GAPS - General AntiParticle Spectrometer

TeV Particle Astrophysics
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www.antideuteron.com
Dark matter signal in cosmic rays?

- unexplained features in positrons → astrophysical origin → pulsars → SNR acceleration → dark matter annihilation
- gamma-ray excess at the galactic center → unresolved millisecond pulsars → 30GeV dark matter particle
- no (?) excess for antiprotons → inconclusive
Status of cosmic-ray antideuterons

Antideuterons are the most important unexplored indirect detection technique!

Examples for beyond-standard-model Physics (compatible with $\bar{p}$):

- **Neutralino**: SUSY lightest supersymmetric particle, decay into $b\bar{b}$, compatible with signal from Galactic Center measured by Fermi
- Late decays of unstable gravitinos
- Astrophysical background: collisions of protons and antiprotons with interstellar medium
- + models with heavy dark matter

More on antideuterons at this conference:
- Johannes Herms: Antideuterons in cosmic rays: Sources and discovery potential
- Are Raklev: Formation models for antideuterons from dark matter
The GAPS experiment

- the General AntiParticle Spectrometer is specifically designed for low-energy antideuterons and antiprotons
- planned for Long Duration Balloon flights from Antarctica
- identification by stopping and creation of exotic atoms tested in KEK testbeam measurements: Astropart. Phys. 49, 52 (2013)
- GAPS has been favorably reviewed by NASA this year. NASA intends to fund it contingent on approval of the NASA budget → first flight 2020

- TOF with PMT or SiPM readout
- 3m × 3m
- weight: 1700 kg
- power: 1.4 kW (Si(Li) 600 W, TOF 400 W)
- 1350 Si(Li) wafers

Columbia U, UC Berkeley, UCLA, U Hawaii, MIT, INFN
**Background rejection:**

- Stopping protons do not have enough energy to produce pions and cannot form exotic atoms (positive charge).
- Deexcitation X-rays have characteristic energies.
- Number of annihilation pions and protons depends on mass of antiparticle.
- Stopping depth in detector.

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**GAPS sensitivity**

Astropart. Phys. 74, 6 (2016)
Predicted primary antiproton fluxes at TOA from neutralinos, LZPs, gravitinos, or PBHs, along with neutralino signals as seen by 1 GAPS LDB flight
Prototype GAPS

Goals:

• demonstrate stable operation of the detector components during flight
• study Si(Li) cooling approach for thermal model
• measure background levels

Astropart. Phys. 54 (2014) 93
Time-of-flight design

- tasks:
  - charged particle trigger
  - velocity measurement (500ps resolution)
  - tracking (5 degree resolution)

- GAPS design:
  - 215 paddles total, 16cm wide, 1.6-1.8m
  - 5mm scintillator (BC-408 or EJ-500)
  - Hamamatsu R7600 PMT or SiPM (Hamamatsu S13360 - 3050CS MPPC with a 3x3mm collection area.)
  - readout: DRS-4 ASIC from PSI
pGAPS Time-of-flight

- stable energy deposition measurement over time
- detectors work flawlessly after the flight in the lab
- only one tube failed during prototype flight → understood (intermittent corona discharge upon reaching float altitude)
pGAPS Si(Li) tracker

- both TRK electronics channels worked very well:
  - **high gain**: X-ray measurement stable over the course of the flight within the expected change due to the temperature increase
  - **low gain**: clear Landau distributions for charged particle energy depositions
- detectors worked flawlessly after the flight in the lab
- flux of coincident charged particles and atmospheric and cosmic X-rays is very small
  - **antideuteron analysis can easily reject this background type by requiring more than one coincident X-ray in the right range**

**X-ray stability**

- 22 keV: Ag Kα
- 25 keV: Ag Kβ
- 59 keV: Am-241

**X-ray flux at 33km**

- Am 241: 59.9 keV/6.1 keV T=46.3°C
- tube: 26.1 keV/4.1 keV T=43.0°C
- tube: 26.1 keV/4.7 keV T=28.9°C
- tube: 26.2 keV/5.0 keV T=18.6°C

94mm preamp

HV filter
Si(Li) detector production

- GAPS will use 1350 4” Si(Li) detectors, 2.5mm thick
- fabrication scheme developed at Columbia U.
- plan is to have detectors produced by private company Shimadzu, Japan
- leakage current ~15nA at -30C
- confirmed performance with cosmic rays (MIPs) and Am-241 source (X-rays)
- already achieved 4.4 keV FWHM at 59 keV
- Si(Li) detector fabrication: NSS/MIC 2013 IEEE 1-3, (2013)
pGAPS cooling system

(dashed components: ground operation only)

- Fluorinert cooling with pump transports heat to radiator
- GAPS representative radiator was tested → thermal model was verified
Oscillating heat pipe cooling system

- alternative cooling approach:
  - small capillary metal tubes filled with a phase-changing refrigeration liquid
  - small vapor bubbles form in the fluid → expand in warm sections/contract in cool sections
  - rapid expansion and contraction of these bubbles create thermo-contraction hydrodynamic waves that transport heat.
  - no active pump system is required
  - development at JAXA/ISAS

S. Okazaki et al., J. Astr.. Instr. 3 (2014)
Path forward

- measurement of antideuterons and antiprotons is a promising way for indirect dark matter searches
- GAPS is specifically designed for low-energetic antideuterons
- all goals for prototype GAPS were met
- Si(Li) detector production understood
- positive news from NASA → first GAPS science flight from Antarctica 2020
- next antideuteron workshop in 2017 → look for announcement
Si(Li) detector development

**No bias applied**

- Undrifthed p-type material

**Reverse bias applied**

(normal detector operation)

- simple fabrication procedure from the 1960s → low cost, high fabrication rate
- Lithium is first applied to the front surface of Boron-doped p-type Si and diffused through a short depth
- Li atoms donate electrons, resulting in an n-type Si lattice layer and leftover free positive Li ions
- under reverse bias, positive Li ions move away from the n-type region → compensate acceptor atoms in the p-type bulk → compensate impurities in the Si
- drifting procedure creates a thick compensated region (<1.5 days at 500V and 130C)
- ultrasonic machining on the n+(Li) contact → guard ring structure, reduces leakage current, much better energy resolution
- electrodes are thermal-evaporated ohmic/blocking contacts
• flux at drift-out “boomerang” altitude (10-15km) is ~30% higher than at float (33km)

• flux as function of velocity compared to simulations with Geant4+PLANETOCOSMICS (incl. geomagnetic, atmospheric effect) shows good agreement

• $\alpha$ particles constitute about ~10% of the flux at 33km (~9g/cm$^2$) → in good agreement with BESS data