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

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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 an 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. We have successfully demonstrated the GAPS method in an accelerator environment and are currently planning a prototype flight from Japan for 2009. This will lead to a long duration balloon (LDB) mission that will complement 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. Planes of coarsely pixilated Si(Li) detectors form the heart of GAPS flight detector, providing both high X-ray resolution and good particle tracking. We will describe the proto-flight mission that will verify the performance of our Si(Li) detectors and cooling system in a flight-like configuration. We also will outline the LDB science payload design.

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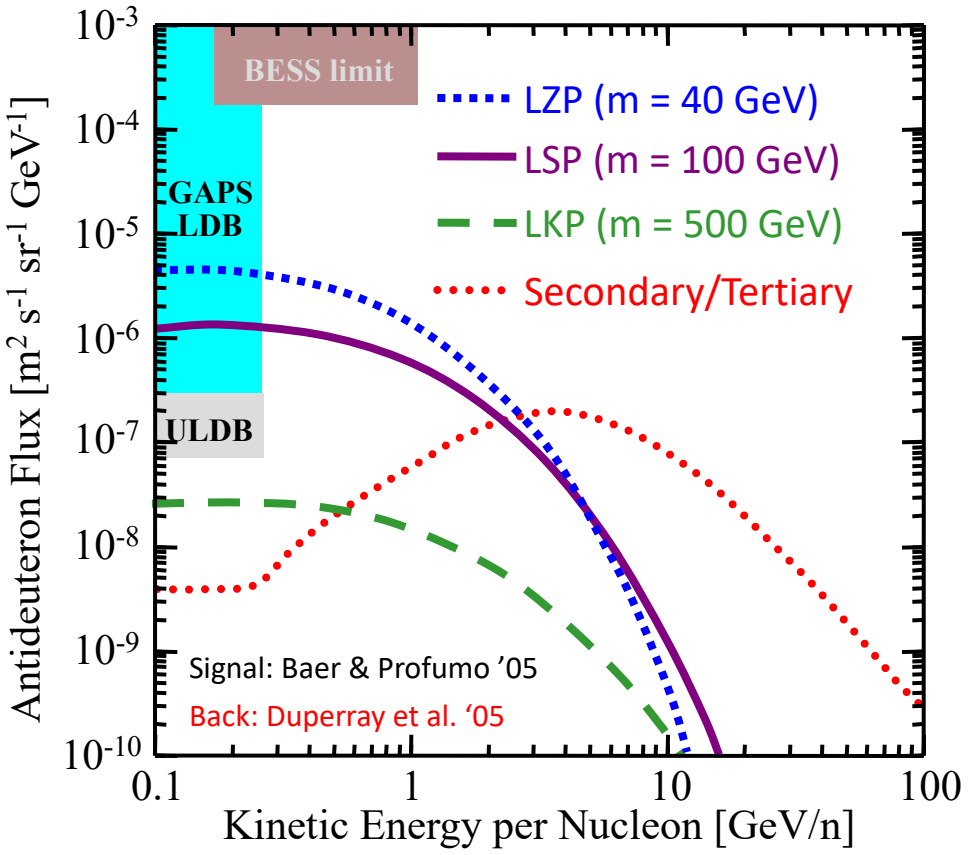
Low energy, neutralino-neutralino produced antideuterons are near background free

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

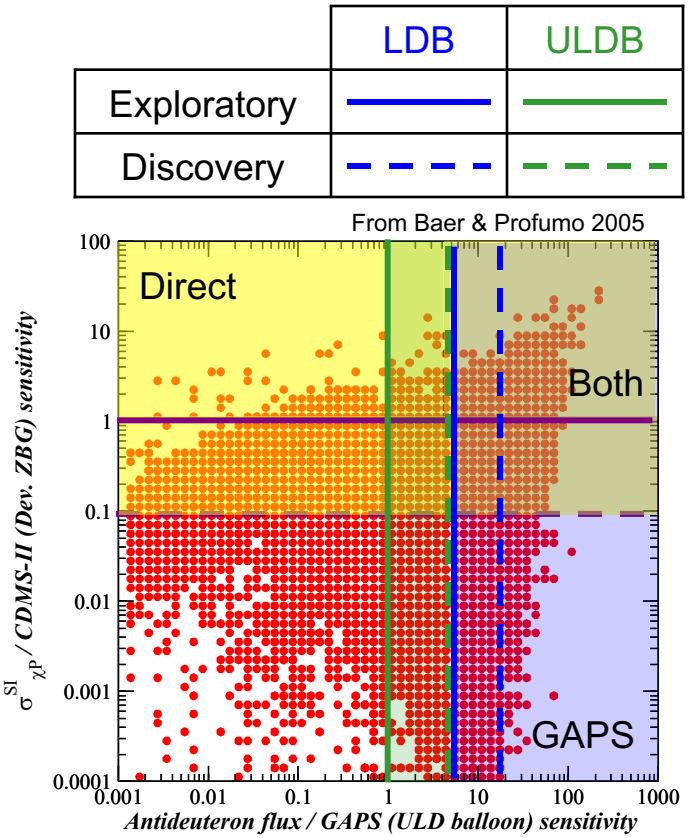


- Primary component:
  → neutralino annihilation
  $X+X \rightarrow \bar{D} + \ldots$
- Secondary component:
  → spallation
  $p+H \rightarrow p+H+\bar{D}+\ldots$
  $p+He \rightarrow p+He+\bar{D}+\ldots$
- GAPS is essentially a background free experiment
- GAPS represents a major improvement over the 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



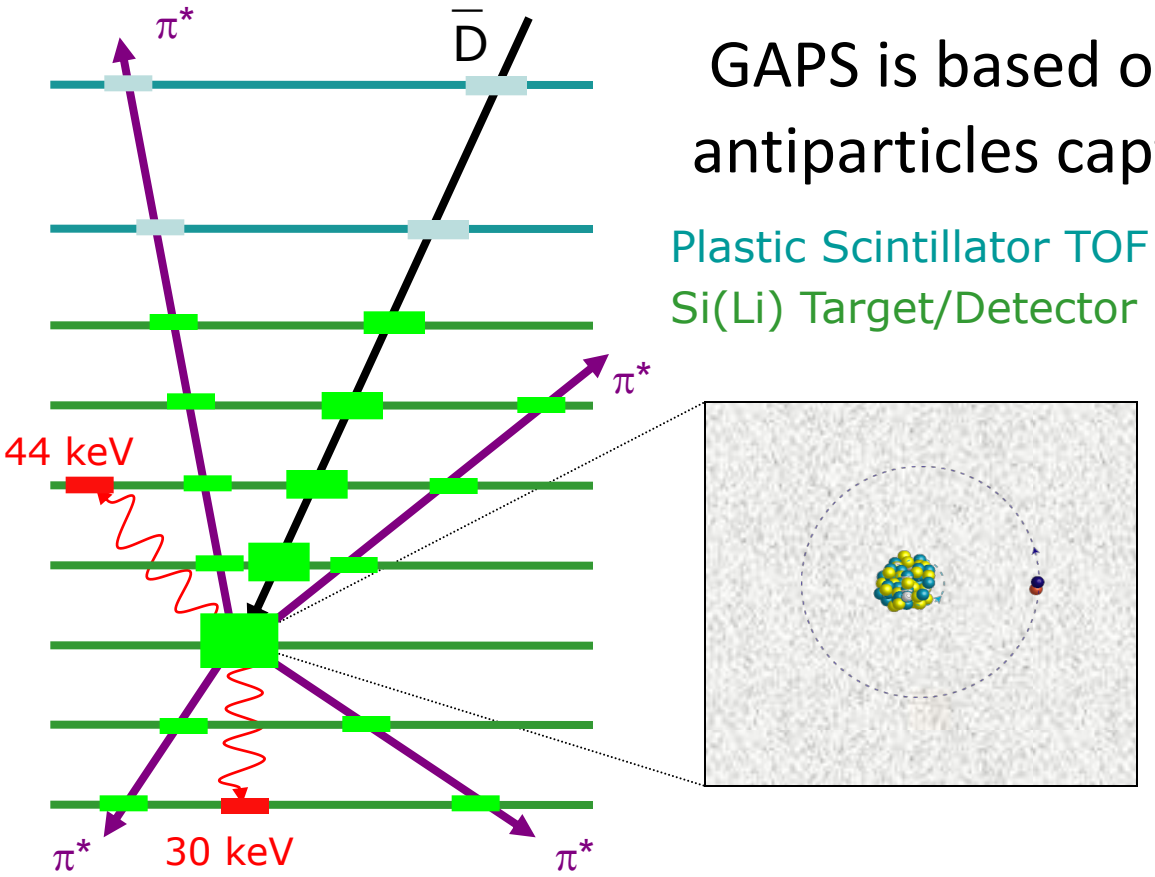
Note: DM theory has an approximate symmetry:

N(experiments) ≈ N(theories)

ANAIS
ArDM
CDMSII
CUORICINO
COSME
CRESST
DAMA
DMRC
DRIFT
ELEGANT V
EDELWEISS
EURECA
GEDEON
GENIUS
Genino
GERDA
HDMS
IGEX
LIBRA
NAIAD
PICASSO
SIMPLE
SuperCDMS
SuperK
WARP
XENON
ZEPLIN

4th generation heavy neutrino
Axinos
Axions
Bino
Brane world DM
CHAMPS
Cryptons
D-matter
Gravitinos
Kaluza-Klein
Higgsino
Light scalars
Minimal DM
Mirror particles
Neutralinos
New symmetry little Higgs
Q-balls
Photino
Self-interacting DM
Simpzillas
SM neutrinos
Sneutrinos
Sterile neutrinos
SWIMPS
Theory space little Higgs
Wimpzillas
Wino

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



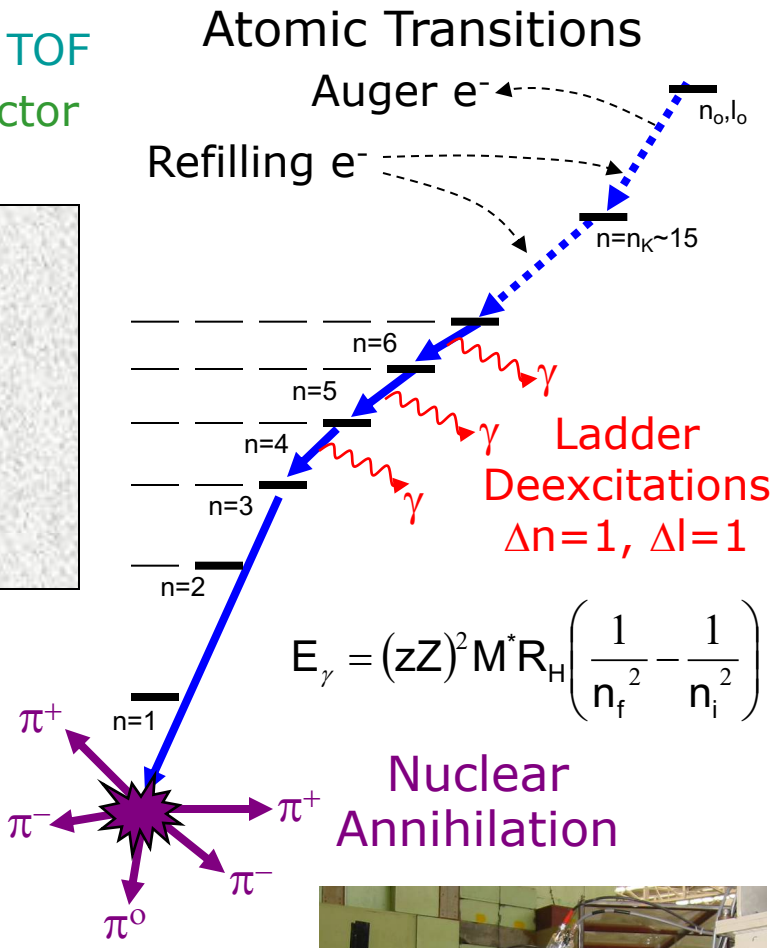
Plastic Scintillator TOF
Si(Li) Target/Detector

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

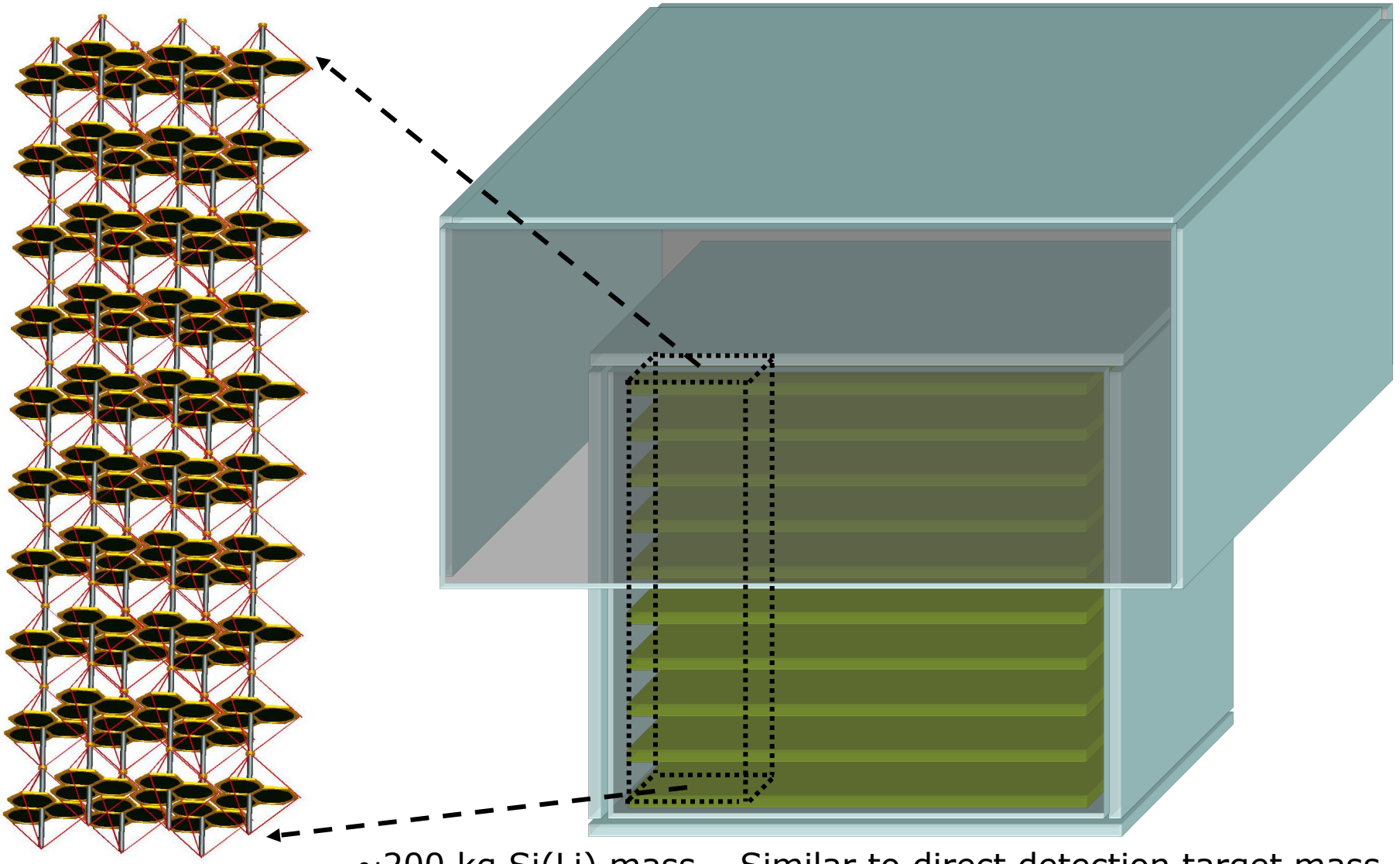
Pions from annihilation provide added background suppression



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

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

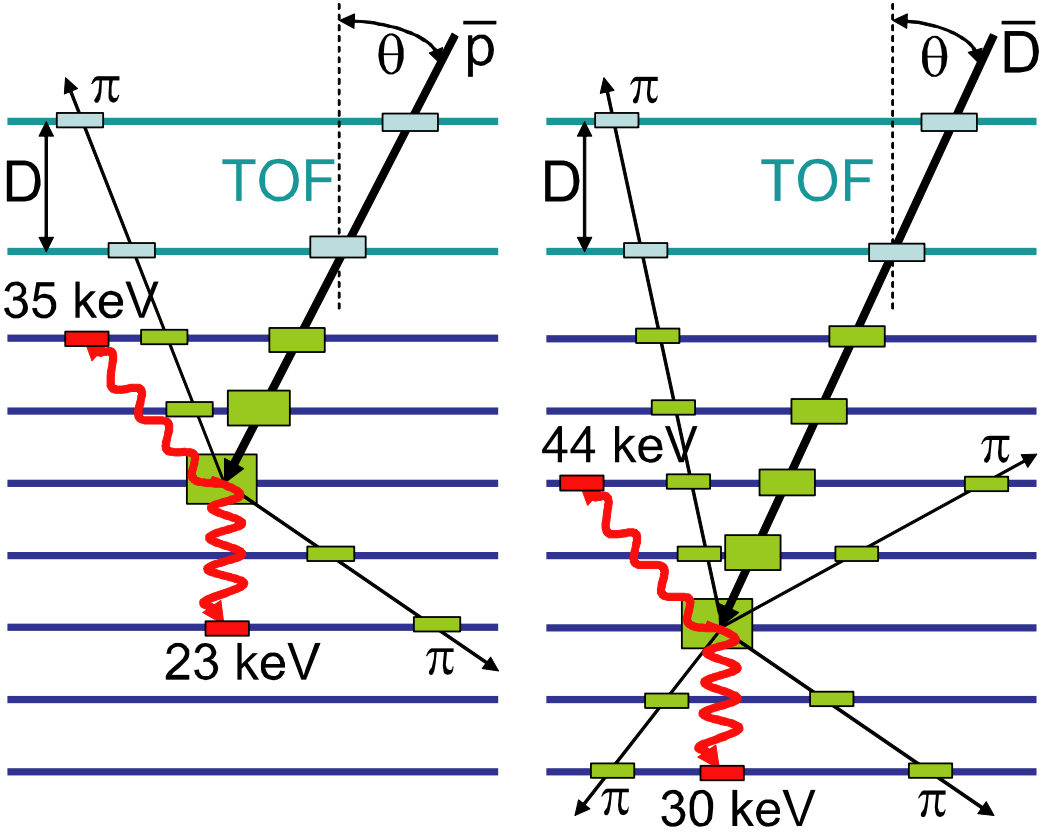


~200 kg Si(Li) mass – Similar to direct detection target mass

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



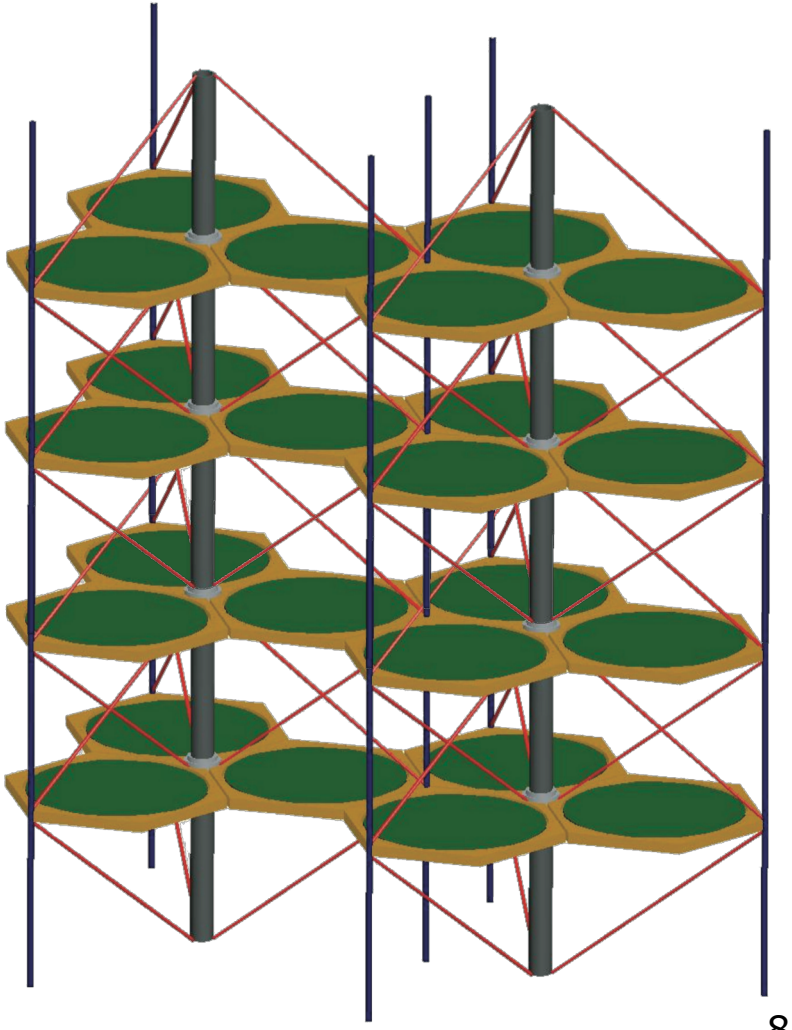
Expected Background for a 300 Day Flight

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

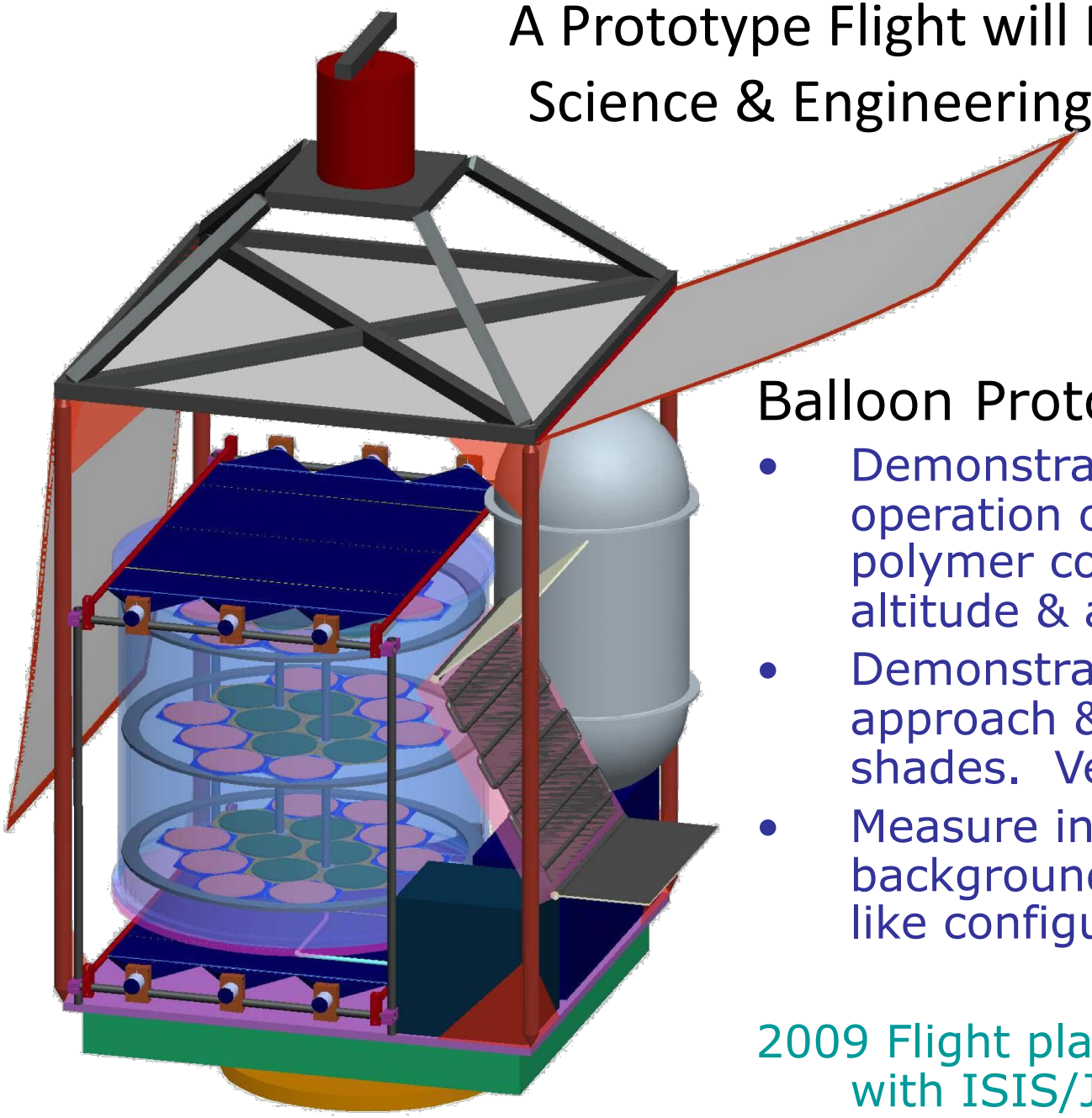
Si(Li) Serves a Target for Stopping Antideuterons as well as an X-ray Detector & Particle Tracker

- 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



A Prototype Flight will Provide a Crucial Science & Engineering Demonstration

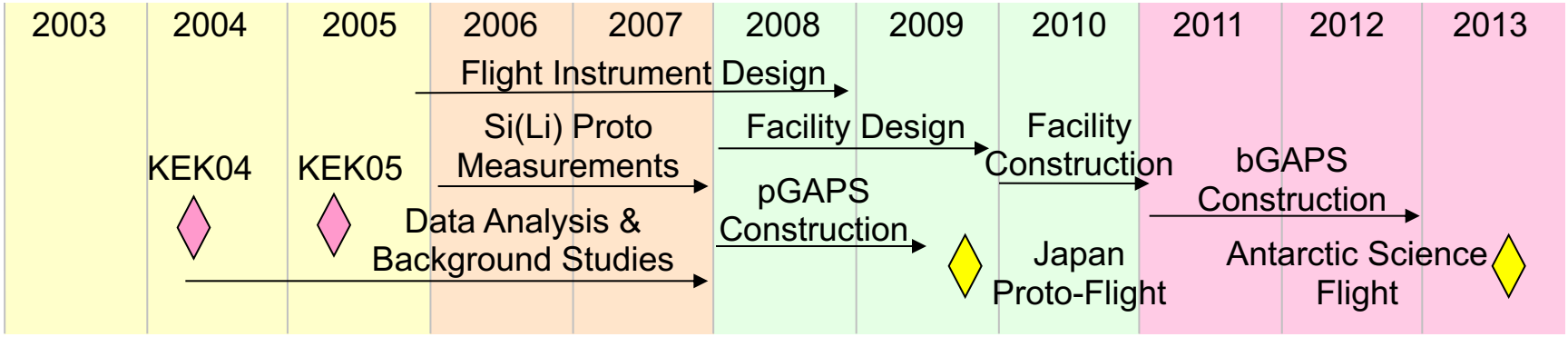


Balloon Prototype Goals:

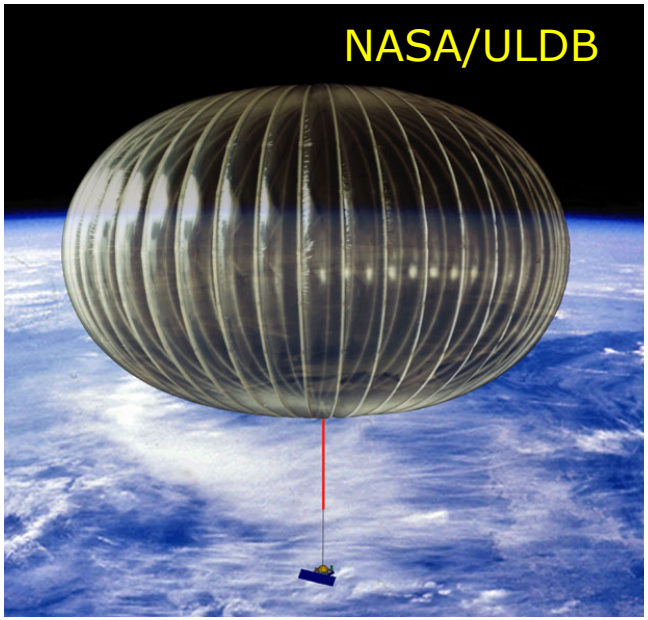
- Demonstrate stable, low noise operation of the Si(Li) with its polymer coating at float altitude & ambient pressure.
- Demonstrate the Si(Li) cooling approach & deployable sun shades. Verify thermal model.
- Measure incoherent background level in a flight-like configuration.

2009 Flight planned from Japan with ISIS/JAXA participation

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

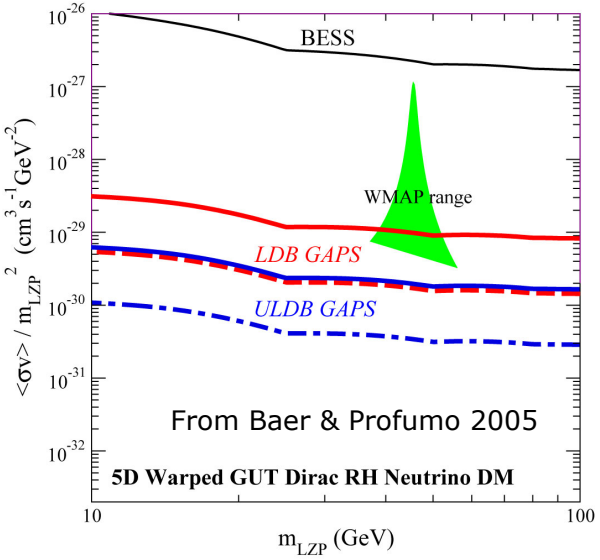


- Flight of GAPS prototype from Japan in 2009
- Long Duration Balloon (LDB) GAPS flight from Antarctica in 2013
- Experiment design will be Ultra Long Duration (ULDB) capable to exploit such a launch if it becomes available; flight duration >100 days



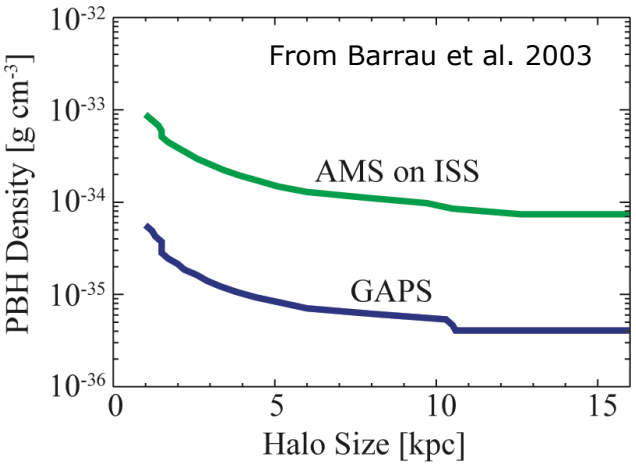
Primary GAPS Science Goals

Antideuteron Dark Matter Signature



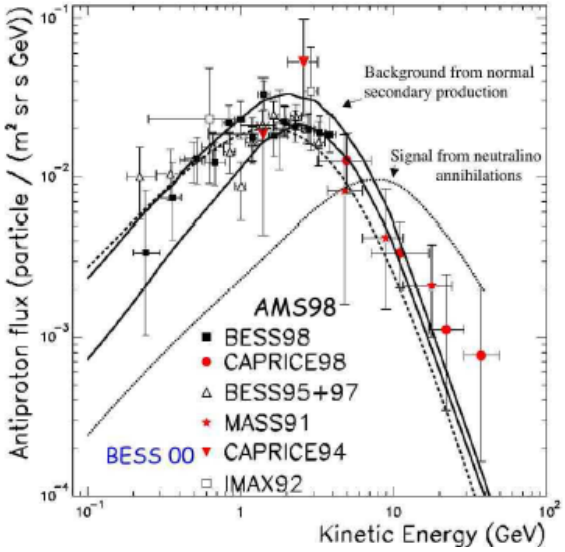
- Execute deep searches for SUSY & UED DM
- Complementary with direct and other indirect measurements

Primordial Black Holes



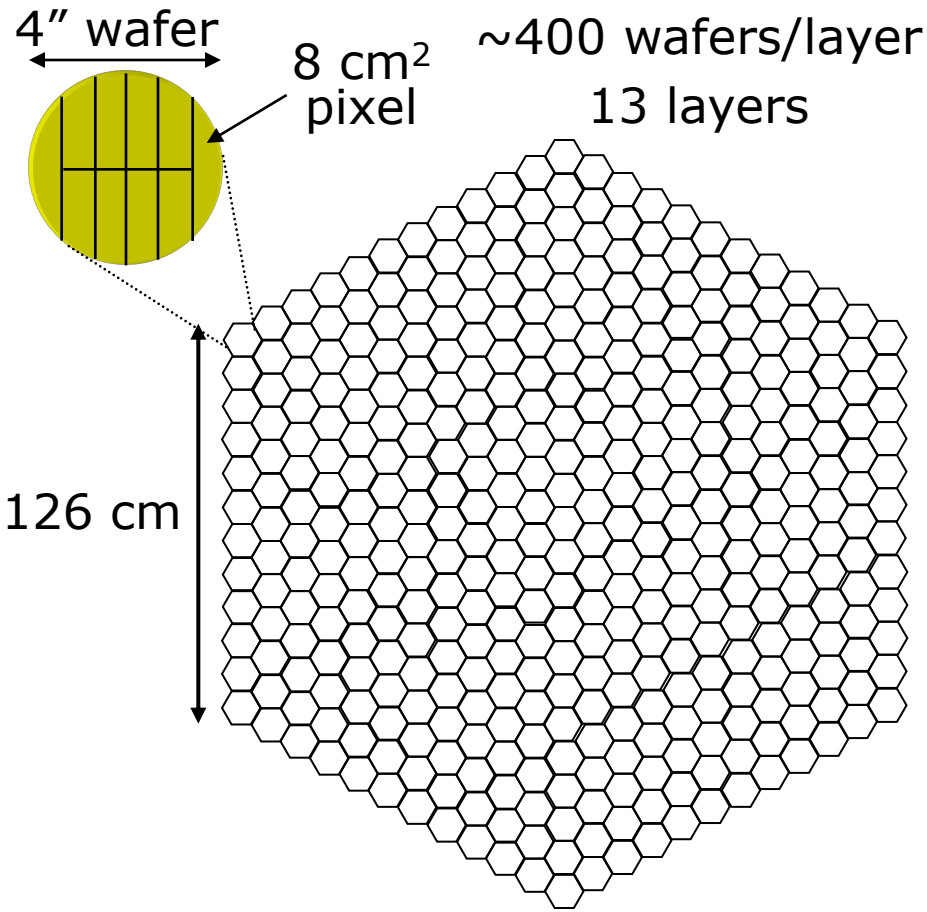
- Measure antideuterons from evaporating PBH's
- Potentially constrain inflation temperature

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

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**