Formation of Strong Drift Field with Cockcroft-Walton Voltage Multiplier in a High-Pressure Xenon Gas TPC

Masashi Yoshida, Kyoto University
for the AXEL Collaboration

Exploration of Particle Physics and Cosmology with Neutrinos
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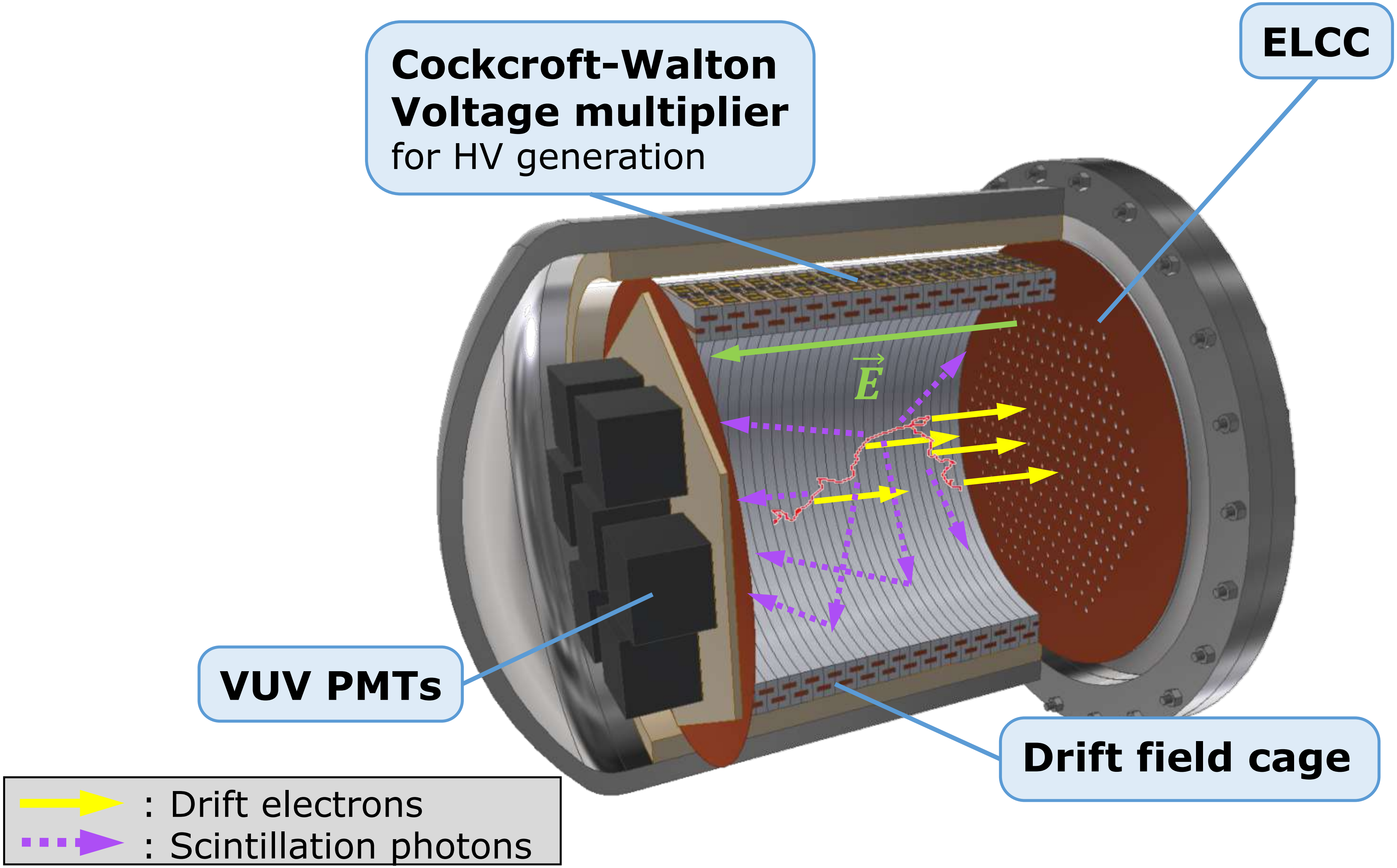
Outline

- Introduction
- Drift Field Cage
- Cockcroft-Walton Voltage Multiplier
- Summary

Introduction

- ✓ AXEL
- ✓ HV Requirements
- ✓ Discharge

AXEL (A Xenon ElectroLuminescence detector)



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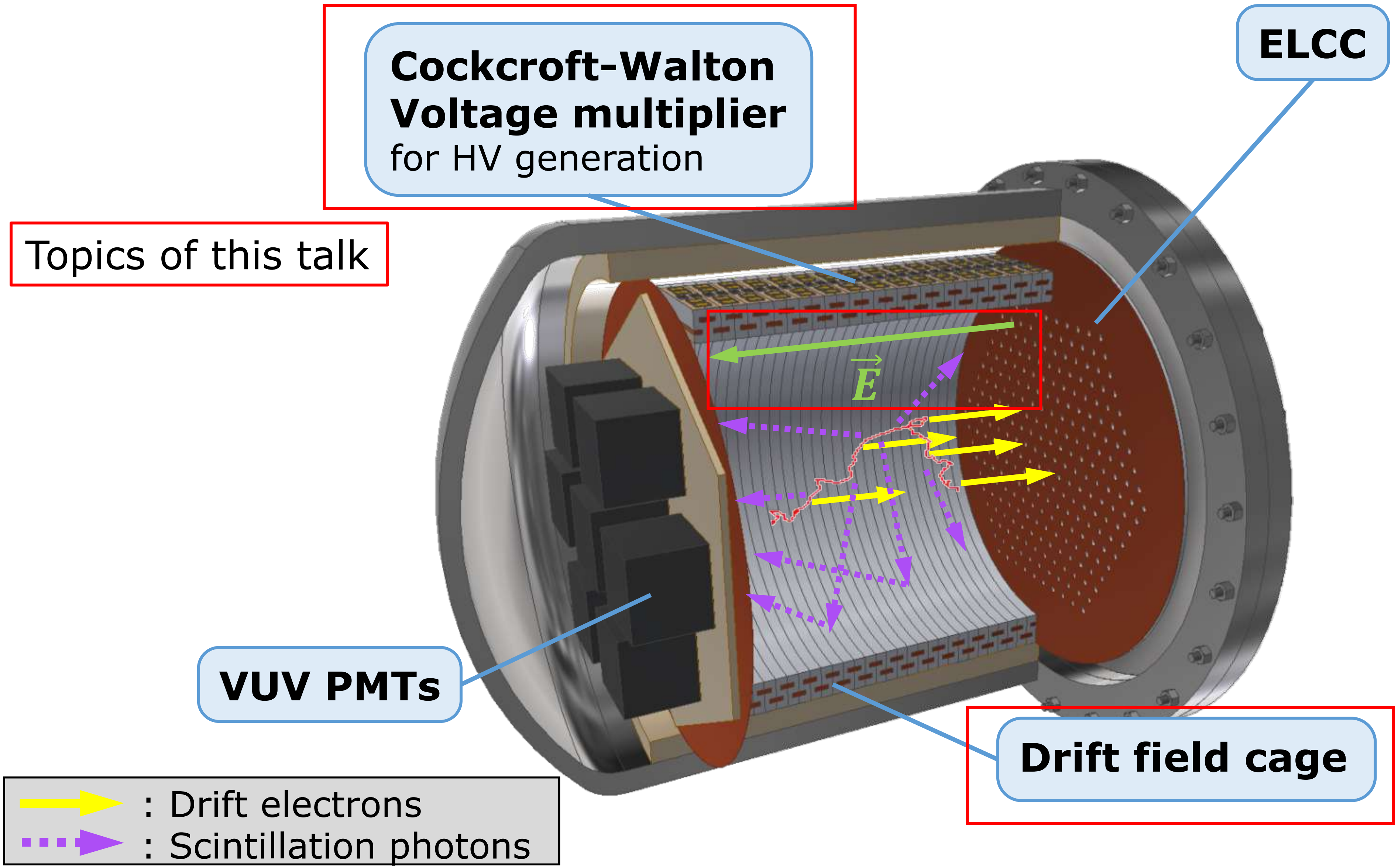
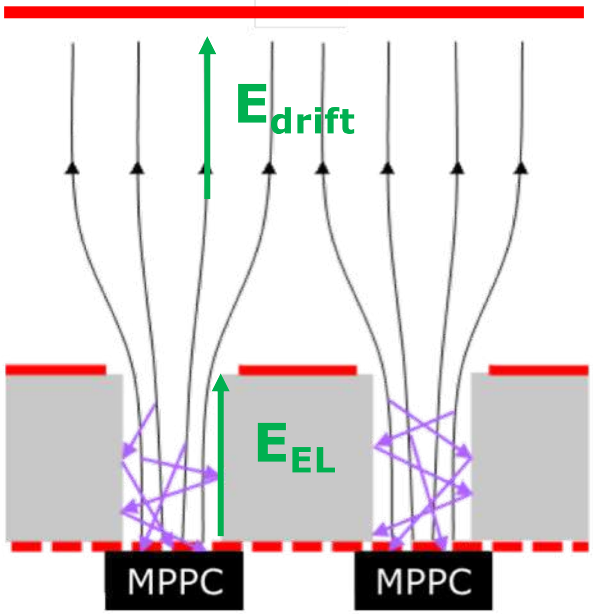


HV Requirements



EL region:

- EL threshold = **1 kV/cm/atm**
- Higher $\mathbf{E_{EL}}$ → Better electron collection
  Higher EL gain

⇨ Better **Energy resolution**

Drift region:

- Higher $\mathbf{E_{drift}}$ → Less diffusion
  Less recombination or attachment

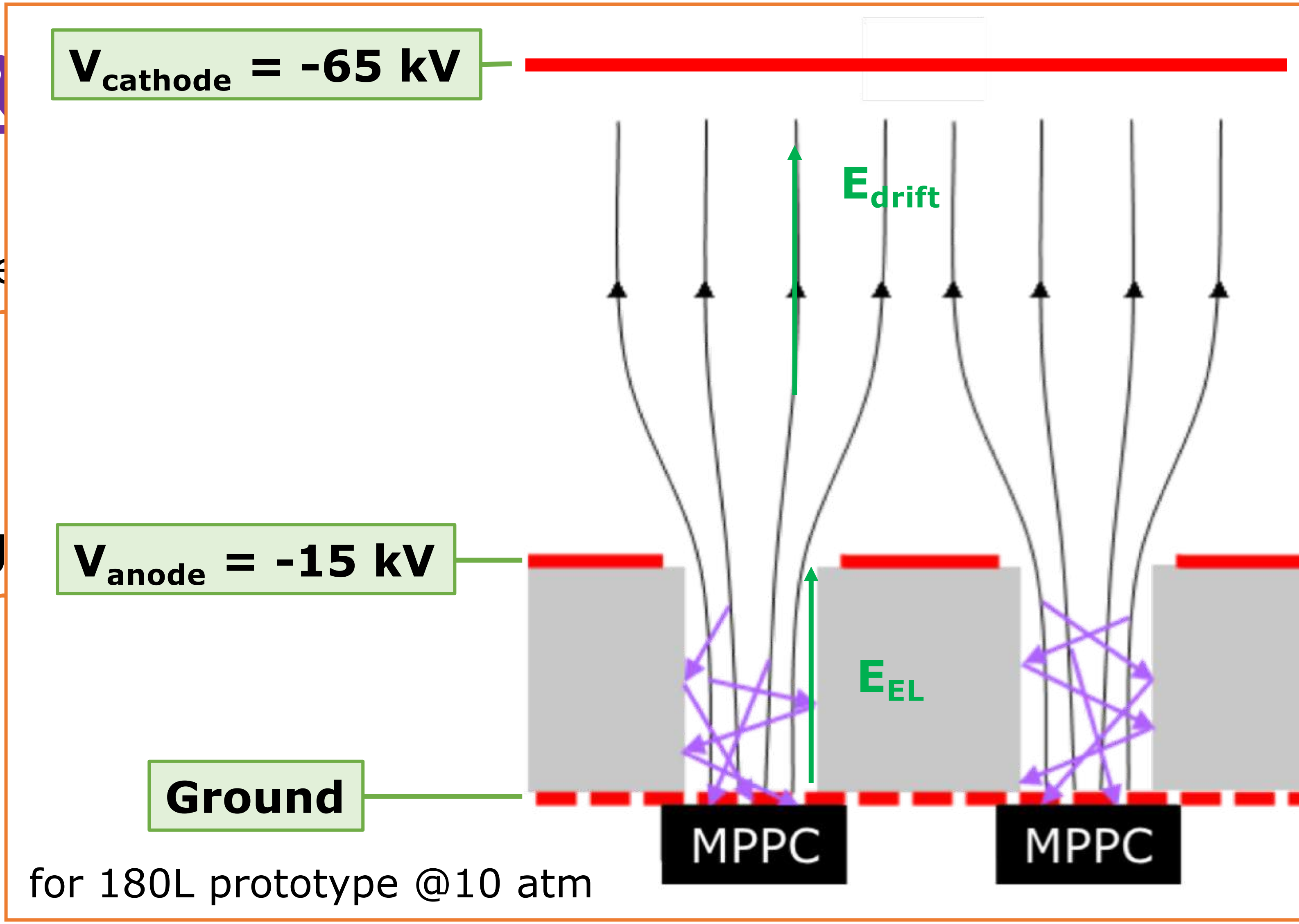
⇨ Better **Track ID** & **Energy resolution**

We use $\mathbf{E_{EL}}$ **= 3 kV/cm/atm** & $\mathbf{E_{drift}}$ **= 100 V/cm/atm**

HV R

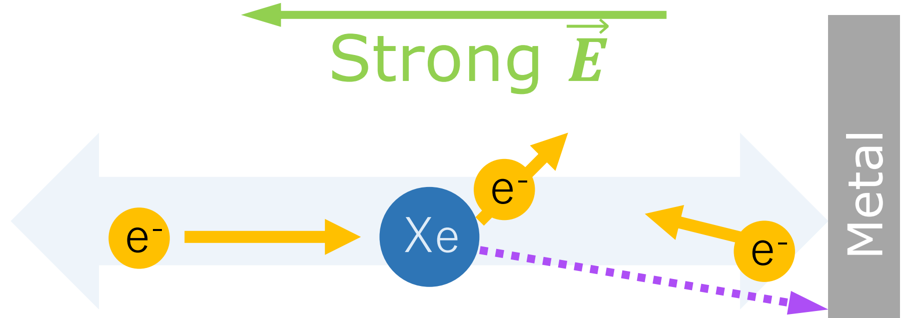
EL regio
- EL thre
- Higher

Drift reg
- Higher



We use E_{EL} = **3 kV/cm/atm** & E_{drift} = **100 V/cm/atm**

Discharge



Mechanism:

- α - process
- γ - process

→ **electron-ion rich electric path**

pure xenon gas → Easily ionized, VUV scintillation

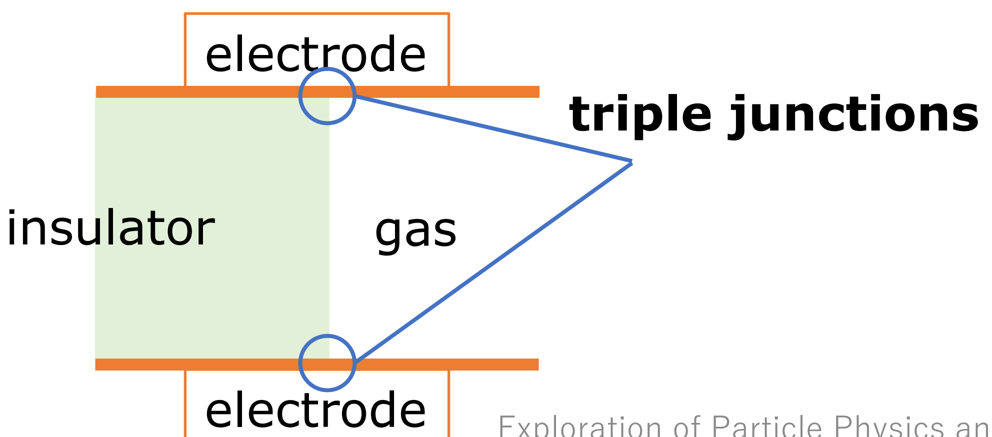
Weak points = strong electric field

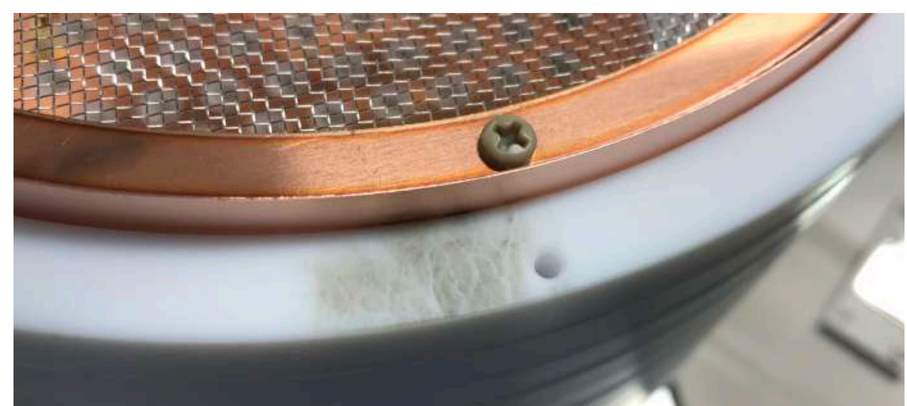
✓ **Spikes or Edges on HV electrode**

→ take distance, round off, or cover by insulator

✓ **Triple junction**

→ path should be blocked





Drift Field Cage

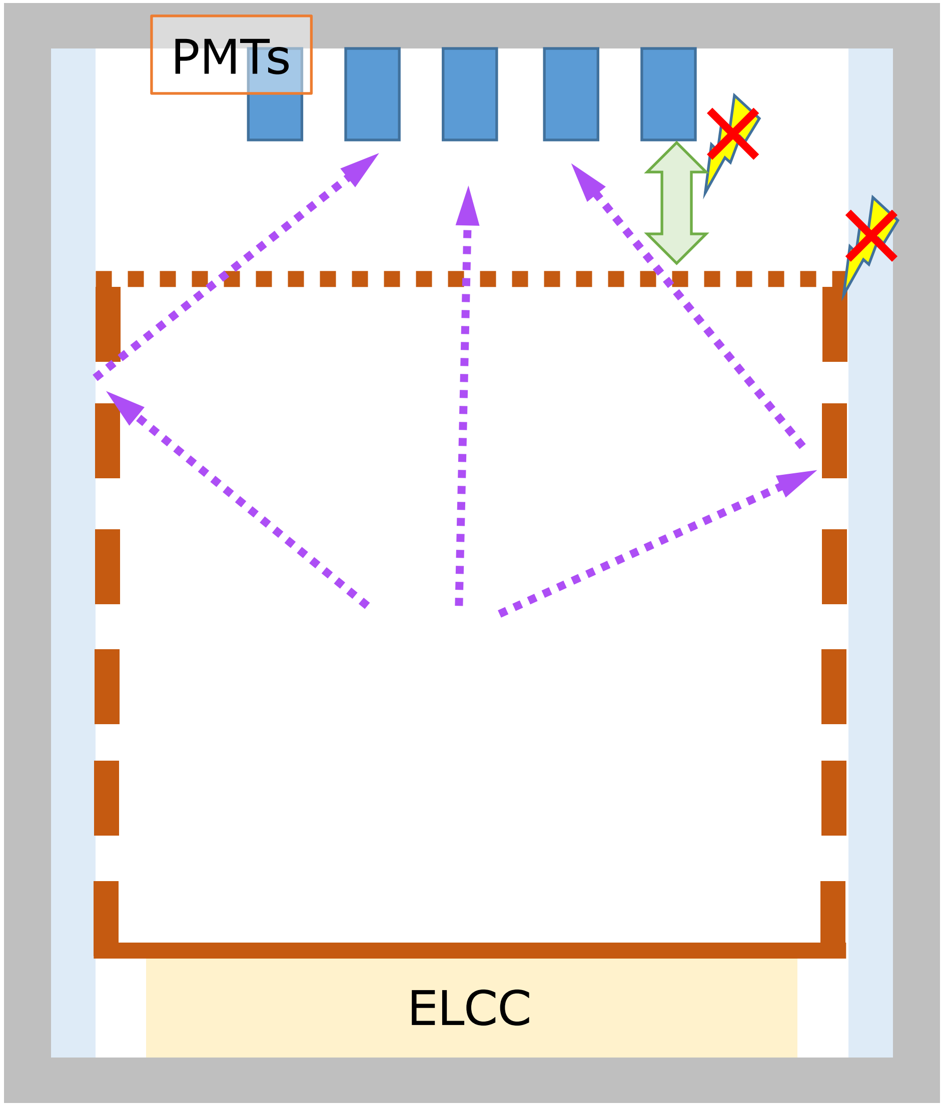
- ✓ Requirements
- ✓ Current Design
- ✓ For 180L Full Size

Requirements

Strong & Uniform Field:
- **0.1 kV/cm/atm ±5%**

No discharge:
- insulation
- take distance

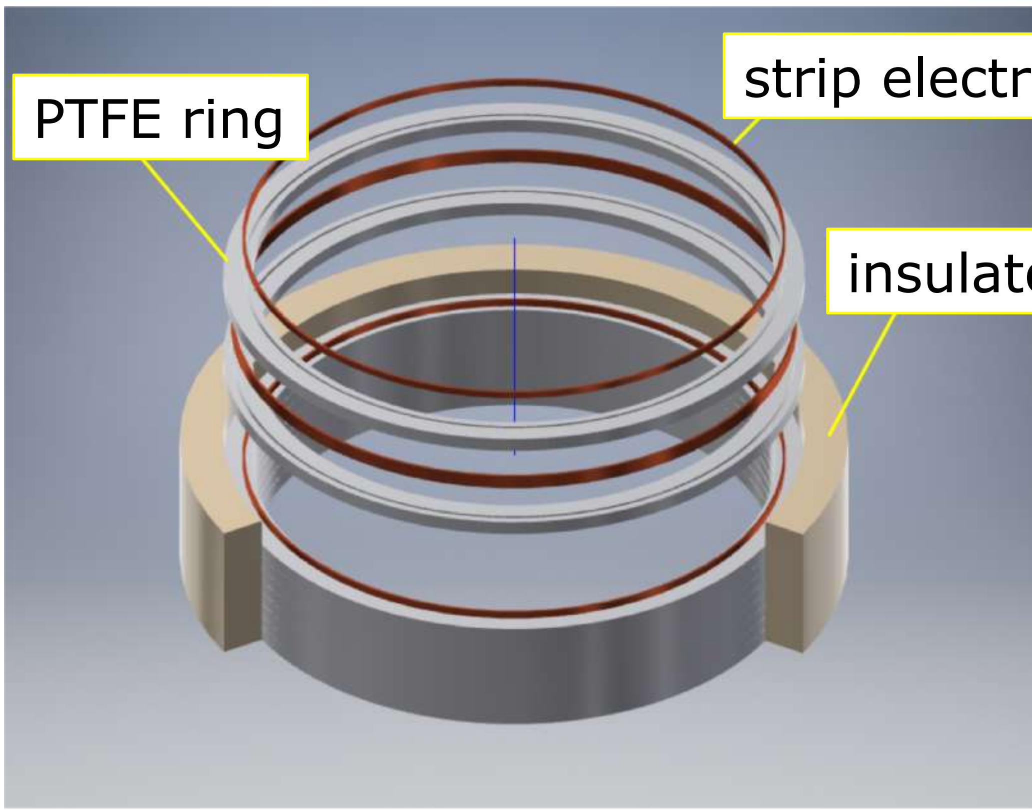
VUV Reflection:
- PTFE or Aluminum

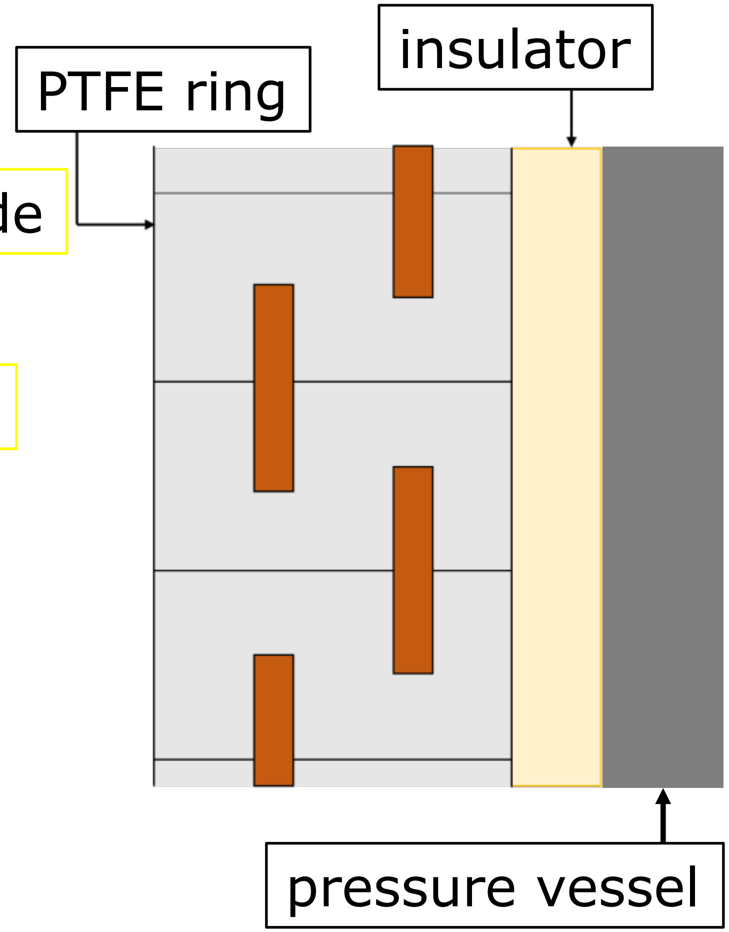


Current Design

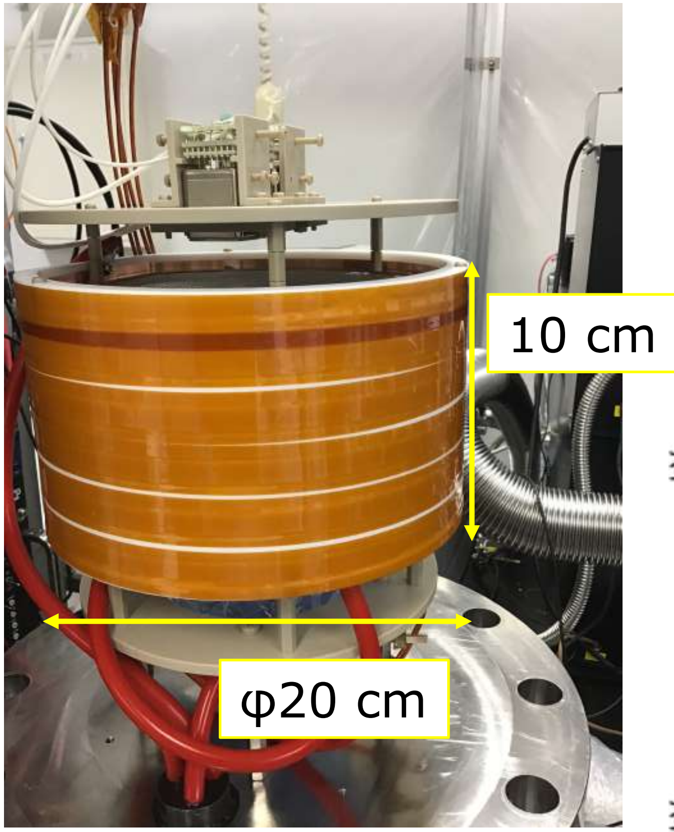
Cause of field distortion = pressure vessel (0 V) → Electric shielding

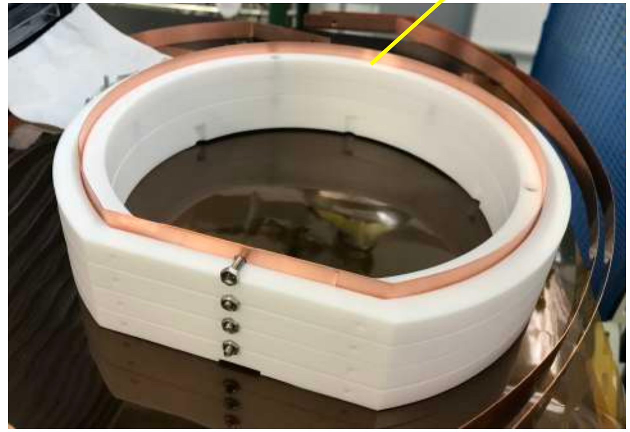
⇨ **Double strip electrodes**

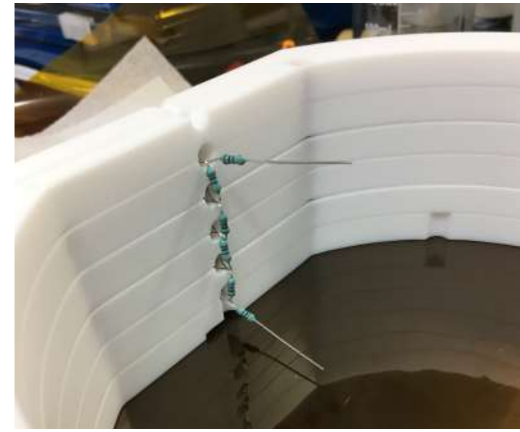


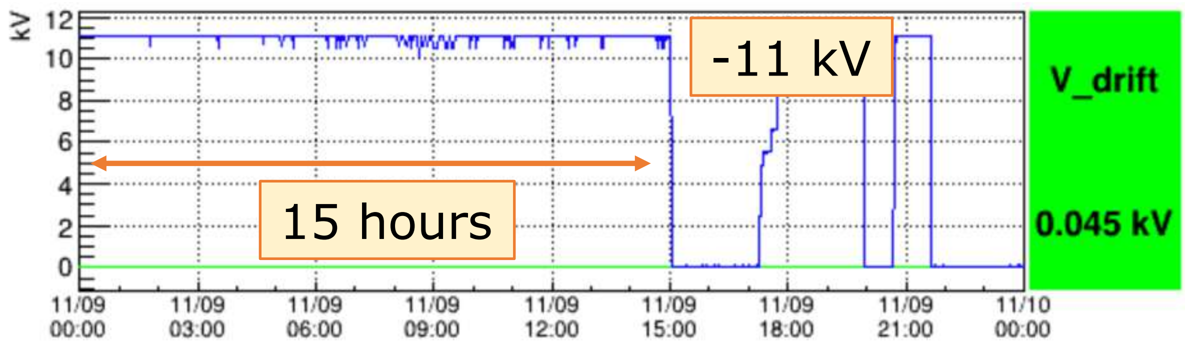


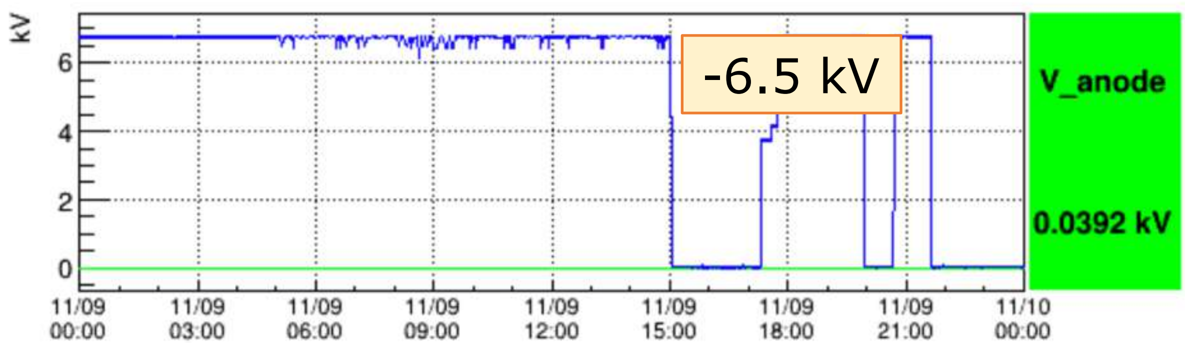
10-L prototype











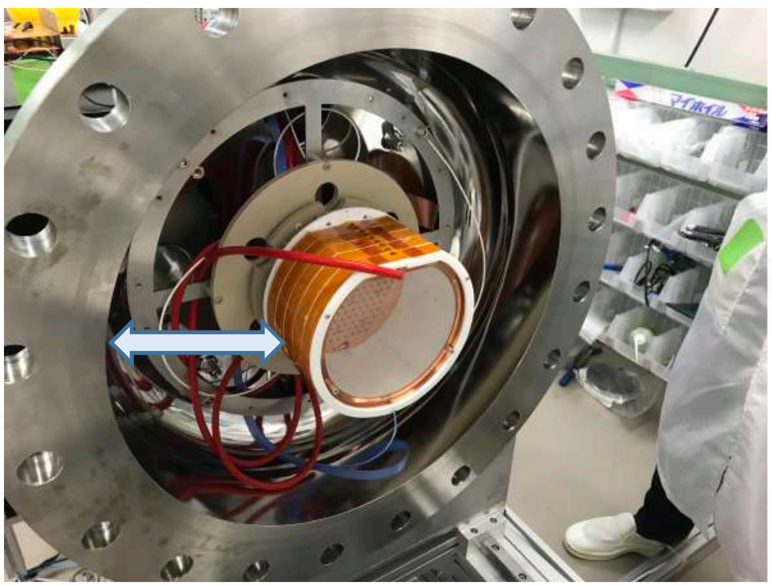
No discharge

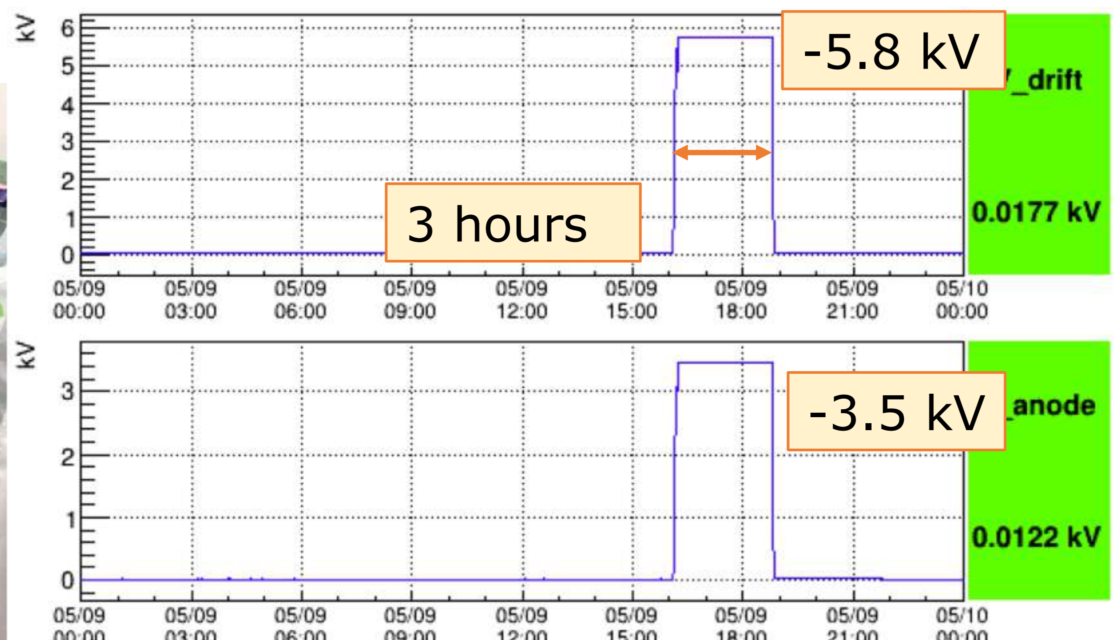
- @6 atm
- E_{EL} = 2.2 kV/cm/atm
- E_{drift} = 75 V/cm/atm

180-L prototype

- For now, field cage is 10-L size……
  - ✓ The pressure vessel is far. → Less probability of discharge

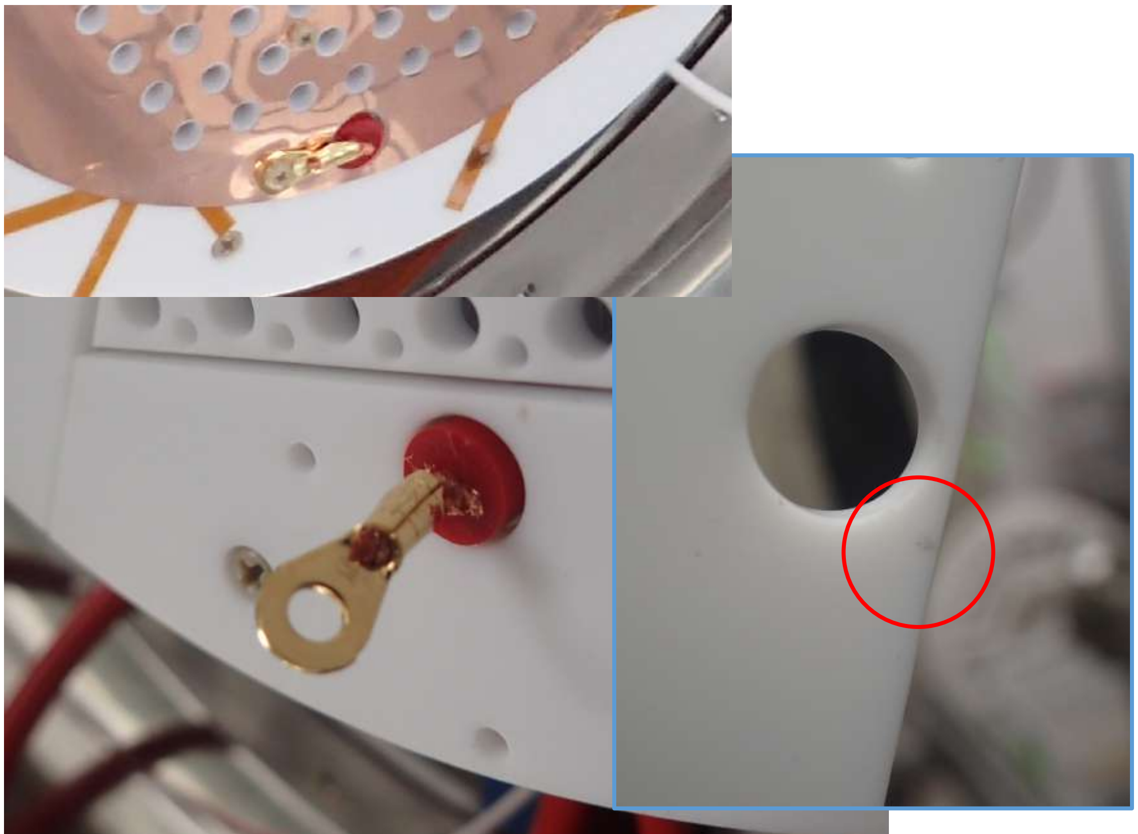
- No discharge
  - ✓ @2.3 atm
  - ✓ E_{EL} = 3 kV/cm/atm, E_{drift} = 100 V/cm/atm (Design Value!)

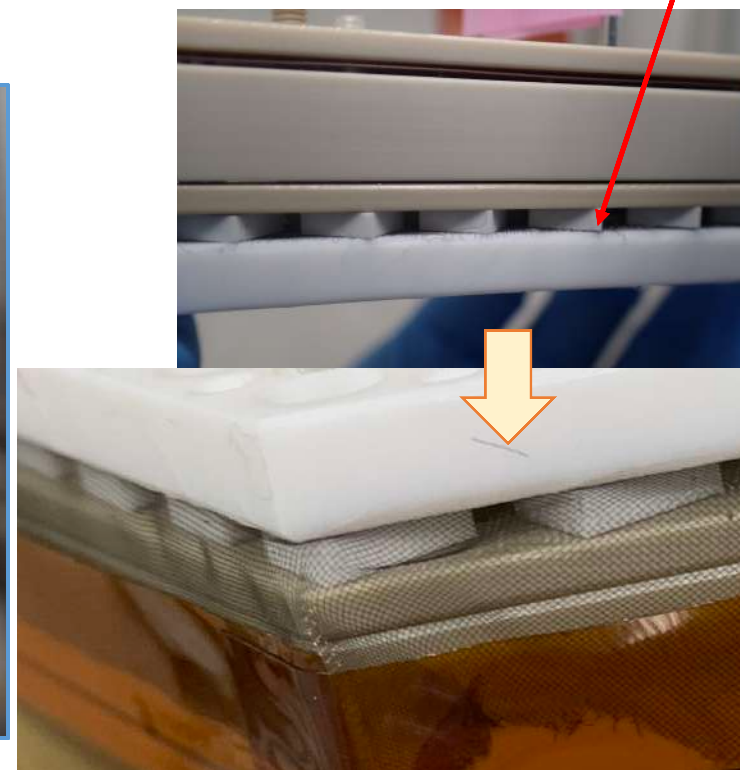




180-L prototype

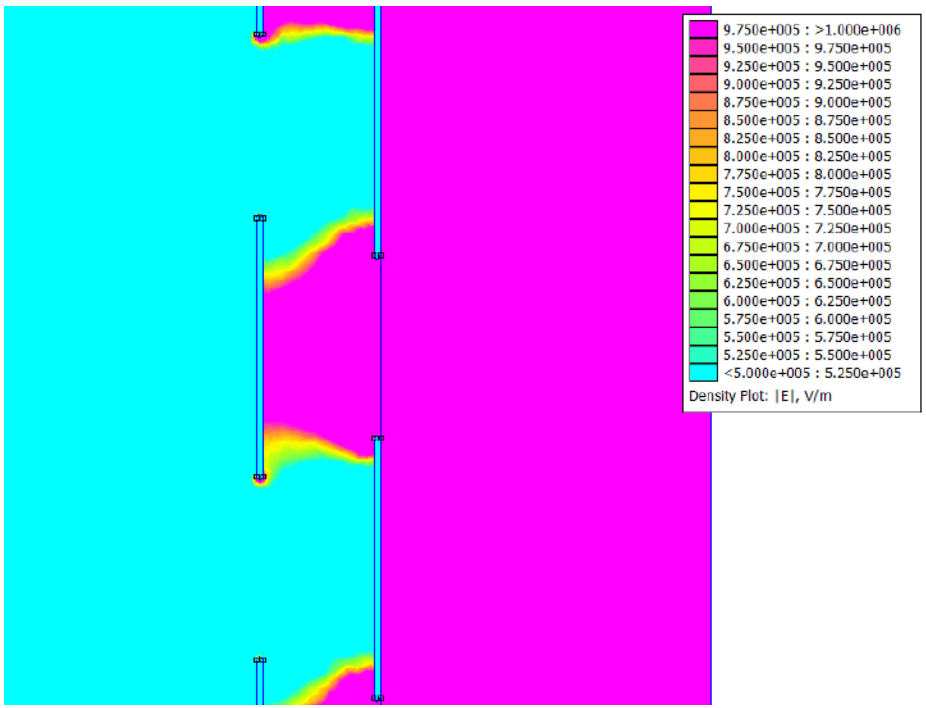
- At 4 atm, discharge occurred at anode 5 kV. (E_{EL} = 2.5 kV/cm/atm)
- Between anode **HV supplying cable** and **ELCC GND mesh**?
- Bending GND mesh will work.
- Cathode and field cage electrodes → No problem

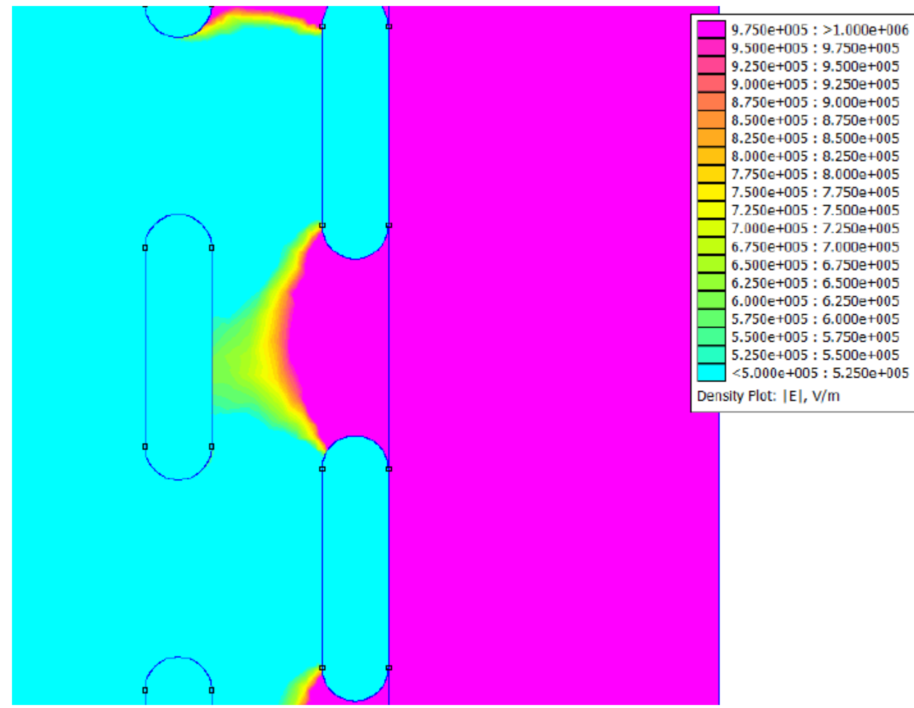




For 180 L Full Size

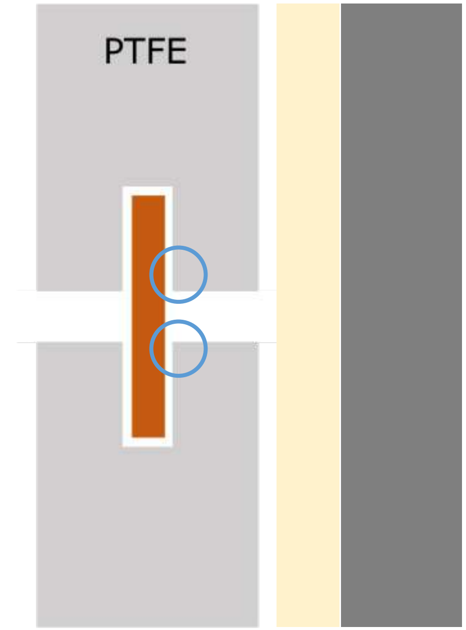
1. Electrode: 0.3 mm → 3 mm, rounded off
   - ✓ No corona discharge





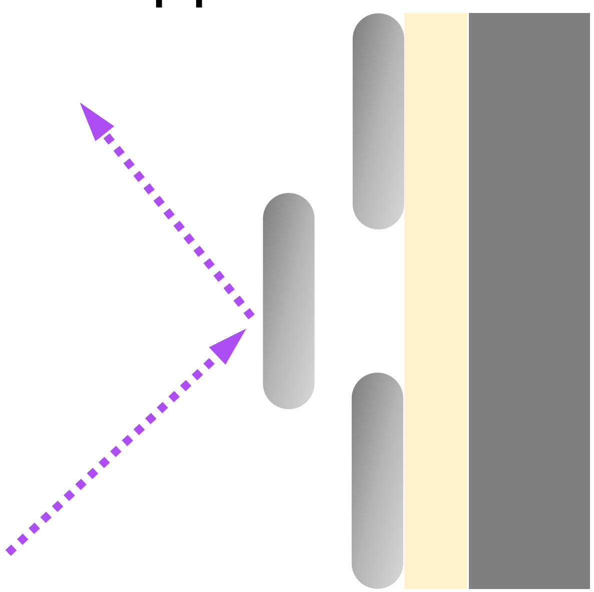
For 180 L Full Size

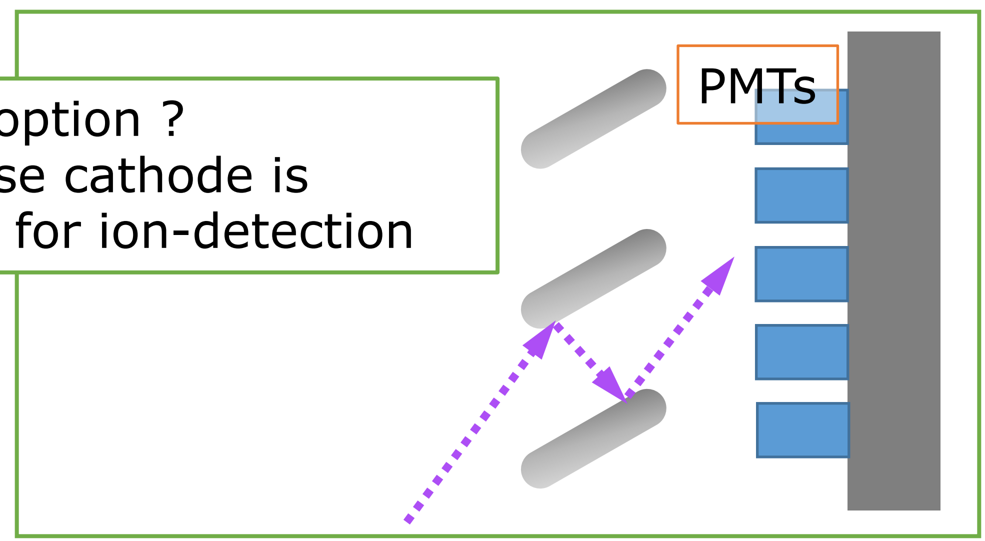
2. remove PTFE
   - ✓ No triple junctions
   - ✓ No charge up
   - ✓ less material → less BG



Less scintillation reflection……

Copper electrode ⇨ **Mirror finished aluminum!!**





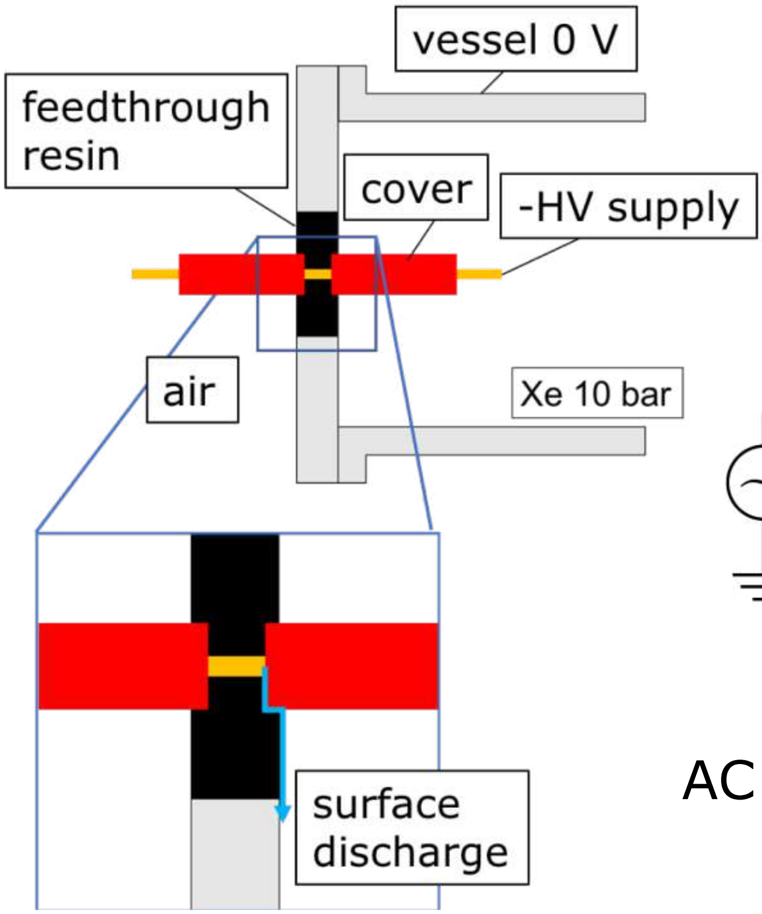
Future option ?
- in case cathode is used for ion-detection

Cockcroft-Walton Voltage Multiplier

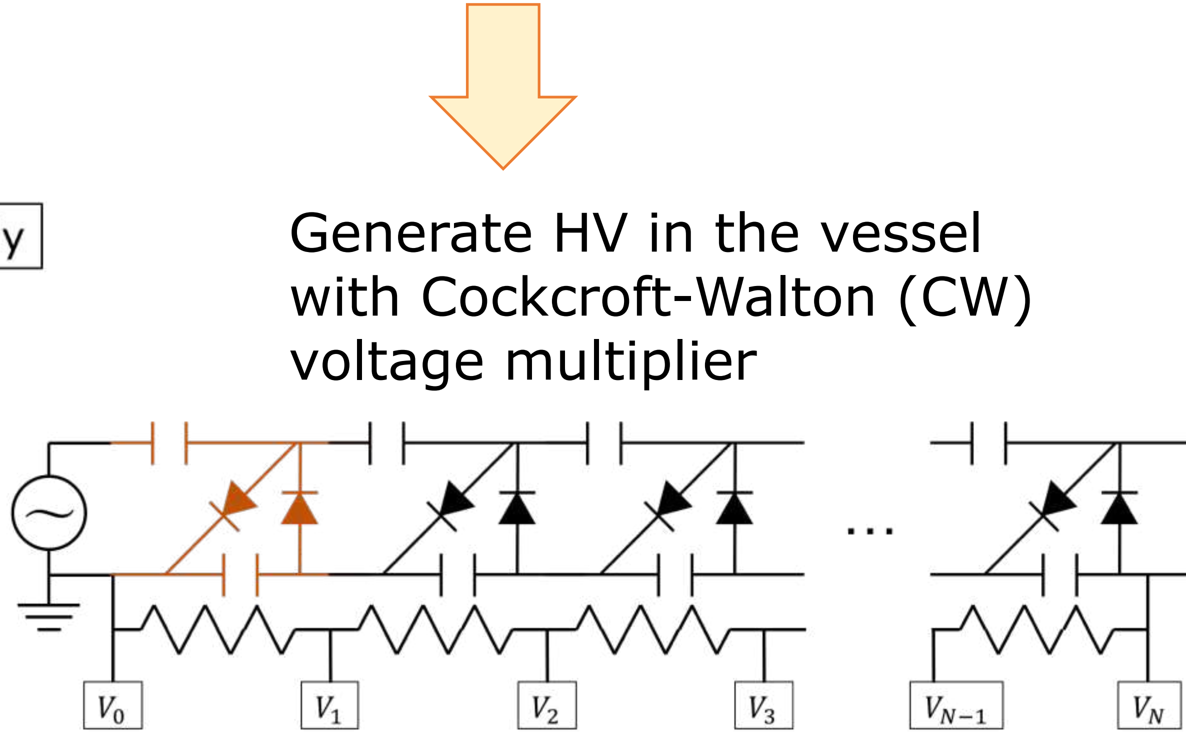
- ✓ FPC CW
- ✓ Output Measurement
- ✓ Frequency Dependence

HV supply into the vessel

- Direct HV supply → **Surface discharge** at feedthrough



Generate HV in the vessel with Cockcroft-Walton (CW) voltage multiplier



AC input; **p-p *2U*** ⇨ DC output; ***2NU***

(ideal)

Voltage Deterioration

- Main cause of output deterioration
  - ➢ Output current

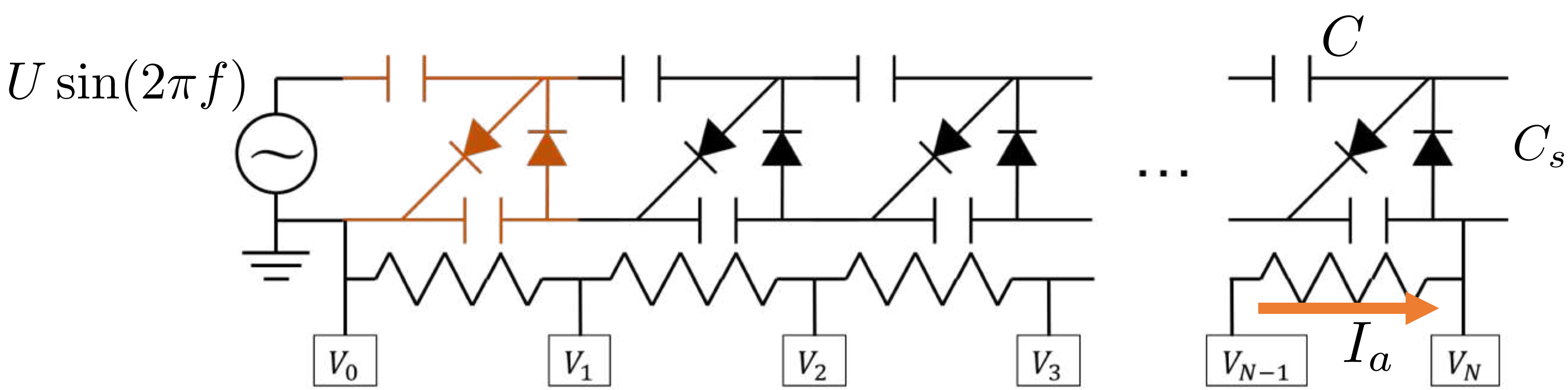
$$\Delta V \simeq \frac{2}{3}\frac{I_a}{fC}N^3$$

  - ➢ Shunt capacitance of diodes

$$F = \frac{\sqrt{C/C_s}}{2N}\tanh\frac{2N}{\sqrt{C/C_s}}$$

$$\Longrightarrow \quad V_{\text{out}} = F\left(V_{\text{ideal}} - \Delta V\right)$$

High *C*, High *R*, High *f* , Low *N* is important

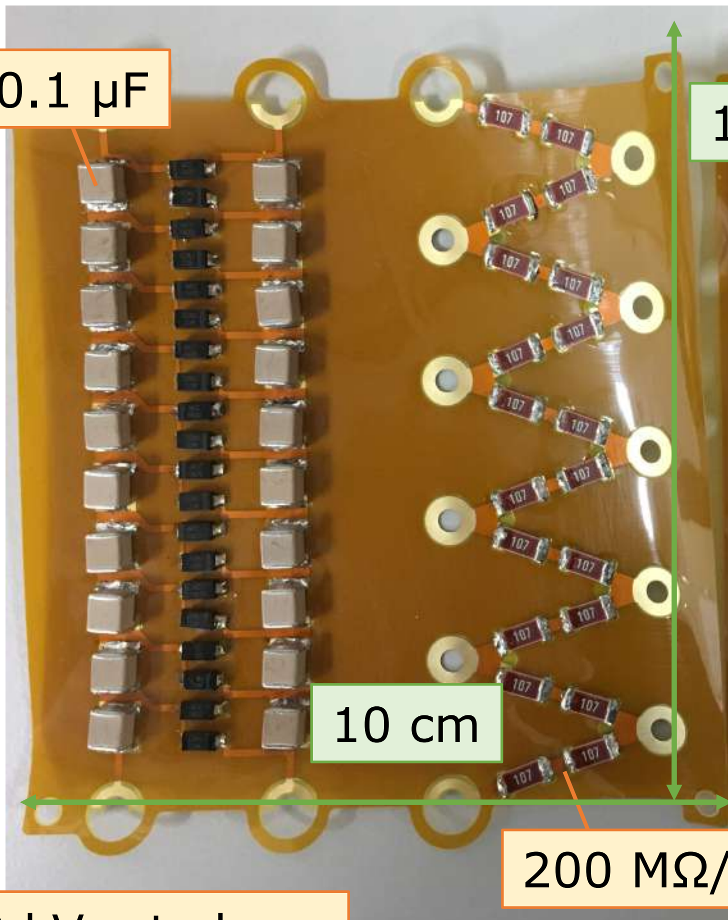


FPC CW multiplier

Placed in Xe gas → Low outgassing is required

- ✓ Kapton base Flexible Print Circuit(FPC)
- ✓ Vacuum solder

extendable by connecting each other



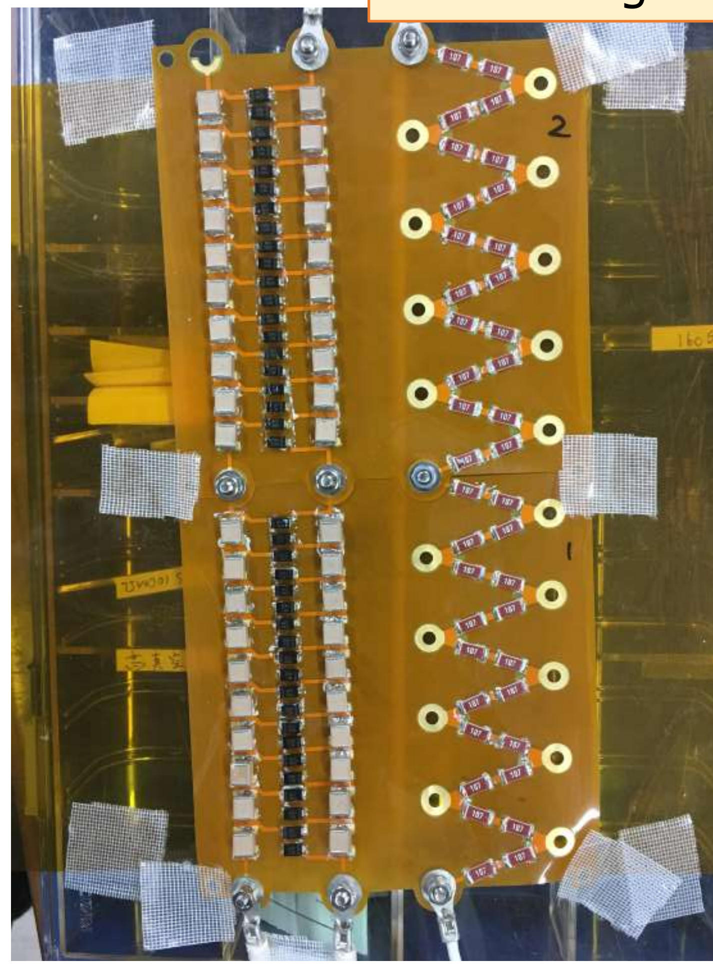
0.1 μF

10 cm

10 cm

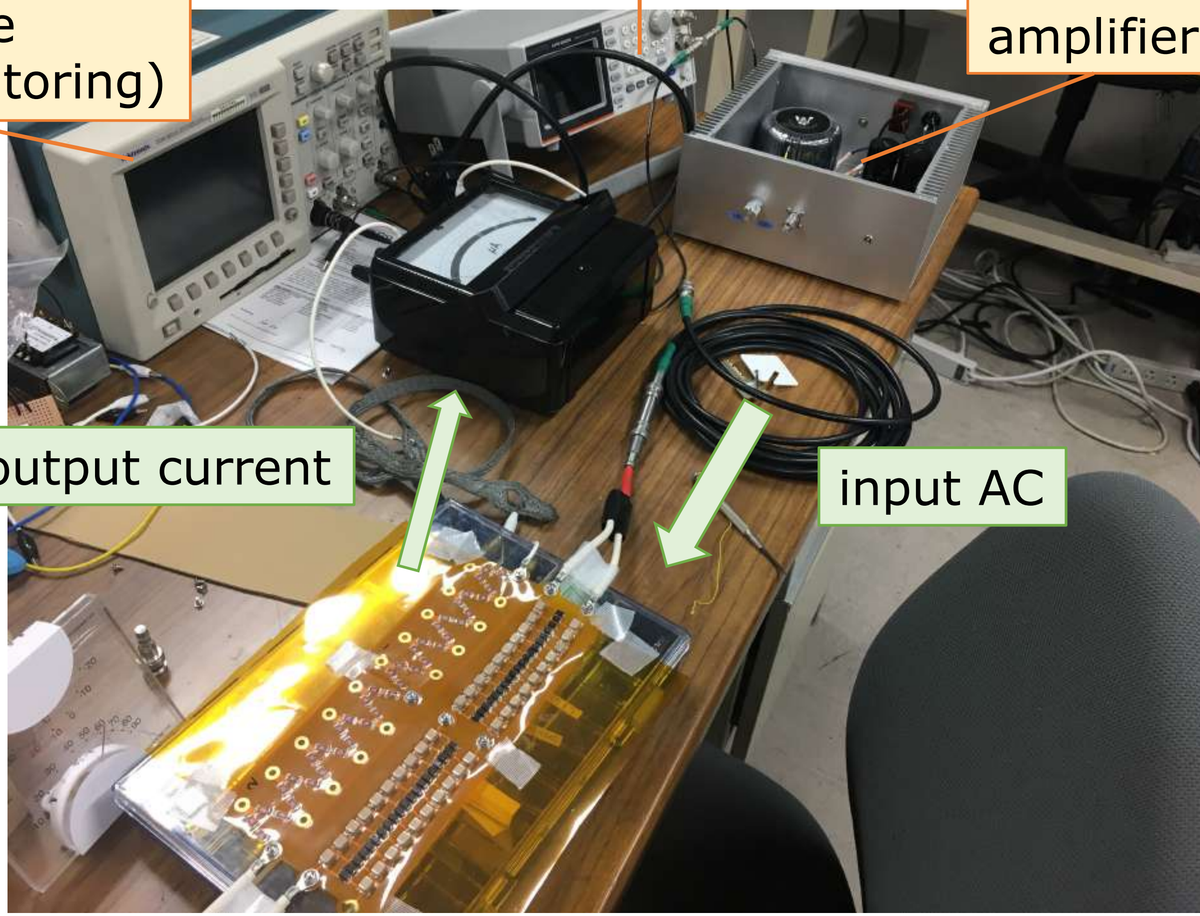
200 MΩ/stage

2 kV rated each elements

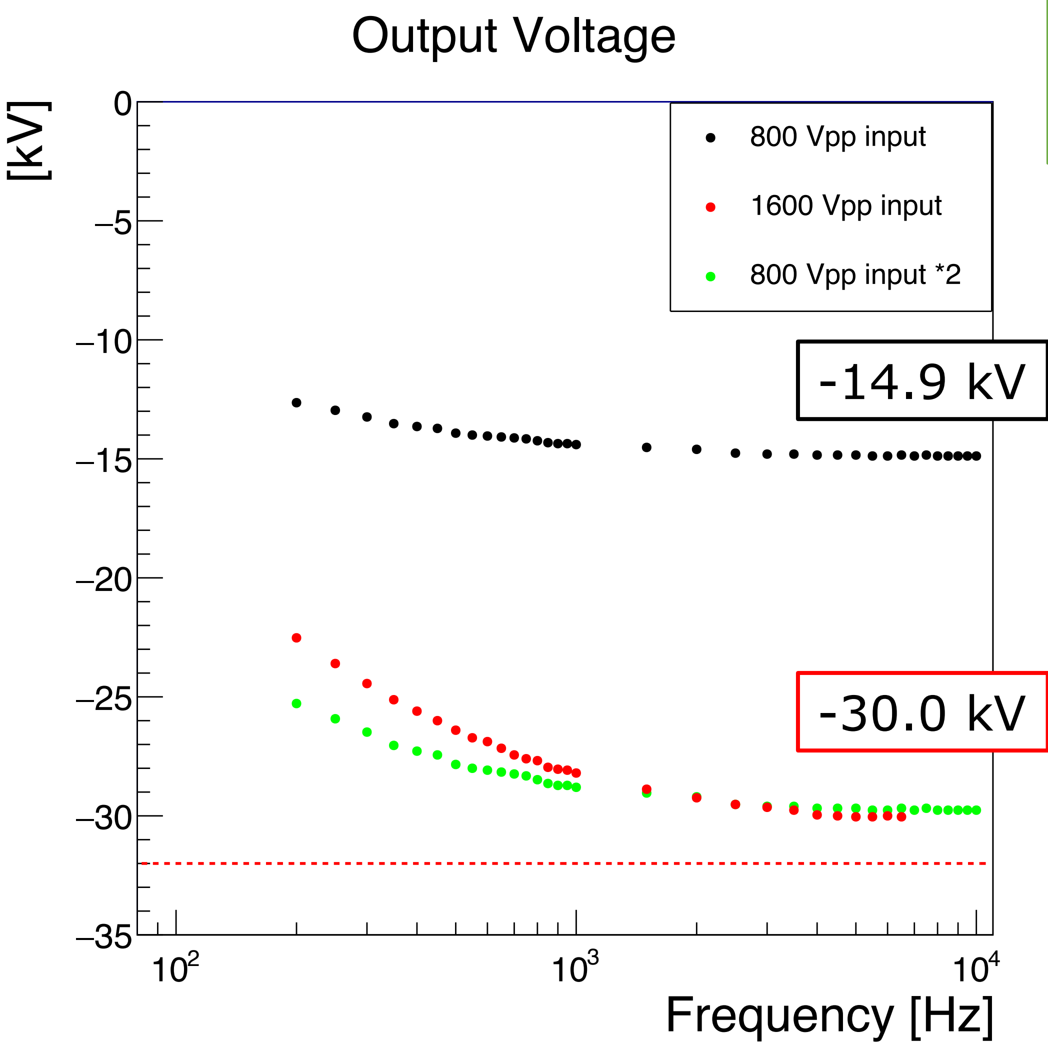


Output Measurement

Function generator (AC generation; Vpp<2 V)
→ amplifier (gain~1000) → CW → ammeter



Frequency Dependence



- ✓ 20-stage CW
- ✓ 800 Vpp & 1600 Vpp input
- ✓ ideal output;
  -32 kV @ 1600 Vpp input

- 1/f components is worse for 1600 Vpp input case → more leak current?
- flat @ >4 kHz

Expectation;
-65 kV is available
- ✓ 50-stage CW
- ✓ ~1800 Vpp
- ✓ 10 kHz

Summary

- Target; E_{EL} = **3 kV/cm/atm**, E_{drift} = **100 V/cm/atm**

  ➡ V_{anode} = **-15 kV**, $V_{cathode}$ = **-65 kV**

- Drift Field Cage
  - ✓ Shaping strong & uniform field 100 V/cm/atm **±5%**

  ➡ **Double strip electrodes**

- 10-L size field cage is stable w/o discharge.

- Cockcroft-Walton Voltage Multiplier
  - ✓ Achieved -30 kV @ 20 stages, 1600 Vpp 4 kHz
  - ✓ -65 kV is available @ 50 stages, 1800 Vpp 10 kHz