The GAPS experiment: a cosmic ray antinuclei detector for dark matter signatures

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On behalf of the GAPS collaboration

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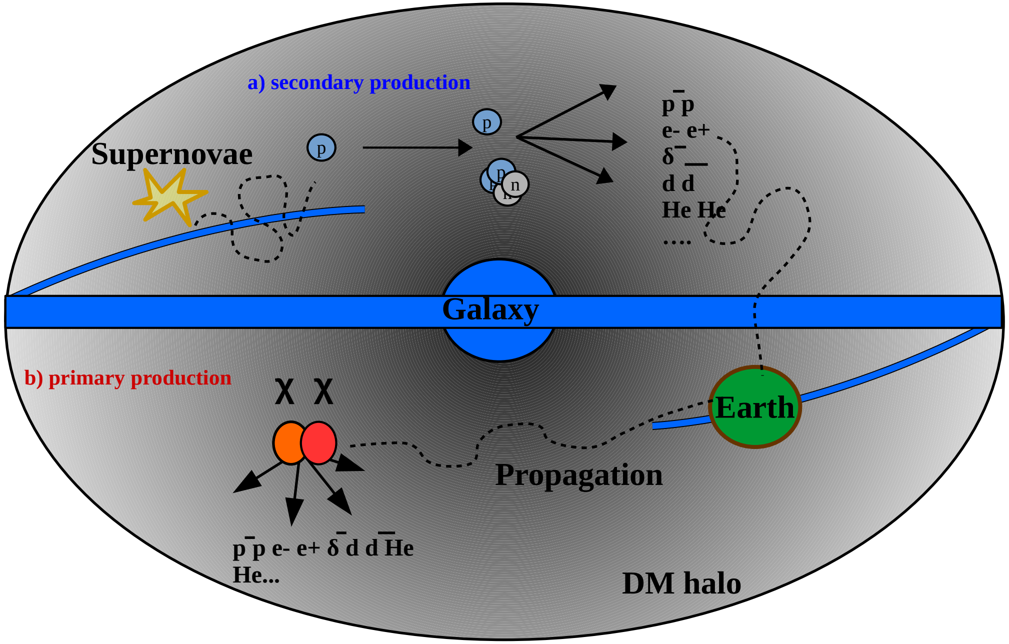
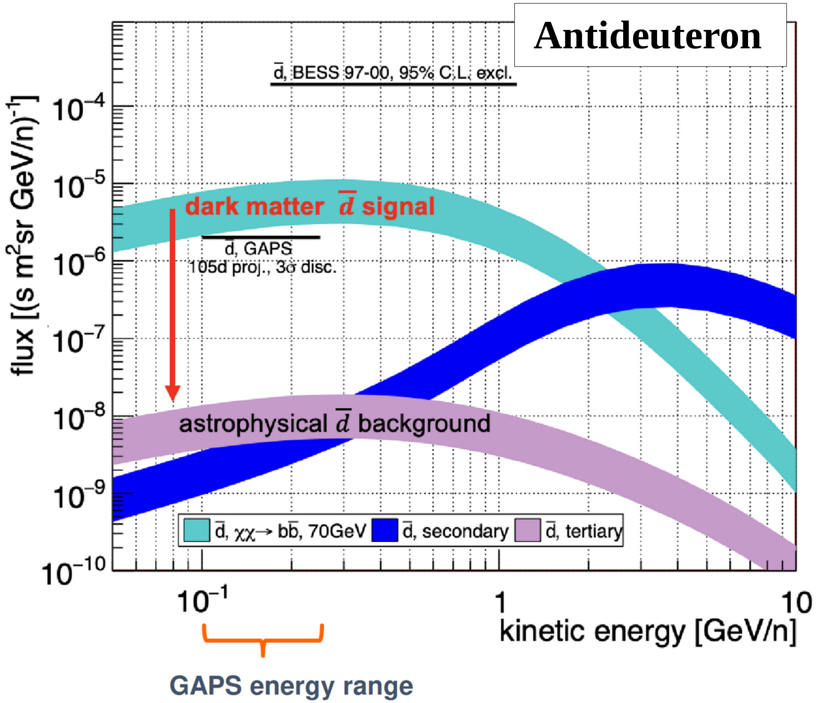
GAPS: antinuclei for dark matter search

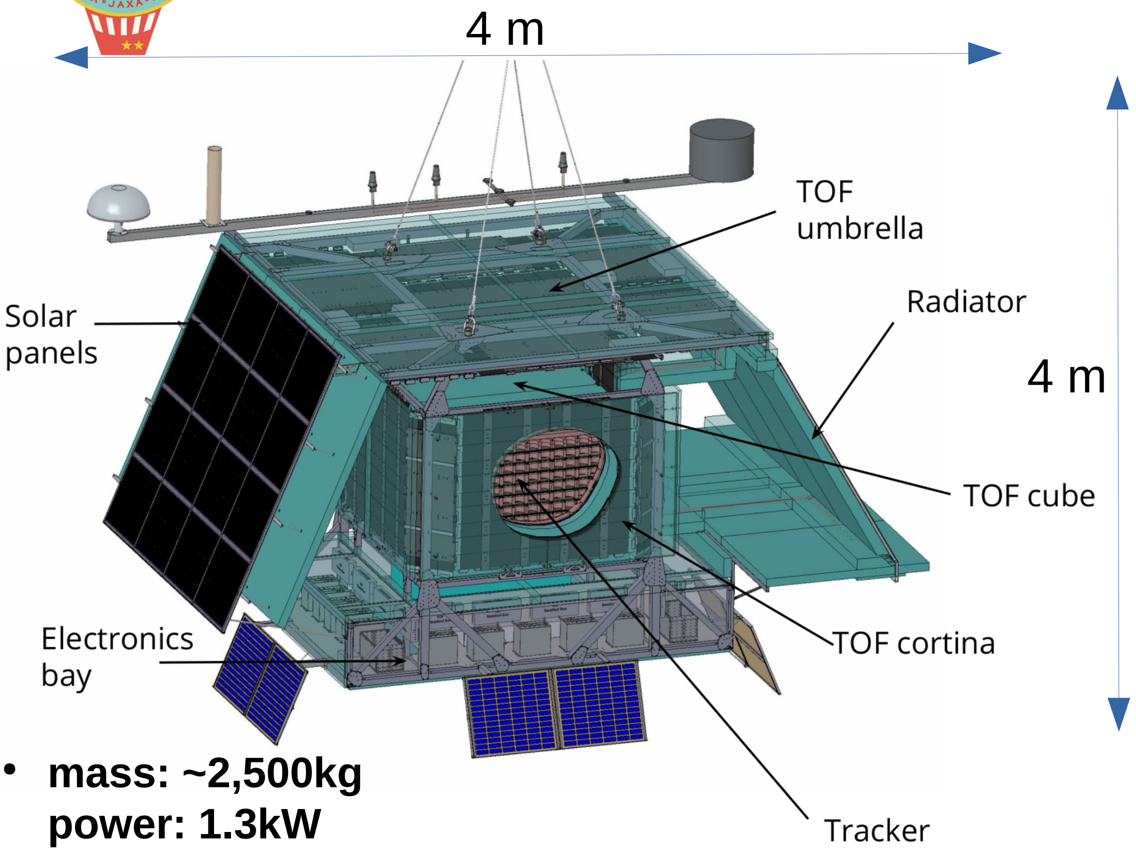
Dark matter decay/annihilation in the Galaxy → antiprotons, antideuterons, antihelium nuclei

Antideuterons and antihelium nuclei at < 250 MeV has an astrophysical background orders of magnitude lower than the signal expected from dark matter decay/annihilation





The GAPS experiment



- **mass: ~2,500kg**
  power: 1.3kW

The **G**eneral **A**nti**P**article **S**pectrometer is the first experiment dedicated and optimized for **low-energy cosmic-ray antinuclei search**

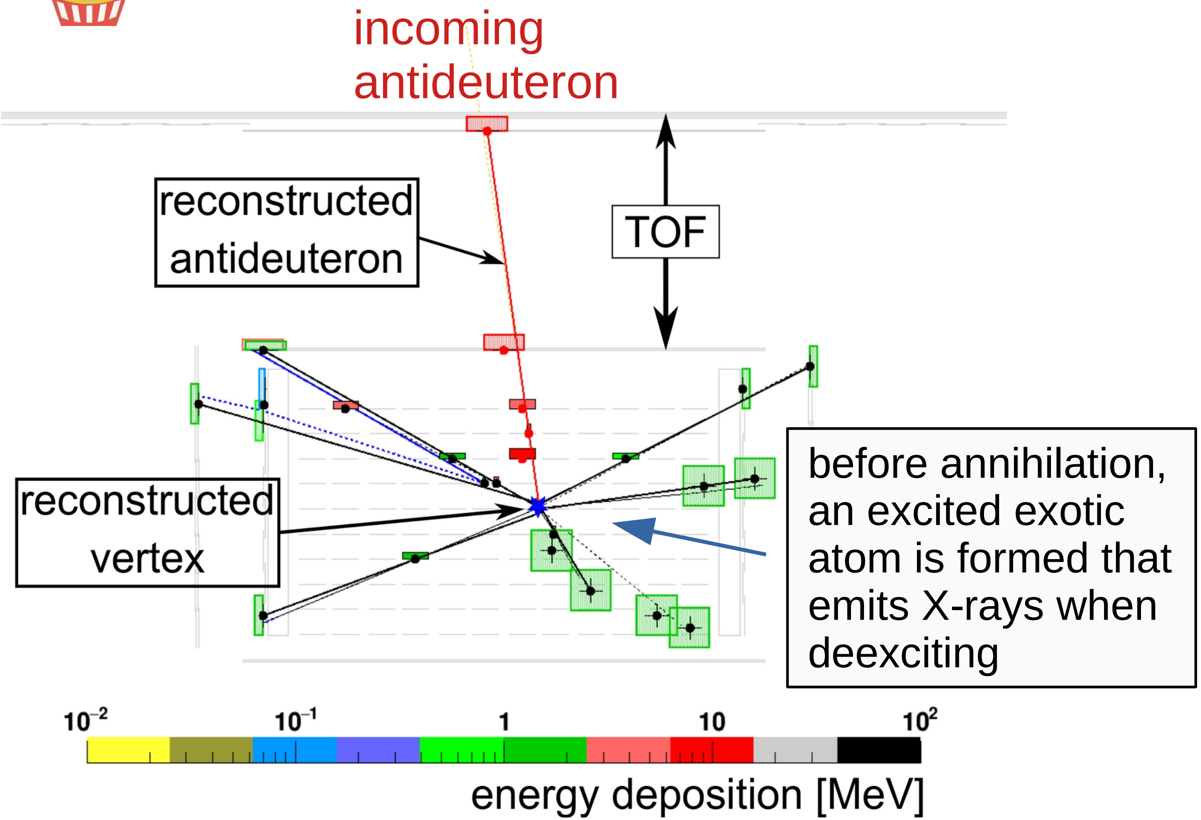
Requirements: long flight time, large acceptance, large identification power

GAPS will deliver:

- a precision antiproton measurement in an unexplored energy range <0.25 GeV/n
- antideuteron sensitivity 2 orders of magnitude below the current best limits, probing a variety of DM models across a wide mass range
- provide leading sensitivity to low-energy cosmic antihelium nuclei

GAPS is under construction, preparing for first Antarctic Long Duration Balloon flight planned for austral summer 2023

GAPS measurment principle



Antiparticle **slows down** and stops in material

Large chance for creation of an **excited exotic atom** (E_{kin}~E_{I})

Deexcitation:

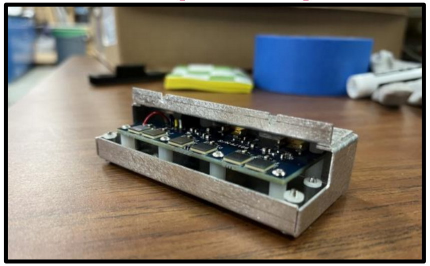
Hydrogen-like exotic atom (nucleus+antideuteron) deexcites via characteristic X-ray transitions depending on antiparticle mass

Nuclear annihilation with characteristic number of annihilation products

Time of Flight

Plastic scintillator (x160)

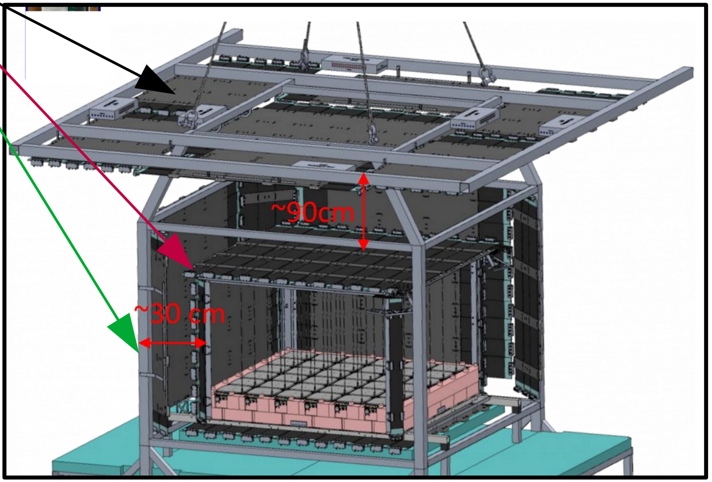
Si-PMs (x6/end)



Inner Cube

Top umbrella

Cortina



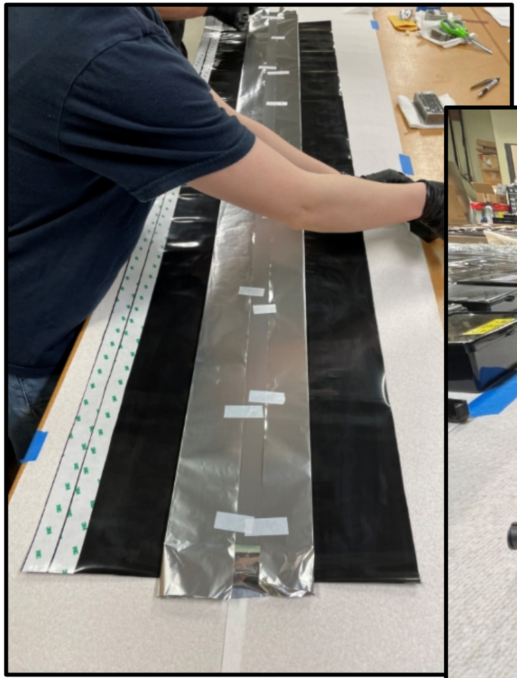
Tasks:
main trigger system, reduce data rate from few tens kHz → 500Hz
velocity measurement, energy losses

Plastic scintillator: Eljen EJ-200: 108-180 cm long, 0.6 cm thick

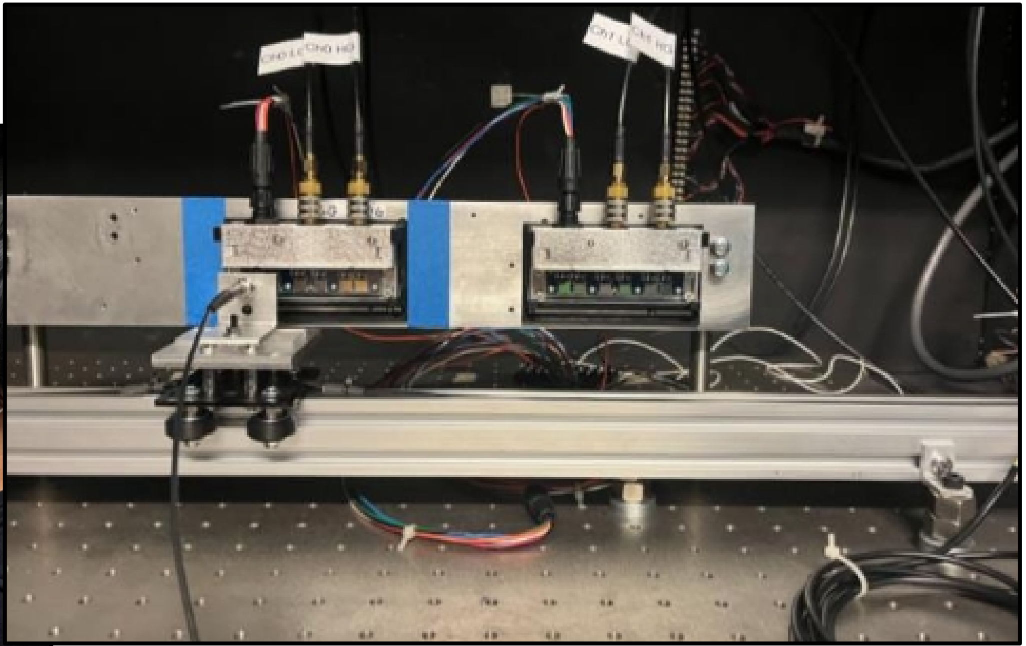
SiPM: Hamamatsu S13360-6050VE

Fast sampling with DRS4 ASIC: < 400 ps **timing resolution** end-to-end/√2 timing has been demonstrated in the lab

Time of Flight: construction



Paddle construction



SiPM Preamp Testing

Construction and tests at UCLA

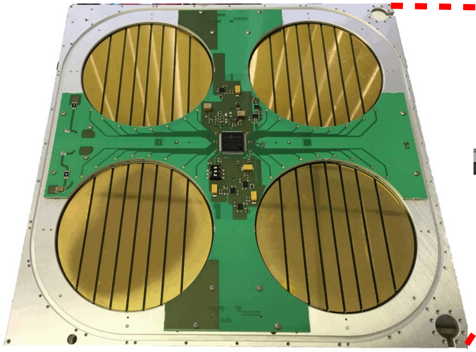
Tracker system

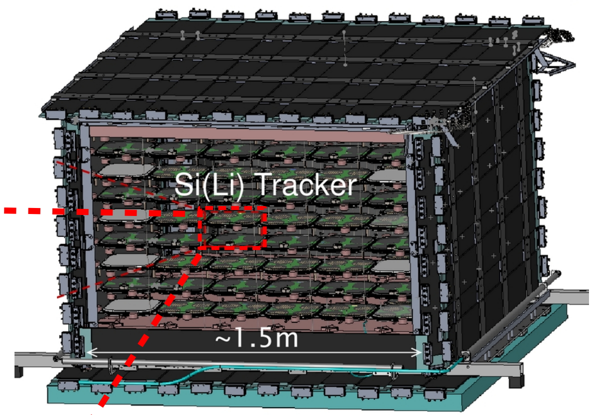
Tracker acts as target and tracking device

Lithium-drifted Silicon

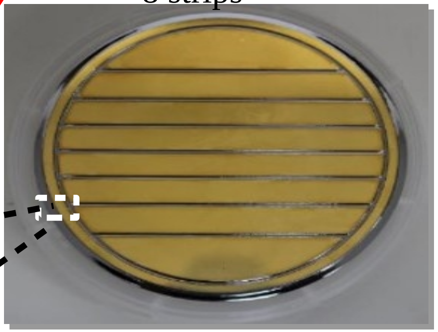
- 10 planes of cylindrical Si(Li) detectors, 2.5 mm thickness and 10 cm in diameter
- Operation at relatively high temp of -35C to -45C, cooling system will use novel OHP approach
- 1100 SiLi detectors (fully equipped 1440)
- Large dynamical range (~20keV → 100 MeV)
- <4 keV FWHM (at ~60 keV) at -37C

6x6 module each plane



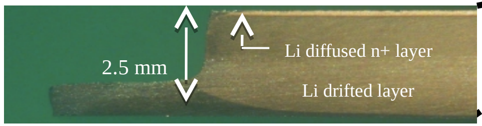


8 strips



10 cm

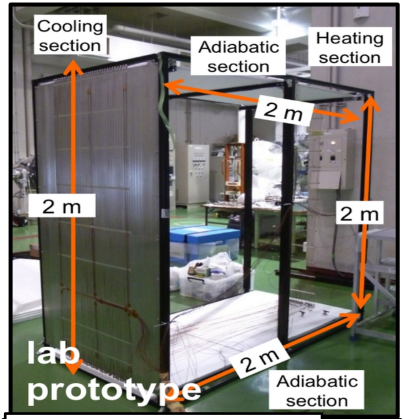
Li ions compensate impurities in boron-doped Si, creating extended thick depleted layer

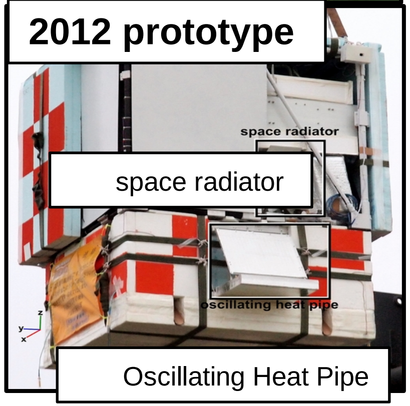


Publications:

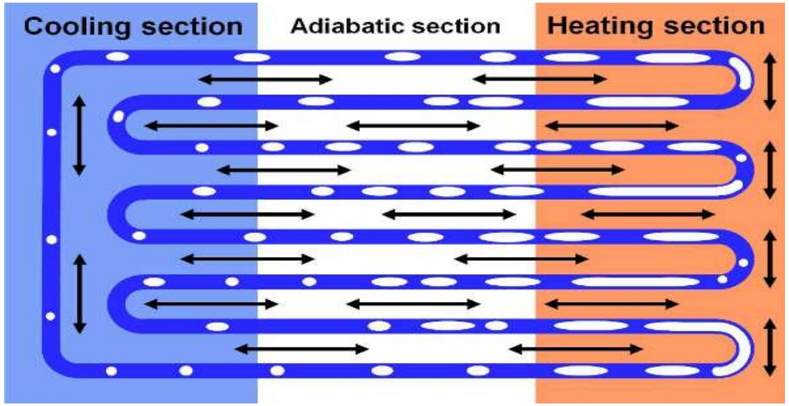
Perez et al., NIM A 905, 12 (2018)
Kozai et al., NIM A 947, 162695 (2019)
Rogers et al., JINST 14, P10009 (2019)
Saffold et al., NIM A 997, 165015 (2021)

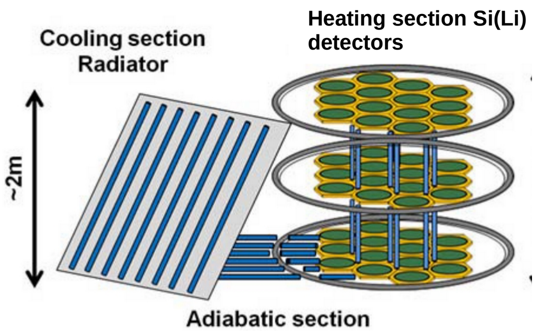
Oscillating heat pipe cooling system





Passive cooling approach developed at JAXA/ISAS:





S. Okazaki et al., J. Astr.. Instr. 3 (2014)

Small capillary metal tubes 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 creat thermo-contraction hydrodynamic waves that transport heat: no active pump system is required.

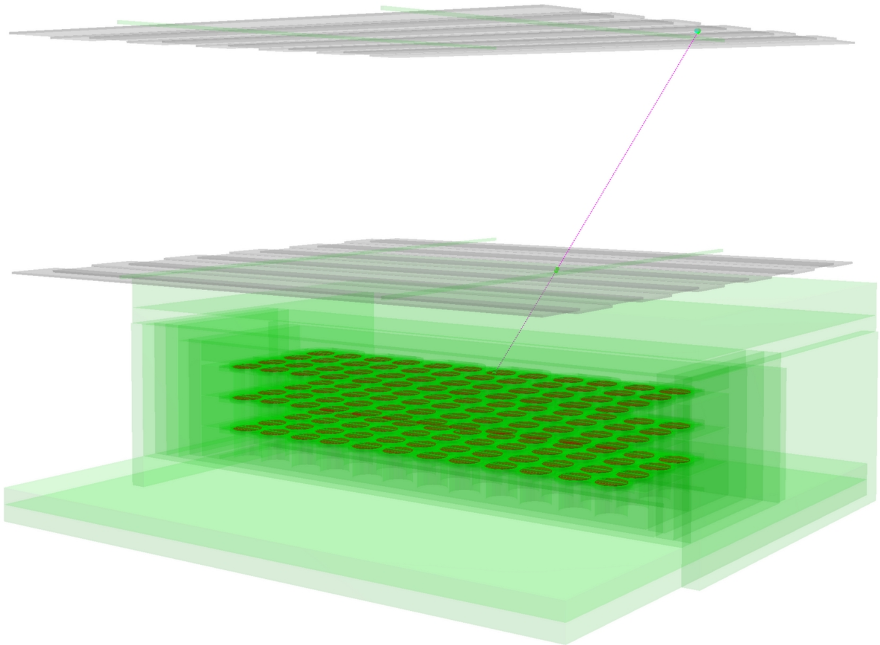
First prototype was flown in 2012 and another prototype from Ft. Summer in 2019

GAPS Functional Prototype (GFP)

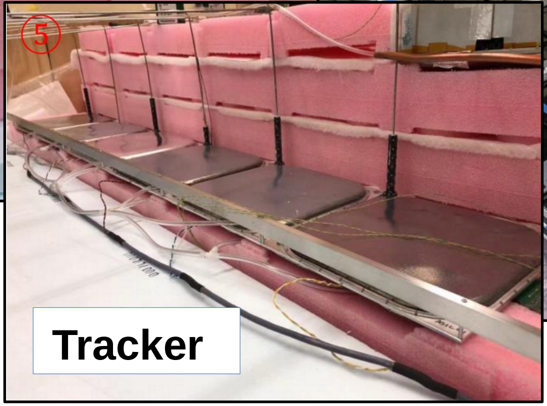
A **prototype** was built in fall 2021:

3 layers of Si(Li) tracker (36 modules):
readout with ASIC electronics
2 layers of TOF above

Test and operate all components together
Test readout chain
Collect muon data → tracking



GAPS Functional Prototype (GFP)



Acquired muon data on ground.

All tracker and ToF detectors did report data.

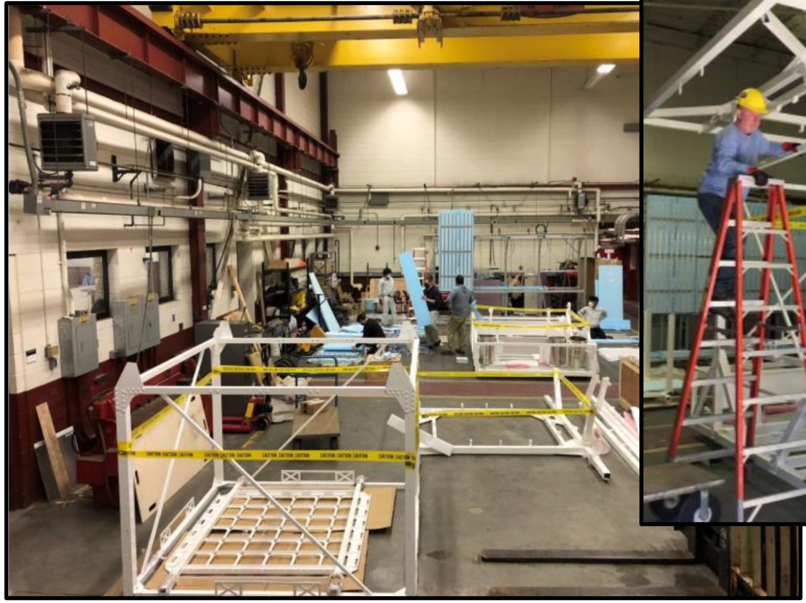
This system demonstrates for the first time all key system interfaces. Reconstruction of cosmic muon tracks demonstrates compliance with the key performance requirements, as well as verification of trigger, event building, and track reconstruction algorithms.

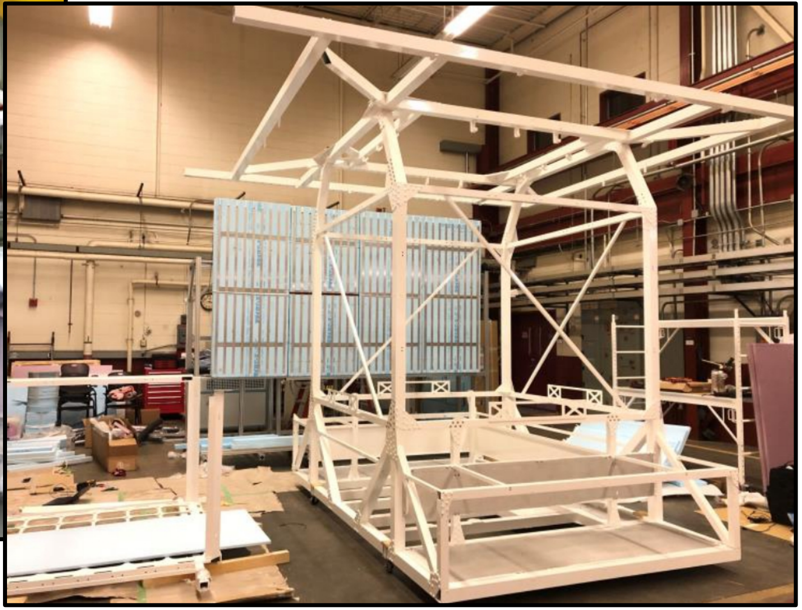
Gondola assembly

March 9th – 11th: Finished the gondola assembly,

Assembly at MIT (Bates)

total weight ~400 kg





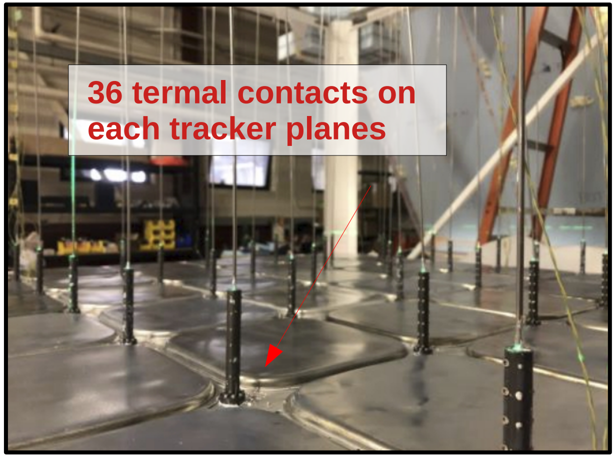
Before assembly → After assembly

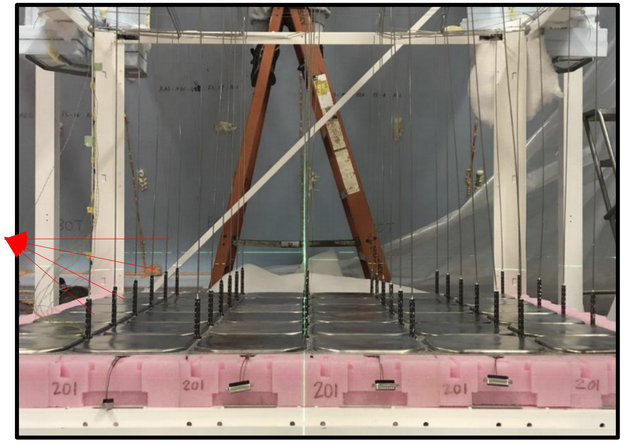
Tracker integration

The integration of the tracker is underway

Oscillating heat pipe cooling system

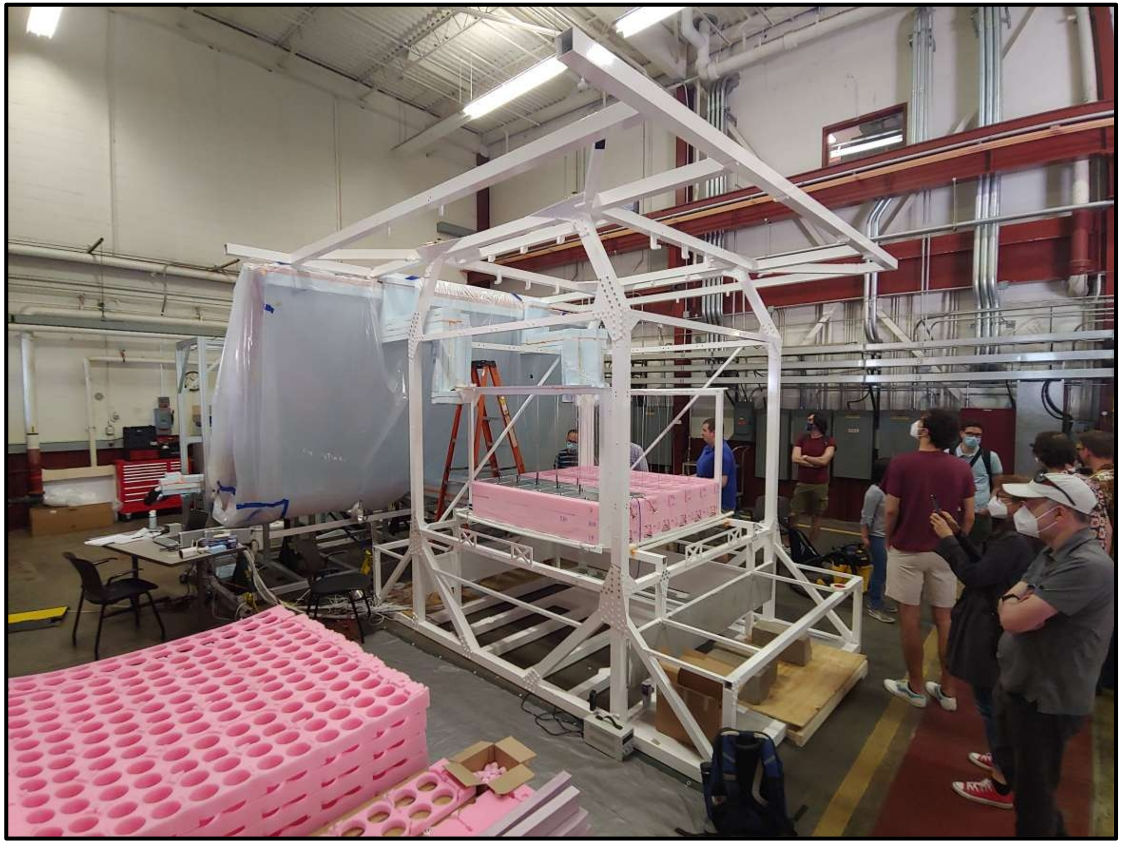
Ground cooling system + flight OHP/radiator equipment





Next steps of GAPS detector

Tracker planes integration

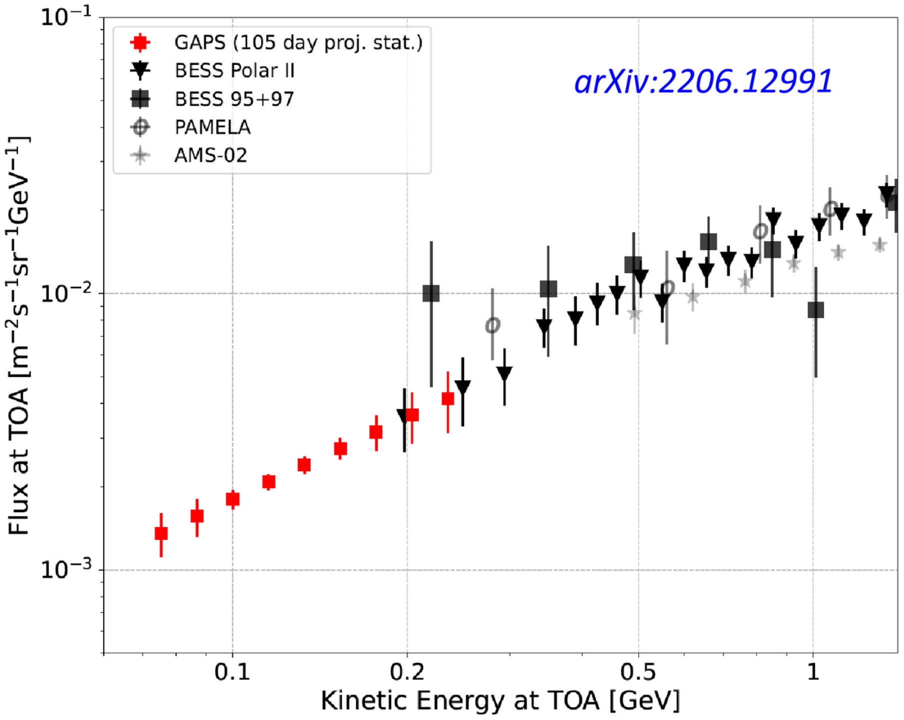


Next steps of GAPS detector

Then the detector has been moved to Berkeley (San Francisco) for the ToF and flight system integration

There will be full system tests in late 2022/early 2023, TVAC in Spring 2023, and first flight in late 2023.

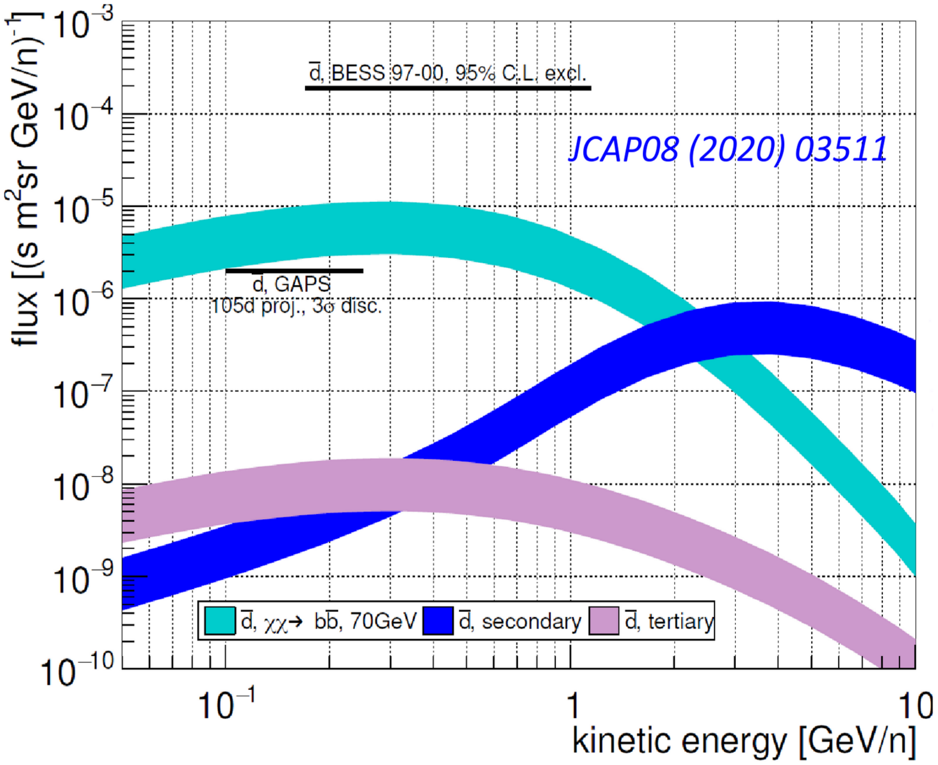
Antiproton sensitivity



$\bar{p}$

- Precision measurements of **antiproton** spectrum in an **unexplored energy range** (<250 MeV/n)
- ~**500** antiprotons expected for each balloon flight:
  - BESS: 29 @ ~ 200 MeV/n
  - PAMELA: 7 @ ~ 250 MeV/n
- Provide constraints on Galactic propagation and solar modulation
- Observed antiproton excess also puts constraints on antideuteron flux predictions
- Sensitive to **light dark matter** and **primordial black hole evaporation**
- Validation of GAPS exotic atom identification technique

Antideuteron sensitivity



$\bar{d}$

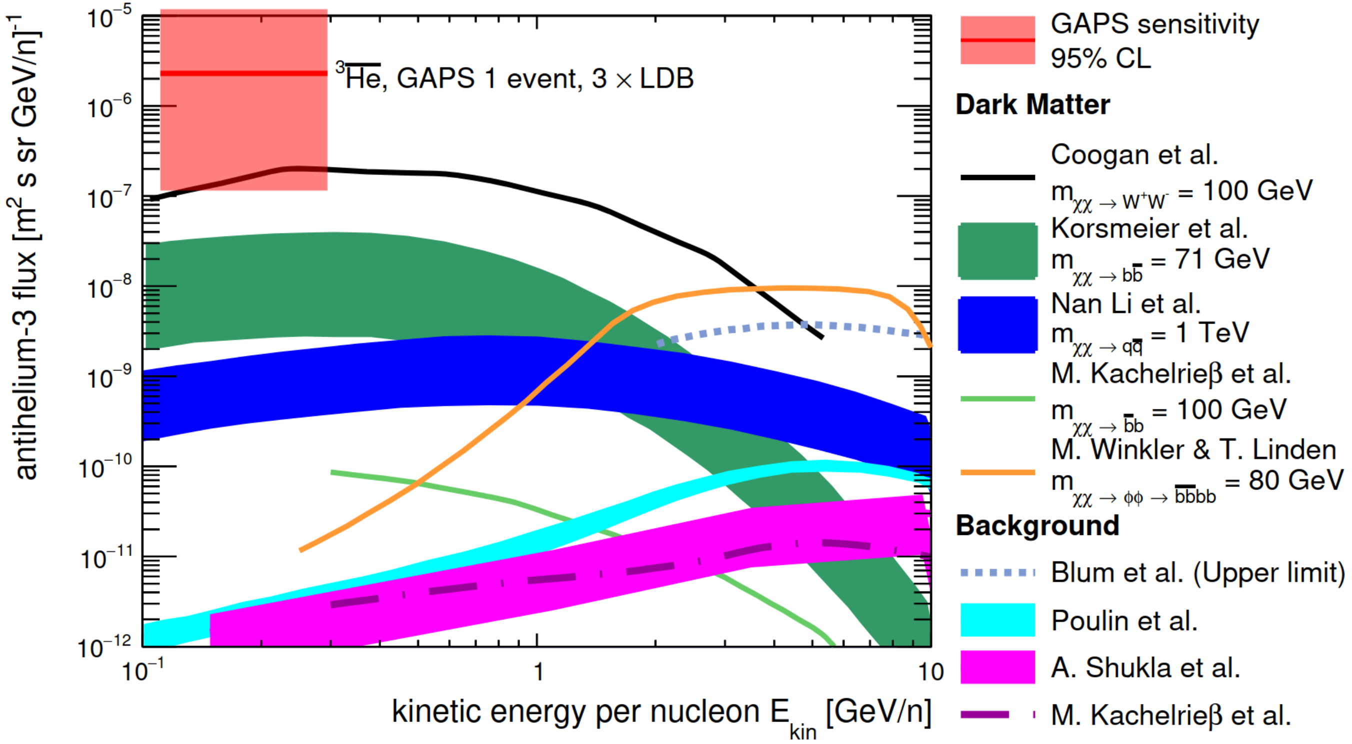
- Predicted **antideuteron** signal from DM annihilation or decay ~ 2 orders of magnitude above astrophysical background below 250 MeV/n
- An essentially **background-free** DM signature
- GAPS sensitivity will be up to 2 orders of magnitude below the BESS limit

Antihelium sensitivity

Astropart. Phys. 102580 (2021)

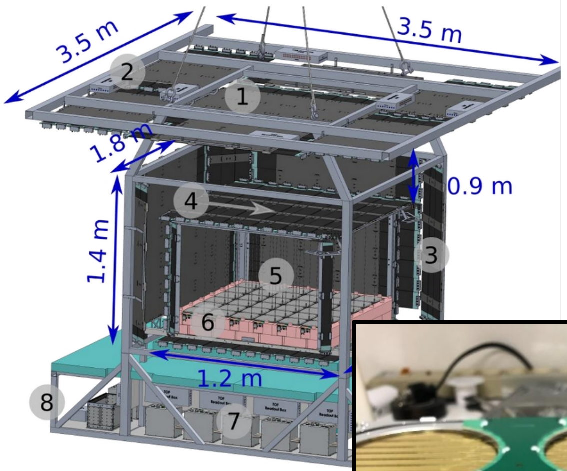
$^{3}\overline{He}$

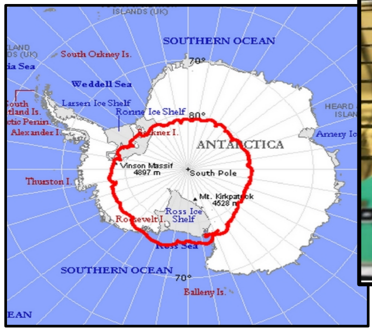
- GAPS will be sensitive to $^{3}\overline{He}$
- $^{3}\overline{He}$ flux ~ 2-3 orders of magnitude below $\overline{d}$ flux
- An observation of $^{3}\overline{He}$ would be a clear indication of **new physics**
- Extend the energy coverage at low energies **(0.1-0.3 GeV/n)**

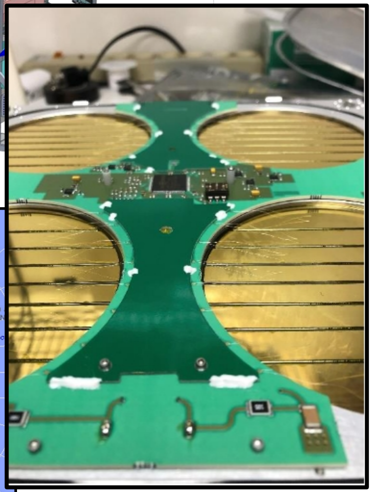


Conclusions

- This is a “background free” channel since the secondary antideuteron from CRs interaction expected to be orders of magnitude lower.
- A functional prototype was built in fall 2021 and tested. This system demonstrates for the first time all key system interfaces. Reconstruction of cosmic muon tracks demonstrates compliance with the key performance requirements, as well as verification of trigger, event building, and track reconstruction algorithms.
- Tracker integration at MIT Bates Laboratory
- TOF and flight systems will be integrated at UC Berkeley's Space Sciences Laboratory in fall 2022. System tests in late 2022/early 2023, and full TVAC test in spring 2023.
- First flight late 2023 from McMurdo station.







GAPS collaboration meeting at MIT, 8-9 June 2022