The General AntiParticle Spectrometer

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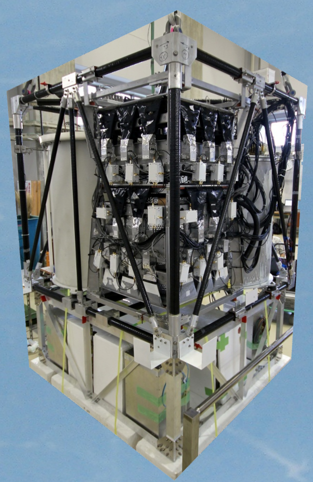
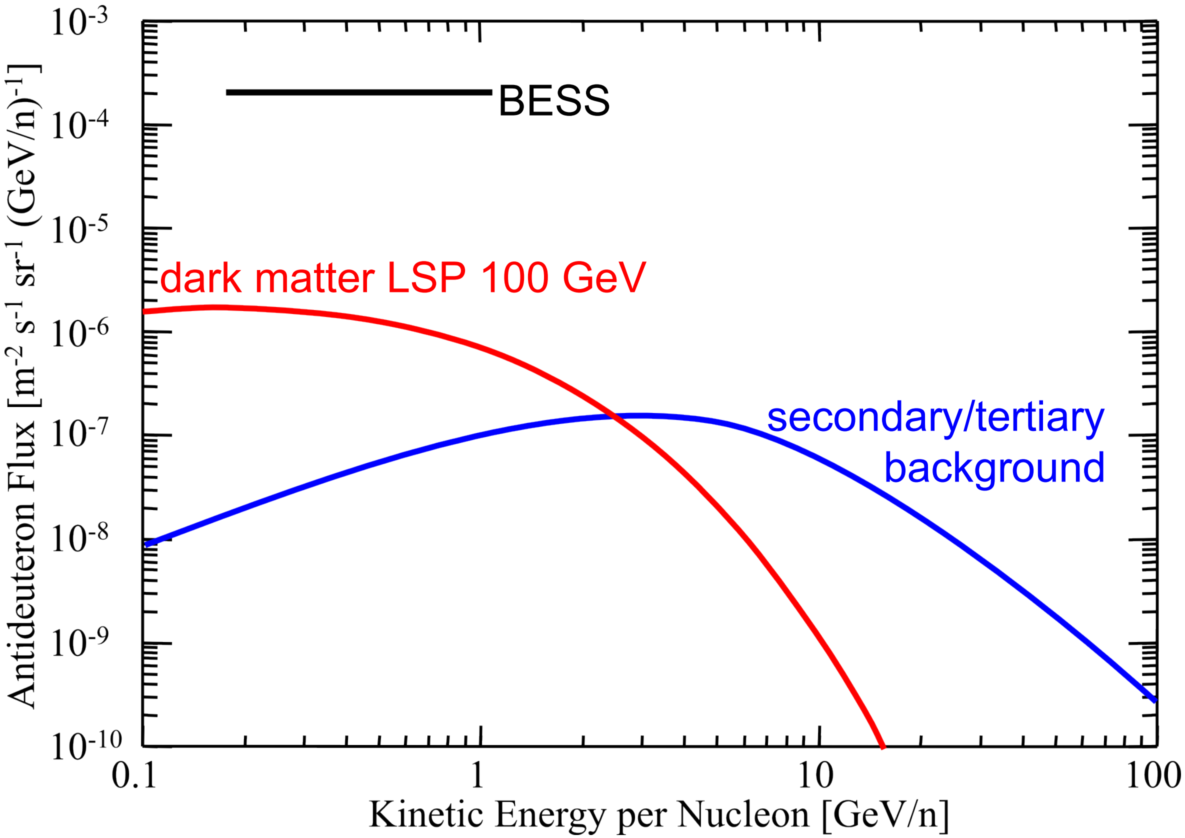
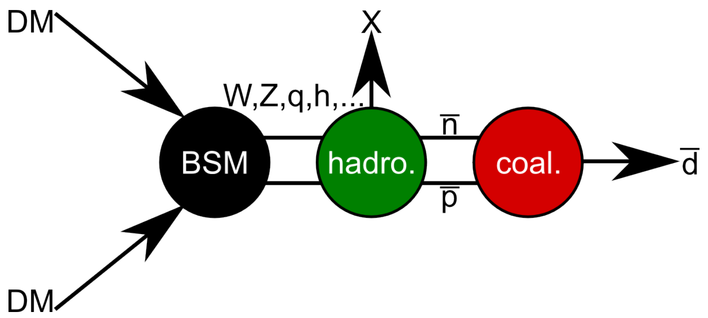


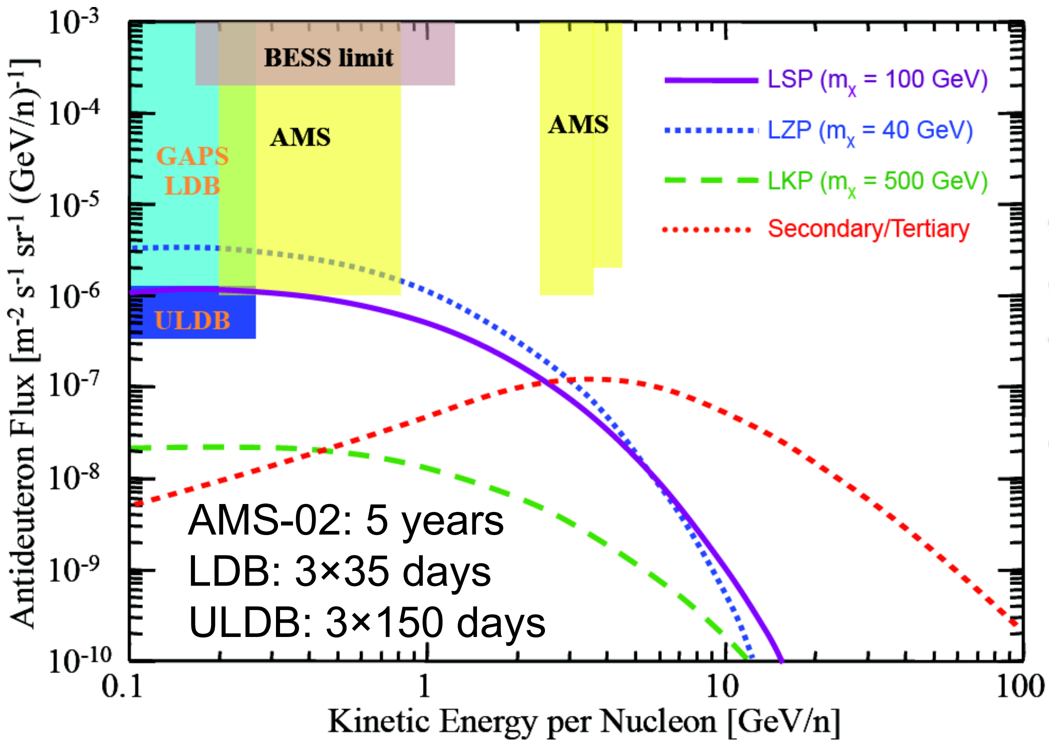
Antideuterons and dark matter

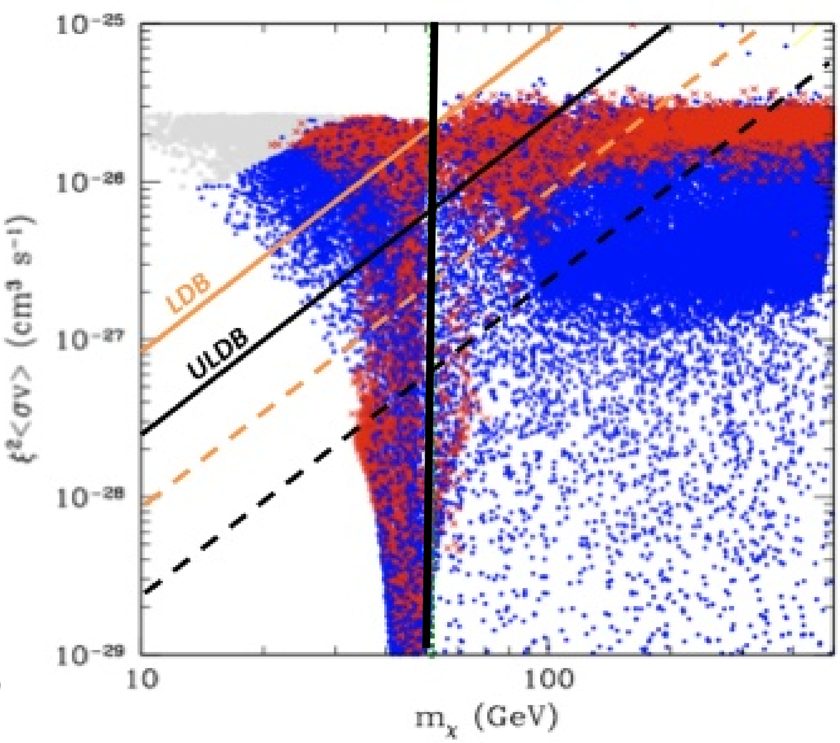




- **antideuterons are the most important unexplored indirect detection technique**
- **uncertainties:**
  - dark matter:
    - concentrated in halo, dominant uncertainty from propagation: factor ~10
    - antideuteron coalescence: factor ~2
    - boost factors
  - background: production in galactic disk dominant uncertainty from production cross-section

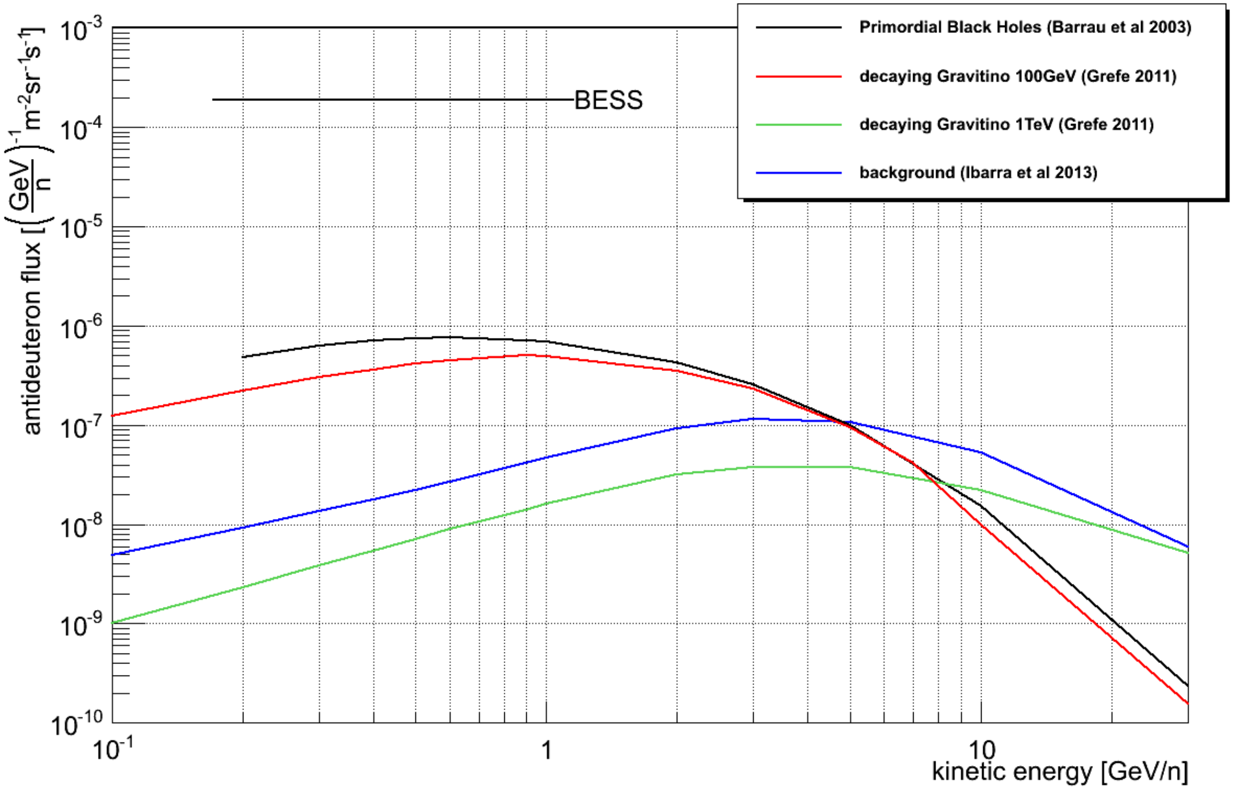
Sensitivity to dark matter models





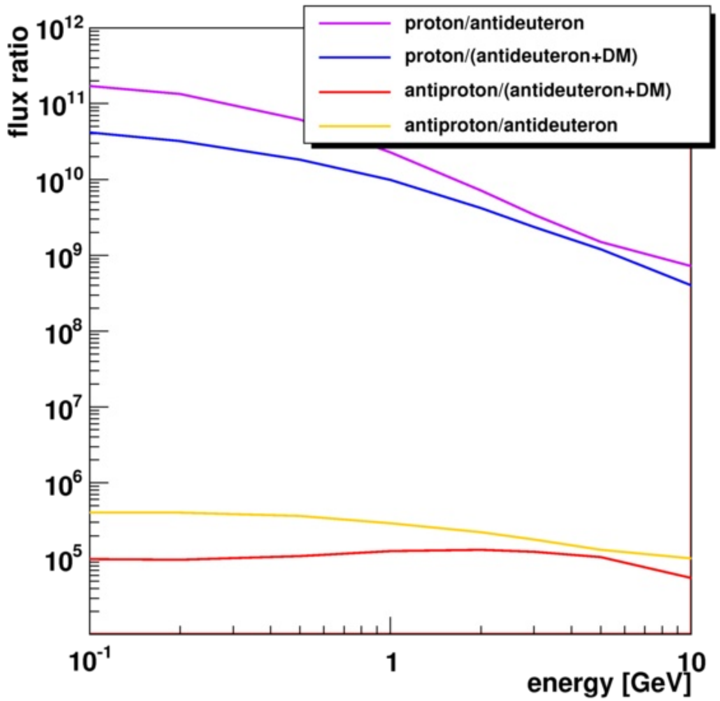
- different scenarios give antideuteron fluxes within sensitivity: Supersymmetry, extra dimensions
- GAPS is very effective to search for light WIMPS such as proposed to explain DAMA/LIBRA/CoGENT results

Primordial black holes and gravitinos

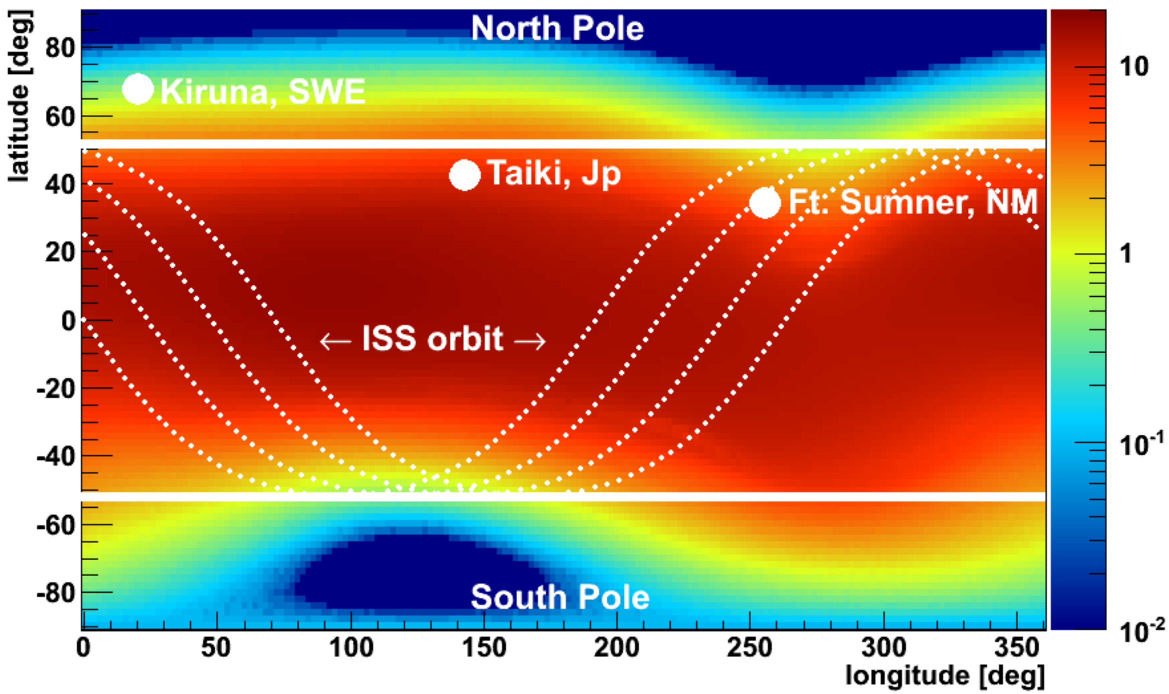


- **primary black holes:**
  - very small black holes could have formed in the early universe due to, e.g., initial density inhomogeneities
  - might evaporate antideuterons and **maybe the only chance to detect primordial black holes**
- **baryon asymmetry/cosmological gravitino problem:**
  - hypothetical mediator of gravity: graviton → superpartner gravitino
  - late decays of unstable gravitinos to standard particles would produce antideuterons

Observational challenges



flux ratios



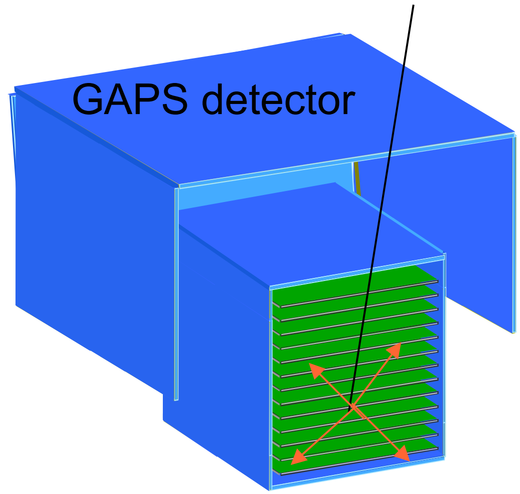
geomagnetic cut-off

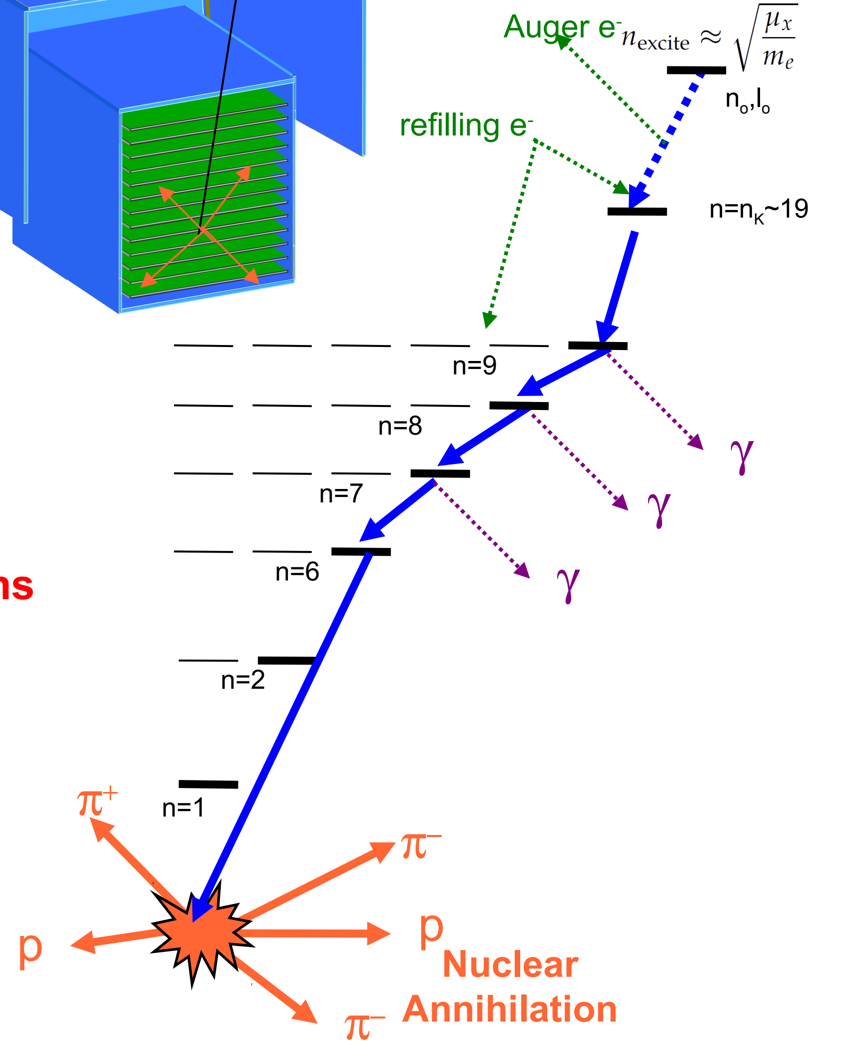
antideuteron measurement with balloon and space experiments requires:

- **strong background suppression**
- **long flight time and large acceptance**
- **geomagnetic location of experiment**

Novel approach for antideuteron identification

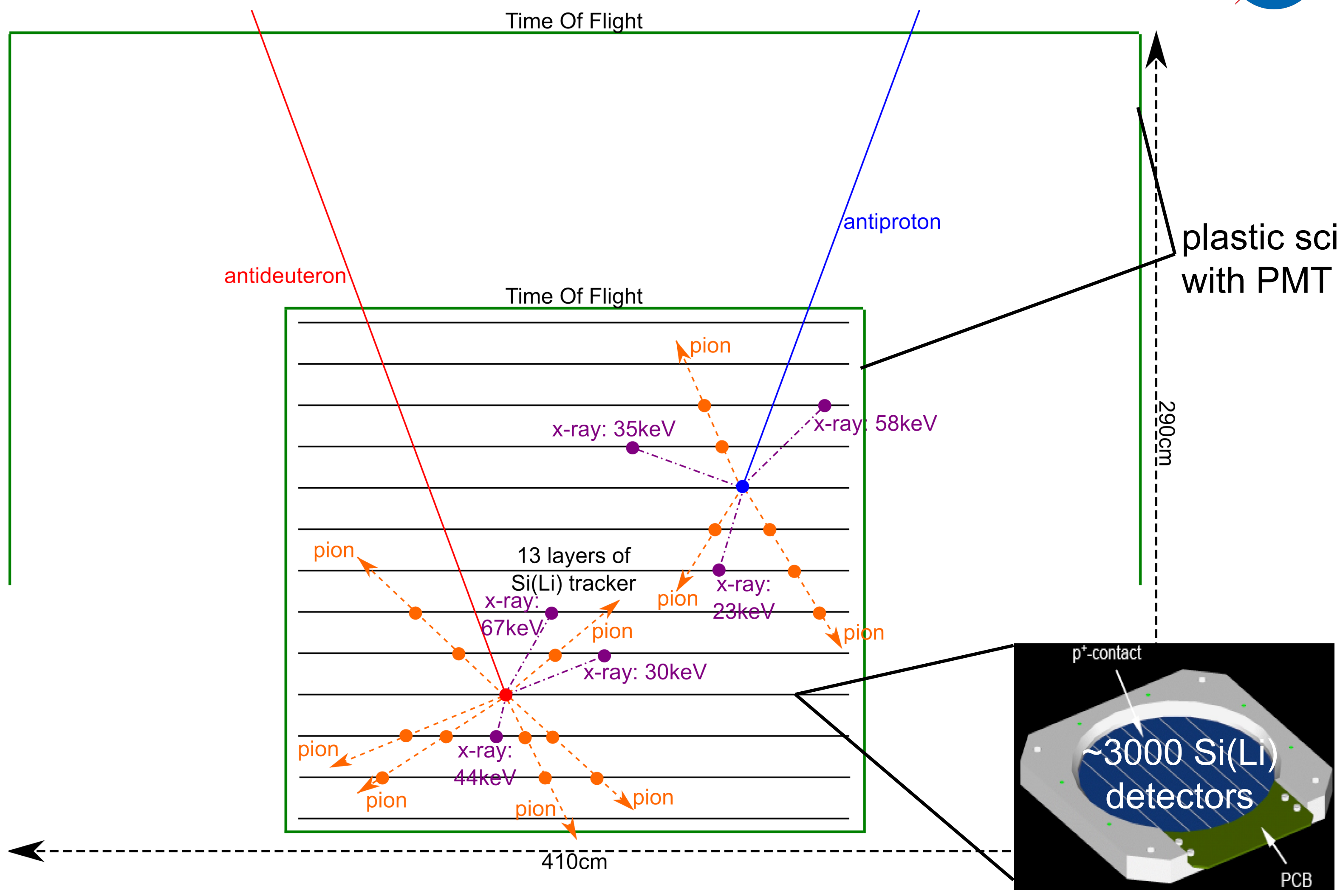
- antideuteron slows down and stops in material
- large chance for creation of an excited exotic atom (E_{kin}~E_I)
- deexcitation:
  - fast ionisation of bound electrons (Auger)
    → complete depletion of bound electrons
  - Hydrogen-like exotic atom (nucleus+antideuteron) deexcites via **characteristic X-ray transitions**
- nucleus-antideuteron annihilation: **pions and protons**
- exotic atomic physics understood (tested in KEK 2004/5 testbeam)





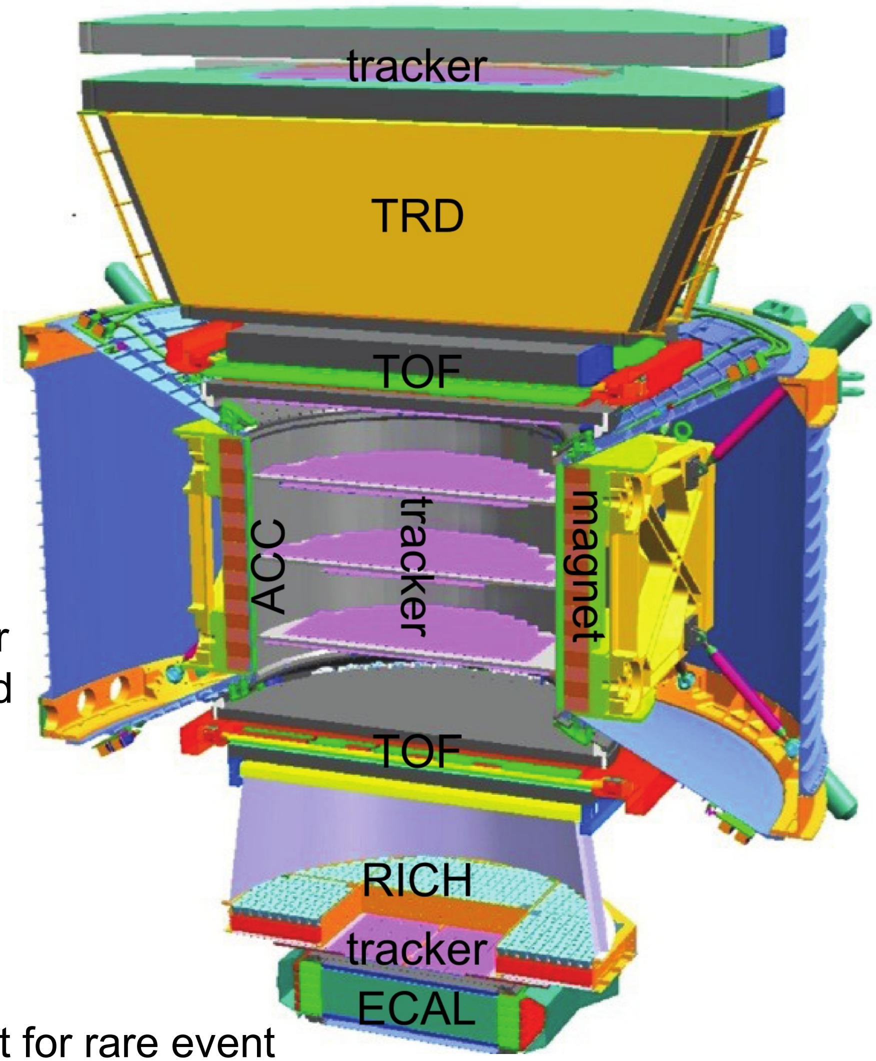
The GAPS experiment

Columbia University,
UC Berkeley, UCLA



- the **G**eneral **A**nti**P**article **S**pectrometer is especially designed for **low-energy antideuterons**
- identification by stopping them in the tracker and creating an exotic atom
- (ultra) long duration balloon flights from Antarctica starting from 2017 (begin of solar minimum)

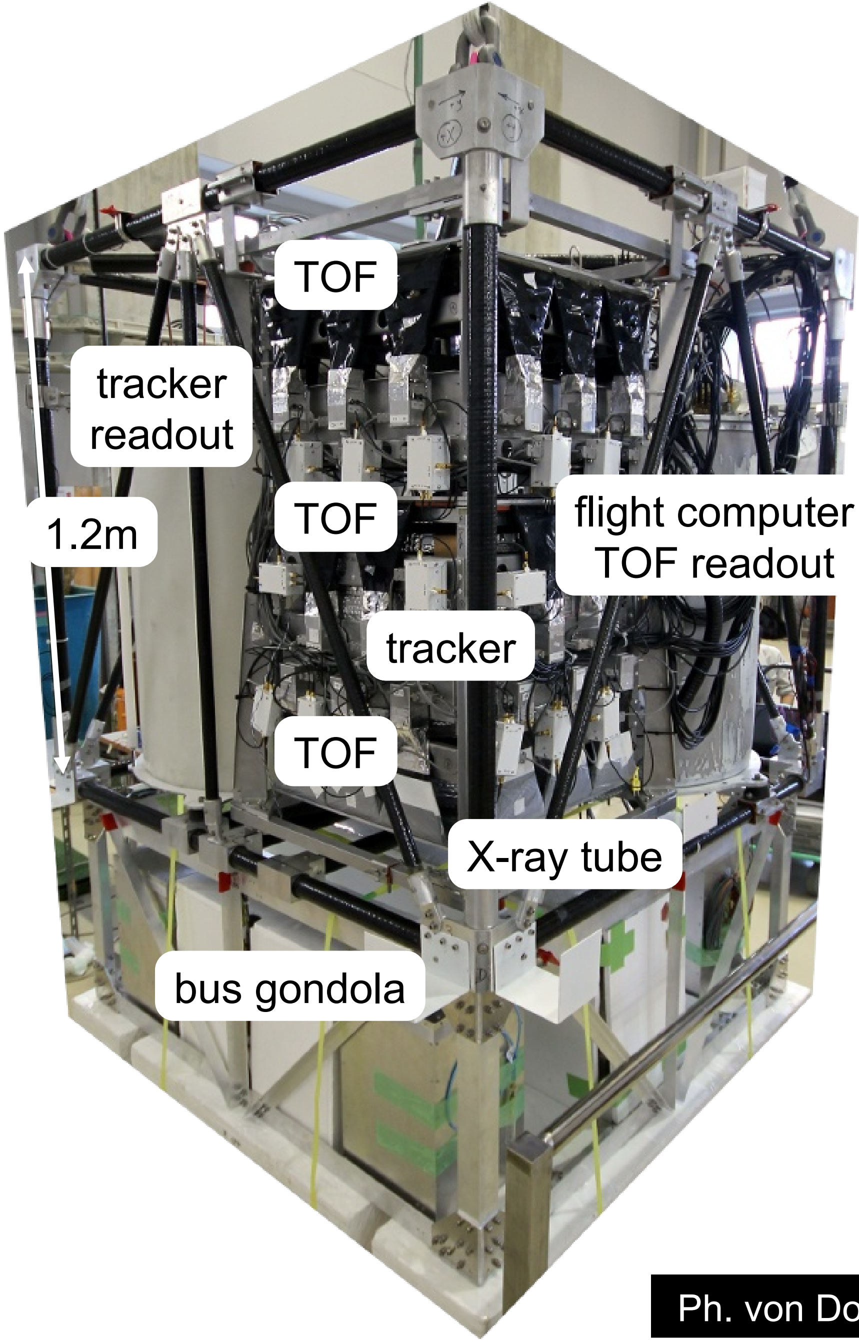
AMS comparison



- AMS is a multi-purpose particle physics detector using subsequent detectors and a magnetic field
- AMS antideuteron analysis challenges: geomagnetic cut-off, multiple scattering

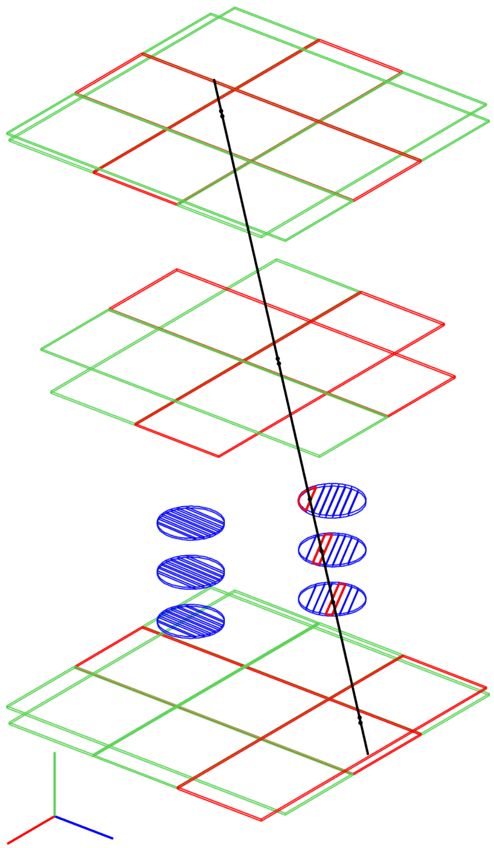
- **if AMS detects $\bar{d}$: confirmation is needed**
  if no detection: GAPS goes deeper
- different detection techniques are very important for rare event search
- building GAPS right now is important for timely comparison

Prototype GAPS



Goals:

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



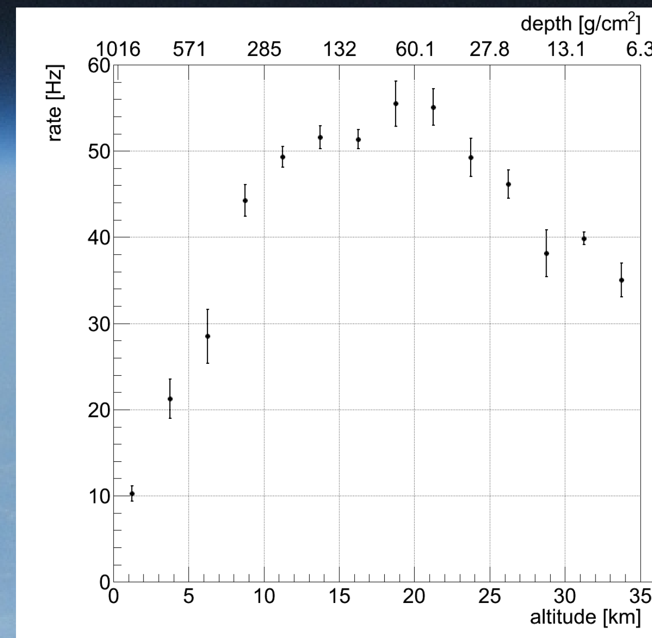
pGAPS launch

preparations 4:36am

release of balloon

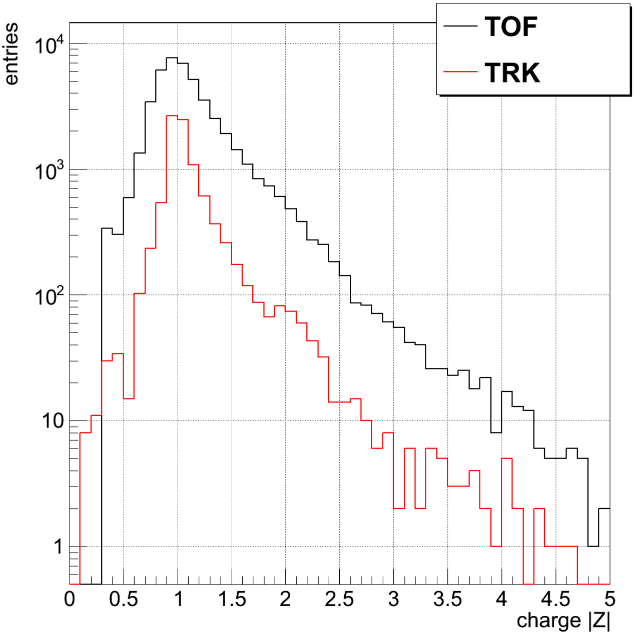
4:55am **take off**

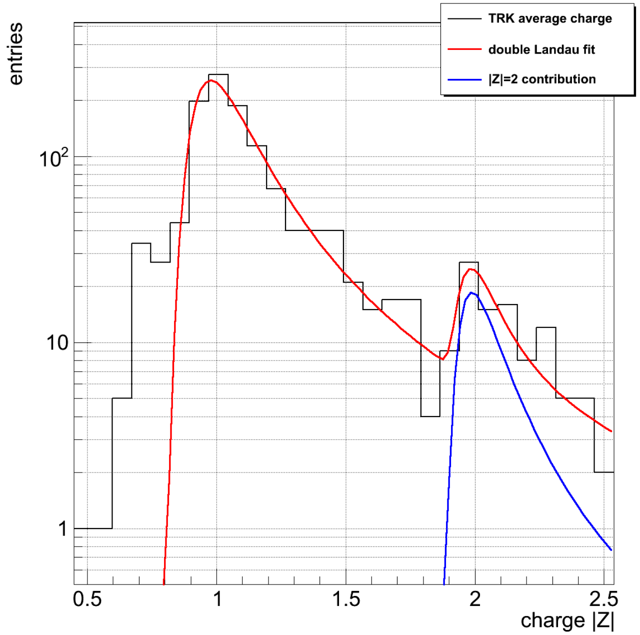
return to the harbor 1:05pm



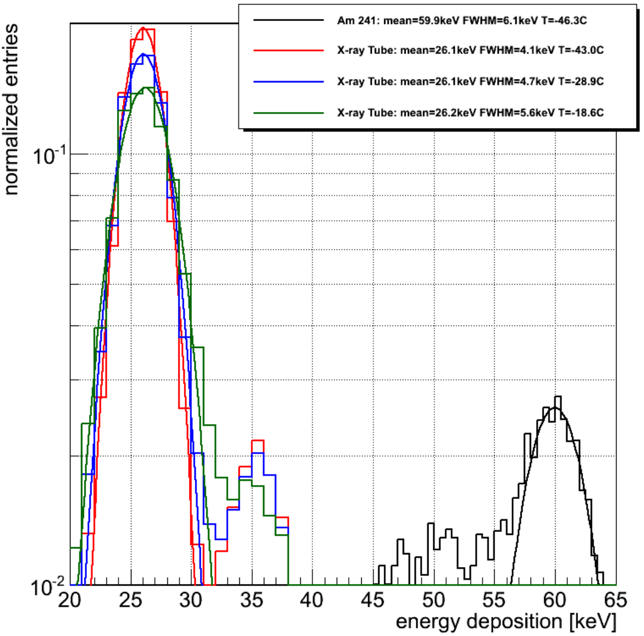
raw Tof trigger rate vs. altitude

Detector operation



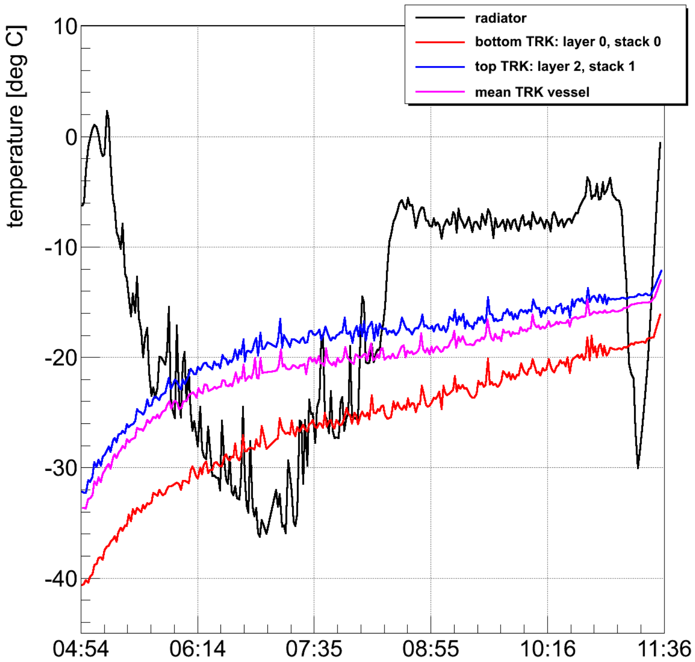


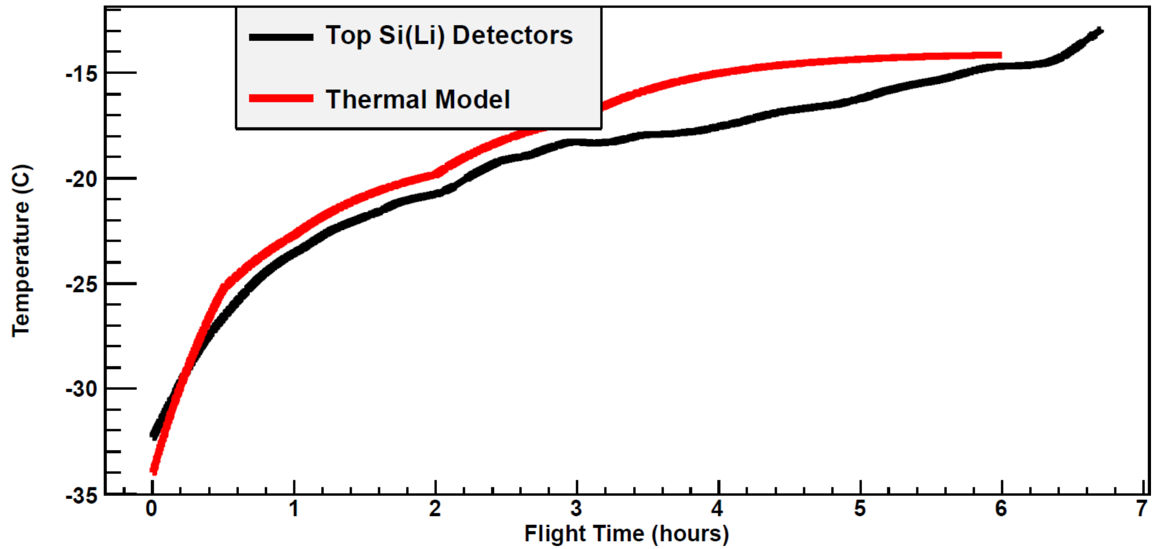
- **well defined TOF trigger and tracker runs**
  - time: 245min
  - ~600,000 triggers
  - stable response of TOF and Si(Li)
  - at float ~5% α particles
  - more flux analysis ongoing

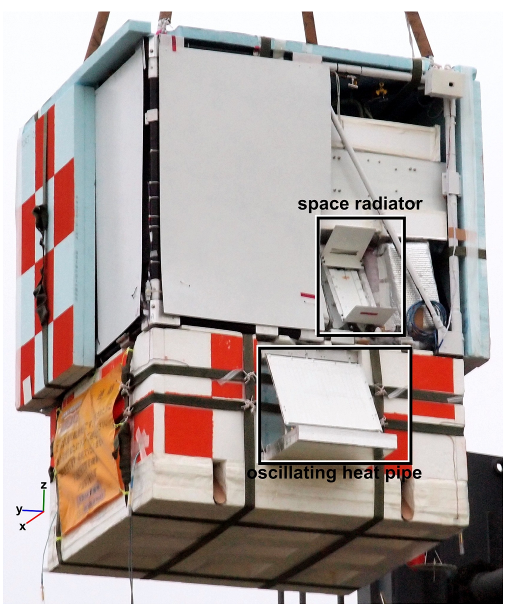


- **carry out in-flight calibration of Si(Li) detectors**
  - run X-ray tube
  - time: 50min
- **trigger on Si(Li) detectors to study incoherent X-ray background**
  - time: 29min
  - Si(Li) shows stable X-ray operation
- **NIM instrument paper submitted [arXiv:1303.XXXX] flight paper to be submitted soon**

Thermal model





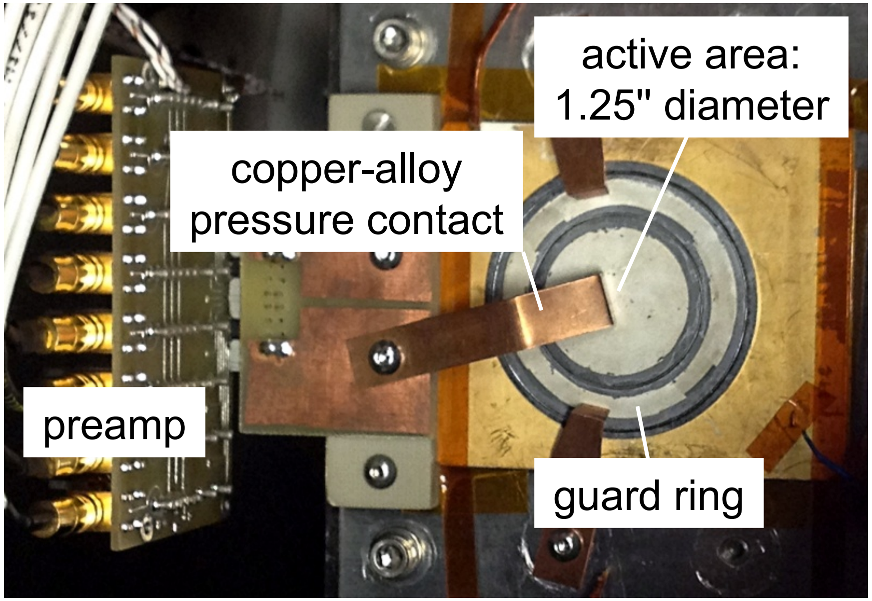


- Si(Li) detectors were cooled down to -46°C to ensure operation during flight
- in addition bGAPS flight representative radiator and cooling pipe system tested

- 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**

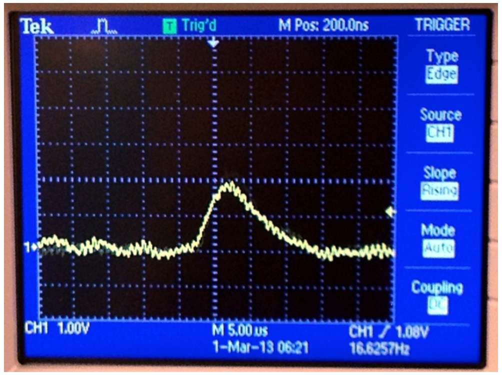
- **cooling approach would have worked with correct pointing**

Si(Li) detector production

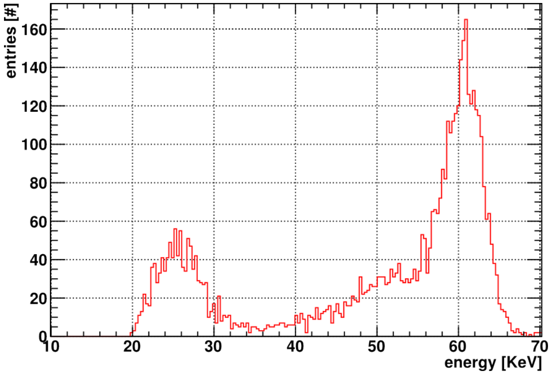


- GAPS will use 2875 4” Si(Li) detectors
- 2”-diameter detectors being produced at Columbia U. using simple fabrication scheme
- successfully drifted diameters from 1" to 2" with >90% yield, both 1 mm (prototype) and 2.5 mm thick

- leakage current ~1nA at -35 C
- confirmed performance with cosmic rays (MIPs) and Am-241 source (X-rays)
- FWHM at 59.5keV: 5keVeasy to improve with better mounting and preamp board
- 4” detector development underway!

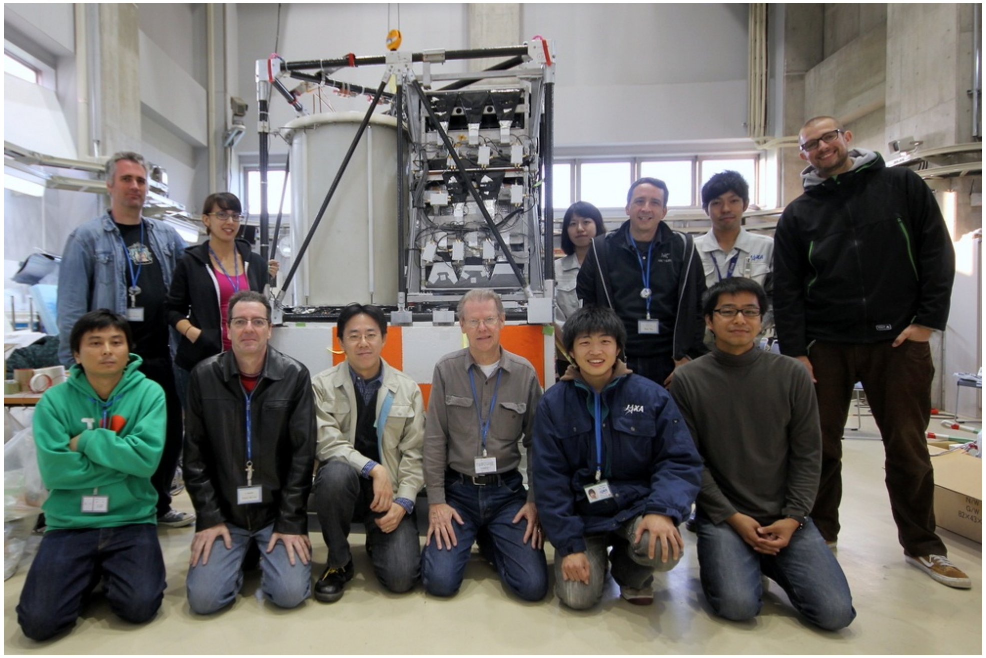


X-rays from Am-241



Timeline for GAPS

- **2000** first idea
- **2004/05** KEK beamtests with antiprotons
- **2006-08** design work
- **2008-12** technical validation
- **2009-12** prototype flight from Japan
- **2013-2017** detailed design and construction
- **2017** first science flight from Antarctica



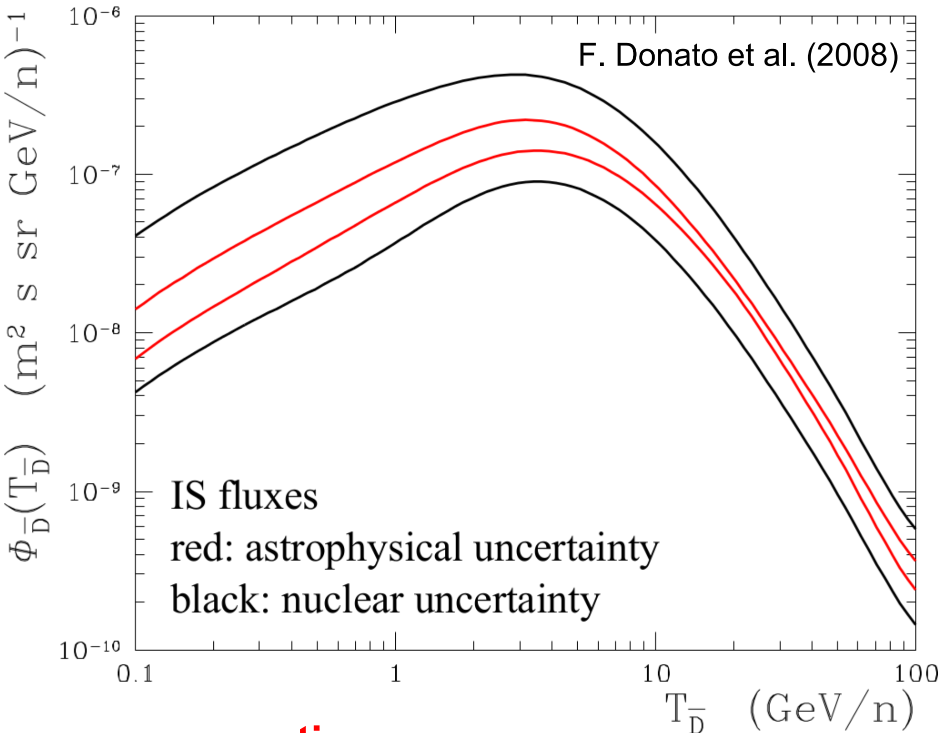
pGAPS team before launch

Columbia University, UC Berkeley, Lawrence Livermore National Laboratory
Japan Aerospace Exploration Agency, UC Los Angeles, U Hawaii

Conclusion

- measurement of antideuterons is a promising way for indirect dark matter search
- GAPS is specifically designed for low-energetic antideuterons
- **all goals for prototype GAPS were met**
- **Si(Li) detector production understood**
- **it is the right time to start building GAPS to compare to AMS and direct searches**

Uncertainties



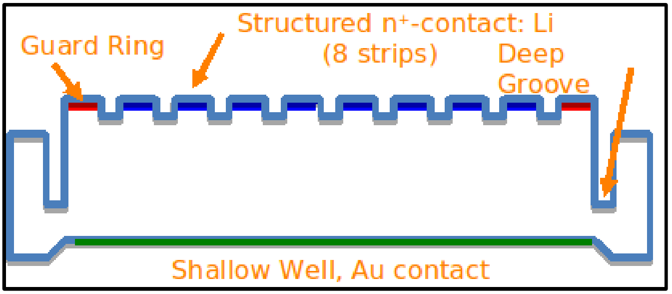
- **dark matter antideuterons:**
  - dark matter concentrated in halo
  - dominant uncertainty from propagation
- **conventional antideuterons**
  - production in galactic disk
  - dominant uncertainty from production cross-section

- **propagation:**
  - parameters not completely fixed
  - larger diffusion sizes seem to be favored (median or best model) → **flux increases**
- **nuclear:**
  - antideuterons can be formed by $\bar{p}$-$\bar{n}$ pair if coalescence momentum p_0 is small

$$\gamma \frac{d^3 N_{\bar{d}}}{d\vec{p}_{\bar{d}}^3} = \frac{4\pi}{3} p_0^3 \left(\gamma \frac{d^3 N_p}{d\vec{p}_p^3} \right)^2 ; \qquad \frac{d^3 N_i}{d\vec{p}_i^3} = \frac{1}{\sigma_R} \frac{d^3 \sigma_i}{d\vec{p}_i^3} .$$

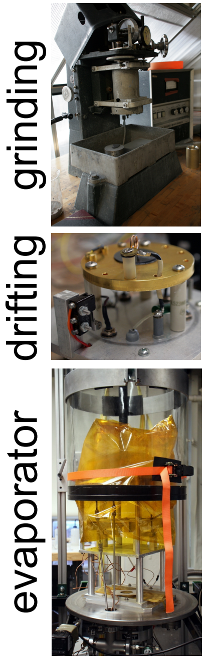
  - literature discusses values from 80-240MeV (better models, collider input needed)
  - dominant production at low energies: $p+p \rightarrow \bar{d}+X$ (>17GeV) and $\bar{p}+p \rightarrow \bar{d}+X$ (>7GeV)

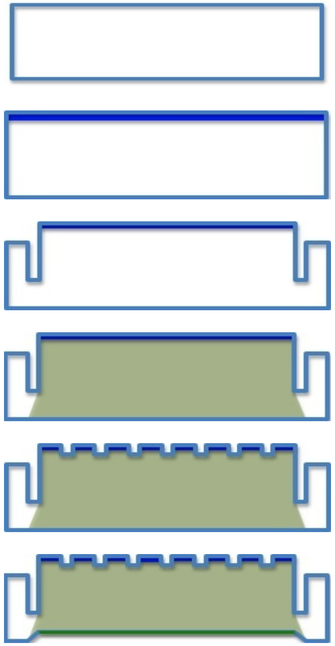
Si(Li) detector production



- GAPS needs ~3000 individual Si(Li) detector modules (4" diameter, 2mm thick)
- production technique well understood:
  - **2" diameter detector delivers good muon and X-ray resolution (close to the desired 3keV FWHM at 59.5keV)**
  - low leakage currents
- ***ready to start building 4" detectors***

Production technique:





1) cut from the ingot
2) cut grove with ultrasonic grinder
3) evaporate Lithium on surface
4) drift the Li into the silicon
5) make strips and guard ring
6) etch the back (shallow well) and evaporate Au