High-Voltage Design Aspects of the LZ Detector

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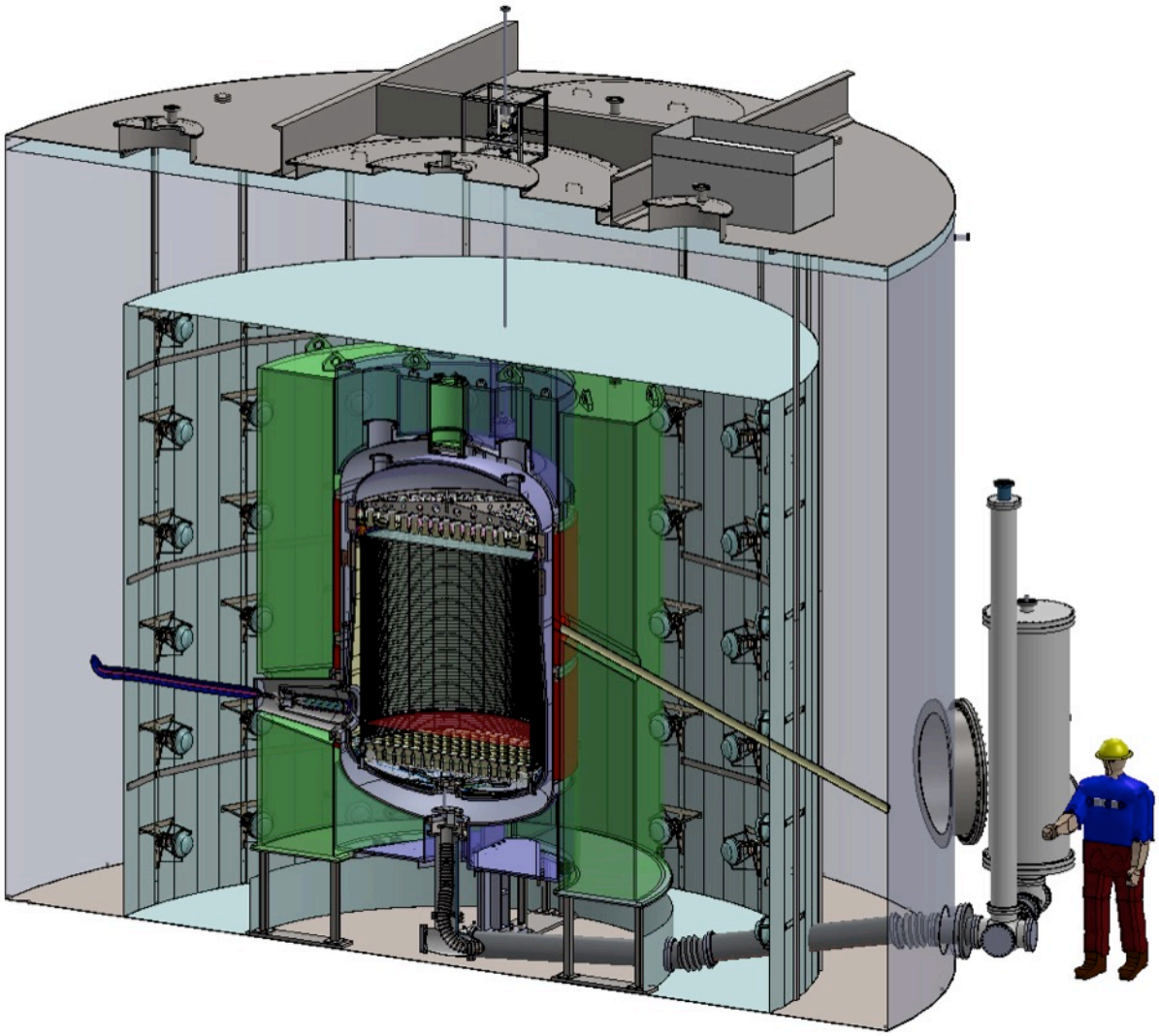


9th Oct. 2016 - CPAD 2016 - Caltech

LZ is the successor to the LUX and ZEPLIN experiments

LZ

Total mass – 10 T
WIMP Active Mass – 7 T
WIMP Fiducial Mass – 5.6 T
145.6 cm TPC drift length

LUX

Total mass – 0.37 T
TPC-instrumented mass – 0.25 T
WIMP fiducial mass – 0.102 T
59 cm TPC drift length

Cryostat fabrication has just begun.

Removed from water tank last week.

High voltage is the most difficult aspect of the design to scale

History of HV growing pains:

Xenon10:
Took data at 13 kV.

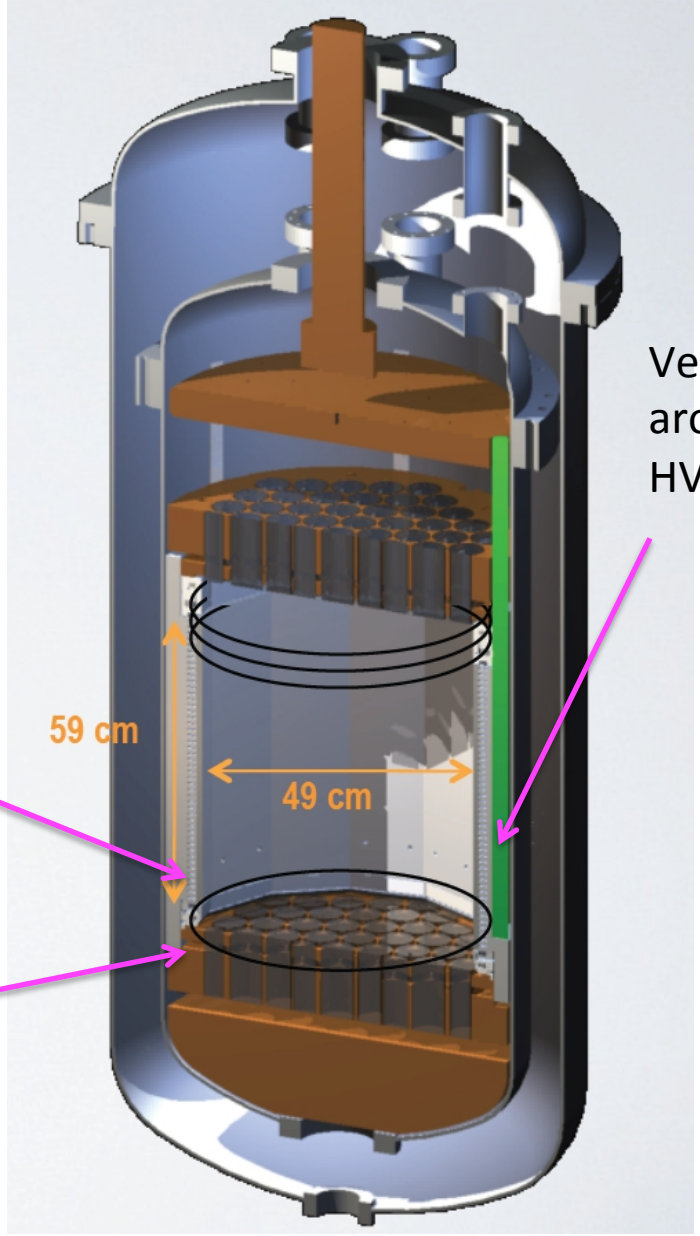
Xenon100:
Planned for 30 kV cathode operation.
Took data at 16 kV.

LUX:
Planned for "up to 100 kV" cathode operation. Took data at 8.5 kV.

LZ is 2.5 times larger in length scale than LUX.

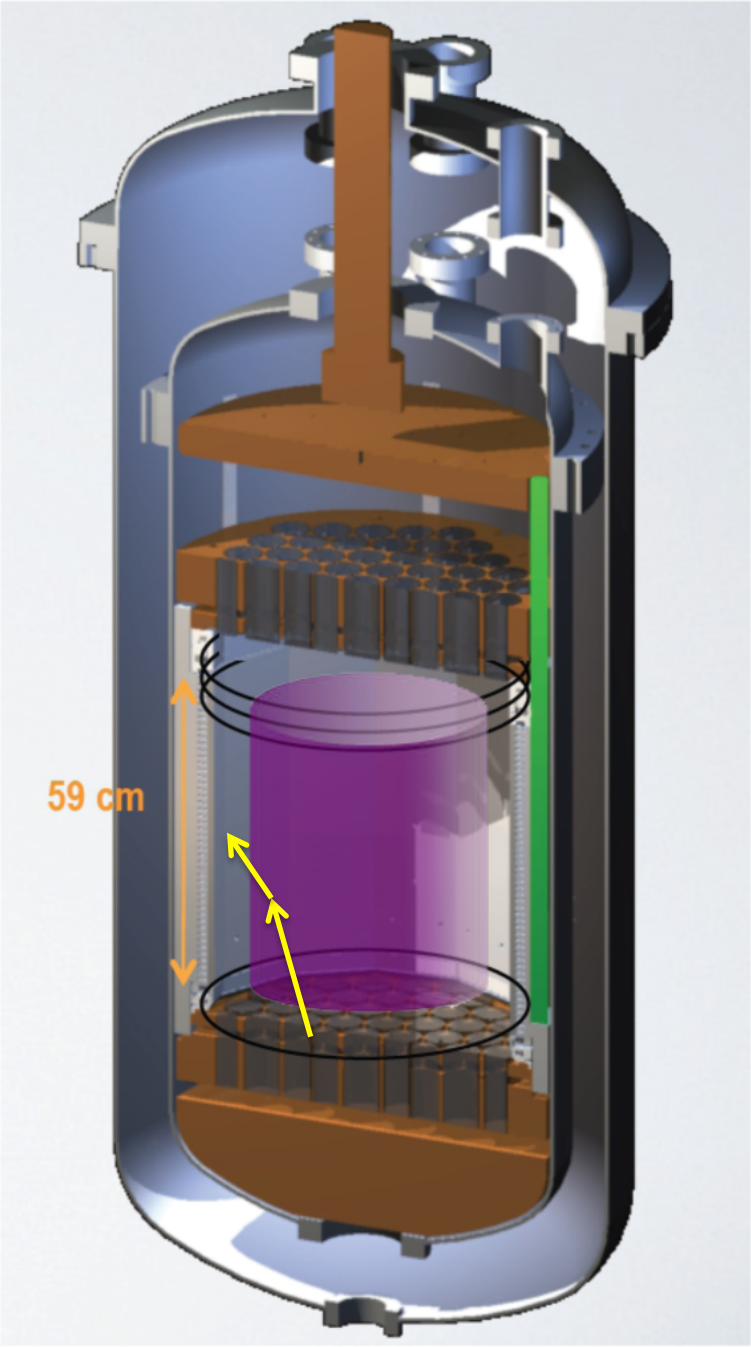
Very high fields between TPC and cryostat wall

Very high fields between cathode and lower PMTs



Very high fields around cathode HV feedthrough

HV problems from simple LUX scale-up



LUX

LUX uses the outer layer of the liquid xenon in the TPC to veto non-WIMP events.

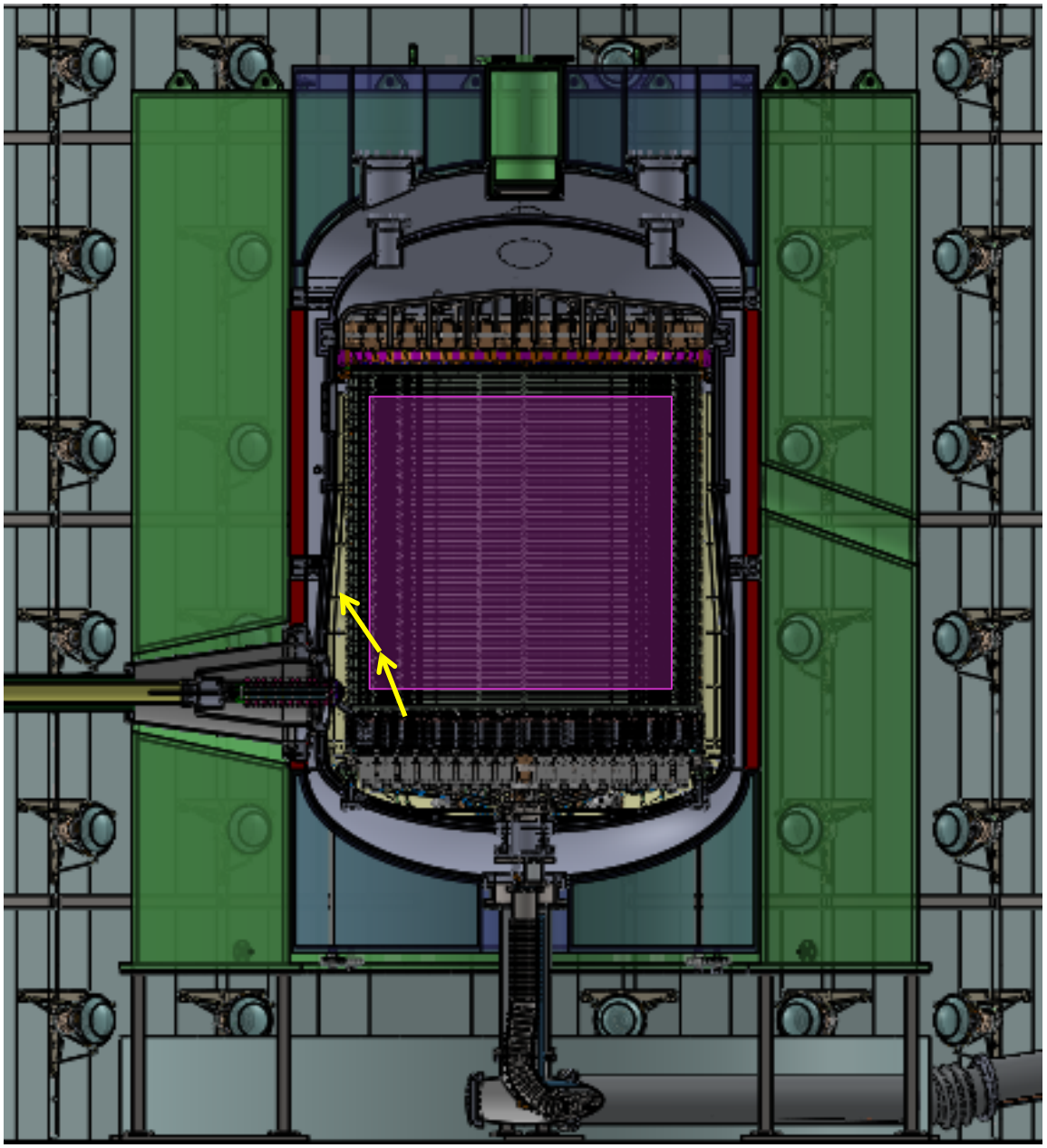
The fiducial volume must be moved far inward from the walls to capture escaping gammas and neutrons.

This works well but it makes inefficient use of the TPC-instrumented xenon.

LUX

Total mass – 0.37 T
TPC-instrumented mass – 0.25 T – 68% of total
WIMP fiducial mass – 0.102 T – 27.5% of total

Skin and outer veto detector allow fiducial layer to approach TPC



LZ

LZ moves the TPC inward from the walls, creating a region of "Xenon skin". This provides HV standoff from the metal wall.

Skin xenon is observed with PMTs from above and below, acting as a veto.

Gammas and neutrons are measured either by the xenon skin or by an additional organic scintillator detector outside the detector.

LZ

Total mass – 10 T
TPC-instrumented mass – 7 T
WIMP fiducial mass – 5.6 T

HV design parameters for LZ

Required drift field in xenon for 99.5% discrimination against electronic recoils: 300 kV / cm (Designing for 600 kV / cm)

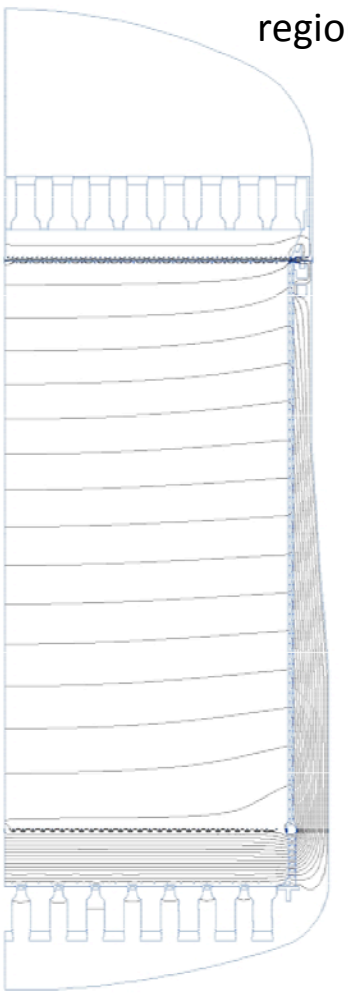
→ This implies: -50 kV on cathode. (Designing for -100 kV)

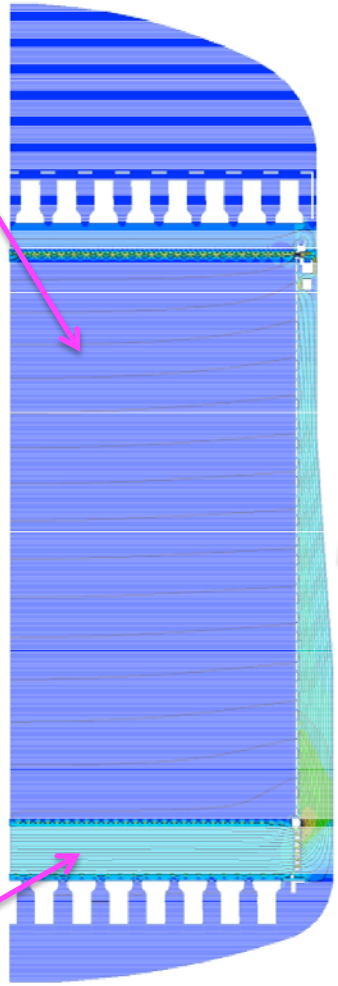
Maximum field in liquid xenon bulk for 100 kV design: 50 kV / cm (except for wire surfaces)

Maximum ungraded voltage across a dielectric surface in 100 kV design: 20 kV

Unwanted light production is the principle concern. (Not breakdown)

LZ HV design – Cryostat



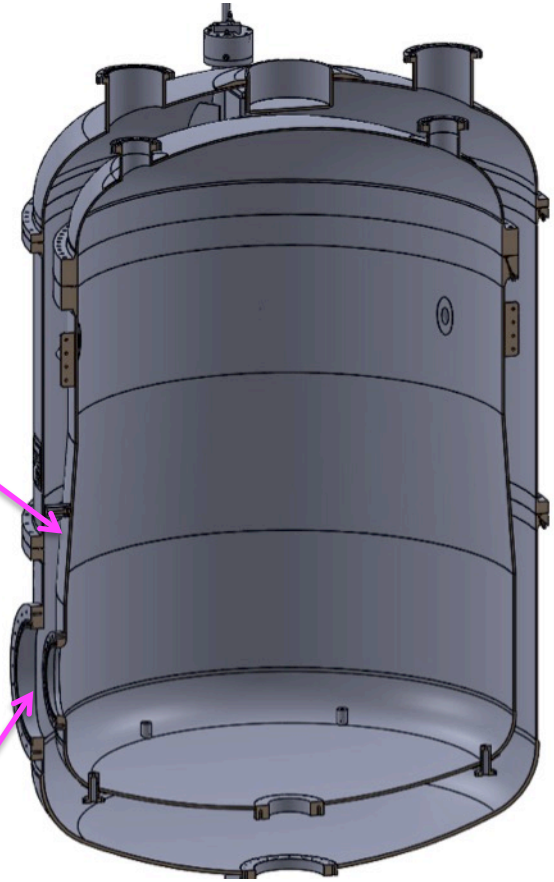


Forward field region (FFR)

Reverse field region (RFR)

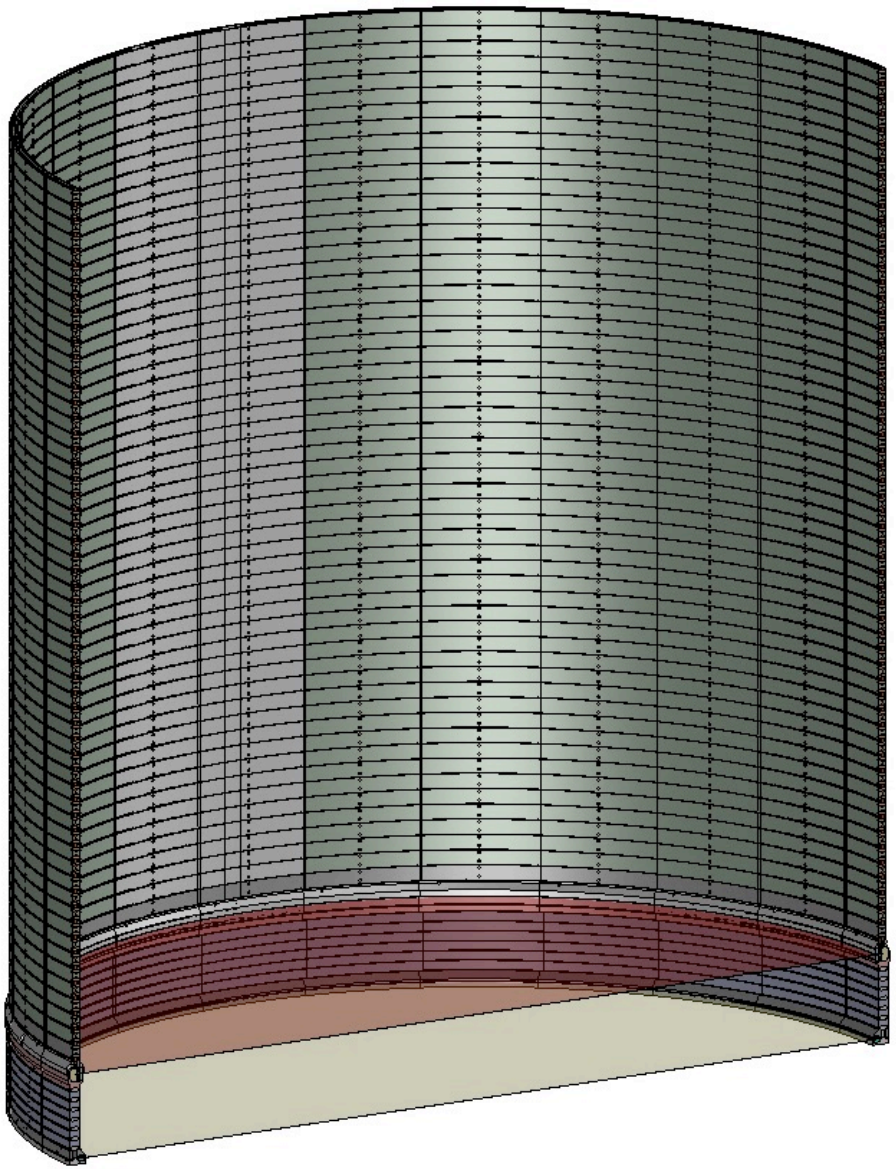
Inner cryostat tapers for optimal spacing from TPC

Cathode HV feedthrough comes in from the side

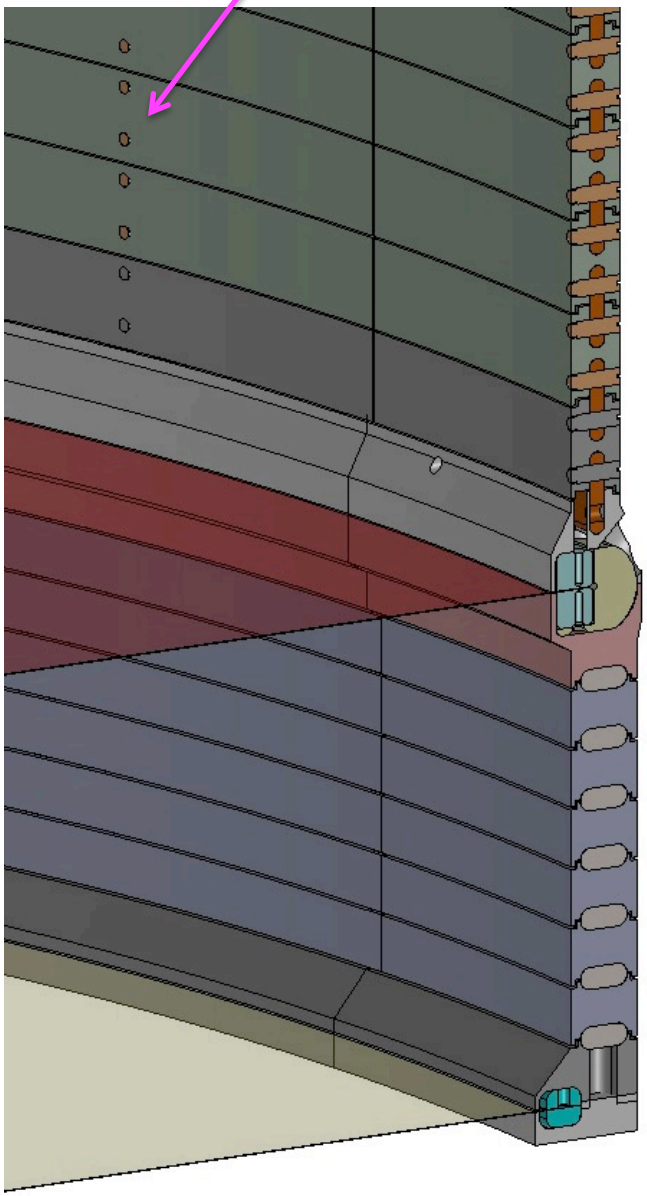


LZ HV design – TPC field cage

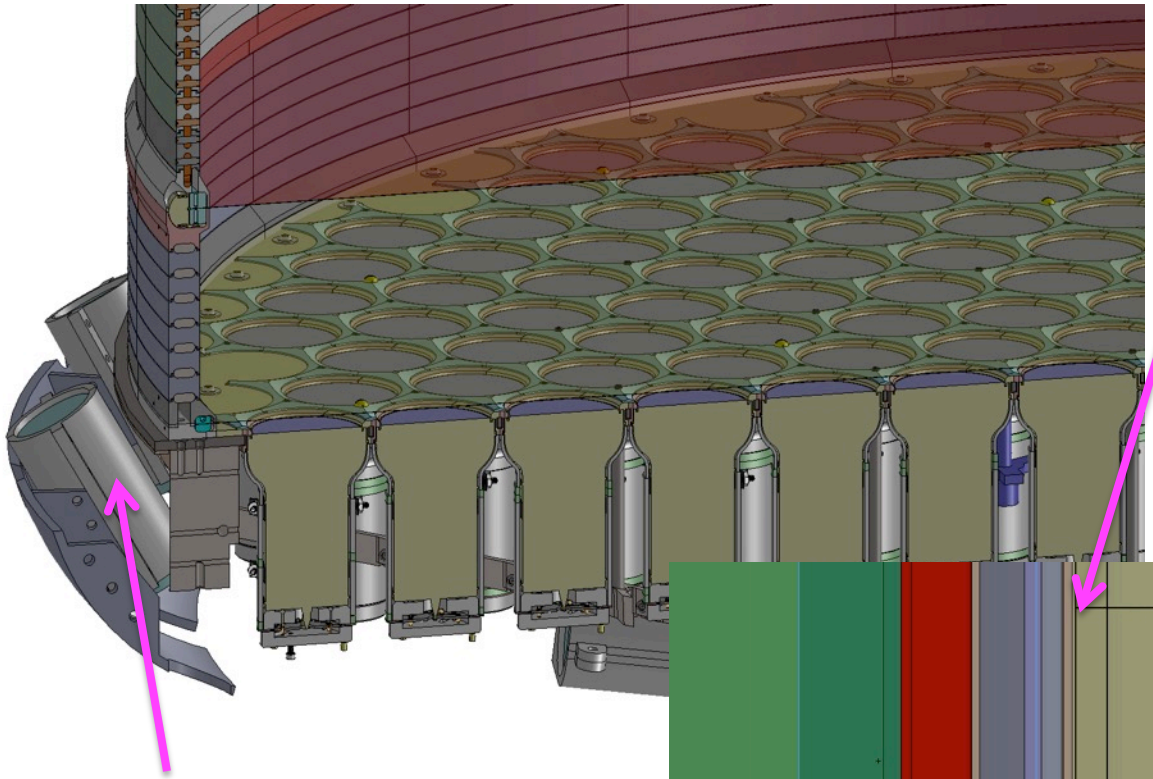
~ 1600 Segmented, interlocking PTFE arcs around 58 + 8 titanium rings



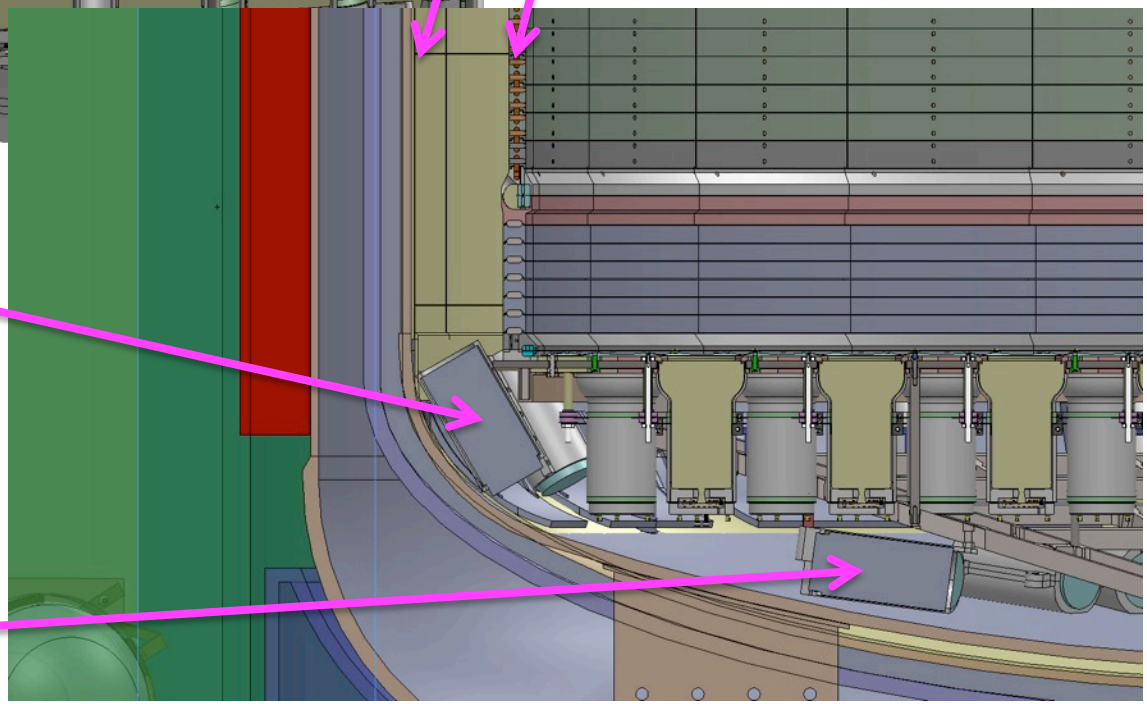
PEEK pegs secure rings to arcs



LZ HV design – Skin viewing PMTs



PTFE cryostat liner and TPC form a light guide in the skin.



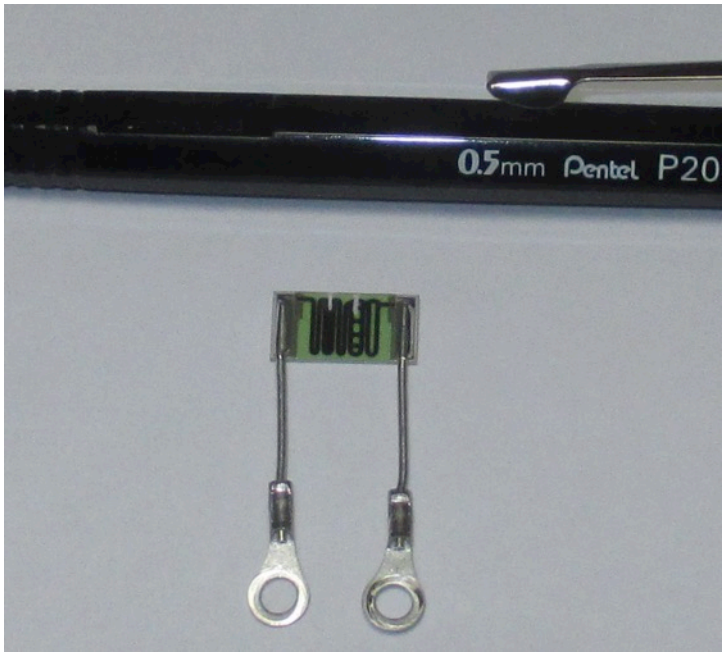
Lower skin PMTs are at an angle and squeezed into the lower corner. 20 2-inch R8778 PMTs from LUX.

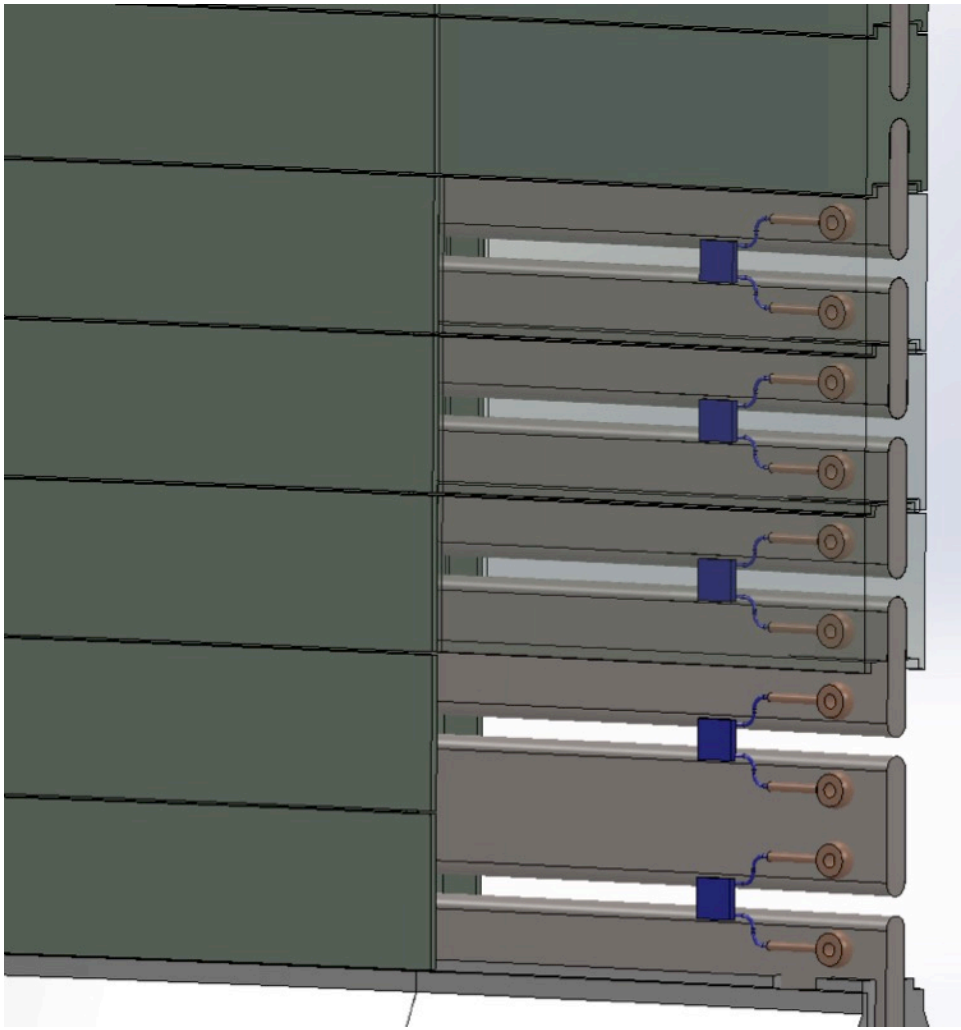
A dedicated ring of PMTs also views the skin from above.

A third array views the xenon in the belly of the cryostat below the lower PMT array.

LZ HV design – TPC grading resistors

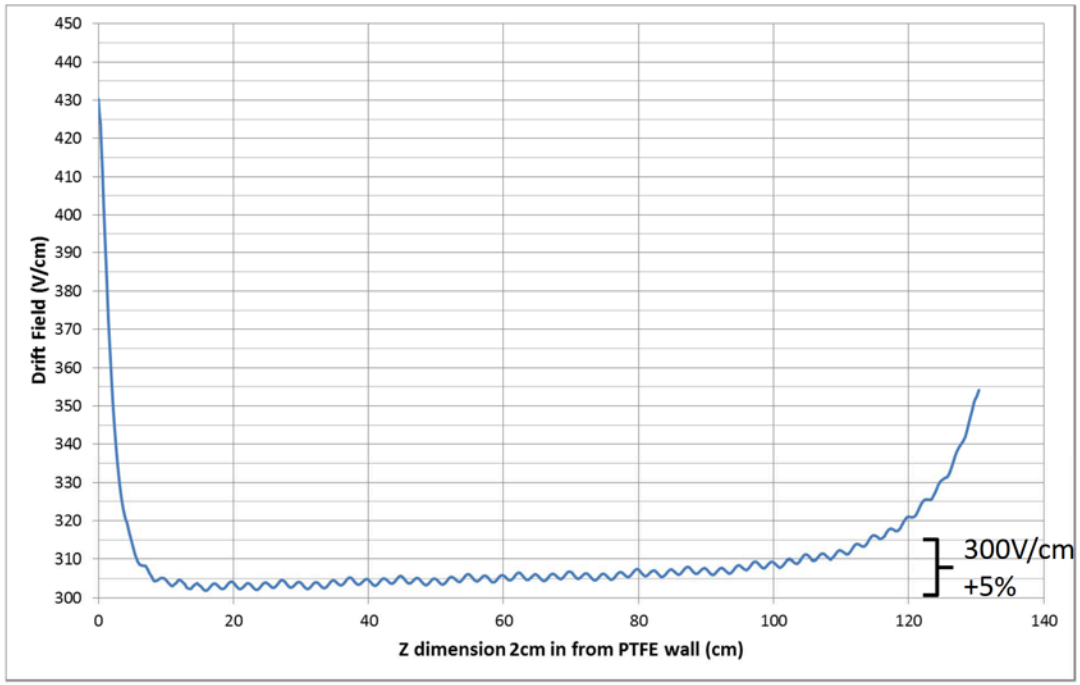
- 2 parallel 1Gohm resistors/section x 58 sections
- 116 resistors
- 29 Gohm total load
- 3.45uA total at 100kV
- 0.345W total
- 5.9mW/resistor (0.5W rating)
- 1.7kV/resistor at 100kV (2kV rating)

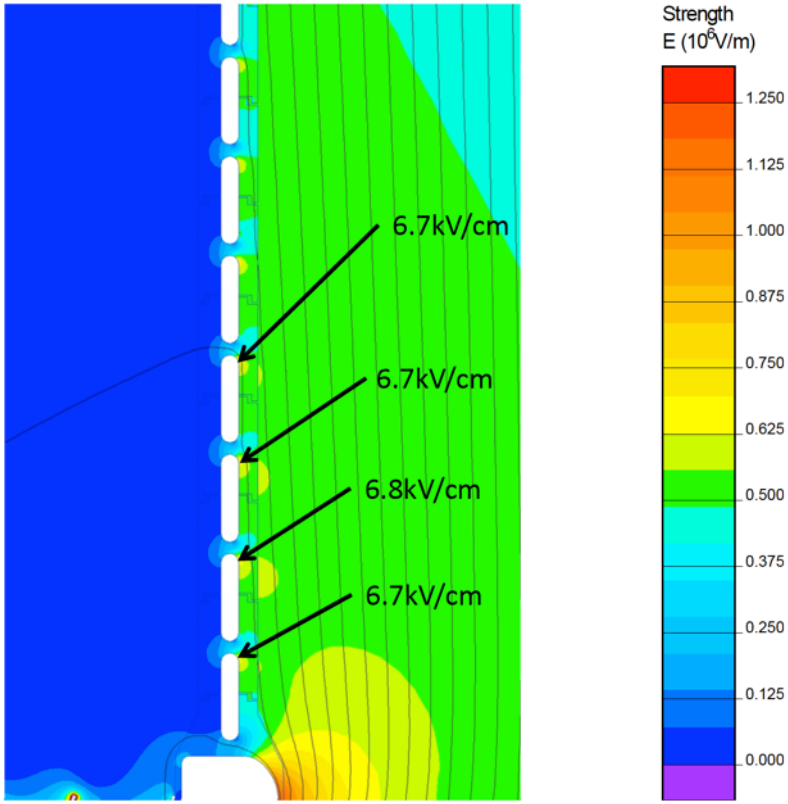




Resistors on inside of grading rings (in grooves in PTFE)

LZ HV design – FFR grading (drift field cage)



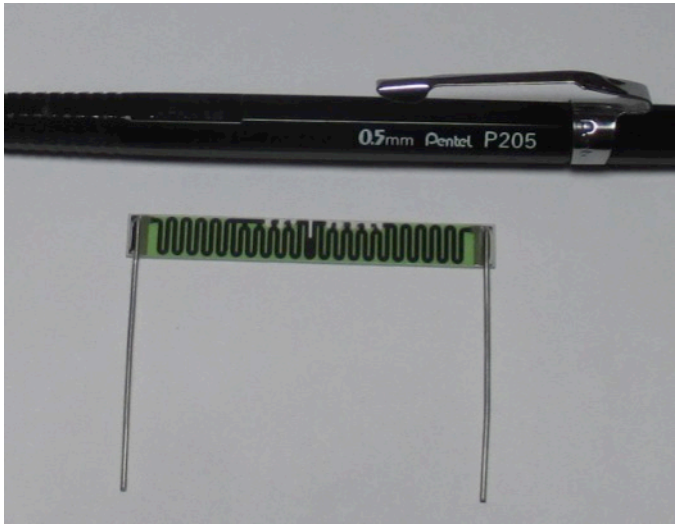


Close electrodes minimize field inhomogeneity

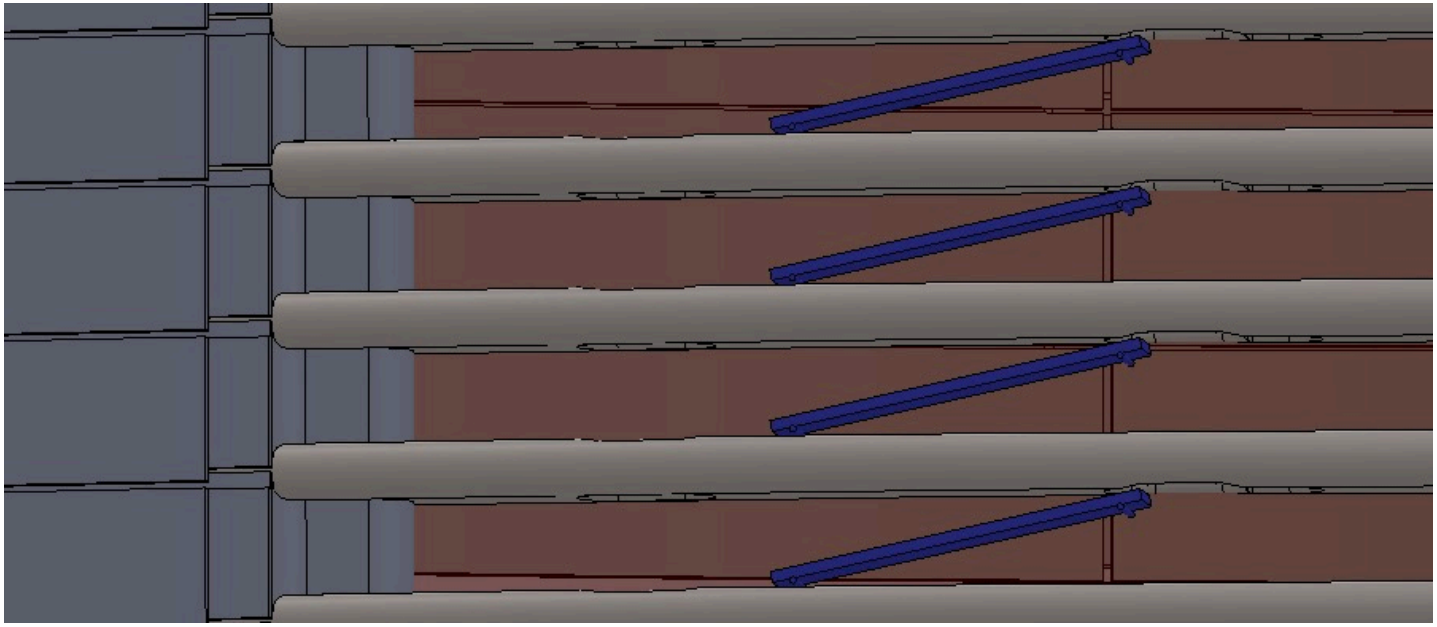
Cathode at -50 kV

LZ HV design – RFR grading resistors

- 2 parallel 5 Gohm resistors/section x 8 sections
- 16 resistors
- 20 Gohm total load
- 5uA total at 100kV
- 0.5W total
- 31mW/resistor (2W rating)
- 12.5kV/resistor at 100kV (15kV rating)

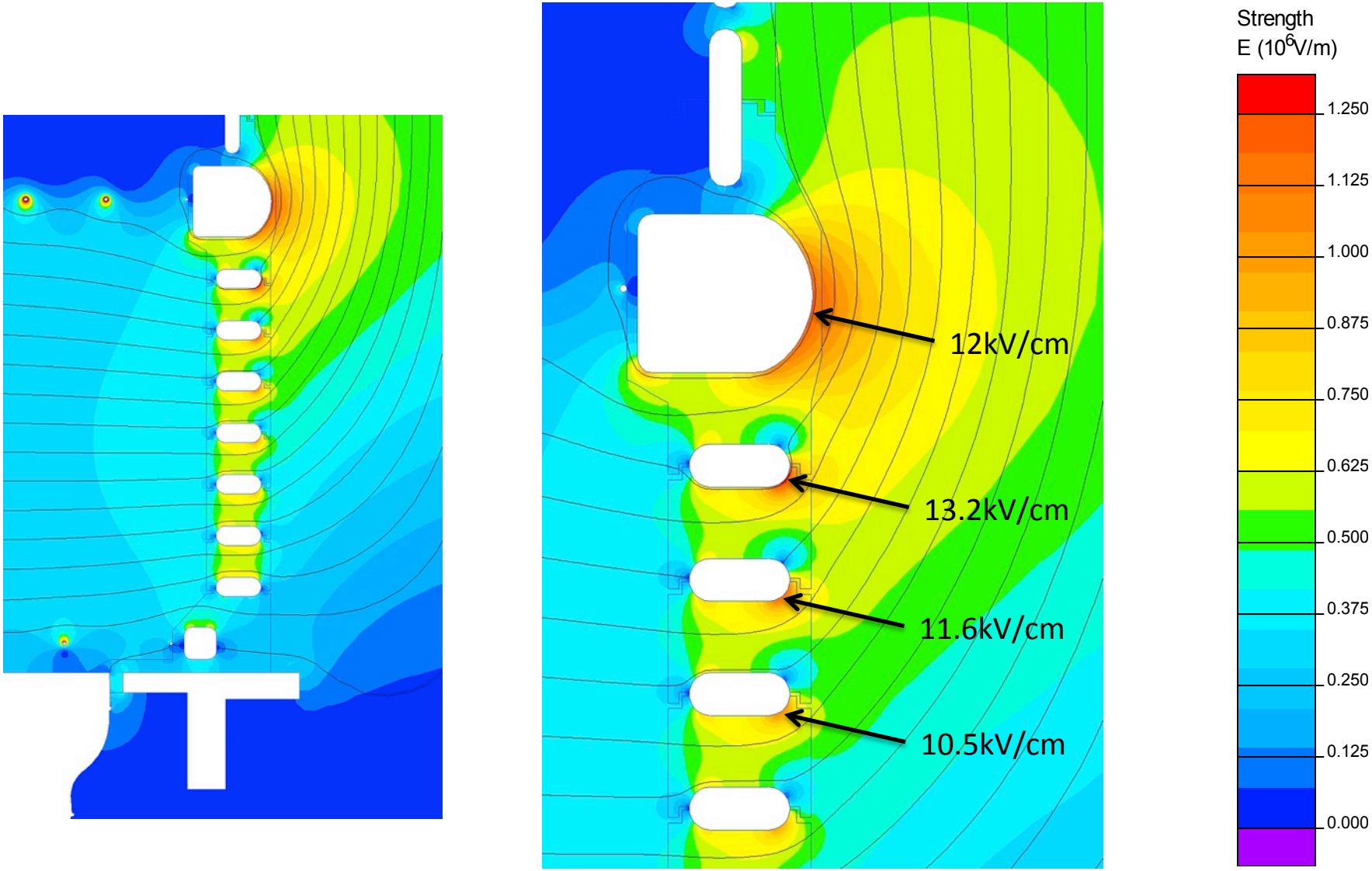


similar resistor



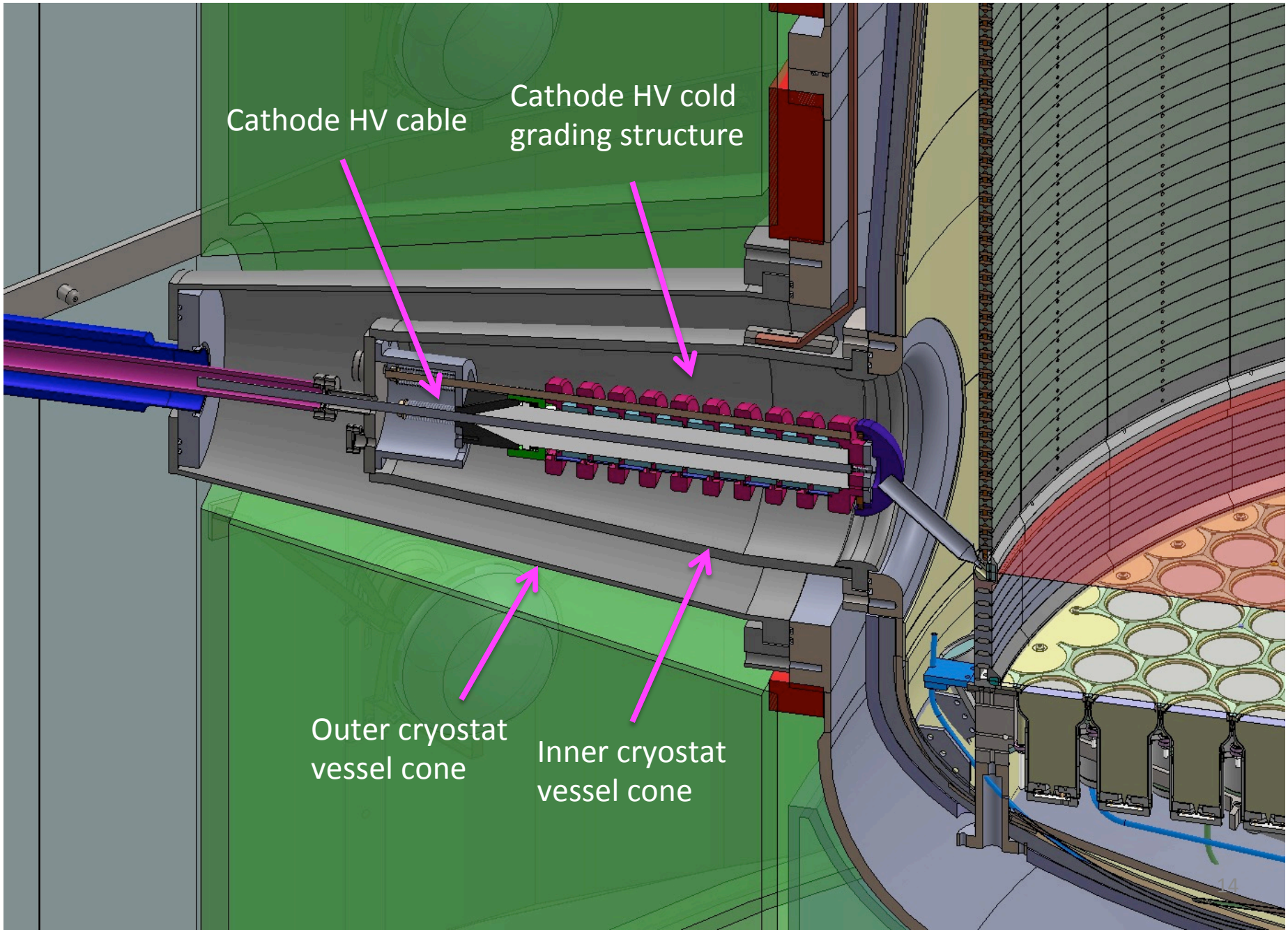
Resistors between RFR grading rings (in grooves in PTFE)

LZ HV design – RFR grading and cathode ring

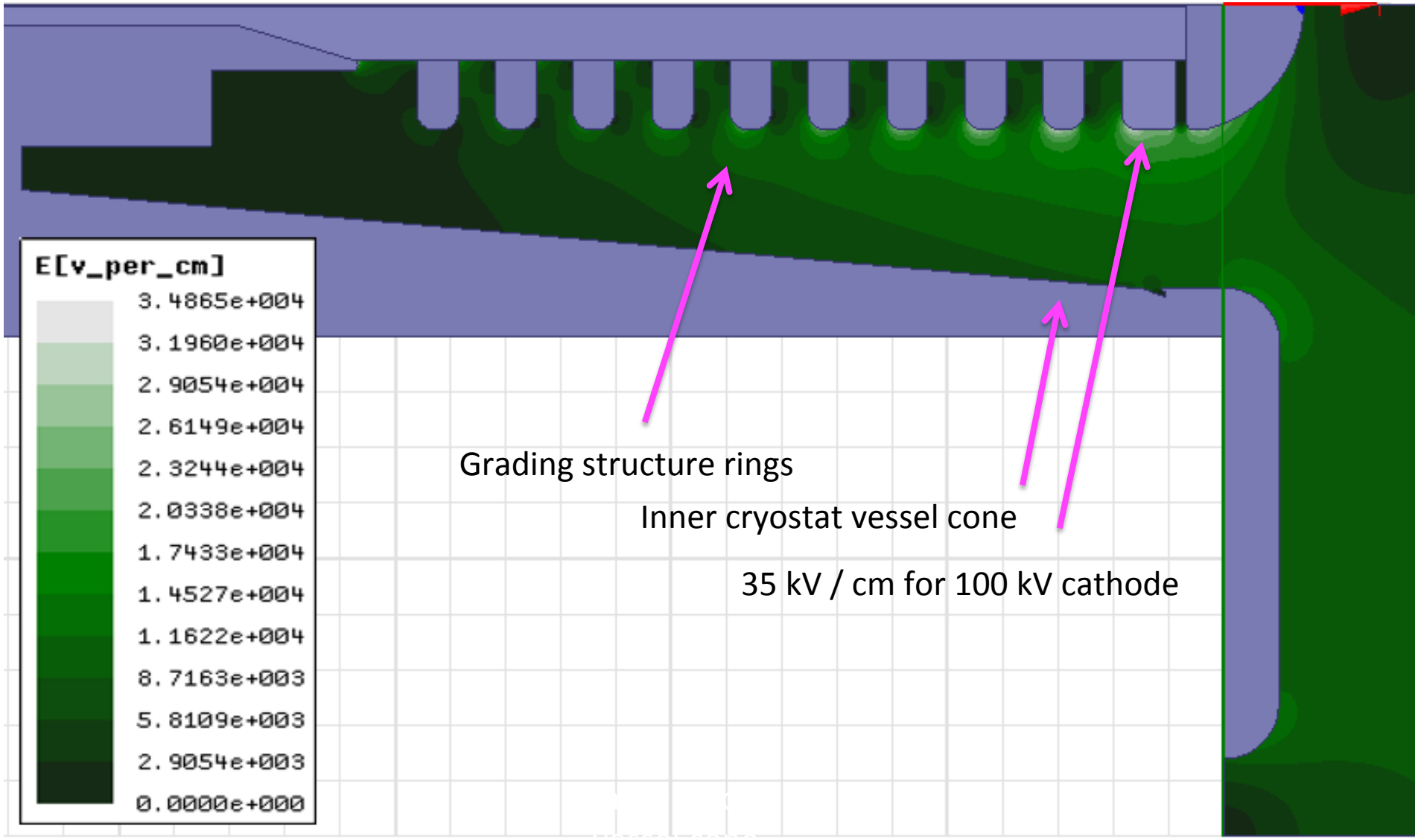


Cathode at -50 kV

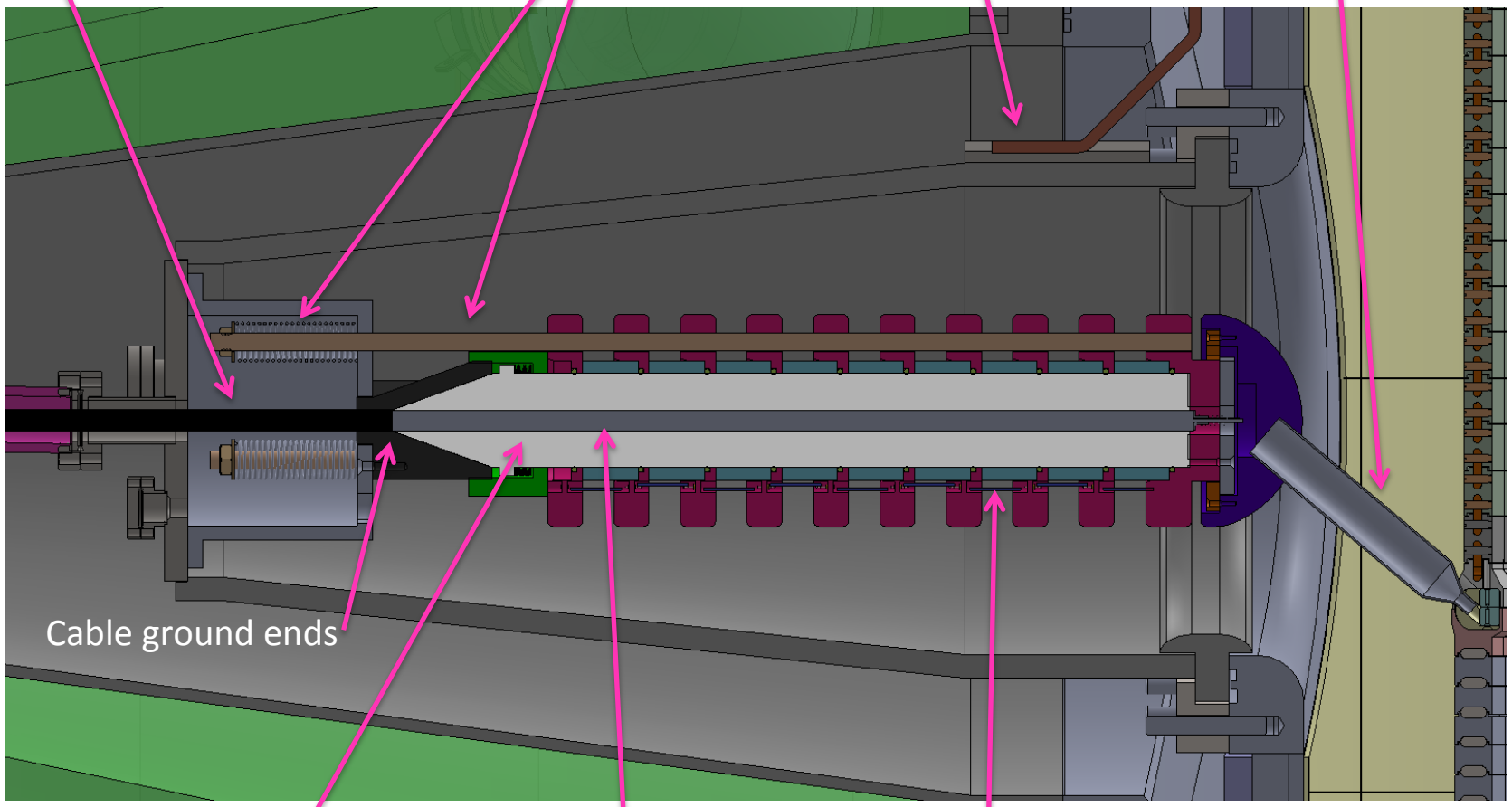
LZ HV design – Cathode HV delivery



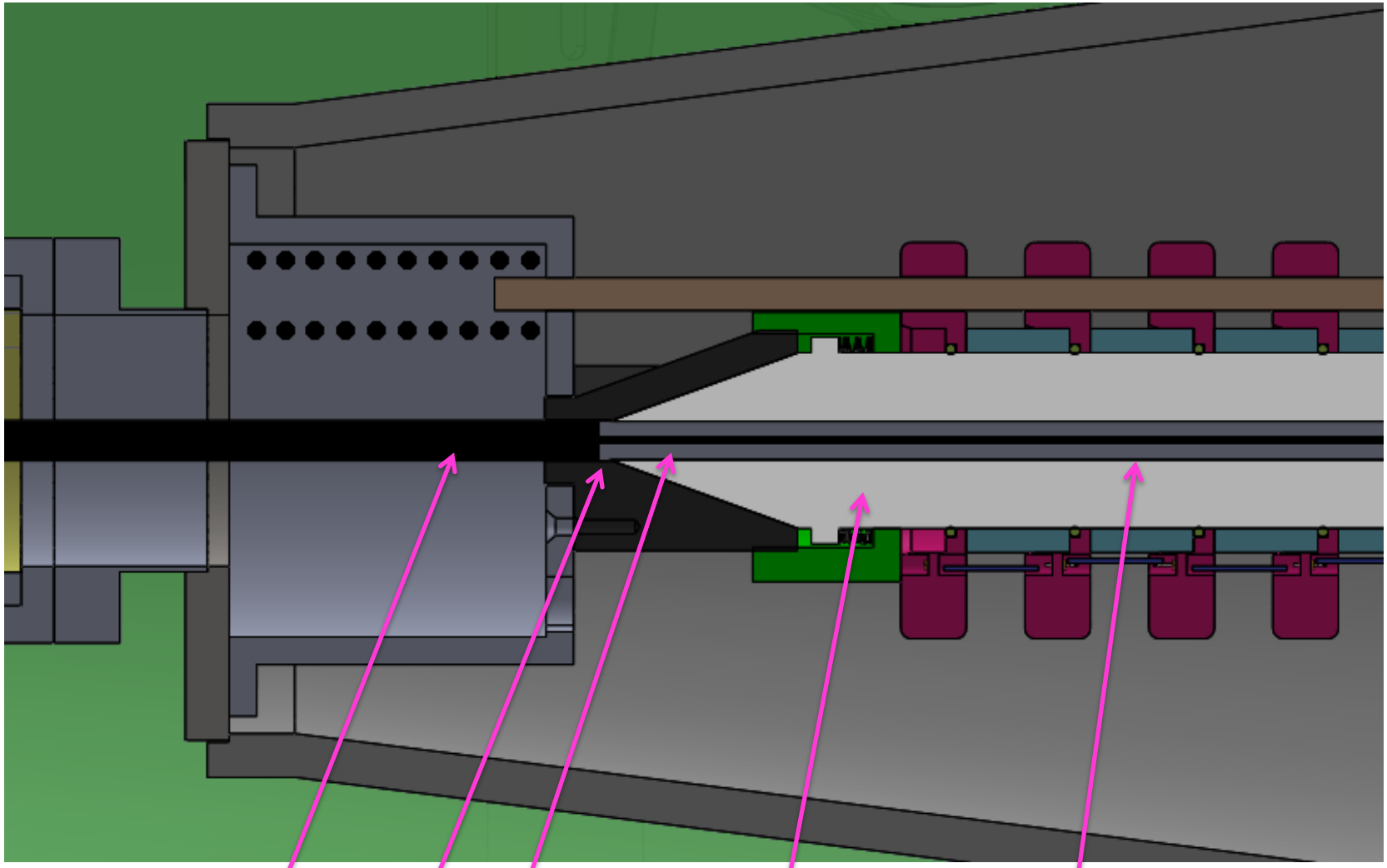
LZ HV design – Cathode HV delivery



LZ HV design – Cathode HV delivery



LZ HV design – Cathode HV delivery

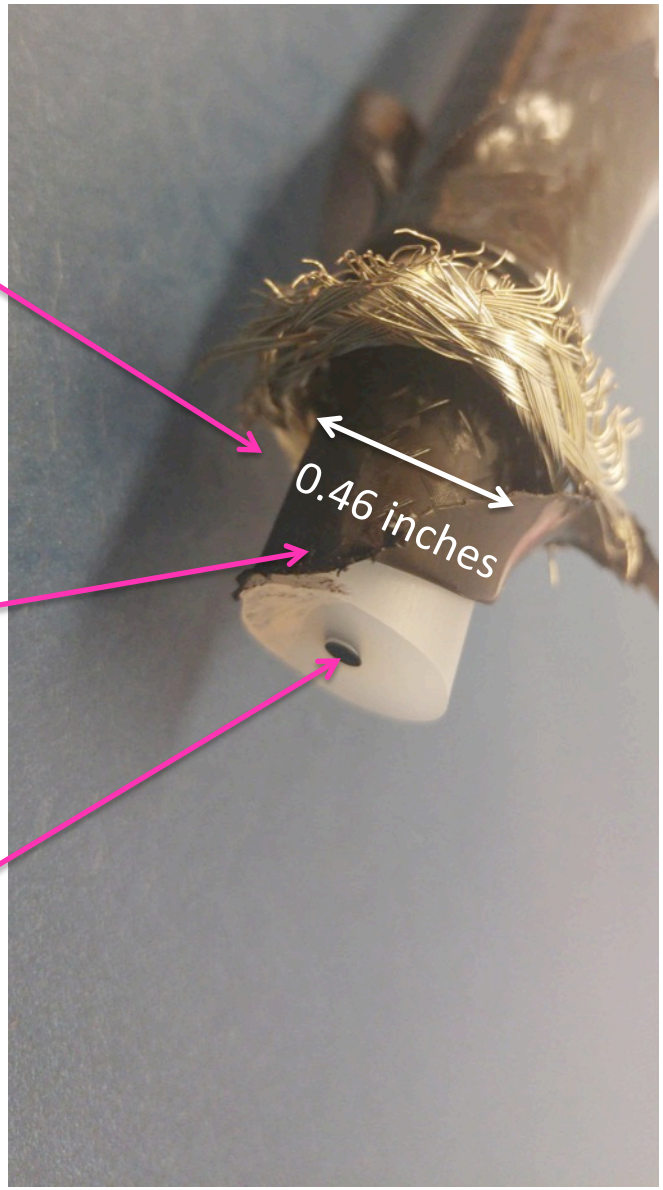


LZ HV design – Cathode HV delivery

Flexibility allows for the cable to turn and emerge from the top of the water tank. A single cable can run from the HV power supply to the cathode. Easy to transport and deploy.

Innermost grounded layer is conductive polyethylene. We can seal to this with o-rings without exposing the high fields within the cable.

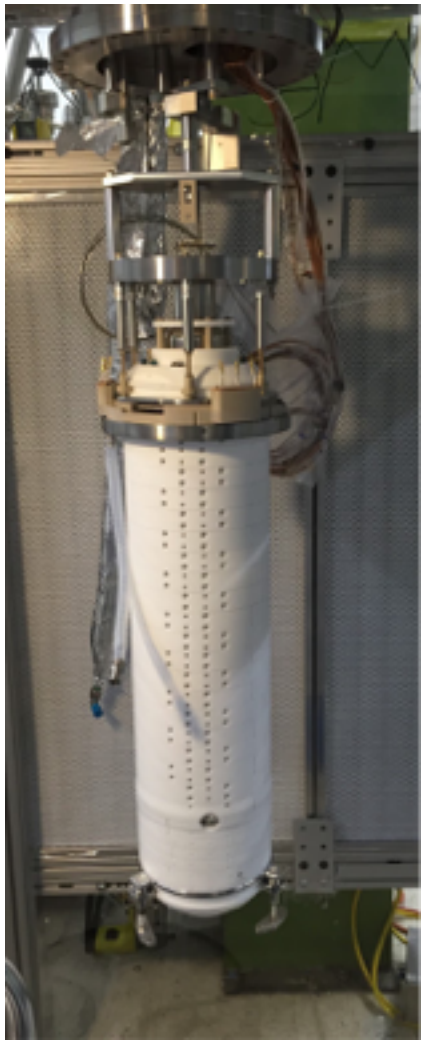
Center conductor is conductive polyethylene plastic. This contracts with the insulating polyethylene when cooled.



Dielectric Sciences SK160318 cable – 150 kV DC

LZ HV testing summary

- Testing reduced scale prototype of TPC at SLAC over the past year.
- FFR, cathode grid and RFR can operate at the fields needed to meet the LZ requirement
  - FFR to 630 kV / cm (300 kV / cm required, 600 kV / cm goal)
  - RFR to 3.5 kV / cm (3.25 kV / cm required, 6.5 kV / cm goal)
  - Light emission and increased power supply suggests fault in the cathode HV feedthrough. (Not the LZ design.)
- Full scale LZ cathode HV feedthrough design will be tested this fall in liquid argon at LBNL



SLAC LZ TPC prototype