Search for Dark Matter with the GAPS balloon-borne experiment

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on behalf of the GAPS Collaboration

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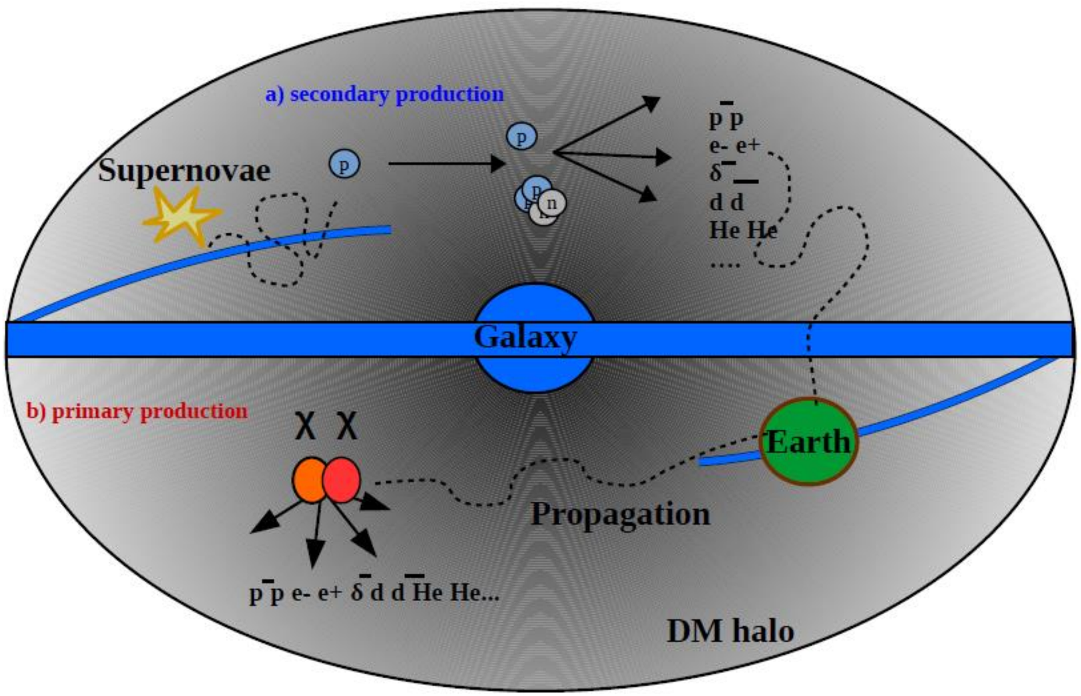
Indirect Search for Dark Matter 1/2

- Dark Matter (DM) decay/annihilation in the Galaxy → antiprotons, antideuterons, antihelium nuclei

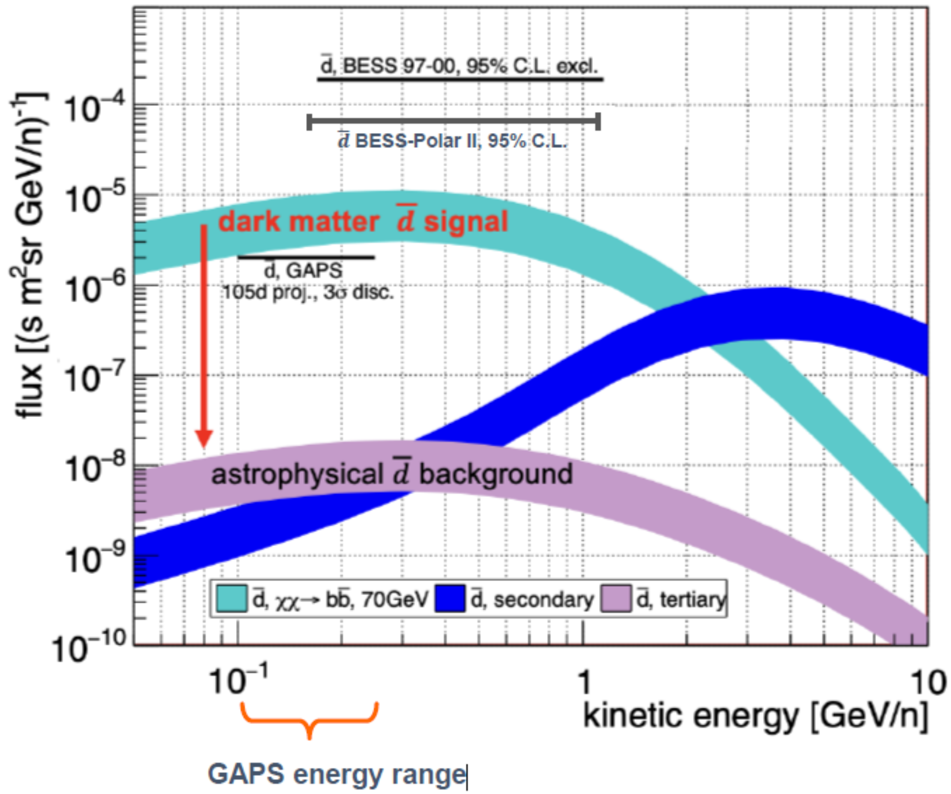


- Positron: AMS-02, PAMELA, Fermi-LAT…
- Gamma-Ray: Fermi-LAT, CTAO,…
- Neutrino: IceCube, ANTARES, KM3NET…
- Antiproton: AMS-02, GAPS…
- Antideuteron: AMS-02, GAPS …
- Antihelium3: AMS-02, GAPS …

Indirect Search for Dark Matter 2/2

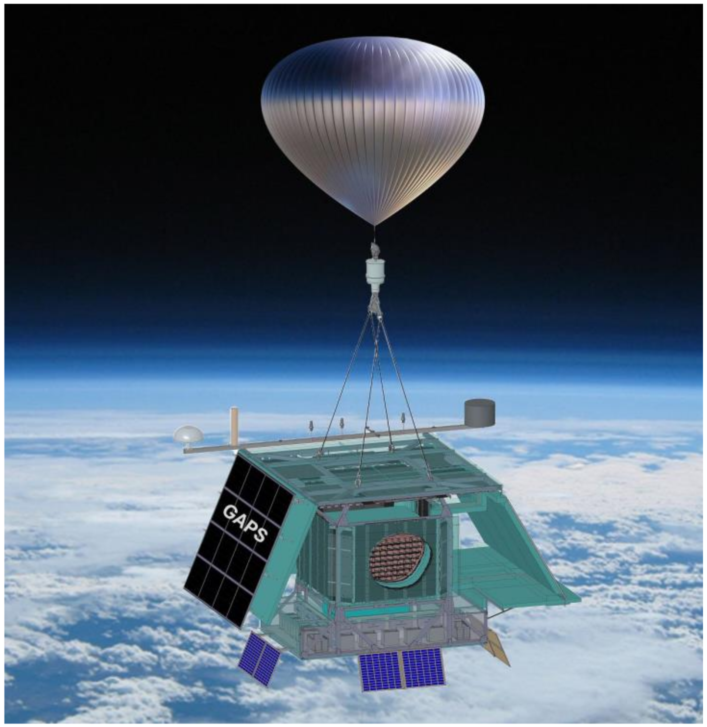
- GAPS antideuterons: generic new physics signature with essentially **zero conventional astrophysical background** → sensitivity will be ~2 orders of magnitude below the current best limits.

Cosmic-ray antinuclei as messengers of new physics: status and outlook for the new decade: JCAP08 (2020) 035



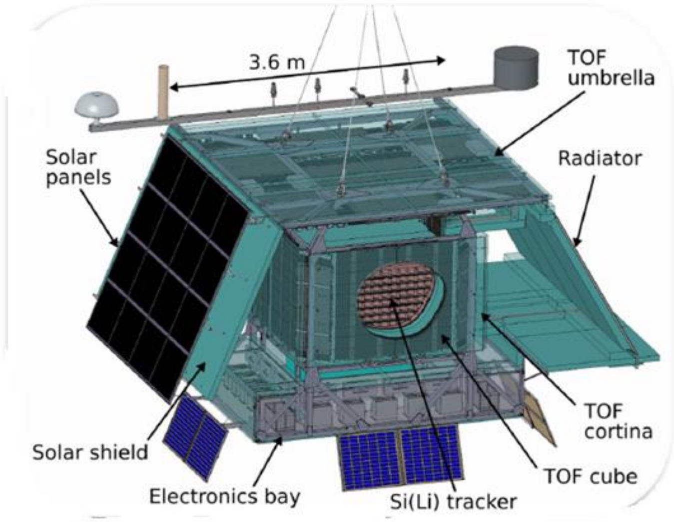
Martucci M

GAPS: Mission Overview



- **GAPS (General AntiParticle Spectrometer)** is a long-duration balloon-borne experiment
- First Antarctic balloon flight scheduled for late-2024, and two follow-up flights already planned
- Unique sensitivity to low-energy cosmic antinuclei using novel exotic atom decay signatures: **X-rays + charged particles**
- Scientific Goals:
    - Low-energy ($E \lesssim 0.25$ GeV/n) **antideuteron** as signature of new physics → can probe many DM models
    - High statistics measurement of low-energy **antiproton**
    - Leading sensitivity to **antihelium3**

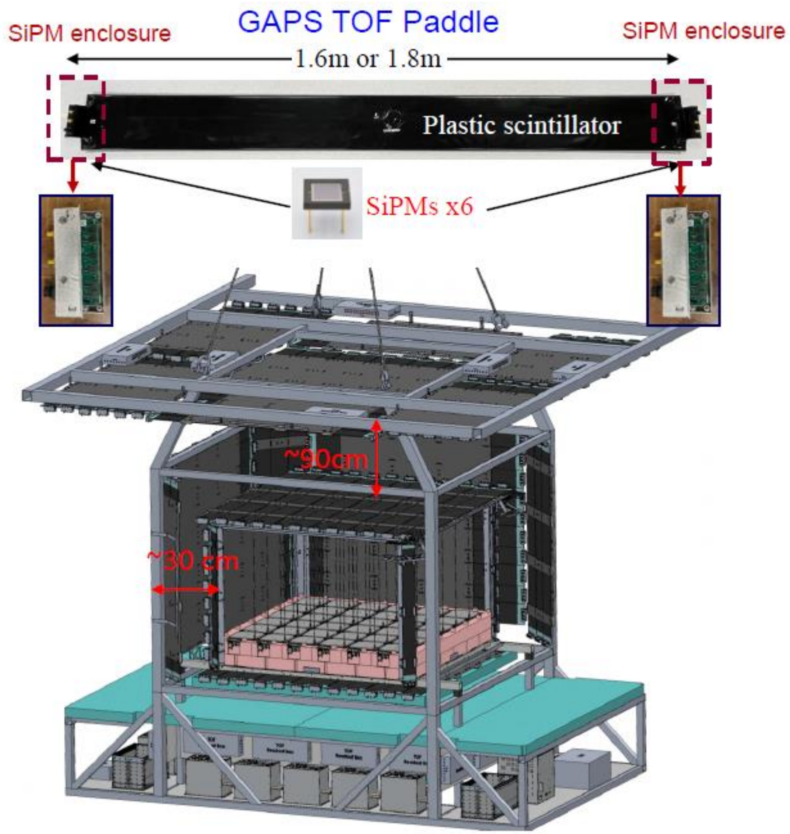
GAPS Detector



- **Time-of-Flight (ToF)**
  - Near-hermetic containment of tracker
  - Velocity, trajectory and *dE/dx*
  - High-speed trigger and veto
- **Si(Li) Tracker**
  - Target to capture light nuclei ≲0.25 GeV/*n*
  - Tracking system for primary and secondary hadrons
  - Spectrometer for de-excitation X-rays
- **Thermal System**
  - Oscillating Heating Pipe for tracker cooling
- **Support instrumentation**
  - Electronics, Solar panels, Gondola mechanics

GAPS size: ~3×3×2 m
GAPS mass: ~2.5 ton
GAPS power consumption: ~1.4 kW

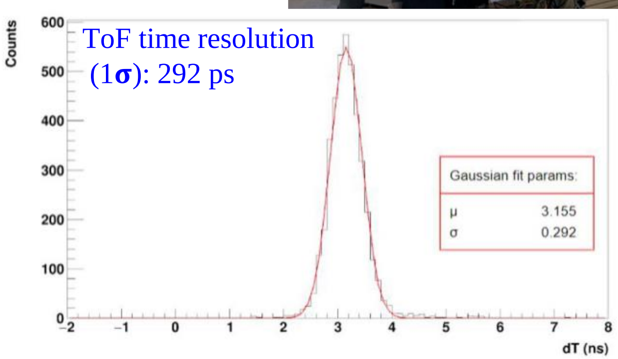
GAPS Detector: ToF 1/2



Bird et al., Proc. ICRC (2019), Quinn et al., Proc. ICRC (2019) Quinn et al., Proc. ICRC (2021), Feldman et al., Proc. ICRC (2023)

- Time-of-Flight plastic scintillator covers ~15 m^2 inner cube and ~25 m^2 outer layer (top umbrella + side cortina)
- It is designed to measure velocity of incoming particles + fast trigger to Si(Li) tracker
- It is built to reach a time resolution $\lesssim$400 ps
- ToF Trigger & Veto → accept ~80% of antinuclei and suppress overall event rate <500 Hz

GAPS Detector: ToF 2/2



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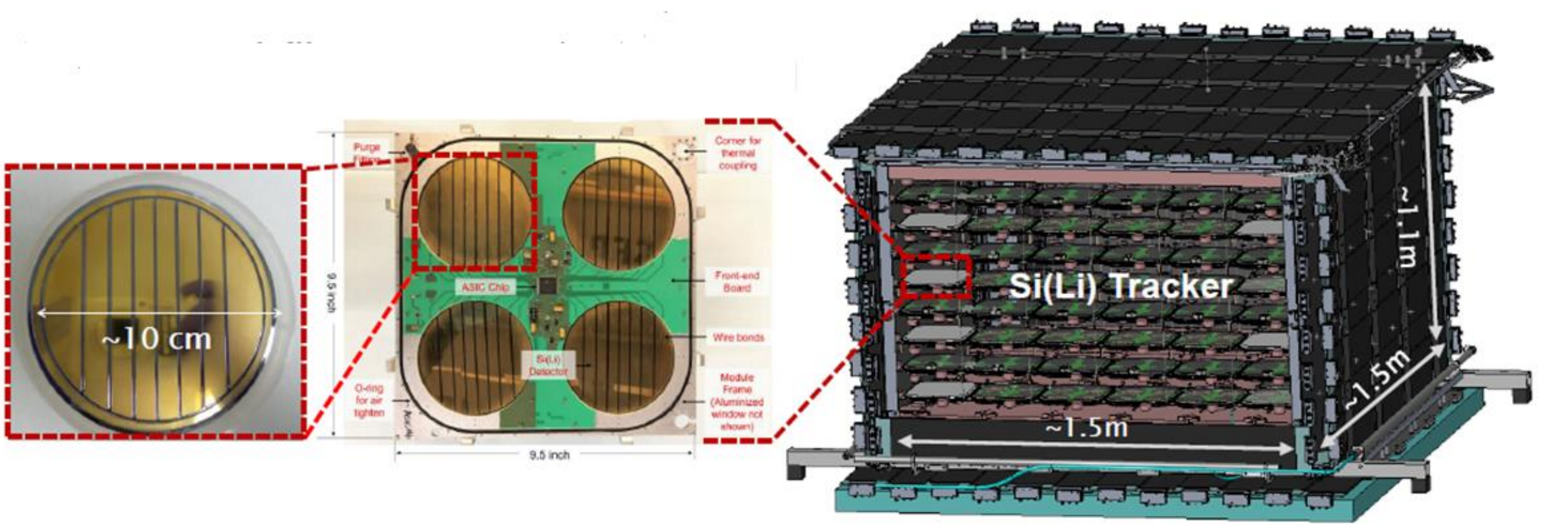
GAPS Detector: Si(Li) Tracker 1/2

- The tracker is composed of ~1100 custom lithium-drifted silicon – Si(Li) detectors resulting in an overall cubic structure of ~1.5 x 1.5 x 1.1 m
- These Si(Li) units are sub-divided within 10 layers

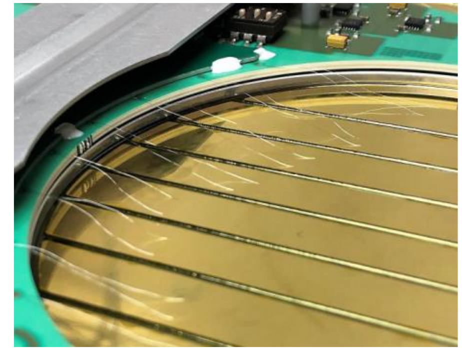


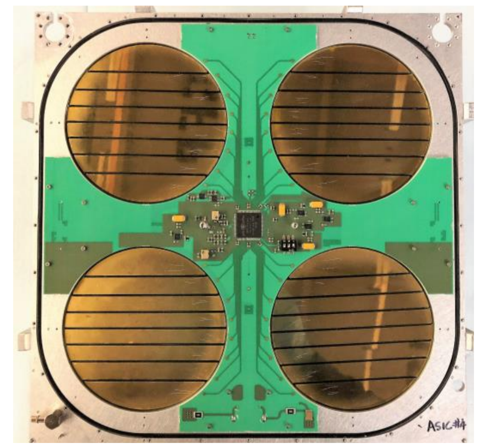
Perez et al., NIM A (2018) , Kozai et al., NIM A (2019) , Rogers et al., JINST (2019) , Saffold et al., NIM A (2021) , Kozai et al., NIM A (2022) , Xiao et al., IEEE 70 (2023)

GAPS Detector: Si(Li) Tracker 2/2

- GAPS custom ASIC (SLIDER-32) has:
  - 180 nm CMOS technology
  - 32 channels and 11-bit ADC
  - 4 keV resolution in 10-100 keV
  - <10% resolution up to 100 MeV → low power consumption

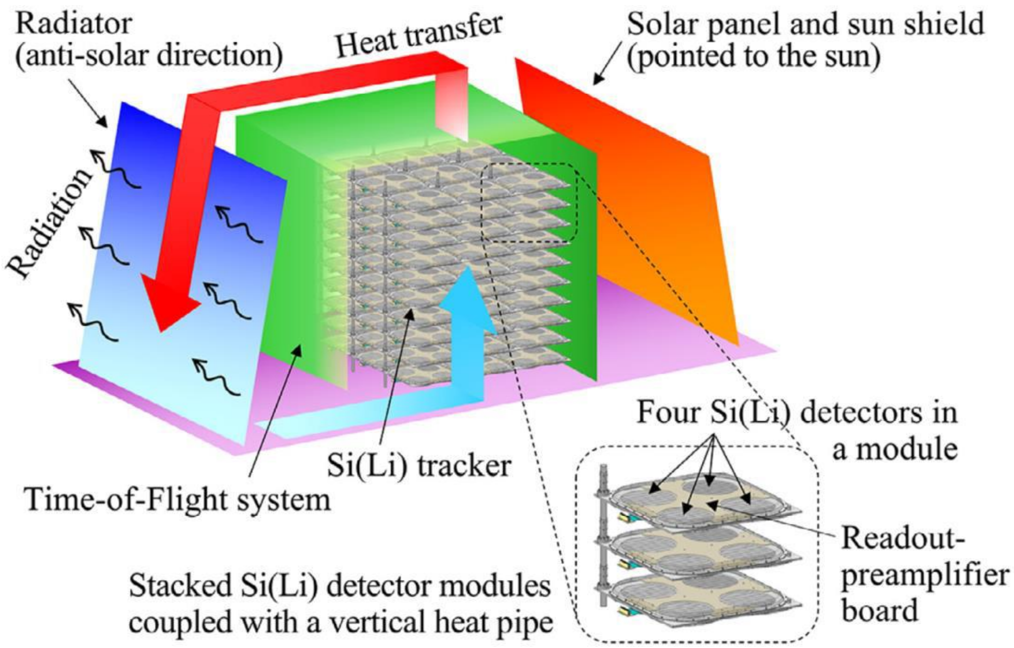
- Wire bounds connect detector strips to ASIC Front-End board, consequently resulting in reduced mass budget, a lower power budget and an improved track reconstruction





Scotti et al., Proc. (ICRC2019), Manghisoni et al., IEEE 62 (2015), Manghisoni et al., IEEE 68 (2021), Manghisoni et al., IEEE 71 (2023)

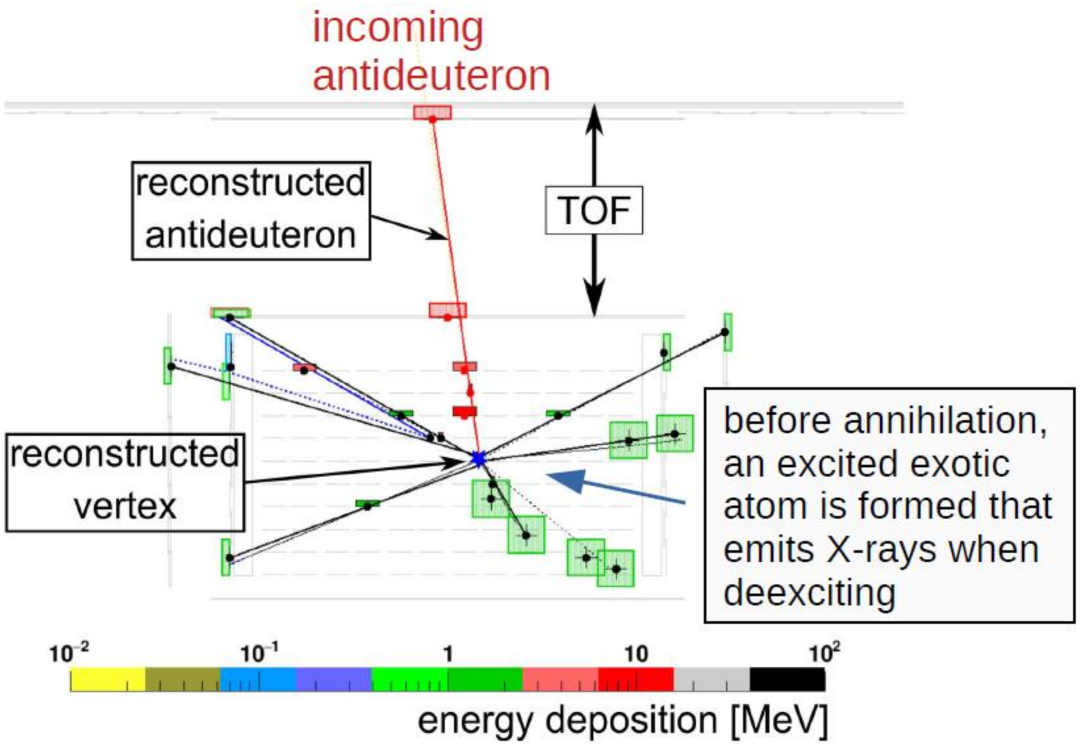
GAPS Detector: Thermal System



- Oscillating Heating Pipe (OHP) is composed of a small capillary metal tube system filled with a phase-changing refrigeration liquid
- Vapor bubbles form in the fluid → expand in warm and contract in cool sections
- Rapid expansion and contraction create thermo-contraction hydrodynamic waves that transport heat
- It is semi-passive → no active pump system is required
- Developed at JAXA/ISA, first prototype flown in 2012

GAPS Detection Technique

- Antiparticle slows down, stops and forms an excited exotic atom
- Hydrogen-like exotic atom de-excites via characteristic X-ray transitions depending on antiparticle mass
- Nuclear annihilation with characteristic number of annihilation products
- Tracker must act like a target, a particle-tracking system and a X-ray spectrometer



The Science of GAPS 1/2

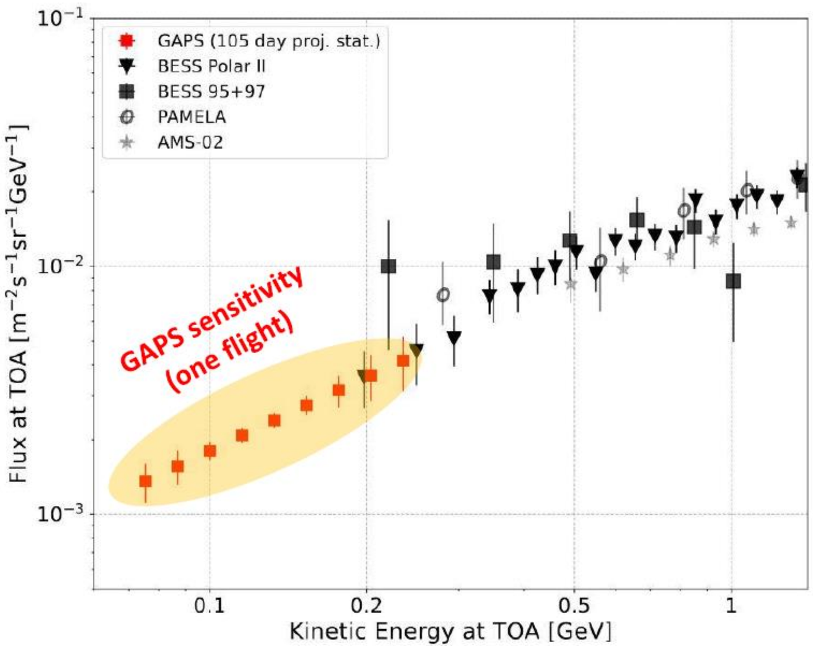
- ~500 antiprotons (≲0.25 GeV/n) for each GAPS flight
  - BESS : 29 at ~0.2 GeV
  - PAMELA: 7 at ~0.25 GeV

antiprotons

- Validate the GAPS novel antinuclei identification technologies and reduce systematic uncertainties for antideuteron search

- Probe a wide variety of models like
  - Generic 70-GeV WIMP annihilation explaining AMS-02 antiproton excess and GC γ-ray excess
  - DM gravitino decay
  - Extra dimensions
  - Dark photons
  - Heavy DM models with Sommerfeld enhancement

Rogers, F. (GAPS), Astropart. Phys. 102791 (2022)



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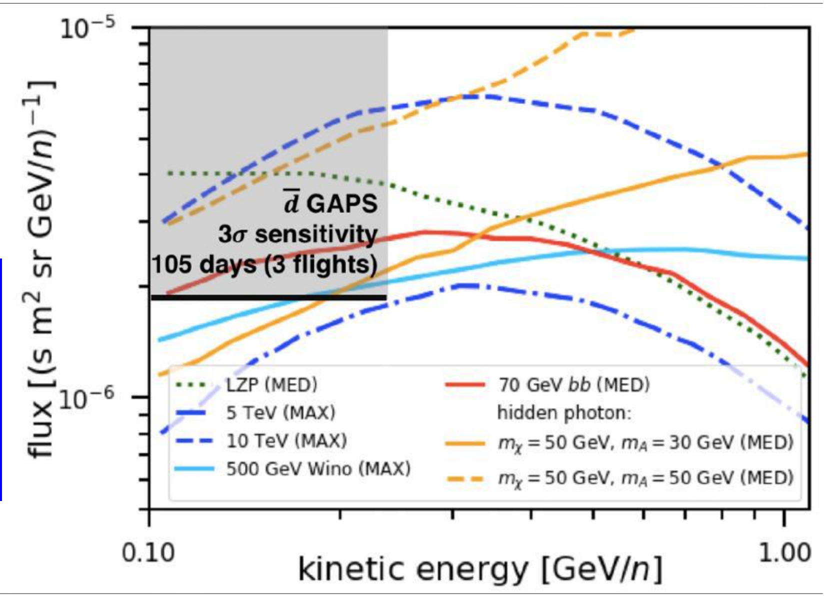
antideuterons



Integration & Testing 1/2

SSL @Berkeley: Half 2022 - May 2023

- Tracker integration
- Partial ToF integration
- Tracker testing and calibration

NTS @Los Angeles: June 2023

- TVAC validated the comprehensive thermal model for the instrument
- The instrument subsystem operated consistent from the coldest to the hottest temperatures expected.
- Muon signal recorder on all sub-units of the tracker

Nevis Labs @Columbia: January - May 2024

- Extensive muon runs
- Tracker calibration
- ToF testing, trigger

Integration & Testing 2/2

CSBF @Palestine July – August 2024

- E&M compatibility + Hang tests
- Muon runs
- Full integration and **shipment to McMurdo for launch**

Summary

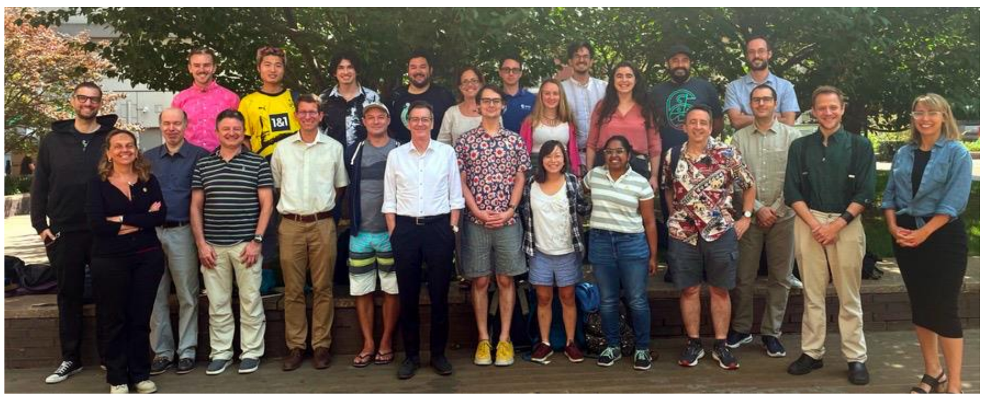
- GAPS is the first experiment optimized specifically for low-energy ($\lesssim$0.25 GeV/n) cosmic antiprotons, antideuterons, and antihelium

- GAPS aims to deliver:

  - First-time detection of cosmic antideuterons with an unprecedented sensitivity ~2 orders of magnitude below the current best limits, “smoking-gun” DM signature.
  - Precision antiproton measurement in an unexplored energy range
  - Open sensitivity to low-energy cosmic anti-He3

- GAPS is completing the on-ground commissioning, towards the first science flight from the Antarctica this year

GAPS Collaboration



In-person collaboration meeting at Columbia in Aug, 2023