GRAMS

for MeV gamma-ray astronomy and dark matter search

小高 裕和

大阪大学

on behalf of the GRAMS Collaboration

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CRCタウンミーティング

GRAMS

Gamma-**R**ay and **A**nti**M**atter **S**urvey

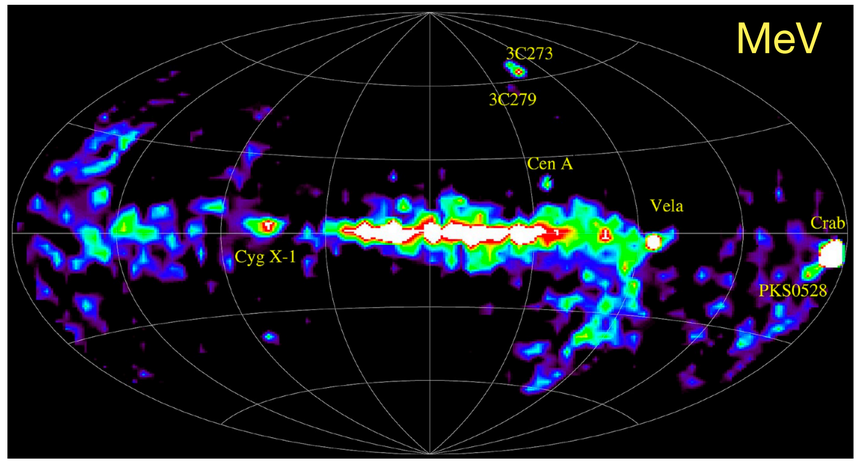
Brining a huge liquid argon detector into the sky

1. an ultra-long duration balloon around late 2020s–early 2030s
2. a satellite-based all-sky deep survey mission in 2030s–2040s

MeV gamma-ray astronomy

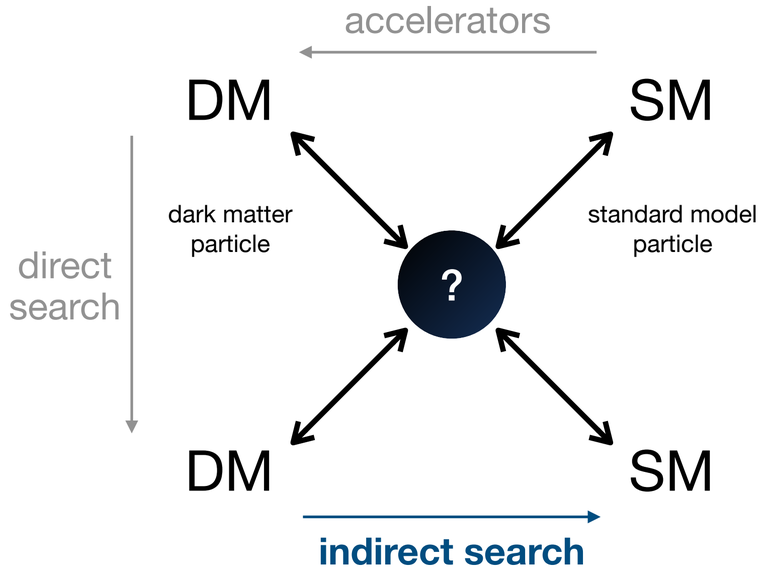
✓ Particle acceleration, thermal-to-nonthermal transition

✓ Nucleosynthesis



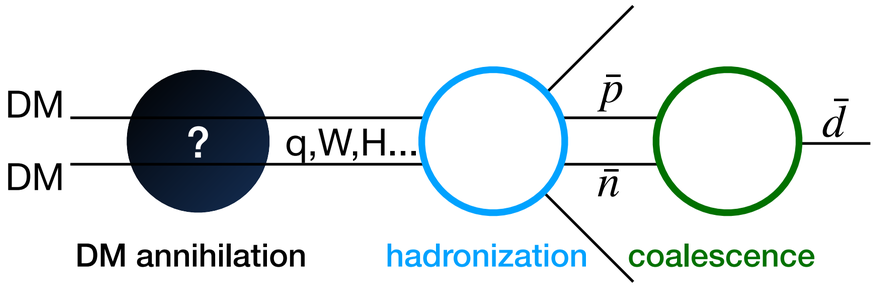
Indirect dark matter search

background-free search using antideuteron/antihelium



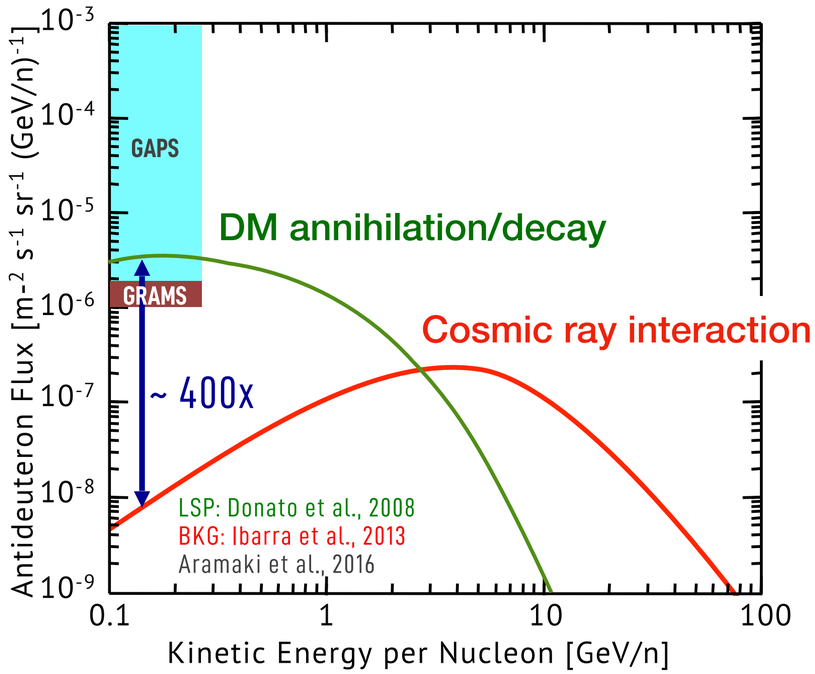
Dark matter search with antideuteron

Primary: dark matter annihilation



Secondary: cosmic ray interaction

$$p(\mathrm{CR}) + \mathrm{H(ISM)} \rightarrow p + \mathrm{H} + p + n + \bar{p} + \bar{n} + \bar{d}$$

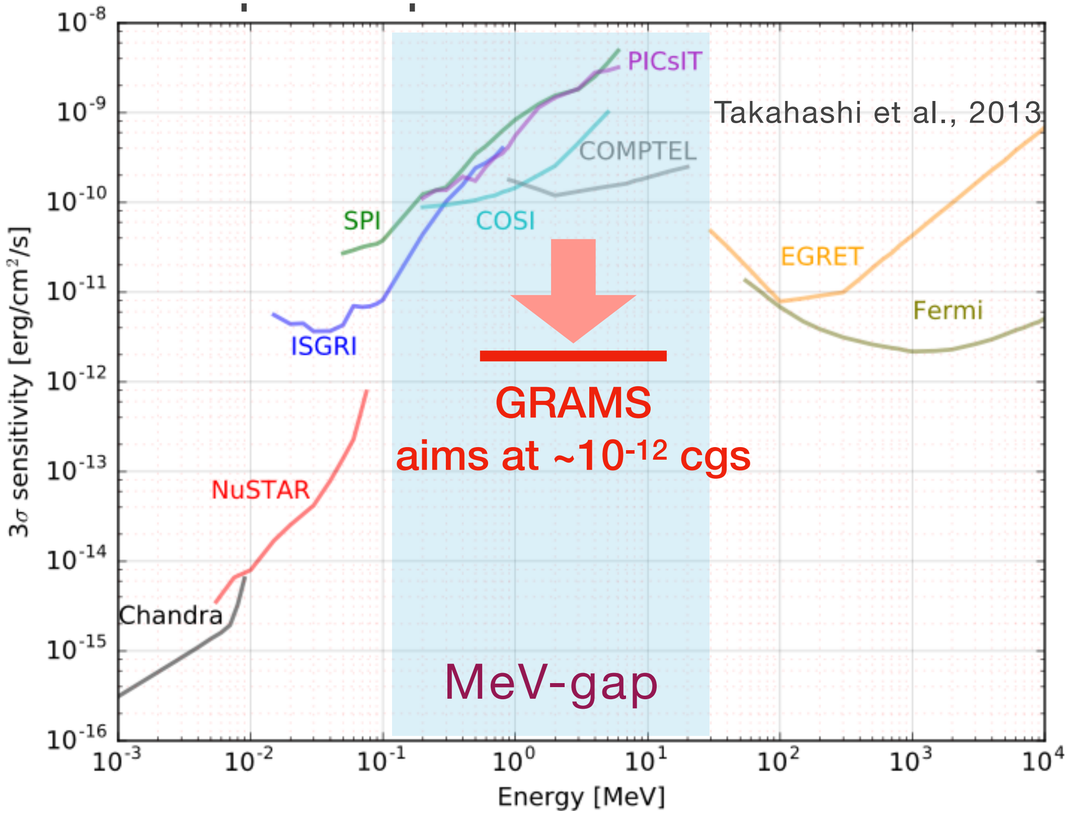


For low-energy antideuterons, the secondary flux is expected to be very low.

→ detection would give a strong evidence of dark matter = background-free search

GAPS experiment in Antarctica (2024–) → GRAMS (next generation)

Sensitivity gap at the MeV band



r-process site candidates

Supernova

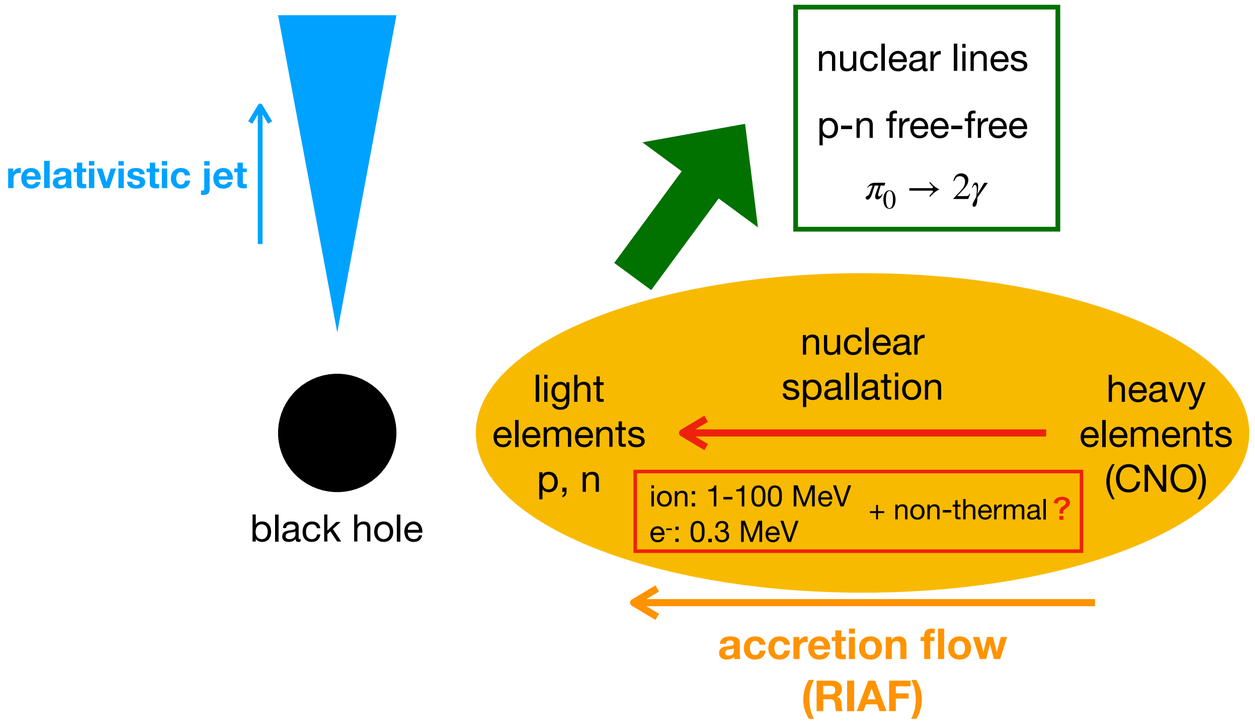
Neutron star mergers

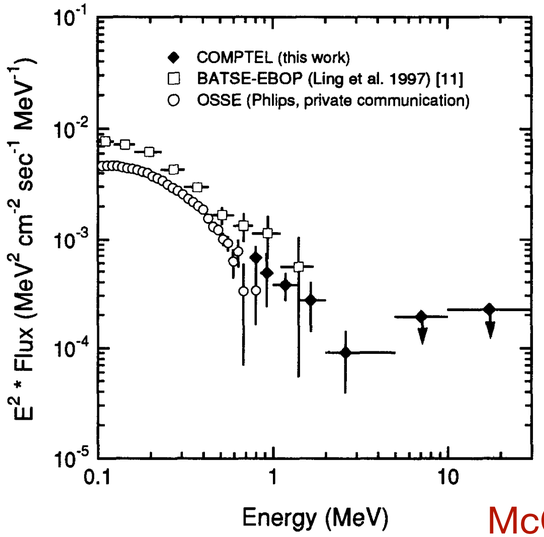
MeV gives us unique probes of cosmic nuclear reactions.

However, nuclear lines are very faint.

For high sensitivity, we need a **large effective area**
to obtain **high photon statistics**, and to obtain **precise background estimate**.

Black hole accretion flow in MeV

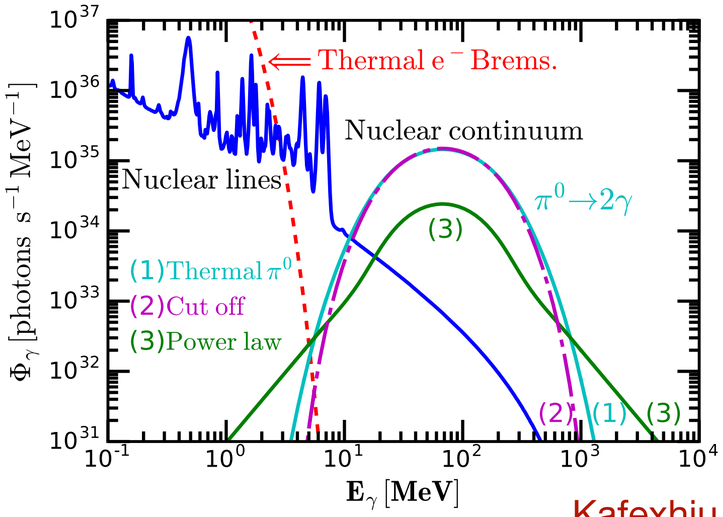




COMPTEL

Cygnus X-1

McConnell et al. (1997)

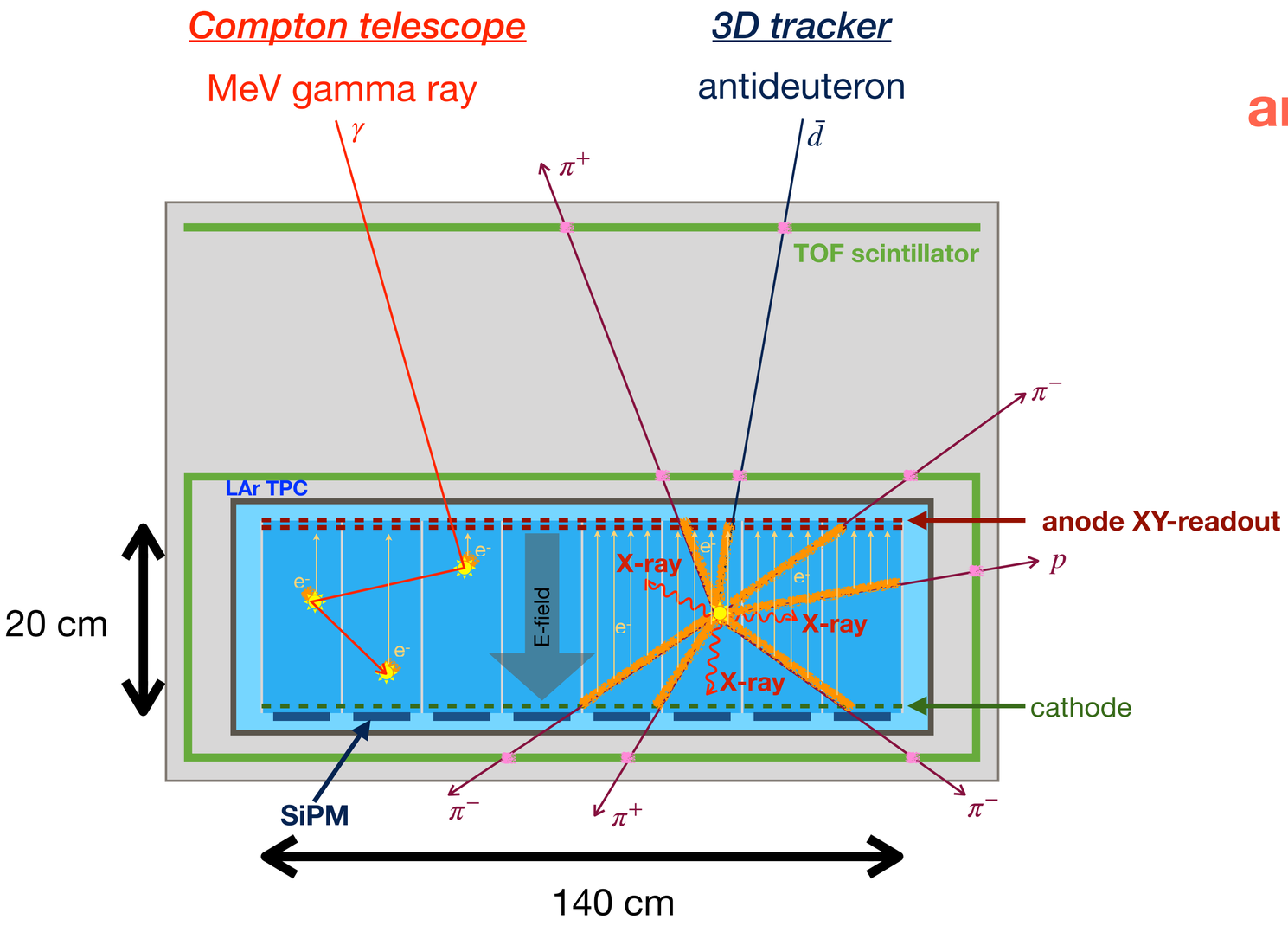


Kafexhiu et al. (2019)

- cosmic-ray accelerator?
- high-energy neutrino source?

→ **MeV gamma is a key probe.**

Liquid argon time projection chamber



Novel approach to realize an extremely large effective area

~2000 cm²

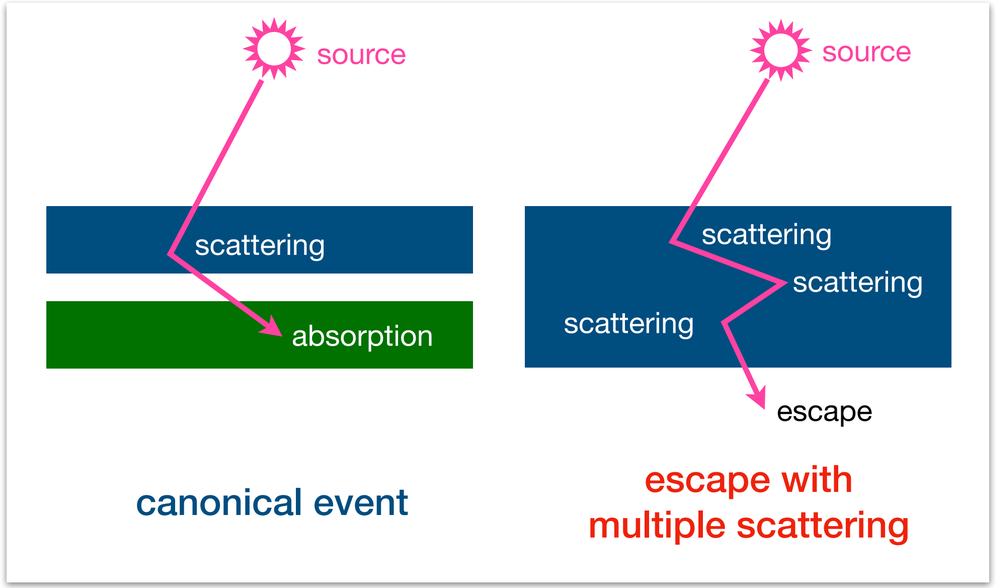
1. Adoption of liquid detector

- high density and large volume

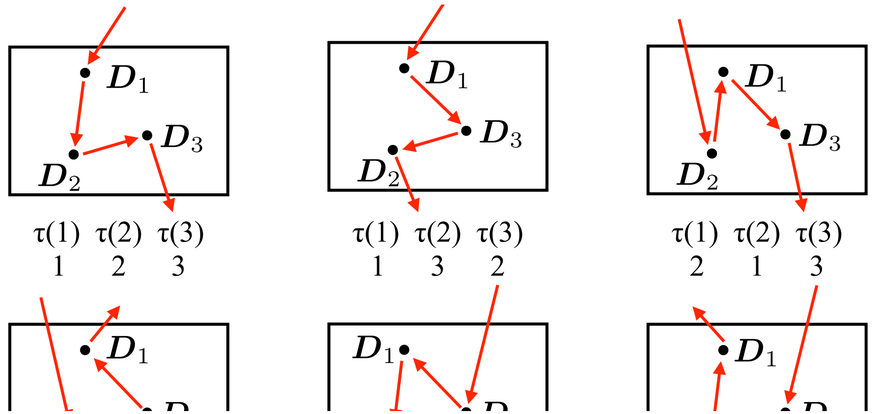
2. Use in particle physics experiments

- neutrino physics
- direct dark matter search
- this technology will be deployed to space missions (balloon/satellite)

Event reconstruction technique



Need to determine the interaction order：N!



GRAMS employs a new Compton camera concept made of only a single **Compton-thick** scatter with **no dead volume** inside the detector.

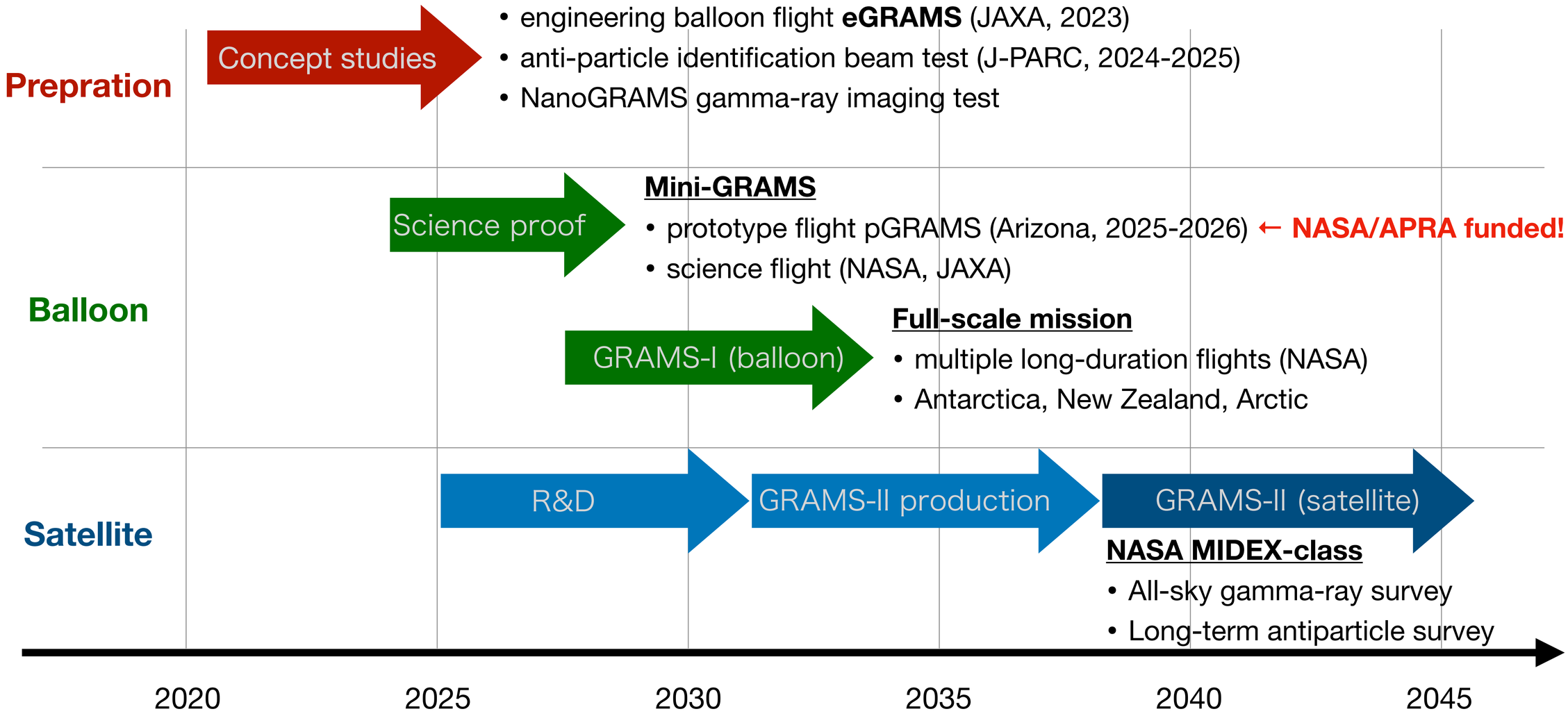
→ GRAMS detects multiple scattering events with high efficiency.

→ We have developed new Compton reconstruction algorithms to treat multiple scattering with escaping.

1. Physics-based probabilistic model
- Yoneda et al. 2023
- giving a benchmark model

2. Multi-task neural network
- Takashima et al. 2022
- outperforming after simulation learning

Timeline


Prepration
Concept studies
• engineering balloon flight **eGRAMS** (JAXA, 2023)
• anti-particle identification beam test (J-PARC, 2024-2025)
• NanoGRAMS gamma-ray imaging test
Balloon
Science proof
Mini-GRAMS
• prototype flight pGRAMS (Arizona, 2025-2026) ← **NASA/APRA funded!**
• science flight (NASA, JAXA)
GRAMS-I (balloon)
Full-scale mission
• multiple long-duration flights (NASA)
• Antarctica, New Zealand, Arctic
Satellite
R&D
GRAMS-II production
GRAMS-II (satellite)
NASA MIDEX-class
• All-sky gamma-ray survey
• Long-term antiparticle survey
2020
2025
2030
2035
2040
2045

GRAMS Collaboration

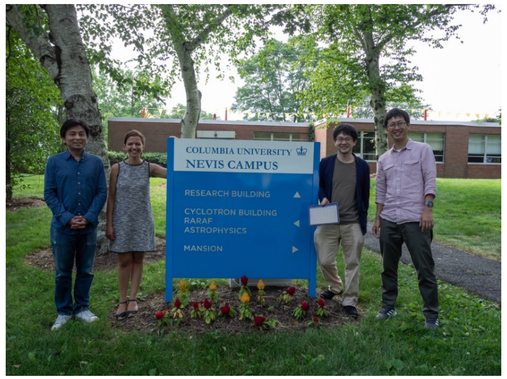
Barnard College
Columbia University
Hiroshima University
Howard University
JAXA
Kanagawa University
Nagoya University
NASA/GSFC
NDMC
Northeastern University
Oak Ridge National Lab
Osaka University
RIKEN
UCB/SSL
University of Tokyo
UT Arlington
Waseda University
Washington University
Würzburg University
Yokohama National University

US-Japan Interdisciplinary Team

X-ray/gamma-ray astronomy, accelerator, neutrino/dark matter experiments

7th Collaboration Meeting, May 2024, Boston

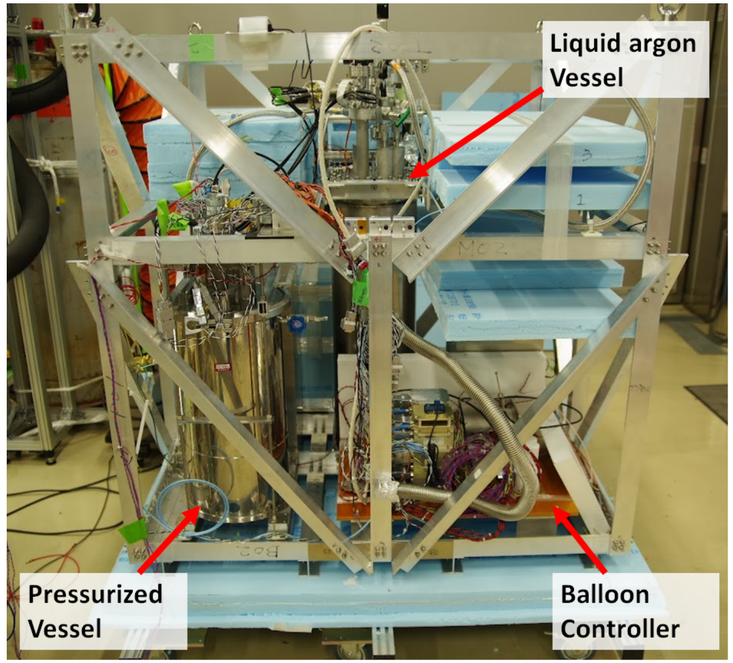
1st GRAMS Collaboration Meeting
July 2019, Nevis Lab, NY



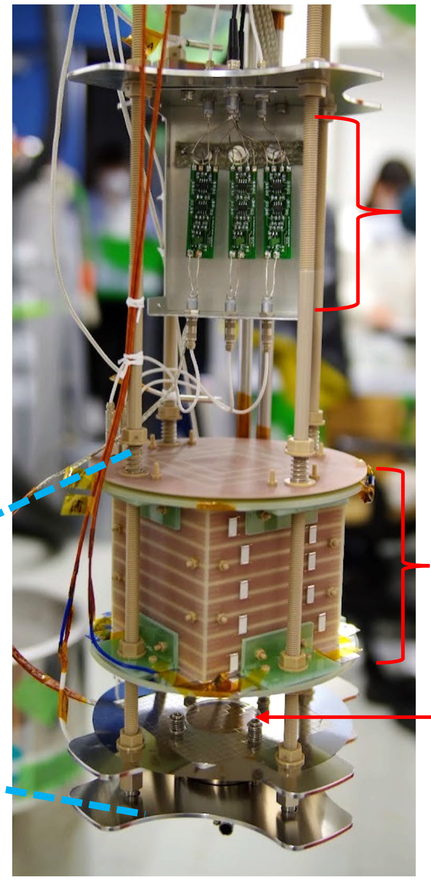
eGRAMS: Engineering flight in Japan

The world's first balloon flight of a LArTPC

- ✓ a minimal set of a LArTPC for an engineering test
- ✓ launched from JAXA balloon facility on 2023 July 27
- ✓ level flight at 29 km for 40 min
- ✓ **successful operations and in-flight measurement of radiation environments**

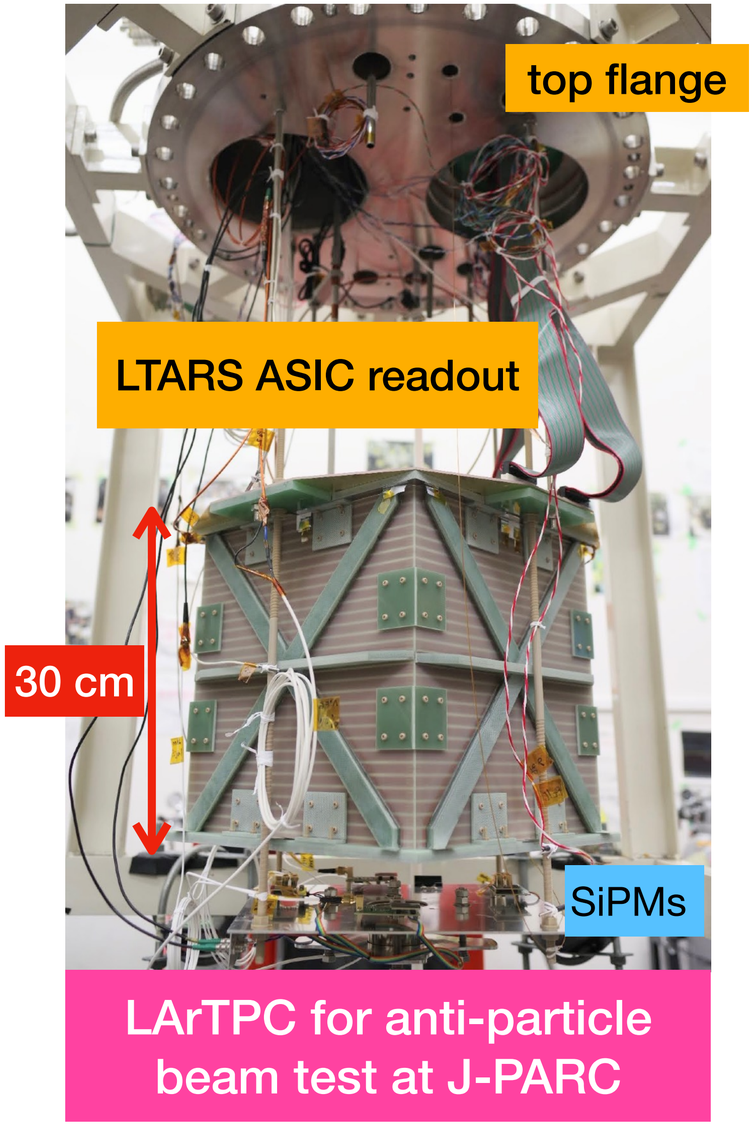


Gondola: 1.2 m

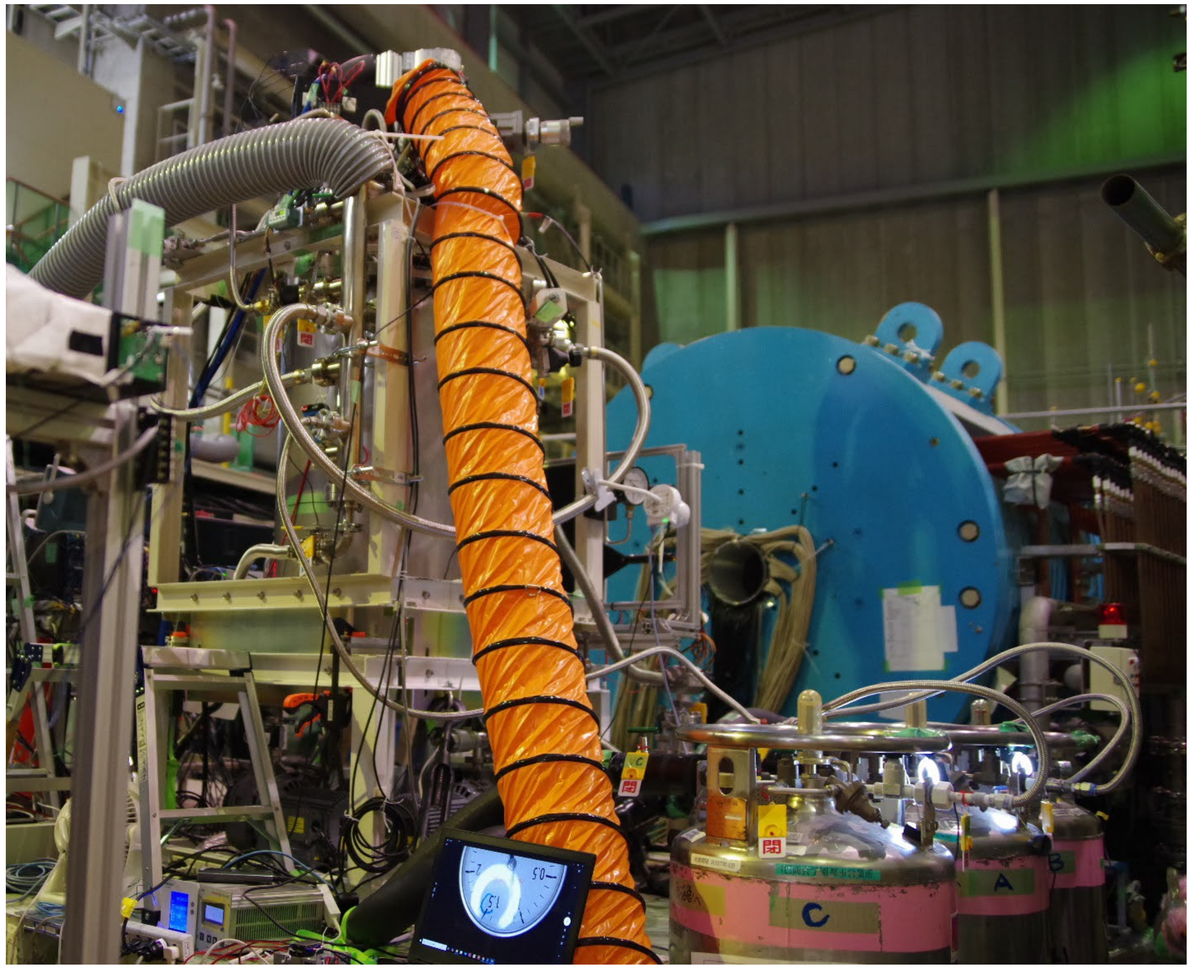


LArTPC

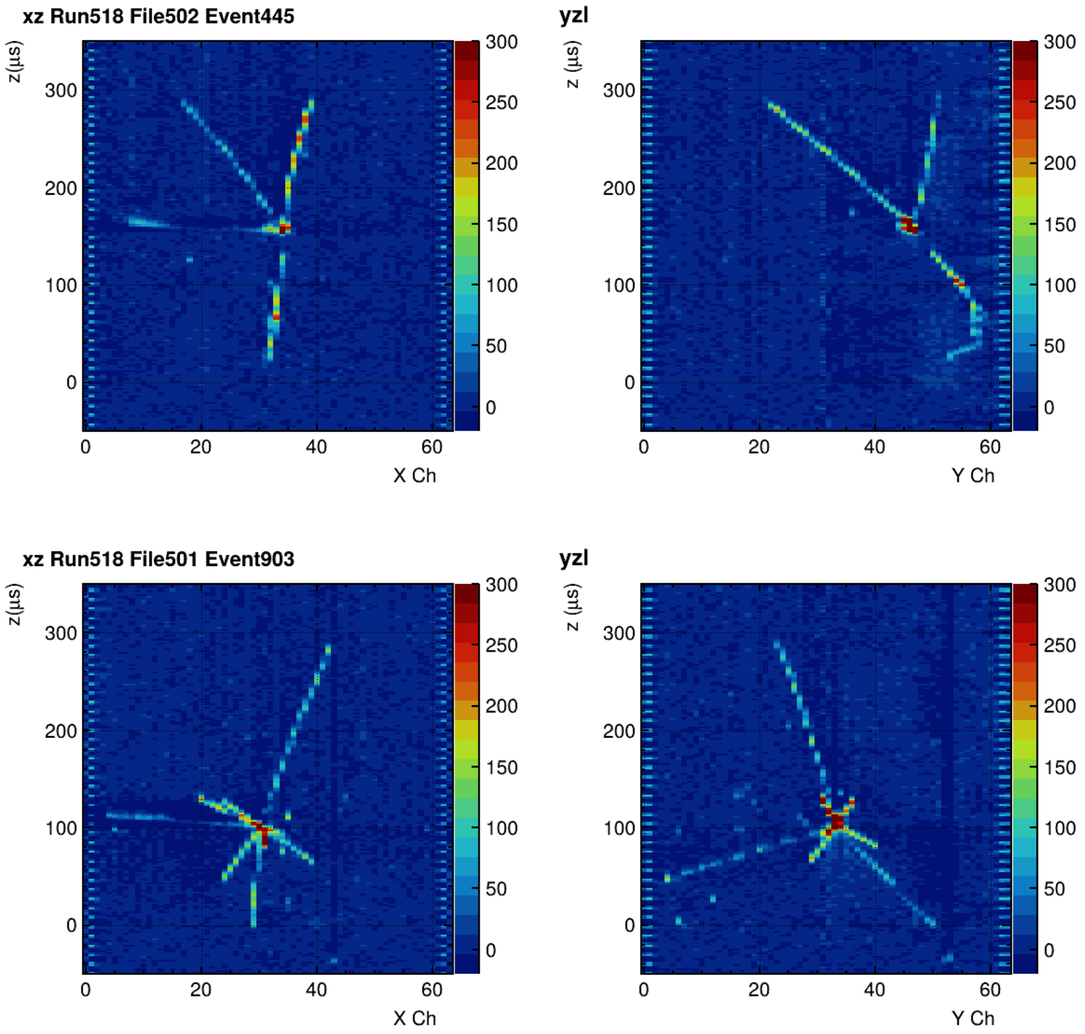
Particle-ID demonstration J-PARC/T98



To evaluate the capability of anti-particle identification using anti-proton at J-PARC K1.8BR beam line.



Preliminary results from J-PARC/T98

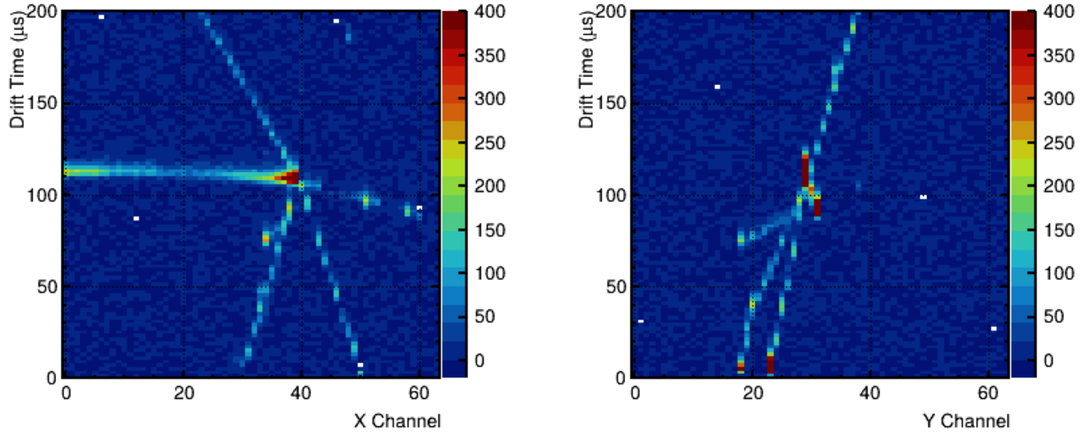


T98 Phase-2: February 2025

antiproton: 0.7 GeV/c

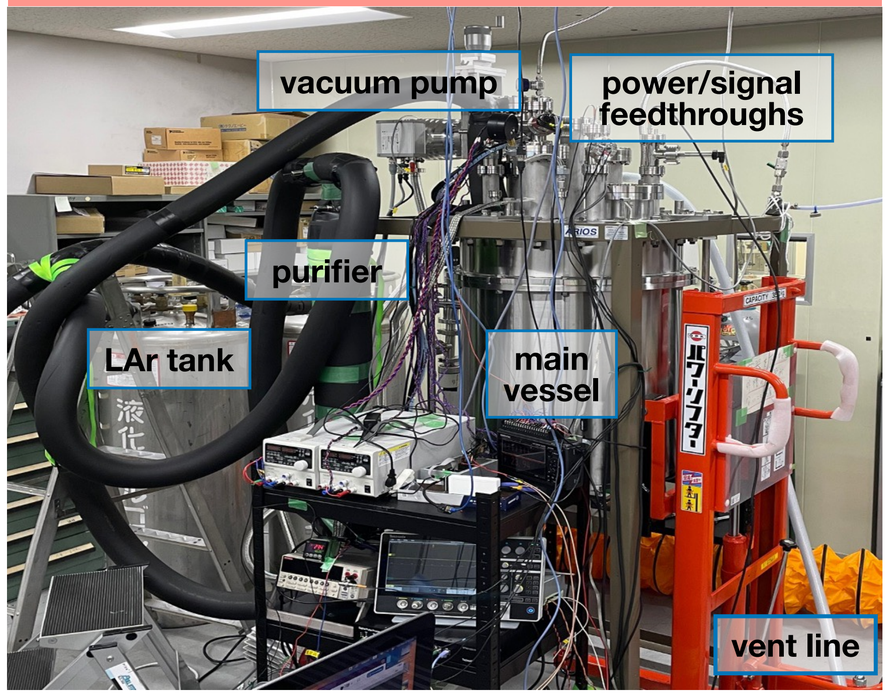
Successfully obtained TPC event data

simulation



Concept studies with NanoGRAMS prototype

LAr test stand



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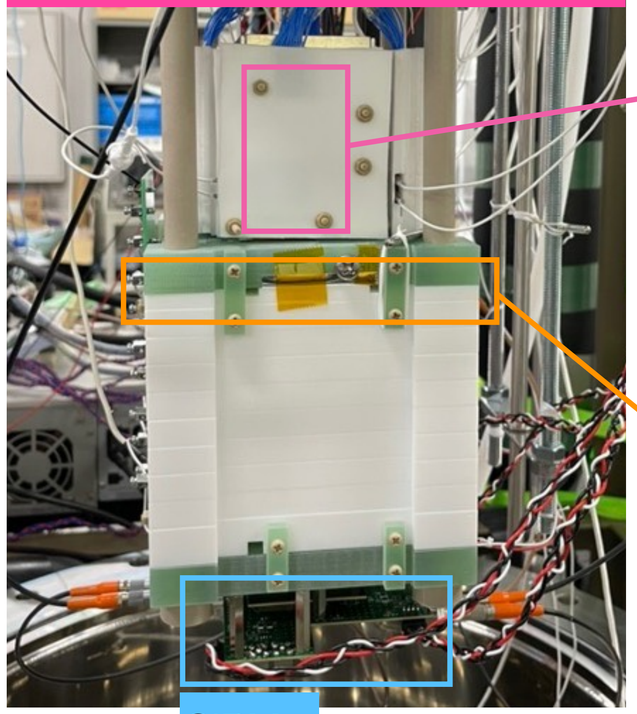
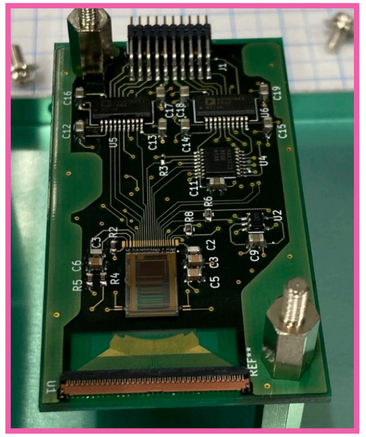
NanoGRAMS for gamma-ray imaging test

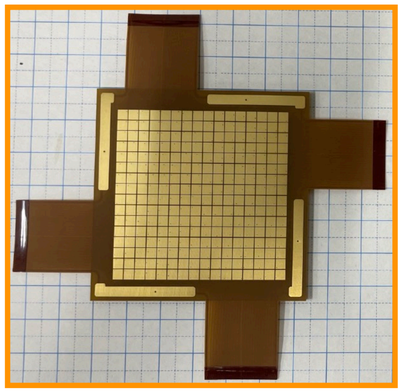


- Four 4×4 arrays covers 5×5 cm^2
  Hamamatsu S13361-6075AE-04 × 4



Electron readout

- VATA-SGD ASIC
- 64 channels/chip
- ENC: 180 e$^-$ at 6 pF (RMS)
- heater



Anode pad

- 16 × 16 pixels
- 51.2 × 51.2 mm^2
- pixel pitch: 3.2 mm
- flexible board

Whet’s next: pGRAMS

The next important step is a prototype of flight of a scientific LArTPC called MiniGRAMS with a size of 30 × 30 × 20 cm^3.

✓ NASA/APRA funded

✓ planned for launch in 2026 in Arizona

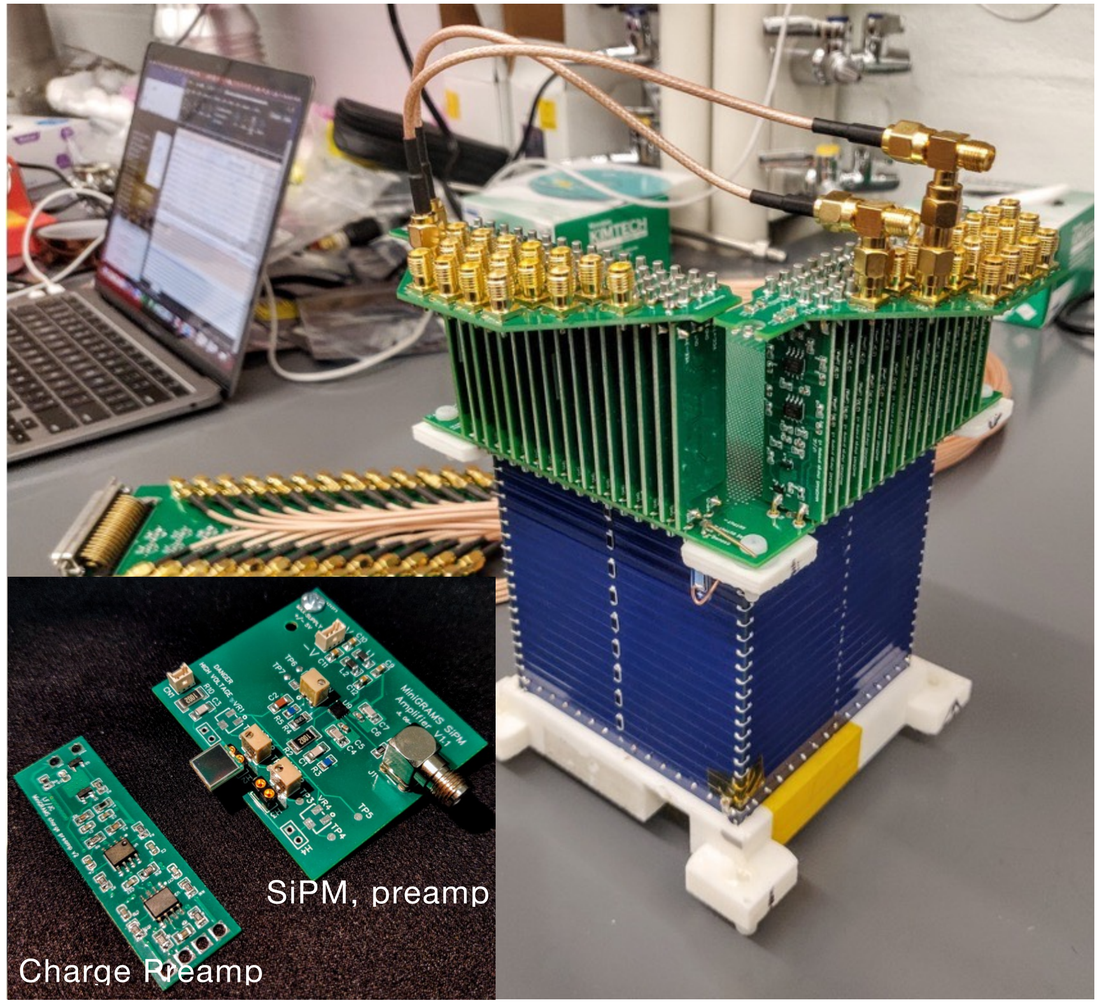
MicroGRAMS—a prototype LArTPC

✓ TPC size: 10 × 10 × 10 cm^3

✓ Tile/pads for x-/y-directions ~3 mm pitch

✓ 60 cryogenic charge preamps operated in 87K liquid argon

✓ 16 SiPMs at the bottom, 6 mm x 6 mm each



Concluding remarks

- GRAMS will bring a **huge LArTPC** into sub-orbital and space-based missions for exploring both MeV gamma-ray astronomy and background-free indirect dark matter search with antiparticles.
- An unprecedentedly large effective area for gamma rays and antiparticles will be realized with a LArTPC.
- The first engineering balloon-borne experiment in Japan, 2023 was successful.
- Several types of detector prototyping are ongoing in US and Japan.
- We demonstrated anti-proton identification using J-PARC beam (very preliminary, 2025 Feb).
- The next step will be a prototype flight of MiniGRAMS in Arizona in 2026.