文部科学省 科学研究費助成事業 学術変革領域研究(A)

極稀事象で探る宇宙物質の起源と進化

新たな宇宙物質観創生のフロンティア

Direction-sensitive dark matter search using low pressure gaseous detectors

Satoshi Higashino

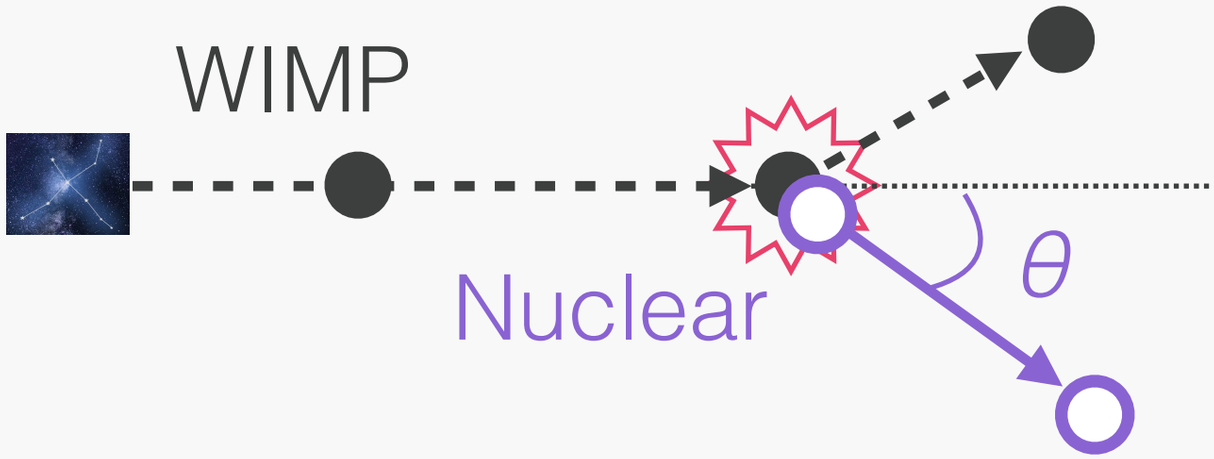
on behave of NEWAGE collaboration

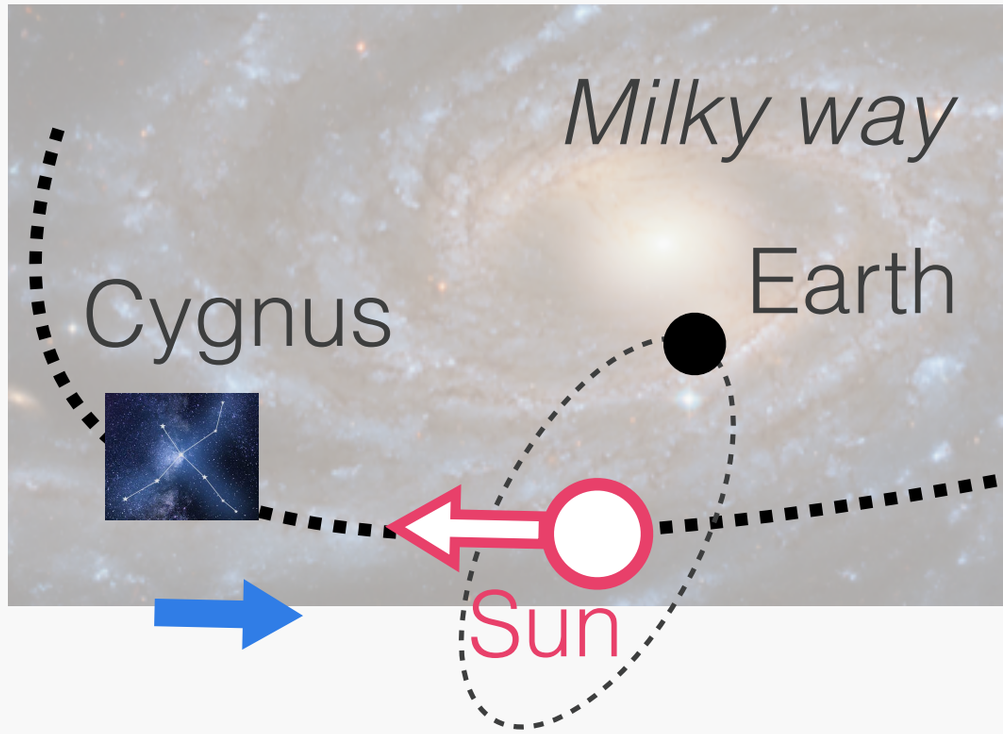
29 / 9 / 2026

Introduction

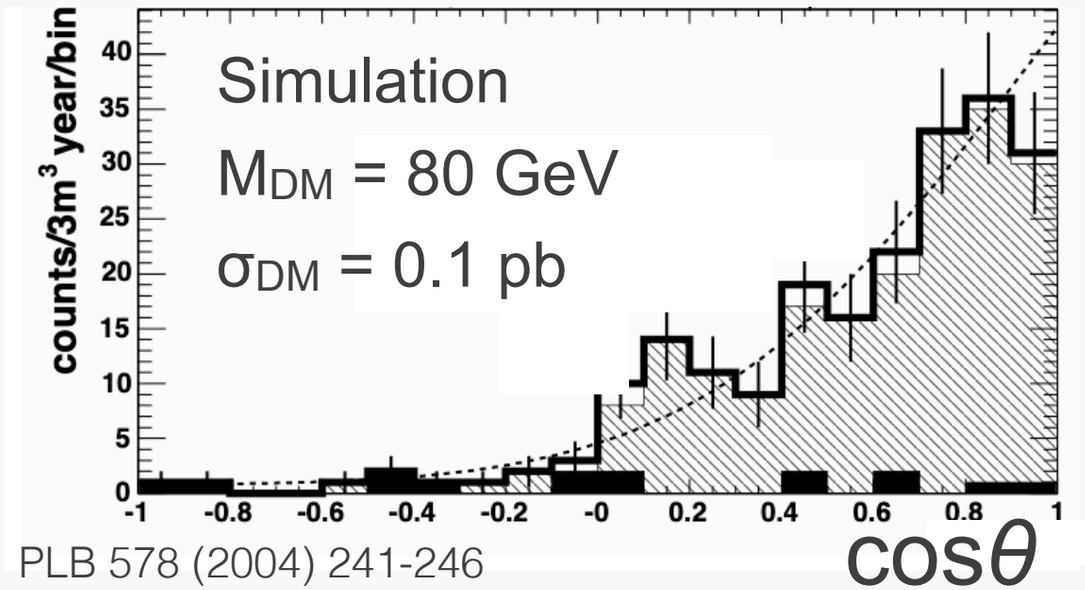
Direction-sensitive DM searches

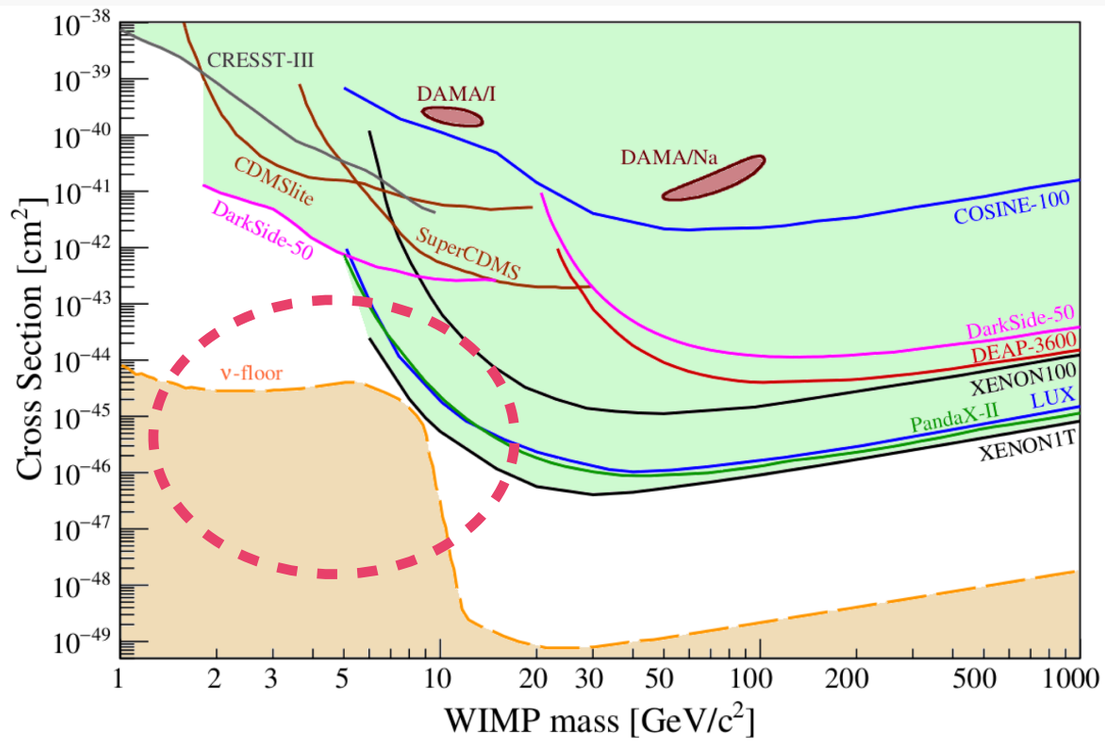
- Detect scattering angle of nuclear recoils (NR) from the “Cygnus direction”
  - ➡ leads a strong signature of WIMP
  - ➡ allows to explore beyond the neutrino fog
- Also sensitive for other directional DM candidates such as “CRDM”





WIMP wind from Cygnus!

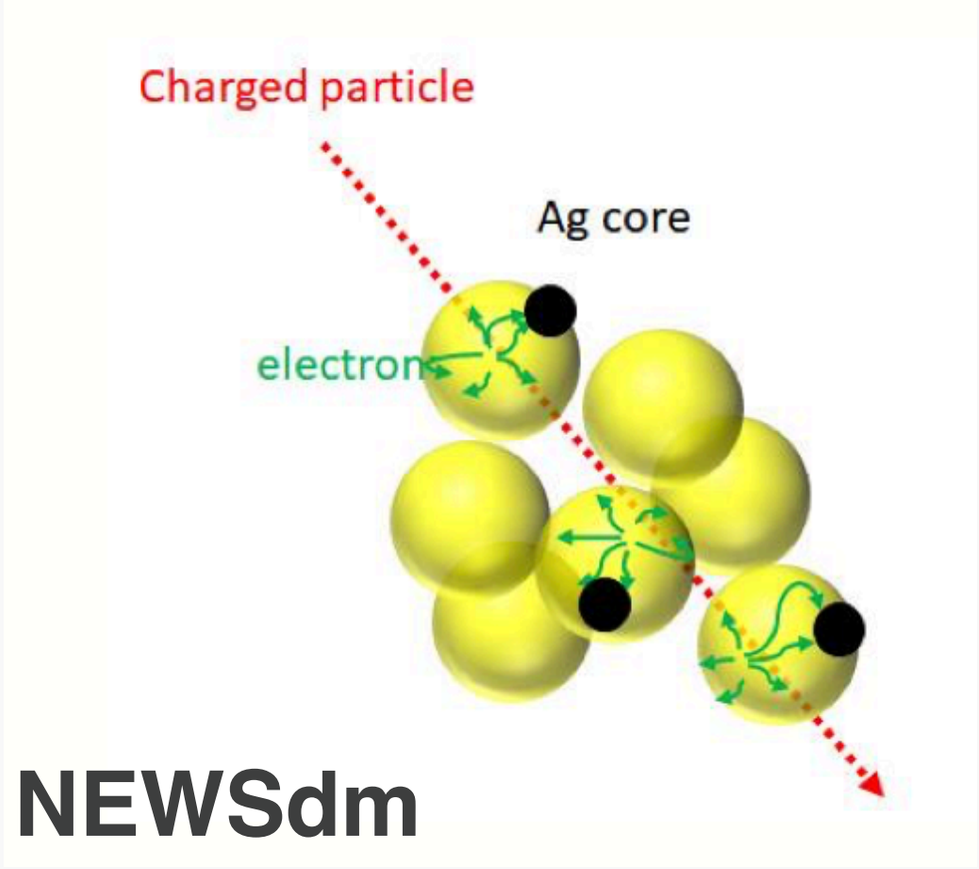




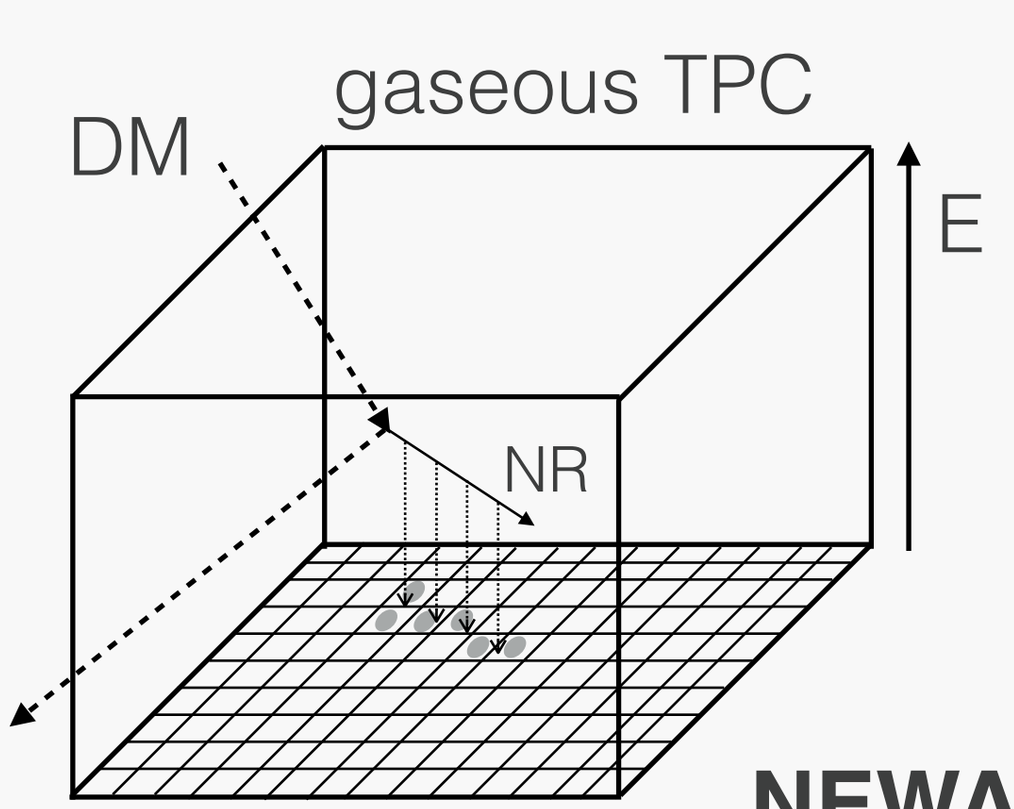
PLB 578 (2004) 241-246

Directional search methods

- **Particle tracking** is necessary to measure scattering angle from the Cygnus direction
  - ➡ Need to measure < 10 keV nuclear recoil (**VERY short track!**)
- To achieve < 10 keV nuclear recoil track reconstruction, …
  - ➡ ultra-fine granularity detector (NEWSdm: *next talk by N.Chin*)
  - ➡ use **low pressure gas** to extend trajectory (e.g. **NEWAGE / CYGNUS**)



NEWSdm



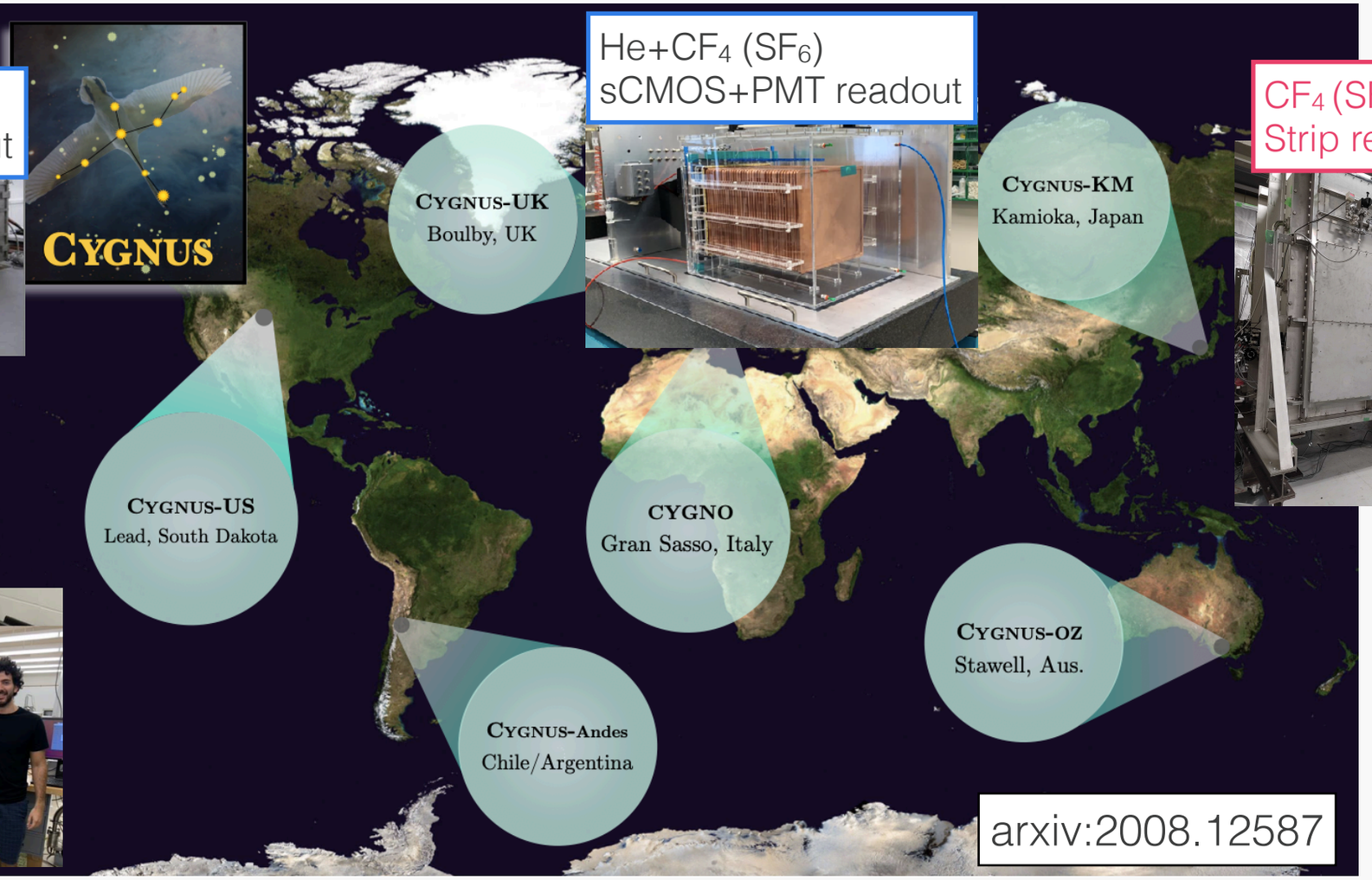
NEWAGE



- CYGNUS: World-wide consortium with low pressure gas + low BG toward DM, neutrino physics
- International workshop “CYGNUS2026” was held at Kobe on February

He+SF_6
GEM+wire readout





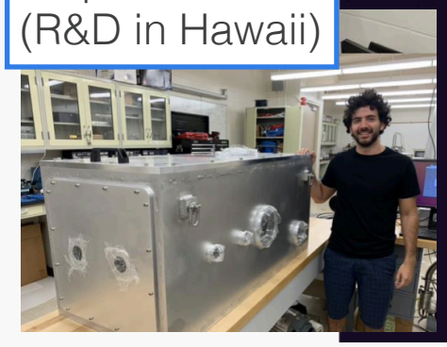
He+CF_4 (SF_6)
sCMOS+PMT readout

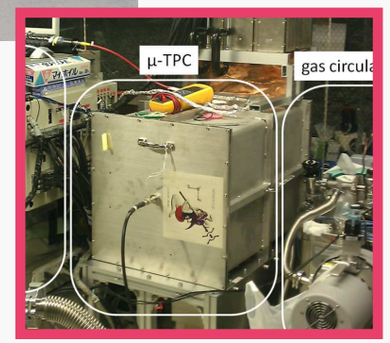
CF_4 (SF_6)
Strip readout



~1 m^3

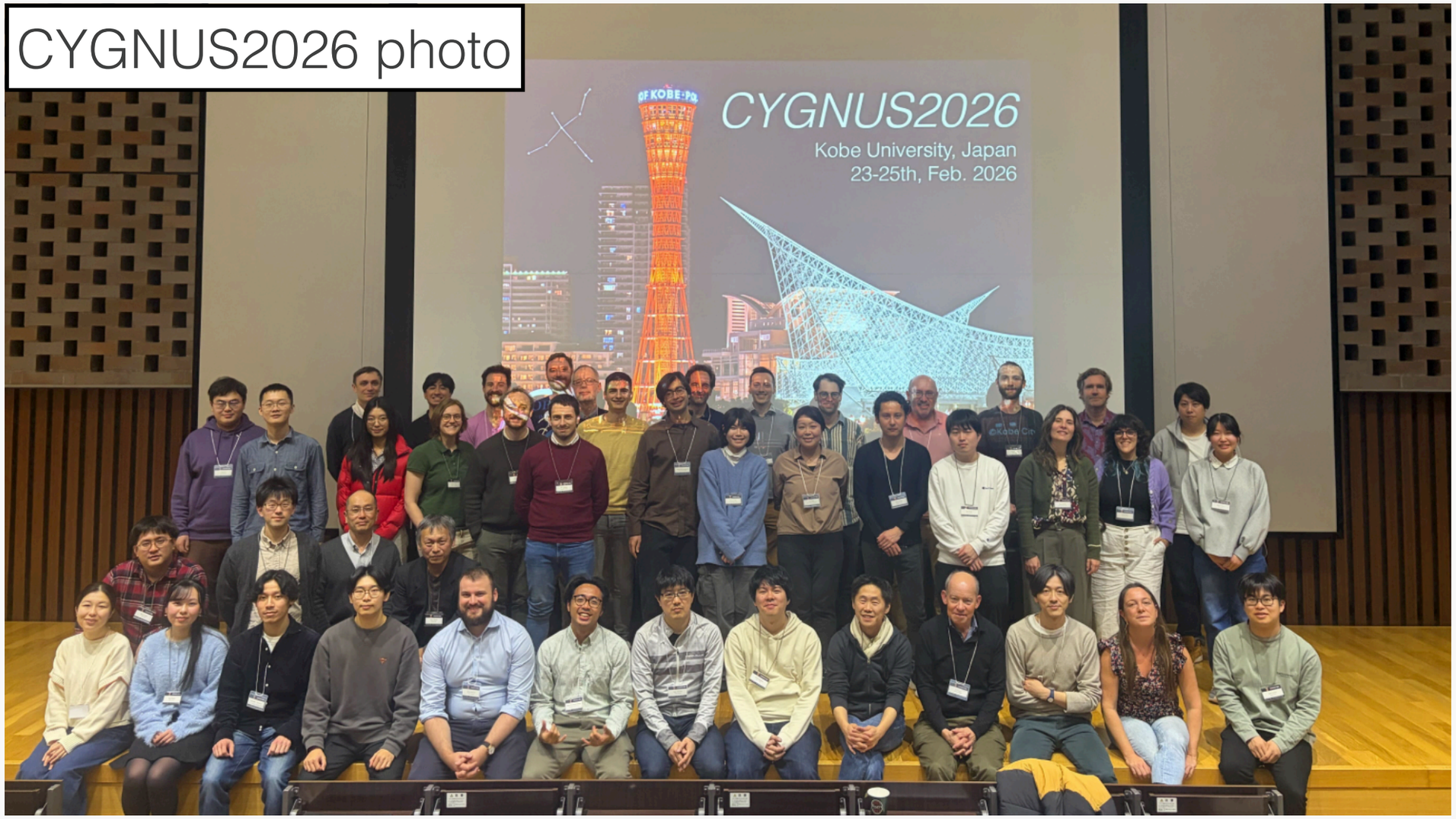
He+CF_4+X
Strip readout
(R&D in Hawaii)





~30 cm^3

CYGNUS2026 photo



Many fruitful discussions there!

Migdal community

It was the first time we've gotten together in person!

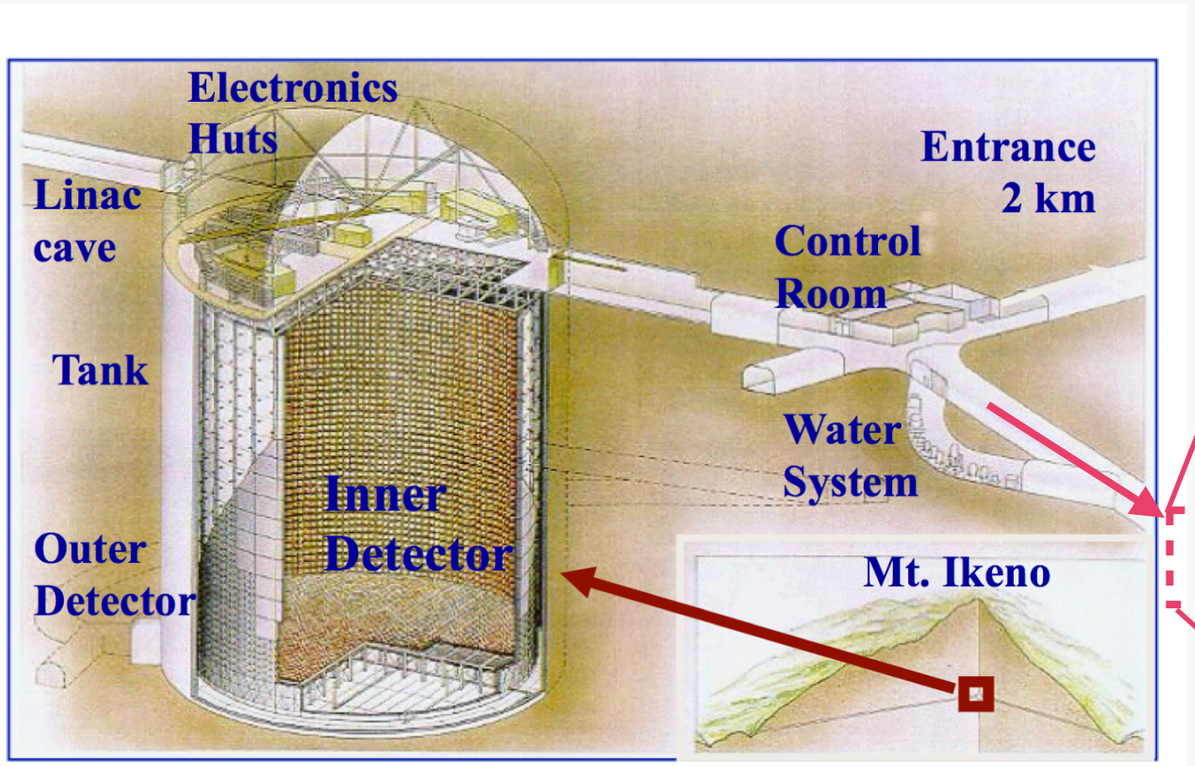


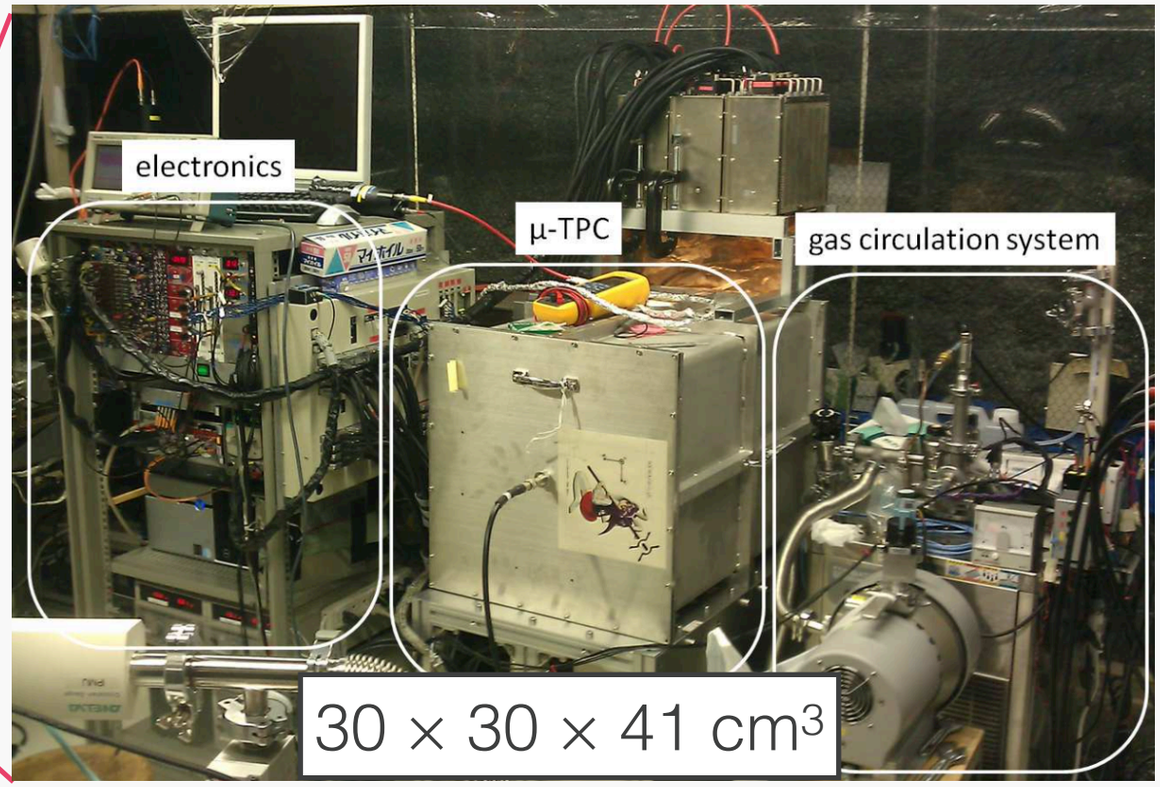


CYGNUS IT + OZ (+JP) joint meeting @Kobe U.

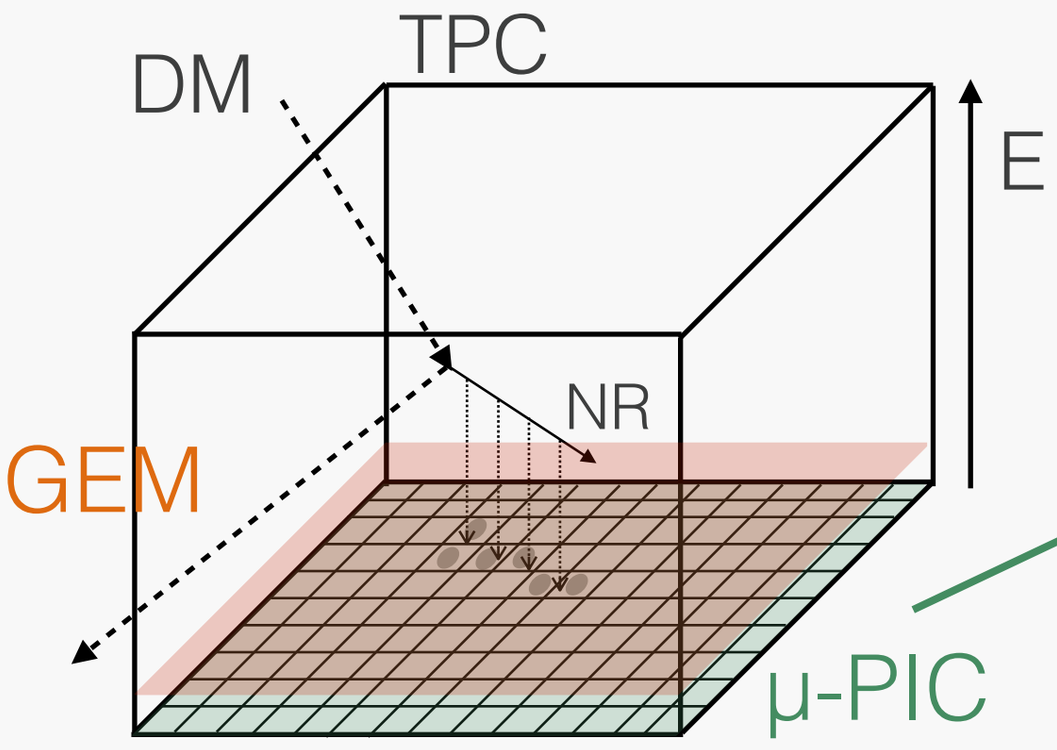
NEWAGE

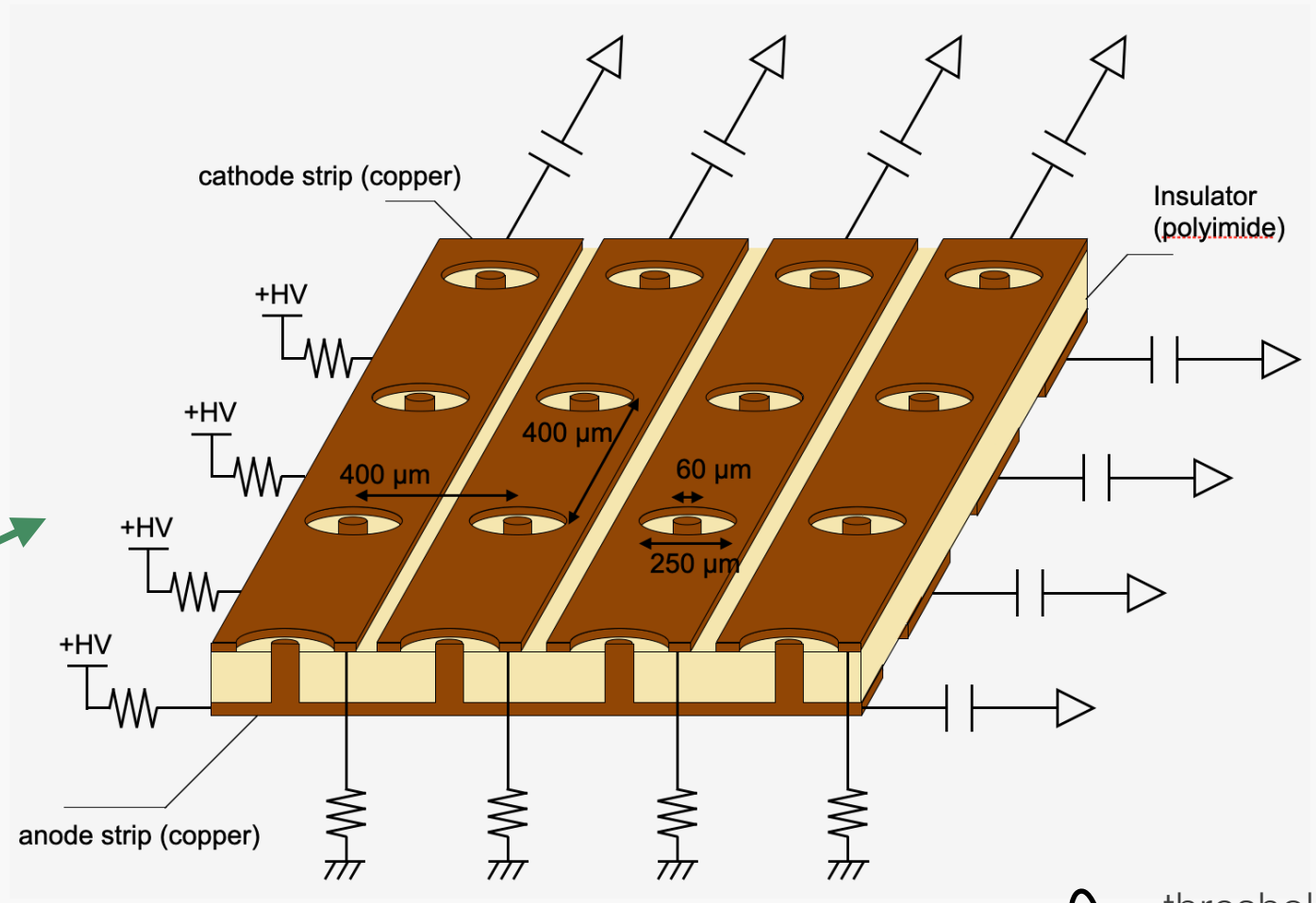
- 1,000 m underground experiment in the Kamioka mine
- Low pressure gaseous TPC
  - ➡ $30 \times 30 \times 41$ cm^3 fiducial volume
  - ➡ filled with CF_4 gas (0.1 atm): spin-dependent search





NEWAGE: 3D track reconstruction



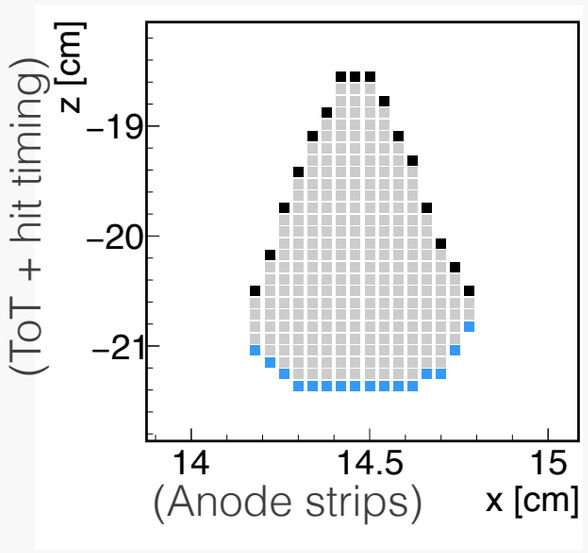


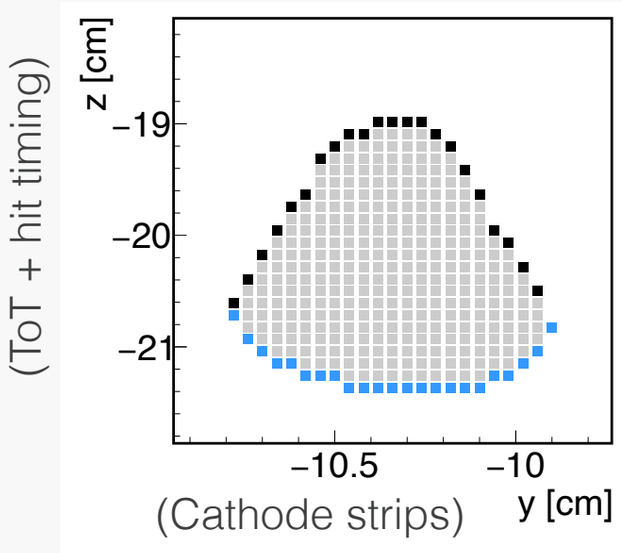
- GEM: Gas amplification
- μ-PIC:
  - ➡400 μm pitch 2D strip readout
  - ➡Gas amplification

2D position + drift time
→WIMP search with 3D track

NR event display



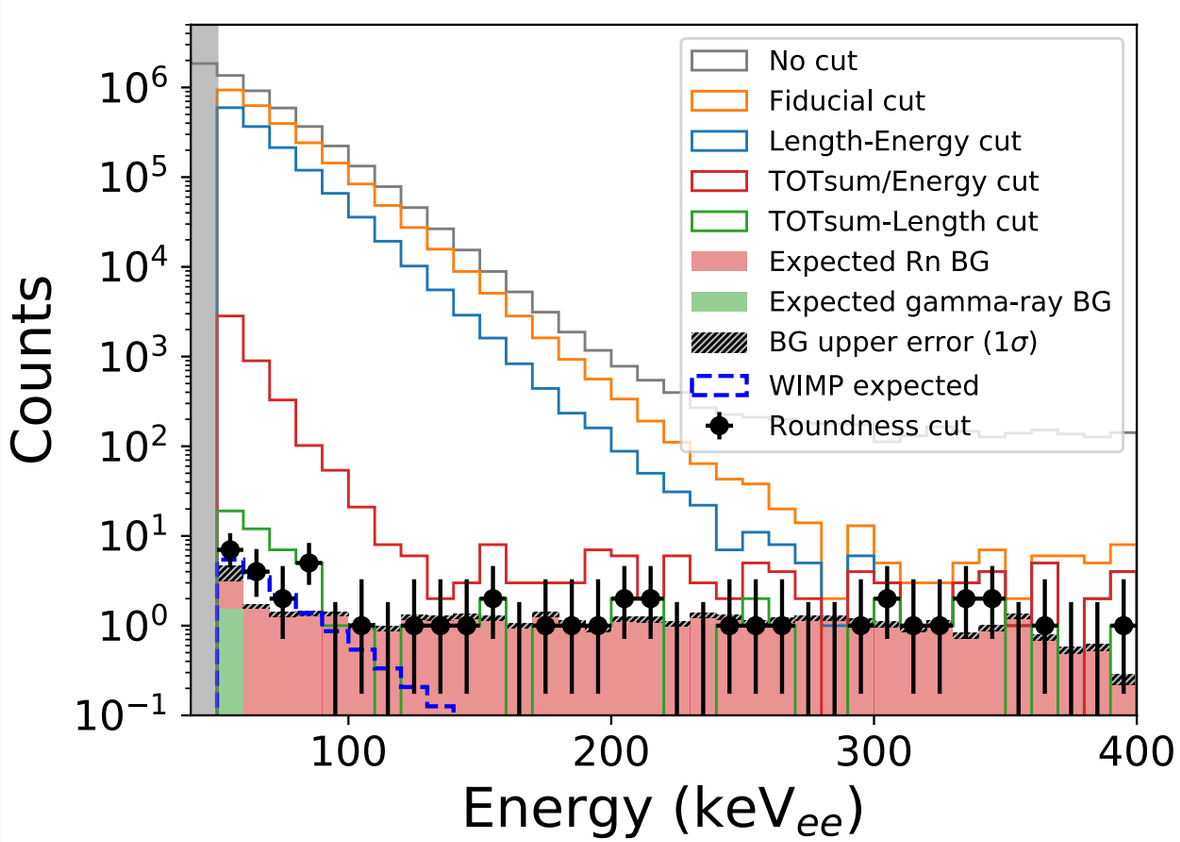


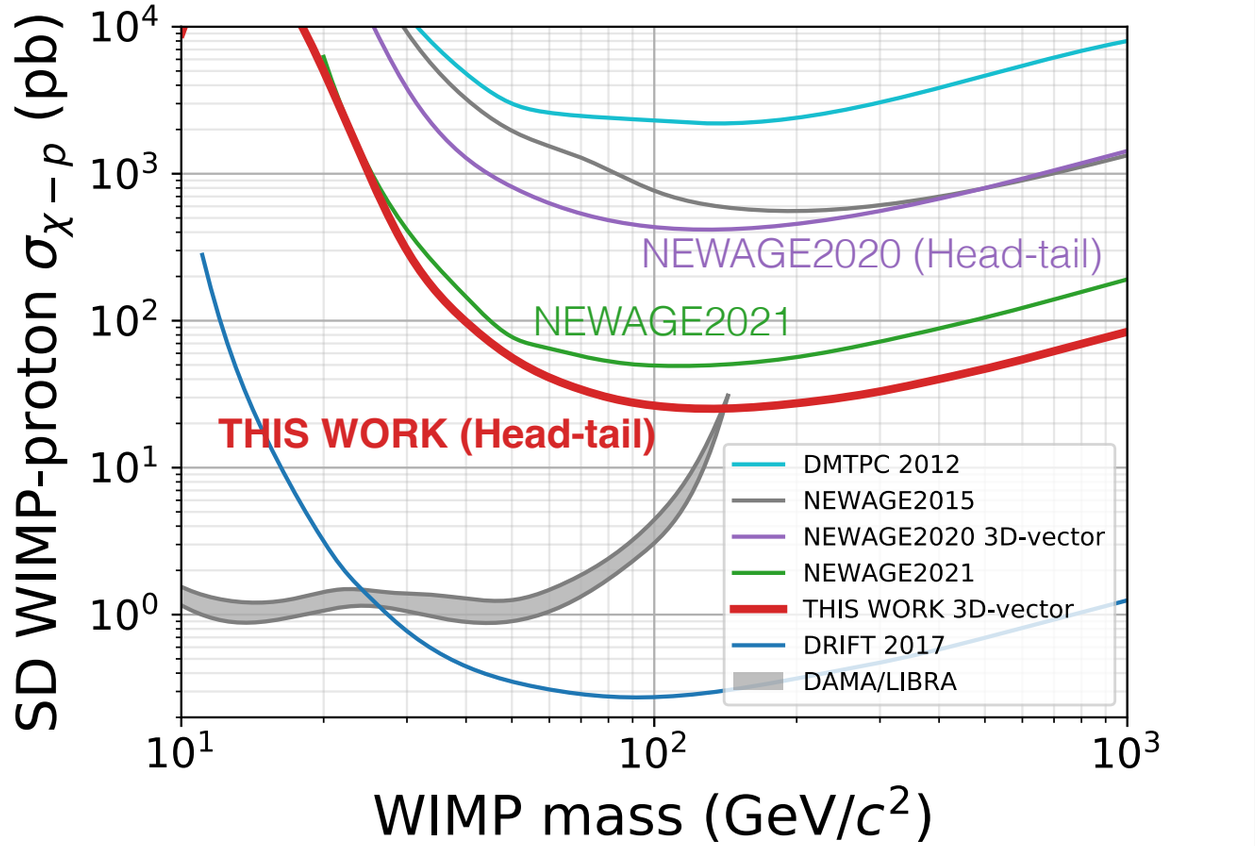


PTEP 2023 (2023) 10, 103F01

Latest result

- Null-consistent result in energy and directional distributions
  - ➡ Electron recoil rejection analysis updated and exposure increased
  - ➡ Limit is approaching DAMA/LIBRA allowed region
  - ➡ Head-tail recognition successfully implemented
- Future work: **BG rejection** and **large target volume**

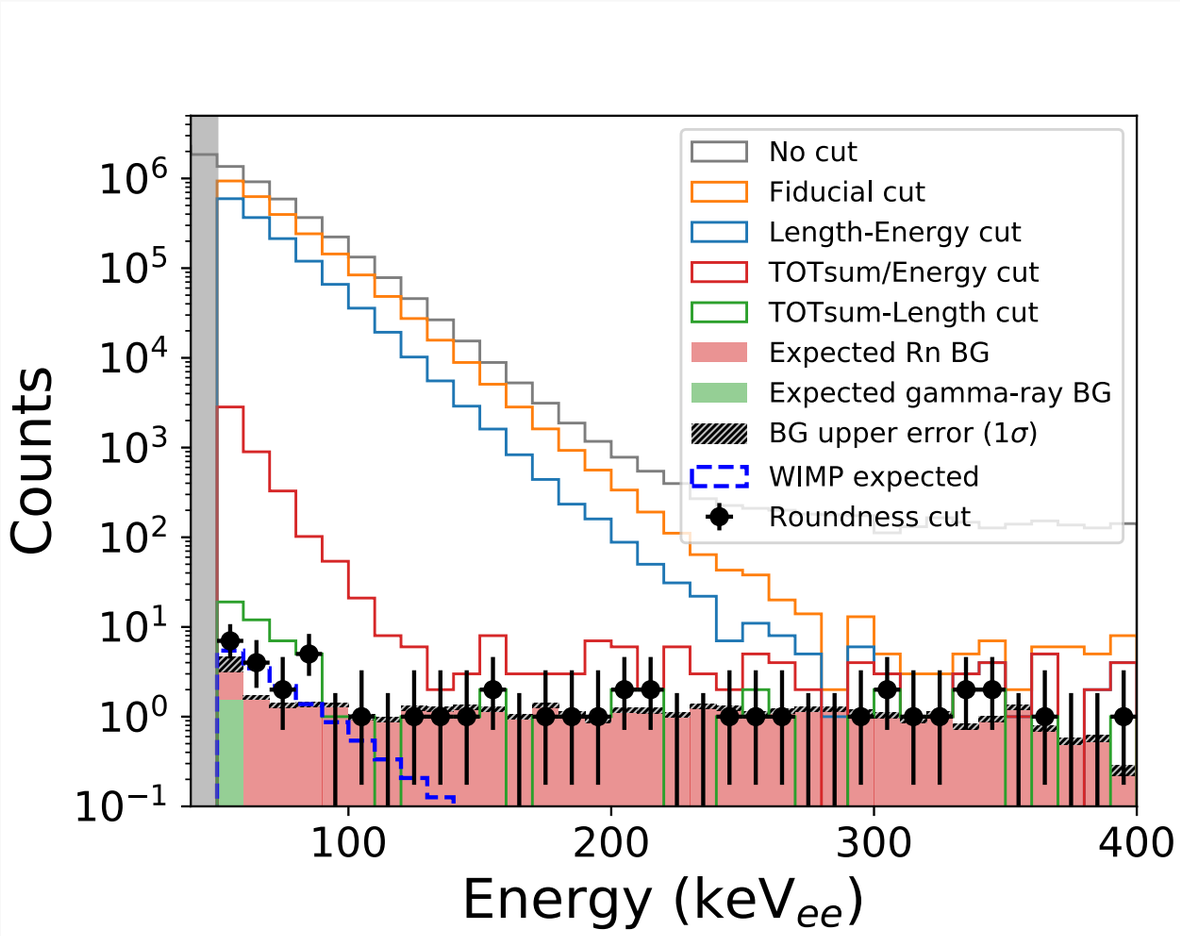


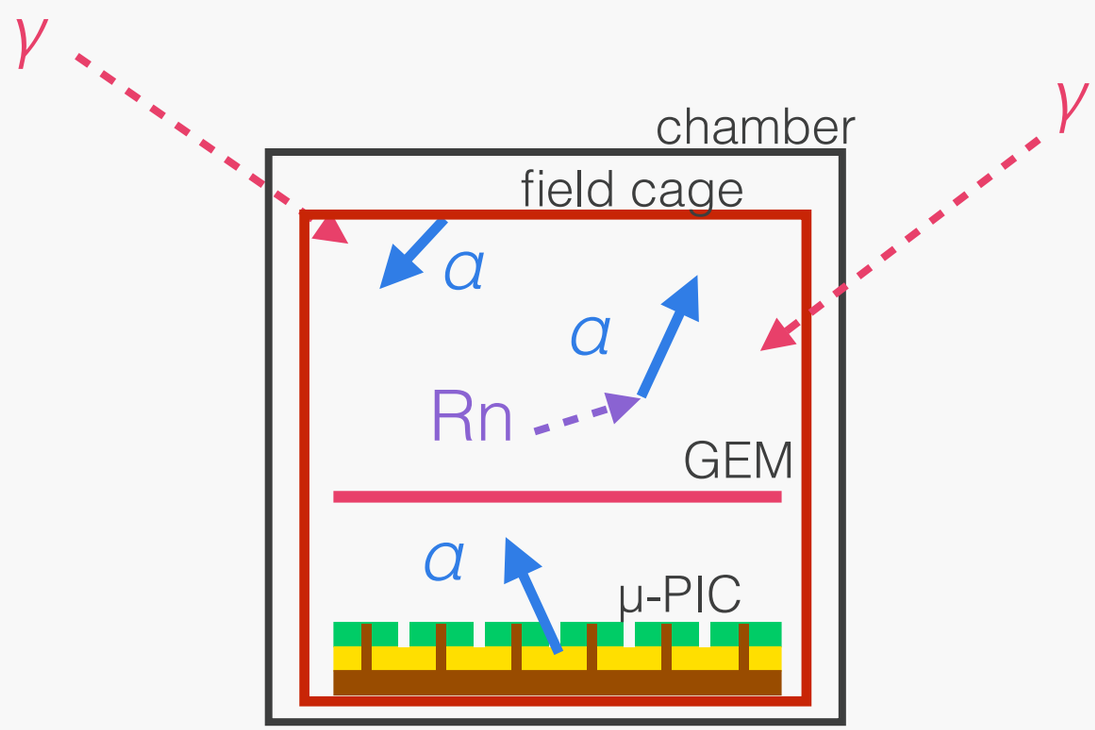


PTEP 2023 (2023) 10, 103F01

Strategy of BG rejection

- External BG
  - ➡ Ambient gamma (and neutron): shielding
- Internal BG
  - ➡ Radon emanation:
    - “clean” detector development and gas purification

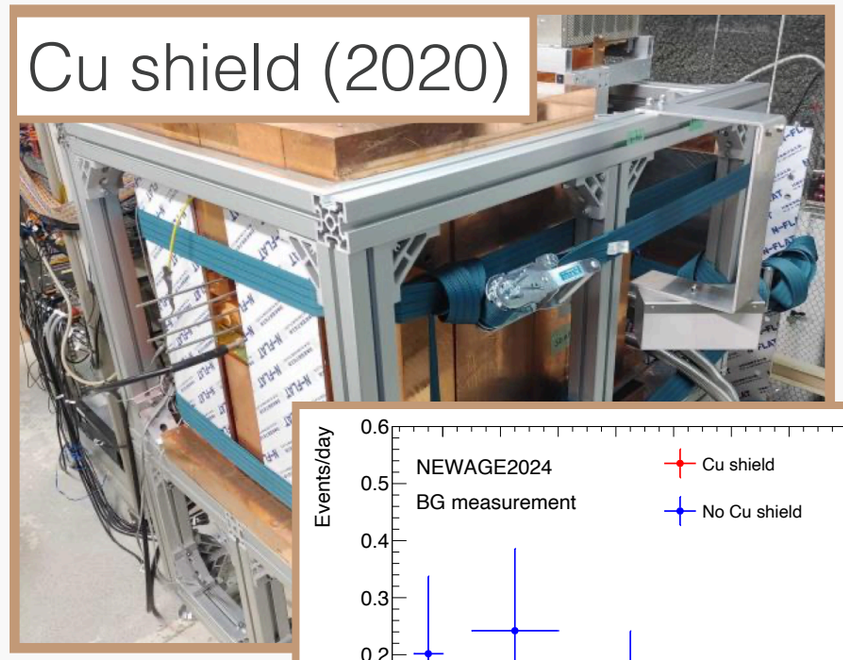


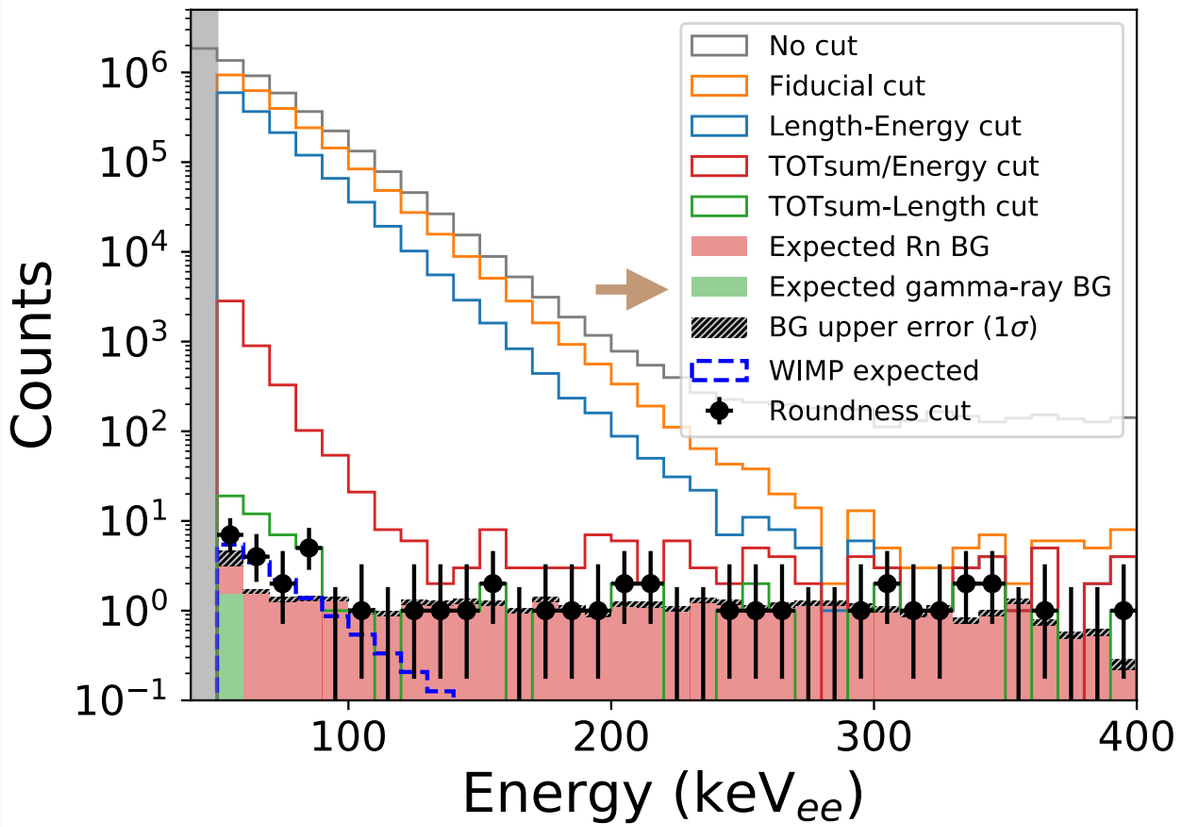


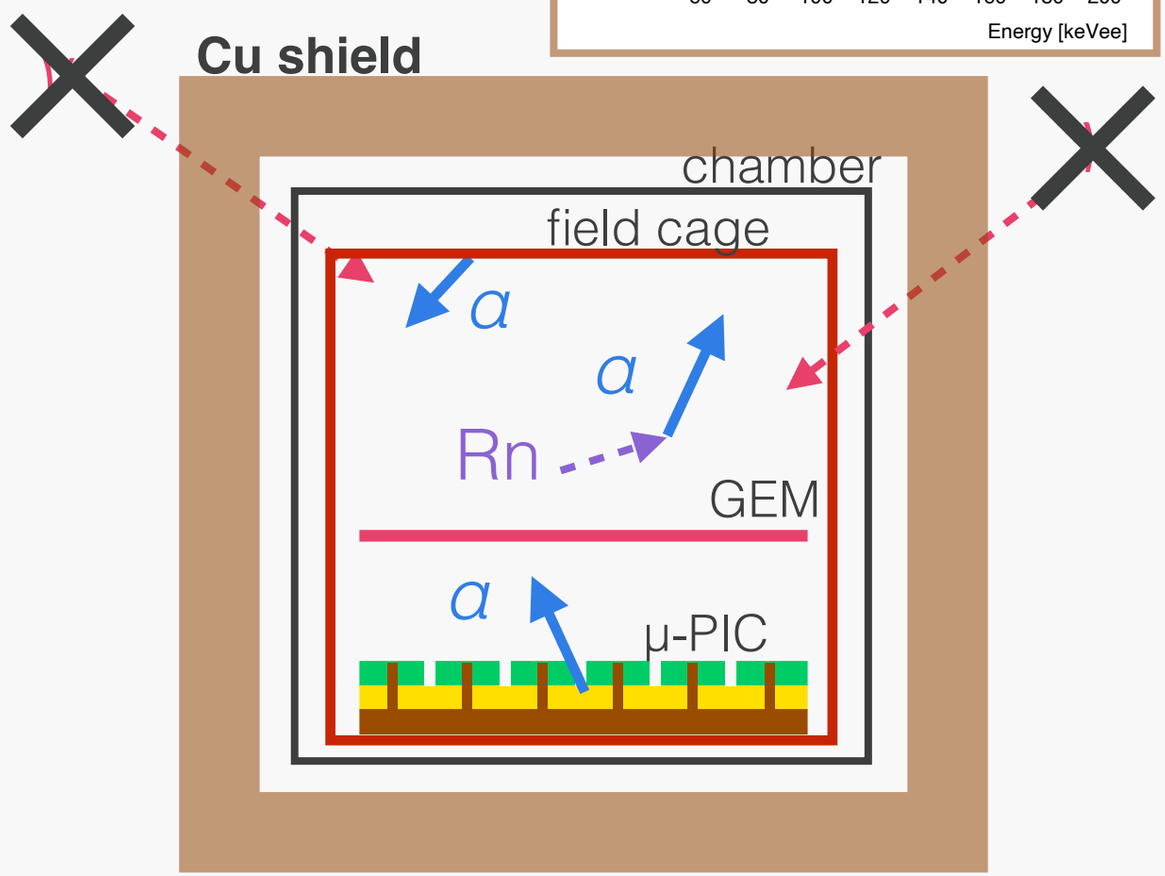
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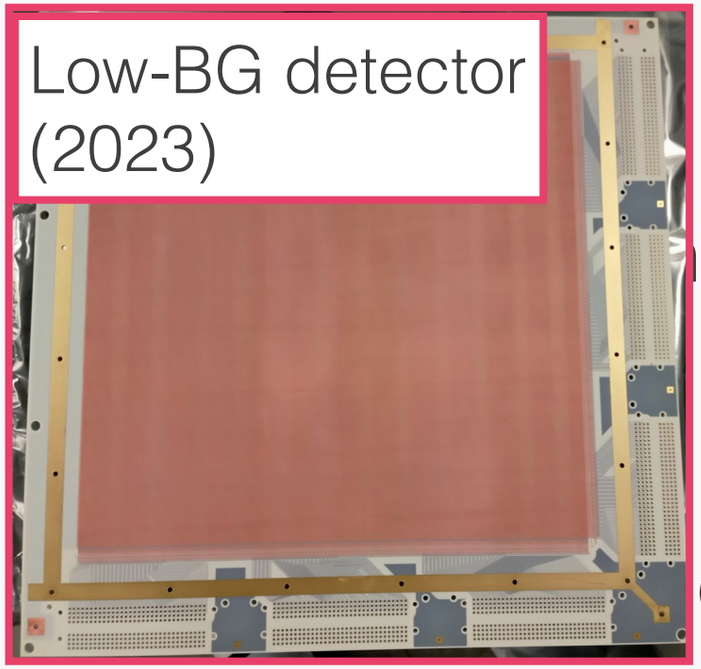




PTEP 2023 (2023) 10, 103F01

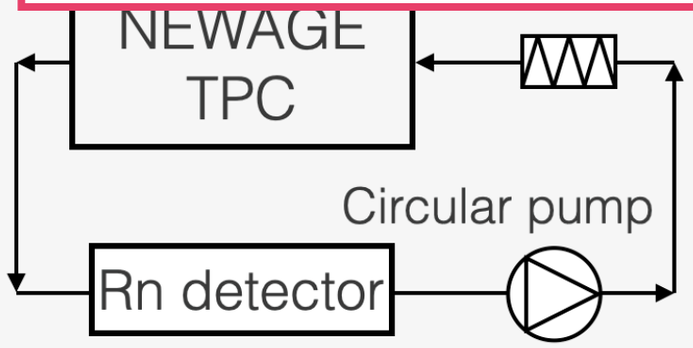
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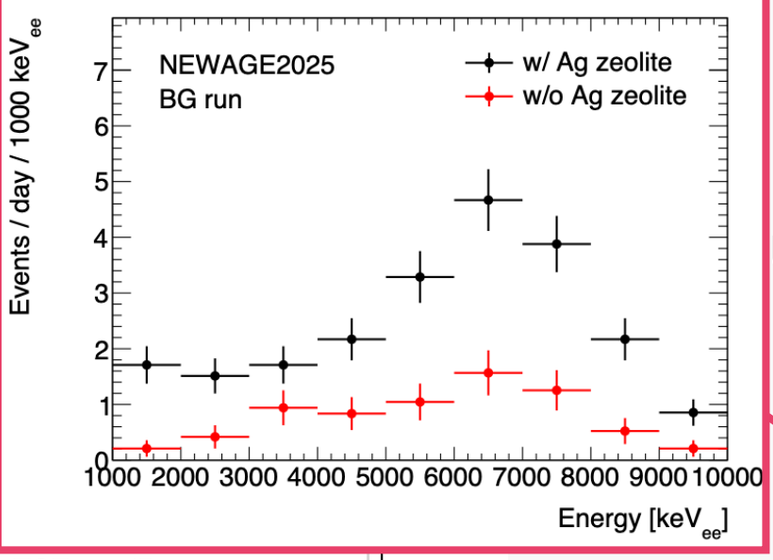
Low-BG detector (2023)



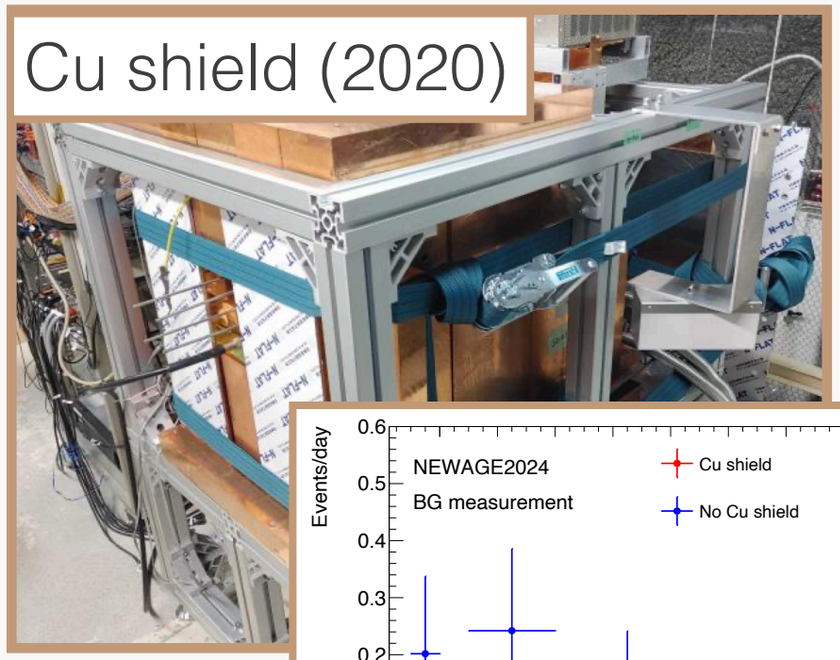
- "clean" detecto … urification

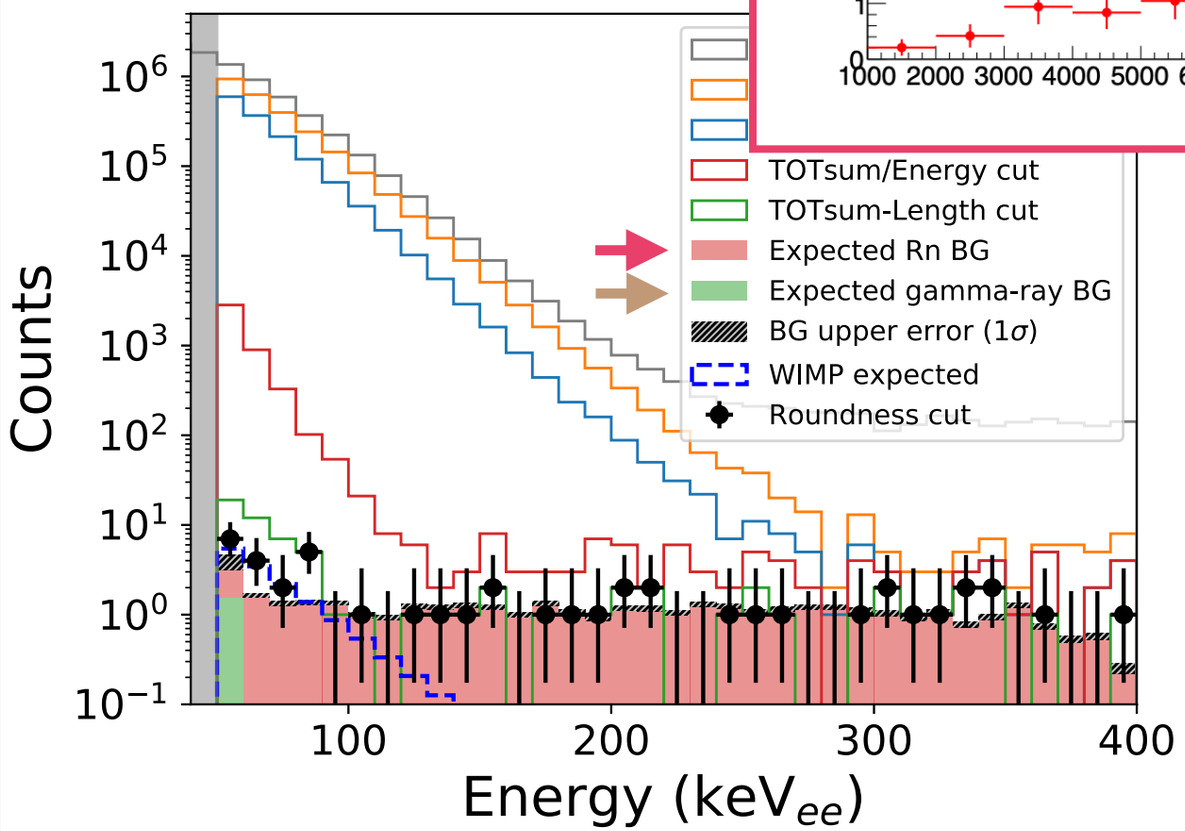
Ag-zeolite filter (2025)



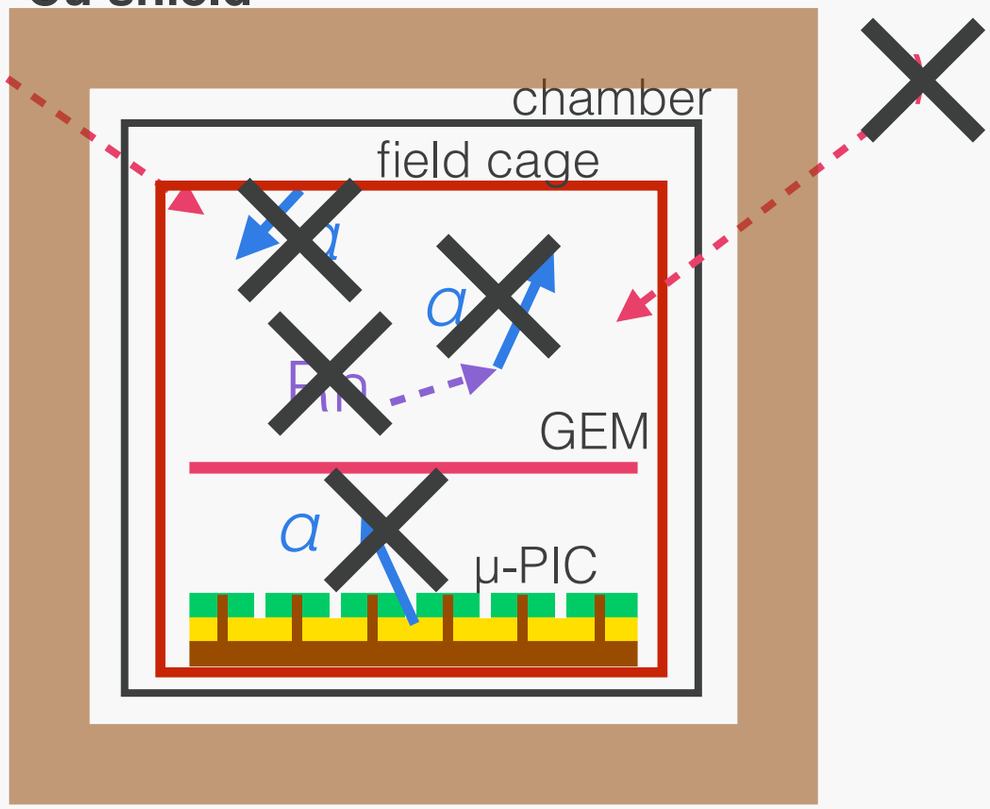


Cu shield (2020)





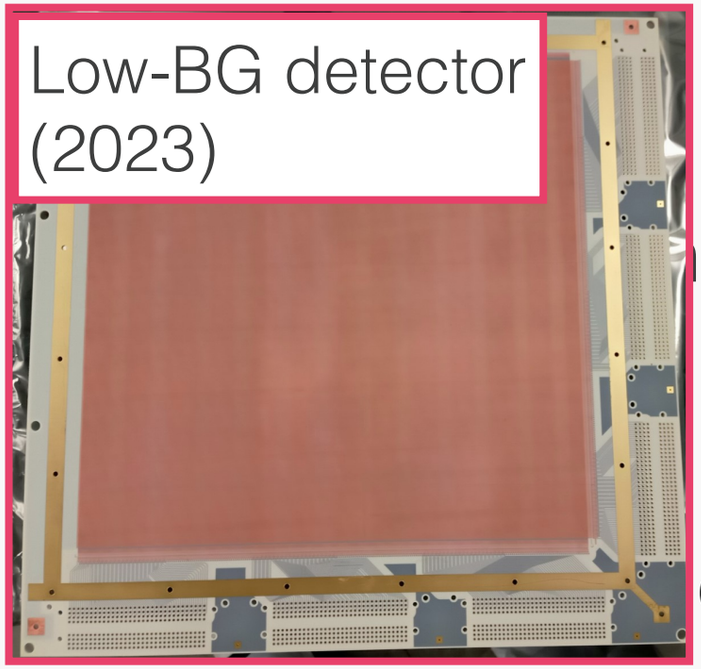
Cu shield



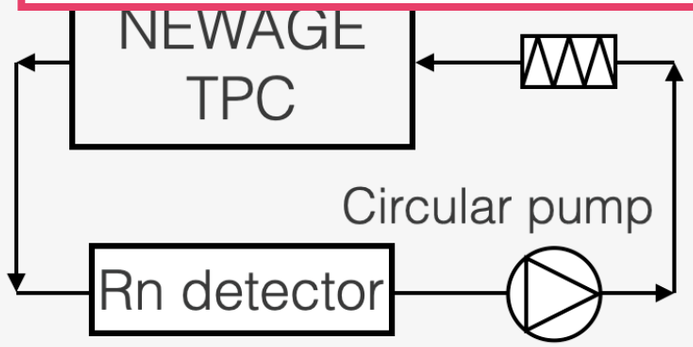
PTEP 2023 (2023) 10, 103F01

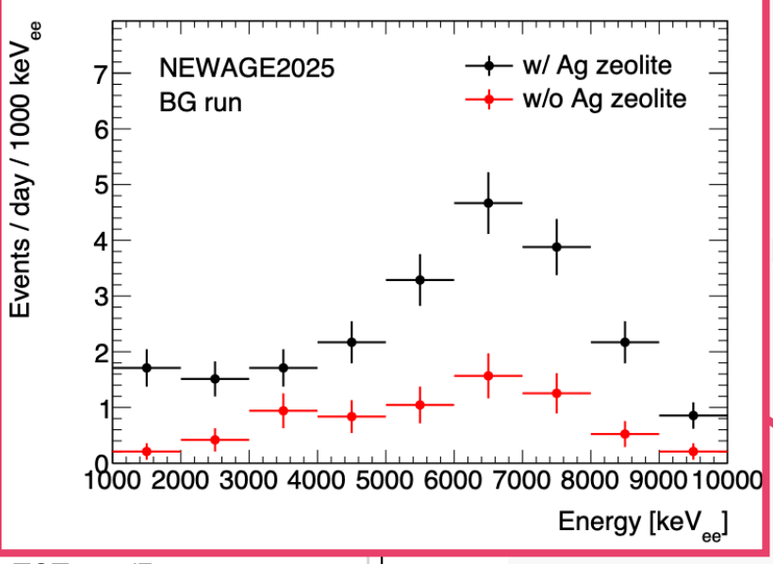
Strategy of BG rejection

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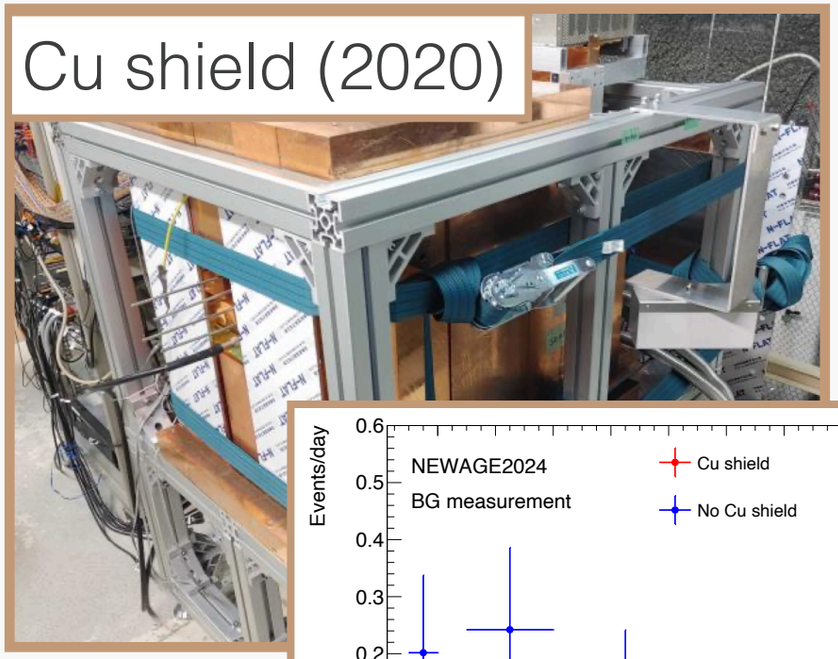


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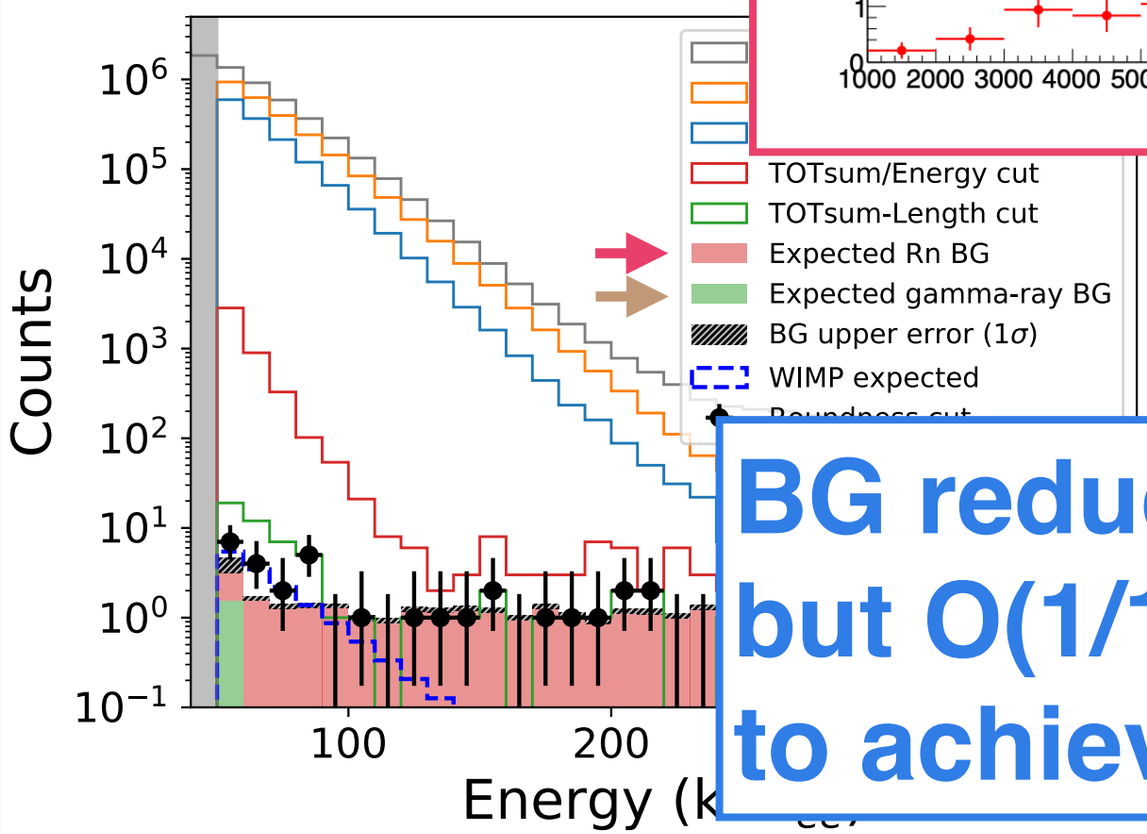


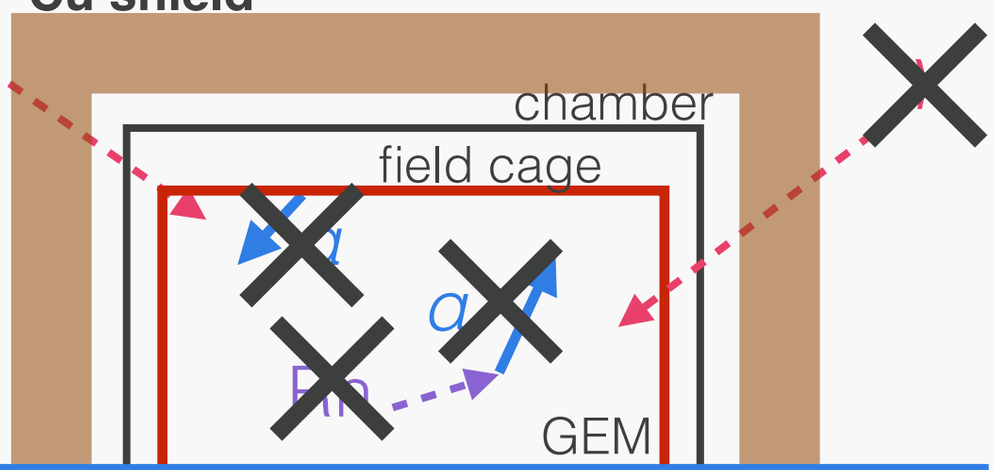


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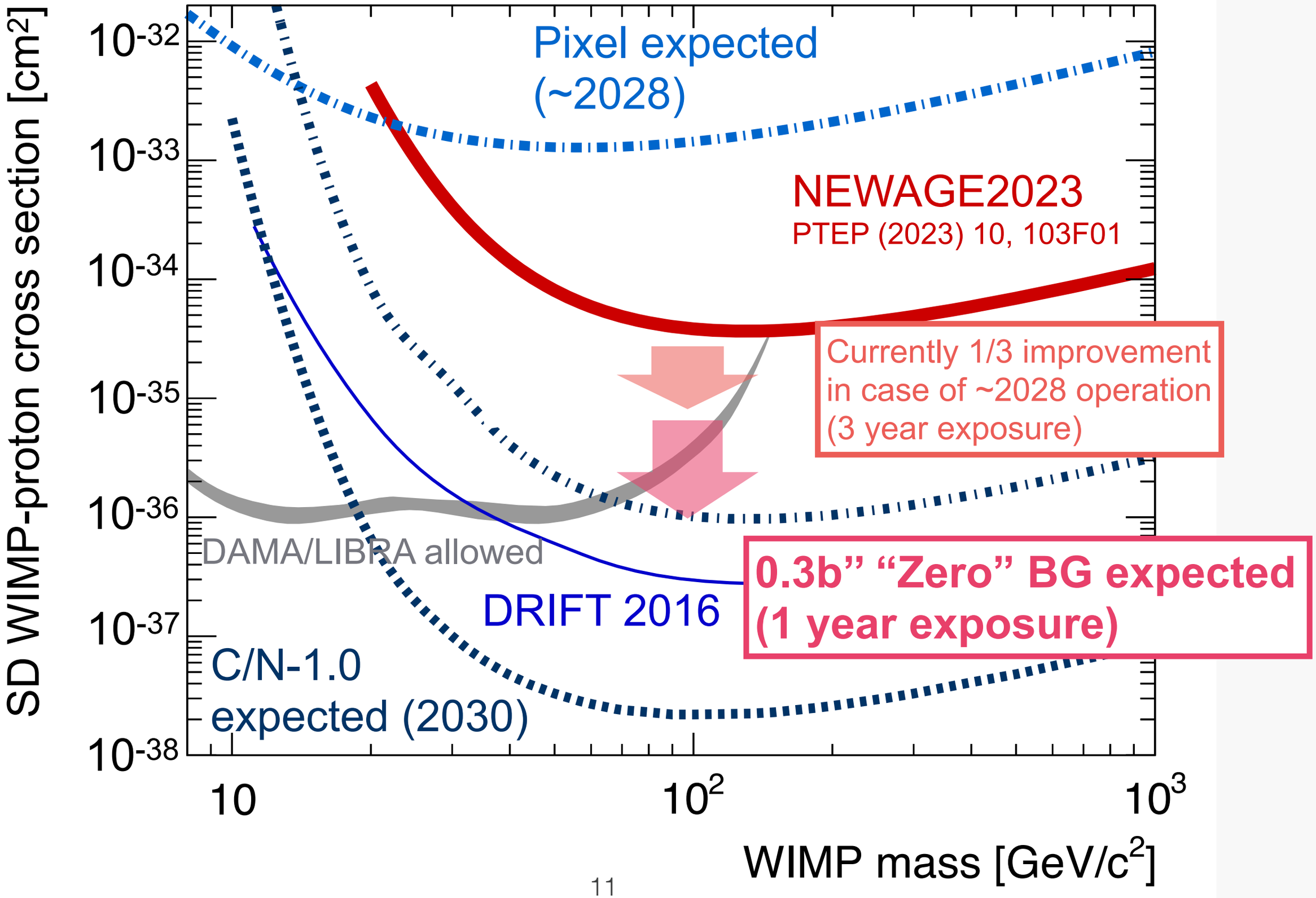
- “clean” detecto… …urification





BG reduced by 1/3!
but O(1/10) reduction required
to achieve “zero” BG measurement

Expected limits

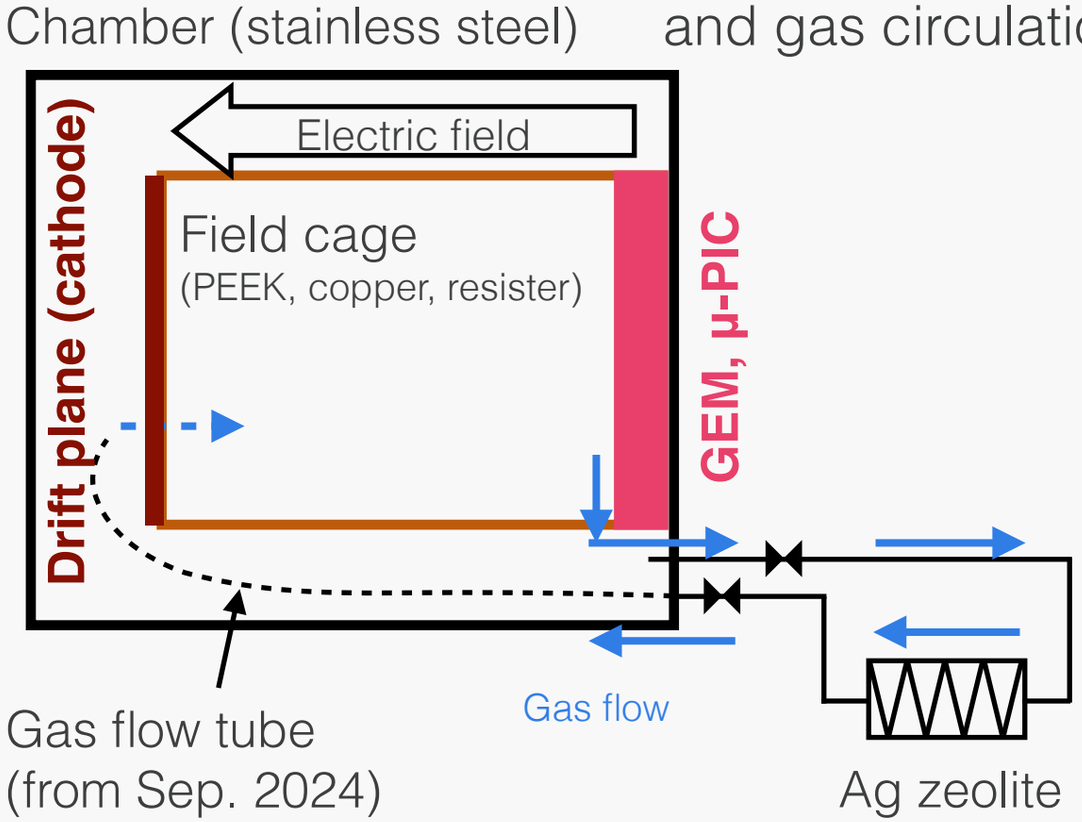


Recent activities

Radon (and its progenies) -oriented alpha rays

- The gas circulation pass is currently constructed inside the chamber
  - ➡ Only radon emanation from the field cage and detector seems to be effective
  - ➡ Radon-alpha emitted nearby the drift top (cathode) and detector surface will be mis-identified as nuclear recoil
- Contribution of surface alpha-rays is also background candidates but estimated to be small
  - ➡ but need to identify its source because the material might also emit radons

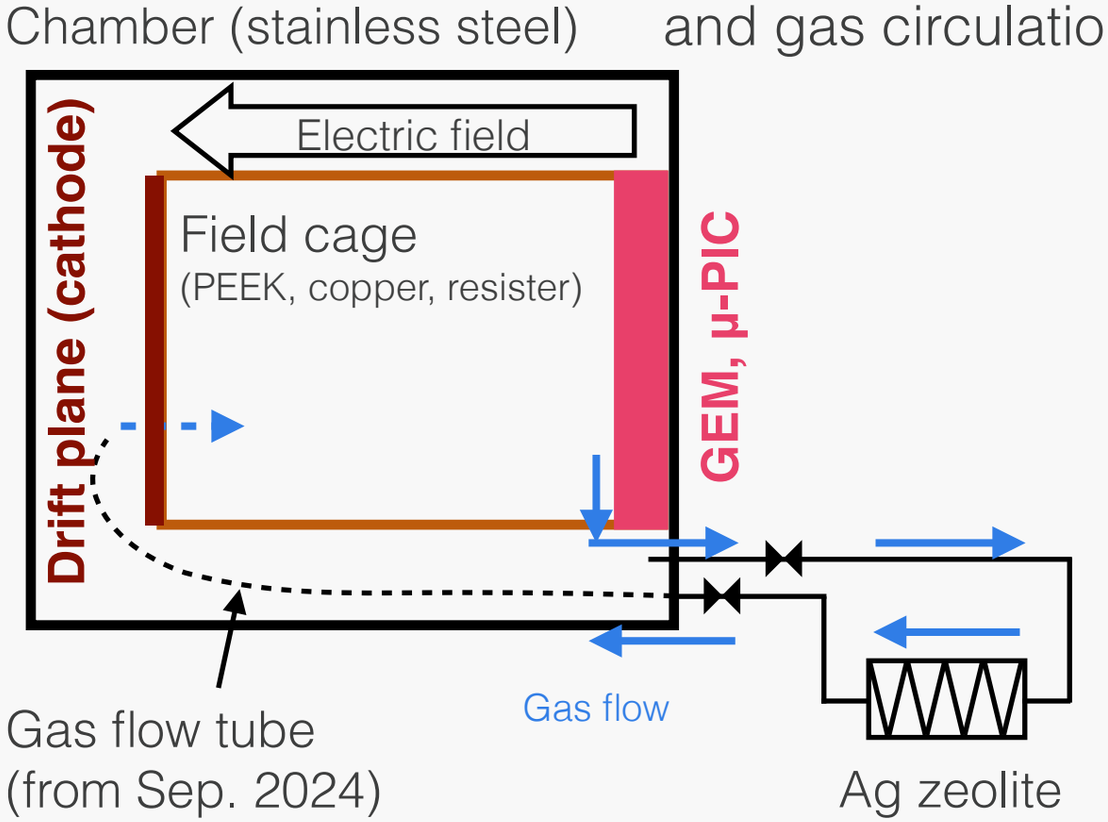
NEWAGE detector
and gas circulation system

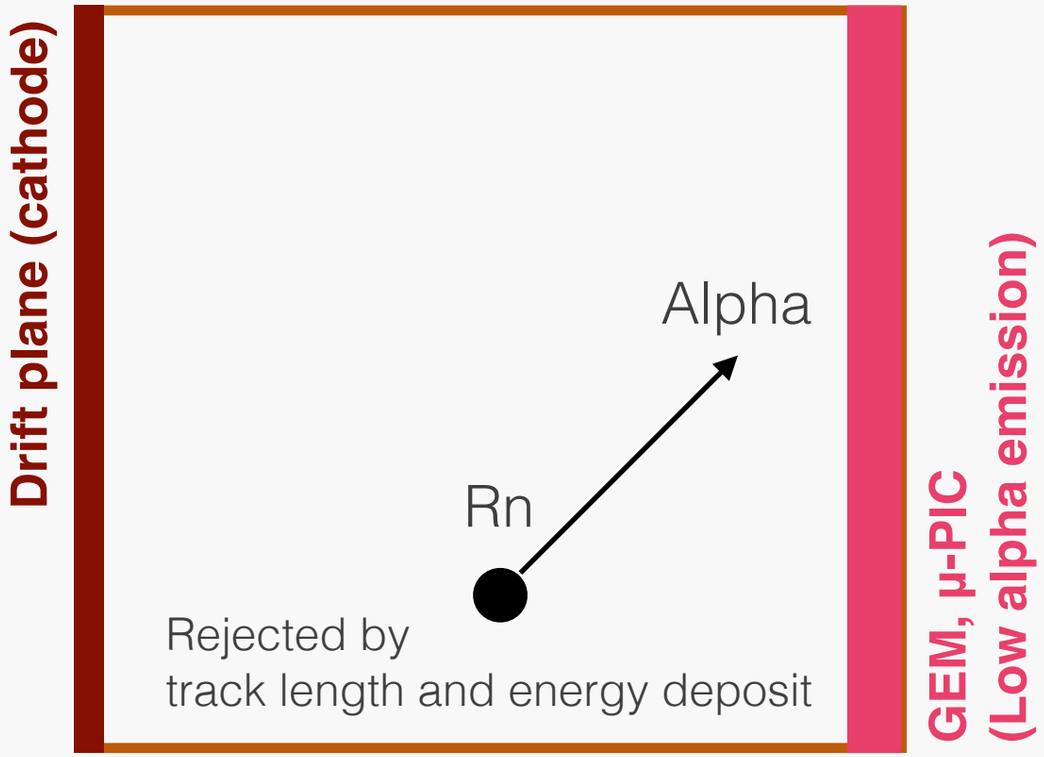


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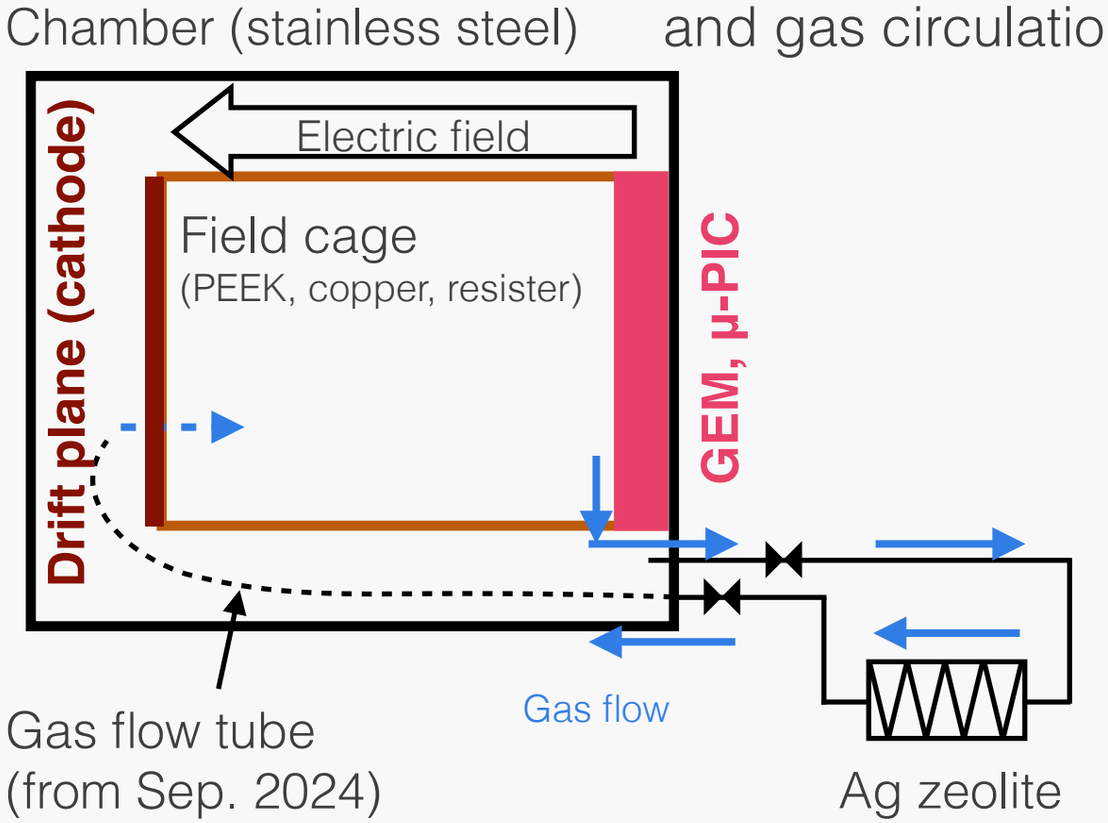


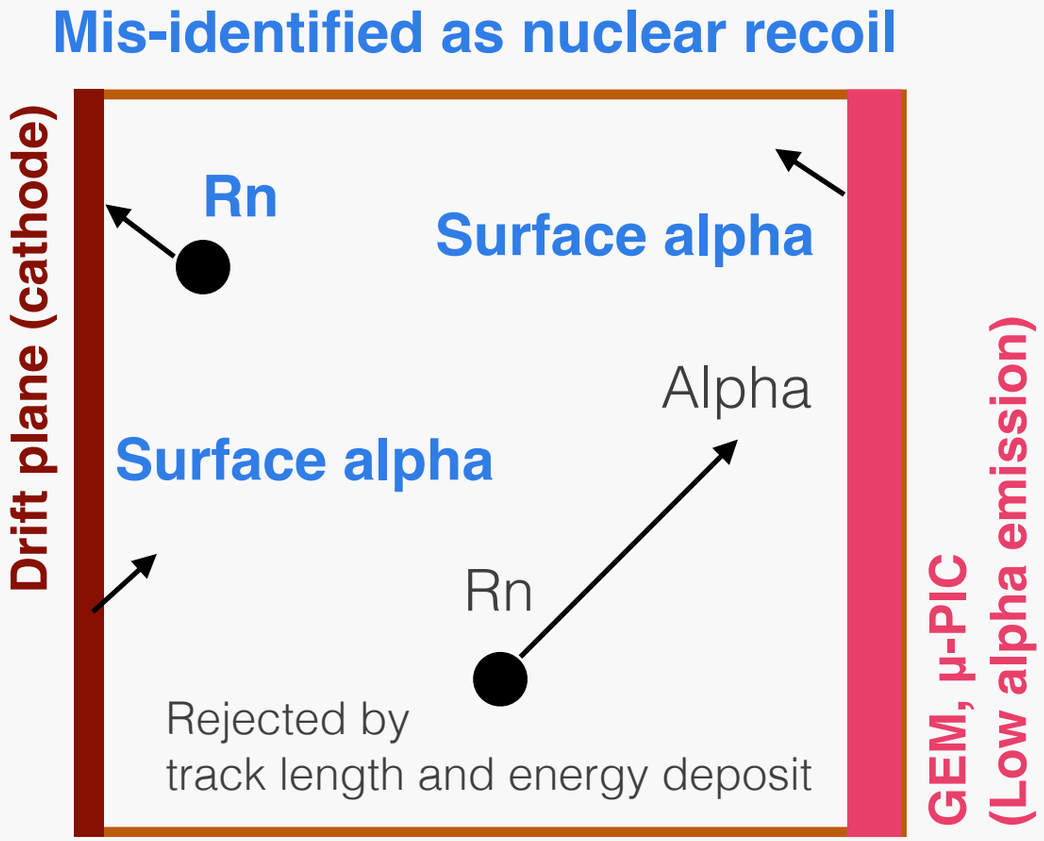


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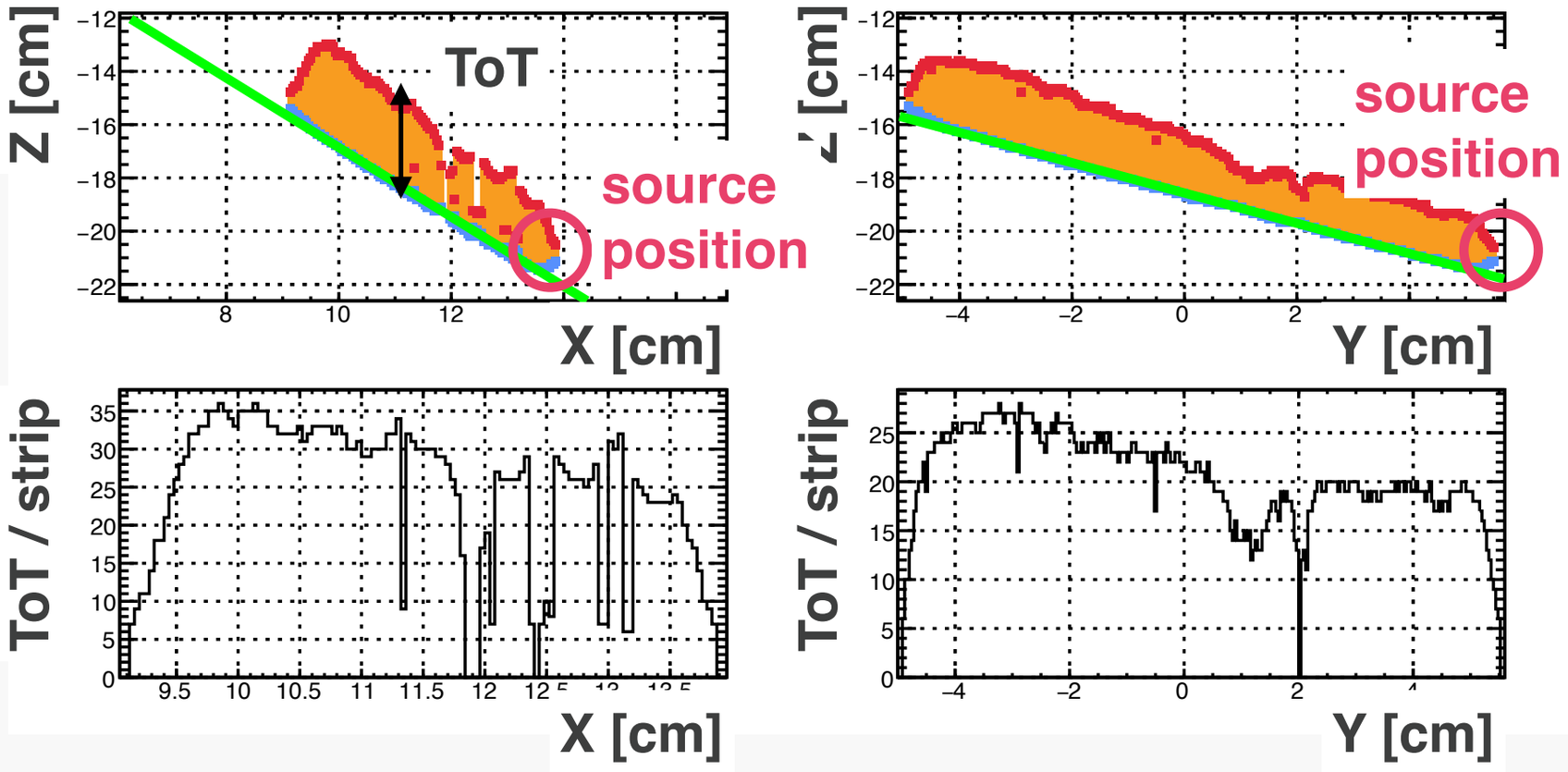
NEWAGE detector
and gas circulation system





Study of alpha-ray source position

- 3D track reconstruction analysis will make identify source position of alpha-rays
  - ➡ Alpha tracks will make a bragg peak just before stopping
  - ➡ Measurement of Time over Threshold for each strip allows to identify a bragg peak
    - ‣ We can determine a particles' direction of flight and consequently identify its source position



NEWAGE Event Display
Dataset : 20260701, period : 33
File ID : 91, Trigger ID : 467

Energy: low = 4621.0, high = 6209.1 [keV]
Track Length = 12.8 [cm]
TOT-sum=8265
Roundness = 0.068

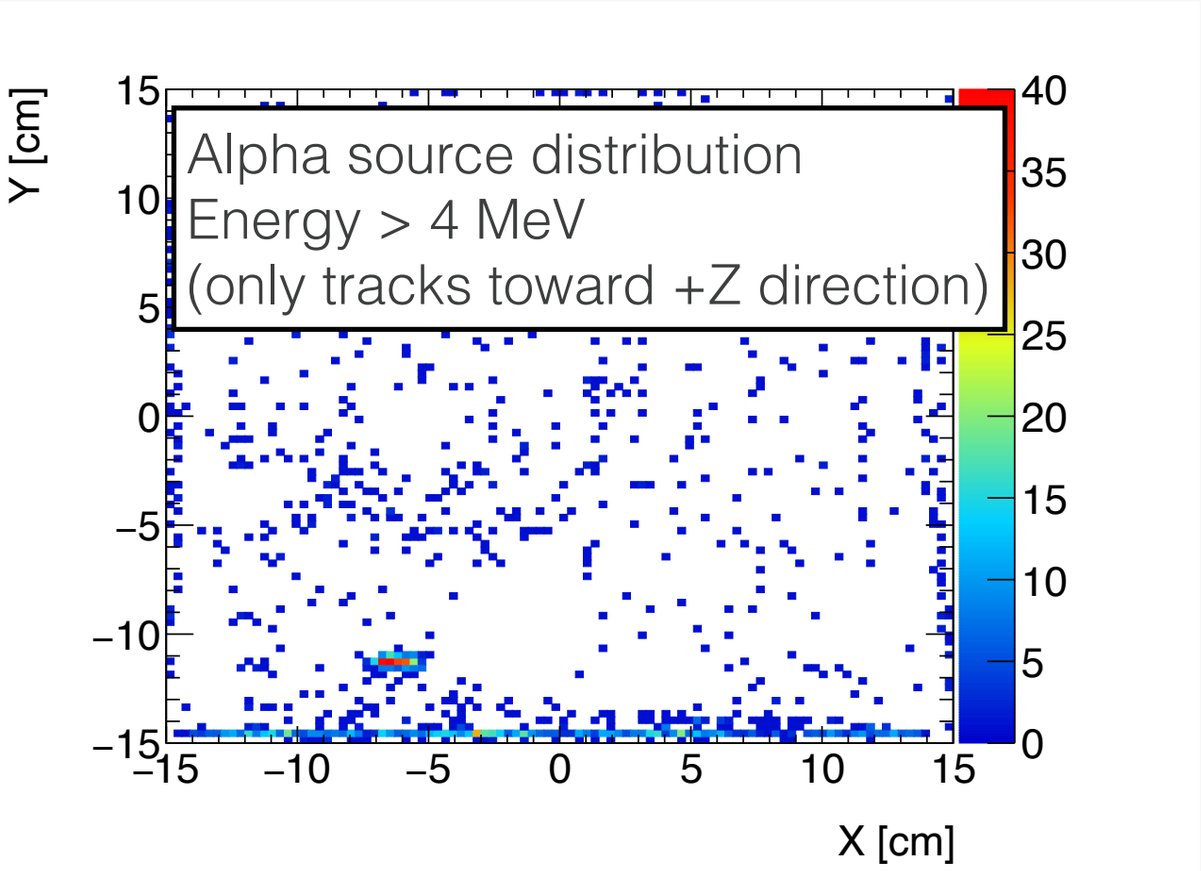
Elevation Angle = -27.51 [deg]
Absolute Azimuth Angle = 66.45 [deg]
Skewness X : -0.031078
Skewness Y : -0.038586
Skewness 2D : -0.021399

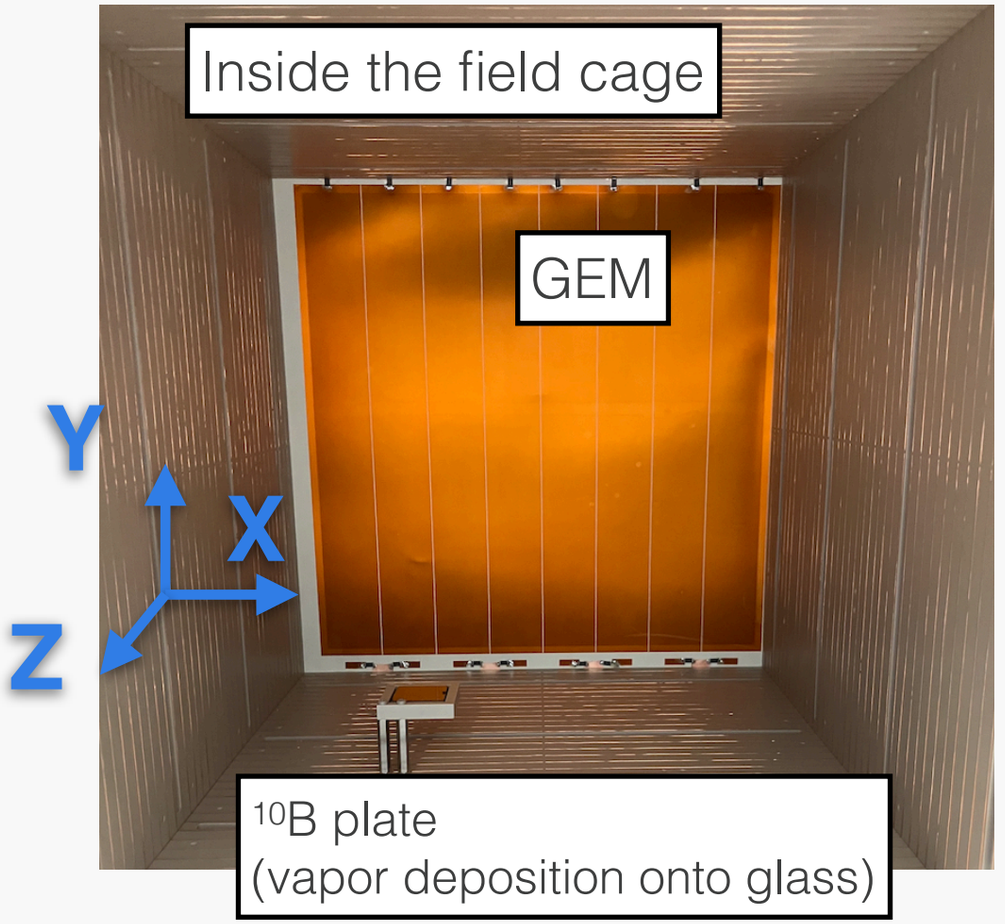


Time over Threshold (ToT)

Alpha source distribution

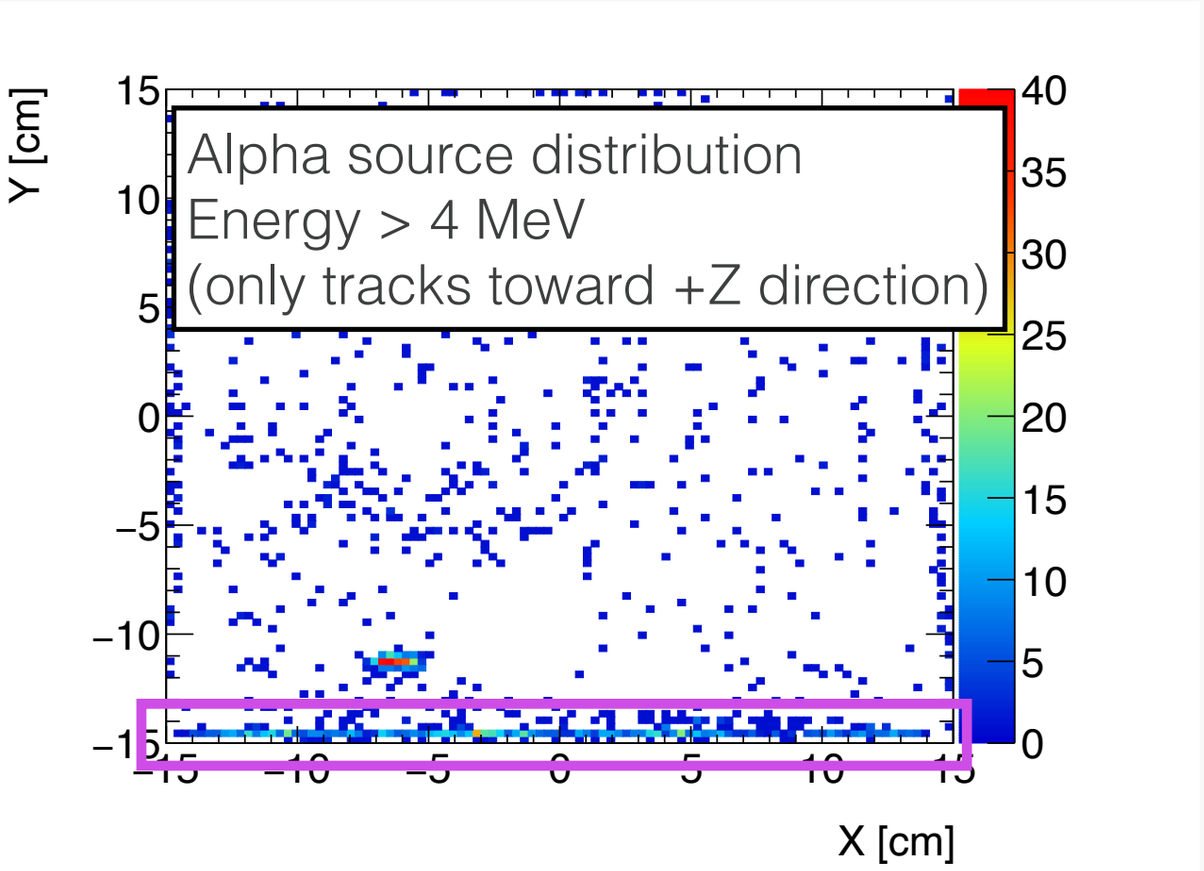
- Track analysis make identify the source position of alpha-rays
  - ➡ ^{10}B plate (for energy calibration) , and unknown distribution in -Y region??
    - ^{10}B plate was already investigated and not a dominant radon emanation source
    - Bias resisters, Pb-free solder and Copper tapes (for GEM bias supply) placed in -Y region
      - Their radon emanation was also measured and was not consistent with NEWAGE BG

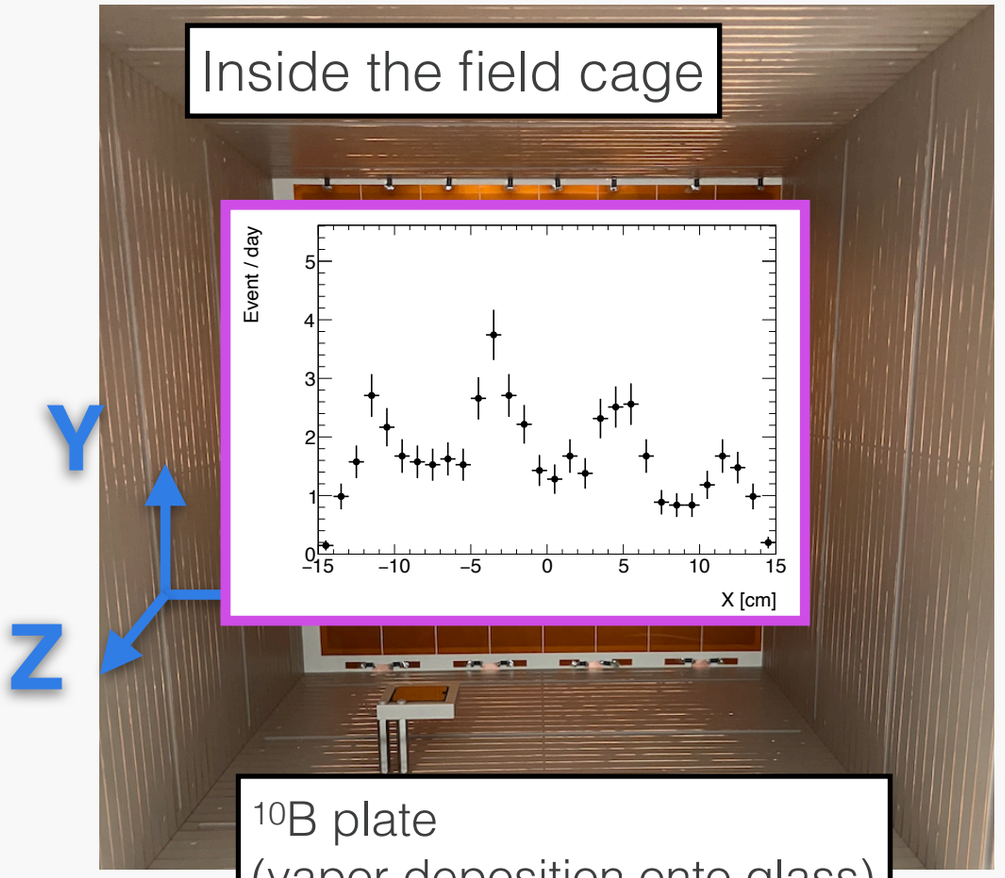




Alpha source distribution

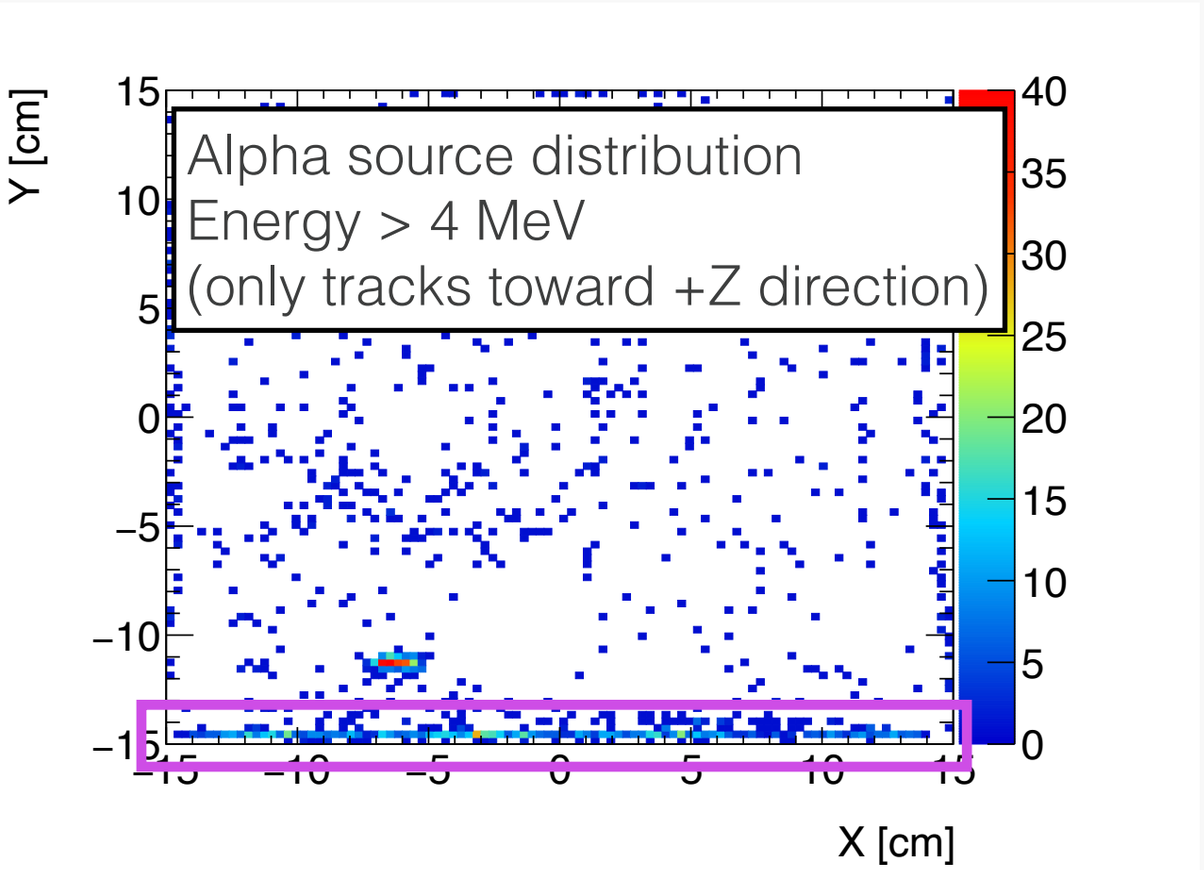
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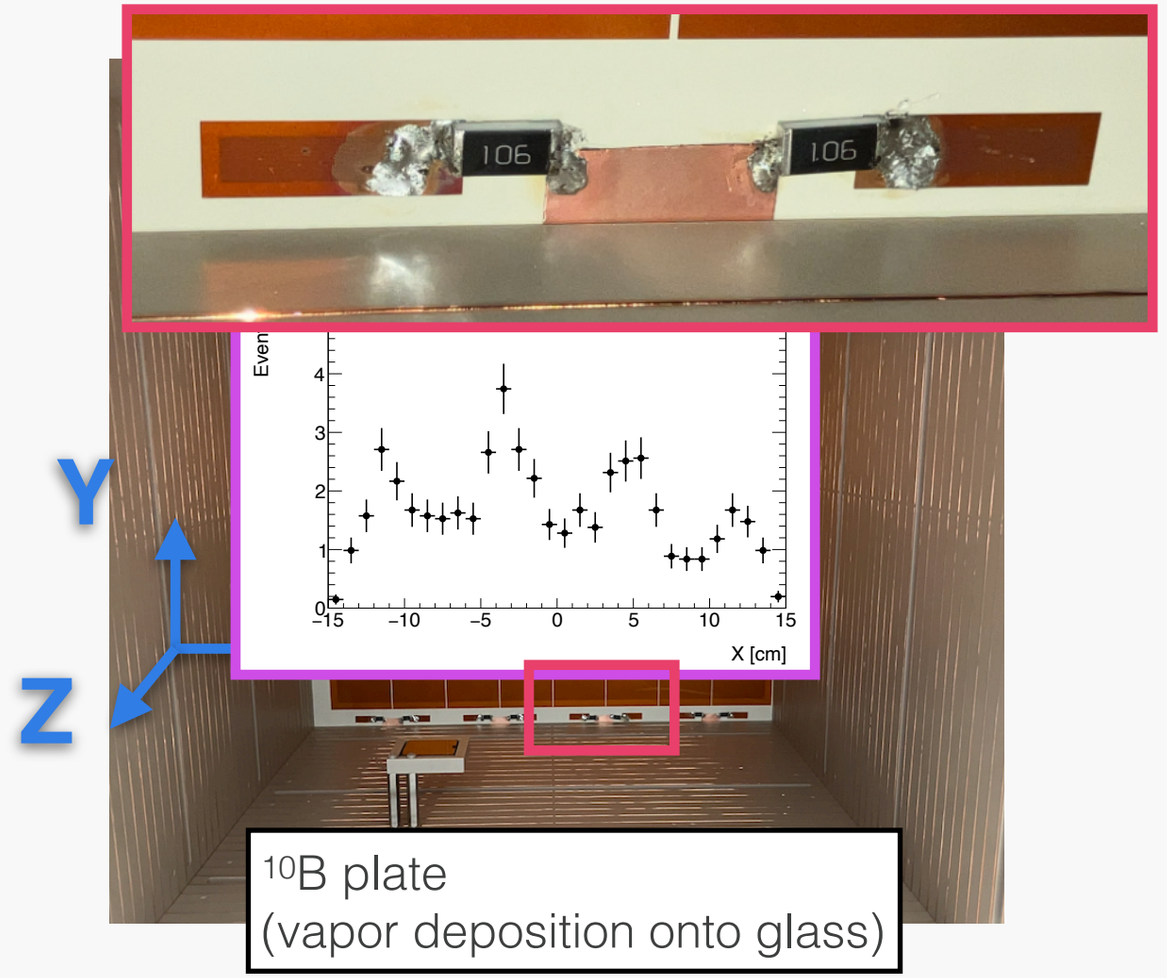




Alpha source distribution

- Track analysis make identify the source position of alpha-rays
  - ➡ ^{10}B plate (for energy calibration) , and unknown distribution in -Y region??
    - ^{10}B plate was already investigated and not a dominant radon emanation source
    - Bias resisters, Pb-free solder and Copper tapes (for GEM bias supply) placed in -Y region
      - Their radon emanation was also measured and was not consistent with NEWAGE BG





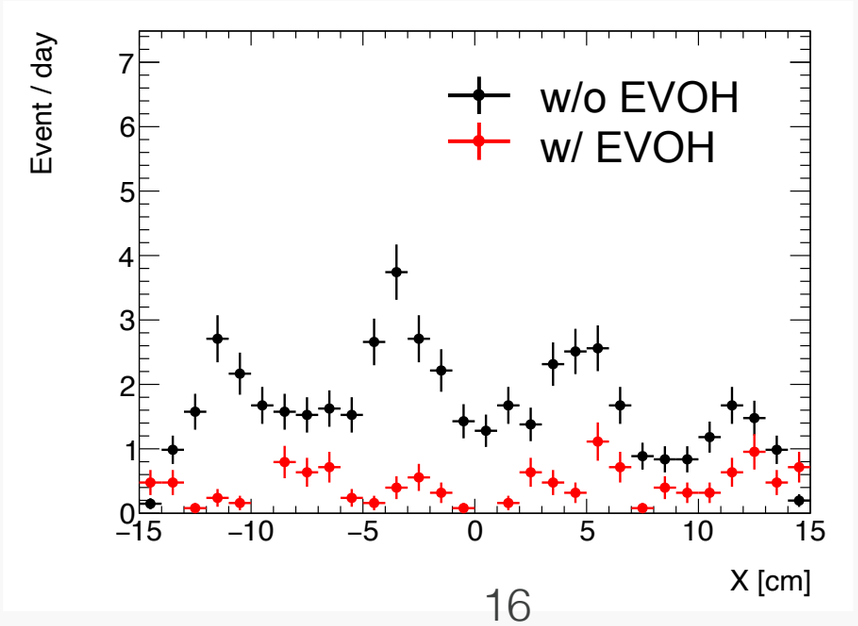
Gas barrier with EVOH film

- Bias resisters was covered with **EVOH** (Ethylene-vinyl alcohol copolymer) film
  - ➡ to suppress surface alpha and radon contamination to the gas region
- **Surface alpha successfully rejected**、but internal radon decays still appear
  - ➡ Slightly decreasing but statistics not sufficient yet to conclude it
  - ➡ Also need to investigate the ROI region in lower energy
- **Demonstration of BG reduction campaign using track analysis achieved!!**

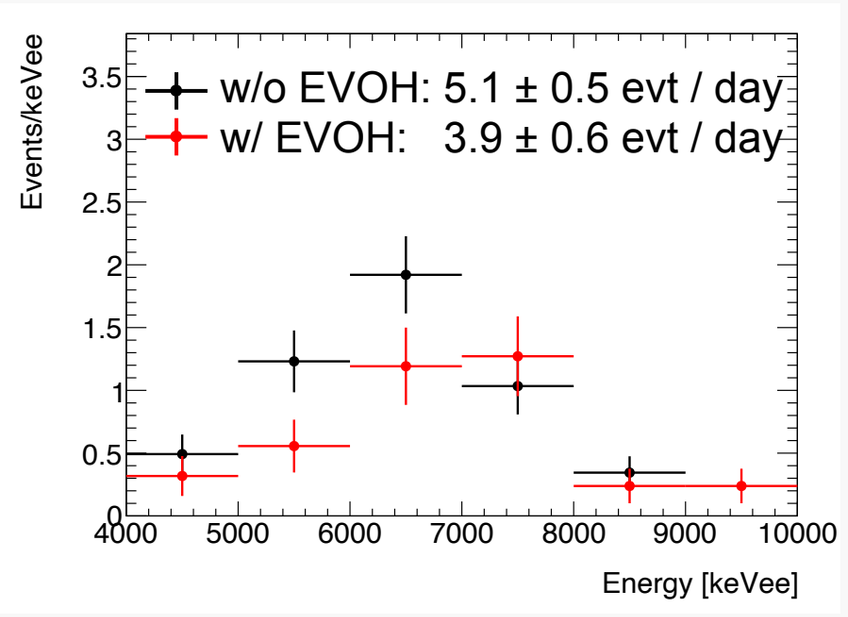
Cover with EVOH film



Track source distribution around -Y region



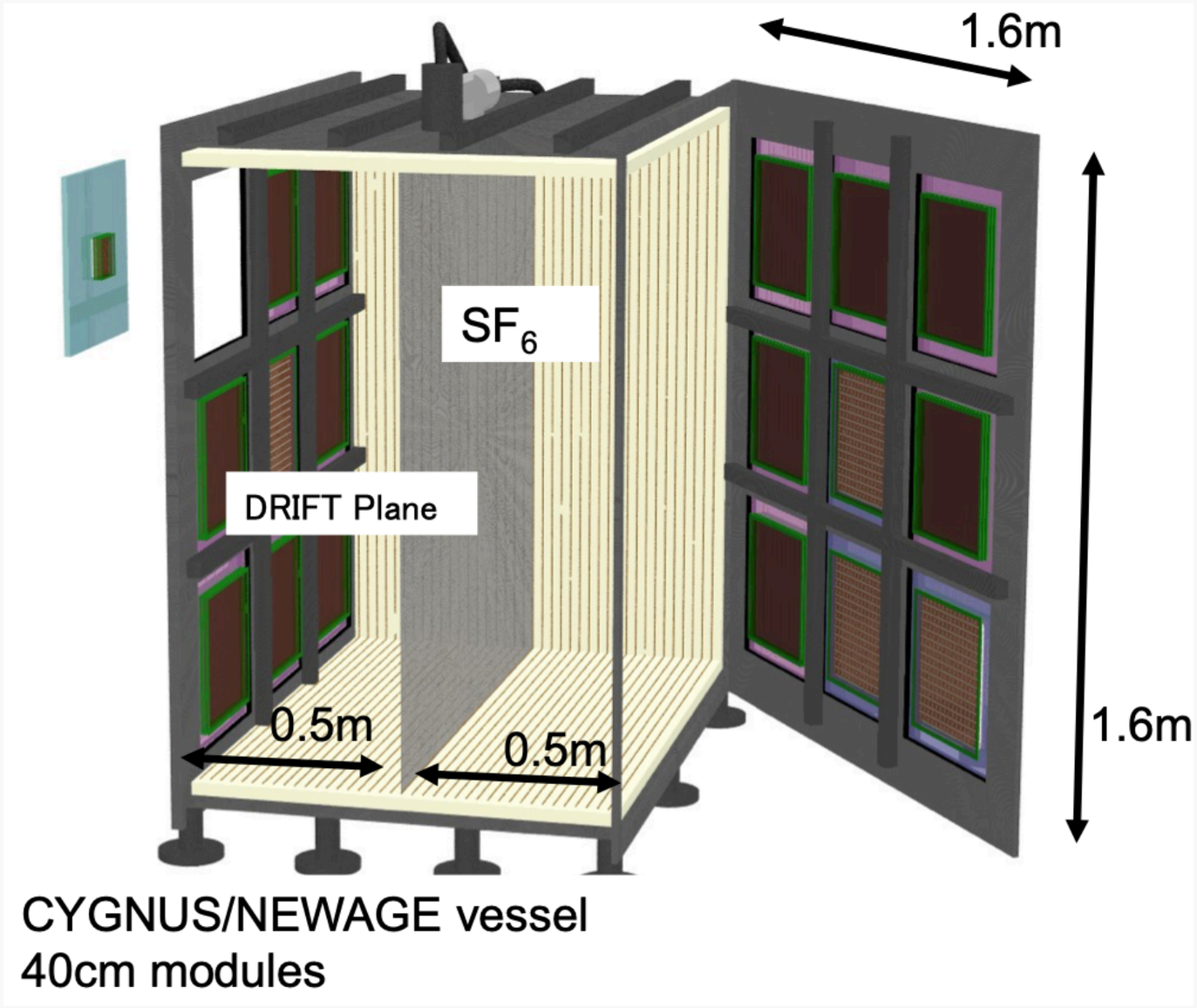
Energy distribution (radon-alpha events will make a peek around 6 MeV)



CYGNUS-KM / NEWAGE (C/N-1.0)

- Modulated chamber (~1 m^3) : 18 module windows are available
  - ➡ Enables to install the conventional NEWAGE detector (30 × 30 cm^2 fiducial area)
  - ➡ We can accept detectors from any other groups: your “clean” detectors are candidates!

Ryota will present the status of C/N-1.0 commissioning!

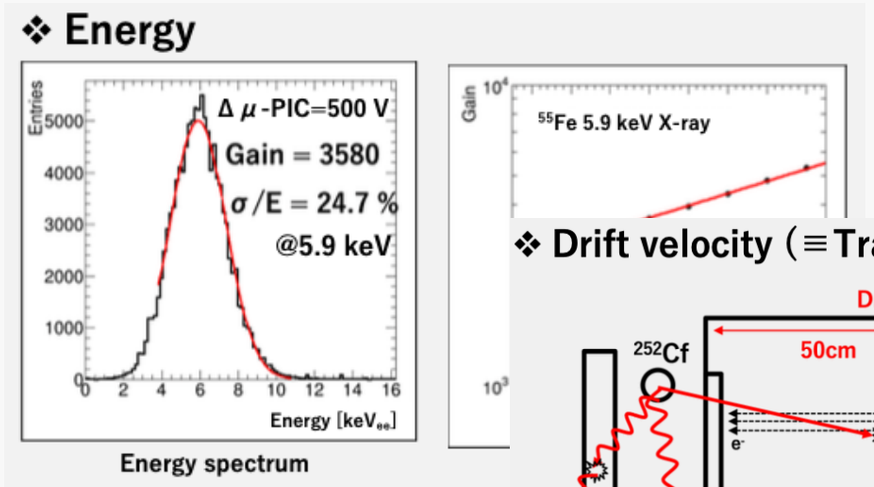


CYGNUS/NEWAGE vessel
40cm modules



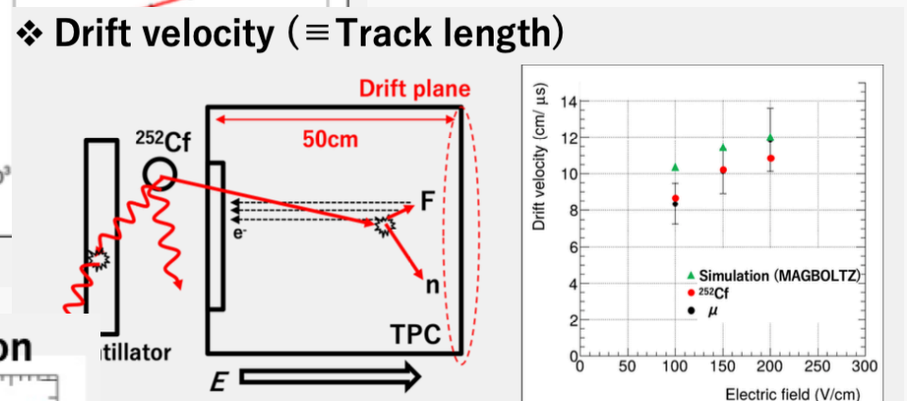
C/N-1.0 commissioning w/ a modular detector

- Test with small area (10 × 10 cm^2) GEM + μ-PIC system
  - ➡ 2 strip bundled readout (≒ 800 μm pitch) due to limited electronics



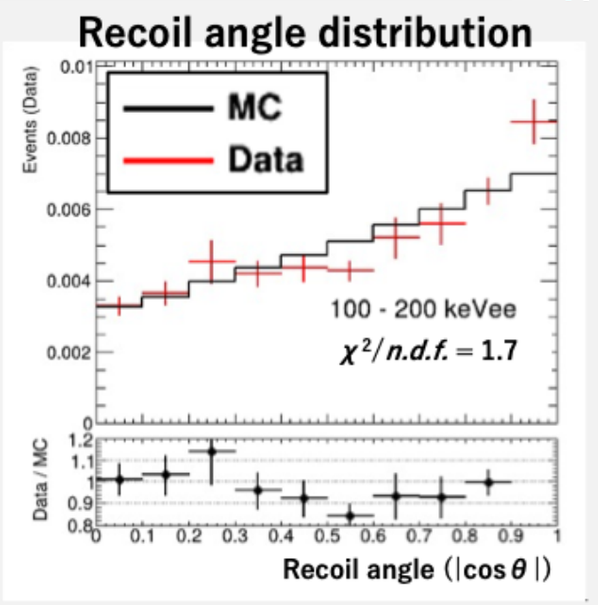
Energy spectrum

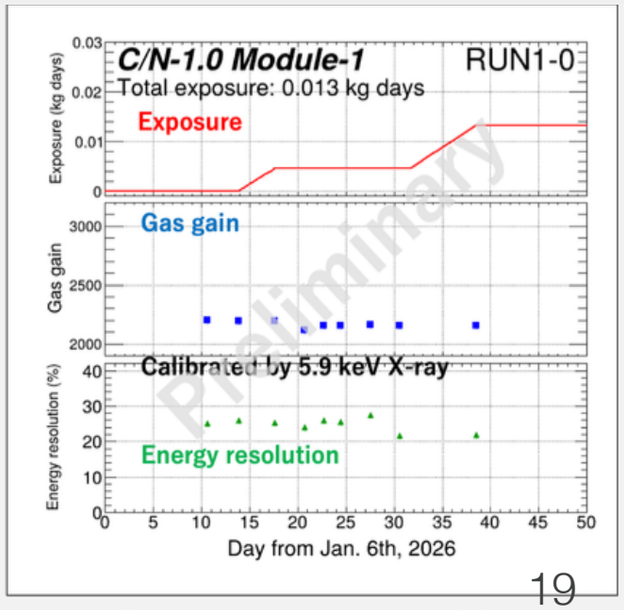
Lots of demonstrations !



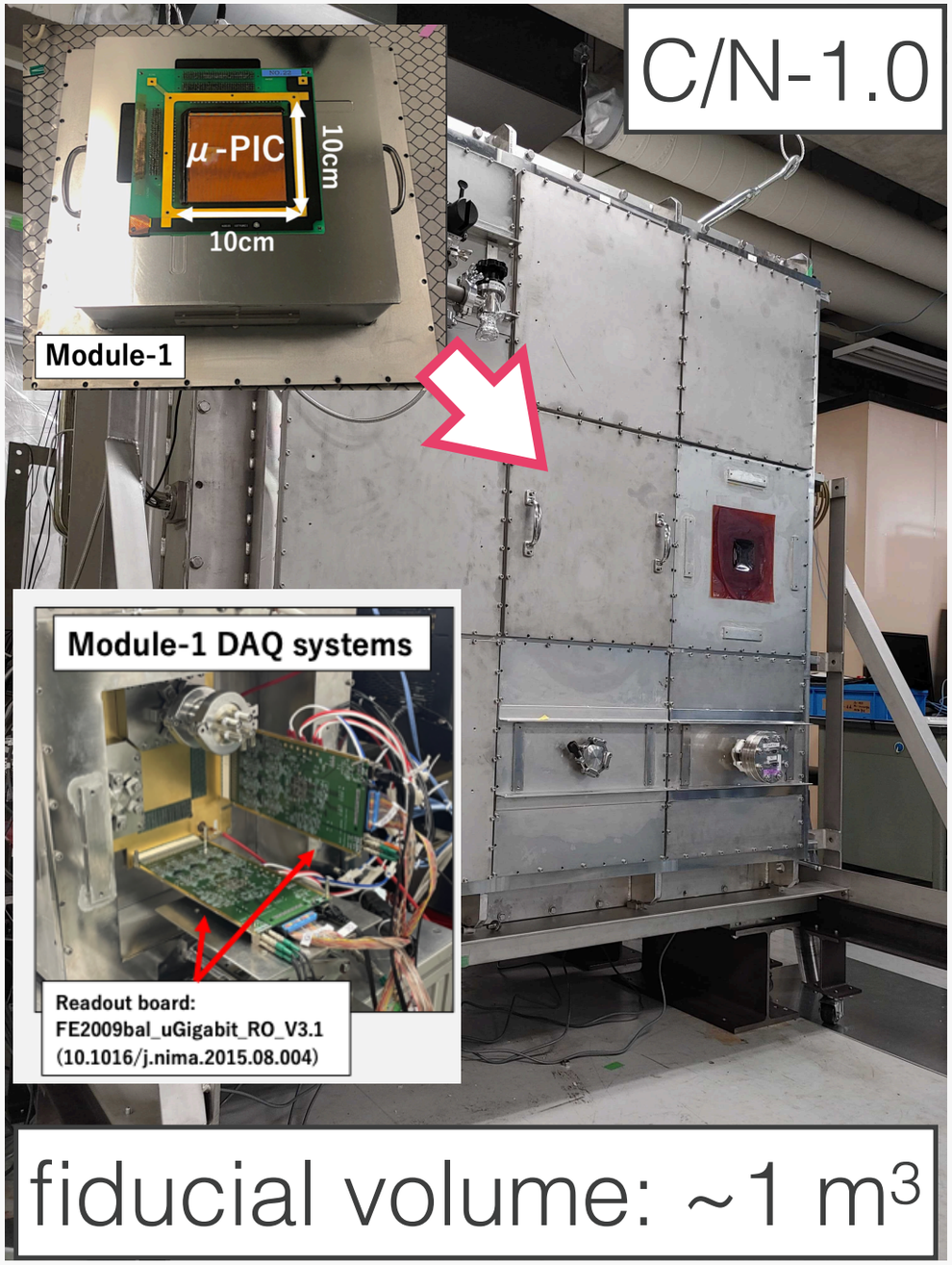
Schematic of measurement

Electric field vs. Drift velocity





Detector status transition



fiducial volume: ~1 m^3

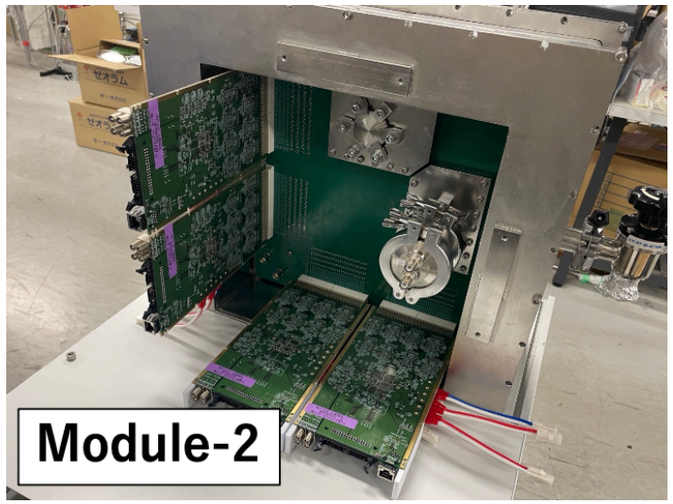
Poster:
(P25 R.Namai)

LAST SURFACE COMMISSIONING!!!

- Test with small area (10 × 10 cm²) GEM + μ-PIC system

400 μm

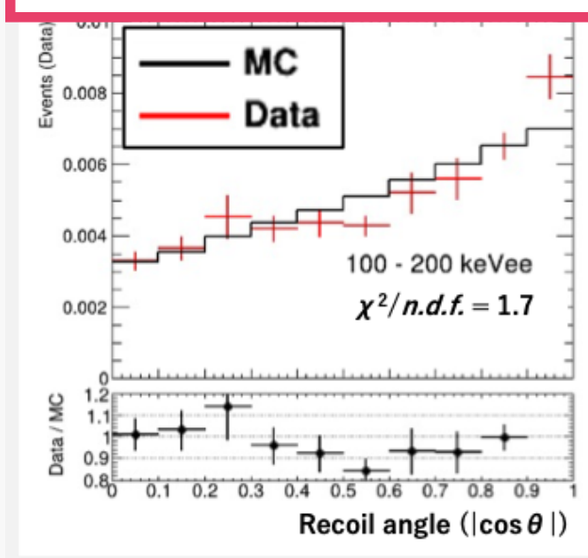
➡ ~~2 strip bundled readout (~ 800 μm pitch)~~ due to limited electronics



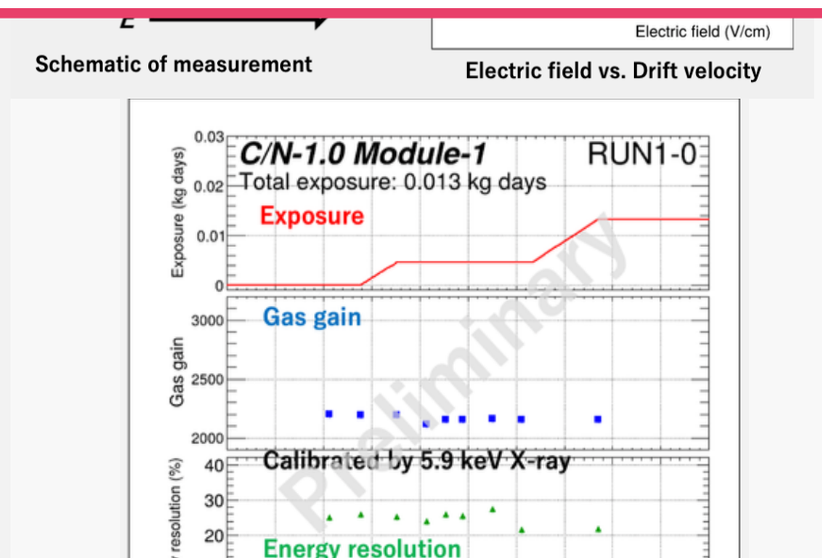
10 × 10 cm² modular detector w/ full electronics already prepared (equivalent to the detector in Kamioka).

Small but more stable detector will achieve high gain operation, allowing to explore **lower mass region**.

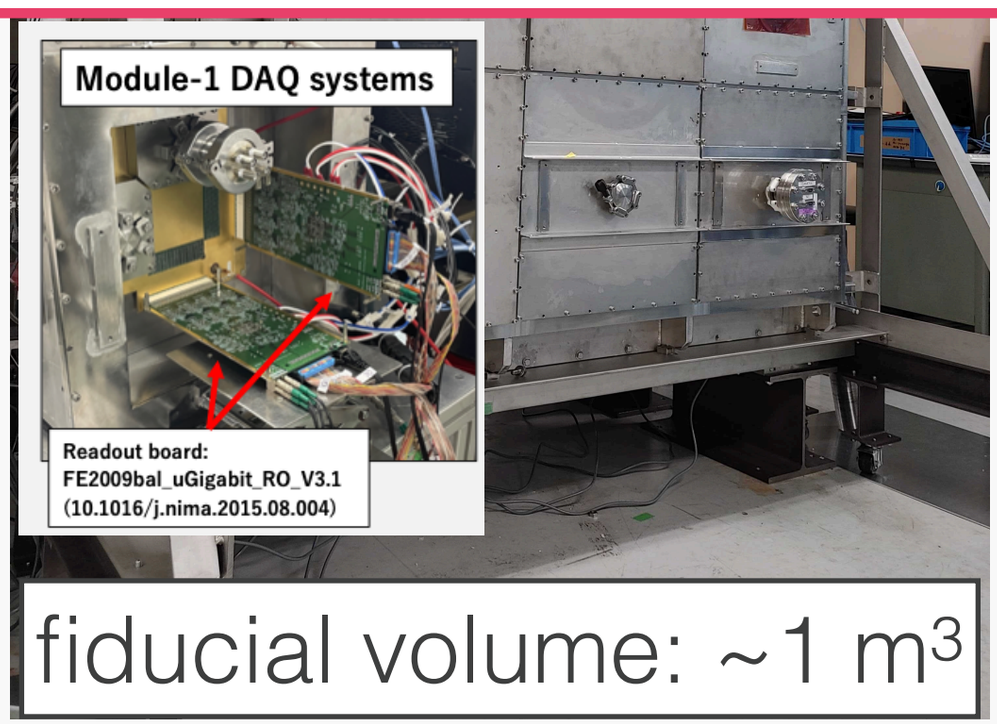
The detector will be installed right after UGRP2026!



Poster:
(P25 R.Namai)



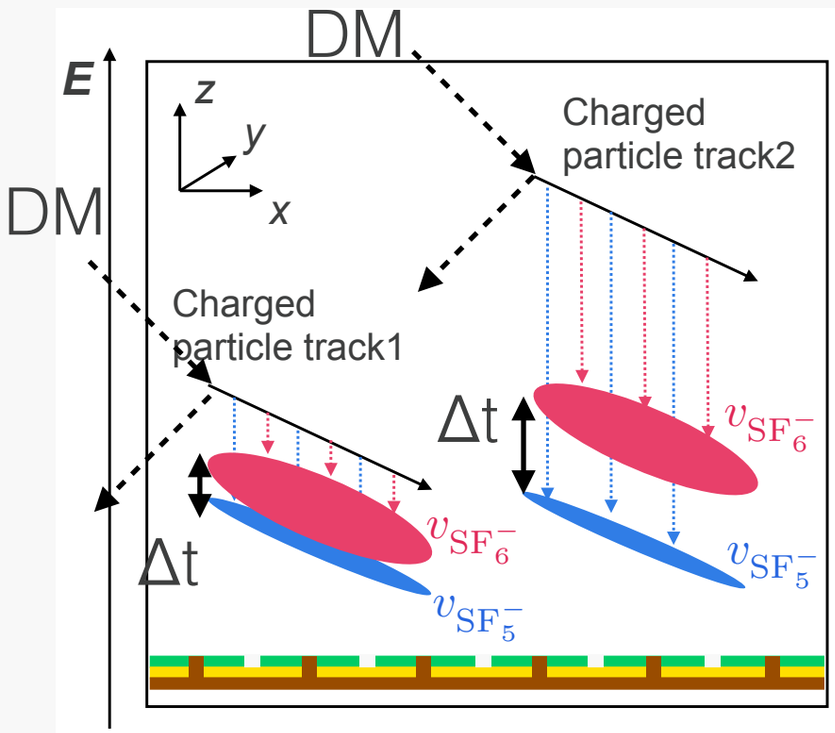
Detector status transition

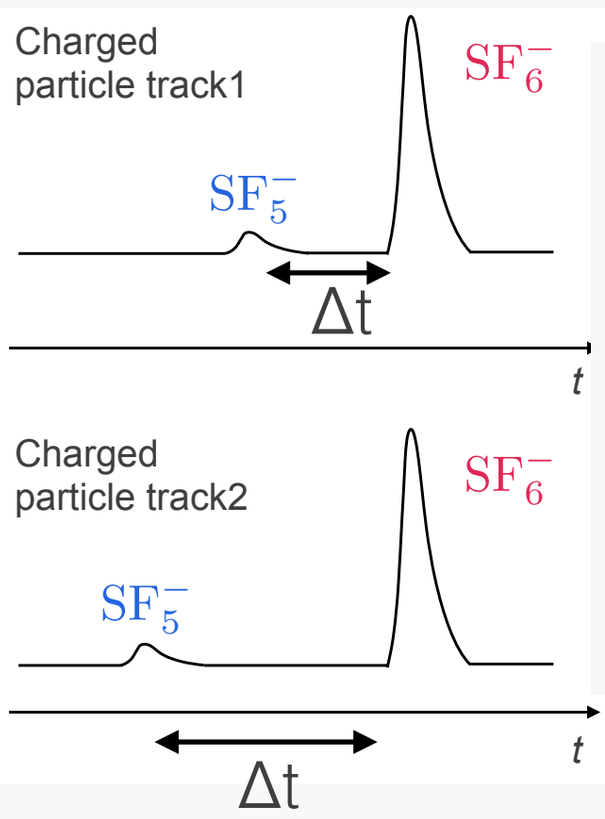


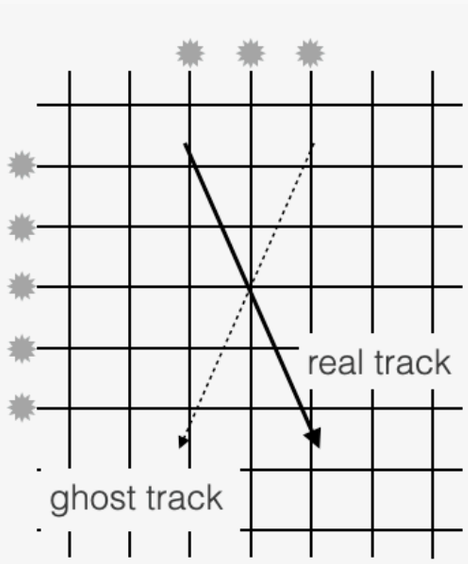
fiducial volume: ~1 m³

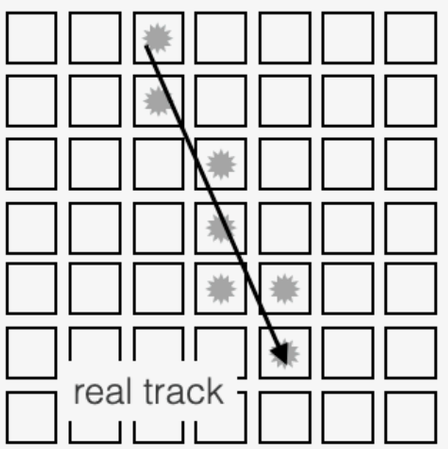
Future detector: Negative-ion × Pixel

- “Negative-ion gas” such as SF_6 allows to reconstruct absolute 3D position
  - ➡ Ionized electrons are attached to SF_6 and form mainly two types of negative ion
    - ▸ Time difference between these pulse corresponds to charged track position along the drift coordinate
    - ▸ **Background events nearby detector surface and drift plane can be rejected analytically**
  - ➡ Diffusion of negative-ion drift is relatively small than electron drift
- Combination of high granularity pixelated electrode leads more precise track reconstruction
  - ➡ Pixel readout resolves track ambiguity





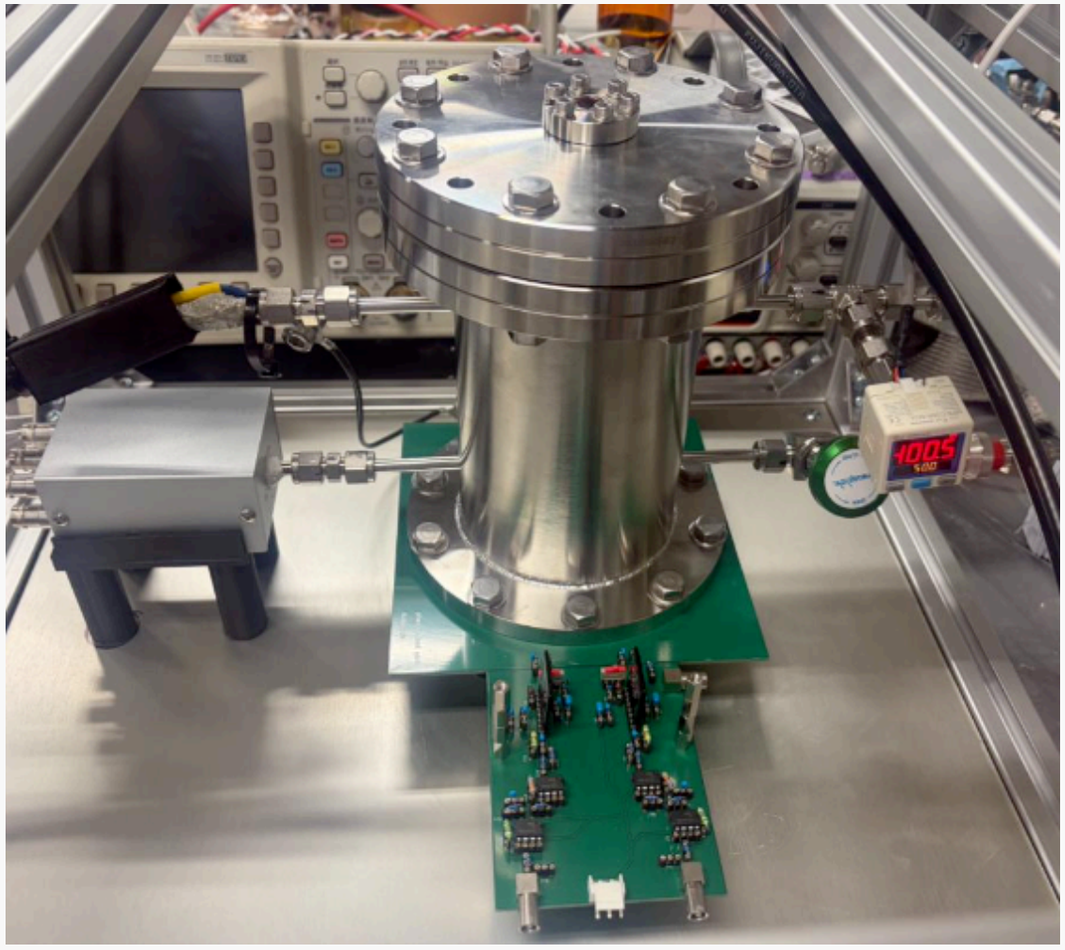


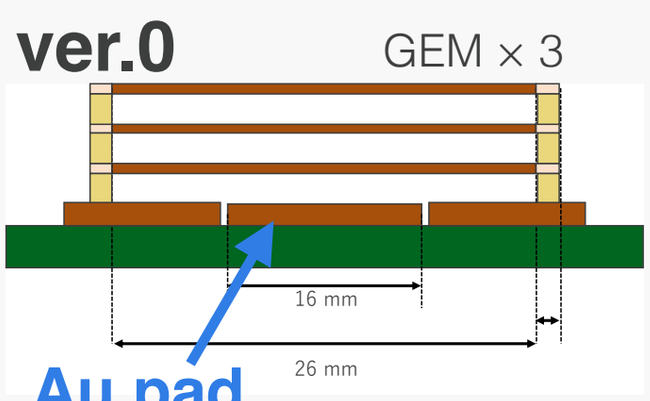


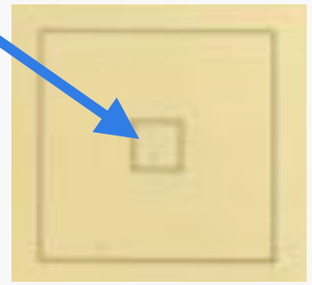
Poster:
(P18 W.Toyama)

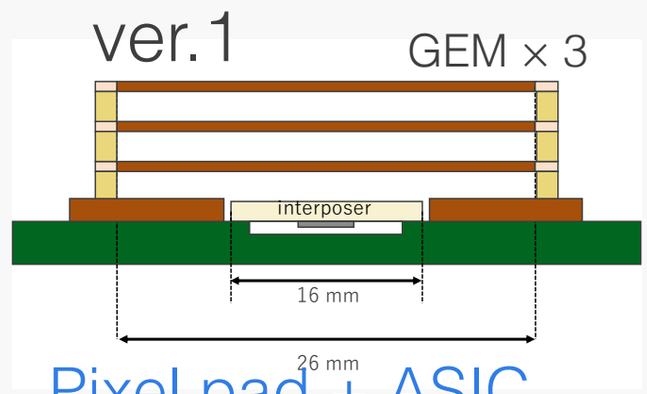
Detector development

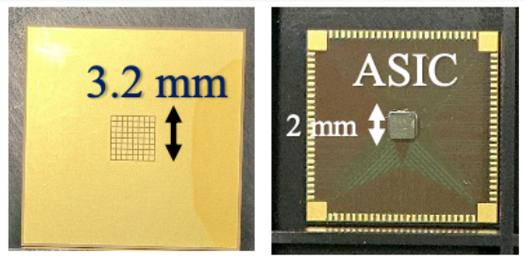
- Prototype detector being preparation
  - ➡ **Ver.0**: Simple 1 channel pad electrode for gas studies
  - ➡ Ver.1: 64 ch, 400 μm pitch pixelated electrodes (electronics under development)







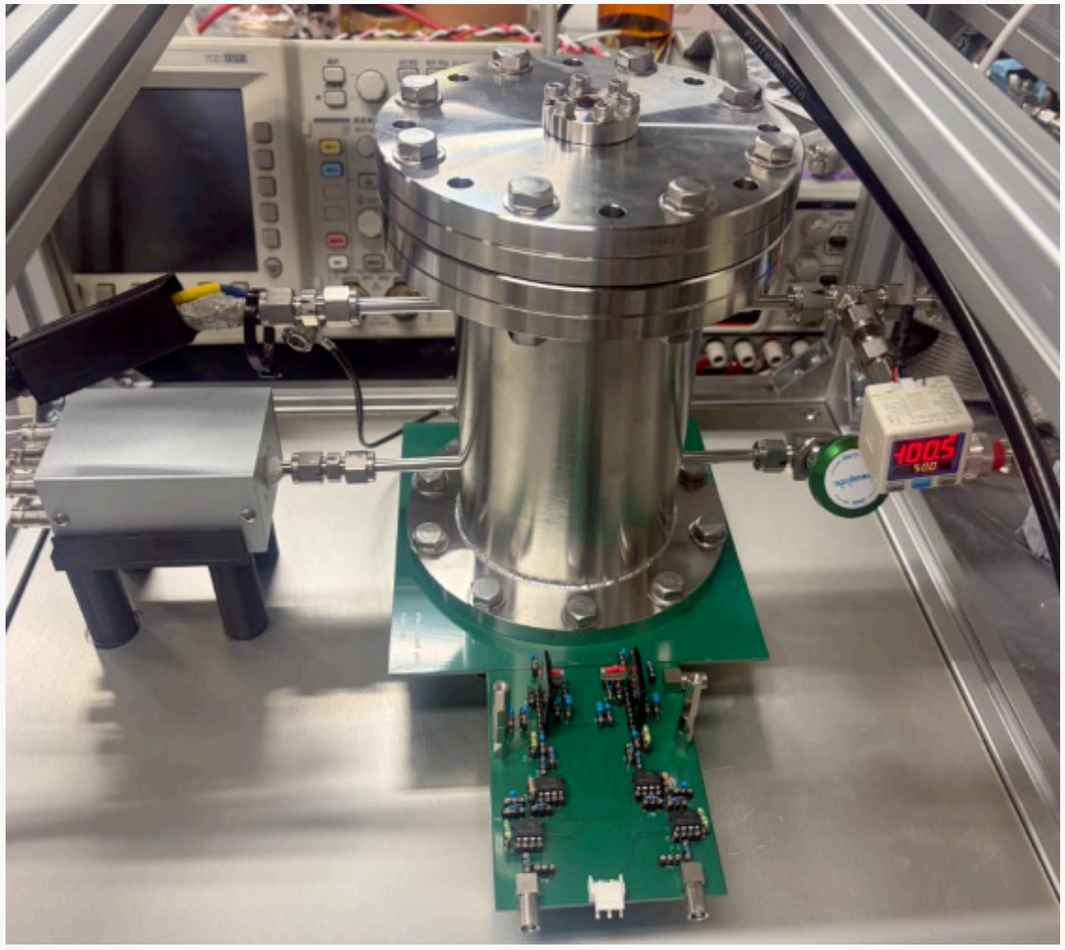


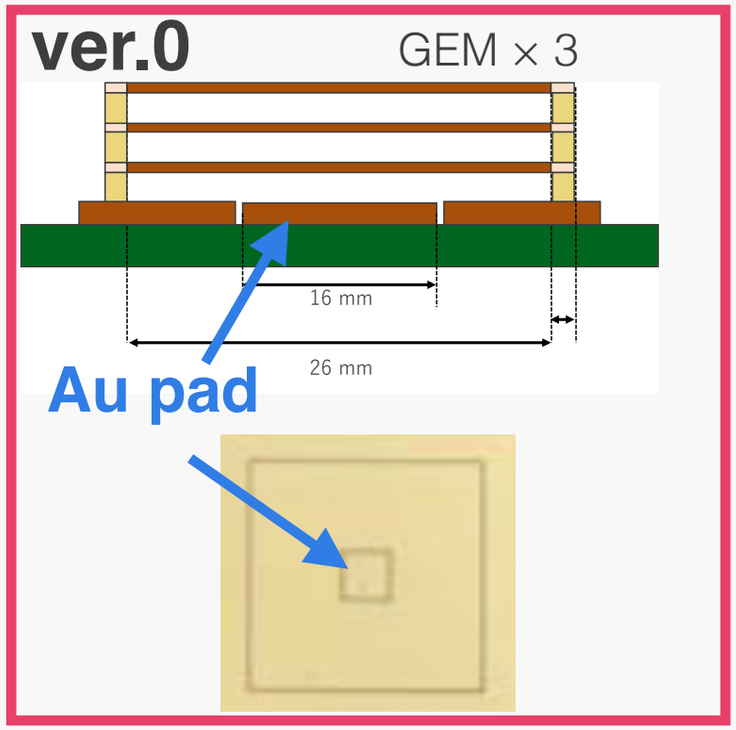


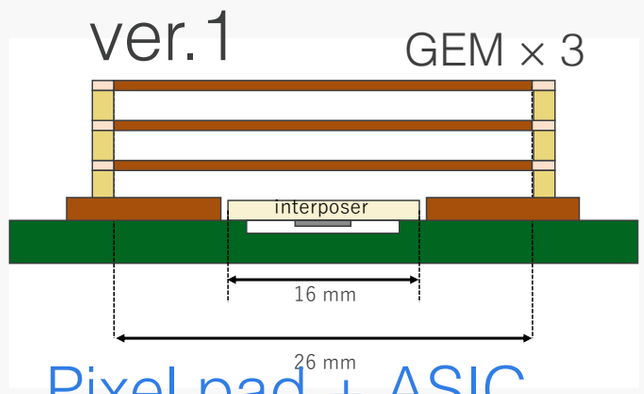
Poster:
(P18 W.Toyama)

Detector development

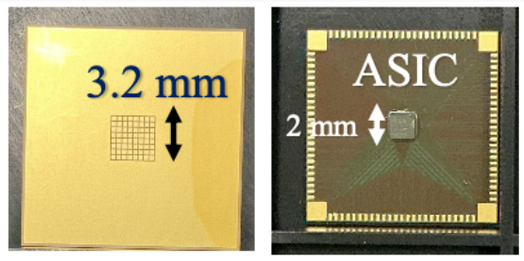
- Prototype detector being preparation
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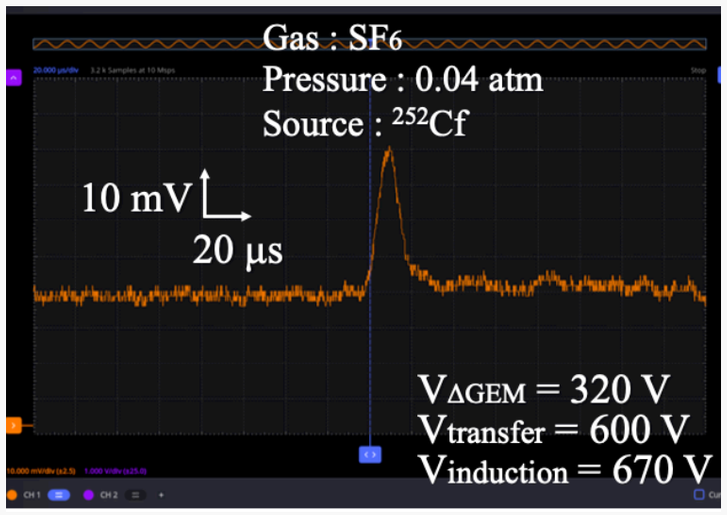






Pixel pad + ASIC





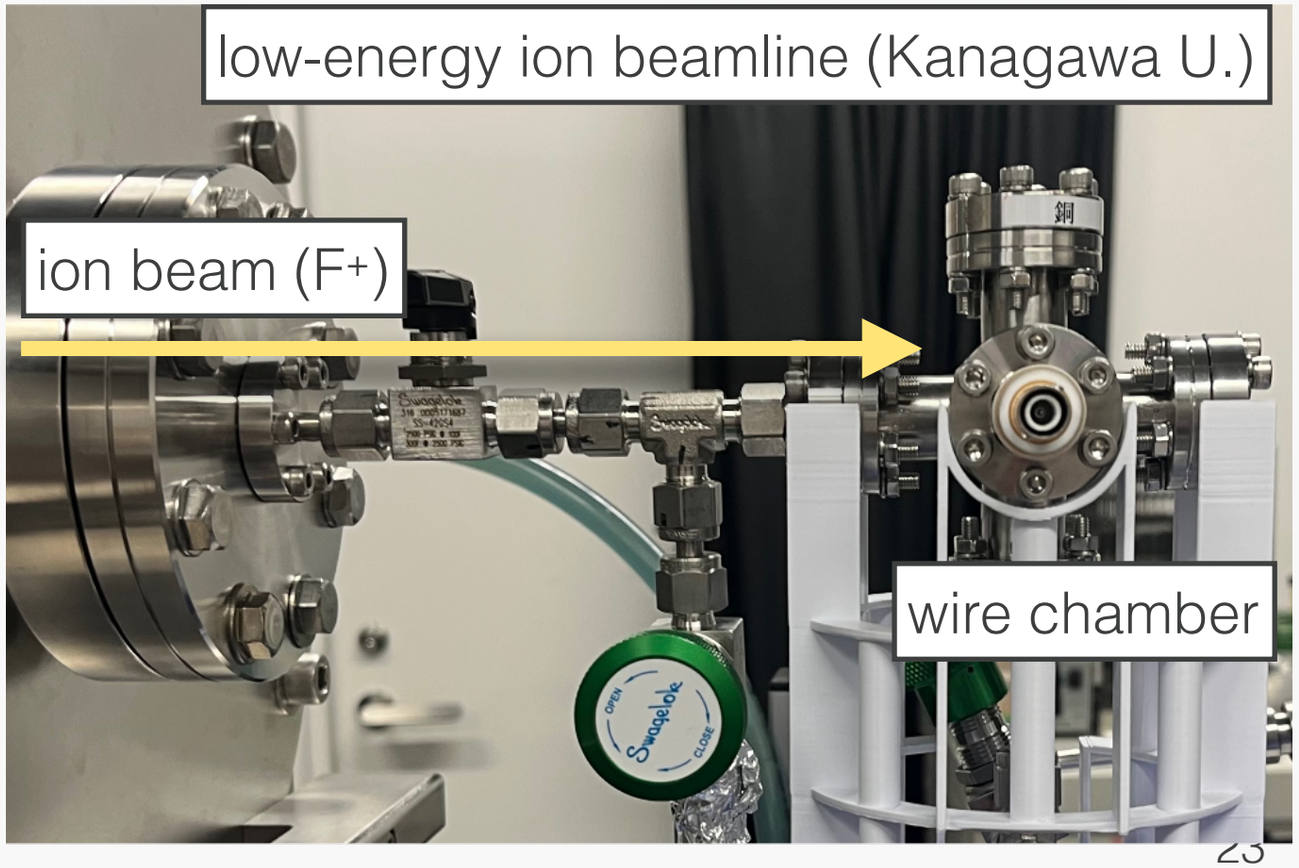
First light for the prototype detector!

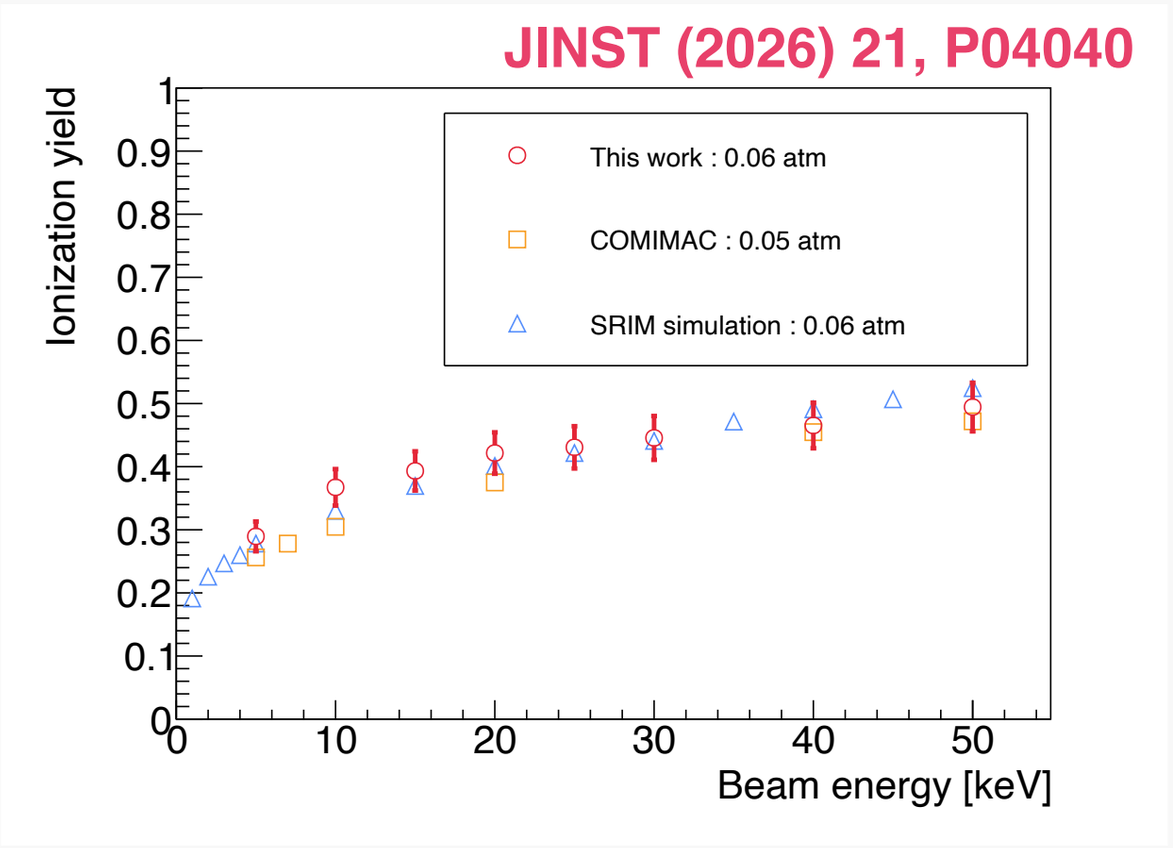
Ver.1 pixelated detector under development

Poster:
(P18 W.Toyama)

Ionization yield measurement

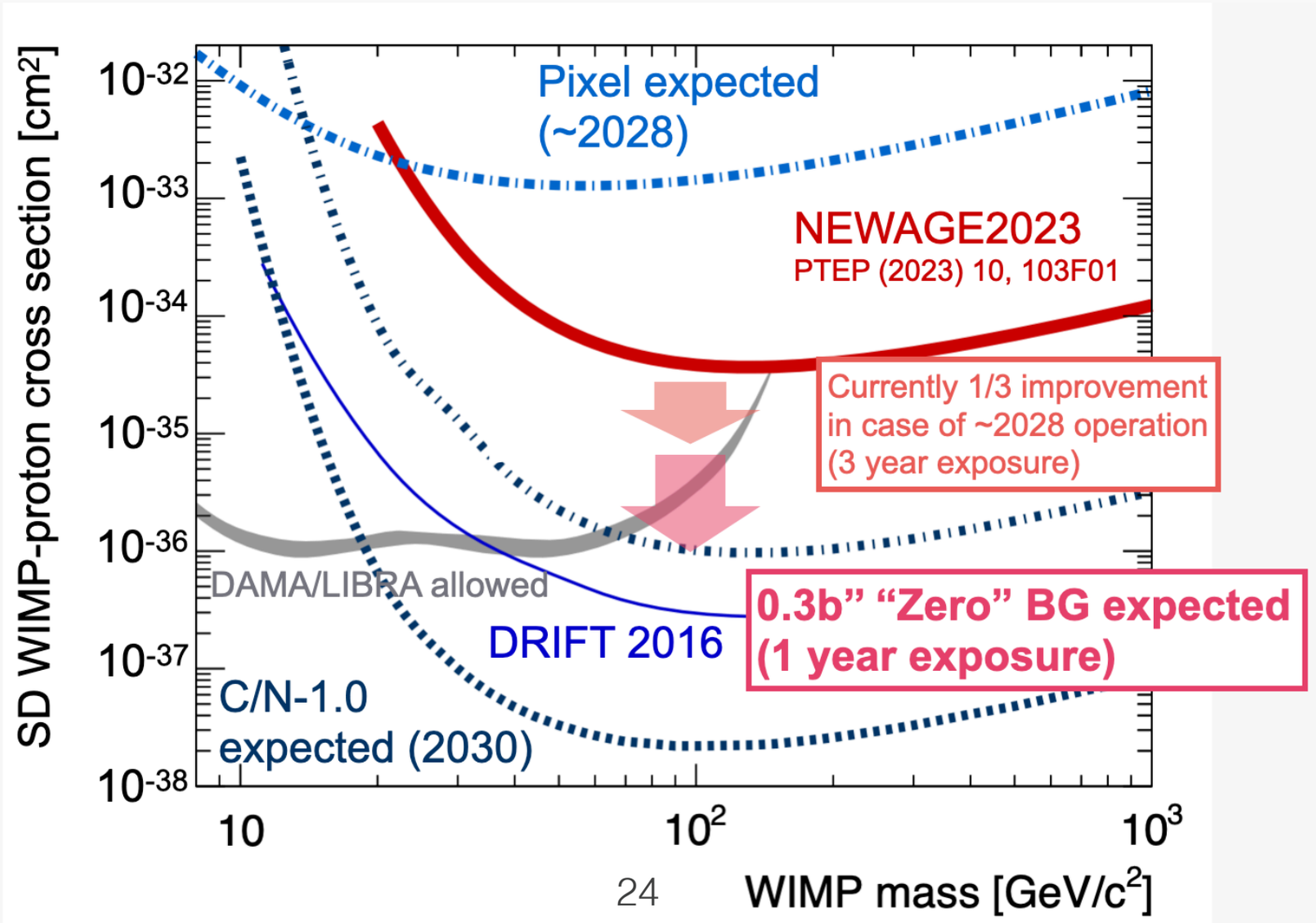
- Precise energy measurement is important as well as the directionality
  - ➡ Low-energy ion beam test was performed at 5-200 kV acceleration facility at Kanagawa U.
- 5 - 50 keV fluorine ions were injected to single-wire proportional chamber
  - ➡ filled with 0.06 atm CF_4 gas (assuming low-pressure NEWAGE operation)
- Result is consistent with COMIMAC and SRIM
  - ➡ Good demonstration of low-energy ion injection into gas detector in Japan!





Conclusion

- NEWAGE conducts direction-sensitive dark matter search using gaseous TPC
  - ➡ Background reduction and scalability studies mainly ongoing to obtain more sensitivity
- Track analysis can make identify radon emanation sources
- Large scale (~1 m^3) chamber will be in a final commissioning phase right after this conference
- Next generation detector: negative-ion gaseous TPC assuming pixelated detection system under development



Backup