131.ND.02.04 Field Structure: Mechanical Design

Knut Skarpaas VIII, Mechanical Engineer- SLAC

ND-LAr Preliminary Design Review

28 June 2022

Who am I

Knut Skarpaas VIII

Designing physics detectors for 32 years (the last 29 years at SLAC)

For the private sector, for **Synergistic Detector Designs**, I designed and oversaw construction of x-ray inspection systems and robotics for – **Battelle** (x-ray camera), **Los Alamos National Lab** (large camera and positioning system), **Westinghouse** (x-ray camera), **United Airlines** (turbine blade weld inspection robot), **Pratt & Whitney** (turbine blade inspection robot), **Bremerton Naval Shipyard** (Ti reclaiming robot), **Unisys** (satellite PC board inspector – 8 axis robot with custom camera), **Chrysler** (transmission gear weld inspection robot), **Toyota** (air bag inspection line), **DuPont** (mammogram collimation robot), etc…

For SLAC-
I designed the vertex detector named **VXD3** for **SLD** along with the first meter of beam pipe in each direction (run at 165K)
(mechanical and electo-mechanical, thermally stabilized – low mass structures – including beryllium metal stiffened flexible circuits)
for Marty Breidenbach and Chris Damerell
I updated and re-built an electron gun for Al Odian and Artem Kulikov (we got to 289kV)
I created a variety of instruments for Charlie Prescott
I was the mechanical reviewer for the **BaBar** SVT detector at LBNL and was recruited to design their novel water cooled Be beampipe
I was selected by Daniel Lehman to serve as the silicon tracker mechanical reviewer for **ATLAS** and **CMS** in their early days
I designed many small detectors including a few time projection chambers to build up to **EXO-200** (in liquid xenon).
I did the mechanical and electro-mechanical designs for the **EXO-200** experiment including-
The ultra low background EXO time projection chamber(s) along with flexible circuit wiring, the calibration system, the seals, the pressure vessel, etc...
I created the “hanging basket TPC” concept used for the **nEXO** detector as well as the initial nEXO design
I did cryogenic HV cable experiments (polymer core up to about 130kV) for Peter Rowson and Ralph DeVoe
I designed the “extraction region”, and grids for the **LZ** time projection chamber (liquid xenon) as well as the concept and mechanical design of the robotic loom
I joined **DUNE** in November of 2018 and worked to integrate multiple systems into the **2x2** format
I created tooling and instruments to assist with the lamination and the testing of field cage panels
I did the mechanical design of the **SLAC Cube** which is 1/16 of a 2x2 module
I have been morphing the concepts of 2x2 to fit the **ND** detector size

Outline

- Overview
- Charge tile interface
- Light collection interface
- Calibration interface
- Module support interface
- Field cage options
- HV input
- Summary

ND LArTPC Module Design

The Field Structure-

The field structure serves many purposes-

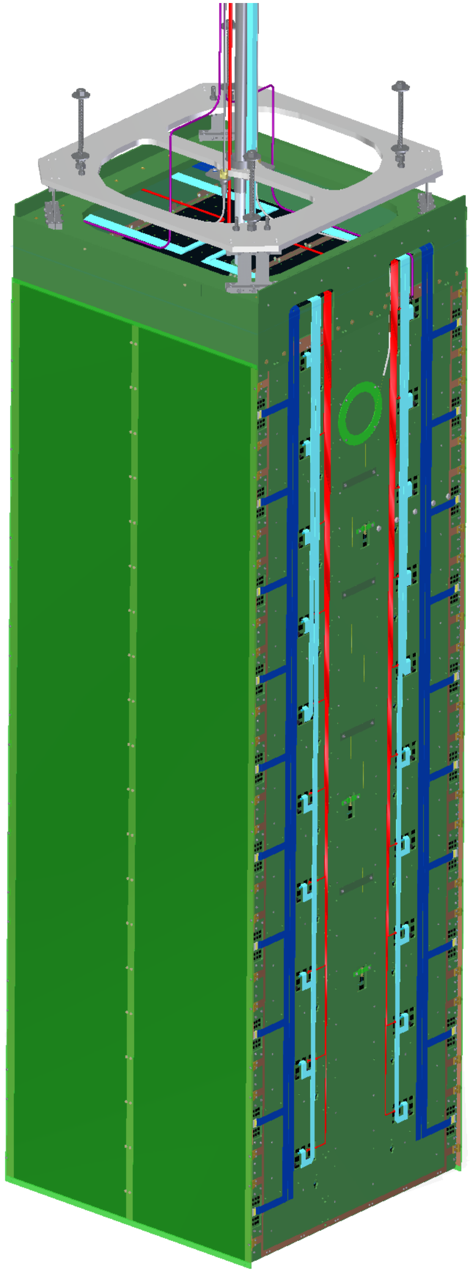
- It is a frameless unibody to which all detector systems are mounted
  - Charge tiles mount to the anode support plate
  - Two different light collection systems mount to the anode support plate with interleaving circuit boards
    - Features at the cathode permit guided thermal contraction of the light systems
  - The calibration system mounts to the anode support plate
  - The liquid level system mounts to the anode support plate
  - The cathode is mounted to the center of the sidewalls
    - The top of the field cage accepts the HV input from above

- The field structure must create the desired electric field

- The field structure provides a support path and location for module mounting

- The field structure provides a current path for the HV return

- The field structure provides a ground / shield plane for the LArPix electronics



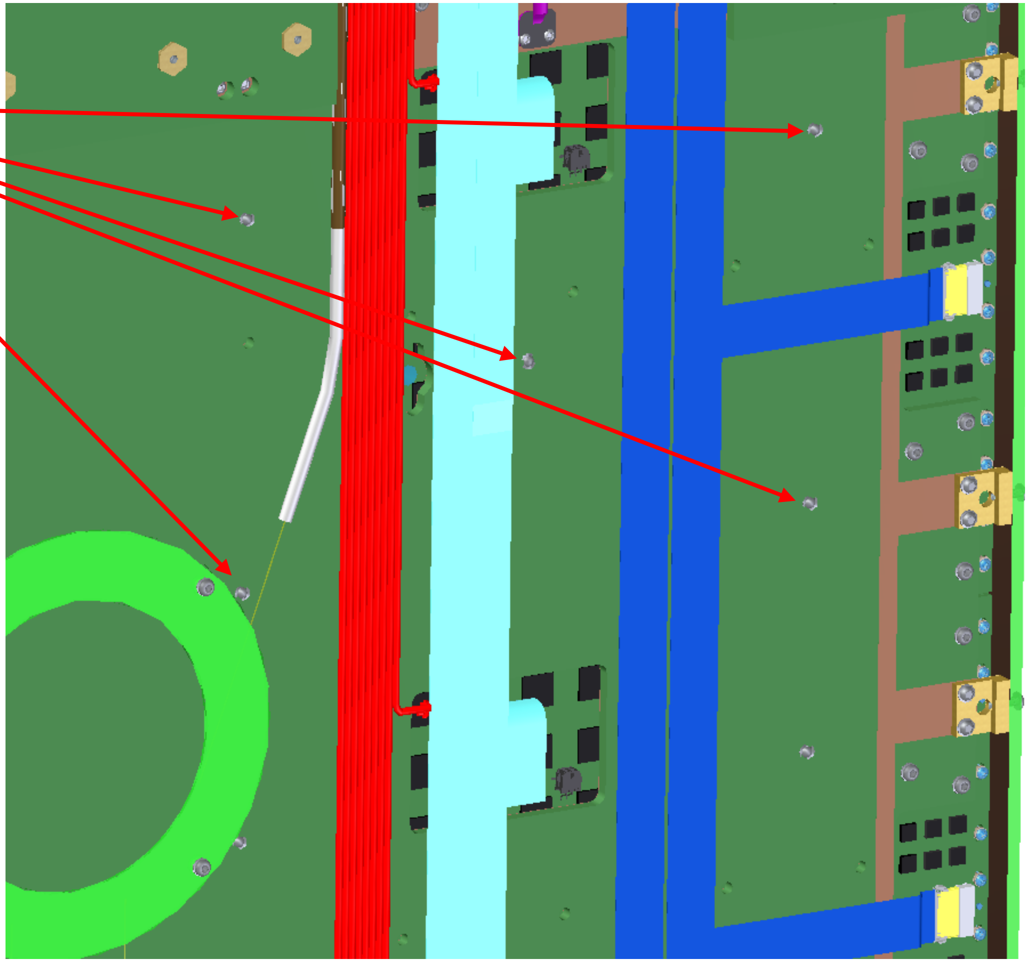
ND Module-
(consists of a field structure with two drifts and other detector components)

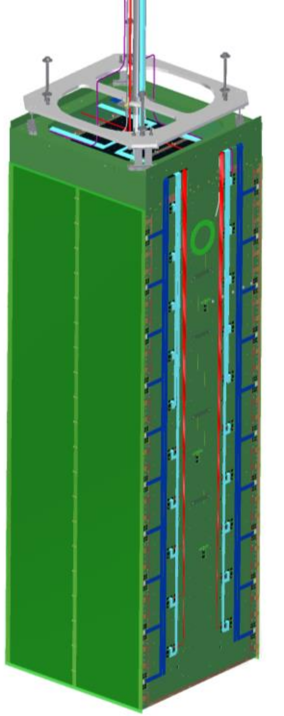
ND LArTPC Module Design

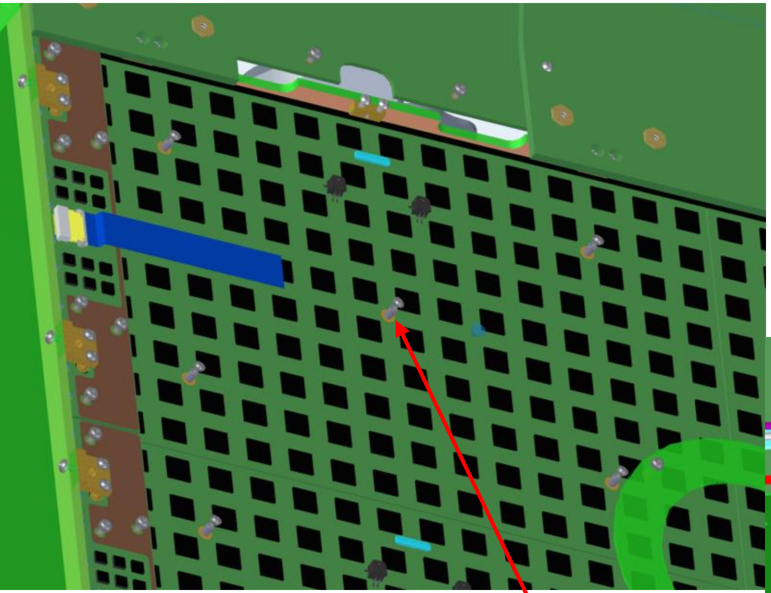
The Field Structure-

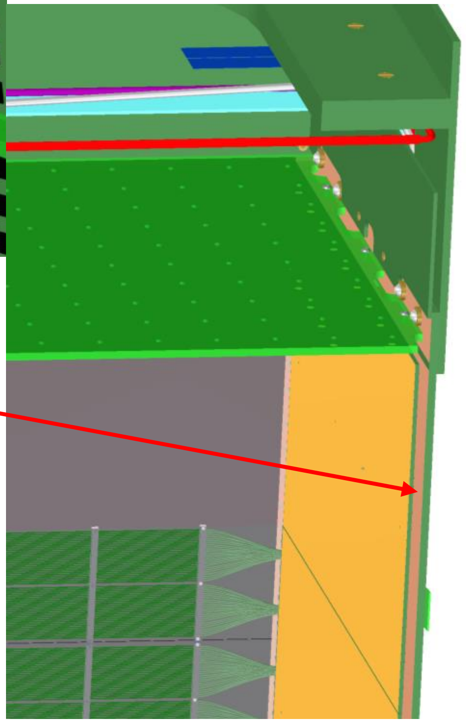
Charge tile support

Each LArPix tile is mounted to the anode support plate with 5 screws to help reduce warping

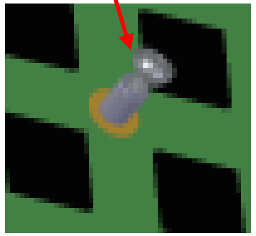






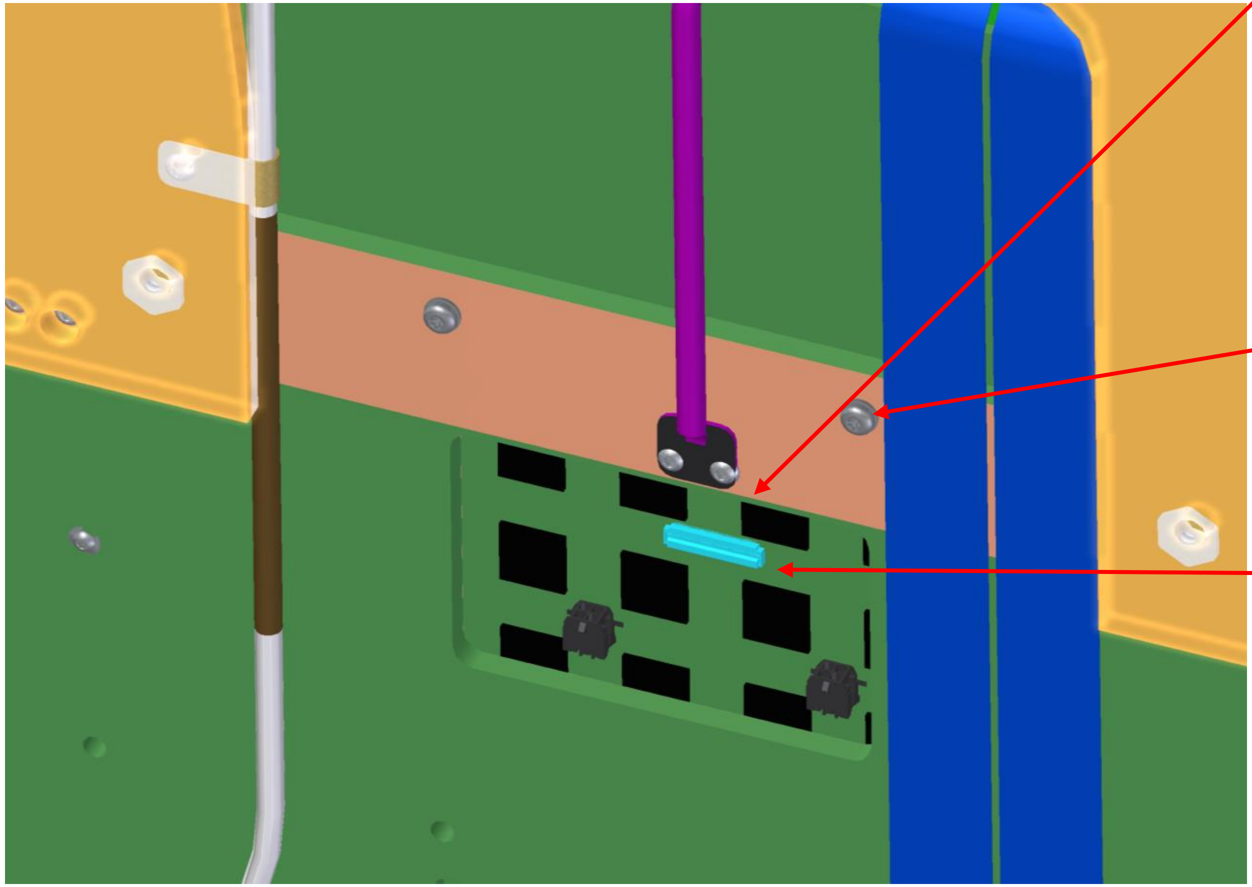


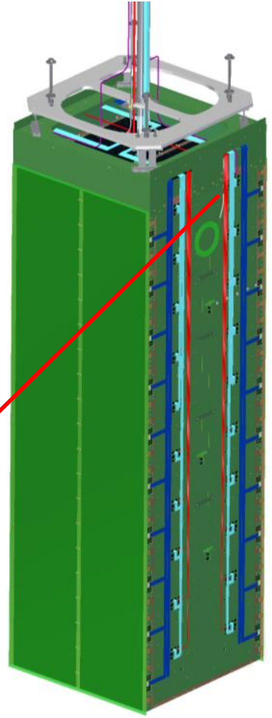
Standoffs on the LArPix board provide clearance for the LArPix electronics and the adjacent light collection PC boards as well as a conductive path to the inner metal ground plane on the anode support plate



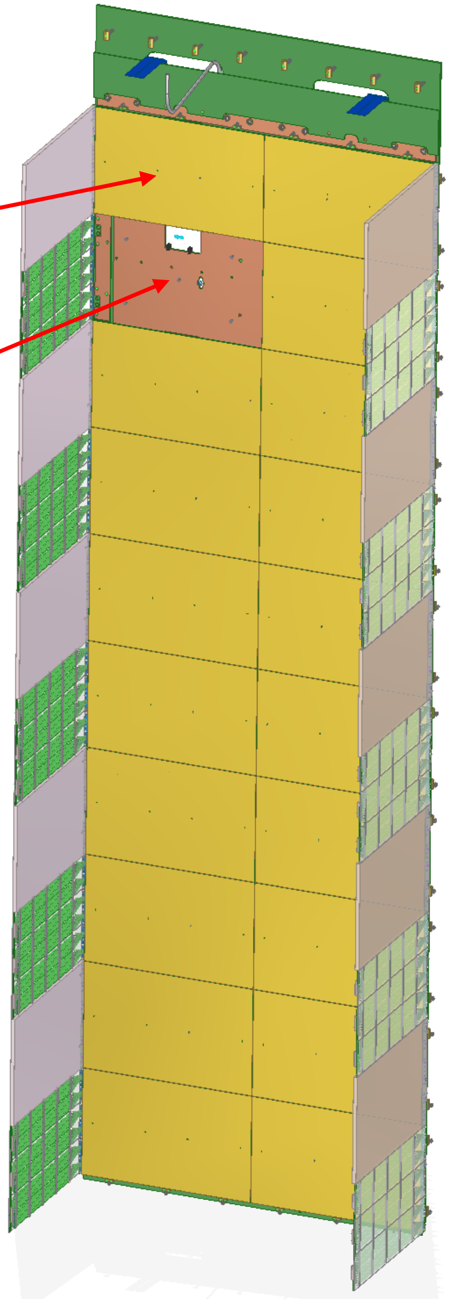
ND LArTPC Module Design

The Field Structure-
Charge tile interface





20 LArPix tiles are mounted to the anode support plate prior to module assembly
The panel is held flat with tooling to assure the tiles see no shear forces from panel flex



A LArPix tile is removed here to show the anode support plate metalization which provides a LArPix ground plane

Screws with the same thread size which have different lengths require different tools so proper assembly can be checked from outside without removing parts (different head types)

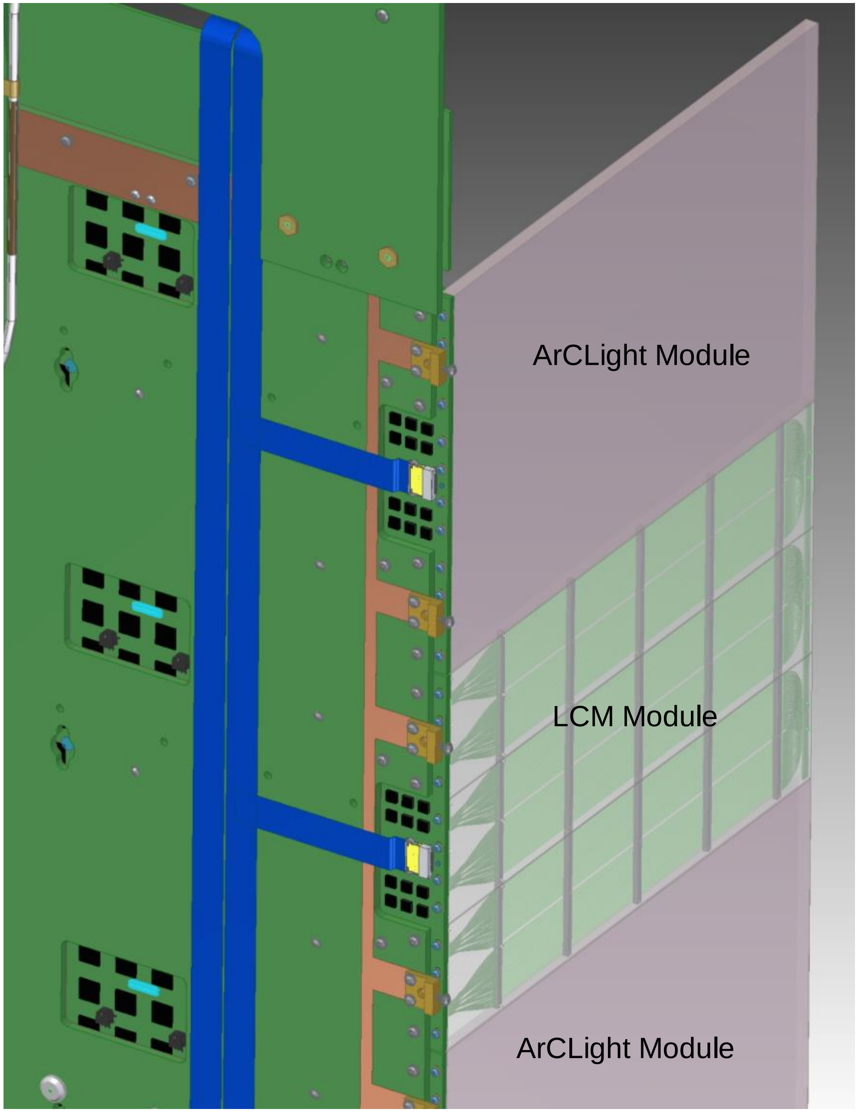
The anode support plane was designed so that connectors to the LArPix tiles could be installed and removed without taking the TPC module apart –

Ease of assembly and testing is a common theme for the module design

ND LArTPC Module Design

The Field Structure-

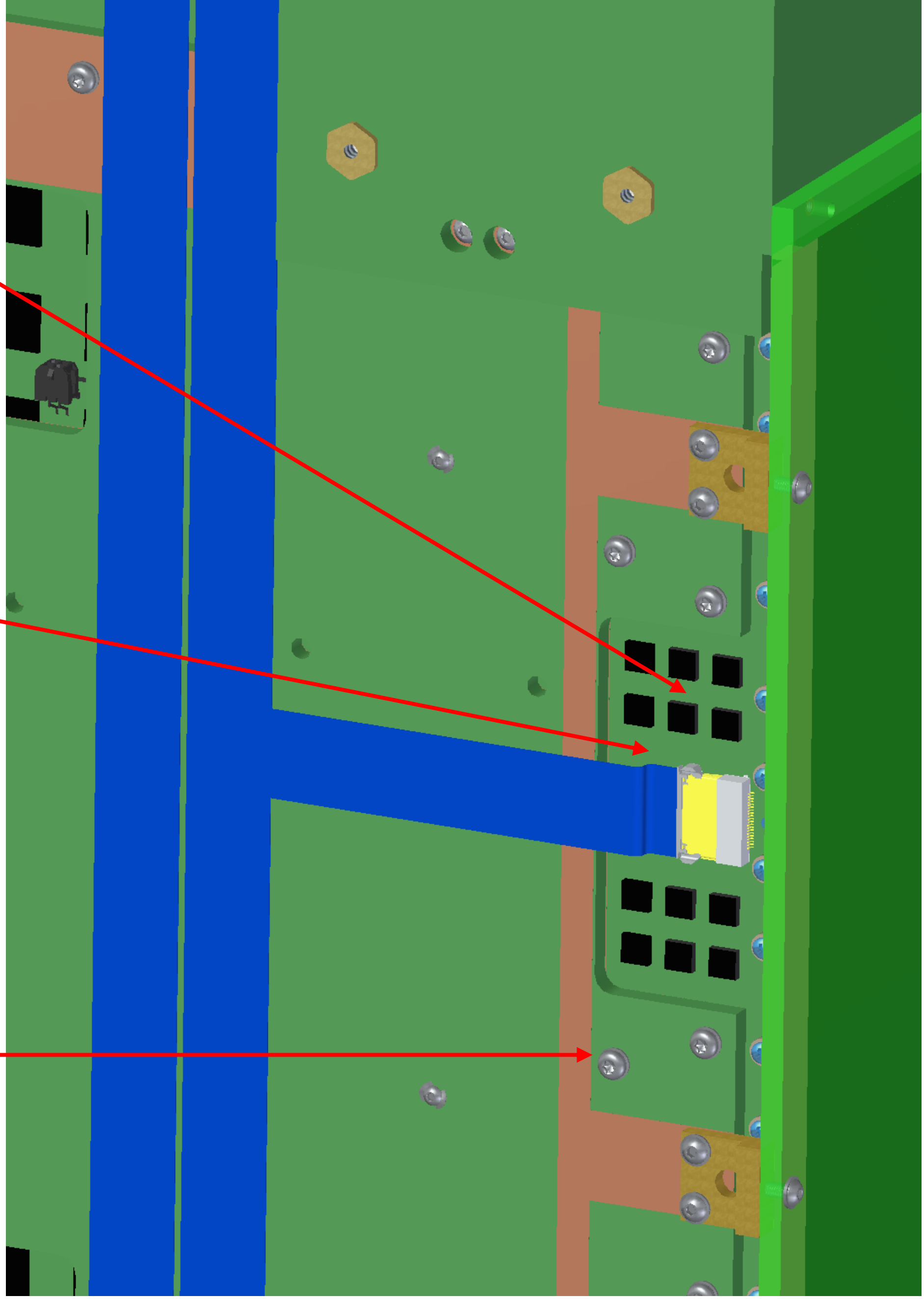
Light collection mounting interface



Combination PC board for the light collection systems (both light collection systems can use the same board and mount)

The anode support plate is notched to accommodate electronics and cable connectors for the light collection systems while maintaining a very low profile

Mounting screws for the light collection systems- Screws terminate in pressed in tee-nuts

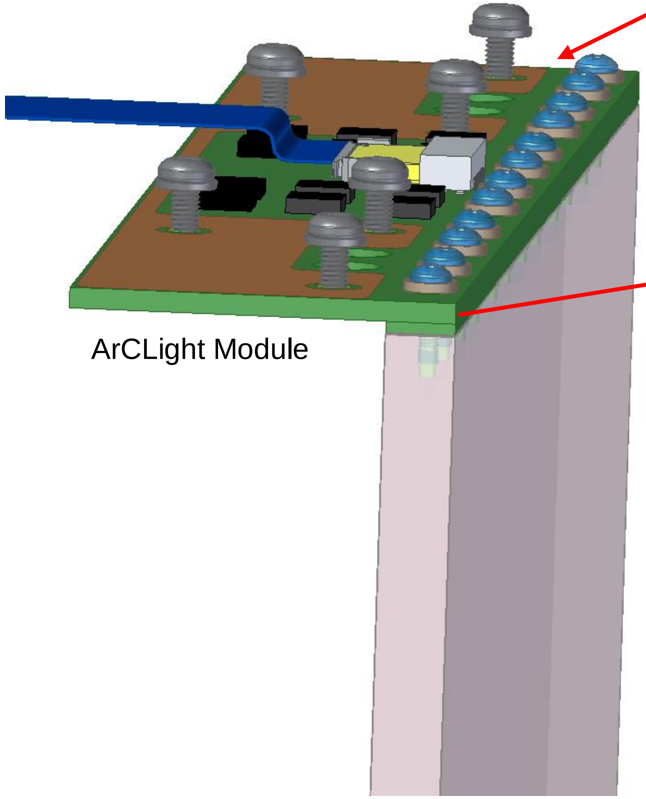


ND LArTPC Module Design

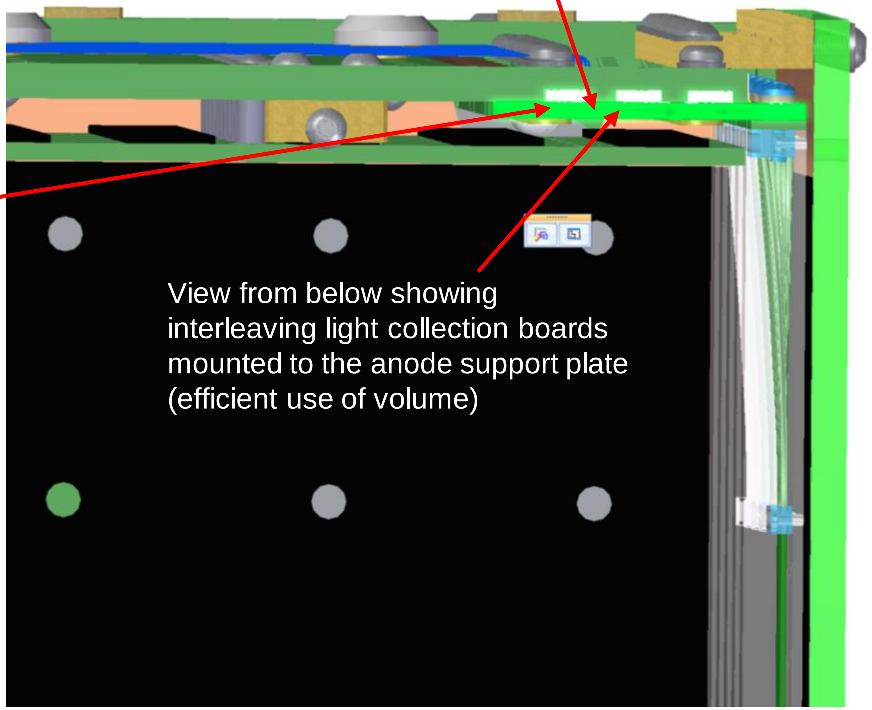
The Field Structure-

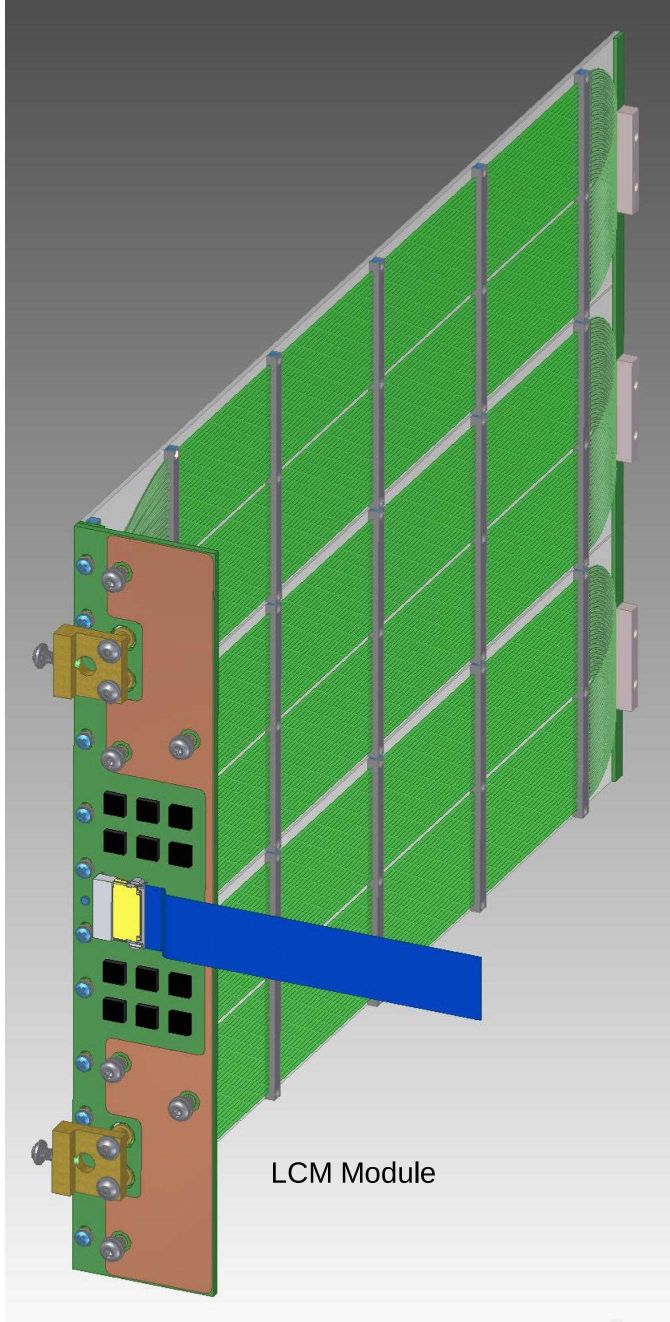
Light collection mounting interface

ArCLight and LCM modules share a common PC board and mounting interface to simplify the anode support plate and to reduce part counts (and spares)



ArCLight Module



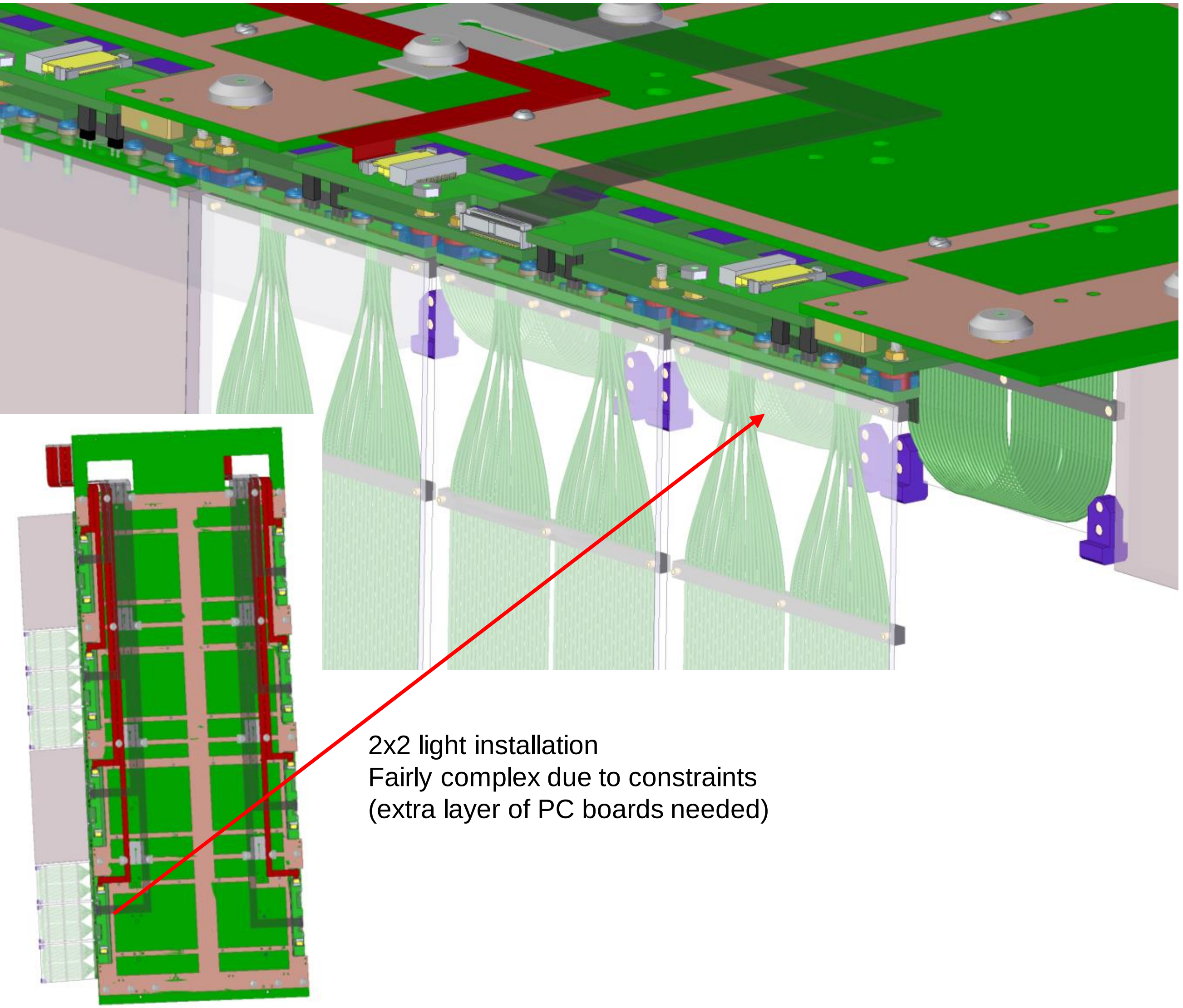


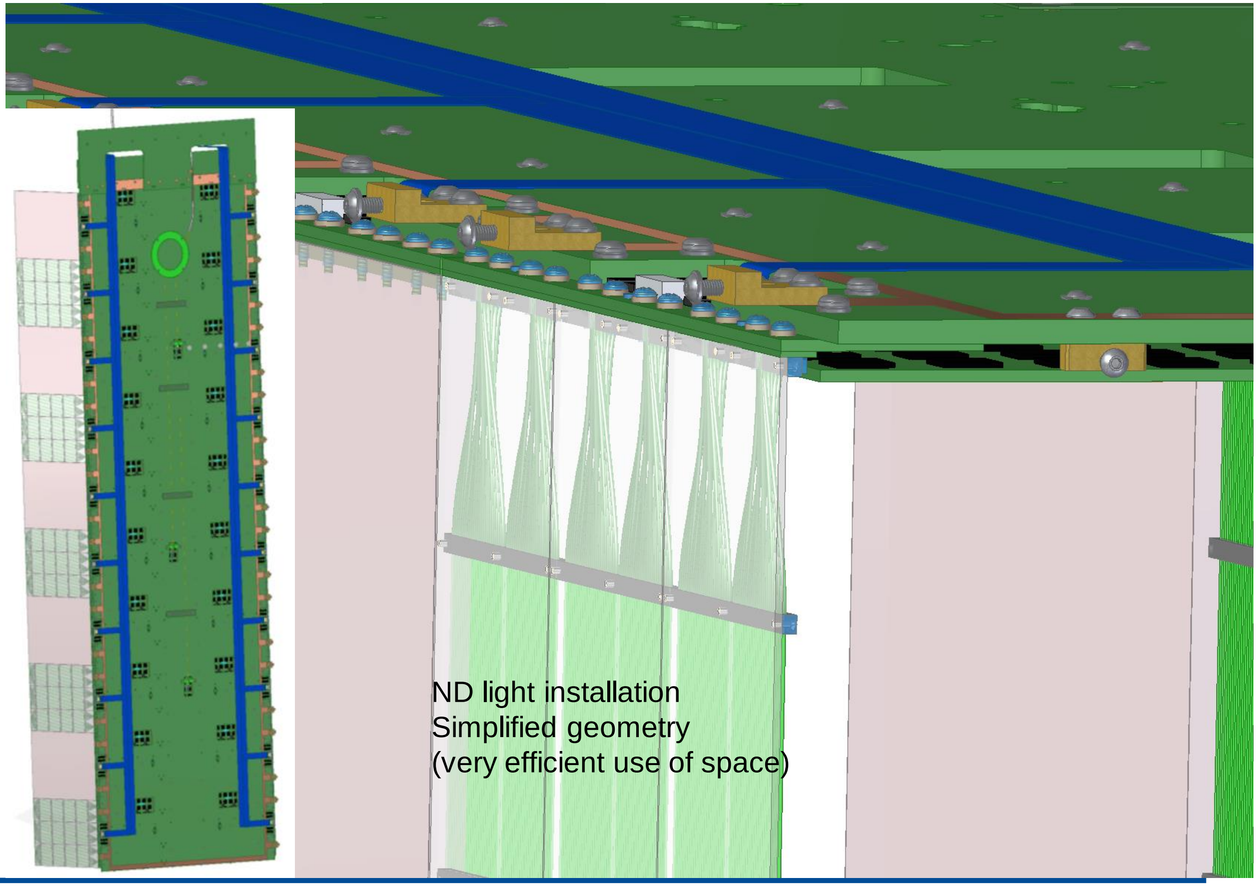
LCM Module

ND LArTPC Module Design
The Field Structure-
Light collection interface

It should be pointed out that the light collection attachment is a significant simplification from the prior 2x2 design.

For 2x2, some light equipment existed already and the LArPix tiles required connectors which were not in the field of ASICs. This meant that LArPix connectors had to be in the same location as light collection electronics. The connector constraint was eased and traded for more system independence. The prior design tied the LArPix and light systems together. They are now fully independent and both supported from the anode support plate



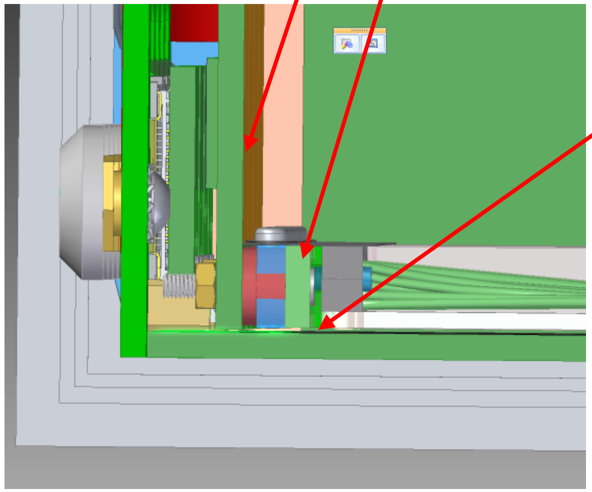


ND LArTPC Module Design
The Field Structure-
Light collection interface

The mounting simplification mentioned on the prior slide has another advantage.
For 2x2, there were some electronics in front of the cathode by a little and the perimeter ground was extended to shield this area
An FEA study of the electric field showed that this lip led to electric field changes in the corners

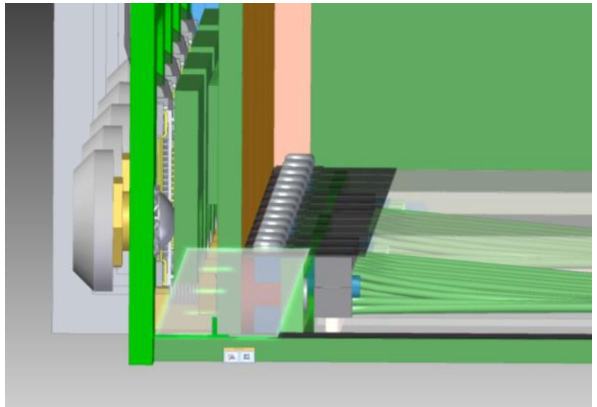
For ND, all electronics is moved behind the anode and out of the electric field.
The conductive rim is much closer to the anode now

Anode
SiPM for light system is in front of the anode



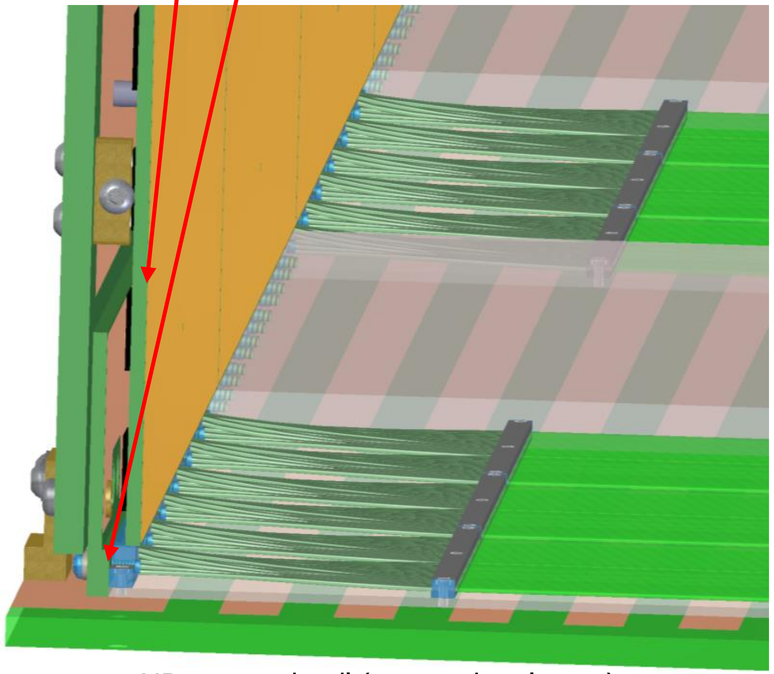
Ground rim is further from the anode (to protect the electronics)

2x2 corner detail (old)



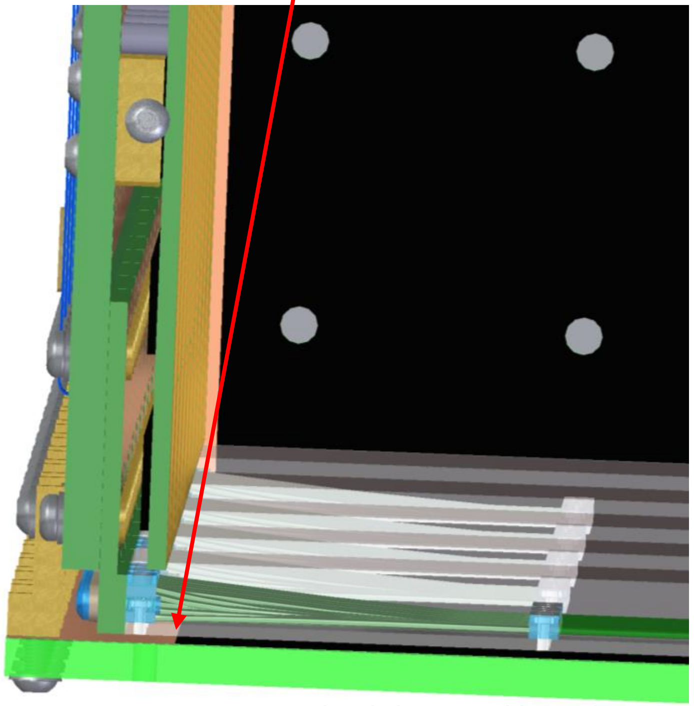
Anode

SiPM for light system is behind the anode

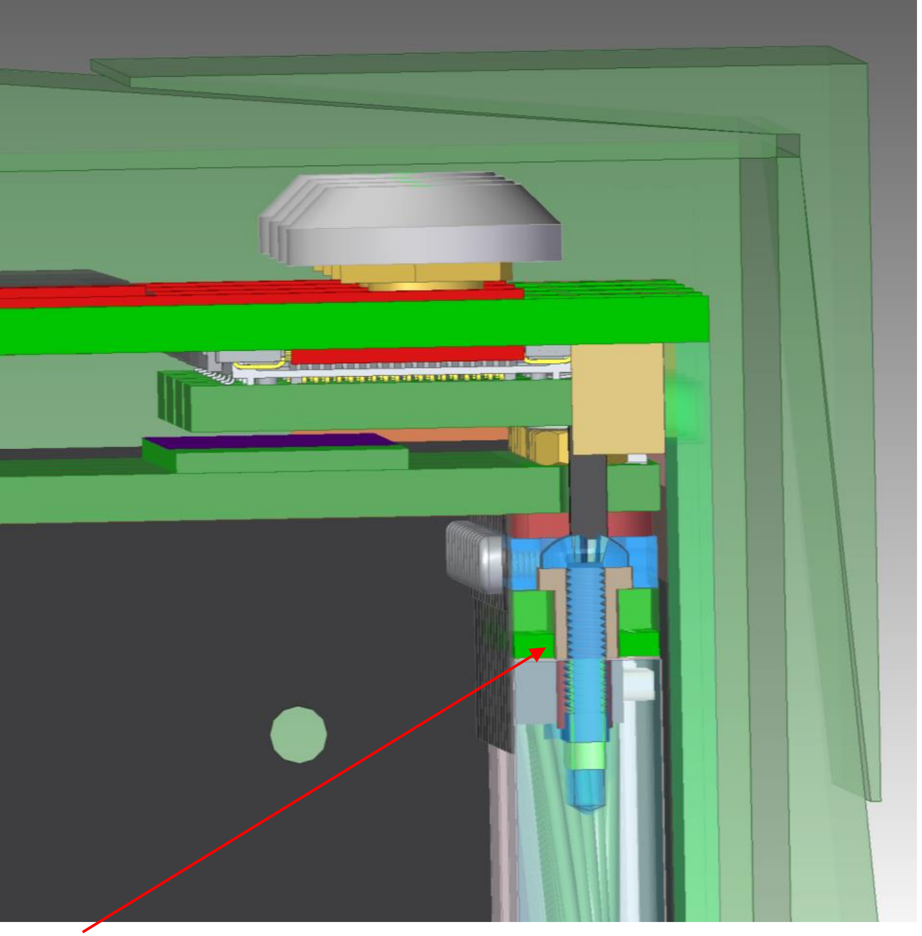


ND corner detail (conventional cage)
(may still trim closer)

Ground rim is closer to the anode



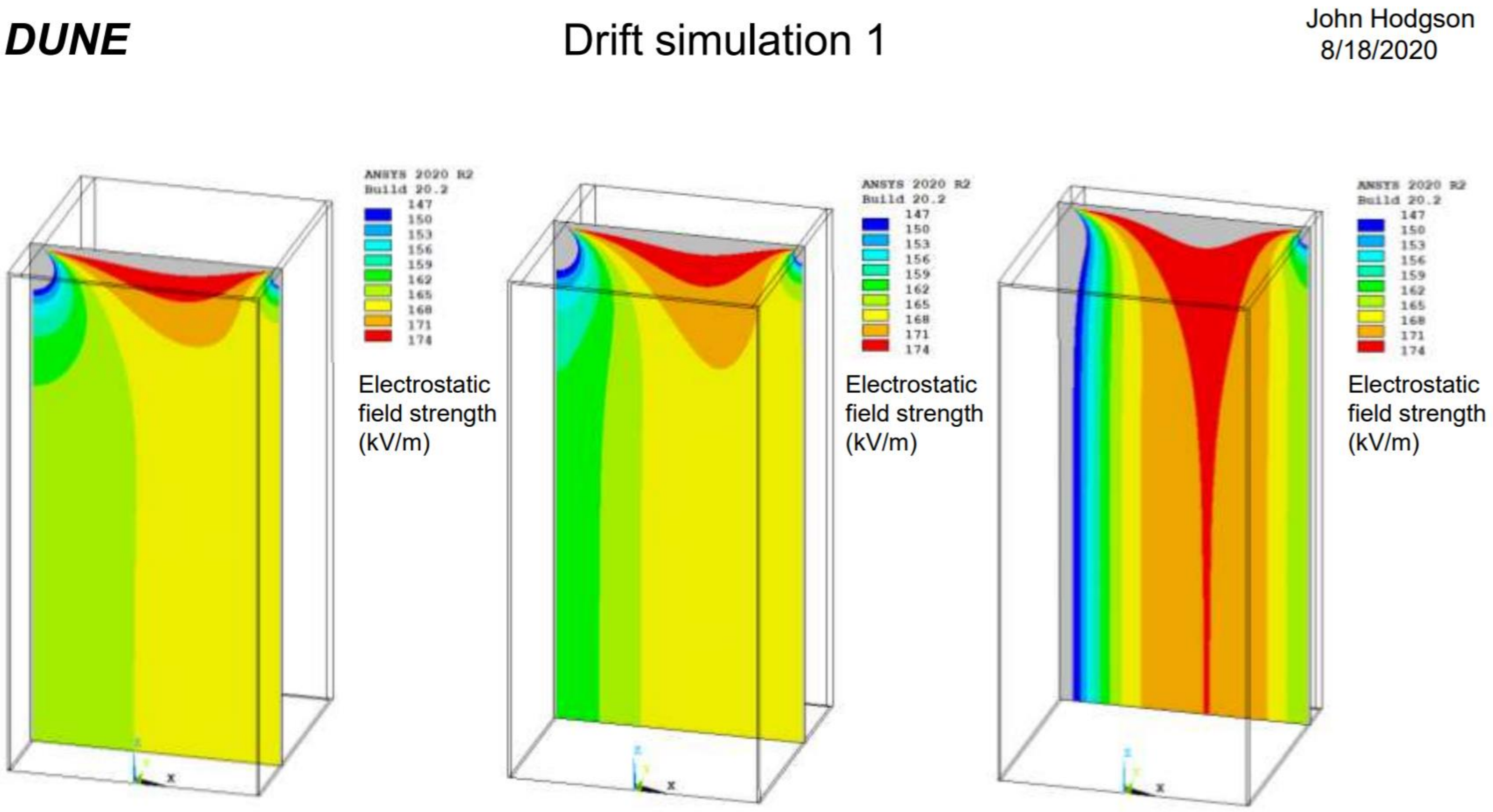
ND corner detail (new and better)



SiPM devices here needed to be shielded, so a small lip was permitted on the field cage (for 2x2)

Later analysis determined that the electric field uniformity suffered from this lip (see right side)

The lip has been reduced for ND and the SiPMs have been pulled back



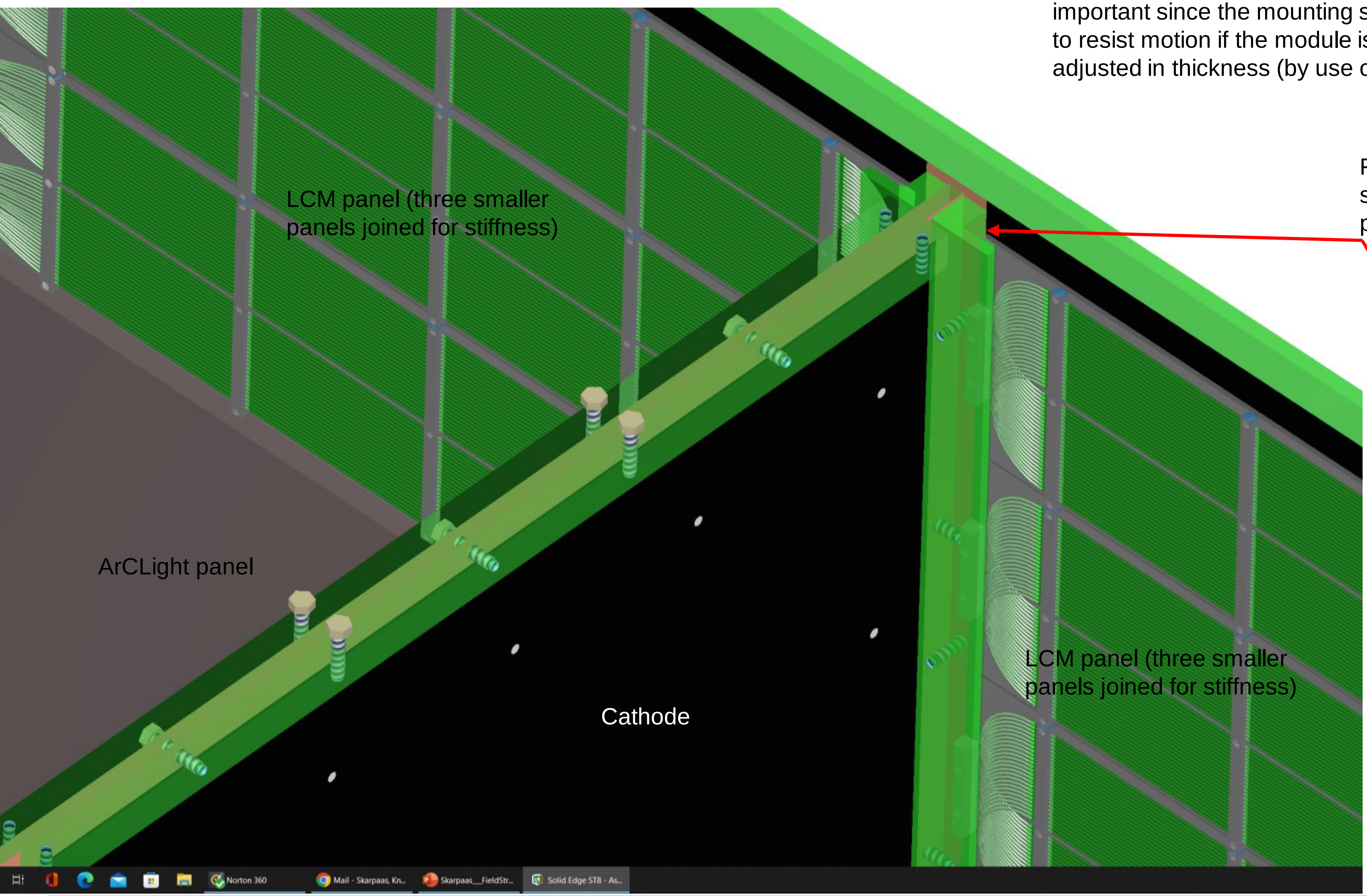
Displaying contours on cut planes at various distances from the center plane shows how the disturbance varies with proximity to the +y side of the field shell.

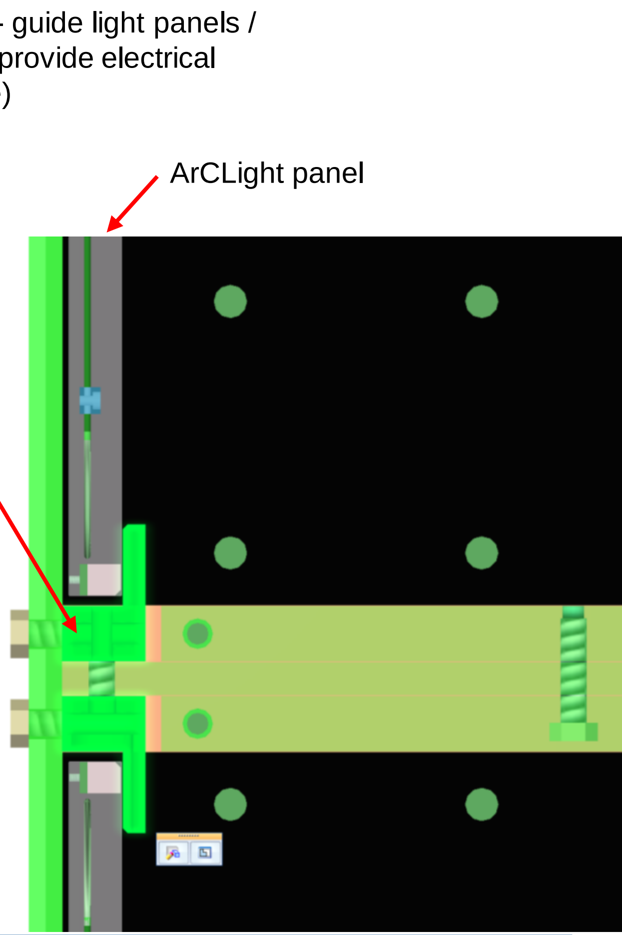
ND LArTPC Module Design

The Field Structure-

Light Collection Mounting – Near Cathode

The light collection systems are plastic (polycarbonate and polyvinyl toluene) and contract a significant amount when cooled. These systems are mounted at the anode support plate and contract away from the cathode. The overall field structure is fiberglass (g-10/ fr-4) and contracts much less than the polymers. For this reason, the support at the cathode simply guides the tips of the light panels and assures that they do not enter the drift volume. This is important since the mounting screws are in a line and can not provide a reasonable moment to resist motion if the module is rotated (at assembly). The tips of each light panel have been adjusted in thickness (by use of spacers) to assure that they are interchangeable.

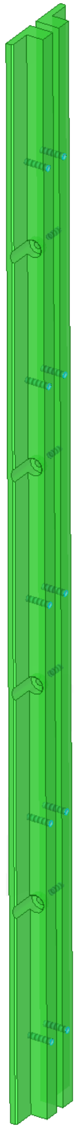




ND LArTPC Module Design

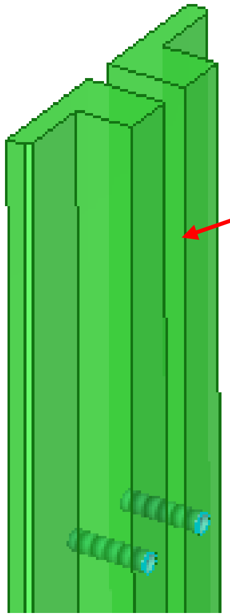
The Field Structure-

Light collection mounting – near cathode

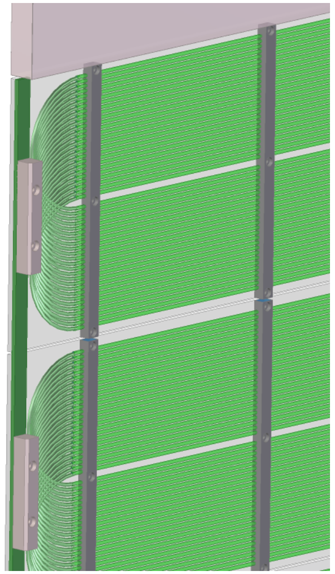


Fiberglass brackets-
One type for sides and one type for the top and bottom
(mating faces covered with foil to create an electrical contact)

A similar shape was used for 2x2



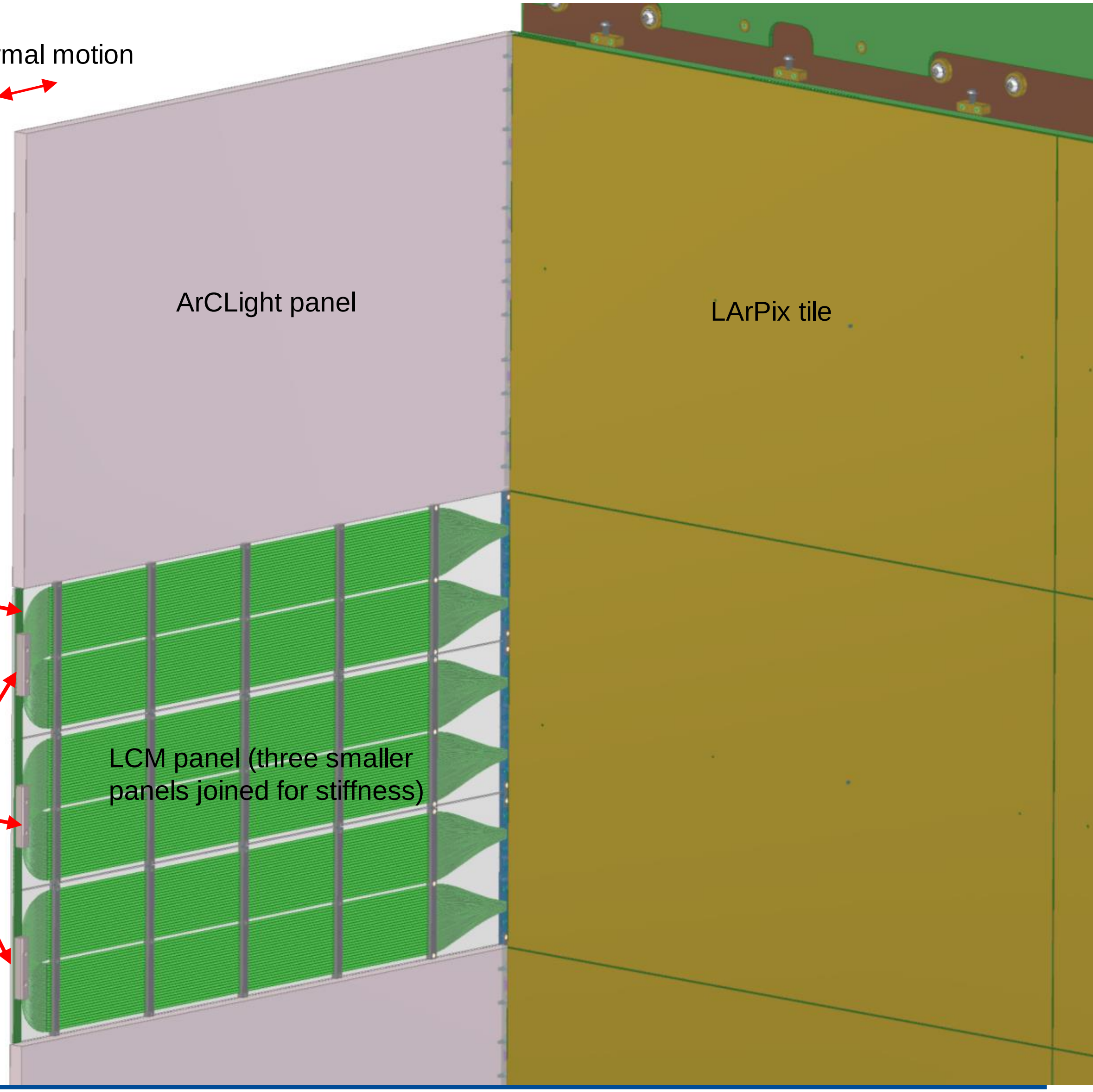
A ½” wide copper tape is wrapped around this corner (and trapped with PEEK screws)



Three narrow panels are joined at the tips with fiberglass to enhance stiffness (while replicating the CTE of the mounts)

Spacer blocks at tips make the two systems interchangeable

Thermal motion



ND LArTPC Module Design

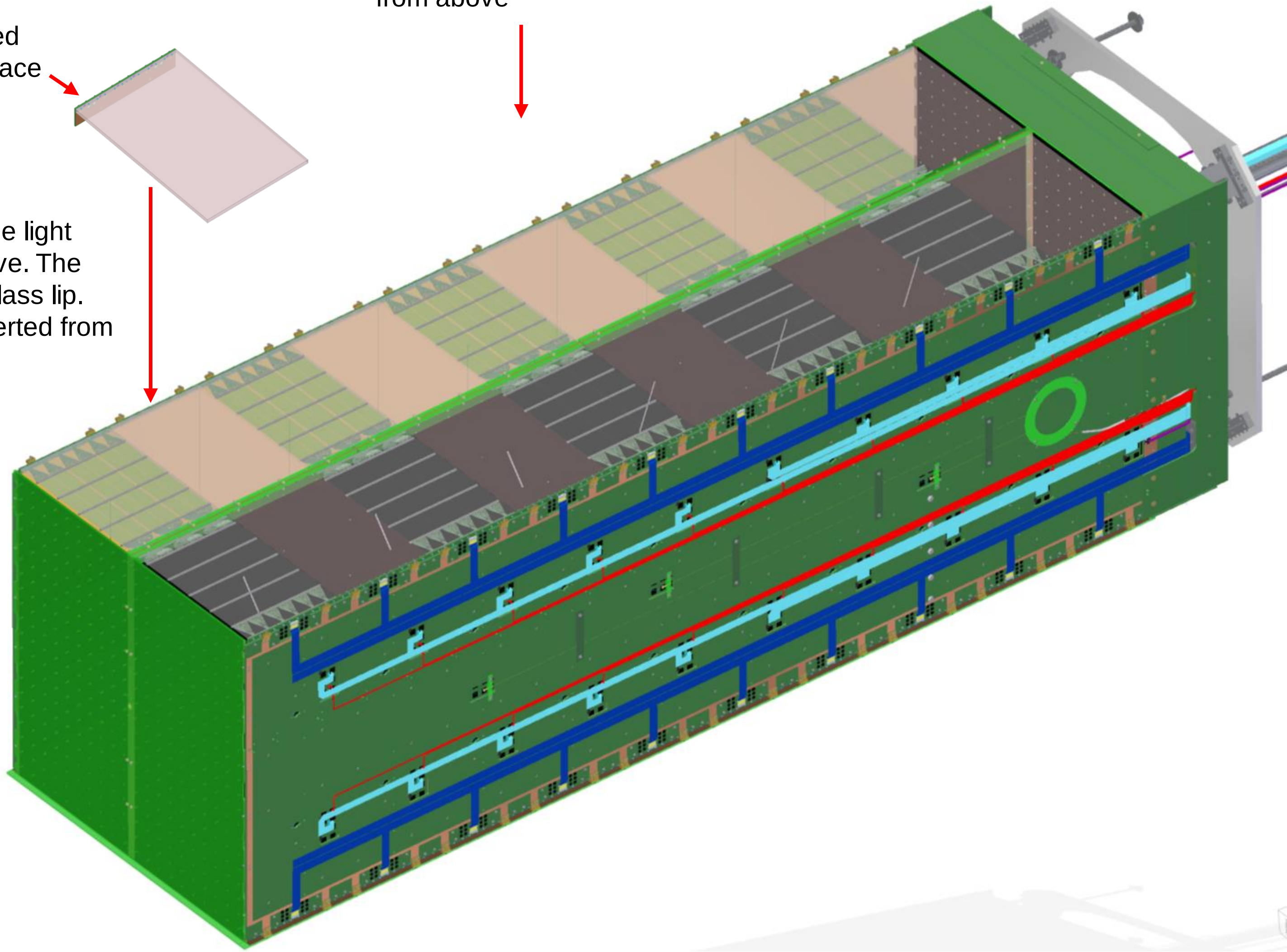
The Field Structure-

Light collection– installation

When all light collection panels are in place, the field cage side panel is mounted from above

Six screws can be inserted when the panels are in place

At assembly, the module is on its side. The light collection panels can be placed from above. The edge near the cathode rests on the fiberglass lip. Nuts are captured and screws can be inserted from the outside

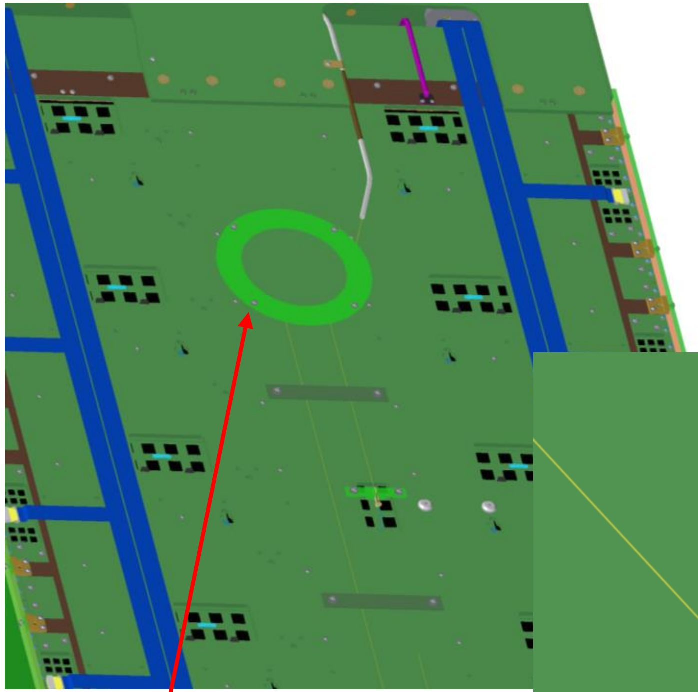


LBNF/DUNE

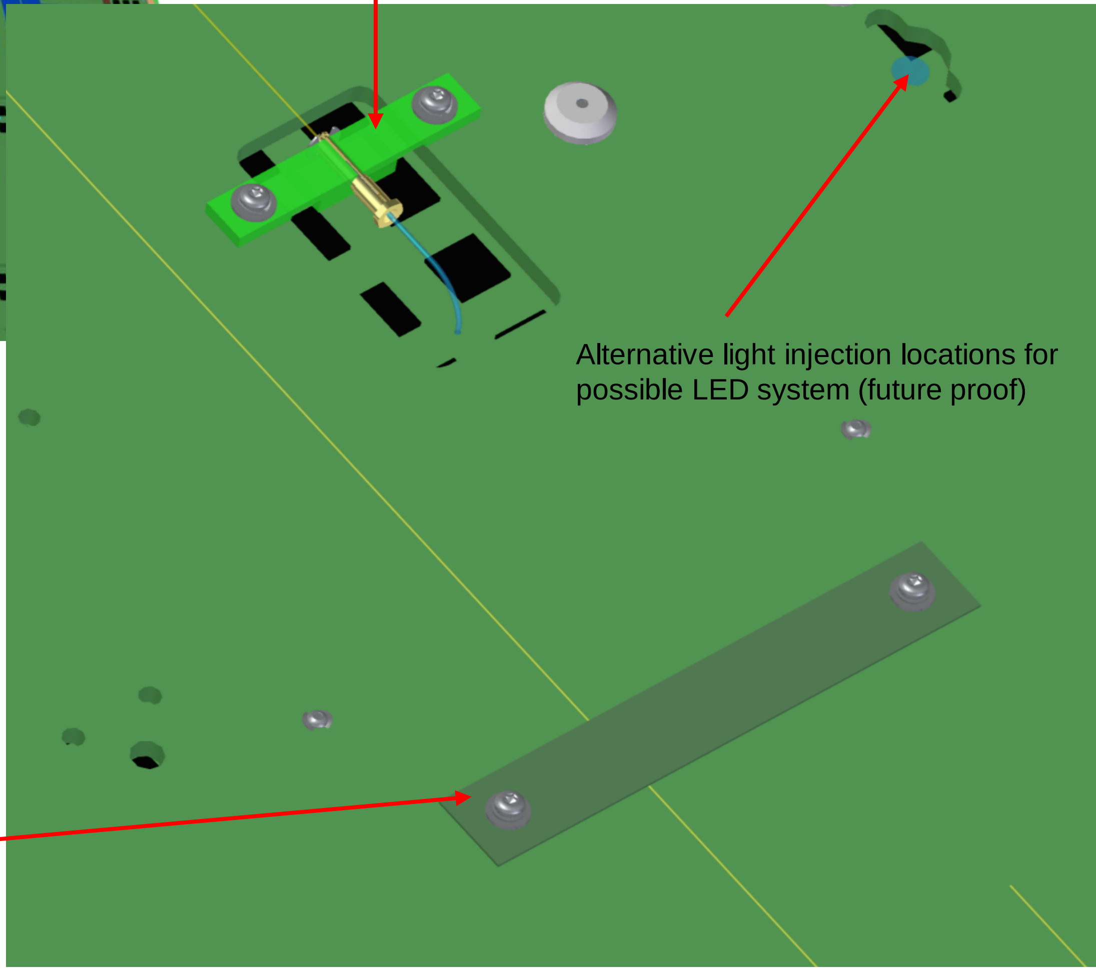
ND LArTPC Module Design

The Field Structure-

Calibration system mounting

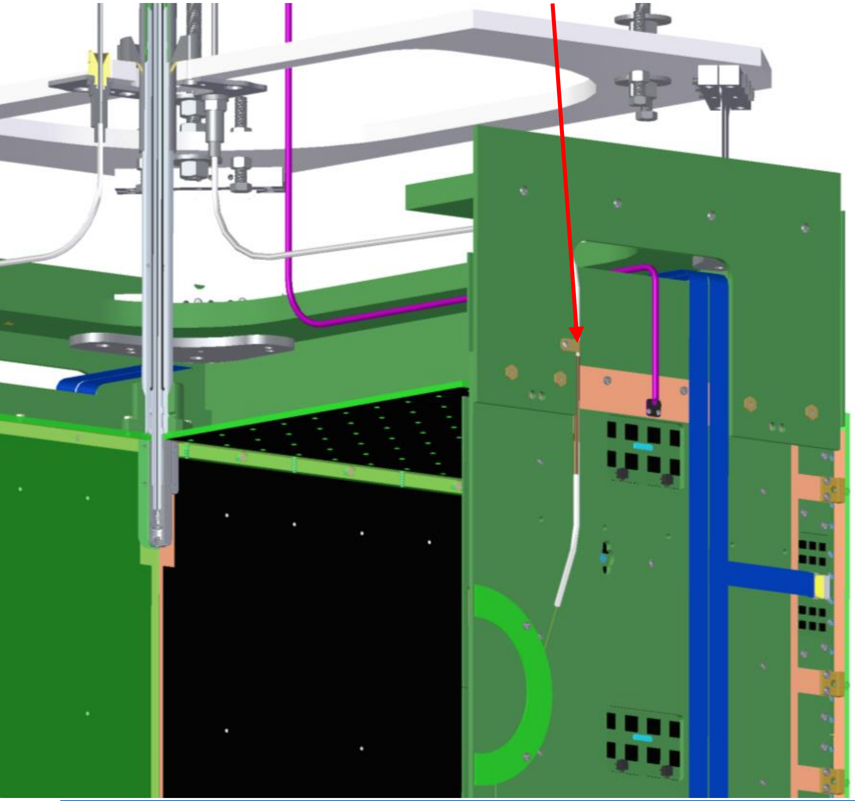


Calibration fiber to light guide splice (provides compliant termination)
Mounted within pocket on the anode support plate
Can be serviced without removing anything



Alternative light injection locations for possible LED system (future proof)

Calibration fiber guide mounted to top of field structure



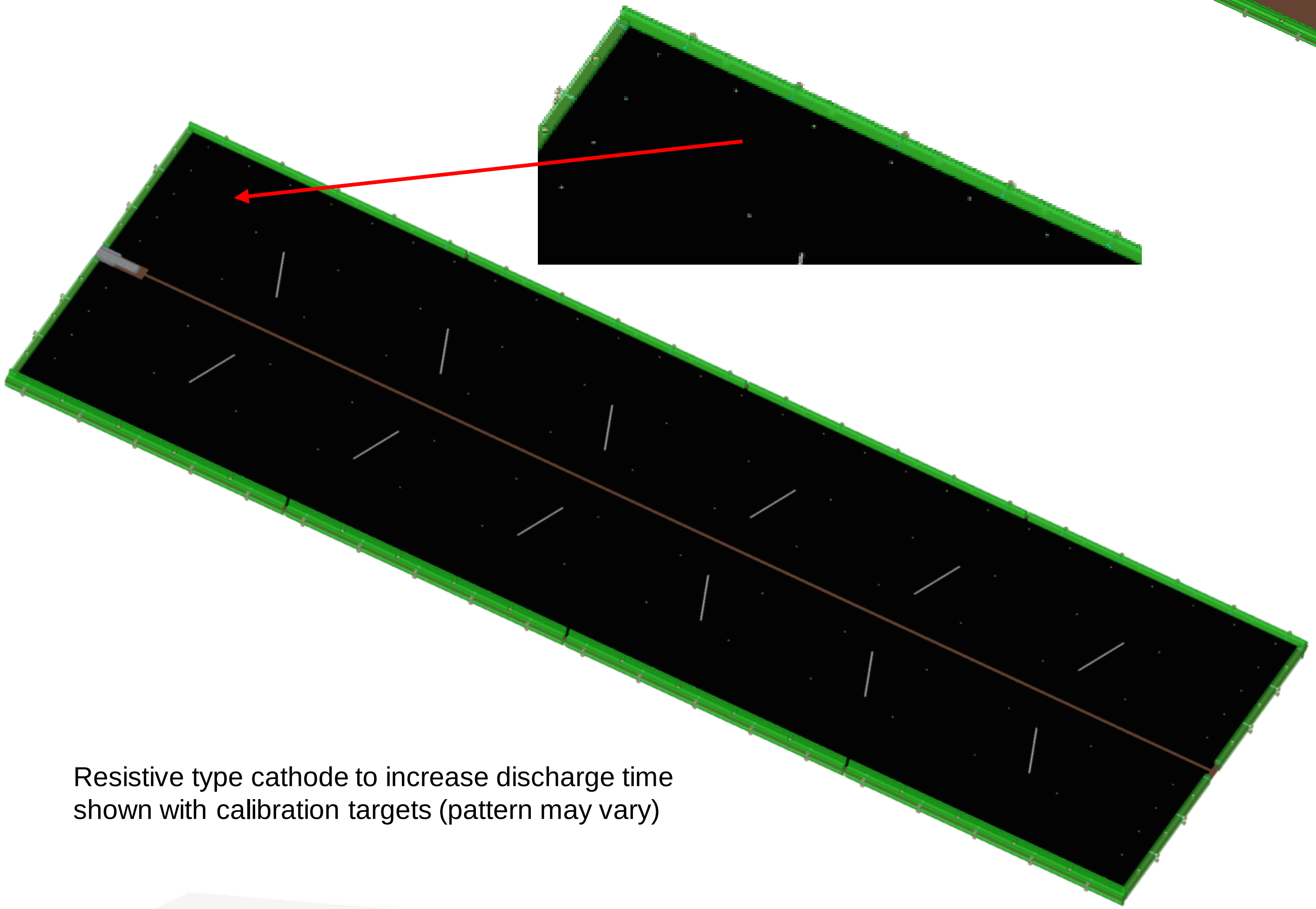
Calibration fiber spool mounted to top of the anode support plate (permits common fiber length for various light insertion locations)

Calibration fiber strain relief mounted to the anode support plate (keeps fiber close to the surface)

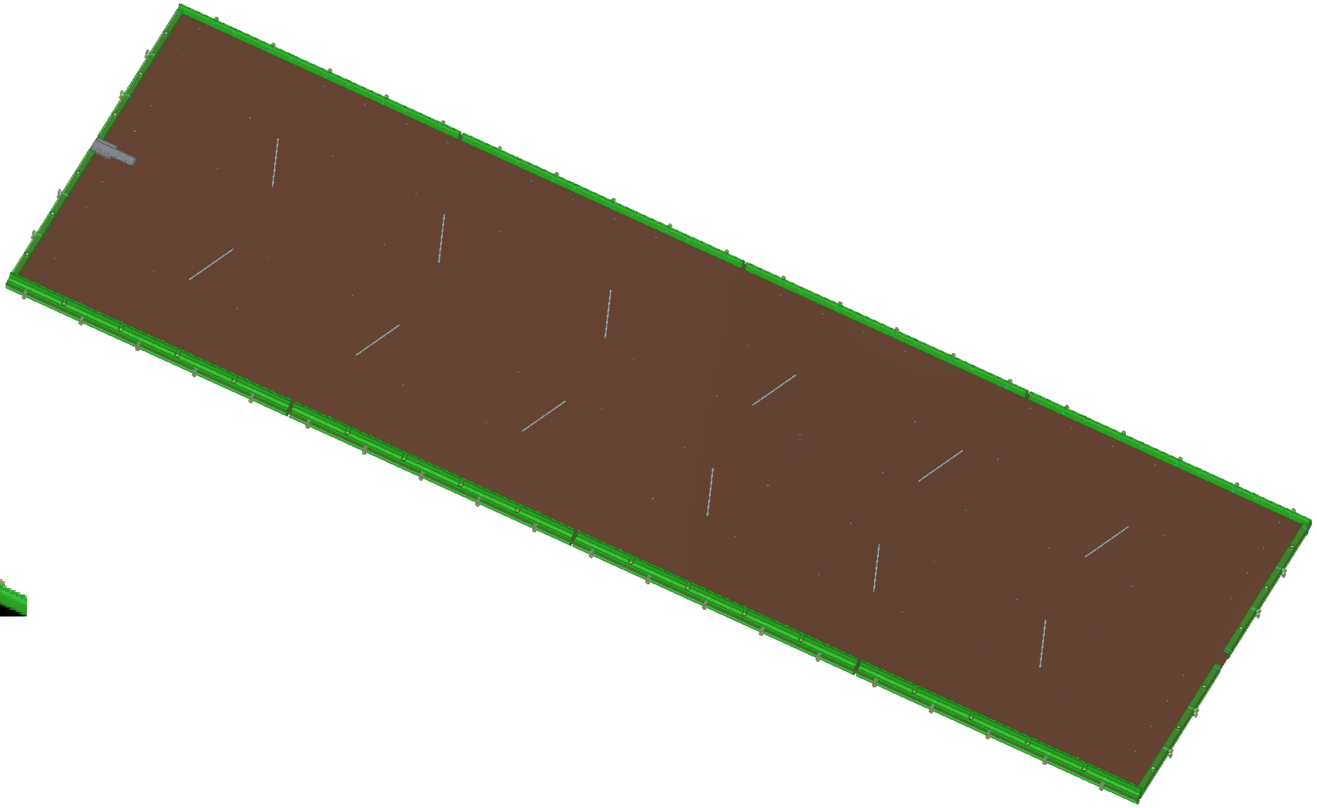
ND LArTPC Module Design

The Field Structure-

Calibration system – at the cathode



Resistive type cathode to increase discharge time shown with calibration targets (pattern may vary)



Conventional conductive cathode with calibration targets (calibration target material needs to have a different work function than the background)

ND LArTPC Module Design

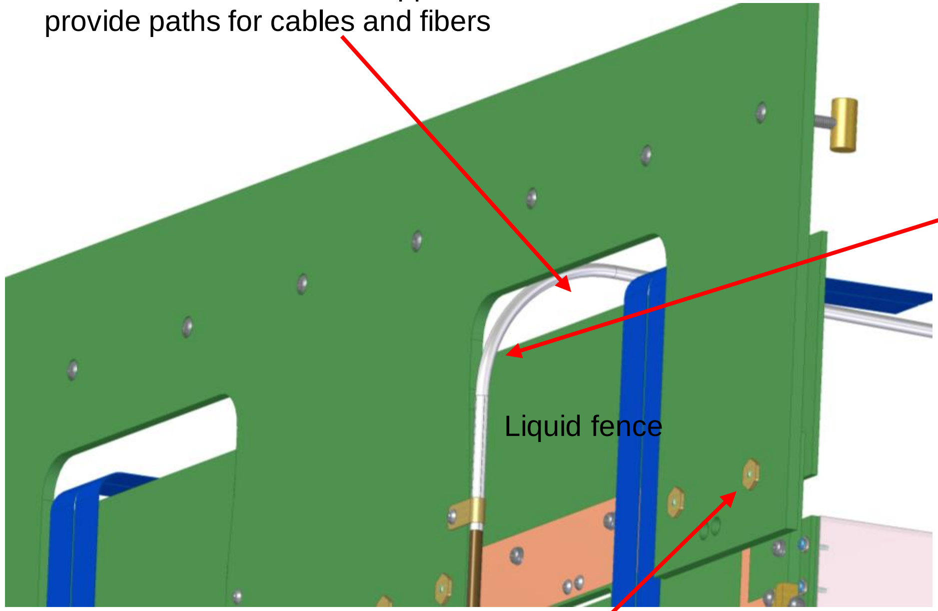
The Field Structure-

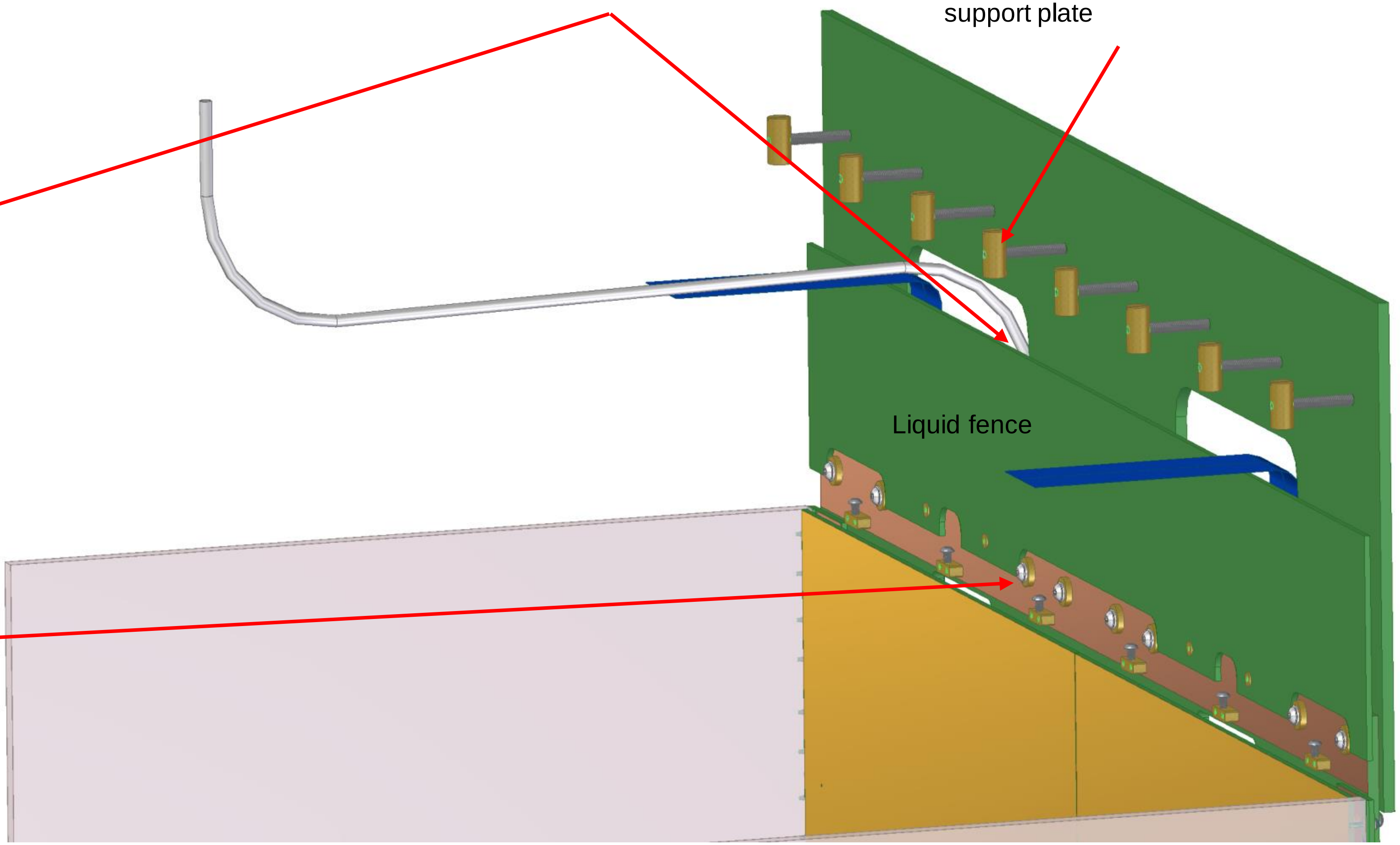
Calibration system interface – fiber routing (building on EXO experience)

The routing of the calibration fibers and the field structure are closely tied since the fiber has a large bend radius and the path must weave between the liquid fence (which directs the flow of cold argon) and the upper supports. A rigid tube is used to define the path

Custom “IKEA” like drop in nuts with long screws transfer load from the “barn door” flexures to the fiberglass support plate

The “barn door” flexures support the module and provide paths for cables and fibers

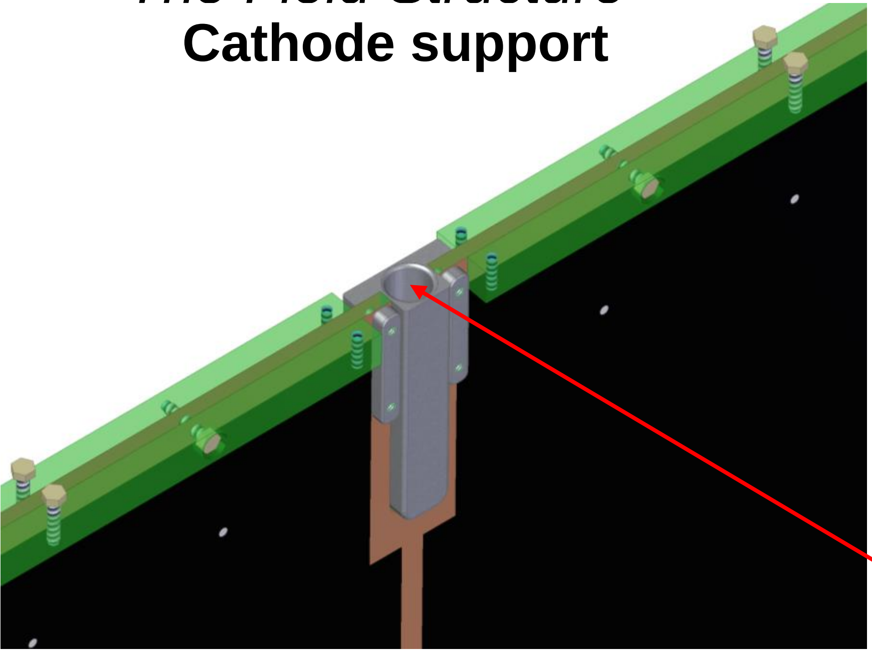




Shouldered shear nuts connect the flexure plate to the anode support plate

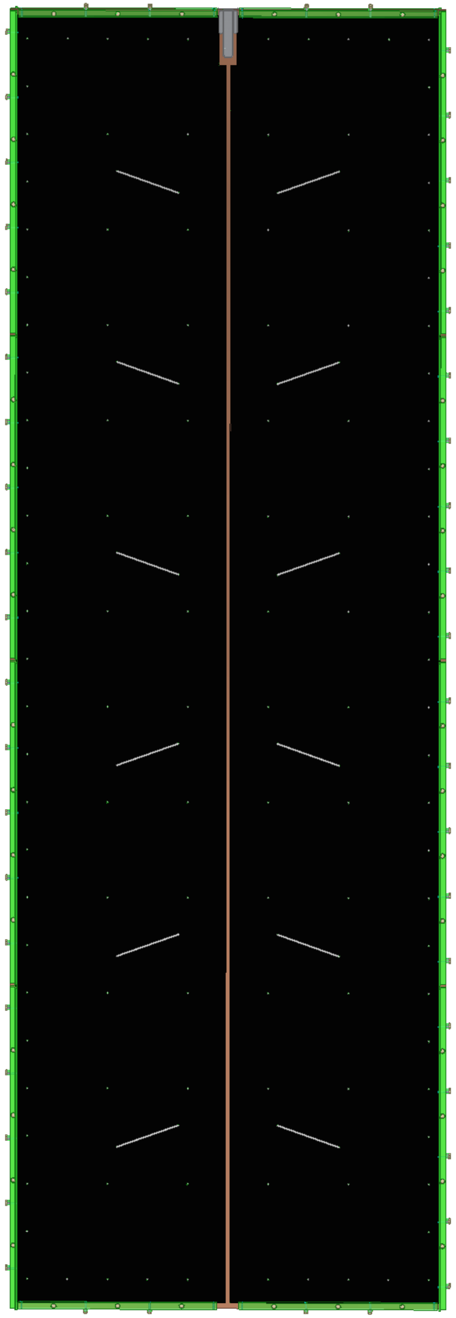
ND LArTPC Module Design

The Field Structure-
Cathode support



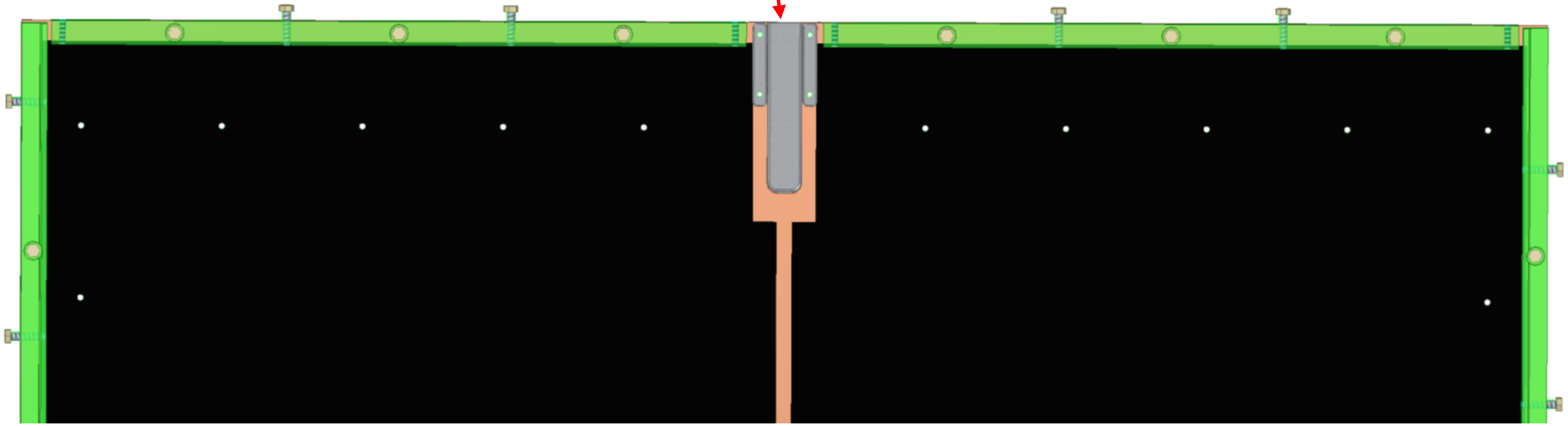
There has been a great effort to optimize the design while keeping the part count low. Since the modules are right next to each other, the plastic screw heads from one module were right next to the plastic screws from the adjacent module. To avoid shearing the screw heads and to eliminate a surface path breakdown route, the screws are high on one side and low on the other side. This was accomplished while still having one type of side panel and one type of side bracket (and the cathode is symmetric).

High side



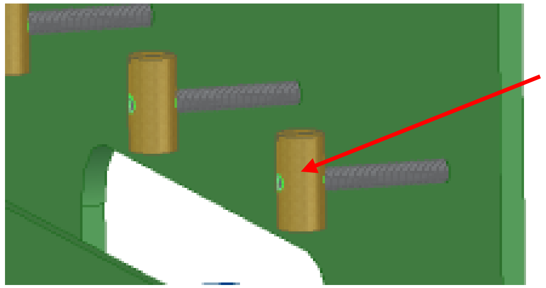
Low side

HV socket accepts the polymer HV cable. A soft spring in a long counterbore allows for cable shrinkage (in height) as the cable cools

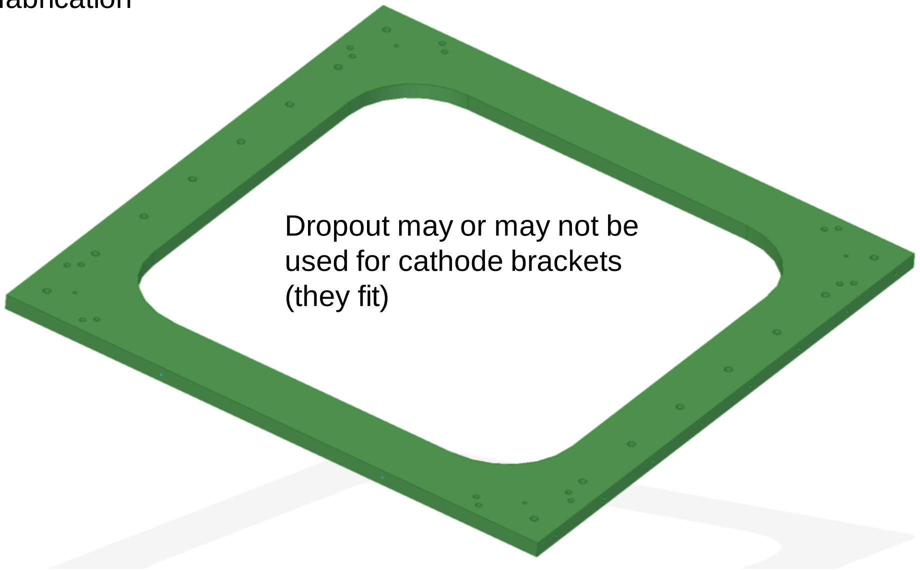


LBNF/DUNE

ND LArTPC Module Design
The Field Structure-
Module support interface

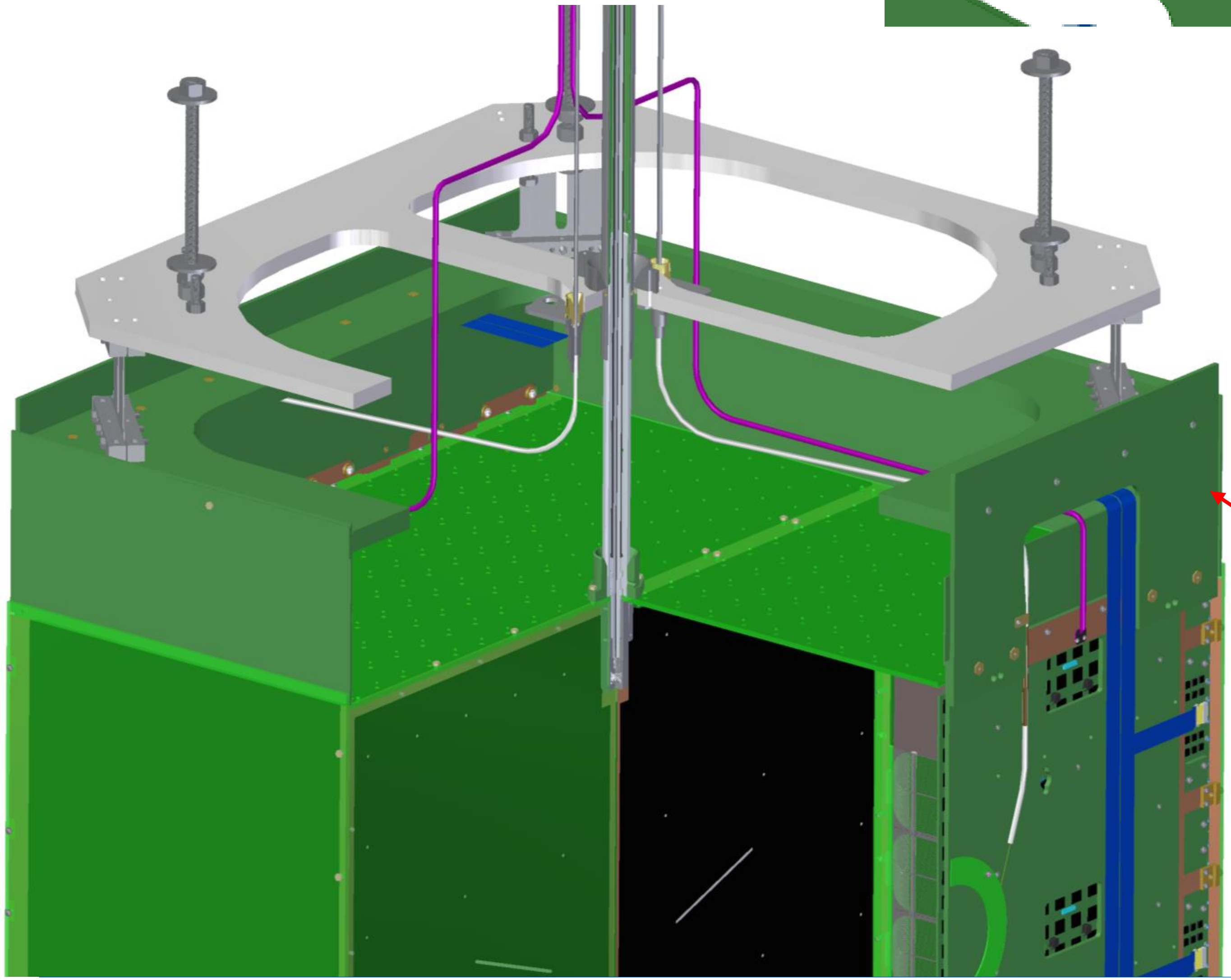


Drop in nuts simplify top plate fabrication



Dropout may or may not be used for cathode brackets (they fit)

All support parts up to the top plate have the same CTE



Load from module transfers up to the fiberglass plate by means of two plates connected to the anode support plates (fairly straight load path)

ND LArTPC Module Design

The Field Structure-

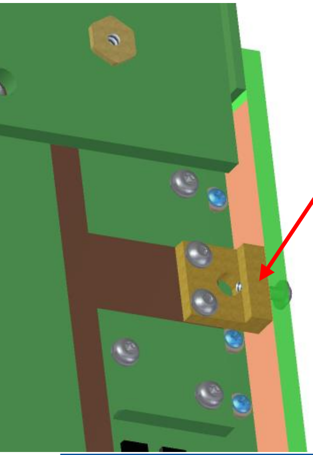
Resistive field cage

The resistive field cage is a fiberglass box with resistive coatings on the inner faces which grade the electric field from the cathode voltage in the center down to ground at each of the two anode support planes

For 2x2, the resistive field cage was made by laminating resistive film on the inner surfaces

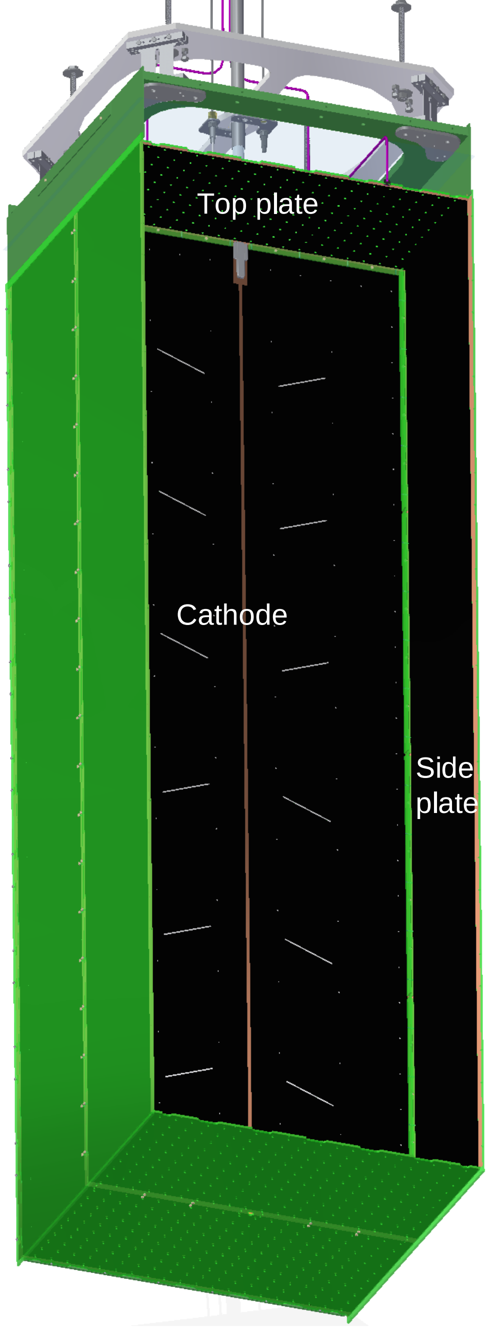
Due to budgetary constraints, a sprayed on resistive coating is being tested now. This coating may be done on the inside with carbon fill and on the outside without fill to prevent warpage (balance the laminate).

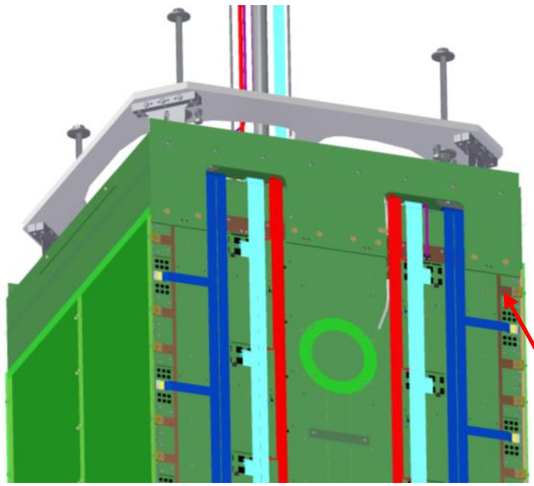
The metal edges are also being tested with deposited conductive coatings now due to the large size of the panels



Structural blocks also ground parts

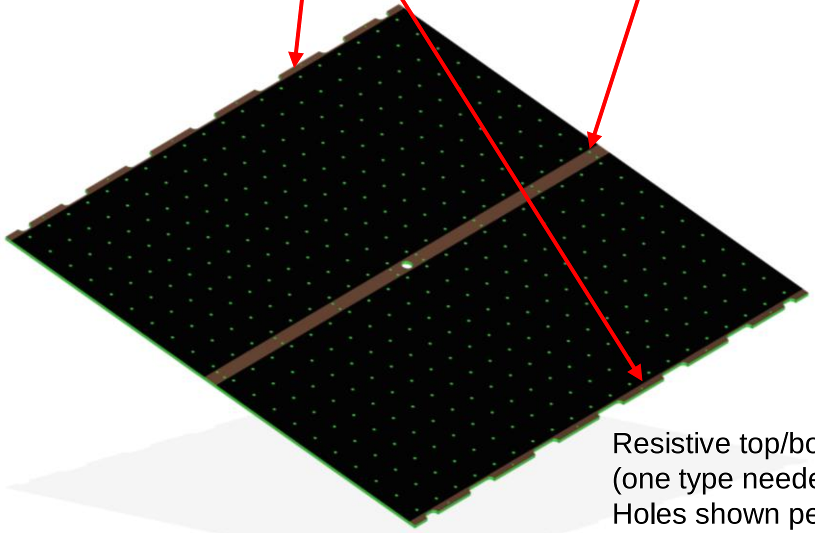
Resistive fiberglass box is stiff when screwed together as a unibody



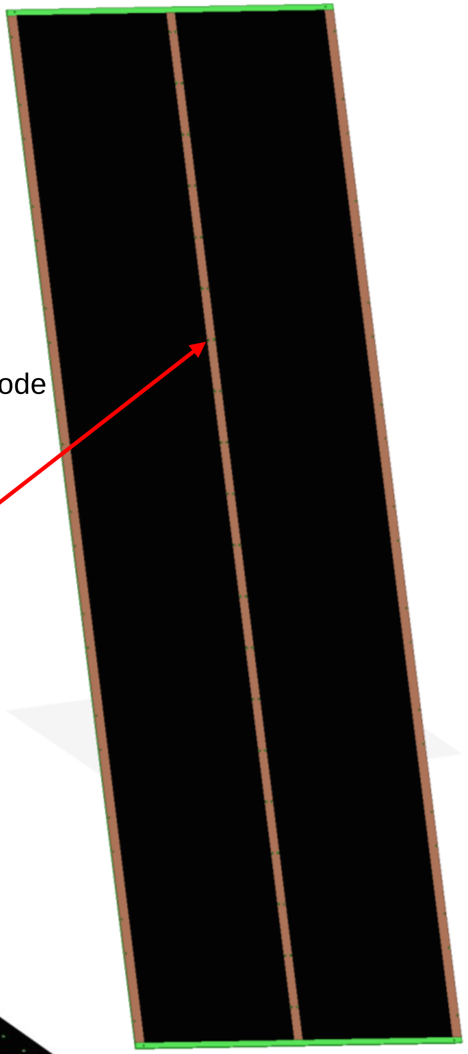


HV return on anode support plate

The center stripes are all “jumpered” together at the cathode and the two conductive edges are connected to each anode support plate to create the HV resistive circuit



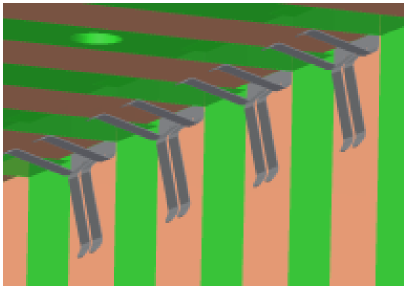
Resistive top/bottom (one type needed)
Holes shown permit fluid flow

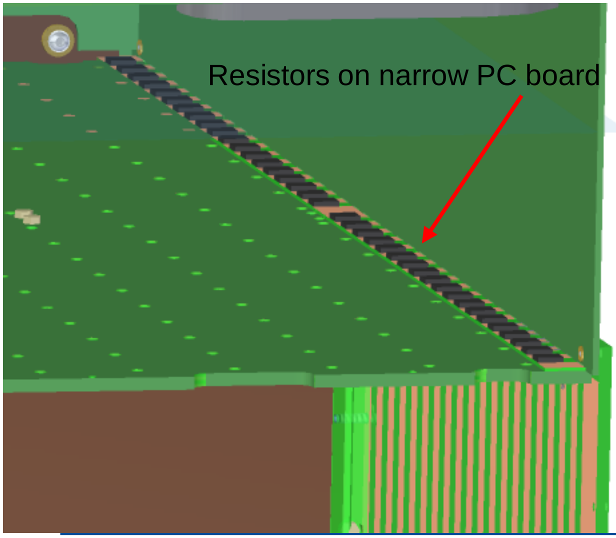


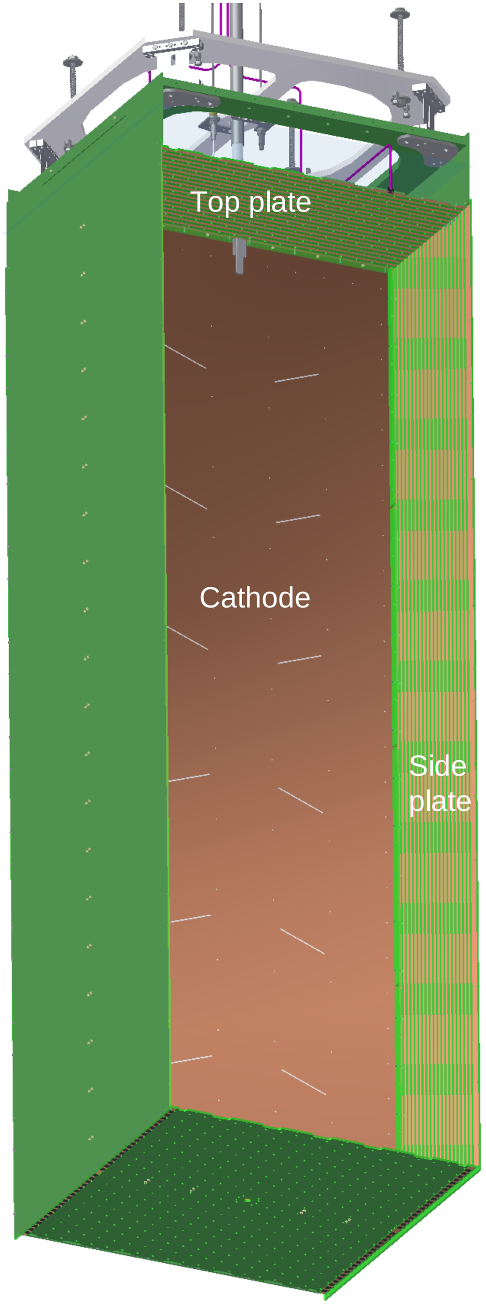
Resistive side panel (one type needed)

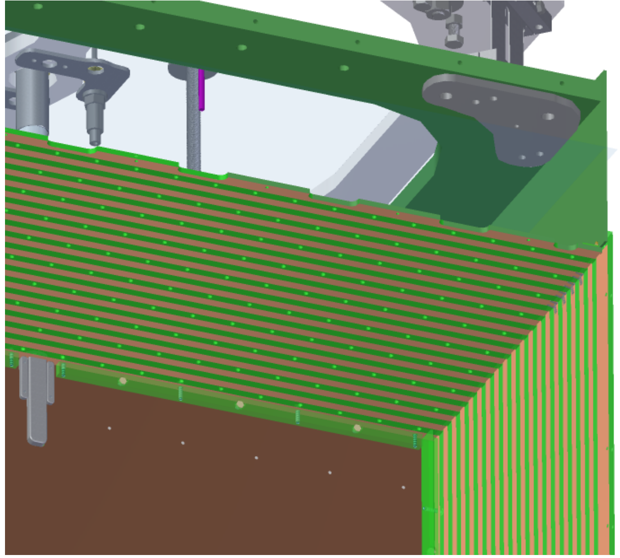
ND LArTPC Module Design
The Field Structure-
Conventional field cage

A conventional metal strip / resistor chain type field cage is also possible as an alternative solution

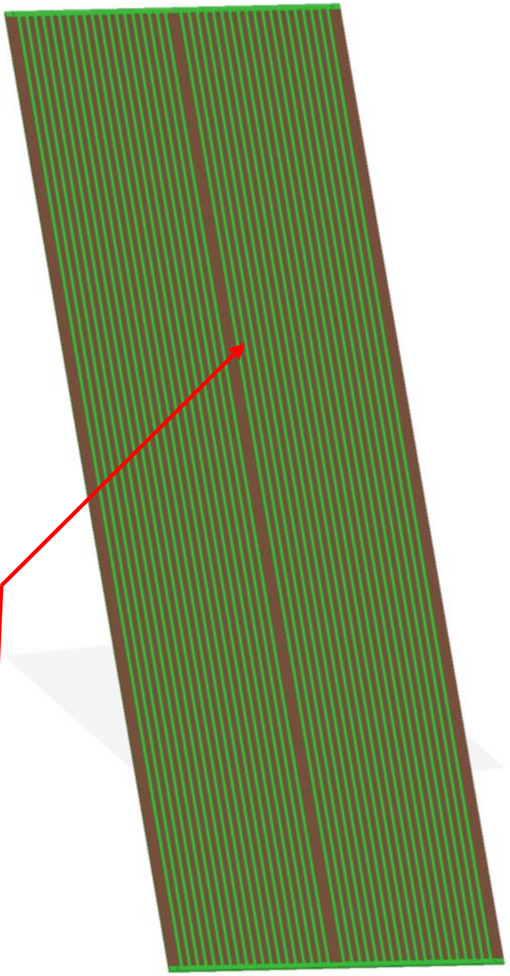




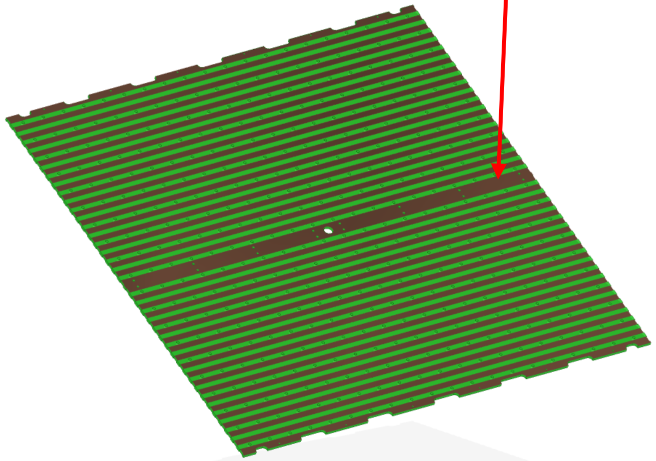




The center stripes are all “jumpered” together at the cathode and the two conductive edges are connected to each anode support plate to create the HV resistive circuit. The stripes are connected to a resistor chain with photo-etched spring clips.



Striped side panel (one type needed)

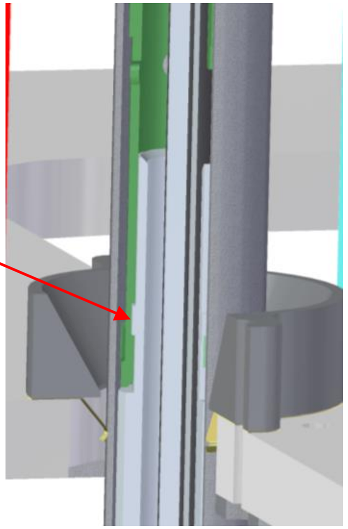


Conventional top/bottom (one type needed) Holes shown permit fluid flow

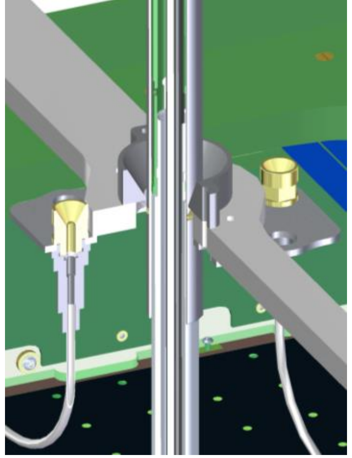
ND LArTPC Module Design

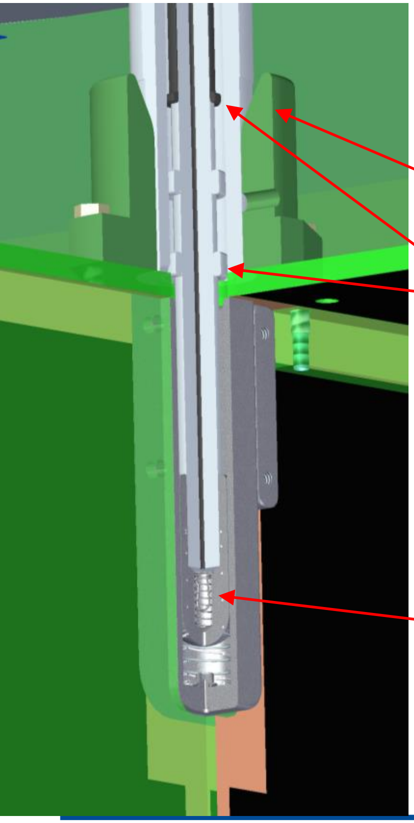
The Field Structure-

HV input -



G-10 tube to PTFE tube joint



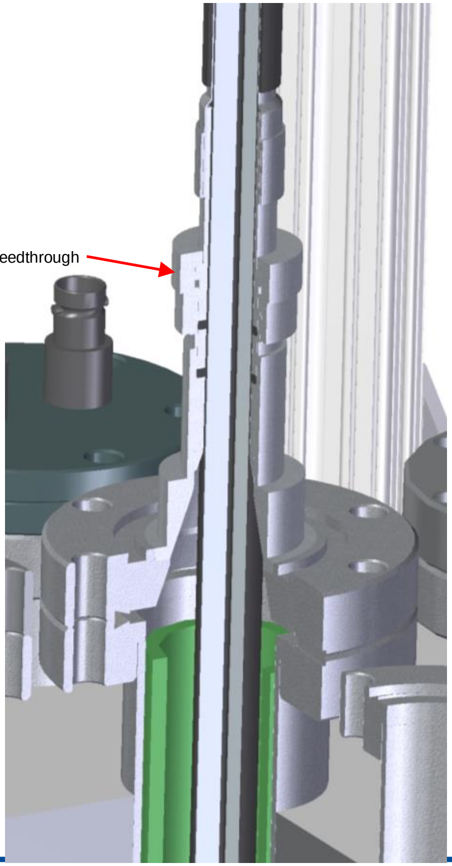


G-10 Funnel guides PTFE tube

Black “roll sock” reduces electric field

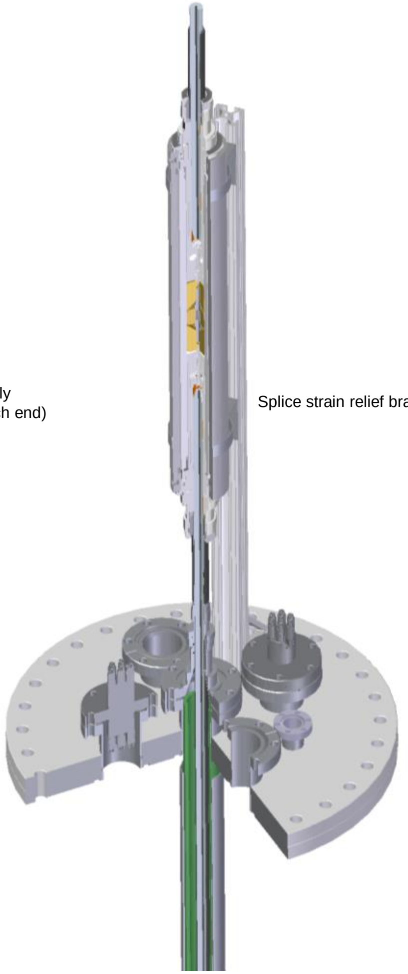
Two PE rings prevent surface tracking

HV “Pill” shown within socket (attached to cathode)
(connections sprung to permit thermal contraction)



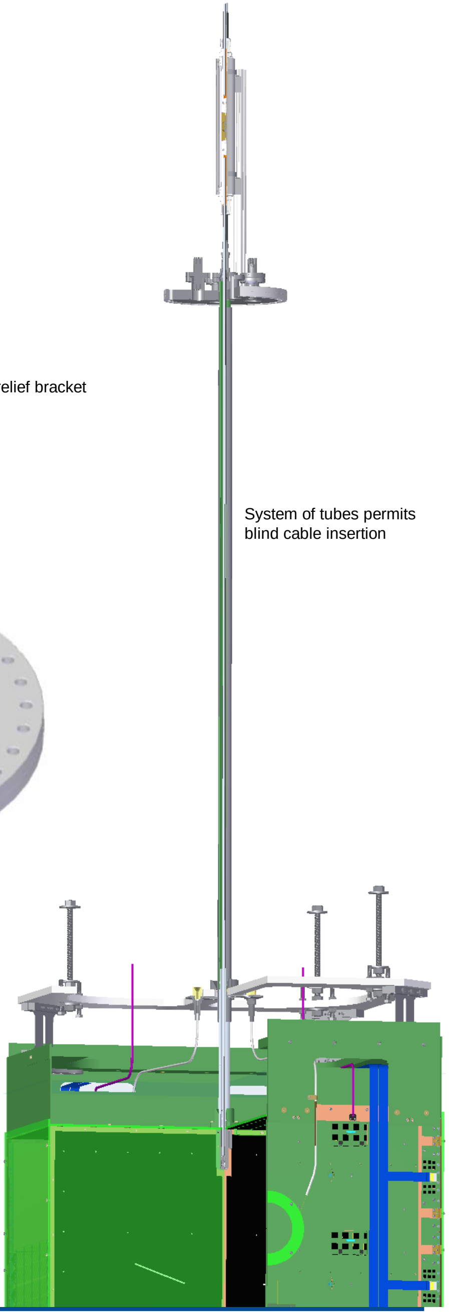
Ultra-Torr to CF feedthrough

Splice assembly
(female on each end)



Splice strain relief bracket

Fiberglass tube shown inside metal tube



System of tubes permits blind cable insertion

Summary

- The **ND field structure** design has been developed to support several sub-systems
  - **Charge collection**
    - Interface has been simplified from 2x2
  - **Light collection**
    - Number of PC boards has been greatly reduced from 2x2
    - Volumetric efficiency increased
    - Electric field near anode has been improved (due to light collection mounting system)
  - The **calibration system** has been integrated with the anode support plate
    - Future proof design at the anode support plate
- The **module support** is well defined
    - Load path fairly linear
- **Field cage**
  - Minor mechanical changes to field shell panels support two electric field shaping options
- The **HV input** is advanced
  - Feedthrough design from prior TPC
  - Splice updated from recent design