SBND and NP04 TPC Design

Bo Yu
Brookhaven National Lab
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Outline

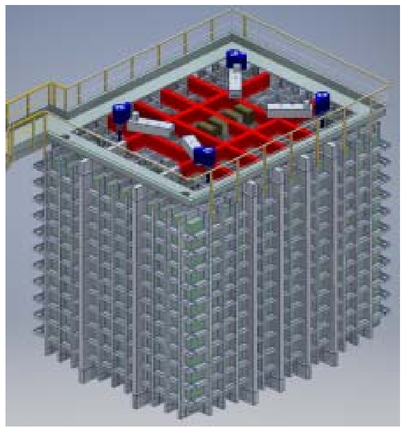
- System Overview
- Compare Design Features
- Subsystem Details
- Summary

The SBND TPC

4 APAs (anode plane assemblies)
2 CPAs (cathode plane assemblies)
16 field cage modules
11k readout channels

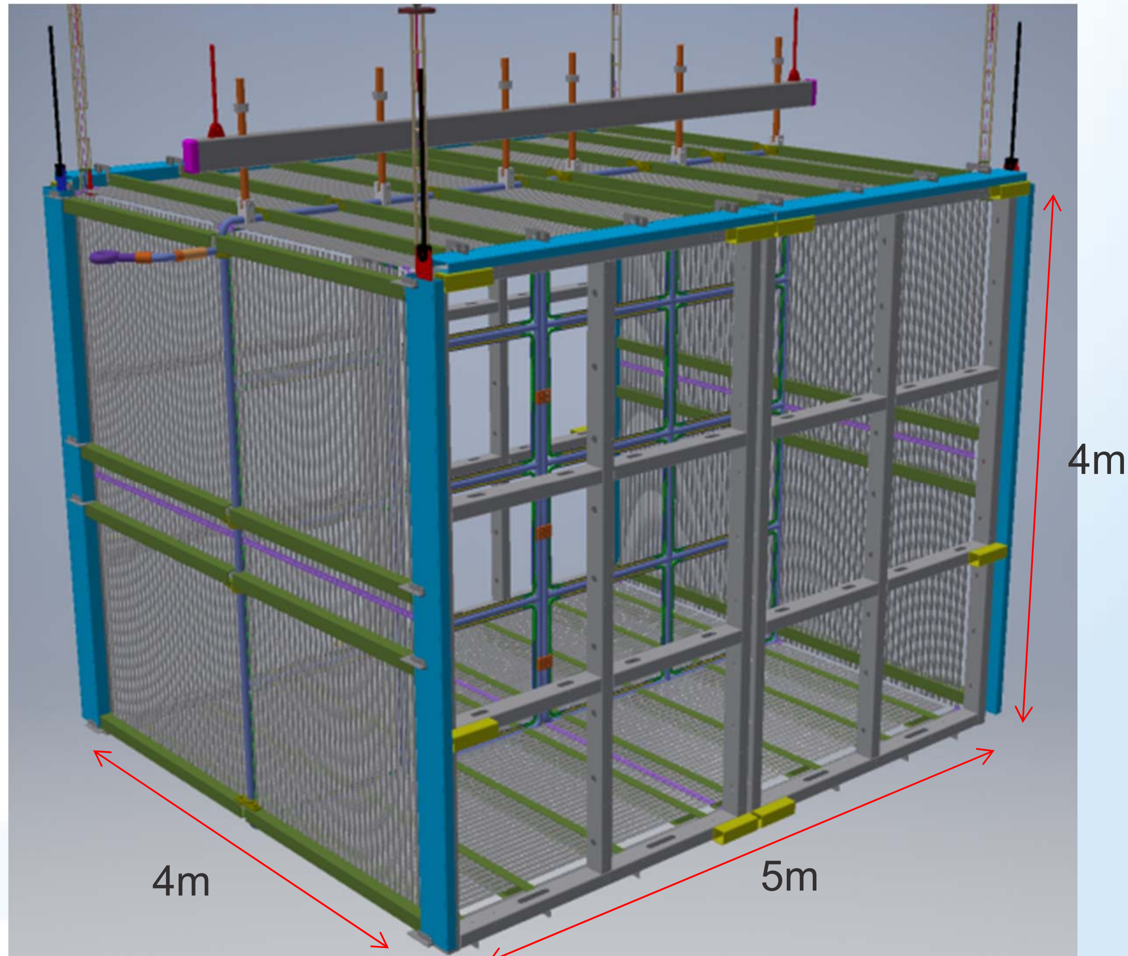
Active volume:
W: 4m, H: 4m, L: 5m,
Active mass: 110ton

Suspended at 6 points under the cryostat ceiling



Innovative Features:

- Cold analog and ADC ASICs and FPGAs
- Induction wires interconnected across APAs
- Modular field cage with metallic profiles
- Cathode plane compatible with TPB coated reflector
- 4 Calibration laser beams



NP04 (ProtoDUNE SP) TPC

Prototype of the single phase DUNE far detector. Full scale modules, but only half height.

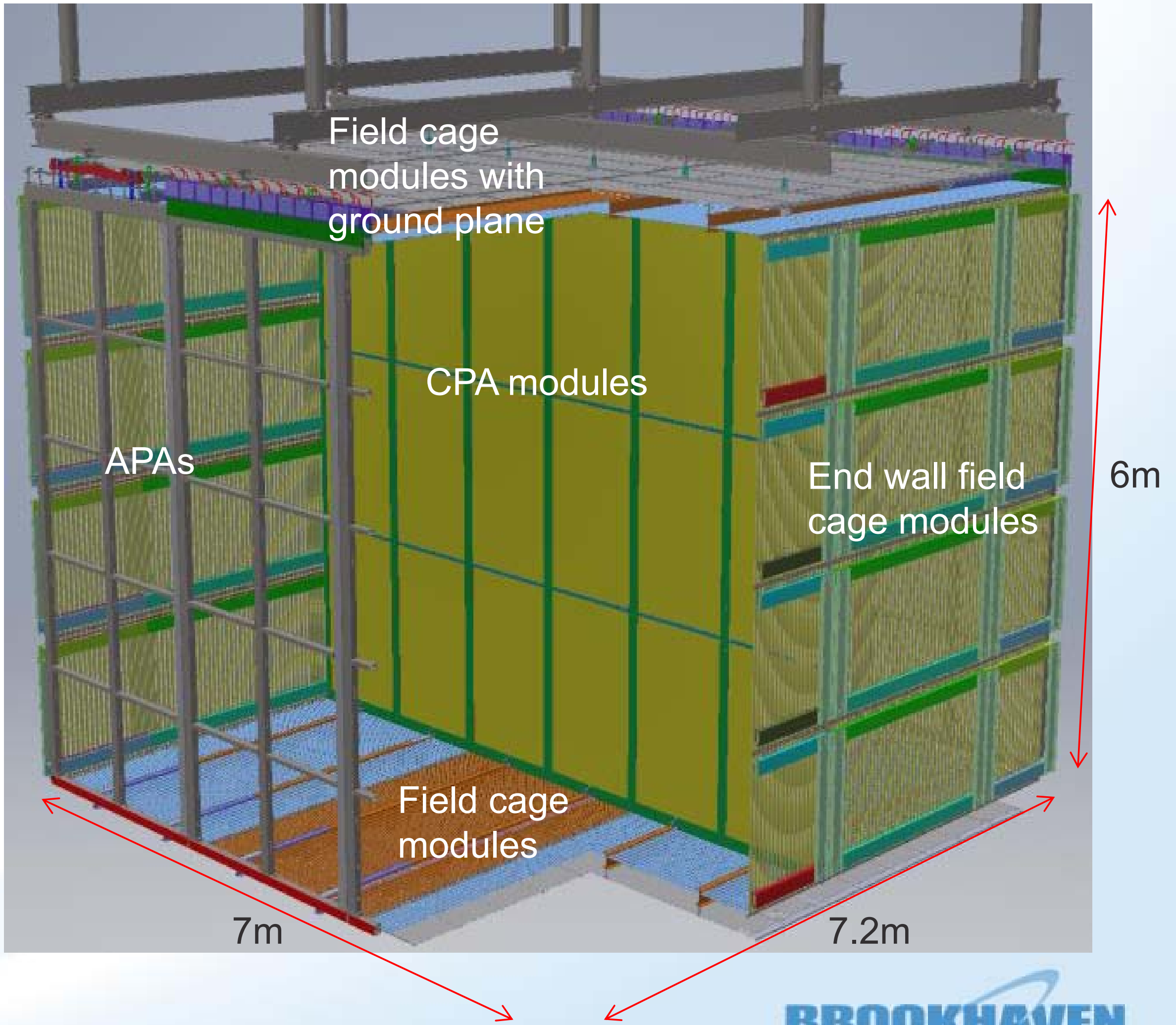
The TPC has 6 APAs, 6 CPAs, 28 field cage modules, 15k readout channels

Active volume:
W: 3.6mx2, H: 6m, L: 7m
300 ton active mass

Installed under 3 mounting rails suspended under the cryostat ceiling

Innovative features:

- Cold analog and ADC ASICs and FPGAs
- Double sided APA readout with electronics on one end only
- All resistive cathode plane
- Modular field cage with metallic profiles
- APAs with integrated photon detectors
- Low mass beam plug on field cage



DUNE FD TPC (Single Phase)

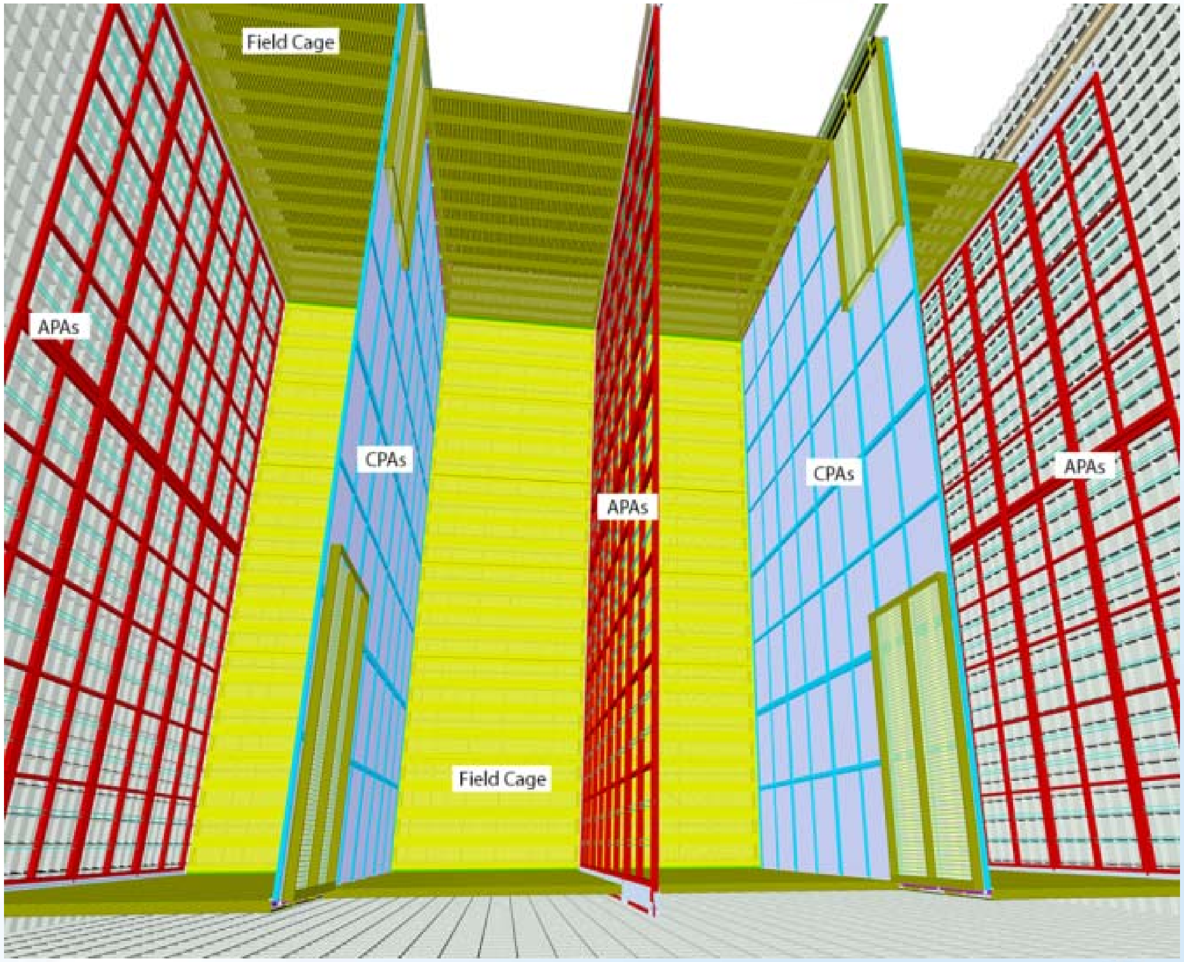
10 kton fiducial cryostat. Each has:
150 APAs, 200 CPAs
2000 m^2 field cage modules
385k readout channels

Active volume:
W: 14.5m, H: 12m, L: 58m

Installed under 5 mounting rails suspended under the cryostat ceiling

Innovative features:

- Cold analog, ADC and digital multiplexer ASICs
- Double sided APA readout with electronics on one end only
- 2 APAs connected end to end for a 12m active height
- All resistive cathode plane
- Modular field cage with metallic profiles



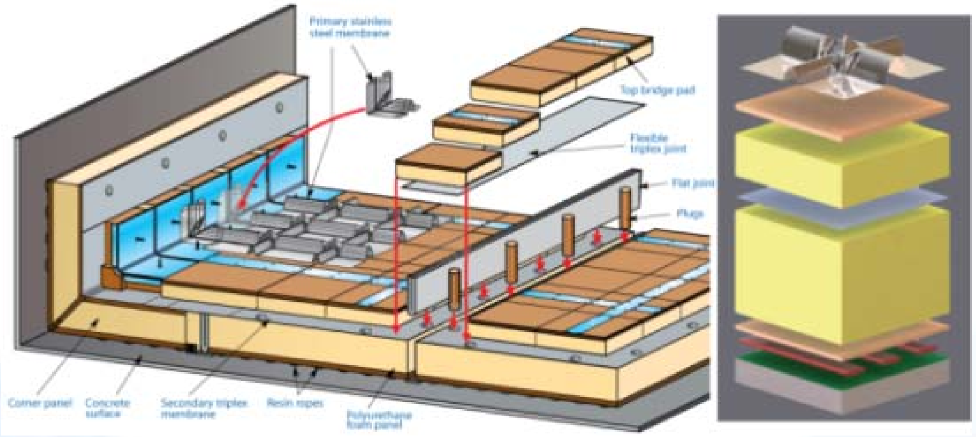
Comparison of Key TPC Features

	SBND	NP04
Common	Operating in ionization mode with multilayer projective readout. Assembled from pre-fabricated, pre-tested modules; supported from cryostat ceiling; nearly identical front end electronics, signal feedthroughs and warm interface electronics; modular, independent field cage modules using roll-formed open metal profiles; 150 μm CuBe glued and soldered to wire bonding boards; wire combs limit unsupported wire length to <1.5m	
Dimensions	2m drift, 4m high, 5m long, 2 planes of 2 APAs	3.6m drift (reconfigurable to 2.5m), 6m (H), 7m (L), 2 planes of 3 APAs
Wire planes	3 sense wire planes, vertical, ±60°, 3mm pitch	1 front grid plane, 3 sense wire planes: vertical, ±36°,~ 4.7mm pitch
APA	Single side sensitive, electronics on top and outside edges, induction wires are bridged across APAs. Additional shimmed leveling bars improve frame flatness to ±0.5mm.	Double side sensitive, electronics on top edge only, electrical isolation between APAs
CPA	Stainless steel frame with transparent wire mesh panels	FR4 bar frame with FR4 sheet panels. All frames and sheets have resistive film lamination
Field cage	4 laser ports for calibrating drift field	Ground planes 20cm beyond the top and bottom field cage electrodes; 1 low mass beam plug to displace LAr
Photon detector	TPB coated PMTs and light guide bars installed behind the APAs	TPB coated light guide bars inserted between the wire planes
HV	100kV, ≥ 30cm ground clearance	180kV, = 20cm ground clearance

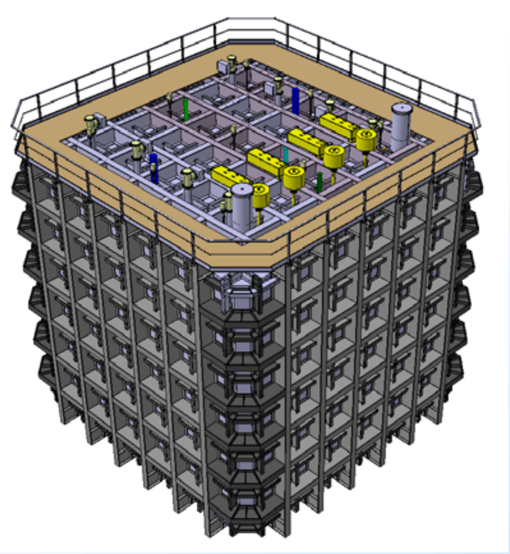
GTT Membrane Cryostat Technology

GTT (Gaz Transport & Technigaz) is one of the two membrane style liquid natural gas storage tank manufactures.

Membrane thickness: 1.2mm stainless steel 304L
Corrugation pitch: 34cm
Corrugation height: 7cm

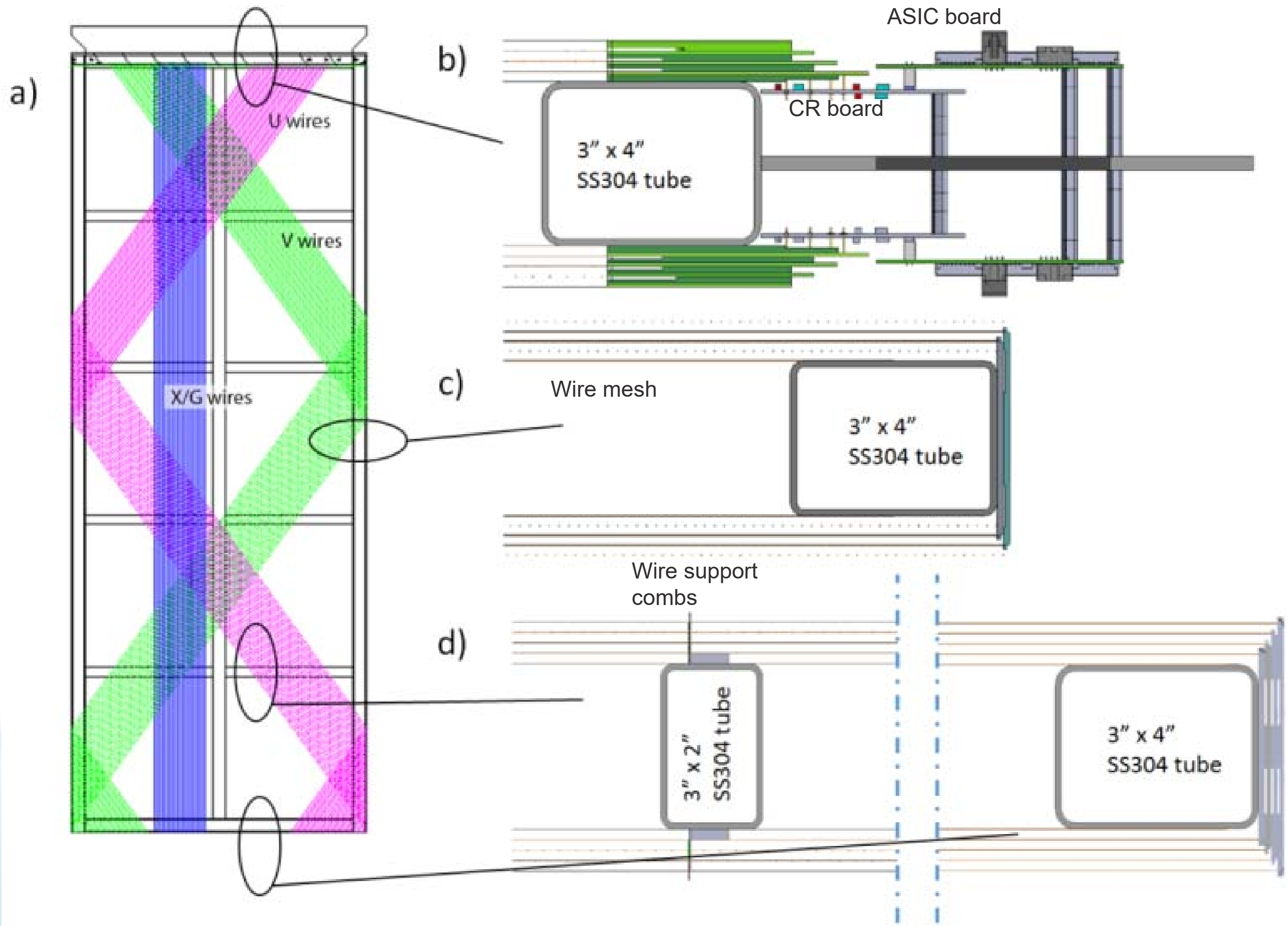


Illustrations of the GTT membrane cryostat construction



CERN's free-standing membrane cryostat design:
A warm steel structure constructed from a matrix of I-beams providing structural support to the inner membrane system.

DUNE SP APA Dimensions and Cross Sections



APA dimensions:
2.3m x 6m active area, 12cm thick

Collection wire angle: vertical

Induction wire angles: ±35.7° from vertical

Grid plane wire angle: vertical

Induction wires wrap less than 1 full revolution

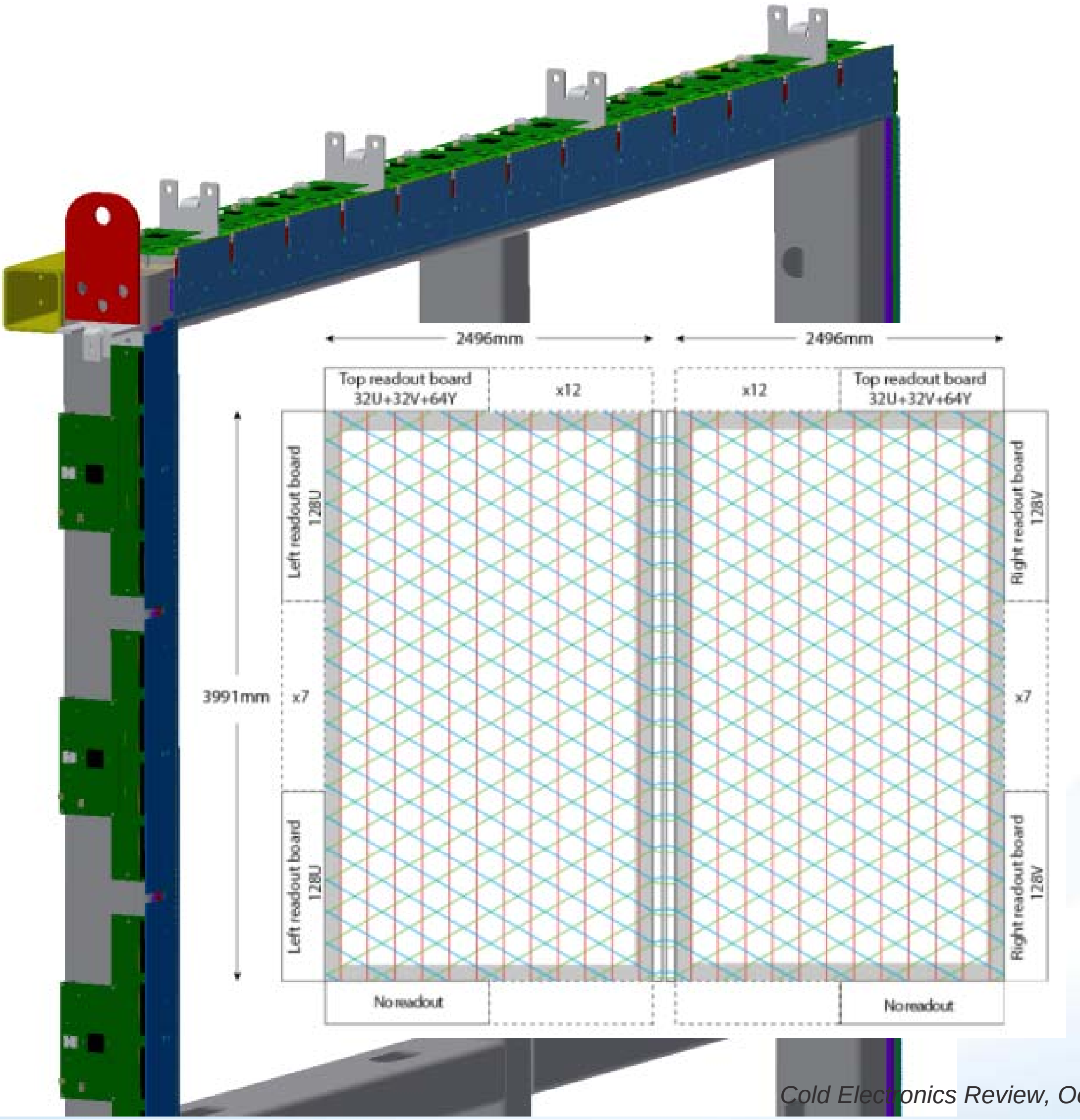
Wire pitch :
X, G: 4.8mm
U, V: 4.7mm

2560 readout channels

Need 150 APAs per 10 kton TPC:
25 deep x 2 high x 3 rows

All tubes are frequently vented to prevent trapped volumes

SBND APA Readout Arrangement

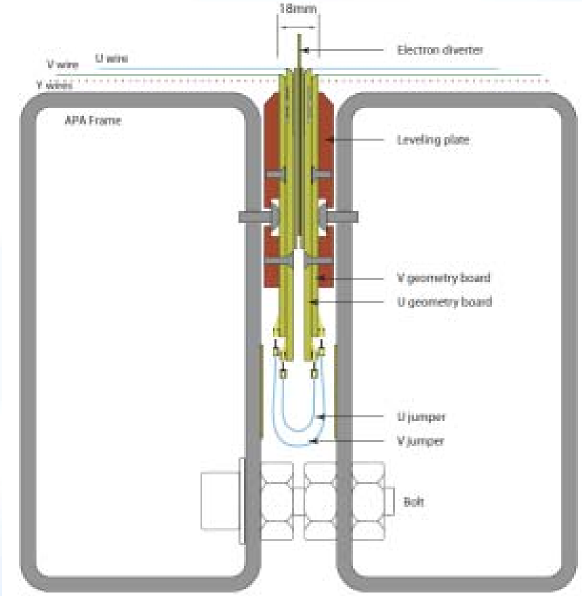


2 bridged APAs

- 5,632 channels
- 26 top mother boards x 128ch per board
- 18 side mother boards x 128ch per board

Entire SBND TPC

- 11,264 readout channels from 4 APAs
- 4 cold cable bundles to 4 signal feedthroughs

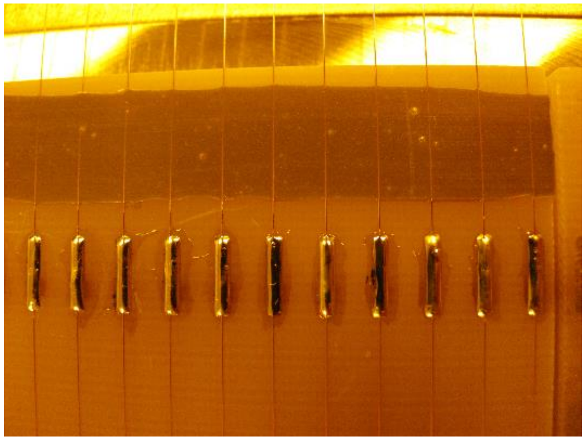


Wire Plane Configurations

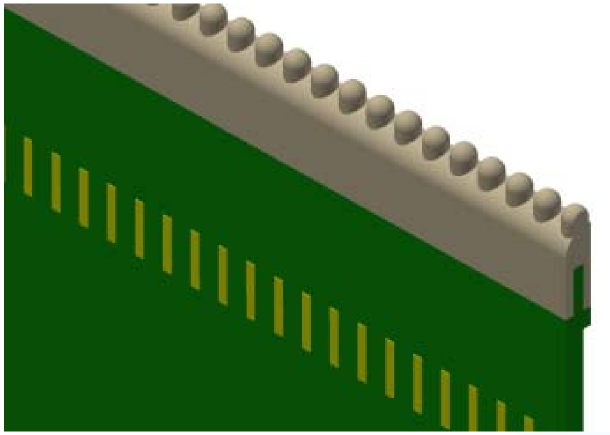
- SBND
  - Designed to be identical to the MicroBooNE wire orientations
    - Collection plane wires vertical; two induction planes at ±60° from vertical
    - Wire pitch and wire place spacing: 3mm
  - A grounded wire mesh ~1cm behind the collection plane
  - CuBe wire (150μm) @ 5N nominal tension
- DUNE/ProtoDUNE
  - Collection plane wires vertical, @ a pitch of 4.79mm
  - Two induction planes at ±35.7° from vertical @ pitch of 4.67mm
  - A grid plane with vertical wires in front of the induction planes @ a pitch of 4.79mm
  - Spacing between all wire planes is 4.76mm
  - A grounded wire mesh 4.76mm behind the collection plane
  - CuBe wire (150μm) @ 5N nominal tension

Wire Holding Methods

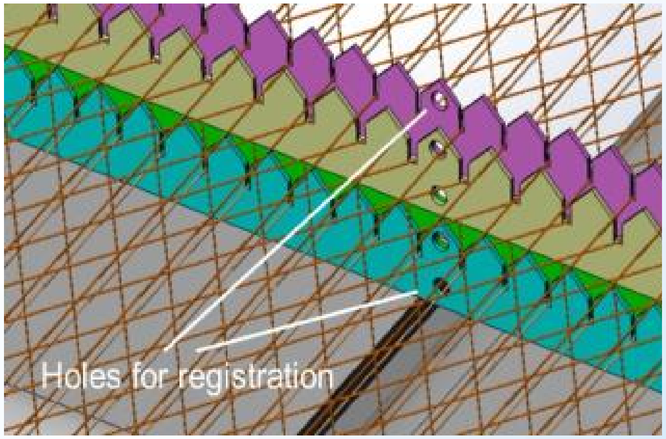
Both TPCs employ similar wire bonding, and positioning methods.



Wires are secured to the wire boards using both epoxy and solder to ensure reliable bond.

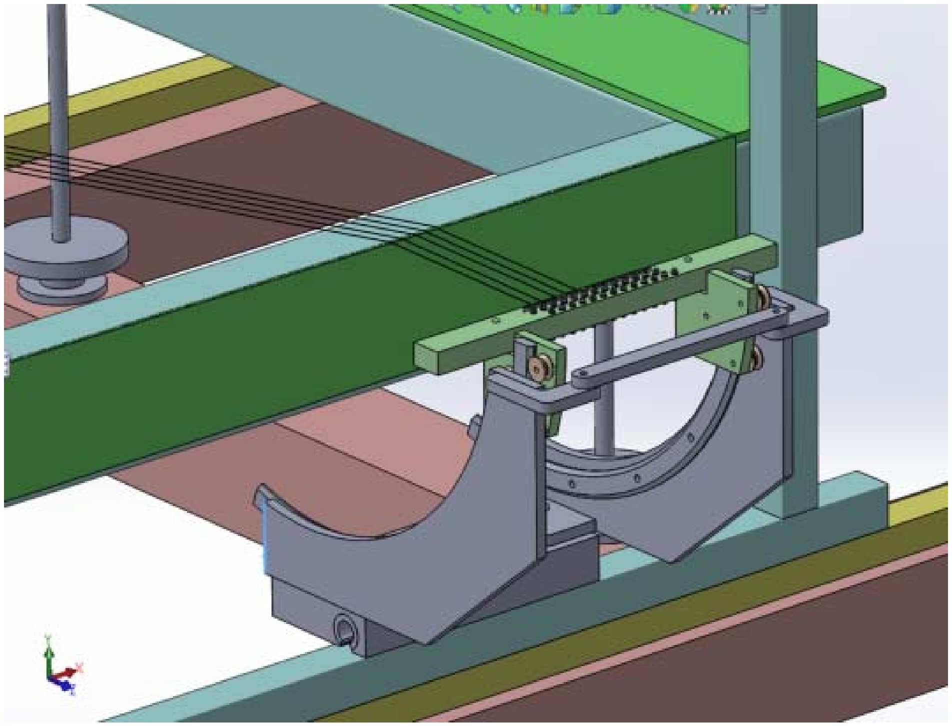


Injection molded board edges provide smooth bending and precise placement of the wires on the wrapped APA edges.



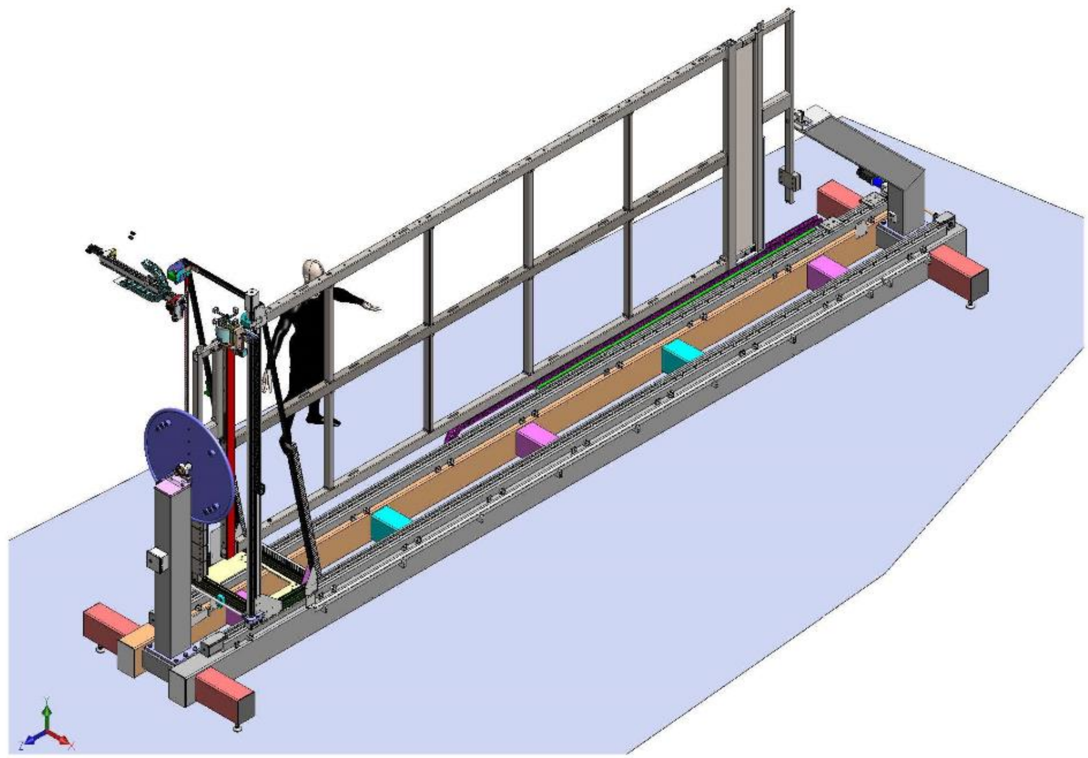
Fiberglass wire combs are placed over the frame members to maintain wire pitch and plane spacing.

Wire Winding

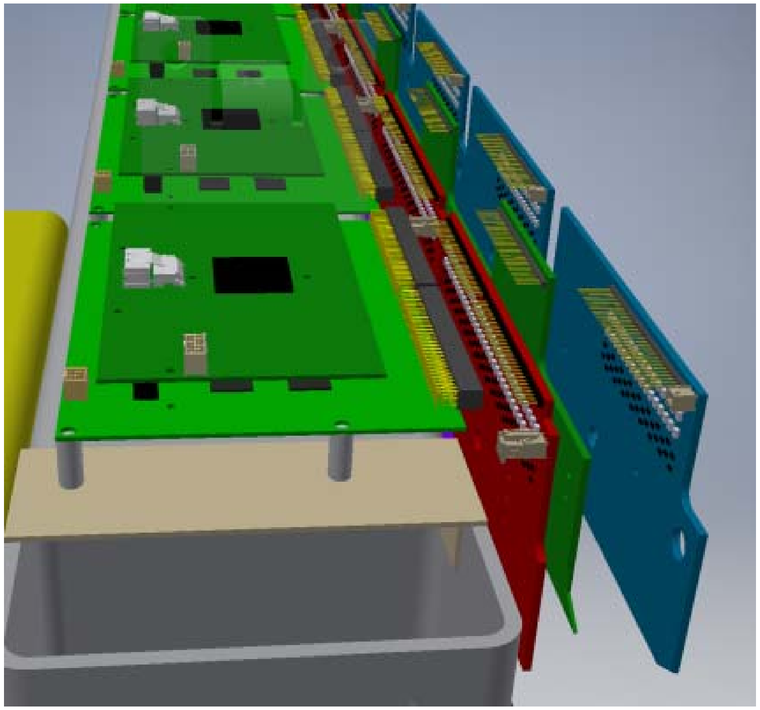


Key components of the manual wire winding machine for SBND for the US production site

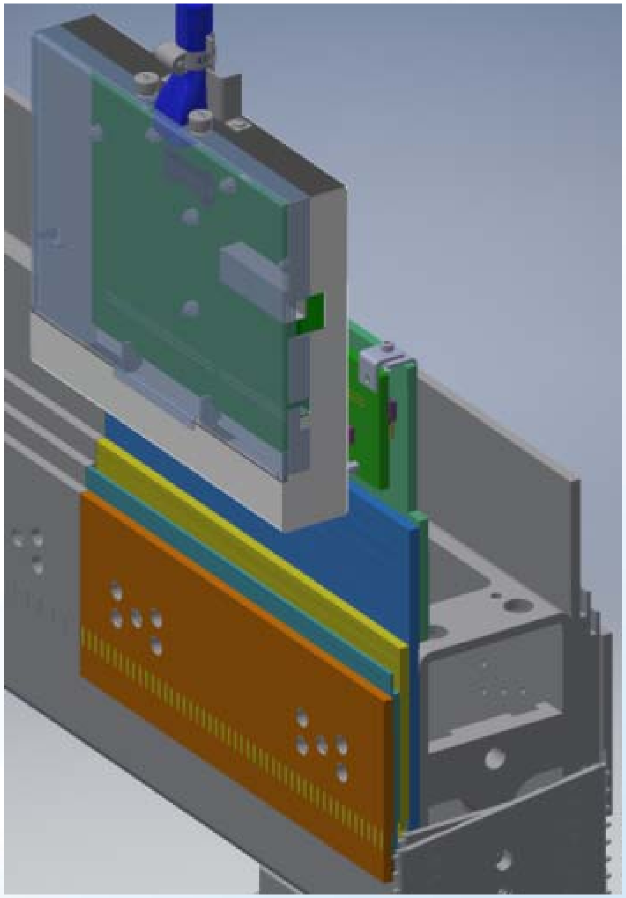
Design of the ProtoDUNE APA winding machine



Wire Connection to the Front End Electronics



SBND geometry board stack and cold electronics board stack

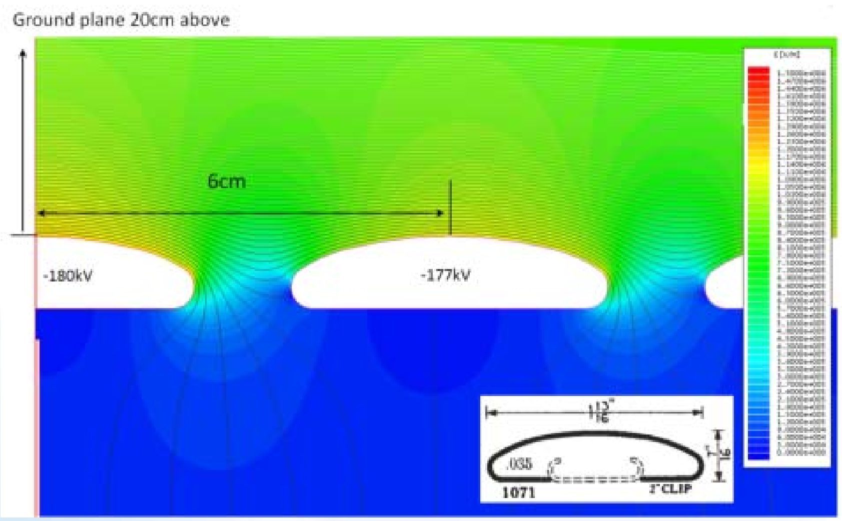


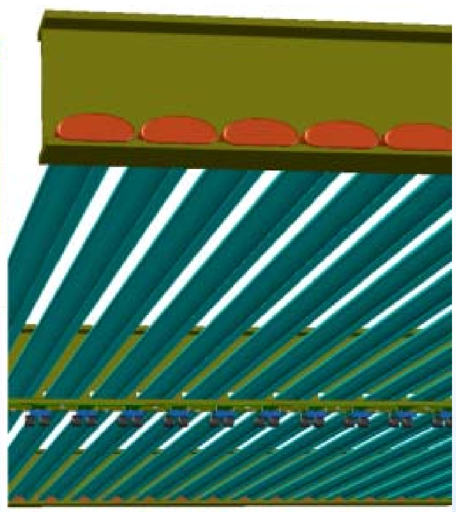
DUNE wire board stack and cold electronics box

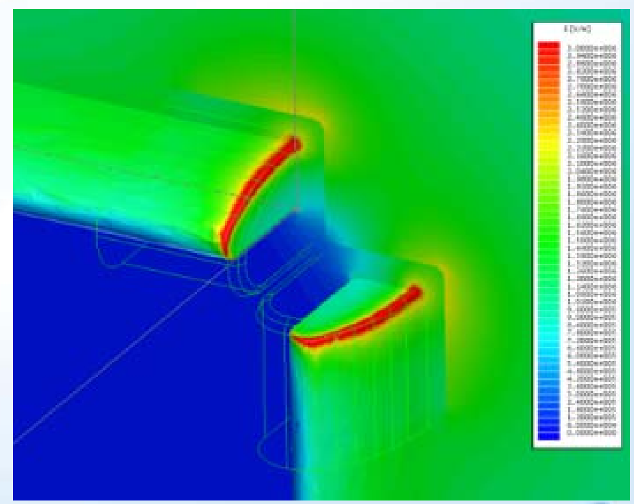
Modular Field Cage Concept for DUNE/SBND

Both DUNE SP and SBND adopted a modular field cage concept: An array of roll-formed open metal profiles supported by fiber glass I-beams forms a field cage module. Each module has its own resistive divider chain connected to both the cathode and the anode plane. Neighboring modules, however, are both mechanically and electrically isolated. This construction simplifies the production and installation of the field cage, and reduces the available energy during a HV discharge.

The example below shows that the electric field on the highest biased field cage electrodes can be controlled to under 12kV/cm using a specific metal profile even with only a 20cm ground clearance. To achieve electrical (HV) isolation, UHMW polyethylene caps are used to cover up the profile ends so the high field region is not directly exposed to the LAr.







Metal Profile HV Tests @ CERN

In order to verify this concept, a small test setup was constructed at CERN with profile to ground clearance of 6.7cm. The test results are:

Polished Aluminum Profiles:

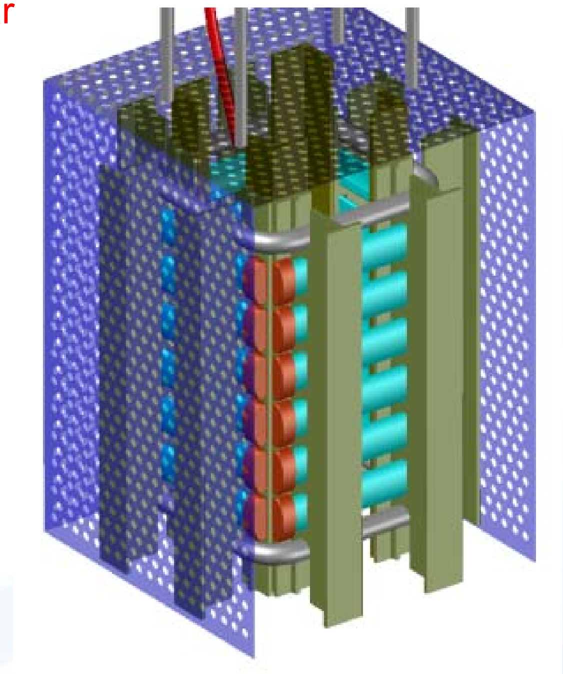
- Held voltage up to 100kV in clean LAr.

Scratched Al profiles:

- Held voltage up to 100kV in open dewar

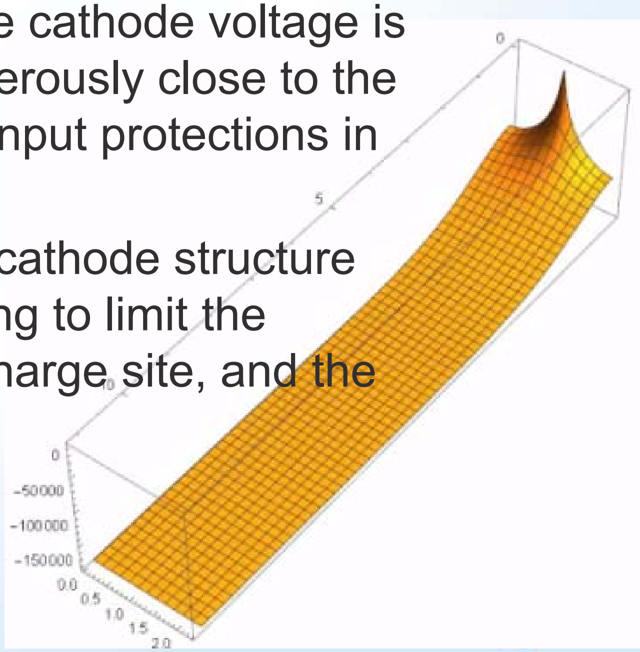
End Caps Breakdown Test

- Held 150kV in open dewar



Reduce the Risk of Charge Injection from HV Breakdown

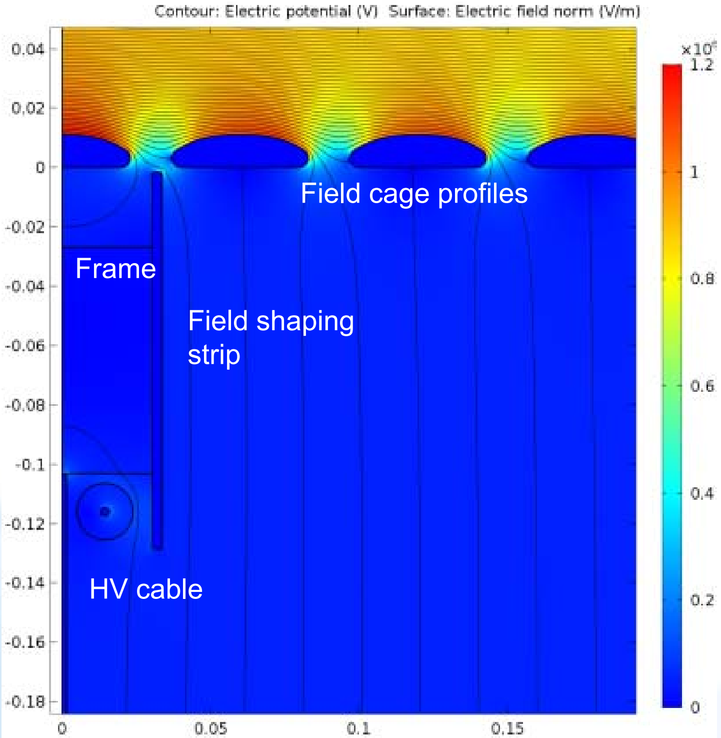
- Discharge mitigation study started from MicroBooNE and continues to understand on the system behavior of the DUNE SP Far Detector. See Veljko's talk on failure mode and system protection.
- A key finding from this study is that if the cathode plane is made from a good conductor, the charge injection from the cathode plane into the front end electronics channels during a high voltage discharge, when the cathode voltage is suddenly pulled to ground at a time scale of 10s of ns, is dangerously close to the threshold of causing damage to the electronics despite of the input protections in the system.
- One solution to this problem is to implement a highly resistive cathode structure such that the RC time constant of the cathode is sufficiently long to limit the instantaneous voltage swing to a very local area near the discharge site, and the rest of the cathode area follows at a much longer time scale.

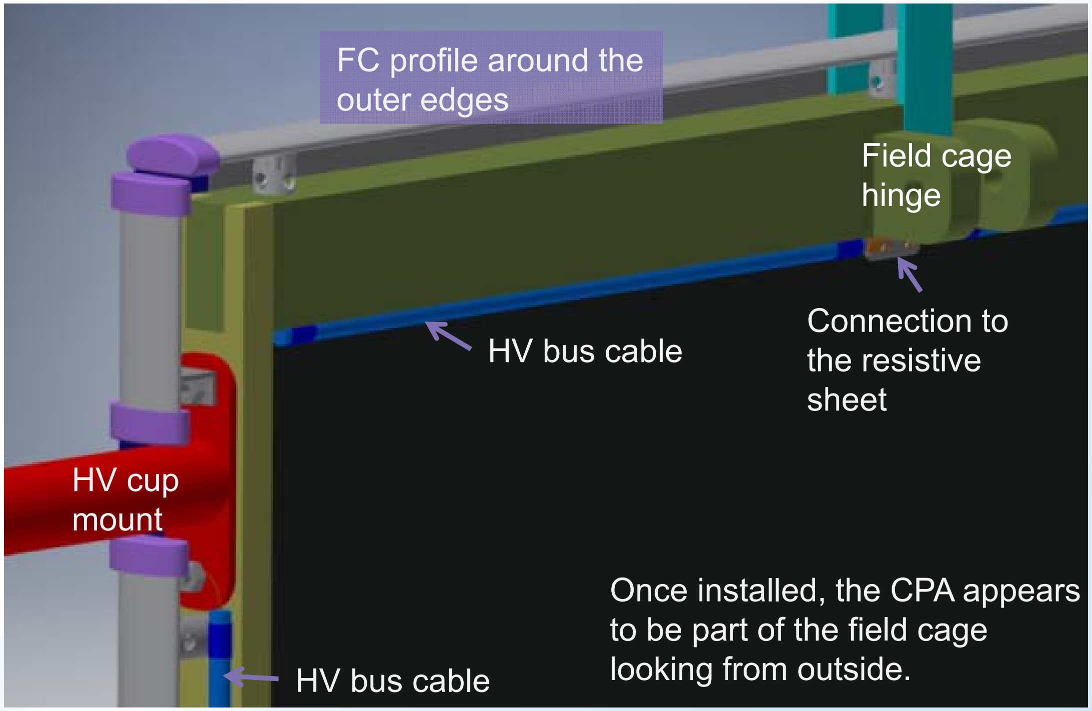


Potential distribution of a resistive cathode at a given moment after a HV discharge

A Resistive CPA with a HV Bus

- The NP04 CPAs are constructed from FR4 frame with 3mm thick FR4 sheets laminated with resistive Kapton film from DuPont (~4MΩ/☐).
- All frame surfaces facing APAs are covered with resistive strips with a different bias voltage.
- Outer edges of the cathode plane is surrounded by the metal profiles used in the field cage.
- A HV bus provides low resistance contact to all field cage resistive dividers



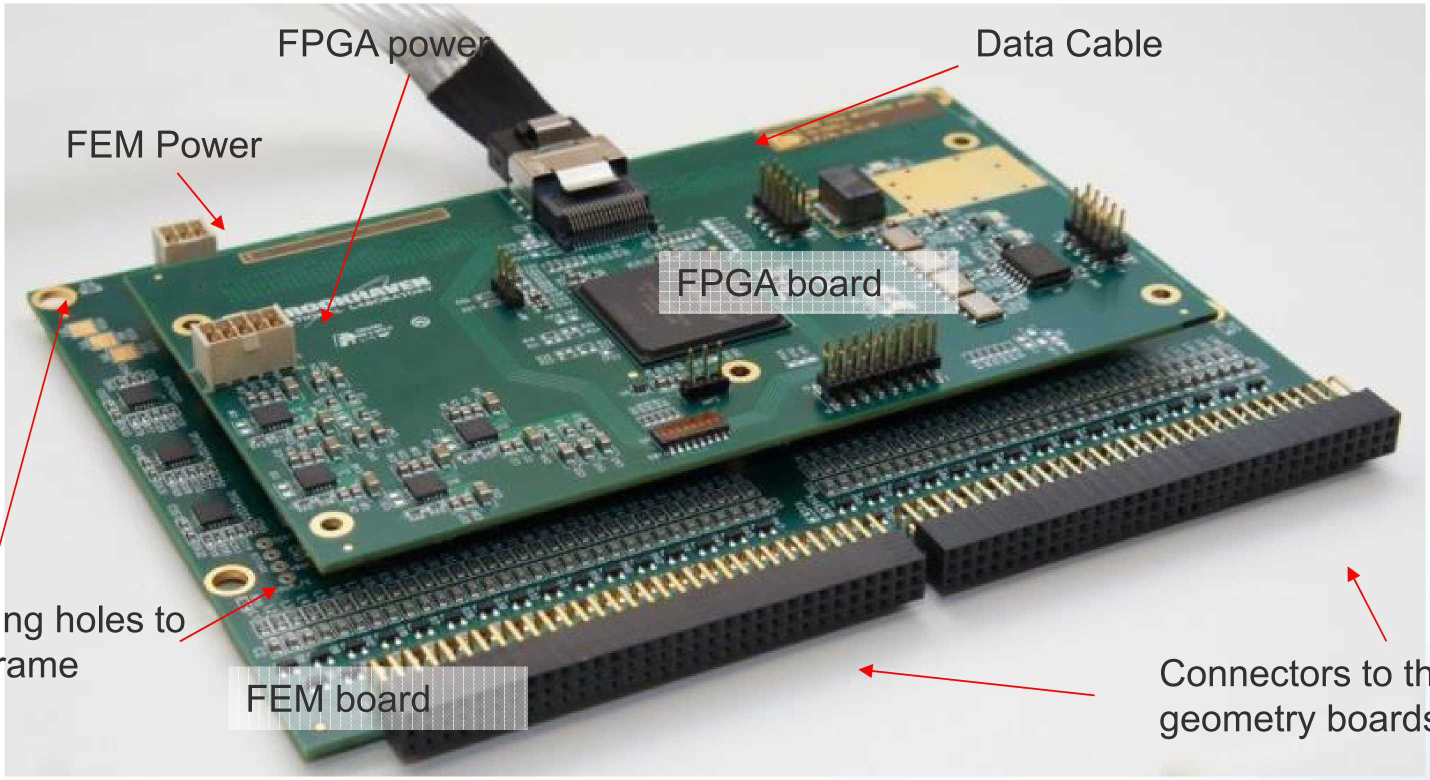


Summary

- Both the SBND and NP04 TPCs are in their final design stage. They share a common development team on the cold electronics subsystem, and share core members among the TPC design teams.
- NP04 is the engineering prototype for the DUNE SP FD and is designed to use the same modules (whenever possible) as the FD. In addition to its physics goals, SBND also serves as an R&D platform for DUNE in terms of technology validation and exploring alternatives.
- Several new technologies will be tested first time in a large scale in these two TPCs:
  - Cold ADC ASICs, cold FPGAs, real time monitoring and diagnostics of FEE
  - Modular and independent field cage design using open metal profiles
  - All resistive cathode to reduce the risk of charge injection in a HV discharge (NP04)
- Cold electronics is the enabling technology for large scale, high performance LArTPCs.

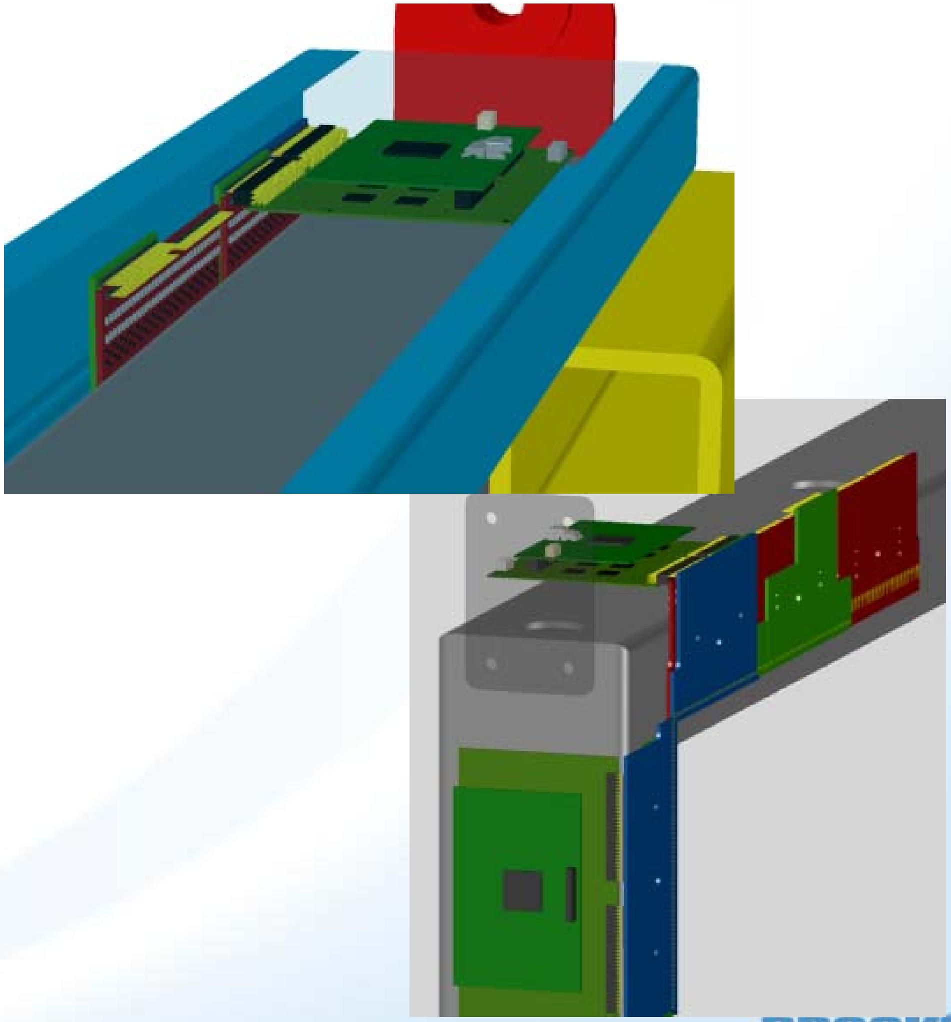
Backup Slides

SBND Cold Electronics Boards (top)



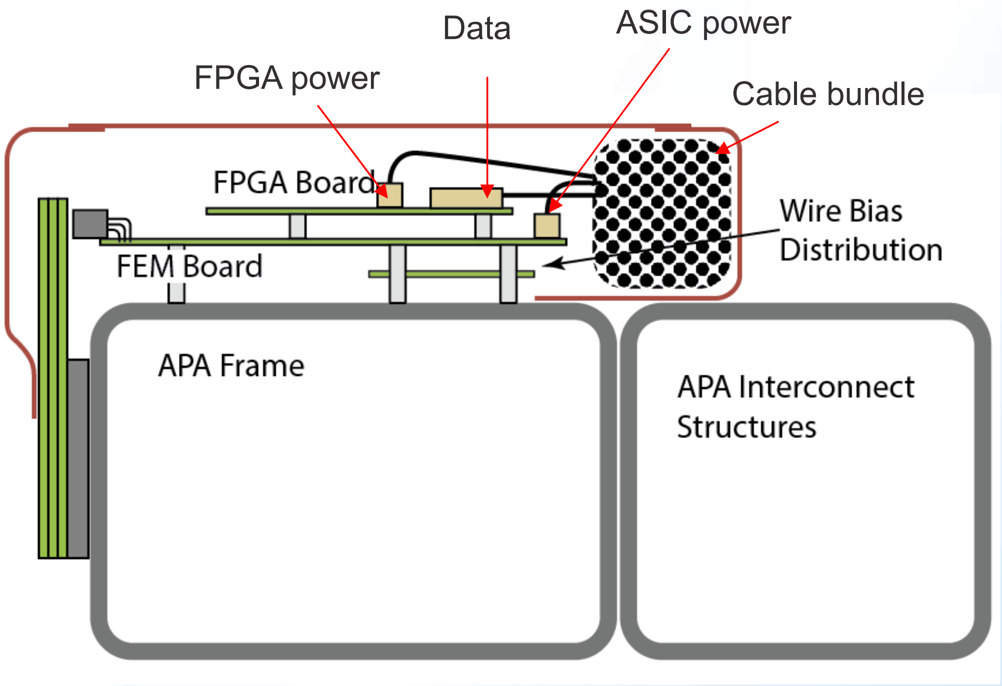
SBND Interface to Cold Electronics

- Interface to top bank of CE boards defined:
  - Input connectors
  - Mounting holes for ASIC board
  - Output cables lay in Faraday cage; two bundles at two upper corners of an APA pair.
- Interface to side CE boards not finalized.
  - 10 mounting holes with a regular pattern assumed in the current model.
  - Changed the side geometry board length to match the FEMB.

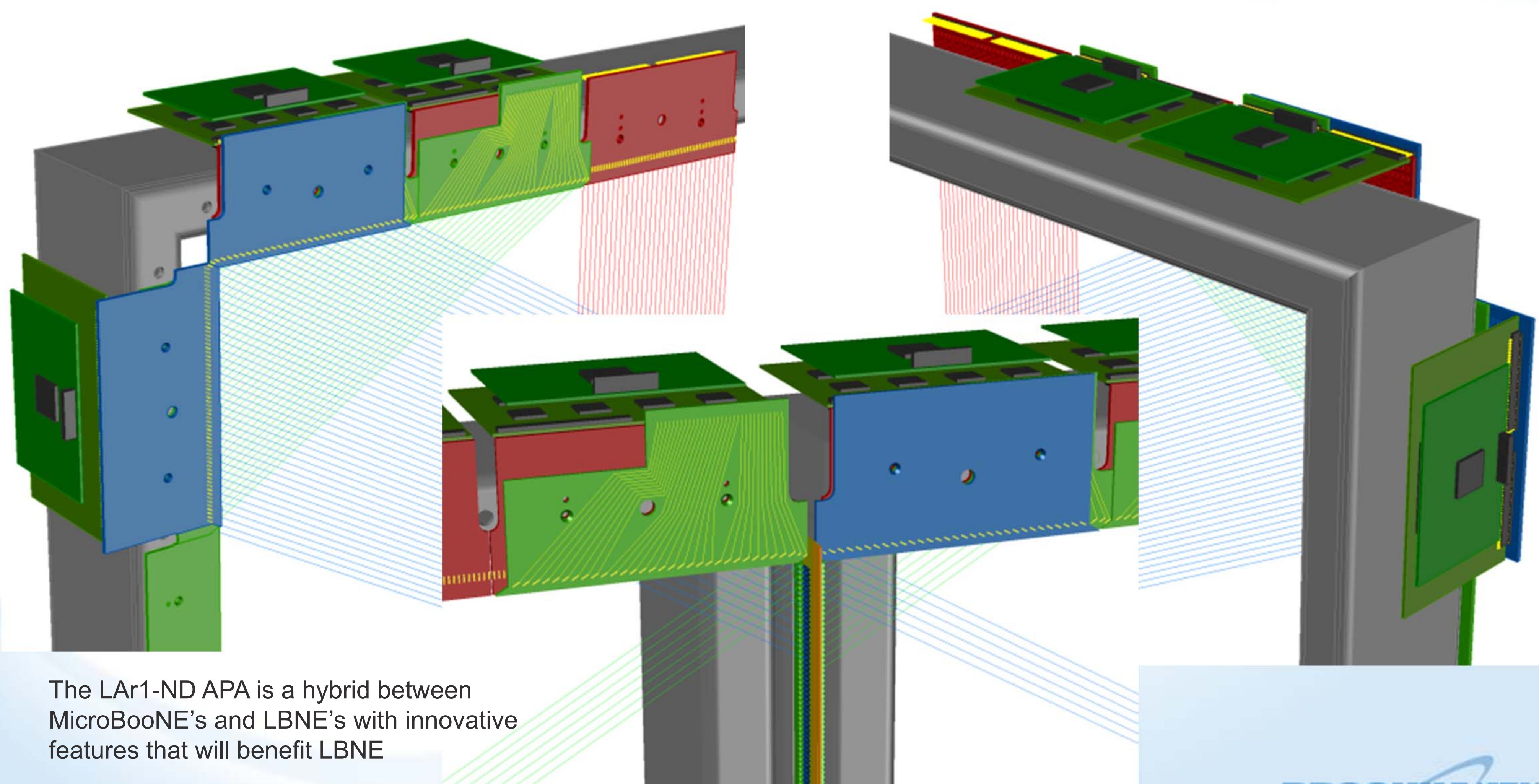


Faraday Cage

- 3 faraday cages are installed over the cold electronics boards.
- The top one has the outer cover perforated to allow gas escape.
- The side ones have solid covers to direct the gas up.
- Cables are routed inside the enclosure and exit at the top two corners of the APAs.
- FEM boards are grounded to the APA frame through their mounting hardware (screws and standoffs): ~ 2 per 10cm along the three APA sides.



The SBND Wire Frame (APA) Design

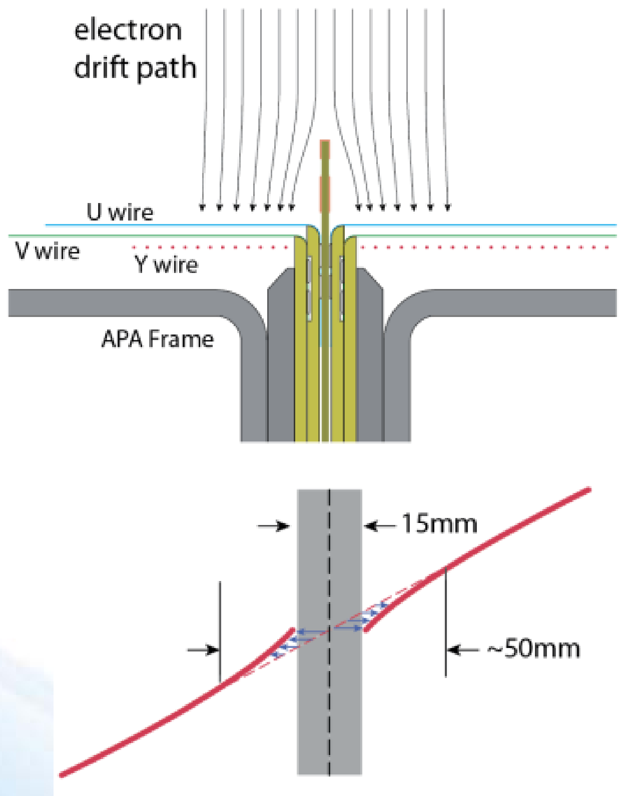


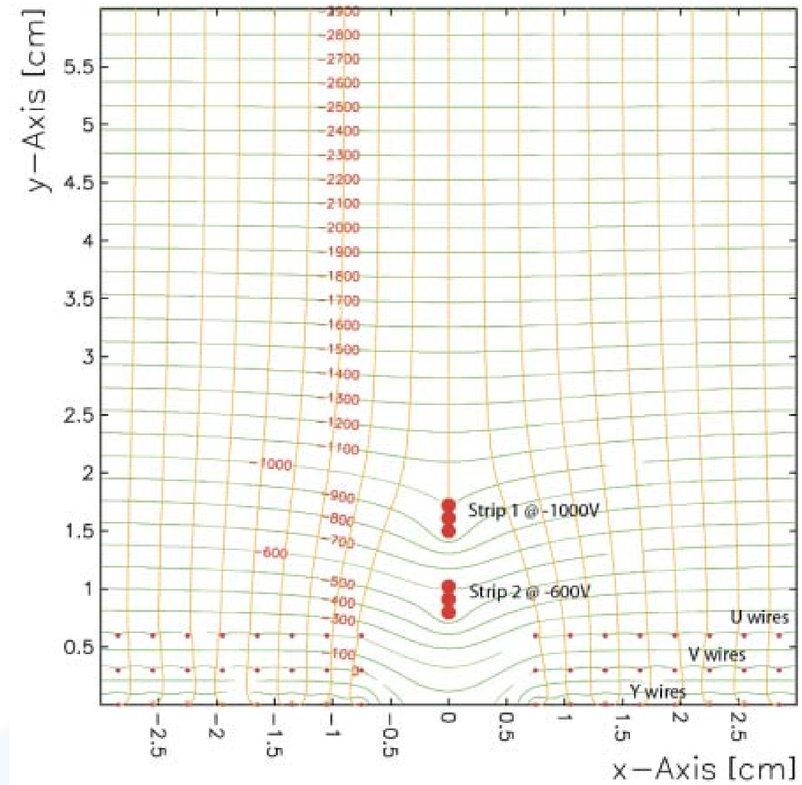
The LAr1-ND APA is a hybrid between MicroBooNE's and LBNE's with innovative features that will benefit LBNE

Eliminate the Dead Space between APAs

Problem: there is a 15-30 mm wide gap between the active areas of the two APAs

Solution: Add a couple of strip electrodes with proper bias voltages to deflect the incoming electrons into the active area

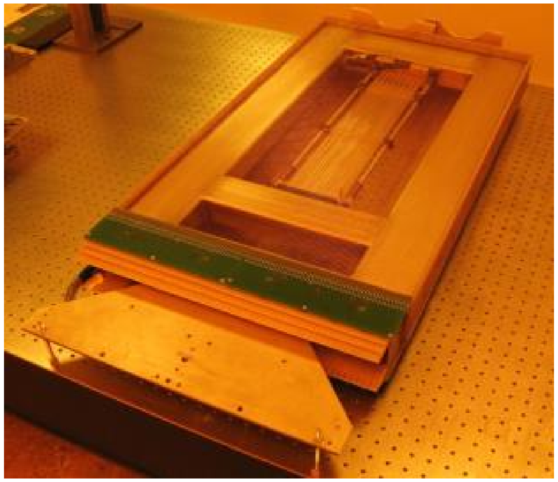




Simulation (Garfield) of the electron drift lines with the presence of the electron diverter.

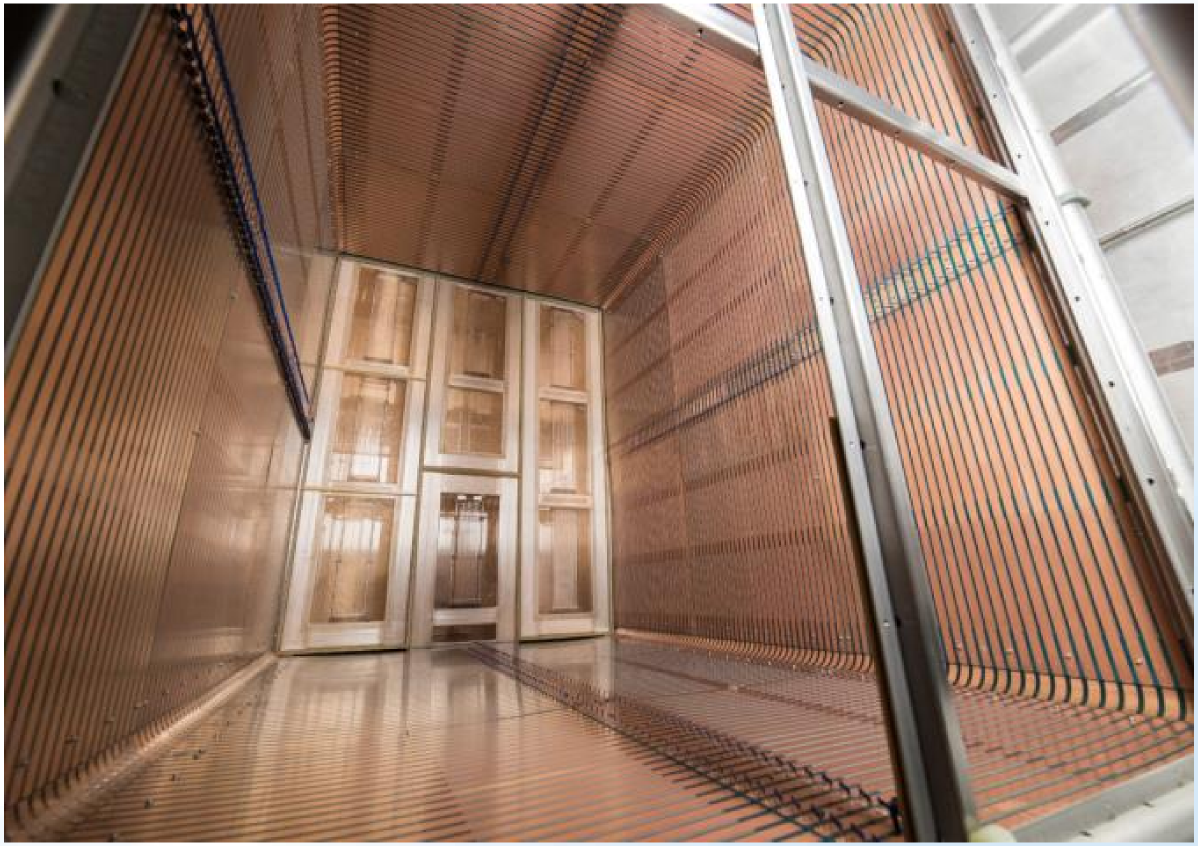
Electrode installed in 35ton

The Construction of the 35ton TPC



One of 4 APAs constructed by U. Wisc.

Portion of the field cage.



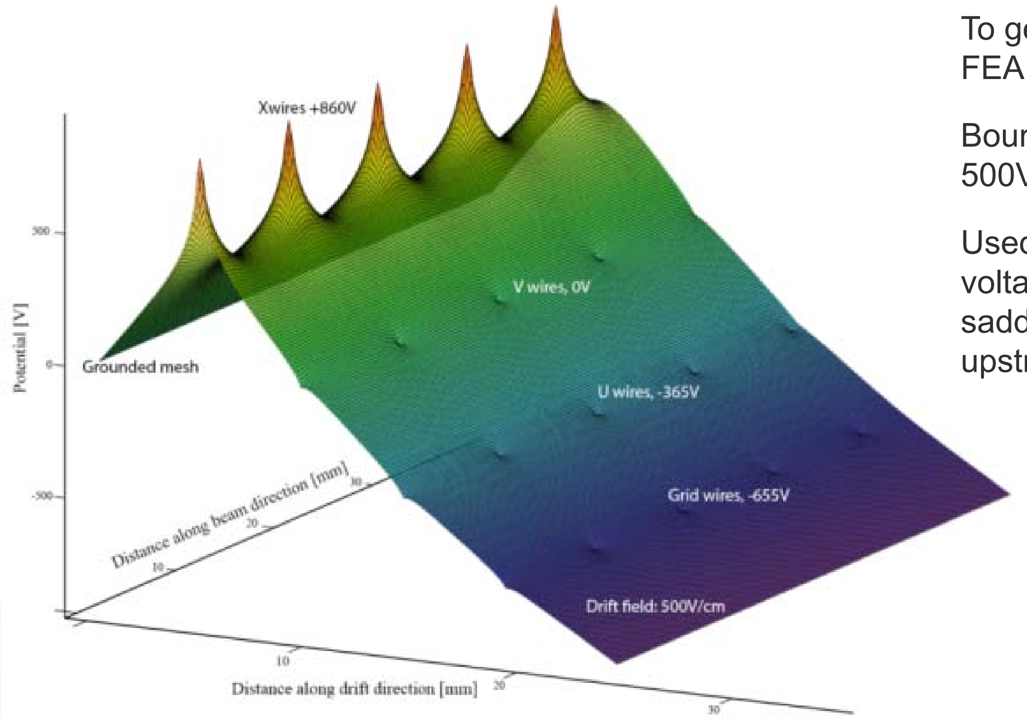
Bias Voltages on the Wires

Transparency condition: (O. Bunemann et al., Canadian Journal of Research, v A27 (1949) pp191-206)

$$\frac{E_2}{E_1} \geq \frac{1+\rho}{1-\rho}$$

Where $\rho = \frac{2\pi r}{d}$, d is the wire pitch and r is the wire radius.

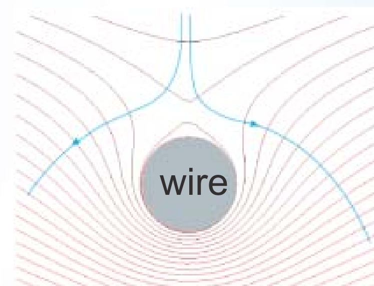
The field ratio needs to be greater than 1.22 for a grid with 150 µm wires at 4.7 mm pitch.



To get the field between the wire plane, we need to run electrostatic FEA.

Boundary conditions:
500V/cm drift, 0V on the mesh.

Used Maxwell 2D, adjust the bias voltages on the wire planes until saddle points emerge on the upstream side of the induction wires.



At 4.7/4.8mm wire pitch, the minimum bias voltages needed for DUNE are:
V_G = -655V
V_U = -365V
V_V = 0
V_X = +860V

For MicroBooNE/SBND:
V_U = -200V
V_V = 0
V_X = +440V

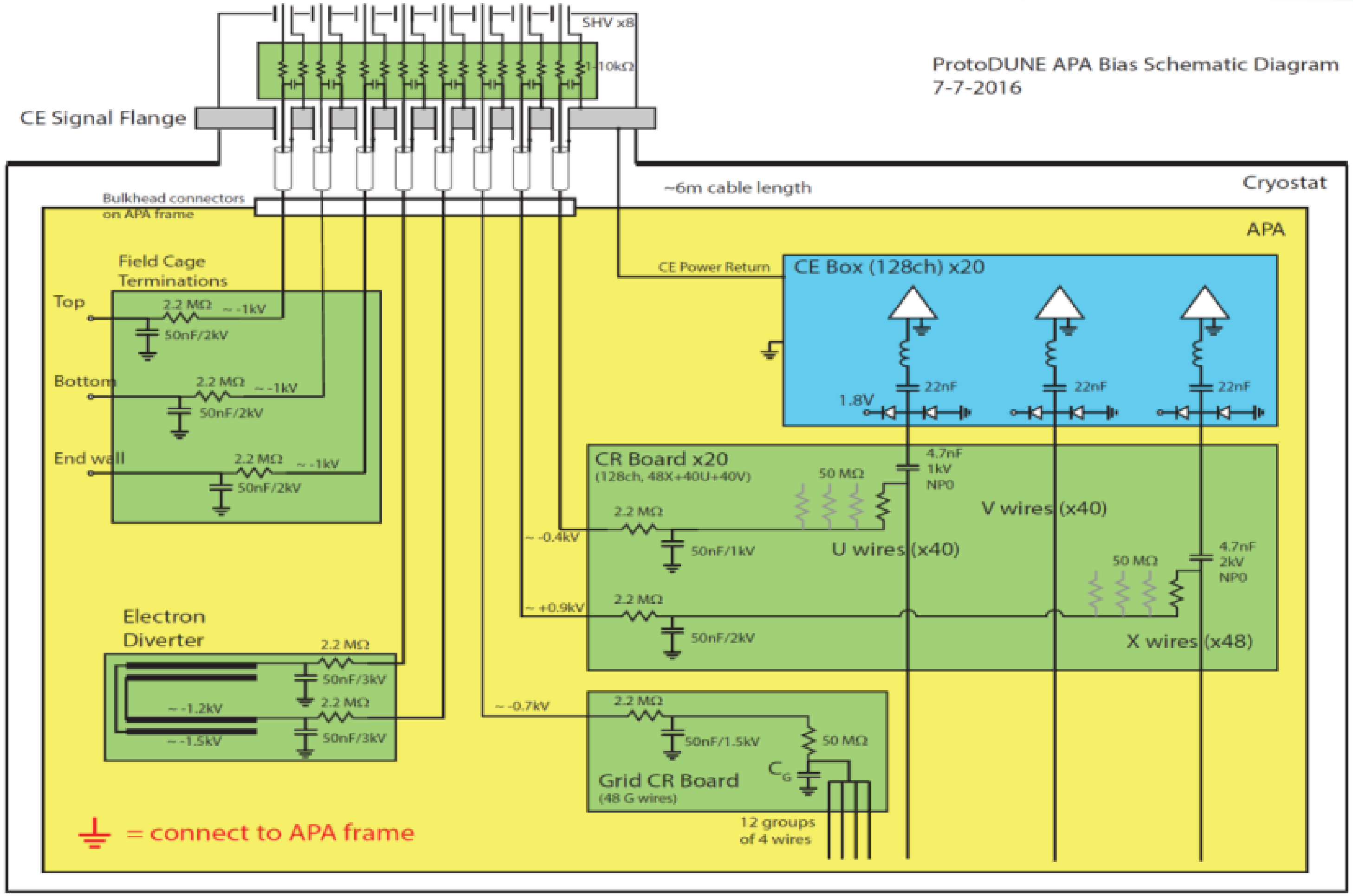
Glenn Horton-Smith has developed analytical calculations to derive the transparency conditions: MicroBooNE docdb 4708

ProtoDUNE APA Bias Schematic Diagram

Up to 8 SHV connectors are on the CE feedthrough flange.

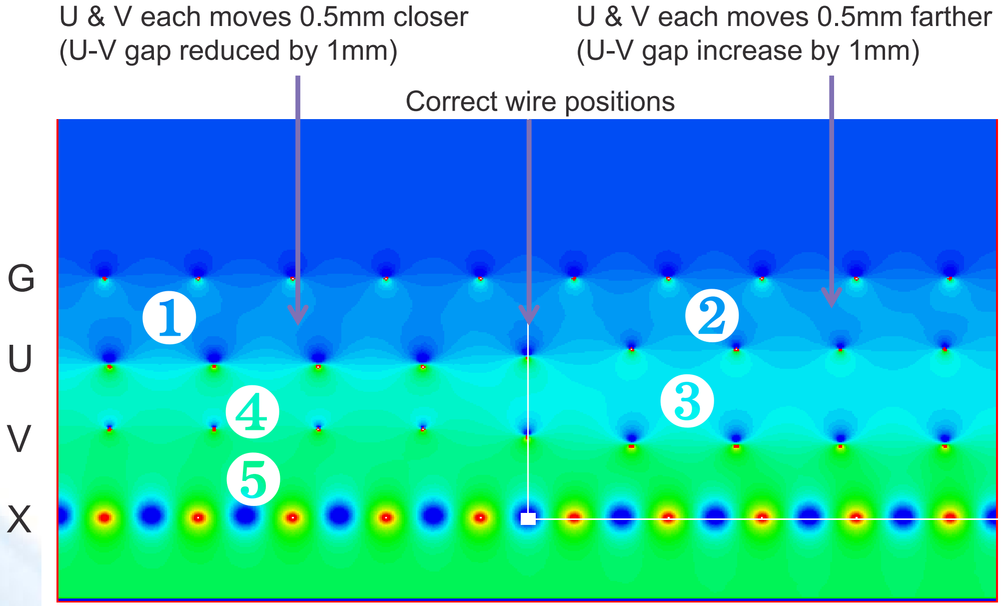
The cables (RG316) need to be terminated on the APA top end on a patch panel, with single ended wires reaching various connection points around the APA.

The filters for the field cage termination lines can be implements on a small PCB mounted on this patch panel.



Bias Voltages Sensitivity to Wire Plane Spacing

Here is an example of a possible wire plane cross section view due to a distorted wire frame: Grid and X wires remain at designed position, U & V wires moves by +/-0.5mm off designed position (a twist in the frame)



At nominal bias, the surface E field on the X wires is already about 20kV/cm!

This study was done with an old LBNE wire geometry. LBNE docdb 7370

❶ gap increases, field decreases. Must increase V_{GU} to pull all electrons through G

❷ field increases due to ❶ and smaller gap

❸ field ratio to ❷ is insufficient. Must increase V_{UV} to pull all electrons through U

❹ field increases due to ❸ and smaller gap

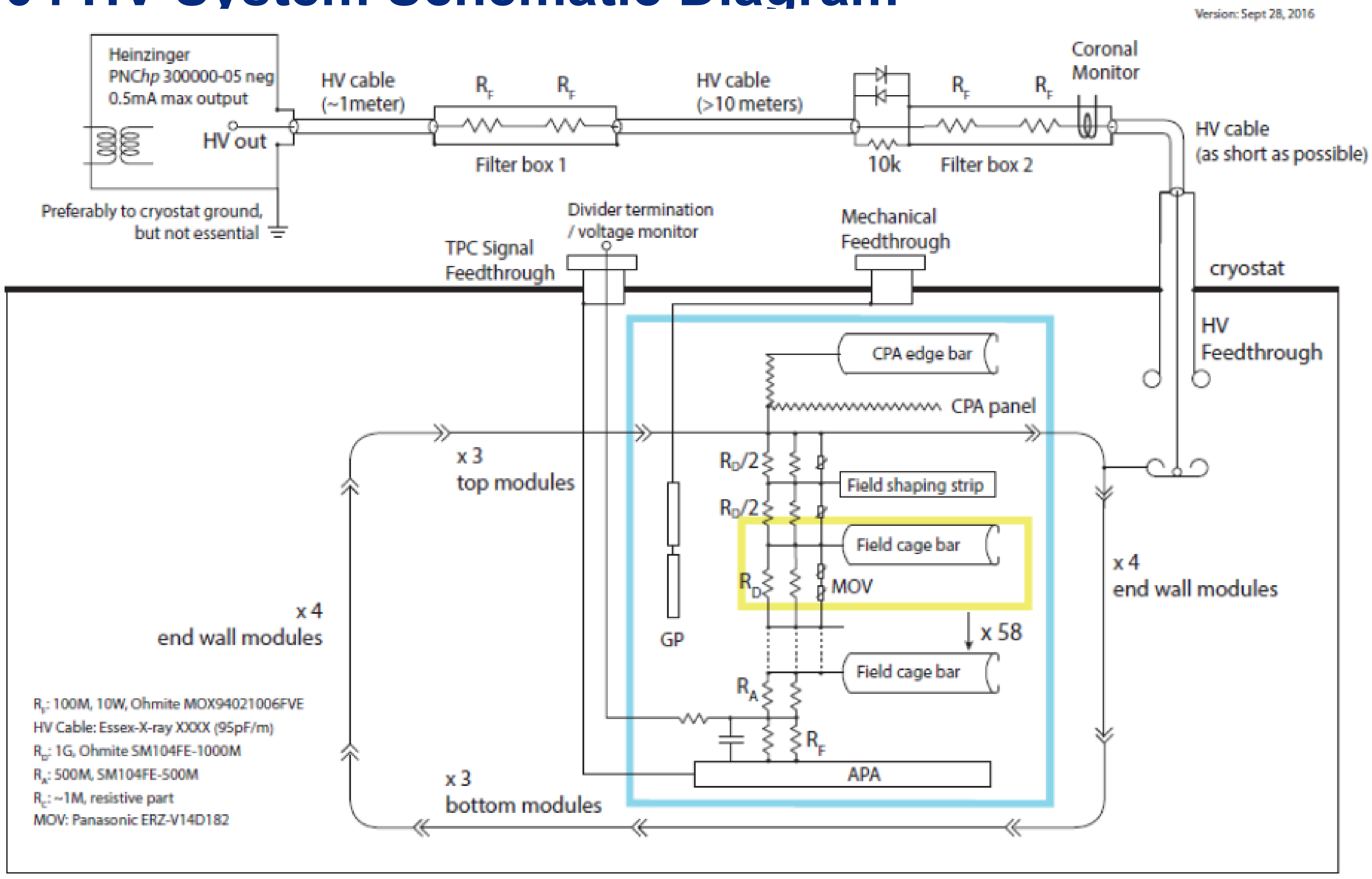
❺ field ratio to ❹ is insufficient. Must increase V_{VX} to pull all electrons through V

In order to be transparent on both sides of this view, the minimum bias voltages must be:

	+/- 0.5mm	+/- 1mm	nominal
Vg	-695	-700	-665
Vu	-415	-430	-370
Vx	+1150	+1600	+820

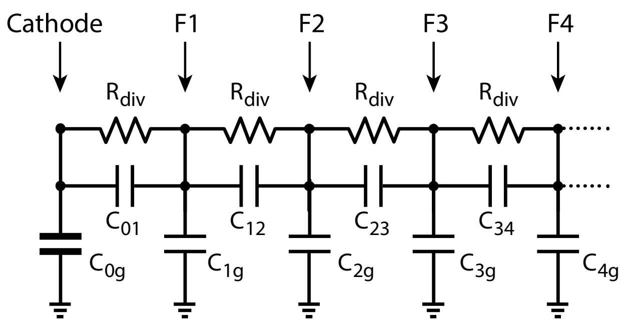
If we don't tightly control the wire plane spacing, we might have to dramatically increase the bias voltages in order to maintain transparency everywhere on the APA. Higher bias voltages require larger, hard to find and expensive capacitors.

NP04 HV System Schematic Diagram



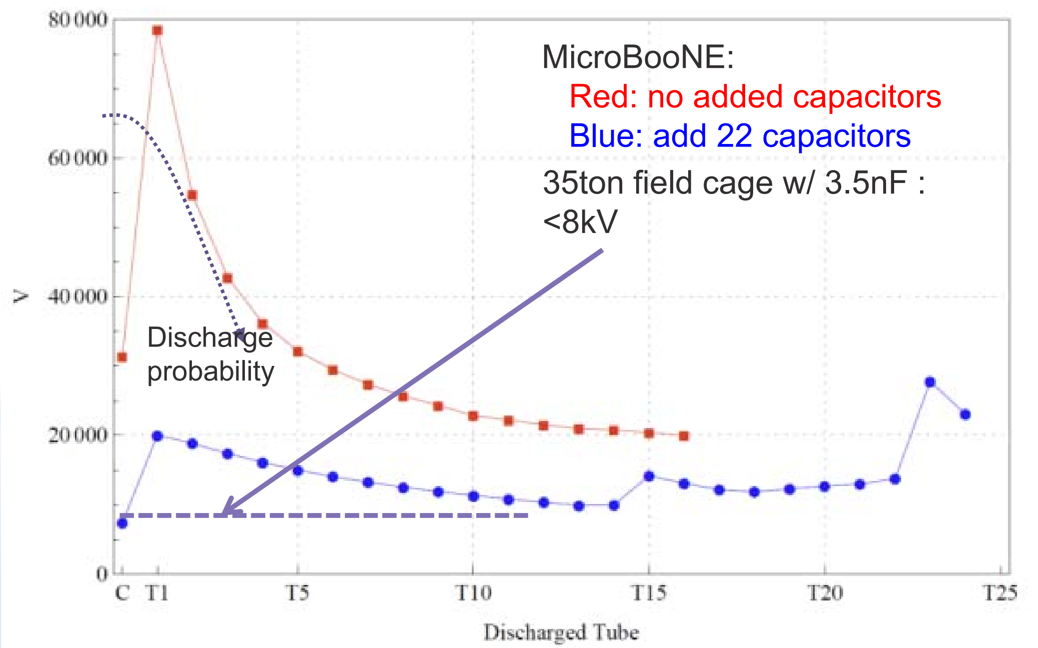
TPC System Transient Response in a HV Breakdown

Field cage equivalent circuit

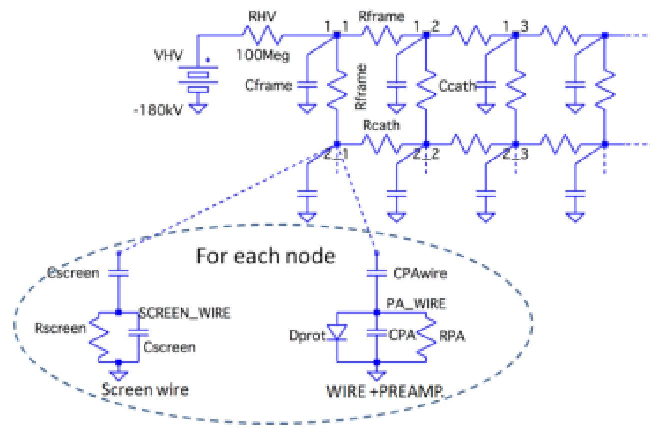


Typically $C_{xy}<C_{xg}$

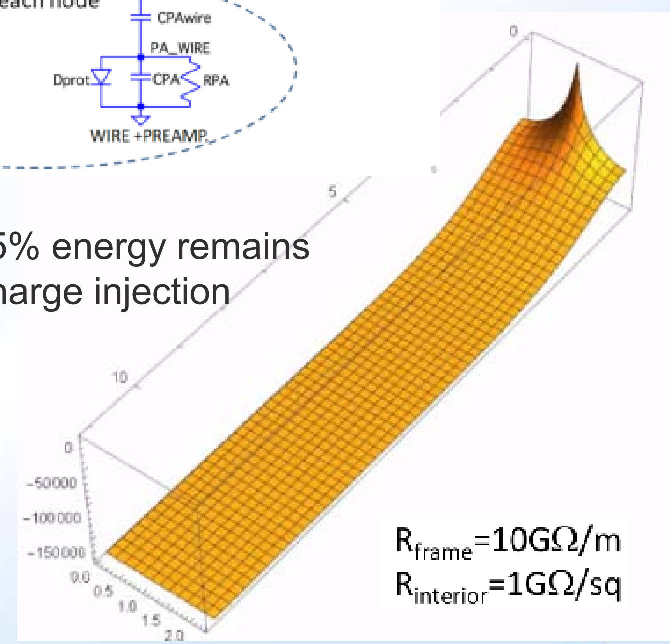
Need to have $C_{xy}>>C_{xg}$ to be a good divider in AC



Resistive cathode equivalent circuit



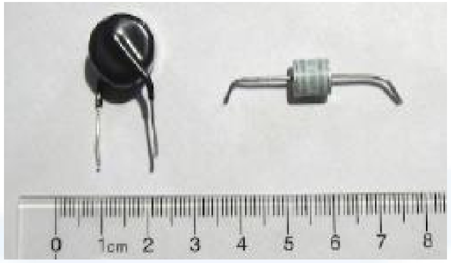
@200ms, 85% energy remains
Negligible charge injection



S. Rescia, DUNE docdb 1320

Surge Suppressor Studies

- An alternative to adding capacitance between divider nodes is to use surge protection
- Extensive tests have been done by MicroBooNE (docdb 3242, arXiv:1406.5216v2) on the use of varistors and GDTs (gas discharge tubes) as a mean of limiting the over voltage condition in the event of a HV discharge in the TPC.
- Both types will work for the purpose of restricting the voltage differential between field cage rings in LAr temperature.
  - A GDT quickly shorts the terminals when the voltage differential exceeds a threshold
  - A varistor changes its resistance to keep the voltage differential near the threshold voltage.
- The smooth transition and well defined clamping voltage of the varistors are preferred to the abrupt switching of the GDTs.
- The varistors would also function as redundant "resistors" in a divider chain.



Left: varistor
Right: GDT

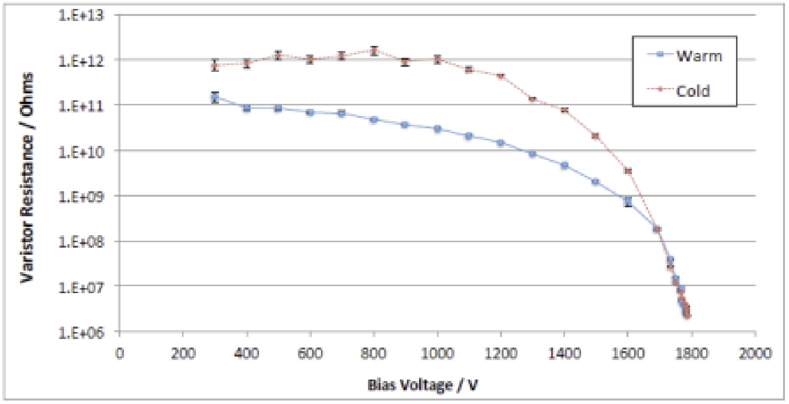


Figure 20: Effective resistance for the Panasonic ERZ-V14D182 varistor operated warm and cold, as a function of the voltage drop across the device.

SBND's Calibration Laser Configuration

- A new calibration laser beam configuration promises nearly full 2 beam coverage in the TPC active volume. It requires a double mirror configuration in the laser periscope, and minor modification of the field cage structure.