Antideuterons as an Indirect Dark Matter Signature: Design and Preparation for a Balloon-born GAPS Experiment

Jason Koglin
Columbia Astrophysics Laboratory
For the GAPS Collaboration

The General Antiparticle Spectrometer (GAPS) exploits low energy antideuterons produced in neutralino-neutralino annihilations as an indirect dark matter (DM) signature that is effectively free from background. When an antiparticle is captured by a target material, it forms exotic atom in an excited state which quickly decays by emitting X-rays of precisely defined energy and a correlated pion signature from nuclear annihilation. The GAPS method of using this combined X-ray and pion signature to uniquely identify antiparticles has been verified through accelerator testing of a prototype detector. I will describe the design of a balloon-born GAPS experiment that complements existing and planned direct DM searches as well as other indirect techniques, probing a different, and often unique, region of parameter space in a variety of proposed DM models. I will also outline the steps that we are taking to build a GAPS instrument and execute multiple long duration balloon flights.

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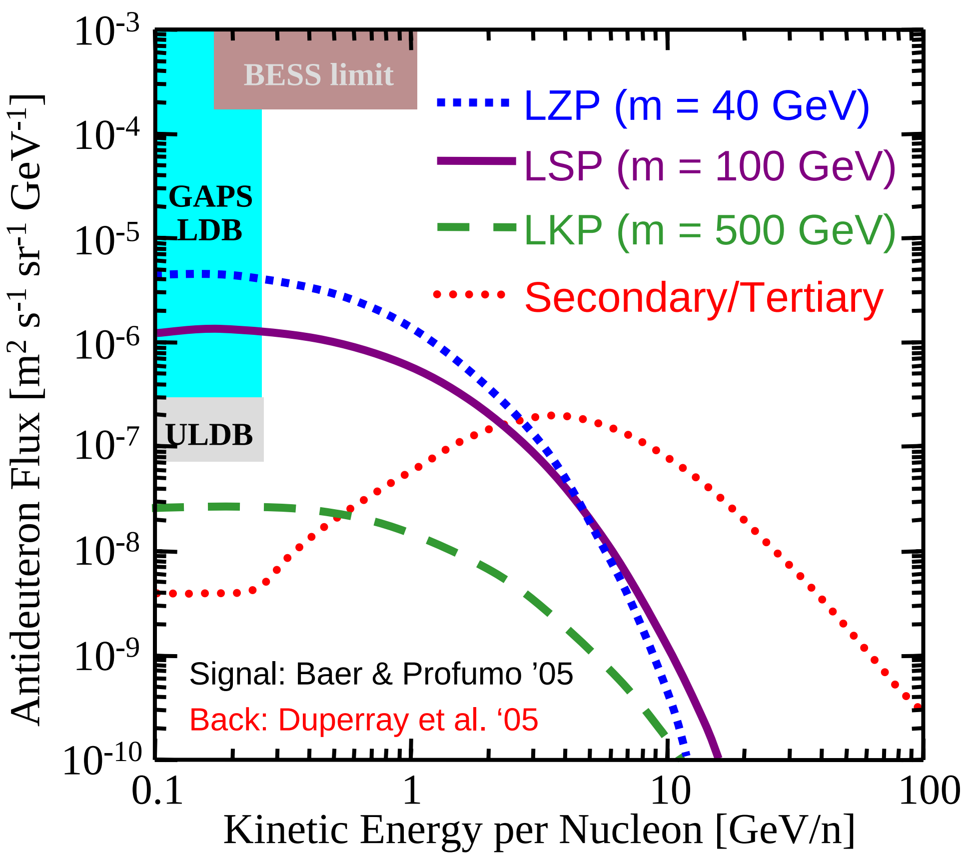
Low energy, neutralino-neutralino produced antideuterons are near background free

Significant antideuteron flux at the earth (with propagation & solar modulation) first pointed out by Donato et al. 2000



- Primary component:
  → neutralino annihilation
  $X+X \rightarrow \bar{D} + \ldots$
- Secondary component:
  → spallation
  $p+H \rightarrow p+H+\bar{D}+\ldots$
  $p+He \rightarrow p+He+\bar{D}+\ldots$
- GAPS is essentially a background free experiment
- GAPS represents a major improvement over the state of the art
- GAPS has outstanding discovery potential for a variety of DM models

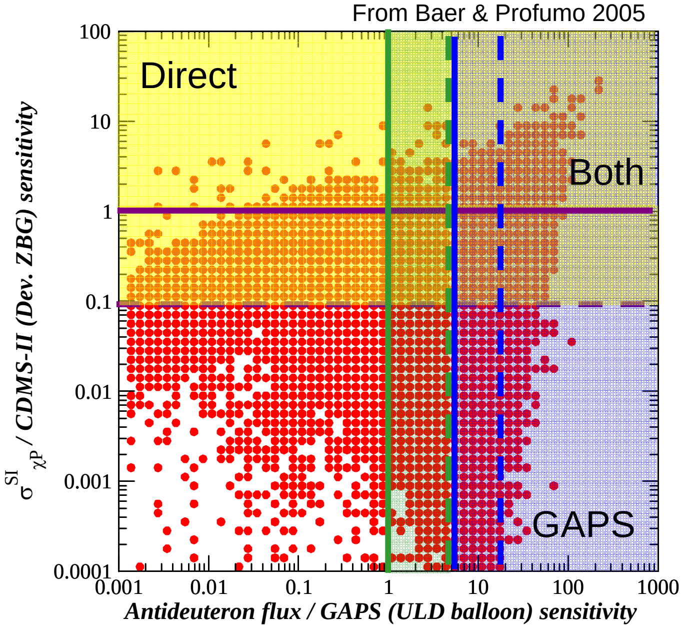
SUSY discovery potential for an antideuteron experiment is similar to direct detection methods

There are over 20 current or planned direct detection experiments to probe SUSY DM

A balloon GAPS antideuteron search offers SUSY parameter space complementarity to direct detection, underground searches

	LDB	ULDB
Exploratory	solid blue line	solid green line
Discovery	dashed blue line	dashed green line

From Baer & Profumo 2005

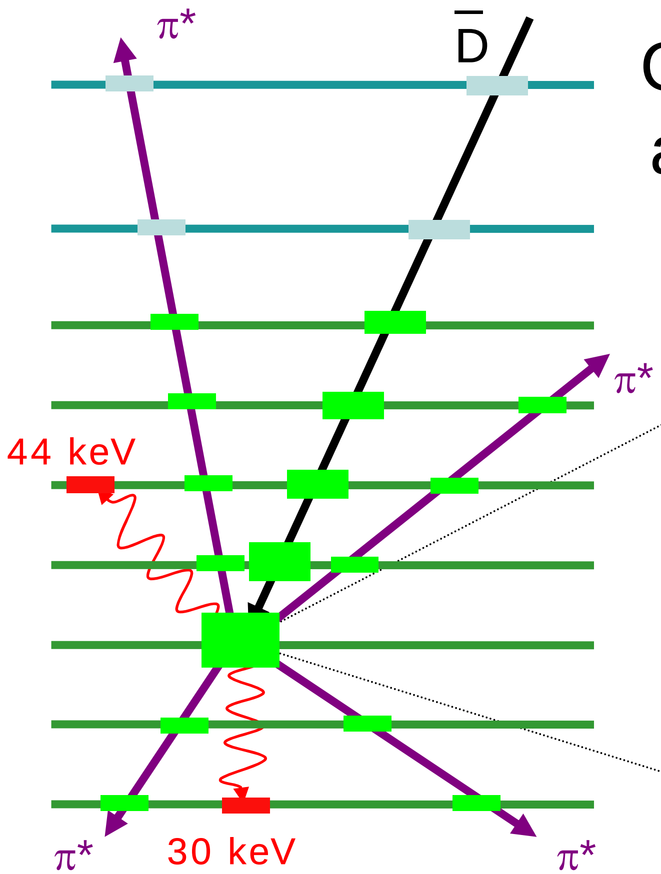


Note: DM theory has an approximate symmetry:

N(experiments) ≈ N(theories)

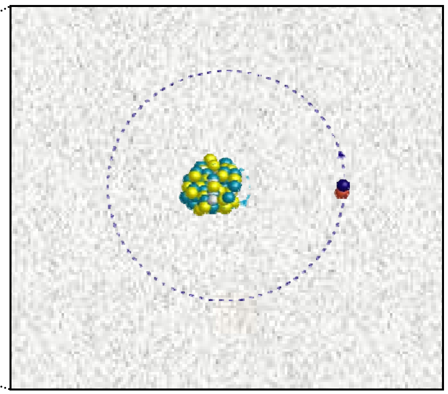
Experiments	Theories
ANAIS	4th generation heavy neutrino
ArDM	Axinos
CDMSII	Axions
CUORICINO	Bino
COSME	Brane world DM
CRESST	CHAMPS
DAMA	Cryptons
DMRC	D-matter
DRIFT	Gravitinos
ELEGANT V	Kaluza-Klein
EDELWEISS	Higgsino
EURECA	Light scalars
GEDEON	Minimal DM
GENIUS	Mirror particles
Genino	Neutralinos
GERDA	New symmetry little Higgs
HDMS	Q-balls
IGEX	Photino
LIBRA	Self-interacting DM
NAIAD	Simpzillas
PICASSO	SM neutrinos
SIMPLE	Sneutrinos
SuperCDMS	Sterile neutrinos
SuperK	SWIMPS
WARP	Theory space little Higgs
XENON	Wimpzillas
ZEPLIN	Wino

GAPS is based on radiative emission of antiparticles captured into exotic atoms



Plastic Scintillator TOF

Si(Li) Target/Detector



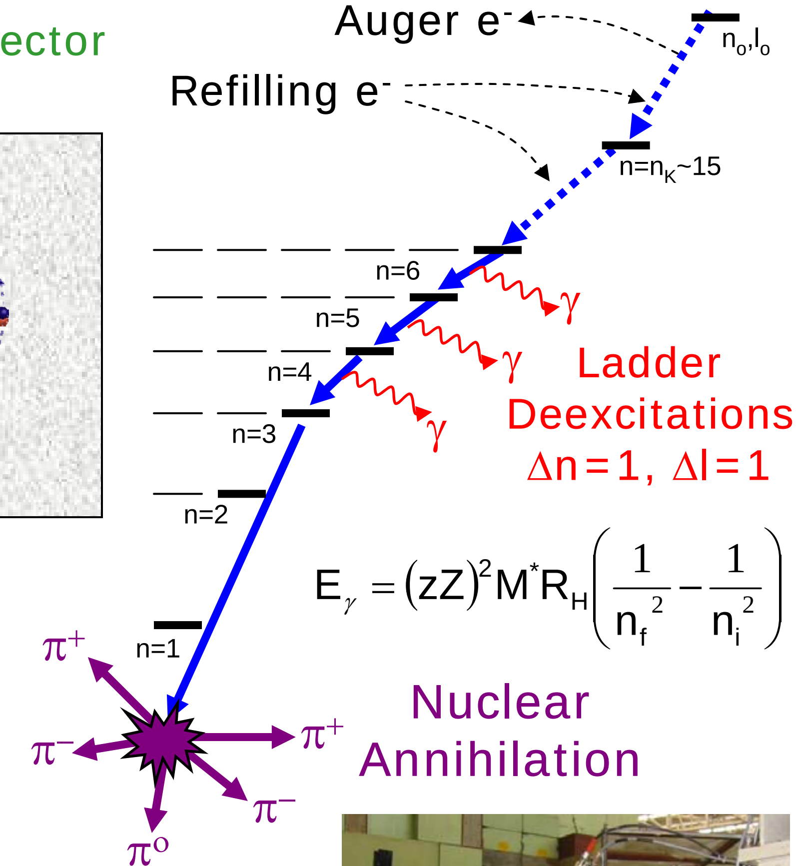
A time of flight (TOF) system tags candidate events and records velocity

The antiparticle slows down & stops in a target material, forming an excited exotic atom with near unity probability

Deexcitation X-rays provide signature

Pions from annihilation provide added background suppression

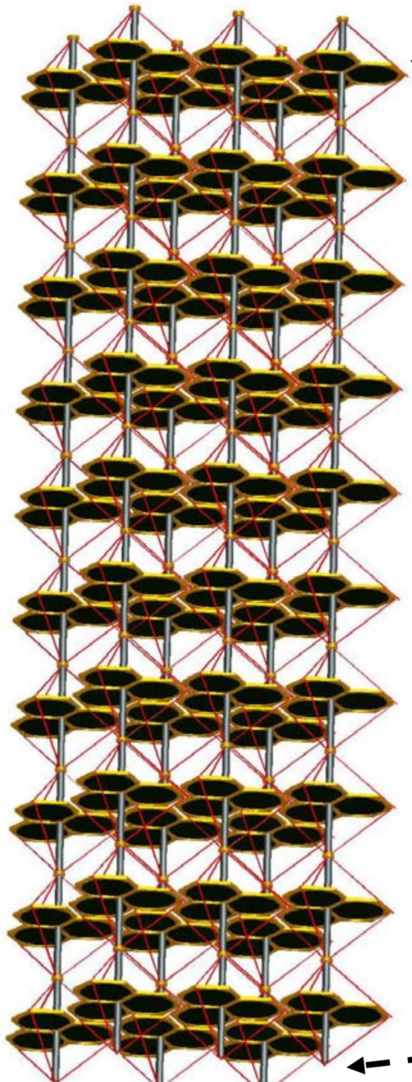
Atomic Transitions

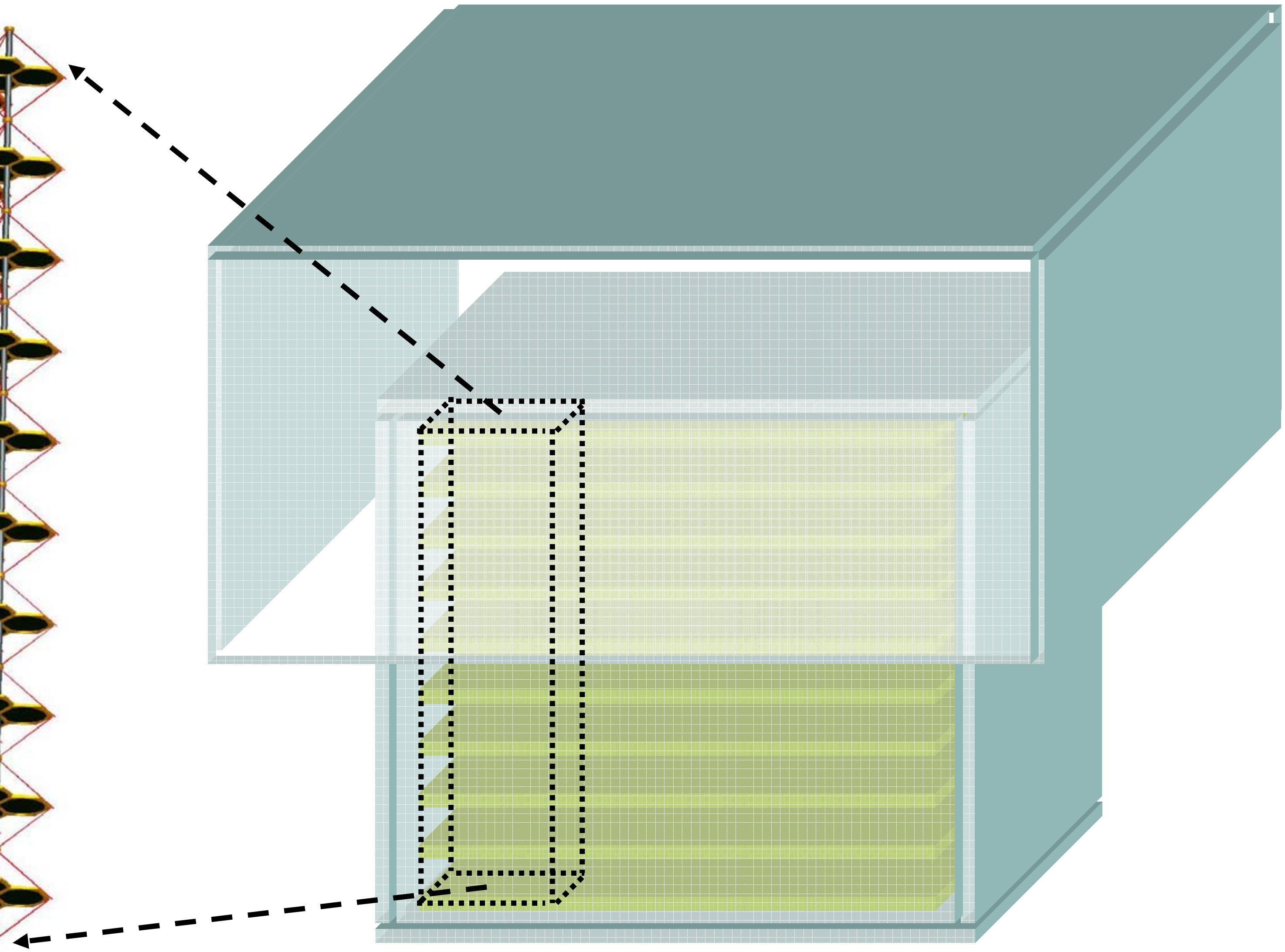


$$E_\gamma = (zZ)^2 M^* R_H \left(\frac{1}{n_f^{\,2}} - \frac{1}{n_i^{\,2}} \right)$$

Antiprotonic yields measured at KEK in 2004 & 2005 in various targets.

Si(Li) Wafers will be hexagonally packed into detector planes & surrounded by segmented Plastic TOF



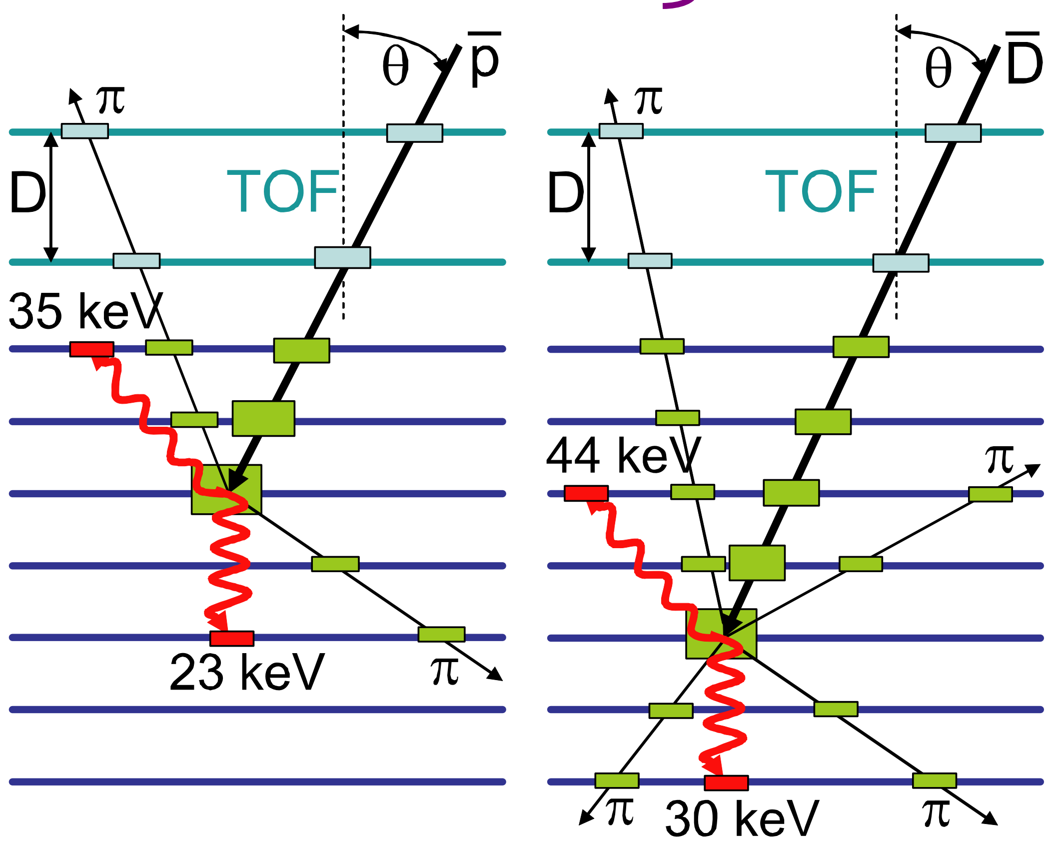


~200 kg Si(Li) mass – Similar to direct detection target mass

GAPS employs three techniques to uniquely identify antideuterons with enormous background suppression

1. Atomic X-rays
2. TOF and Depth Sensing
3. Charged Pion Multiplicity

} Exploratory



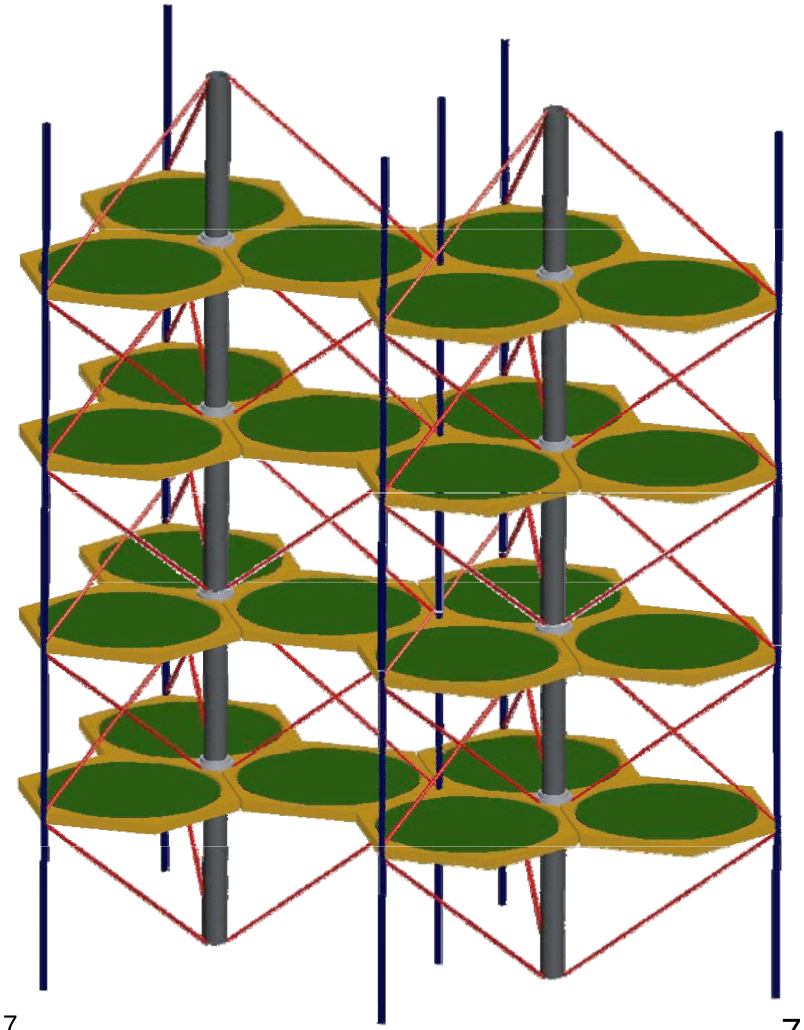
Expected Background for a 300 Day Flight

Type of Background	Expected Events	Basis for estimate
Temporally incoherent X-rays	< 0.003	Scaling from γ-ray telescopes
Temporally coherent X-rays	0.001	Measured at GAPS-KEK experiment
Elastic neutrons	0.002	Monte-Carlo of evaporative & cascade model, KEK limits
Secondary-tertiary-atmospheric antideuterons	0.006	Propagate calculated spectra through atmosphere to instrument
Nuclear γ-rays, π^o shower photons, internal bremastrahlung	negligible	Data on energy & branching ratio of all possible lines; analytic calc.; GEANT4 sim.
Exploration trigger	0.2 (total)	Analytic & Monte-Carlo Simulations

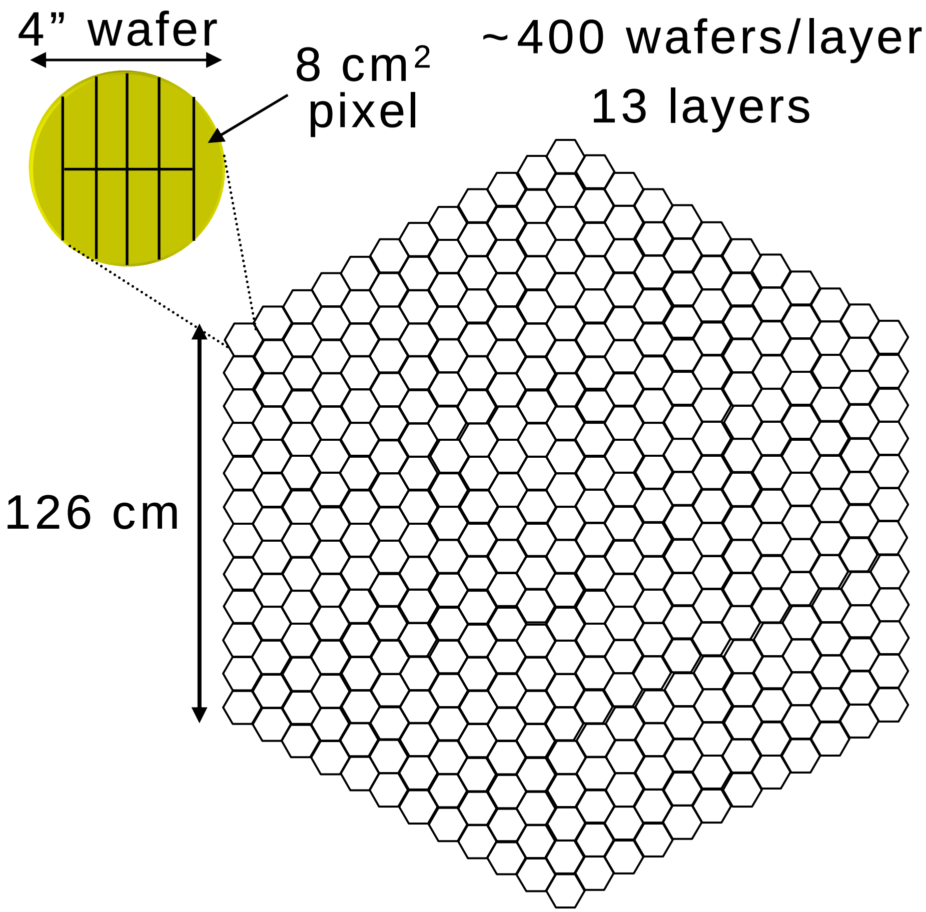
Si(Li) Serves a Target for Stopping Antideuterons as well as an X-ray Detector & Particle Tracker

- Relatively low Z provides:
  → good compromise between X-ray escape and detection
  → Low internal background.
- Excellent timing (50 ns) & energy resolution (2 keV – much better than NaI, but modest for Si)
  → 2 X-ray coincidence sufficient (previous designs used 3 X-rays)
- Relatively course pixels (8 cm^2)
  → Keeps channel count low but still provides for low pileup.
- Dual channel electronics (5-200 keV & 0.1-200 MeV)
  → Good charged particle tracking for depth sensing & annihilation product tracking
- Proven technology dating to 60's

- Modular approach for ease of in-field assembly



We have tested a prototype detector that exceeds our requirements – fabrication scale-up challenge remains

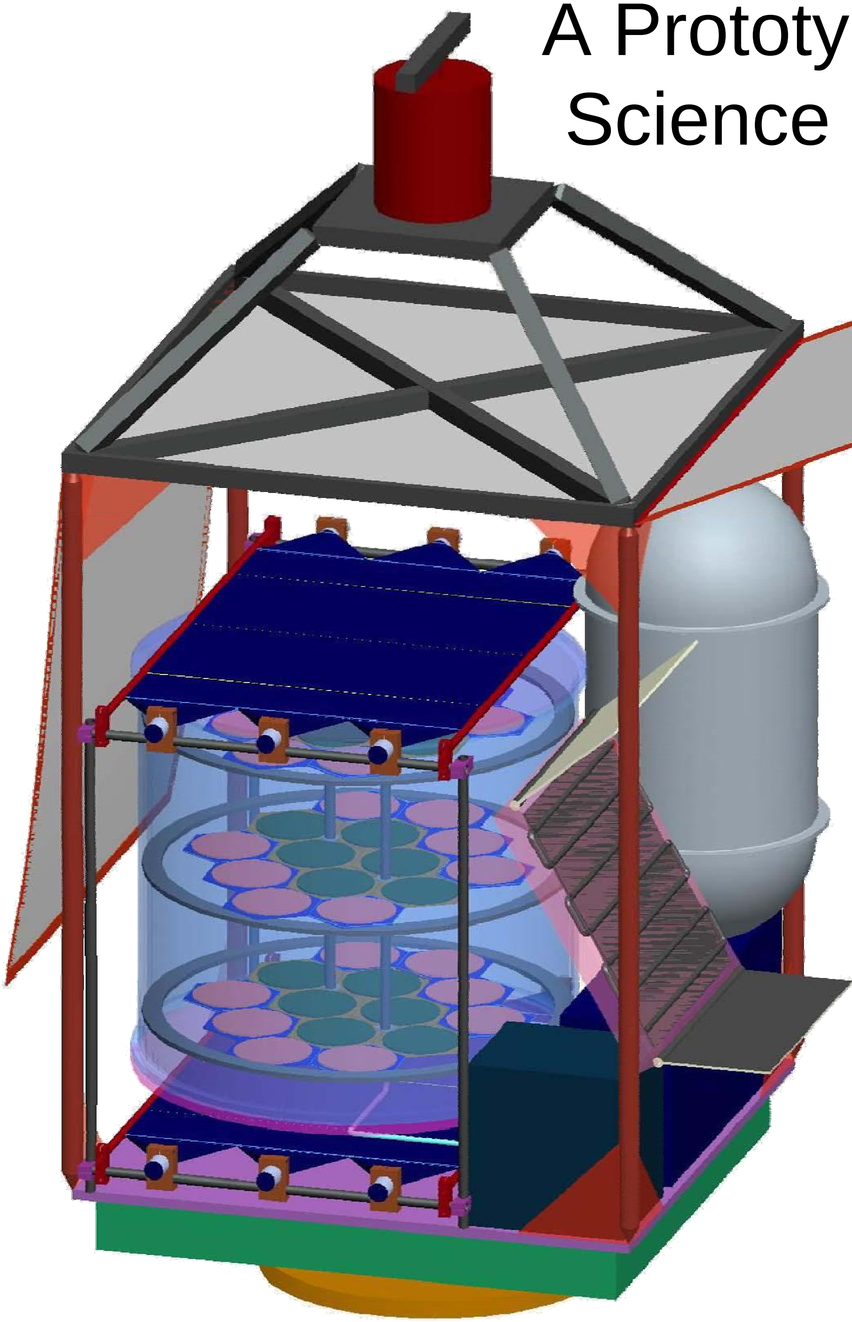


Design based on tested 4” prototype Si(Li) detector. We are studying 5”-6” detectors to ease implementation.

Heat Dissipation & Power Load	**[W]**
Heat Dissipation per Si(Li) channel	0.005
Solar and other heat	130
Total Heat Dissipation	**400**
Power for Si(Li) Detector System	1622
Power for Plastic Detector System	186
Other power requirements	200
Total Power	**2008**

Mass Breakdown	**[kg]**
Si(Li) Detectors	204
Si(Li) Electronics, Cables, Support & Cooling	315
Plastic Scintillator	151
PMT, Light-guide, Cables, Electronics, Wrapping Support	190
Gondola, Computers, Telemetry Power, Radiator,	376
Total	**1237**

A Prototype Flight will Provide a Crucial Science & Engineering Demonstration

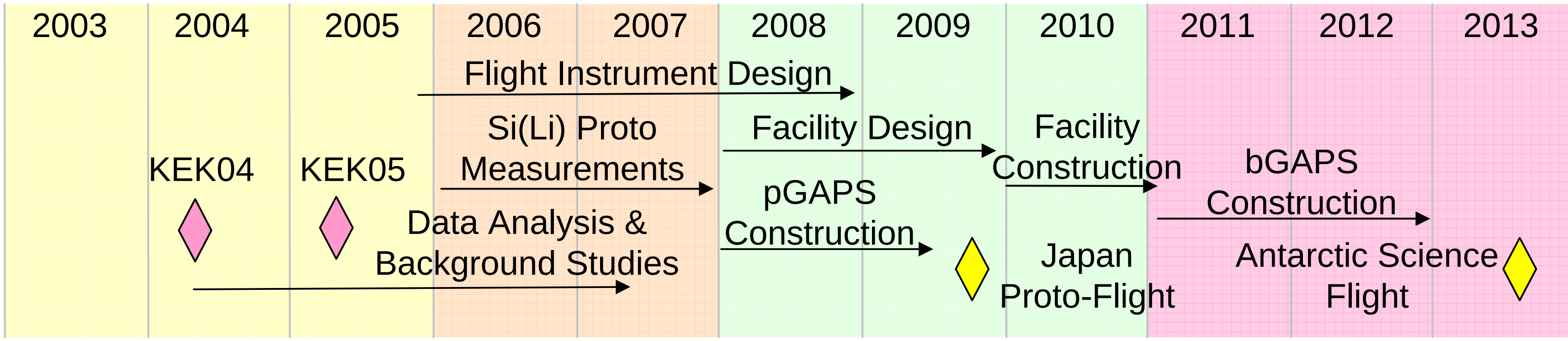


Balloon Prototype Goals:

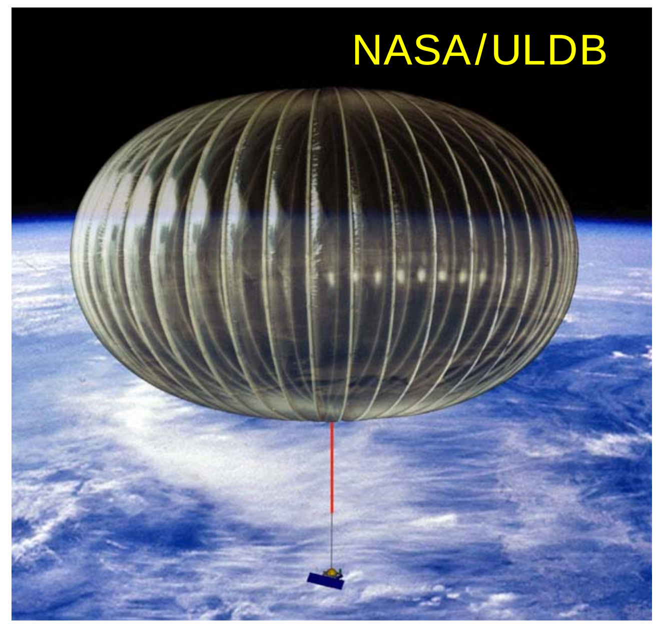
- Demonstrate stable, low noise operation of the Si(Li) with its polymer coating at float altitude & ambient pressure.
- Demonstrate the Si(Li) cooling approach & deployable sun shades. Verify thermal model.
- Measure incoherent background level in a flight-like configuration.

2009 Flight planned from Japan with ISIS/JAXA participation

GAPS Development Plan Culminates in a Long-Duration Balloon (LDB) Experiment

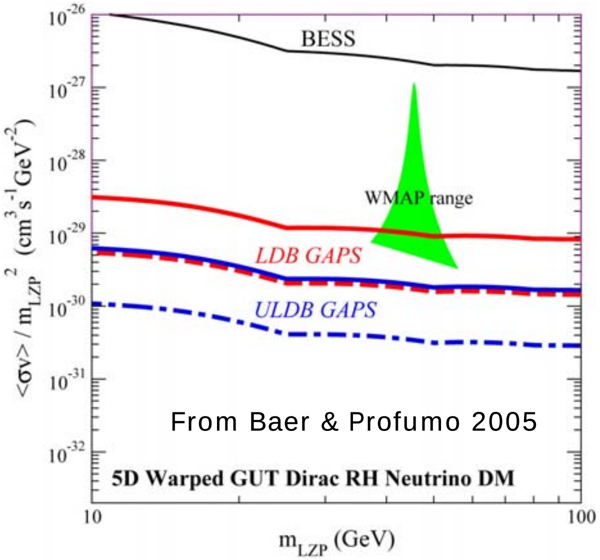


- Flight proposal submitted to NASA in Spring 2007
- Flight of GAPS prototype from Japan in 2009
- LDB GAPS flight from Antarctica in 2013
- Experiment design will be ultra long duration (ULDB) capable to exploit such a launch if it becomes available; flight duration >100 days
- Growing collaboration & adding expertise to execute this plan



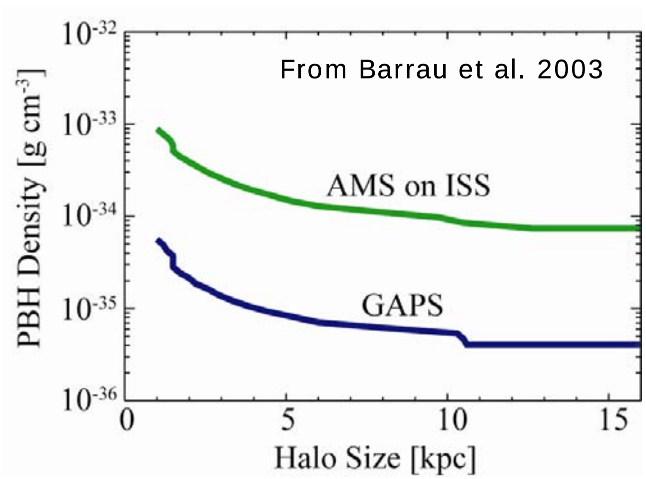
Primary GAPS Science Goals

Antideuteron Dark Matter Signature



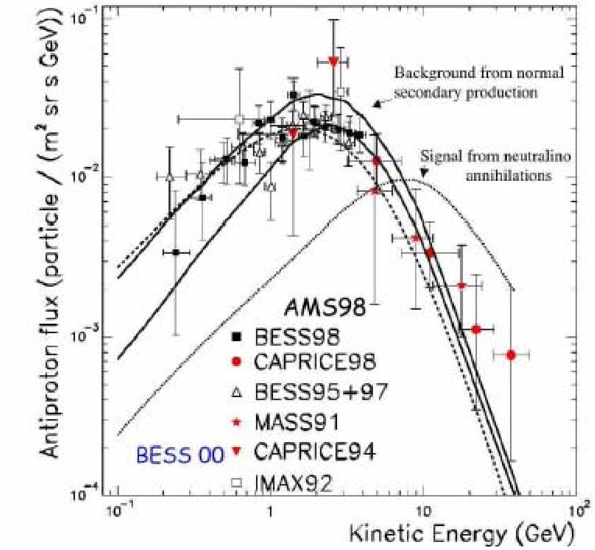
- Execute deep searches for SUSY & UED DM
- Complementary with direct and other indirect measurements

Primordial Black Holes



- Measure antideuterons from evaporating PBH's
- Potentially constrain inflation temperature

Low-Energy Antiproton Spectroscopy



- Measure 10^4-10^5 antiprotons <0.3 GeV (BESS-polar measured 26 @ <0.3 GeV)
- Perform both DM and cosmic-ray physics