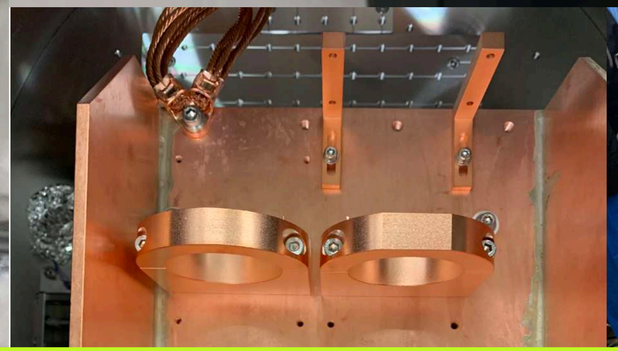
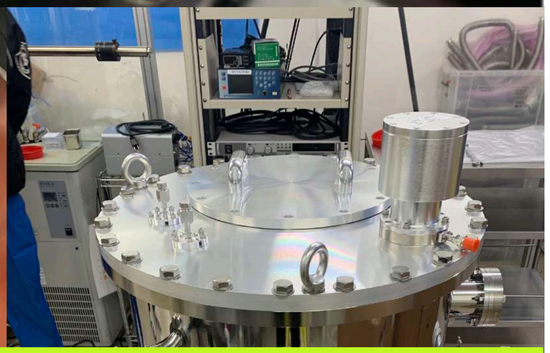




(Experimental) Activities in Nagoya group

MASATOSHI KOBAYASHI (ISEE) , 2023/03/29 B1 HEAVY FLAVOR AND DM JOINT SYMPOSIUM

XENON

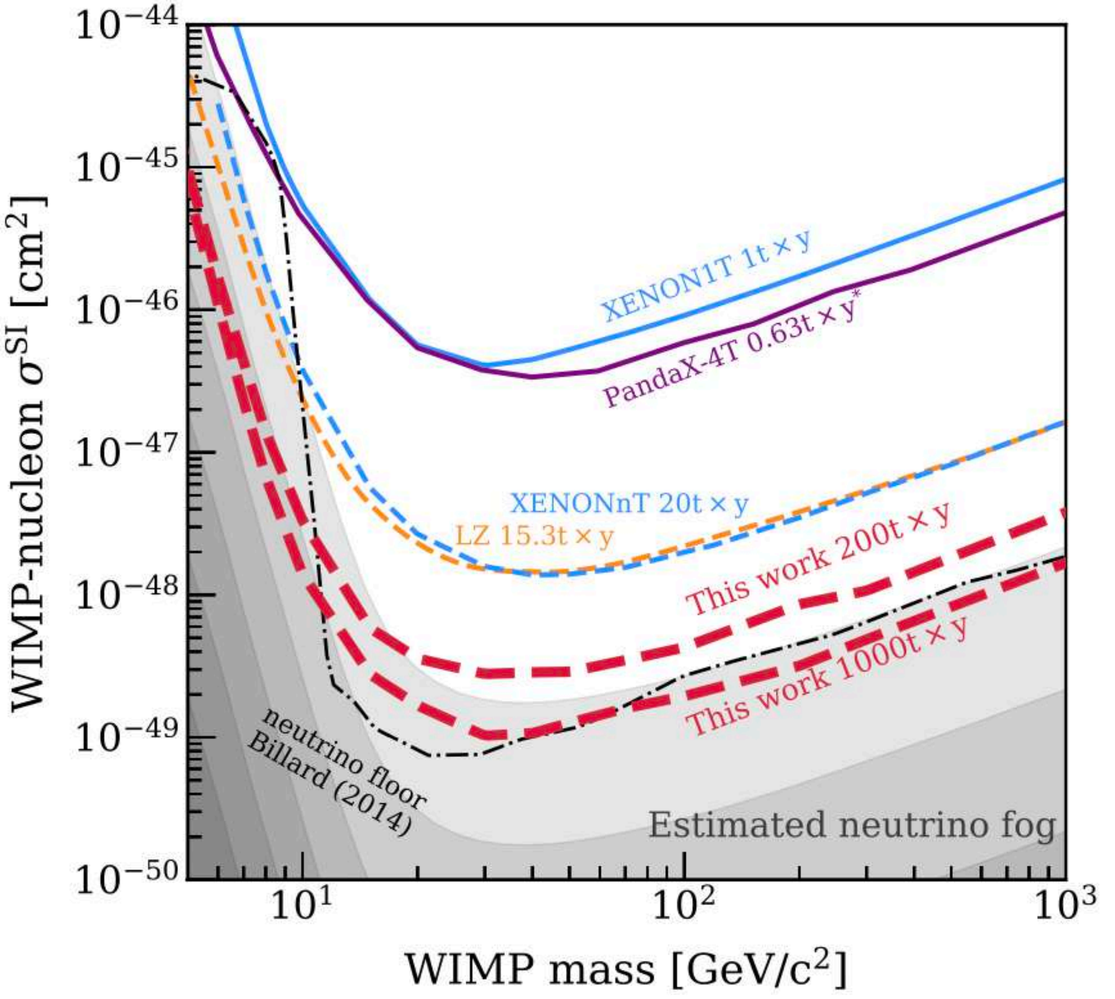
DARWIN

ISEE

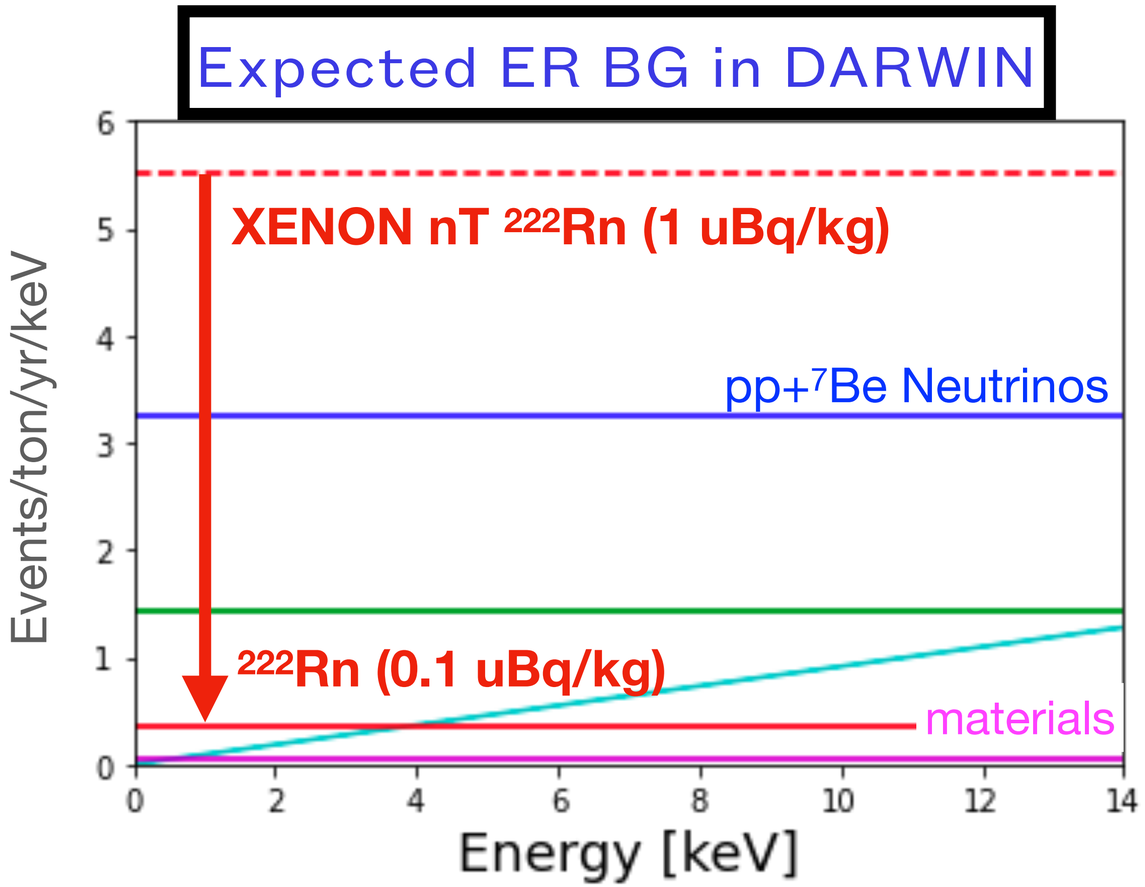
Institute for Space-Earth Environmental Research

Direct DM direction with DARWIN

- The target sensitivity of DARWIN:
  ~10^{-49} cm^2 at few 10 GeV WIMPs
- This “ultimate sensitivity” is limited by the BG of neutrinos
  - ER BG: pp, ^{7}Be ν
  - NR BG : ^{8}B, hep, atm, DSN
- Other BG from detector material or environment needs be suppressed less than these neutrino BGs



ER BG reduction

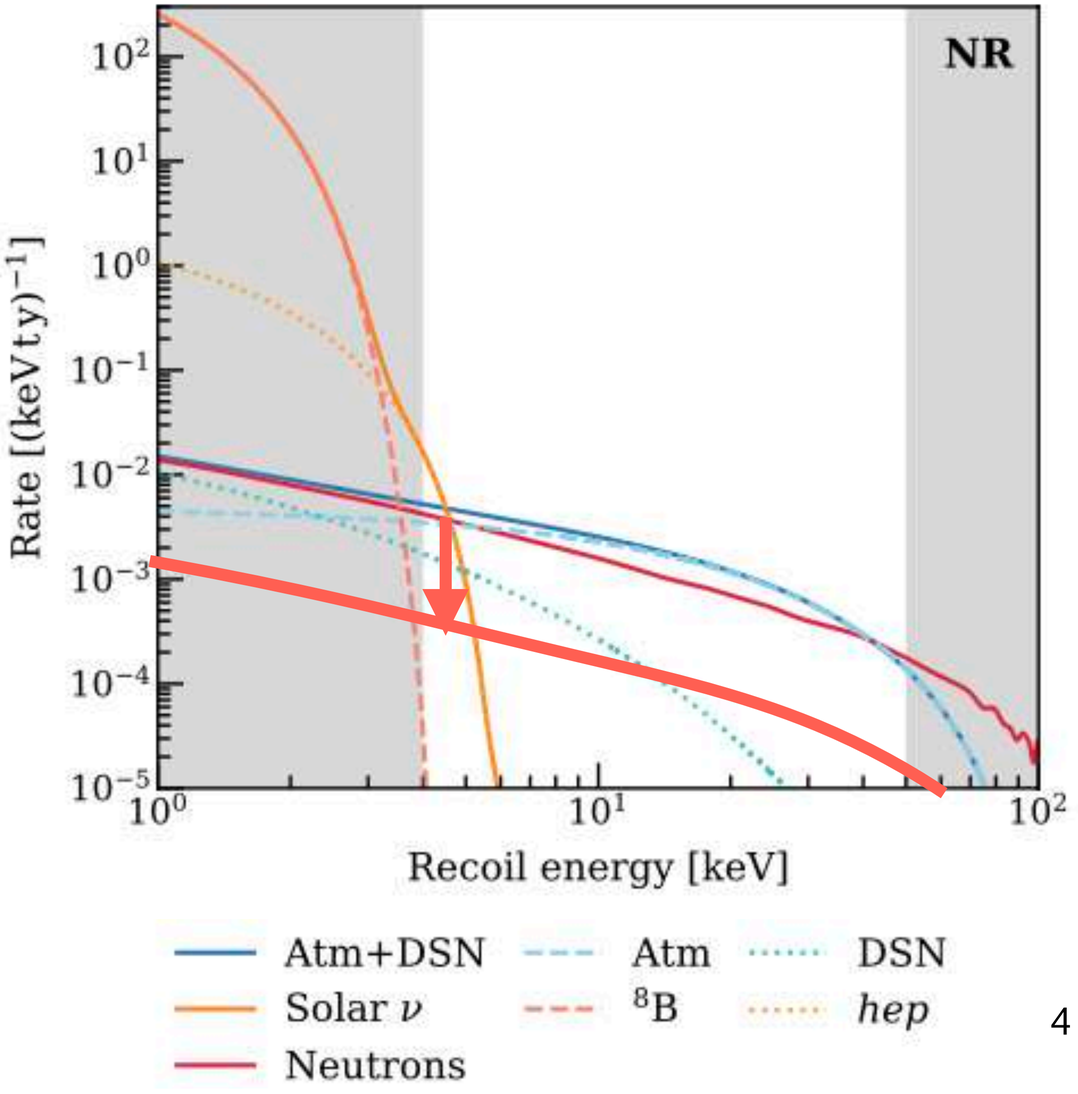


- In the XENONnT detector, current main ER BG is ^{222}Rn induced ones.
  - Emanated from materials, then contaminate into LXe
  - XENONnT target: 1uBq/kg
- For DARWIN
  - Target ^{222}Rn level: 0.1uBq/kg
  - => 1/10 of XENONnT

NR BG reduction

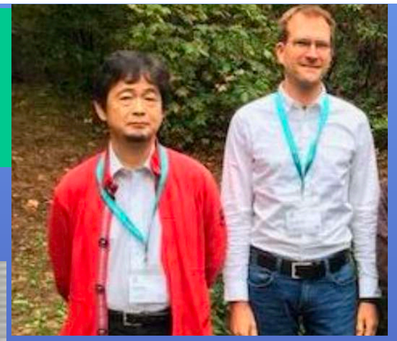
- According to the study by XENON, we have 3 major radiogenic neutron sources
  - Cryostat
  - PTFE
  - Photosensor (PMT)
- For DARWIN:
  - Target: 1/10 of ν BG
  - Reduce RIs by ~ 1/5 - 10

Expected NR BG in XENONnT



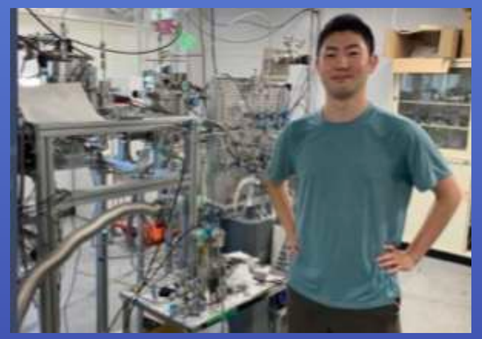
XENON/DARWIN Nagoya group

Junji HISANO
Marc SCHUMANN
- Member for DM unit

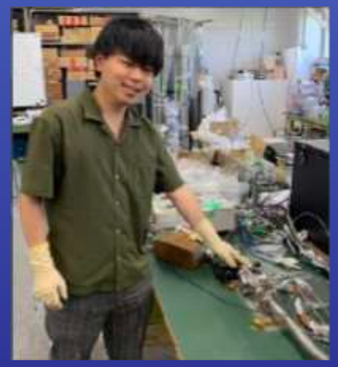


Yoshitaka ITOW
- PI
- SuperK/HyperK, LHCf/RHICf, XENON/DARWIN

Shingo KAZAMA
- Associate Professor
- Analysis coordinator
- New photosensors

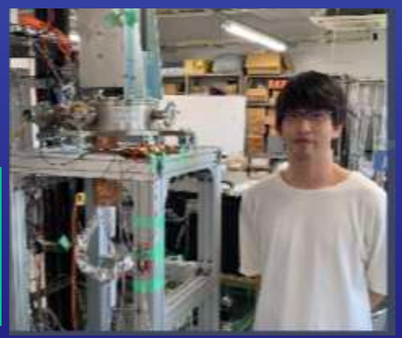


Masatoshi KOBAYASHI
- Postdoc
- LXe purification
- Hermetic TPC



Tomoya HASEGAWA
- Master student (DARWIN)
- Hybrid Photosensor

Naoki AOYAMA
- Master student (DARWIN)
- Coated Electrode
- QE measurement



Shun SAKAMOTO
- Master student (DARWIN)
- SiPM

Activities in Nagoya group

Reduction of ER BG: **Hermetic Quartz TPC**

- Hermetic Quartz chamber to shield Rn
- Development of coated low QE electrode

Reduction of NR BG: **New Photosensors**

- Low DCR SiPM sensor
- Hybrid detector

Activities in Nagoya group

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- Hermetic Quartz chamber to shield Rn
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- Low DCR SiPM sensor
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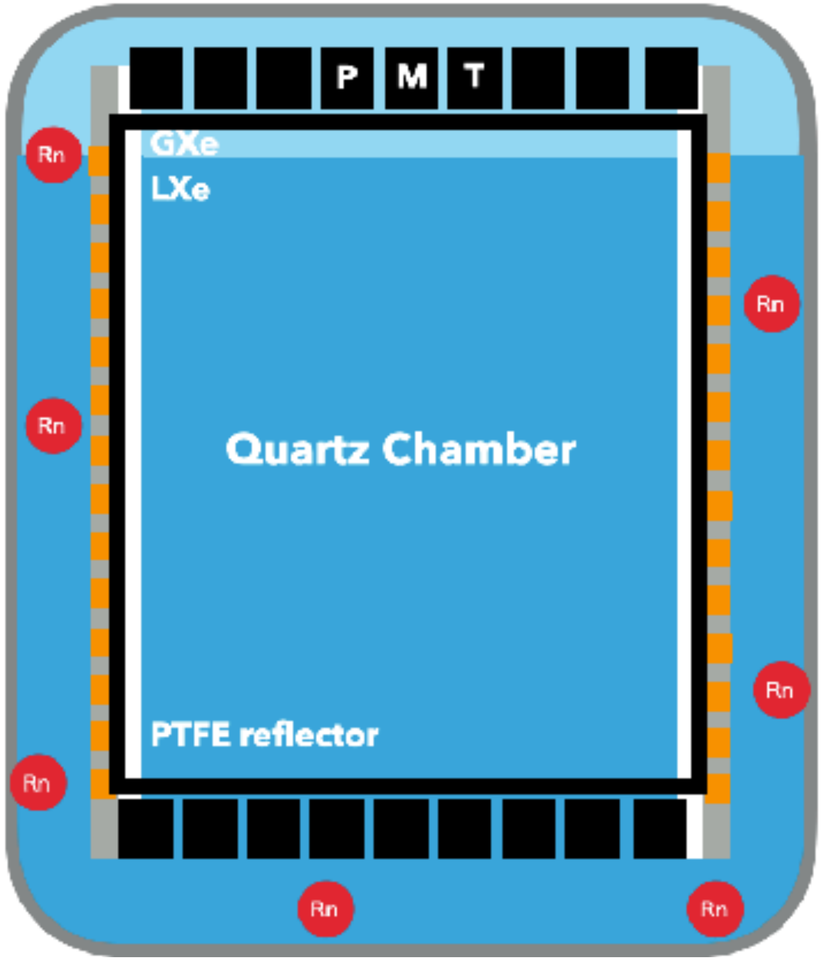
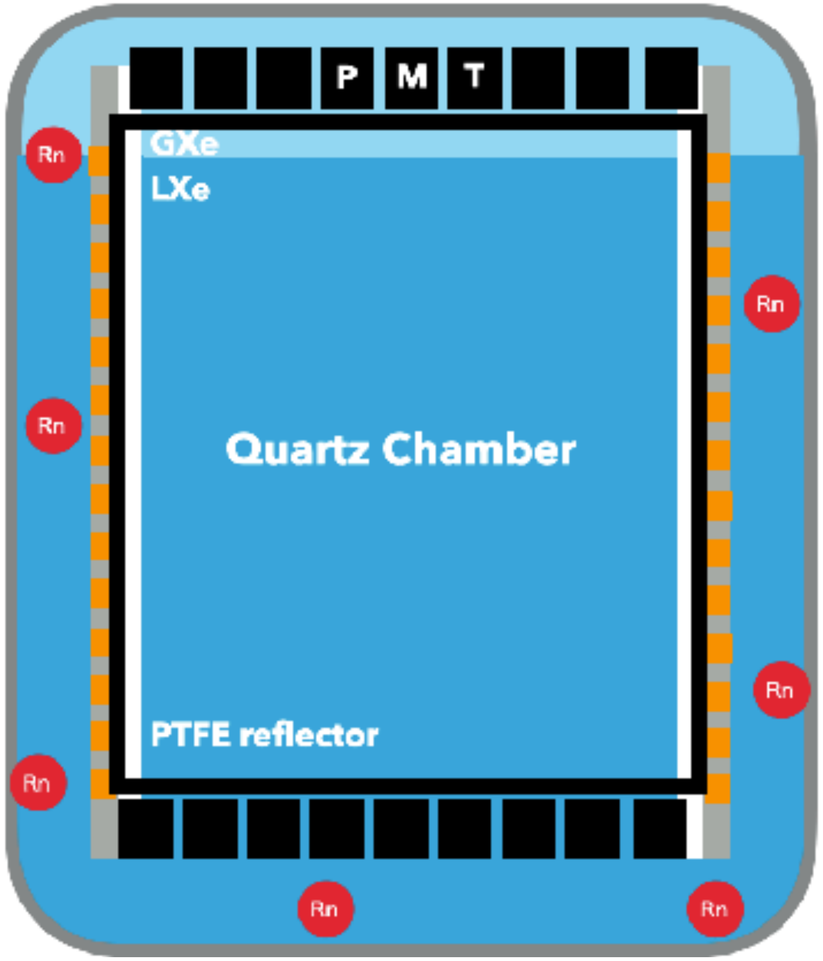
Hermetic Quartz TPC



- To reduce ^{222}Rn, we are studying about Heretic Quartz TPC.
  - Fully Isolating the TPC volume using VUV transparent quartz with low RI
- Non-hermetic quartz TPC was already tested: PTEP, 2020, 113H02
- Next step: Fully hermetic TPC

Hermetic Quartz TPC



Advantages

- Almost no Rn222 emanation
- Less O_2/H_2O outgassing
- Coating electrode (no sagging)

Challenges

- How tightly can we close?
- Which material for coating?
- How to stabilize the detector?

Activities in Nagoya group

Reduction of ER BG: **Hermetic Quartz TPC**

- **Hermetic Quartz chamber to shield Rn**
- Development of coated low QE electrode

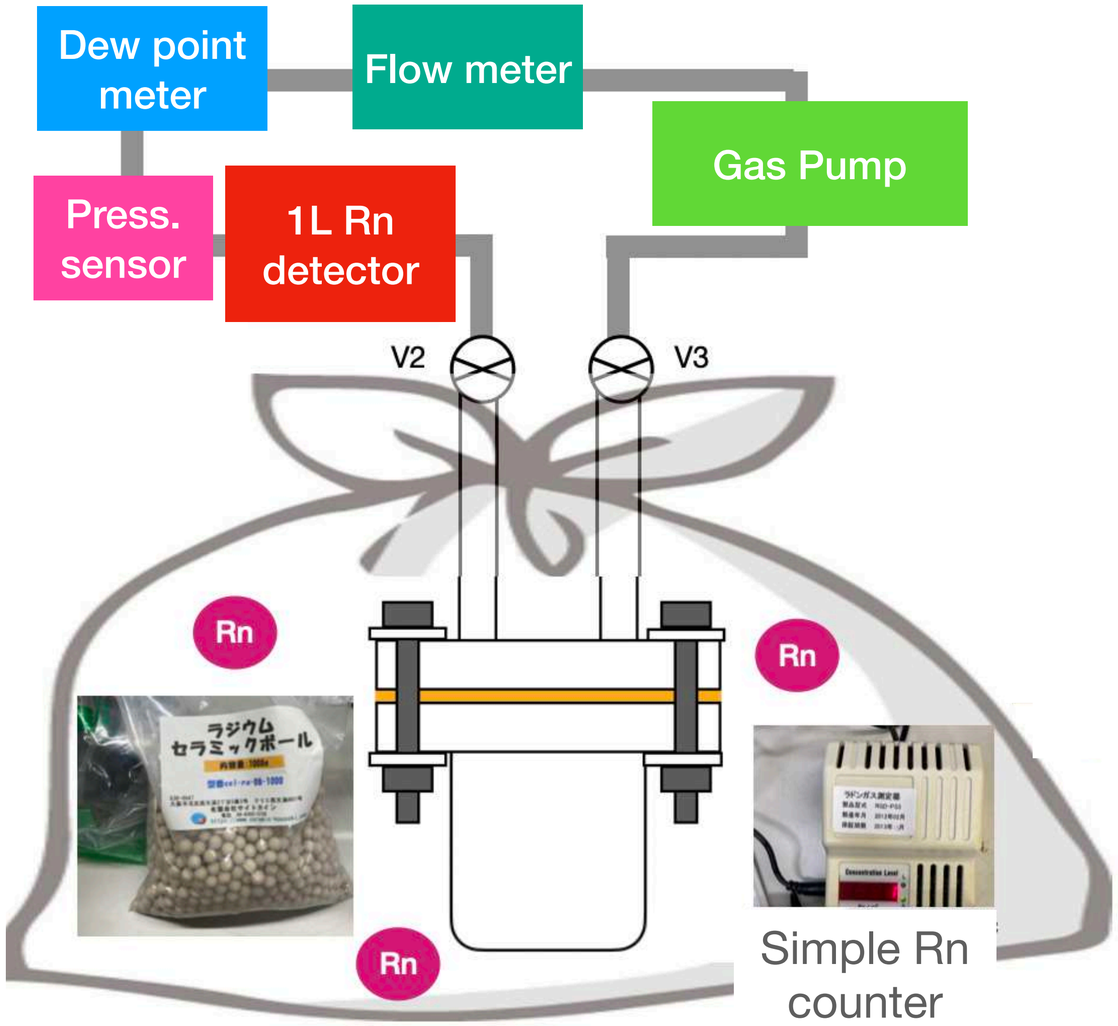
Reduction of NR BG: **New Photosensors**

- Low DCR SiPM sensor
- Hybrid photodetector

Hermetic Quartz TPC

- We tested several flange conditions with small quartz flanges
  - Torque, connections, gasket thickness…
  - Tested with vacuum leak checker
- Then, Rn shielding was also performed
  - Ceramic ball and Quartz chamber was put in the Al coated bag
  - Use Rn detectors to measure Rn levels

Hermetic Quartz TPC



Simple Rn counter

- We tested several flange conditions with small quartz flanges
  - Torque, connections, gasket thickness…
  - Tested with vacuum leak checker
- Then, Rn shielding was also performed
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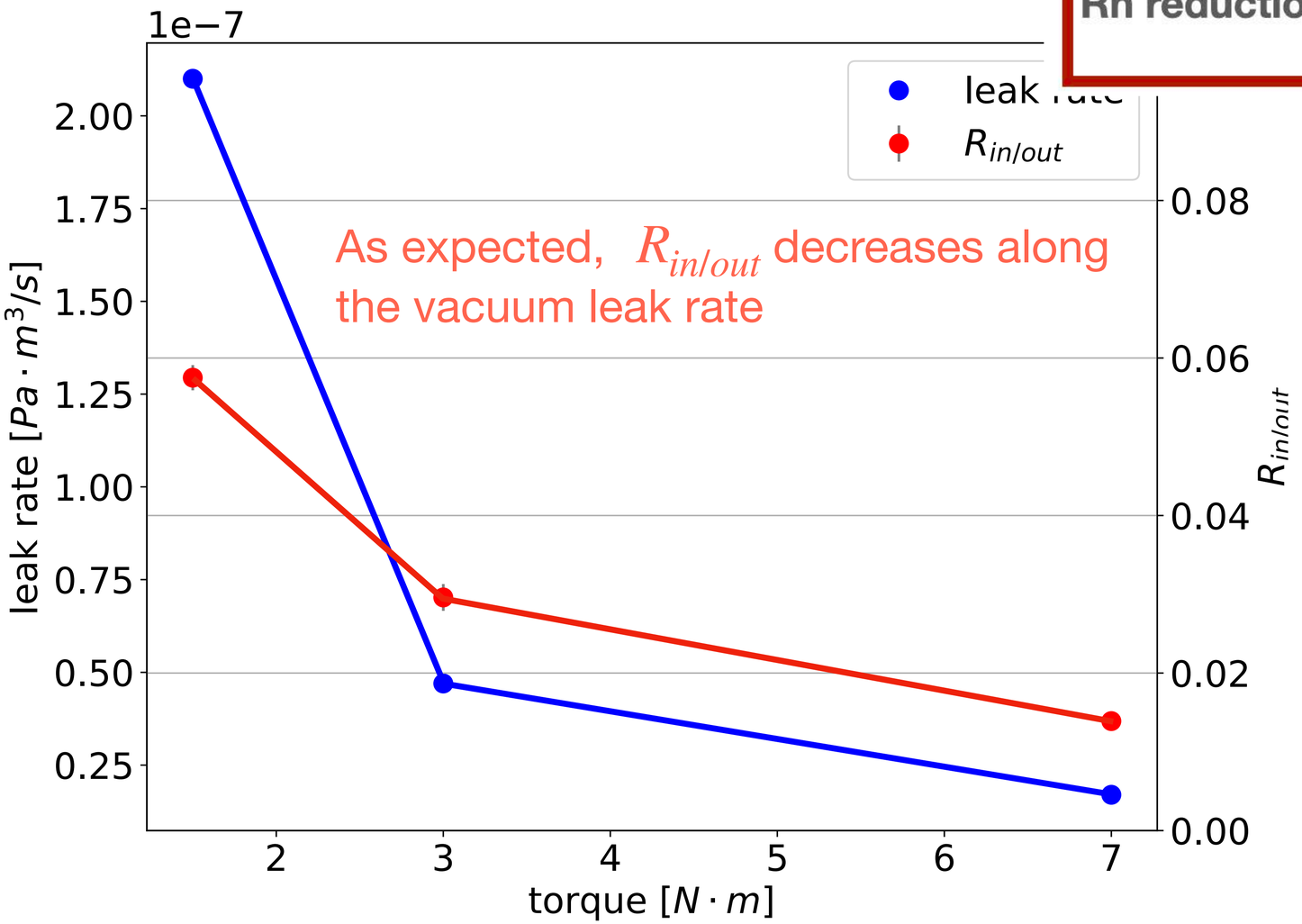
Hermetic Quartz TPC

Rn reduction factor: $R_{in/out} = \frac{^{222}\text{Rn concentration inside quartz}}{^{222}\text{Rn concentration outside quartz}}$



- By comparing the Rn concentration inside and outside, we achieved:

$$R_{in/out} = (1.39 \pm 0.03) \times 10^{-2}$$

Activities in Nagoya group

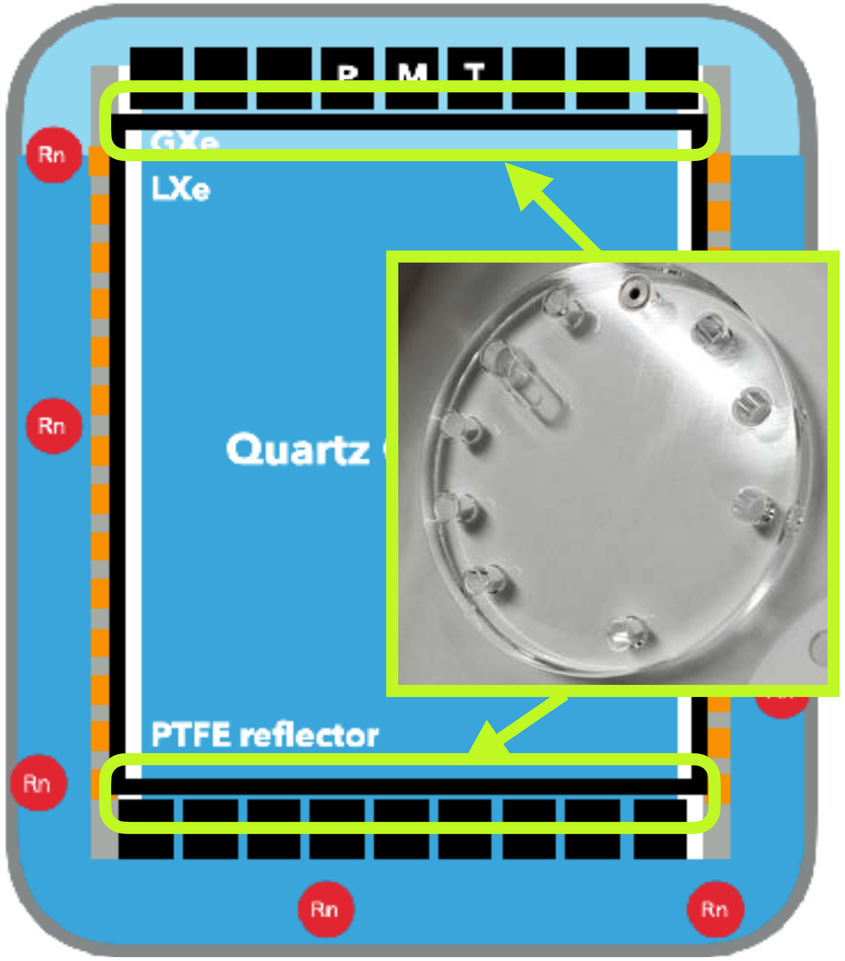
Reduction of ER BG: **Hermetic Quartz TPC**

- Hermetic Quartz chamber to shield Rn
- **Development of coated low QE electrode**

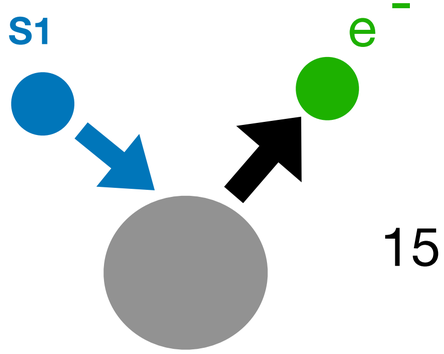
Reduction of NR BG: **New Photosensors**

- Low DCR SiPM sensor
- Hybrid photodetector

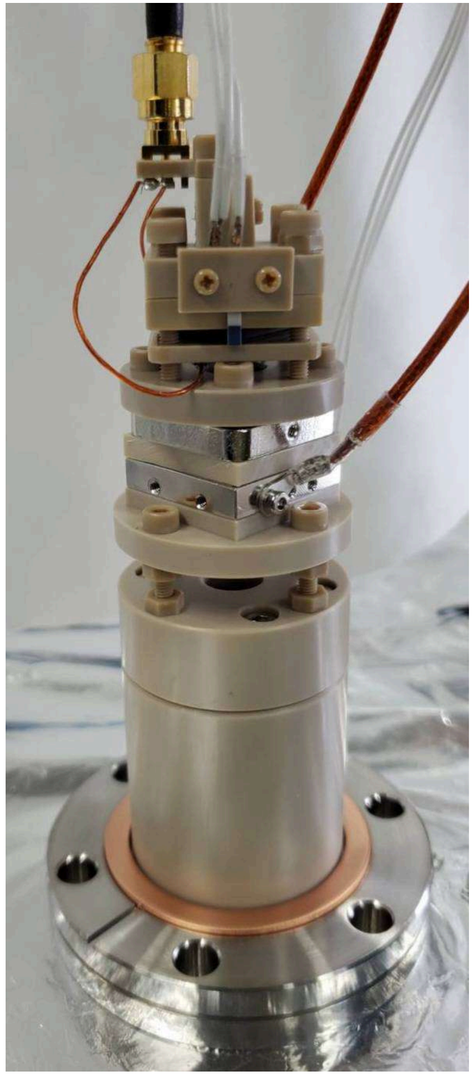
Coated electrode with low QE

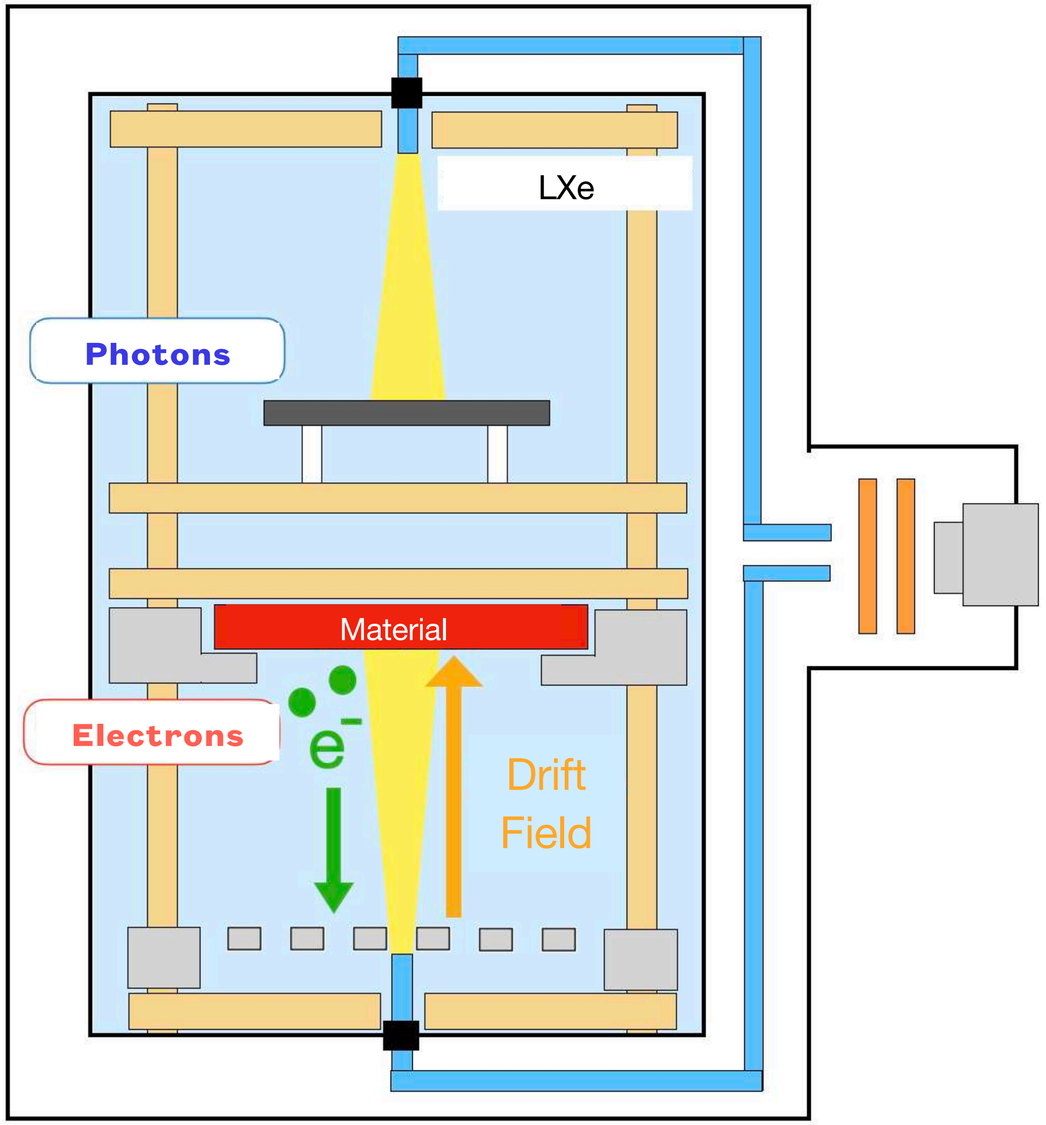


- In addition to shield ^{222}Rn, top/bottom flanges allow us to have coated electrodes
  - Expected to be more static than current wire-based ones (ex. no sagging)
- Suitable coating material: low-QE
  - To prevent photoionization by Xe scintillation photon, which can be the BG for low threshold analysis

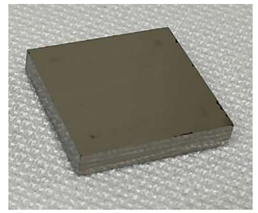


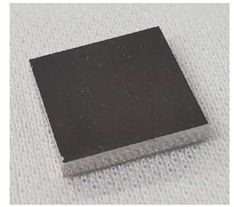
Coated electrode with low QE



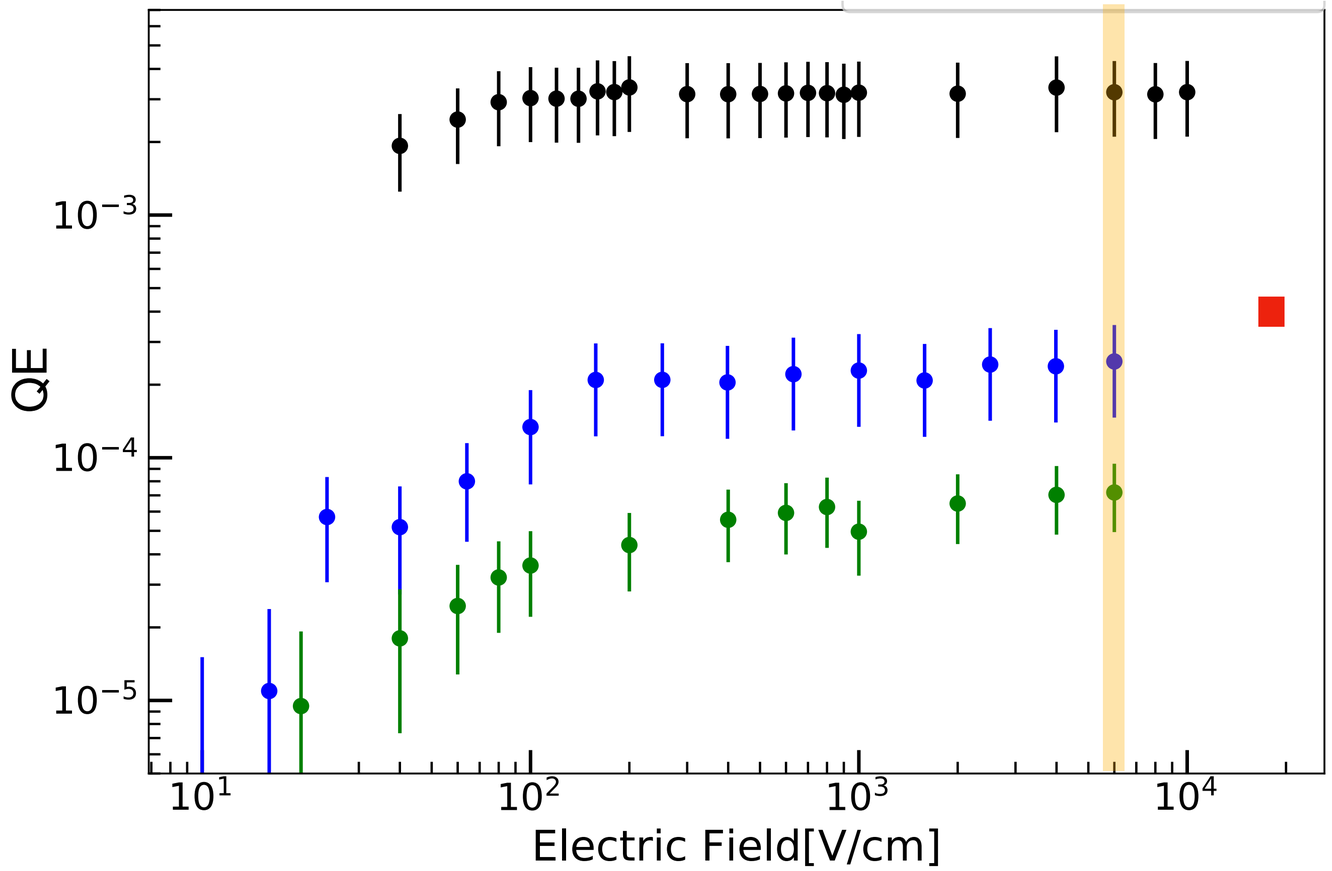


- Using the dedicated setup, QE of several material were measured in LXe.
  - Pt, Al+MgF_2, stainless
    - Stainless: SUS304





Coated electrode with low QE



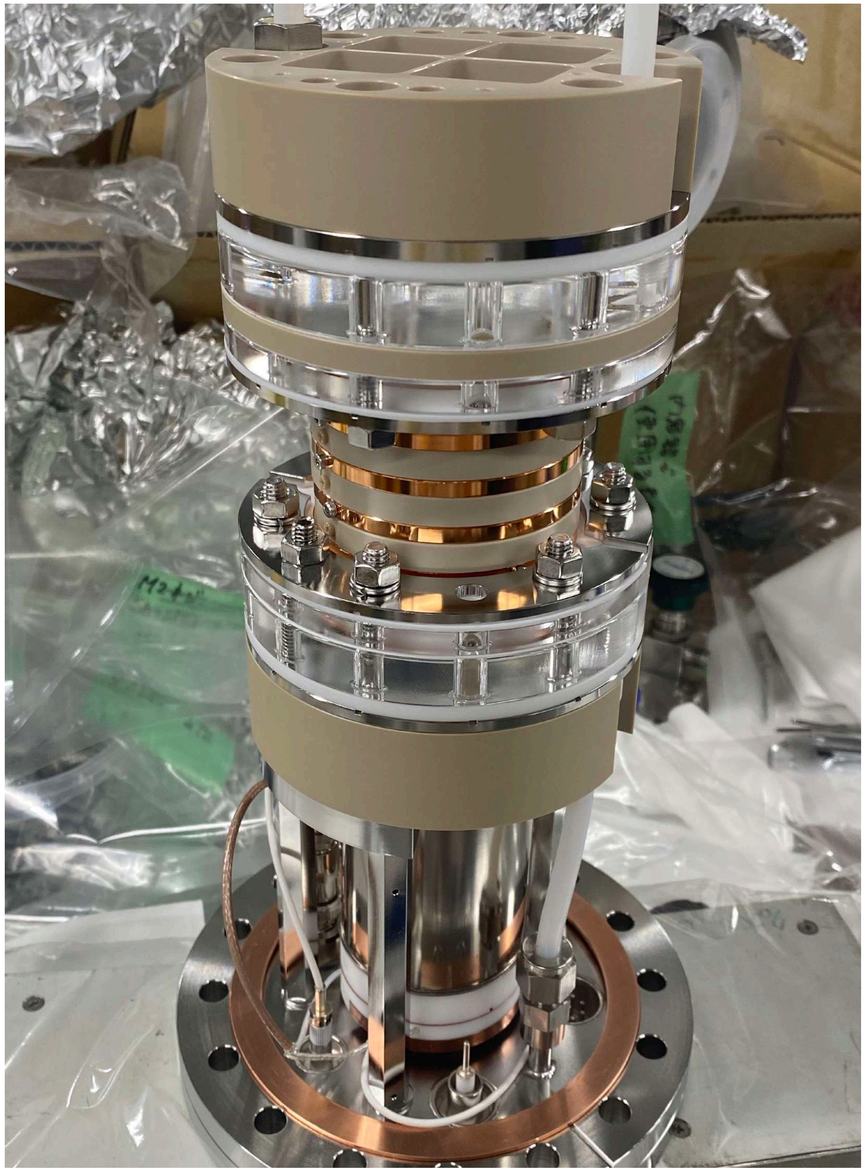
	QE @ 6 kV/cm
: Pt	$(3.21 \pm 1.10) \times 10^{-3}$
: SUS304	$(2.49 \pm 1.03) \times 10^{-4}$
: Al+MgF2	$(7.19 \pm 2.25) \times 10^{-5}$

■ : SS304 (literature value) $\sim 4.0 \times 10^{-4}$

(LUX collaboration, PhysRevD.104.012011)

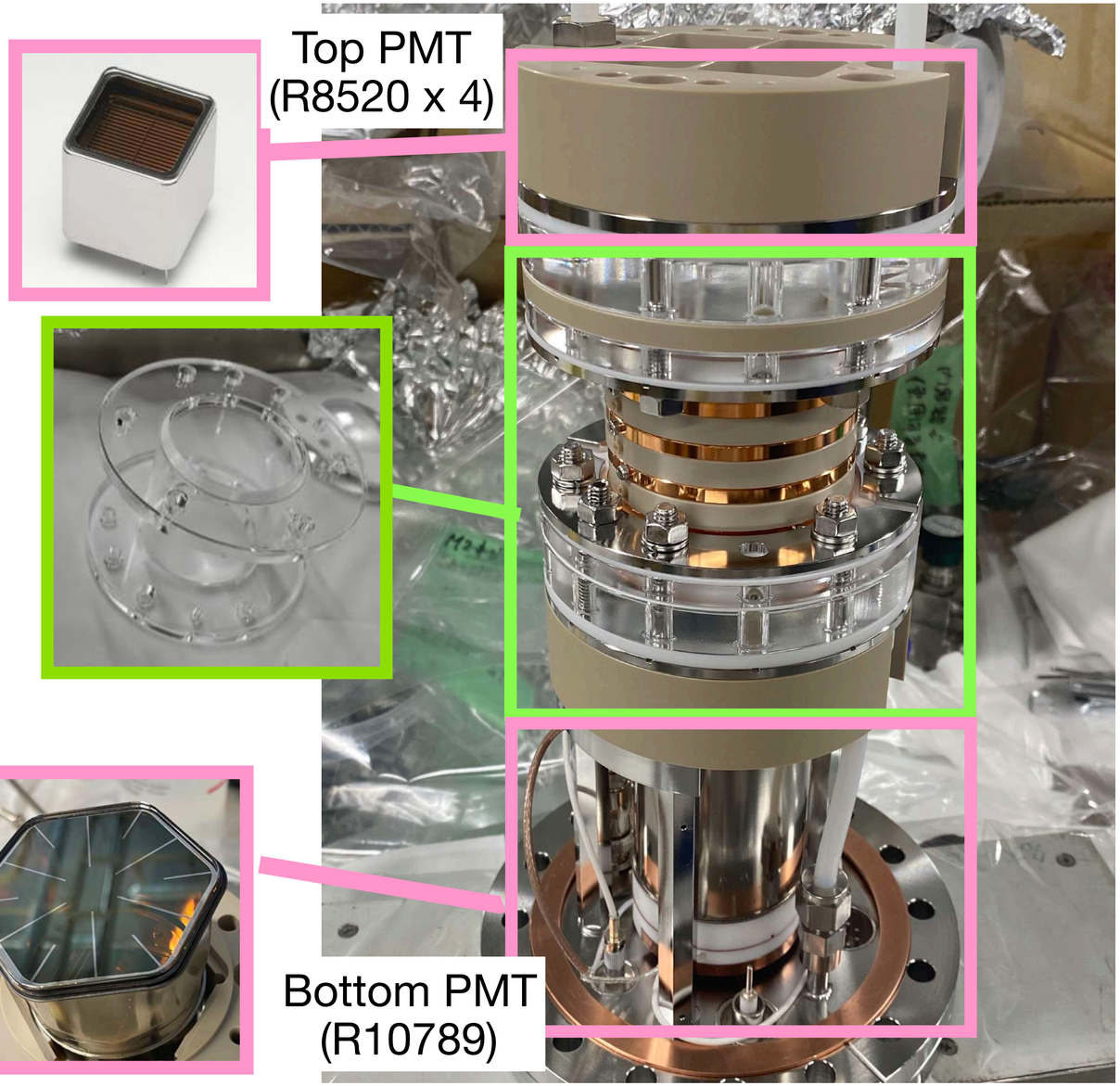
- As the result of measurement, Al + MgF_2 shows the lowest QE
- We will start making the real coated electrode on the quartz plate

Hermetic Quartz TPC



- Based on the result of Rn shielding test, we built the TPC setup
  - Using PMTs on top/bottom of chamber
- Currently, no electrode yet
- Test for the Rn shielding in GXe/LXe is ongoing as first step

Hermetic Quartz TPC



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Activities in Nagoya group

Reduction of ER BG: **Hermetic Quartz TPC**

- Hermetic Quartz chamber to shield Rn
- Development of coated low QE electrode

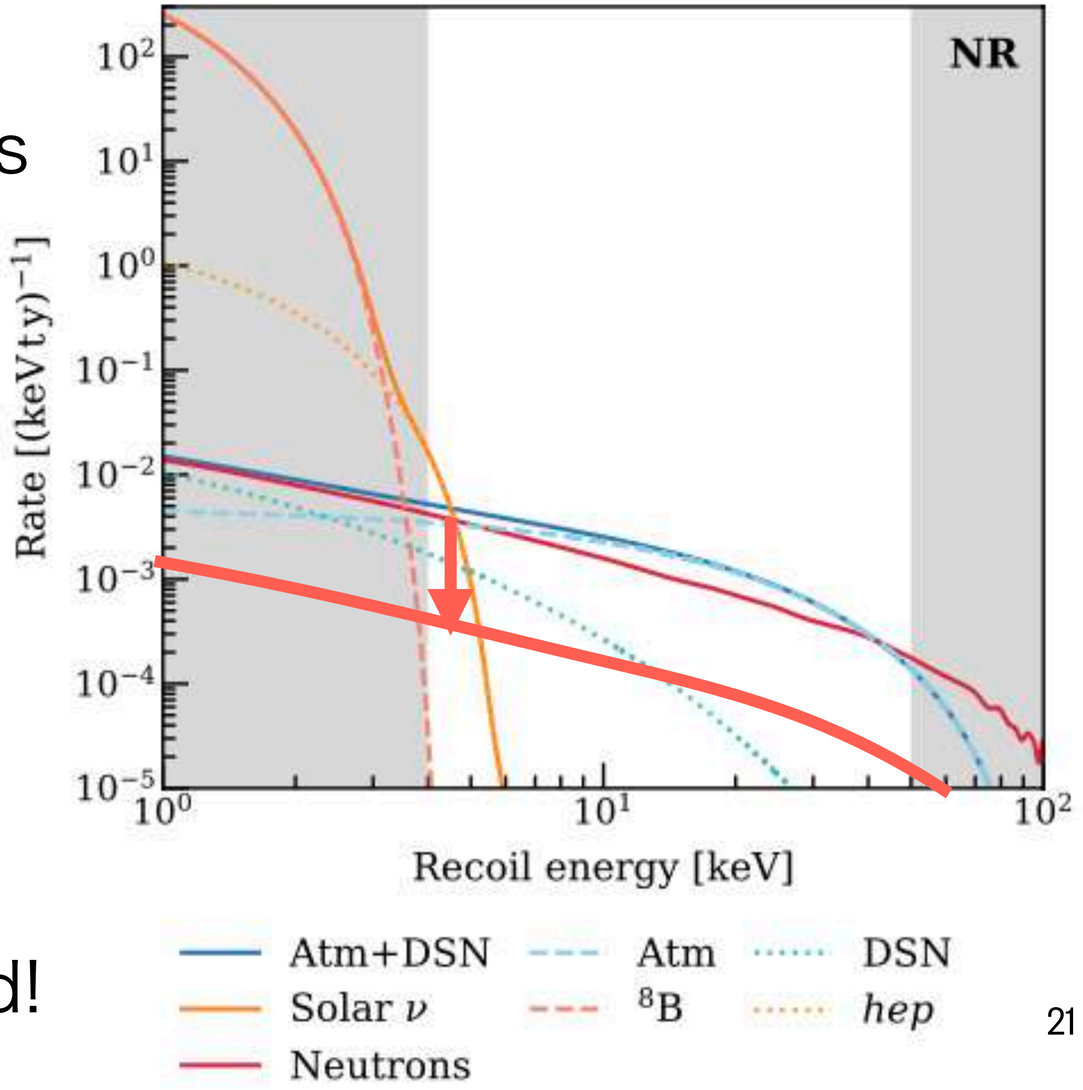
Reduction of NR BG: **New Photosensors**

- Low DCR SiPM sensor
- Hybrid photodetector

NR BG reduction

- According to the study from XENON group, we have 3 major NR BG sources
  - Cryostat
  - PTFE
  - Photosensor (PMT)
- Radiogenic neutrons from these detector components causes fake WIMP events
  - Additional reduction of RI is required!

Expected NR BG in XENONnT



NR BG reduction

- According to the study from XENON group, we have 3 major NR BG sources
  - Cryostat
  - PTFE
  - Photosensor (PMT)

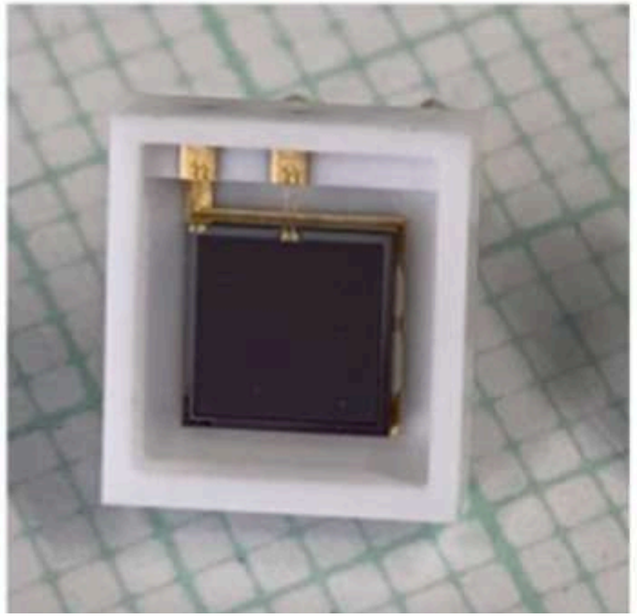
~1/3 of total neutron BG

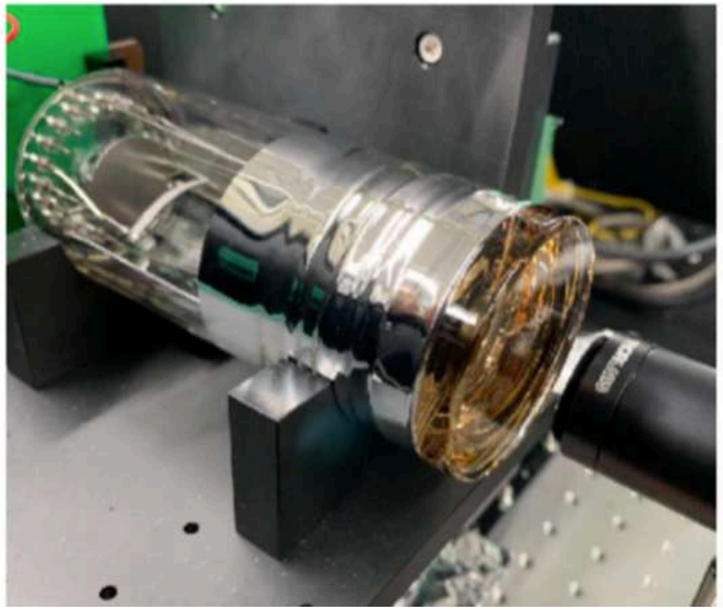
- Radiogenic neutrons from these detector components causes fake WIMP events
  - Additional reduction of RI is required!

Current Photosensors

- We are developing SiPM based new sensors
  - High purity of Si — low RI expected
    - *bonding material still needs to be improved
  - The main problem of SiPM: High DCR
    - ~ x10-100 of requirement: 0.01Hz/mm^2
- Two new sensors to solve this DCR issue
  - **Low DCR SiPM**
  - **Hybrid detecor**

SiPM(S12572-015C-SPL)





Activities in Nagoya group

Reduction of ER BG: **Hermetic Quartz TPC**

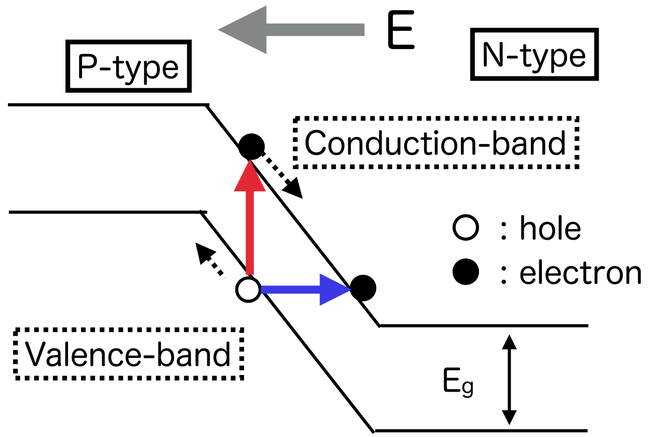
- Hermetic Quartz chamber to shield Rn
- Development of coated low QE electrode

Reduction of NR BG: **New Photosensors**

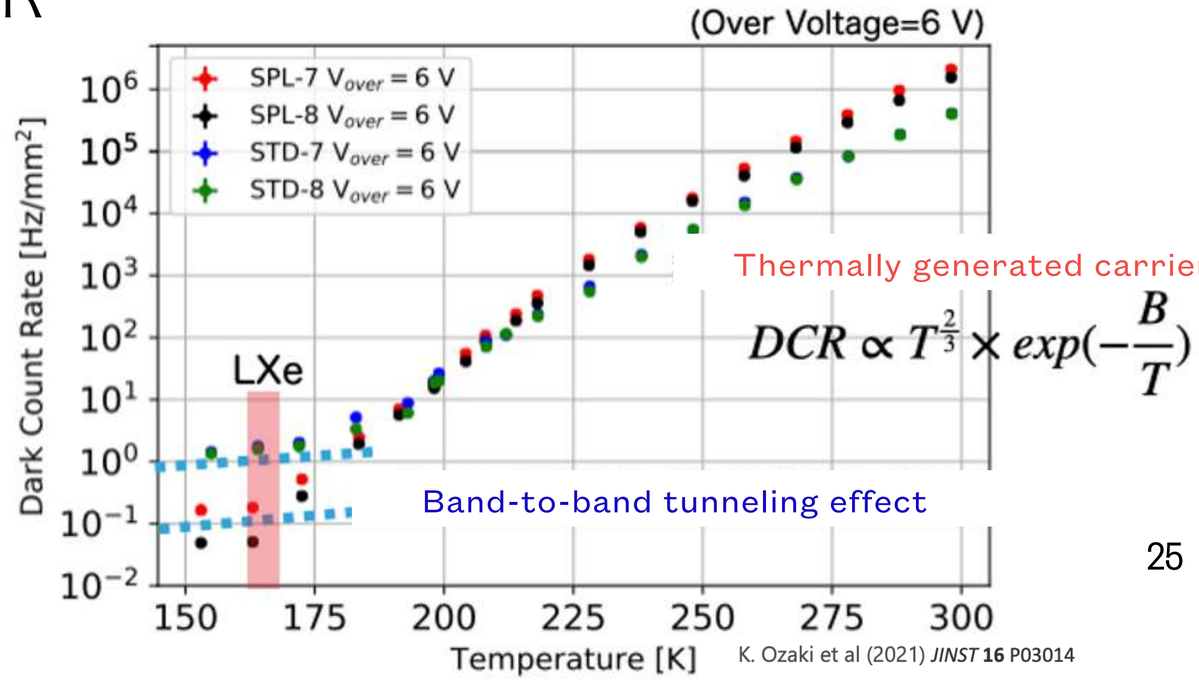
- **Low DCR SiPM sensor**
- Hybrid photodetector

New Photosensors: Low DCR SiPM

- Production of dark count in SiPM:
  - Thermally generated carriers:
    - strong temperature dependence
  - Band-to-band tunneling effect:
    - weak temperature dependence
- Hamamatsu developed prototype low DCR SiPM by modifying the inner field configuration
  - The test by our group showed clear reduction of DCR at LXe temperature: ~1/6-60
  - Not VUV-sensitive (cannot be used for DARWIN)



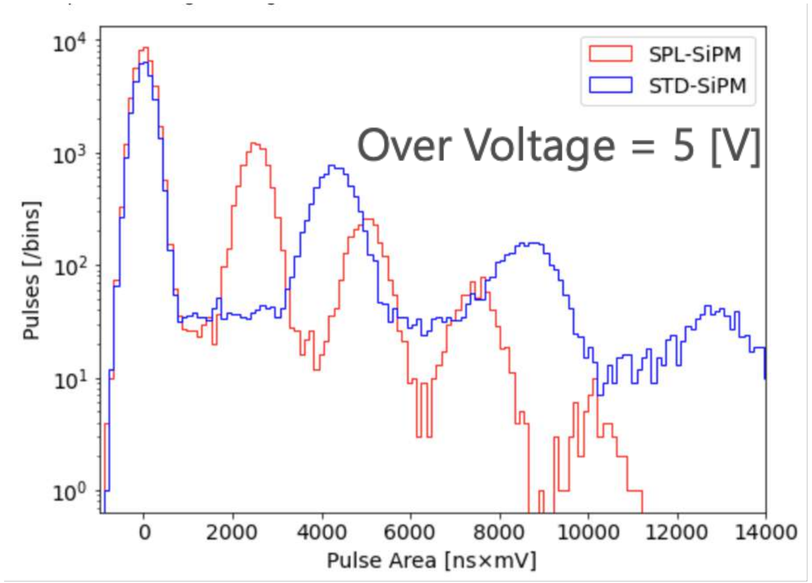
E_g : Band-gap energy

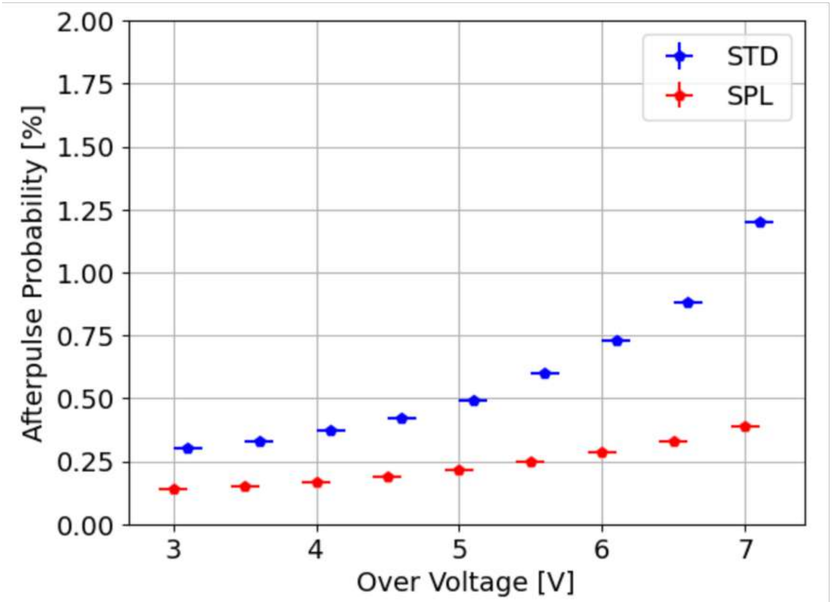


K. Ozaki et al (2021) *JINST* **16** P03014

New Photosensors: Low DCR SiPM

- Recently, low DCR SiPM with VUV sensitive model is developed too: tests ongoing
- Basic checks in room temperature conditions are finished: **no problem so far**
  - Slightly small gain (as expected)
  - Smaller after pulse rate (as expected)
  - Other characteristics are similar to the normal model
- **Test with LXe temperature is about to start**





Activities in Nagoya group

Reduction of ER BG: **Hermetic Quartz TPC**

- Hermetic Quartz chamber to shield Rn
- Development of coated low QE electrode

Reduction of NR BG: **New Photosensors**

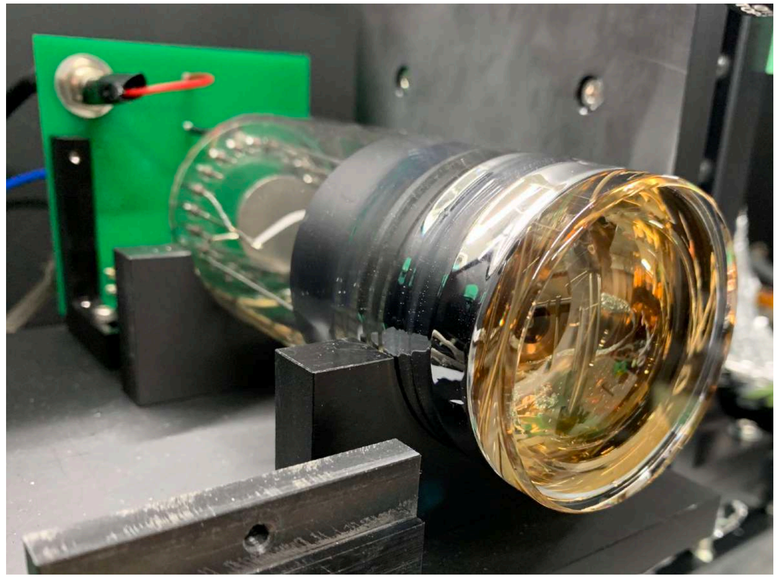
- Low DCR SiPM sensor
- **Hybrid detector**

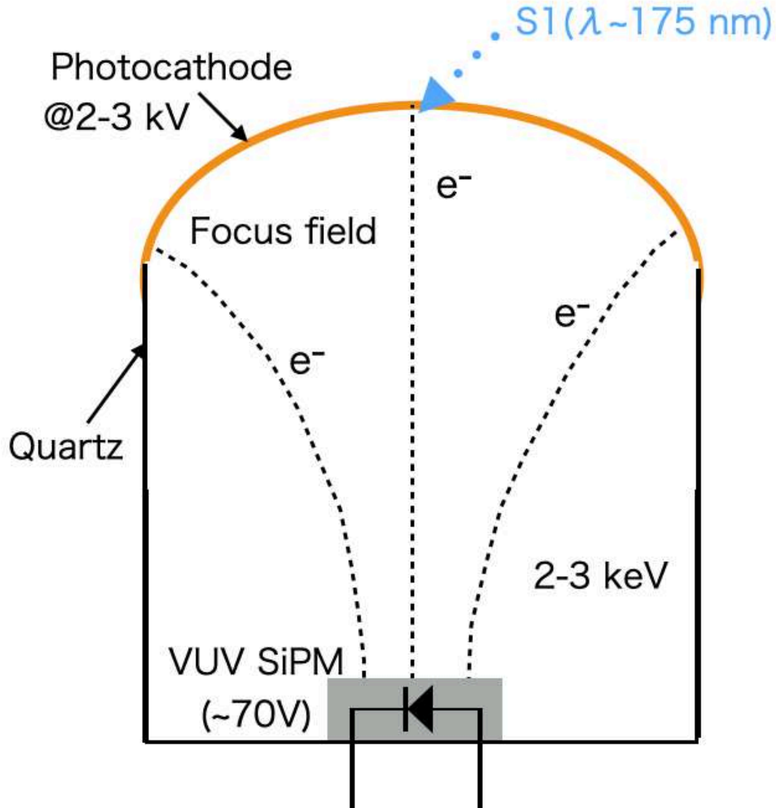
New Photosensors: Hybrid detector

- Hybrid detector: PMT + SiPM
- Use the photocathode of PMT and SiPM for multiplication

- The effective DCR (area normalized) is reduced by O(100)
- However: PDE is very small (~4%)

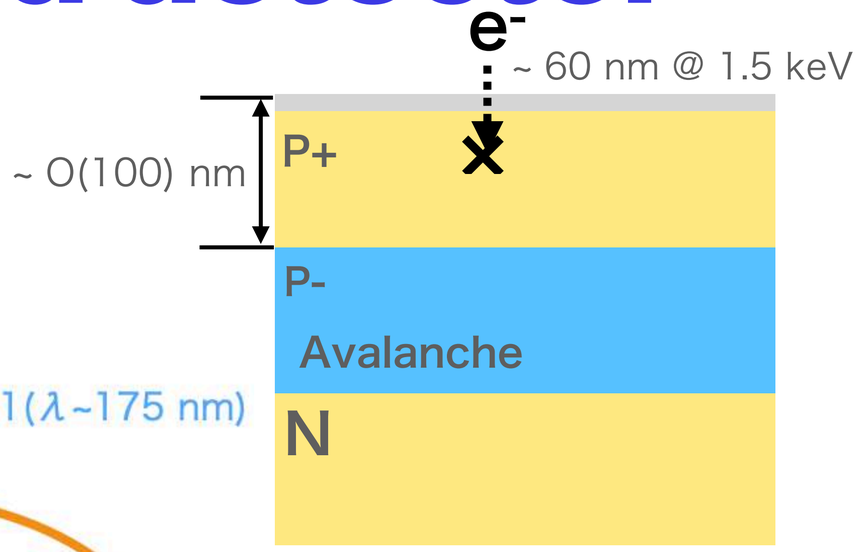
Hybrid (XE5859)

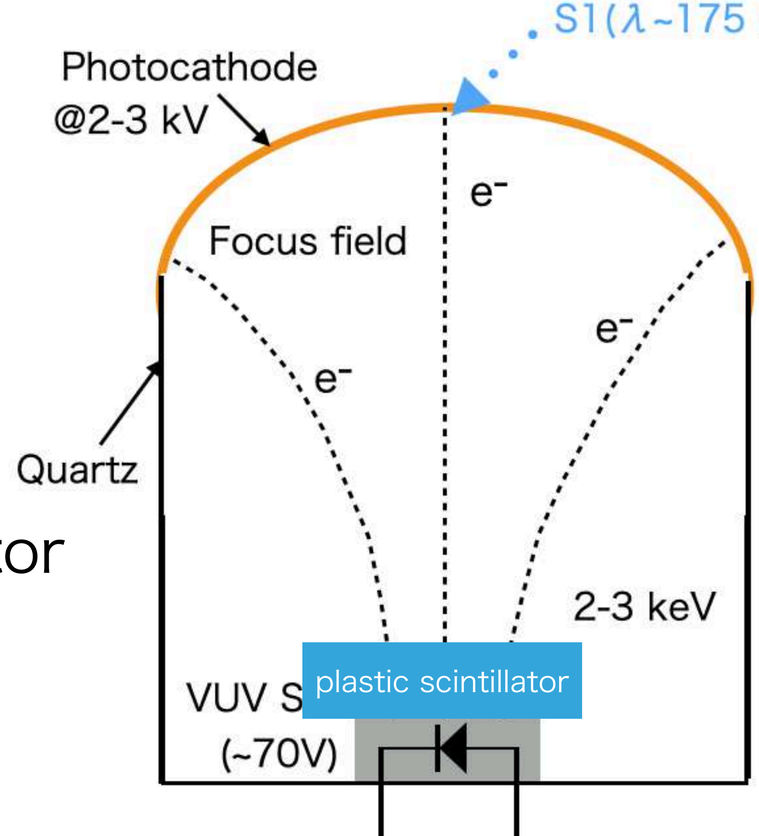




New Photosensors: Hybrid detector

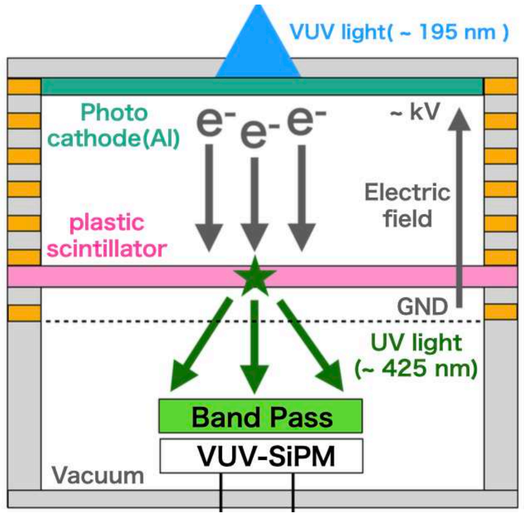
- Why PDE is so small?
  - With nominal HV (1.5kV), e^- cannot reach to the avalanche layer…
- **New idea: put thin plastic scintillator on top of SiPM**
  - Convert photo-electron into UV photons
  - The light yield of plastic scintillator affects to the PDE

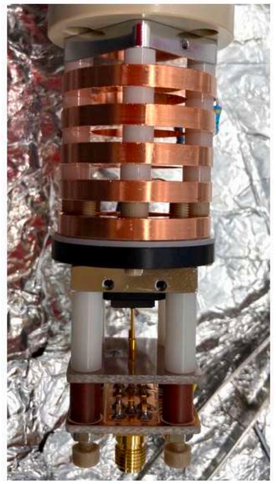


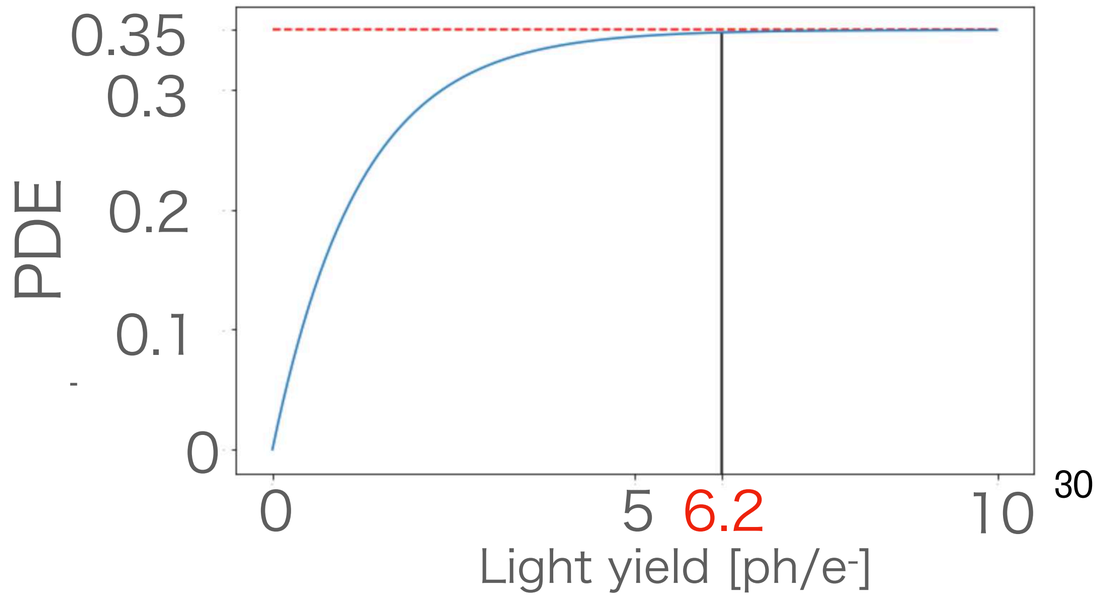


New Photosensors: Hybrid detector

- Measurement with dedicated setup
  - Drifting electrons with E-field and measure the light from scintillator
- After considering detector effect, light yield is: **6.2 ± 2.2 ph/e @2keV**
  - Corresponds to **34.8%** of PDE!
- Test with other material is also ongoing



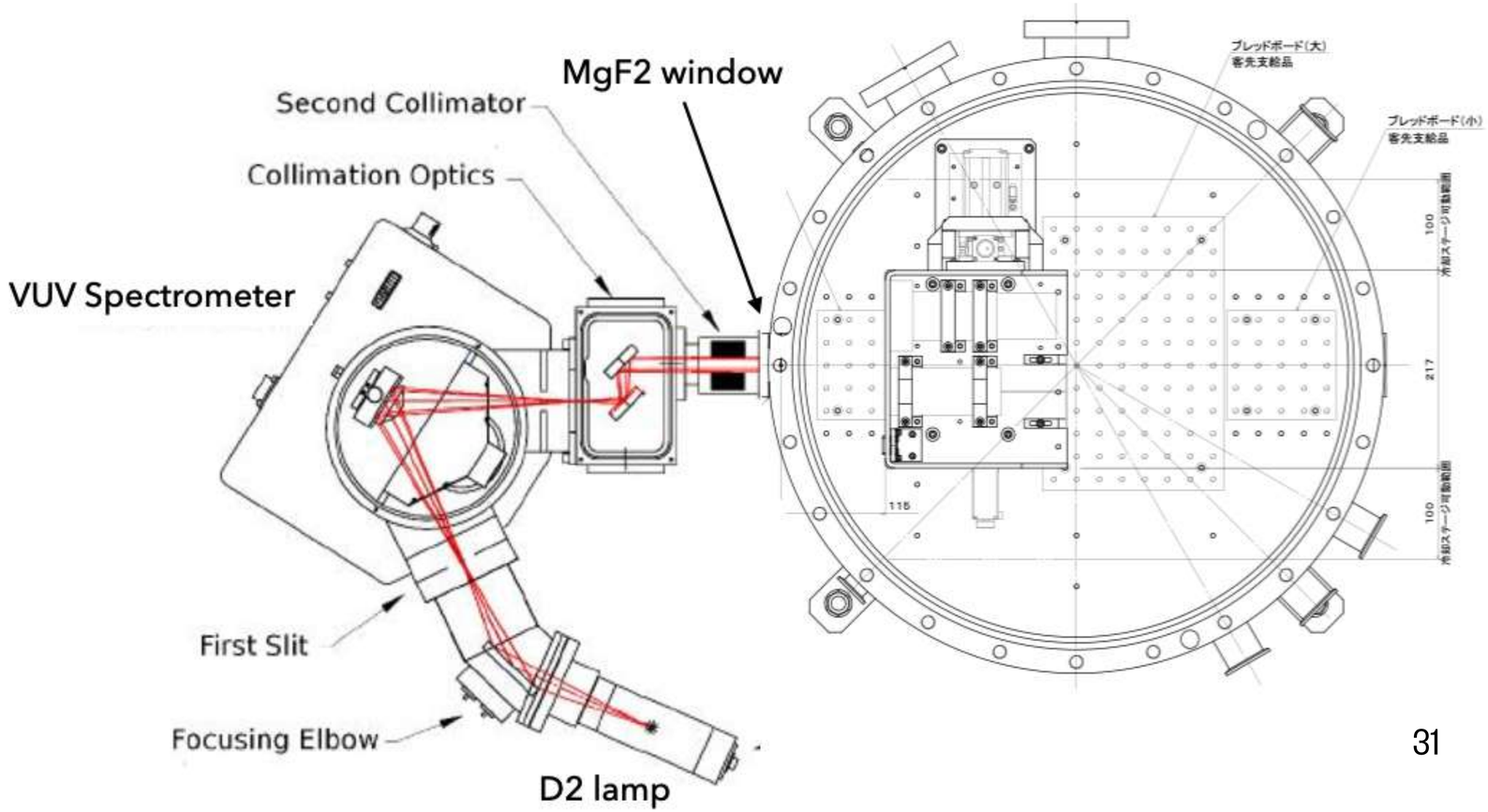




New Setup for VUV spectrometer

- To perform the further measurement of photosensors with VUV light (ex. X-Y scan of PDE) new spectrometer system is being prepared

- Big Vacuum chamber with PTR and motorized stage (X-Y scan)
- VUV spectrometer
  - D2 lamp
  - Xe flash lamp



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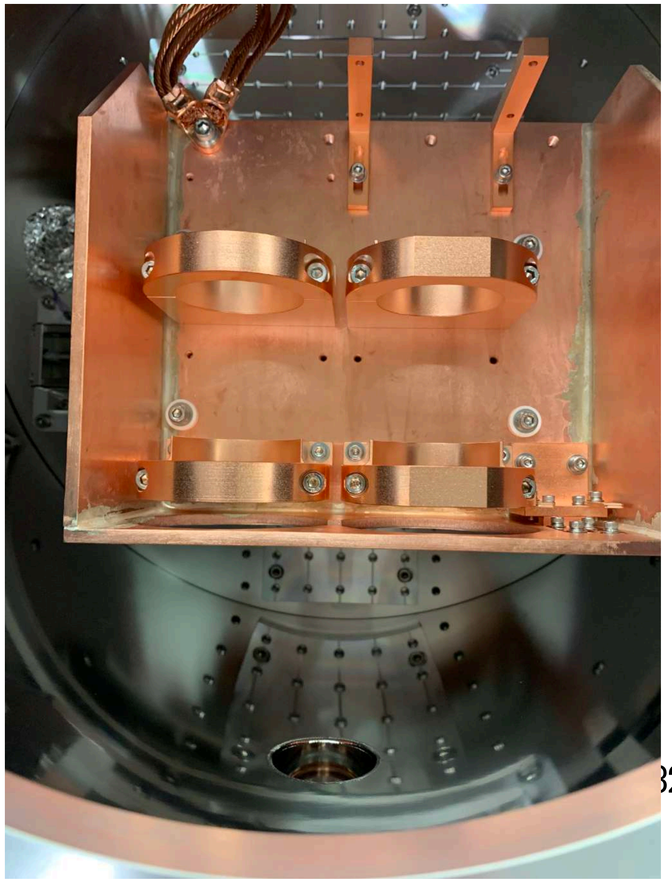
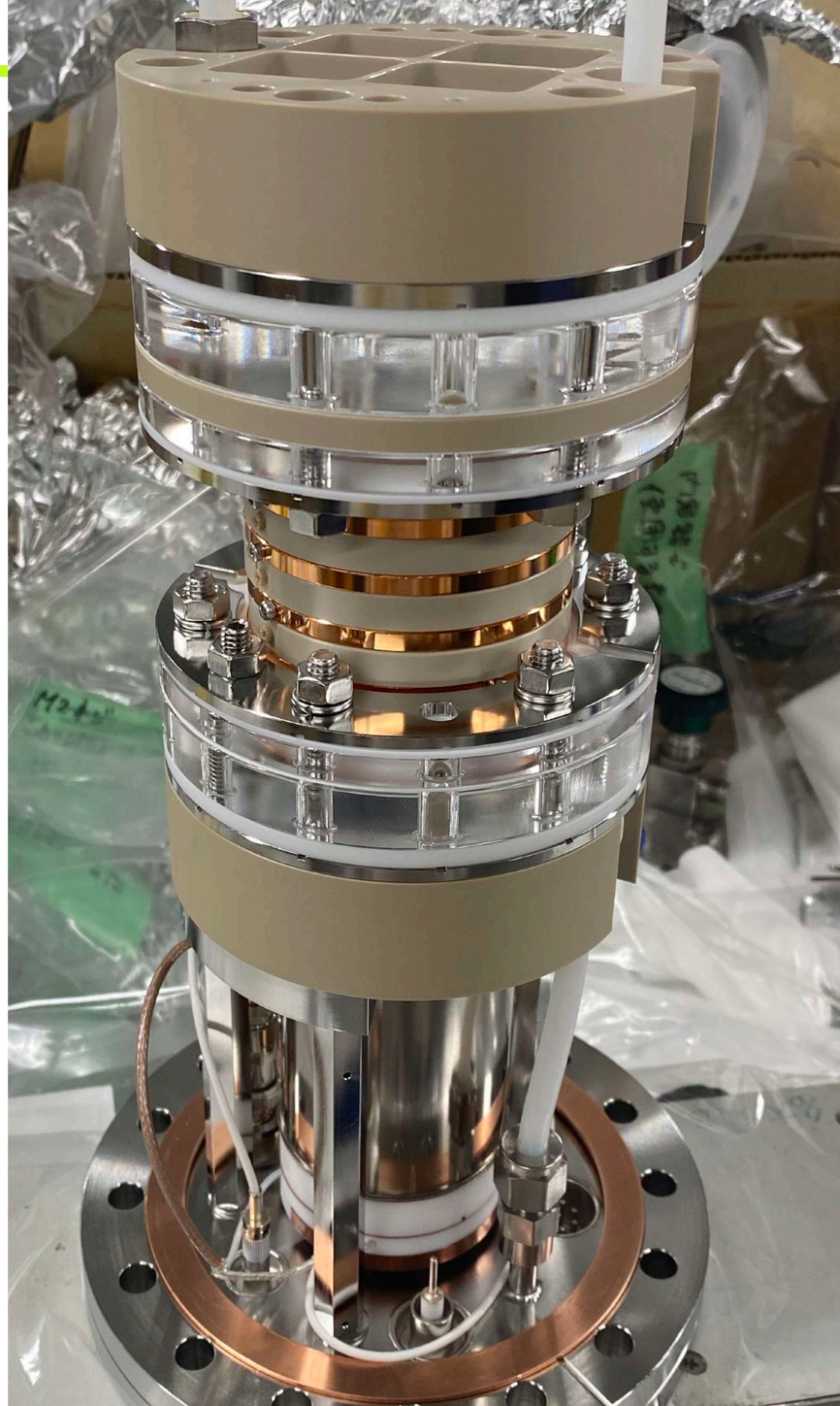


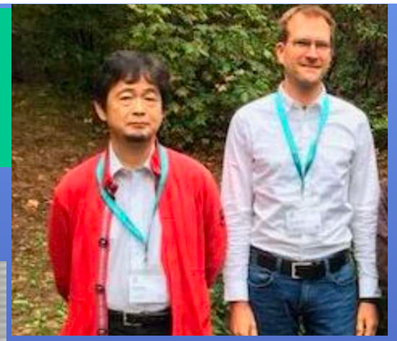
Summary

- To achieve the ultimate sensitivity with DARWIN, we need to suppress both ER and NR BGs to be less than ν
- Several R&D project are ongoing in Nagoya group
  - **Hermetic Quartz TPC**
    - The test of small TPC with GXe is ongoing, LXe is being prepared. Coated electrode will be prepared soon.
  - **New photosensors: SiPM based photosensors**
    - **Low DCR SiPM**
      - New prototype from Hamamatsu is under testing. Test with LXe temp is about to start
    - **Hybrid detector**
      - Conceptual test with new setup shows good result, expected to have higher PDE
  - **New facility for VUV spectrometer is being built**



XENON/DARWIN Nagoya group

Junji HISANO
Marc SCHUMANN
- Member for DM unit



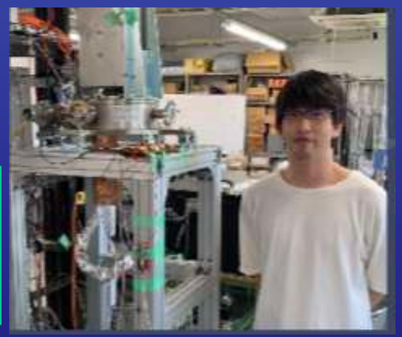
Yoshitaka ITOW
- PI
- SuperK/HyperK, LHCf/RHICf, XENON/DARWIN

Shingo KAZA
- Associate
- Analysis
- New photo

Masatoshi KOBAYASHI
- Postdoc
- purification
- metic TPC

THANK YOU FOR YOUR ATTENTION!

Tomoya HASEGAWA
- Master student (DARWIN)
- Hybrid Photosensor



Shun SAKAMOTO
- Master student (DARWIN)
- SiPM

Naoki AOYAMA
- Master student (DARWIN)
- Coated Electrode
- QE measurement

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