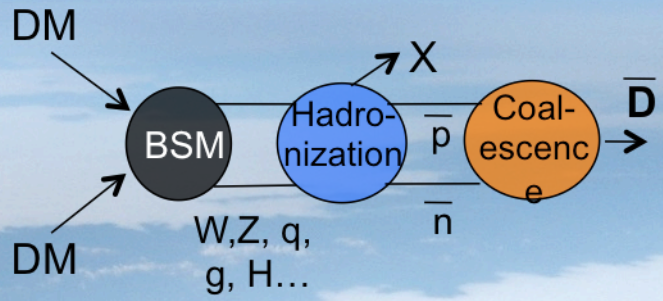
The GAPS Experiment
for Cosmic-Ray Antinuclei Signatures of Dark Matter



Kerstin Perez

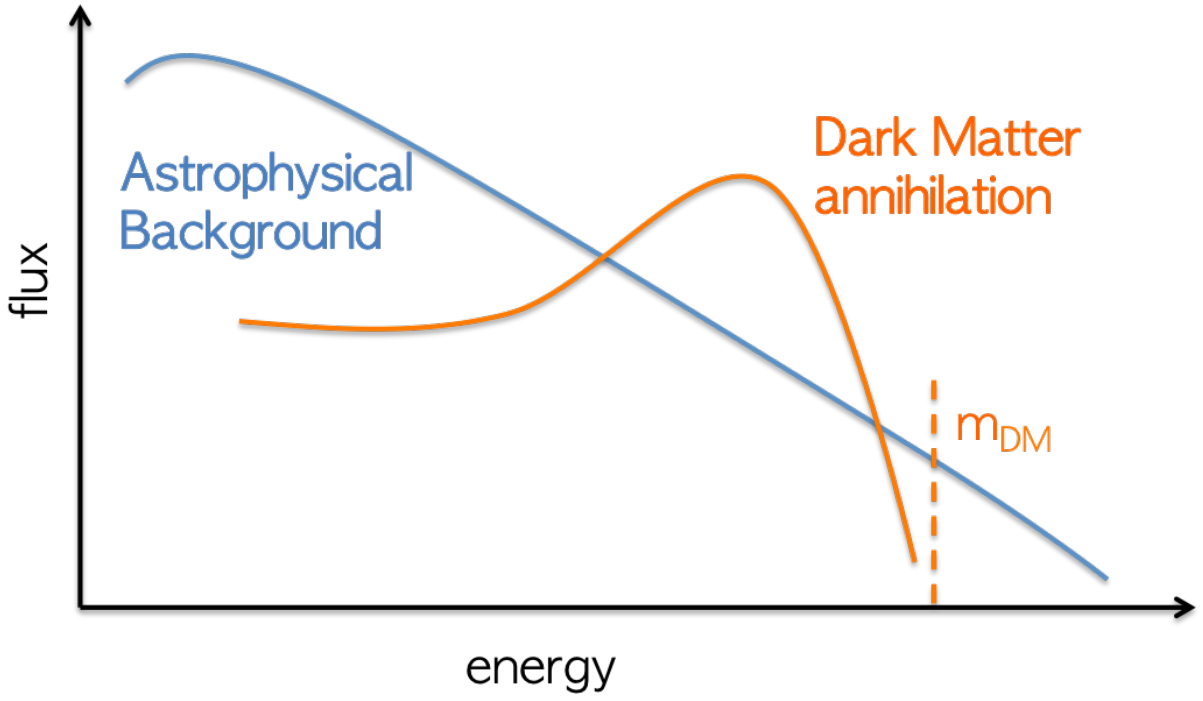
on behalf of the GAPS Collaboration

TeV Particle Astrophysics

August 11, 2017

The trouble with cosmic-ray searches…

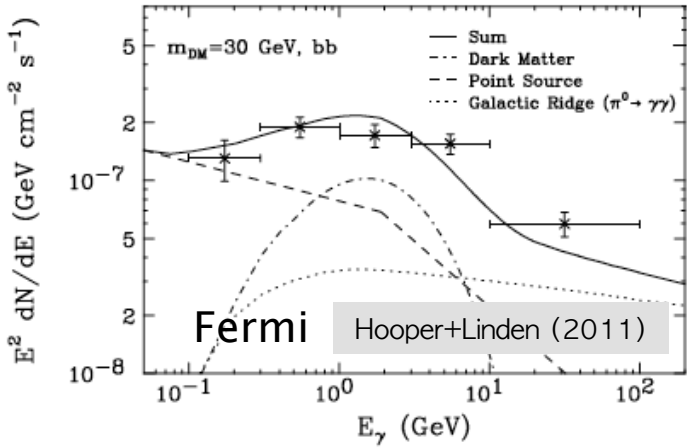
There have been tantalizing possible detections! But vulnerable to poorly-constrained astrophysical background predictions



The trouble with cosmic-ray searches…

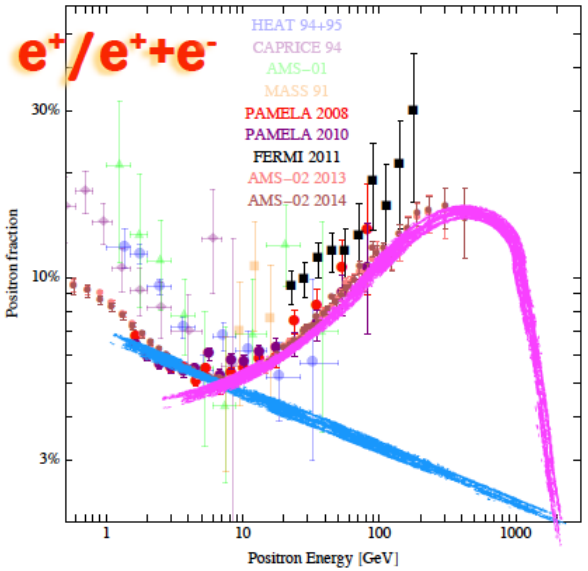
There have been tantalizing possible detections! But vulnerable to poorly-constrained astrophysical background predictions

γ-rays from the Galactic Center

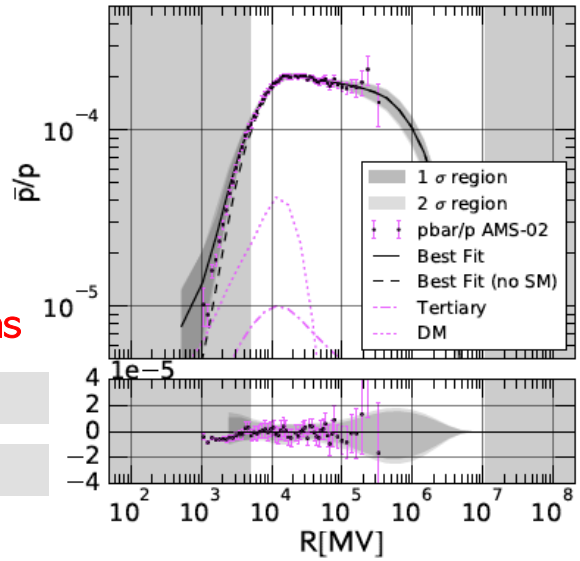


Hooper+Linden (2011)

M. Cirelli (TAUP 2015)



antiprotons



A. Cuoco+(2016)

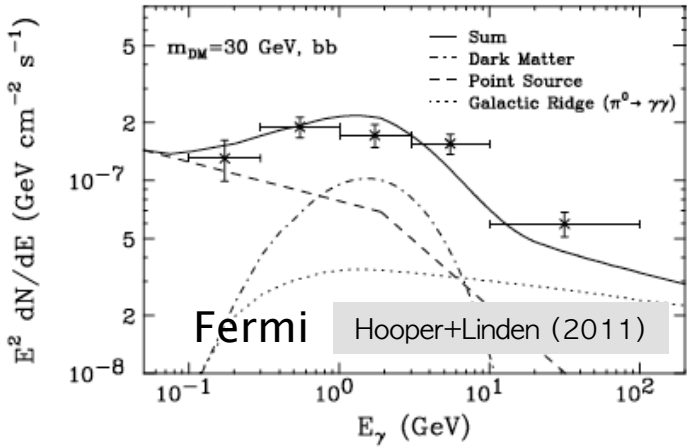
M-Y. Cui+(2016)

1. Cosmic rays are full of surprises!
2. Surprises are difficult to interpret due to uncertain astrophysical backgrounds

The trouble with cosmic-ray searches…

There have been tantalizing possible detections! But vulnerable to poorly-constrained astrophysical background predictions

γ-rays from the Galactic Center



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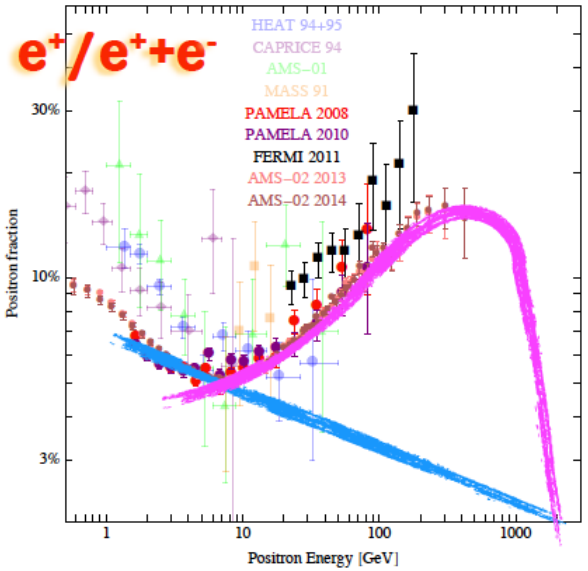

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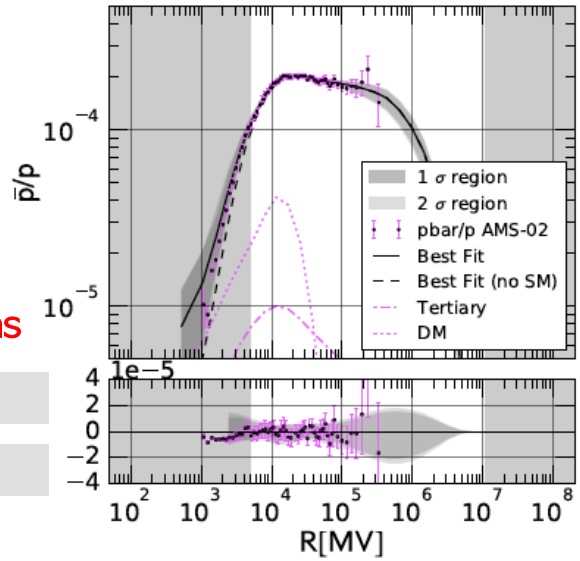


A. Cuoco+(2016)

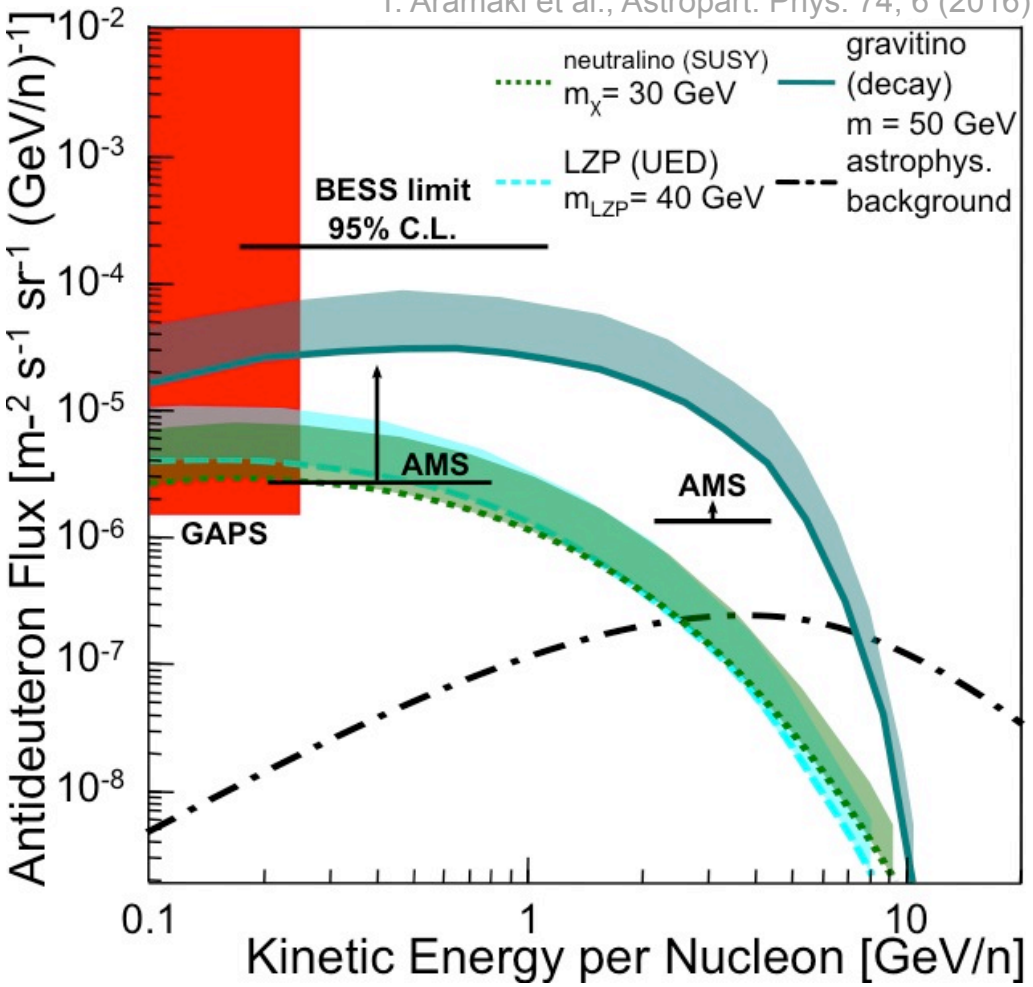
M-Y. Cui+(2016)

Low-energy $\bar{d}$ give an essentially astrophysical background-free new physics signature

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)



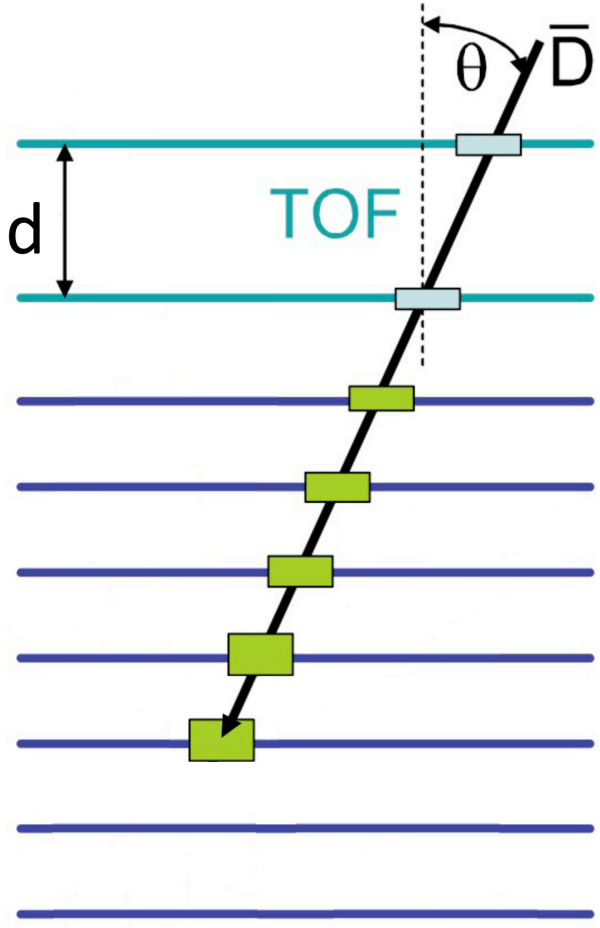
- Probes a variety of dark matter models that evade or complement collider, direct, or other cosmic-ray searches
- GAPS first experiment optimized specifically for low-energy antinuclei signatures
- **First Antarctic flight: late 2020**

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

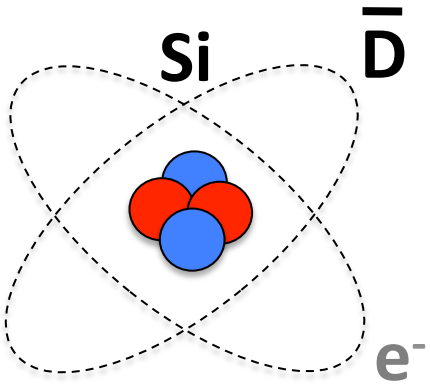
The GAPS Team

GAPS Detection Concept

GAPS uses ***novel detection technique*** based on exotic atom capture and decay



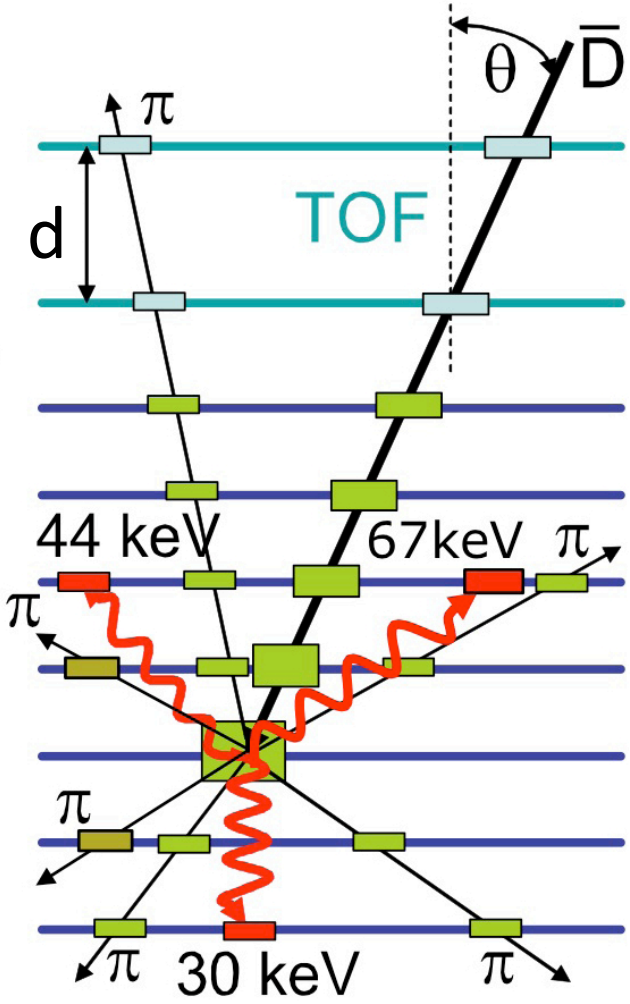
- **Time-of-flight** system measures velocity
- Loses energy in layers of semiconducting **Silicon targets/detectors**
- Stops, forming **exotic excited atom**



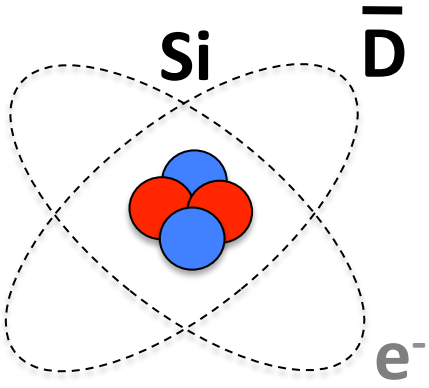
T. Aramaki et al. (2013) 1303.3871

GAPS Detection Concept

GAPS uses ***novel detection technique*** based on exotic atom capture and decay

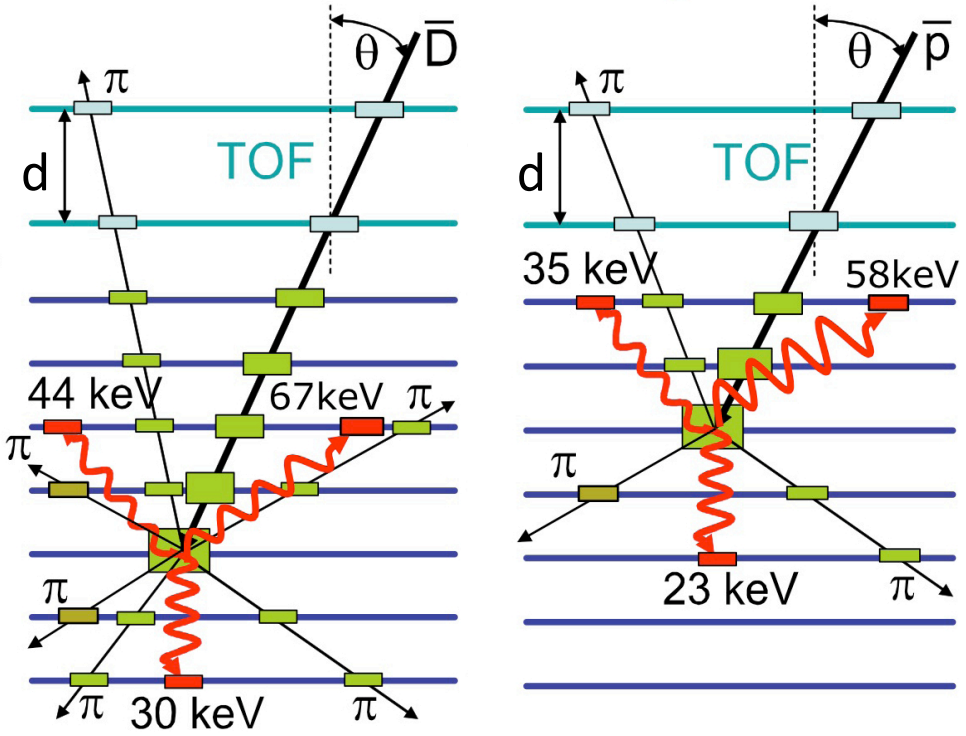


- **Time-of-flight** system measures velocity
- Loses energy in layers of semiconducting **Silicon targets/detectors**
- Stops, forming **exotic excited atom**
- Atom de-excites, emitting **x-rays**
- Remaining nucleus annihilates, emitting **pions and protons**

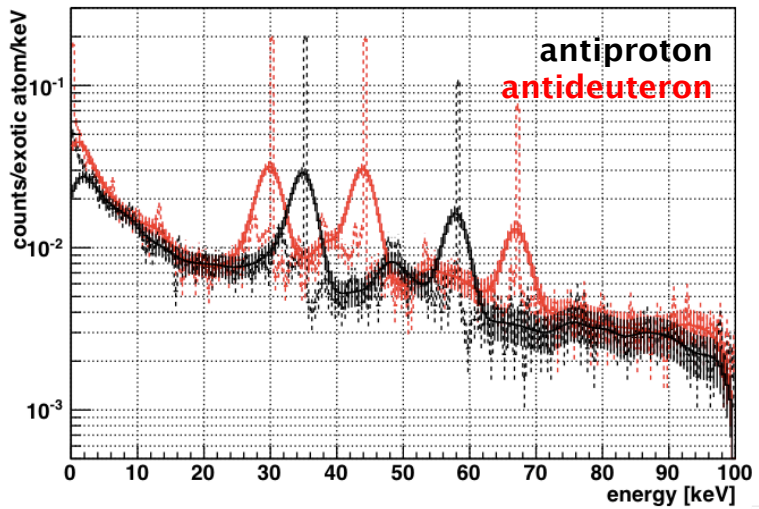


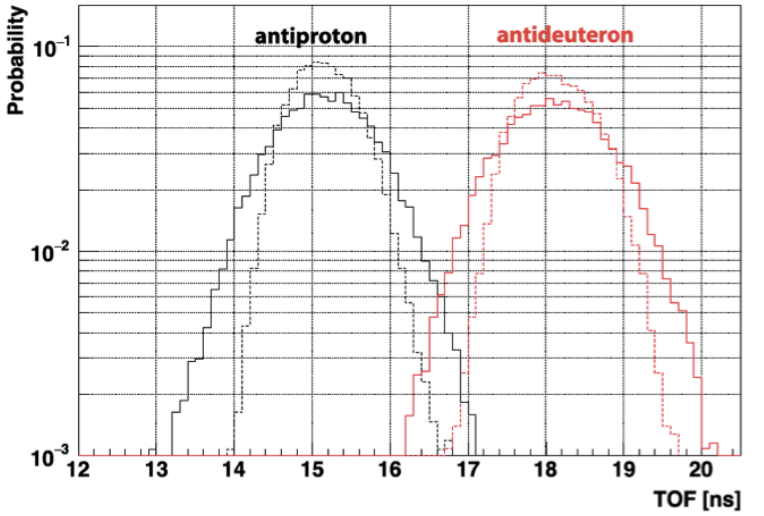
T. Aramaki et al. (2013) 1303.3871

GAPS Background Rejection



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

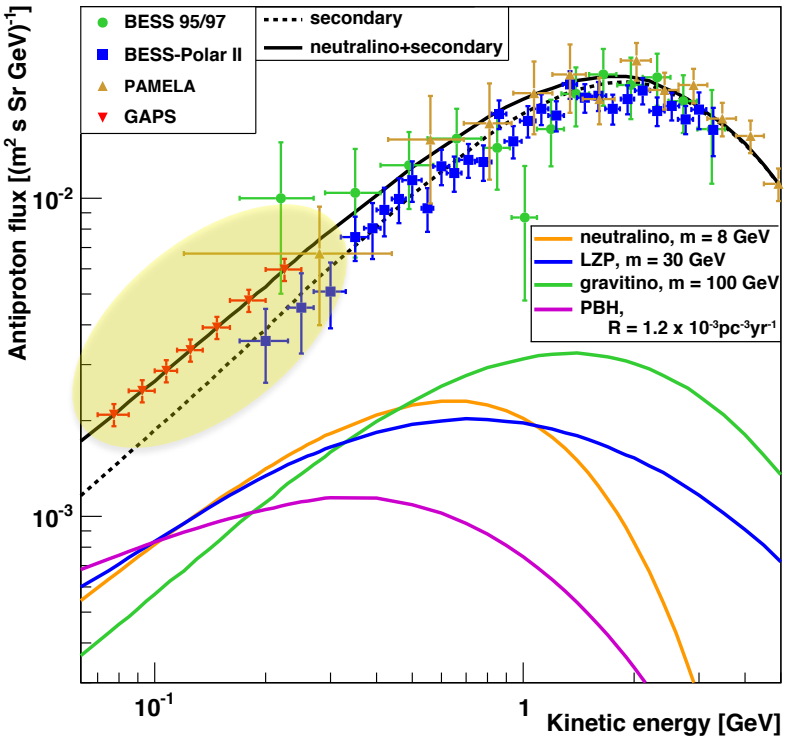




Combination of time-of-flight + depth-sensing, X-ray, and π detection yield rejection >10^6

Precision antiproton spectrum

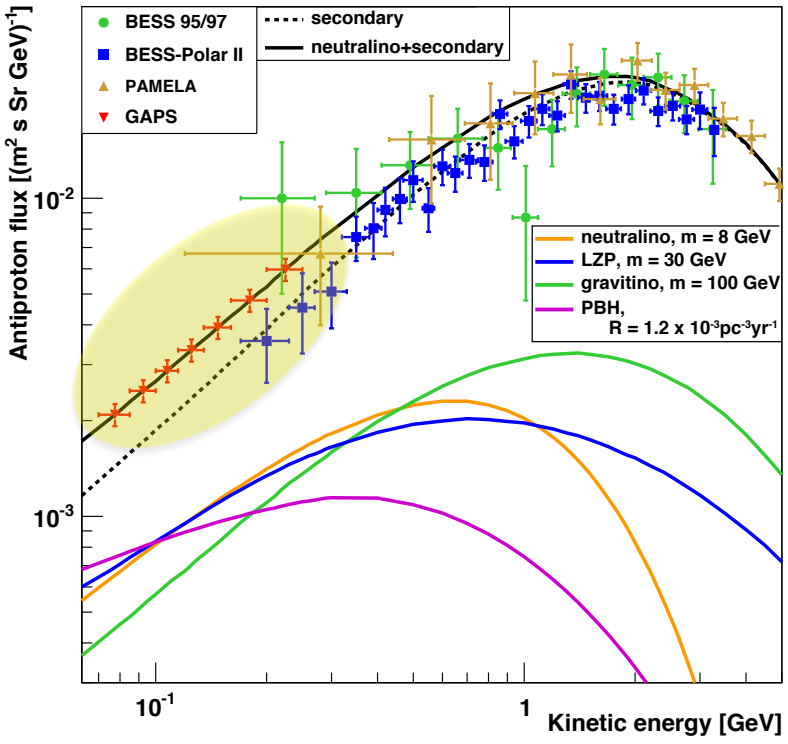
Aramaki et al. (2015) 1401.8245



- GAPS will measure >1500 antiprotons per flight, in ***unprecedented low energy range***
- Sensitive to signals that evade higher-energy experiments
- Input to propagation models used for antideuteron search!

Precision antiproton spectrum *and anti-He search*

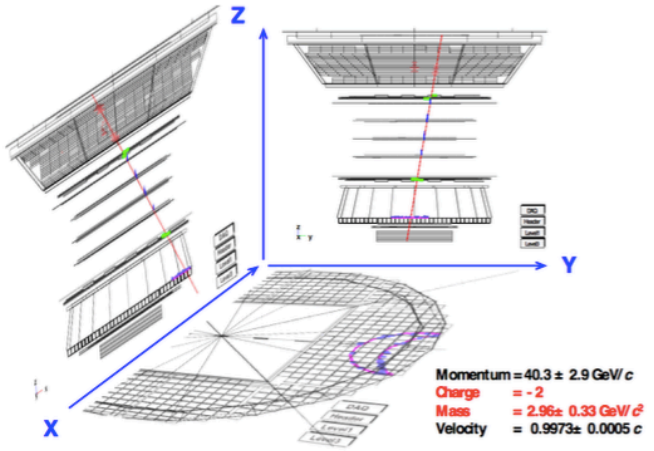
Aramaki et al. (2015) 1401.8245



- GAPS will measure >1500 antiprotons per flight, in ***unprecedented low energy range***
- Sensitive to signals that evade higher-energy experiments
- Input to propagation models used for antideuteron search!

GAPS also sensitive to anti-He, with orthogonal detection method to AMS. Studies ongoing to estimate and optimize sensitivity.

e.g. Googan+Profumo arXiv:1705.09664, Blum+ arXiv:1704.05431

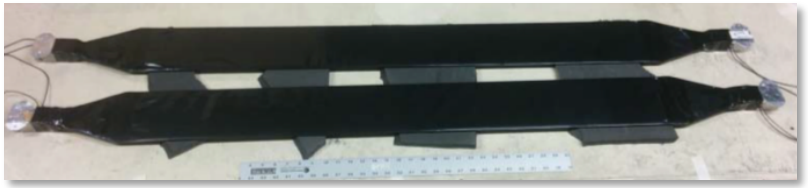


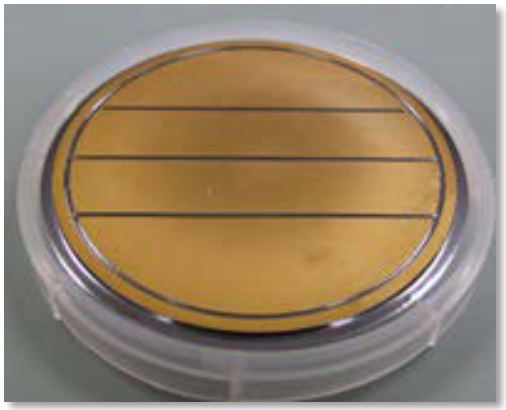
"To date we have observed a few Z = -2 events with mass around ^{3}He." -AMS, Dec. 2016

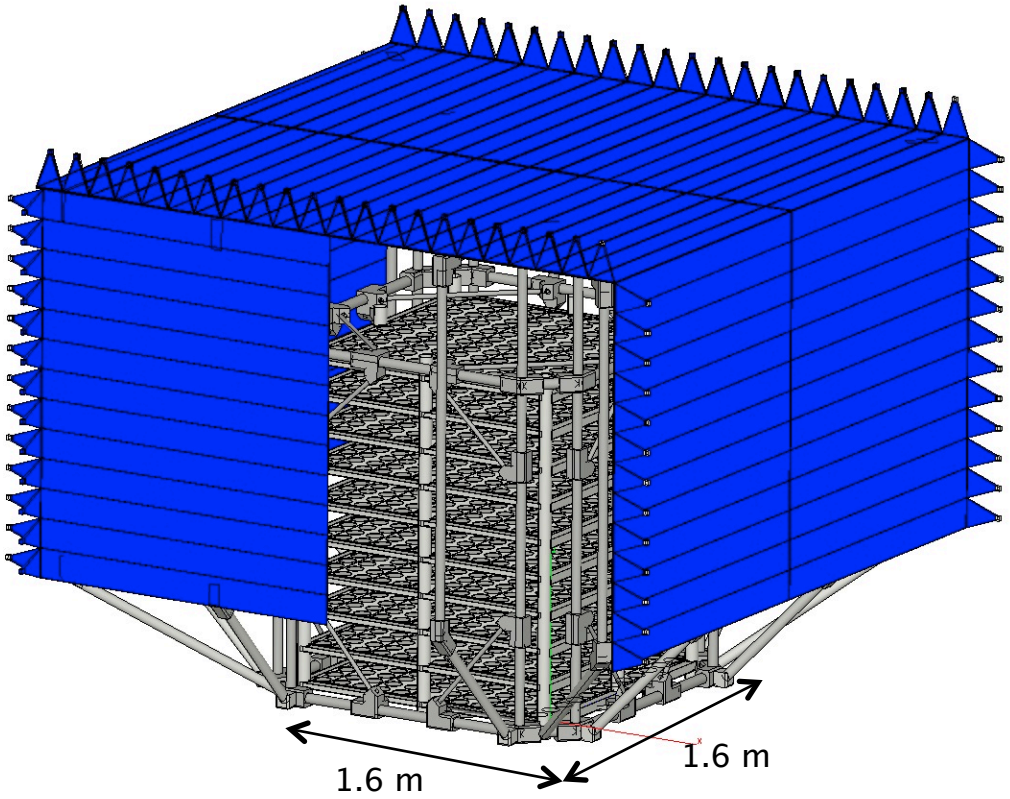
GAPS Detector Design

Plastic scintillator TOF

- high-speed trigger and veto
- 160-180 cm long, 0.5 cm thick
- read out both ends
- ~500 ps timing resolution







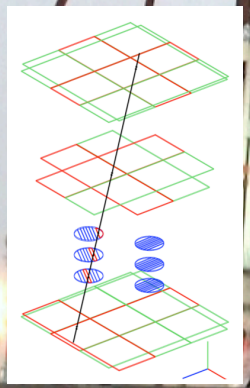
Si(Li) targets/detectors

- 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



100% of flight goals met!

- ✓ 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

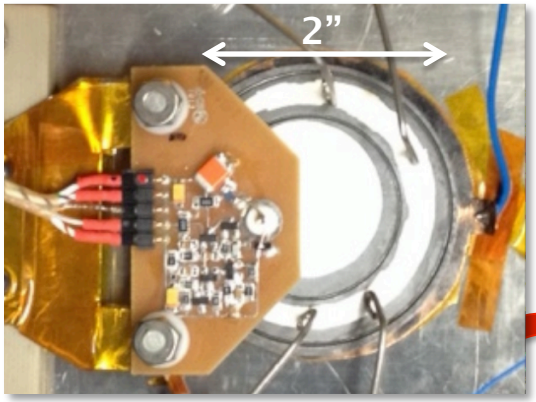
Mognet et al., Nucl. Instrum. Meth. A735 (2014) 24
von Doetinchem et al., Astropart. Phys. 54 (2014) 93

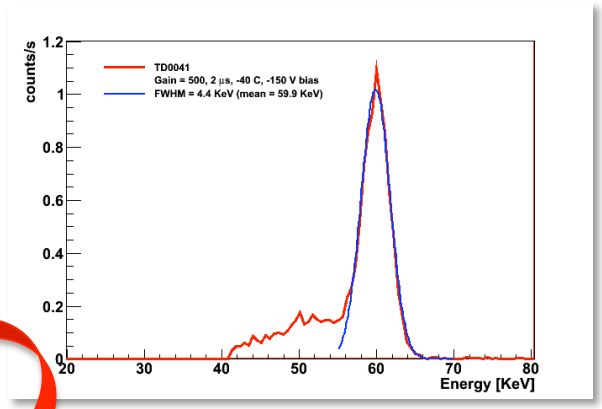
Ongoing work: Si(Li) detectors

GAPS will need >1000 Si(Li) detectors!

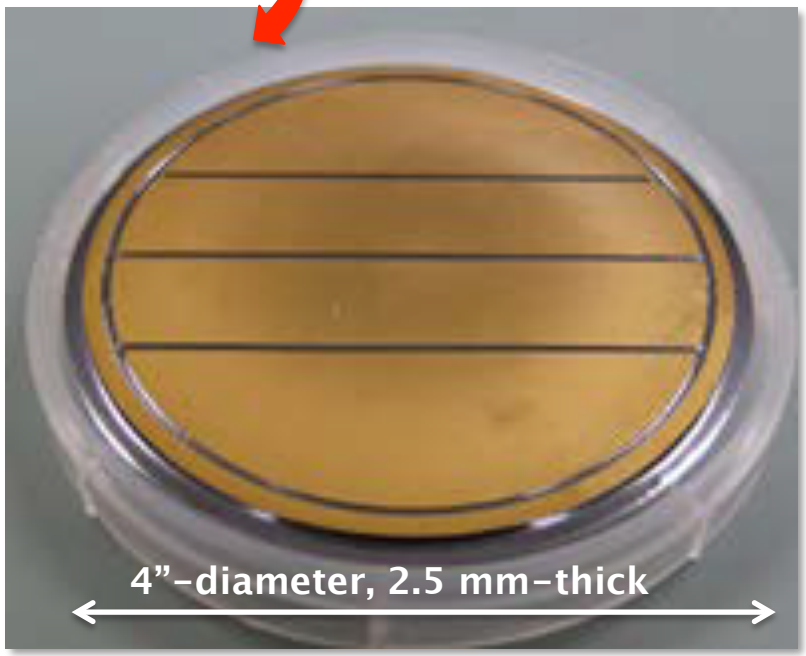
- ✓ Low-cost fabrication scheme developed to achieve required 4 keV energy resolution

  Perez+ Proceedings IEEE (2013), Aramaki+ NIM A, 682 (2012) 90-96

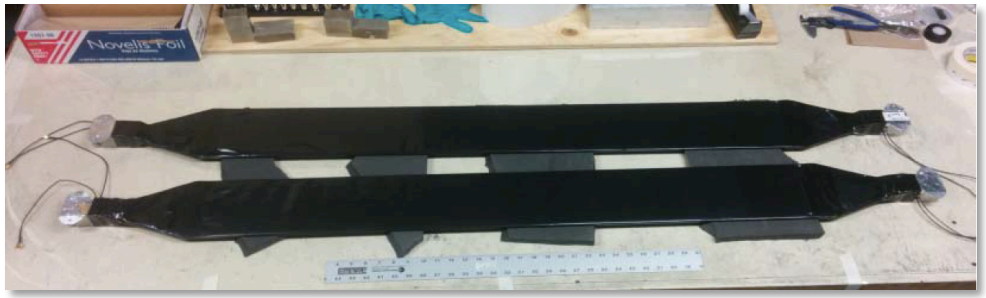




- ✓ Transferring technology to Shimdadzu Corp. for large-scale production
- ✓ Optimizing 4”, 4-strip design
- ✓ First production runs in early 2018



Ongoing work: TOF and cooling

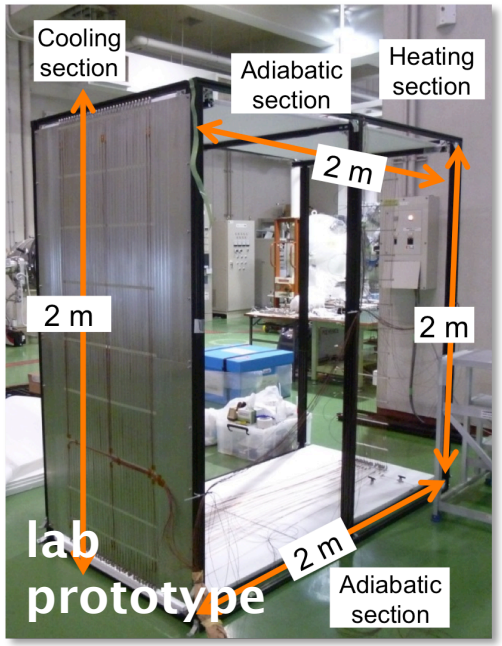


TOF will use 225 scintillation counters, read out on both ends

- evaluating PMT vs SiPM
- custom DRS-4 ASIC @ 2GSps
- optimizing trigger algorithm

Oscillating heat pipe (OHP) validated on pGAPS, developed for GAPS

- small capillary tubes filled with a phase-changing refrigeration liquid
- rapid expansion and contraction of bubbles in liquid create thermo-contraction hydrodynamic waves that transport heat



Okazaki+ Conference, 2014 IEEE, 1-9 (2014).
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

2017 detector and system design

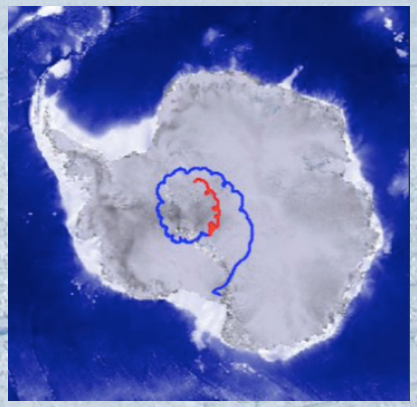
TOF and Si(Li) fabrication

2020 GAPS payload integration

First flight, data analysis, and subsequent flights!

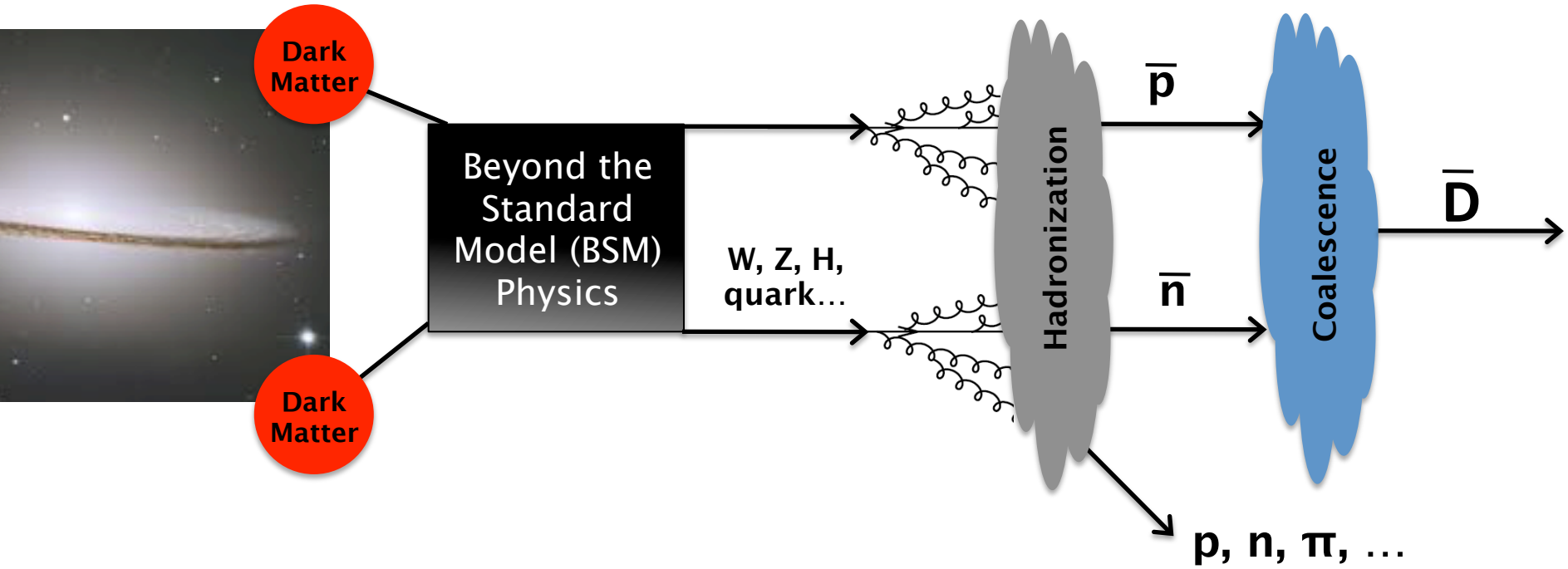
- First GAPS flight will ***improve current antideuteron limit by 1.5 orders of magnitude***, deliver ***first precision antiproton flux below 0.25 GeV/n***, orthogonal detection technique to AMS
- Rapid timeline from funding start to GAPS construction, integration and first science flight in late 2020

Long-duration balloon flight (~30 days)



Backup

Antideuteron Signal of Dark Matter

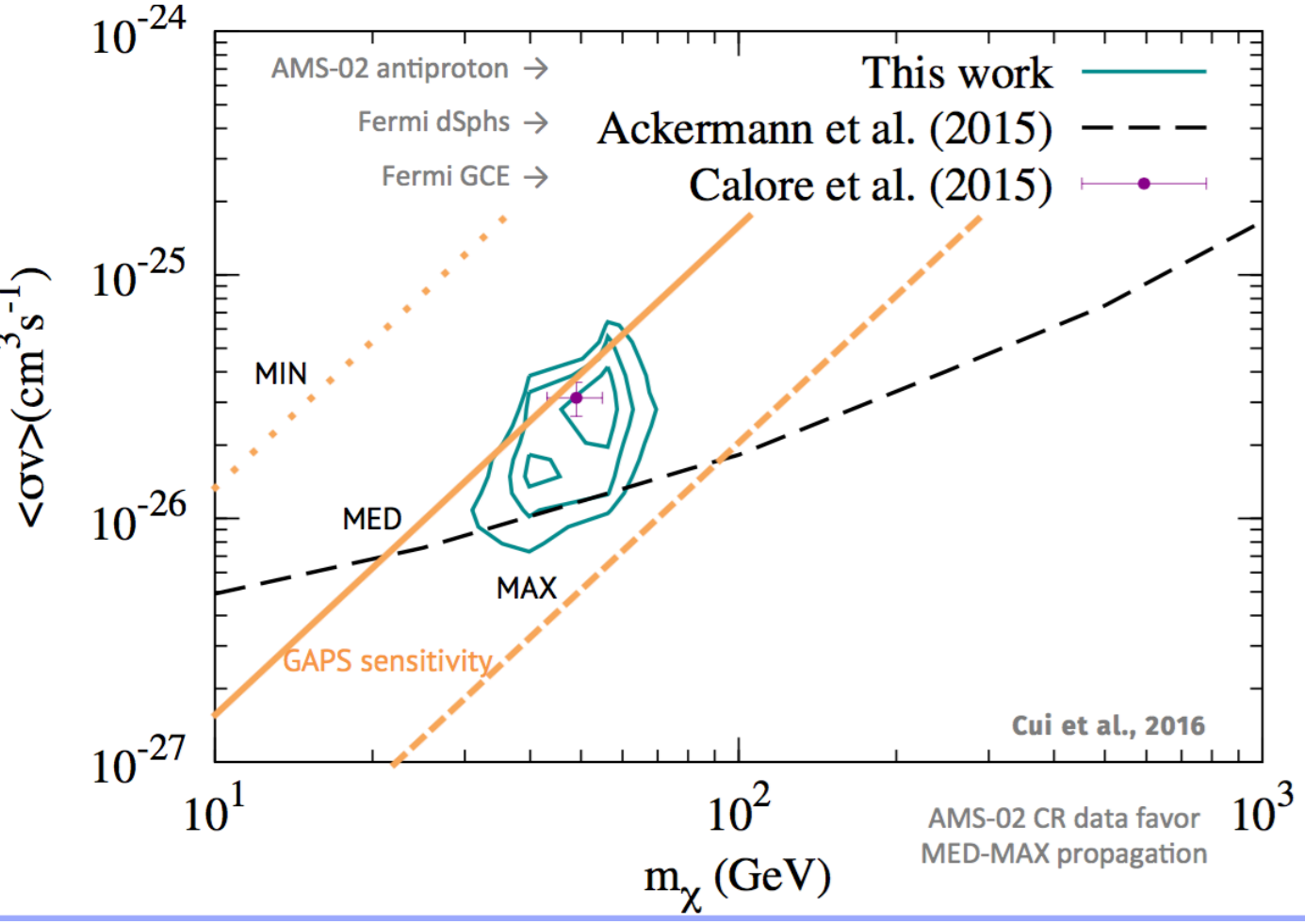


Dark matter particles annihilate…

…create jets of Standard Model particles…

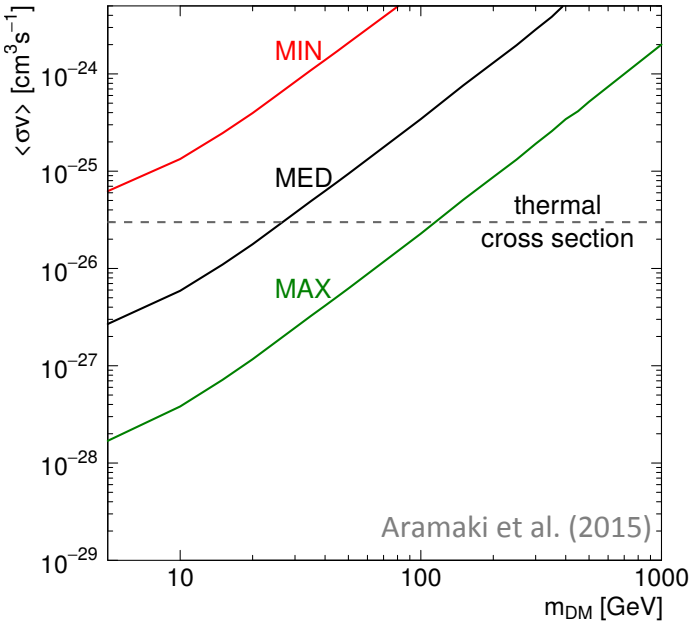
…some of which can make an antideuteron…

Fermi GC excess and antideuterons

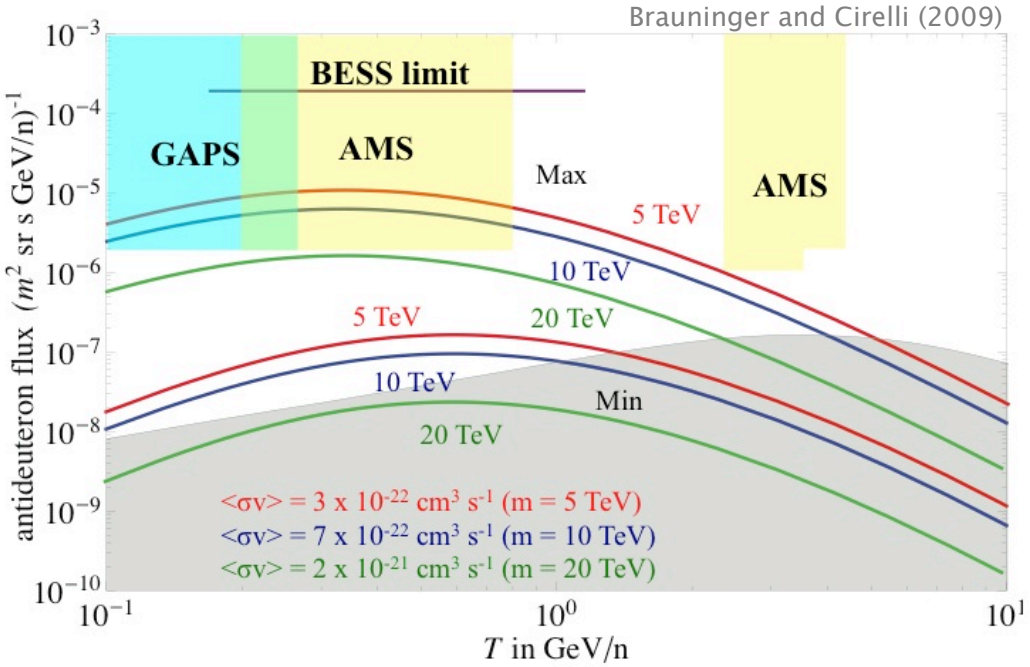


Sensitive to Viable Light and Heavy DM

• Sensitive to low-mass DM models, as invoked to explain CDMS-II Si, COGENT, Fermi observations



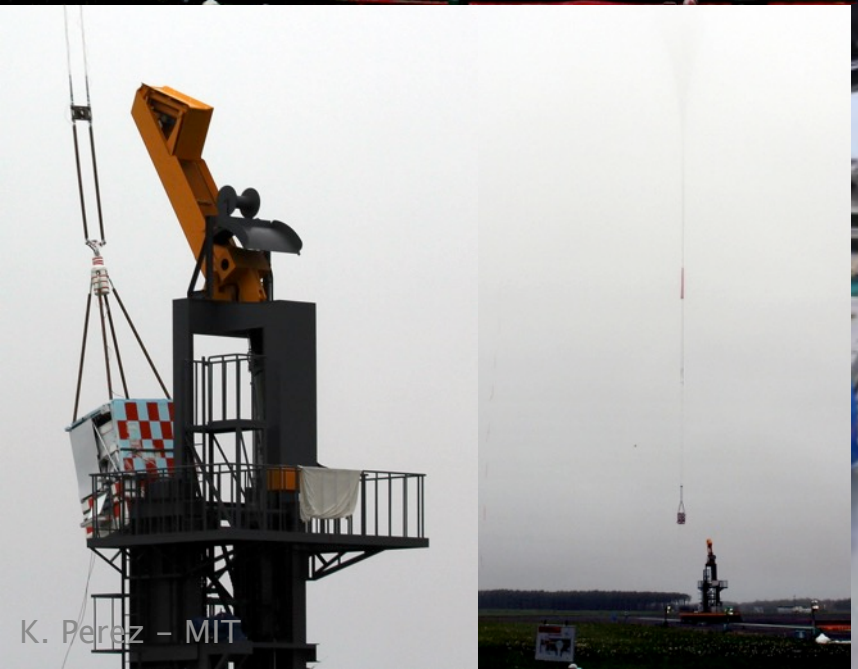
Brauninger and Cirelli (2009)



• Sensitive to heavy DM models, as invoked to explain PAMELA, AMS observations of positron excess

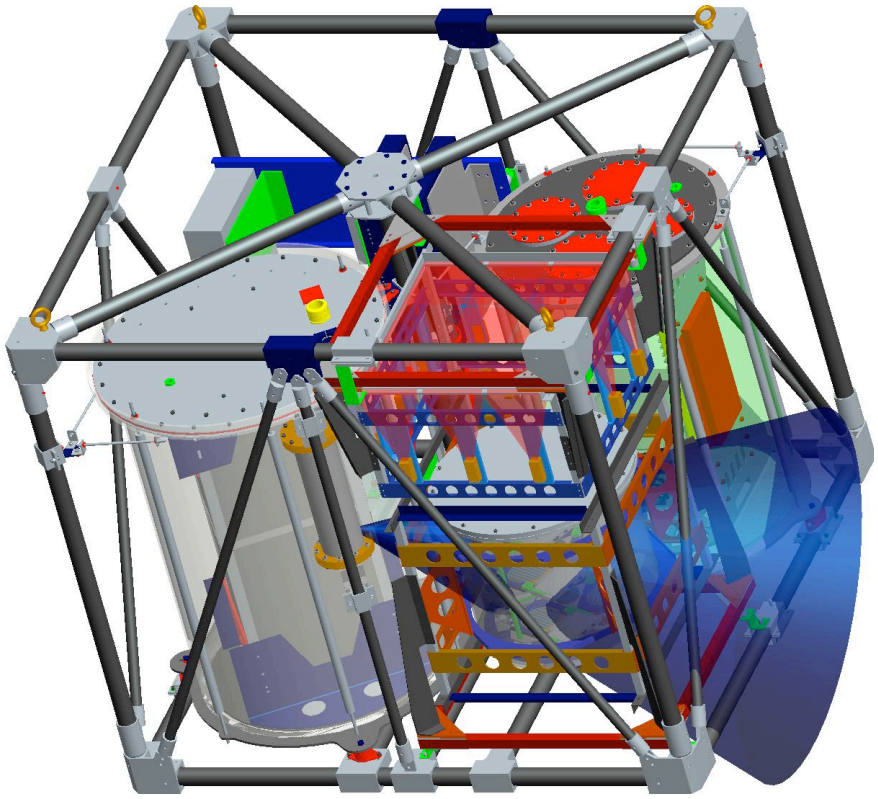

Liftoff!
4:55 am

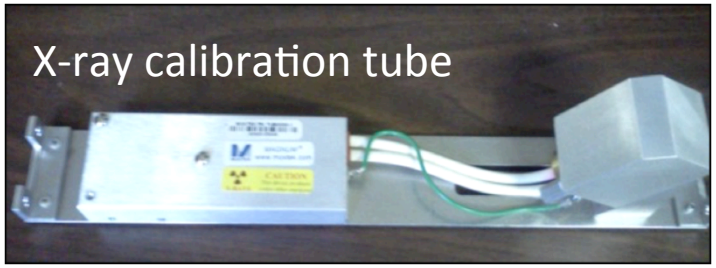

Float altitude = ~33 km
10:22 am
2012:06:03 10:22:14

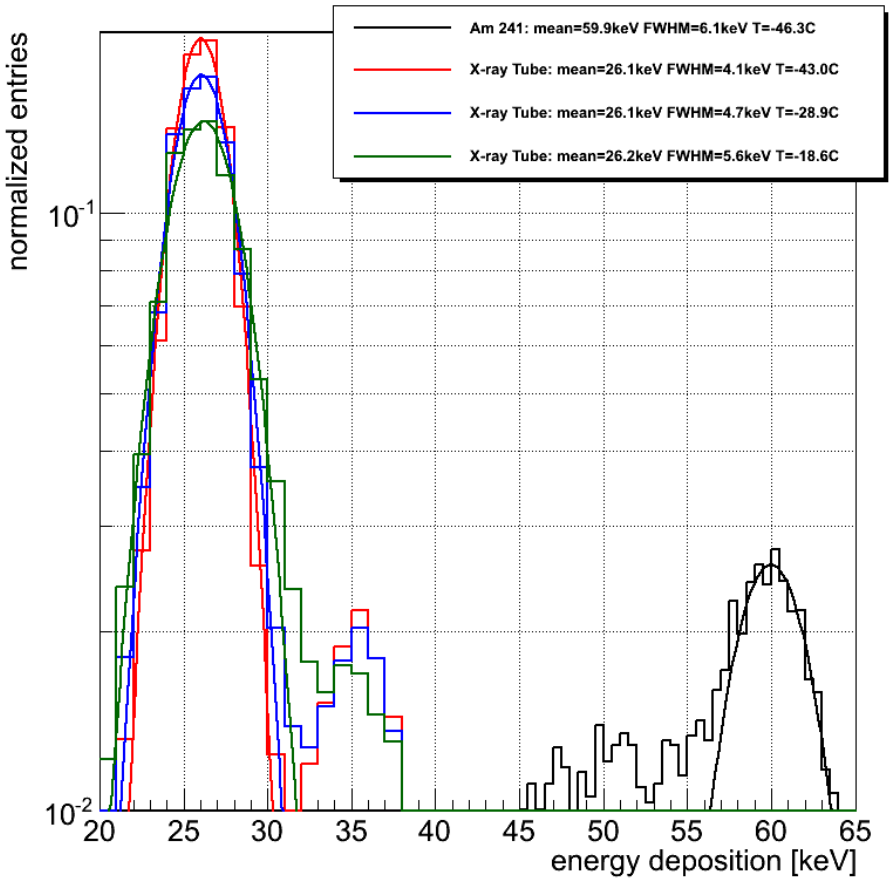



Recovery
11:45 am

pGAPS Detector Results



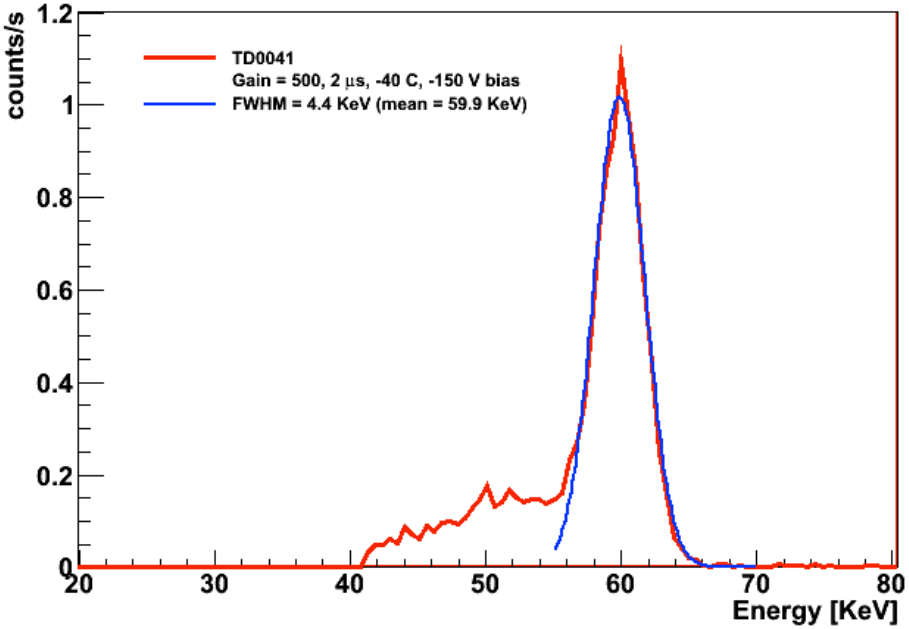




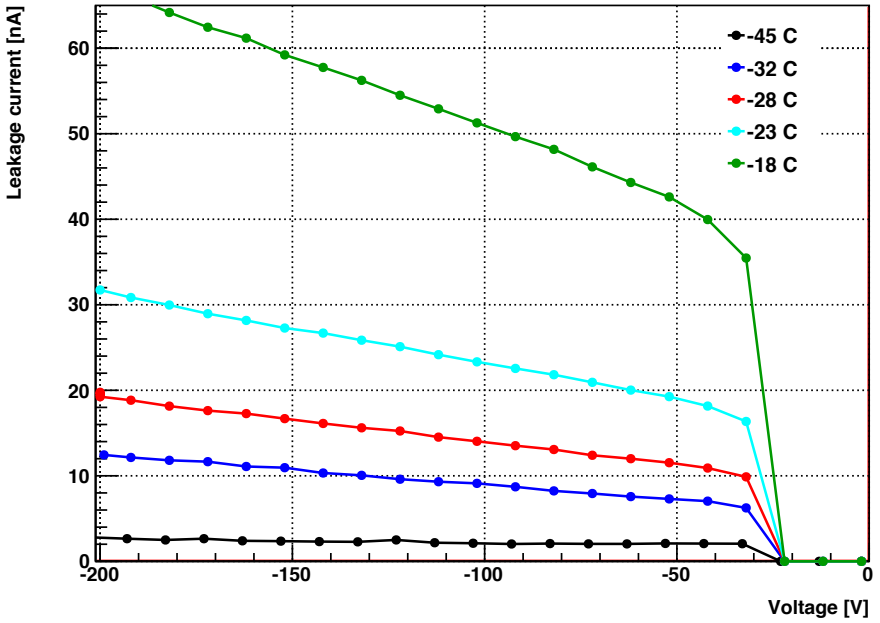
Si(Li) resolution consistent with temperature-dependent predictions

Si(Li) Detector Performance

2”-diameter, 1 mm thick prototype detectors have been produced with the required performance!



Resolution measured with an Am-241 X-ray source



Operational temperature range for 1 mm thick prototype detector