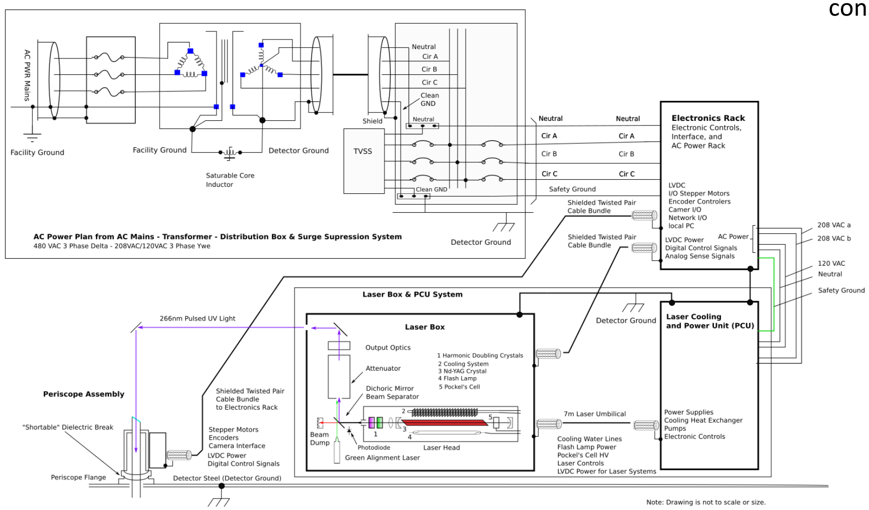
Review of the DUNE-SP Ionization Laser System initial design

2020 September 16

# Title: ioLaser System Electrical Grounding

Presenter: Vern Sandberg

consulting physicist to Los Alamos National Laboratory



Note: Drawing is not to scale or size.

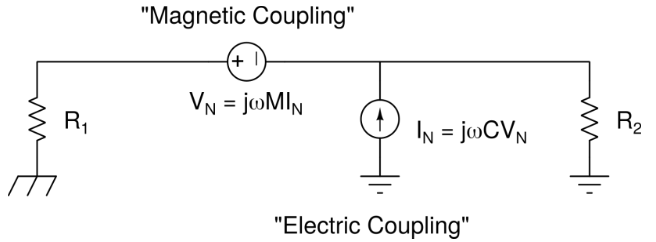
ioLaser Grounding and Shielding Plan
v 0.1 Initial draft 2020 Sep 10
v 0.2 Added FNAL EE Comments 2020 Sep 11
v 0.3 Added SC's gnd clarifications 2020 Sep 15

# Electrical Systems and Grounding

This is what we are going to cover

(*It's good to get it all on one slide.*)

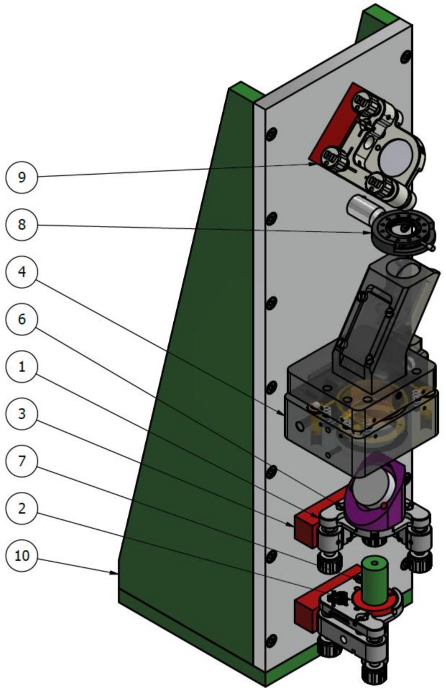
$$\int_{\partial a} E \cdot dl = -\iint_{a} \dot{B} \cdot da$$

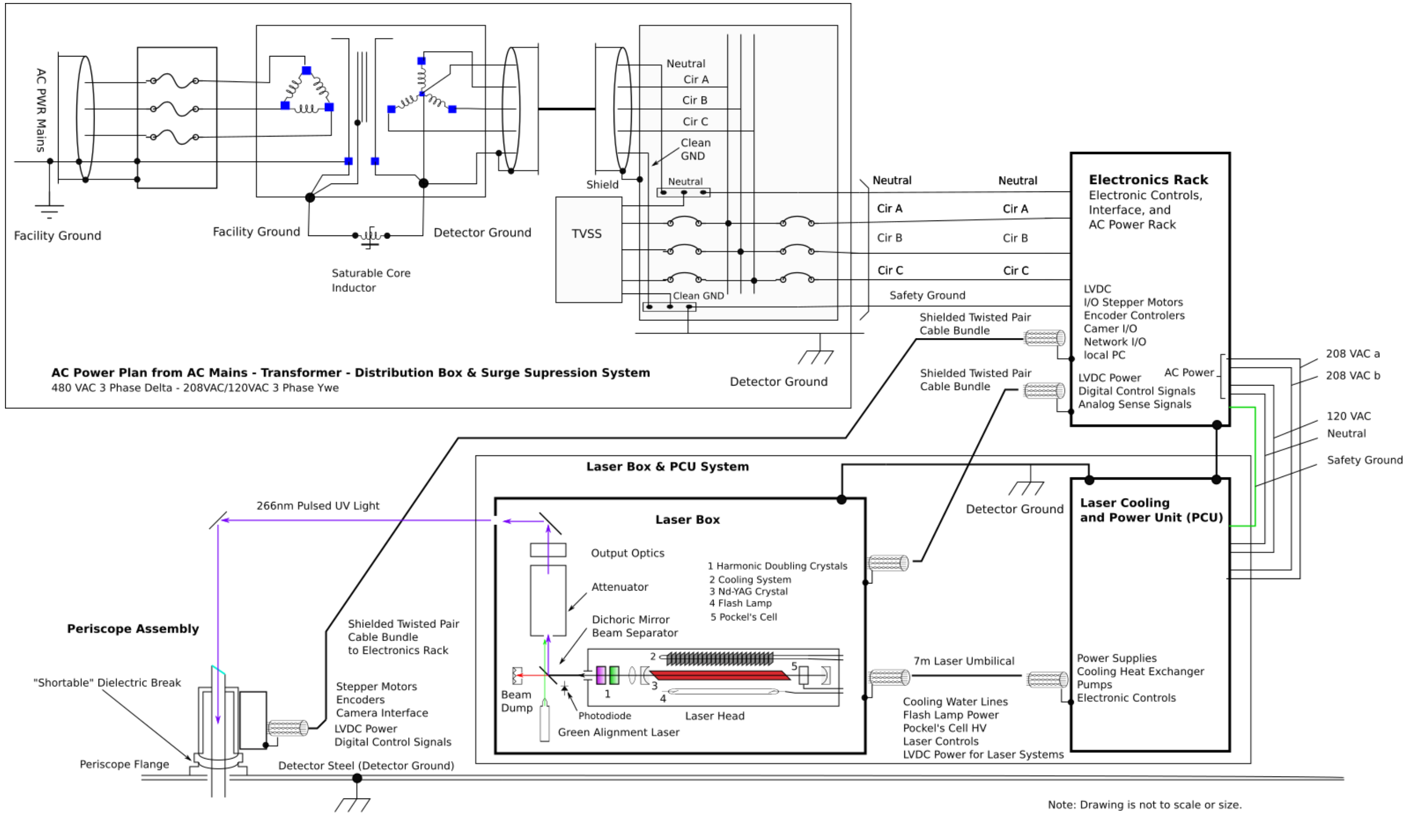


A special acknowledgement to Teresa Shaw, Linda Bagby, Steve Chappa, and Arnab Ghosh of FNAL for their help and advice.

**Cable Group A**

| **Periscope – ioLaser Rack** | **On Periscope** | **ioLaser Rack** |
|---|---|---|
| Motion Control: | | |
| Motor 1 power/control cable | Motor 1 in periscope rotary stage | Motor driver box (MDB |
| Motor 2 power/control cable | Motor 2 in periscope linear actuator | Motor driver box (MDB) |
| Motor 3 power/control cable | Motor 3 in periscope bellows retraction system | Motor driver box (MDB |
| Encoder 1 supply/readout cable | Encoder 1 in periscope rotary stage | Encoder interface box (EIB) |
| Encoder 2 supply/readout cable | Encoder 2 in periscope linear actuator | Encoder interface box (EIB) |
| Encoder 3 supply/readout cable | Encoder 3 in periscope bellows retraction system | Encoder interface box (EIB) |
| Camera: | | |
| Illuminator – LVDC voltage controller | Periscope illuminator | LVDC supply |
| USB 3.0 active extension cable | Periscope camera | server in laser rack |
| Power cable for camera, 2 conductor | Periscope camera | 12V 3A power supply |
| Photodiode/photomultiplier: | | |
| DC high voltage | PMT base | HVDC supply |
| Anode signal | PMT anode | pulse processing module |
| Inclinometer RS-485 readout cable: | | |
| (assuming 1 interface per 4 periscopes) | Inclinometer | USB-to-RS485 interface |





Note: Drawing is not to scale or size.

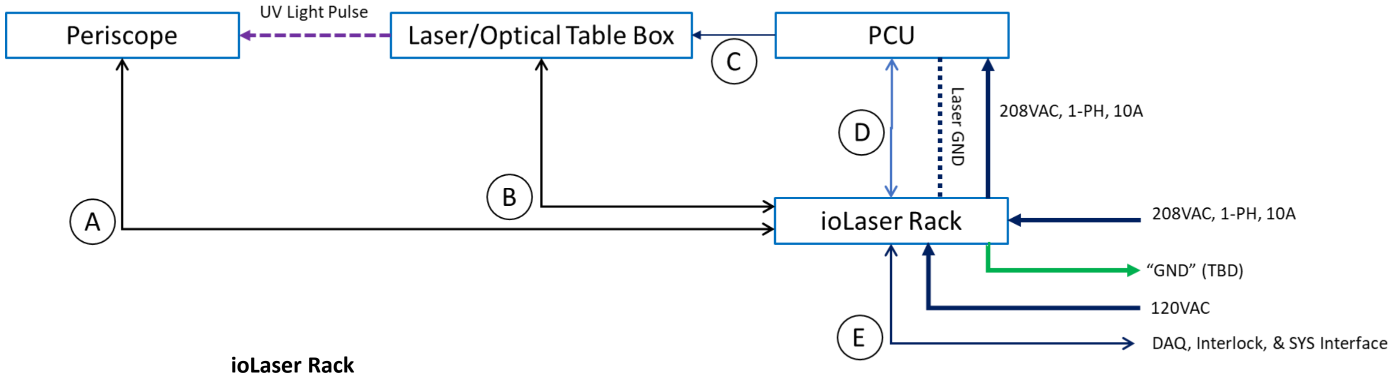
Cables running through time-changing magnetic fields (with the consequent induced emfs) present many problems that require creative solutions.

ioLaser Grounding and Shielding Plan

| | | |
|---|---|---|
| v 0.1 | Initial draft | 2020 Sep 10 |
| v 0.2 | Added FNAL EE Comments | 2020 Sep 11 |
| v 0.3 | Added SC's gnd clarifications | 2020 Sep 15 |

# Electrical Interconnection Summary for Ionization Laser system (top-of-the-TPC)

**Abbreviations used**
**PCU** = Power/Cooling Unit
**MDB** = Motor Drive Box
**EIB** = Encoder Interface Box
**LIC** = Laser Instrumentation Control box
**LILV** = Laser Instrumentation Low Voltage chassis



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| Anode signal | PMT anode | pulse processing module |
| Inclinometer RS-485 readout cable:<br>(assuming 1 interface per 4 periscopes) | Inclinometer | USB-to-RS485 interface |

**Cable Group B**

| **Laser Optical Table Box – ioLaser Rack** | **Laser Box** | **ioLaser Rack** |
|---|---|---|
| Altechna Attenuator Watt-Pilot: | | |
| Attenuator power cable | Attenuator | LV chassis |
| Attenuator control/readout cable | Attenuator | LIC box |
| Motorized iris: | | |
| Iris control/readout cable | Iris | LIC box |
| Monitor photodiode | | |
| Photodiode power cable | Photodiode | LV chassis in laser rack |
| Photodiode control/readout cable | Photodiode | LIC box |
| Alignment laser: | | |
| Green-laser power cable | Alignment laser | LV chassis |
| Motorized mounts: | | |
| Power/control cable | Motorized mounts | LIC box |

**Cable Group C**

| **Laser Optical Table Box – PCU** | **Laser Box** | **Power/Cooling Unit** |
|---|---|---|
| Laser Head: | | |
| HV head plug cable | Laser head | PCU, hardwired, vendor supplied cable |
| Cooling/control umbilical | Laser head | Cooling lines & control cables |

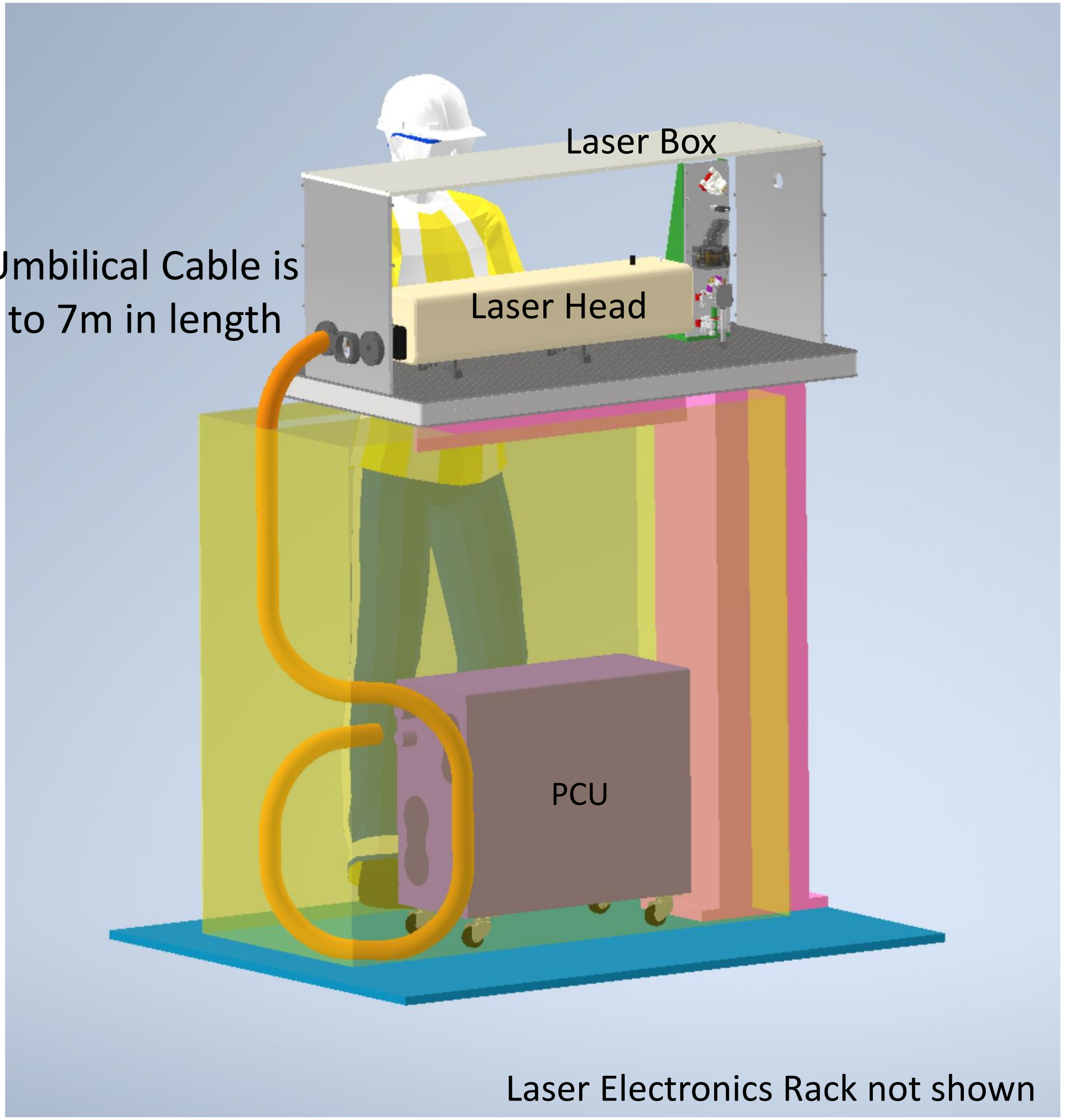
**Cable Group D**

| **PCU - ioLaser Electronics Rack** | **Power/Cooling Unit** | **ioLaser Rack** |
|---|---|---|
| AC Pwr 208VAC 1-Phase, 10A | 3-wire 12AWG or equivalent | approved 208VAC 1-phase receptacle |
| Laser Ground connection | Under discussion, TBD | Under discussion, TBD |
| Interface control signals | multiwire control cable (TBD) | LIC |

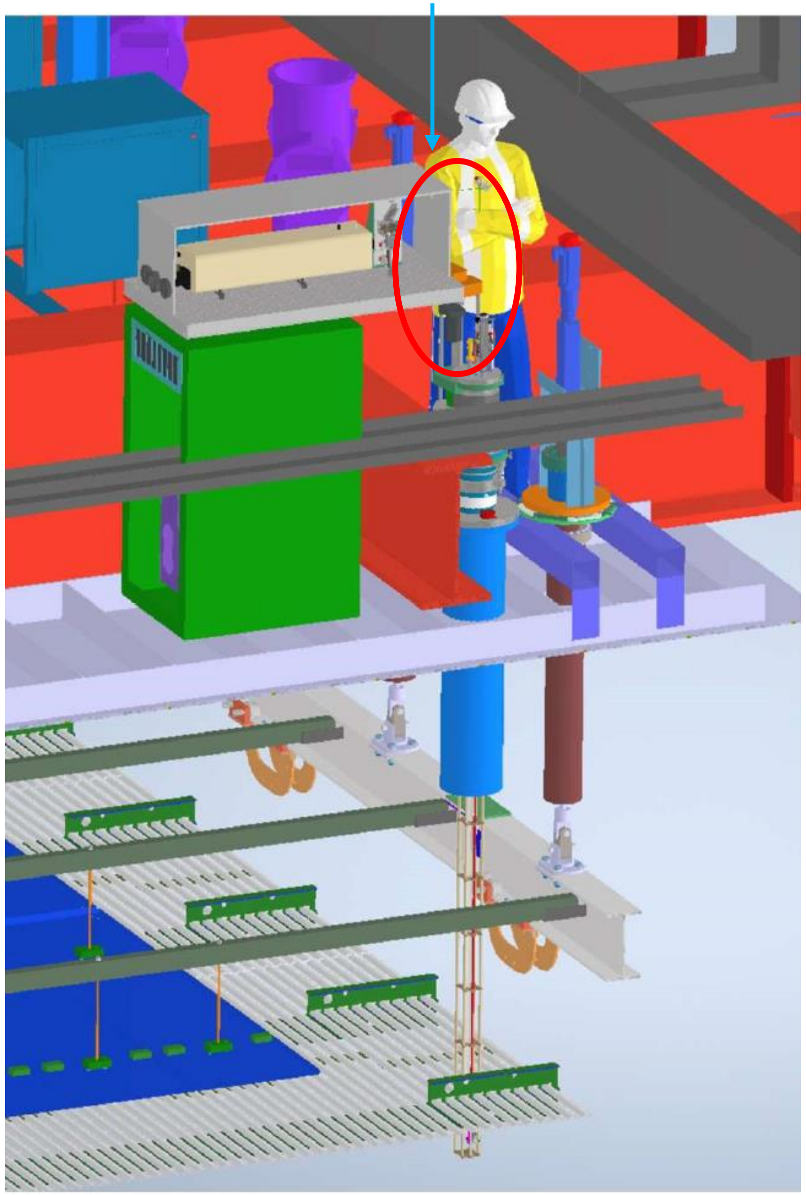
VS 2020 07 24, v0.3

Note: Distance from Laser Box to Periscope can be from 1m to 10m-20m.

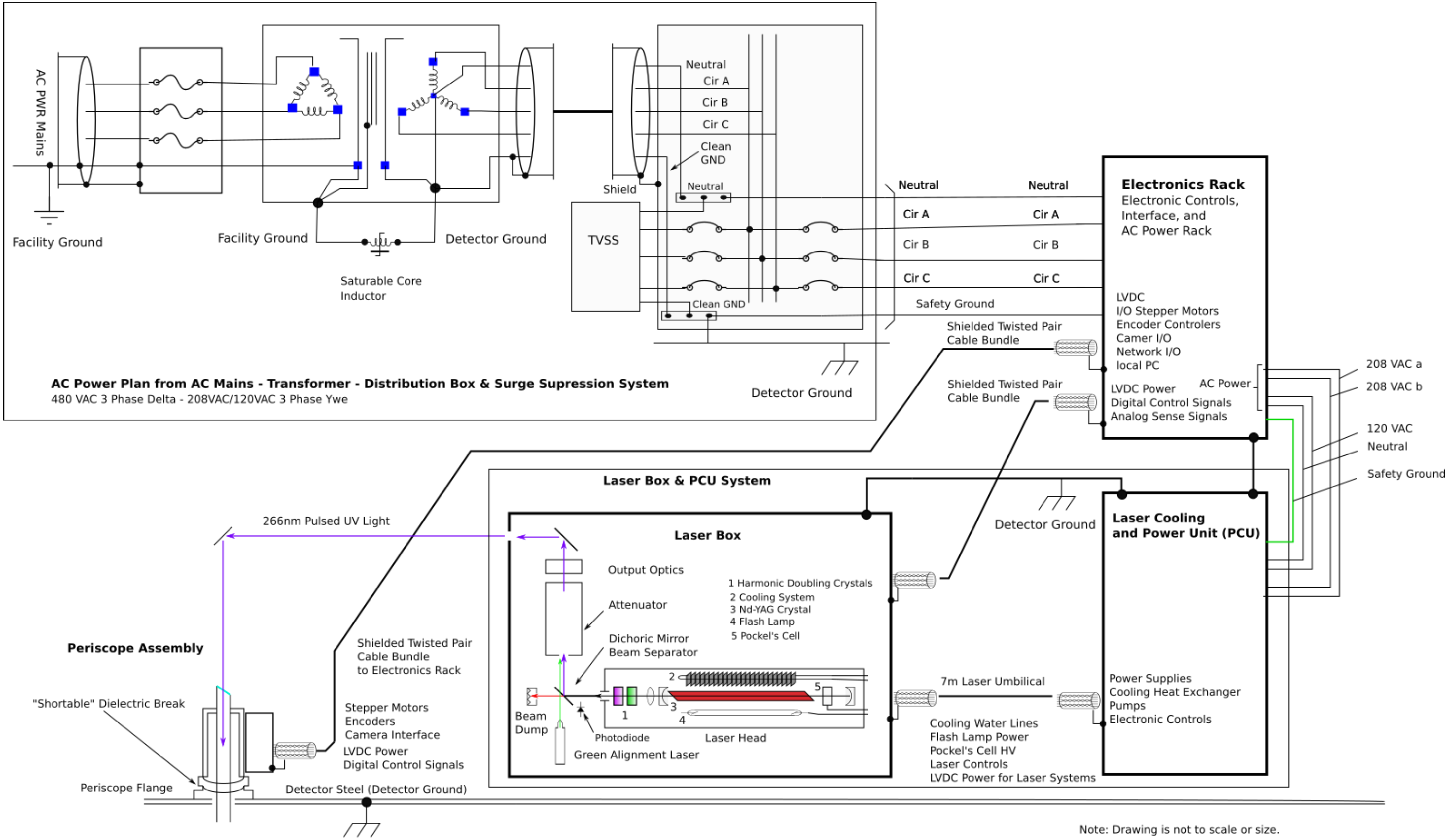
Note: Umbilical Cable is limited to 7m in length



ioLaser Station, PCU on bottom, Laser Box on top



ioLaser Station connecting (optically) to a periscope
(Illustration is shown on the ProtoDUNE-II Cryostat)



Note: Drawing is not to scale or size.

## ioLaser System AC Power and Grounding and Shielding Plan

ioLaser Grounding and Shielding Plan

| | | |
|---|---|---|
| v 0.1 | Initial draft | 2020 Sep 10 |
| v 0.2 | Added FNAL EE Comments | 2020 Sep 11 |
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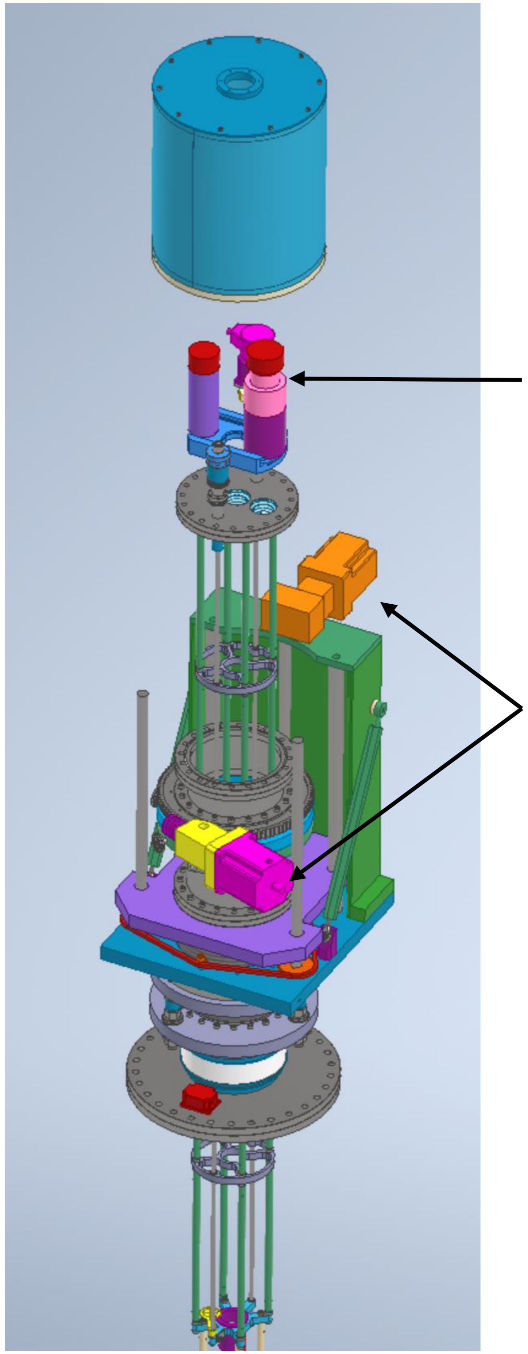
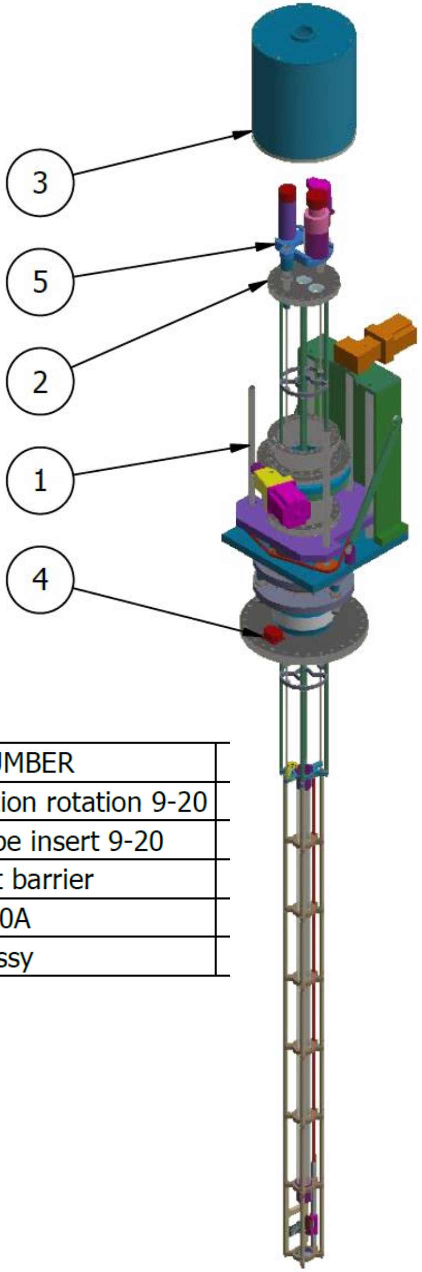
# ioLaser Periscope



Connections to
Camera and Photodiode:
USB & Coaxial Cable

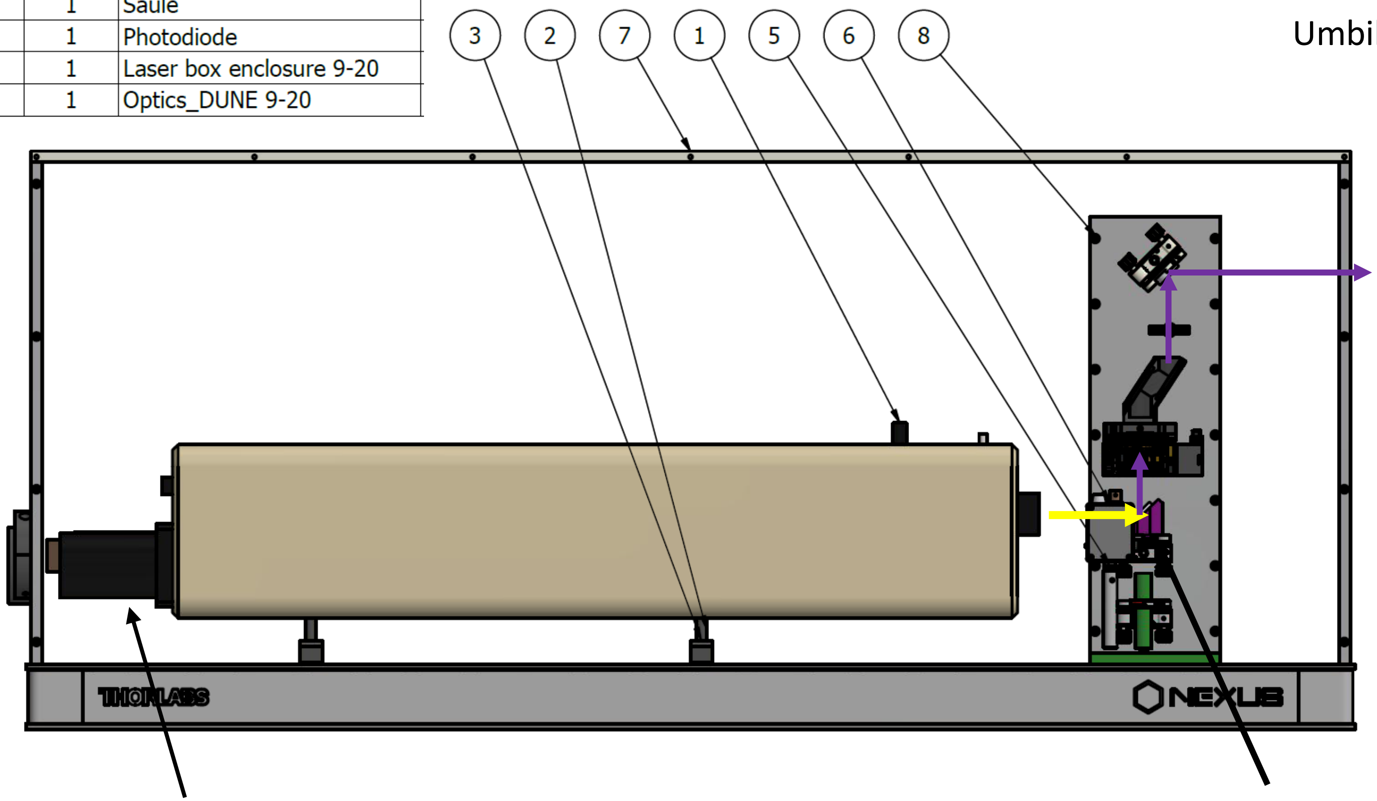
Connections to
Stepper Motors & Encoders:
Shielded Twisted Pair

| ITEM | QTY | PART NUMBER |
|---|---|---|
| 1 | 1 | thermionics translation rotation 9-20 |
| 2 | 1 | DUNE laser periscope insert 9-20 |
| 3 | 1 | laser periscope light barrier |
| 4 | 1 | inclinometer TILT-30A |
| 5 | 1 | camera - PMT subassy |



# ioLaser “Laser Box”

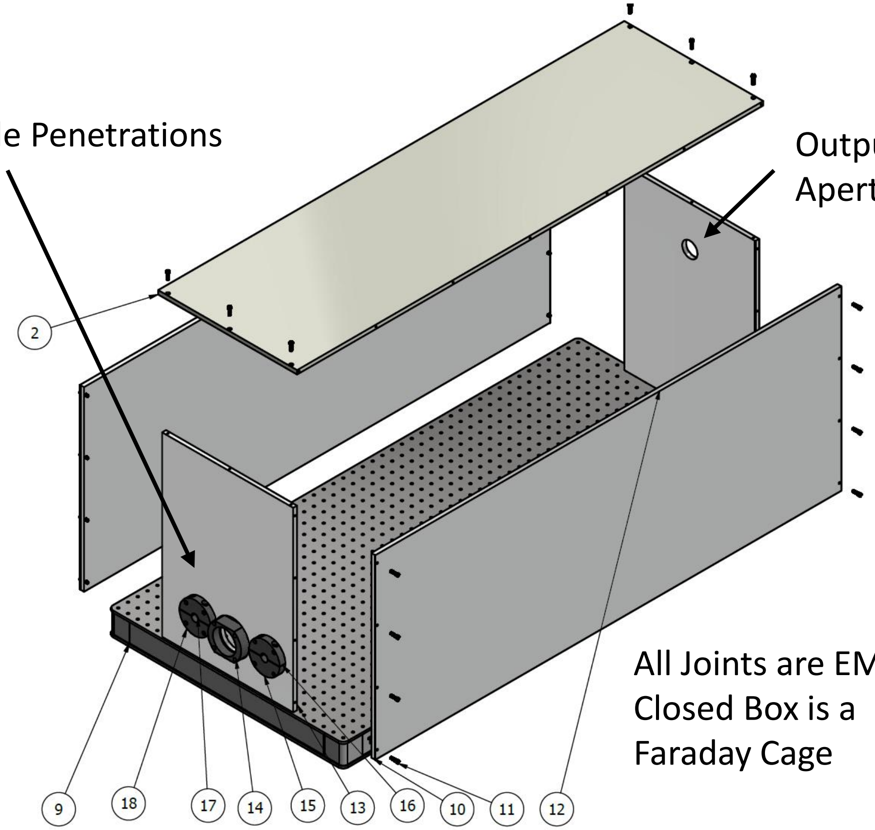
| ITEM | QTY | PART NUMBER |
|---|---|---|
| 1 | 1 | Laser |
| 2 | 4 | Laserfuss |
| 3 | 4 | Laserfixwinkel |
| 4 | 1 | Distanzbock |
| 5 | 1 | Säule |
| 6 | 1 | Photodiode |
| 7 | 1 | Laser box enclosure 9-20 |
| 8 | 1 | Optics_DUNE 9-20 |



Umbilical Cable Connectors

Dichroic Mirror
Separates beams by wavelength

Umbilical Cable Penetrations

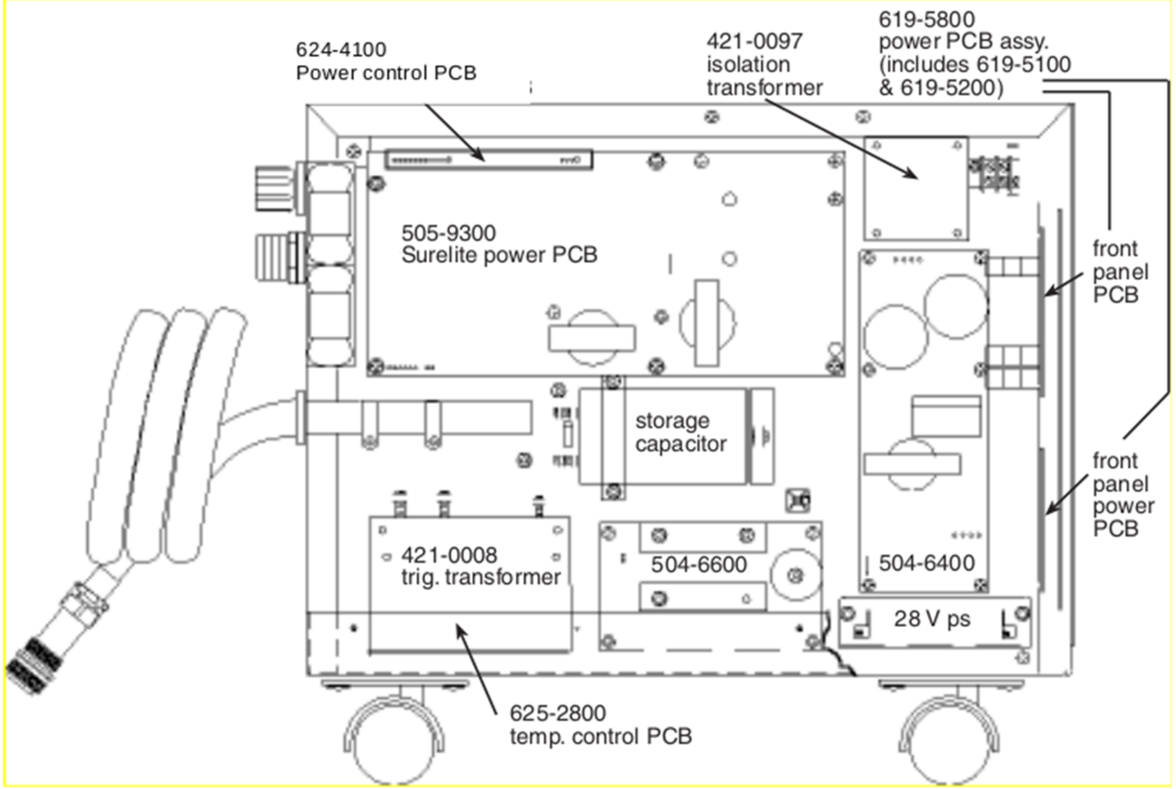


Output Aperture

All Joints are EMI tight
Closed Box is a
Faraday Cage

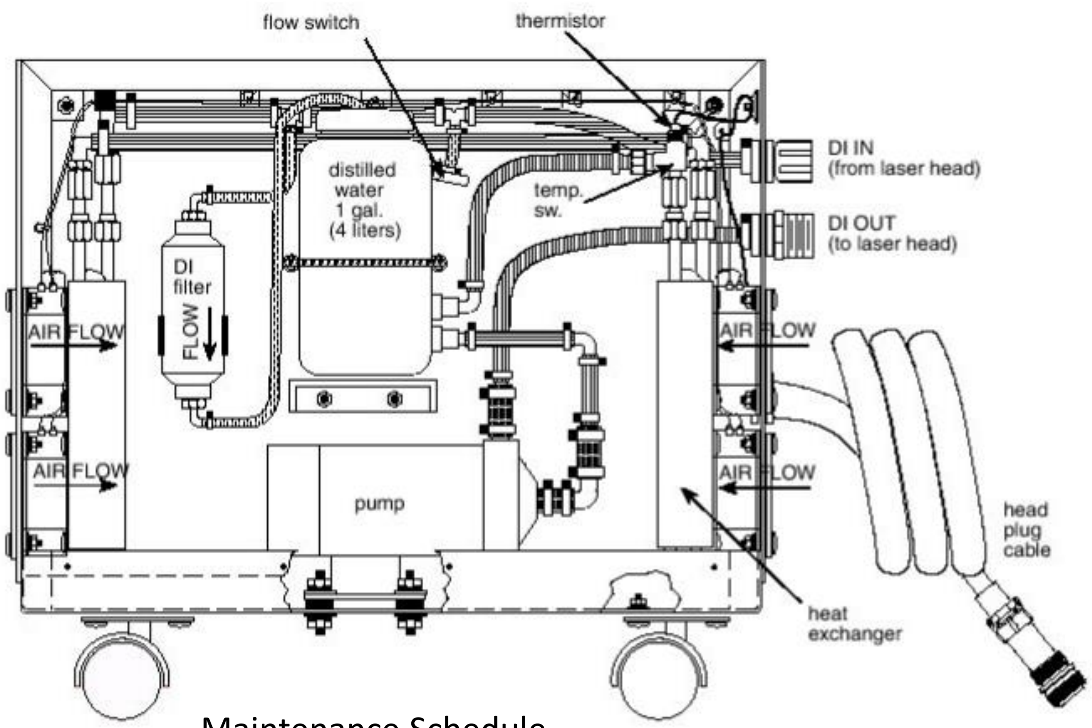
| ITEM | QTY | PART NUMBER |
|---|---|---|
| 2 | 1 | laser box top |
| 9 | 1 | B2448F-Step |
| 10 | 2 | laser box side plate |
| 11 | 22 | 91292A118_TYPE 18-8 SS SOCKET HEAD CAP SCREW |
| 12 | 1 | laser box front plate |
| 13 | 1 | laser box rear plate |
| 14 | 1 | laser box cable strain relief C |
| 15 | 1 | laser box cable strain relief B |
| 16 | 1 | laser box cable strain relief A |
| 17 | 1 | laser box cable strain relief D |
| 18 | 1 | laser box cable strain relief E |

Figure 43  Power supply chassis assembly

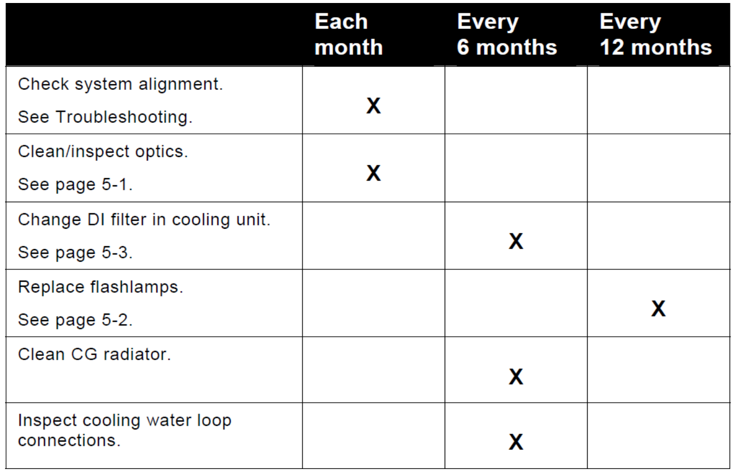


## Continuum Surelite Laser

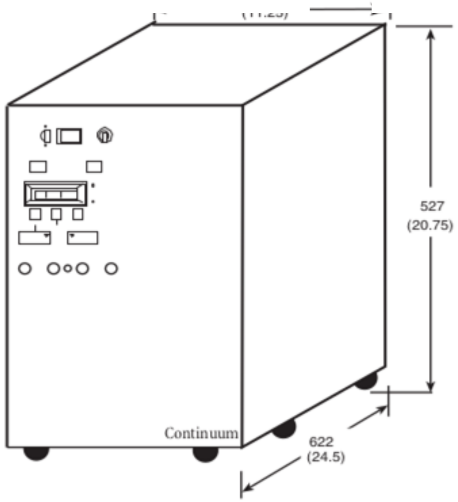
Figure 5  Cooling group chassis assembly for SL I-20 Hz.



Maintenance Schedule



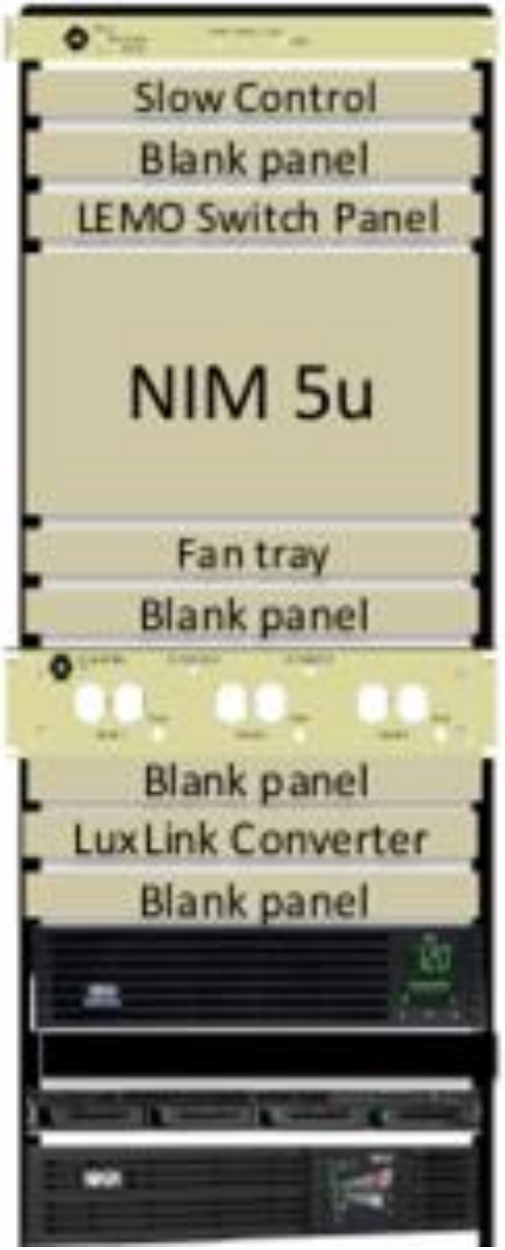
| | Each month | Every 6 months | Every 12 months |
|---|---|---|---|
| Check system alignment.<br>See Troubleshooting. | X | | |
| Clean/inspect optics.<br>See page 5-1. | X | | |
| Change DI filter in cooling unit.<br>See page 5-3. | | X | |
| Replace flashlamps.<br>See page 5-2. | | | X |
| Clean CG radiator. | | X | |
| Inspect cooling water loop connections. | | X | |

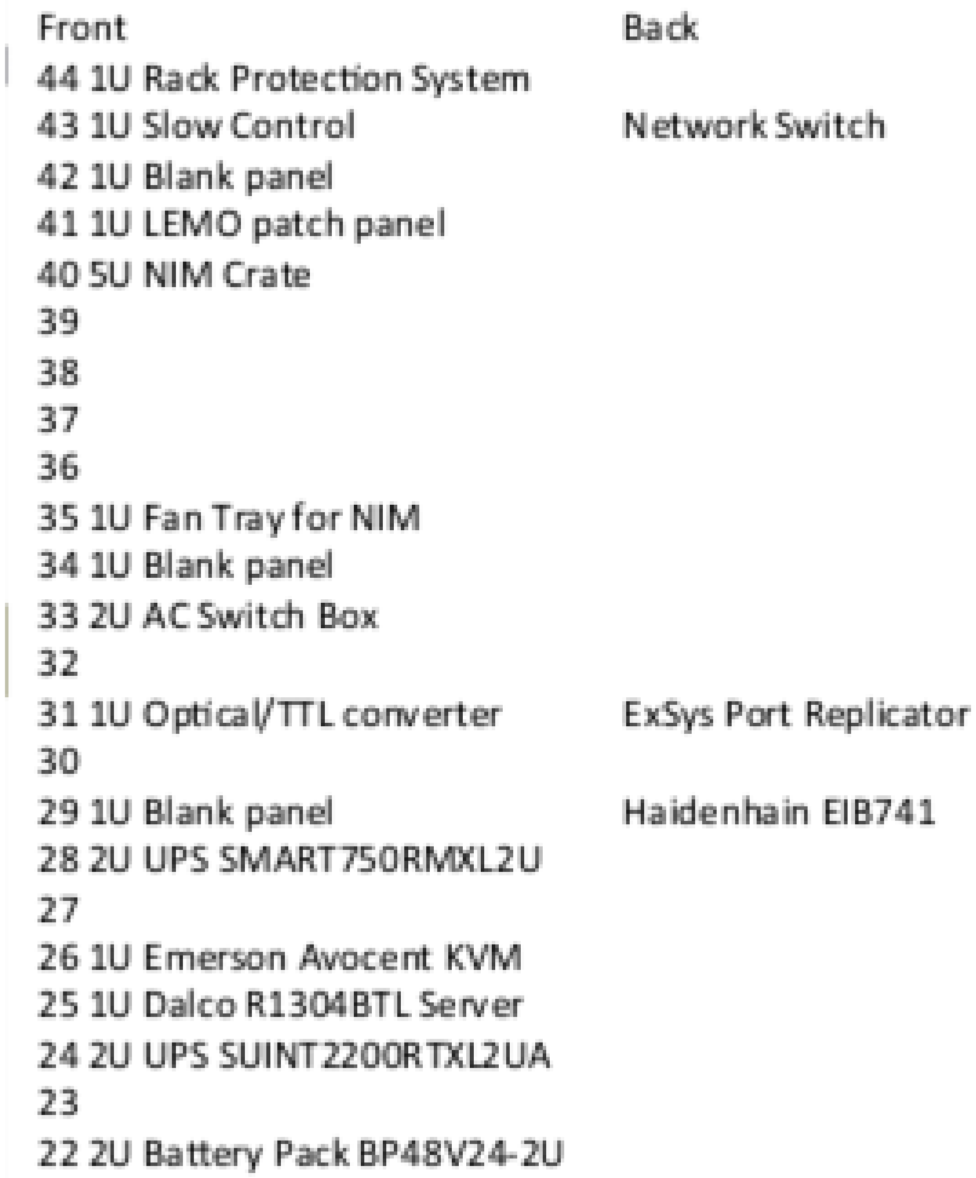


## Surelite Laser “PCU”
## Power and Cooling Unit

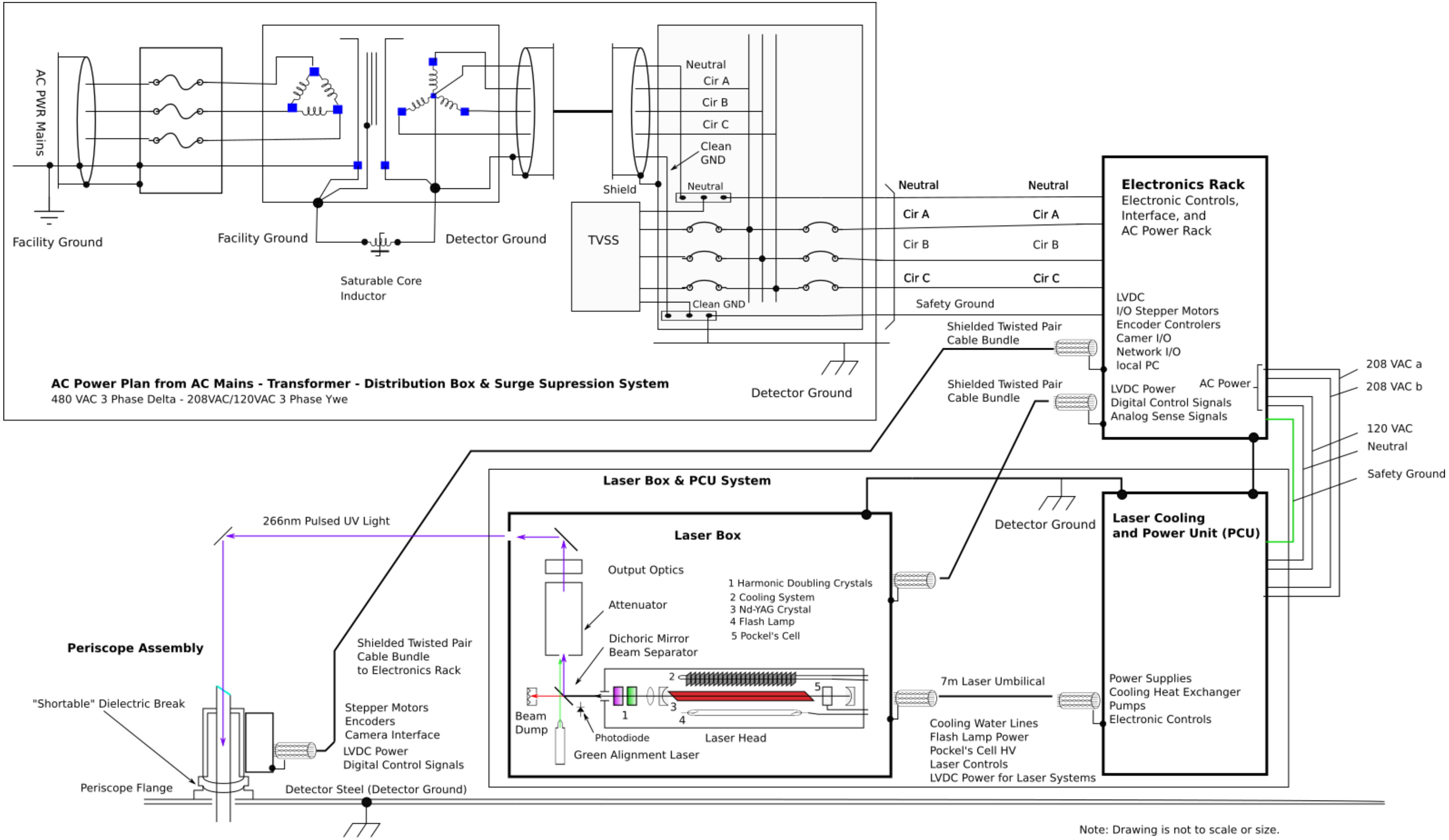
AC Power: 208 VAC 1-ϕ 10A

# ioLaser Electronics Rack
(modeled on MicroBooNE’s design)





| Front | Back |
|---|---|
| 44 1U Rack Protection System | |
| 43 1U Slow Control | Network Switch |
| 42 1U Blank panel | |
| 41 1U LEMO patch panel | |
| 40 5U NIM Crate | |
| 39 | |
| 38 | |
| 37 | |
| 36 | |
| 35 1U Fan Tray for NIM | |
| 34 1U Blank panel | |
| 33 2U AC Switch Box | |
| 32 | |
| 31 1U Optical/TTL converter | ExSys Port Replicator |
| 30 | |
| 29 1U Blank panel | Haidenhain EIB741 |
| 28 2U UPS SMART750RMXL2U | |
| 27 | |
| 26 1U Emerson Avocent KVM | |
| 25 1U Dalco R1304BTL Server | |
| 24 2U UPS SUINT2200RTXL2UA | |
| 23 | |
| 22 2U Battery Pack BP48V24-2U | |



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# ioLaser System AC Power and Grounding and Shielding Plan

ioLaser Grounding and Shielding Plan

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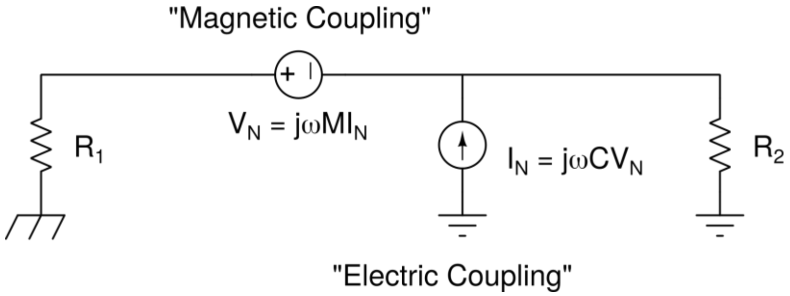


**Discussion points for grounding and shielding for the ioLasers and periscopes in the DUNE calibration system**

- Review noise sources, inductive fields, penetration, etc. Review ground and power systems used in uBooNE: 2 grounds (system and detector) bounded together at a single point and monitored across an inductor.
- Surelite laser's flashlamp pulse power: Note Continum Laser report on EMC testing gives confidence that the laser power supply box, laser head enclosure, and connecting cable can be configured to control EMI (e.g., a CM choke to reduce radiating currents, cable shielding if necessary).
- Rack layout and filtering of power. Power distribution, noise sources.
- Laser platform in DUNE: locations on cryostat, electrical & communication cabling, optical isolation. Identify alternative locations and use optical transfer lines.
- RFI emissions, noise induction (capacitive and inductive), cable noise (source and pickup), RF excitations inside the cryostat.
- Mitigation: Isolation flange, RFI absorbing material, light blocking material, screens, access ground loops in terms of the source of noise: "magnetic" or "electric" coupling.

**Discussion points for grounding and shielding for the ioLasers and periscopes in the DUNE calibration system, continued**

- the problem of determining how to best "ground" something depends upon the environment, the frequency of the noise producing signal, and the nature of the signal (i.e., electrical or magnetically inductive).
- We are currently pursuing a proposal to the MicroBooNE experiment to evaluate the effects of facility ground and detector ground. The plan is to switch the MicroBooNE ioLaser system grounding from building to detector this year and then record cosmic ray and laser data to understand noise effects. We expect to perform similar tests in protoDUNE-II next year.
- Ideally, all laser system components, located on the detector, should be connected to the detector ground through a single "star point" grounding connection.
  - The components of the ioLaser system will be isolated electrically from the detector envelop and connected to the detector ground through a single, controlled cable or bonding path.
  - The periscope has an insulating isolation ring located at the detector mounting flange. Arrangements will be made to allow this ring-flange assembly to be "shorted" or "opened", as determined by operating conditions.
- Test of the electrical noise environment will be made on the protoDUNE-II detector.
- The grounding configuration for the ioLaser for the DUNE far detector will be determined from information gained in the protoDUNE-II tests. Similar tests will be made to determine how to best connect to data processing equipment and related instruments to mitigate noise.
- Careful attention will be paid to the grounding and shielding guidelines and requirements described in https://edms.cern.ch/document/2095958 and https://edms.cern.ch/document/2095975.

In the DUNE far-site cavern and in the protoDUNE-II detector laser system, all ground connections to the periscope head, the laser box, the laser power supply, and the electronics rack are connected to the detector ground. There are no direct ground connections to the facility ground structure within this laser system. The *detector ground is connected through a saturable inductor to the facility ground at a single point*.

# Supplemental Material

# Amplitude/Continum Laser “Surelite I-10”

## SURELITE™ FEATURES & BENEFITS

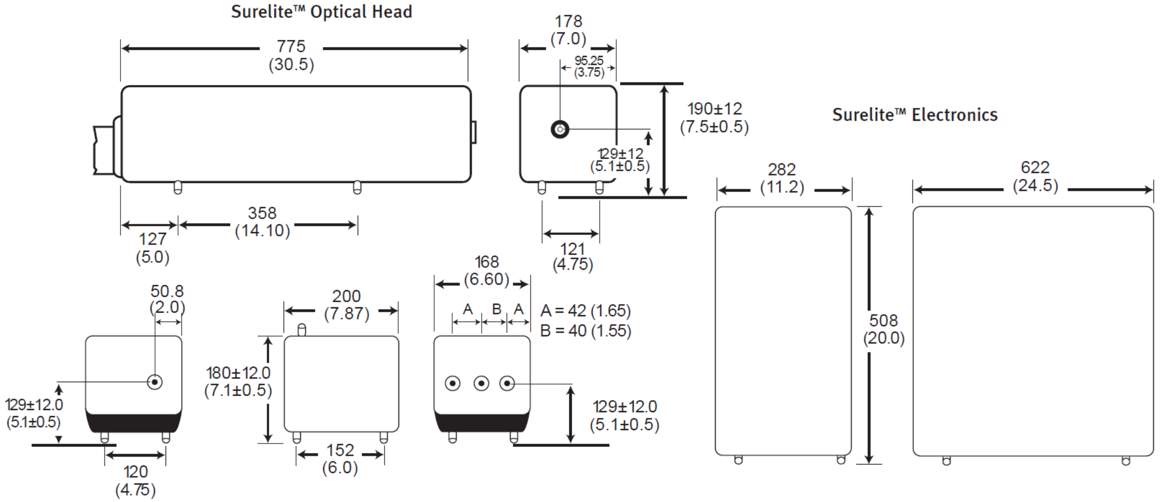
*RS-232 or TTL interface for remote or local operation*

*Water to air heat exchanger eliminates the need for external water cooling*

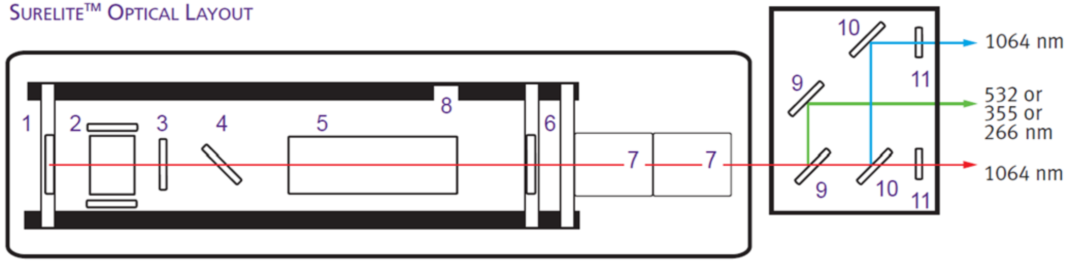
*Gaussian optics incorporated to provide low divergence and high spatial uniformity in beam*

*Graphite resonator structure ensures long-term therma and mechanical stabilit*

| | | |
|---|---|---|
| **Size** | Optical Head ( L x W x H ) | 775 x 178 x 190 mm ( 30.5 x 7.0 x 7.50 in. ) |
| | Power Supply ( L x W x H ) | 622 x 282 x 508 mm ( 24.5 x 11.20 x 20.0 in. ) |
| **Weight** | Optical Head | 24 kg ( 52 lbs ) |
| | Power Supply | 44 kg ( 96 lbs ) |
| **Water Service** | | Closed loop water to air heat exchanger: external cooling water not required (1 gal deionized water) |
| **Electrical Service** | | 220/240 V, single Φ, 10 A |
| | | 208 V, single Φ, 10 A |
| **Room Temperature** | | 18.3 to 29.4°C ( 60 to 85°F ) |



## SURELITE™ OPTICAL LAYOUT



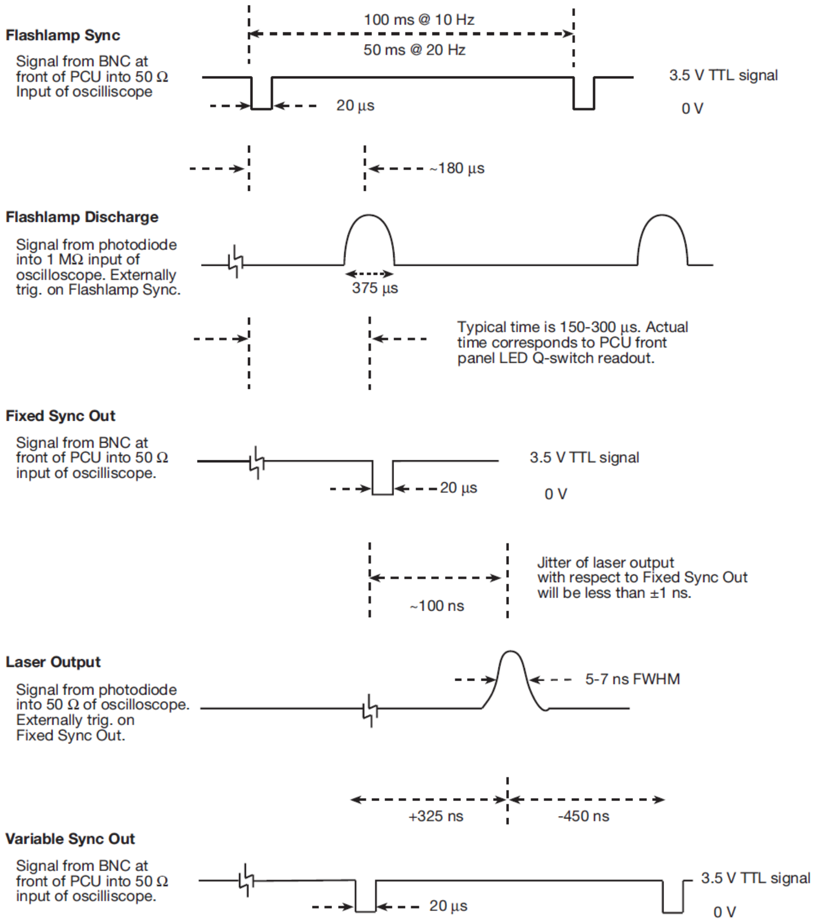
1. Rear Mirror
2. Pockels Cell
3. λ/4 Plate
4. Dielectric Polarizer
5. Oscillator Rod
6. Gaussian Output Coupler
7. Optional Harmonic Generators
8. Graphite Resonator Structure
9. Dichroic Separation
10. 1064 nm Mirrors
11. Beam Block

| **DESCRIPTION** | **I-10** |
|---|---|
| **Repetition Rate (Hz)** | 10 |
| **Energy (mJ)** | |
| **1064 nm** | 450 |
| **532[1] nm** | 200 |
| **355 nm** | 65/100[2] |
| **266 nm** | 60 |
| **Pulsewidth[3] (nsec)** | |
| **1064 nm** | 5-7 |
| **532 nm** | 4-6 |
| **355 nm** | 4-6 |
| **266 nm** | 4-6 |
| **Linewidth (cm$^{-1}$)** | |
| **Standard** | 1 |
| **Injection Seeded [4]** | 0.005 |
| **Divergence [5] (mrads)** | 0.6 |
| **Rod Diameter (mm)** | 6 |
| **Pointing Stability (±µrads)** | 30 |
| **Jitter [6] (±ns)** | 0.5 |
| **Energy Stability [7] (±%)** | |
| **1064 nm** | 2.0; 0.7 |
| **532 nm** | 3.5; 1.2 |
| **355 nm** | 4.0; 1.3 |
| **266 nm** | 7.0; 2.3 |
| **Power Drift [8] (±%)** | |
| **1064 nm** | 3.0 |
| **532 nm** | 3.0 |
| **355 nm** | 3.0 |
| **266 nm** | 6.0 |
| **Beam Spatial Profile [9]** | |
| **Near Field (<1 m)** | 0.70 |
| **Far Field (∞)** | 0.95 |
| **Deviation from Gaussian [10]** | |
| **Near Field (<1 m)** | 30 |

## NOTES

1. With Type II doubler
2. High Energy UV option with Type I doubler
3. Full width, half maximum
4. Injection seeding reduces energy by 20 %
5. Full angle for 86% of energy
6. With respect to external trigger
7. The first value represents shot-to-shot for 99.9% of pulses, the second value represents RMS.
8. Average for 8 hours with $\Delta T_{room} < \pm 3$ °C
9. A least squares fit to a Gaussian profile. A perfect fit would have a coefficient of 1
10. Maximum deviation at beam center (±%)

All specifications at 1064 nm unless otherwise noted.
As a part of our continuous improvement program, all specifications are subject to change without notice.



**Flashlamp Sync**

Signal from BNC at front of PCU into 50 Ω Input of oscilliscope

**Flashlamp Discharge**

Signal from photodiode into 1 MΩ input of oscilloscope. Externally trig. on Flashlamp Sync.

Typical time is 150-300 µs. Actual time corresponds to PCU front panel LED Q-switch readout.

**Fixed Sync Out**

Signal from BNC at front of PCU into 50 Ω input of oscilliscope.

Jitter of laser output with respect to Fixed Sync Out will be less than ±1 ns.

**Laser Output**

Signal from photodiode into 50 Ω of oscilloscope. Externally trig. on Fixed Sync Out.

**Variable Sync Out**

Signal from BNC at front of PCU into 50 Ω input of oscilliscope.

Figure 1 Location of labels on front and rear panels of Surelite oscillator

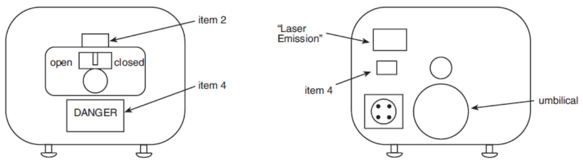
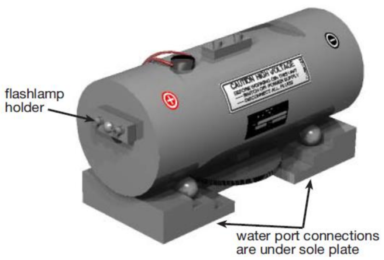


Figure 3 Labels on the 811 Laser Head

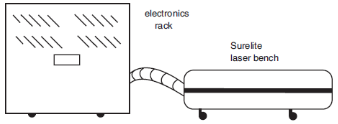


| | Each month | Every 6 months | Every 12 months |
|---|---|---|---|
| Check system alignment.<br>See Troubleshooting. | X | | |
| Clean/inspect optics.<br>See page 5-1. | X | | |
| Change DI filter in cooling unit.<br>See page 5-3. | | X | |
| Replace flashlamps.<br>See page 5-2. | | | X |
| Clean CG radiator. | | X | |
| Inspect cooling water loop connections. | | X | |

## Power/Cooling Unit (PCU)

The PCU unit generates the following:

- control of the system with the necessary power-up time delays, clock rep rate signals, charge/fire commands and Q-switch delays.
- monitoring of the 9 security loops on the front panel.
- power for state-of-the-art MOSFET switching power boards that run at a drive frequency of 40 kHz. Current from the board charges up the storage capacitor.
- capacitance of 30 µF at 2.0 kV. In addition to energy storage for the flashlamp, the system also provides an initial trigger pulse to ionize the gas in the flashlamps.



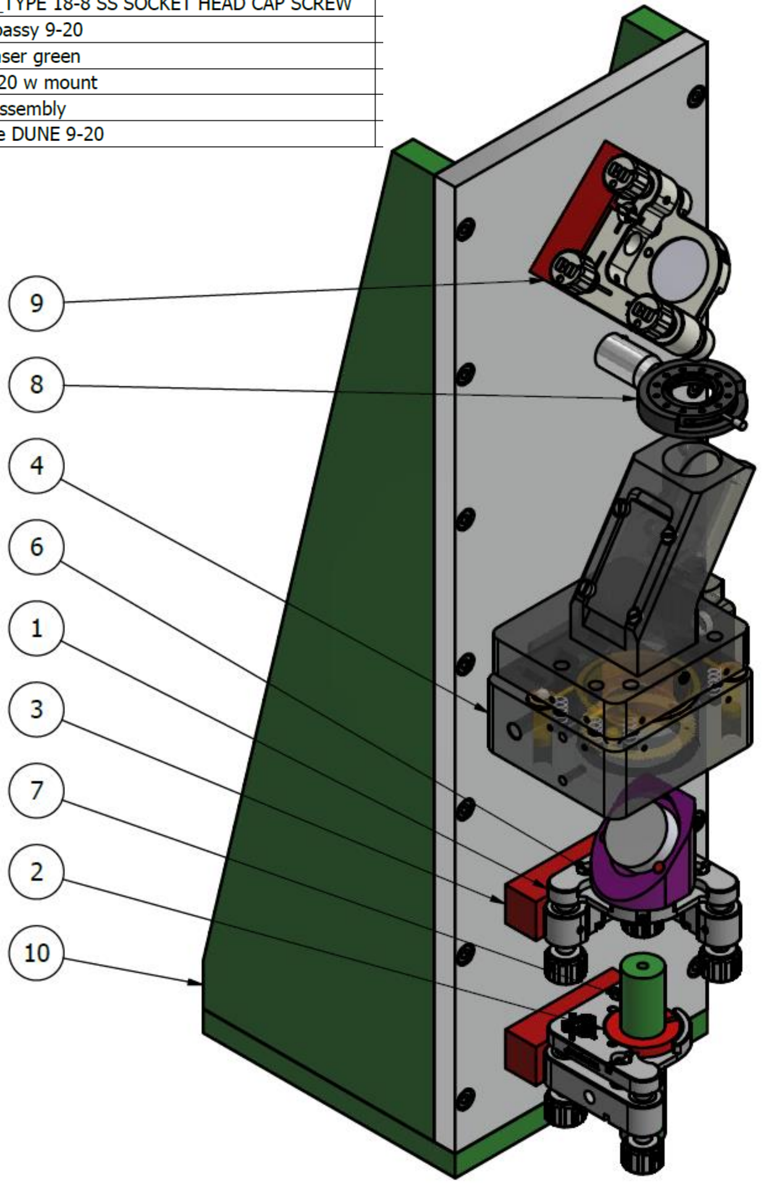
### MARX BANK (750V)

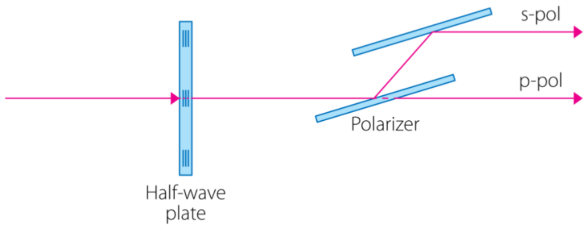
This board charges 7 capacitors in parallel and then discharges them through fast switching transistors in series so that the voltage on each capacitor is summed. This generates an ~-4 kV pulse with a rise time of 20 ns. This board is in a metal box next to the Pockels cell.

### 750 VOLT POWER BOARD

This board, located above the oscillator cavity in a small box with the Marx bank, generates the dc voltage necessary to power the Marx board. The dc voltage is adjustable by a pot accessible through a hole in the top of the laser bench. Turning the pot clockwise raises the voltage.

| ITEM | QTY | PART NUMBER |
|---|---|---|
| 1 | 2 | EO-Verstellung |
| 2 | 1 | Spannring |
| 3 | 2 | optics mount spacer block DUNE |
| 4 | 1 | attenuator |
| 5 | 10 | 91292A118_TYPE 18-8 SS SOCKET HEAD CAP SCREW |
| 6 | 1 | mirror A subassy 9-20 |
| 7 | 1 | alignment laser green |
| 8 | 1 | Thorlabs ID20 w mount |
| 9 | 1 | mirror top assembly |
| 10 | 1 | Optics frame DUNE 9-20 |





Attenuator Operation

**Watt Pilot - Motorized Attenuator Enhanced Version**

Product ID: EWP-R-0266

Clear aperture, mm: Ø18

Recommended maximum input beam diameter at $1/e^2$, mm: Ø12

Wavelength, nm: 266 (±5)

Attenuation range, Tmin - Tmax: 0.3-99%

Configuration: λ/2 Optically bonded waveplate + 2 x TFP

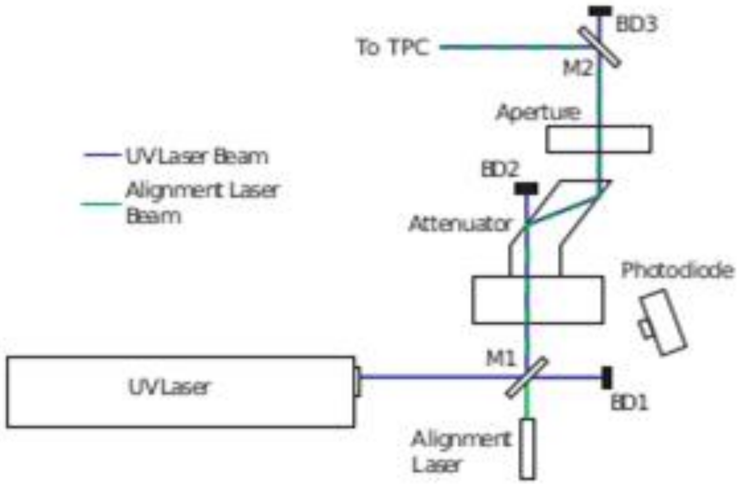
Optimization: Reflection

Open - close time, sec: <3

Resolution, arcsec/step: <42

Laser induced damage threshold: >1 J/cm$^2$ @ 266 nm; 10 ns; 10 Hz

Dimensions H x L x W, mm: 63 x 108 x 91



## ioLaser Optical Bench

**General Shield Guidance (Warm cables outside of the cryostat)**

- All conductive cables should be shielded.
- All cable shields should be connected at both ends of the cable.
- Connectors should be selected to give a full 360 degree connection to the shield when possible.
- Filter elements should be placed on printed circuit boards which are close to or plug into the connectors located on the penetrating flange.
- A shield connection may not directly pass through into the cryostat; this is a violation of the faraday cage and will bring outside environmental noise into the cryostat.

## Grounding Point Summary

At the SURF 4850 Level where the Neutrino Detectors will be located, the electrical conductivity of the various rock masses are unknown but expected to have extremely poor and inconsistent conductive properties. To insure adequate sensitivity of the detectors a special ground systems must be put in place that will isolate the detectors from all other electrical systems and equipment, and minimize the influence of inductive and capacitive coupling and ground loops. The objective of the following grounding system requirements is to reduce or eliminate ground currents through the detector which will affect detector sensitivity, maintain a low impedance current path for equipment short circuit and ground fault currents, and insure personnel safety by limiting equipment/equipment and equipment/ground touch potentials.

## Basic Ground Structures

**Cavern Ground** consists of overlapping welded wire mesh supported by rock bolts and covered with shotcrete. The LBNF/DUNE **Cavern Ground** includes all walls and crown areas above the 4850 sill level in the North and South detector caverns and their associated central access drifts, plus tin plated copper bus bars specified to run the length of the detector vessels on each side along the cavern walls and mounted external to the shotcrete. The **Cavern Ground** structure:

- Spans the full length of the cavern from the West end access drift entrance through the mid-chamber to the East end access drift entrance.
- Spans the full width of the cavern from the 4850 sill (top of the detector vessels and mid-chamber floor) on both sides up and across the crown of the cavern.
- Includes the East and West end walls of the cavern, from the 4850 sill to the crown.

**Detector Ground** consists of the steel containment vessel enclosing the cryostat and all metal structures attached to or supported by the detector vessel.

**UFER Ground** consists of the metal rebar embedded in the concrete floors The LBNF/DUNE **UFER Ground** system includes the concrete floors in the cavern mid-chambers, center access drifts, and central utility cavern.

# LBNF/DUNE Far Site Detector Grounding System Requirements 4/8/2018

**High Level Requirements** (apply to both North and South caverns and all detector chambers)

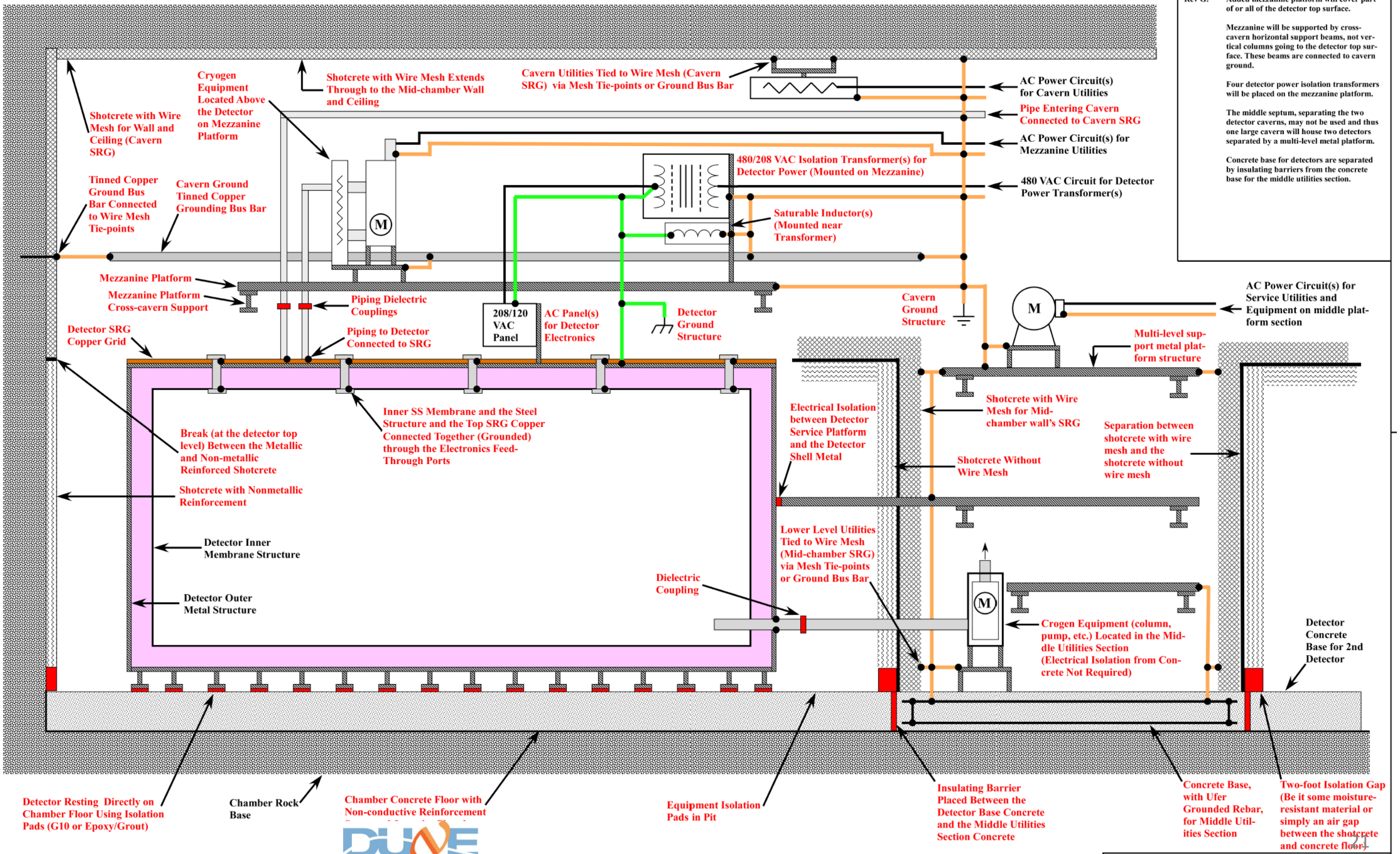
1. Require a solid electrical bond between all welded wire mesh panels that make up the **Cavern Ground**.
2. Require that copper buss bars be installed on each side of the cavern parallel to the detector vessels, and across the width of the detector chambers, for grounding electrical equipment located within the caverns. The buss bars must be made of flat copper bar to provide sufficient surface area and ground conductor properties. They must be tin plated to resist copper oxidation. Splice connections must be made with overlapping buss bar plates to maintain a minimum cross sectional area.
3. Require that the buss bars be tied to the **Cavern Ground** wire mesh at 5 foot intervals along the entire length of the ground buss.
4. Require that the **Cavern Ground** wire mesh be tied to the **UFER Ground** rebar in the mid-chamber and central access drifts, to create a single, solid, and continuous low inductive grounding system.
5. Require that the concrete floor rebar in the mid-chamber, center access drifts, and central utility cavern all be tied together to form a single, continuous **UFER Ground** system that originates at the electrical substation transformers.
6. Require that the **Detector Ground** be electrically isolated from everything including the concrete chamber floor. The only allowable conductive connections to the detector vessels are through saturable inductors.
7. Require the concrete detector cavern floor to have non-conducting fiber reinforcement.
8. Require that **NO** welded wire mesh be installed on the chamber walls from the 4850 sill down to the chamber floor, except for the chamber wall existing in the mid-chamber as described below. (This assumes that there is no electrical equipment installed between the vessel and the other chamber walls.)
9. Require welded wire mesh and shotcrete on the chamber wall only at the mid-chamber between detector caverns where cryogen piping, valves, pumps, fans, and other electrical equipment are located. The wire mesh on these chamber walls must be tied to both the mid-chamber **UFER Ground** rebar and the central access drift **UFER Ground**.
10. Require a minimum 2 foot high, moisture resistant **exclusion zone** between the chamber floor and the bottom of the shotcrete on all four chamber walls to isolate the Detector from the **Cavern ground**.
11. Require that ground monitoring instrumentation be installed to insure that the **Detector ground** remains electrically isolated from all other grounding systems.

**Other Detailed Requirements**

12. Require all shotcrete areas, which do not contain wire mesh, to use non-metallic containing shotcrete.
13. Require that tin plated copper bus bars shall be ~6” wide and a minimum of 3/8” thick.
14. Require all conductive piping and conduit entering/exiting the cavern must be bonded to local **Cavern Ground**. This can be accomplished with copper cable ties to the shotcrete mesh or through the creation of a local bus bar.
15. Require that the only AC distribution transformer(s) located inside a detector cavern are the detector double-shielded isolation transformers.
    a. The location of this transformer will be on the detector mezzanine structure.
    b. Galvanized Rigid Conduit (GRC) for 480 VAC circuits must be isolated from the **Detector Ground**.
16. Require a minimum of two saturable inductors to be located near the detector double shielded transformer with some separation >6 feet between the pair.
17. Require all metal structures to be bonded to a ground structure – No floating metal. (Note: This rule does not apply to isolated rock bolts.)
18. Require that no VFDs or motor controllers shall be used in the detector caverns unless reviewed by and approved by DUNE Grounding Committee.
19. Require galvanized rigid metal conduit (GRC) to be used for all electrical circuits.
20. Require that cavern light fixtures must be non-arcing or non-sparking.
21. Require dielectric isolators on piping between **Cavern** and **Detector Ground** structures. The Cryogenics team should work with DUNE Grounding Committee so that capacitive coupling can be minimized.
22. Require a local bus bar tied to **Cavern Ground** and **UFER Ground** mesh in the mid-chamber area to provide a reference for any cryogenic equipment located in that area.
23. The concrete of the slab under each cryostat warm structure shall be kept dry from naturally occurring water.

If the rock septum is to be removed either partially or entirely, the mid-chamber floors will now be at lower level(s). The following additional requirements are to be added.

24. The mid-chamber floor will remain part of the **UFER Ground** and the newly created mid-chamber wall, which shall contain wire mesh and is part of the **Cavern Ground**, shall provide a well bonded path between the central access drift floor **UFER Ground** and the mid-chamber floor **UFER Ground** .
25. Concrete pours between the cryostat/chamber pad areas and the mid-chamber area between the cryostat pads shall be isolated from each other. Use of a rubber barrier, or equivalent, is required.



Shotcrete with Wire Mesh for Wall and Ceiling (Cavern SRG)

Cryogen Equipment Located Above the Detector on Mezzanine Platform

Shotcrete with Wire Mesh Extends Through to the Mid-chamber Wall and Ceiling

Cavern Utilities Tied to Wire Mesh (Cavern SRG) via Mesh Tie-points or Ground Bus Bar

AC Power Circuit(s) for Cavern Utilities

Pipe Entering Cavern Connected to Cavern SRG

AC Power Circuit(s) for Mezzanine Utilities

480/208 VAC Isolation Transformer(s) for Detector Power (Mounted on Mezzanine)

480 VAC Circuit for Detector Power Transformer(s)

Tinned Copper Ground Bus Bar Connected to Wire Mesh Tie-points

Cavern Ground Tinned Copper Grounding Bus Bar

Saturable Inductor(s) (Mounted near Transformer)

Mezzanine Platform

Mezzanine Platform Cross-cavern Support

Piping Dielectric Couplings

Piping to Detector Connected to SRG

AC Panel(s) for Detector Electronics

Detector Ground Structure

Cavern Ground Structure

AC Power Circuit(s) for Service Utilities and Equipment on middle platform section

Detector SRG Copper Grid

Multi-level support metal platform structure

Shotcrete with Wire Mesh for Mid-chamber wall's SRG

Inner SS Membrane and the Steel Structure and the Top SRG Copper Connected Together (Grounded) through the Electronics Feed-Through Ports

Break (at the detector top level) Between the Metallic and Non-metallic Reinforced Shotcrete

Electrical Isolation between Detector Service Platform and the Detector Shell Metal

Shotcrete Without Wire Mesh

Separation between shotcrete with wire mesh and the shotcrete without wire mesh

Shotcrete with Nonmetallic Reinforcement

Detector Inner Membrane Structure

Lower Level Utilities Tied to Wire Mesh (Mid-chamber SRG) via Mesh Tie-points or Ground Bus Bar

Dielectric Coupling

Detector Outer Metal Structure

Crogen Equipment (column, pump, etc.) Located in the Middle Utilities Section (Electrical Isolation from Concrete Not Required)

Detector Concrete Base for 2nd Detector

Detector Resting Directly on Chamber Floor Using Isolation Pads (G10 or Epoxy/Grout)

Chamber Rock Base

Chamber Concrete Floor with Non-conductive Reinforcement

Equipment Isolation Pads in Pit

Insulating Barrier Placed Between the Detector Base Concrete and the Middle Utilities Section Concrete

Concrete Base, with Ufer Grounded Rebar, for Middle Utilities Section

Two-foot Isolation Gap (Be it some moisture-resistant material or simply an air gap between the shotcrete and concrete floor)

Rev G: Added mezzanine platform will cover part of or all of the detector top surface.

Mezzanine will be supported by cross-cavern horizontal support beams, not vertical columns going to the detector top surface. These beams are connected to cavern ground.

Four detector power isolation transformers will be placed on the mezzanine platform.

The middle septum, separating the two detector caverns, may not be used and thus one large cavern will house two detectors separated by a multi-level metal platform.

Concrete base for detectors are separated by insulating barriers from the concrete base for the middle utilities section.

Title: DUNE Far Detector Conceptual Grounding Diagram (1 of 2 Detector Sections)

| Project: LBNF/DUNE | Drawn: Steve Chappa | Date: 03-05-2018 | Sheet: 1 of 1 | Rev: G |
|---|---|---|---|---|