DMNet

NAGOYA UNIVERSITY

ISEE
Institute for Space–Earth Environmental Research

LIDINE 2022 September 22th 2022

Development of coated electrodes with low quantum efficiency for future direct dark matter experiments with liquid xenon

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Challenges for Dual-Phase LXe TPC

- Direct DM experiments based on dual-phase LXe TPC have some problems related to electrodes and they cause some problems:

    1. Applying high electric field for ton-scale LXe TPC might be challenging due to disconnection, sagging, discharge and etc (ex: electric field in XENONnT is operated at 23 V/cm).
       ➡ **Mechanically stable electrodes are needed.**

    2. In S2-only analysis, there are lots of instrumental BGs related to electrodes where their BG models are not well understood.
       ➡ **Reducing such instrumental BGs is the key for the discovery of low mass DM.**

- We are trying to solve these problems by
  coated electrodes with low quantum efficiency (QE).

Instrumental S2-Only BGs

- ① **Delayed extraction**
  Some of electrons are trapped at the liquid surface and their extraction is delayed.
- ② **Field emission**
  High electric field near electrodes can produce electrons.
- ③ **Photoelectric effect**
  Photoelectric effect on electrodes and electronegative impurities.
- ④ **Capture and release by impurities**
  Electronegative impurities like O_2 in Xe capture and release electrons.
- ⑤ **Decay of radioactive impurities on cathode**
  Decay of ^{222}Rn daughters which plate out on electrodes.

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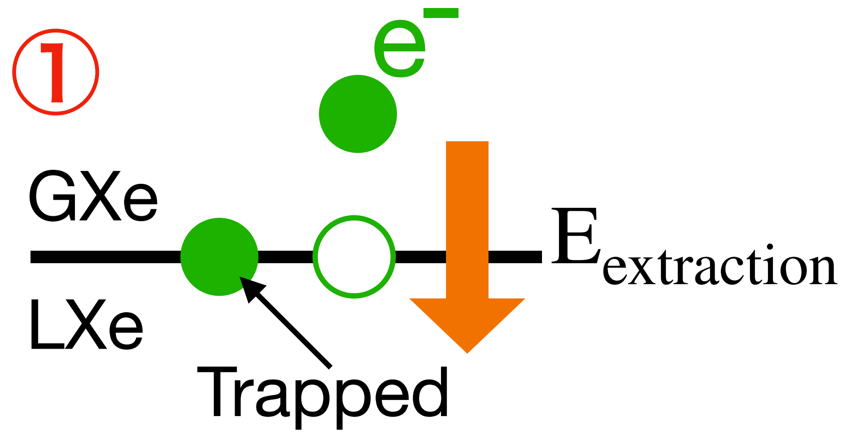

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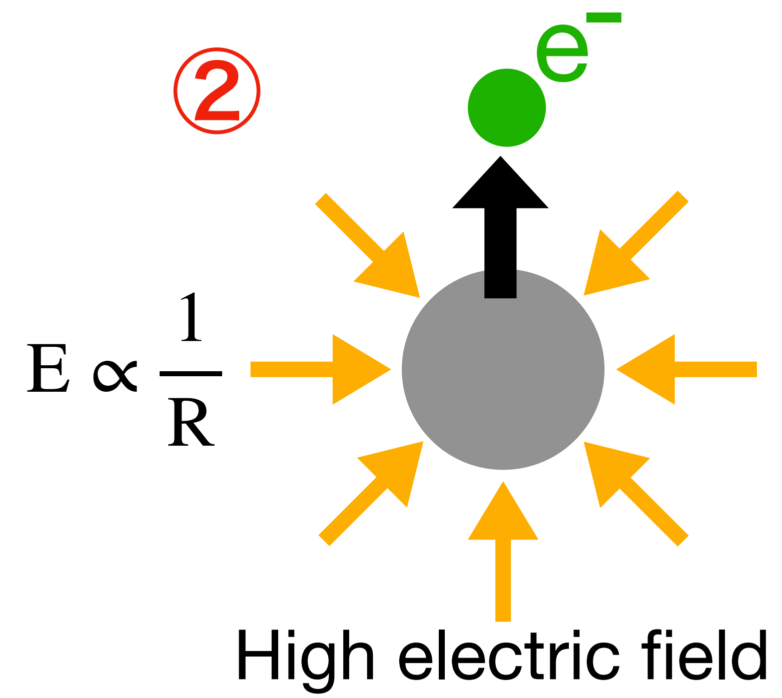

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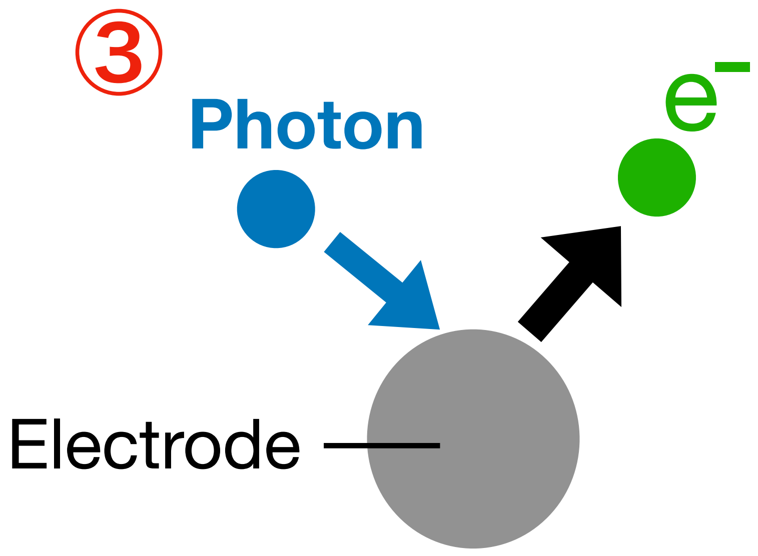

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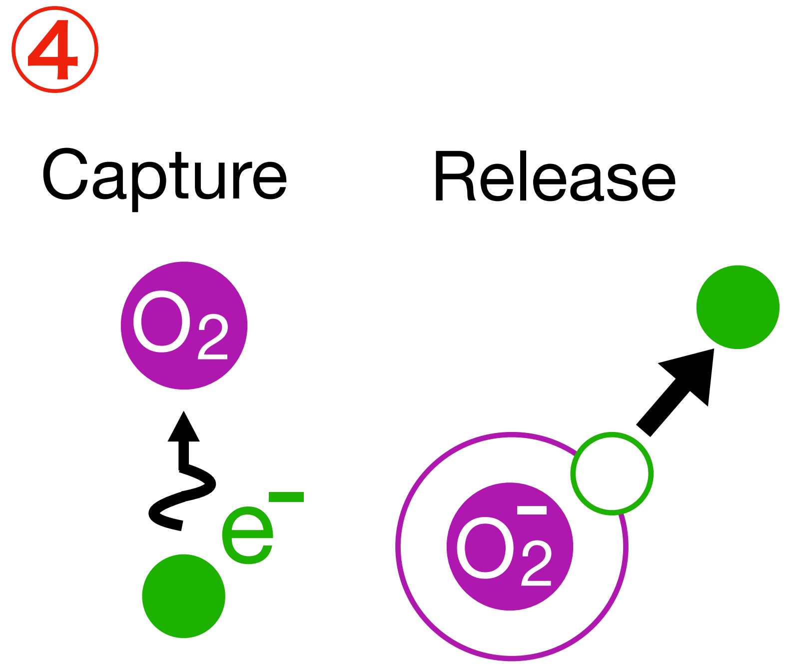

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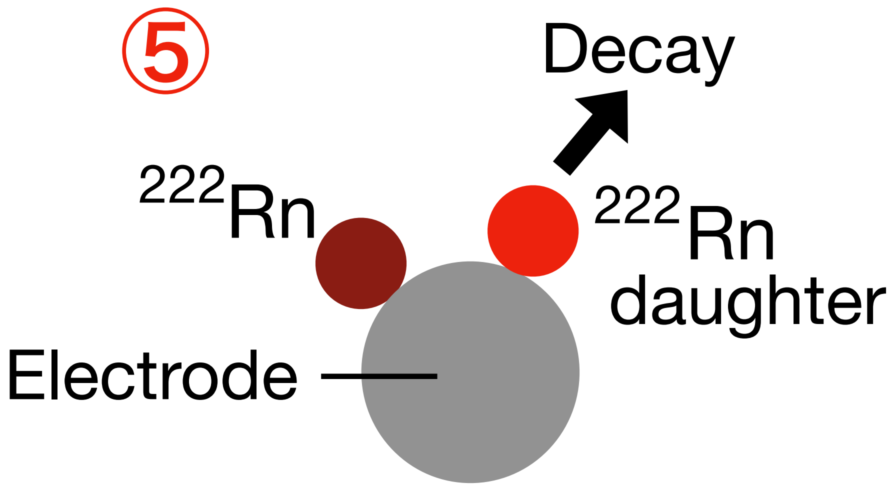

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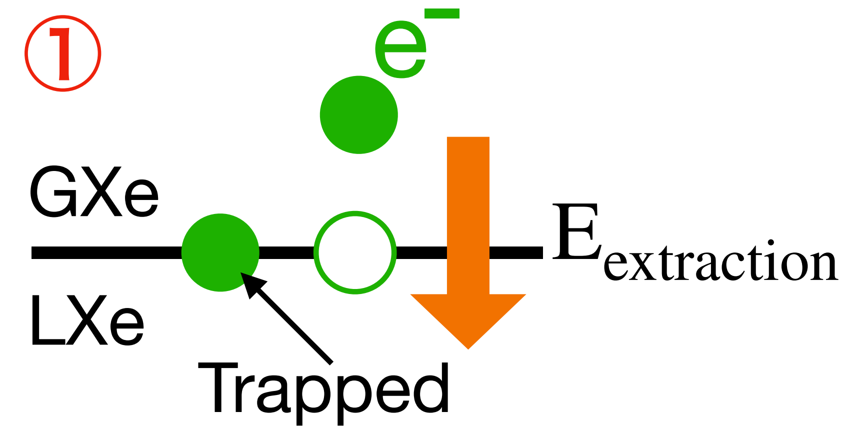
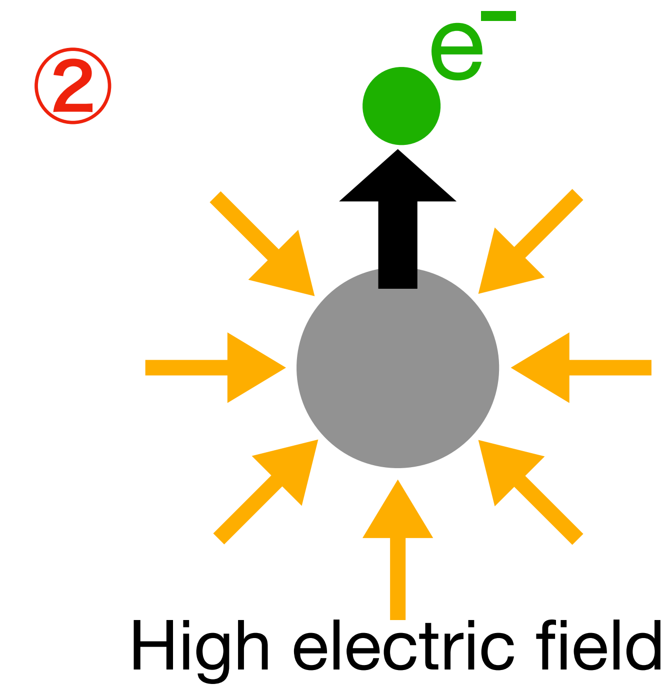
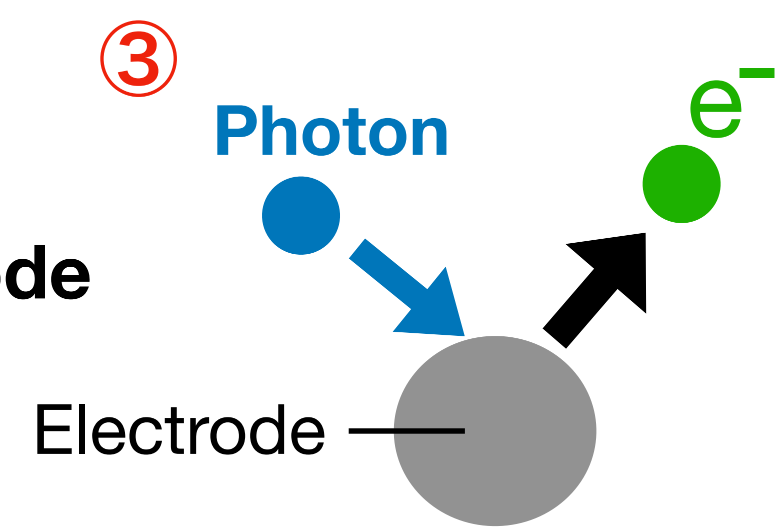
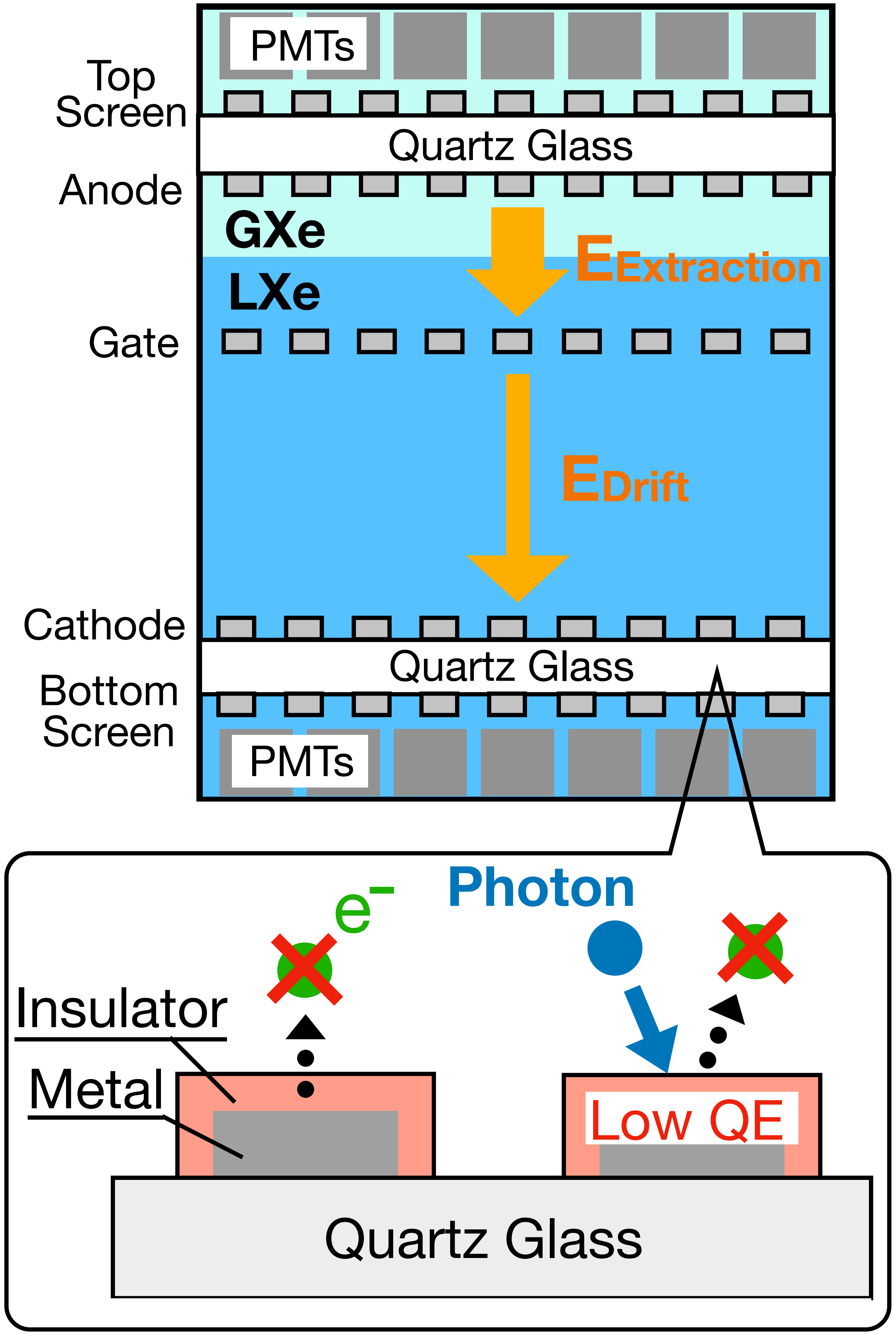






Advantages of Coated Electrodes with Low QE

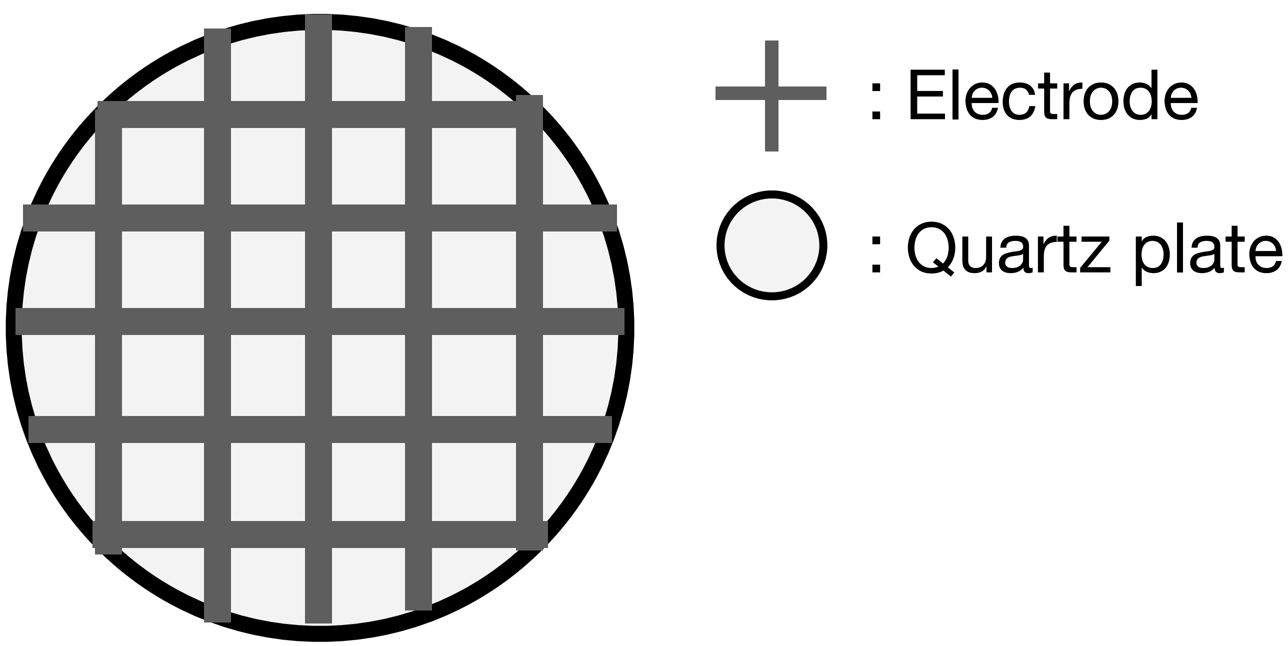


- No disconnection and less sagging :
  - Mechanically stable because it is coated on quartz glass.
- Less S2 only BGs :
  - Low QE material can reduce electrons produced by **photoelectric effect**.
  - Additional layer of insulator may reduce the electrons from the metal surface by **field emission**.
  - Because of less sagging, it might be also possible to apply high-extraction field, which may reduce trapped electrons (**delayed extraction**).

Toward LXe TPC with Coated Electrodes

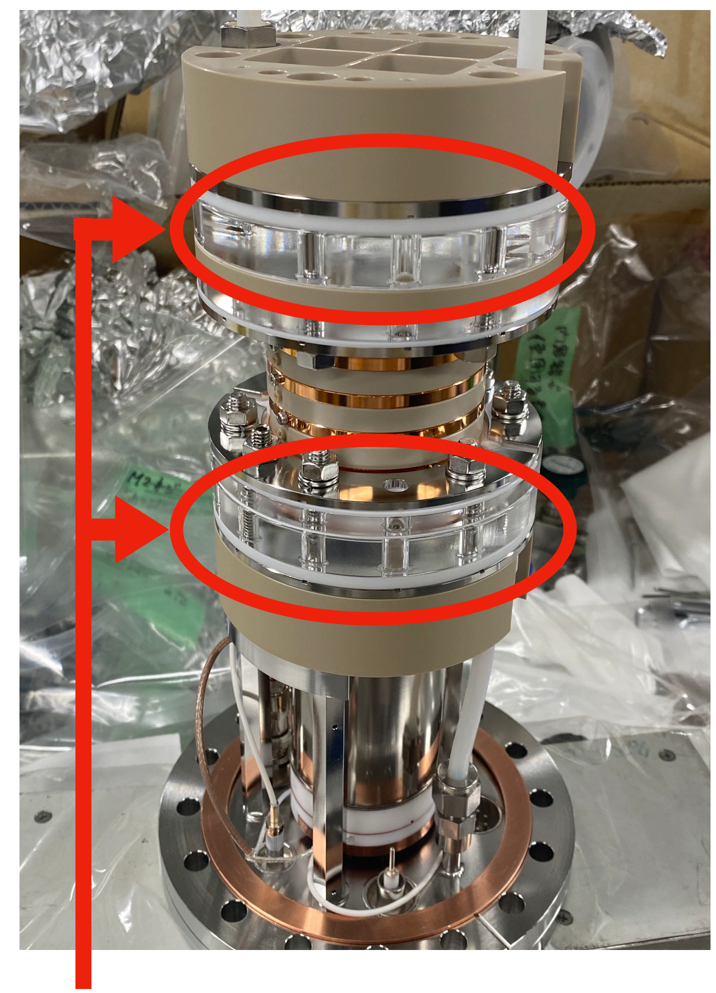
Development of coated electrodes with low QE

- Find a good material with low QE.
- Optimize coating pattern and coating method



  - Optimize coating area such that total transparency reaches ~ 90%.
- Build a dedicated LXe TPC with the selected electrode and characterize its performance.

Prototype of LXe TPC



Quartz Plate

We will coat electrodes on them.

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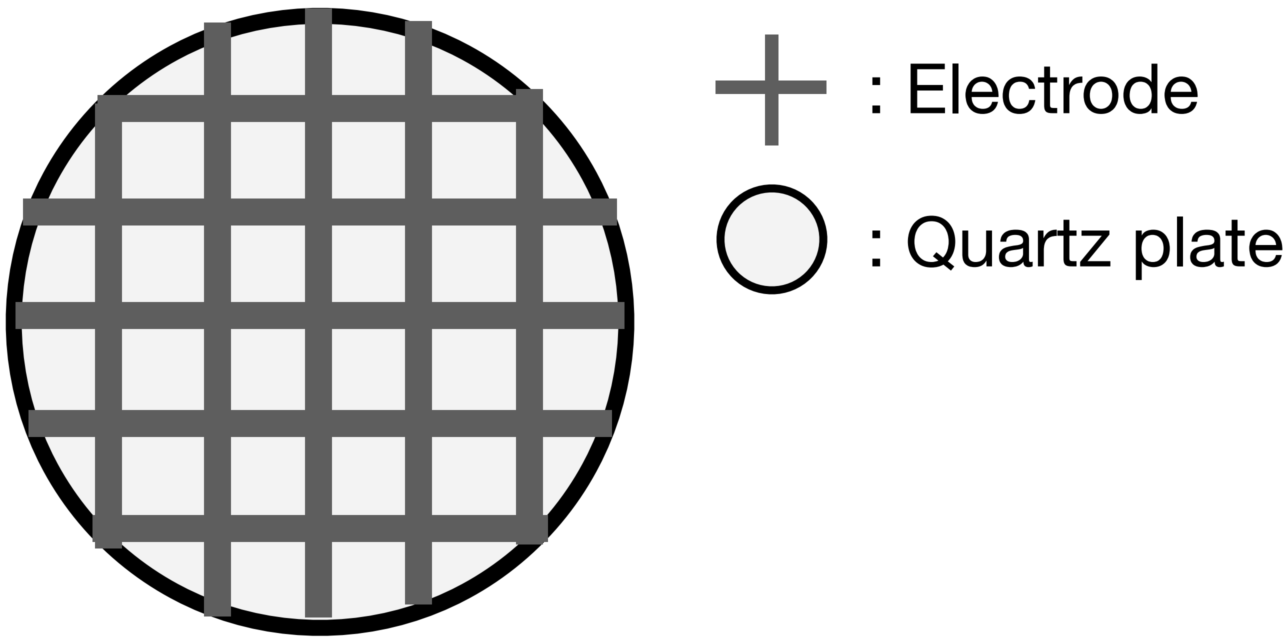

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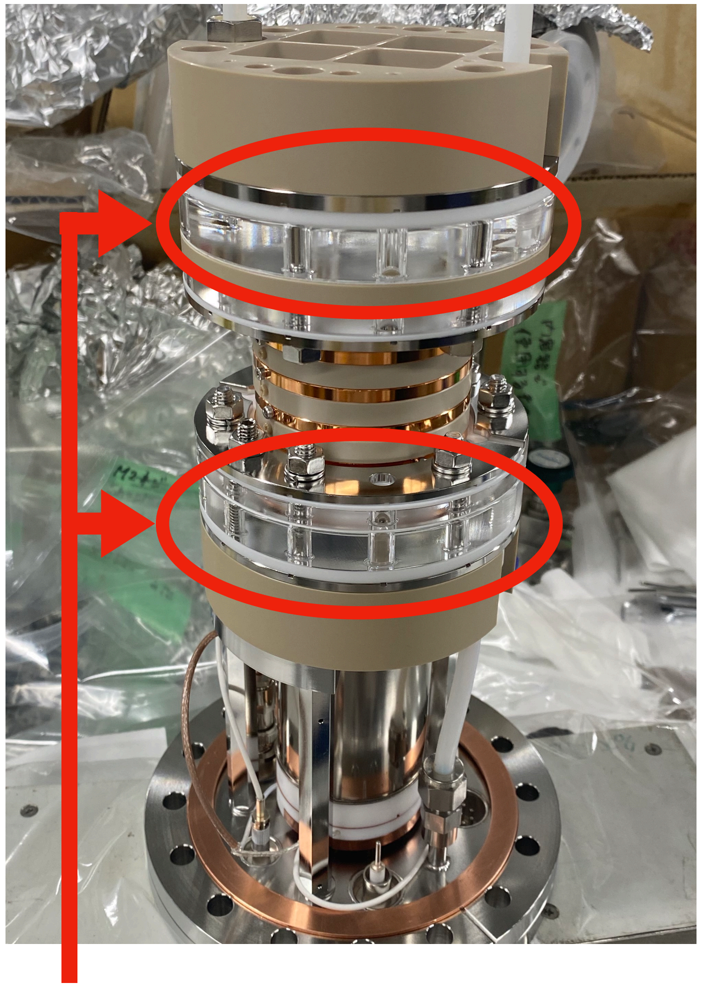

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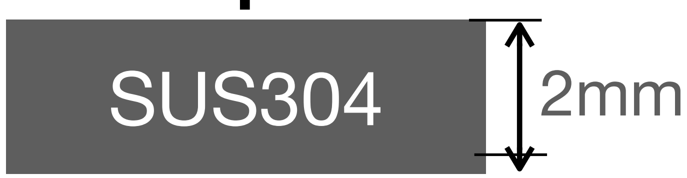
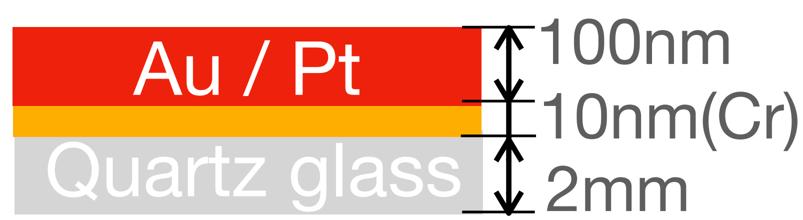
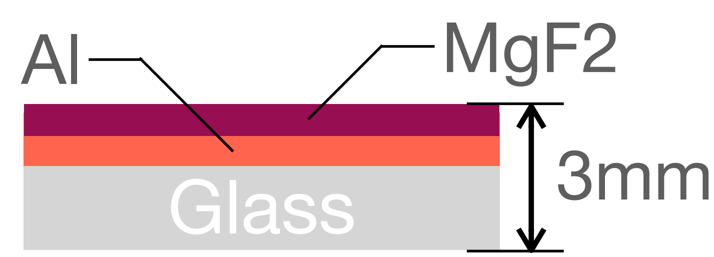
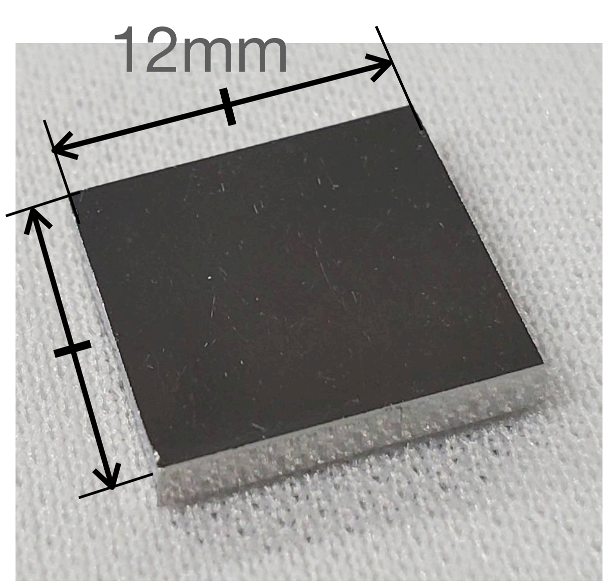
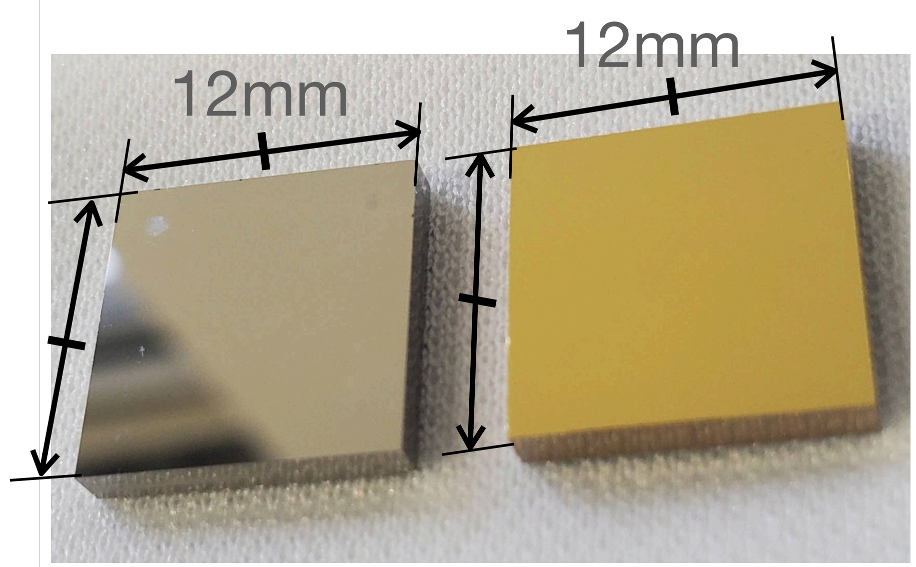
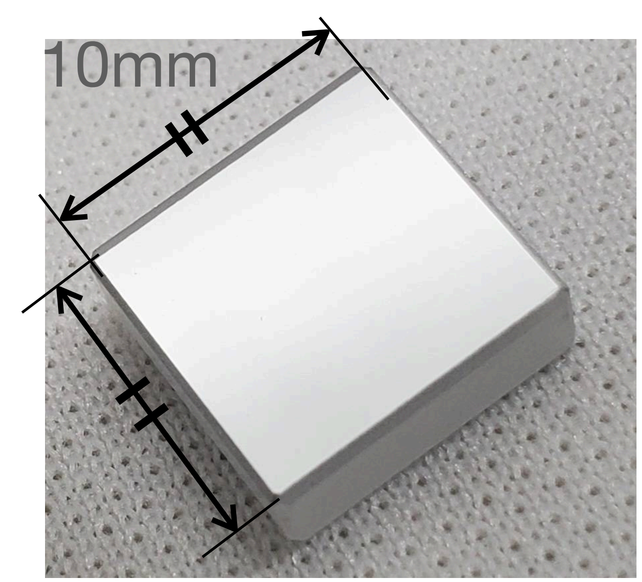
Candidate Electrodes

Measured Samples

Stainless steel : Used in XENONnT and LZ
Measured as a reference.

Au / Pt : Metals with high work function

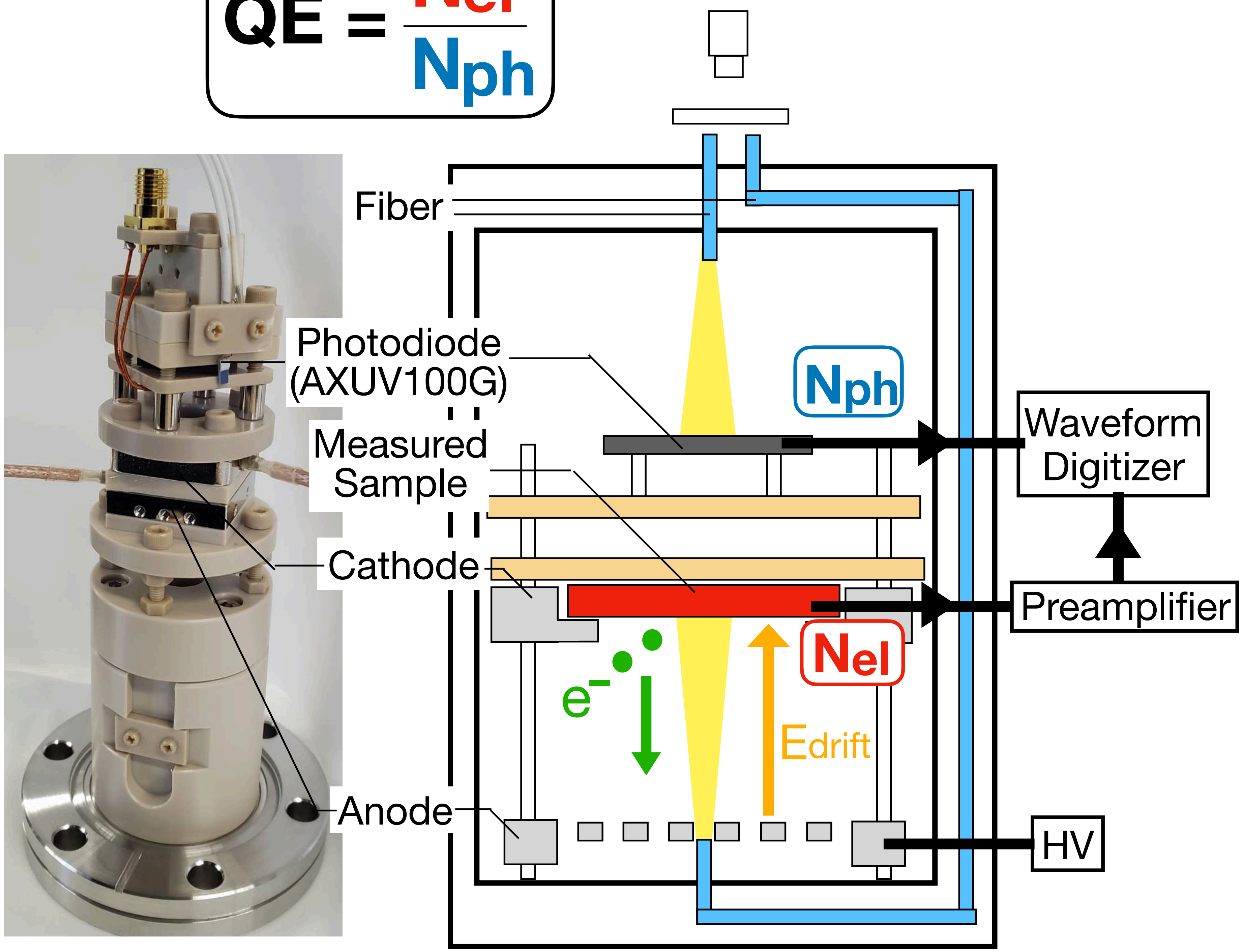
Al + MgF2 : Metal-surface coated with insulator

Stainless steel(SUS304)	Au / Pt	Al + MgF2
Electropolished 		
		

Measurement Setup

Measurement system
in vacuum, GXe and LXe.

$$QE = \frac{N_{el}}{N_{ph}}$$



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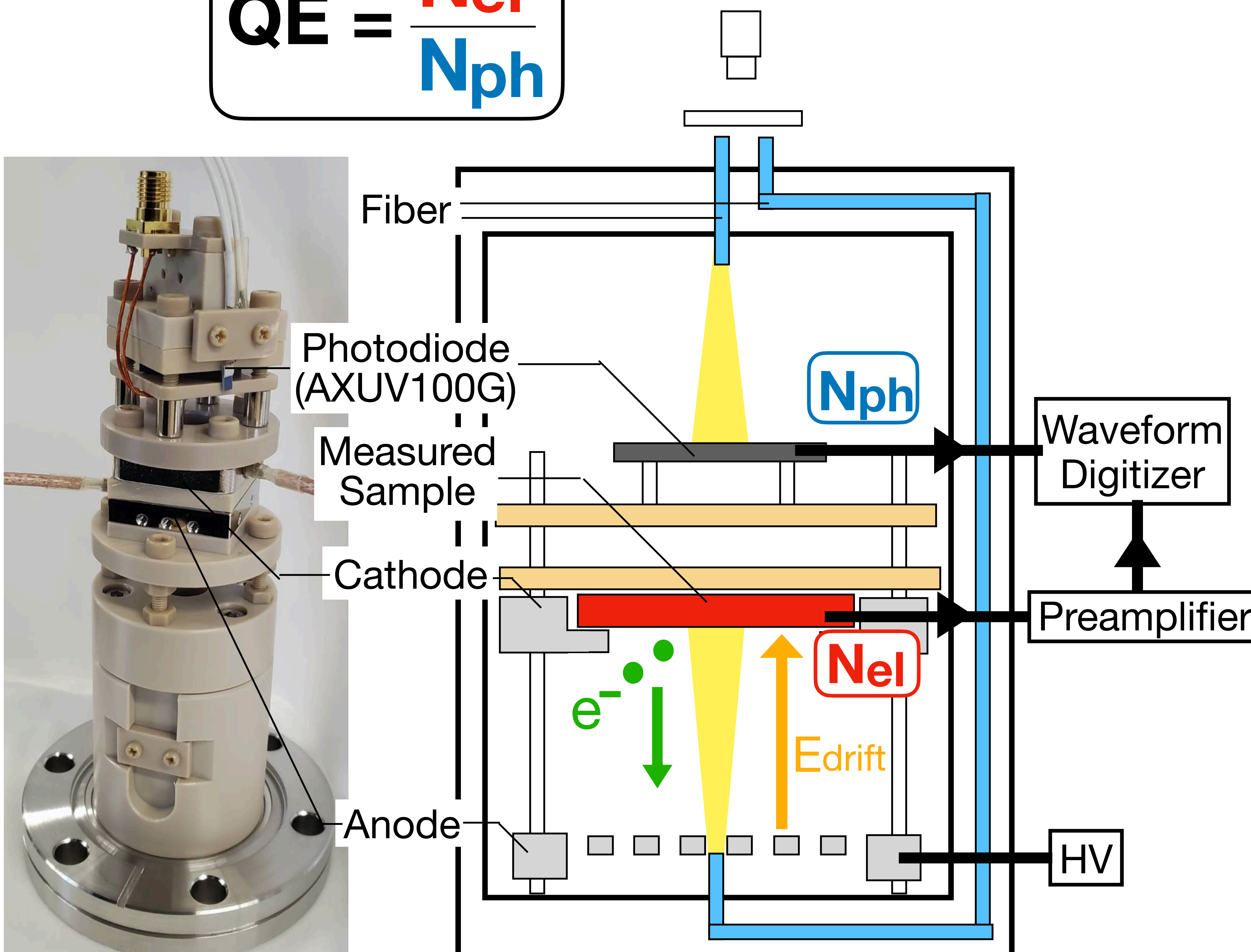
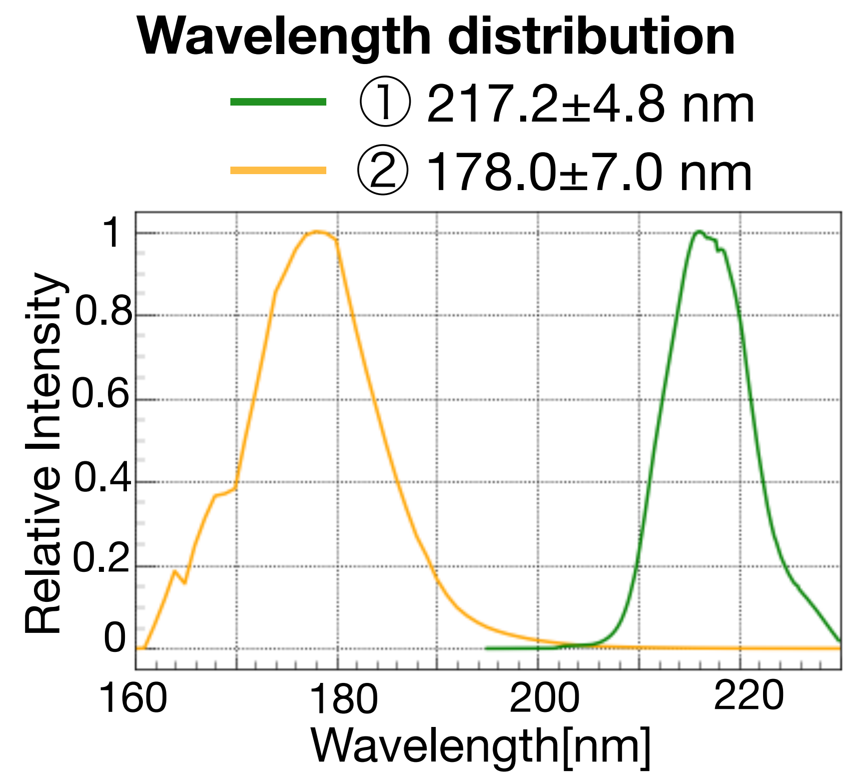
Light Sources

① Xe Flash Lamp + Bandpass filter[217 nm]
② H2D2 Lamp + Bandpass filter[172 nm]





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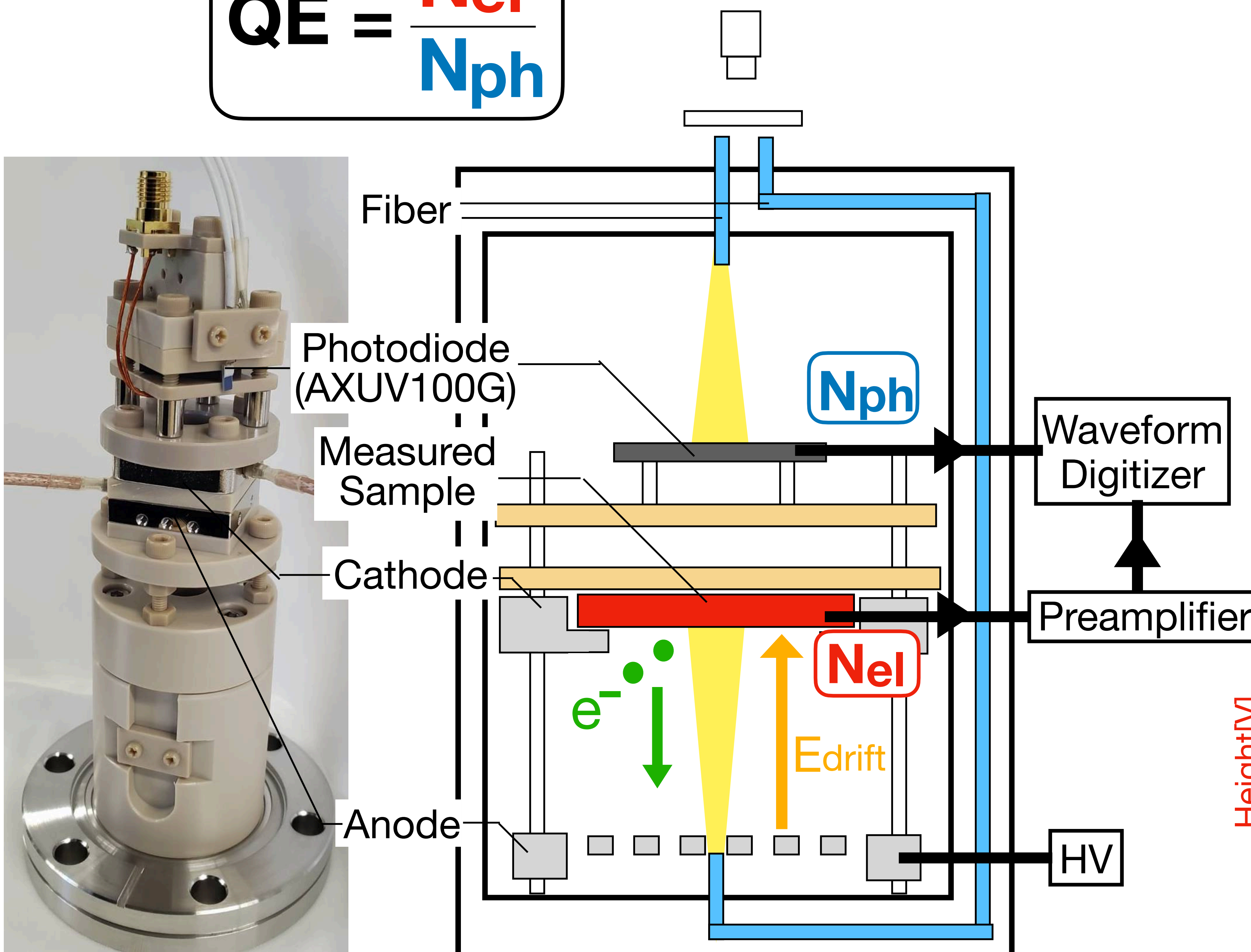
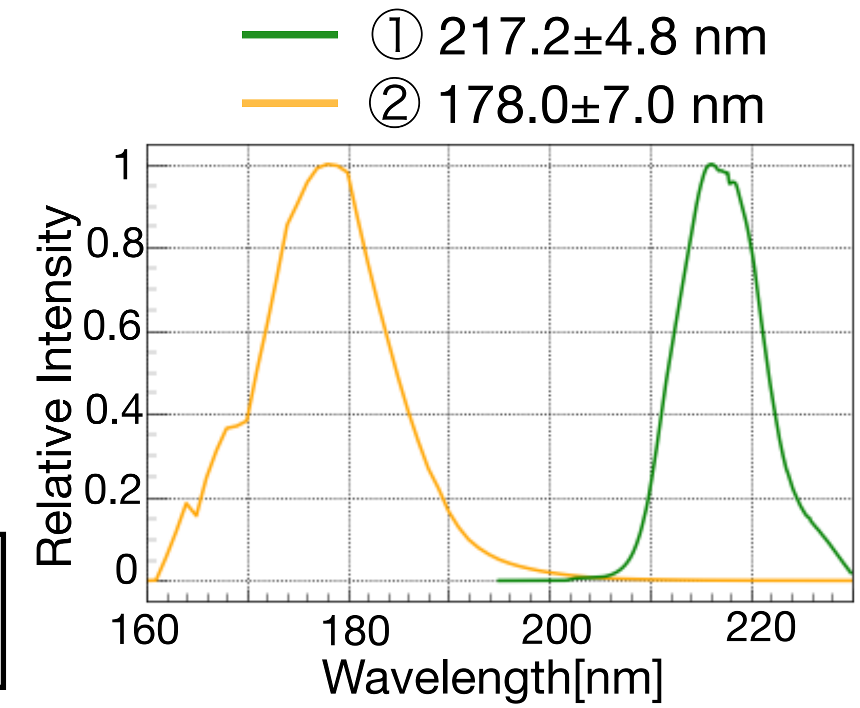
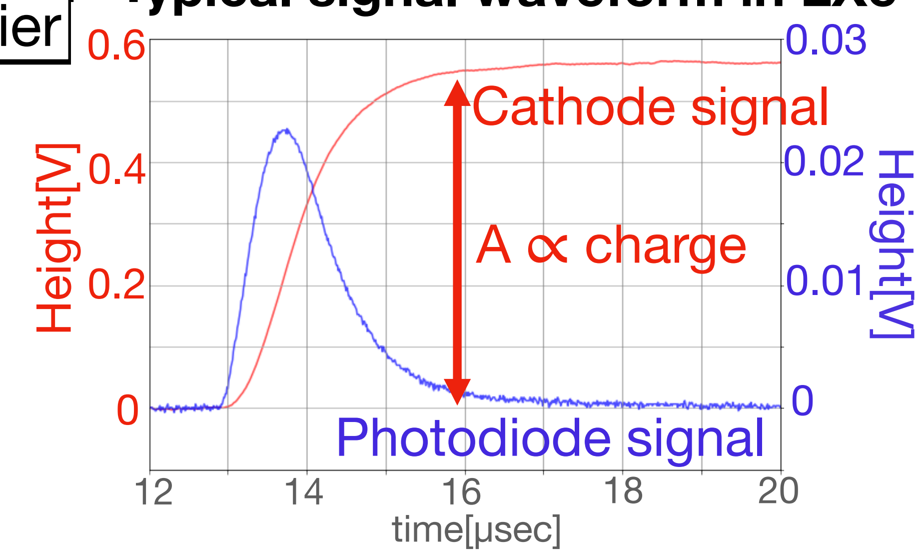


Wavelength distribution

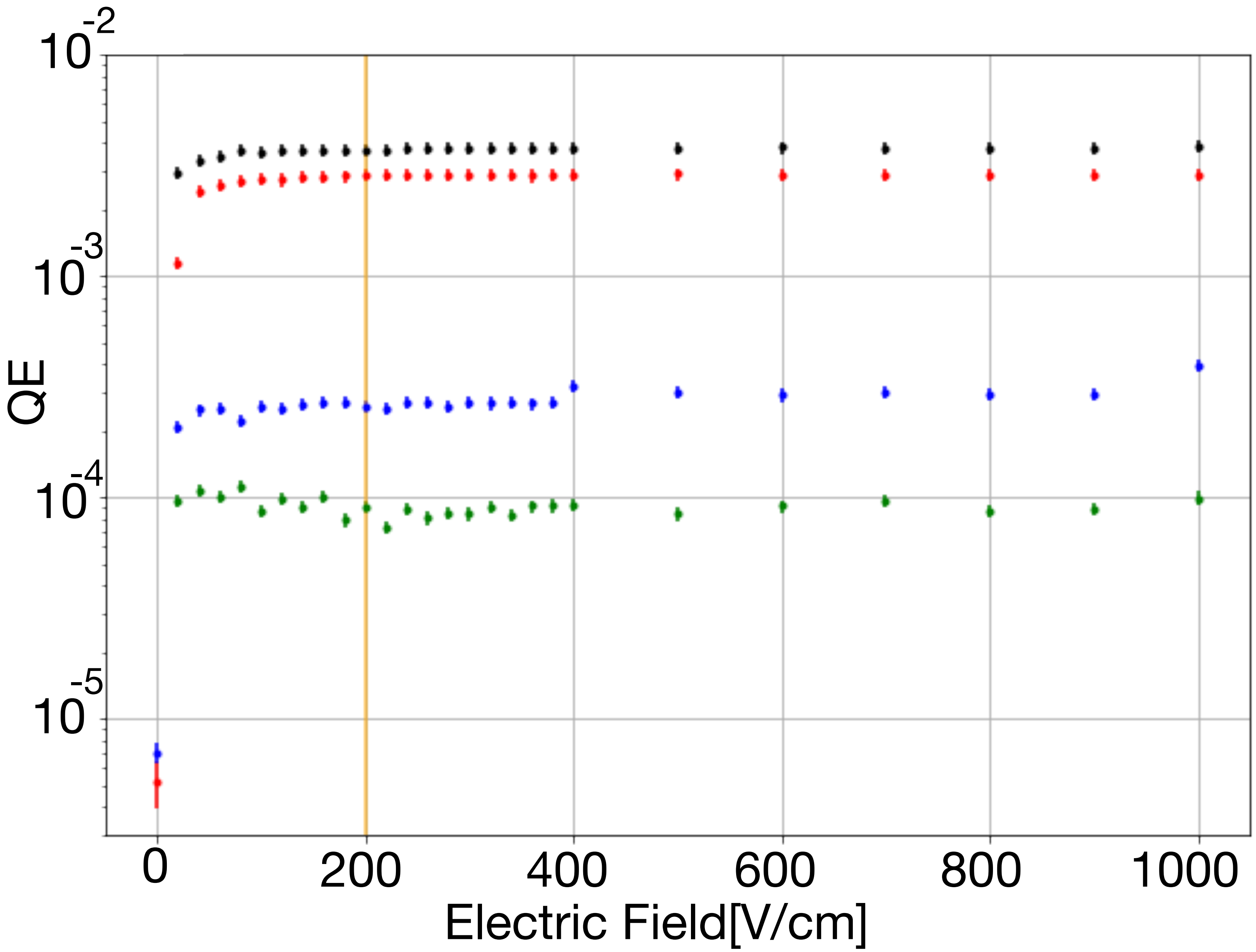


Typical signal waveform in LXe



Results In Vacuum

QE in vacuum (wavelength : 178.0±7.0 nm)

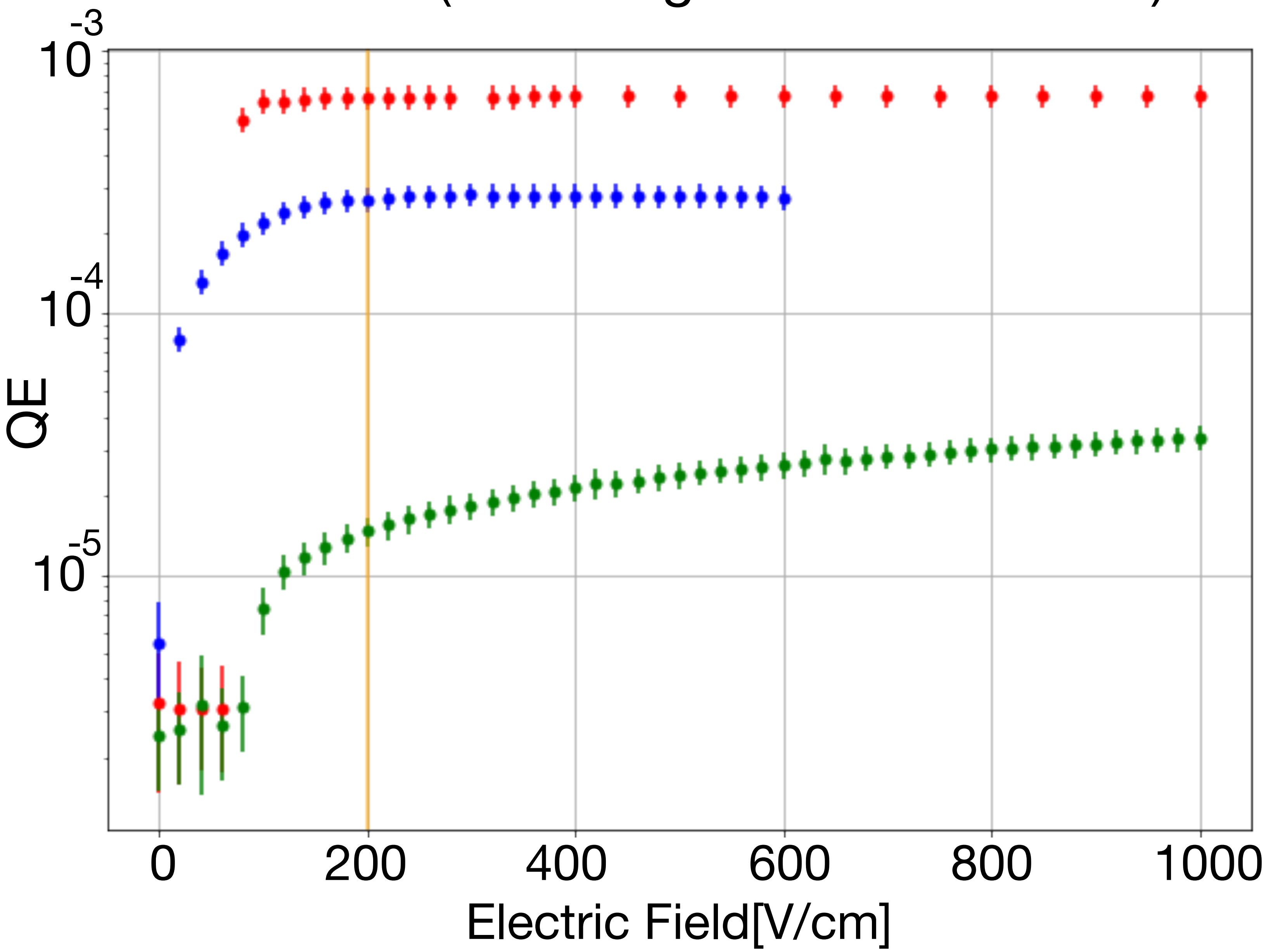


	QE @ 200 V/cm
: Pt	$(3.72 \pm 0.24) \times 10^{-3}$
: Au	$(2.85 \pm 0.18) \times 10^{-3}$
: SUS304	$(2.59 \pm 0.16) \times 10^{-4}$
: Al+MgF2	$(8.99 \pm 0.58) \times 10^{-5}$

- SUS304 has a smaller QE than Pt and Au. It's probably due to the passivation layer on the surface.
- Al+MgF2 has the smallest QE among measured materials.

Results of Pt In LXe

QE of Pt (wavelength : 217.2±4.8 nm)



	QE @ 200 V/cm
: Vacuum	$(6.40 \pm 0.56) \times 10^{-4}$
: LXe	$(2.65 \pm 0.24) \times 10^{-4}$
: GXe	$(1.56 \pm 0.17) \times 10^{-5}$

- QE of Pt in LXe is higher than that in GXe, and less than that in Vacuum.
- Same behavior has been observed for CsI in a previous study (NIM A 338 ,328-335(1994)).
- The previous study suggests that it may be due to differences in potential barriers and backscattering at the surface of electrode.
- QE in LXe and Vacuum are totally different, thus we will measure QE for all the materials in LXe and then find the best one.

Summary & Prospect

Summary

- Ton-scale LXe TPCs have some problems originated from disconnection and sagging of electrodes.
- Reducing S2-only BGs is important to improve the sensitivity for low mass DM.
- **Coated electrode with low QE** is mechanically stable and possible to reduce such S2-only BGs.
- We have developed a dedicated system to measure QE in Vacuum, GXe and LXe to find a good material of electrodes.
    - QE (MgF_2) < QE (SUS304) < QE (Au) < QE (Pt) in Vacuum
    - QE (GXe) < QE (LXe) < QE (Vacuum) for Pt

Prospect

- We will measure QE for other electrode candidates (Au,Al+MgF_2…) in LXe, and find the electrode with the lowest QE among them.
- Finally, we will characterize the performances of selected electrodes with a LXe TPC.