Neutrinoless double beta decay with the nEXO experiment: R&D

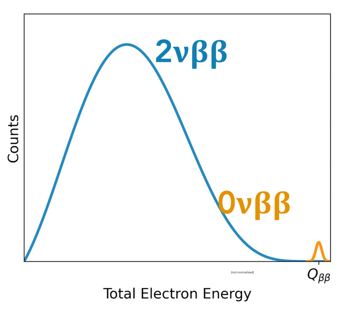
Marie Vidal, on behalf of the nEXO collaboration

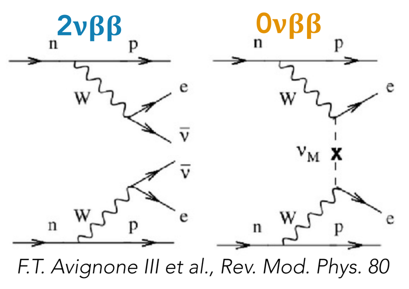
Neutrino 2024

nEXO: Search for $0\nu\beta\beta$ with ^{136}Xe

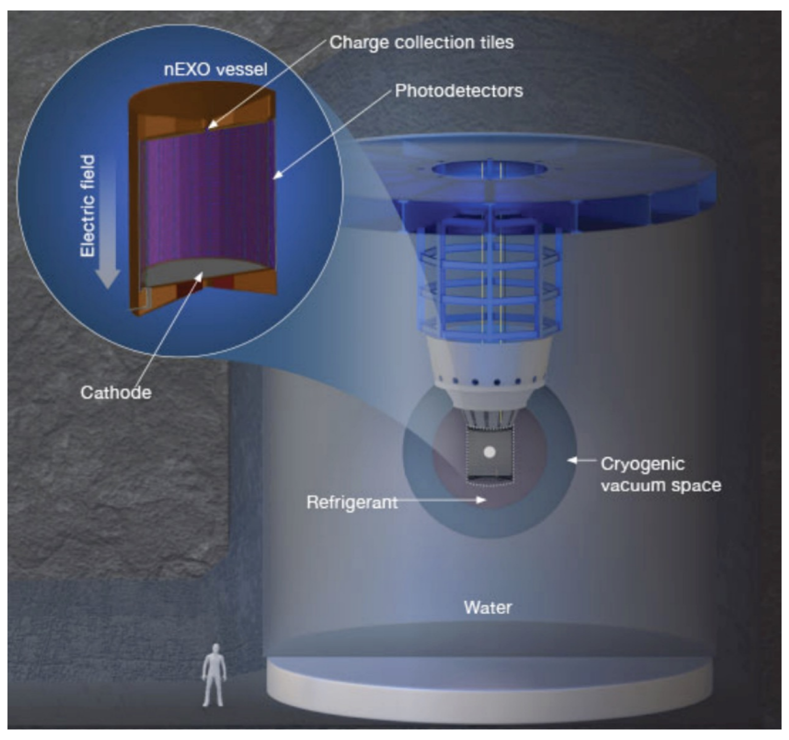
Physics $0\nu\beta\beta$:

- $\nu = \bar{\nu}$ → Majorana fermion
- Lepton number violation
- The existence of a Majorana fermion could provide a path to explain the matter/antimatter asymmetry of the Universe via leptogenesis



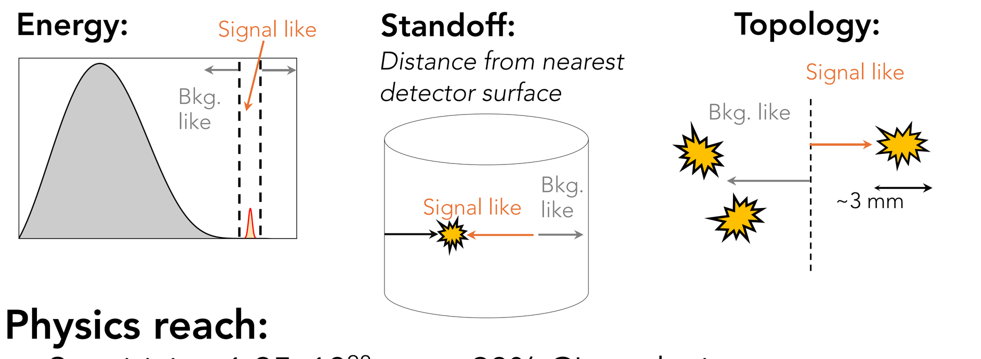


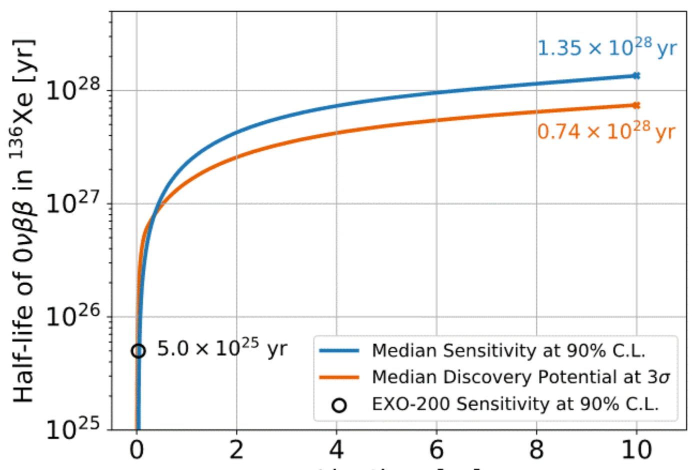
F.T. Avignone III et al., Rev. Mod. Phys. 80



Liquid xenon Time Projection Chamber (TPC):

- 5 tonnes of liquid xenon (LXe)
- 90% enriched in ^{136}Xe
- Energy resolution <1%: scintillation + charge
- Multidimensional analysis: based on topology, 3D position reconstruction, and energy





J. Phys. G: Nucl. Part. Phys. 49, 015104 (2022)

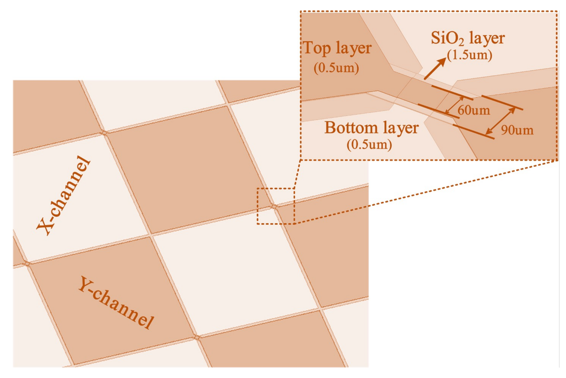
Physics reach:

- Sensitivity: 1.35×10^{28} years 90% CL exclusion
- Discovery potential: 0.74×10^{28} years 3σ
- $\langle m_{\beta\beta}\rangle$ exclusion band: 4.7 – 20.3 meV comes from full range of nuclear matrix elements (NMEs) available

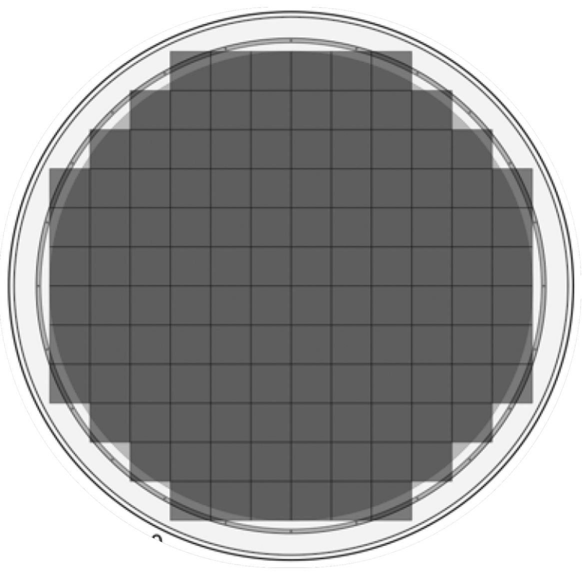
Charge detection in nEXO

nEXO anode:

- **Gridless** segmented modular tiles: 120 tiles
- Less mechanical stress: forces easier to manage than a tensioned wire grid
- Electronics: **cryogenic ASIC** (digitization) submerged in LXe
- Can mount electronics directly at the back of the modules: noise reduction and reduction of electromagnetic pick up
- Simplifies the installation: cable reductions
- **Multilayered tiles**, with quartz substrate and deposition of a layer of Au for the collecting material.



1 tile: 10x10 cm square, with strips along x and y for 2D position reconstruction



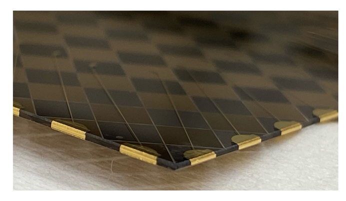
Layout of the 120 charge tiles at the top of nEXO

Prototyping for **traces sent to the back** of the tile. Testing of 2 different methods:

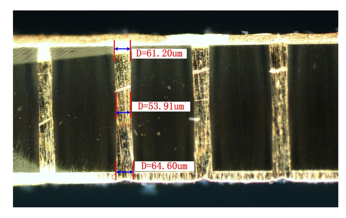
- SLAC: around the edge deposition
- IHEP-IME: through-quartz vias

Both methods were tested and demonstrated

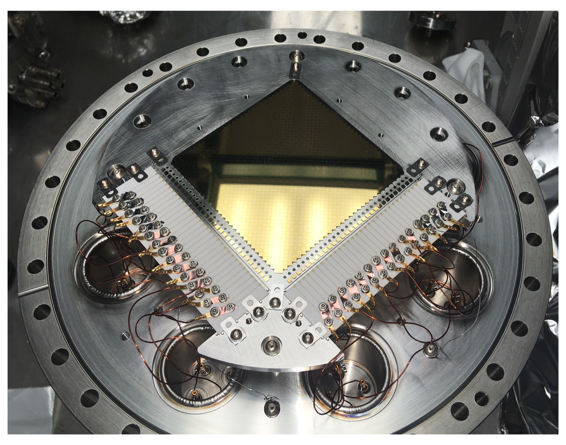
Wrap-around traces
The traces are sent to the back of the tile by wrapping a layer of gold on the edge of the tile.

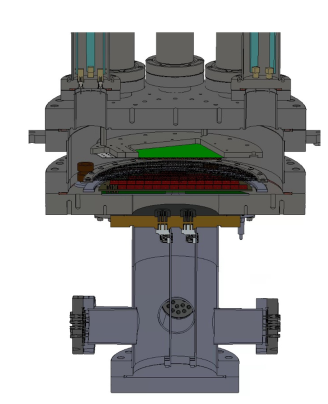


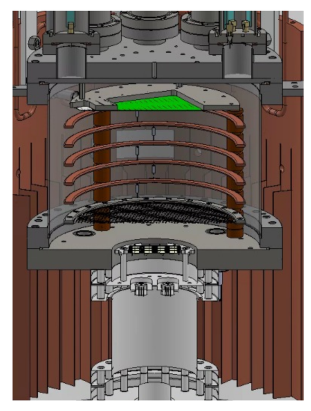
Through-quartz vias
TQVs are obtained by drilling with a laser, and then electroplated with copper. Cross section of a tile with TQVs.



Anode prototype:







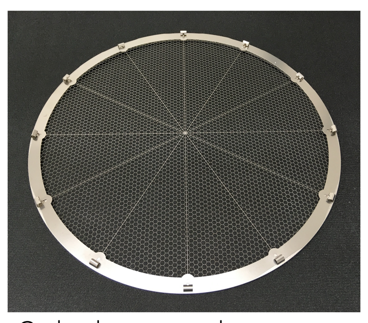
Existing detectors @Stanford:

- Same diameter (12/30.5 cm conflat flange)
- Drift length: 2.1 to 3 cm
- Drift length: 13 cm
- Can only accommodate 1 tile

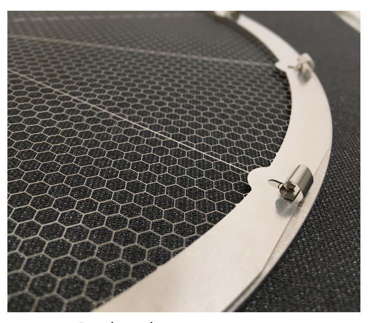
- **Testing of prototype tile** @Stanford (IME), *M. Jewell et. al JINST 13 P01006* Proof of concept
- Tile used as default charge readout of all TPC detectors @Stanford (using external electronics)
- **nEXO: 120 charge tiles** → Study multiple charge tile configuration

Multiple tiles:

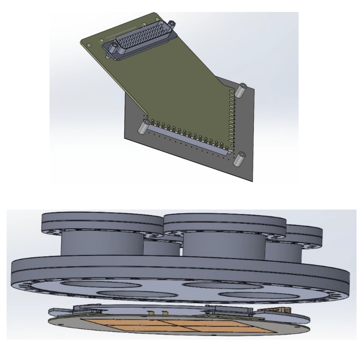
- Impact on energy resolution
- Possible cross-talk between modules
- Design and construction of a new and larger TPC to perform tests with 4 charge tiles
- Mass: 64 kg LXe
- Improve design of existing electric field cage detectors (3D COMSOL simulations): uniformity
- Construction phase



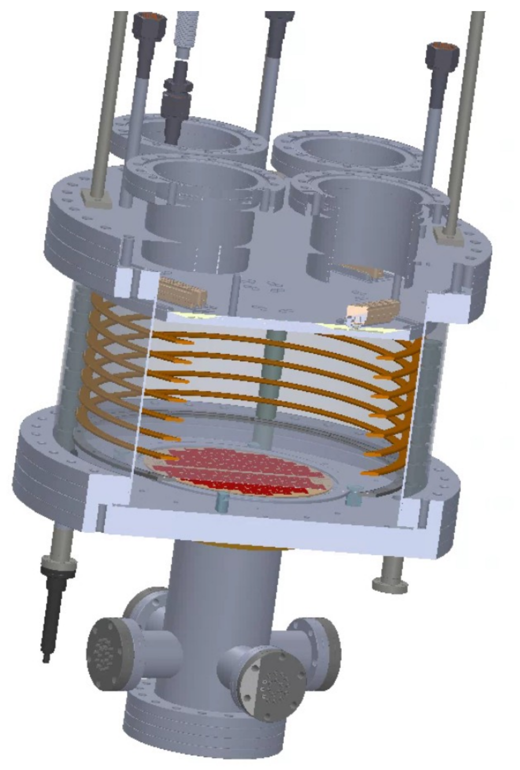
Cathode mounted on support



Cathode tensioning



CAD model for the charge tile, ASIC board and ASIC

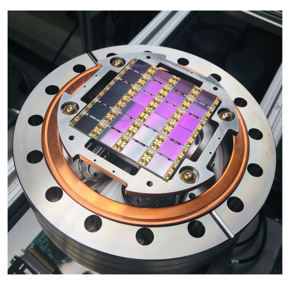


CAD model of the TPC accommodating 4 charge tiles

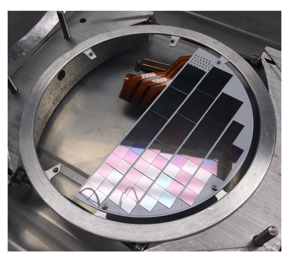
Light detection in nEXO

Light detectors: Silicon Photomultipliers (SiPMs)

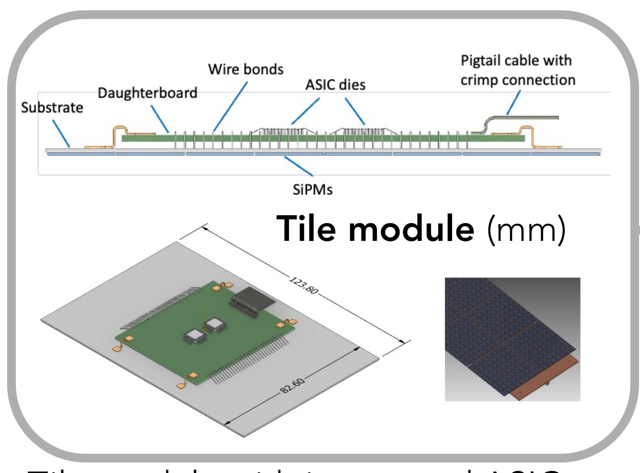
Cover the barrel of the nEXO detector.
~46000 SiPMs grouped into 7680 readout channels



SiPM array @Stanford



Increase density of SiPMs

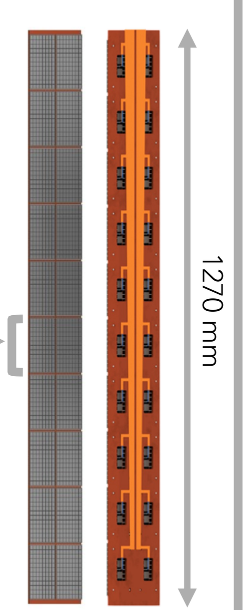


Tile module (mm)

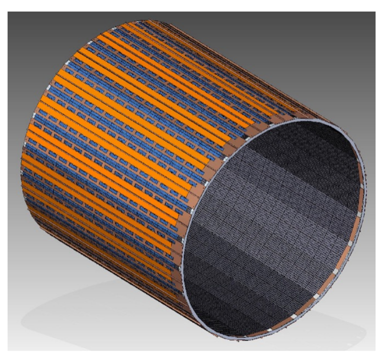
Tile module with integrated ASICs

20 light tile modules per stave

SiPM stave



Full assembly of the light readout



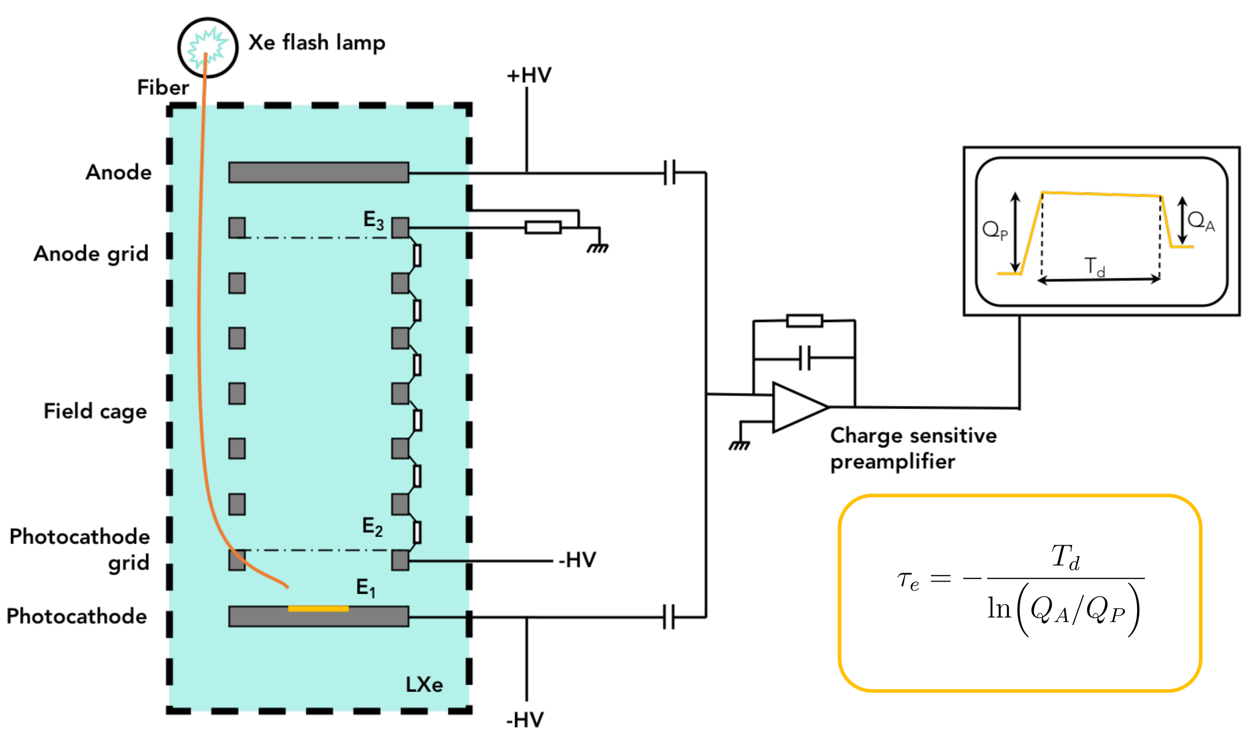
Total light area for nEXO: 4.5 m^2

24 staves around the TPC barrel

LXe purity in nEXO

Motivation:

- Measurement of the ionization energy relies on drifting electrons
- If **electronegative impurities** are present in LXe, there will be **electron attachment**: the reconstructed energy will no longer be proportional to the energy deposited
- nEXO: need to test every material in contact with the LXe to avoid outgassing of electronegative impurities
- Put in place **strategies to study outgassing** in vacuum and in LXe
- Build a purity monitor to test samples of material in LXe @Stanford (existing purity monitor @Yale and @SLAC)



$$\tau_e = -\frac{T_d}{\ln\left(Q_A/Q_P\right)}$$

The **xenon flash lamp** emits UV light that goes through a solarization-resistant fiber.

There is **one channel readout** combining the photocathode and anode.

The anode and photocathode are separated by a double-gridded drift region. The grids screen the photocathode and anode against induced current from the drifting electrons.

Q_p and Q_A are proportional to the number of charges drifting in regions 1 and 3.

Working principle of purity monitor:

Measure the number of remaining electrons after a travelled distance L (*Nucl. Instr. and Meth. in Phys. R A305: 1991*)

1. Region 1: create electrons via photoelectric effect, xenon flash lamp shines on gold layer (100 nm)
2. Current induced on photocathode from electrons drifting to region 2
3. Region 2: electrons travel, possibly are lost due to the presence electronegative impurities
4. Region 3: remaining electrons arrive
5. Current is induced on the anode by the electrons drifting towards it

Purity expressed in electron lifetime: τ_e

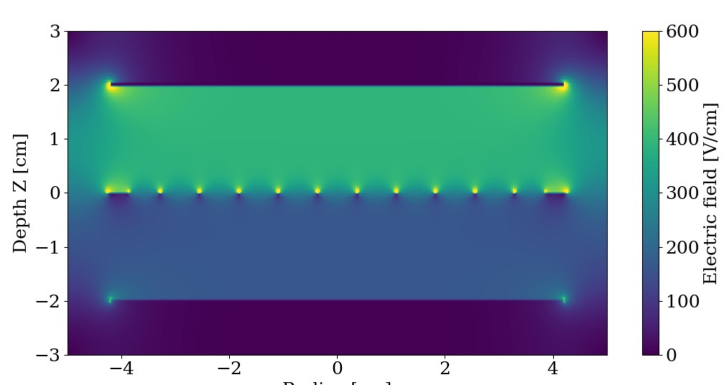
$$N_e(t) = N_0\ e^{\frac{-t}{\tau_e}} \qquad \tau_e = \frac{1}{\sum k_i C_i}$$

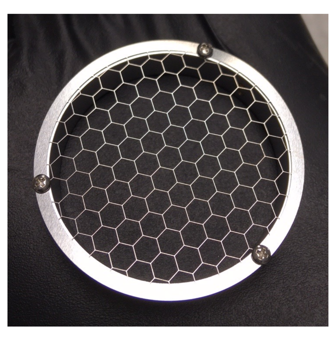
With k the attachment rate and C the concentration of the impurity.

$$\frac{1}{\tau_e} = \sum_i \frac{1}{\tau_{e,i}}$$

How the total τ_e is related to the individual $\tau_{e,i}$ samples/species tested.

COMSOL simulation of the electric field
$E_{max} \approx 2$ kV/cm hidden by color scale





Grid mounted on ring

$$\frac{1-\rho}{1+\rho} < \frac{E_2}{E_1}$$

$$\rho = \frac{2\pi r}{d}$$

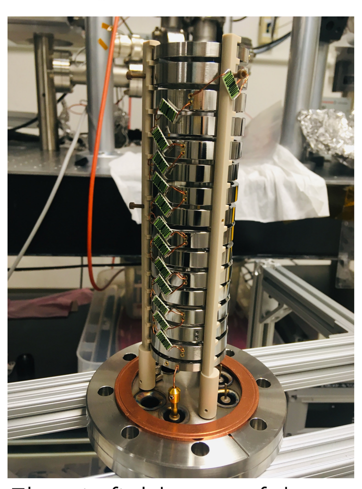
r = radius wire
d = distance wires

Electronic transparency: condition that allows the electrons to go through the grid, depends both on the values of the fields before and after the grid, and on the geometrical quantities of the grid.

Design, construction and commissioning:

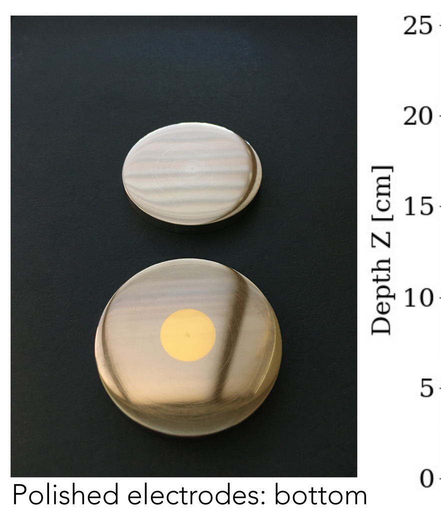
- 3D COMSOL simulation to check high electric field regions
- Regions 1 and 3: 1 cm drift length
- Region 2: 12.5 cm drift length

- Construction of the purity monitor is complete
- Commissioning in progress: seeing induced pulses on photocathode in vacuum and LXe.

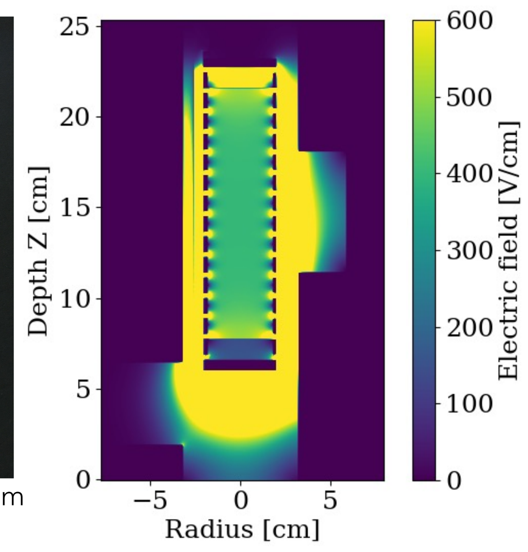


Electric field cage of the purity monitor. Each potential drop along z is possible thanks to low-outgassing ceramic resistors.

Inside view of the purity monitor field cage. The fiber is inserted in the photocathode grid ring. In the picture the fiber is pointing upward. The photocathode is installed in the last slot of the PEEK holder, with the gold layer facing down.



Polished electrodes: bottom photocathode, and top anode. The photocathode has a gold layer to extract photoelectrons. The electrodes have a diameter of 4.2cm.



COMSOL simulation of the electric field
$E_{max} \approx 20$ kV/cm hidden by color scale