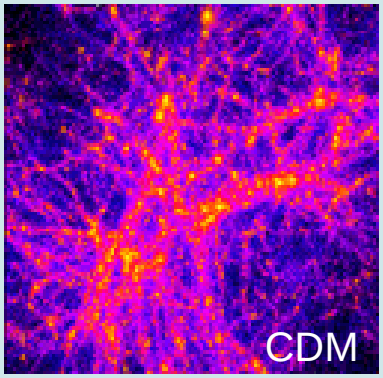
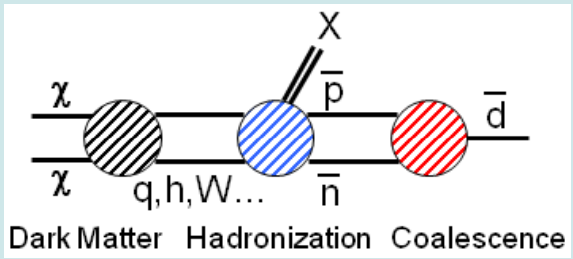
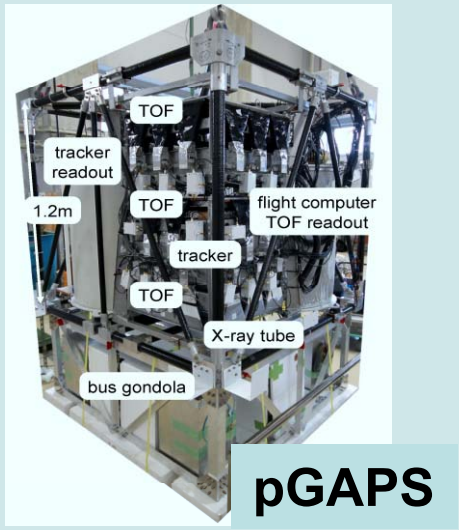
# GAPS: A Dedicated Search for Anti-Deuterons in the Cosmic Rays

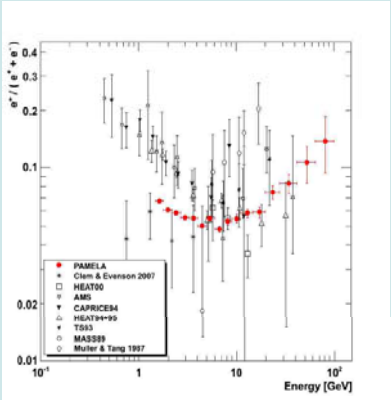


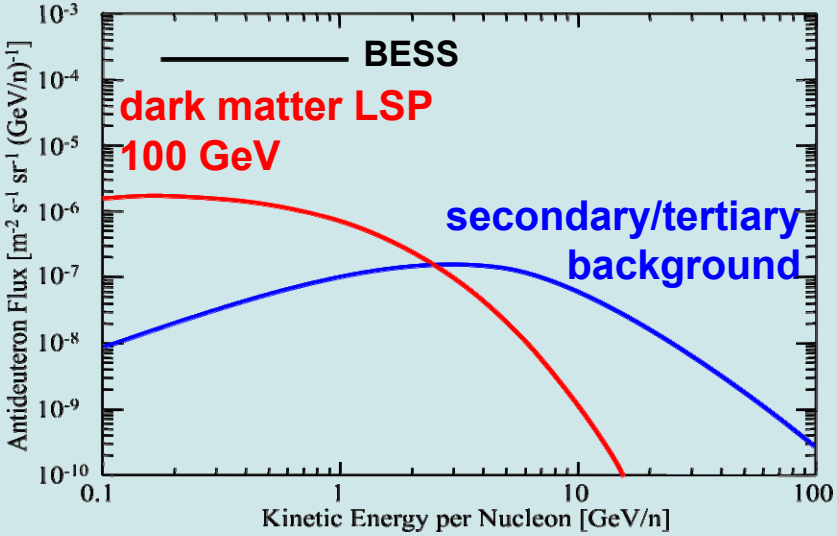

anti-deuterons ?

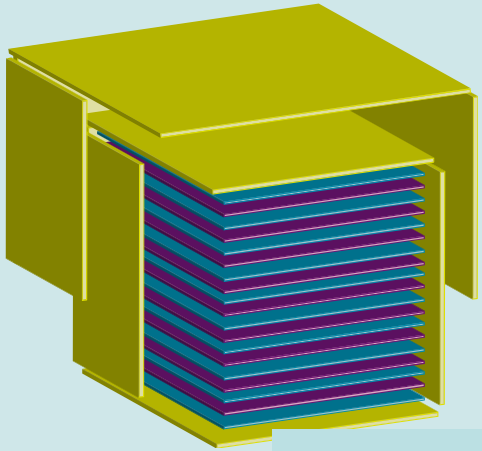



positrons ?




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*

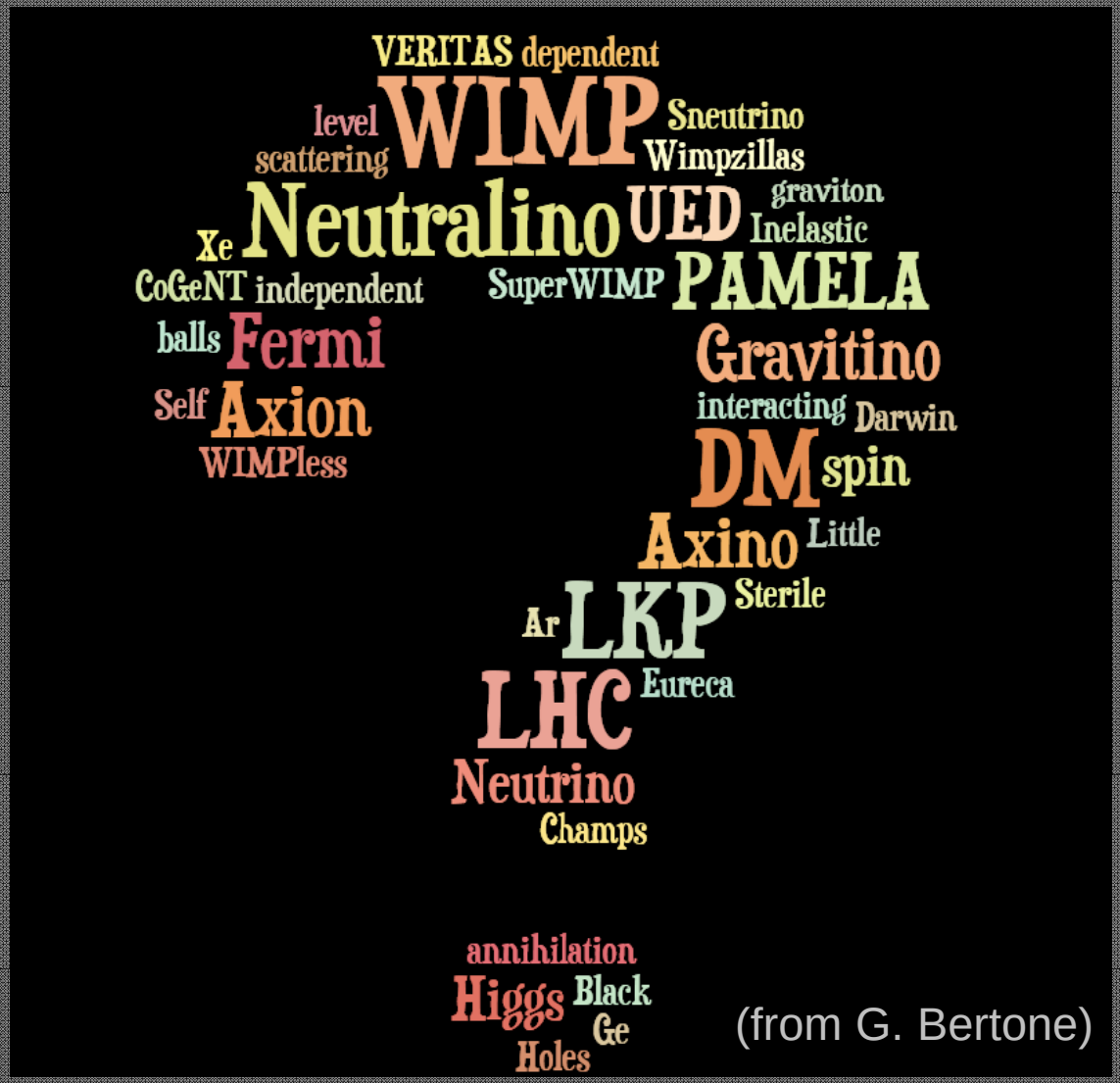
- DM search: Unique, low-bkgnd capability
- Uncertainties & relation to CF-6
- Complementarity to other approaches

## 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.

Primary Component (DM):

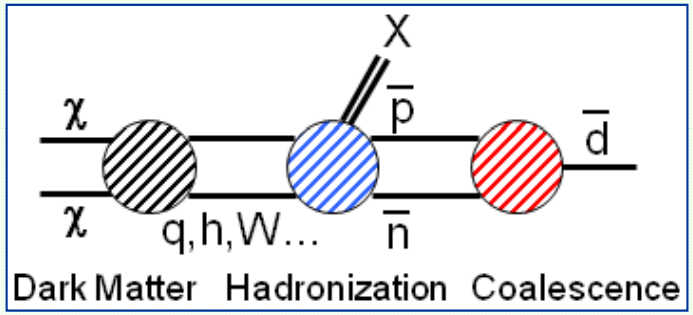
$$\chi\,\chi \rightarrow e^{+}, \bar{p}, \bar{d}$$

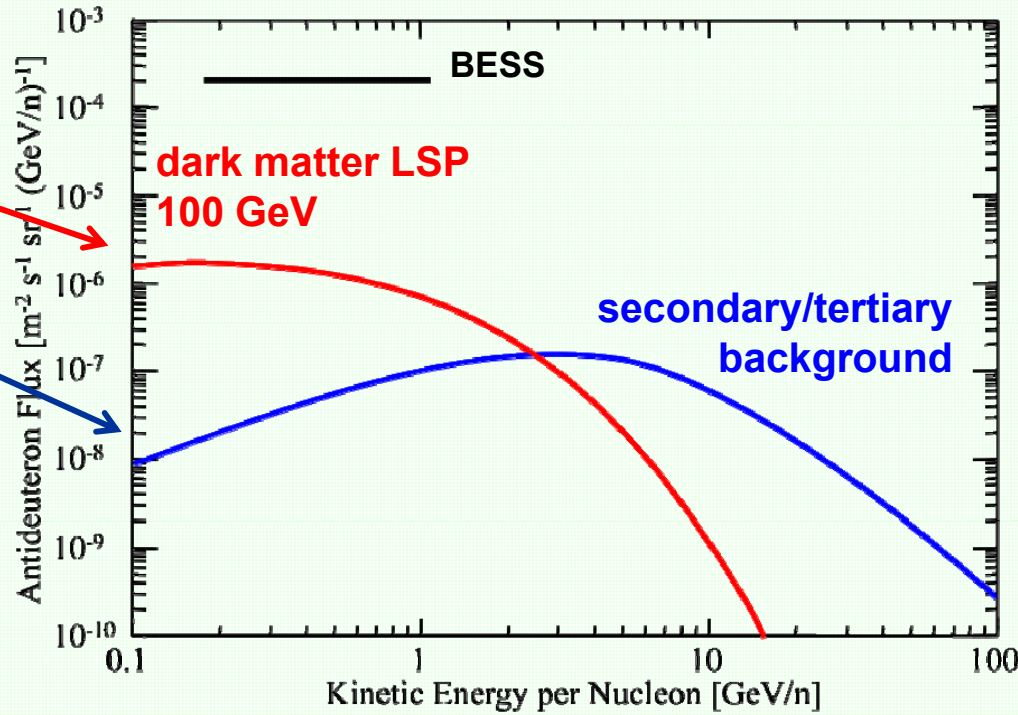
Secondary Component, includes:

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

where A = p, He

DM production of $\bar{d}$



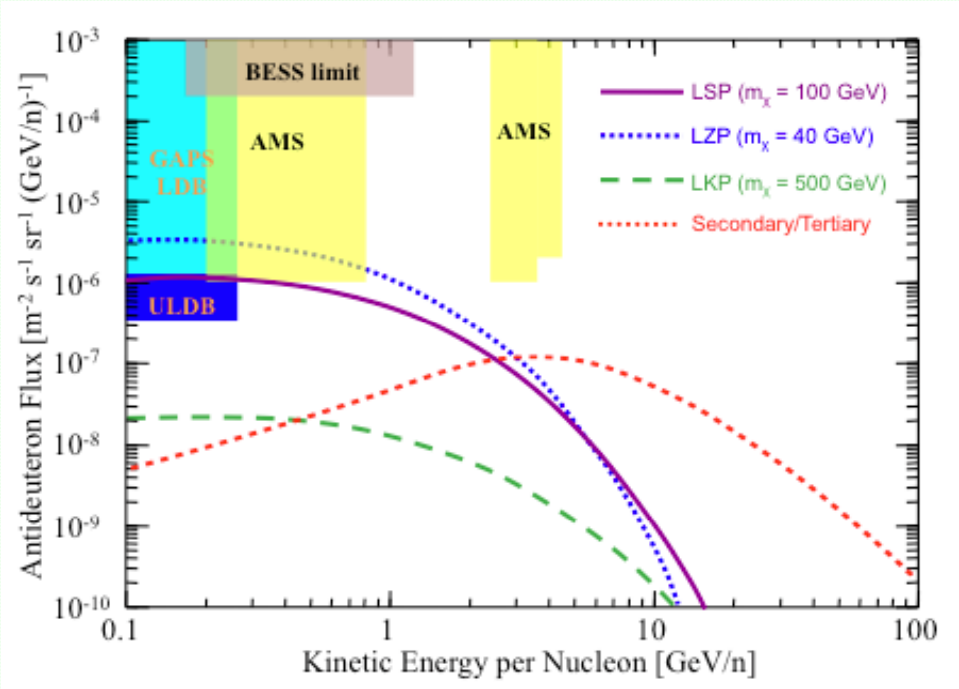




**1) Anti-deuterons provide extremely clean signature.**
**2) Detection of even a few events would be very interesting.**
**3) Low fluxes require a very sensitive detector.**

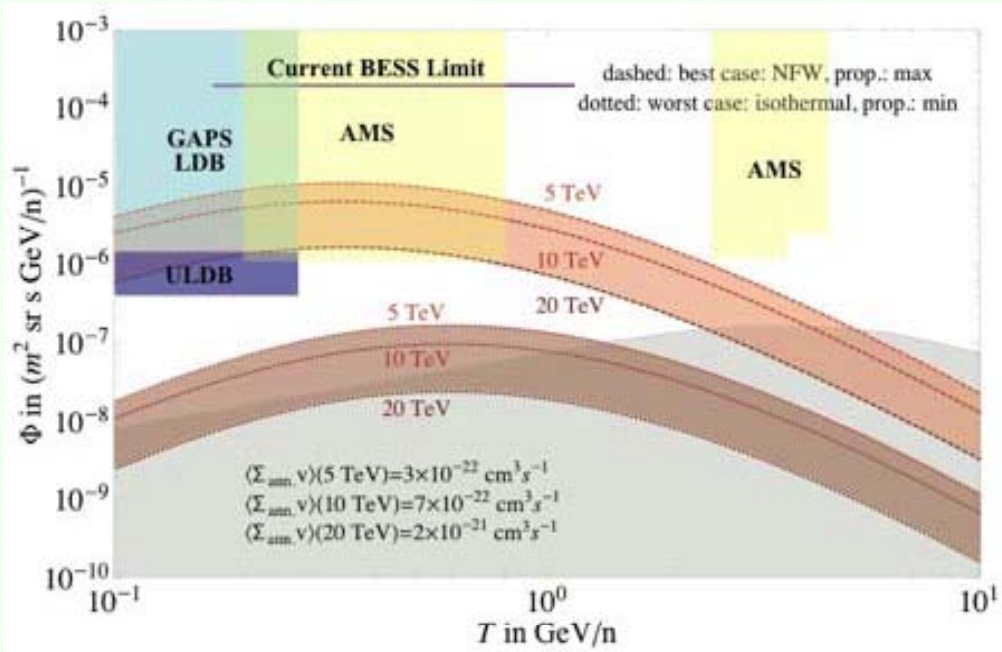
**No dedicated anti-deuteron exists → GAPS**

# 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*

C. Hailey[1], T. Aramaki[1], P. von Doetinchem[2], and R. A. Ong[3]

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[2]Space Science Laboratory, University of California, Berkeley, CA 94720, USA

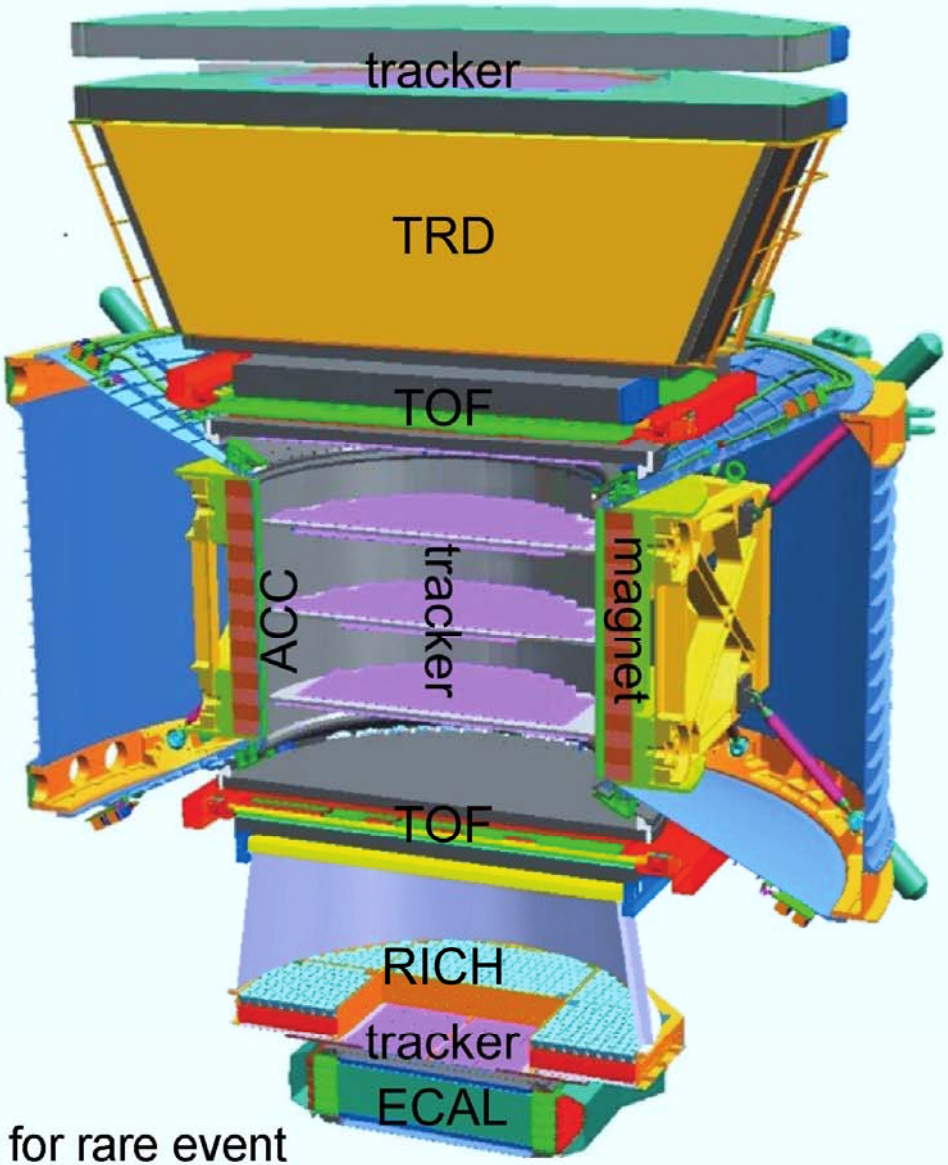
[3]Dept of Physics and Astronomy, University of California, Los Angeles, CA 90095, USA

### 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

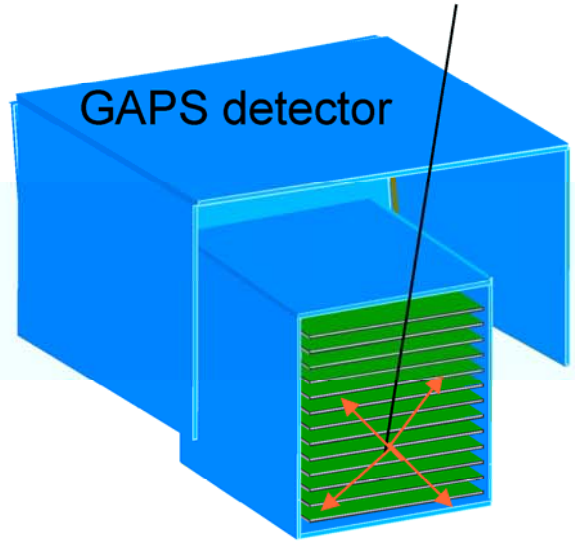
- **if AMS detects $\bar{d}$: confirmation is needed**
  **if no detection: GAPS goes deeper**
- different detection techniques are very important for rare event search
- building GAPS right now is important for timely comparison

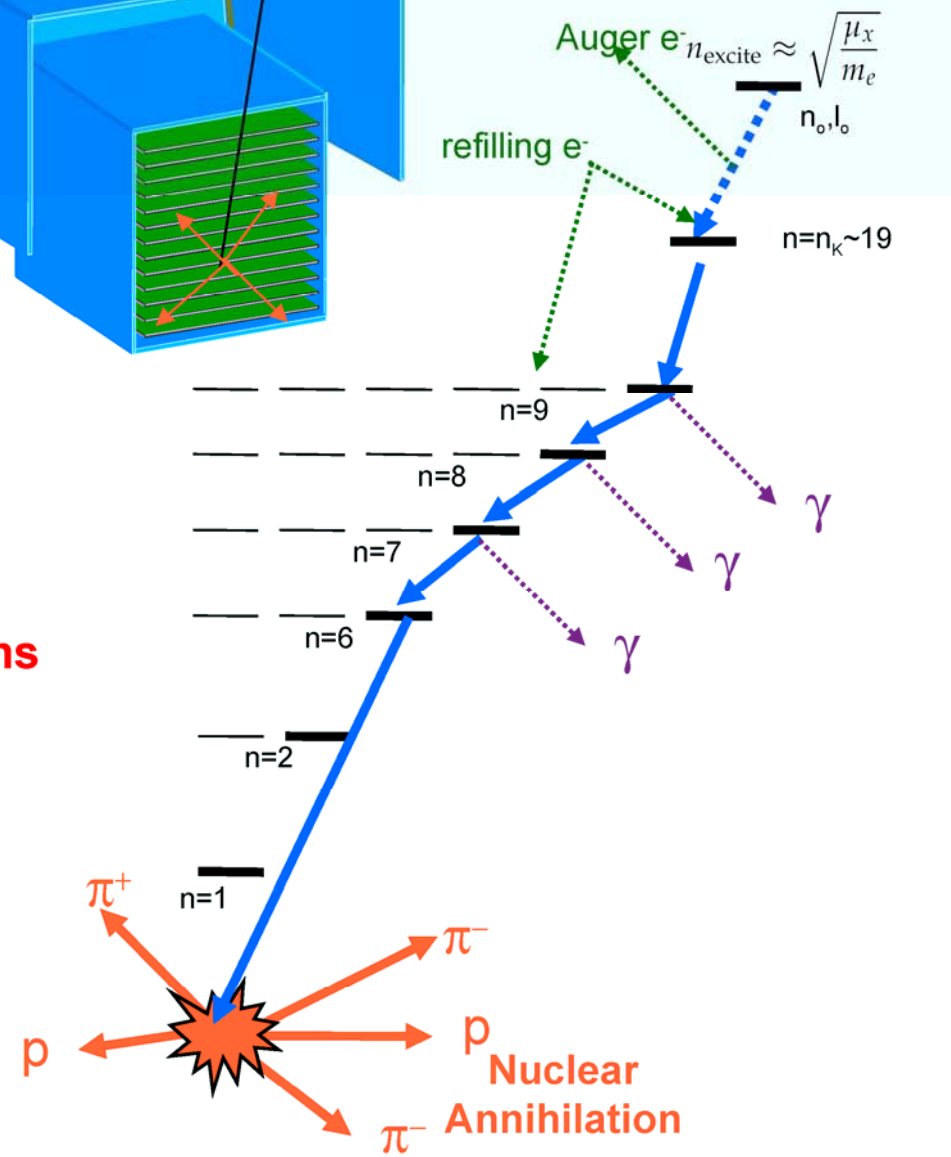
# Novel approach for antideuteron identification

## GAPS

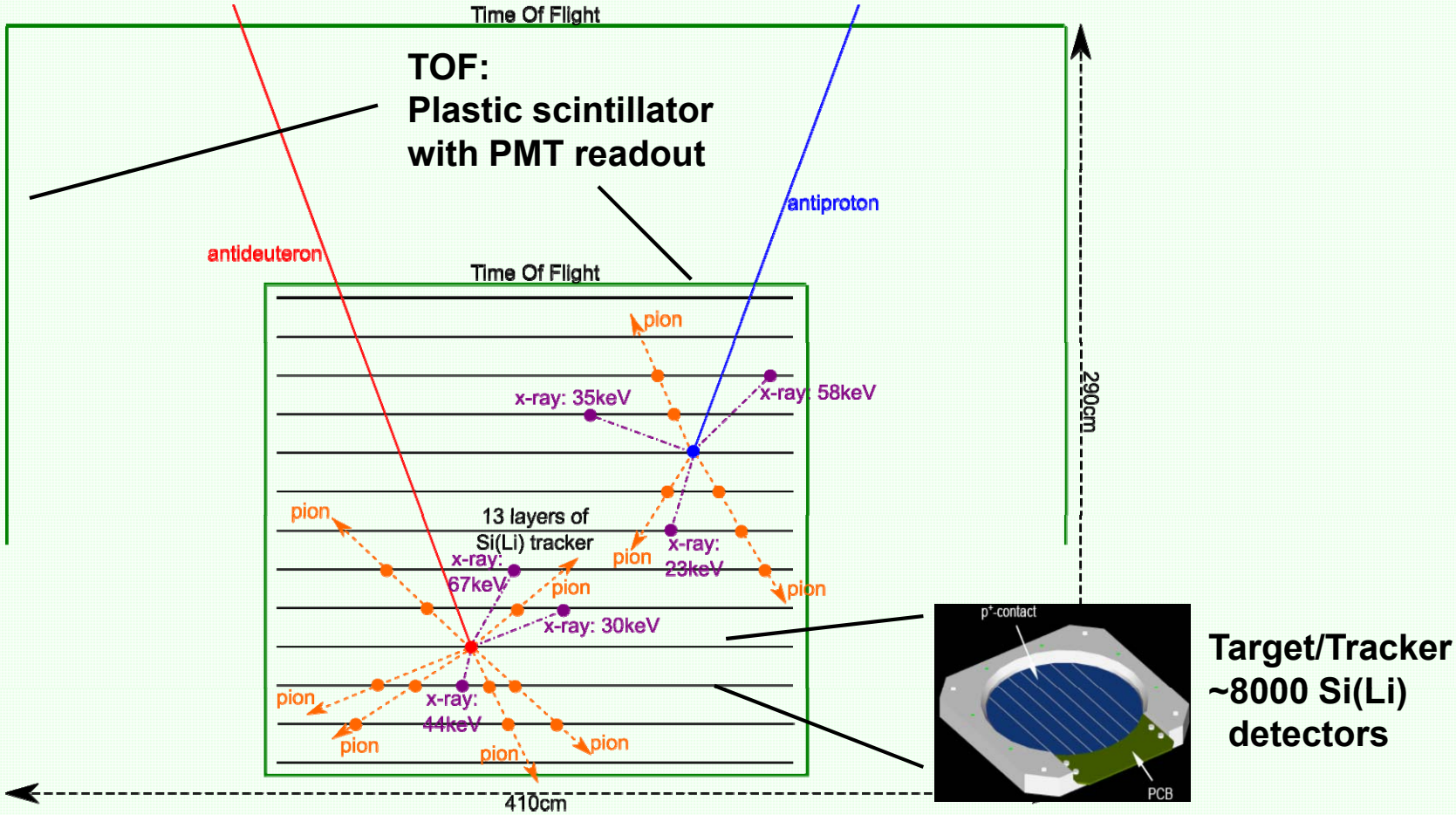
- antideuteron slows down and stops in material
- large chance for creation of an excited exotic atom ($E_{kin}$~$E_I$)
- deexcitation:
  - fast ionisation of bound electrons (Auger)
    → complete depletion of bound electrons
  - Hydrogen-like exotic atom (nucleus+antideuteron) deexcites via **characteristic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

Competely different technique than AMS



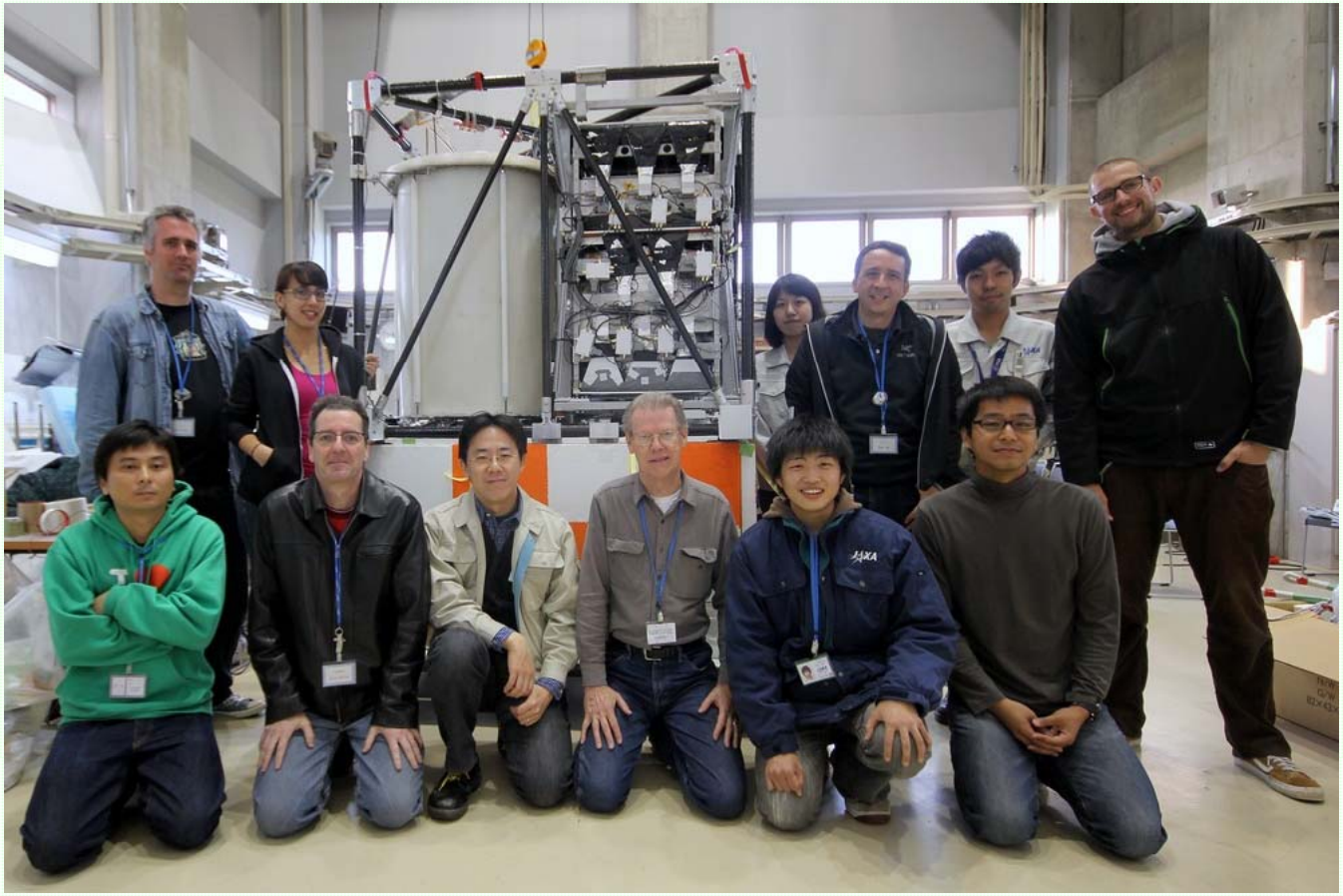



# GAPS Experiment




- 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)

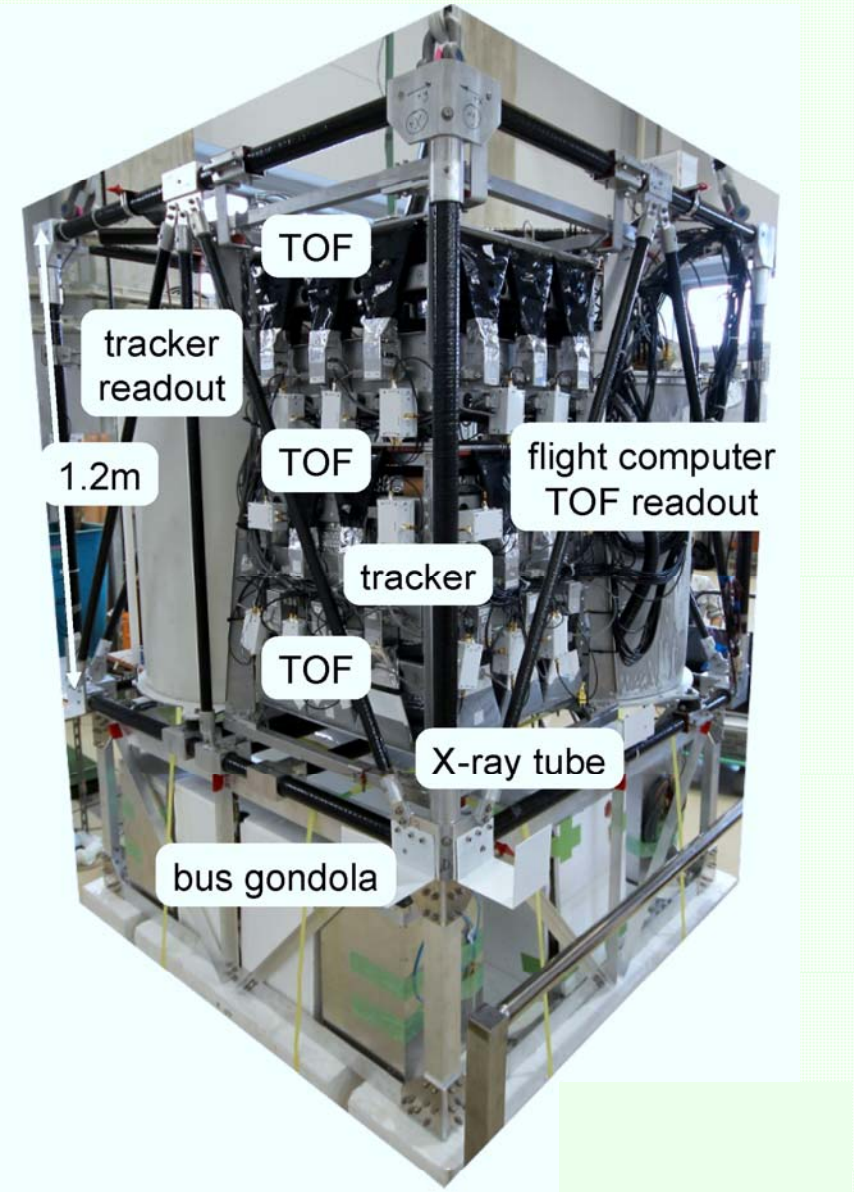
# GAPS Collaboration



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

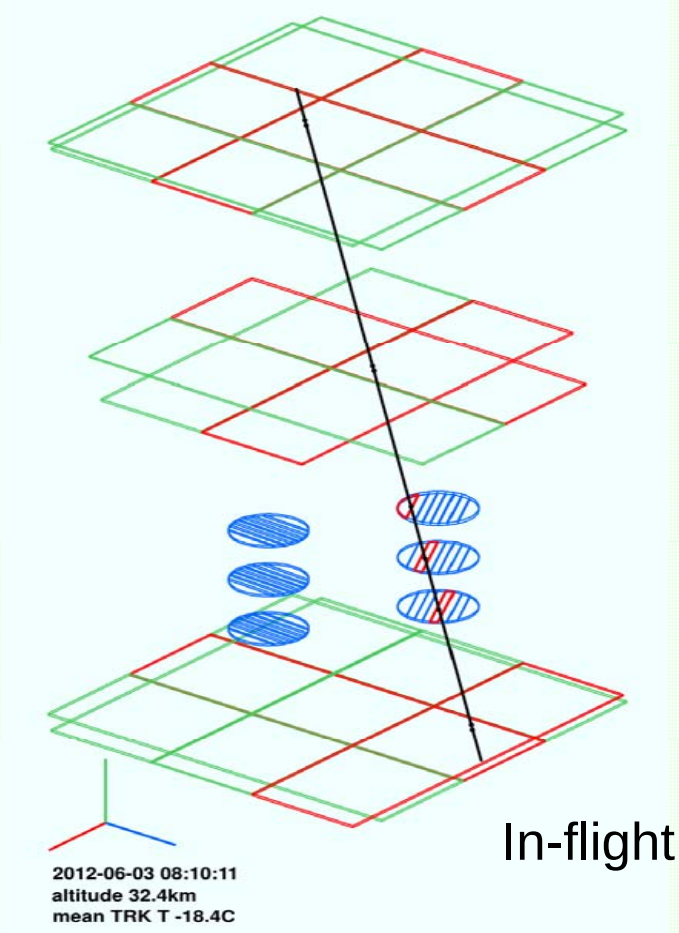
# Prototype GAPS Instrument




**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

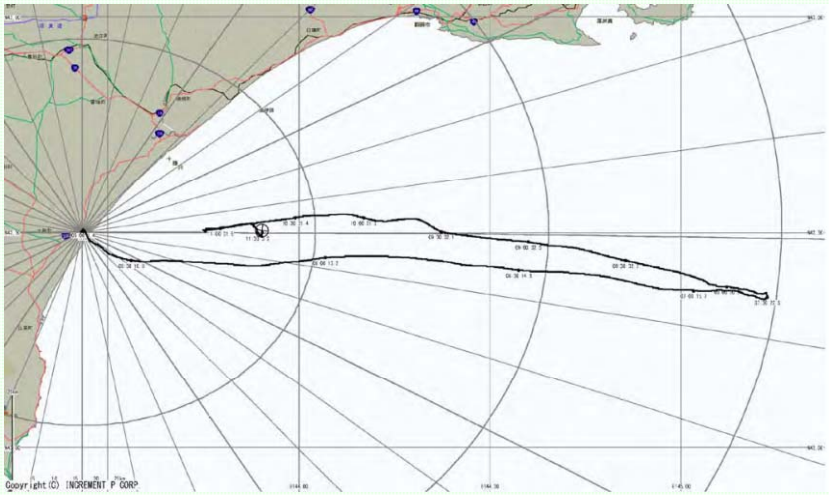
# pGAPS Flight – Taiki, Japan, 3 June 2012

**30 Minutes Before Launch**

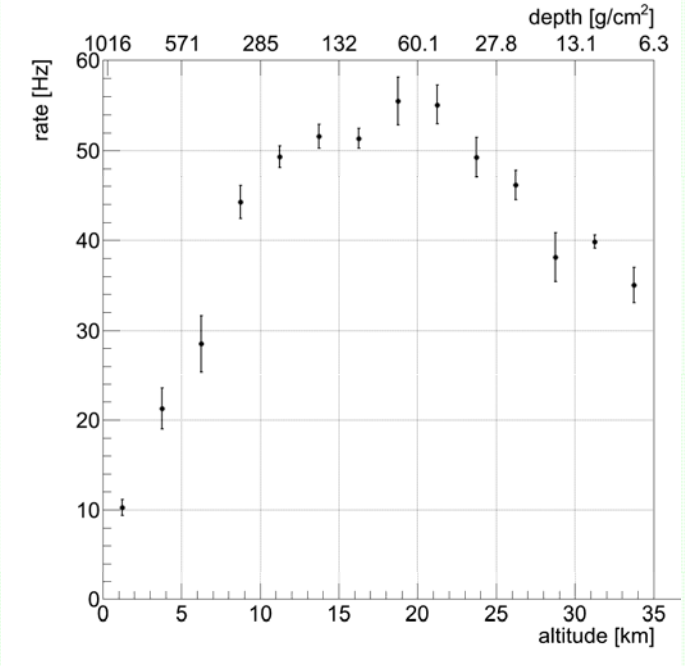
# pGAPS Flight – Taiki, Japan, 3 June 2012

30 Minutes Before Launch

# Results from pGAPS Flight



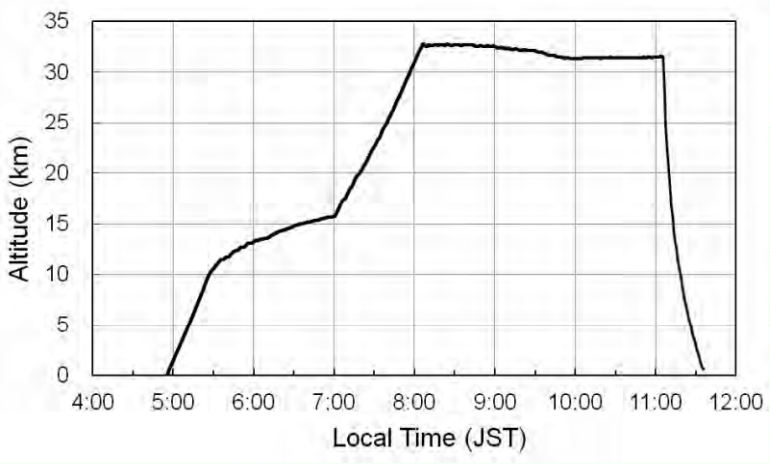
Flight Path over Pacific



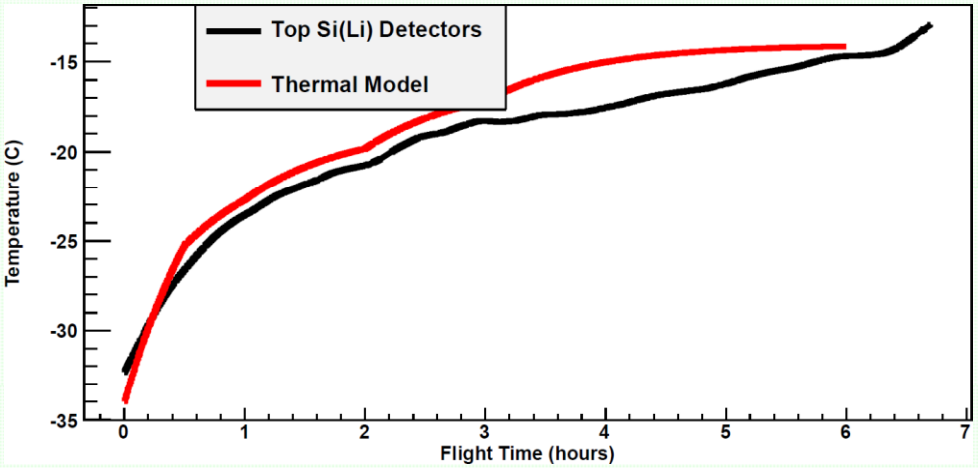

Stable operations @ Float Alt.

~600,000 triggers

Trigger rate vs Altitude

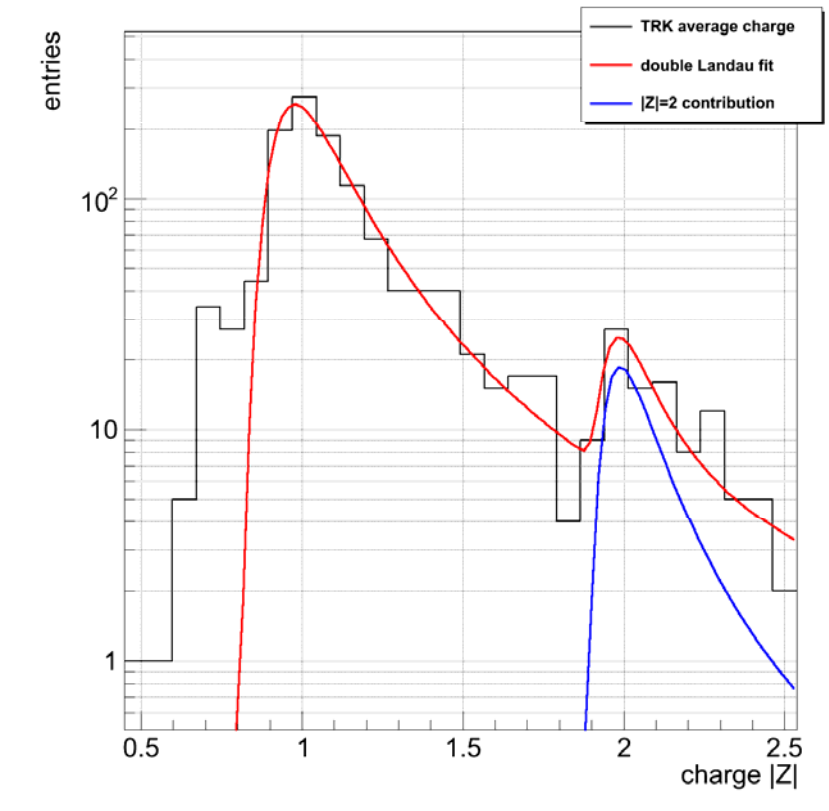



Flight Profile

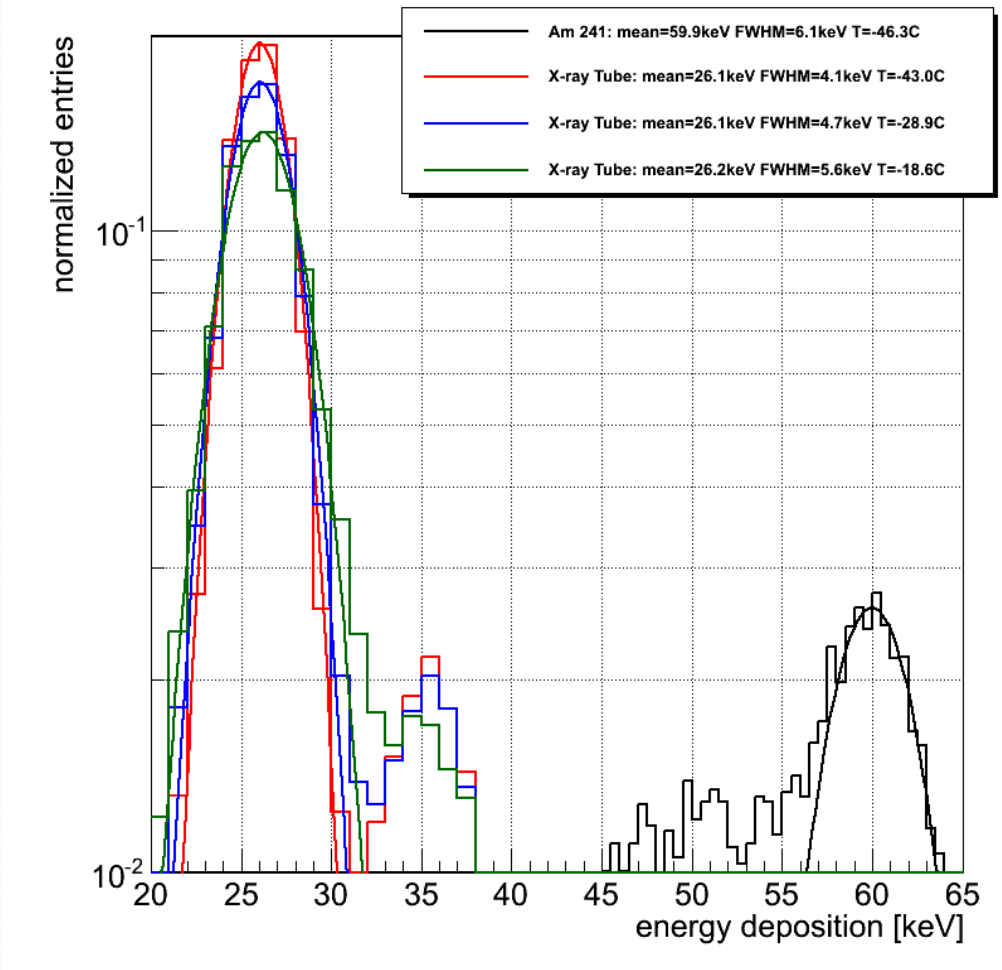



Thermal History

# 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

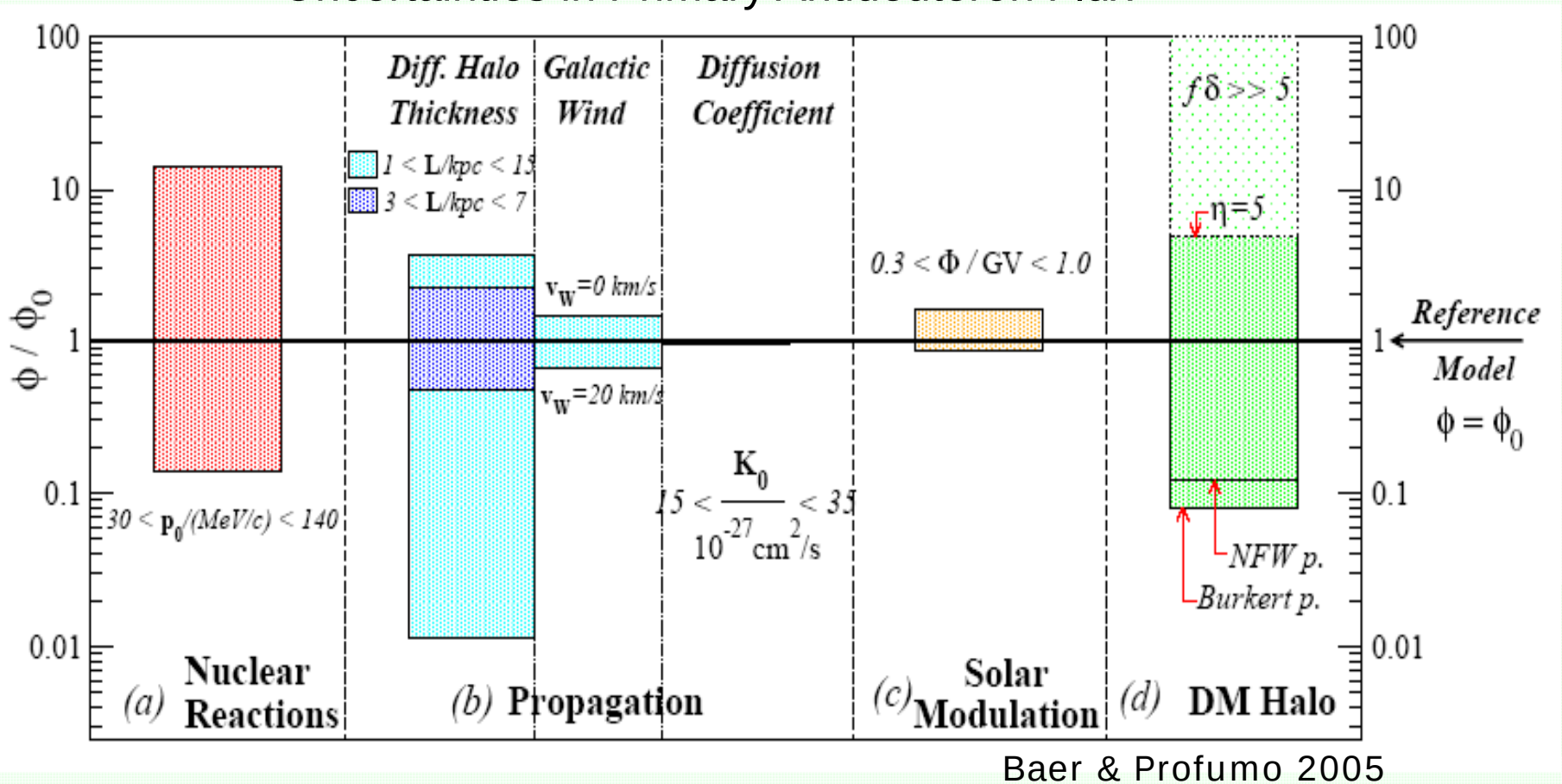
- **Anti-deuterons have never been detected in the CR's. They provide unique avenue into attacking the DM problem.**
- **Currently no dedicated anti-D search exists. GAPS is specifically designed for low-energy anti-D's.**
- **Anti-deuterons and GAPS technique both offer complementary aspects to other 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.

# Backup

# anti-D Flux Uncertainties

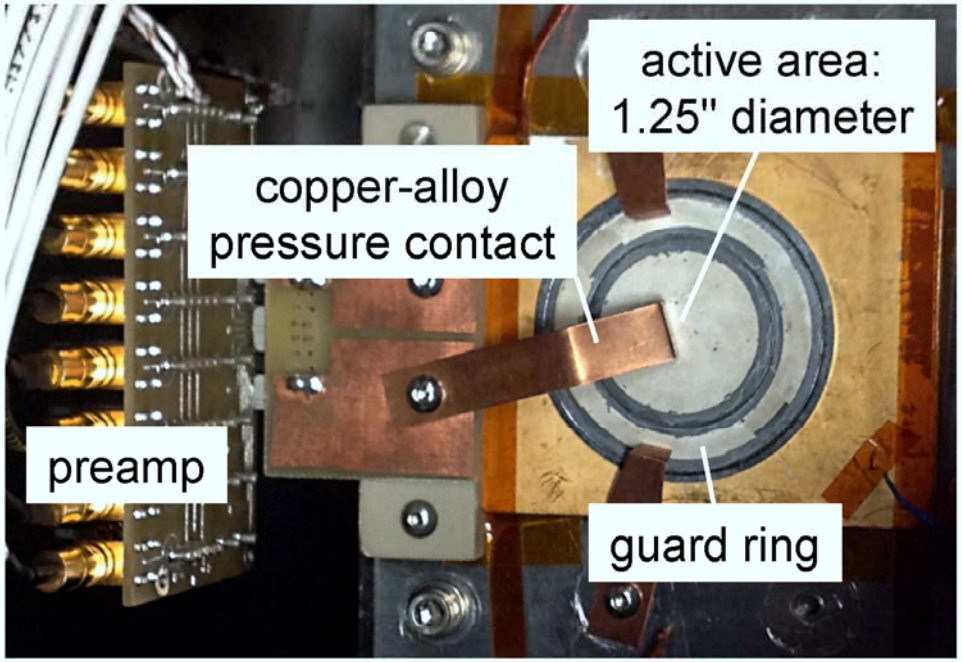
Uncertainties in Primary Antideuteron Flux




Baer & Profumo 2005

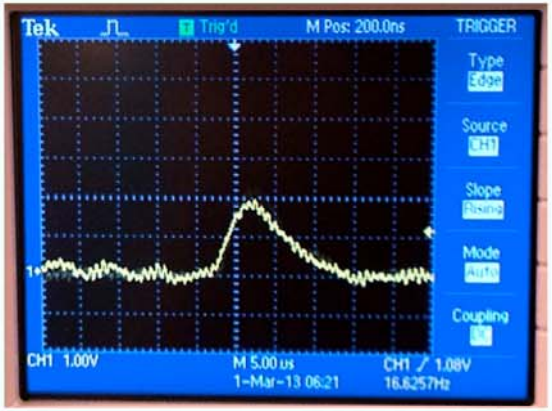
Flux uncertainty is dominated by propagation
(e.g. see Cui, Mason & Randall 2010)

# Si(Li) detector production

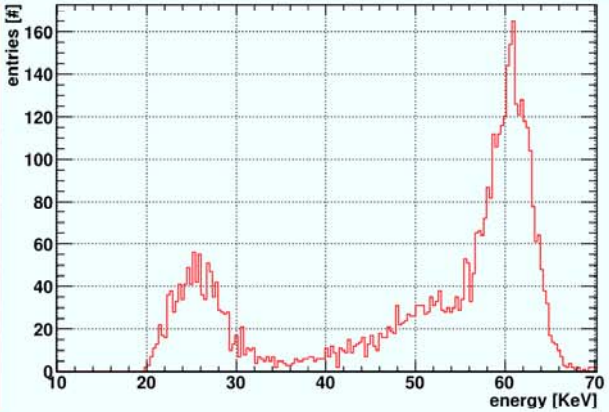



- GAPS will use 2875 4” Si(Li) detectors
- 2”-diameter detectors being produced at Columbia U. using simple fabrication scheme
- successfully drifted diameters from 1" to 2" with >90% yield, both 1 mm (prototype) and 2.5 mm thick

- 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!



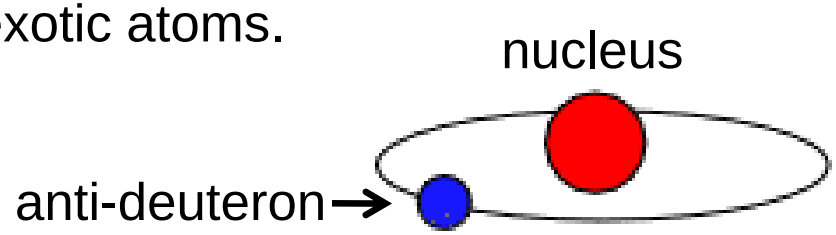

X-rays from Am-241



# GAPS Detection Technique

- Conventional method of magnetic mass spectrometer is not optimal for GAPS. (Very large magnets with thin detector materials are needed for a deep survey).

- GAPS introduces an original method. GAPS utilizes the de-excitation sequence of exotic atoms.



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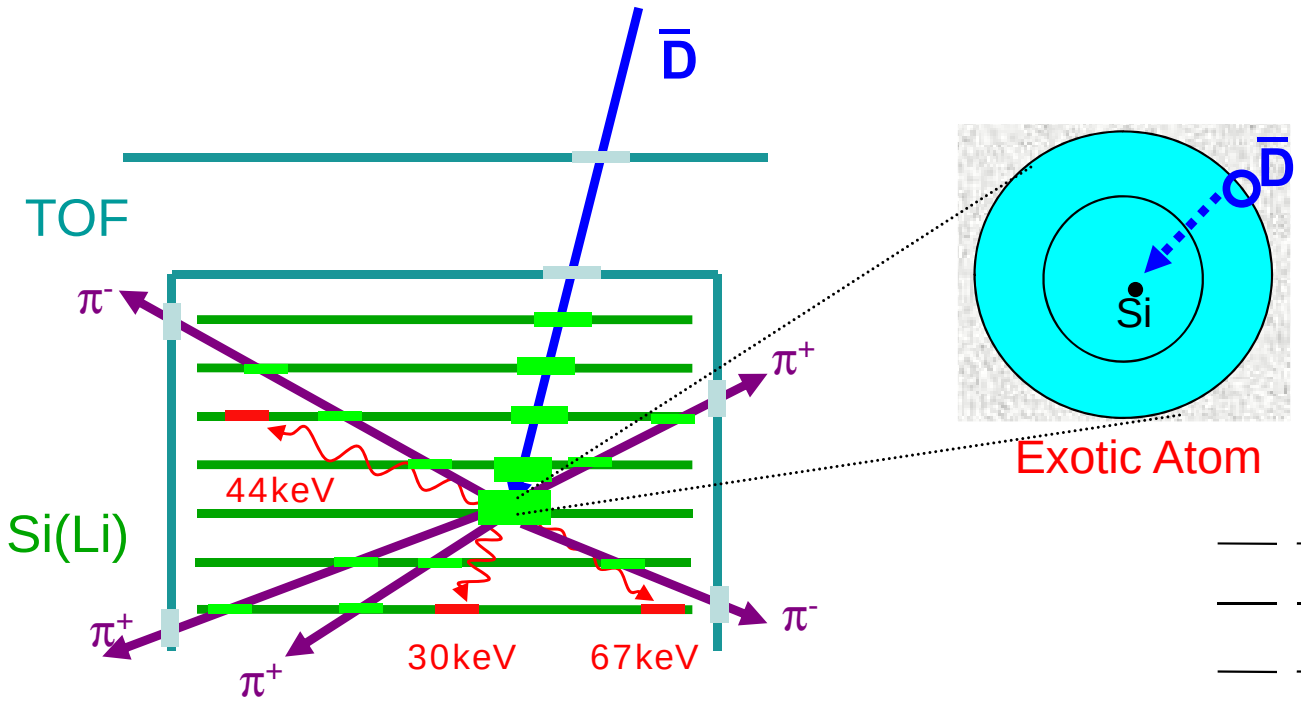
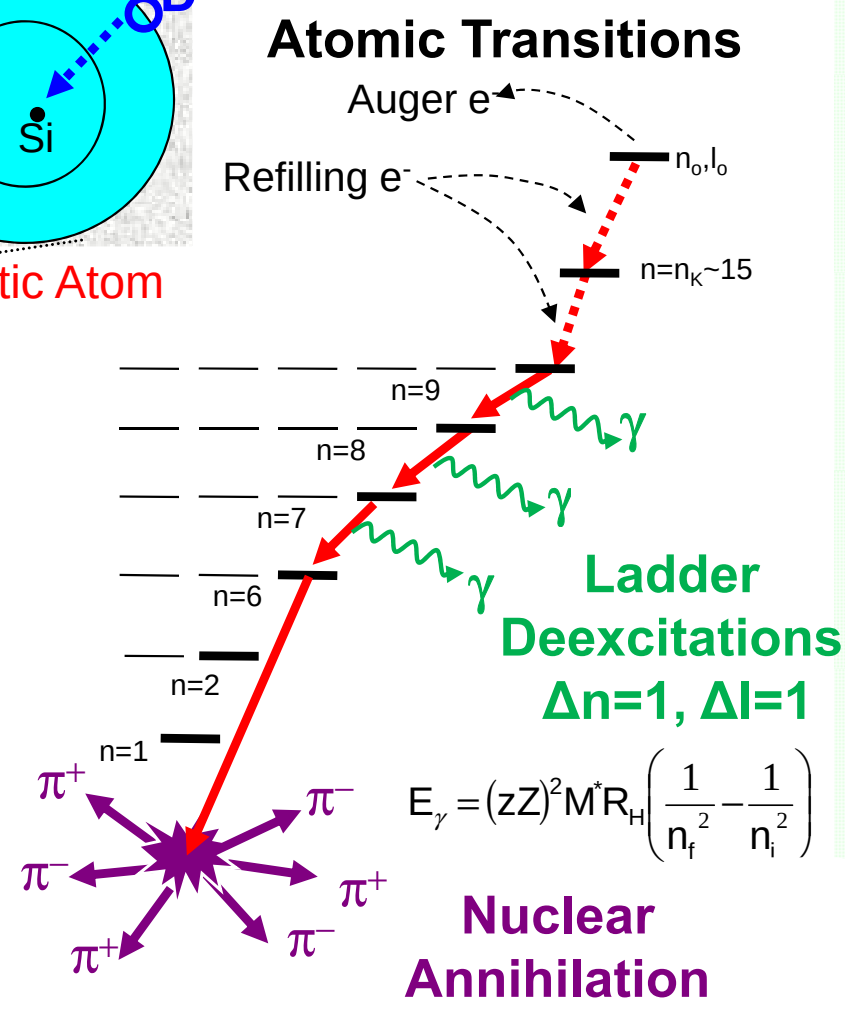


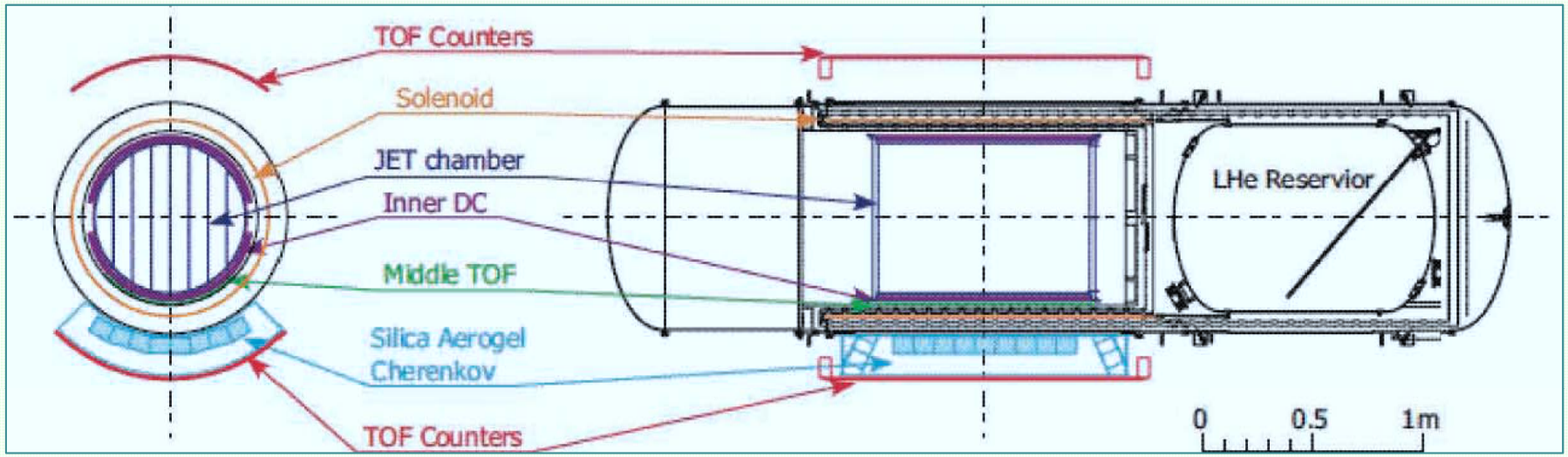




1. Once $\bar{D}$ is slowed down and stopped in the target,
2. an excited exotic atom is formed,
3. which deexcites with emitting X-rays,
4. and annihilates with producing a pion shower.

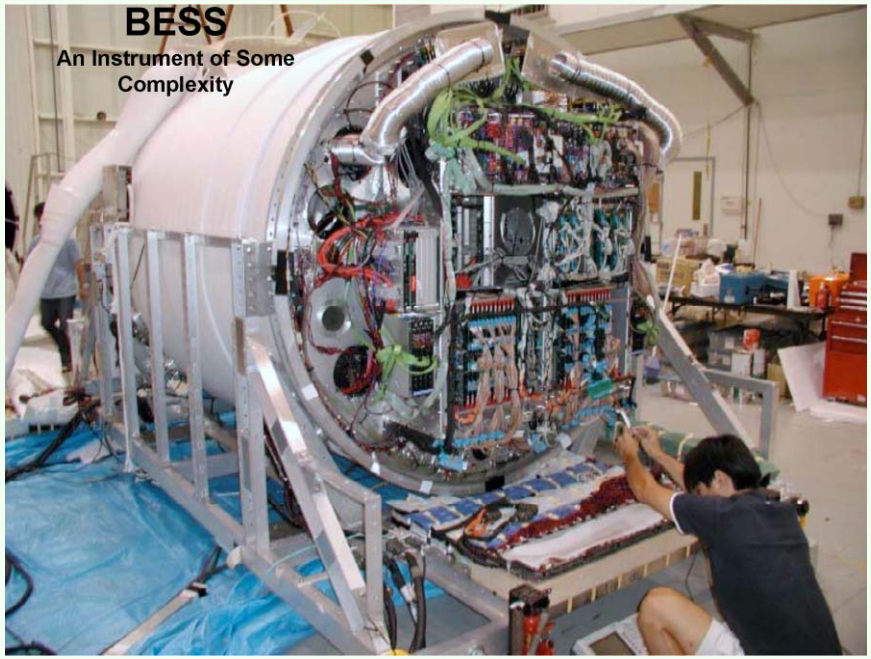
- Detection principle was verified and high X-ray yield was shown in accelerator tests (KEK antiproton beam, '04 - '05).

# BESS

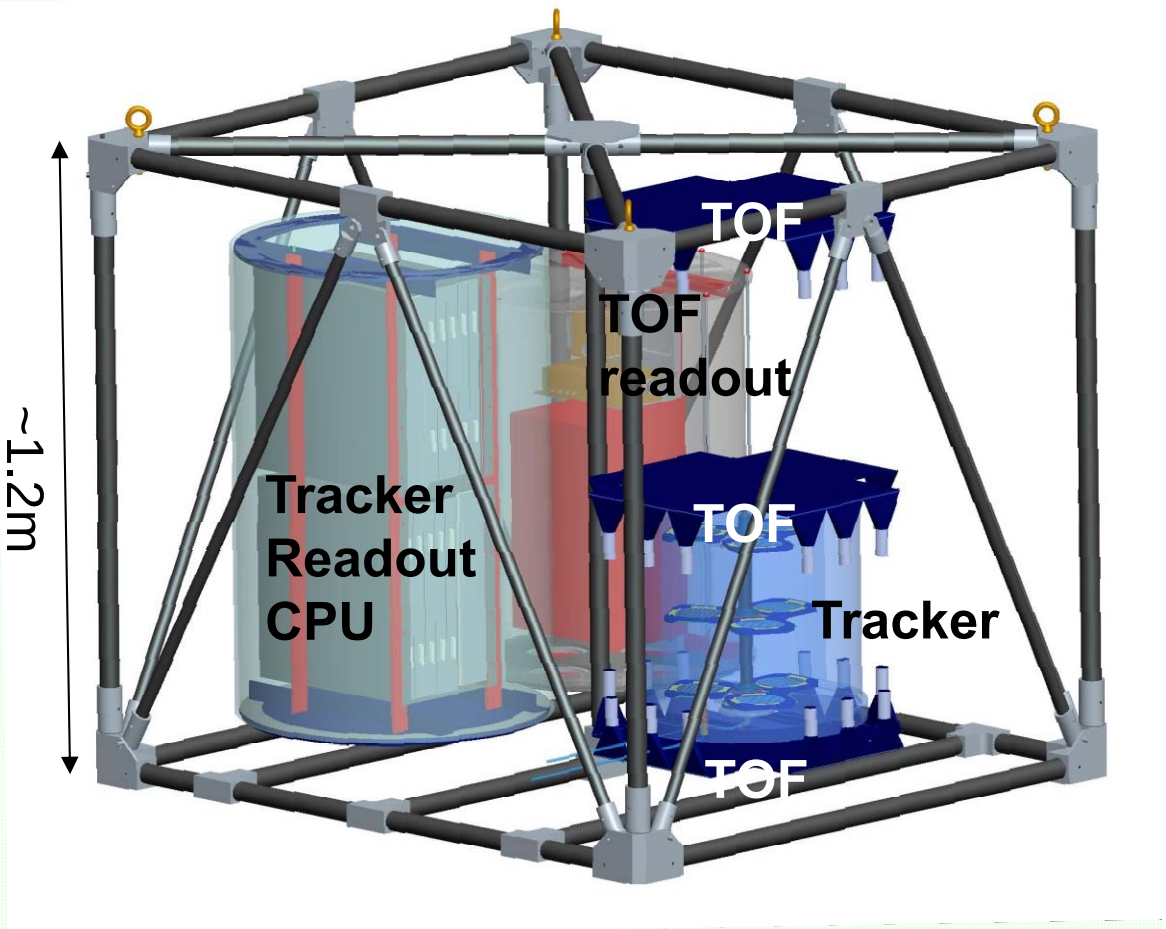
Balloon-borne Experiment with Superconducting Solenoid
(Japan-US Collaboration)

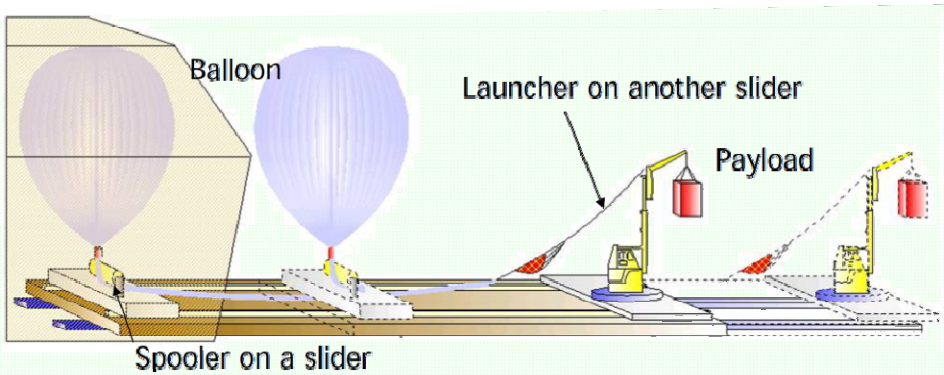



- Series of flights of increasing duration between 1993-2008.
- Large, uniform magnet (1T), precision tracker.
- Best limits on anti-He, anti-D.
  F(anti-D) < $10^{-4}/m^2/s/sr/GeV$
- **Heavy, complex experiment !**



# Prototype Experiment



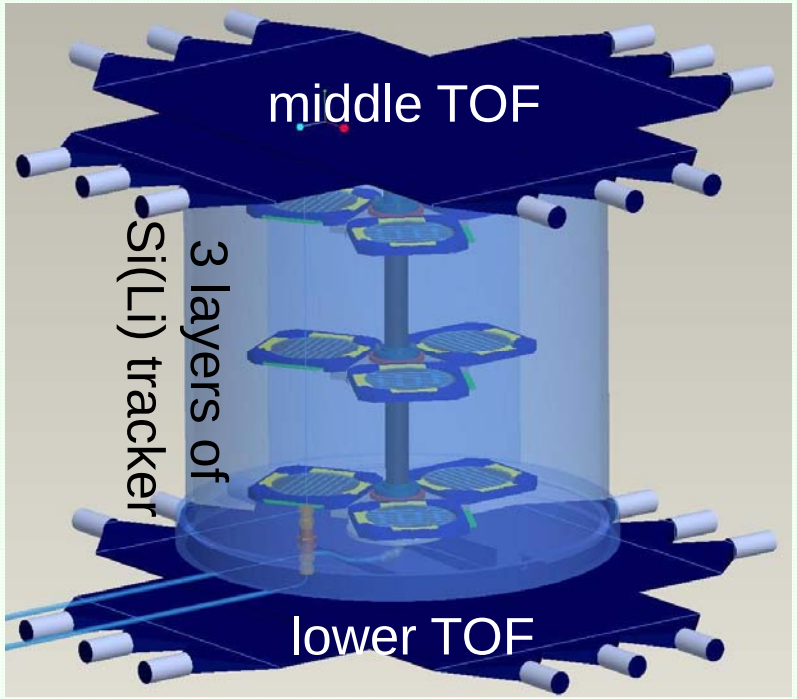



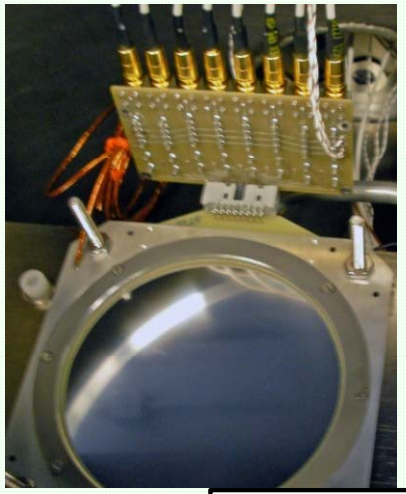

**Prototype GAPS (pGAPS) goals:**

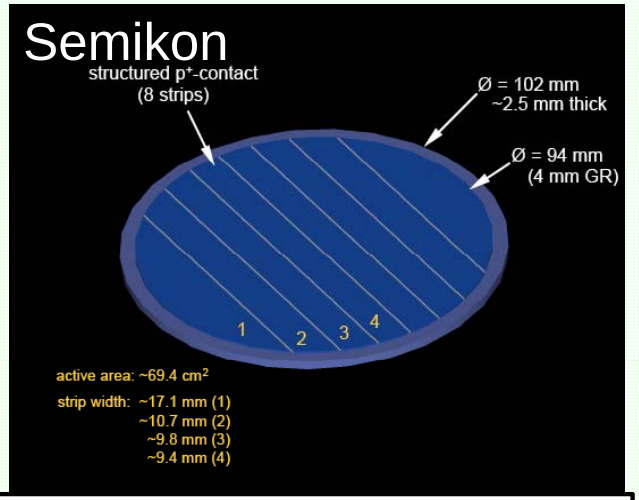
- demonstrate stable, low noise operation of components at float altitude and ambient pressure.
- demonstrate the Si(Li) cooling approach and verify thermal model.
- measure incoherent background level in a flight-like configuration.

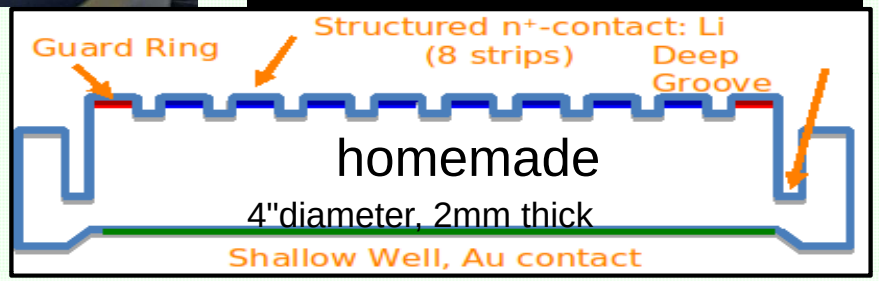
**Would fly from Taiki, Japan**

# pGAPS Si(Li) Tracker

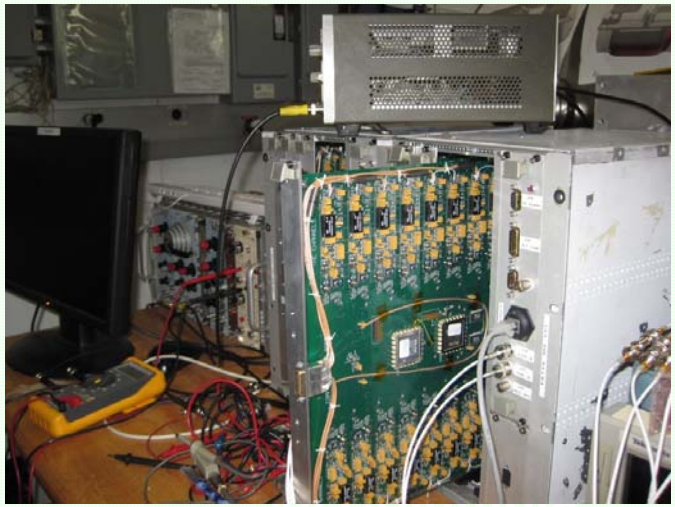




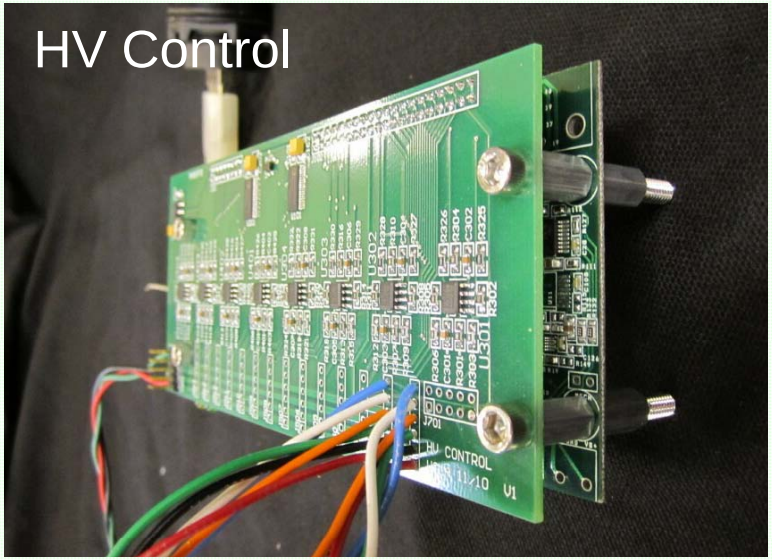



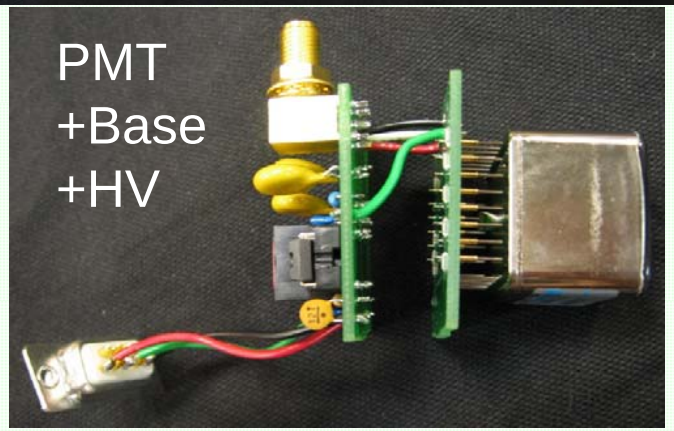

- 6 commercial Semikon detectors.
- Homemade detectors (test for bGAPS fabrication).
- Energy resolution **< 3 keV @ 60 keV**.
- Operation at ambient pressure. (8mbar).
- Readout using proven system (NCT electronics).

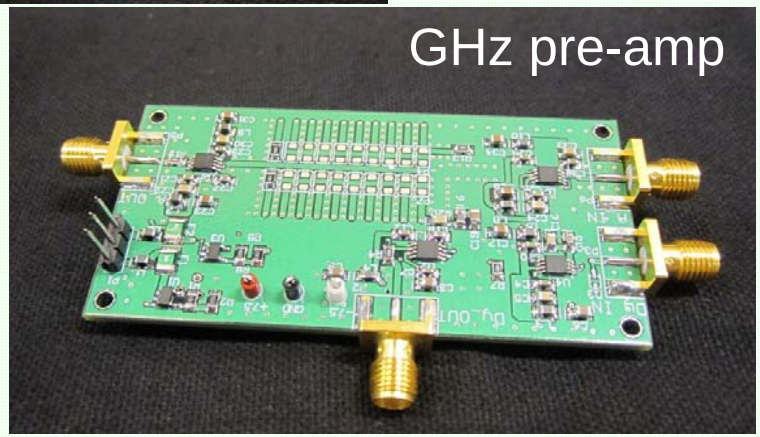


Readout Electronics

# pGAPS Time-of-Flight System






- 3 planes of TOF
  1 plane = 3×3 crossed paddles
- 3mm scintillator (EJ-200, BC-408)
- Hamamatsu R-7600 PMT (UBA)
- timing resolution: **< 400 ps**
- charge resolution: **< 0.30 e**
- angular resolution: **8°**