AC Power & Grounding
WBS 130.05.06.06

Marvin Johnson
mjohnson@fnal.gov

Outline

- Grounding and shielding
- AC Power distribution
- LAR 1 Grounding and AC Power

Introduction

- A low noise design is crucial to the successful operation of the detector
  - need noise levels ~1000 electrons
- The detector is too large to patch at the end
- Need a comprehensive design that addresses all aspects of power and grounding

Two Possible Design Approaches

- Use a “single point “ ground for detector components
  - isolate each component such as an anode plane array and ground it at one point
  - Requires good AC isolation which is difficult
    - D0 silicon detector achieved only 6 ohms at 7 MHz
- Connect all components at multiple points to a common ground
  - must control ground current paths to avoid noise from ground loops
  - Best choice for LBNE

Multipoint Ground

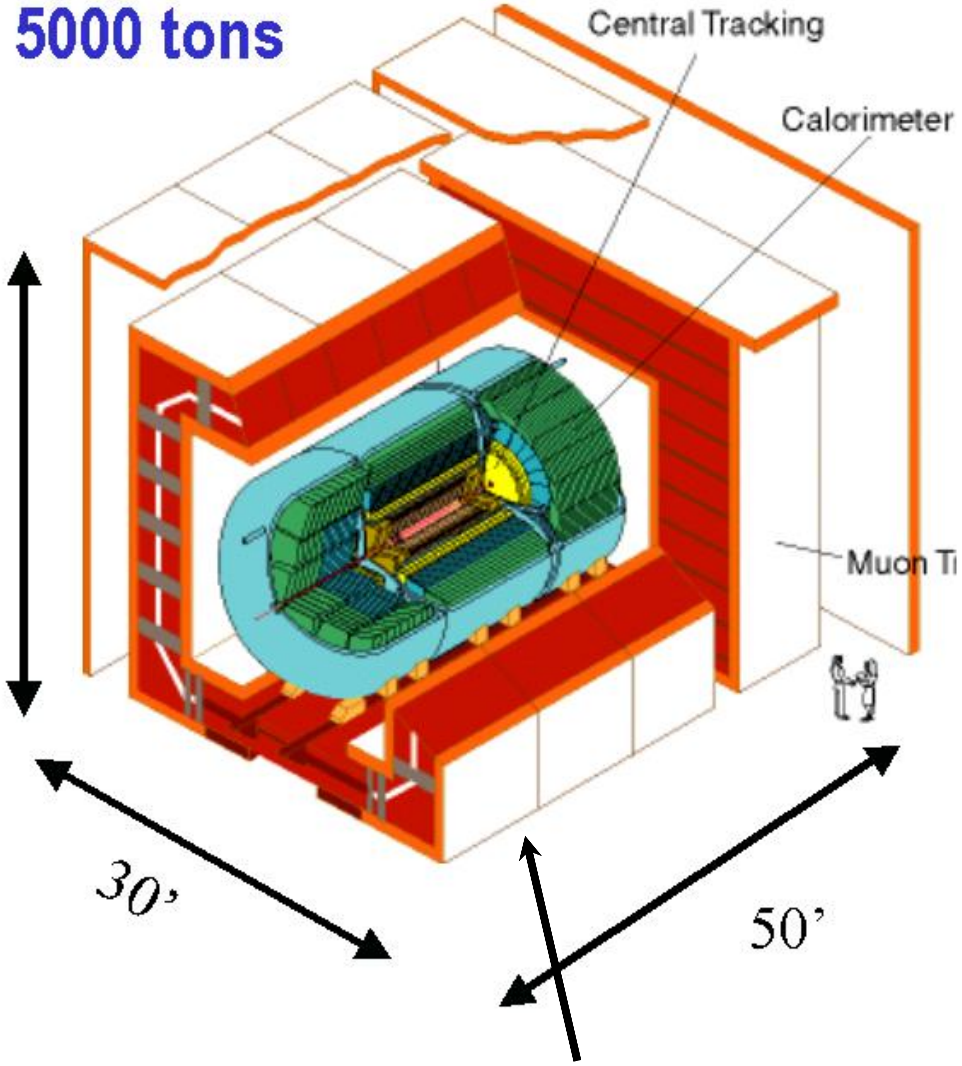
- Two main design requirements
  - Routing unwanted ground currents away from sensitive electronics
  - Providing a low impedance ground connection between components so that all measurements are made relative to the same potential.
- D0 LAR calorimeter is an example of a successful design
- Adopt this approach for LBNE

D Zero Calorimeter

- The calorimeter can measure single muon tracks so signal levels are comparable to LBNE
- Digitization rates are also very close (396 ns for D0 and 500 ns for LBNE)
- Physical size is smaller (~8 M long by ~6 M in diameter) but it the same scale as LBNE

Ground Current Control

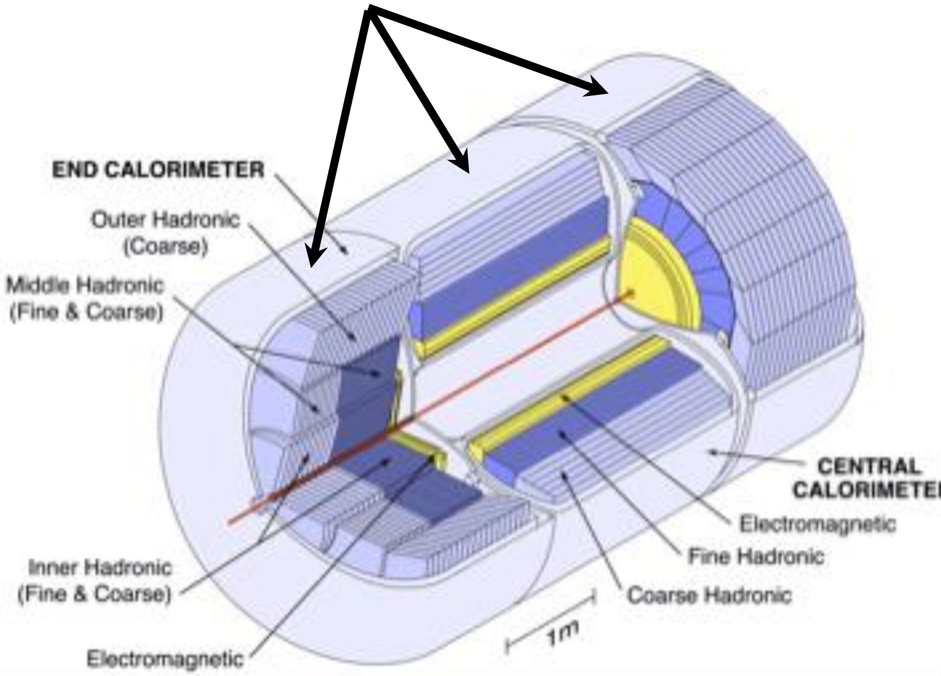
- Copper ground plane under the detector (~90% coverage and 1/16" thick)
- Most electronics (~70 racks) located on the ground plane
    - Low impedance so most ground currents flow on the ground plane rather than through the detectors



Copper Ground Plane under entire detector

Common Signal Reference

- Preamps and HV distribution located on the calorimeter body
- Cover top third of calorimeter with a copper sheet and tie HV and preamp grounds to sheet
  - –signals are measured with respect to the sheet so if ground sheet has some noise pick up, it is not seen in the readout


Copper sheet over top 1/3 of each cal cryostat

Two More D0 Features

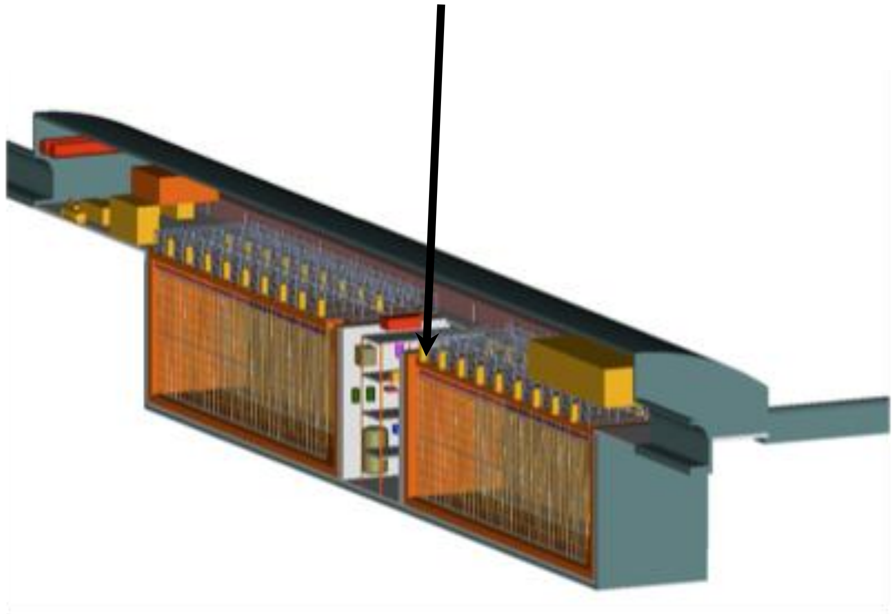
- Digital electronics that is not on the ground plane (e.g. muon readout) is run at 53 MHz which is well above the calorimeter front end bandwidth of < 10 MHz
  - Calorimeter does not see any noise from the muon readout
- Isolate entire detector from building ground
  - Reduces noise from external devices such as the computer farm and building crane

LBNE Cryostat Grounding

- Membrane cryostat thickness is ~ 2 mm of 304 stainless steel
- Slow drift time so lower frequency limit is ~20 KHz
  - Skin depth of 304 is 30.3 mm at 20 KHz so cryostat is not a good shield or ground
    - Resistance of the thin shell will make it easier to keep ground currents off the shell

LBNE Ground Plane

- Locate below the 5/8" steel floor plate
  - –Separated from cryo shell by insulation (0.8M)
    - need good connection to cryostat (described below)
  - –Racks and associated equipment connected to this plane
  - –Plane also serves as the voltage reference plane (different from D0)



Copper ground plane located under 5/8" steel floor plate

Ground Plane

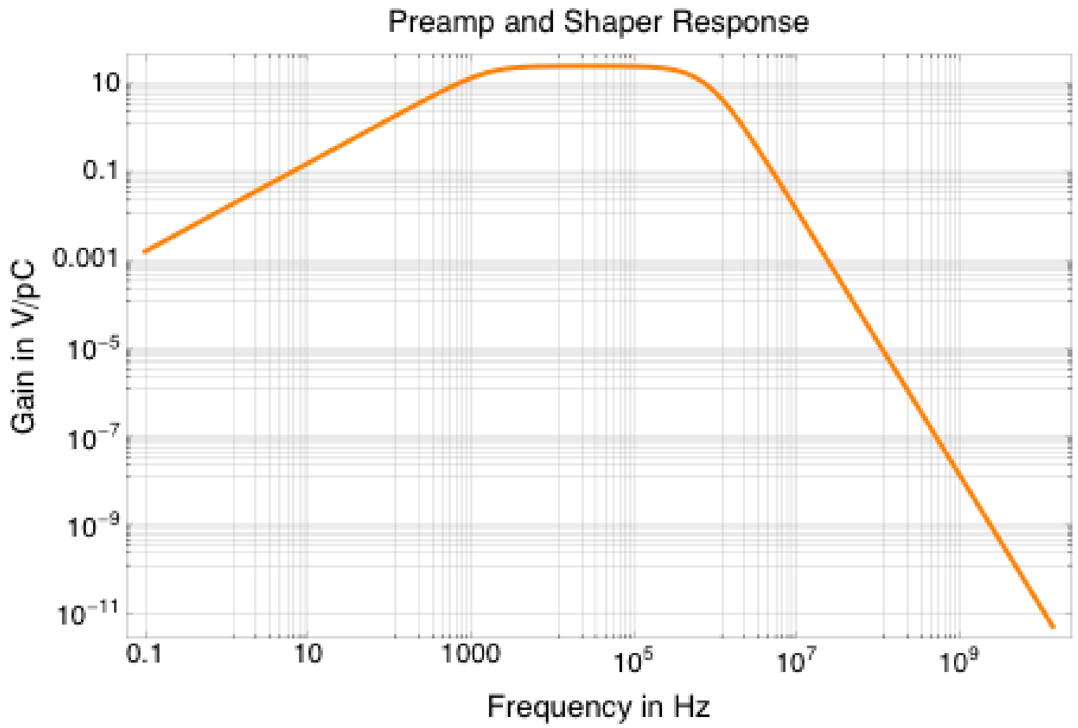
- Slow drift time so lower frequency is ~20 KHz.
- Skin depth of copper at 20 KHz is 466 µm
- Skin depth of steel is ~1” so get some help from 5/8” steel floor
  - need ~1/8” copper sheet for high quality ground

Cryostat Connections

- Keep ground currents off the cryostat shell
  - An example is digital noise from the clock coupling to the shell through the APA support connections.
- Low impedance requires multiple connections
- Connection spacing is determined by wavelength of highest frequency signal
  - This is determined by the maximum bandwidth of the preamp-shaper circuit

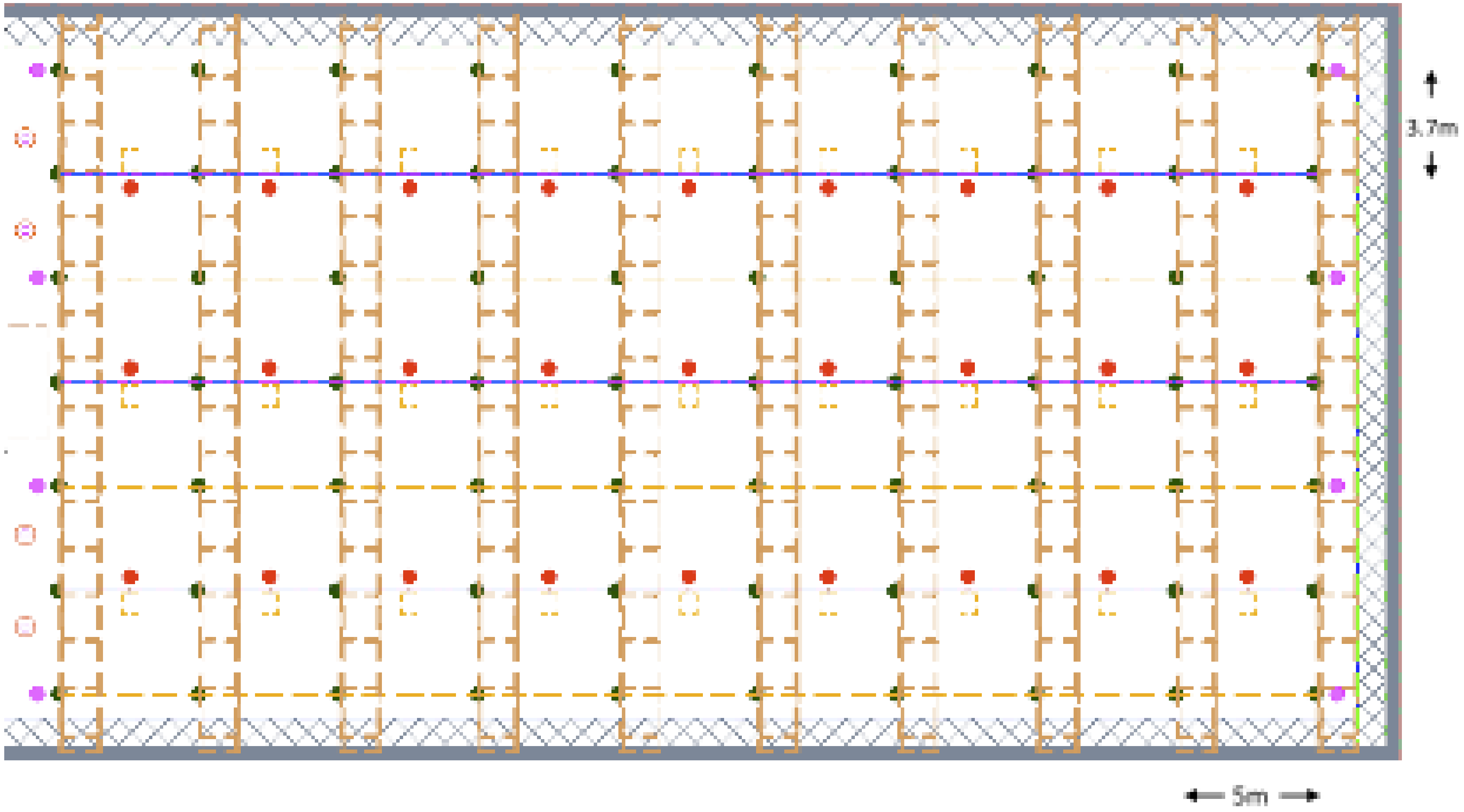
Cryostat Connections

- Front end response is down by ~60 db at 10 MHz (30 M wavelength)
- Choose spacing =10% of wavelength (3 M)
- Port spacing is 5 meters with a APA support centered between them
  - Reducing inductive impedance also requires parallel lines



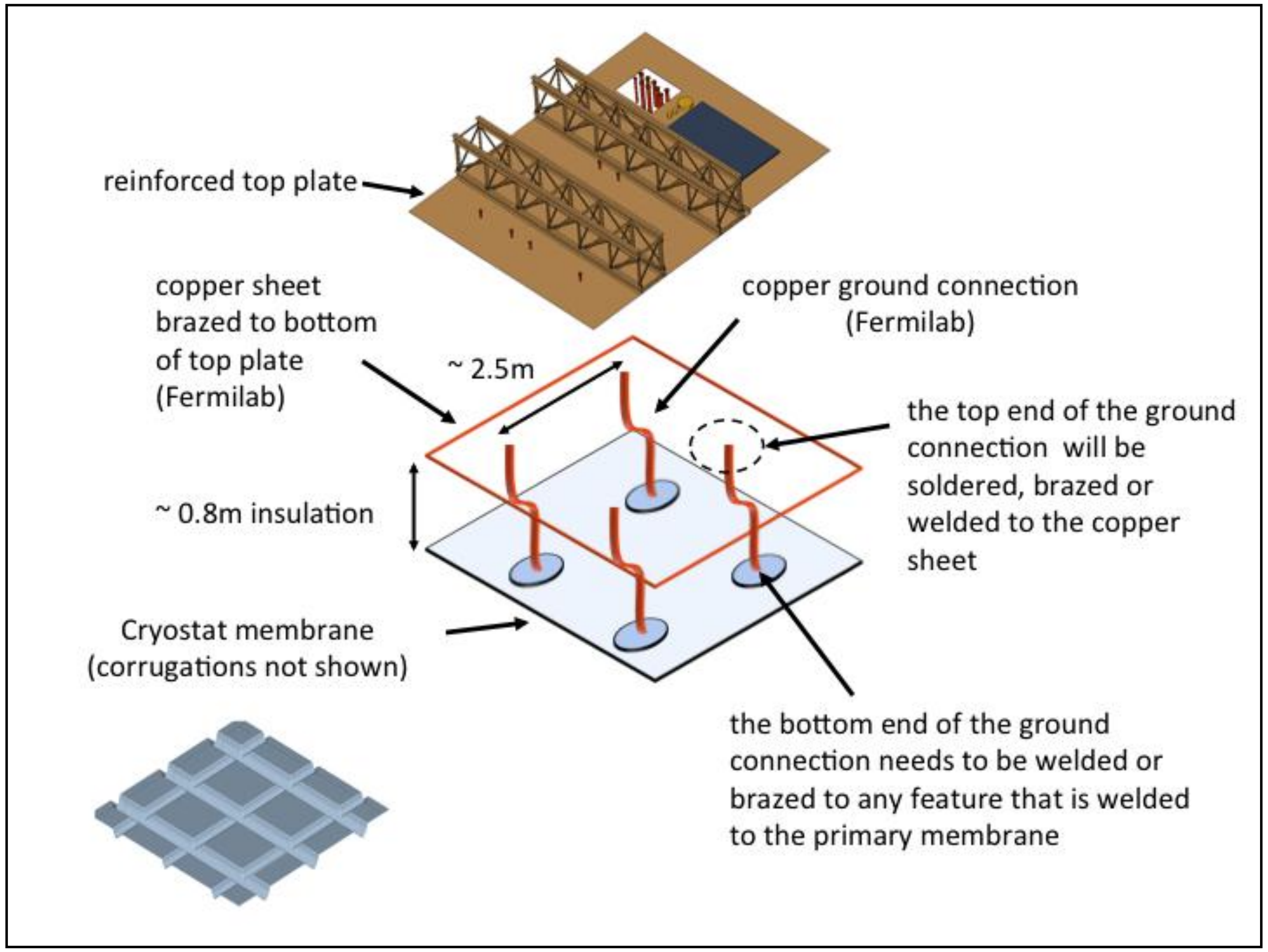
Ground Locations

Ground connections are made at red (feedthrough ports) and green (APA supports) points. Additional connections will be added to give a roughly uniform 2.5 meter spacing



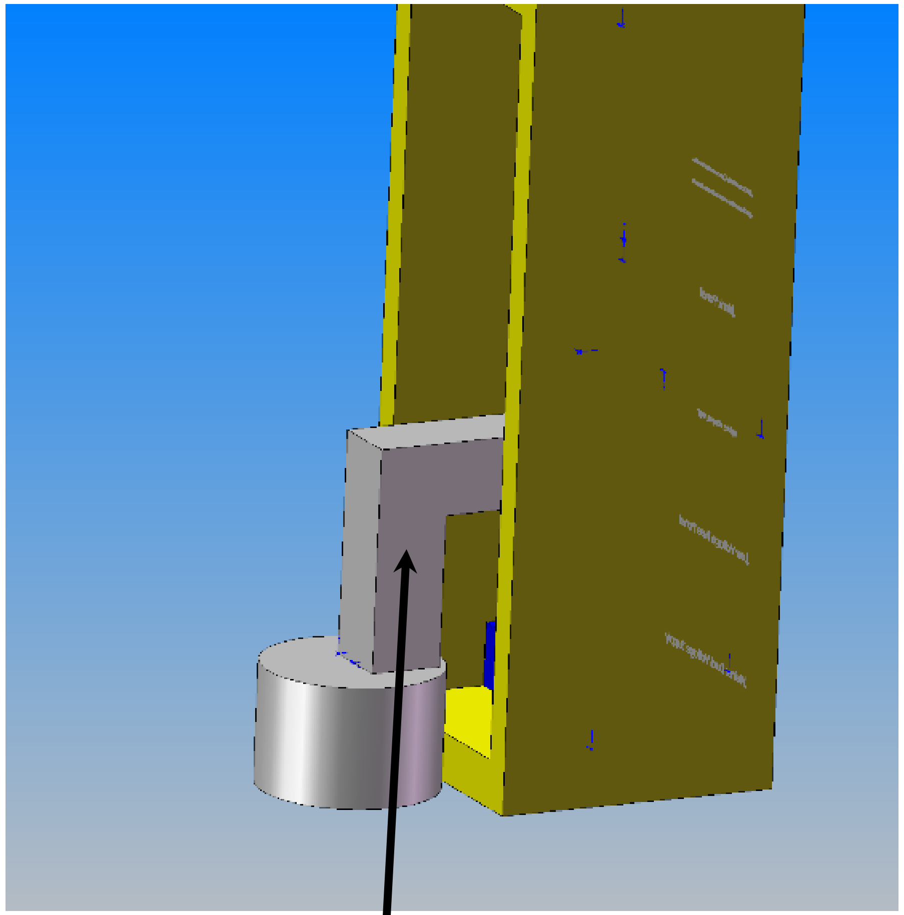
Ground Connections

Connection details from LAR 1



Racks and Ports

- Racks bonded to copper ground plane at each port
- Ground plane is reference for all rack mounted equipment (DCM's, Low Voltage PS, High Voltage PS etc.
- External rack connections are fiber optic except for power



Separate shielded trays for analog and digital systems

Inside the Cryostat

- APA’s are bonded to cryostat and to each other
- Clock frequency and all digital communications 24 MHz or greater
  - Well above shaper bandwidth so there is no pickup
  - Cables are individually shielded twisted pair to avoid any possible cross talk
- Power and signal cables are routed in separate channels in the APA frame
- All parts are grounded together except those at HV.

“Earth” Connection

- A connection to a large conducting body with enough self capacitance so that charge flowing onto the body does not change its voltage is very desirable
  - V=q/C so we want C large compared to the charge that we might transfer to it
  - For detectors such as CMS or D0 the magnet steel and support structure provide a lot of this capacitance.
- LBNE has little support structure and is surrounded by rock

Ufer Ground

- Developed by Herbert Ufer for the US army in WW II to ground ammo dumps from lightning strikes in deserts and other harsh climates
- Utilizes the conductivity of concrete/rebar to provide a large area of contact to high impedance earth connections
  - Concrete remains somewhat moist in almost all conditions
    - High ph so there are a lot of free ions for conduction
  - large contact area gives a net low impedance to the surrounding earth

Ufer Ground

- Used very successfully for communication towers in mountainous regions with little soil
- The NOvA far detector building is located mostly on granite so we developed a Ufer style grounding system for the building
  - This is the first use for an instrumentation ground that I know of

NOvA Ground

- Low Cost
  - No extra rebar was added
- Rebar connected together with copper wire and brought out to ground locations on the inside wall
- Connected to steel catwalk to provide connection points to the detector

NOvA Ground

- Plan a test next fall when some of the NOvA electronics is installed
  - –Much easier to use the detector readout than to develop a specialized readout system
  - –All we need for the test is a strong signal source such as an arc welder to generate noise in the detector
- If successful, we will use it in LBNE
  - –It should work in principle so if there are problems, we will need to understand them and make adjustments to the LBNE design
    - Most likely problem would be contact resistance

Detector Power

- Power will be the only conductive link to the outside world
- Also connects many conventional facilities such as HVAC to the detector system
- Design is based on experience with both D0 and CMS detectors

Power Usage

- Facilities Power ~1MVA
- Cryogenics systems ~3 MVA (2 cryostats)
- Detector Power <0.05 MVA (2 cryostats)
  - Non detector power consumption dominates so it is crucial to minimize the impact from these sources

Design Approach

- Minimize use of digitally controlled power
  - –Variable frequency drives
  - –SCR controlled heaters etc.
  - –Probably not practical to eliminate all of them
- Isolate the 3 main users with Faraday shielded transformers and CL filters

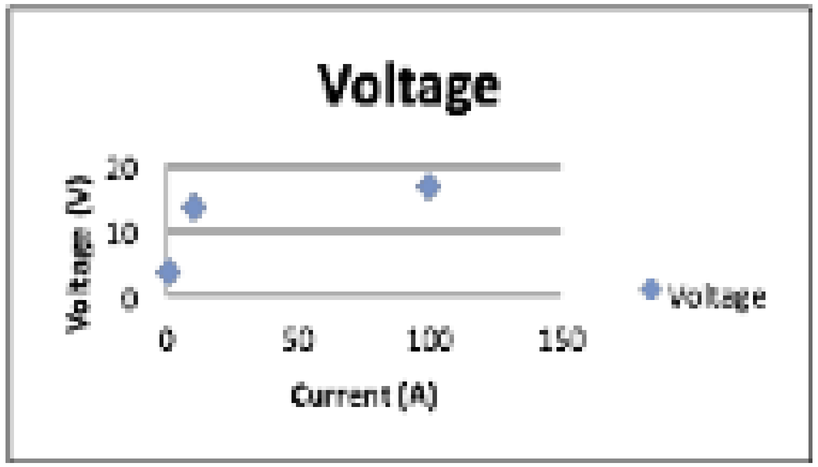
15 KV to 480 V

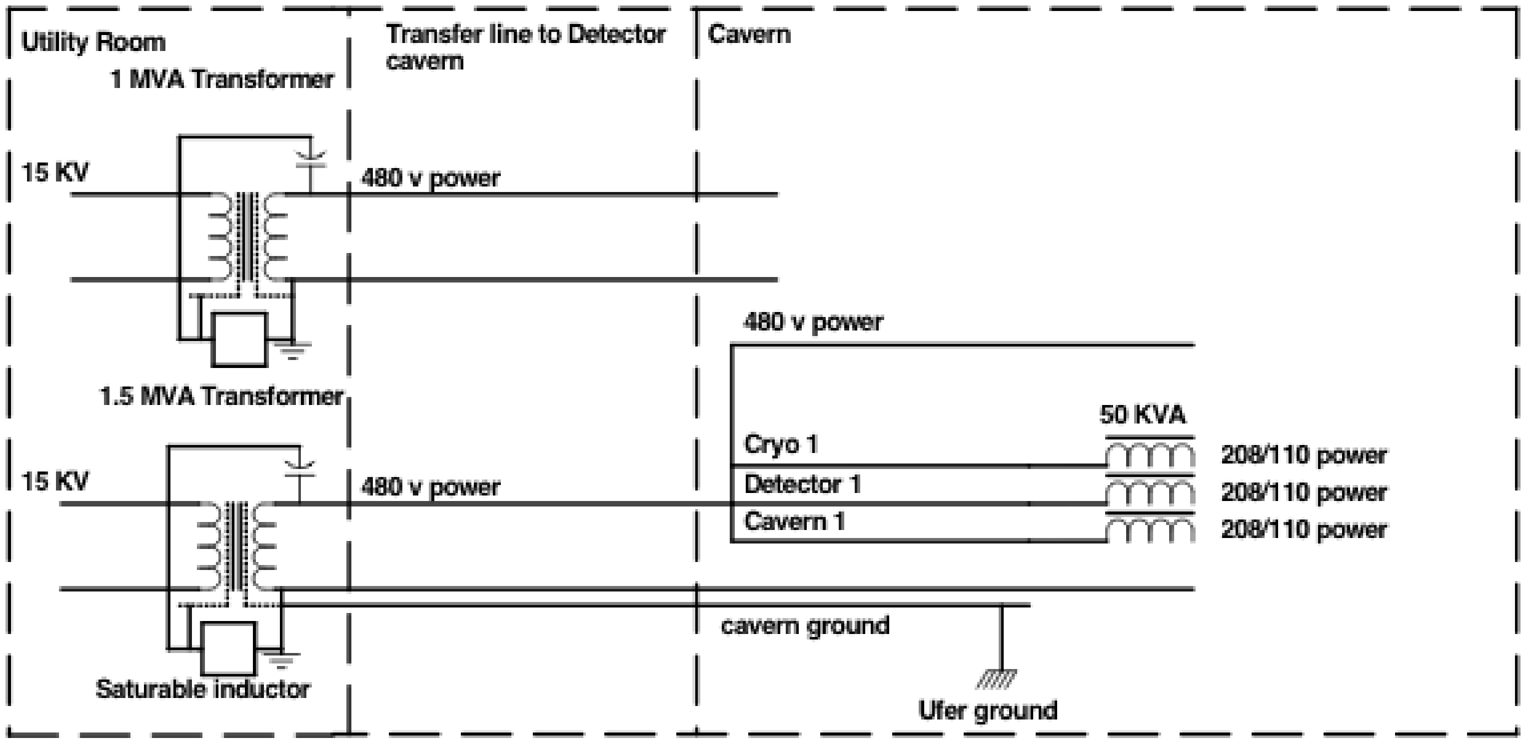
- Located few hundred feet from main cavern
  - –Use the inductance of the leads as part of a CL filter
  - –Exact length is flexible
- One MVA transformer for conventional power
- Two 500 KVA transformers for cryo and detector power (one for each detector)
  - –Double faraday shielded with ground isolation
    - Depending on location of transformer vault and mine cable routing, may use a single faraday shield and common ground

Saturable Inductor

- Secondary of transformer is locally grounded
- Primary is grounded via feeder and saturable inductor
- Used at D0 for 20 years
- Installed in microboone
- Provides high inductance at low current
  - –10 mH at 1 amp
  - –16 volt drop at 60 Hz, 100 amps

Saturable inductor at D0





Grounds are separated with saturable inductors at the substation location

LC

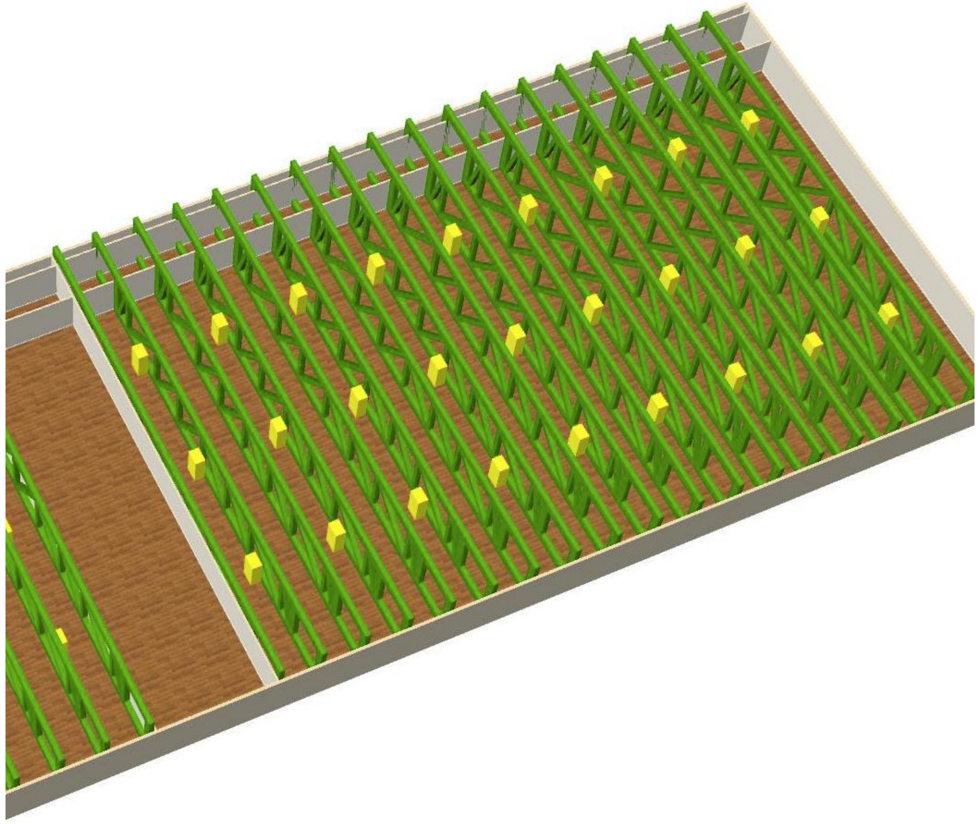
- Self inductance of 800 feet of 500 MCM cable is 600 µH
  - scales directly with length
- Coupled with C=10 µF gives a 3 db point of ~2 KHz with 6 db/octave roll off.
  - Use larger capacitors if cable length is less

Switch Gear

- Separate switch gear for each use
- Locate detector and cryo switch gear next to the detector
- 480 power to cryo fed directly from switch gear
- Lower voltages pass through a local transformer
  - Detector transformer at end of center row of racks

Rack Power

- 27 racks arranged in 3 rows of 9 for each cryostat.
  - transformer located at end of center row
- Fed by 4” by 4” raceway along each row
- Each rack supplies power and readout for 4 APA’s



LAR 1

- LAR 1 grounding and power will be somewhat different than LBNE because LAR 1 is less isolated
- LAR 1 is located at D0 so it has the advantage of an environment designed for a low noise detector
- We will take advantage of much of the existing D0 infrastructure

LAR 1 Grounding

- Follow procedures that were used for the D0 detector
  - Similar to those adopted for microboone
- Provide AC isolation from the outside world
  - This requires isolating either the cryostat or the bottom of the external concrete shell
    - Isolating the concrete shell may be impractical because of the capacitance between the shell and the building floor
  - The precise method will depend on the detailed mechanical design

Isolation

- D0 already has ground isolated connections for such things as ethernet, FIRUS and ODH detectors so we will use them
- Maintaining ground isolation during the construction is difficult
  - Use an audible alarm similar to that used by Atlas and microboone to alert people that the detector has been grounded to the outside world
  - D0 mechanical crew is well experienced in working with an isolated detector

Cryo

- Isolate the cryo system from the cryostat using dielectric breaks in the transfer lines
- Methods are similar to those used in D0
- LAR1 will likely use variable frequency drives
  - None are currently used in D0
  - The one system installed in CMS required extra effort to shield the experiment
  - Noise performance will need to be one of the criteria for selection

Power

- D0 already has three 150 KVA isolated transformers on the roof of the moving counting house
  - We will rewire one of them to provide isolated power to LAR1

Summary

- LBNE is a large detector with low signal levels
- Signal levels are fairly comparable to the D0 calorimeter so many of the techniques used successfully in D0 can be applied to LBNE
- Good noise control will require careful design and attention to detail during installation
- LAR 1 can make use of much of the low noise infrastructure at D0
  - The noise performance of LAR1 should be similar to that of D0