The GAPS experiment: low energy cosmic-ray antinuclei for indirect dark matter searches

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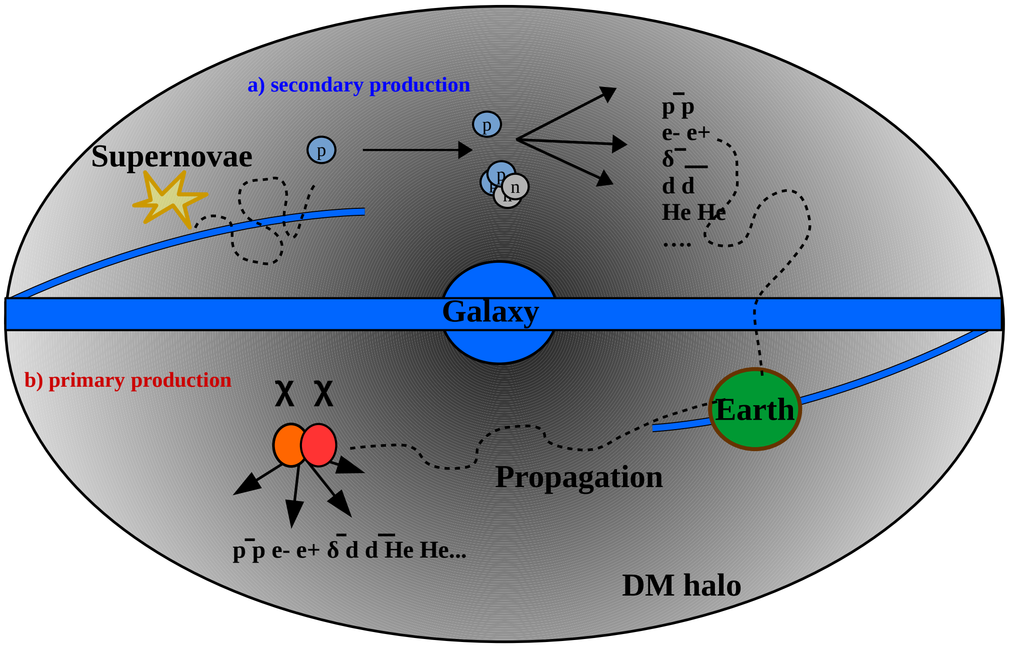
On behalf of the GAPS collaboration

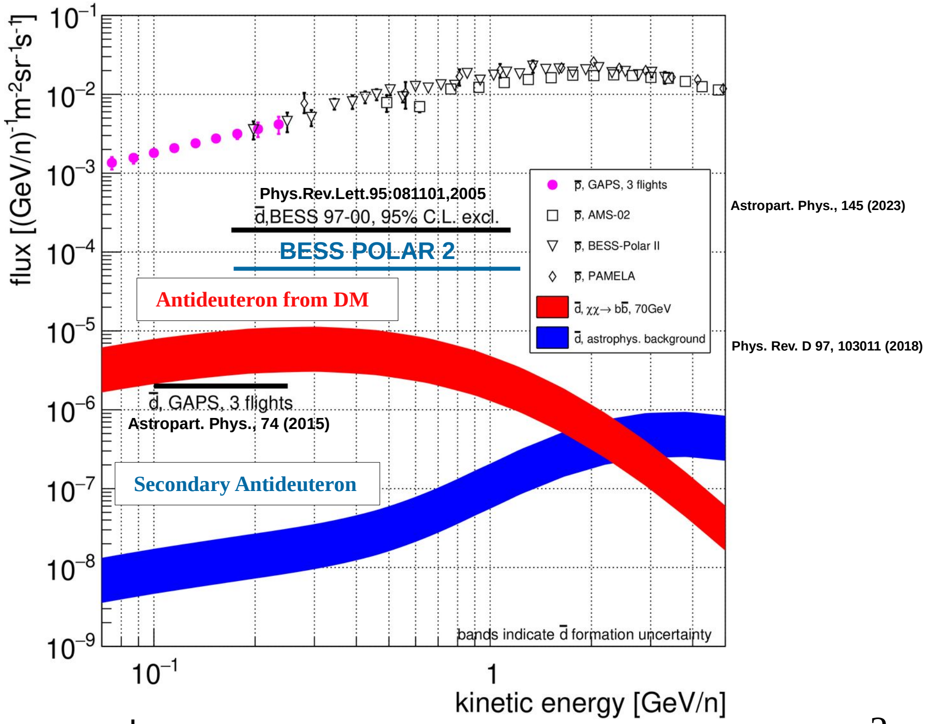
IDM 2024, L'Aquila,
11 July 2024

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

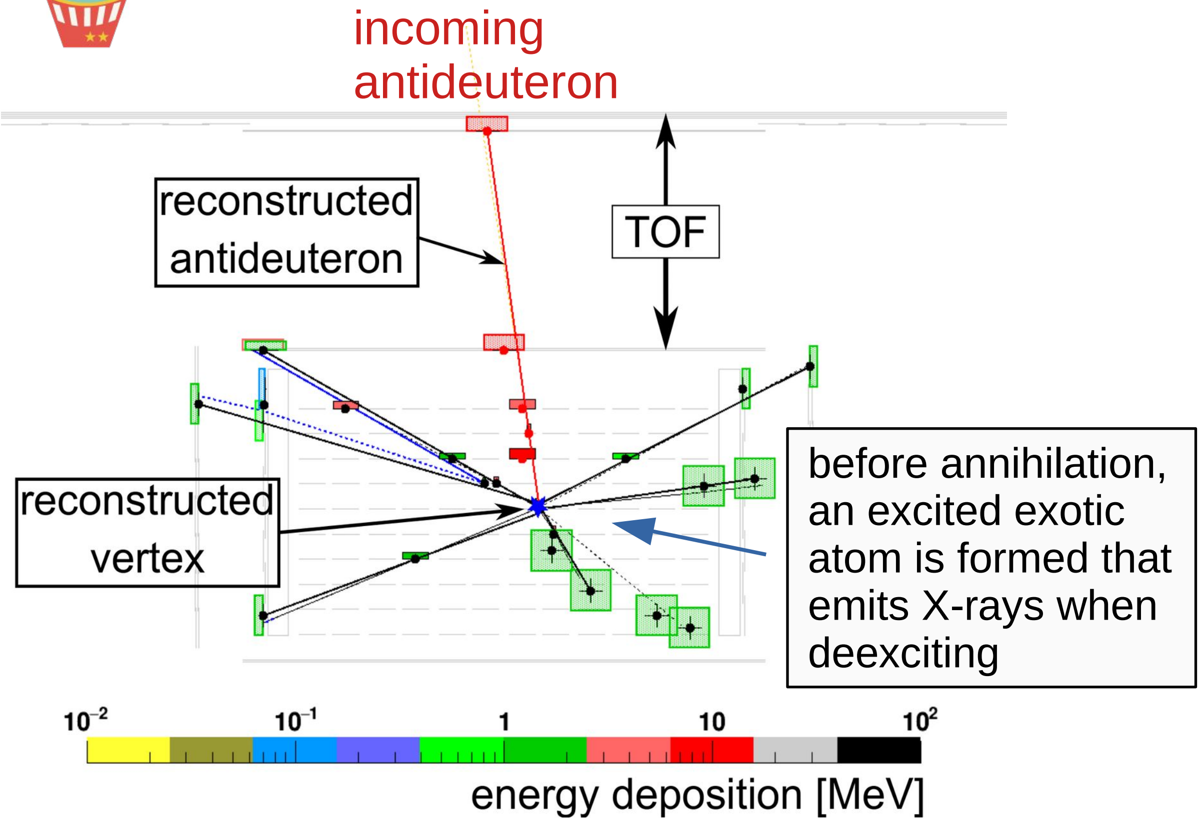




The General AntiParticle Spectrometer

Mass: ~2,500kg
Power: 1.3kW

GAPS measurment principle



Detection tecnique

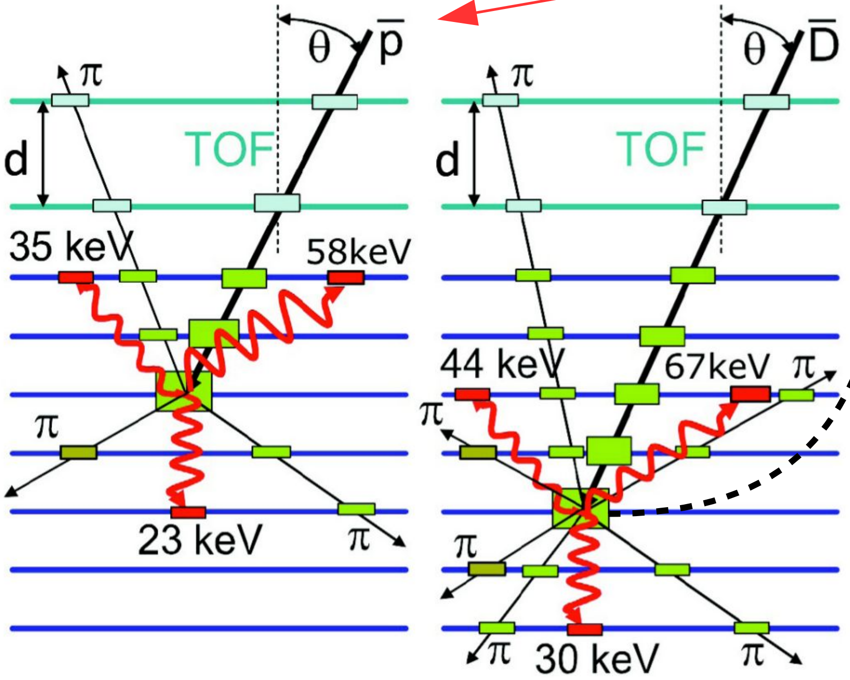
- Antiparticle **slows down,** stops and forms an **excited exotic atom**. **Complementary to magnetic spectrometer.**
- Hydrogen-like exotic atom **deexcites** via characteristic X-ray transitions depending on antiparticle mass
- **Nuclear annihilation** with characteristic number of annihilation products

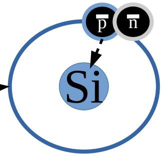
GAPS will provide

- 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
- Leading sensitivity to low-energy cosmic **antihelium** nuclei

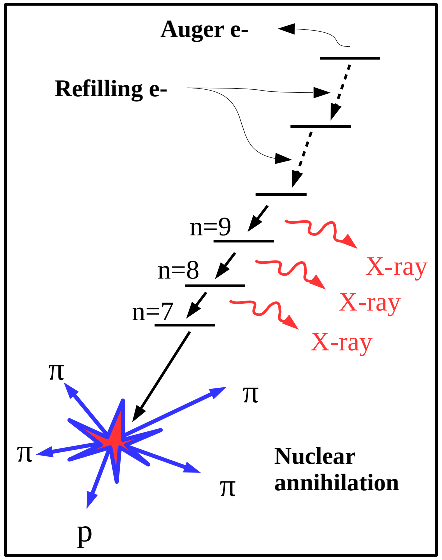
GAPS detection tecnique

Same initial velocity





Exotic nucleus – atomic transitions

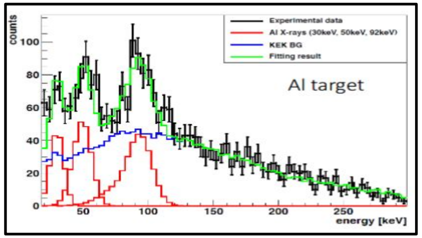


$$E_{X-ray}=(zZ)^2\frac{M}{m_e}R_H\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)$$

AntiD - antiP identification

- Time of flight
- Depth - multiple dEdx
- X-rays emission
- Pion multiplicity

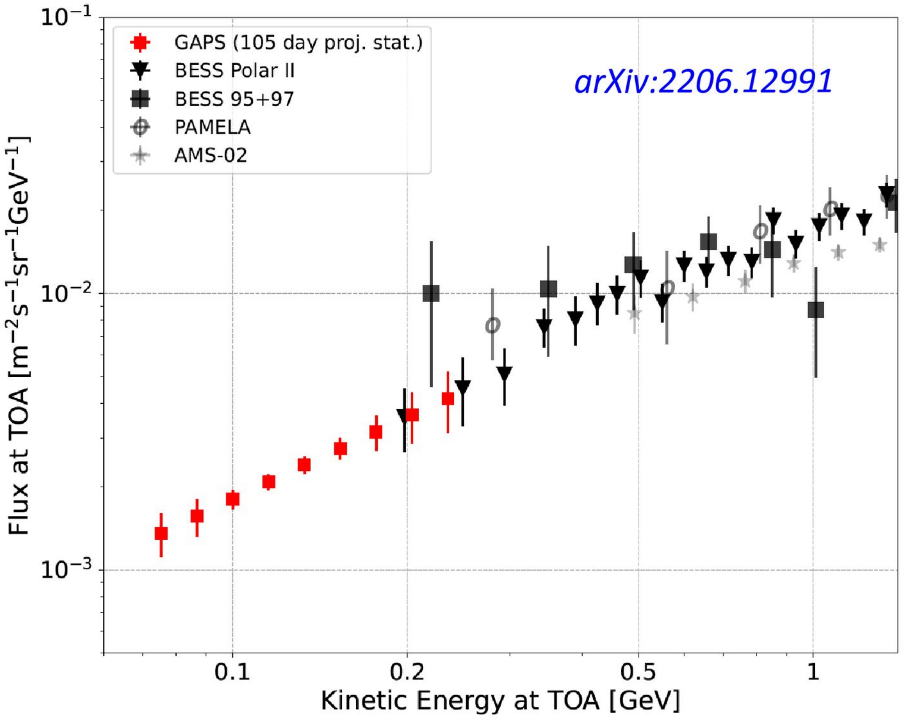
Aramaki et al. Astro.Ph. 49 (2013) 52



X-raymeasured at KEK in 2004/2005

Stopping particles inside tracker volume

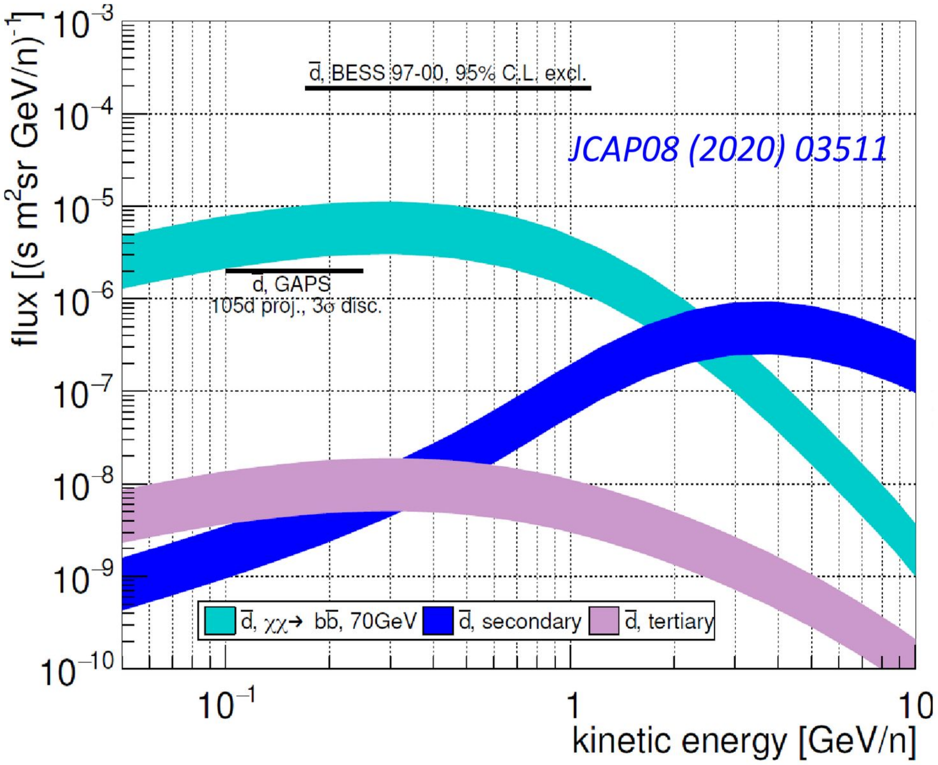
Antiproton sensitivity



$\bar{p}$

- 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



$\bar{d}$

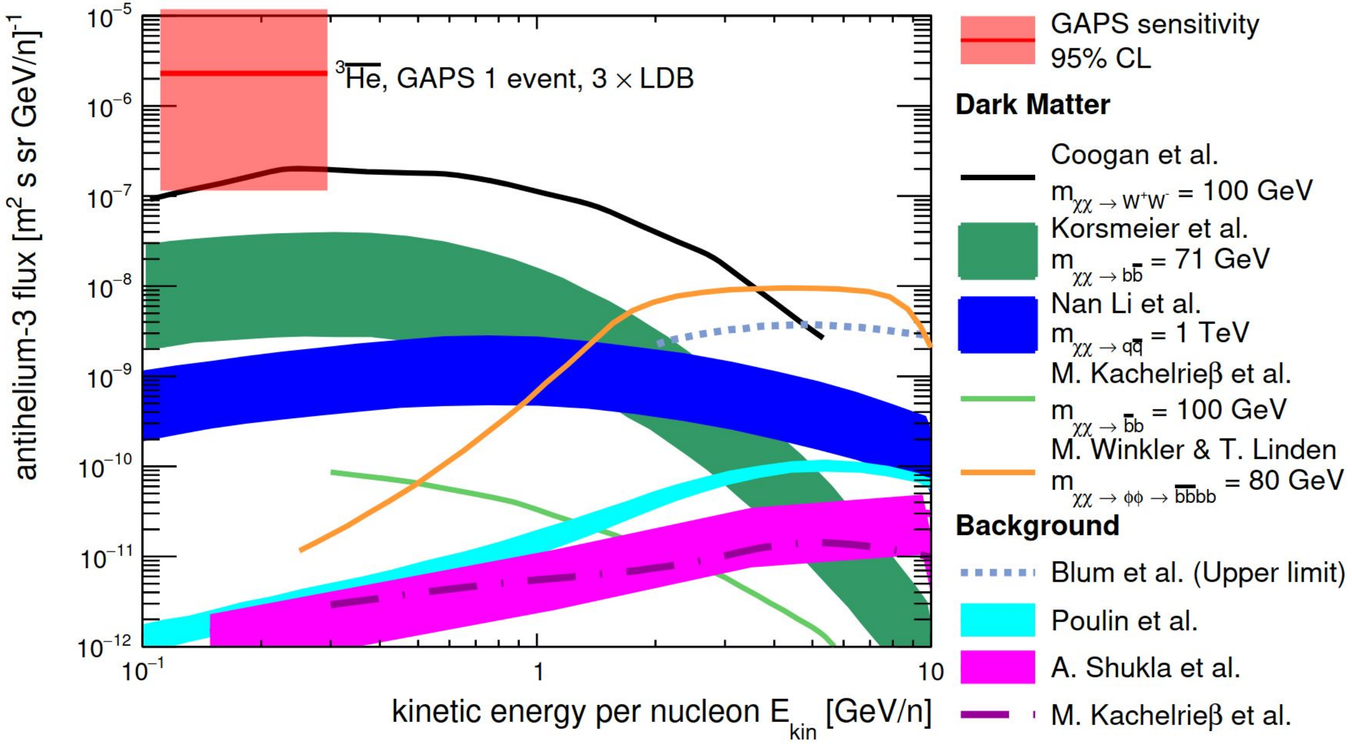
- Predicted **antideuteron** signal from DM annihilation or decay ~ 2 orders of magnitude above astrophysical background below 250 MeV/n
- An essentially **background-free** DM signature
- GAPS sensitivity will be up to 2 orders of magnitude below the BESS limit

Antihelium sensitivity

[Astropart. Phys. 102580 (2021)](#)

$^3\overline{He}$

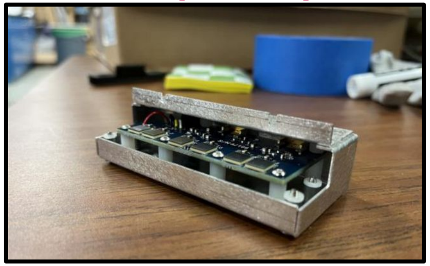
- GAPS will be sensitive to $^3\overline{He}$
- $^3\overline{He}$ flux ~ 2-3 orders of magnitude below $\overline{d}$ flux
- An observation of $^3\overline{He}$ would be a clear indication of **new physics**
- Extend the energy coverage at low energies **(0.1-0.3 GeV/n)**



Time of Flight

Plastic scintillator (x160)

Si-PMs (x6/end)



Tasks:
Main trigger system, reduce data rate from few tens kHz → 500Hz. Velocity measurement, energy losses.

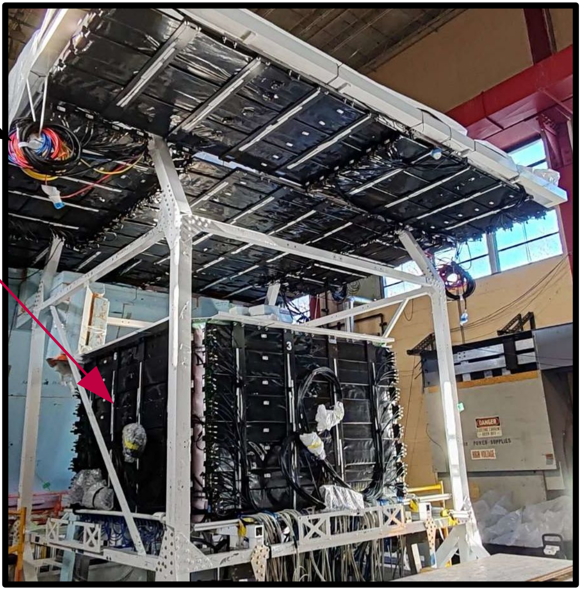
Plastic scintillator: Eljen EJ-200: 108-180 cm long, 0.635 cm thick

SiPM: Hamamatsu S13360-6050VE

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

Inner Cube

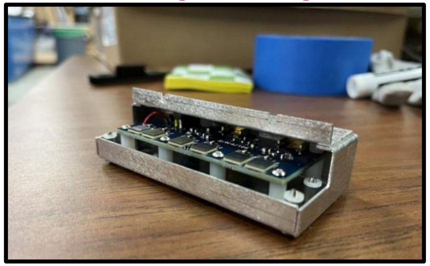
Umbrella



Time of Flight

Plastic scintillator (x160)

Si-PMs (x6/end)



Umbrella

Cortina

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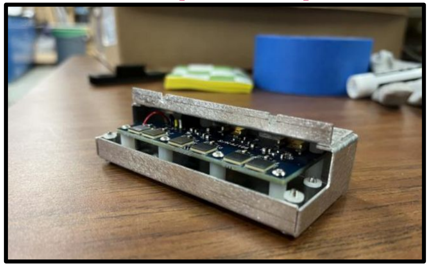
Time of Flight

Plastic scintillator (x160)

Si-PMs (x6/end)



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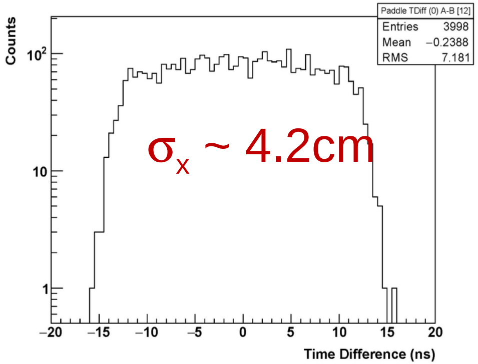
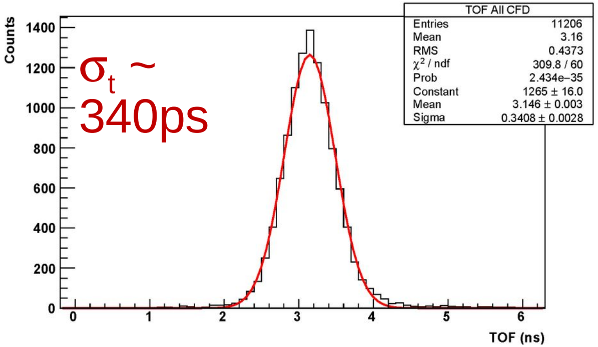
- TOF position location and timing



End-End time diff (ns)



TOF over 0.95m distance

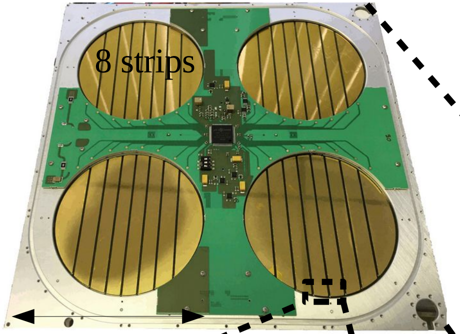
Tracker system

Tracker acts as target and tracking device

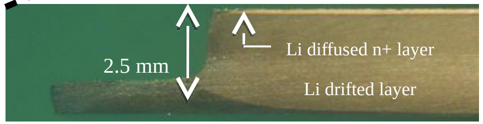
Lithium-drifted Silicon

- 7 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

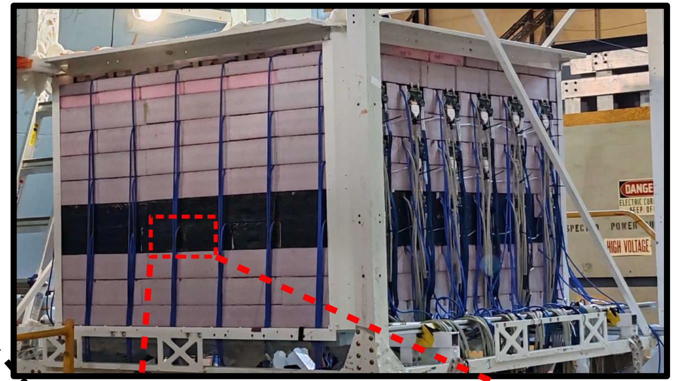
6x6 module each plane

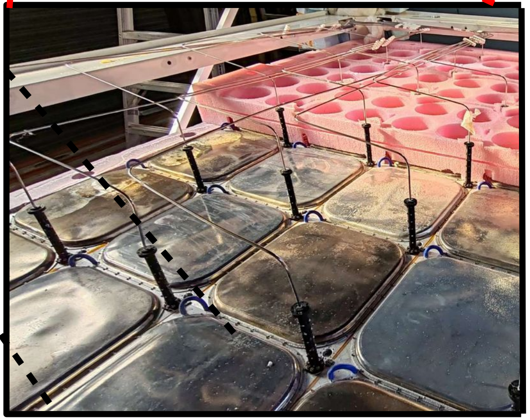


10 cm



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

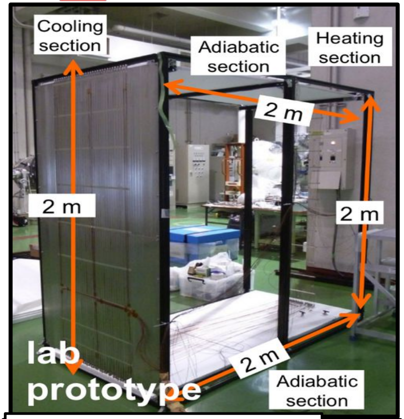


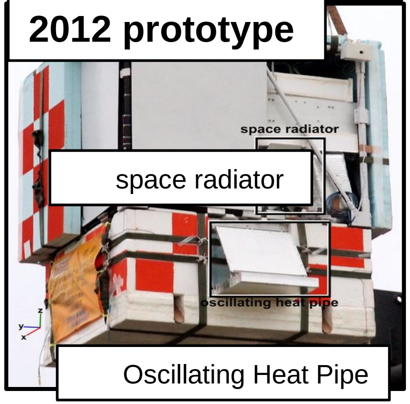


Publications:

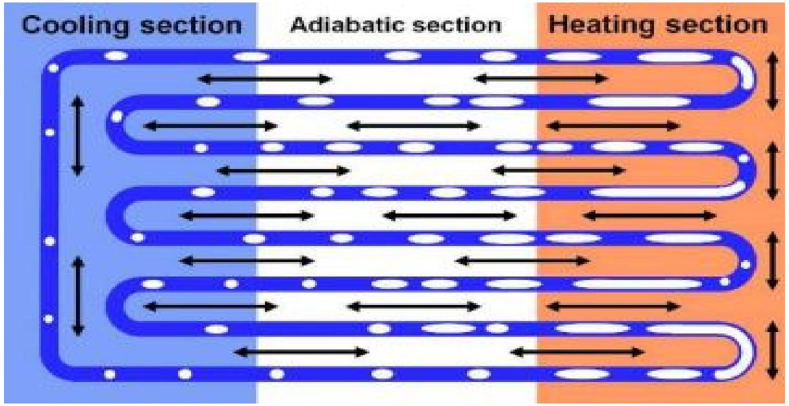
Perez et al., NIM A 905, 12 (2018)
Kozai et al., NIM A 947, 162695 (2019)
Rogers et al., JINST 14, P10009 (2019)
Saffold et al., NIM A 997, 165015 (2021)

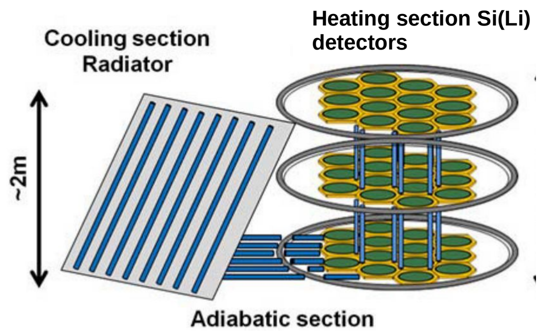
Oscillating heat pipe cooling system





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

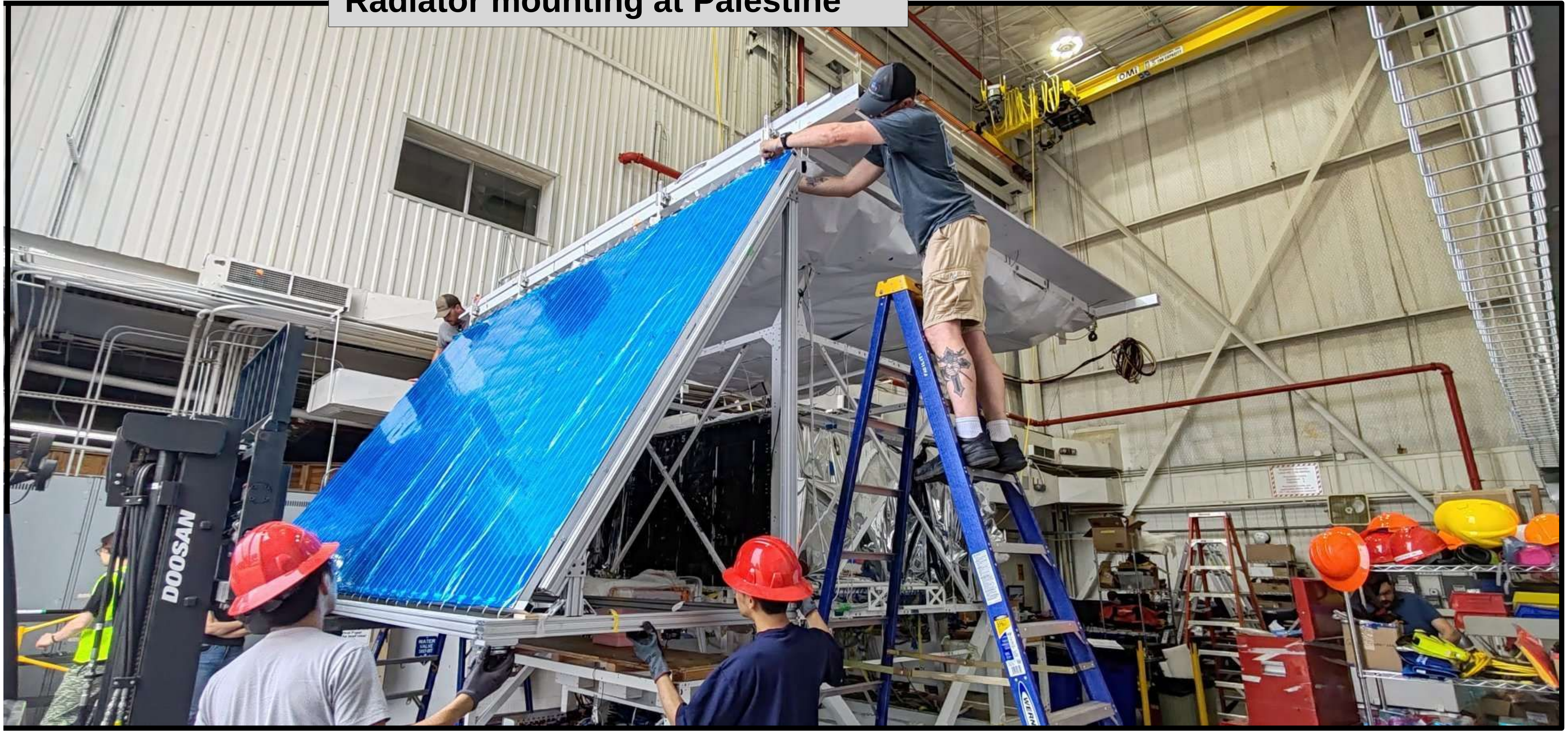
Vapor bubbles form in the fluid → expand in warm and contract in cool sections.

Rapid expansion and contraction create 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

Oscillating heat pipe cooling system

Radiator mounting at Palestine

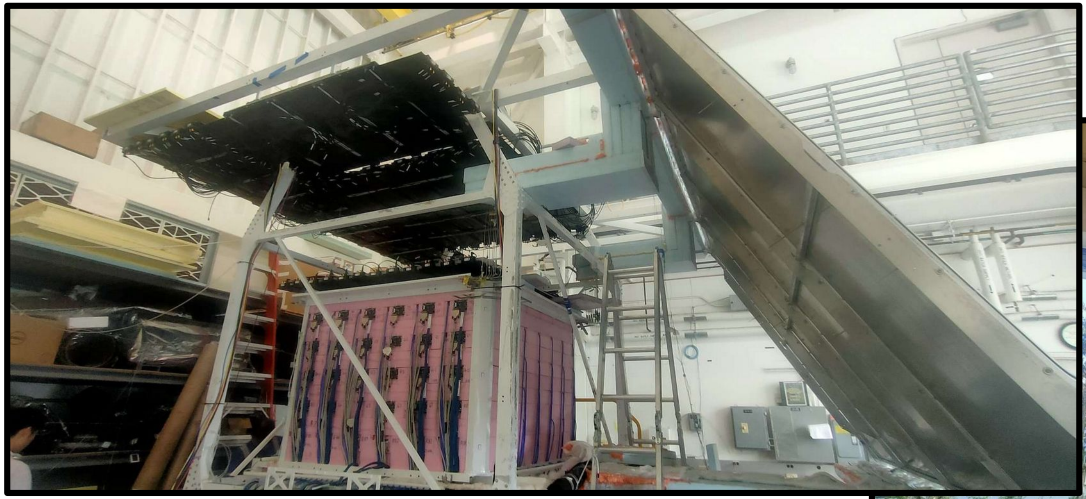


GAPS integration and testing

SSL - Berkeley

Half 2022 → May 2023

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



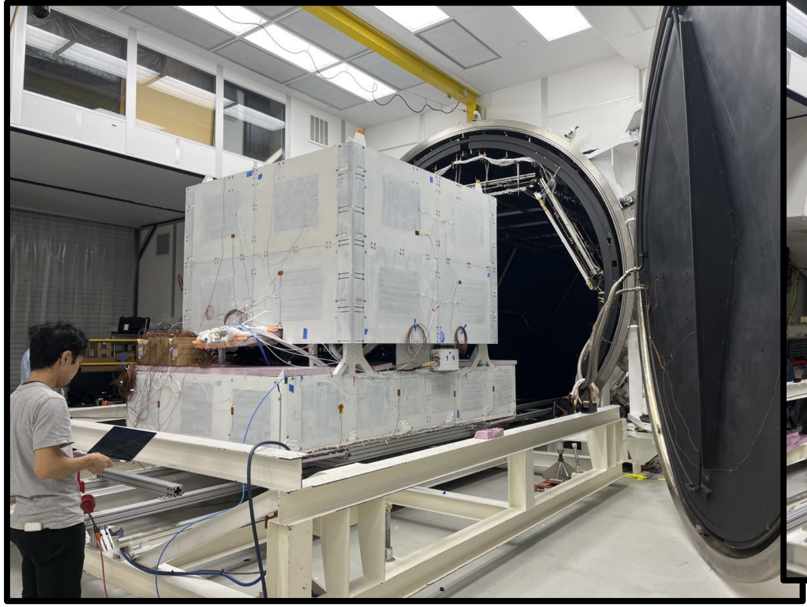
GAPS integration and testing

SSL - Berkeley

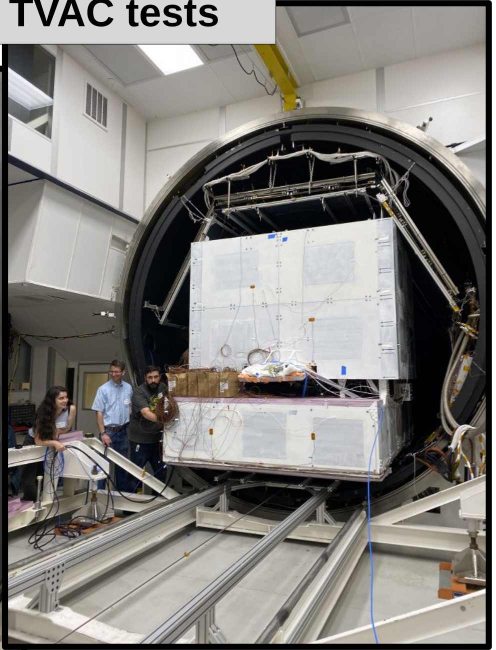
NTS – Los Angeles

Half 2022 → May 2023

June 2023



TVAC tests



- 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 modules

GAPS integration and testing

SSL - Berkeley | NTS – Los Angeles | **Nevis - Laboratories**

Half 2022 → May 2023 | June 2023 | **July 2023 → May 2024**

GAPS at Nevis

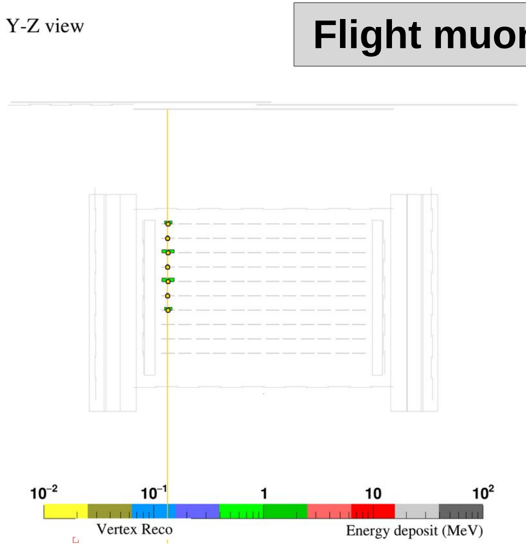
- Exstensive muon runs
- Tracker calibration
- ToF testing, trigger

GAPS integration and testing

SSL - Berkeley | NTS – Los Angeles | **Nevis - Laboratories**

Half 2022 → May 2023 | June 2023 | **July 2023 → May 2024**

Flight muon



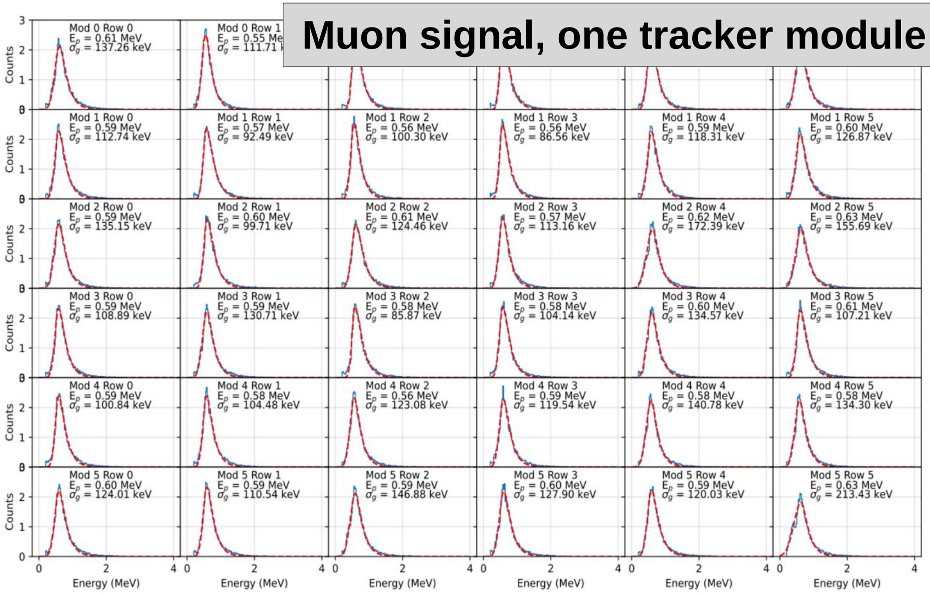
- Exstensive muon runs
- Tracker calibration
- ToF testing, trigger

GAPS integration and testing

SSL - Berkeley | NTS – Los Angeles | **Nevis - Laboratories**

Half 2022 → May 2023 | June 2023 | **July 2023 → May 2024**

Muon signal, one tracker module



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

GAPS integration and testing

SSL - Berkeley — Half 2022 → May 2023

NTS – Los Angeles — June 2023

Nevis - Laboratories — July 2023 → May 2024

CSBF - Palestine — May → August 2024

Integration at CSBF

- Full integration
- Compatibility and hang test.

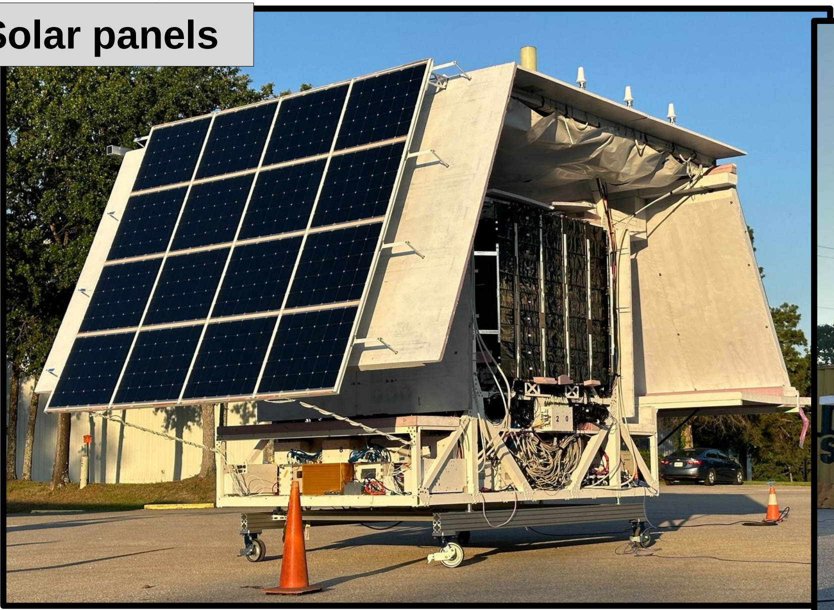
Flight white foam to protect from the Sun

GAPS integration and testing

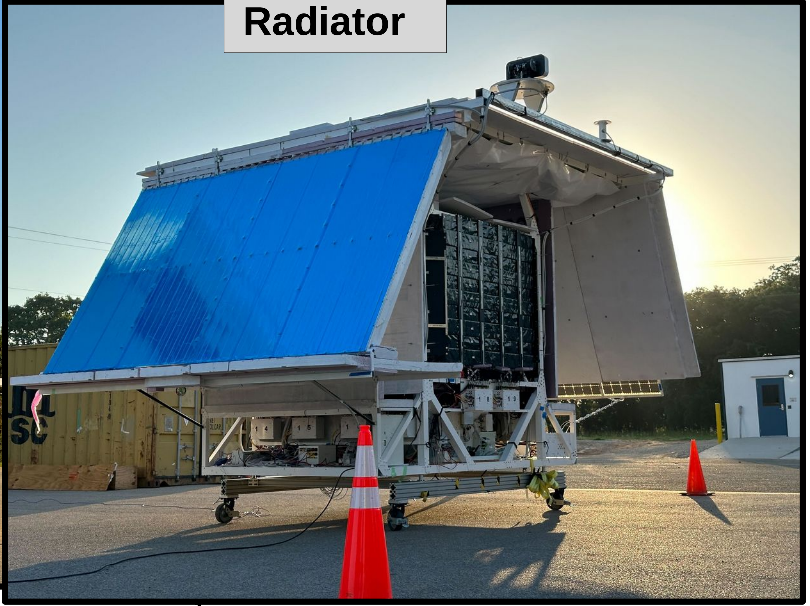
SSL - Berkeley | NTS – Los Angeles | Nevis - Laboratories | **CSBF - Palestine**

Half 2022 → May 2023 | June 2023 | July 2023 → May 2024 | **May → August 2024**

Solar panels



Radiator



GAPS integration and testing

2 July 2024 - Compatibility test succesfully performed!
Comunications ok! Weight ok!

GAPS integration and testing

SSL - Berkeley — Half 2022 → May 2023

NTS – Los Angeles — June 2023

Nevis - Laboratories — July 2023 → May 2024

CSBF - Palestine — May → August 2024

Shipment to MucMurdo — **August 2024 → October 2024**

McMurdo — October – November 2024

McMurdo — Half December 2024

- Tracker will be shipped with plane, ToF, electronics, e-bay will be shipped by boat.

GAPS integration and testing

SSL - Berkeley: Half 2022 → May 2023

NTS – Los Angeles: June 2023

Nevis - Laboratories: July 2023 → May 2024

CSBF - Palestine: May → August 2024

Shipment to MucMurdo: August 2024 → October 2024

McMurdo: **October – November 2024**

McMurdo: Hald December 2024

- Full integration and testing.

GAPS integration and testing

SSL - Berkeley — Half 2022 → May 2023

NTS – Los Angeles — June 2023

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CSBF - Palestine — May → August 2024

Shipment to MucMurdo — August 2024 → October 2024

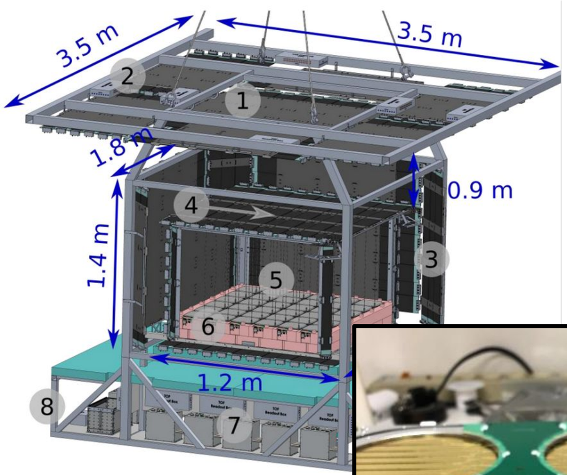
McMurdo — October – November 2024

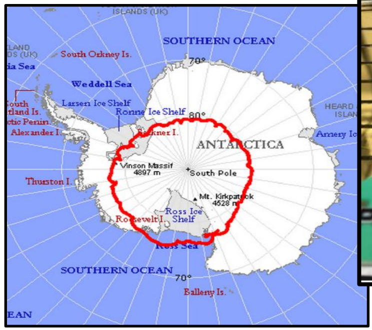
McMurdo — **Half December 2024**

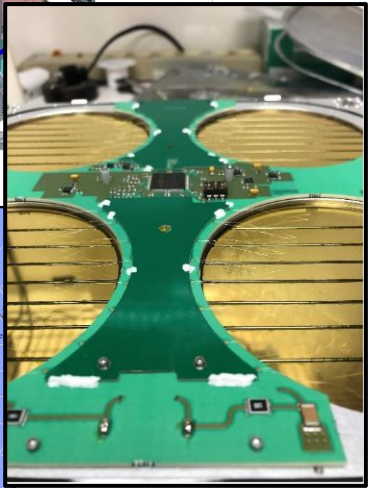
- GAPS will be “flight-ready” from the half of December for a long flight of > 30 days

Conclusions

- This is a “background-free” channel since the secondary antideuteron from CRs interaction is expected to be orders of magnitude lower.
- GAPS has been fully integrated and extensively tested at SSL and Nevis laboratories. Muon runs have been conducted and the tracker energy response was calibrated. ToF and trigger were tested.
- A TVAC test was successfully conducted at NTS in Los Angeles.
- Between May and August 2024 at Palestine CSBF the detector was fully integrated and hang tests were performed.
- Late August 2024 GAPS will be shipped to Mc Murdo for the integration during October-November 2024
- GAPS will be flight-ready in the middle of December 2024.







Integration team at Palestine (partial)

Thanks!