`. In the toolbar of the block diagram, you'll find menus to align, distribute, group/layer, and clean up selected components.

7.2.2 Projects and VIs

> A collection of LabVIEW files and [*non*-LabVIEW files] that you can use to create build specifications and deploy or download files to targets.
>
> —Definition of *project* from *Getting Started with LabVIEW*

A *project* in LabVIEW is a somewhat informal collection of files which can aggregate dependencies and help build and deploy files to targets. A project is not even necessary for most tasks in LabVIEW and VIs can be designed and run without creating a project. This is a little different from a lot of development suites, which use projects to define the development environment. (VIs run in the proprietary LabVIEW runtime environment, which handles things like execution, compilation, and dependency resolution.)

You need to use a project if you need to build and deploy a file to a target, such as an FPGA or some other statically programmed instrument. Other than that, projects have little to do with the programming and running of VIs.

7.2.3 Documentation

There are a number of useful sources of documentation for LabVIEW.

One of the most useful tools is the `Context Help`, found under `Help` → `Show Context Help`. This will reveal a palette window that will give you information about whatever component you hover the mouse over. For instance, when hovering over a wire it will tell you the data type the wire caries. If you hover over a component on the block diagram, it will tell you what that component does, what its connections are, and which are optional. You can also get detailed help on anything you can get context help on by clicking the question mark on the lower edge of the context help window. (Select the component to keep the context help fixed on it.)

Usually the best way to find out how to do something new is to find an example. The example search engine can be found in LabVIEW by navigating to Help → Find Examples.... One of the directories listed under "Browse" tab is called "Fundamentals," which will show you how to deal with the basics, such as basic data types, control structures, and file I/O. Going through most of the examples in this directory will help you become familiar with the visual vocabulary of LabVIEW.

The official National Instruments forums are also a useful source of information.

In addition, the UVa Site License includes a support contract. For help ...[FIXME] .

7.3 ReadyNAS (RNAS)

The ReadyNAS (RNAS) is a ready-made NAS solution. NAS is an acronym for *Network-Attached Storage*, a file-level (as opposed to block-level) remote storage system. The NetGEAR ReadyNAS NV+ acts as a network filesystem for the PXI Crate in addition to the crate's native filesystem on its local SATA hard drive. The RNAS is backed up daily by Brian Wright.

Much of your interaction with the crate will happen indirectly, via the RNAS. You'll usually want to edit VIs locally and then upload them to the RNAS when its time to update the experiment's software. VIs are usually programmed to log their data to the RNAS, so you'll retreive the latest data from the RNAS as well.

The main exception to this is any VI which requires access to the crate's peripheral hardware, such as the FPGA, DMM, oscilloscope, or switches. These components need to be programmed and tested from LabVIEW on the PXI Crate itself, as in §9.1 Logging into the PXI Crate (RDP).

The RNAS is configured for FTP access. For FTP directions, see §8.2 Installing the VPT VIs and §8.3 Getting the Latest Data.

✗ **DO NOT** upload VIs without first making sure that LabVIEW on the crate has closed those VIs.

✗ **DO NOT** directly edit VIs or use viewing or processing VIs to view or edit data directly from the RNAS if you have chosen to mount the remote filesystem. You may corrupt LabVIEW state (on the crate or your own computer), or cause availability or timing errors in ongoing experiments.

✓ **DO** make a local copy of any VI or data you wish to use. You may safely copy data files while they are being written to.

Part II

Operations Manual

8 Getting Started

8.1 Installing LabVIEW 2009

You will need access to LabVIEW to start and stop experiments, to view data, and to export data.

As of Summer 2010, you'll need LabVIEW 2009. The National Instruments site-licensed installation discs are located in the HEP building in a small square black CD-sized zipper pouch with a blue spine. The pouch's spine is labeled *National Instruments Academic Site License 2009: Software for Classrooms, Labs & Research.*

8.1.1 Mac

Locate the white DVD labeled "NI LabVIEW 2009." This disc also bears the label "Third Quarter 2009" on the left-hand side. Insert the disc and install the package titled LabVIEWPro2009.mpkg. You're done.

8.2 Installing the VPT VIs

Copy the most recent VPT VIs from the ReadyNAS to a convenient location. Their remote location is:

`ftp://hep-diskarray.physics.virginia.edu/teststand/VPT Stability Scanner/v3.0 - 5 VPTs`

All data is stored on the ReadyNAS (see 7.3) and accessible via FTP. Open an FTP connection to

`ftp://hep-diskarray.physics.virginia.edu/`

The "/teststand/" directory contains all of the data which is intended for use by the PXI Crate. To install the latest version of the VPT Stability Scanner VIs, download the directory

`/teststand/VPT Stability Scanner/v3.0 - 5 VPTs`

If you're unfamiliar with FTP, you may use any of the following methods:

8.2.1 Method 1: Using Finder

First, connect to the server. To do this for the first time:

1. Select Finder from the Dock.
2. Press ⌘K (or select Go → Connect to Server from the menubar)
3. Enter the server address as
   `ftp://teststand:labview@hep-diskarray.physics.virginia.edu`
4. (optional) Click the "+" button to add it to your favorite servers.
5. Press the Connect button.

If you've added the server to your favorites and later "eject" the server, you can reconnect by the following procedure:

1. Select Finder from the Dock.
2. Press ⌘K (or select Go → Connect to Server from the menubar)
3. Select `ftp://teststand:labview@hep-diskarray.physics.virginia.edu` from the favorites list.
4. Press the Connect button.

Opening an FTP site in Finder works exactly like any regular folder in Finder. If you like, you can switch the view to "Browser Mode" by hitting the clear oblong oval in the far upper right hand corner of the window.

Navigate to `teststand` → `VPT Stability Scanner` and drag `v3.0 – 5 VPTs` to a convenient location.

Note: Do not attempt to view data on the remotely mounted server. Copy the VIs and the data to your local hard drive before working on them. It was discovered through trial and error that it's best to view the data on a machine separate from the one that is taking data. Working non-locally with data or VIs while an experiment is running may cause problems for you or the experiment.

8.2.2 Method 2: Using `wget`

If you have a unix-like operating system (Linux, Mac OS X), or use Cygwin on Windows, and are comfortable on the command line, `wget` is an excellent tool to use. This method duplicates the directory structure of hep-diskarray, which can be very convenient for maintaining consistency between your local copy and the PXI Crate. Open a terminal and `cd` to a directory where you'd like to store your mirrored directories.

To mirror only the latest running VPT VI software, run:

```
wget -m "ftp://teststand:labview@hep-diskarray.physics.virginia.edu\
/teststand/VPT Stability Scanner/v3.0 - 5 VPTs"
```

This will copy the VIs (*.vi) in the following directory structure to your working directory:

```
hep-diskarray.physics.virginia.edu/
  teststand/
    VPT Stability Scanner/
      v3.0 - 5 VPTs/
        C/
          ...
        FPGA Bitfiles/
          ...
        *.vi
```

If you don't want to copy the directory structure and just want the VIs themselves, `cd` to your own directory and run a command like the following to copy the desired files directly without the directory structure above.

```
wget "ftp://teststand:labview@hep-diskarray.physics.virginia.edu\
/teststand/VPT Stability Scanner/v3.0 - 5 VPTs/*.vi"
```

8.3 Getting the Latest Data

The location of the latest data is always subject to change. All data is usually located in a `/data/` directory under the particular experiment's main directory on the RNAS, such as `/teststand/VPT Stability Scanner/`. Check with the current experiment maintainer for the latest location. For demonstration purposes, we'll assume the latest data is located on the RNAS in the following files:

```
/teststand/VPT Stability Scanner/data/Taken with v3.0/Raw Data/
    VPT2181.dat
    VPT2182.dat
    VPT2183.dat
    VPT2814.dat
    VPT2185.dat
```

8.3.1 Method 1: Using Finder

If hep-diskarray.physics.virginia.edu is not already mounted, mount it. If you're not sure if it's mounted:

1. Open Finder from the Dock.
2. Press ⇧⌘C
3. Look for hep-diskarray.physics.virginia.edu in the window presented.

Now you're ready to locate and copy the data.

1. Navigate to hep-diskarray.physics.virginia.edu → teststand → VPT Stability Scanner → data → Taken with v3.0 → Raw Data
2. Select VPT2181.dat through VPT2185.dat.
3. Copy them to a convenient location on your hard drive.

8.3.2 Method 2: Using `wget`

Note: The `bash` *shell is assumed.*

To mirror the most recent data for local viewing, run:

```
wget -m "ftp://teststand:labview@hep-diskarray.physics.virginia.edu\
/teststand/VPT Stability Scanner/data/Taken with v3.0/Raw Data/VPT218[12345].dat"
```

If you don't want to copy the directory structure, just drop the "`-m`" option.

9 PXI Crate

9.1 Logging into the PXI Crate (RDP)

9.1.1 Mac

You'll need to download and install Microsoft's Remote Desktop Connection Client for Mac.

1. Launch Remote Desktop Connection for Mac.
2. In the "Computer:" field, enter the IP address `128.143.196.230`. Press Connect.
3. When prompted, use the username `administrator` and password `!UVAVPT`

If desired, you can make local (Mac) hard drives and printers available to the PXI Crate while you're logged in by editing the connection. (File → Edit a Connection)

9.1.2 Linux

You'll need to download and install rdesktop for accessing Windows Termainal Services. Rdesktop is available through the package management systems of most distributions, such as Debian, Ubuntu, and Redhat. A Gnome frontend to rdesktop is also available, called grdesktop.

These directions assume rdesktop:

1. [FIXME]

9.2 Launching LabVIEW

9.3 Opening Project *VPT Stability*

9.4 Starting Data Acquisition

1. Open the *VPT Stability* project as in §9.3.
2. Open the Host – Main.vi VI from the project file viewer.
3. Press the Run Once button. You will be prompted for information:
   - VPT 1–5 reference numbers
   - Angle in field (degrees)
   - Min. wait time (seconds)
   - Load on/off time (hours)

9.5 Stopping Data Acquisition

1. If necessary, log into the PXI crate as in §9.1 Logging into the PXI Crate (RDP).
2. Locate the Host – Main.vi window, listed under the Window menu of any LabVIEW window. The front panel is preferable, but not necessary.
3. Hit the Stop button.

9.6 Restarting Data Acquisition

Follow this procedure if you were taking data and wish to start over with the same VPTs:

1. If desired, copy the old data files to a safe location.
2. Delete the original data files.
3. Begin following §9.4 Starting Data Acquisition.

9.7 Resuming Data Acquisition

Follow this procedure if you wish to resume recording data to the same files after an interruption:

1. If necessary, log into the PXI crate as in §9.1.
2. Locate one of the data files and open it in a text editor. Copy the first column of the last line. This is the time offset to resume at.
3. If necessary, start LabVIEW (§9.2), open project *VPT Stability* (§9.3), and/or open **Host – Main.vi**.
4. On the top row of the **Host – Main.vi** front panel is a text input box labeled **Test Start Time Offset**. Click to edit the contents and paste the time offset from step 2.
5. Press the **Run Once** button. When prompted, enter the original VPT numbers, and the rest of the information as before.

9.8 Shutting Down The Crate (software)

Follow this procedure if you wish to shut down the PXI Crate to later reboot it:

1. If necessary, log into the PXI crate as in §9.1 Logging into the PXI Crate (RDP).
2. If necessary, shut down DAQ as in §9.5 Stopping Data Acquisition.
3. Close LabVIEW. [FIXME] menu commands; do not save VIs?
4. [FIXME] Click the start button and navigate to **Start** → **Logout**, then choose **Power Off** when prompted.

9.9 Powering On Hardware

1. Locate the power button on the lower left-hand side of the front of the PXI Crate. Next to the button is an LED light.
2. If the light near the button is lit, the crate is already powered on. If it is not lit, press the power button.

9.10 Powering Down Hardware

1. First perform a software shutdown as in §9.8 Shutting Down The Crate (software).
2. Check if the power LED is still lit. It is located on the lower left-hand side of the front of the PXI Crate, near the power button.
3. If still powered, press the power button once.

10 Low Voltage Supply

For operating instructions, including troubleshooting, reference the BK Precision 9130 User Manual, or the BK Precision Model 9130 product page.

10.1 Panel Controls

The On/Off key controls the output state (on/off) of all three channels simultaneously. To control the output state of an individual channel, use the number keys 1–3.

Use the 1–3 keys to set the output state of channels 1–3. Similarly, use 4–6 keys to set the voltage, and 7–9 keys to set the current for each channel.

10.2 Setting Voltage

There are three different methods to set the voltage:

1. Press V-set. Enter a numeric value with the keypad, then press Enter.
2. Press V-set. Then use the ↑↓ arrow keys to select a channel. Adjust the voltage with the knob.
3. Press the 4, 5, or 6 key to select channel 1, 2, or 3. Then enter a numerical value on the keypad. Then press Enter.

10.3 Setting Current

There are three different methods to set the current. They are identical to the methods to set the voltage, except that you press I-set instead of V-set, and the keys 7, 8, or 9 instead of 4, 5, or 6.

1. Press I-set. Enter a numeric value with the keypad, then press Enter.
2. Press I-set. Then use the ↑↓ arrow keys to select a channel. Adjust the voltage with the knob.
3. Press the 7, 8, or 9 key to select channel 1, 2, or 3. Then enter a numerical value on the keypad. Then press Enter.

10.4 System Set

System Set is a menu available from the Menu button. One of the things it allows you to do is set channels for series or parallel operation. Supply two should have Out Serial Set set to 1+3. For serial use, Ch1− should be connected to Ch3+, and Ch1+ and Ch3− should connect to the load. (Ch 2+3 serial operation is not permitted.)

11 High Voltage Supply

All high voltage supply directions are carried out with the small LCD display and keyboard attached to the large red *CAEN Nuclear* `SY1527LC` rack-mounted system.

11.1 Verifying Cable Configuration

Inspect the back of the high voltage unit. The module inserted in the middle, marked “12 CH POS” near the bottom in blue, should have ten cables connected to channels 0 through 9. Verify the layout by reading the cable labels and comparing them with Table 5 (p. 30).

Table 5: High Voltage Group 01

Channel	Cable Label	Channel Name	Voltage	Current
0	HV Anode 1	VPT1-Anode	800.00 V	20.00 µA
1	HV Dynode 1	VPT1-Dynode	600.00 V	20.00 µA
2	HV Anode 2	VPT2-Anode	800.00 V	20.00 µA
3	HV Dynode 2	VPT2-Dynode	600.00 V	20.00 µA
4	HV Anode 3	VPT3-Anode	800.00 V	20.00 µA
5	HV Dynode 3	VPT3-Dynode	600.00 V	20.00 µA
6	HV Anode 4	VPT4-Anode	800.00 V	20.00 µA
7	HV Dynode 4	VPT4-Dynode	600.00 V	20.00 µA
8	HV Anode 5	VPT5-Anode	800.00 V	20.00 µA
9	HV Dynode 5	VPT5-Dynode	600.00 V	20.00 µA

Inspect the rig inside the superconducting solenoidal magnet. When viewed from the rear, which faces the exterior door, the high voltage cables enter from the front (opposite) side and are attached to the VPT mounting rig on the left-hand side. Visually verify that the top five cables facing you are labeled “HV Anode 1” through “HV Anode 5” from top to bottom. Verify from the front side that the top five cables facing you on the right-hand side are labeled “HV Dynode 1” through “HV Dynode 5.”

11.2 Verifying the Voltage Settings

From the front of the rack, examine the color LCD monitor below the high voltage unit. Verify that the voltage settings correspond to Table 5 (p. 30).

11.3 Killing the High Voltage

⚠ **AVOID** killing the high voltage unless it’s worth the risk of damaging the equipment.

1. Turn the key to the *off* position.

✓ **DO** ramp the voltage down before shutting the system down whenever possible. See §11.4 Ramping Down the High Voltage for ramp-down instructions.

11.4 Ramping Down the High Voltage

[FIXME] Placeholder until detailed walkthrough can be practiced

1. Toggle group mode from the Groups menu.
2. Turn off any channel; while group mode is enabled all grouped channels will ramp down together.

11.5 Ramping Up the High Voltage

[FIXME] Placeholder until detailed walkthrough can be practiced

1. Toggle group mode from the Groups menu.
2. Turn on any channel; while group mode is enabled all grouped channels will ramp up together.

11.6 Turning Off the High Voltage System

The system rarely needs to be entirely turned off. Channel boards and power supplies may be hot swapped and channels only need to be ramped down before disconnecting cables. However, there is an additional safety factor in powering the entire system down before tampering with high voltage.

1. Ramp down the voltage (see 11.4, p. 30).
2. Turn the key to the *off* position.

11.7 Turning On the High Voltage System

To turn the high voltage on from a power-off state:

1. Turn the key to the *local* position.
2. Ramp up the voltage (see 11.5, p. 31).

Note: In the future, the key may need to be turned to remote. *Check with the experiment maintainer if there are additional cables connected to the front panel.*

12 Vaccum Photo-triodes (VPTs)

12.1 Cleaning

Only the photocathode face needs to be cleaned. Fingerprints should be wiped away using disposable lens cloths. A small green cardboard box of *Kimwipes Delicate Task Wipers* is usually located near the rig for easy access.

Figure 20: Kimtech Science Kimwipes

12.2 Mounting VPTs

Each VPT has three cables connected to the anode (tan/white), dynode (blue), and cathode (gold/yellow). The cathode is sometimes labeled with the letter "K" from the Russian spelling. The dynode and cathode colors can be remembered with the euphemistic mnemonic as "KY dB."

13 Maintainence

13.1 Schedule

This section lists tasks which must be done regularly to maintain the experimental equipment or ongoing experiments. The following vocabulary is used in this section:

DAILY	Once per day, at any time unless otherwise specified
SEMI-DAILY	Every other day
BIWEEKLY	Twice a week, or every 3-4 days
MONTHLY	Once per month
AS NEEDED	As often as necessary; frequency determined by another maintenance step

13.1.1 Under All Conditions

The following tasks must be carried out whether or not an experiment is currently under way.

DAILY	Measure cryogen levels
AS NEEDED	Fill LN2 cryogen
AS NEEDED	Fill LHe cryogen
MONTHLY	Measure magnetic field strength

13.1.2 Experiment: VPT Stability

The following tasks are only required during VPT Stability experiments.

DAILY	Verify DAQ is still running
BIWEEKLY	Examine data for experimental errors

13.2 Measuring Cryogen Levels

Cryogen levels should be checked daily. Under normal conditions the cryogen evaporation rate is virtually constant. However, checking daily will reveal if a fill was done improperly, or if a quench occured.

1. Locate the cryogen lab notebook near the cryogen gauges.
2. Record the current date and time in the notebook.
3. Read the liquid nitrogen gauge, which is always on. Record the measurement in the notebook.
4. To begin taking a liquid helium measurement, press the green power button to turn on the gauge.
5. Wait several seconds, then press the black "MAN" button to take a measurement. The "Sample" light will light up.
6. Wait until the "Sample" light goes out, then read the measurement from the LCD display. It's a percentage.
7. Record the LHe measurement in the notebook.
8. Press the green power button to turn off the LHe gauge.

✗ **DO NOT** leave the liquid helium gauge powered on. It will unnecessarily heat the cryogens and cause them to boil off more rapidly.

13.3 Filling LN2 Cryogen

✓ **DO** consider filling Monday and Friday, and always well before reaching 10 % capacity.

1. Measure and log the cryogen levels, as in §13.2.
2. Climb up the ladder and unscrew the wingnut from the c-clamp at the base of the black ventilation tower.
3. Remove the c-clamp, ventilation tower, **and the o-ring** beneath the tower.
4. Climb down and slowly turn the blue valve (connected by pipe to the magnet). Allow the LN2 to flow slowly at first to cool the valve and piping, then open the valve all the way. A constant plume of white vapour will shoot from the valve where the ventilation tower was removed.
5. Return to the LN2 gauge and monitor the fill. It takes 10 min on average to fill 25 %.
6. Dust frost off the ventillation tower valve every 5–10 min or so.
7. Once the gauge reaches 100 %, return to the LN2 dewar and shut off the blue valve.
8. Climb up the ladder and thoroughly clean the tower valve.
9. Replace **the o-ring**, ventillation tower, and re-attach the c-clamp.
10. Firmly tighten the wingnut on the c-clamp by hand.
11. Return to the cryogen gauges and record the 100 % LN2 level, as in §13.2.

✗ **DO NOT** forget to replace the o-ring. Failing to replace the o-ring is the easiest mistake to make during an LN2 fill and will cause LN2 to boil off more rapidly.

✓ **DO** move the empty dewar through the computer room and out the doors to the concrete patio.

13.4 Ordering LN2 Cryogen

[FIXME] Chris in the stock room in the Beams building handles orders.

13.5 Filling LHe Cryogen

✓ **DO** fill between 20–30 % capacity to use an entire LHe dewar.

[FIXME] Placeholder for practiced fill

✓ **DO** move the empty dewar through the computer room and out the doors to the concrete patio.

13.6 Ordering LHe Cryogen

Mike (HEP) handles orders. Takes 2–3 weeks.

Glossary

BNC: A common type of RF connector for terminating coaxial cable. Cables terminated at both ends by BNC connectors are colloquially called BNC cables. BNC connectors are 50 Ω terminators. BNC stands for Bayonet Neill-Concelman. « 5 »

DAQ: An abbreviation for Data Acquisition, DAQ refers to the process of capturing digital representations of physical processes. By definition DAQ, involves (typically analog) sensors, circuitry to translate the analog signal into a digitizable form, and an ADC (Analog to Digital Converter). Colloquially, DAQ can also refer to the process of capturing those digital signals and recording them. « 18 »

FPGA: **F**ield **P**rogrammable **G**ate **A**rray: A Reconfigurable I/O (RIO) device; essentially a programmable integrated circuit (IC). It can be programmed through LabVIEW (from the system controller only) to provide real-time signalling, triggering, or processing. « 3, 19 »

LabVIEW: Software development environment created by National Instruments' for building and deploying programs, called Virtual Instruments, written in the visual programming langauge G. « 2, 24 »

LED board: LED pulser board designed and built by Mike Arenton. Receives electrical triggers from the PXI Crate and sends optical pulses to the VPTs and PIN diodes. « 3 »

MOLEX: Molex is a large supplier of electronic interconnects. *Molex connector* is a vernacular term for the two-piece interconnects manufactured by Molex. « 5 »

NI: **N**ational **I**nstruments « 18, 19 »

PXI Crate: The National Instruments crate and contents, including hardware modules and software to control the experiment and perform data acquisition (DAQ). « 3, 18, 22, 24, 25 »

quench: An abnormal termination of magnet operation, caused by part of the superconducting material entering the normal resistive state. A quench has not yet occured under HEP supervision. A quench should not damage the magnet itself, but it can induce kilo-volt spikes and arcing and the rapid boil-off of cryogens can cause asphyxiation. « 33 »

ReadyNAS: See RNAS « 19 »

rig: Aluminum mounting brace attached to the supersolenoidal magnet, housing the LED pulser boards, VPT mounting enclosure, and anode amplifier boards. « 3 »

RNAS: ReadyNAS, a specific NAS product produced by Netgear. RNAS is a specific independent hardware module located in the HEP Computer Room [FIXME] . « 22, 35 »

System Controller: Generic term for the device that is housed in slot 1 of a National Instruments PXI chasis. This is almost always an Embedded Computer. « 19 »

VI: **V**irtual **I**nstrument « 20 »

VPT: **V**acuum **P**hoto-**T**riodes « 9 »

VPT VI: Literally Vacuum Photo-triode Virtual Instruments; Refers to the HEP software written in LabVIEW for the National Instruments hardware. Includes software and hardware logic. « 24, 25 »