Cosmic-ray antideuteron searches

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Review of the theoretical and experimental status of dark matter identification with cosmic-ray antideuterons

Dark matter signal in cosmic rays?

- unexplained features in positrons
- proposed theories:
  - astrophysical origin → pulsars
  - SNR acceleration
  - dark matter annihilation
- gamma-ray excess at the galactic center → 30GeV dark matter particle?
- No (?) excess for antiprotons → inconclusive
Status of cosmic-ray antideuterons

Antideuterons are the most important unexplored indirect detection technique!

Examples for beyond-standard-model Physics:

Neutralino:
SUSY lightest supersymmetric particle, decay into $b\bar{b}$, compatible with signal from Galactic Center measured by Fermi

Late decays of unstable gravitinos

Astrophysical background:
collisions of protons and antiprotons with interstellar medium

+ models with heavy dark matter
Uncertainties

- Dark matter annihilation or decay
- Dark matter clumping
- **Antideuteron production**
- **Galactic propagation**
- Solar modulation
- **Geomagnetic deflection**
- Atmospheric interactions
- Interactions in detector
Antideuteron formation

- \( \bar{d} \) can be formed by an \( \bar{p} - \bar{n} \) pair if coalescence momentum \( p_0 \) is small

\[
\frac{dN_{\bar{d}}}{dT_{\bar{d}}} = \frac{p_0^3}{6} \frac{m_{\bar{d}}}{m_{\bar{n}} m_{\bar{p}}} \frac{1}{\sqrt{T_{\bar{d}}^2 + 2m_{\bar{d}}T_{\bar{d}}}} \frac{dN_{\bar{n}}}{dT_{\bar{n}}} \frac{dN_{\bar{p}}}{dT_{\bar{p}}}
\]

- Important differences for different experiments and MC generators exist → more data would help
Propagation is a large uncertainty source for low-energy antideuterons: halo size for diffusion calculation is poorly constrained.

- Antiproton and positron results tend to exclude MIN halo models and favor larger halo sizes.
Geomagnetic cutoff

Proton backtracing in geomagnetic field:
- 0.5 GV
- 1.0 GV
- 2.0 GV
- 4.0 GV

Vertical cutoff values: IGRF field only
Geomagnetic cutoff for AMS-02 and GAPS

- Geomagnetic environment is influenced by solar activity
- AMS-02 is installed on the ISS (latitude ±52°)
- GAPS is planned to fly from Antarctica (~-80°)
Geomagnetic cutoff for AMS-02 and GAPS

- Geomagnetic environment is influenced by solar activity
- AMS-02 is installed on the ISS (latitude ±52°)
  → understanding of geomagnetic environment crucial for low energies
- GAPS is planned to fly from Antarctica (~-80°)
  → geomagnetic corrections are minimal
Identification challenge

Required rejections for antideuteron detection:

- protons: \(> 10^8 - 10^{10}\)
- He-4: \(> 10^7 - 10^9\)
- electrons: \(> 10^6 - 10^8\)
- positrons: \(> 10^5 - 10^7\)
- antiprotons: \(> 10^4 - 10^6\)

Antideuteron measurement with balloon and space experiments require:

- strong background suppression
- long flight time and large acceptance
AMS-02 antideuteron analysis

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- Operating on the ISS since 2011
- antideuteron identification:
  - lower velocities: Time Of Flight scintillator system
  - higher velocities: Ring Image Cherenkov detector
- self-calibrated analysis:
  - calibrate antideuteron analysis with deuterons and antiprotons (simulations and data)
  - geomagnetic cut-off and solar effects: study much more abundant low-energy protons, antiprotons, and deuterons for calibration

Analysis ongoing!
The General Antiparticle Spectrometer (GAPS) is specifically designed for low-energy antideuterons and antiprotons.

- Planned for Long Duration Balloon flights from Antarctica.
- **GAPS is ready to go to the next step → all prototyping done**

**Publications:**
- Si(Li) detector fabrication: NSS/MIC 2013 IEEE 1-3, (2013)
Path forward

- antideuteron searches are experimentally challenging
  → multiple experiments for cross-checks are important

- AMS-02 and GAPS have very different event signatures AND very different backgrounds
  → very good for independent confirmation

- two independent flight trajectories
  - AMS-02 has a factor of 10 geomagnetic cutoff correction
  - GAPS analysis has nearly no geomagnetic correction

- low-energy antiproton flux measurement will be the most important cross-check between AMS-02 and GAPS
Path forward

- measurement of antideuterons is a promising way for indirect dark matter search

- more exchange between theory and experiments

→ we started a bigger community effort in 2014
Prototype GAPS

Met all goals:
- demonstrated stable operation of the detector components during flight
- validated Si(Li) cooling approach for thermal model
- measured background levels
Solar flare event: 7-March-2012

Significant decrease of geomagnetic cutoff
Magnetic field changes

5-Dec-11

7-March-12