Results From the pGAPS Test Flight

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on behalf of the GAPS collaboration

UCLA

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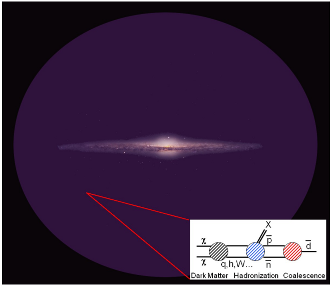
The GAPS Collaboration

- JAXA / ISAS: Fuke, Bando, Takada, Yoshida
- Columbia Univ.: Aramaki, Gahbauer, Hailey, Perez, Madden, Mori, Tajiri
- UC Berkeley: Boggs, von Doetinchem
- LLNL: Craig
- UCLA: Buchovecky, Mognet, Ong, Zweerink

pGAPS is funded by NASA grants in the US and by MEXT-KAKENHI grants in Japan.



For positrons and antiprotons, backgrounds are a serious issue.

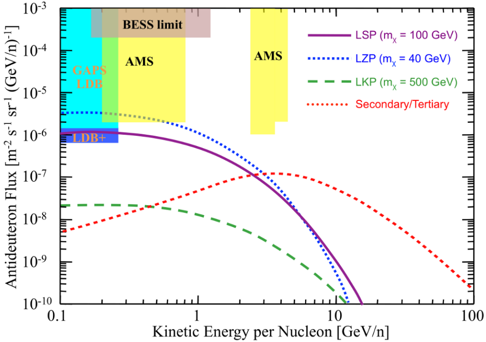
Antideuterons are expected to have very small backgrounds from secondary production compared to $\overline{p}$, e^+. **The most unexplored potential channel.**

Many dark matter candidates could make cosmic ray antimatter (SUSY Neutralino, Extra Dimensions, Primordial Black Holes, Gravitino, etc).

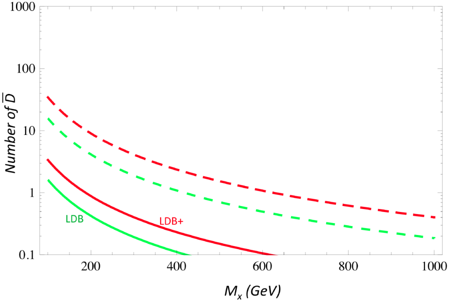
See:

Baer, H. and Profumo, S.,JCAP 12, 008, 2005.
Salati, P, Donato, F and Fornengo, N., Particle Dark Matter: Observations, Models and Searches, ed. G. Bertone, Cambridge University Press, pp. 521-546, 2010.
Fuke, H. et.al., Phys. Rev. Lett. 95, 081101, 2005.
P. v. Doetinchem et.al., Dark Matter 2012, UCLA, GAPS presentation, Feb. 2012.

Others...



GAPS: Expected Count Rate



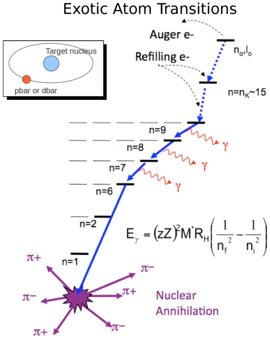
GAPS count rate (gluon-gluon channel) for nominal (green) and maximal (red) propagation models.(Cui, Y., Mason, J. and Randall, L., arXiv:1006.0983v1).

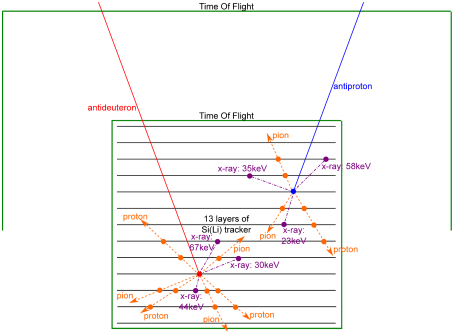
Rare event search, but our backgrounds are very low!

Theoretical Uncertainties:

- Propagation (largest)
- Boost factor (1–10)
- Hadronization and coalescence models
- DM Halo density (small)

Light antinuclei can form excited exotic atom states with normal matter.





GAPS with Si target material.

Atomic transition x-rays, charged pion multiplicity, and other products provide distinct signature for antinuclei.

Plastic scintillator time-of-flight with with Si(Li) target/detector.

Not a magnetic spectrometer:

- Smaller Mass
- Larger Acceptance
- Independent Technique (complimentary to AMS)

(Potentially) an essentially background free channel for dark matter detection.

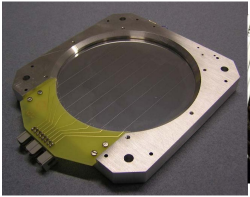
Exotic atom technique successfully tested in 2004-2005 KEK beam tests. (T. Aramaki et al., Astroparticle Physics (2013), arXiv:1303.3871)

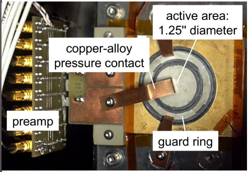
GAPS: Detector Development

Lithium drifted silicon provides:

- Both degrader, target and detector.
- Excellent x-ray energy resolution ($\sim 3keV$).
- Tracking of primary particle.
- Tracking of annihilation products.

Proper operation around -35 °C.





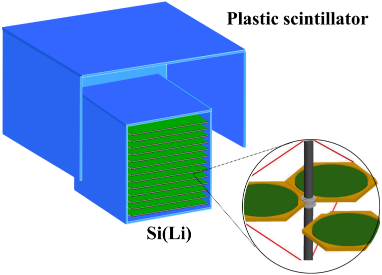
- In-house development of Si(Li) detectors well underway.
- Drifting of 2" detectors at 90% yield.
- 4" development underway!

Plastic scintillator based time-of-flight system.

- Read out at both ends with very compact, fast Hamamatsu (R7600-200) Ultra-Bialkali PMTs.
- Each PMT base has dedicated internal HV supply (total power consumption <0.5W per PMT in prototype).
- 0.5 m prototype version counters already flight tested, will extend to 2 m for GAPS.

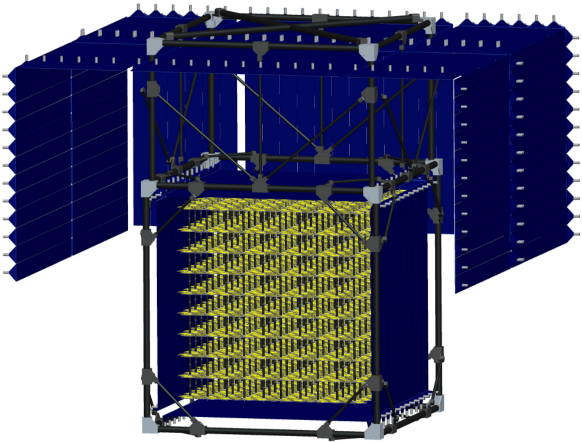
Proposed Antarctic flight at the end of 2017.

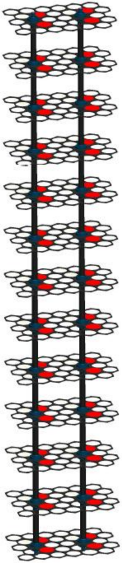
Geometrical Acceptance	1.8 $m^2 sr$
Energy	0.05-0.25 GeV/n
Exposure Target	105 days (3 LDB flights)
Sensitivity (CL)	1.3×10^6 $(m^2 * sr * s * GeV/n)^{-1}$
Expected Bkgd Events	0.009



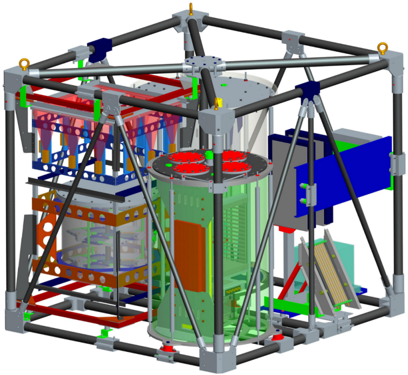
- Overall width of $\sim$ 4 m.
- $\sim$ 3000 Si(Li) detectors in 13 layers (138 kg of silicon).
- Active cooling system
- Plastic scintillator based time-of-flight system (72 m^2).

GAPS Preliminary Design



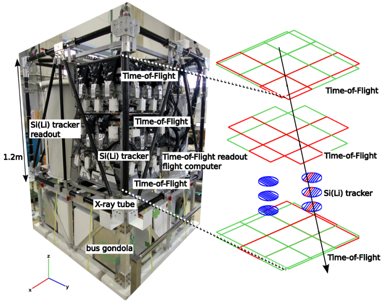


Cut-away GAPS design concept (Spring 2013) showing carbon fiber frame, plastic scintillators, and Si(Li) detector layers.

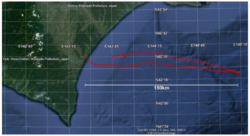


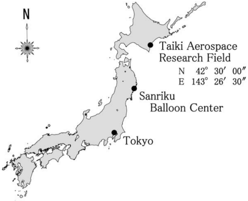
- Test Si(Li) detectors at balloon altitude.
- Test the prototype TOF system.
- Measure natural cosmic ray and x-ray backgrounds.
- Validate thermal model and cooling approach.
- Test new OHP cooling technique.

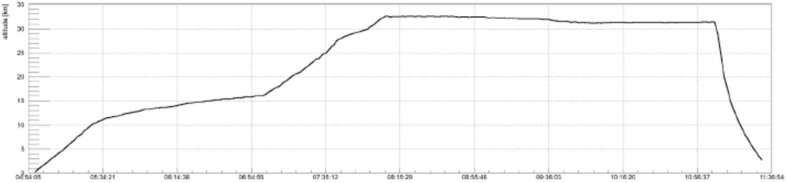
- Six 4" Si(Li) detectors.
- Active cooling system.
- TOF system for β measurement.
- X-ray tube for calibration.
- Oscillating Heat Pipe (OHP) test.
- Battery power.

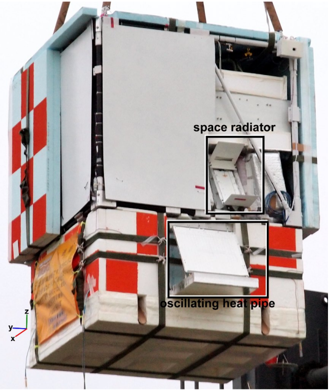


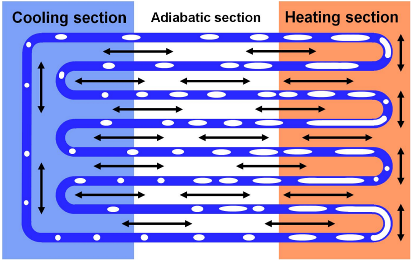
pGAPS Balloon Flight, June 3, 2012

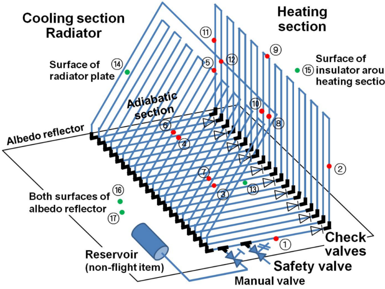




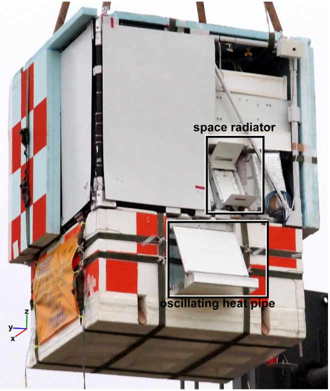




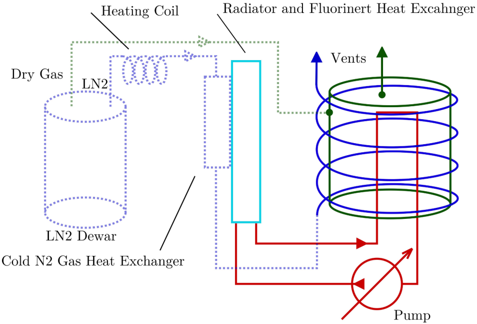




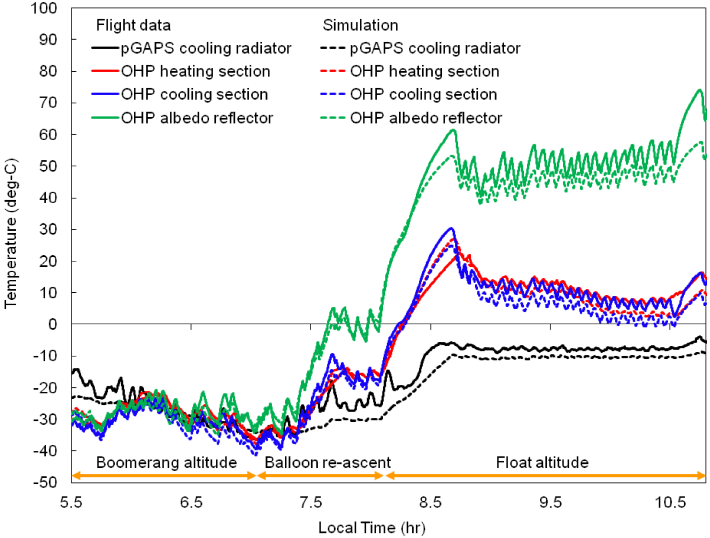
- First balloon flight of an OHP.
- Innovative new passive cooling system design.
- Being investigated for use in GAPS.



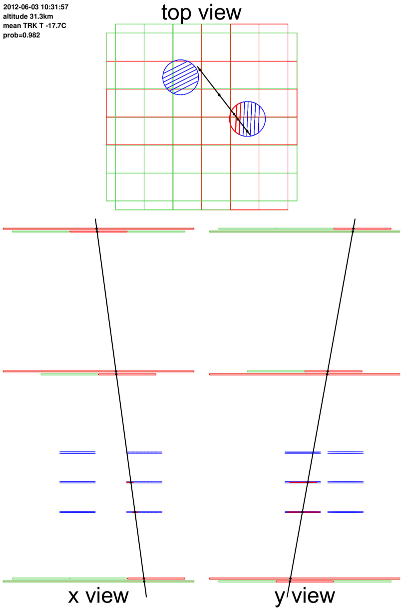
- Used for cooling the Si(Li) detectors.
- Space radiator, Fluorinert phase-changing coolant, pump.
- Default design for GAPS.



Performance - Thermal



Rotator failure prevented most active cooling in flight, however the thermal model was fully validated with the collected data.



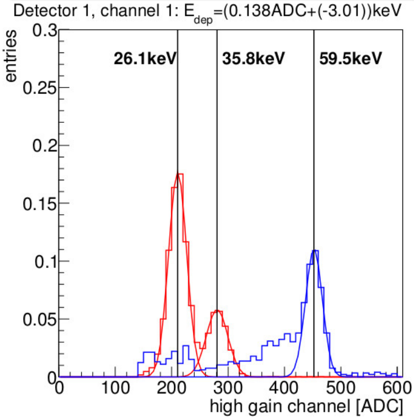
- TOF Trigger Mode (245 minutes at float):
  - $\sim$ 600000 triggers.
  - $\sim$ 5% α particles at float.
- Calibration with on-board X-ray tube (50 minutes).
- Si(Li) trigger for study of incoherent X-ray backgrounds (29 minutes).

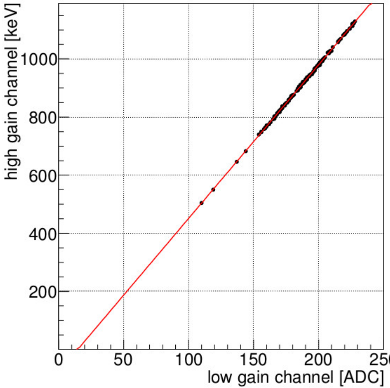
Si(Li) Energy Calibration

Two calibration sources used:

- X-ray tube (red)
- AM-241 (blue)

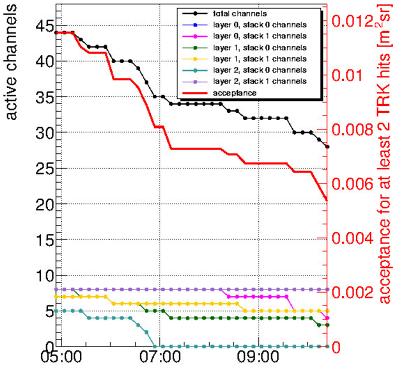
AM-241 used on ground only.



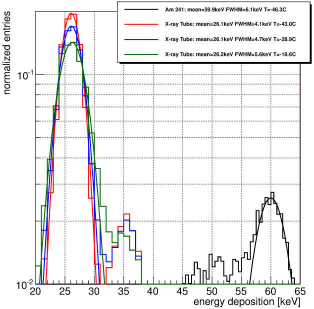


Each Si(Li) strip read out with low gain (for charged particles) and high gain (for x-rays) ADC channels.
Cross-calibration done in overlap region.

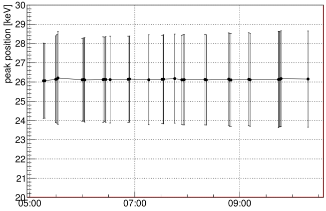
Si(Li) Response and Performance

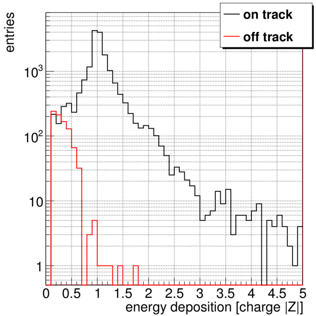


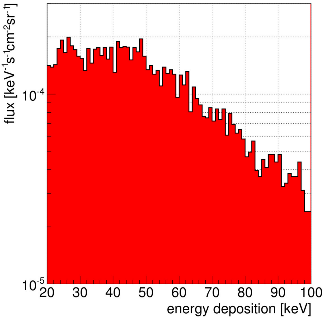
Si(Li) x-ray resolution was not a strong function of temperature.



Since there was little active cooling in flight, the Si(Li) detector operation relied on the pre-launch cool-down. Even so, more than half of strips were still operational at the end of the flight.

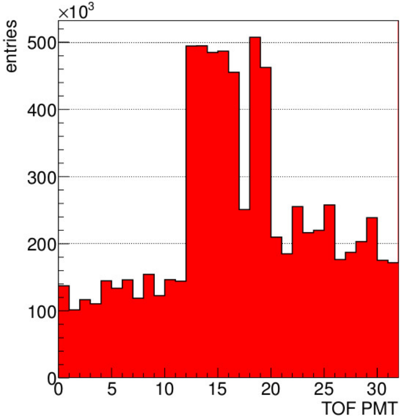




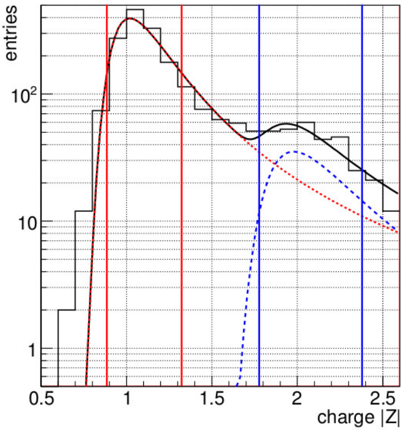


The charge response of the Si(Li) detectors for on track (black) and off track (red) hits. Corrected to charge units.

The measured incoherent x-ray flux during flight was quite small (32 km altitude, geometrical detector acceptance of 436 $cm^2 sr$ (both sides), 27 min of livetime)



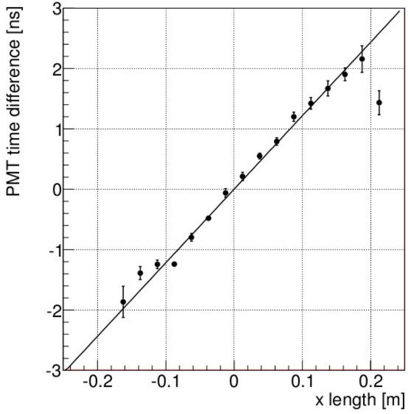
Combined charge measurement at float (Si(Li) + TOF).

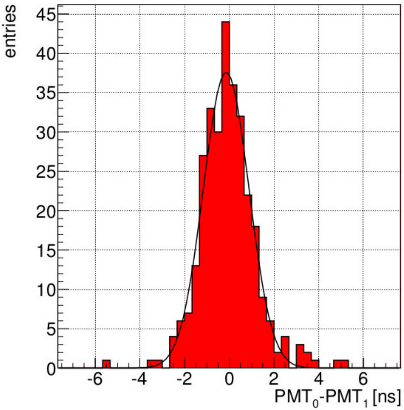


31 of 32 phototubes operated throughout the flight.
One tube operated intermittently after the ambient pressure dropped below ∼40 torr (consistent with HV breadown).

TOF Timing Response

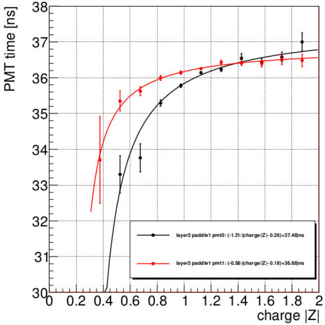
The TOF TDC timing shows a very linear relationship to the track hit position.





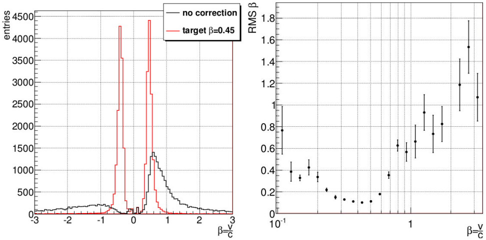
TDC difference distribution for a 2.5 cm slice in the center of one paddle. Distribution width has $\sigma = (0.90 \pm 0.10)ns$ which implies a single tube timing resolution of $(0.64 \pm 0.07)ns$.

TOF Timing Response

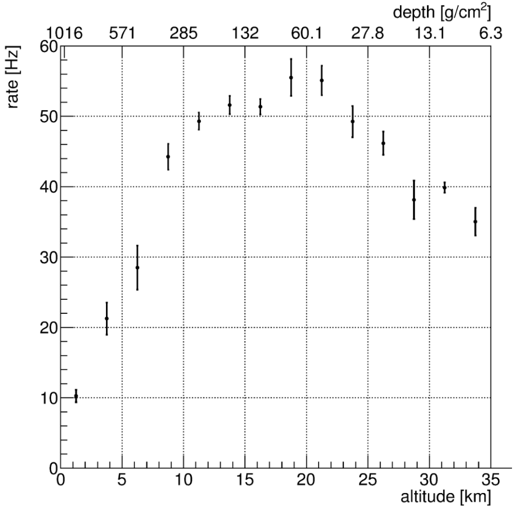


Slewing corrections were necessary for the TDC values since a fixed threshold discriminator was used ($\sim 5\%$ improvement).

Offset calibration between TDCs has been the most challenging aspect of the TOF analysis.

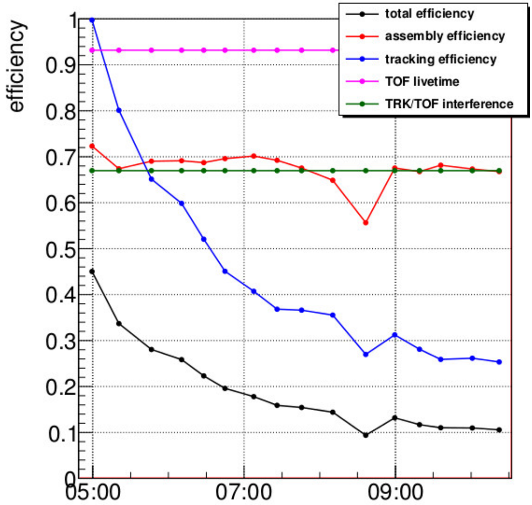


Trigger Rate

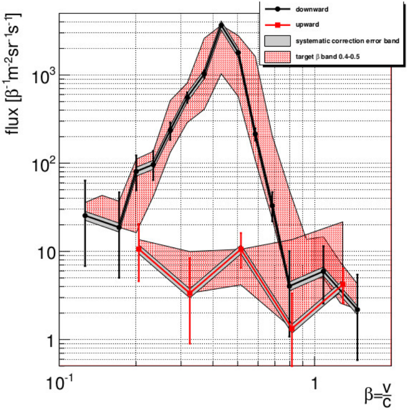


The raw TOF trigger rate as a function of altitude is shown. Shower maximum is clearly visible at around 20 km.

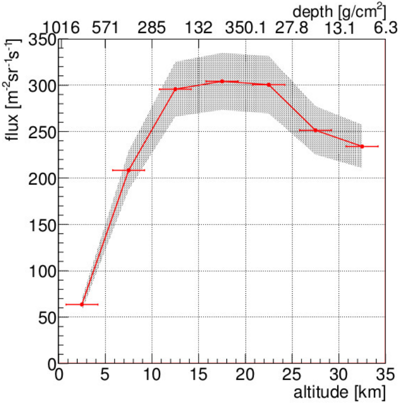
Flux Corrections



Various corrections to the flux were necessary.



The measured flux (at float) for downward-going (black) and upward-going (red) particles. The upward-going flux is not corrected for shielding by the instrument components.



Total charged particle flux as a function of altitude with all corrections applied.

pGAPS Flight Performance

- Both TOF and Si(Li) systems worked very well.
- Rotator failed so no pointing (no active cooling available).
- Si(Li) operated for duration of flight from initial ground cooling (64% of strips still depleted at termination).
- OHP test very successful (first operation in a balloon flight).
- Thermal model fully validated (with pointing, active cooling would have worked).

The pGAPS flight was a great success!

Instrument Paper

S. A. I. Mognet et al., submitted to Nucl. Inst. Meth. B (2013)
http://arxiv.org/abs/1303.1615

Flight Paper

P. von Doetinchem et al.
http://arxiv.org/abs/1307.3538v1

Conclusions

- Antideuteron provide a potentially background free signature for dark matter.
- GAPS is a promising approach to antideuteron searches.
- Very successful prototype GAPS flight in 2012.
- Design of GAPS science payload underway.
- In-house production of Si(Li) detectors demonstrated.
- Science flight in $\sim$ 2017.

Thank You!