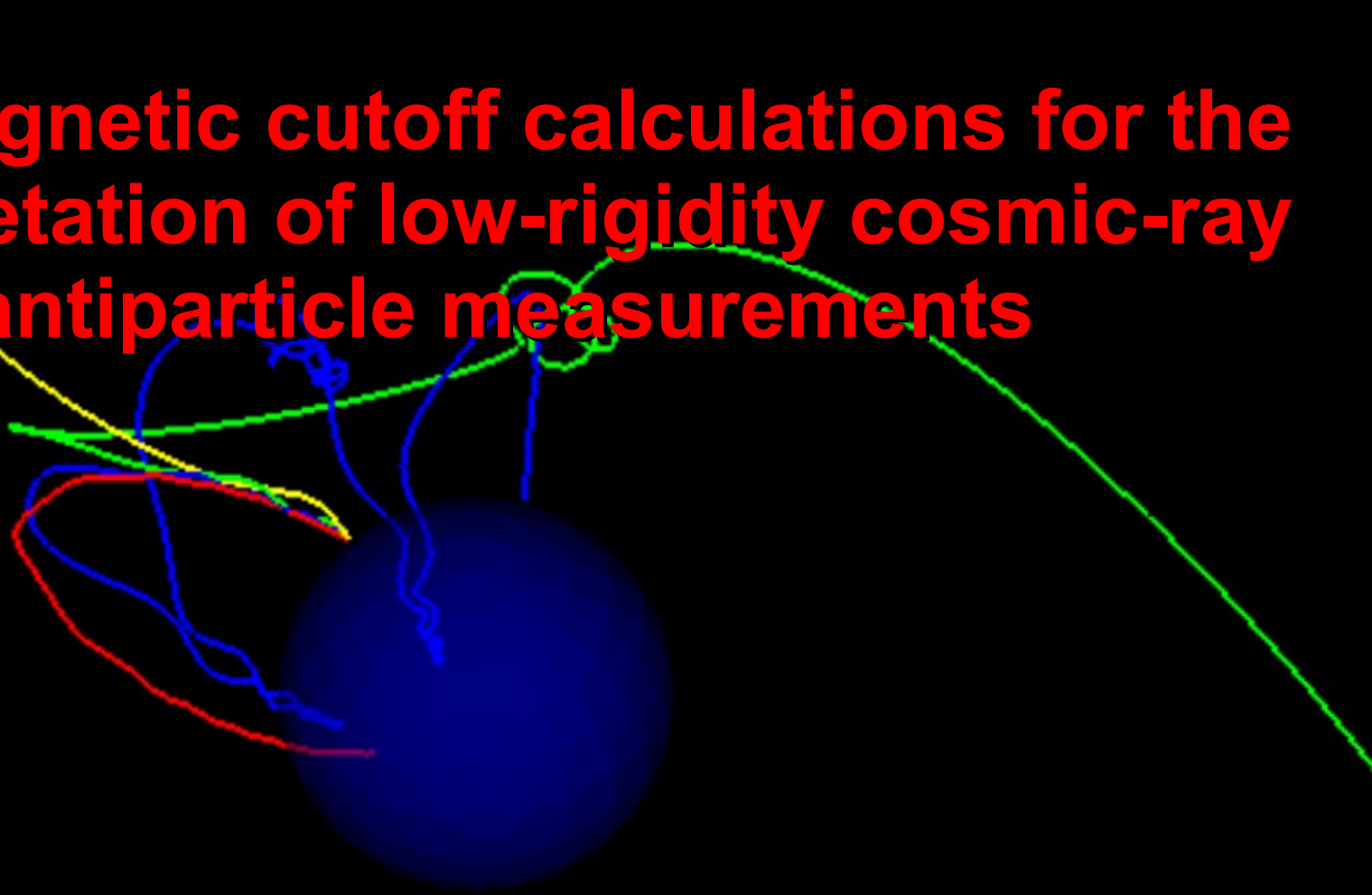
Geomagnetic cutoff calculations for the interpretation of low-rigidity cosmic-ray antiparticle measurements



ICRC
Busan, July 2017

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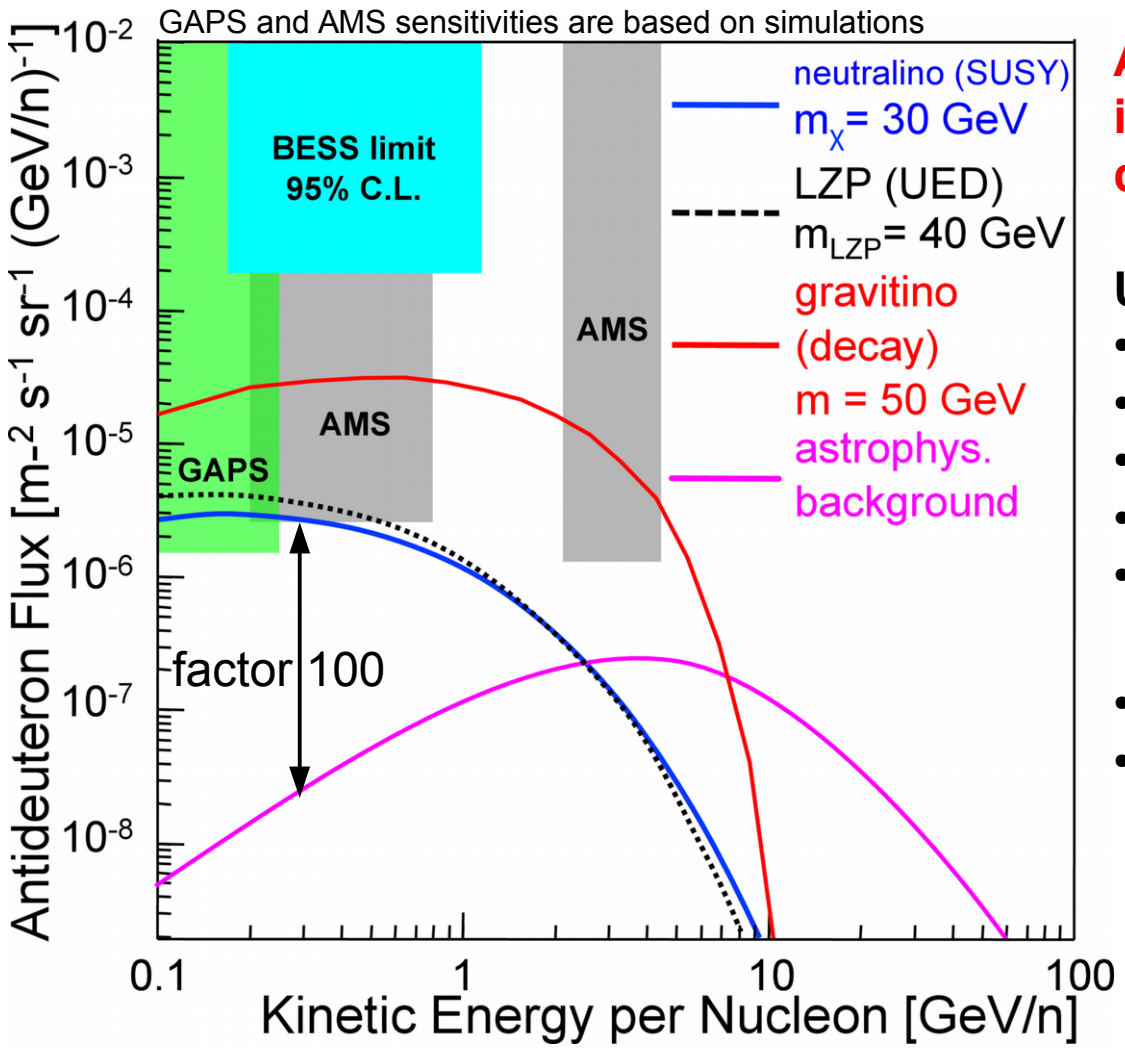
Low-energy $\bar{d}$ and dark matter



Antideuterons are the most important unexplored indirect detection technique!

Uncertainties:

- dark matter annihilation or decay
- dark matter clumping
- antideuteron production
- Galactic propagation
- solar modulation

  → **geomagnetic deflection**
- atmospheric interactions
- interactions in detector

Outline of geomagnetic calculations

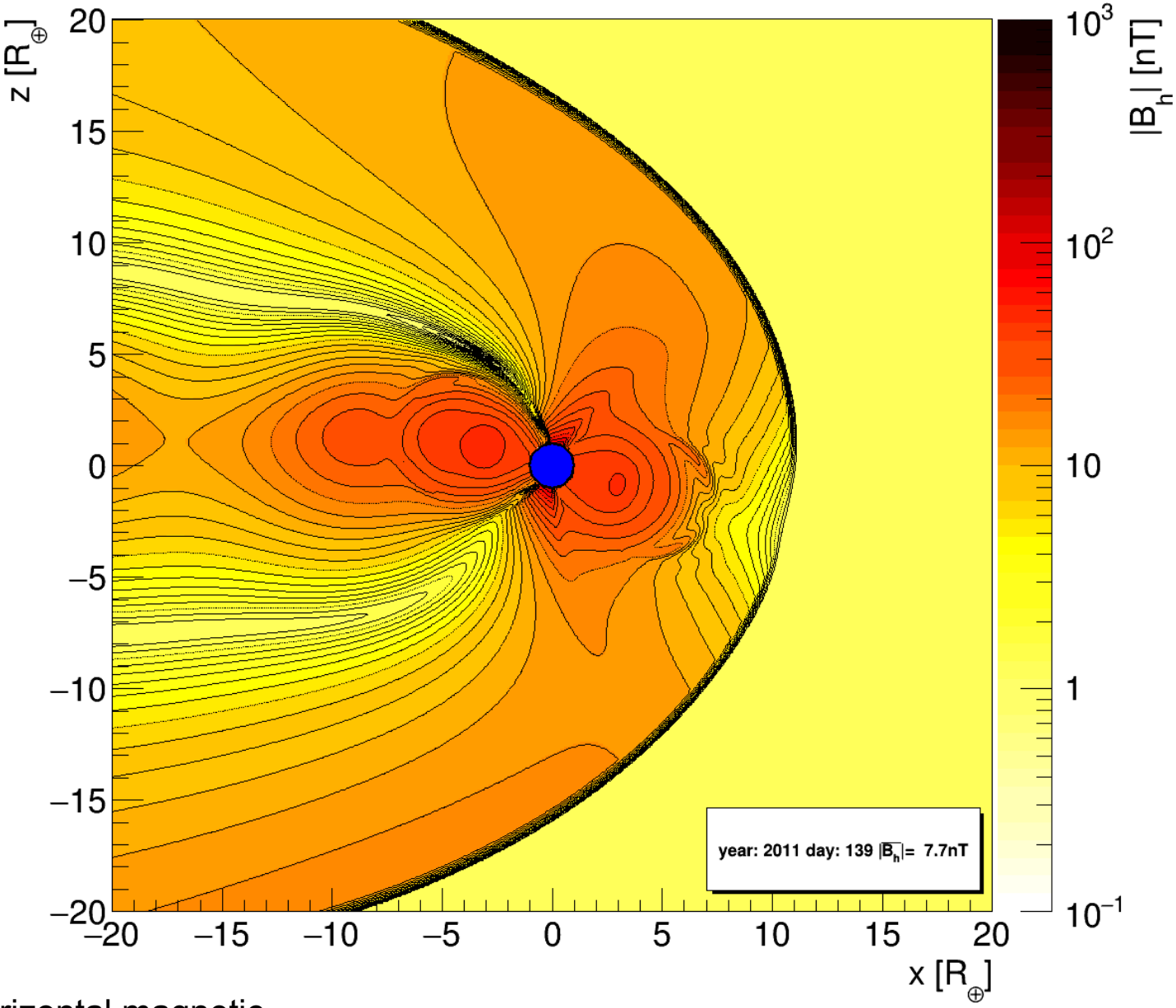
Geomagnetic simulations with **PLANETOCOSMICS** (L. Desorgher) based on Geant4:
http://cosray.unibe.ch/~laurent/planetocosmics/

- **Geomagnetic cutoff calculations with backtracing**
  - added latest IGRF-12 coefficients
  - added Tsyganenko 2004 [N. Tsyganenko, J. Geophys. Res. 110, A03208 (2005)]
    - dynamical data-based model of the inner magnetosphere, representing its structure and temporal variation during geomagnetic storms
    - data base of all parameters as a function of time available
      http://geo.phys.spbu.ru/~tsyganenko/modeling.html

- **Backtracing method:** [Cooke et al., Il Nuovo Cimento 14C, 213, 1991]
  - trajectories of cosmic rays with different rigidities, arriving at the same observing position and from the same direction of incidence are computed backward in time
  - all cutoff values shown are effective cutoff rigidities R_c

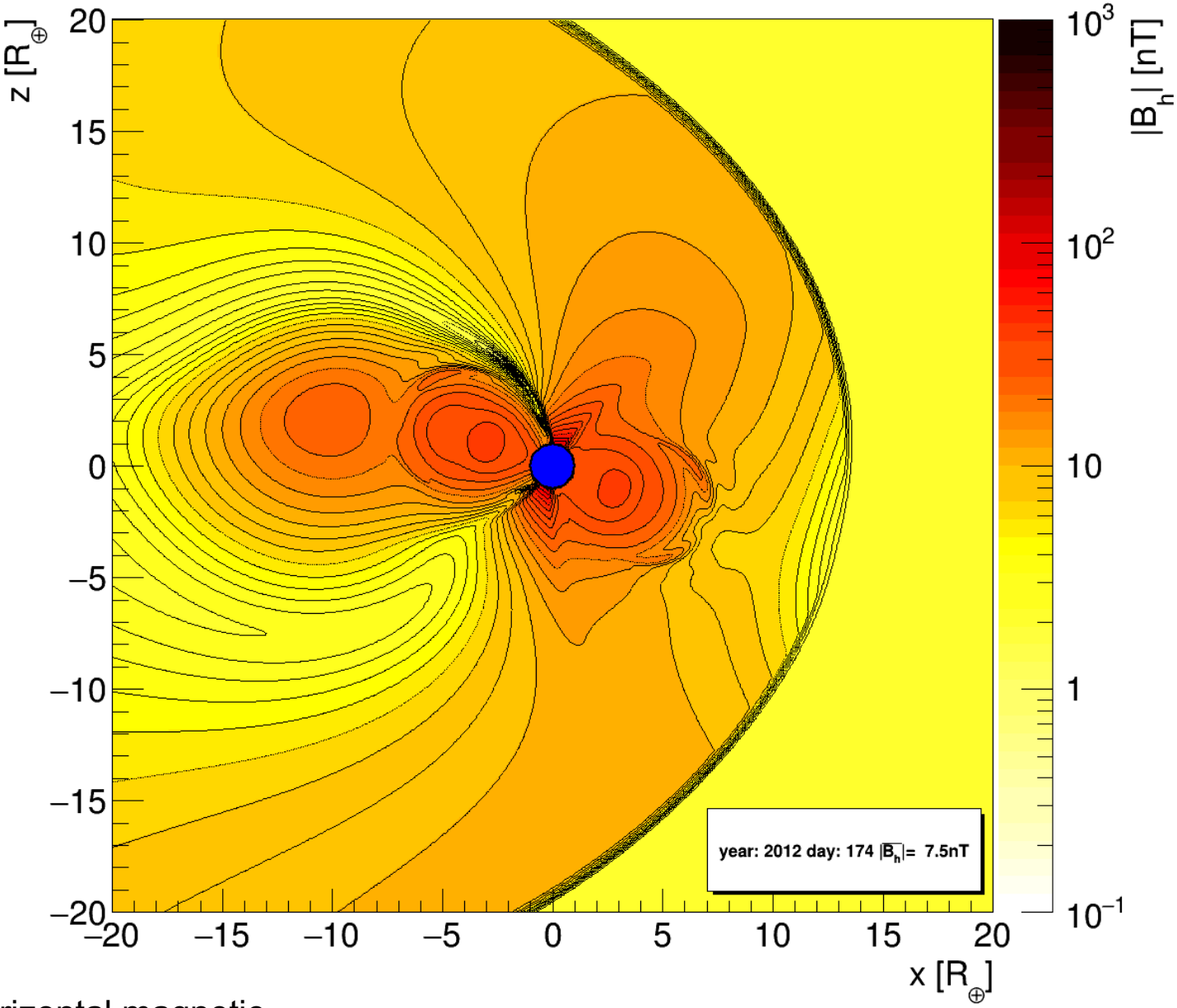
- **Sampling of geomagnetic cutoff behavior for time of AMS-02 operation**
  - study of protons and antiprotons as function of time, location, direction
  - compare to (U)LDB trajectories
  - University of Hawaii HPC cluster: **~more than 100years of CPU time**

Magnetic field – 5/19/2011



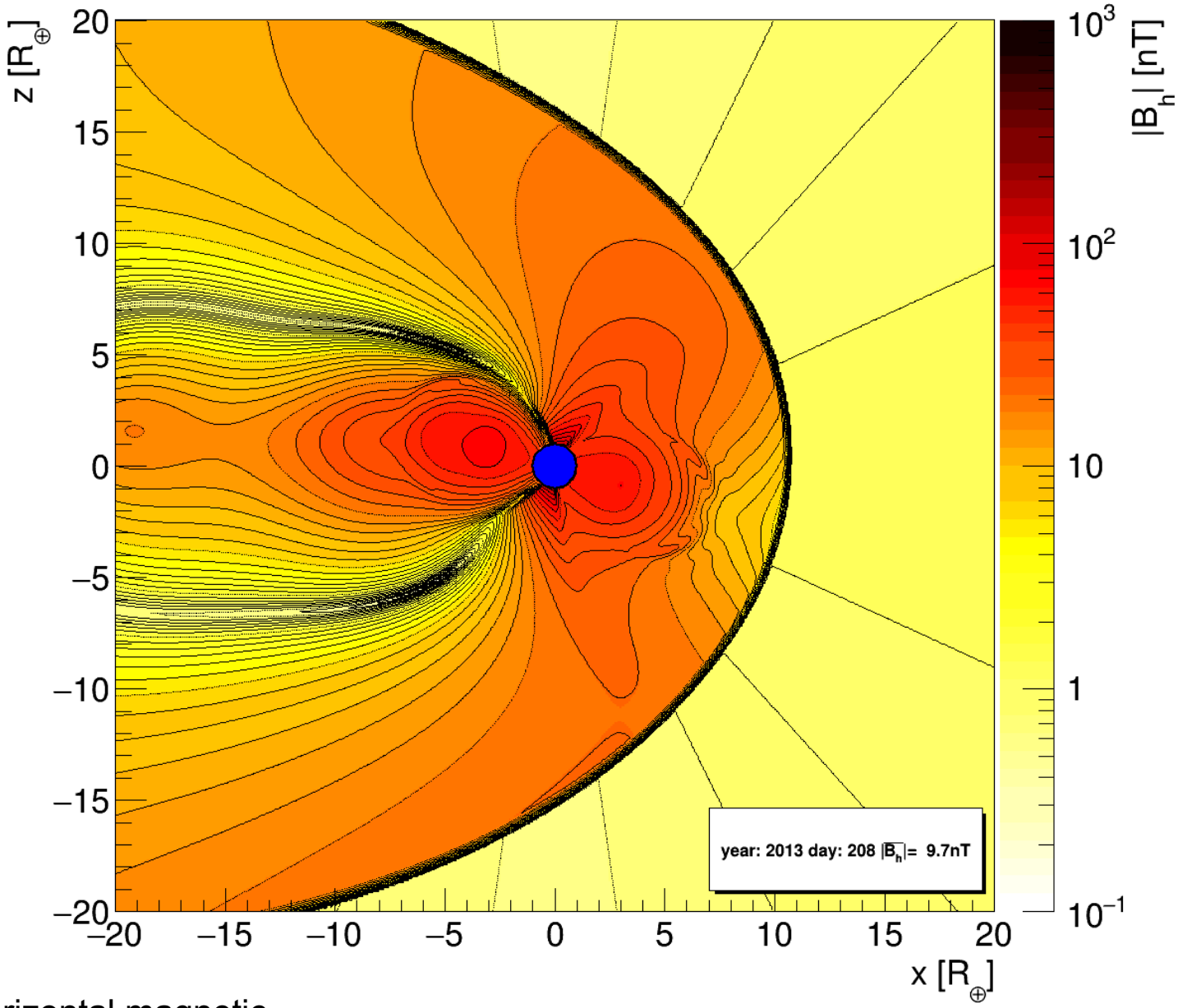
Absolute horizontal magnetic field with respect to Earth surface

Magnetic field – 6/22/2012



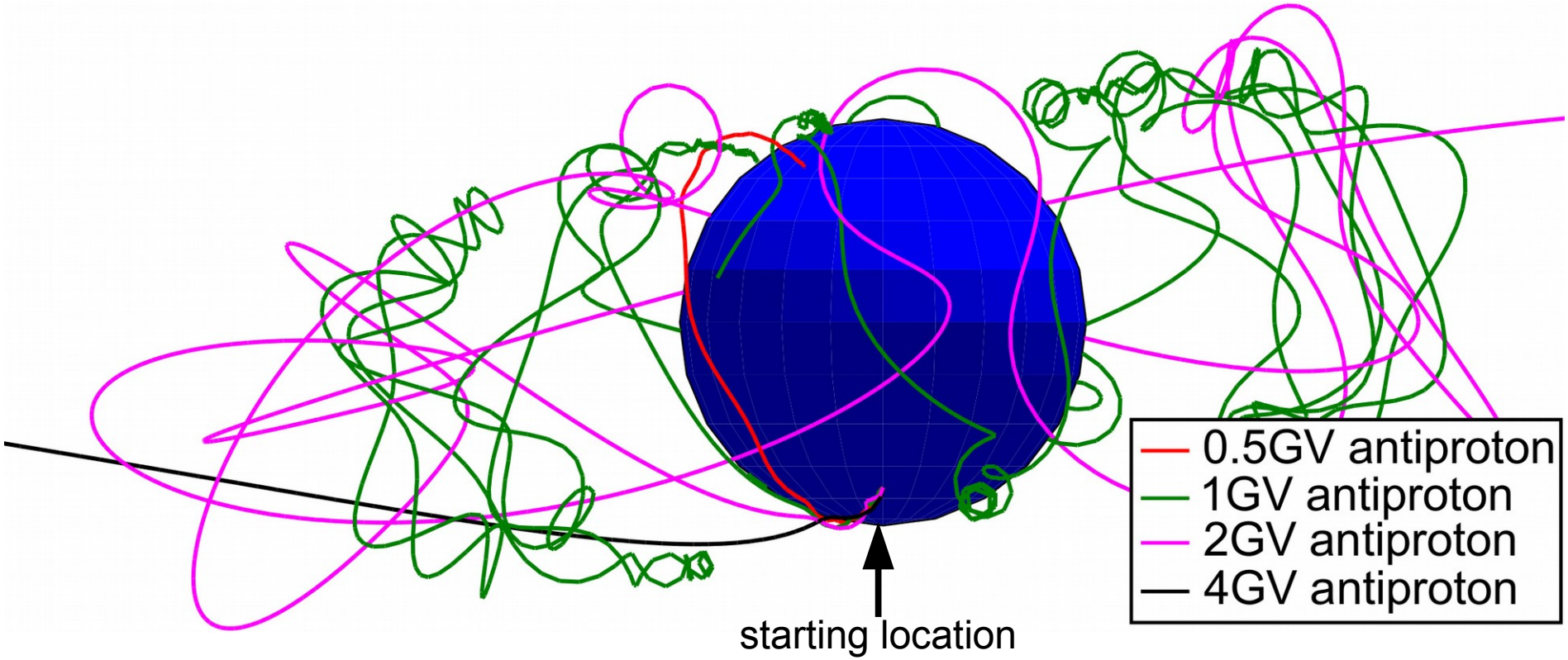
Absolute horizontal magnetic field with respect to Earth surface

Magnetic field – 7/27/2013



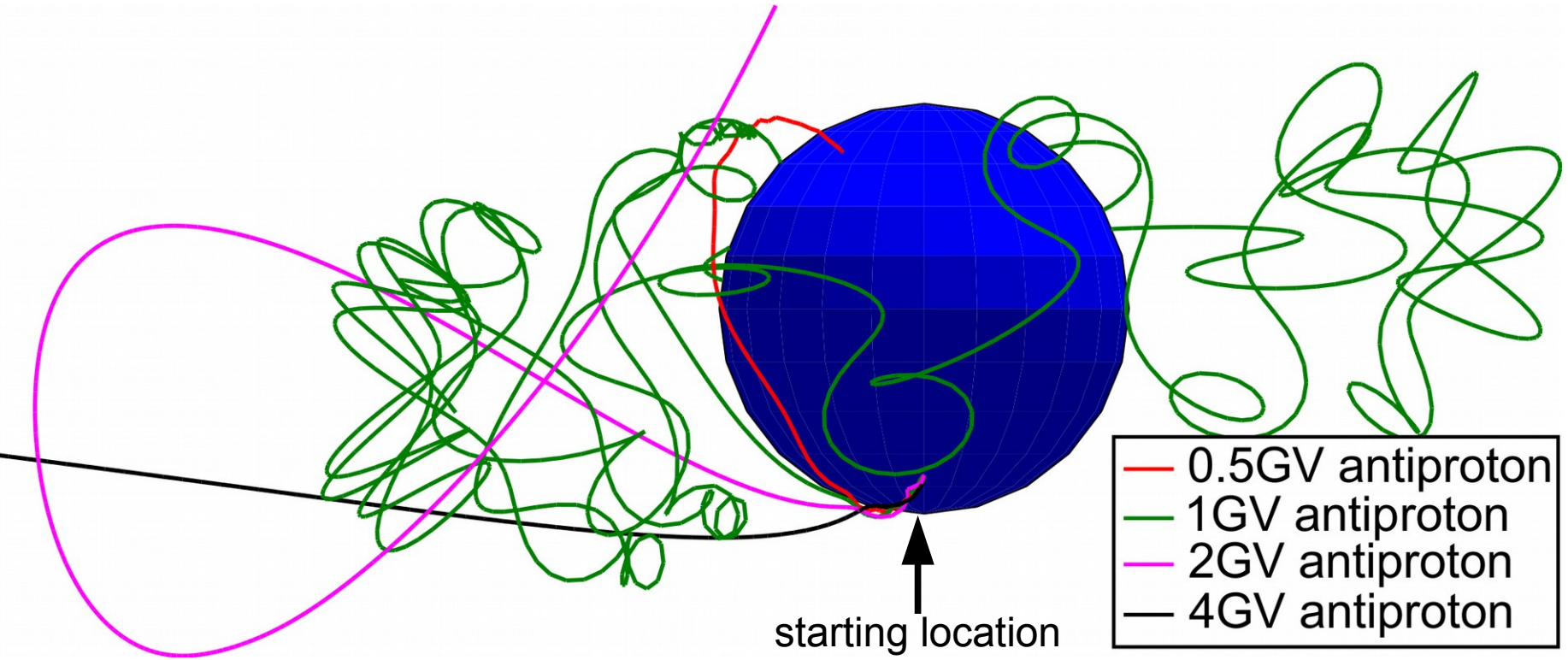
Absolute horizontal magnetic field with respect to Earth surface

Backtracing – 5/19/11



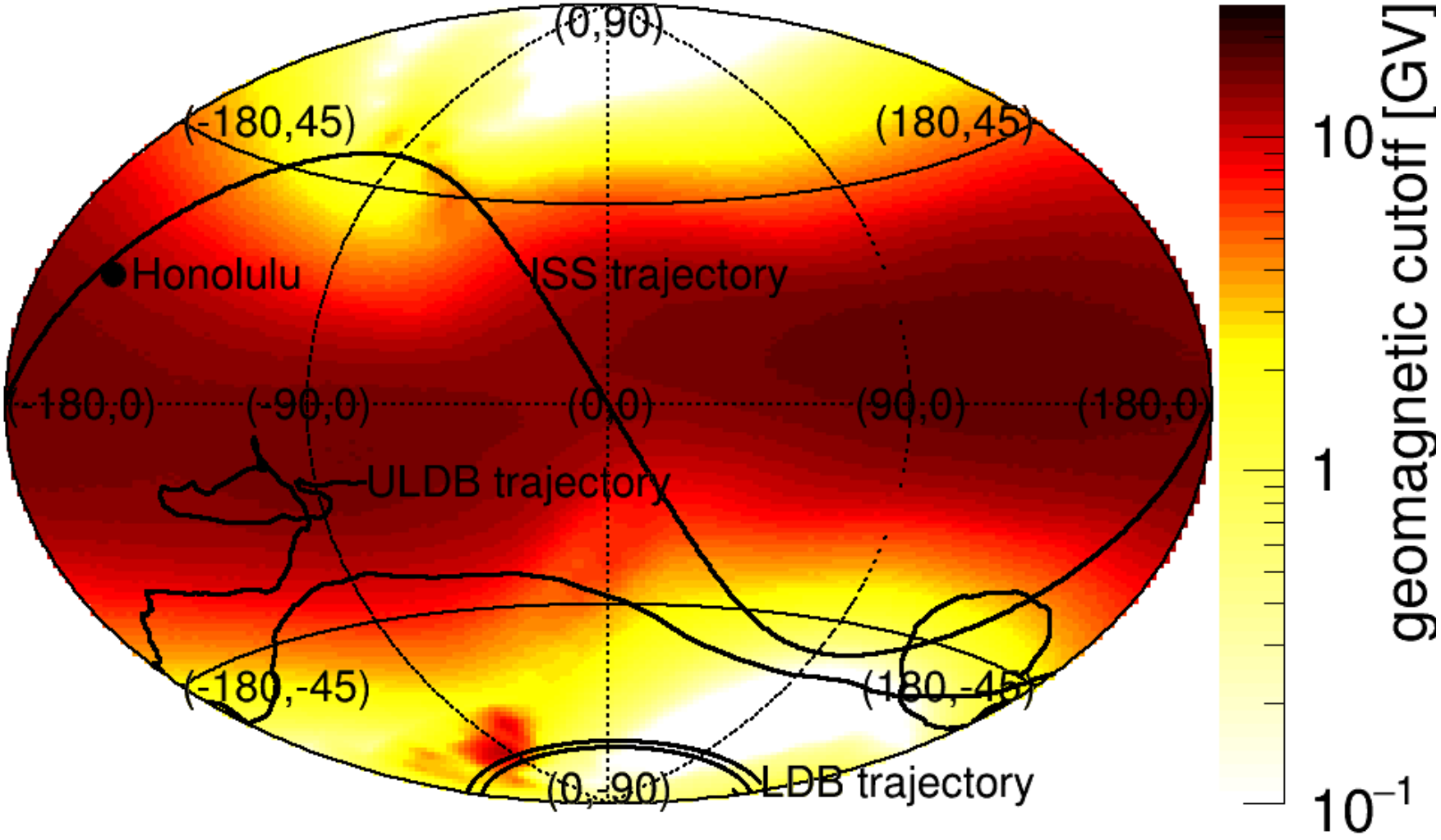
- reverse computation of antiproton trajectories starting at the same location with different rigidities

Backtracing – 3/7/12



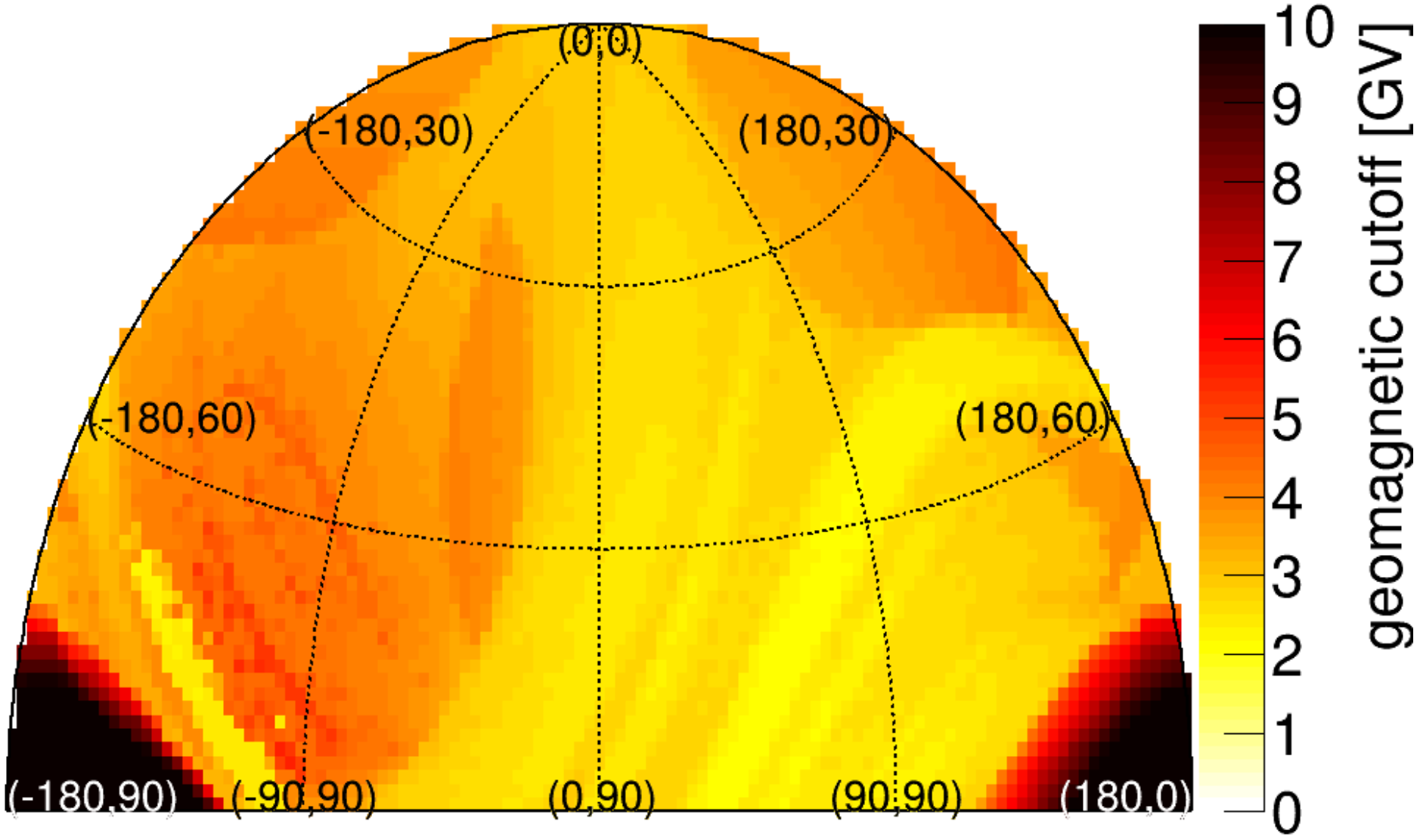
- reverse computation of antiproton trajectories starting at the same location with different rigidities
- change in magnetic environment changes the trajectories drastically
  → changes geomagnetic cutoff values

Averaged cutoffs – 5/19/11



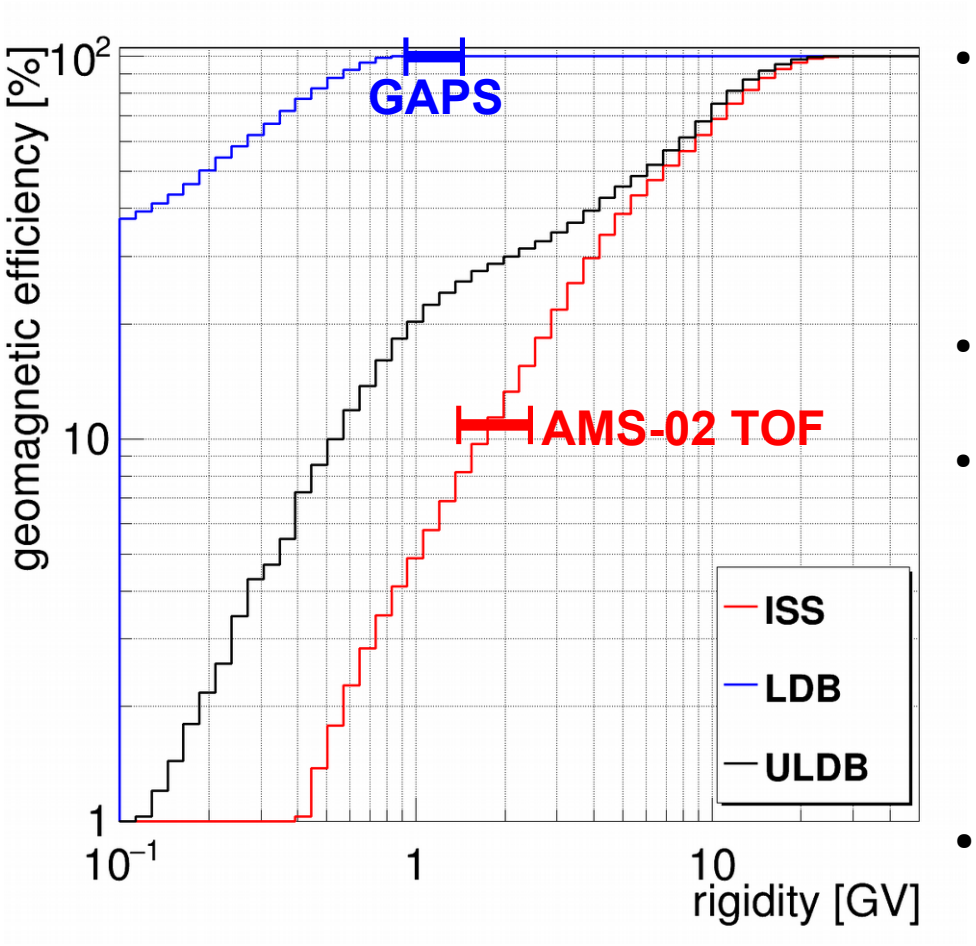
- geomagnetic cutoff for antiprotons averaged over an isotropic incoming particle distribution for cos(zenith) between 0.6-1 (typical opening angles)

Cutoff as function of direction – 5/19/11



- cutoff values as a function of direction for 50°S, 0°W
- **depend not only on zenith, but also on azimuth → need to evaluate both**

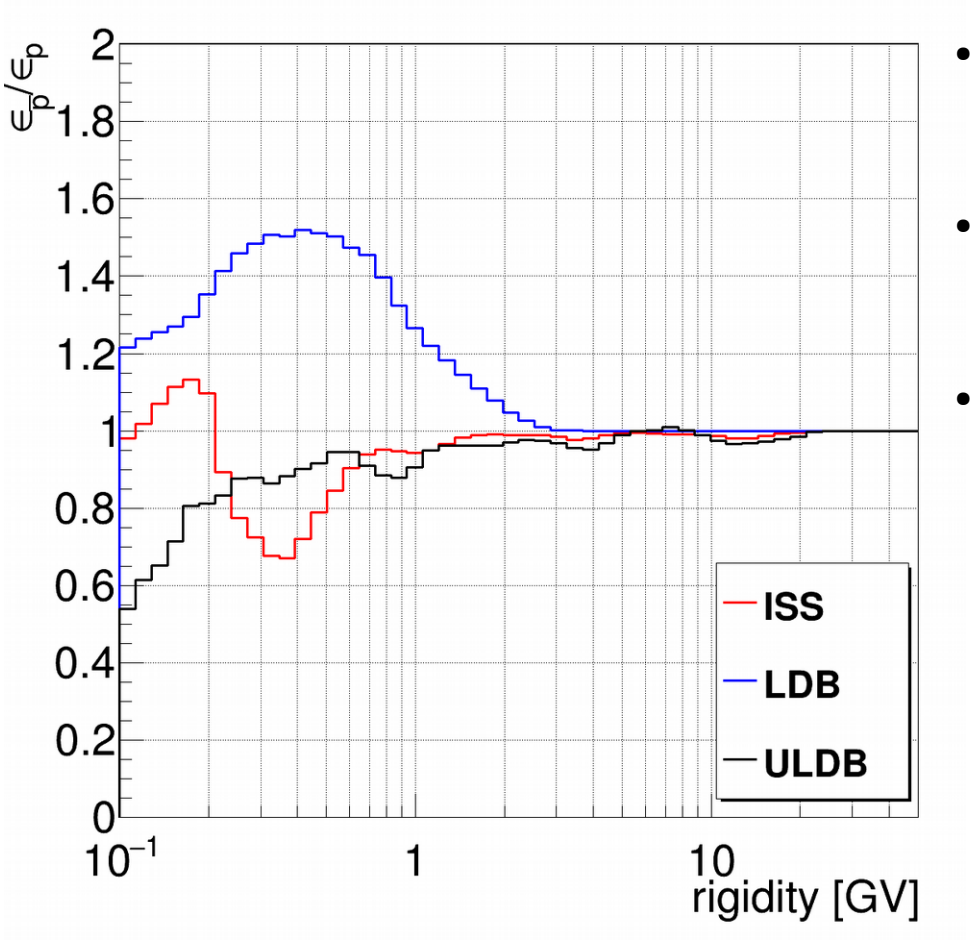
Geomagnetic efficiency for antiprotons



- ISS averaged over calculations from 5/19/11 - 10/6/15 with 100 day steps
- (U)LDB averaged over 5/12/11, 13/1/8, 2/12/14, 12/10/14

- **geomagnetic cutoff efficiency:** ratio of measurement time of particles of cosmic origin within acceptance and total measurement time
- efficiency averaged over flight trajectory
- AMS-02 is installed on the ISS (latitude ±52°)
  → **understanding of geomagnetic environment crucial for low rigidities**
- GAPS is planned to fly from Antarctica (~-80°)
  → **geomagnetic corrections are minimal**

Antiproton-proton comparison



- ISS averaged over calculations from 5/19/11 - 10/6/15 with 100 day steps
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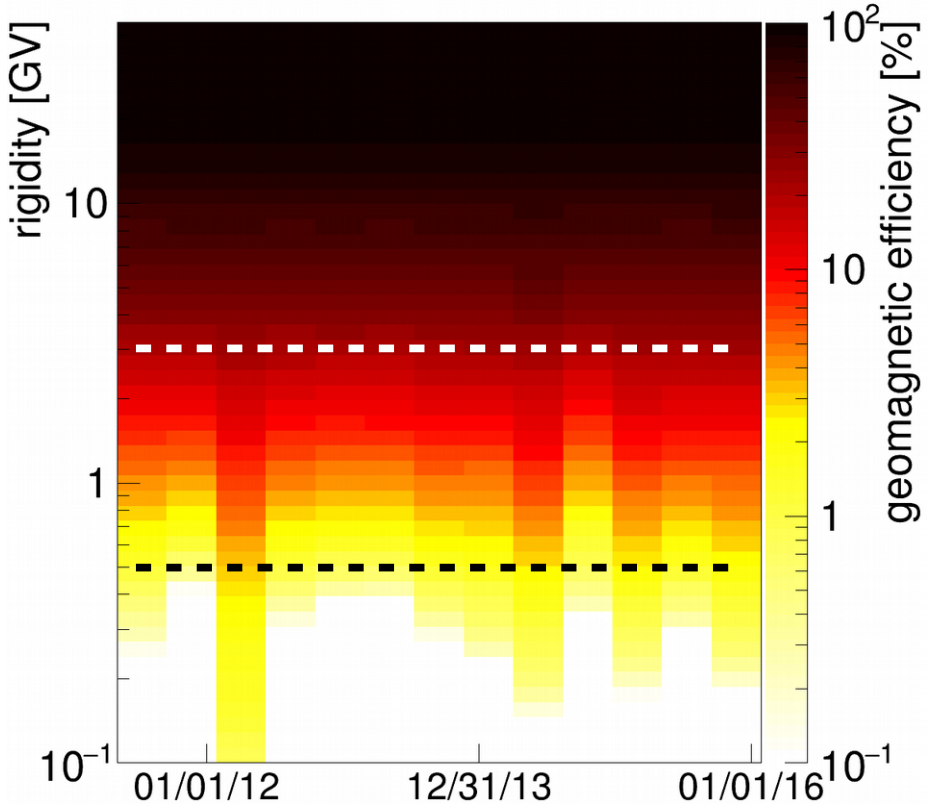
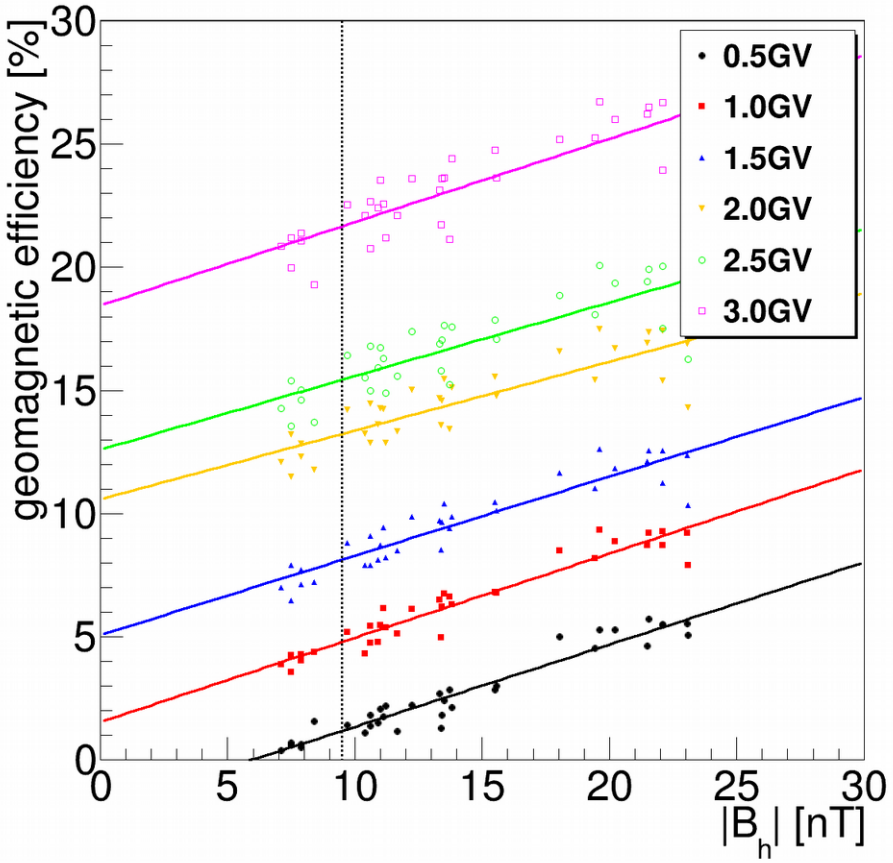
- ratio of antiproton and proton efficiencies for the same trajectories and times
- below ~3GV all three trajectories show a dependence on the charge
- LDB flights from Antarctica:
  → **antiprotons are less suppressed compared to protons**
  → **better suited for antiproton measurements**

Time dependence for antiprotons

ISS trajectory

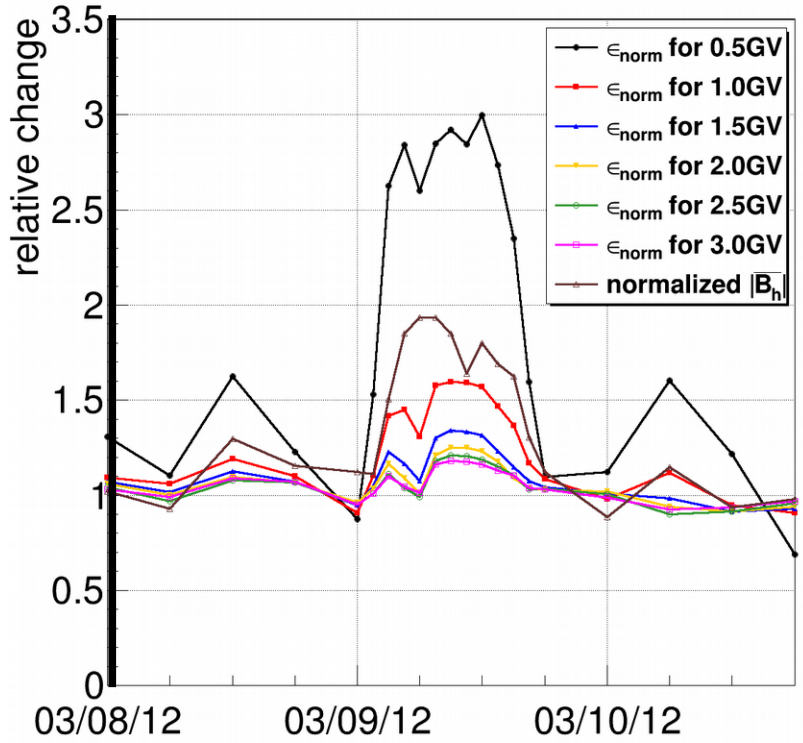


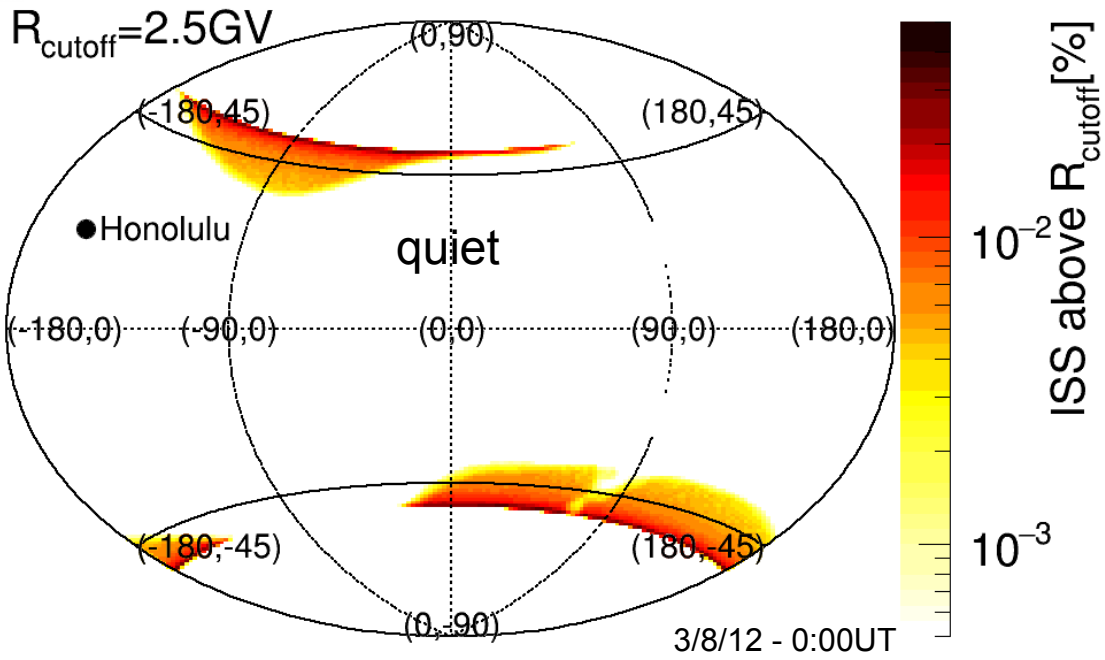


- low-rigidity range exposes strong cutoff efficiency variations as a function of time without an apparent trend
- correlation of mean value of the horizontal magnetic field with geomagnetic efficiencies at different rigidity steps → **stronger field results in a larger geomagnetic efficiency for all rigidity steps**
- from straight line fits at mean $|\overline{B}_H|$=9.5nT (over the whole period):
  (4.8±0.3)% at 1GV
  (21.7±0.7)% at 3GV

Solar X-ray flare event

ISS trajectory





- extreme UV flash of X5-class solar flare March 7, 2012
- **significant increase of geomagnetic cutoff efficiency**
- geomagnetic efficiency is again correlated with $|\overline{B}_H|$
- “windows” in the geomagnetic field open and close quickly

Solar X-ray flare event

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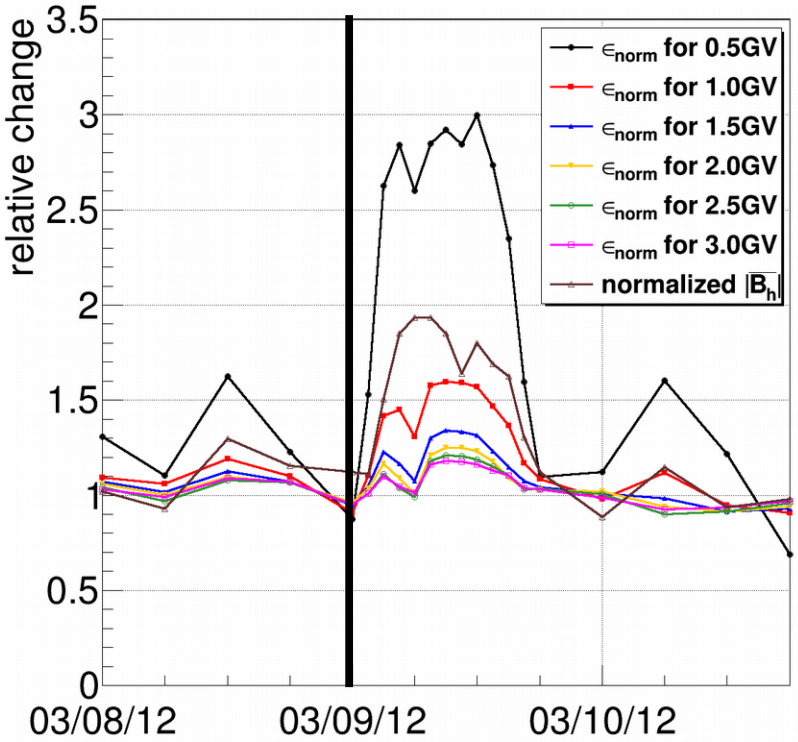

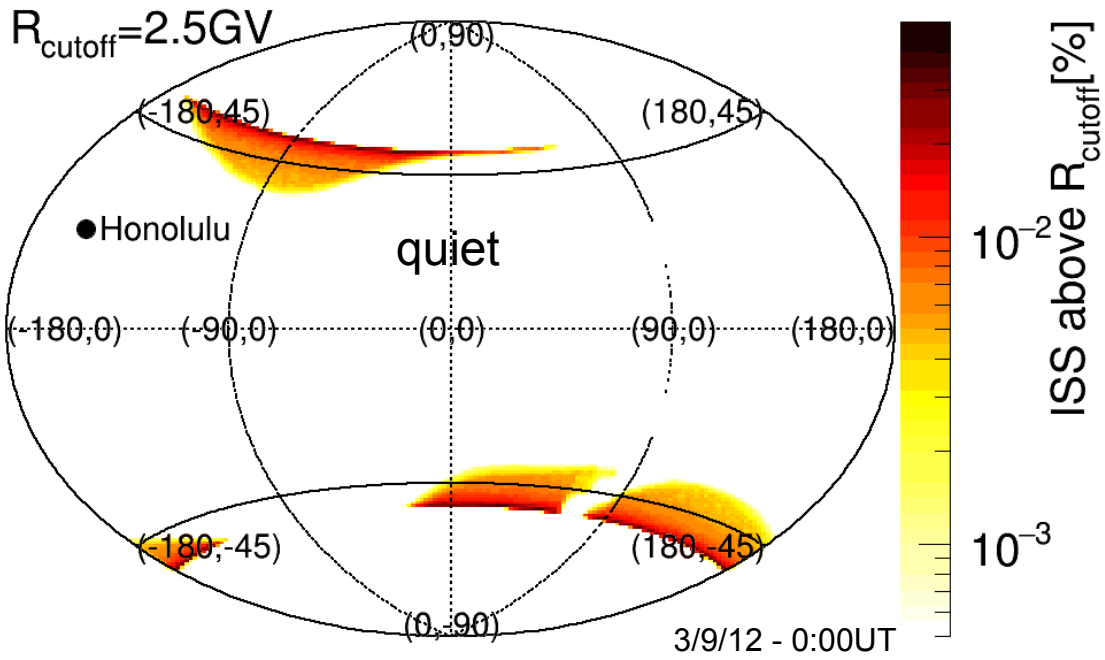

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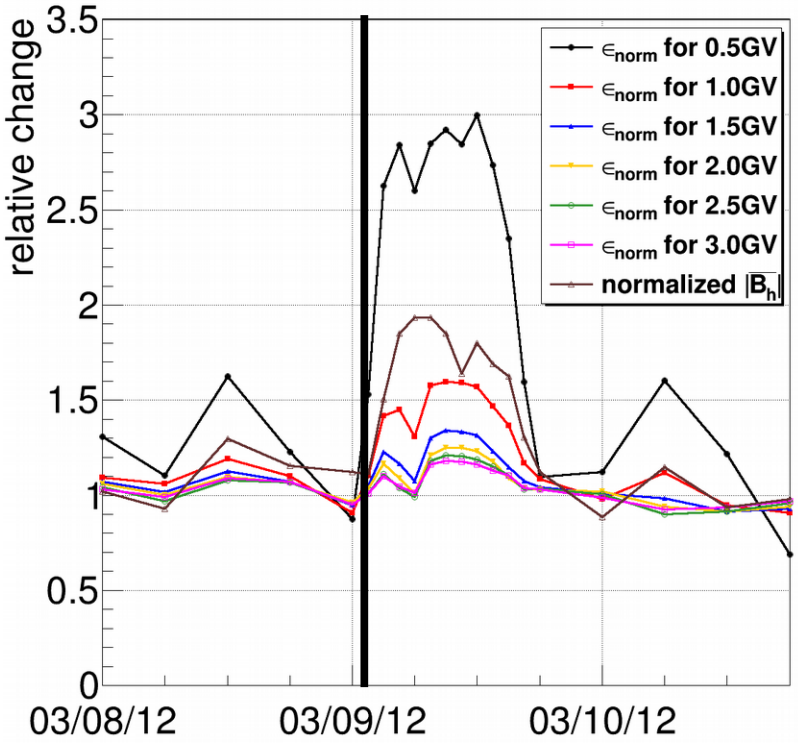

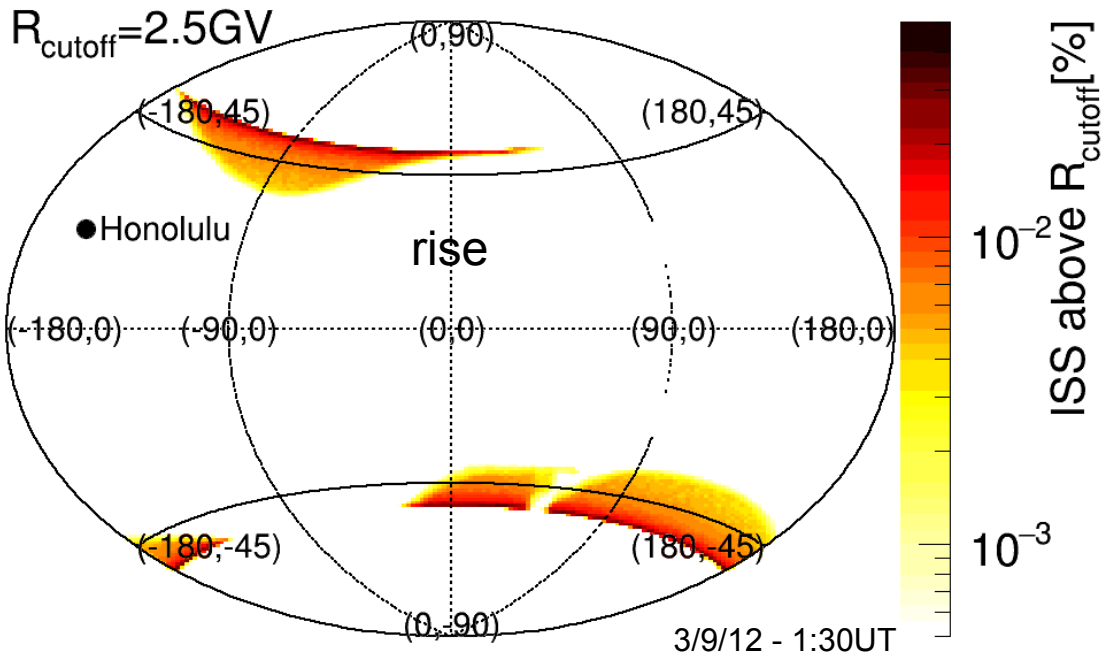

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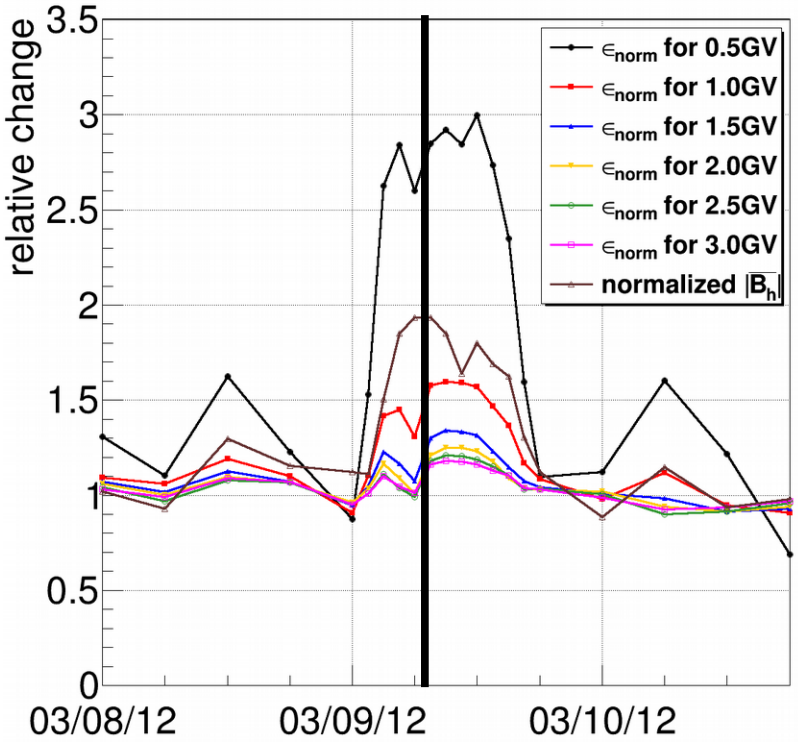

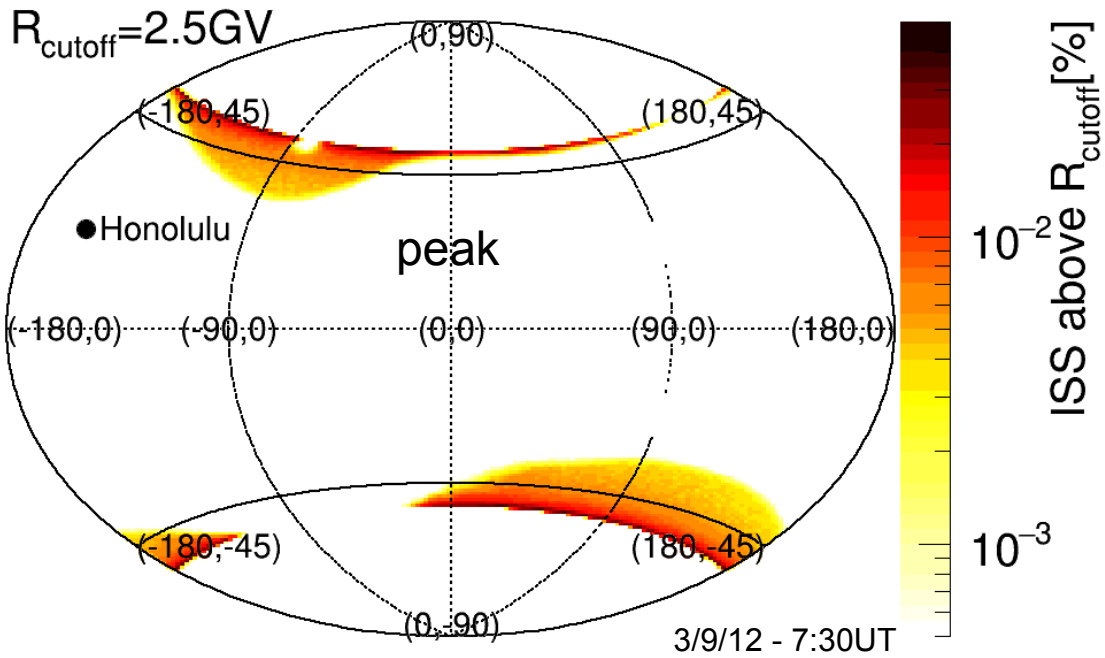

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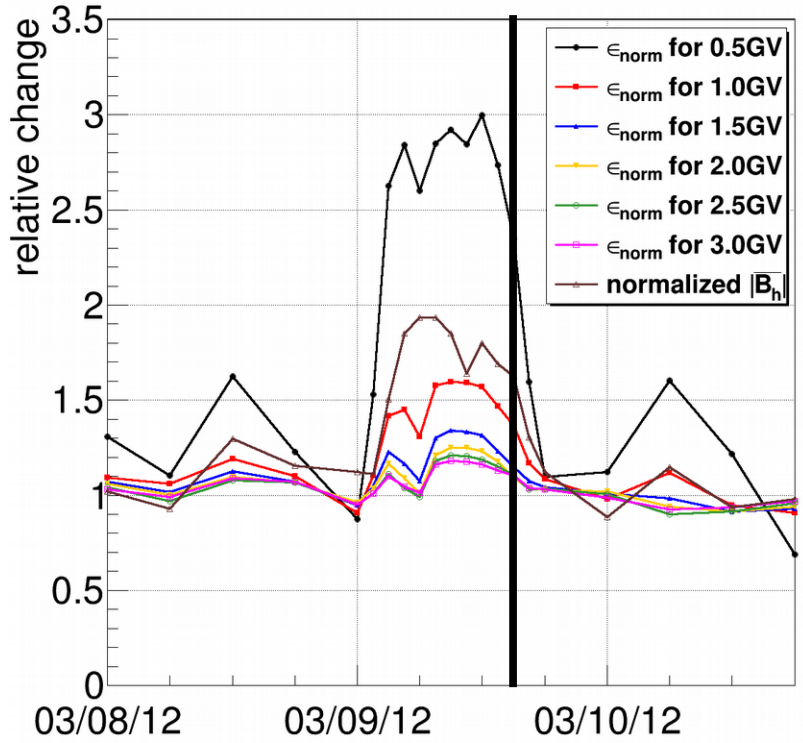

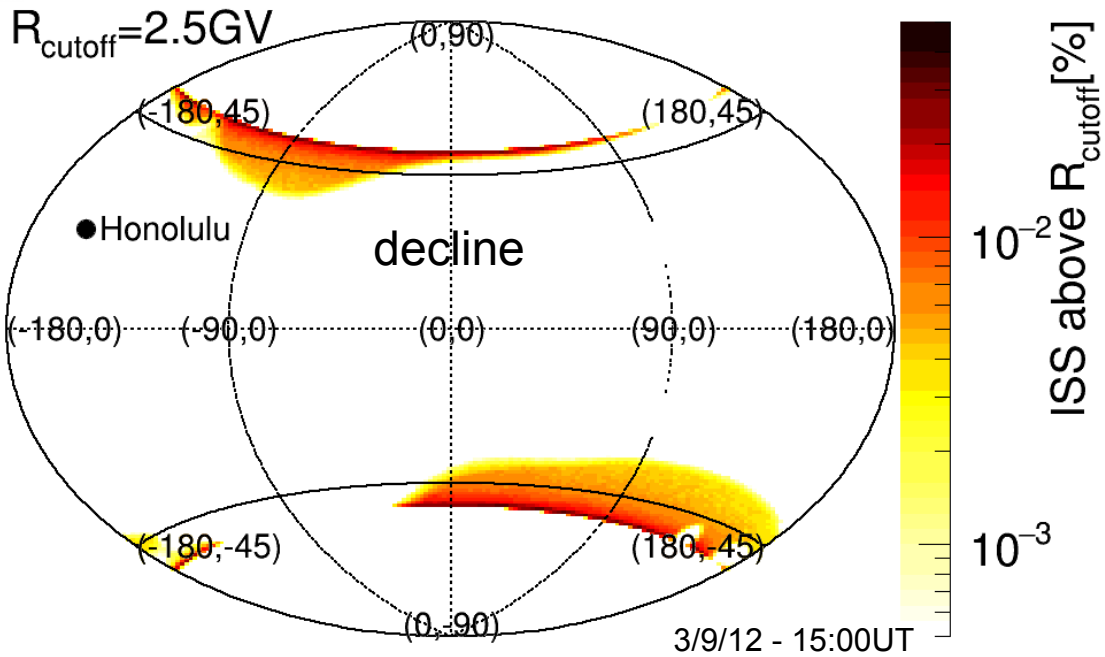

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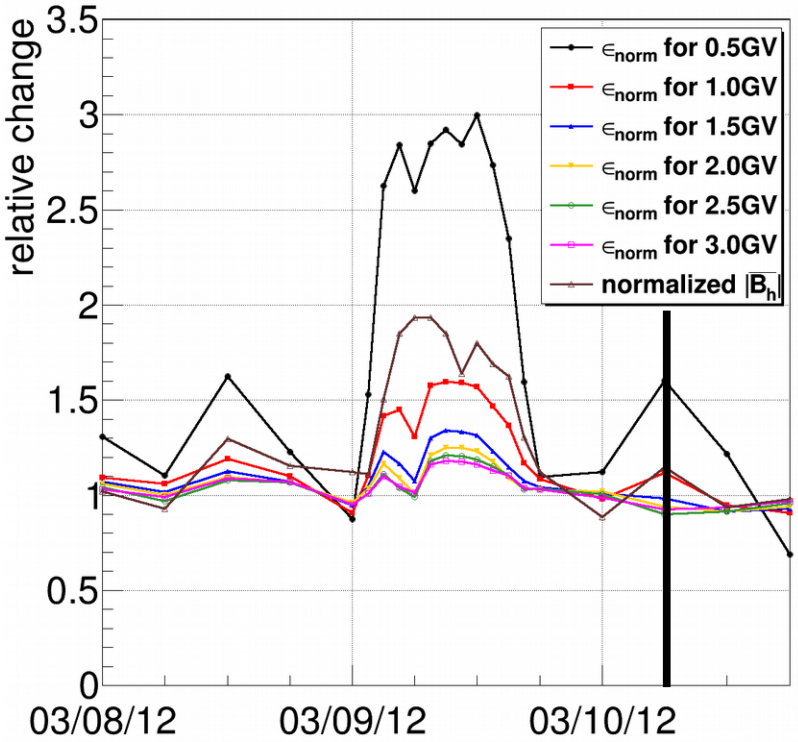

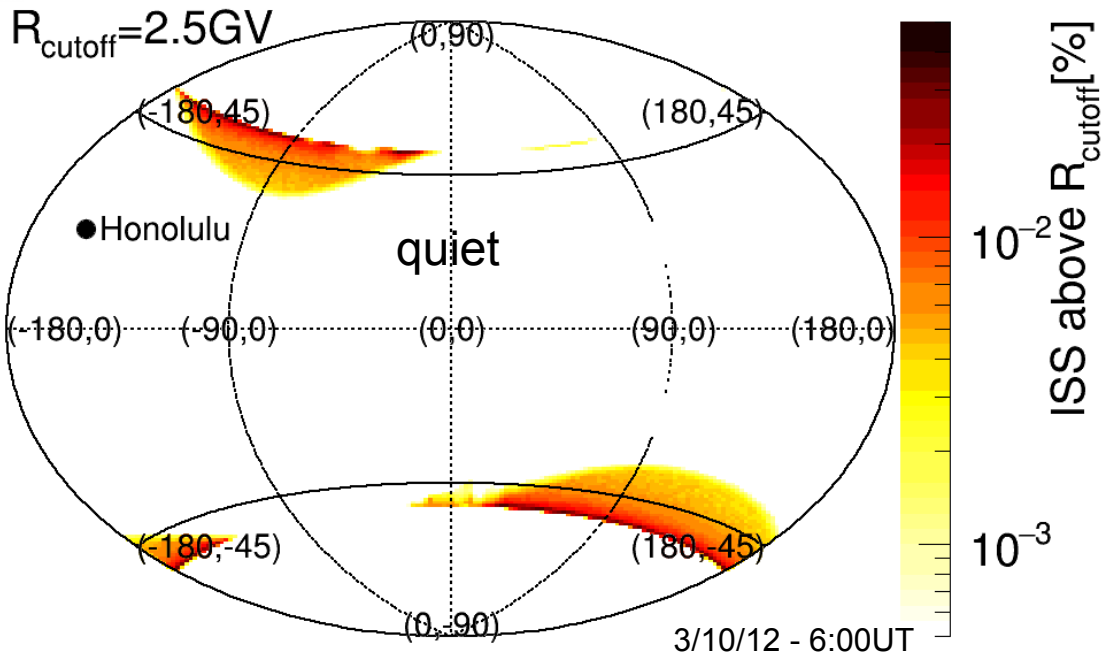

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- **significant increase of geomagnetic cutoff efficiency**
- geomagnetic efficiency is again correlated with $|\overline{B}_H|$
- "windows" in the geomagnetic field open and close quickly
  → **geomagnetic efficiency increase due to enlarged "allowed" windows**

Postdoc opening in Hawaii for GAPS

North Shore

View from the office

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Astroparticle Physics

Hawaii U. - Postdoc

Field of Interest: astro-ph, hep-ex
Experiment: GAPS
Deadline: 2017-07-31
Region: North America

Job description:
Duties and Responsibilities:
The successful candidate will participate in the balloon-borne cosmic-ray antideuteron experiment GAPS. Cosmic-ray antideuterons are an important new probe for indirect dark matter identification. Detailed design and construction of the payload will start in 2017 and the first flight from Antarctica is planned for the end of 2020. The Hawaii group is mainly involved in the simulation tools and analysis software development as well as the calibration and qualification of lithium-drifted-silicon detectors.

Minimum Qualifications:
Applicants must hold a doctoral degree, preferentially in (astro)particle physics. Extensive experience with simulation tools (Geant4) and data analysis (ROOT) as well as hands-on lab experience with solid-state particle physics detectors is expected.

To Apply:
Send application (cover letter, curriculum vitae, list of publications, and contact information for at least two references) to philipvd@hawaii.edu. Please specify in the subject of the email: Postdoctoral fellow for the GAPS experiment.

Other Conditions:
The initial term of this position is for one year. Renewal subject to satisfactory performance.

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Contact: Philip von Doetinchem
Email: philipvd@hawaii.edu
More Information: http://www.phys.hawaii.edu/~philipvd/
Letters of Reference should be sent to: philipvd@hawaii.edu

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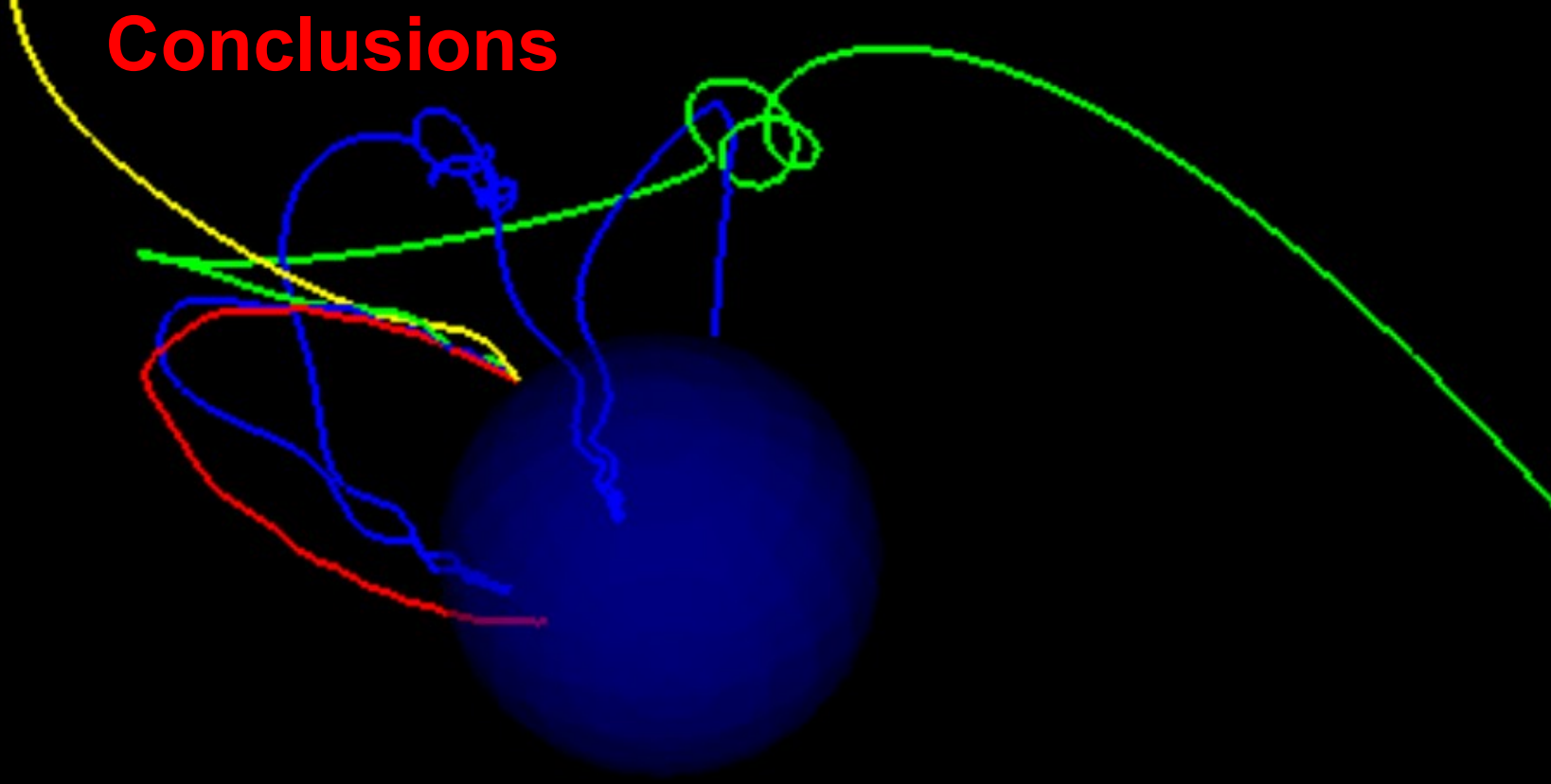
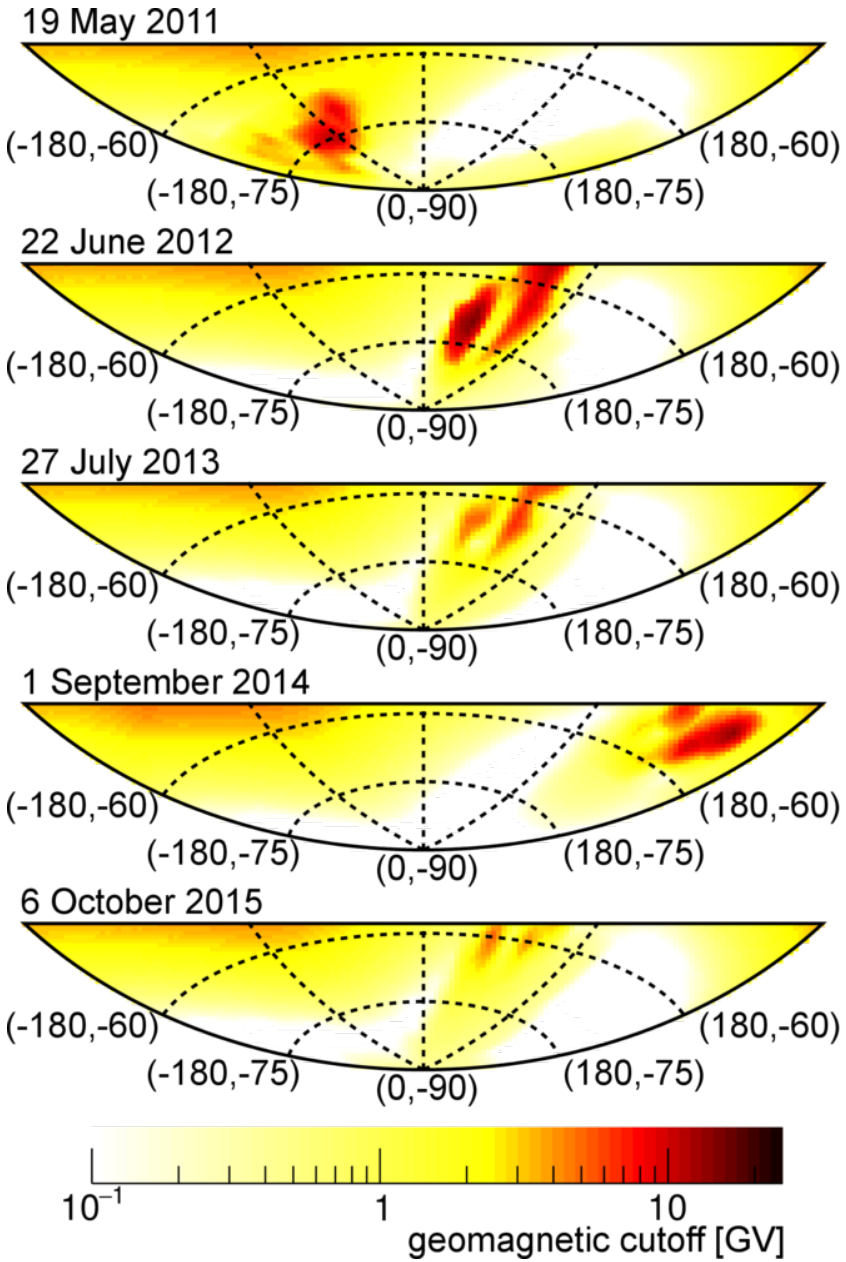
Conclusions



- extensive geomagnetic cutoff calculations were carried out with PLANETOCOSMICS with the Tsyganenko 2004 model during which AMS-02 was operational
- cutoff has to be treated as function of position and direction of the incoming particle
- most suitable location for low-rigidity antiparticle measurements is an Antarctic flight
- large variability of geomagnetic efficiency at low rigidities, depends linearly on the mean of the absolute horizontal magnetic field component
- variability can happen on timescales as short as a few hours for extreme solar events

Regions of increased cutoffs



- increased geomagnetic cutoff regions for antiprotons for the lower part of the Southern Hemisphere
- regions with increased cutoffs change location, size, and maximum value over time
- similar behavior was also found for protons, but location of regions with increased cutoffs differ between antiprotons and protons

→ **needs more studies**