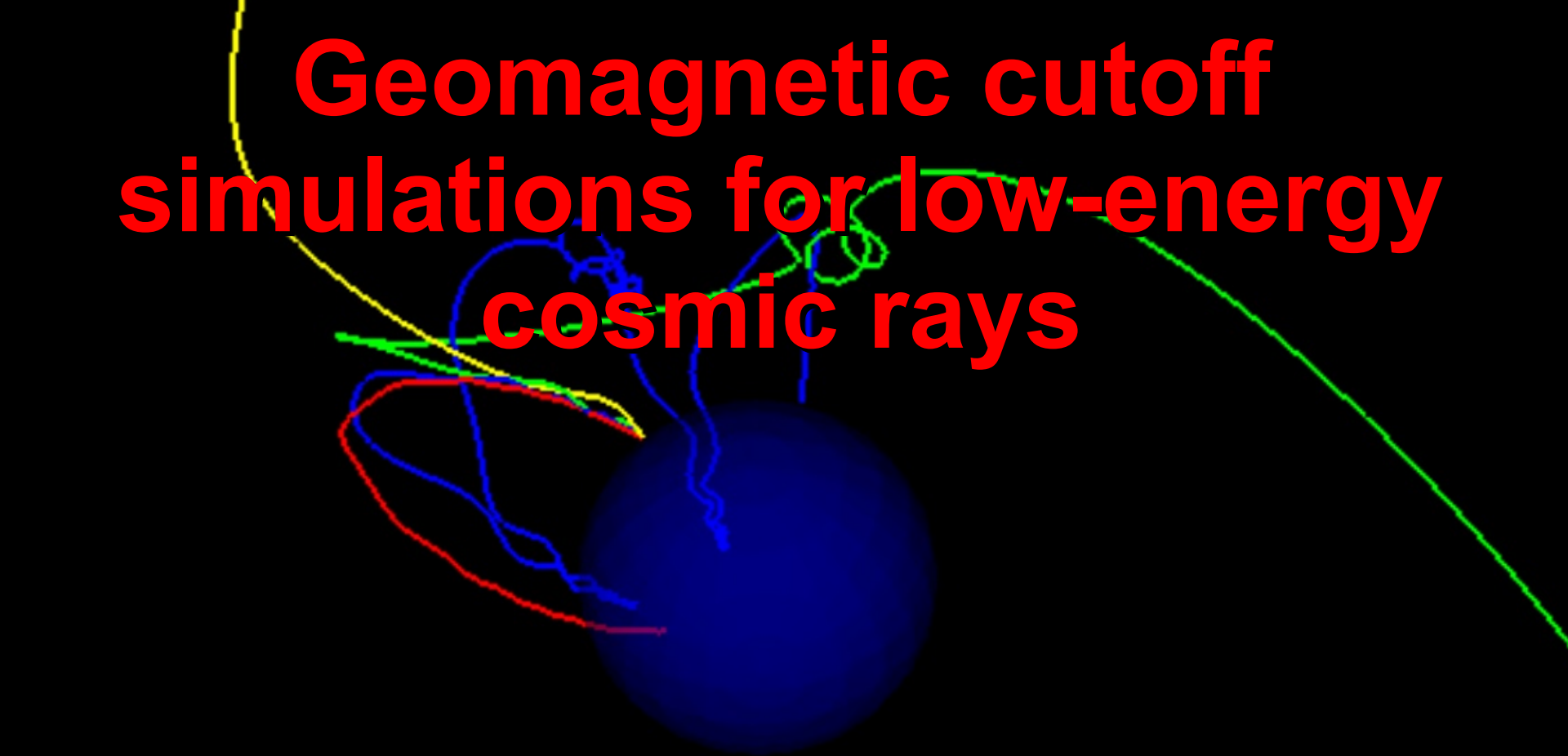
Geomagnetic cutoff simulations for low-energy cosmic rays

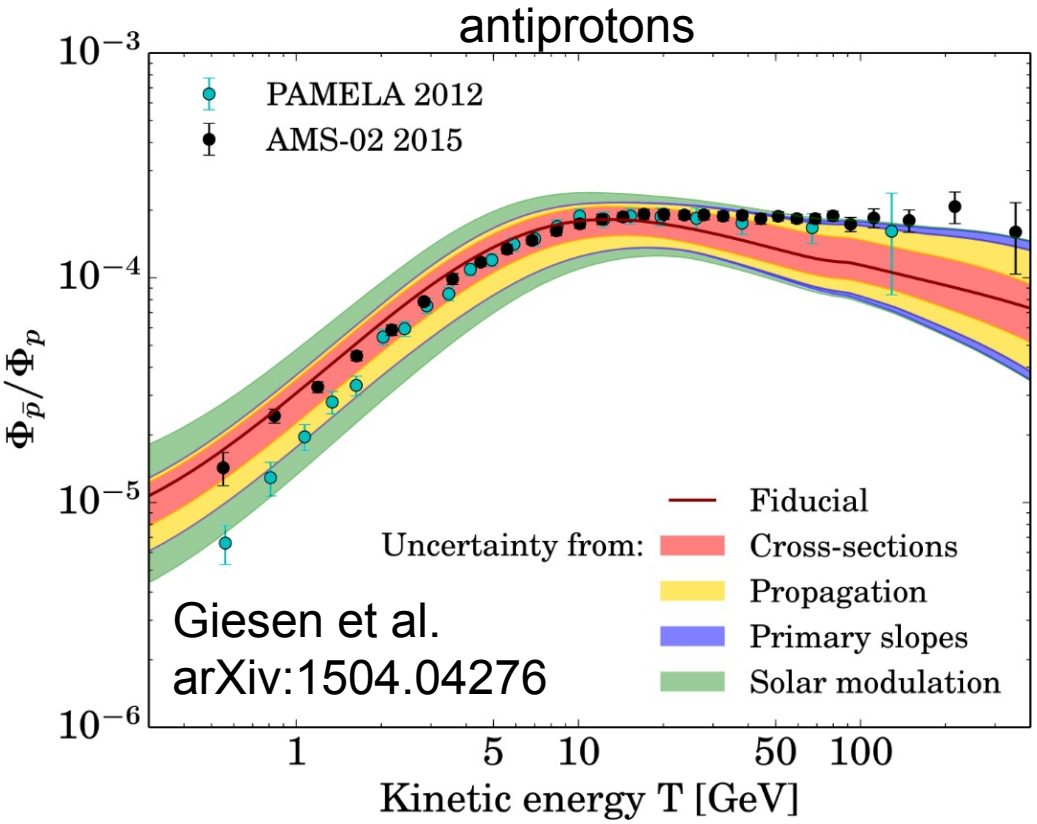


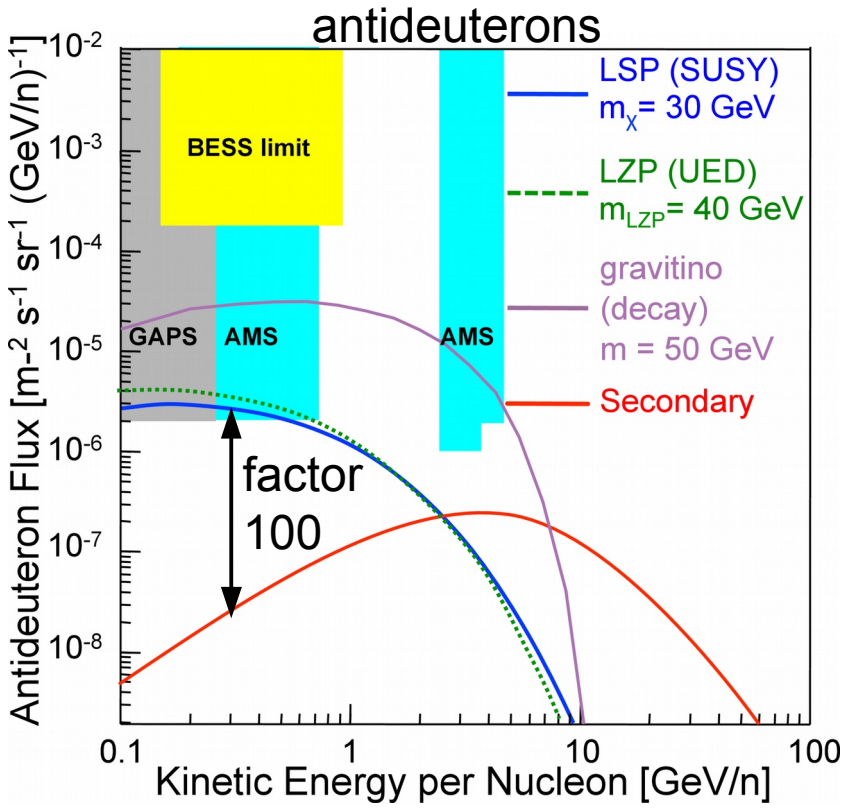
Solar Energetic Particles (SEP), Solar Modulation and Space Radiation: New Opportunities in the AMS-02 Era
Honolulu, October 2015

Philip von Doetinchem
philipvd@hawaii.edu
Department of Physics & Astronomy
University of Hawai'i at Mānoa

http://www.phys.hawaii.edu/~philipvd
www.antideuteron.com

Low-energy antiprotons and antideuterons

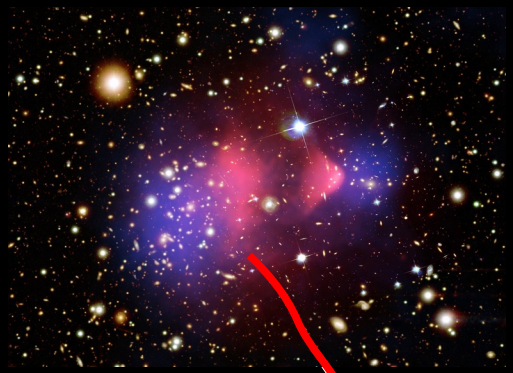




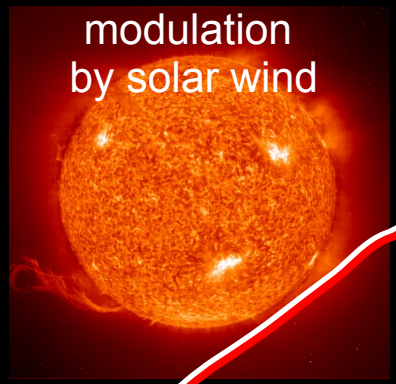
- Low-energy cosmic-ray antiprotons and antideuterons are very interesting probes for new physics → dark matter annihilations or decay

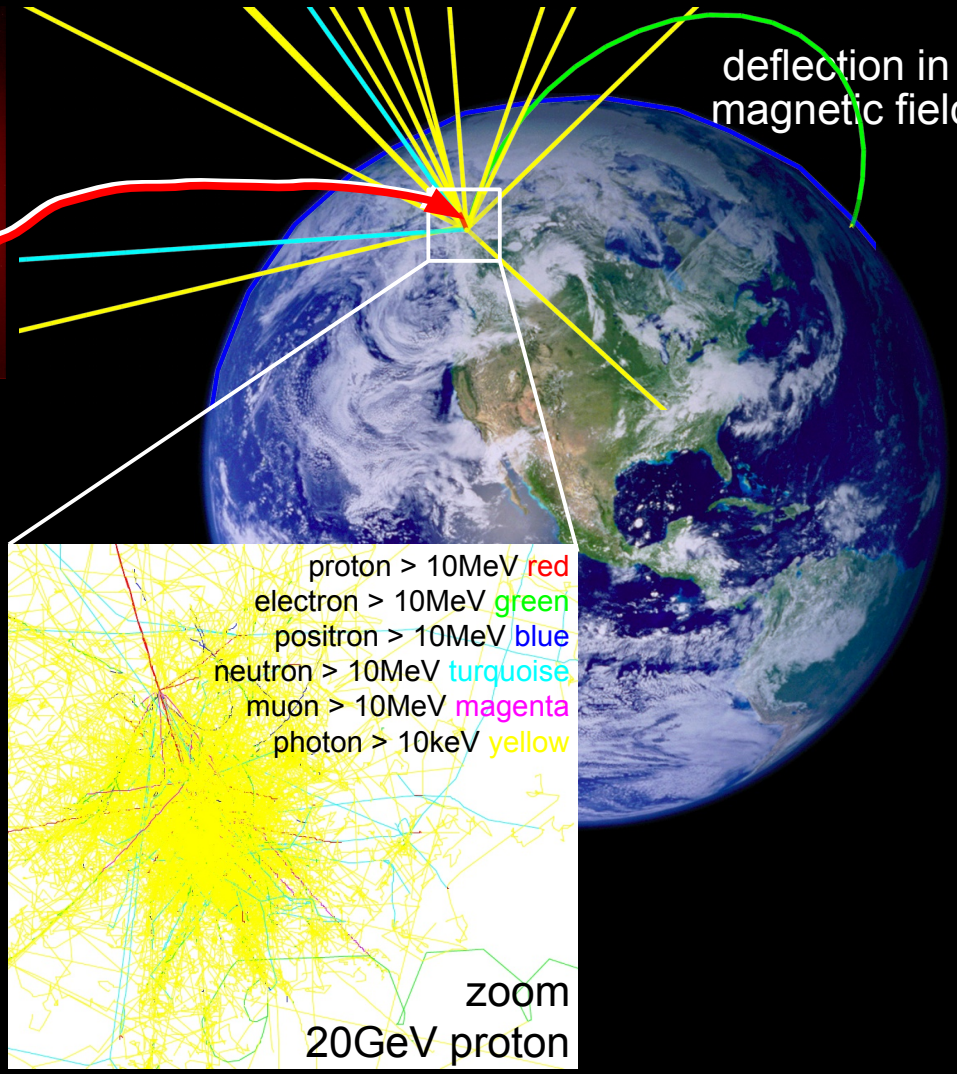
- **Antideuterons are the most important unexplored indirect dark matter detection technique!**

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**

Warning

This is work in progress.
I highly welcome input.

PLANETOCOSMICS

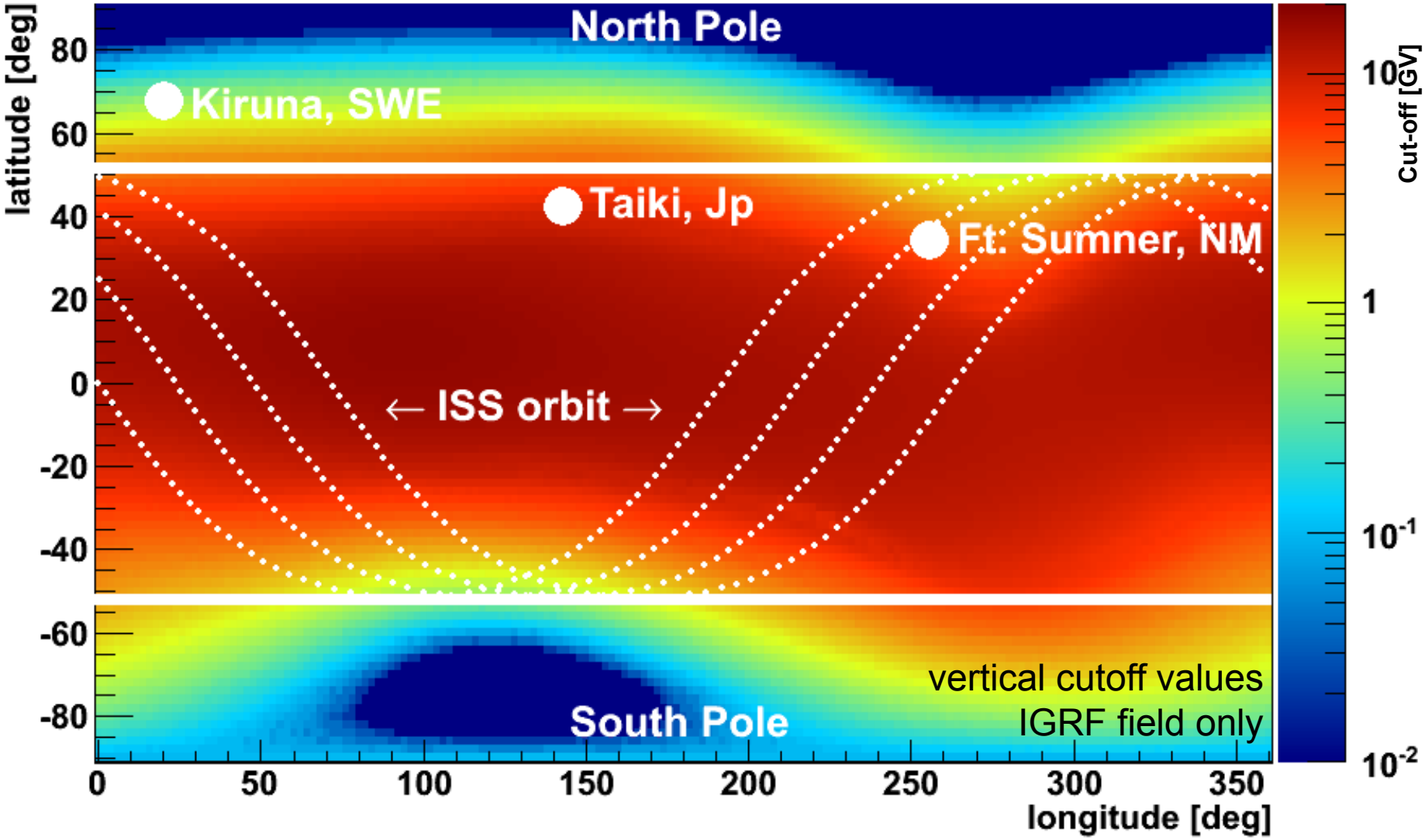
Atmospheric and geomagnetic simulations with **PLANETOCOSMICS** (Desorgher, Universitaet Bern) based on Geant4: http://cosray.unibe.ch/~laurent/planetocosmics/ [latest version on website from 2006]

- **Atmospheric interactions:**
  - updated to Geant 4.9.2 in 2010
    → plan to upgrade to Geant 4.10 soon (light nuclei physics!)
  - modified code validated with various data sets
    → works very reliably in predicting atmospheric backgrounds

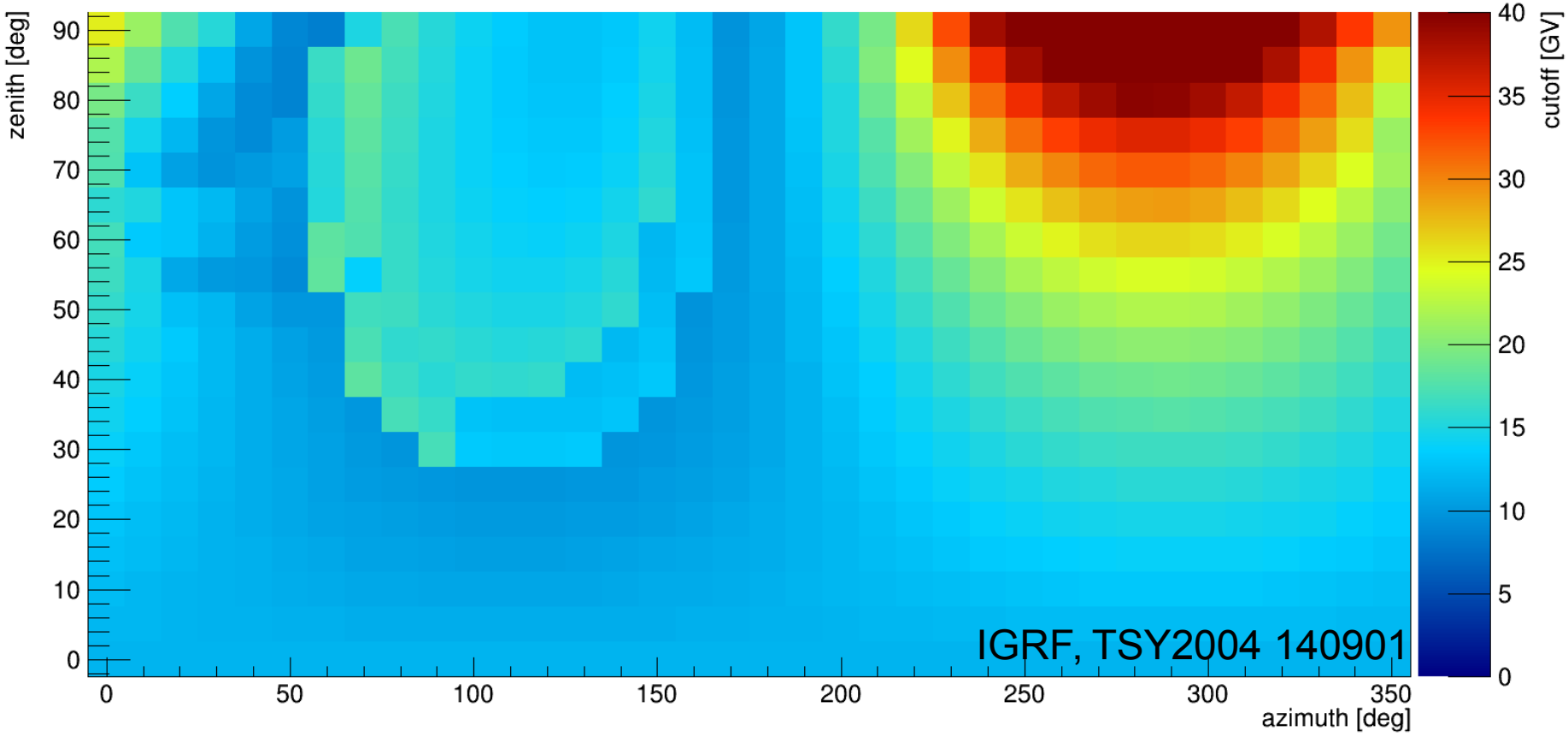
- **Cutoff calculations with backtracing**
  - IGRF geomagnetic field (+simplified/earlier models)
  - added latest IGRF-12 coefficients
  - just added Tsyganenko 2004

- **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 using the Geant4 tracing of charged particles through magnetic fields
  - all cutoff values shown are effective cutoff rigidities R_c

Geomagnetic cutoff

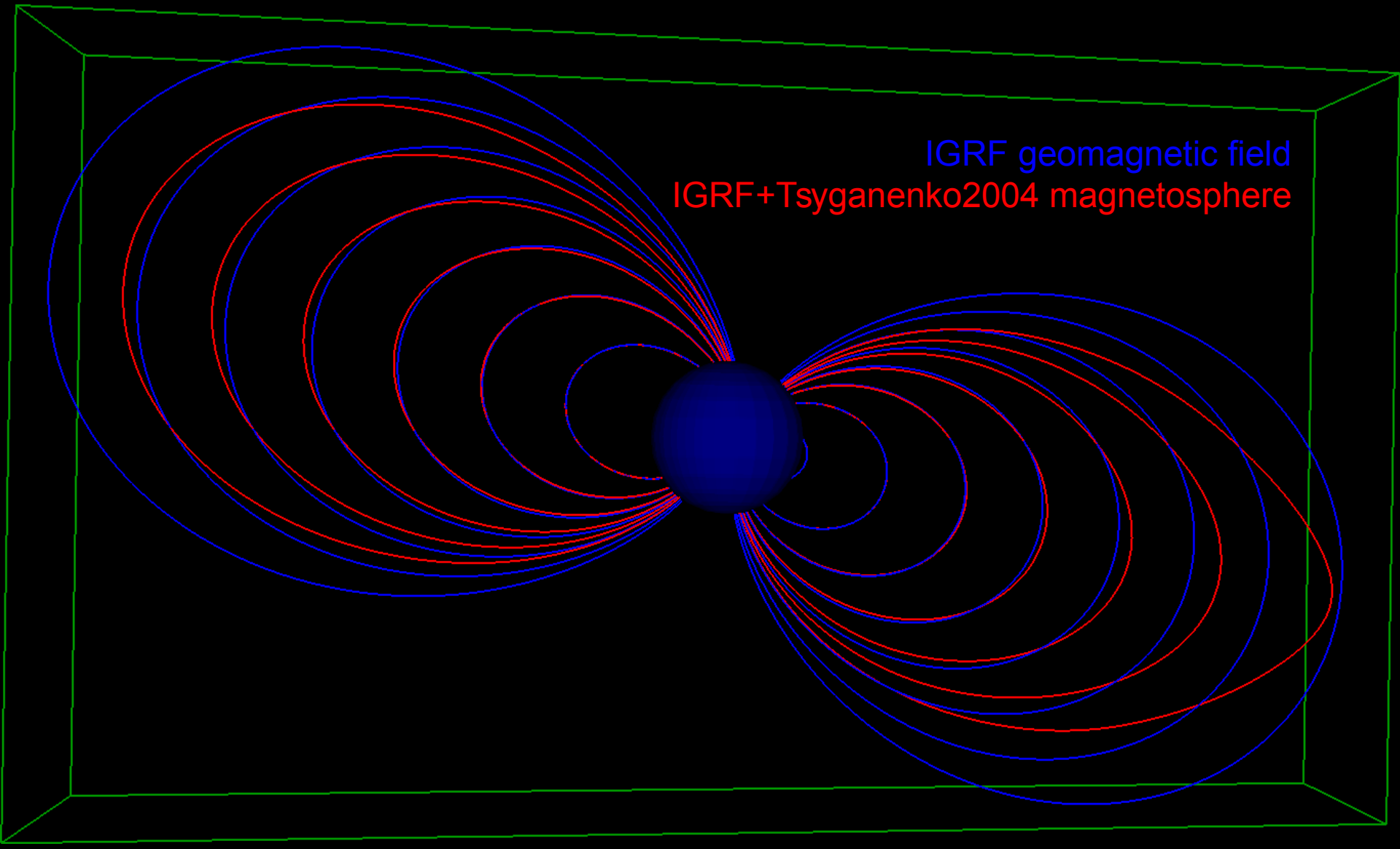


Cutoff and particle direction



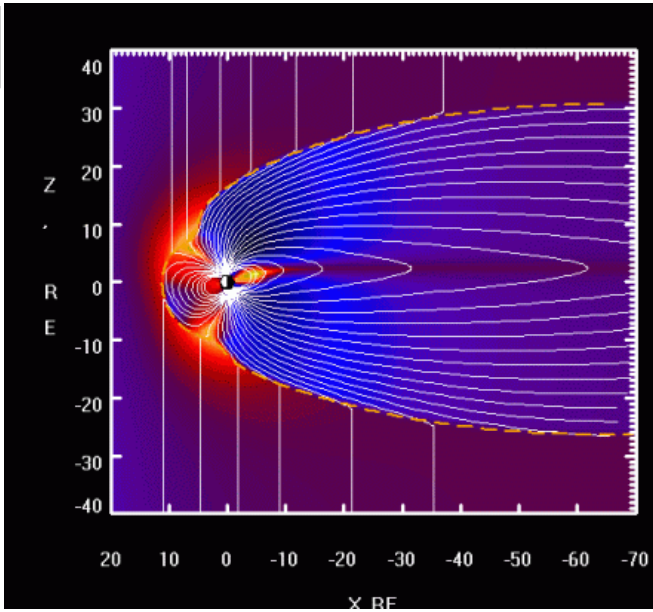
Geomagnetic rigidity cutoff for antiprotons in Hawaii as function of direction

Magnetic field lines



Tsyganenko 2004 magnetosphere

- 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

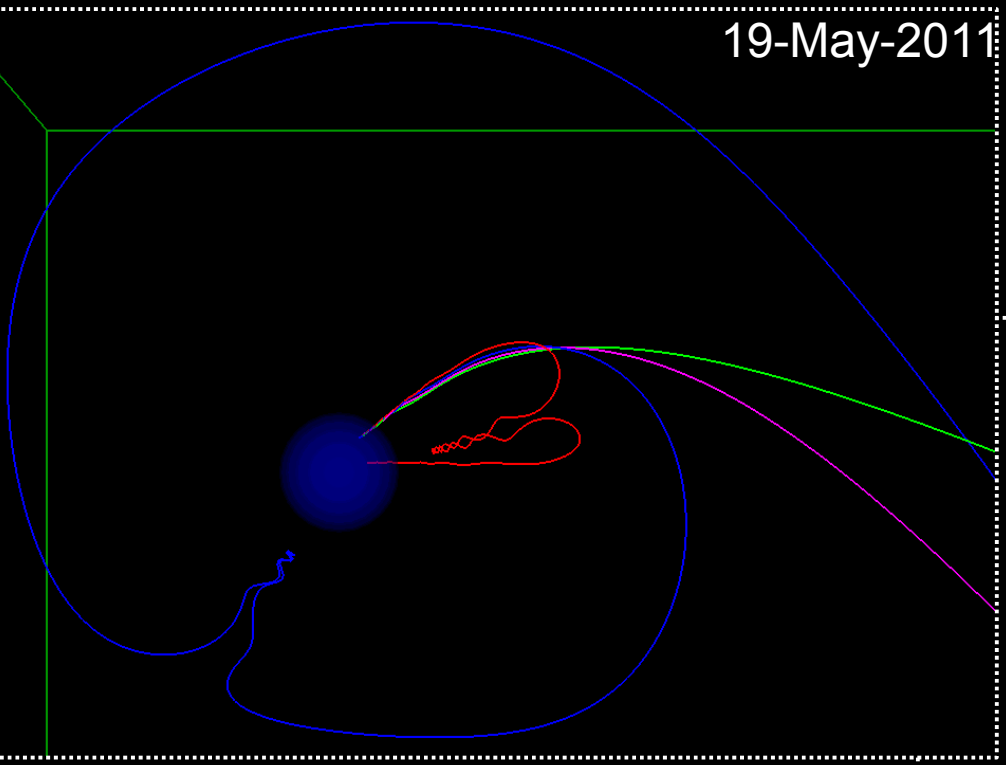


http://geo.phys.spbu.ru/~tsyganenko/modeling.html

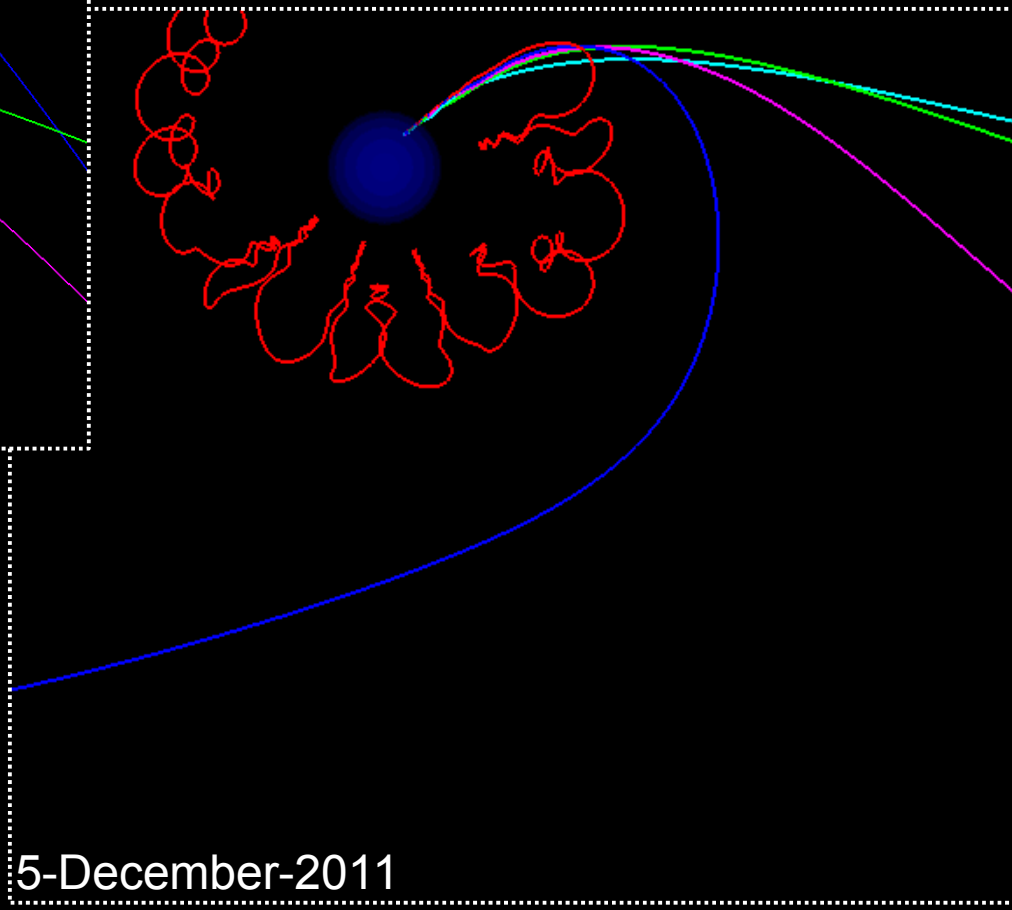
- **Parameters:**
  - **tilt angle** of geomagnetic dipole
  - structure of the magnetosphere is influenced by disturbance storm index (***Dst***) *index* and solar wind dynamic pressure $\boldsymbol{P_{dyn}}$
  - $\boldsymbol{B_y}$ and $\boldsymbol{B_z}$ components of the interplanetary magnetic field
  - **6 parameters** describing: the total magnetic field composed of the tail field, the Chapman-Ferraro field, symmetrical ring current, the field of a partial ring current, Birkeland current systems, a penetrated component given by an ‘‘interconnection’’ term

- data base of all parameters as a function of time available

Time dependence of cutoff: events



Red: 0.5GV
Blue: 1.0GV
Magenta: 1.5GV
Green: 2.0GV
Cyan: 2.5GV



Reverse computation of antiproton trajectories starting at the same location in the same direction for two different times

→ magnetic environment change changes the trajectories drastically and influences the cutoff values

Geomagnetic cutoff scanning

Sampling of geomagnetic cutoff behavior for AMS-02 operation

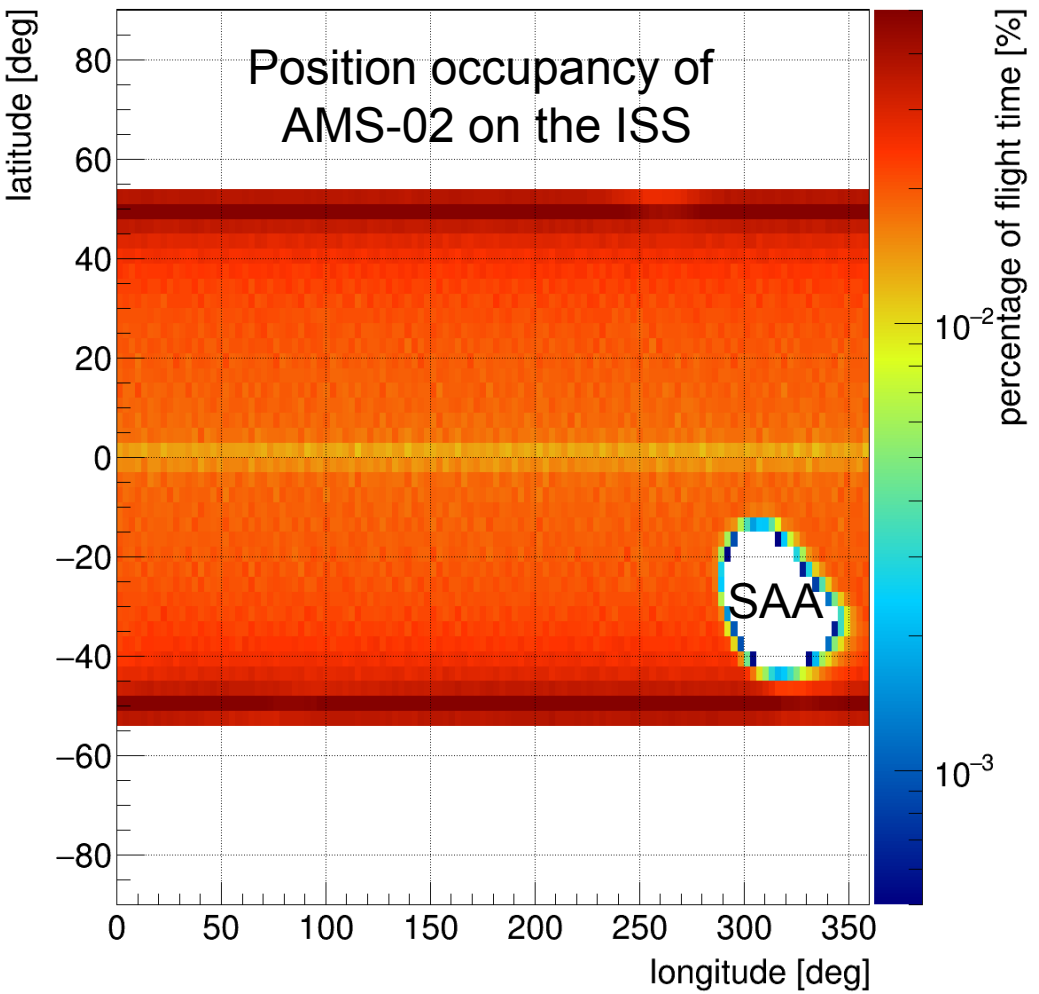
- study of protons and antiprotons
- every 200days
- as a function of location and direction
- use of University of Hawaii HPC cluster: so far about **~20years of CPU time**

Scanning range for cutoffs:

- latitude: -90-90° [bin width: 5°]
- longitude: 0-360° [bin width: 10°]
- zenith:0-90° [bin width: 5°]
- azimuth 0-360° [bin width: 10°]
  → **create database**

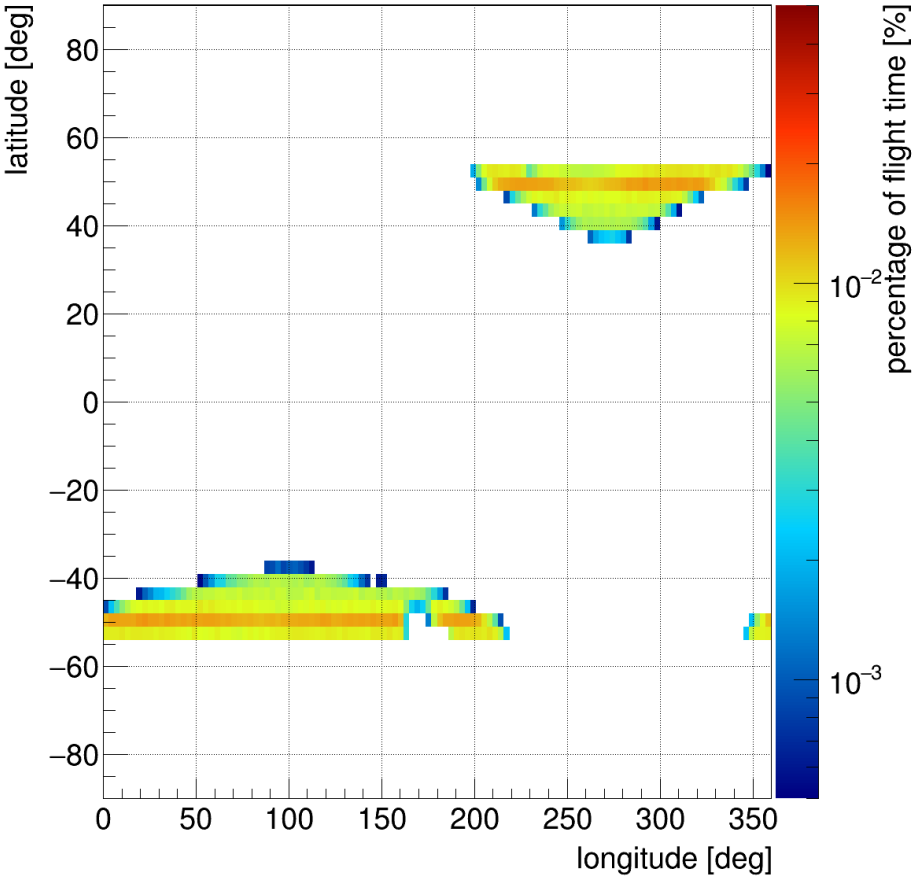
Calculate cutoff for AMS-02:

- take location from AMS-02 data [1Hz sampling]
- generate isotropic random direction
- calculate cutoff for this location and direction from **database** by interpolation
- only use events cos(zenith) > 0.6

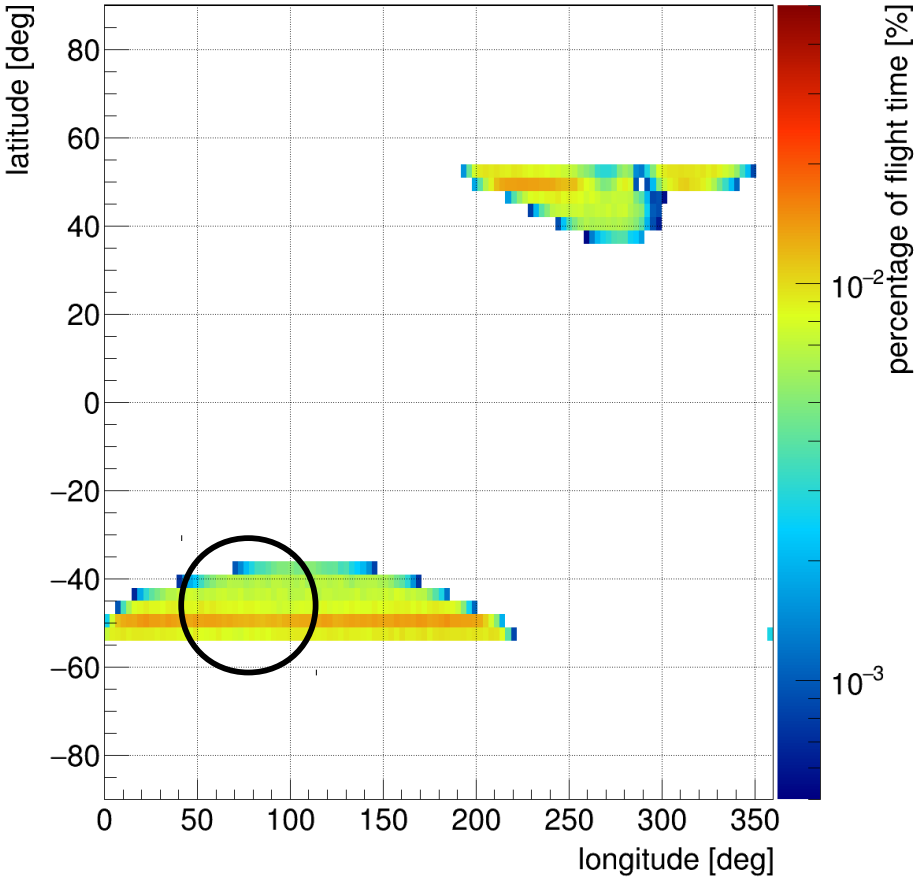


Time dependence of cutoff: maps

→ differences for protons and antiprotons visible



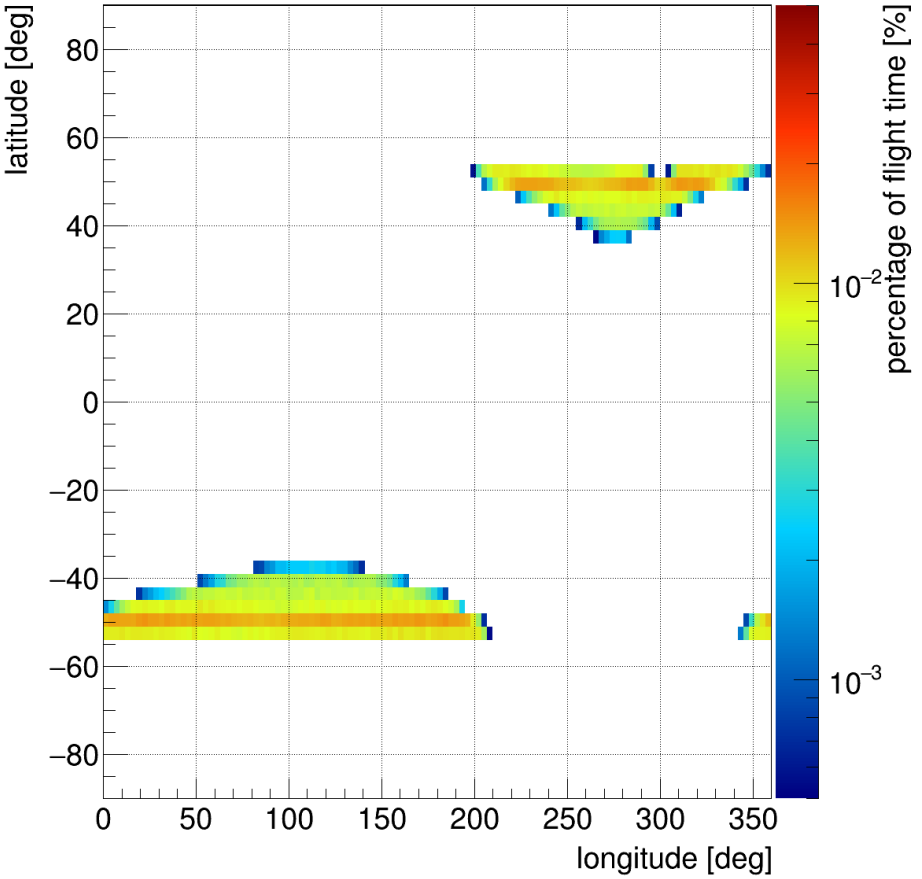
proton



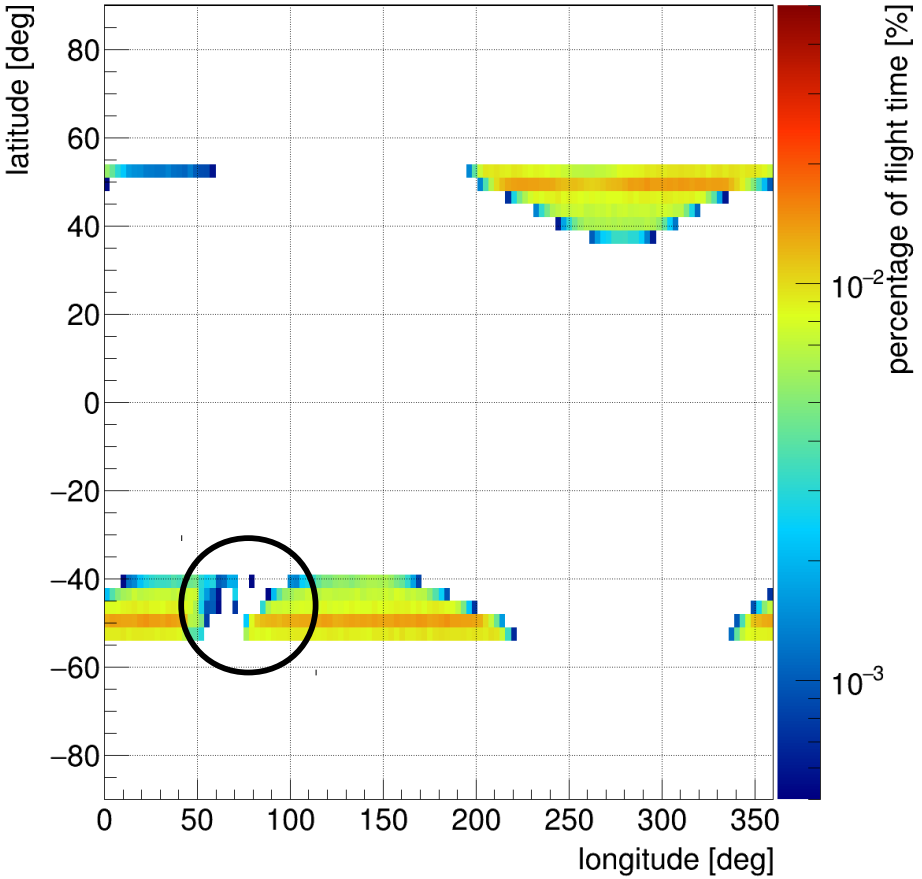
antiproton

19-May-2011
location of rigidity cutoffs of less than 2.5GV

Time dependence of cutoff: maps



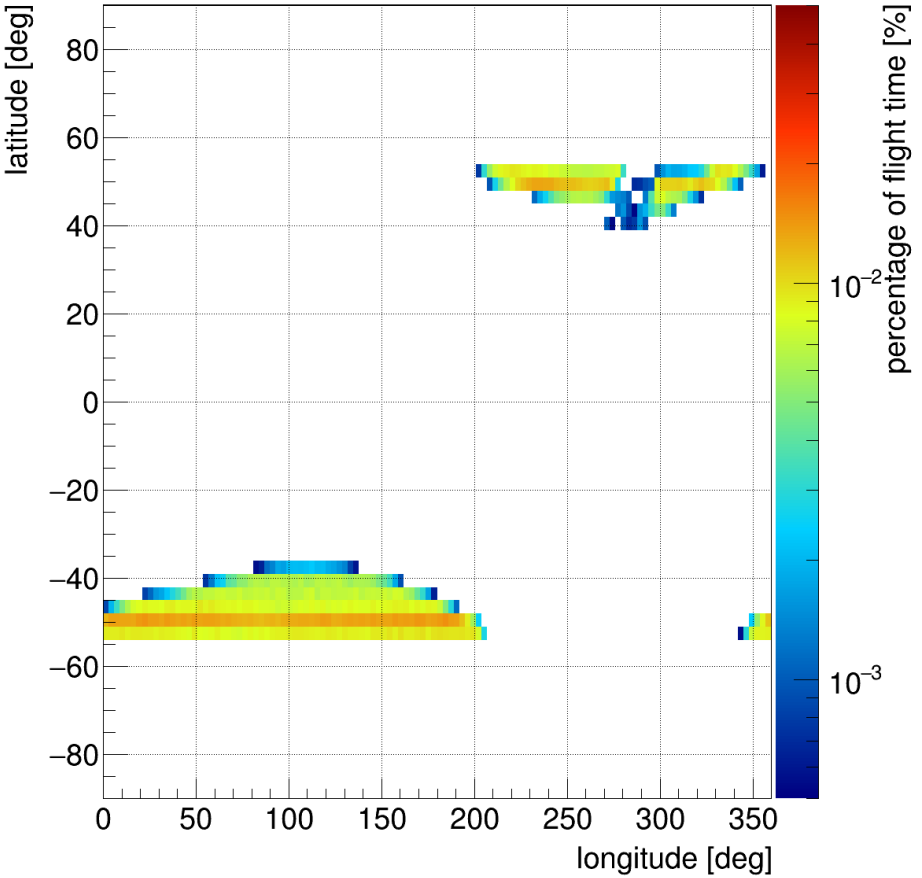
proton



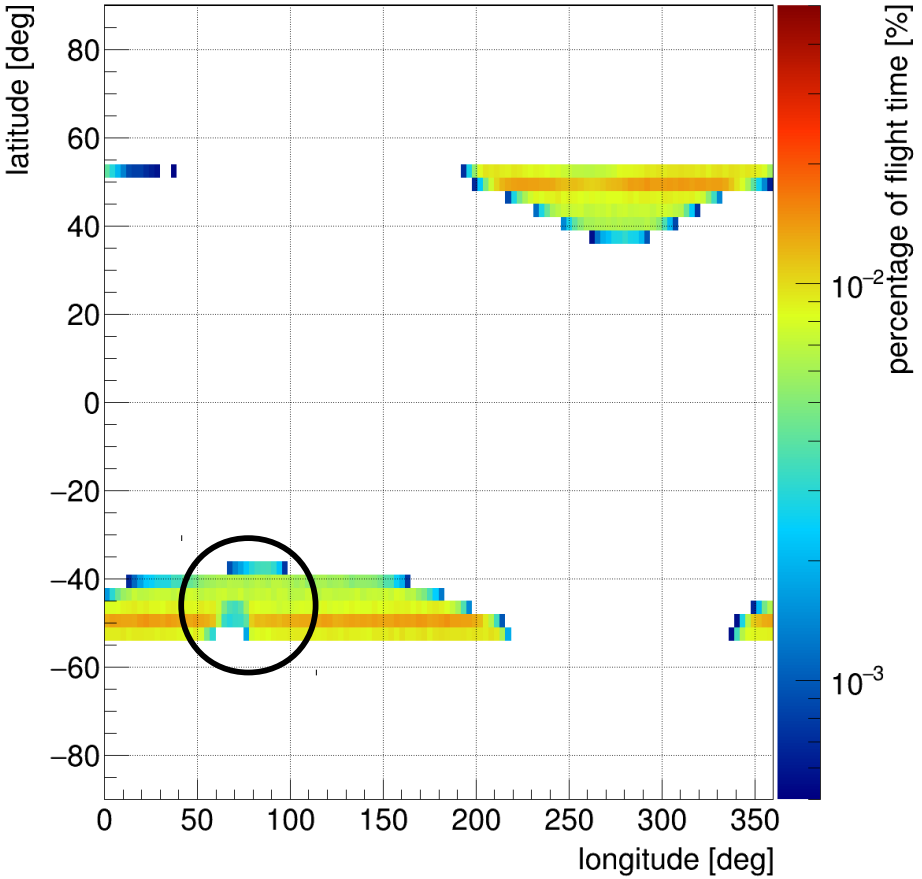
antiproton

5-Dec-2011
location of rigidity cutoffs of less than 2.5GV

Time dependence of cutoff: maps



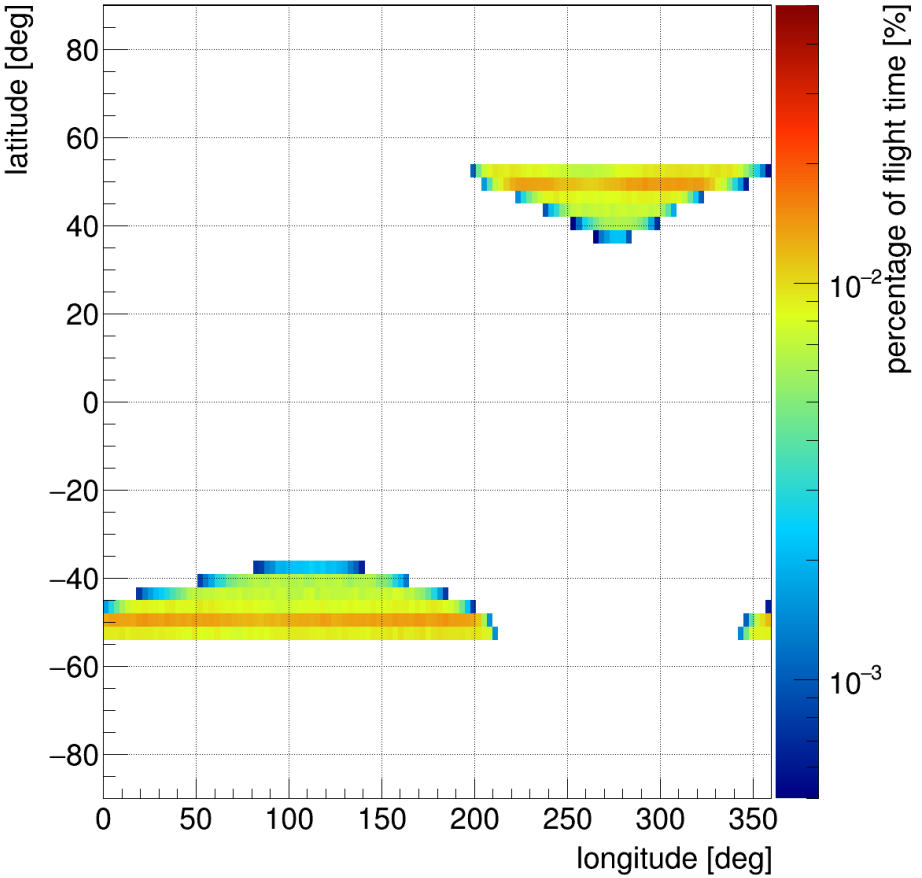
proton



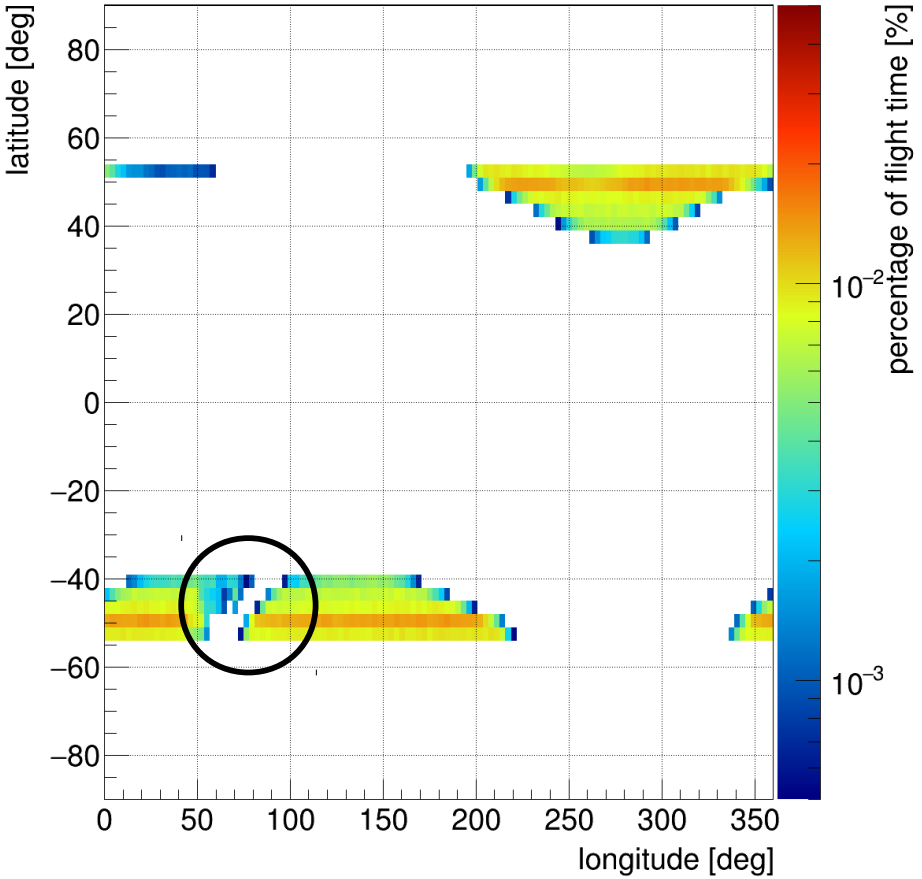
antiproton

22-June-2012
location of rigidity cutoffs of less than 2.5GV

Time dependence of cutoff: maps



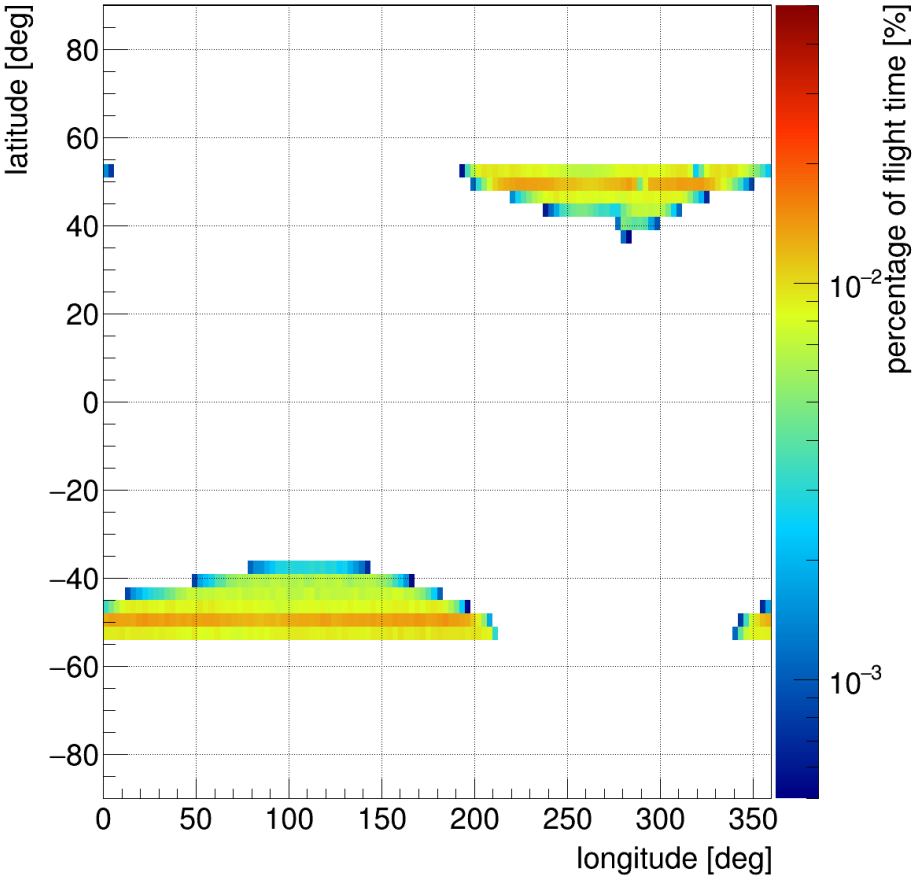
proton



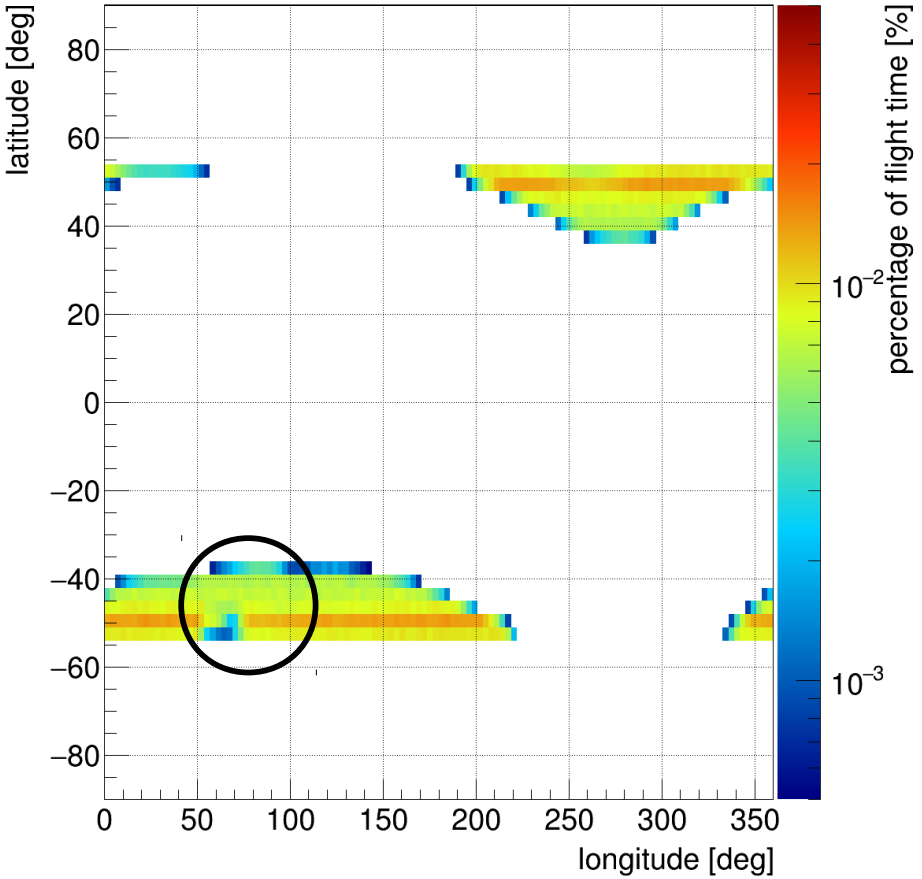
antiproton

8-January-2013
location of rigidity cutoffs of less than 2.5GV

Time dependence of cutoff: maps



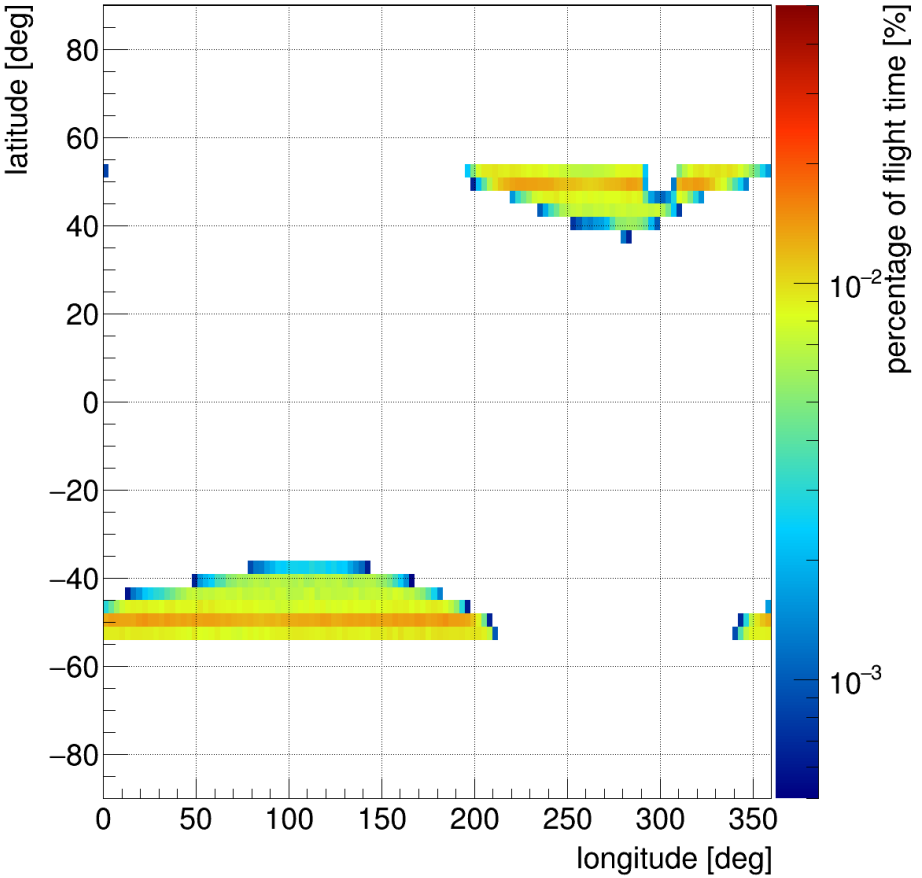
proton



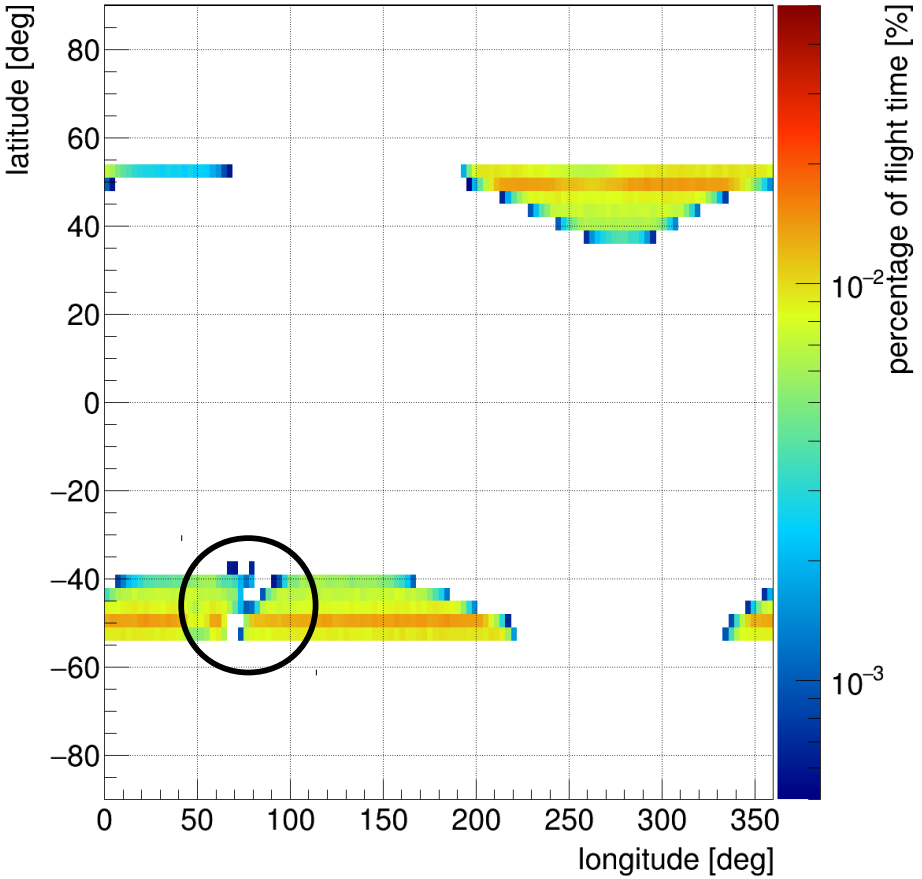
antiproton

27-July-2013
location of rigidity cutoffs of less than 2.5GV

Time dependence of cutoff: maps



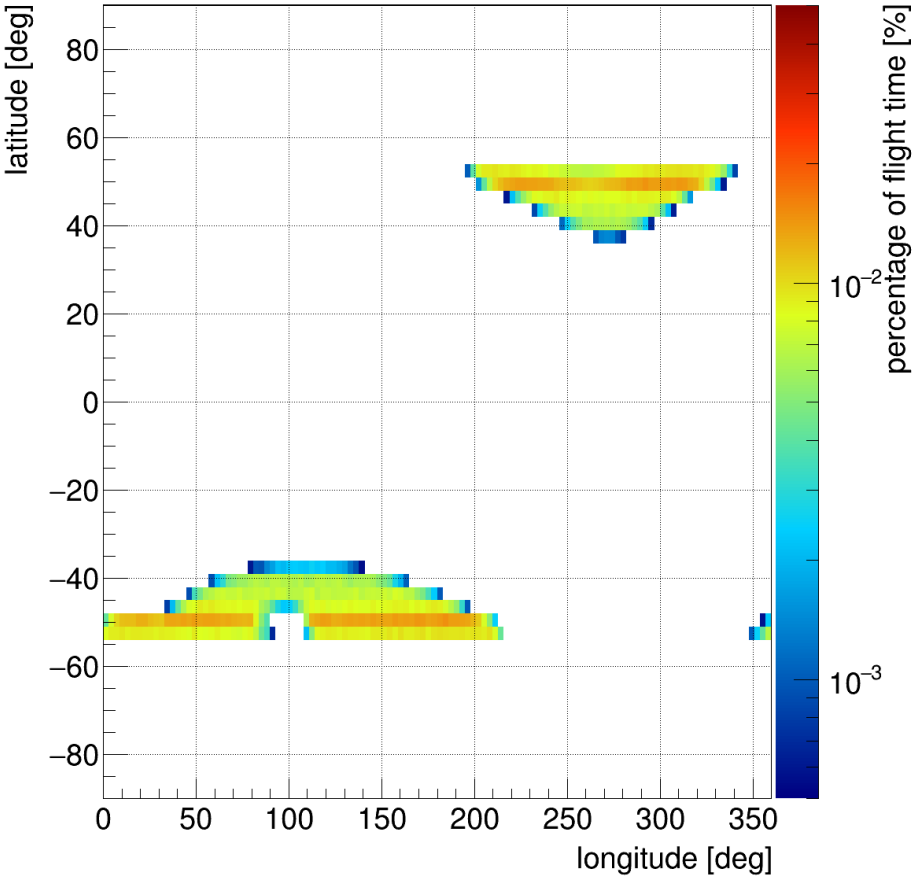
proton



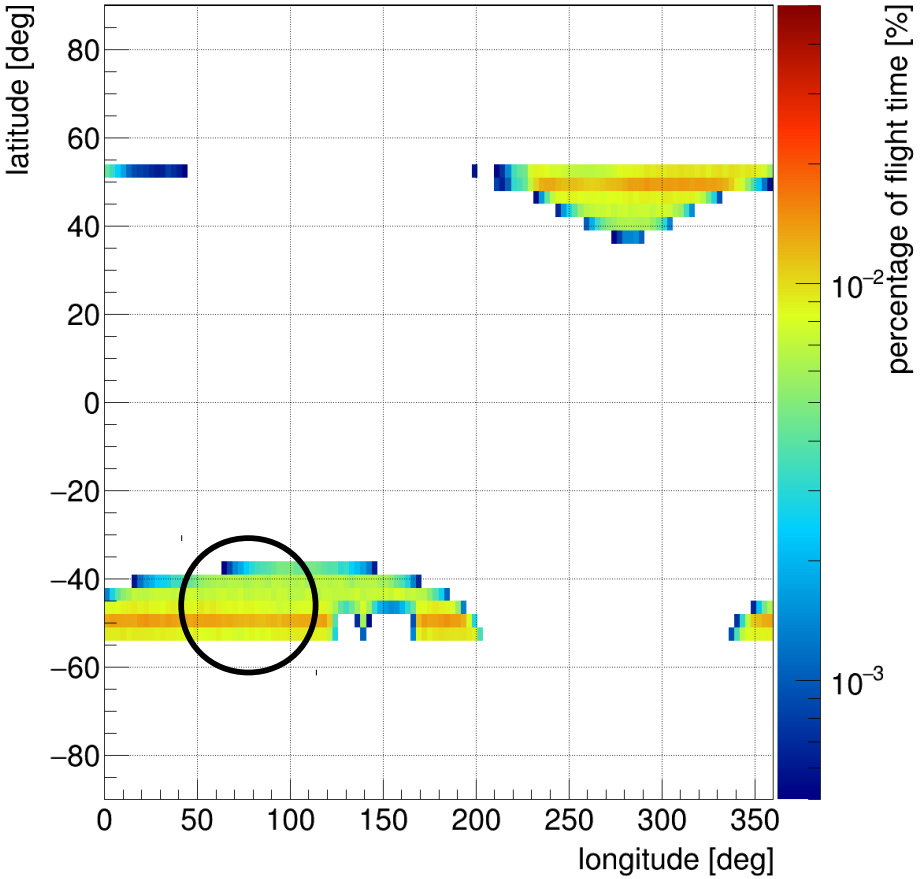
antiproton

12-February-2014
location of rigidity cutoffs of less than 2.5GV

Time dependence of cutoff: maps



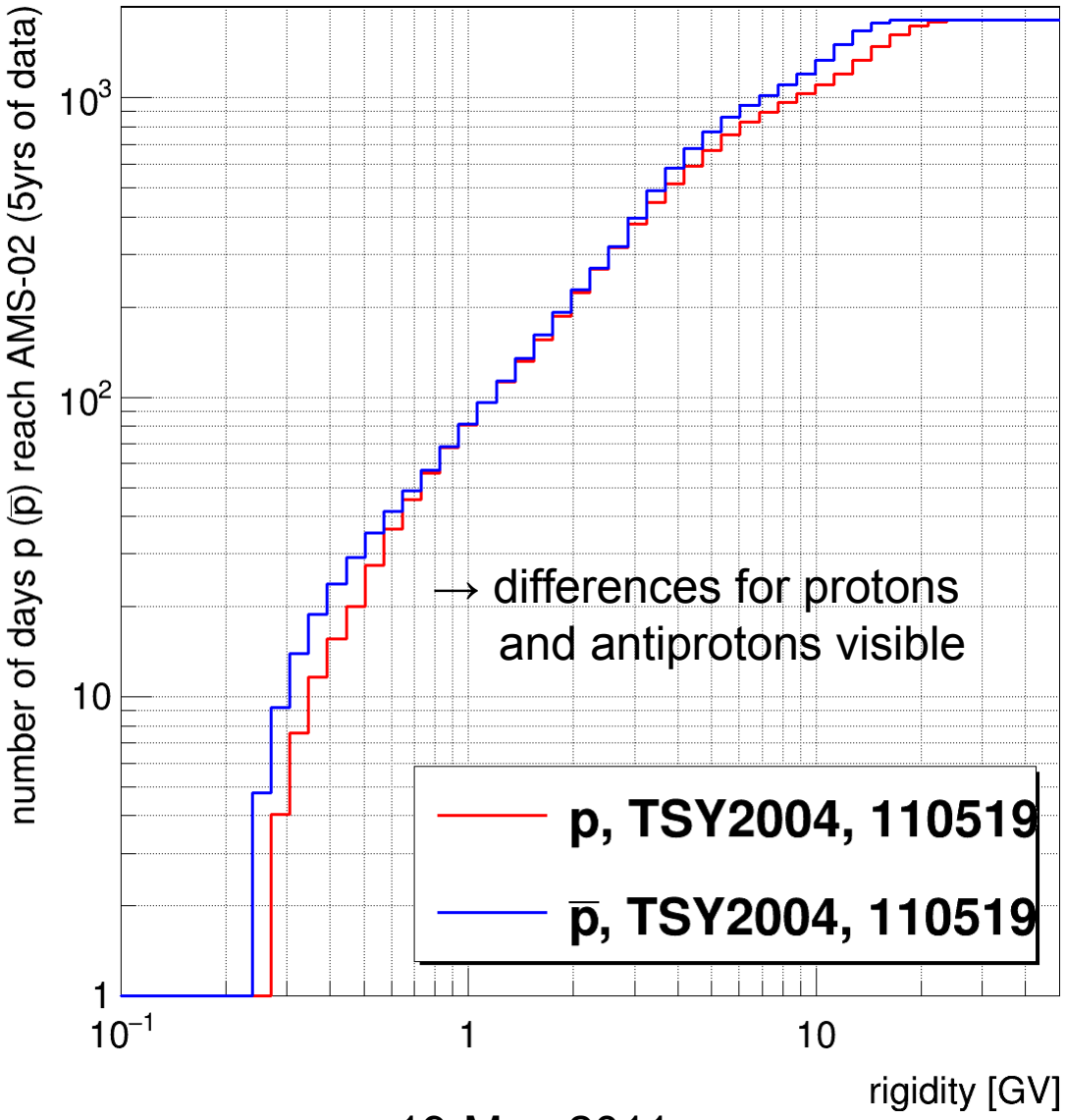
proton



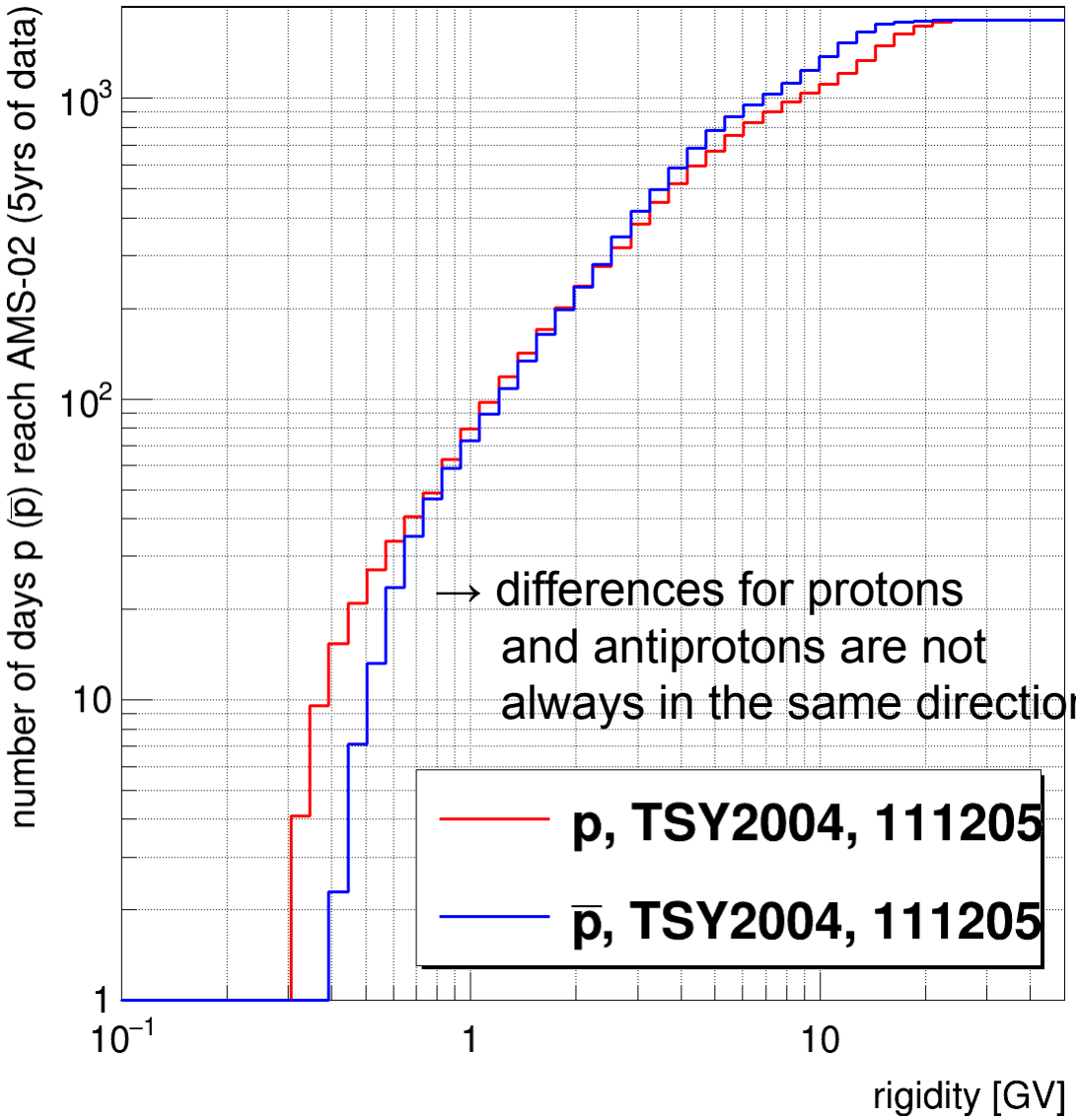
antiproton

1-September-2014
location of rigidity cutoffs of less than 2.5GV

Cutoff efficiency: p and $\bar{p}$

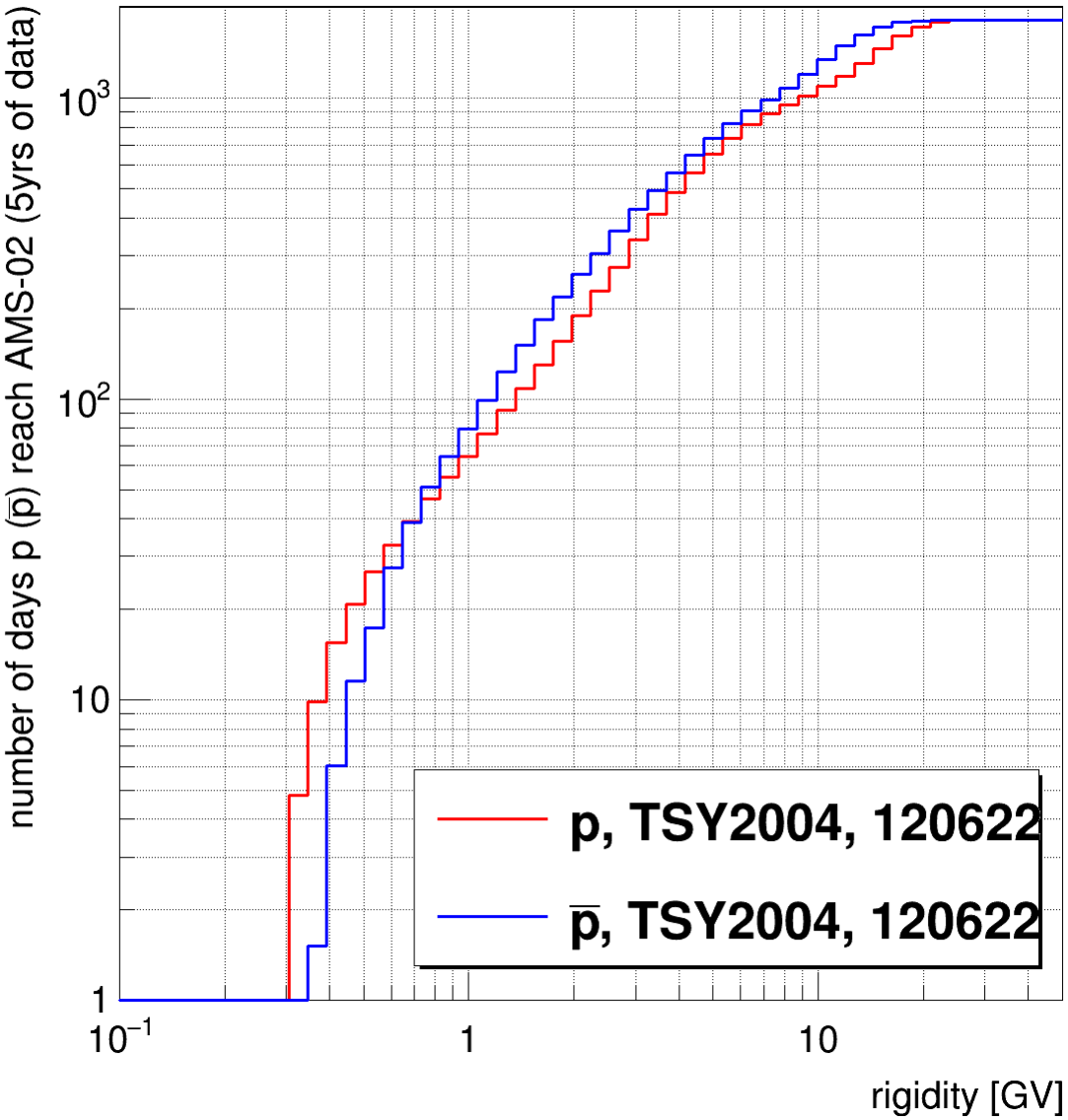


Cutoff efficiency: p and $\bar{p}$

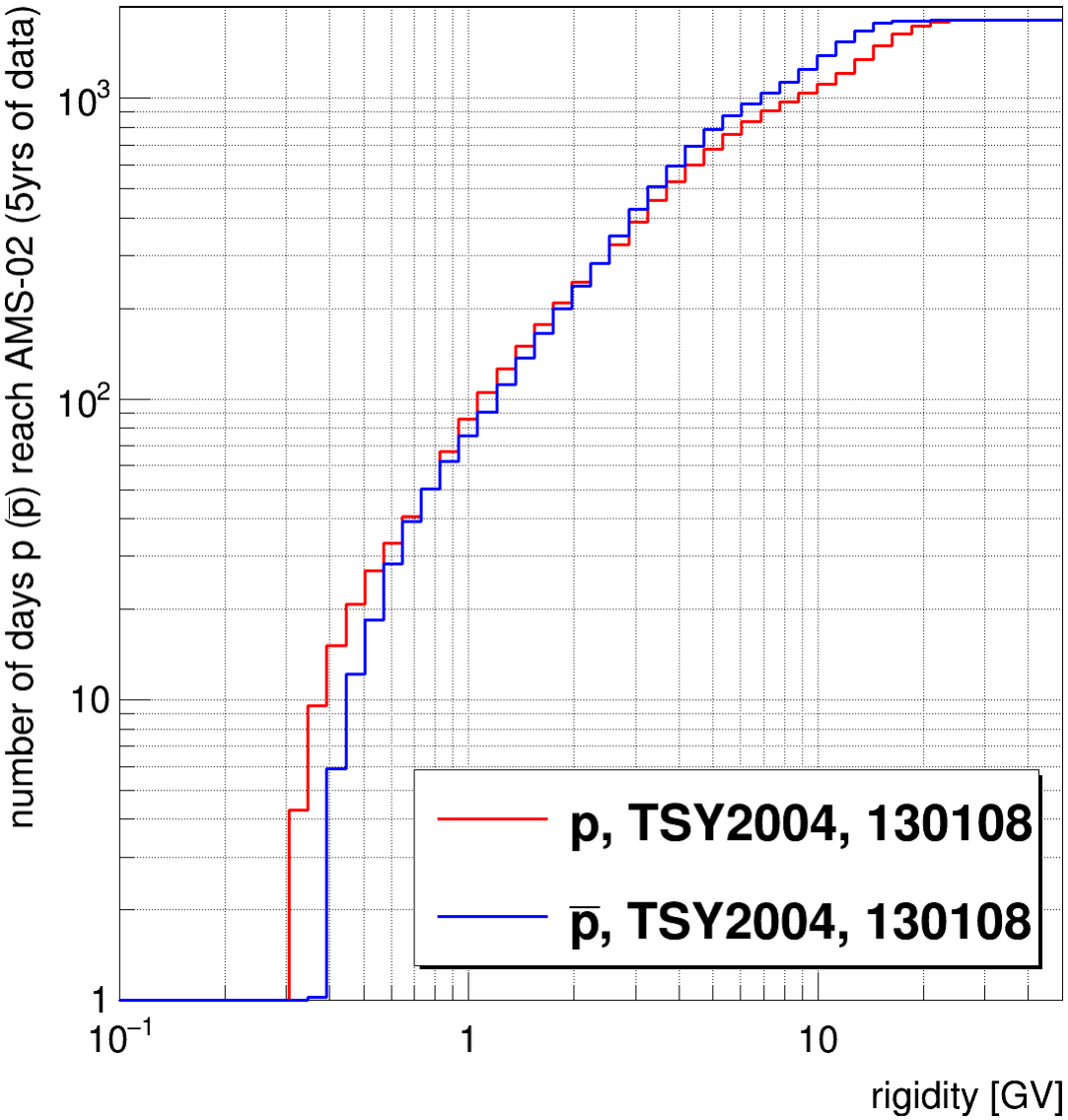


5-December-2011

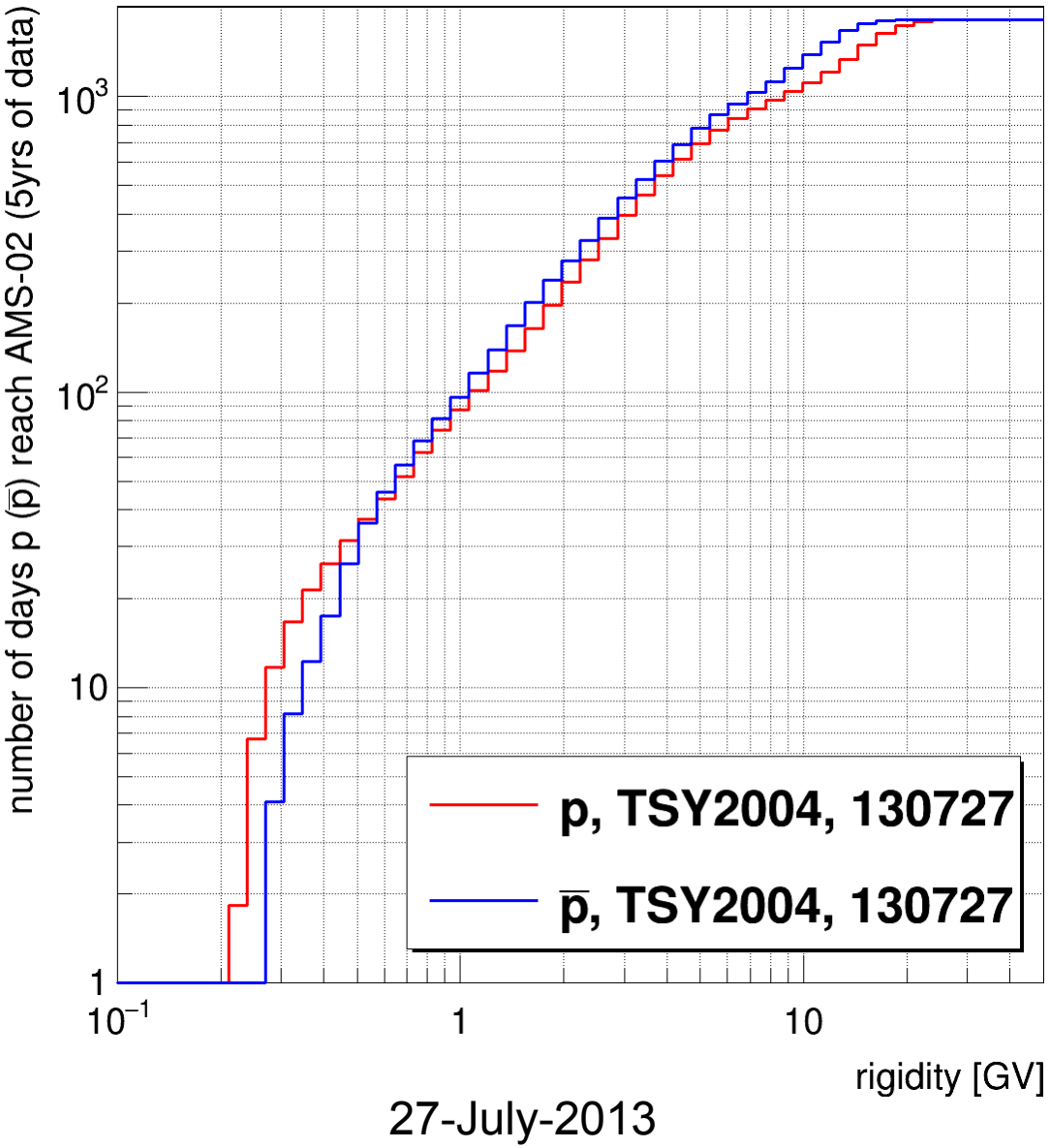
Cutoff efficiency: p and $\bar{p}$



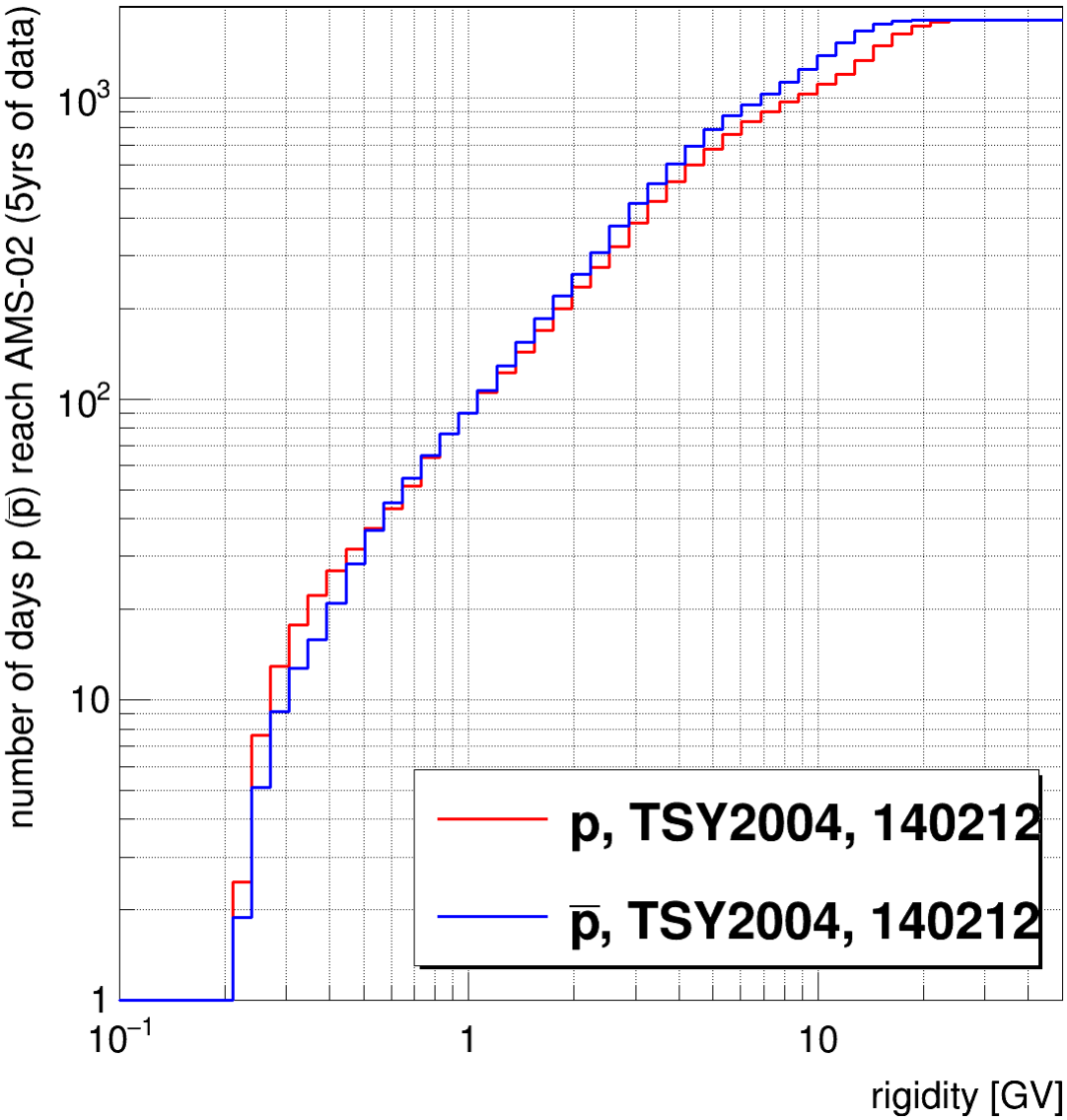
Cutoff efficiency: p and $\bar{p}$



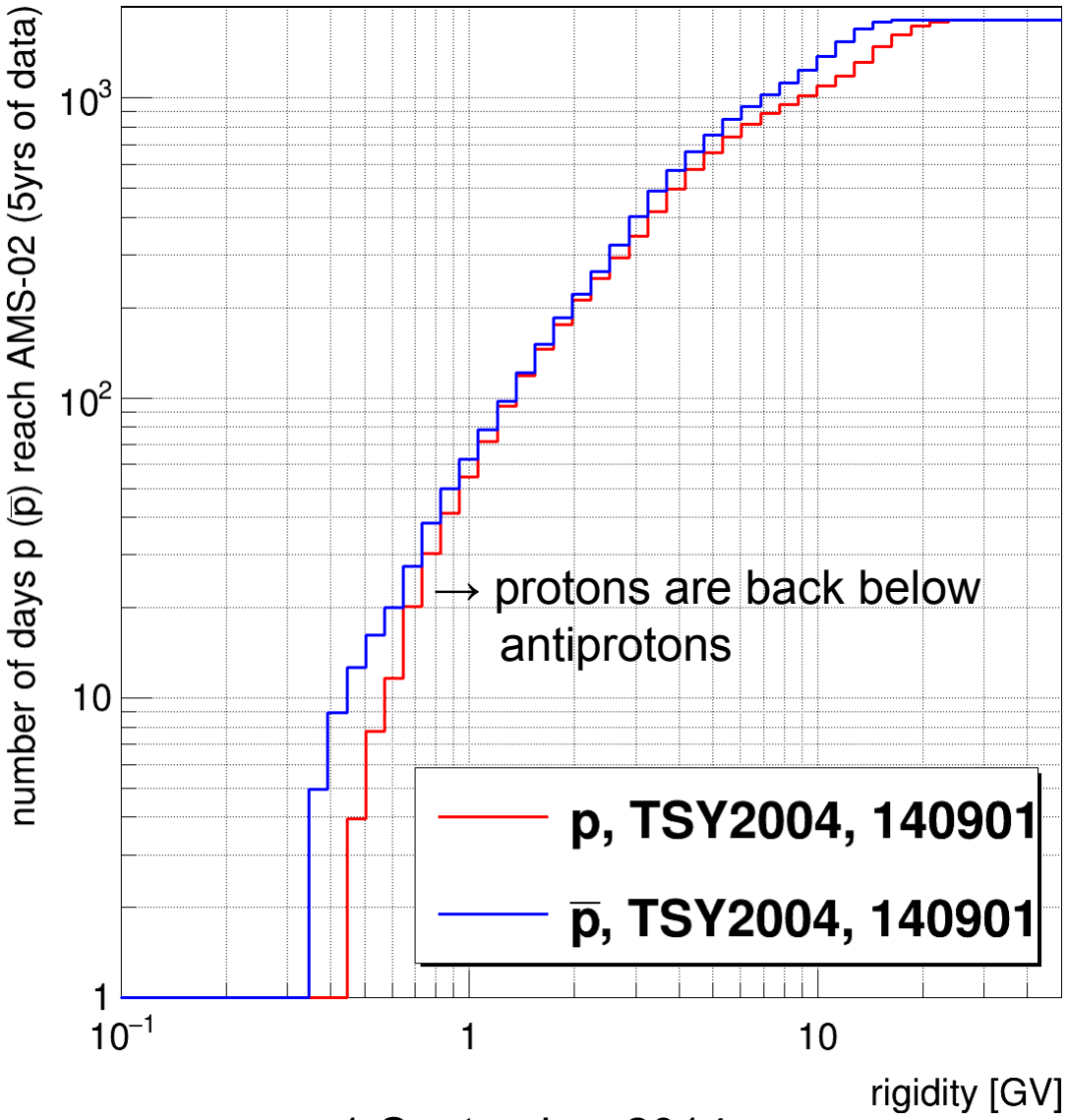
Cutoff efficiency: p and $\bar{p}$



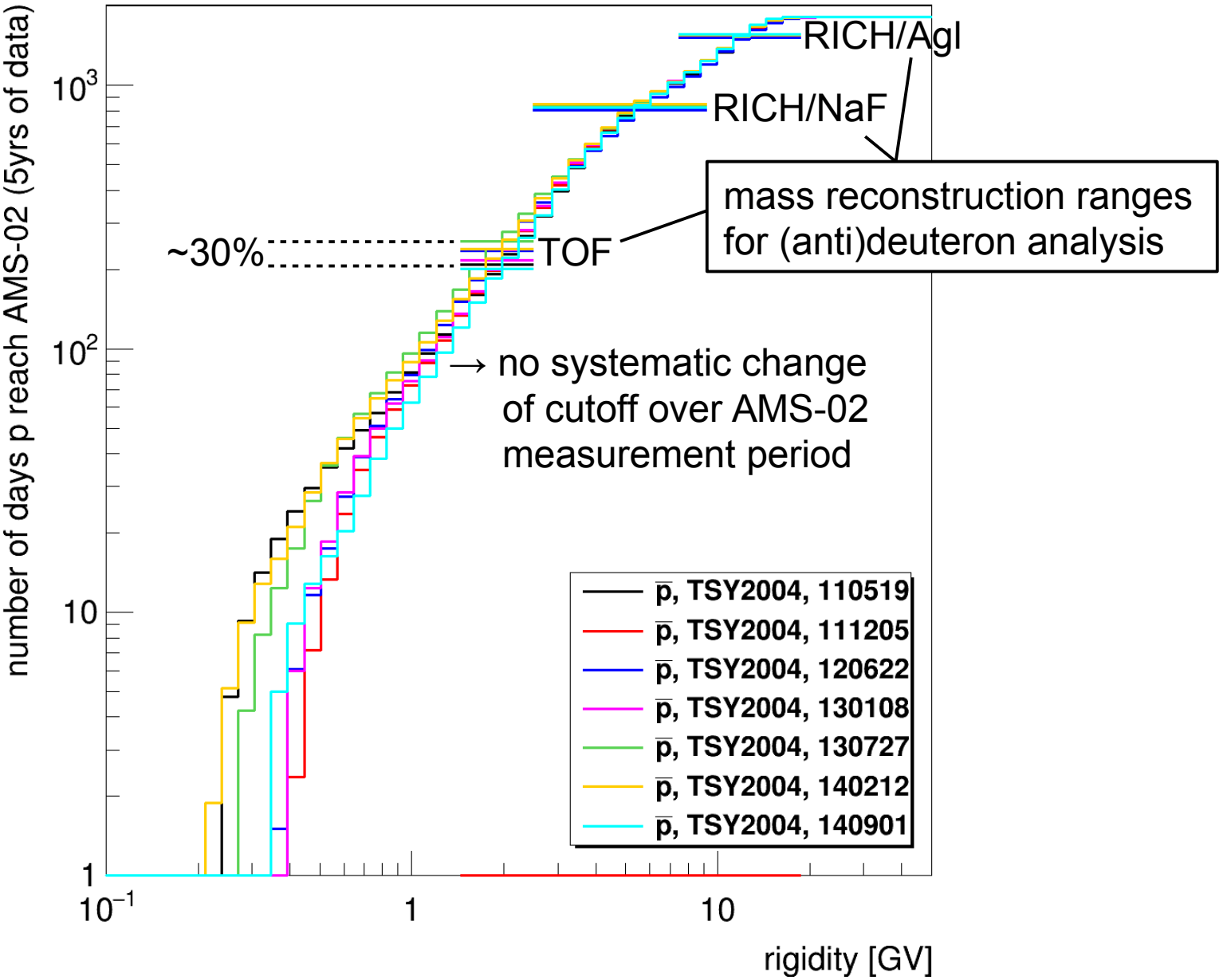
Cutoff efficiency: p and $\bar{p}$



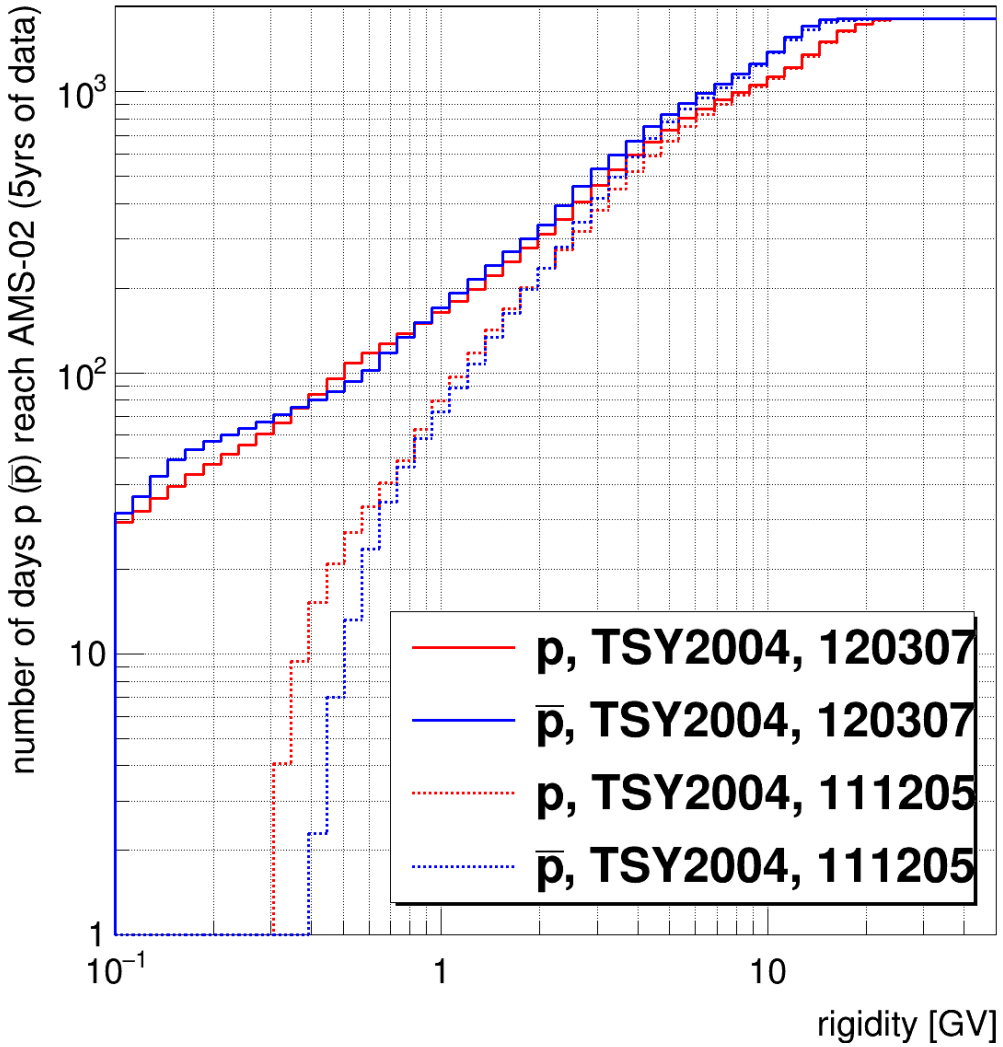
Cutoff efficiency: p and $\bar{p}$

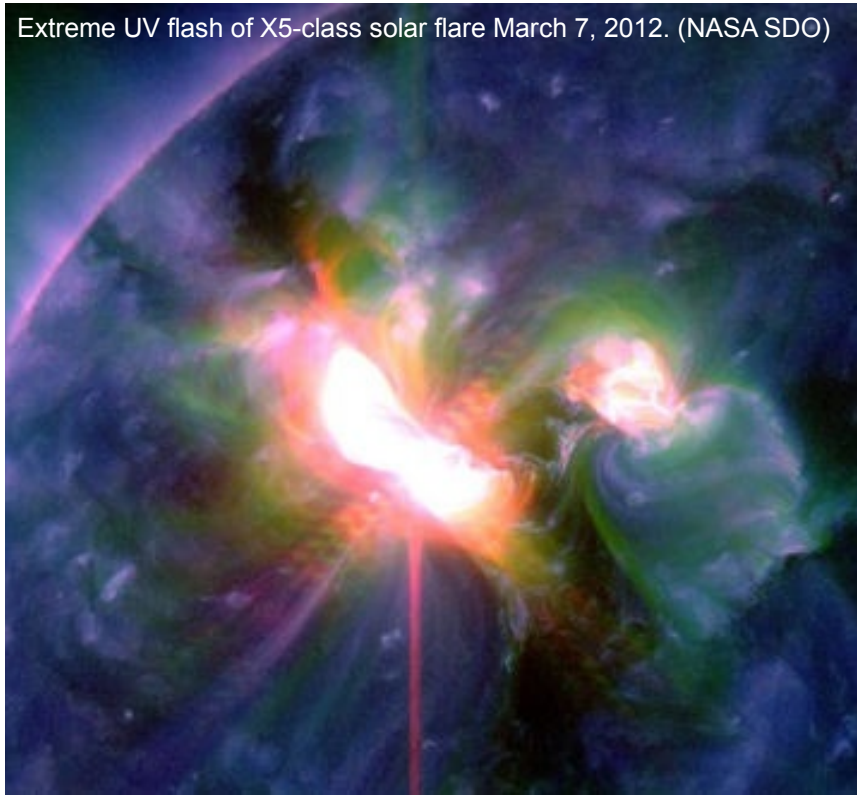


Time dependence of cutoff: efficiencies



Solar flare event: 7-March-2012





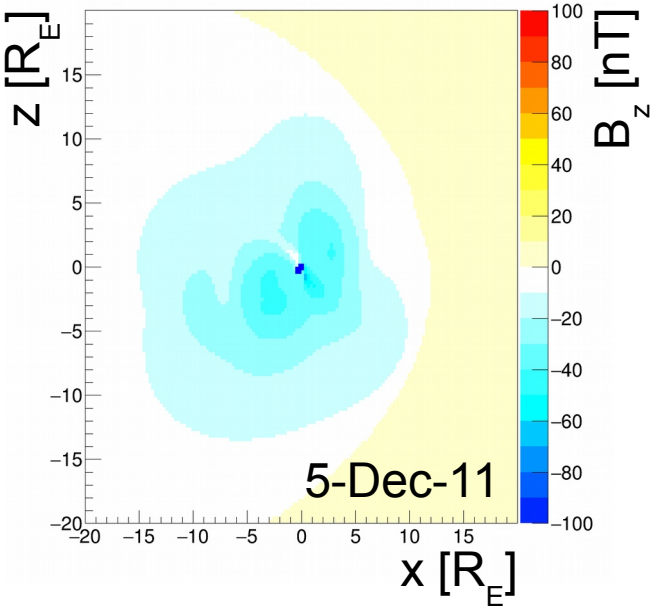
Significant decrease of geomagnetic cutoff

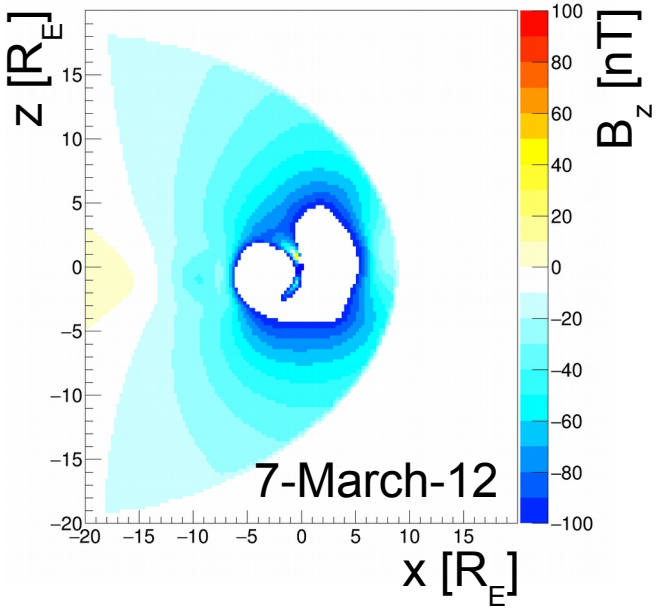
P_{dyn} = 5.3nPa, Dipole tilt angle = -0.1633°, **Dst = -98nT**

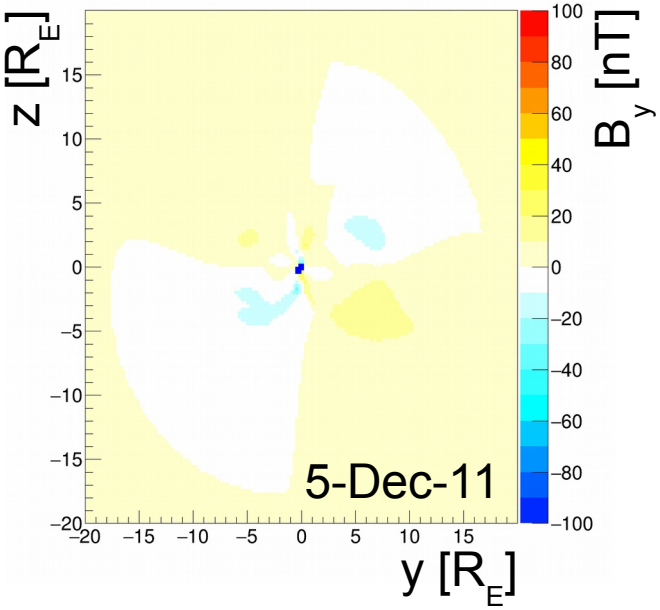
interplanetary magnetic field: B_y = -10.65nT, B_z = -12.53nT

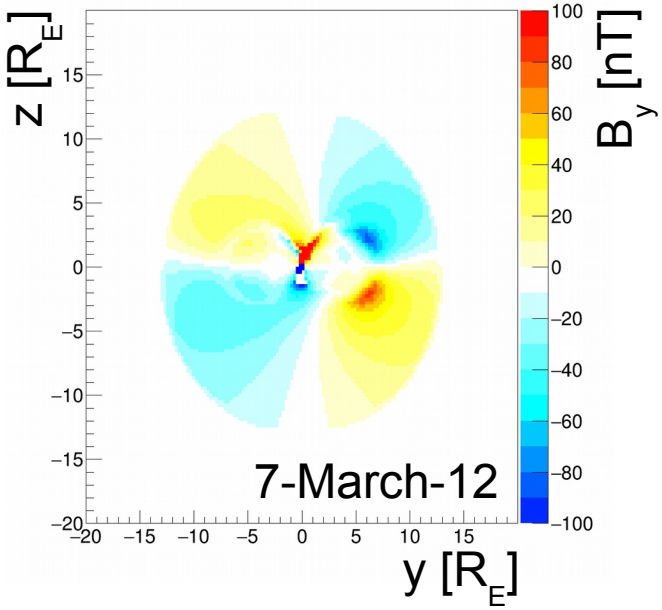
W_1=3.65, W_2=4.65, W_3=1.19, W_4=6.45, W_5=3.46, W_6=9.51

Magnetic field changes

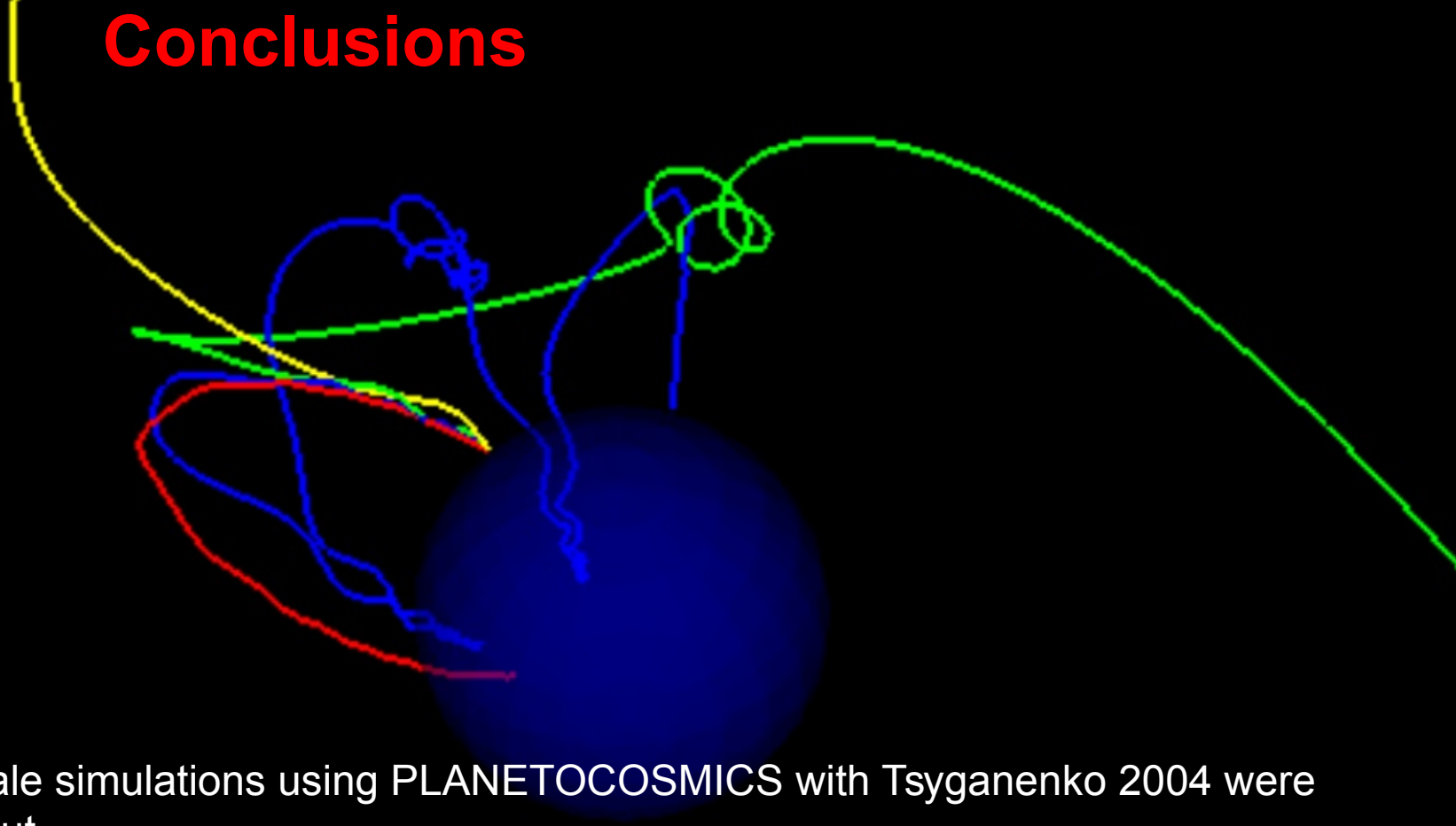








Conclusions



- large-scale simulations using PLANETOCOSMICS with Tsyganenko 2004 were carried out
- geomagnetic cutoff depends on charge sign
- geomagnetic cutoff depends on the magnetospheric parameters
- during solar flares (like March 7, 2012) a strong decrease of geomagnetic cutoff is possible

→ study of low-rigidity cosmic rays (~<3GV) certainly requires to use a time dependent geomagnetic cutoff model