High Voltage Feed-Through for Liquid Noble Gas Detectors

For previous work, see DocDB#5730-v1

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LArTPC Workshop @ FNAL
03 21 2013

What is a HV FT

- A HV FT is a simple device to bring HV from one volume into another penetrating a wall or multi-walls
- A TPC (LAr/LXe) requires HV on cathode
- Ultra-High Vacuum Compatible
- Ultra-High Purity compatible
- For cryogenic use (in case of LAr/LXe)
- Long term reliability >10 years

Why home made?

- Commercial Ceramic based Feedthrough are designed for vacuum applications and simply can not be used directly in LAr/LXe TPC
- In case of Noble Gas TPC, near the feedthrough HV tip , the gas is a perfect carrier for sparking
- In Liquid Noble gas detector, Any possible bubbling, if migrated near high field regions, discharge could happen
- Contrary to HV FT in vacuum, HV FT design for Liquid Noble gas detector must consider also the operating environment of the FT (gas and liquid).

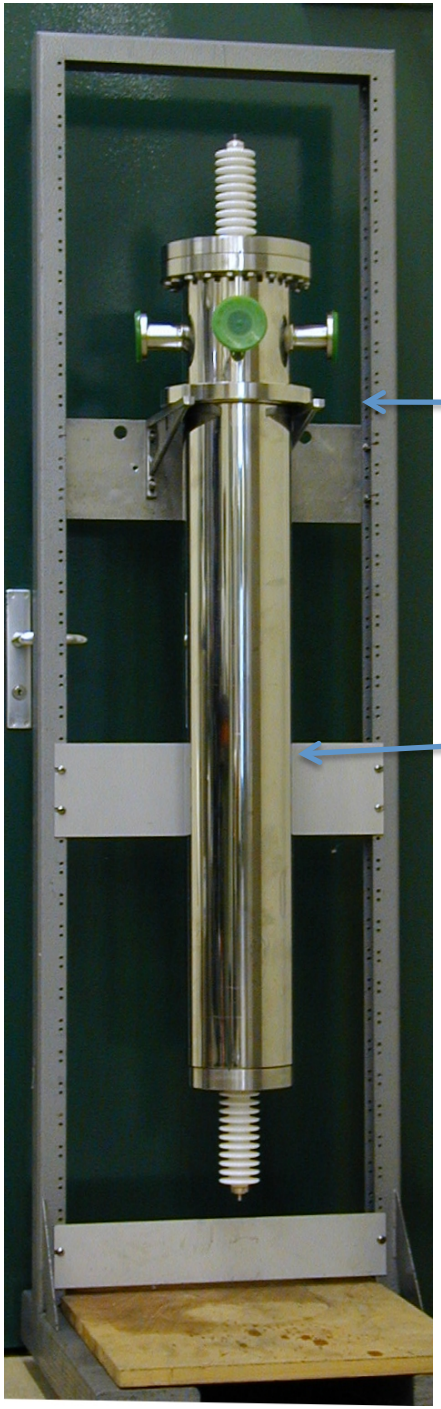
Vacuum Side

Air Side

Commercial HV FT

Vacuum Side

Custom Ceramic FT assembly

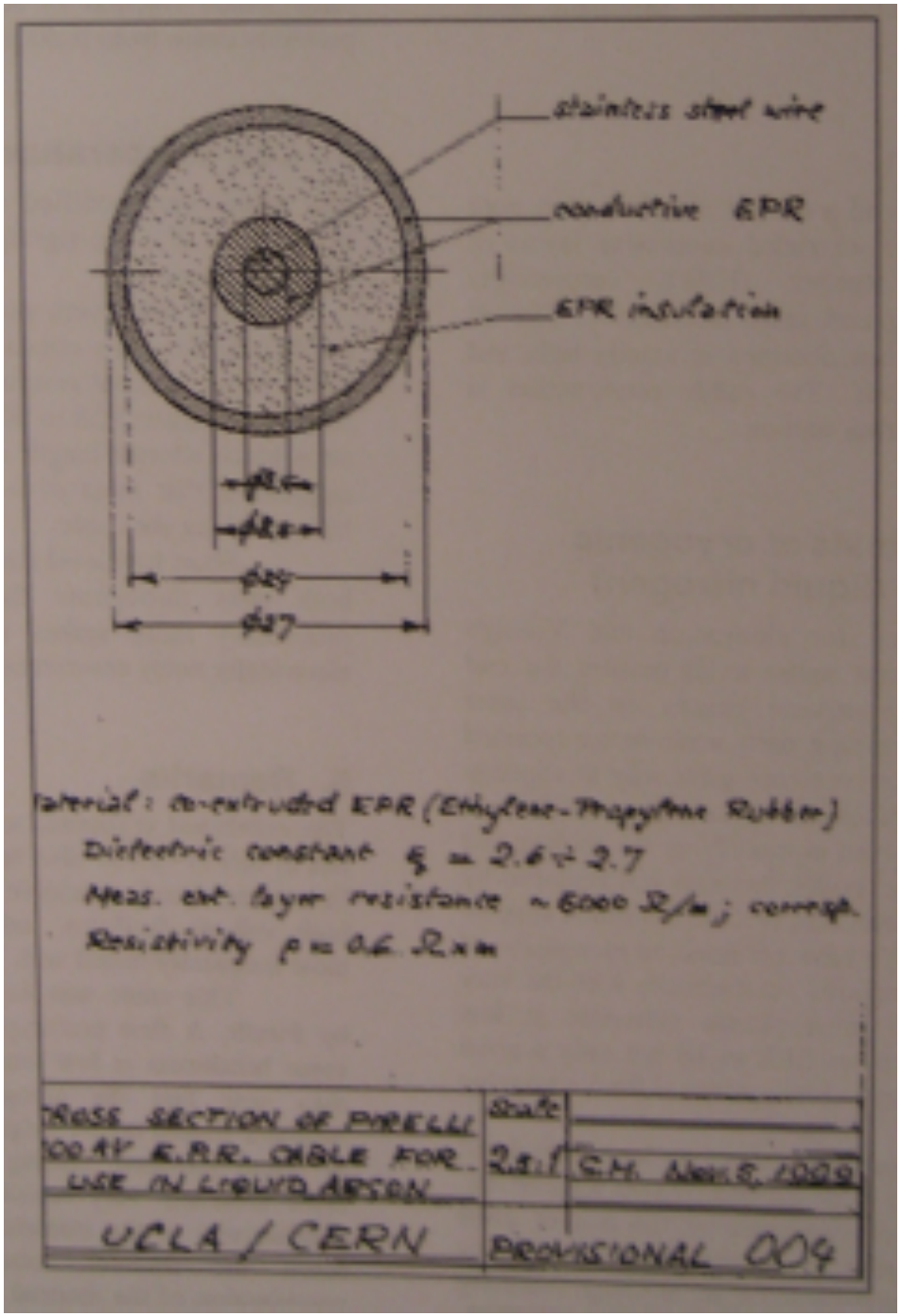


Cable FT

provided free of charge
by Pireli cable

4 layers of Ethylene-Propylene Rubber (EPR) Co-extruded on a SS core, respectively: conductive, insulating, insulating and again conductive.

Development (mid 90's)



Development of Cable FeedThrough by UCLA for ICARUS

CERN SL-Note 99-052 (MS)

Tested at 190kV in LN2

(design goal: 300kV, tests limited by availability of power supply)

(For Information Only)

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH
CERN - SL Division

SL-Note 99-052 (MS)

TESTS OF INDUSTRIAL ETHYLENE-PROPYLENE RUBBER HIGH VOLTAGE CABLE FOR CRYOGENIC USE

B. Balhan[1], M. Blin[1], B. Goddard[1], G.Muratori[2],
S. Otwinowski[2], J.-M. Rieubland[1] and H. Wang[2]

Abstract

At the beginning of 1999 the University of California at Los Angeles has received a prototype High Voltage Cryogenic Cable supplied free of charge by Pirelli. The cable is intended for more than ten years of service at 100 kV D.C. and liquid argon temperature. The cable uses an all welded construction, which is axially tight and free of ionizable voids. The cable was submitted to a number of mechanical and electrical tests as described below.

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[2] UCLA, University of California at Los Angeles, 405 Hilgard Ave., Los Angeles, CA-90095, USA

Geneva, Switzerland
10 November 1999

ICARUS HV FT Concept

- Stainless Steel OD
- Stainless Steel ID
- UHMW PE insulation
- Cryofitted
- Very large Safety factor.
  - -75kV and operated at -150kV.

Designed by Franco Sergiempietri
Fabricated at UCLA

Total of 3 built at UCLA

Two are installed on ICARUS and still in operation

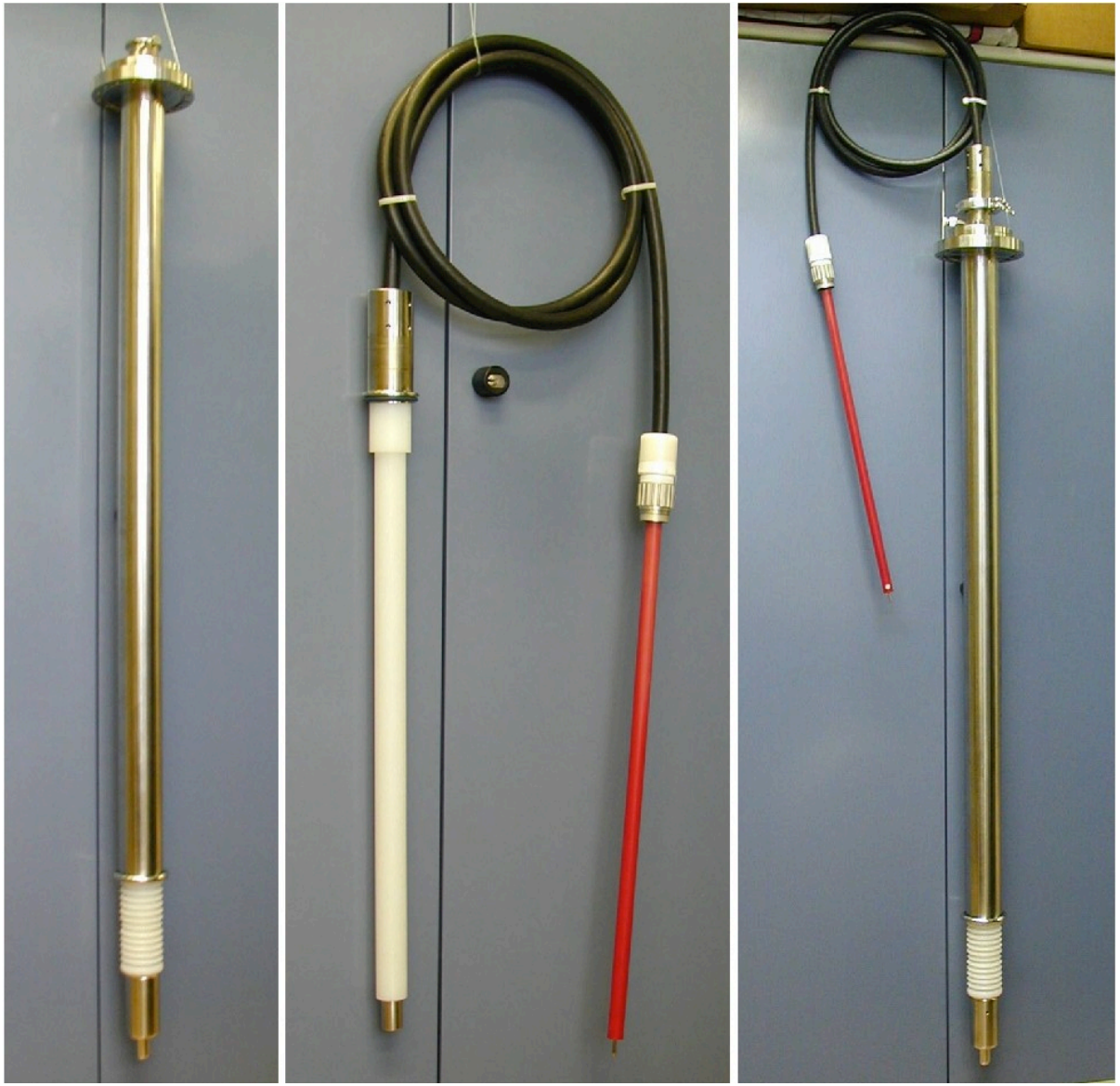
One is installed on LANNDD 5m drift detector (to operate at 250kV)

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

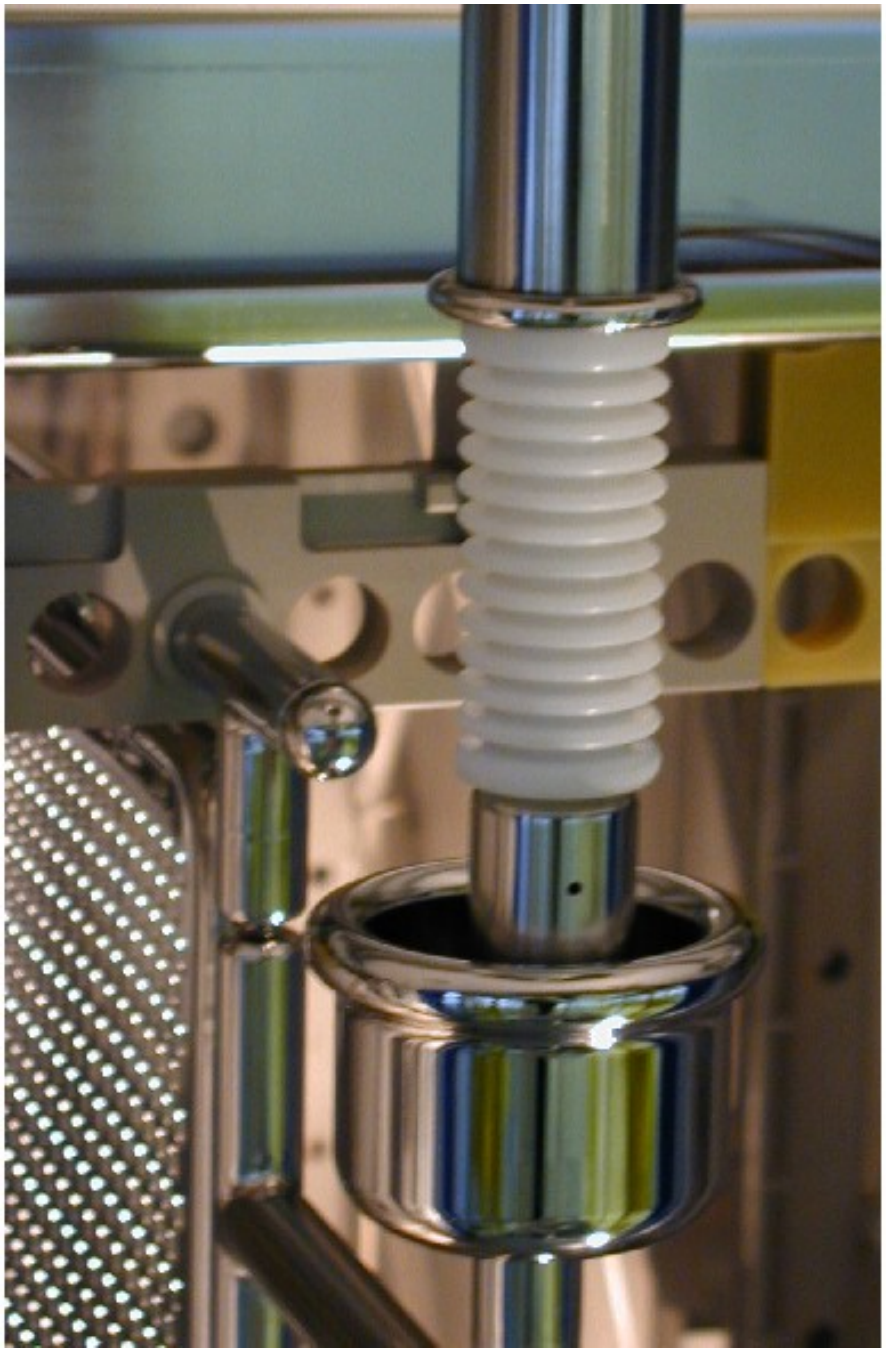
Required voltage:
-75kV

Operated at:
-150kV on ICARUS

(Not to scale)



FT Cable Plug Plugged IN



Installation in ICARUS

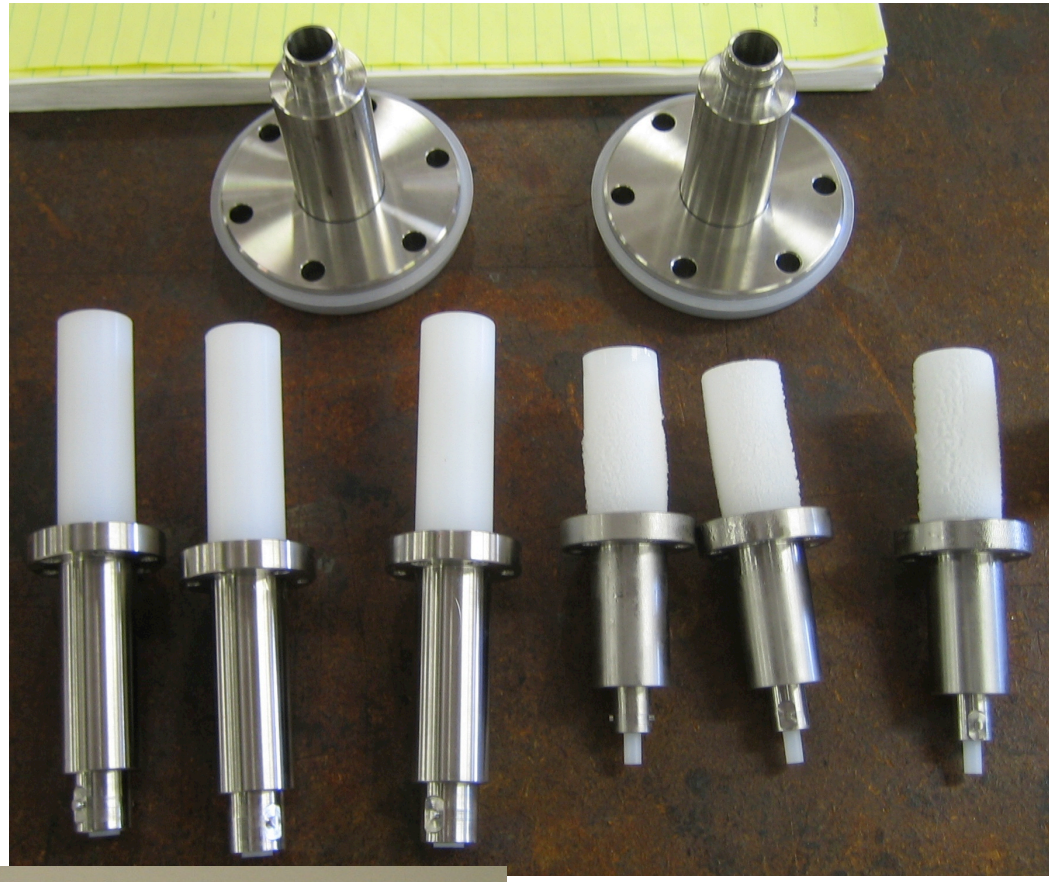
FT Removable
while Detector
Is filled

Spring loaded HV tip to sit on
Cup fixed on Cathode

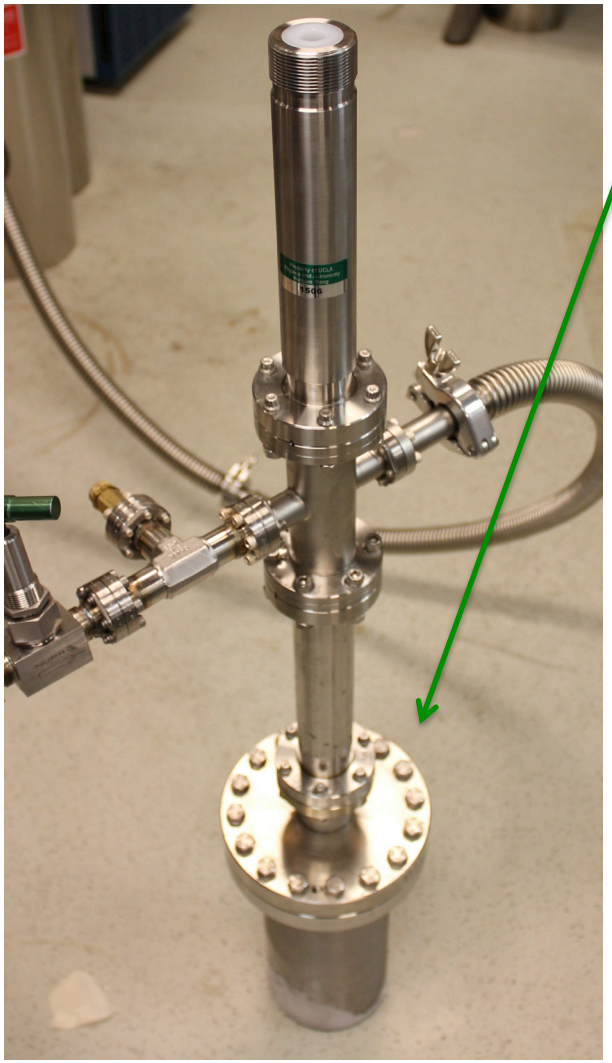
Home made HV FT
of smaller sizes
With integrated
SHV-20
and SHV-10 connector

Used on ZEPLIN II

No leak after >10years



Pre-Prototype Test FT: 0.87” PE OD and 0.5” ID



Tested in Liquid Argon up to -130kV (limited by available power supply)

Varies FTs of same construction concept has been tested vigorously in systems with both liquid xenon and liquid argon up to 110kV In a very limited space compared to LBNE (with tip center to ground distance only 0.75”)

Construction for XENON1T, DarkSide50 and CAPTAIN

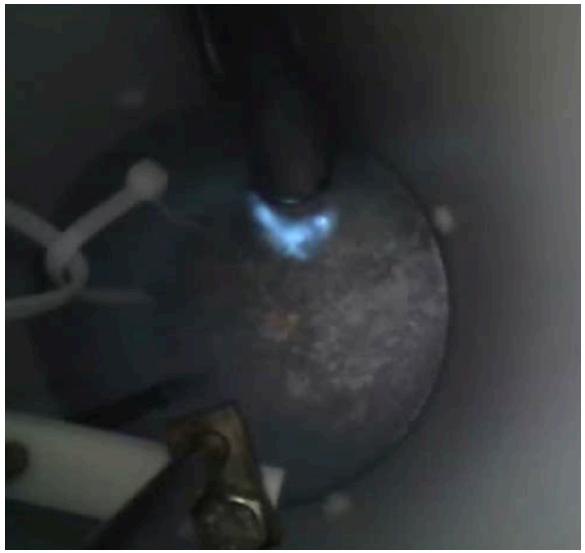
Before “destructive” test in liquid argon

Extreme “destructive” test (sparking)

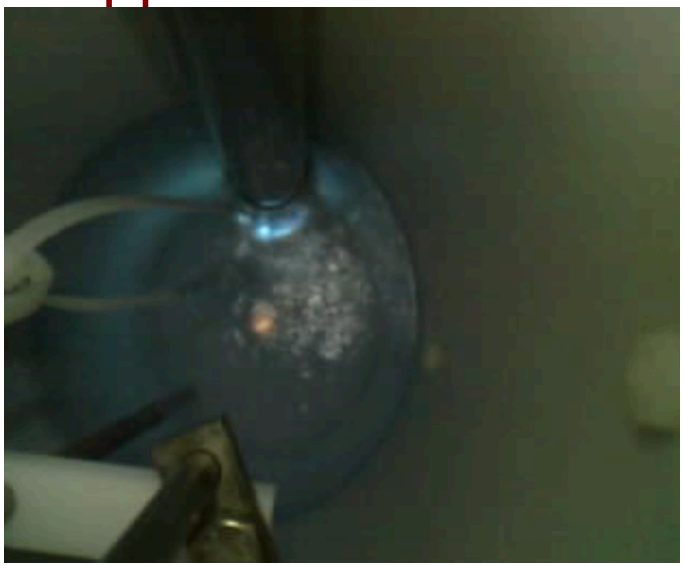
Glowing UHMW-PE after Continues Breakdown in Liquid Argon: No damage to FT

HVFT + PTFE cup close to the cryostat wall (video frame in liquid xenon)

- HVFT with a tip and a smooth PTFE cup around it. Distance to ground <1cm.
- Sparking inside the cup between -70kV and -100kV. P~1.2bar. Stable at 95kV for 2h. Test stopped.



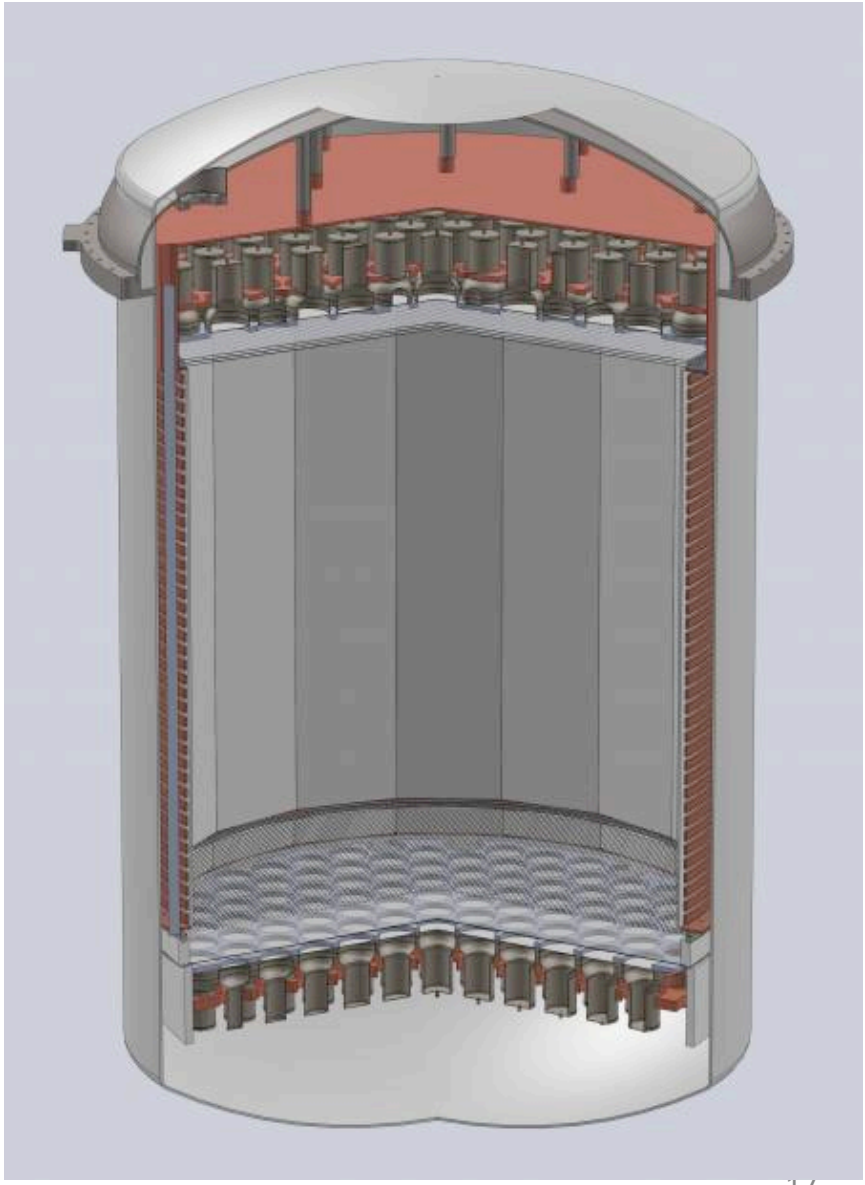
- HVFT with a tip and a grooved PTFE cup around it. Distance to ground <1cm.
- Sparking inside the cup above -95kV. P~1.6bar. Stable at 110kV for 1h. Test stopped.



Greatest Challenge: XENON1T HVFT

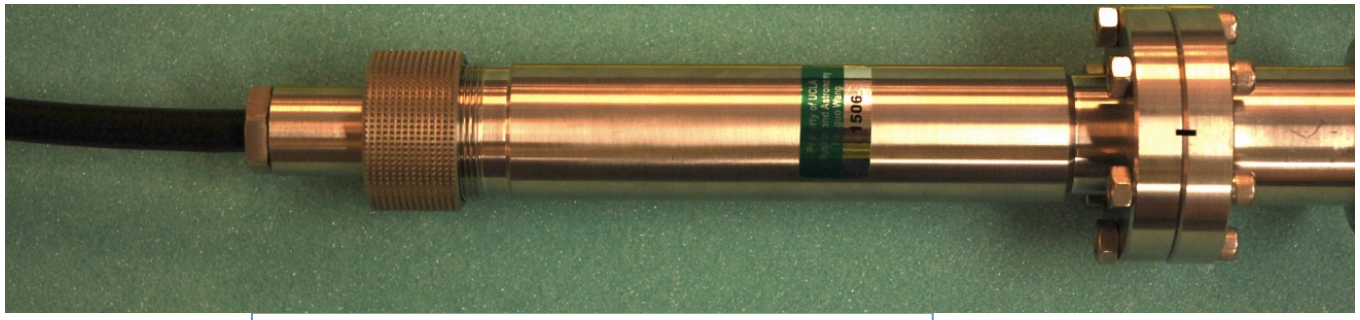
- XENON1T Cathode @ -100kV for 1kV/cm drift field for 1m TPC
- Cathode very close to cryostat wall ~4cm. HVFT has to fit in here.
- HVFT has to be made out of low background material

Main challenge: Limited space. Electric field between the tip of HVFT and the cryostat can be very high.



UHMWPE HVFT Design

Low background material: Stainless Steel and polyethylene



Cable connector

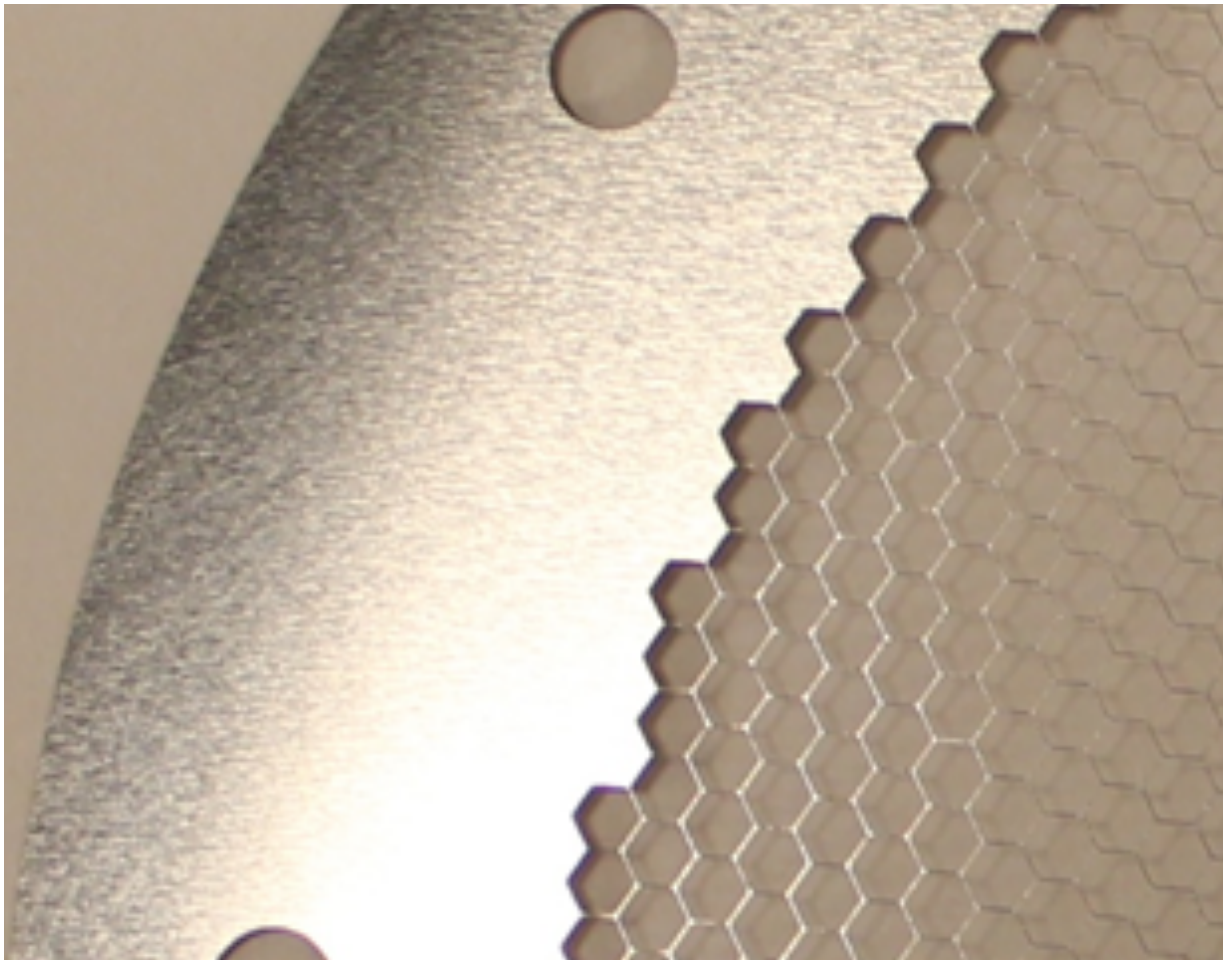
1” diameter

High voltage feedthrough

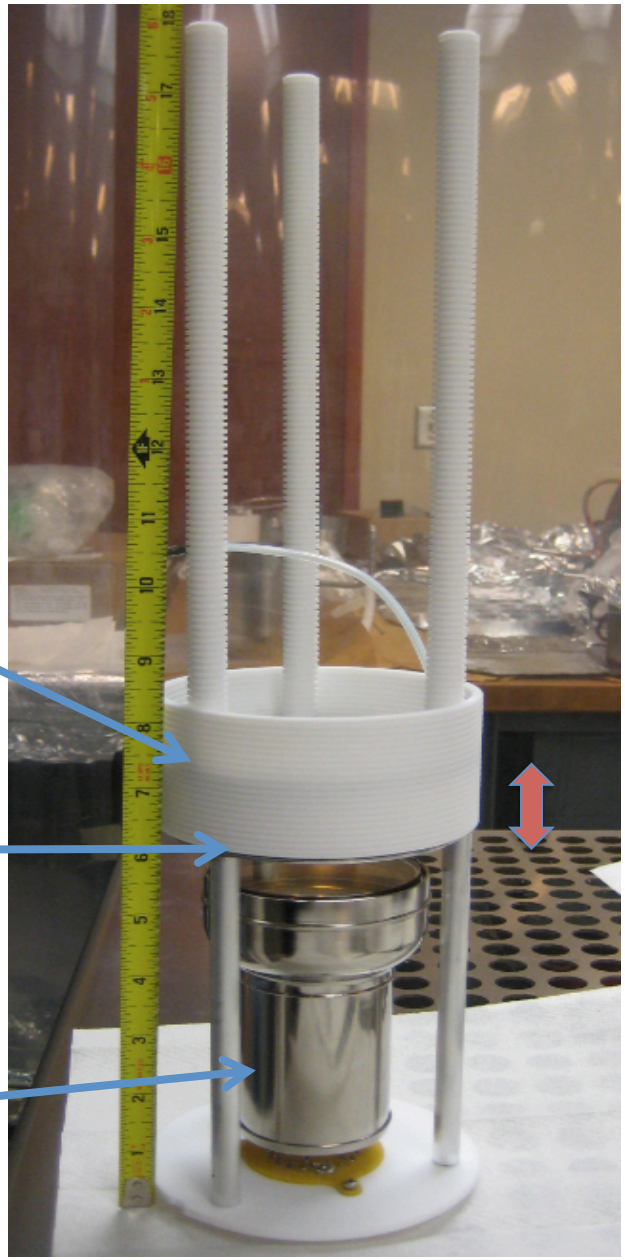
-100kV to cathode

Very fine Etched Grid for Cathode @100kV 3cm from ground

Grid: hexagonal, 50um strip width, 2mm pitch, 3” diameter.
Optical transparency about 95%.



HVFT with “TPC” and 3” PMT



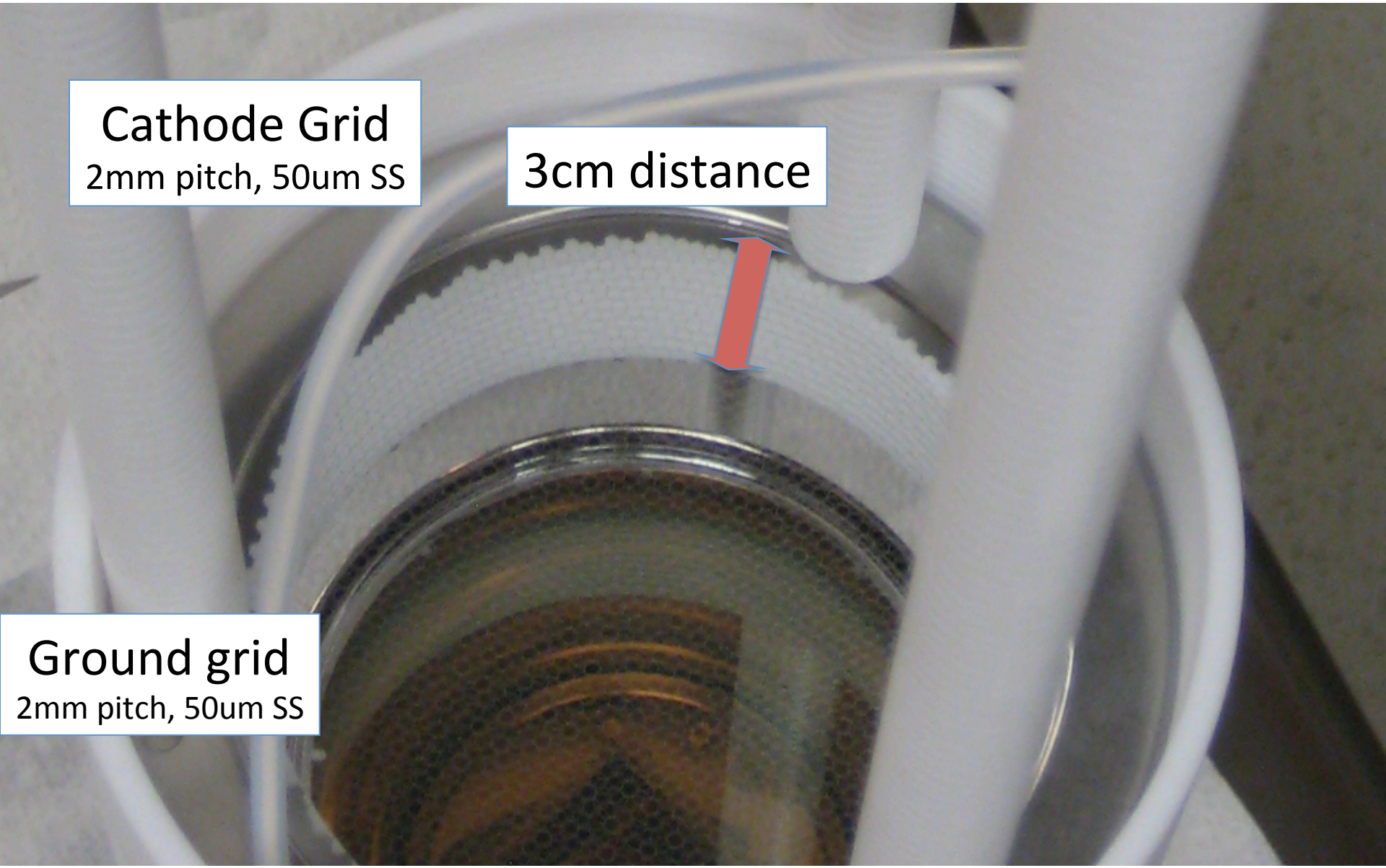
Cathode Grid
2mm pitch, 50um SS

Ground grid
2mm pitch, 50um SS

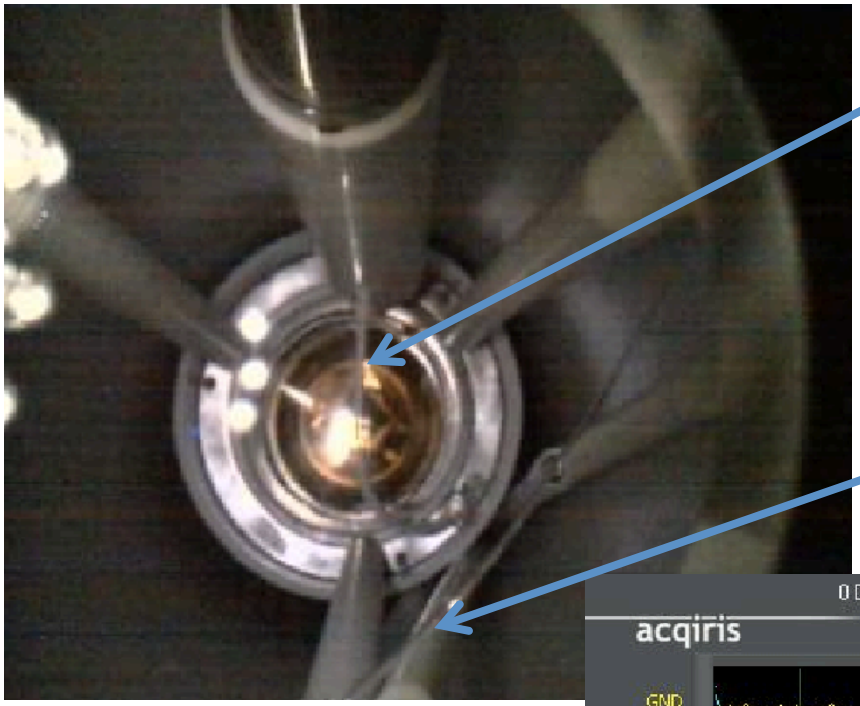
3” PMT

PTFE TPC
3cm distance

HVFT with “TPC” and 3” PMT



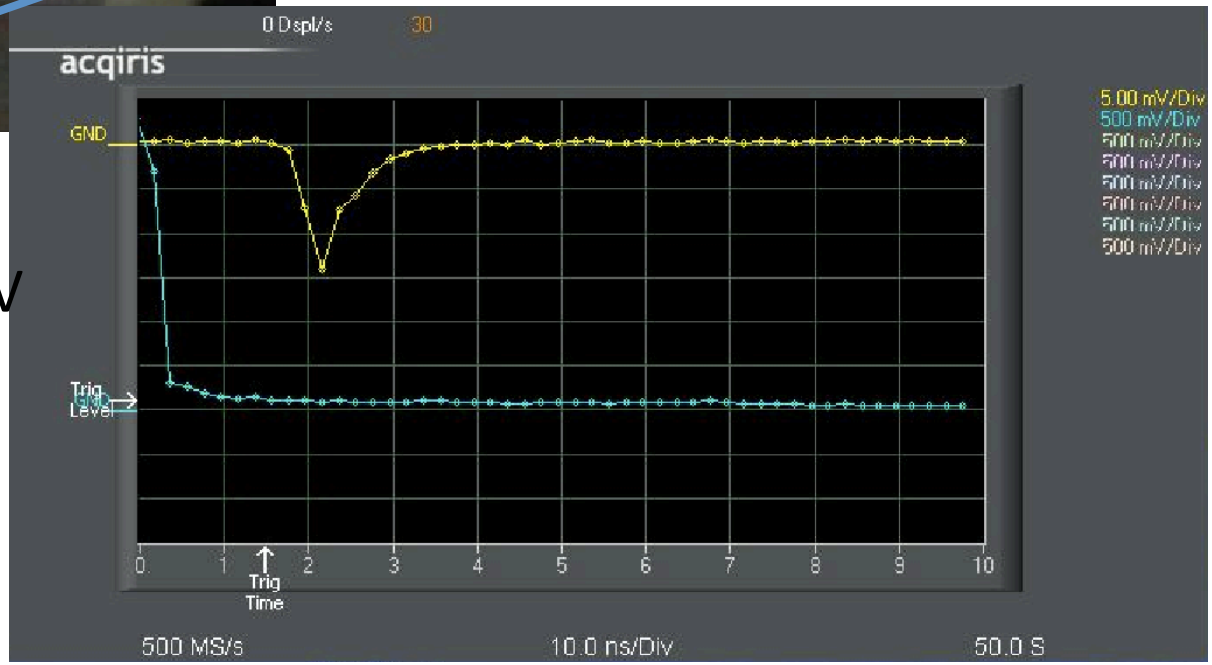
HVFT with “TPC” and 3” PMT



HVFT to cathode connection

Fiber

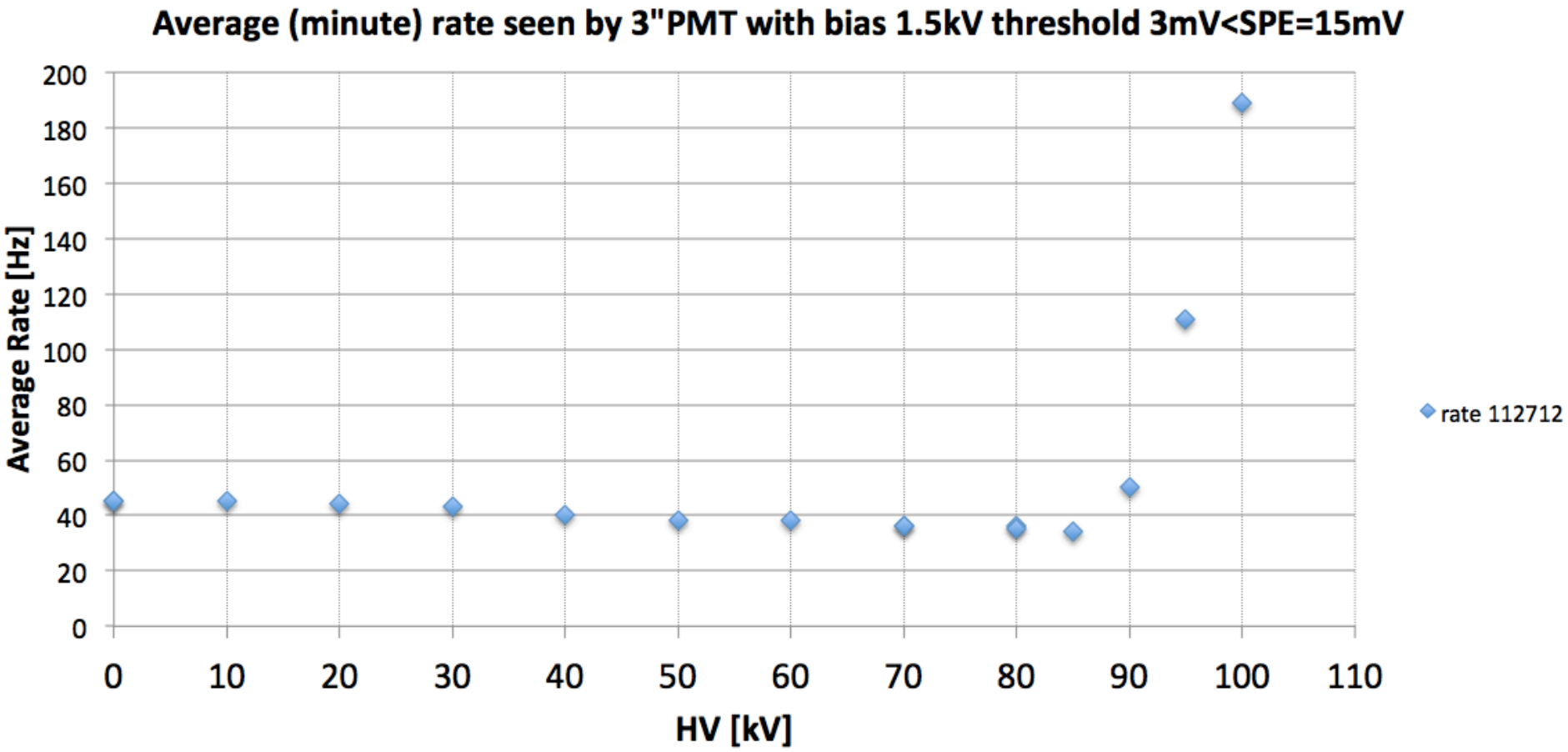
SPE at 1.5KV bias ~15mV



HVFT with “TPC” and 3” PMT

Trigger at 3mV with PMT bias 1.5kV and take the average rate of about minute to 5 minutes.

Rate is stable until 90kV, above some occasional “bursts” are seen.
We tested until 100kV and observed no spark. We repeated the test twice.



LBNE Cathode HV Feedthrough

Use the proven Cryofit concept
but optimize for LBNE:

- Simple but robust construction
- High Reliability
- High Performance
  (worry free operation)
- Virtually indestructible

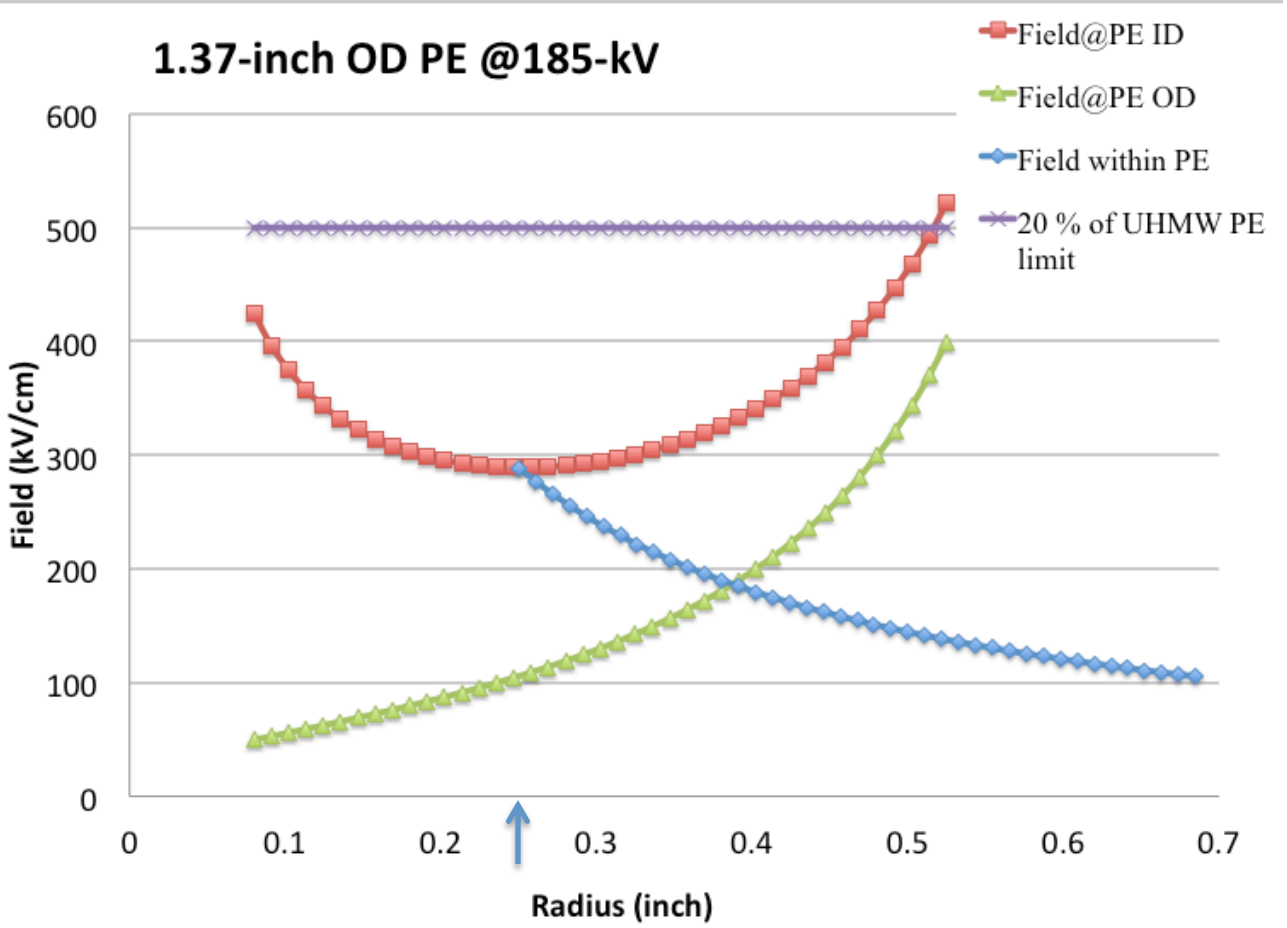
Geometry Optimization

For a given OD, there exist an optimum ID such that the field strength on the ID surface is minimized. In the case of a 1.37” OD tube, the optimum ID is ~ 0.5”.

Then the field strength within PE is shown in blue ranging from 105kV/cm up to 289kV/cm.

The dielectric strength of UHMW PE is 2500kV/cm. Theoretically, such geometry FT can hold 1,600kV. For Safety, it would be safe to operate it at 800kV with a 100% safety margin,

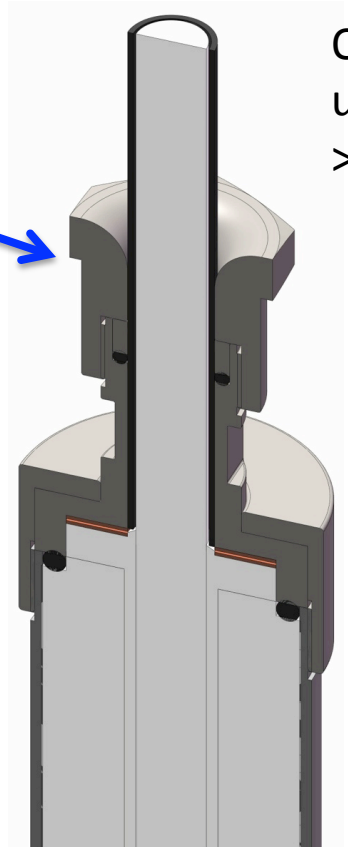
In reality, the real limit comes from the overall TPC design



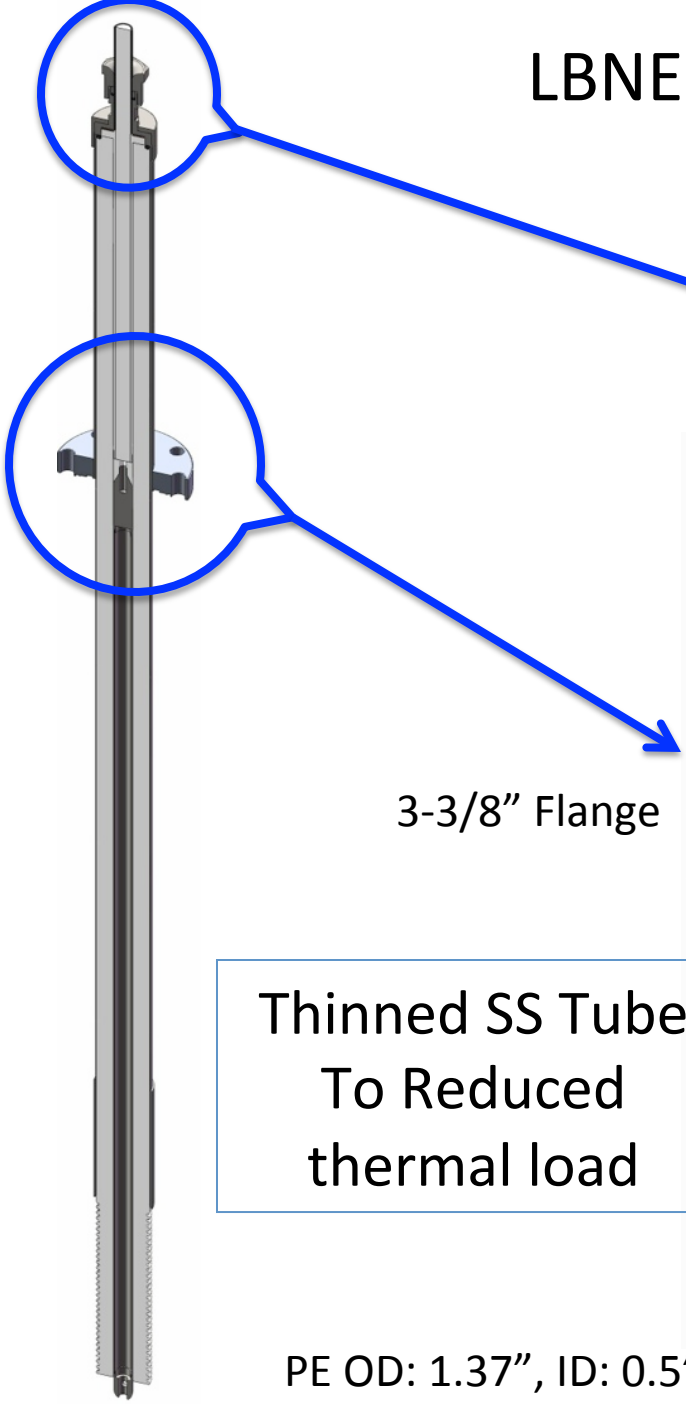
LBNE HV FT Prototype

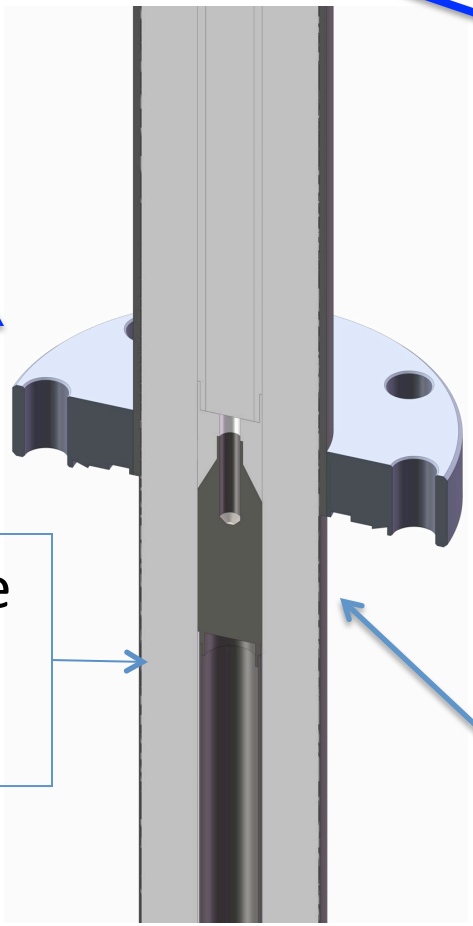
Total number of
Machined parts: 12

Proven water tight cable plug



Operated under water > one week





3-3/8” Flange

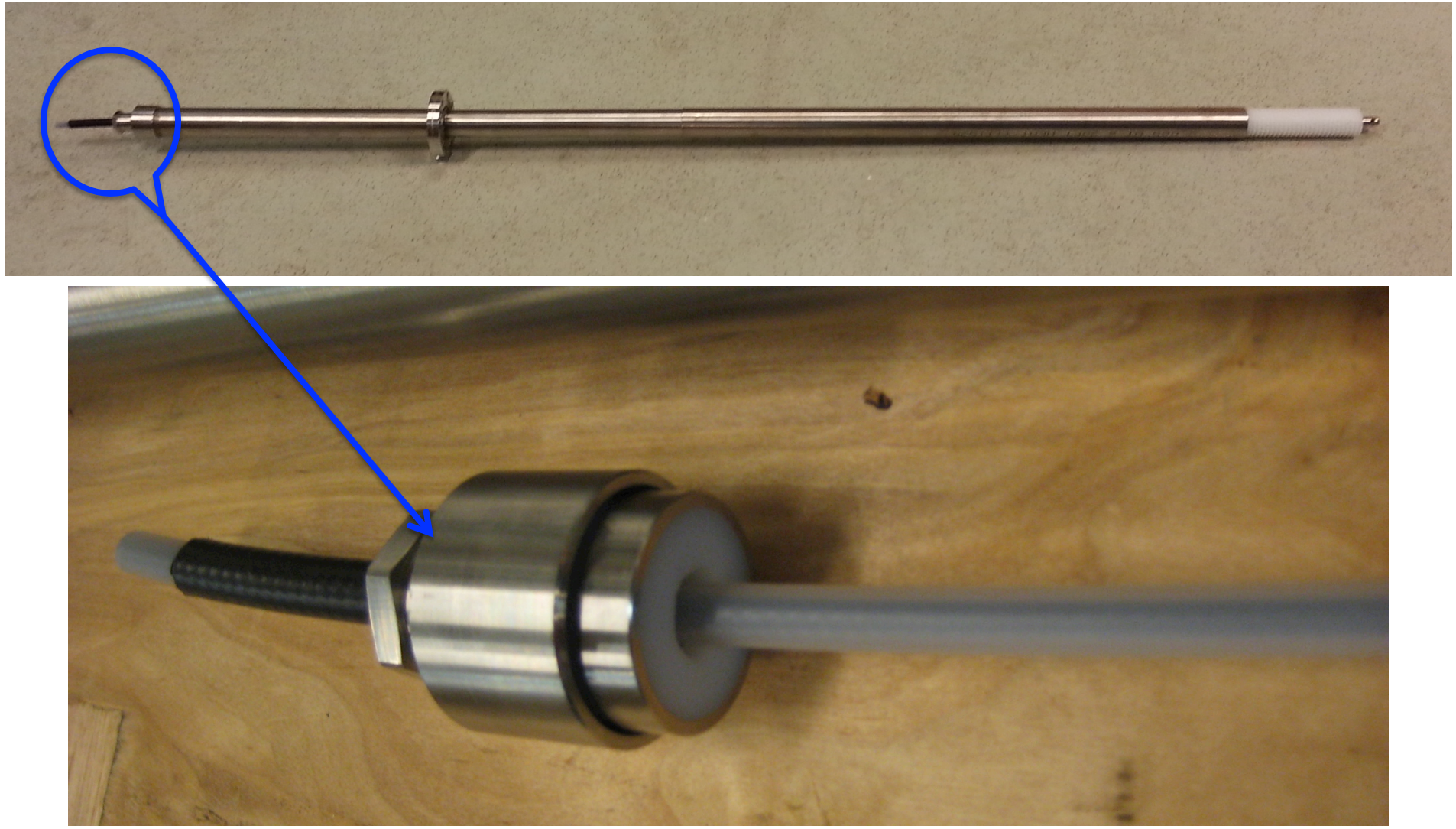
Thinned SS Tube To Reduced thermal load

Helium tight seal near flange at room T

PE OD: 1.37”, ID: 0.5”

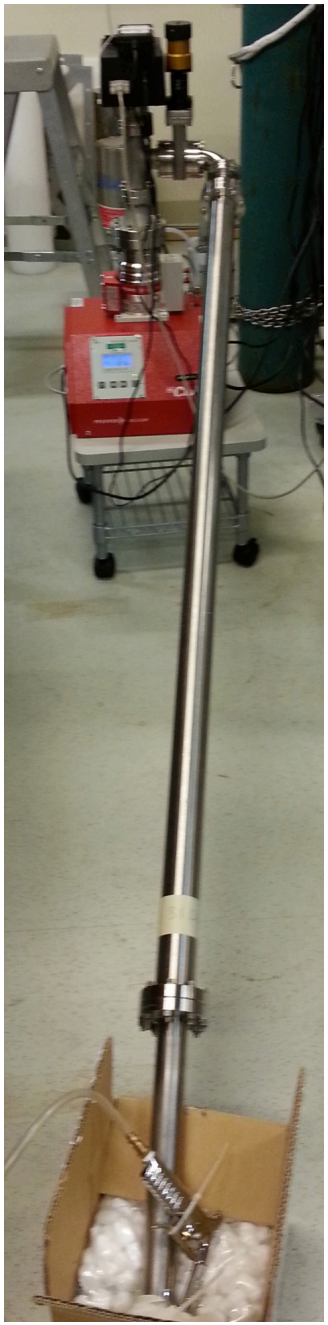
Exercise to test of procedure

Prototype FT and Cable Assembly



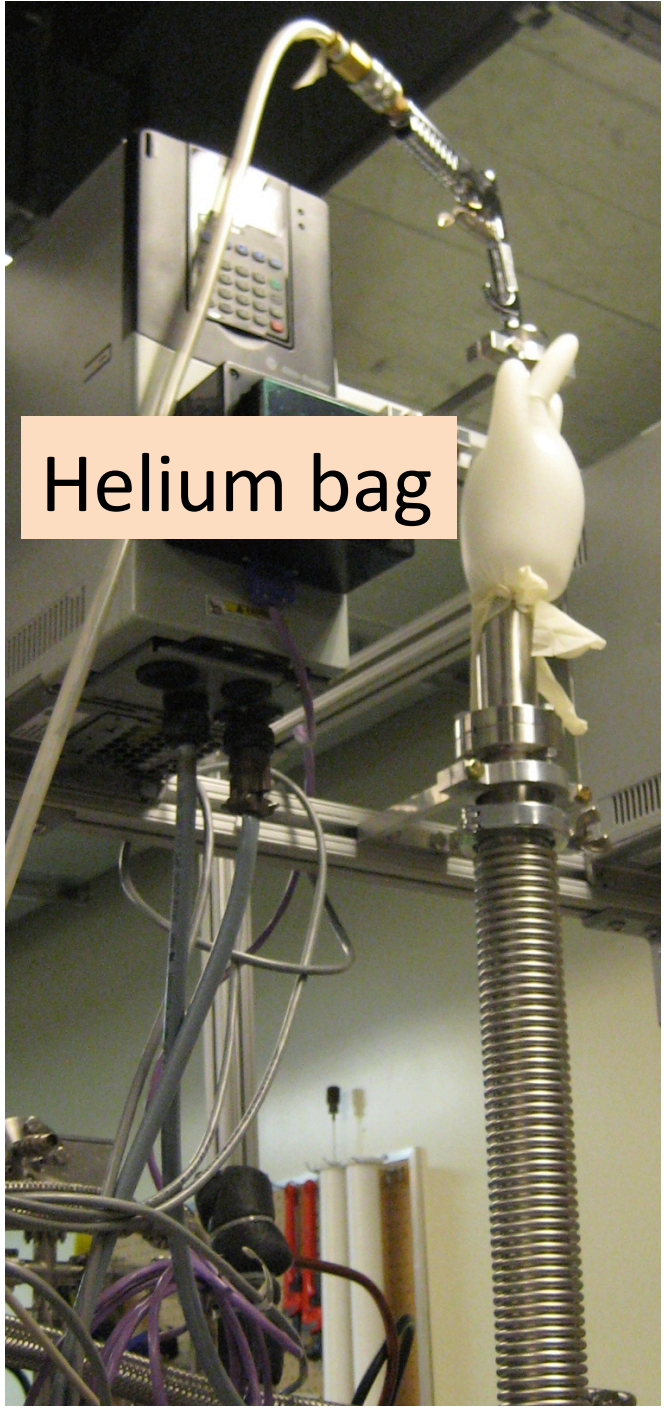
For LBNE and DarkSide G2

First LBNE HV FT Prototype

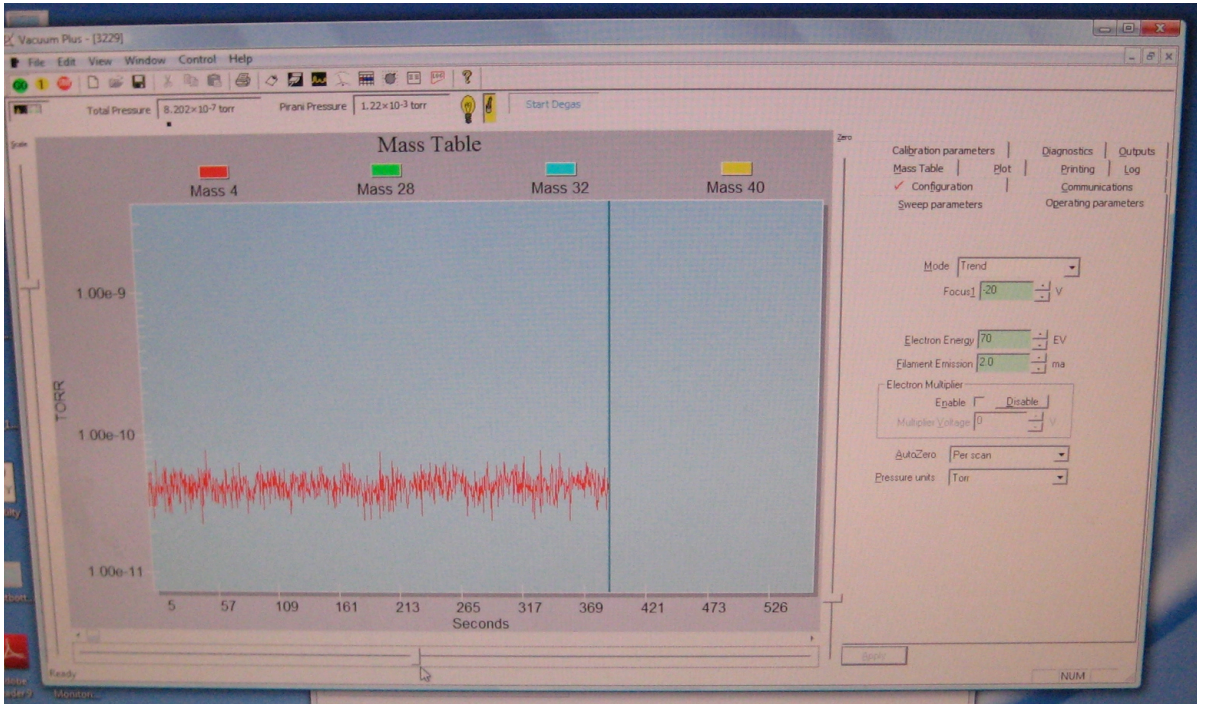


Helium bag

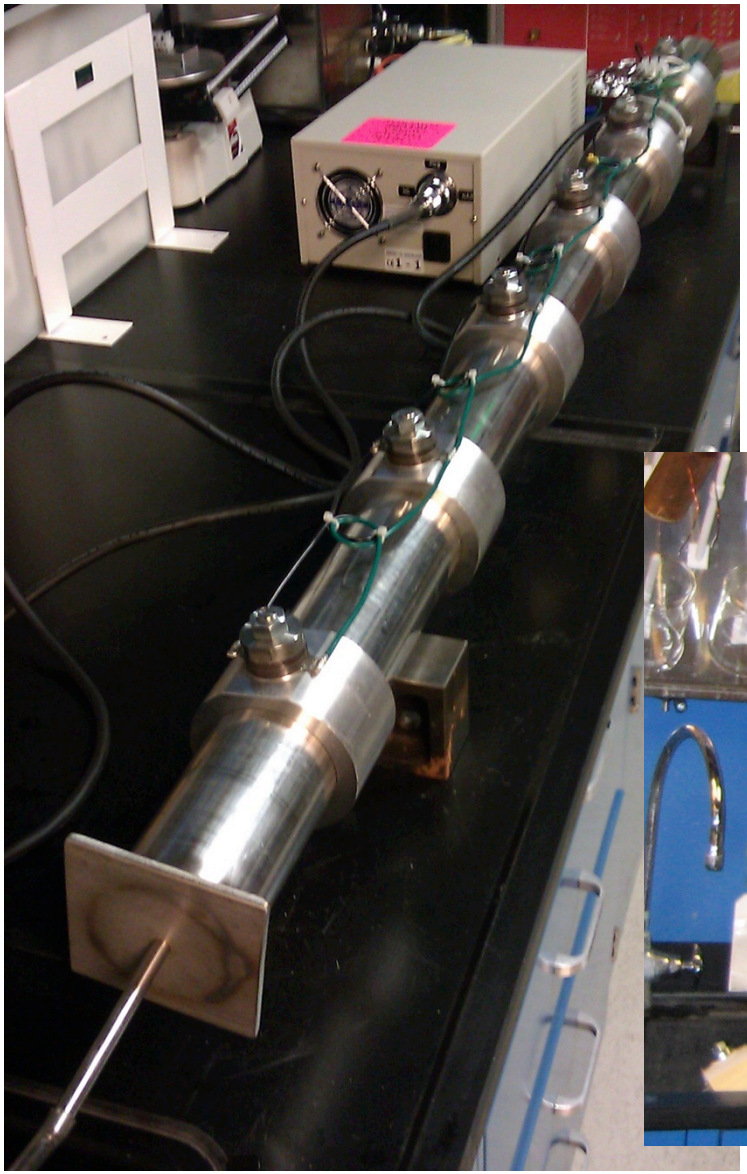
Leak Test with RGA



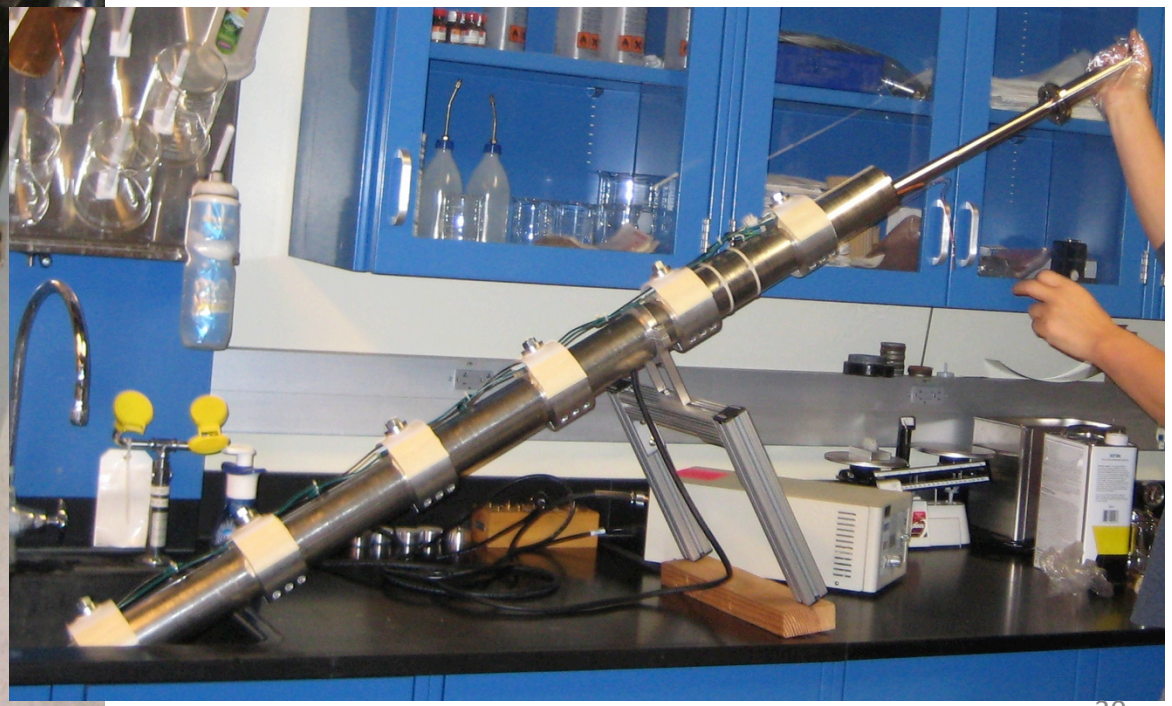
Leak tested with integrated He input without RGA response after few hundred seconds



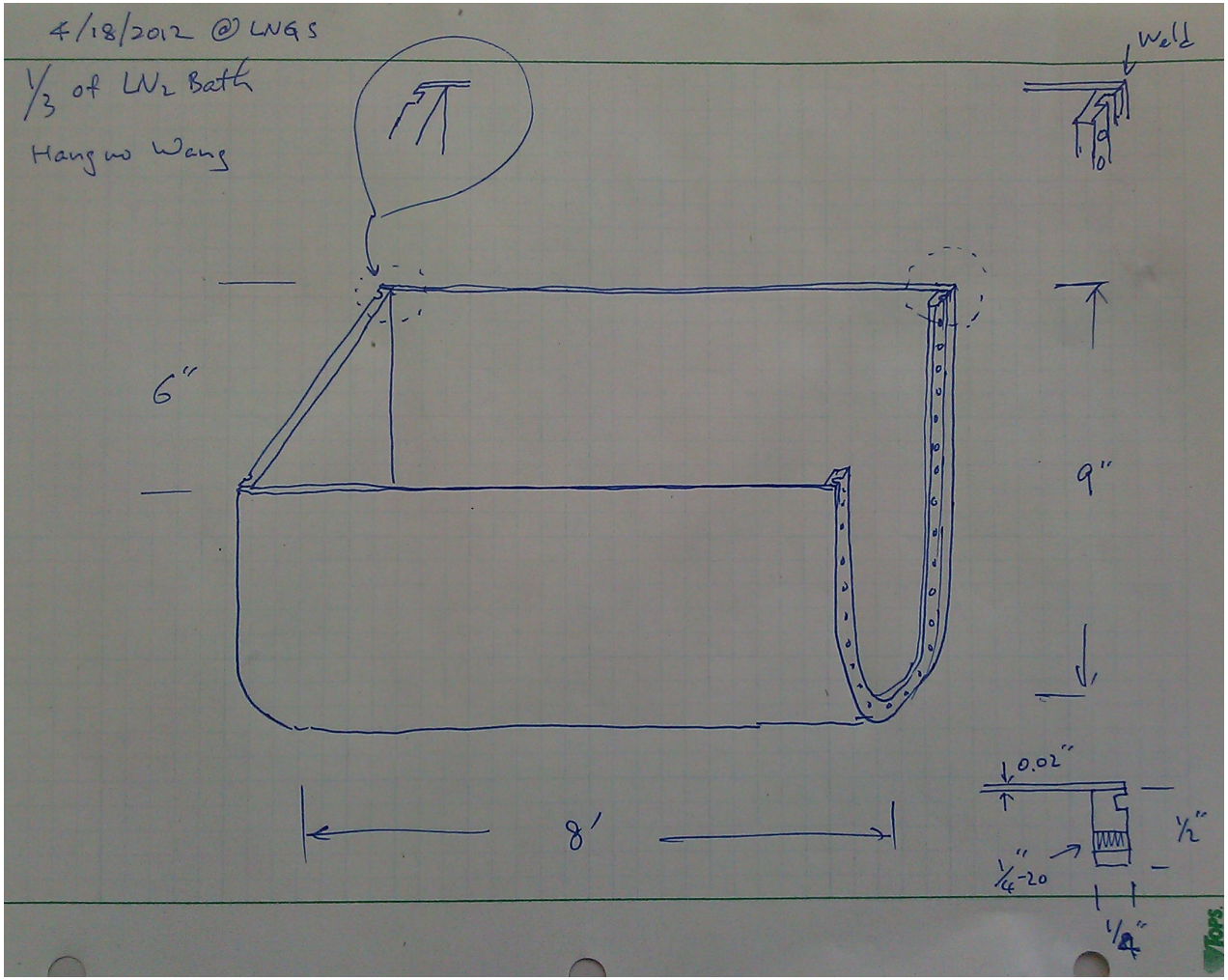
Facility 1: Home made long tube like Ultrasonic cleaning machine



6-heads 300W total power
Recently upgraded to 12 head 600W total power and double the length for LBNE long FT



Facility 2: Home Made LN2 Cryo-fit bath
Three sections can be connected
to cryo-fit 3.7m long FT for LBNE-FD



Nest Step

- Constructed a Real 185kV Feedthrough (with very high safety margin)
- Proposed OD: 1.37-inch
- Proposed ID: 0.5-inch
- Proposed Length: TBD (35T and LBNE-FD)?

Concept proven, but still a lot of engineering details and tooling development needed:

New arrival:

-200kV Heinzinger
0.001% Ripple

R&D for DarkSide G2
FT Development

Activities in FY13

1. Extensive Test on the prototype FT in Liquid Argon
2. Study Filter Box Requirement and Filter Box Design and construction
3. Design and construct two HV FT For 35 ton test by end of FY13. Overall design is fixed except to determine the length to fit in 35-ton detector.

Beyond FY13: Test FT at full LBNE voltage (-185kV) with contingency, prepare full engineering details of HV FT for LBNE