The General Antiparticle Spectrometer (GAPS) - Hunt for dark matter using low energy antideuterons

Identification of Dark Matter - July 2010
Montpellier

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Collaboration

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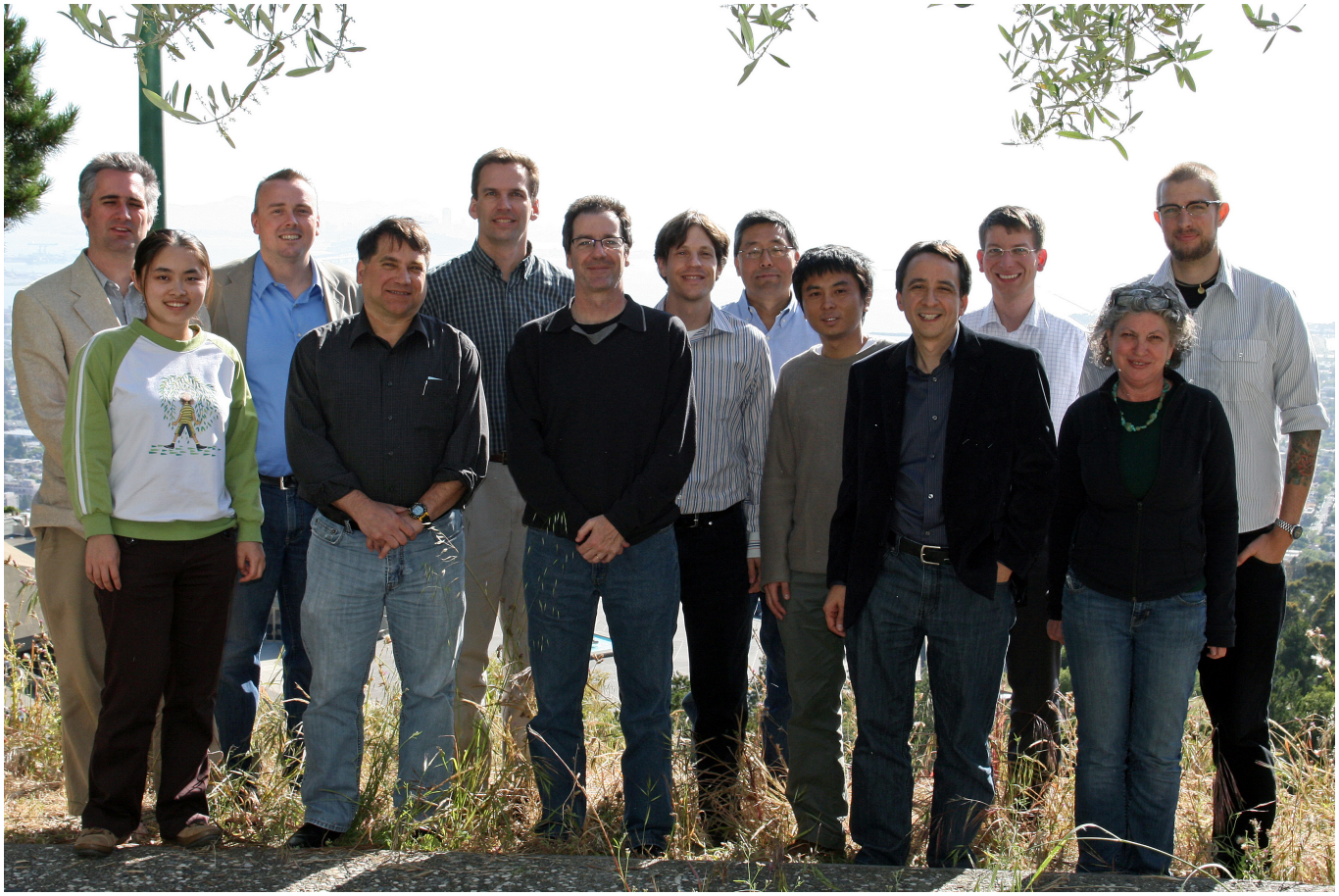
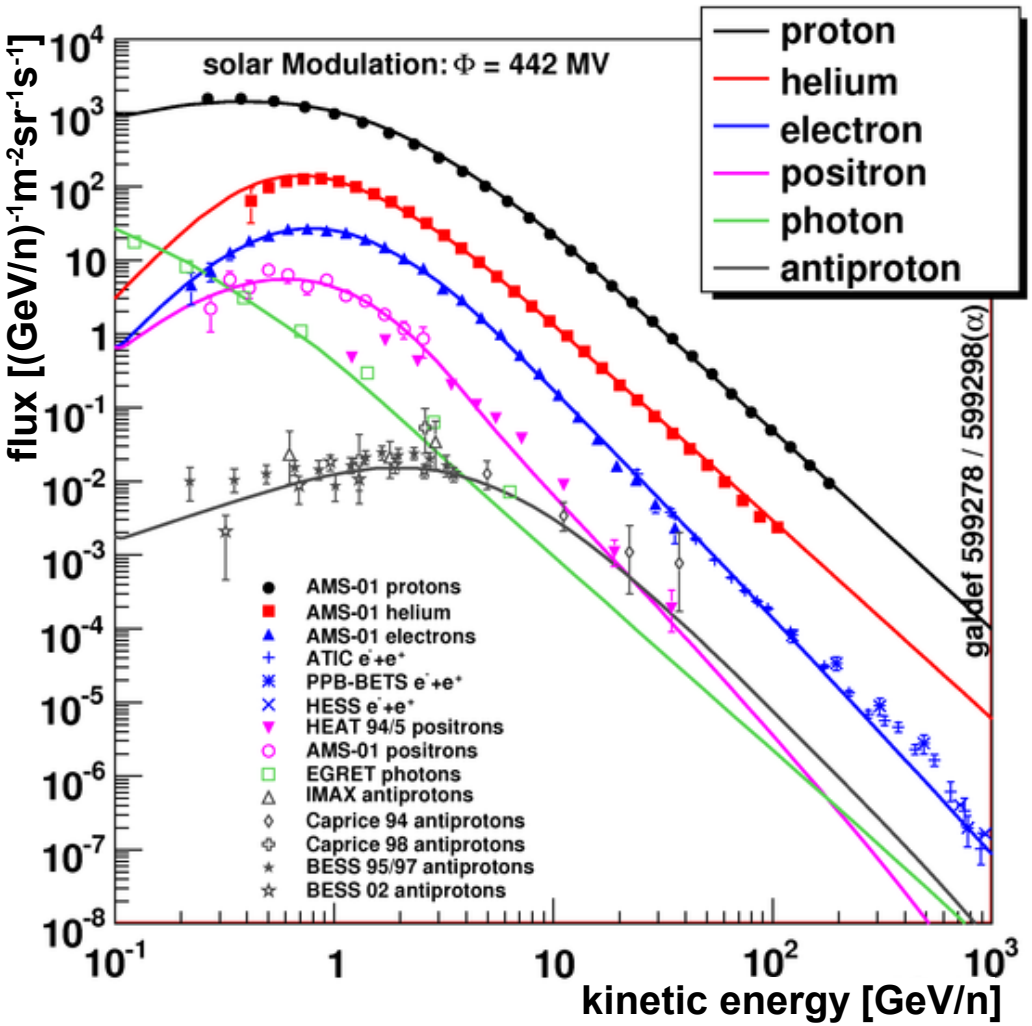
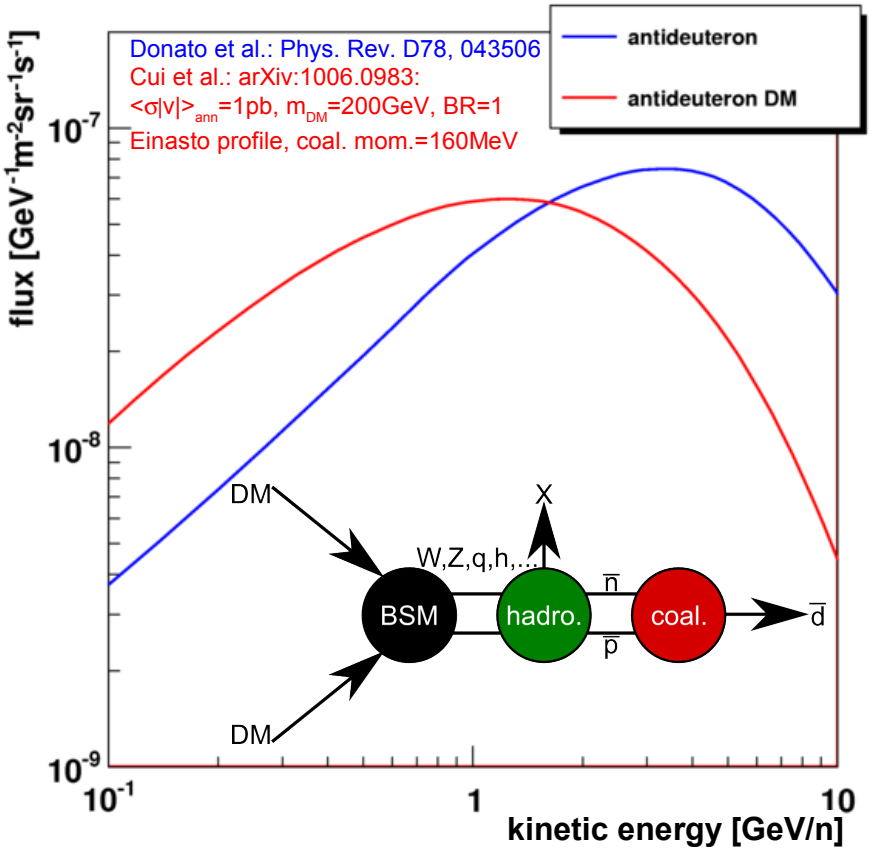


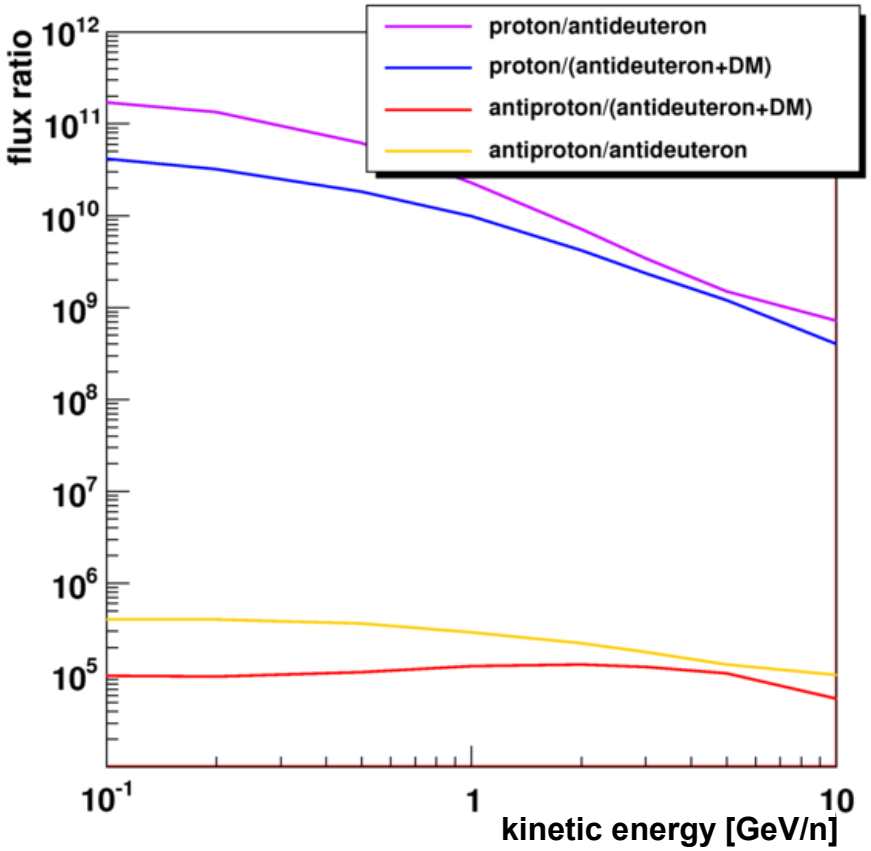
Cosmic rays



- what we already learned:
  - particle physics
  - interstellar medium
  - γ-astronomy
  - …
- in general good agreement of models
- **search for new phenomena**:
  - dark matter
  - astrophysical objects
  - baryogenesis
  - unexpected things?

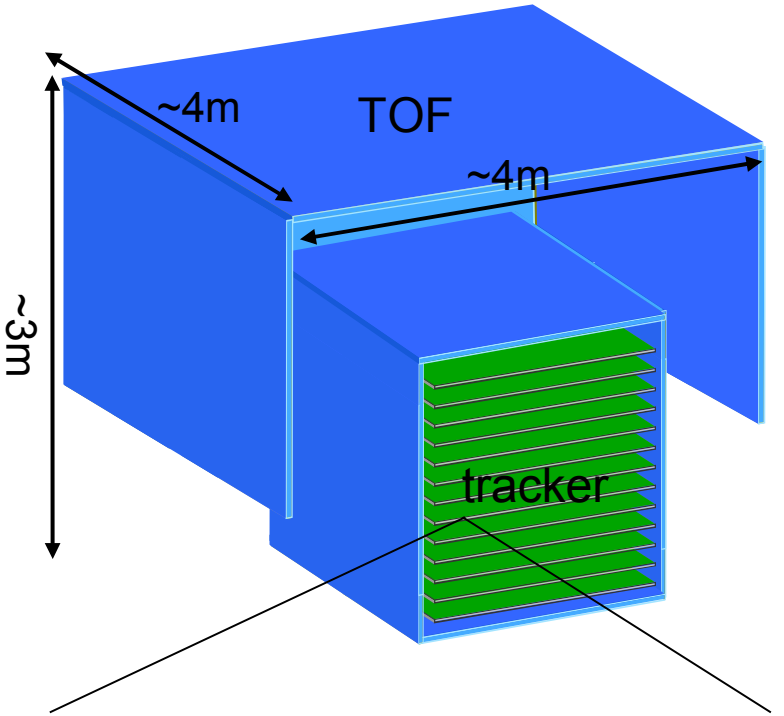
Antideuterons and dark matter

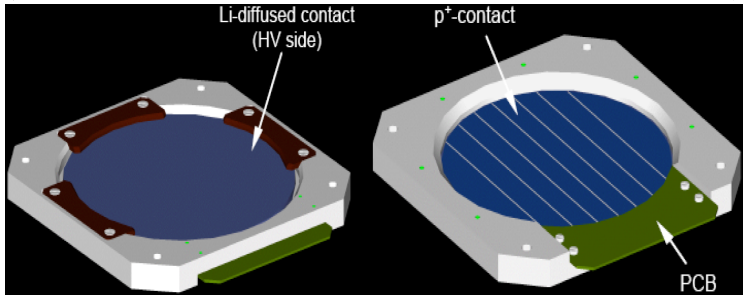




- **antideuteron flux is very small**:
  - challenging to measure the first antideuterons in cosmic rays (secondary interactions of protons with interstellar gas)
  - good source to **study new phenomena**
- theories with **dark matter** self-annihilation predict **"large" low-energy antideuteron signals**

GAPS concept





Balloon flights planned from 2014

GAPS consists of two detectors (accep.: ~2.7m²sr):

Si(Li) tracker:

- Si(Li) tracker:13 layers composed of Si(Li) wafers
- relatively low Z material (2/3mm,escape fraction ~20keV) →target and detector
- Lithium doped Silicon detectors for a good x-ray resolution
- circular modules segmented into 8 strips, ~8cm² each →3D particle tracking
- 270 per layer (total: ~3500)
- timing: ~50ns
- dual channel electronics
  5-200keV: X-rays (resolution:~2 keV)
  0.1-200MeV: charged particle

Time of flight and anticoincidence shield:

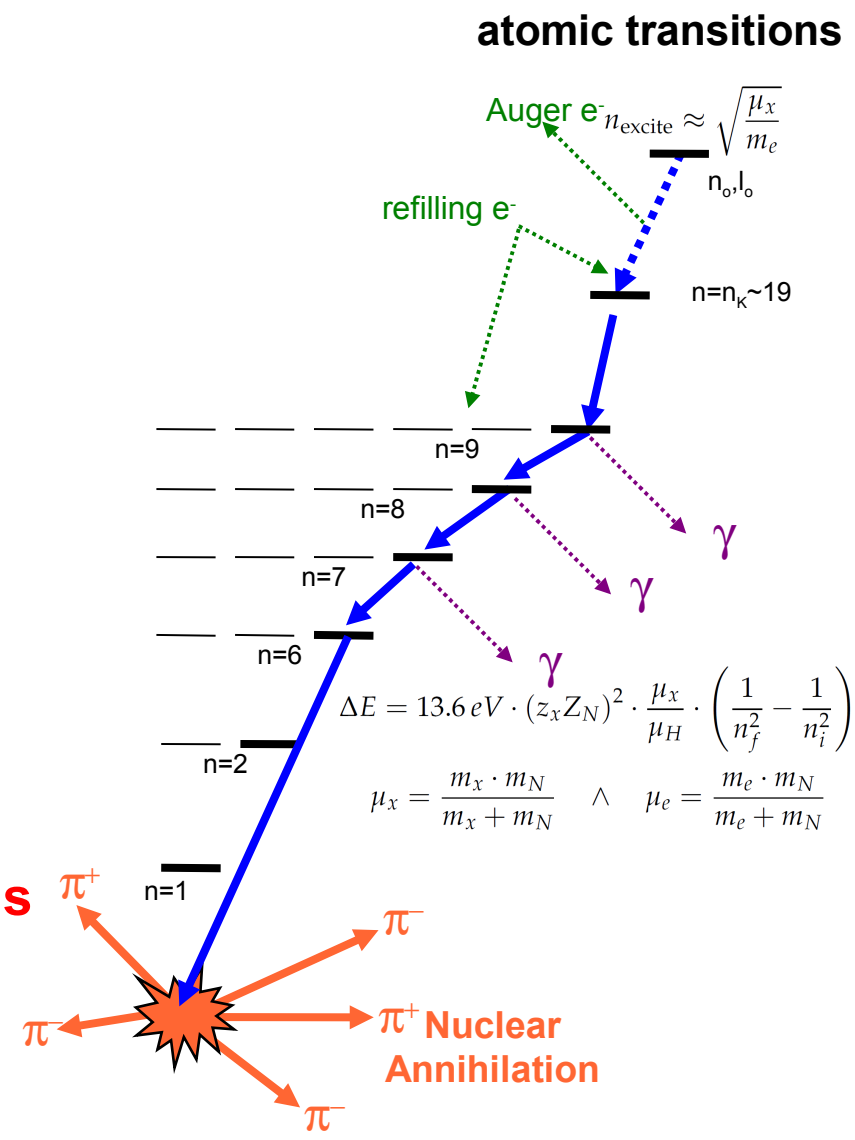
- plastic scintillator with PMTs surrounds tracker
- track charged particles
- velocity measurement
- anticoincidence for charged particles

Designed for low-energy antideuterons:

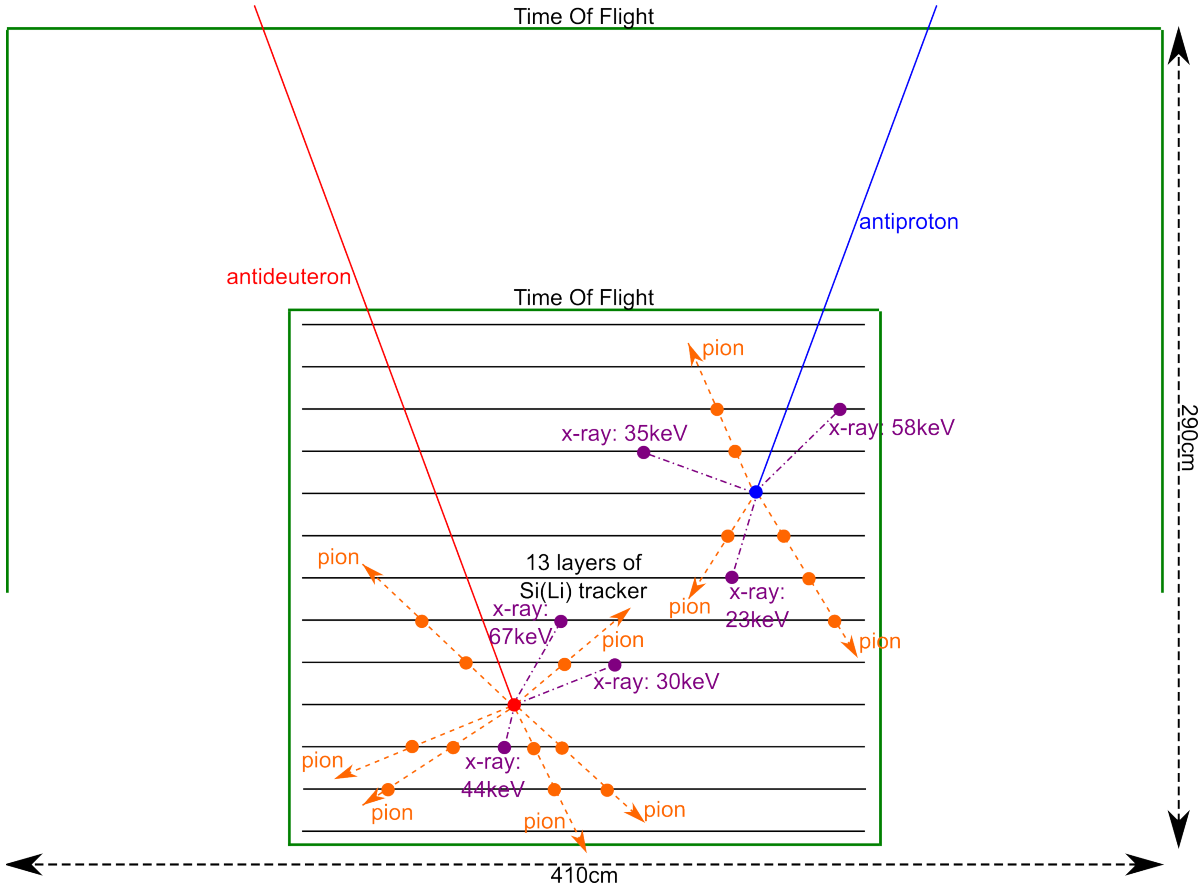
- no need for a magnet (heavy, sometimes complicated/expensive)

Antideuteron identification

- 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) rad. deexcitation:
    characteristic x-ray transitions
- nucleus-antideuteron annihilation: **pions**
- exotic atomic physics quite well understood (tested in KEK 2004 testbeam)



Backgrounds



GAPS needs a very reliable particle identification:

- identification uses:
  - TOF velocity and tracks
  - depth in tracker
  - x-rays and pions from annihilation

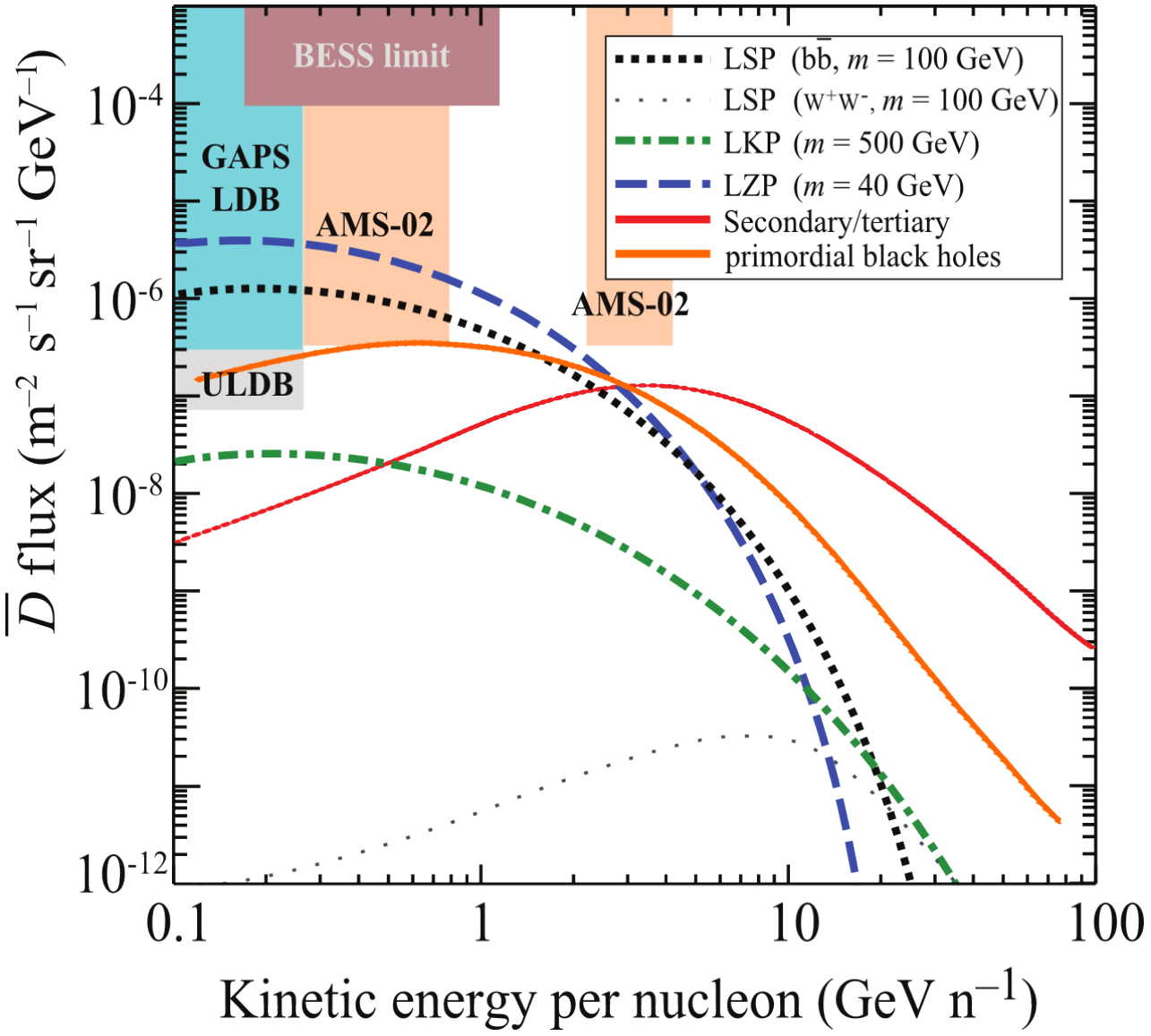
- important background sources for antideuteron events:
  - antiprotons
  - protons, electrons, neutrons in coincidence with cosmic x-rays
  - atmospheric production of antideuterons
  - etc...needs to studied in great detail

GAPS antideuteron sensitivity

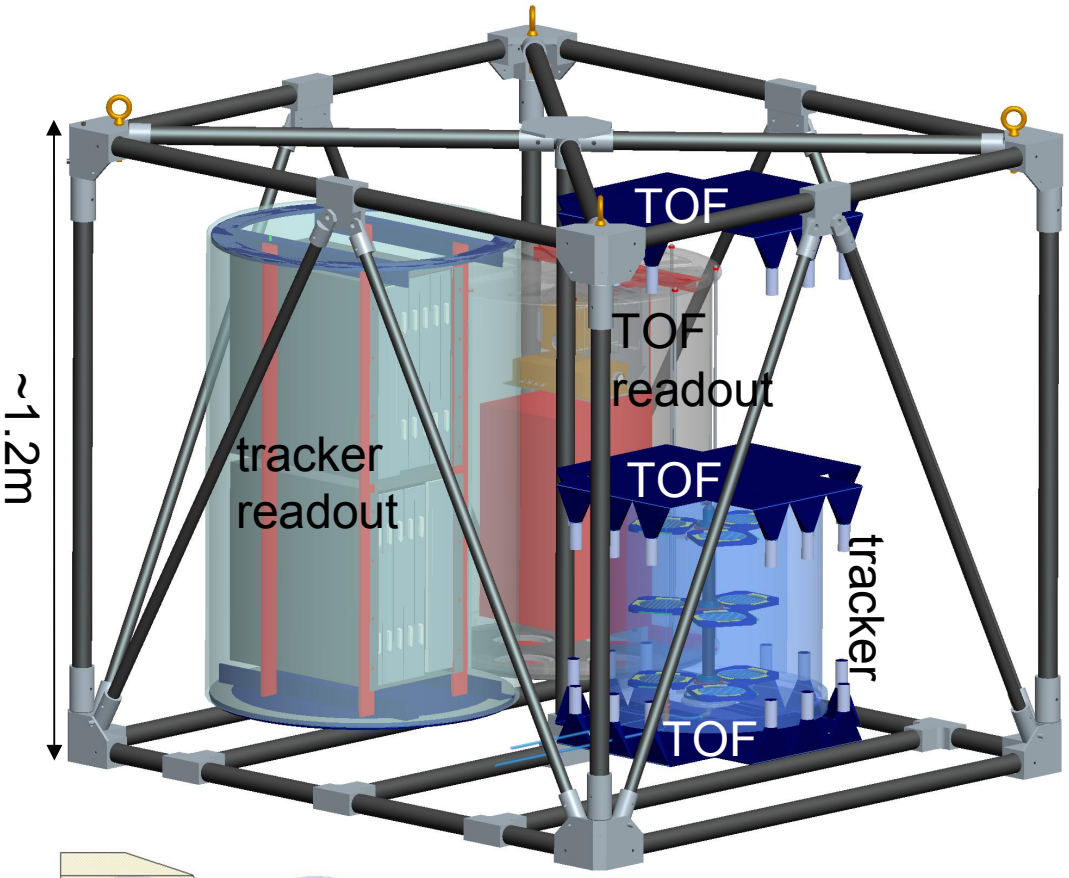
- GAPS need small geomagnetic cut-off
  →therefore (ultra) long duration balloon flights from South Pole are planned: 60 (300) days

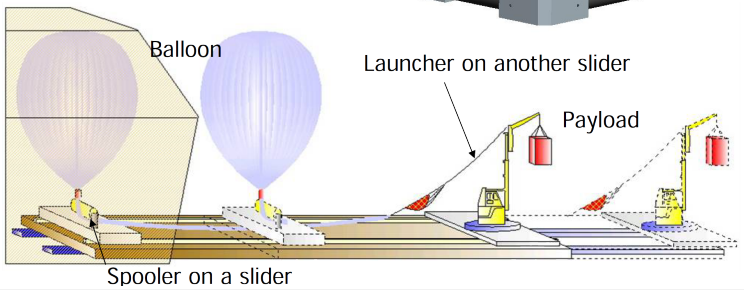
- different scenarios give reasonable antideuteron fluxes within sensitivity:
  Supersymmetry:
  LSP: neutralino (majorana)
  Kaluza-Klein UED:
  LKP: 1st excitation of photon (boson)
  Warped extra dimensions:
  Dirac fermion with flavor dependent couplings to Z'
  primordial black holes:
  flux from Hawking radiation

- synergy with direct searches and neutrino telescopes:
  GAPS covers complementary dark matter regions!



Prototype experiment



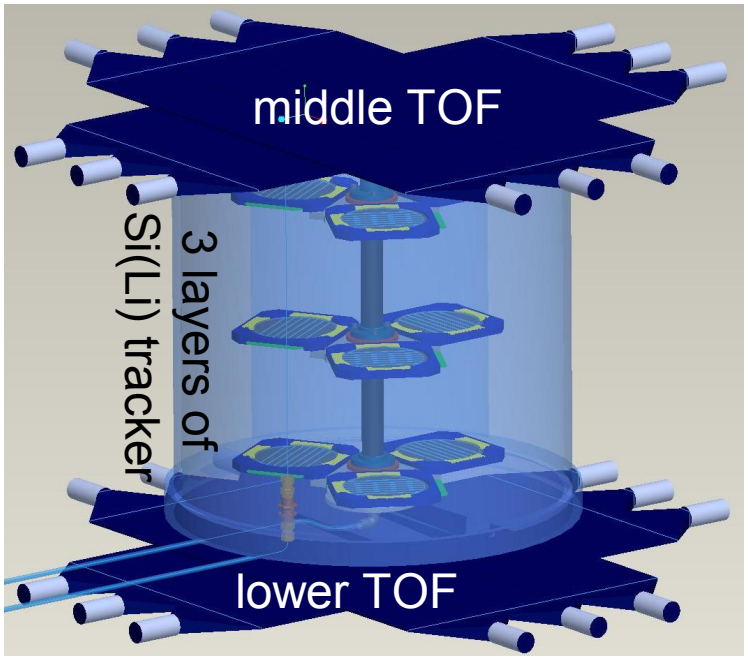


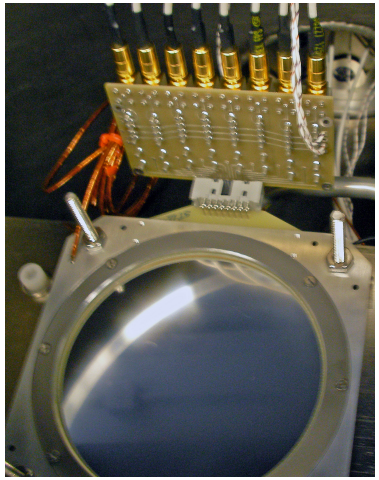
Prototype GAPS (pGAPS) goals:

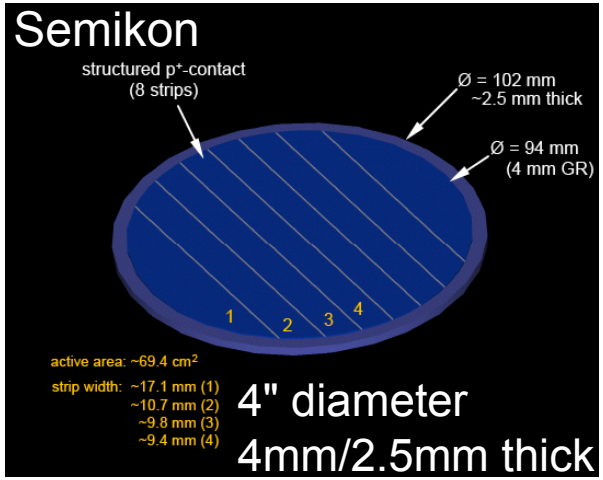
- demonstrate stable, low noise operation of the detector components at float altitude and ambient pressure.
- demonstrate the Si(Li) cooling approach and verify thermal model
- measure incoherent background level in a flight like configuration.

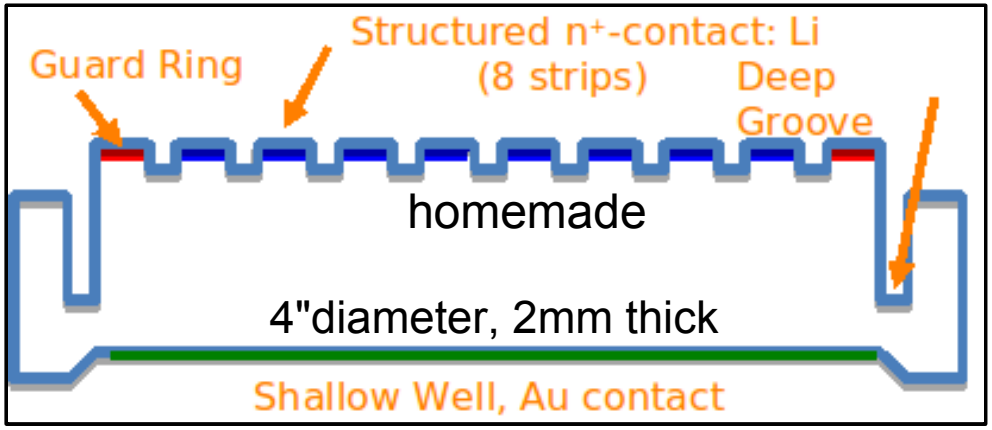
2011 scheduled flight from Taiki, Japan

Si(Li) tracker







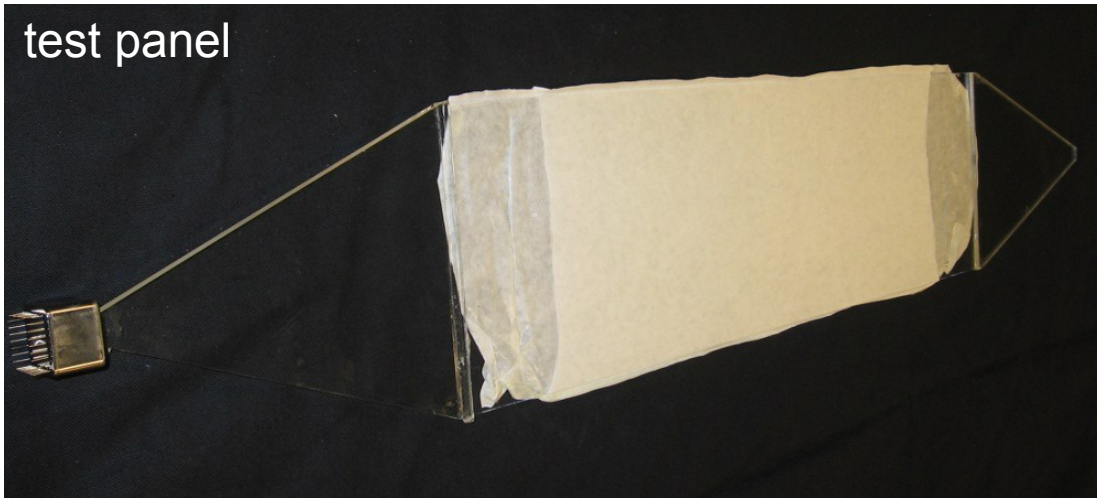


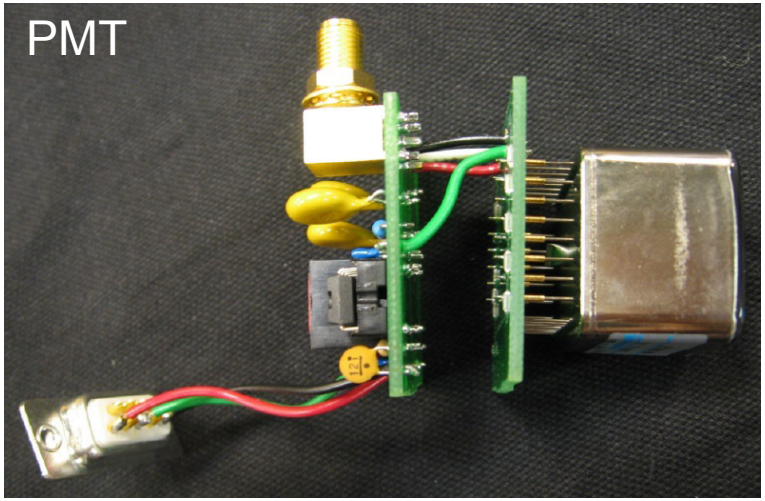
- 7 commercial Semikon detectors
- 2 homemade detectors
  (test for the bGAPS fabrication)
- energy resolution at 60keV should be 3keV
- operation at ambient pressure (8mbar)
- cooling system delivers: -35°C

Semikon: N+: Lithium contact
P+: Boron implanted (strips)

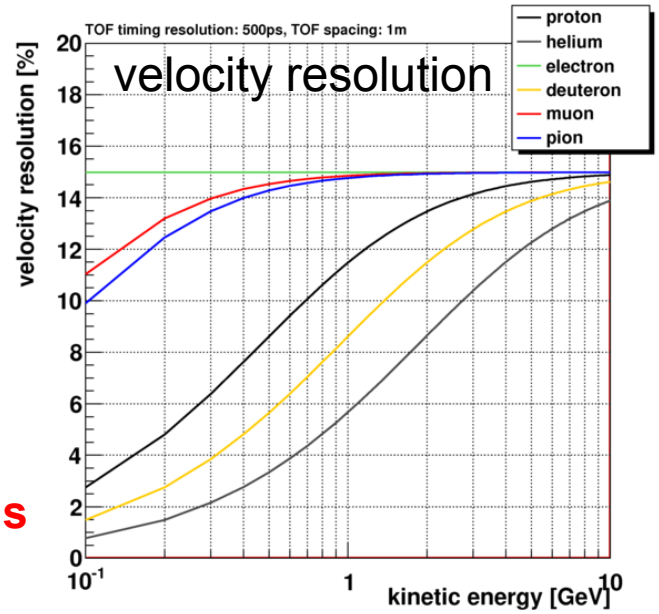
Homemade: N+: Lithium contact (strips)
Au contact with shallow well

Time of flight system

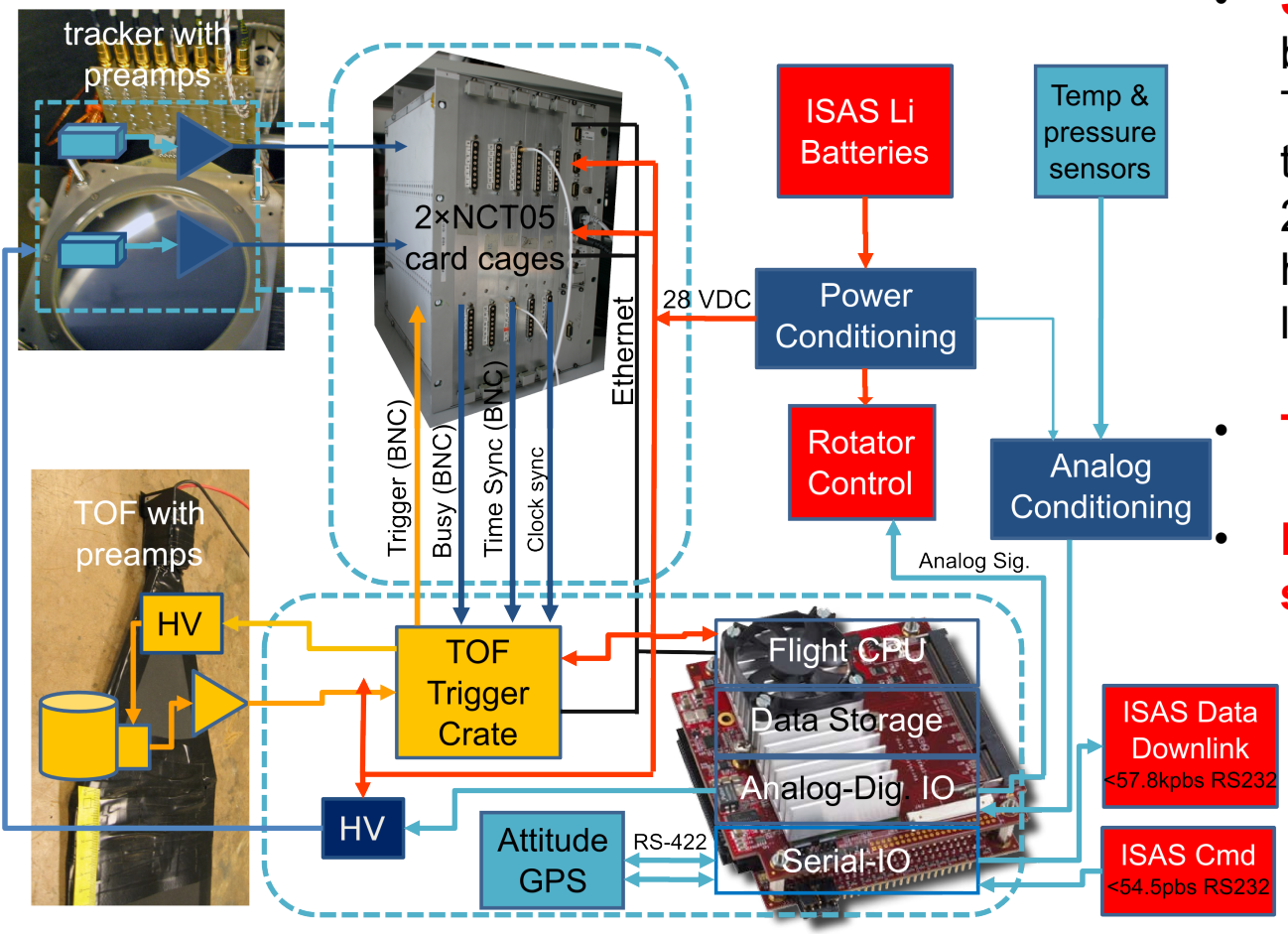




- 3 planes of TOF
  1 plane consists of 3×3 crossed panels
  1 panel has 2 PMTs
  = **18 panels and 36 PMTs**
- 3mm scintillator from Eljen (EJ-200)
  or Bicron (BC-408)
- Hamamatsu R-7600 PMT
- timing resolution: **500ps**
- charge resolution: **0.35e**
- MOP value: **~15 photo electrons**
- angular resolution: **8°**



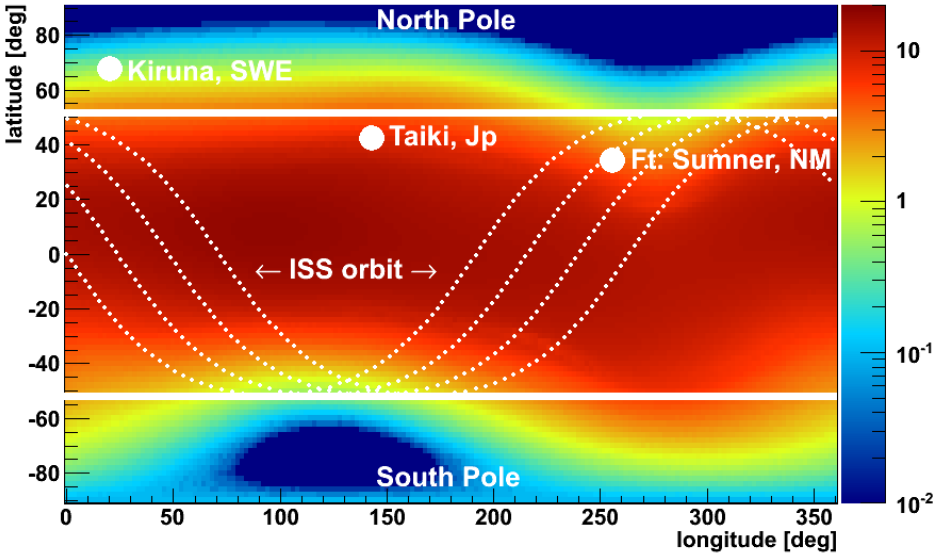
Readout

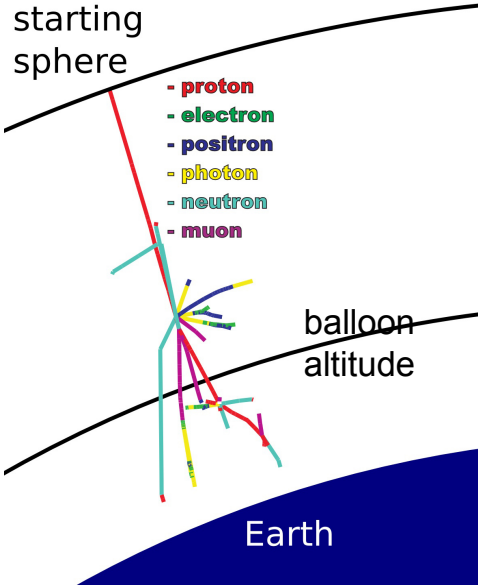


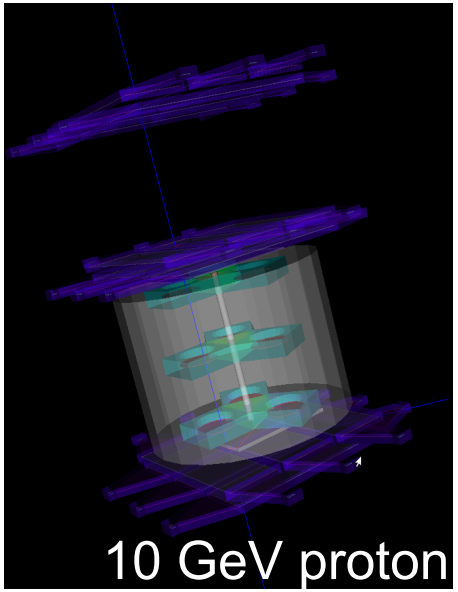
- **Si(Li) tracker** will be read out by **NCT** (Nuclear Compton Telescope) **card cages** from the 2005 flight:
  2×72 channels
  high gain: 0-2MeV
  low gain: 0.1-100MeV
- **TOF** readout by **VME** crate
- **Flight computer: PC-104 stack**
  - communicates via Ethernet
  - store data on compact flash
  - send housekeeping, portion of data to ground
  - commanding

Simulation

cosmic antideuterons	atmospheric simulation	detector simulation	exotic atomic physics







Atmospheric and geomagnetic simulations with PLANETOCOSMICS based on GEANT 4.9.2

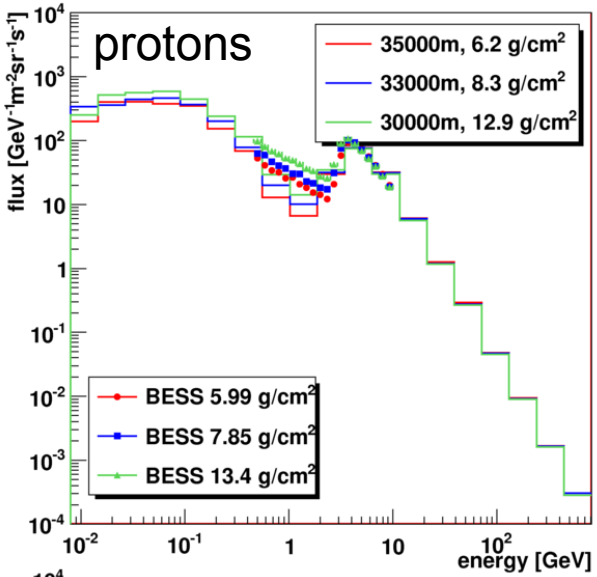
- geomagnetic simulations as a function of position and direction
- atmospheric fluxes is in good agreement with measurements

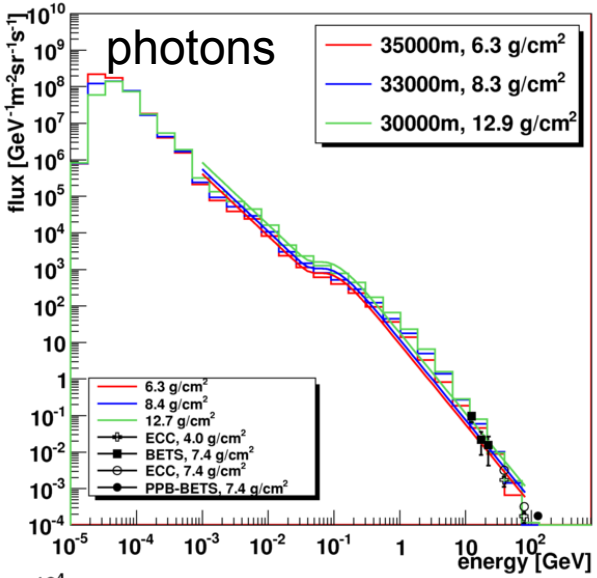
Instrument simulation with GEANT, ROOT output format:

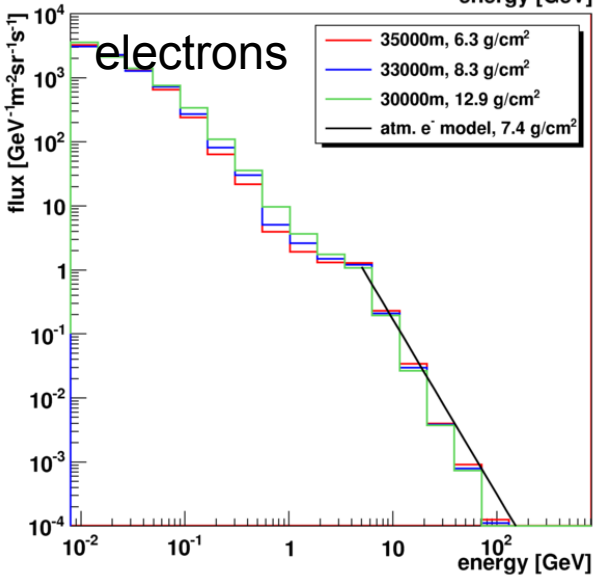
- electromagnetic, hadronic, optical physics are running
- basic components are implemented, frames and structures must be added
- ion and exotic physics are under development

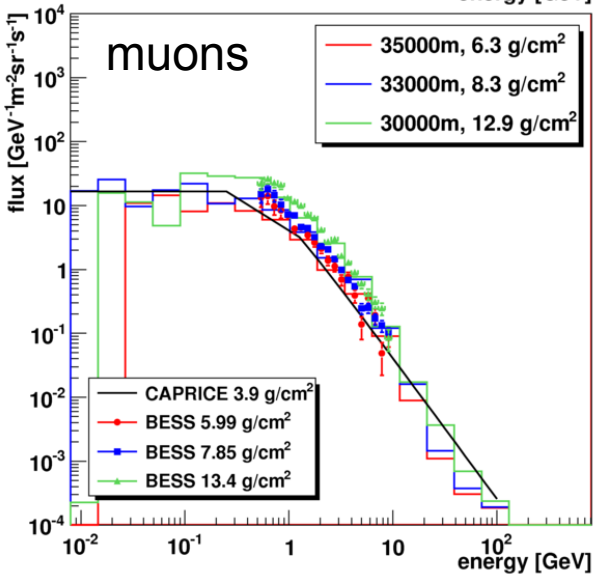
more details at Geant4 Space Users Workshop 2010, Seattle

Validation of simulation



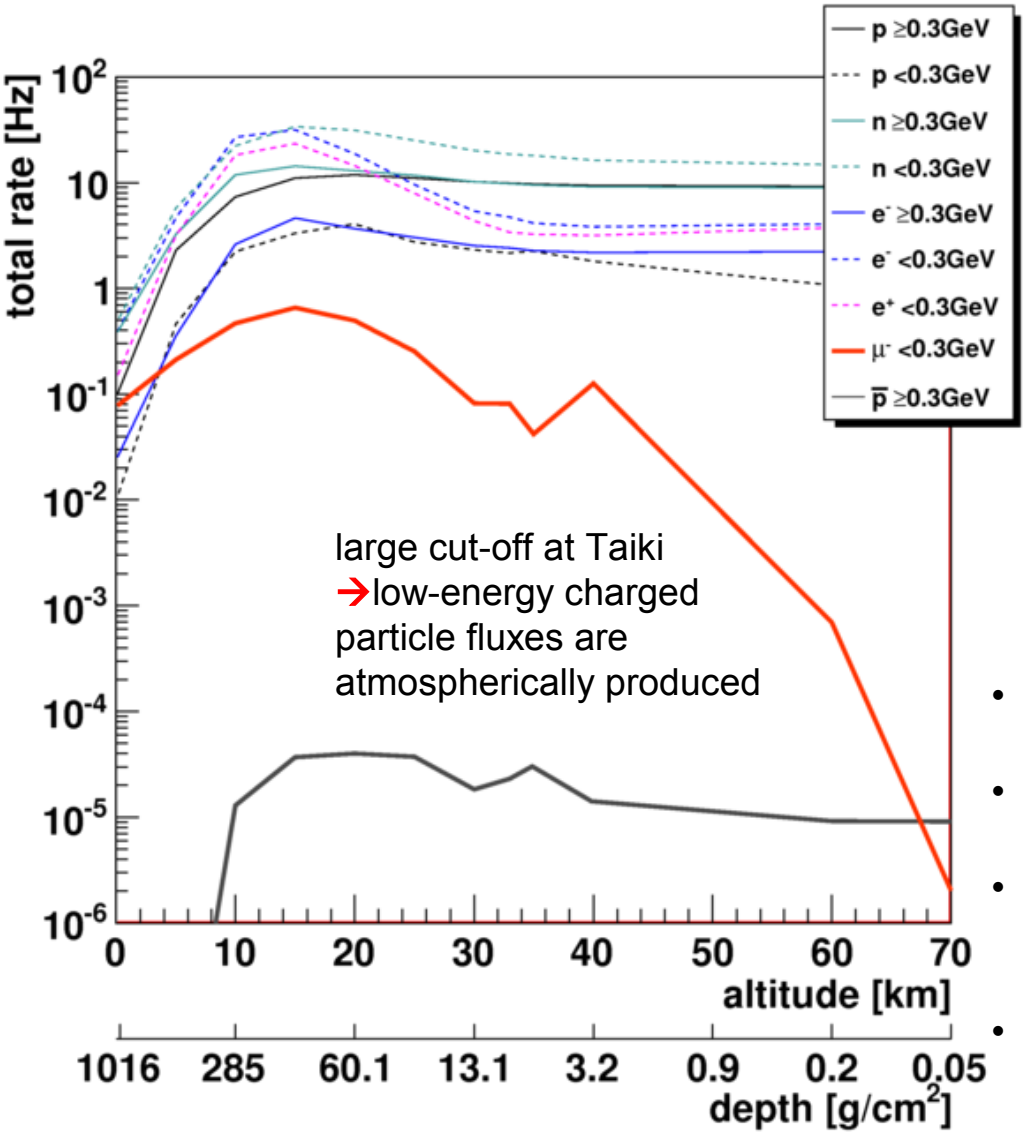


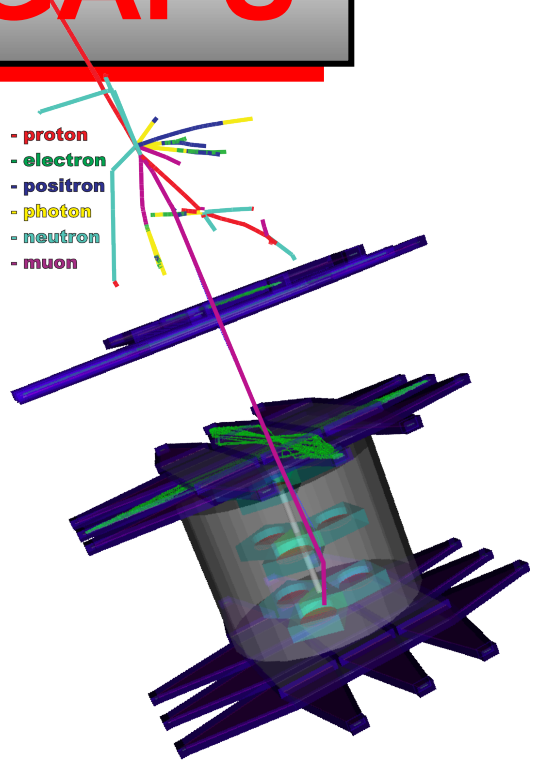




- particle fluxes (ATM+CR) for certain particle types at different altitudes
- comparison of atmospheric simulations shows **good agreement** with BESS, ECC, BETS, PPB-BETS, CAPRICE measurements and models
- simulations may need check for light ion physics

Particle rates for pGAPS



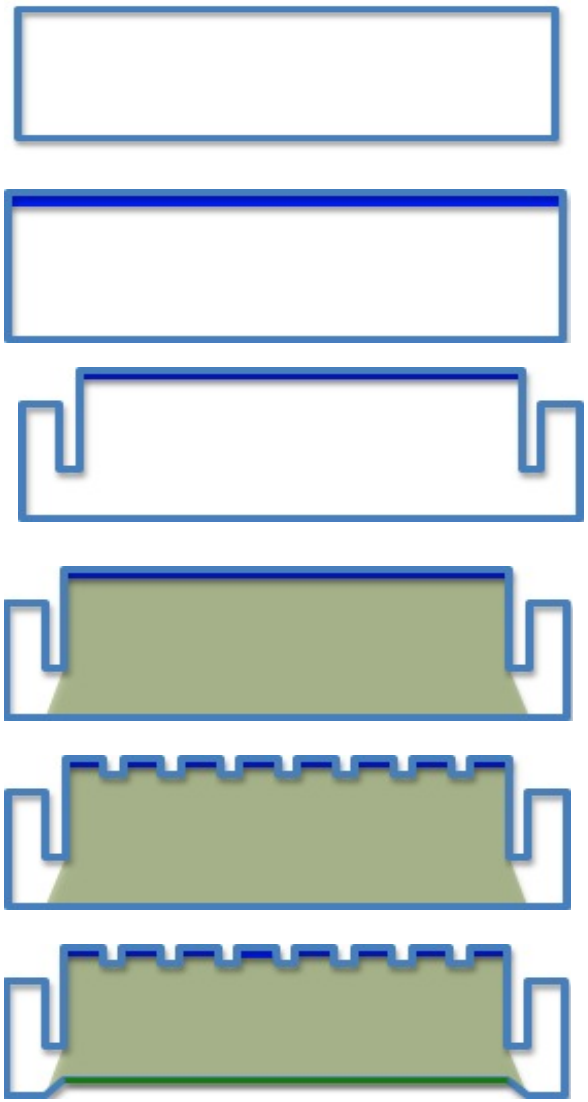


- particle rate at 33km at Taiki: **total ~10-50Hz** (accep.: 0.054m^{2}sr)
- strongest backgrounds by neutrons, protons, electrons, positrons
- no antiprotons will be measured, but muons might be used to create muonic atoms to study exotic physics at flight
- exotic atomic events faked by x-ray coincidences with cosmic rays in the detector need to be studied **carefully!**

Conclusion & Outlook

- measurement of low-energetic **antideuteron flux** is a promising way for **indirect dark matter search** (probably even more than positrons and antiprotons)
- GAPS is specifically designed for low-energetic antideuterons with a unique detection technique using the creation of **exotic atoms**
- GAPS is planned to have (U)LDB flights from **South Pole starting from 2014**
- prototype experiment is currently under construction and a flight is scheduled for **Summer 2011 from Taiki, Japan**:
  - hardware development: Si(Li), TOF, readout, structure, thermal model
  - simulation of particle fluxes in atmosphere and detector

Si(Li) fabrication



1. Cut from the ingot

2. Evaporate Lithium

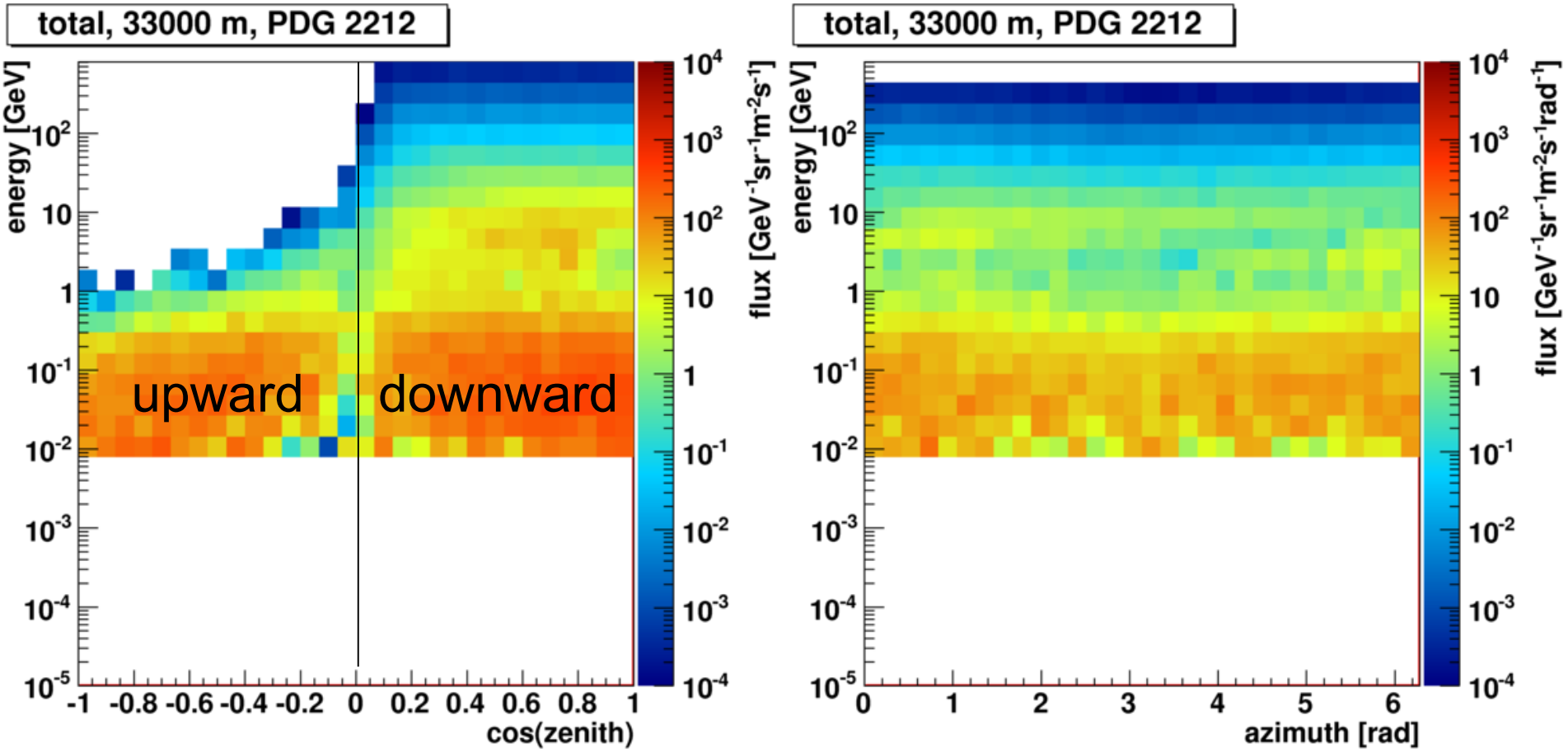
3. Produce the deep groove and mesa (optional)

4. Drift the Li into the silicon

5. Make strips and guard ring

6. Etch the back (shallow well) and evaporate Au

Proton fluxes at Taiki



- total proton fluxes (cosmic + atmospheric) at 33km altitude
- upward fluxes have smaller energies
- no dependence on azimuth angle