

DIPC efforts on electroluminescence detectors

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iKUR
estrategia

DIPC



European Research Council

Established by the European Commission

ikerbasque
Basque Foundation for Science

DIPC neutrino group

- Involved in different neutrino experiments and physics cases:
 - Neutrinoless double beta decay: NEXT
 - Neutrino nucleus coherent scattering: nuESS
 - Neutrino oscillations: Hyper-Kamiokande

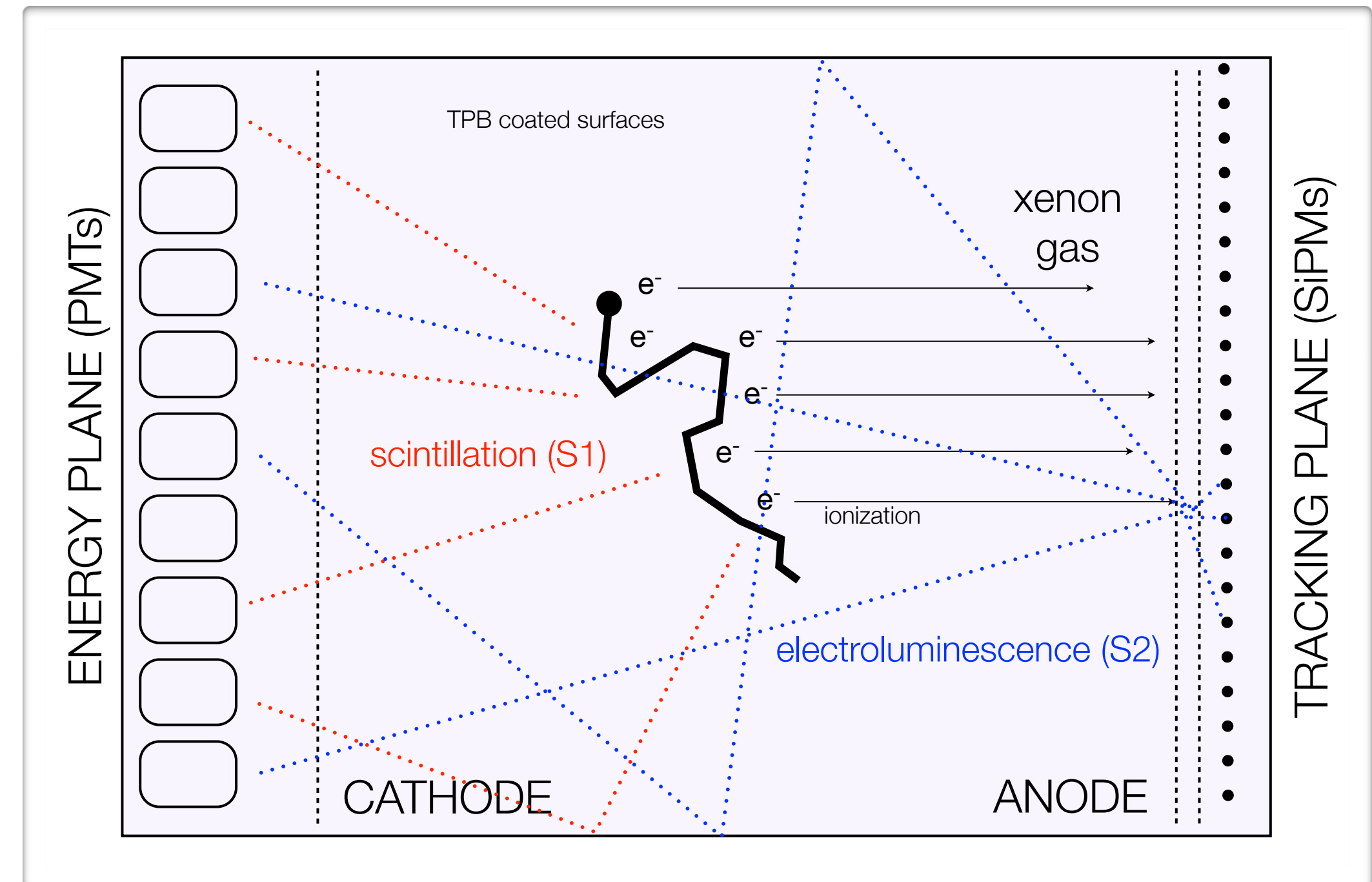
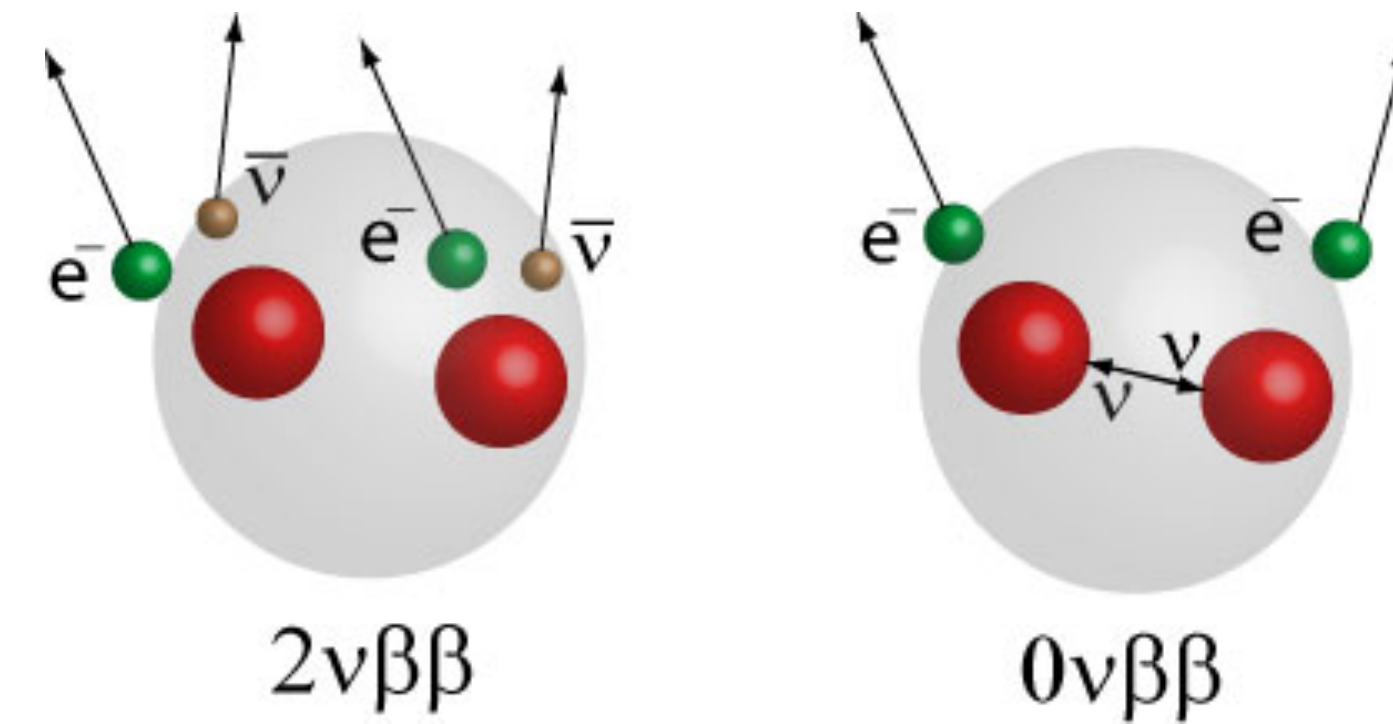
DIPC neutrino group

- Involved in different neutrino experiments and physics cases:
 - Neutrinoless double beta decay: NEXT
 - Neutrino nucleus coherent scattering: nuESS
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What is NEXT

The NEXT Collaboration is searching for the neutrino-less double beta decay in Xe-136.

It uses a high pressure TPC with electroluminescent amplification.



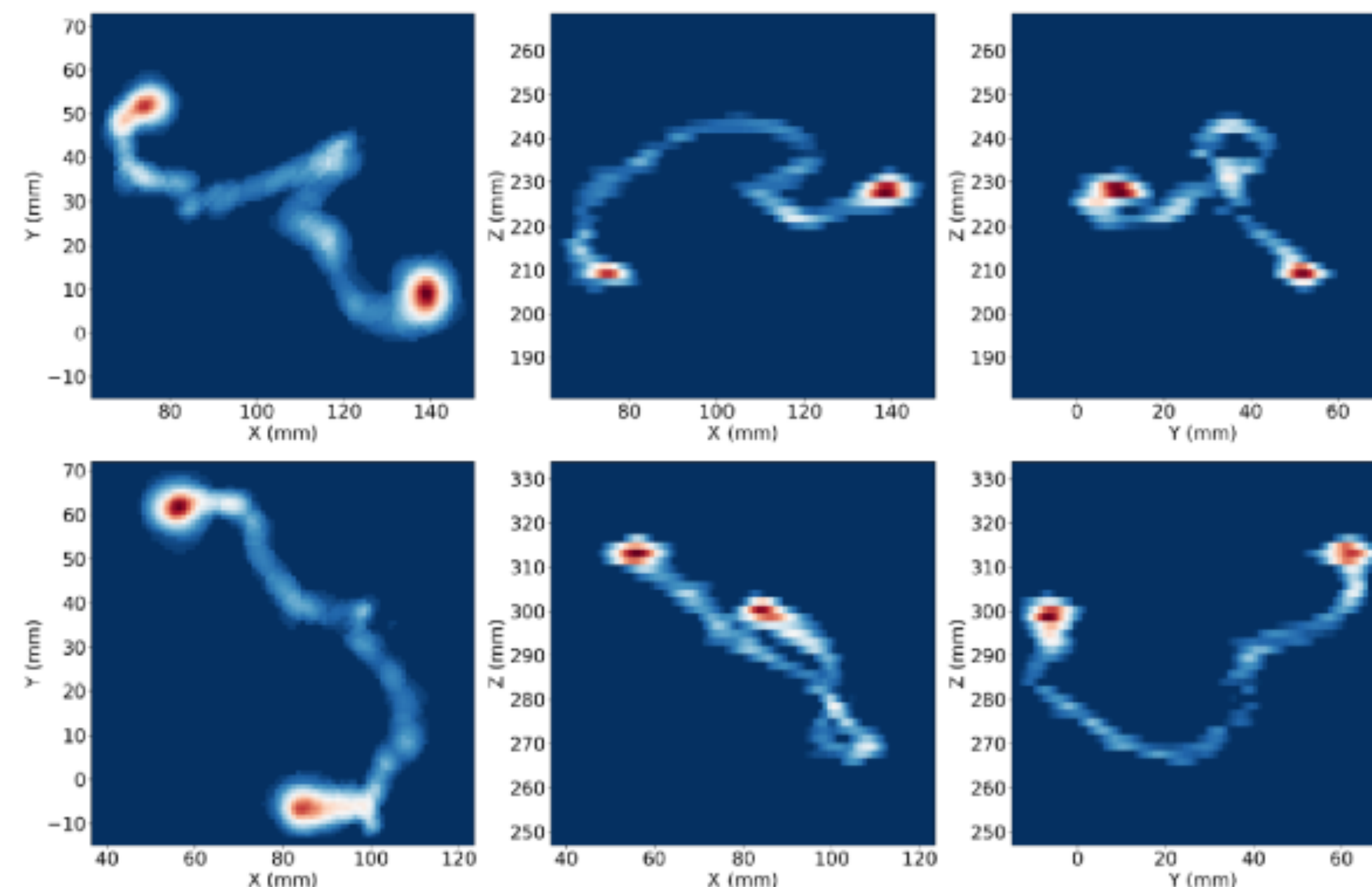
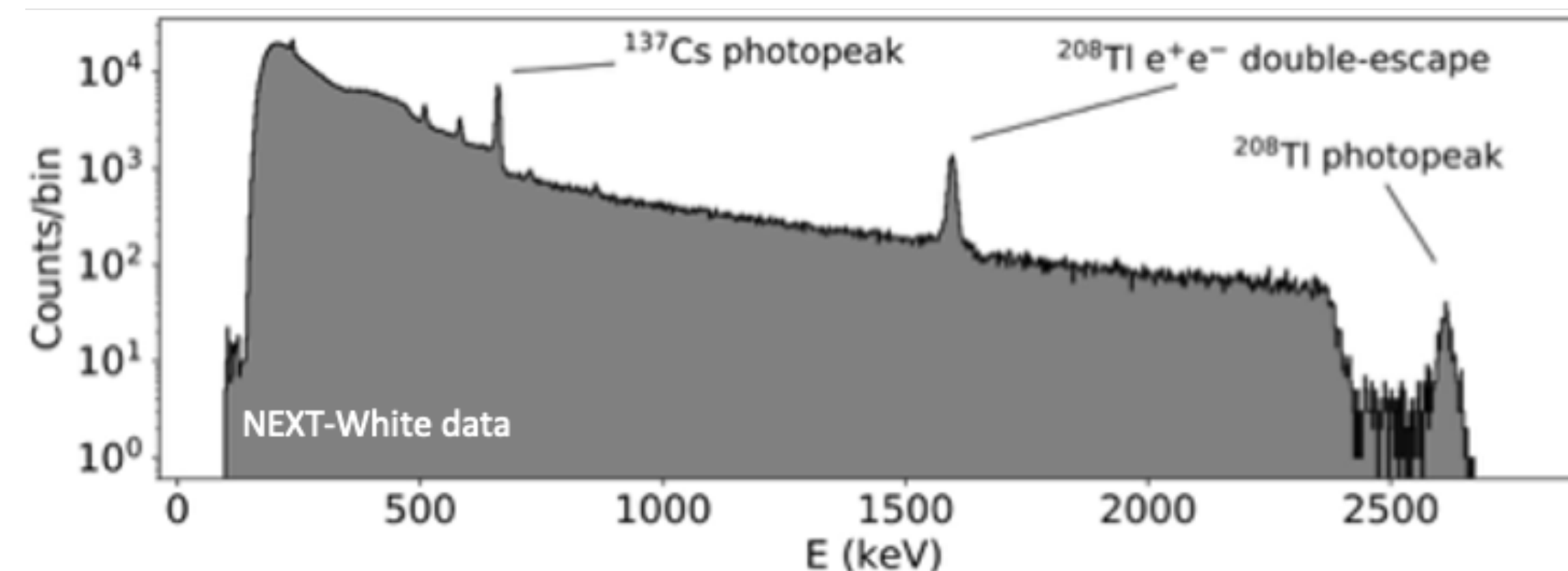
Capabilities of High-Pressure Xenon Gas Time Projection Chambers

Precise energy resolution of $<1\%$ FWHM achievable in xenon gas.

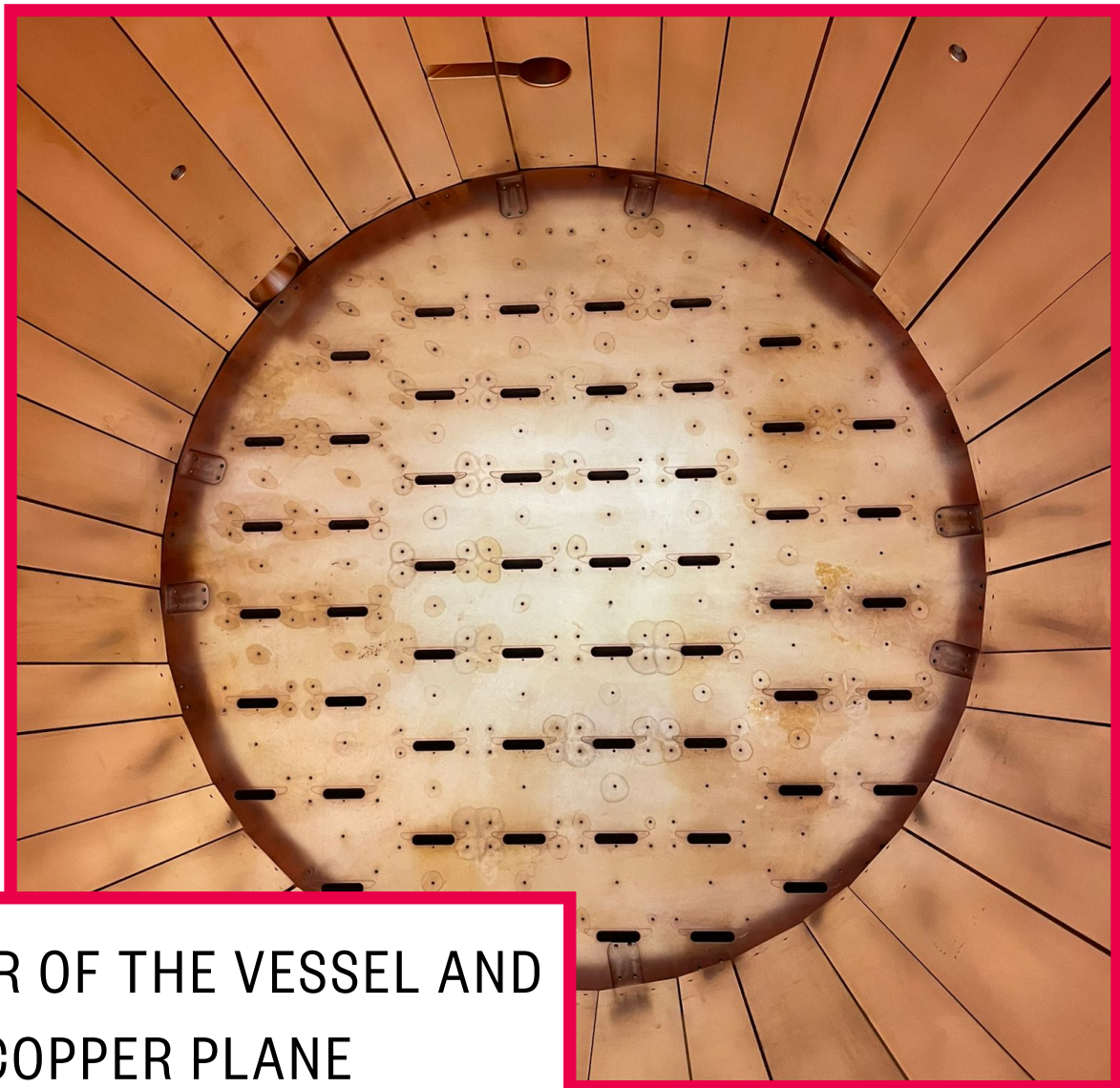
Scalability to large masses of isotopically-enriched ^{136}Xe

Topological event identification in xenon gas distinguishes 2e from 1e events

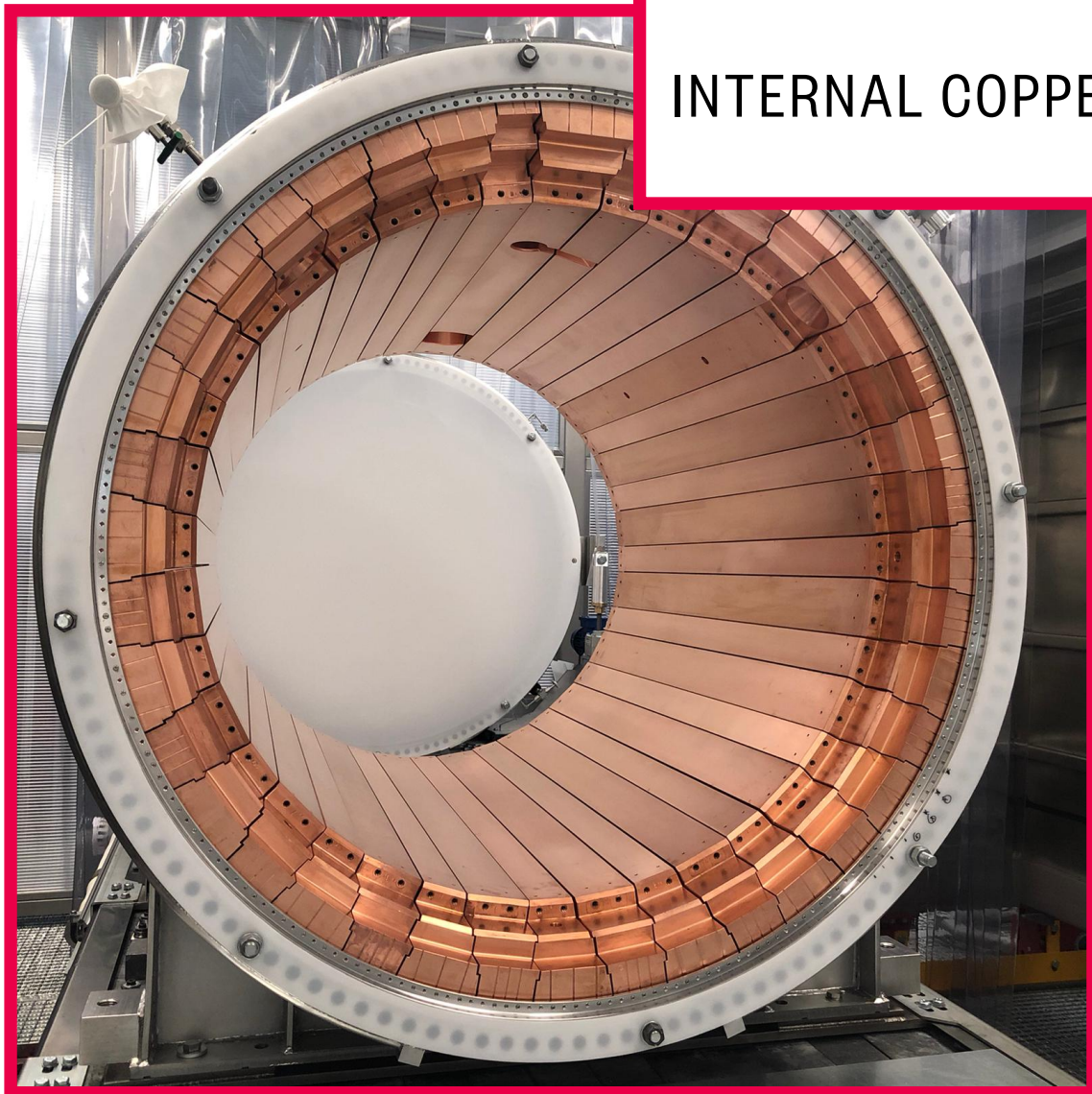
Possibility to detect daughter ion ($^{136}\text{Ba}^{++}$) in coincidence with decay electrons



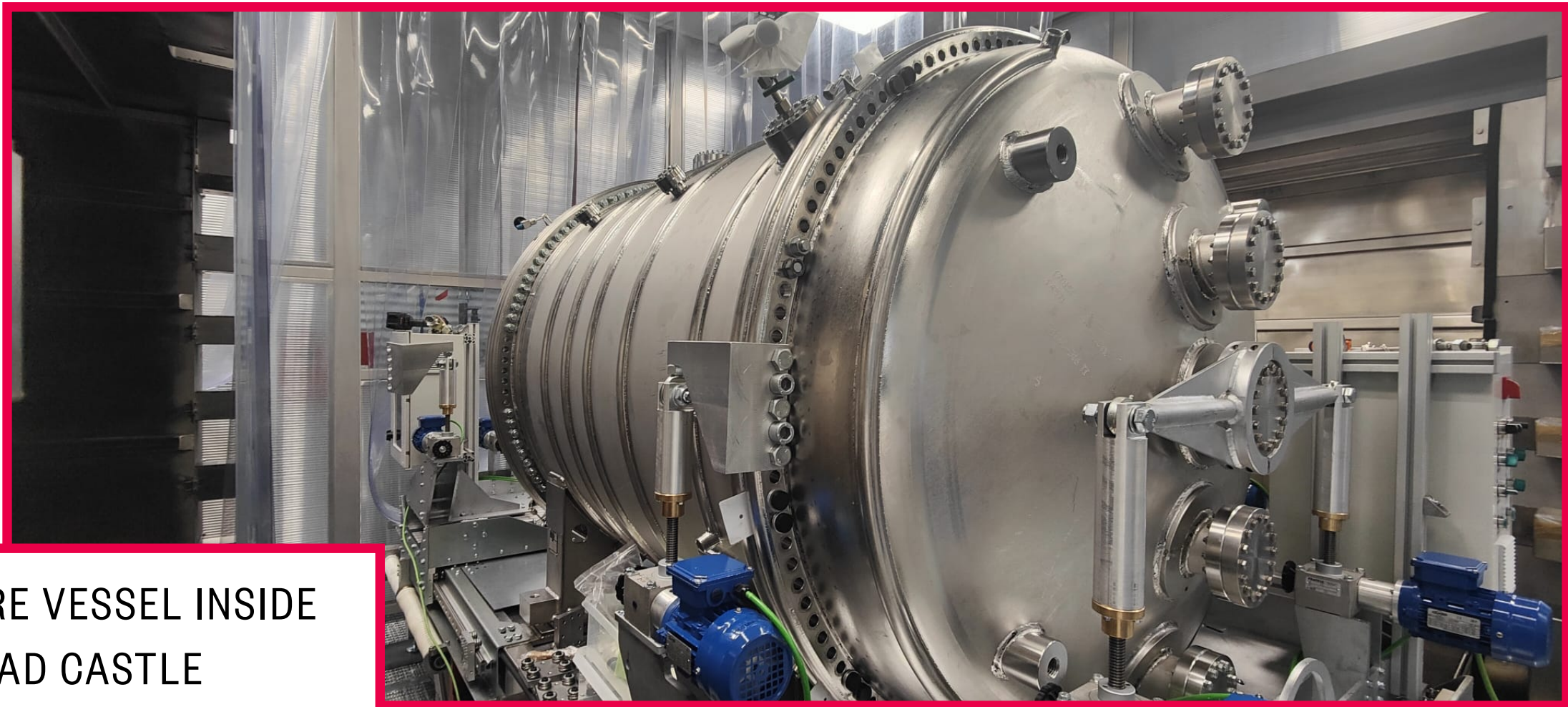
The NEXT-100 detector assembly @ LSC



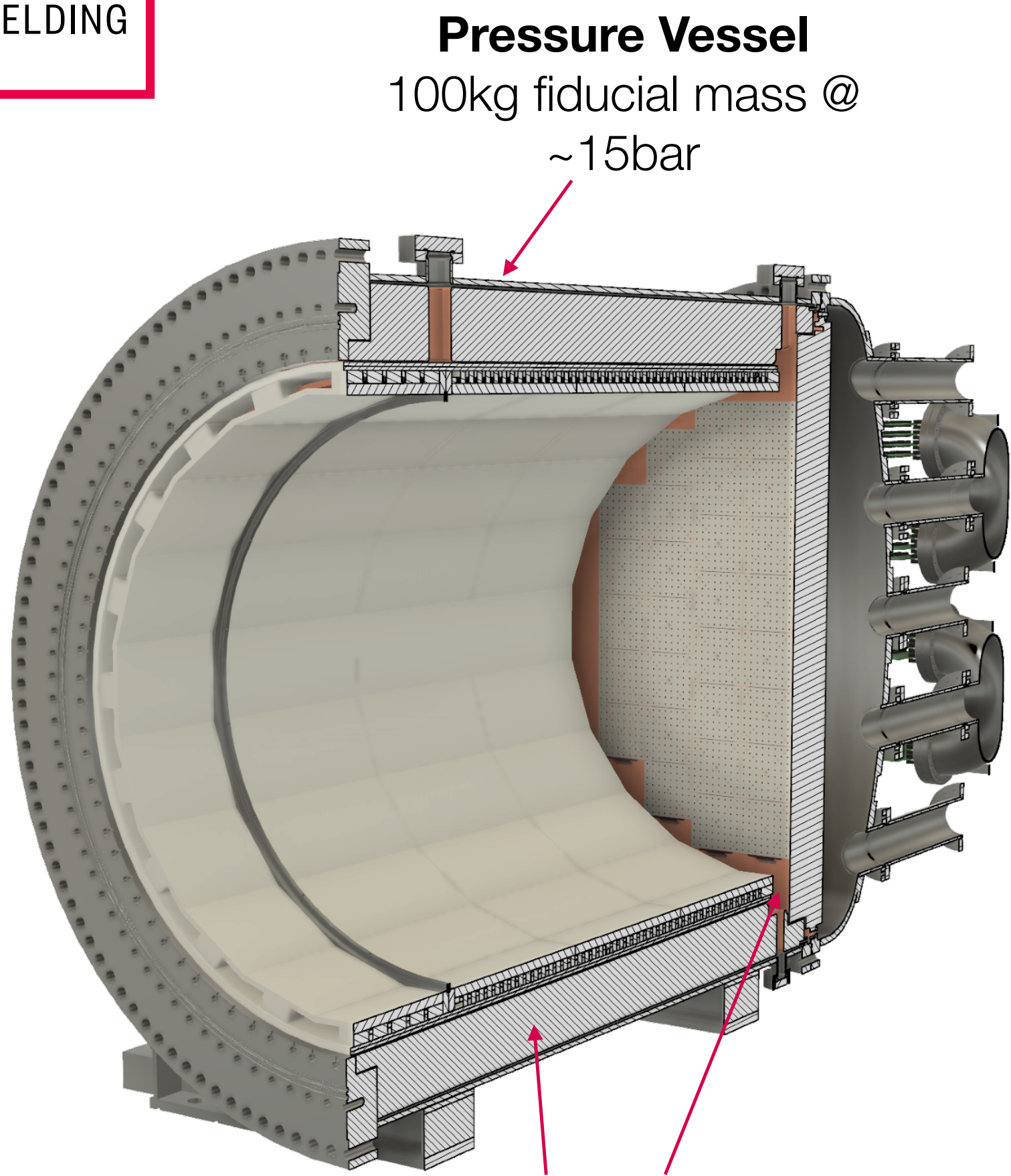
INTERIOR OF THE VESSEL AND
COPPER PLANE



INTERNAL COPPER SHIELDING



PRESSURE VESSEL INSIDE
LEAD CASTLE



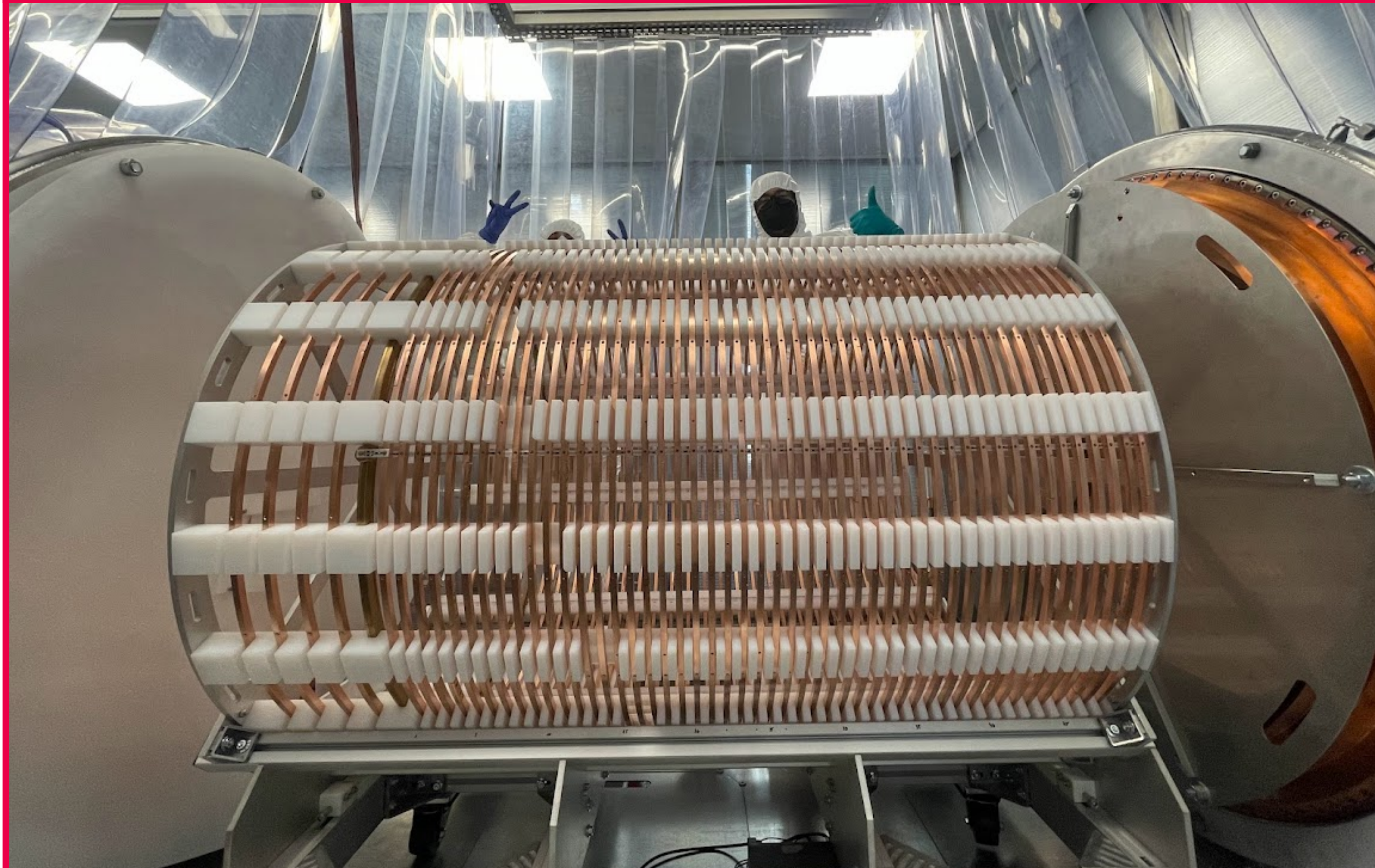
Pressure Vessel
100kg fiducial mass @
~15bar

Copper Shielding
Thicker (12cm) ultra-pure copper shielding
Big machinery for production

The NEXT-100 detector assembly @ LSC

FIELD CAGE DESIGN:

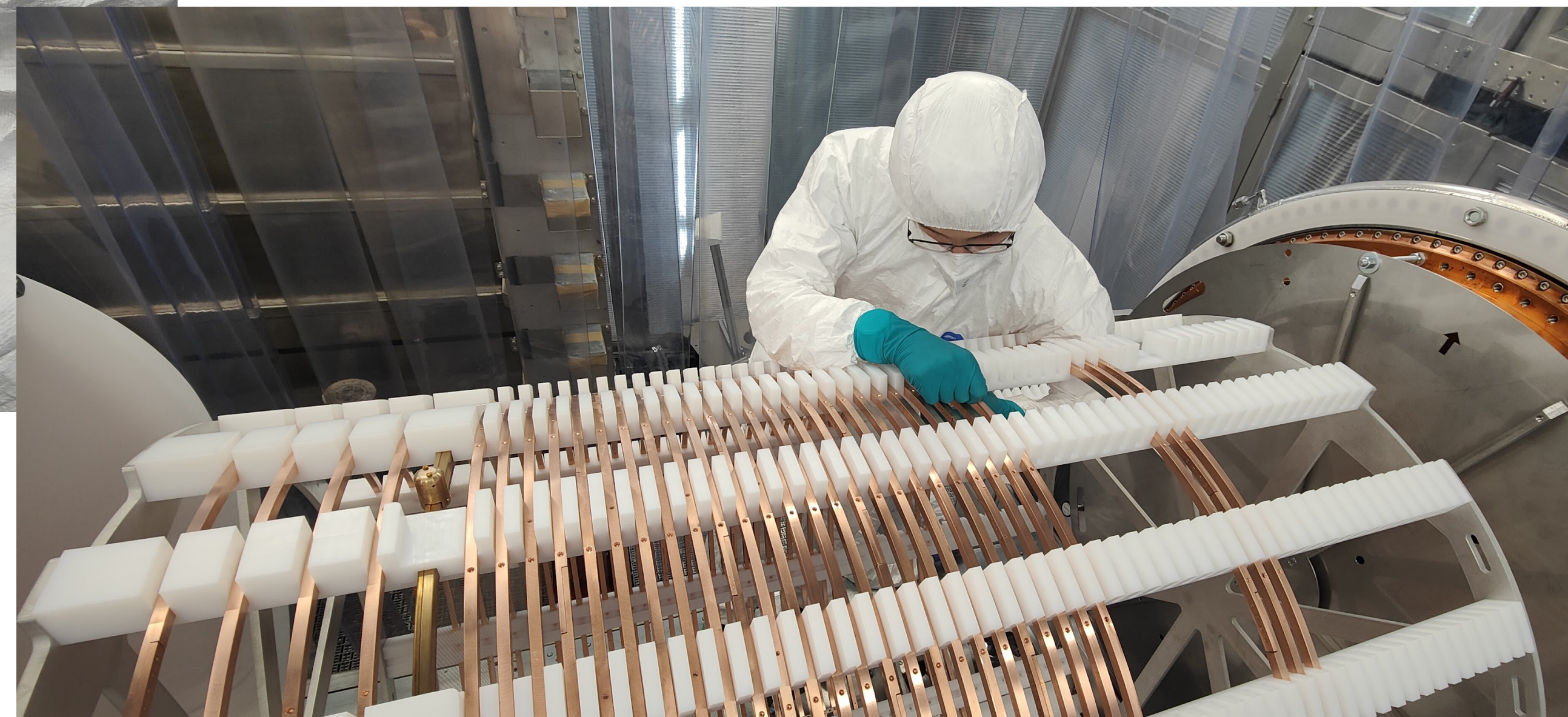
- COPPER RINGS TO CREATE FIELD UNIFORMITY.
- RINGS SUPPORTED BY POLY BARS ALONG THE FIELD CAGE AND BUFFER.
- THESE BARS HAVE SMALL SPACES TO ALLOW THE CATHODE CABLE TO WRAP AROUND THE FIELD CAGE AND EXIT NEAR THE GATE, IN THE REGION WITH LOWER ELECTRIC FIELD.



The NEXT-100 detector assembly @ LSC



RINGS ARE BUILT IN THREE PARTS AND NEED TO BE ASSEMBLED WITH SCREWS DIRECTLY INTO THE POLY



The NEXT-100 detector assembly @ LSC



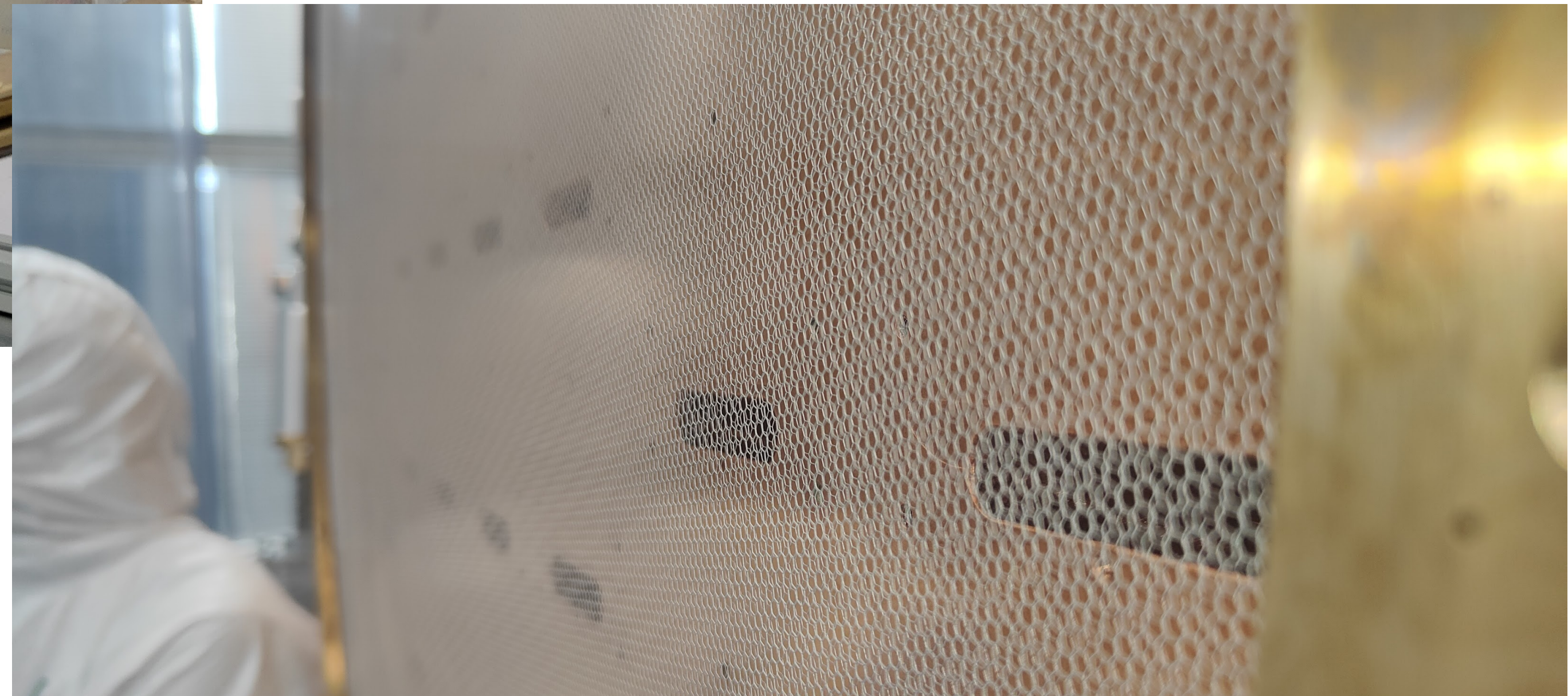
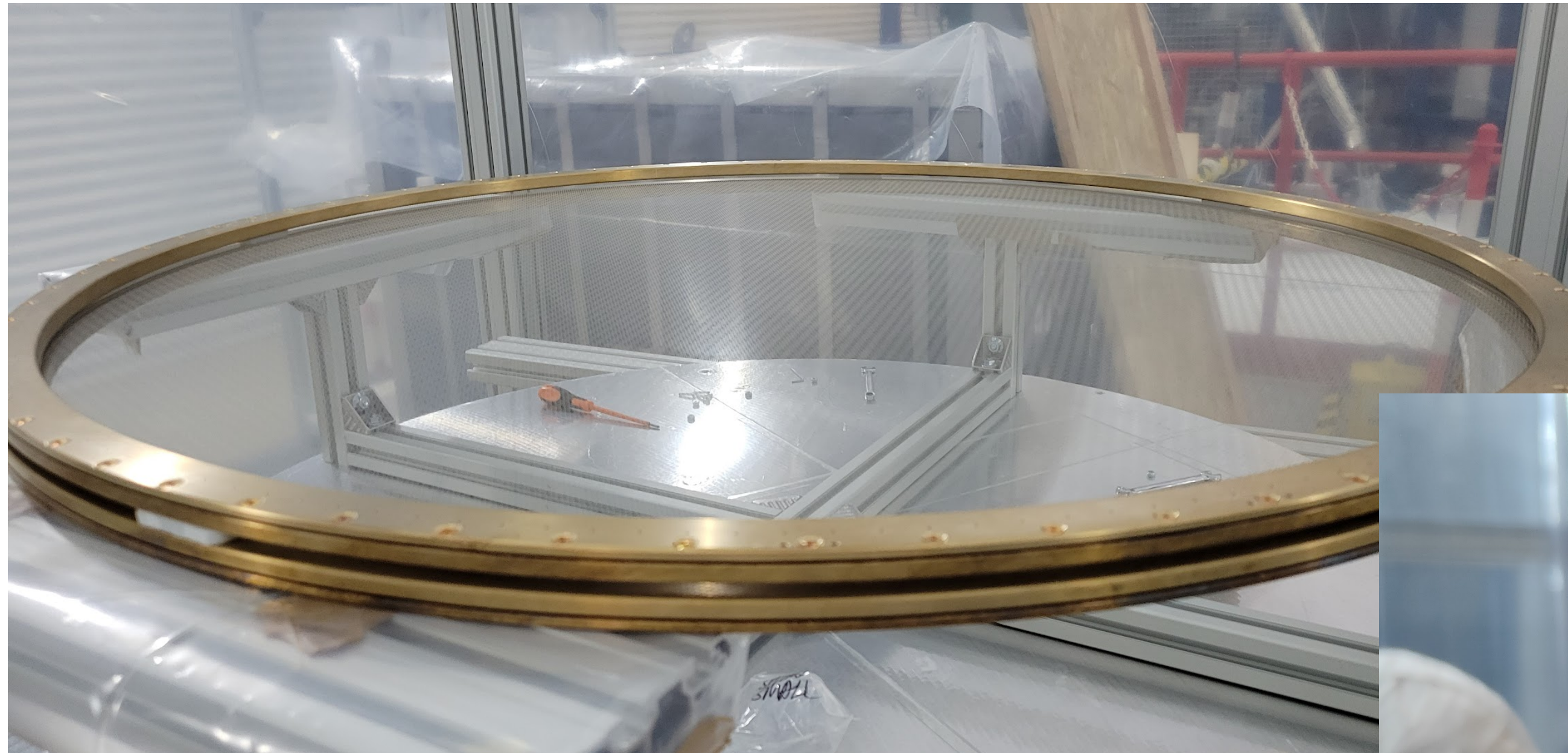
FC WAS PUSHED INTO THE VESSEL WITH A TROLLEY



The NEXT-100 detector assembly @ LSC



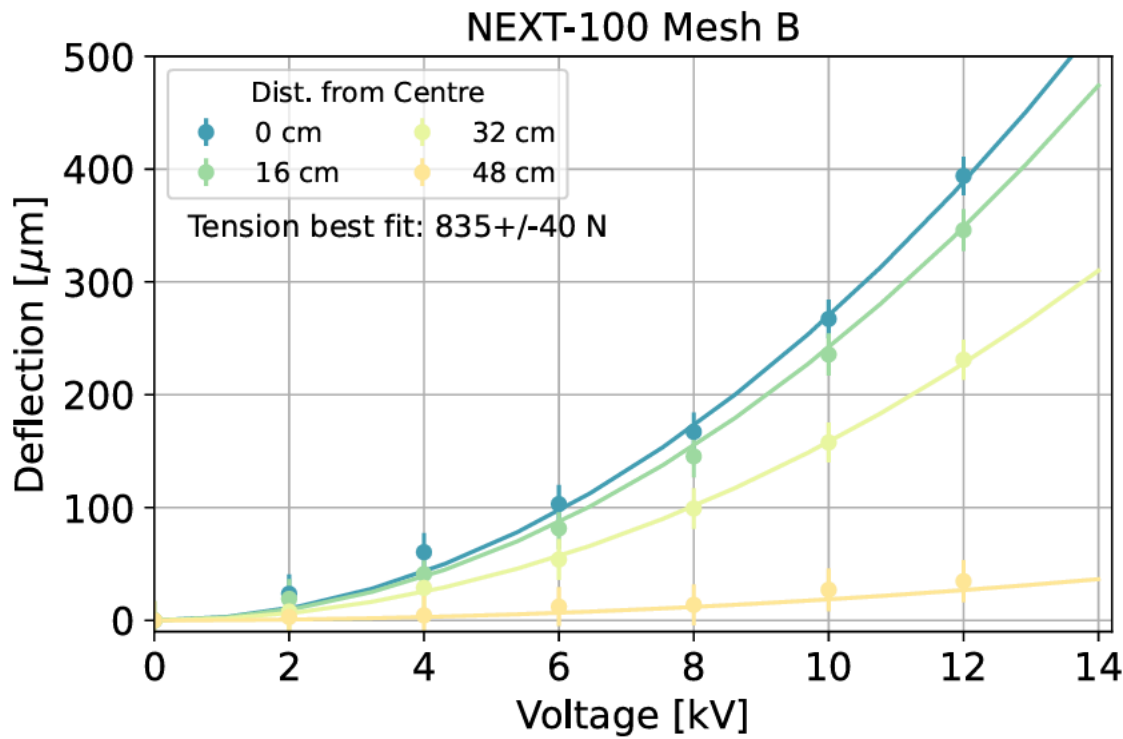
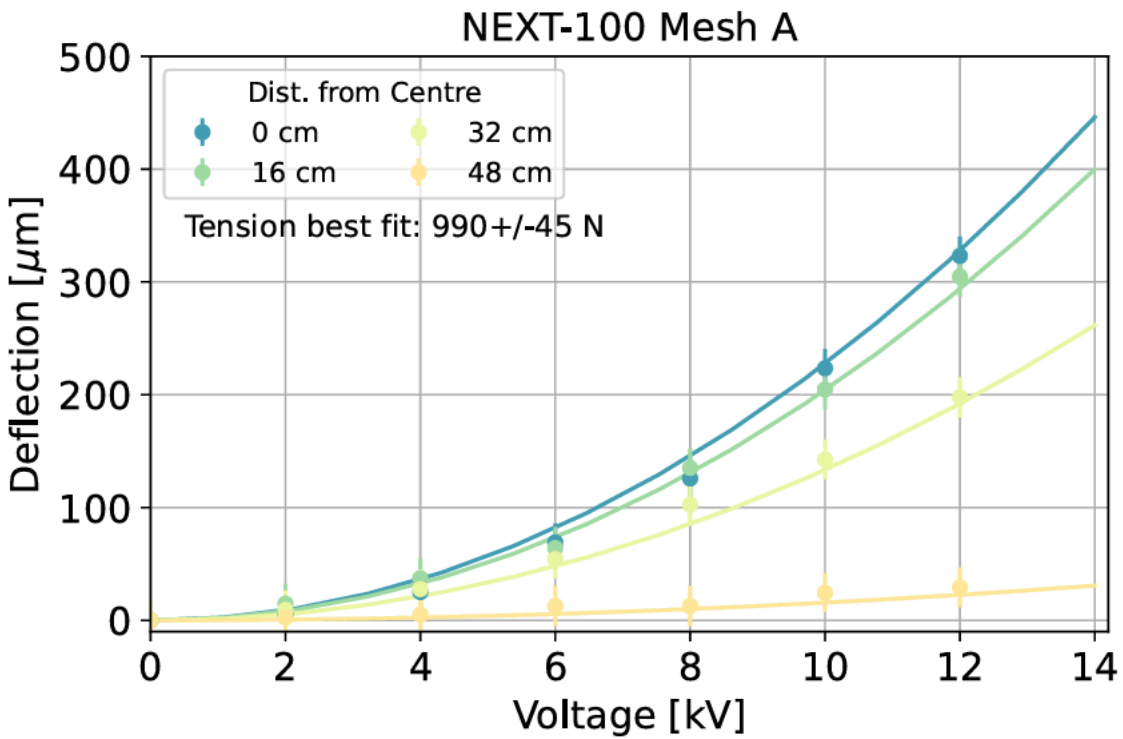
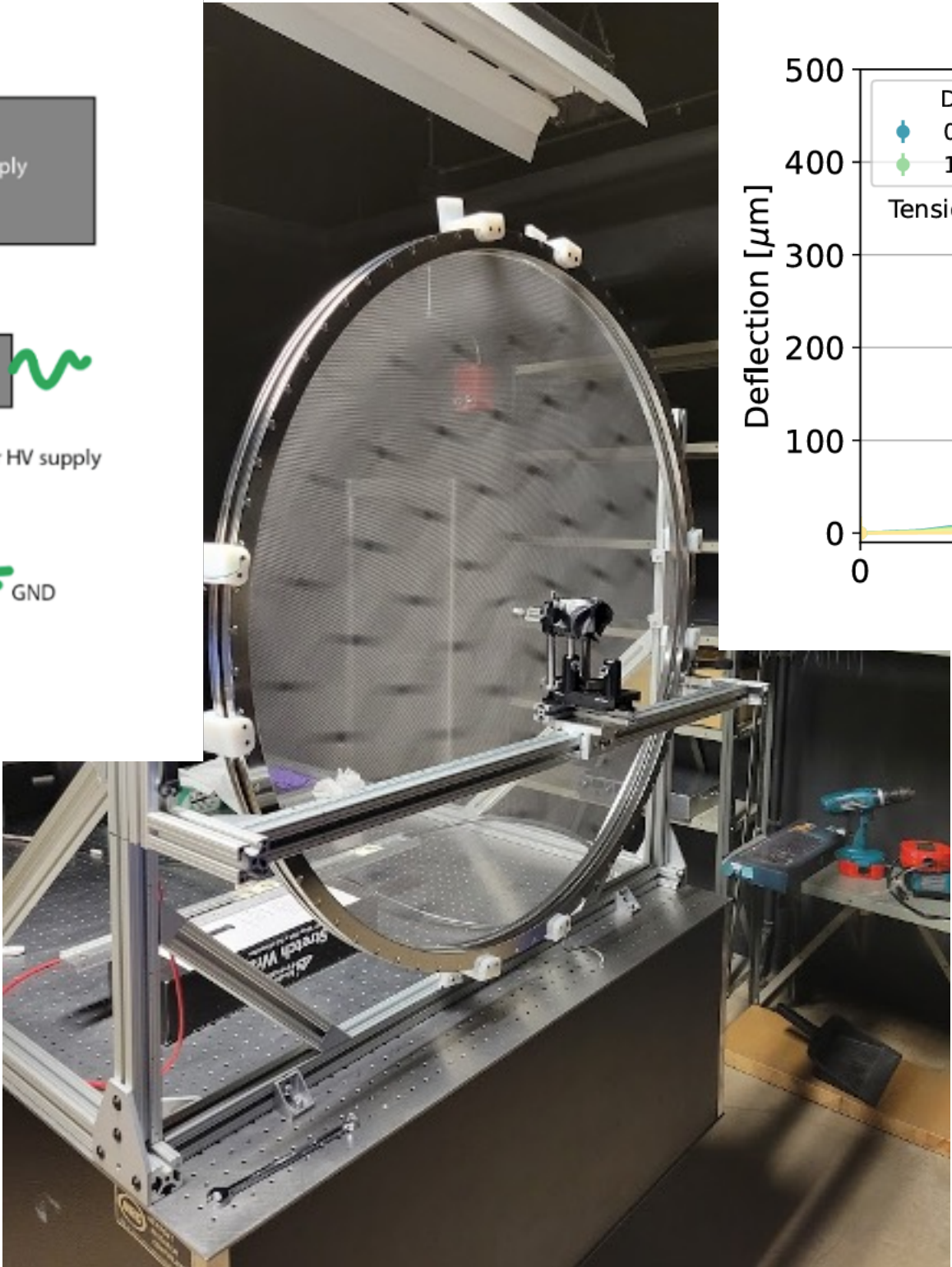
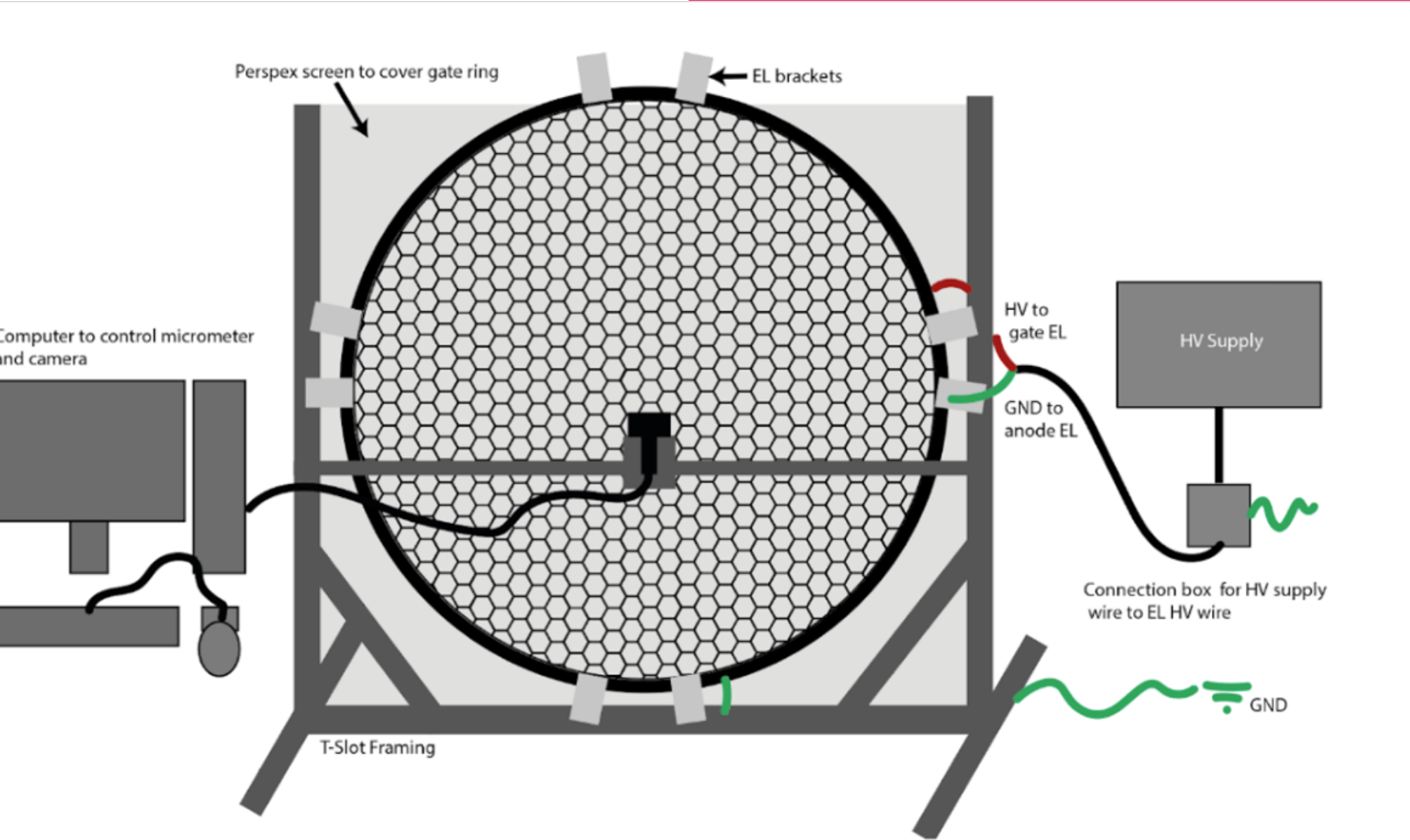
EL REGION, GATE AND ANODE, ARE BUILT WITH ELECTROFORMED MESH.
IT HOLDS ANY POSSIBLE SPARK WITHOUT DAMAGE AND PREVENTS TOO MUCH DEFORMATION UNDER ELECTRIC FIELD
RINGS ARE MADE OF SILICON BRONZE, HARD MATERIAL BUT MORE RADIO PURE THAN STEEL.



The NEXT-100 detector assembly @ LSC



THE EL REGION WAS TESTED AND DEFORMATIONS WHERE MEASURED WITH A MICROSCOPE TO ENSURE PROPER TENSIONING OF THE MESHES.

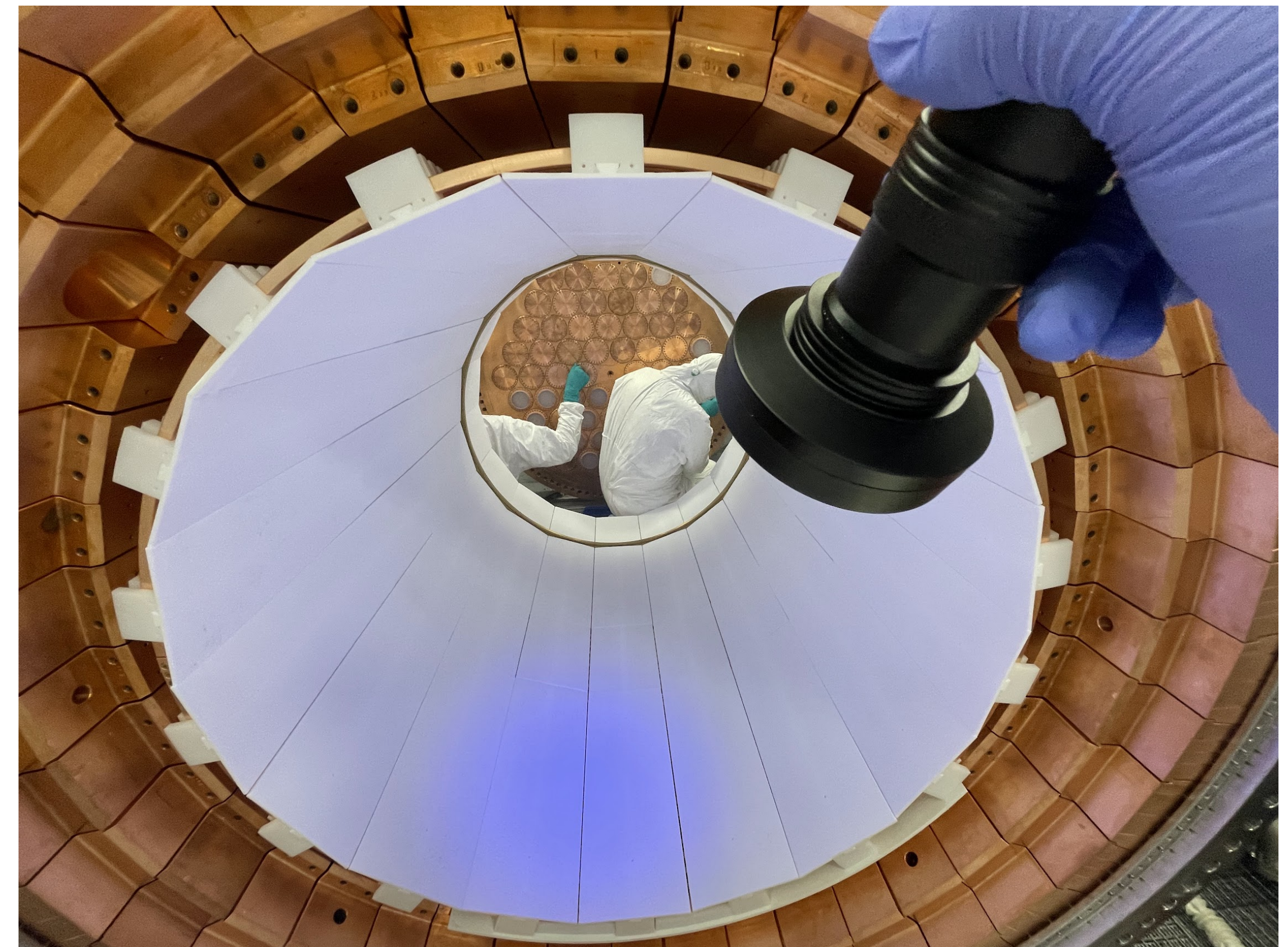


JINST 19 (2024) 02, P02007

The NEXT-100 detector assembly @ LSC



LIGHT TUBE FOR NEXT-100 IS CREATED BY A SERIES OF TEFLON PANELS COATED WITH TPB SLID INTO THE FIELD CAGE SUPPORT BARS.



The NEXT program



Prototypes
2010-2014

Demonstration of detector concept

~1 kg

NEXT-White
2015-2021

Background model assessment
 $2\nu\beta\beta$ measurement for ^{136}Xe

~5 kg

NEXT-100
2022-2026

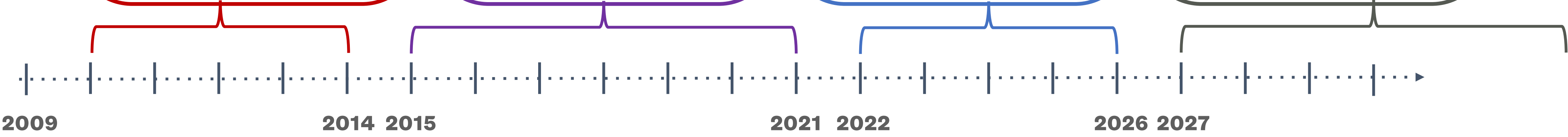
Neutrinoless double beta decay
search in ^{136}Xe (10^{27} y)

~100 kg

**NEXT-HD
NEXT-BOLD**

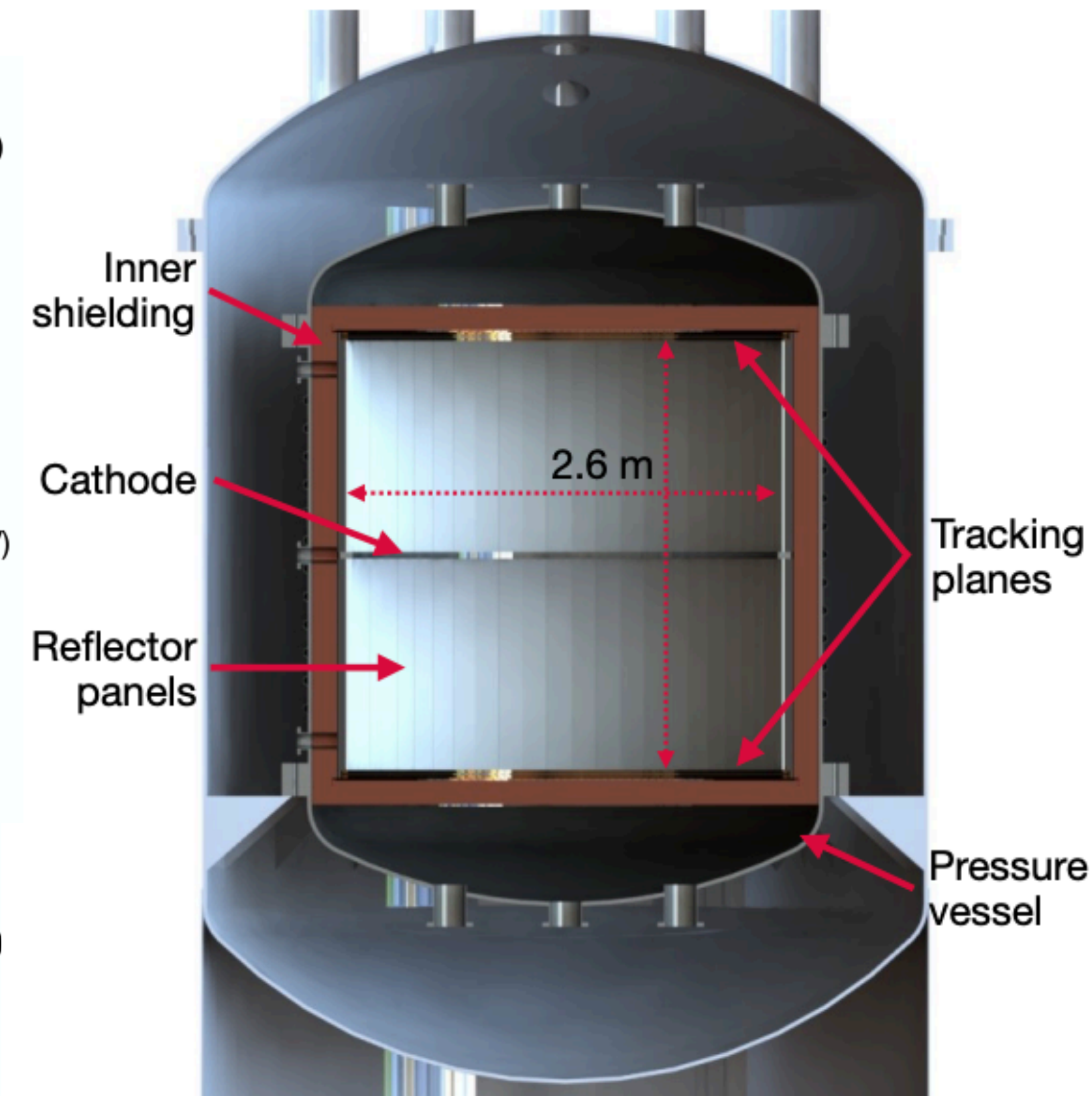
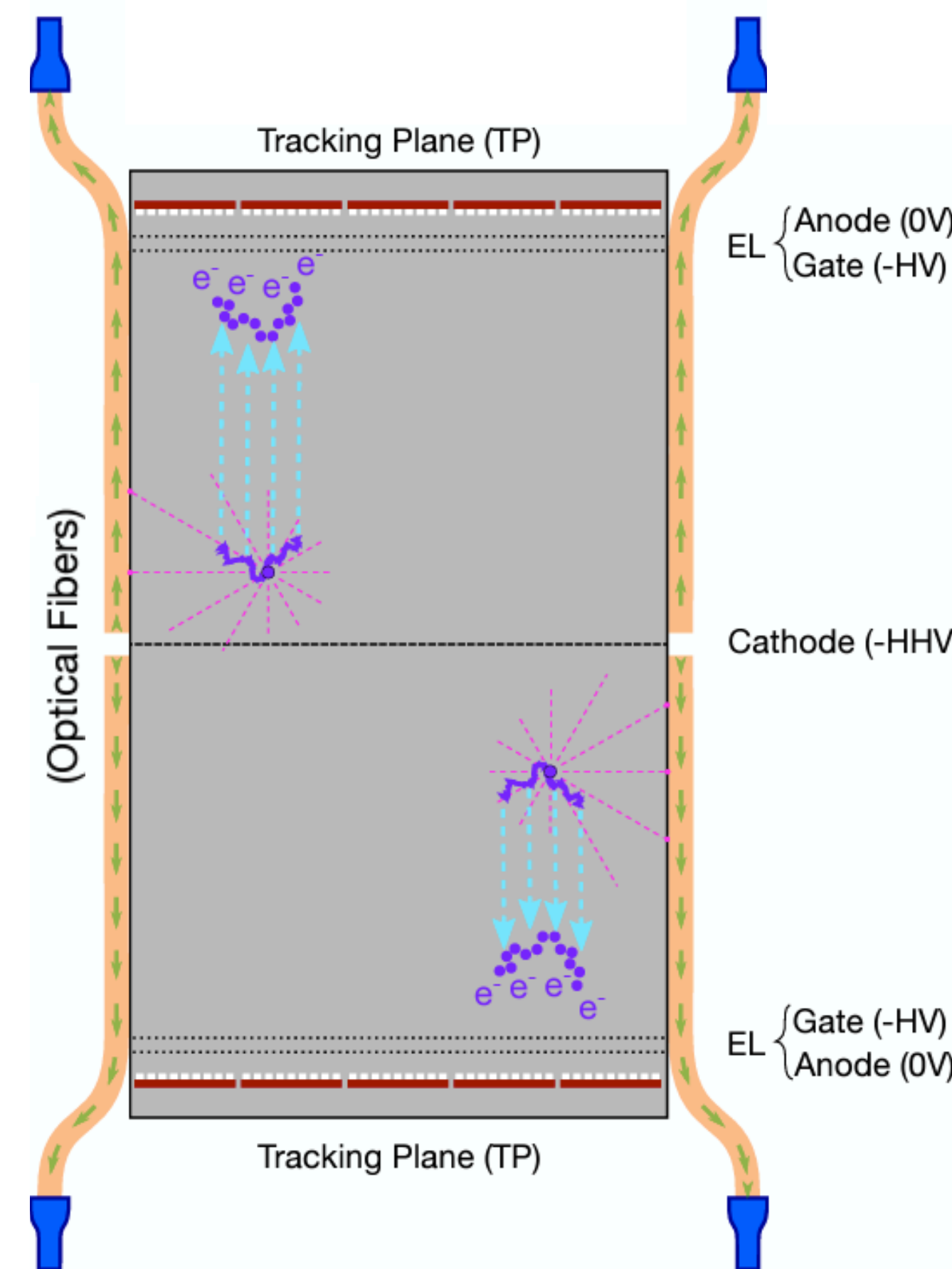
Ton-scale and barium tagging for
background-free experiment in
 ^{136}Xe (10^{28} y)

1 Tonne

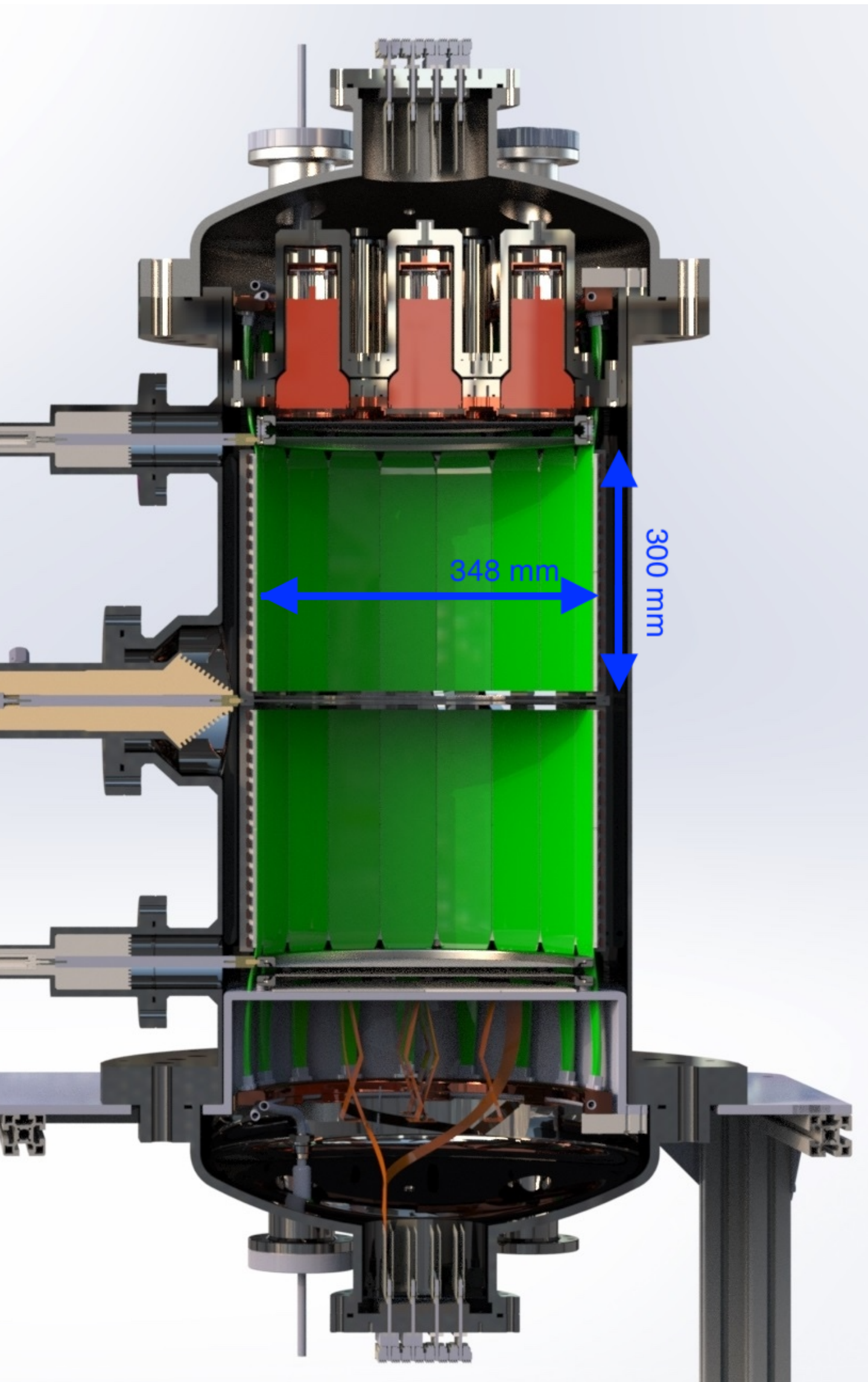


NEXT-HD

- **Multi-module system** with first 1-ton module at Laboratorio Subterráneo de Canfranc
- Use of **gas additives** (eg, ^4He) to reduce diffusion
Nucl.Instrum.Meth.A 905 (2018) 82-90; JHEP 01 (2019) 027; JINST 14 (2019) P08009; JHEP 04 (2020) 034)
- Potential for **^3He doping** to reduce cosmogenic ^{137}Xe backgrounds
J.Phys.G 47 (2020) 7, 075001
- Estimated background **0.09 to 0.27 ct** [ton yr ROI]-1
JHEP 2021 (2021) 08, 164
- **Baseline concept**
 - Symmetric TPC with central cathode
 - Dense SiPM plane readout
 - Optical fibers around barrel for energy measurement



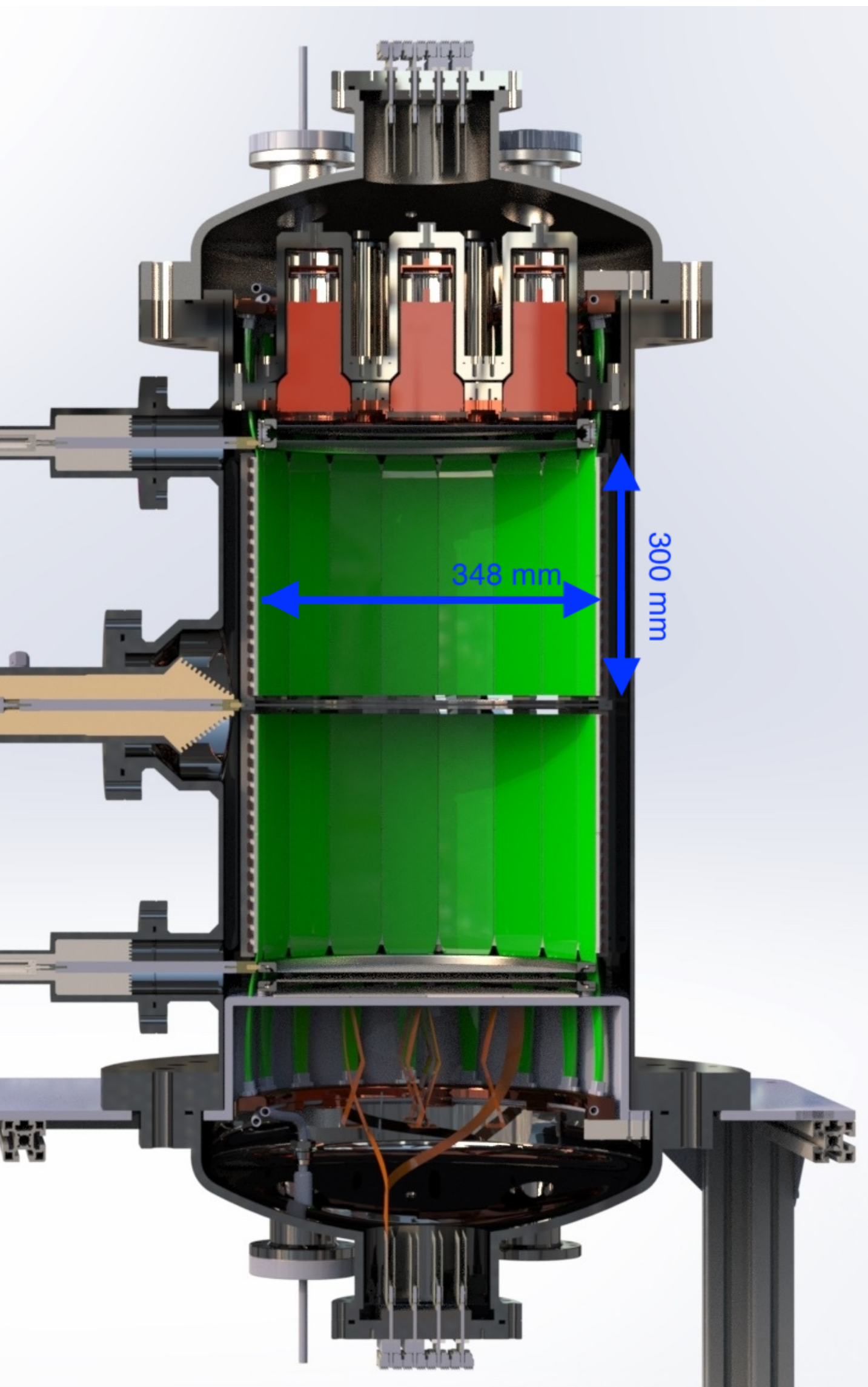
R&D: DEMO-HD



A new prototype aiming to test the different solutions to be implemented in the tonne scale detector is being design and will be built at DIPPC

DEMO-HD will allow to test under realistic conditions the proposed technical solutions for the NEXT-HD detector, mainly fibre read-out and dense SiPM tracking planes

R&D: DEMO-HD

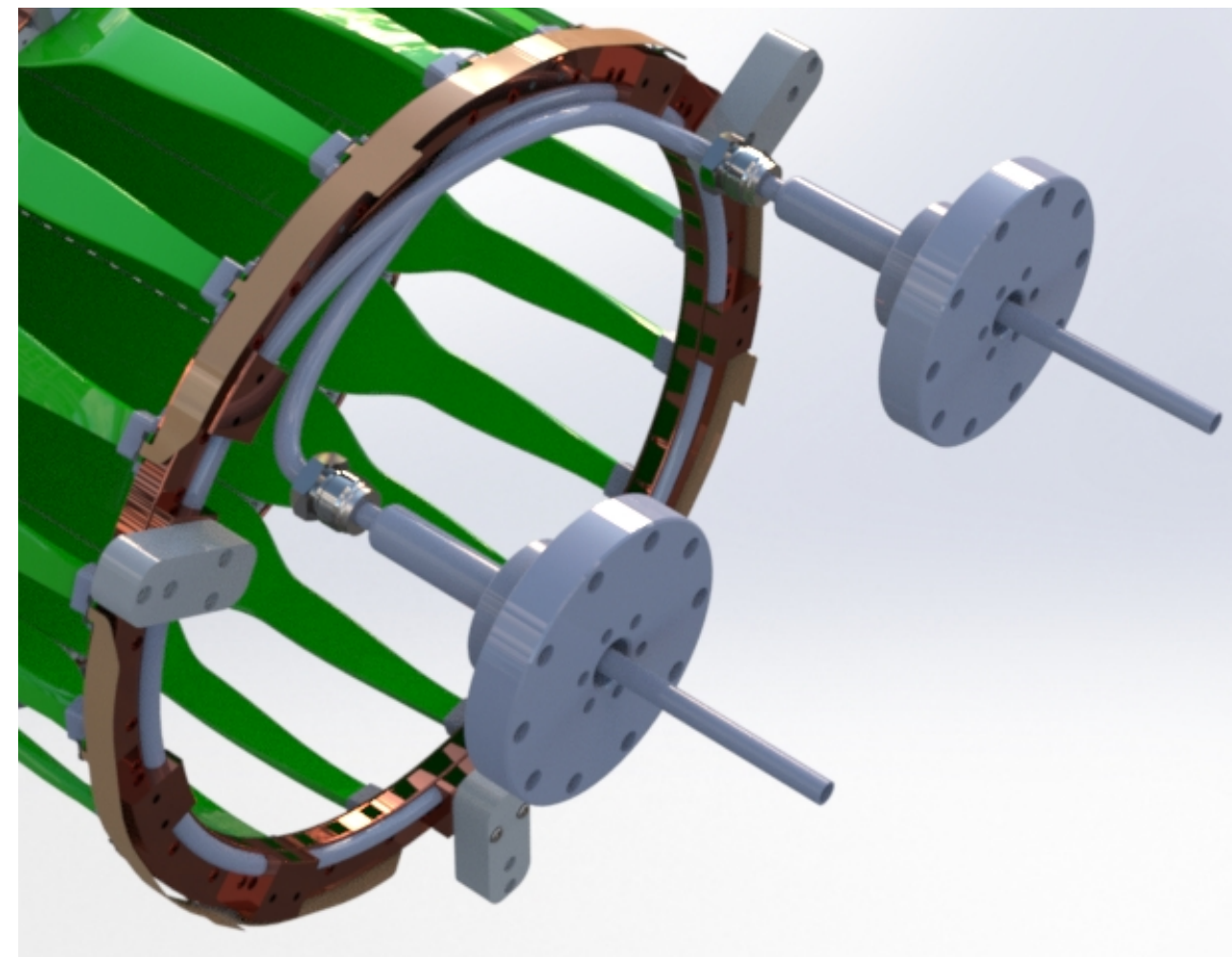


Aiming to test new light collection techniques to allow reduced radioactive budget.

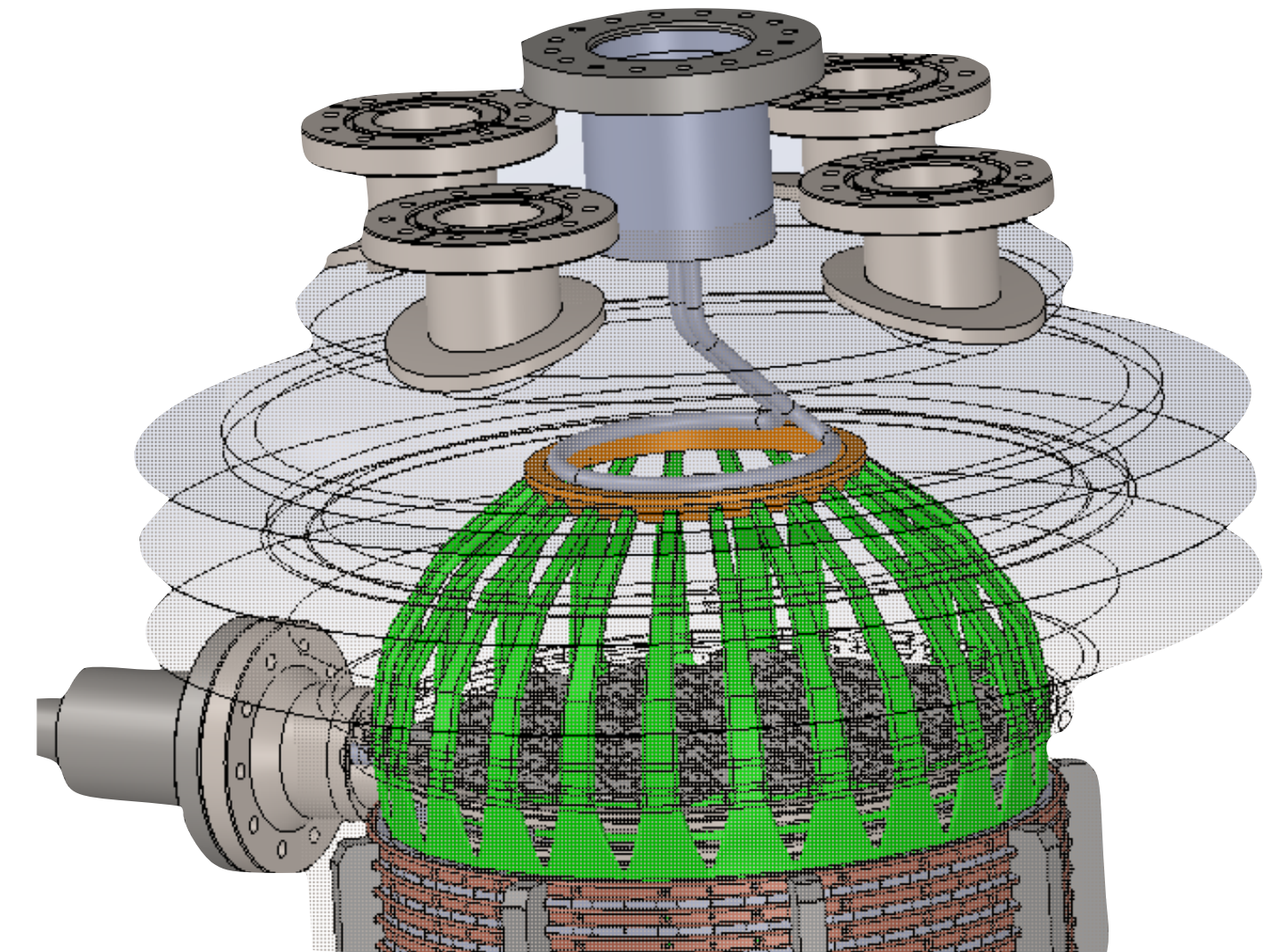
Use of wavelength shifting fibers to collect light

Use SiPMs to detect fibers light.

SiPMs need to be cooled to be sensitive to S1.



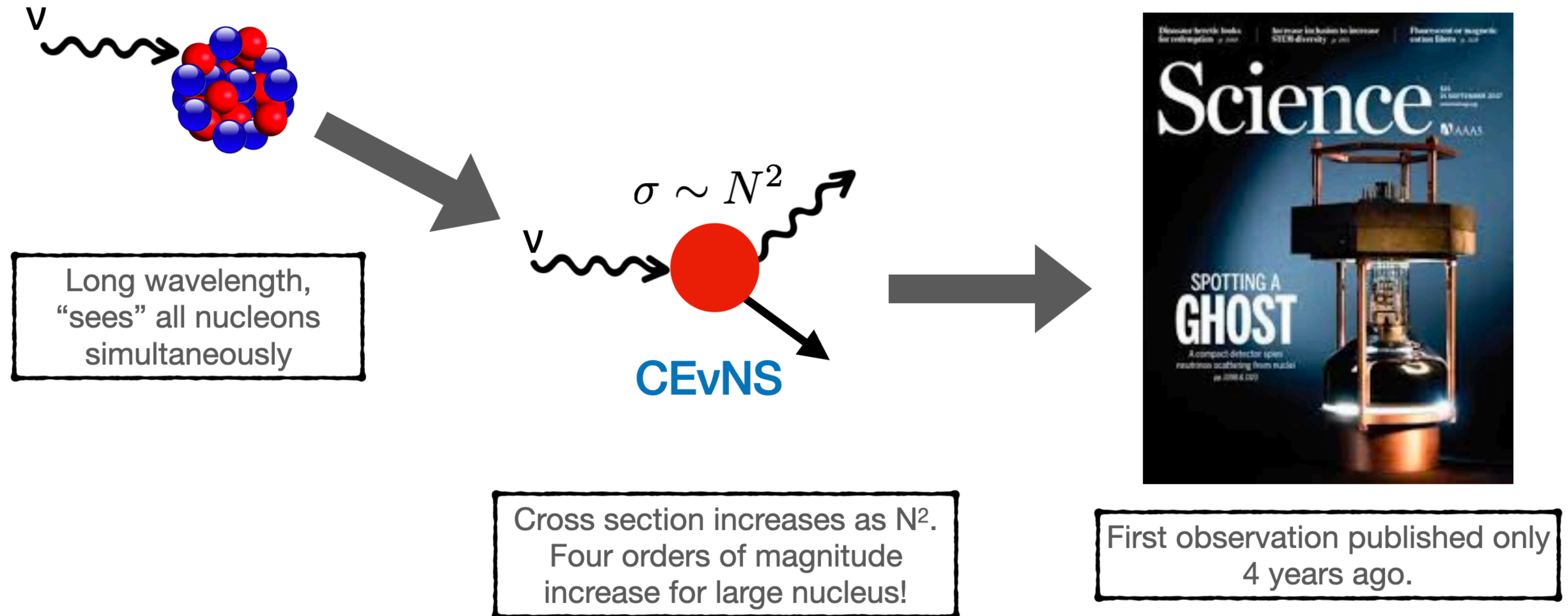
Cooling system into the vessel at pressure
in thermal contact with the SiPMs



Coupling of the fibers to the SiPMs

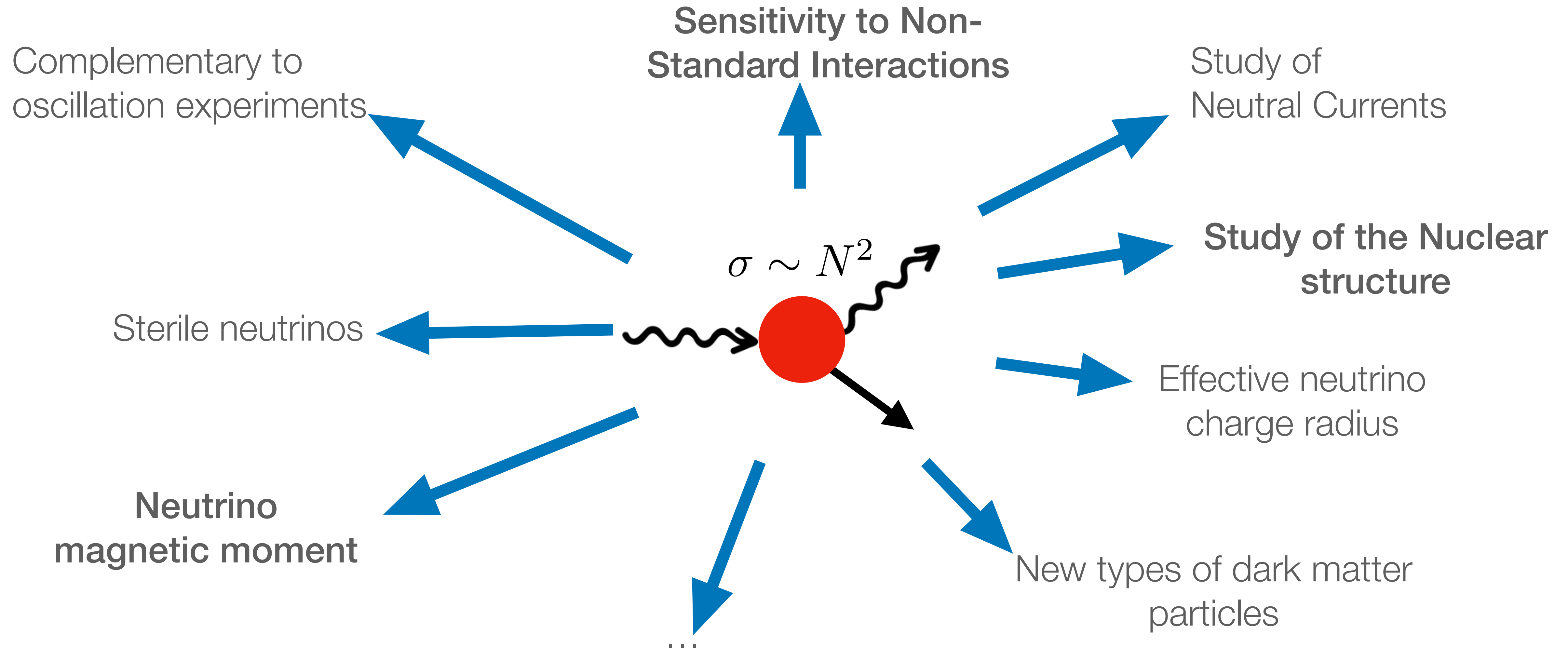
Coherent Elastic Neutrino-nucleus scattering

Coherent Elastic Neutrino-nucleus scattering



Coherent Elastic Neutrino-nucleus scattering

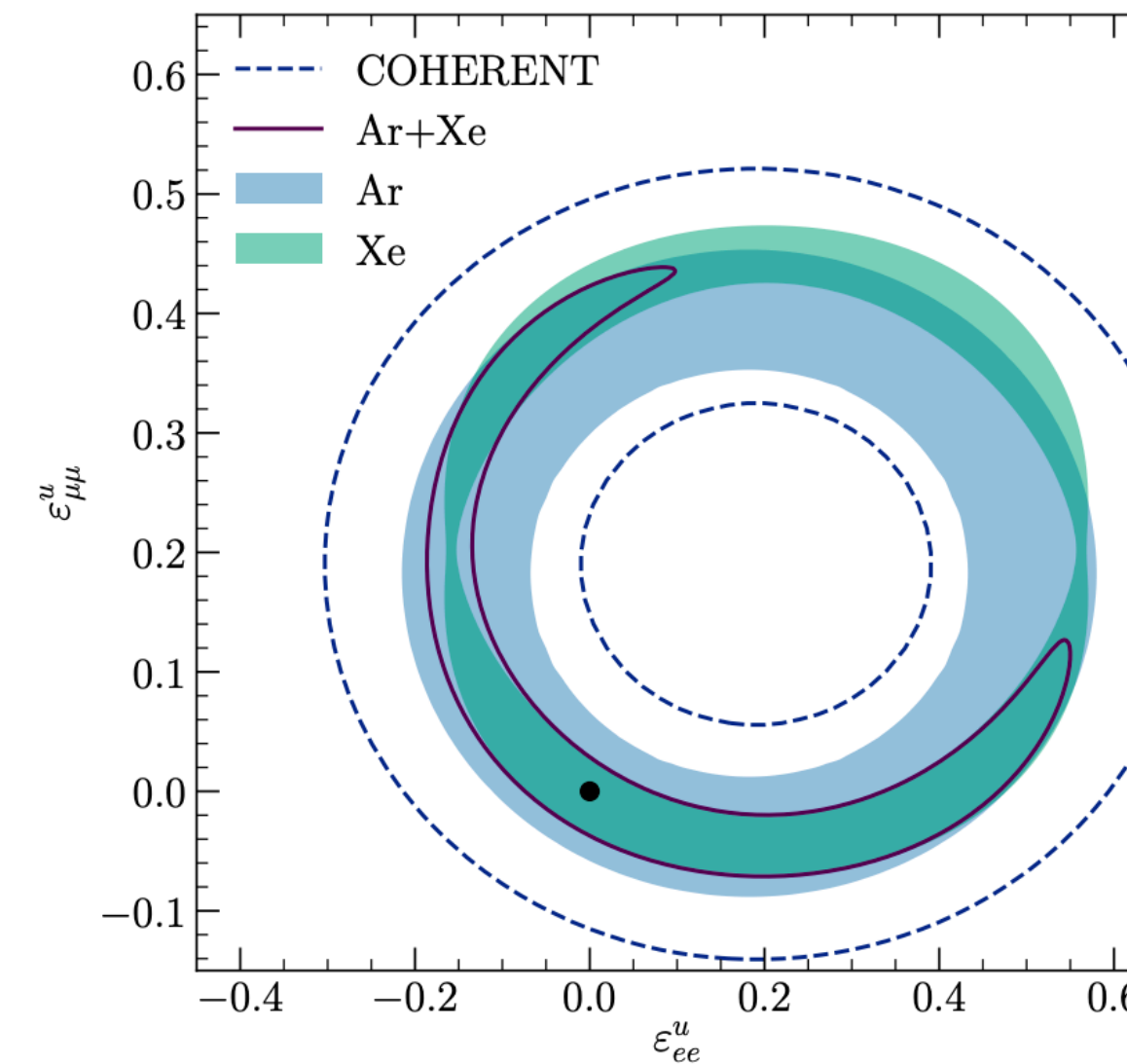
Very rich physics



Gaseous detectors?

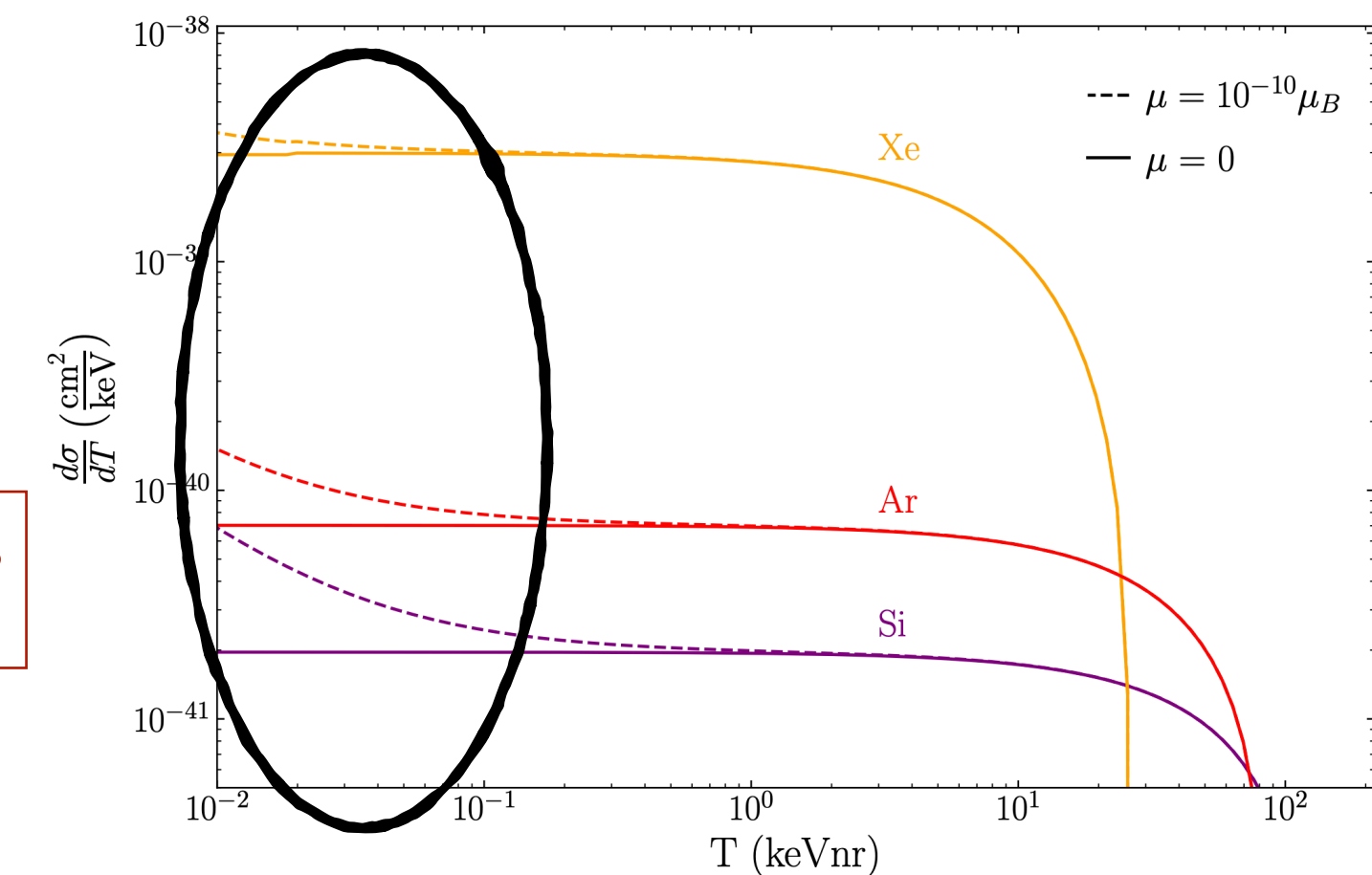
High pressure gaseous detectors have other advantages:

- Simpler, no need of a cryogenic system.
- Larger EL amplification: Signals as low as 1-2 ionized electrons can be detected. This reduces the expected energy threshold to less than 1 keVee.
- Allow to operate with different nuclei in the same set-up with minimal increase of the costs.



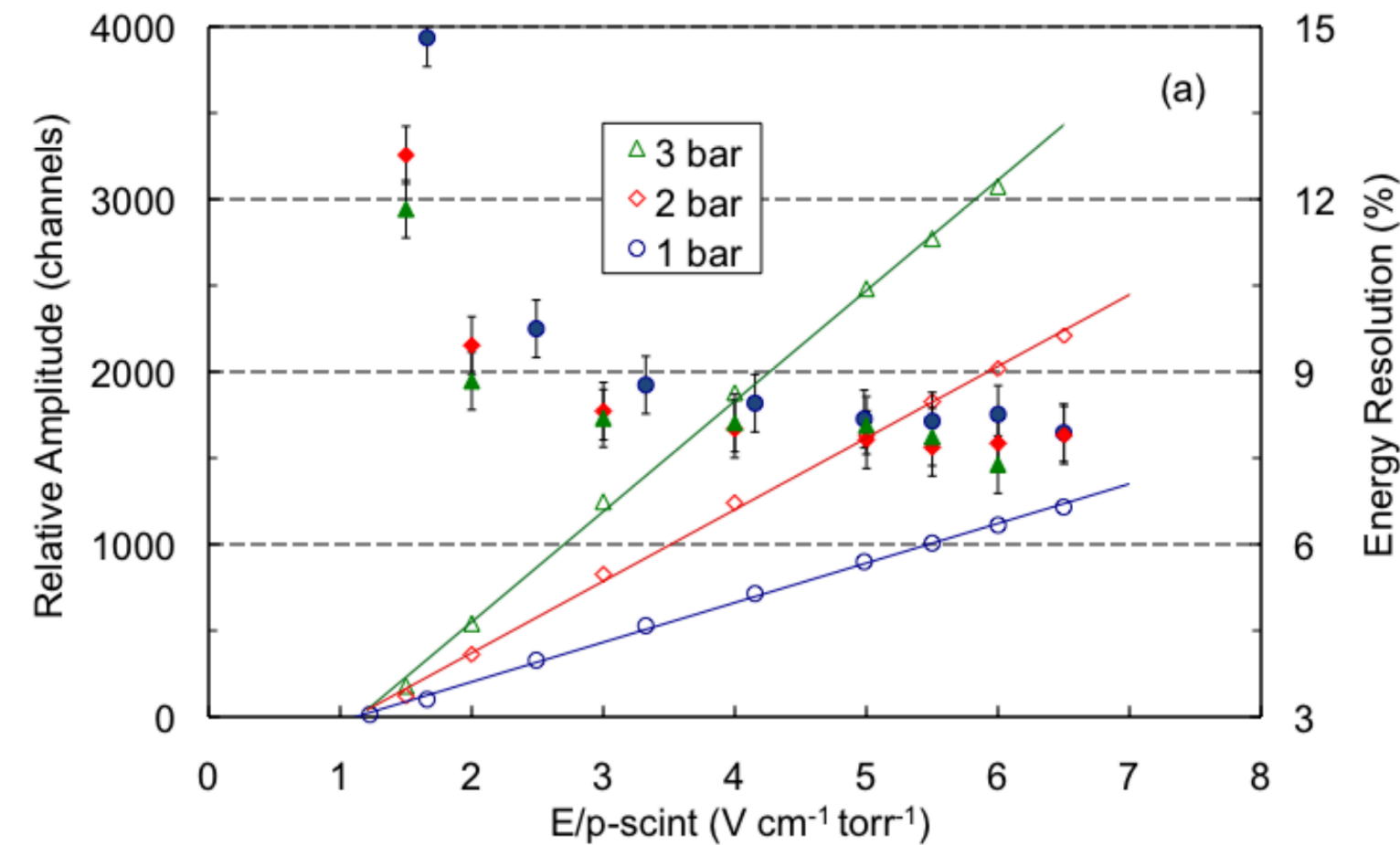
Sensitivity to non-standard neutrino interaction for a detector running with Xe only, Ar only, and a combination of both

Interesting physics at low energies

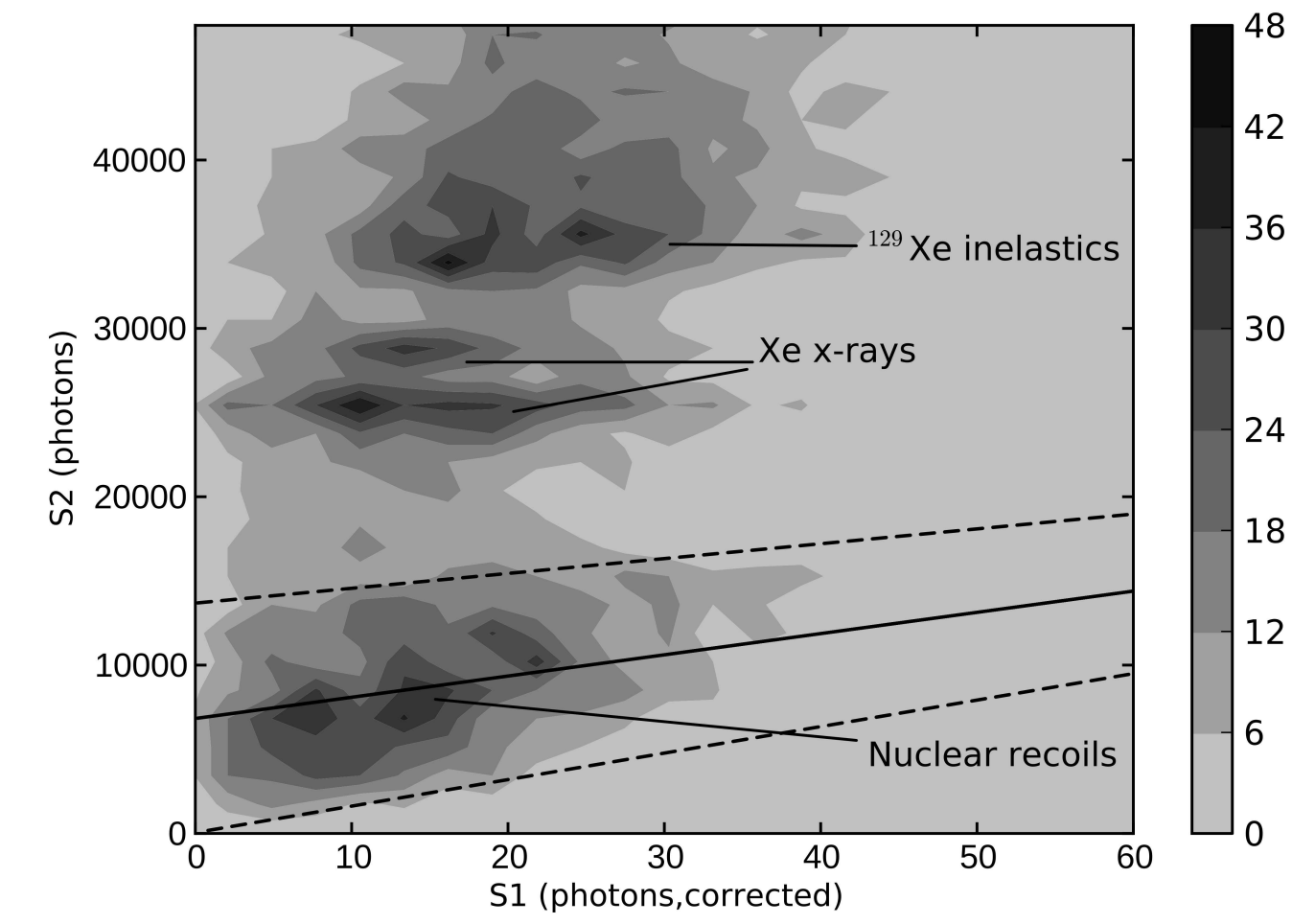


Gaseous detectors?

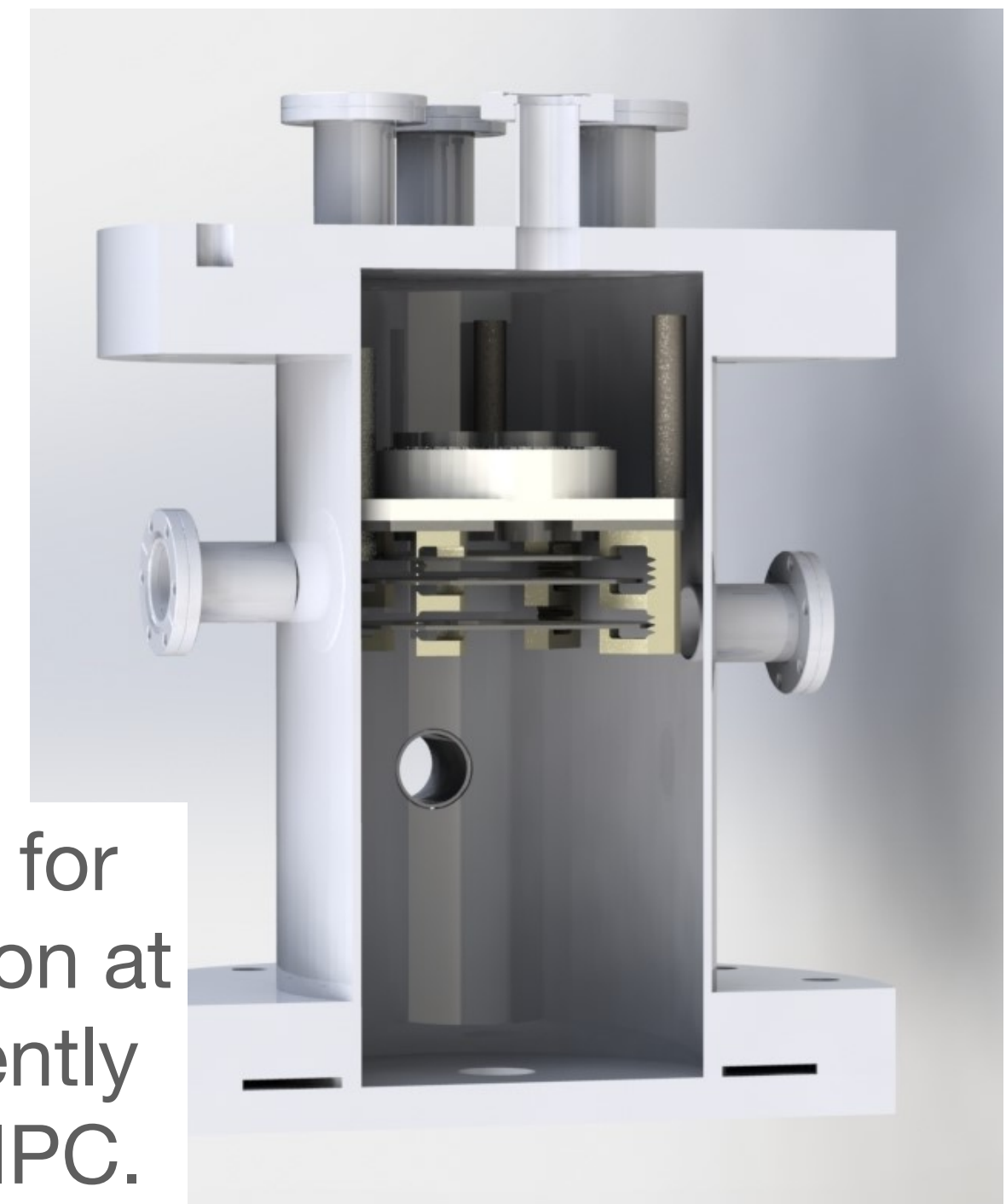
- Electroluminescence amplification increases with pressure. Signals as low as 1-2 ionized electrons can be detected. This reduces the expected energy threshold to less than 1 keVee.
- We'll also need larger voltages.
- Dedicated studies of the response of gaseous detectors to few-keV nuclear recoils will be necessary to reduce the present uncertainty on the quenching factor.
- A dedicated set-up is operated at DIPC that will also serve to test the technology at very low energies and take decision for the large detector.
- Optimisation of the optics for different emission spectra needed to operate with different gases.
- R&D for very high pressures will allow to increase the mass in lighter gases.



Dependence of EL yield with the reduced field for different Xe pressures



S2 vs S1 signals in xenon gas.

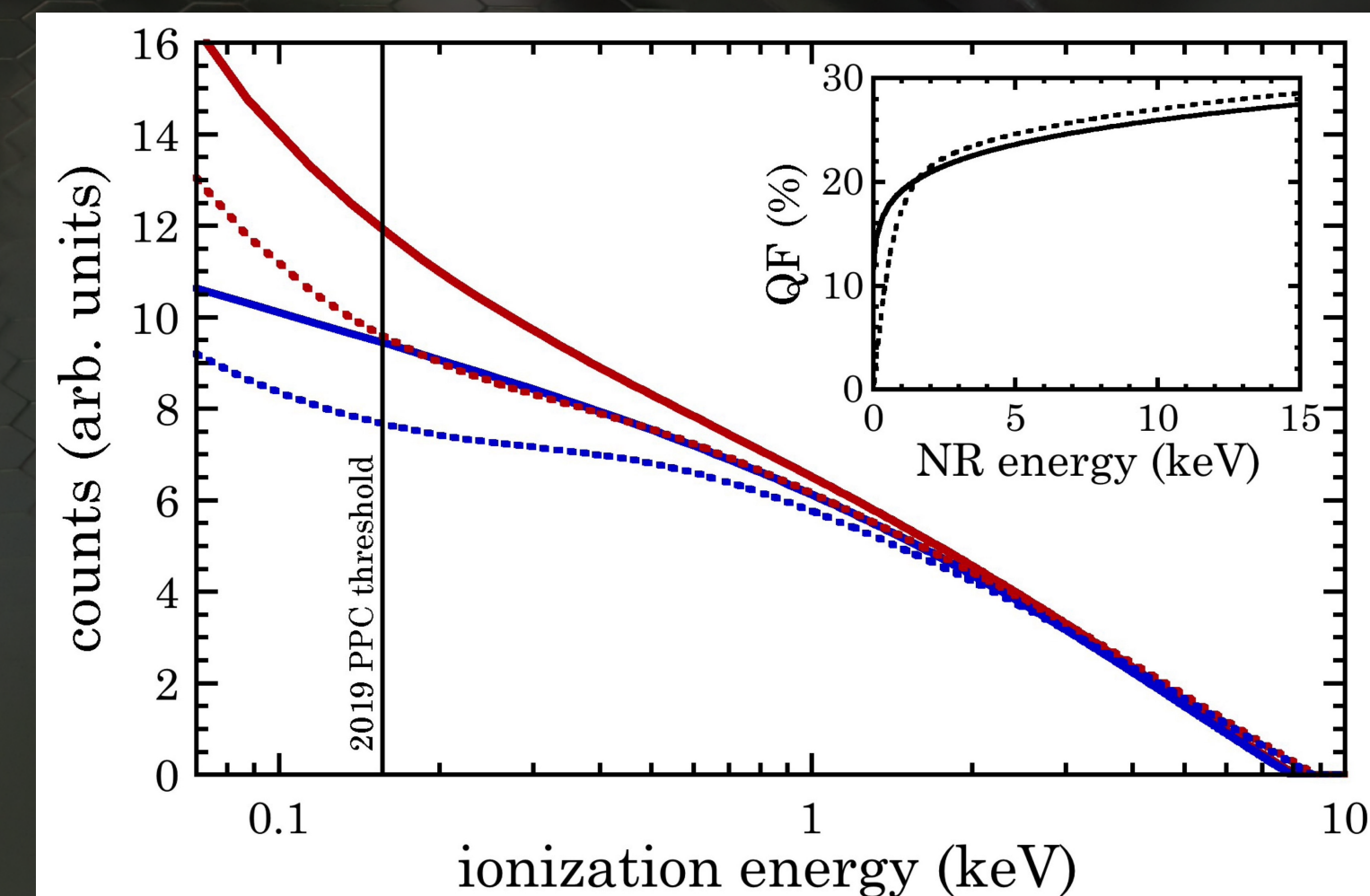
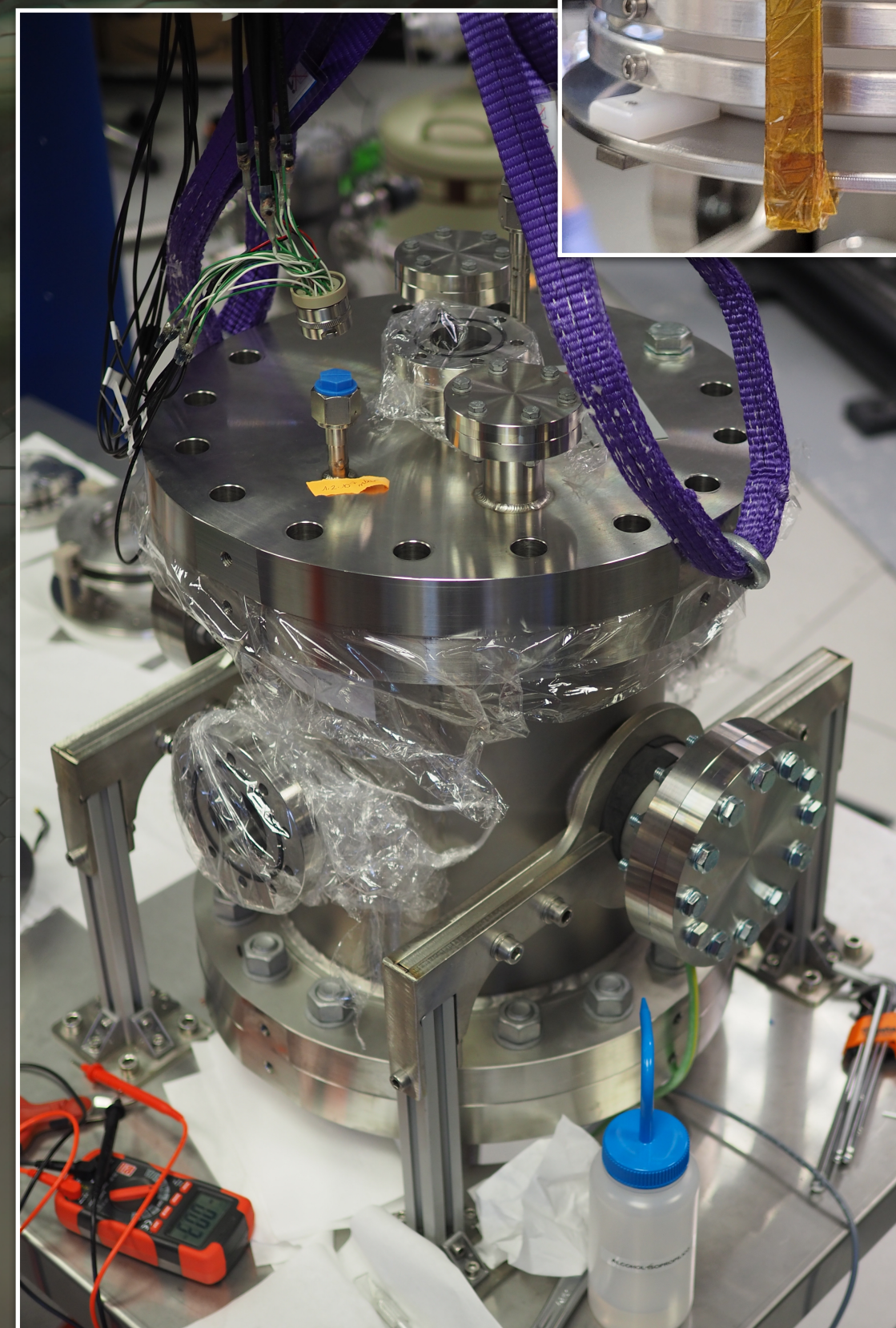
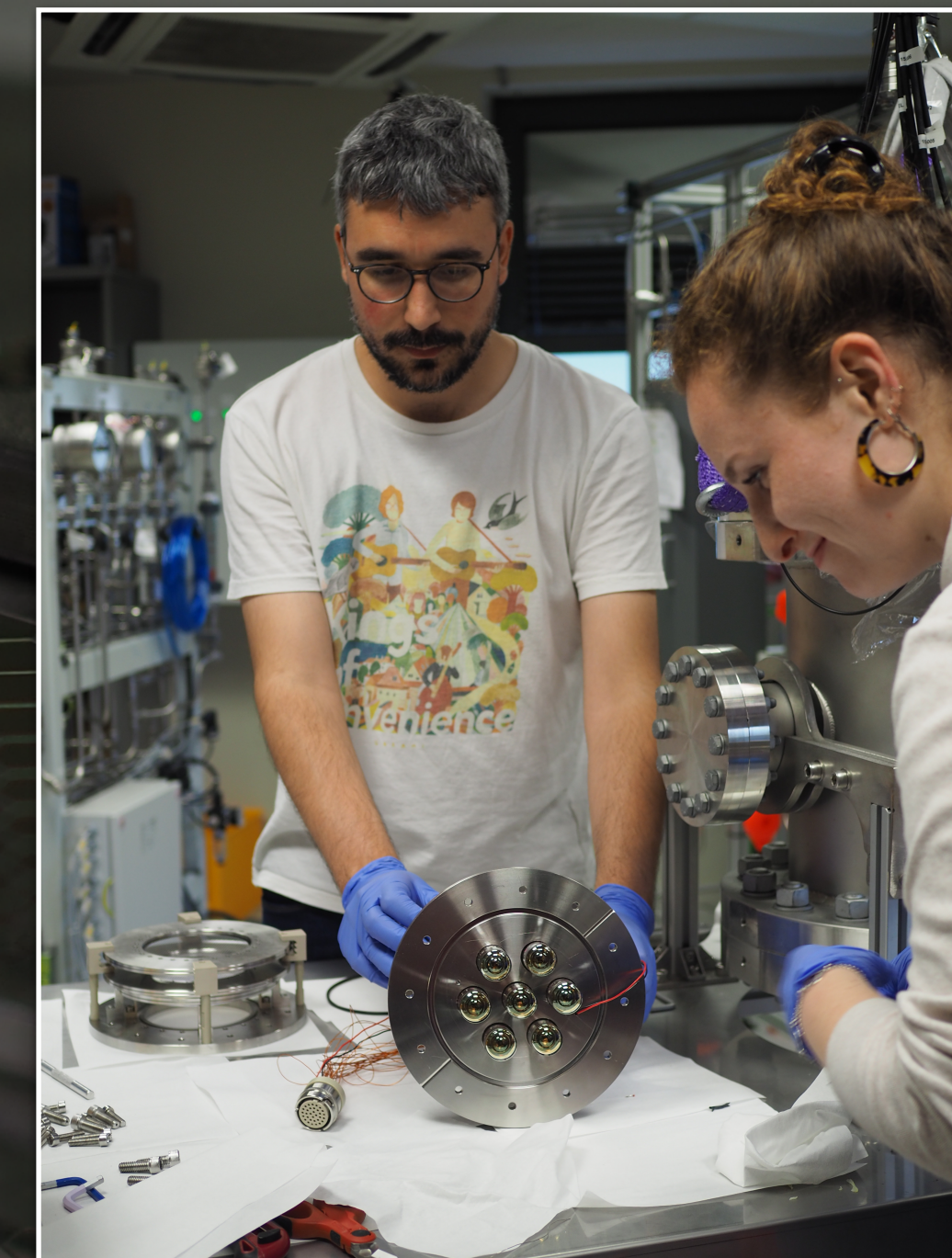
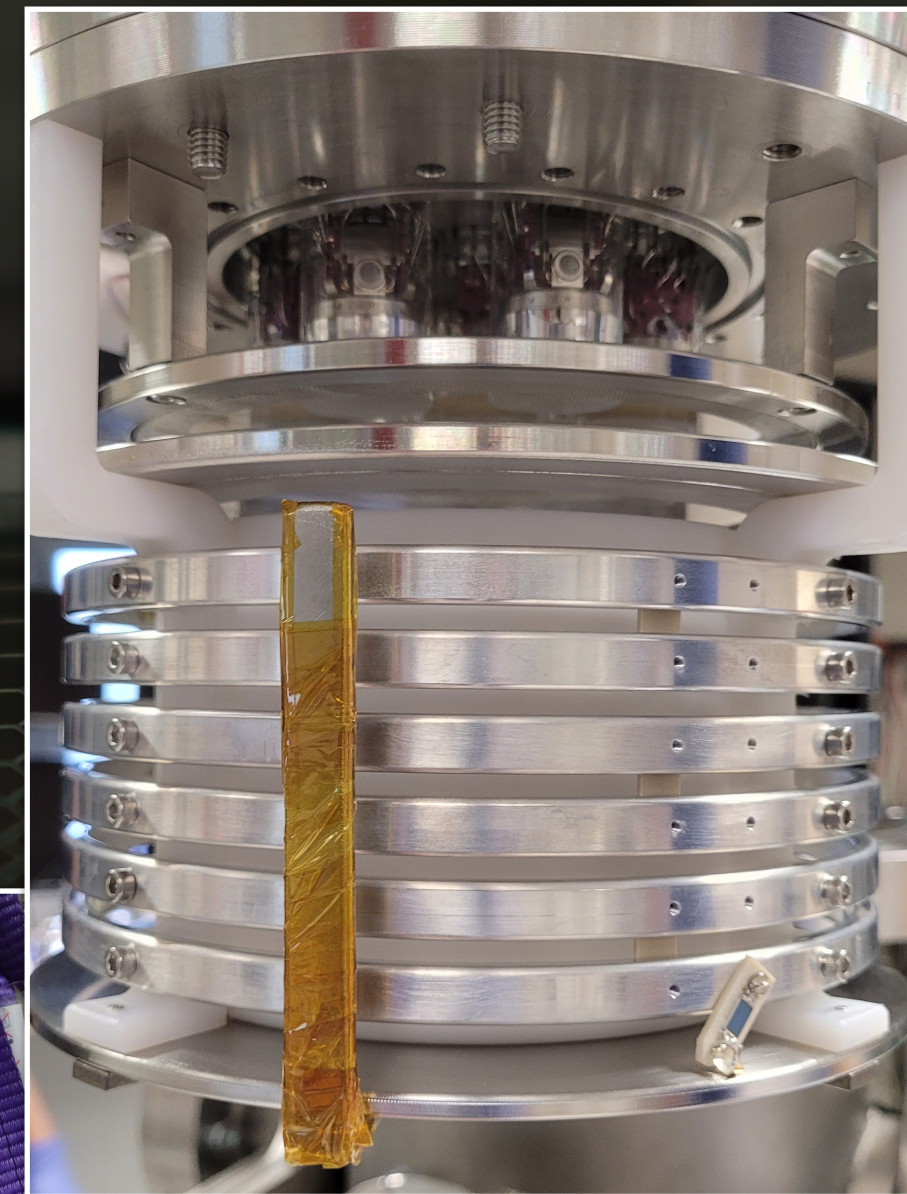


Dedicated set-up for the QF determination at low energies currently under design at DIPC.

GanESS project: GaP

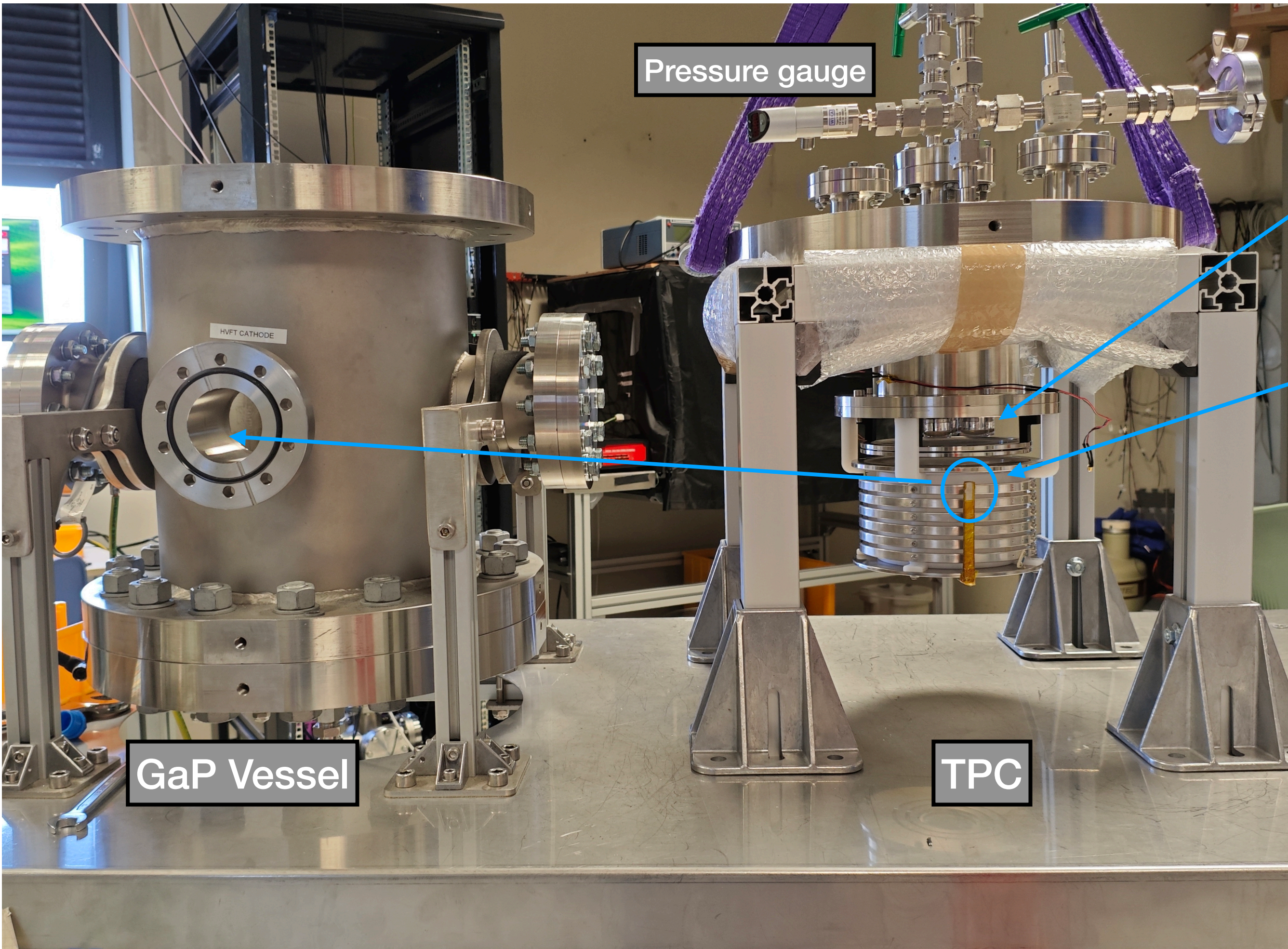
The Gaseous Prototype (GaP) system

- Opportunity to evaluate the technique in different conditions
 - Multiple noble gases: Xe, Ar, Kr.
 - Pressure up to 50 bar.
- Characterization of low-energy **response to nuclear recoils**
 - Quenching factor measurements.
 - Detection threshold.

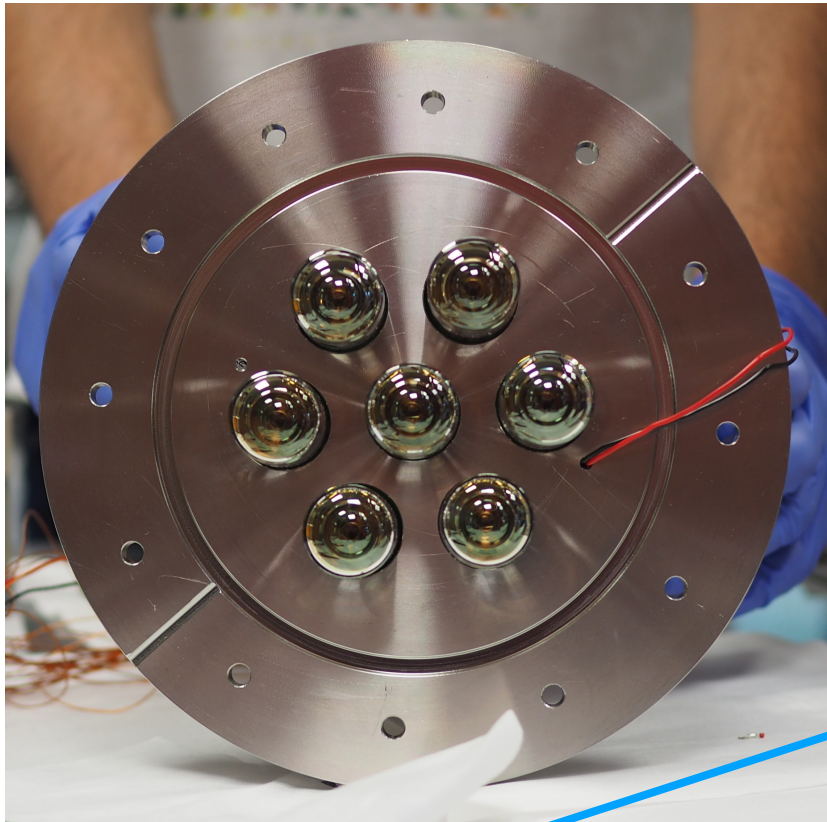


Differences in the expected distributions given different quenching factor models (solid/dashed)

Gaseous Prototype (GaP)



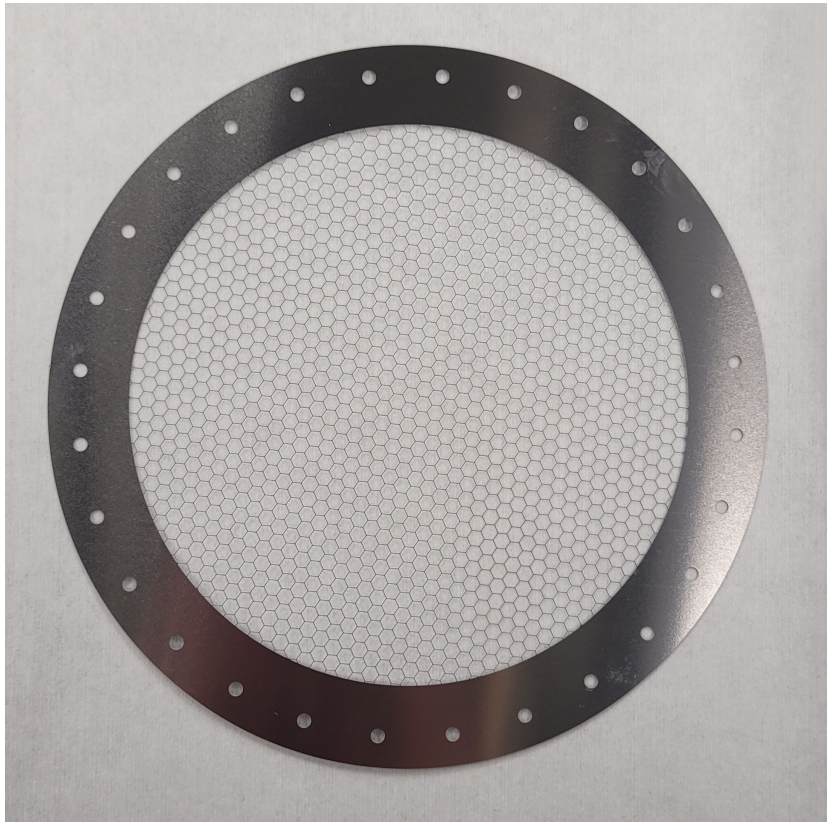
7 Hamamatsu R7378 PMTs



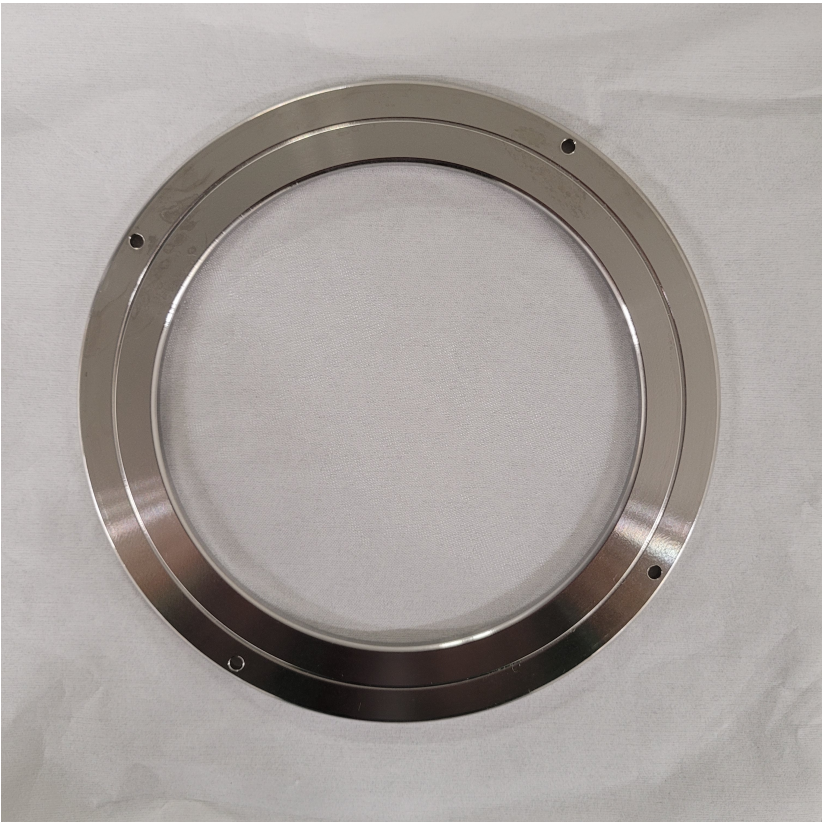
HVFT



Photochemical etched mesh:
75 μm thick
(0.89 transparency)

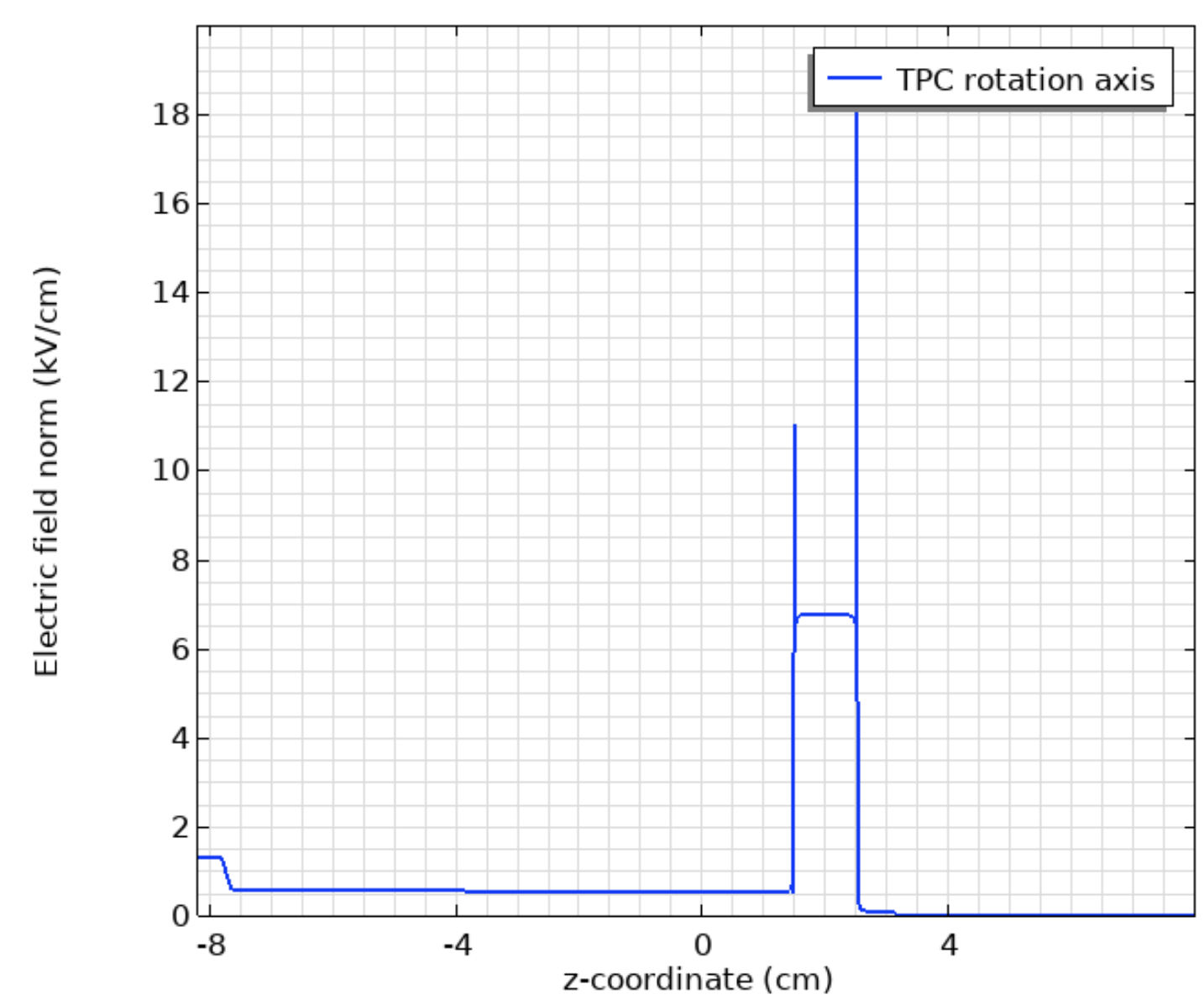
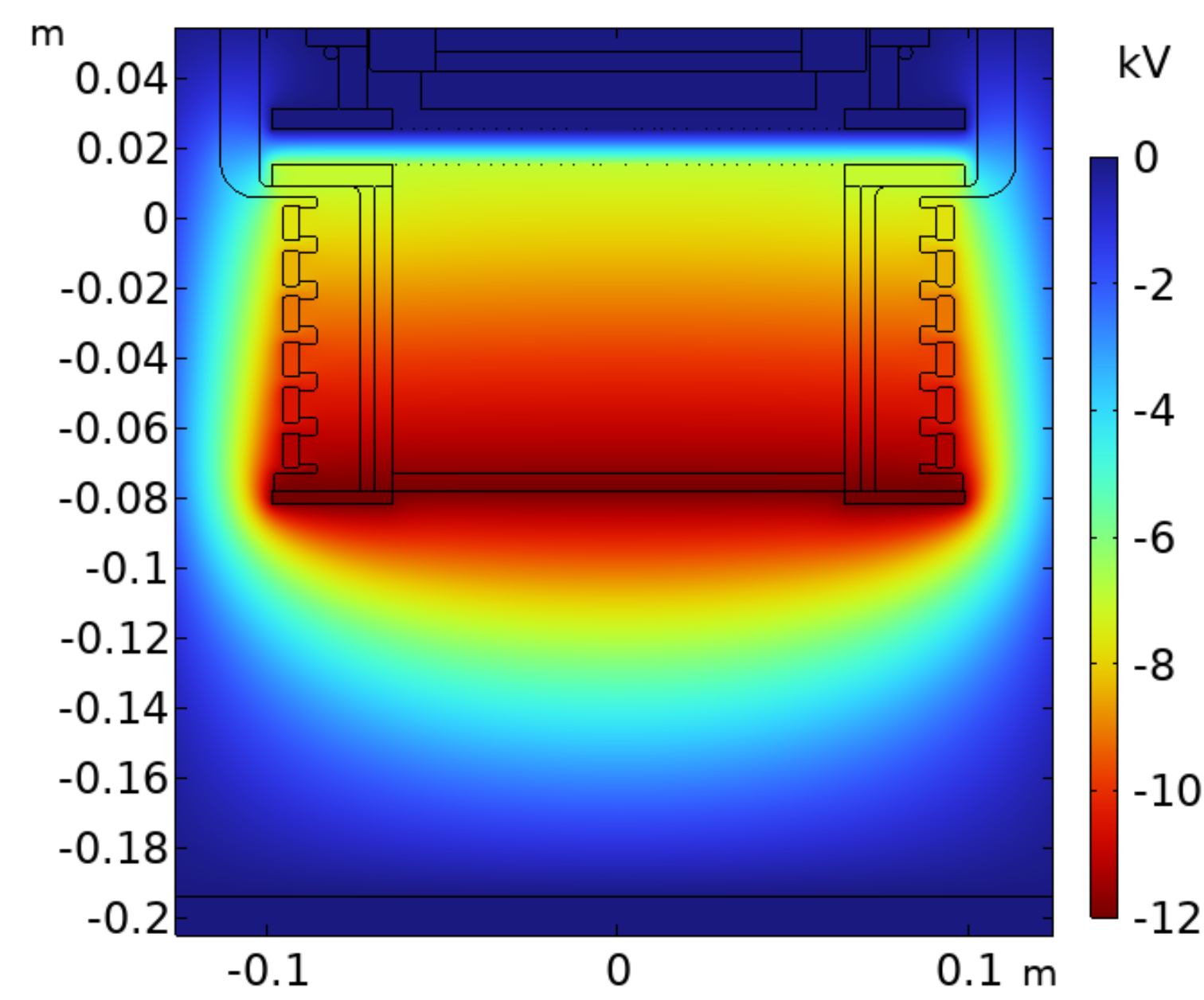
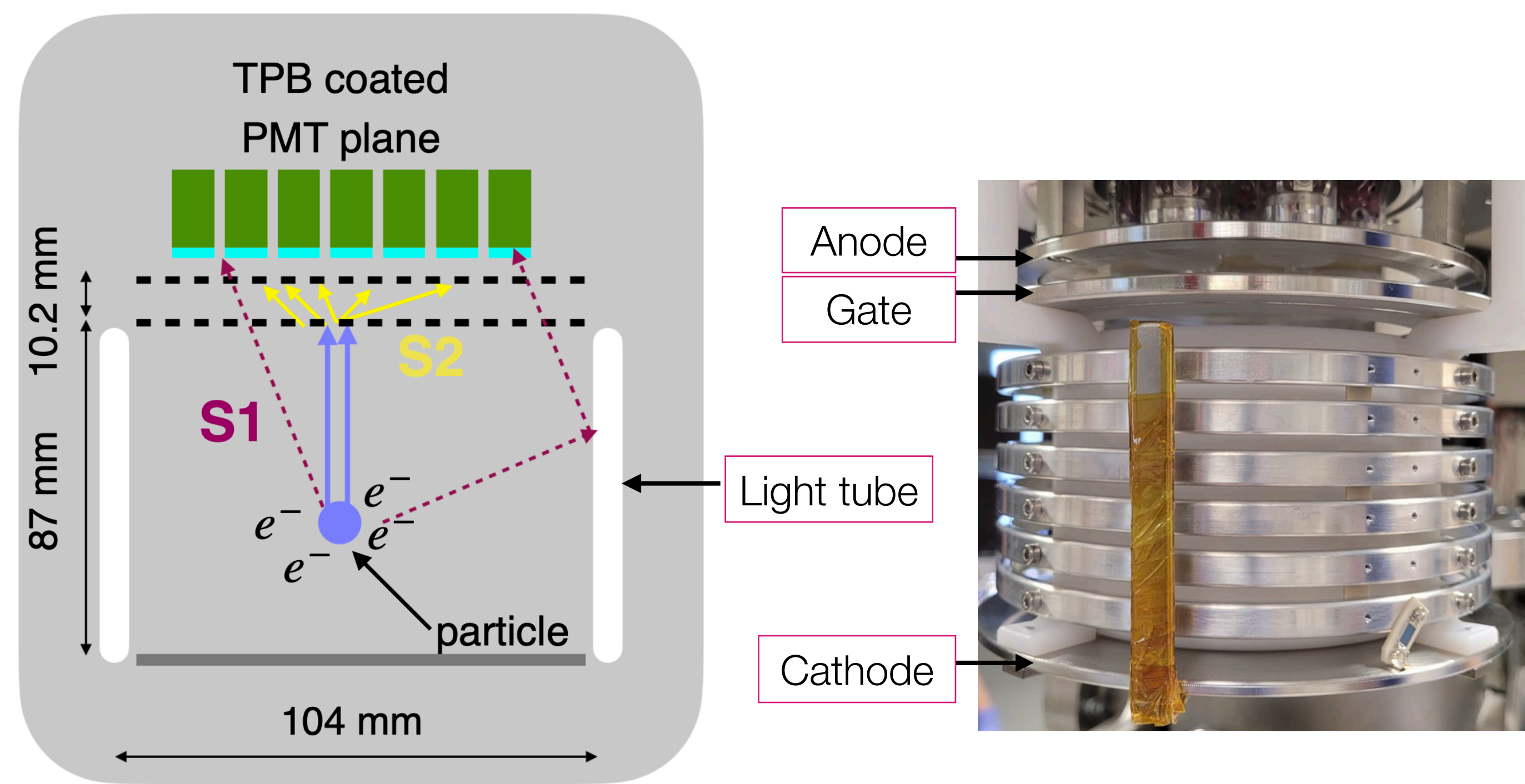


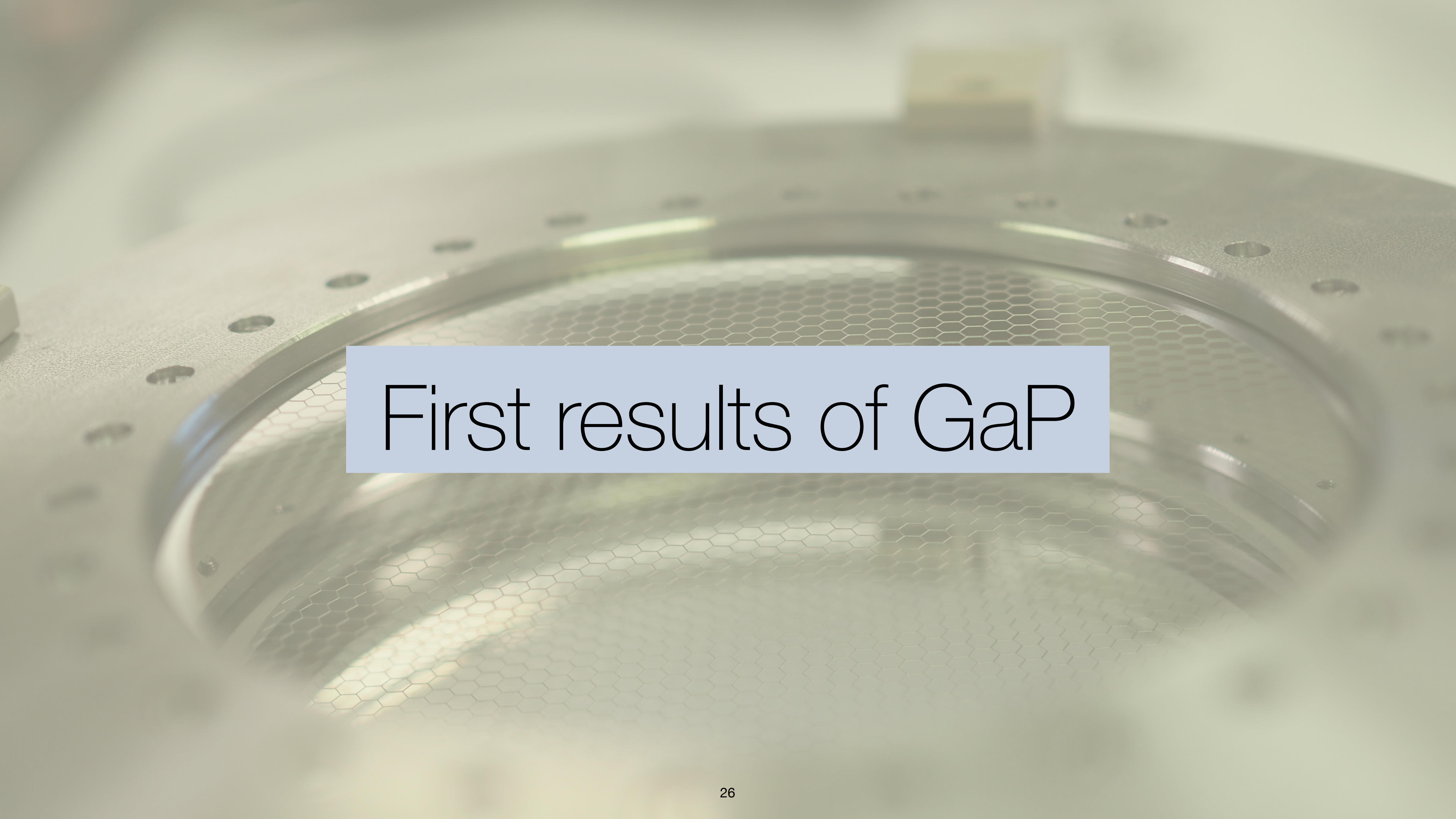
Thin wire mesh:
50 μm thick
(0.81 transparency)



GaP: time projection chamber

Concept



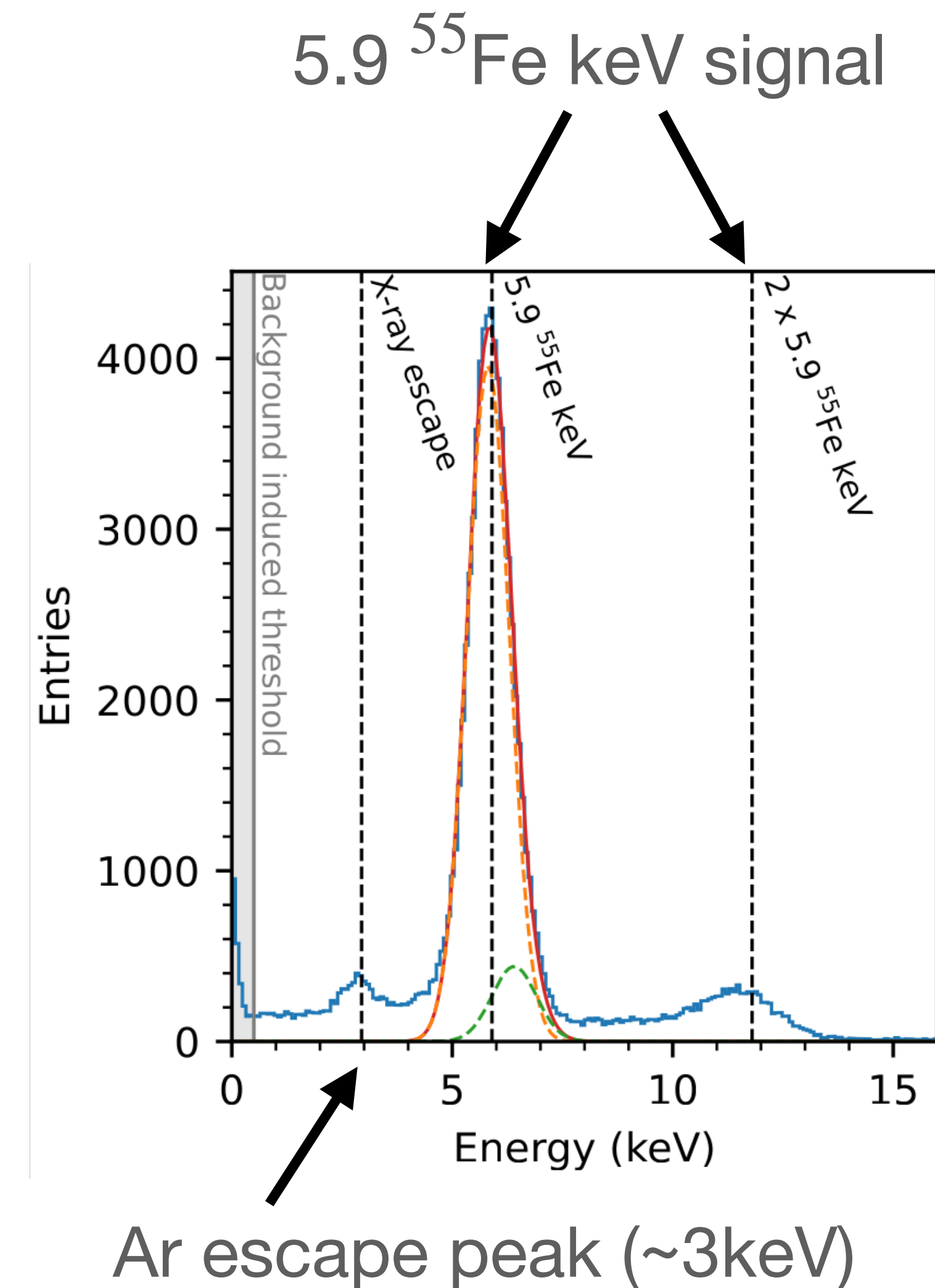
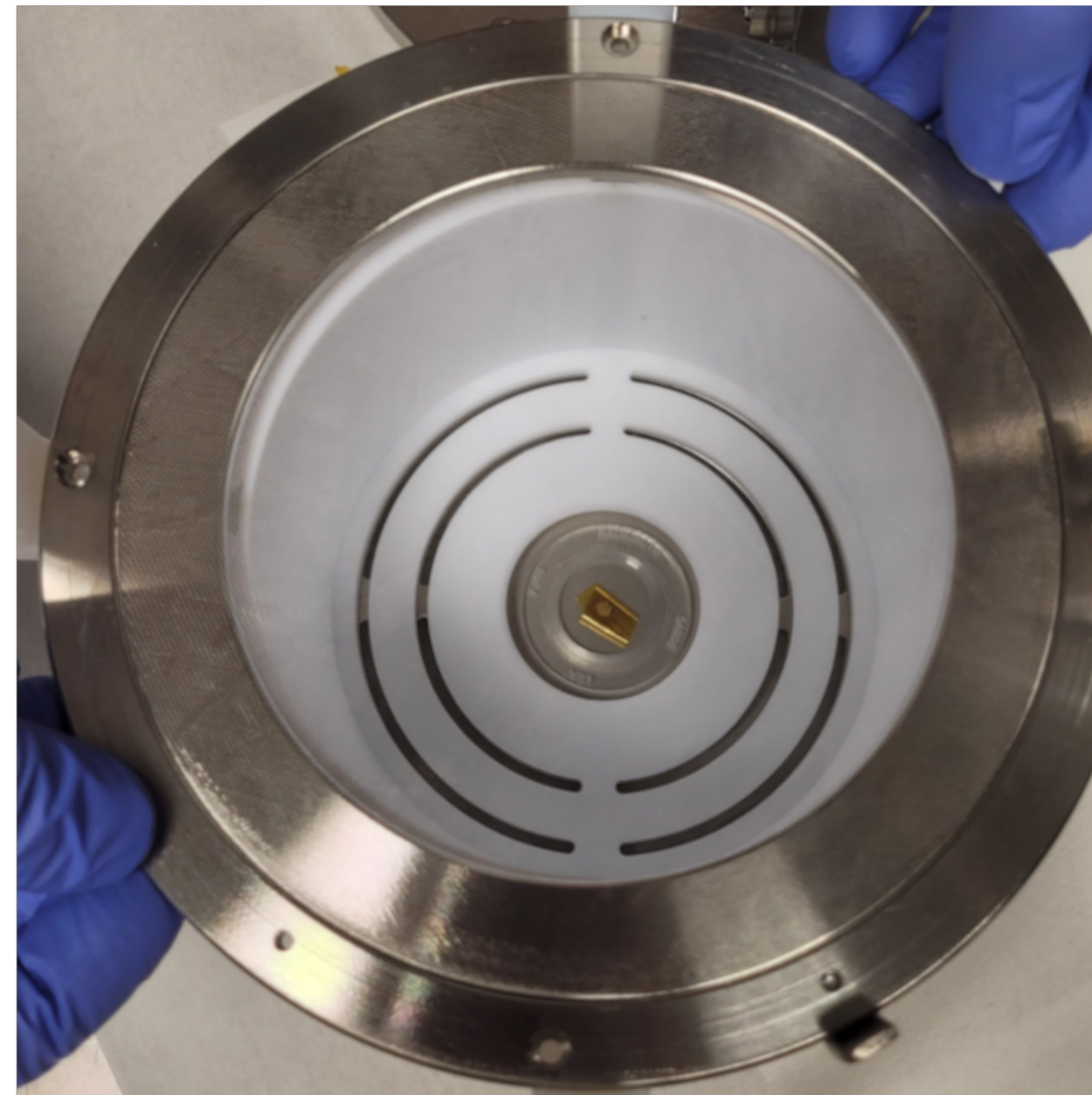
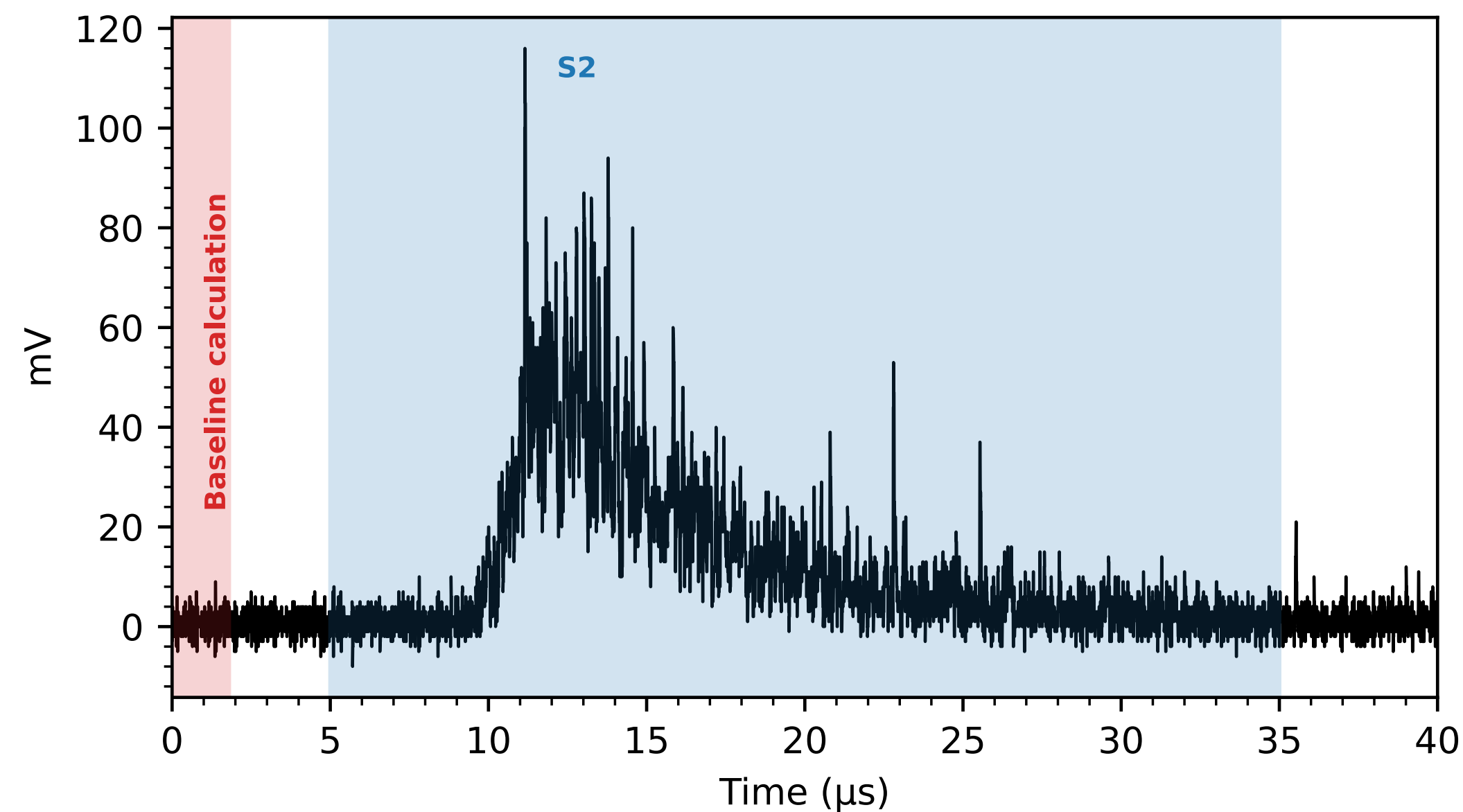


First results of GaP

GaP: first run results

Operation with Ar at different pressures (<10 bar)

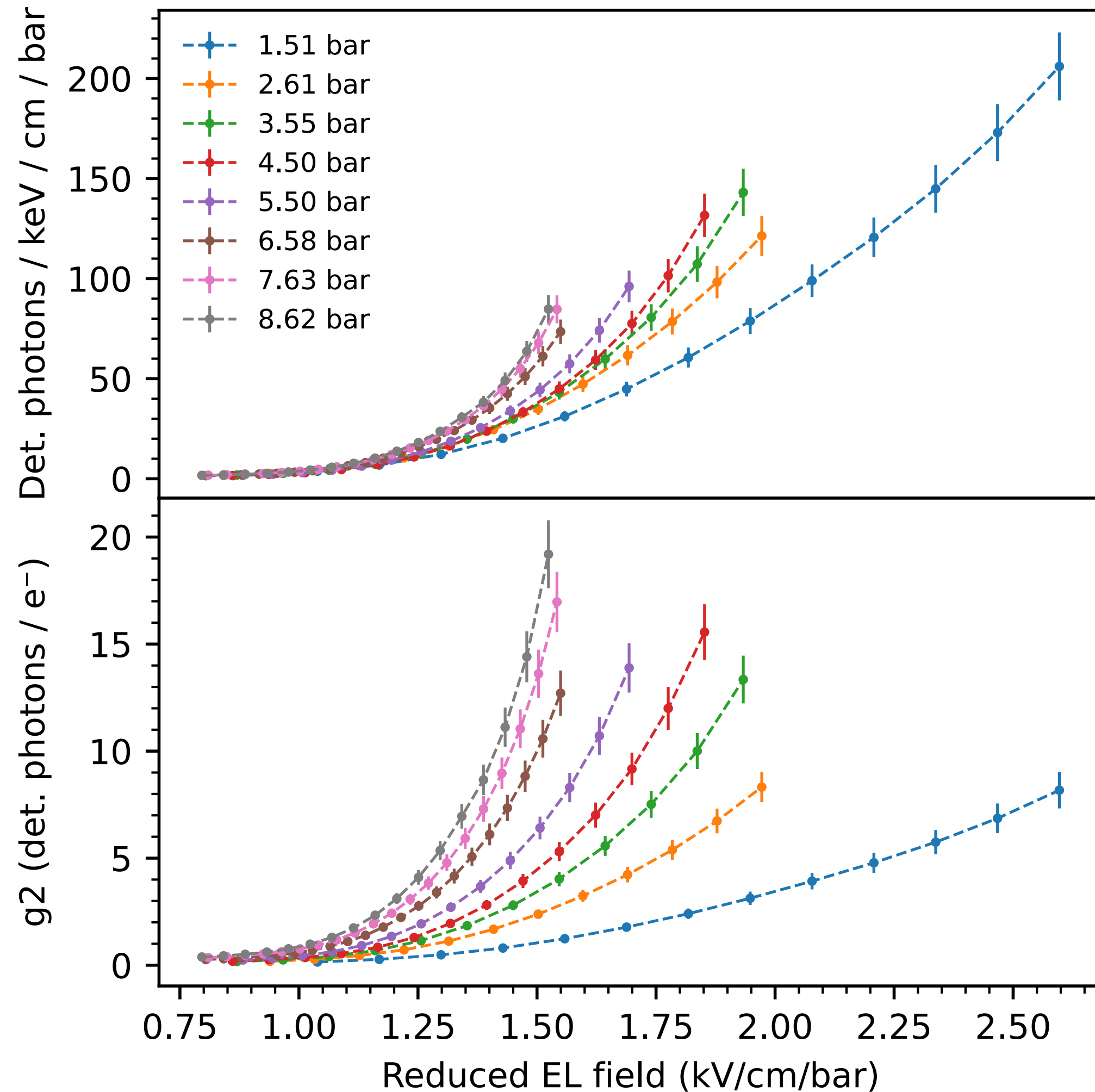
⁵⁵Fe source is visible



Charge yield and light collection efficiency

Operation with Ar at different pressures (<10 bar)

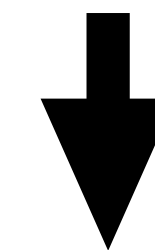
Literature precedents



- Reduced electroluminescence yield depends **only** on the reduced electric field.
- Behave linearly up to at least ~ 3 kV/cm/bar.

Counter-intuitive result compared to literature

- Reduced electroluminescence yield depends not only on the reduced electric field but **also** on the **absolute pressure**.
- **Exponential** behavior.



Extra light production mechanism

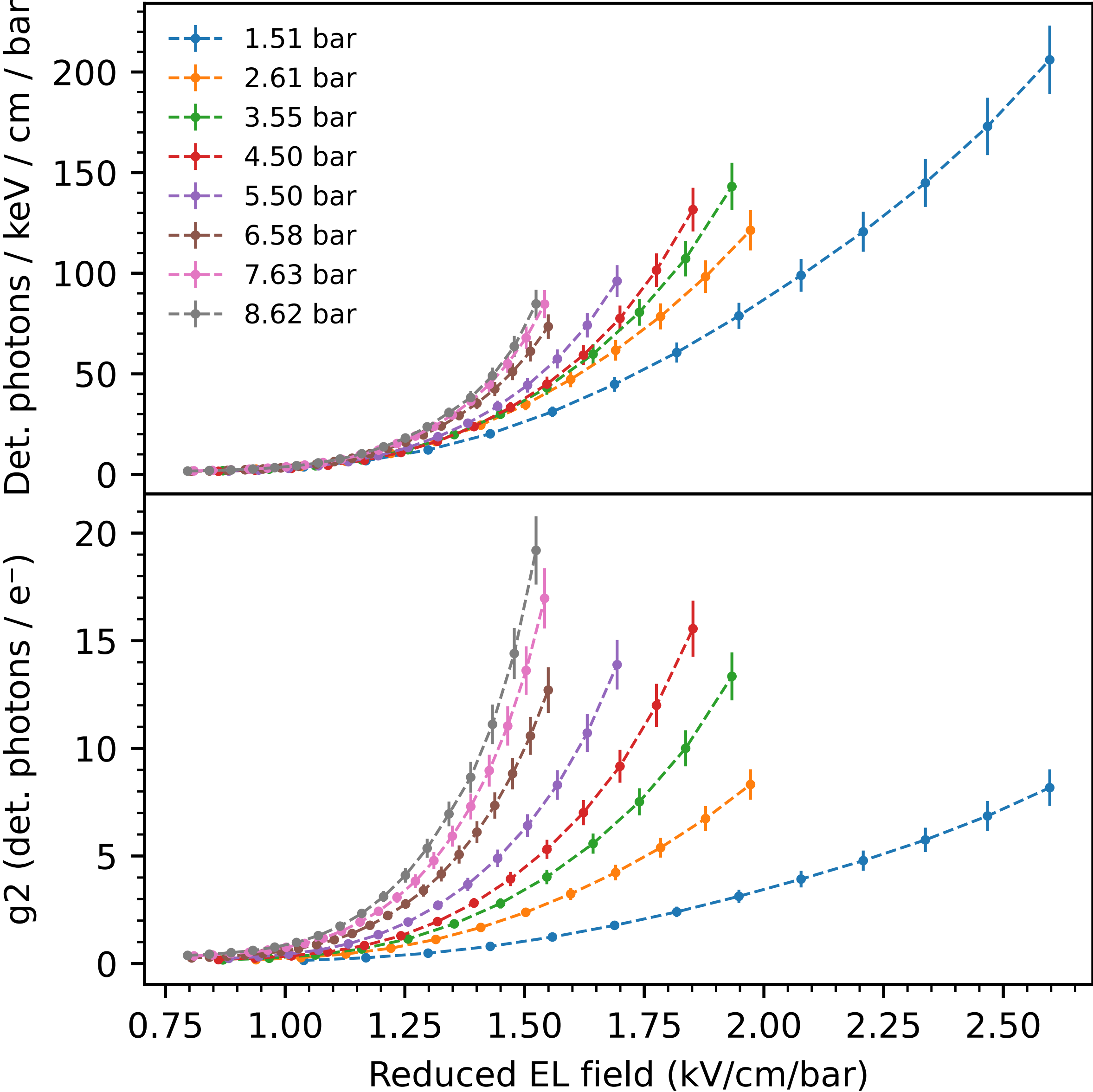
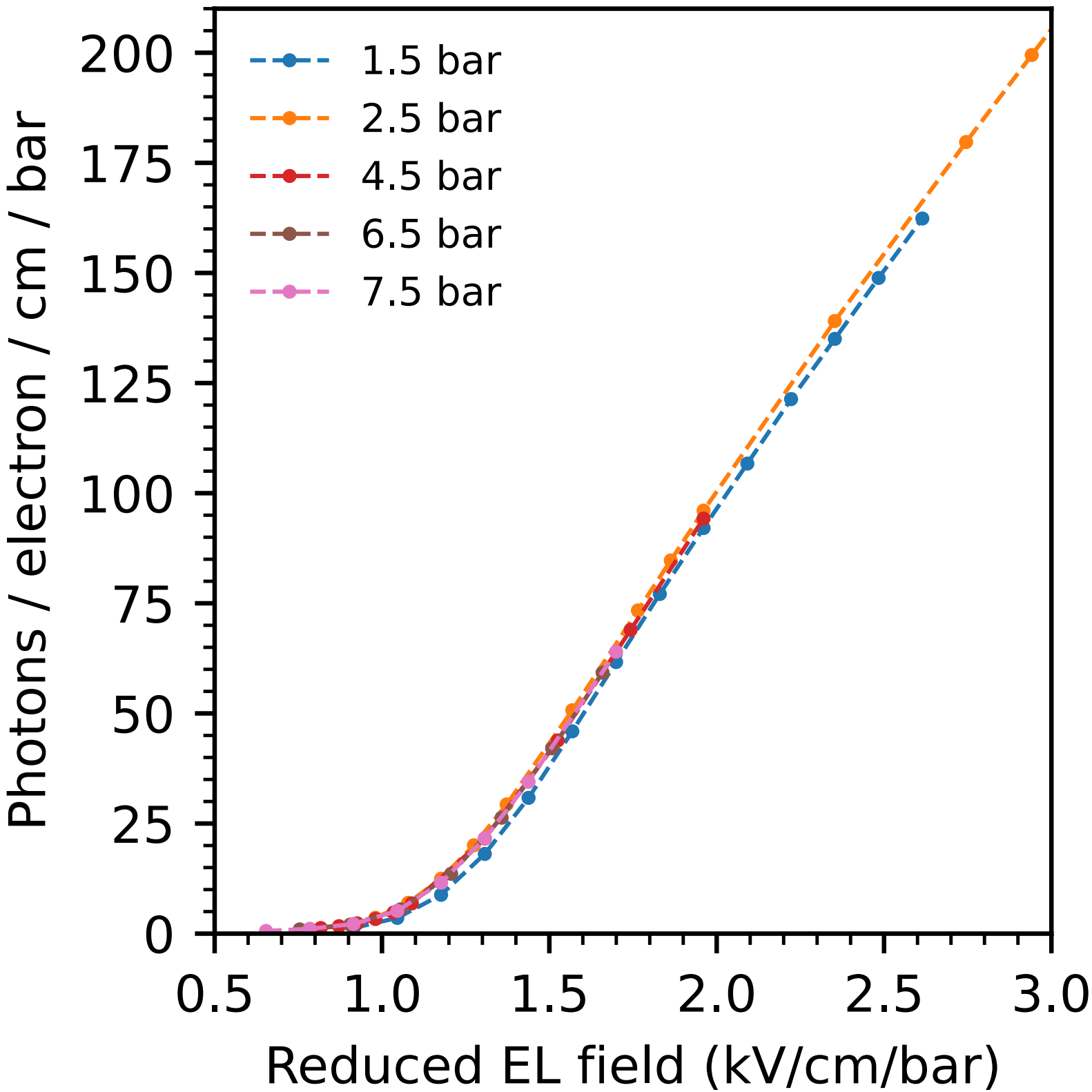
Due to charge amplification?

Electroluminescence yield

The question remains unsolved...
Gas impurities?

Non-linearity of the
amplification region observed

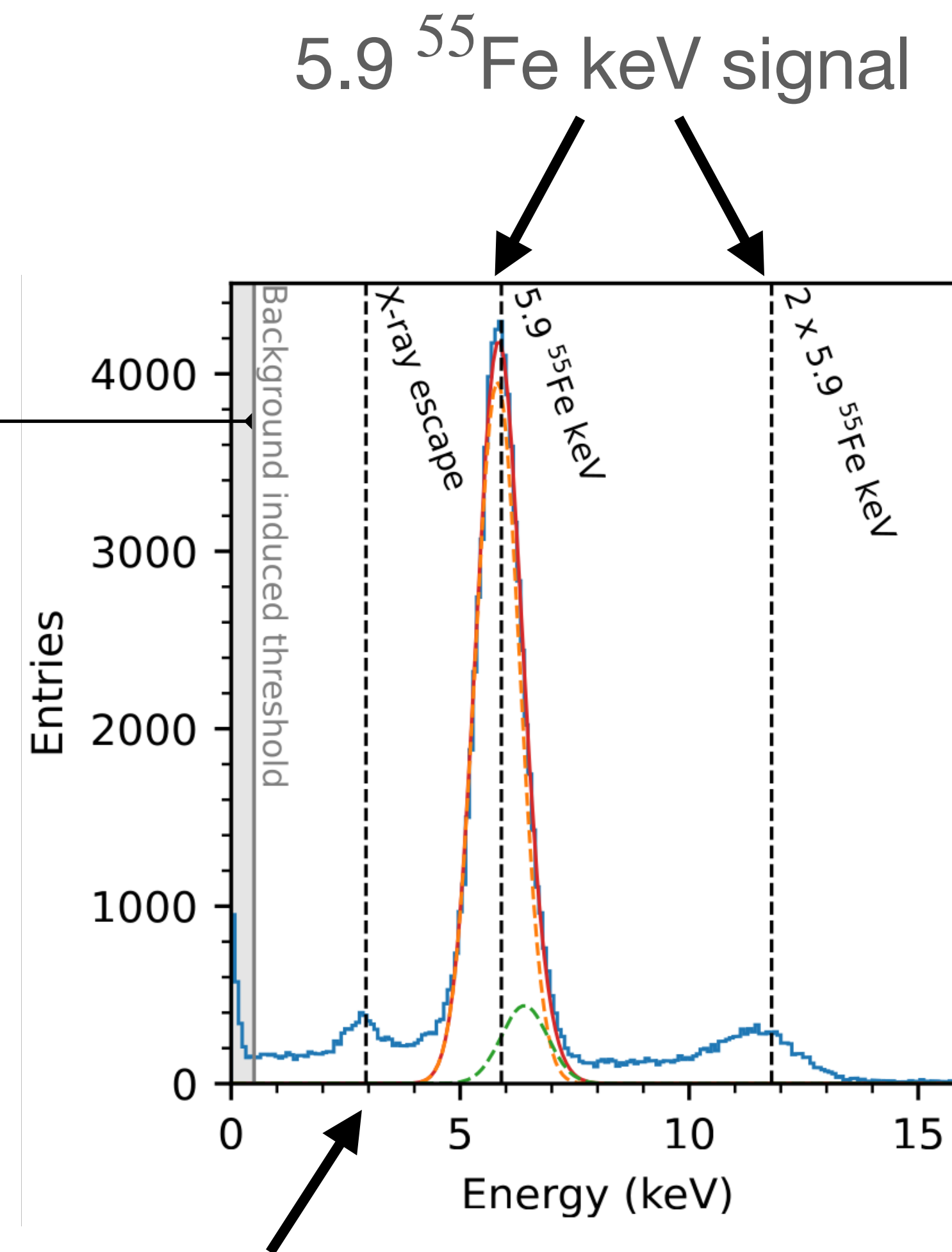
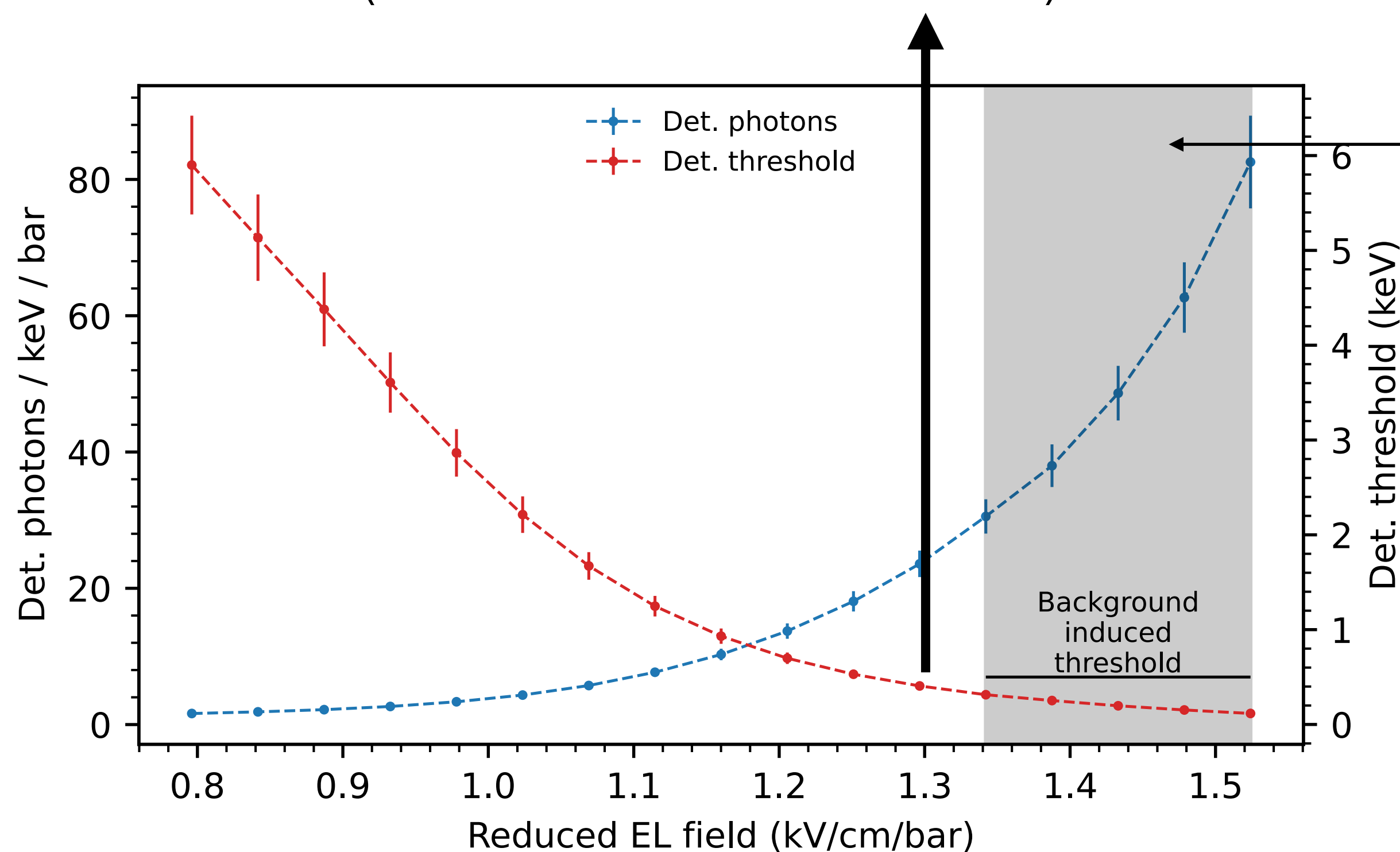
Results from Garfield++



Evaluation of the detection threshold

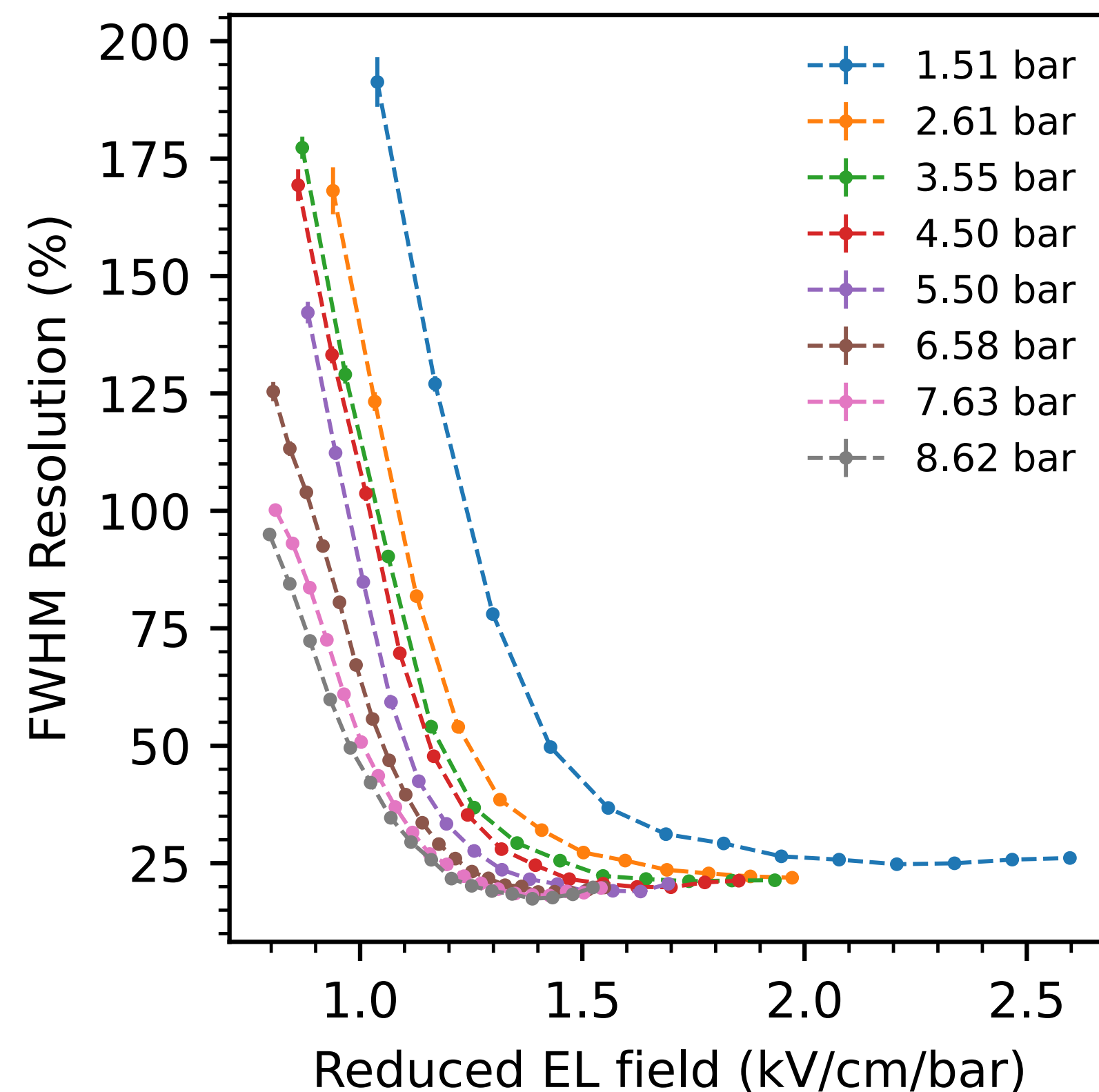
Operation with Ar at 8.62 bar

Energy threshold at the level of $0.42 \pm 0.04 \text{ keV}_{ee}$
(~16 ionization electrons)



GaP: first run results

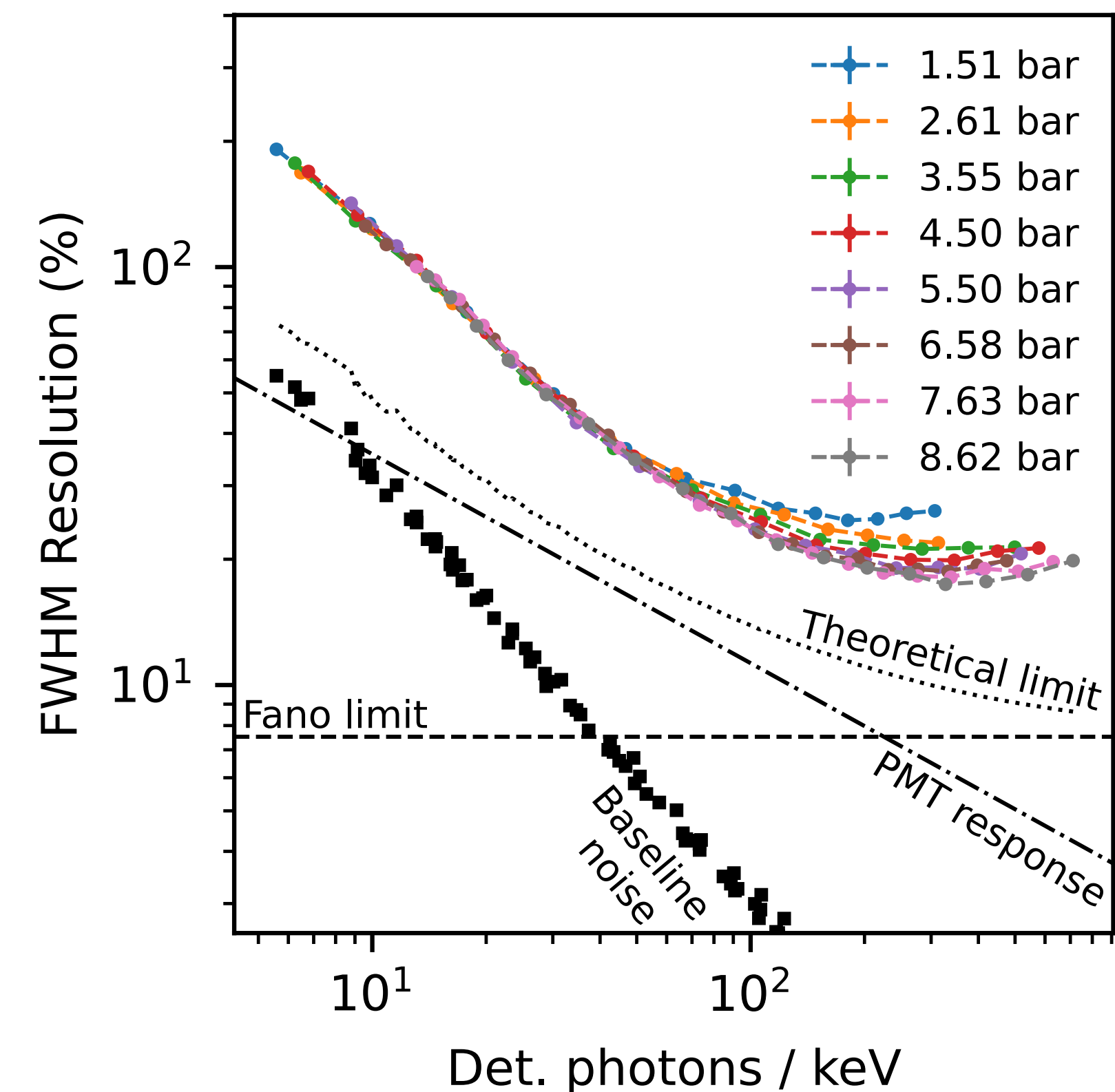
Operation with Ar at different pressures (<10 bar)



Resolution enhanced with pressure increase

Large fields: ~80% worse resolution than theoretical value.

Small fields: higher slope than theoretical limit.

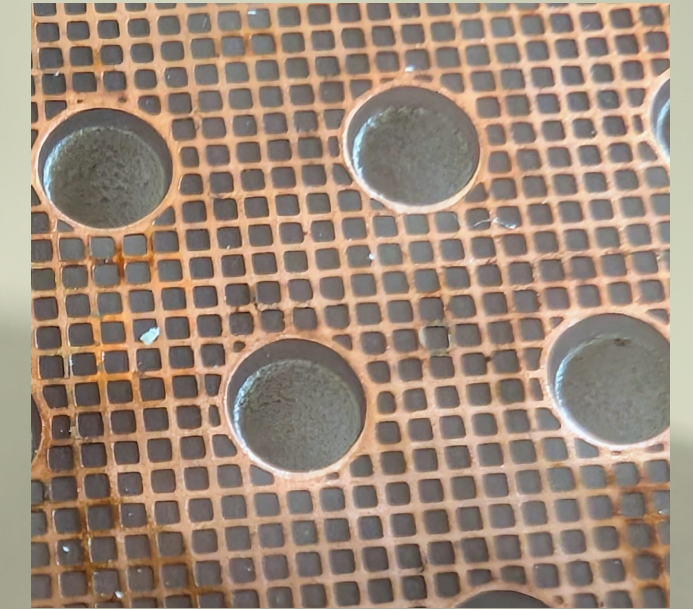
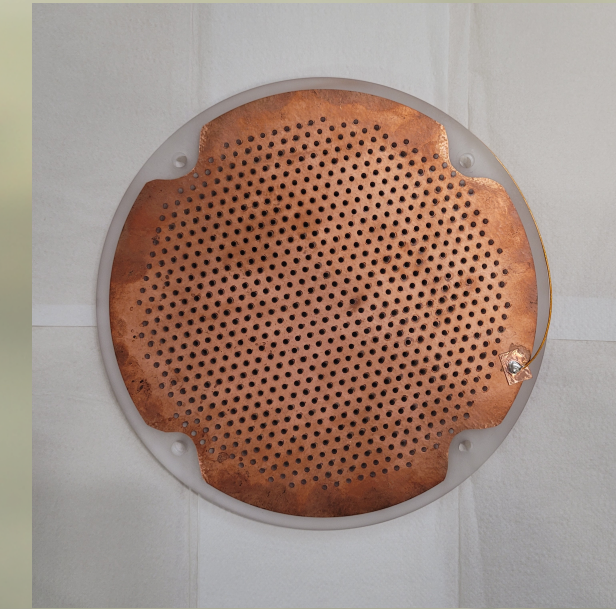


*electrons can travel a few millimeters inside the EL gap before producing any excitation
LCE varies with the position of the photon production

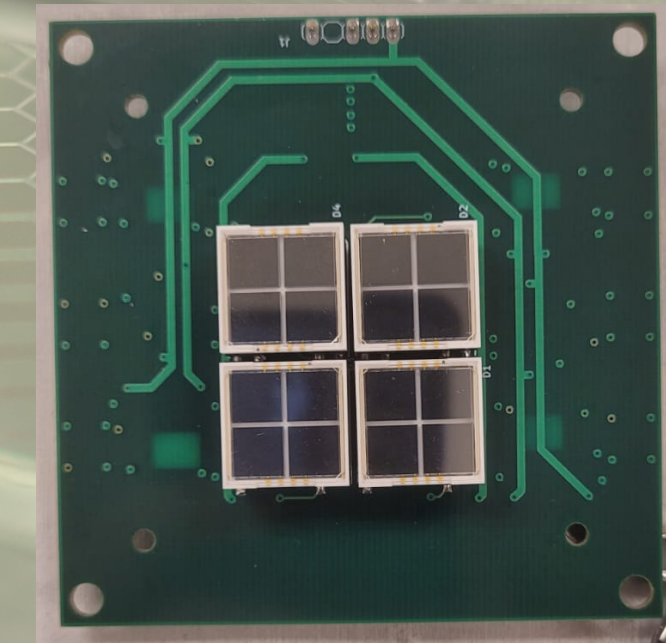
From GaP to GanESS

- GaP is the first phase of the GanESS project
- Very useful prototype to understand:
 - Detection energy threshold (first promising result)
 - Quenching factor
 - Electroluminescence at high pressures (still unclear)
 - Behavior of different noble gases (moving soon to Xenon)
- Ideal to test modifications that may improve and ease the operation of a larger detector:
 - SiPMs
 - GALA (GEMs)

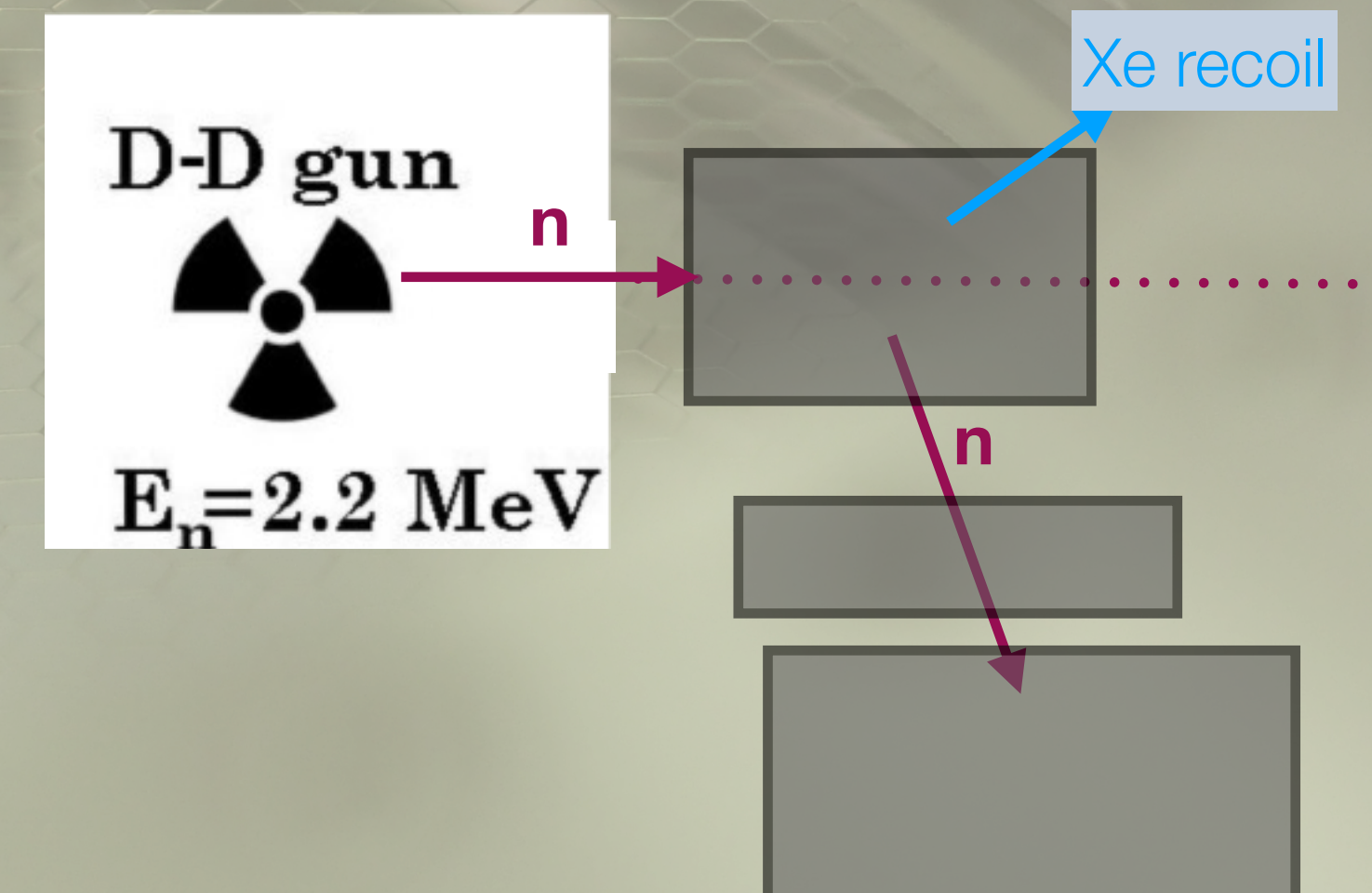
GALA



SiPMs



QF



Summary

- DIPC neutrino group is involved in developing gaseous instrumentation for rare events searches:
 - Double beta
 - Neutrino nucleus coherent scattering
- Use of high pressure, radiopure, gaseous optical TPCs operating with noble gases.
- Development of improved light collection techniques
- Working on improving the amplification structures at high pressure.
- Testing energy threshold.

Eskerrik asko