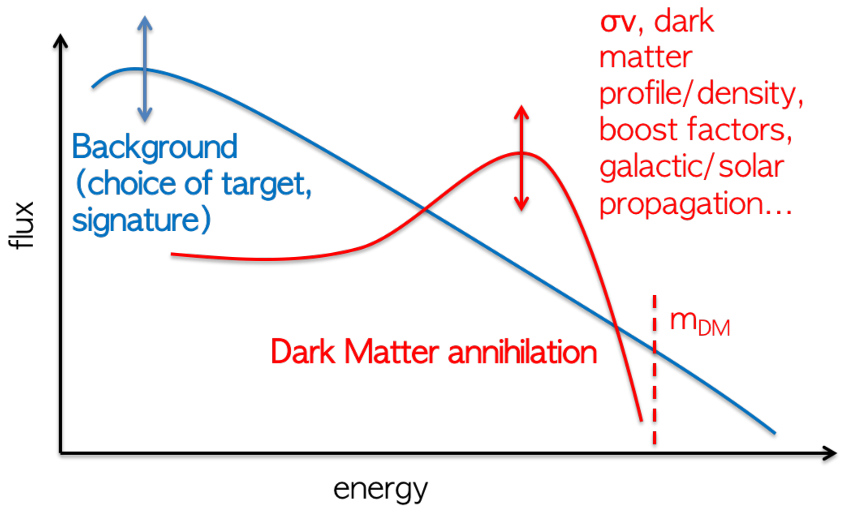
GAPS:
Cosmic-Ray Antinuclei for Dark Matter Searches

Kerstin Perez MIT
on behalf of the GAPS Collaboration

IDM Brown University
July 27, 2018

The challenge of astrophysical searches…

Common challenge = minimize/constrain astrophysical background,
maximize predicted dark matter signal



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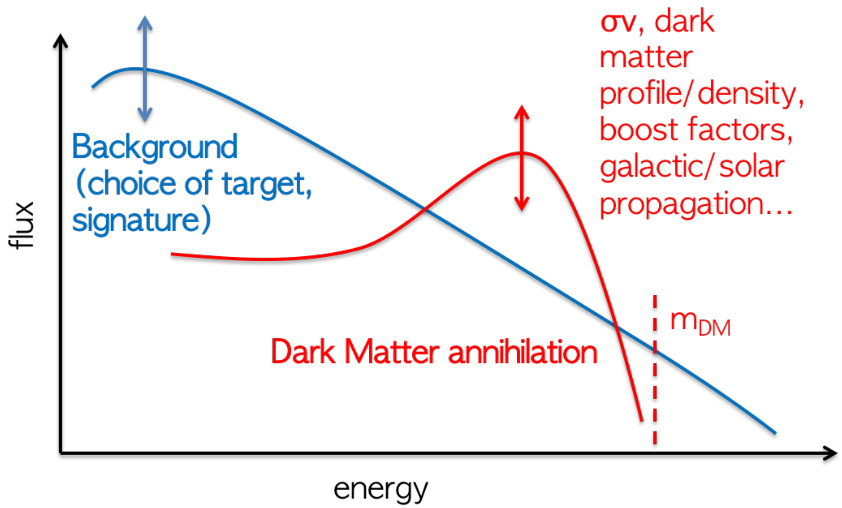
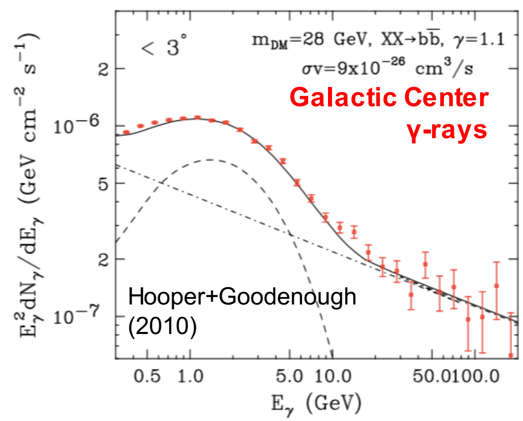
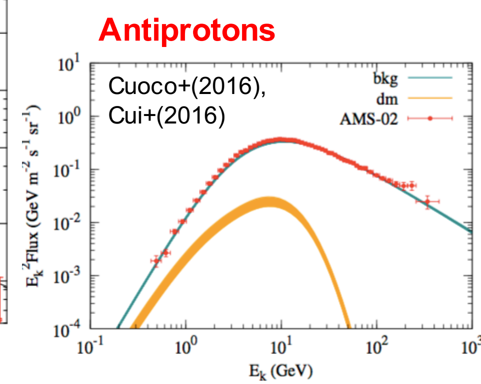
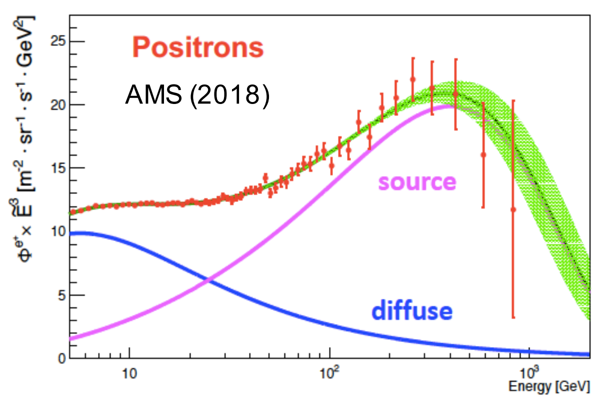






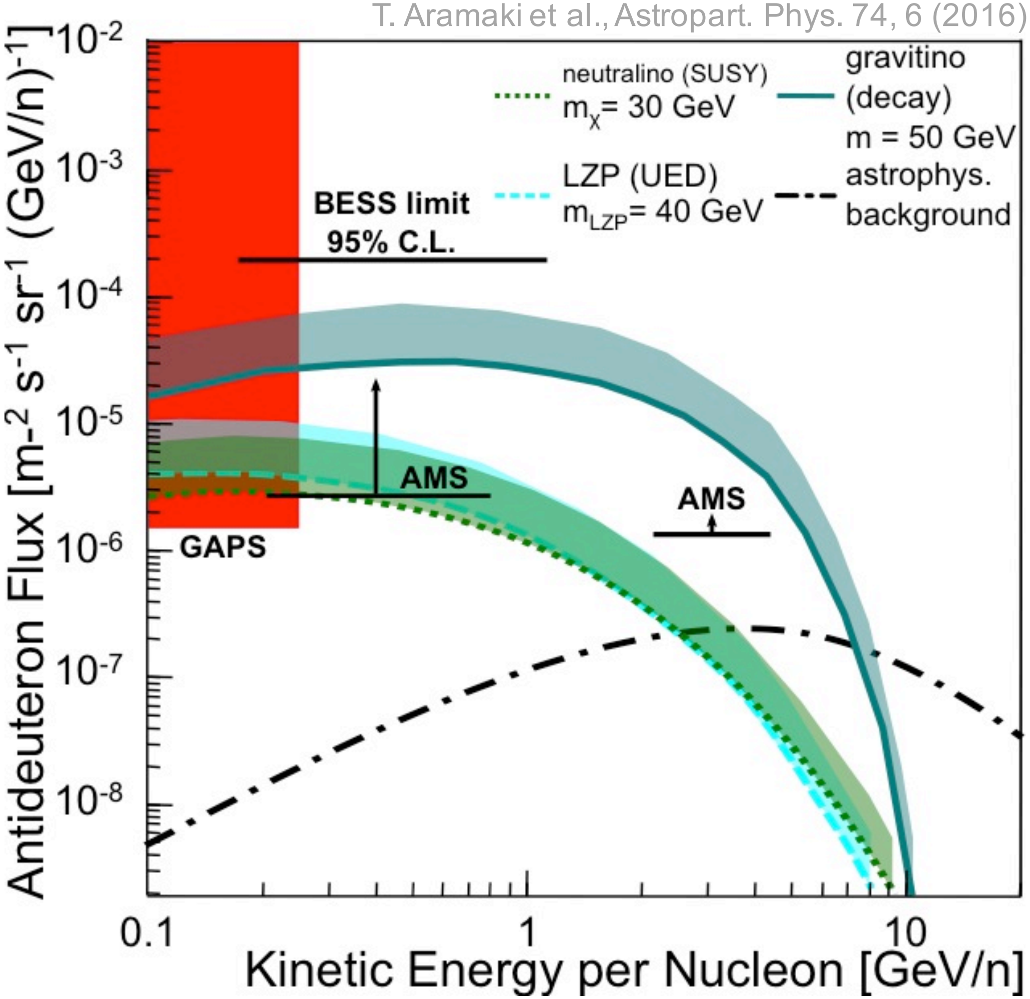


1. **Cosmic rays are full of surprises!**
2. **Surprises are difficult to interpret due to large/uncertain astrophysical backgrounds**
3. **Need cross-correlation with different signatures**

New physics in cosmic-ray **antideuterons**

A generic ***new physics*** signature with ***essentially zero*** conventional astrophysical background

T. Aramaki et al., Astropart. Phys. 74, 6 (2016)



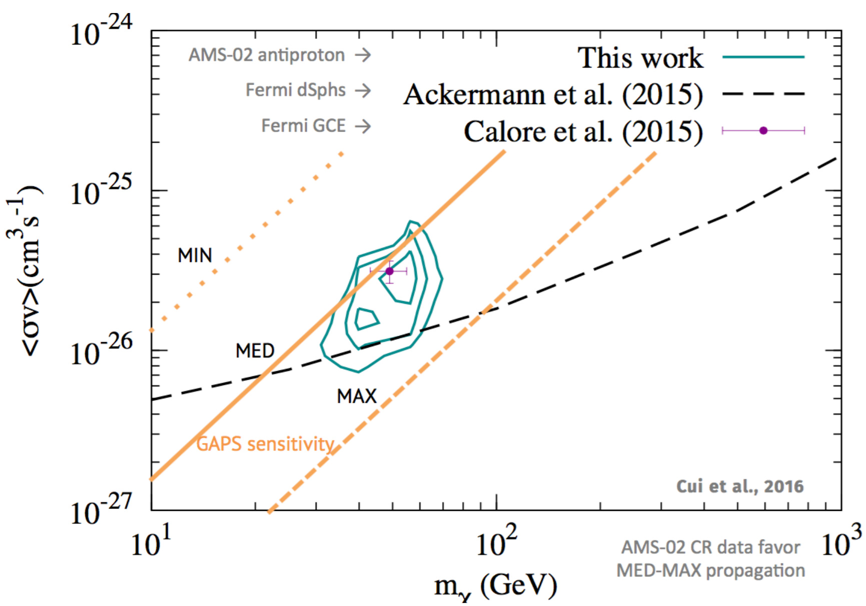
- Probes a variety of dark matter models that evade or complement collider, direct, or other cosmic-ray searches
- GAPS first experiment optimized specifically for low-energy antinuclei signatures
- **First Antarctic flight: late 2020**

Review of antideuteron experiment and theory:
Phys. Rept. 618 (2016) 1-37

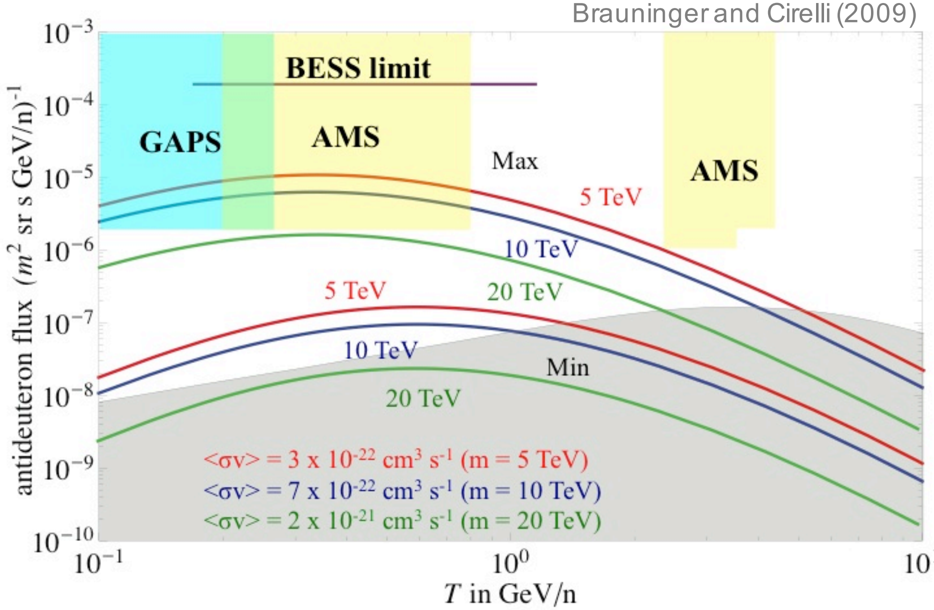
Complementary sensitivity to viable DM signatures

See also: Korsmeier, Donato, Fornengo 1711.08465 (2018), Aramaki+ 1505.07785 (2016)

- Sensitive to ~10s of GeV mass DM models, ***as invoked to explain gamma-ray and antiproton observations***

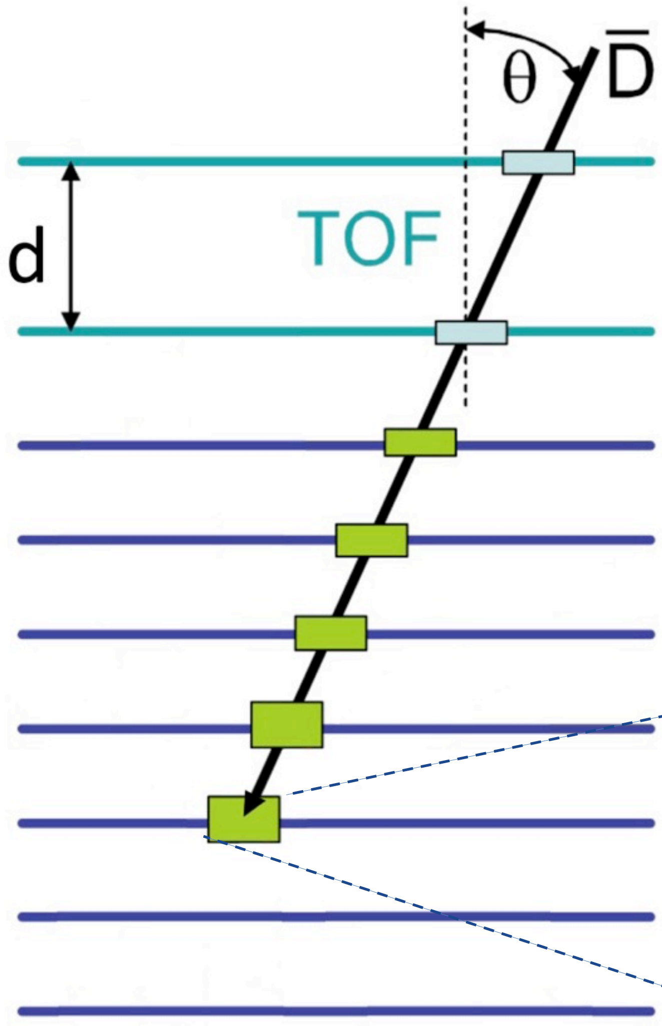


Brauninger and Cirelli (2009)

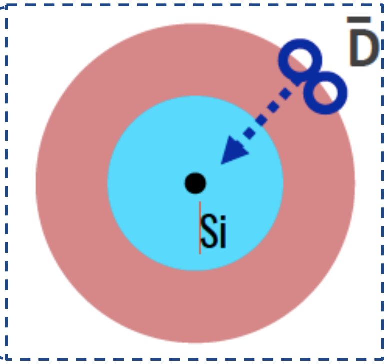


- Sensitive to heavy DM models, ***as invoked to explain positron observations***

GAPS detection: exotic atom capture and decay



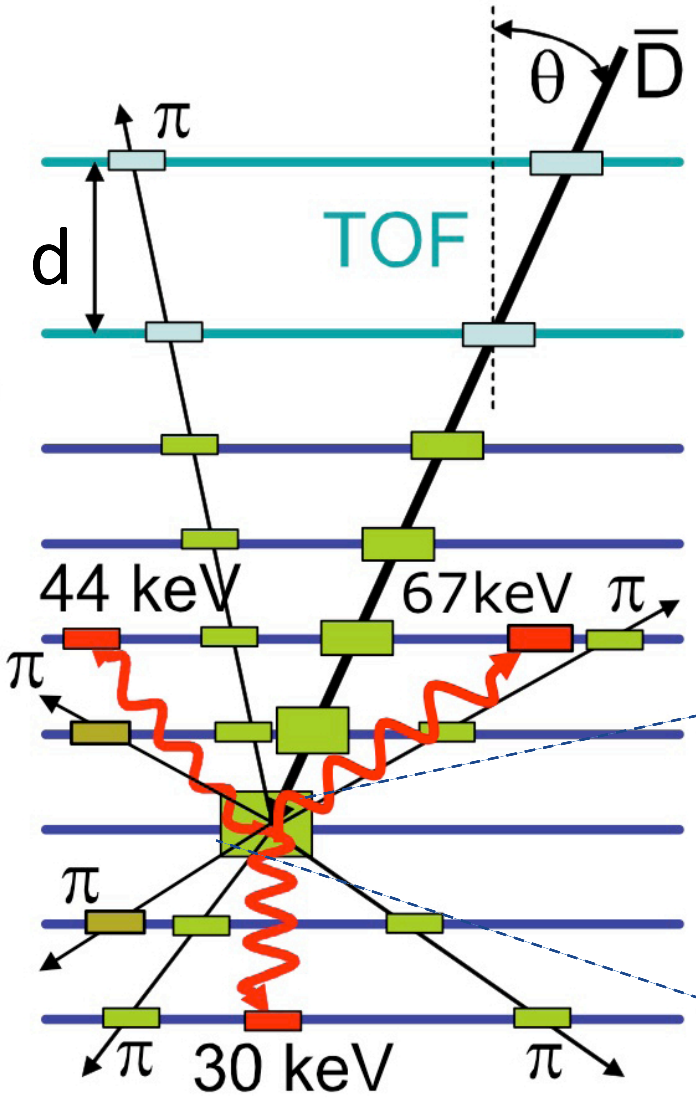
- **Time-of-flight** system measures velocity and dE/dx
- Loses energy in layers of semiconducting **silicon targets/detectors**
- Stops, forming **exotic excited atom**



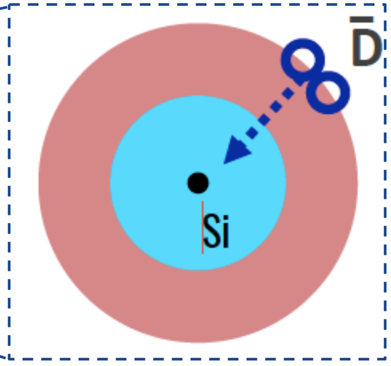
Aramaki et al. Astropart.Phys. 49 (2013) 52-62 (2013)

Aramaki et al., Astropart. Phys. 74, 6 (2016)

GAPS detection: exotic atom capture and decay



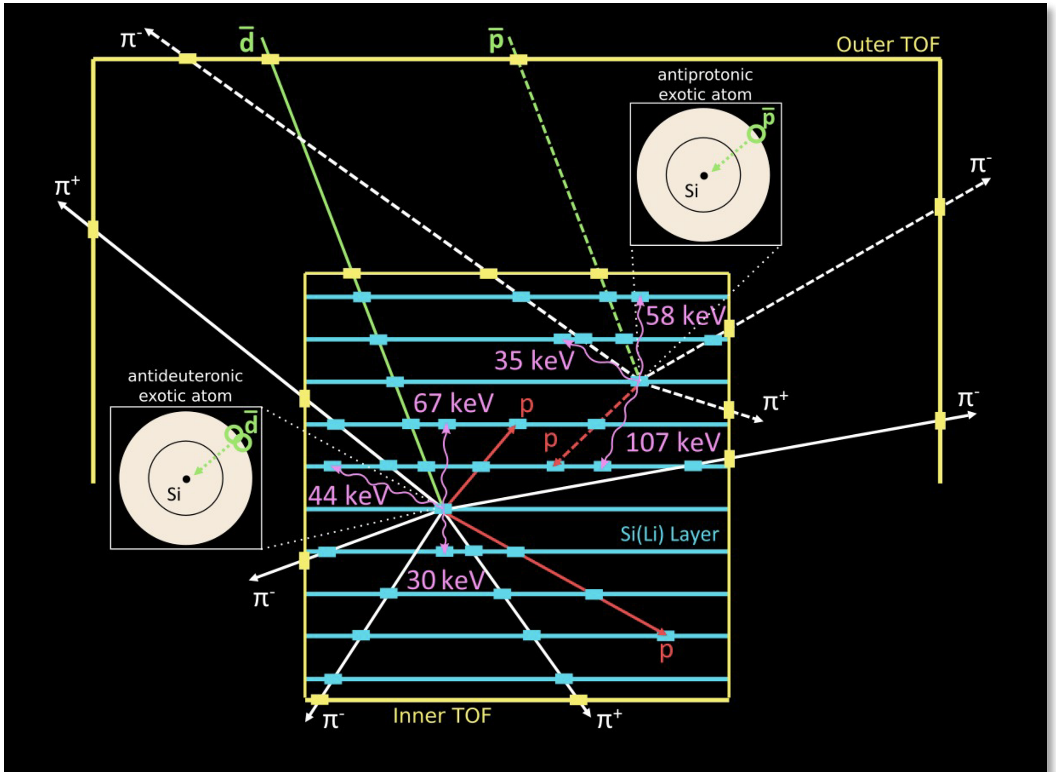
- **Time-of-flight** system measures velocity and dE/dx
- Loses energy in layers of semiconducting **silicon targets/detectors**
- Stops, forming **exotic excited atom**
- Atom de-excites, emitting **X-rays**
- Remaining nucleus annihilates, emitting **pions and protons**



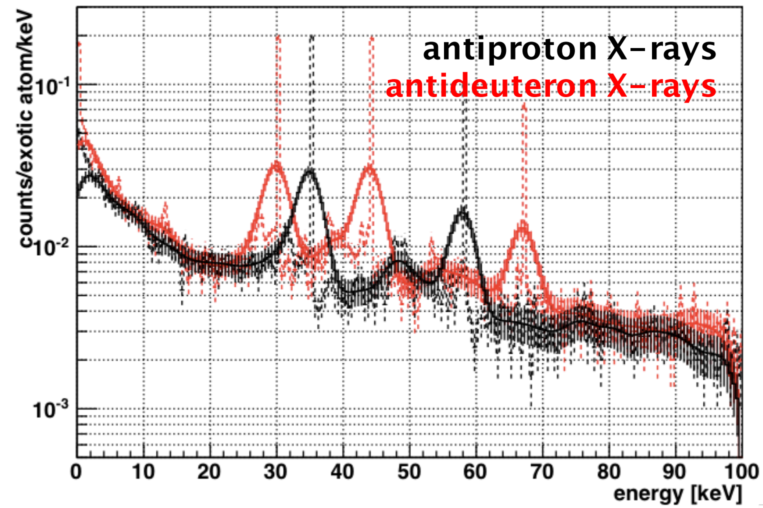
Aramaki et al. Astropart.Phys. 49 (2013) 52-62 (2013)

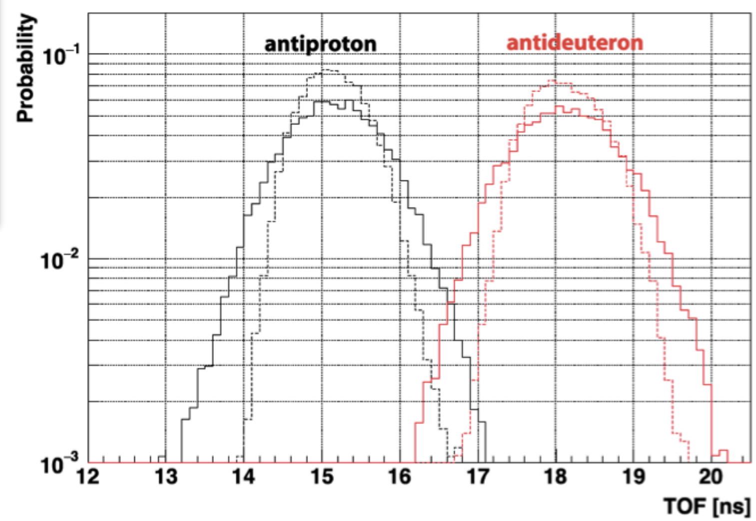
Aramaki et al., Astropart. Phys. 74, 6 (2016)

GAPS Background Rejection



T. Aramaki et al., Astropart. Phys. 74, 6 (2016)

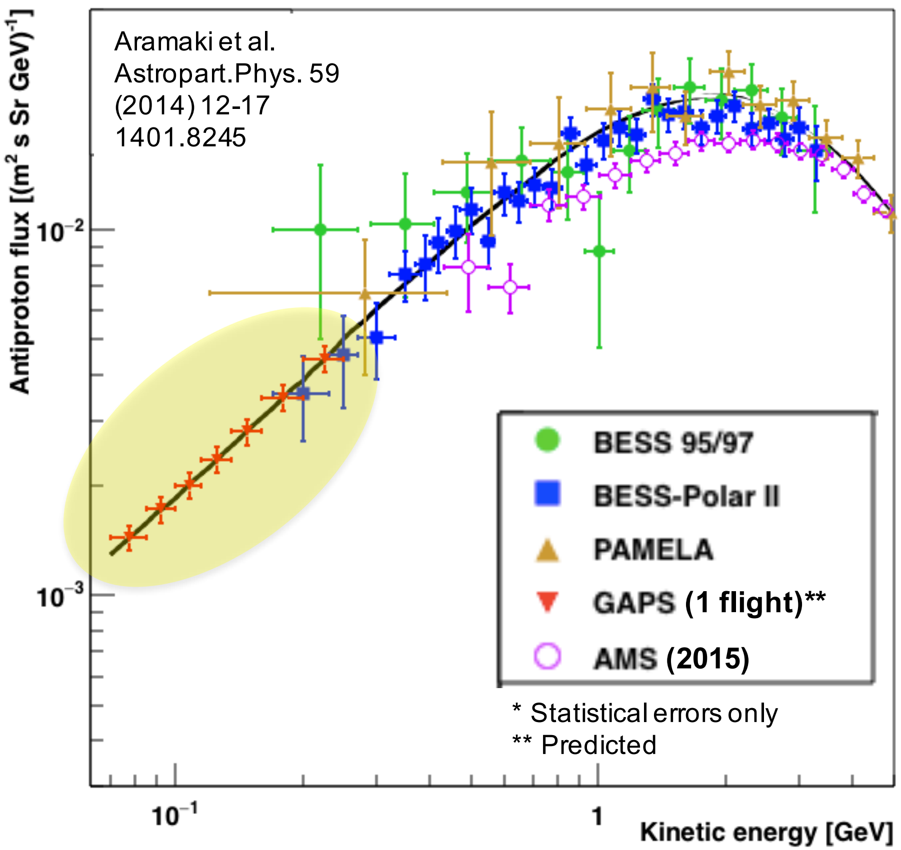




Combination of time-of-flight + depth-sensing, X-ray, and π detection yield rejection >10^6

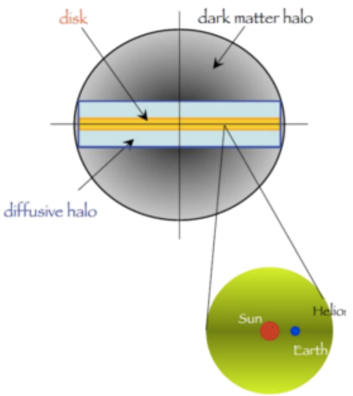
Extoic atom technique verified at KEK
Aramaki et al. 1303.3871 (2013)

Precision *low-energy* antiproton spectrum



GAPS will measure ***>1000 antiprotons in each flight, in unprecedented low-energy range***

- Reduces systematic uncertainties for antideuteron search, both experimental and theoretical



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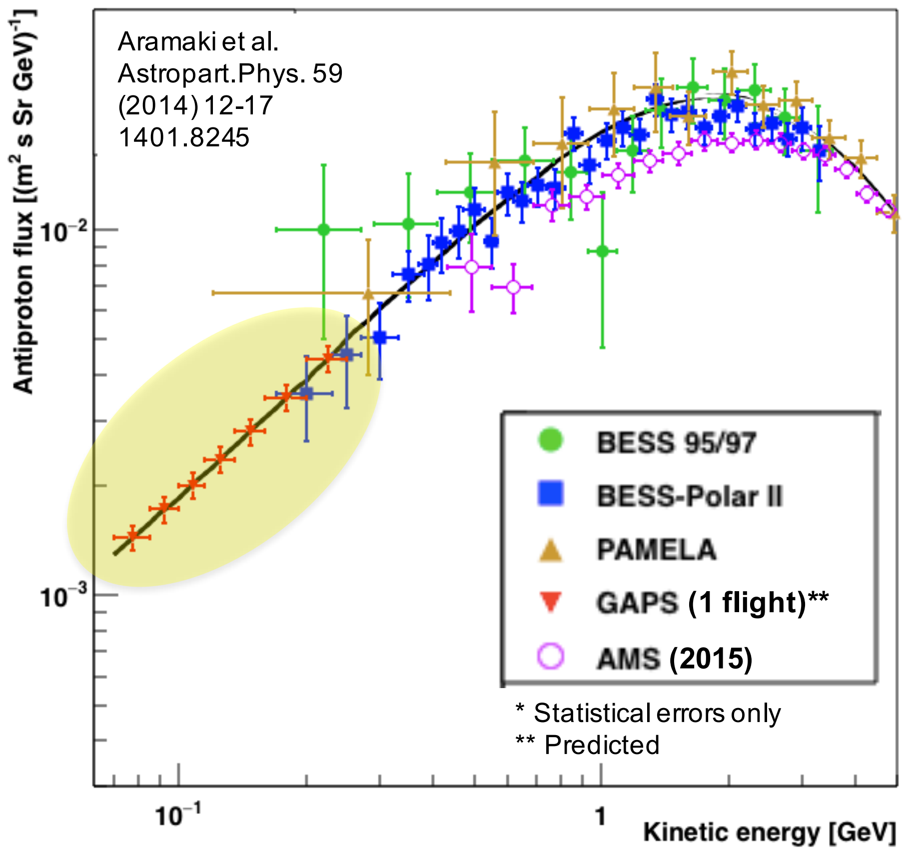

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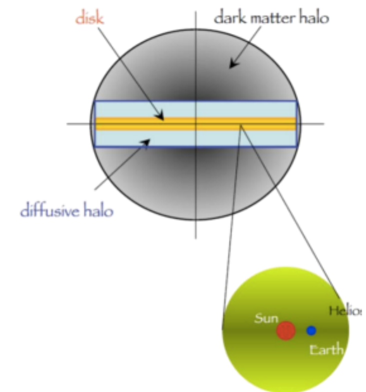
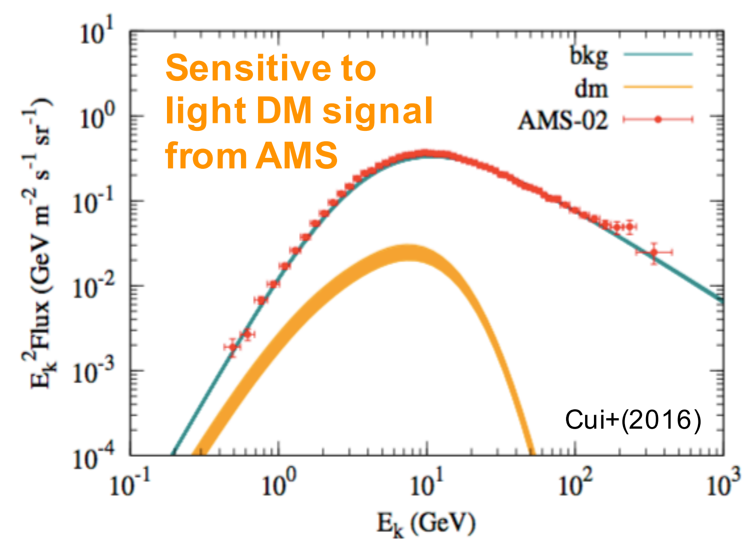


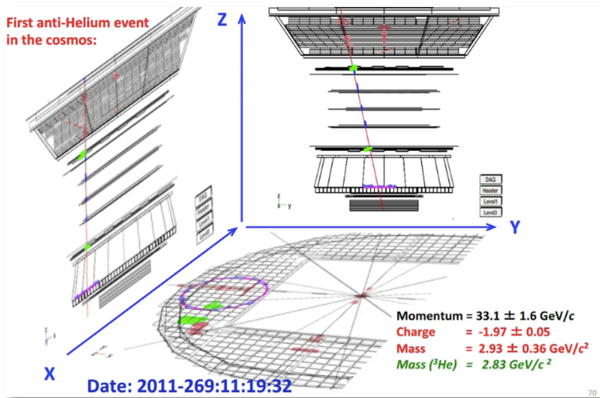
- Can probe light dark matter (e.g. decaying gravitino, LZP from extra-dimensional theories, primordial black holes)



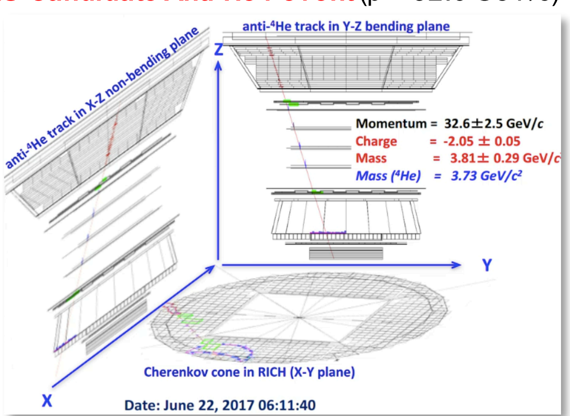
Low-energy anti-helium search

- GAPS exotic atom technique also sensitive to ***anti-He***, in complementary lower energy range to where AMS has reported candidate events.
- Ongoing work to estimate and optimize GAPS sensitivity to anti-helium.

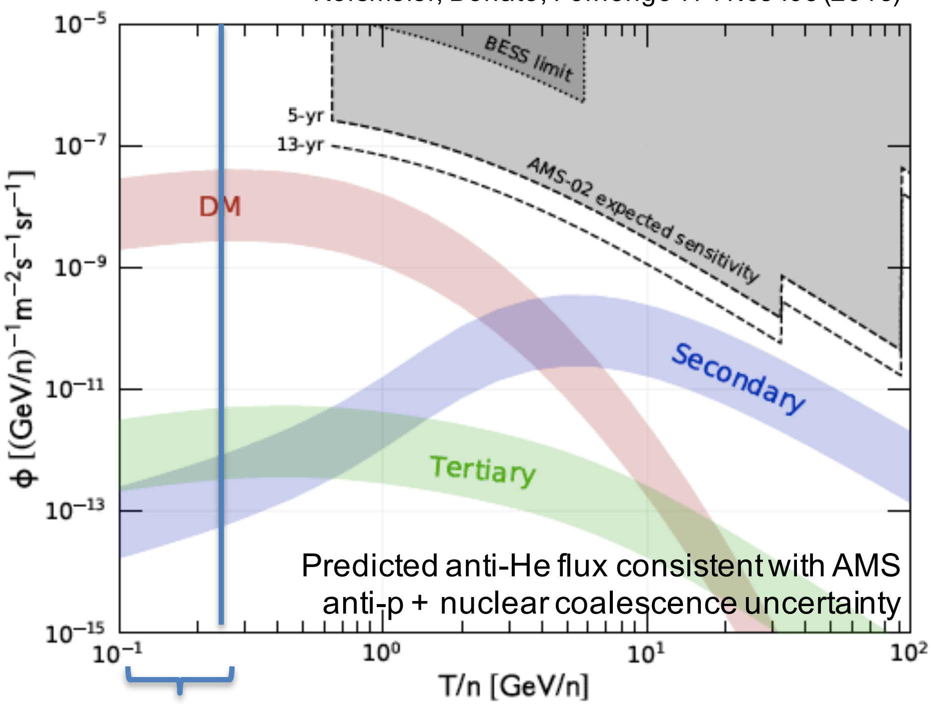
AMS Candidate Anti-He3 event (p = 33.1 GeV/c)



AMS Candidate Anti-He4 event (p = 32.6 GeV/c)



Korsmeier, Donato, Fornengo 1711.08465 (2018)



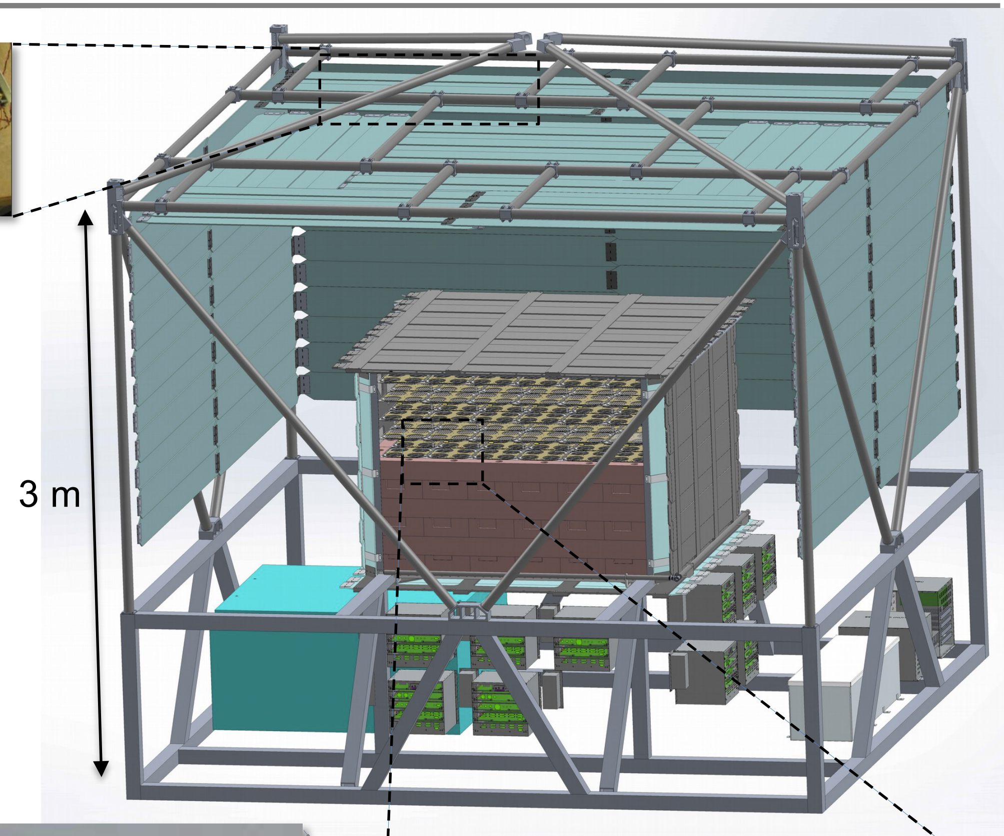
GAPS energy range

See also: Googan+Profumo 1705.09664,
Blum+ 1704.05431

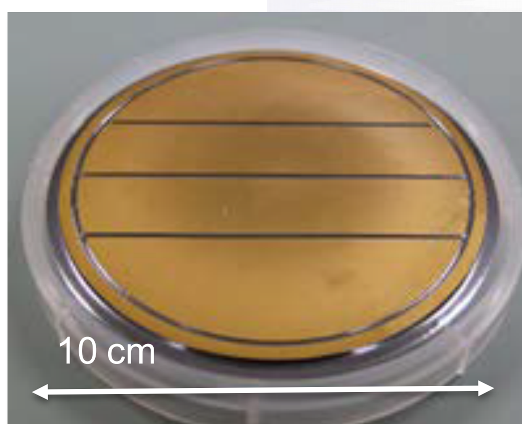
The GAPS Team

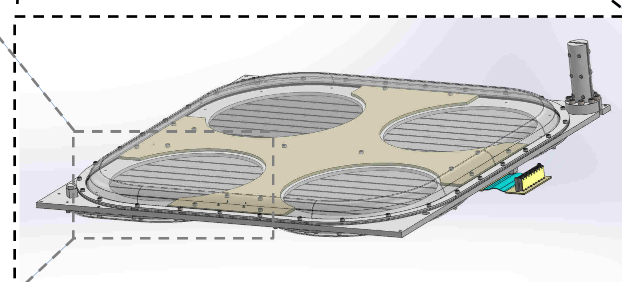
GAPS Detector Design

Plastic scintillator TOF
- high-speed trigger and veto
- 160-180 cm long, 0.6 cm thick
- read out both ends
- < 500 ps timing resolution



Si(Li) tracker
- X-ray identification, dE/dx, stopping depth, and shower particle multiplicity
- 2.5 mm thick, 4” diameter
- 4 keV resolution for X-rays

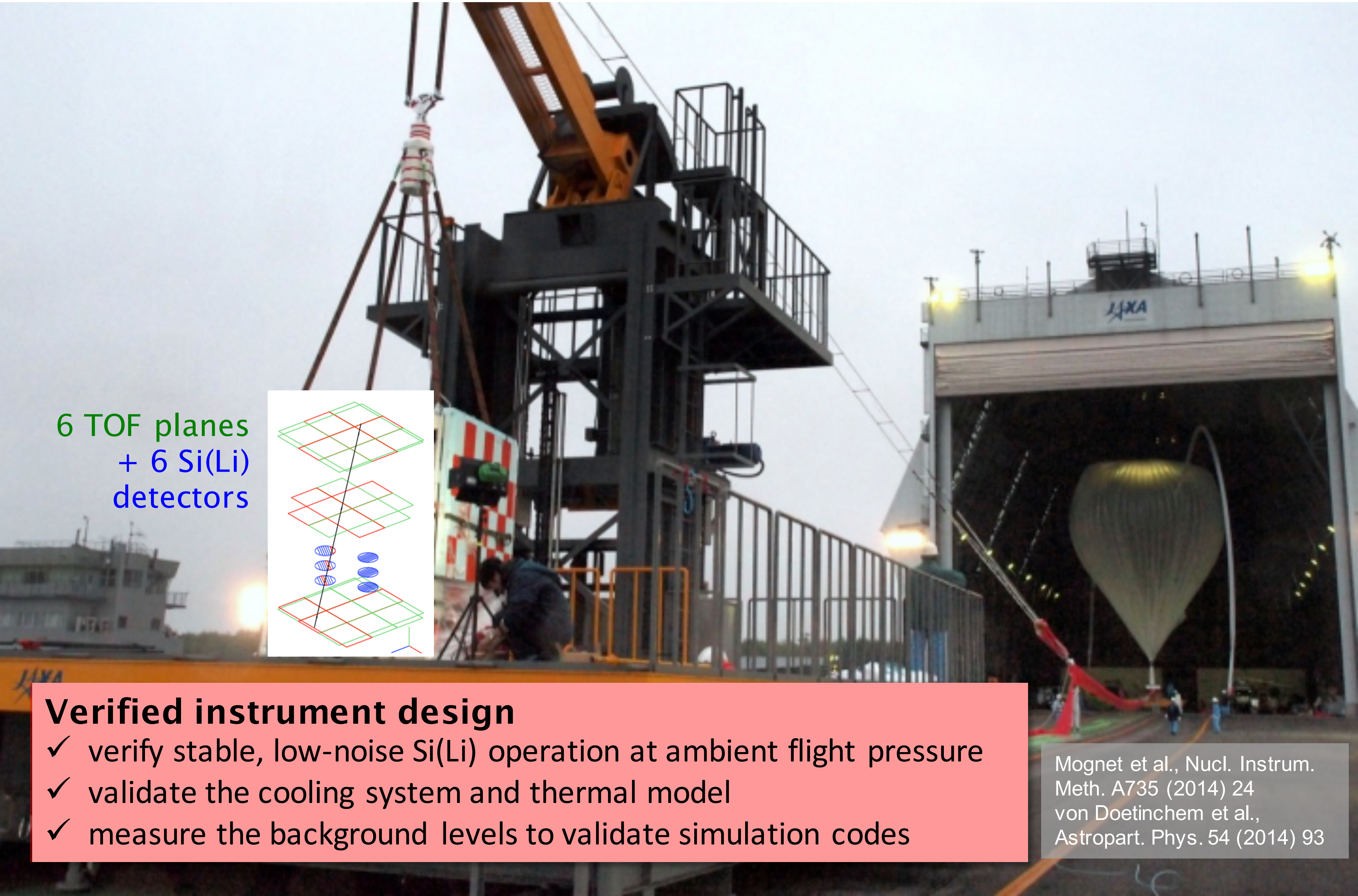




Prototype flight (pGAPS)

Taiki, Japan
2012

6 TOF planes
+ 6 Si(Li)
detectors



Verified instrument design

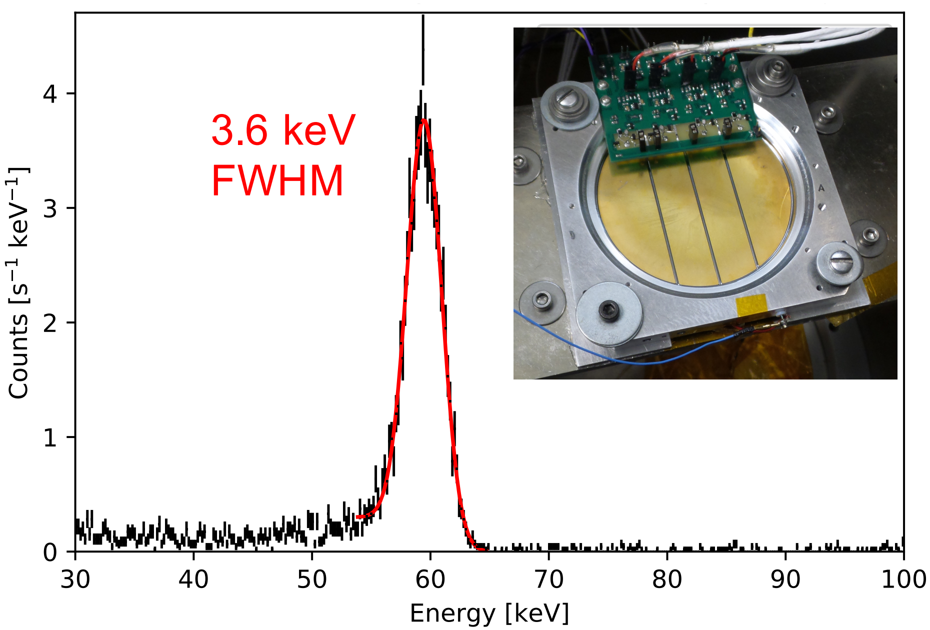
- ✓ verify stable, low-noise Si(Li) operation at ambient flight pressure
- ✓ validate the cooling system and thermal model
- ✓ measure the background levels to validate simulation codes

Mognet et al., Nucl. Instrum. Meth. A735 (2014) 24
von Doetinchem et al., Astropart. Phys. 54 (2014) 93

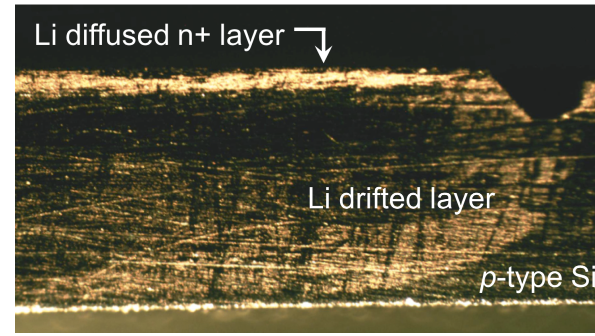
Development and construction: Si(Li) detectors

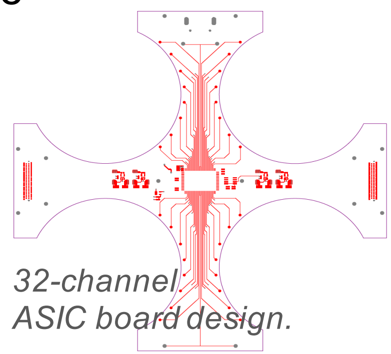
GAPS will need ~1000 Si(Li) detectors

- ✓ Low-cost fabrication scheme developed in partnership with Shimadzu Corp.
- ✓ Demonstrates required ~4 keV energy resolution at relatively high temp of -35 to -45 C
- ✓ Readout via custom ASIC: integrated low-noise preamplifier, dynamic range compression 20 keV to 50 MeV



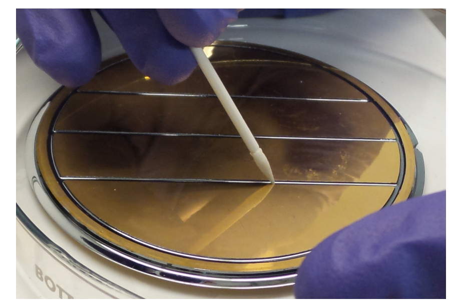
Perez+ in press NIM A (2018) 1807.07912.

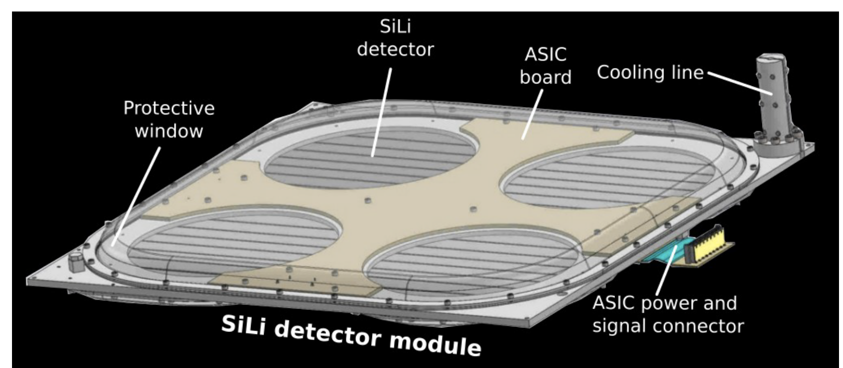




32-channel ASIC board design.

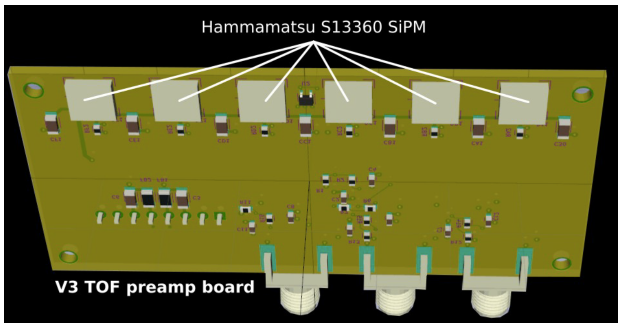
Investigating passivation procedures





Development and construction: TOF and cooling

TOF preamp boards (404 total)

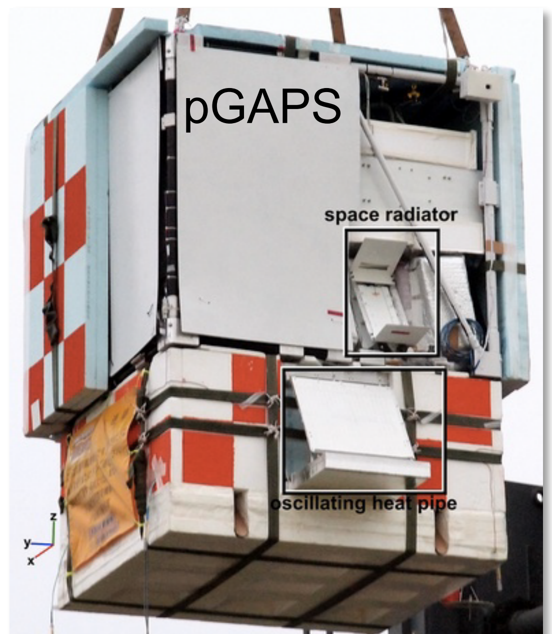


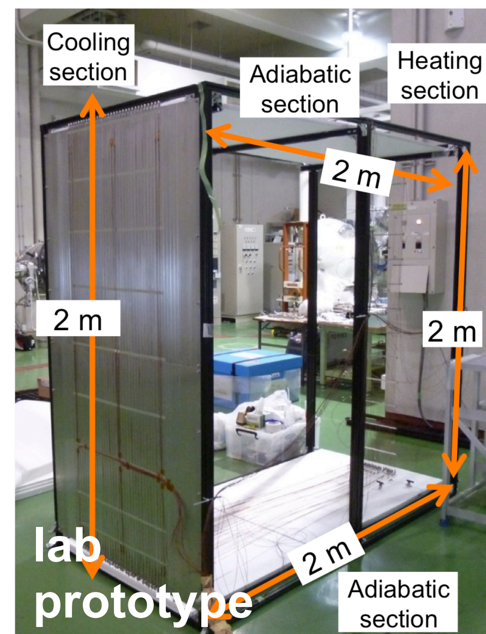
TOF will use 202 EJ-200 scintillators

- SiPM readout, digitized with DRS4 ASIC
- < 500 ps timing resolution demonstrated
- optimizing trigger, accepts ~80% of antinuclei while reducing proton/alpha rate by 10^3-10^4

Oscillating heat pipe (OHP) developed for GAPS

- rapid expansion and contraction of bubbles in liquid create thermo-contraction hydrodynamic waves that transport heat





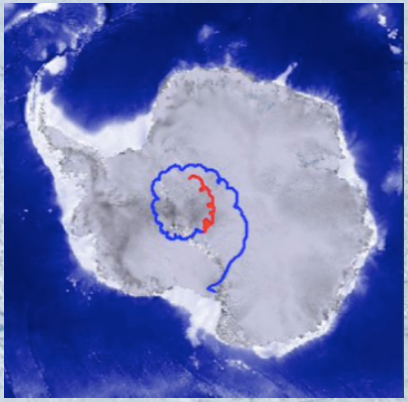
Okazaki+ Applied Thermal Engineering 141 (2018)
Fuke+ vol. 39 of COSPAR Meeting, 568 (2012)
Okazaki+ Journal of Astronomical Instrumentation 3 (2014).

Initial Antarctic flight in late 2020!

- 2000 — First idea
- 2004 — KEK beam tests
- 2012 — pGAPS flight
- detector and system design
- 2018
- TOF and Si(Li) fabrication
- 2020
- GAPS payload integration
- **First flight!** 2 follow-up flights planned

- **First GAPS flight will *improve current antideuteron limit by 1.5 orders of magnitude*, deliver *first precision antiproton flux below 0.25 GeV/n*, orthogonal detection technique to AMS**
- **Rapid timeline from funding start to GAPS construction, integration and first science flight in late 2020**

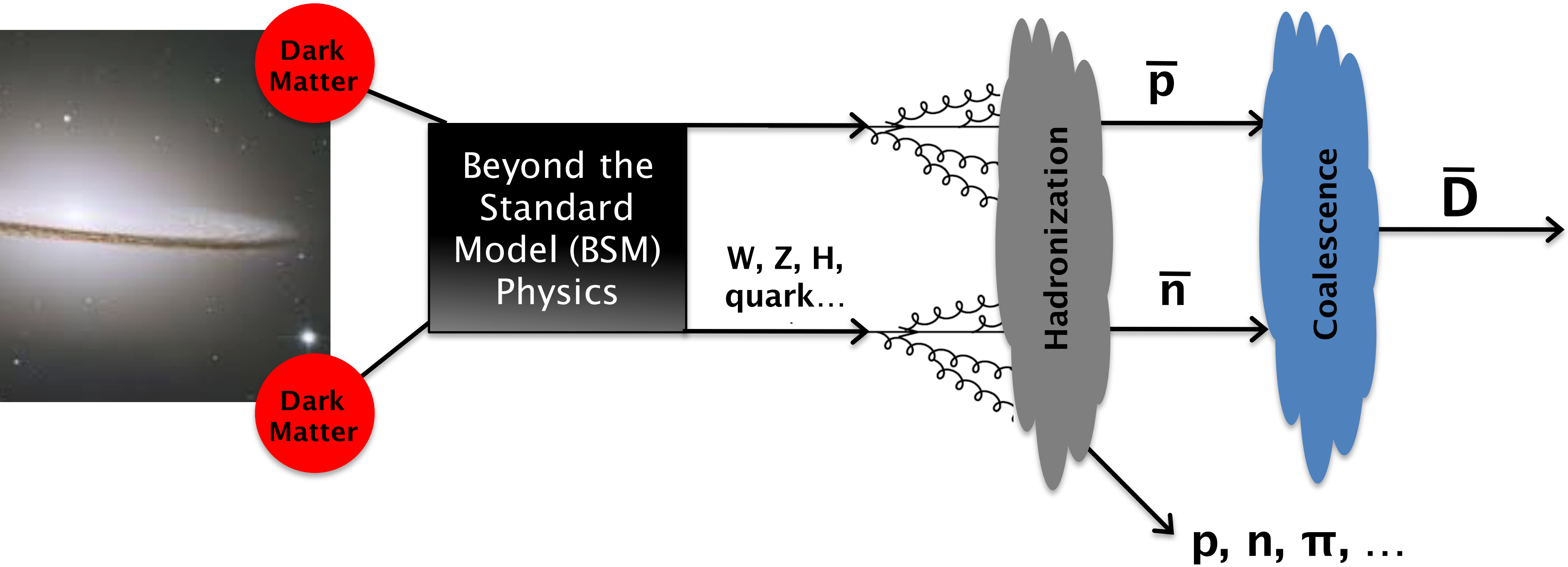
Long-duration balloon flight (~30 days)



K. Perez – MIT

Backup

Antideuteron Signal of Dark Matter

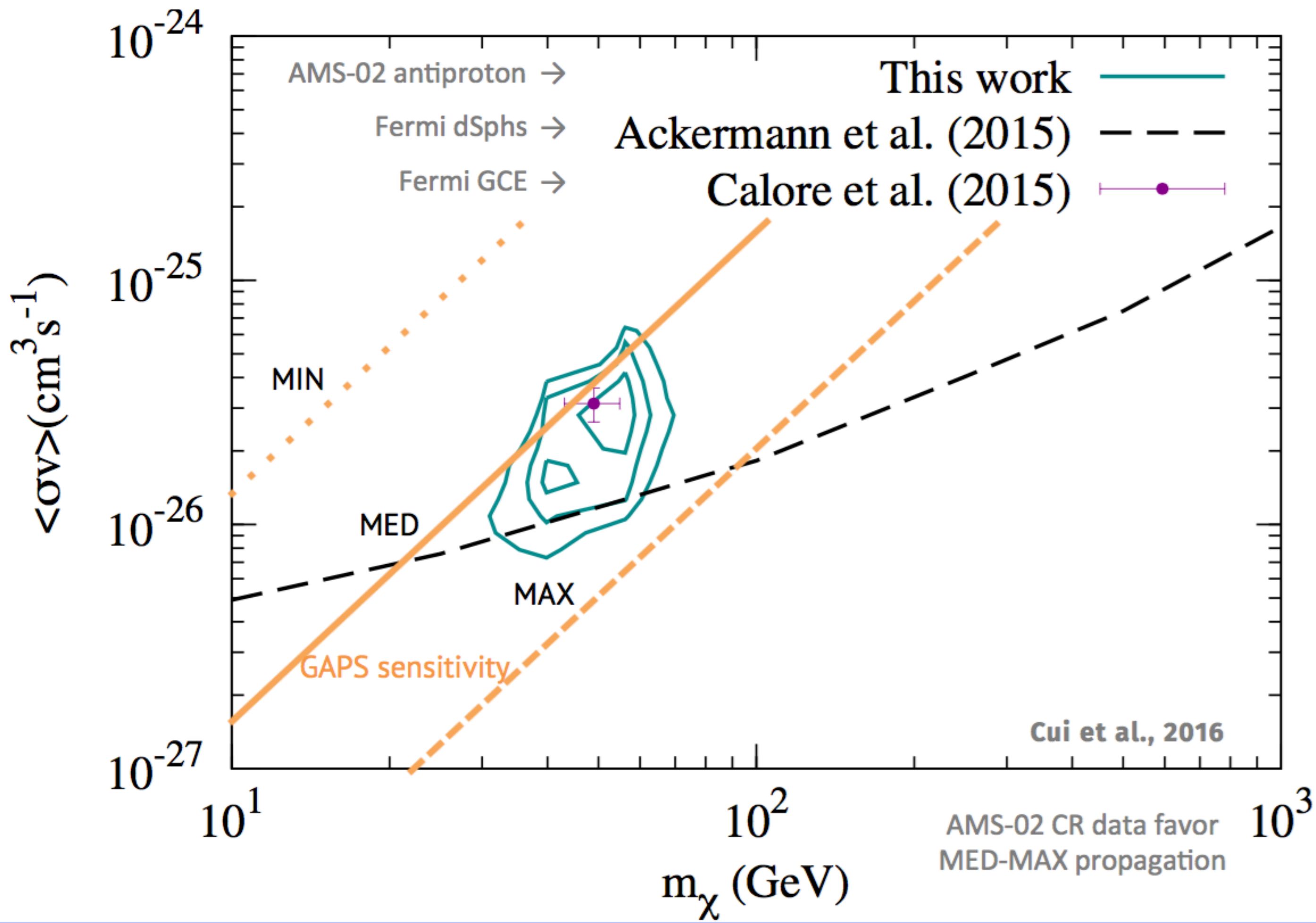


Dark matter particles annihilate…

…create jets of Standard Model particles…

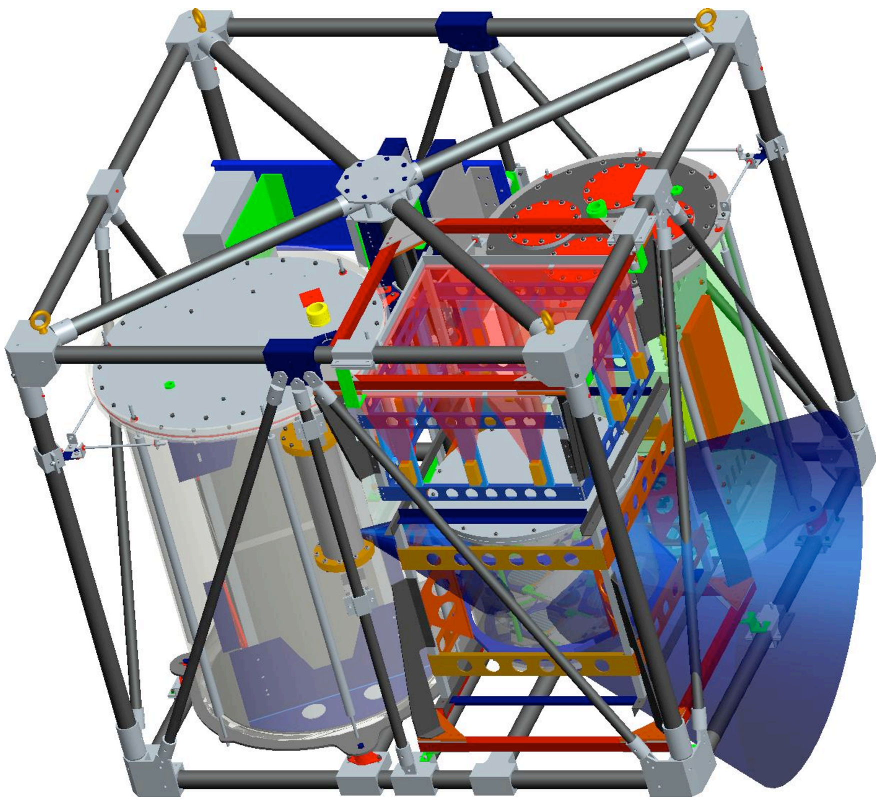
…some of which can make an antideuteron…

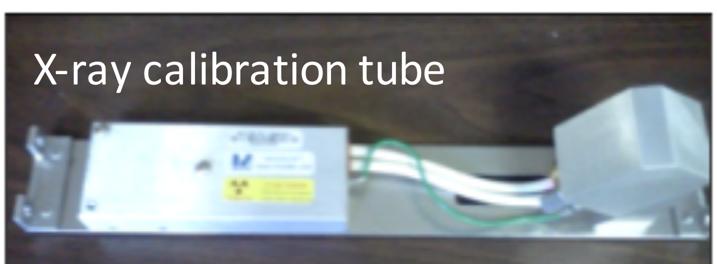
Fermi GC excess and antideuterons

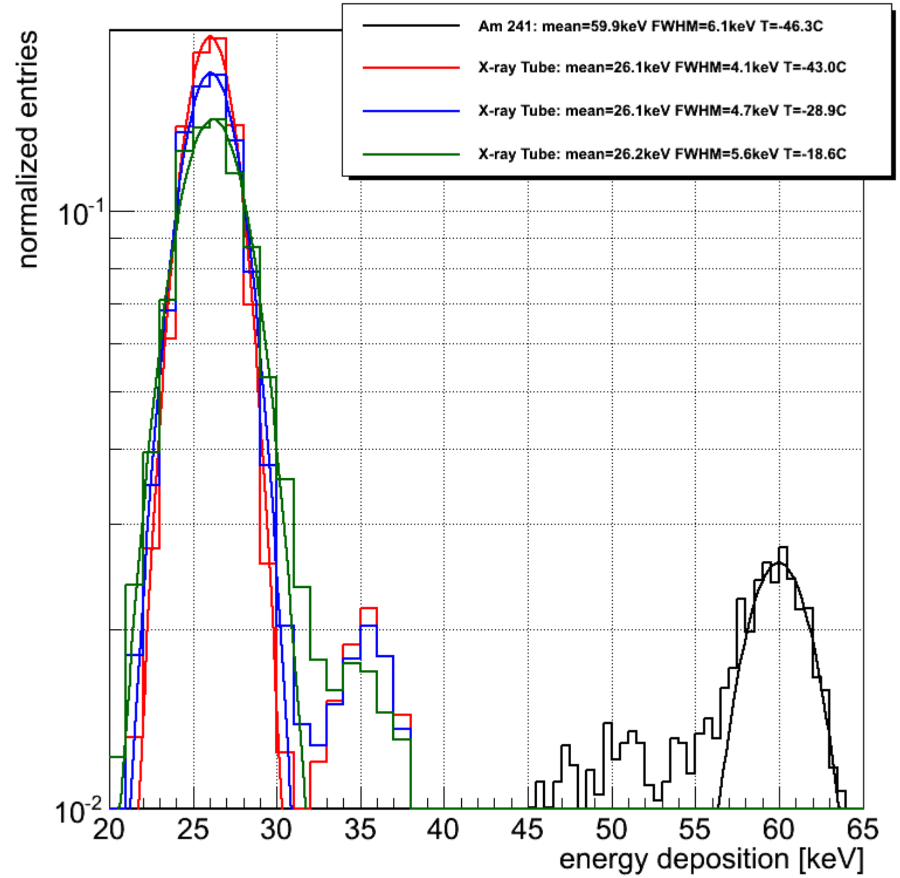


AMS-02 CR data favor MED-MAX propagation

pGAPS Detector Results







Si(Li) resolution consistent with temperature-dependent predictions