ProtoDUNE Single Phase In-Cryostat Beam Plug System

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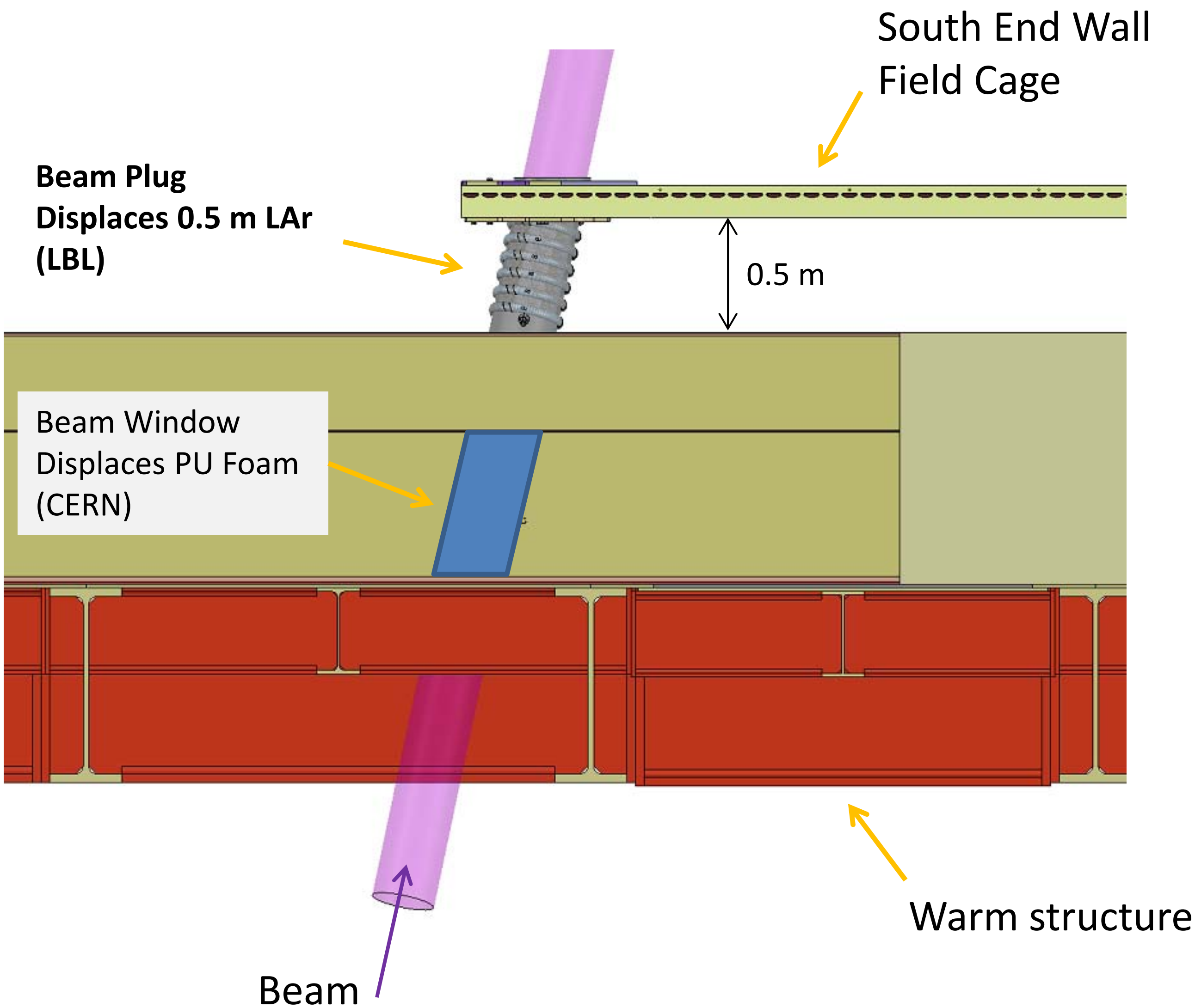
November 9, 2016

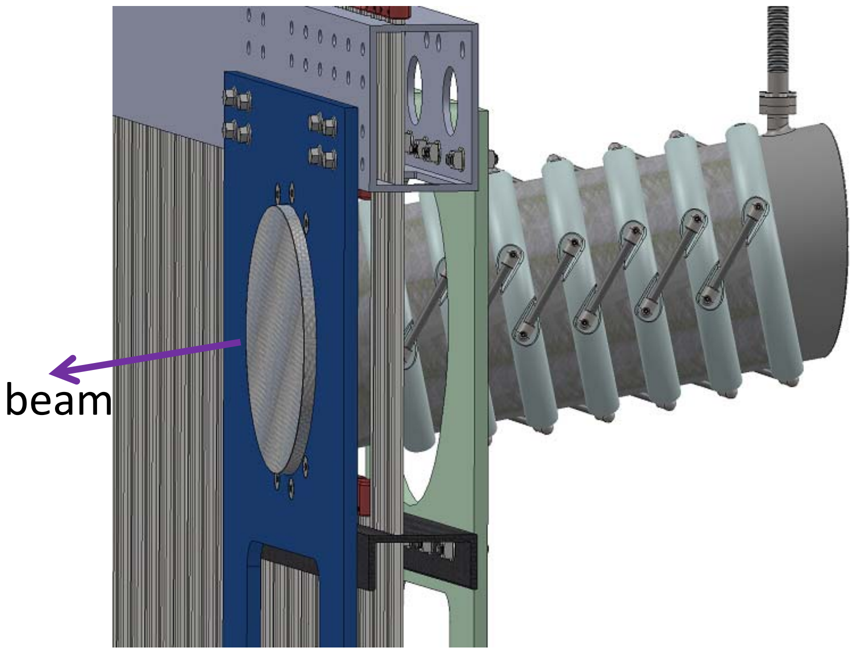
Introduction

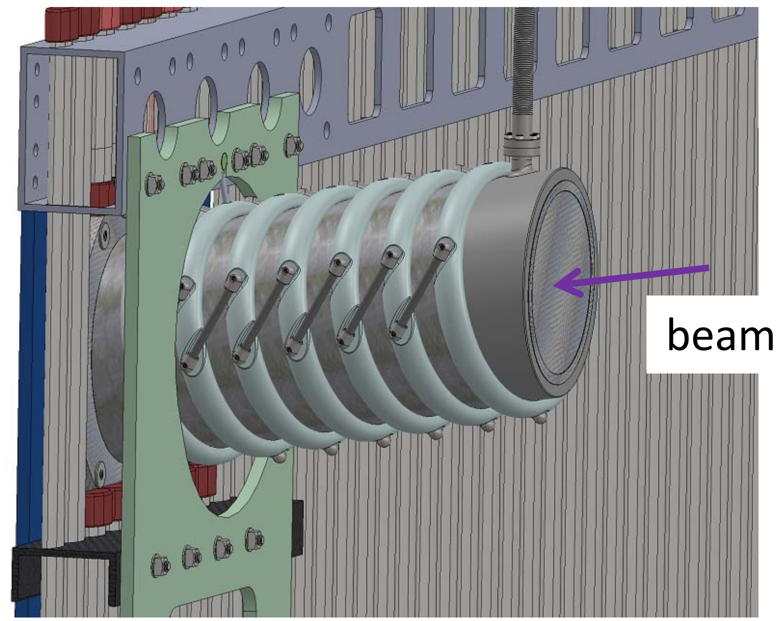
- Field Cage Interface
- Beam Plug Components
- Component Testing
- Resistor Chain
- Nitrogen Line
- Installation
- Material Testing

Beam Plug Location in Cryostat



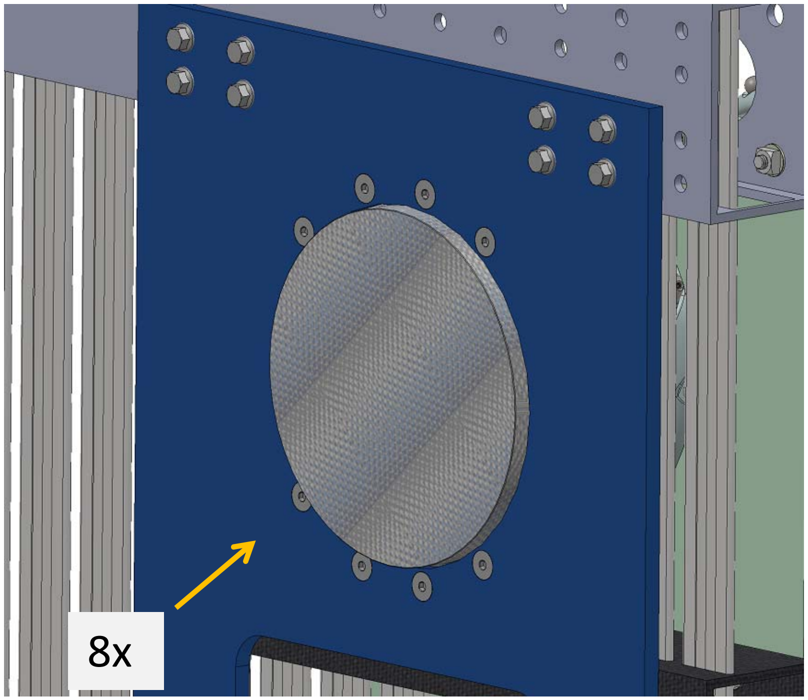
Field Cage Mounting

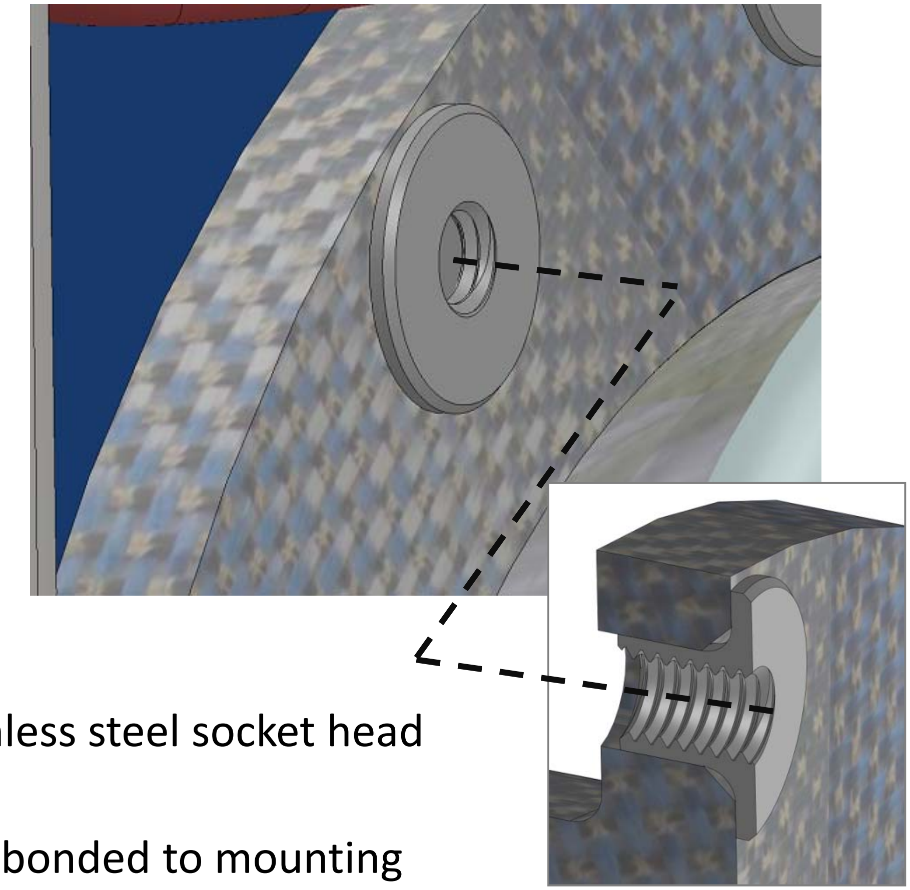




Beam Plug mounted to end wall field cage.
Bolted connection transfers load to both sides of field cage.
Non-metallic hardware used on cryostat side.
Profiles 3-7 modified with field shaping strip.
Beam plug extends 5 cm into active region beyond the profile.

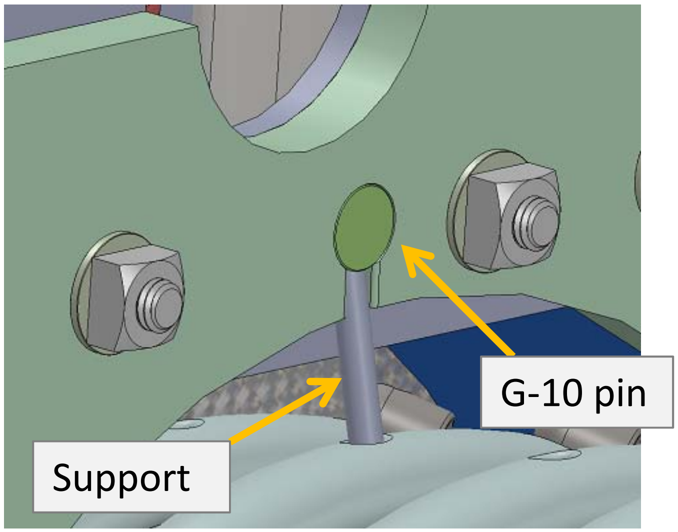
Structural Mounting to Field Cage

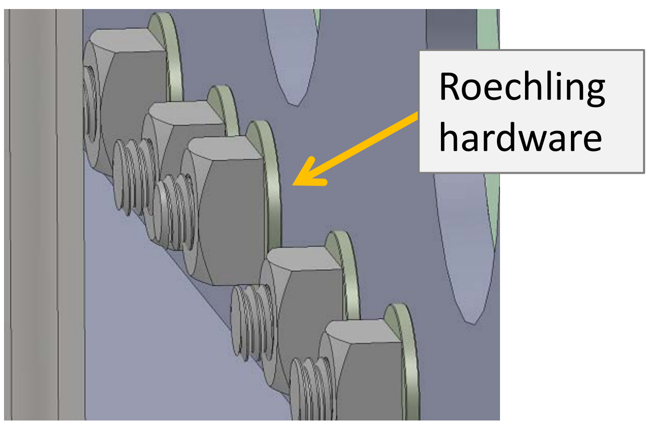




- Eight flush or low-profile silver-plated stainless steel socket head screws. Sized at M10 or 3/8".
- Screws thread into stainless thread inserts bonded to mounting flange with Hysol high strength cryogenic epoxy.
- 0.1 mm needed at screw head or within joint for differential contraction between glass fiber/epoxy and stainless steel.
- Screws installed and removed from one side.

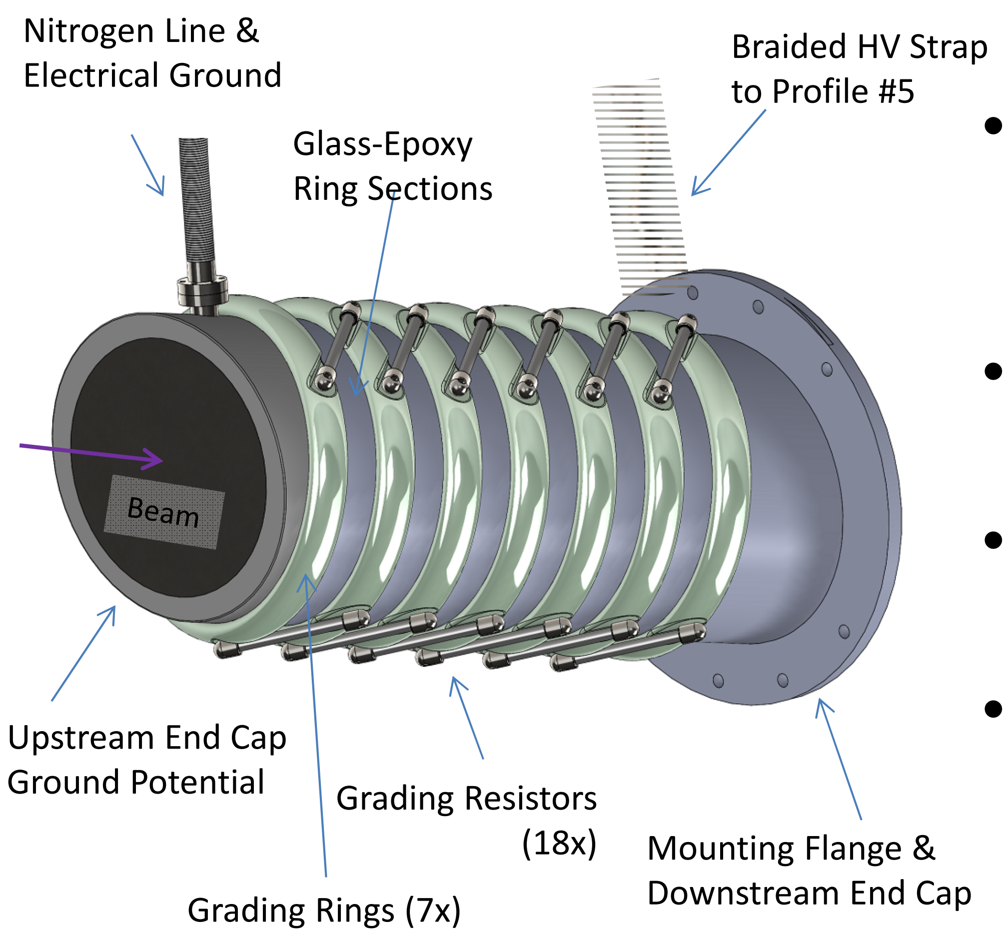
Upstream Field Cage Support





- FEA results show support transfers nearly half the beam plug's gravity load to box beam (approx 50 lbf). Resolves pure moment load cantilever into combined force-couple type of reaction for lower deflection.
- Semi-rigid support member and material is under further study. G-10 CR, Roechling composite & Torlon are candidate materials.
- Accommodates field cage material contraction stack up of up to several millimeters without over constraint.
- Support connects to field cage sheet and box beam in double shear via modified version of the standard 5/8" G-10 pins. Roechling composite fasteners retain pin from back side.
- Connects to second electrode ring (162 kV) at radiused threaded holes used elsewhere for attaching installation tool. 3D electrostatic analysis planned to ensure adequate spacing.

Assembly with Grading Resistors



- Seven electrode rings comprising six graded sections.
- First electrode tied to profile #5 (165 kV)
- Three parallel paths for failure redundancy
- Last electrode grounding connection to warm structure feedthrough flange
- Insulated connection at DSS structure

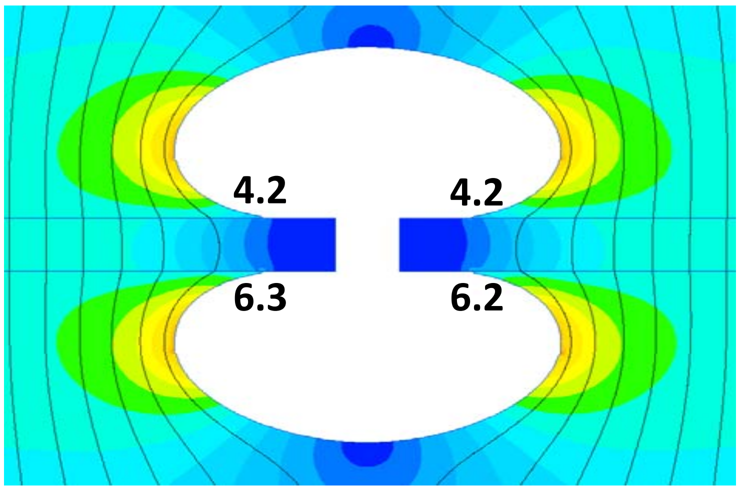
Beam Plug Performance Parameters

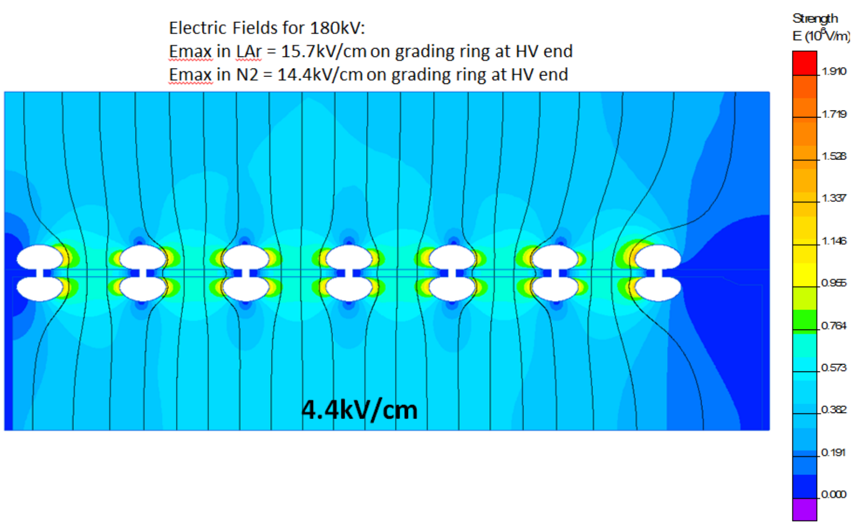
Parameter	Value
Dimensions	
Internal Diameter (est)	194 mm
Wall thickness (est)	8 mm
Length (est)	495 mm ± 1 mm 577 mm ± 1 mm
Metal End Cap Angle	$(16.2 \pm 0.25)^{\circ}$
Composite End Cap	$(16.2 \pm 0.5)^{\circ}$
Flange Angle	$(16.2 \pm 0.25)^{\circ}$
Tolerances	ASME Y14.5 2009
Epoxy system	Hysol 9309.2 NA
Electrode Rings	304 Stainless steel
Resistor Type	OHMITE Super-Mox 940 Series
Resistor Value	27.5 GΩ
Number of resistors	Three chains of six = 18
Power dissipation	
Per resistor	≈0.1W
Total	≈0.6W

Parameter	Value
Operating Voltage	Up to 180 kV end-to-end
Operating Temperature	25° C -185° C
Operating Pressure	< 1.5 bar
Pressure Environment (External)	19.9 psi
Internal Volume	15.5 liter (est.) 22 liter (est.)
Permeability/Leak Rate Range	7.8×10^{-5} scc/s to 15.6×10^{-5} scc/s
Operating Lifetime	1 yr
Lifetime Operational Thermal Cycles to 77 K	4
Shock Loading	
Vibration Loading	
Flange Profile	
Weight (est.)	85+ lb
Buoyancy Load (est.)	67.5 lb [31 kg]
Pressure Port	
Design Safety Factor	2
Pressure Test Factor	1.5
High Voltage Tests	(180 kV equivalent)

Grading Ring Electrostatic Design

Middle grading ring triple point fields (kV/cm)



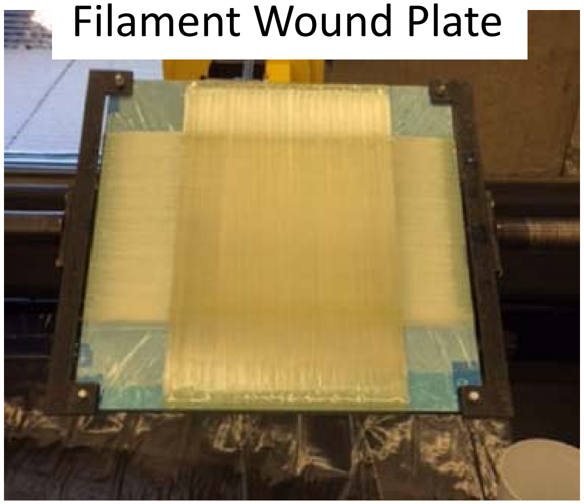


- Simulation Results:
  - Peak fields are 14-16kV/cm on worst case grading ring surfaces in LAr and N2
  - Triple point fields are 4-6.5kV/cm in LAr and N2
  - Surface fields on FR4 in LAr and N2 are ~7kV/cm
- These 2D simulations indicate that fields are acceptably low
- Will be working on a more complete 3D electrostatic simulation including resistors and field cage elements.

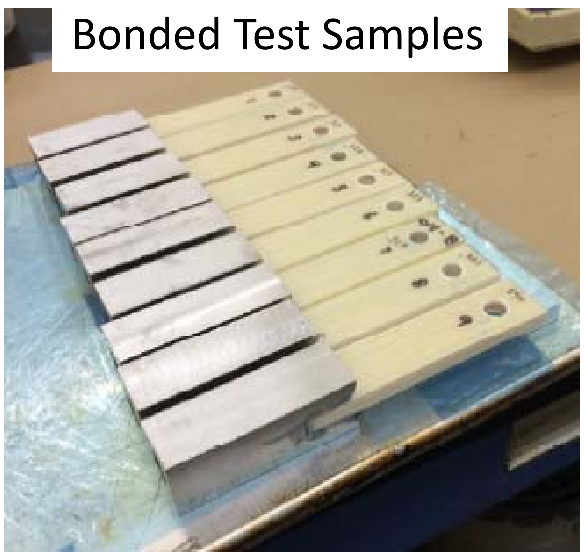
Courtesy: Will Waldron LBL

Adhesive Bond Cryo Tension Test

Filament Wound Plate



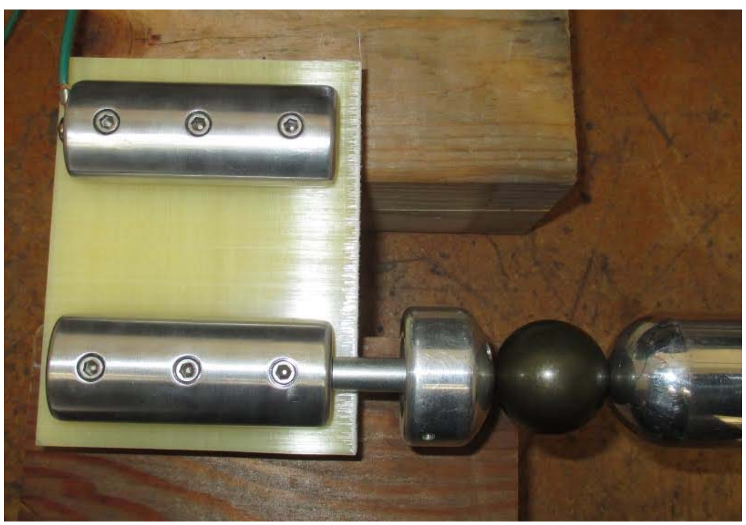
Bonded Test Samples



77K LN Tension Test

- Tested the bond shear strength between metal electrodes and composite ring sections.
- Results indicated that the ultimate shear load can be increased linearly by increasing bond length from 5mm up to 10mm.
- After considering the coupled effect on the electrode geometry profile and electrostatics, a value of 8 mm was selected.

Glass/Epoxy Composite HV Test



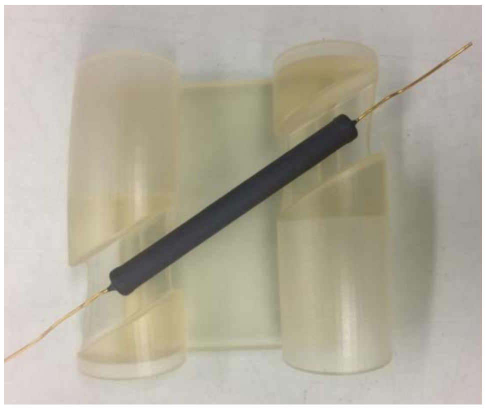
- Testing in air at 50 kV for surface breakdown.
- No significant voltage drop across 5MOhm series resistor.
- Beam plug grading rings will only be 30 kV intervals.
- Additional tests are planned with grading rings and glass/epoxy sections submerged in LAr.

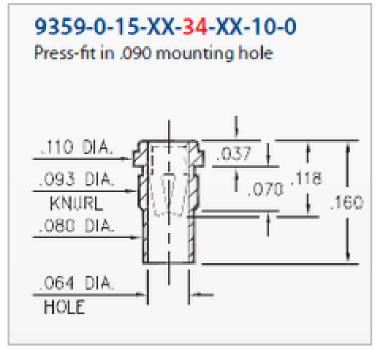
Courtesy: Will Waldron LBL

Resistor Mounting to Grading Rings

3D Printed Prototypes

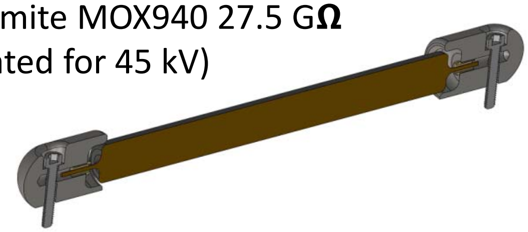
Trial Thru-Slot Concept





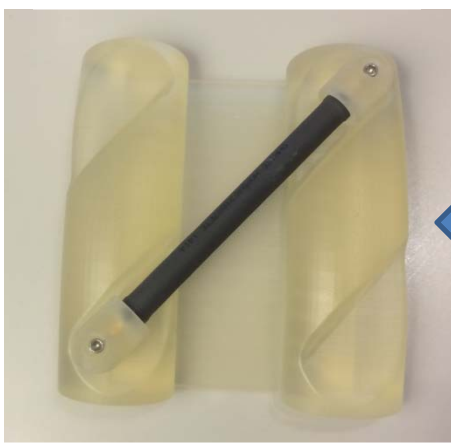
Mill-Max press-fit receptacles for resistor leads proven use in LZ experiment.

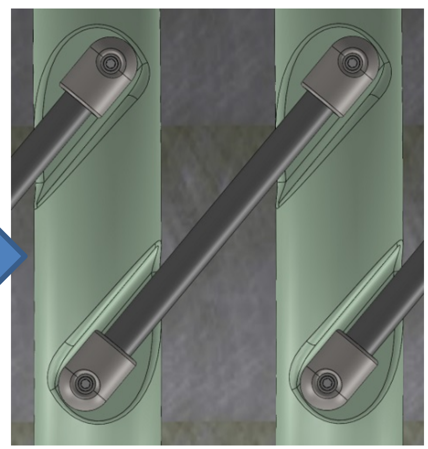
Ohmite MOX940 27.5 GΩ
(Rated for 45 kV)



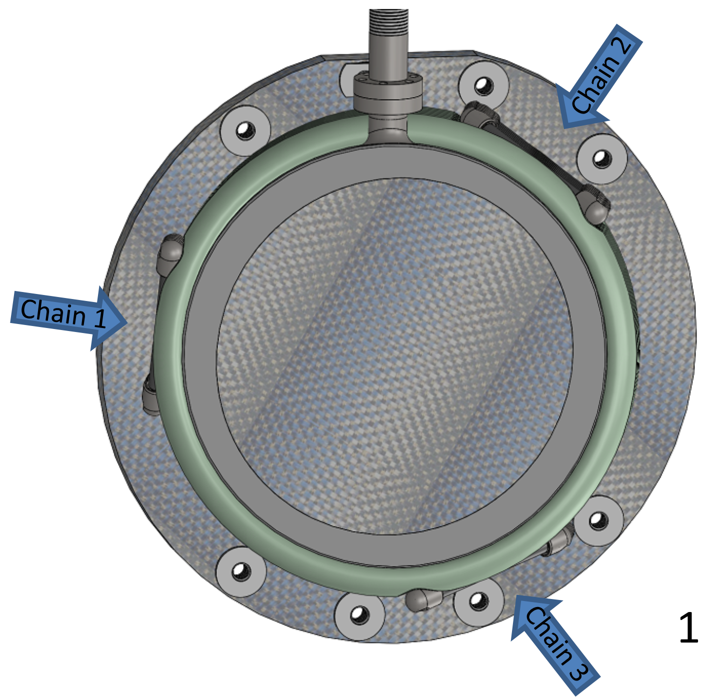
End caps secure resistor ends while allowing 2-3 mm each end for thermal contraction and structural deflection.

Final Terraced Concept

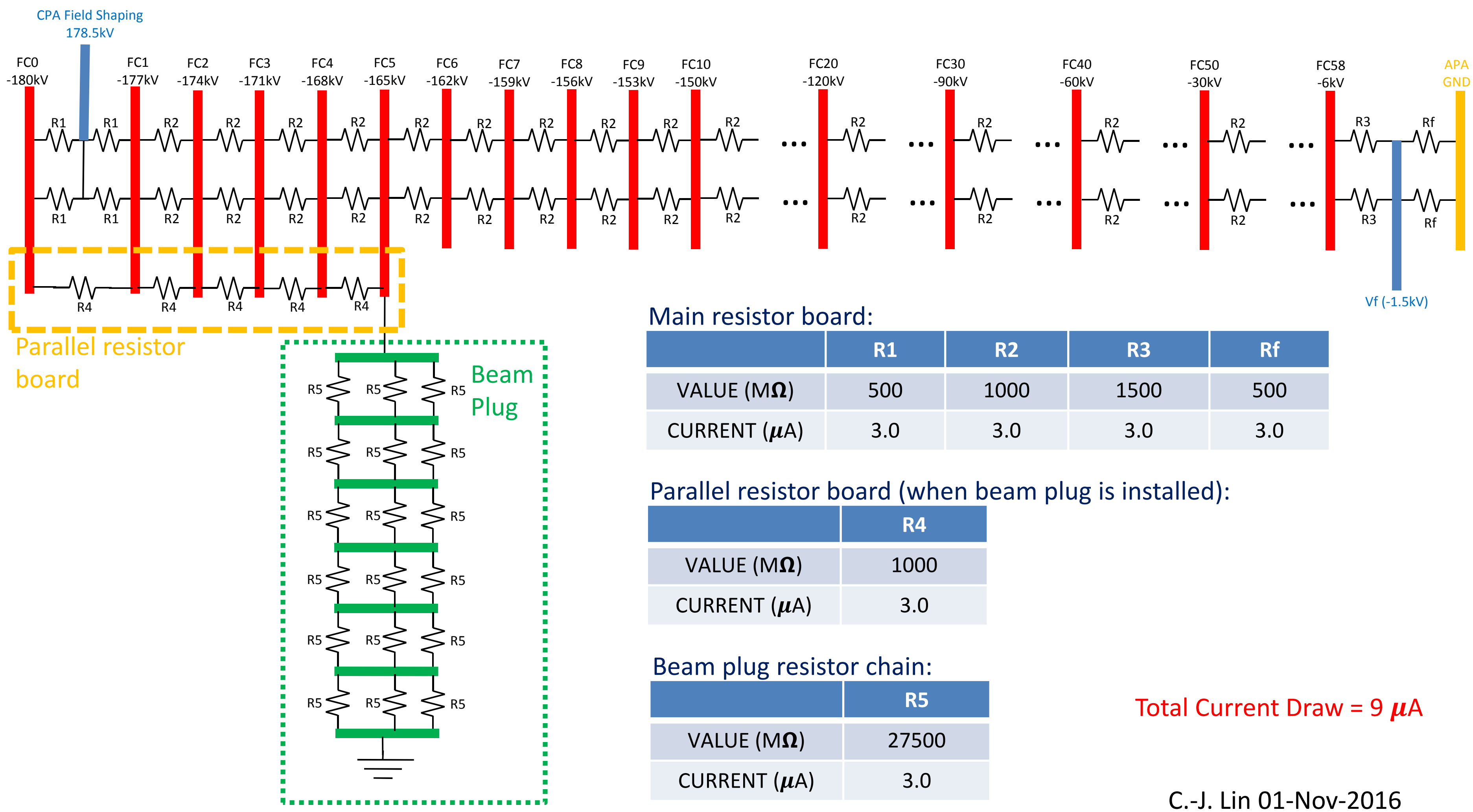




Three redundant resistor chains:



Resistor Chain



Main resistor board:

	R1	R2	R3	Rf
VALUE (MΩ)	500	1000	1500	500
CURRENT (μA)	3.0	3.0	3.0	3.0

Parallel resistor board (when beam plug is installed):

	R4
VALUE (MΩ)	1000
CURRENT (μA)	3.0

Beam plug resistor chain:

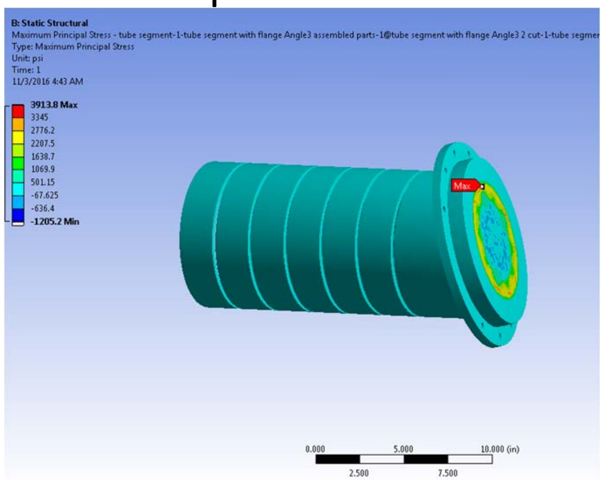
	R5
VALUE (MΩ)	27500
CURRENT (μA)	3.0

Total Current Draw = 9 μA

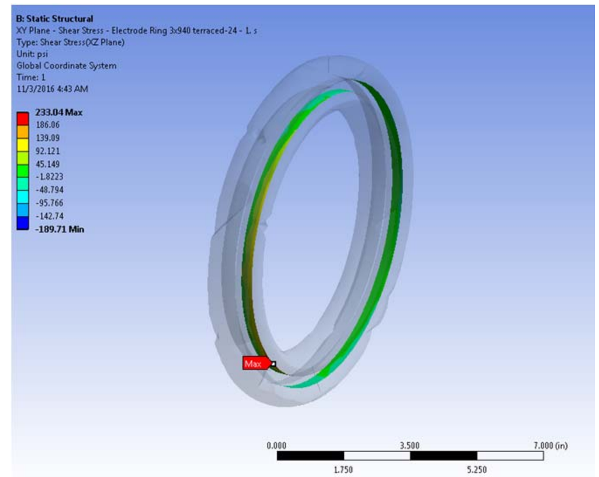
C.-J. Lin 01-Nov-2016

Analysis Design Studies & Verification

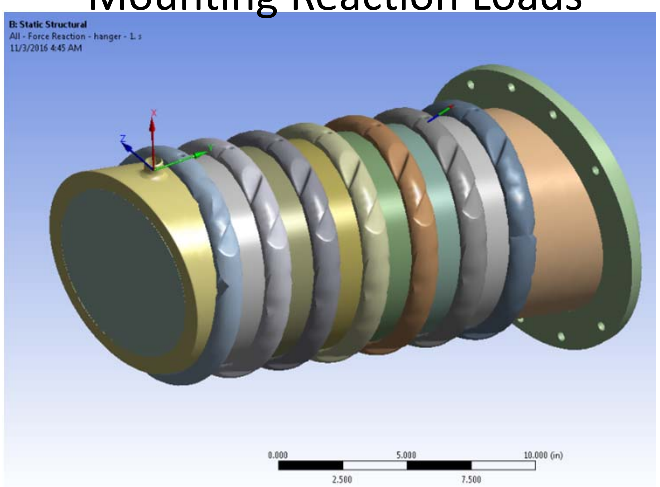
Composite Sections



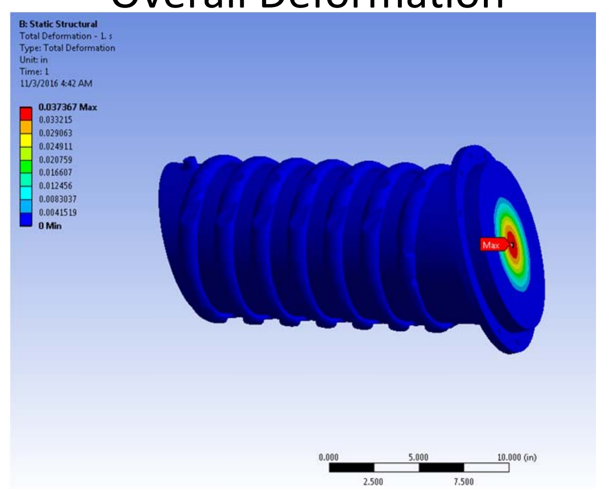
Adhesive Shear



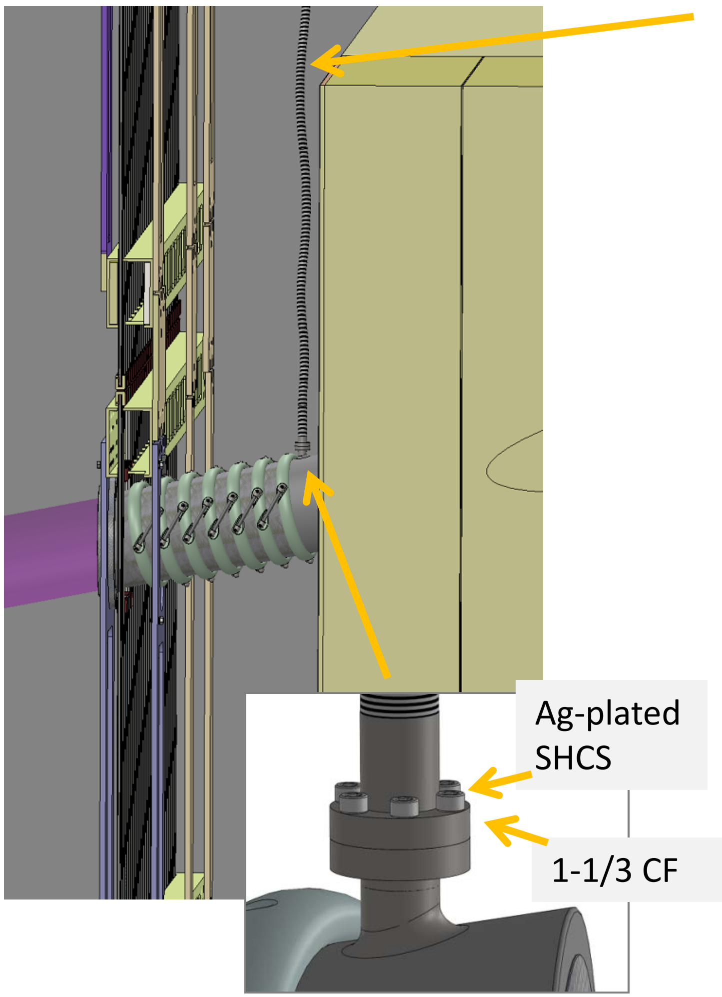
Mounting Reaction Loads



Overall Deformation

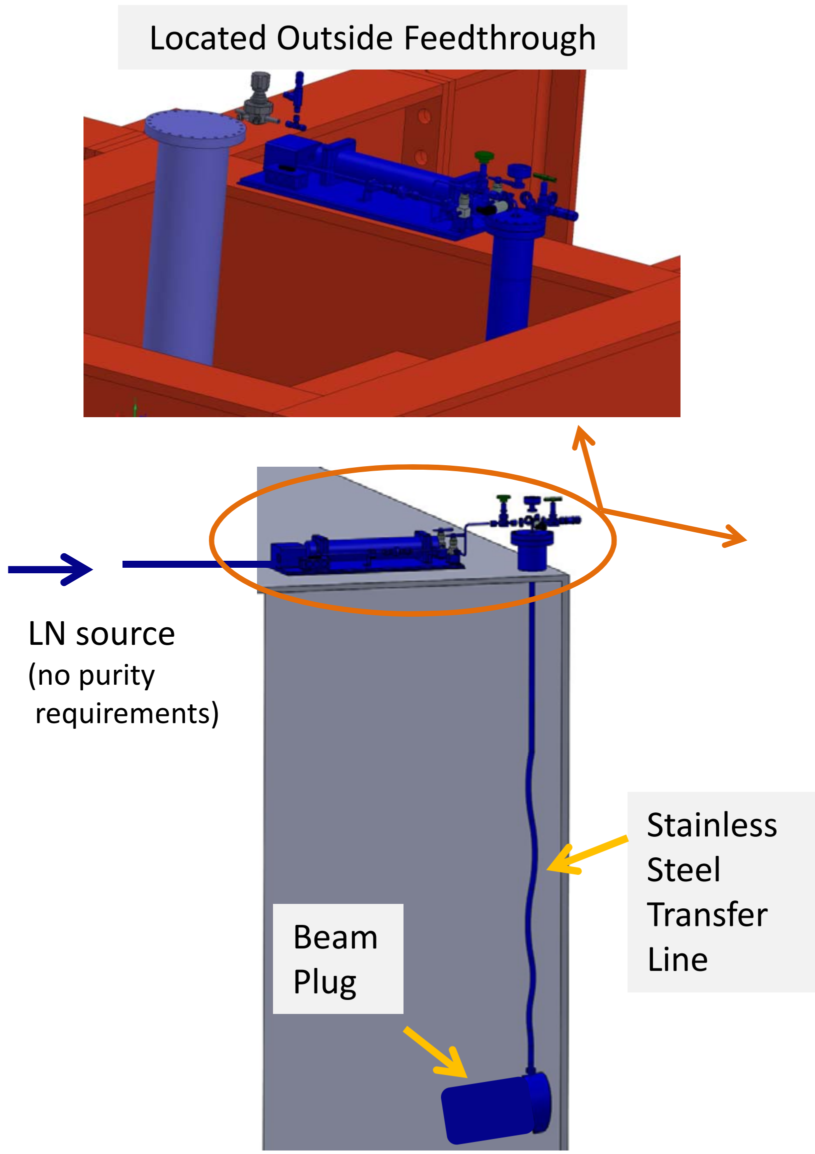


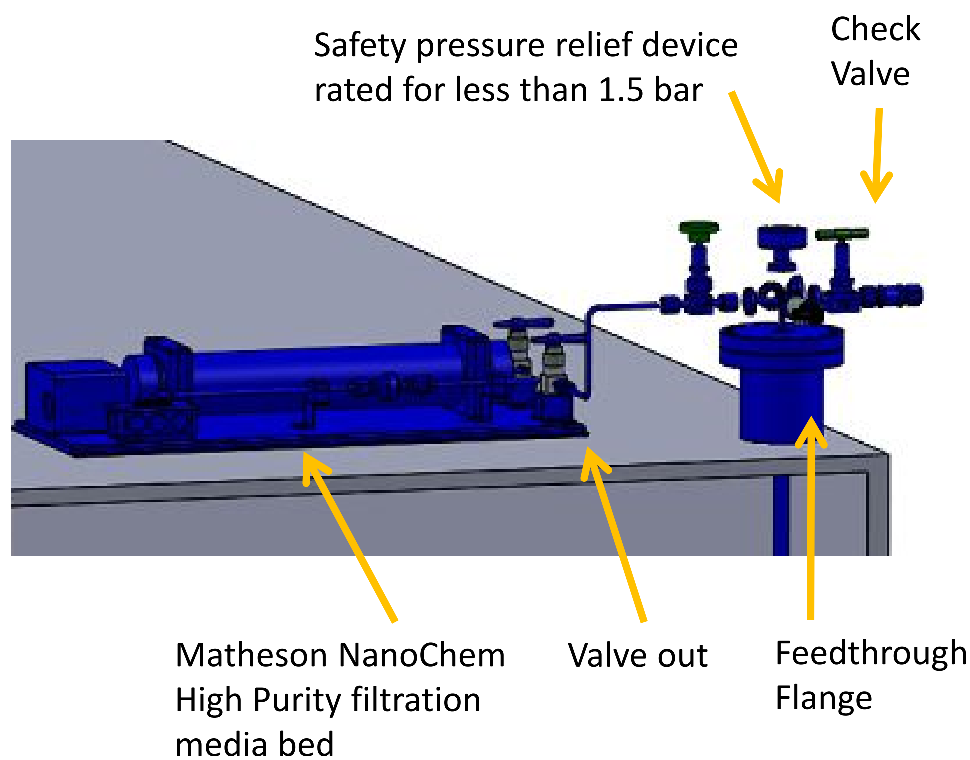
Nitrogen Line Interior Cryostat



- Braided semi-flexible stainless steel line from beam plug to feedthrough
- Weight is supported from DSS runway I-Beam
- Maintain distance from cryostat membrane clear of corrugations
- Cryo break inside the feedthrough
- Grounding continuity to feedthrough flange
- Pre-operation prep, cleaning, purging
- Install into FC, connect grounding and nitrogen line
- Manual control, closed system with low-flow constant flow option
- Pre-cool with pressure ramped during cryostat filling
- Two temperature and two pressure sensors requested for slow control system

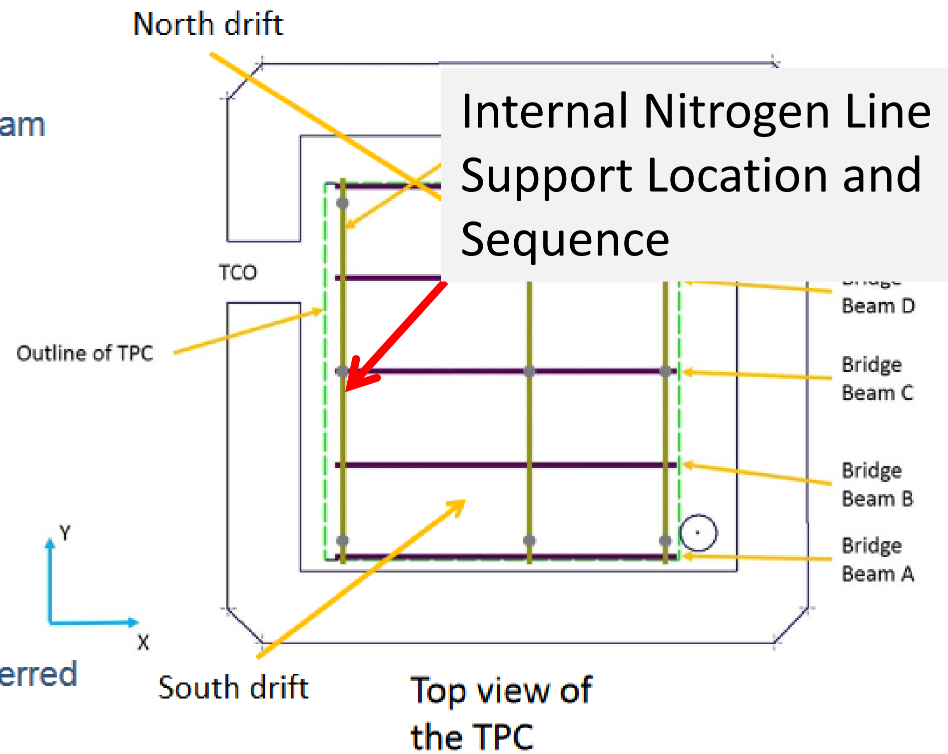
Ultra Pure Nitrogen Supply System



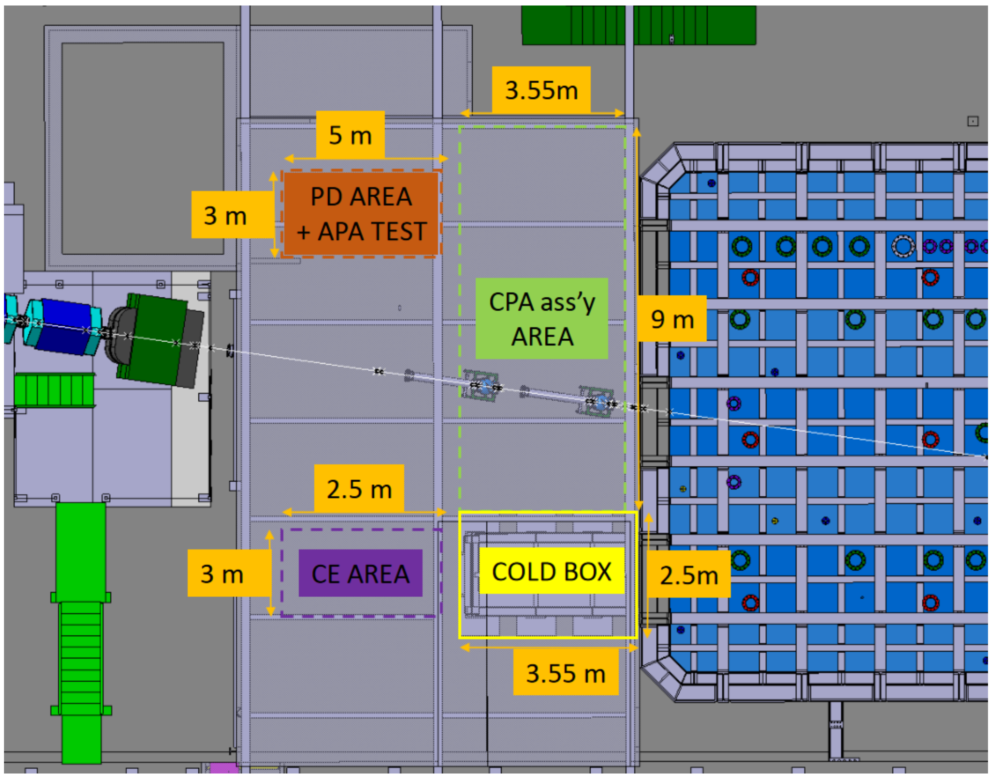


Summary of the installation process

- South Drift
  - APAs delivered on Beam A
  - EWs delivered on Beam B
  - CPAs with FCs delivered on Beam
  - EW load transfer
  - South Drift FCs are deployed
- North Drift
  - APAs stored on Beam E
  - EWs stored on Beam D
  - TCO is closed
  - EW (TCO) is delivered
  - APAs positioned
  - EW (TCO) load transfer
  - Last EW is delivered and transferred
  - North Drift FCs are deployed

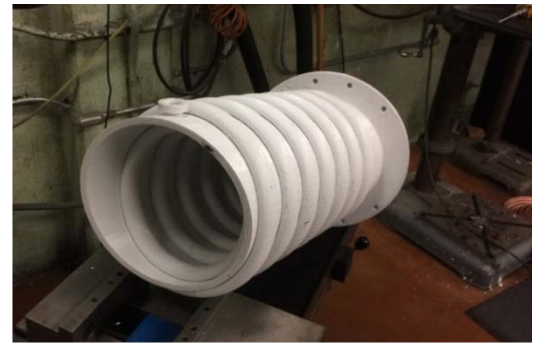


Installation



- Installed to south end wall field cage outside of TCO
- Lifting device mounts to electrode rings, balanced about the center of mass.

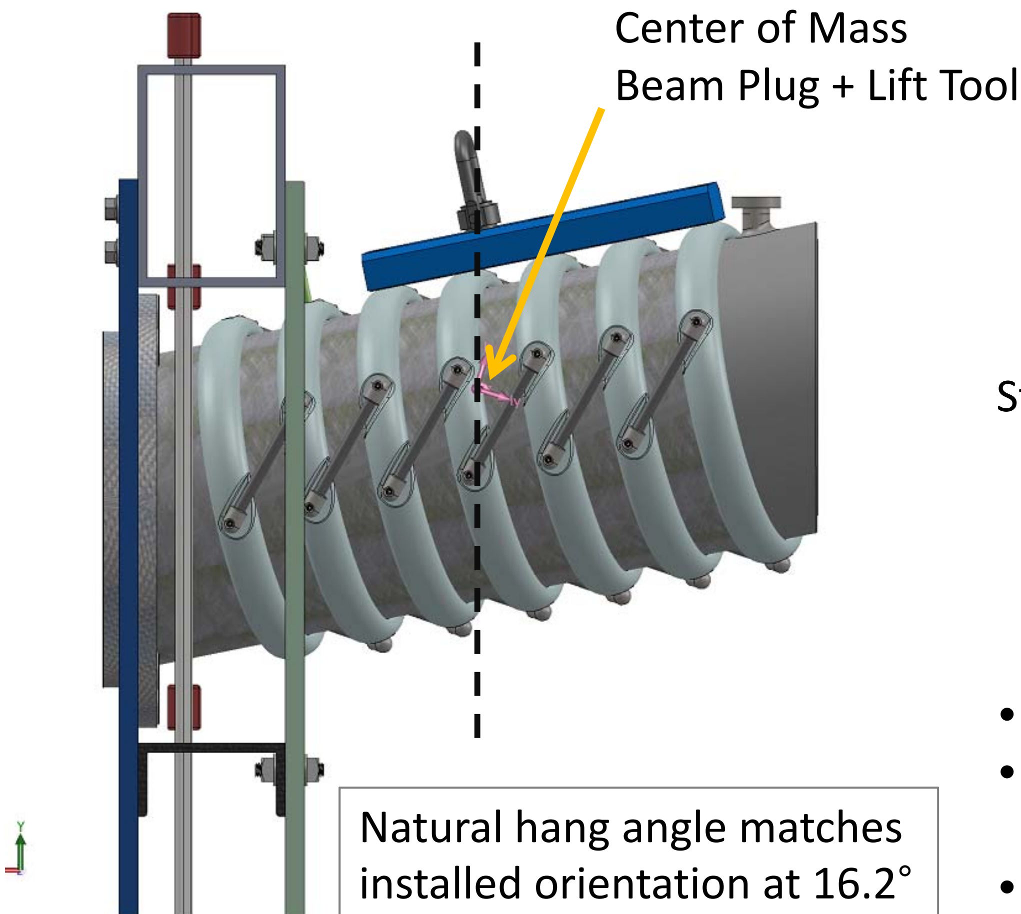
Two Beam Plugs for Ash River Test

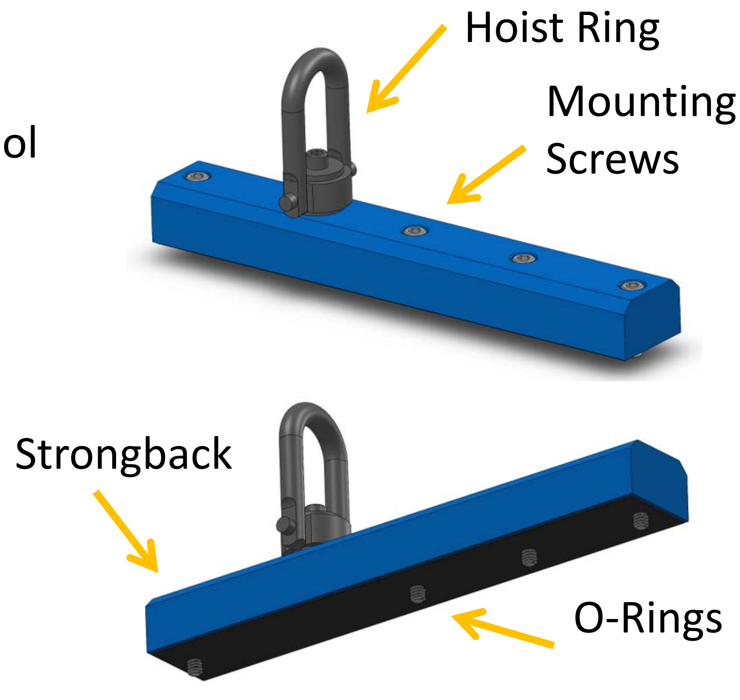


- Rugged aluminum “mule”
- Can be weighted to match
- Dimensionally accurate
- Integrated into endwall field cage at LSU in October.

- 3D Printed full-scale ABS plastic beam plug.
- Weight and balance to match.
- Dimensional replicate.
- Mountable from flange.

Lift and Mounting Tool





Natural hang angle matches installed orientation at 16.2° (compound angle)

- Annodized Al 6061 Bar strongback
- Four 6 mm silver-plated socket head cap screws
- A80 Buna-n or Teflon o-rings at joints
- Stainless steel swivel safety hoist ring rated for 300 lb

Material Selection

- Materials used:
  - Composite Rings: S-2 Glass/epoxy matrix composite; filament wound.
  - Metal Electrodes: Stainless steel 304
  - Cryogenic adhesive: Hysol 9309.2 NA epoxy
  - Ground End Cap: Stainless Steel 304
  - HV End Cap: S-2 glass/epoxy matrix composite; filament wound. Bonded to machined G-10 CR plate.
  - HV Flange Mounting Hardware: Stainless Steel 304
  - Secondary Support: Torlon rod

- Materials have and are being tested for LAr purity and radioactivity levels.

Material Radioactivity Levels

- Some samples have been counted at the Low Background Counting Facility at LBNL

MATERIAL	STATUS
Cryogenic Epoxy (Hysol 9309.2 NA)	Very low activity
Stainless Steel 304	Not yet counted
OHMITE MOX 940 resistors	In queue; expected to be high, but low mass quantity and outside active region volume.
S-2 Glass/Epoxy Composite	^{40}K rate is ~ 5 Bq but net effect expected to be low
Torlon	Not yet counted
G-10 Plate	Not yet counted

Results presented to the DUNE Radio Purity working grop last month. Materials were officially "blessed" for use in ProtoDUNE

Conclusion

- Field Cage Interface
- Beam Plug Components
- Component Testing
- Resistor Chain
- Nitrogen Line
- Installation
- Material Testing