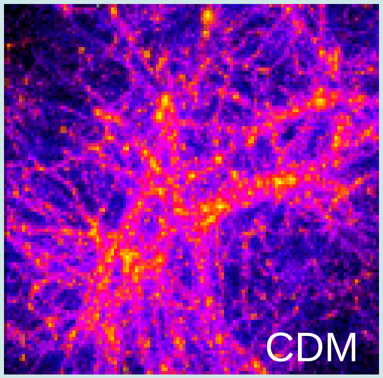
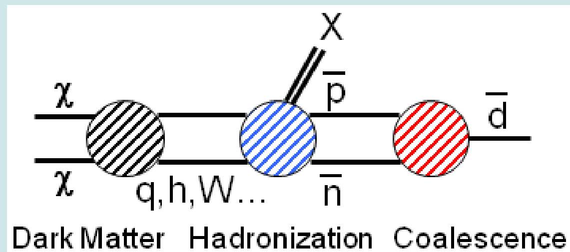
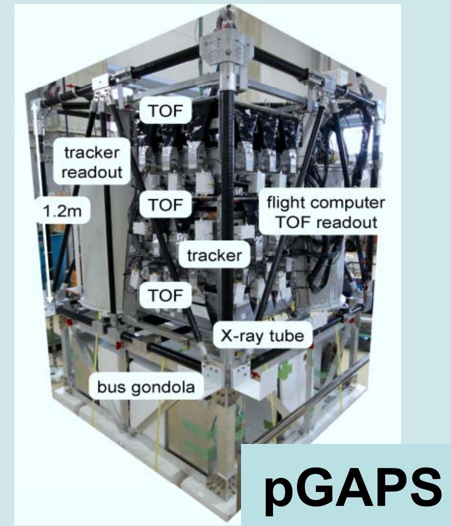
GAPS: A Dedicated Search for Anti-Deuterons in the Cosmic Rays

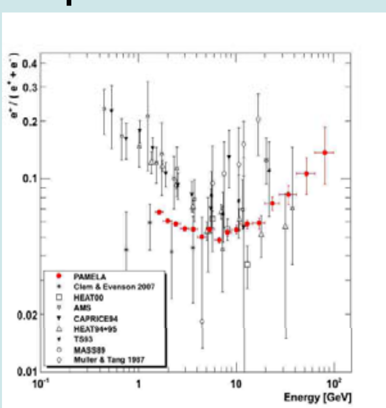


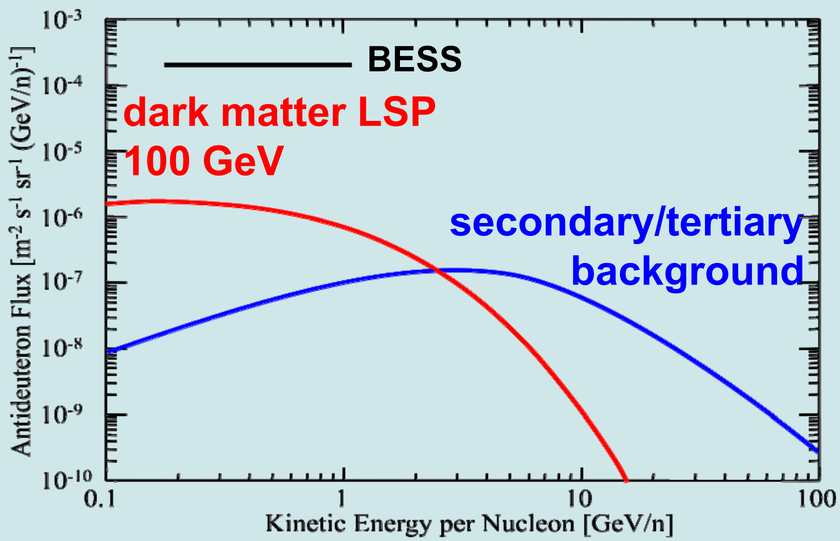
anti-deuterons ?

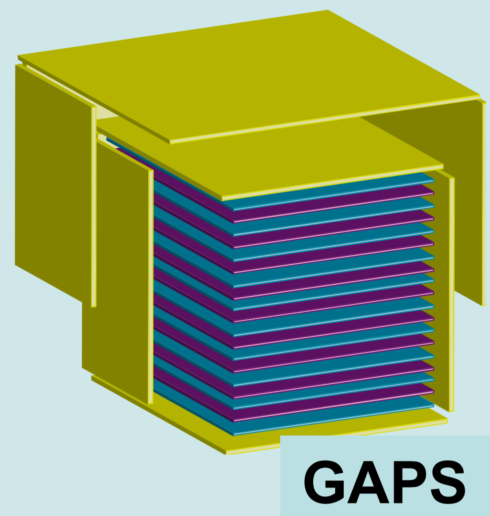




positrons ?







Rene A. Ong (UCLA),
for the GAPS Collaboration

Snowmass 2013
CF-6 Subgroup

SLAC Workshop
08 March 2013

Outline

Anti-deuterons: *never detected in cosmic rays*

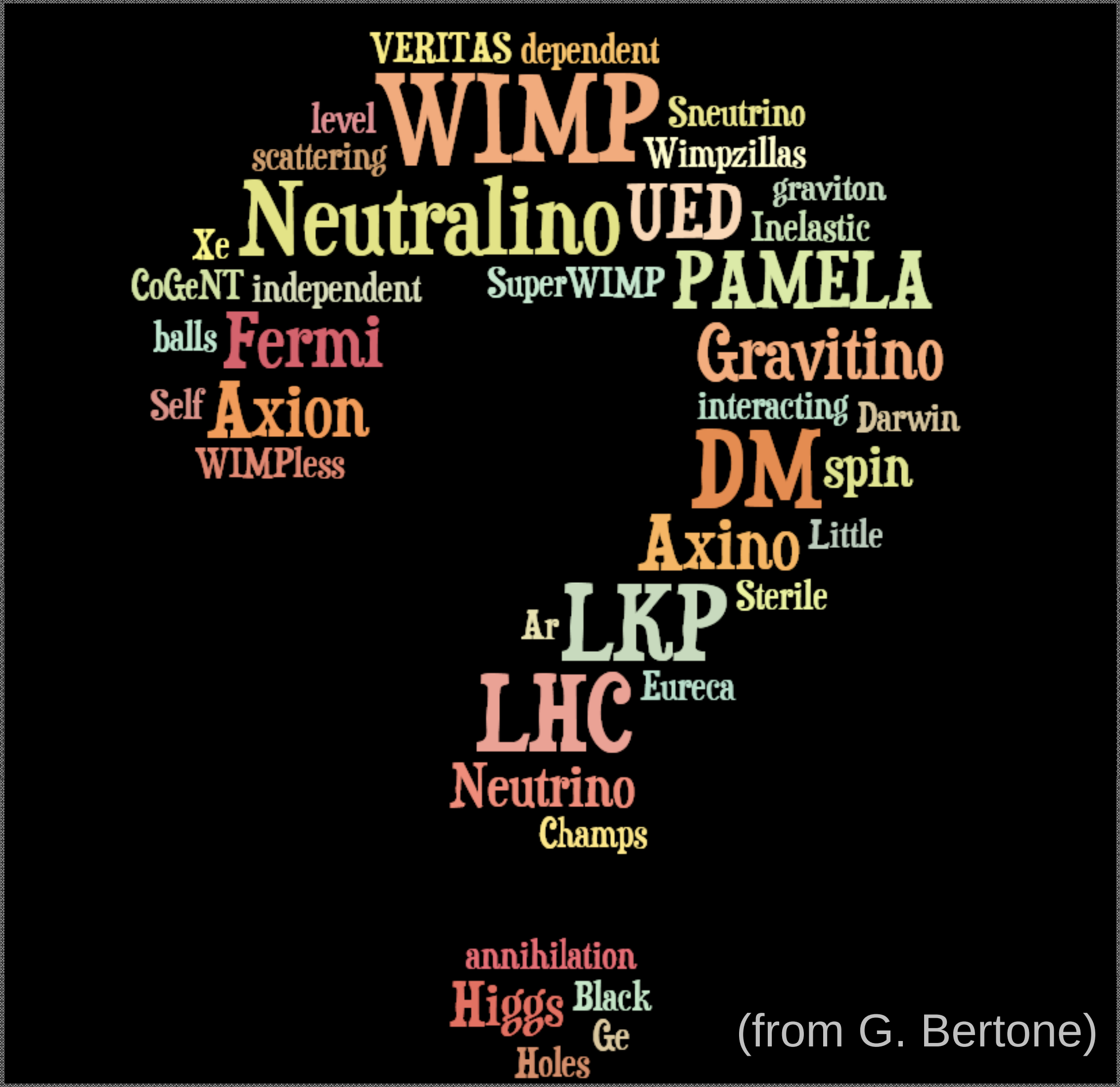
- DM search: Unique, low-bkgnd capability
- Uncertainties & relation to CF-6
- Complementarity to other approaches

CF White Paper - Completed

GAPS

- Novel technique !
- Complementary to AMS
- Prototype (pGAPS) flight
- Future Plans

We have no idea what dark matter is !



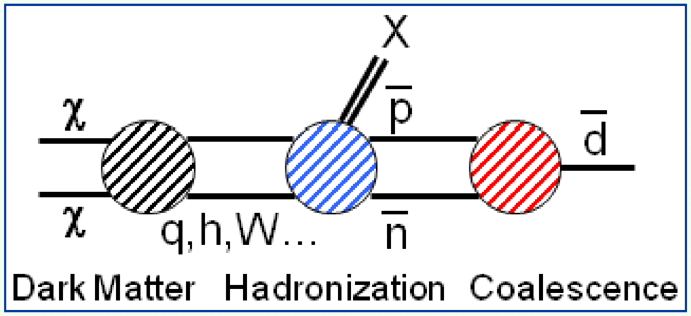
(from G. Bertone)

… and we need to search for DM particles using any (all) well-motivated techniques.

Why Anti-deuterons ?

Unlike anti-protons, which are easy to produce as secondary particles, anti-deuteron secondaries are severely suppressed at low energies.

DM production of $\bar{d}$



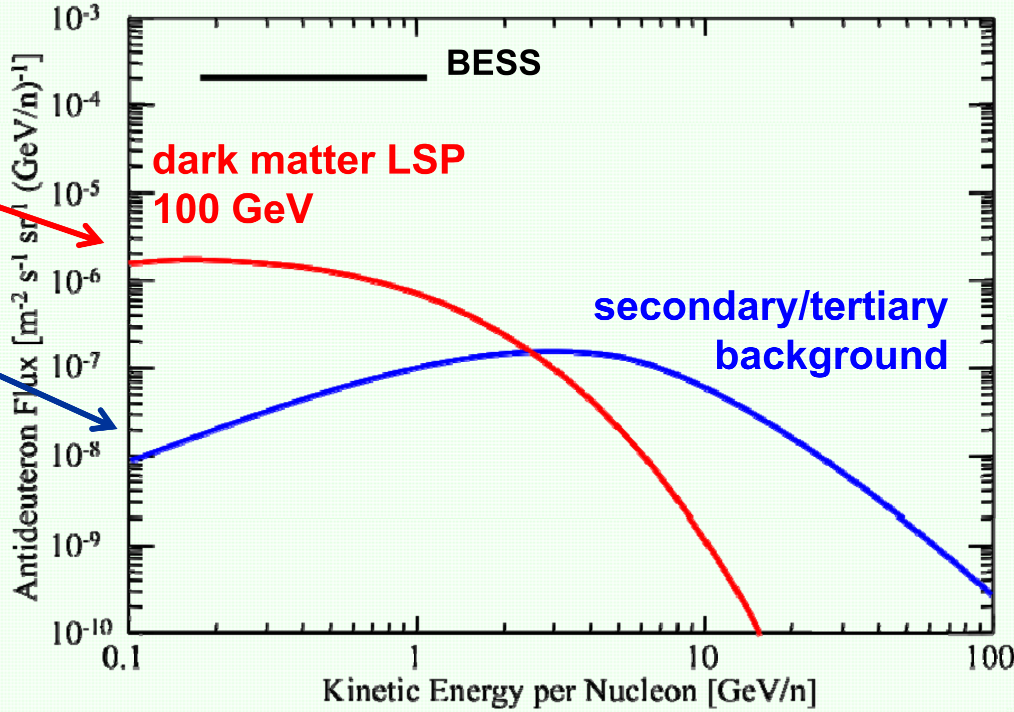
Primary Component (DM):

$\chi\,\chi \rightarrow e^{+}, \bar{p}, \bar{d}$

Secondary Component, includes:

$p\,A \rightarrow \bar{d}\,X$ [via $p(\overline{pn})n$]

where A = p, He

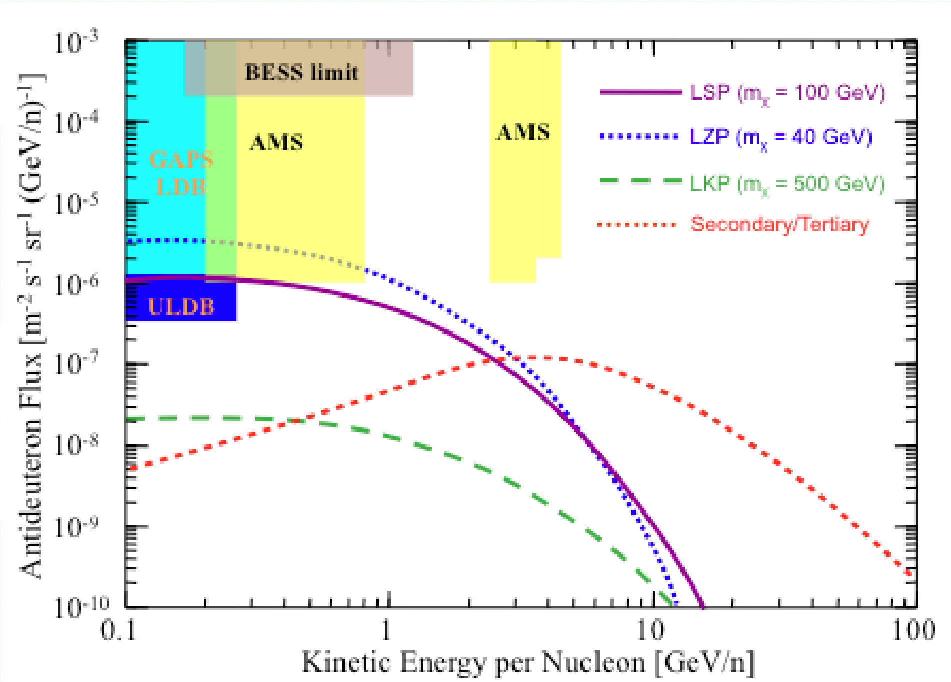


1) Anti-deuterons provide extremely clean signature.
2) Detection of even a few events would be very interesting.
3) Low fluxes require a very sensitive detector.

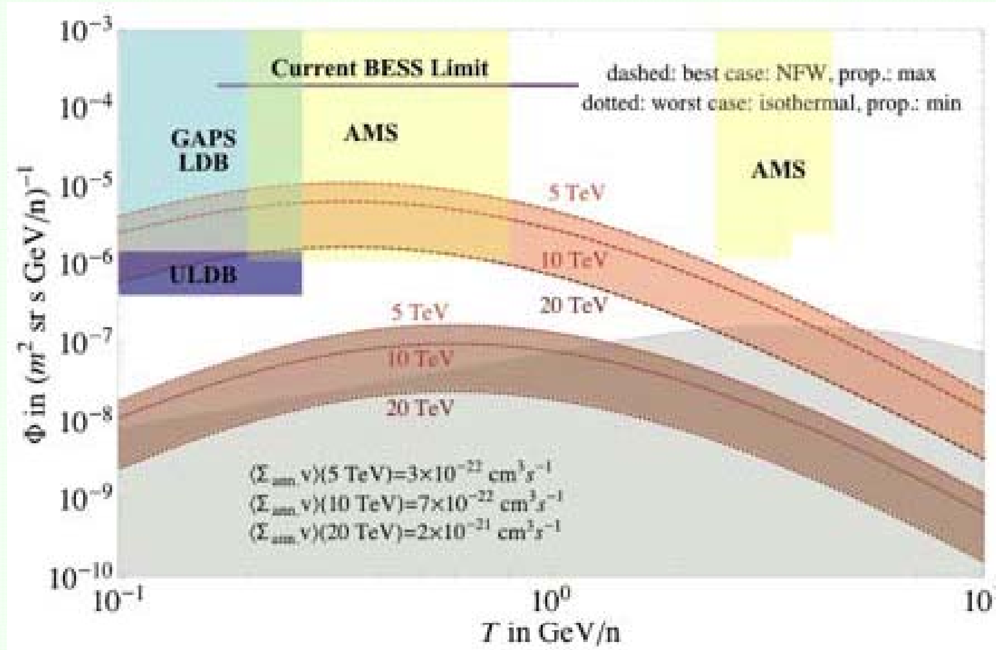
No dedicated anti-deuteron exists → GAPS

Unique DM Reach

LSP, LZP, LKP models (Baer & Profumo, 2005)



Massive Neutralinos
DM models (Brauninger & Cirelli, 2009)
Sensitivities & bkgnd (Hailey et al., 2013)



DM Reach & Complementarity

- DM Detection can be well above bkgnds.
- New expts provide ~3 orders of magnitude improvement over BESS limits.
- Compementarity:
  Anti-deuterons vs other indirect/direct
  GAPS and AMS

Uncertainties

Significant uncertainties exist:

- Signal: propagation, production
- Bkgnd: production in Galactic disk

Uncertainties & Relation to CF-6

Key uncertainties

SIGNAL:

- **DM Produced in Galactic Halo**
- **Propagation uncertainties dominate (~10)**
- **Anti-deuteron production (coalescence, ~3)**
- **Also case for primordial BH's**

BKGND:

- **Secondaries produced in Galactic Disk**
- **Uncertainties in cross section, propagation (~3)**

EXPERIMENTAL:

- **Instrument aperture, performance, etc.**
- **Bkgnd (coherent/incoherent) rejection**

Questions & program discussed in CF-6 can have a clear impact on understanding both the signal and background.

Snowmass White Paper

Snowmass Summer Study 2013

White Paper for Cosmic Frontier (CF) Sub-Group

Dedicated Indirect Searches for Dark Matter Using Antideuterons

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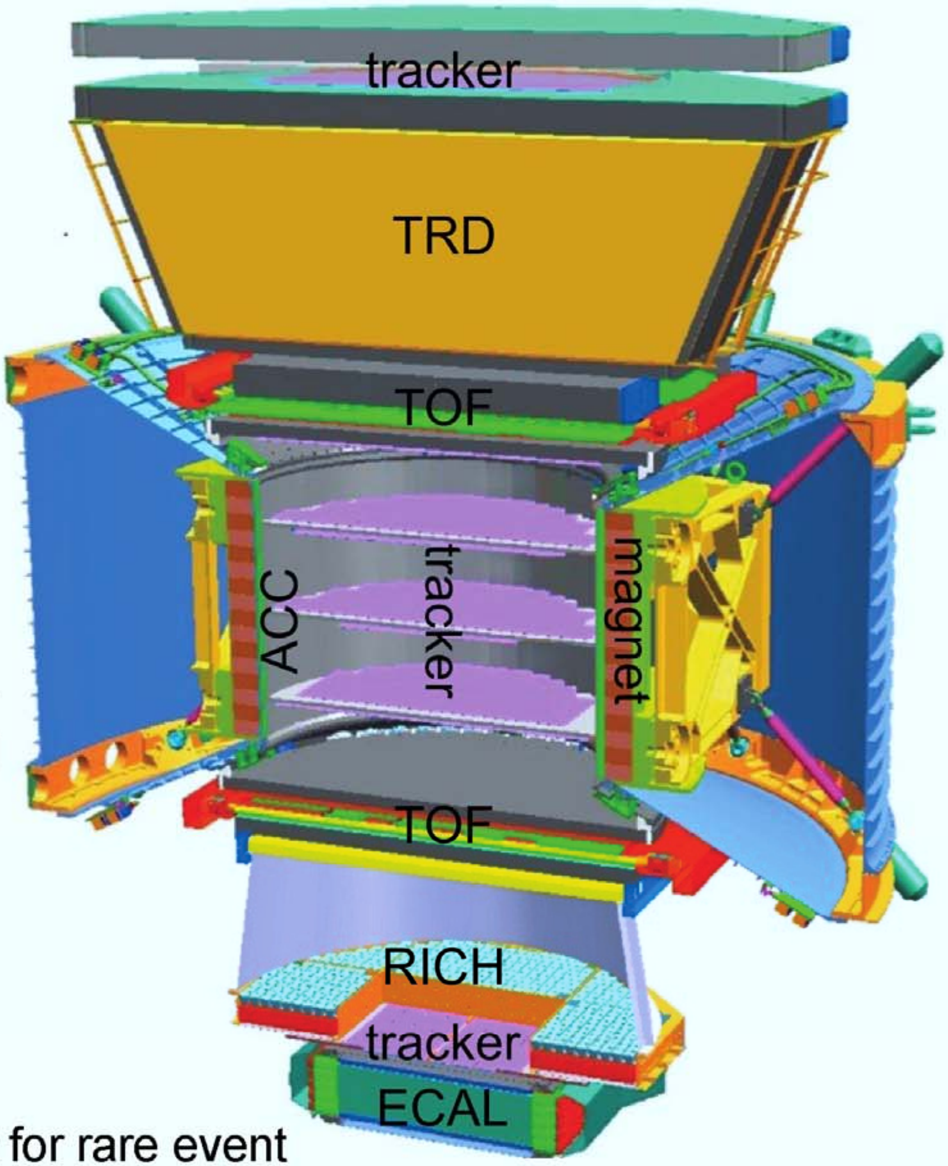
1.) Basic Idea of Antideuteron Searches

About a decade ago it was pointed out that antideuterons produced in WIMP-WIMP annihilations (the "primary" antideuterons) offered a potentially attractive signature for cold dark matter (CDM) (1, hereafter DFS). The reason is that the flux of primary antideuterons is fairly flat in the ~ 0.1 – 1.0 GeV/n energy band, while the "secondary/tertiary" antideuterons (those produced in cosmic ray interactions in the interstellar medium (secondaries) and subsequent reprocessing (tertiaries)) have fluxes which sharply decrease with decreasing energy. Thus, a search for antideuterons can in large part avoid being confounded by astrophysical background. Poorly understood astrophysical backgrounds are the primary challenge which must be addressed in the increasingly popular indirect searches. In particular, the antideuteron search is a great improvement over searches for WIMP-WIMP annihilation using antiprotons. For antiprotons the primary and secondary fluxes have spectral shapes which are nearly identical, and the primary antiproton flux is subdominant. The lower antideuteron background results because of the higher cosmic ray energy required to create an antideuteron, compared to an antiproton, combined with a cosmic ray spectrum steeply falling with energy. In addition, the collision kinematics disfavors the formation of low-energy antideuterons.

C. Hailey et al. 2013, at: **http://gamma1.astro.ucla.edu/gaps/**
See also talk by Ph. Von Doetinchem, Snowmass CF-2, March 7, 2013

AMS comparison



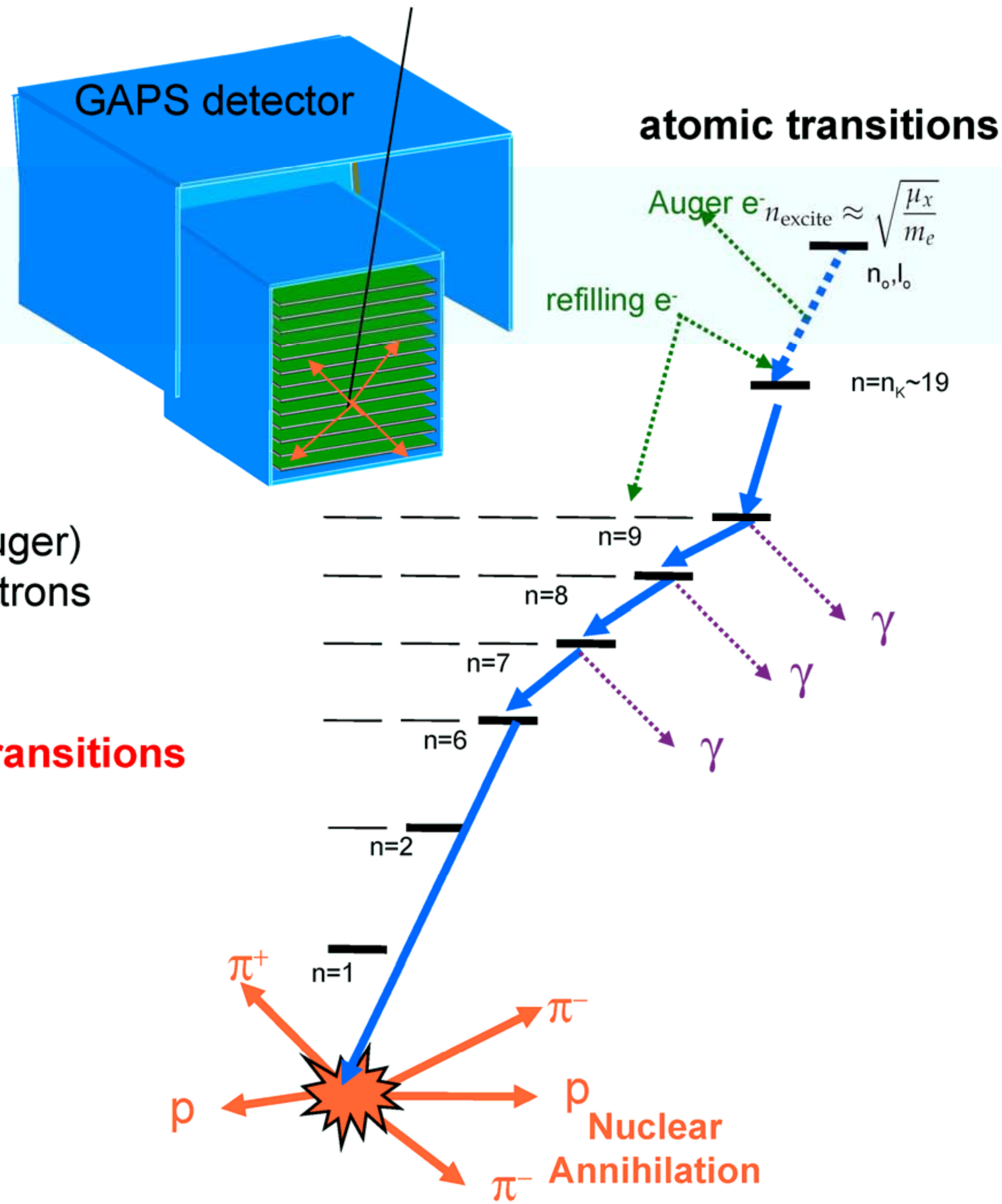
- AMS is a multi-purpose particle physics detector using subsequent detectors and a magnetic field
- AMS antideuteron analysis challenges: geomagnetic cut-off, multiple scattering
- **if AMS detects $\bar{d}$: confirmation is needed**
  if no detection: GAPS goes deeper
- different detection techniques are very important for rare event search
- building GAPS right now is important for timely comparison

Novel approach for antideuteron identification

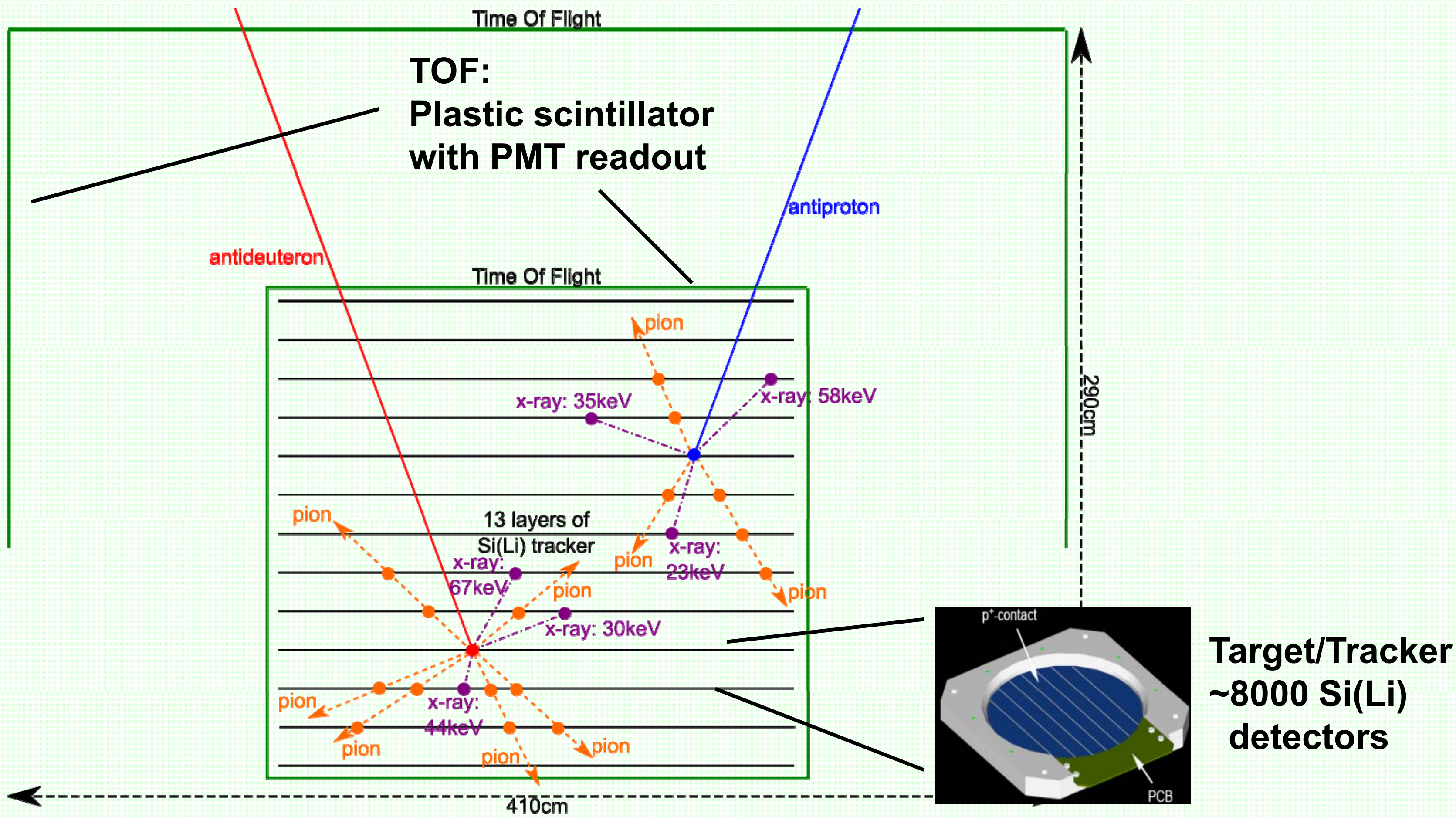
GAPS

- 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)

Competely different technique than AMS

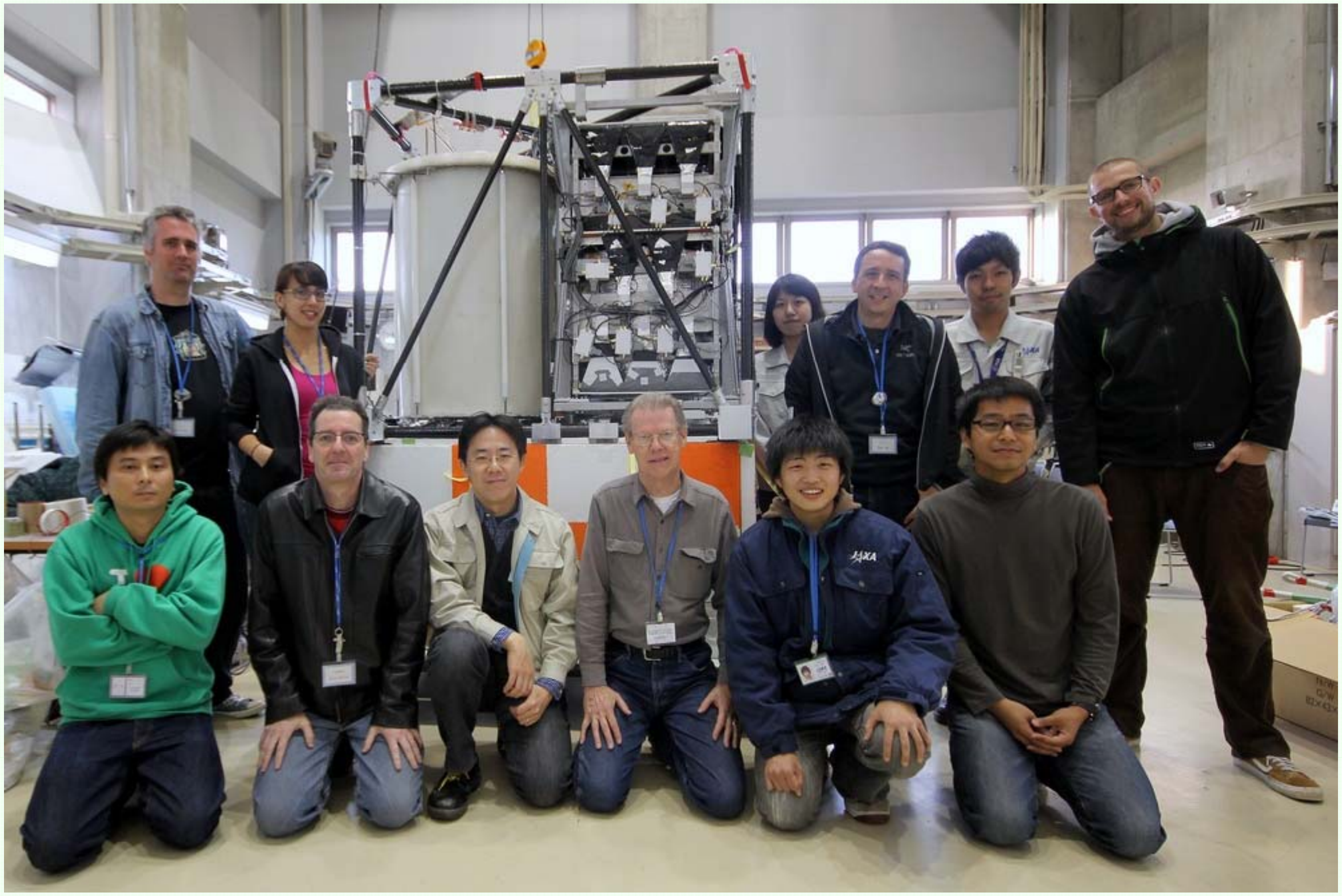


GAPS Experiment



- GAPS is especially designed for **low-energy antideuterons**
- Identification by **dE/dX, range, X-rays, pions & protons**
- (Ultra) Long duration balloon flights from Antarctica starting from 2017 (beginning of solar minimum)

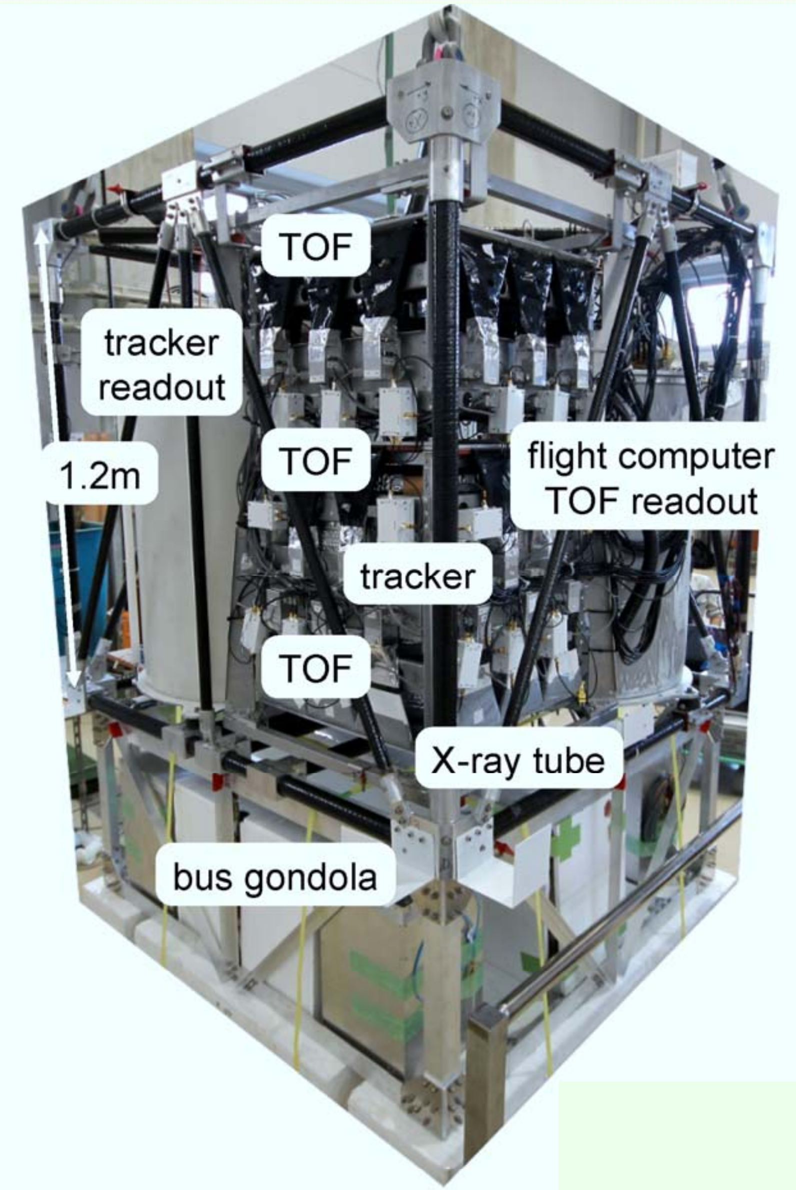
GAPS Collaboration



GAPS team in Taiki, Japan (2012)

T. Aramaki, N. Bando, S. Boggs, W. Craig, P. von Doetinchem, H. Fuke, F.H. Gahbauer, C. Hailey(PI), N. Madden, S.I. Mognet, K. Mori, S. Okazaki, R.A. Ong, K. Perez,T. Yoshida, J.A. Zweerink

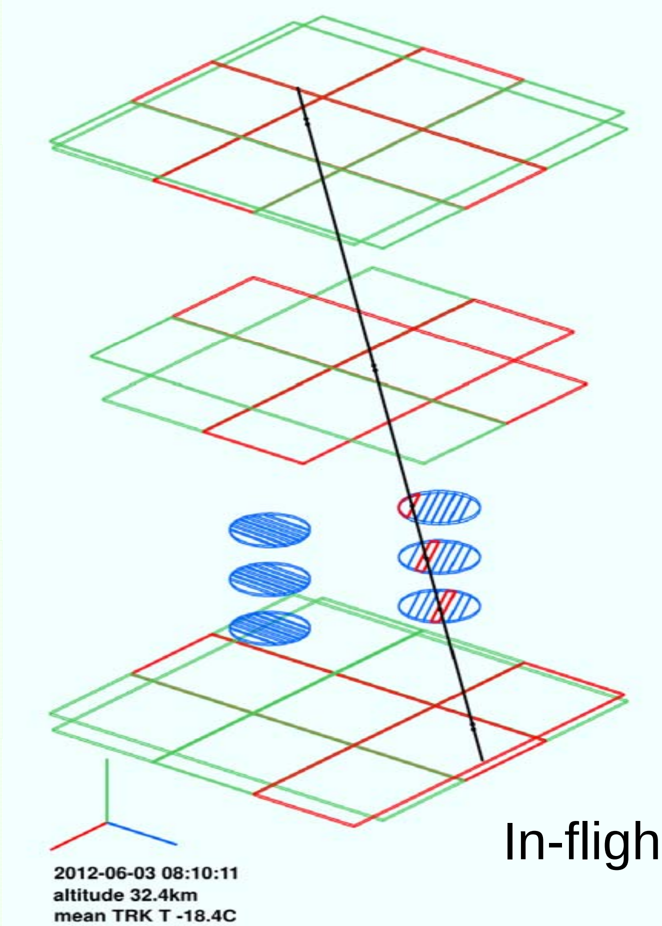
Prototype GAPS Instrument



pGAPS Payload

GOALS:

- Demonstrate stable operations of detector components: Si(Li), TOF
- Si(Li) cooling: verify thermal model
- Measure incoherent backgrounds



In-flight event

pGAPS Flight – Taiki, Japan, 3 June 2012

Balloon Filling

pGAPS Payload on Launcher

pGAPS Flight – Taiki, Japan, 3 June 2012

30 Minutes Before Launch

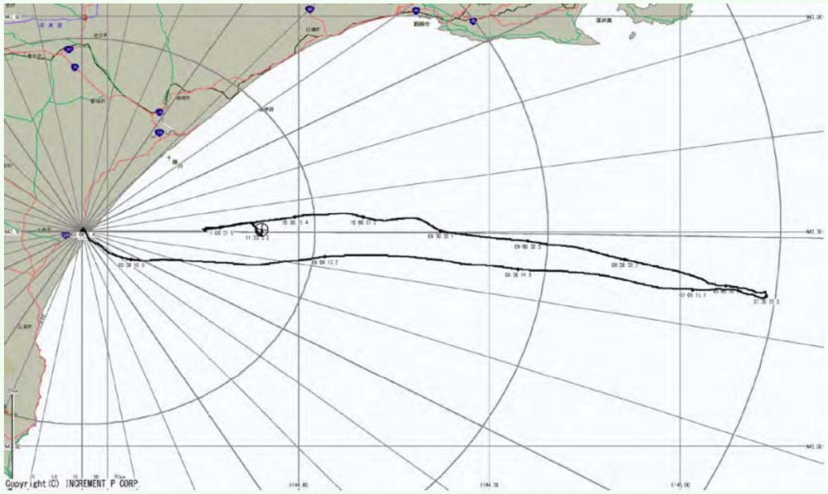
pGAPS Flight – Taiki, Japan, 3 June 2012

30 Minutes Before Launch

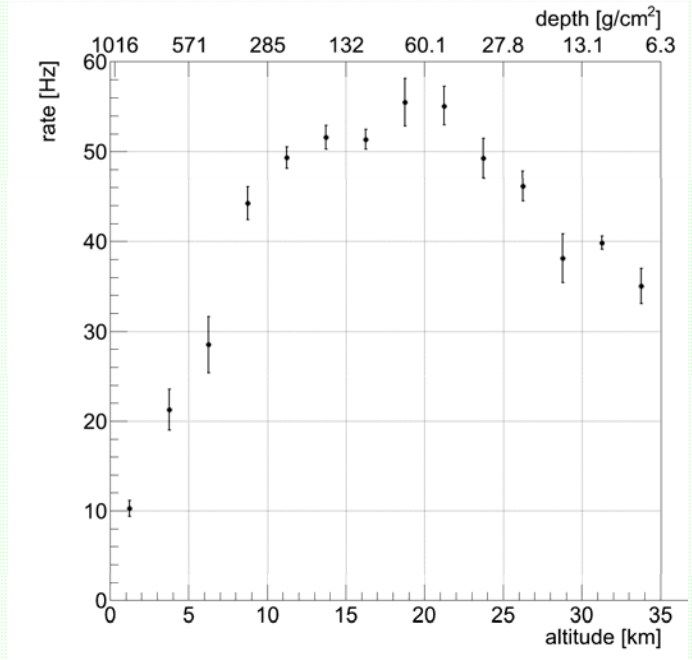
Launch @4:55am

Recovery in Harbor @1:05pm

Results from pGAPS Flight



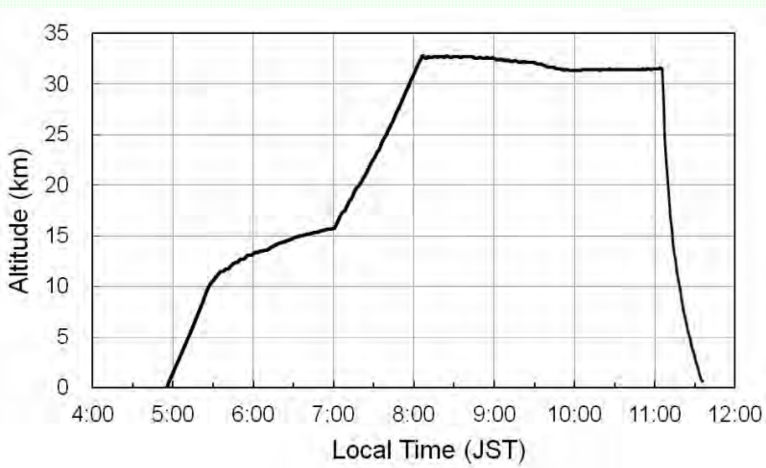
Flight Path over Pacific



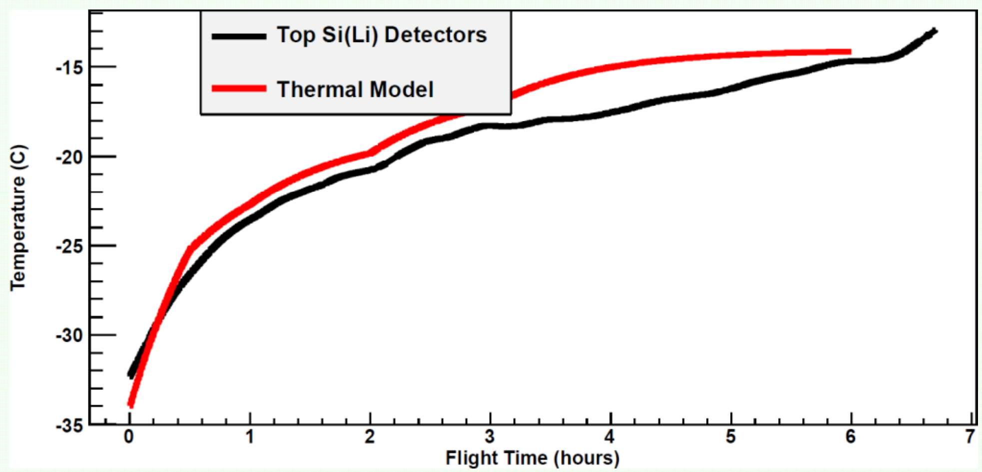
Trigger rate vs Altitude

Stable operations
@ Float Alt.

~600,000 triggers

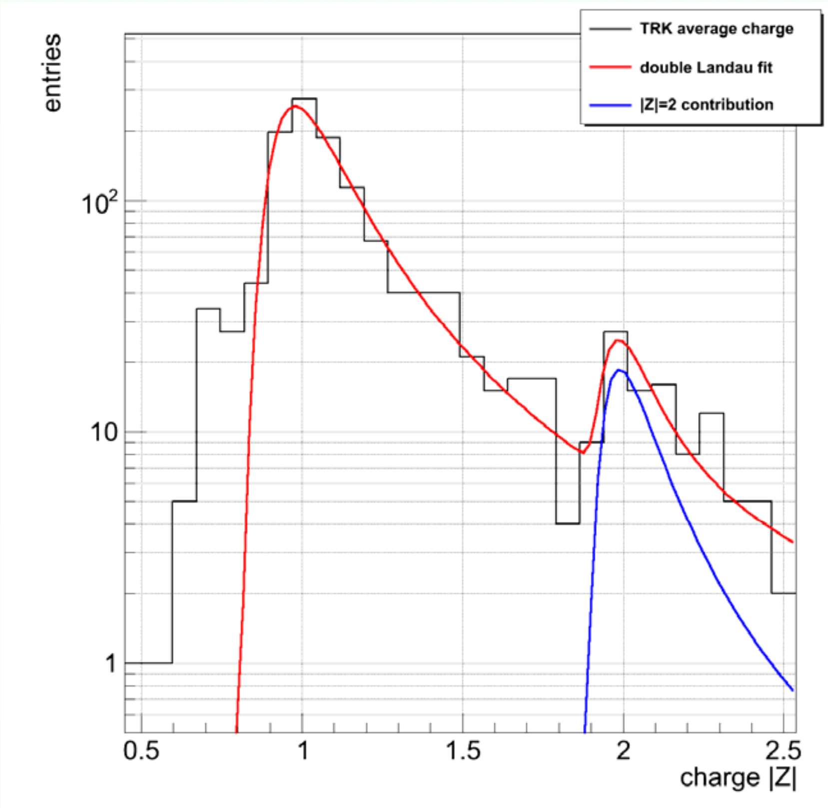


Flight Profile

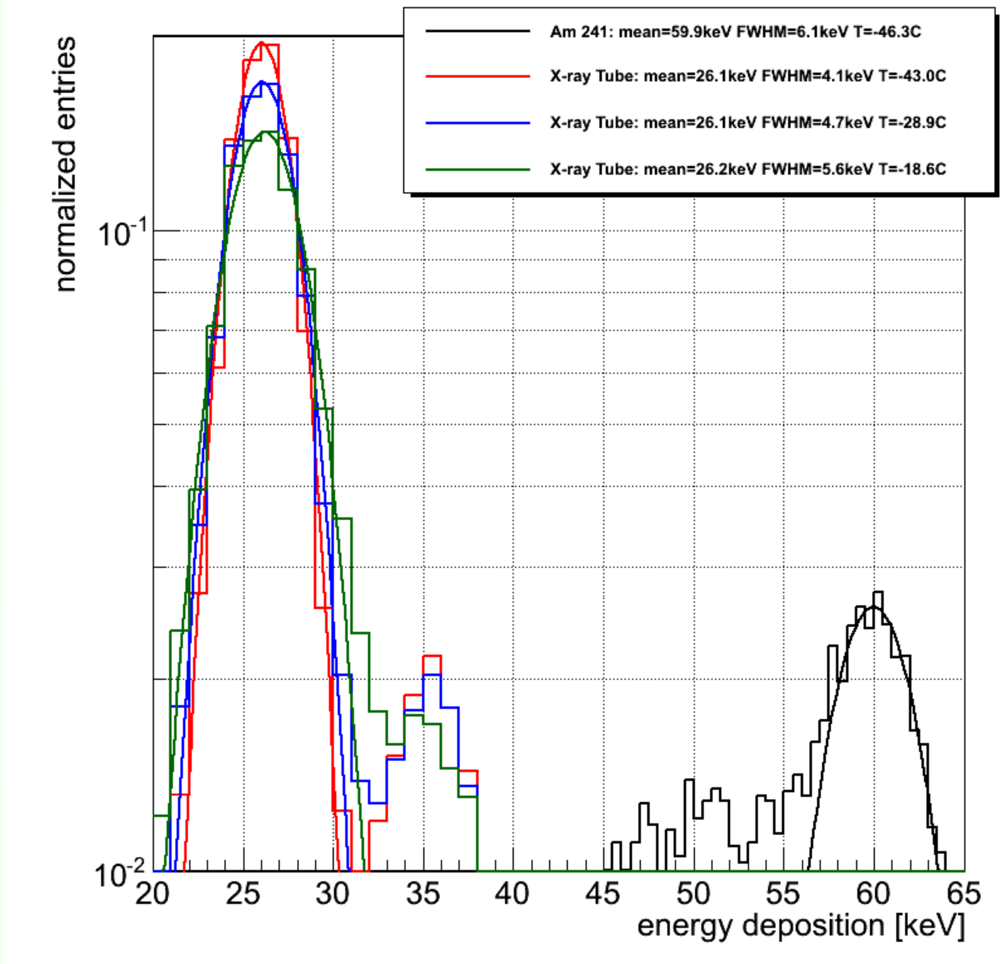


Thermal History

Results from pGAPS Flight



Charge Distribution in TOF



Si(LI) Performance

Many more details:

- H. Fuke, R.A. Ong et al., http://arxiv.org/abs/1303.0380
- I. Mognet et al., submitted to Nucl. Inst. Meth B (2013)
- Ph. Von Doetinchem et al., in preparation (Flight paper)

GAPS Timeline

- **2000** Initial Idea
- **2004/5** KEK beam tests with anti-protons
- **2008-12** Design and technical validation
- **2012** Prototype flight in Japan
- **2013-2015** Detailed Design
- **2015-2017** Construction (proposed)
- **Late 2017** First science flight from Antarctica

GAPS Summary

- **Anti-deuterons have never been detected in the CR's. They provide unique avenue into attacking the DM problem.**
- **Currently no dedicated anti-D search exists. GAPS is specifically designed for low-energy anti-D's.**
- **Anti-deuterons and GAPS technique both offer complementary aspects to other instruments.**
- **pGAPS – successful prototype flight that met all goals.**
- **Now is the right time to start building GAPS to compare to AMS and the full suite of direct/indirect DM detectors.**

"Great scientific discoveries have been made by men seeking to verify quite erroneous theories about the nature of things, " Aldous Huxley, 1929.