NOBLE LIQUID DETECTOR TECHNOLOGY

韩 柯 *HAN, Ke (SJTU)*

PART2: LIQUID XENON DETECTORS

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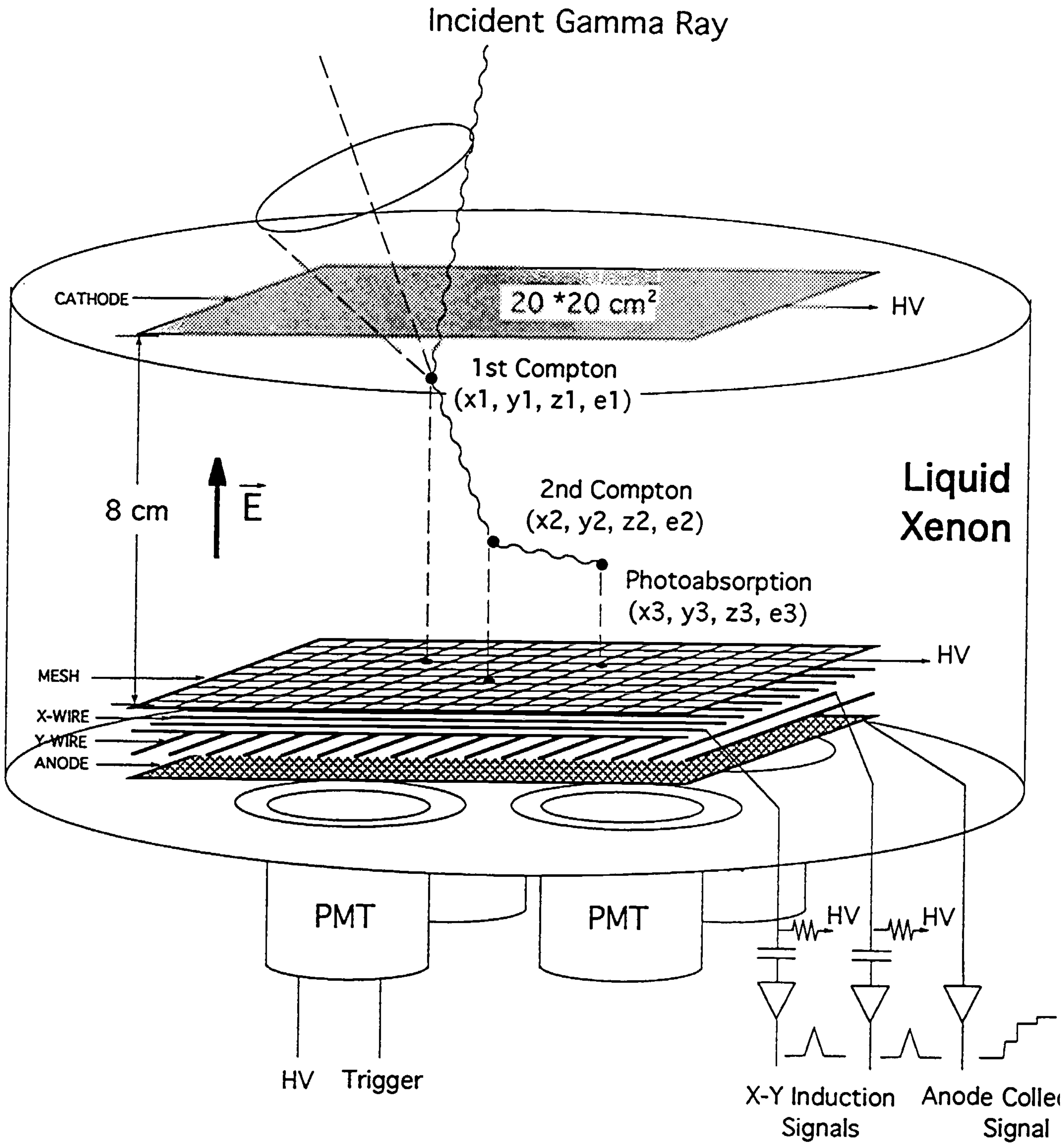
OUTLINE FOR LIQUID XENON DETECTORS

- Advantage of Xenon
- Ionization detectors
  - LXeGRIT
- Scintillation detectors
  - XMass
  - MEG II LXe gamma ray detector
- Ionization+scintillation
  - Single phase TPC: EXO-200, etc
  - Dual phase TPC: PandaX-4T, etc
- … …

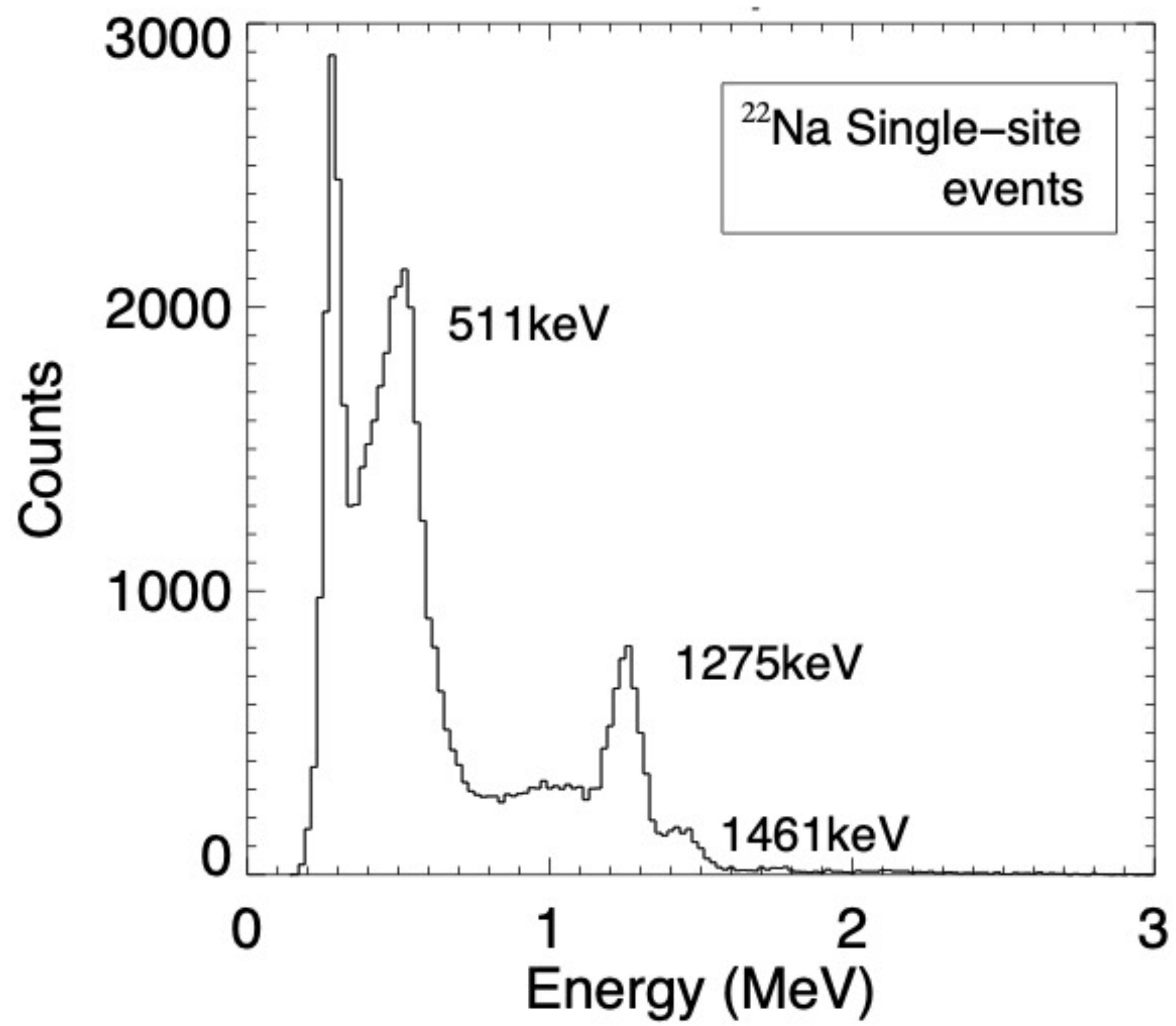
ADVANTAGE OF XENON

- Compared to other noble liquids:
  - High light yield with PMT-compatible wavelength
  - High Z for gamma detection
  - Multiple isotopes, rich physics
  - Easiest cryogenics requirement
- But
  - Expensive

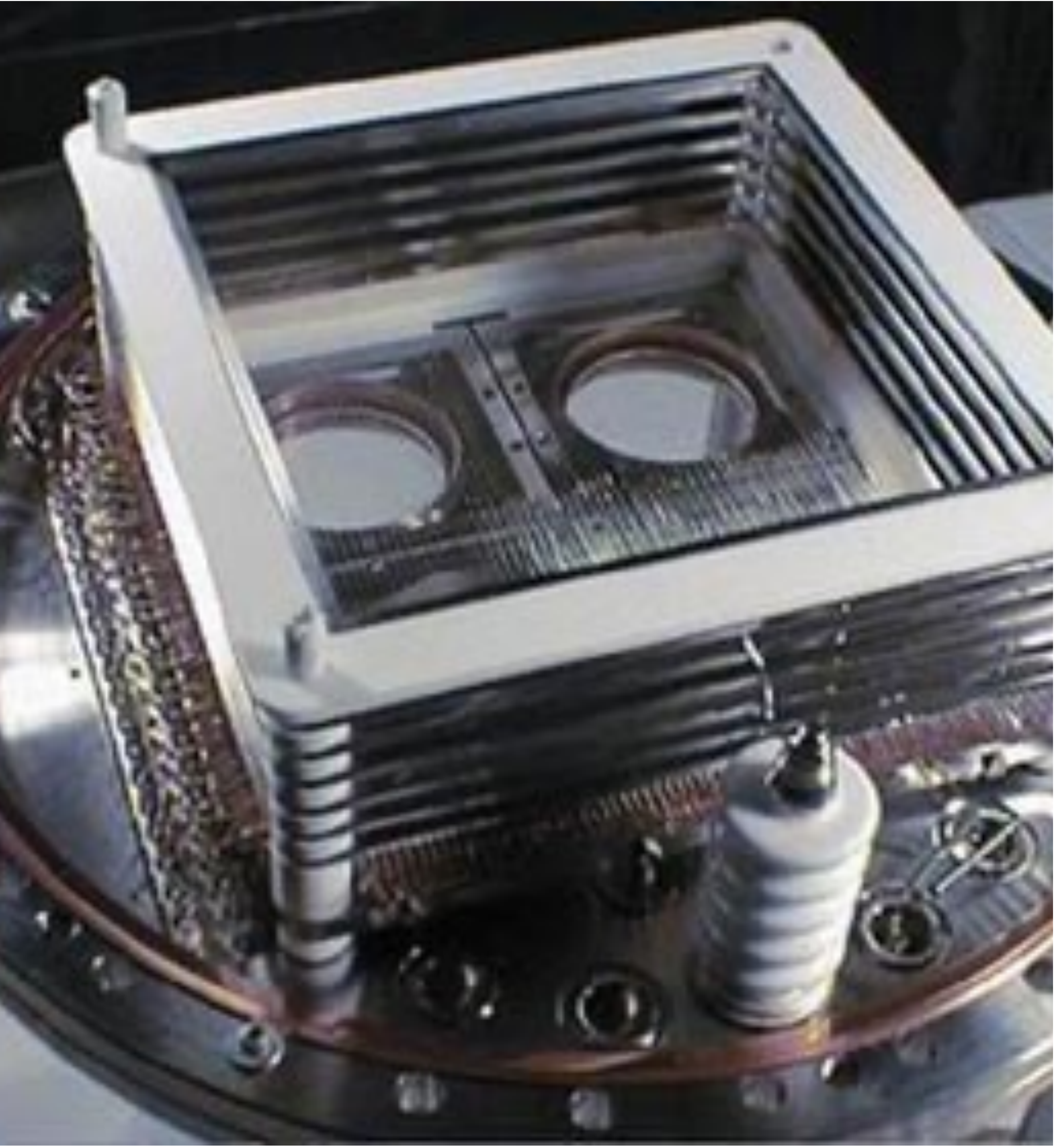


IONIZATION DETECTORS

- LXeGRIT: A Liquid Xenon Gamma-Ray Imaging Telescope
- Energy range: 0.15 -10 MeV
- Energy resolution: 8.8% FWHM at 1 MeV



LXeGRIT

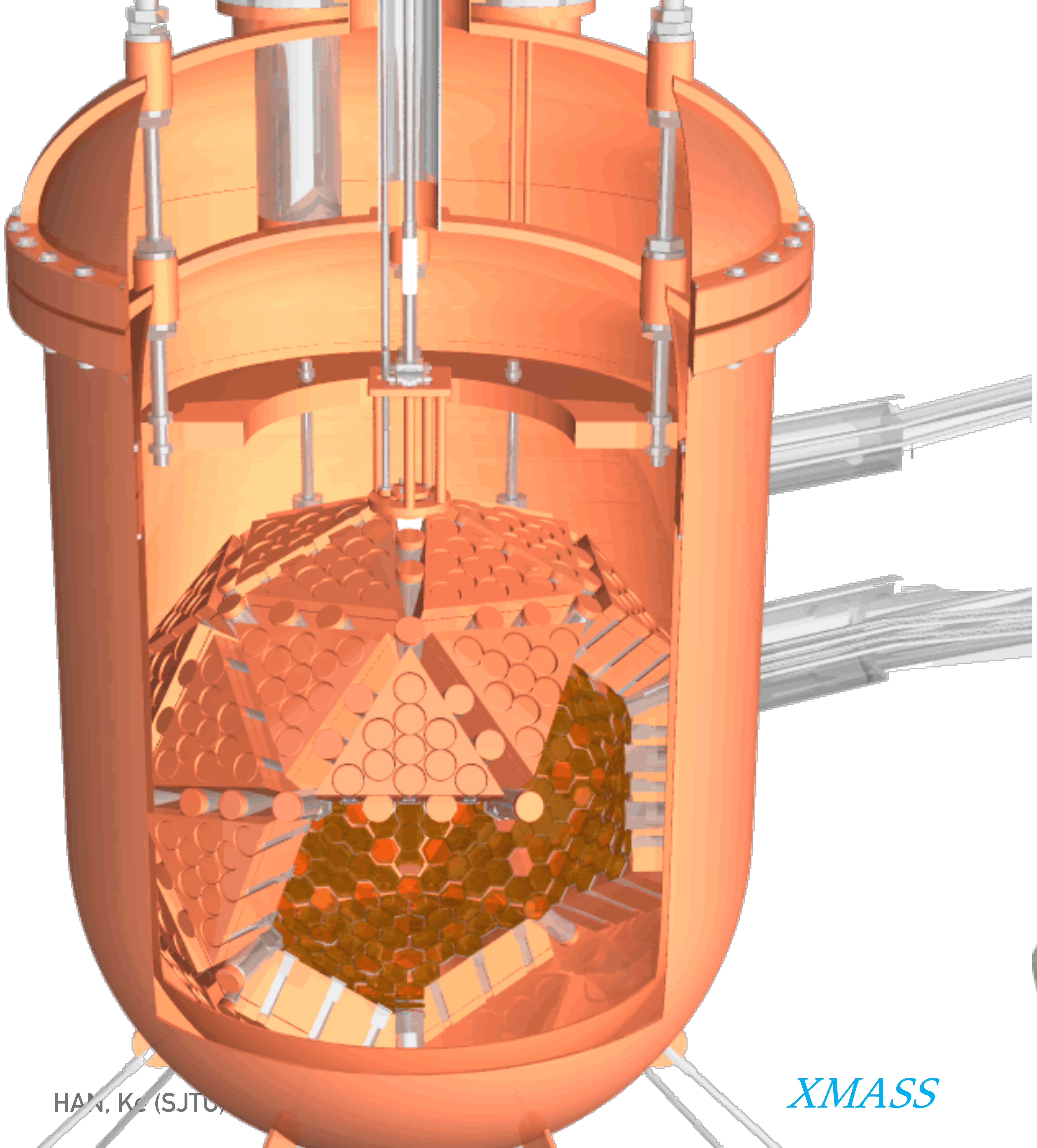


IONIZATION DETECTORS

LXeGRIT

SCINTILLATION DETECTORS: XMASS

- 800 kg of LXe with 642 PMT
- Simpler structure compared to TPC
- Low energy threshold (0.5 keV_{ee})
- Scintillation time profile for
  - Discrimination between nuclear recoil and Electron/gamma-ray
  - Vertex reconstruction
- Suffered from high background

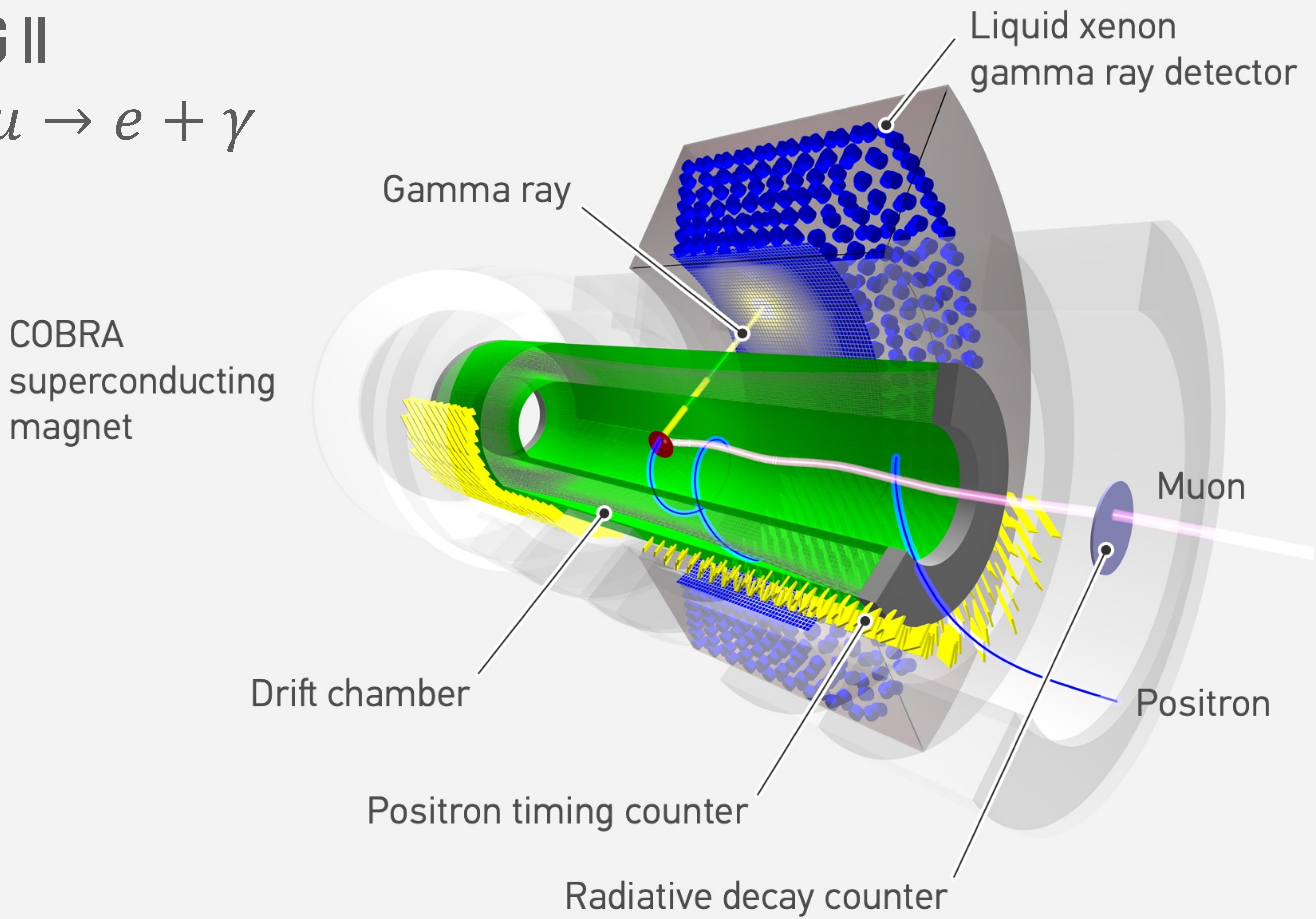


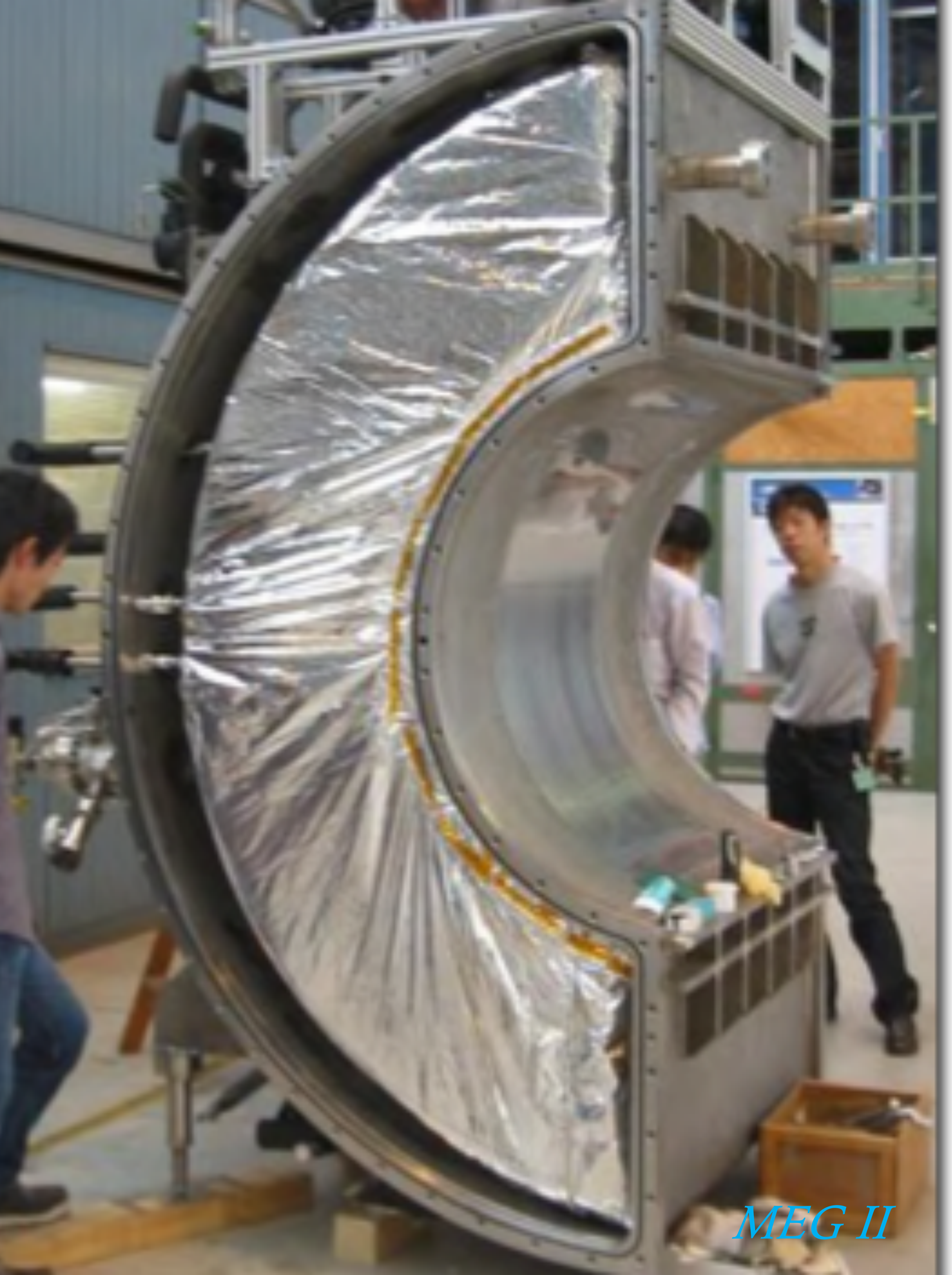
XMASS


XMASS

MEG II

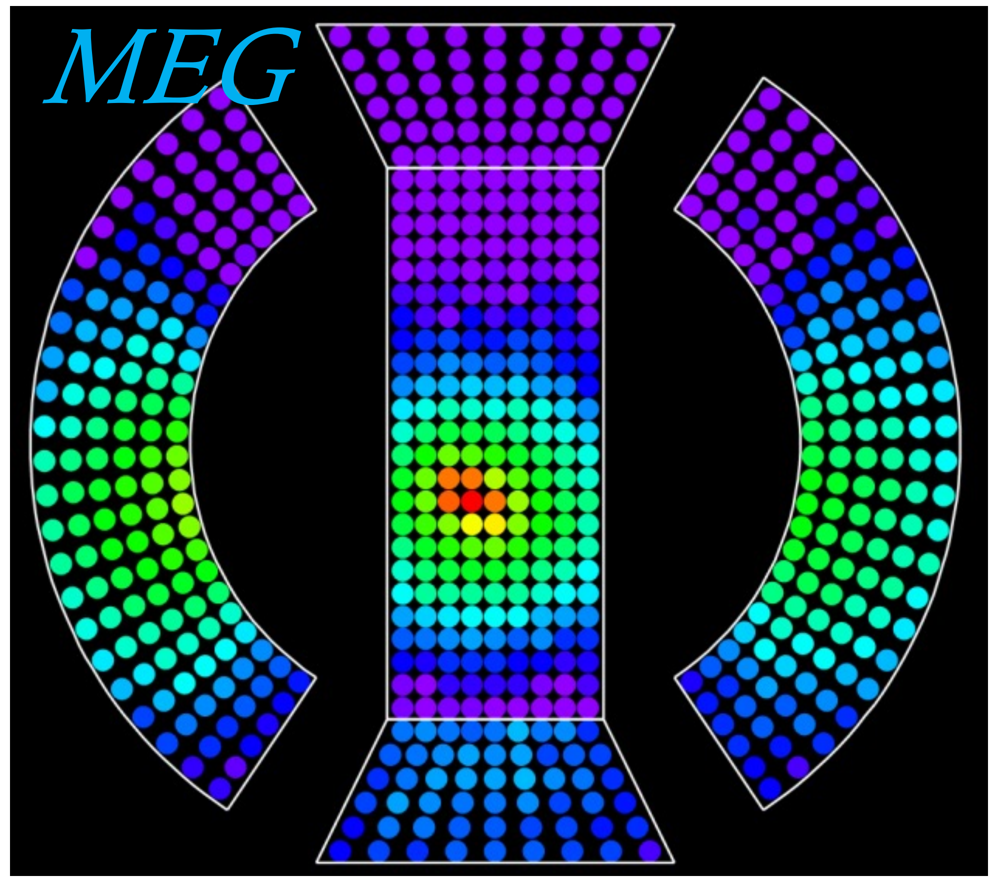
$$\mu \to e + \gamma$$

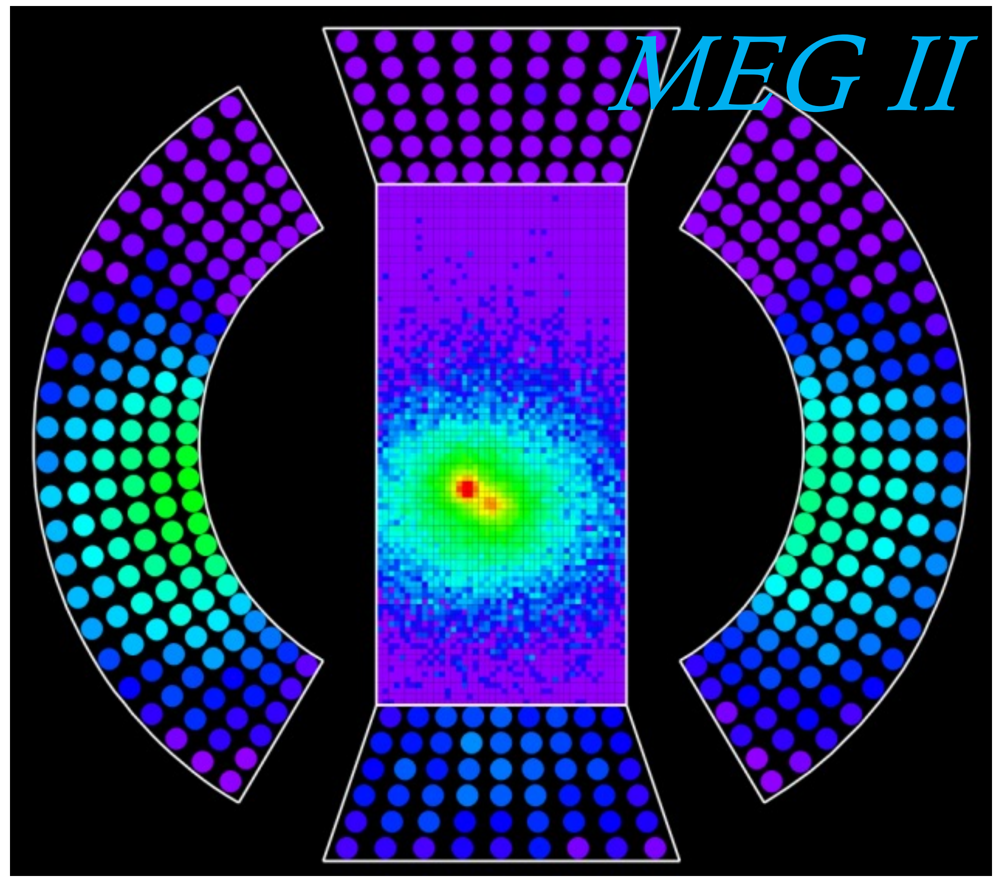


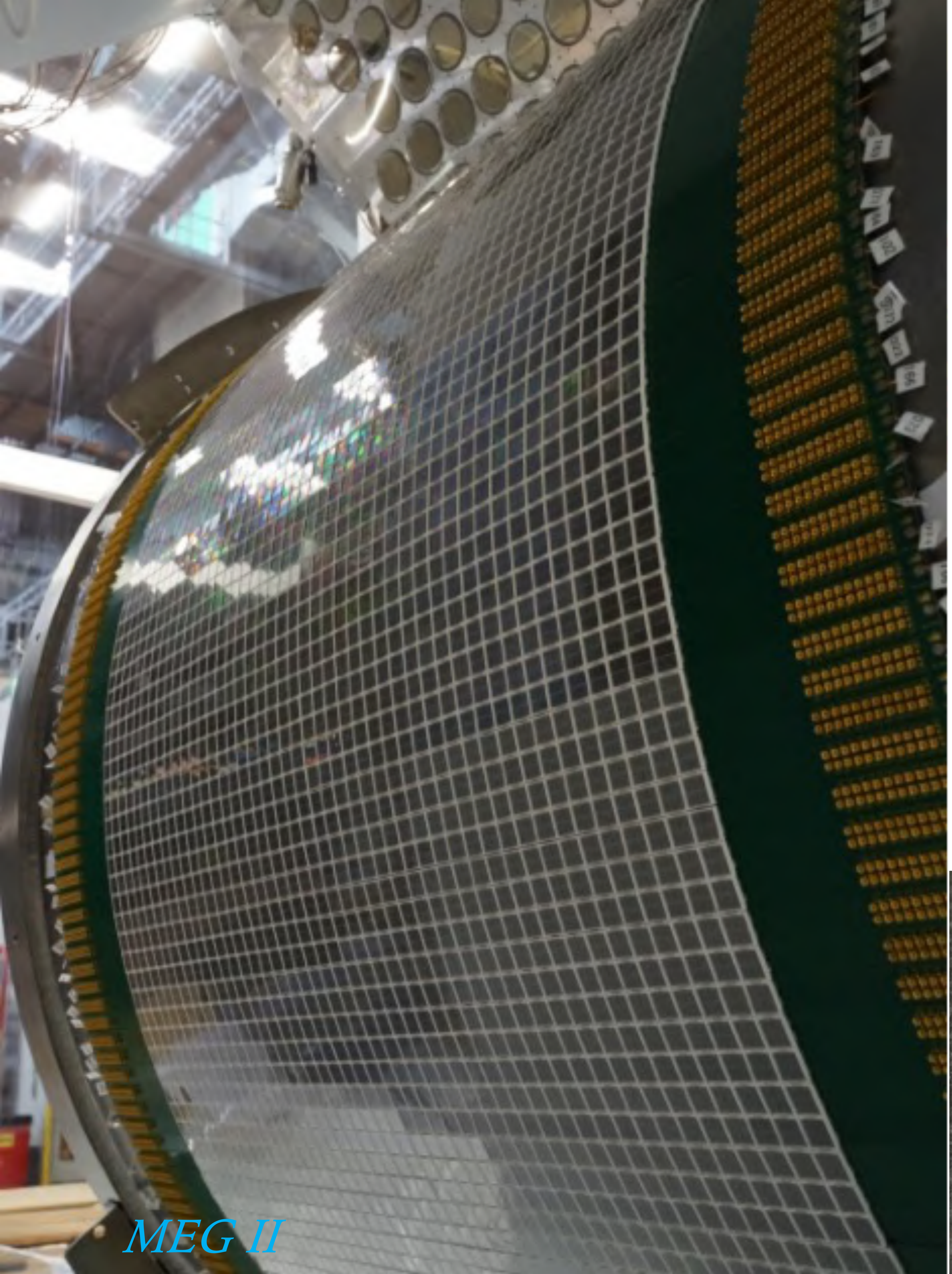


MEG II LXE DETECTOR

- 900L LXe detector
- Measures energy, position and timing of gamma-ray (52.8 MeV)
- Expected peformance:
  - Efficiency: 70%
  - Position resolution: 2.5 mm
  - Energy resolution ~1%
  - Timing resolution: 40-60 ps

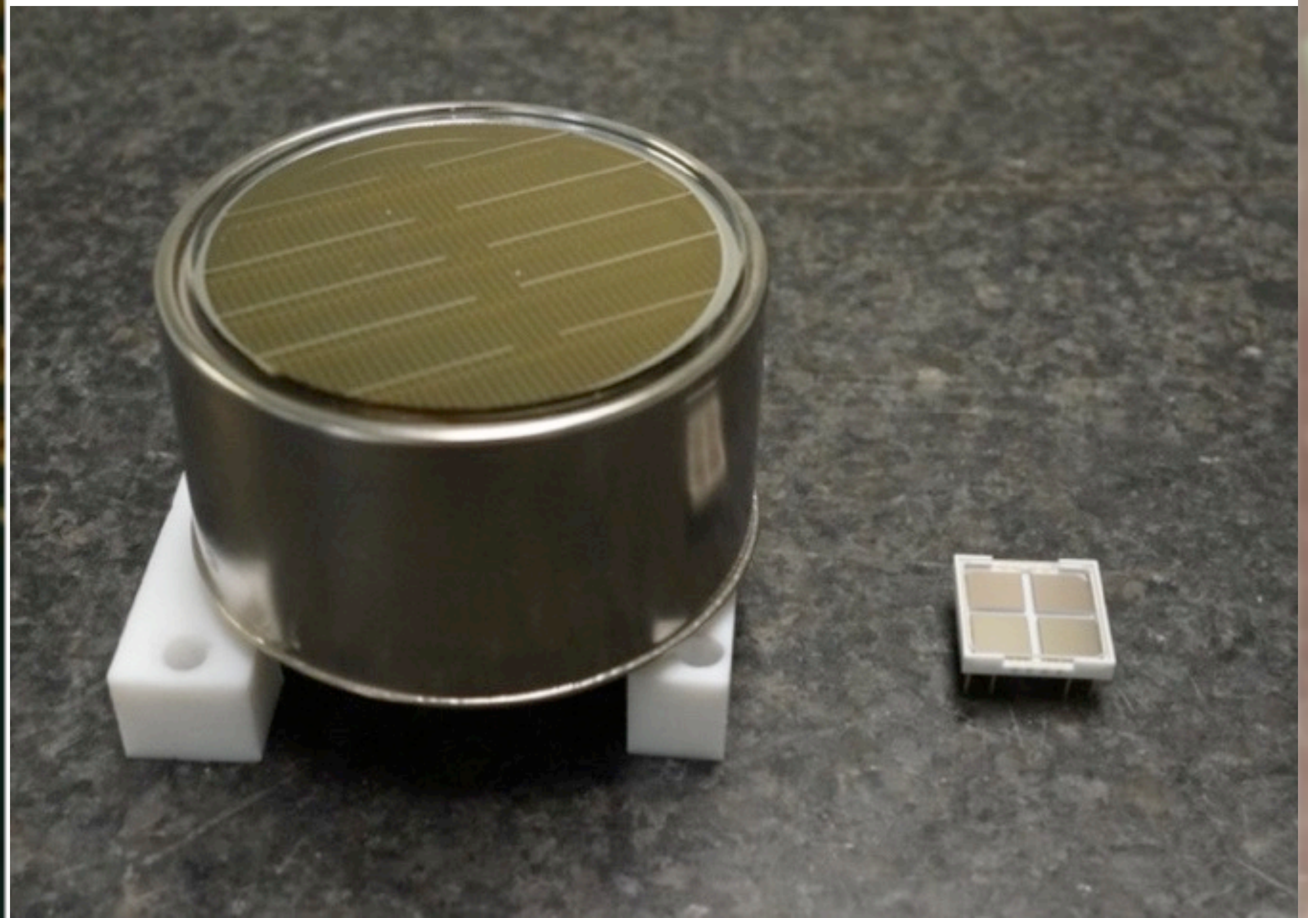


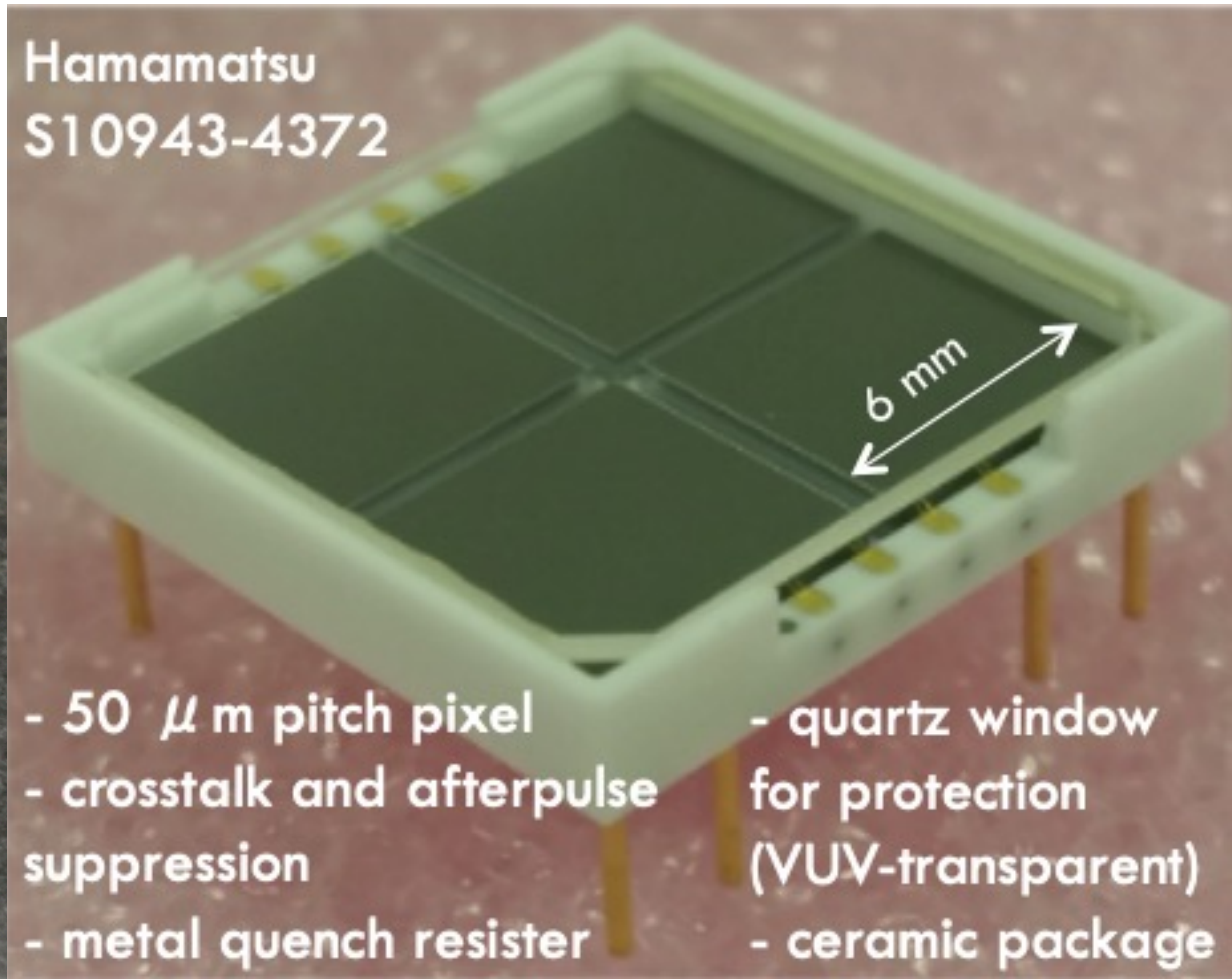


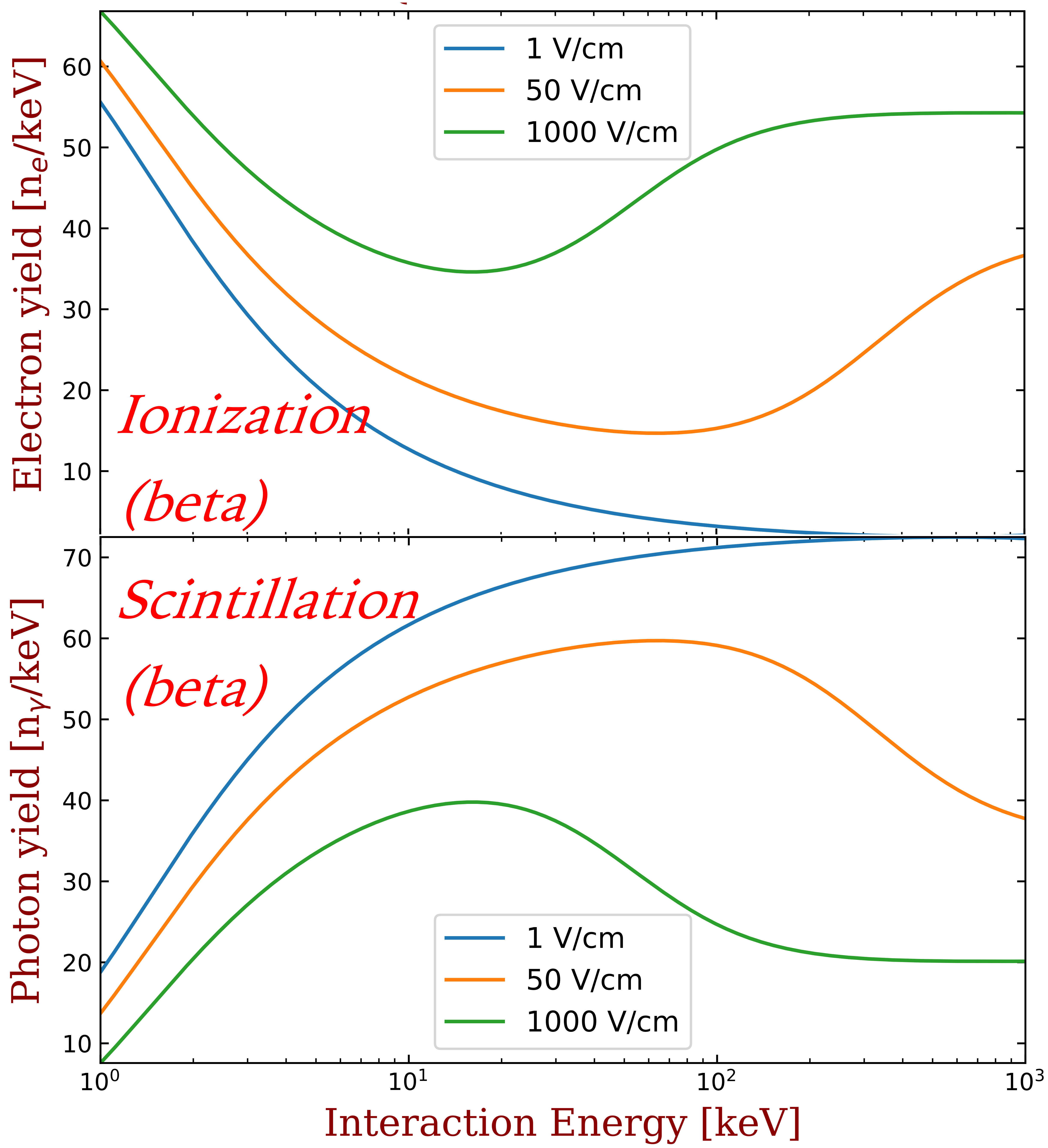


MEG II PHOTO SENSOR UPGRADE

- Replace 216 2-inch PMTs with 4092 12×12 mm^2 SiPMs
- VUV sensitive SiPM co-developed by MEG II and Hamamatsu
- Improve energy/pos resolution by 2×

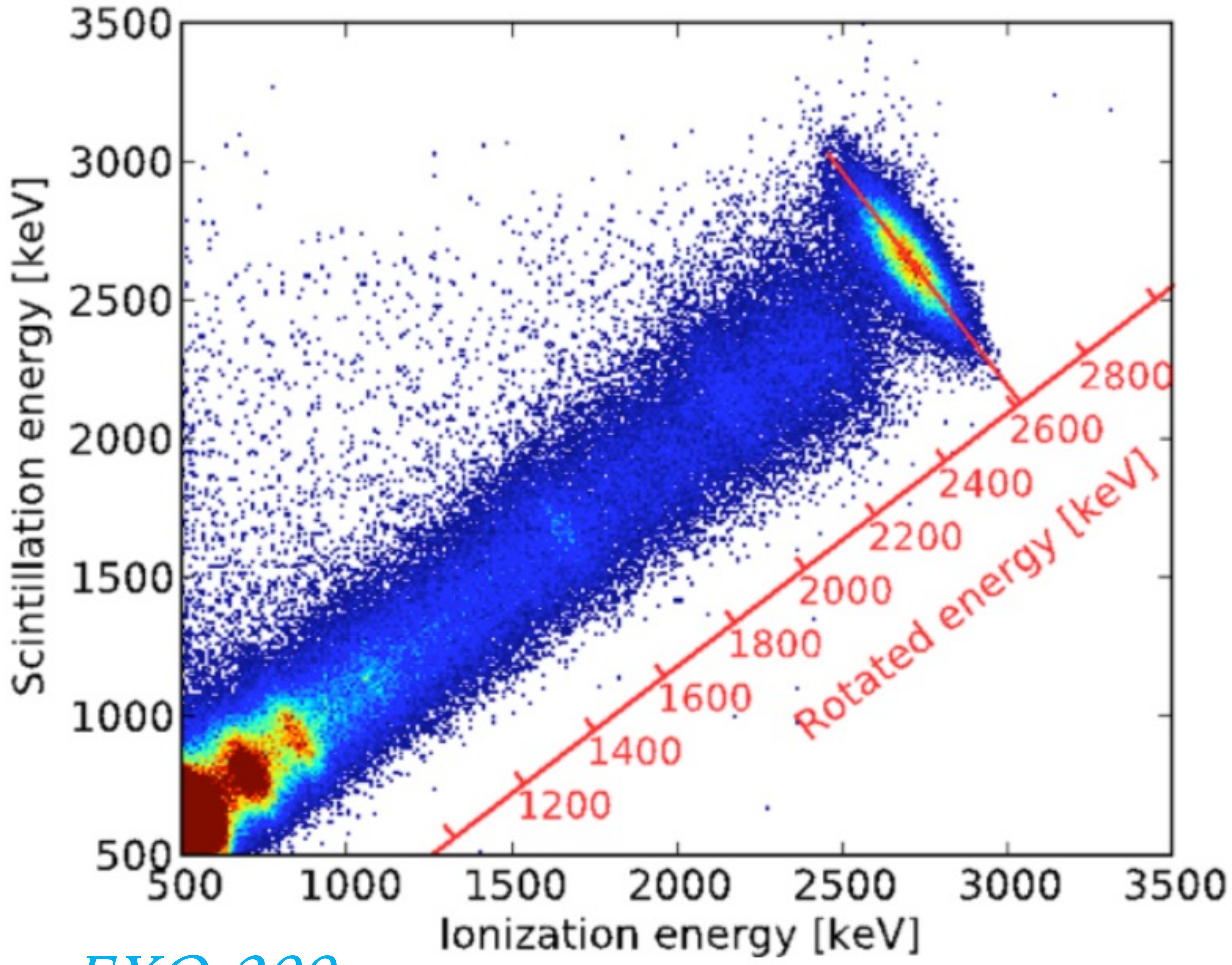




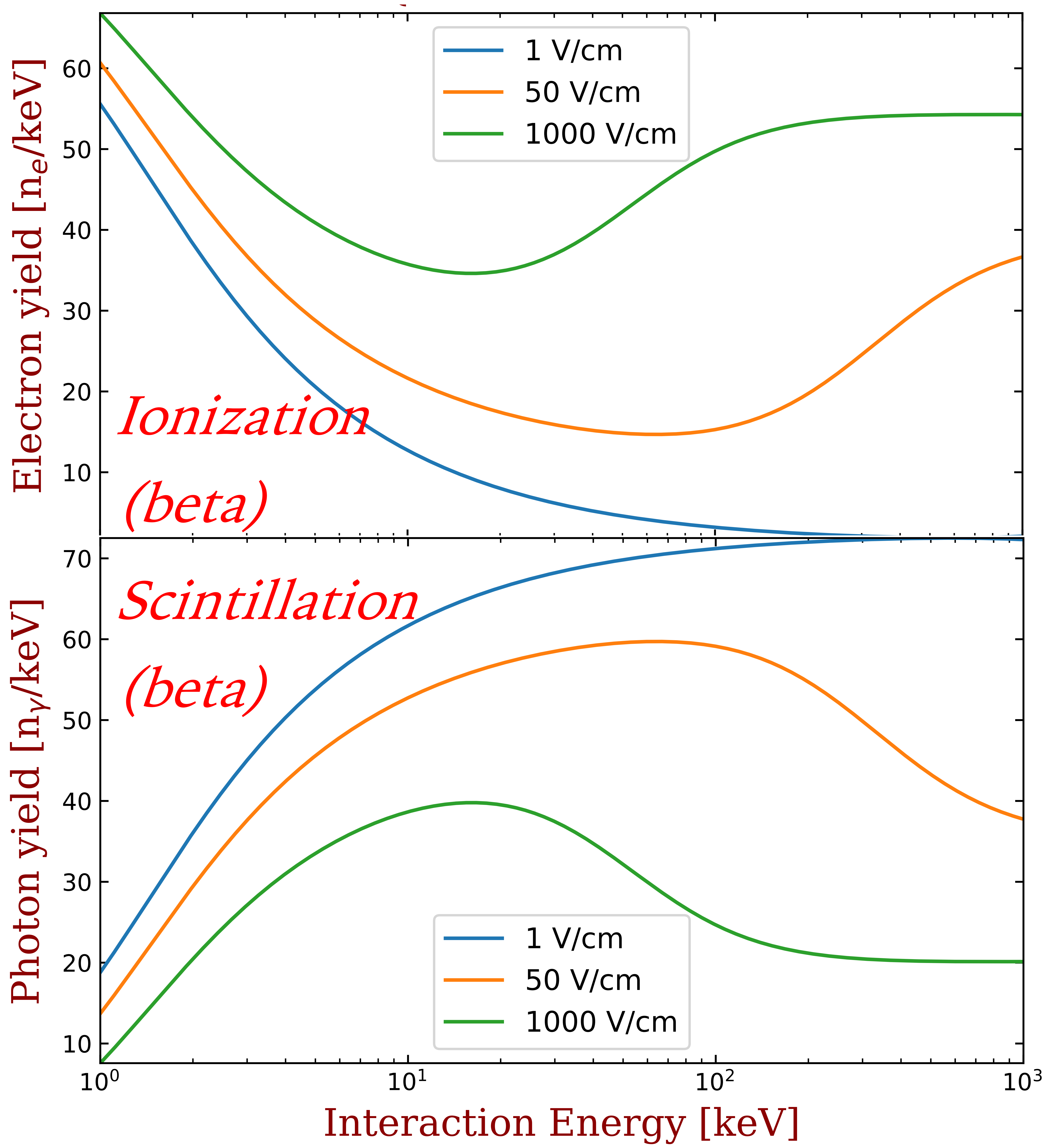


IONIZATION+SCINTILLATION

- Clean anti-coorelation
- Best energy resolution can be achieved with a combinations of two channels



EXO-200



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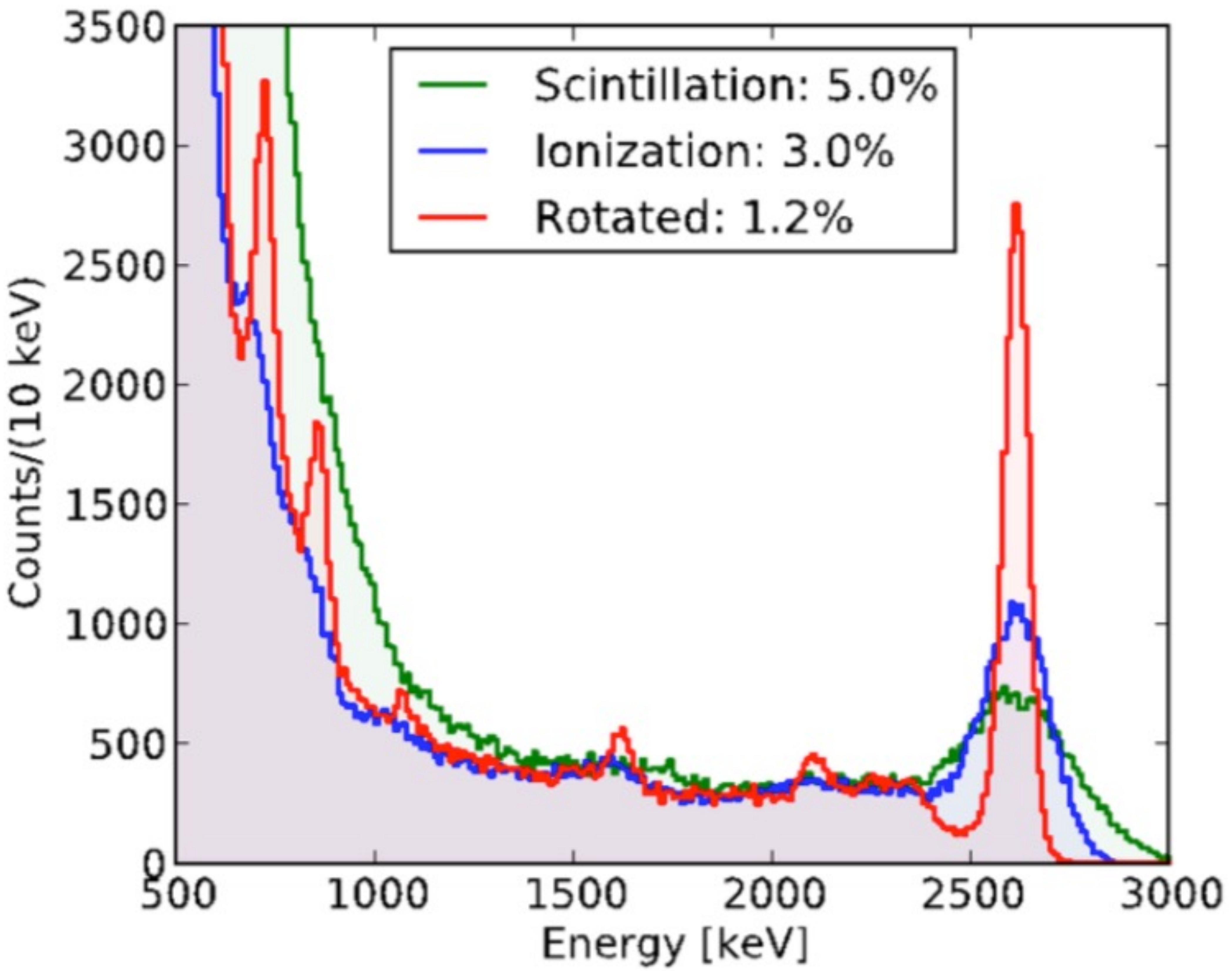
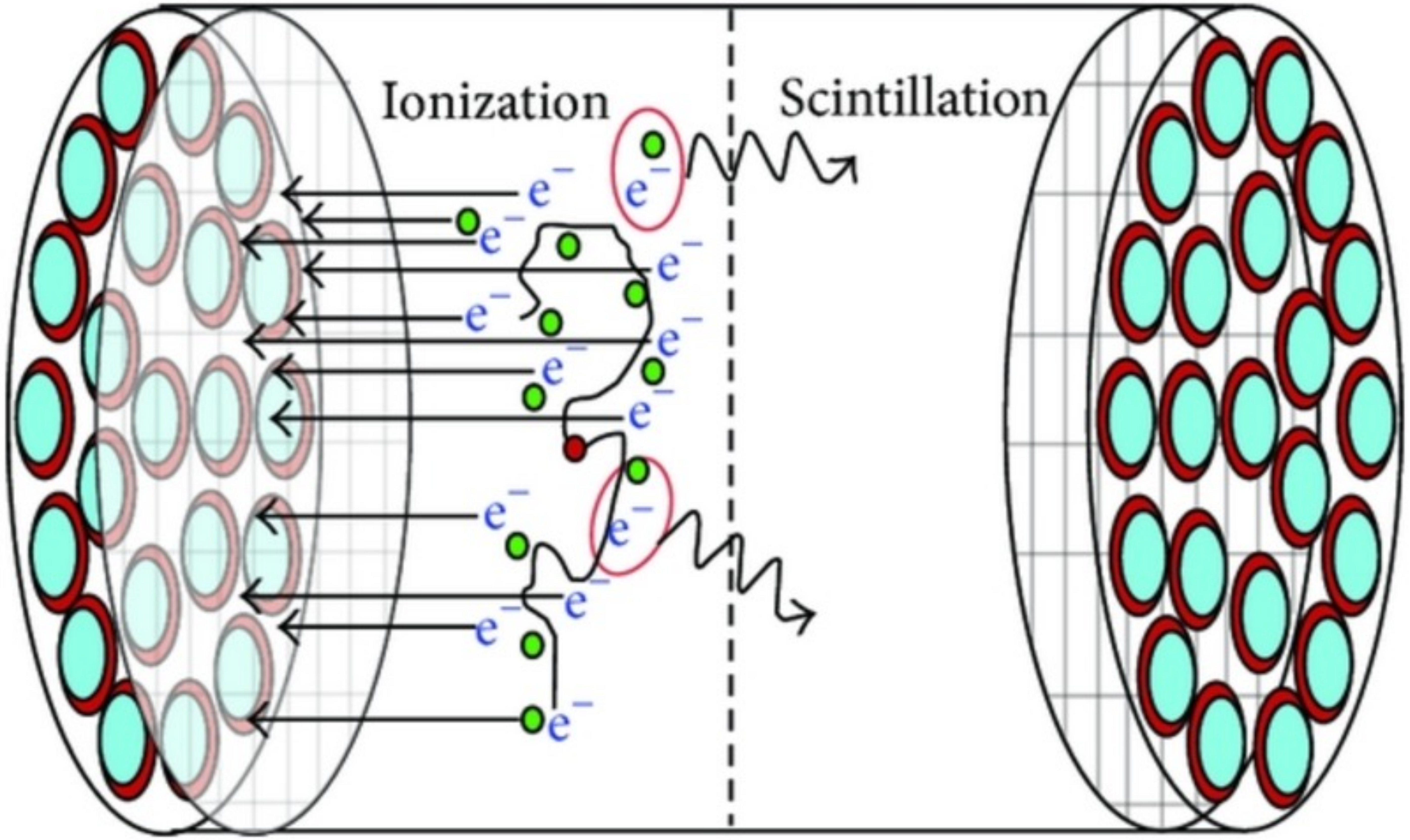
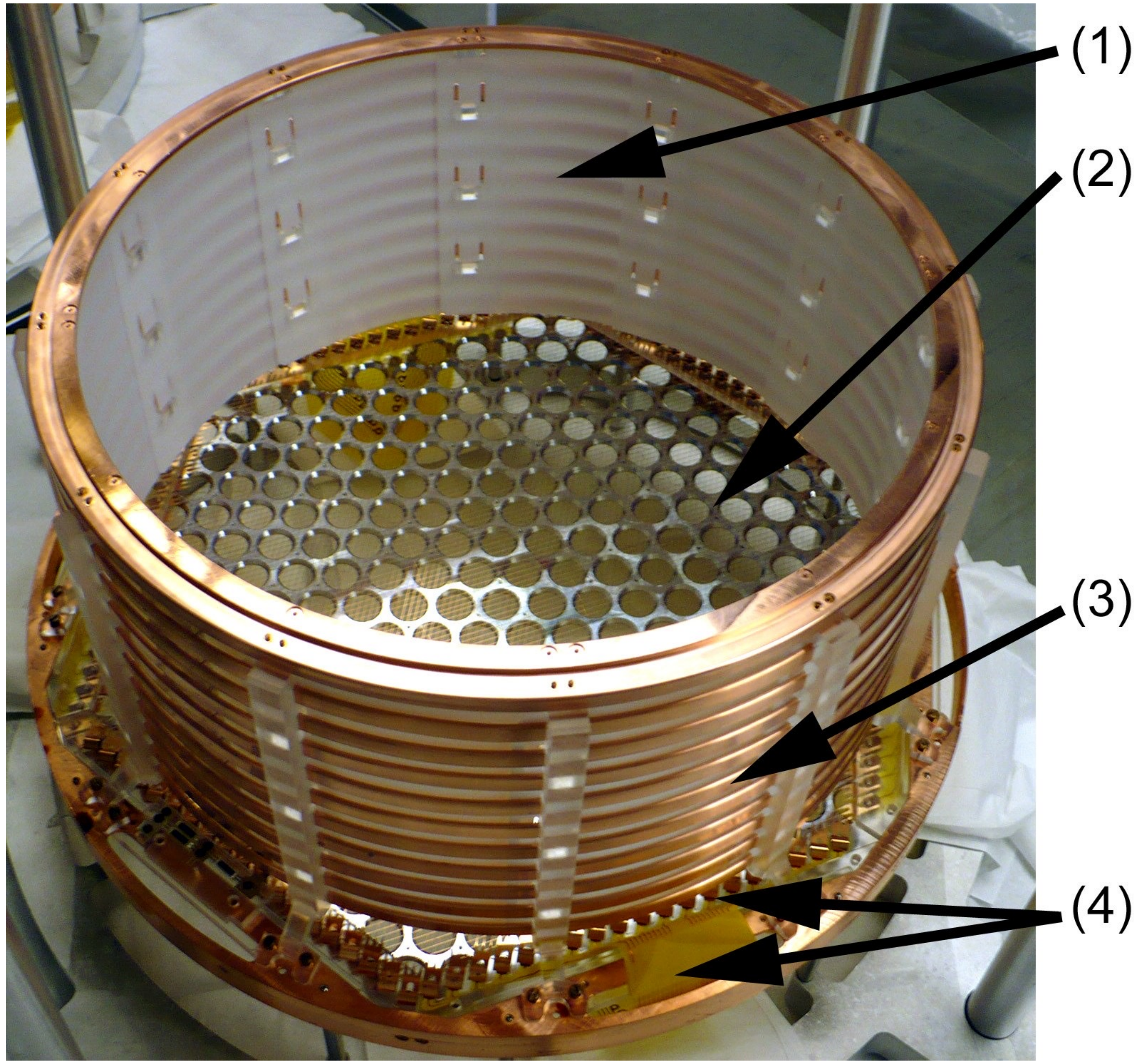


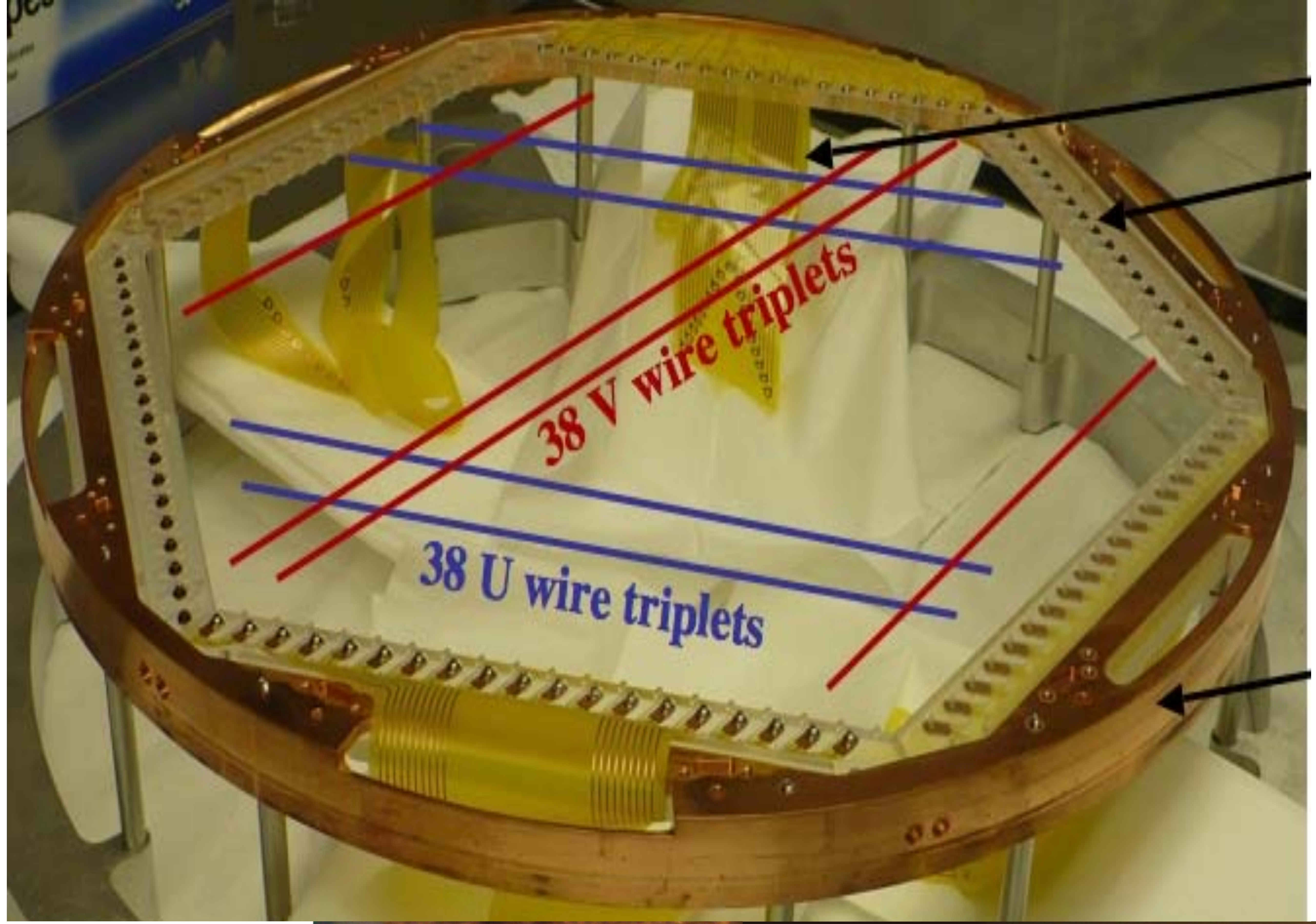
EXO-200

EXO-200 NEUTRINOLESS DOUBLE BETA DECAY EXPERIMENT

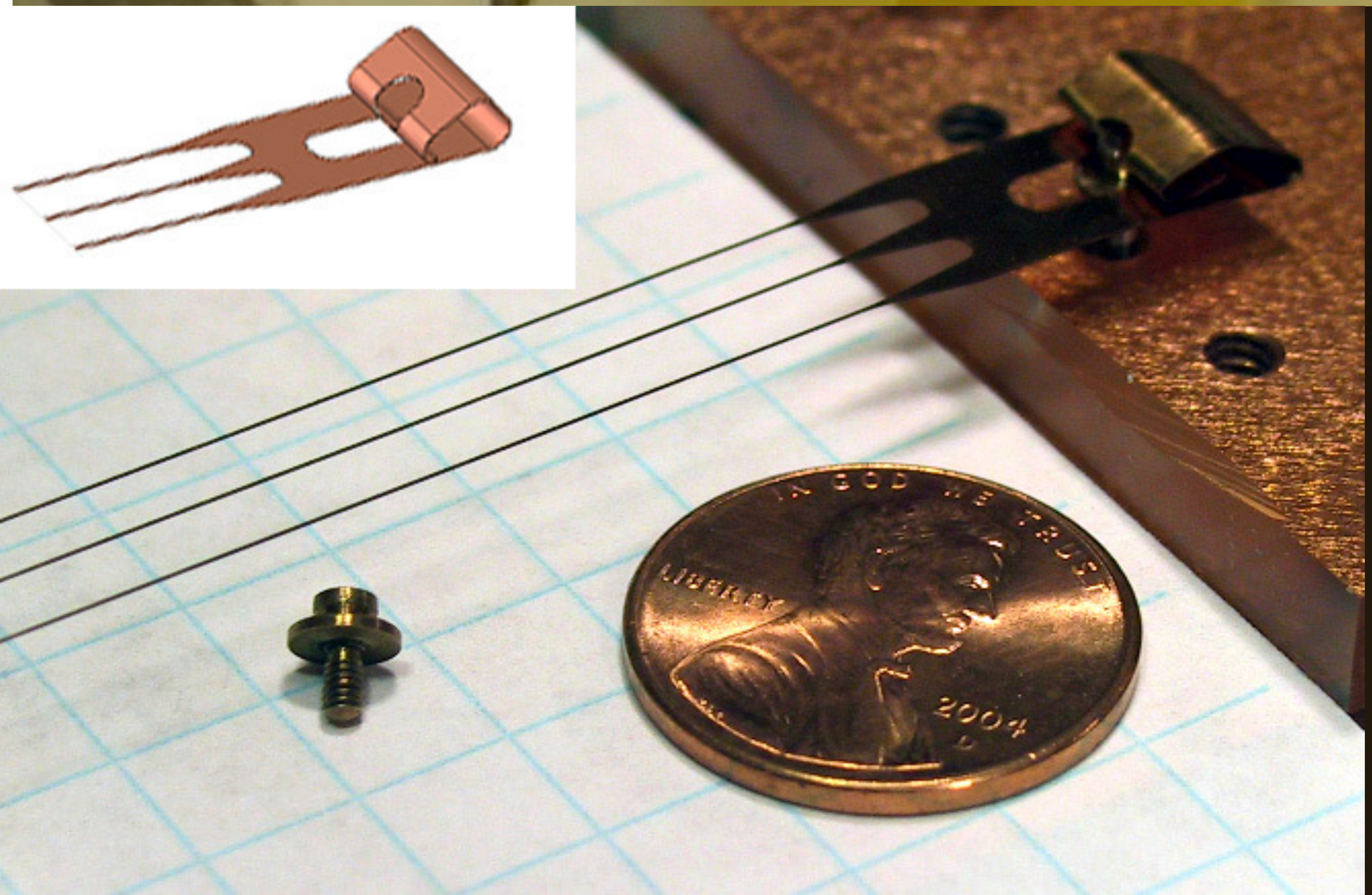


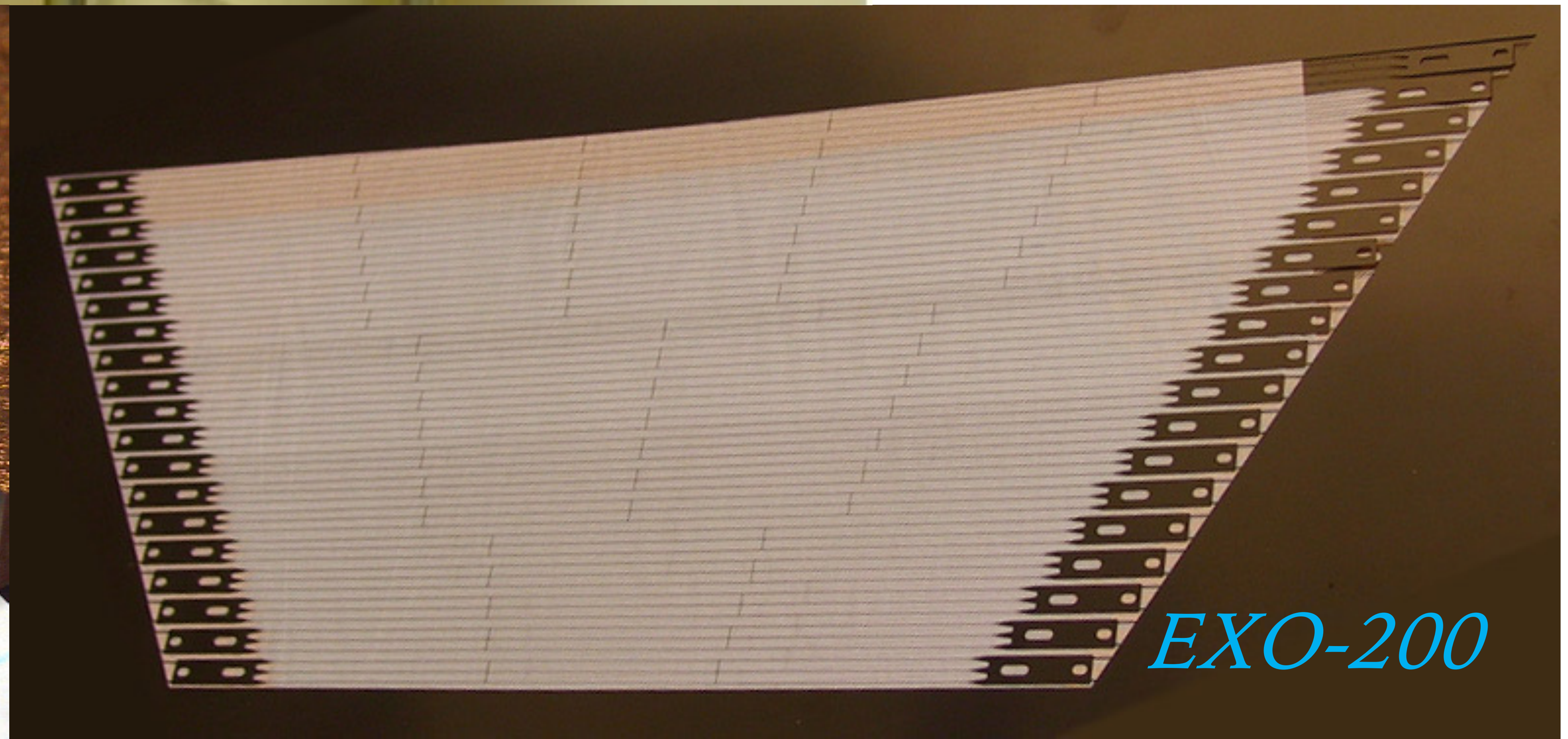


READOUT IONIZATION SIGNAL



- U and V wire planes to allow 2D position reconstruction of ionization signal
- 3 mm pitch decided by electric field uniformity, electron transparency
- 9 mm pitch from signal readout standpoint
- The solution: wire triplets
- Etched from a sheet of phosphor bronze

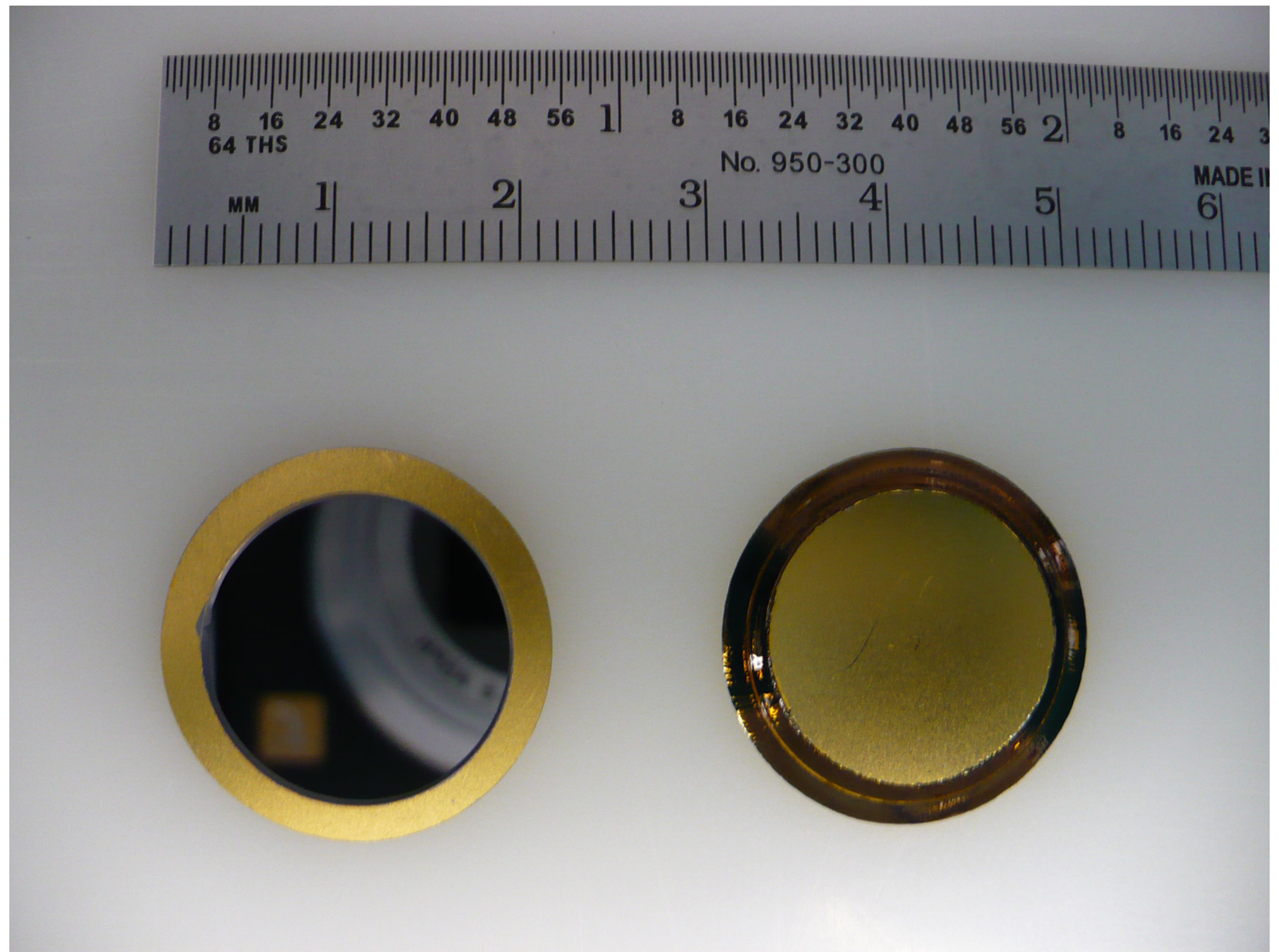




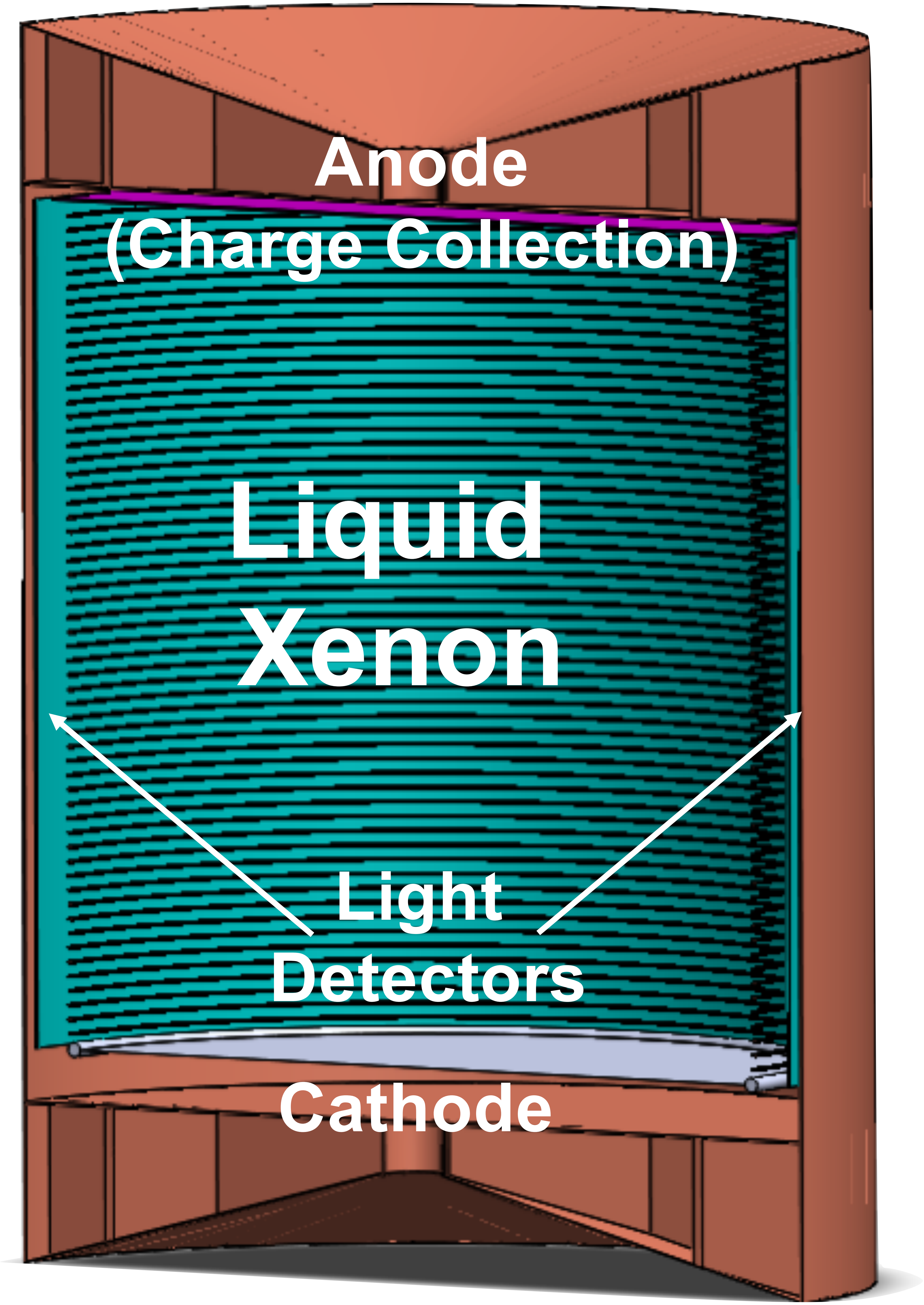
- Ends of each triplets are folded as springs
- Sqaure cross section: no gain.
- 95.8% transparency each plane

READOUT SCINTILLATION

- 468 large arae APDs (200mm^2)
  - Low radioactivity (w/o ceramic encapsulation)
  - More compact
  - Higher QE
  - Low gain and high noise: not an issue for double beta decay (MeV scale signal)

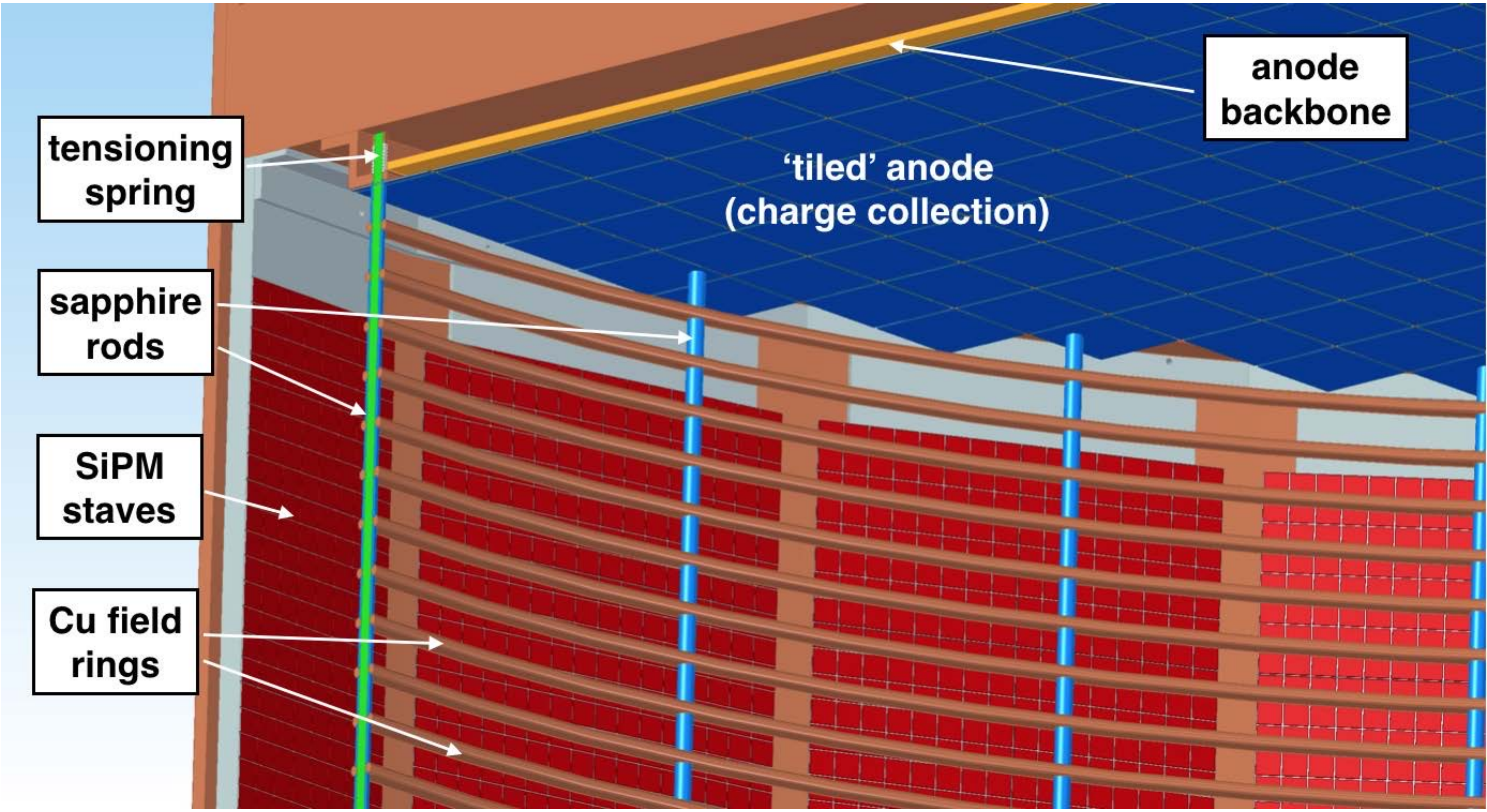


EXO-200

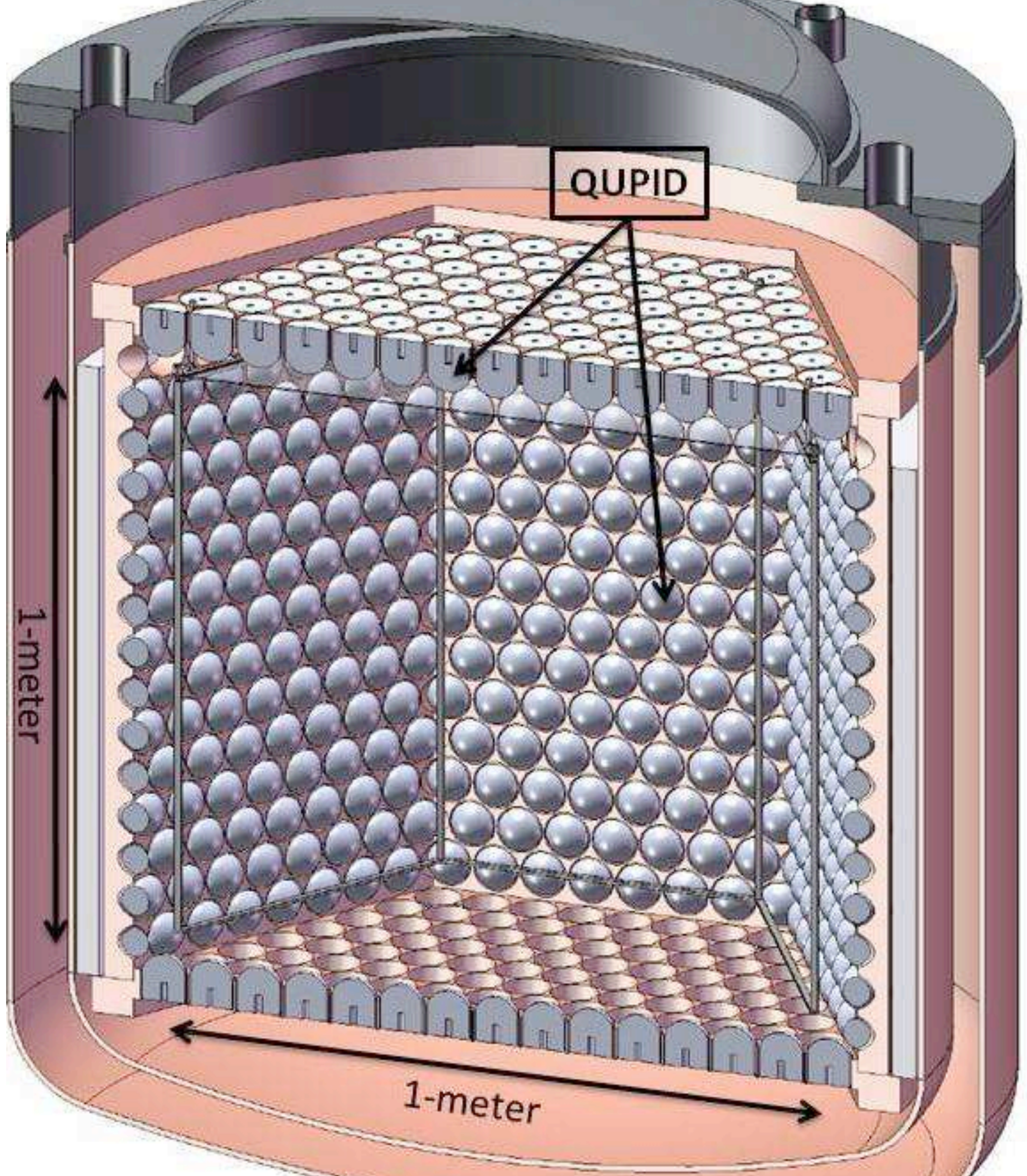


NEXO

- Top/bottom charge readout tiles
- Side light readout SiPMs
- ”Enabling technology”



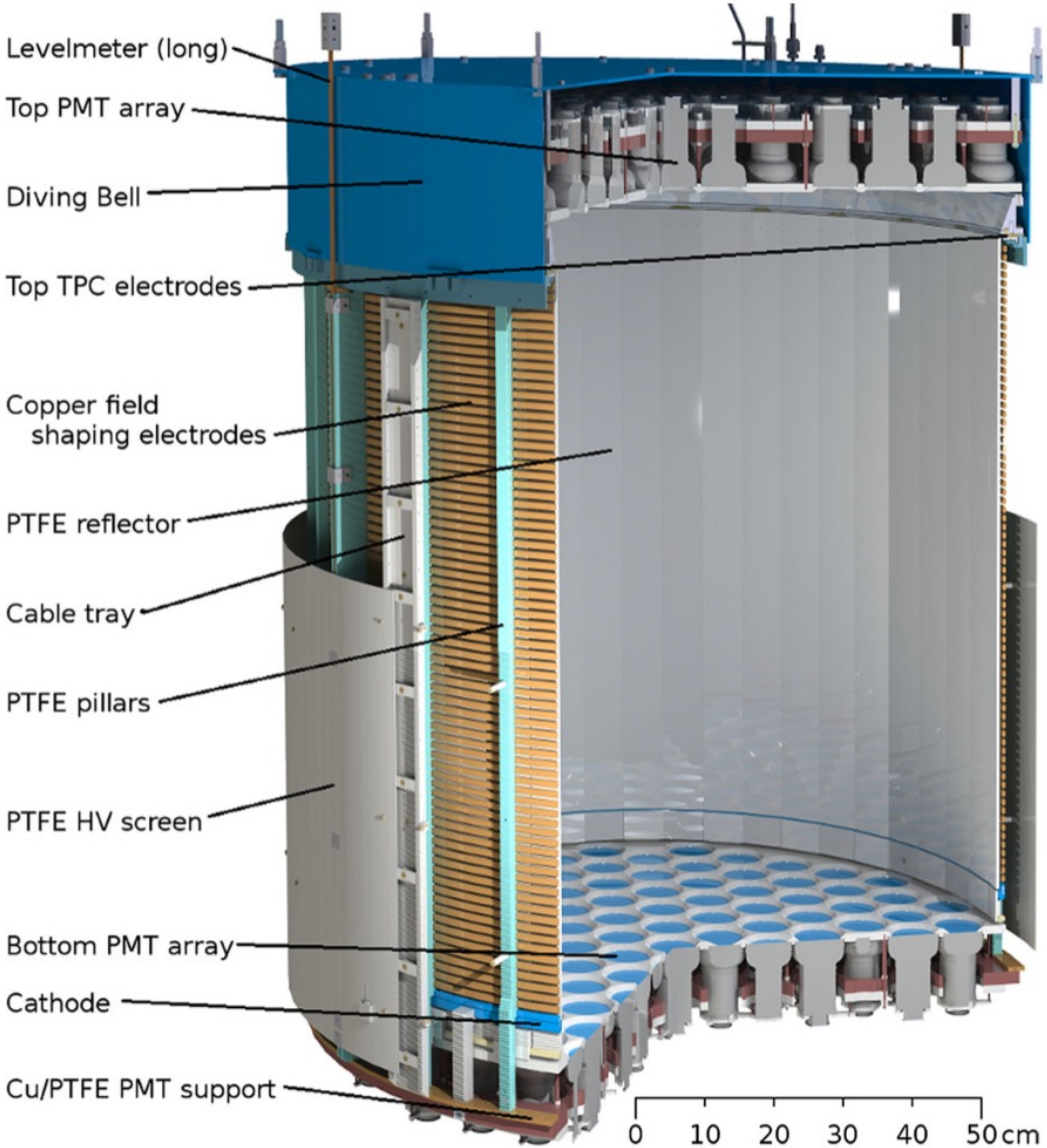
nEXO



DUAL-PHASE TPC

- Convert ionization to photon signals via Electroluminescence in gas
- USE PMT or other light sensors TWICE for one event
- Ideally photosensors have 4Pi coverage, but …
- Electroluminescence requires a higher E field

XENON1T early concept



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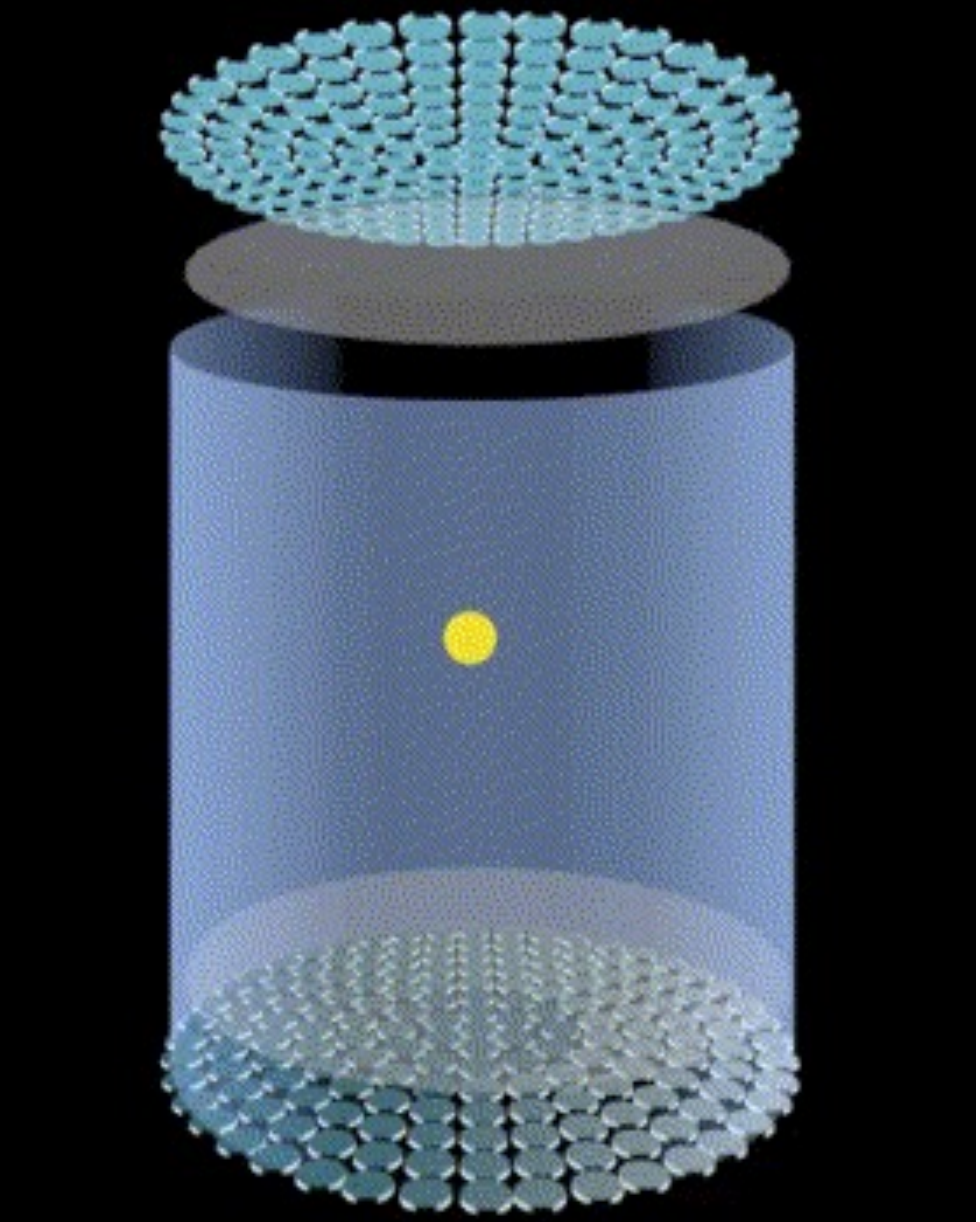
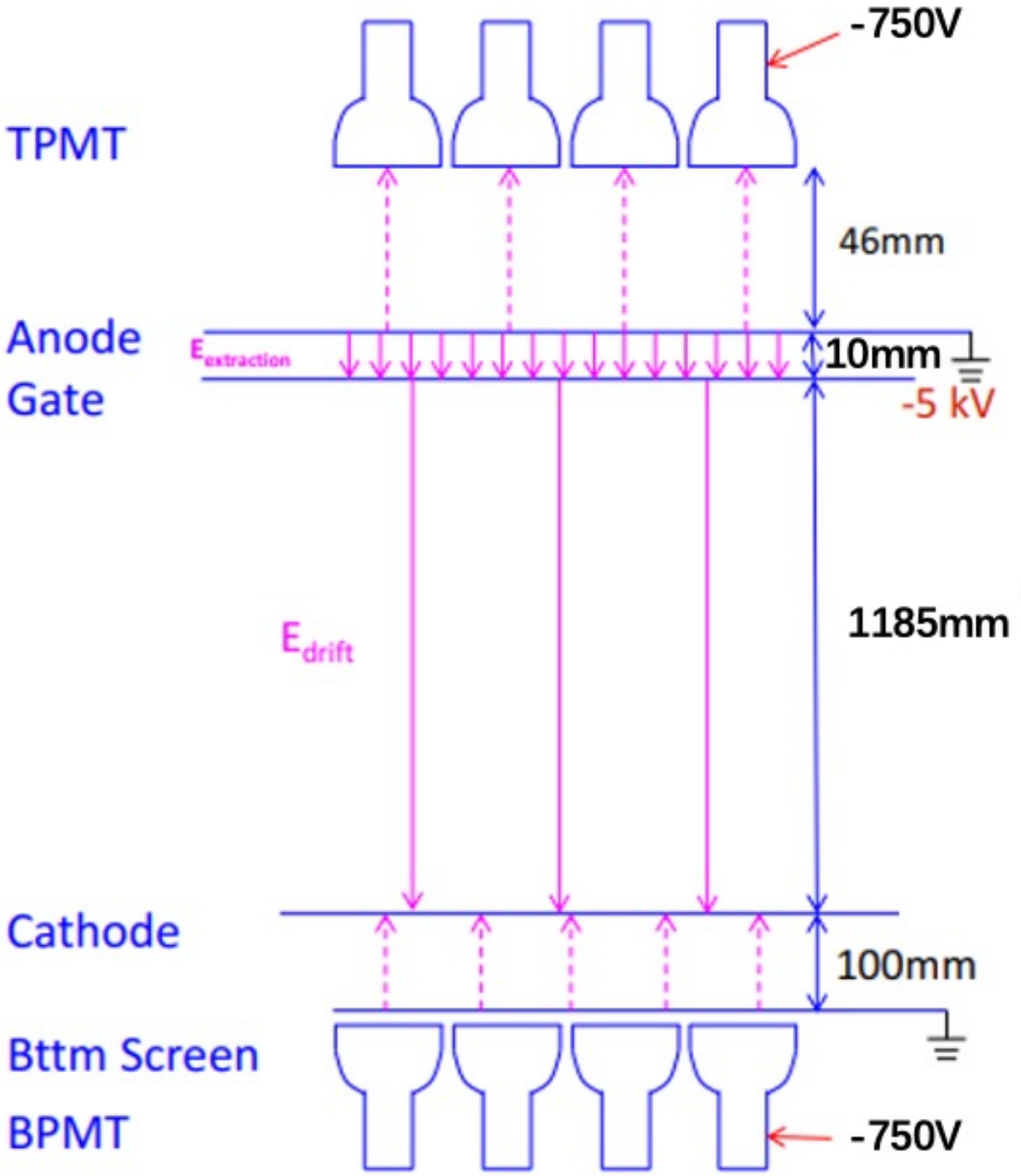
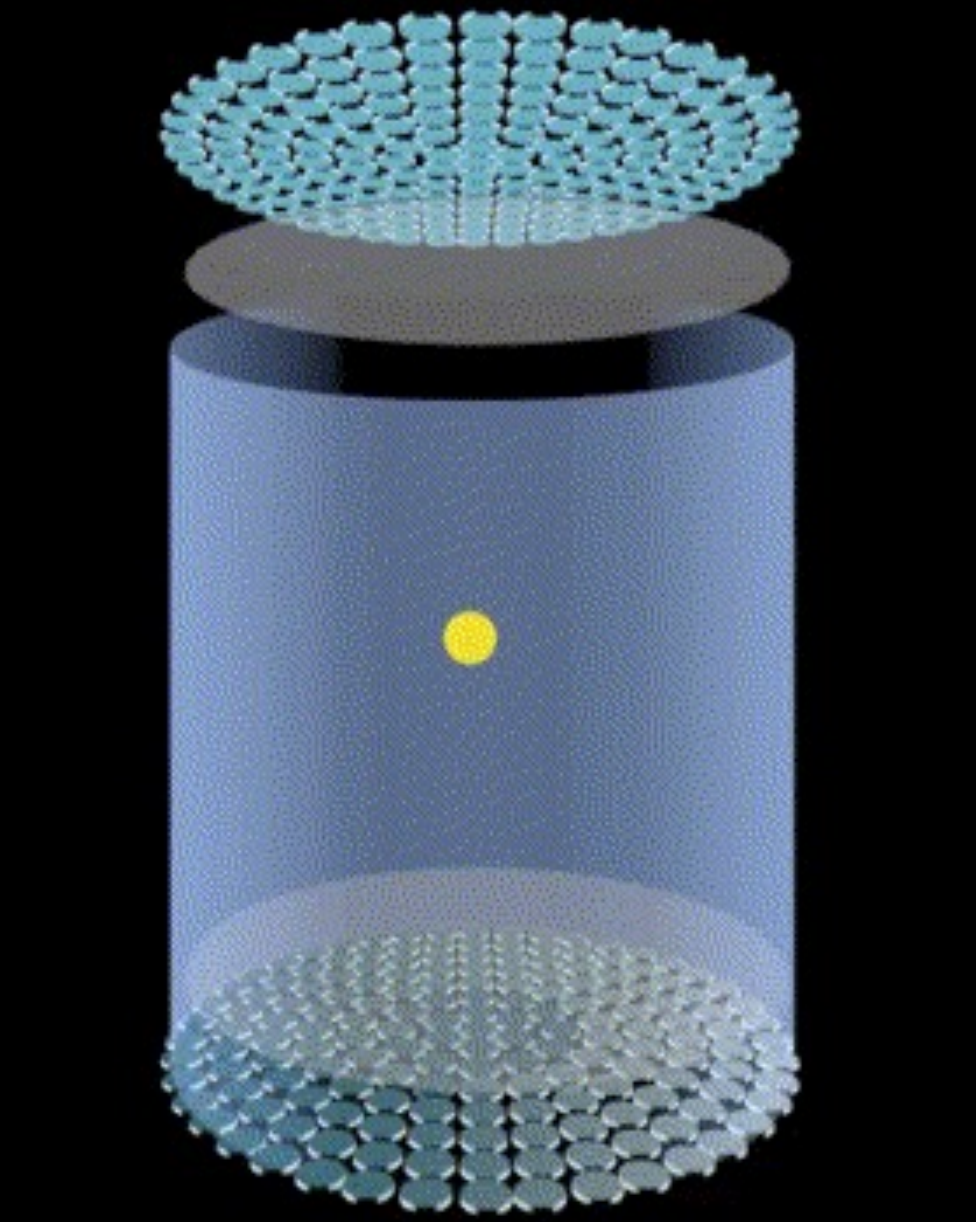
XENON1T

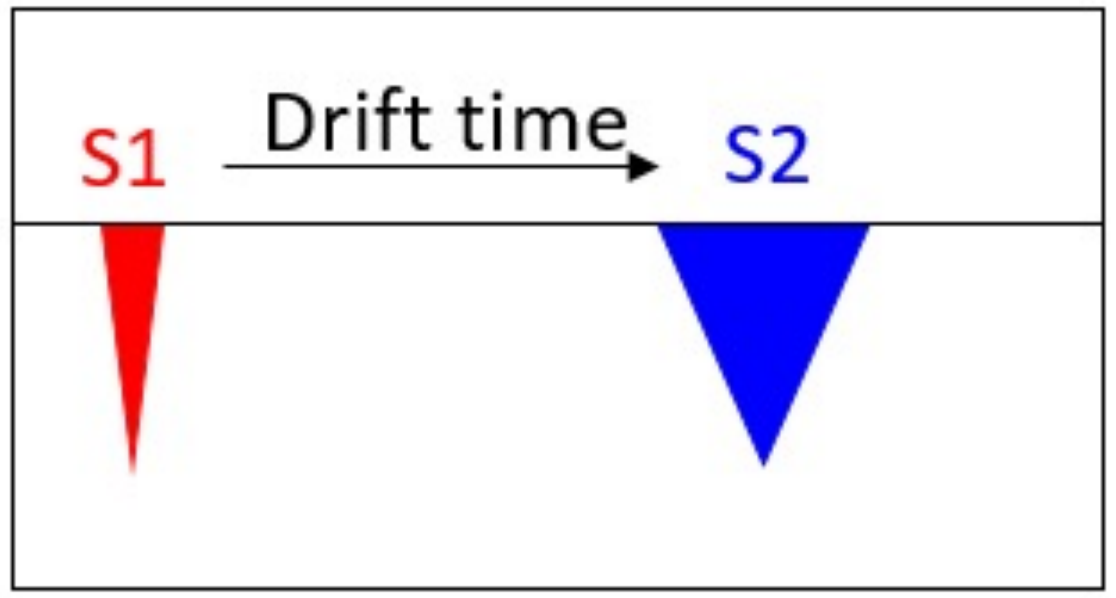



-750V
TPMT
46mm
Anode
E extraction
10mm
Gate
-5 kV
E drift
1185mm
Cathode
100mm
Bttm Screen
BPMT
-750V

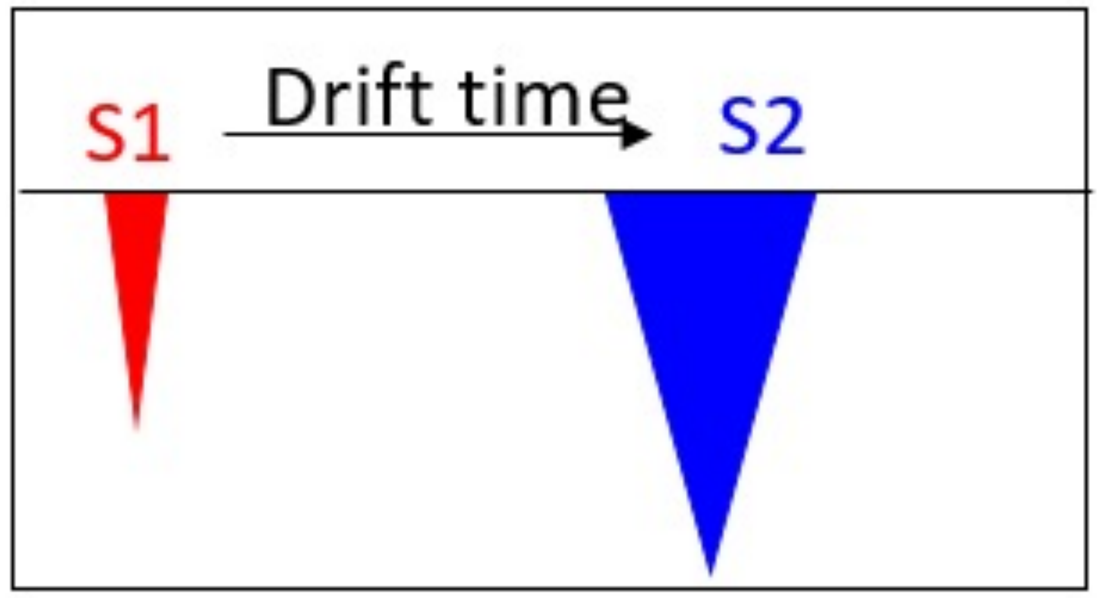


PERFECT FOR DM DETECTION

Dark matter: nuclear recoil (NR)

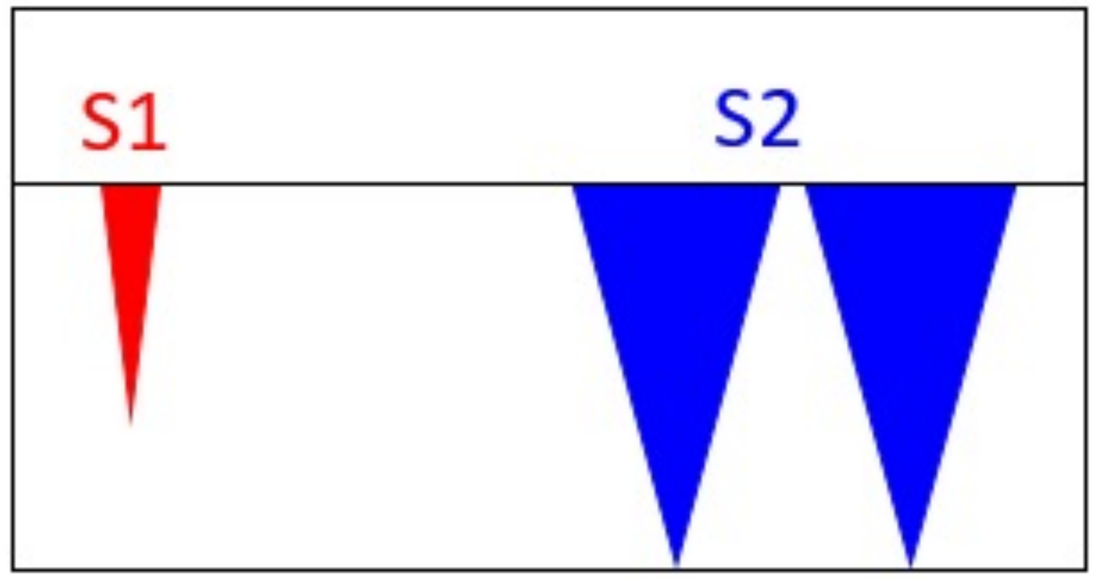


γ background: electron recoil (ER)

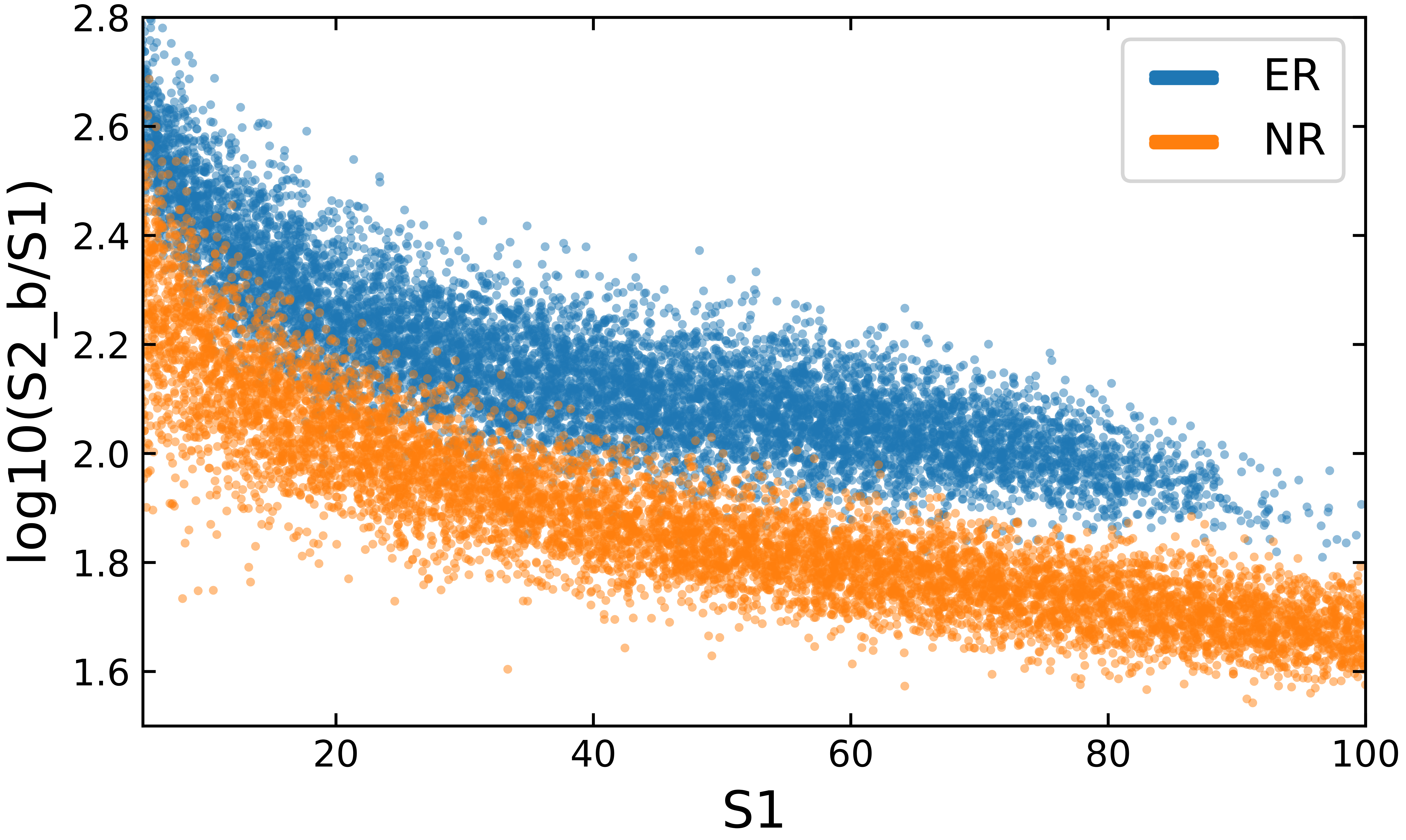


$$(S2/S1)_{NR} << (S2/S1)_{ER}$$

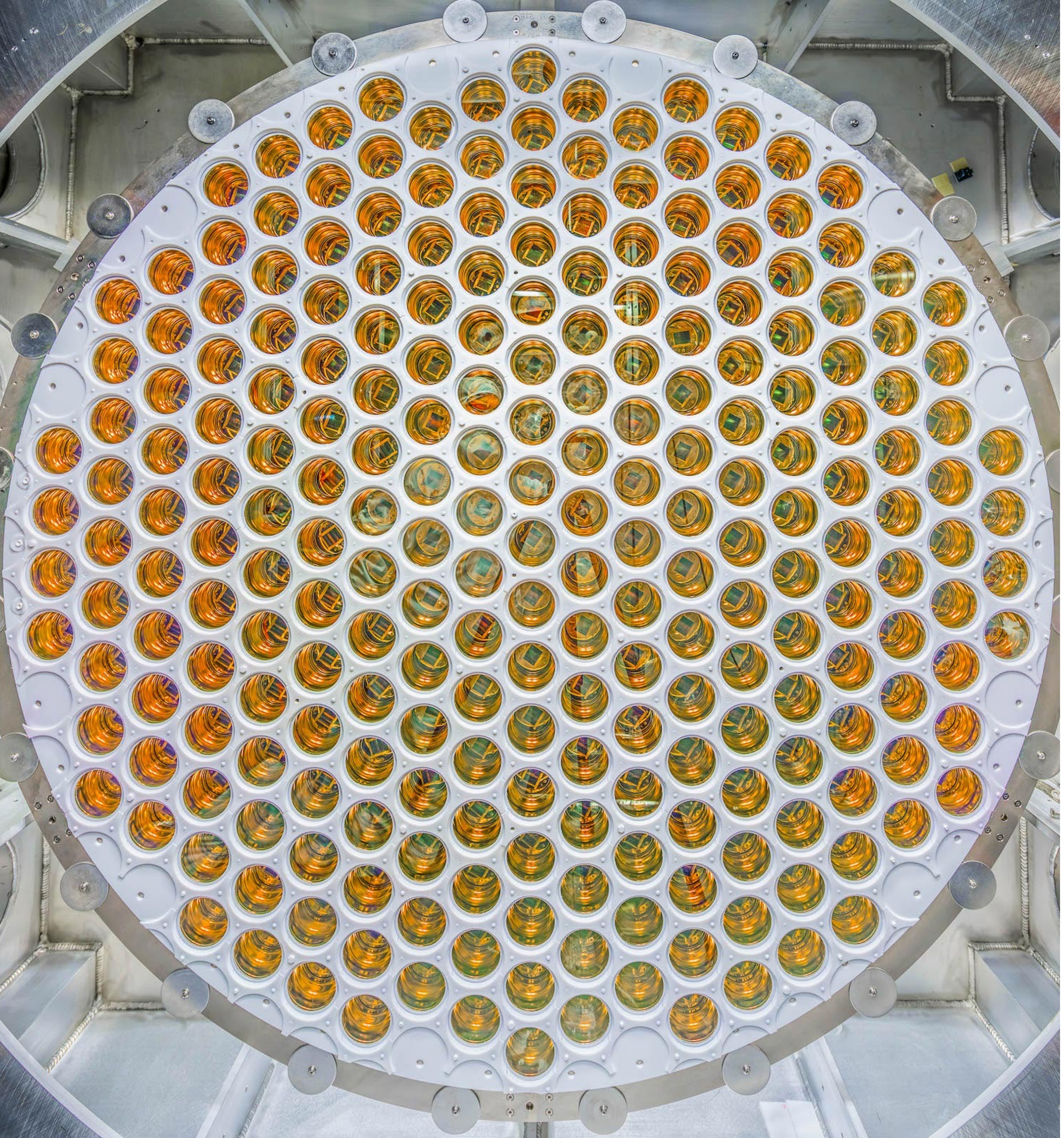
Multi-site scattering background (ER or NR)



ER VS. NR BANDS

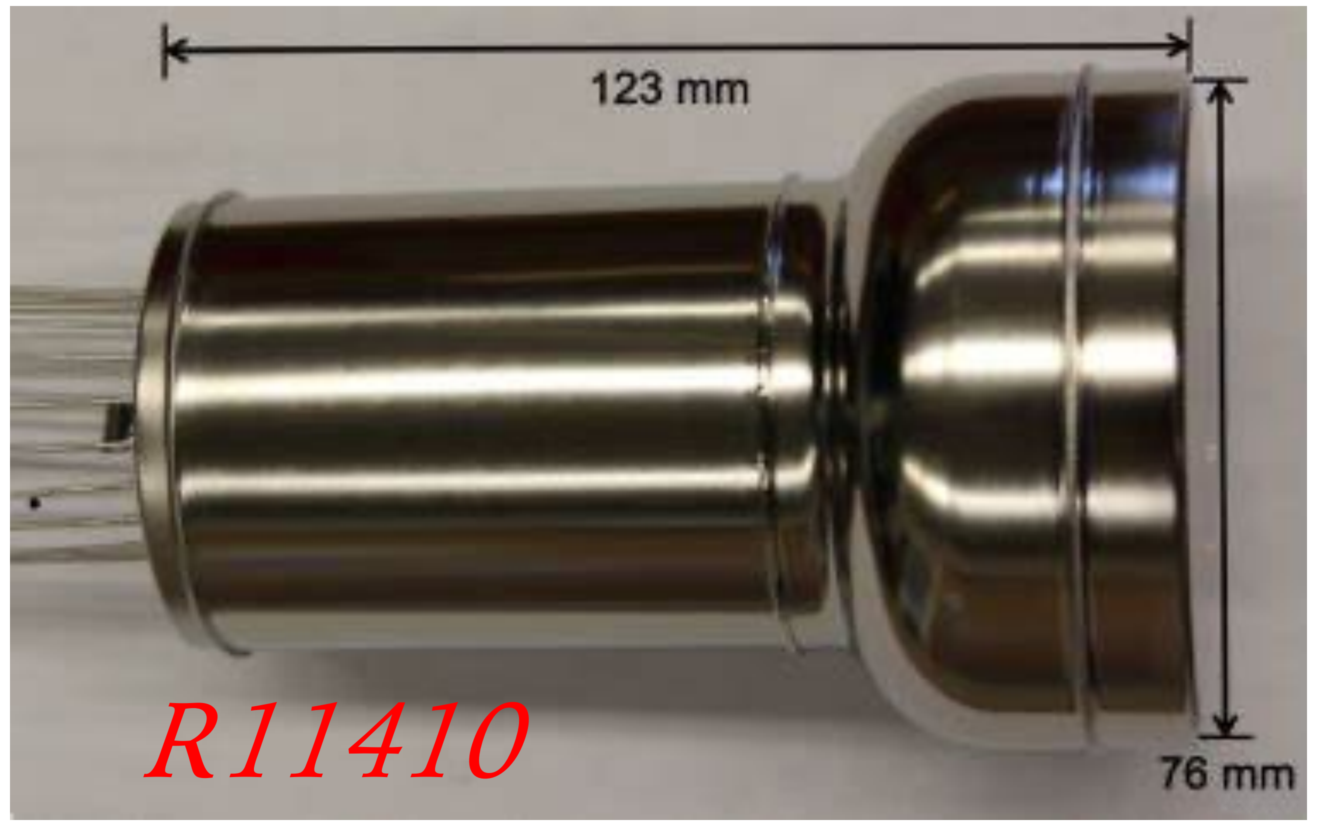


NEST Simulation



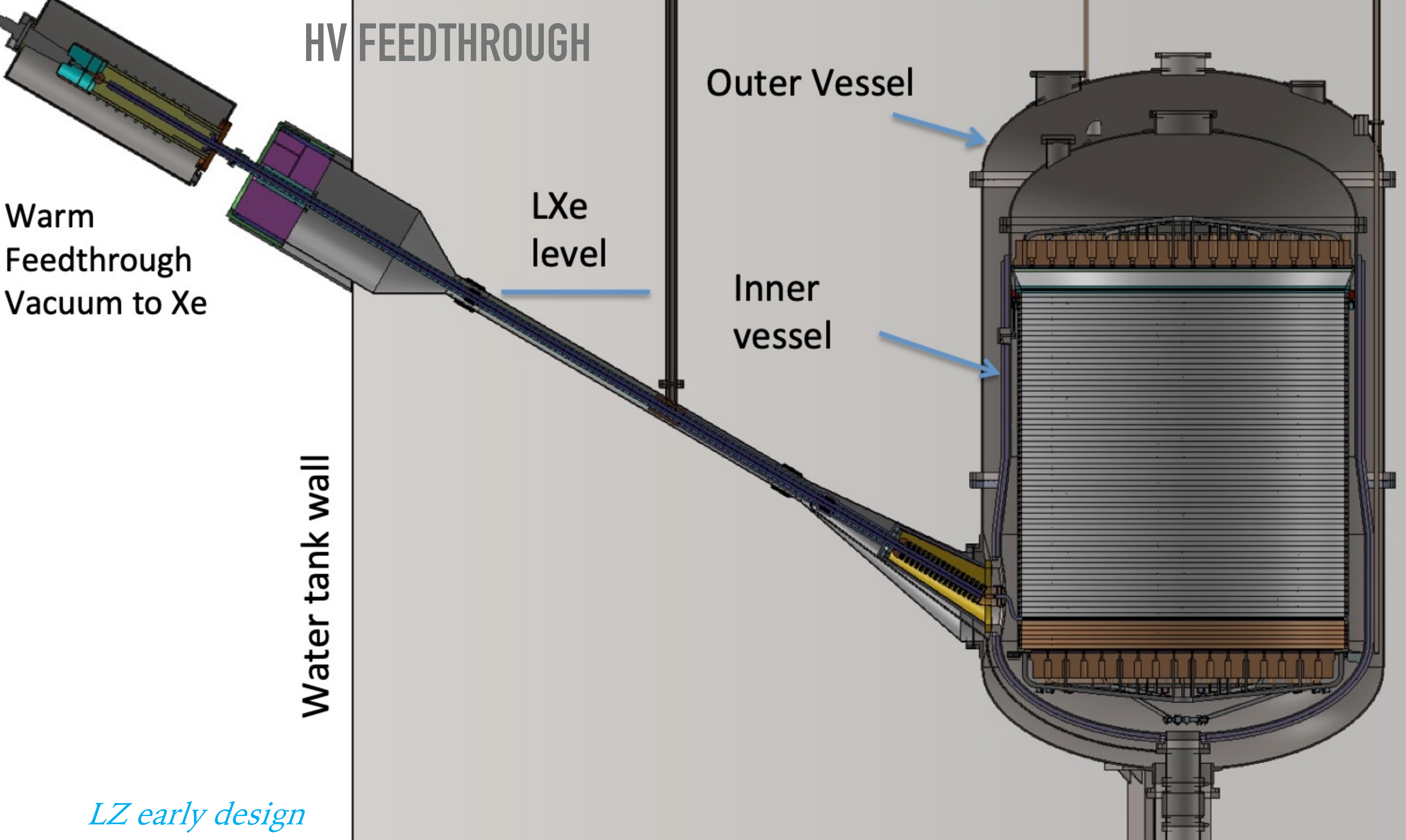
PHOTOSENSORS

- VUV sensitive, crogenic-compatible low-radioactivity PMTs
- The same type of Hamamatsu PMTs used by PandaX-4T, LZ, and XENON
- Cover the TPC with as many as PMTs and cover the rest surface with PTFE.
- Exploring other options: SiPMs and potentially better PMTs

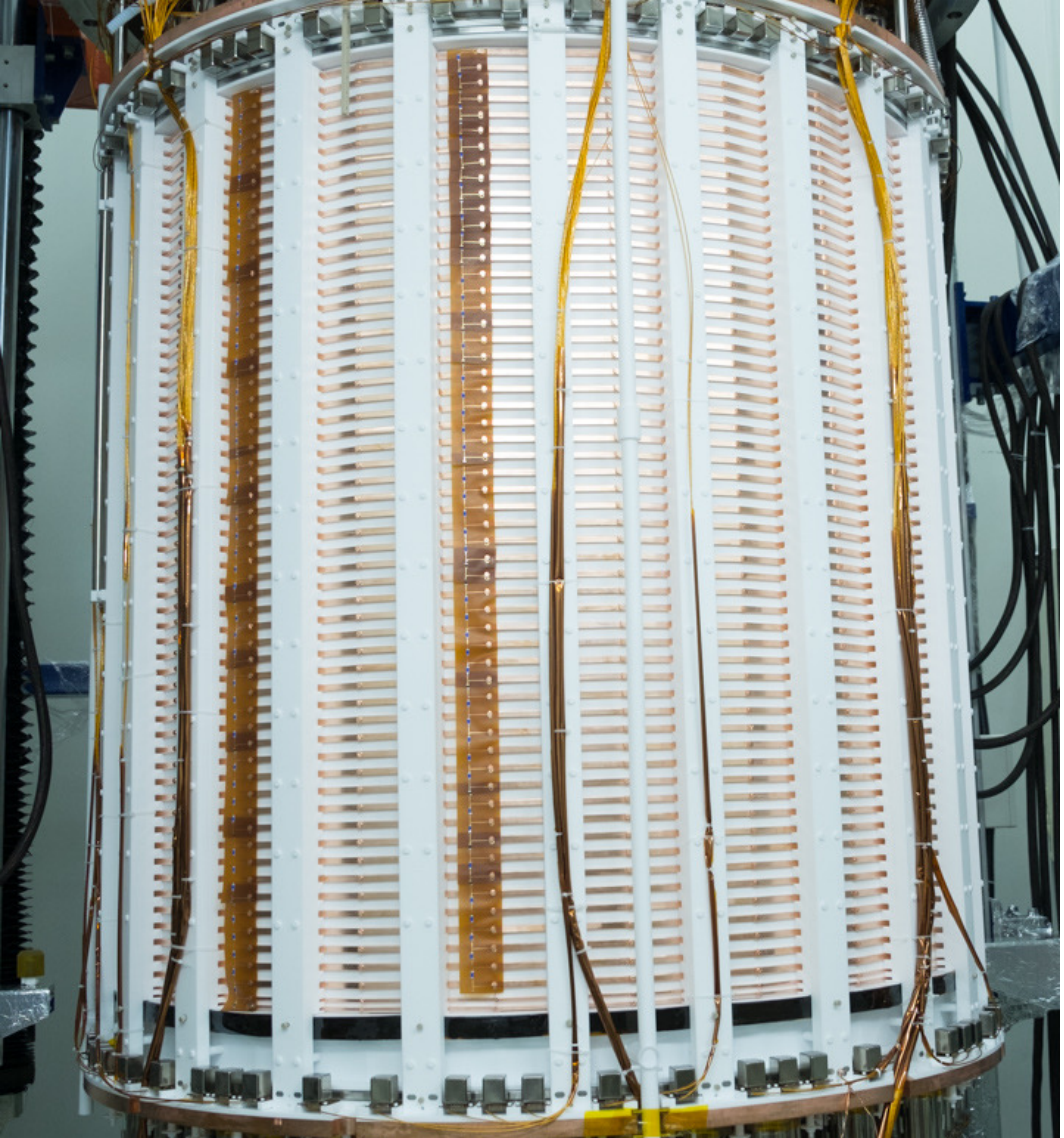


LZ

HV FEEDTHROUGH



LZ early design



FIELD CAGE

- Copper rings with resistors for field degradation
- PTFE for VUV light reflection
- Chanllenging machining and assembly
- Innovative designs need validations for performance and radioactivity requirement.


Distillation Tower
Electronics and DAQ System
Cryogenics and Circulation System
Clean Room
Xenon Gas Storage System
Xenon Emergency Recuperation System
Water Shielding Tank
Φ: 10m
H: 13m
Dual-Phase Liquid/Gas Xenon Time Projection Chamber (TPC)

Can we use TPC for MEG II gamma-ray measurement?