Cosmic-ray antideuteron searches

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

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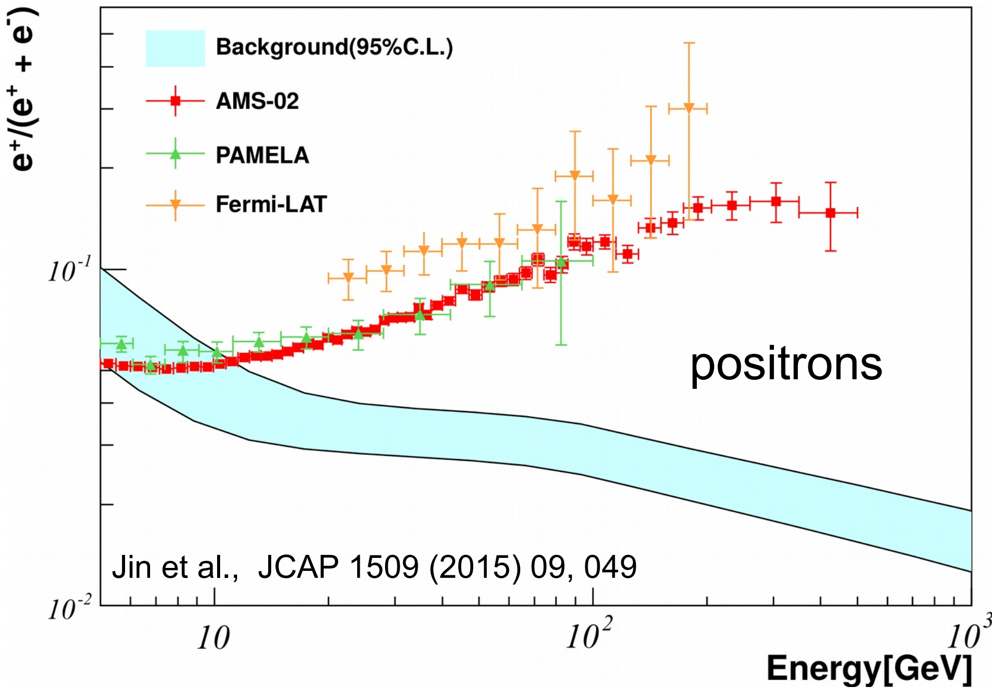
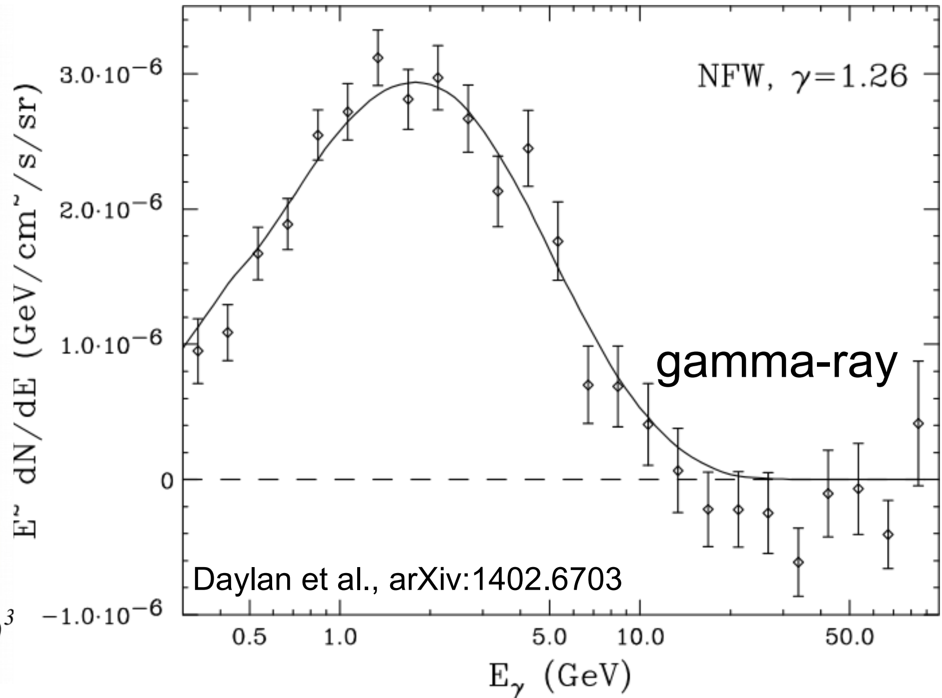
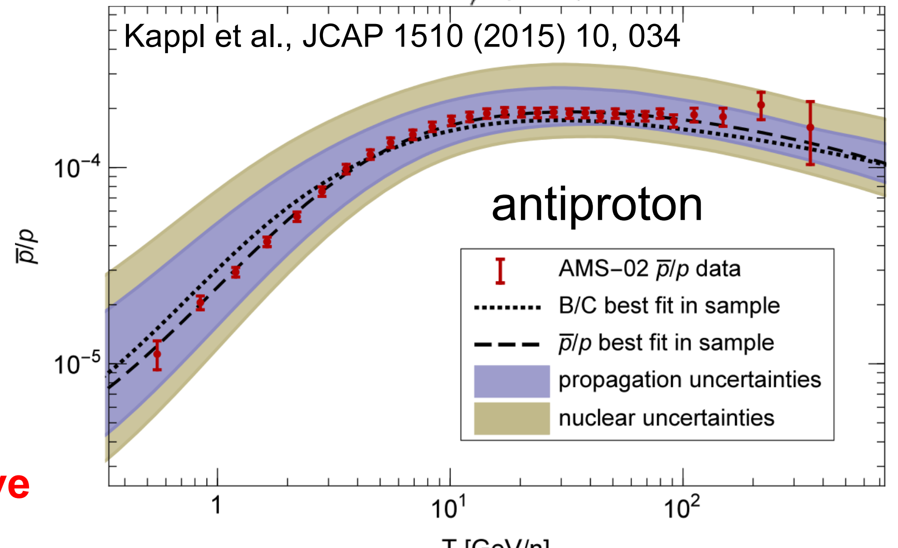
Dark matter signal in cosmic rays?

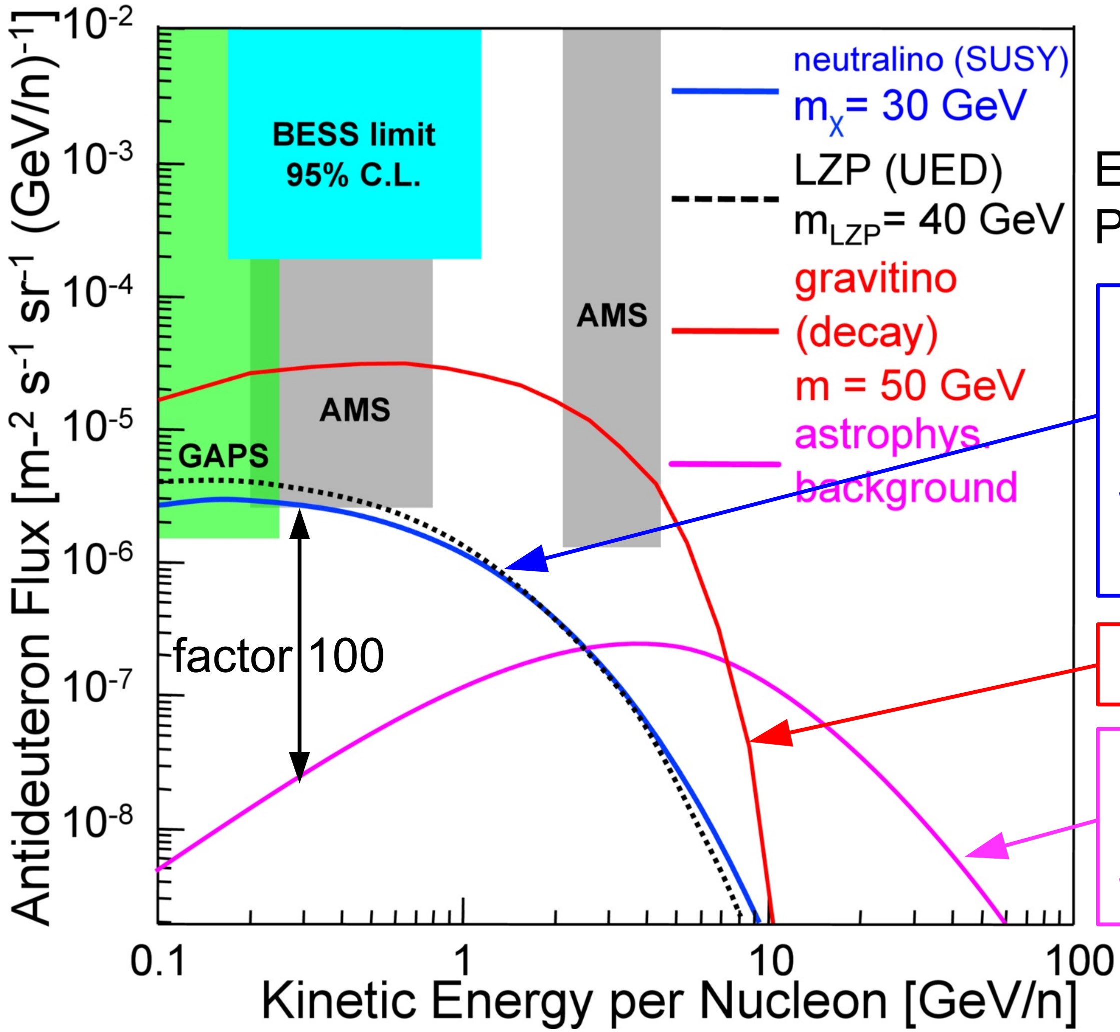






- unexplained features in positrons
- proposed theories:
  - astrophysical origin → pulsars
  - SNR acceleration
  - **dark matter annihilation**
- gamma-ray excess at the galactic center → 30GeV dark matter particle?
- **No (?) excess for antiprotons → inconclusive**

Status of cosmic-ray antideuterons



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

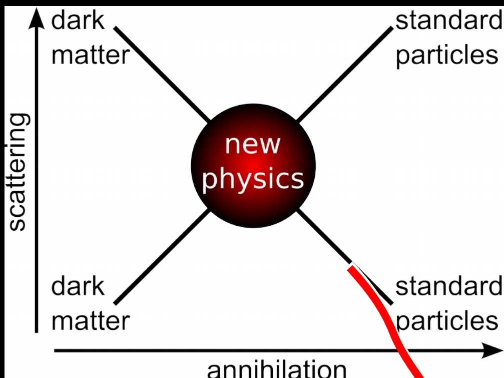
late decays of unstable gravitinos

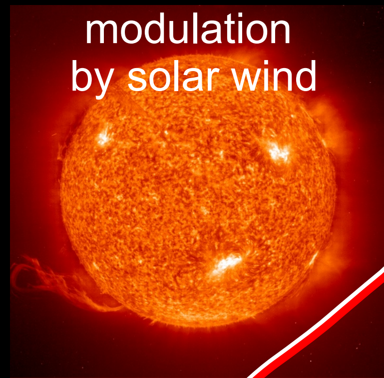
astrophysical background:
collisions of protons and antiprotons with interstellar medium

+ models with heavy dark matter

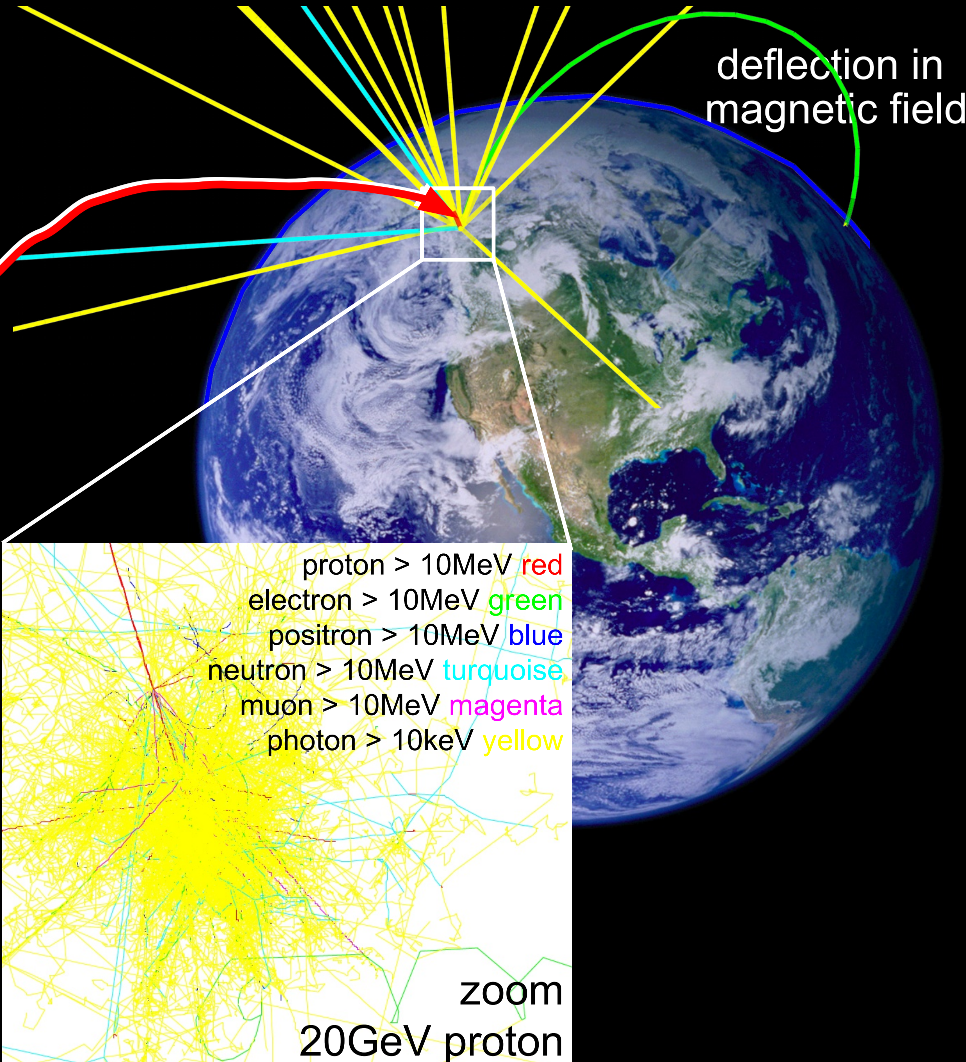
Antideuterons are the most important unexplored indirect detection technique!

Uncertainties





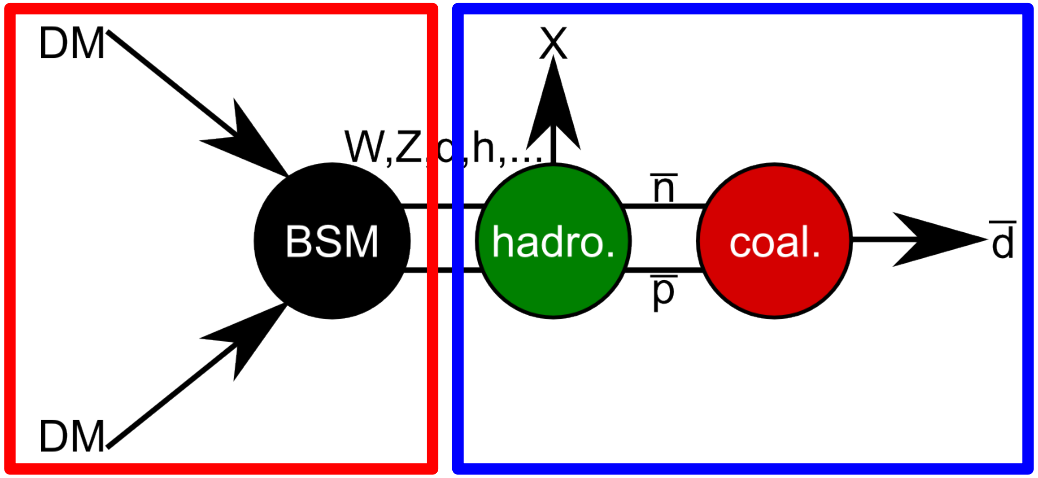
scattering in
magnetic fields,
interaction with
interstellar medium



interactions with
atmosphere

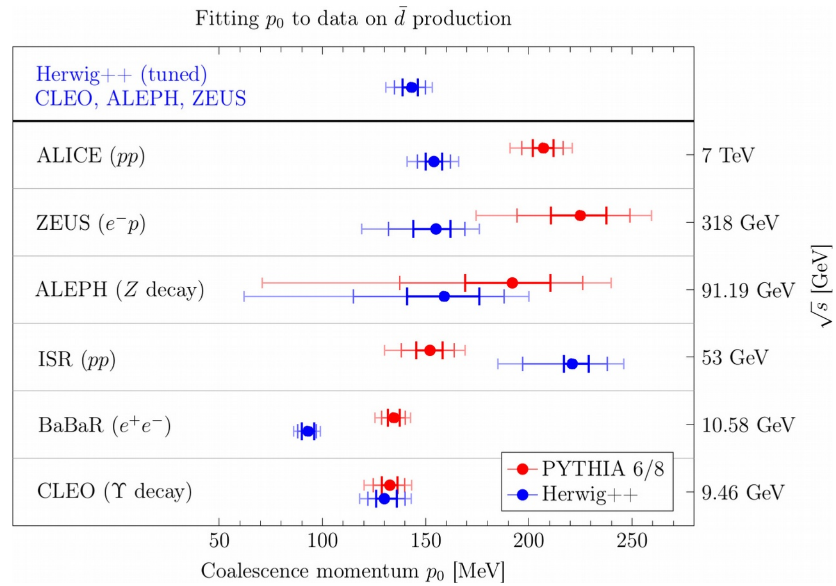
- Dark matter annihilation or decay
- Dark matter clumping
- **Antideuteron production**
- **Galactic propagation**
- Solar modulation
- **Geomagnetic deflection**
- Atmospheric interactions
- Interactions in detector

Antideuteron formation



dark matter

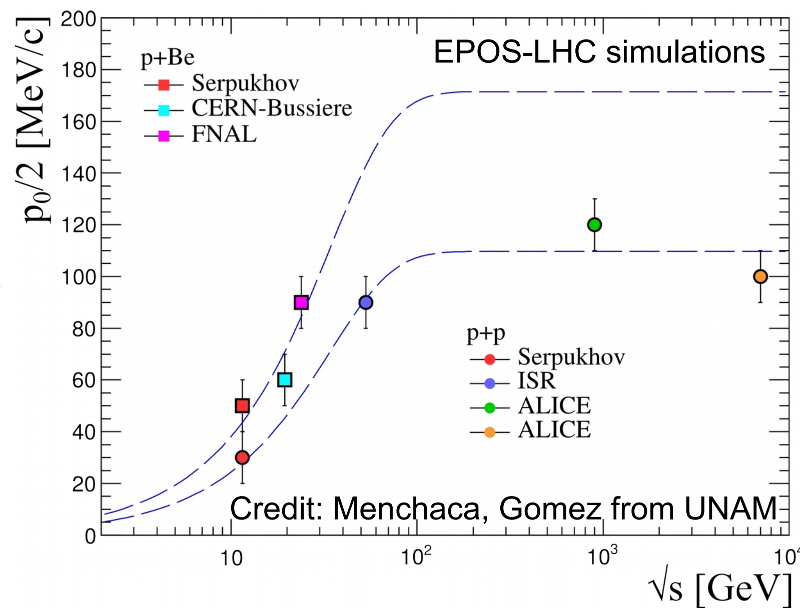
conventional production (e.g., p+ISM) & dark matter



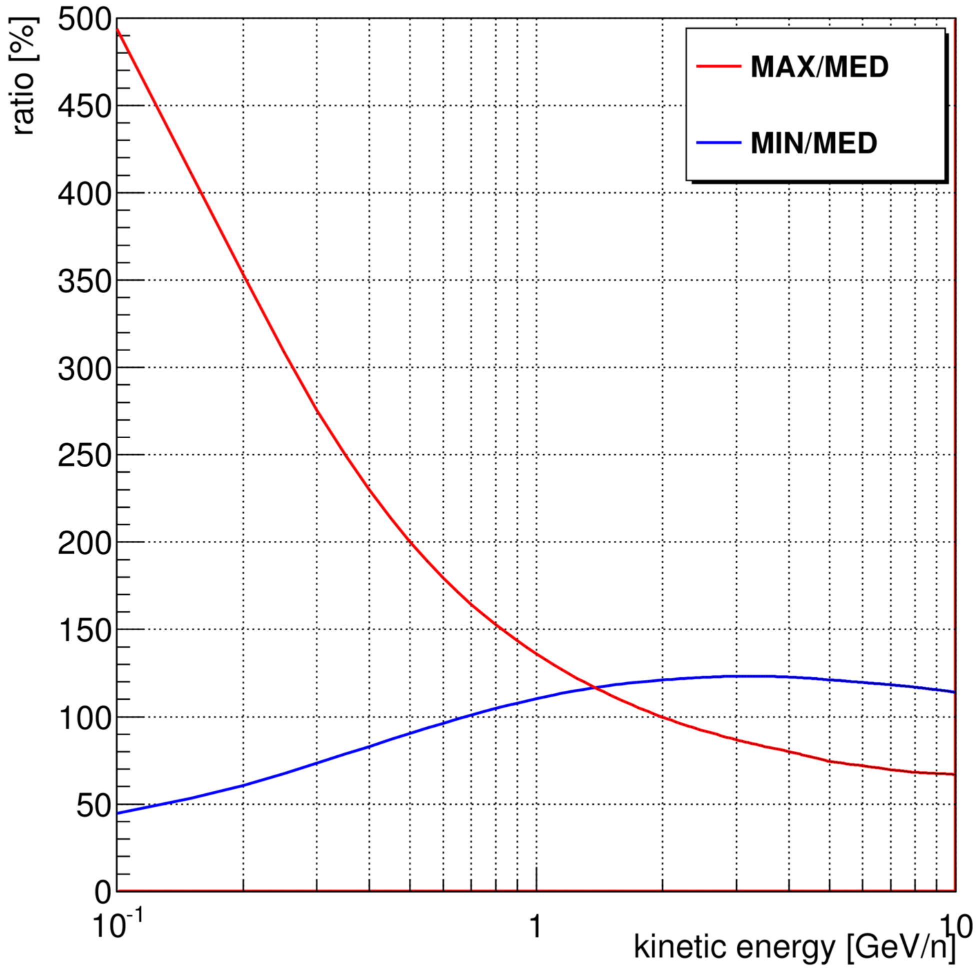
- d̄ can be formed by an p̄-n̄ pair if coalescence momentum p_0 is small

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

- **important differences for different experiments and MC generators exist → more data would help**

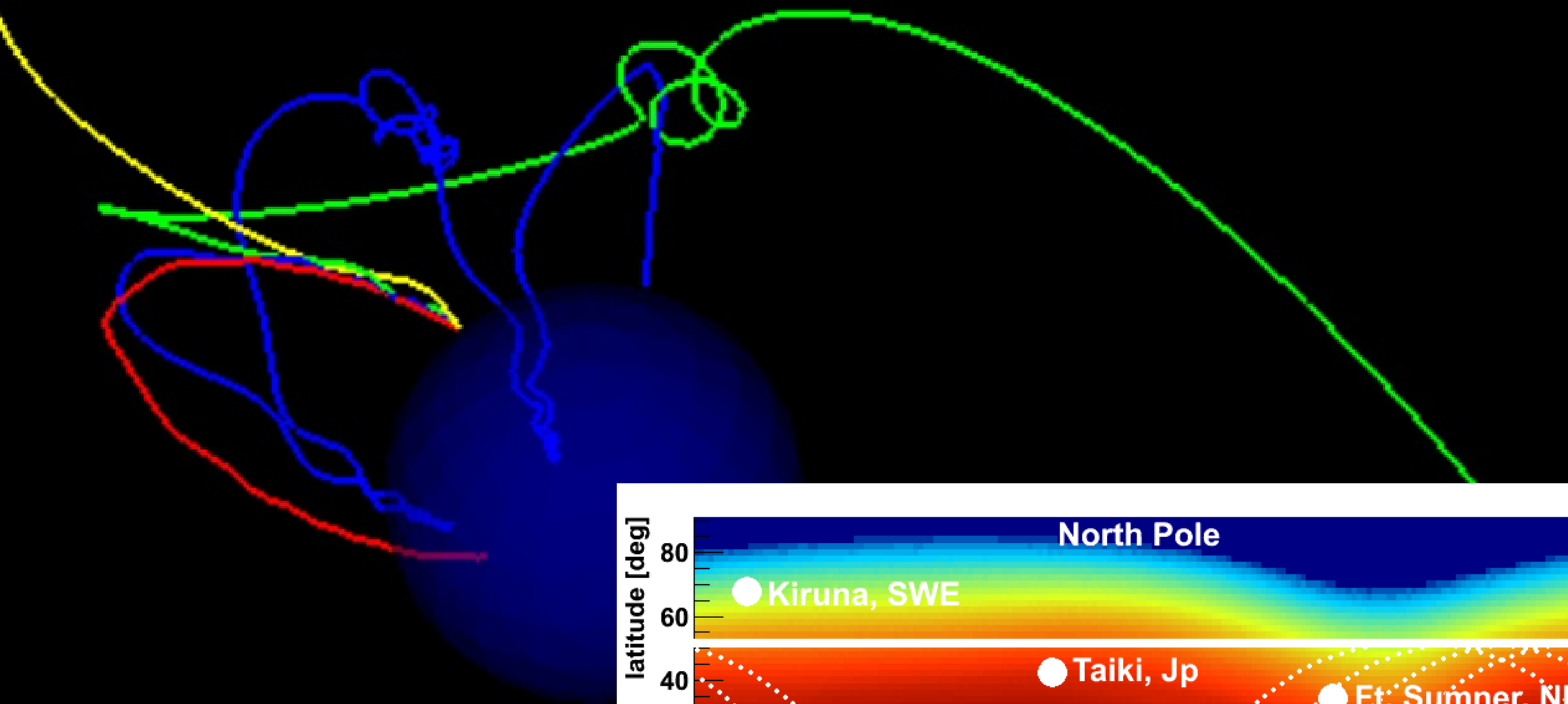


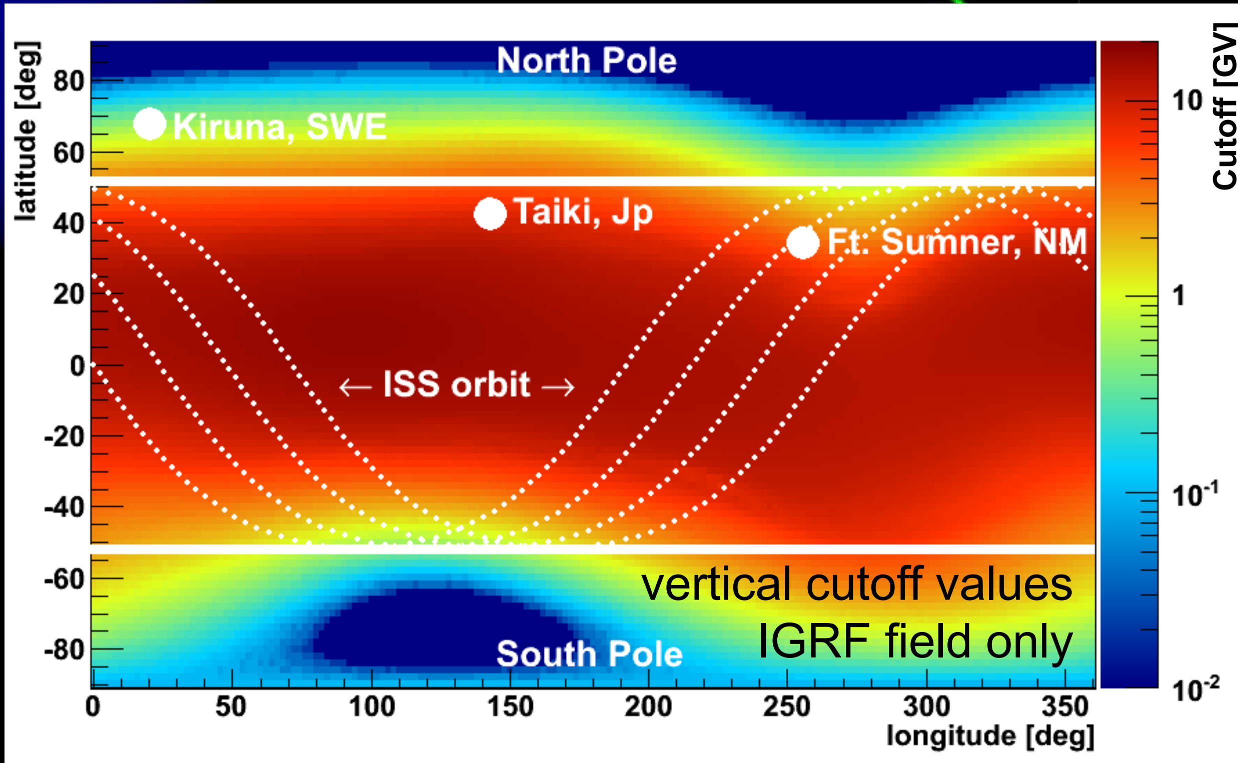
Propagation uncertainty



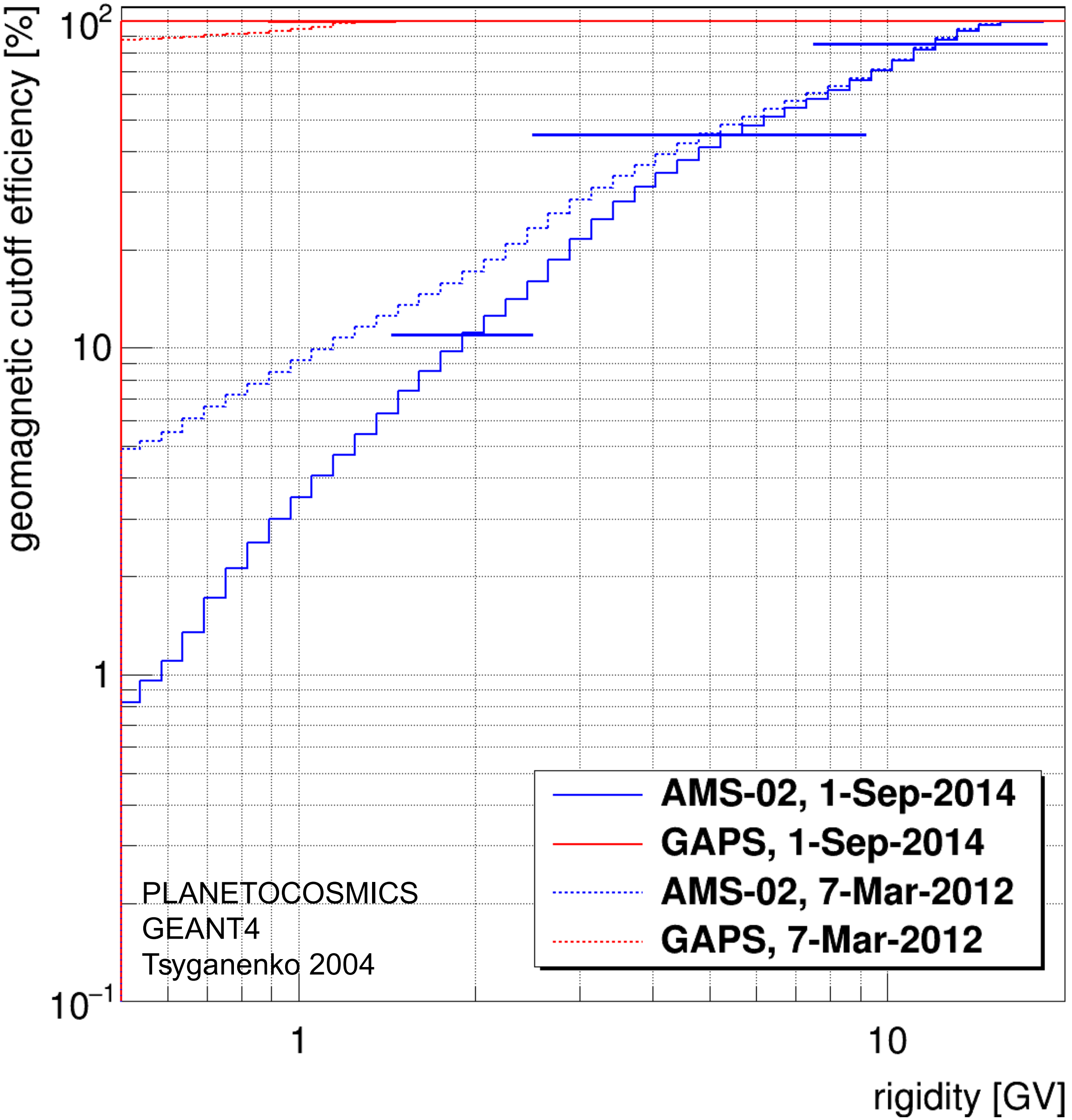
- Propagation is a large uncertainty source for low-energy antideuterons: **halo size for diffusion calculation is poorly constrained**
- **Antiproton and positron results tend to exclude MIN halo models and favor larger halo sizes**

Geomagnetic cutoff



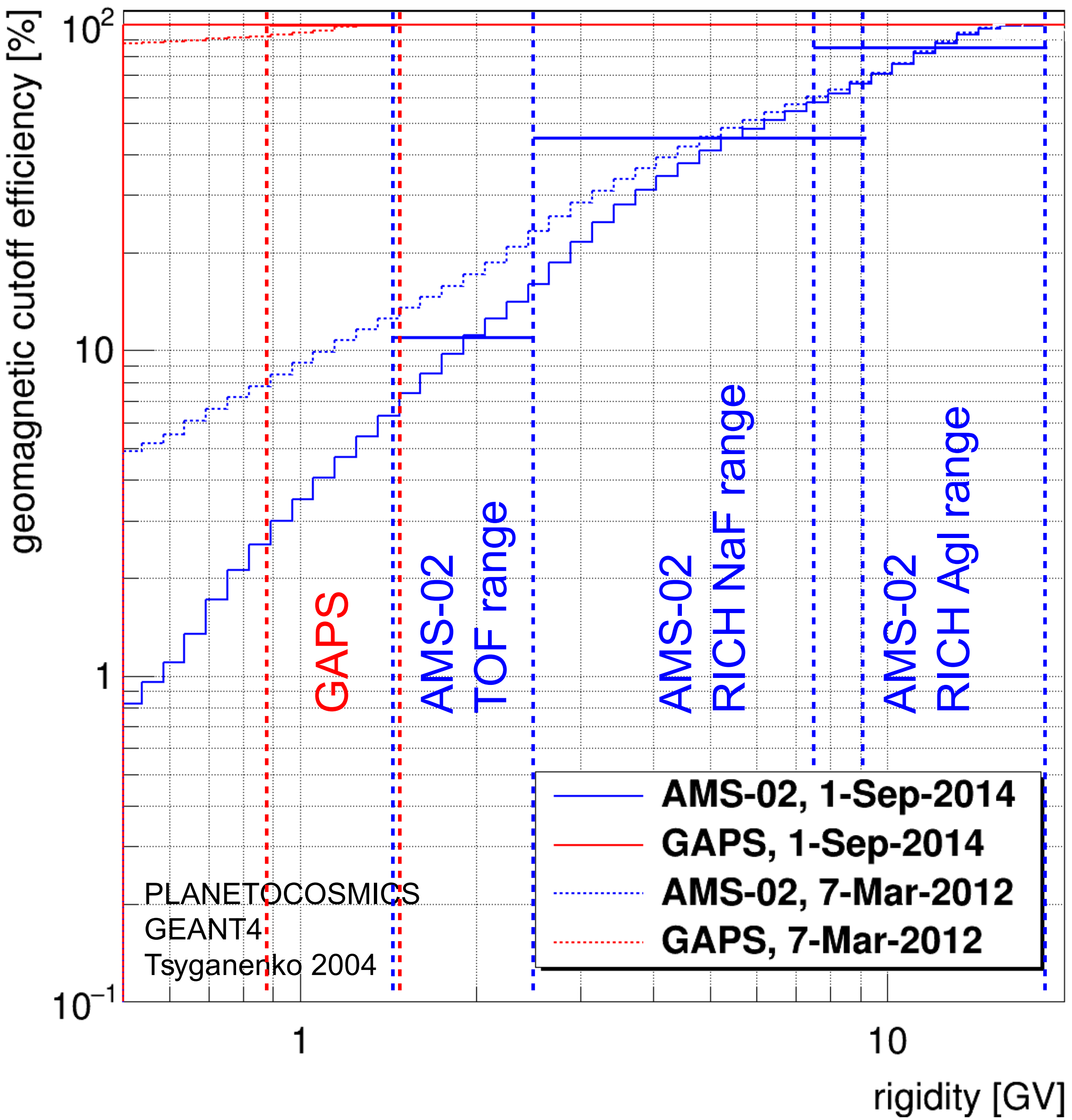


Geomagnetic cutoff for AMS-02 and GAPS



- 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

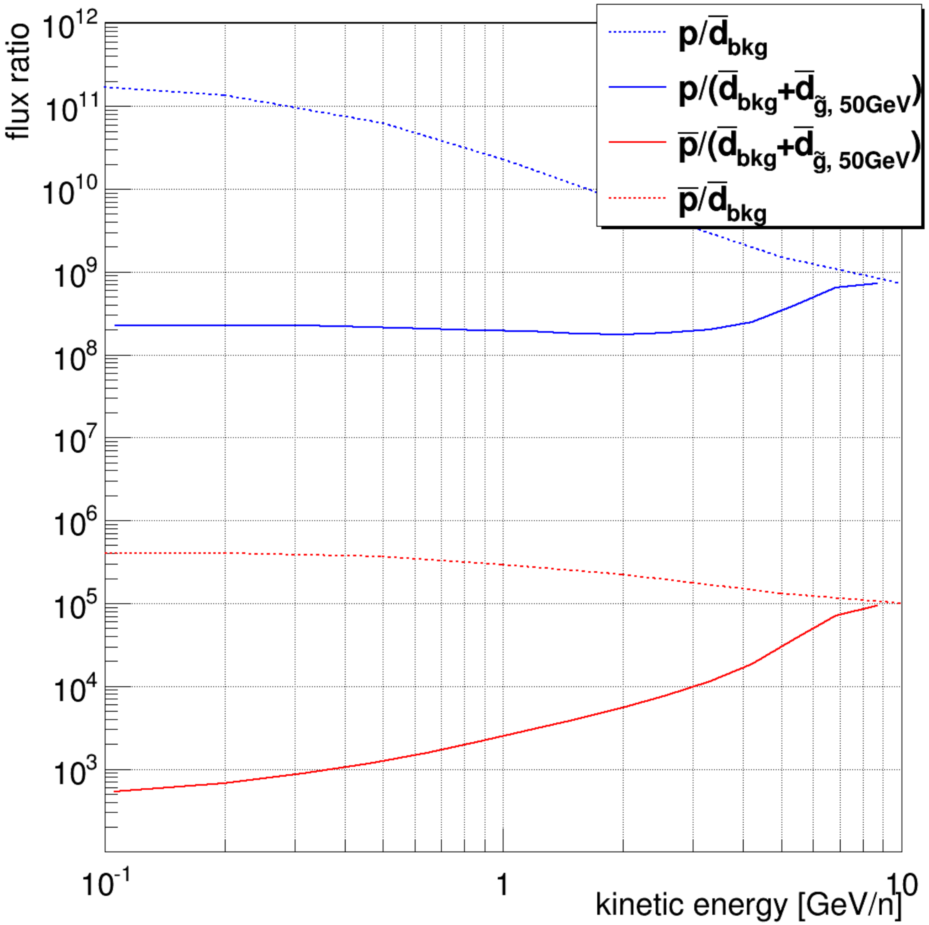
Identification challenge

Required rejections for antideuteron detection:

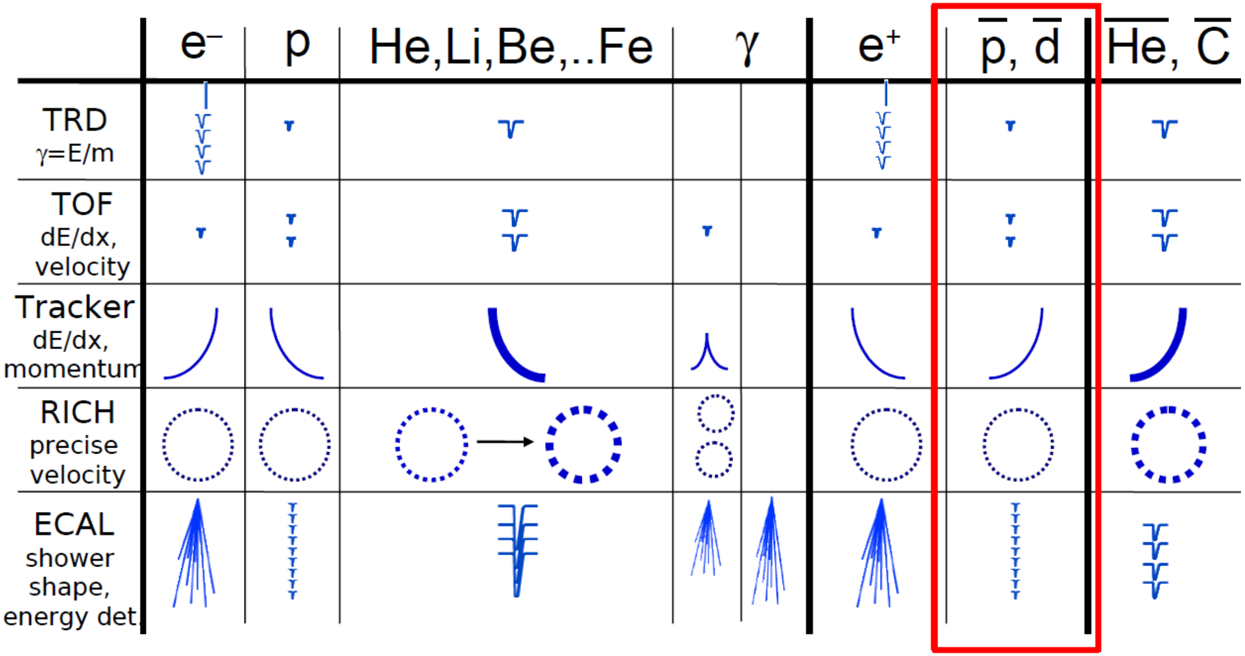
- **protons**: > 10^8 - 10^{10}
- **He-4**: > 10^7 - 10^9
- **electrons**: > 10^6 - 10^8
- **positrons**: > 10^5 - 10^7
- **antiprotons**: > 10^4 - 10^6

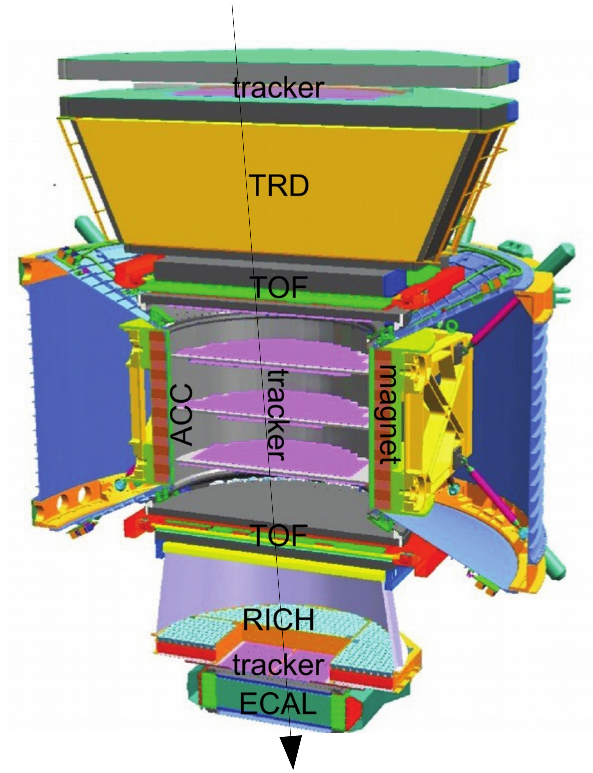
Antideuteron measurement with balloon and space experiments require:

- **strong background suppression**
- **long flight time and large acceptance**



AMS-02 antideuteron analysis





- **Operating on the ISS since 2011**
- **antideuteron identification:**
  - lower velocities: **T**ime **O**f **F**light scintillator system
  - higher velocities: **R**ing **I**mage **Ch**erenkov detector

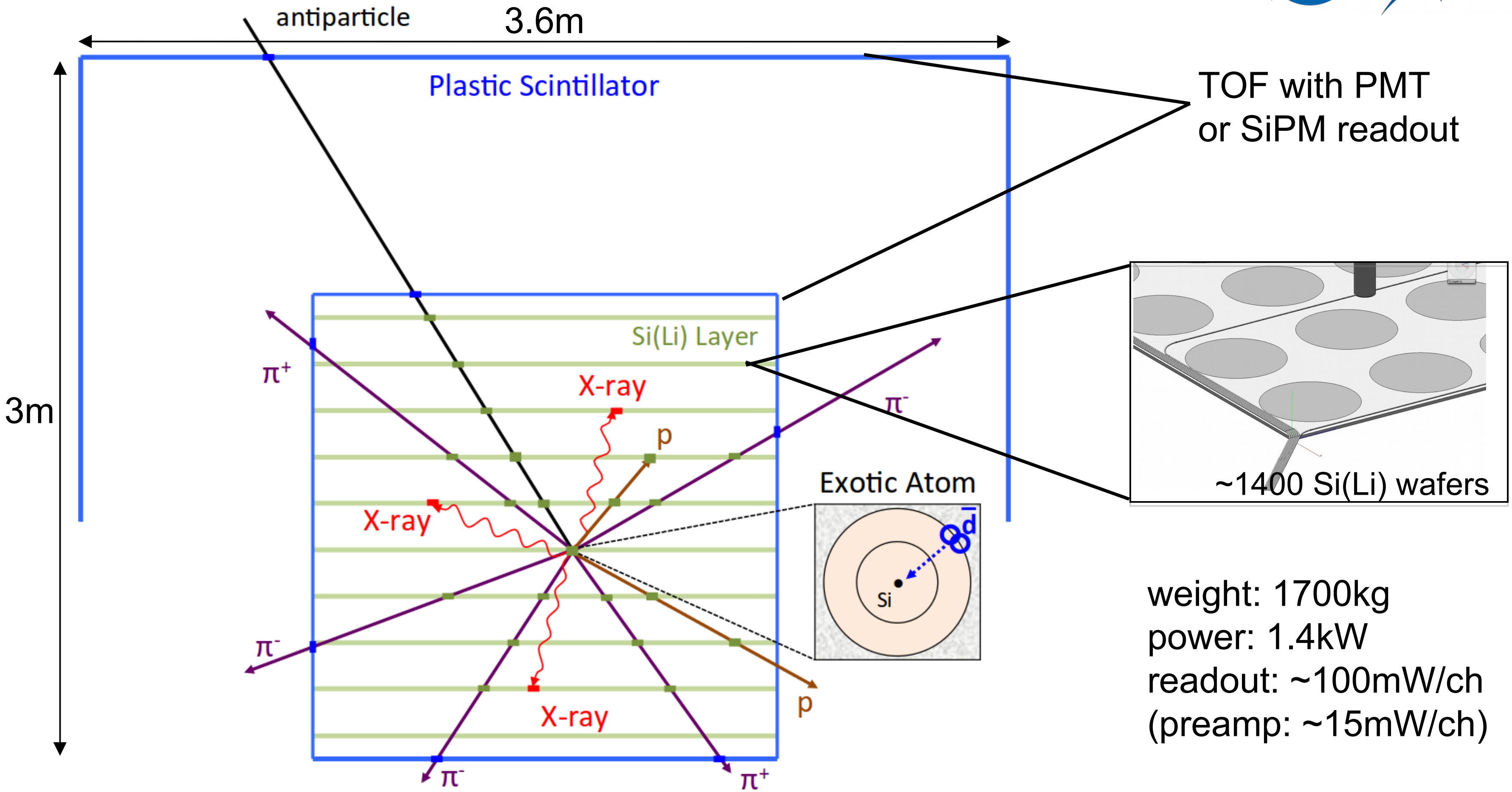
$$m = R \cdot Z \sqrt{\frac{1}{\beta^2} - 1}$$

- **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 GAPS experiment

Columbia U, UC Berkeley
UCLA, U Hawaii,
Haverford, MIT, INFN



weight: 1700kg
power: 1.4kW
readout: ~100mW/ch
(preamp: ~15mW/ch)

- the **G**eneral **A**nti**P**article **S**pectrometer 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:
  - $\bar{d}$, $\bar{p}$ Sensitivity: Astropart. Phys. 74 (2016) 6, Astropart.Phys. 59 (2014) 12
  - identification by stopping and creation of exotic atoms in KEK testbeam measurements: Astropart. Phys. 49, 52 (2013)
  - Successful prototype flight: Nucl. Instrum. Meth. A735 (2014) 24, Astropart. Phys. 54 (2014) 93
  - 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**

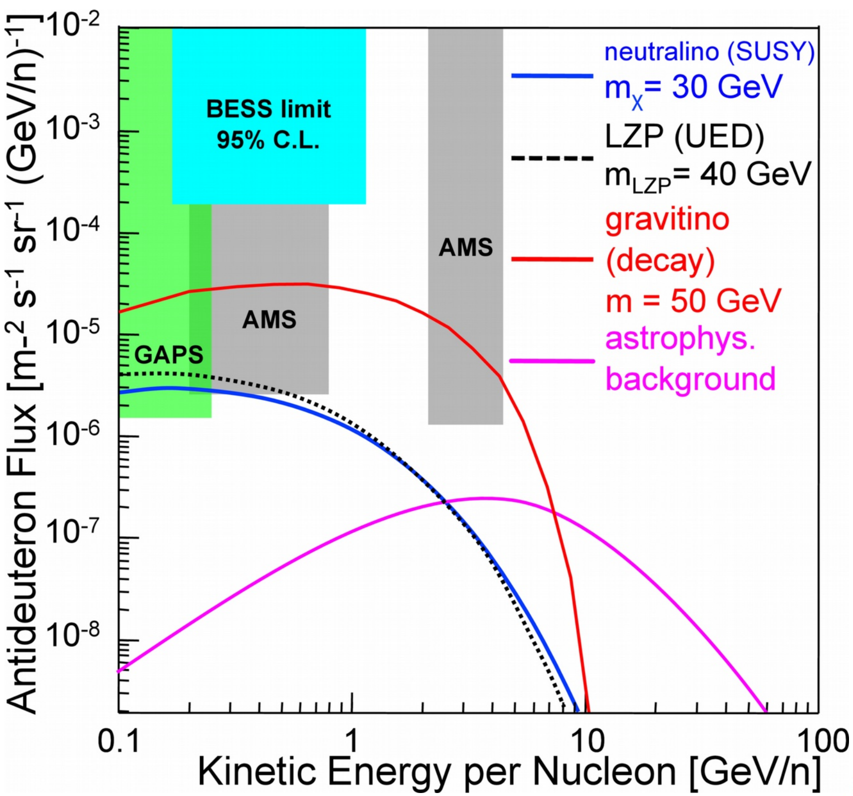
- AMS-02 and GAPS have very different event signatures **AND** very different backgrounds
  → **very good for independent confirmation**

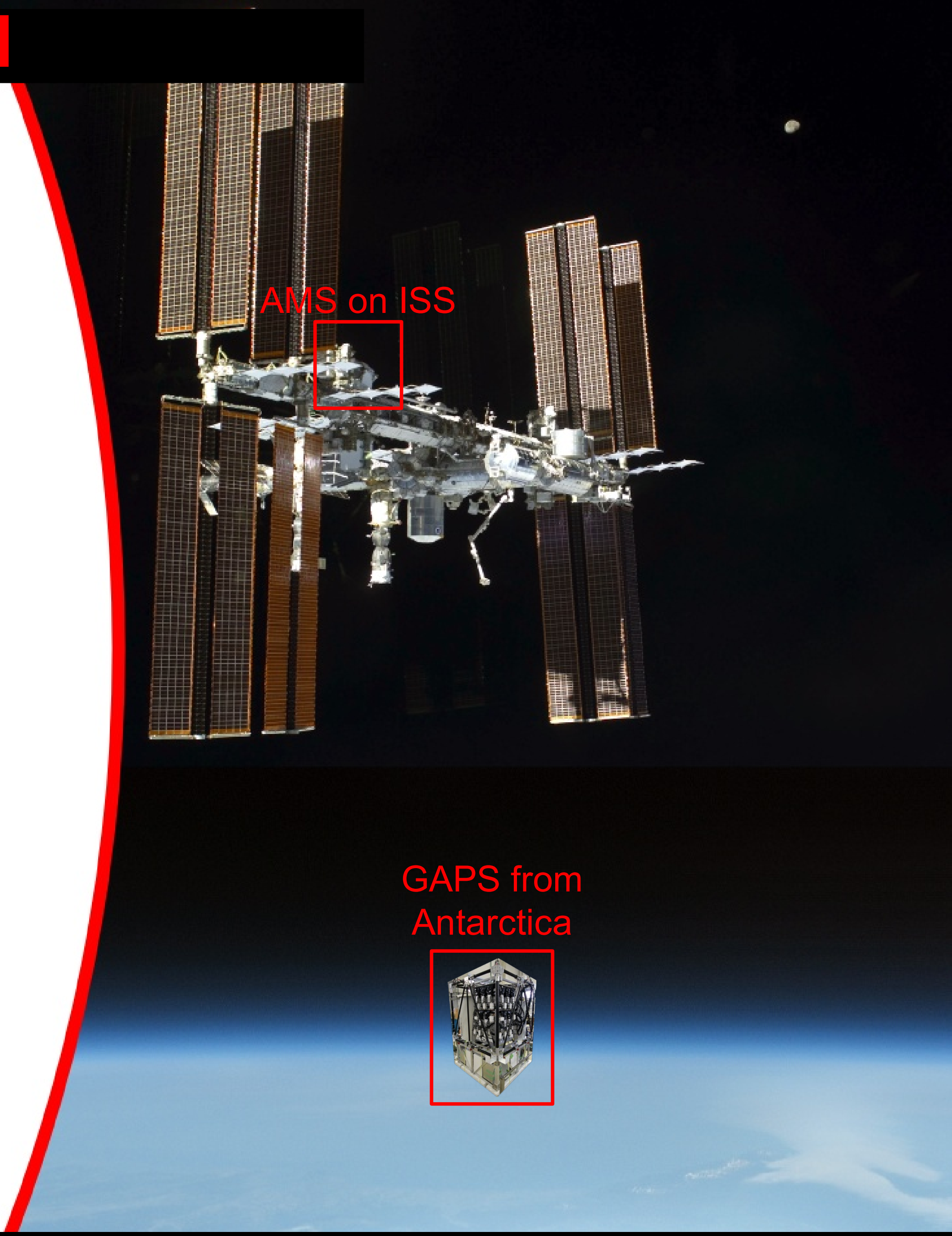
- two independent flight trajectories
  - AMS-02 has a factor of 10 geomagnetic cutoff correction
  - GAPS analysis has nearly no geomagnetic correction

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

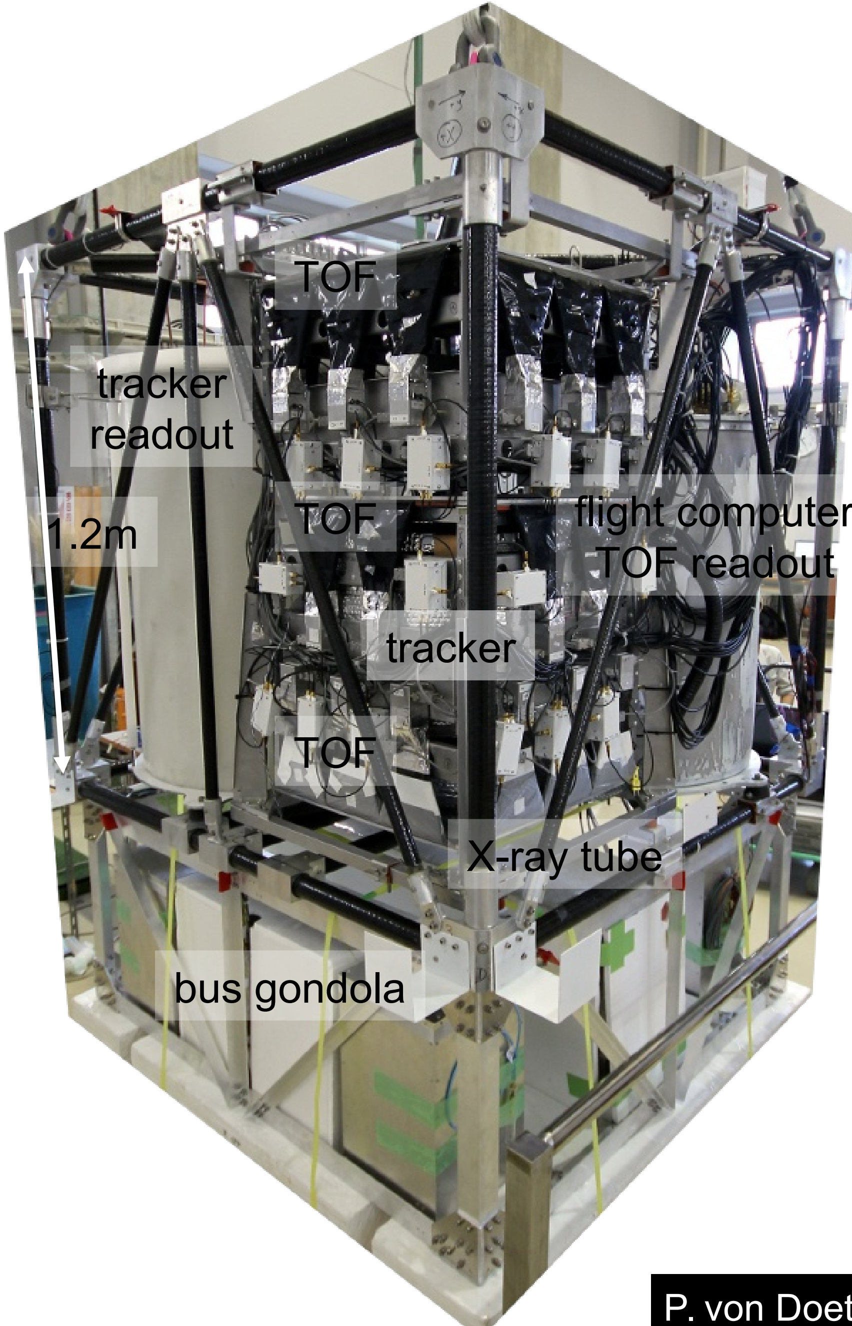
Path forward

- 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



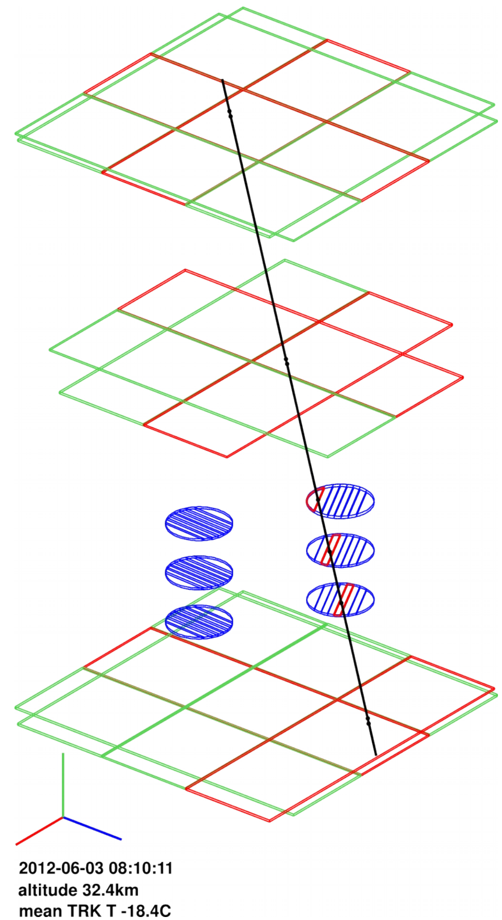


Prototype GAPS

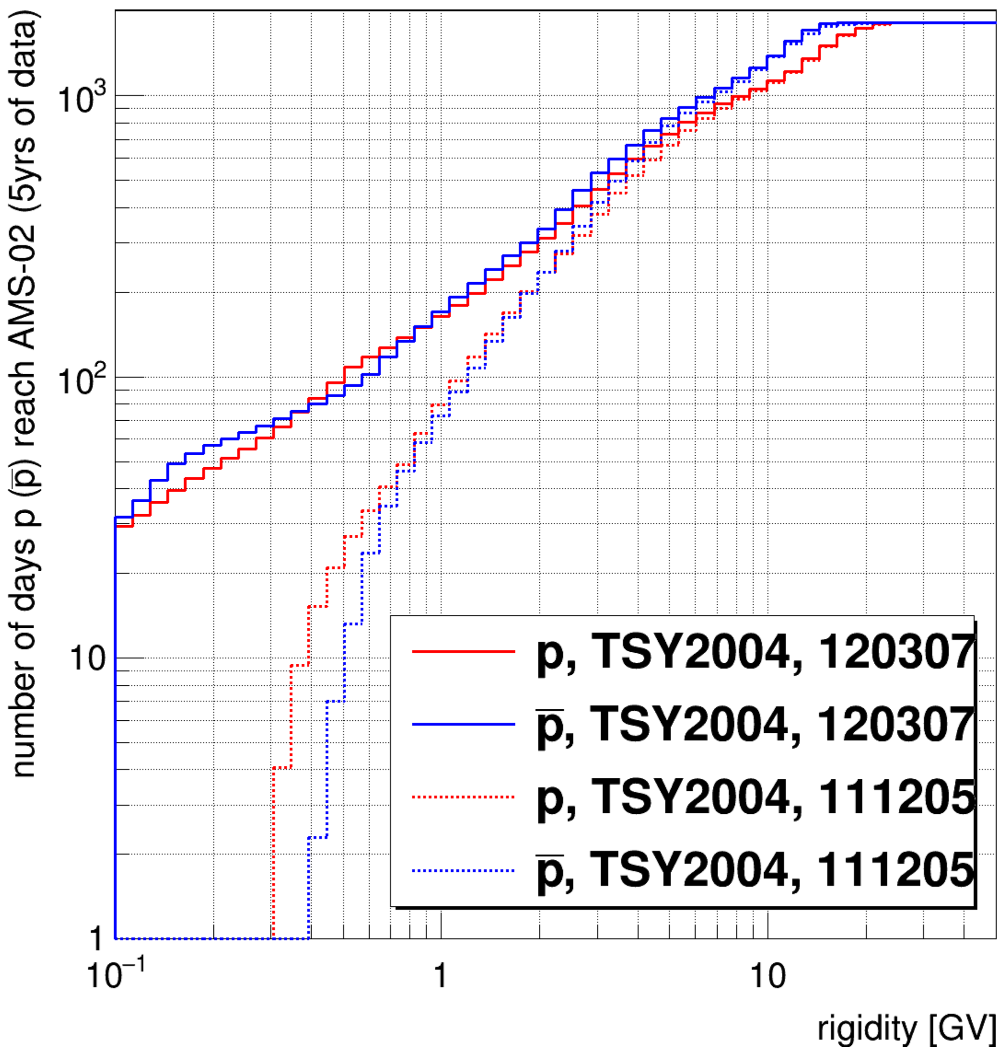


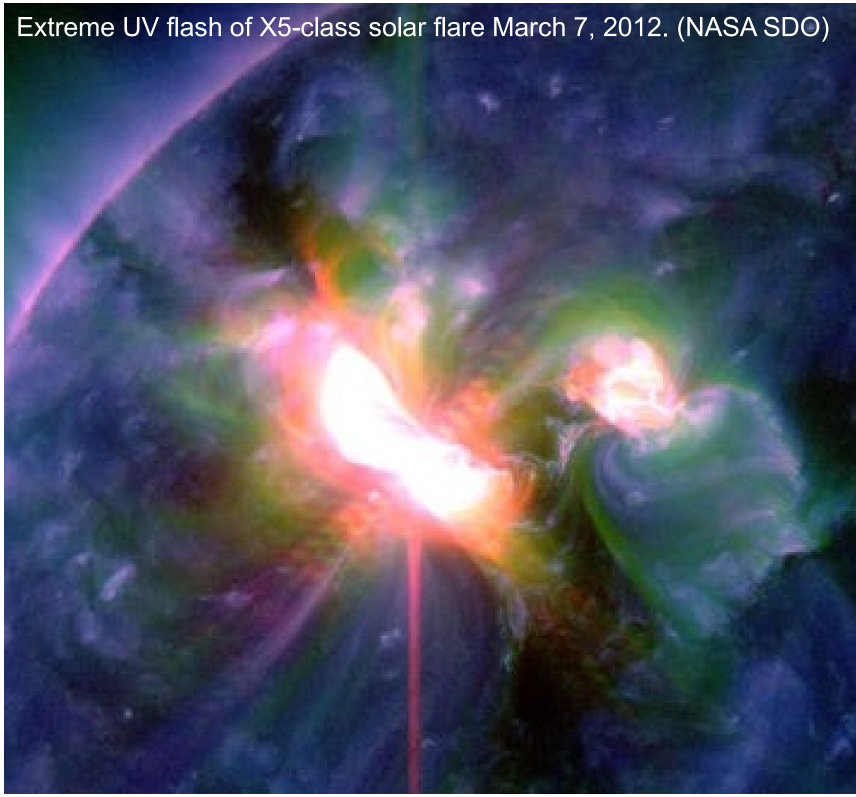
Met all goals:

- 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