GAPS: Searching for Dark Matter using Antinuclei in Cosmic Rays

WIN 2019, Bari, 3-8 June 2019

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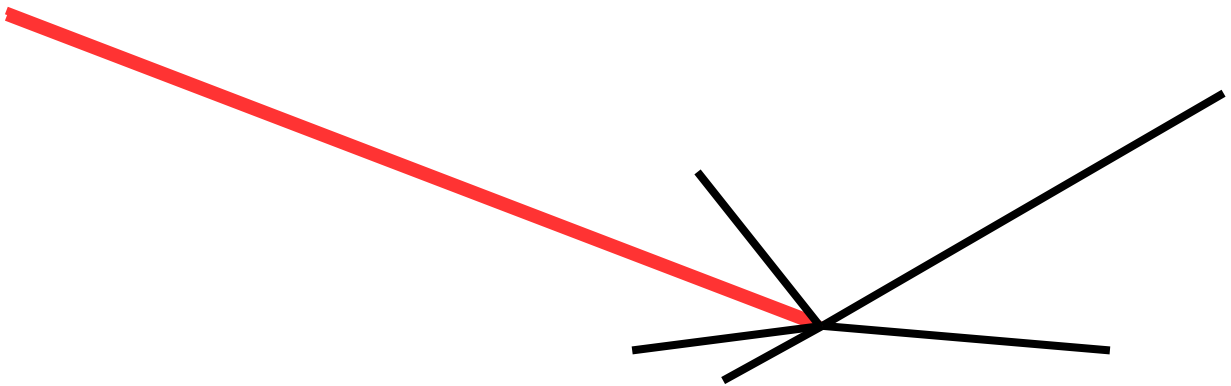
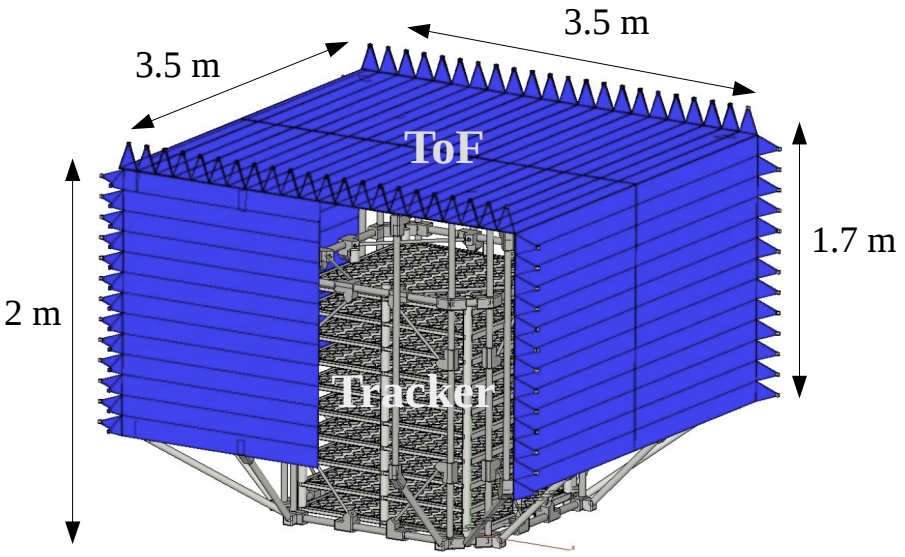
On behalf of the GAPS collaboration



The GAPS experiment

- GAPS is a balloon flight experiment for low energy (<0.25 GeV/n) **antideuteron in cosmic rays** (CRs) that would result from certain dark matter (DM) interactions
- GAPS will also conduct a high statistics measurement of low energy **antiproton** and will search for **antihelium**
- The first of a series of flight from Antarctica is expected for late 2021
- The detector is composed by a ToF system and a Tracker made of 10 plane of SiLi detector
- GAPS uses a detection technique based on exotic atom formation and subsequent decay and annihilation with X rays and pions emission

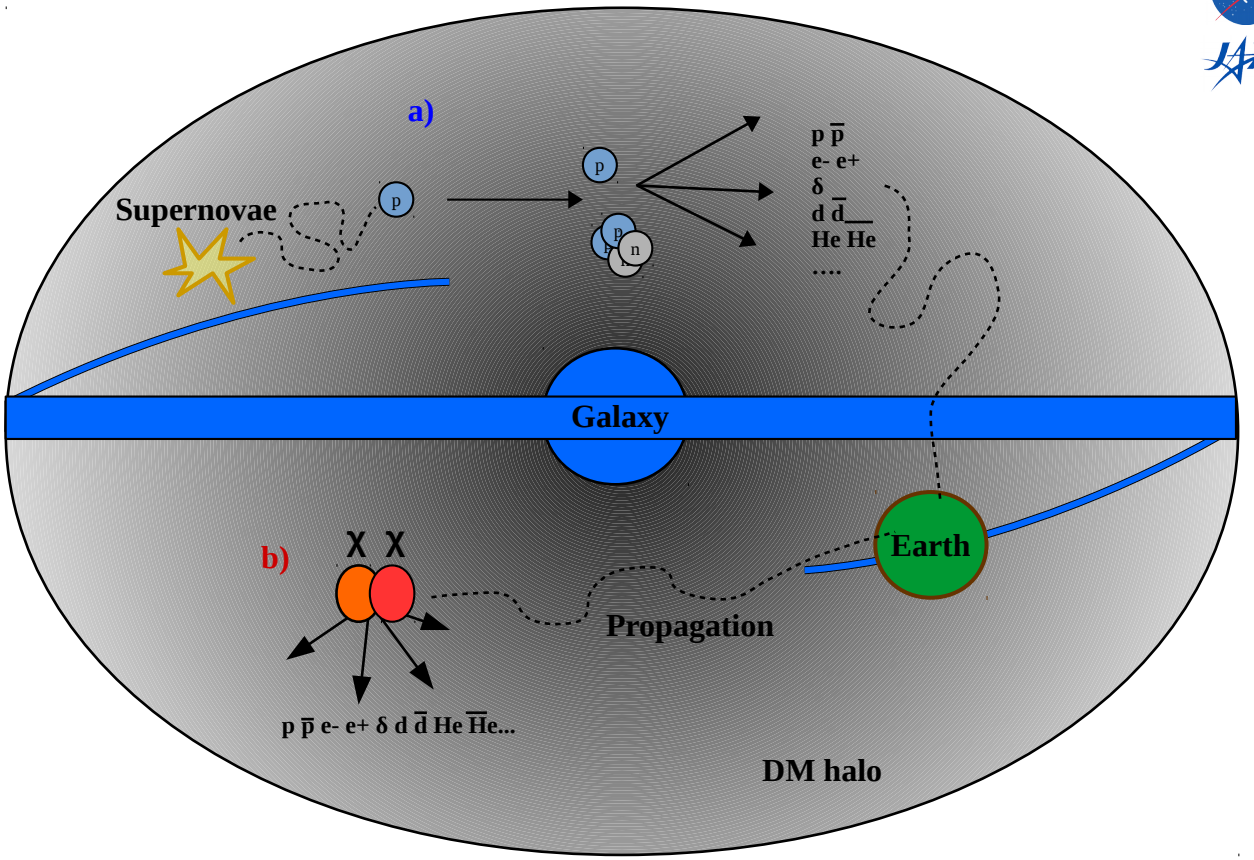


Antimatter production in CRs

a) Primary CRs interacting with interstellar medium (IM)

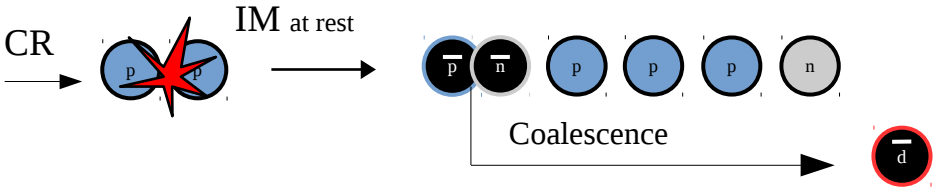
b) Decay or annihilation of DM particles in galactic halo (beyond standard model theories)

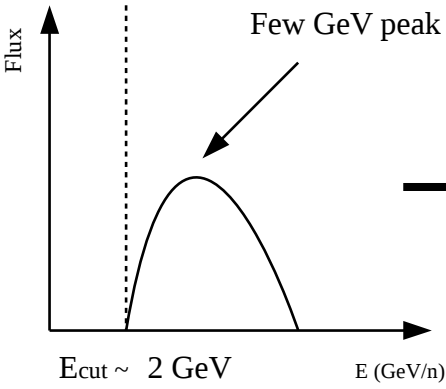
Antimatter from DM is expected to be a significant fraction (antiproton) or higher (antideuteron) with respect to secondaries CRs



Antideuteron production

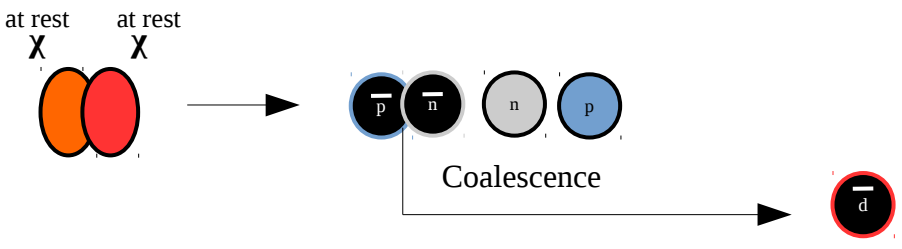
Secondary antideuteron

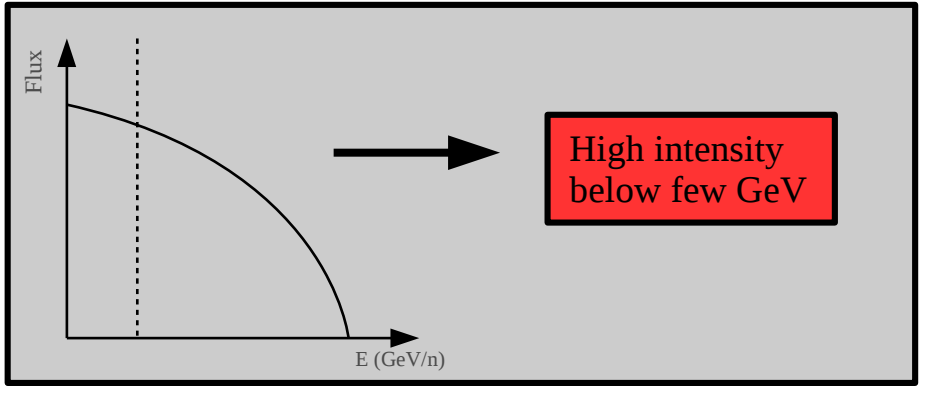




Strongly suppressed below few GeV

Primary antideuteron





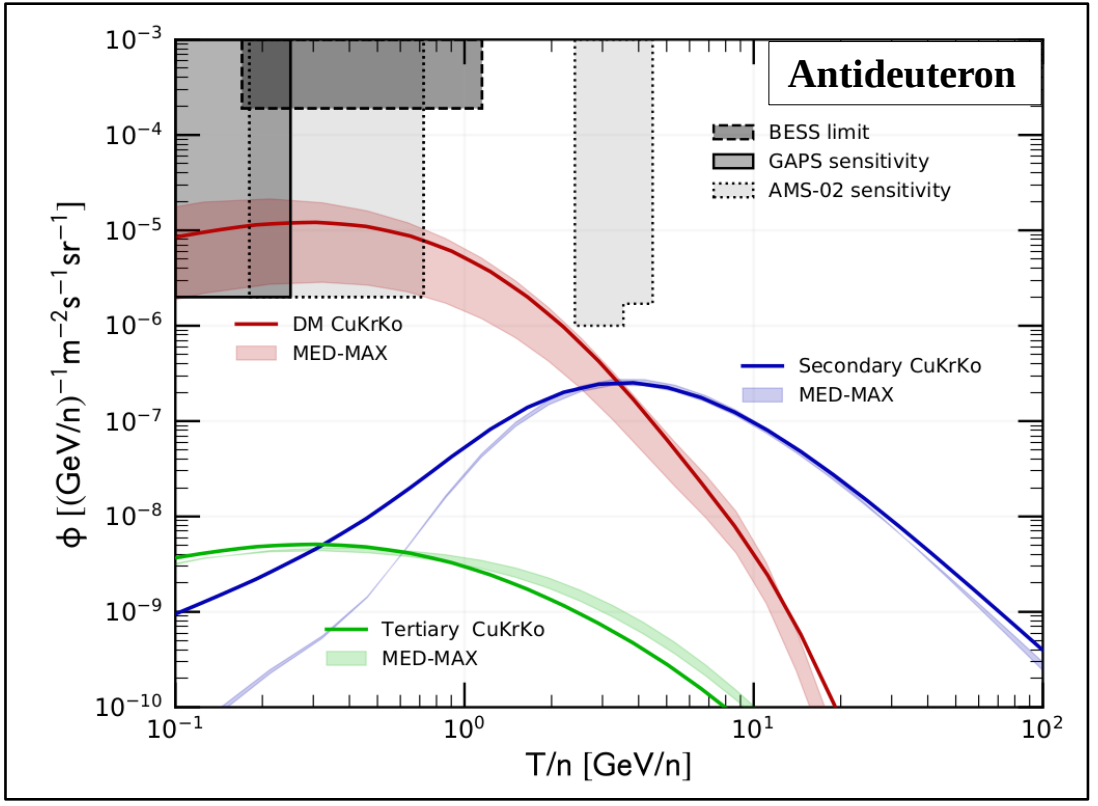
High intensity below few GeV

Why antideuteron for DM search?

- Models predict antideuteron from DM decay or annihilation to be order of magnitude higher than the secondaries

Even a single antideuteron detection with GAPS would point to new physics

Korsmeier et al.,Phys.Rev.D97,103011(2018)



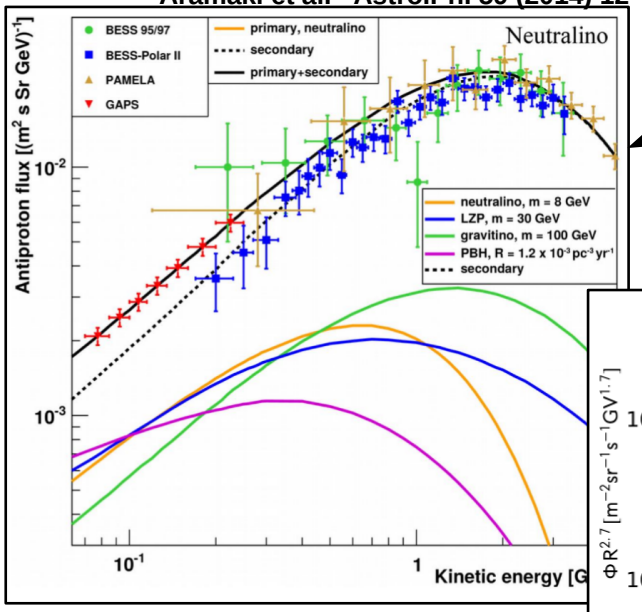
Antiproton from DM

- Models predict antideuteron from DM decay or annihilation to be order of magnitude higher than the secondaries

Even a single antideuteron detection with GAPS would point to new physics

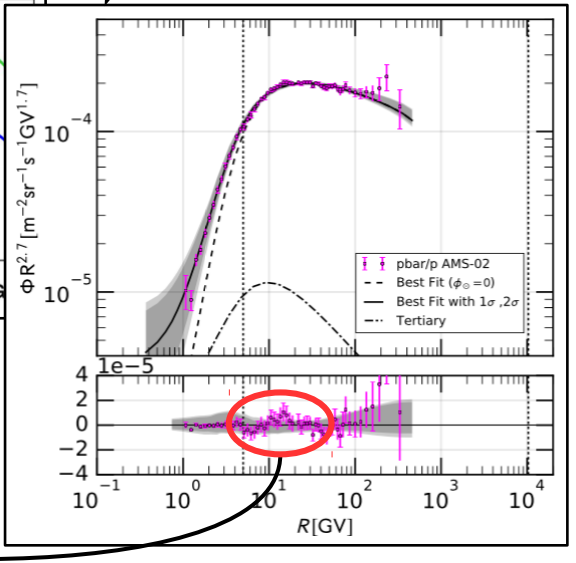
- Antiproton signal from dark matter is expected to be a fraction (10-30%) of the secondary from CR interaction.

Aramaki et al. –Astro.Ph. 59 (2014) 12



Antiproton

Cuoco et al., arXiv:1610.03071



Possible excess in AMS02 data at 10 GV

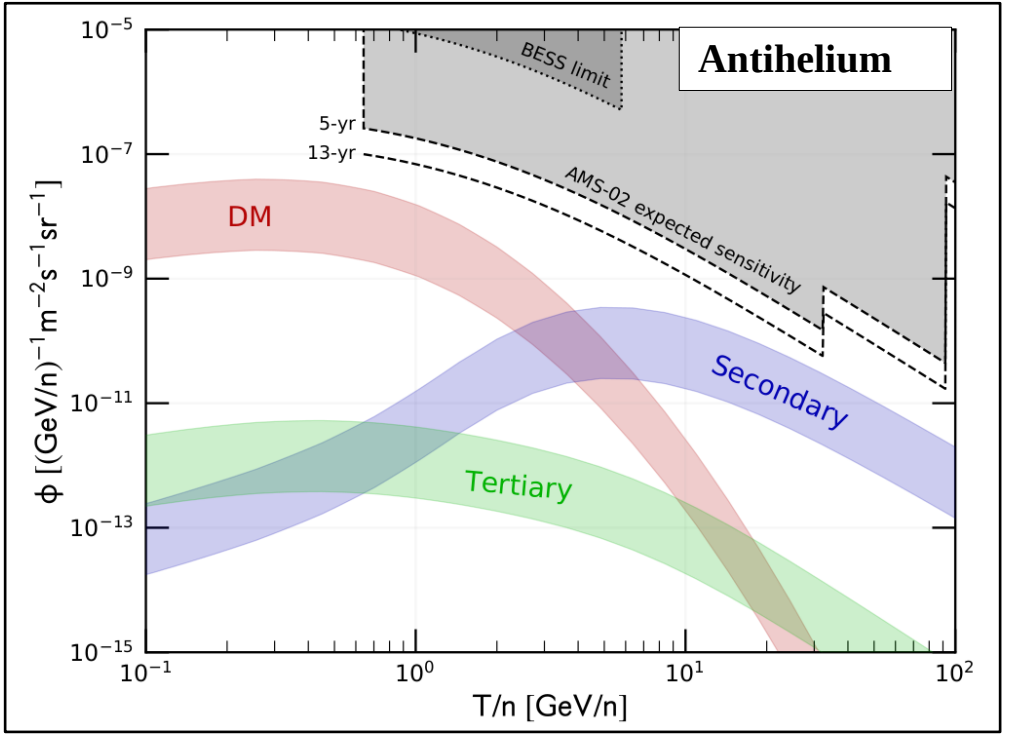
AntiHelium from DM

- Models predict antideuteron from DM decay or annihilation to be order of magnitude higher than the secondaries

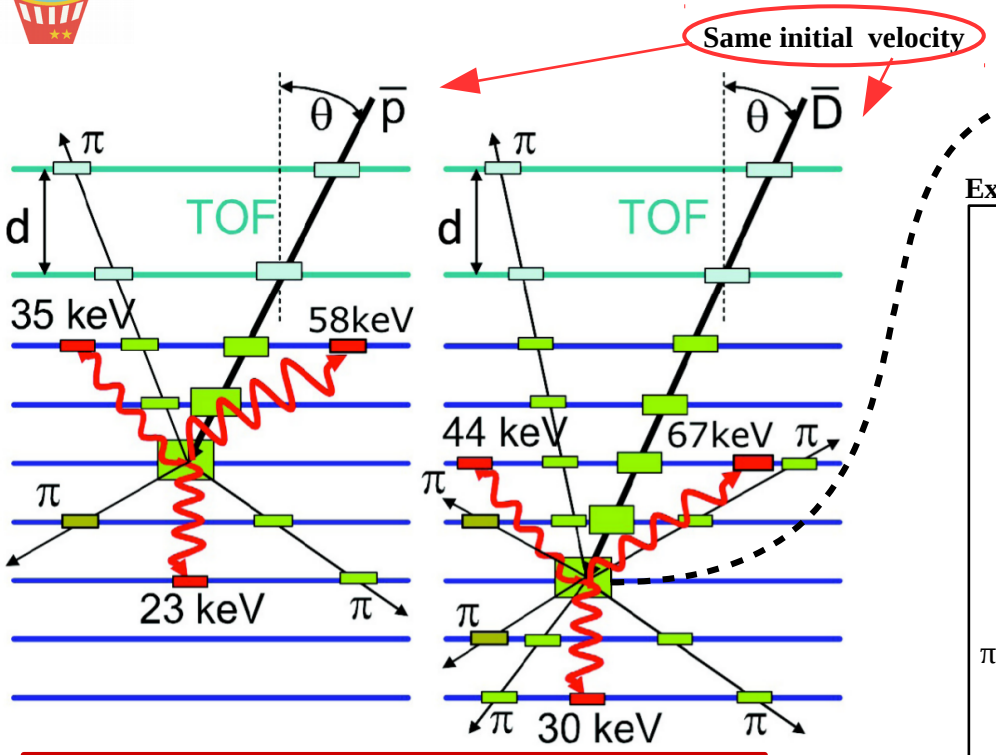
Even a single antideuteron detection with GAPS would point to new physics

- Antiproton signal from dark matter is expected to be a fraction (10-30%) of the secondary from CR interaction.
- Antihelium is also expected but with much lower intensity

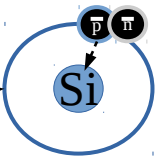
Korsmeier et al.,Phys.Rev.D97,103011(2018)



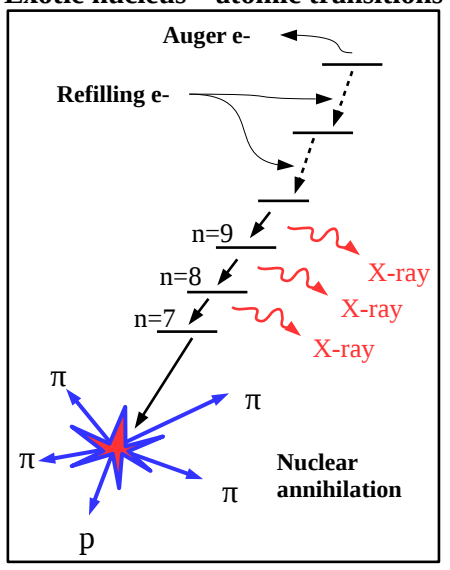
GAPS detection tecnique



Stopping particles inside tracker volume



Exotic nucleus – atomic transitions

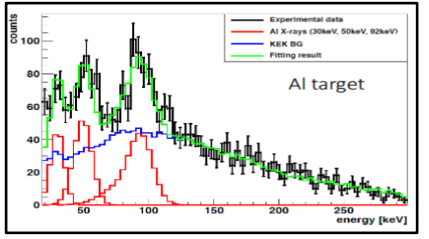


$$E_{X-ray} = (zZ)^2 \frac{M}{m_e} R_H \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

AntiD - antiP identification

- Time of flight
- Depth - multiple dEdx
- X-rays emission
- Pion multiplicity

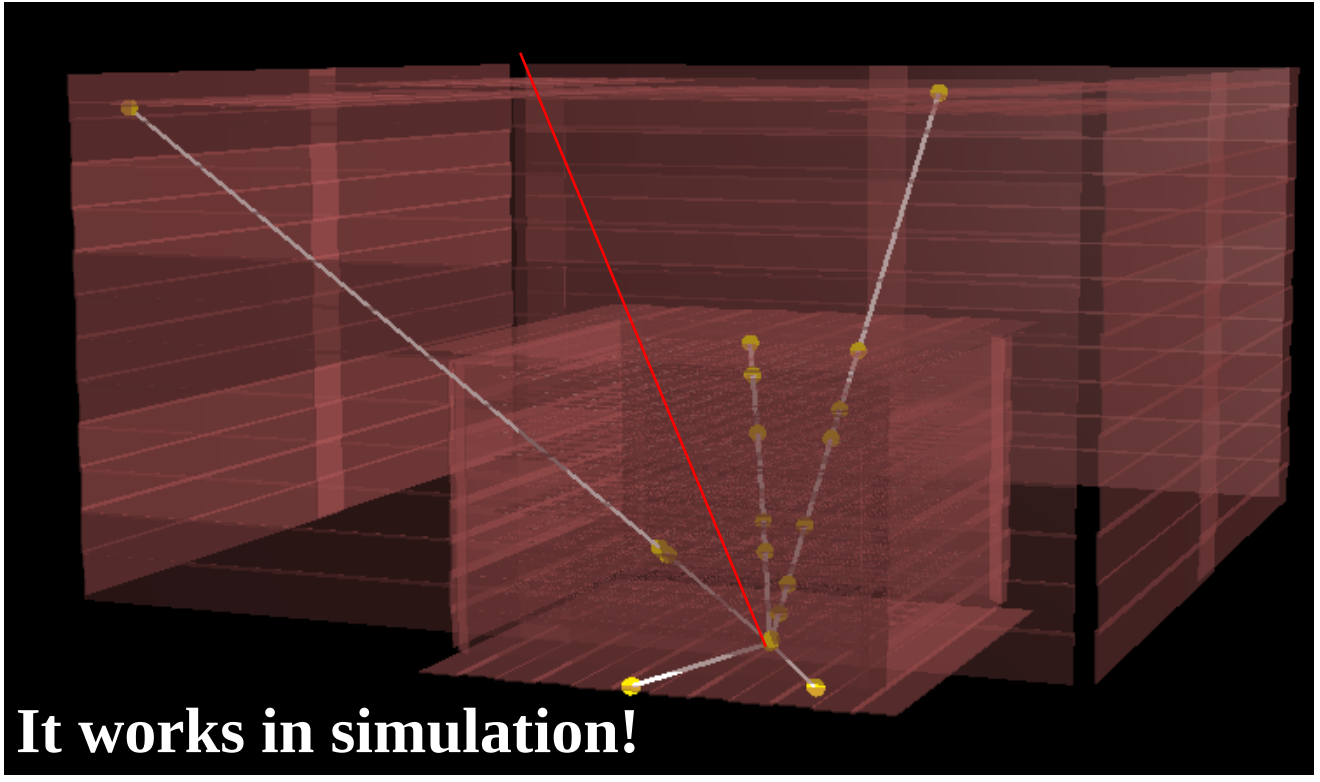
Aramaki et al. Astro.Ph. 49 (2013) 52



X-raymeasured at KEK in 2004/2005

Antideuteron event with GAPS

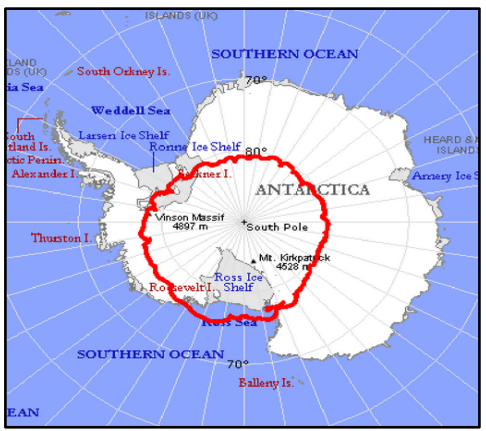
Simulated antideuteron event: beta = 0.4

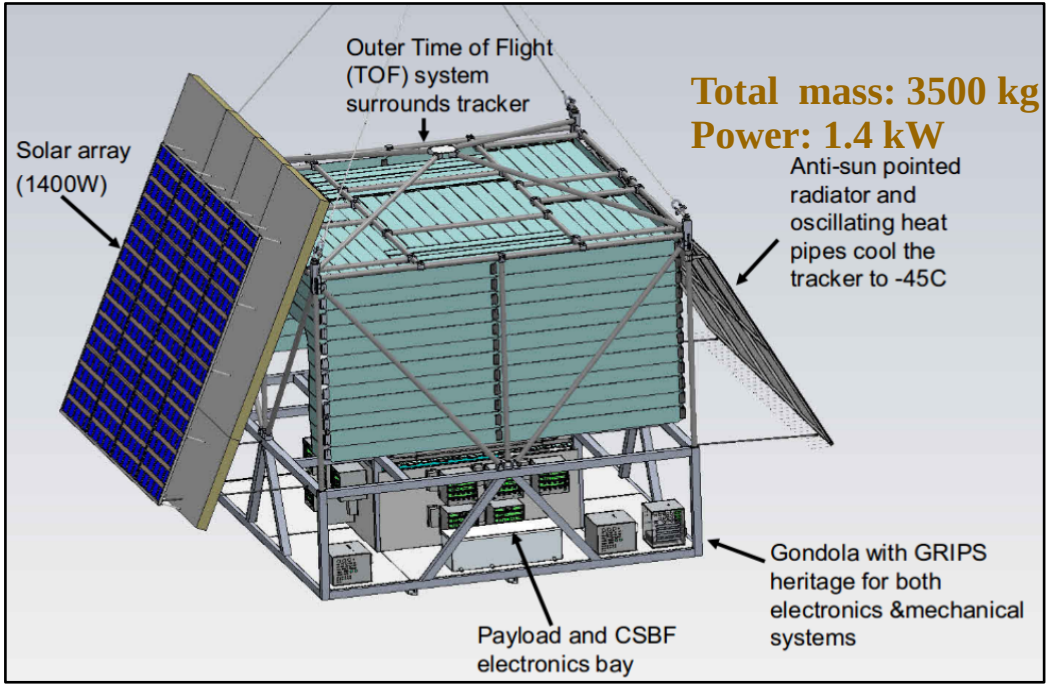


Instrument overview

General requirements

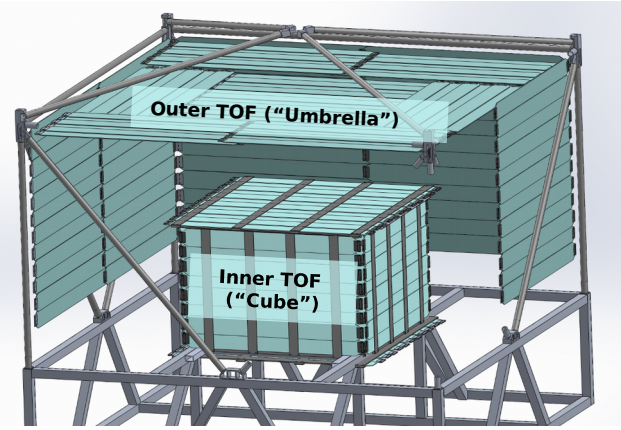
- Large acceptance
- Restrictive trigger
- Velocity measurements
- Background rejection
  - X-rays detection
  - Track primary
  - Track secondaries





1 LDB flight (35 days) → **high-statistic antiP:** 1500 (100< BESS, 7 PAMELA)
3 LDB flights (105 days) → **antiD sensitivity**: $2 \cdot 10^{-6}\, m^{-2} s^{-1} sr^{-1} GeV/n^{-1}$

TOF system



1.6-1.8m

196 plastic scintillator

Si-PMs (x6)
Better performance
Save mass, power, cost

Item	Value	Comments
TOF resolution Velocity resolution	σ_T < 400 ps $\Delta\beta/\beta$ < 0.12	Laboratory
Charge resolution	$(\sigma_q)_{68\%}$ < 0.20e	Initial study
Position resolution	σ_x = 3.0 cm (length) σ_y = 4.6 cm (width)	Laboratory
Angular resolution	σ_θ < 3° (typical)	

Trigger based on:

- **Beta**: rejects high beta particles.
- **Charge**: rejects high Z particles.
- **Hit**: count the number of paddles hit.

Expected Trigger Rates (H, He, C)
Raw : 82,000 Hz → After cuts : 550 Hz

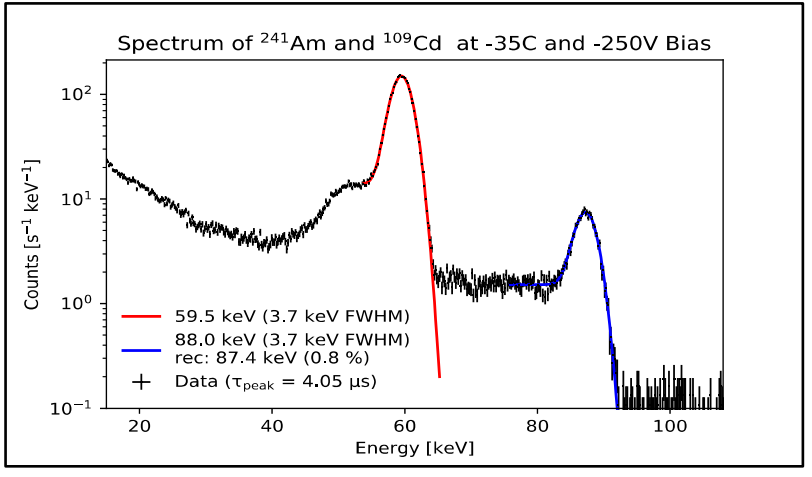
Antiprotons Trigger	36%
Antideuterons Trigger	76%
Proton Rejection Factor	>2500

1.8m SiPM paddles

Tracker system

Requirements

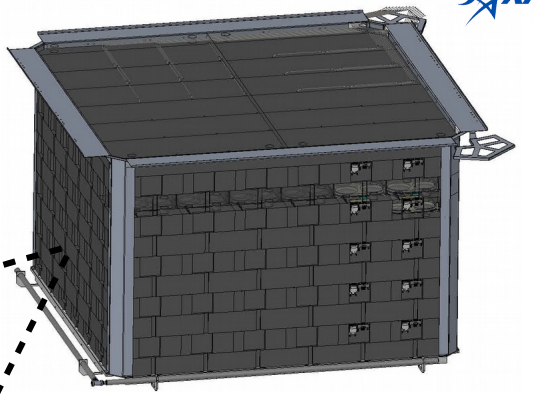
- 4 keV FWHM resolution (100 KeV)
- Large area, relatively high temperature
- Leakage current < 5 nA/strip
- Huge dynamical range (~keV → 100 MeV)
- Low cost, high-yield fabrication process



Li ions compensate impurities in boron-doped Si, creating extended charge-free regions

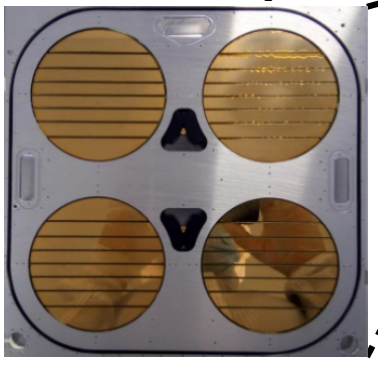
Lithium-drifted Silicon

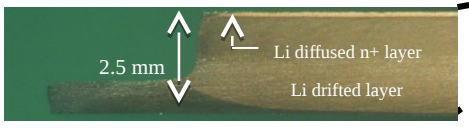
- Cylindrical detector
- -43C operational T
- 1100 SiLi detectors
- 10 plane

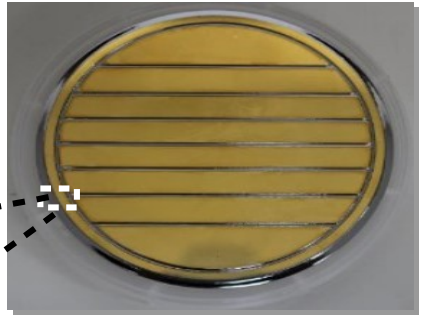


8 strips

6x6 module each plane







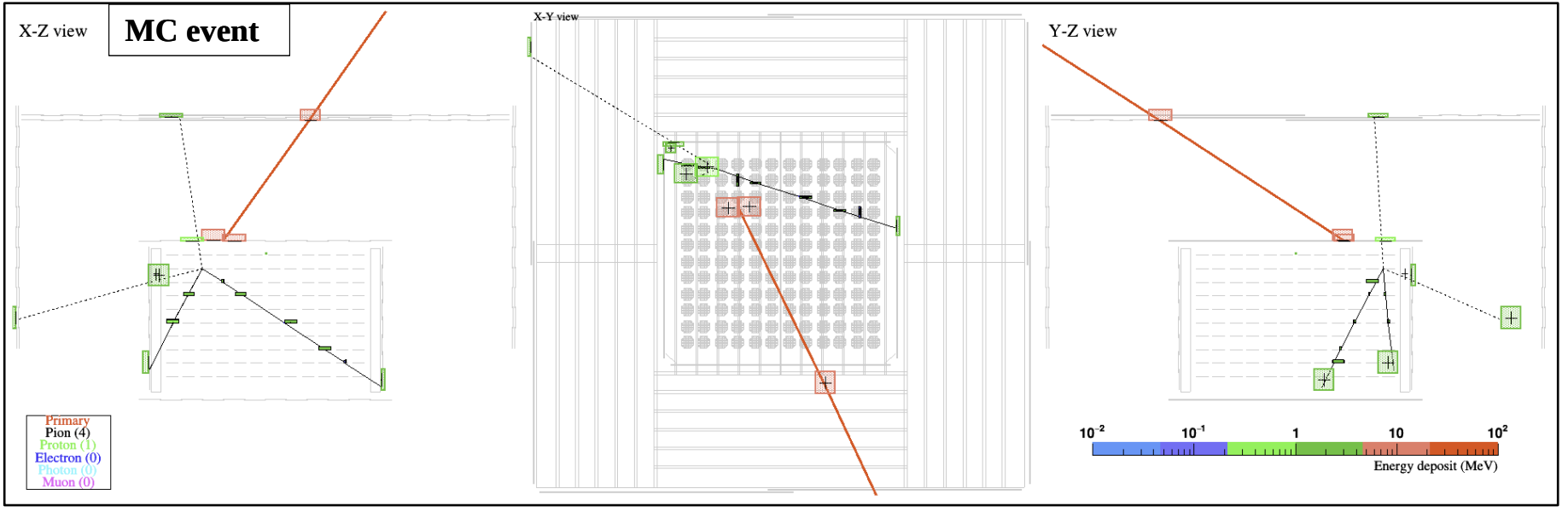
10 cm

Simulation and reconstruction

Vertex reconstruction based on:

- Kalman-like filter for primary reconstruction
- Hough transformation for secondaries
- Vertex reconstruction with minimization

Fully detector simulation with (GEANT4)



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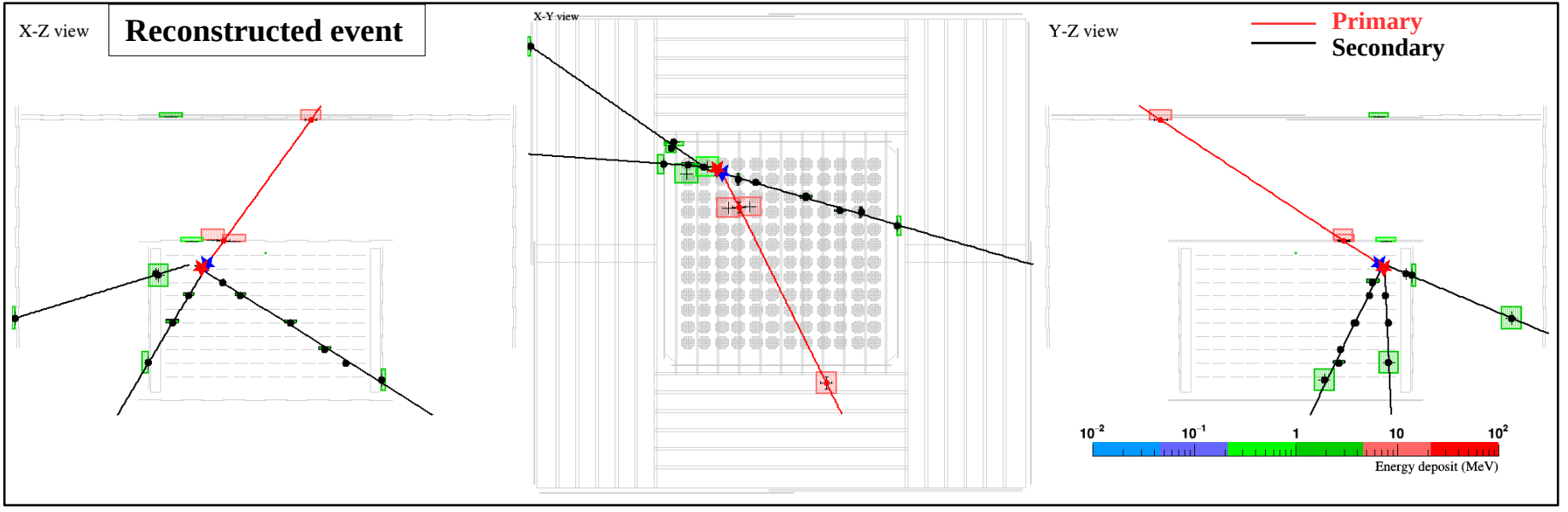
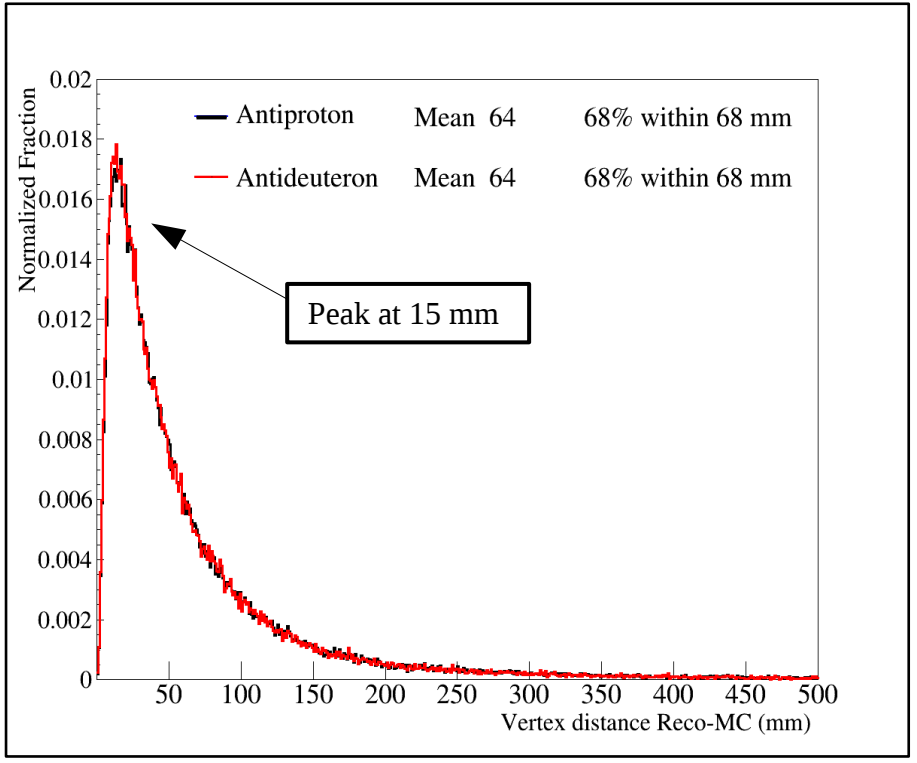
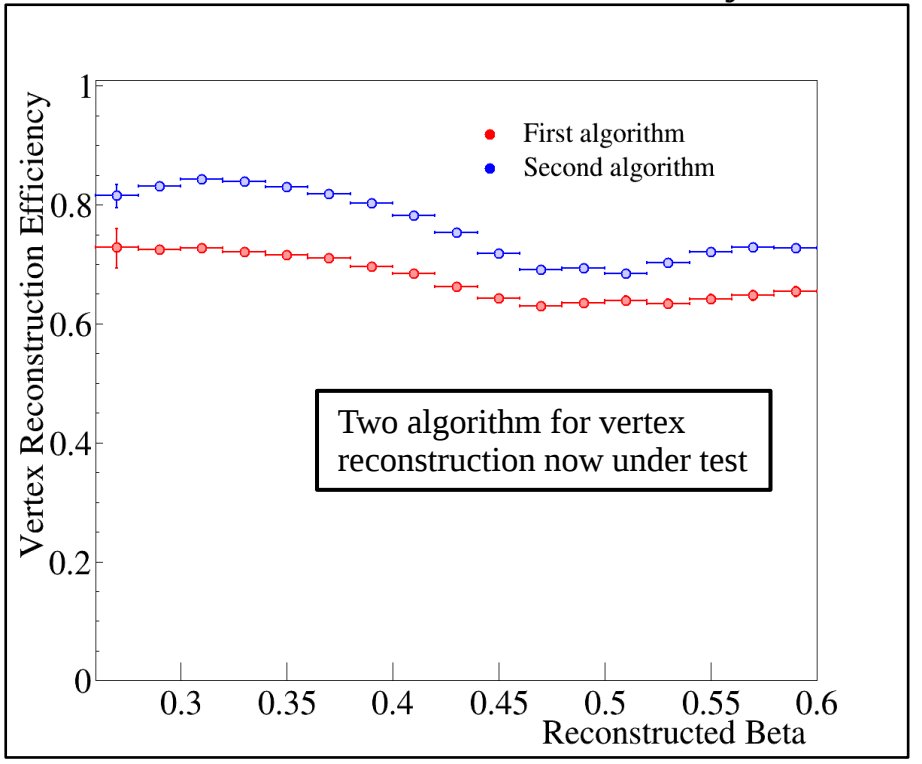


Reconstruction performances

Vertex resolution



Reconstruction efficiency



Acceptance and identification

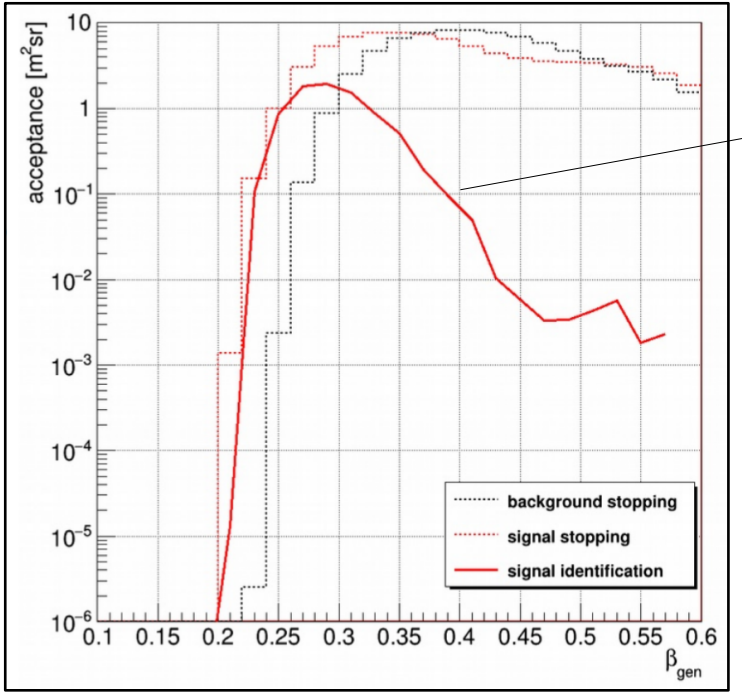
The main background for antideuteron identification is antiprotons ($\bar{p}/\bar{d}$ ~ 10^3)

Identification

Multivariate approach (Likelihood):
- Depth vs beta
- Number of secondaries
- X-rays
- "Calorimetric" approach
  - Total hit number
  - Total energy deposition
  - Energy pattern deposition
  - ...

Neural network (developing)

Machine learning (developing)

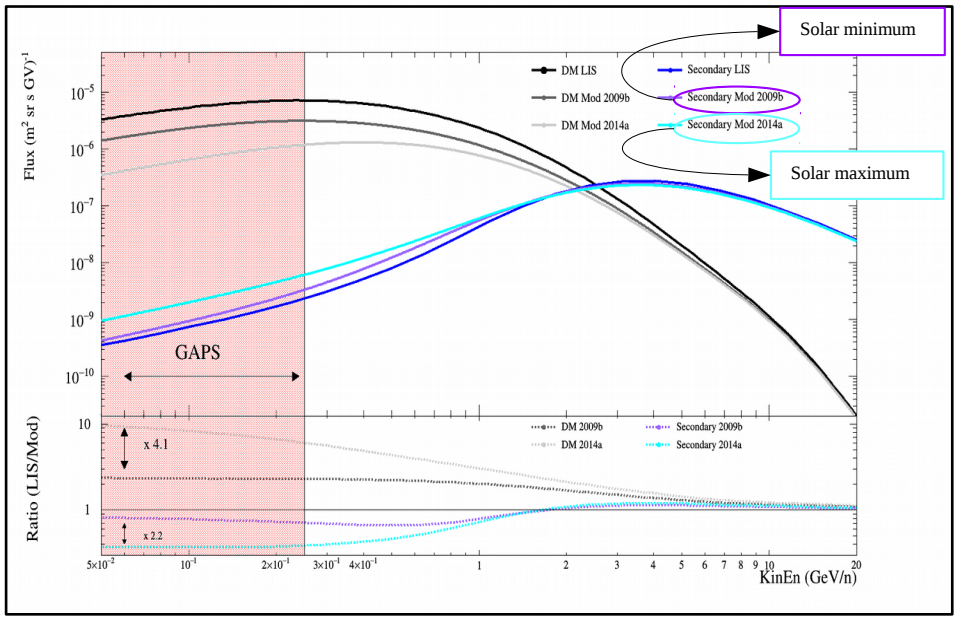


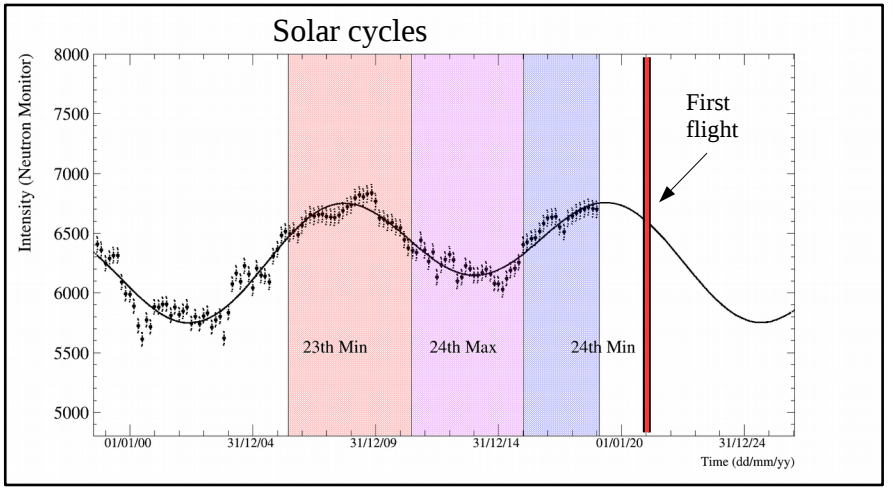
Acceptance for antideuterons after applying identification cuts (10^5 antiP rejection)

Under study:
Identification using reconstructed variable

GAPS and solar modulation

GAPS will measure antiP - antiD at energies where CRs are heavily affected by **solar modulation**





Precise modeling of the solar modulation has to be taken into account to interpret the data.

3D numerical model for CRs propagation inside heliosphere: factor 4 of intensity variation for DM antiD between solar minimum and maximum

Conclusions

- GAPS will search low energy (<0.25 GeV/n) antideuteron in cosmic radiation as indirect signal of dark matter.
- This is a “background free” channel since the secondary antideuteron from CRs interaction is expected to be orders of magnitude lower.
- Complementary detection technique with respect to magnetic spectrometer with exotic nucleus formation and annihilation.
- GAPS will also perform the highest statistical antiproton measurement at these energies and will search for antihelium.
- Construction is proceeding along with simulation and identification studies.
- First flight late 2021 from McMurdo station.