Development of the General AntiParticle Spectrometer (GAPS)

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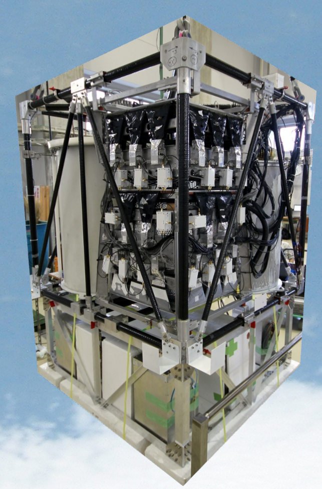
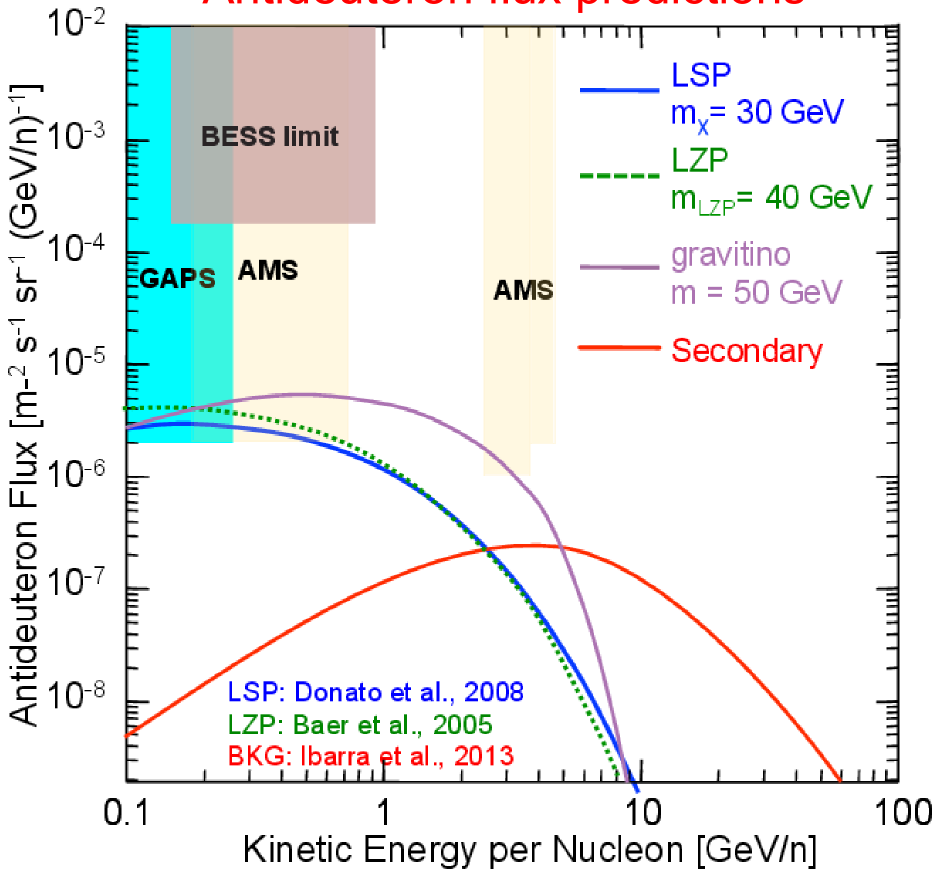
on behalf of the GAPS collaboration
Columbia University

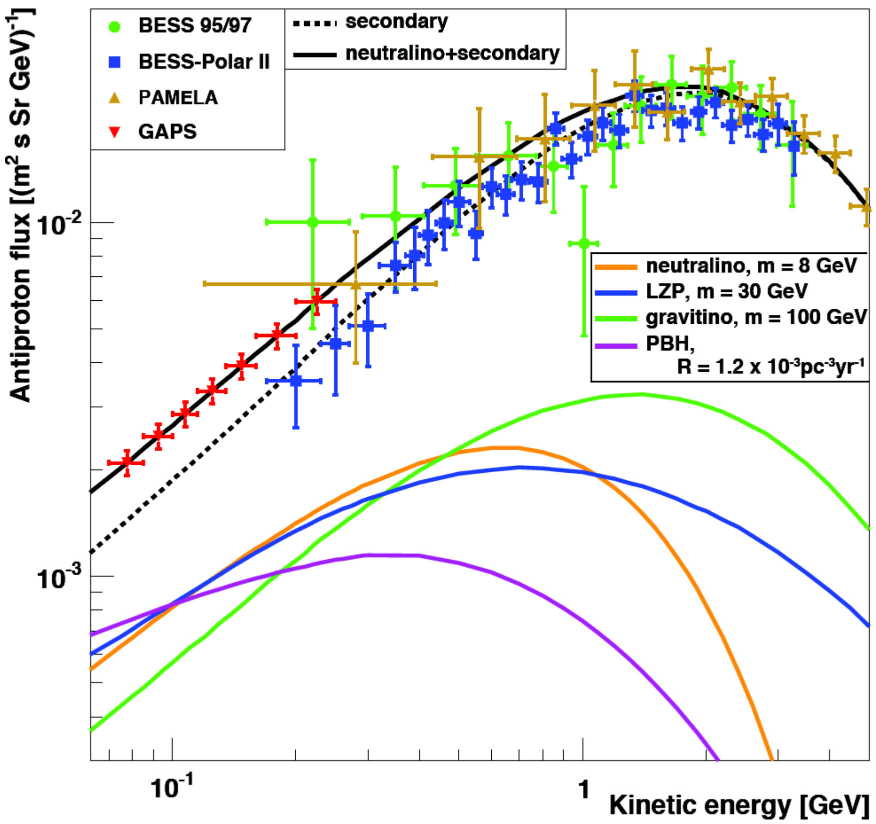


Dark matter search with *dbar* and *pbar*

Antideuteron flux predictions



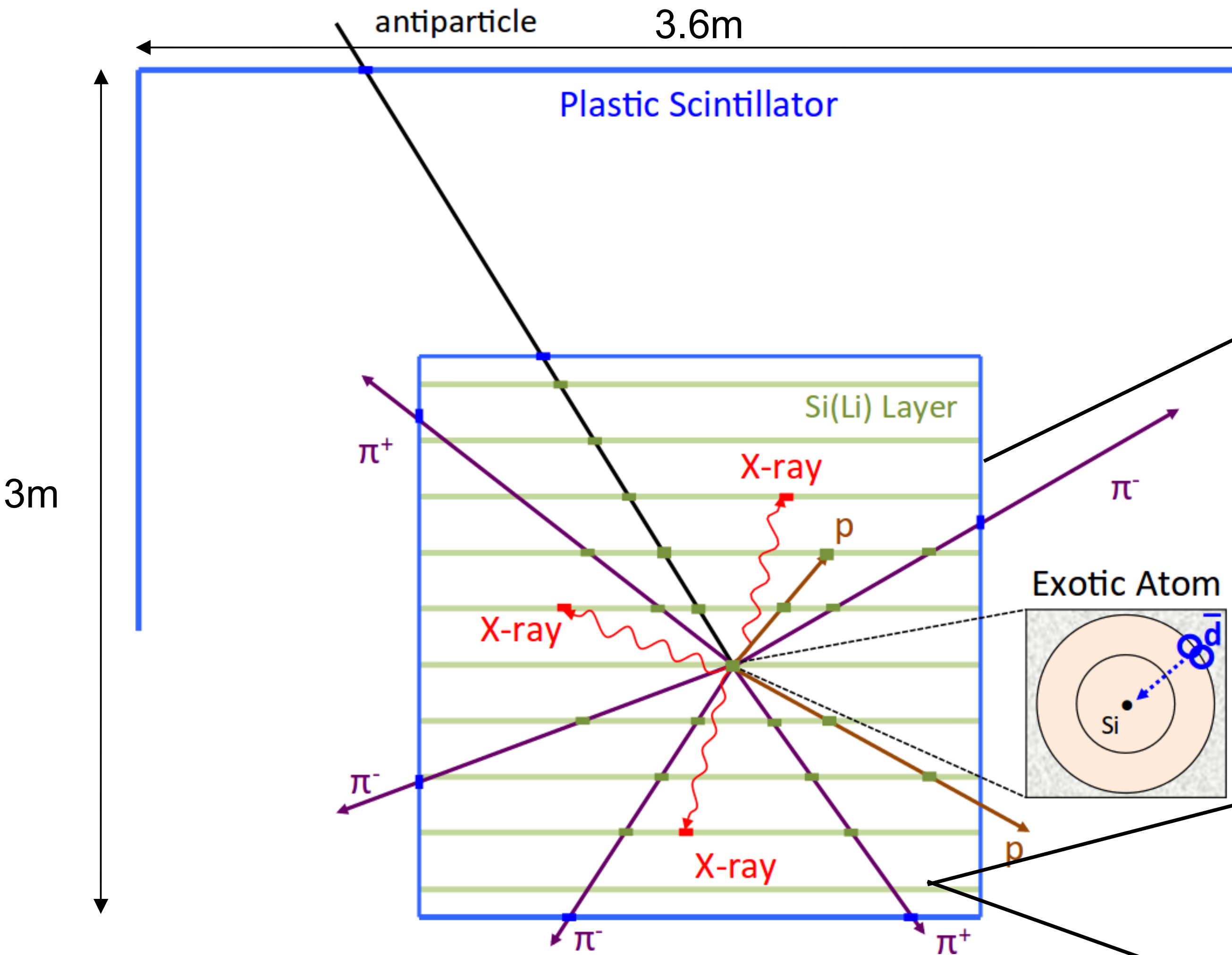
Antiproton data and predictions



- low-energy antideuterons and antiprotons cosmic ray measurements are sensistive to a wide range of dark matter models and primordial black holes
- **antideuterons are the most important unexplored indirect dark matter detection technique**
- GAPS results will provide essential independent overlap with direct dark matter searches (DAMA/LIBRA, CoGENT, CDMS, LUX, XENON, etc.) and open up new low/high-mass dark matter phase space

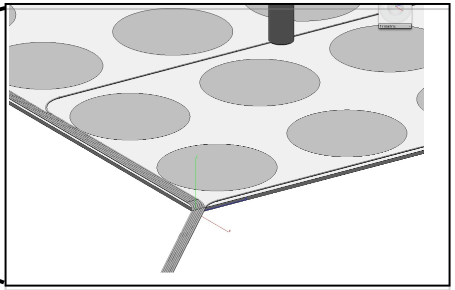
The GAPS experiment

Columbia U, UC Berkeley
UCLA, U Hawaii,
Haverford



plastic scintillators with PMT readout

weight: 1700kg
power: 1.4kW
readout: ~100mW/ch
(preamp: ~15mW/ch)

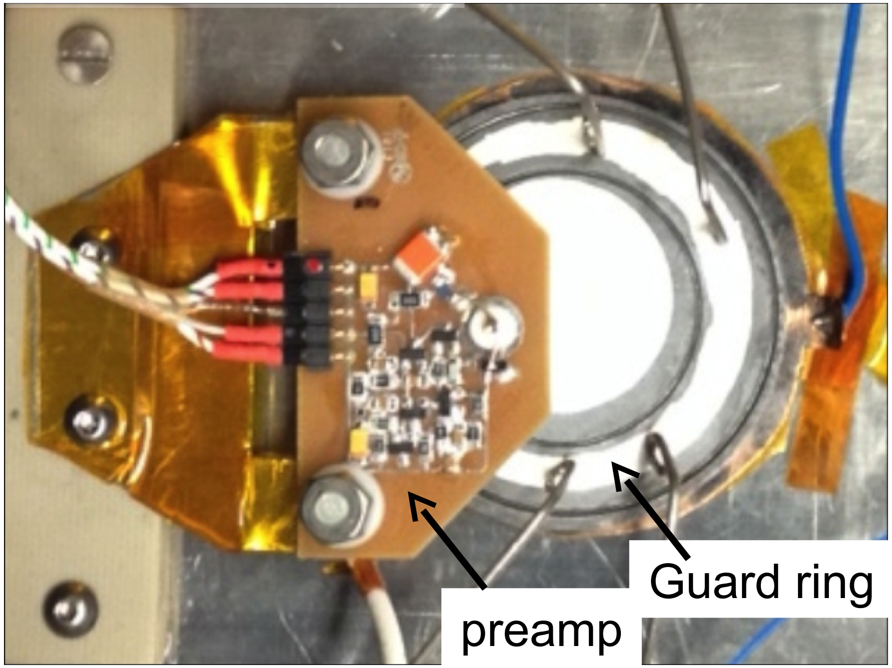


~1400 Si(Li) wafers

- the **G**eneral **A**nti**P**article **S**pectrometer is especially designed for **low-energy antideuterons and antiprotons**
- identification by stopping and creation of an exotic atom [KEK testbeam measurements → Astropart. Phys. 49, 52 (2013)]
- LDB flights from Antarctica

Si(Li) detector production

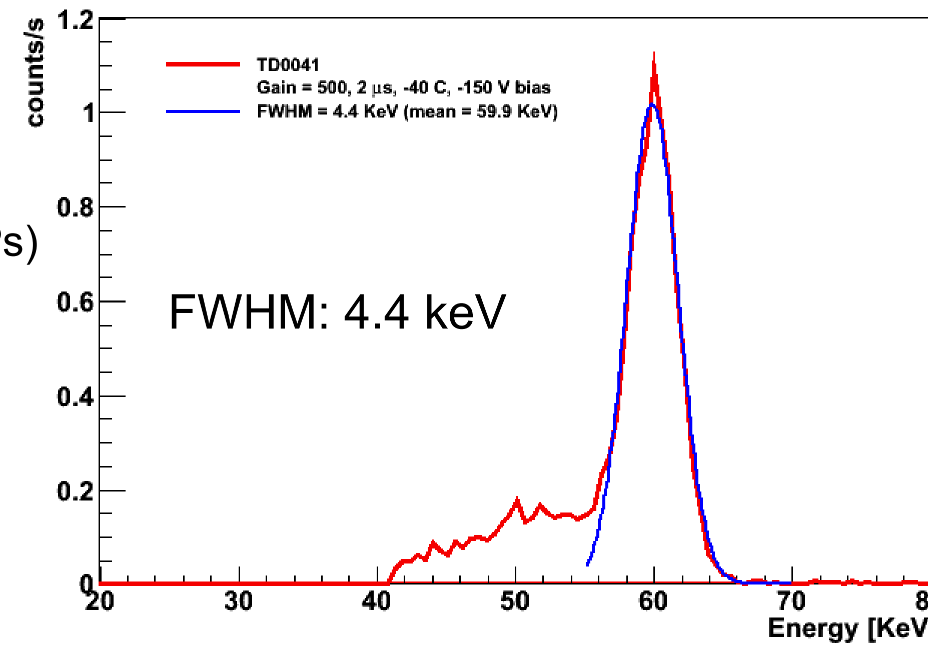
2” homemade Si(Li)



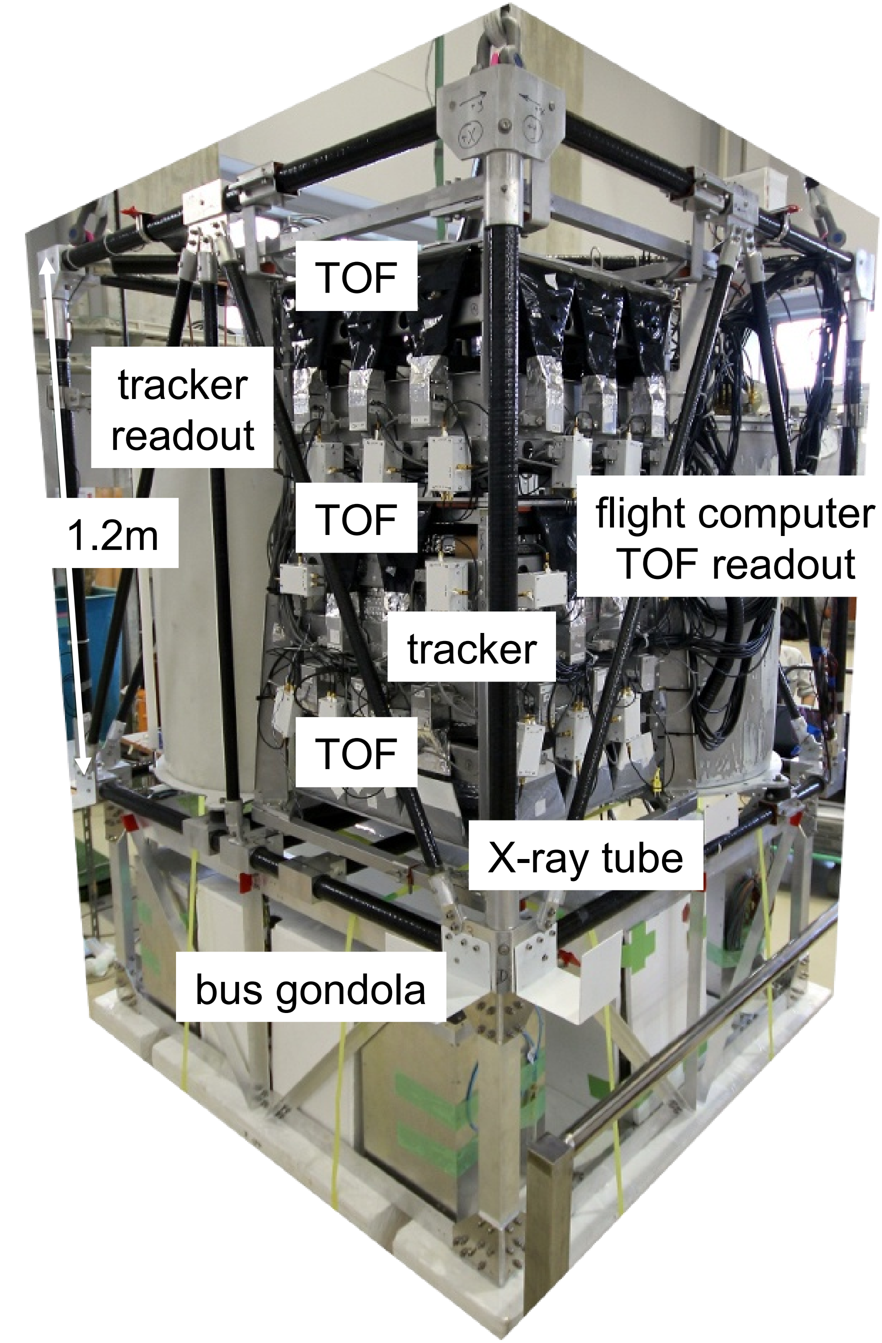
- GAPS will use ~1400 4” Si(Li) detectors
- 2”-diameter detectors being produced at Columbia U. using simple fabrication scheme
- successfully drifted diameters from 1" to 2" with >90% yield, both 1 mm (prototype) and 2.5 mm thick

- leakage current ~1nA at -35 C
- confirmed performance with cosmic rays (MIPs) and Am-241 source (X-rays)
- already achieved 4.4 keV FWHM at 59 keV
    - can be improved with better Li drifting
- 4” detector development underway!

Am-241 59 keV source

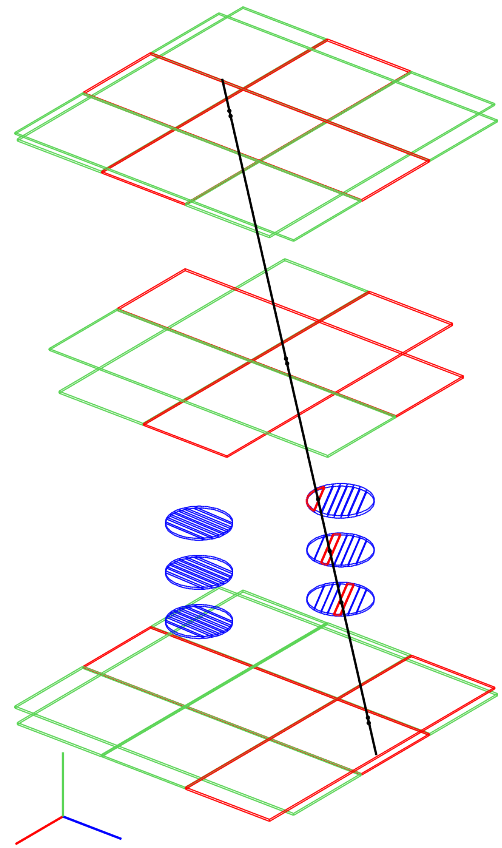


Prototype GAPS

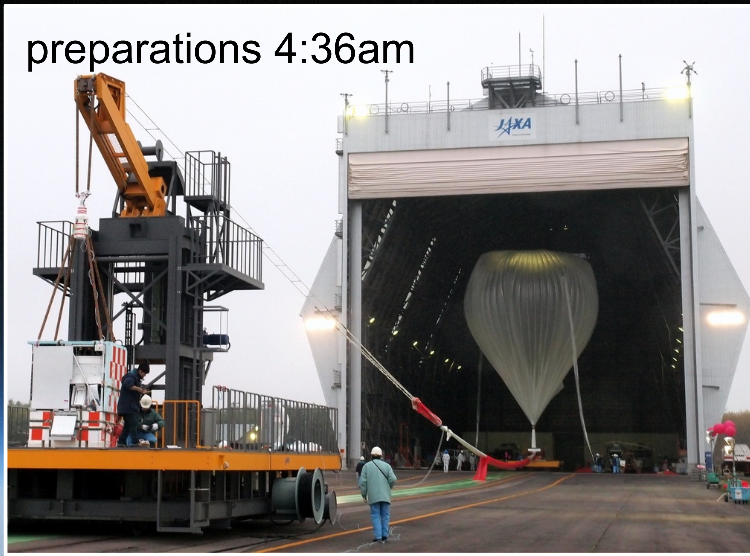


Goals:

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



pGAPS flight: June 3rd 2012 from Taiki, Japan



preparations 4:36am

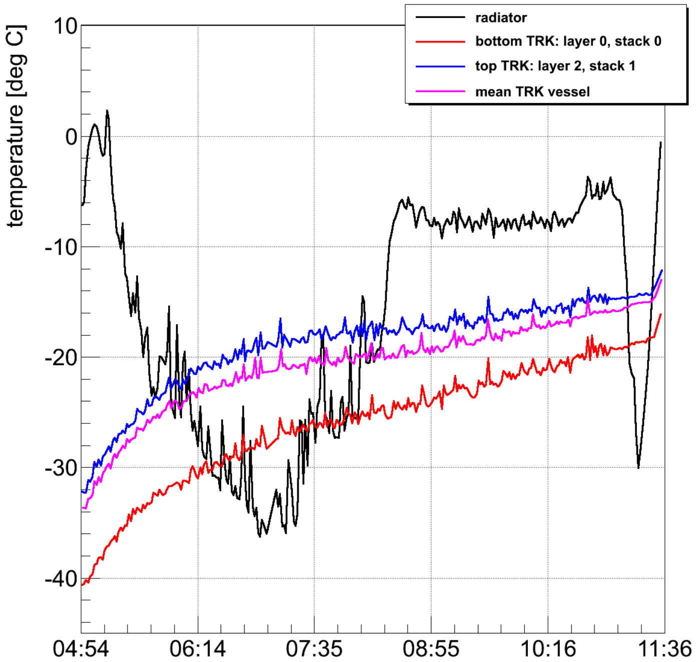
release of balloon

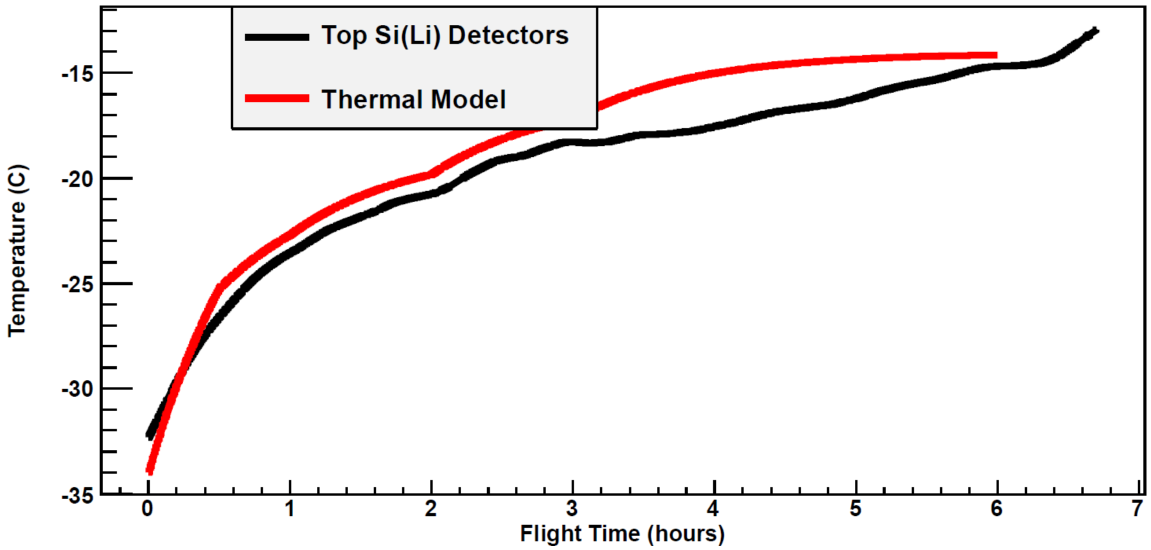
4:55am
take off

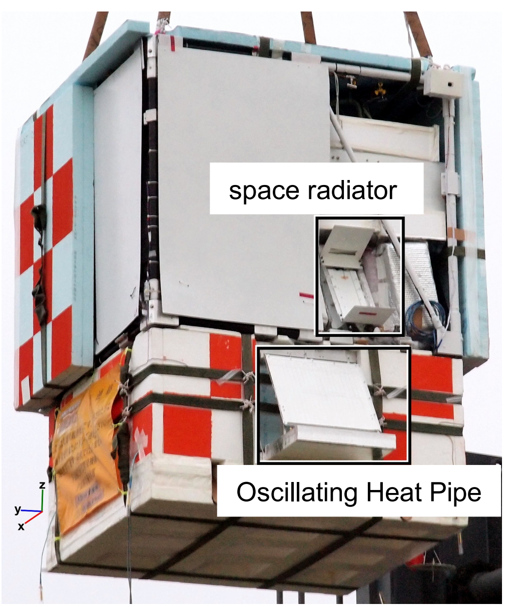
return to the harbor 1:05pm

- **well defined TOF trigger and tracker runs**
  - time: 19×13min
  - ~600,000 triggers
- **carry out in-flight calibration of Si(Li) detectors**
  - run X-ray tube
  - time: 13×4min
- **trigger on Si(Li) detectors to study incoherent X-ray background**
  - time: 9×3min

Thermal model







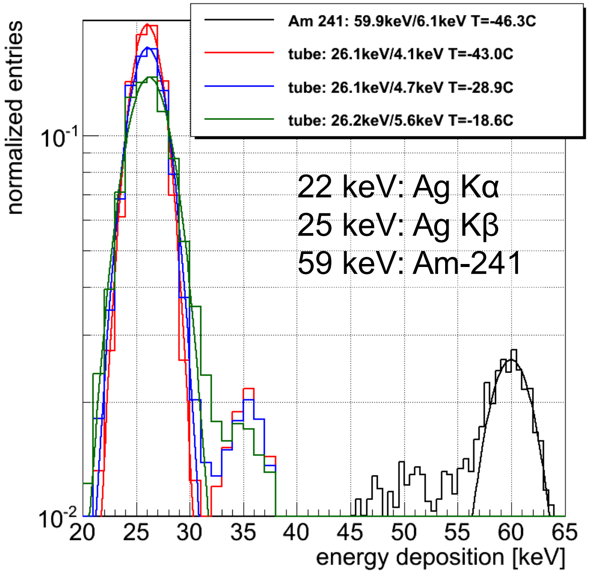
- Si(Li) detectors were cooled down to -46°C to ensure operation during flight
- in addition to the bGAPS flight representative radiator, oscillating heat pipe cooling pipe system was tested

- unfortunately: rotator failure → detectors warmed up (64% still depleted by the end of the flight)
- **BUT** all critical parts were equipped with temperature sensors and **thermal model was verified**

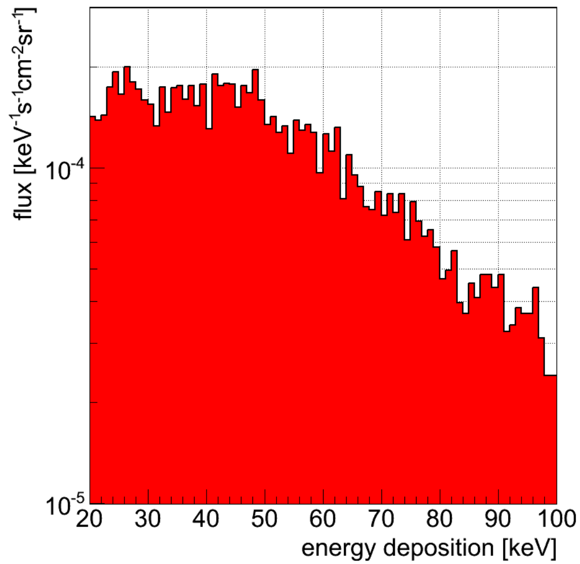
- **cooling approach would have worked with correct pointing**

Si(Li) tracker

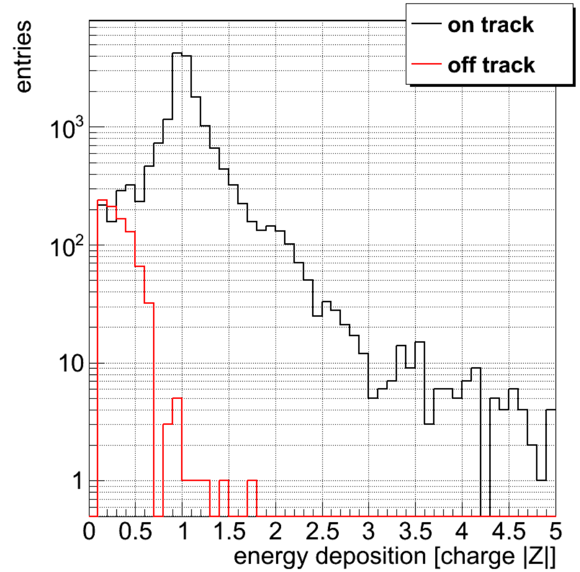
X-ray stability



X-ray flux at 33km



particle charge on/off track

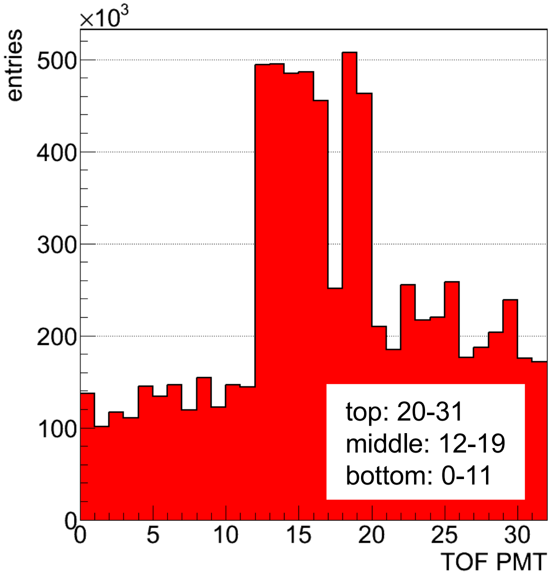


- both TRK electronics channels worked very well:
  - **high gain:** X-ray measurement stable over the course of the flight within the expected change due to the temperature increase
  - **low gain:** clear Landau distribution for energy depositions on track
- detectors work flawlessly after the flight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

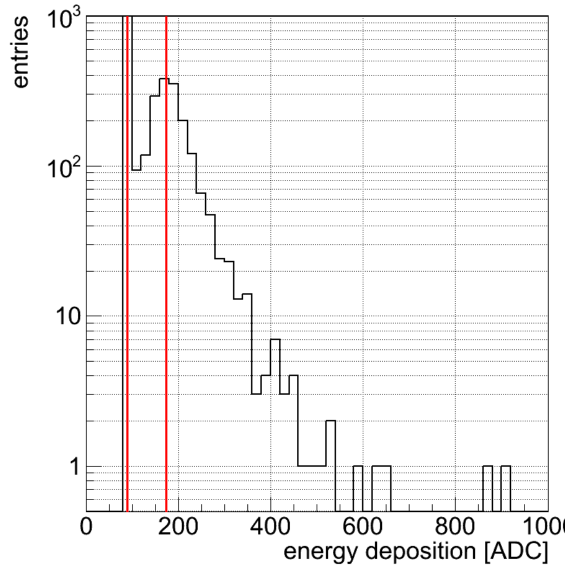
- flux of coincident charged particles and atmospheric and cosmic X-rays is very small
  → antideuteron analysis can easily reject this background type by requiring more than one coincident X-ray in the right range

Time-of-flight

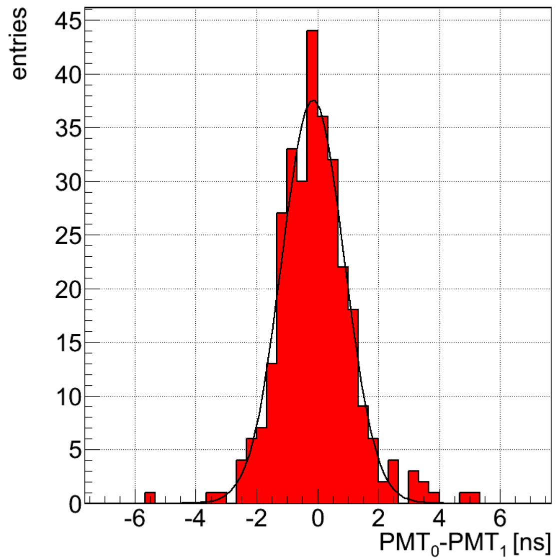
PMT occupancy



typical energy deposition



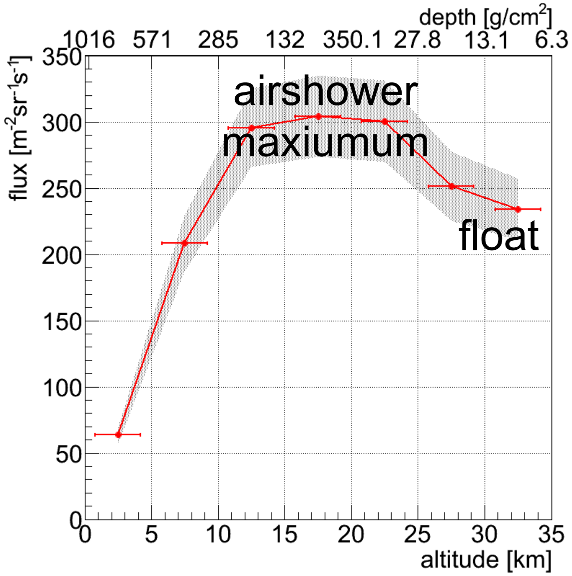
timing resolution



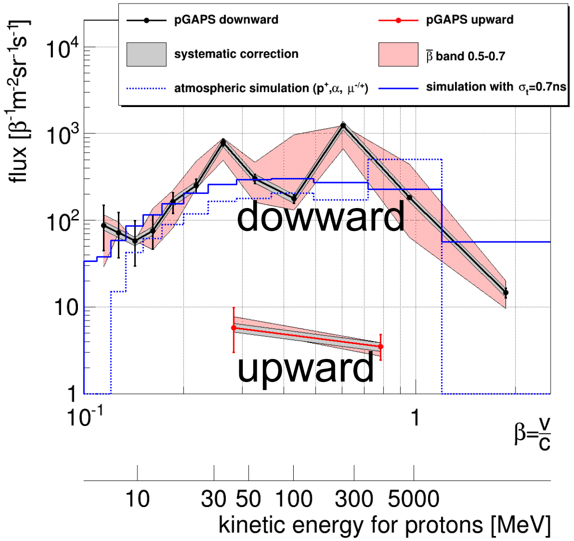
- only one tube failed → understood why → no problem in the future (intermittent corona discharge upon reaching float altitude)
- stable energy deposition measurement over time
- detectors work flawlessly after the flight in the lab (after careful cleaning of salt water)
- average of 640ps timing resolution per PMT
  → under further investigation for improvements in the future
    - better light guides and couplings to scintillators
    - thicker scintillator material (3mm → 5mm)
    - PMTs with larger photocathode
    - more photons from slow particle
    - better particle tracking with 1m TOF separation + multi Si(Li) hits

pGAPS flux measurement

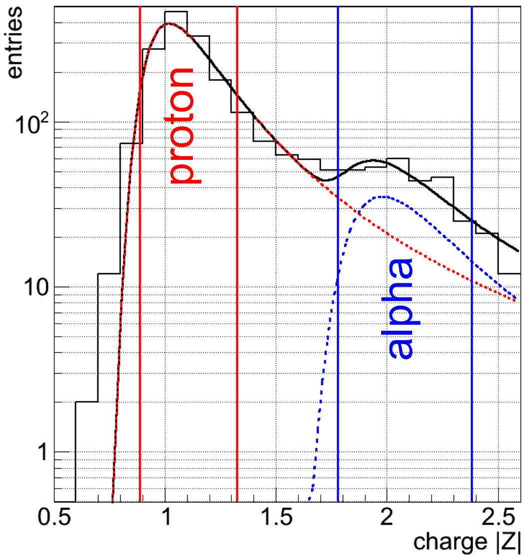
total flux vs. altitude



flux vs. β at 33km



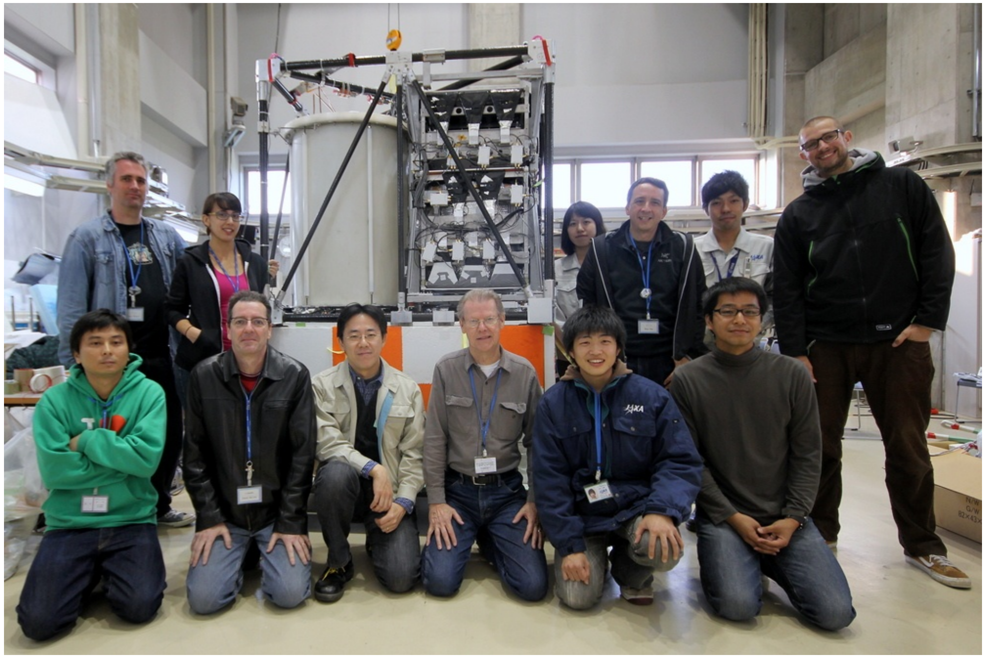
particle composition at 33km



- 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)
  - $\beta<0.2$ ($E_{kin,proton}$~20MeV) very good agreement
  - $\beta=0.3$-0.5 ($E_{kin,proton}$~50-150MeV) within systematic errors
  - $\beta>0.7$ ($E_{kin,proton}$~400MeV) good agreement
  - deviations at 0.3 and 0.6 visible → more simulation work at low energies in the future
- α particles constitute about ~10% of the flux at 33km (~9g/cm^2) → in good agreement with BESS data

Conclusion

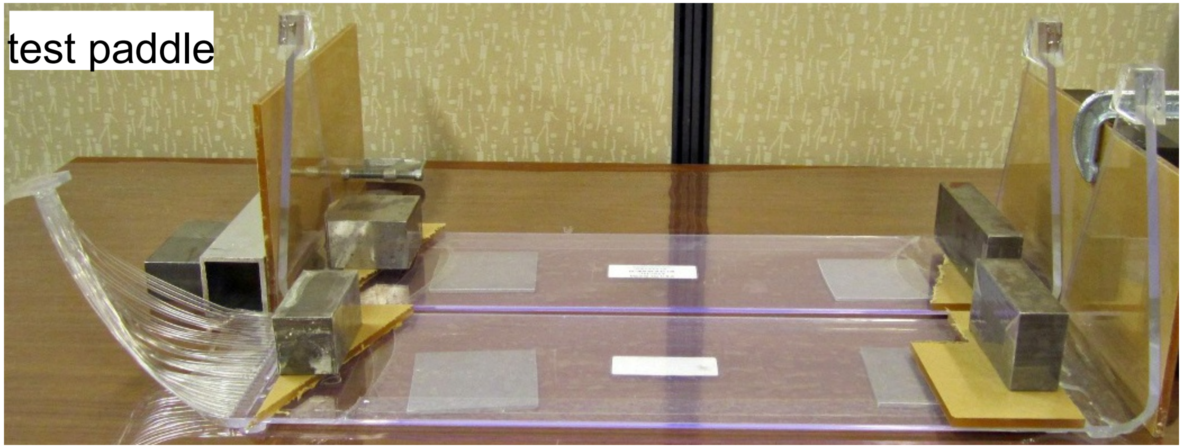
- measurement of antideuterons and antiprotons is a promising way for indirect dark matter searches
- GAPS is specifically designed for low-energetic antideuterons
- **all goals for prototype GAPS were met**
  - Nucl. Instr. Meth. A 735, 24 (2014)
  - Astropart. Phys 54, 93 (2014)
- **Si(Li) detector production understood**
- **it is the right time to start building GAPS to compare to AMS and direct searches**
- first GAPS science flight from Antarctica 2018

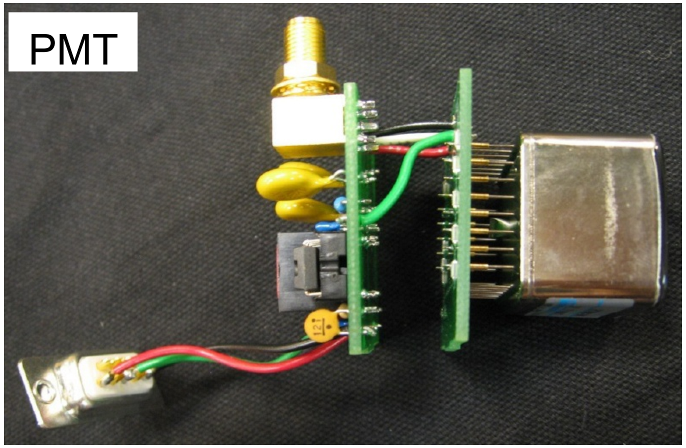


pGAPS team before launch

Columbia University, UC Berkeley, Japan Aerospace Exploration Agency, UC Los Angeles, U Hawaii, Haverford College

Time of flight

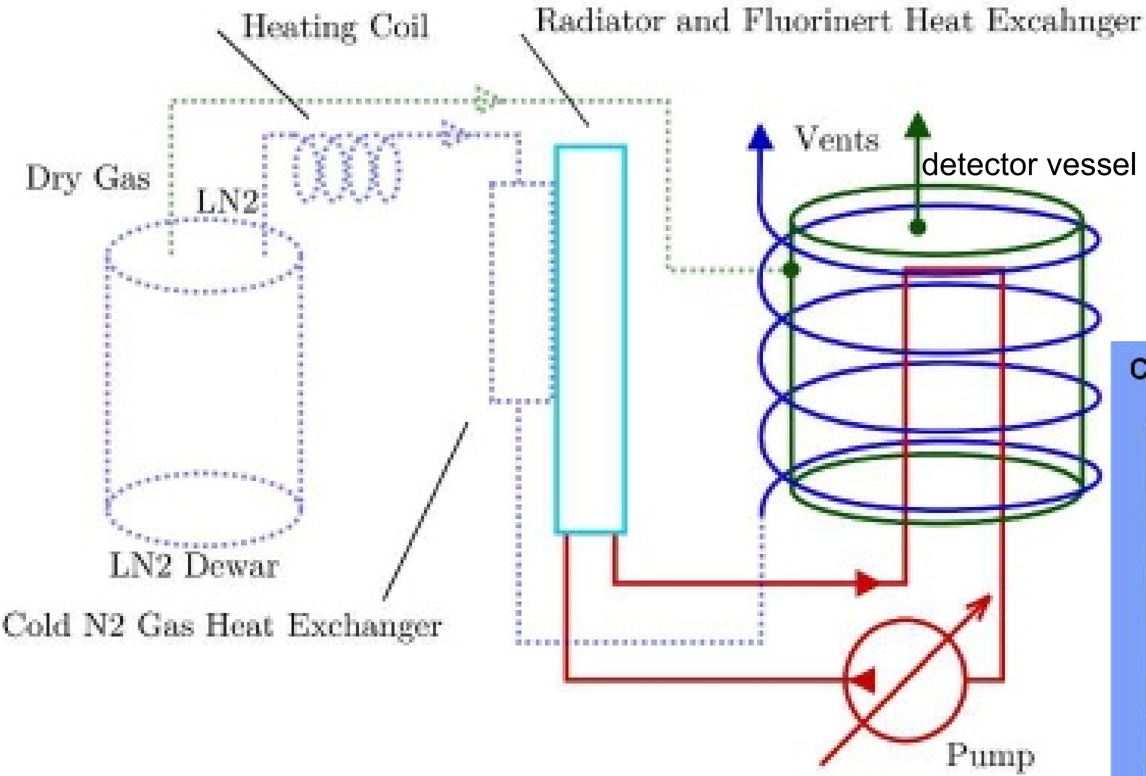




- **tasks:**
  - charged particle trigger
  - velocity measurement
  - tracking
- **design:**
  - 3 planes of TOF
    outer planes consists of 3×3, middle plane 2×2 crossed paddles
    1 paddle has 2 PMTs = **16 paddles and 32 PMTs**
  - 3mm scintillator from Saint-Gobain (BC-408)
  - Hamamatsu R-7600 PMT

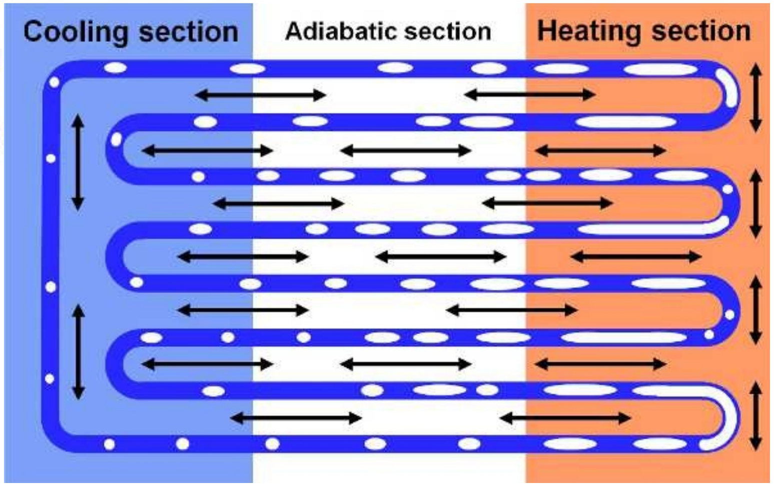
Cooling System

pGAPS cooling system
(dashed components: ground operation only)



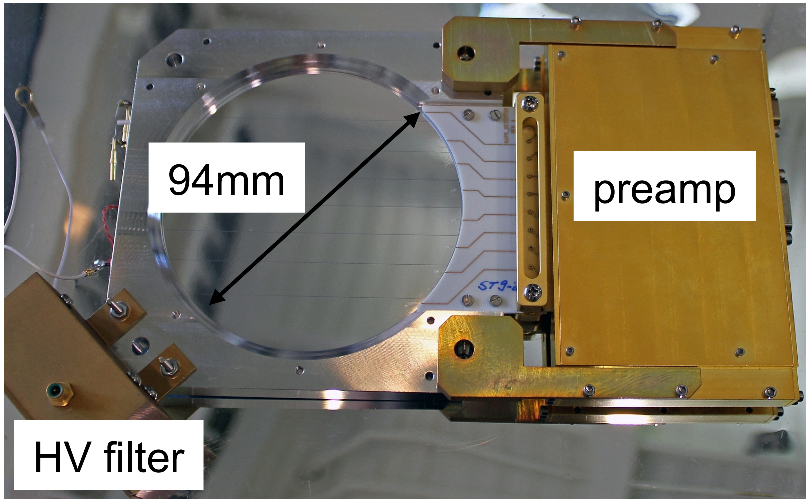
Nucl. Instr. and Meth. A 735 pp. 24-38, 2014

Oscillating heat pipe



- metal capillary tubes
- no mechanical pump
- expansion/collapse of vapor bubbles

Si(Li) tracker



- 6 detectors
  2 stacks with 3 layers
- 4mm/2.5mm thick, 8 strips
- N+: Lithium contact
  P+: Boron implanted (strips)
- operation at ambient pressure during flight (8mbar)
- closed-loop coolant pumping system (Fluorinert)
- first time Si(Li) on a balloon payload