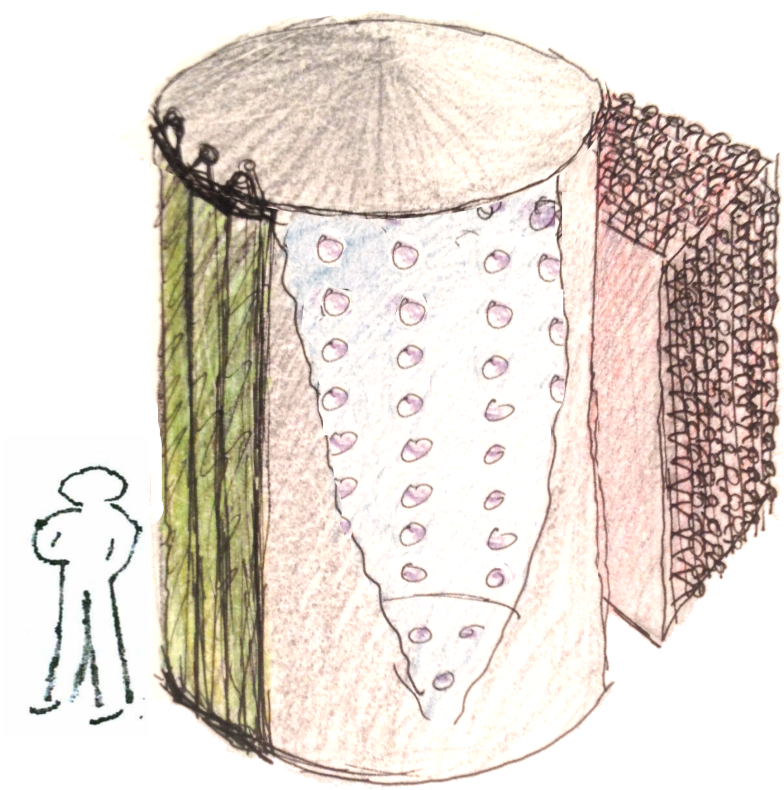
# Operational Readiness Document for
# The Accelerator Neutrino Neutron Interaction Experiment
# ANNIE(T-1063)

Sunday 10$^{\text{th}}$ April, 2016



# Contents

# I Introduction

*Description of the Tests:*

The long term goal of ANNIE is to measure final state neutron yields from neutrino interactions in water, as a function of the kinematic properties (and types) of the interactions. This Technical Scope of Work document, outlines the goal of ANNIE Run I [1,2]: a measurement to quantify and understand neutron backgrounds.

Several sources introduce neutron backgrounds to the ANNIE detector. A continuum of ambient neutrons from cosmic radiation and long-lived isotopes will be present, but can be largely suppressed by strict time cuts around the beam window, and characterized with data from an off-beam trigger. Neutrinos from the BNB can interact with dirt and rock upstream of the experimental hall, producing a correlated neutron background. While this background may appear slow with respect to the prompt component of an event, it is fast on the time scale of Gd neutron captures.

An initial estimate of the neutron flux from neutrino interactions in and outside the tank was obtained from simulations performed by Robert Hatcher (FNAL), using fluxes provided by Zarko Pavlovic (FNAL). For the neutrino interactions that occur in the tank approximately 49.2% of these interactions yield one or more neutrons. The simulation leads to an expectation of one neutron arising from interactions outside the tank, within in the building itself or the surrounding dirt, for every $\sim$87 spills. The kinetic energy spectrum of the neutrons on the left of Fig 1 is dominated by a spike of thermalized neutrons in the first bin. The spatial distribution of dirt events that contribute to the flux is shown on the right of Fig 1.

An additional neutron background is that of sky-shine, namely secondary neutrons produced at targets and beam stops that leak onto the atmosphere and make it into the detector after undergoing multiple scatterings. Preliminary results from SciBooNE indicate an observable excess of events after the beam time window with a clear dependency on the height. Fig. 2 shows the distributions of the vertical-component for reconstructed vertices of events with at least one track, in three different time windows: before, during and after the BNB spill. Events appearing in the before window correspond to mostly cosmic background, whereas events in the after window have a combination of cosmic and sky-shine interactions. Note that the longer time window in the right-most figures affecting overall normalization. The y-dependence of the event count in the detector suggests that the optimization of the fiducial volume allows for the reduction of skyshine and cosmic related backgrounds.

The approved phase I of ANNIE will measure the neutron backgrounds directly in the target water volume as a function of distance distance from the wall and the top of the detector. The non-uniformities in neutron capture can be measured by limiting the Gd-loaded water volume to a smaller portion of the total water volume. A Gd-loaded transparent target will moved from top to bottom and in the beam direction, for beam-on events with no interaction and the water volume and for bunches with full-contained interactions.

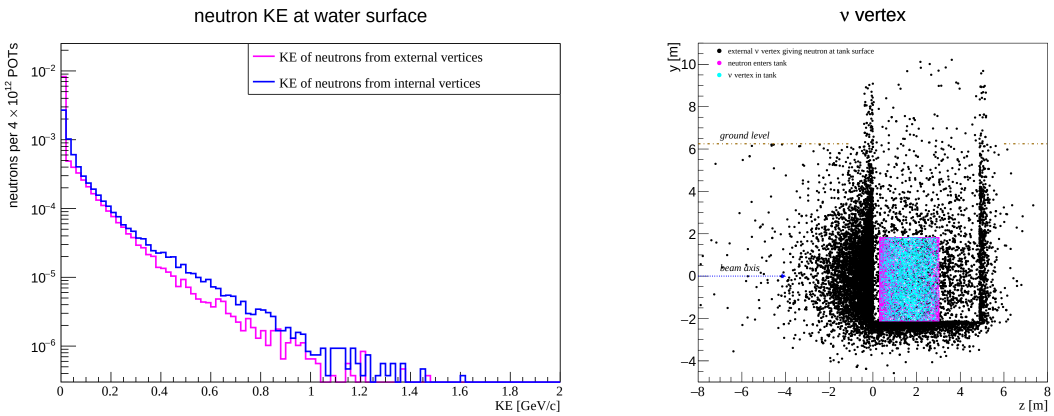



Figure 1: LEFT: Kinetic Energy spectrum of the neutrons reaching the water in the tank from outside (magenta) and those originating from neutrino vertices within the tank (blue). RIGHT: The distribution of neutrino vertices that contribute neutrons that reach the tank (black points). Magenta points are where the neutrons enter the tank. Neutrino interactions inside the tank are cyan.

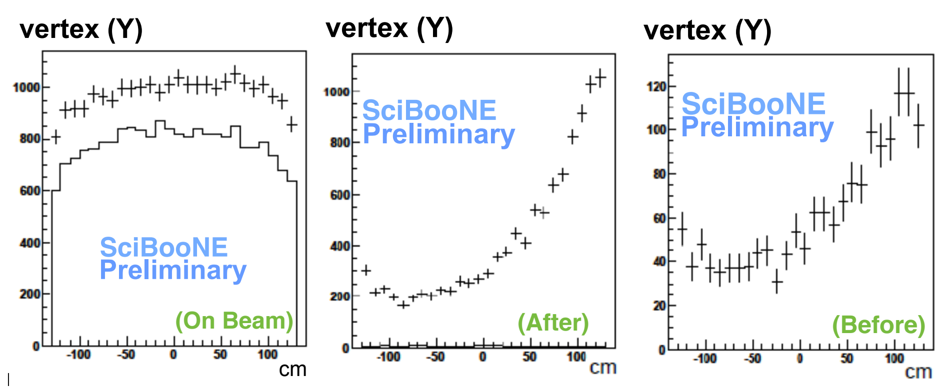



Figure 2: Vertical position of the reconstructed vertices in the SciBoone experiment. LEFT: before the beam time window ($-2 \leq t < 0\mu s$). CENTER: during the beam spill ($0 \leq t \leq 2\mu s$). RIGHT: after the beam time window ($2 < t < 20\mu s$).

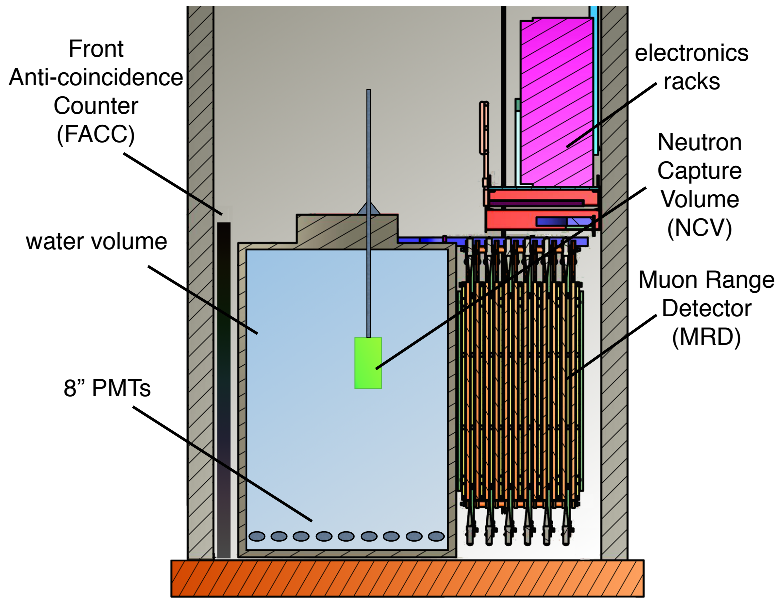



Figure 3: A concept drawing of the ANNIE detector system.

*Overview of the Detector:*

A concept drawing of the ANNIE Run I detector is shown in Fig 3. The main volume consists of an upright cylindrical tank (10 ft diameter x 13 ft tall), initially filled with 30 tons of ultra-pure water. A smaller Neutron Capture Volume (NCV), consisting of a transparent acrylic vessel loaded with Gd-enhance scintillator oil, will be lowered into the water. The Gd enhances the neutron-capture cross section of the target and produces a detectable (8 MeV) photon signal within a much shorter time frame than that of hydrogen (20 $\mu$s vs. 200 $\mu$s). Neutrons that thermalize in this sub-volume will be detectable from the high light yields of scintillating oil, collected by an array of 60 upward-facing 8” (Hamamatsu) PMTs at the bottom of the tank. Position dependence of the neutron rates from different overburdents of water can be studied by raising and lowering the NCV and traslating it along the beam axis. Muons entering and exiting the tank will be tagged using muon paddles in a newly installed Forward Veto detector and several recommissioned layers of the existing Muon Range Detector (MRD) from SciBooNE.

# II Electronics Design

## II.1 Overview

The Phase I ANNIE readout consists of 3 parallel systems: a VME-based FADC system designed at U Chicago (KOTO electronics), a CAMAC/NIM based system for the MRD and forward veto based on the electronics used by the SciBooNE experiment, and the custom PSEC4 electronics designed at UC for the LAPPD system and controlled by VME-housed “ANNIE Central Cards” (ACC).

The primary and highest priority system is the VME-based KOTO electronics. The CAMAC/NIM system provides useful, fine-grained reconstruction of hits in the MRD and veto system but is not critical for Phase I. In a minimal configuation of Phase I, the CAMAC system is installed but only used for a useful feature of the CAMAC discriminators which will allow the 96 channels of the MRD/veto to fan-in to 4 channels of the VME system. The PSEC4 electronics is high priority on longer time scales, but is beyond the scope of this document, which will focus on the immediate needs of Phase I.

Figure 4 schematically shows the arrangement of the Phase I electronics systems for the two unit cells of the ANNIE detector systems: 8” PMTs in the ANNIE water volume and 2” PMTs on scintillator paddles in the veto and MRD. Each water PMT has a single cable used for both the positive high voltage and for the signal readout. These cables are plugged into an ISU designed splitter box (described in Sec 2.8), which connects to the HV system and provides two equal signal outputs. One of these outputs plugs into the VME system and the other, currently 50 Ω terminated will eventually connect to the PSEC electronics system.

Phototubes from the veto and MRD paddles receive a negative voltage directly from the HV system. Signal, leaving the veto and MRD PMTs, goes to a panel of SciBooNE designed splitters. Half of the signal goes to discriminators and TDCs in the CAMAC system. The other half of the signal is delayed and sent to the CAMAC ADC cards. Additionally, digital outputs from the backs of the CAMAC discriminators (one per card) are delayed, daisy-chained and sent into three spare channels of the VME system.

## II.2 Channel Count and Readout Needs

The ANNIE detector consists of 3 subsystems: the water volume containing 60 8” Hamamatsu phototubes, the Front Anti-Coincidence Counter (FACC) consisting of 26 scintillating paddles instrumented with 2” phototubes, and the Muon Range Detector (MRD) consisting in 362 scintillating paddles, of which 2 layers (56 channels) are instrumented in Phase I.

### II.2.1 Water Volume

The most important detector system in Phase I is the water volume consisting of 60 upward-facing 8” R5912 Hamamatsu PMTs pointing at the Neutron Capture Volume. To ensure correct beam timing, it is necessary to identify prompt events in the detector: Charged current neutrino interactions that produce high energy muons track through the water. For the main measurement of Phase I, it is necessary to measure neutron captures on Gd in the NCV. These occur on time scales of tens of microseconds. This sets the large size of the ANNIE readout buffer of at least 80

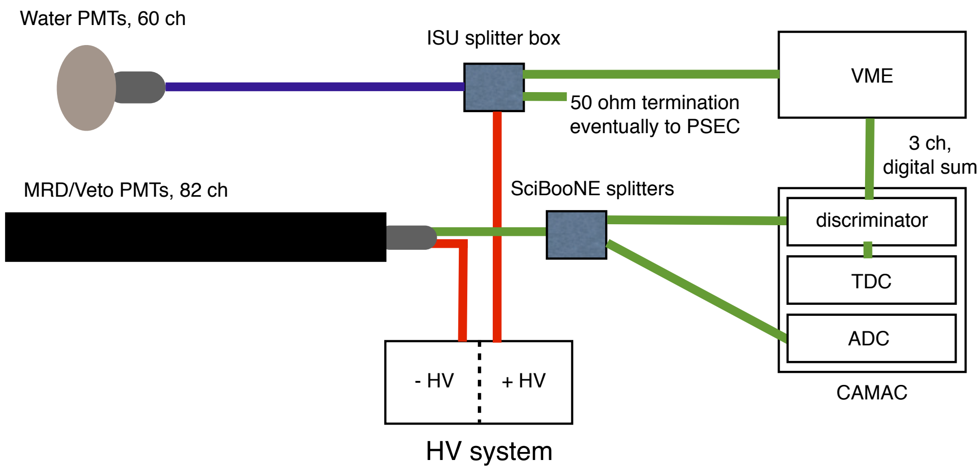



Figure 4: A schematic of the signal and high voltage arrangements for water-volume PMTs and veto/MRD muon-paddle PMTs.

microseconds. Based on the need for a long buffer, the need for time *and* charge information from the water PMTs, and the availability of free ADC electronics, the ANNIE Phase I detector uses a VME system designed at U Chicago for the KOTO experiment. The KOTO electronics consist of 4-channel, 500 MHz waveform sampling ADC cards and Master Timing (MT) cards, situated in two VME crates. The 60 water PMTs necessitate a minimum of 15 FADC cards, with a 16th card used to record the beam timing and 3 digital inputs from the MRD/FACC systems. To provide a clean and synchronized clock for these cards, the minimal configuration also requires 2 MT boards. This minimal configuration technically requires only 1 VME crate. However, since the readout is rate limited by the VME backplane, we have decided to split the cards between two VME crates. For a basic overview, see Ref [3] and for detailed schematics, see Ref [4, 5].

The 60 Hamamatsu R5912 PMTs in the water volume require positive high voltages of $\sim$2 kV. These are provided by CAEN A734P modules loaded in our CAEN SY527 HV crate, as described in Sec 2.8.

### 2.2.2 MRD and FACC

As far as the electronics are concerned, the FACC and MRD are essentially the same system. Both detectors are composed of scintillating paddles and small phototubes, and both detectors follow the same rectilinear geometry. The FACC consists of 2 layers of 13 horizontal paddles, for a total of 26 channels. In Phase I, we read out one vertical and one horizontal layer of the MRD (layers 2 and 3, respectively). Layer 2 consists of 2 sets of 13 horizontal paddles, for a total of 26 channels. Layer 3 consists of 2 sets of 15 paddles for a total of 30 channels.

To summarize the number of needed readout channels from these two subsystems:

- 26 FACC channels (2 layers of 13 paddles)
- 26 MRD layer 2 channels (2 sets of 13 paddles)
- 30 MRD layer 3 channels (2 sets of 15 paddles)

For a total of **82** channels.

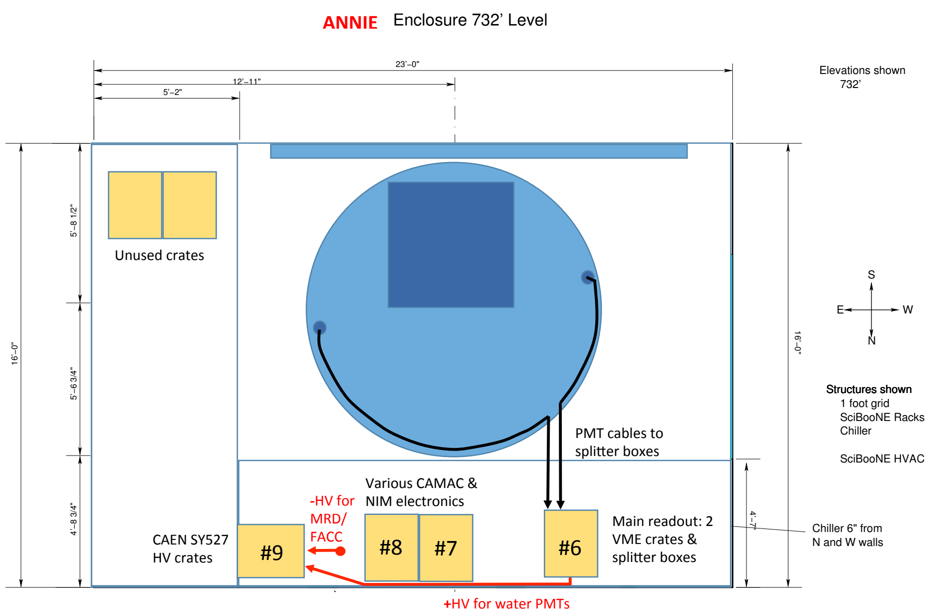



Figure 5: Layout of the 732 level.

All FACC and MRD tubes require negative HV. The MRD uses a mix of 2" PMTs. However, in Phase I, we use only Layers 2 and 3 which are exclusively instrumented with EMI 9954KB tubes inherited from KTeV. These 56 tubes draw roughly 1 mA at their operational voltages of ∼2 kV. The FACC uses 26 EMI 9815 PMTs, which draw 880 mA at 2kV. These necessitated 4 (24 ch) A938AN CAEN modules loaded in our CAEN SY527 crate, as described in Sec 2.8.

The SciBooNE readout, if completed, can enable independent readout of each channel. However, the minimum requirement for these two subsystems is the ability to discriminate between events where muons enter the tank, muons are produced in the tank, and muons leave the tank. For this purpose a simple time-tagged sum of channels from the FACC, MRD-2, and MRD-3 could be fed into the VME system and would suffice for the basic analysis. Thus, the nominal plan is to use the CAMAC electronics only to sum the MRD and FACC channels and the VME system as the primary readout. If the VME system is working well, time permitting, the CAMAC system could be integrated with the primary ANNIE DAQ and provide more detailed information.

## 2.3 Overview of Rack Layout, Power Distribution, and Safety

ANNIE Phase I uses 4 racks, located on the North side of the second (732) level of the hall. Two additional racks are located in the SE side of the level and will be available for ANNIE Phase II (assuming the leaks on that side of the Hall can be fixed). The arrangement of these racks is pictures in Fig 5.

Rack 6 contains the primary readout system, consisting of VME-based sampling electronics and related components. Rack 7 will contain a NIM bin and the necessary CAMAC crates to reproduce the SciBooNE system for the 86 channels of MRD layers 2 and 3, and the FACC. Rack 8 is a spare in Phase I, and rack 9 houses the High Voltage (HV) system. The layout of these racks is shown

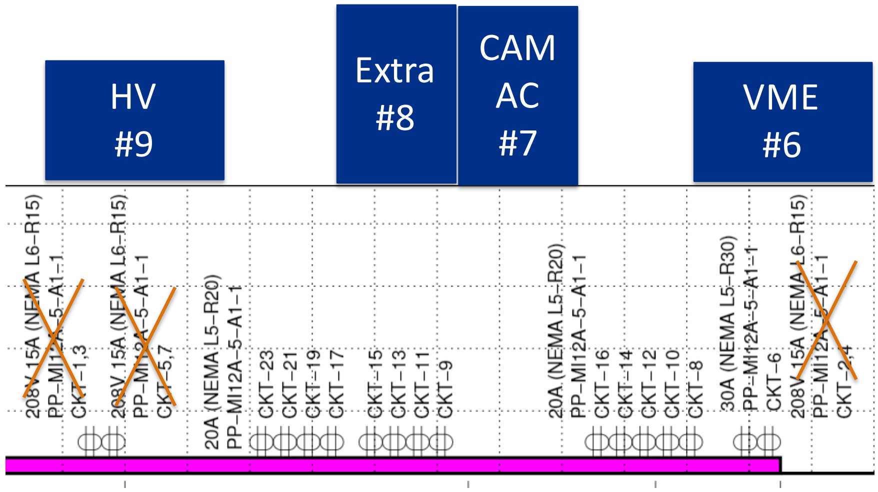



Figure 6: Layout of the L5-R20 plugs on the North wall of the 732 level at SciBooNE.

in Fig 7.

A half-rack for the DAQ and gateway computers will be located on the ground floor in the far NW corner.

In this section, we describe the layout, power distribution, and safety concerns for each of these racks.

### 2.3.1 General Power Issues in the Hall

There are two available sources of power on the Northern wall of the 732 Level: A series of standard 15 amp sockets on the bottom, and 13 L5-R20 (20 amp) sockets located at a height just above the racks, as shown in Fig 6. Most of the 15 amp plugs share common circuit breakers and will unlikely handle the current load of the racks. Each of the 20 amp sockets is individually fused.

Ideally, the 20 amp sockets would be replaced with a bus providing 208V 30A 3-phase power, allowing each rack to be powered by a single, 3-phase PDU system. Given the schedule and cost considerations of Phase I, racks 6, 7 and 8 use 2 20 Amp Bira 8885 Power Distribution Units (PDUs) per rack, and 1 Pulizzi Model 1294. Each of these PDUs is plugged into its own 20 amp socket. Both the Biras and Pulizis were modified with longer cables consisting of thicker gauge wire, L5-R20 twist-lock type plugs, and 15 amp fuses. These changes are described in detail in Appendix I, and References [6, 7]

The specific PDU needs of each rack will be discussed individually.

## 2.4 Rack 6 (VME System)

This rack contains two 9U VME crates for the main ANNIE Phase I readout, provided by a VME-based ADC system developed for the KOTO experiment by University of Chicago. In addition, there is a passive LVDS translator unit (1U), a NIM module mostly used for a NIM/TTL/ECL translator (6 U with fan), and the 5 (1U) splitter boxes which take separately the single cable from

| U | rack 6 | U | rack 7 | U | rack 8 | U | rack 9 HV system |
|---|---|---|---|---|---|---|---|
| 1 | Empty | 1 | MRD splitter 7u marcus | 1 | MRD Splitter 6u marcus | 1 | |
| 2 | Rack | 2 | | 2 | | 2 | |
| 3 | | 3 | | 3 | | 3 | |
| 4 | Empty | 4 | | 4 | | 4 | |
| 5 | VME Crate 0 (15 Amp) | 5 | | 5 | | 5 | |
| 6 | water PMTS | 6 | | 6 | | 6 | |
| 7 | signal | 7 | | 7 | | 7 | |
| 8 | | 8 | | 8 | | 8 | |
| 9 | | 9 | CAMAC crat(15 Amp) | 9 | | 9 | |
| 10 | | 10 | MRD/Veto | 10 | | 10 | |
| 11 | | 11 | Timing signal | 11 | | 11 | |
| 12 | | 12 | | 12 | | 12 | HV patch panel 6u, by eye |
| 13 | | 13 | | 13 | | 13 | |
| 14 | | 14 | | 14 | | 14 | |
| 15 | PDU | 15 | | 15 | | 15 | |
| 16 | Splitter boxes | 16 | PDU | 16 | | 16 | |
| 17 | water PMTS | 17 | | 17 | | 17 | |
| 18 | signal + HV | 18 | Rack | 18 | | 18 | |
| 19 | | 19 | | 19 | | 19 | Empty |
| 20 | | 20 | CAMAC crat(15 Amp) | 20 | | 20 | CAEN Sy527 8u online |
| 21 | Timing | 21 | MRD/Veto | 21 | | 21 | |
| 22 | PDU | 22 | Timing signal | 22 | | 22 | |
| 23 | | 23 | | 23 | | 23 | |
| 24 | | 24 | | 24 | | 24 | |
| 25 | | 25 | | 25 | | 25 | |
| 26 | | 26 | | 26 | | 26 | |
| 27 | | 27 | | 27 | | 27 | |
| 28 | VME Crate 1 (15 Amp) | 28 | | 28 | | 28 | Empty |
| 29 | water PMTs | 29 | Nim Bin 1 (5 Amp) | 29 | | 29 | Empty |
| 30 | MRD/Veto (3) | 30 | | 30 | | 30 | PDU pulizzi 1 |
| 31 | RWM (1) | 31 | | 31 | | 31 | PDU pulizzi 2 Extra |
| 32 | signal | 32 | | 32 | | 32 | Empty |
| 33 | | 33 | | 33 | | 33 | Rack protection uBoone |
| 34 | | 34 | NIM fan | 34 | | 34 | empty |
| 35 | | 35 | PDU | 35 | | 35 | |
| 36 | | 36 | | 36 | | 36 | |
| 37 | | 37 | ADC Patch 9u mayly | 37 | | 37 | CAEN Sy527 8u online |
| 38 | PDU | 38 | | 38 | | 38 | EXTRA |
| 39 | Nim Bin 0 (5 Amp) | 39 | | 39 | ADC Patch 7u marcus | 39 | |
| 40 | | 40 | | 40 | | 40 | |
| 41 | | 41 | | 41 | | 41 | |
| 42 | | 42 | | 42 | | 42 | |
| 43 | | 43 | | 43 | | 43 | |
| 44 | NIM fan | 44 | | 44 | | 44 | |
| 45 | Empty | 45 | | 45 | | 45 | |

Figure 7: Arrangement of the 4 ANNIE racks (from left to right) 6,7,8, and 9.

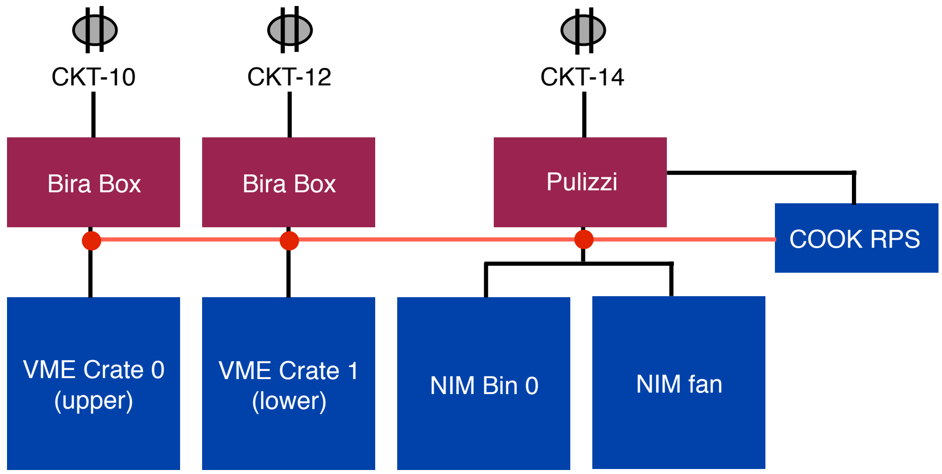



Figure 8: AC Distribution for Rack 6.

each water PMT into an HV in, and two signal-outs. Eventually the second signal-out will go to the PSEC system. For now, it is 50 ohm terminated. 60 LEMO cables will bring the signals from the PMTs into the channels of the KOTO FADC cards.

### 2.4.1 Power Distribution and Rack Protection

The AC power distribution for Rack 6 is shown in Fig 8. The high possible current draw of the FADC system necessitates 2 (2U) Bira 8885 power distribution units, one for each of the VME crates, and one Pulizzi 1294 for the remaining electronics: the NIM bin, NIM fan, and RPS. The Bira boxes are fused at 15 amps and individually plugged into the L5-R20 (20 amp) sockets above the rack, as is the Pulizzi 1294.

Rack 6 uses a 2U Cook rack protection system, designed for the D0 experiment and is attached to 1 smoke detector at the top of the rack.

### 2.4.2 Custom Equipment

This rack uses the following custom or modified equipment:

- Two WIENER VME64X crates, modified to provide +/-7V power by Fermilab technicians.
- Custom VME modules designed at the University of Chicago.
  - 4-channel, 500 MHz waveform sampling ADC cards.
  - Master Timing (MT) modules for clock and synchronization of the ADC system.
- Five 1U Splitter boxes designed at ISU to separate the Hamamatsu cables into HV, and two signal outputs.
- A 1U LVDS converter module used to convert the final trigger

Modifications to the WIENER VME64x crates are discussed in Appendix II and in reference document [8]. The U Chicago VME modules are described in Ref [4, 5]. After a preliminary ORC review, several changes were made. These changes are discussed in Appendix III of this document.

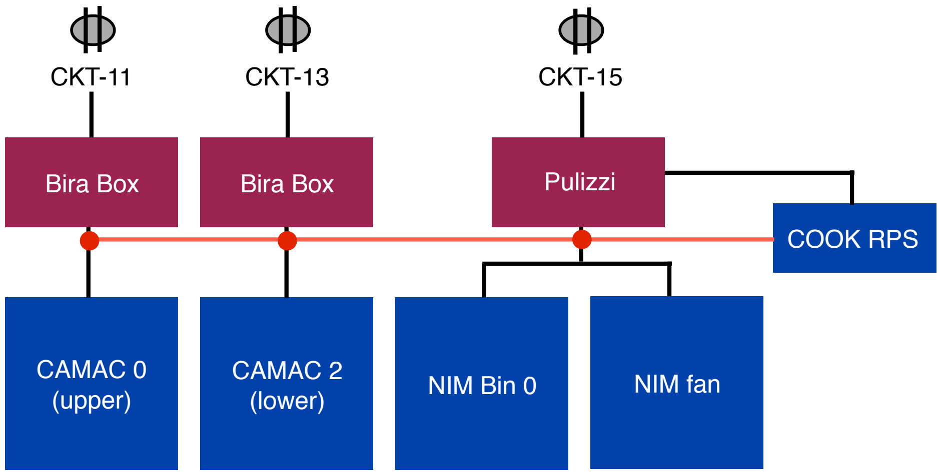



Figure 9: AC Distribution for Rack 7.

The design of the Splitter Boards is discussed in Appendix IV and Refs [10,11]. And a schematic of the LVDS converter box is shown in Appendix V.

#### 2.4.3 Commercial Equipment

This rack also contains the following standard equipment:

- 1 CAEN E1495 VME-based FPGA card
- 1 NIM crate with a Level Translator Module
- 1 NIM fan

### 2.5 Rack 7 (CAMAC System)

Rack 7 was one of the two racks used by the SciBooNE experiment for the readout of the full MRD. For Phase I of ANNIE, where we only readout a limited number of MRD channels (and 26 FACC channels), Rack 7 alone will suffice. Much of the layout will remain the same as it was in SciBooNE. The top of the rack consists of panels with passive splitters. The bottom of the rack contains a patch panel to transition from the BNC delay cables to the 16 channel ribbon cables that attach to the CAMAC ADC cards.

Rack 7 contains two CAMAC crates. The upper crate houses the discriminators and TDCs, and the lower crate houses the ADC modules. The rack also holds a NIM bin used for trigger logic in the CAMAC system. On the most basic configuration the upper crate will hold 6 discriminators. Additional modules will be added later.

#### 2.5.1 Power Distribution and Rack Protection

The AC power distribution for Rack 7 is shown in Fig 9. The high possible current draw of the CAMAC system necessitates 2 (2U) Bira 8885 power distribution units, one for each of the CAMAC crates, and one Pulizzi 1294 for the remaining electronics: the NIM bin, NIM fan, and RPS. The Bira boxes are fused at 15 amps and individually plugged into the L5-R20 (20 amp) sockets above the rack, as is the Pulizzi 1294. Currently, only one of the two CAMAC crates is mounted on the rack. At a later time, we would like to add the second crate, following the proposed scheme.

Rack 7 uses the same 2U Cook rack protection system as Rack 6, with 1 smoke detector at the top of the rack.

#### 2.5.2 Custom Equipment

- Passive 2-way splitters inherited from the SciBooNE experiment.
- Patch panel from BNC to 16 pin ribbon cables, inherited from SciBooNE.

#### 2.5.3 Commercial Equipment

- 2 CAMAC crates with
  - Lecroy 4413 (16 ch) Discriminator modules
  - Lecroy 3377 (32 ch) TDC modules
  - Lecroy 4300B/610 (16 ch) FERA ADC modules
  - Jorway scalars
  - WIENER CCUSB controller
- 1 NIM crate with
  - LRS:620D discriminators
  - LRS:380A multiplicity logic units
  - LRS:380A 4-fold coincidence units
  - a Jorway:1880 scalar
- 1 NIM fan

### 2.6 Rack 8 (Spare)

#### 2.6.1 Rack Layout

In SciBooNE, rack 8 was necessary to house an additional 2 CAMAC crates and 1 NIM bin for the rest of the MRD readout. In ANNIE Phase I, this rack is left empty, except for the passive splitter panel on top and patch panel on the bottom.

#### 2.6.2 Power Distribution and Rack Protection

The AC power distribution for Rack 8 is shown in Fig 10. Rack 8 currently holds no active components. Nonetheless, we built a duplicate AC power distribution to that of rack 7, allowing the future installation of 2 CAMAC and 1 NIM crate, as was the case in SciBooNE.

Rack 8 uses the same 2U Cook rack protection system as Rack 6, with 1 smoke detector at the top of the rack.

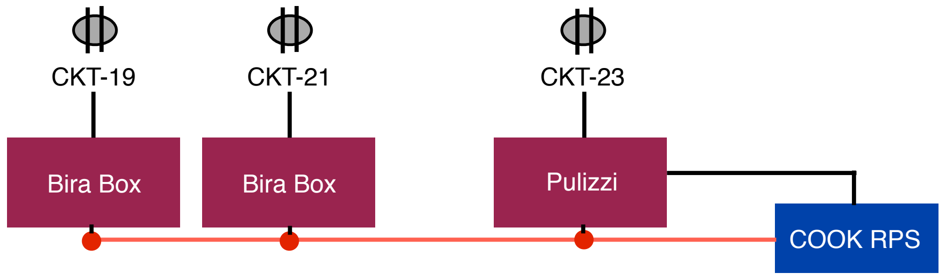



Figure 10: AC Distribution for Rack 8.

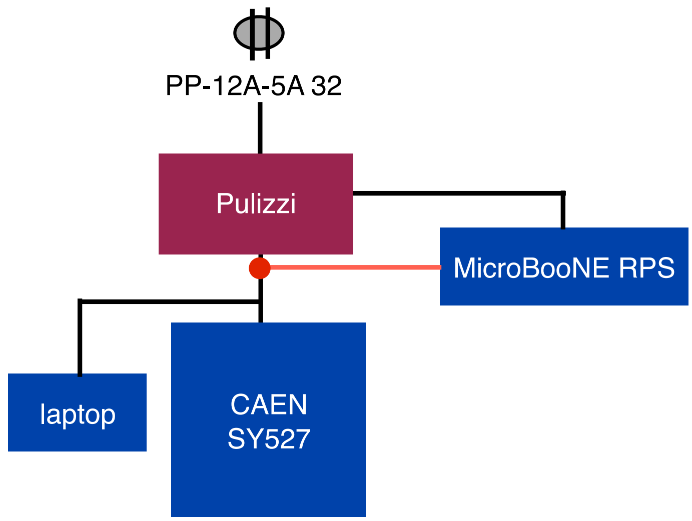



Figure 11: AC Distribution for Rack 9.

### 2.6.3 Custom Equipment

Nominally, no custom equipment is being used in Rack 8.

### 2.6.4 Commercial Equipment

Nominally, Rack 8 uses no commercial equipment.

## 2.7 Rack 9 (High Voltage)

### 2.7.1 Rack Layout

Rack 9 consists of two (8U) CAEN SY527 crates (1+spare), two (1U) Pulizi PDUs (1+spare) plugged into the 15 wall socket, a MicroBooNE RPS (1U), and a patch panel transitioning from the high density negative HV cables to standard SHV bulkhead connectors.

Rack 9 has already passed preliminary review and remains unchanged since that time.

### 2.7.2 Power Distribution and Rack Protection

Both because the HV system was implemented before considering the power needs of the other Racks, and because the power consumption of the SY527 is low, Rack 9 uses standard 15 amp power from the lower sockets.

Power distribution, shown in Fig 11, is provided by a single Pulizzi plugged into one of the 15 amp wall sockets. Rack protection is provided by a single MicroBooNE prototype RPS, connected to two smoke detectors.

### 2.7.3 Custom Equipment

The patch panel is custom designed and has already been reviewed by S. Chappa and D. Mertz.

### 2.7.4 Commercial Equipment

The rack also houses:

- A CAEN SY527 crate
- CAEN A734P modules
- CAEN A938AN modules
- A standard laptop for computer control

## 2.8 HV and Slow Controls

Here we describe the ANNIE Phase I HV system. For more information, see Ref [12, 13]. For Run II, ANNIE will require 60 positive high voltage channels with very low current draw (the 8" PMTs in the water volume), and 82 negative HV channels to power the 26 FACC PMTs, and 26+30 MRD (layers 2 and 3) phototubes. The 2 EMI 9954KB and EMI 9815 tubes of the MRD and FACC, repectively, require a high voltage around 2 kV and high current (as much a 1 mA per channel), necessitating the use of CAEN A938AN modules. The 8 Hamamatsu R5912 require a positive high voltage of roughly 2 kV, but draw smaller currents. CAEN A734P modules were identified for this purpose.

The primary ANNIE Phase I HV system fits into a single CAEN SY527 crate, with a second crate on hand as a spare.

The A734P modules contain 16 channels per card, requiring only 4 cards to power the water volume. The A938AN modules instrument 32 channels per card, requiring 4 cards to address the 82 2 PMTs. Rack 9 is mounted with two SY527 crates, one active and one spare. The active crate is stuffed with 5 A734P modules (4+1 hot spare) and 5 A938AN modules (4+1 spare). Pictures of the racks are shown, as installed at D0 in Fig 12, and at SciBooNE in Fig 13.

The positive HV A734P modules have SHV jacks (see Fig 14) and are thus directly cabled to the splitter boxes via 60 cables running on trays above the racks. The negative A938AN modules use special, high-density 32-channel connectors. Special cables and a patch panel with bulkhead SHV connectors were made to allow the connection of the SHV cables from the FACC and MRD paddles (see Fig 15). This arrangement has already been reviewed and approved. Computer control of the HV system is provided by a laptop, mounted on the rack and connected to the SY527 crate.


Figure 12: Front (left) and back (right) of the HV rack (9).


Figure 13: Two views of the HV rack (9), as installed in ANNIE Hall.

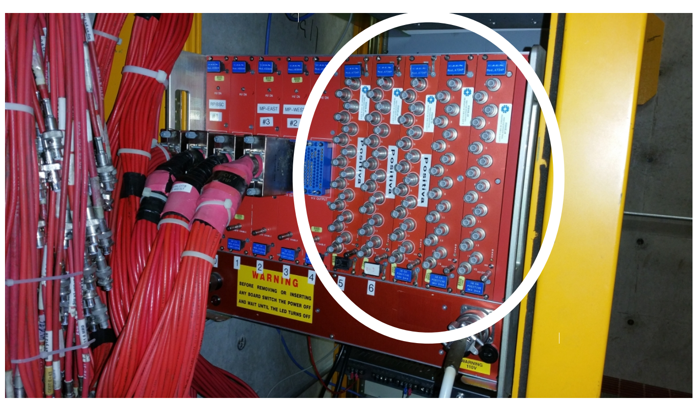



Figure 14: Positive HV connectors on the HV rack.


Figure 15: LEFT: The high density, negative HV connectors on the HV rack. RIGHT: The negative HV patch panel.

# Appendix I: Modified Power Distribution and Rack Protection Systems

Fermilab
**PPD / EED / Infrastructure and Support Group**
Technical Note: IG_ 20160005
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3-Mar-16

## Rack Protection and Current Interruption for ANNIE Racks in the SciBooNE Experimental Hall

**Overview:**

The ANNIE Experiment will soon be operating racks containing various crates of electronics in the experimental hall that once housed the SciBooNE Experiment. This note describes equipment used to provide Rack Protection / Power Interruption capabilities for these racks.

**DZero Rack Monitor Interface Chassis:**

The heart of the Rack Protection / Current Interruption system is the re-purposed DZero Rack Monitor Interface Chassis. For this application the 2U high device interfaces with a photo-electric smoke detector and provides an interlock signal (indicating when it is safe / unsafe to pass AC current) to current interruption devices in series with AC power connections into a rack. A copy of the DZero Rack Monitor Interface Chassis Specification has been included in the Appendix.

For this application, the Rack Monitor Interface is set up to only monitor the status of the smoke detector unit.

Basic Operation:

Particulate in the air passes through the sensing region of the smoke detector. Light reflecting from the particulate is captured by a photodetector. The output of the photodetector is proportional to the amount of particulate. Sufficient particulate in the monitoring region will result in a trip condition. Circuitry found in the smoke detector base monitors the operation of the smoke detector and latches the trip condition. The trip status is relayed to the Rack Monitor Interface via the 4-conductor cable. Internally, the Rack Monitor Interface also latches the tripped state of the smoke detector. The front panel LED for “Smoke Detector” changes color from green to red. If the annunciator switch is in the “Enable” position, the Rack Monitor Interface also emits an audible alarm. Further, if the Rack Monitor Interface does not sense that a smoke detector is connected, either by disconnected cable or remove smoke detector head, the unit will indicate a "Smoke Detector" trip and inhibit the interlock signal.

Pressing the "Reset Alarms" momentary switch on the front panel of the Rack Monitor Interface does two things; interrupts the power delivered to the smoke detector, which is the method by which it is reset, and clears the internally latched trip condition(s). Once particulate has cleared from the smoke detector and no longer sends a tripped indication, the Rack Monitor Interface will silence the audible alarm and change the front panel LED back to green.

**Pulizzi Power Controller:**

Commercial Pulizzi Power Controllers (model 1294) have also been repurposed from the D0 Experiment. These 1U high devices contain four interlock enabled NEAM 5-15 duplex receptacles. Each set of two receptacles is in series with a 15A front panel mounted circuit breaker. An internal relay is in series with the non-grounded connection to the receptacles. To operate properly, the Rack Monitor Interface requires a non-interlocked source of AC power. We've modified the Pulizzi Power Controller to provide the non-interlocked power by disconnecting one pair of receptacles from the contacts of the internal relay and connecting them directly to the output of one of the circuit breakers. Labelling applied to the chassis indicates the location of the two non-interlocked receptacles. The remaining two receptacles are available for interrupting power to ANNIE Experiment electronics crates, subject to a maximum total current of less than 15A. The plug end of the power cord to this device was re-terminated to match the twist-lock receptacles located in the SciBooNE Experimental Hall.

The interlock function of this device is controlled by an external normally closed contact. A RG-58 coaxial cable is terminated with the proper 4-contact Molex connector to mate with the front panel header is provided. The other end of the cable will be connected to the BNC connector labeled "Blower Interlock Normally Closed Contact" on the rear panel of the Rack Monitor Interface. Figure 1 indicates the position of this BNC connector.

**Bira Systems Model 8885 Interlocked AC Outlet**:

The Bira Interlocked AC Outlet is a commercial device consisting of a NEMA 5-20 duplex receptacle and an internal Crydom D2425 25A solid state relay. The plug end of the power cord to this device was re-terminated to match the twist-lock receptacles located in the SciBooNE Experimental Hall. Two Bira Outlets are provided for each ANNIE rack.

The interlock function of this device is controlled by an applied dc voltage in the range 3 – 32V. A standard BNC terminated RG58 coaxial cable is provided to connect the interlock BNC on the Bira Outlet to the BNC connector labeled

"Blower Interlock Normally TTL High" on the rear panel of the Rack Monitor Interface. Figure 1 indicates the position of this BNC connector.

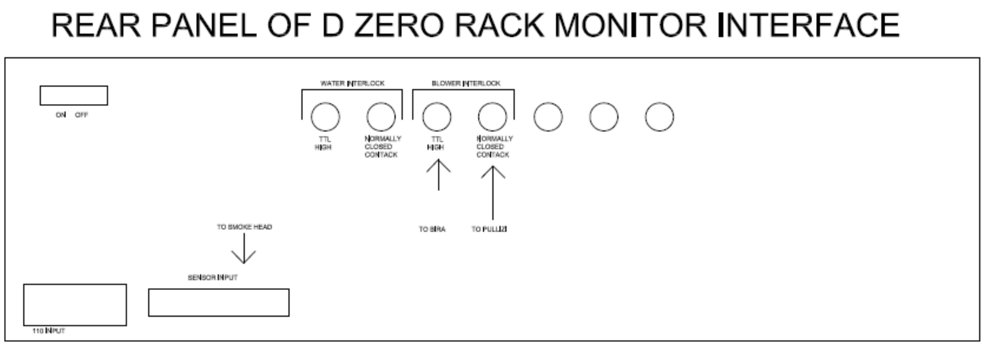


**Figure 1. Cable connections**

**Appendix:**

"DZERO Rack Monitor Interface Chassis Specification". Revision date; 1/30/91.

# Appendix II: Modified VME Crates

Fermilab

**PPD / EED / Infrastructure and Support Group**

Technical Note: IG_ 20160003
Michael L. Cherry
Michael S. Matulik
29-Feb-16

## ANNIE VME64x Crate for SciBooNE Hall Installation Power Distribution

**Overview:**

The ANNIE experiment wants four 6U VME64x crates for installation in the SciBooNE experimental hall. These crates differ from the one described in document IG_20160001 "*ANNIE VME64x Crate Power Distribution*" which was assembled from assorted components for software and hardware development. For the final run of the D0 Detector, the Level 1 Calorimeter collaboration installed a number of integrated VME64x backplane, fan tray, power unit and from panel assemblies provided by Wiener. It was determined that these assemblies could be made compatible with ANNIE requirements by modifying the voltages for two of the outputs and making small changes to the wiring from the Wiener power unit back plane to the VME64x backplane. This document reviews the how the power connections for the crate are realized. A wiring diagram is included for completeness.

**VME64x Crate:**

The crate into which the VME64x backplane is secured is integrated into the chassis that holds the Wiener power unit. Wired connections are made between the power unit backplane and the VME64x backplane. The two higher current power connections were made via large tinned copper bus work connected to multiple power taps. The two low current power connection were made via direct connection to multiple power taps. The return current connections for all four are made common to a single wide tinned copper bus connected to many multiple backplane power taps.

**Low-Voltage Power Supply:**

The integrated VME64x crate contains a Wiener power unit backplane that provides four outputs. As recovered from their use for D0 L1 Cal, the four outputs were connected to the following labeled power connections on the VME64x backplane:

- U0 to the +5V power taps, with a nominal output voltage of +5V
- U1 to the +12V power taps, with a nominal output voltage of +5V

- U3 to the +3.3V power taps, with a nominal output voltage of +3.3V
- U5 to the -12V power taps, with a nominal output voltage of -5V

Connections to the bus work and individual backplane power tap were made via 10AWG wire.

The cards that ANNIE plans to insert into the VME64x crate require 4 power connections to operate; +5V, +3.3V and +/- 7.5V. These cards look for the first two voltages on the standard 5V and 3.3V pins. +/-7.5V are expected to be found on the +/-V1 pins so modification of the wiring between the power unit backplane and the VME64x backplane was necessary.

Sense lines connect the VME64x backplane to the Wiener power unit. The power unit will not operate if any of the sense lines are unconnected. As used for D0 L1 Calorimeter operation, the +/-5V low current outputs were wired to the +/-12V power taps on the VME64x backplane. The sense lead connections are integrated into the backplane and are not modifiable. Connections to the +/-12V power taps need to be maintained, even though ANNIE cards will not be make connections to these nets, to ensure proper operation of the Wiener power unit.

Examination of the wiring used by Wiener to connect the two backplanes caused us to make certain modifications. In all cases multiple conductors were used to make connections to and from the VME64x backplane. We elected to install series fuses into all of the individual non-ground current carrying conductors for safety. The rating of all fuse holders is 30A / 300V. Identifying information for the backplane power taps is not available. The current rating of these terminals is unknown.

**AC Power:**

AC power for the Wiener PL6000 power unit is provided via a standard 120V / 15A 5-15 plug / cord. It is expected that this power cord will be connected to a 120V / 15A 5-15 receptacle in the power distribution chassis that's protected with a 15A circuit breaker

**+3.3Vdc:**

The U3 output of the Wiener power unit is indicated to have a maximum current of 115A. After modification this output is connected to the VME64x backplane 3.3V and return busses with four gray and four black 10AWG wires. A 20A / 250V 3AG fuse is placed in series with each non-grounded conductor. The output voltage is adjusted to deliver 3.3V.

**+7.5Vdc (+V1 and +12V):**

The U1 output of the Wiener power unit is indicated to have a maximum current of 30A. This output is connected to +V1 power taps on the VME64x backplane with white and black 10AWG wire. A 30A / 32V 3AG fuse is placed in series with the non-grounded conductor. The output voltage is adjusted to deliver +7.5V.

This output is also connected to the +12V power taps on the VME64x backplane with orange (before the fuse), red (after the fuse) and black 10AWG wire. A 10A / 250V 3AG fuse is in series with the non-grounded conductor.

**-7Vdc (-V1 and -12V):**

The U5 output of the Wiener power unit is indicated to have a maximum current of 30A. This output is connected to -V1 power taps on the VME64x backplane with violet and black 10AWG wire. A 30A / 32V 3AG fuse is placed in series with the non-grounded conductor. The output voltage is adjusted to deliver -7.5V.

This output is also connected to the -12V power taps on the VME64x backplane with gray and black 10AWG wire. A 10A / 250V 3AG fuse is in series with the non-grounded conductor.

**+5Vdc:**

The U0 output of the Wiener power unit is indicated to have a maximum current of 115A. After modification this output is connected to the VME64x backplane +5V and return busses with four red and four black 10AWG wires. A 15A / 32V 3AG fuse is placed in series with each non-grounded conductor. The output voltage is adjusted to deliver 5V.

**Wiring Diagram:**

Please find “ANNIE SciBooNE Hall VME64x Crate Wiring Diagram”, drawing number 176948 attached.

# Appendix III: Changes to University of Chicago VME Modules

Several changes were made on the VME cards to meet ORC compliance. Specifically these changes addressed consistency of fuses and traces with the appropriate current limits. Most of the fuses were rated for currents well above those of the regulators. Fuse values were chosen so that the fuses were be the first components of the circuit to fail in an overcurrent scenario. We also require fuses to trip at currents more than a third larger than the expected operational currents.

Each ADC card has 4 input voltages: 5V, 3.3V, +7.5V, and -7.5V. The 5V and 3.3V circuits are both current limited by the sockets that the fuses are attached to. The sockets are rated for 5 amps. We therefore removed the 10 amp fuses previously in the cards and replaced them with 5 amp fuses.

The +7 and -7 volt circuits were previously populated with 5 amp fuses. Maximum current on these circuits is limited by the VME connector (on the card side), which is rated for 1.5 amps at 20 C. Maximum current on the -7V path is 0.2 amps, so we replaced the 5 amp fuses with 1.5 amp fast-acting fuses on this circuit without a problem. The +7V circuit runs at $\sim$1.18 amps and we felt that 1.5 amp fuses were too close. After discusson with Steve Chappa and Dave Mertz, we replaced the 5 amp fuses on this circuit with 2 amp, slow-blow fuses.

The regulators on the VME cards draw a maximum of 3 amps. They are currently populated with 5 amp fuses. Steve and Dave requested that the fuses fall below the current limits of the traces from the regulators to fuses. For these 40 mil traces, 3 amp fuses were determined to meet the criteria. Fast-acting fuses were used on all regulators except for the 1.2V regulator, which used a slow-blow fuse.

Two additional small changes needed to be made to the MT cards. The MT cards have two regulators, 1.2 V and 2.5 V, to supply the FPGA. The trace connecting the output of the regulator and the fuse was accidentally undersized as a 10 mil signal trace. The analogous path in the FADC cards uses a 40 mil trace. The 1.2V supply to the FPGA draws 0.8 amps, which falls too close to the current limit on the trace. With Steve Chappa's help we opted to solder a jumper wire to augment the trace to accommodate higher currents, allowing us to fuse these at 3 amps. The soldered wire connects two through-hole components and is both robust and reasonably reversible.

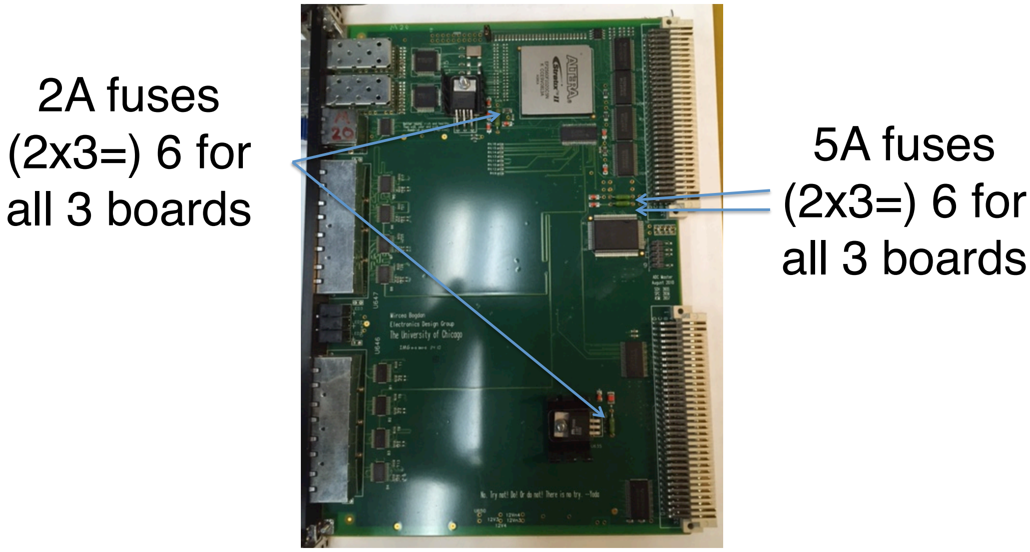


Figure 16: New fuses used in the MT modules.

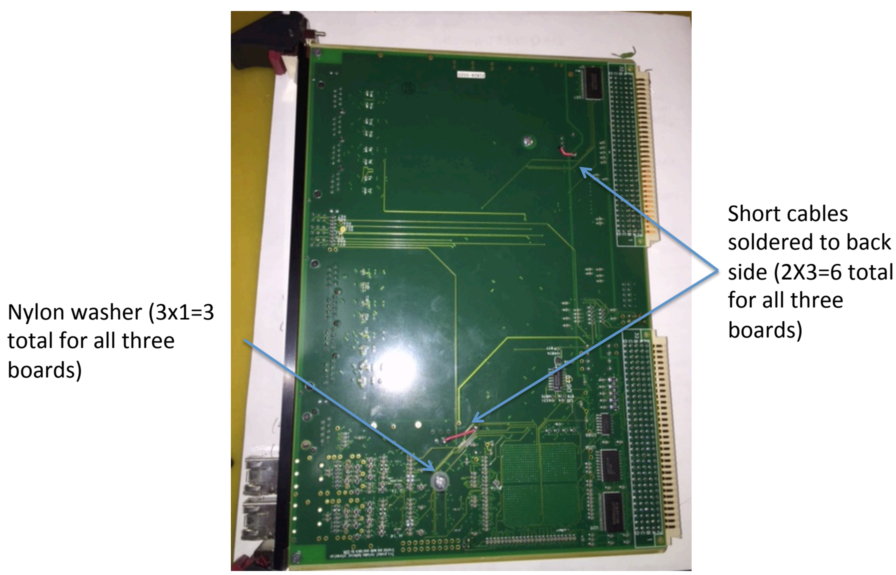


Figure 17: The wires soldered onto the MT boards and nylon washers.

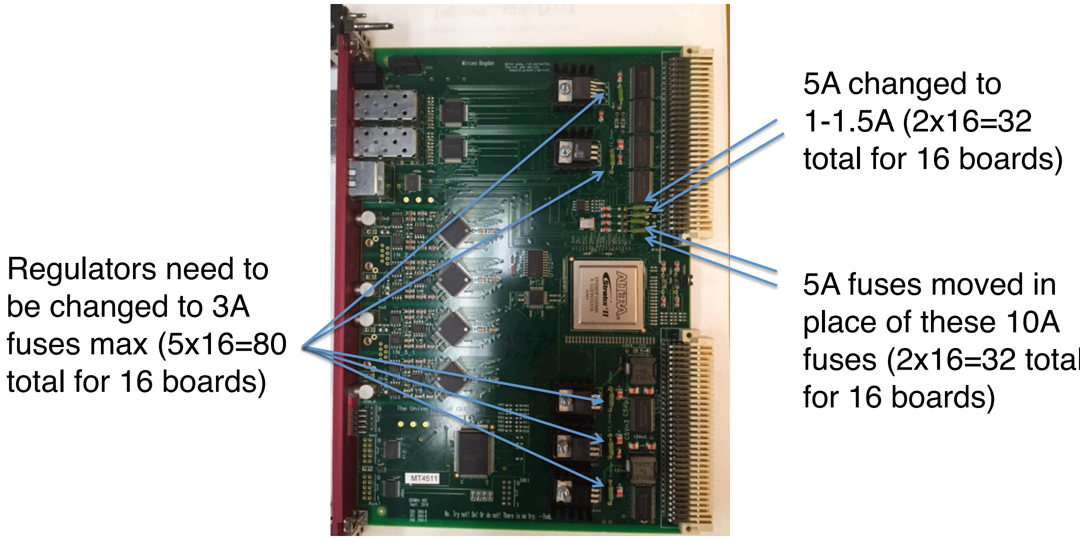


Figure 18: Fuses on the FADC modules.

## Appendix IV: ISU Splitter Boxes

The ANNIE water-volume PMTs are positive-high voltage type and have the anode directly attached to the HV supply cable. The signal (3ns rise time) from the PMT rides on top of the HV supply voltage.

The ISU HV splitter box has SHV connections for the HV supply and the PMT. The PMT signal is capacitively coupled to an output circuit, which also (optionally) attenuates and splits the signal.

Each splitter box consists of a grounded enclosure containing a 12 channel splitter board. The 15.3" x 2.85" board, pictured in Fig 19, is made of 0.062" thick FR4 with 1 oz copper and lead-free solder finish. The output signals are board-mount BNC and SMA connectors. All components are 0805 (2012 metric) or larger. On the bottom of the board is a ground plane, with traces only on the top and no HV through holes. Output signals are provided on board-mount BNC and SMA connectors.
The board is grounded on the enclosure, as pictured in Fig 20, via brass standoffs and the SHV bulkhead attachment points. The internal HV attachments are shown in Fig 22, and consist of RG-58C/U stripped to 12mm with a common stripping tool. The braid is pulled away and twisted, then soldered to the ground plane on the bottom. The center conductor is cut to size, tinned and soldered to a pad at the top. All HV components are on one side (the back) of the board. On the side of the bulkhead connectors, each shield will be grounded to a ring lug on each of the bulkheads. Solder connections will be insulated with Scotch Rubber Splicing Tape 70 or similar.

An illustration of the layout of a single splitter-board channel can be found in Fid **??**.
More detailed technical drawings can be found at References [**?**, **?**, **?**].

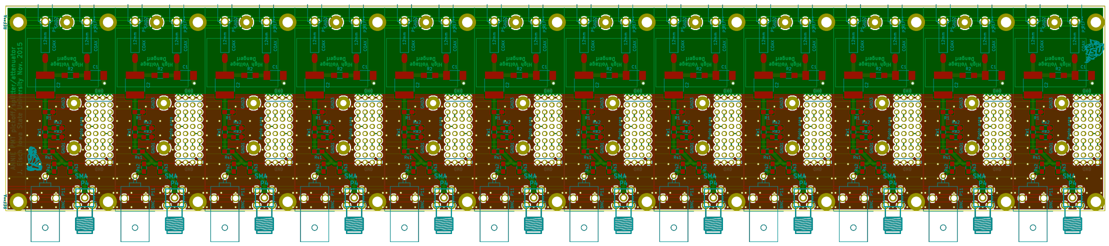

Figure 19: Diagram of the 12-channel splitter board.

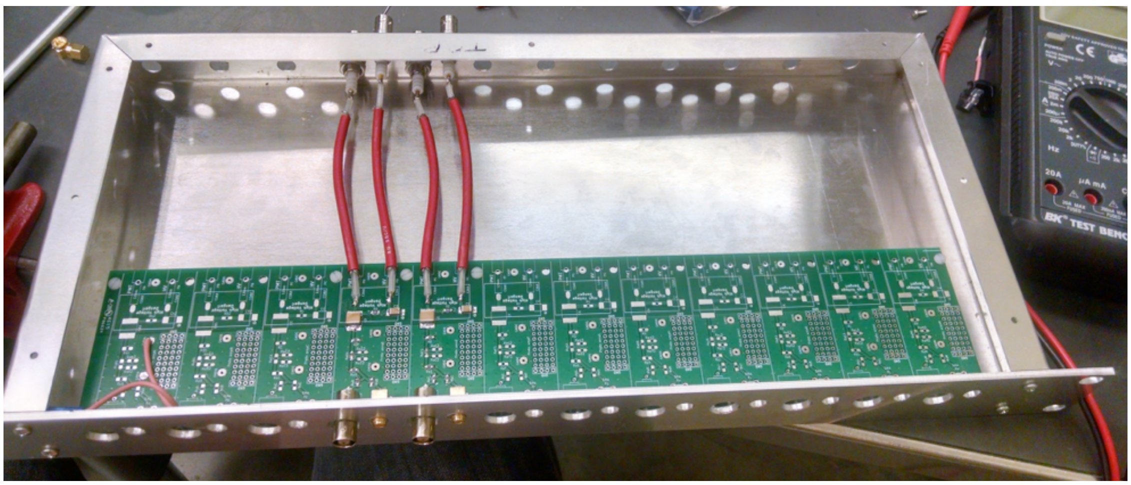

Figure 20: A picture of the splitter board sitting in the enclosure.

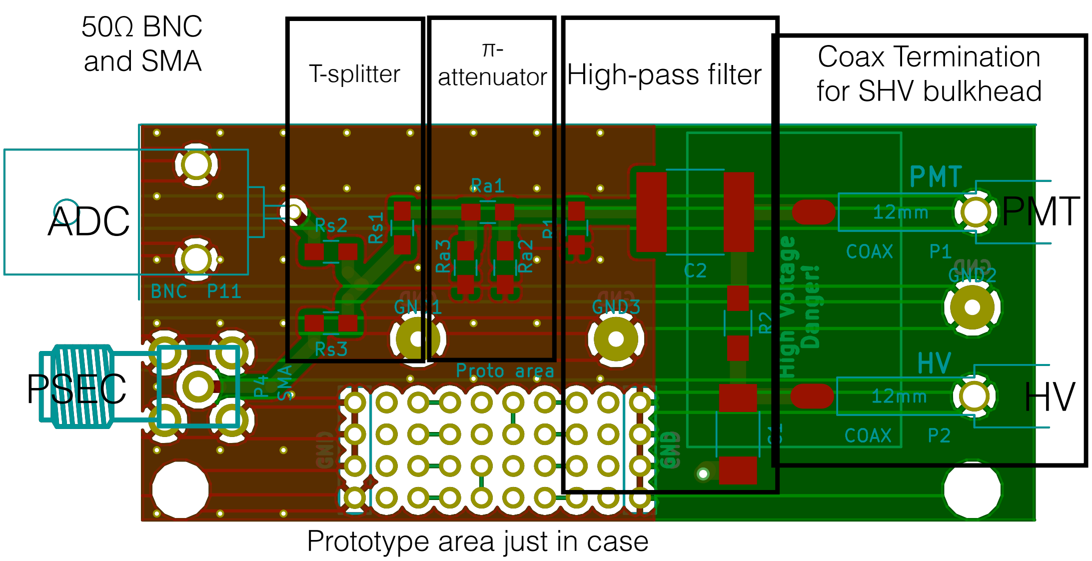


Figure 21: The layout of a single splitter channel.

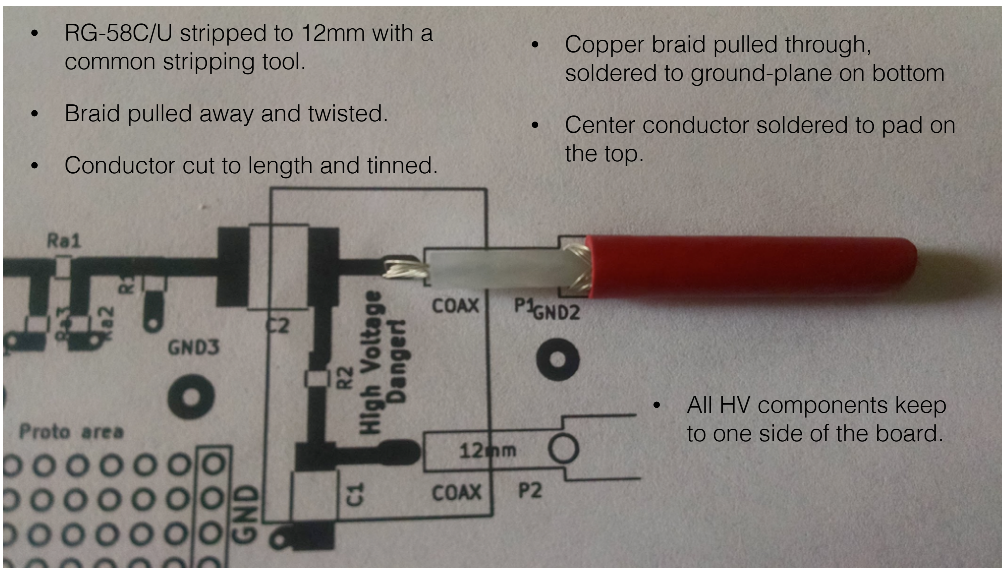

Figure 22: A picture illustrating how the HV connections are made inside the enclosure.

# Appendix V: LVDS Converter Module

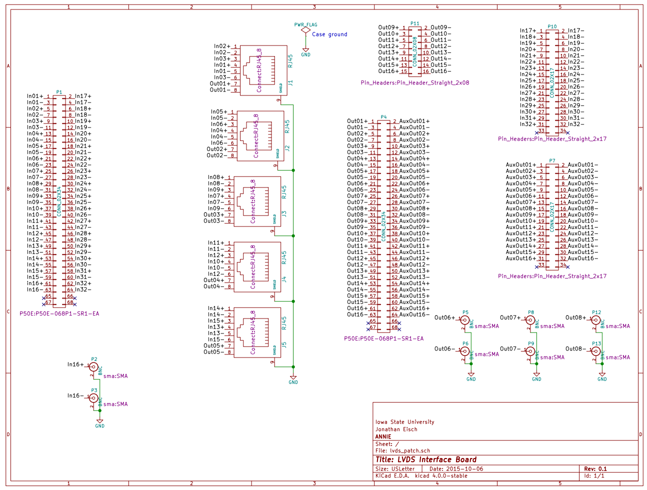

Figure 23: The schematic of the LVDS patch board used to interface between the external timing signals and the VME cards.

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