



Directional dark matter search with gaseous detectors

Satoshi Higashino

Kobe University

15 / 6 / 2022



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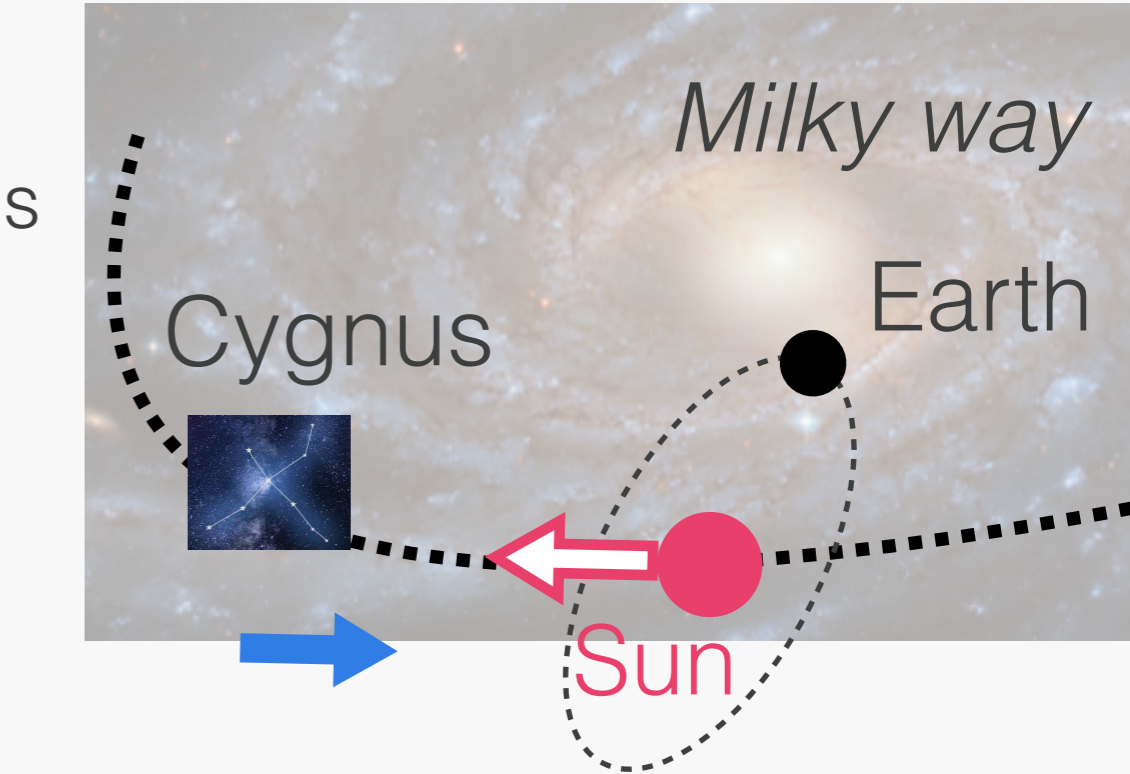
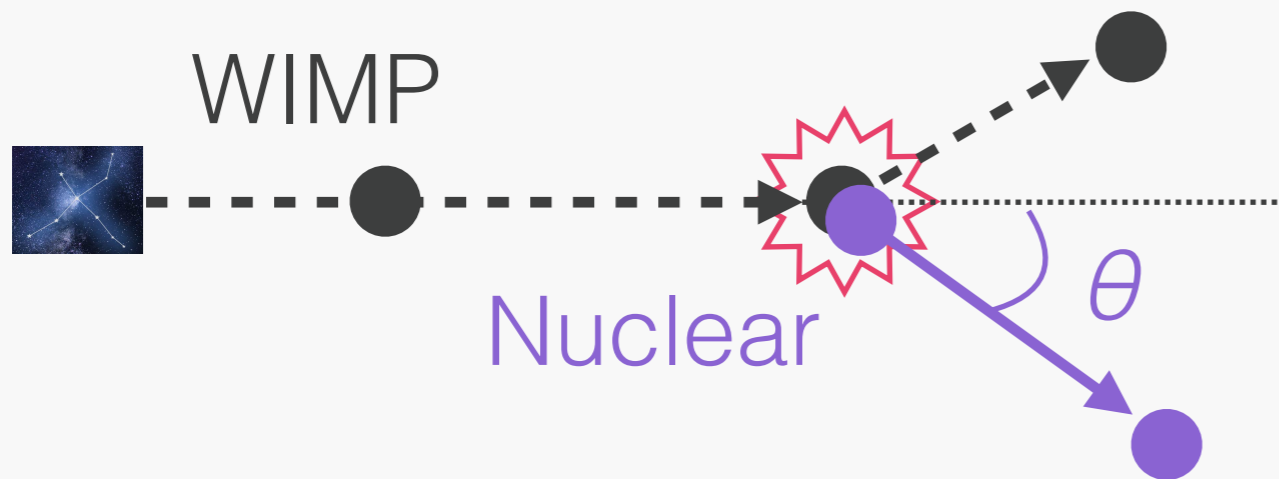
15 / 6 / 2022

Picture of this building
(14/6/2022)

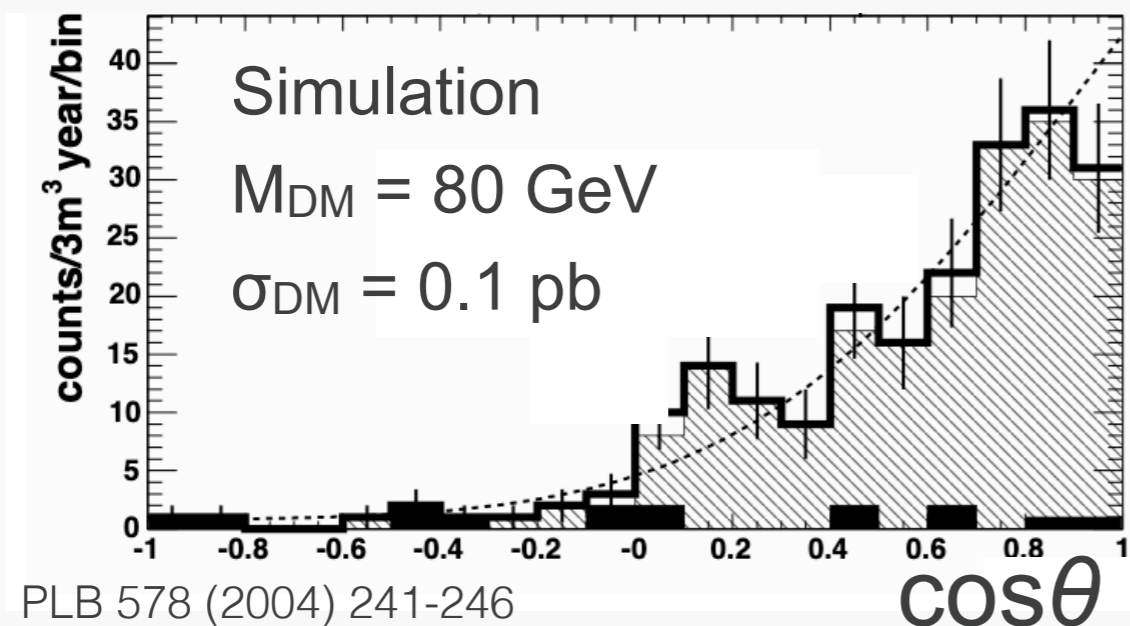
Introduction

Direction-sensitive DM searches

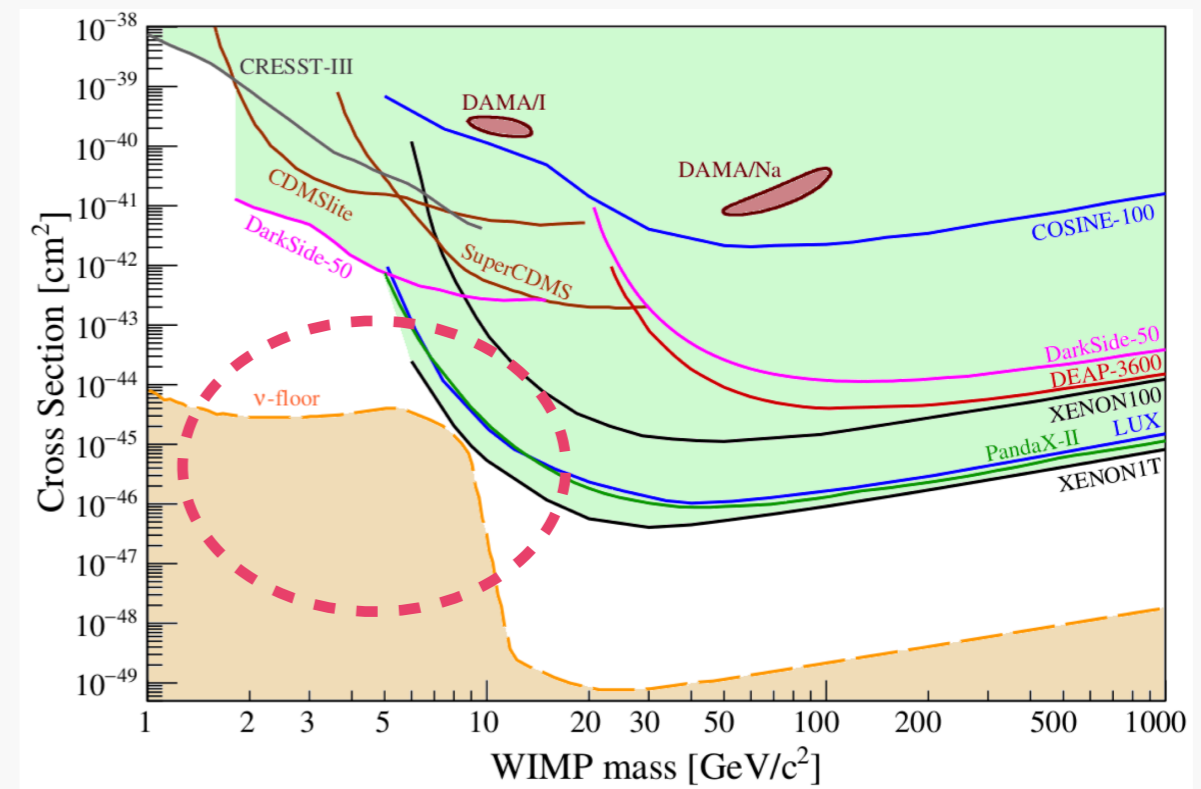
- Detection of NR scattering angle from Cygnus
 - ➔ leads a strong signature of WIMP
 - ➔ allows to explore beyond the neutrino-floor



WIMP wind from Cygnus!

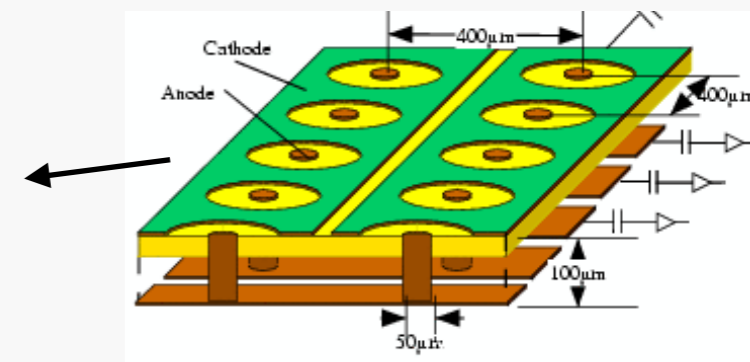
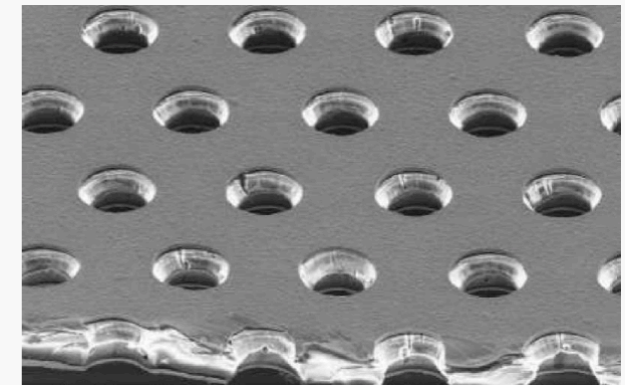
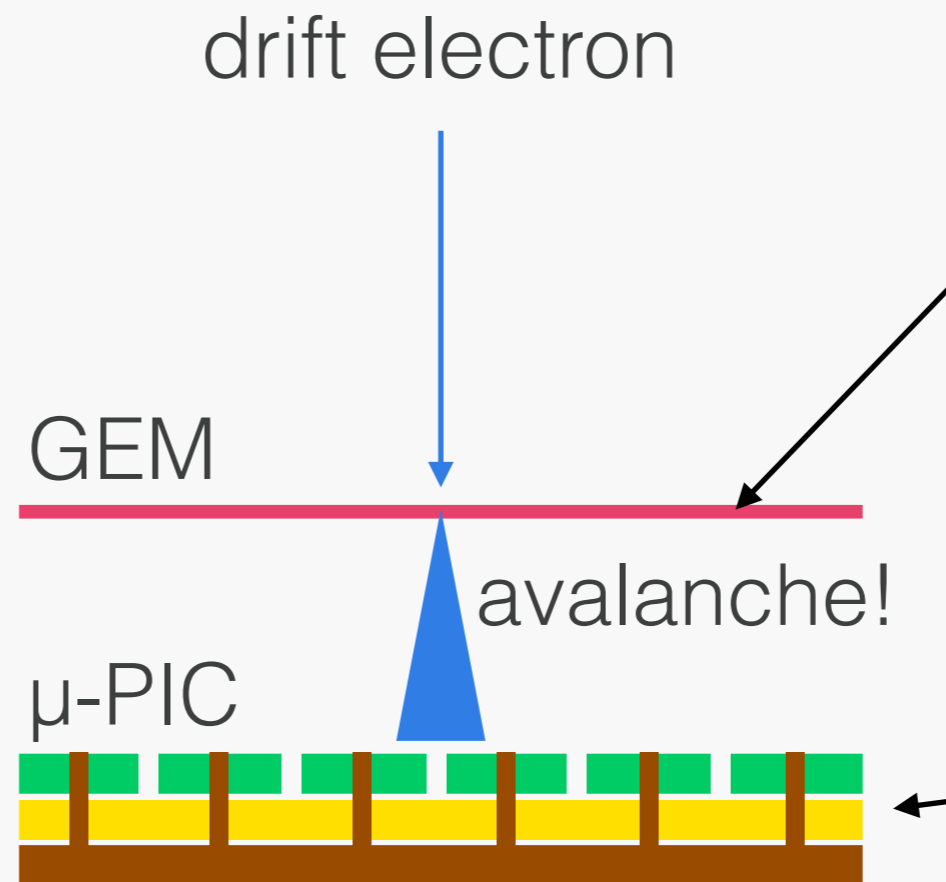
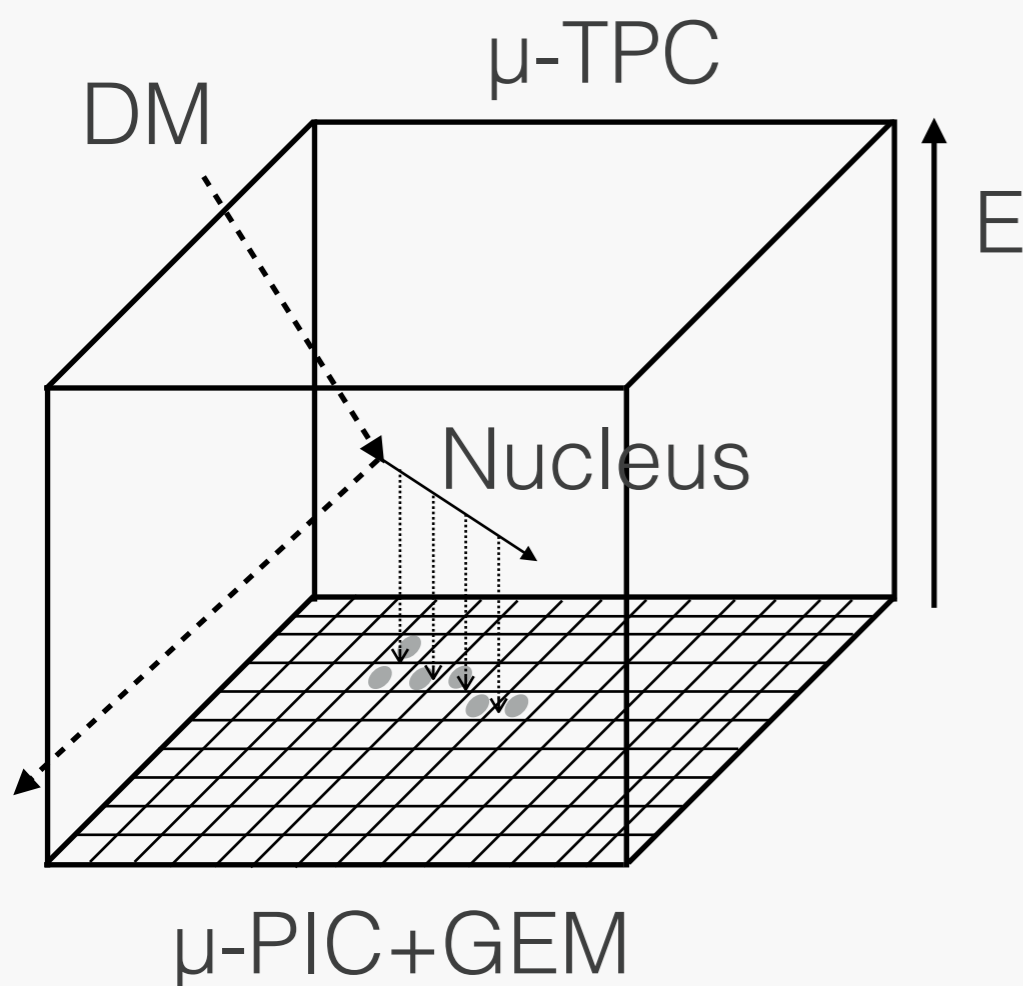


PLB 578 (2004) 241-246



NEWAGE

- 3D track reconstruction using a gaseous TPC
 - ➔ Gas: pure CF_4 at 76 Torr (0.1 atm) for Spin-Dependent search
 - ➔ Readout: μ -PIC (400 μm pitch 2D strip)
 - ➔ Gas amplification: μ -PIC + GEM (Gas Electron Multiplier)



Recent activities

成果 B02 方向に感度をもった暗黒物質直接探

<https://www.lowbg.org/ugap/result-b02.htm>

■ 論文発表 (査読あり)

2021年度

4 publications (21 in total)

Scintillation light increase of carbontetrafluoride gas at low temperature Keita Mizukoshi, Takeshi Maeda, Yuuki Nakano, Satoshi Higashino, Kentaro Miuchi 2021 JINST 16 P12033 T, arXiv:2108.13929

Evaluation of radon adsorption efficiency of activated carbon fiber using tetrafluoromethane, Y Kotsar, Y Nakano, Y Takeuchi, K Miuchi, Progress of Theoretical and Experimental Physics, (2021) ptac005, doi.org/10.1093/ptep/ptac005

w/ C01

"Test of low radioactive molecular sieves for radon filtration in SF6 gas-based rare-event physics experiments" R.R. Marcelo Gregorio, N.J.C. Spooner, J. Berry, A.C. Ezeribe, K. Miuchi, H. Ogawa and A. Scarff, (2021) JINST 16 P06024 <https://doi.org/10.1088/1748-0221/16/06/P06024>

international activity

"Direction-sensitive dark matter search with a low-background gaseous detector NEWAGE-0.3b" Tomonori Ikeda, Kiseki Nakamura, Takuya Shimada, Ryota Yakabe, Takashi Hashimoto, Hirohisa Ishiura, Takuma Nakamura, Hiroshi Ito, Koichi Ichimura, Ko Abe, Kazuyoshi Kobayashi, Toru Tanimori, Hidetoshi Kubo, Atsushi Takada, Hiroyuki Sekiya, Atsushi Takeda, Kentaro Miuchi Progress of Theoretical and Experimental Physics, ptab053, <https://doi.org/10.1093/ptep/ptab053>

latest result

Kentaro was on a broadcast!
(12/6/2022 "Galileo-X")

international conference: 4 (24 in total)

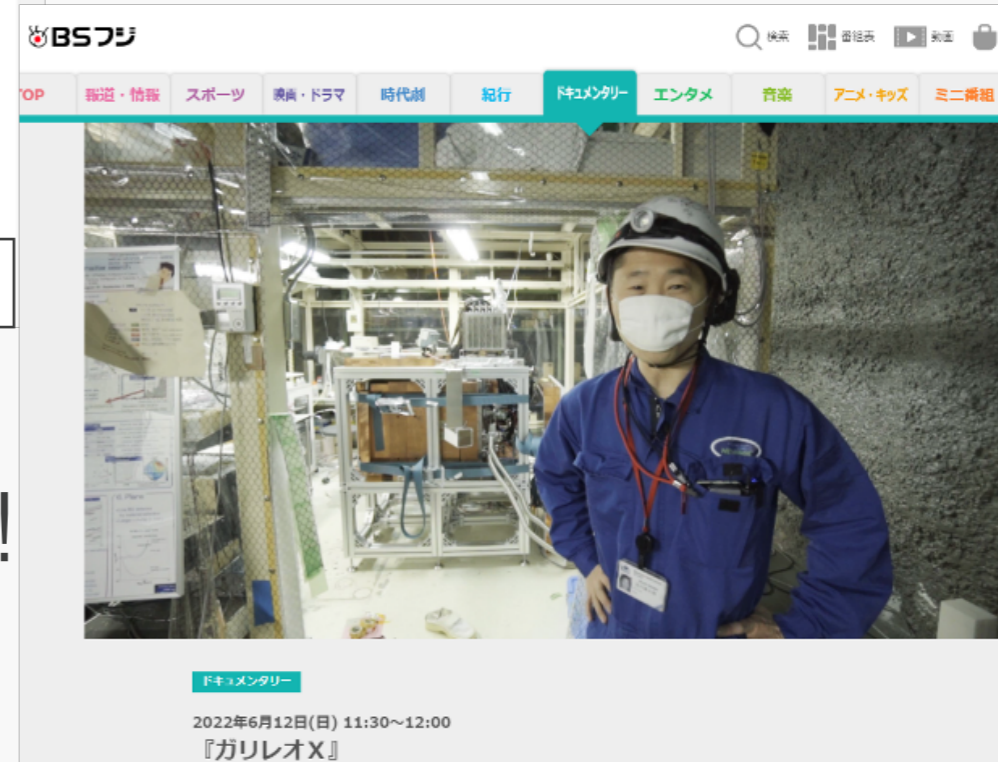
Domestic conference: 49 (106 in total)

Outreach: 1 (7 in total)

Award: 1 (7 in total)

PhD thesis: 1 (3 in total)

Master thesis: 1 (5 in total)



Recent activities

DM run

Physics

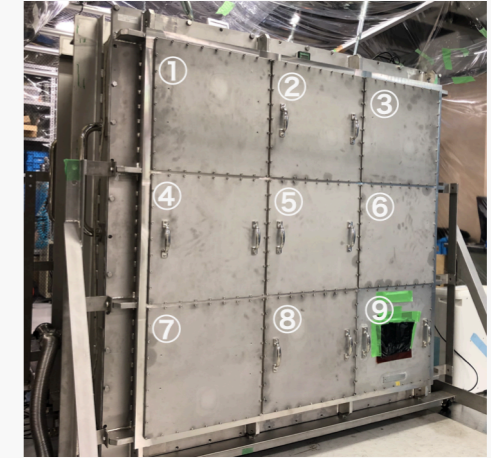
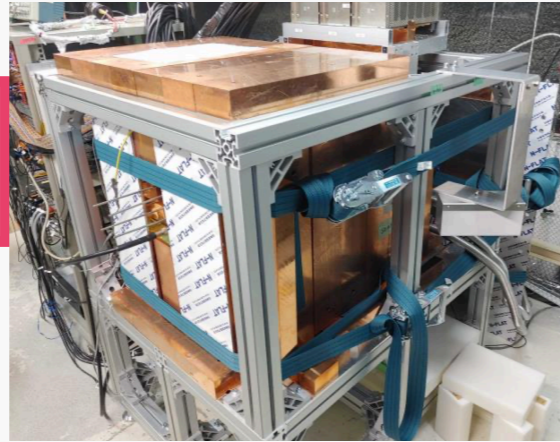
Technologies

Recent activities

Measurement
in Kamioka

Next-generation
large chamber

DM run



Physics

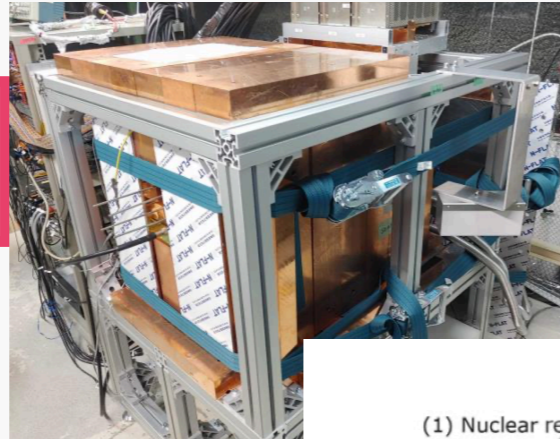
Technologies

Recent activities

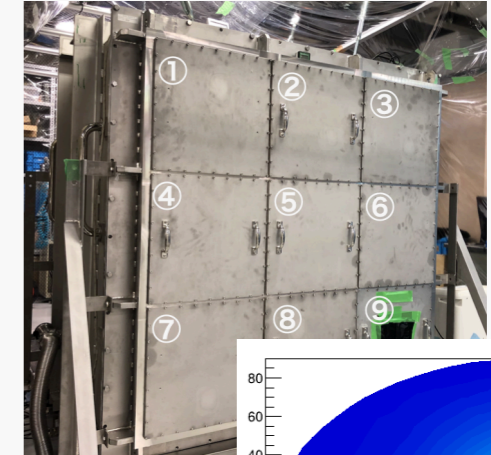
Measurement
in Kamioka

Next-generation
large chamber

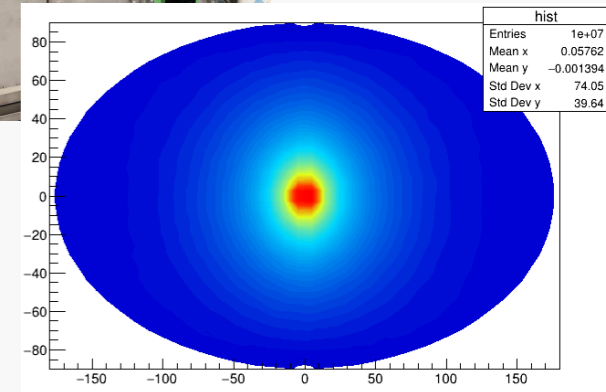
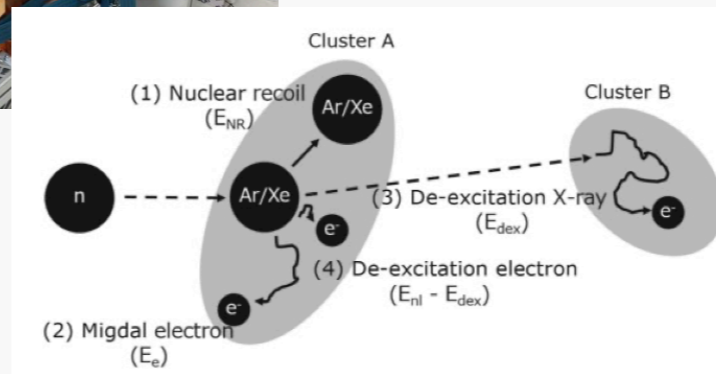
DM run



Migdal



CRDM



Physics

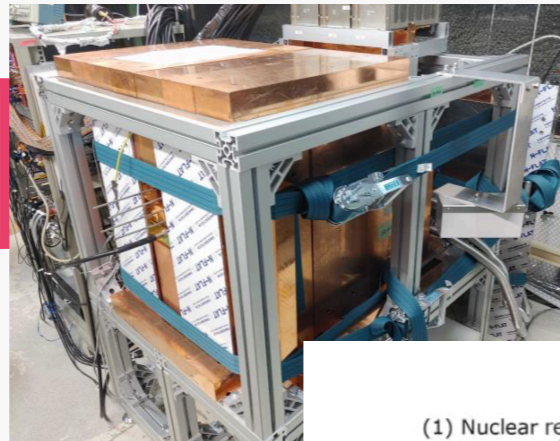
Technologies

Recent activities

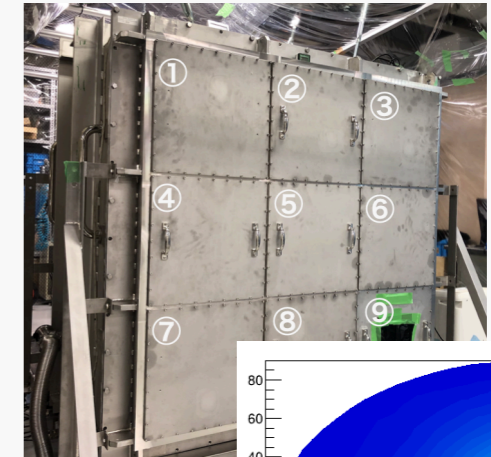
Measurement
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Next-generation
large chamber

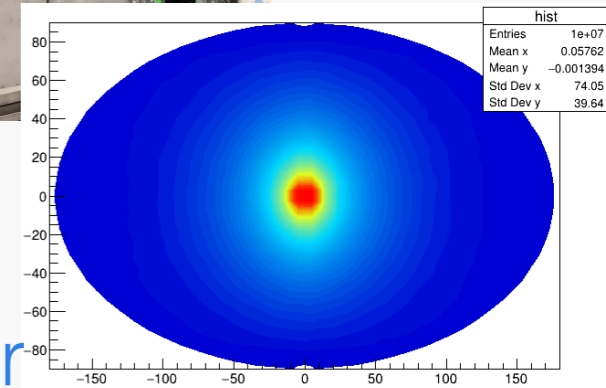
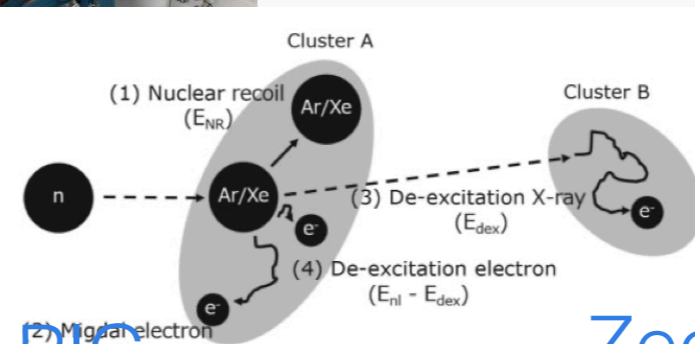
DM run



Migdal



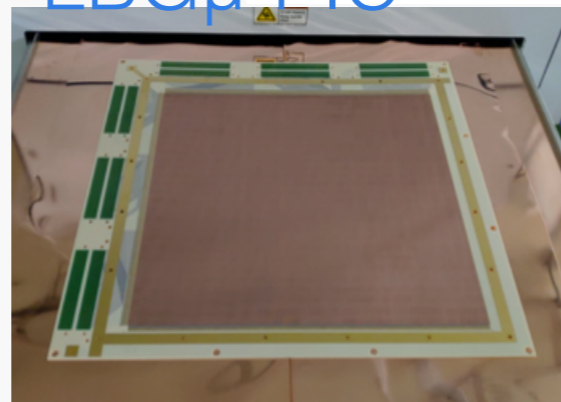
CRDM



Physics

LBGμ-PIG

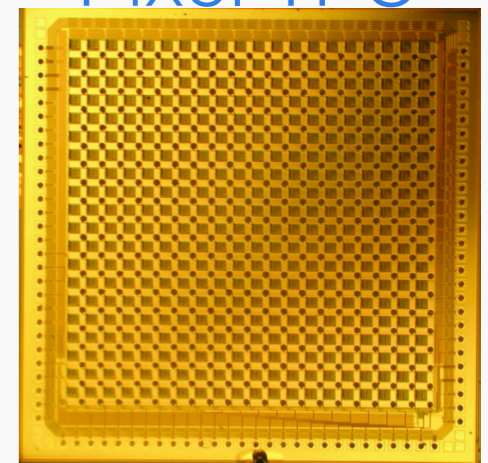
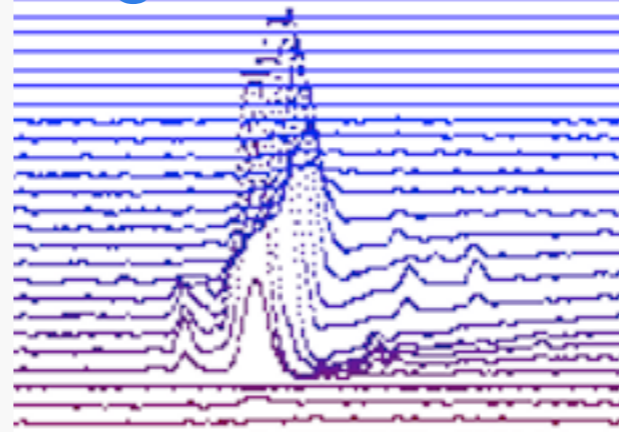
Zeolite filter



Technologies

Negative Ion TPC

Pixel TPC

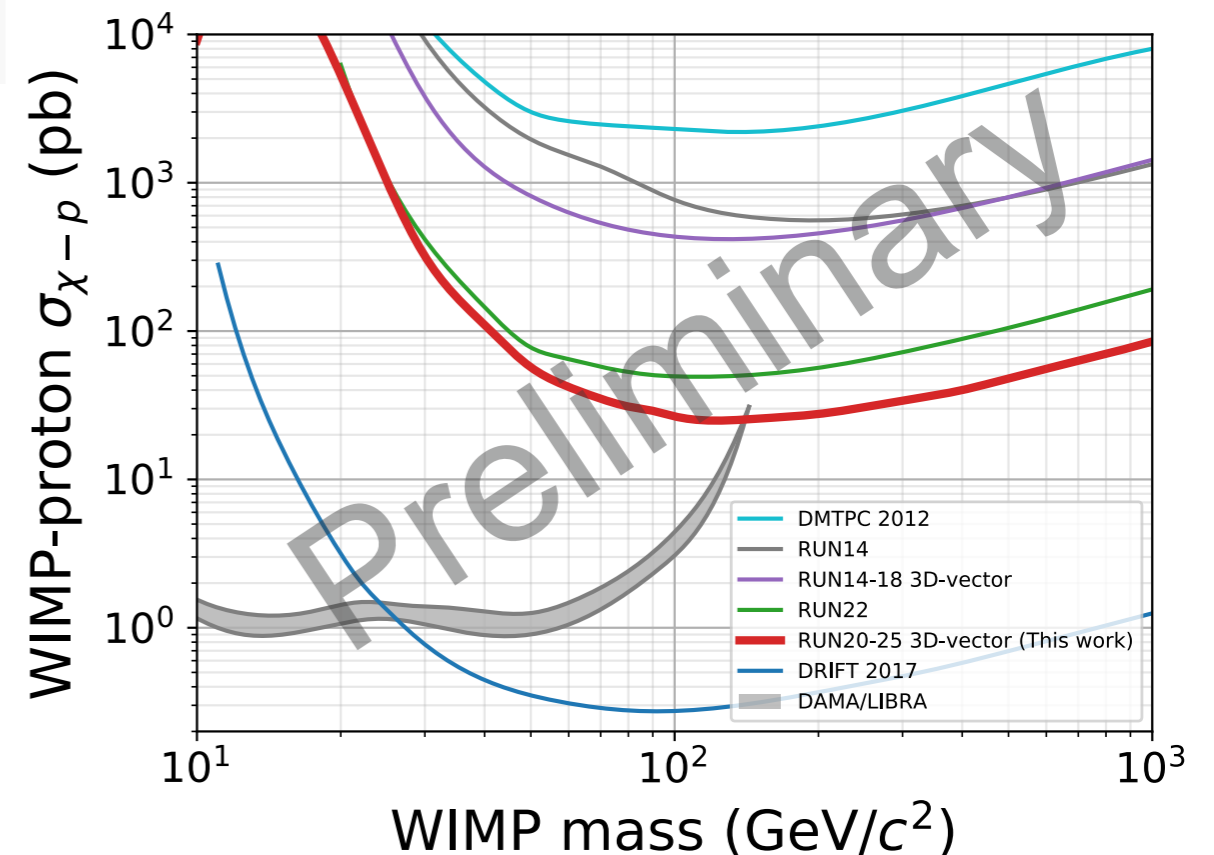
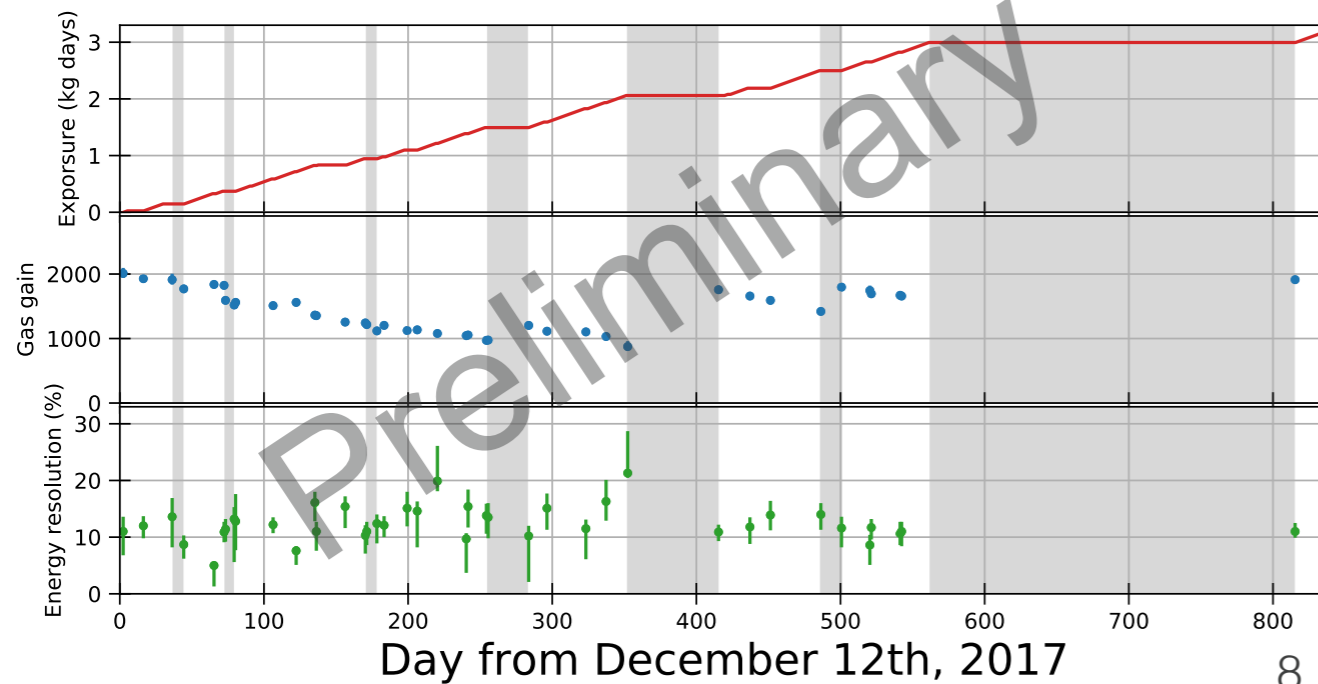
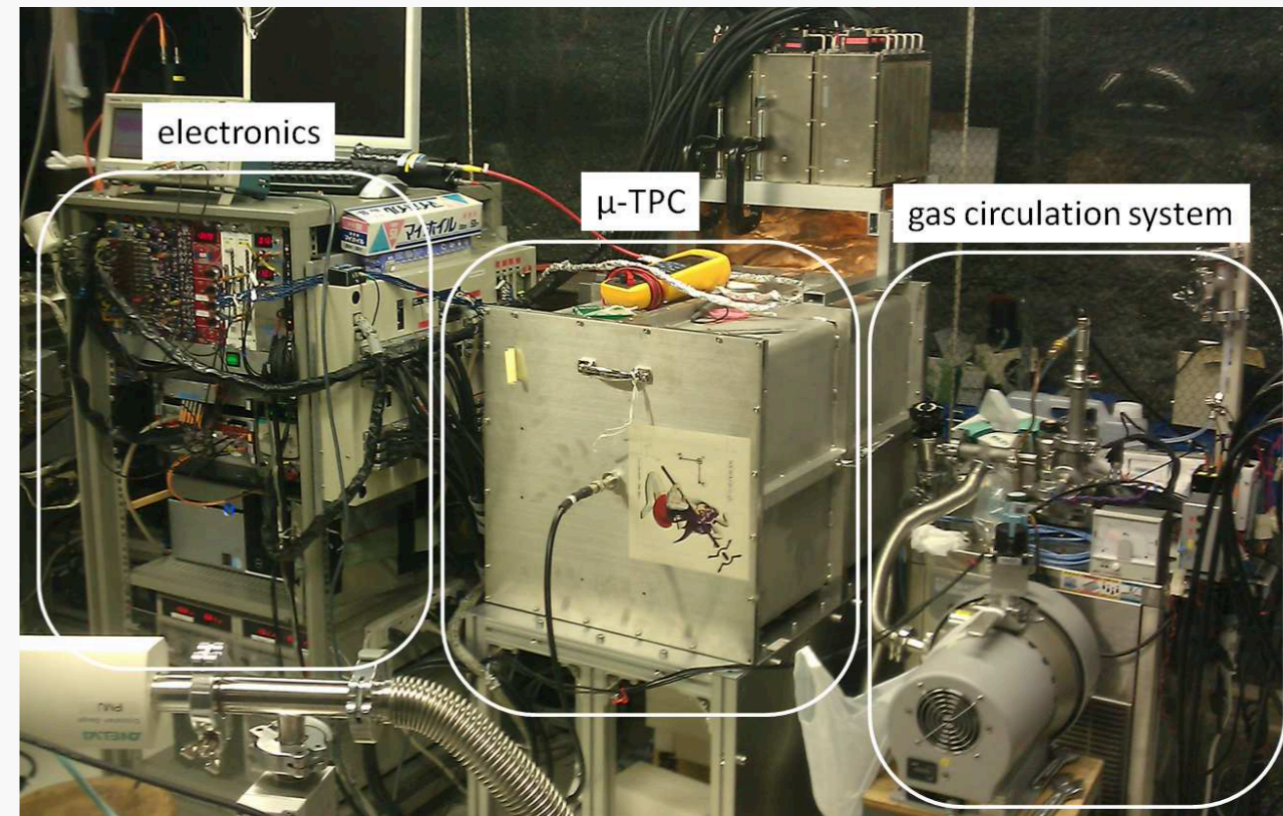


very busy slide
because of our many updates!

Dark matter run

Measurement in Kamioka observatory

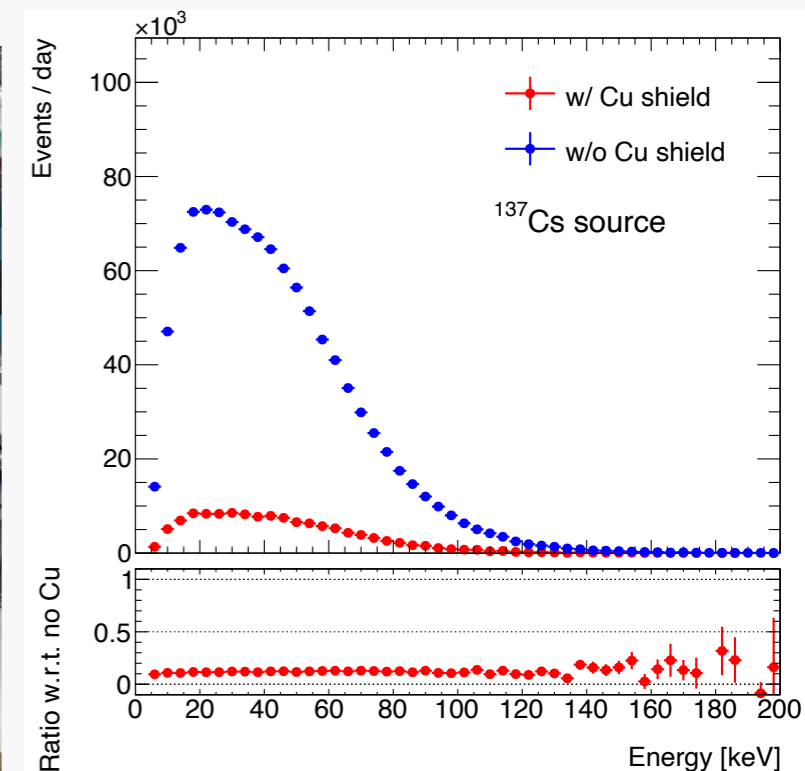
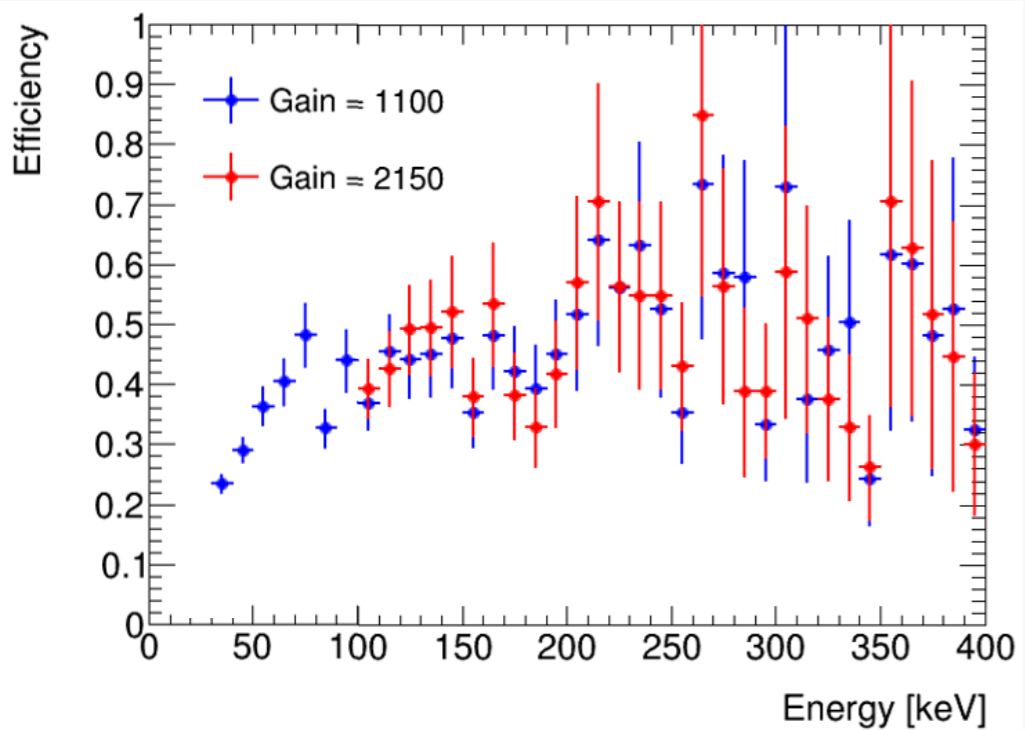
- New result will be submitted soon!
 - ➔ Data taking period: 2017 - 2020
 - ▶ live time: 318 days
 - ➔ New gamma rejection analysis
 - ➔ 3D vector track reconstruction
 - ➔ Improve BG estimation
- Limit is $\times 1.5$ improved from the previous result



Updates

Poster:
A. Nakayama (Kobe U.)

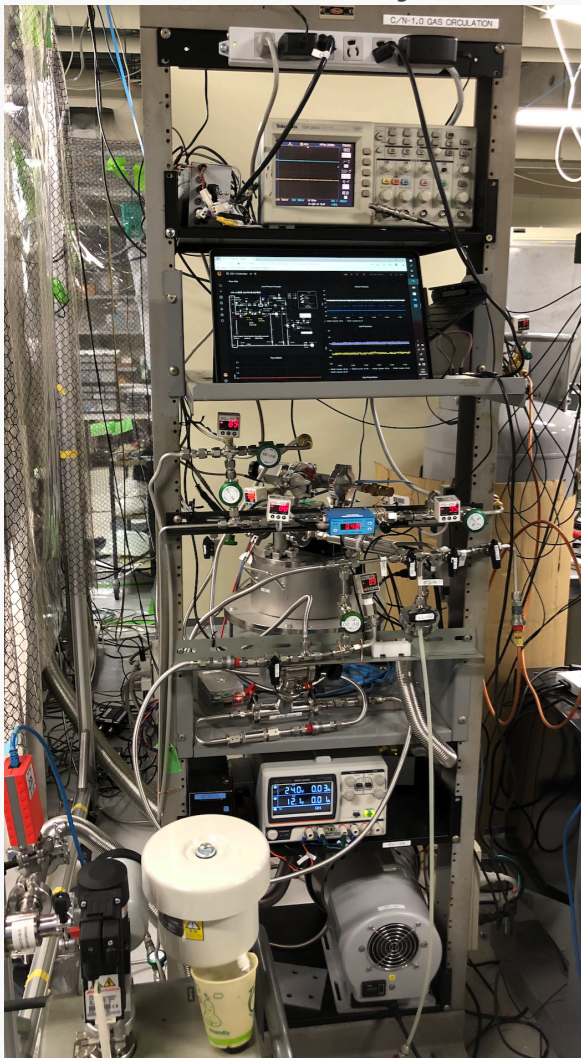
- Measurement to be improved by...
 - ➔ Higher gas gain to improve NR detection efficiency especially in low energy region
 - ➔ Lower pressure CF_4 gas (76 Torr \rightarrow 50 Torr) to explore lower energy threshold
 - ➔ Cu shield to reduce ambient gamma background (the most crucial enemy!)
- This measurement is ongoing (June. 2021 -)



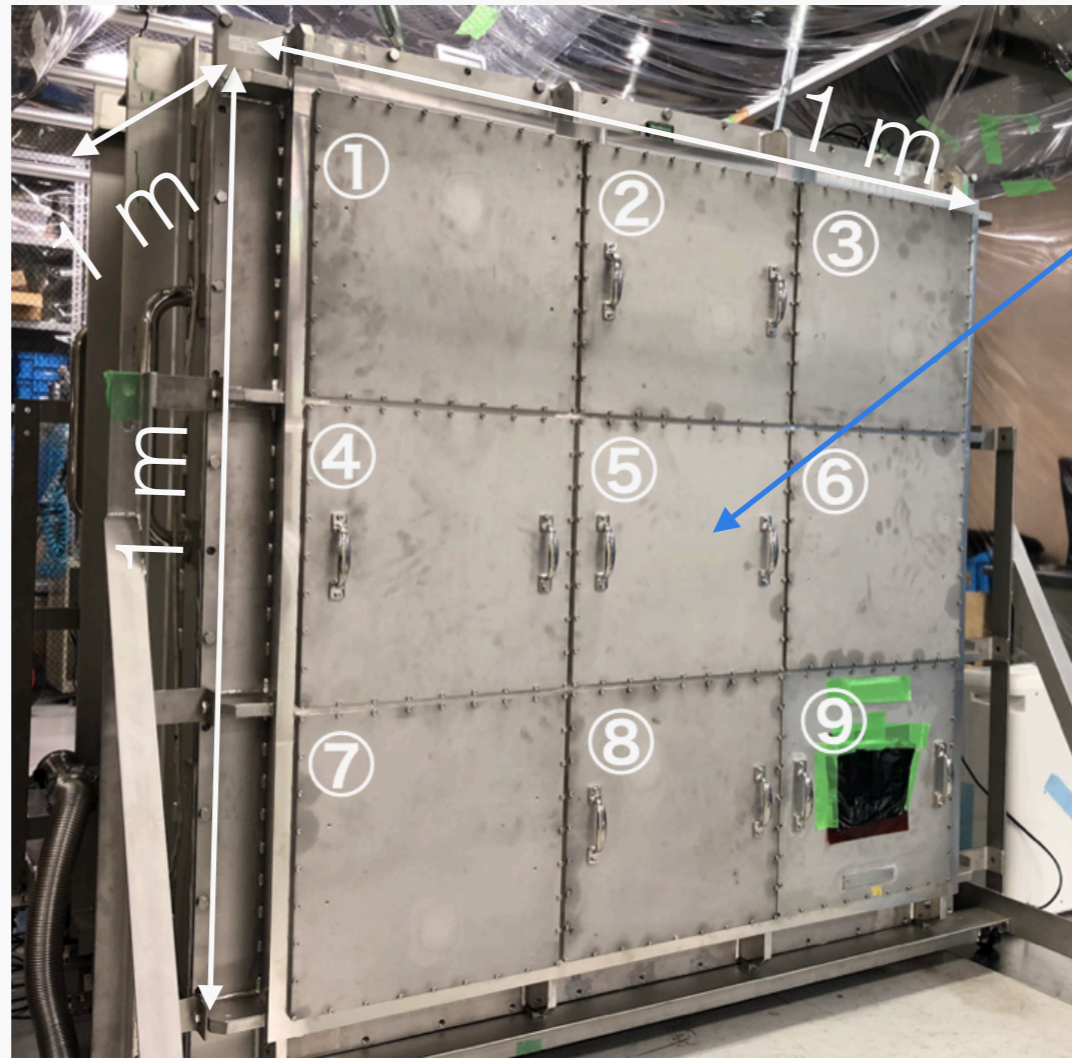
Future plan: “C/N-1.0”

- 1 m³ scale modular chamber (C/N-1.0) is under preparation
 - ➔ Development with “CYGNUS” international collaboration
 - ▶ Commissioning will be held with Sheffield group this August (in Kobe U.)
- C/N-1.0 will be moved to Kamioka observatory this Autumn

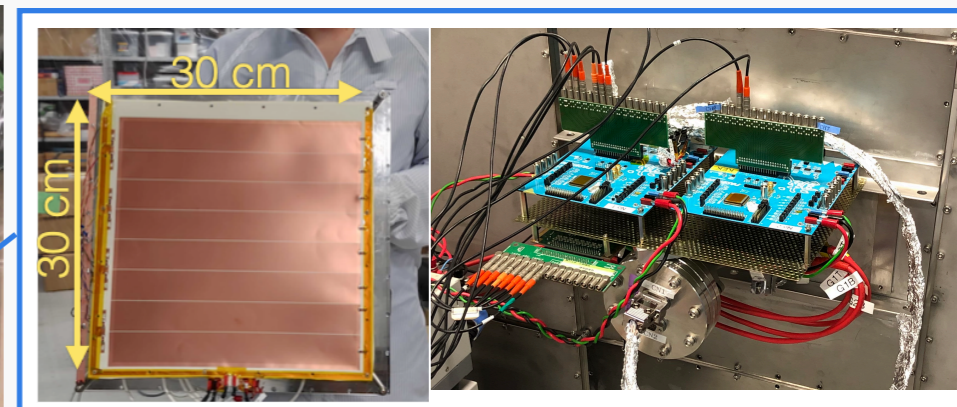
Circulation system



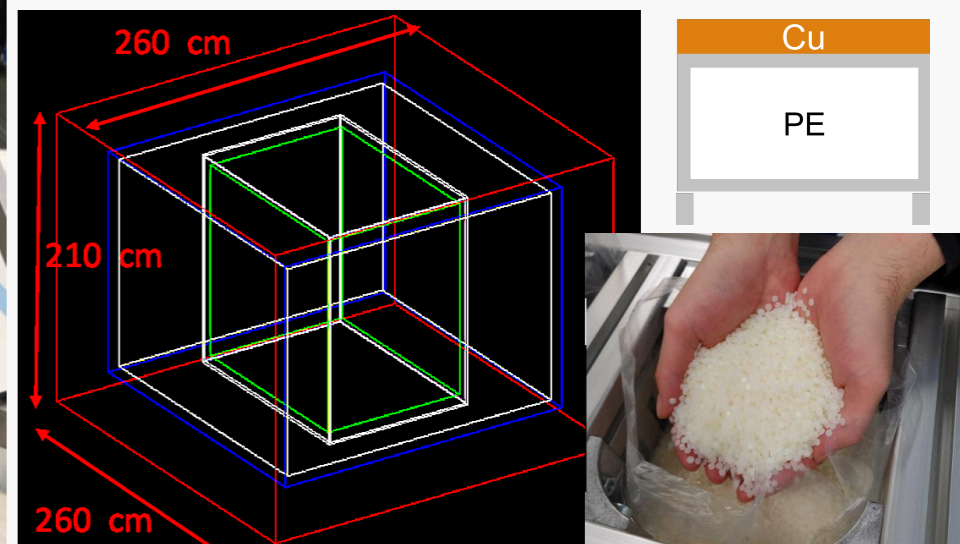
C/N-1.0



“Module-0”



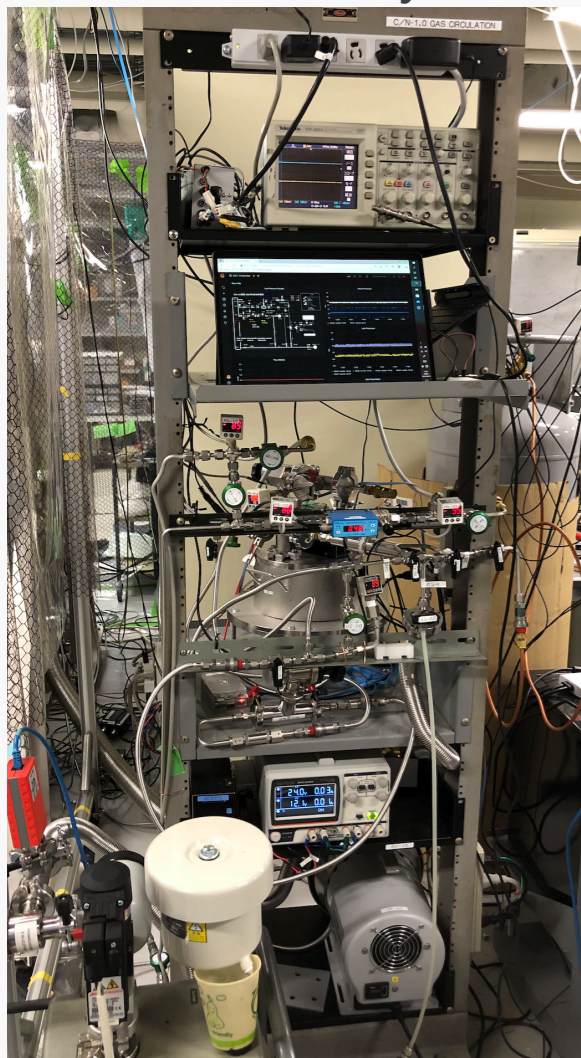
Shield design



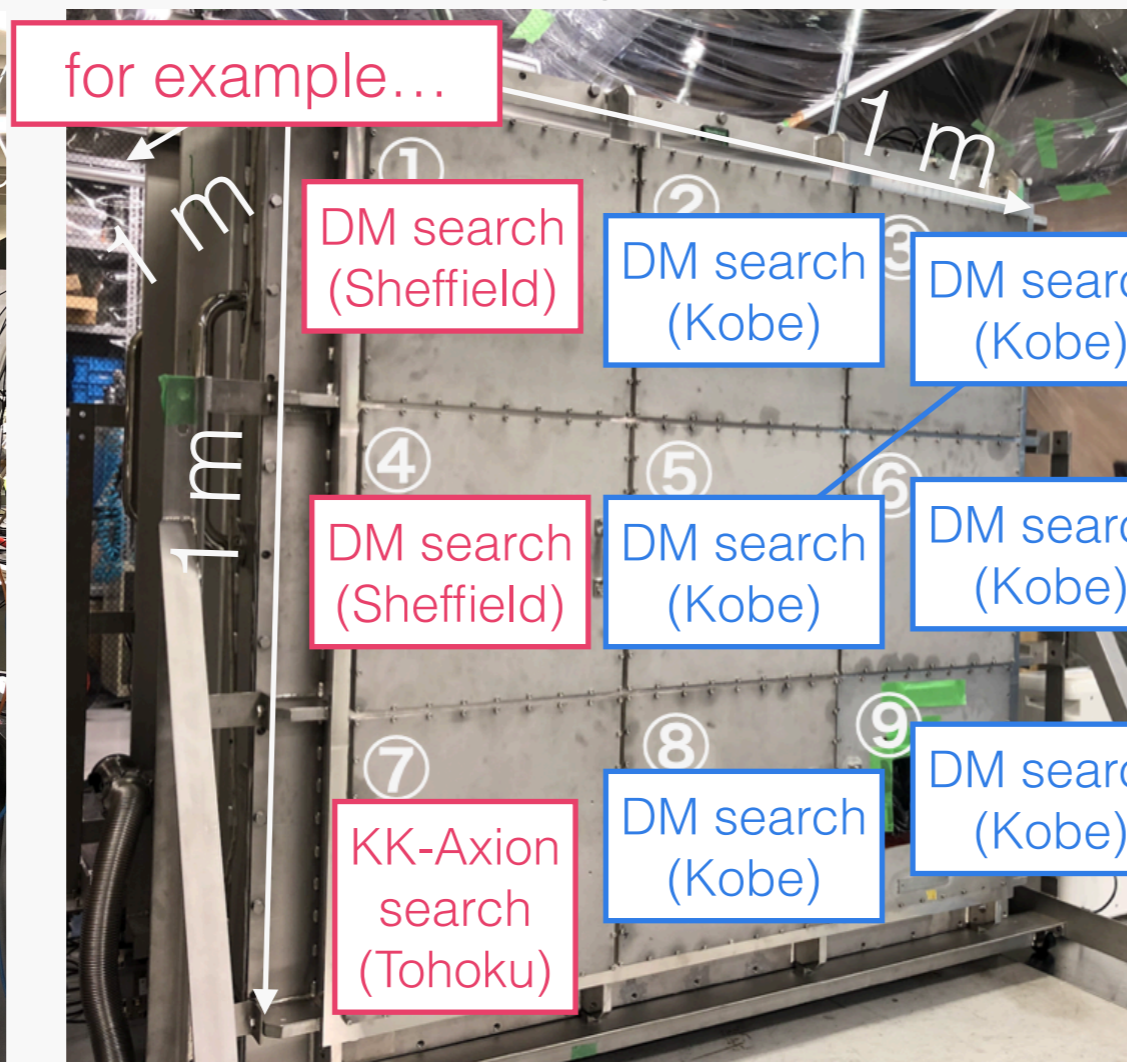
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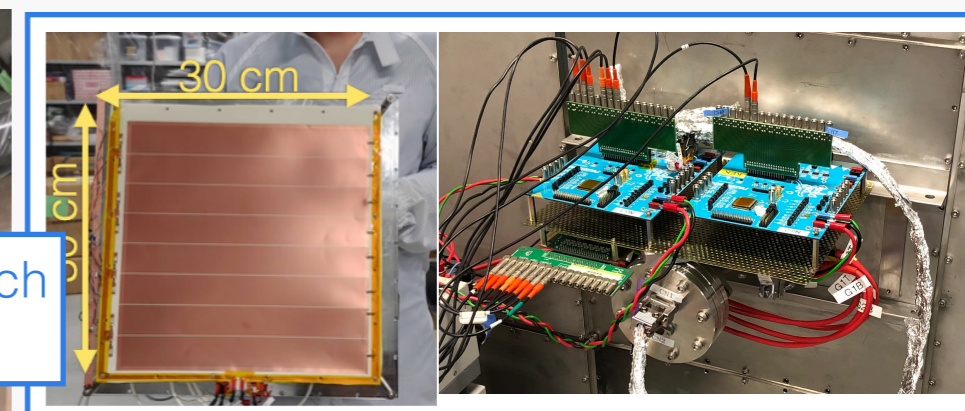
Circulation system



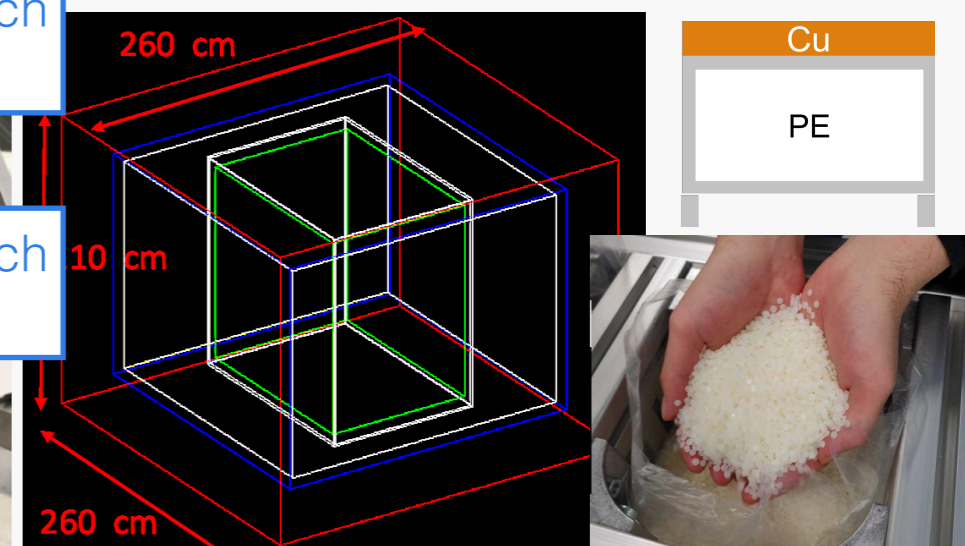
C/N-1.0



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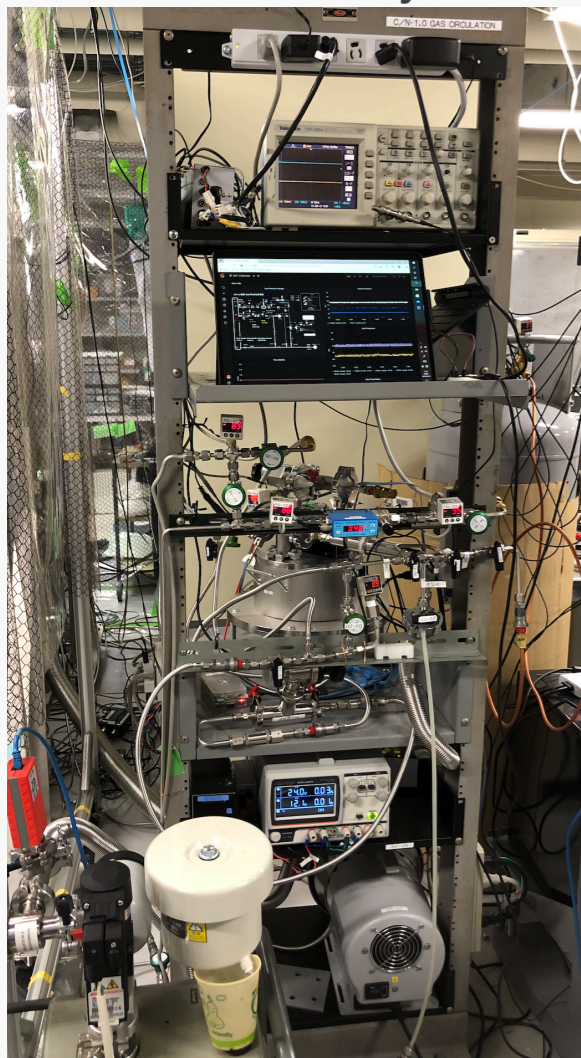
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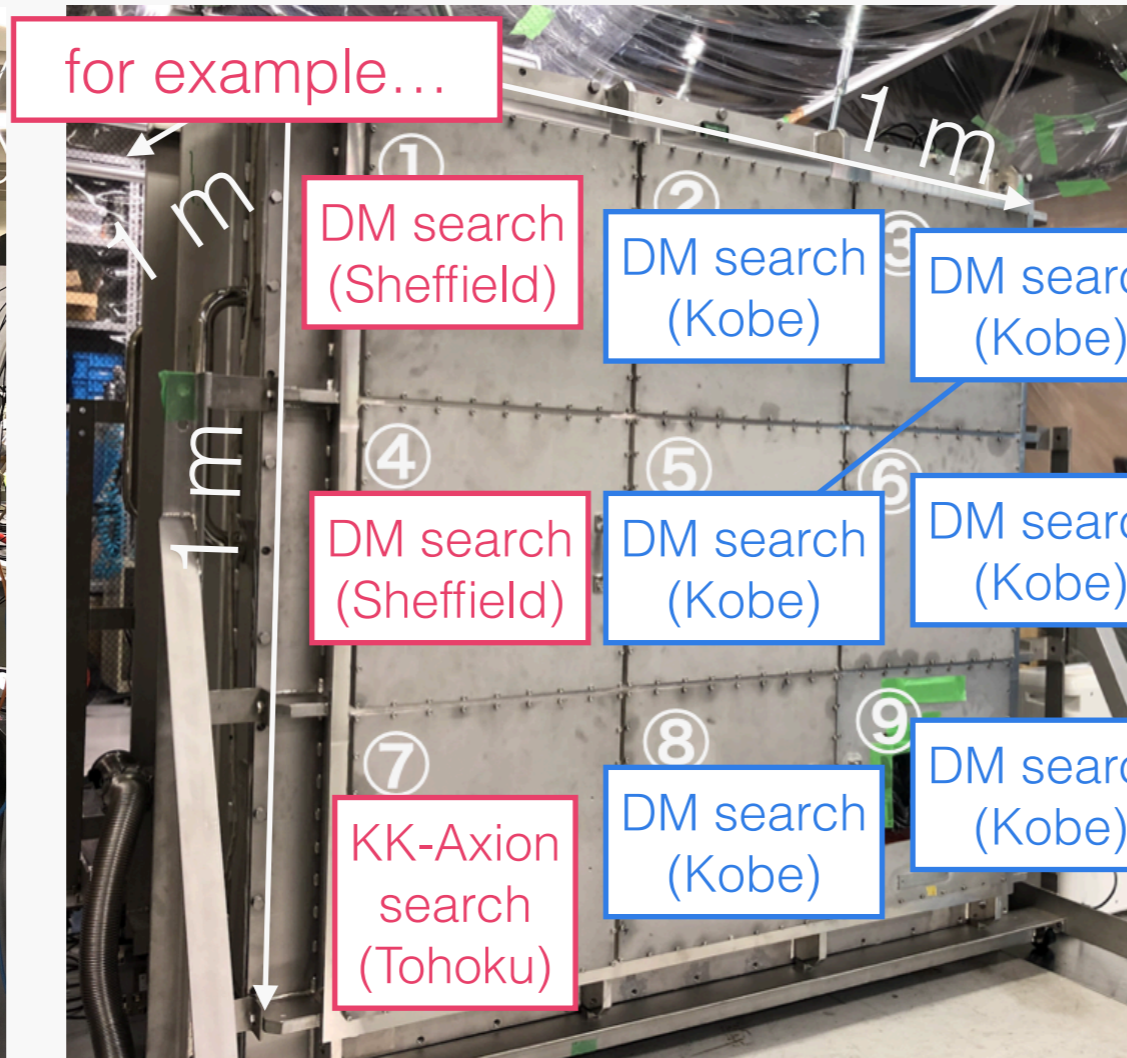
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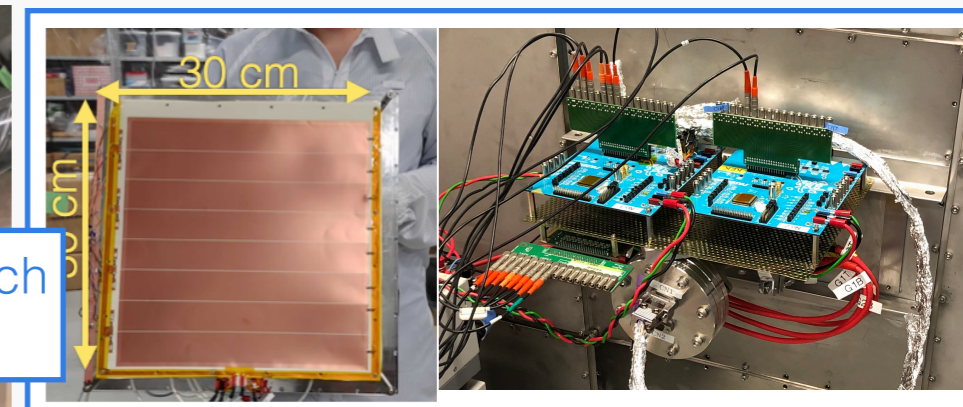
Circulation system



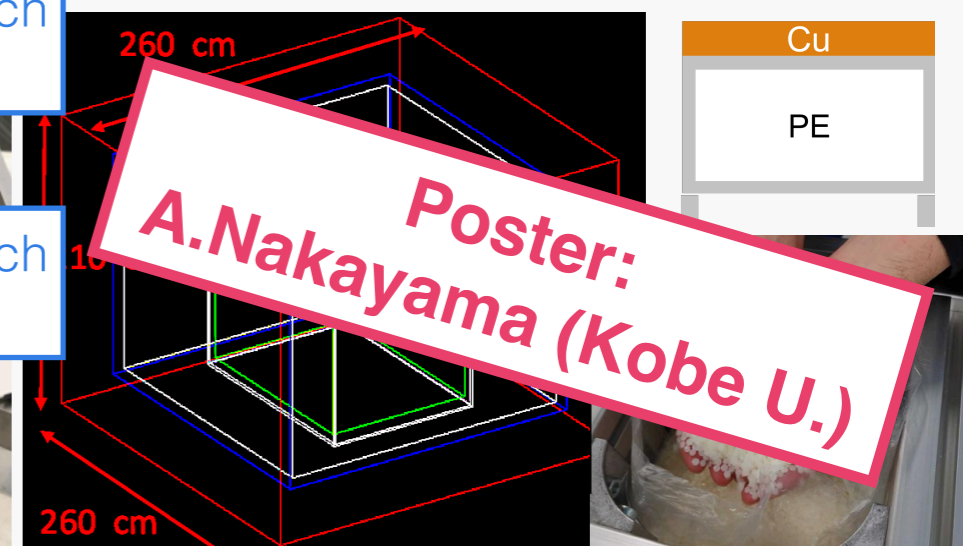
C/N-1.0



“Module-0”

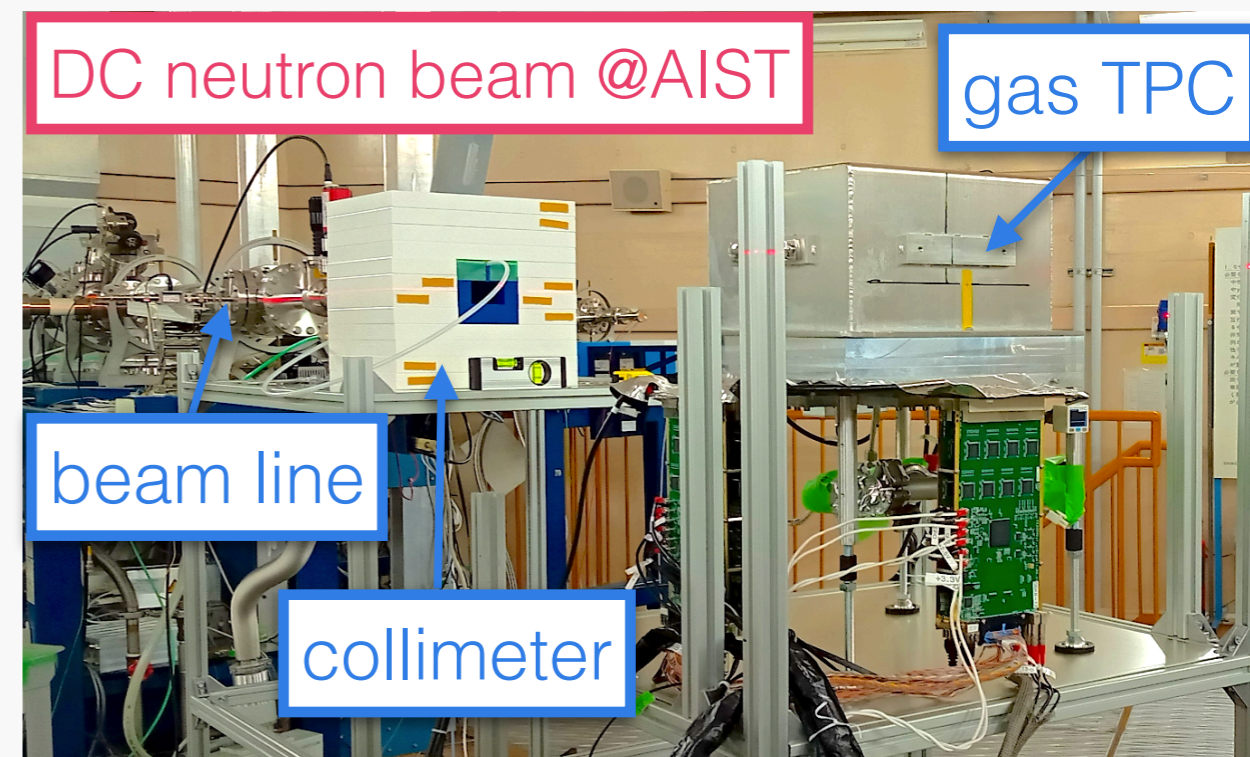
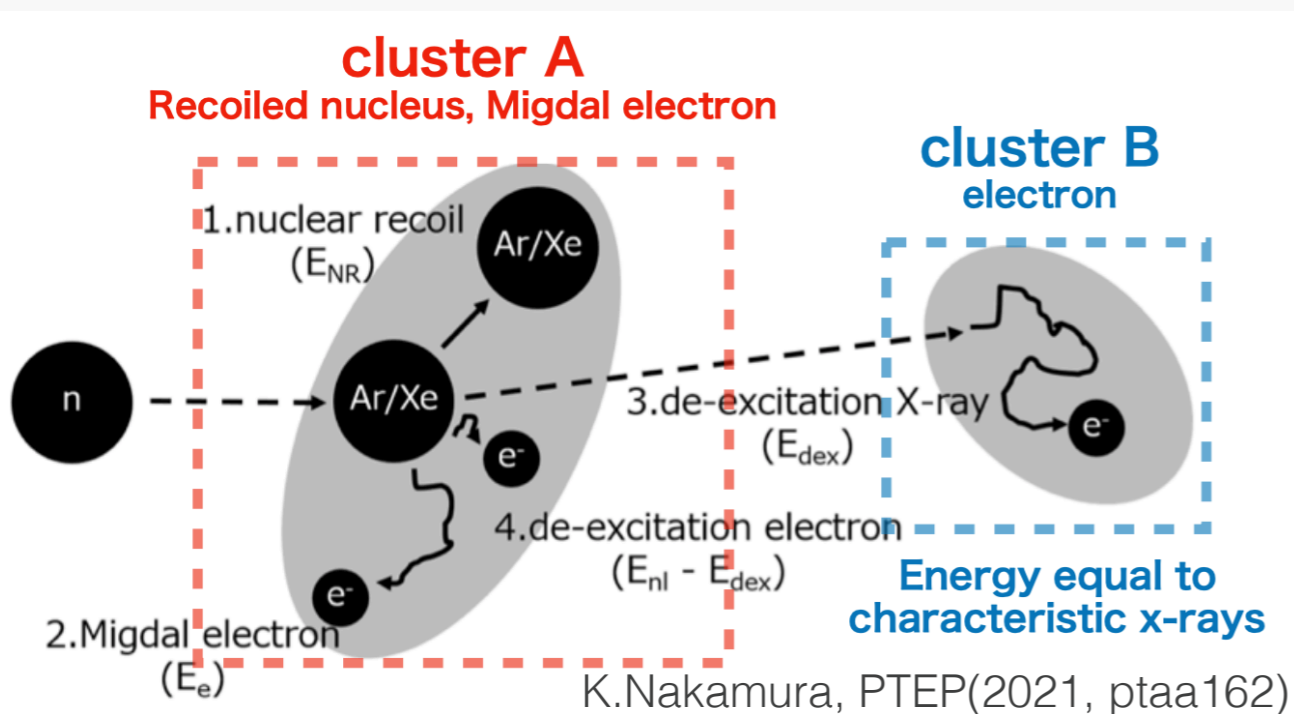


Shield design



Physics

- **Migdal effect** (NR): immediate excitation or ionization of recoil atoms
 - ➔ The effect is considered for direct DM search in low-mass region although it has not been observed yet...
- We built up “**MIRACLUE**” experiment with 公募研究 (K.Nakamura) FY2020-2021
 - ➔ Search for Migdal effect via nuclear recoil using neutron beam
 - ➔ First beam tests were carried out on Mar. and Apr. for background studies

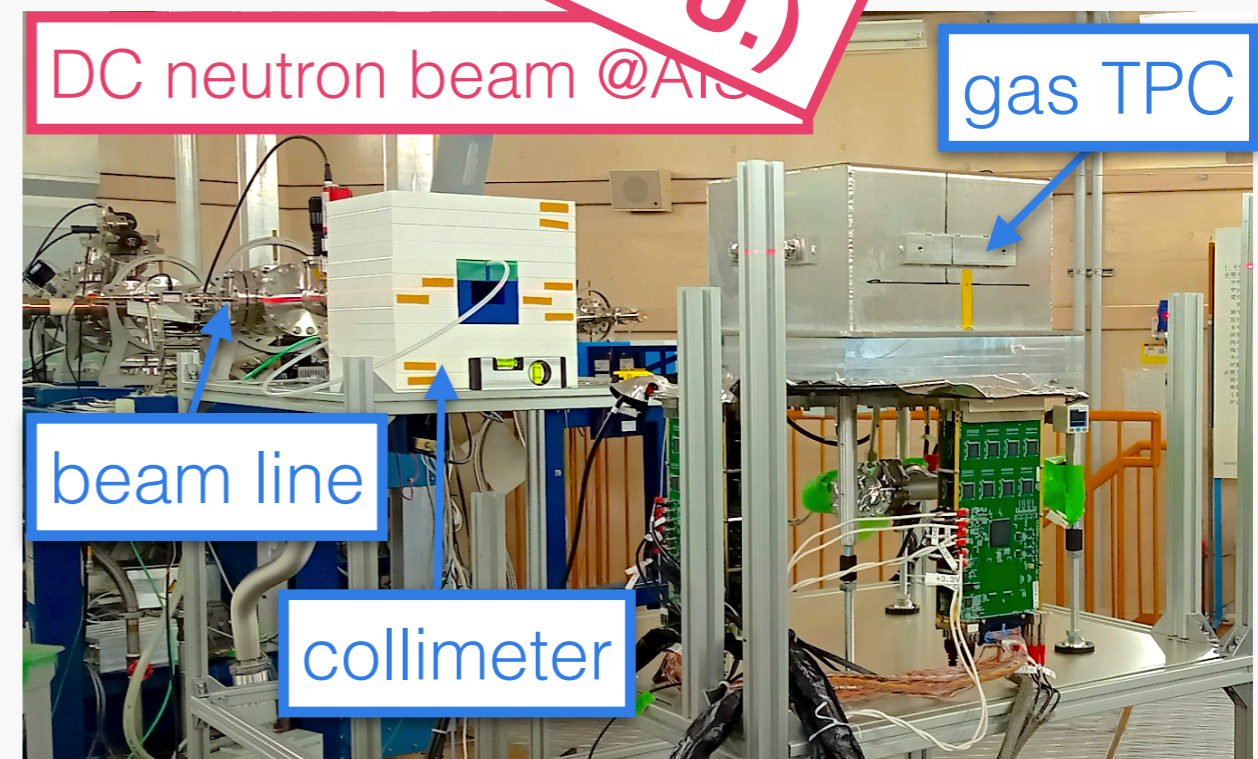
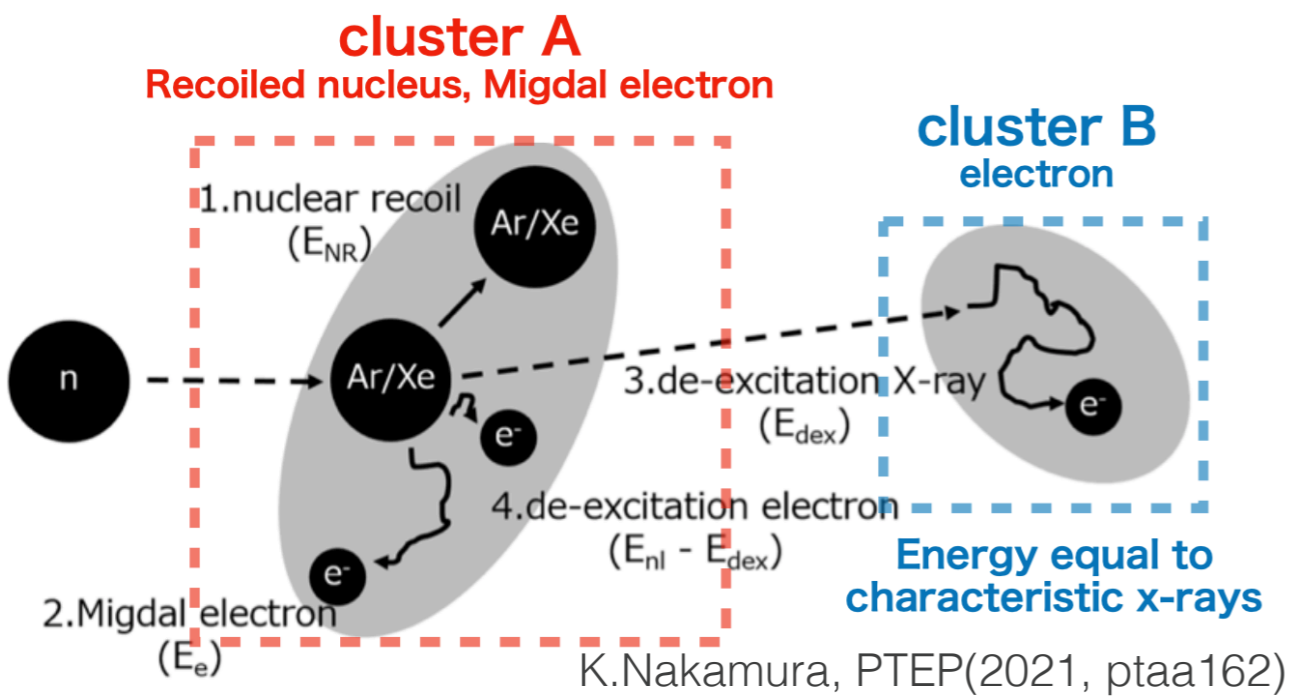


“Two cluster” event topology

- Migdal effect → immediate excitation or ionization of recoil atoms
 - The effect is important for DM search in low-mass region although it has not been observed
- We built up “**MIRACLUE**” experiment
 - Search for Migdal effect via nuclear recoil beam
 - First beam tests were carried out on Mar. and Apr. 2021 and studies

K.Kanezaki, M.Ofuji and Y.Hamada (Kobe U.)
 Poster:

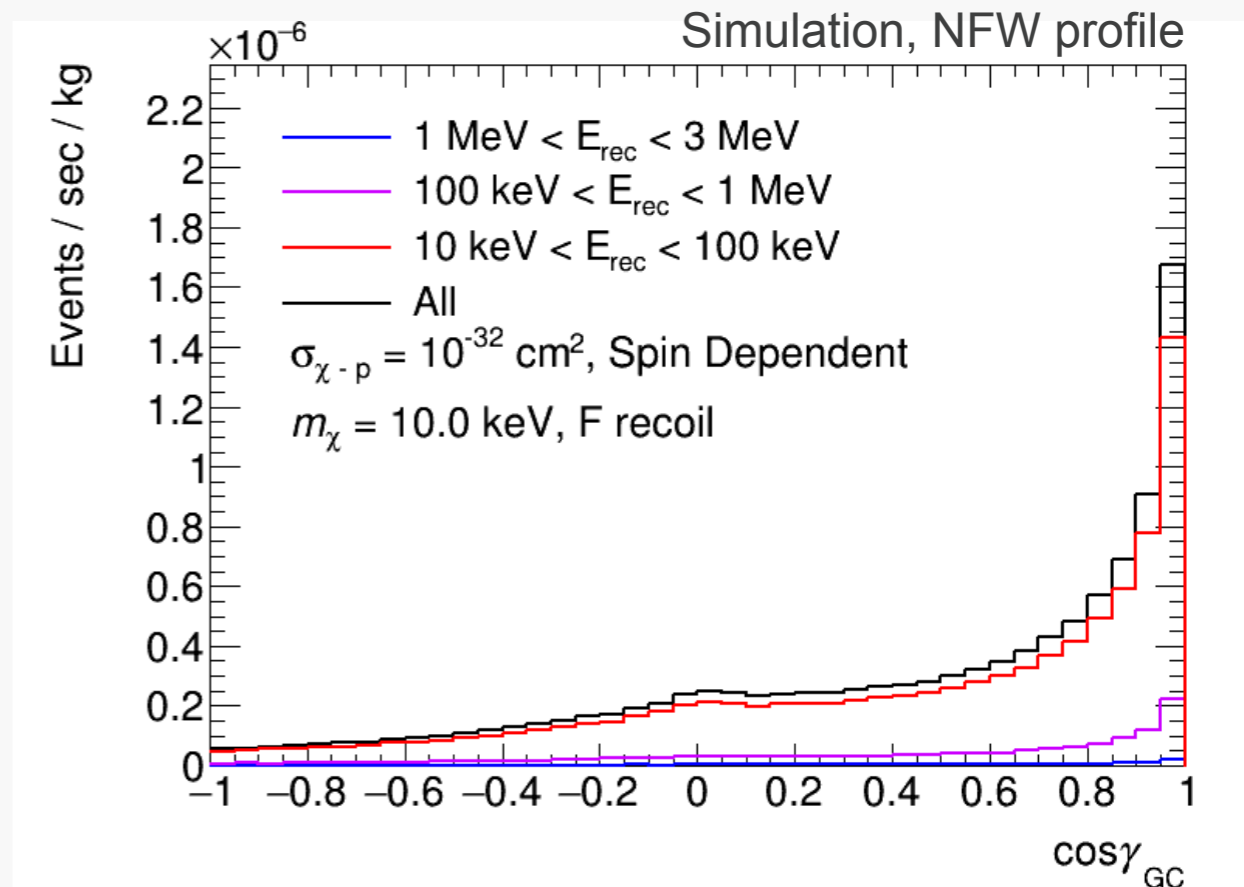
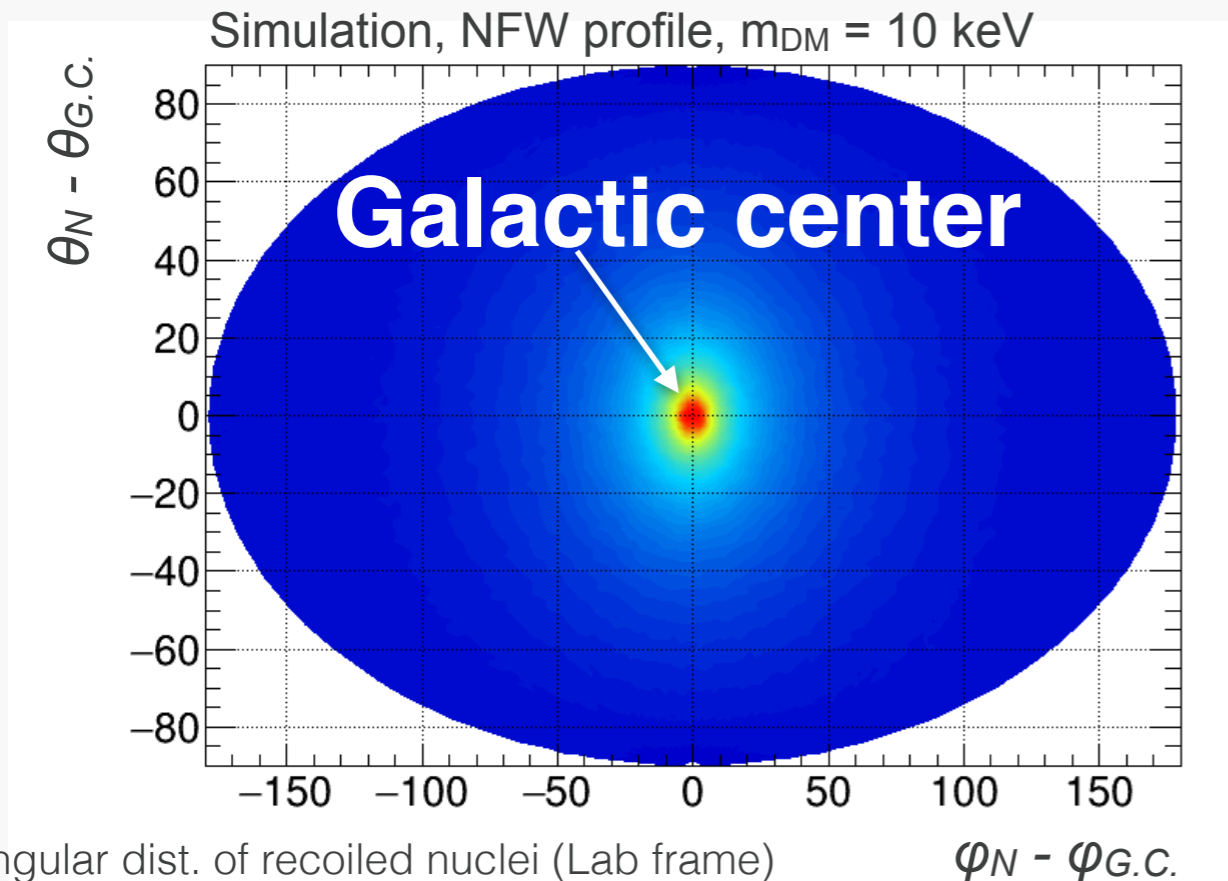
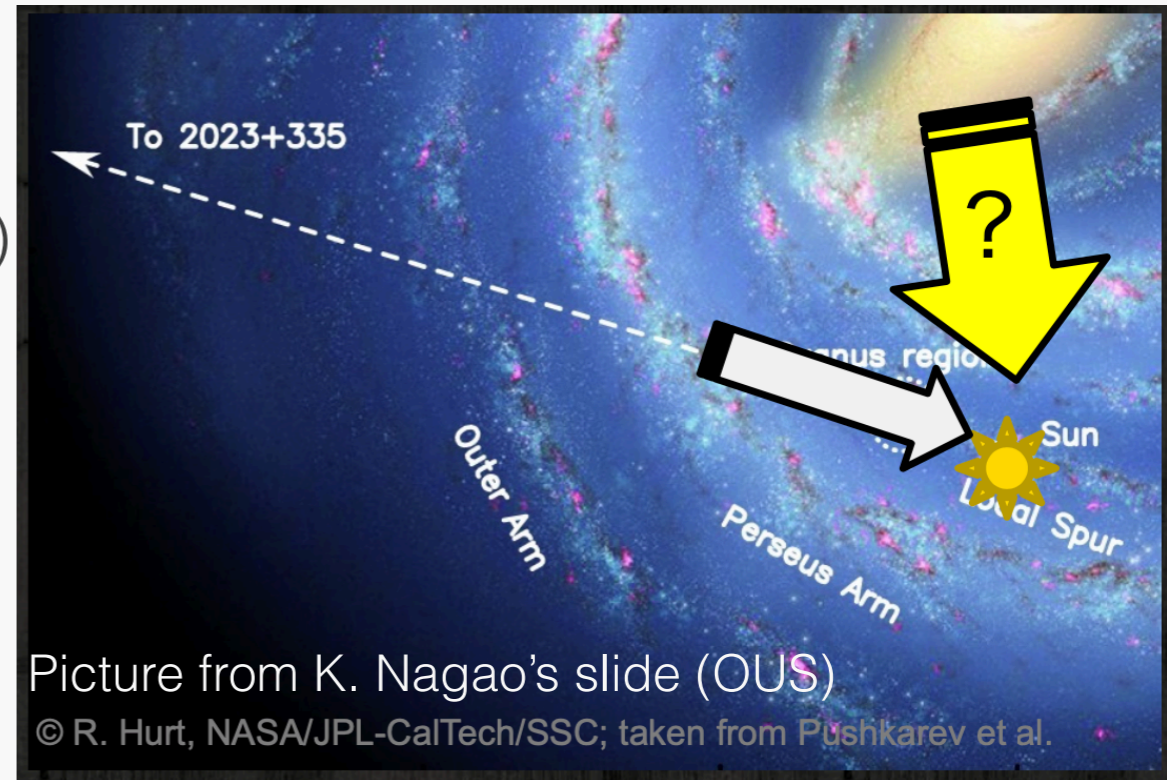
草研究 (K.Nakamura) FY2020-2021



“Two cluster” event topology

Directionality of CR-boosted DM

- Cosmic ray (CR) can scatter DM
 - Higher kinetic energy than ordinary DM (WIMP)
- DM is considered to be abundant in the galactic center
 - Directional DM searches are sensitive in low mass DM assuming CRDM hypothesis

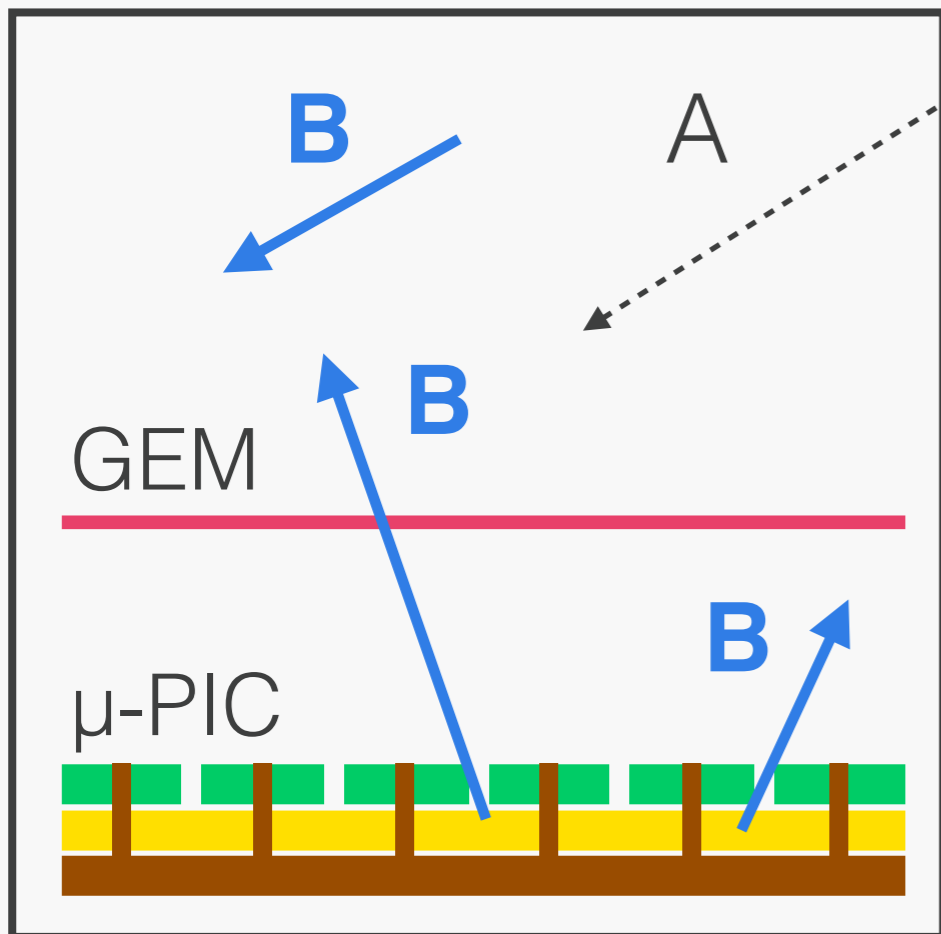


Technologies

- Background reduction
- Negative-Ion gaseous TPC

Strategy for BG reduction

- A: External BG: ambient neutron and gamma
 - ➔ Reduced by shielding
- **B**: Internal BG: radiative sources (α -decay in U-Th chain)
 - ➔ Today's topic!



Decay in gas

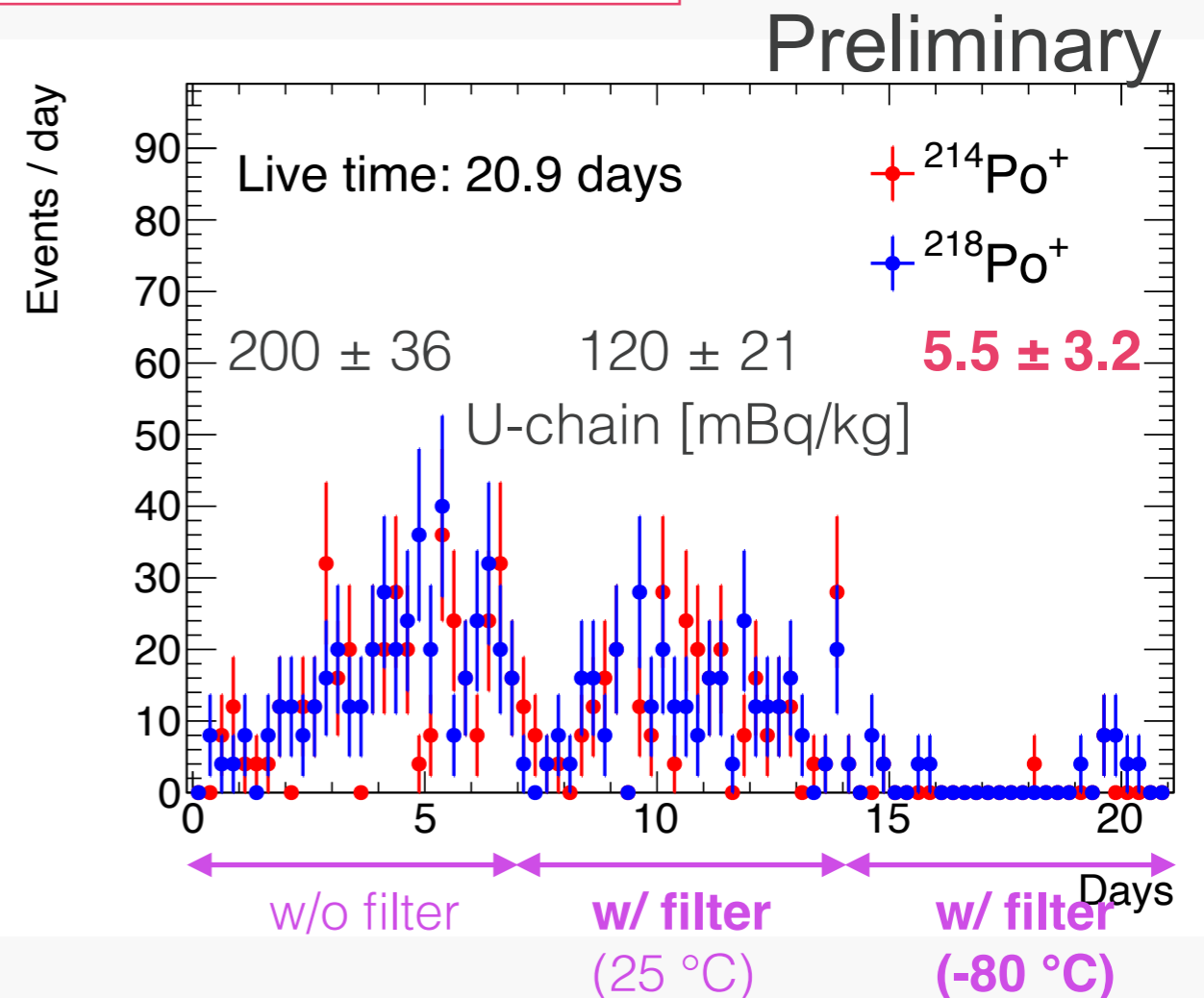
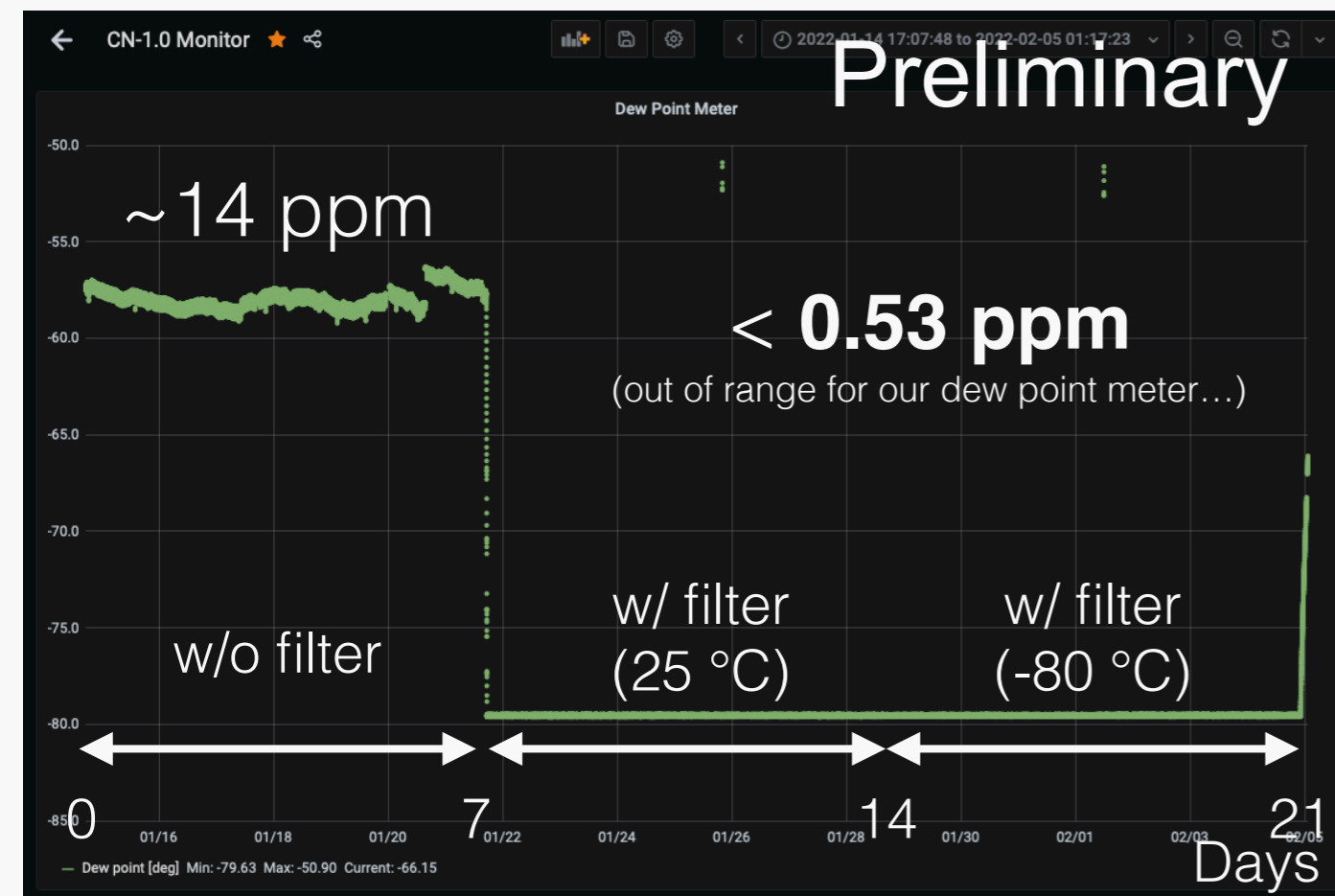
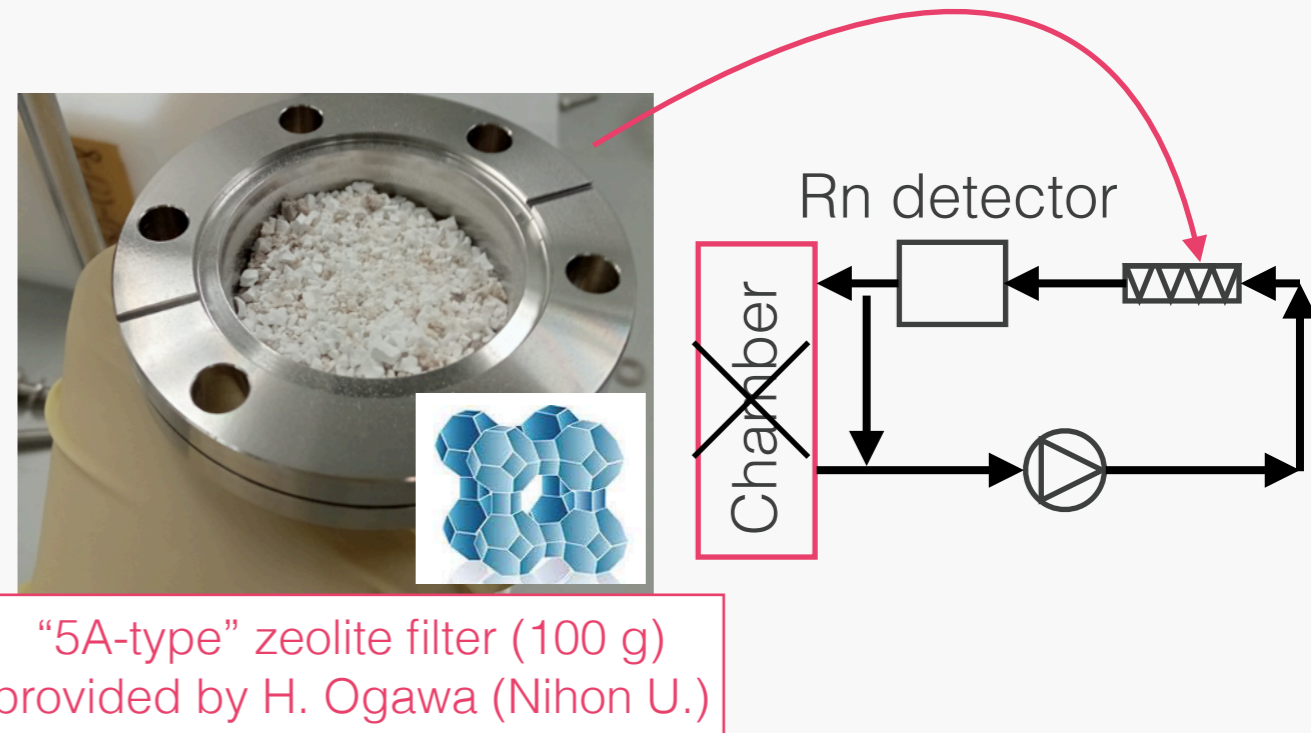
➔ gas filtering system using zeolite

Decay in materials

➔ “clean detector” development

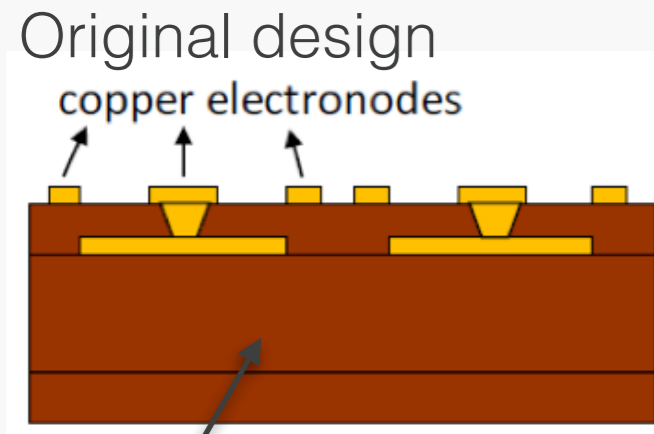
Zeolite gas filter (H.Ogawa)

- 5Å pore size zeolite can be used to purify gas
 - Radon and water removal
- “Clean zeolite” was developed by Nihon U. group
 - JINST (2021) 16P06024
 - Radon & water removal test was carried out in Kobe



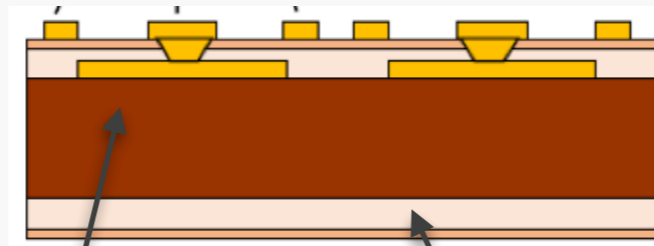
Low-BG μ -PIC (LBG μ -PIC)

- Proto-type Low-BG μ -PIC is developed and evaluated



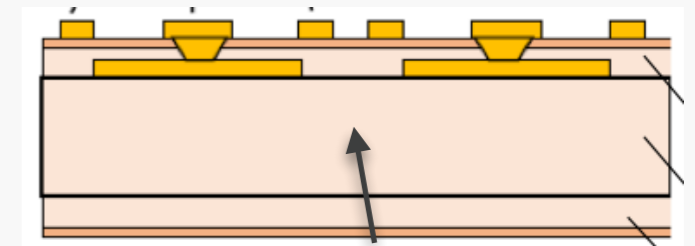
Polyimide
w/ glass cloth
(Rn contaminated)

Low **surface** alpha version
(LA μ -PIC: 2017-)



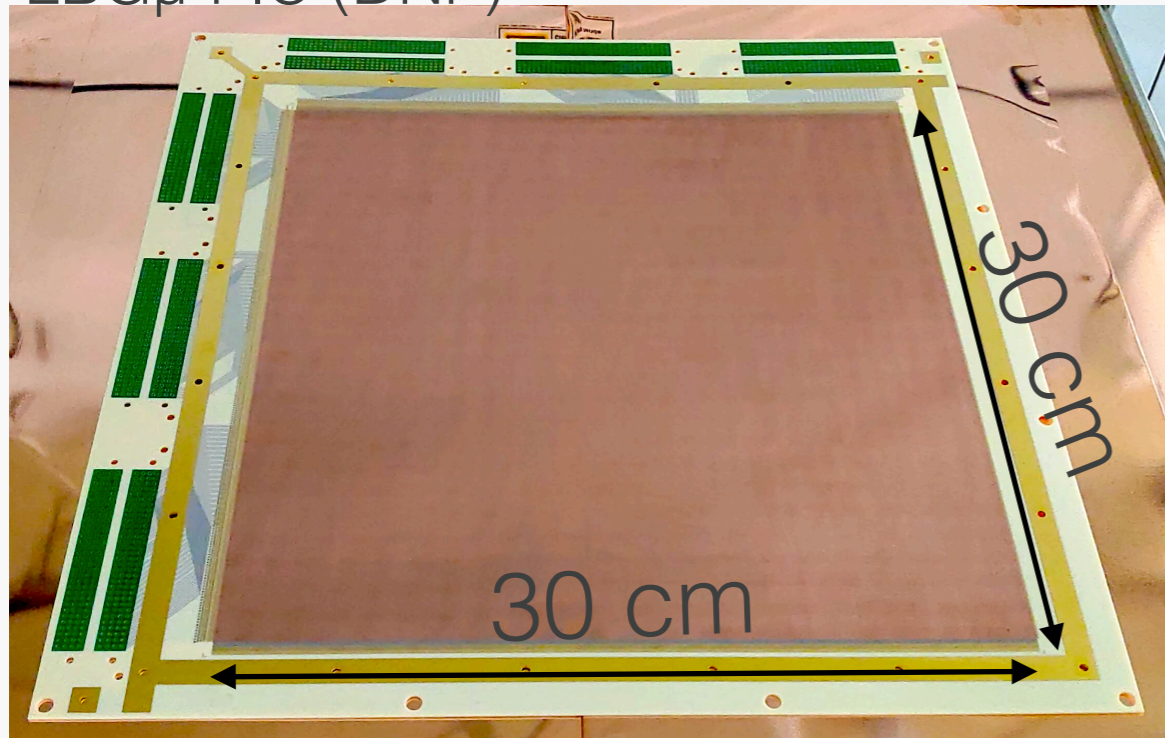
Polyimide
w/ glass cloth

LBG μ -PIC
(2022?-)



Quartz + Resin

LBG μ -PIC (DNP)



Radon emanation measurement:
LA μ -PIC: **2.3 ± 0.5** [mBq / μ -PIC]

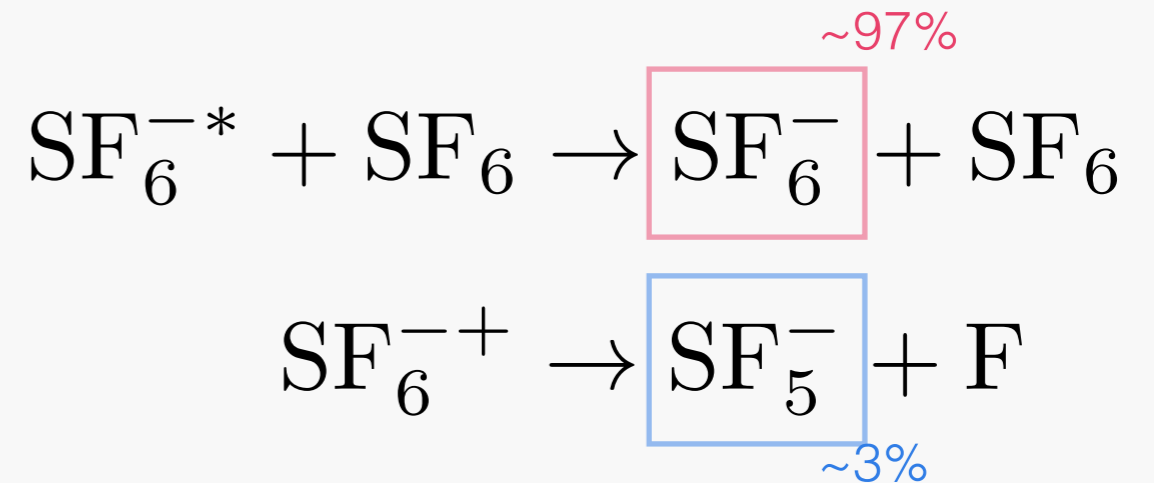
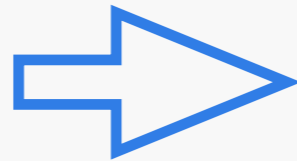
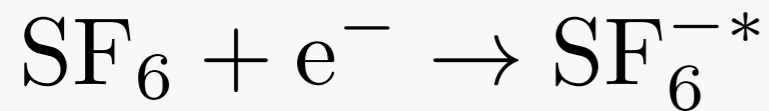


LBG μ -PIC: **<0.17** [mBq / μ -PIC]
(90% C.L.)

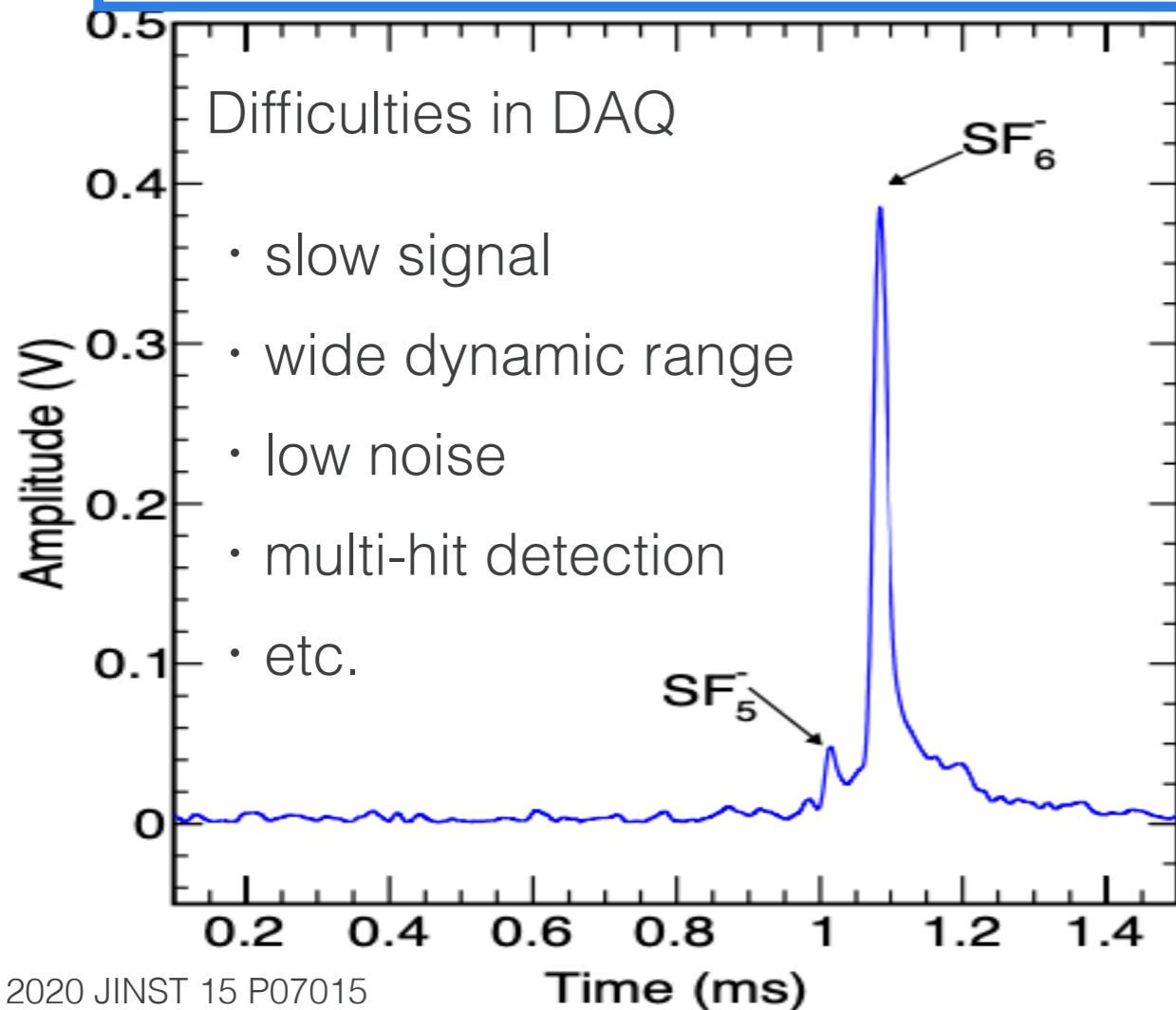
Next LBG μ -PIC production will be started soon (specification fixed)

SF₆: Negative-Ion gaseous TPC

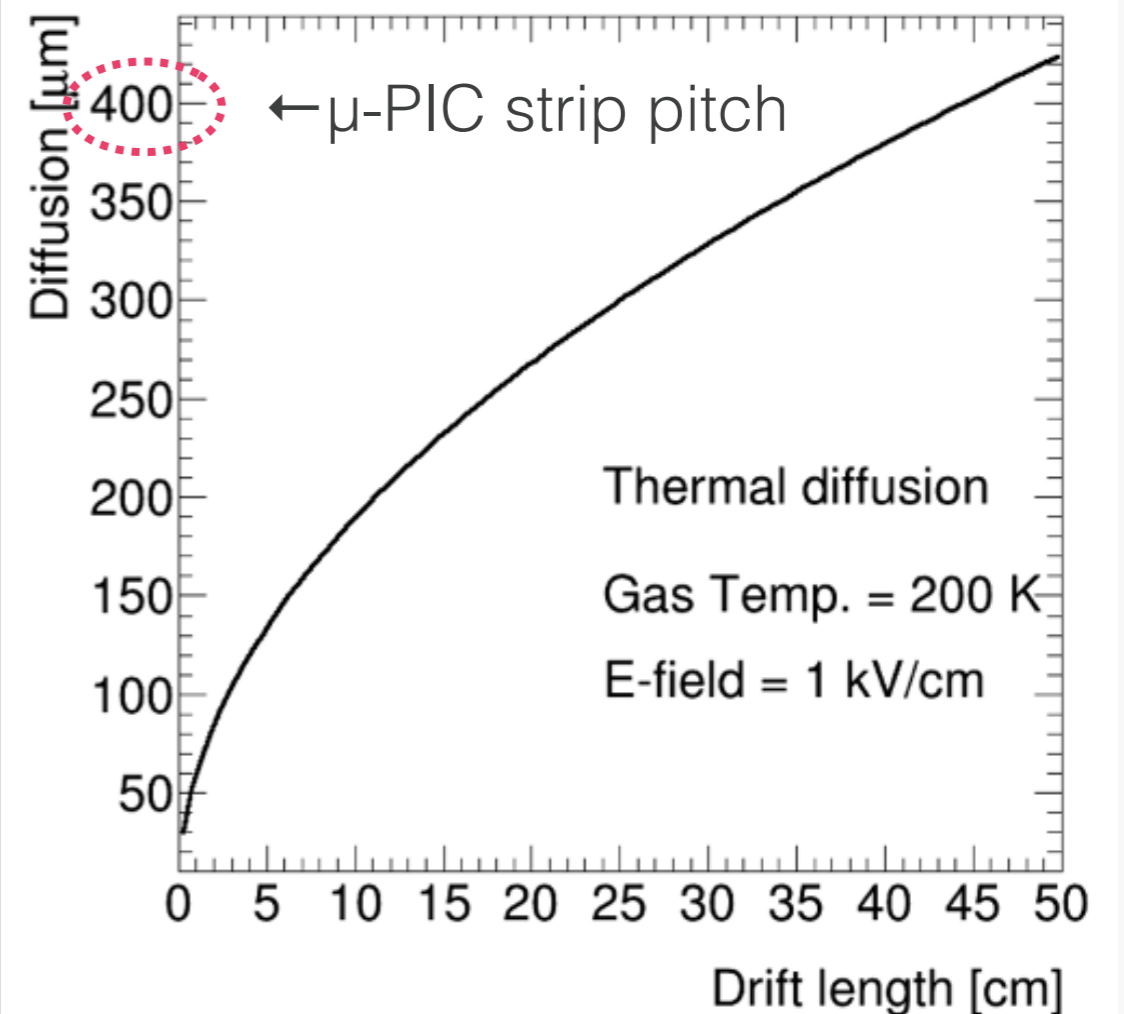
↓ ionized electron



Specific readout system is required

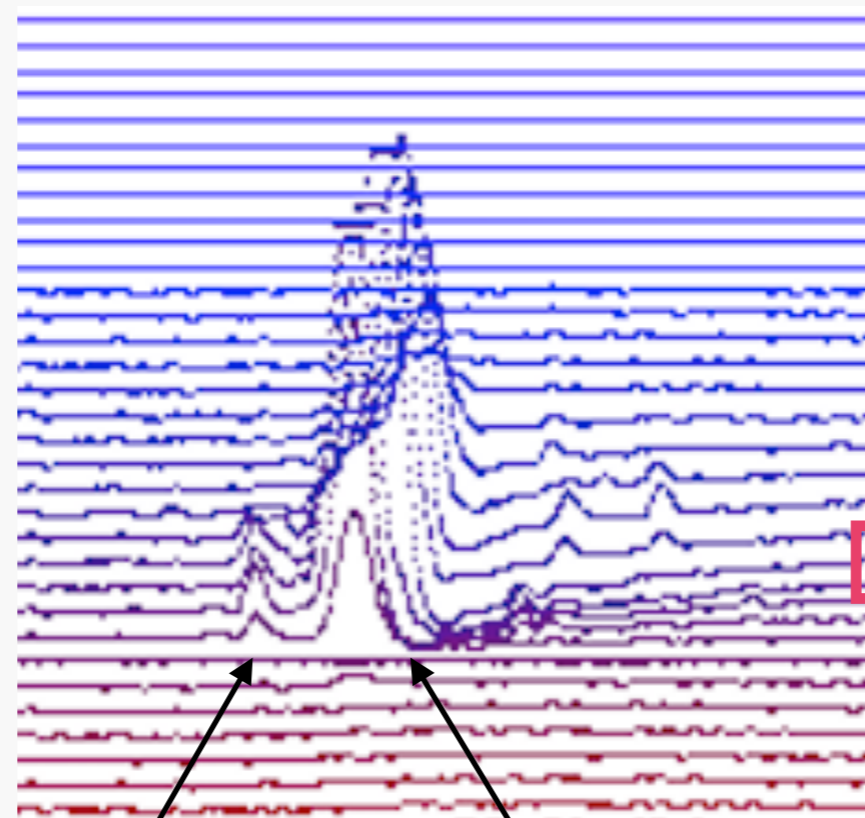
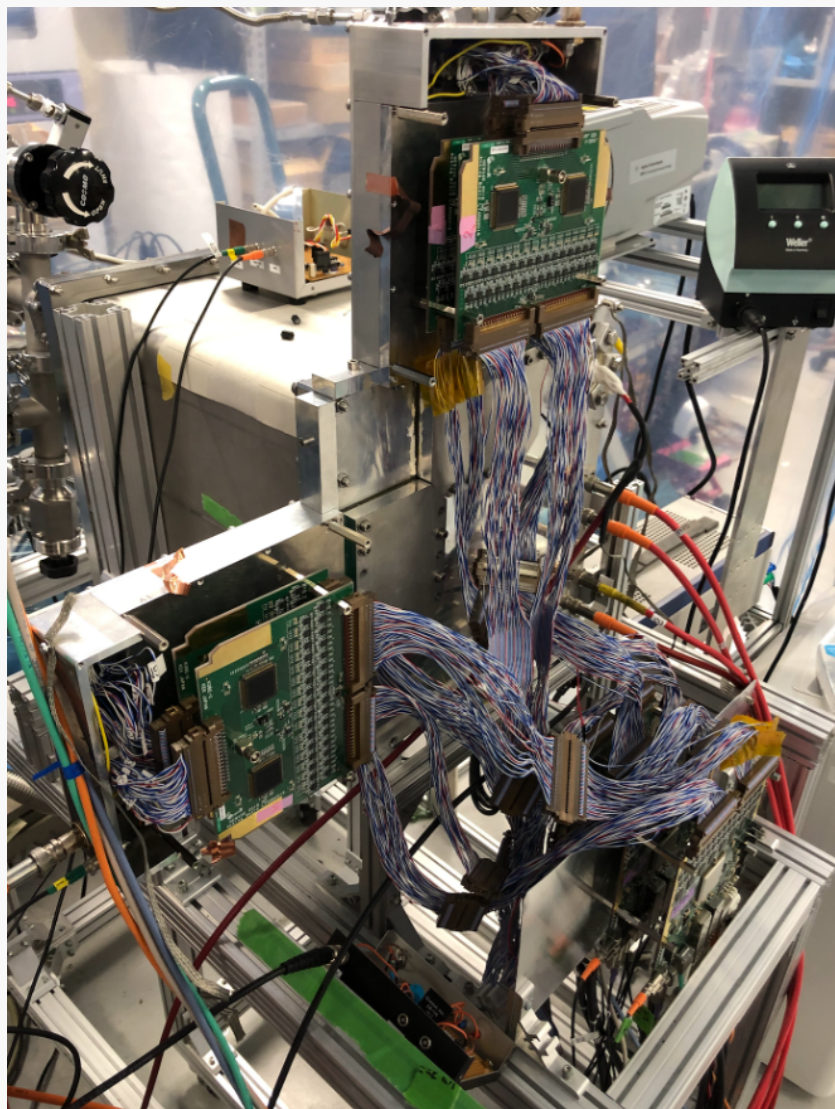


Benefit for fine granularity readout



First detection of nuclear recoil

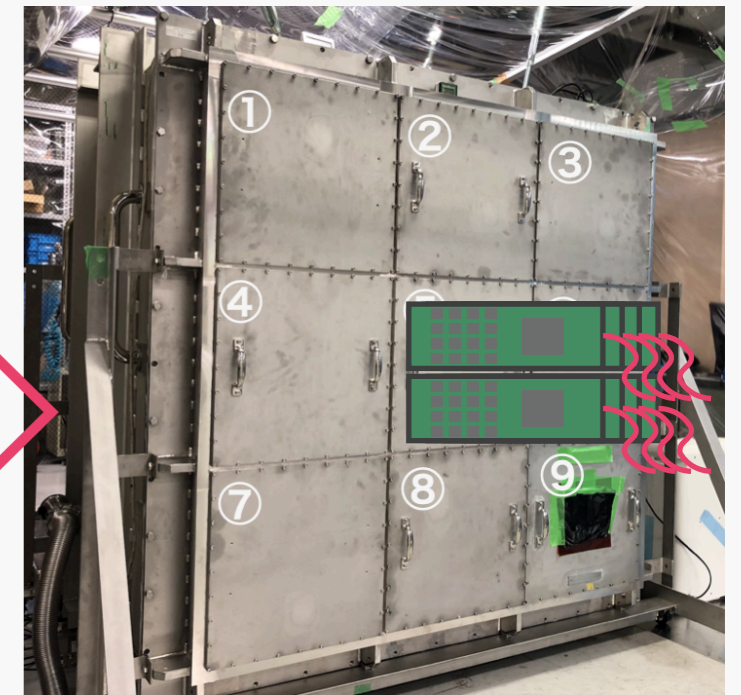
- Small-size chamber and its DAQ are developed to demonstrate about SF₆ gas TPC
 - LTARS2018 ASIC: slow peaking, wide dynamic range and good S/N amplifier
 - T. Kishishita et al, 2020 JINST 15 T09009
 - Firmware development for self triggering
- First nuclear recoil event is detected using ²⁵²Cf neutron source



SF₅⁻

SF₆⁻

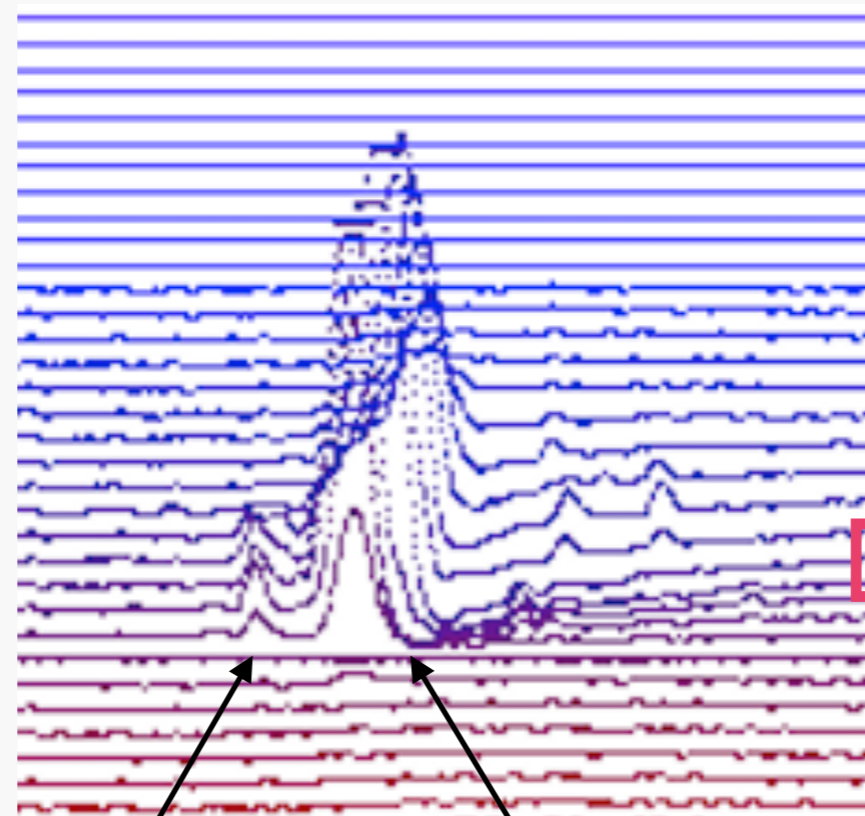
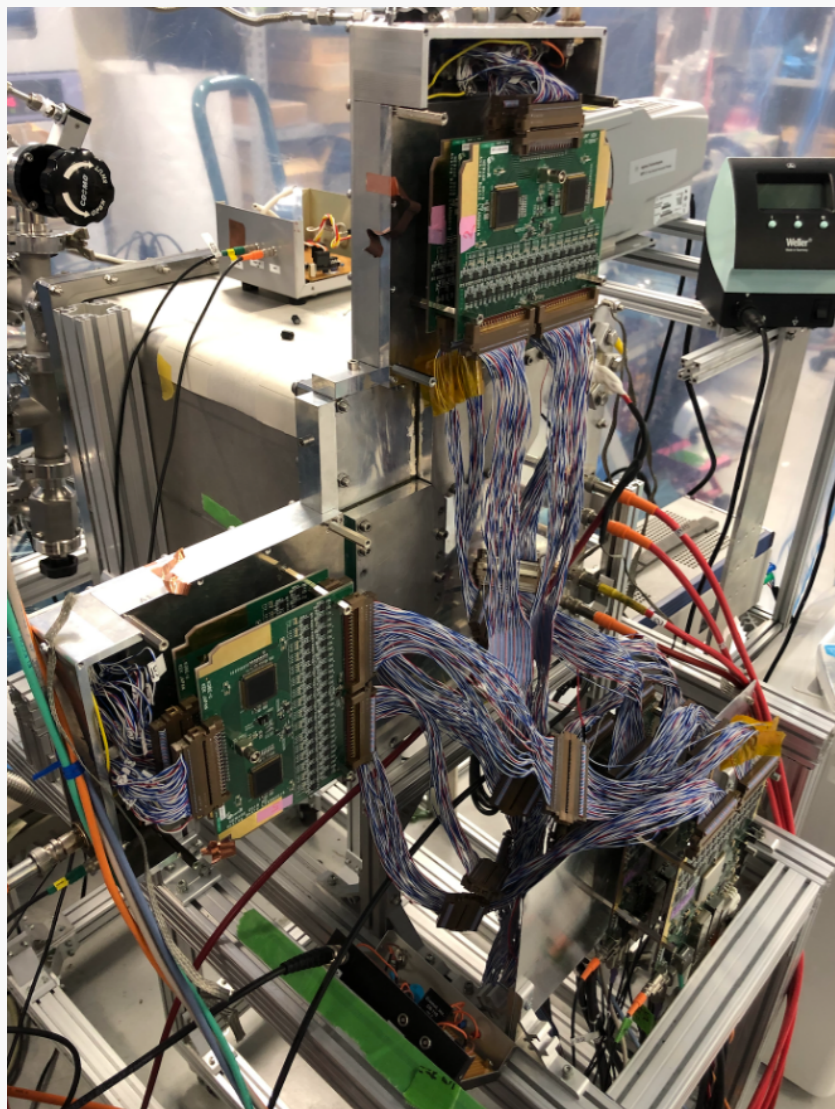
Development of new electronics is started!



To be installed in C/N-1.0
→ compact DAQ system

First detection of nuclear recoil

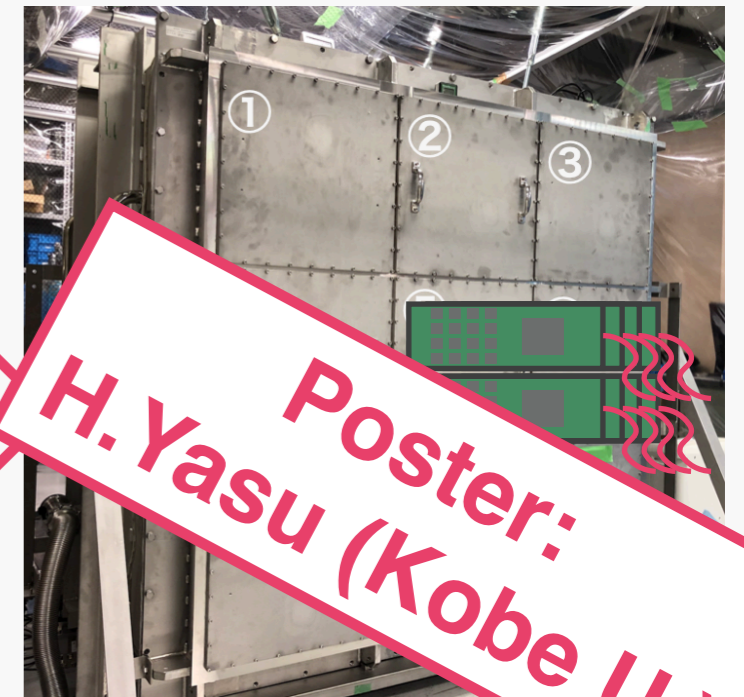
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SF₅⁻

SF₆⁻

Development of new electronics is started!



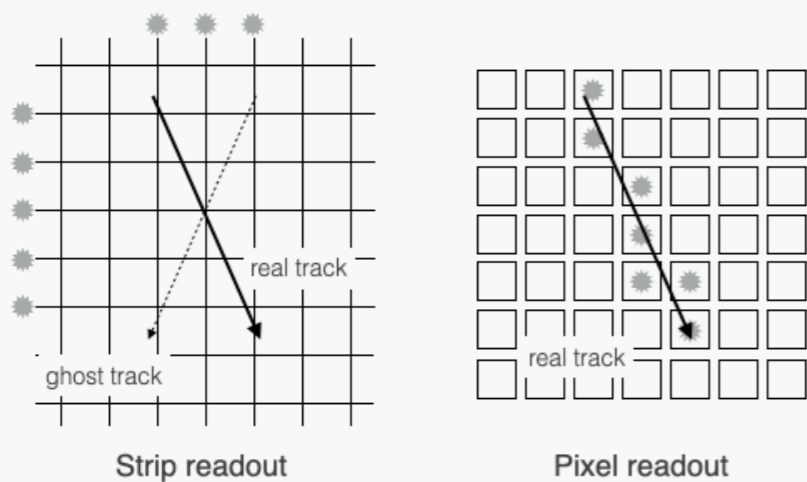
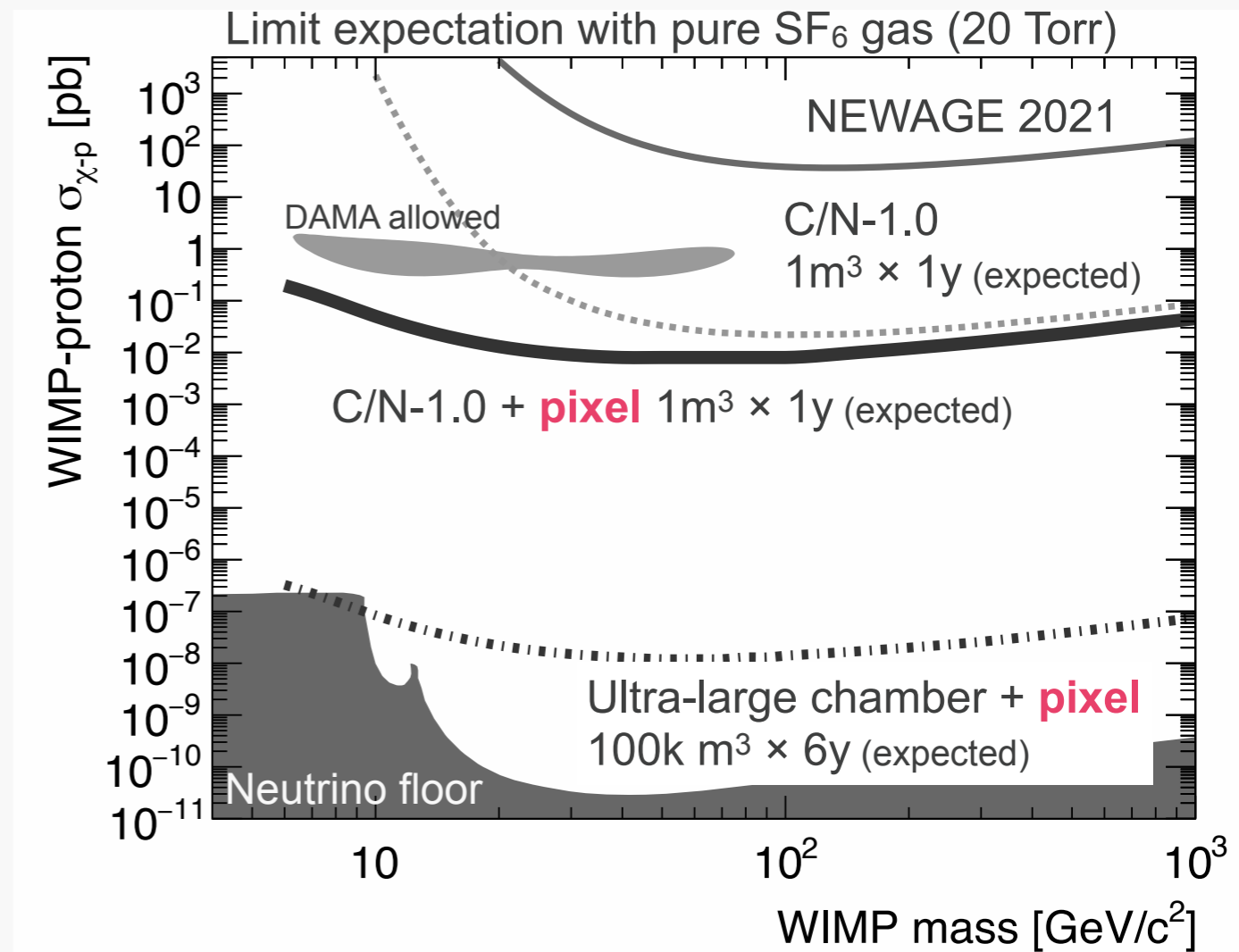
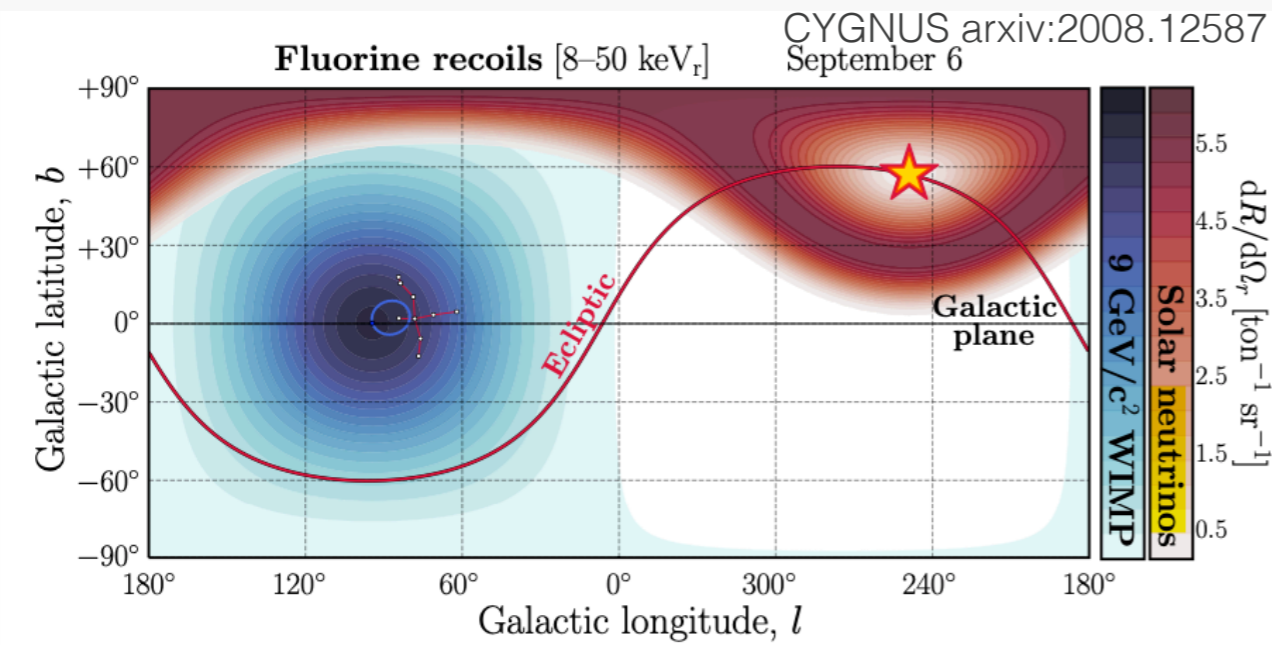
Poster:
H. Yasu (Kobe U.)

To be installed in C/N...
→ compact DAQ system

Pixel readout

公募研究 (S.Higashino)
FY2022-2023

- High granularity pixel readout allows to reconstruct short track nuclear recoil
 - It leads lower energy threshold ($\sim 100 \text{ keV}_r \rightarrow 10 \text{ keV}_r$!!!) = lower mass DM search
 - Pixel readout also benefits to solve track ambiguity
- Possibility to access neutrino floor in future!
- Readout ASIC is designed with KEK E-Sys group and will be submit (**deadline is TODAY!!!**)



Summary

- Various activities are significantly updated by NEWAGE group!
- Development of zeolite gas filtering system contributes low BG environment in our DM search



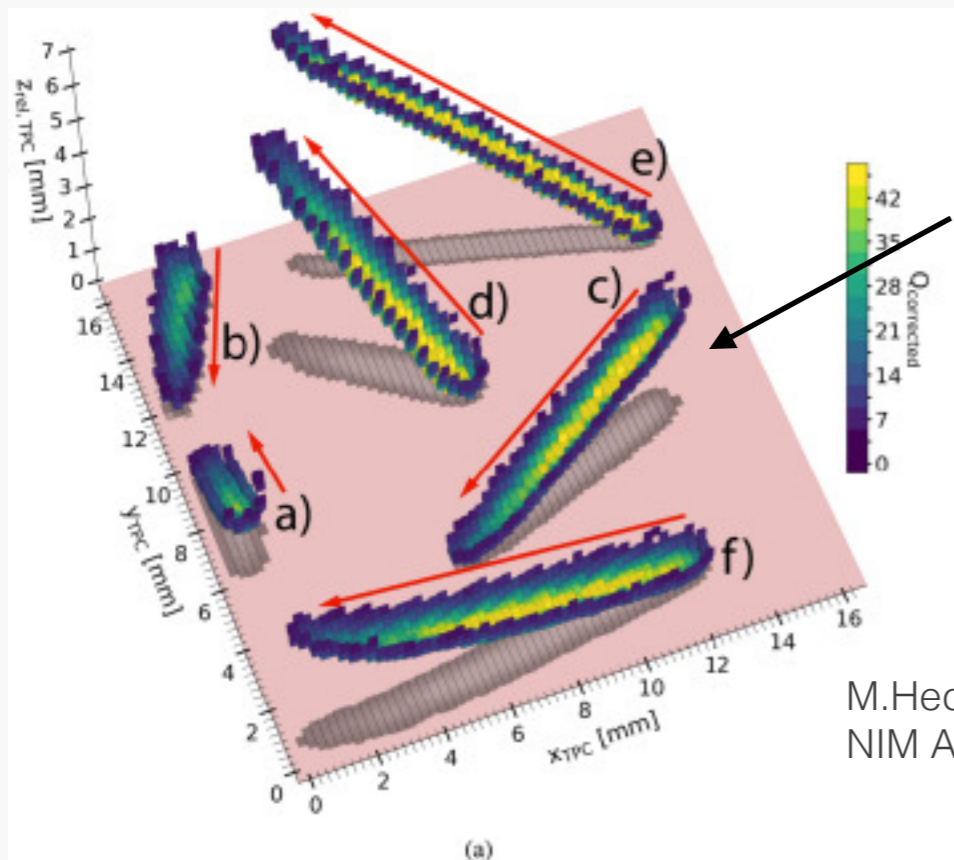
+ 2 master students

Backup

Pixel readout for gaseous detectors

- One of the difficulties is readout electronics
 - ➔ due to the large number of readout channels
- Some existing ASIC's are applied for gaseous TPC's

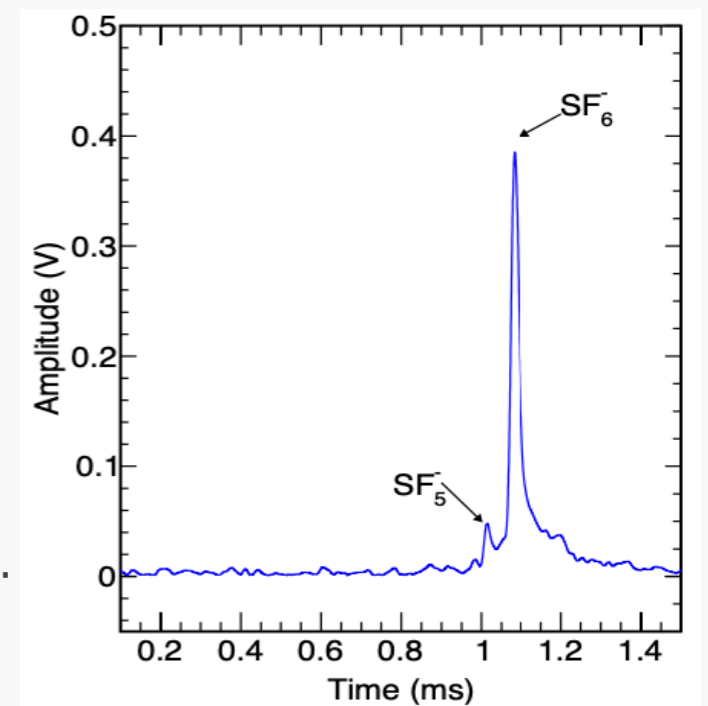
ASIC	TimePix	FE-I4
Application	Gas TPC	Silicon (ATLAS:IBL) Gas TPC (SuperKEKB)
Digitization	Time over Threshold	Time over Threshold



TPC @KEK (w/ FI-I4)

Excellent track reconstruction!

however... ➔



multi-hit readout is not supported
➔ decided to **develop new ASIC**

M.Hedges, S.Vahsen, et. al.
NIM A, Volume 1026, 1 March 2022, 166066

New Pixel ASIC: multi-hit readout