

GRAMS Project Overview



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Northeastern University



UCLA Dark Matter 2023 3/29 - 4/1, 2023



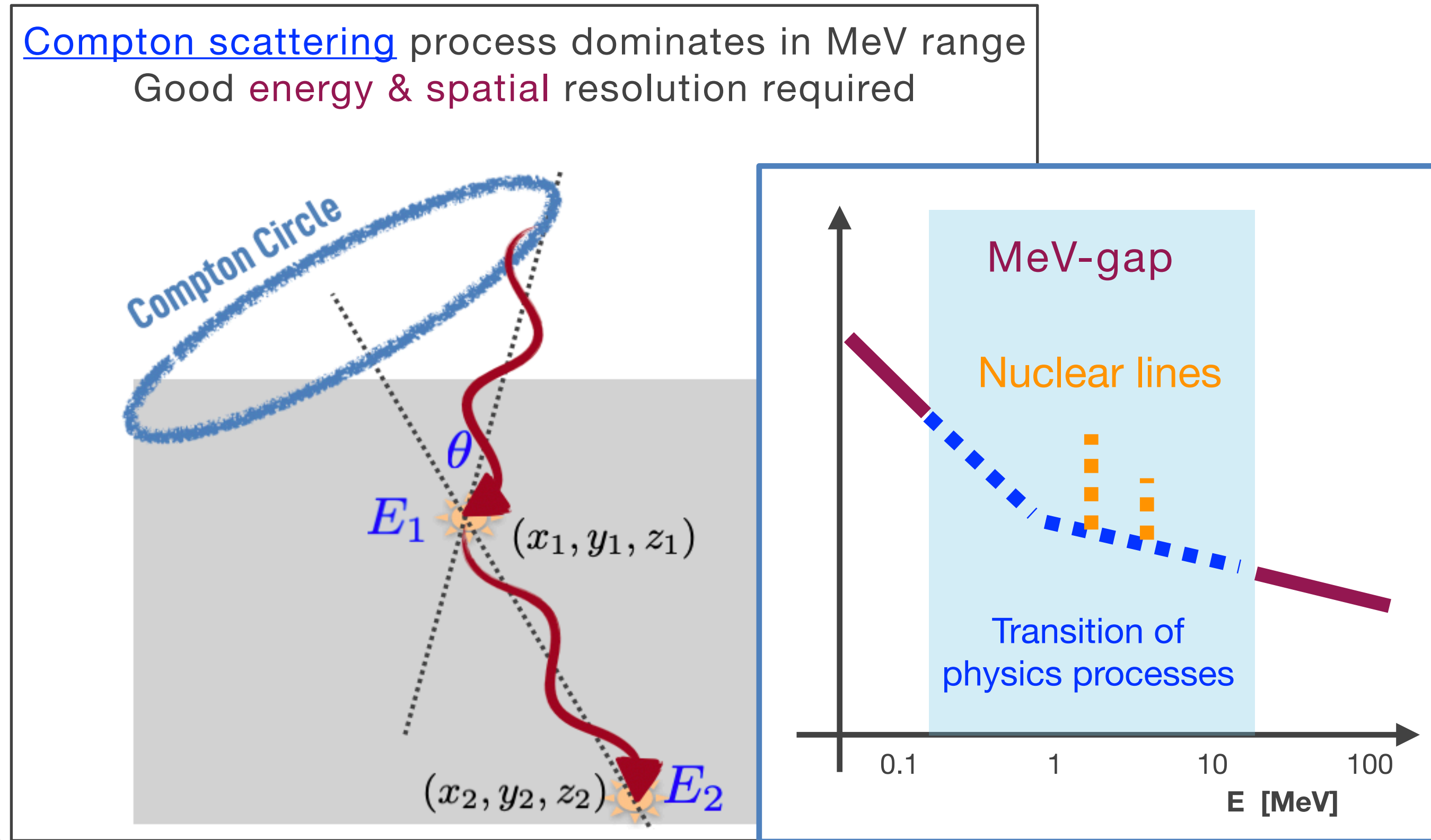
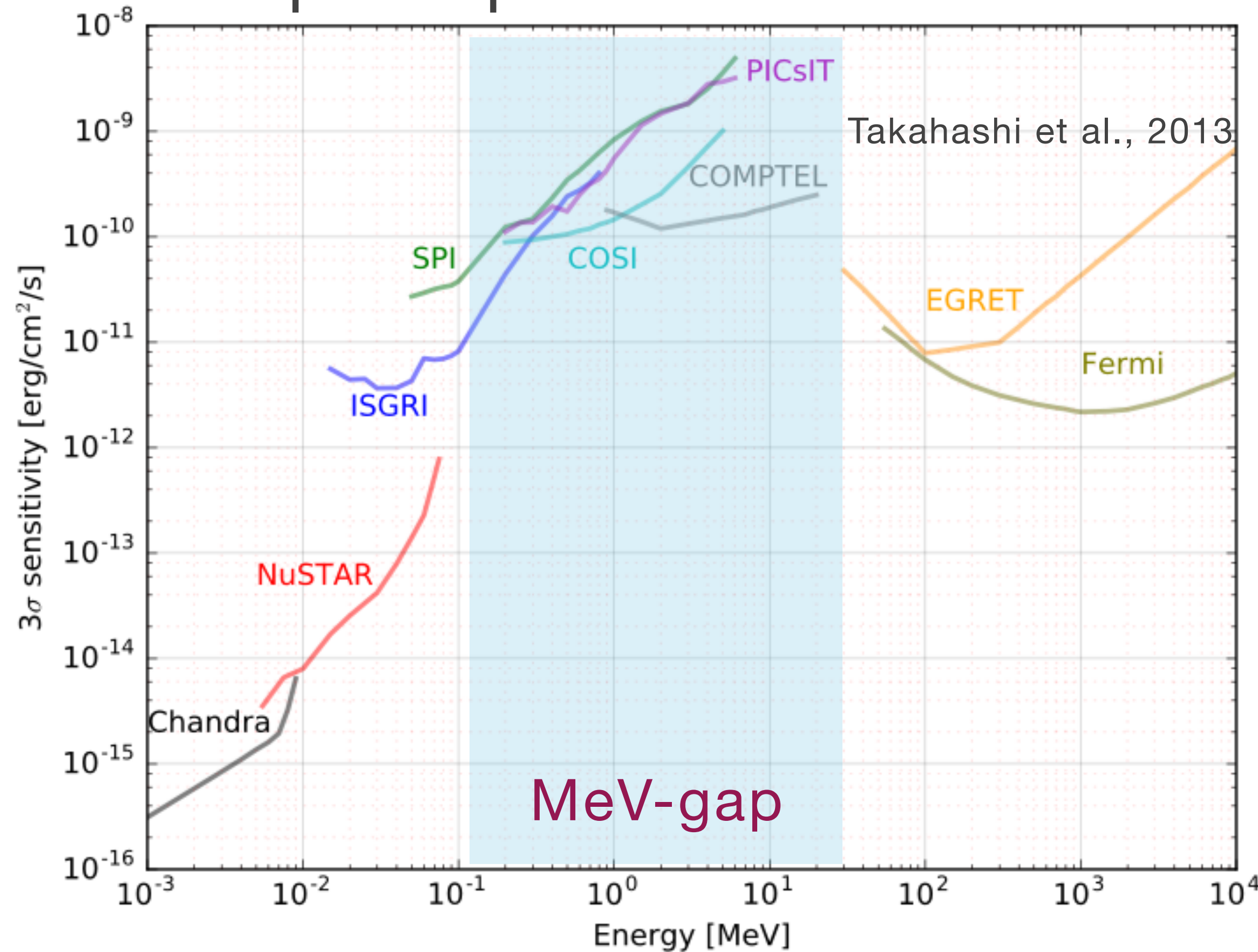
GRAMS = Gamma-Ray and AntiMatter Survey

A newly proposed project with international collaboration

First balloon/satellite mission with a **low-cost**, **large-scale** LArTPC detector

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

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



MeV gamma-ray continuum/line spectrum

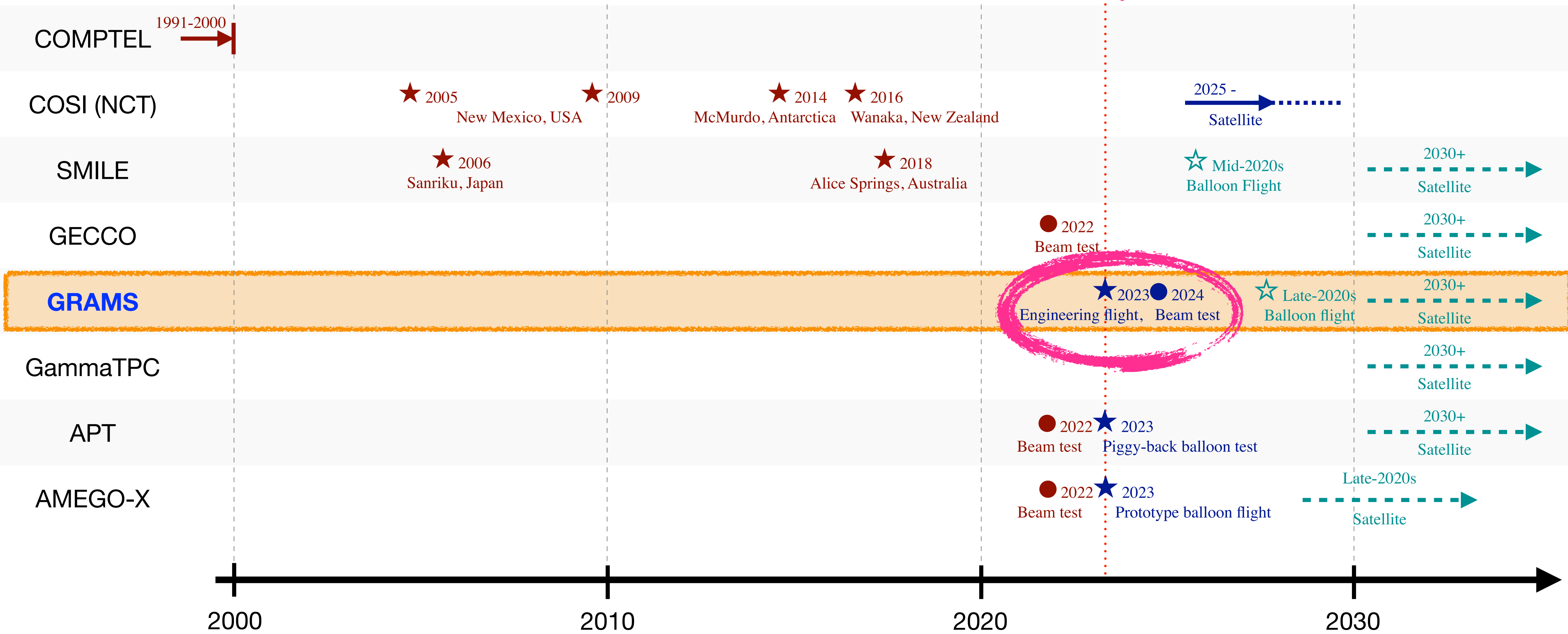
- Physics processes/**nucleosynthesis**
- **Multi-messenger** astronomy: EM counterparts of GW from NS-NS/BH Mergers
- Indirect **dark matter** searches/**PBH** searches



MeV Gamma-ray Missions (Snowmass CF1)

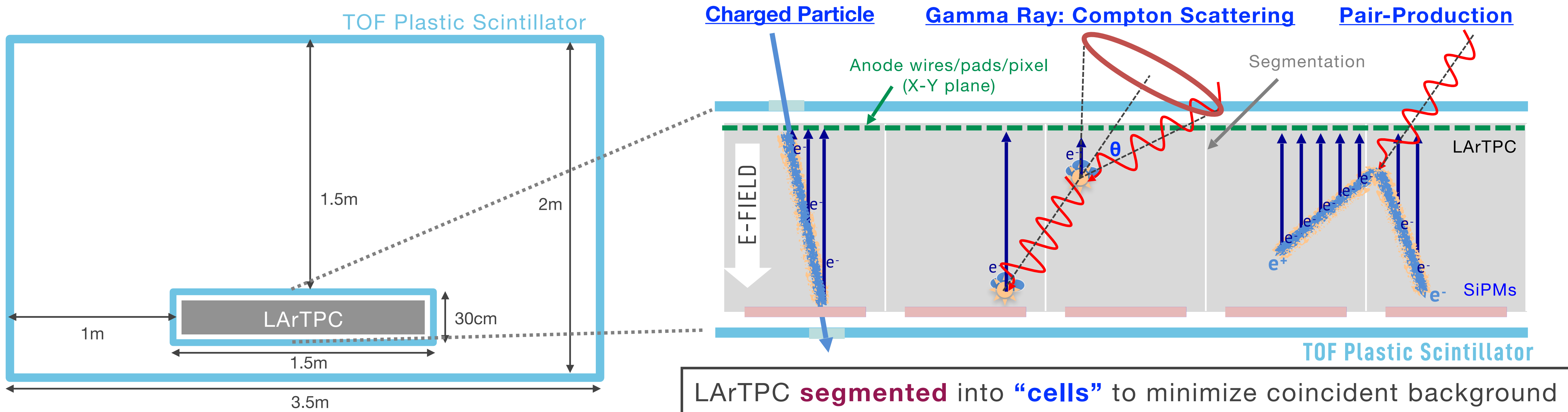
Past, near-term, and long-term future plans

Snowmass White Paper:
Aramaki+, 2022



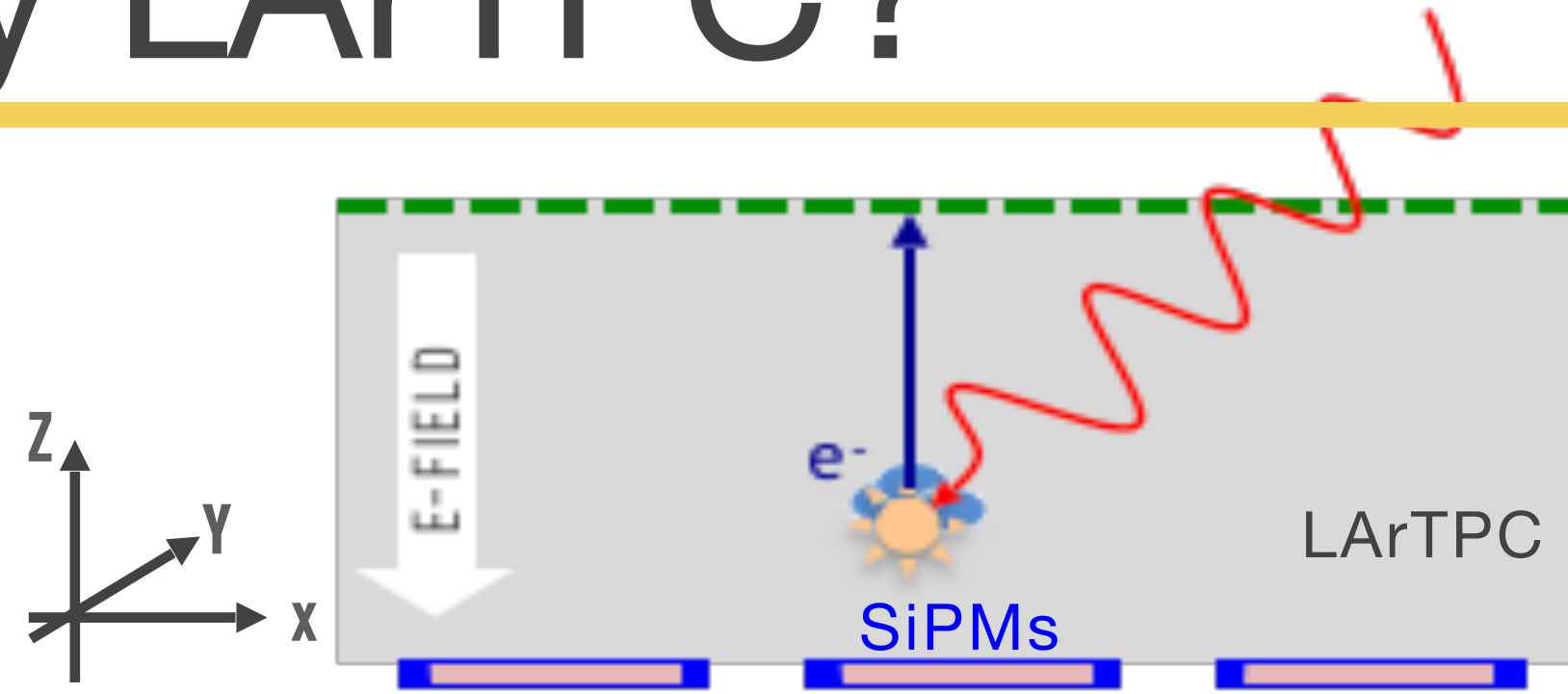
LArTPC surrounded by plastic scintillators

	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/widely-used** in underground **dark matter/neutrino** experiments

Why LArTPC?

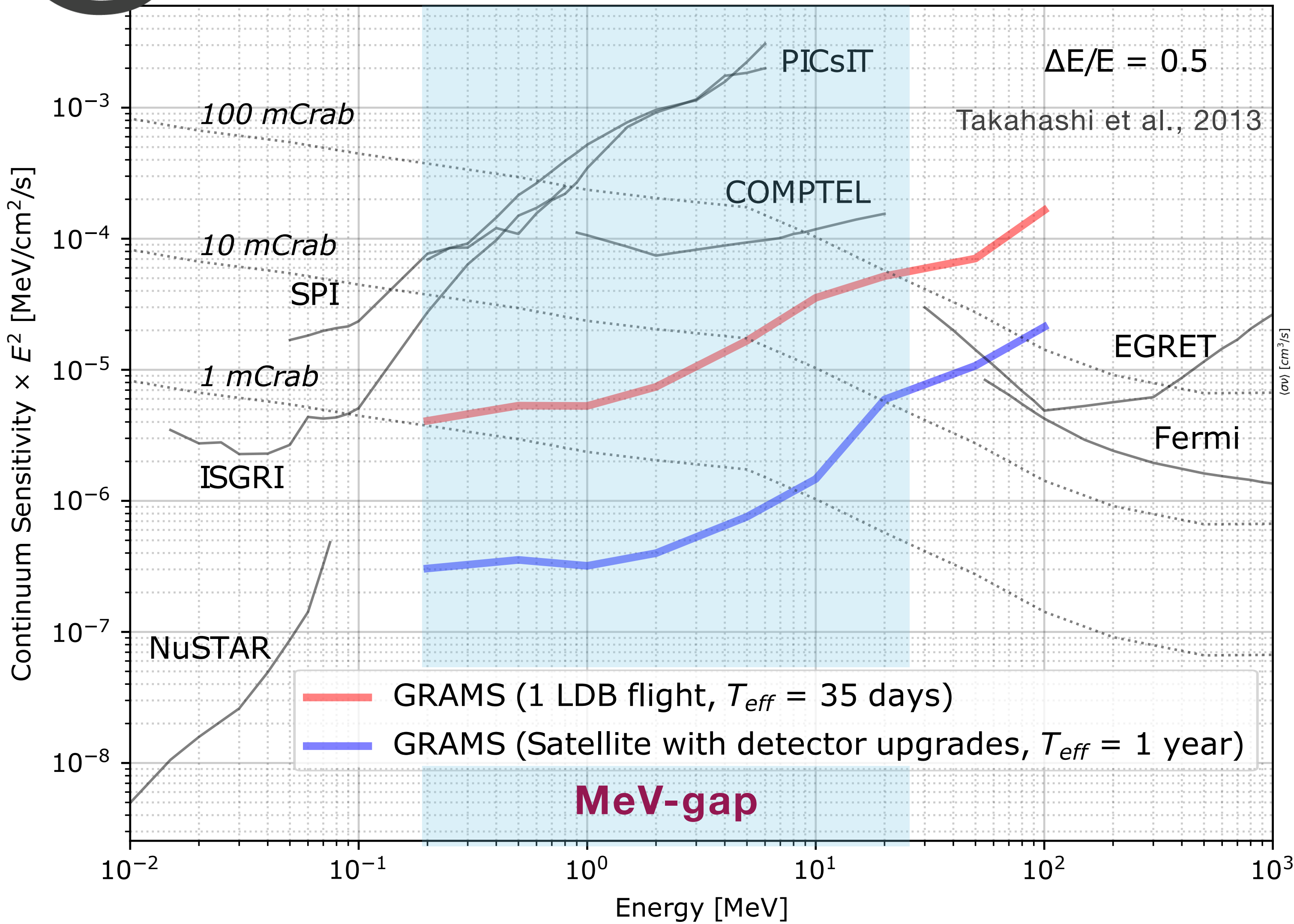


	LArTPC	Semiconductor/Scintillator
ρ (g/cm ³)	1.4	2.3/5.3 (Ge/Si)
T _{operation}	~80K	~240K/~80K
Cost	\$	\$\$\$
Signals	scintillation light + ionization electrons	electrons, holes
X, Y positions	Wires/pads on anode plane (X-Y)	double-sided strips
Z position	From drift time	from layer #
# of layers	Single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

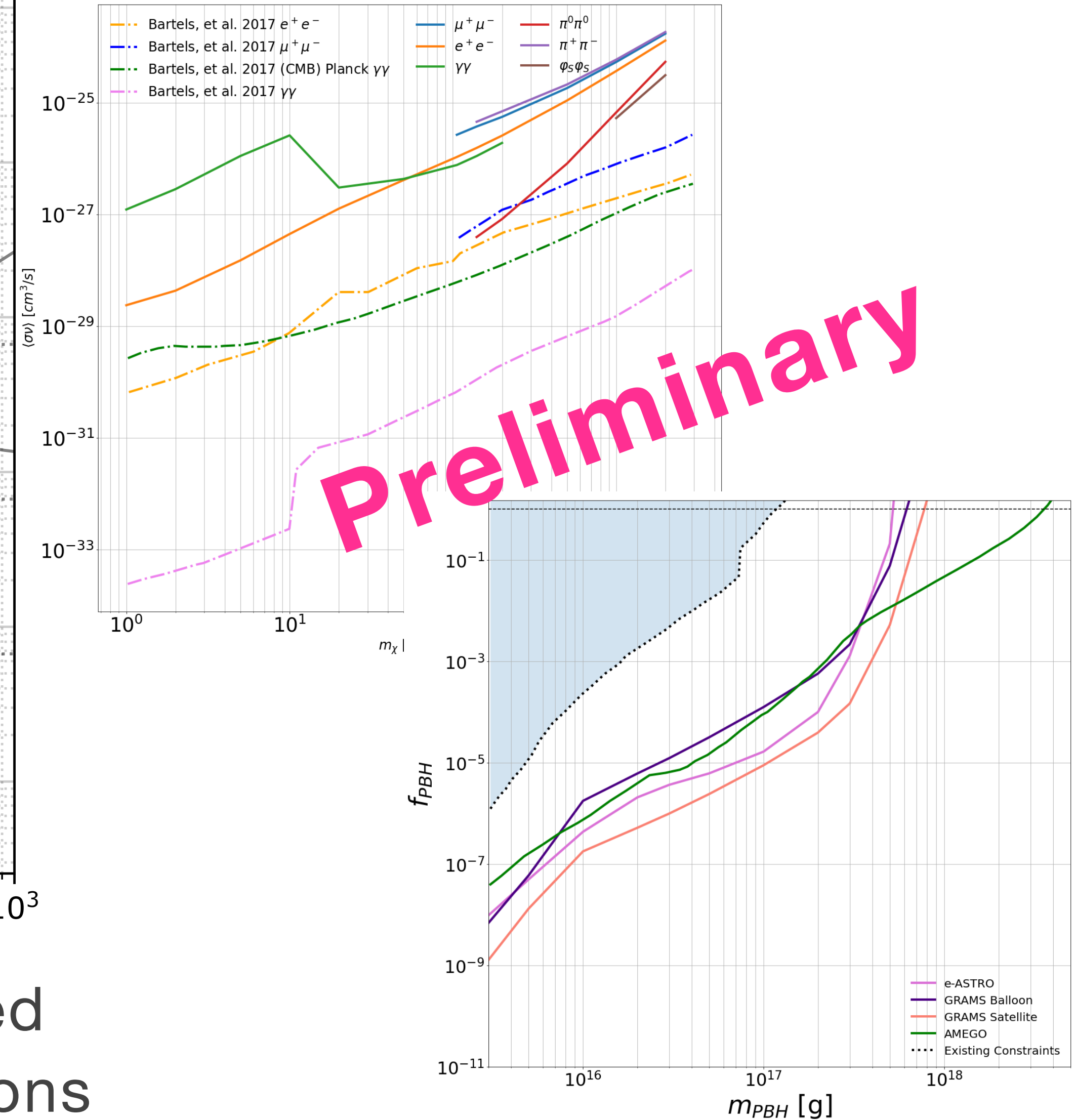
- LArTPC is **cost-effective** and almost **no dead volume**
- Easily expandable to a **larger scale** with **high detection efficiency**



MeV Gamma-ray Observations



Annihilating DM and evaporating PBHs



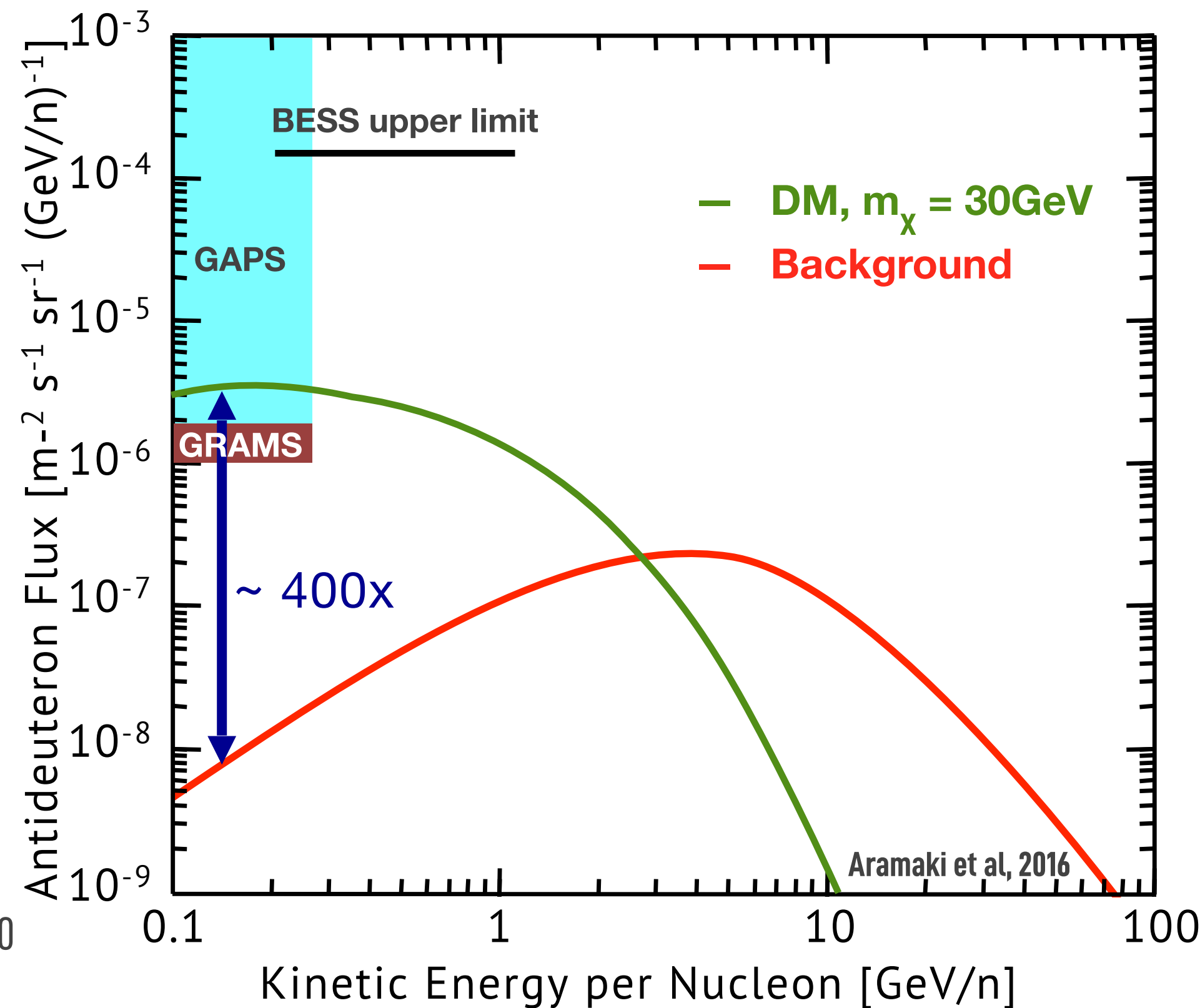
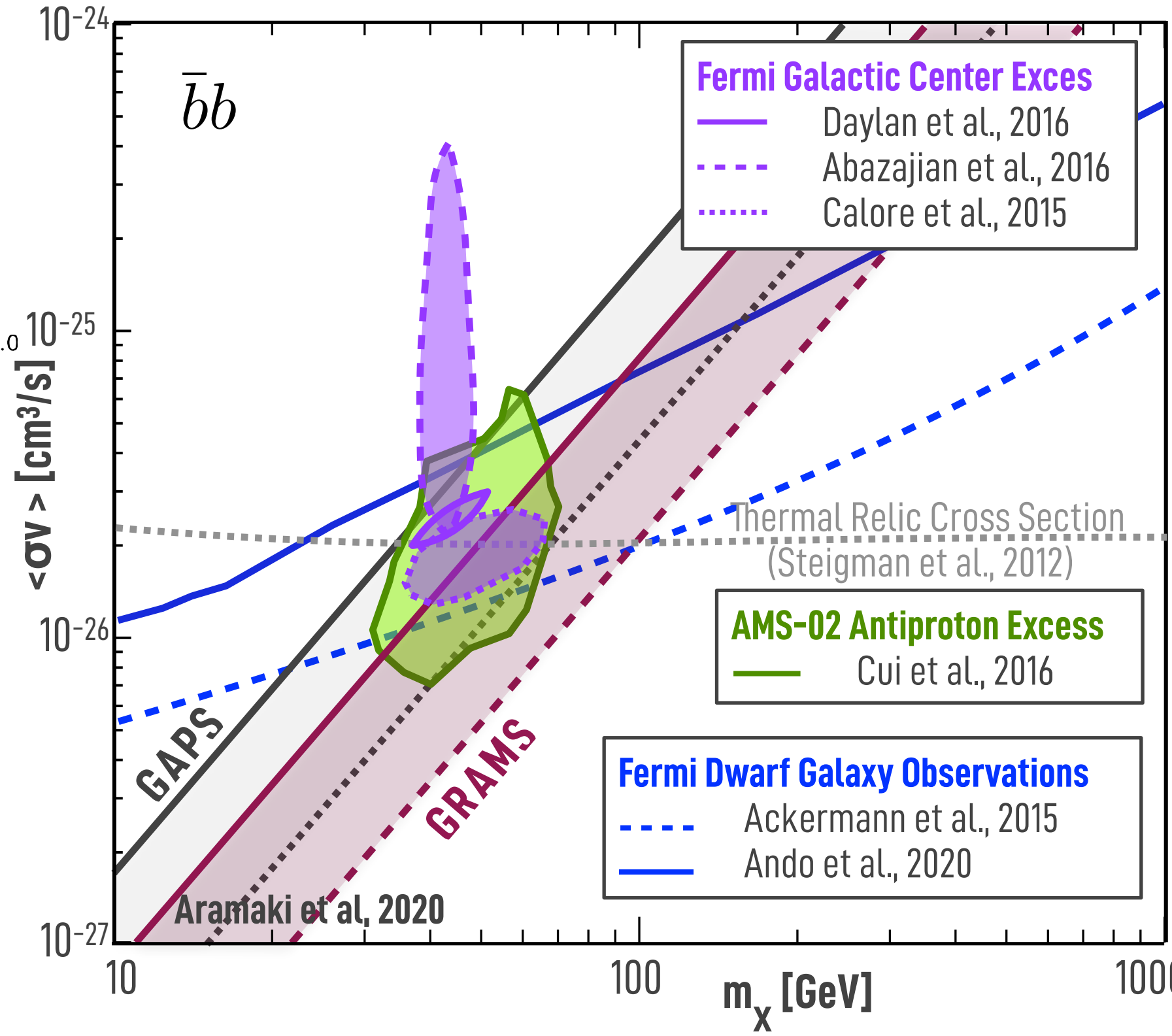
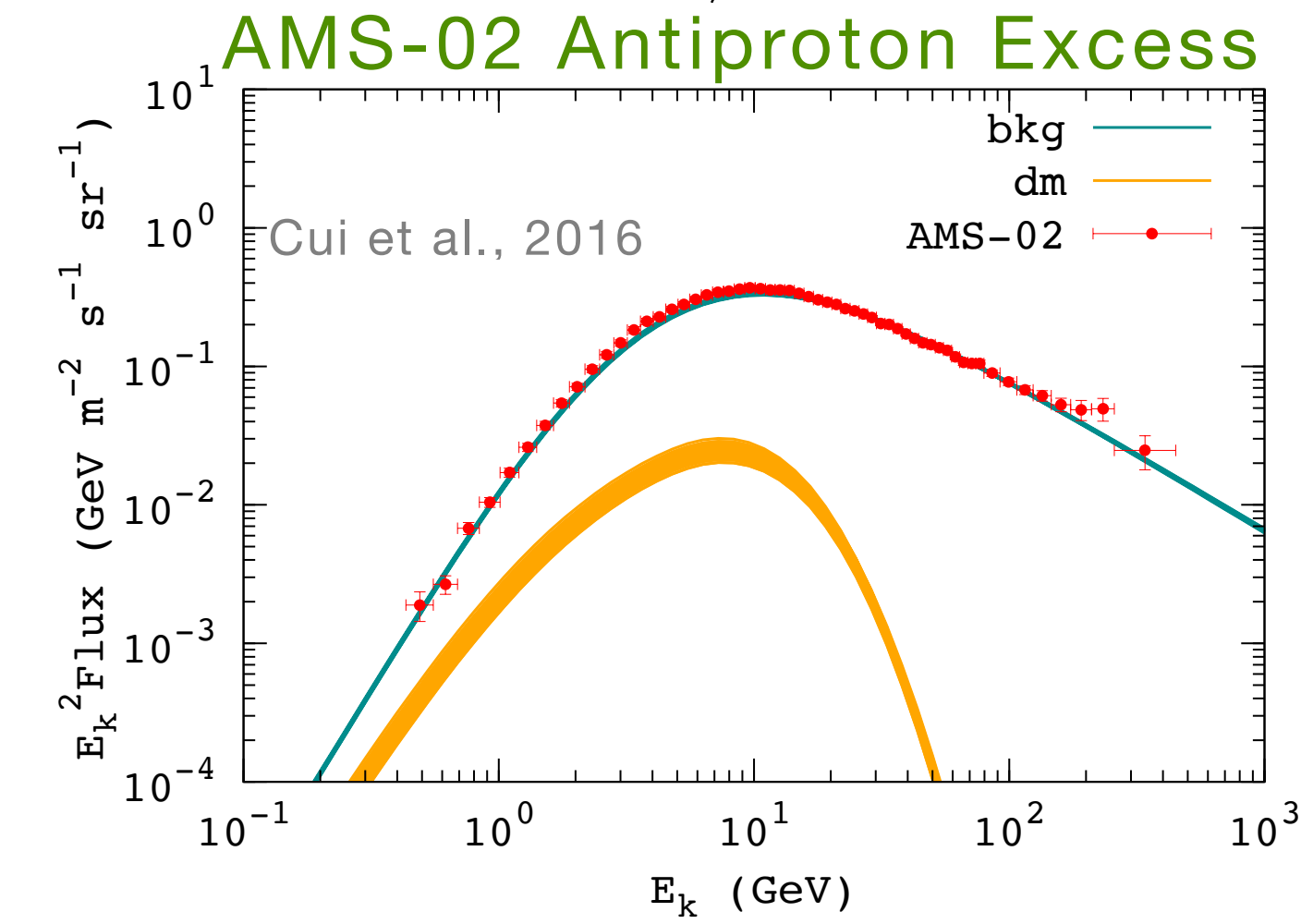
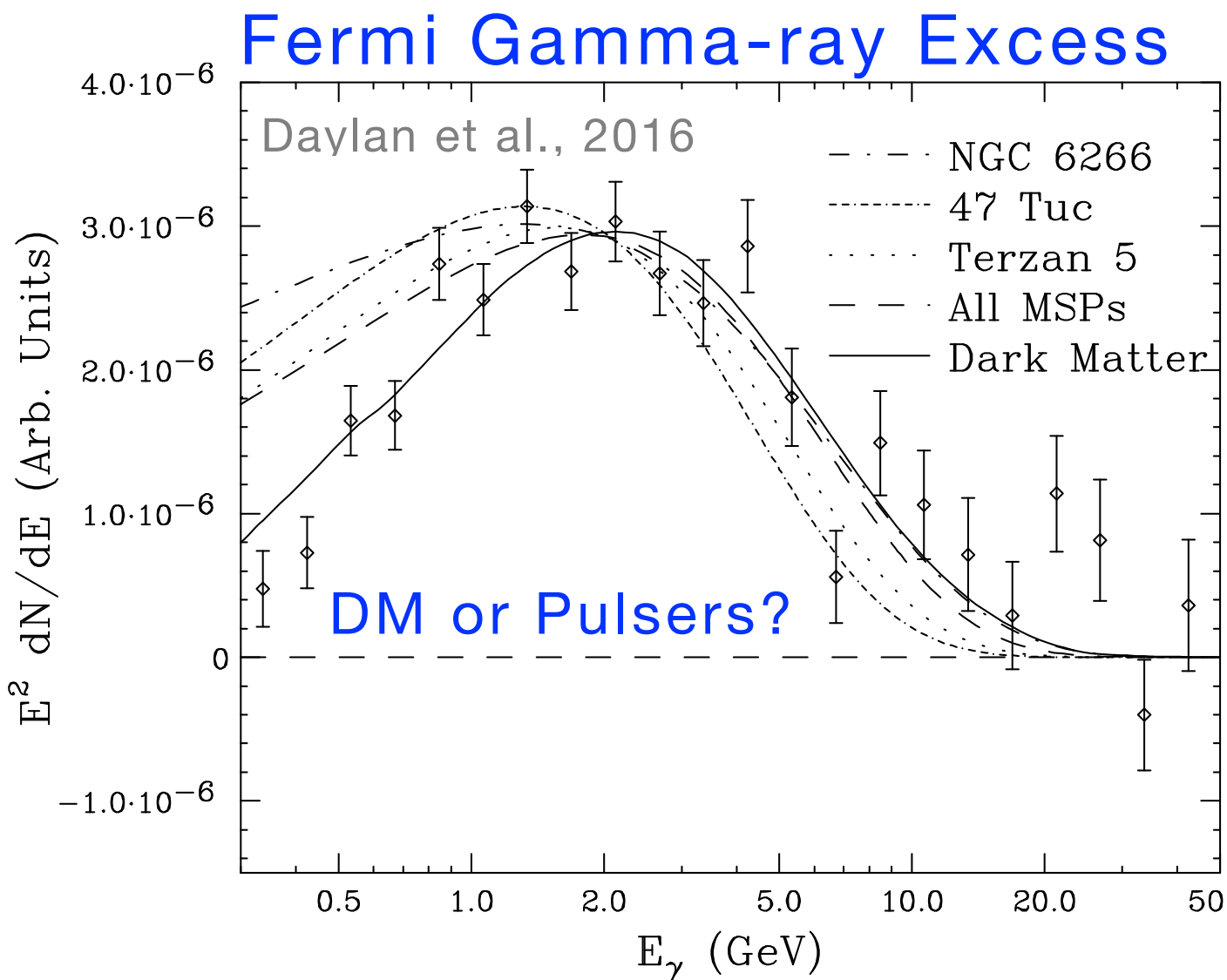
- **Balloon** flight: an order of magnitude improved
- **Satellite** mission: comparable to future missions



Indirect DM Searches with Antinuclei

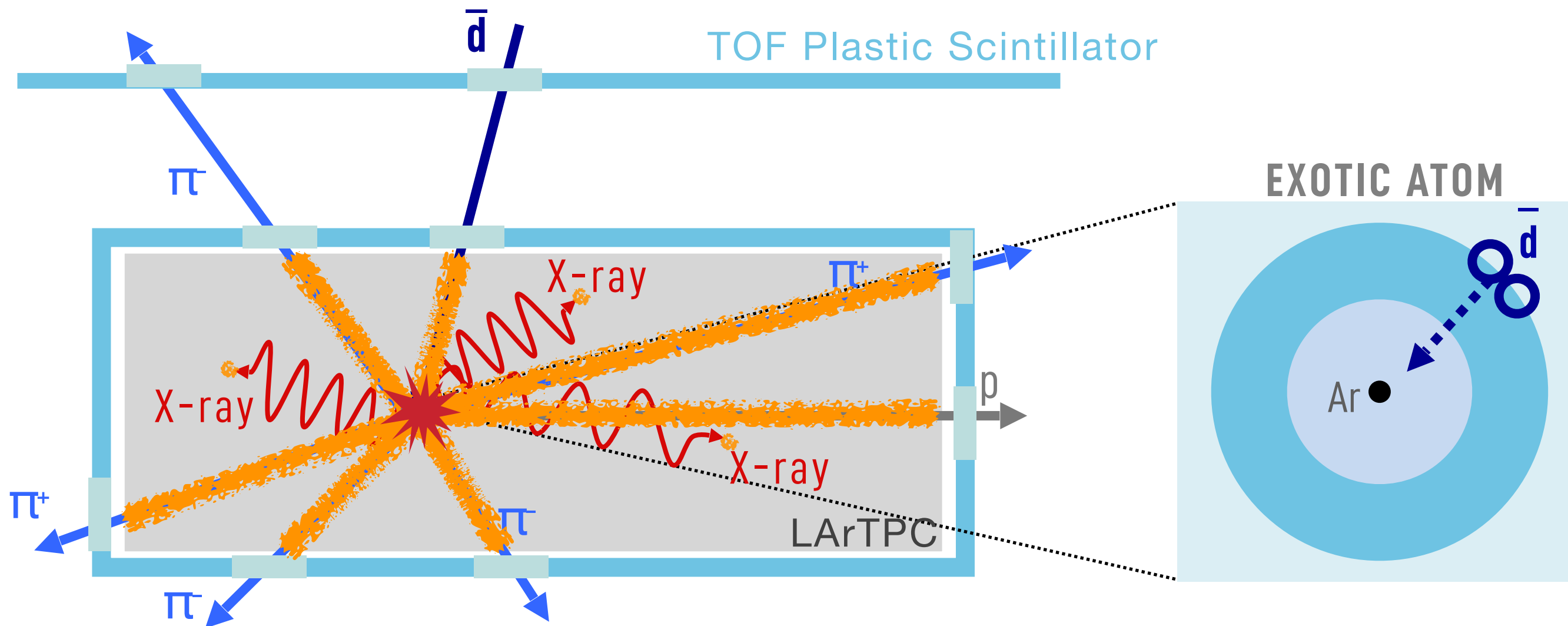
- Possible DM signature in **FERMI GCE**, **AMS-02 antiproton** excess
- AMS-02 detected **antihelium-like** events

How do we validate these results?

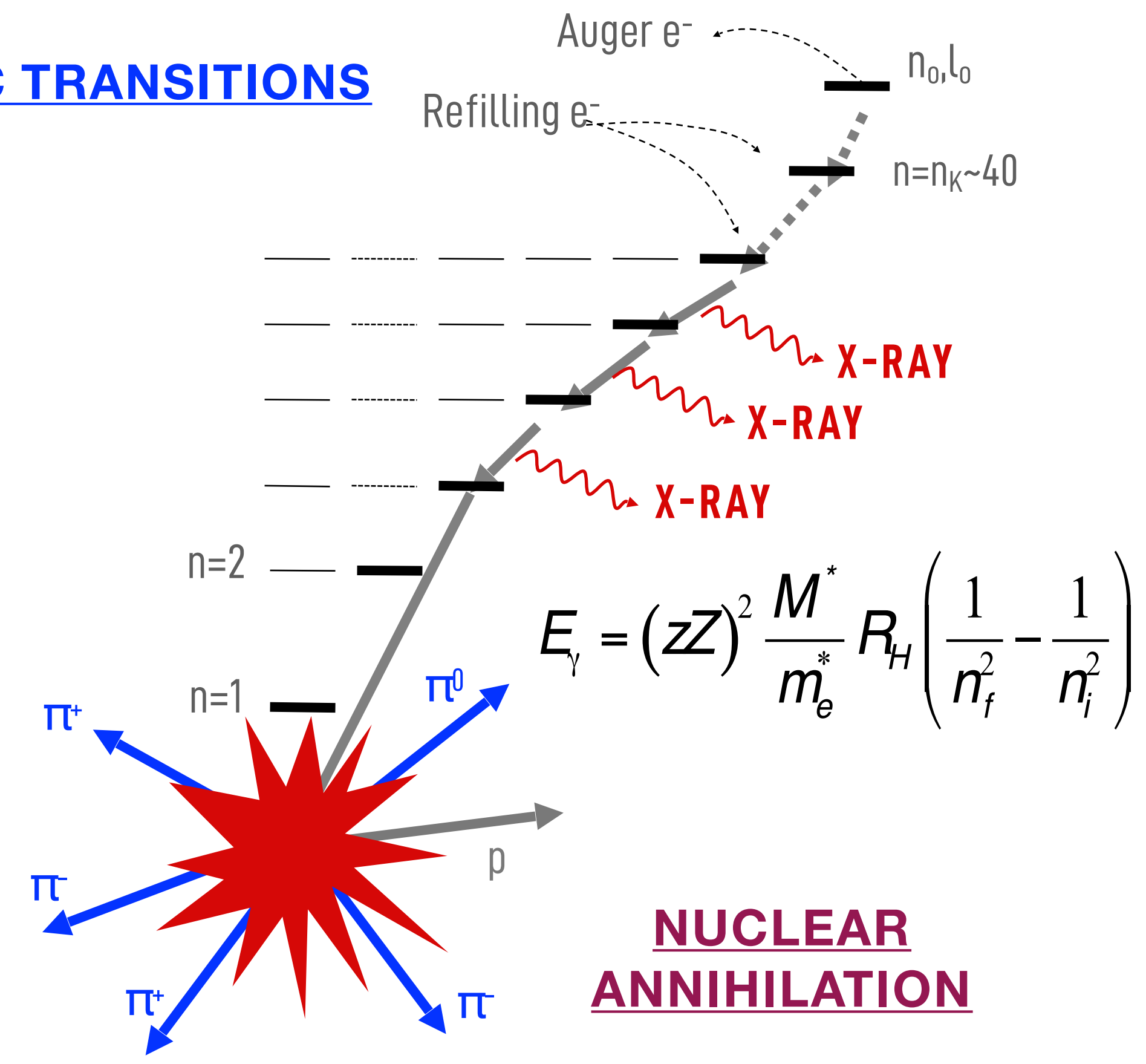


- **Background-free** DM search with low-energy antideuterons
- GRAMS can **extensively** explore DM parameter space

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



ATOMIC TRANSITIONS



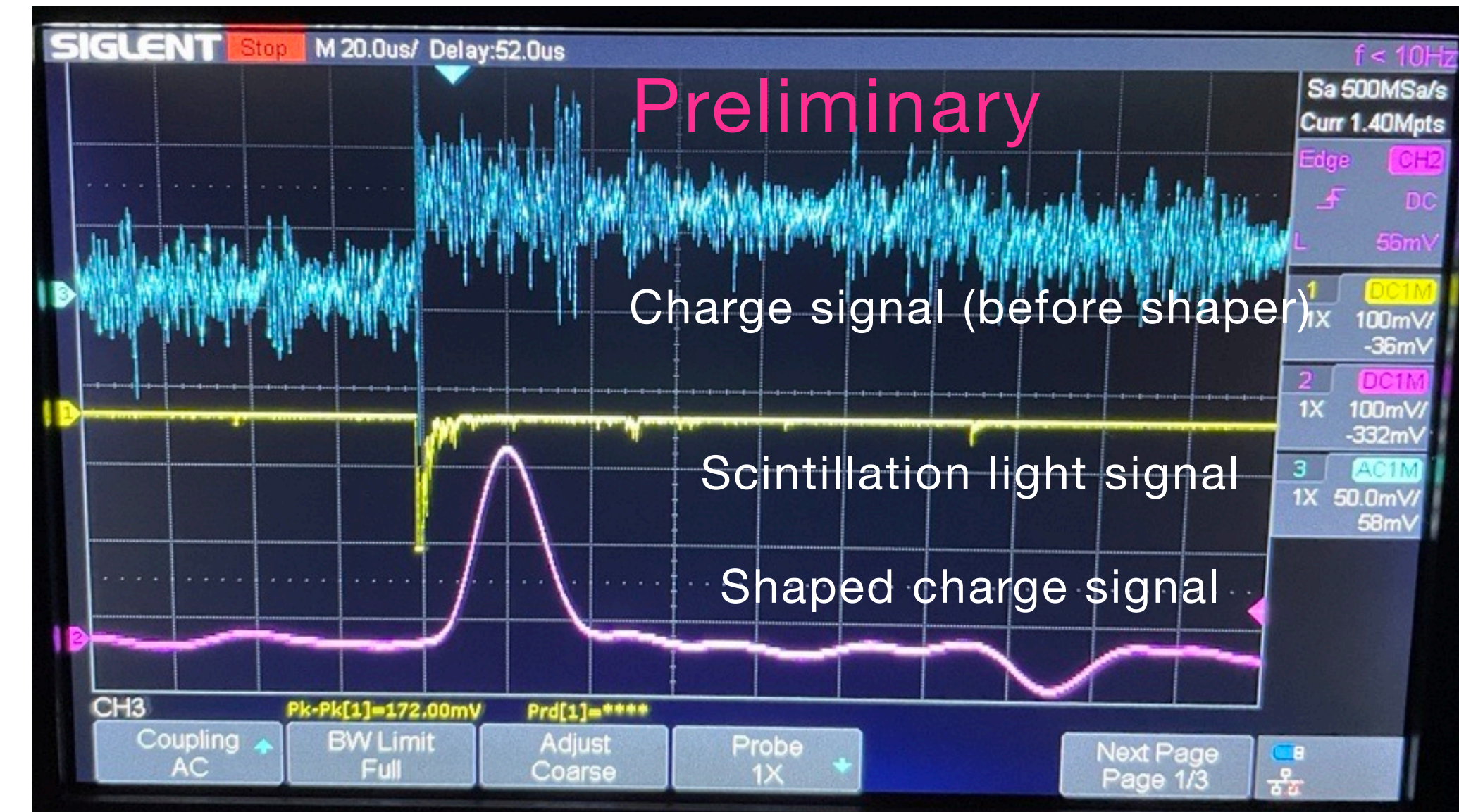
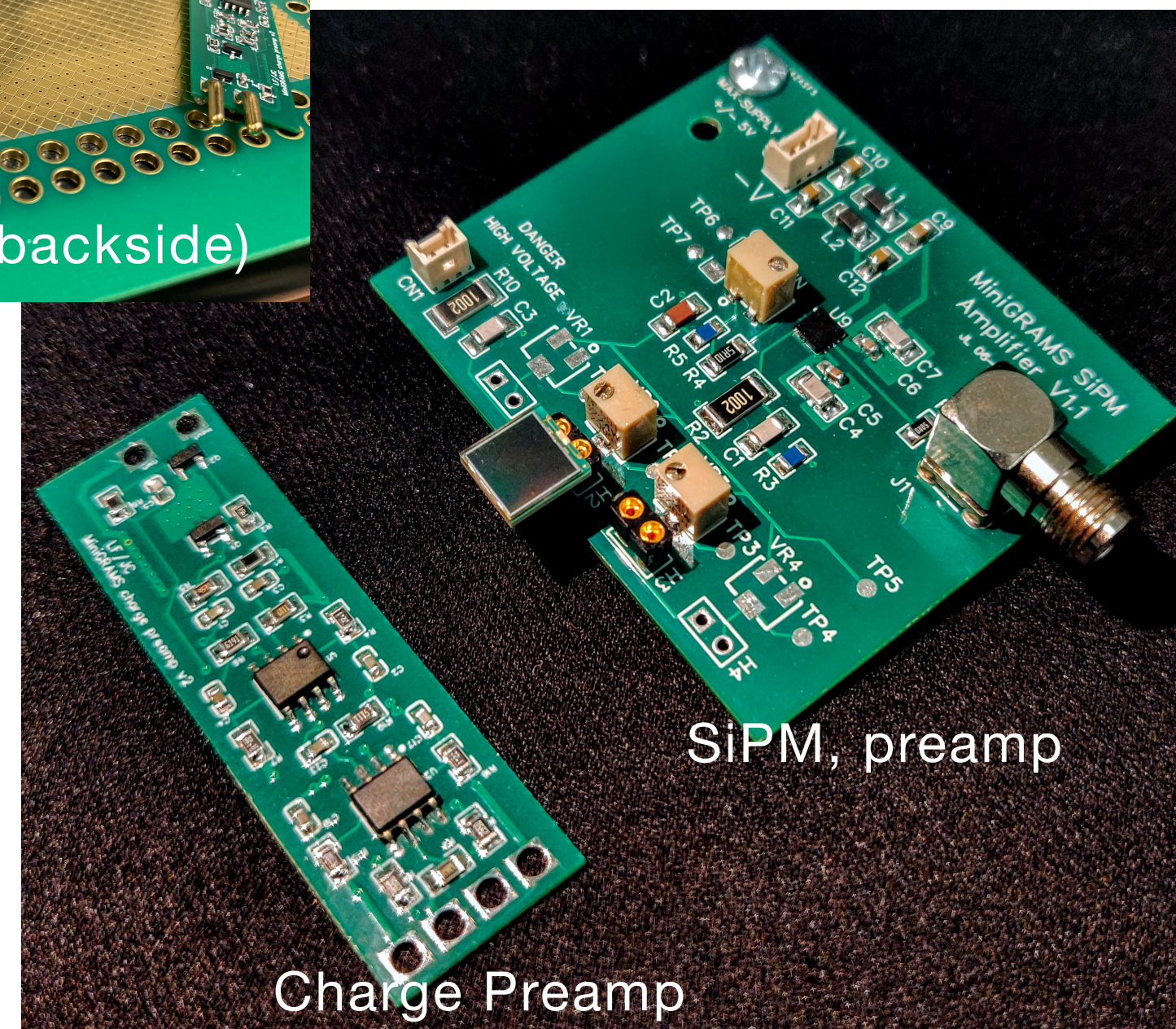
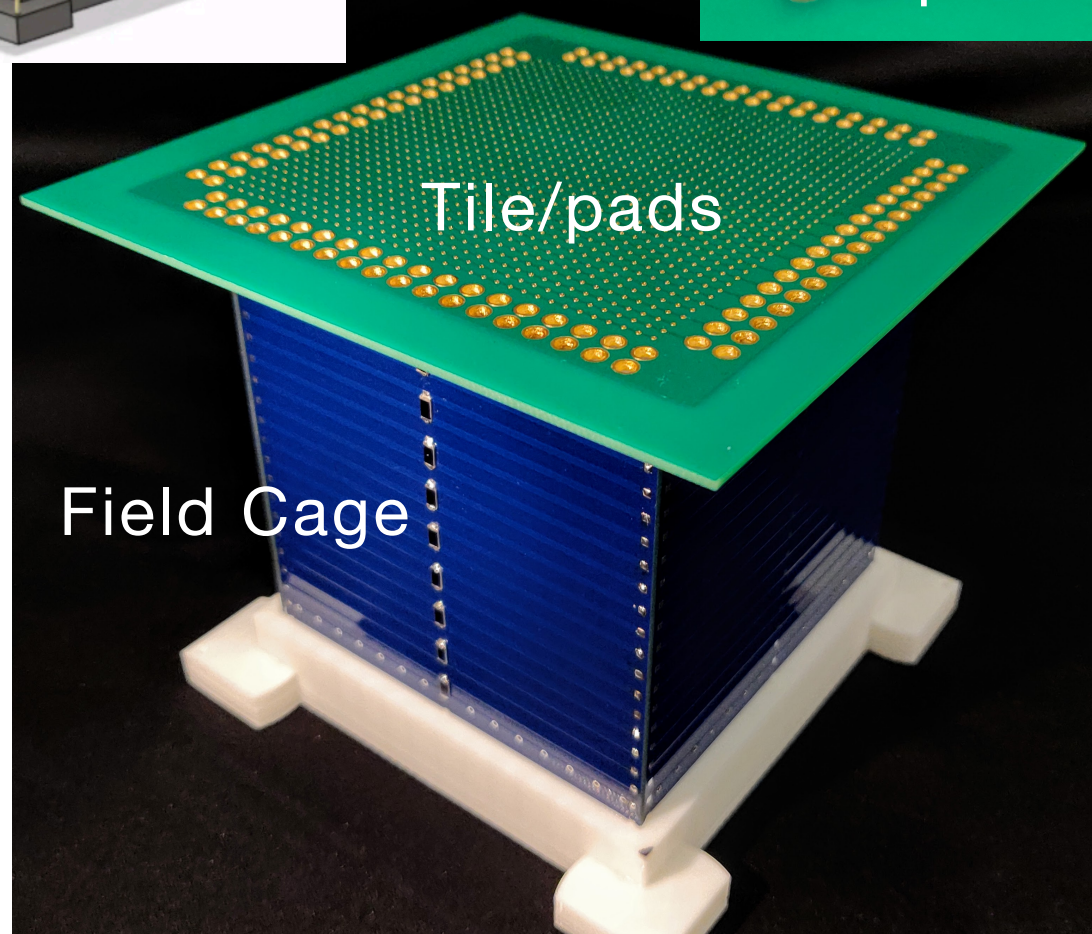
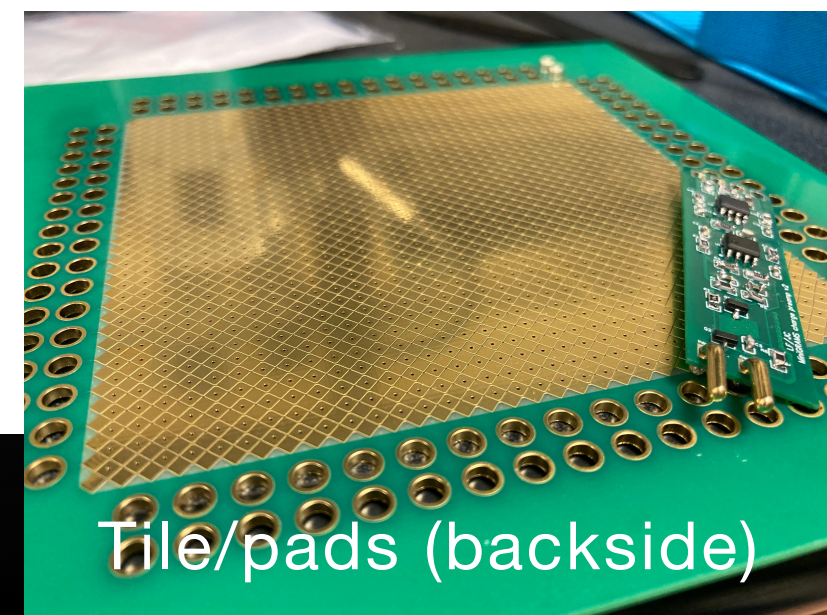
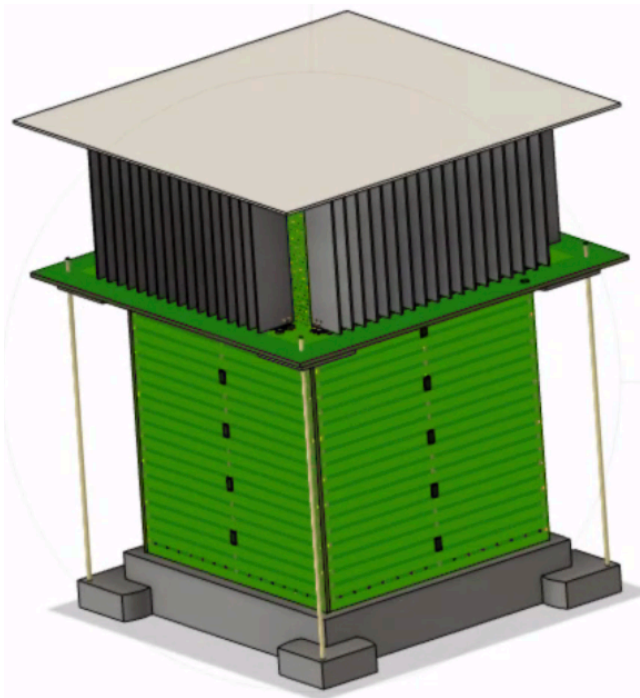
- A time of flight (TOF) system tags candidate events and records velocity
- The antiparticle slows down & stops, forming an excited exotic atom
- De-excitation X-rays provide signature
- Annihilation products provide additional background suppression

LArTPC (almost no dead volume) provides

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

TPC: 10 x 10 x 10 cm³ @Northeastern

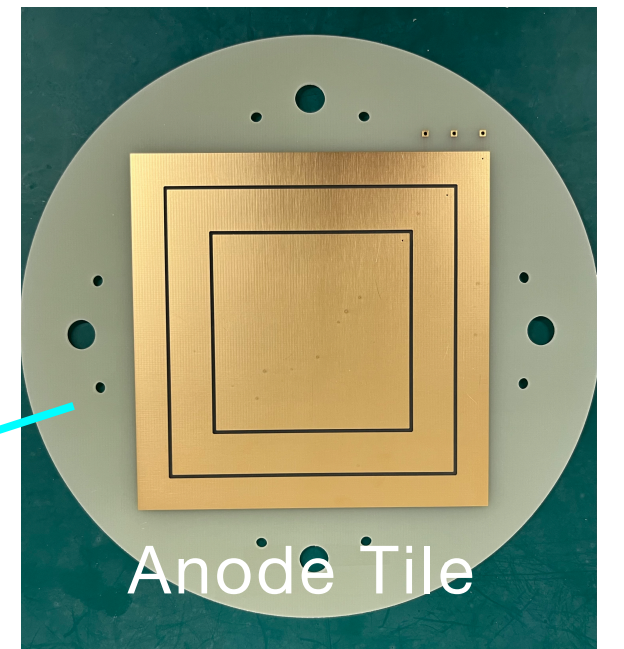
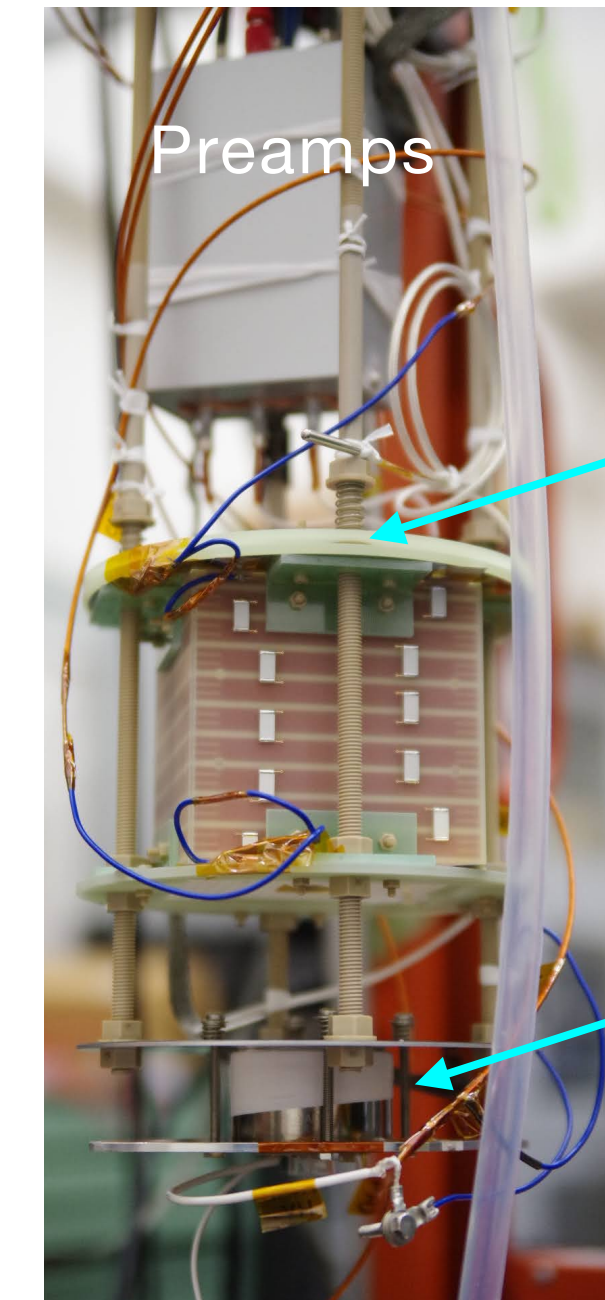
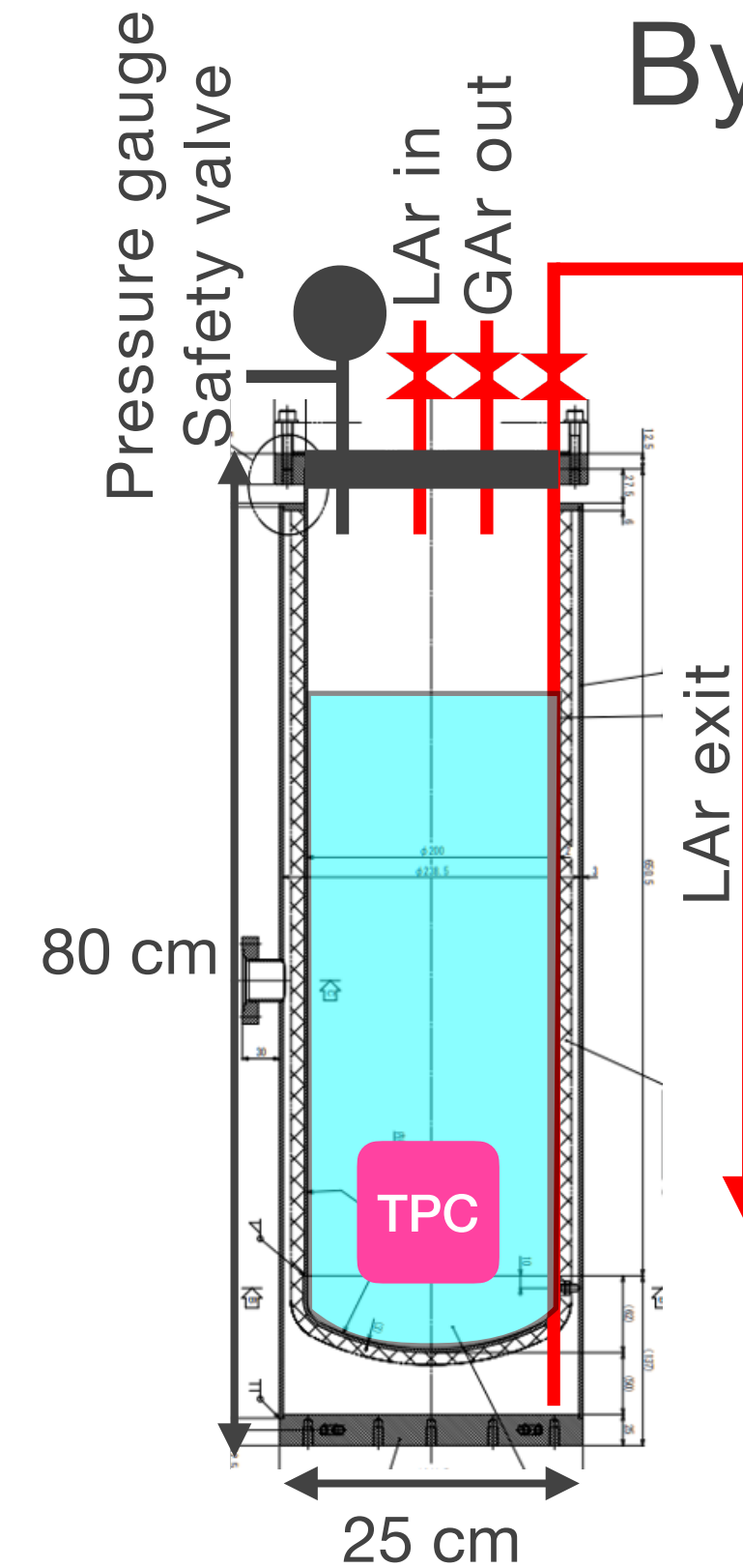
- Tile/pads (~3mm pitch) for x/y directions
- 60 charge preamps in total
- 16 SiPMS (6 mm x 6mm each) at the bottom
- TPB inside TPC



- Coincident signals in LAr
 - Only **one** charge preamp, **one** SiPM
- Validate event reconstruction techniques with gamma-ray sources
- Expand the size to 30 x 30 x 20 cm³, **MiniGRAMS**, segmented into 9 **cells**
 - > **Prototype (science) flight**

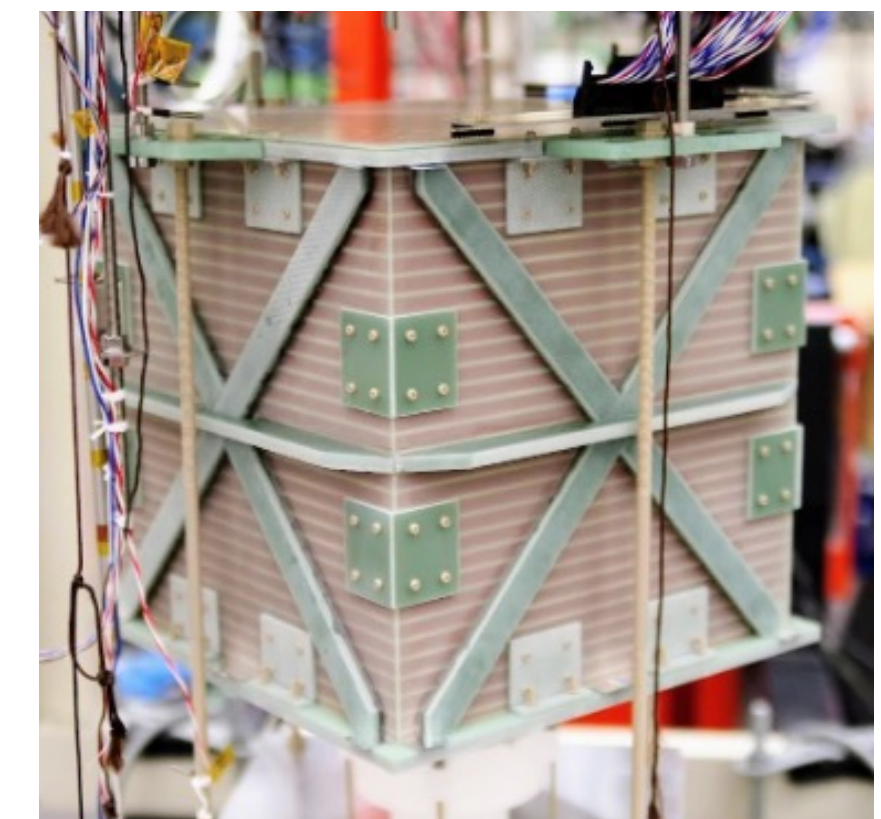
Engineering flight

- Scheduled to launch in **July 2023**
- @JAXA Taiki Aerospace Research Field
- **First** LArTPC operation at stratosphere (≤ 10 min level flight at ≥ 25 km)
- TPC: $10 \times 10 \times 10 \text{ cm}^3$ by Waseda
 - PMT (Hamamatsu R6041-06) at the bottom
 - 3 charge channels (Northeastern preamps)
 - No cooling system
- Pressure vessel for RPi/DAQ



Antiproton beam test (may include some antideuterons)

- Scheduled @J-PARC in **2024**
- **Validate** LArTPC performance as an antimatter detector
 - Measure atomic X-rays/annihilation products
- WasedaTPC (MiniGRAMS) x 2



Waseda TPC ($30 \times 30 \times 30 \text{ cm}^3$)



GRAMS Collaboration

Multidisciplinary team with different backgrounds/expertise

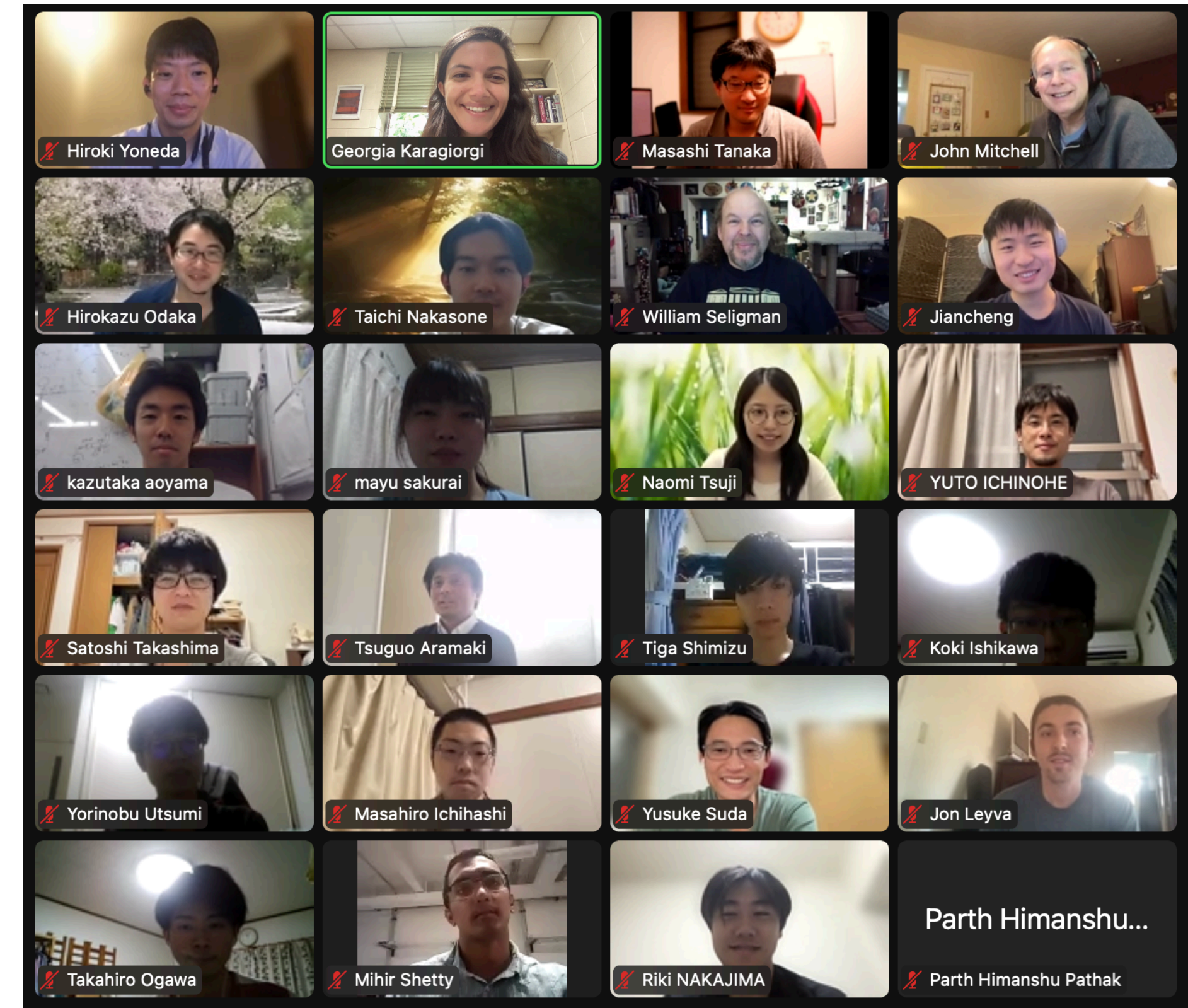
Gamma-rays, X-rays, Cosmic-rays, Neutrinos, Direct/Indirect DM searches

USA

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

International (Japan)

- Hiroshima University
- Kanagawa University
- Osaka University
- RIKEN
- Rikkyo University
- University of Tokyo/NDA
- Waseda University





Summary

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- GRAMS is a proposed next-generation mission to target both **gamma-ray** observations in the **poorly explored MeV** range and **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 **more than an order of magnitude improved** compared to previous experiments with a **single balloon flight**.
- We have developed the **event reconstruction algorithms** for multiple Compton scattering events, based on multi-task neural network/physics-based probabilistic methods.
- GRAMS **antideuteron** measurements can be essentially **background-free** dark matter searches while investigating and validating the possible dark matter detection indicated in **Fermi GCE** and **AMS-02** antiproton excess.
- We are currently testing **MicroGRAMS** in the US and preparing for the **engineering flight (July 2023)** and **antiproton beam test (2024)** @ J-PARC in Japan