

GRAMS

(Gamma-Ray and AntiMatter Survey)



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FIGSAG Meeting, Aug 22, 2024



What is GRAMS?

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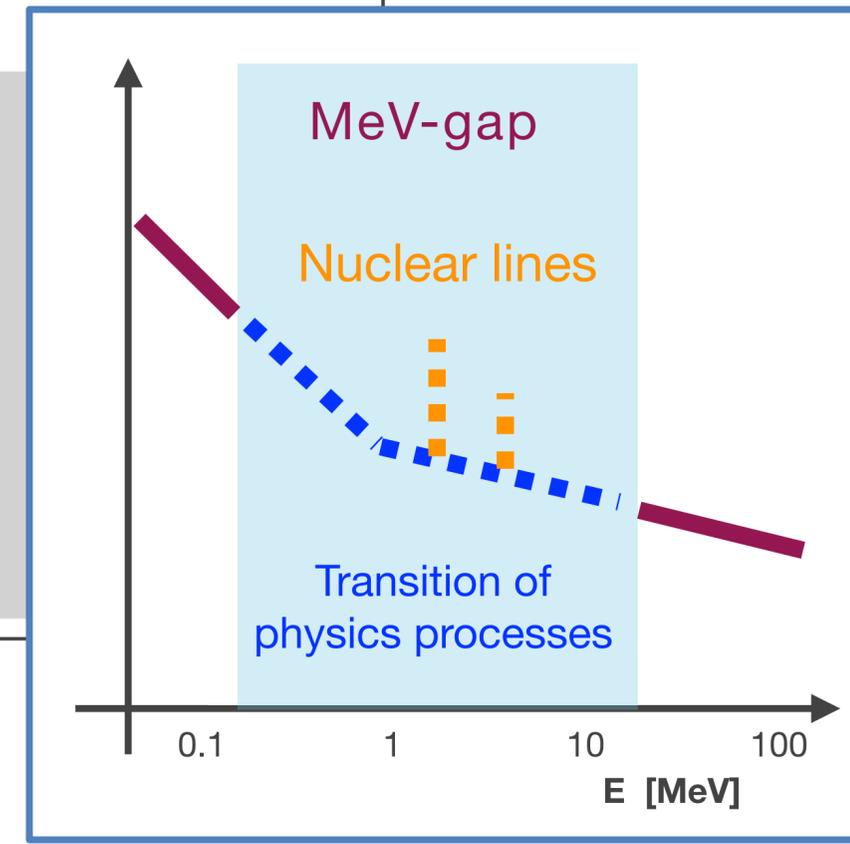
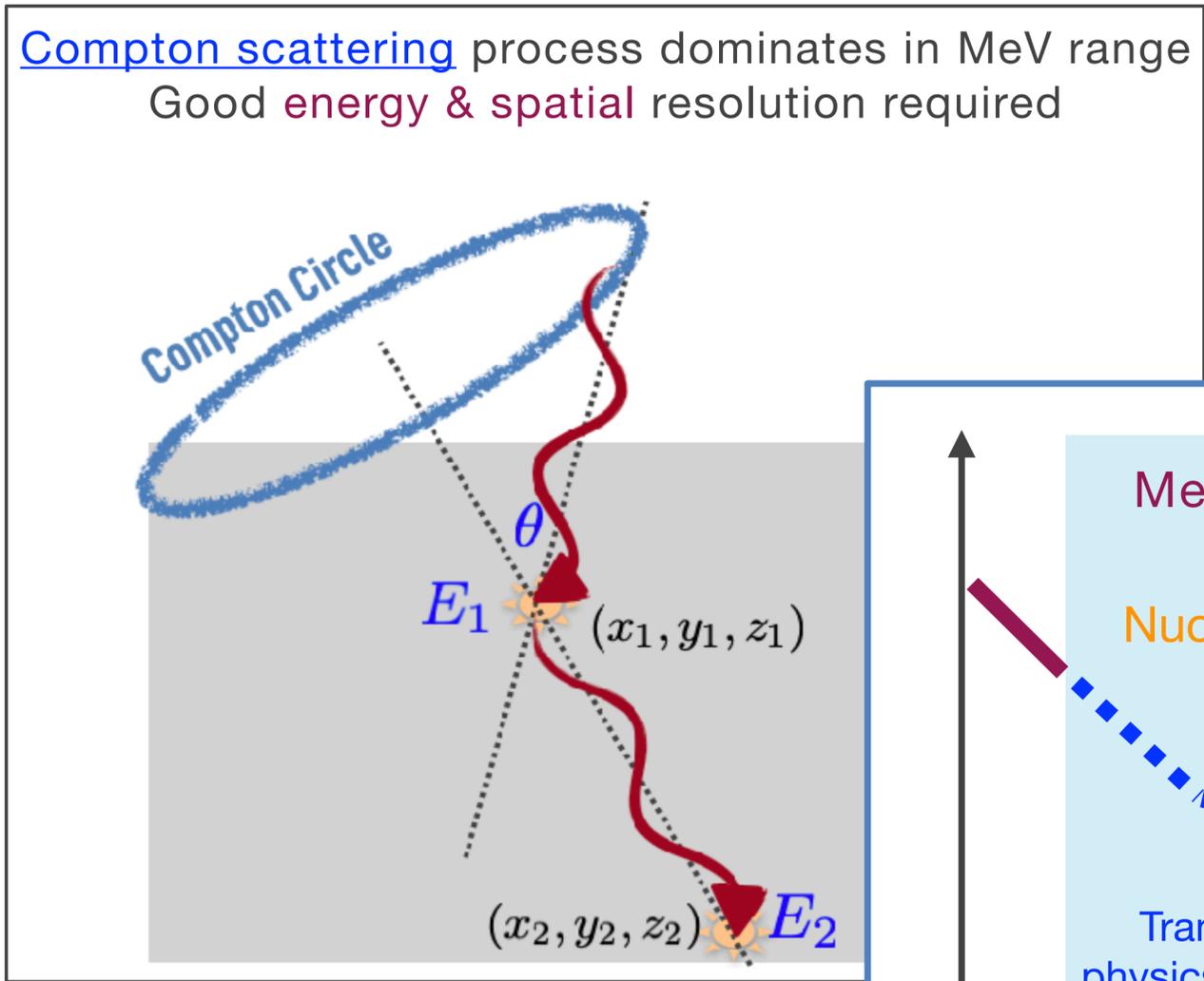
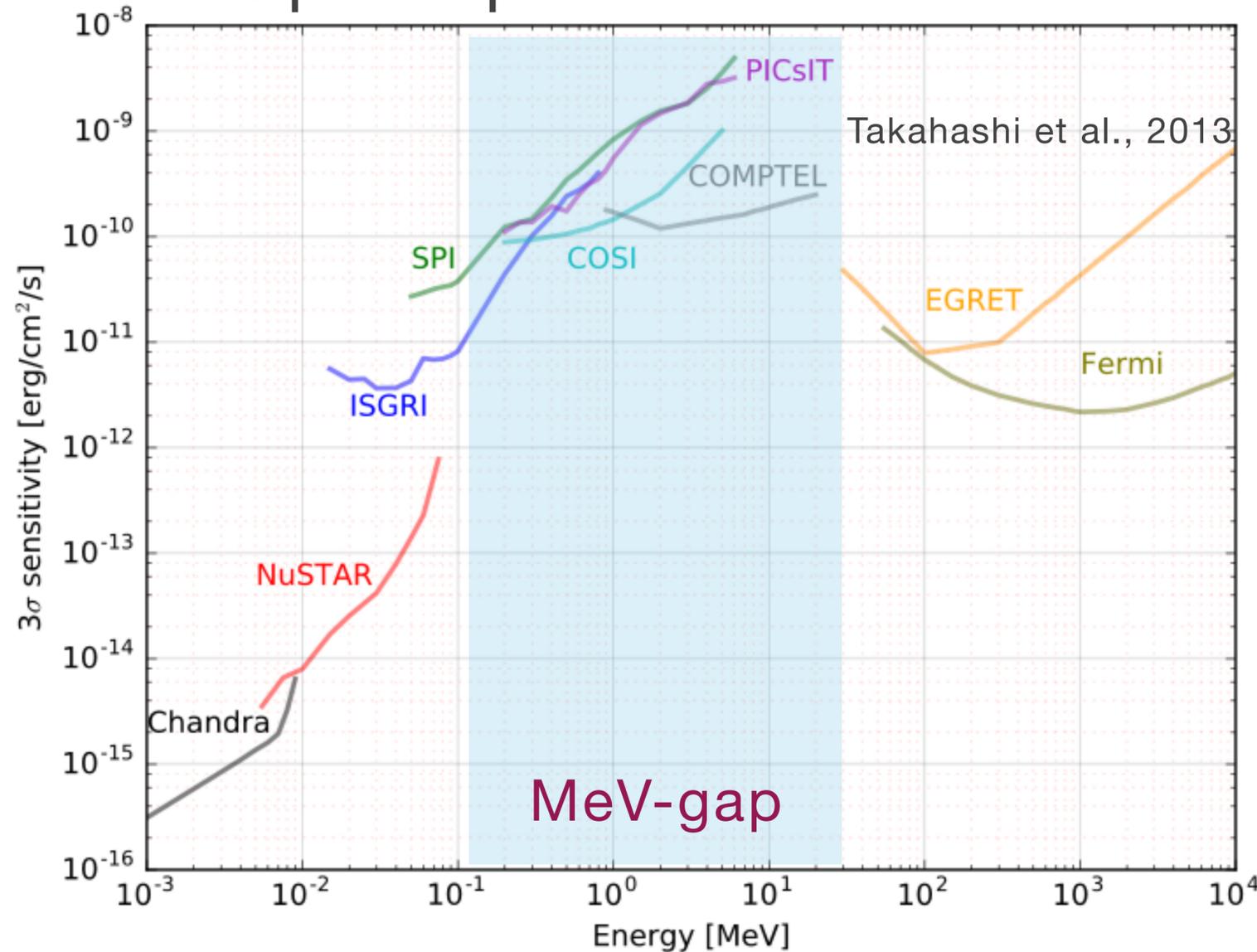
GRAMS = Gamma-Ray and AntiMatter Survey

First experiment to target both astrophysical observations with **MeV gamma rays** and indirect dark matter searches with **antimatter**

First balloon/satellite mission with a low-cost, large-scale **LArTPC** (Liquid Argon Time Projection Chamber) detector

A prototype flight is scheduled in 2025/2026 under **NASA APRA22**

Open up a new window into the **poorly-explored** MeV sky region



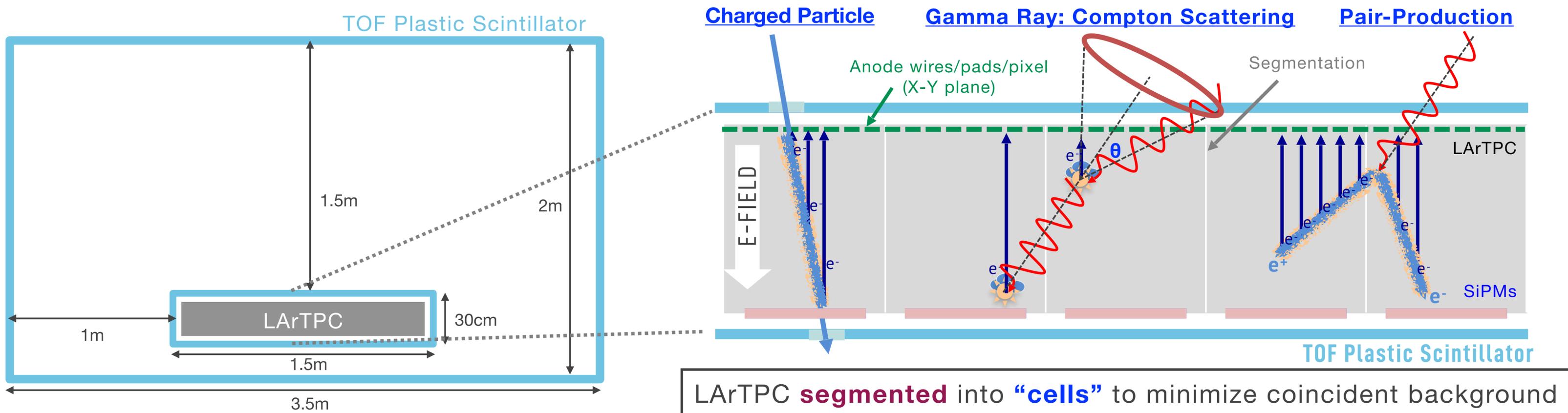
**Various discussions
in Snowmass 2021**

MeV gamma-ray continuum/line spectrum

- Physics processes/**nucleosynthesis**
- **Multi-messenger** astronomy: EM counterparts of GWs and high-energy neutrinos
- Indirect **dark matter** searches/**PBH** searches

LArTPC surrounded by plastic scintillators

	Antimatter	Gamma ray
Plastic Scintillator	Time of Flight to measure velocity	VETO Counter to reject charged particles
LArTPC	Particle Tracker, Calorimeter	Compton Camera, Calorimeter



Large-scale, low-energy threshold LArTPC has been **well-studied** and **widely-used** in underground **dark matter** and **neutrino** experiments

Why LArTPC?

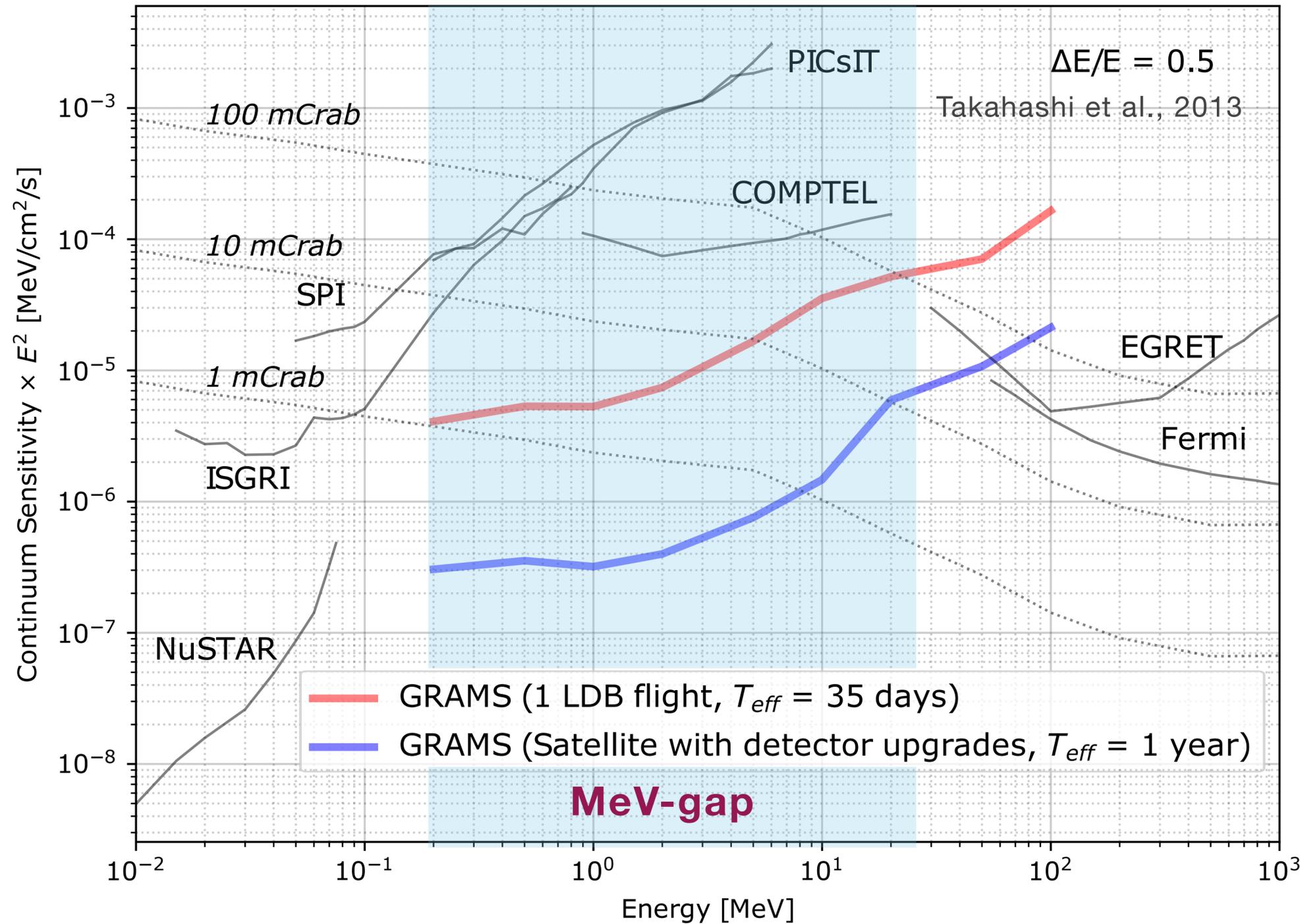


	LArTPC	Semiconductor/Scintillator
ρ (g/cm ³)	1.4	2.3/5.3 (Ge/Si)
T _{operation}	~80K	~240K/~80K
Cost	\$	\$\$\$
Signals	scintillation light + ionization electrons	electrons, holes
X, Y positions	Wires/pads on anode plane (X-Y)	double-sided strips
Z position	From drift time	from layer #
# of layers	Single layer	multi-layers
# of electronics	#	###
Dead volume	Almost no dead volume	detector frame, preamps
Neutron bkg	Identified with pulse shape	no rejection capability

LArTPC is **cost-effective** and almost **no dead volume**
 Easily expandable to a **larger scale** with **high detection efficiency**



MeV gamma-ray sensitivity

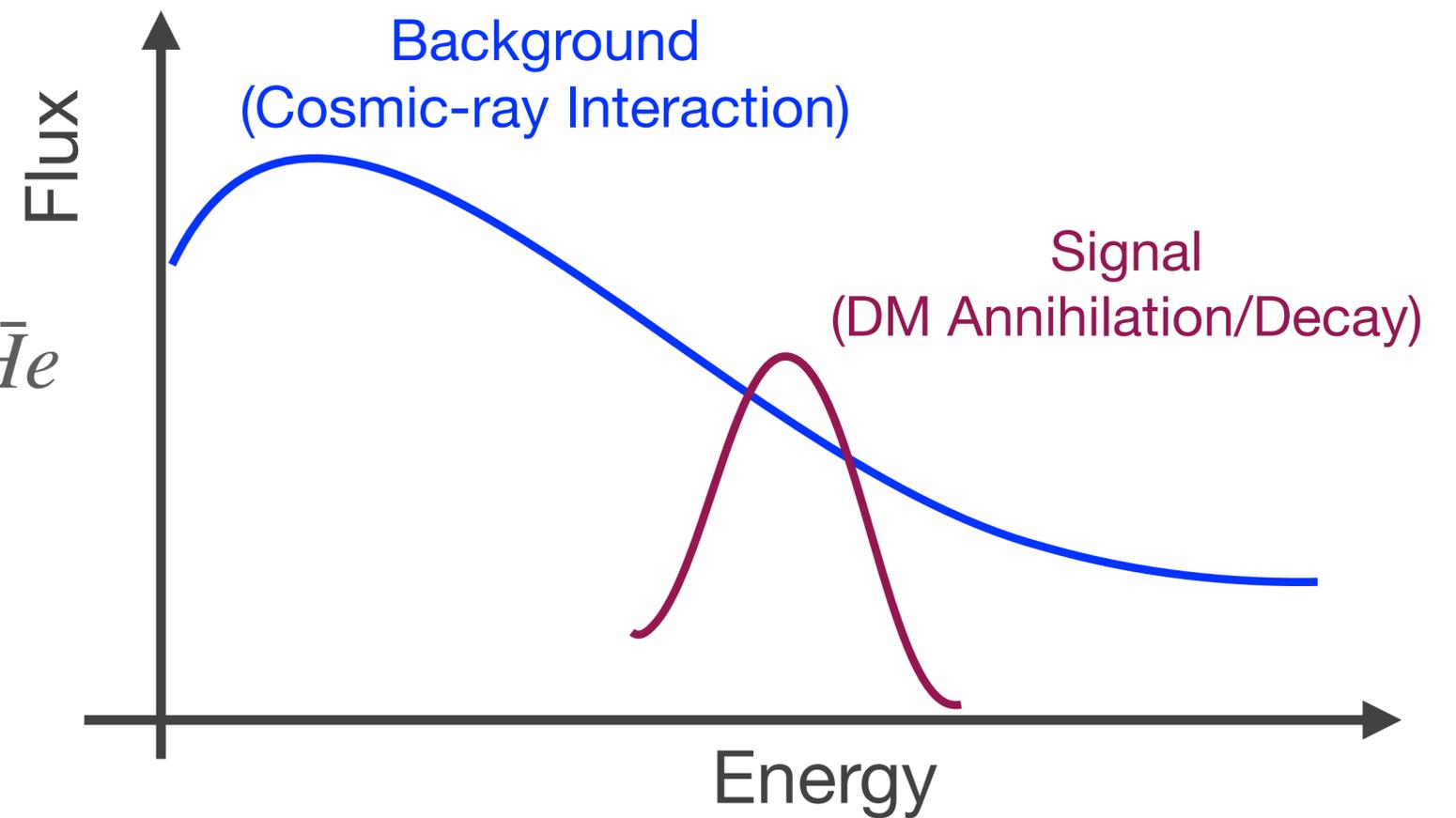
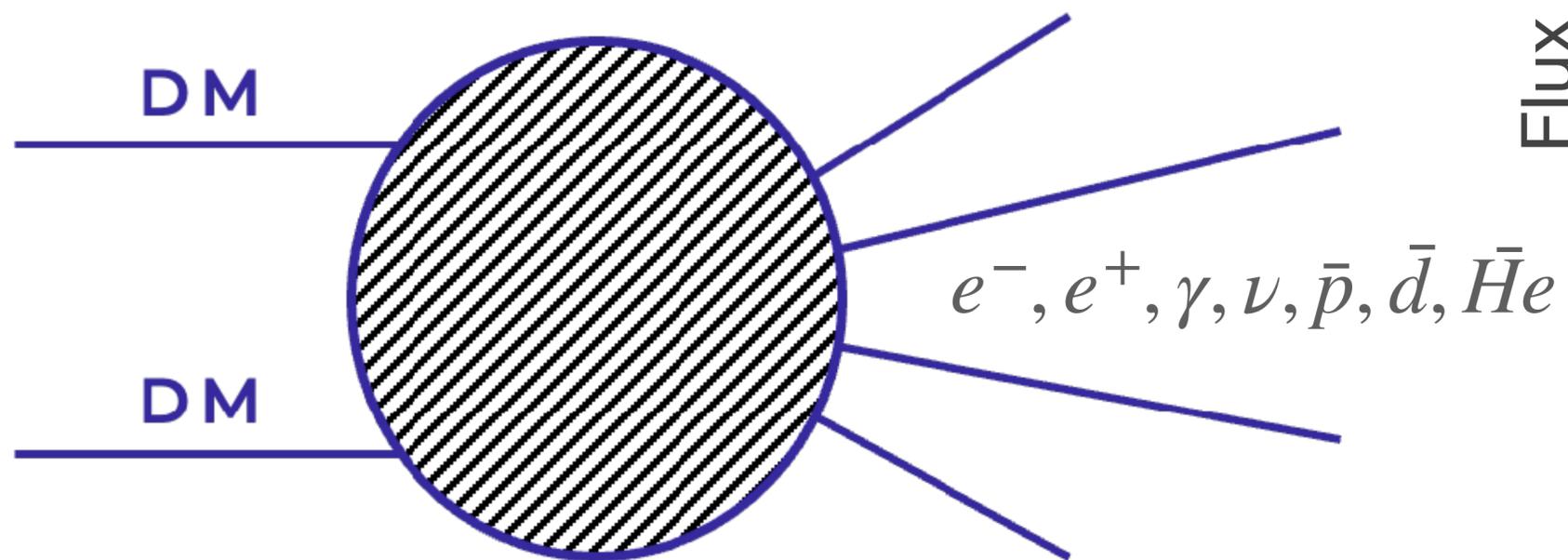


Updating sensitivity

- New event reconstruction methods
- 3+ Compton scatterings events
- Physics probability
- Machine learning

LDB Balloon flight: an order of magnitude improved
Satellite mission: comparable to future missions

Measure DM annihilation/decay products



- Positron: AMS-02, PAMELA, Fermi-LAT ...
- **Gamma-ray**: Fermi-LAT, CTA, **GRAMS**, VERITAS...
- Neutrino: IceCube, ANTARES...
- **Antiproton**: AMS-02, BESS, GAPS, **GRAMS**
- **Antideuteron** : AMS-02, BESS, GAPS, **GRAMS**
- **Antihelium**: AMS-02, GAPS, **GRAMS**

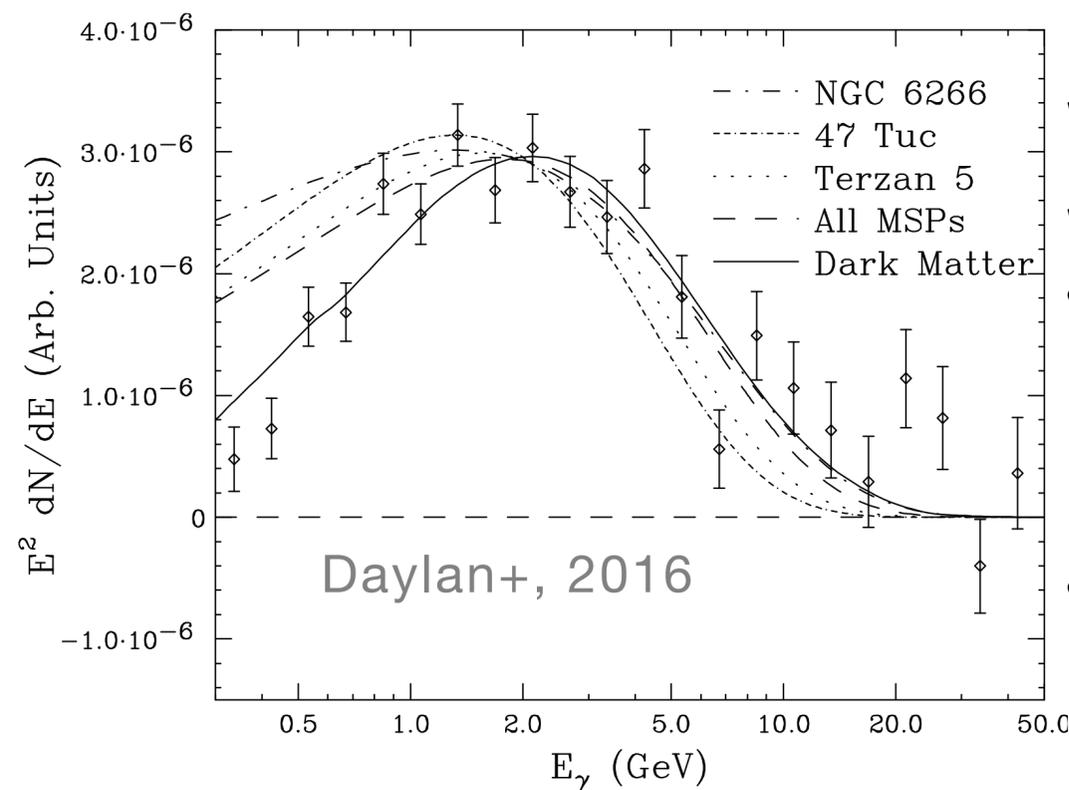


Puzzling excesses in indirect DM searches

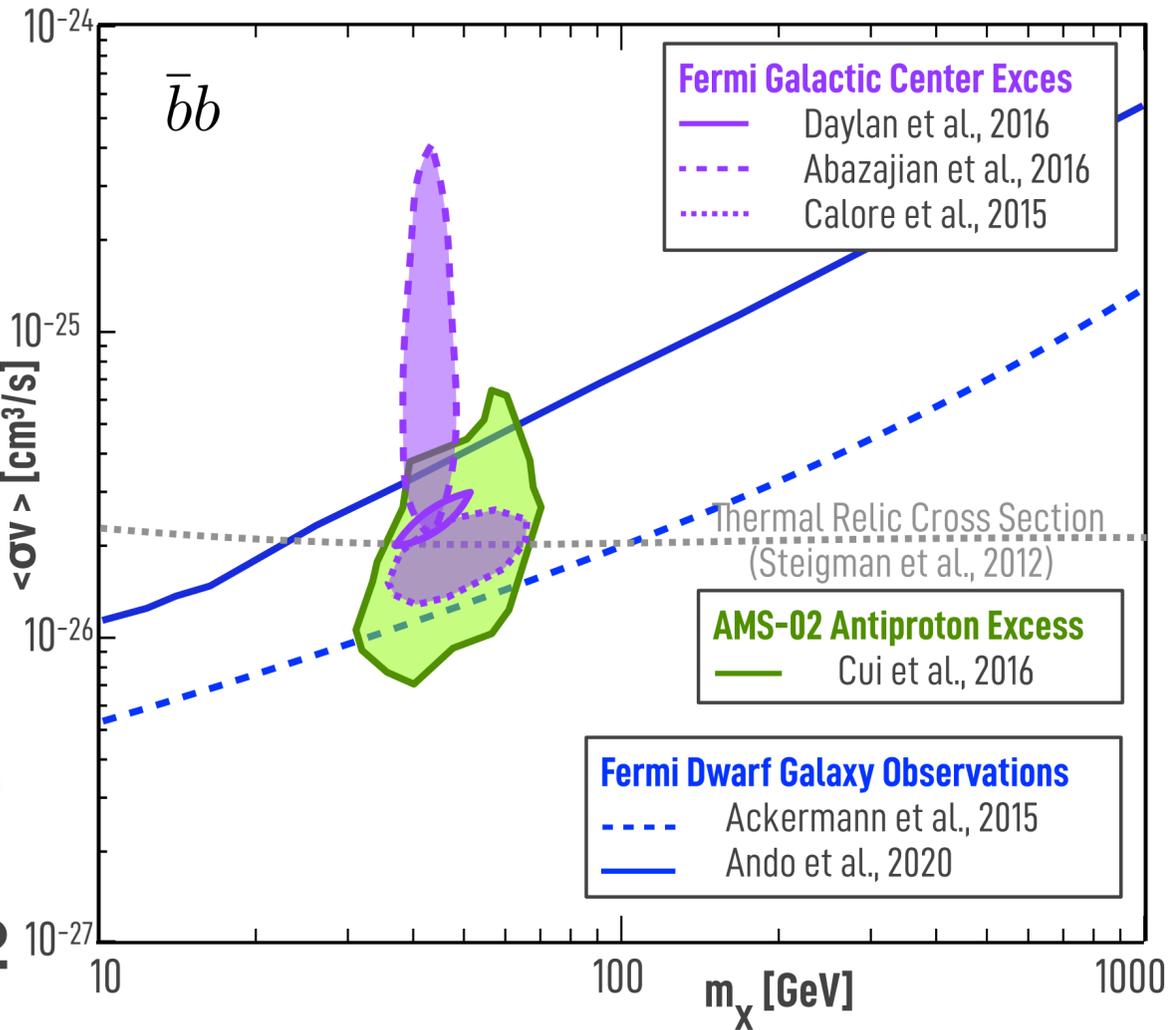
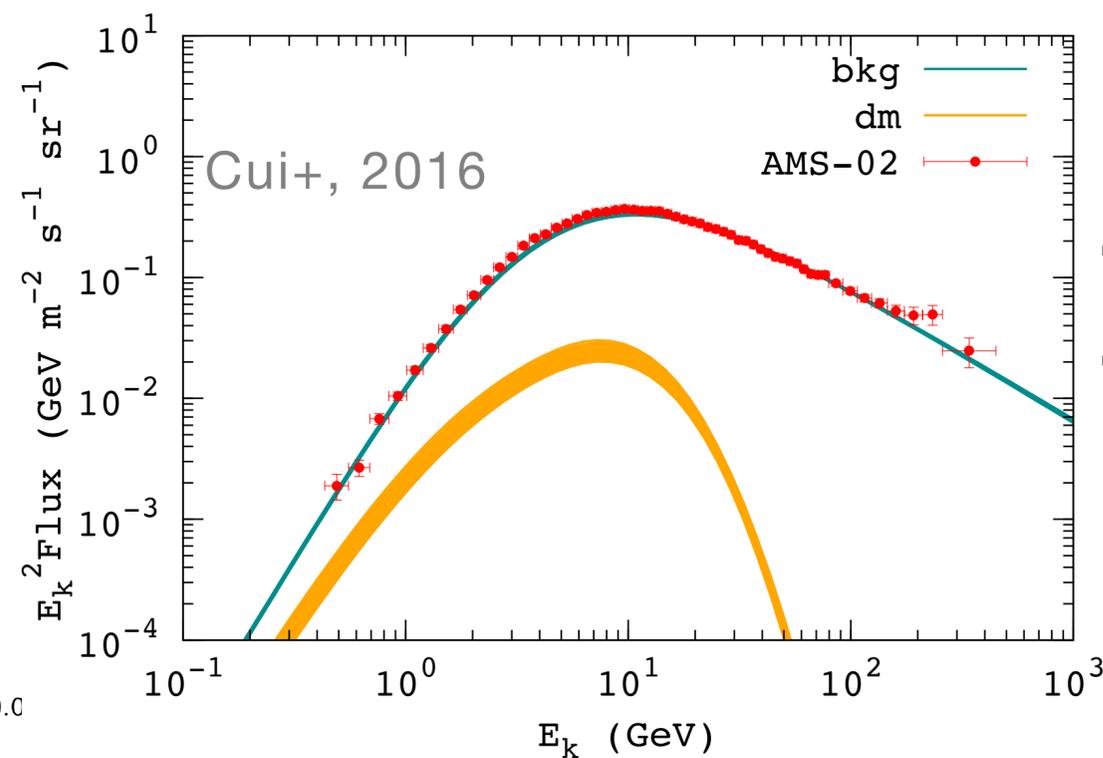
Snowmass2021 CF White Paper

- arXiv:2209.07426: Report of the Topical Group on Particle Dark Matter for Snowmass 2021
- arXiv:2203.06859: Puzzling Excesses in Dark Matter Searches and How to Resolve Them:
- arXiv:2203.06894: The landscape of cosmic-ray and high-energy photon probes of particle dark matter

Fermi gamma-ray excess



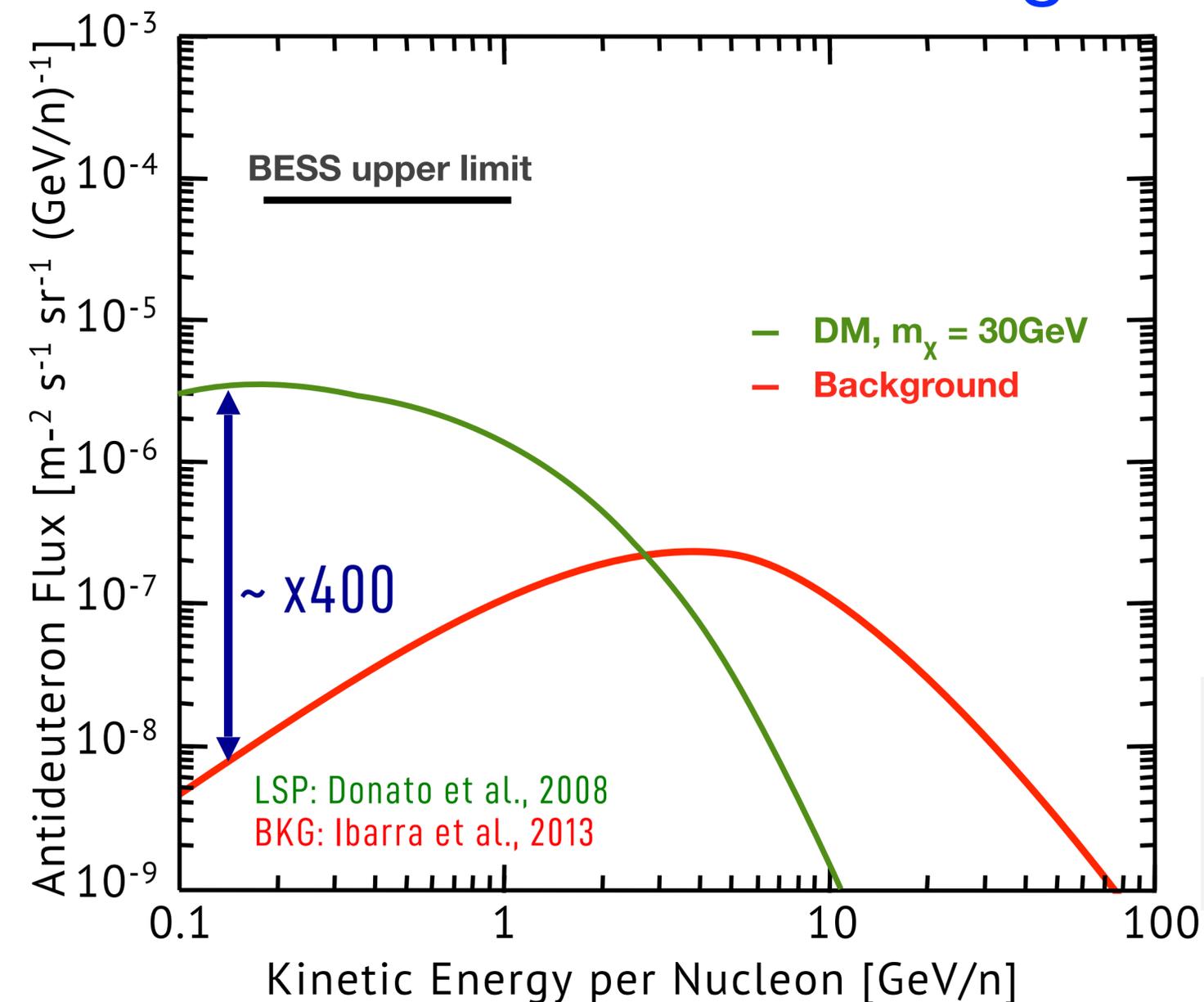
AMS-02 antiproton excess



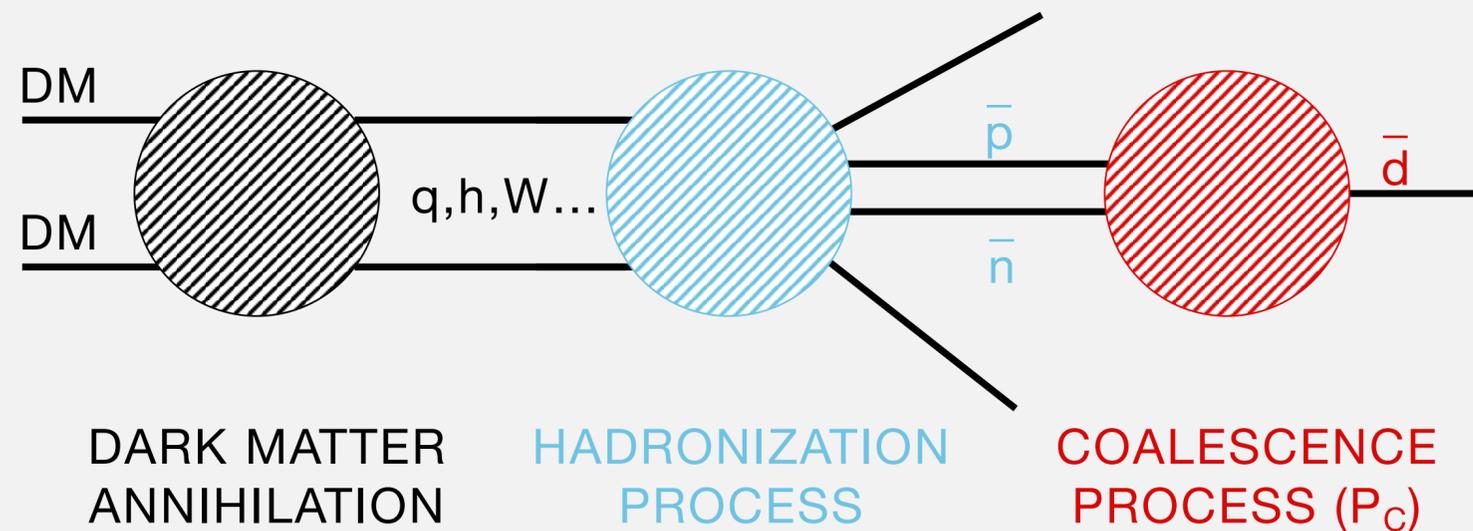
Detection of antideuteron/antihelium-like events in AMS02

How do we validate these results?

Background-free DM search



PRIMARY FLUX = DM ANNIHILATION/DECAY

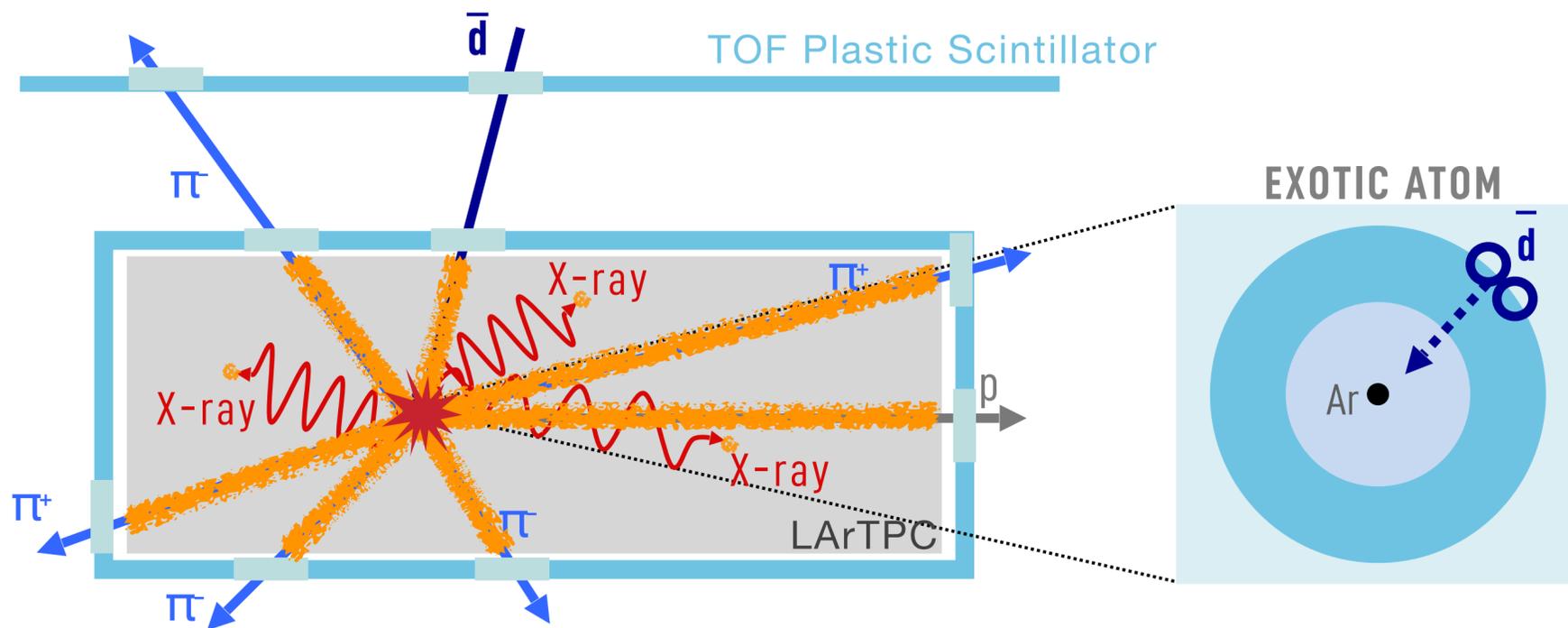


SECONDARY FLUX = COSMIC RAY INTERACTION

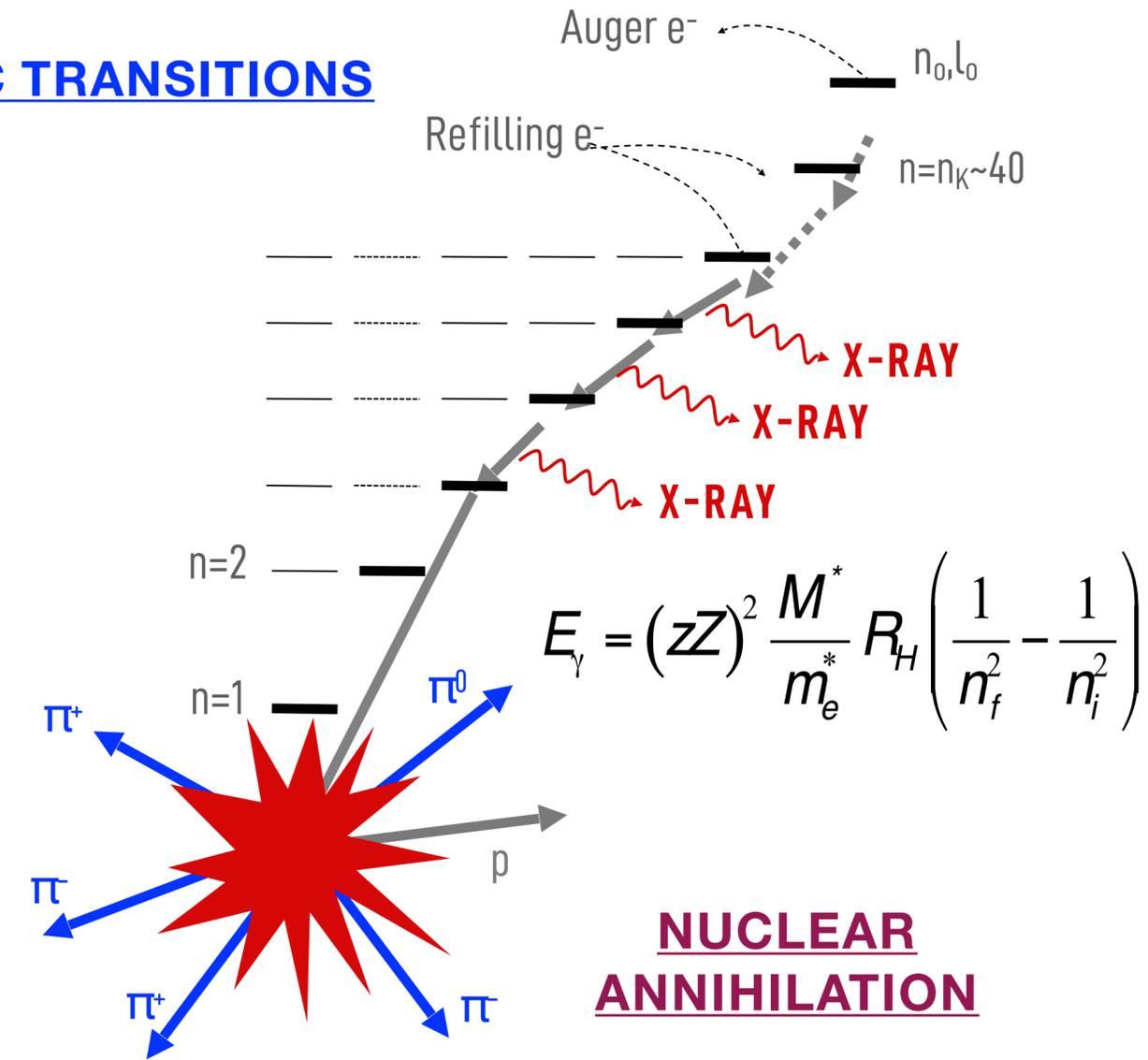


Balloon experiments from the Antarctic are optimized for low-energy antideuteron measurements considering geomagnetic cut-off

Measure atomic **X-rays** and **annihilation** products



ATOMIC TRANSITIONS



NUCLEAR ANNIHILATION

- A time of flight (TOF) system tags candidate events and records velocity
- The antiparticle slows down & stops, forming an excited exotic atom
- De-excitation X-rays provide signature
- Annihilation products provide additional background suppression

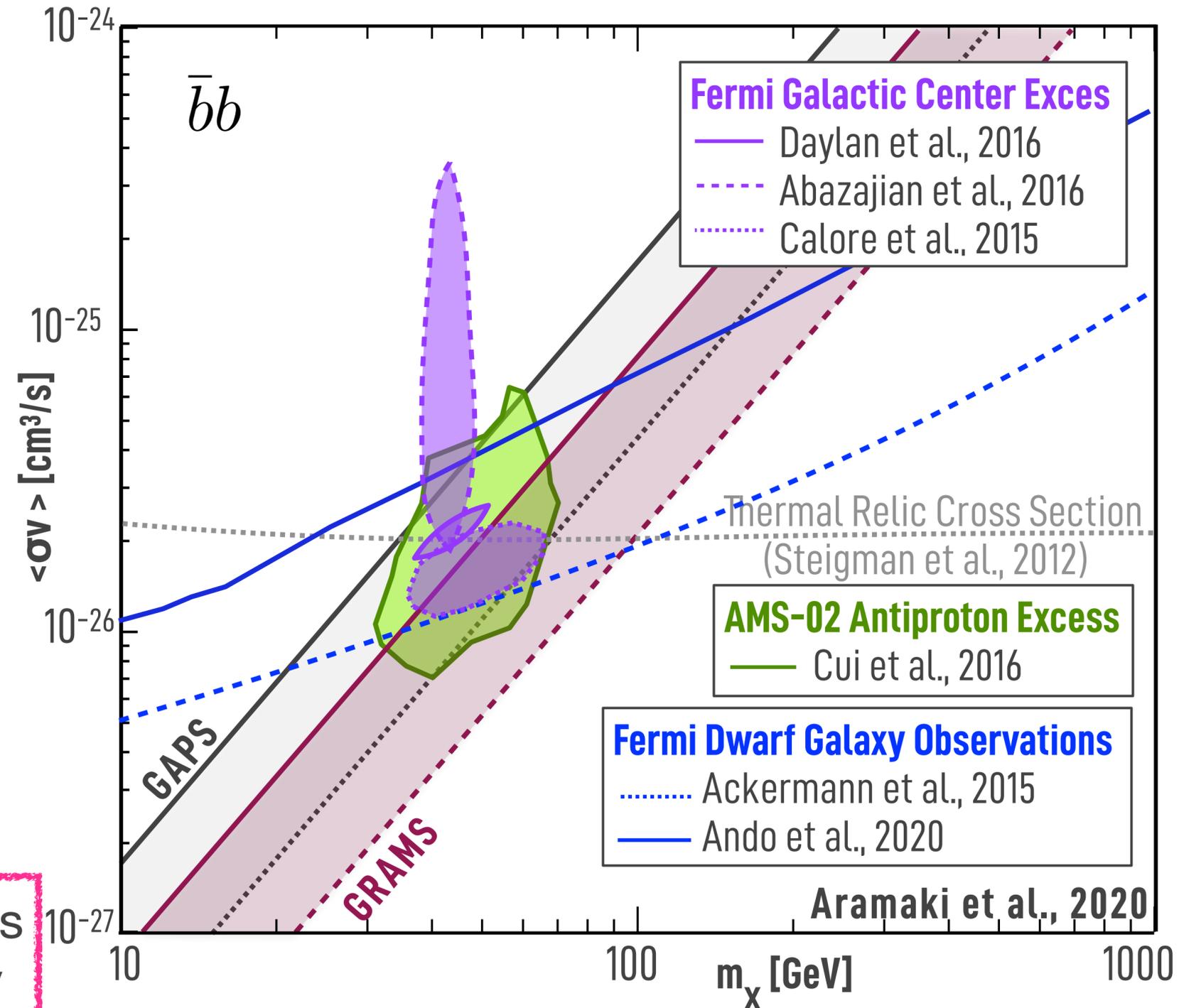
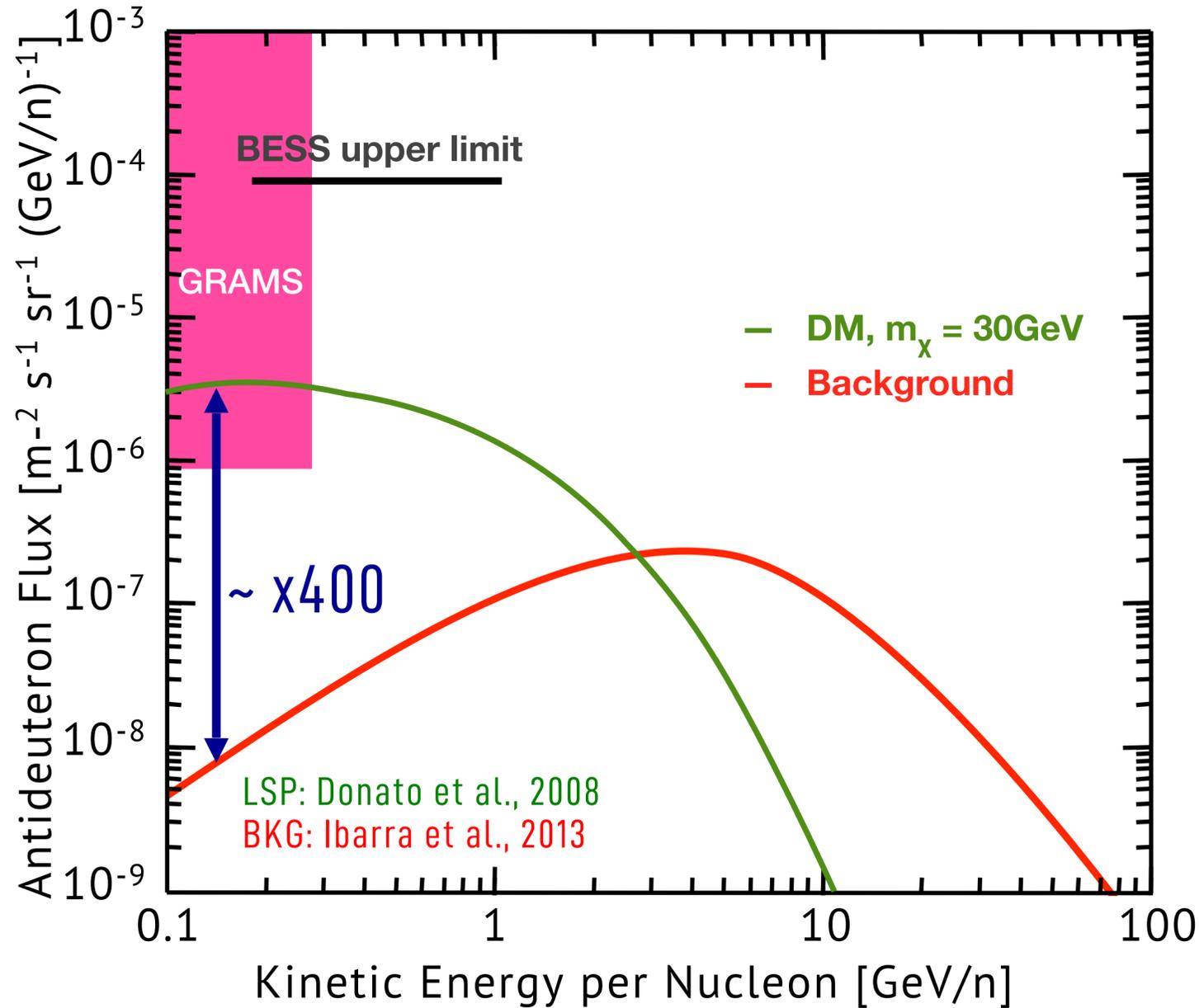
LArTPC (almost no dead volume) provides

- **Excellent** 3D particle tracking capability
- **High** particle detection efficiency



GRAMS Sensitivity in DM Parameter Space

Extensively explore DM parameter space and validate Fermi/AMS-02 results

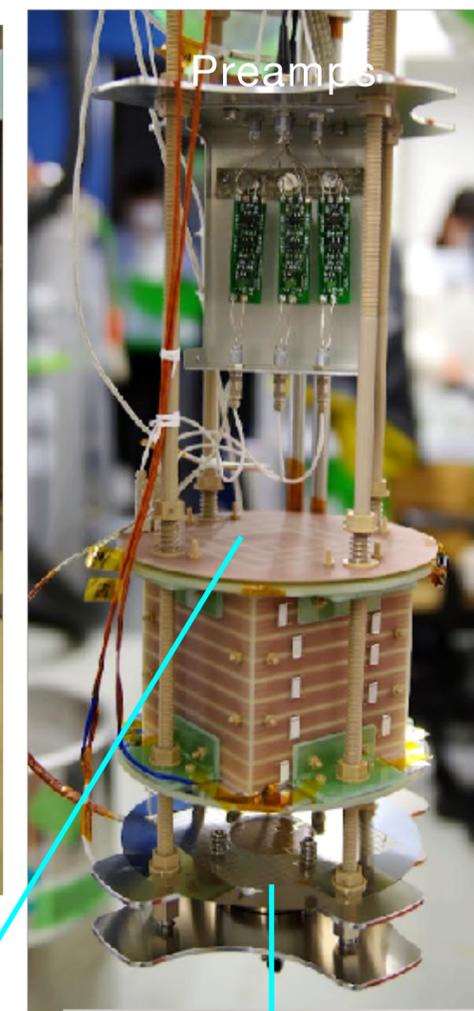
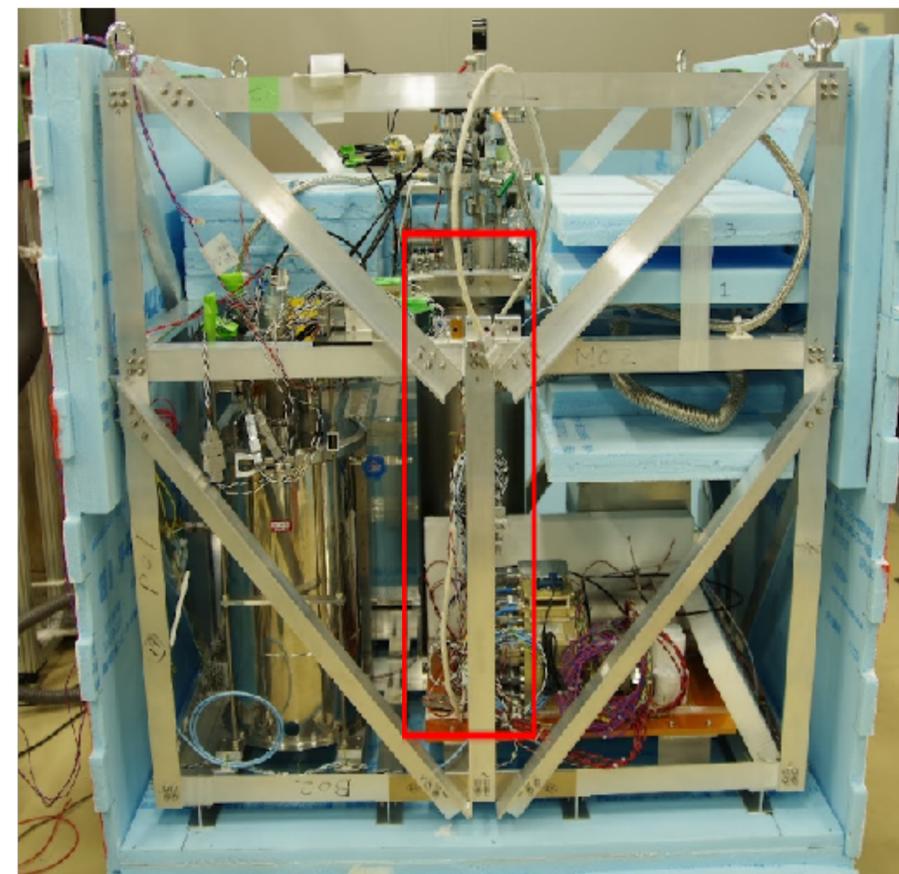


Cost-effective/fast recovery/more frequent flights with LArTPC can further enhance the sensitivity

Masa's talk in PSB.1 (Tue)

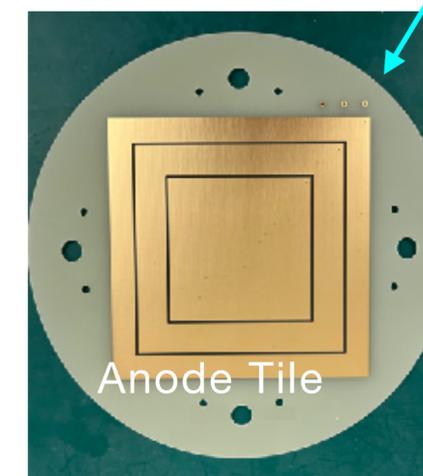
Engineering flight

- Launched in **July 2023** @JAXA TARF
- **First** LArTPC operation at stratosphere
- TPC: 10 x 10 x 10 cm³
 - PMT (Hamamatsu R6041-06) at the bottom
 - 3 charge channels (pGRAMS preamps)
 - No cooling/circulation system
- Pressure vessel for RPi/DAQ
- Obtained ~400k stable events with light + charge



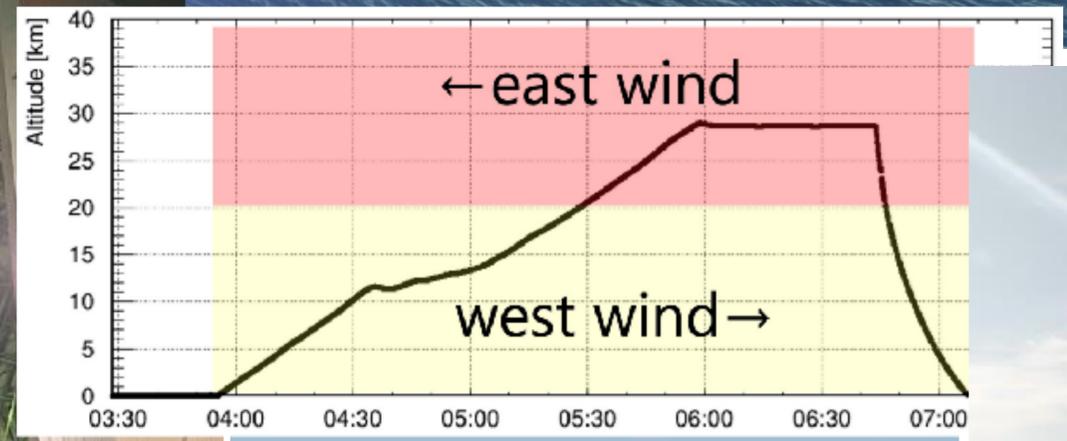
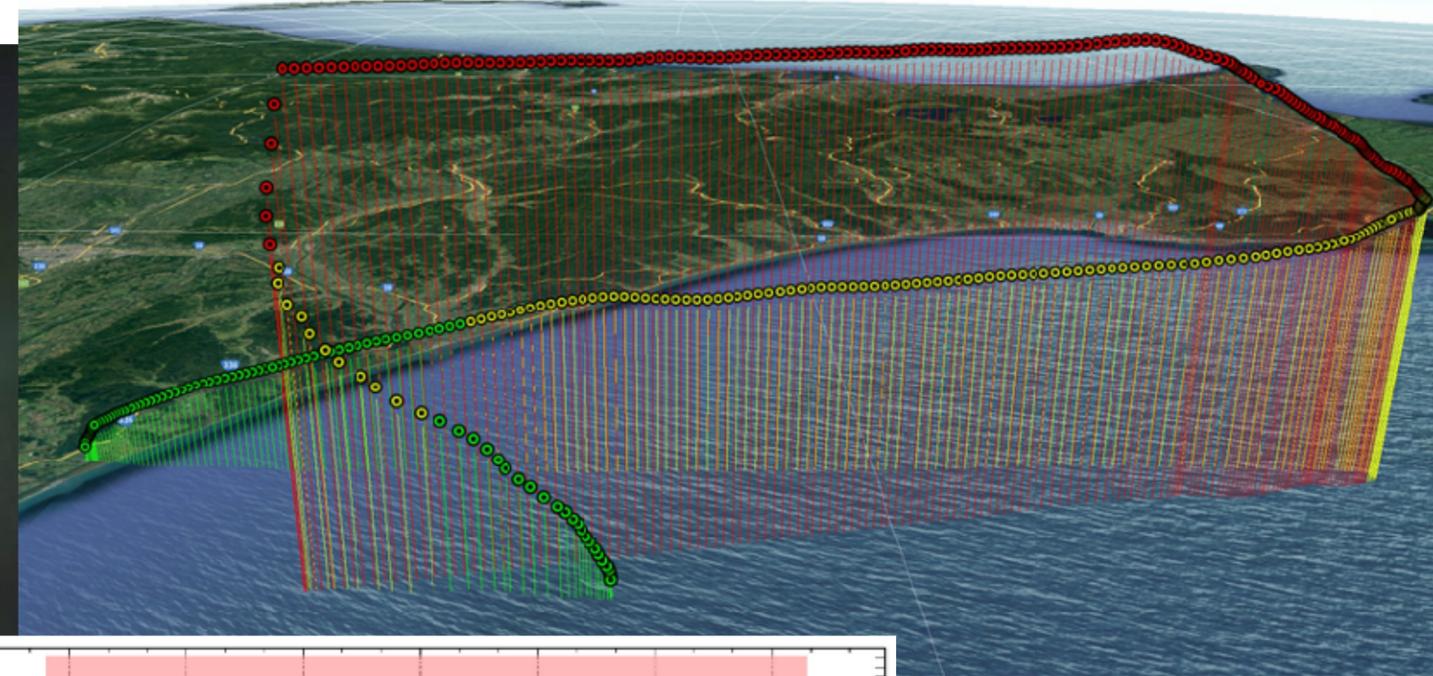
Antiproton beam test

- Scheduled @J-PARC in **2024**
- **Validate** LArTPC performance as an antimatter detector
 - Measure annihilation products (and atomic X-rays)
- May include some **antideuterons**





Engineering flight (eGRAMS) in Japan



Currently testing **MicroGRAMS** @Northeastern

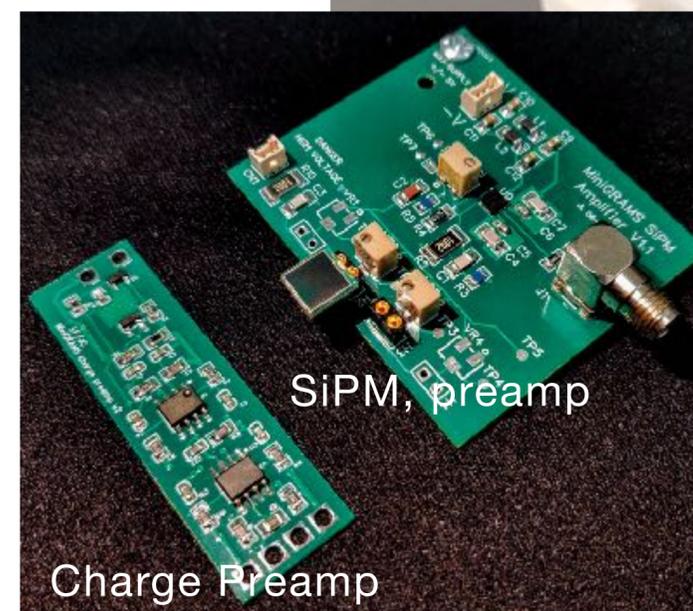
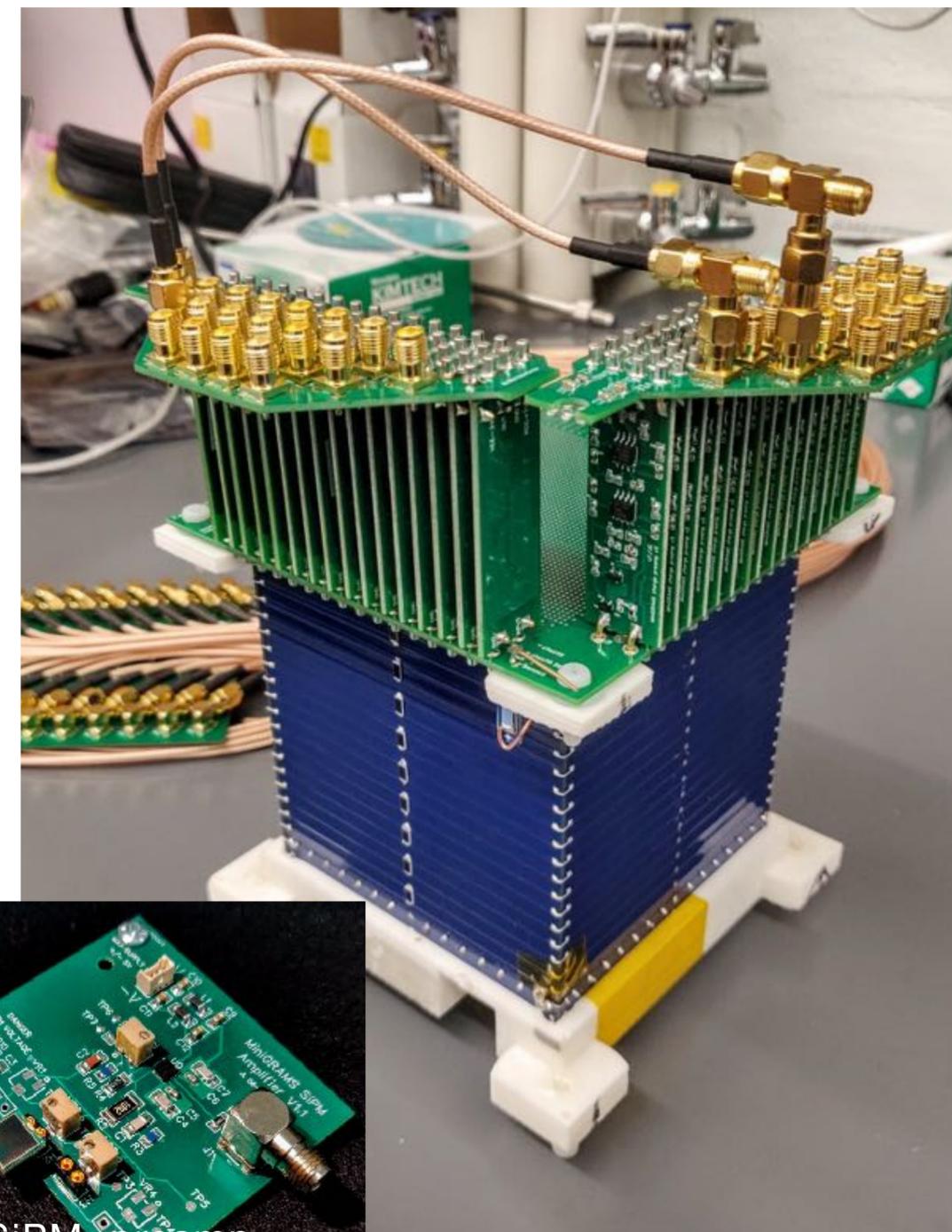
- TPC size: 10 x 10 x 10 cm³ (TPB inside TPC)
- Demonstrate the **particle tracking capability** and **event reconstruction techniques** with gamma-ray sources

Prototype flight scheduled **in 2025/2026**

- Demonstrate LArTPC performance in flight
 - Particle tracking for charged particles
 - Gamma-ray detection
- **MinGRAMS**: 30 x 30 x 20 cm³ segmented into **9 cells**
 - Tile/pads (~3mm pitch) for x/y directions
 - 180 charge preamps in total
 - 16 SiPMs (6 mm x 6mm each) per cell

Followed by science flights with **MiniGRAMS**

- One of the largest Compton cameras
- Cooling/circulation system onboard





GRAMS Collaboration

International collaboration with different backgrounds/expertise

Gamma-rays, X-rays, Cosmic-rays, Neutrinos, Direct/Indirect DM searches

USA

- Barnard College
- Columbia University
- Howard University
- NASA GSFC
- Northeastern University
- Oak Ridge National Lab
- UCB/SSL
- UT Arlington
- Washington University
- Yale

International

- Hiroshima University
- Tokyo University of Science
- Kanagawa University
- Nagoya University
- National Defense Medical College
- Osaka University
- Universität Würzburg
- RIKEN
- Rikkyo University
- University of Tokyo
- JAXA
- Yokohama National University
- Waseda University

2024 May Collaboration Meeting





Summary

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- GRAMS aims for both **gamma-ray** observations in the **poorly-explored MeV** range, as well as **indirect dark matter searches** with **antimatter**. The project will begin with a **balloon** experiment as a step forward to a **satellite** mission.
- With a cost-effective, large-scale LArTPC detector, the sensitivity to MeV gamma rays can be **an order (two orders)** of magnitude improved with a **single balloon flight (Satellite)** compared with the previous missions.
- GRAMS **antideuteron** measurements can be essentially **background-free** dark matter searches while investigating and validating the possible dark matter signatures indicated in **Fermi GCE** (Galactic Center Excess) and **AMS-02** antiproton excess.
- We are currently testing **MicroGRAMS** for the particle tracking capability and gamma-ray event reconstruction techniques and preparing for the **antiproton beam test** (late 2024),
- We will have a **prototype flight** with **MiniGRAMS** in 2025/2026, funded by the **NASA APRA (2022)** program.

