Development of Cathode High Voltage Feedthrough for LBNE and CAPTAIN

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UCLA

HVNL13 @ FNAL
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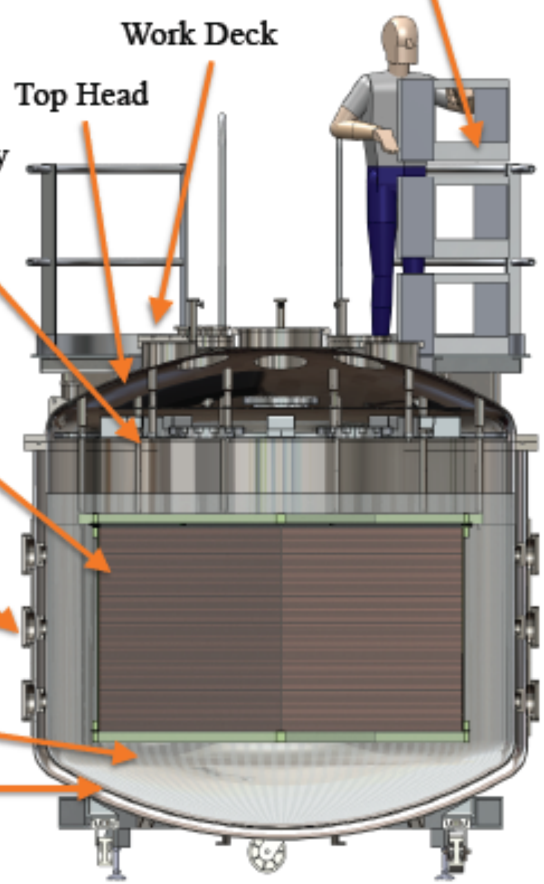
CAPTAIN: a 5 ton liquid argon TPC

CAPTAIN – Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos

- Funded by LANL Laboratory Directed Research and Development (LDRD)
- Now a multi-institutional collaboration
- "Portable" Liquid Argon TPC(s) being built at LANL
- 500 V/cm drift field
- 3-mm wire spacing
- Photon detection system (Hamamatsu R8520-500 PMTs)
- Laser system for calibration
- Uses MicroBooNE electronics



CAPTAIN Collaboration

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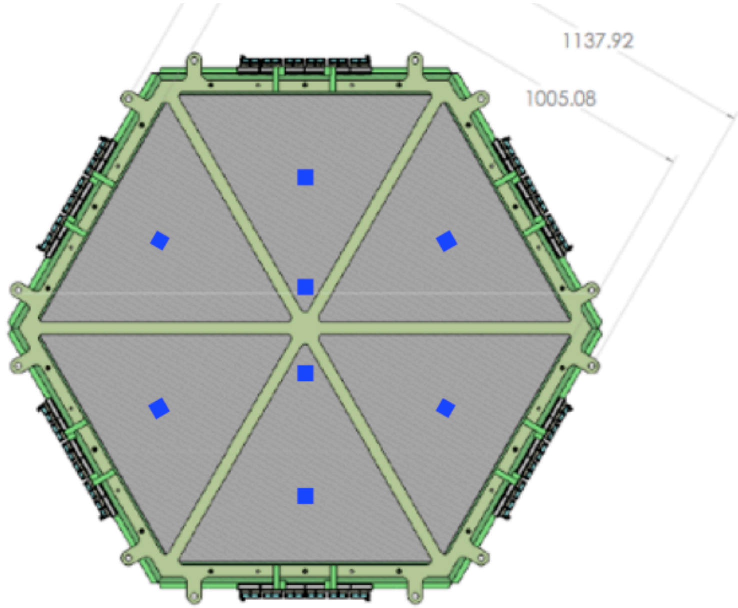
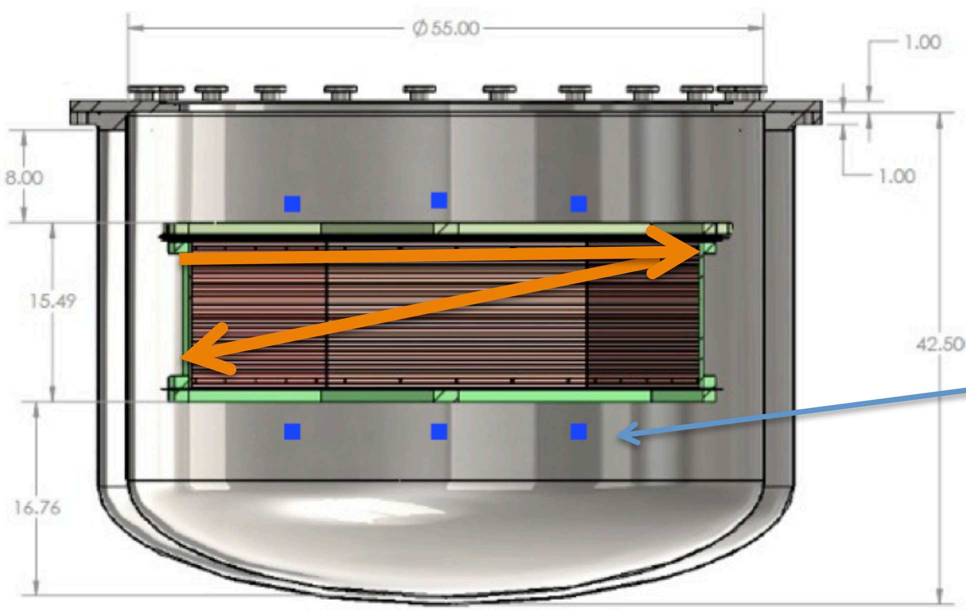
CAPTAIN: 5 ton LAr portable TPC



Hexagonal shape TPC
75μm diameter CuBe wire
1m maximum drift distance
Electric Field 500V/cm – 50kV
~2000 readout channels



Nd-YAG laser system
measure electron lifetime in situ and study LAr ionization and electron recombination

Photon detection with PMTs
trigger non-beam events and improve energy resolution.
Wavelength shifter needed.

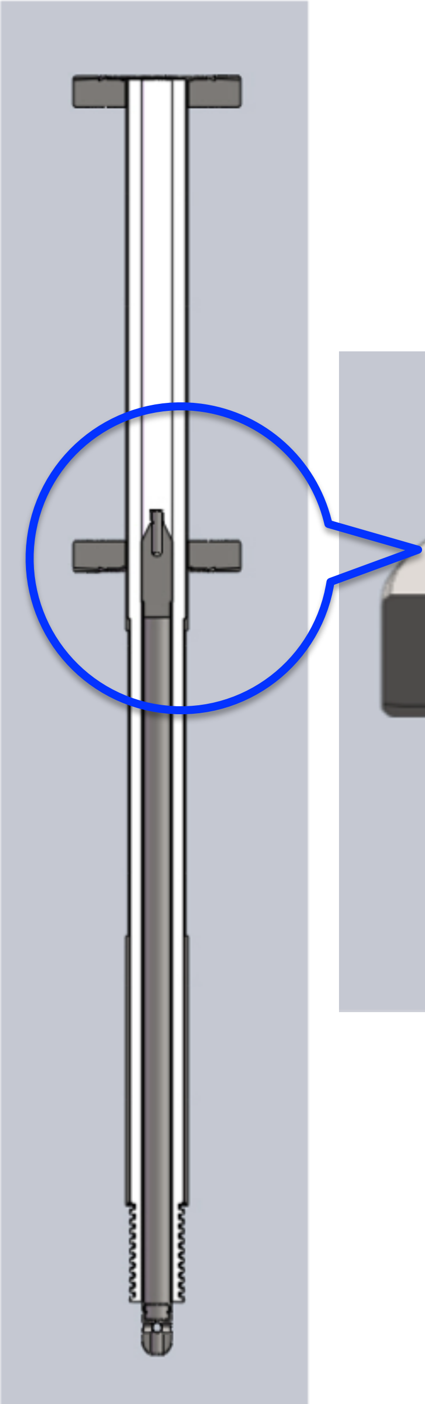
HVFT Fabricated for CAPTAIN

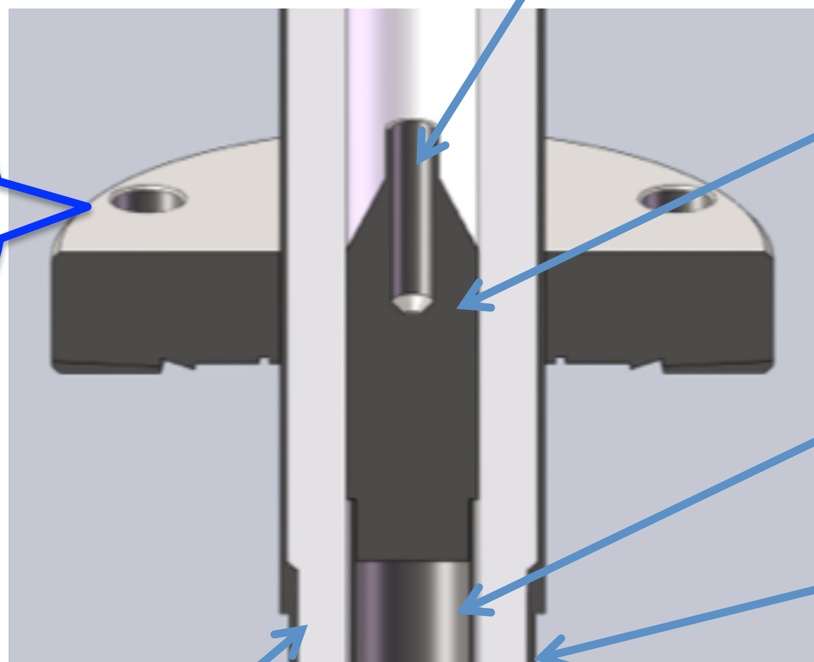
material: Stainless Steel and UHMW PE

Cable connector

High voltage feedthrough

UHMWPE HVFT Design-1





Cable plug special shape to avoid region with high E_field

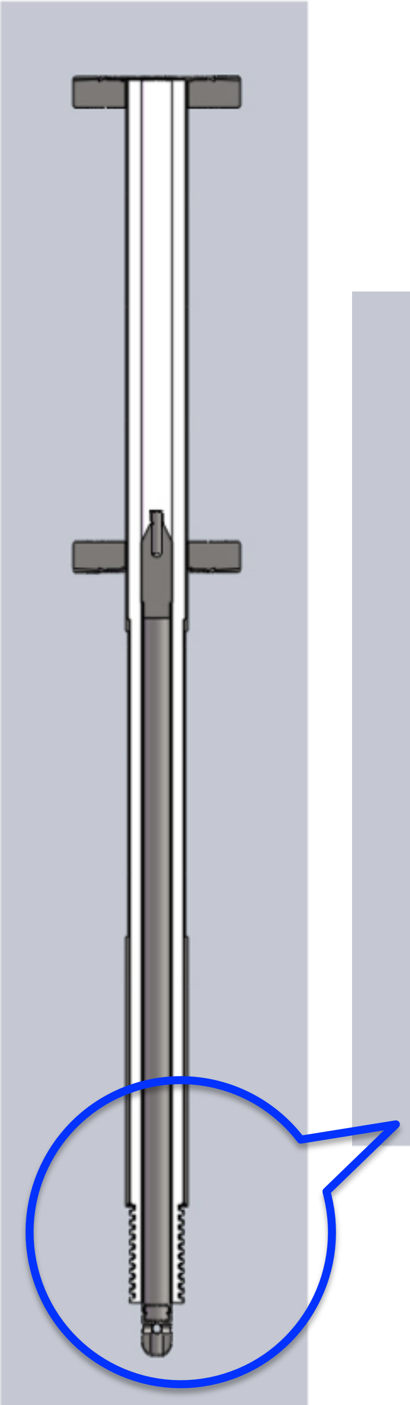
CryoFit Vacuum Seal

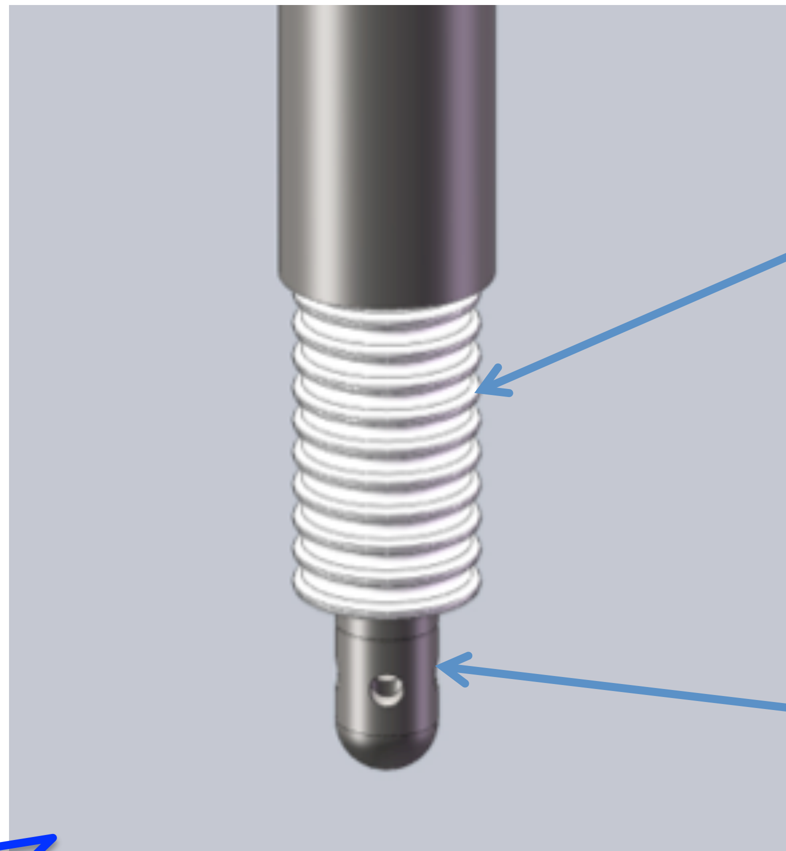
0.5” OD SS tube for HV, hollow to reduce material, filled with Ar

1” OD SS tube for ground, thin to reduce heat load

¼” thick UHMWPE
Material can stand 158kV at the central conductor and ground at the outer with 100% of margin

UHMWPE HVFT Design-2



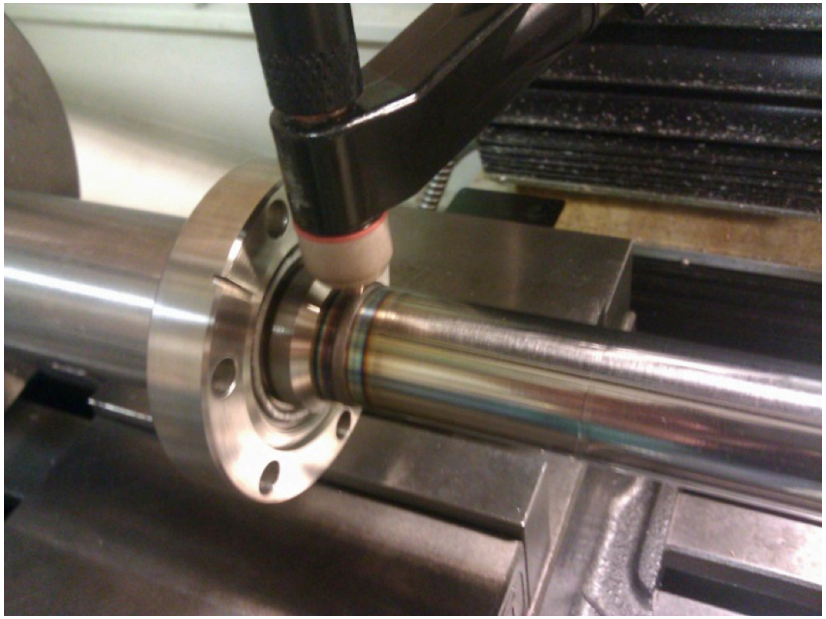


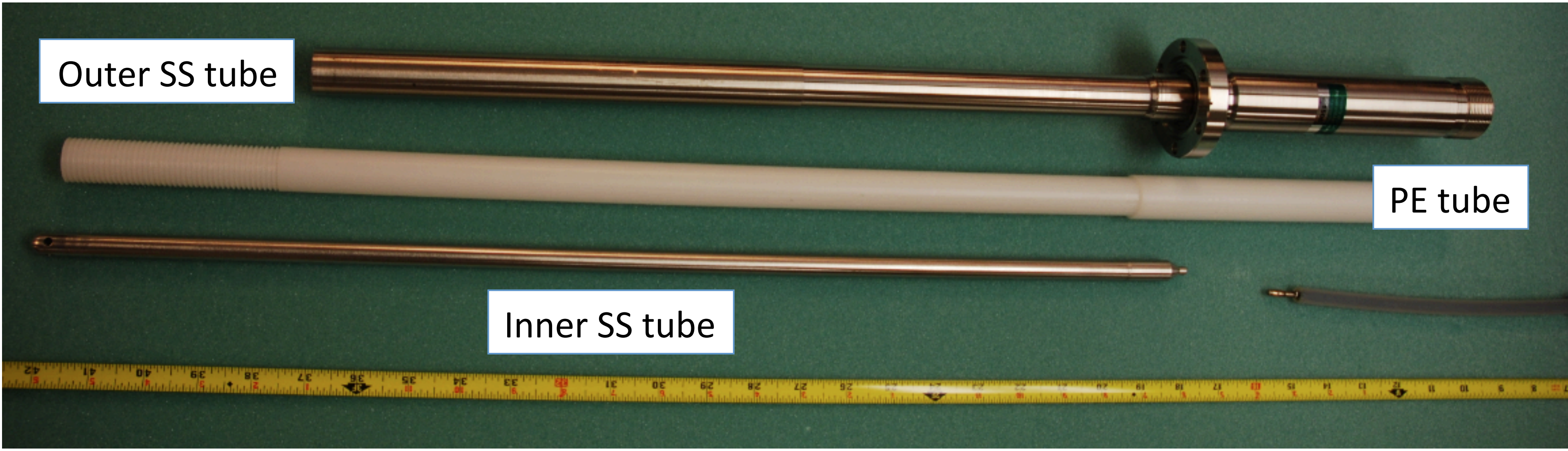
UHMWPE extends ~ 4" Grooved to prevent leakage of surface charge. Charge-up essential for reducing the field in the constrained space.

SS Tip holds the connection to the cathode and is hollow.

HVFT Construction - machining

Plasma CNC Welding of SS parts



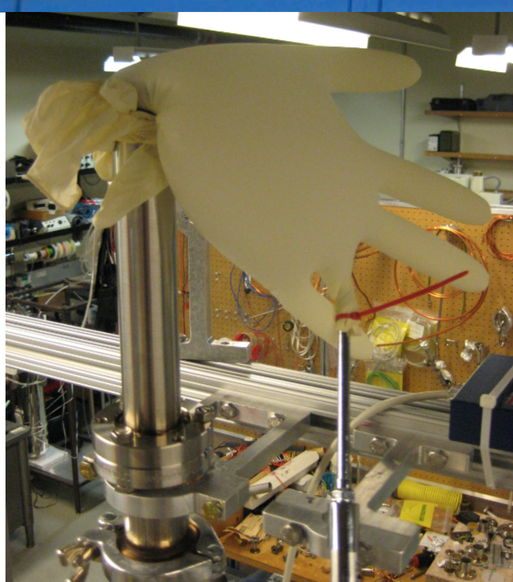


Parts before assembly

HVFT Construction – cleaning, cryofiting, leak testing

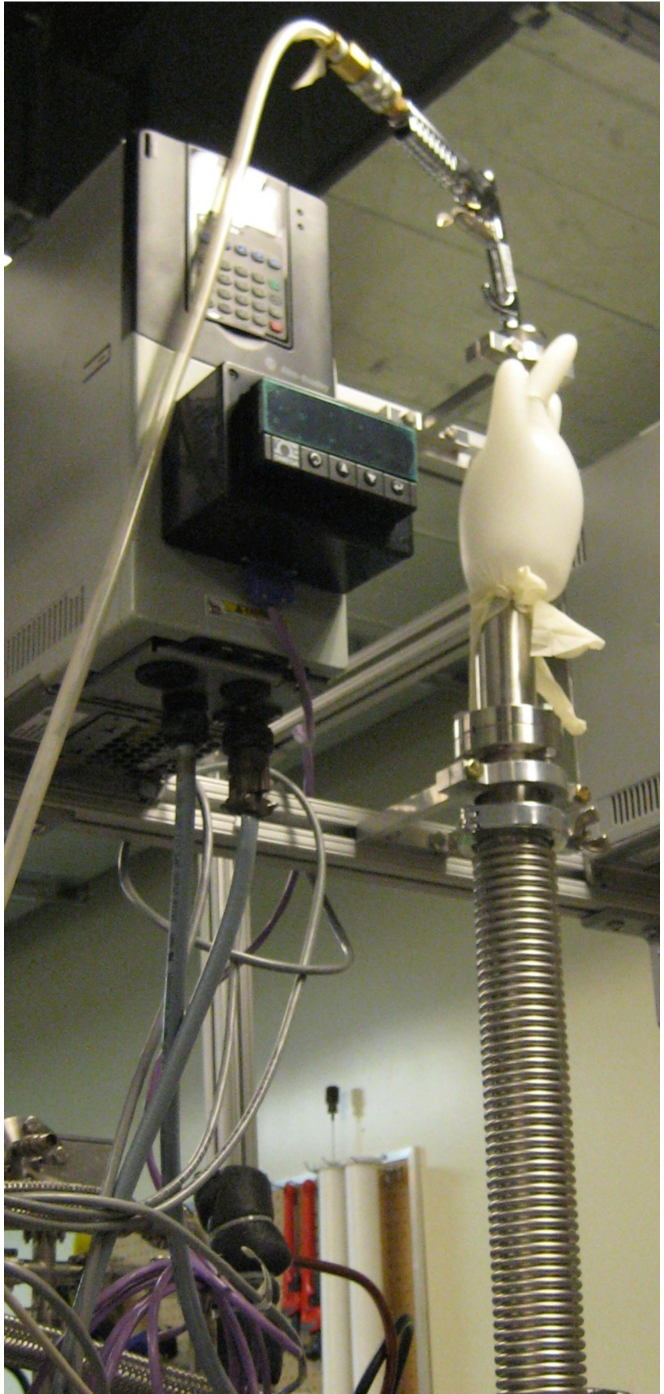
Long Ultrasonic tube cleaner

Cryofit

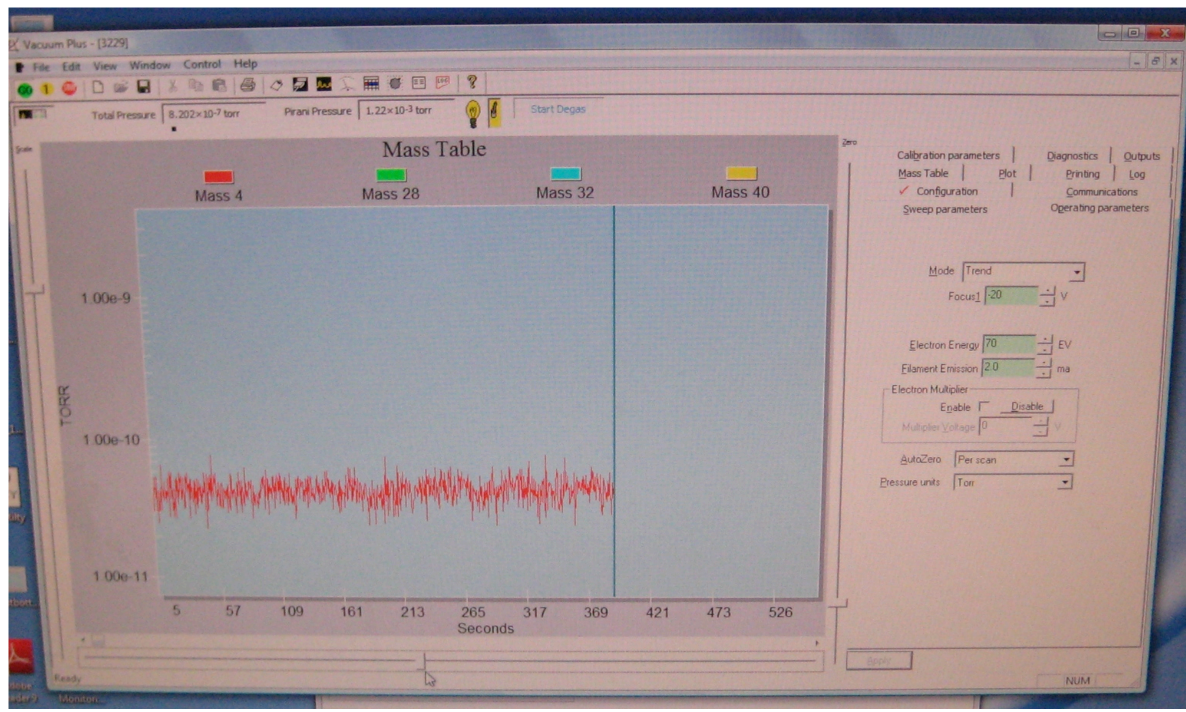


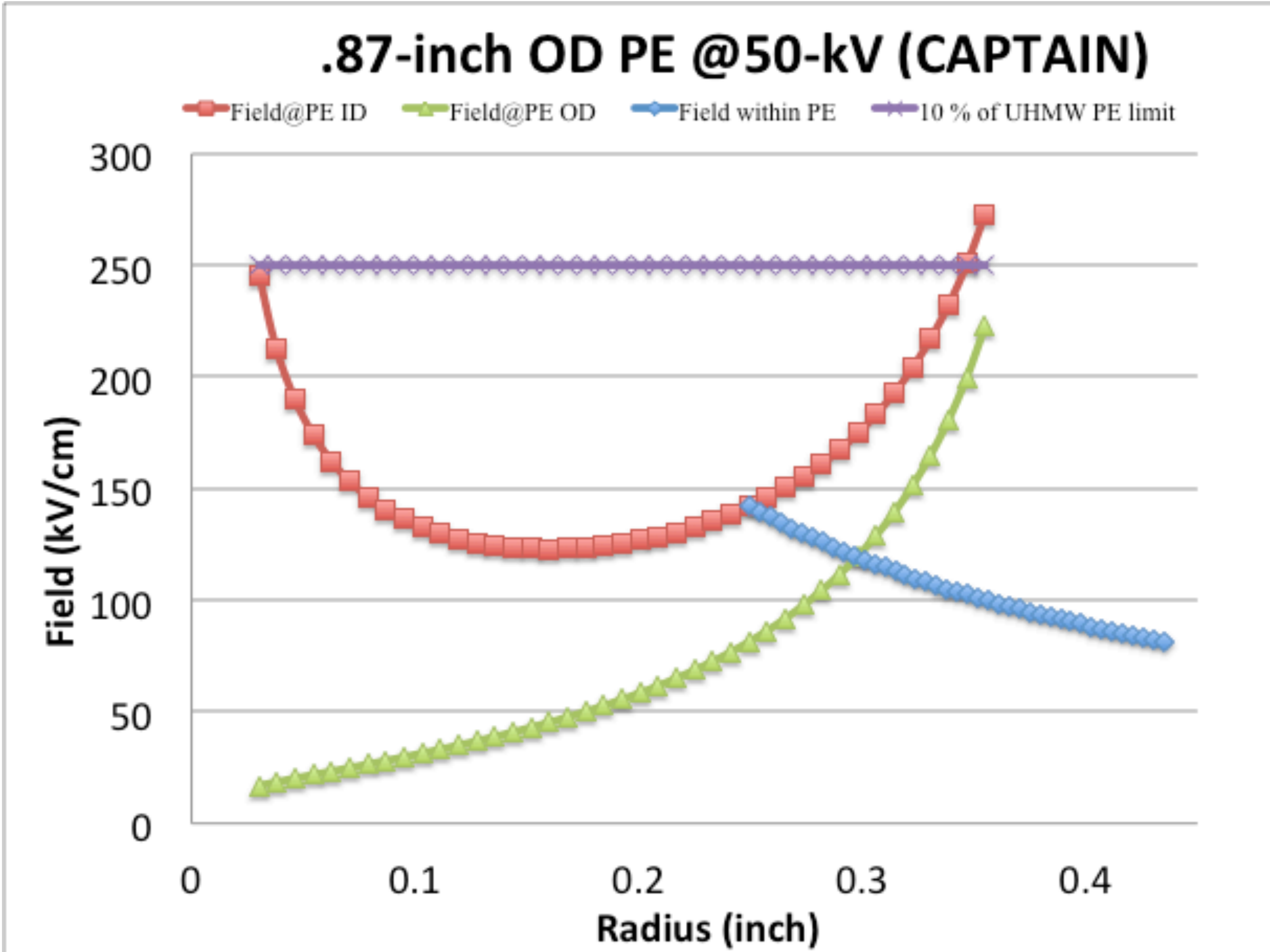
Integrated He Leak Test

Leak tested with integrated He input and without RGA response



Helium bag

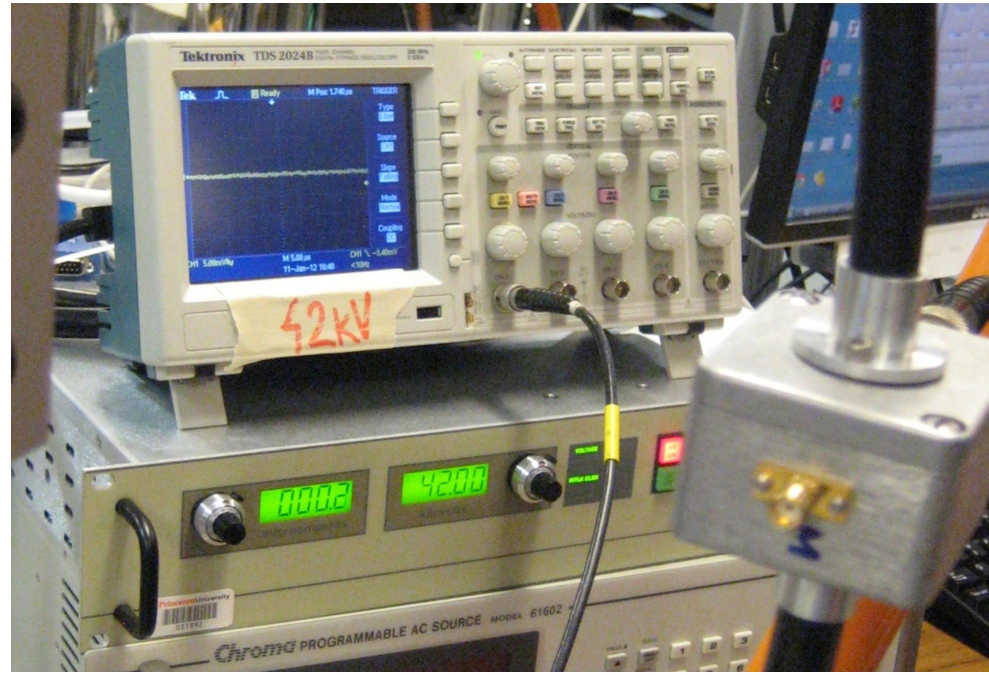


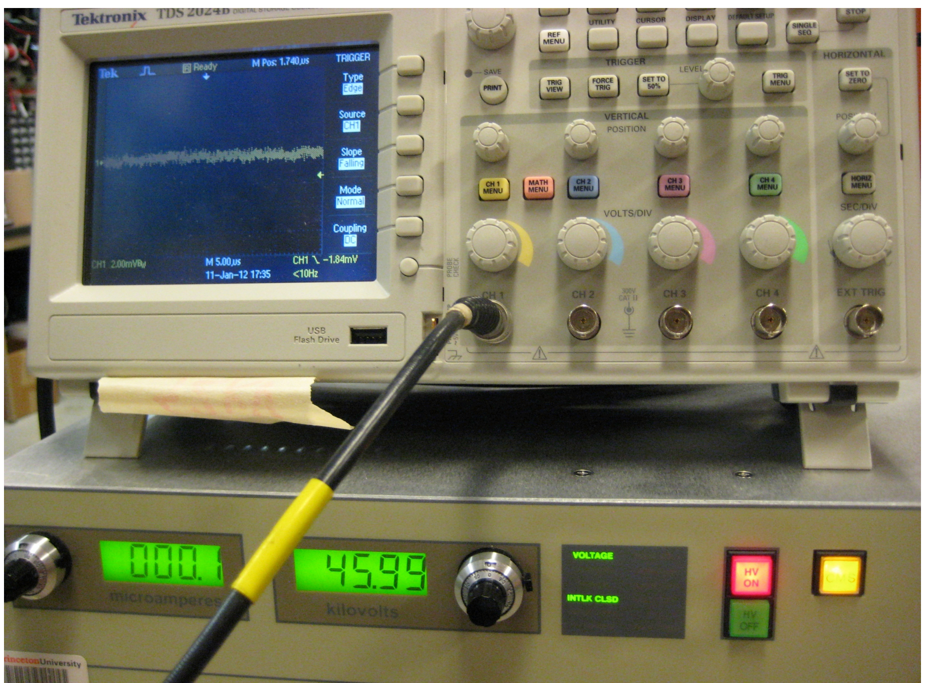


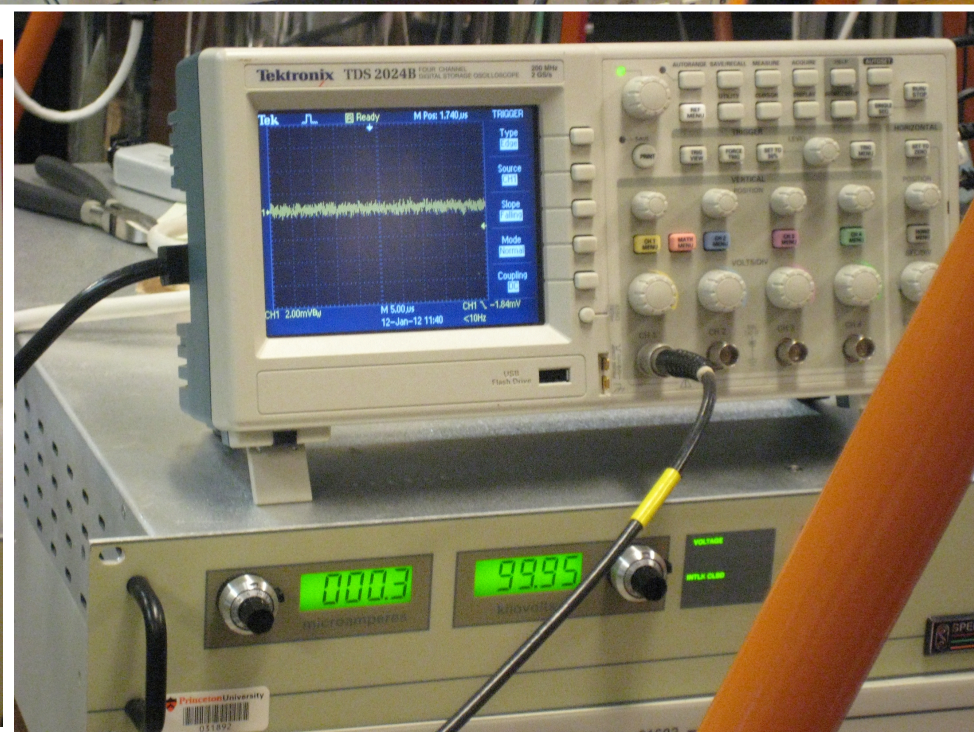
.87-inch OD PE @50-kV (CAPTAIN)
Field@PE ID
Field@PE OD
Field within PE
10 % of UHMW PE limit
300
250
200
150
100
50
0
Field (kV/cm)
0
0.1
0.2
0.3
0.4
Radius (inch)

Tested with bottom tip in LN2:

42kV, 46kV, 100kV
-42kV, -46kV, -100kV

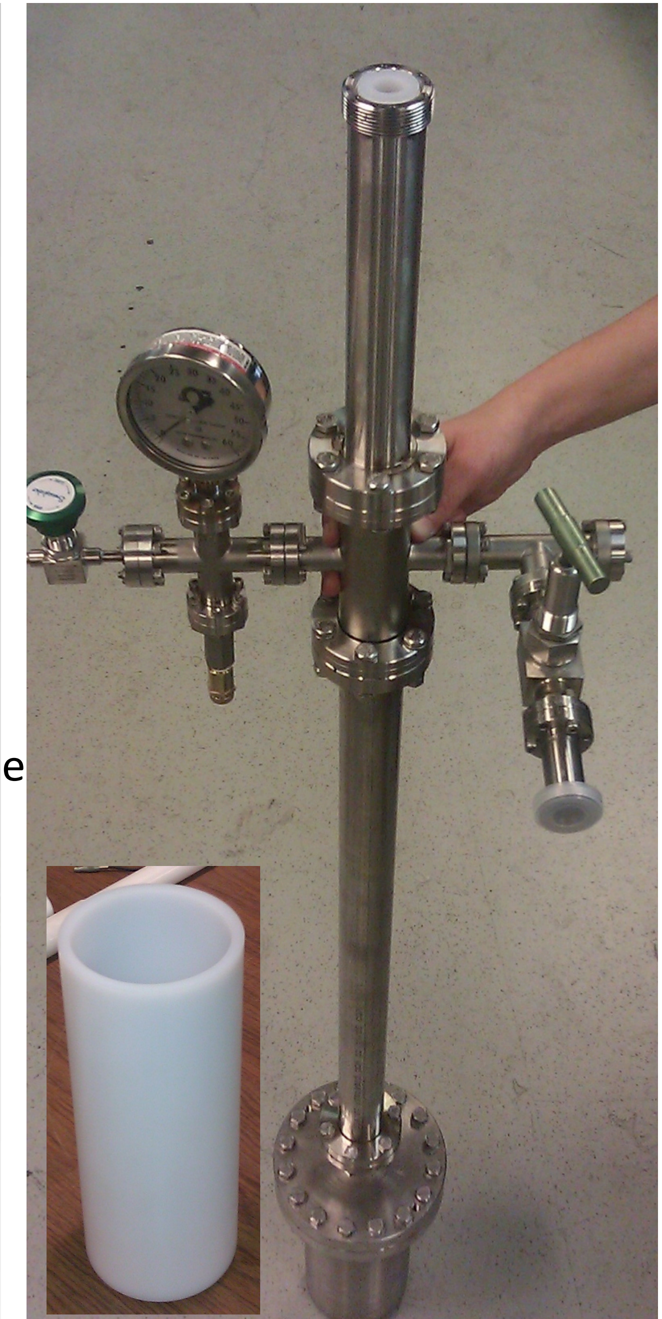






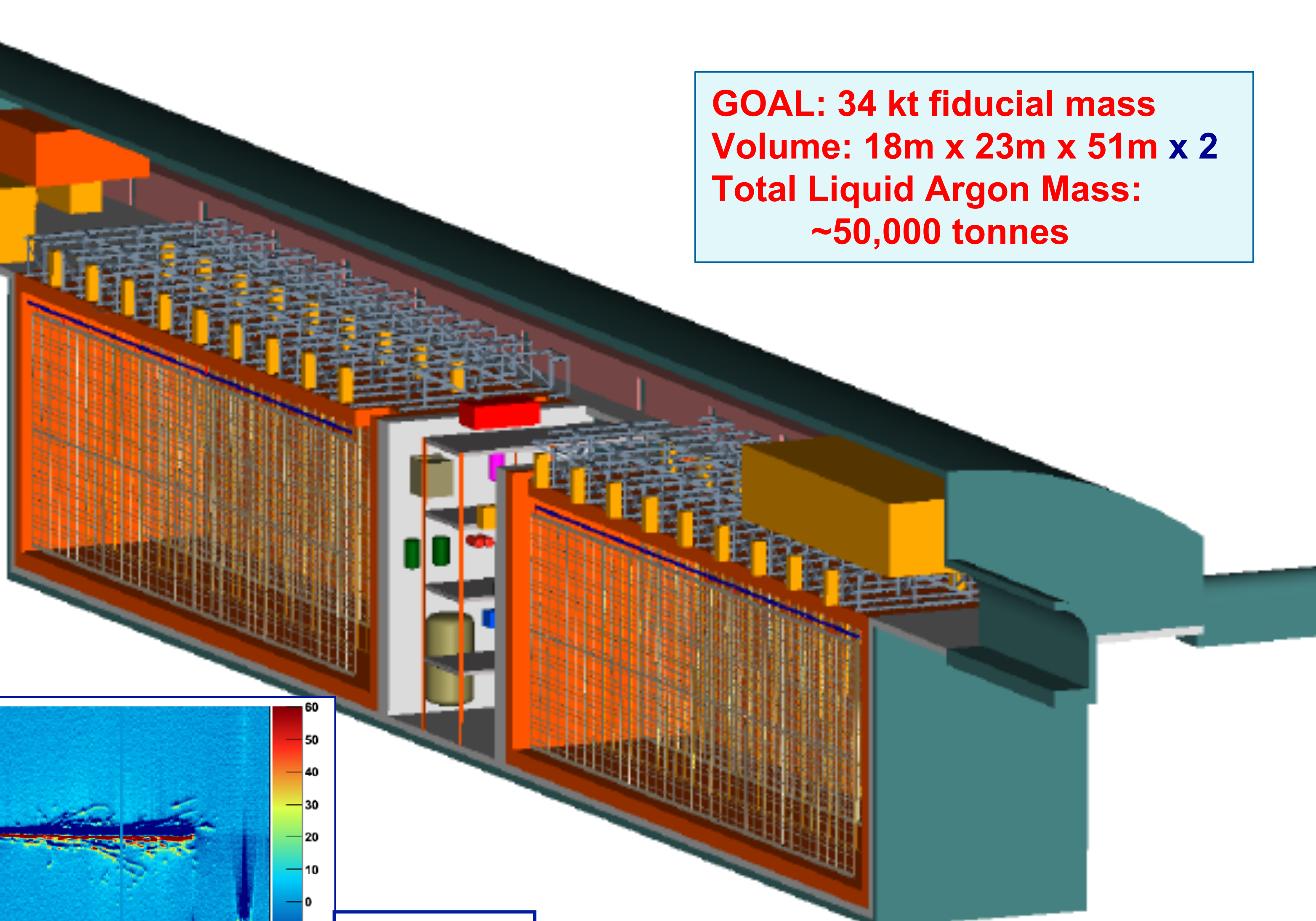
Glowing PE after Continues Breakdown in Liquid Argon
During destructive test!

e

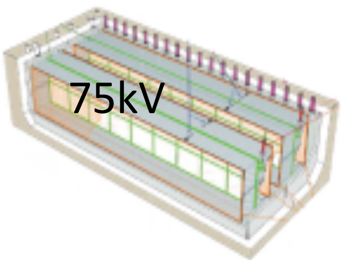


Setup to test FT at real working temperature and pressure

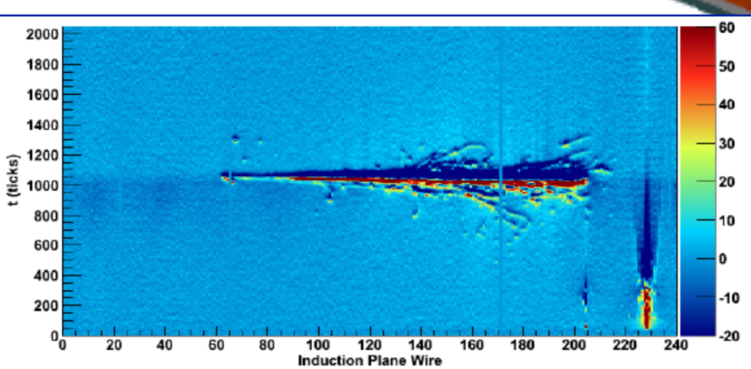
LBNE Liquid Argon TPC



GOAL: 34 kt fiducial mass
Volume: 18m x 23m x 51m x 2
Total Liquid Argon Mass:
~50,000 tonnes



ICARUS T600



ArgoNeuT

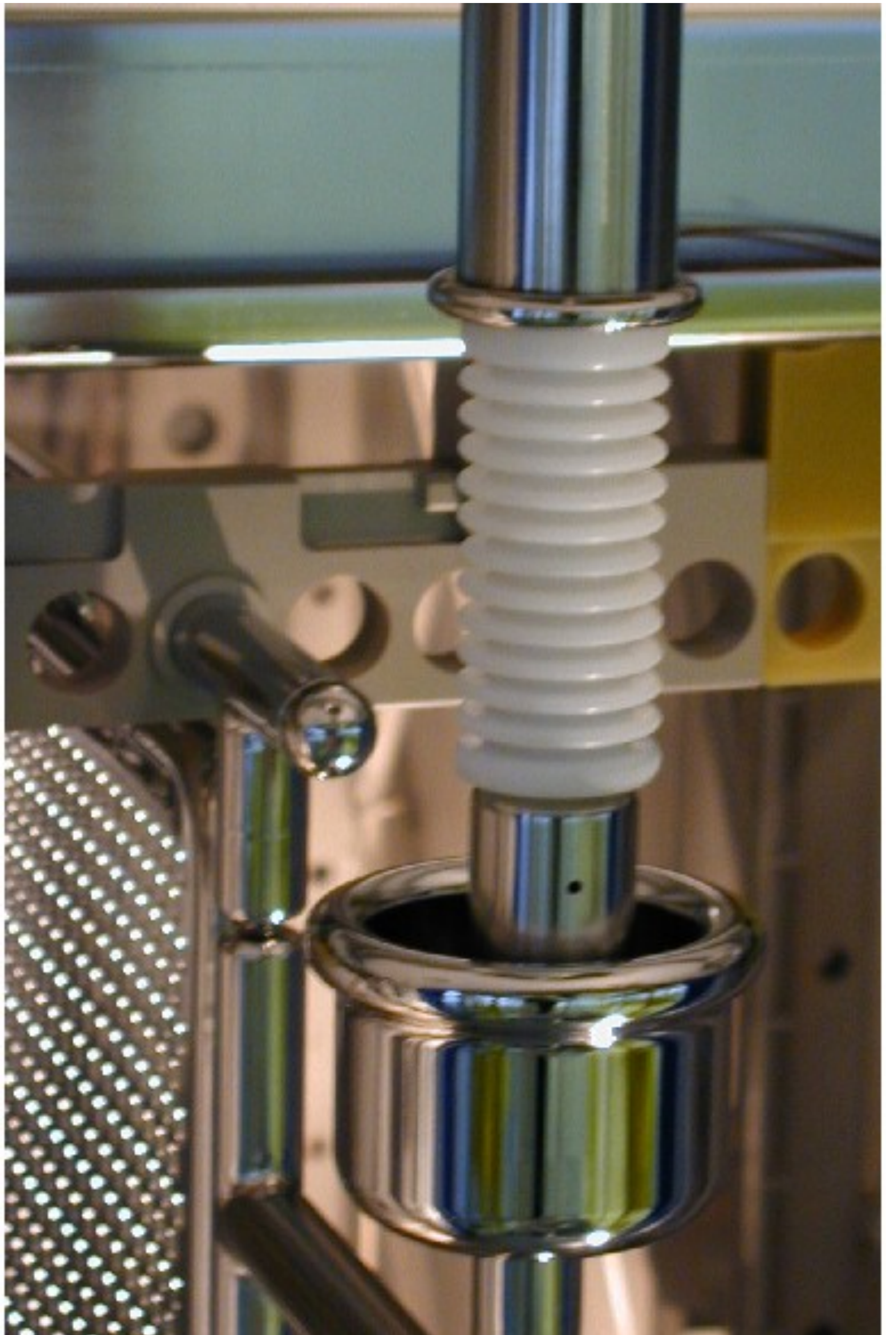
mm-scale resolution!

TPC total Drift: 3.4m -
170kV@500V/cm

ICARUS HV FT Concept

- Stainless Steel OD
- Stainless Steel ID
- UHMW PE insulation
- Cryofit the whole length
- Every large Safety factor.
  - 75kV and operated at 150kV.

Designed by Franco Sergiempietri



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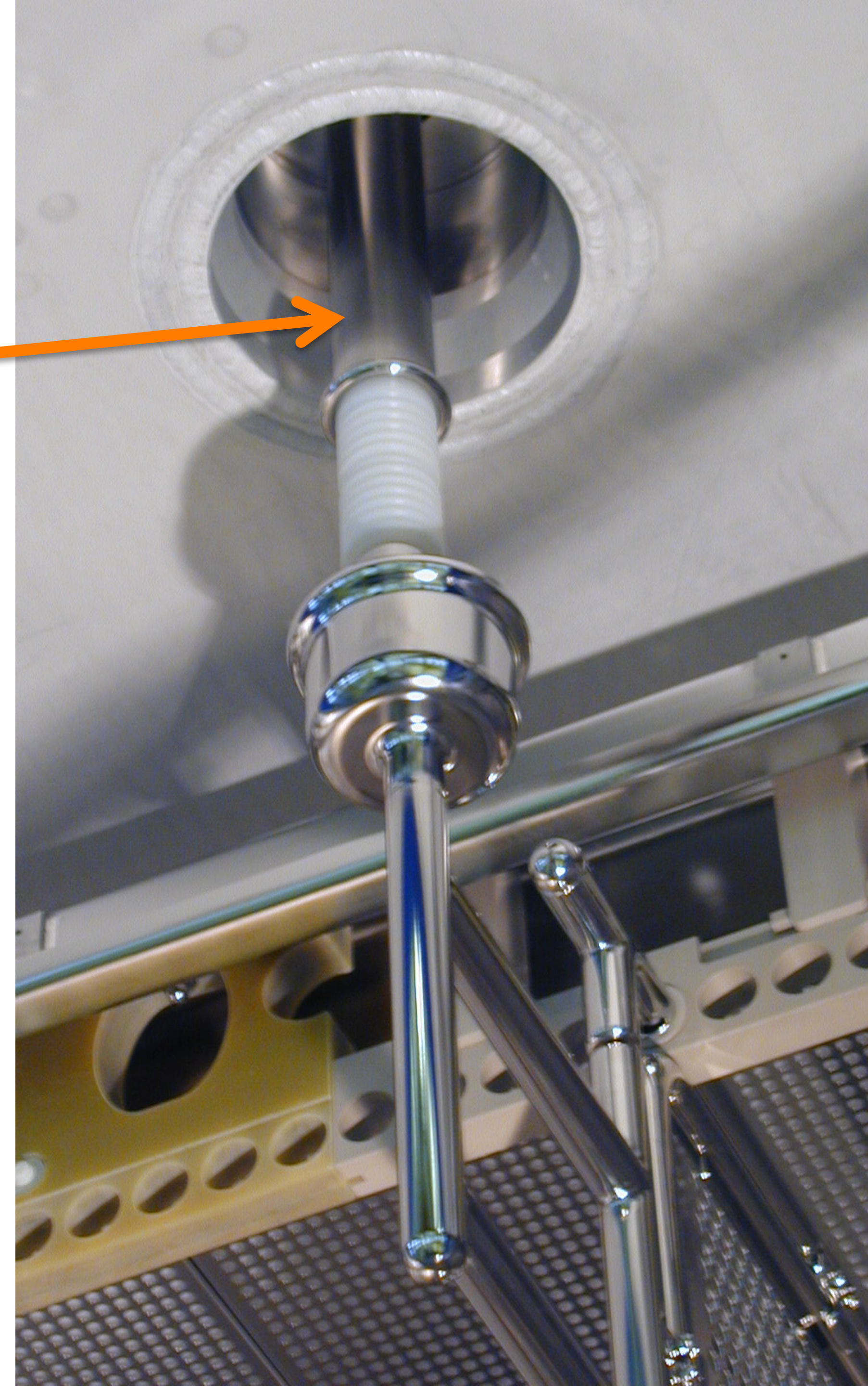


Total of 3 built at UCLA

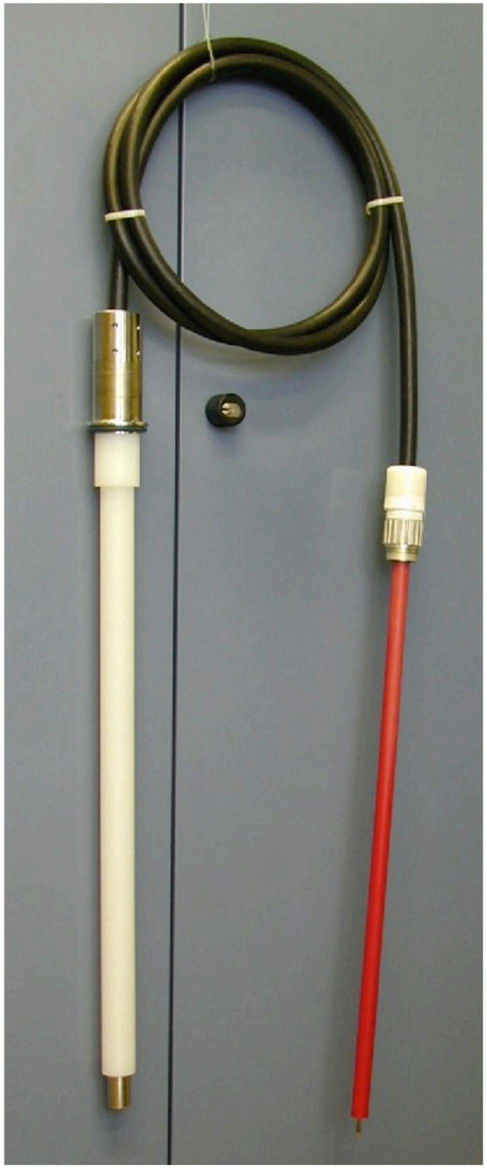
Two were installed on ICARUS and operated at 75kV and 150kV

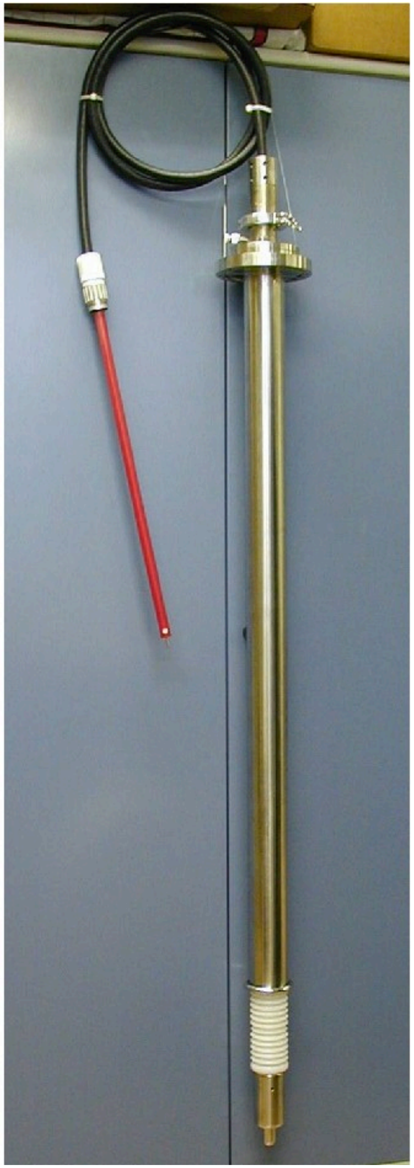
ICARUS HV FT (left), Cable Plug (middle), Assembled (Right)

Required voltage: 75kV

Operated at 75kV on ICARUS

Tested at 150kV on ICARUS for three days





LBNE HV FT

1.5” OD
0.5” ID

Tested up to 140kV in open Dewar with liquid argon

200kV DC power supply
HV FT Testing system

ICARUS Geometry FT
Being tested at
150kV in open
mouth Dewar

Consideration During Design of the HV FT

1. Maximum Voltage (LBNE:170kV rated 200kV,
   CAPTAIN: 50kV Max)
2. UH Vacuum Tight
3. Thermal load (minimized)
4. Choice of material (Low background?)
5. Xe/Ar environments (Or vacuum)?
6. TPC Space constrains and Cathode Details
   (Integral part of the whole HV problem!)
7. Connection between HV FT and Cathode!
   Critical as well!

Material Properties
dielectric strength and breakdown

1. Liquid Argon 1.1-1.42MV/cm
2. Gas Argon 0.18 relative to nitrogen gas
3. UHMW PE 900kV/cm (new data)

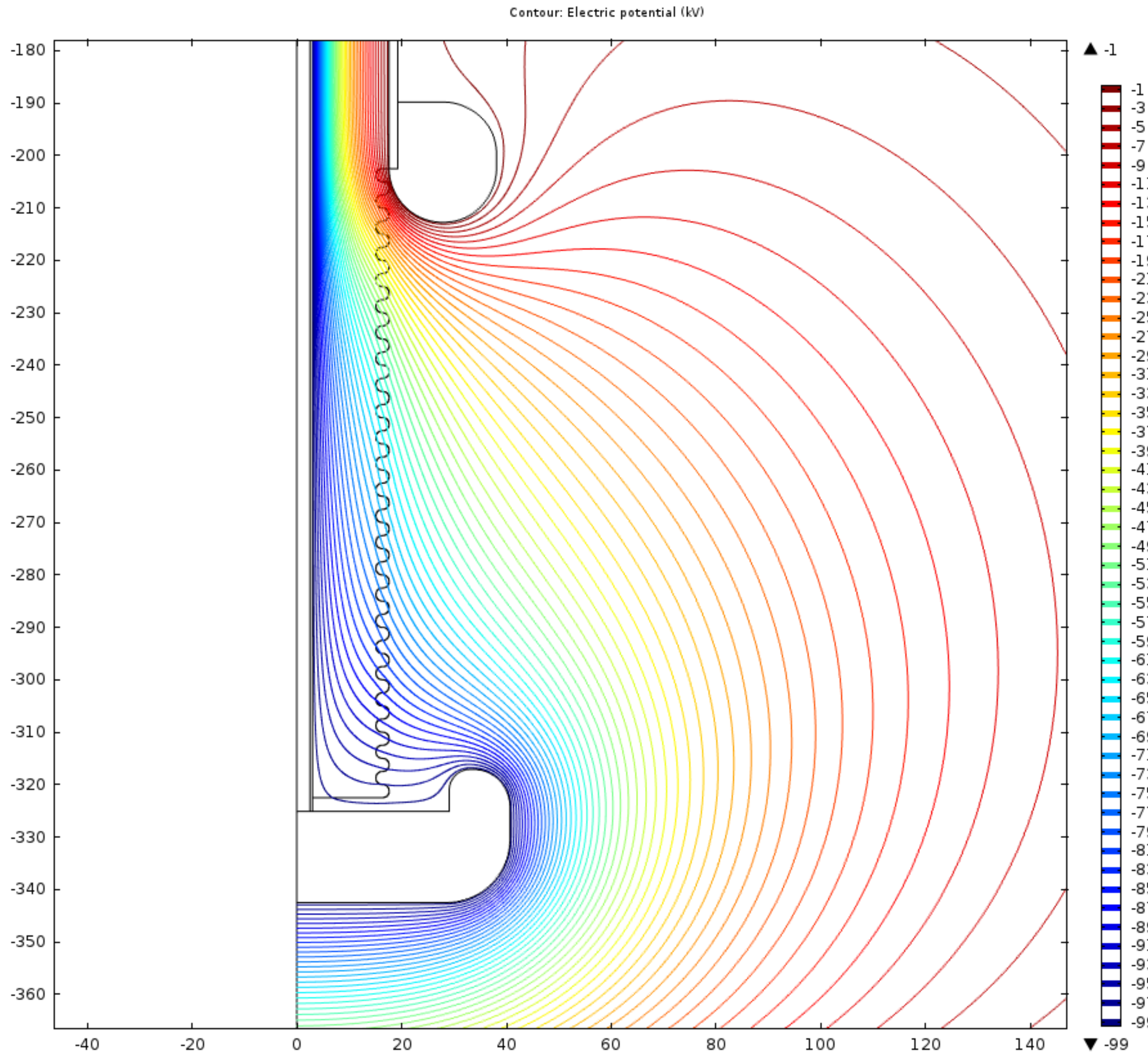
With HV Feedthrough directly penetrating into liquid argon, there should be no problem in theory! But in practice, almost every detector has problems!

Two main Issues:

1. Possible gas bubble present near high field region
2. charge particle induced gas bubble near high field region

Must map field within entire TPC and minimize high field to below gas breakdown value

If insulators are used in the TPC, insulator surface geometry must be specially designed to avoid charge migration after charged up!



Contour: Electric potential (kV)
-180
-190
-200
-210
-220
-230
-240
-250
-260
-270
-280
-290
-300
-310
-320
-330
-340
-350
-360
-40
-20
0
20
40
60
80
100
120
140
▲ -1
-1
-3
-5
-7
-9
-11
-13
-15
-17
-19
-21
-23
-25
-27
-29
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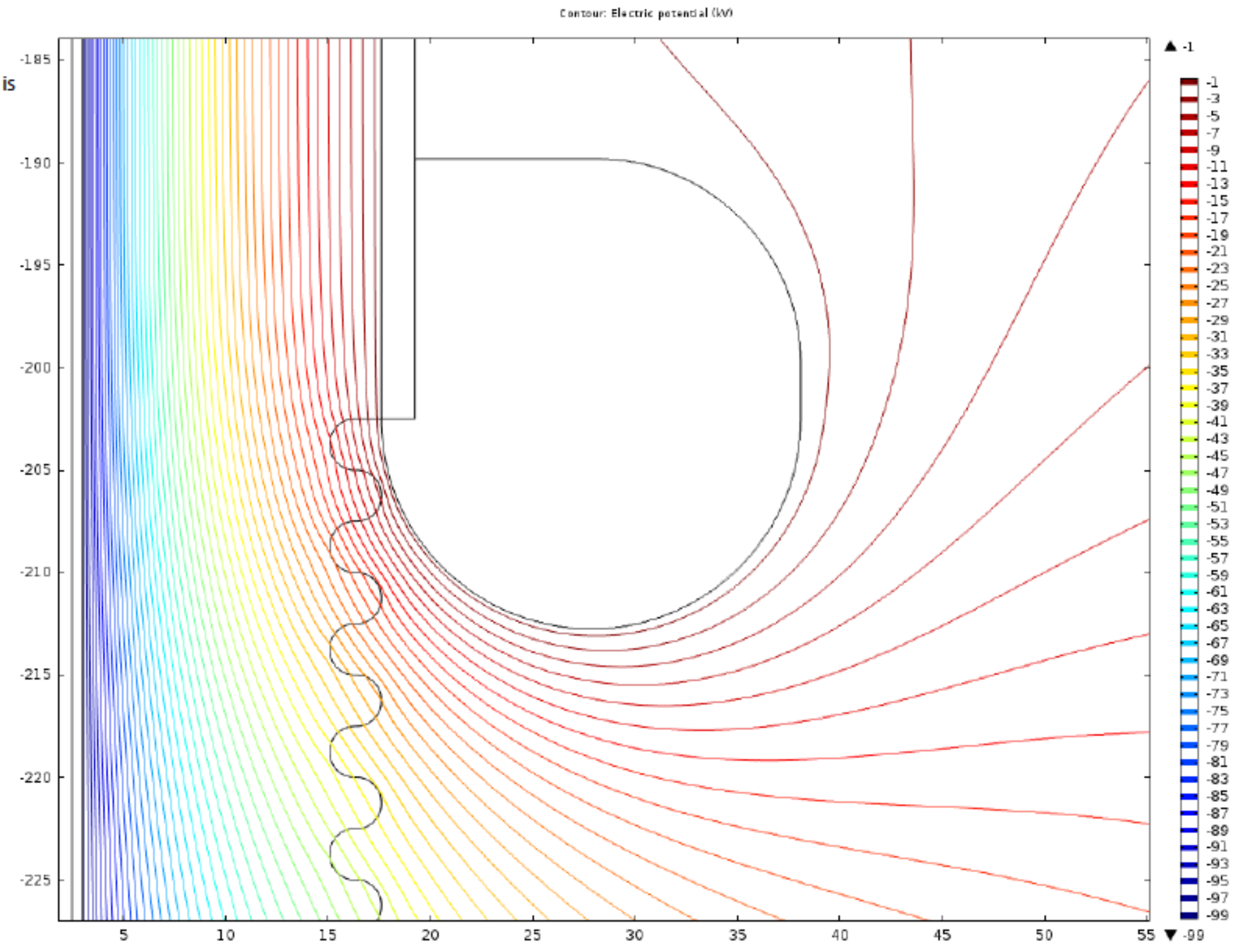
-71
-73
-75
-77
-79
-81
-83
-85
-87
-89
-91
-93
-95
-97
-99
▼ -99

Horizontal and vertical axis unit is mm



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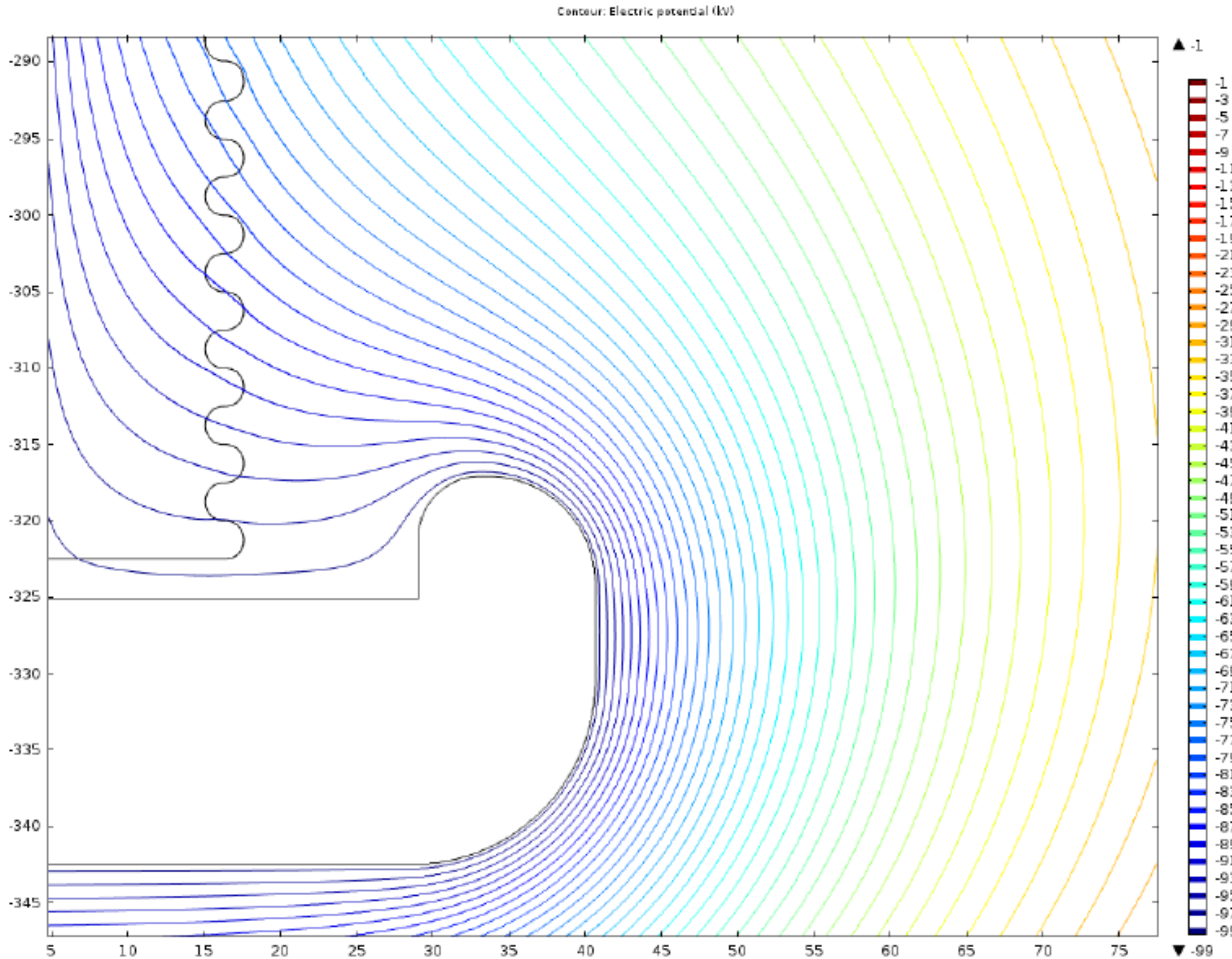
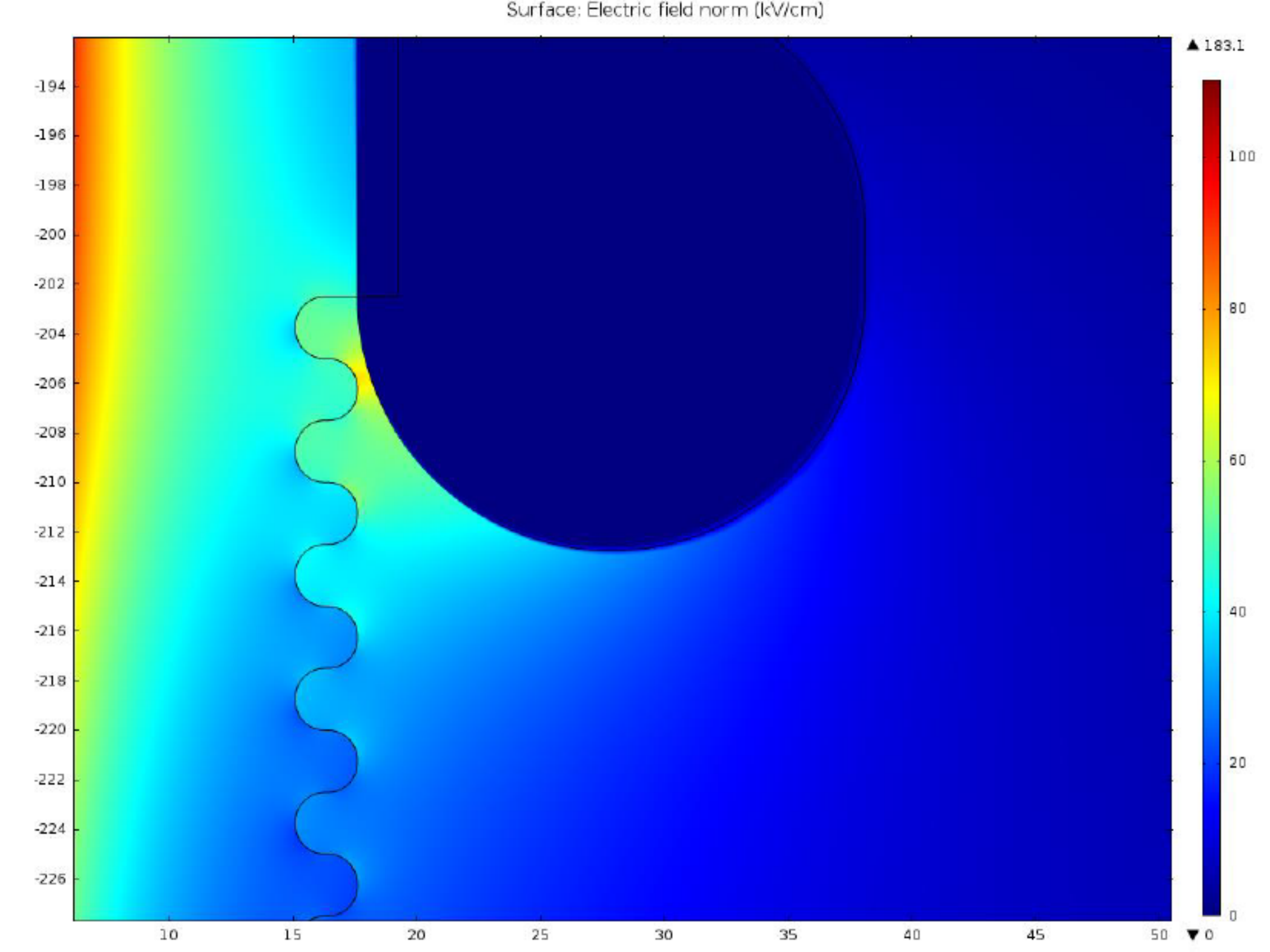
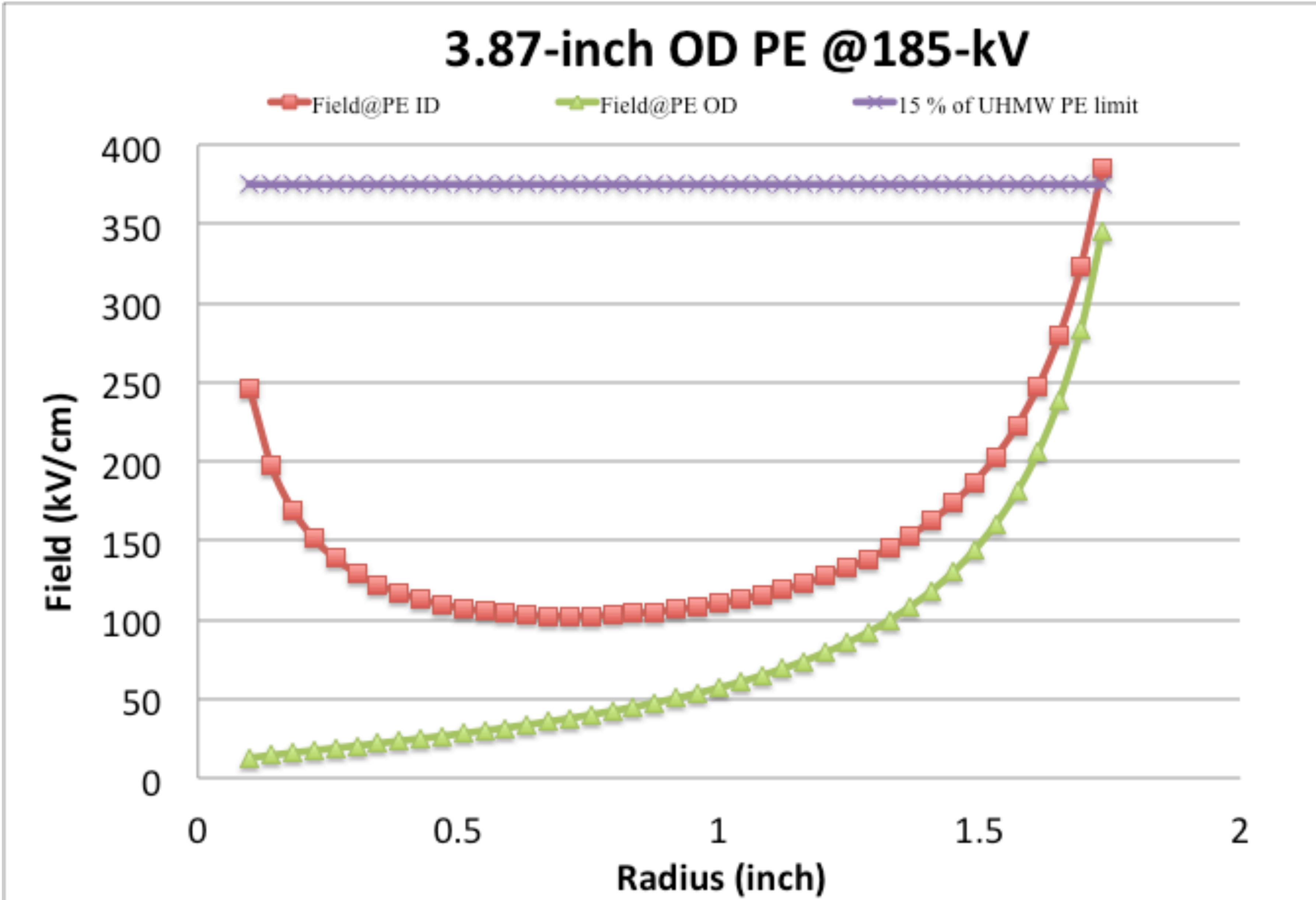
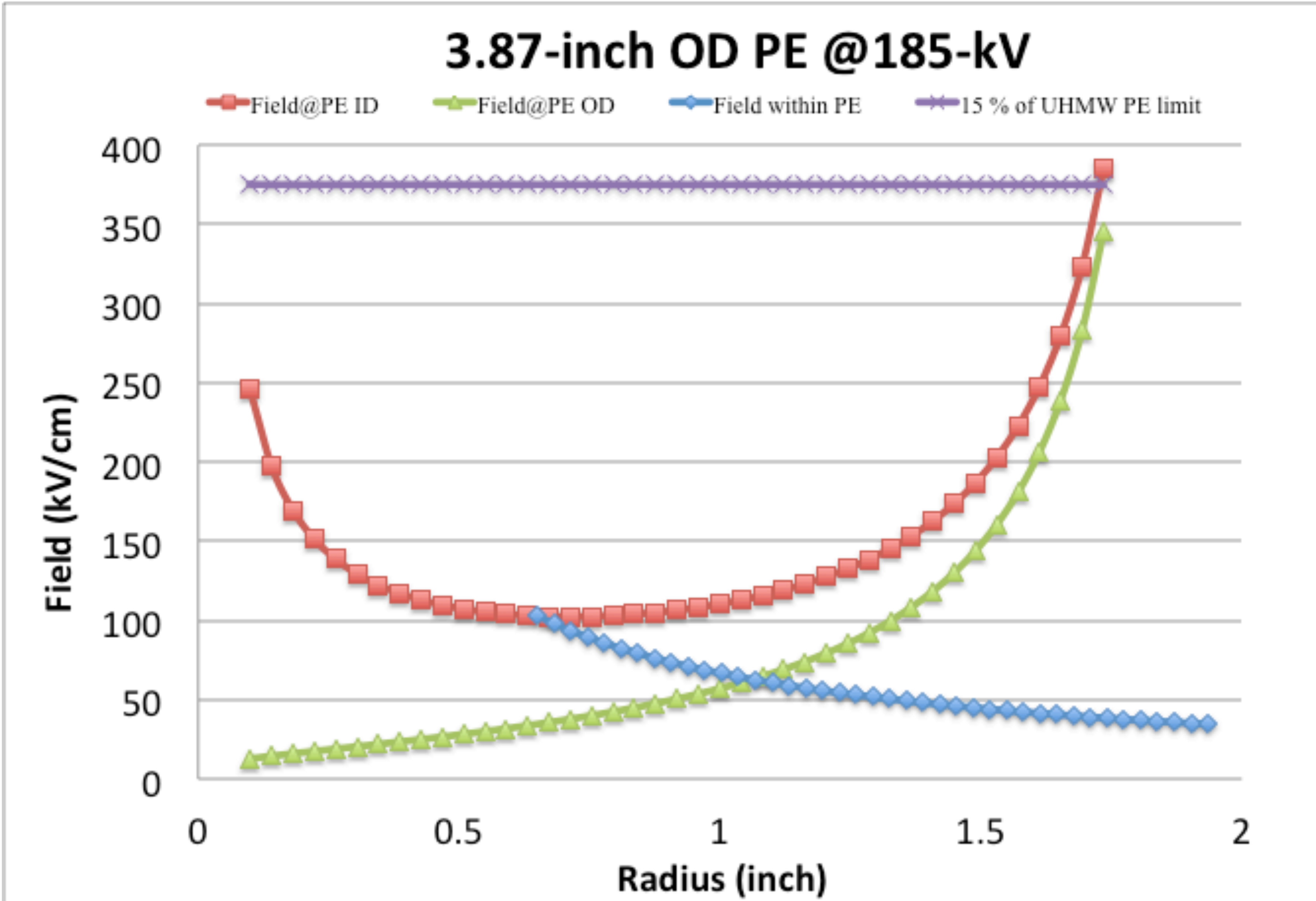


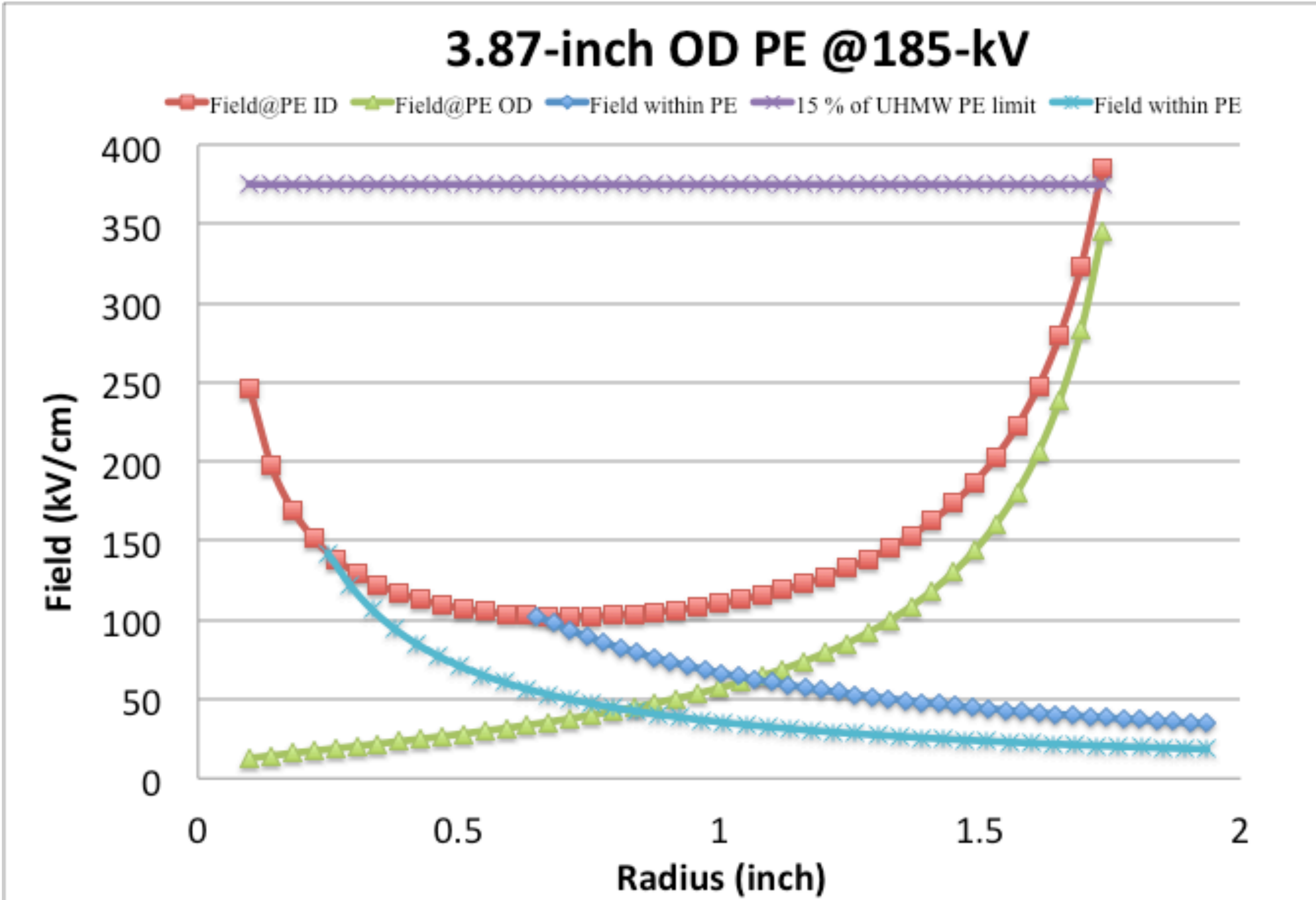


Surface: Electric field norm (kV/cm)
▲ 183.1
▼ 0
-194
-196
-198
-200
-202
-204
-206
-208
-210
-212
-214
-216
-218
-220
-222
-224
-226
10
15
20
25
30
35
40
45
50
100
80
60
40
20
0



3.87-inch OD PE @185-kV
Field@PE ID
Field@PE OD
15 % of UHMW PE limit
Field (kV/cm)
400
350
300
250
200
150
100
50
0
0
0.5
1
1.5
2
Radius (inch)


3.87-inch OD PE @185-kV
Field@PE ID
Field@PE OD
Field within PE
15 % of UHMW PE limit
400
350
300
250
200
150
100
50
0
Field (kV/cm)
0
0.5
1
1.5
2
Radius (inch)



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15 % of UHMW PE limit
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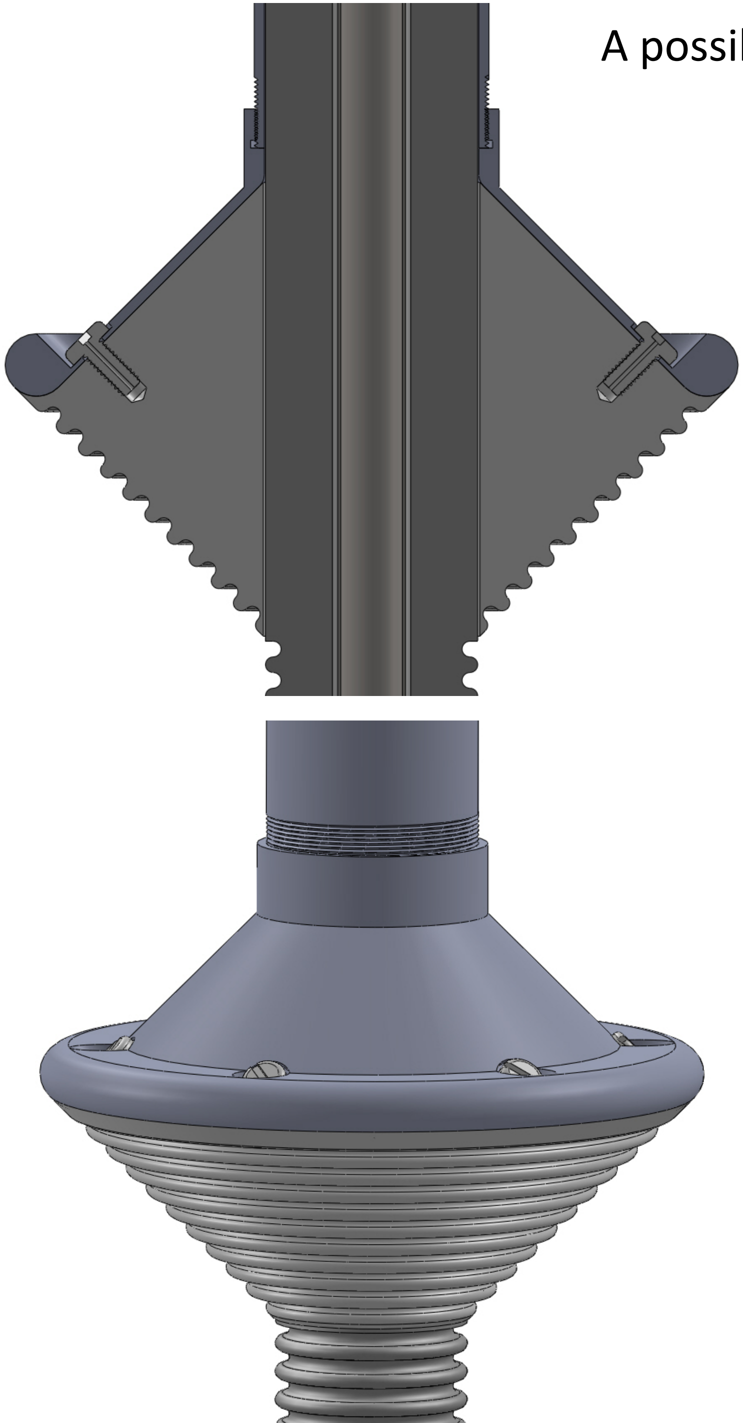
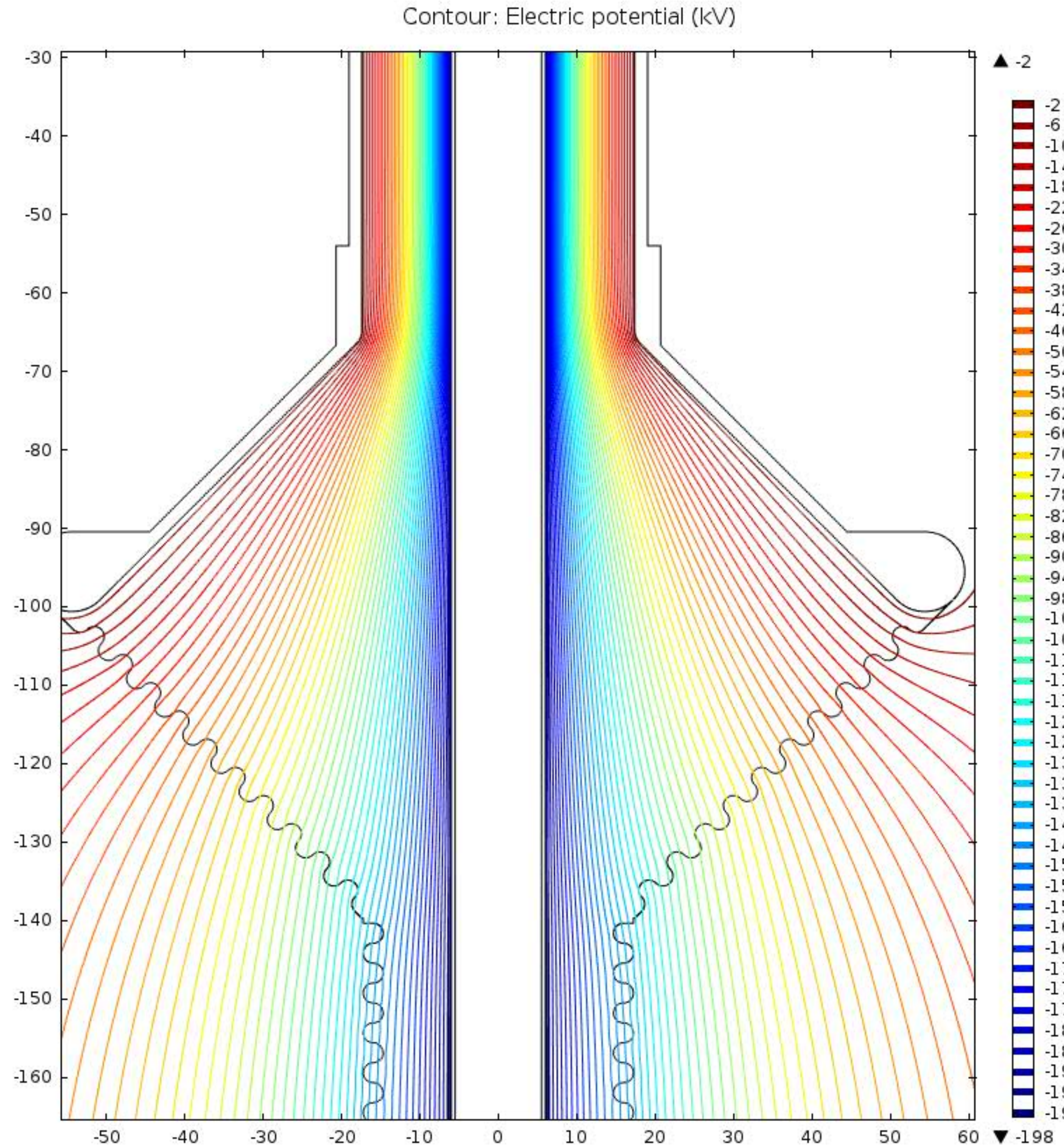
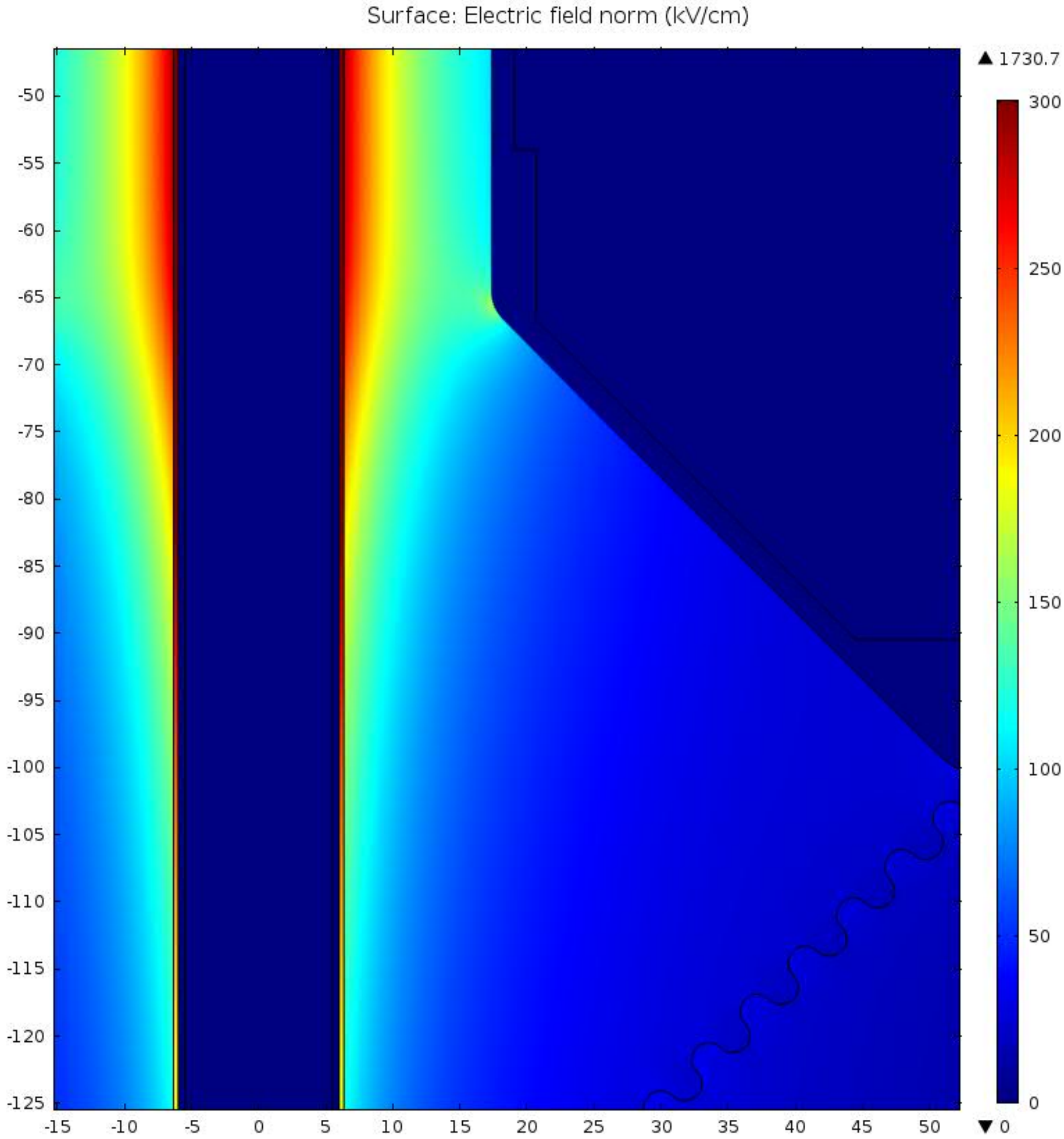
400
350
300
250
200
150
100
50
0
Field (kV/cm)
0
0.5
1
1.5
2
Radius (inch)

A possible way to relax the maximum field strength on the OD (being fabricated and to test soon)







Field Strength Map

To limit maximum field strength on surface

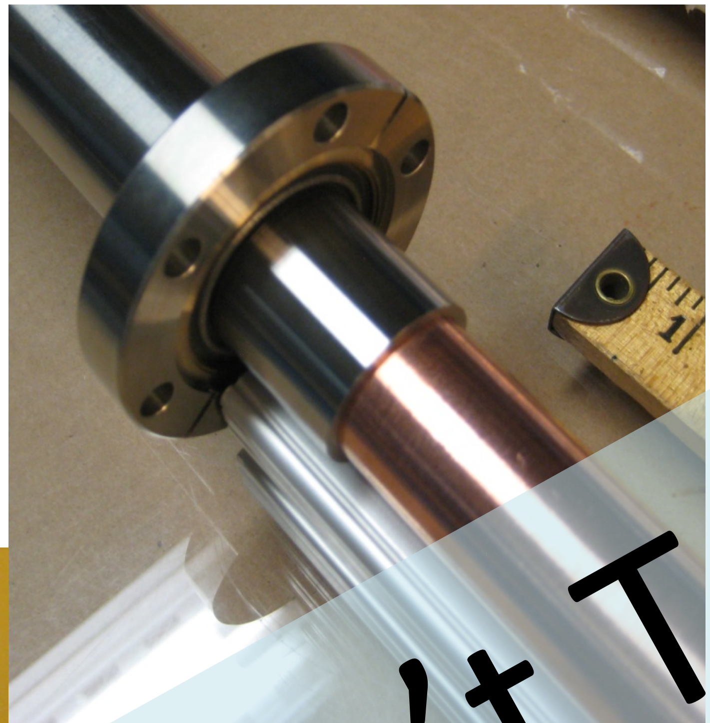
Summary

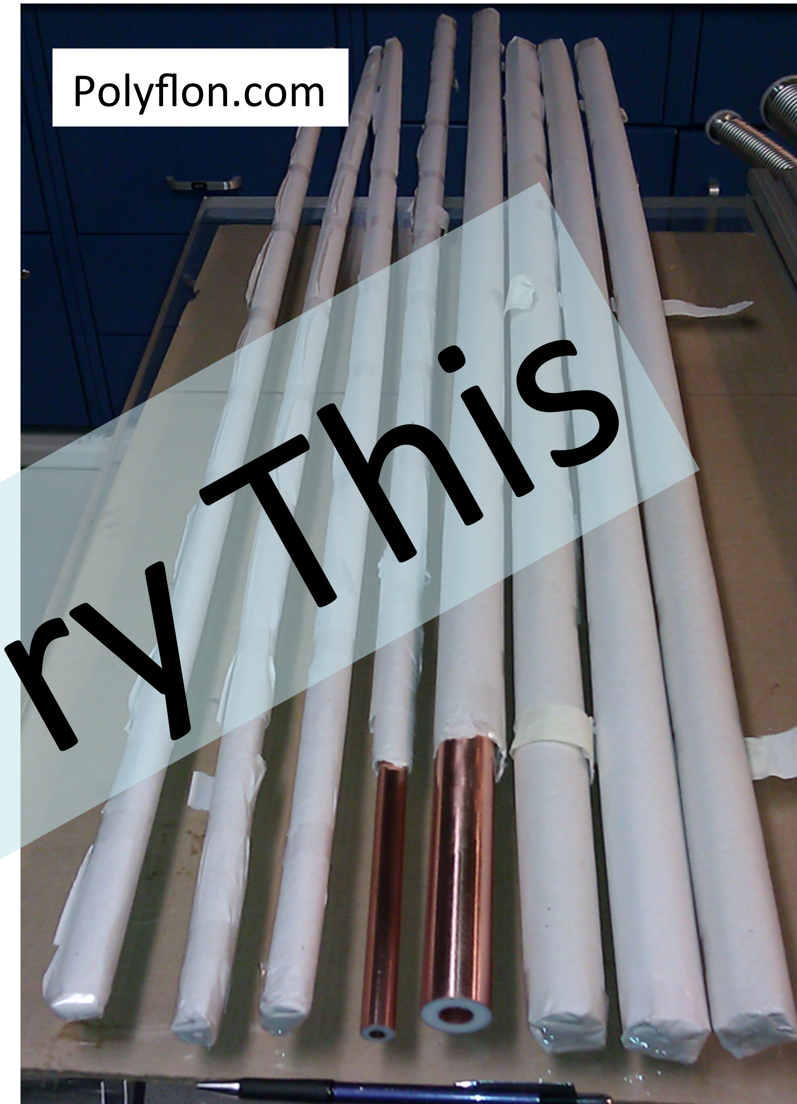
- 50kV CAPTAIN HV FT Constructed and tested, no issue expected.
- No success yet on LBNE HV FT above 150kV with both 1.5” and 2.5” construction in open mouth Dewar tests
- Likely need FT OD beyond 4”. No off the shelf materials available. Quoted UHMWPE extrusion and price reasonable.
- Modified tip region could work but need more test. Successful test will avoid extensive large FT fabrication

Initial LBNE proposal Copper coated PTFE tube

- OD 1” Wall ¼” (Type I), OD ½” Wall 1/8” (type II)

For proof of principle test only





Don’t Try This