The GAPS Experiment
A Search for Cosmic-ray Antinuclei

Tsuguo Aramaki for GAPS Collaboration
Northeastern University

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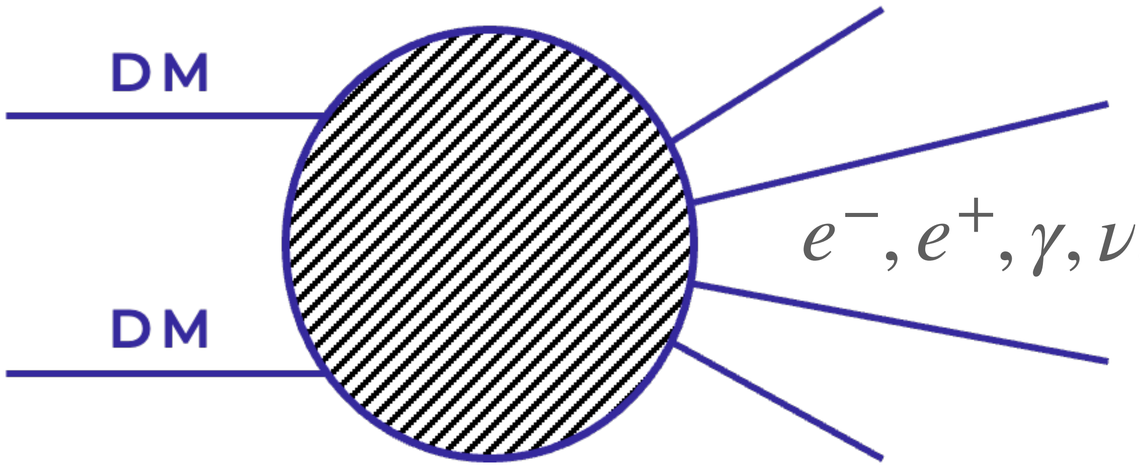
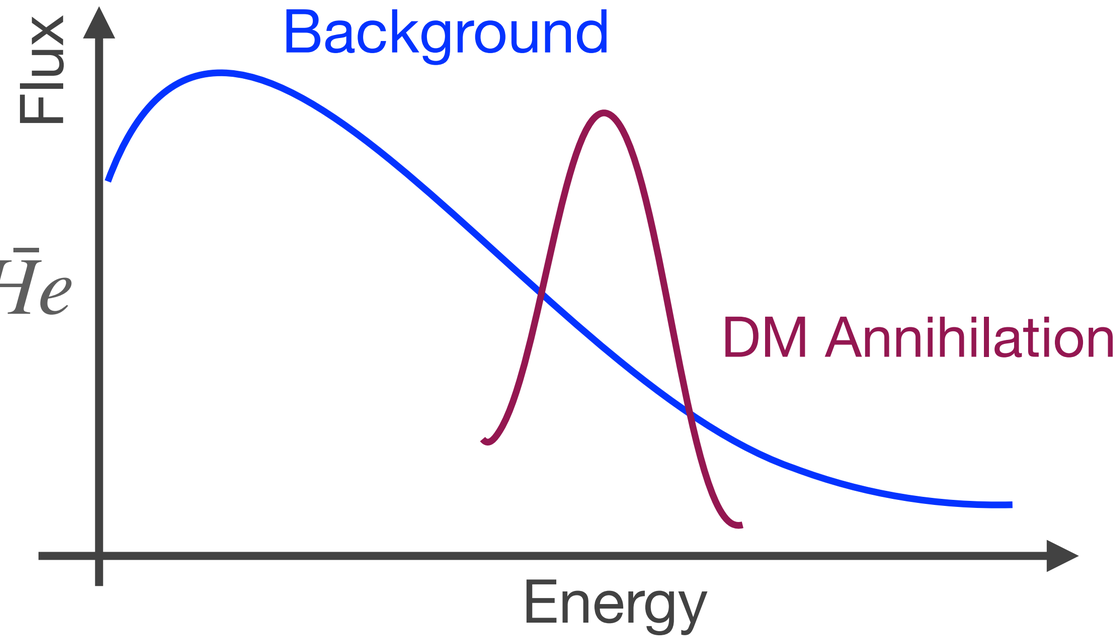
Outline

- Indirect DM searches
- GAPS mission
  - Detector design
  - Detection method/particle identification techniques
  - Current status
- Summary

Indirect Dark Matter Searches

Measure annihilation/decay products





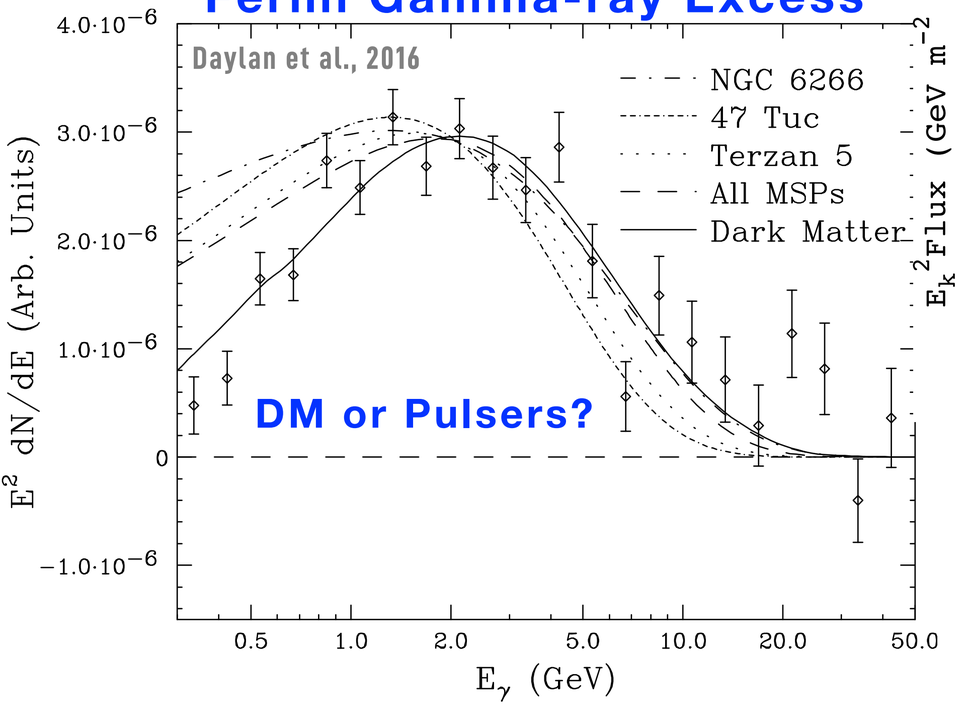
- Positron: AMS-02, PAMELA, Fermi-LAT …
- Gamma-ray: Fermi-LAT, CTA, HESS, VERITAS…
- Neutrino: IceCube, ANTARES…
- Antiproton: AMS-02, PAMELA, **GAPS**
- Antideuteron : AMS-02, **GAPS**
- Antihelium: AMS-02, **GAPS**

Indirect Dark Matter Searches: Recent Results

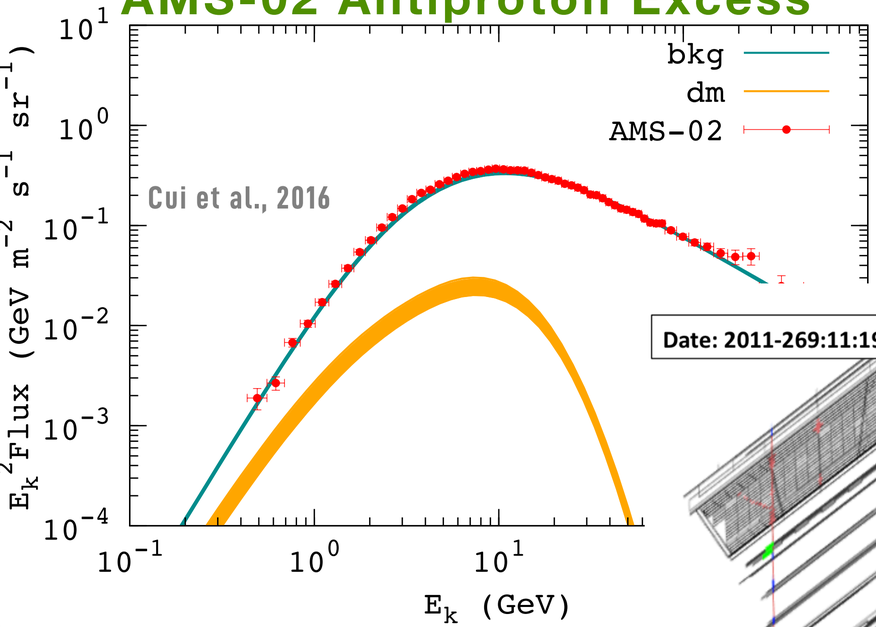
Potential DM signatures in Fermi/AMS-02 measurements

Need to validate signals

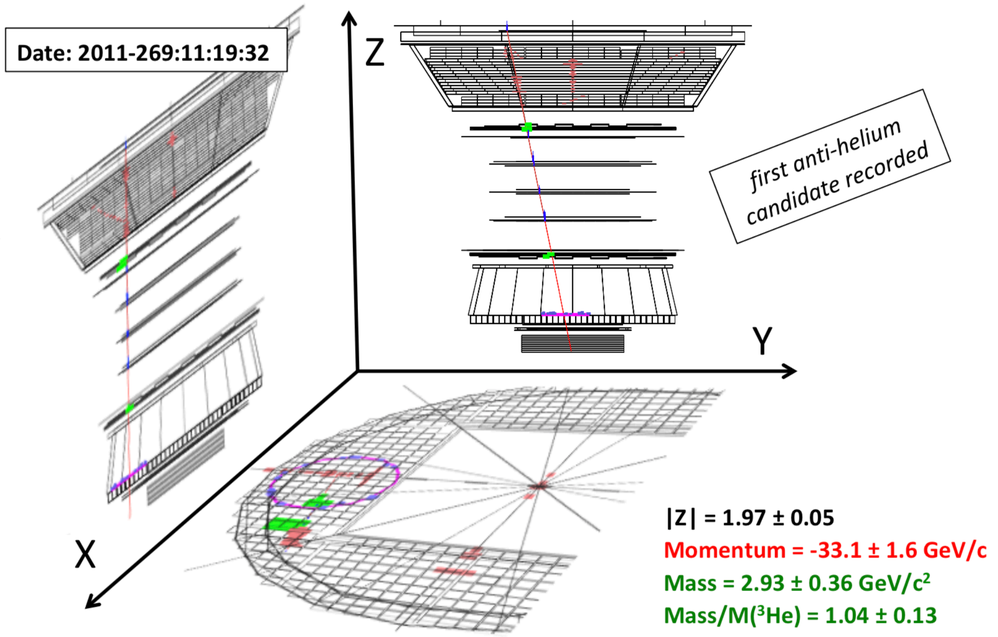
Fermi Gamma-ray Excess



AMS-02 Antiproton Excess



AMS-02 AntiHe-like Events



GAPS Mission

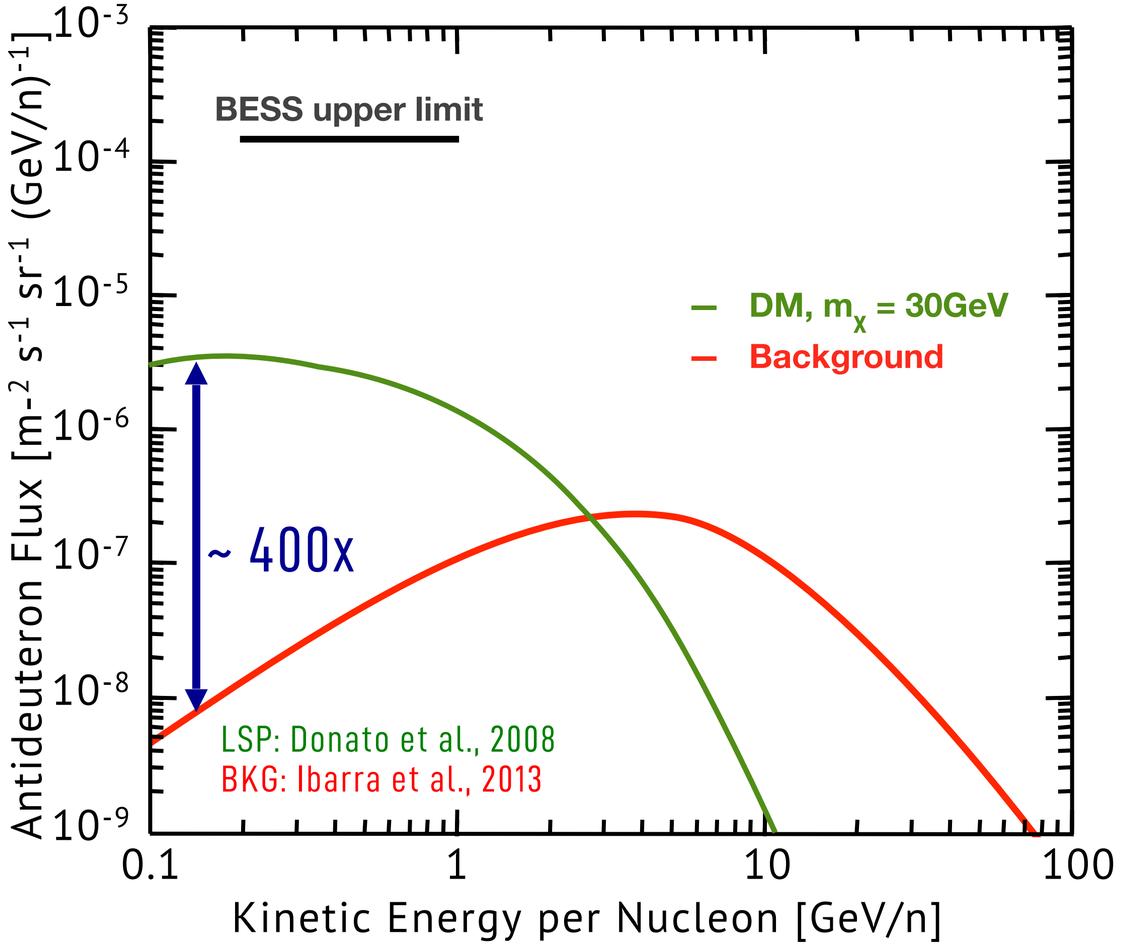
GAPS = General AntiParticle Spectrometer

- First experiment optimized for low-energy antinuclei
  - Background-free dark matter searches with antideuterons
  - High-statistics antiproton measurements
  - Uniquely approach and potential detection of antiheliums

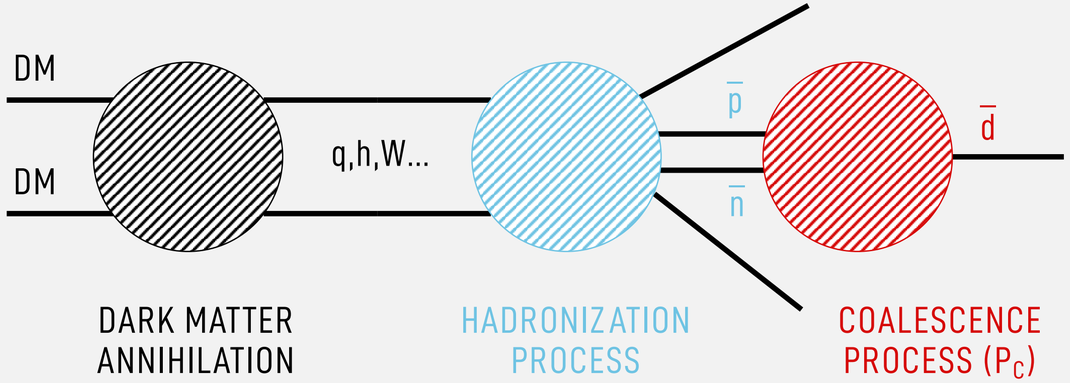
- First science balloon flight is scheduled from the Antarctic in 2023

Why Antideuterons?

Background-free dark matter searches at low energy



PRIMARY FLUX = DM ANNIHILATION/DECAY



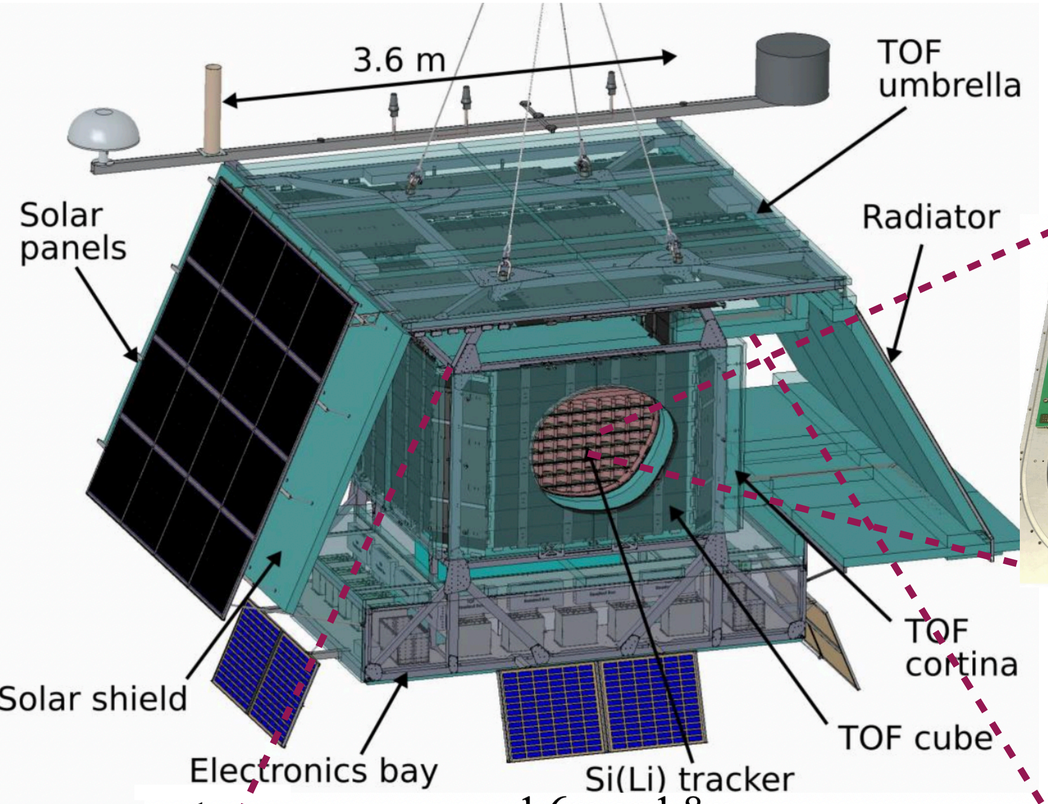
SECONDARY FLUX = COSMIC RAY INTERACTION

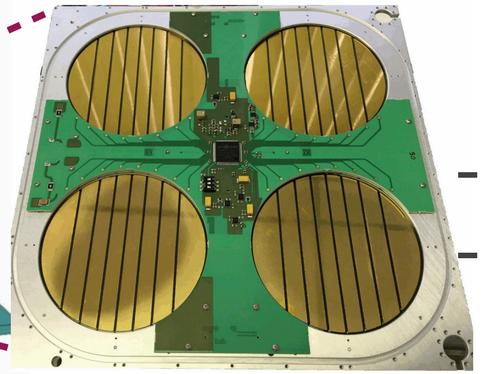
$$p\,(CR) + H\,(ISM) \rightarrow p + H + p + n + \bar{p} + \bar{n}$$

$\bar{d}$

GAPS Detector Design

Si(Li) tracker surrounded by plastic scintillators





Total Power: ~1.3 kW, Mass: ~2,500 kg

Si(Li) Tracker

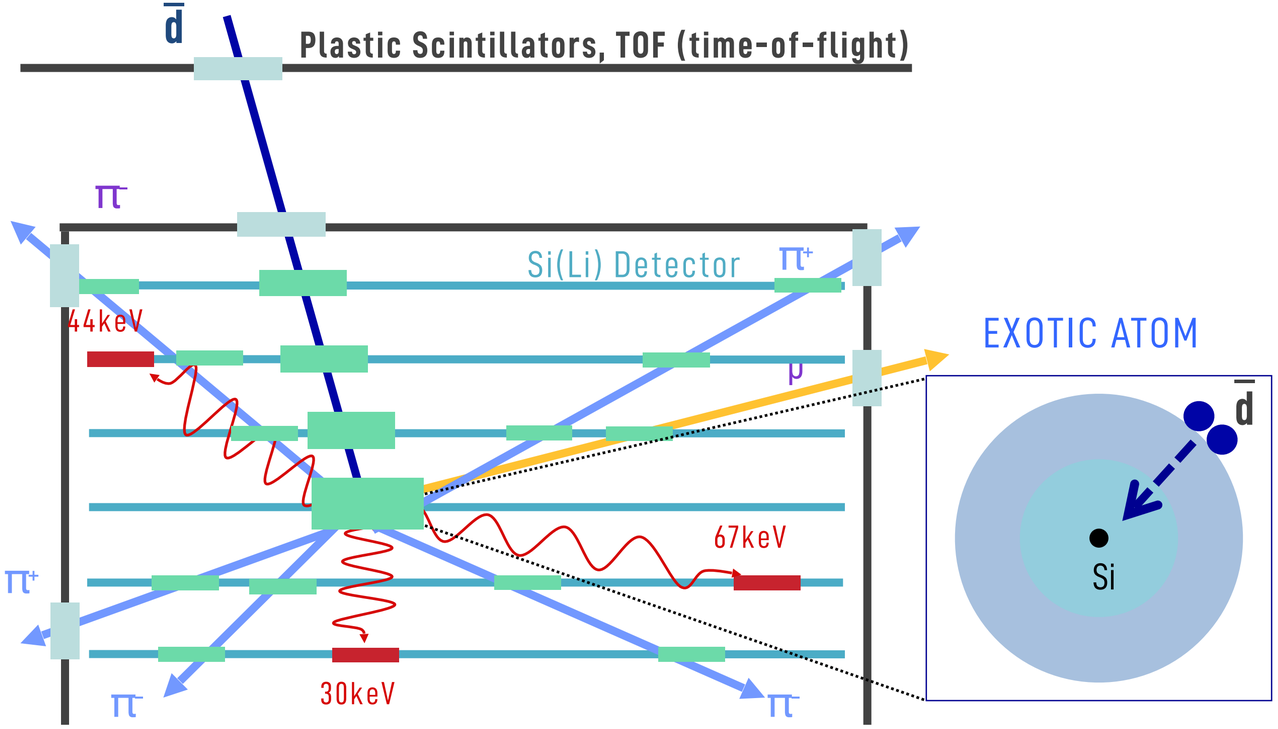
- 10 layers of Si(Li) detectors
  - 4 inch diameter 2.5 mm thick
  - 8 strips -> 3D tracking
- FWHM energy resolution: 4 keV
- Operation at ~-40C
  - OHP cooling system
- Dual channel electronics
  - High gain: X-rays
  - Low gain: charged particles

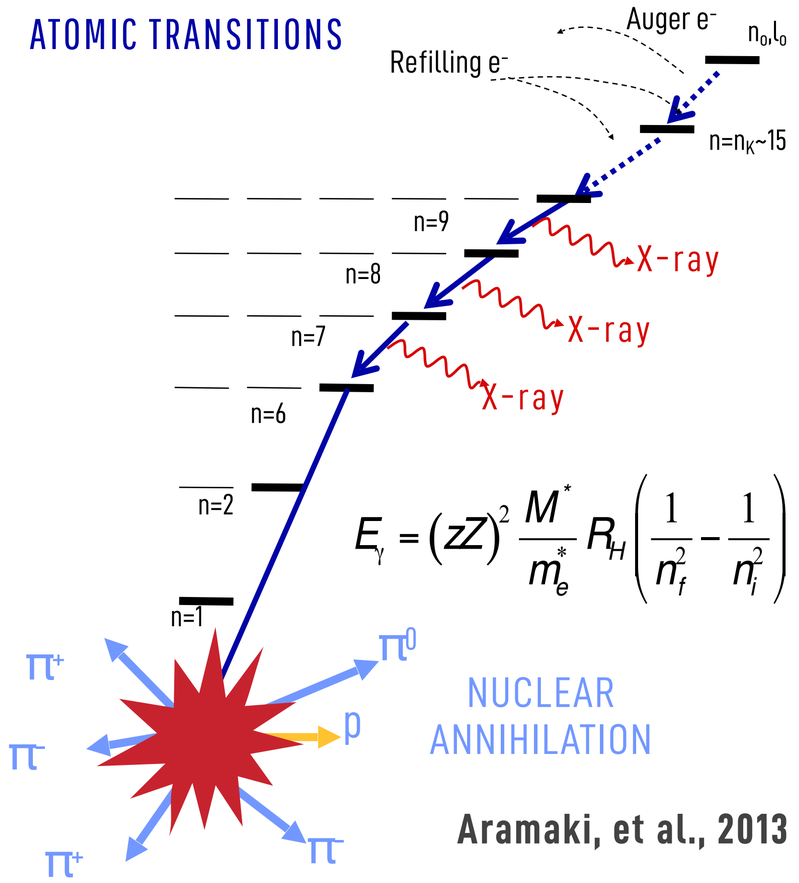
Time of Flight (TOF)

- Plastic paddle with SiPMs on each end
- Timing resolution: 0.4ns

GAPS Detection Concept

Measure atomic X-rays and annihilation products





- 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

- Concept proven with accelerator beam test
- Cascade model developed for X-ray yields

GAPS Antideuteron Identification Techniques

CR p, e± rejection = antiproton and antideuteron selection

- Select **slow particles** with TOF
- Simultaneous detection of secondary/**annihilation products (pions/protons)**
  - Slow CR p and e± **may not be able to produce secondary particles**

Antideuteron identification techniques

atomic X-rays from exotic atom

- different energy

pion/proton multiplicity

- different energy more for antideuterons

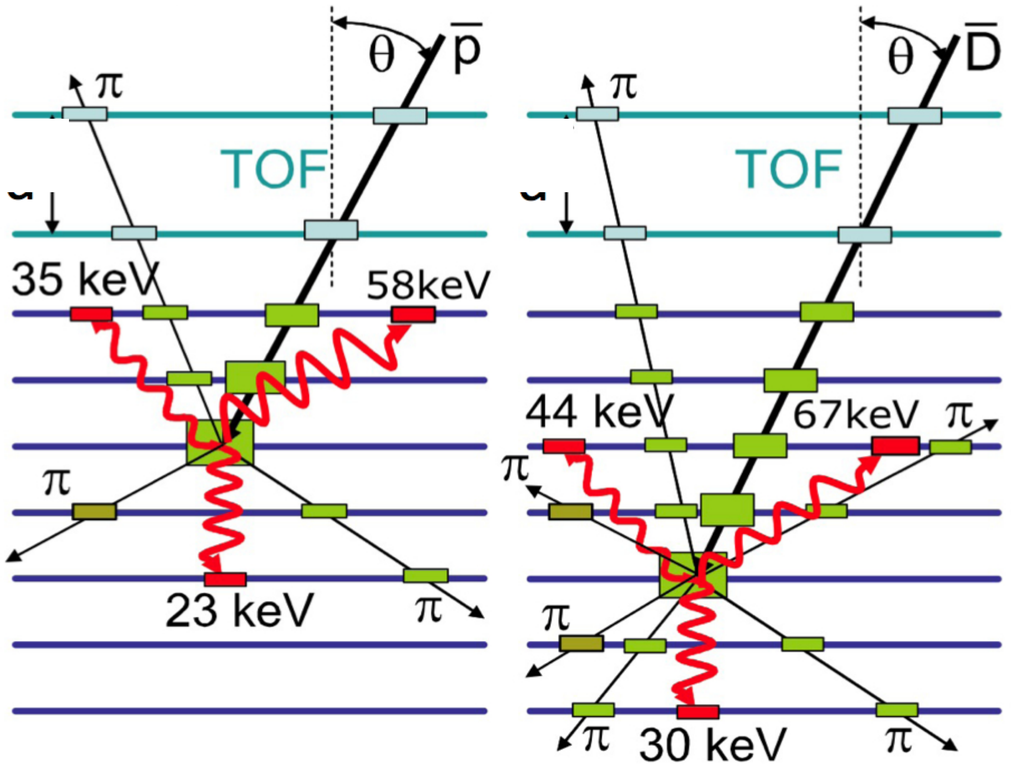
stopping range (depth sensing)

- antideuterons go deeper

dE/dX energy deposit in layers

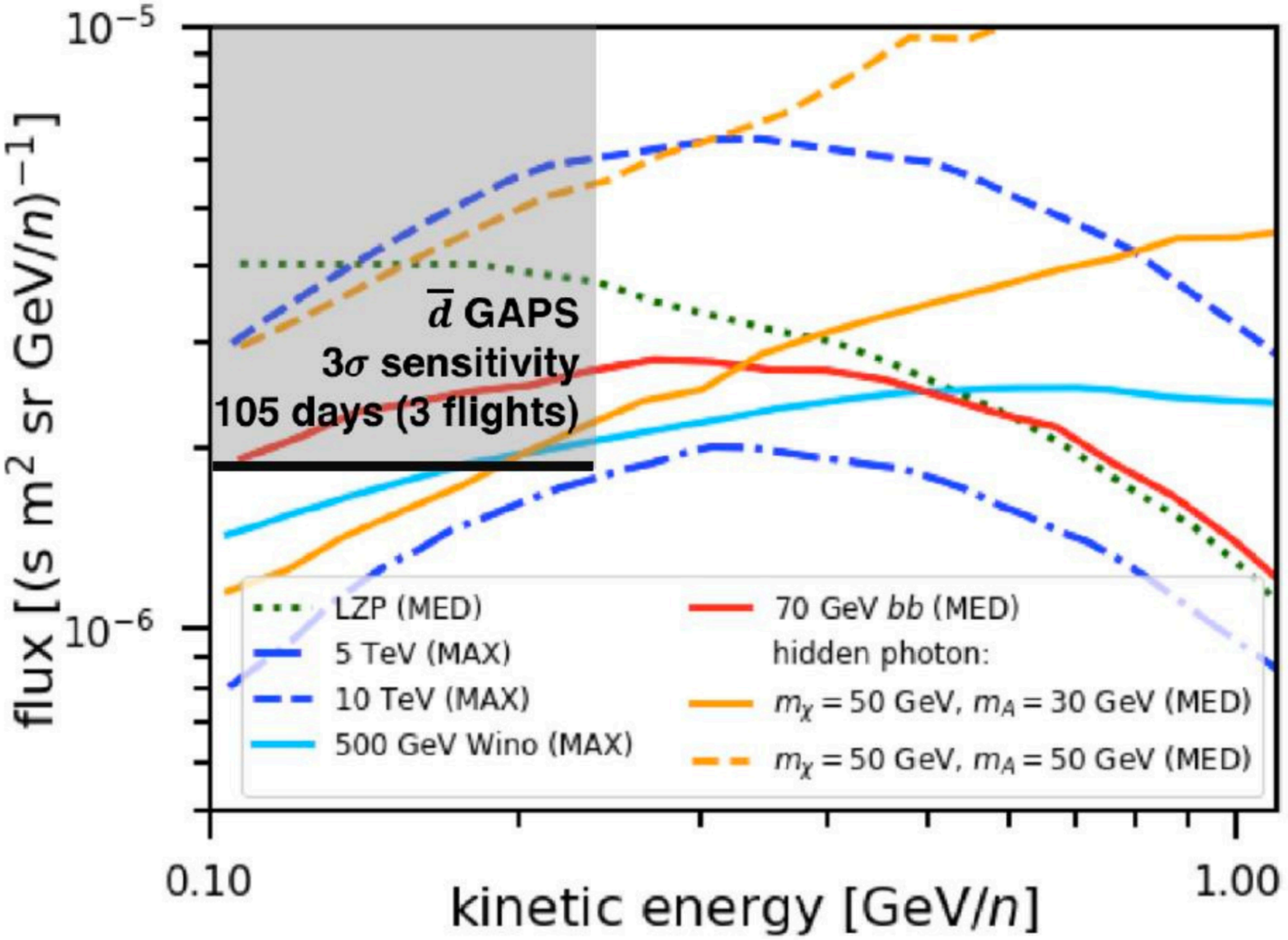
- more for antideuterons

Expected background: ~ 0.01 events



Sensitivities to Antideuterons

Sensitive to a wide range of dark matter models



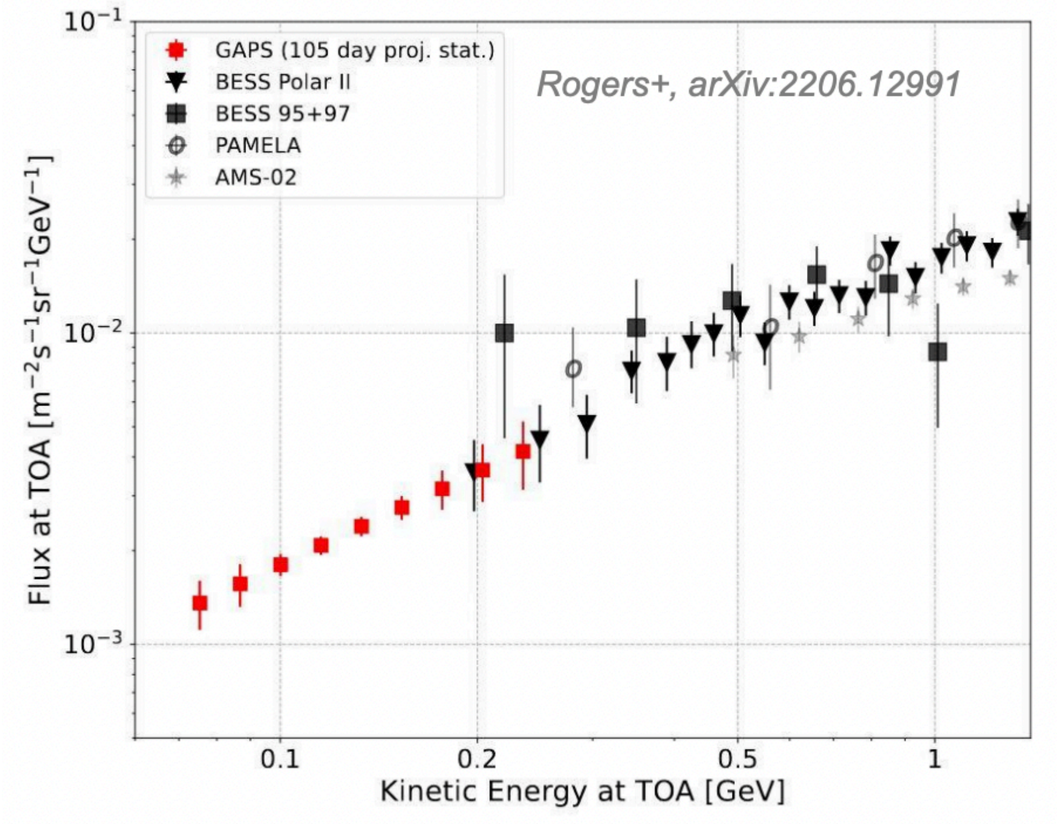
- Generic 70-GeV WIMP annihilation
  - Could explain Fermi/AMS results
- Gravitino dark matter decay
- Extra dimensions theory
- Dark photons
- Heavy DM models
  - Sommerfeld enhancement

Korsmeier+ 2018, Dal+ 2014, Baer+ 2005, Randall+ 2020, Braeuninger+ 2009, Hryczuka+ 2014

Sensitivities to Antiprotons and Antiheliums

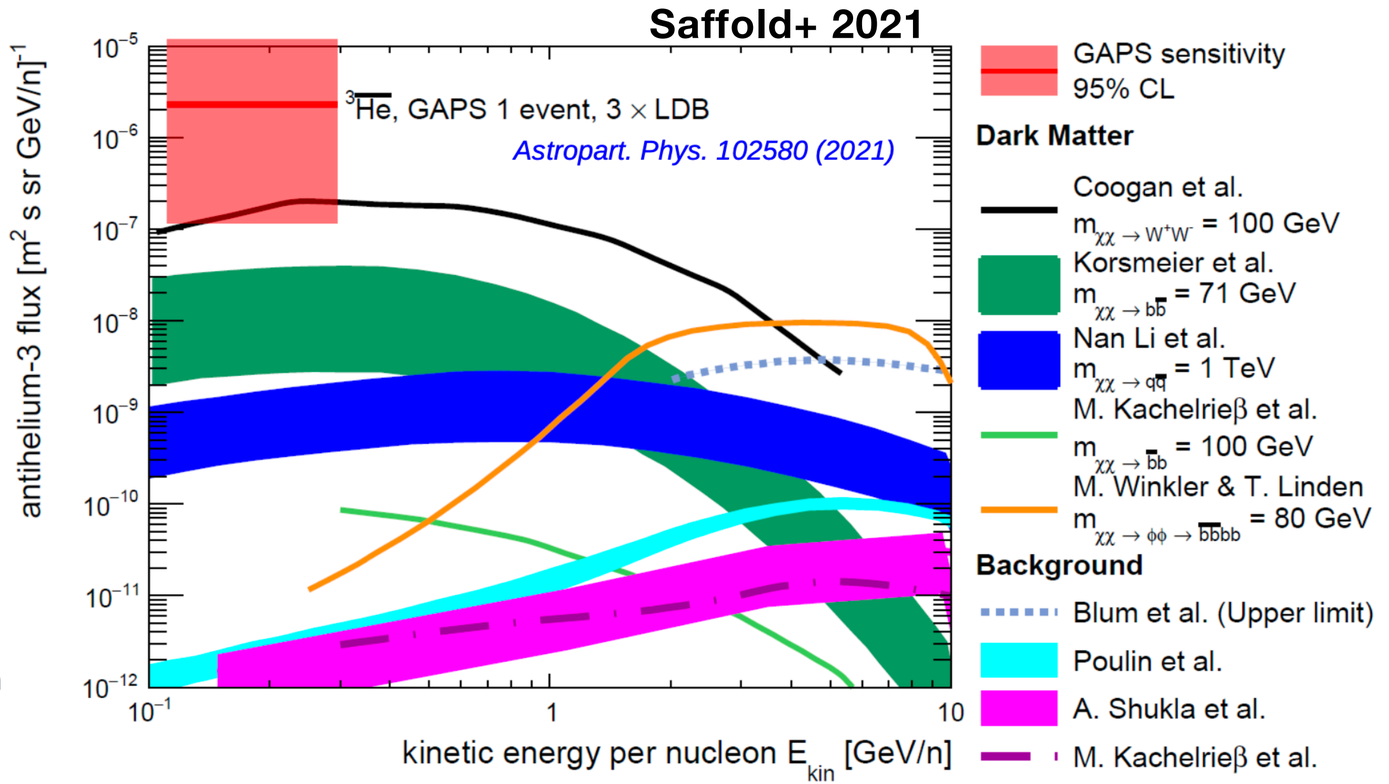
Antiprotons

- Precision measurements (~20x statistics)
- Low-mass DM search
- propagation model study
- Verification of antiparticle detection



Antiheliums

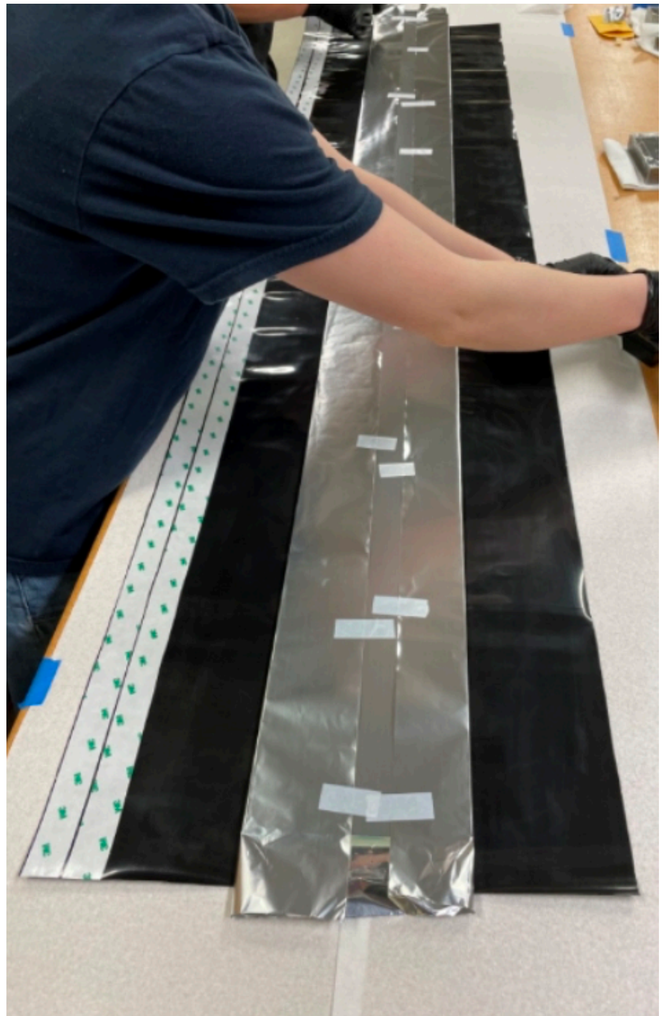
- Complementary to AMS-02
- Potentially explore some DM models

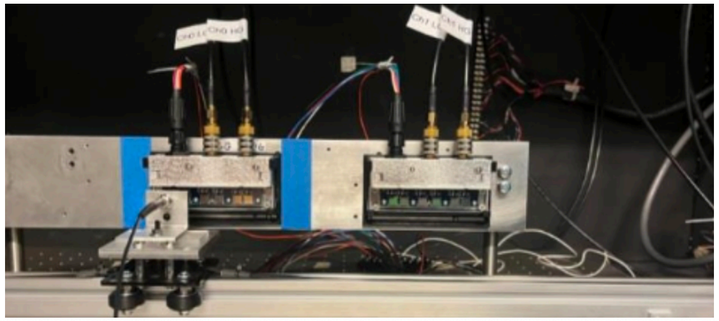


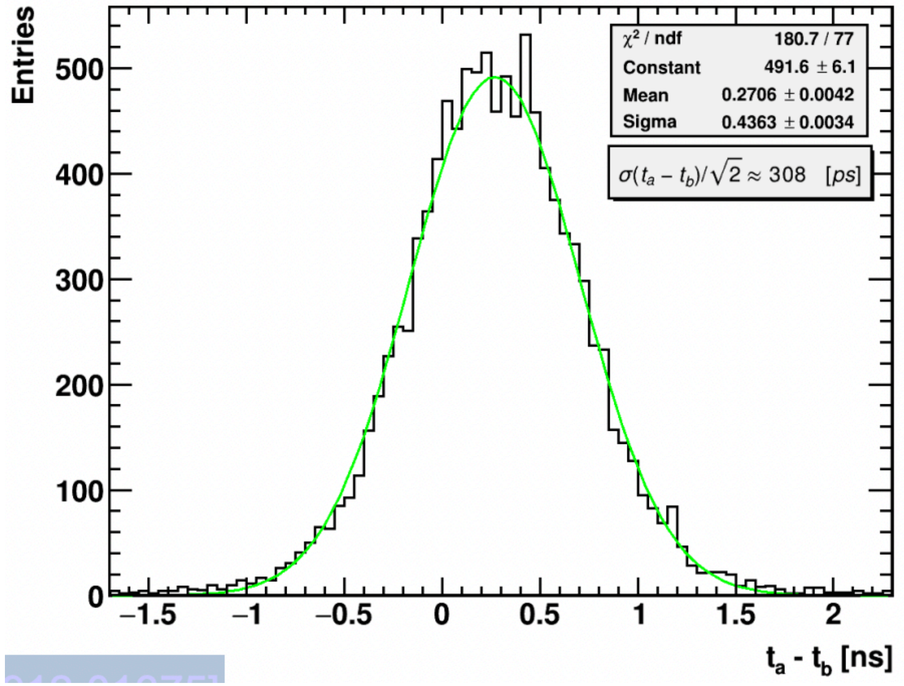
Current Status: TOF

~300 ps achieved, assembly in progress

@UCLA, paddle assembly, SiPM calibration

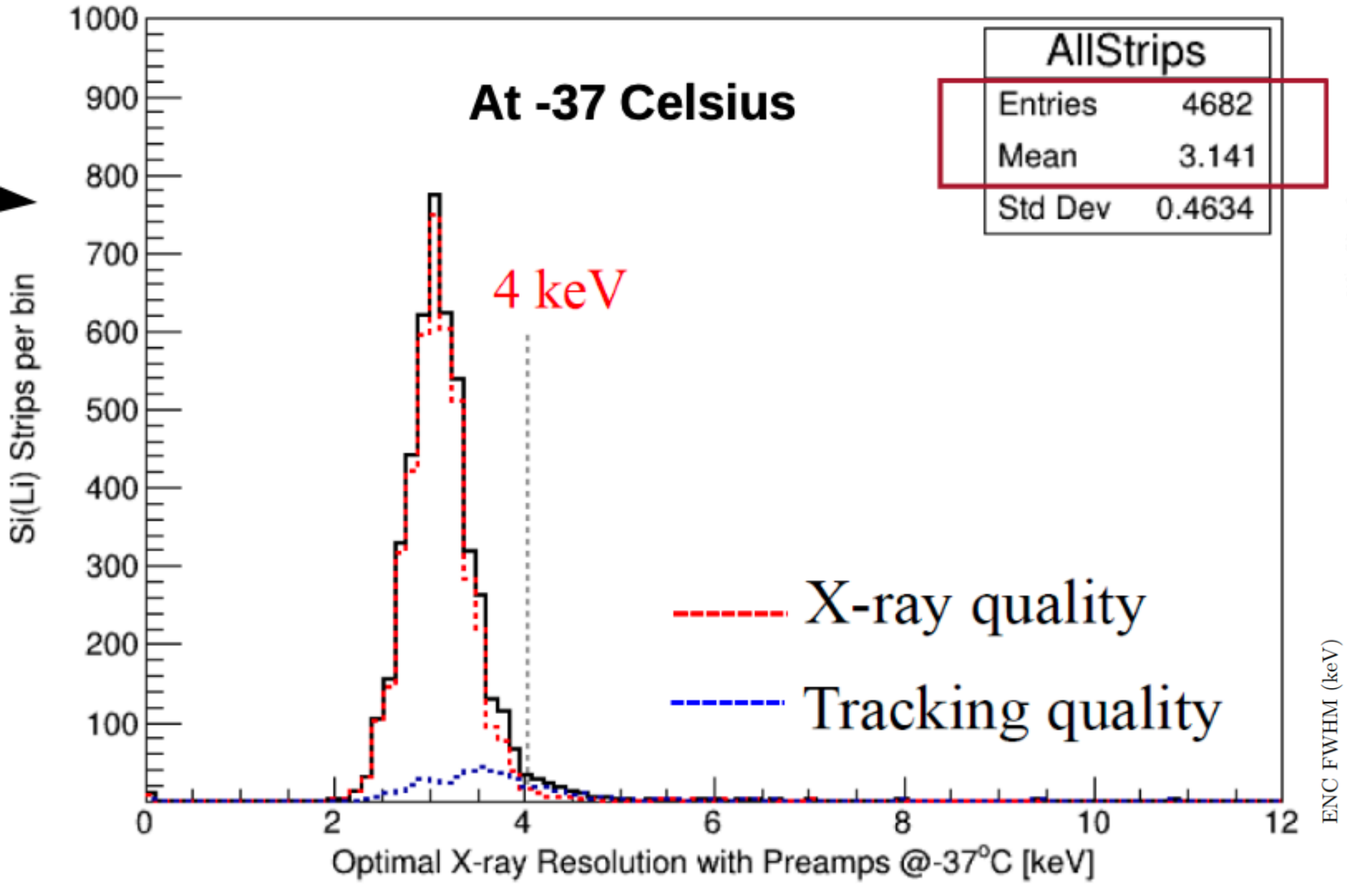


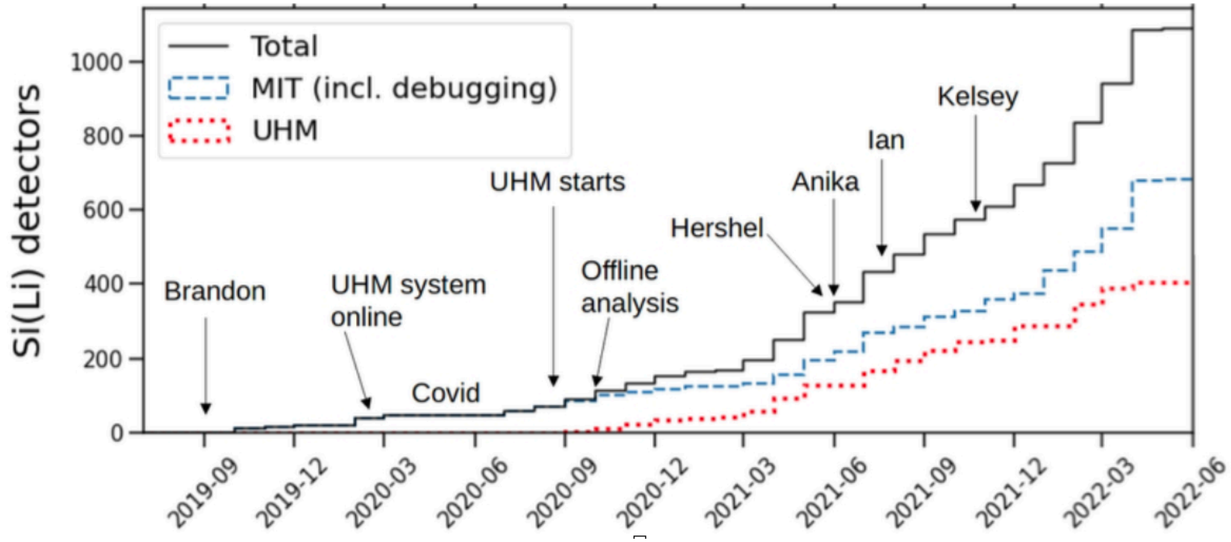


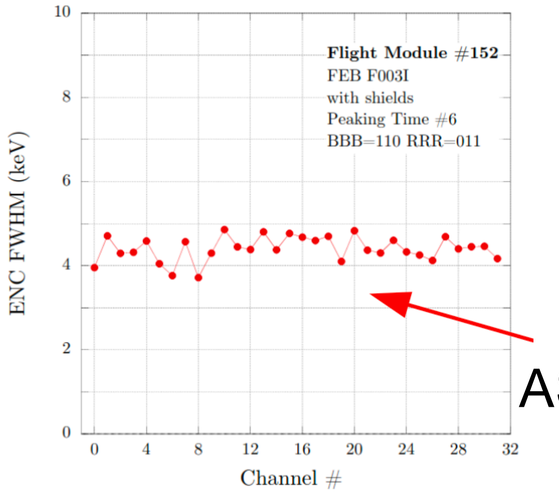


Current Status: Si(Li)

Tracker qualification test completed in May 2022

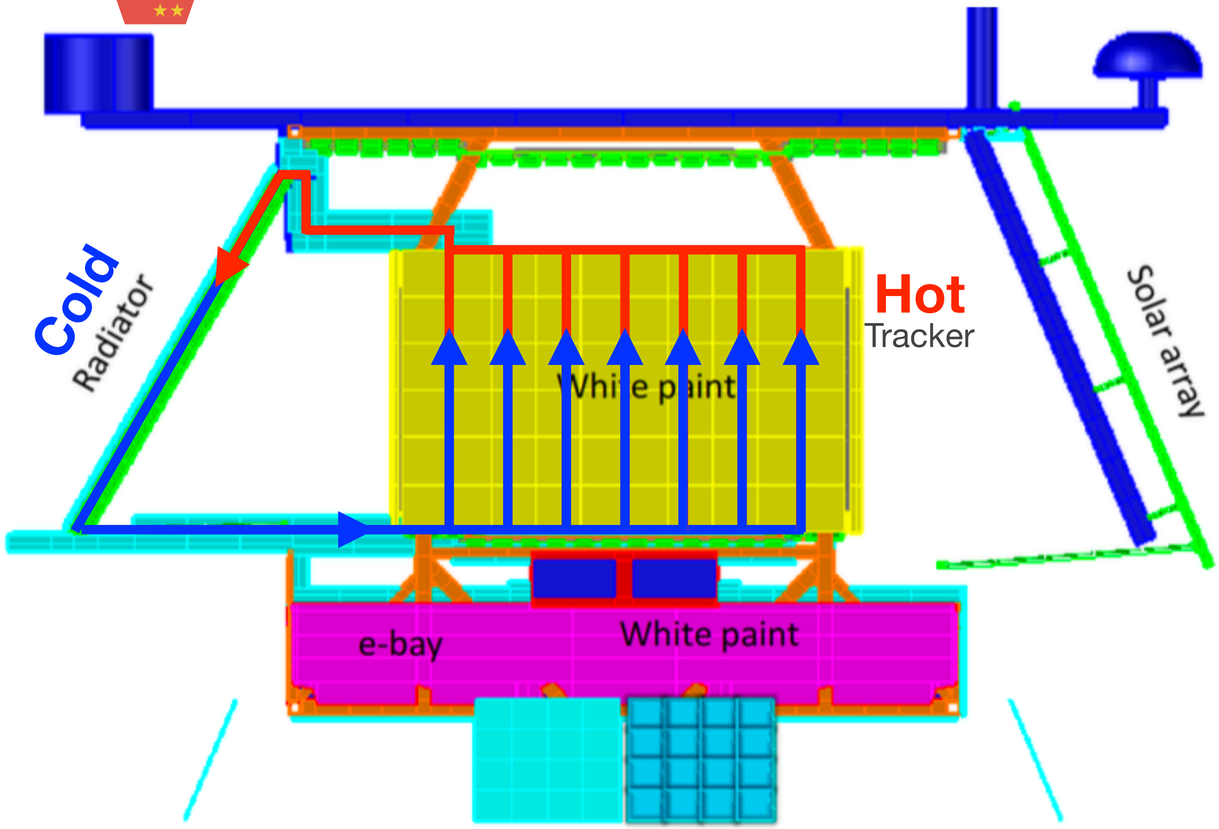






ASICs resolution: ~ 4 keV

Current Status: OHP Cooling System



- Developed at JAXA/ISAS (10+ years), but first time for the balloon mission
- Low-power, low-mass cooling system without an active pump
- Capillary tubes with a two-phase fluid self-oscillating/circulating

- Thermal model developed and confirmed in two piggyback balloon flights at Ft. Sumner.
- Thermal performance demonstrated in Functional Prototype and Integration/Testing

GAPS Functional Prototype Testing: 2021 -

Assembly completed at MIT Bates Research Lab

Si(Li) Tracker

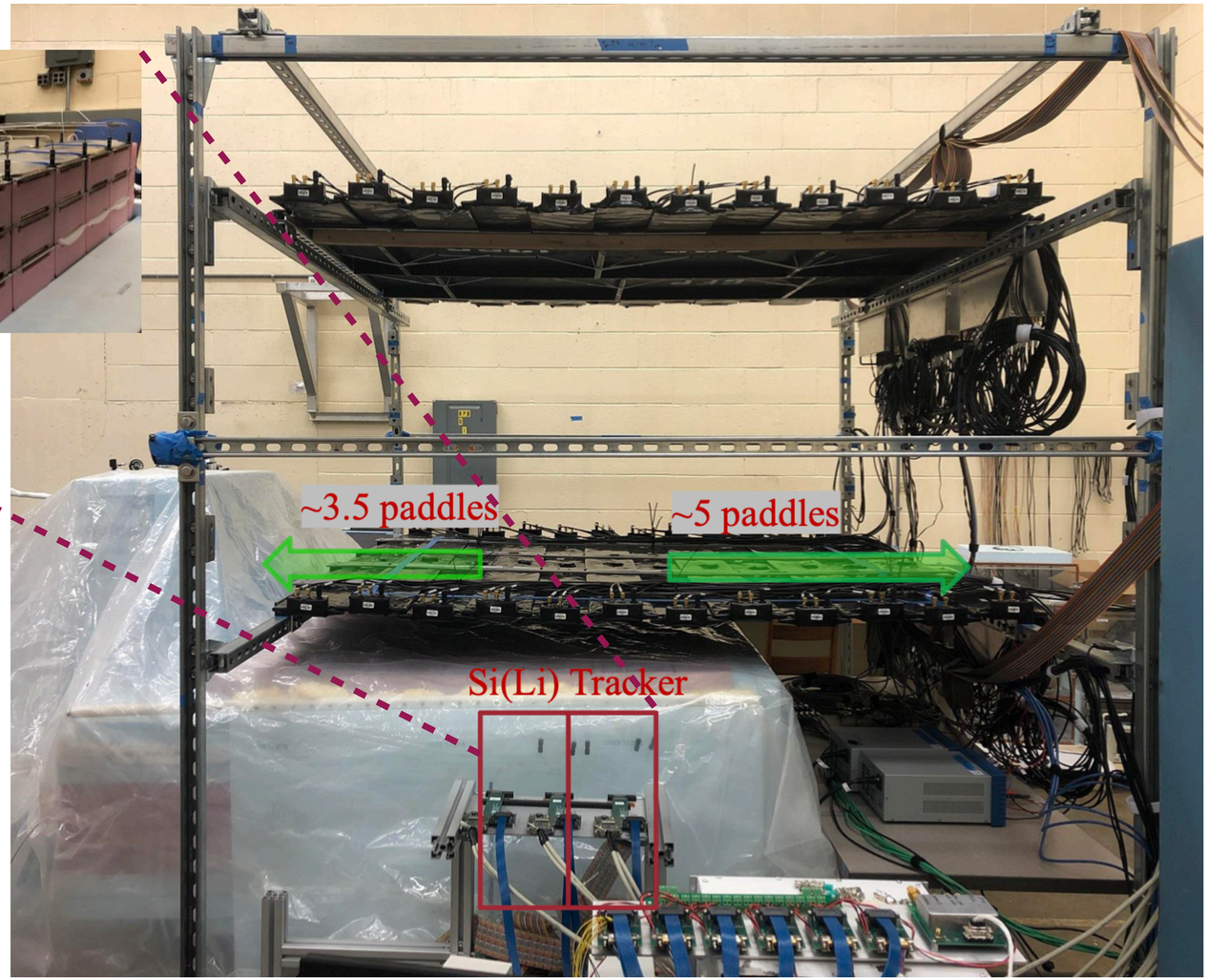
- 3 layers, 36 modules
- Readout with ASICs

Time of Flight (TOF)

- 2 layers above Si(Li) tracker

Successfully demonstrated

- **Interface of all key components**
- **Readout chain**
- **Reconstruct muon events**
  - **Trigger, event building, track reconstruction algorithms**



Integration and Testing: 2022 -

Assembly in progress at MIT Bates Research Lab

Full-scale cooling test

- Cool down radiator with GCS
  - Ultra-low temperature chiller
  - Water cooler

Tracker integration (as of 7/20)

- Layer 8,9 dummy modules
- Layer 7: low-quality modules
- Layer 6: X-ray quality modules

Gondola will be shipped to UCB/SSL

- TOF and flight system integration

Timeline and Collaboration

- 2002: GAPS concept paper published
- 2004/2005: Beam test at KEK
- 2012: Prototype/engineering flight
- 2016: NASA APRA program selected
- 2021: GAPS Functional Prototype started
- 2022: Integration and Testing started

Upcoming:

- 2023.5: Thermal vacuum test
- 2023.12: First balloon flight from the Antarctic

Summary

- GAPS is the first experiment optimized for low-energy (< 250 MeV/n) antinuclei measurements
  - Antideuteron measurements are essentially background-free DM searches
  - Precision antiproton measurements could allow us to investigate low-mass DM models and propagation models
  - GAPS could detect low-energy antiheliums, complementary to AMS-02
- We assembled the small-scale functional prototype and tested the interface of all components, readout chain, and trigger/event building/reconstruction algorithms
- Gondola assembly started this year, and the OHP cooling system and tracker layers 6-9 are already installed.
- The first balloon flight is scheduled from the Antarctic in late 2023