GAPS - General AntiParticle Spectrometer

TeV Particle Astrophysics
September 2016

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on behalf of the GAPS collaboration
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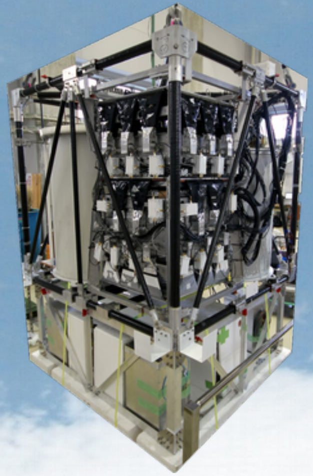
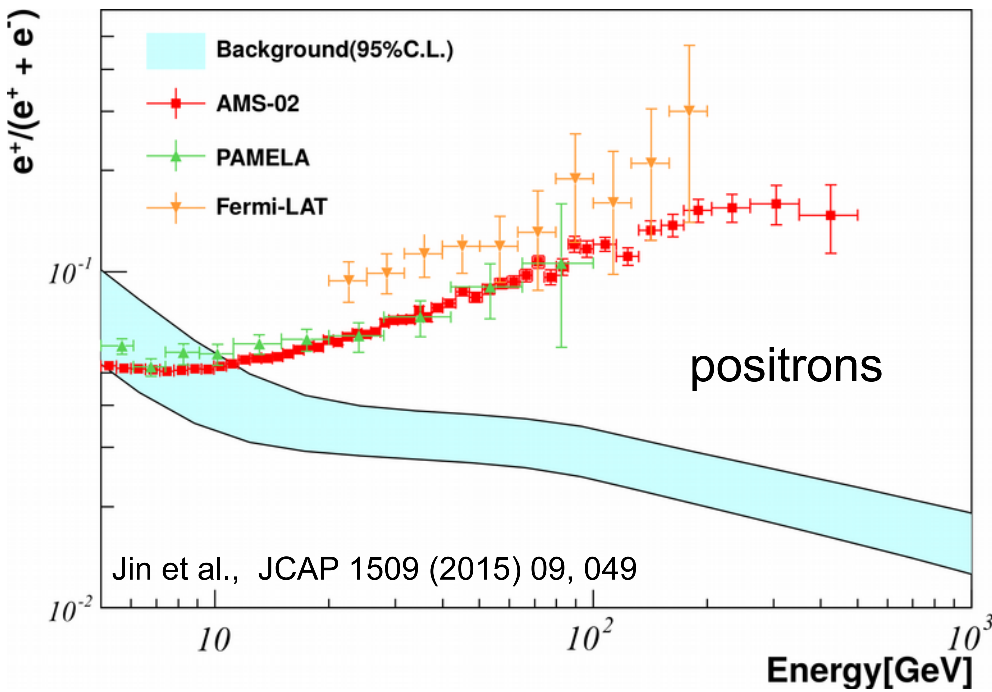
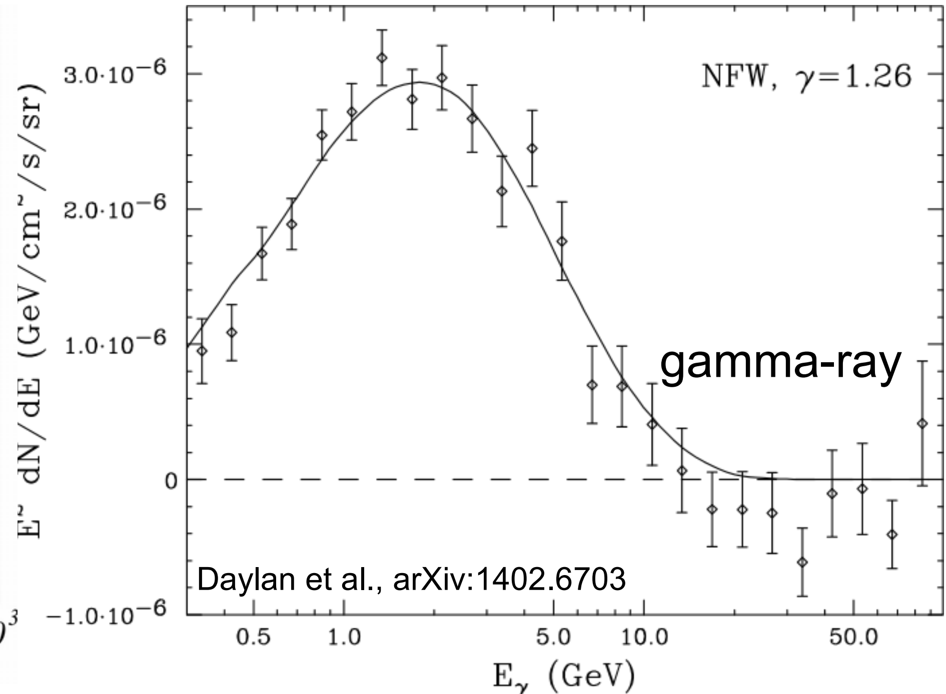
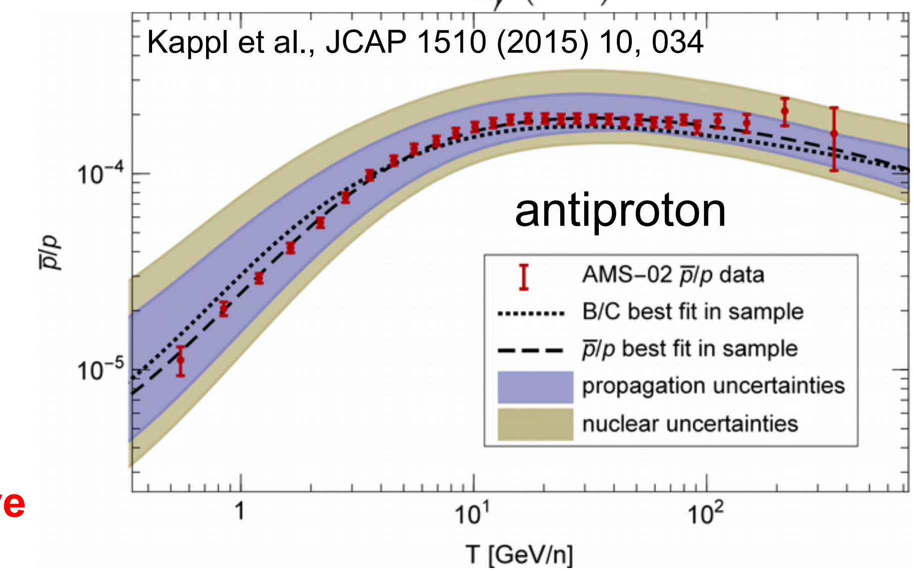
http://www.phys.hawaii.edu/~philipvd
www.antideuteron.com



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

ELSEVIER
Physics Reports
Volume 618, 7 March 2016, Pages 1–37
Review of the theoretical and experimental status of dark matter identification with cosmic-ray antideuterons

Review of the theoretical and experimental status of dark matter identification with cosmic-ray antideuterons

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arXiv:1505.07785

doi:10.1016/j.physrep.2016.01.002
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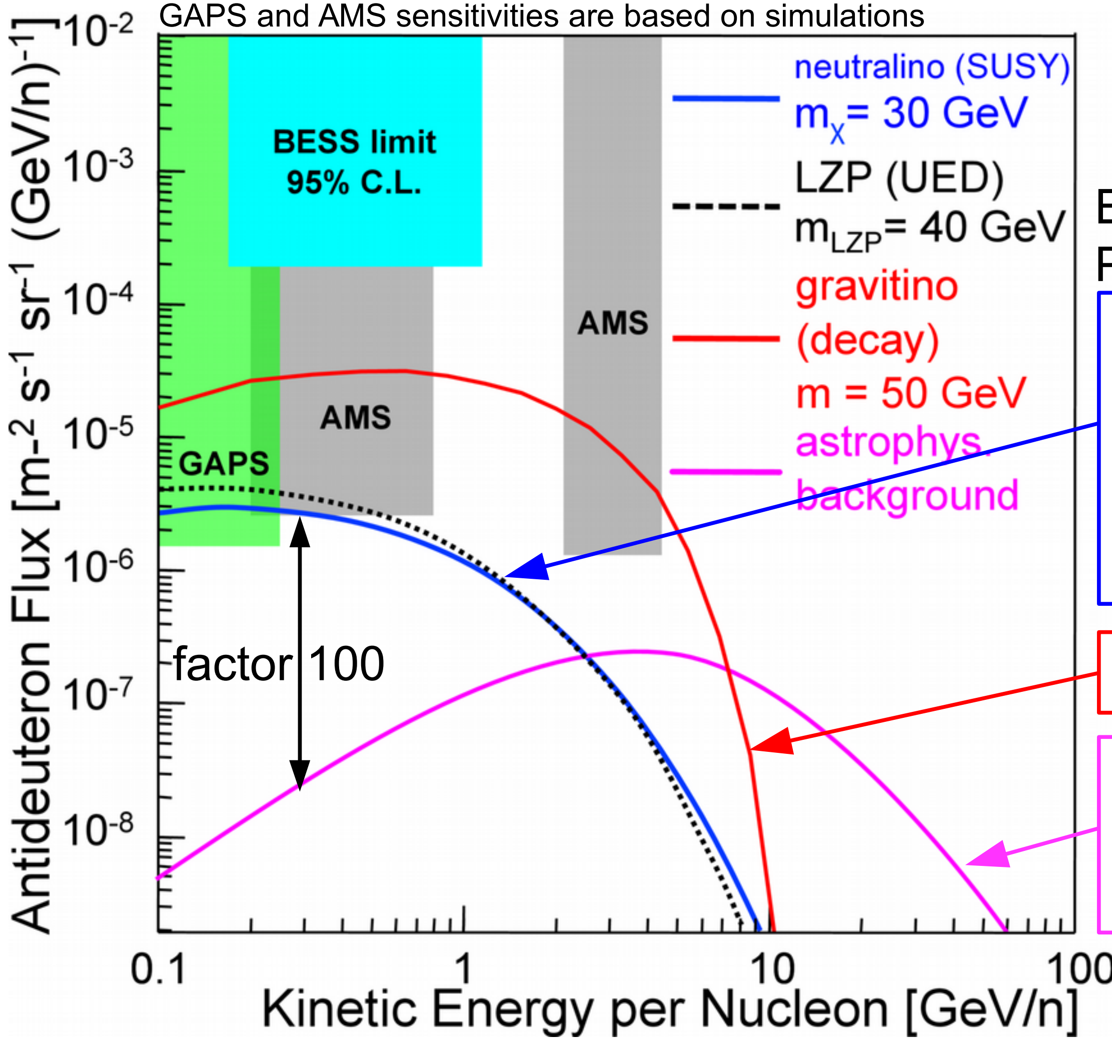
GAPS and AMS sensitivities are based on simulations



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

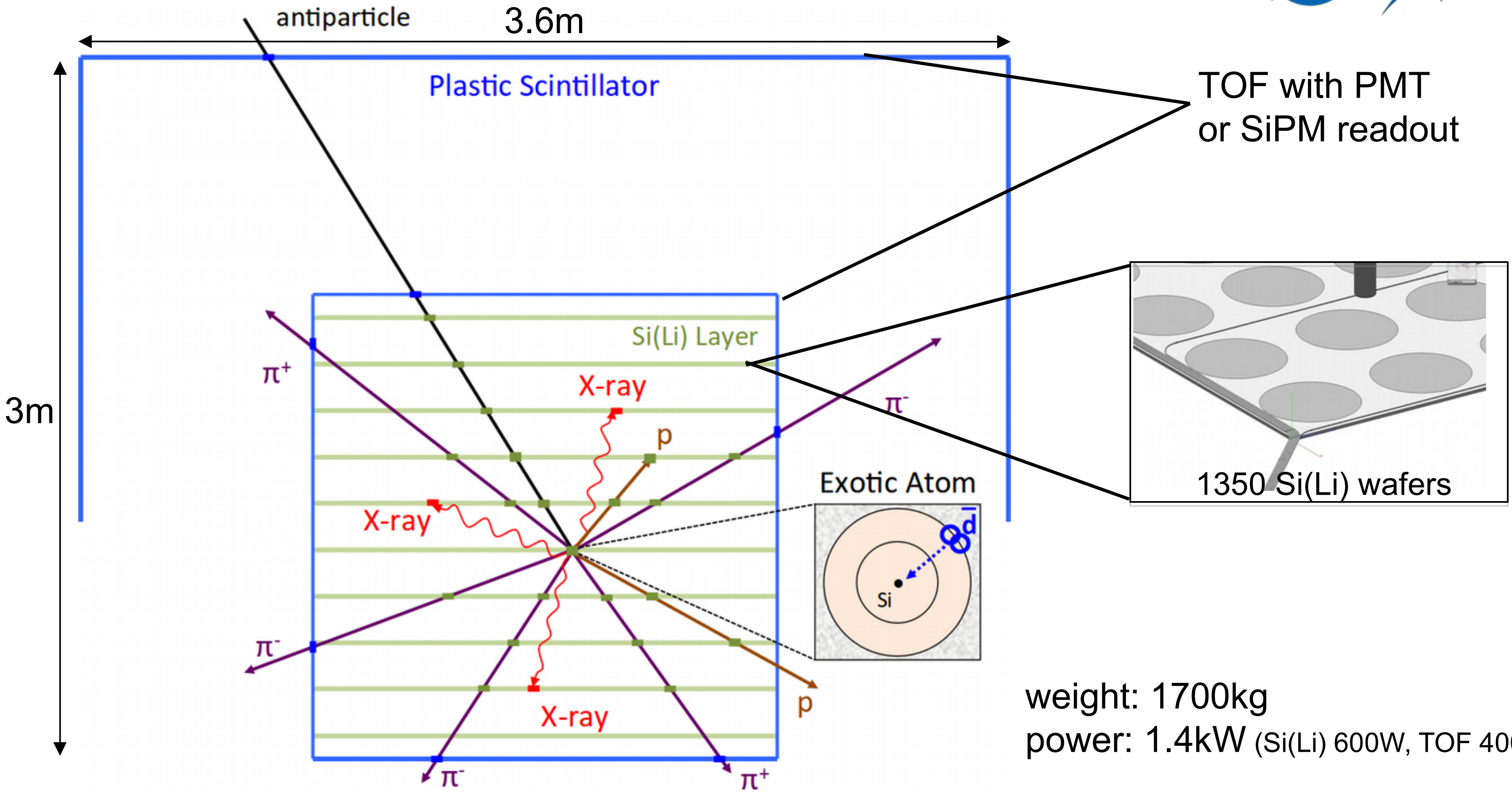
+ models with heavy dark matter

Antideuterons are the most important unexplored indirect detection technique!

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

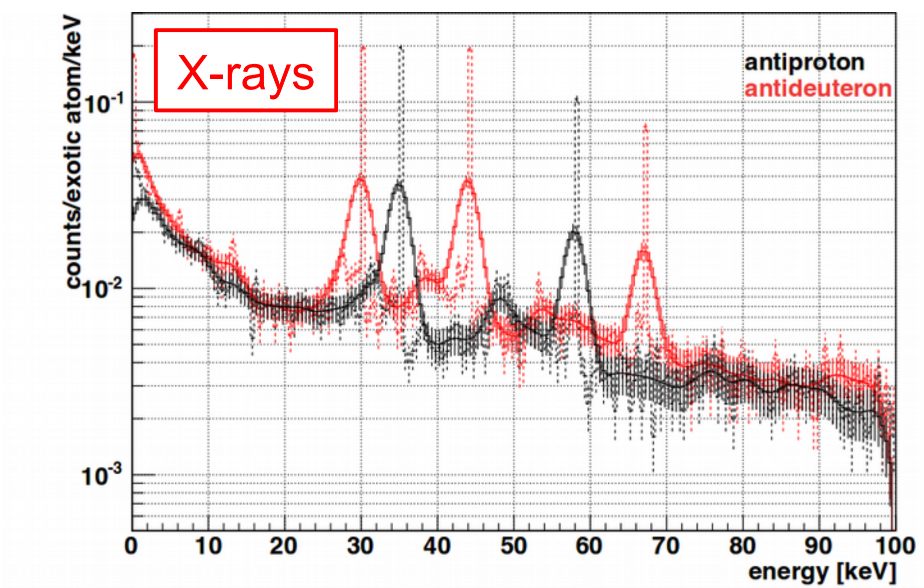
Columbia U, UC Berkeley
UCLA, U Hawaii,
MIT, INFN



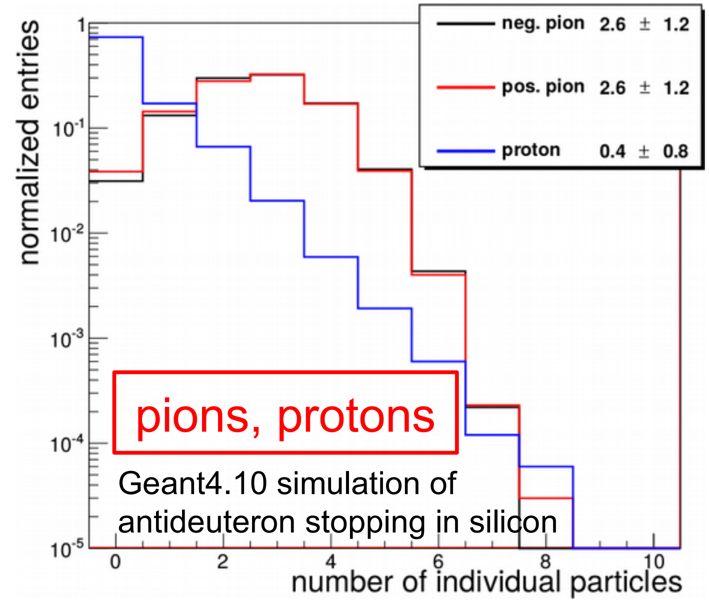
weight: 1700kg
power: 1.4kW (Si(Li) 600W, TOF 400W)

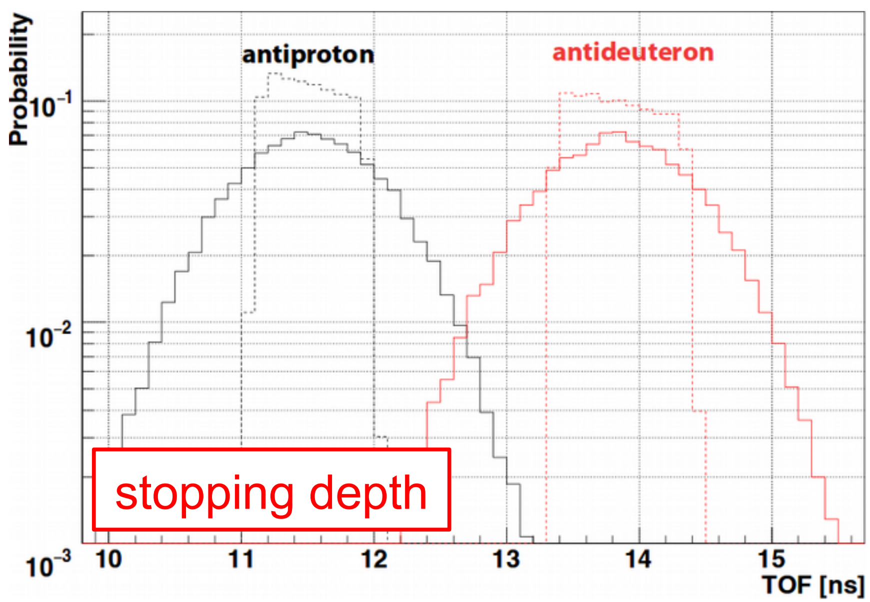
- the **G**eneral **A**nti**P**article **S**pectrometer is specifically designed for low-energy antideuterons and antiprotons
- planned for Long Duration Balloon flights from Antarctica
- identification by stopping and creation of exotic atoms tested in KEK testbeam measurements: Astropart. Phys. 49, 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**

GAPS sensitivity



Astropart. Phys. 74, 6 (2016)



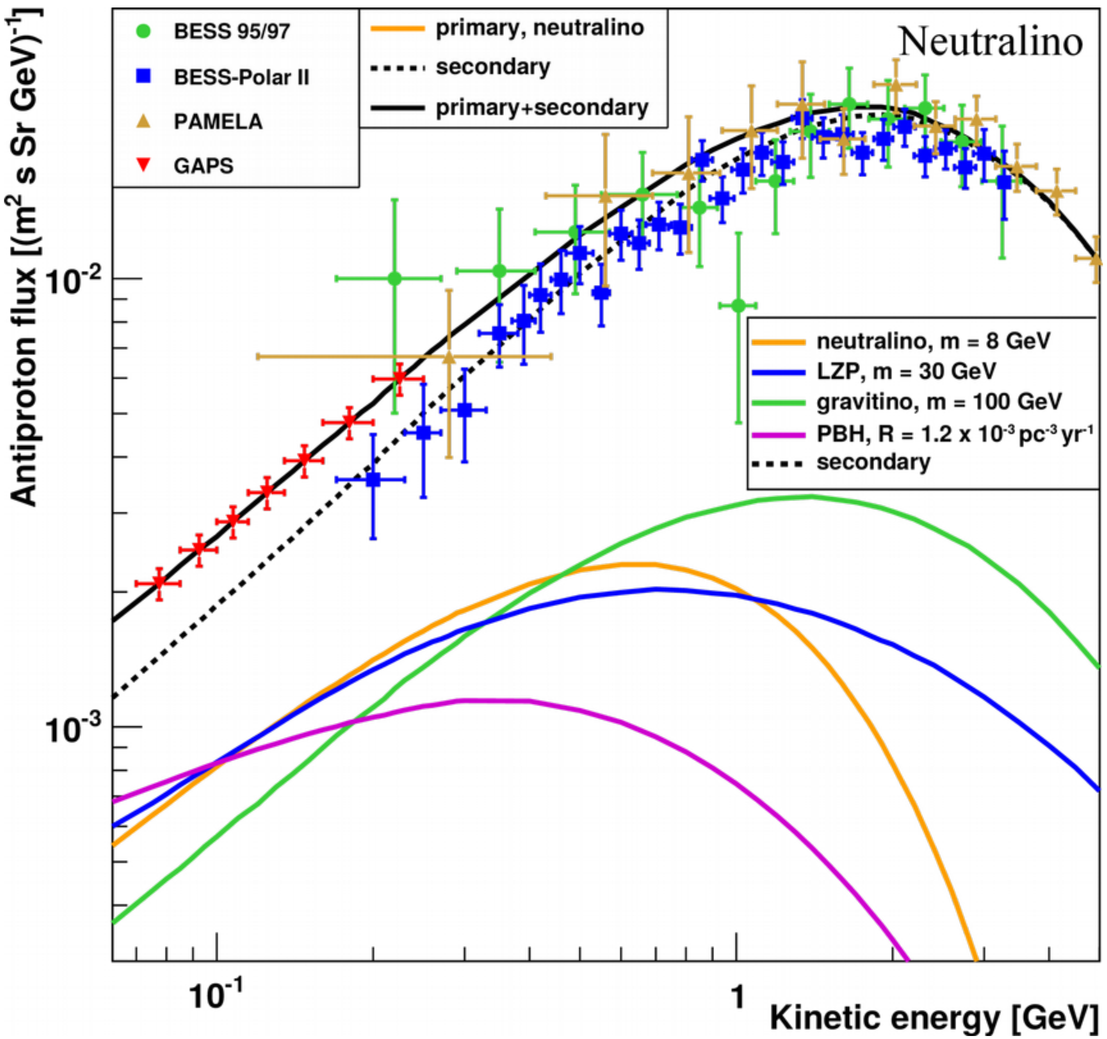


Background rejection:

- 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

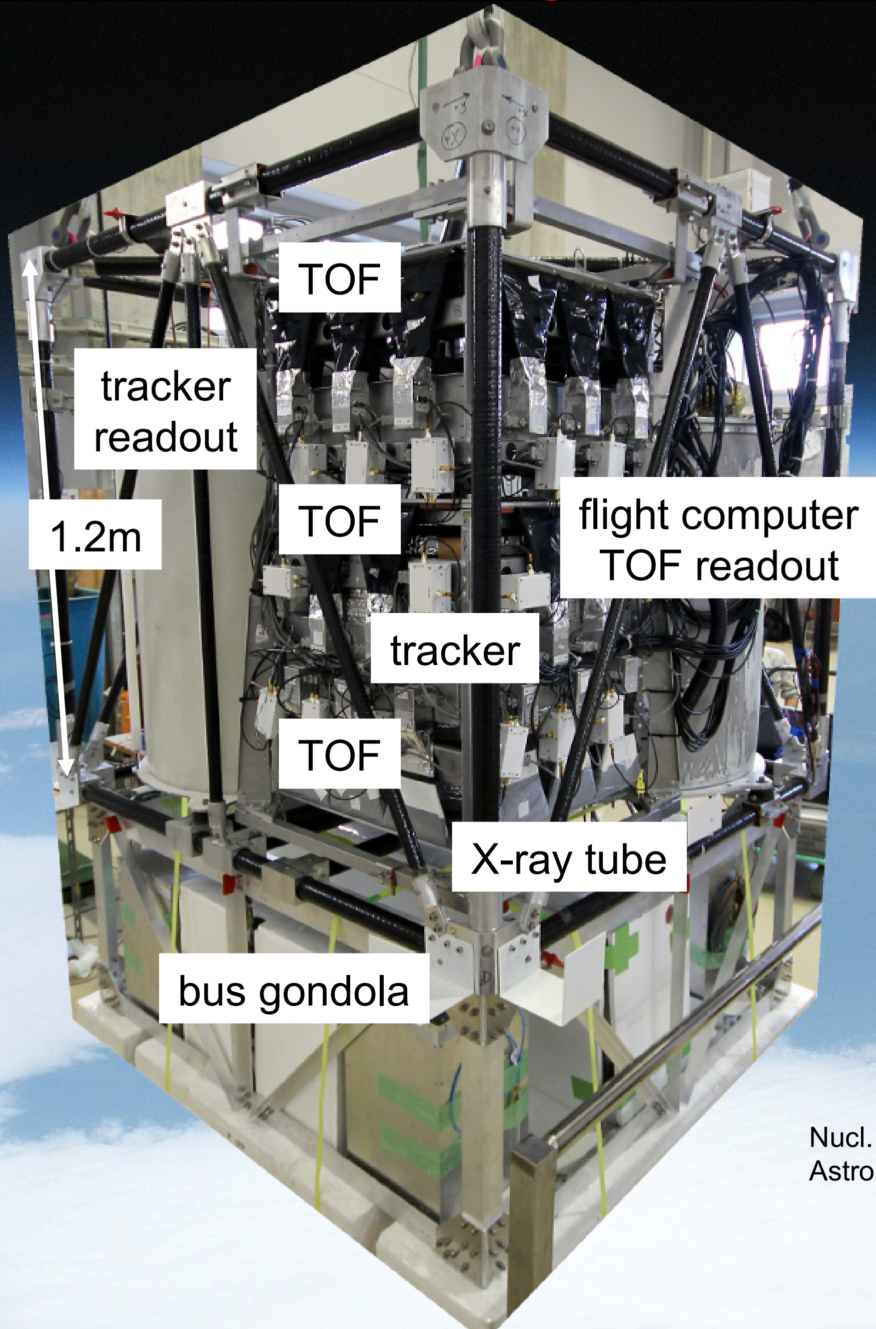
GAPS antiproton

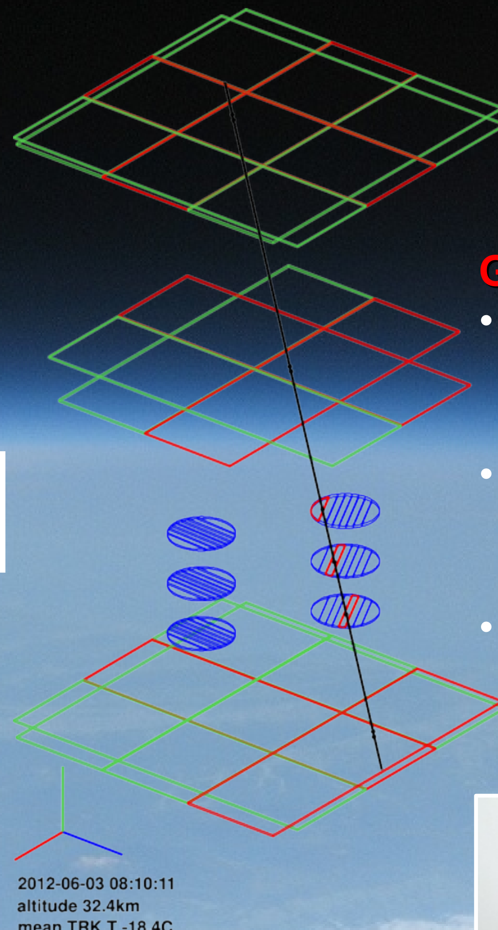
Astropart. Phys. 59 (2014) 12



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



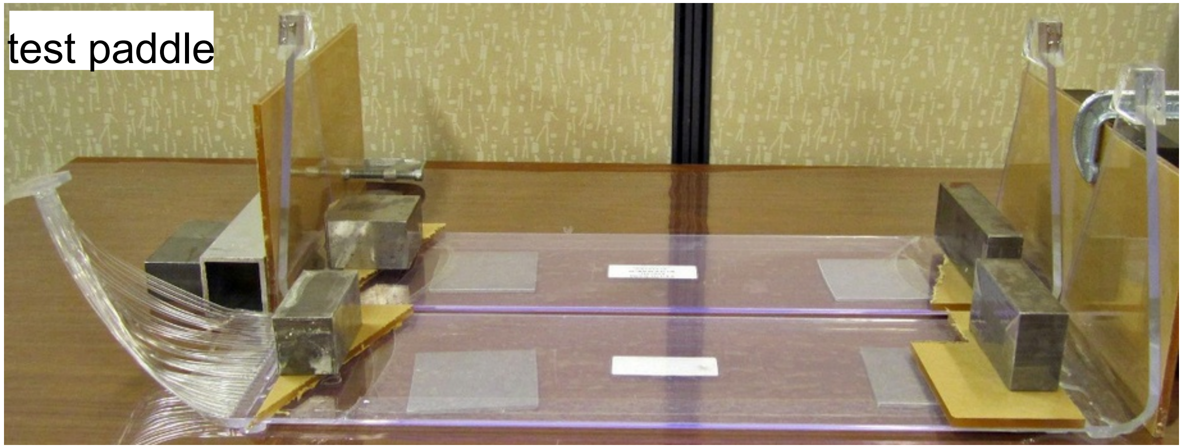


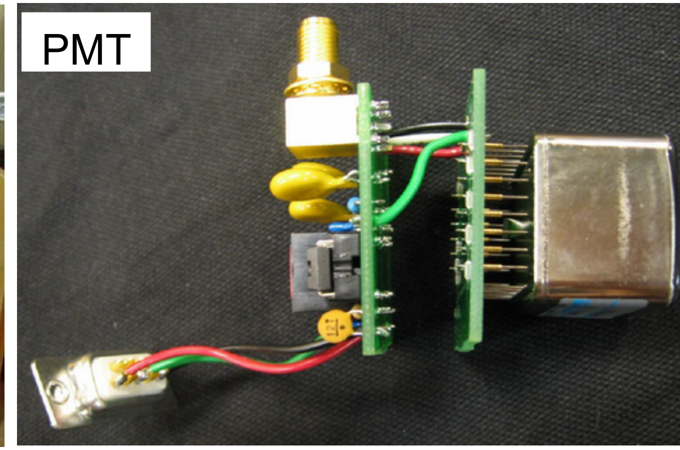
Goals:

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

Nucl. Instrum. Meth. A735 (2014) 24
Astropart. Phys. 54 (2014) 93

Time-of-flight design



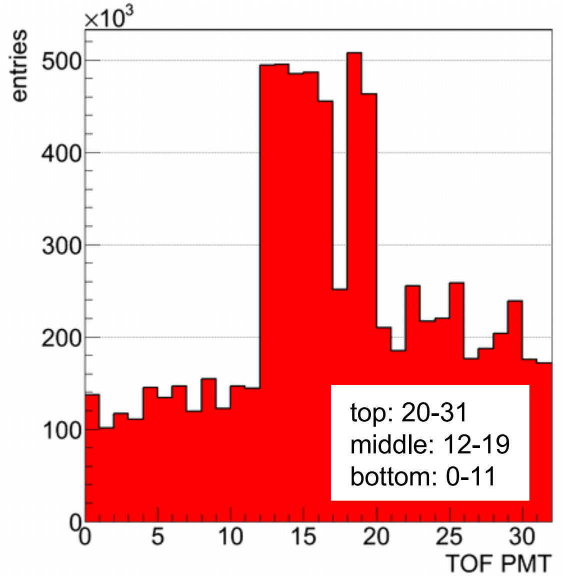


- **tasks:**
  - charged particle trigger
  - velocity measurement (500ps resolution)
  - tracking (5 degree resolution)

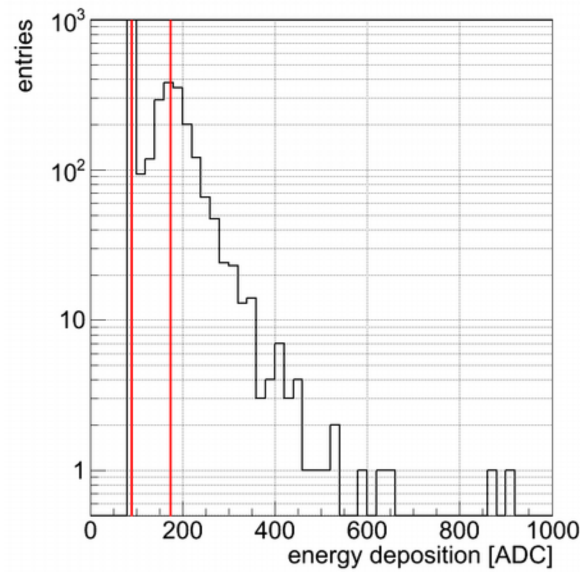
- **GAPS design:**
  - 215 paddles total, 16cm wide, 1.6-1.8m
  - 5mm scintillator (BC-408 or EJ-500)
  - Hamamatsu R7600 PMT
    or SiPM (Hamamatsu S13360 -3050CS MPPC with a 3x 3mm collection area.)
  - readout: DRS-4 ASIC from PSI

pGAPS Time-of-flight

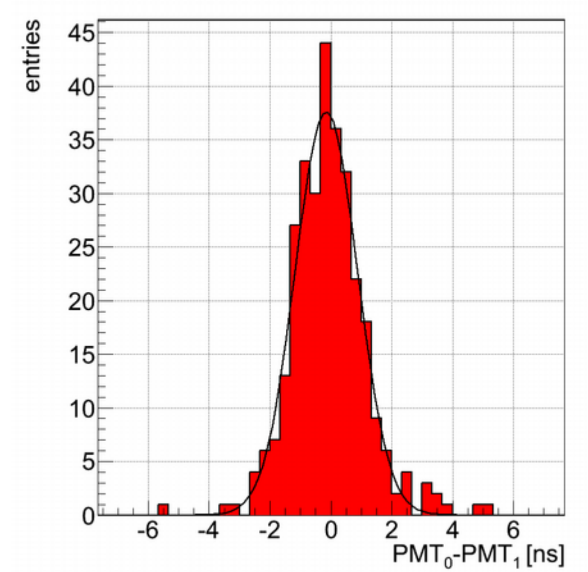
PMT occupancy



typical energy deposition



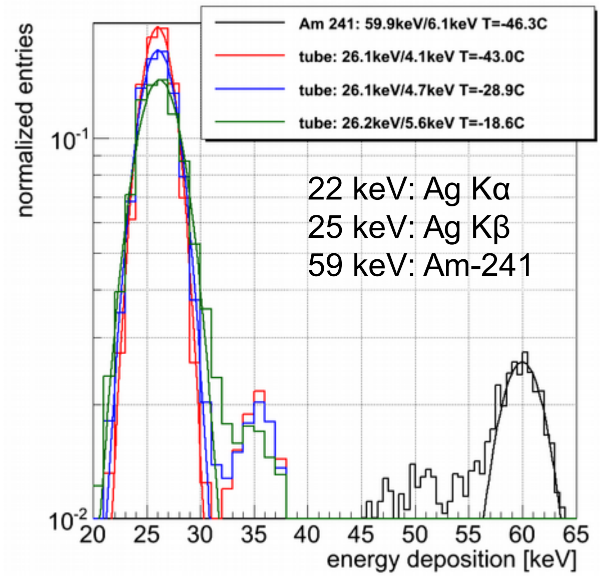
timing resolution



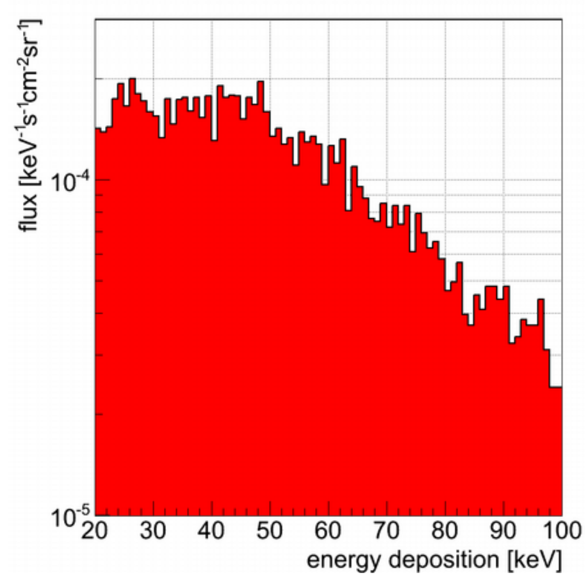
- stable energy deposition measurement over time
- detectors work flawlessly after the flight in the lab
- only one tube failed during prototype flight → understood
  (intermittent corona discharge upon reaching float altitude)

pGAPS Si(Li) tracker

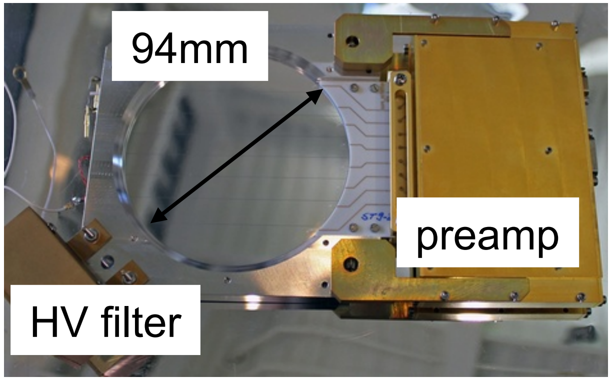
X-ray stability



X-ray flux at 33km



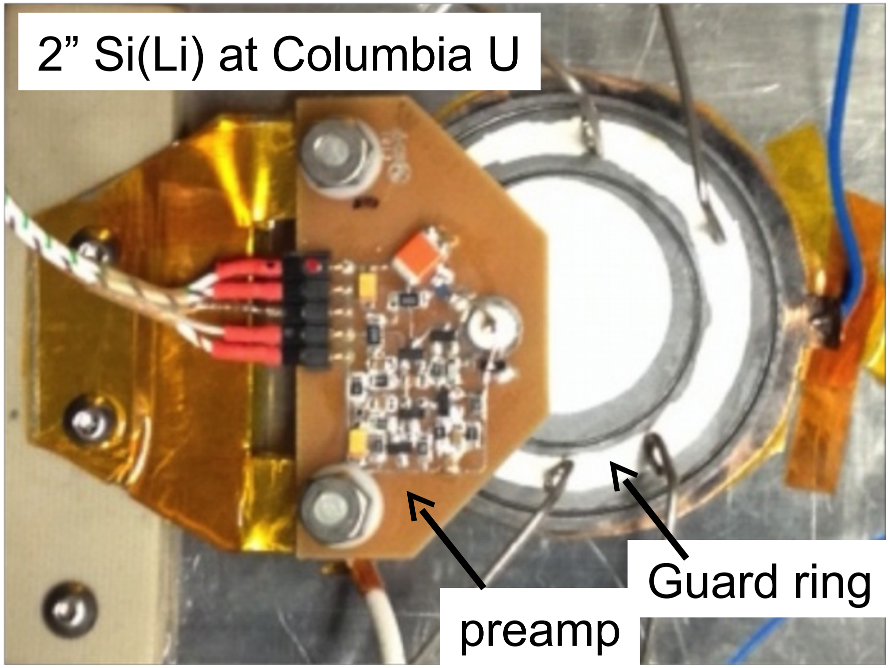
- both TRK electronics channels worked very well:
  - **high gain:** X-ray measurement stable over the course of the flight within the expected change due to the temperature increase
  - **low gain:** clear Landau distributions for charged particle energy depositions
- detectors worked flawlessly after the flight in the lab



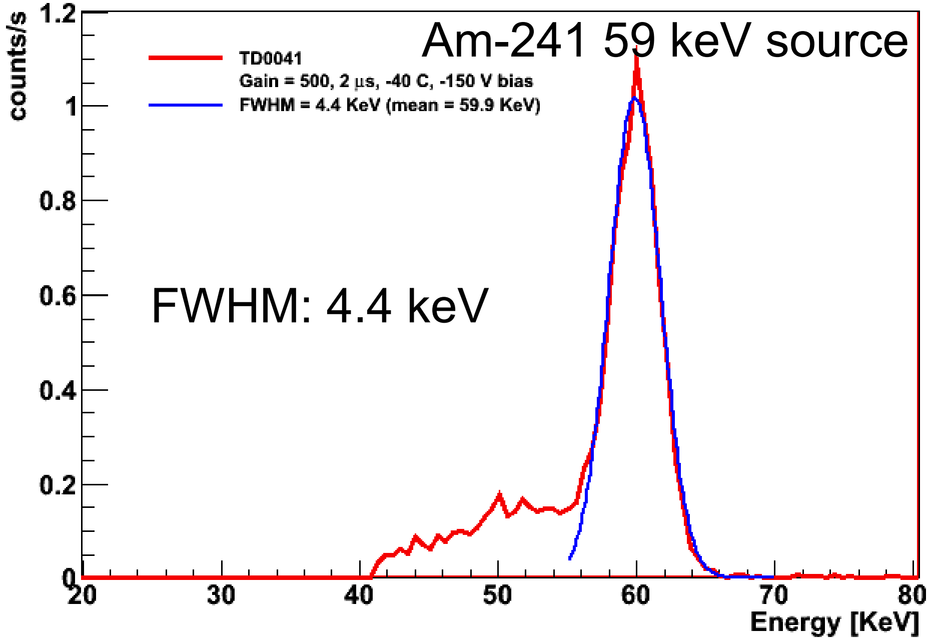
- flux of coincident charged particles and atmospheric and cosmic X-rays is very small

  → antideuteron analysis can easily reject this background type by requiring more than one coincident X-ray in the right range

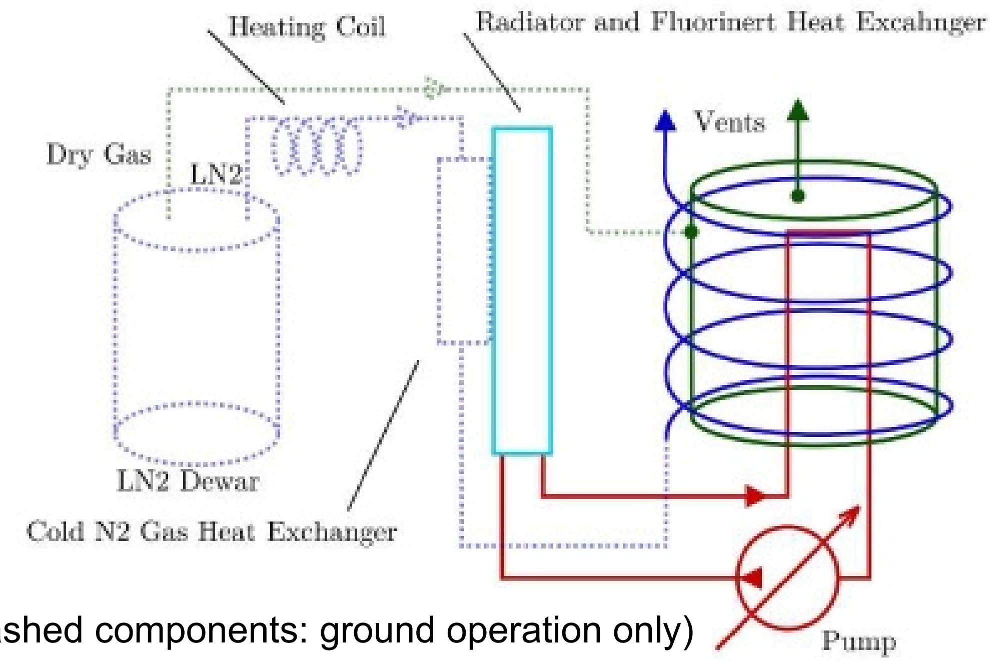
Si(Li) detector production



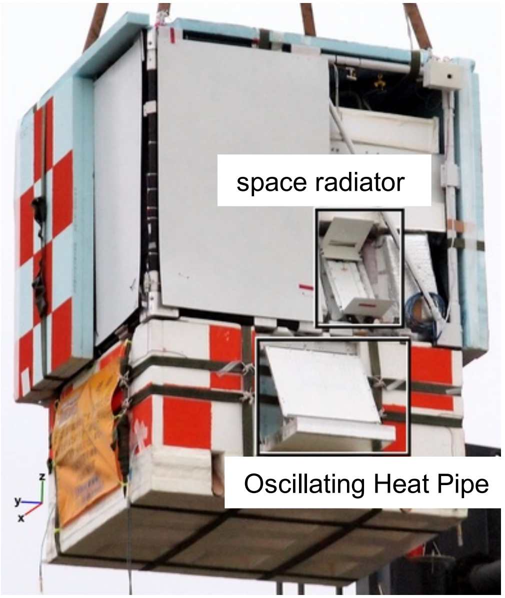
- GAPS will use 1350 4" Si(Li) detectors, 2.5mm thick
- fabrication scheme developed at Columbia U.
- plan is to have detectors produced by private company Shimadzu, Japan
- leakage current ~15nA at -30C
- confirmed performance with cosmic rays (MIPs) and Am-241 source (X-rays)
- already achieved 4.4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

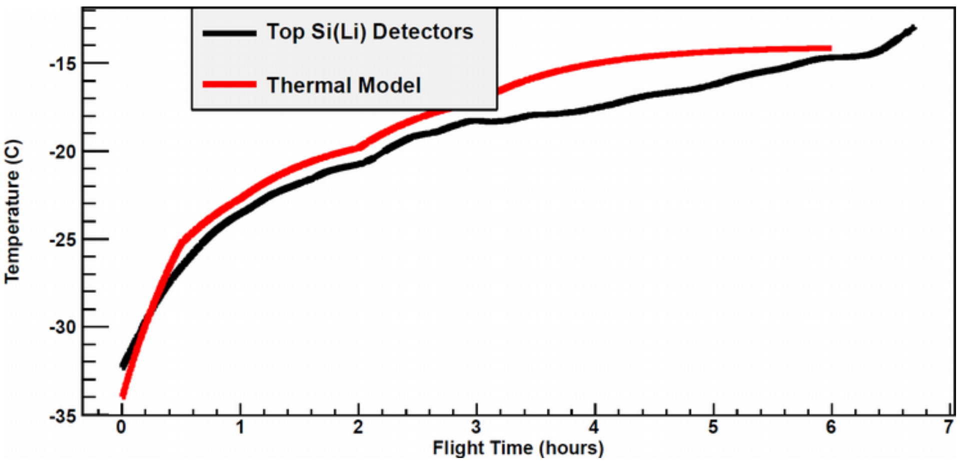


pGAPS cooling system



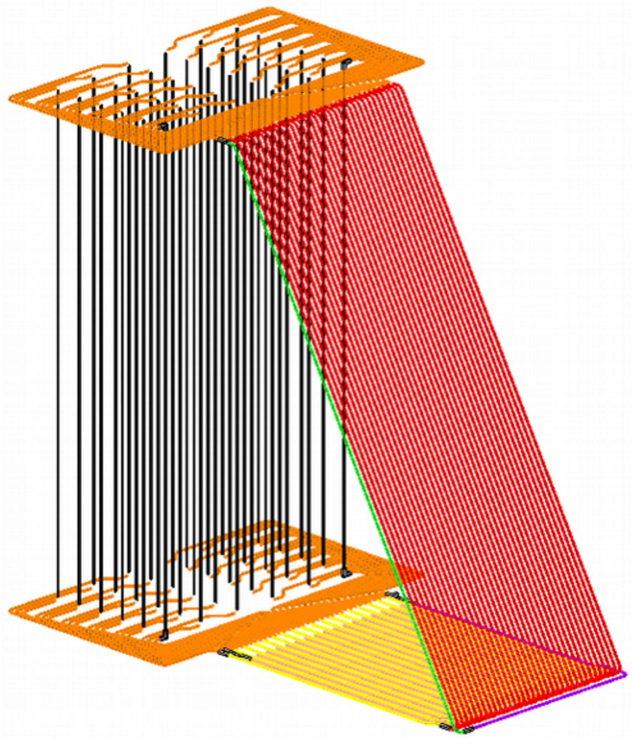
(dashed components: ground operation only)

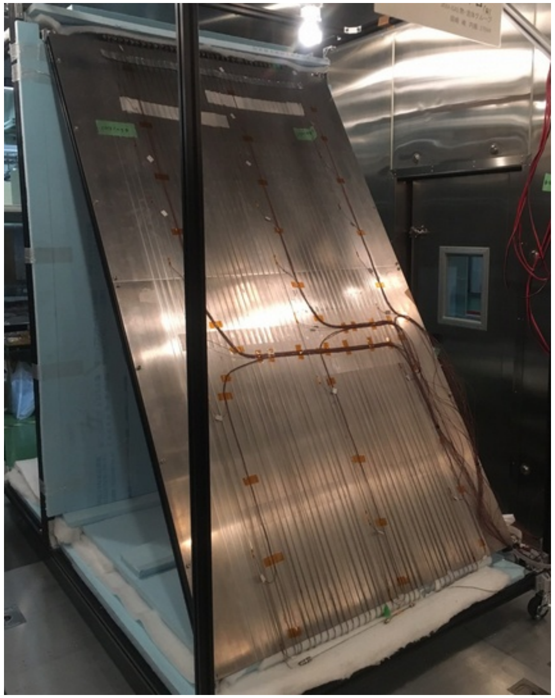


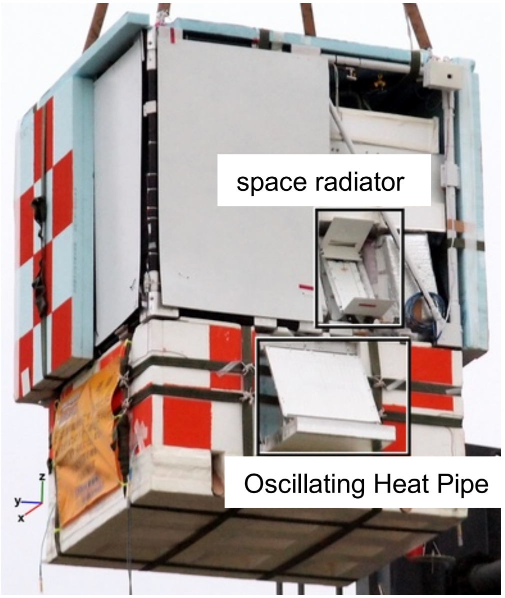


- Fluorinert cooling with pump transports heat to radiator
- GAPS representative radiator was tested → **thermal model was verified**

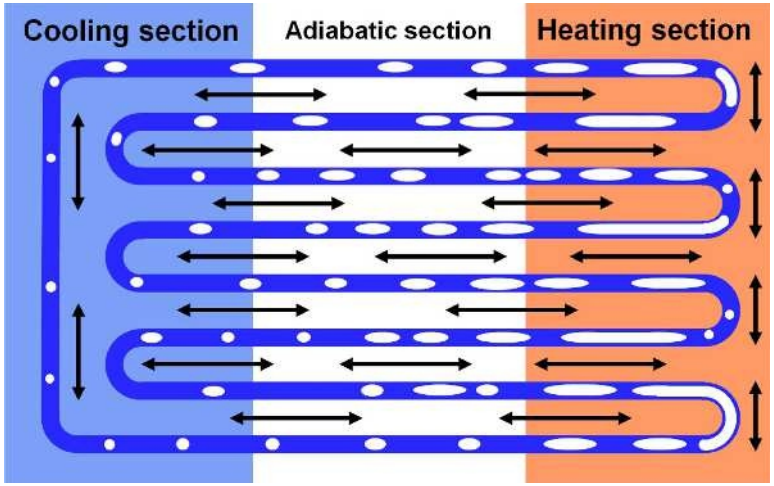
Oscillating heat pipe cooling system







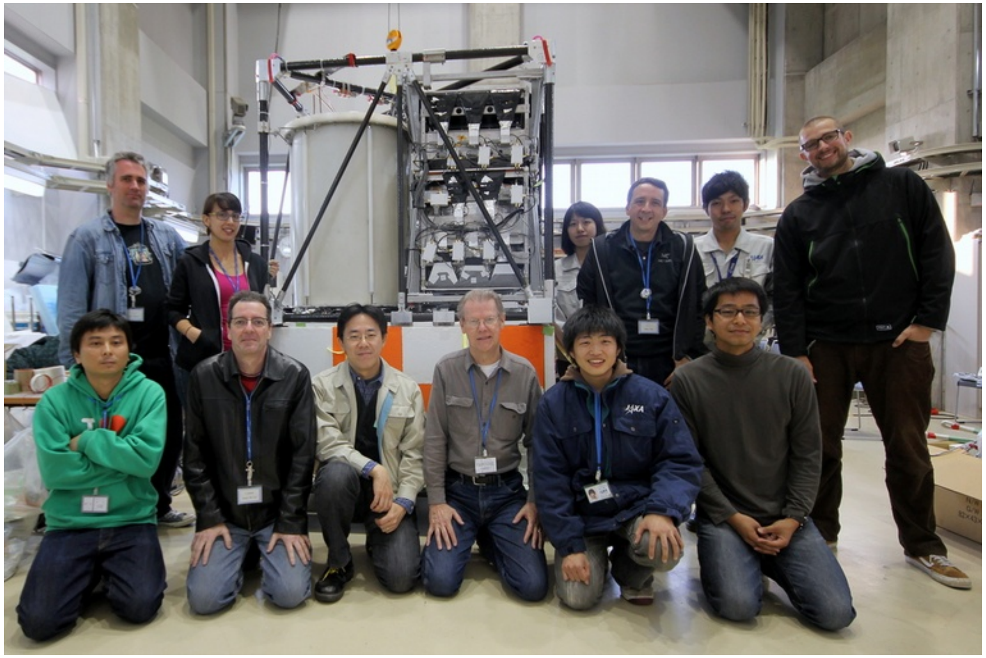
S. Okazaki et al., J. Astr.. Instr. 3 (2014)



- 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

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



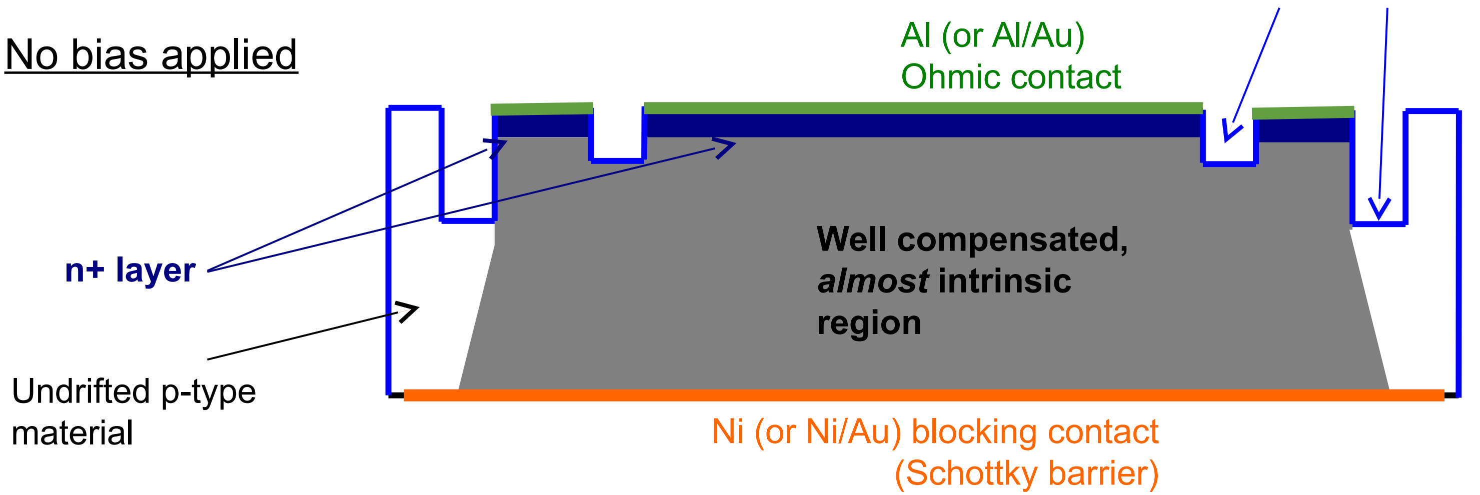
pGAPS team before launch

d̄17 **2nd cosmic-ray antideuteron workshop**

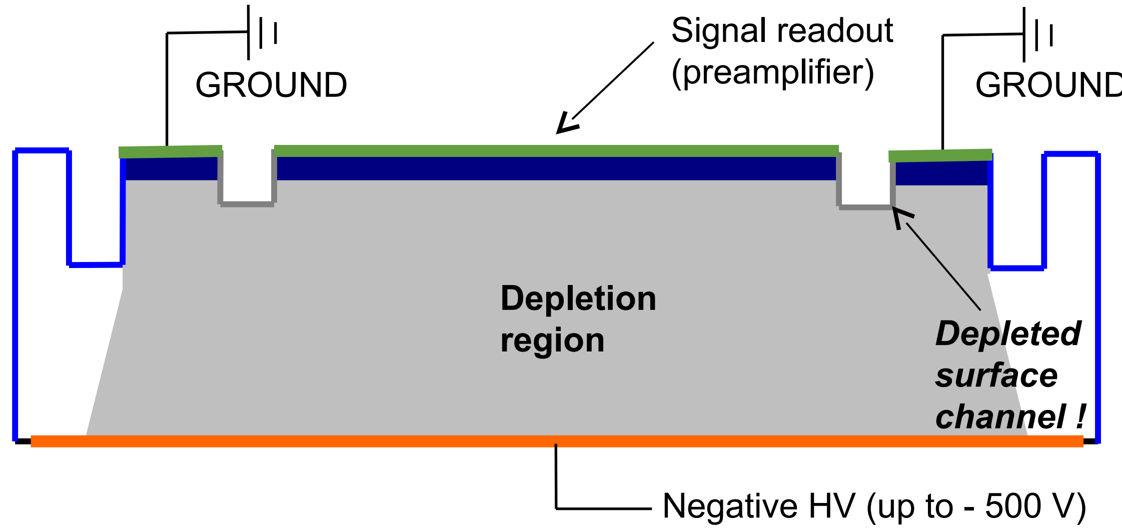
Columbia University, UC Berkeley, Japan Aerospace Exploration Agency, UC Los Angeles, U Hawaii, MIT, INFN

Si(Li) detector development

No bias applied



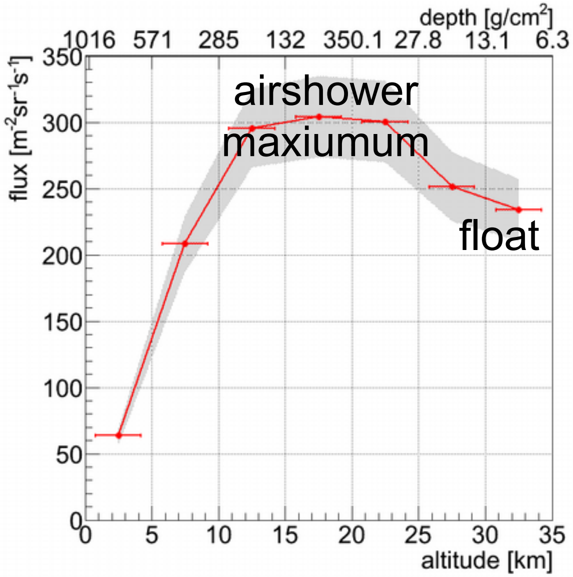
Reverse bias applied
(normal detector operation)



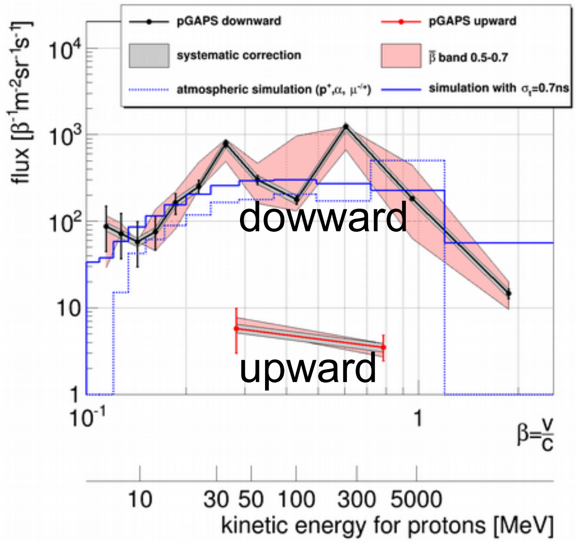
- simple fabrication procedure from the 1960s
  → low cost, high fabrication rate
- Lithium is first applied to the front surface of Boron-doped p-type Si and diffused through a short depth
- Li atoms donate electrons, resulting in an n-type Si lattice layer and leftover free positive Li ions
- under 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

pGAPS flux measurement

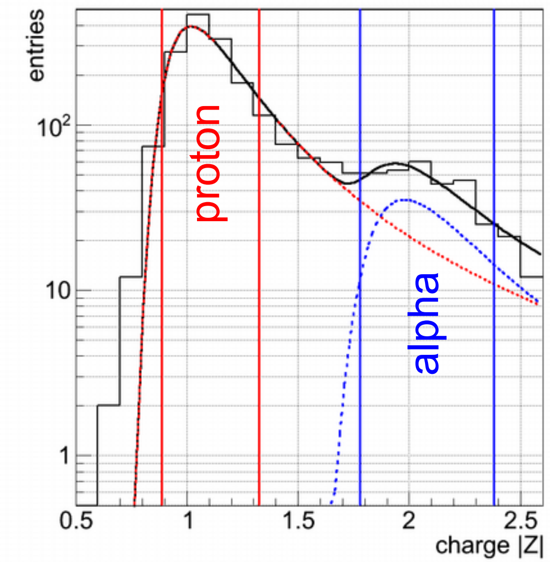
total flux vs. altitude



flux vs. β at 33km



particle composition at 33km



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