9th International
Fermi Symposium

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GRAMS PROJECT

GAMMA-RAY AND ANTIMATTER SURVEY

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On behalf of the GRAMS Collaboration

GRAMS = Gamma-Ray and AntiMatter Survey

A newly proposed project with an international collaboration

Aims to be the first balloon/satellite mission with a low-cost, large-scale LArTPC detector

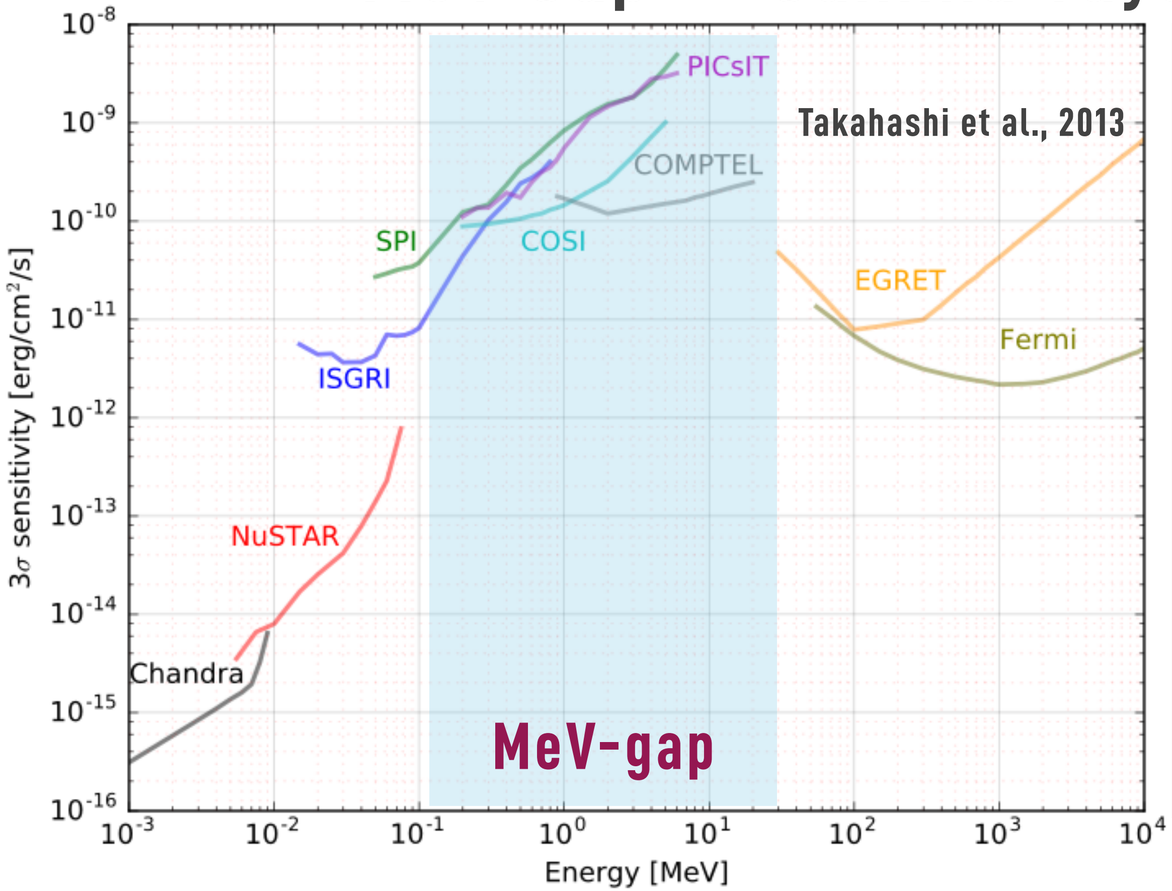
First experiment to target both astrophysical observations with MeV gamma rays and dark matter searches with antimatter

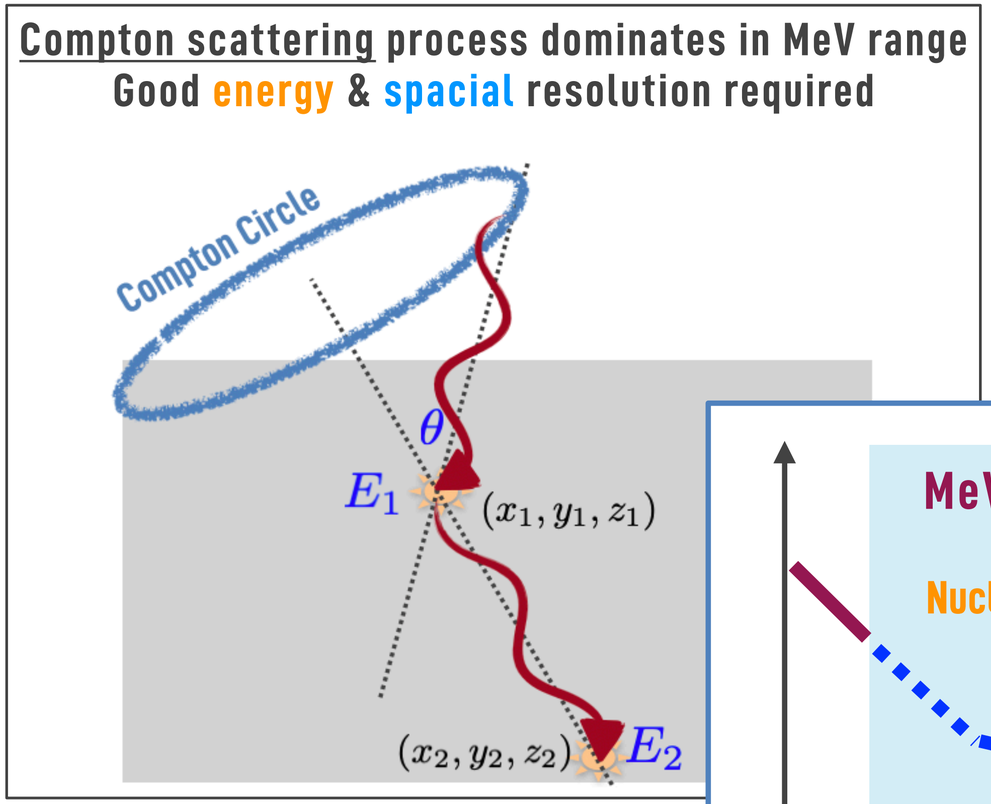
GRAMS First Paper: (1901.03430, Astropart. Phys)

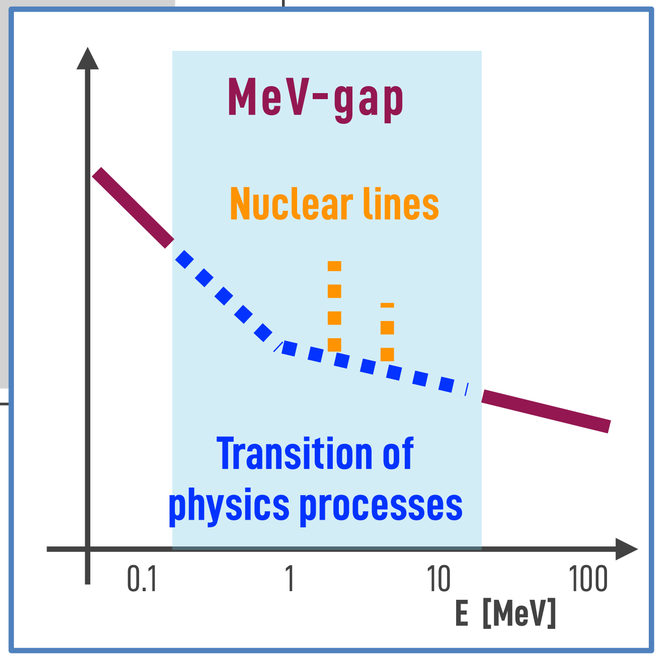
Snowmass-2021 LOI: arXiv:2009.03754

GRAMS MeV Gamma-Ray Observations

"MeV Gap" = Gamma-rays in MeV region poorly explored







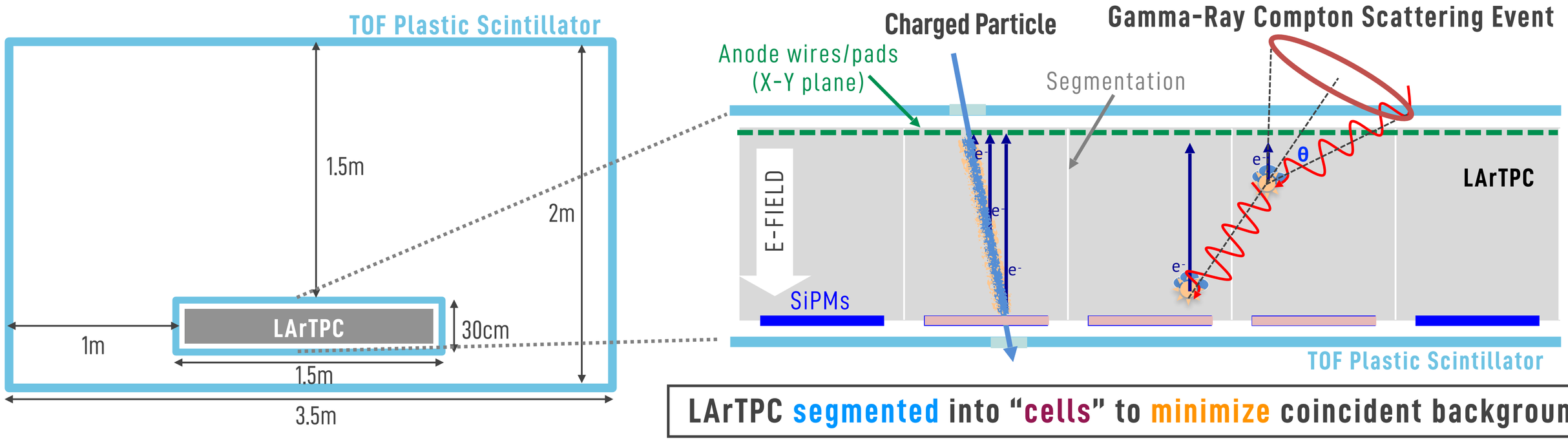
MeV gamma-ray spectrum/lines

- Physics processes/nucleosynthesis
- Multi-messenger astronomy
- Indirect dark matter searches/PBH searches

GRAMS Detector Design

LArTPC detector surrounded by plastic scintillators
LArTPC measures scintillation light and ionization electron

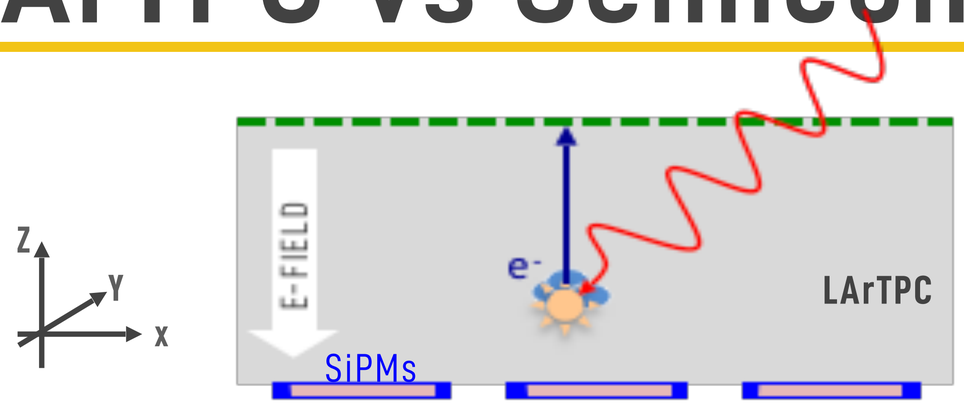
	Antimatter	Gamma Rays
Plastic Scintillators	Time of Flight to measure velocity	VETO Counter to reject charged particles
LArTPC	Particle Tracker, Calorimeter	Compton Camera, Calorimeter

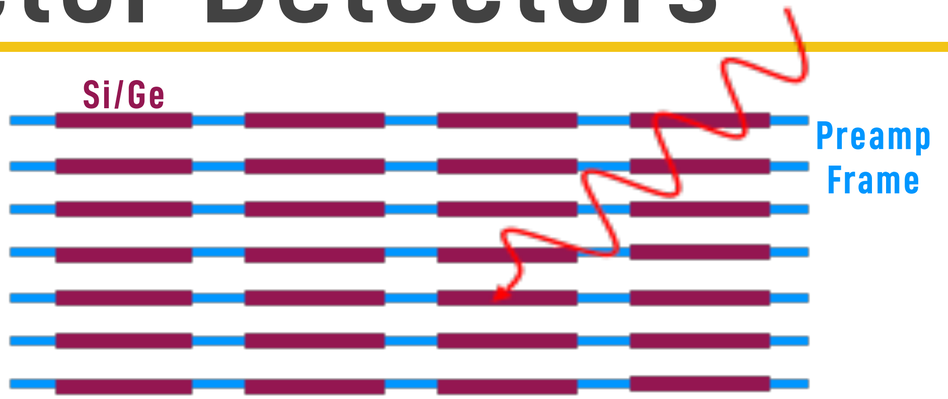


LArTPC segmented into "cells" to minimize coincident background

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

LArTPC vs Semiconductor Detectors

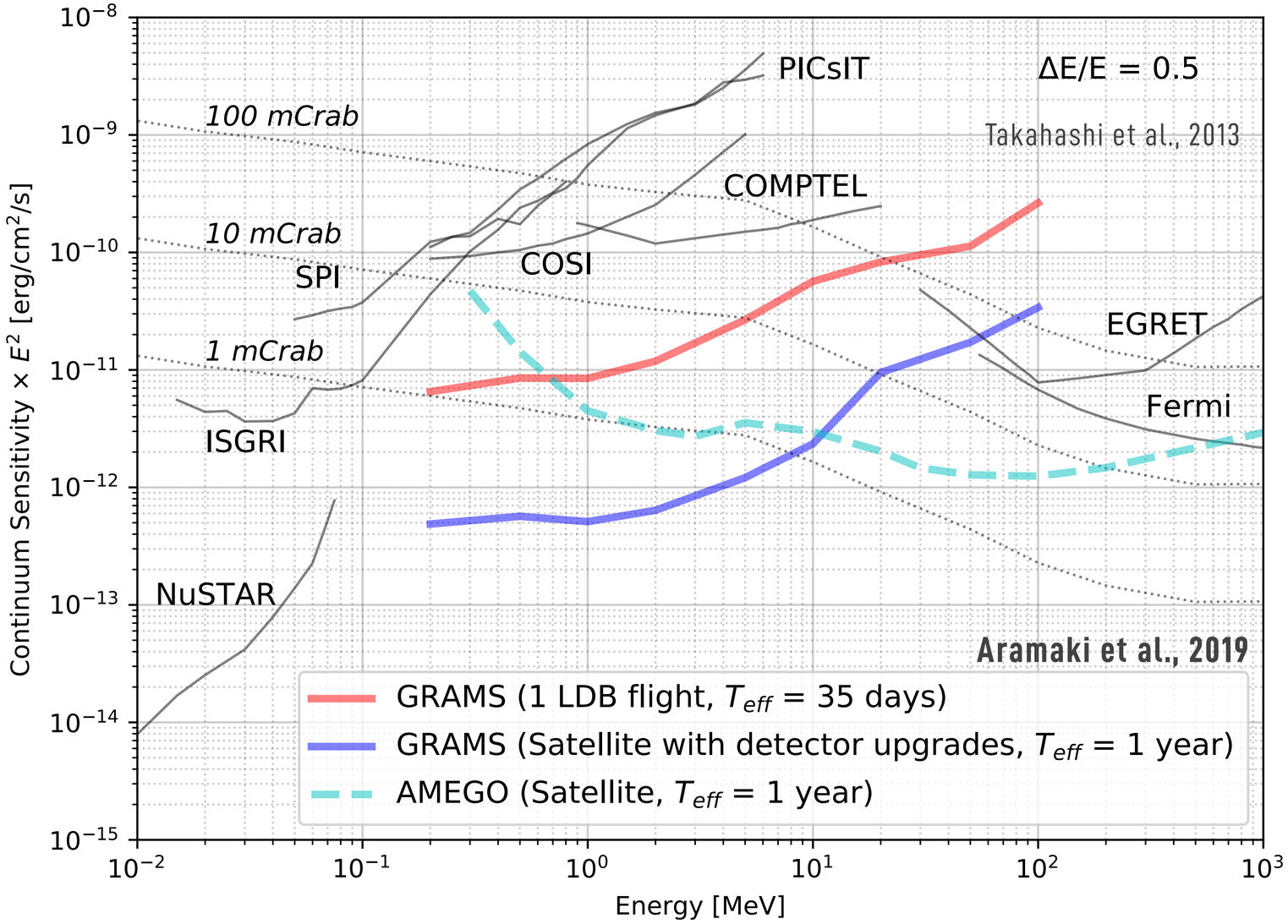




	LArTPC	Semiconductor Detector (Ge/Si)
ρ (g/cm^3)	1.4	2.3/5.3
$T_{operation}$	~80K	~240K/~80K
Cost	**$**	$$$
Signals	scintillation light + Ionization electrons	electrons, holes
X, Y Positions	wires on anode plane (X-Y)	double-sided strips
Z position	from drift time	from layer #
# of Layers	**1 layer**	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 can be easily expandable to a larger scale with high detection efficiency

GRAMS MeV Gamma-ray Continuum sensitivity



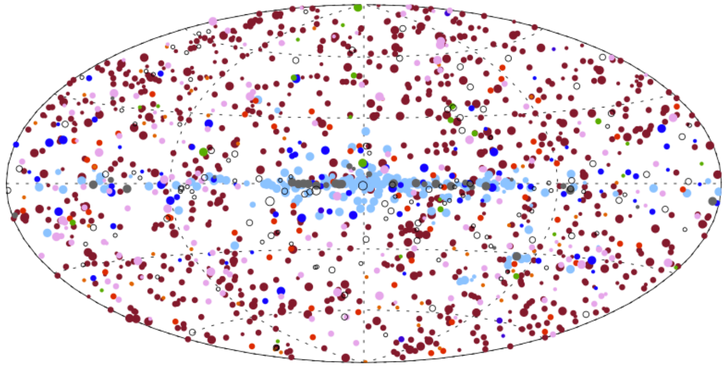
Balloon flight: an order of magnitude improved

Satellite mission: comparable to future missions

MeV Sky Map by Swift-BAT/Fermi-LAT Cross-Match

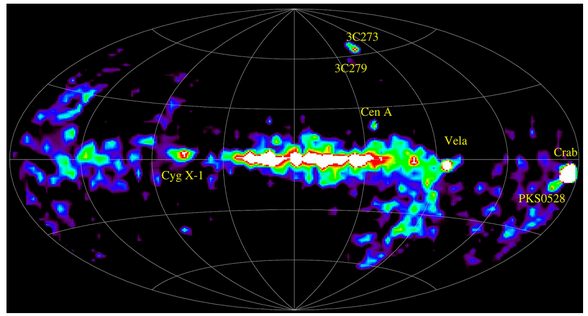
"MeV gap"

Swift-BAT 105 month catalog
1632 source in 14–195 keV
(Oh+ 2018)

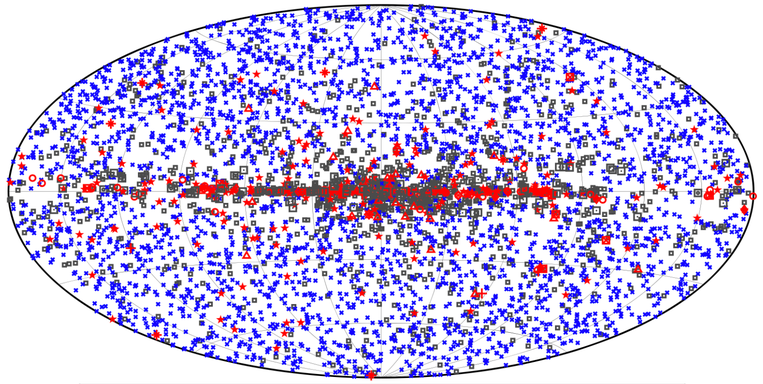


○ Unidentified ● Unknown AGN ● Seyfert Galaxies ● CVs/Stars ● X-ray Binaries
● LINER ● Galaxy Clusters ● Beamed AGN ● Pulsars/SNR

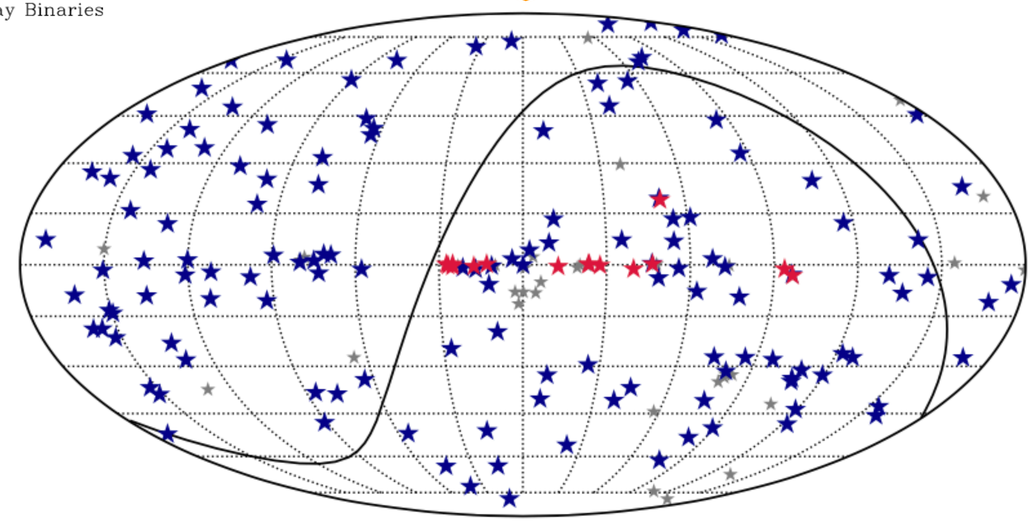
COMPTEL catalog
32 steady sources in 1–30 MeV
(Strong et al. 1999)



Fermi-LAT 10-yr catalog
5788 source in 50 MeV–1 TeV
(Ballet+ 2020)



▫ No association ▪ Possible association with SNR or PWN ▪ AGN
★ Pulsar △ Globular cluster ✦ Starburst Galaxy ♦ PWN
⊠ Binary + Galaxy ○ SNR ✸ Nova
✷ Star-forming region ▫ Unclassified source



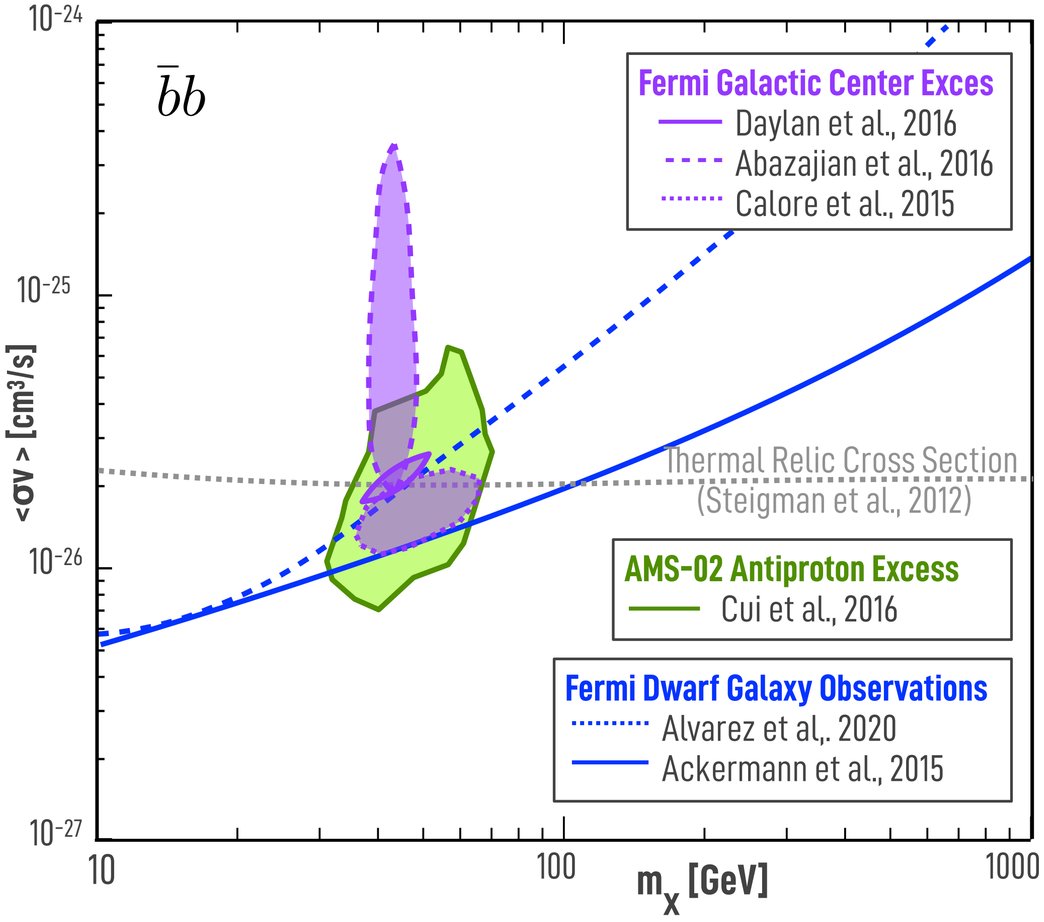
★ Falsely matched
★ Point sources
★ Extended sources

151 sources are firmly matched
Tsuji et al., submitted

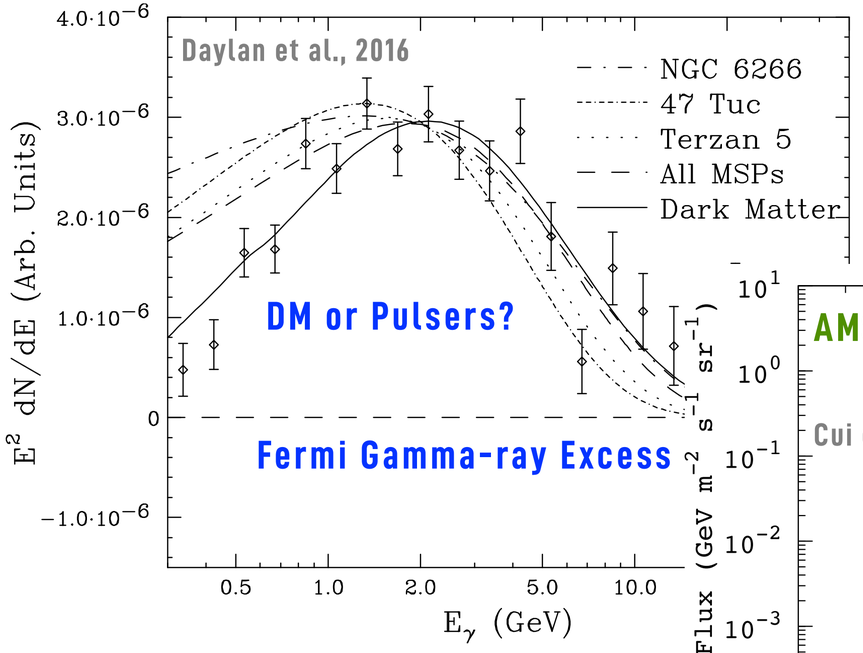
See Naomi Tsuji's poster (DM/CR/Catalogs-3 session) for details

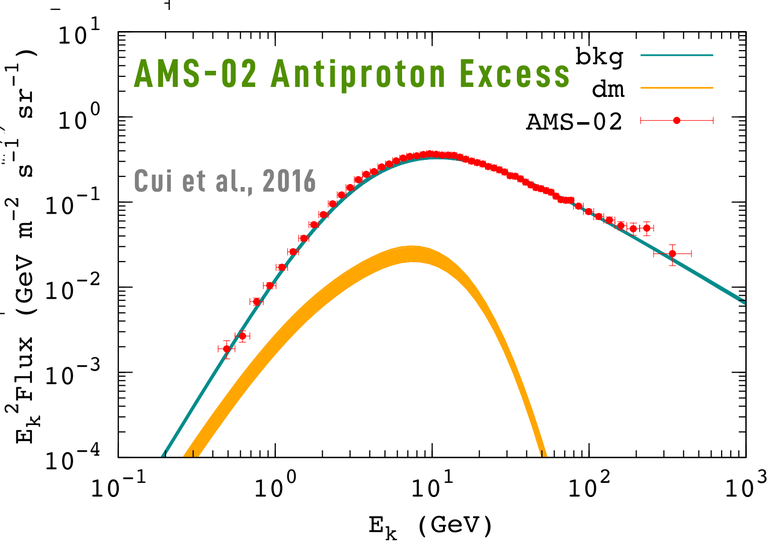
Fermi and AMS-02 Results

Possible DM signature in FERMI GCE and AMS-02 antiproton excess?
AMS-02 detected antiheliums?



How do we validate these results?



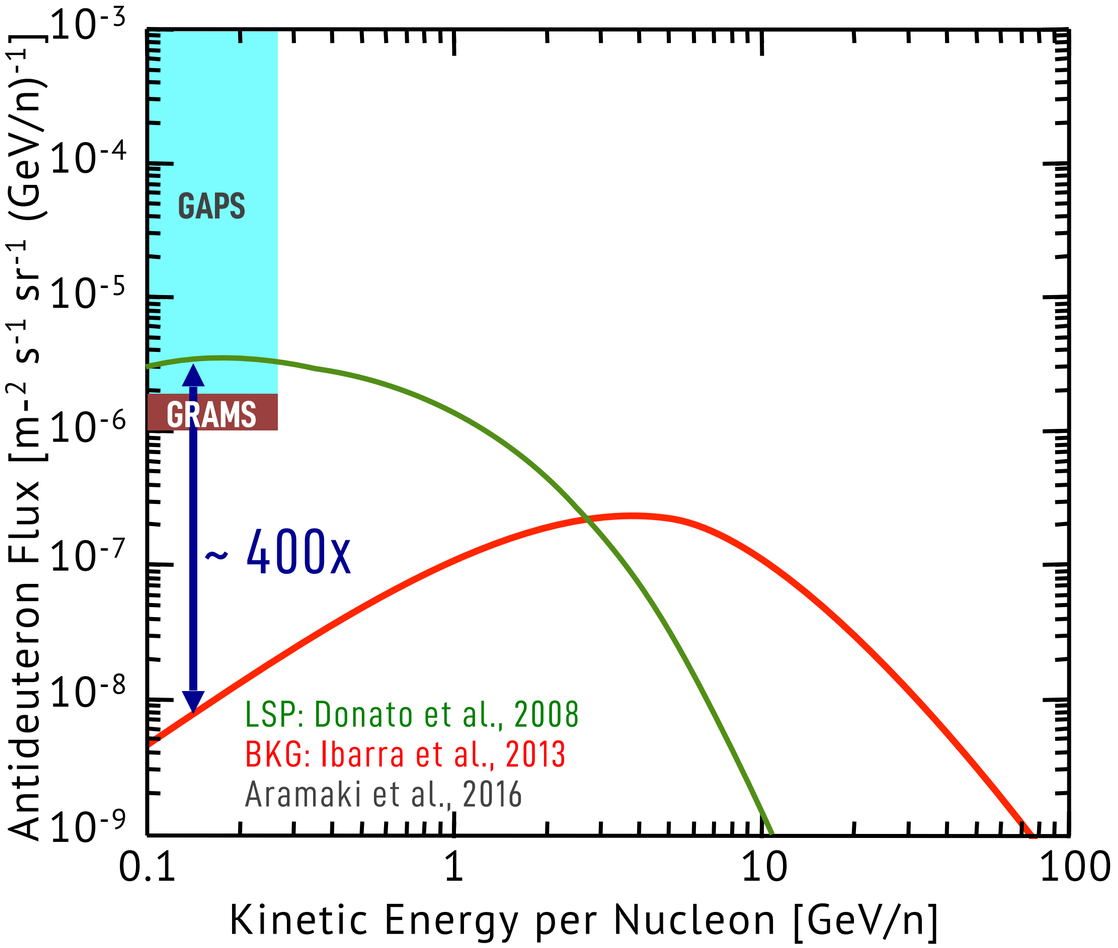


Difficult to verify DM signatures due to background/uncertainty

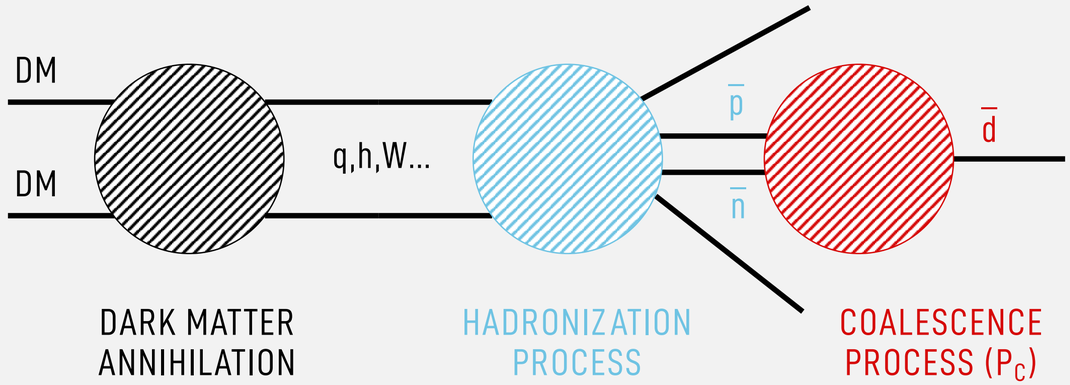
A new approach/experiment is crucial to investigate these results

Why Antideutetrons?

Background-free DM Search at low-energy region



PRIMARY FLUX = DM ANNIHILATION/DECAY



SECONDARY FLUX = COSMIC RAY INTERACTION

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

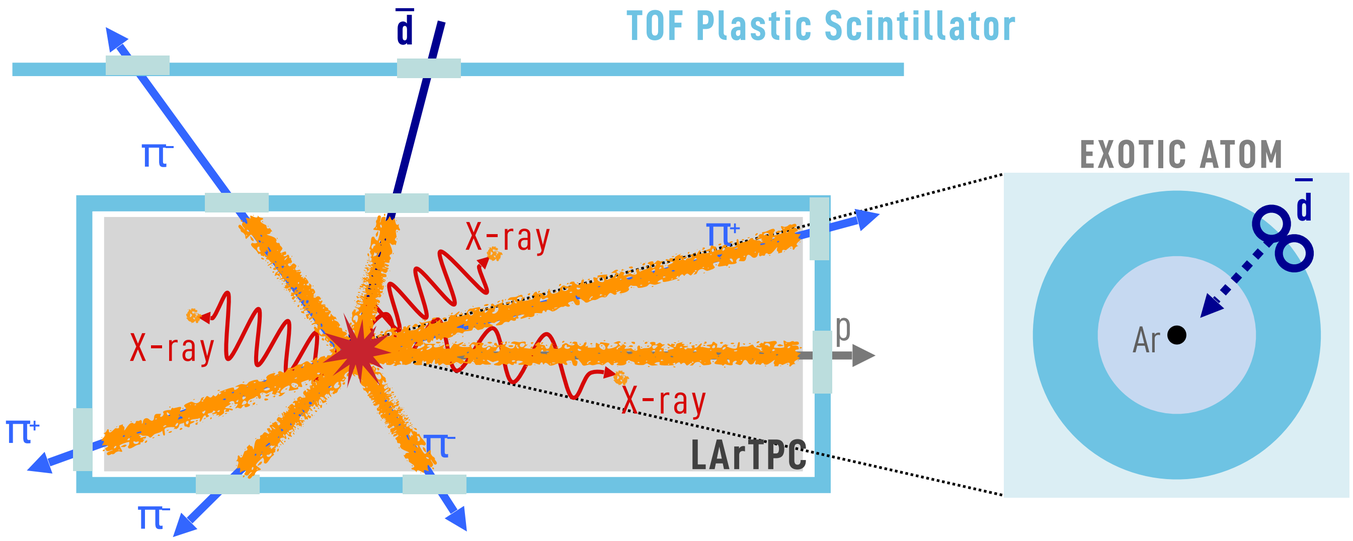
$\bar{d}$

GAPS first science flight from Antarctic in 2022/2023

GRAMS: next generation mission

GRAMS Antimatter Detection Concept

Plastic Scintillators: TOF, LArTPC: 3D particle tracker/calorimeter
Measure atomic X-rays and annihilation products

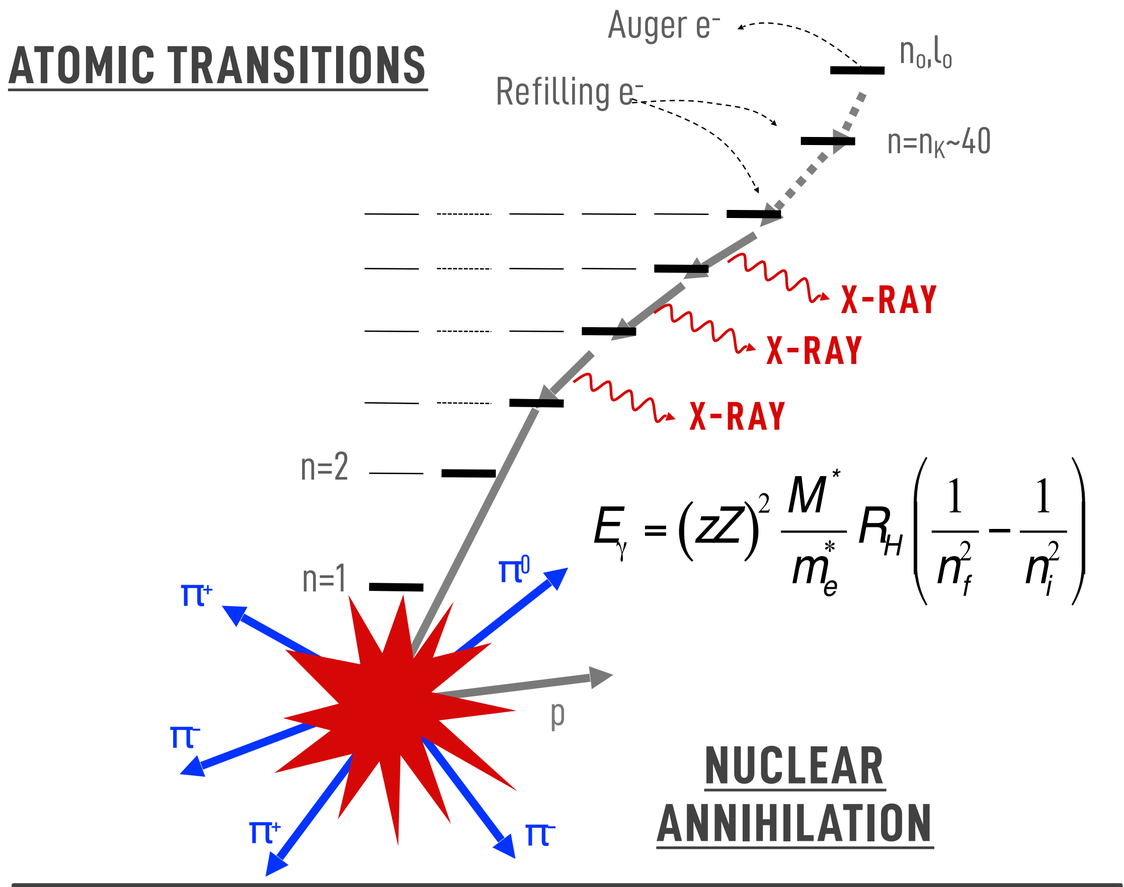


A time of flight (TOF) system tags candidate events and records velocity

The antiparticle slows down & stops, forming an excited exotic atom

De-excitation X-rays provide signature

Annihilation products provide additional background suppression

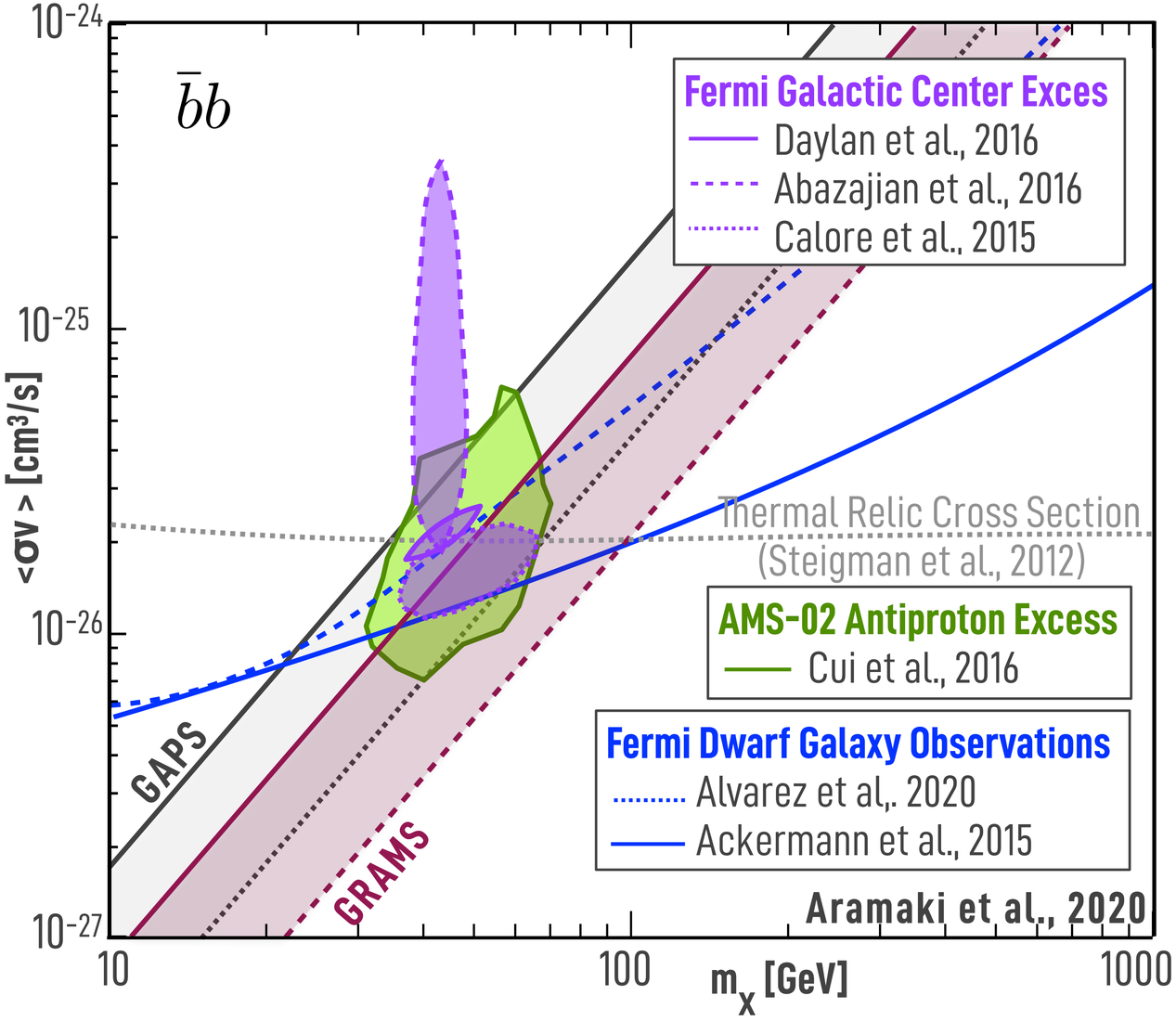


$$E_\gamma = (zZ)^2 \frac{M^*}{m_e^*} R_H \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

LArTPC (almost no dead volume) provides
- Excellent 3D particle tracking capability
- High particle detection efficiency

GRAMS Sensitivity in DM Parameter Space

Strong tensions with Fermi GCE/dSphs and AMS-02 results



GRAMS can extensively explore DM parameter space and Fermi/AMS-02 results

Timeline

R&D FOR PROOF OF CONCEPT - Present

- Validate **detection concept** with a small-scale prototype detector
- Develop **event reconstruction techniques**

Analysis started with gamma-ray calibration data at ANKOK (Waseda U) LArTPC
Building a prototype detector (MiniGRAMS) at Northeastern University

FIRST BALLOON FLIGHT - IN 5-10 YEARS

- MeV gamma-ray observations focusing on **bright objects,** nuclear lines
- Indirect DM search with antimatter

SATELLITE MISSION - IN > 10+ YEARS

- **All sky survey** in the MeV energy domain
- Antimatter-based (including **antihelium**) DM search

Summary

- GRAMS is a proposed next-generation mission to target both **gamma-ray observations** in the poorly explored **MeV energy band** and **indirect dark matter searches with antimatter**.
- 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.
- GRAMS antideutron detection can provide essentially **background-free dark matter signatures** while investigating and validating the possible dark matter detection indicated in **Fermi GCE** and **AMS-02 antiproton excess**.
- The project is currently in the **R&D phase** to demonstrate the detection concept using the **gamma-ray calibration data** taken at the ANKOK dark matter search experiment.
- **A small-scale prototype detector**, **MiniGRAMS,** is currently being built at Northeastern University.

GRAMS Collaboration

WE ARE EXPANDING OUR COLLABORATION! PLEASE JOIN US!

Barnard College
Reshmi Mukherjee

Columbia University
Georgia Karagiorgi, William Seligman

MIT
Kerstin Perez

Northeastern University
Tsuguo Aramaki, Jon Leyva, Jiancheng Zeng

Osaka University/RIKEN
Yoshiyuki Inoue, Hiroki Yoneda, Naomi Tsuji

Oak Ridge National Lab
Lorenzo Fabris

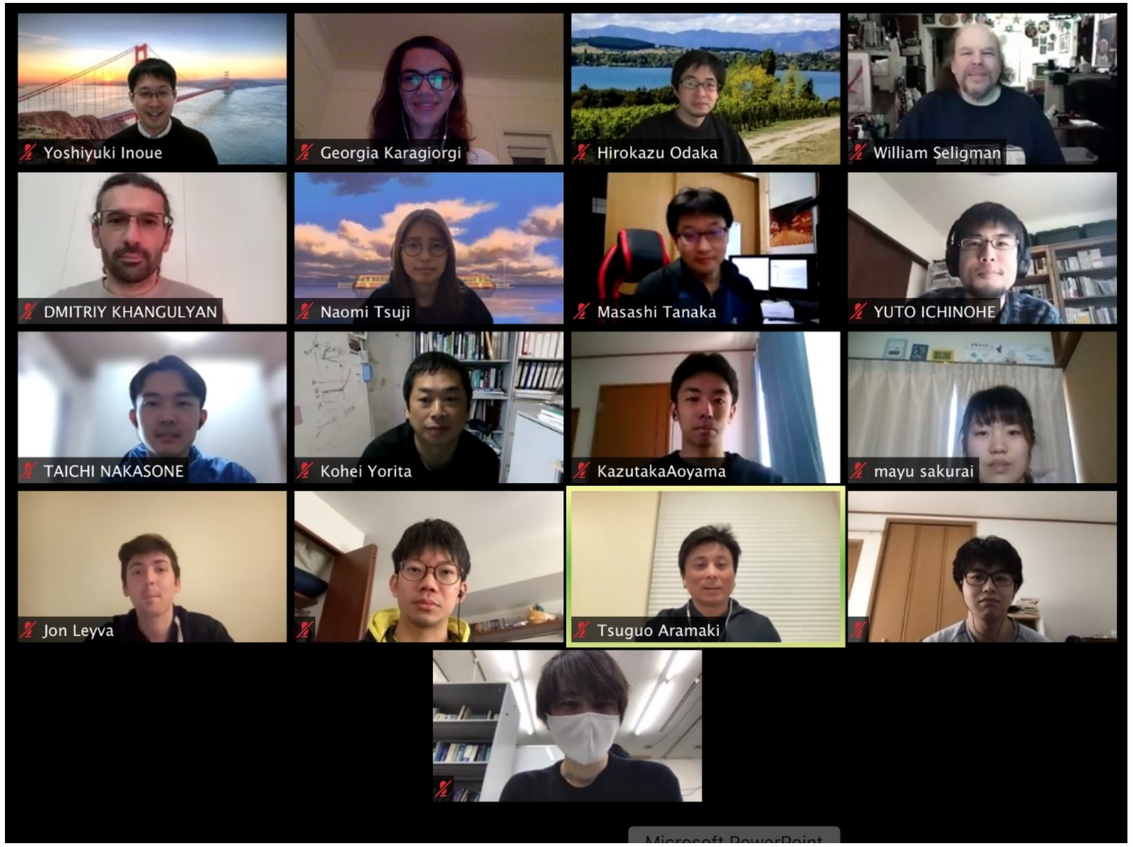
Rikkyo University
Yuto Ichinohe, Dmitry Khangulyan

UT Arlington
Jonathan Asaadi

University of Tokyo
Hirokazu Odaka, Satoshi Takashima

Waseda University
Kohei Yorita, Masashi Tanaka, Masato Kimura
Kazutaka Aoyama, Taichi Nakasone, Mayu Sakurai

3rd GRAMS Collaboration Meeting, Feb 2021



Theoretical support/advice
Brian Metzger (Columbia U), Meng-Ru Wu (Academia Sinica)