Dec 11th, 2023
- CYGNUS 2023
Sydney, Australia

NEWAGE/ CYGNUS-KM

Kentaro Miuchi
(Kobe University)

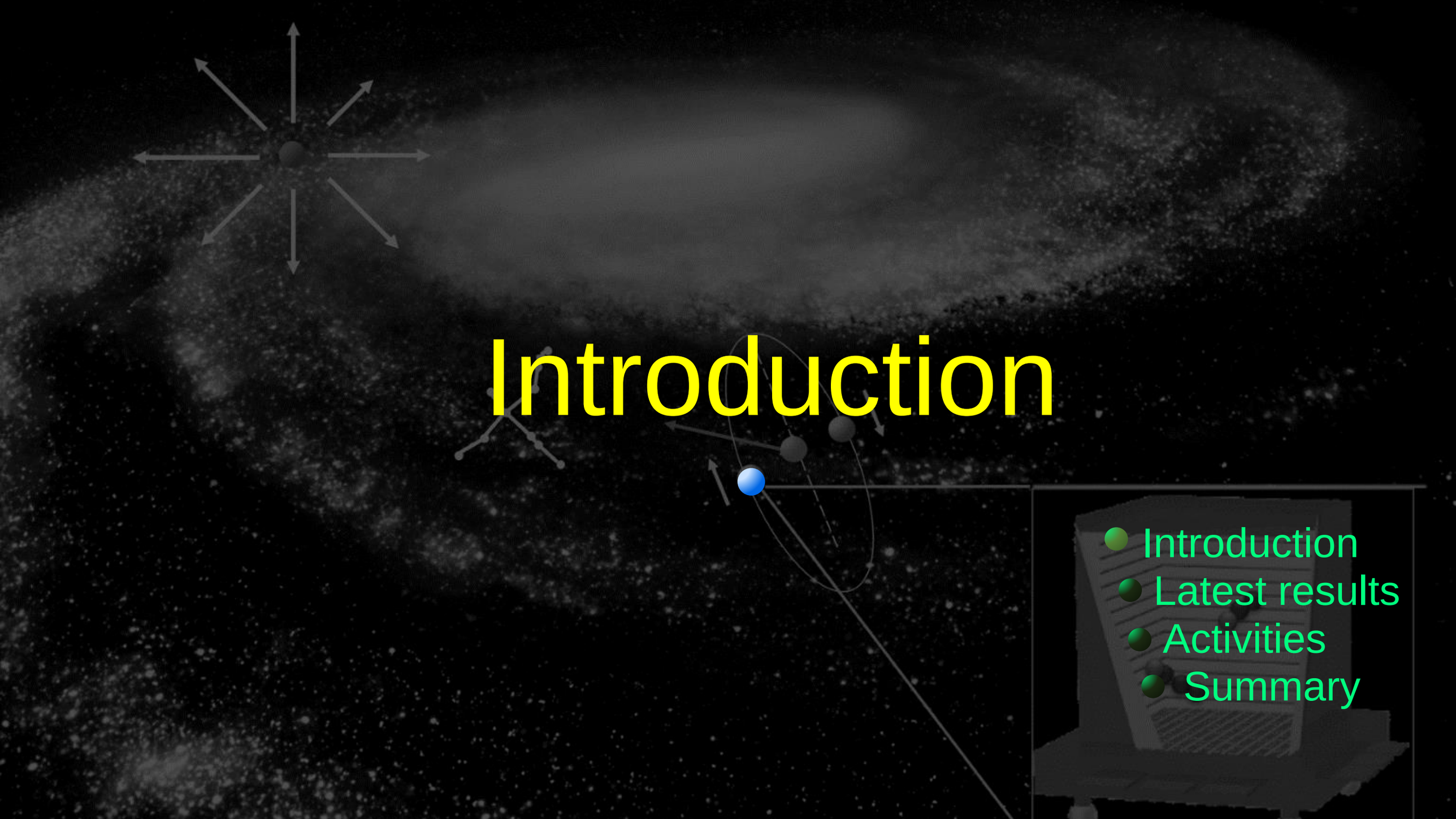
- Introduction
- Latest results
- Activities
- Summary

科研費
KAKENHI

地下から解き明かす宇宙の歴史と物質の進化
Unraveling the History of the Universe and Matter Evolution with Underground Physics

Direction-Sensitive WIMP-search NEWAGE

Introduction



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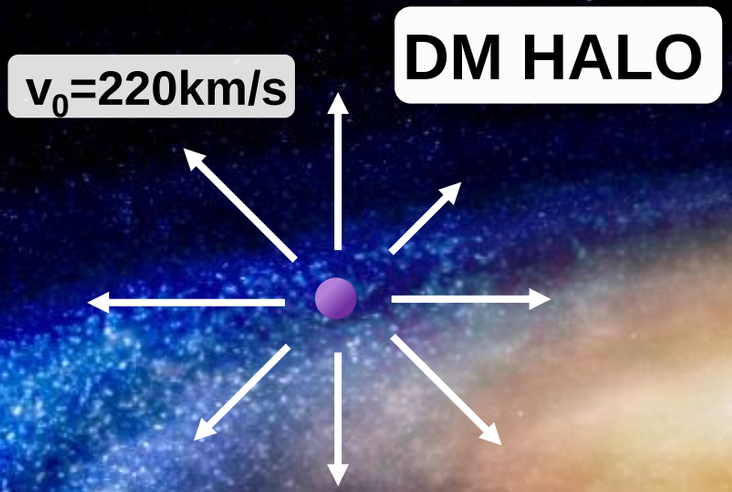
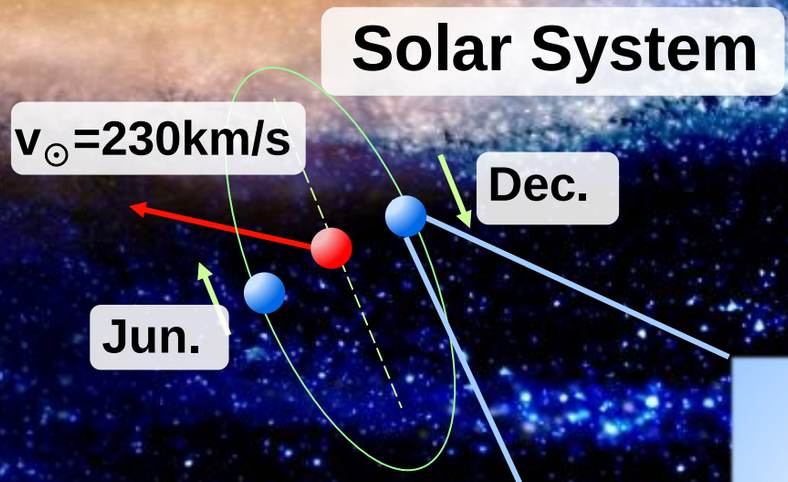
“CYGNUS” concept

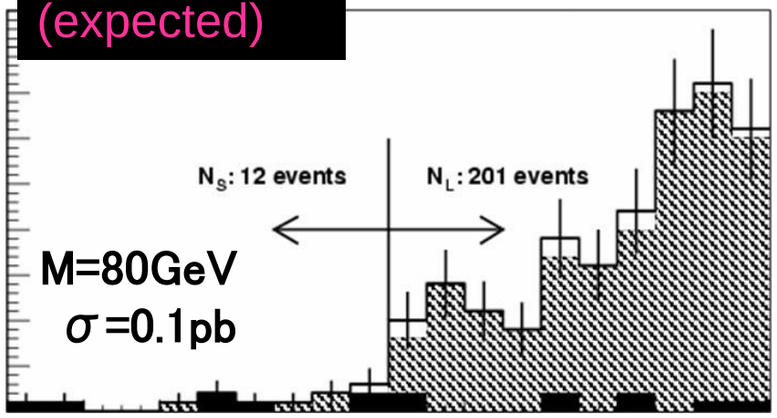
WIMP-wind detection



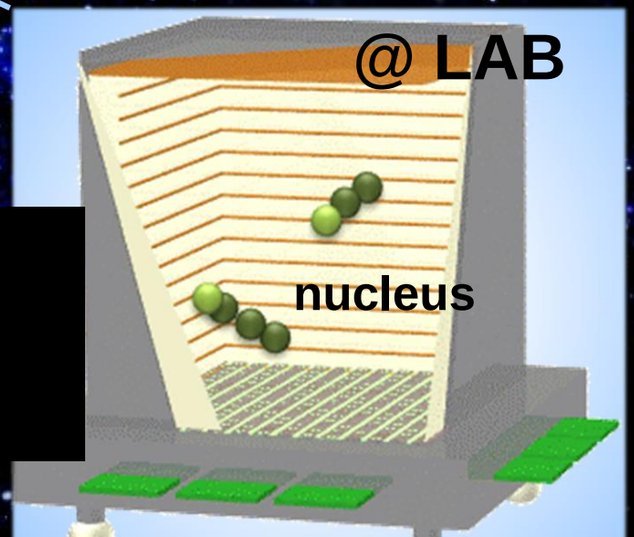
G. C.



directionality (expected)



Physics Letters B 578 (2004) 241–246



detector:
low pressure gas
emulsions
diamond detectors, scintillators...

CYGNUS 2023

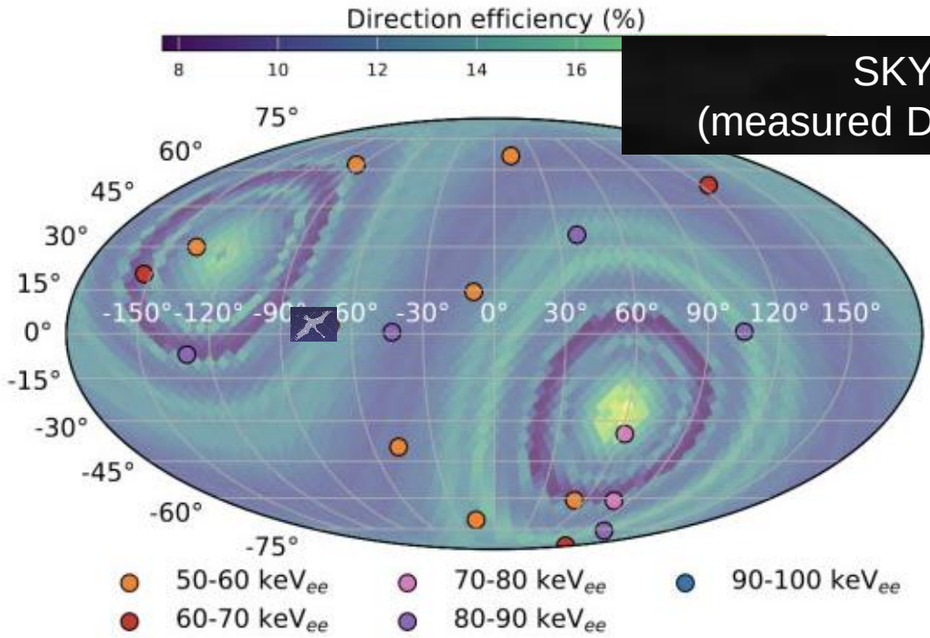
NEWAGE history

- μ-PIC(MPGD) based TPC
  - 3-D tracks SKYMAP
- CF4 gas for SD search

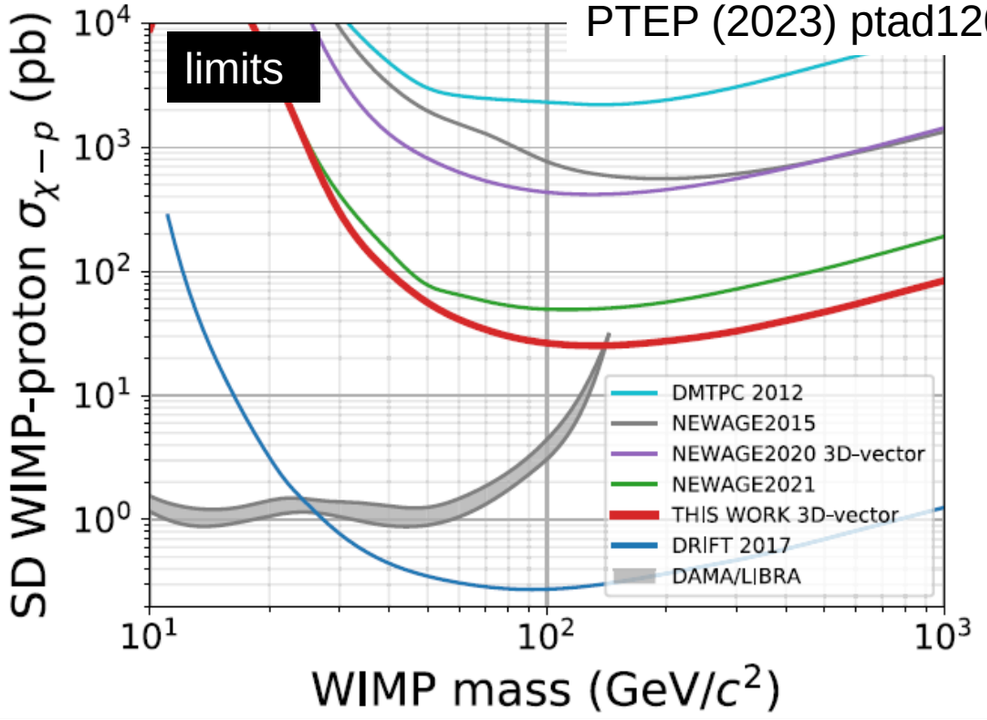
- Proposal PLB 578 (2004) 241
- First direction-sensitive limits

  PLB654 (2007) 58 ~10^4pb
- Underground results

  PLB686 (2010) 11, PTEP(2023)ptad120 26 pb
- lower BG, larger volume



SKYMAP
(measured DATA)

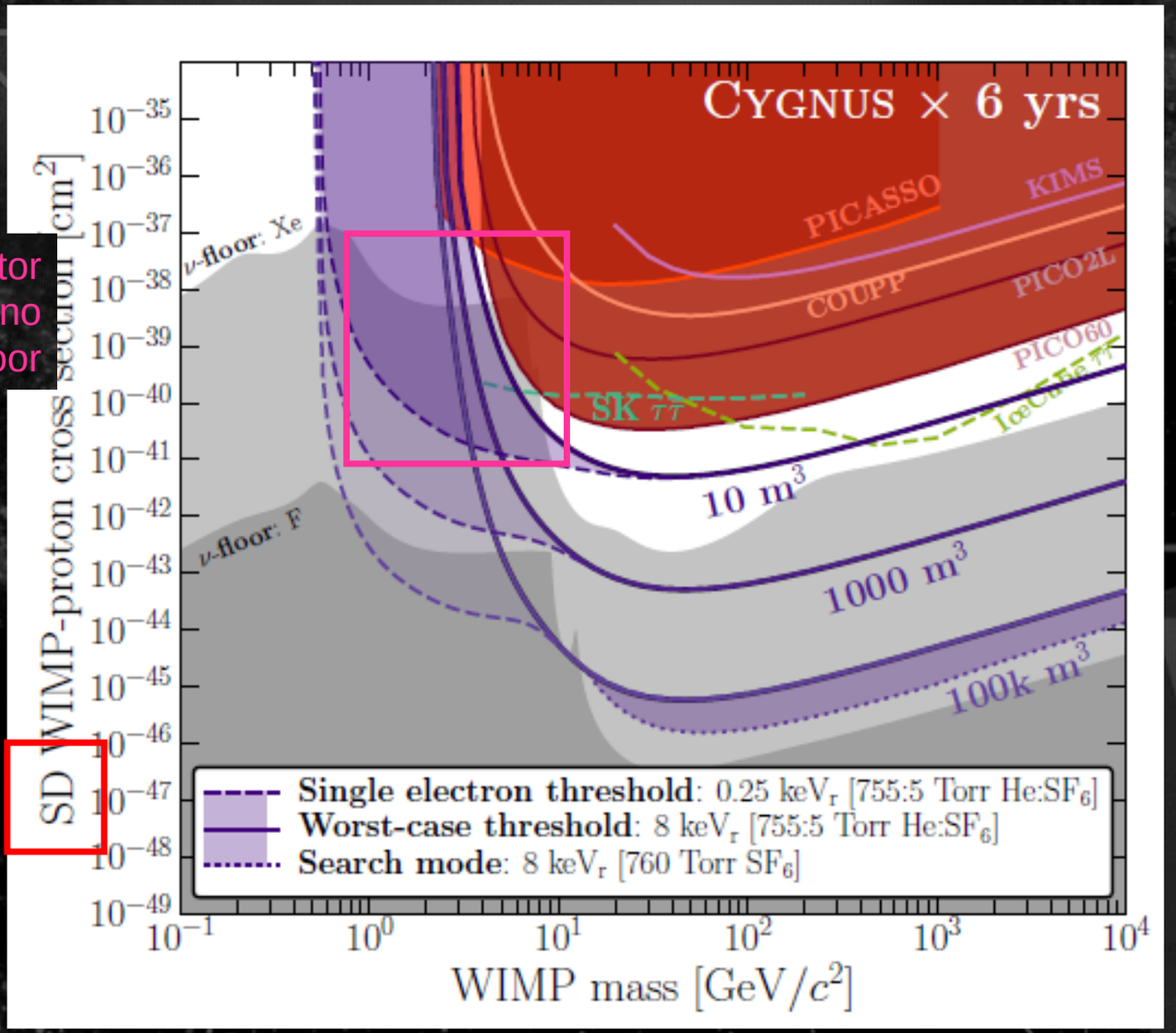


PTEP (2023) ptad120

• Fluorine advantage

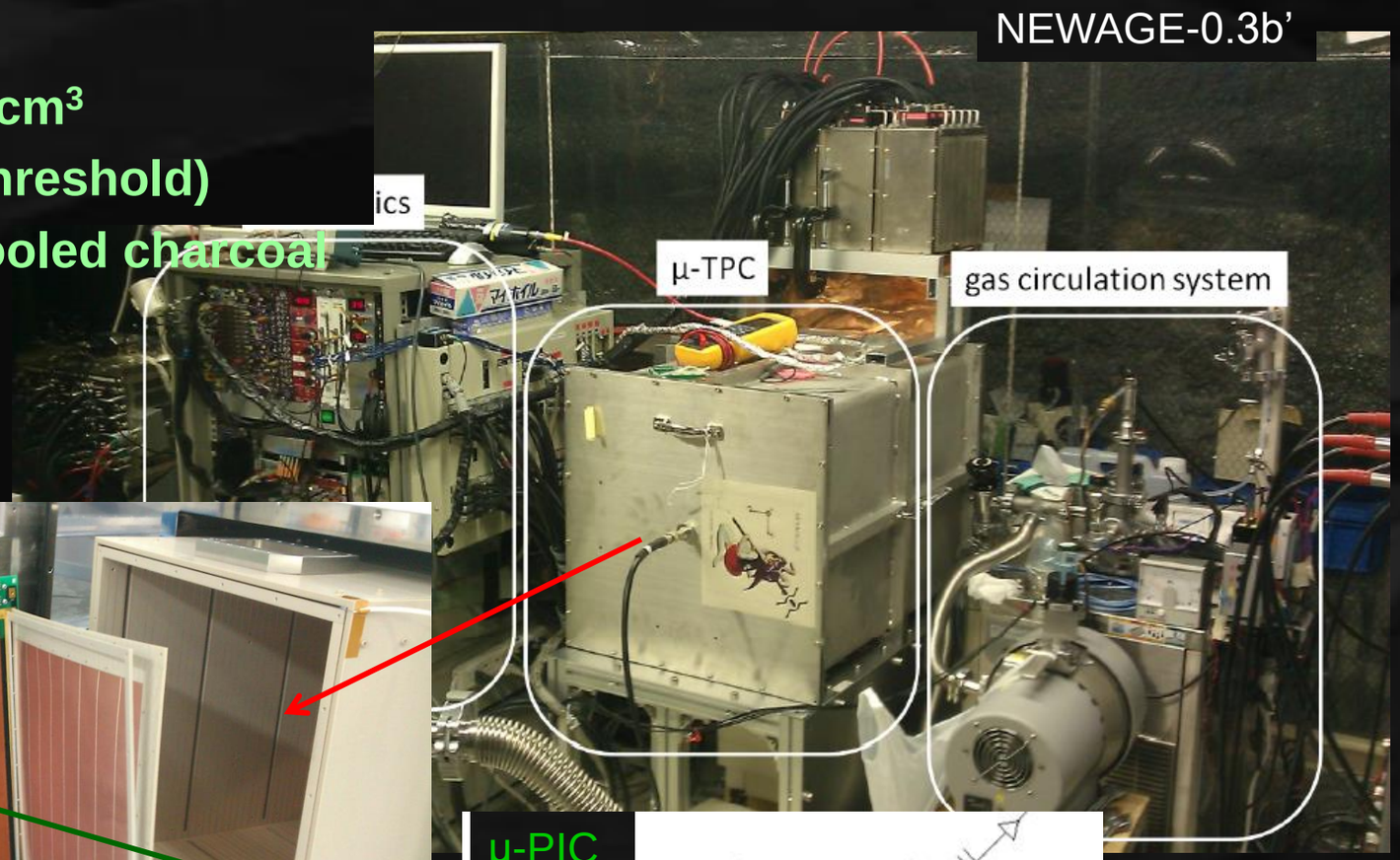
arXiv 2008.12587

even 10m^3 detector
can start exploring Xe neutrino floor

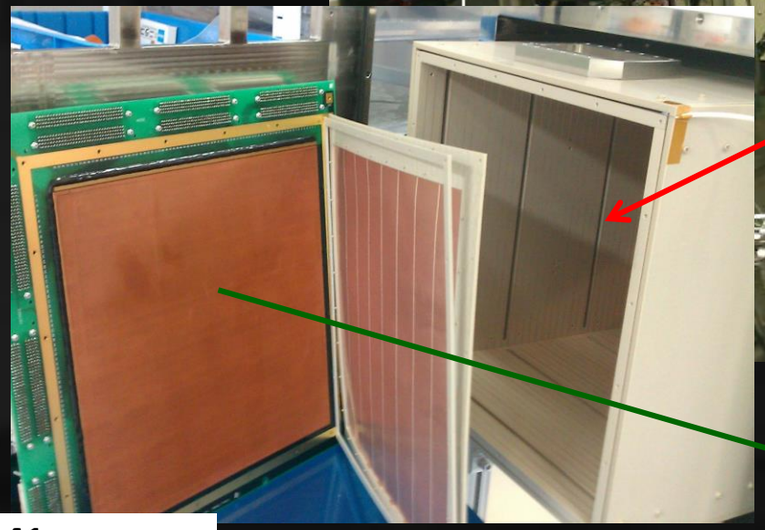


NEWAGE detector

- Kamioka underground
- NEWAGE-0.3b''
- Detection Volume: 31×31×41cm^3
- Gas: CF4 at 0.1atm (50keVee threshold)
- Gas circulation system with cooled charcoal

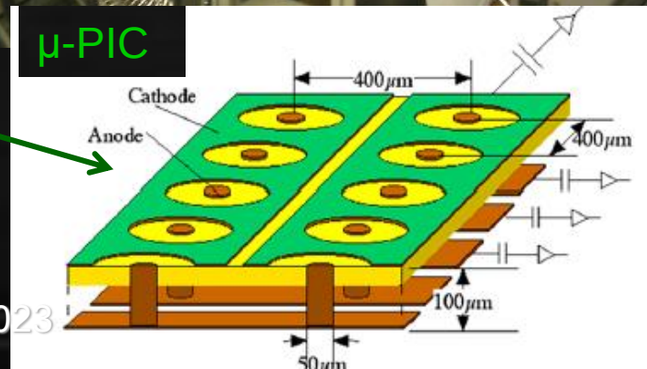


μ-TPC



Drift length: 41cm
PEEK + copper wires

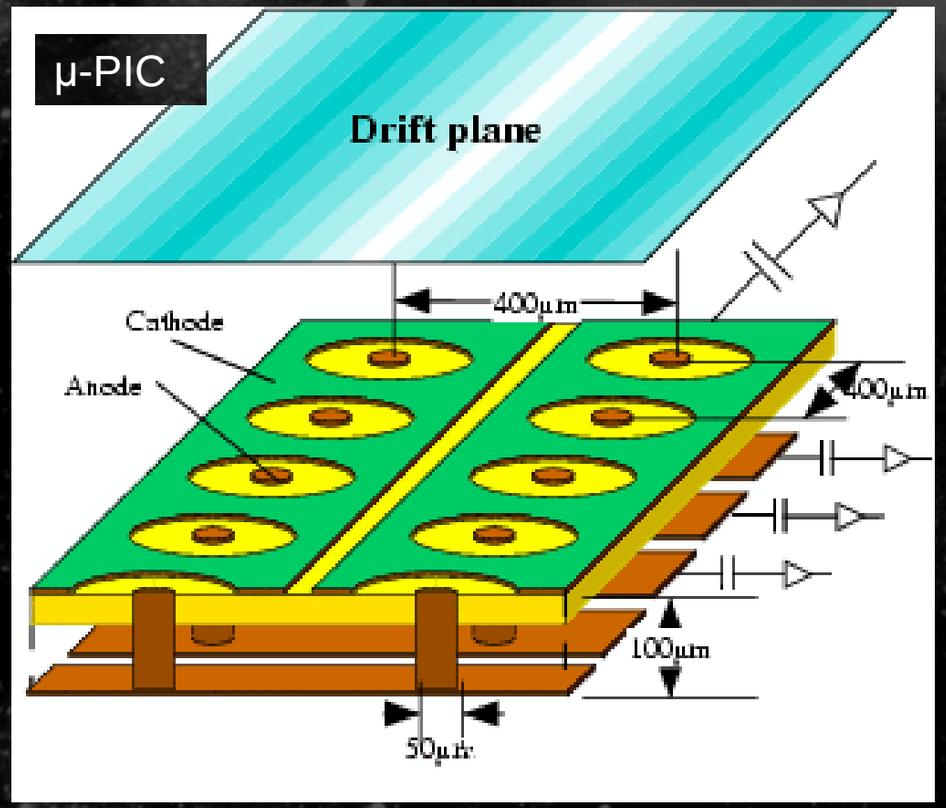
μ-PIC

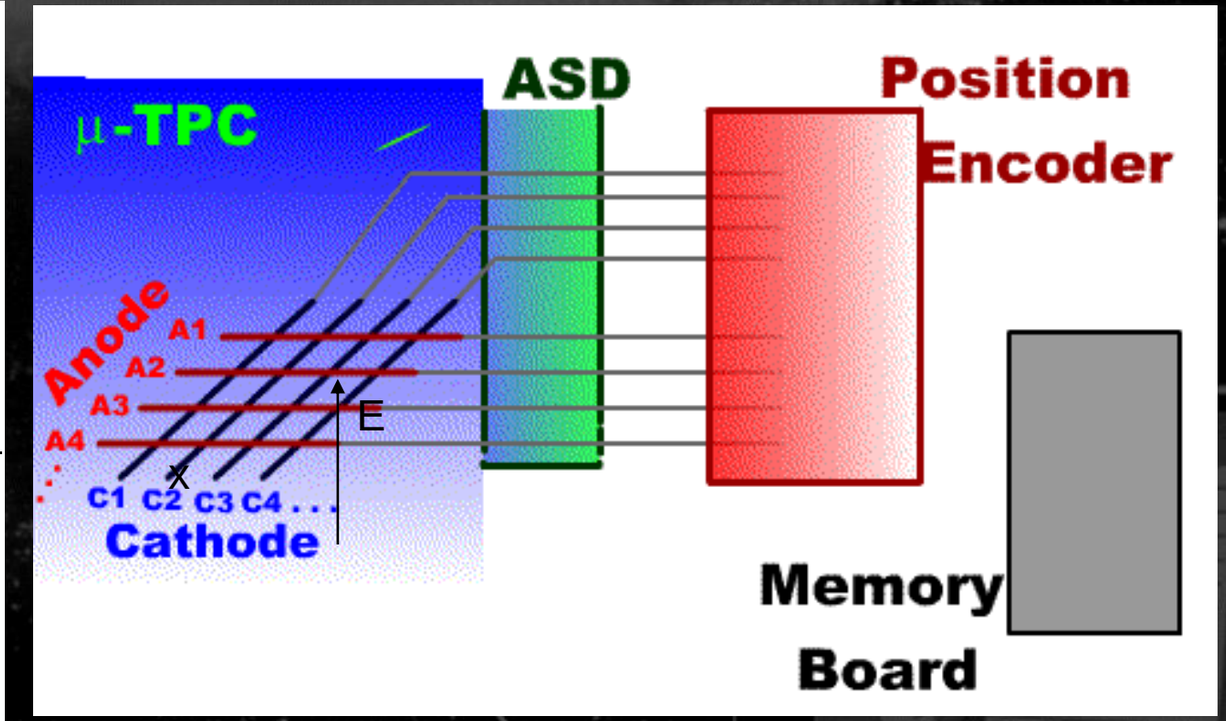


- 31 × 31cm^2
- pitch : 400μm
- gain : ~1000
- made by DNP, Japan

- Key technology: Gaseous Time Projection Chamber
  - 2-dimensional image: Micro Patterned Gaseous Detector (MPGD)
  - timing information: 3rd dimension
  - realtime 3-dimensional tracking

MPGD:
GEM, micromegas, μ-PIC

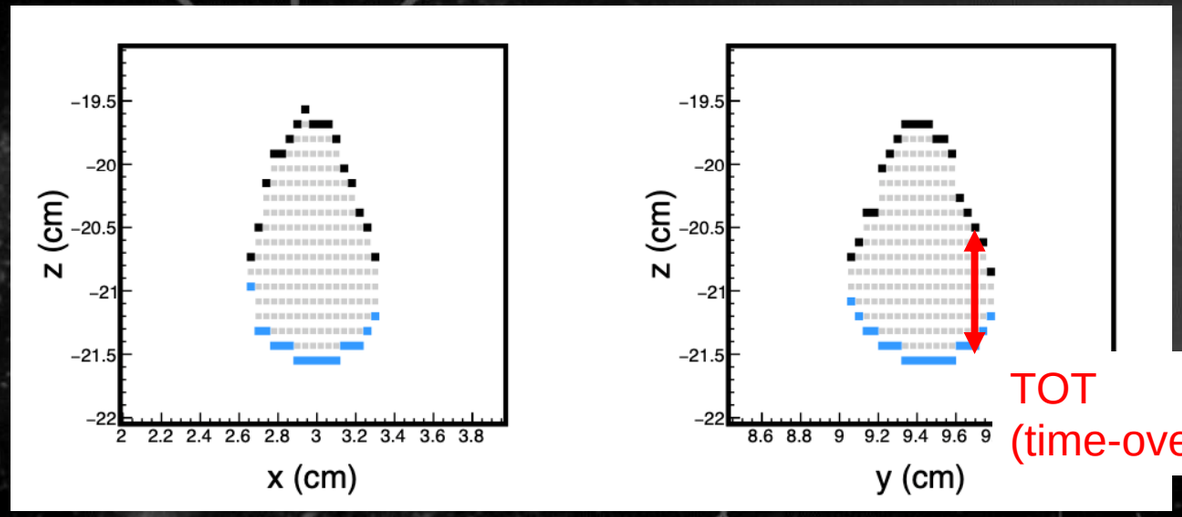




- drawback: small mass O(kg) / m^3

- Data we record

track data

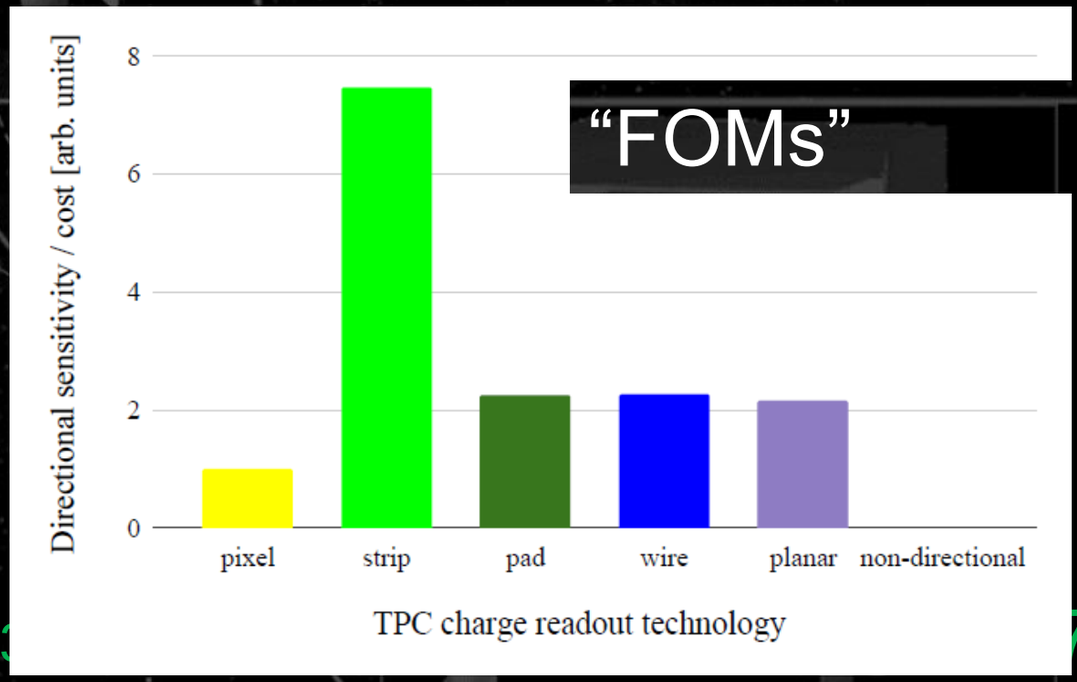


+summed waveform

- Interestingly, 2d strip was found to be the “ideal” for us.

CYGNUS: Feasibility of a nuclear recoil observatory with directional sensitivity to dark matter and neutrinos

(Anode strips) (Cathode strips) 2008.12587



- Publications since last CYGNUS
  - DM search
    - First limits from a 3d-vector directional dark matter search with the NEWAGE-0.3b' detector
      PTEP, (2020) ptaa147 DOI: 10.1093/ptep/ptaa147
    - “Direction-sensitive dark matter search with a low-background gaseous detector NEWAGE-0.3b”
      PTEP (2021) ptab053
    - "Direction-sensitive dark matter search with three-dimensional vector-type tracking in NEWAGE”,
      PTEP(2023)ptad120
  - Technical papers
    - Development of a low-α emitting μ-PIC as a readout device for direction-sensitive dark matter detectors
      NIM A Volume 977, 11 October 2020, 164285
    - Development of an alpha-particle imaging detector based on a low radioactive micro-time-projection chamber
      NIM A Volume 953, (2020), 163050 , arXiv1903.01090
    - LTARS: analog readout front-end ASIC for versatile TPC-applications
      JINST (2020) 15 T09009
    - Development of a Negative Ion Micro TPC Detector with SF6 Gas for the Directional Dark Matter Search
      JINST (2020), P07015
    - "Test of low radioactive molecular sieves for radon filtration in SF6 gas-based rare-event physics experiments"
      JINST (2021) 16 P06024
  - Future physics
    - "Detection capability of Migdal effect for argon and xenon nuclei with position sensitive gaseous detectors"
      PTEP(2020) ptaa162
    - "Directional direct detection of light dark matter up-scattered by cosmic-rays from direction of the Galactic center”,
      JCAP07(2023)061,

Latest results

PTEP (2023) ptad120

Direction-sensitive dark matter search with 3D-vector-type tracking in NEWAGE

Takuya Shimada[1], Satoshi Higashino[1,*], Tomonori Ikeda[2], Kiseki Nakamura[3], Ryota Yakabe[1], Takashi Hashimoto[1], Hirohisa Ishiura[1], Takuma Nakamura[1], Miki Nakazawa[1], Ryo Kubota[1], Ayaka Nakayama[1], Hiroshi Ito[4], Koichi Ichimura[5], Ko Abe[6,7], Kazuyoshi Kobayashi[8], Toru Tanimori[2], Hidetoshi Kubo[2], Atsushi Takada[2], Hiroyuki Sekiya[6,7], Atsushi Takeda[6,7], and Kentaro Miuchi[1]

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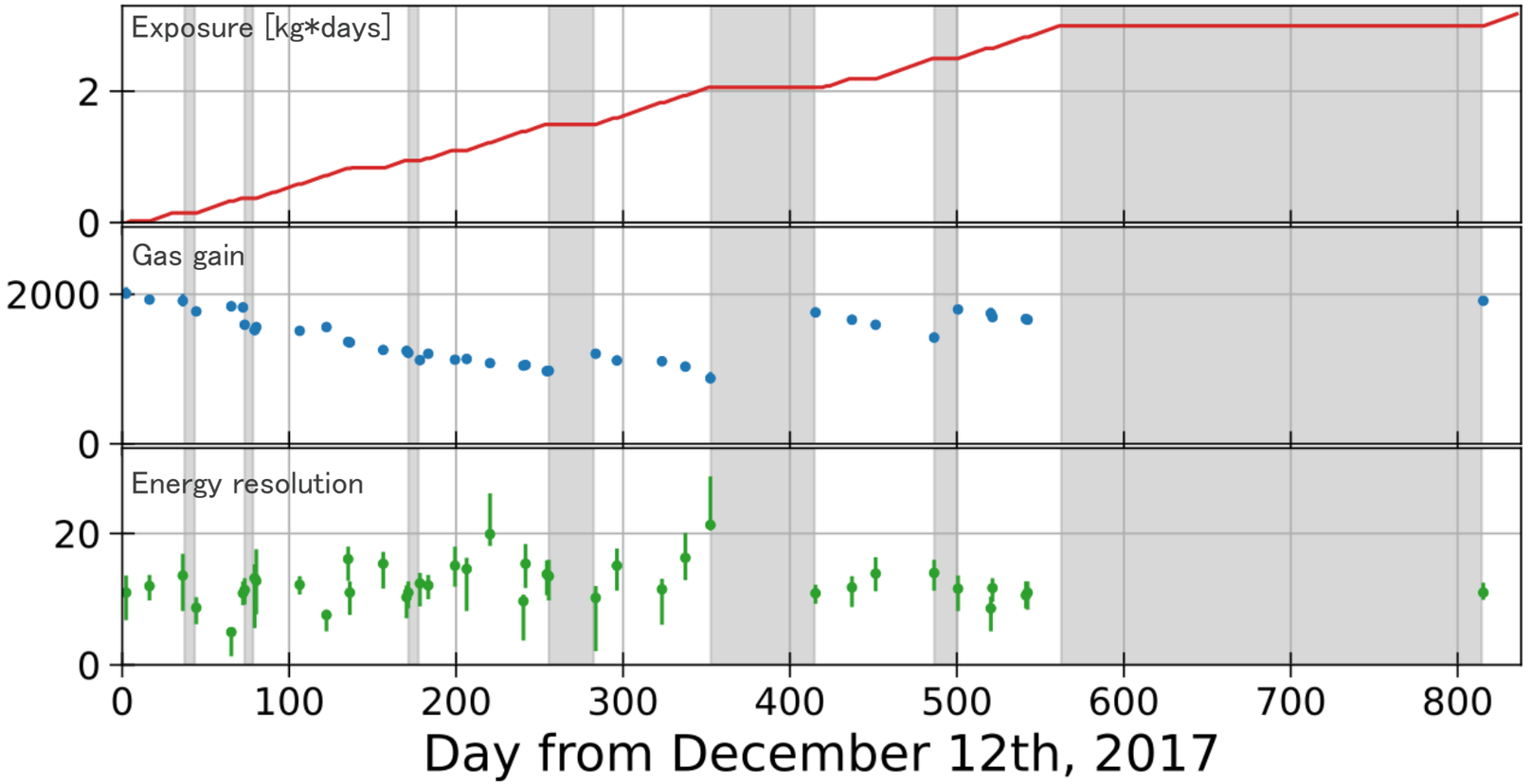
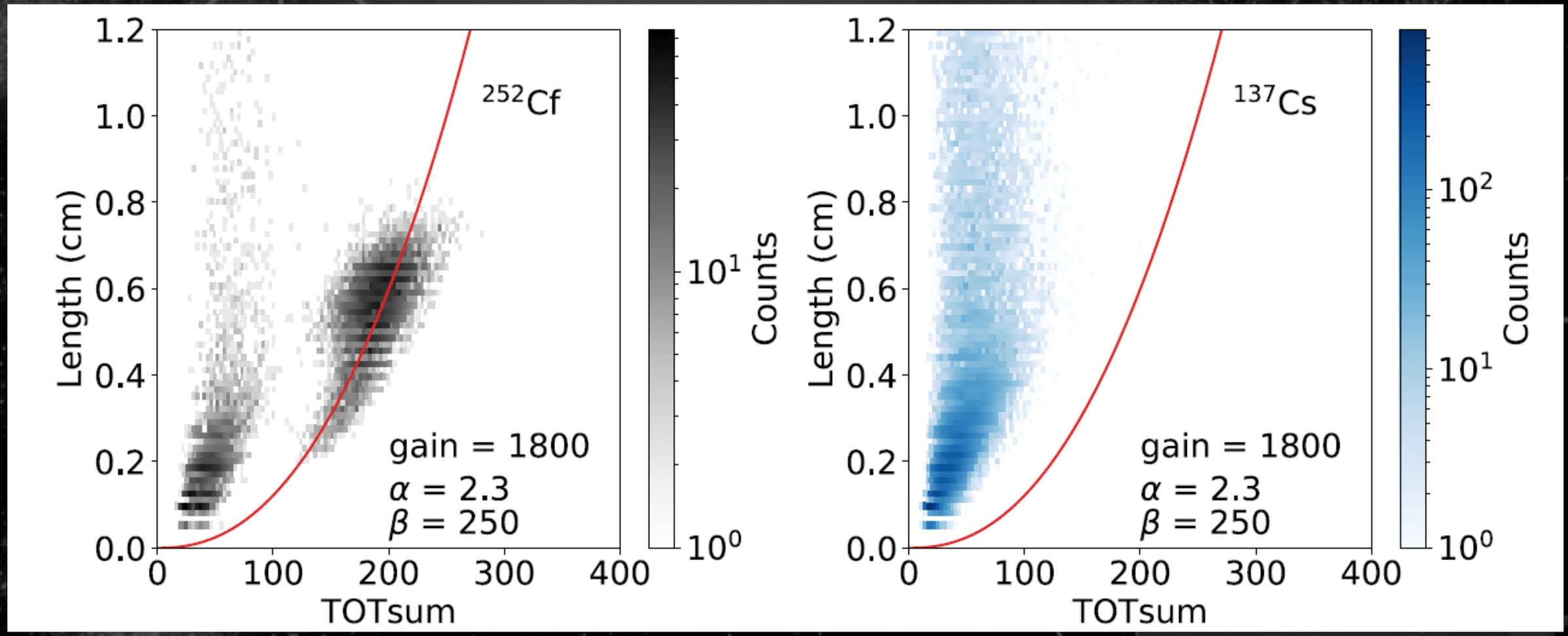
- Underground measurements
  - 28 × 24 × 41cm^3 fiducial volume (10g)
    out of 31 × 31 × 41cm^3 active volume
  - 318 live-days

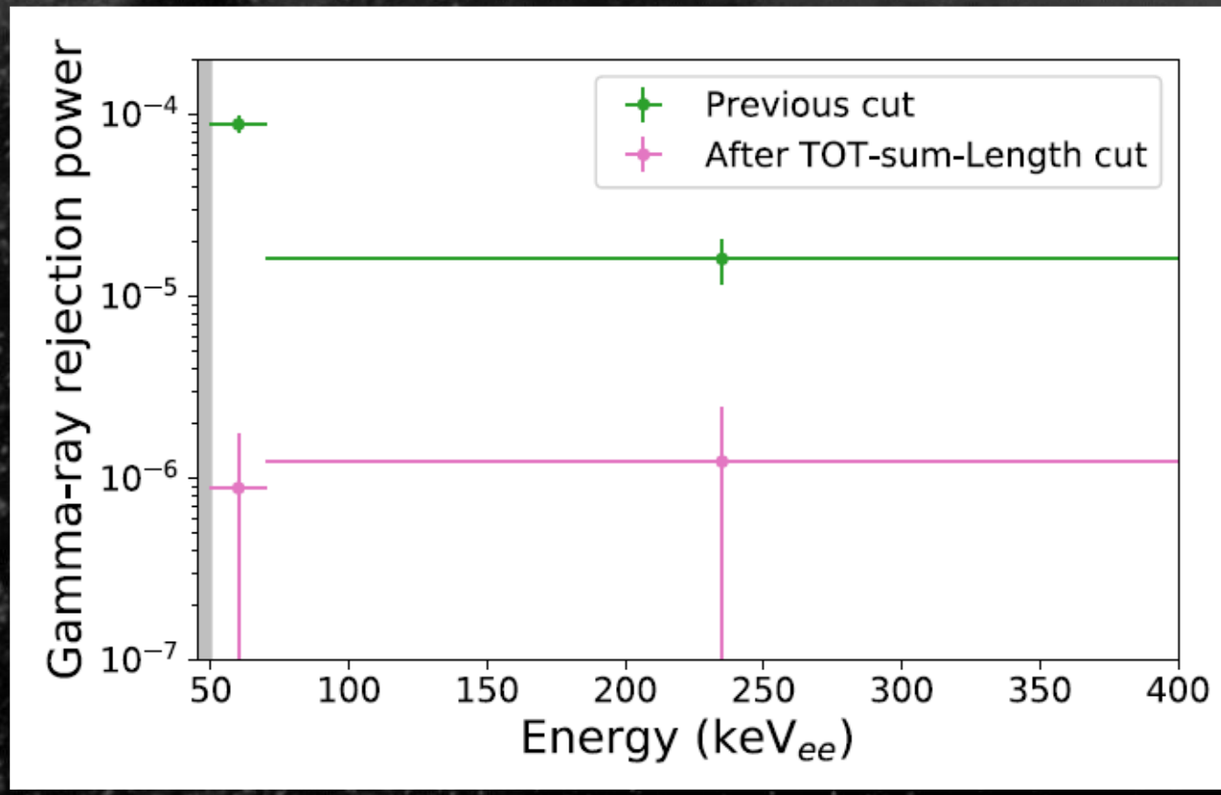
PTEP (2023) ptad120

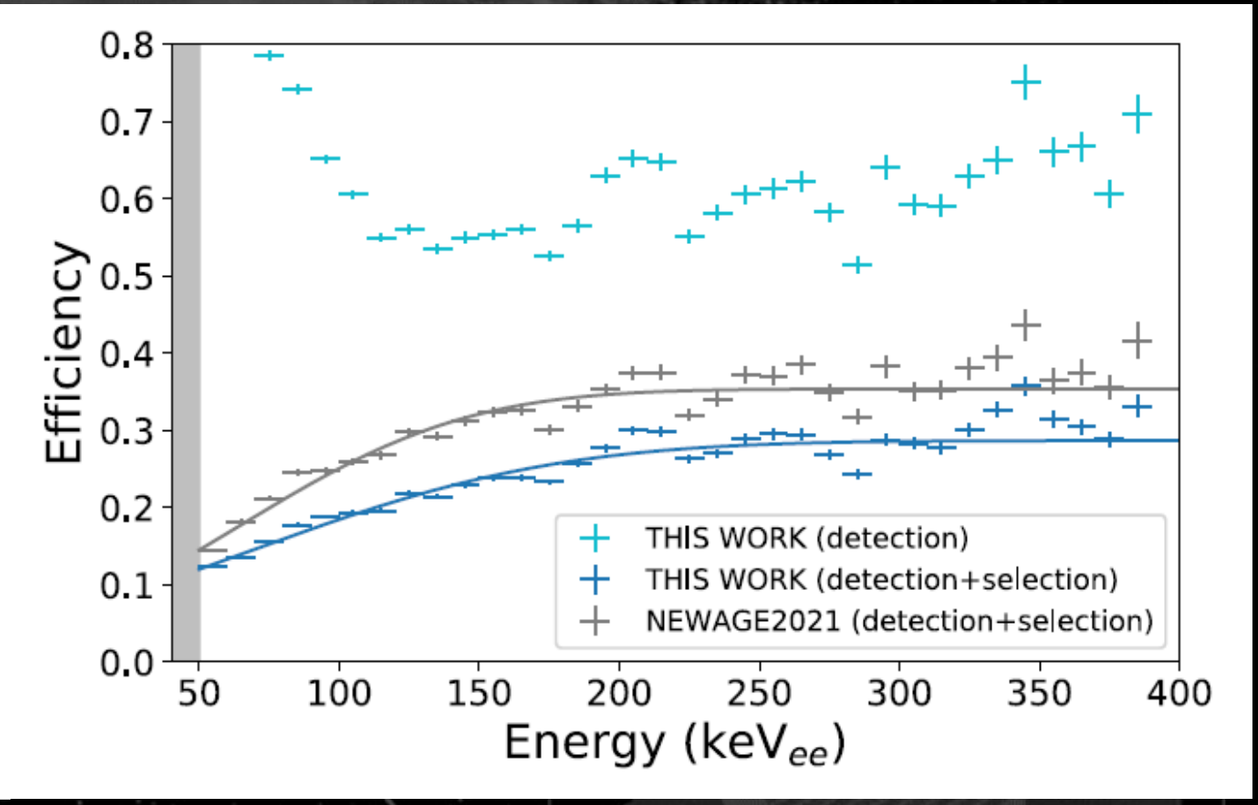


- Event selections
  - Additional selection applied with multi-variate analysis to reject electron recoil (ER) events



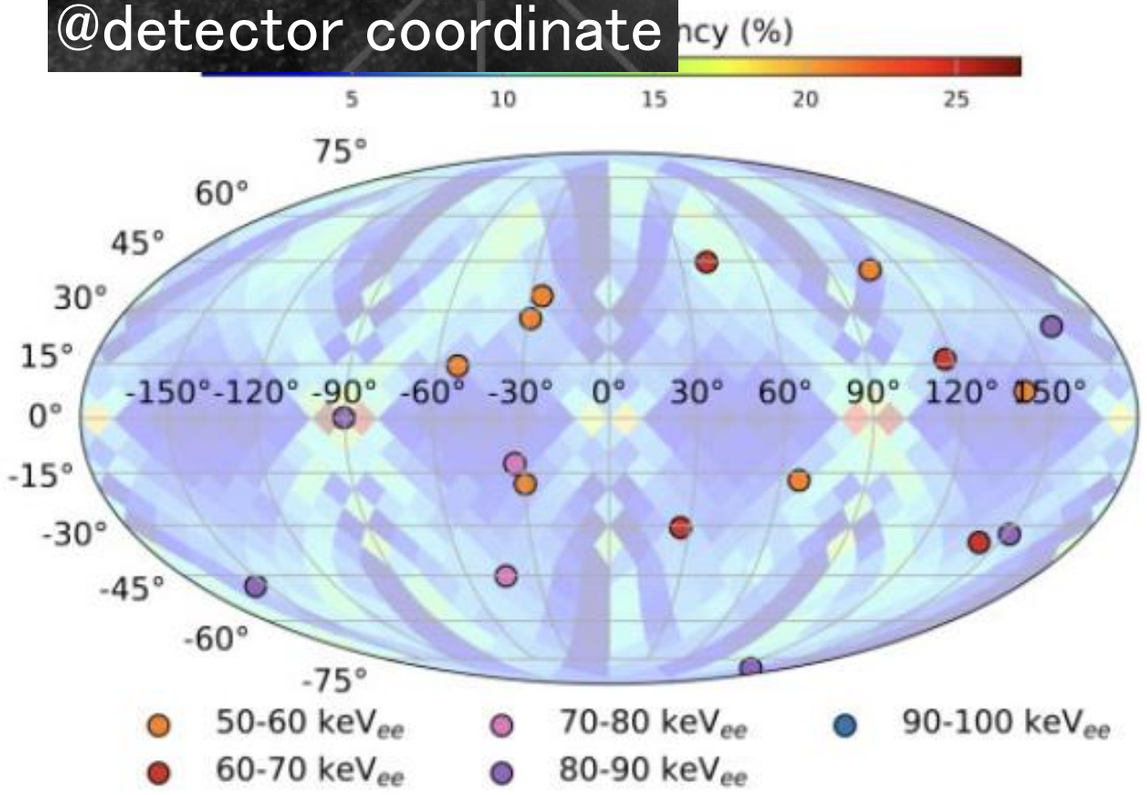
- Event selections
  - Additional selection applied with multi-variate analysis to reject electron recoil (ER) events
  - at a cost of some efficiency loss





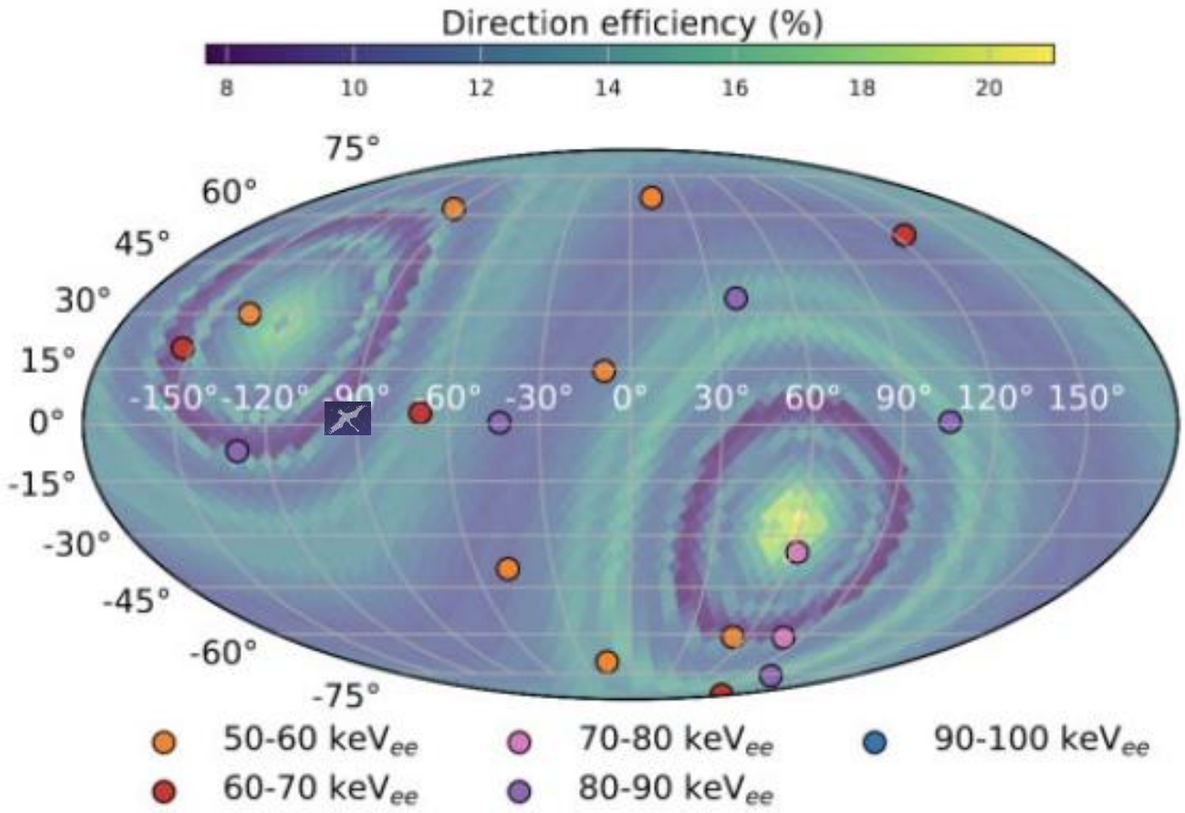
• Results: sky maps

sky map
@detector coordinate



(a) Nuclear-recoil directions in the detector coordinate

sky map
@detector galaxy coordinate



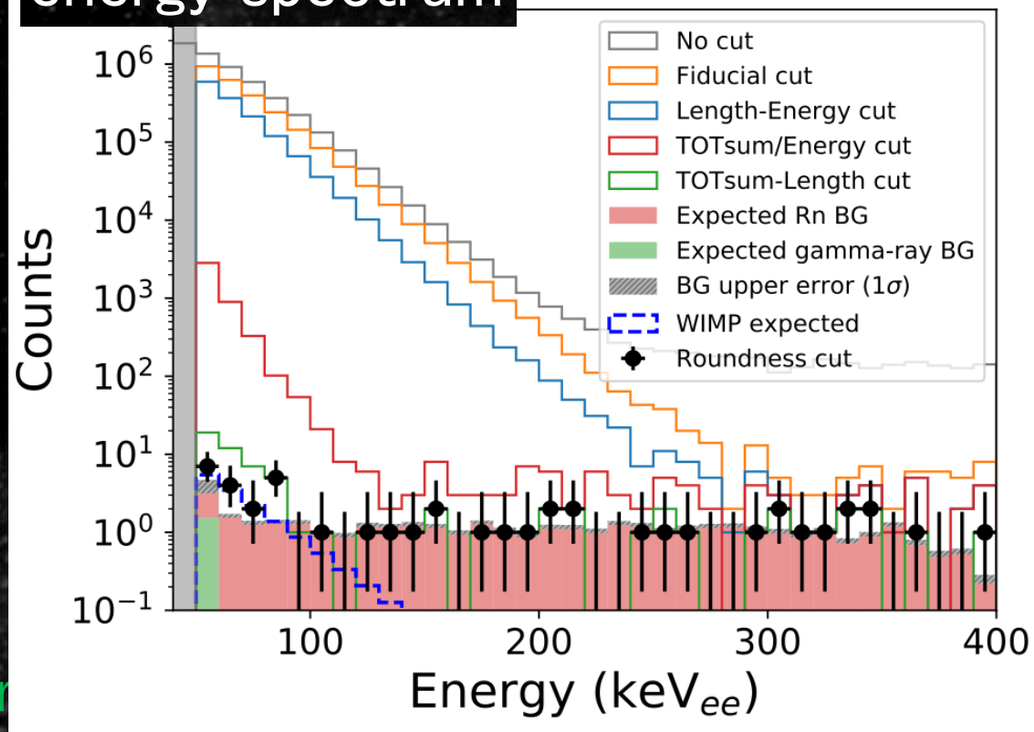
(b) Nuclear-recoil directions in the galaxy coordinate

• no “unexpected” was seen

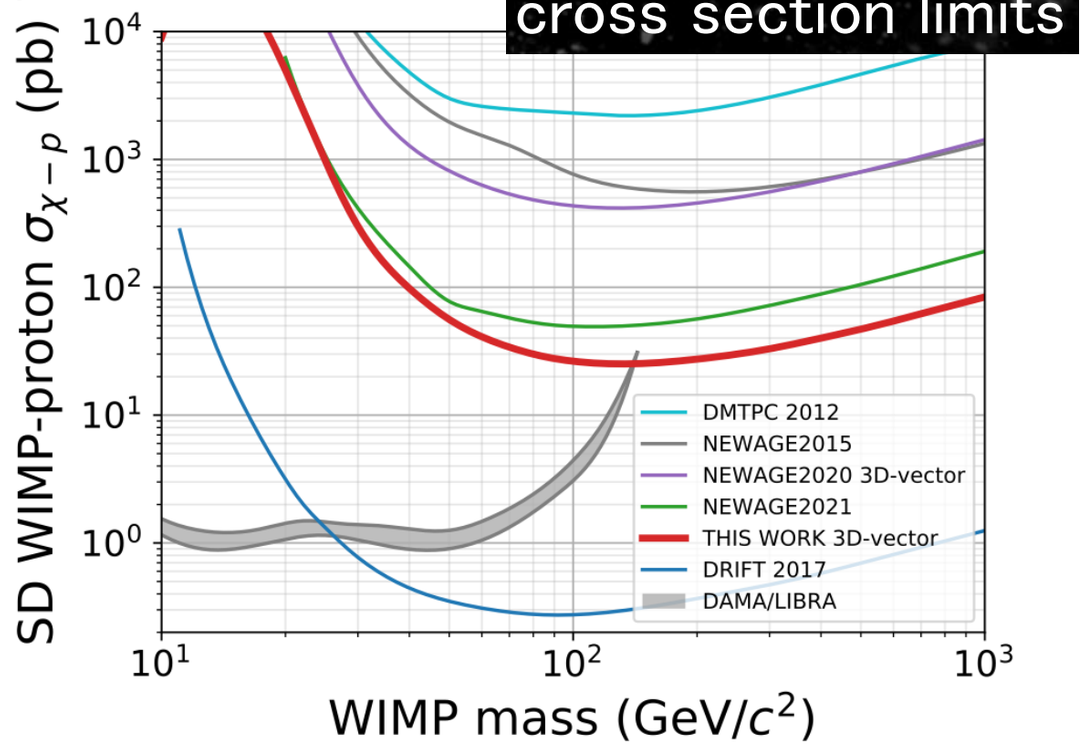
- Results
  - Best limits with directional analysis
    ×～2 improvement in a DM mass range of > 100 keV
  - Cutting into DAMA/LIBRA interpretation region
  - Best limits with directional and head-tail analysis
    ×10 improvement from NEWAGE2020 (first head-tail analysis)

PTEP (2023) ptad120

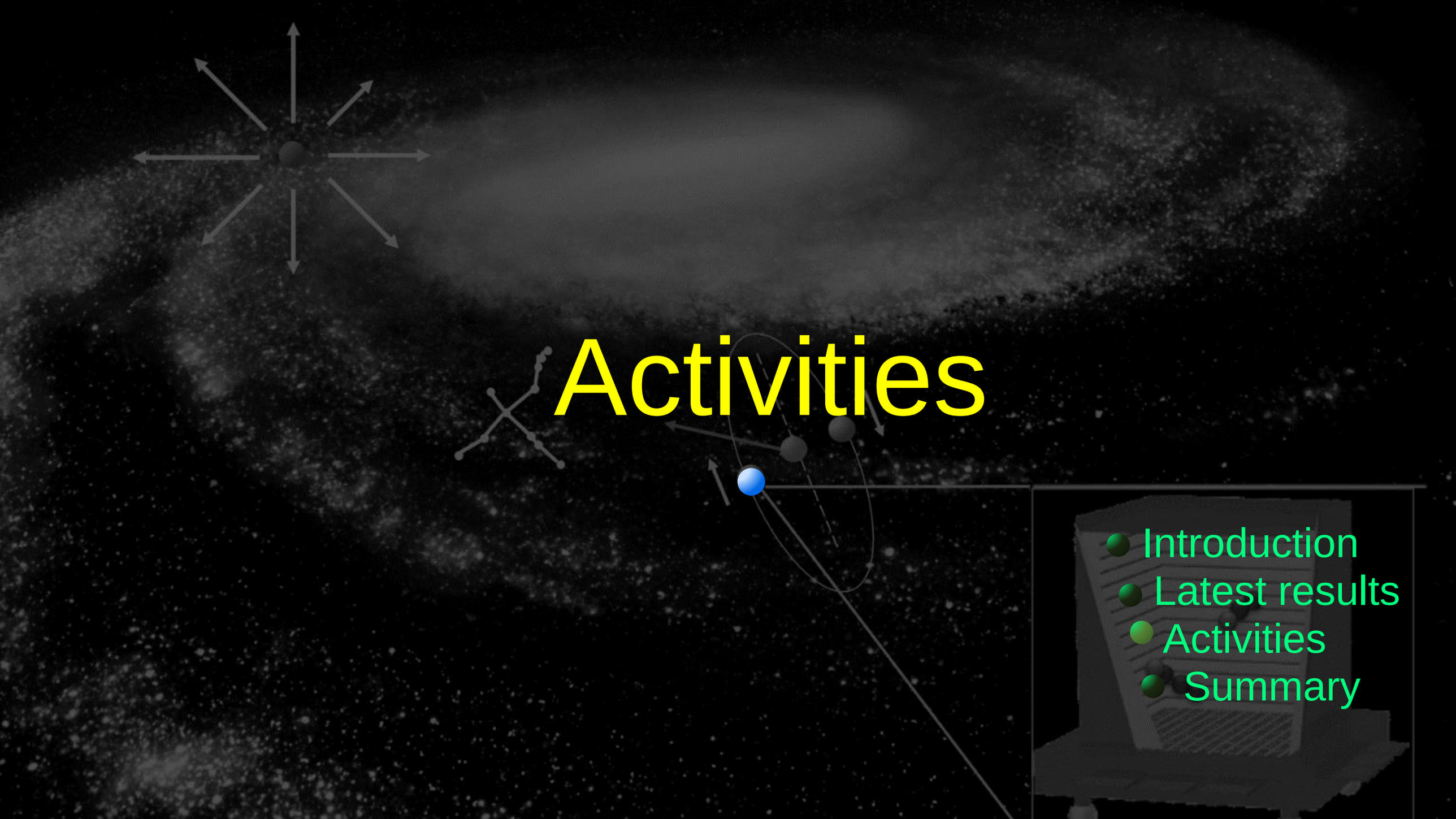
energy spectrum



cross section limits



Activities



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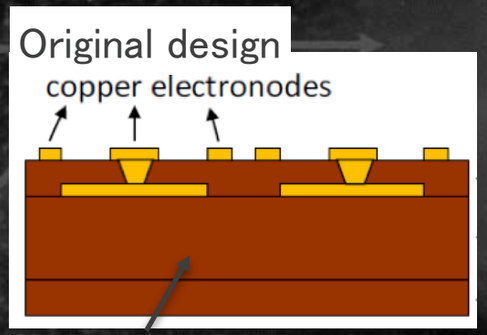
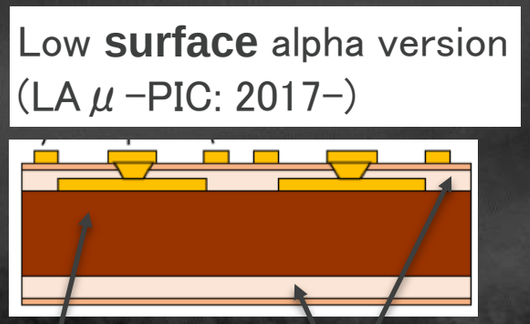
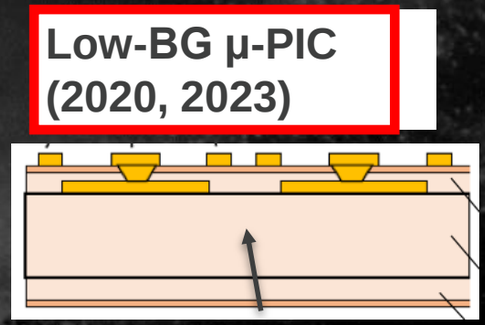
Making μ-PIC low BG



Polyimide
w/ glass cloth
(Rn contaminated)



Polyimide
w/ glass cloth



Polyimide
w/o glass cloth

Quartz + Resin (Shinetsu)

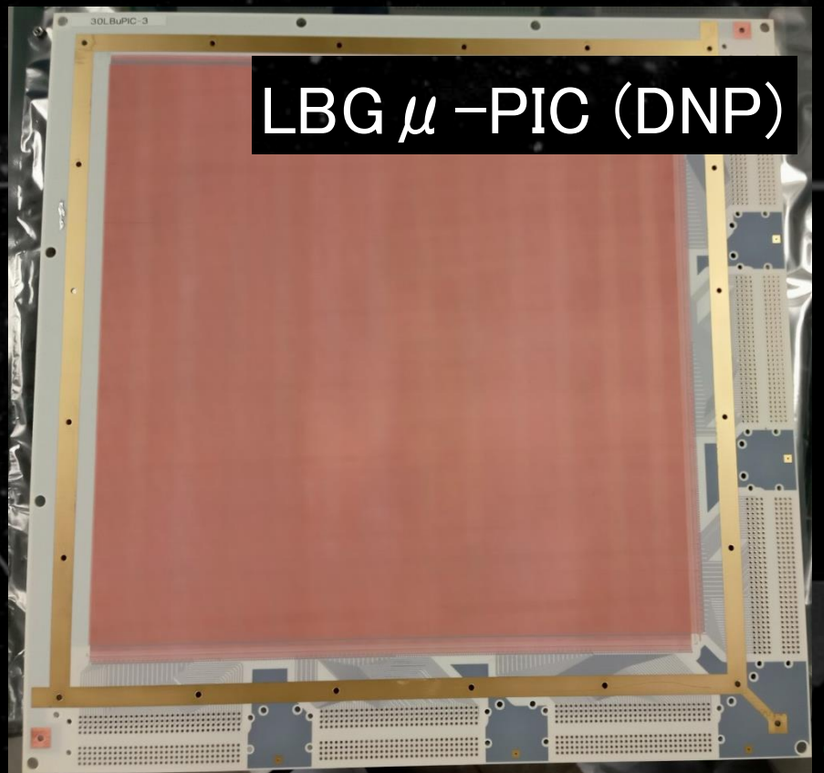
Radon emanation measurement:

LA μ-PIC: **2.3 ± 0.5** [mBq / μ-PIC]

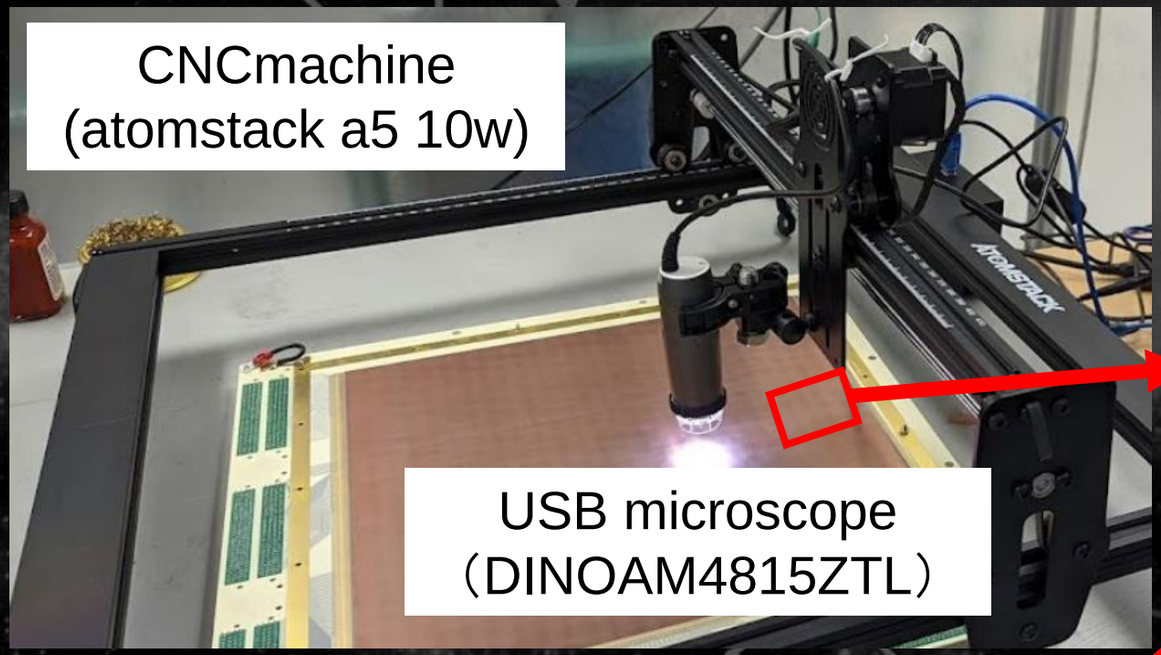
LBG μ-PIC (2023) : <**0.10** [mBq / μ-PIC]

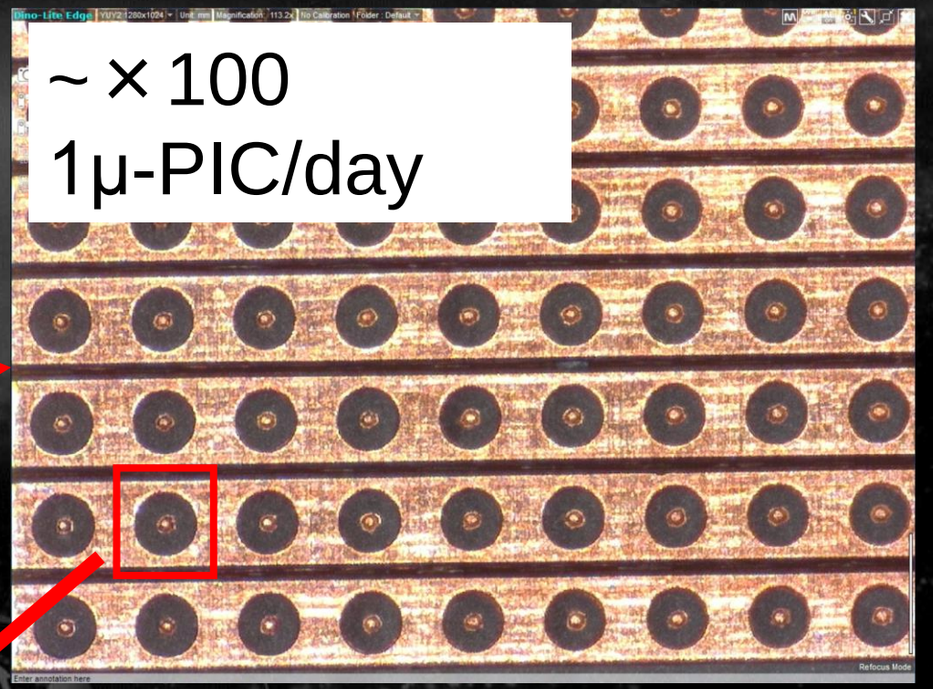
(90% C.L.)

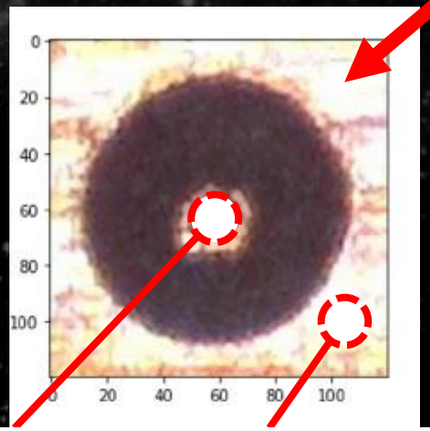
paper in preparation



• Visual inspection (R.Namai)



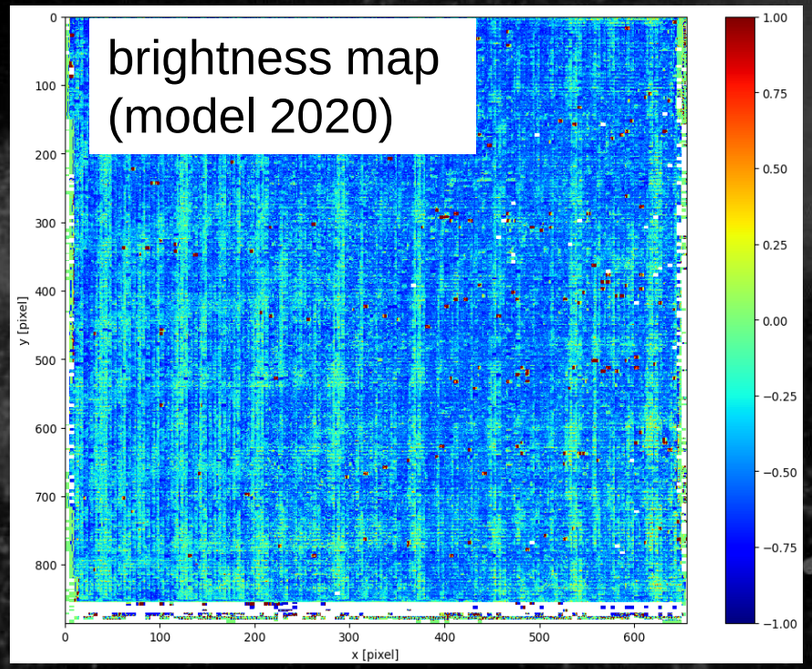


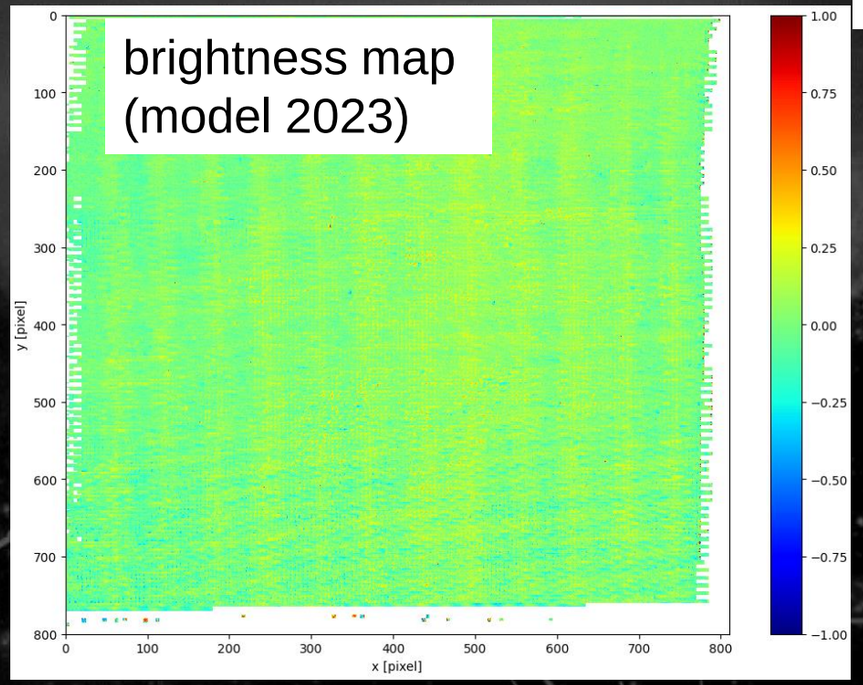


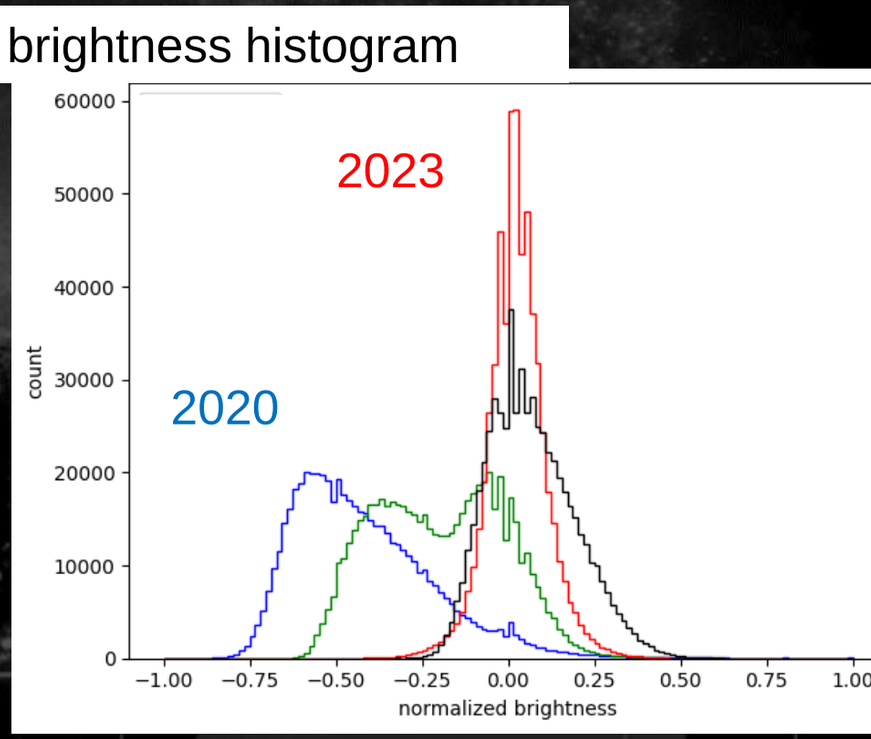
anode cathode

- anode pixel formation matters
- ”brightness” =
  (anode - cathode) / cathode

- Anode “brightness” comparison





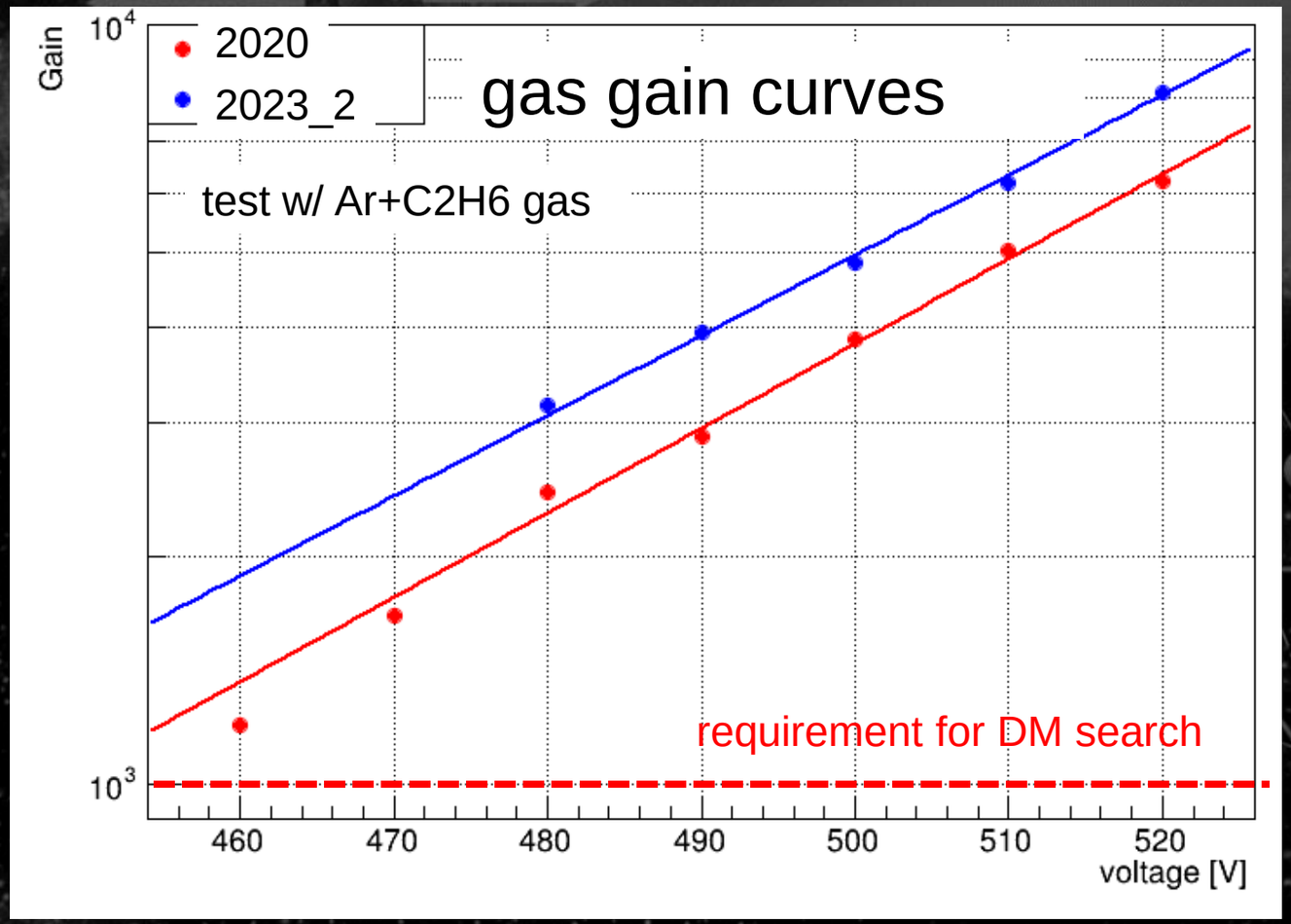


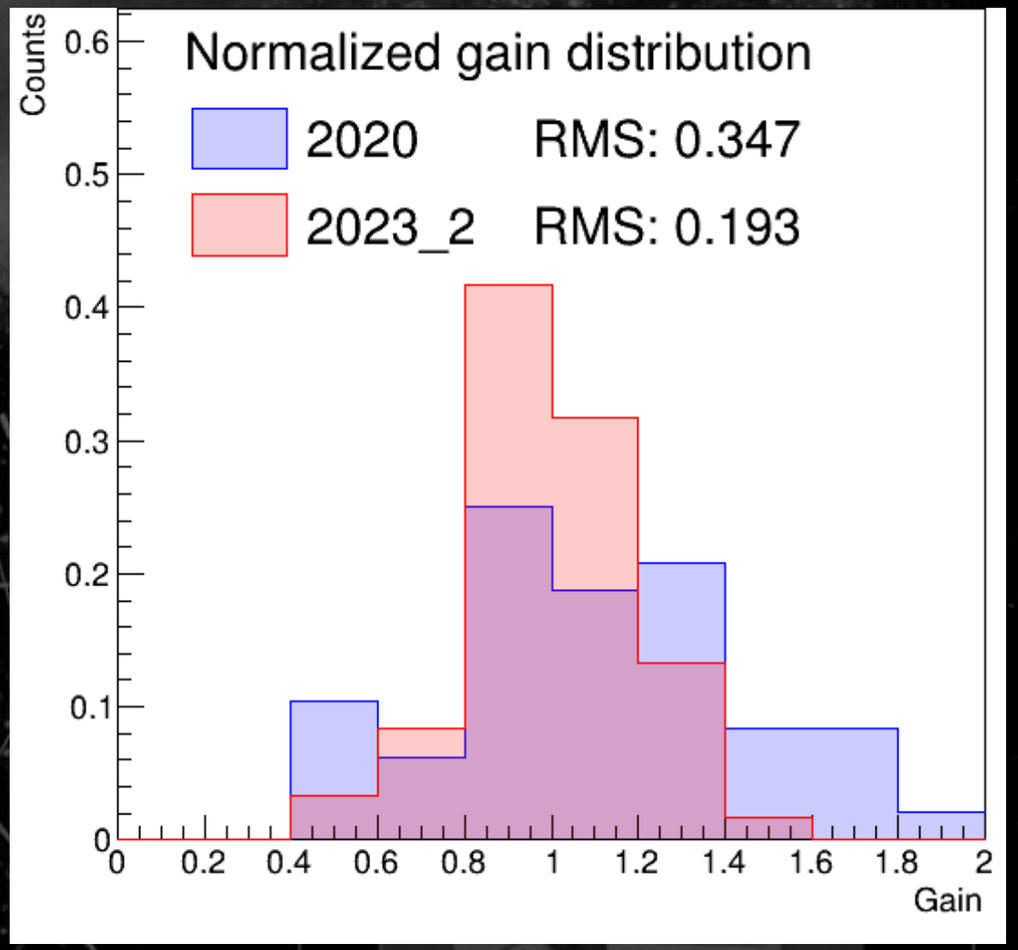
- Model 2020 had line structure.
- Same pattern was seen in the gas gain
- Great improvement was seen for model 2023.

Kentaro Miuchi

- Low BG μ-PIC performance

gas gain distribution

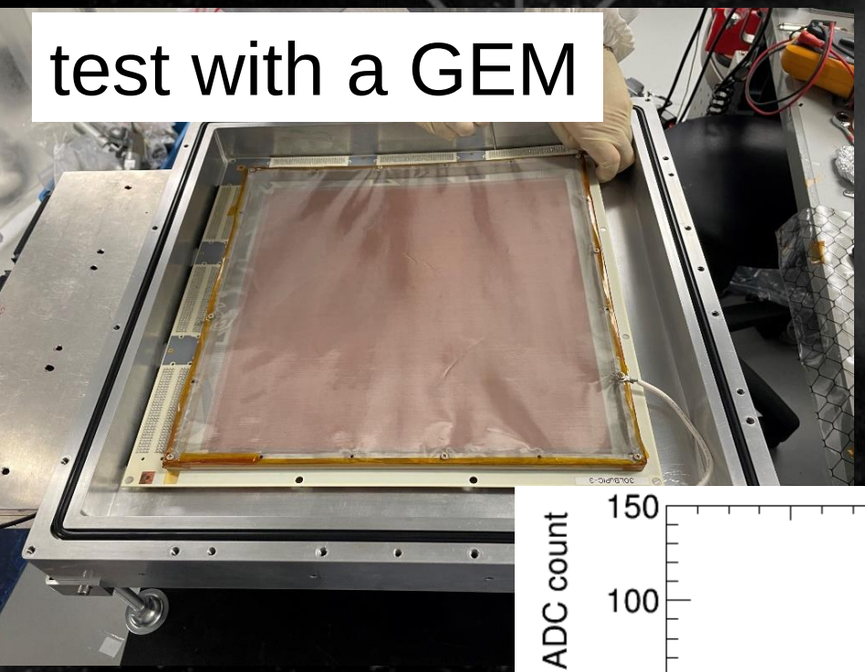


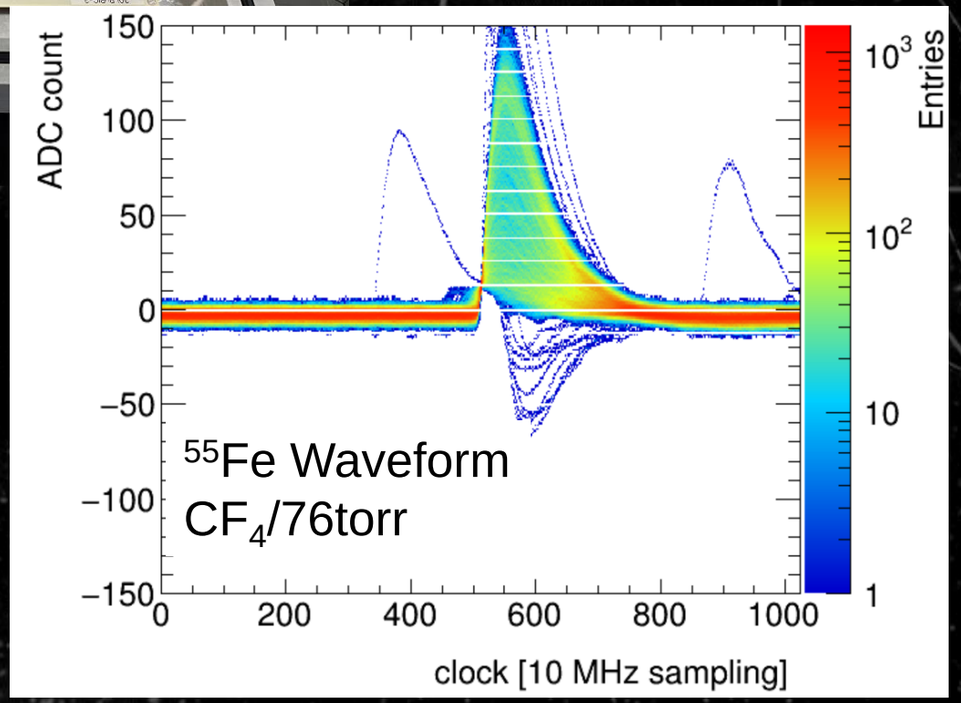


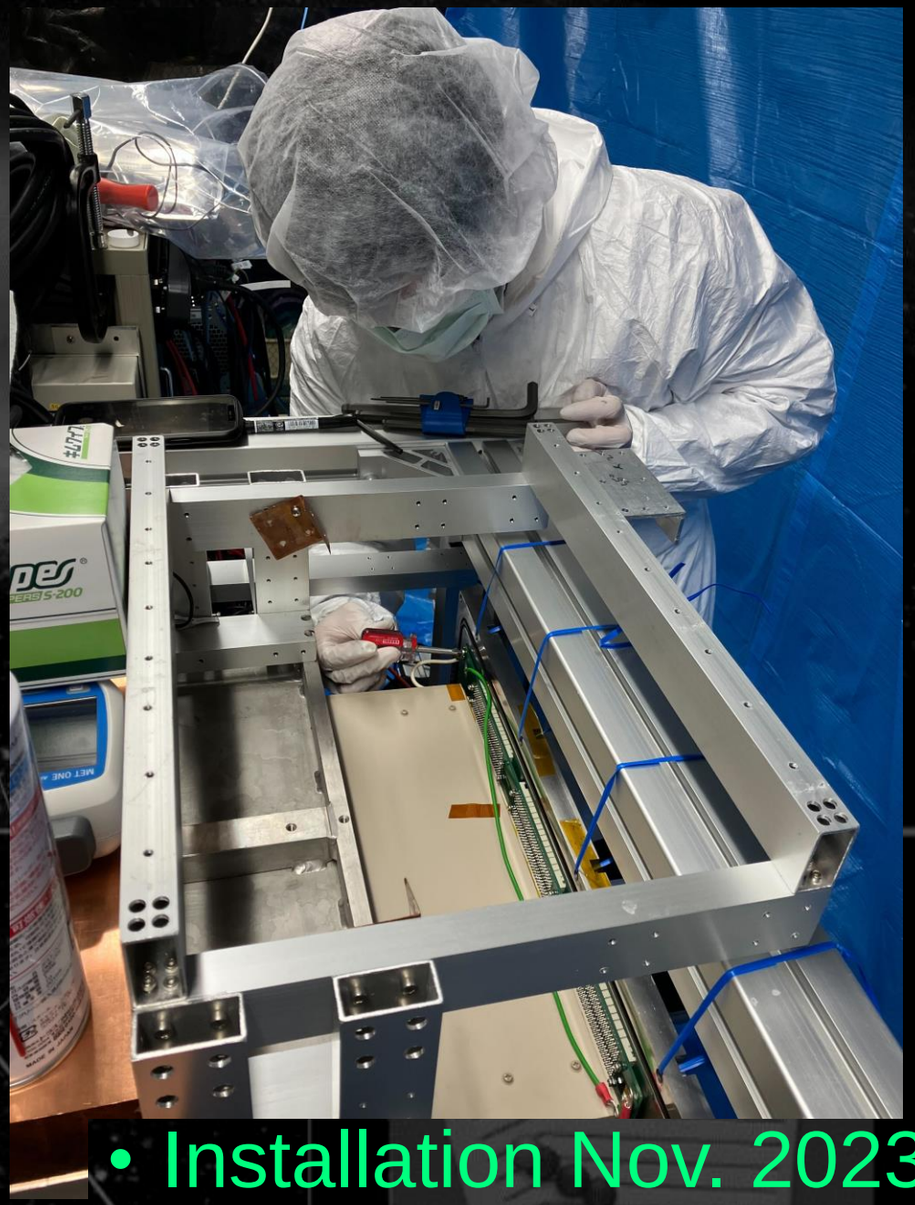
- 2023 model shows sufficient performance

- Low BG μ-PIC for Kamioka run

test with a GEM

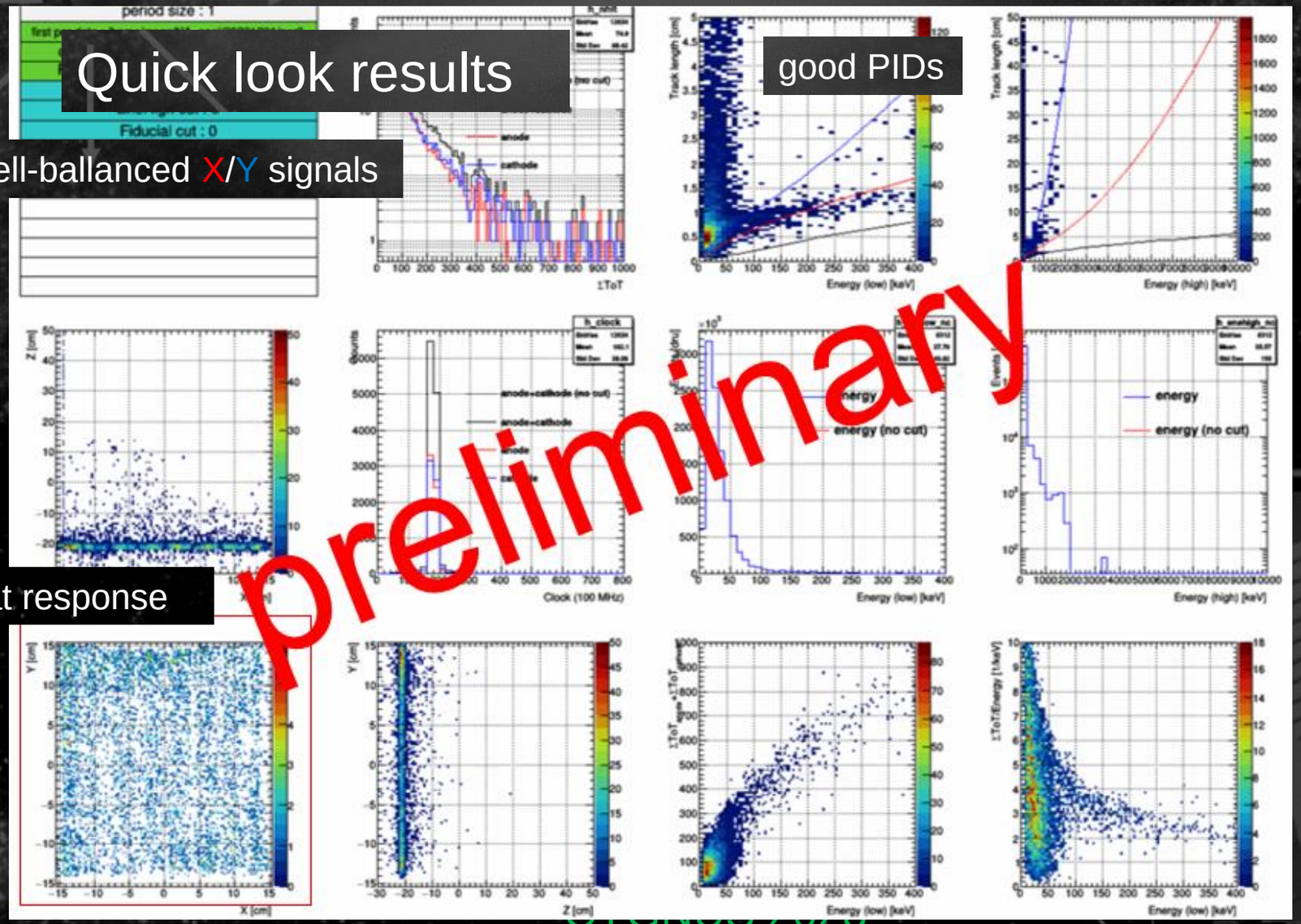






- Installation Nov. 2023
- NEWAGE-0.3 b ’’’ : commissioning ongoing

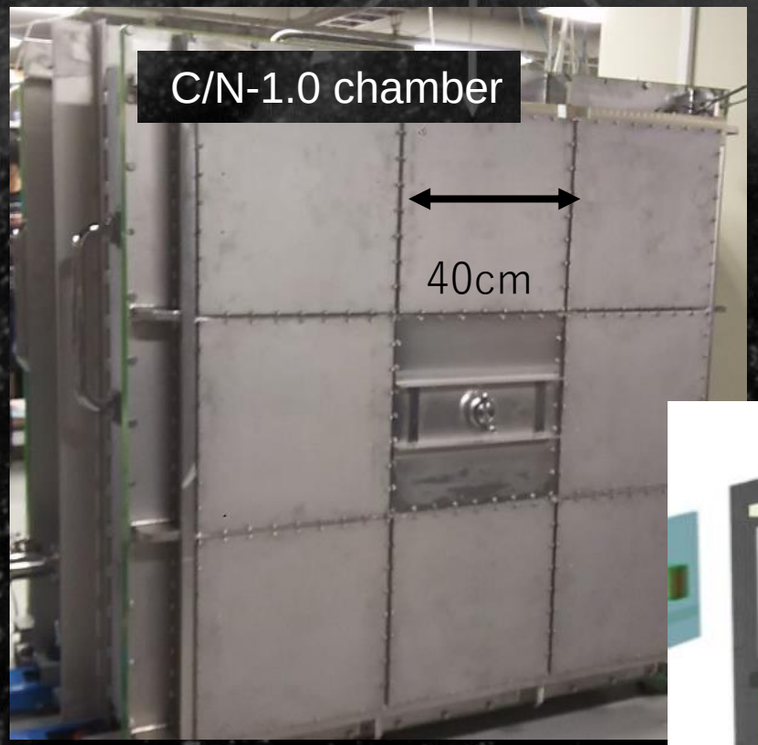
- NEWAGE-0.3b’’’status: so far so good!
  - Details will be reported in a few months



“CYGNUS”-KM chamber

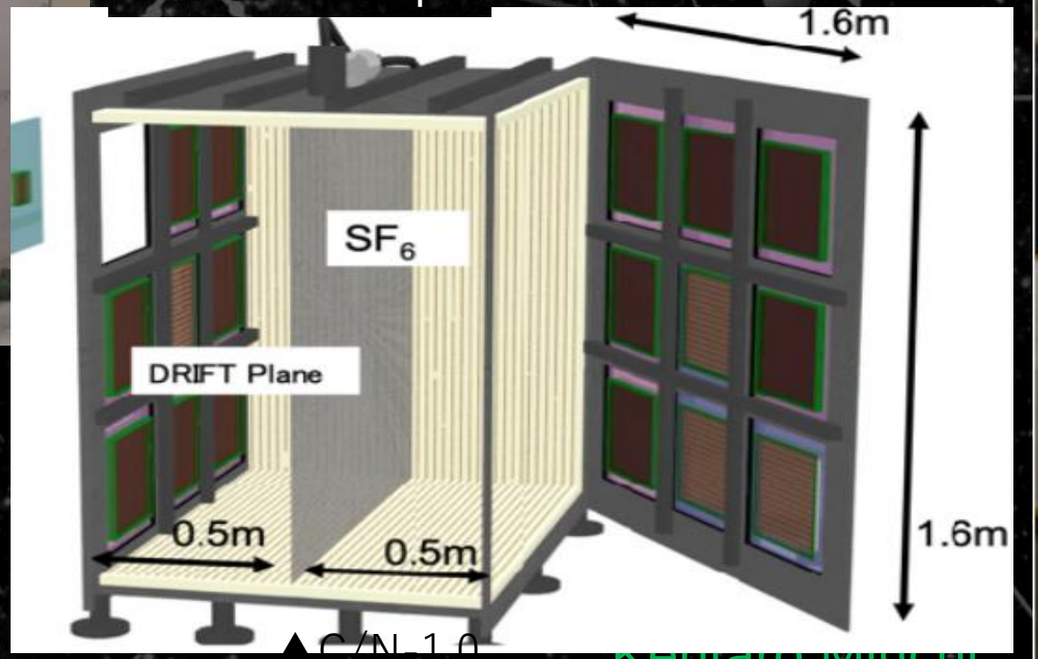
S. Higashino

- C/N-1.0 chamber (18pcs × 40×40 cm^2 windows)



- Originally we planned to use resistive sheet for the field cage.
- Performance degradation was seen in a long-term use...

C/N-1.0 concepts



▲C/N-1.0

• Low BG Molecular Sieve production (H. Ogawa)

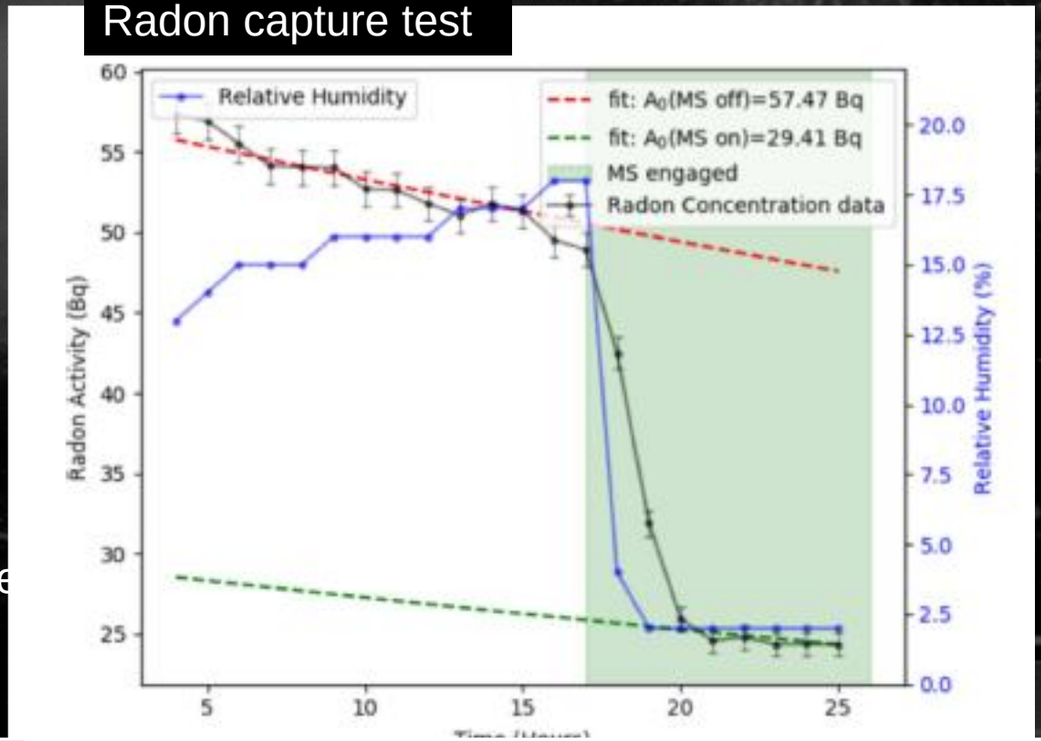
• production procedure established

JINST (2021) 16P06024

This work
(Nihon University)

Commercially available one
(Sigma-Aldrich)

Radon capture test



Results

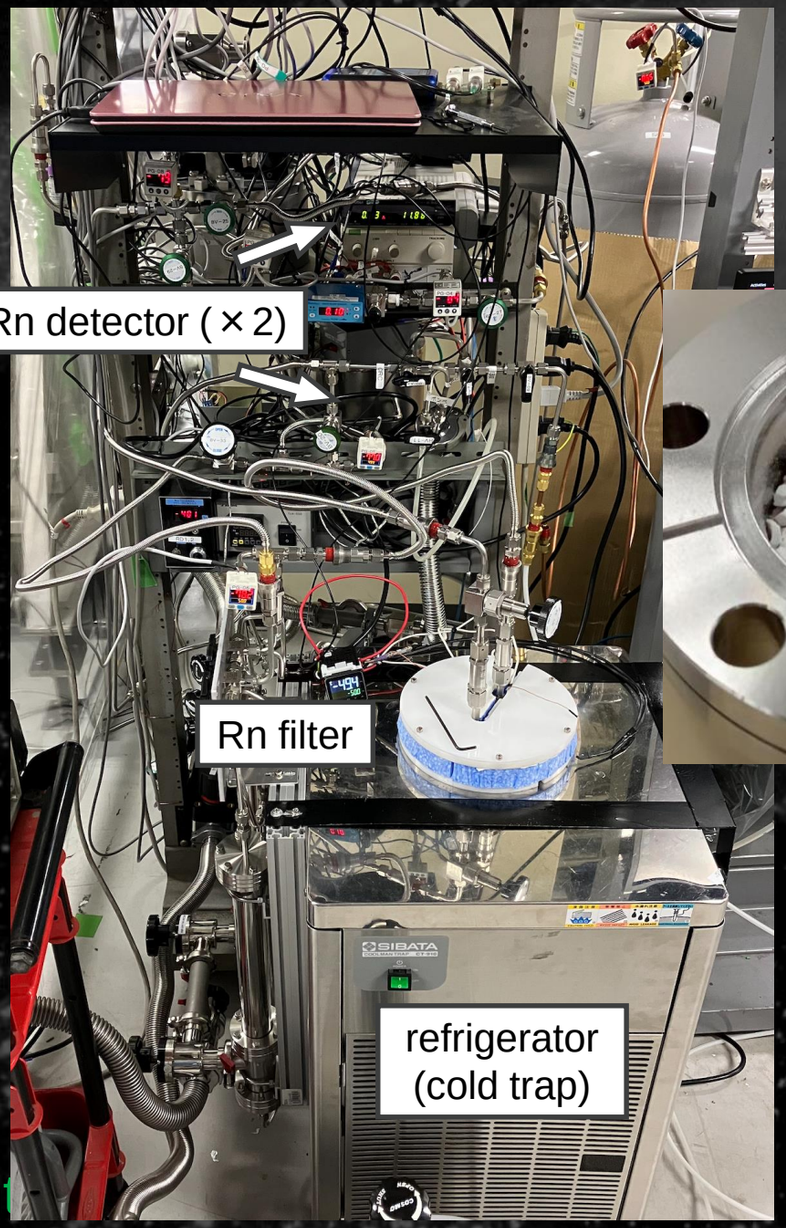
Molecular Sieve	^{222}Rn Emanated per ^{222}Rn captured ($\times 10^{-3}$)
NU-developed	2.8±0.7
Sigma-Aldrich	5.4±0.4

NU-developed MS	^{222}Rn Captured per kg (Bq kg^{-1})	^{222}Rn Emanated per kg (mBq kg^{-1})	^{222}Rn Emanated per ^{222}Rn Captured ($\times 10^{-3}$)
Granules	35±2	99±23	2.8±0.7
Powder	330±3	680±30	2.1±0.1

CYGNUS 202

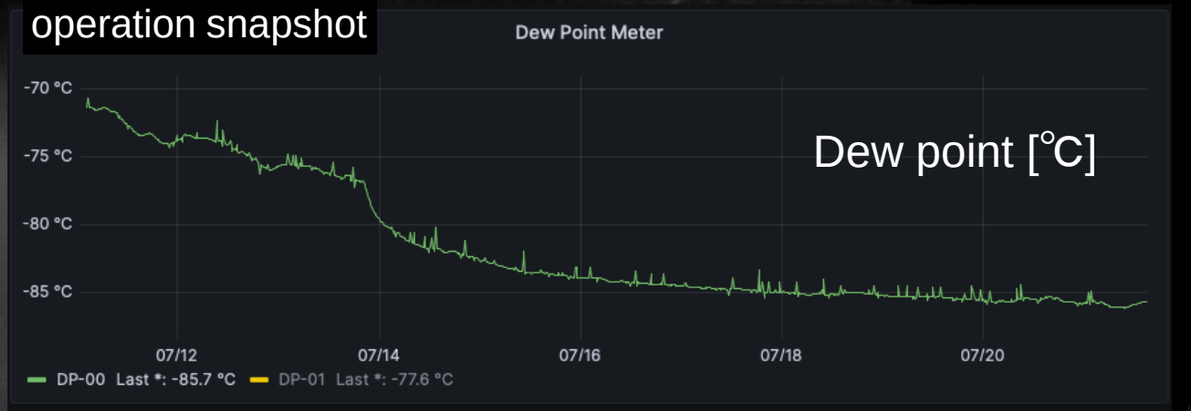
- Better performance
- Repeating O(kg) productions

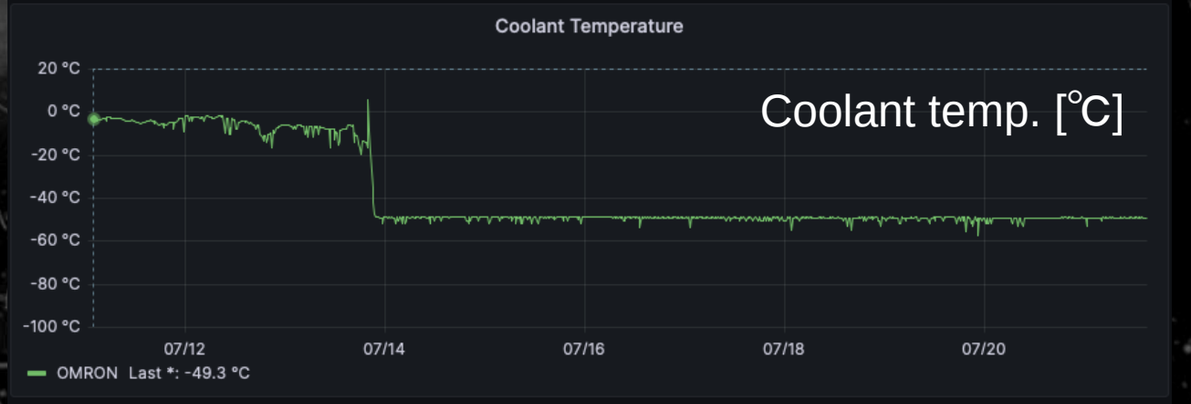
• Gas circulation system

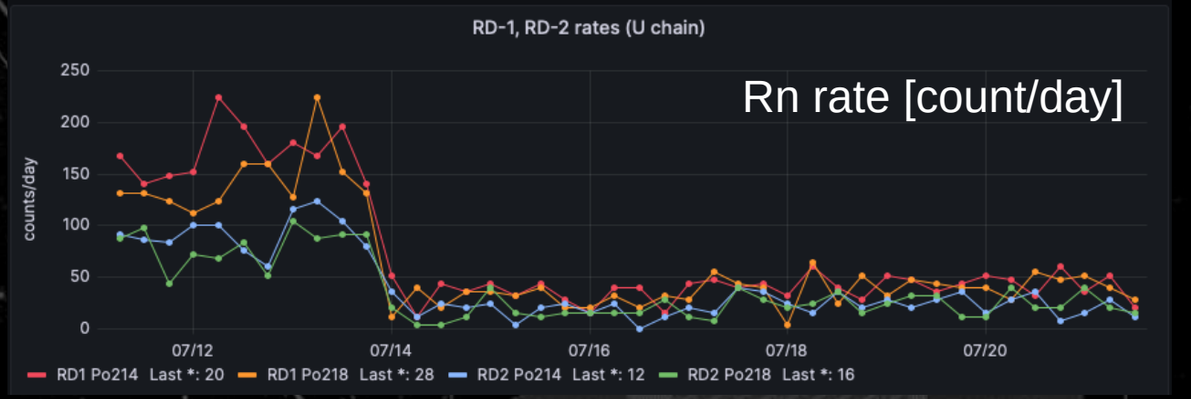


low-BG zeolite (5A)

operation snapshot



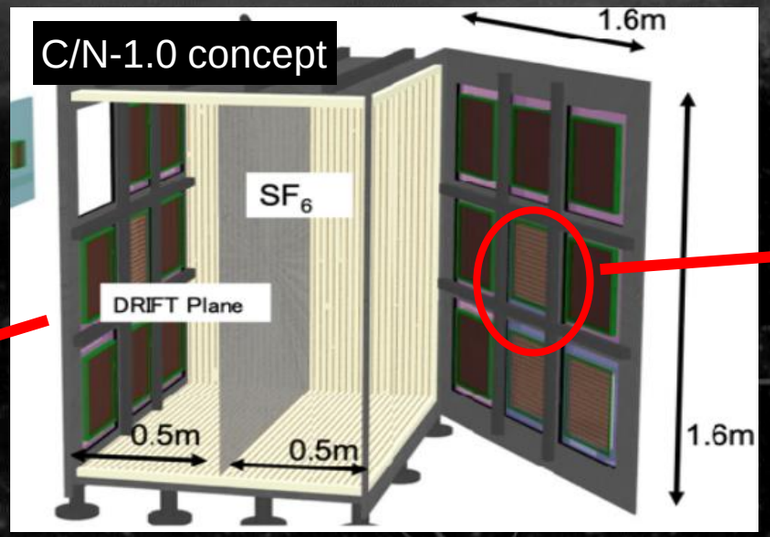


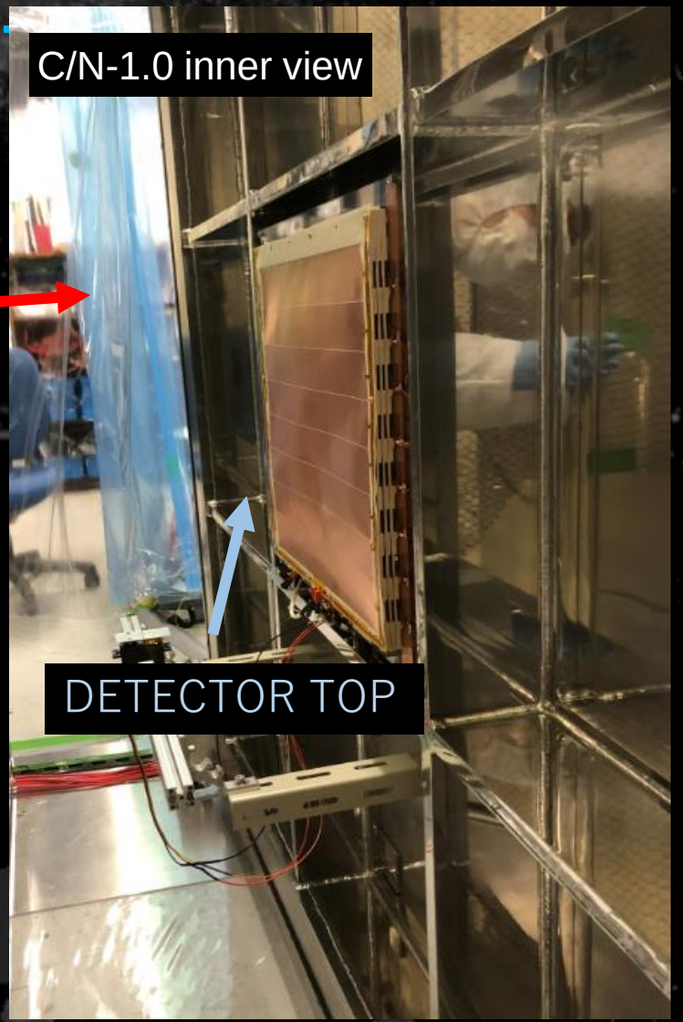


• ready for housing detectors

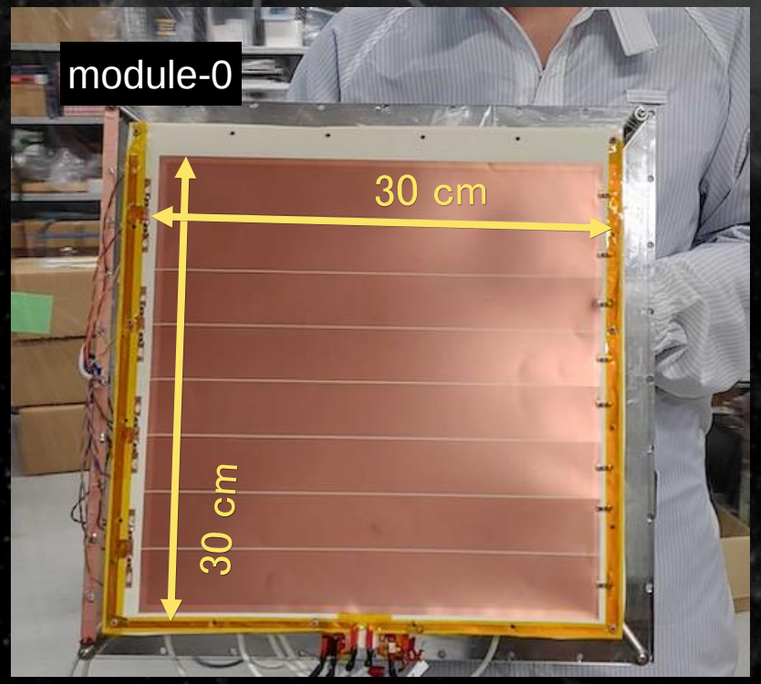
Detectors for C/N-1.0

- Two requirements for the detector modules
  - Electronics needs to fit 46 × 46 cm^2.
  - Detector top needs to be at the electrical ground level.

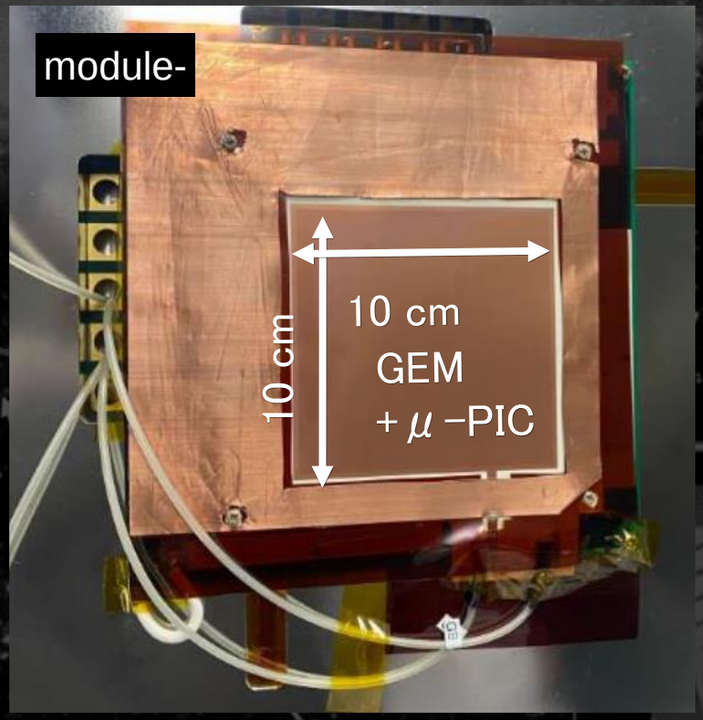




- Two Kobe modules for C/N-1.0 (M. Ofuji)
  - Module-0: larger, w/o tracking for BG measurement
  - Module-1: smaller, w/ tracking as a DM detector

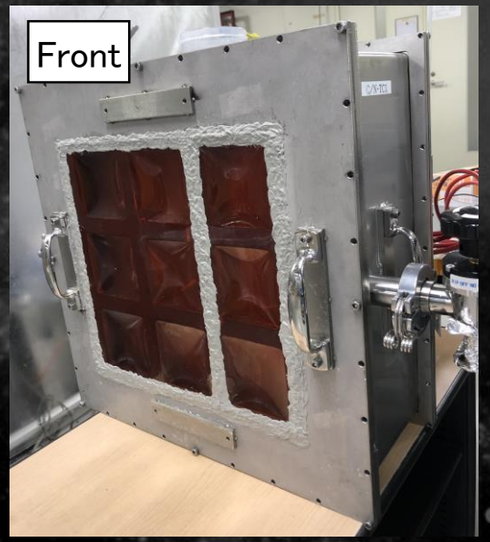


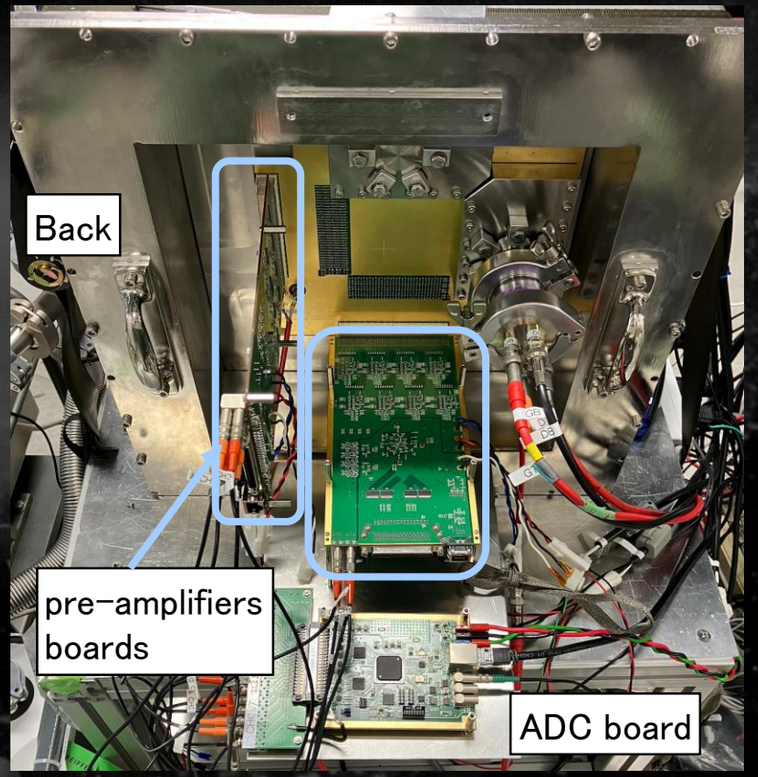
3 GEMs
30 × 30 cm^2 detection area
read by 8 pads
8 readout channels

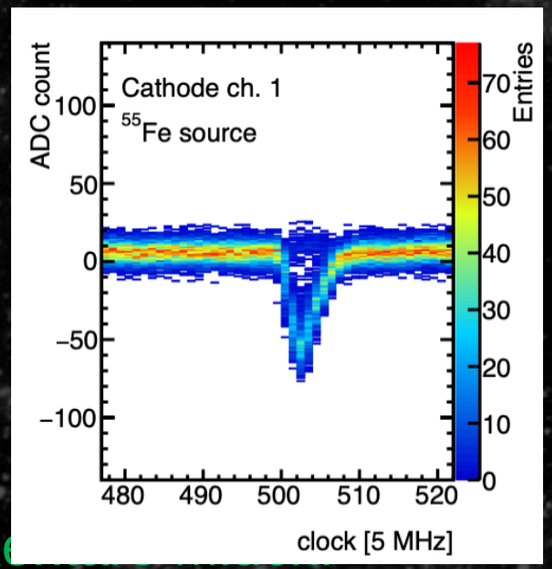


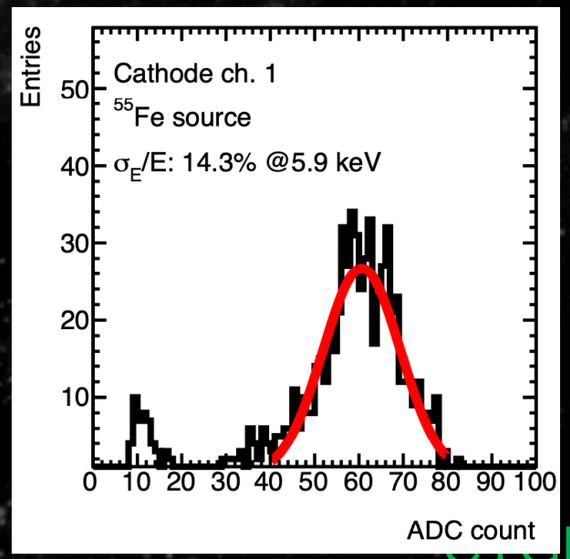
GEM + μ –PIC
10 × 10 cm^2 detection area
read by 256 strips
Track reconstruction

- Module-1 test status
  - being tested in a test chamber



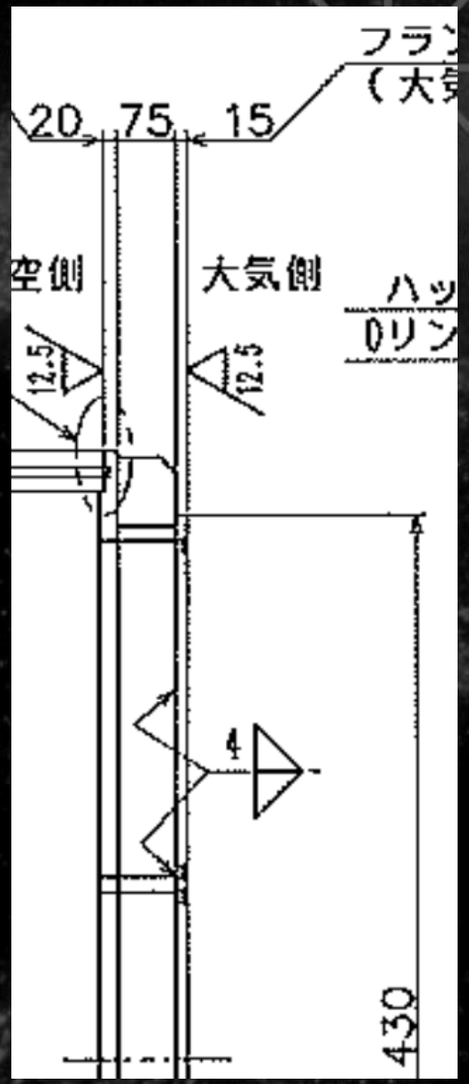


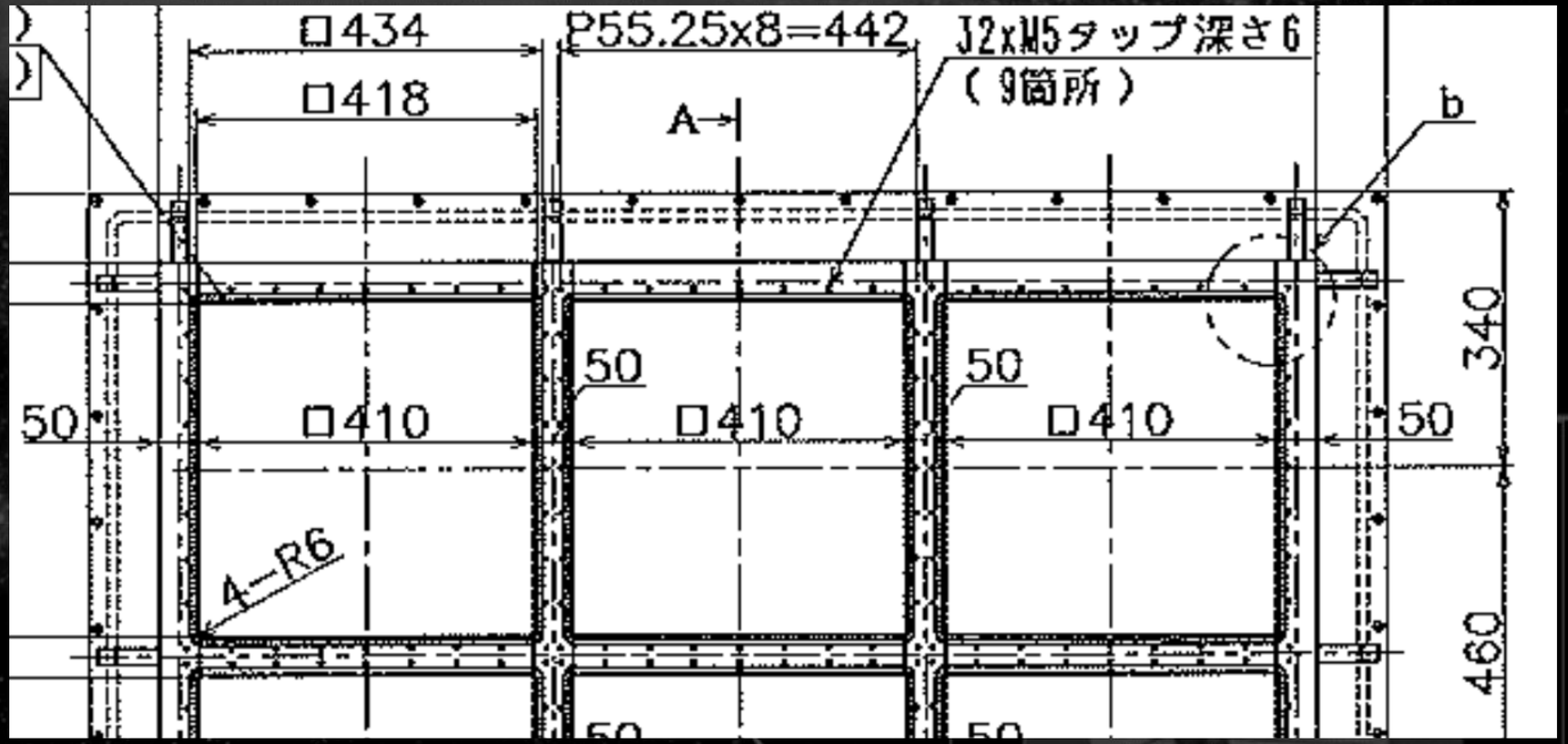




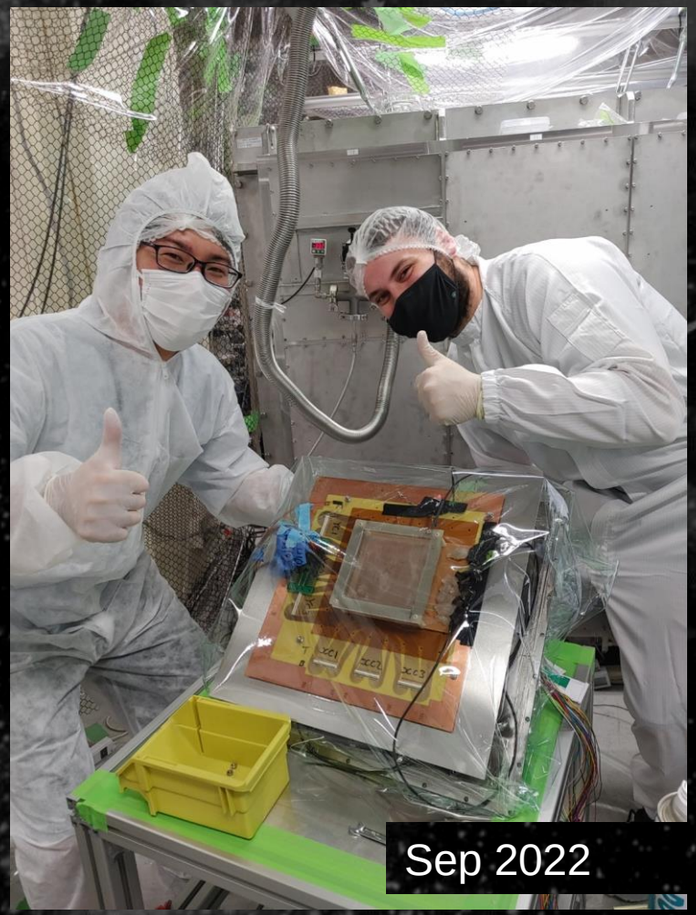
- Fundamental test as a gas detector was completed.
- Tracking performance is being tested

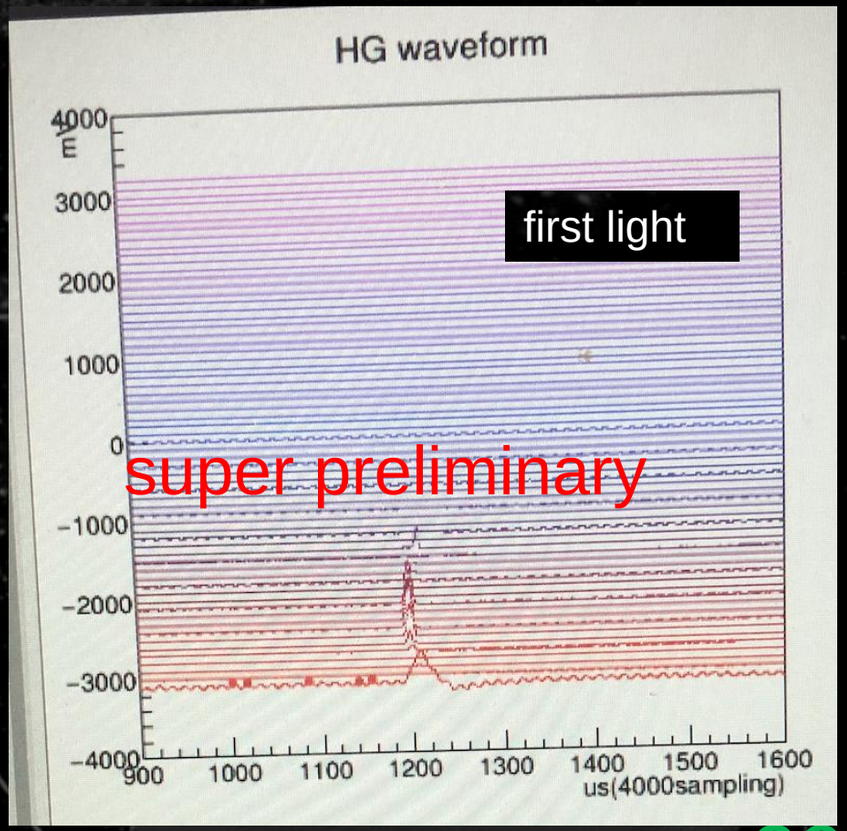
- Details to welcome your modules...





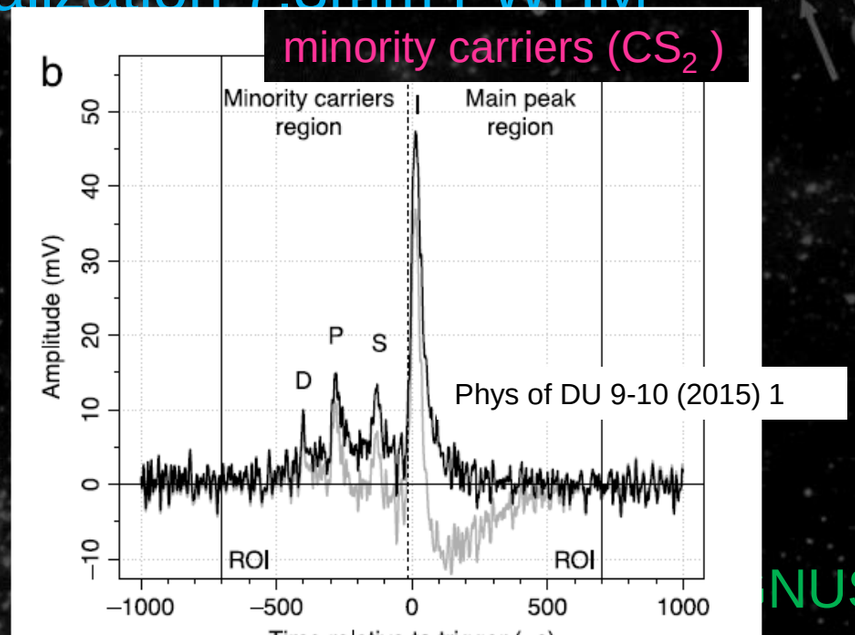
- and, actually welcomed.
  - Sheffield MICROMEGAS detector test

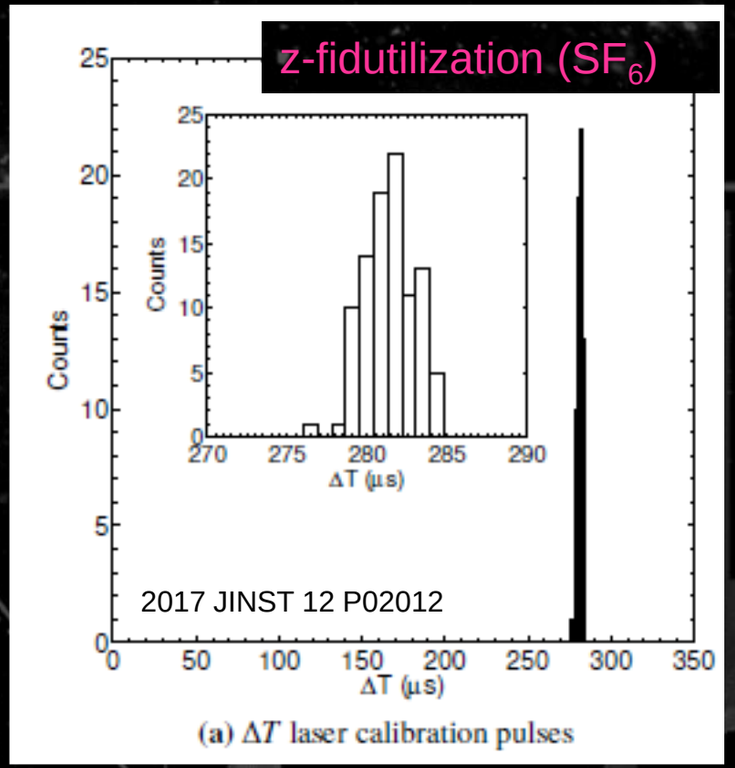




Negative ion TPC Study

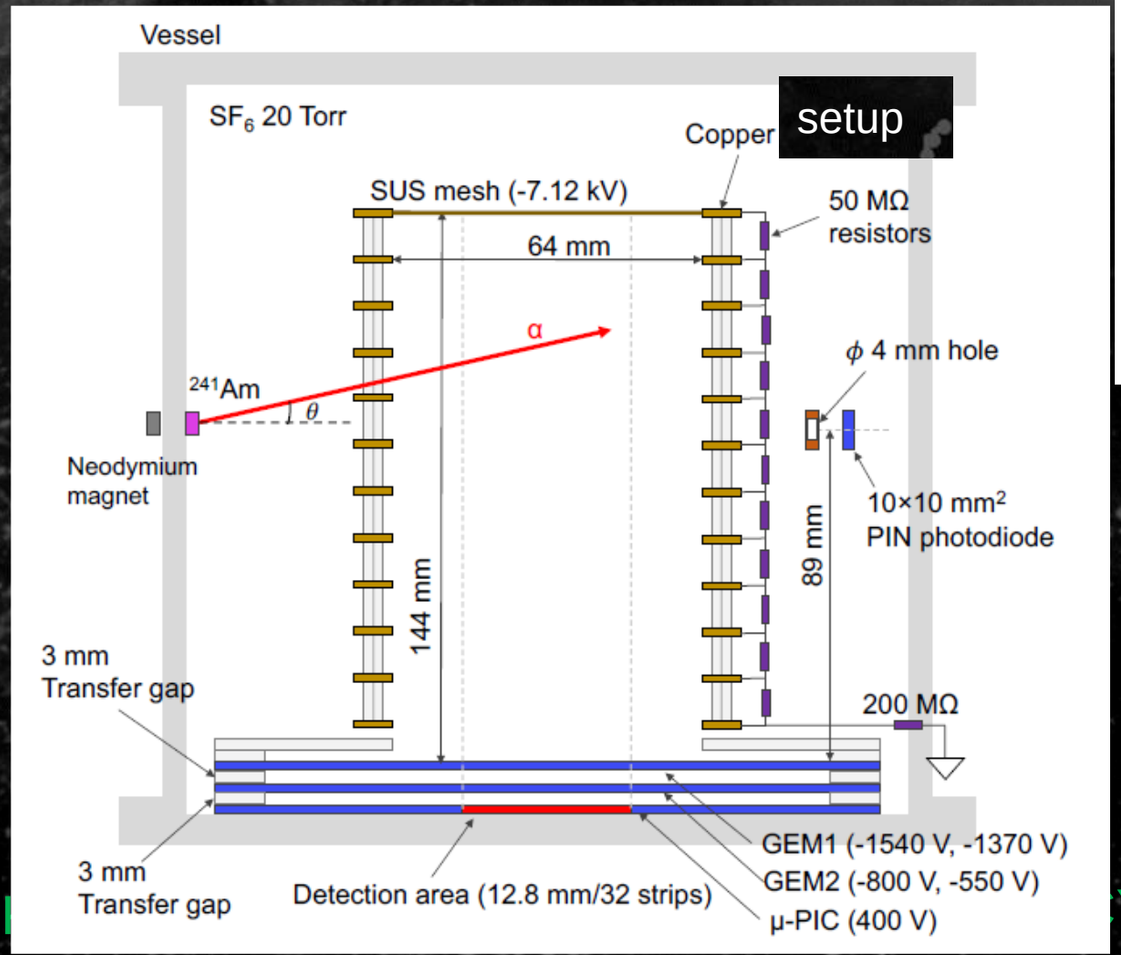
- no “S1” signal
- Pioneered by DRIFT group
- Minority carrier discovery (CS_2+O_2, Occidental group)
  - use several ion species with different drift velocities
  - small diffusion
  - ⇒ z fiducialization possible ⇒LOW BG !
- SF_6 discovery (2015, UNM group).
  - z-fiducialization 7.3mm FWHM



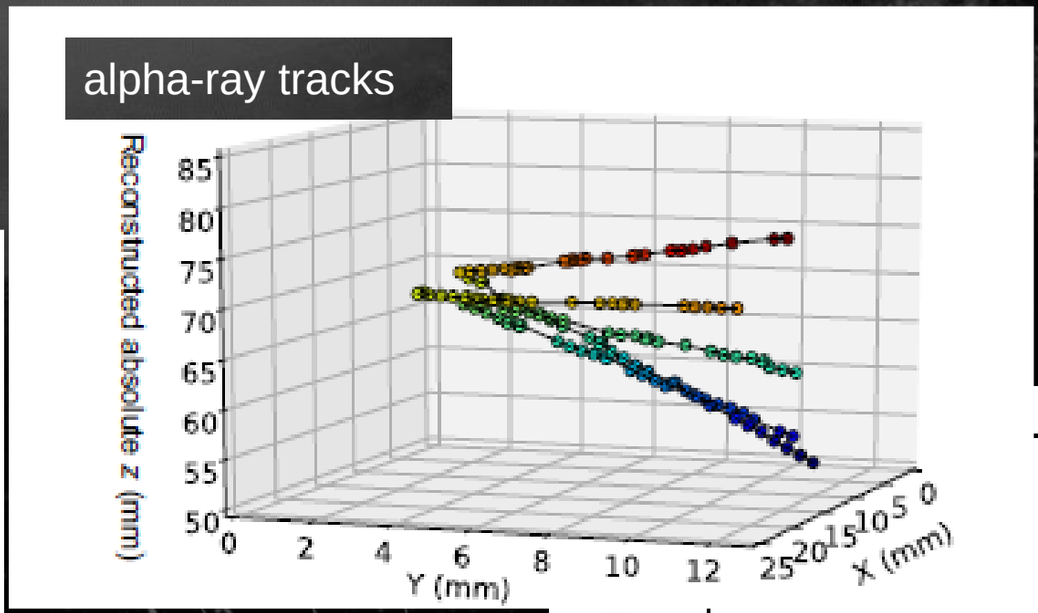


- Nuclear tracks detection in SF_6
  - strip readout + dedicated ASICs
  - z-reconstruction
  - tracking

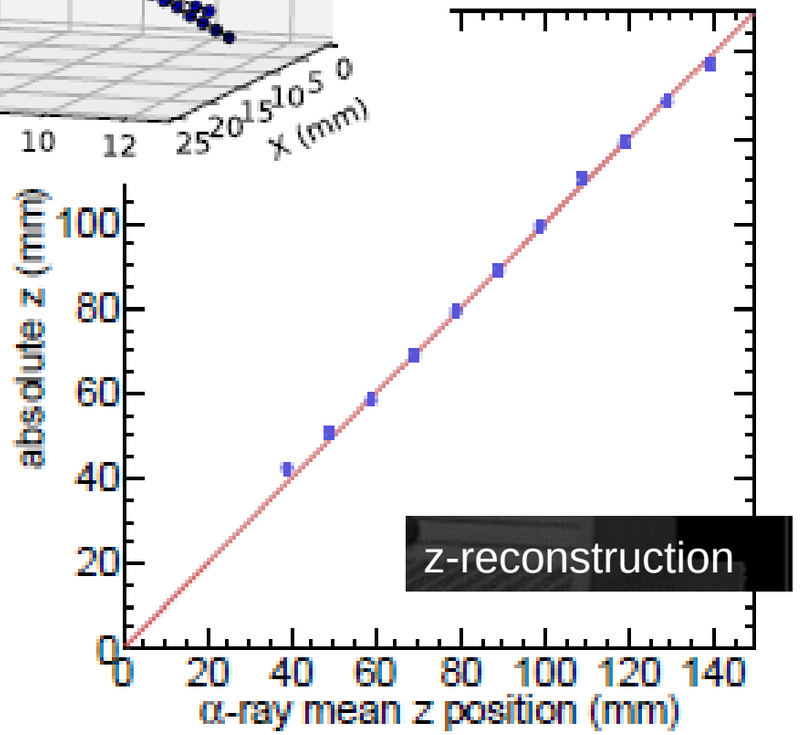
T. Ikeda+
JINST (2020), P07015



setup



alpha-ray tracks



z-reconstruction

- ASIC development for negative ion TPCs
  - “LTARS” series with Liq. argon groups at KEK, Iwata
  - LTARS 2018 at hand

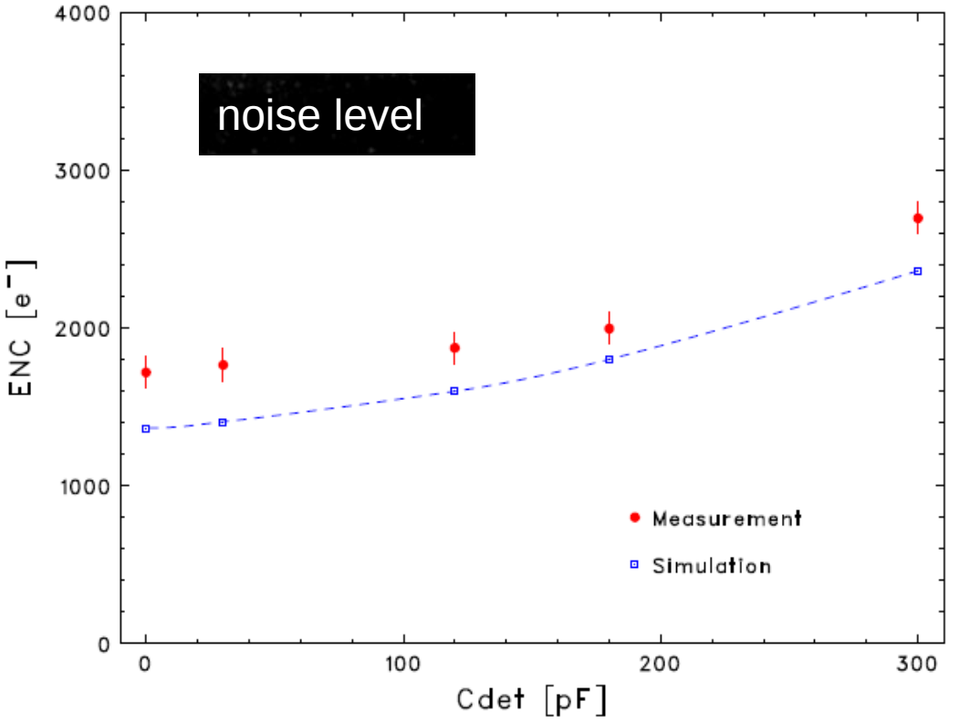
T. Kishishita+
JINST (2020) 15 T09009

LTARS 2018 SPECS

Table 1. Technological parameters and requirements to the ASIC.

Technology	Silterra 180 nm CMOS	
Chip size	2.5×5 mm^2	
The number of channels	16	
Supply power	1.8 V core/IO, max. 2.4 mW/ch	
Fabrication options	6 metals, deep N-well, high-value poly res., MIM cap.	
Detector type	NIμ-TPC	LAr-TPC
Minimum signal charge	≈3 fC	≈10 fC
Shaping time	4 μs	1 μs
Operating condition	room temperature	−185 °C
Detector capacitance (C_{det}) [a]	~300 pF	
Dynamic range	±80 fC for narrow range, ±1600 fC for wide range	
Voltage gain	10 mV/fC for narrow range, 0.5 mV/fC for wide range	
ENC	3000 e$^-$ (S/N>20) for small signals, < 6.4 × 10^4 e$^-$ for large signals	

[a]: Estimated from the pad size of MPGDs.



- “TIGAr”, a compact board to fit with C/N-1.0

T. Shimizu (Waseda)

TIGArBoard　構造/仕様

ASIC
・LTARS2018A chip

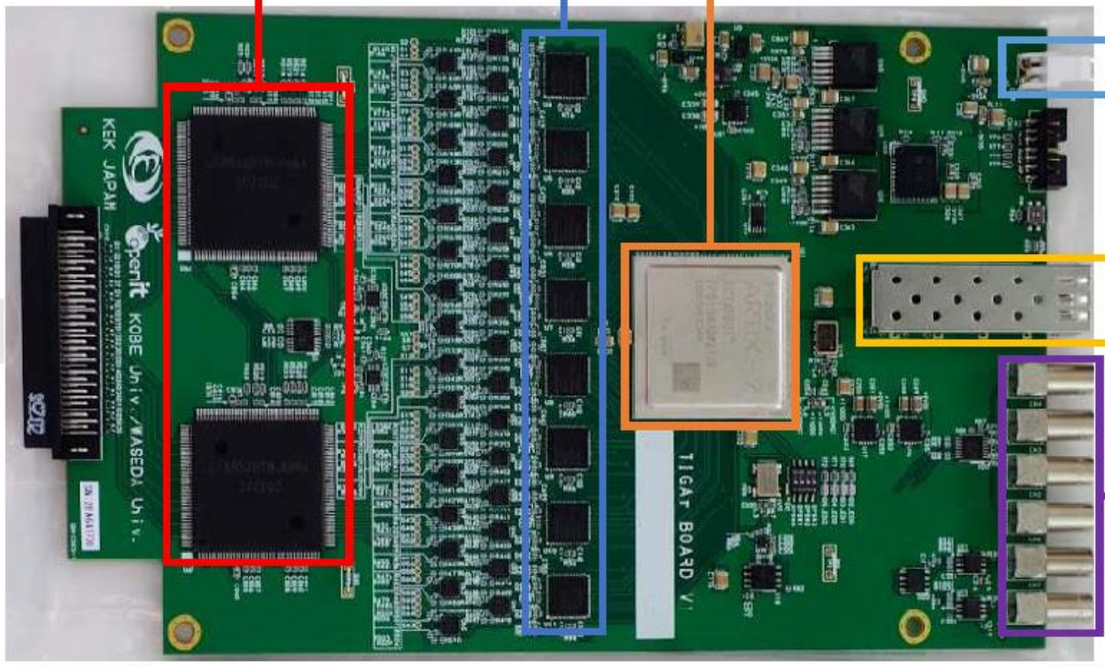
ADC
・12bit
・8ch/chip
・2.5M sampling

FPGA
・Xilinx : Artix7 XC7A200T

電源供給
・単電源+5.0V / 3.0A

SFP
・Send to data by GTX

NIMコネクタ(同期/クロック)
・NIM_IN:4
・NIM_OUT:2

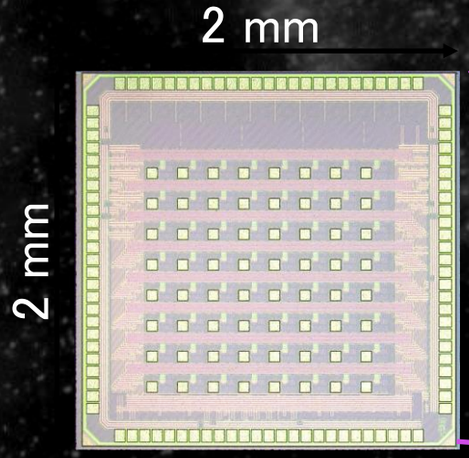


- 仕様
  - Input : 32ch処理可能
  - Output : 64ch (HG/LG)
  - SiTCP通信, UDP通信
  - I/Oコネクタ数の見直し
  - フランジを想定
    - I/O片側統一
    - 角を削り干渉を防ぐ

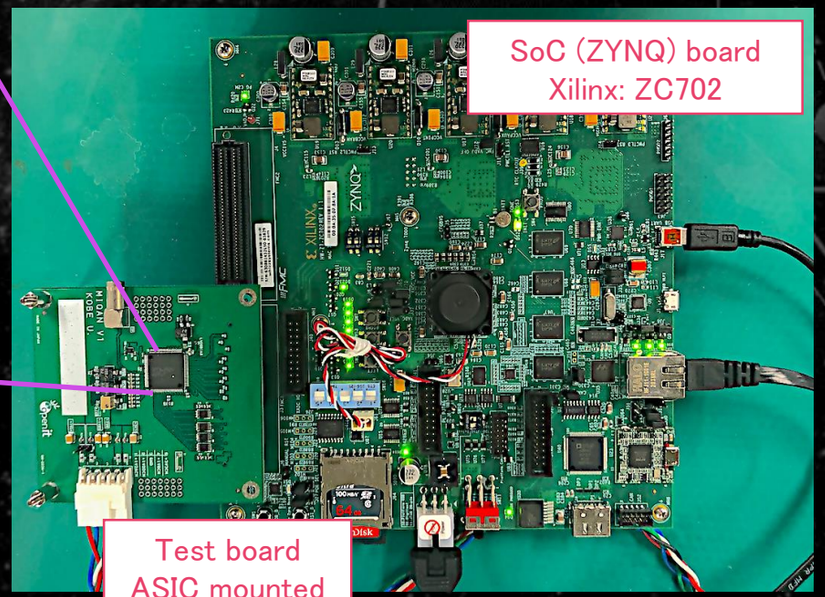
PIXEL readout (QPIX NEO v1)

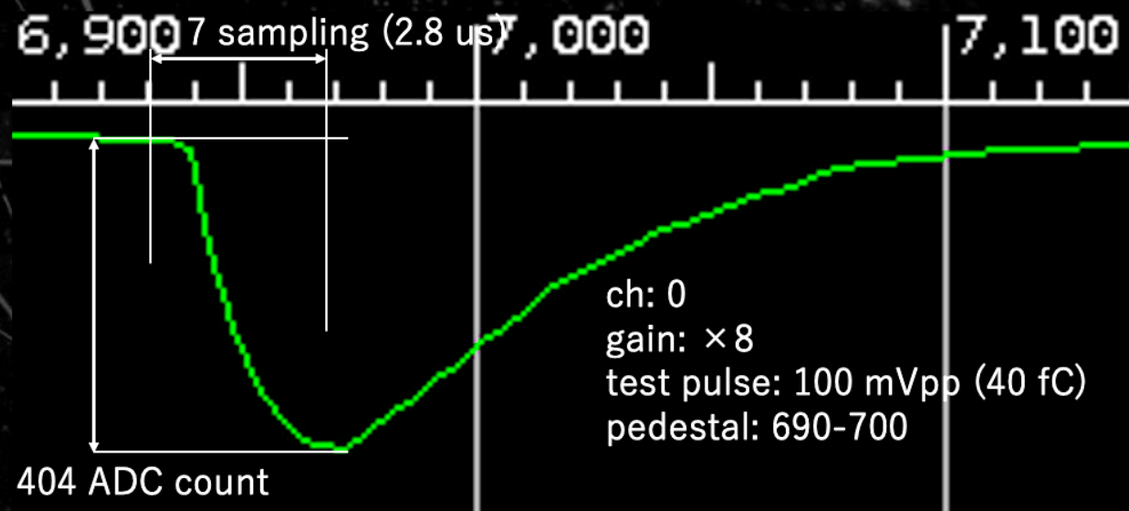
S. Higashino

- Energy threshold is limited due to electrode's strip pitch (400 μm)
  - Started to develop fine granularity "pixel" readout detector
  - 64 ch ASIC developed and testing its performance



readout ASIC
$(155\ \mu m)^2$ pixel pad
connecting to electrodes
by bump bonding



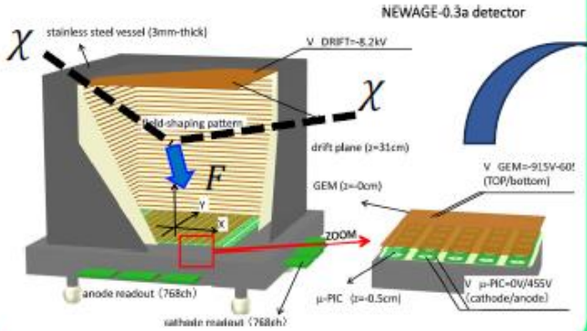


Analog circuit + ADC
successfully working!

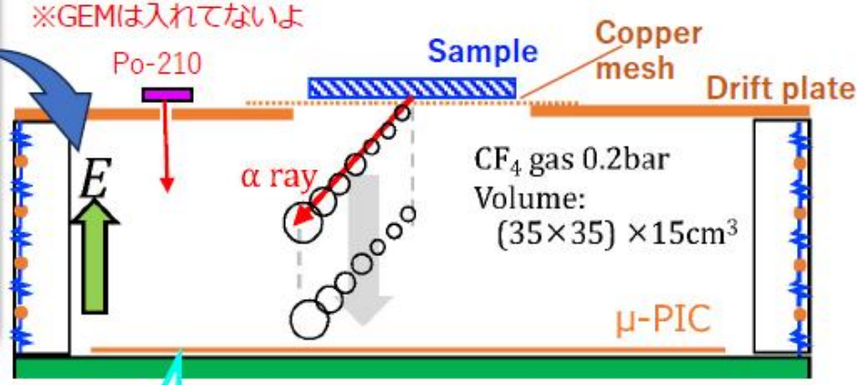
α-ray Imaging

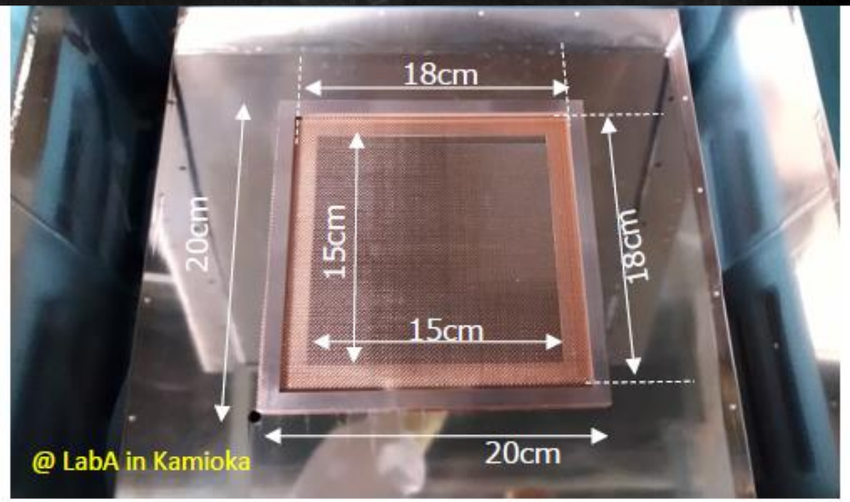
H.Ito
NIM A Volume 953, (2020), 163050

Reusing NEWAGE-0.3a
(Sep. ~ Dec. 2008 in 神岡)
PLB 686 (2010) 11.

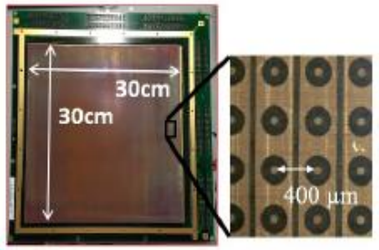


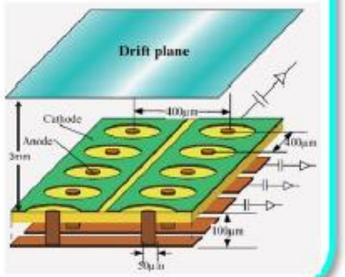
AICHAM: Alpha-particle Imaging CHAMber
表面アルファ線イメージ分析のための、
μ-PICを用いたガスTPC(time-projection chamber)
NIMA 953 (2020) 163050.
※GEMは入れてないよ

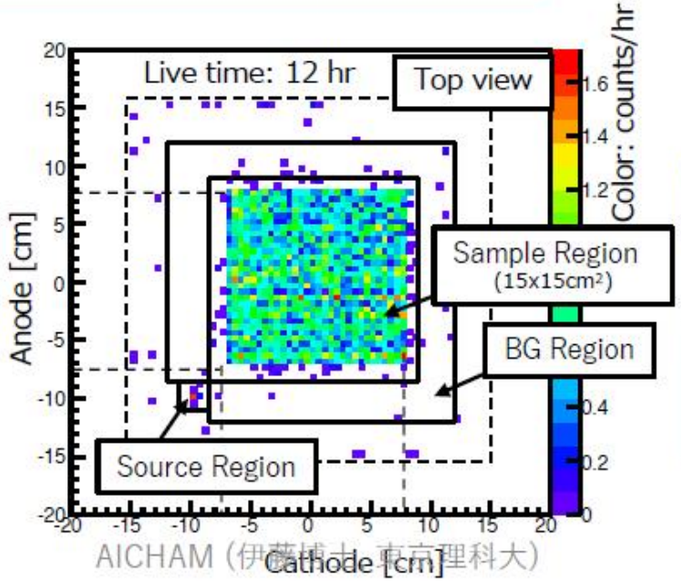




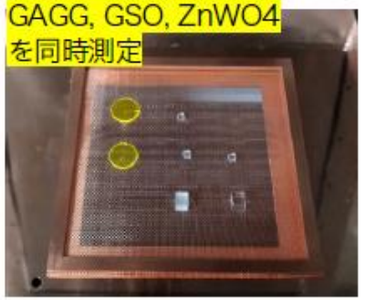
Low-α μ-PIC (micro-pixel imaging chamber)
- Anode and cathode 2-D strip sensor.
- 400 μm pitch, 768ch+768ch, 300 x 300 mm² covered.
- Low alpha emission from the surface
  MINA 977 (2020) 164285.

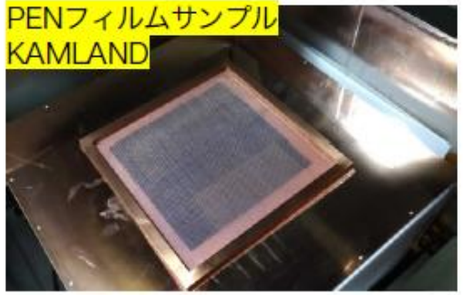






AICHAMを使った分析は、
感度~10^{-3} a/hr/cm² (90%CL)
@E>2.5MeV, 15x15cm²で、
measuring samples of various experiments





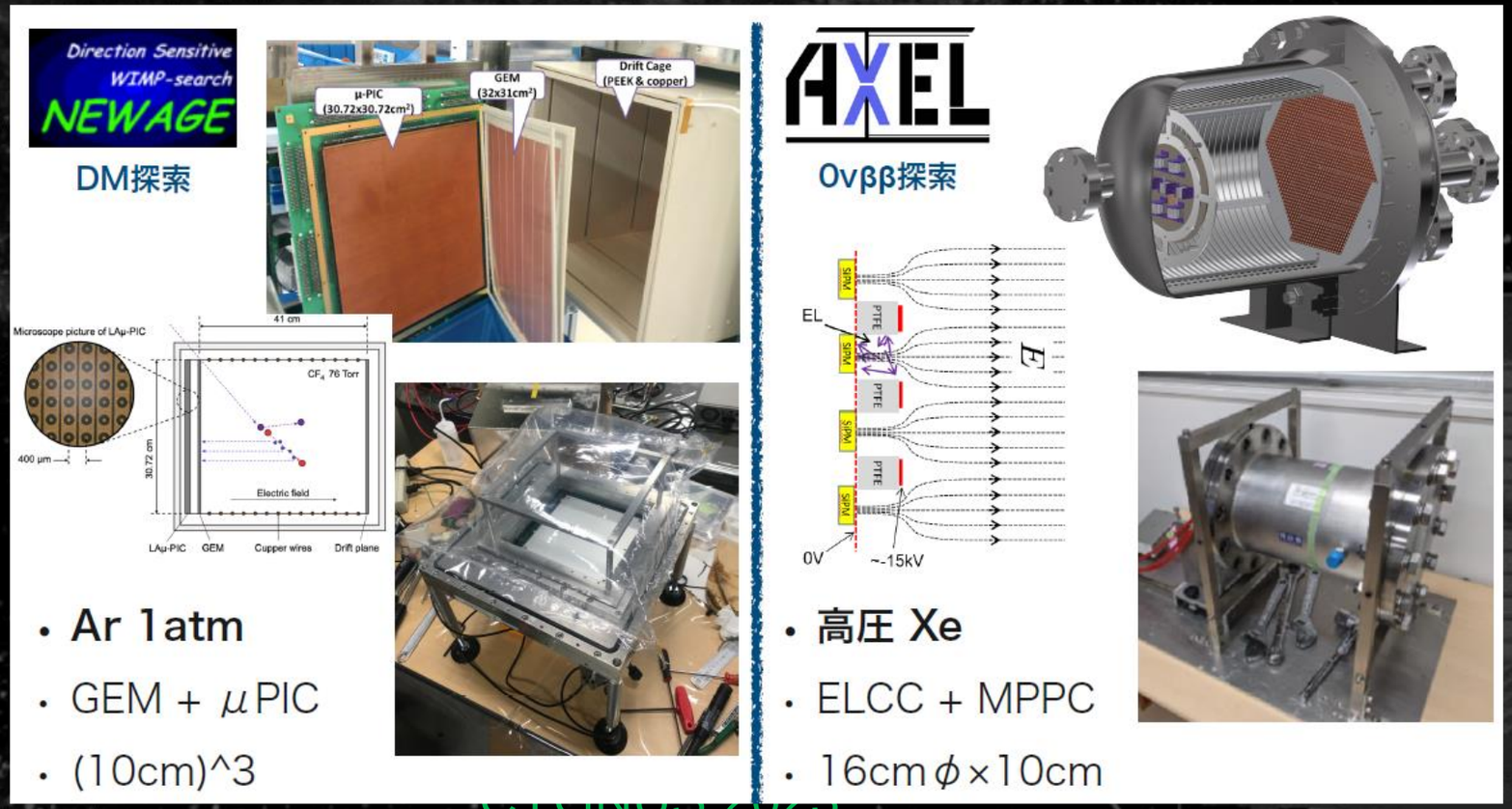
学会・研究会公開を条件に、現在無償で測定してます。

MIRACLUE (MIGDAL study)

PTEP 2021 013C01

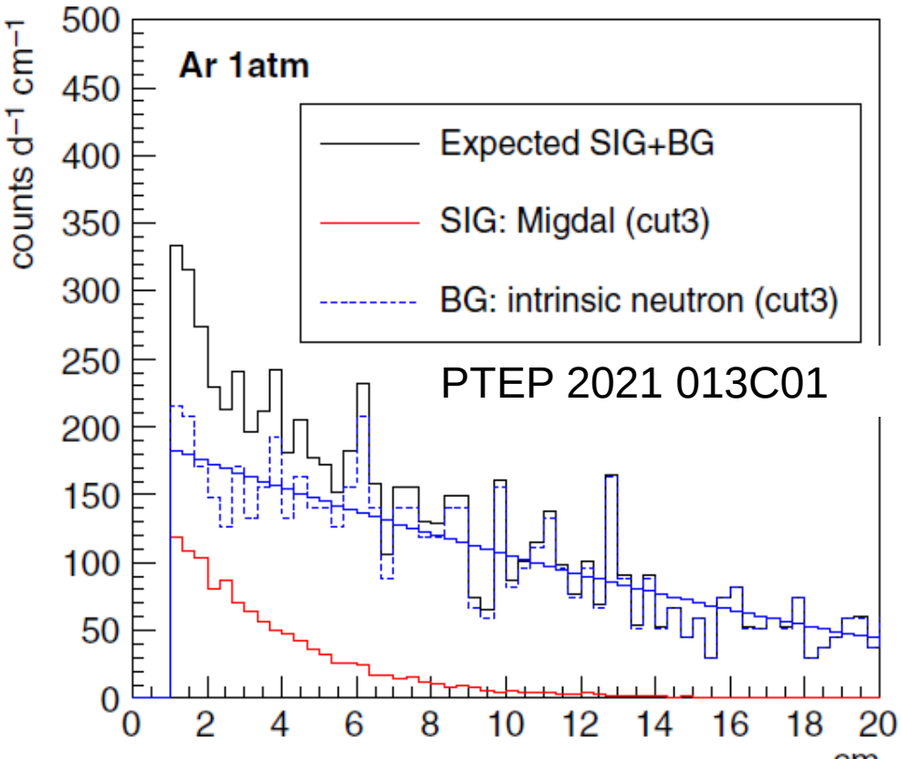
K. Nakamura (Tohoku)

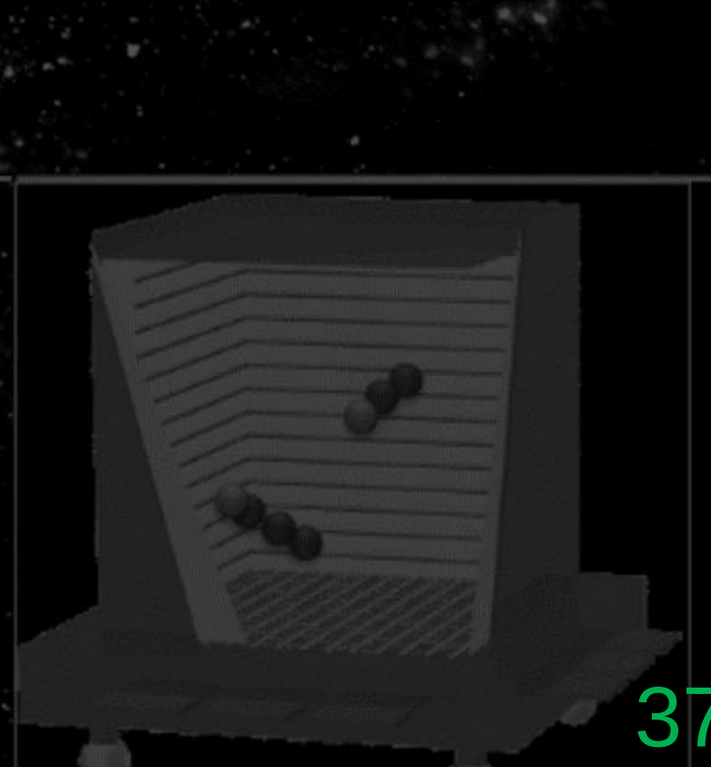
- Ar (1atm) and Xenon (8 atm) gas
  - direct interests in DM search
- start with existing technologies
  - less R&D



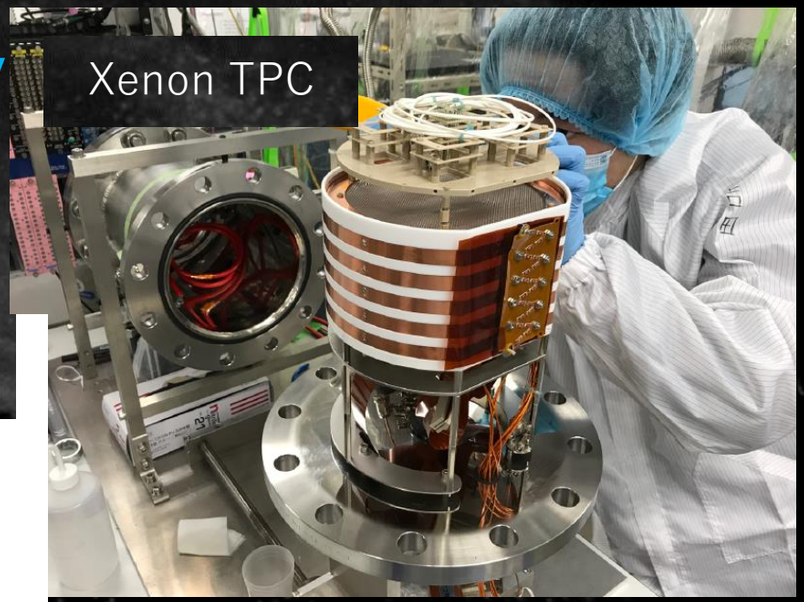
- Characteristic X-ray channel for 2-cluster detection (first step)
  - less BG
- Low energy (565keV) neutrons (@AIST, Japan)
  - less BG

expected signature
（2-cluster distance）

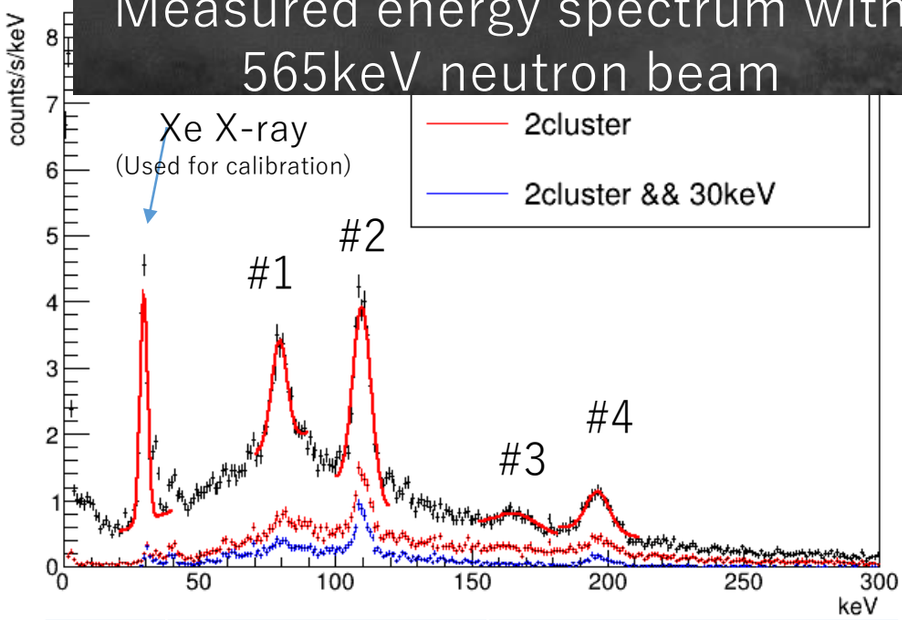




- High pressure Xenon TPC
  - Xenon TPC worked with neutron beam successfully
  - Energy & topology were measured
  - Analysis for Migdal branching is ongoing

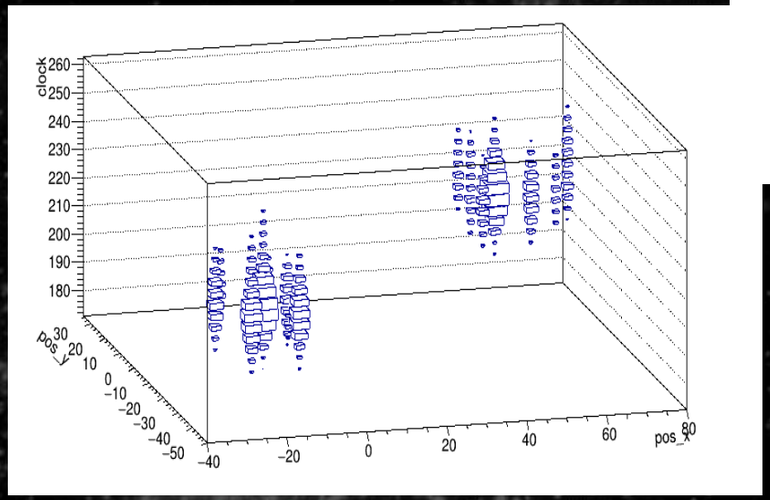


Measured energy spectrum with 565keV neutron beam



No.	Energy [keV]	Note
#1	79.3 ± 0.14	escape peak of #2
#2	109.7 ± 0.08	$^{19}F(n,\gamma)$ 110keV
#3	166.5 ± 0.74	escape peak of #4
#4	196.5 ± 0.25	$^{19}F(n,\gamma)$ 197keV

“2 cluster“ event



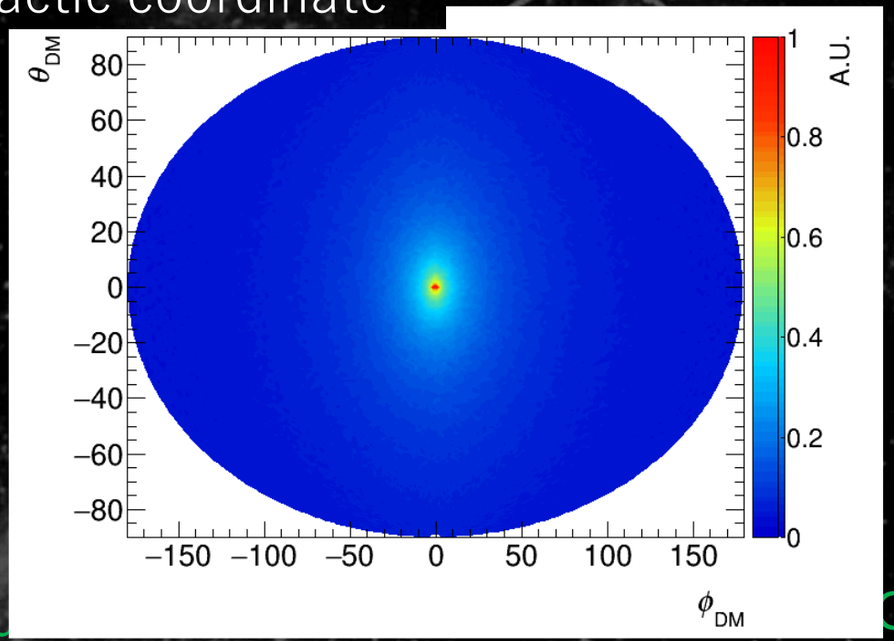
Cosmic-ray up-scattered DMs(CR-DM)

JCAP07(2023)061
K. Nagao

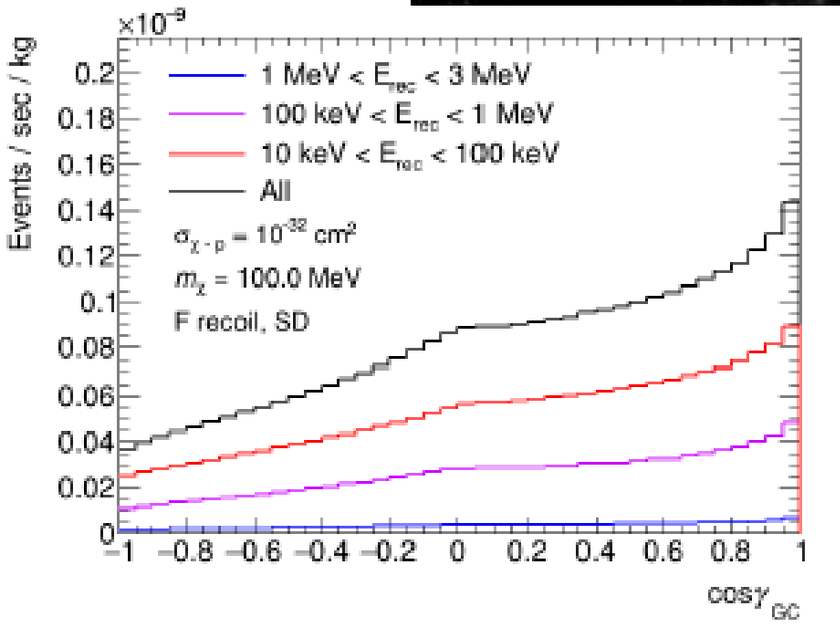
- Light (1~100MeV) DMs would be up-scattered at Galactic Center by cosmic-ray protons
- Can be detected with directional detectors
- Studied for gaseous TPCs and emulsions

also in Nicole's talk

Incoming DM maps
@Galactic coordinate

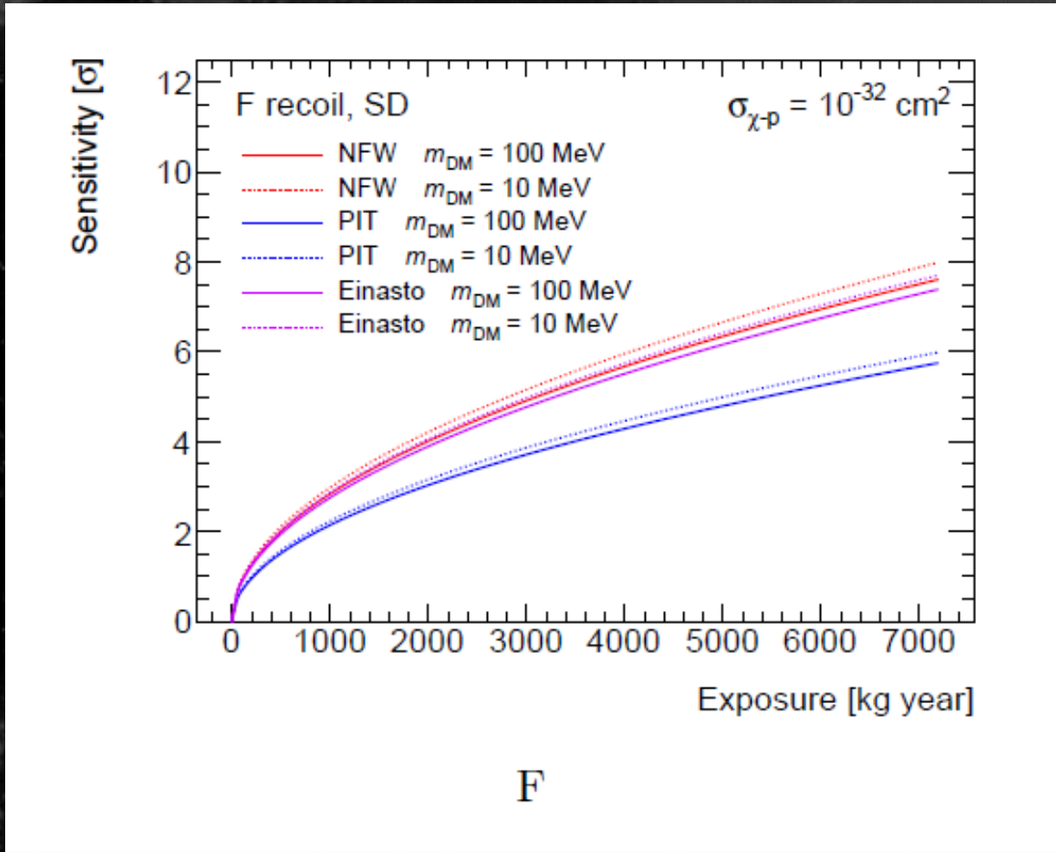


expected recoils

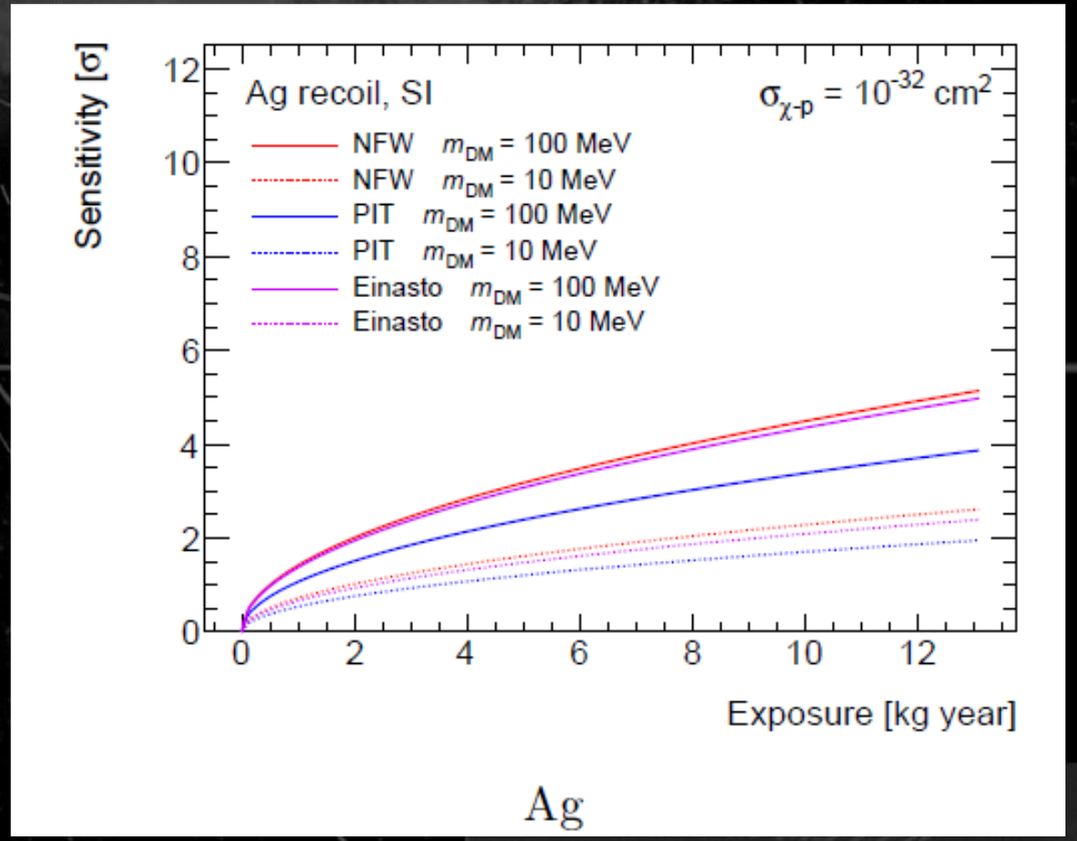


NFW, $m_\chi = 100\,\mathrm{MeV}$

- Results
  - Need LARGE exposures
  - CYGNUS framework (even with emulsions) is necessary



F



Ag

SUMMARY

- Since last CYGNUS,

- DM search
  - First limits from a 3d-vector directional da… e NEW
    PTEP, (2020) ptaa147 DOI: 10.1093/pter…
  - "Direction sensitive dark matter search w… seous
    …tab053
  - …sitive dark matter search w… ctor-type tracki
    …tad120
  - …of a low… irection-sensitiv
    …977, 11…
  - …g readou… ions
    …15 T090…
  - …of a Neg… s for
    …P07015…
  - …dioactiv… 6 ga
    JINST (2021) 16 P060…
- Future physics
  - "Detection capability o… with
    PTEP(2020) ptaa162…
  - "Directional direct dete… cosm
    center",
    JCAP07(2023)061,