The General AntiParticle Spectrometer - Search for Dark Matter using Cosmic-ray Antinuclei

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on behalf of the GAPS Collaboration

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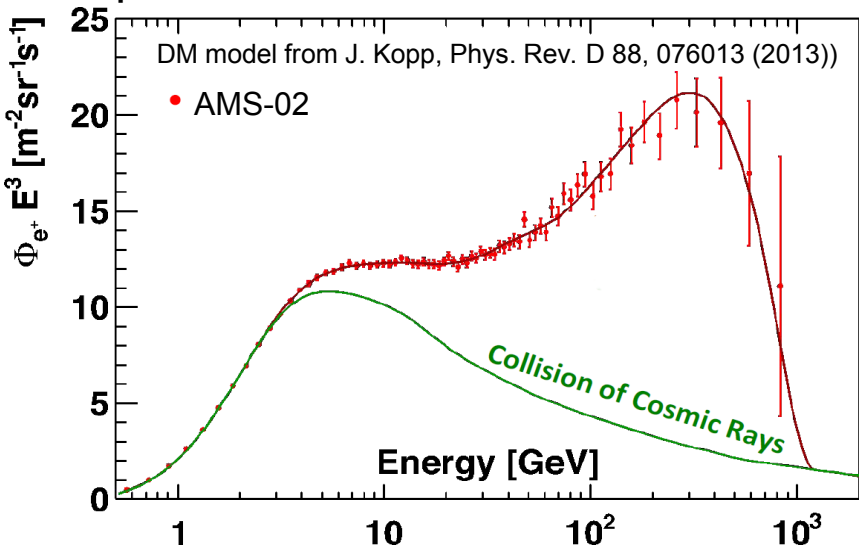
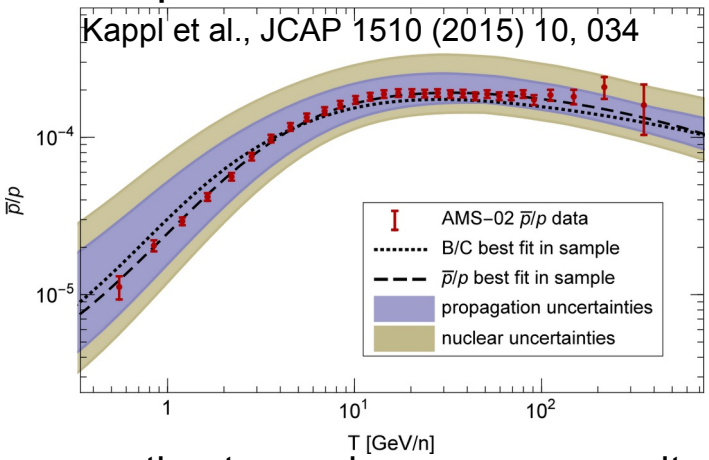
Dark matter signal in cosmic rays?

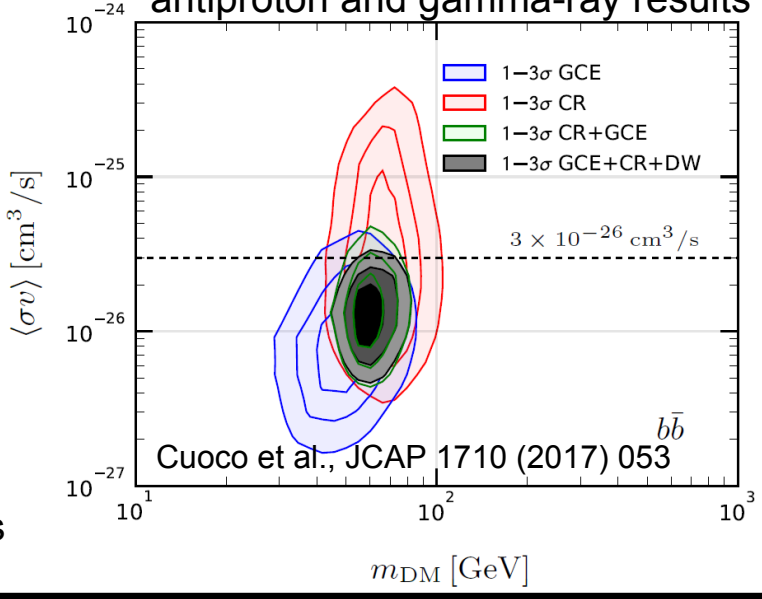
positron



antiproton



antiproton and gamma-ray results



- unexplained feature in positrons:
  - astrophysical origin → pulsars
  - SNR acceleration
  - **dark matter annihilation**
- combined fit with antiproton and diffuse gamma-rays from the Galactic Center → 80GeV DM particle?

- understanding astrophysical background is a challenge better constraints on cosmic-ray propagation and astrophysical production are needed

Status Cosmic-ray Antinuclei Searches

- A **small $\bar{p}$ excess** in AMS-02 data above secondary background predictions at R~10 GV was found in various studies
  → significance level unclear

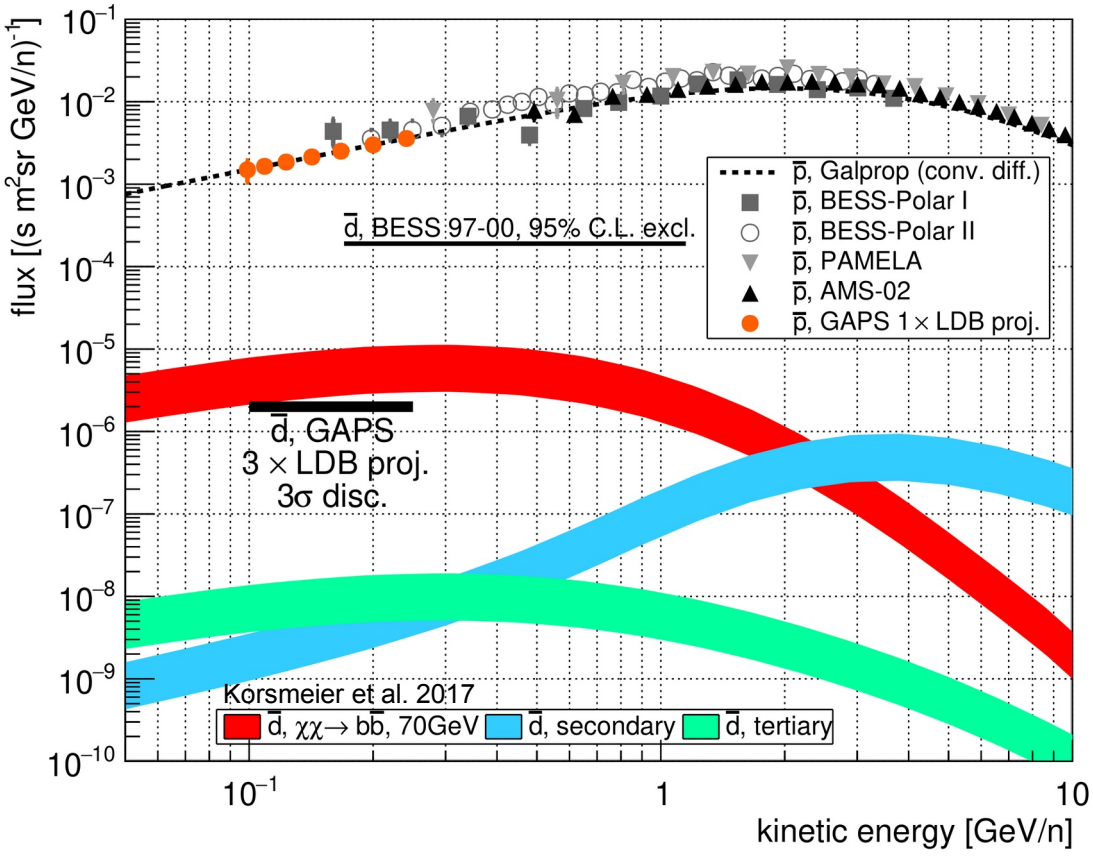
- AMS-02 reported that **several $\overline{He}$ candidate events have been observed**
  → interpretations are actively ongoing

- Antiproton and antihelium both constrain antideuterons
  → **no explanation of antihelium should overproduce antiprotons and antideuterons**

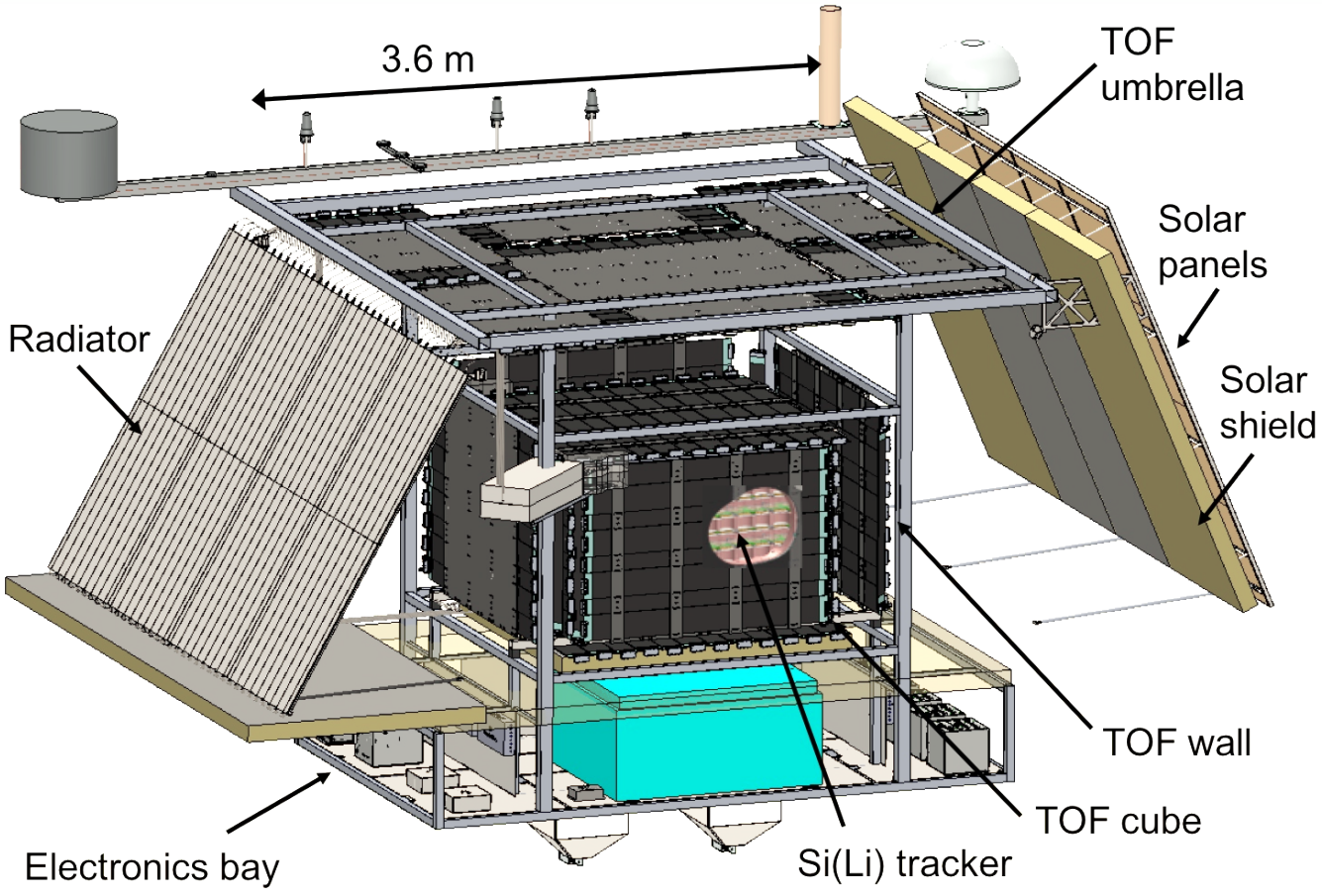
- **Possible antihelium candidate explanations include:**
  - Secondary astrophysical background
  - Dark matter annihilation or decay
  - Nearby antistar: at distance of ~1pc

- **Search for antinuclei with independent technique is critical**

- **Just out:** Review based on 2nd Cosmic-ray Antideuteron Workshop "Cosmic-ray Antinuclei as Messengers of New Physics: Status and Outlook for the New Decade" [JCAP08(2020)035, arXiv:2002.04163]



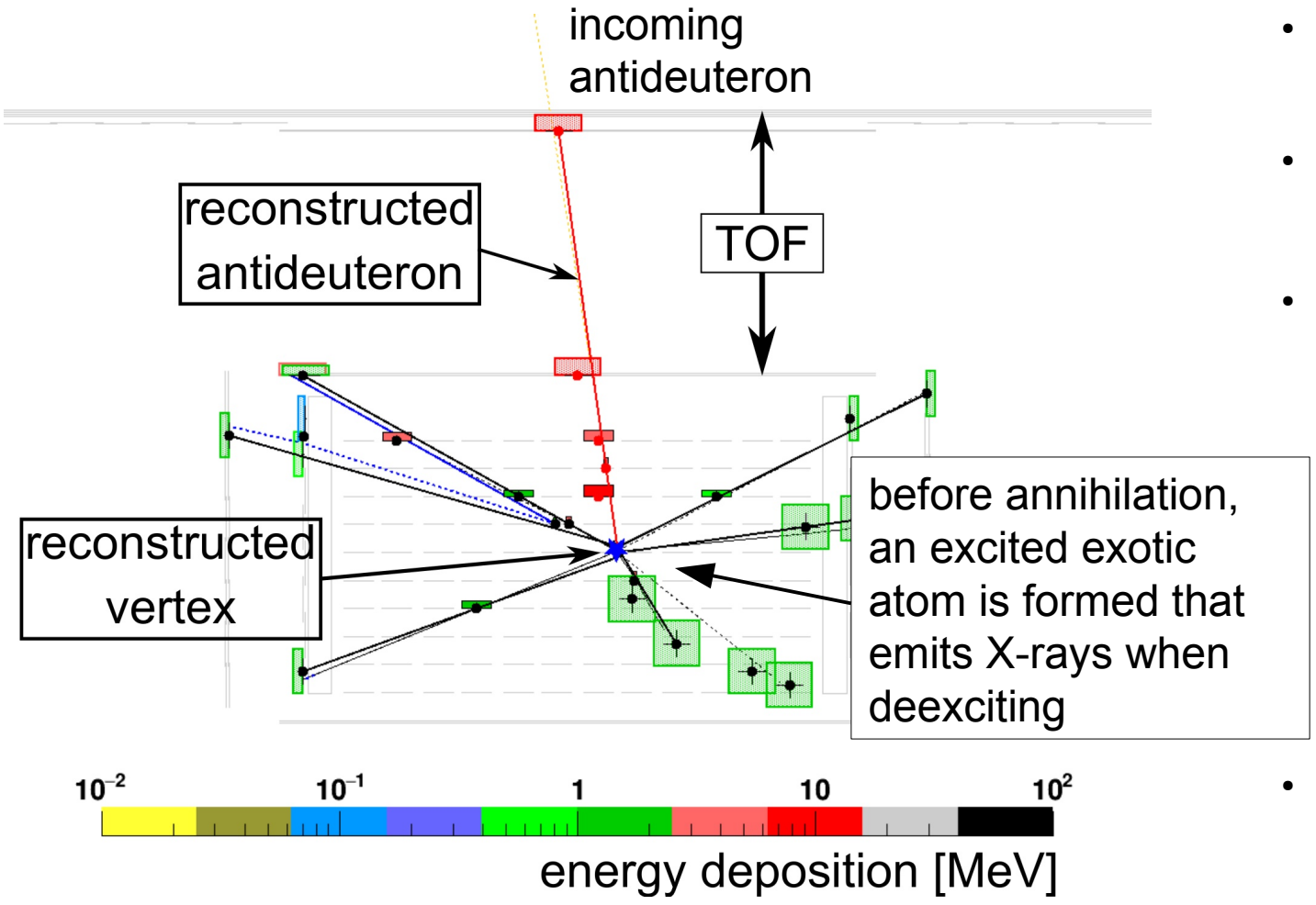
The GAPS experiment



mass: ~2,500kg
power: 1.3kW

- The **G**eneral **A**nti**P**article **S**pectrometer is the first experiment dedicated and optimized for low-energy cosmic-ray antinuclei search
- Requirements: long flight time, large acceptance, large identification power
- **GAPS will deliver:**
  - a precision antiproton measurement in an unexplored energy range <0.25 GeV/n
  - antideuteron sensitivity 1-2 orders of magnitude below the current best limits, probing a variety of DM models across a wide mass range
  - provide leading sensitivity to low-energy cosmic antihelium nuclei
- **GAPS is under construction**
  → first Long Duration Balloon flight from Antarctica in late 2022

GAPS Technique

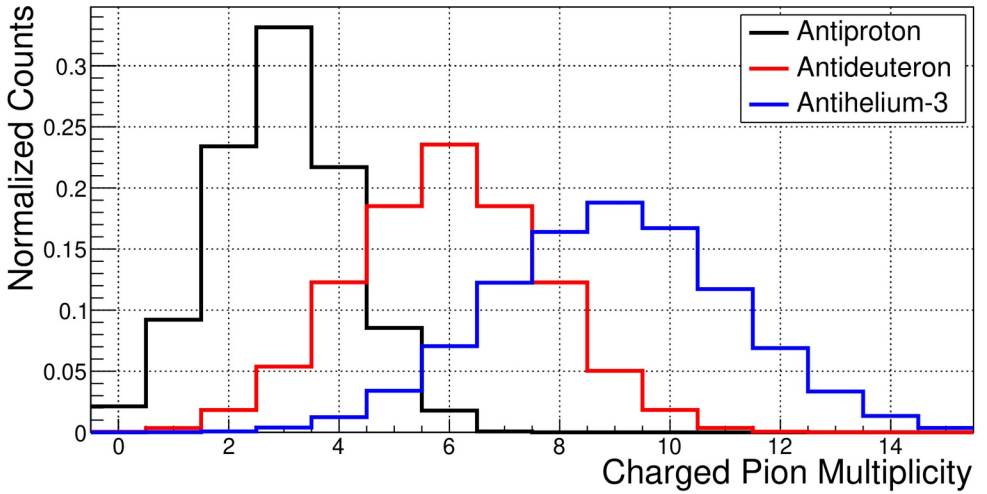


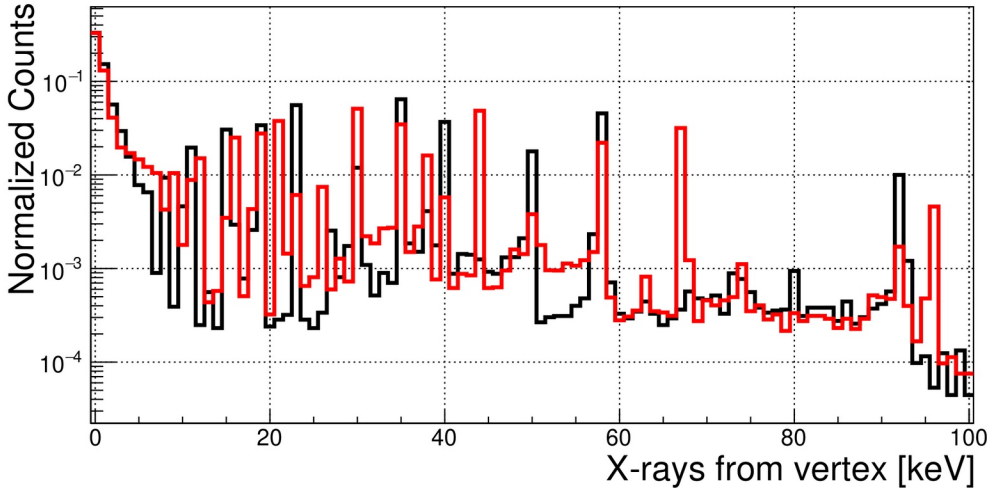
- antiparticle slows down and stops in material
- large chance for creation of an excited exotic atom (E_{kin}~E_I)
- deexcitation:
  fast ionization of bound electrons (Auger)
  → complete depletion of bound electrons
  Hydrogen-like exotic atom (nucleus+antideuteron) deexcites via characteristic X-ray transitions depending on antiparticle mass
- Nuclear annihilation with characteristic number of annihilation products

GAPS Identification Technique

GAPS identification technique uses:

- Energy loss in the detector of the antinucleus (depends on Z and β)
- Deexcitation X-rays from exotic atom
- Multiplicity of charged annihilation products

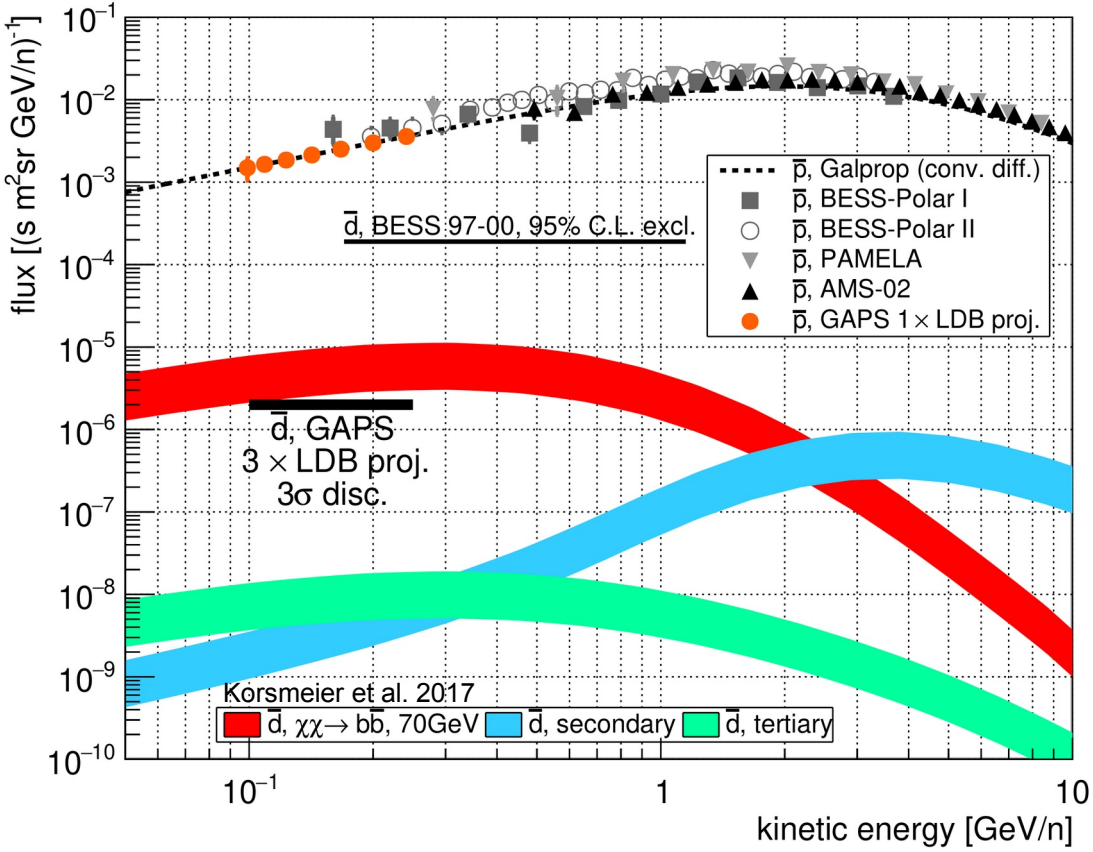




GAPS Antinuclei Sensitivity

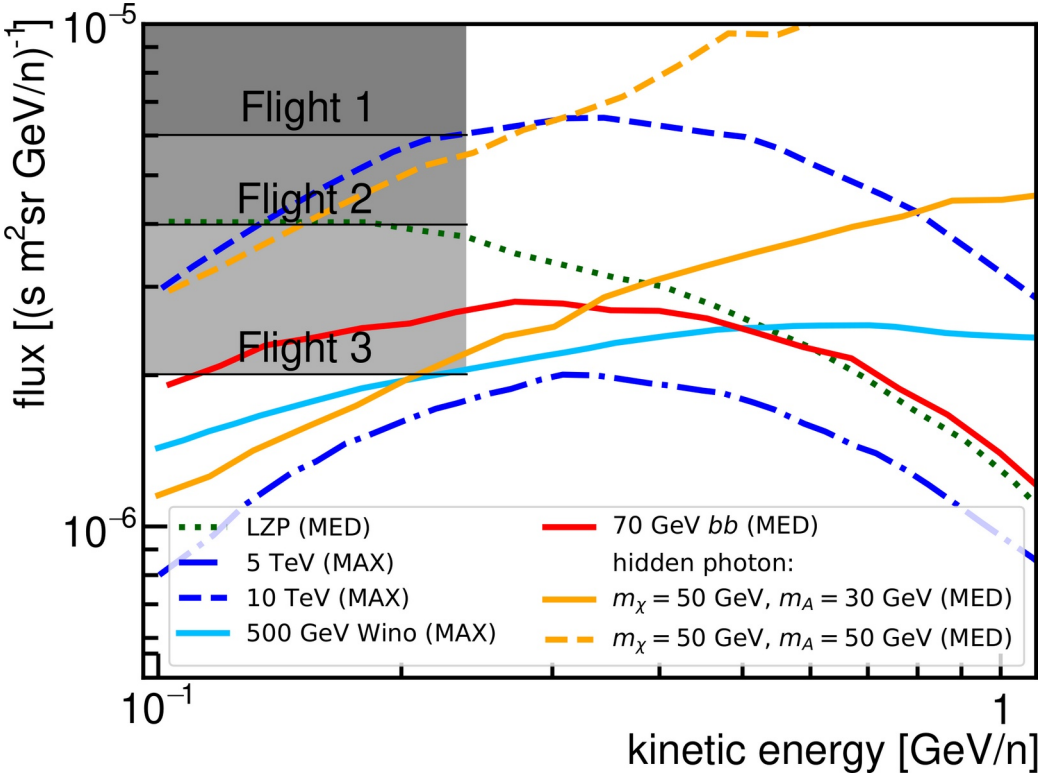
Aramaki et al., Astropart. Phys. 74, 6 (2016)
Aramaki et al., Astropart. Phys. 59, 12 (2014)

- Independent confirmation of magnetometer-based cosmic-ray measurements is critical
- GAPS will provide precision measurement of low-energy antiprotons <0.25GeV/n
- GAPS has 1-2 orders more sensitivity to low-energy antideuterons compared to BESS
- GAPS will also provide precision measurement of low-energy particle fluxes (*p*, *d*, He)

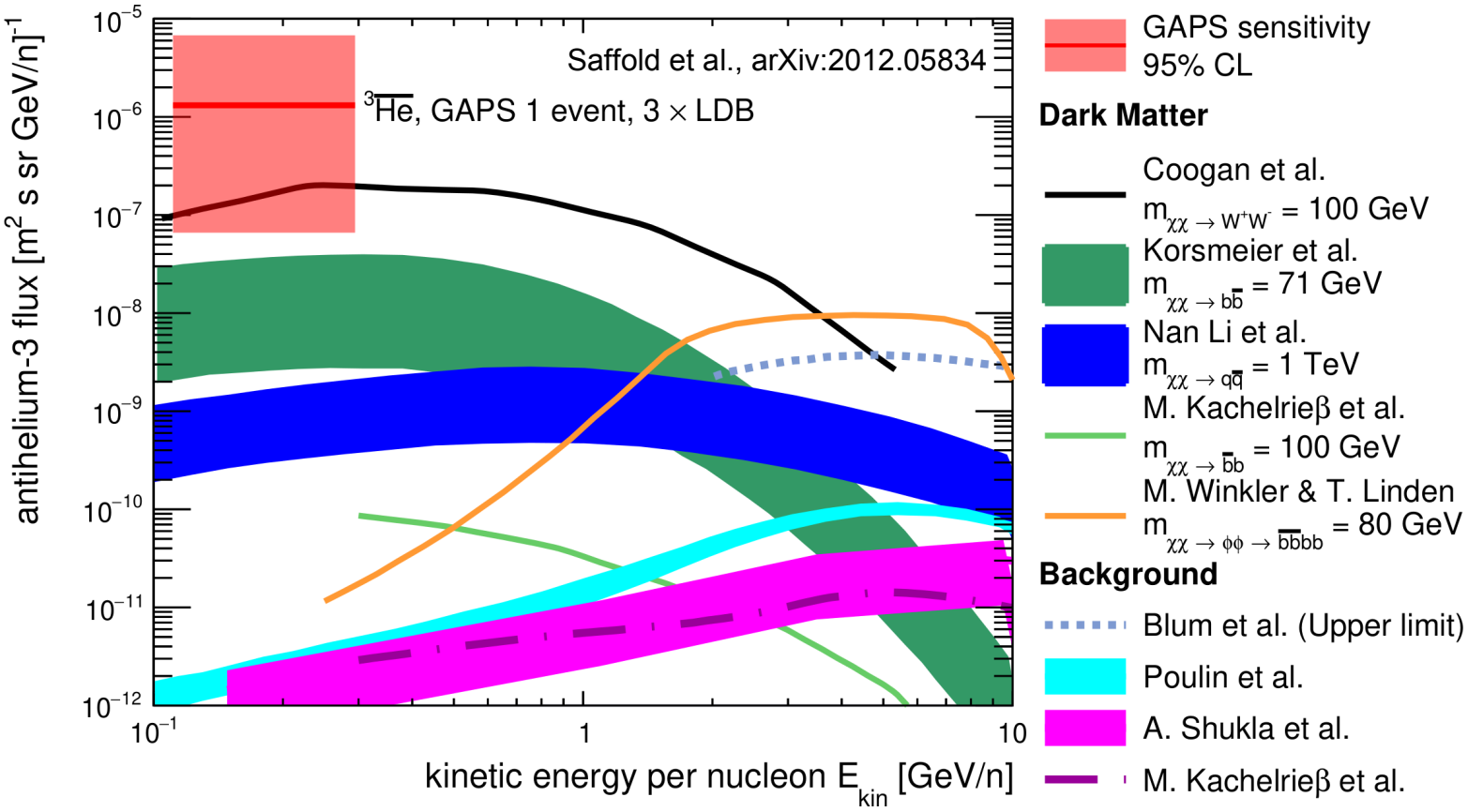


GAPS Model Sensitivity

- GAPS is sensitive to a **wide range of dark matter models**, e.g.:
  - Generic 70GeV WIMP annihilation model that explains antiproton excess and γ-rays from Galactic center
  - Dark matter gravitino decay
  - Extra dimensions
  - Dark photons
  - Heavy DM models with Sommerfeld enhancement
  - Primordial black holes (antiprotons)



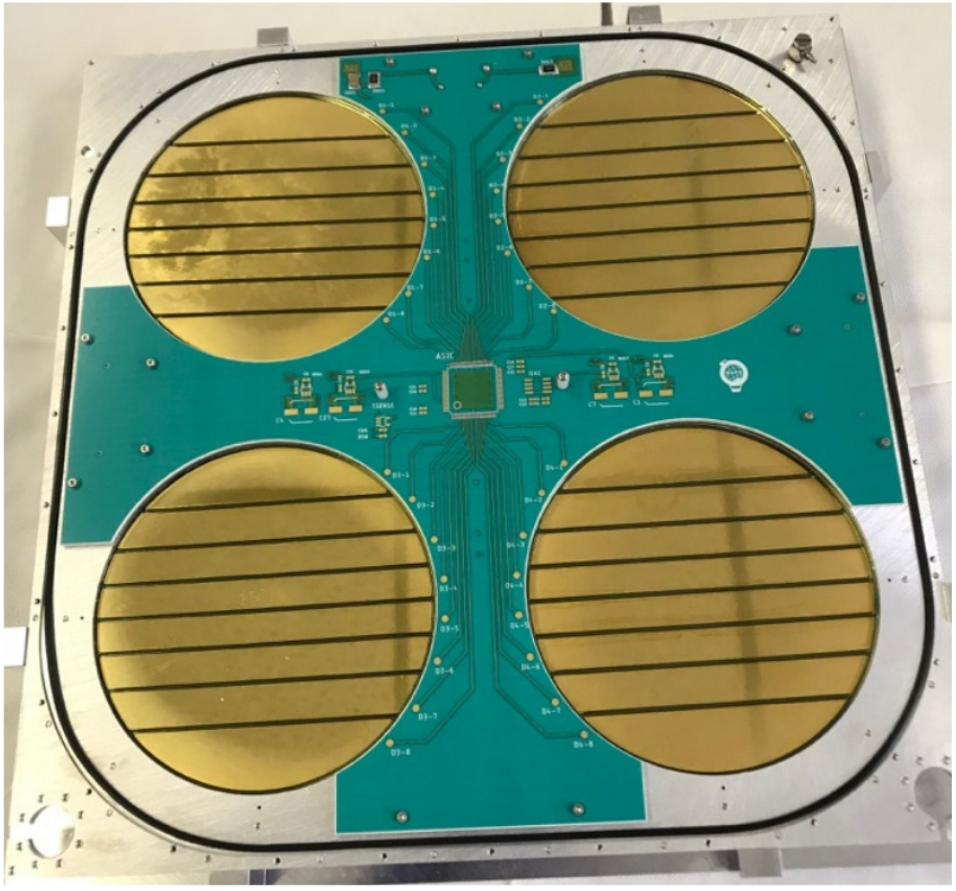
GAPS Antihelium Sensitivity



- Finding low-energy antihelium would be truly revolutionary new physics
- More on antihelium with GAPS at COSPAR by Nathan Saffold: H0.2-0015-21

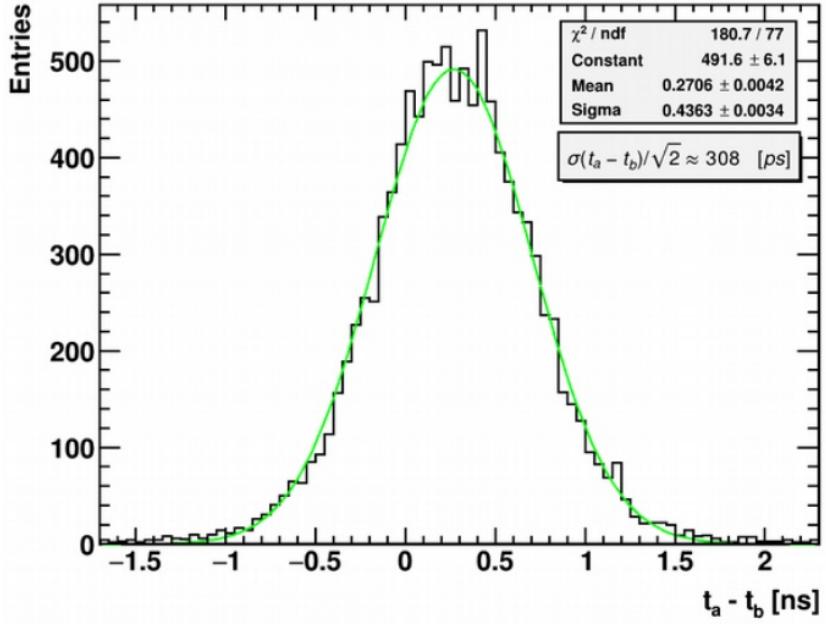
Tracker

- Tracker acts as target and tracking device
- GAPS will use 1,440 4” Si(Li) detectors, 2.5mm thickness
- Operation at relatively high temp of -35C to -45C, cooling system will use novel OHP approach
- Fabrication scheme developed at Columbia U and MIT, produced by private company Shimadzu, Japan
- **Fabrication completed, calibration and flight qualification is ongoing**
- Publications:
  - Perez et al., NIM A 905, 12 (2018)
  - Kozai et al., NIM A 947, 162695 (2019)
  - Rogers et al., JINST 14, P10009 (2019)



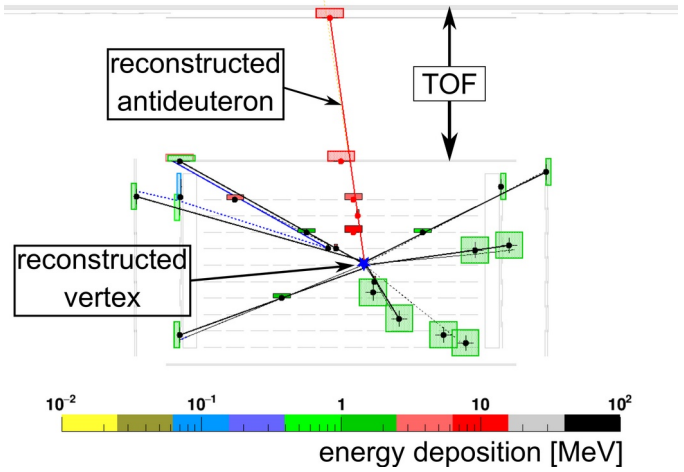
Time-of-Flight

- Tasks:
  - main trigger system, critical to reduce data rate to manageable level (~500Hz)
  - Velocity measurement
- Plastic scintillator: Eljen EJ-200: 160-180cm long, 0.6 cm thick
- SiPM: Hamamatsu S13360-6050VE
- fast sampling with DRS4 ASIC: ~300ps timing resolution end-to-end/√2 timing has been demonstrated in the lab



GAPS Path Forward

Additional GAPS talks at COSPAR:
Kozai Masayoshi: PSB.1-0016-21
Nathan Saffold: H0.2-0015-21



- GAPS is the first experiment optimized specifically for low-energy antiprotons, antideuterons, and antihelium

- **GAPS will deliver:**
  - a precision antiproton measurement in an unexplored energy range <0.25 GeV/n
  - antideuteron sensitivity 1-2 orders of magnitude below the current best limits, probing a variety of DM models across a wide mass range
  - the only complementary probe of the AMS-02 antinuclei signal

- GAPS instrument integration beginning now, on schedule for **first science flight from Antarctica in 2022**