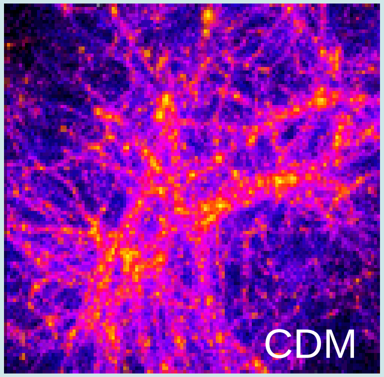
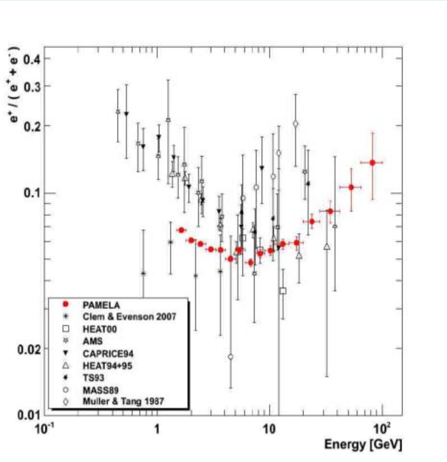
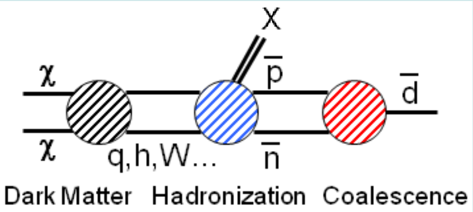
GAPS: An Indirect DM Search Using Anti-Deuterons

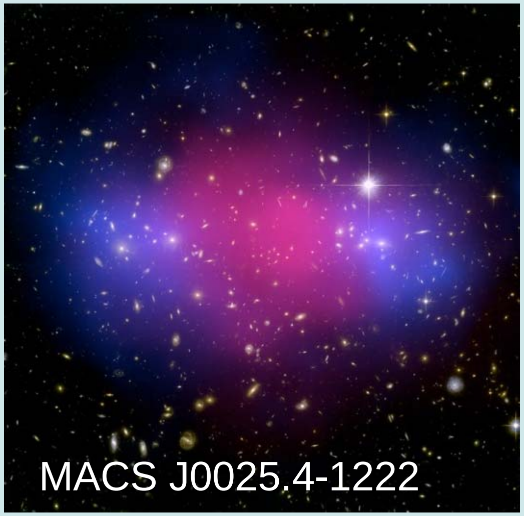


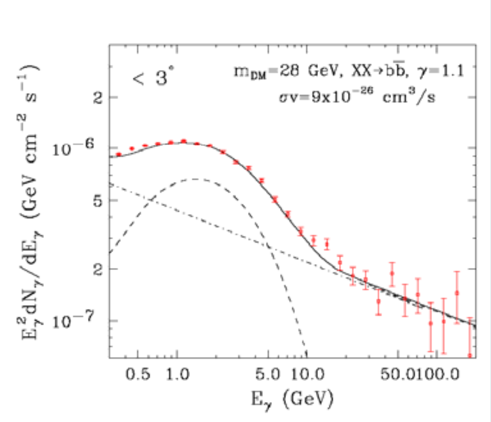


positrons ?

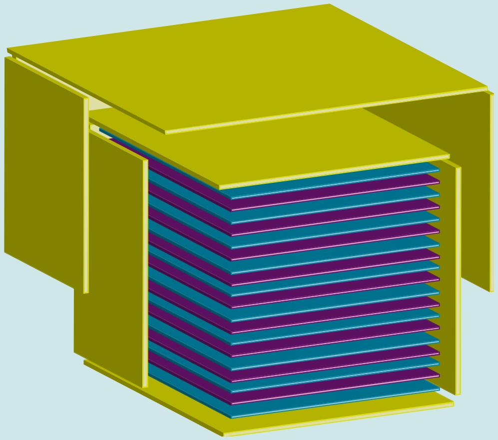
anti-deuterons ?







γ–rays?



GAPS

Rene A. Ong
(UCLA / LLR-Ecole Polytechnique)

TeVPA 2011

01 August 2011

Outline

- Astrophysical particle DM and indirect detection.
- Searching for the **anti-deuteron** – the *why* and *how*.
- **GAPS:**
  An anti-deuteron search using a novel technique.
  - GAPS technique.
  - Sensitivity reach and uncertainties.
  - Current status and future prospects.

Scientific Motivation

- DM postulated as early as the 1930's.
  Gravitational evidence strengthened considerably over time.

- Cosmology tells us that DM is <u>non-baryonic</u> and is <u>not hot</u>.

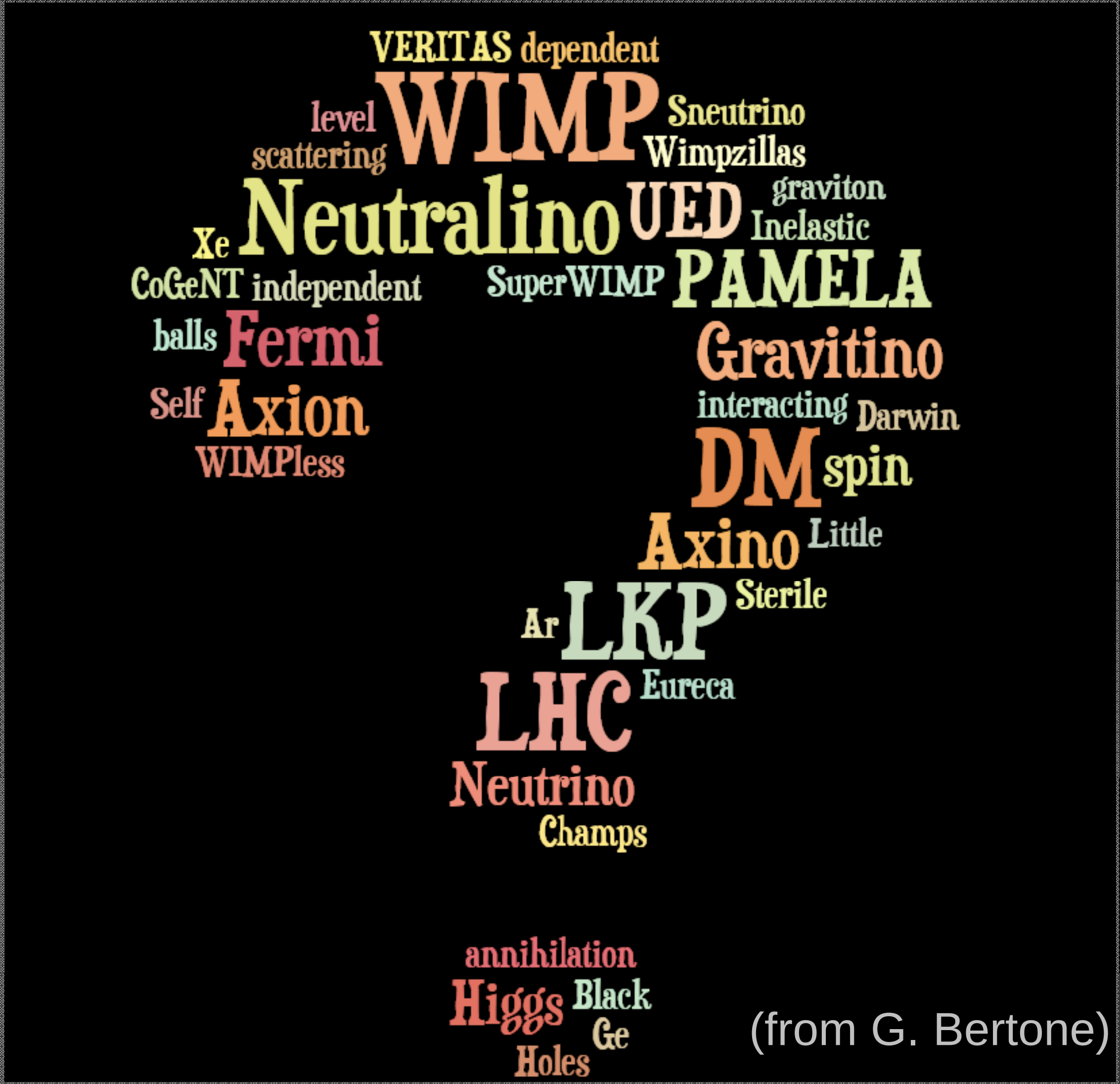
- Among CDM possibilities, **WIMP** is particularly attractive:
  Relic density consistent with weak-scale particle and new
  interactions at weak-scale can explain EWSB.

- There has been an <u>enormous</u> amount of theoretical activity
  for possible WIMP candidates and ways to detect them.

- A "**Grand Search for DM**" is now underway.

However, after all these years …

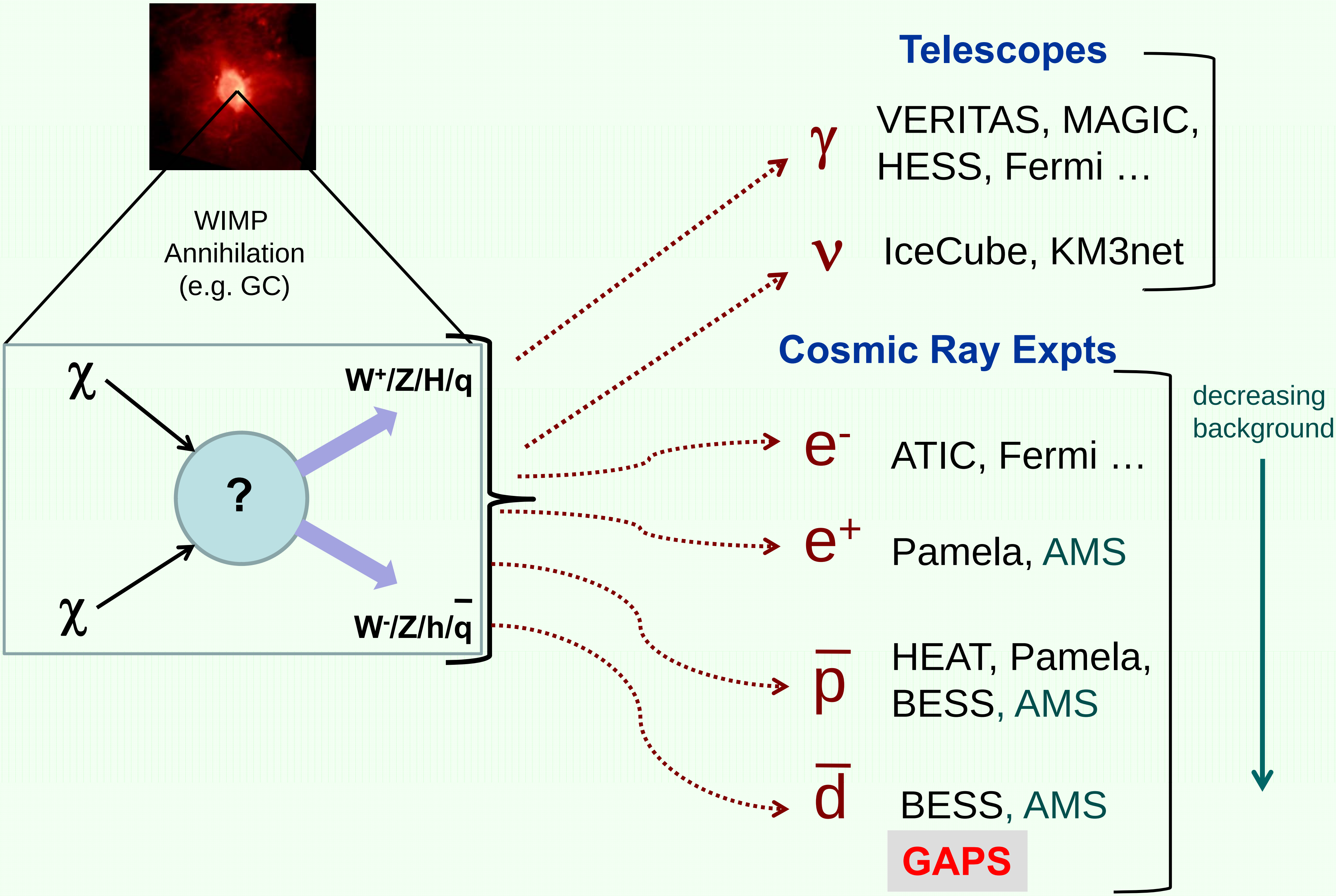
… actually, we have no idea !



(from G. Bertone)

… and we really need to search for DM particles using any (all) possible techniques.

Indirect Detection



Summary of cosmic-ray probes

Particle	Kinematic Range	Experimental Challenges	Backgrounds
e^-	> 100 GeV	particle ID	e^-'s are ubiquitous in CR's !
e^+	> 20 GeV	p background	local sources secondary production
$\bar{p}$	> 20 GeV	large aperture	secondary production
$\bar{d}$	**< 1 GeV**	**low flux**	**v. small background**

The unique possibilities of anti-deuterons as a background-free probe of new physics → a big interest from theoretical community, e.g.:

F. Donato, N. Fornengo & P. Salati, Phys. Rev. **62**, 043003 (2000)
J. Edsjo et al, JCAP Phys. **09**, 004 (2004)
H. Baer & S. Profumo, Astroparticle Phys. **12**, 008 (2005)
F. Donato, N. Fornengo, & D. Maurin, Phys. Rev. D **78**, 043506 (2008)
M. Kadastik et al, arXiv:0908.157 (2009)
C. Brauninger & M. Cirelli, arXiv:0904.1165 (2009)
Y. Cui, J. Mason, & L. Randall, arXiv:1006.0983 (2010)
… and many more (apologies if your paper is not here!).

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):

$\chi\,\chi \rightarrow \gamma, \bar{p}, \bar{d}$

Secondary Component, includes:

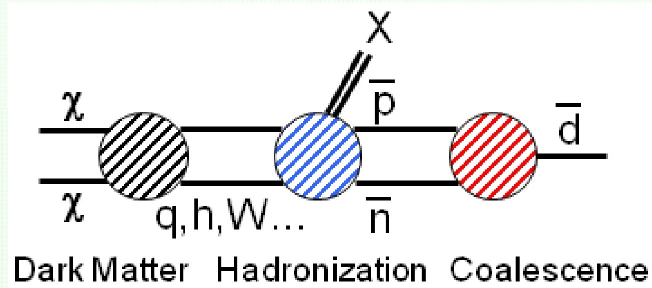
$p\,A \rightarrow \bar{d}\,X$ [via $p(\overline{pn})n$]

where A = p, He

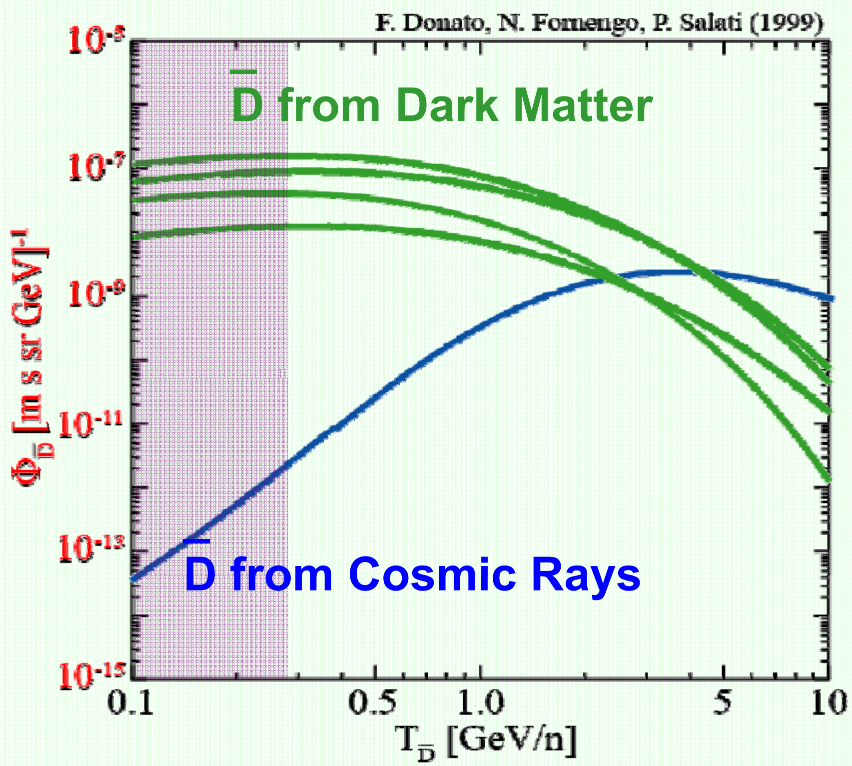
Anti-deuterons provide extremely clean signature, but low fluxes result in a daunting experimental challenge !

New experiment:
General AntiParticle Spectrometer (GAPS)

DM production of $\bar{d}$

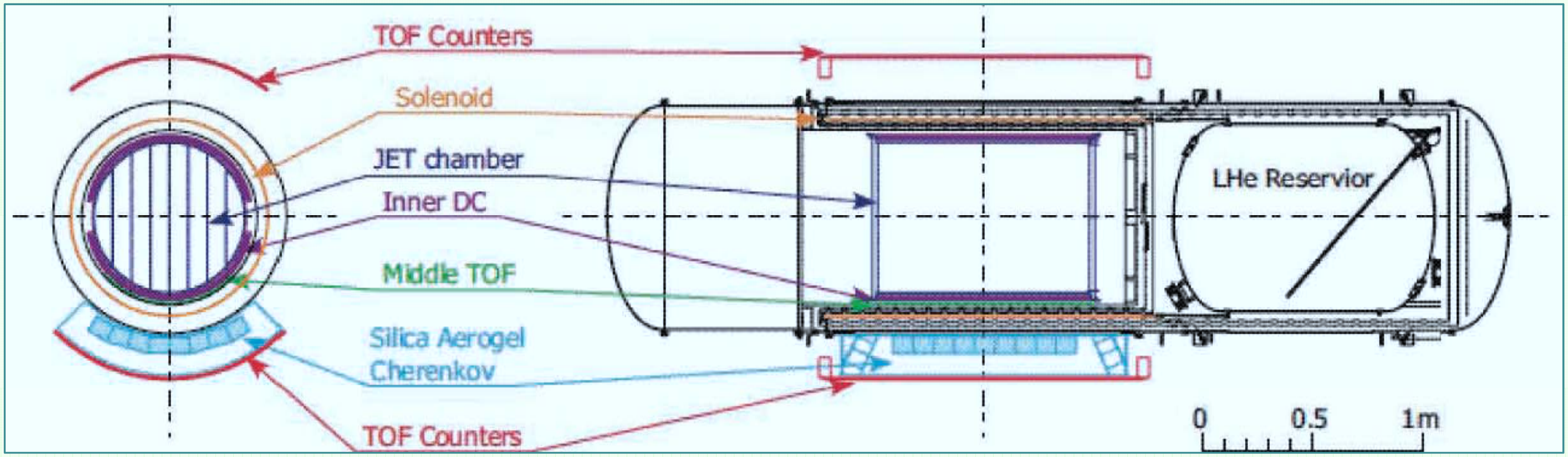


Anti-deuteron flux at the earth (w/propagation and solar modulation)

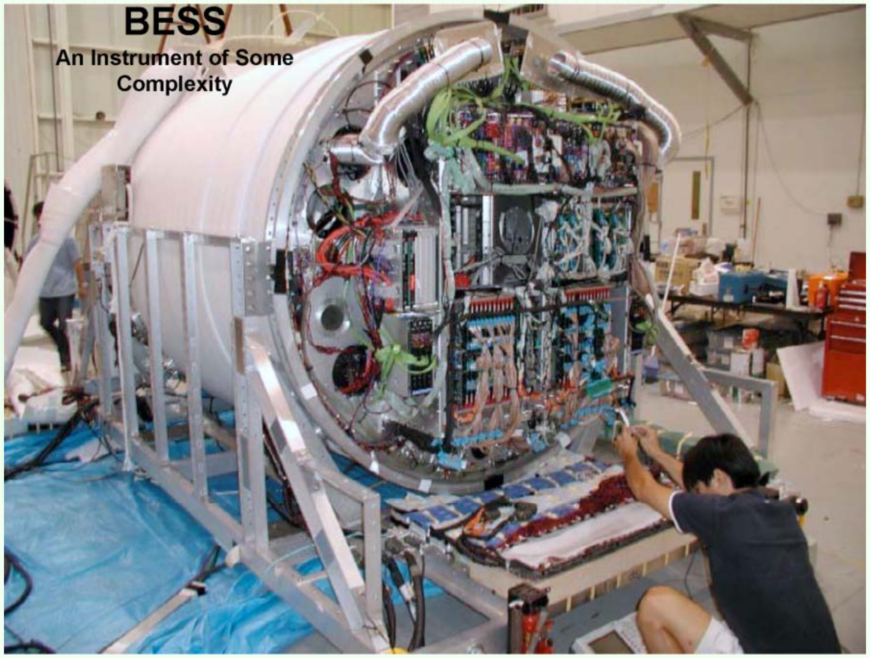


BESS

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 !**



GAPS Collaboration

Columbia University in the City of New York

Berkeley University of California

UCLA

JAXA Japan Aerospace Exploration Agency

LLNL

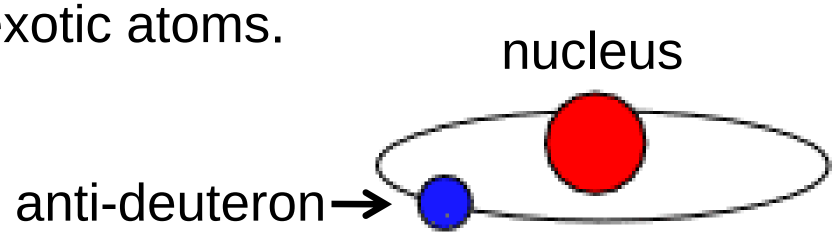
Collaboration meeting, UCB (2010)

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

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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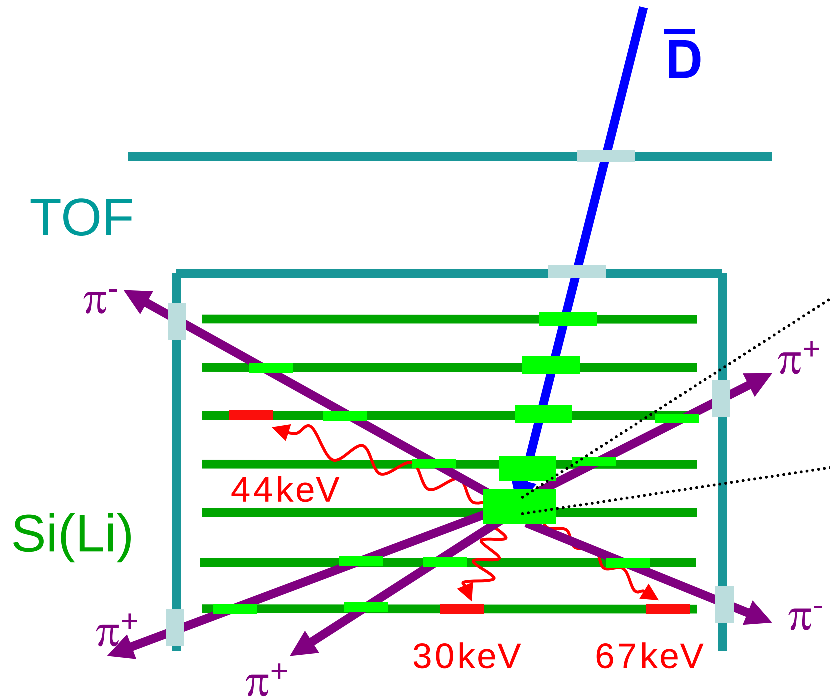
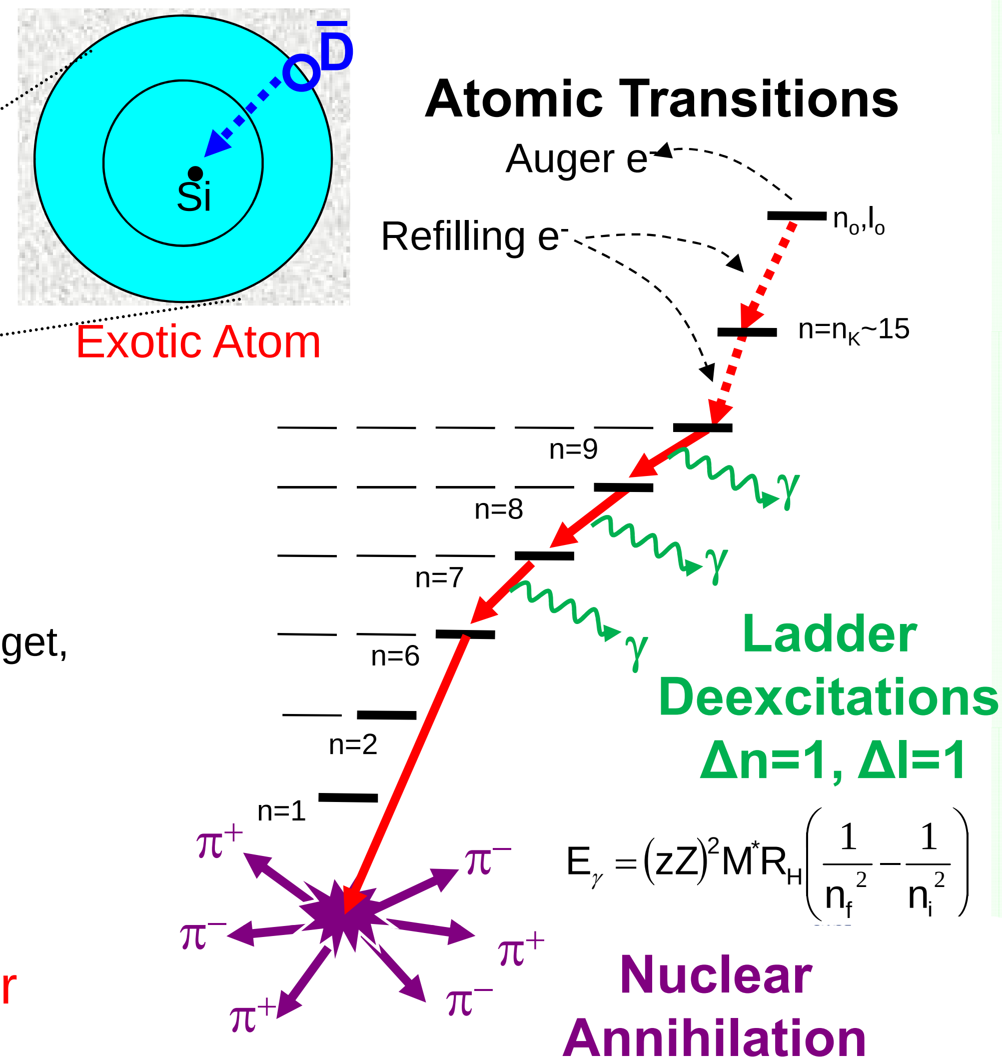
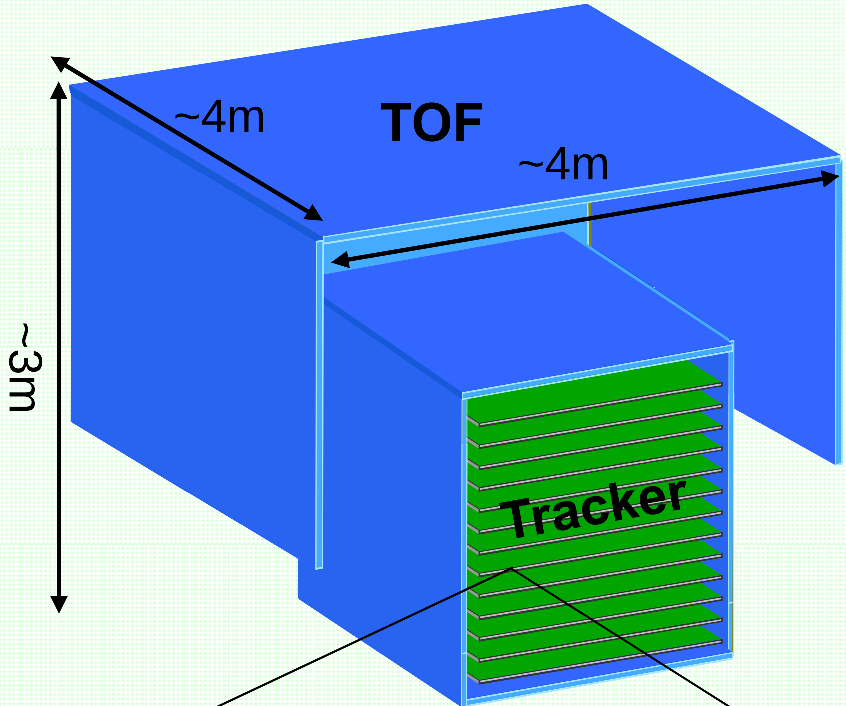


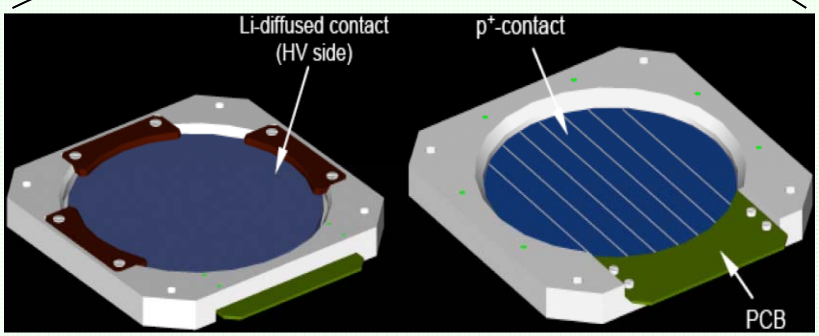


1. Once $\bar{D}$ is slowed down and stopped in the target,
2. an excited exotic atom is formed,
3. which deexcites with emitting X-rays,
4. and annihilates with producing a pion shower.

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

GAPS Concept





GAPS consists of two detectors (acceptance ~2.7 m^{2}sr):

Si(Li) Detector (target and tracker):

- Si(Li) tracker:13 layers of Si(Li) wafers
- relatively low Z material
- good X-ray resolution
- circular modules segmented into 8 strips
  → 3D particle tracking
- 270 per layer (total: ~3500)
- timing: ~50 ns
- dual channel electronics
  5-200 keV: X-rays (resolution:~2 keV)
  0.1-200 MeV: charged particle

TOF and Anticoincidence Shield:

- plastic scintillator with PMTs surrounds tracker
- track charged particles, dE/dX
- velocity measurement
- anticoincidence for charged particles

Main Challenges for GAPS

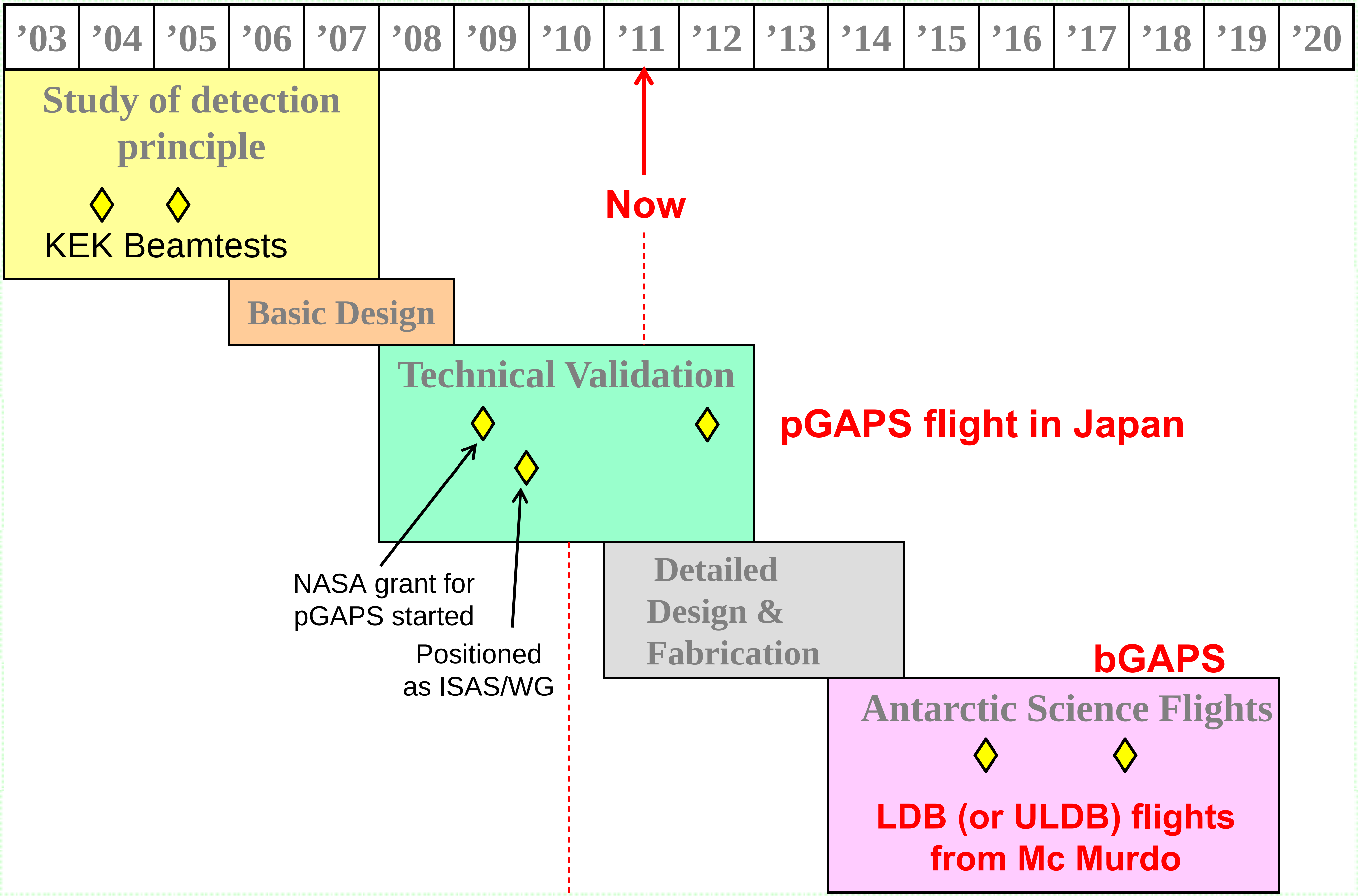
- Basic detection technique has been established, but the difficulty is to translate to a full-scale instrument.
  - Large scale Si(Li) production at reasonable cost.
  - Building a hermetic detector (i.e. no cracks, etc.).

- Rare-event detector → backgrounds need to be fully modeled and understood.

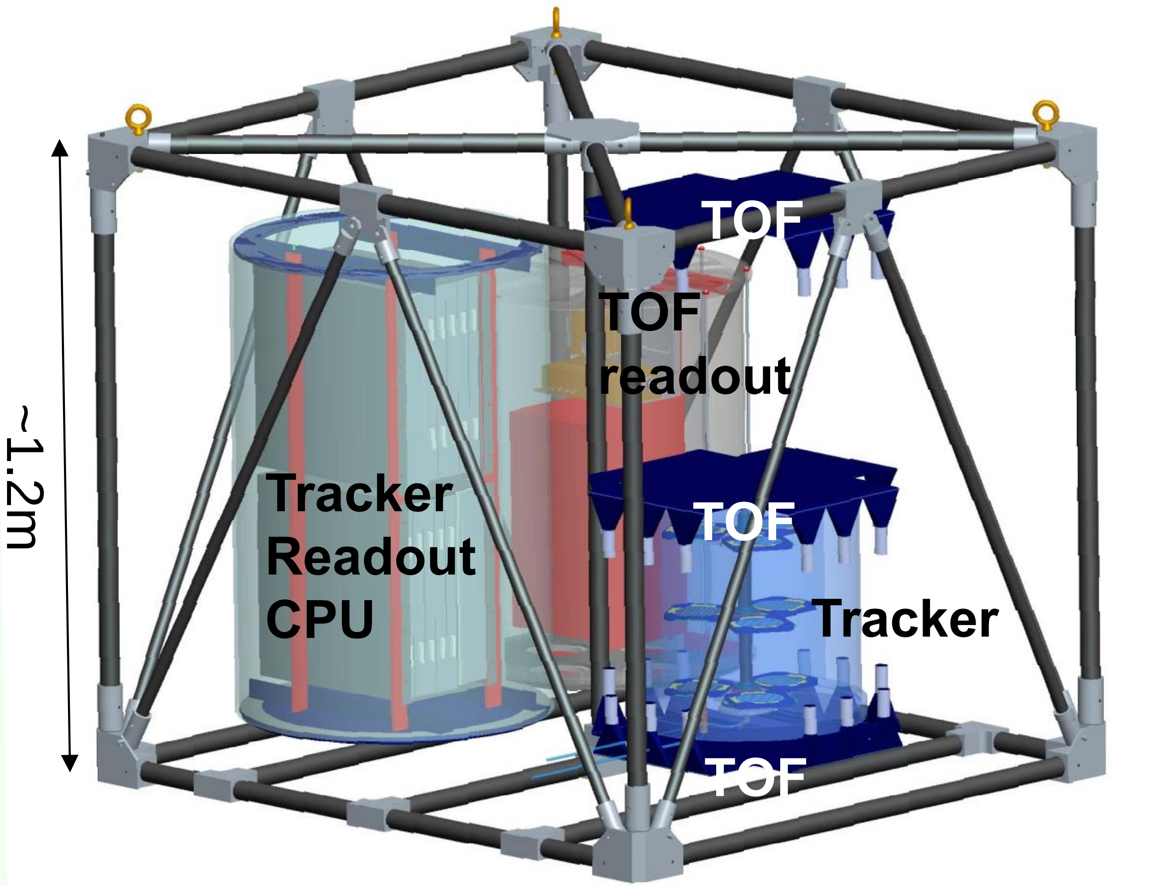
  Important: with GAPS, there are three ways to reject background:
  1. Particle ID: TOF β, TOF veto, dE/dX & depth
  2. X-rays
  3. Pion track multiplicity

- A prototype / test experiment is essential: pGAPS (2012).

GAPS Timeline

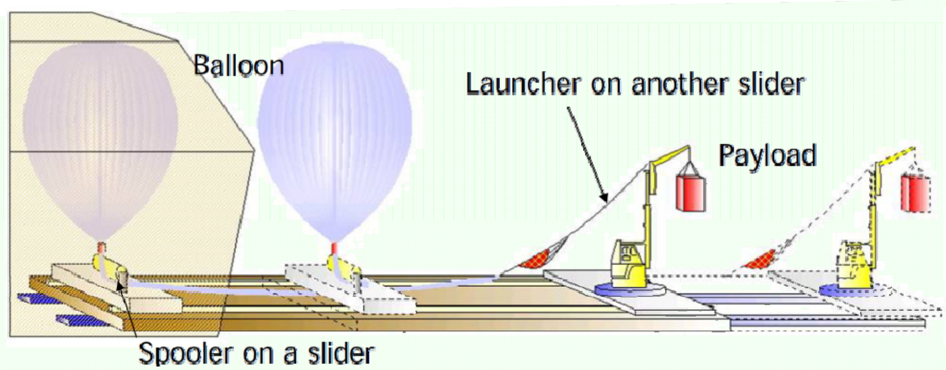


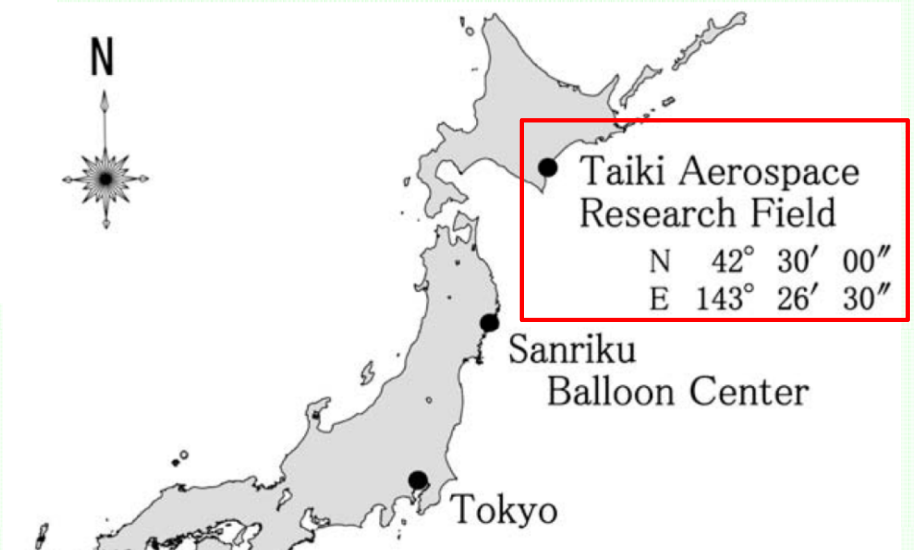
Prototype Experiment



Prototype GAPS (pGAPS) goals:

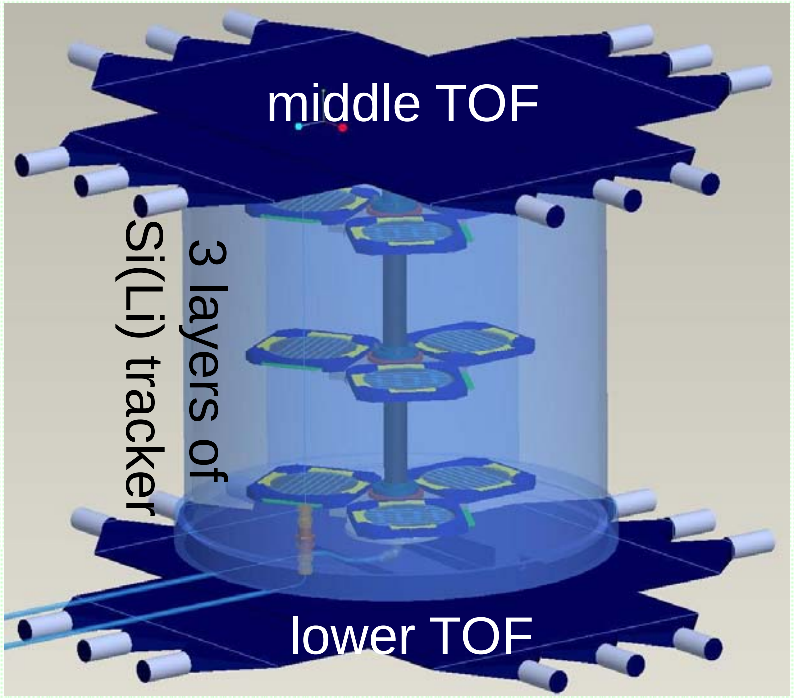
- demonstrate stable, low noise operation of components at float altitude and ambient pressure.
- demonstrate the Si(Li) cooling approach and verify thermal model.
- measure incoherent background level in a flight-like configuration.

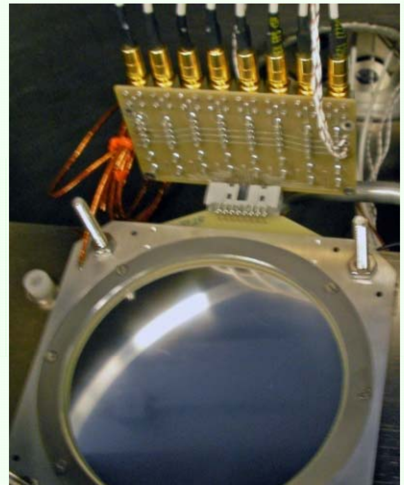


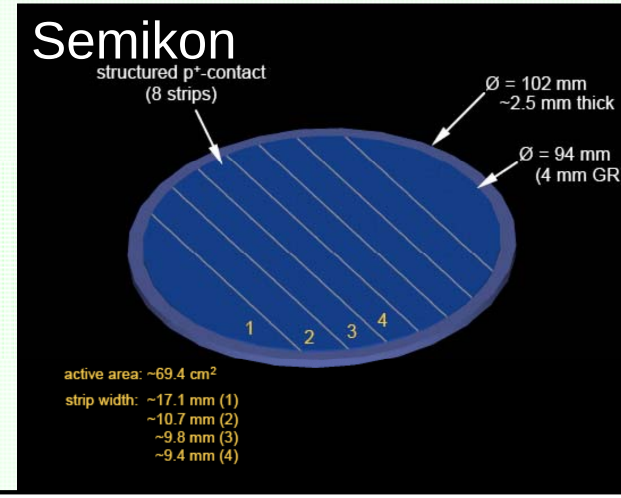


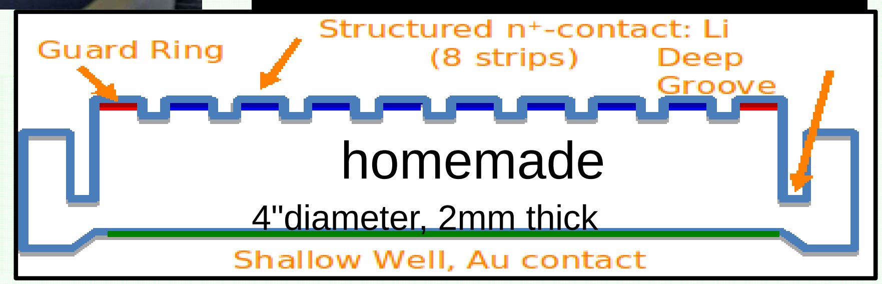
Would fly from Taiki, Japan

pGAPS Si(Li) Tracker

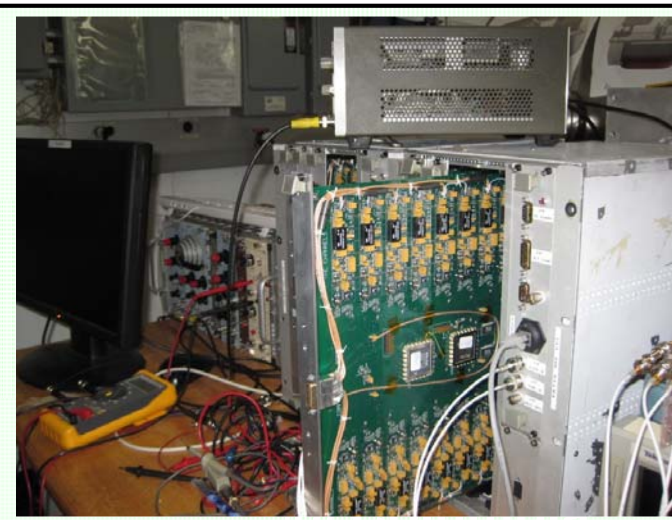






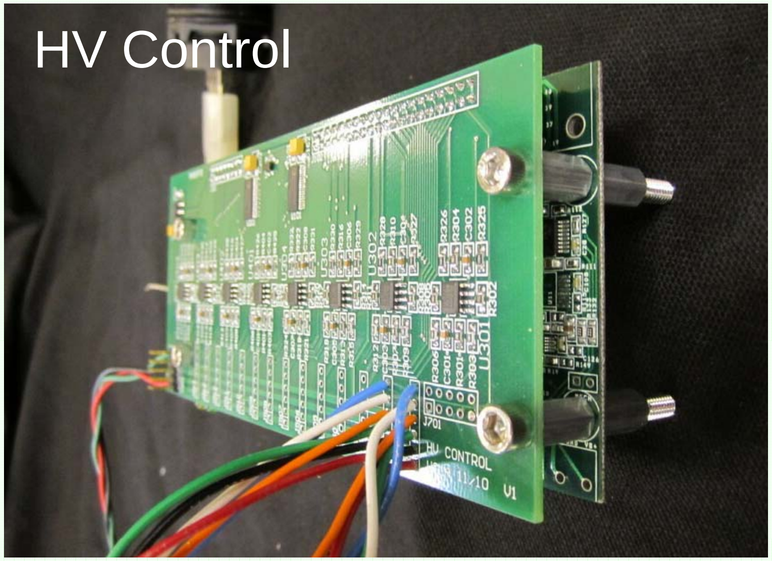


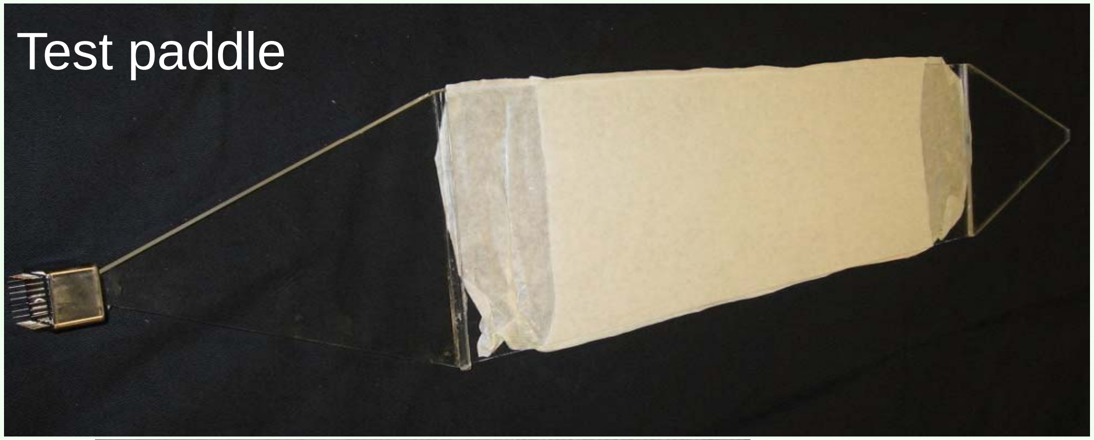
- 6 commercial Semikon detectors.
- Homemade detectors
  (test for bGAPS fabrication).
- Energy resolution **< 3 keV @ 60 keV**.
- Operation at ambient pressure.
  (8mbar).
- Readout using proven system
  (NCT electronics).

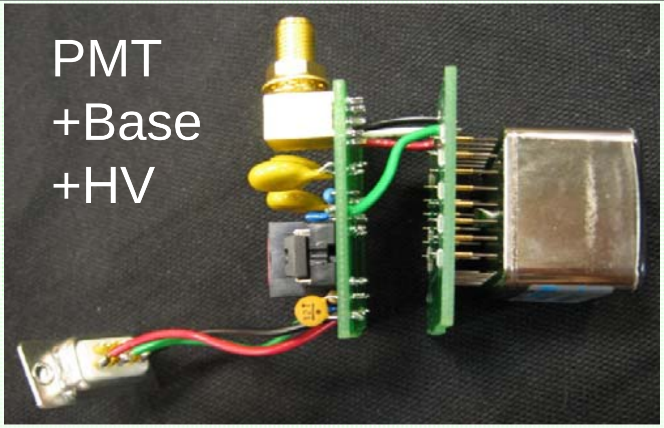


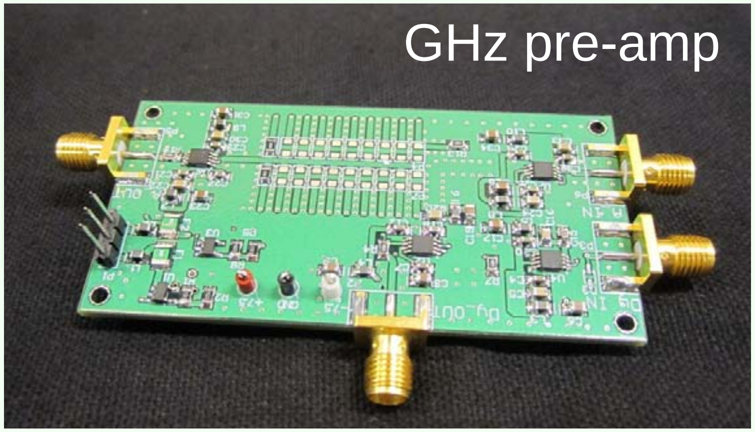
Readout Electronics

pGAPS Time-of-Flight System







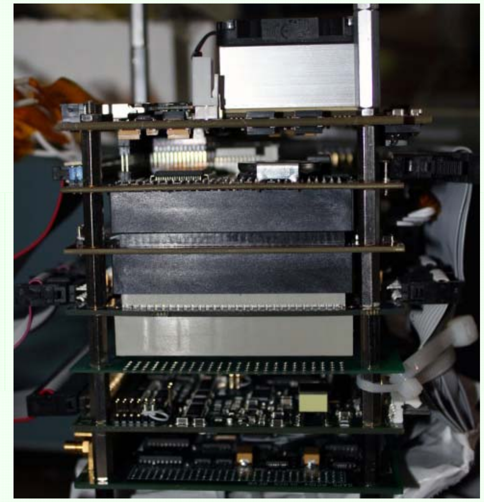


- 3 planes of TOF
  1 plane = 3×3 crossed paddles
- 3mm scintillator (EJ-200, BC-408)
- Hamamatsu R-7600 PMT (UBA)
- timing resolution: **< 400 ps**
- charge resolution: **< 0.30 e**
- angular resolution: **8°**

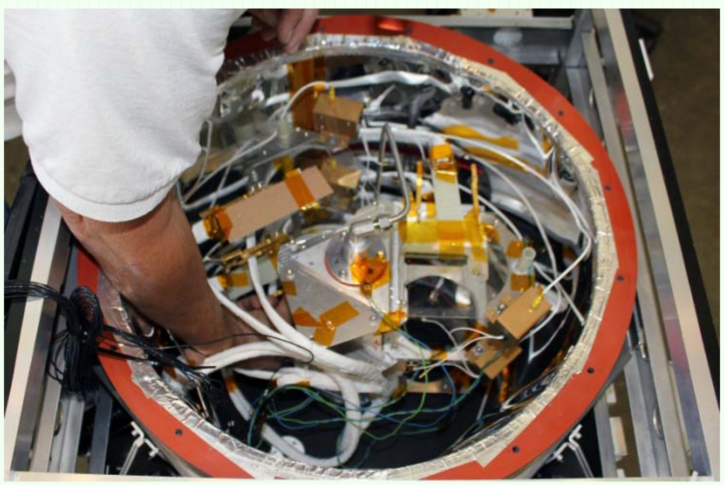
Integration at UCB/SSL (July 2011)

TOF Pre-amp assembly

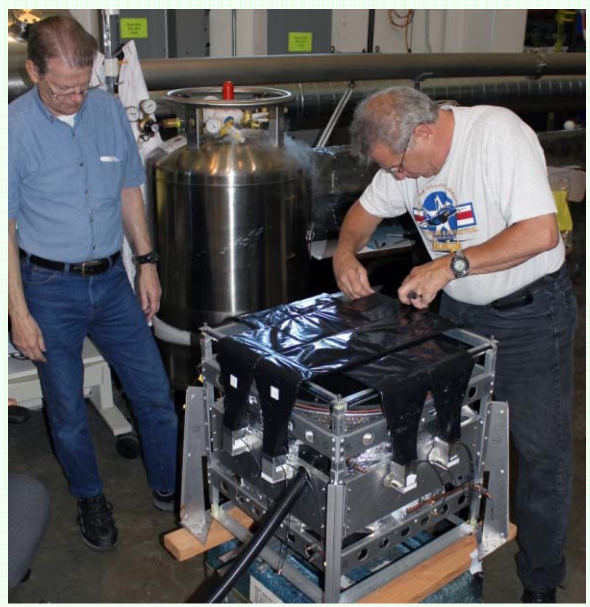
Detector, Si(Li) electronics, and pressure vessels



Flight computer



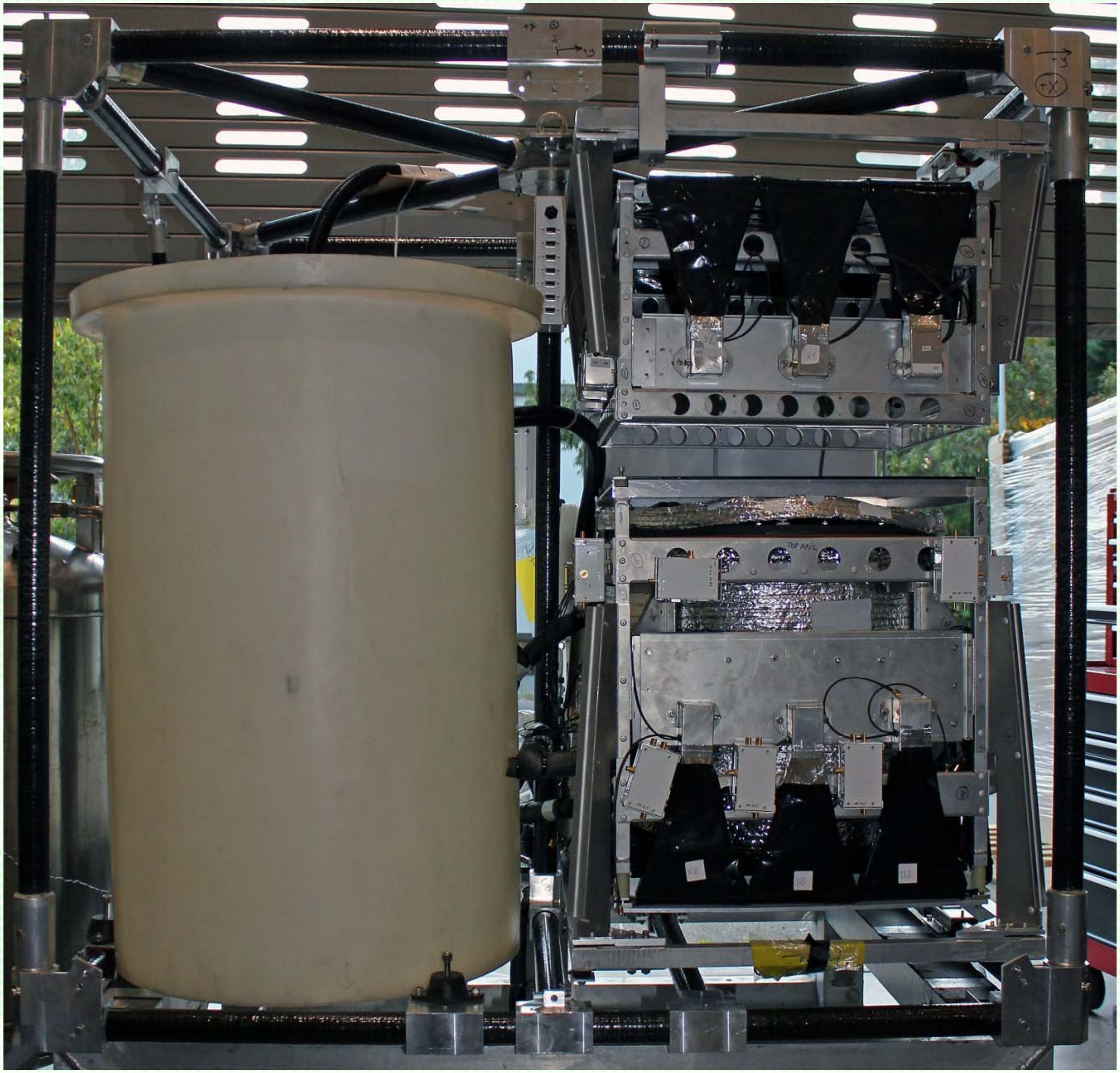
Inside the detector vessel



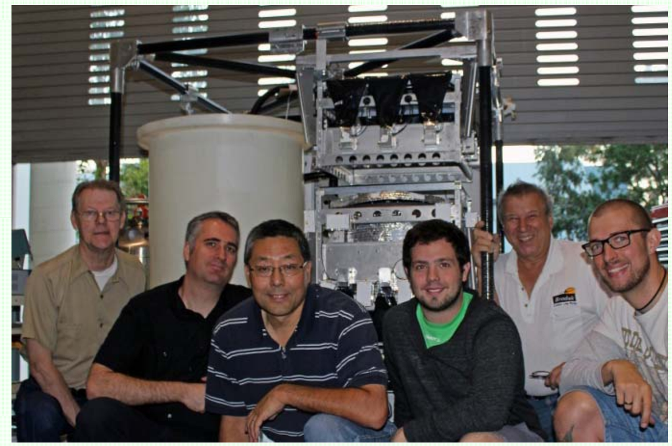
Installing TOF layer

Thermal system

Integration at UCB/SSL (July 2011)



Integrated pGAPS Detector (26 July 2011)



Tired, but happy, team

Status & Future Prospects

GAPS Program:

- Prototype integrated & ready for flight in 2012.
- Proposing LDB instrument (for first flight in several years).
- ULDB (300 day) flights, when available, would greatly improve sensitivity reach.
- (**Possible future satellite instrument**).

AMS now launched, anti-D results perhaps in several years.

What is actual sensitivity of new AMS to anti-D ?

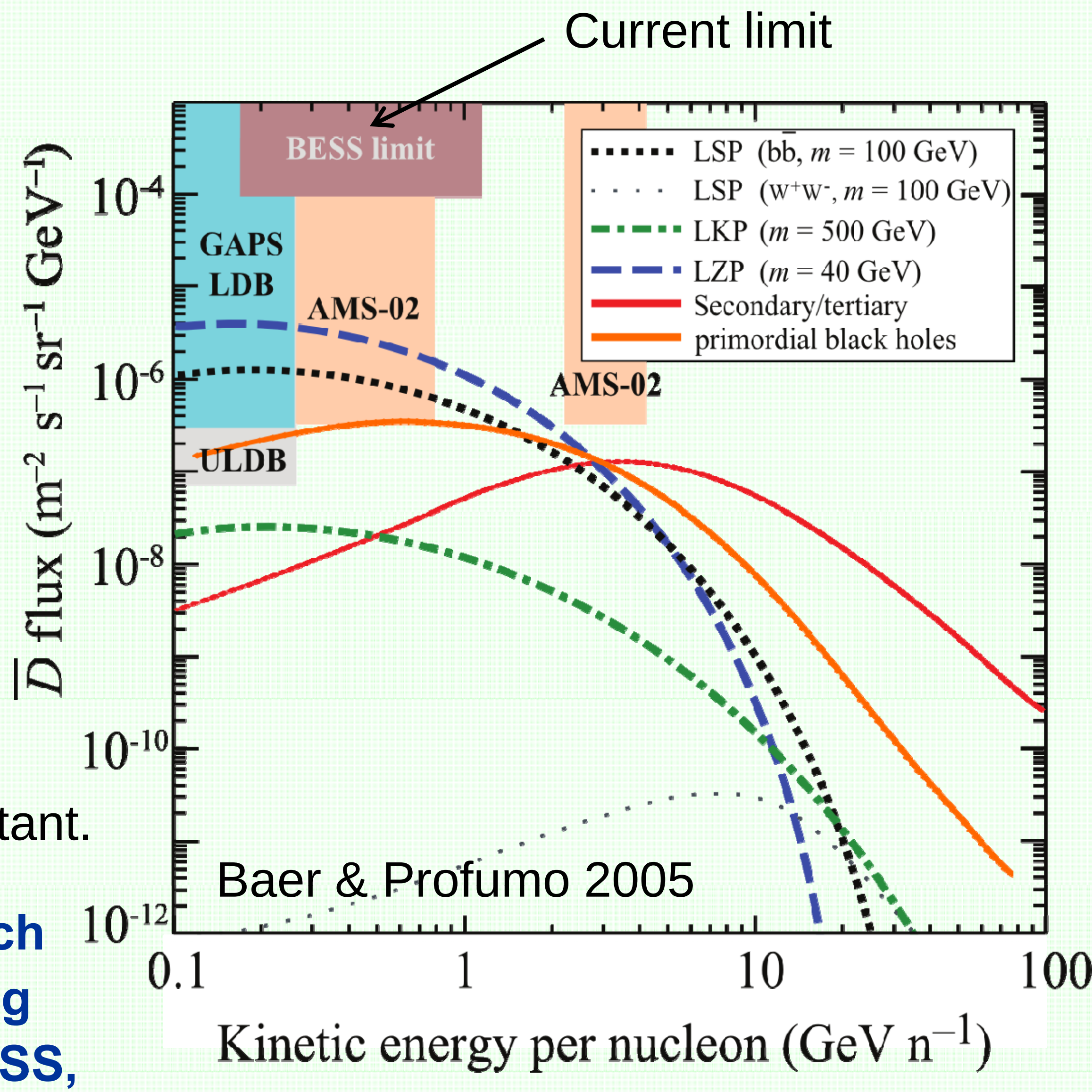
What is effective aperture, including geomagnetic cutoff ?

→ Importance of developing GAPS to flight status:

- Anti-D is a unique probe; currently only two experiments considered for next decade (c.f. ~20 direct detection).
- GAPS is completely complementary to AMS:
  - GAPS uses different technique, has different backgrounds
  - GAPS can be scaled to reach much greater sensitivity.
- Long timetable →essential to start bGAPS development now.

GAPS anti-D Sensitivity Reach

- Cosmic anti-D have never been detected. Could be produced by new physics.
- Primary anti-D production:
  - Supersymmetry (LSP)
  - Kaluza-Klein UED (LKP)
  - Warped ED (LZP)
  - Primordial BH's
- Sub-GeV region essentially background free; the detection of even a single, clean event is important.
- **GAPS will extend sensitivity reach by 2-3 orders of magnitude, using very different technique than BESS, AMS or any previous experiment.**



Uncertainties

There are a number of key uncertainties:

Experimental:

- Instrument aperture:
  detector performance, trigger/recon. strategies, etc.
- Backgrounds (astrophysical, instrumental)

Prototype flight will help understand these items.

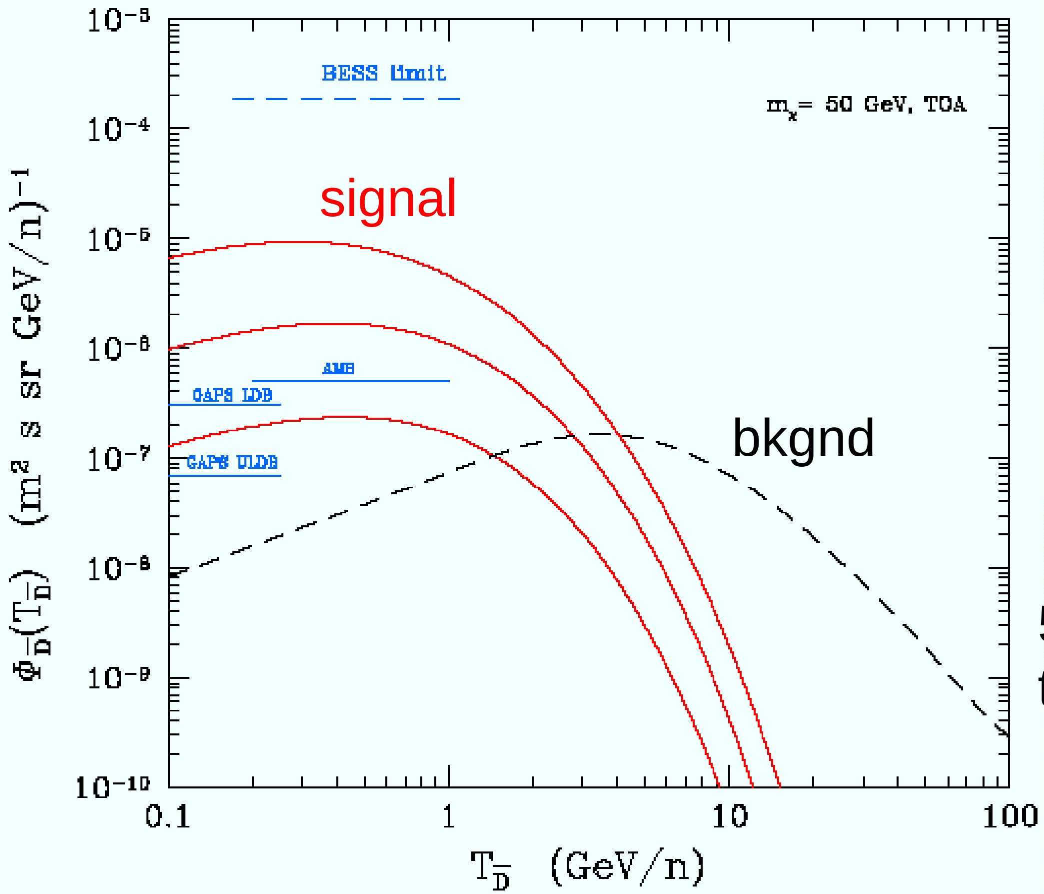
Theoretical (model) expectations:

- DM density: DM halo model.
- Production of anti-D (coalescence of anti-baryons).
- **Propagation in MW.**
- Solar modulation.

Propagation appears to give the largest overall uncertainty;
Uncertainty larger in primary signal than in secondary background.

Overall S/N: A recent calculation

Donato, Fornengo & Maurin 2008



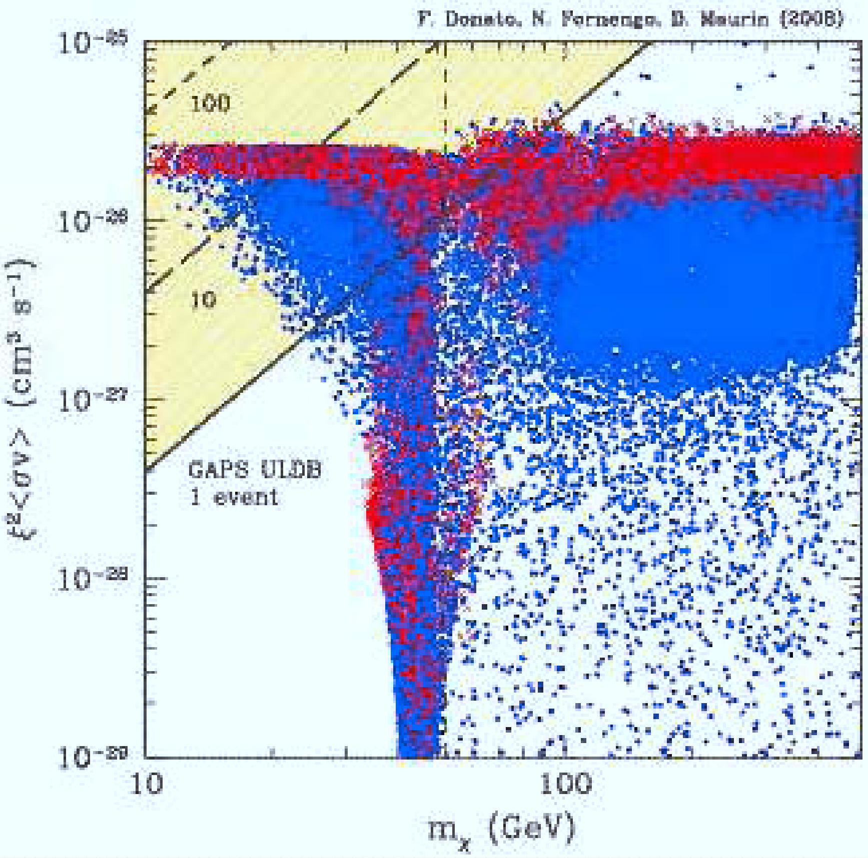
50 GeV WIMP
three propagation models

- Some uncertainty in background, but background only matters for ULDB.
- Dominant uncertainty relates to signal estimate, coming from propagation
  → will PAMELA (AMS) results help with this?
- **GAPS will provide a major improvement over earlier measurements.**

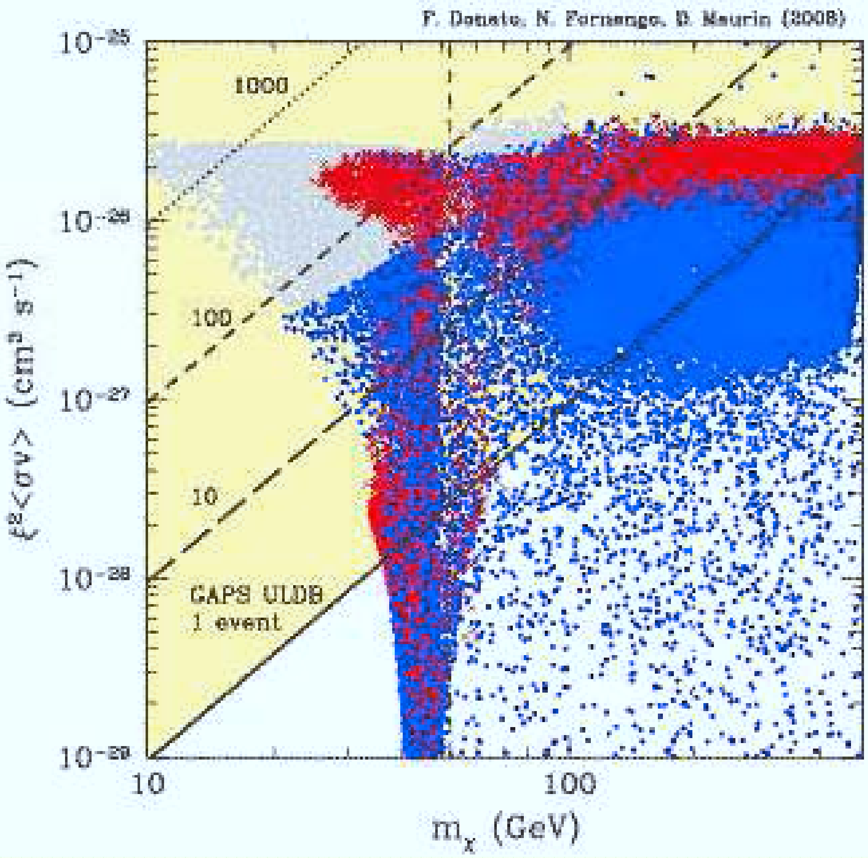
New Physics Reach

Donato, Fornengo & Maurin 2008

“Minimal” signal case



“Maximal” signal case



GAPS will explore a substantial fraction of the allowed parameter space. Reach is complementary to direct-detection experiments.

GAPS Summary

- **Particle DM has strong motivation** from astrophysics & particle physics.
- **Indirect detection is promising**; it is able to test the particle hypothesis and complementary to direct detection, LHC.
- Anti-deuterons are a unique probe of DM, **but as interesting is the question of whether they even exist in the cosmic rays.**
- GAPS is a new balloon instrument using the exotic atom technique to search for anti-deuterons.

  Prototype flight scheduled for 2012.

  LDB instrument would:

  - give 3 orders of mag. improvement over previous expts.
  - cover a large amount of NP parameter space
  - provide different capabilities than AMS

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