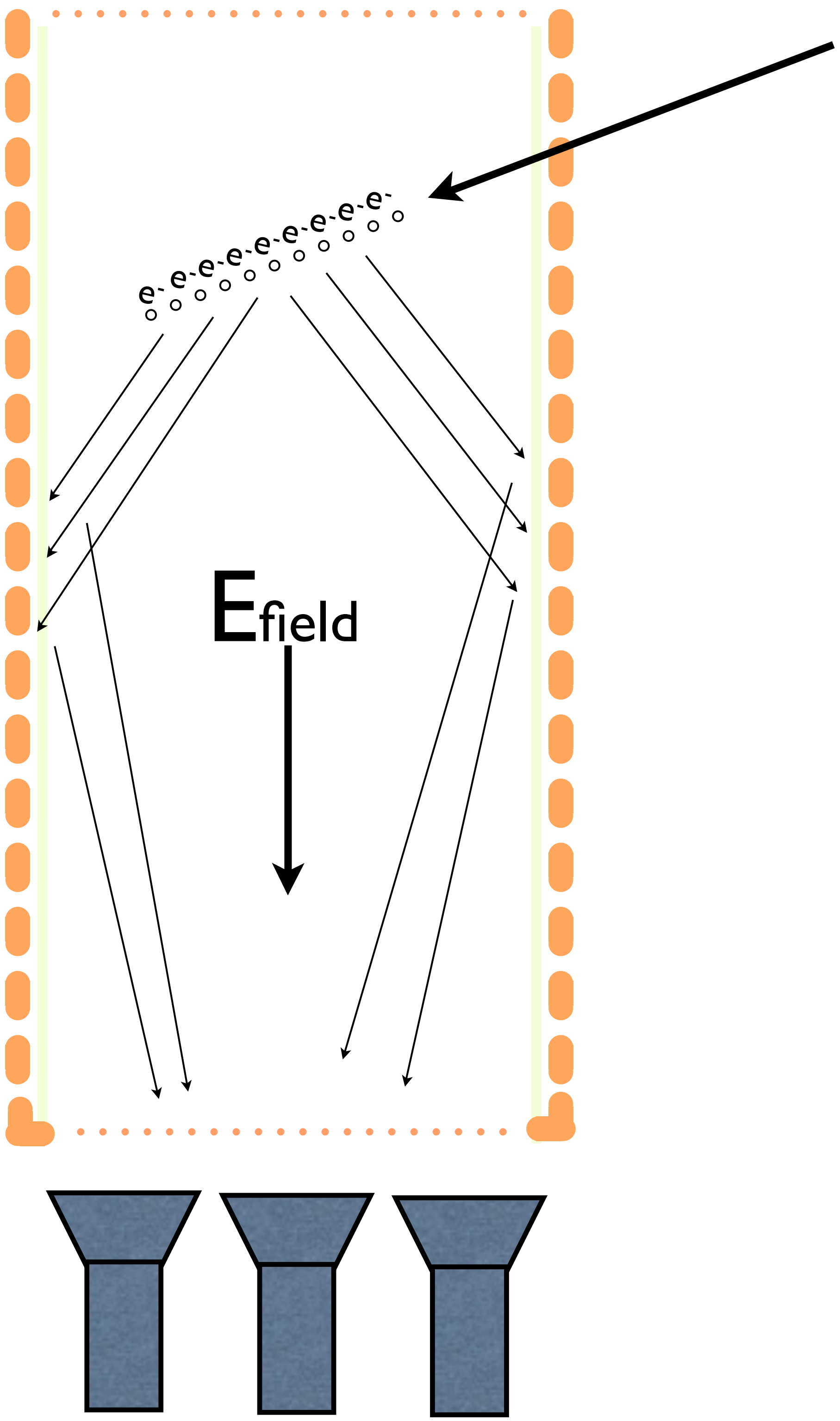
COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

The High Voltage in the XENON project

High Voltage in Noble Liquid
Chicago, Fermilab 8-9 November 2013
M. Messina Columbia University

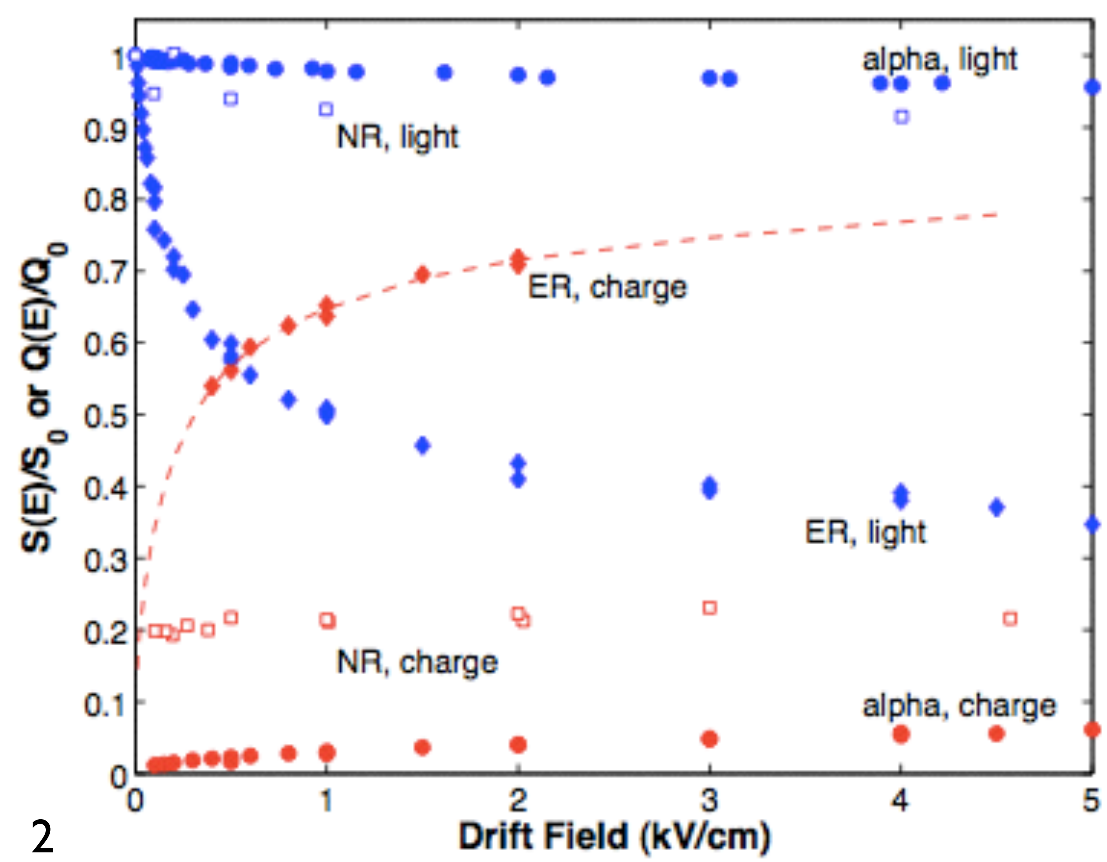
Why the Voltage/E-field is specially important for a TPC

Typical field amplitude from 0.1 to 1 kV/cm



- First purpose
  - drift the particles and allowing for a 3D reconstruction.

- Second purpose
  - Enhancing the charge yield. This can be equally important in the double-phase TPC, for the Dark Matter search, and in the TPC for neutrino physics.



In many parts of a TPC withstanding very High Voltage can be a challenge

1. Feed-Through
2. Field shapers
3. Cathode
4. Electrical components in case you need voltage dividers
5. Surface conduction below the cathode
6. Bubbles in the high-gradient field region.

There is a solution for all of these

XENON experiment

A Project lasting for almost 10 years

Two Double phase LXe TPCs have been built.
In those detectors the liquid and the gas phase are exploited.
The former as active target the latter as amplification medium.

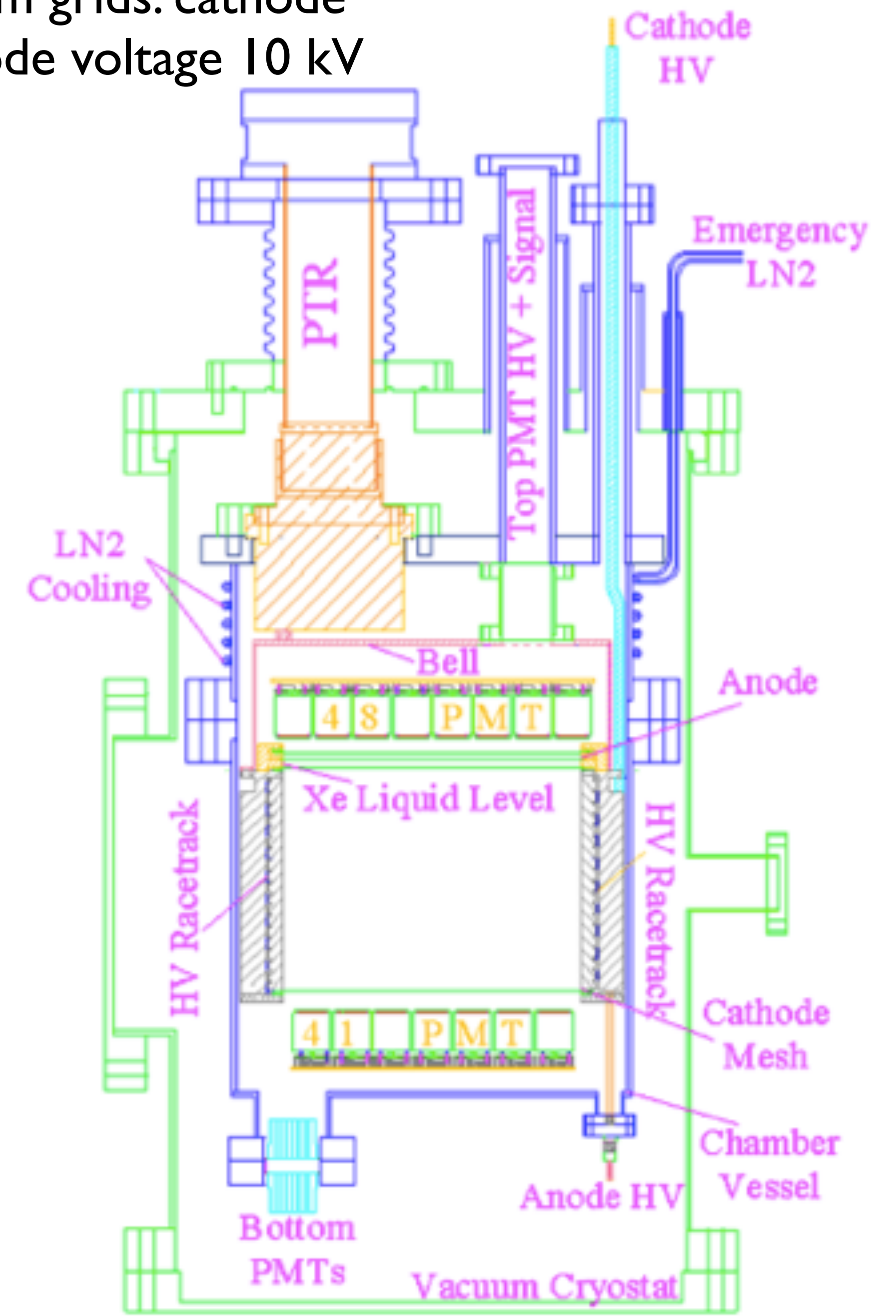
- XENON10: 10.5 kV (The past)
- XENON100 15 kV (The present)
- XENON1T 100 kV (The future)

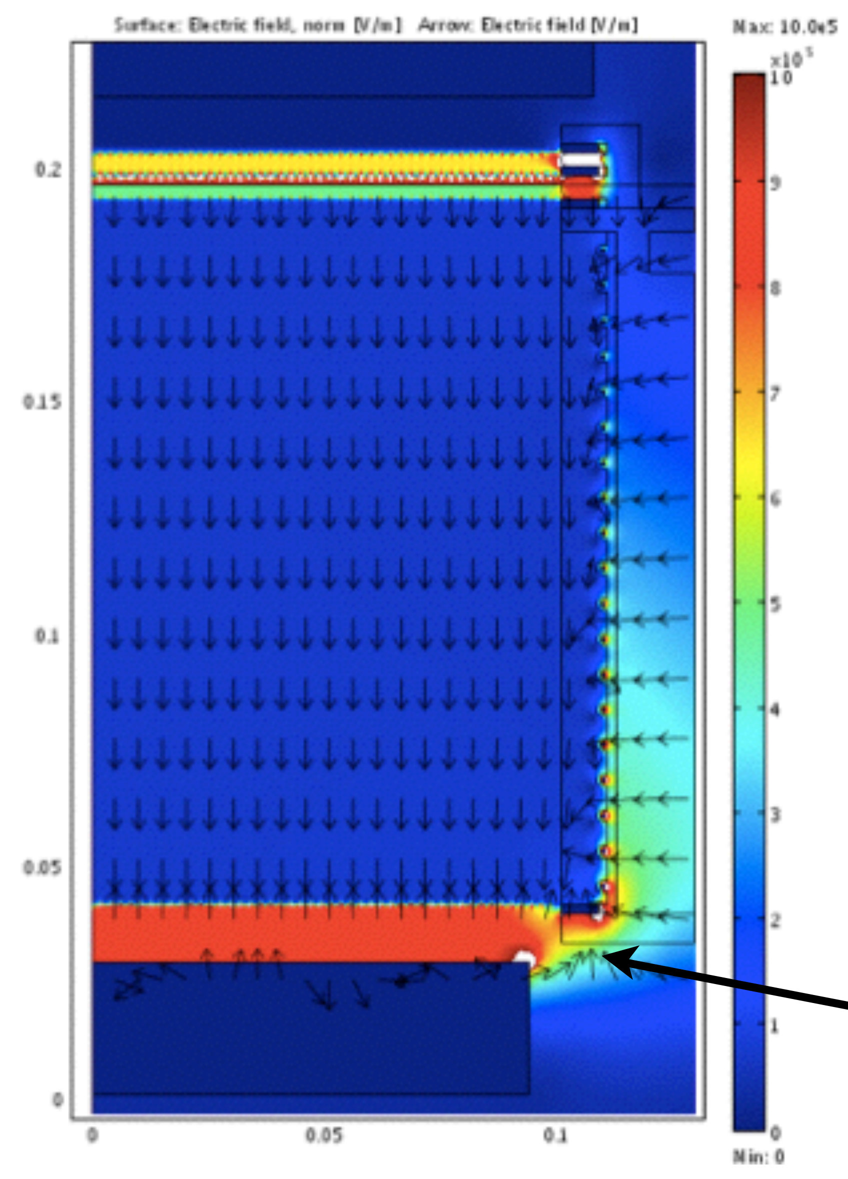
★ DEMONSTRATOR R&D facility

XENON10 detector

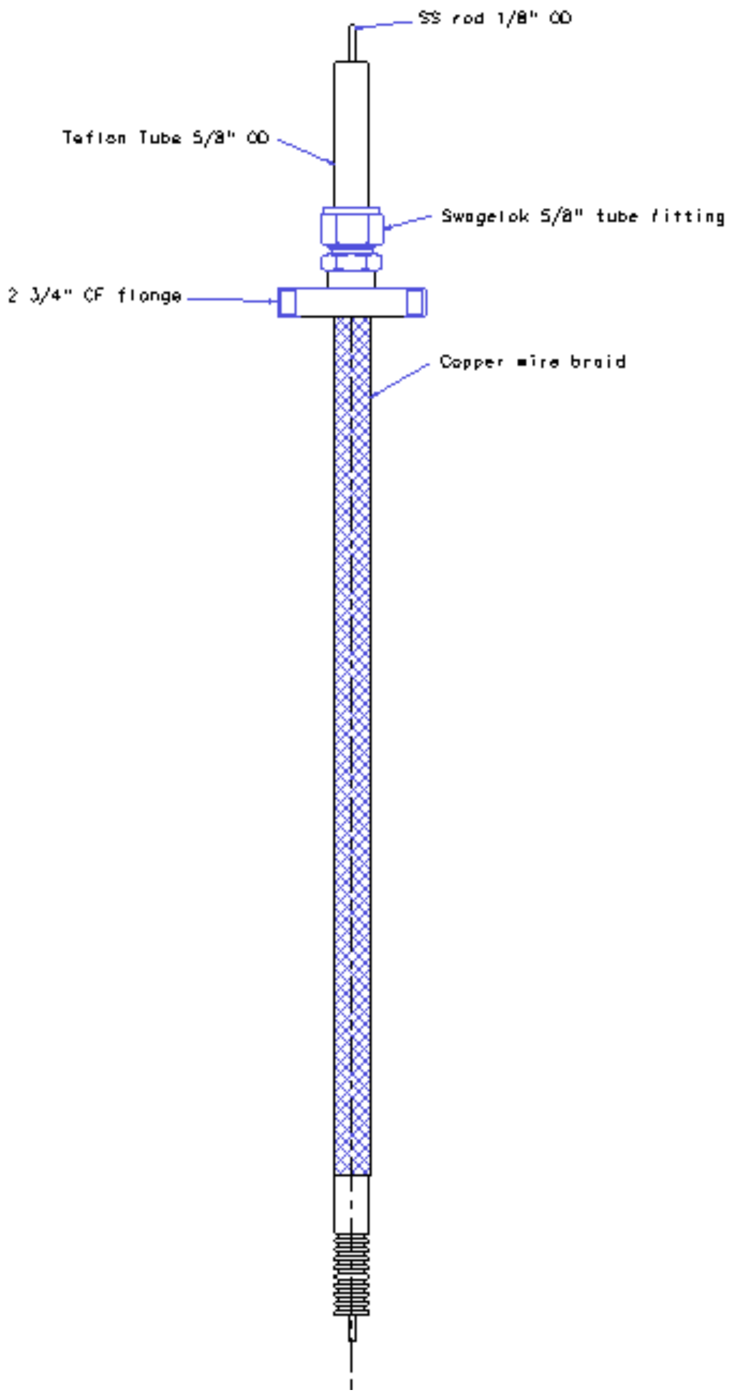
In this schematic drawing we can see the first example of HV feed-through developed at Columbia University

- 15 cm drift length
- 1.5 mm OD field-shaping wires
- Two PMTs arrays (top and bottom)
- Top grids: gate, anode, screening
- Bottom grids: cathode
- Cathode voltage 10 kV





A simple and effective idea to make a Feed-Through for LXe



Challenging items:

-Transition from gas to liquid can bring to surface polarization with consequent light emission and sparks.

-Boundary conditions on the contact surface between the two medium

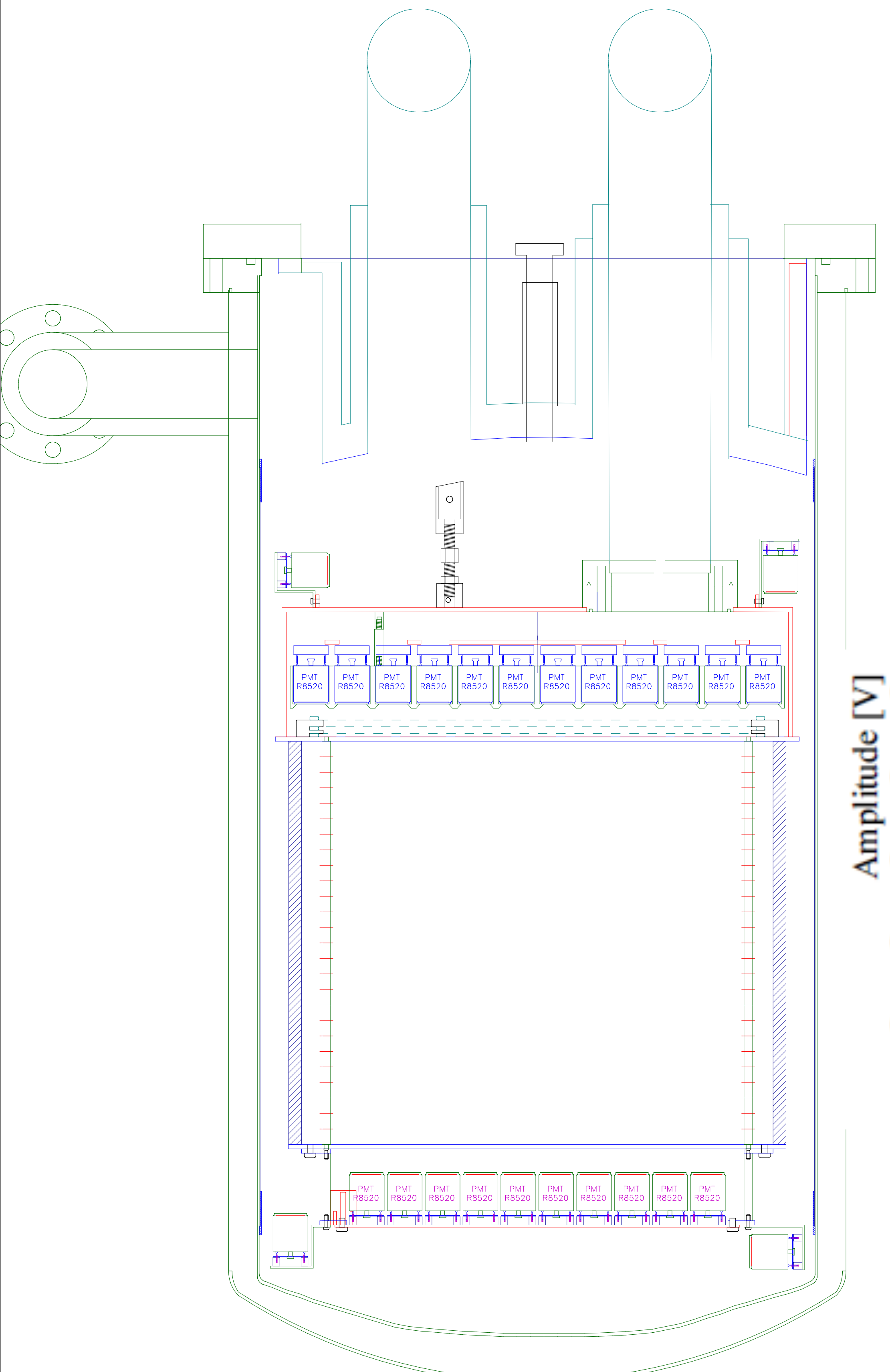
$$D_{1N} - D_{2N} = \rho_S$$

$$\varepsilon_1 E_{1N} - \varepsilon_2 E_{2N} = \rho_S$$

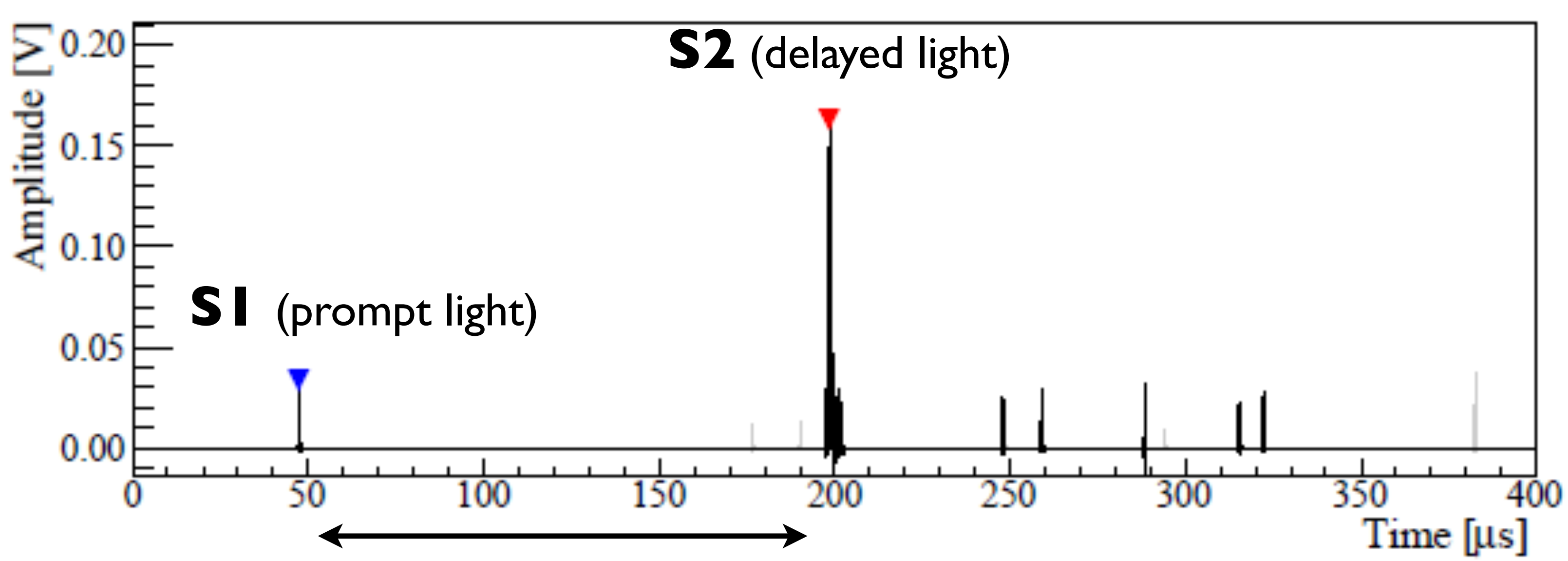
for Xe and Teflon $\varepsilon_1 = \varepsilon_2$

- Cylindrical capacitor
- Teflon as insulator
- Smooth grounding metal surface from gas to liquid
- leak tightness obtained via cryo-fit or standard sealing
- The edge of the dielectric must be corrugated and far form the ground
- The core made out of a nice and smooth rod

XENON100 Detector



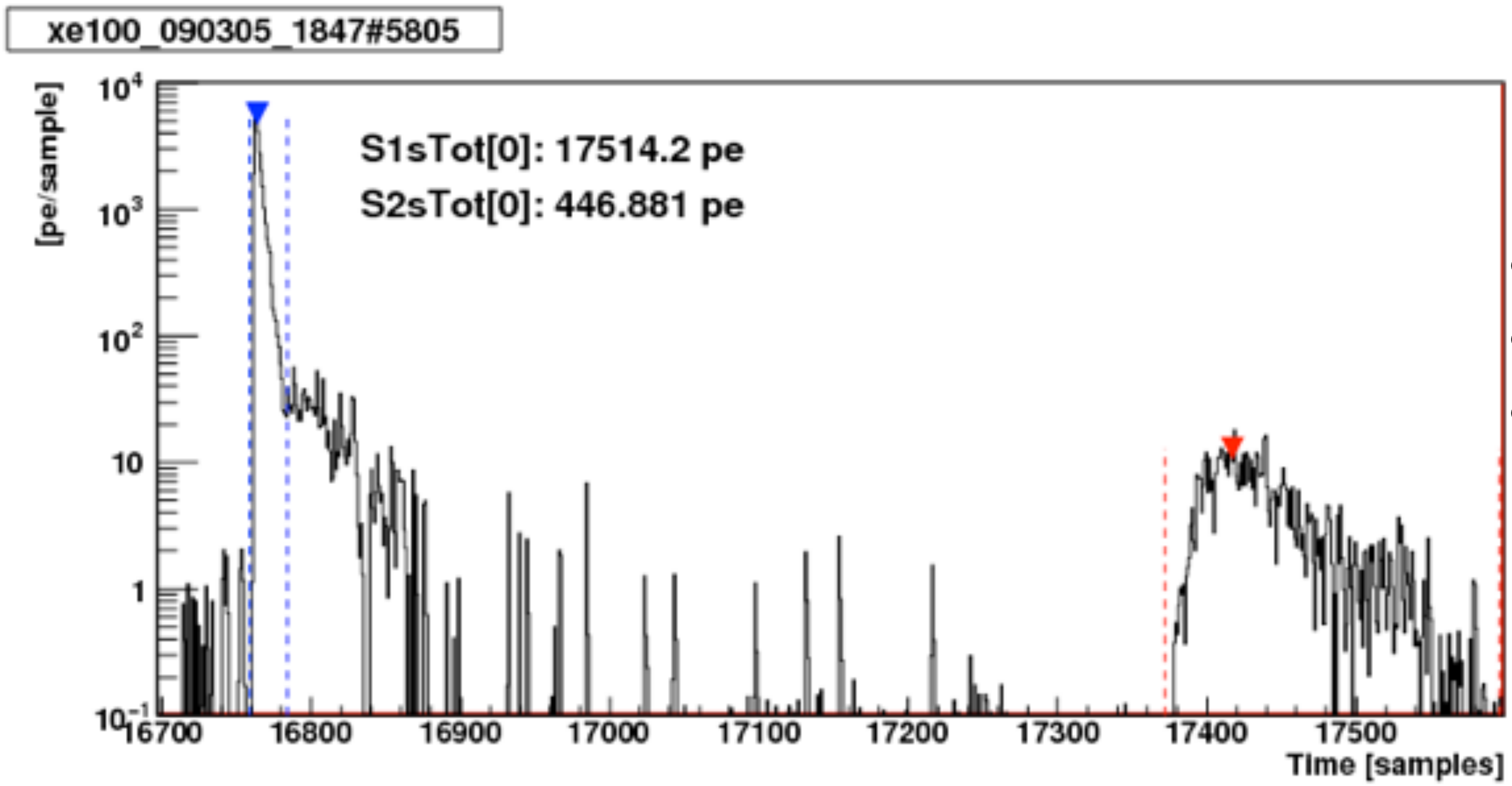
- 30 cm drift distance
- 1 mm OD field-shaping wires
- Two PMTs arrays (top and bottom)
- Top grids: gate, anode, screening
- Bottom grids: cathodes and screening
    - Cathode wire 70 μm
    - screening grid wires 50 μm
- Cathode voltage 15 kV



drift time=150 μs, v=1.74 cm/μs @ 0.5 kV/cm, 26 cm

So called "hair" events in XENON100

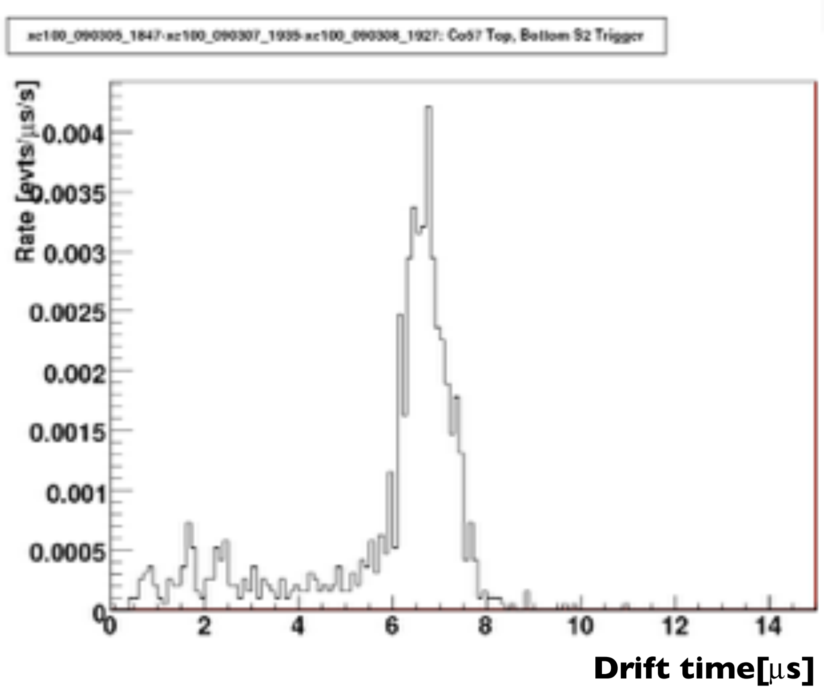
They start above 15 kV

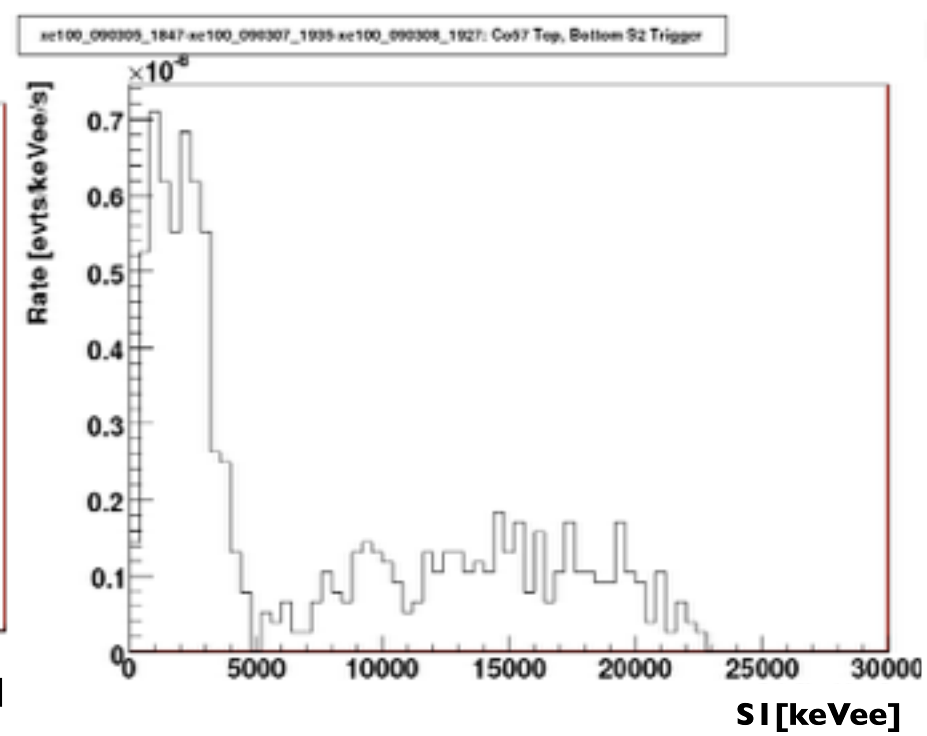


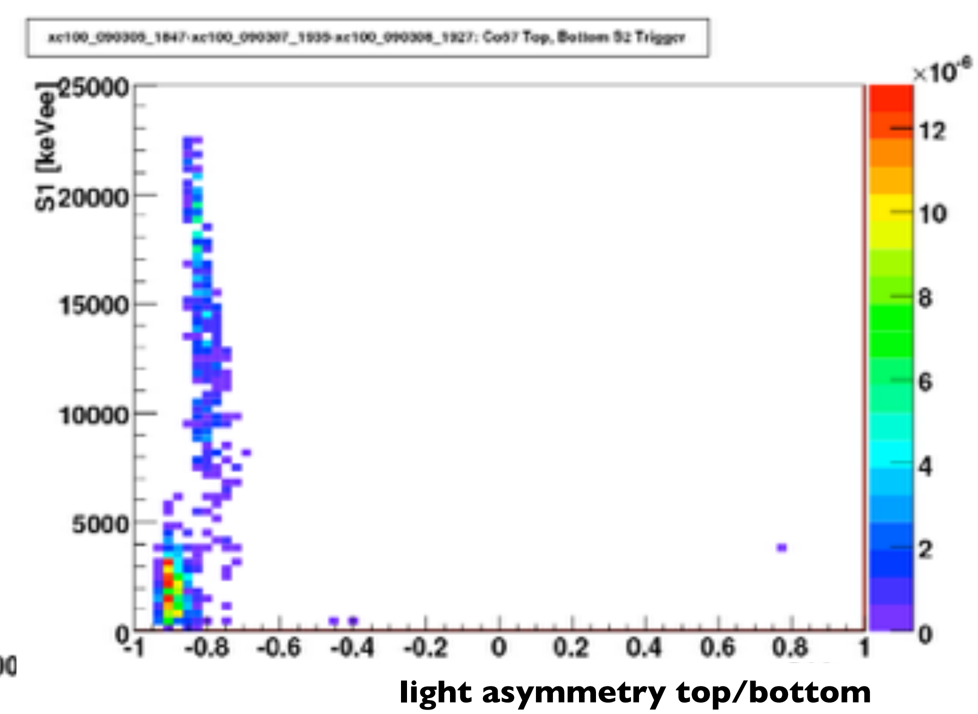
Preliminary

Features:

- High S1 and low S2
- peak in the drift time distribution
- peak at -1 in the asymmetry distribution



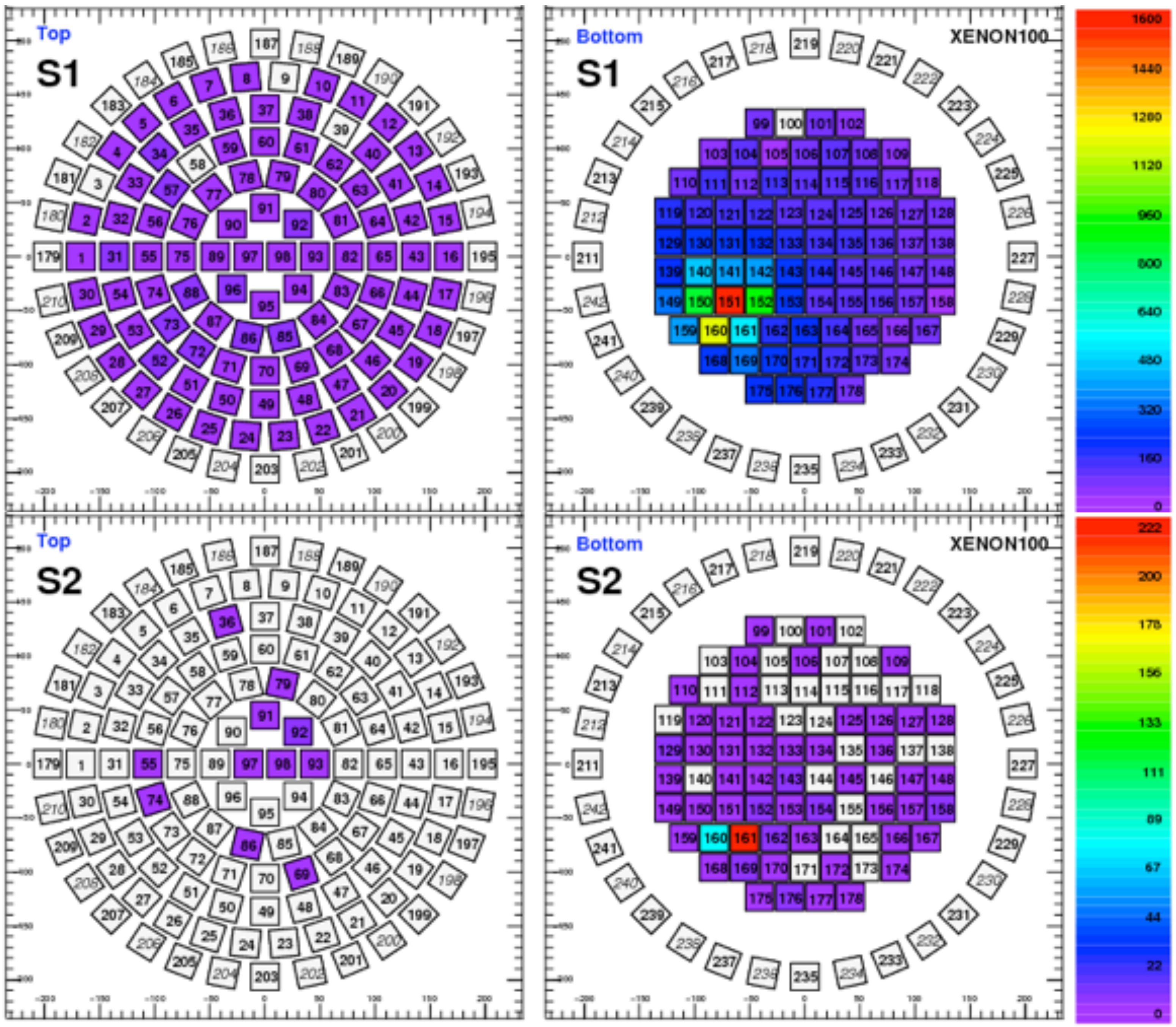




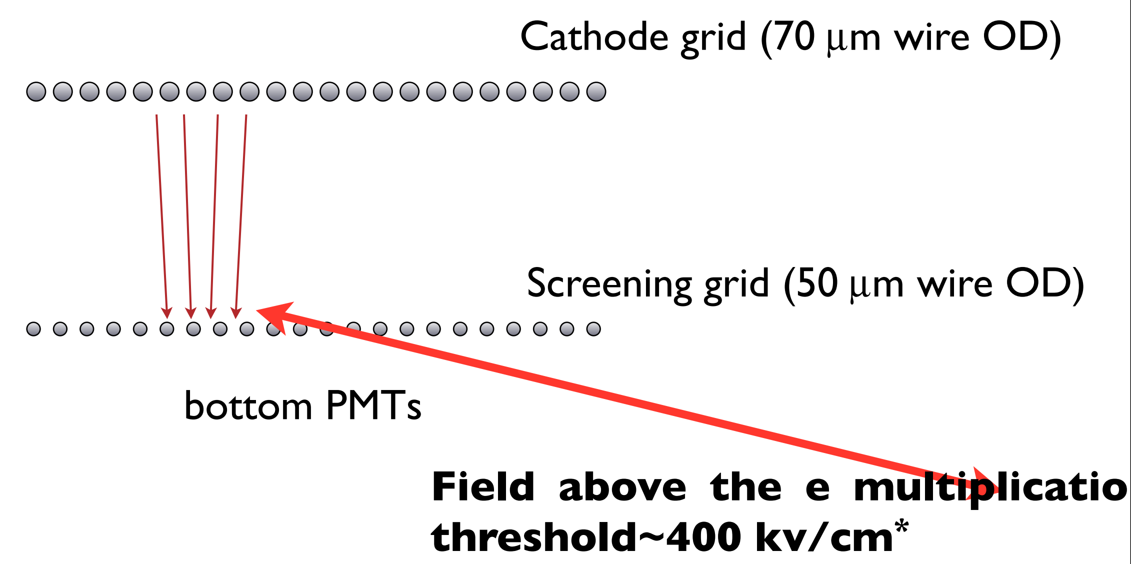
Interpretation of the hair events

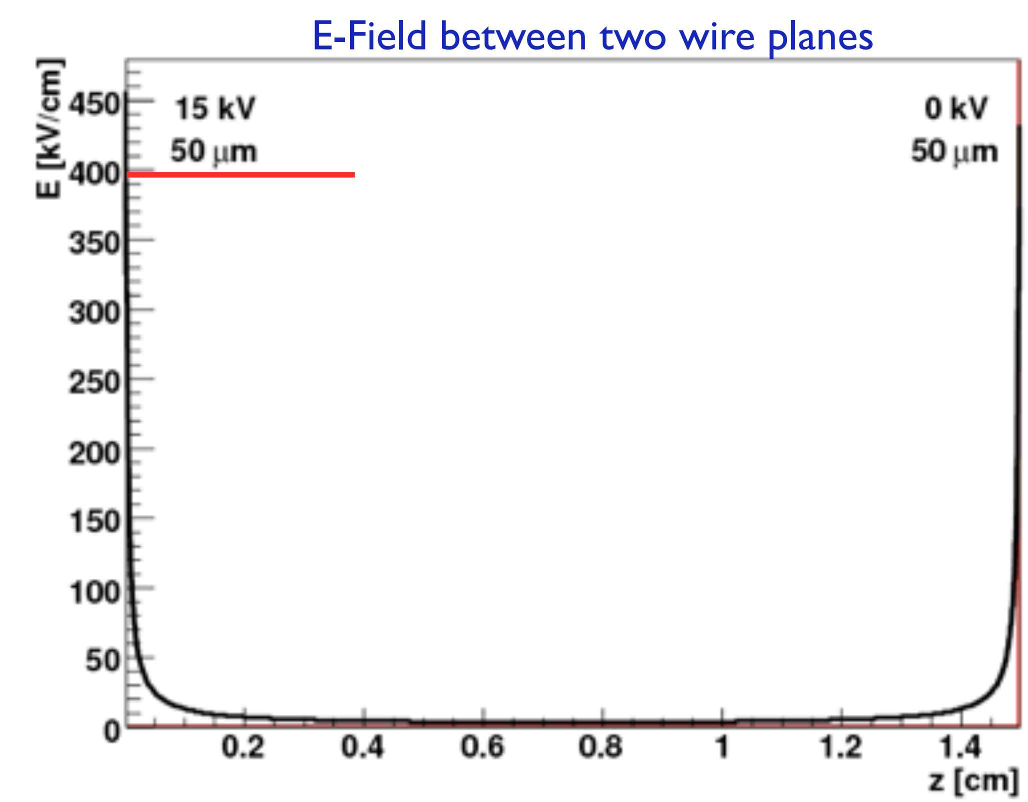
Started around the screening grid

Preliminary



Schema of the Cathode+Screening grid





* Masuda, NIM 160, 1979, p.249)

XENON100

the field shapers and the FT

The FT of XENON100 was rated for more than 30 kV

THE XENON R&D effort called DEMONSTRATOR

- At Columbia University the R&D effort started in 2010 aiming at answering the key questions about the design and construction of Xenon1T: **fast circulation, HV, and drift on long distances**
- The demonstrator consists of a Cryogenic facility where TPC detectors with several tens of kg of LXe can be operated. The capability to circulate at high flow rate (~100 SLPM) to purify the LXe is also provided.
- The systems allows to test the TPC with different drift lengths. Presently **1 m TPC** is taking data with **52** kg of LXe in it.

DEMONSTRATOR facility

Heat Exchanger

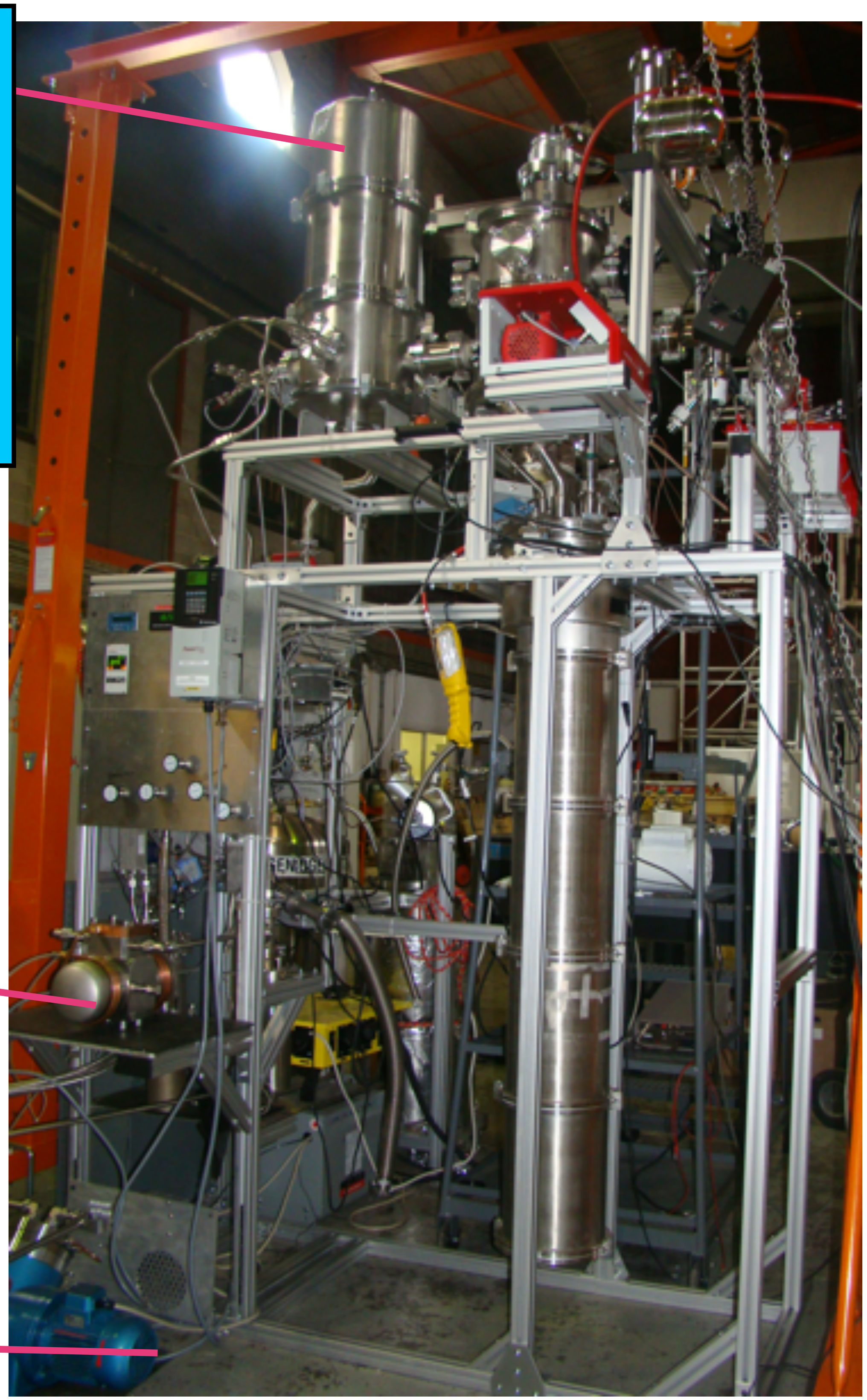
A System of two heat exchangers used to allow a fast liquid Xe circulation.

QDrive Full Metal Seal

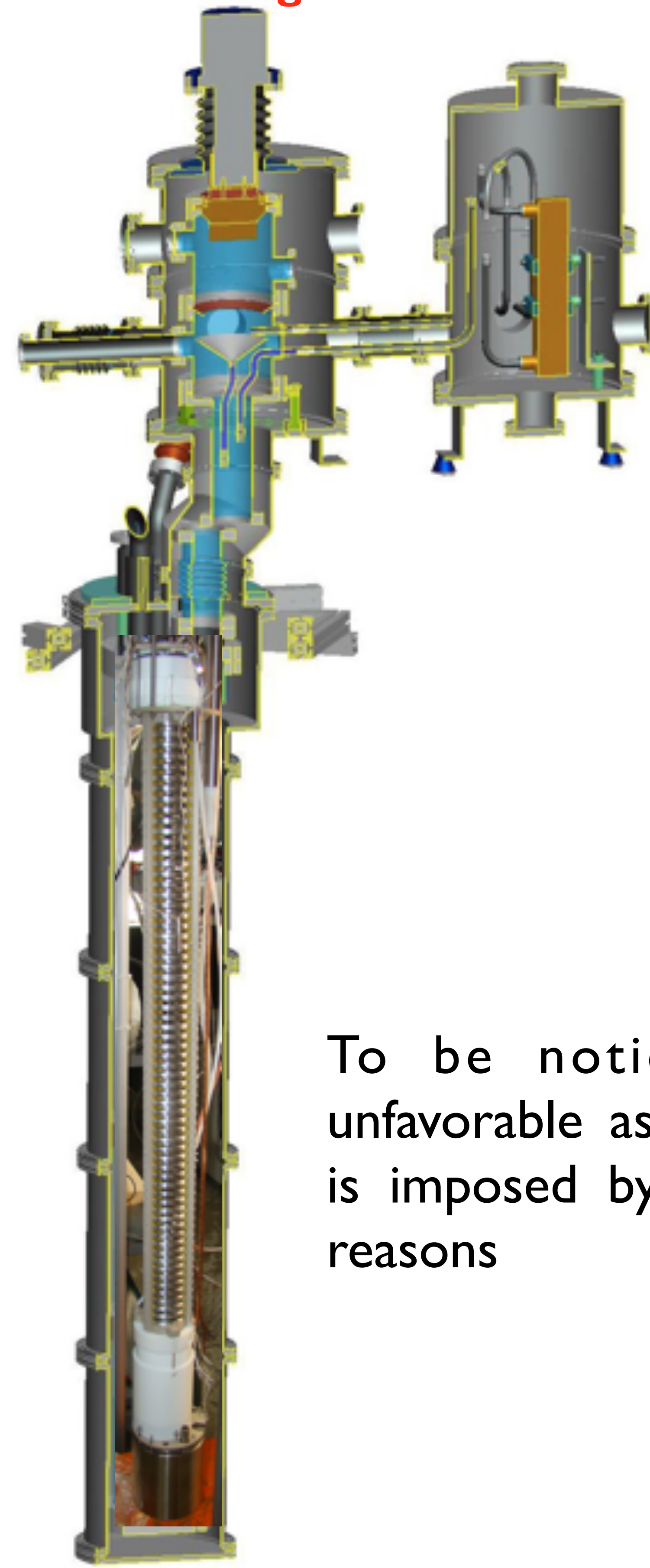
Gas circulation pumps

KNF Diafragm

Real facility



Design

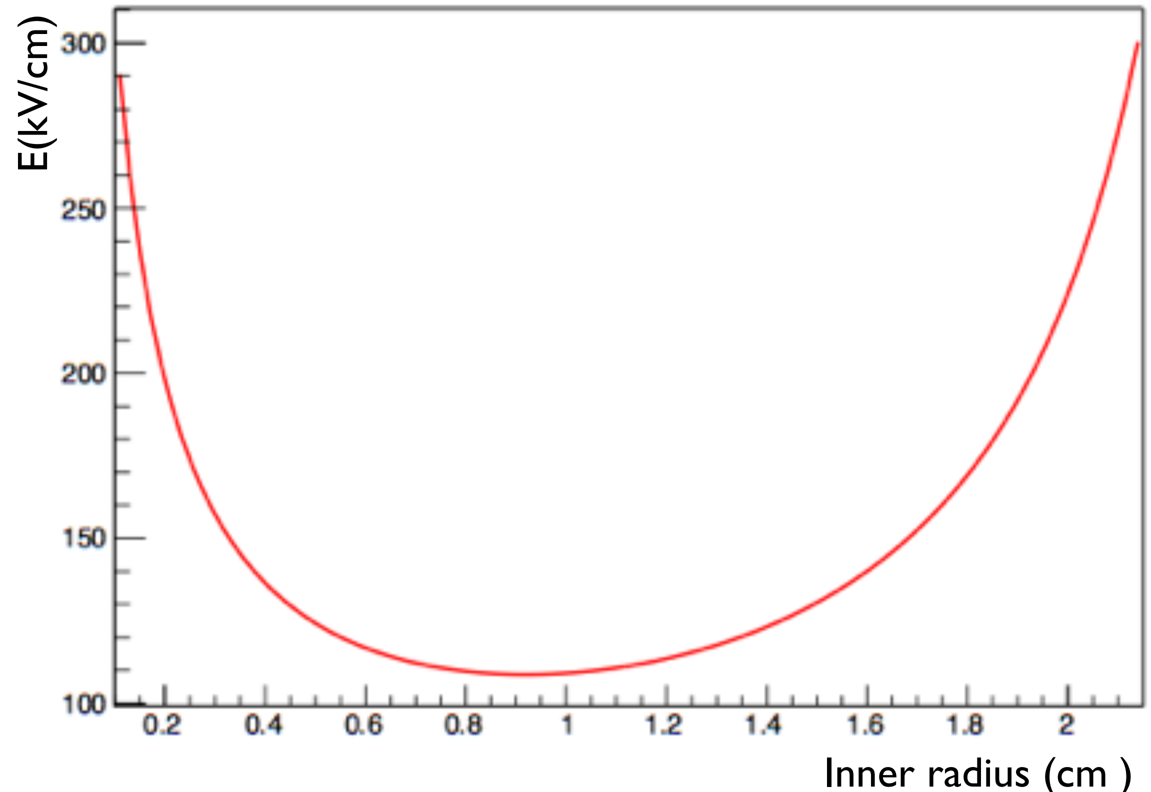


To be noticed: the unfavorable aspect-ratio is imposed by practical reasons

Why is important to build a custom made FT

One can select the components from very clean material as required by the physics goal (lowest number of background events)

E field in a cylindrical capacitor w.r.t. the inner radius when the outer tube is 1" and a dV=100 kV is applied to the core

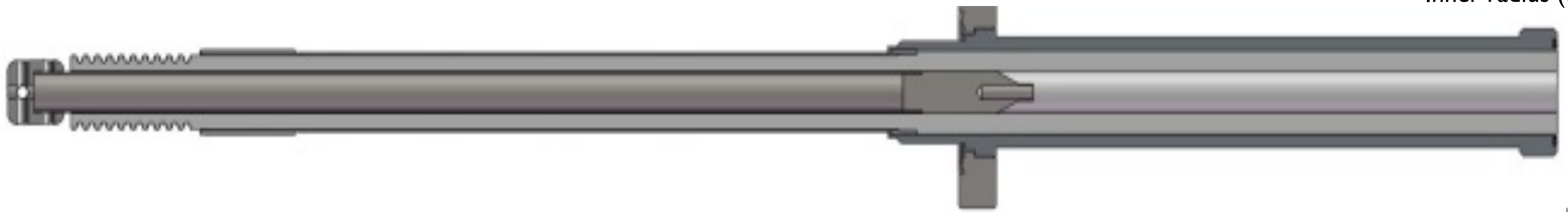


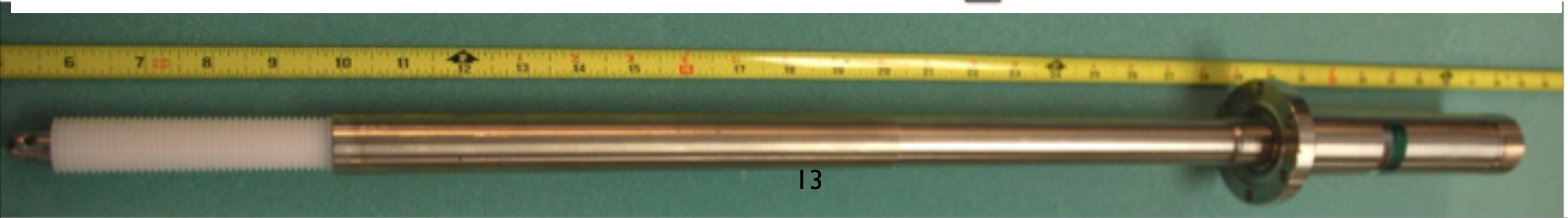
Dimensions:

•Overall length is ~30 ".CF40 flange to the tip of FT is ~21".

•SS grounding tube 1" OD, HV hollow rod 0.47 " (12 mm)

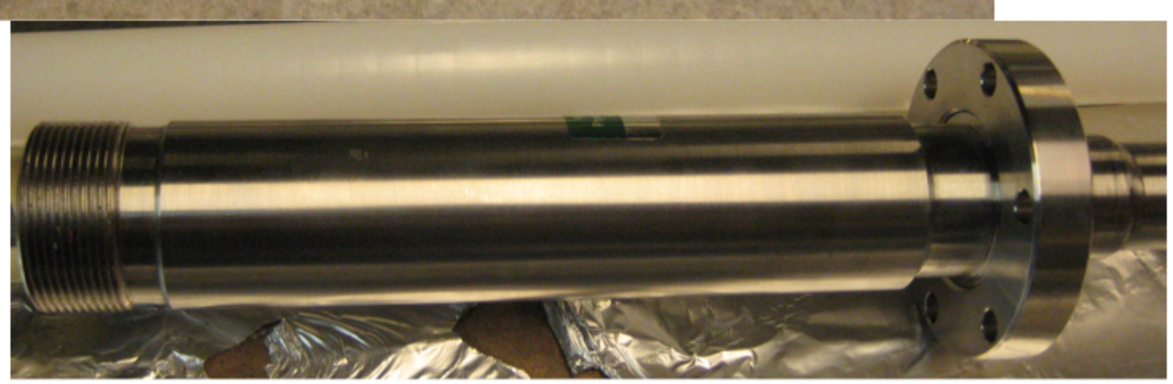
•All the parts are cryo-fit into each other





Details of the FT assembly

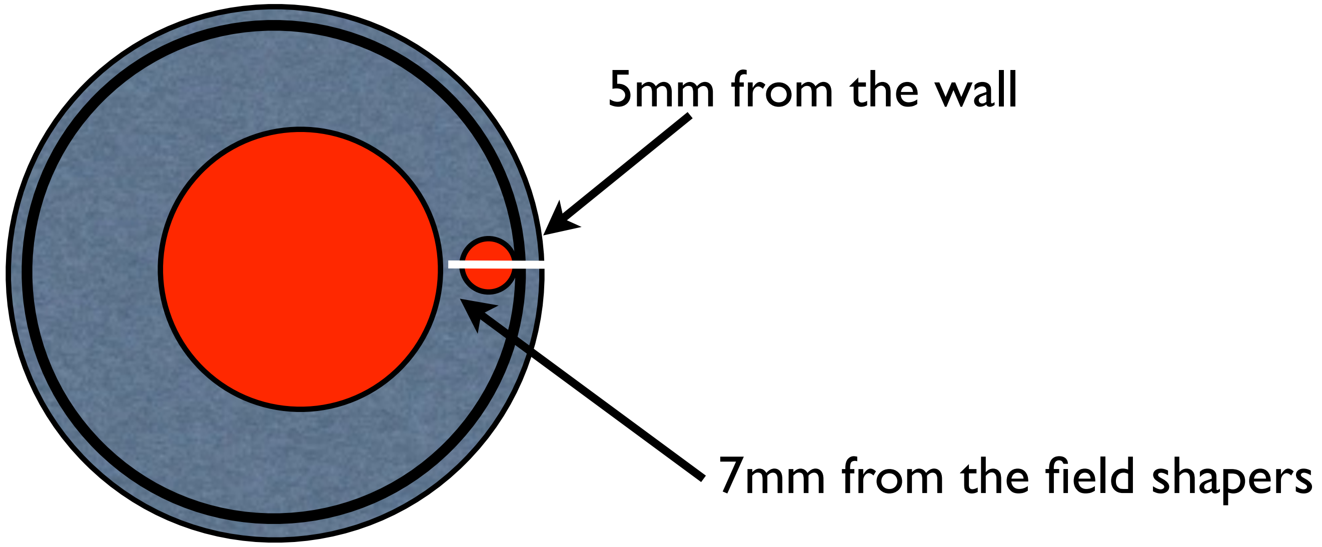
- Air side connector (Heizinger 100 kV). A mineral oil is used to fill the gap between the PE tube and the cable cladding
- Bottom of the PE is corrugated to disable direct charge path.
- Tip of the FT has a polished SS "ball" which is attached to the inner core via 2 set of SS screws.



FT installed in the instrumented volume of the demonstrator

First test: LXe in the demonstrator.

- Pressure in the gas phase at 1.49 bar HV stable up to ~40 kV
- Pressure in the gas phase at 1.73 bar HV stable up to 50 kV.
- Given the proximity to the wall a PTFE sheet (2 mm thickness) was installed to better insulate and to prevent discharges to ground. In this case a stable voltage of 96 kV was reached

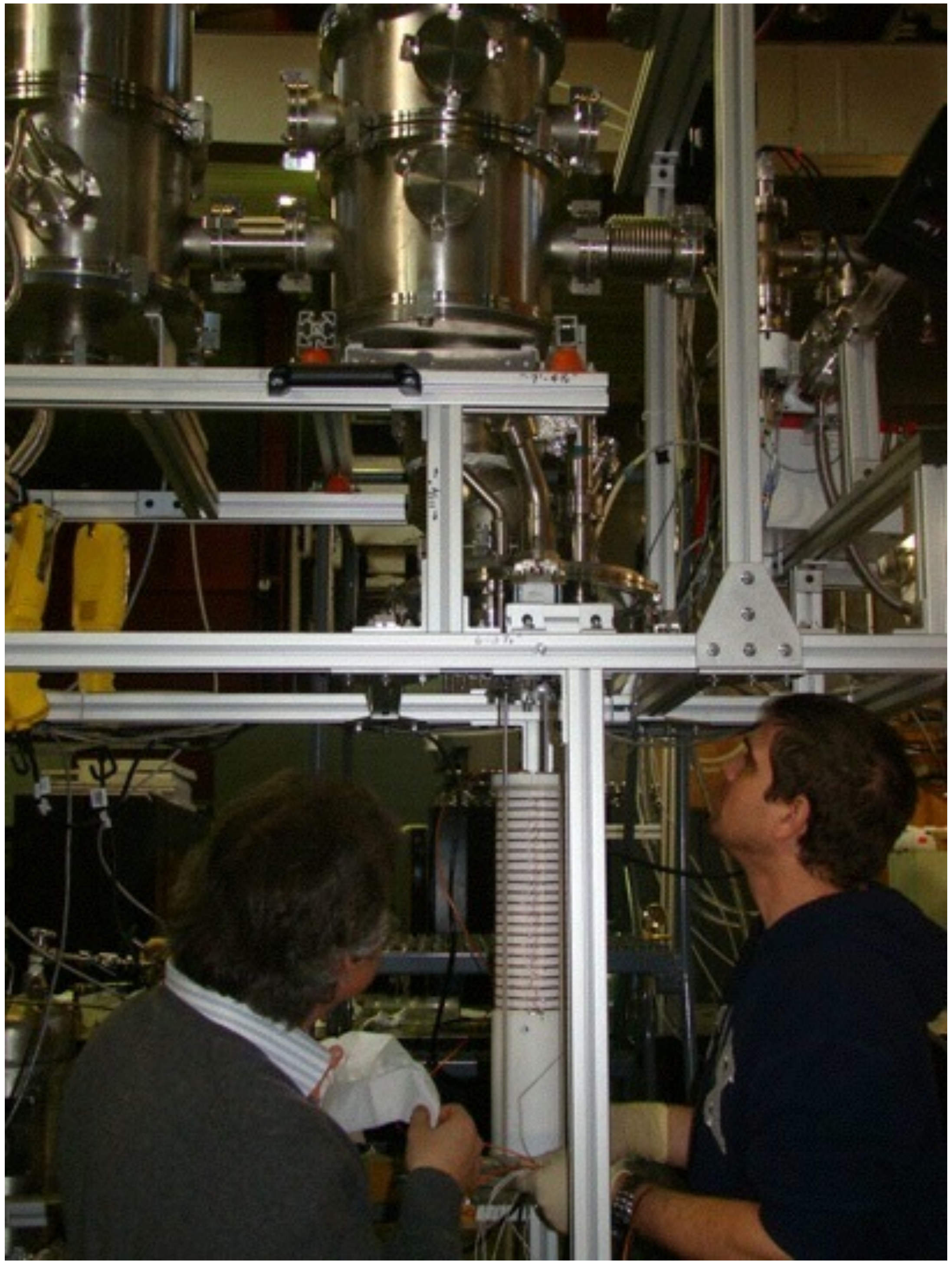


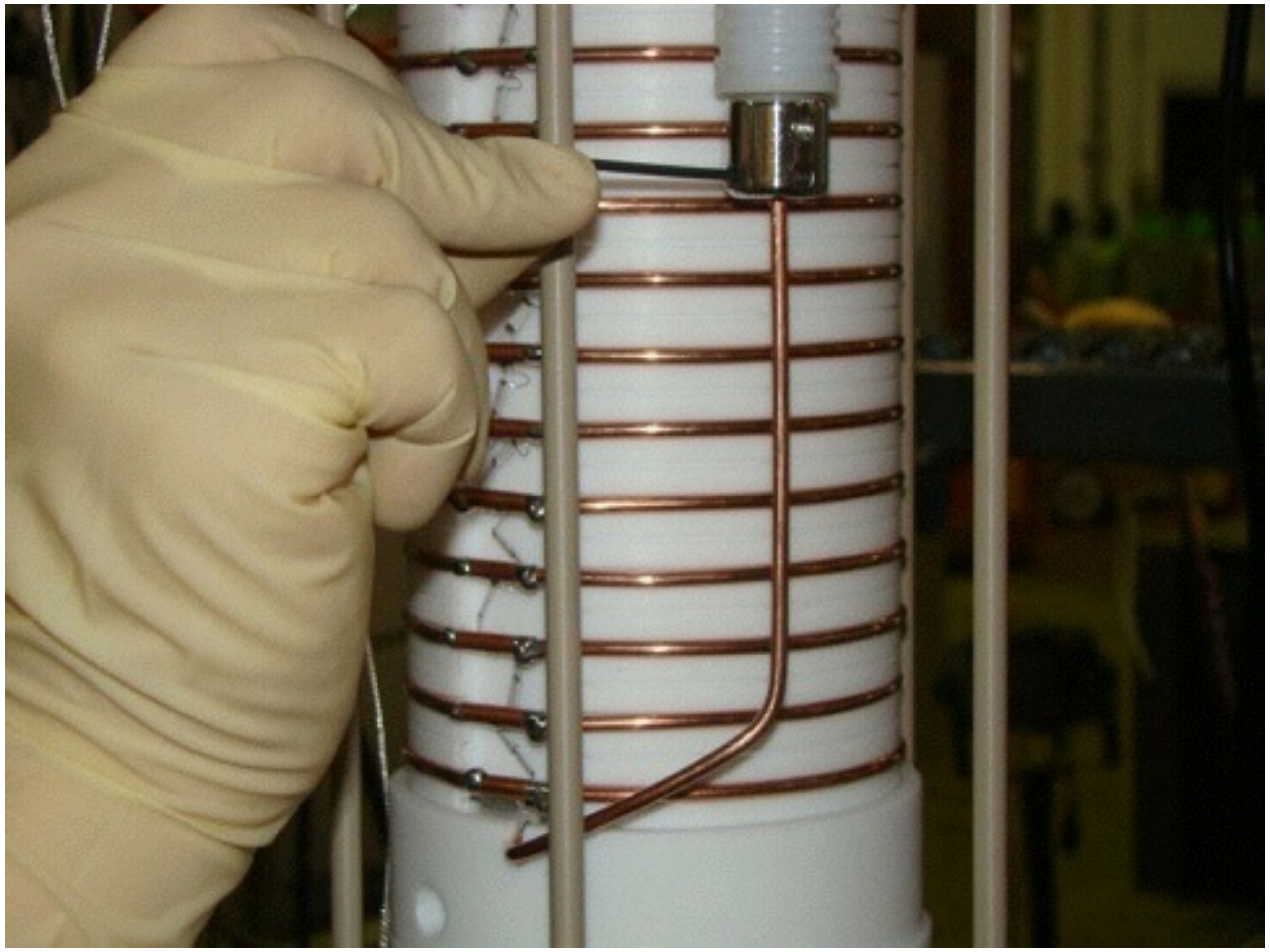
Critical items of the HV system of a TPC

1. Feed Through
2. Field shapers
3. Cathode
4. Electrical components in case you need voltage dividers
5. Surface conduction below the cathode
6. Bubbles in the high-gradient field region.

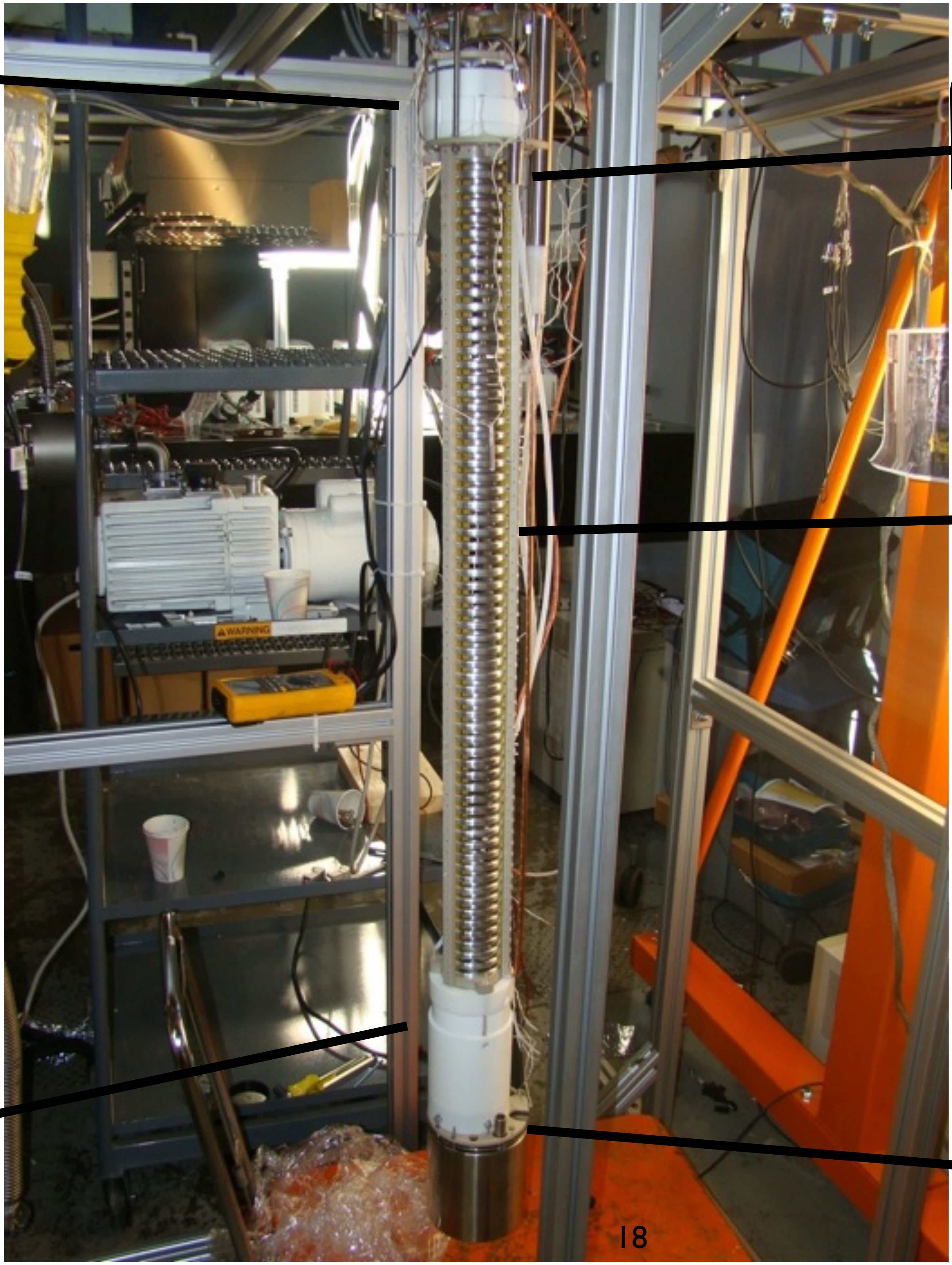
The first LXe TPC in the DEMONSTRATOR

The first step towards the demonstration of the 1 meter drift capability.
30 cm drift and 30 kV maximum voltage. The first LXE TPC with the highest voltage



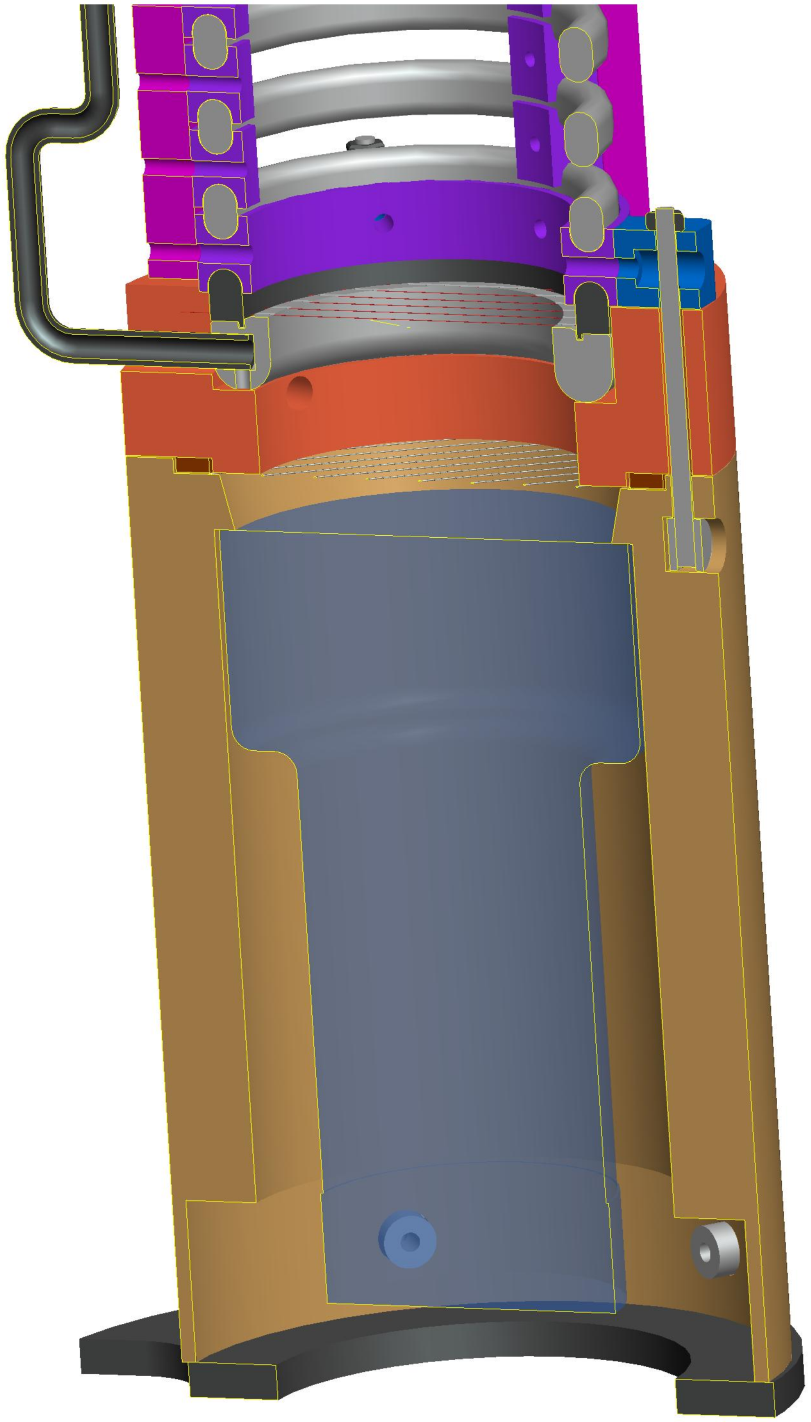


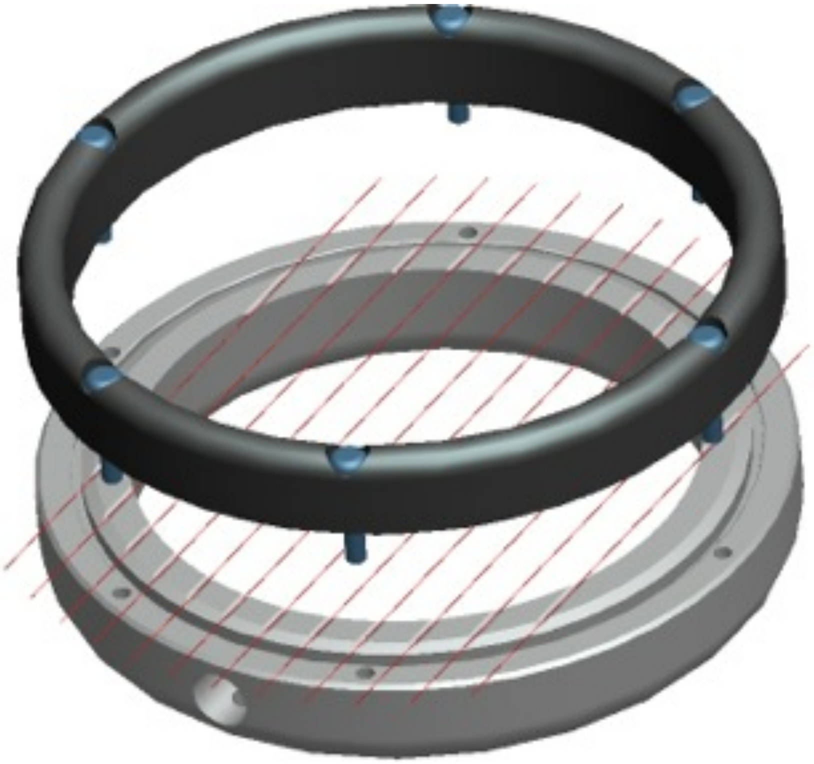
DEMONSTRATOR 1m TPC



DEMONSTRATOR 1m TPC components

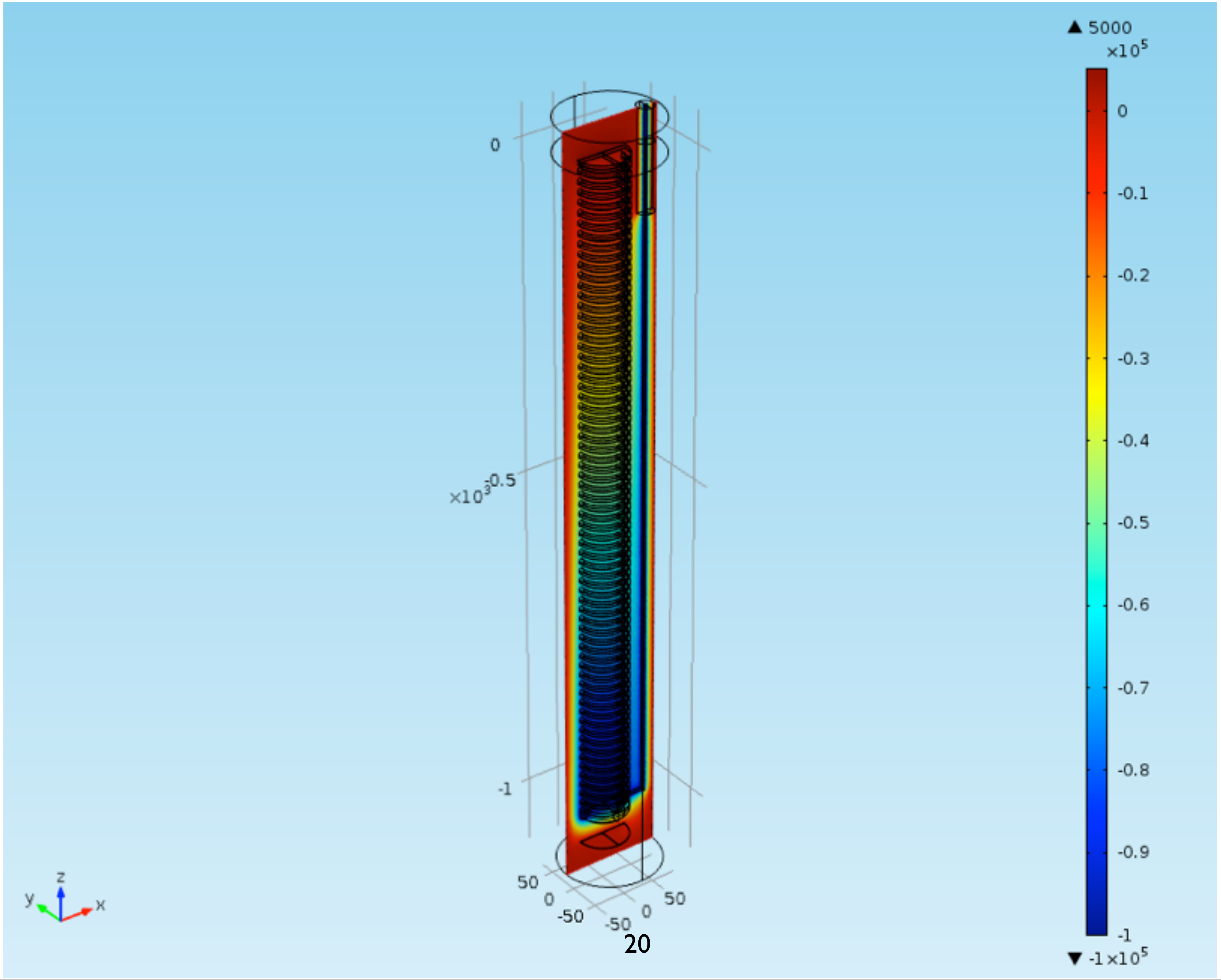
wire of 200 μm OD





E-Field simulation

A detailed filed simulation (3 D) confirms that the field never exceeds 100 kV/cm.
This must be compared to the 400 kV/cm where e multiplicartion is expected.

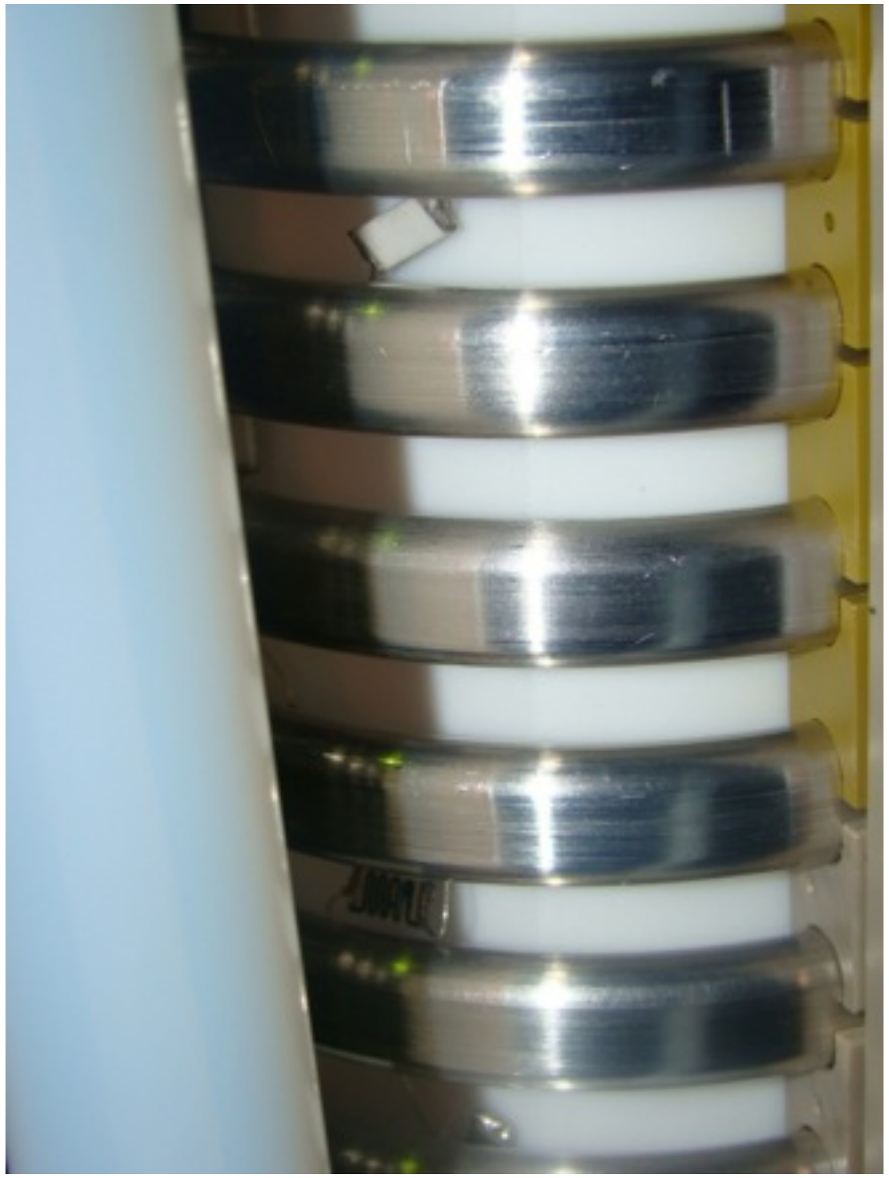


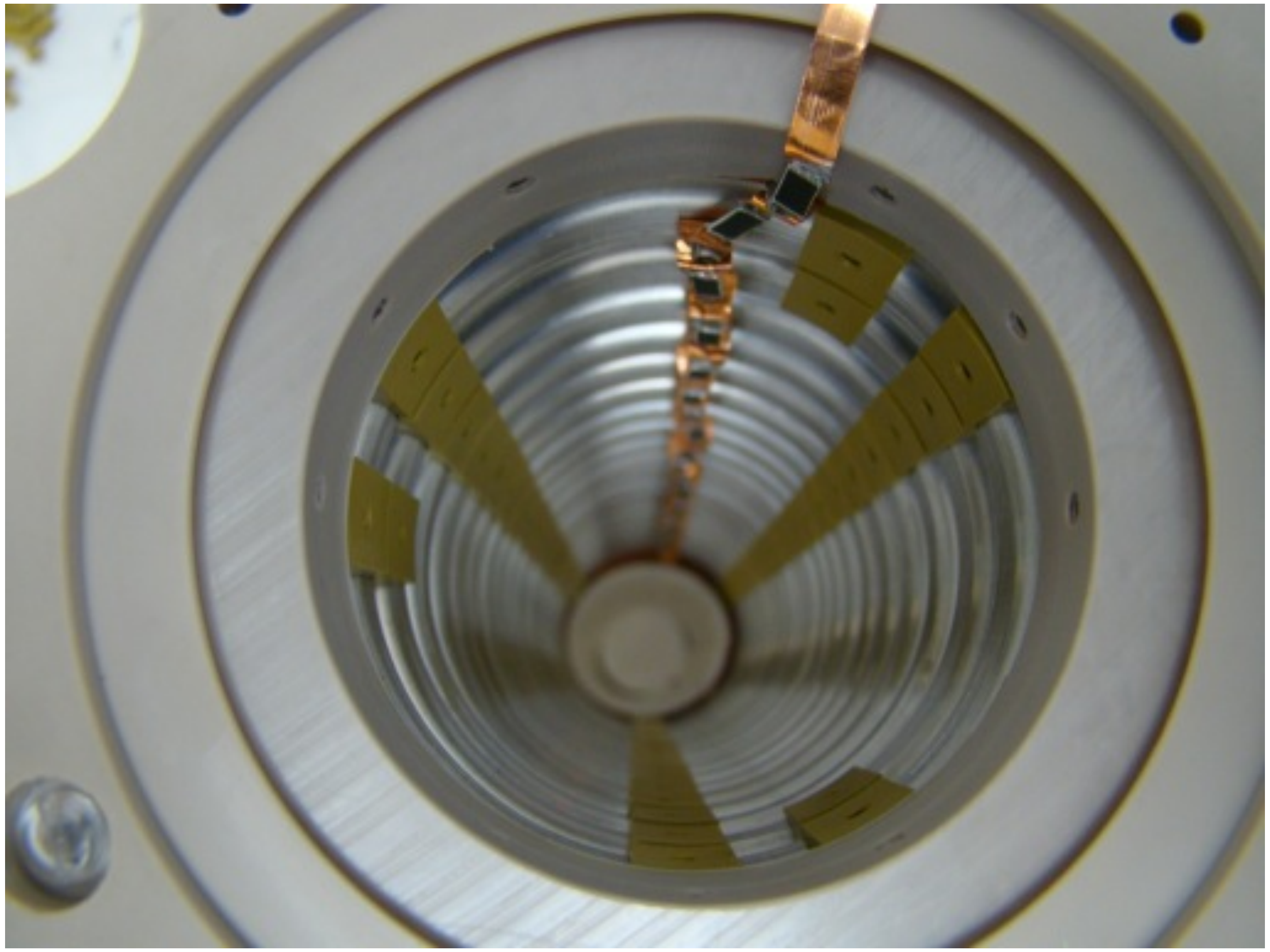
Critical items of the HV system of a TPC

1. Feed Through
2. Field shapers
3. Cathode
4. Electrical components in case you need voltage dividers
5. Surface conduction below the cathode
6. Bubbles in the high-gradient field region

The resistive chain

The installation of the resistors in the field region, where i.e. E < 1 kV/cm, prevent the field amplitude from getting very high on tiny components, welds and anywhere else we can not control. In this case the possibility to have discharges is reduced significantly.

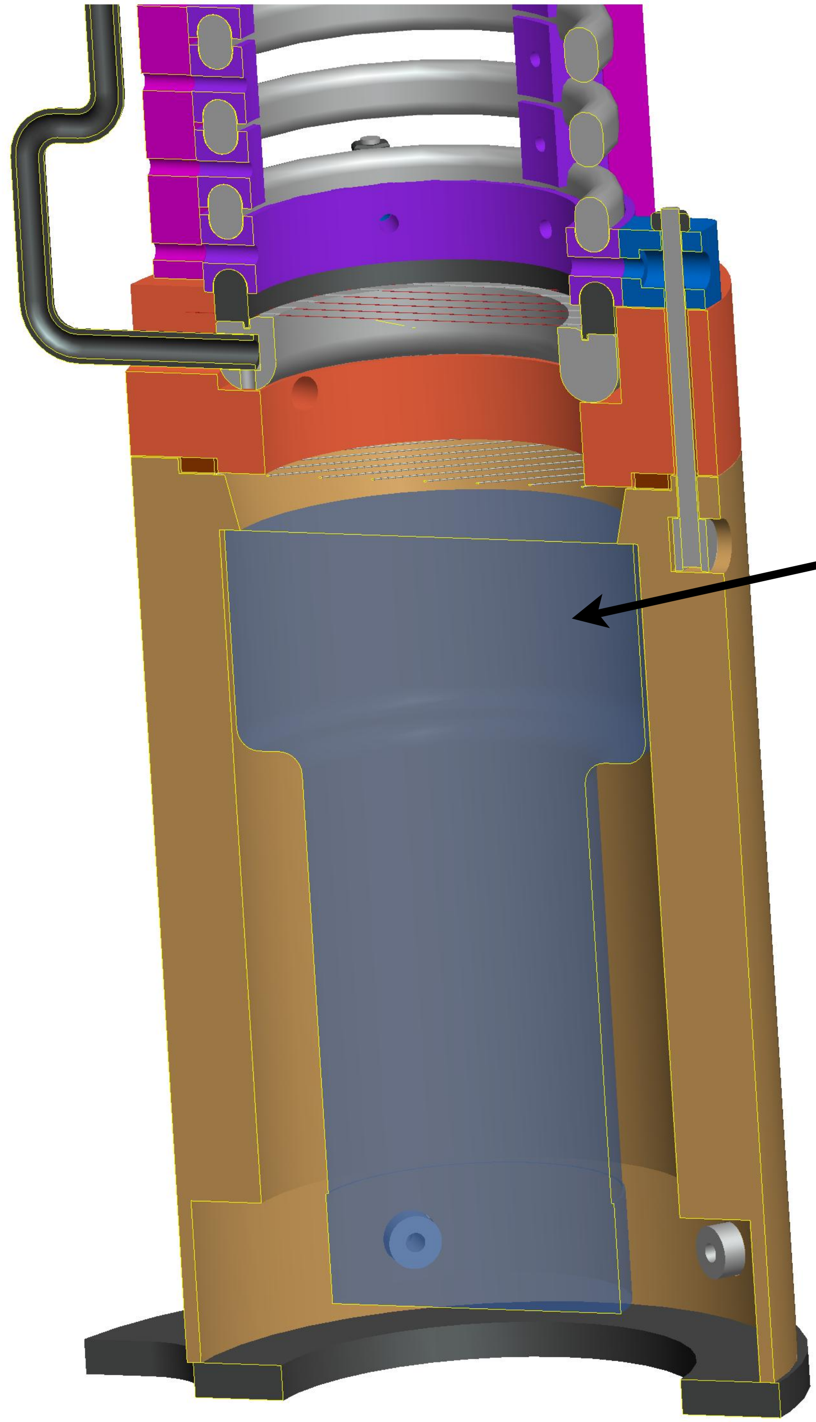




Critical items of the HV system of a TPC

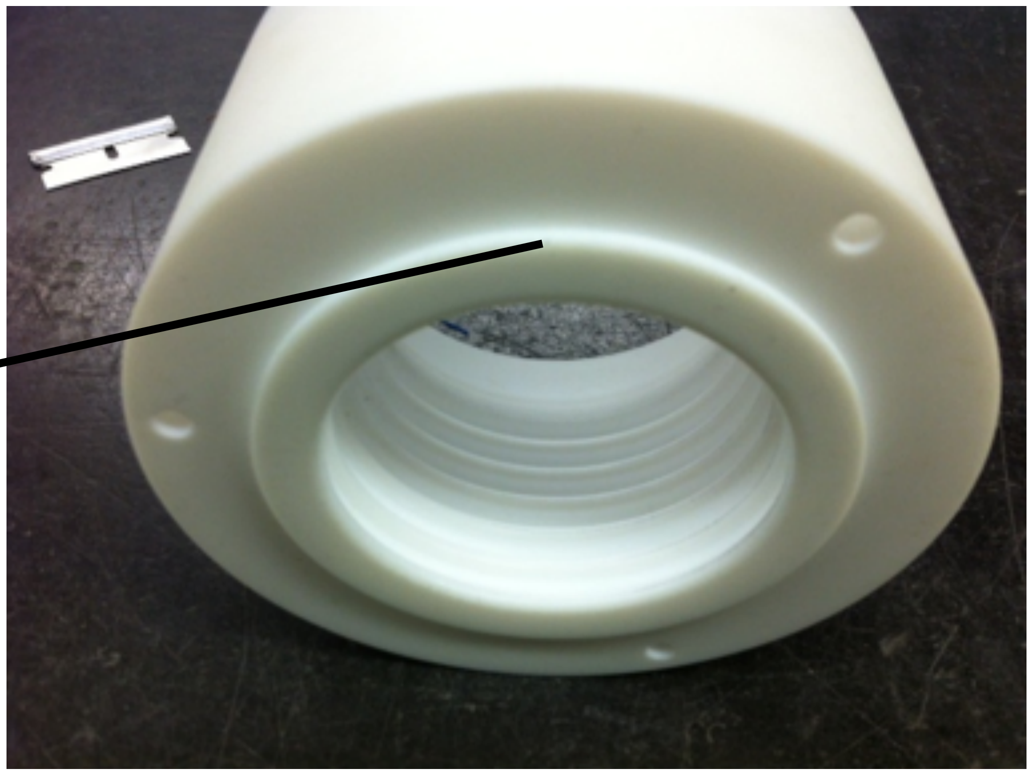
1. FT
2. Field shapers
3. Cathode
4. Electrical components in case you need voltage dividers
5. Surface conduction below the cathode
6. Bubbles in the high-gradient field region.

Spacer between the cathode and the screening grid



Clipping State:SEC1

5 cm spacers between the cathode and screening mesh



The strong field below the cathode can start surface conduction and generate light. This wavy surface reduce a lot the possibility to have such a phenomenon.

All the components in contact with high voltage electrodes should have such a feature. The wavy surface has the capability to trap ionization electrons, reducing the electric field.

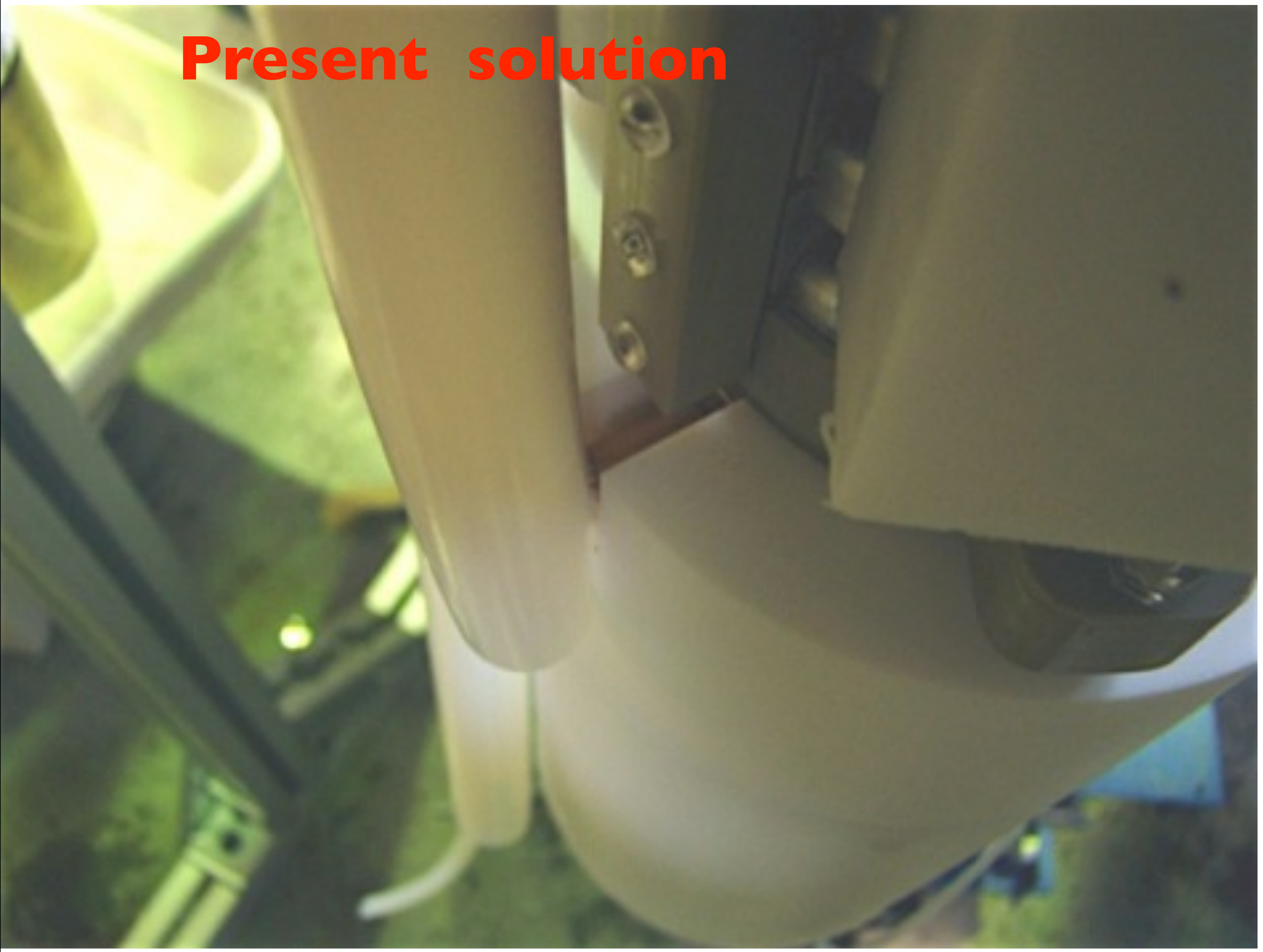
Critical items of the HV system of a TPC

1. Feed Through
2. Field shapers
3. Cathode
4. Electrical components in case you need voltage dividers
5. Surface conduction below the cathode
6. Bubbles in the high-gradient field region.

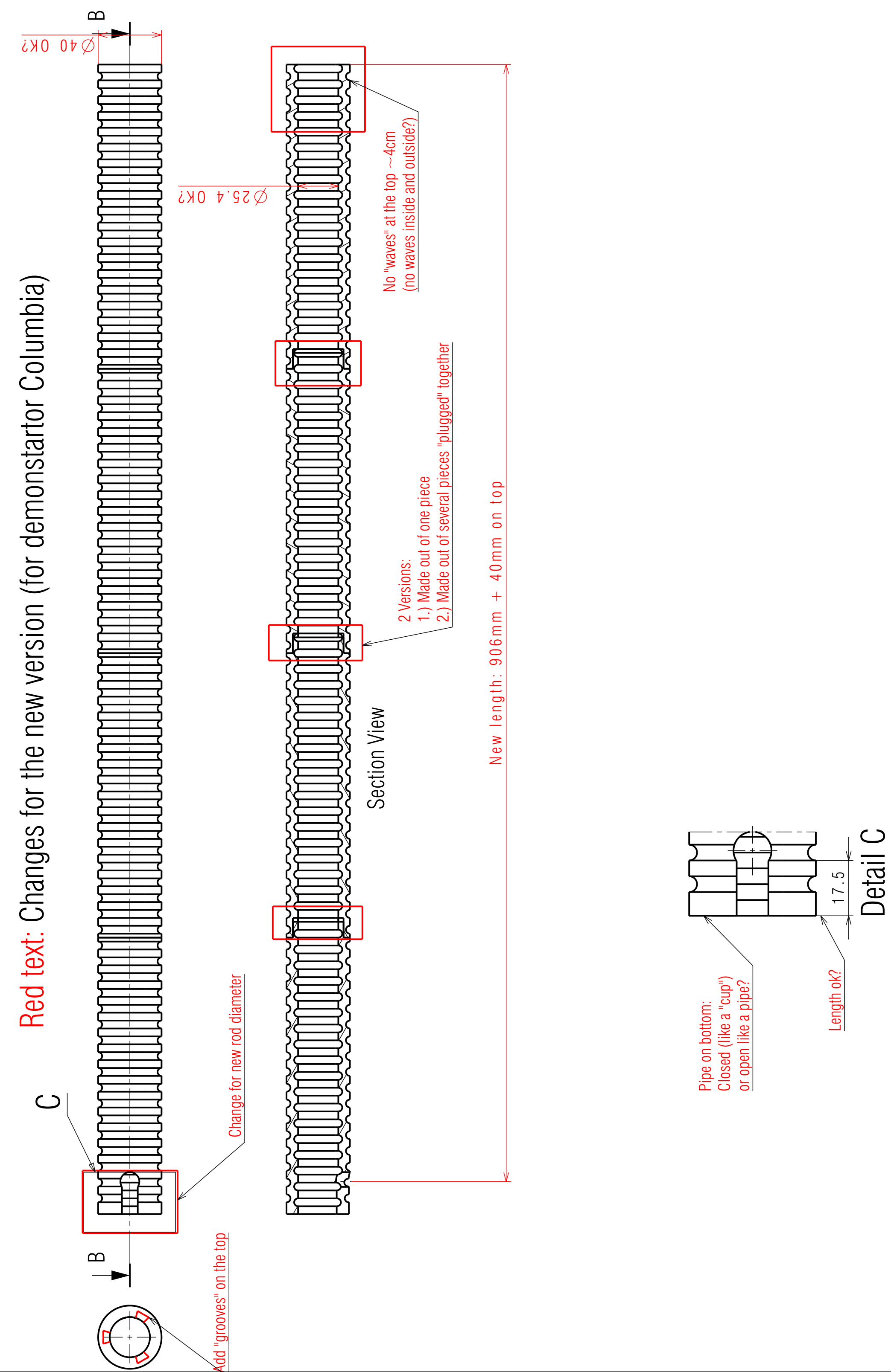
“Cup” around the HV contact for bubbles deflection

The bubbles tends to be attracted into the region of high-gradient field because of the high electric polarizability. The cup prevent this phenomenon.

Present solution



Current design

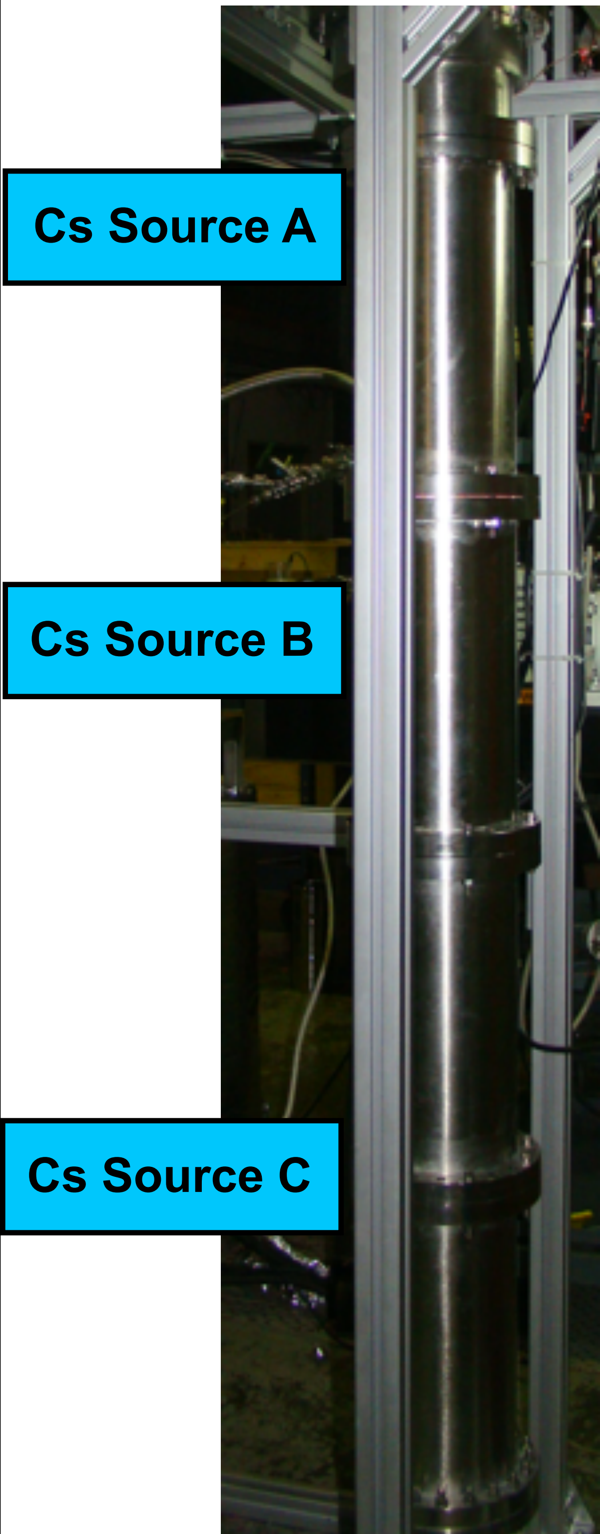


Critical items of the HV system of a TPC

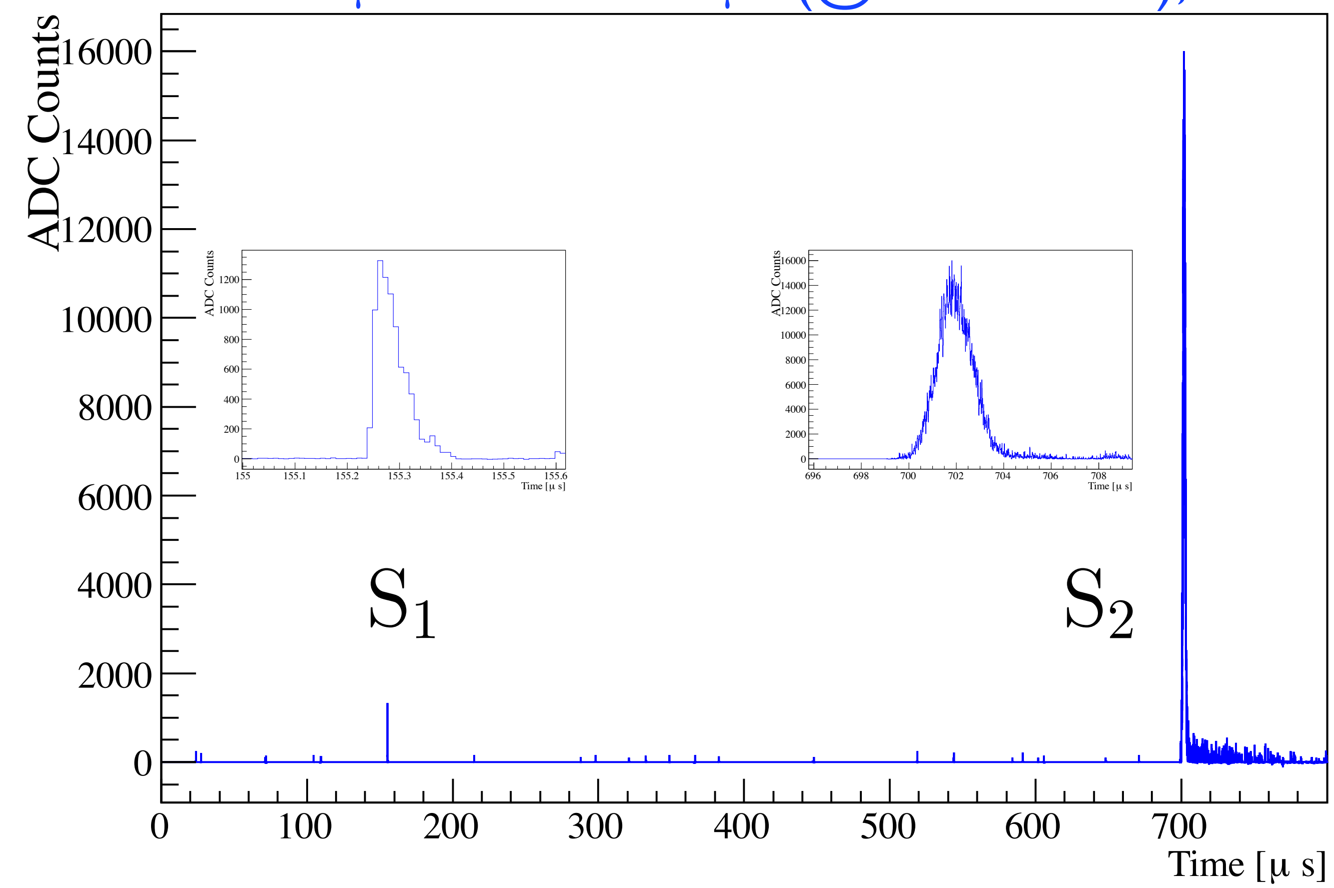
1. Feed Through
2. Field shapers
3. Cathode
4. Electrical components in case you need voltage dividers
5. Surface conduction below the cathode
6. Bubbles in the high-gradient field region.

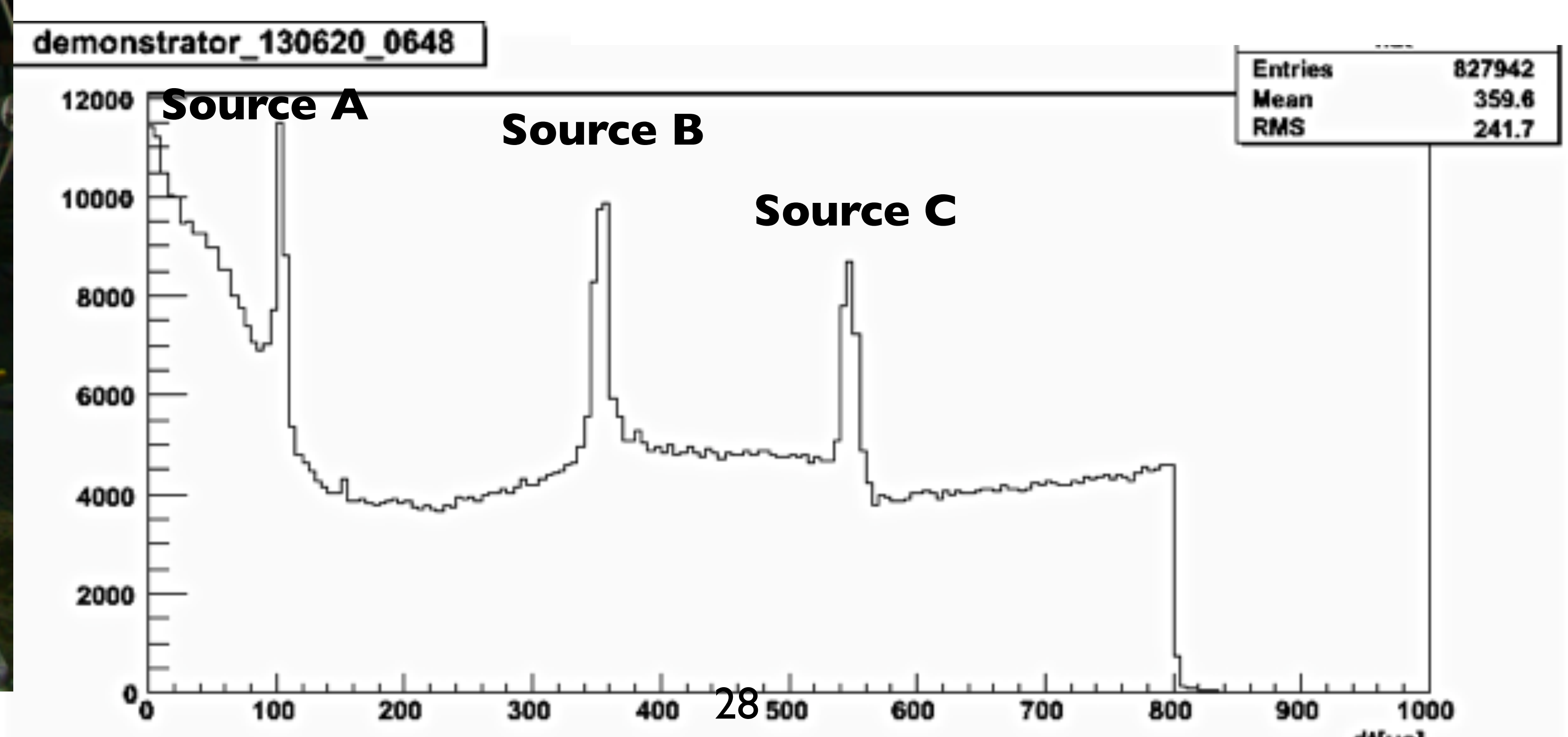
Demonstrator data

taken at 0.61 kV/cm (60 kV on the cathode). The largest voltage applied so far on a TPC cathode in LXe

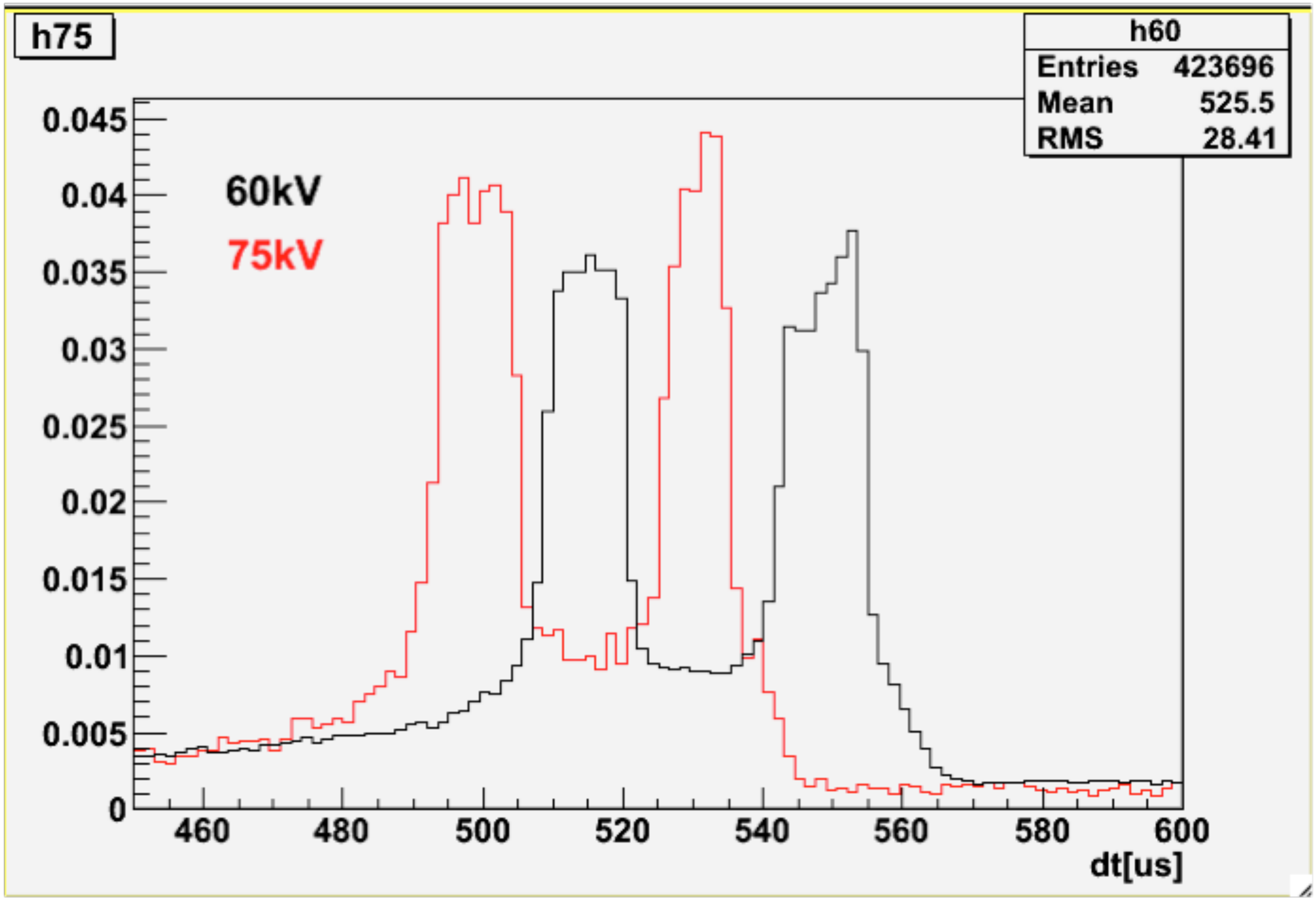


Drift time=550 μs v=1.74 mm/μs (@ 0.62 kV/cm), drift=96. cm





We went even further

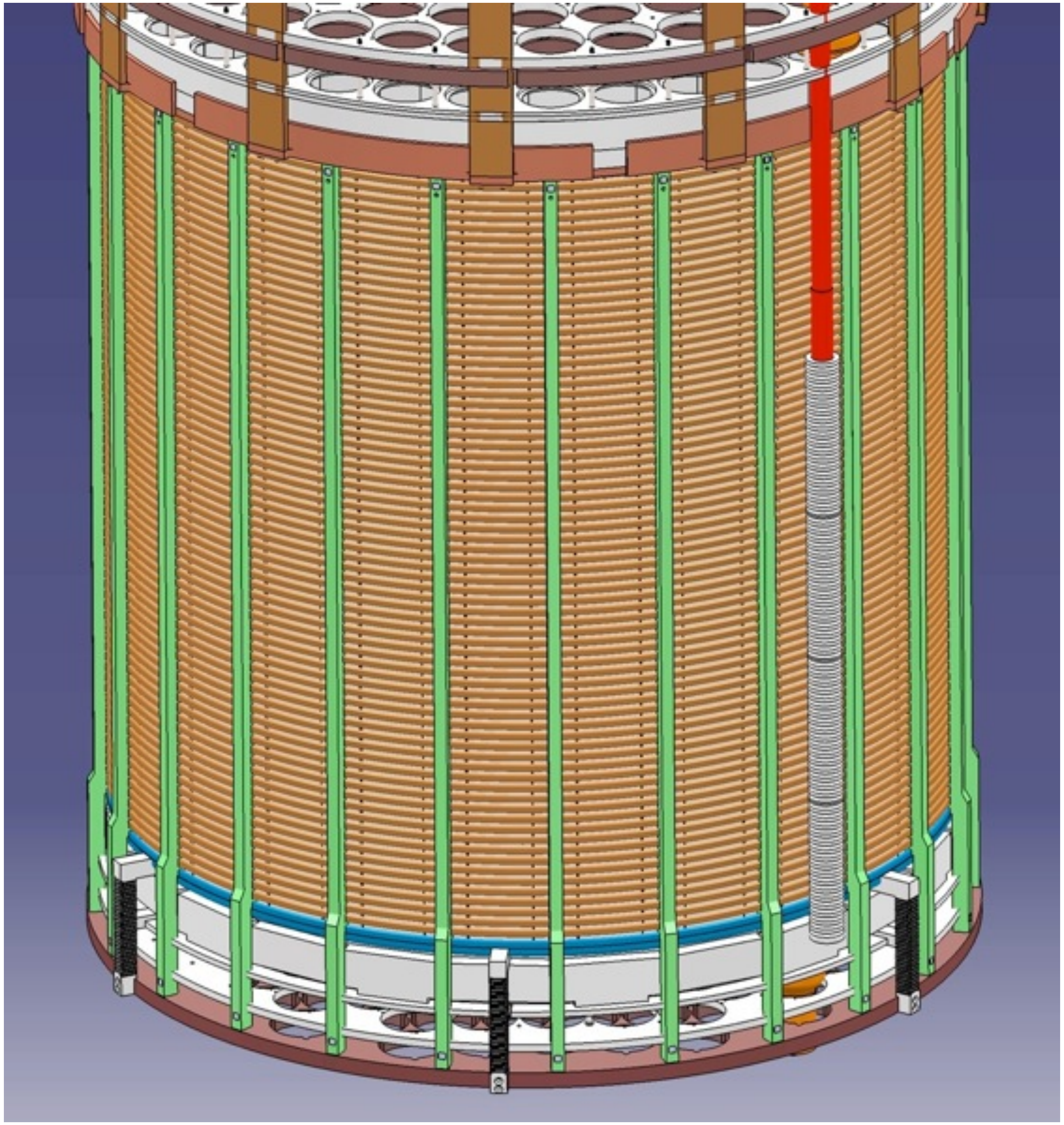


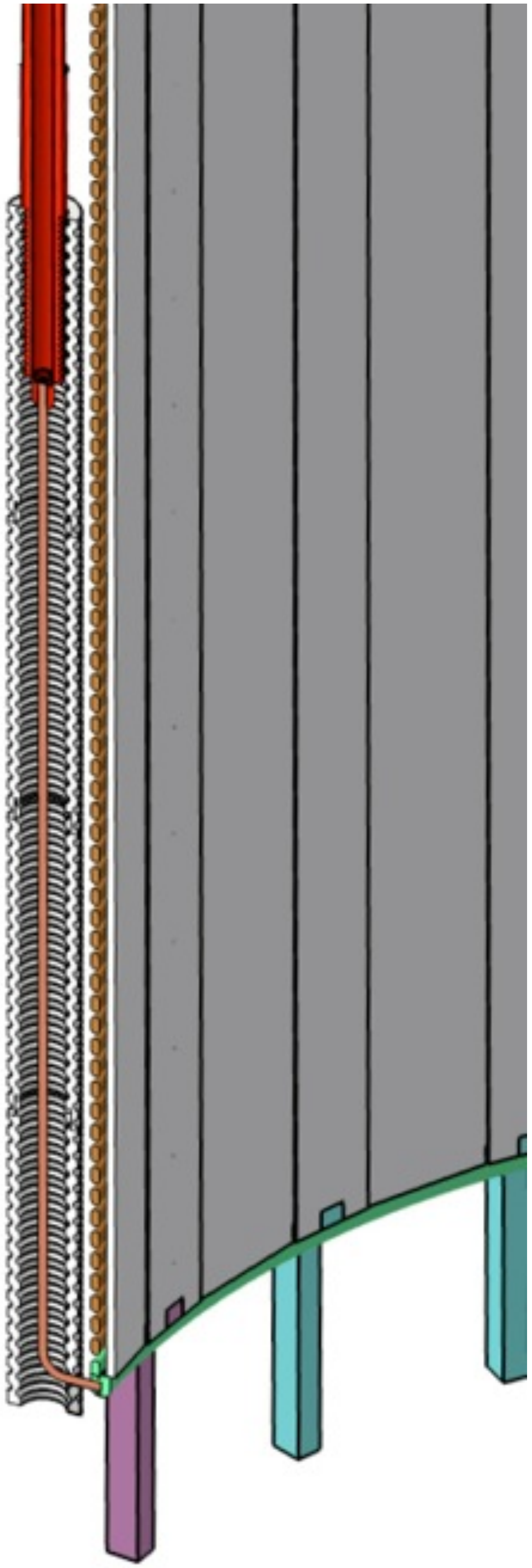
The shift of the red peak to lower drift time is explained by the field increase and consequently also the drift velocity increased

XENON1T

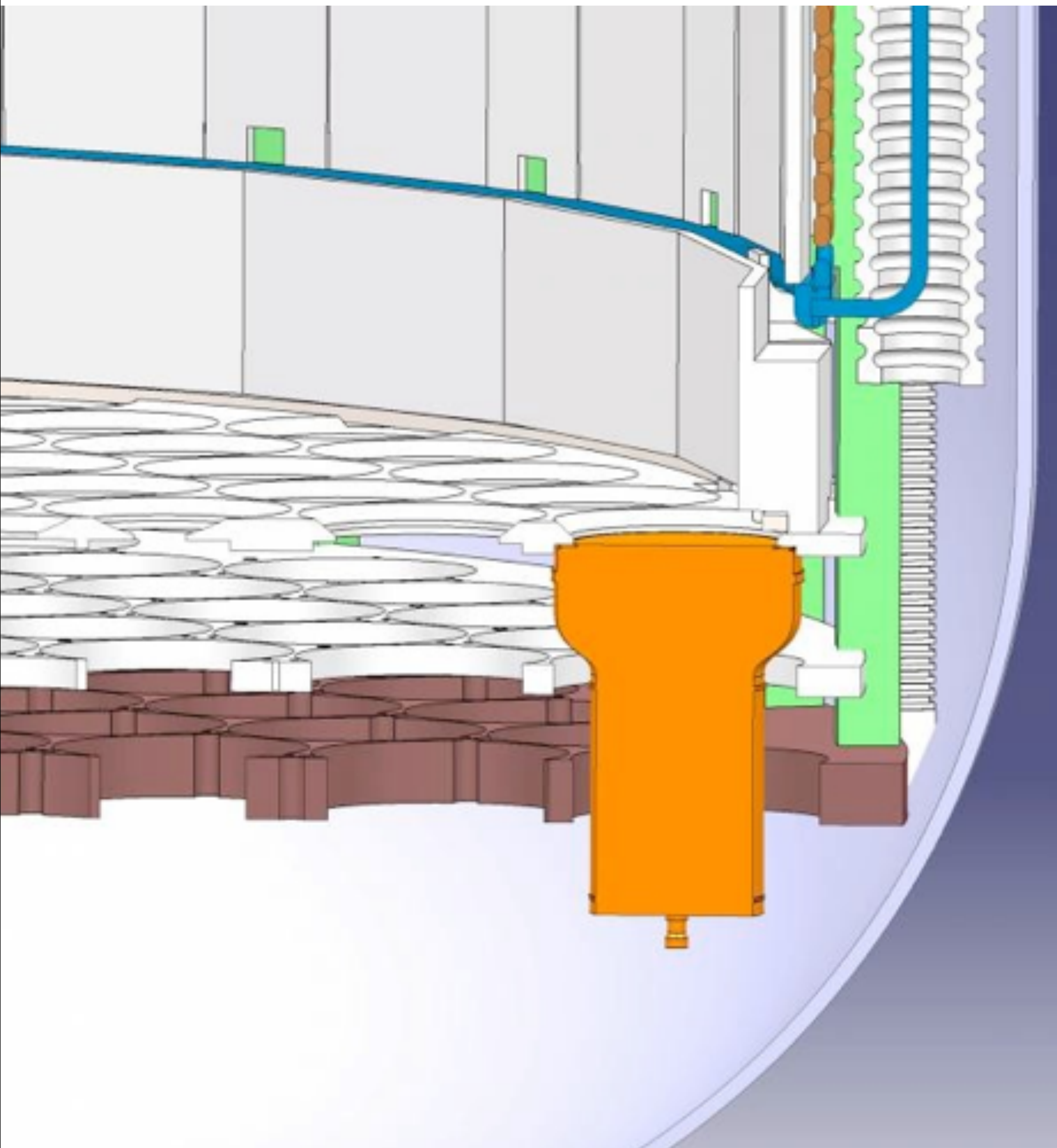
All the successful features proven so far in the DEMONSTRATOR went into the 1 ton TPC design

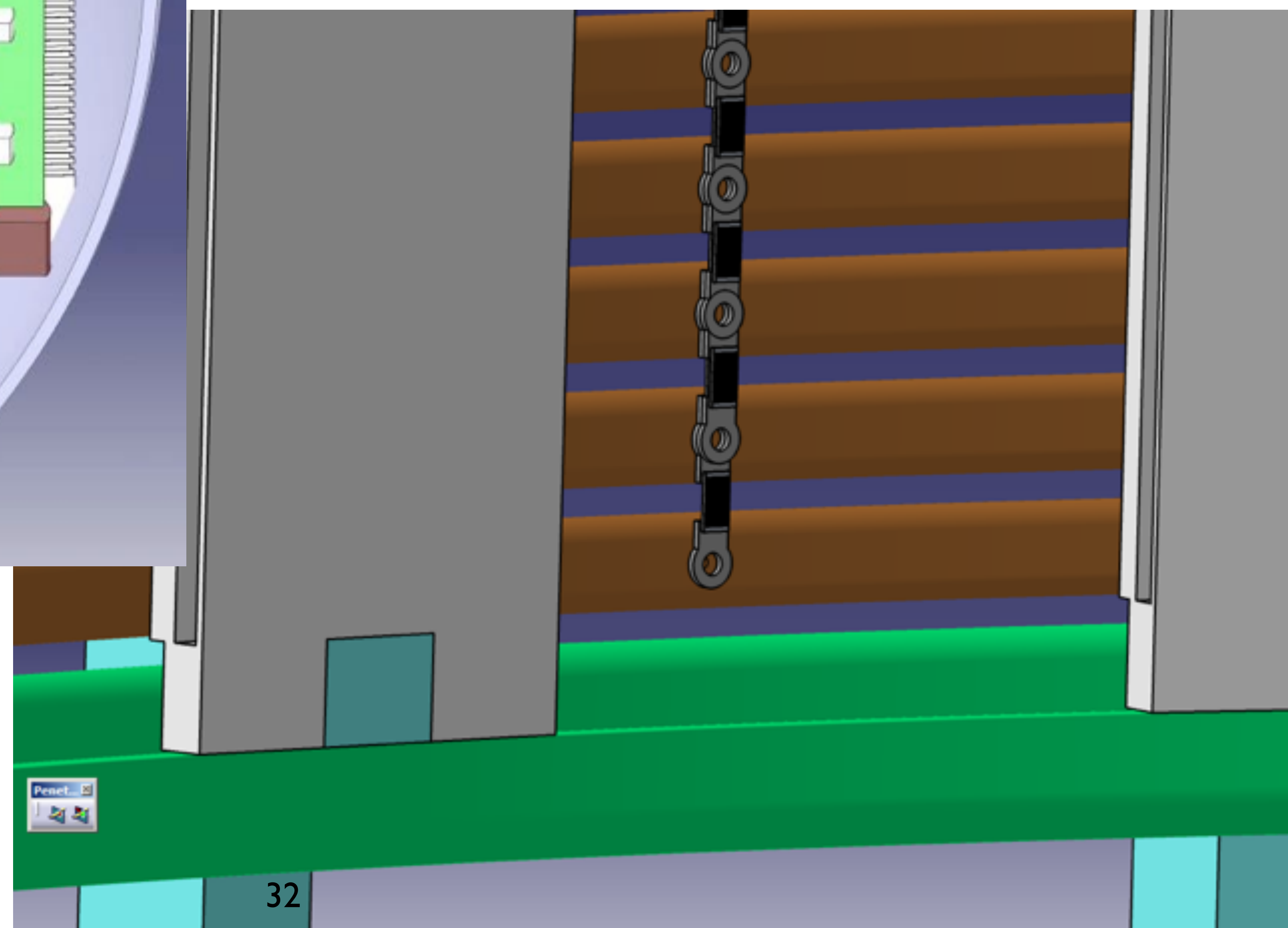
The XENON1T TPC





More details of the XENON1T design





Conclusions

- High Voltage in LXe is possible!
- A double phase TPC has been operated with a voltage up to 75 kV on the cathode.