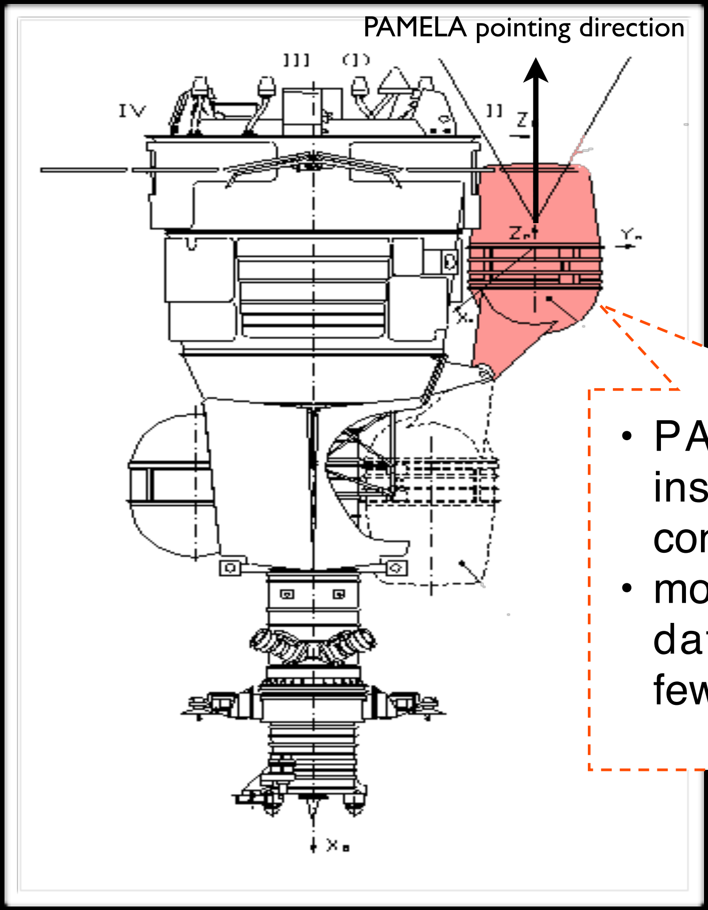
Cosmic-Ray mapping with PAMELA

William GILLARD
ON BEHALF OF THE PAMELA COLLABORATION

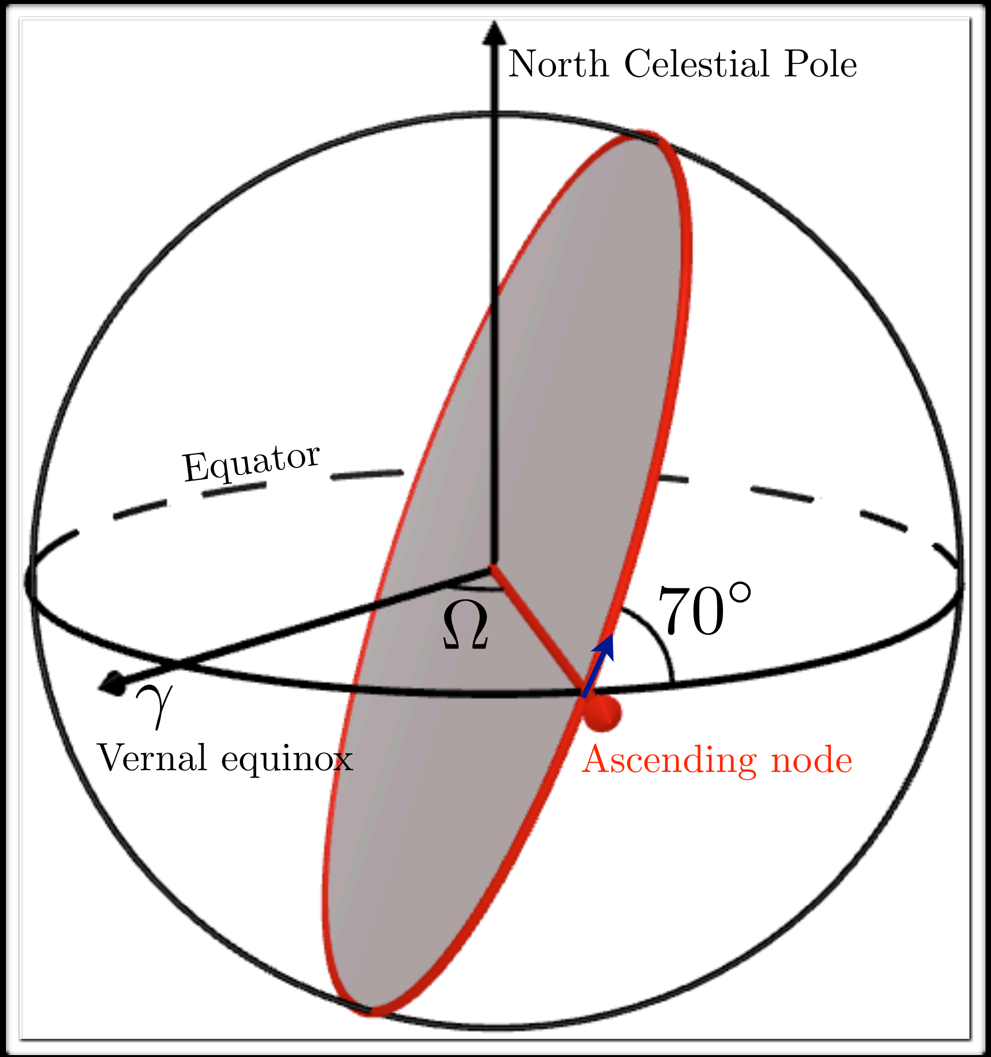
Overview

1. The Resurs-DK1 Satellite.
2. Earth's magnetic field
3. Reconstruct CR sky map.
4. Search for anisotropies.

Resurs-DK1

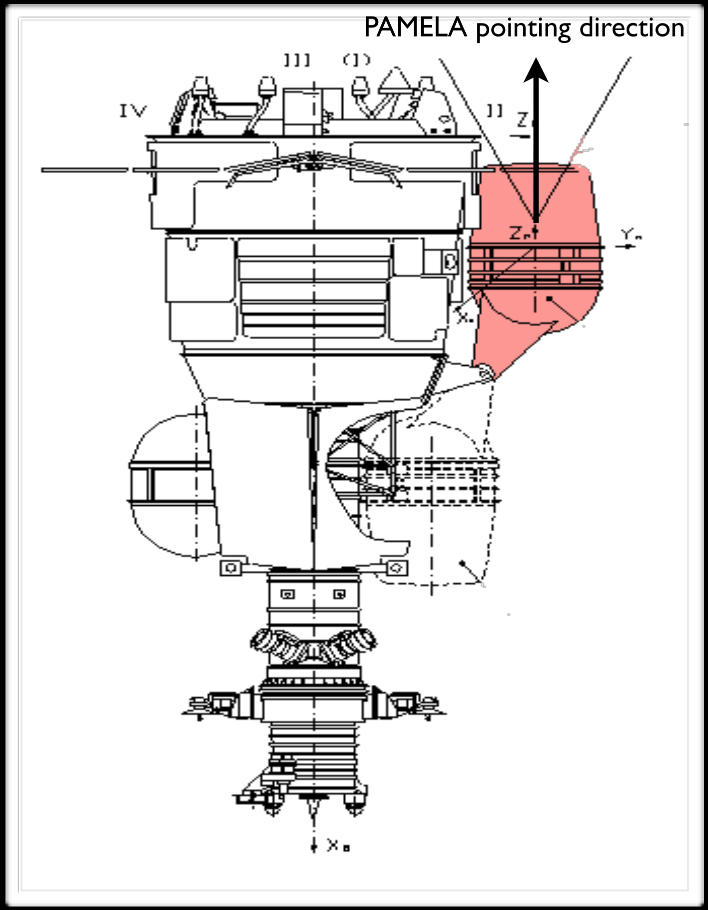


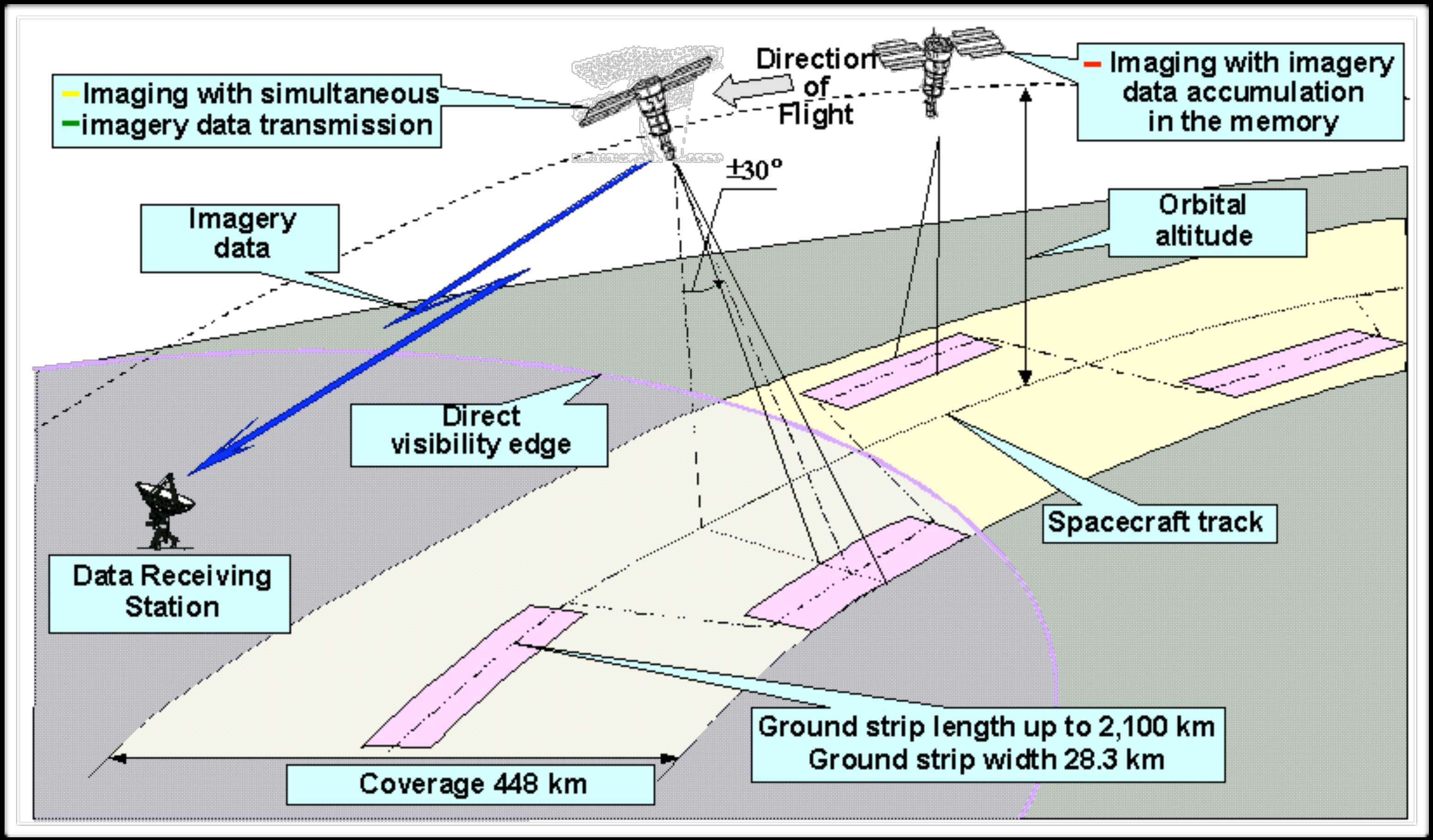
- PAMELA mounted inside a pressurised container
- moved from parking to data-taking position few times/year



- The ascending node Ω varies in time with a period of six months.

Resurs-DK1

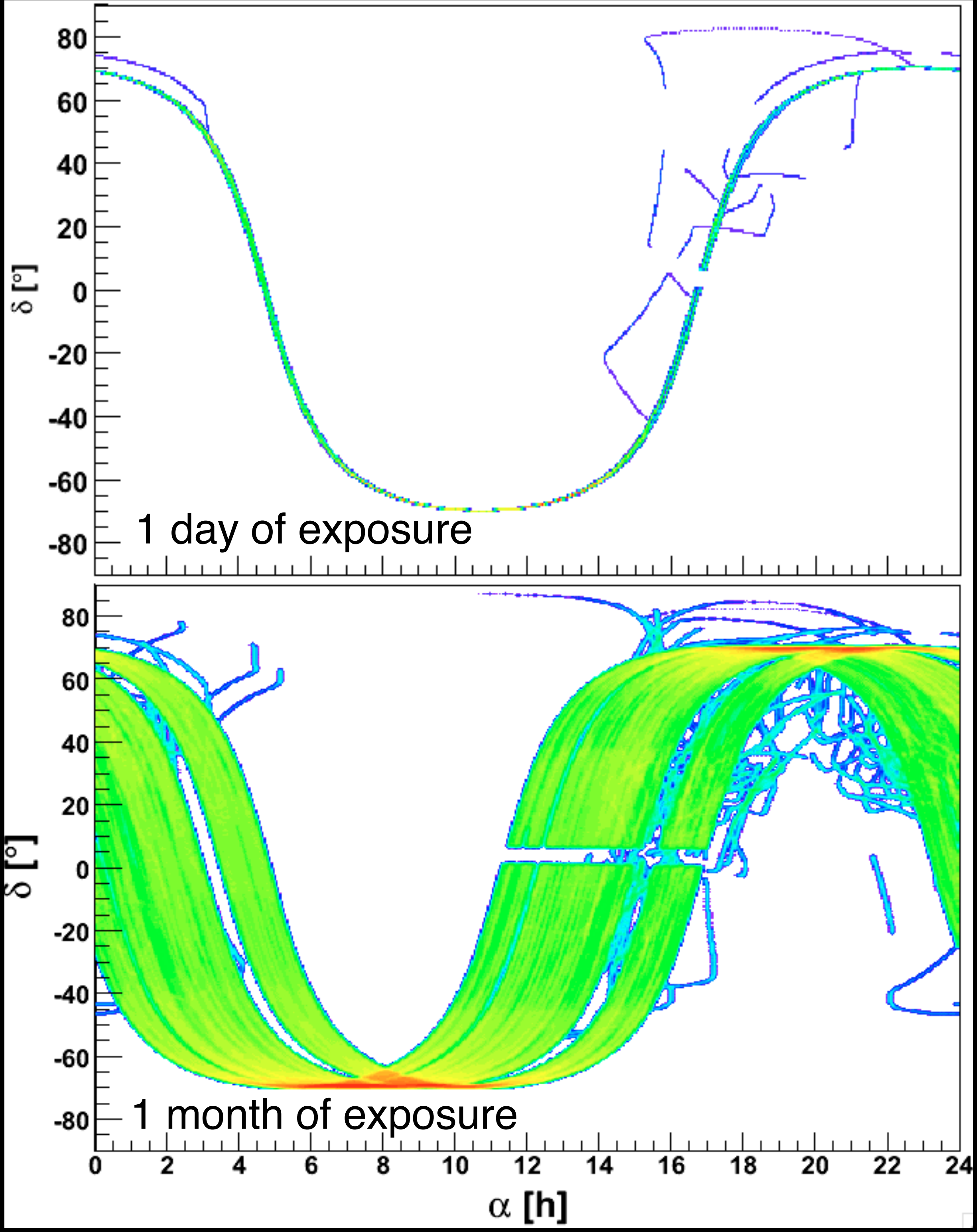




- The ascending node Ω varies in time with a period of six months.
- Satellite inclination may vary up to 30°.
- Satellite inclination is stored into the Resurs-DK1 on board memory before being transmitted to PAMELA.

Resurs-DK1

Track of the PAMELA pointing direction onto the Celestial Sphere.

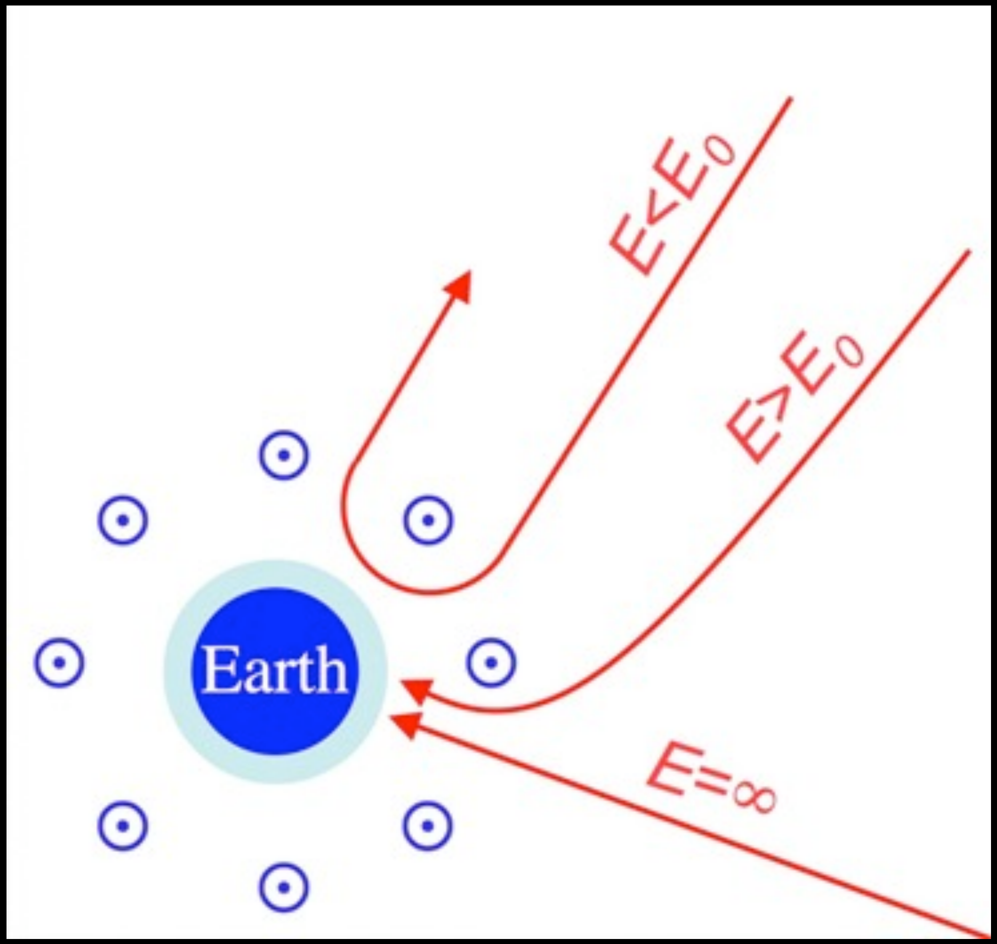


Each 90 min, the *sinusoidal* track of the PAMELA pointing direction is slightly shifted.

Deviations from the sinus like function indicate manual changes of the satellite inclination.

All tracks overlap close to the celestial poles (|δ| ≈70°) ➠ Longer exposure near the poles.

Earth's Magnetic Field

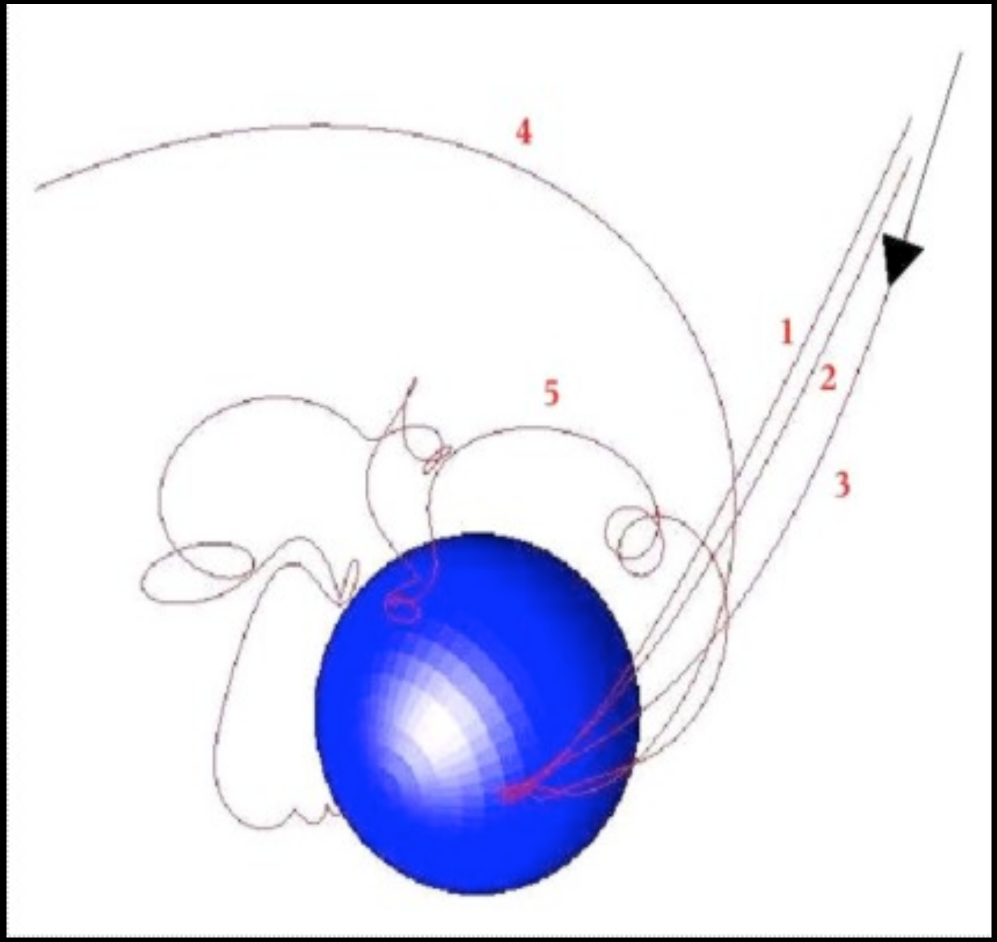


Earth magnetic field deflects trajectory of incoming charged particles.

Some particles of low energy may not reach the PAMELA experiment.

The energy threshold E_0 depends on position and altitude of the Satellite.

Earth's Magnetic Field



Simulation of trajectories of particles with decreasing energy from 1 to 5 [L. Desorgher]

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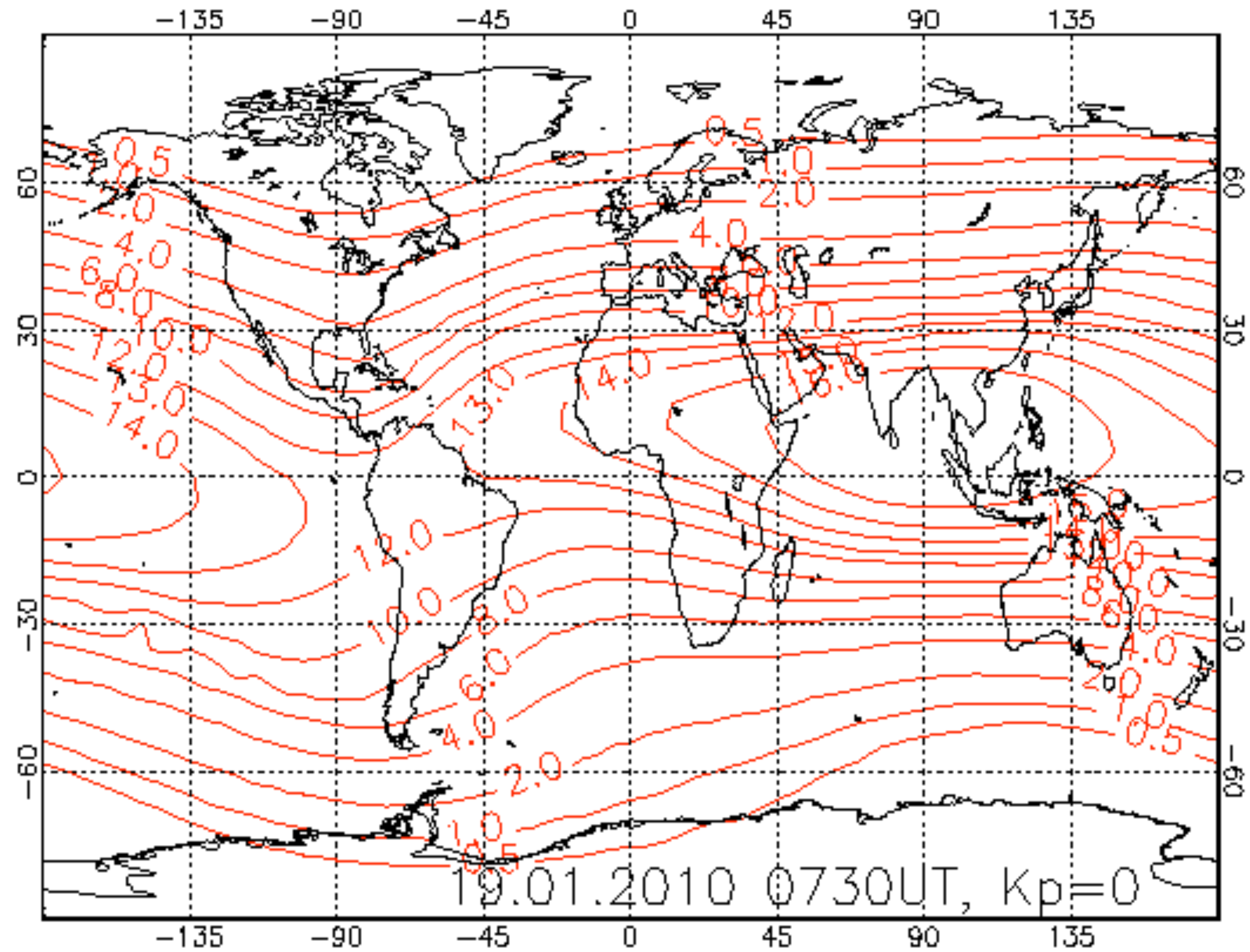
Earth's Magnetic Field



The effective vertical rigidity cutoffs [Cooke et al., 1991] from *http://se.crd.yerphi.am/*

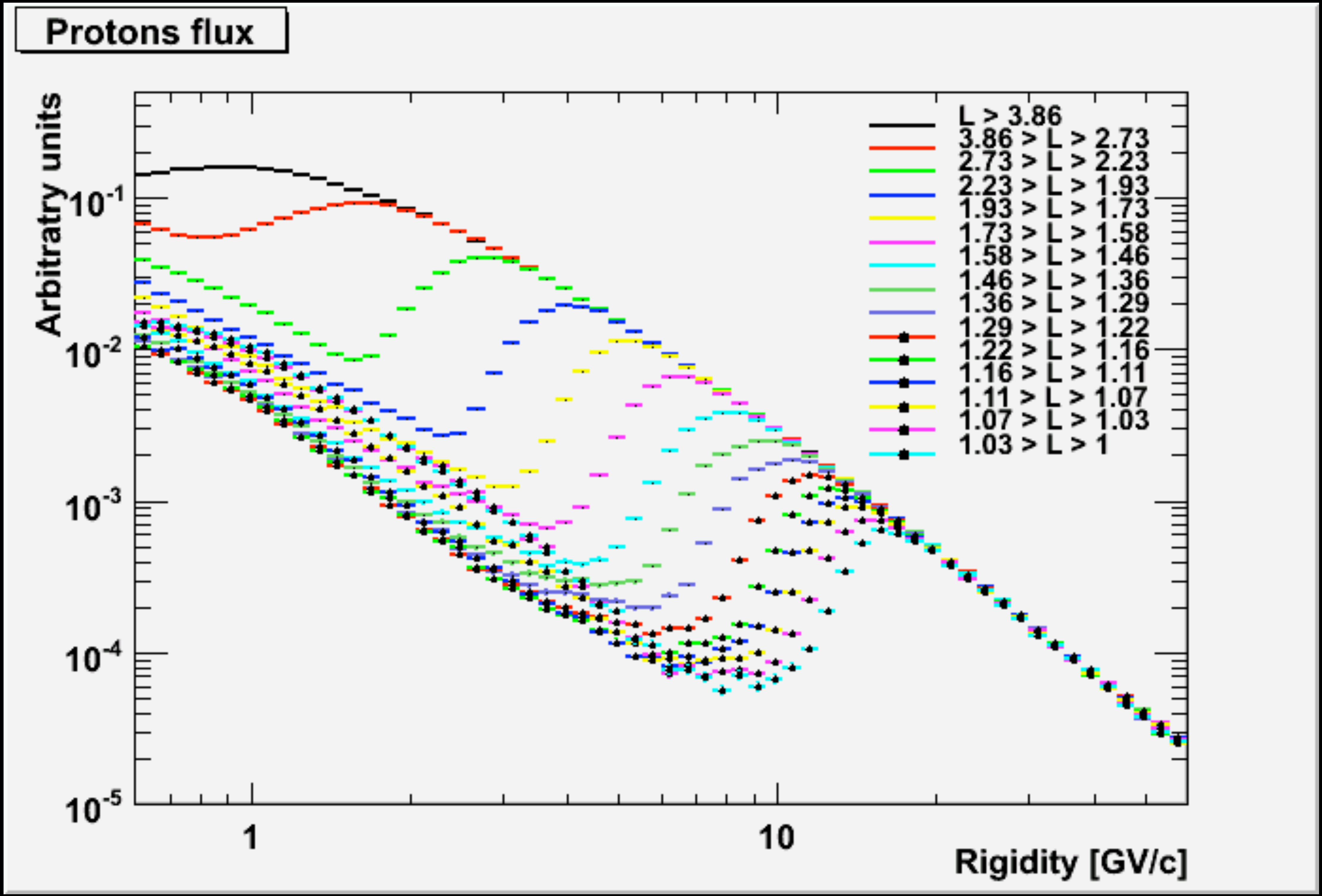
Earth's Magnetic Field

Resurs-DK1

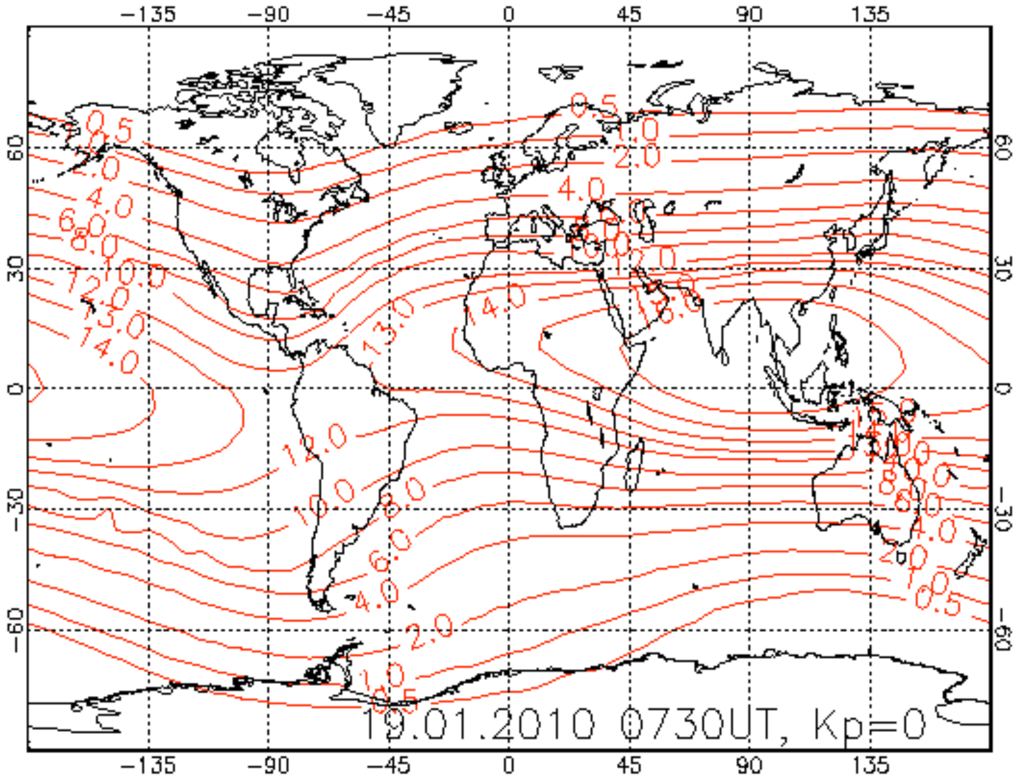
Magneto-sphere

CR Mapping

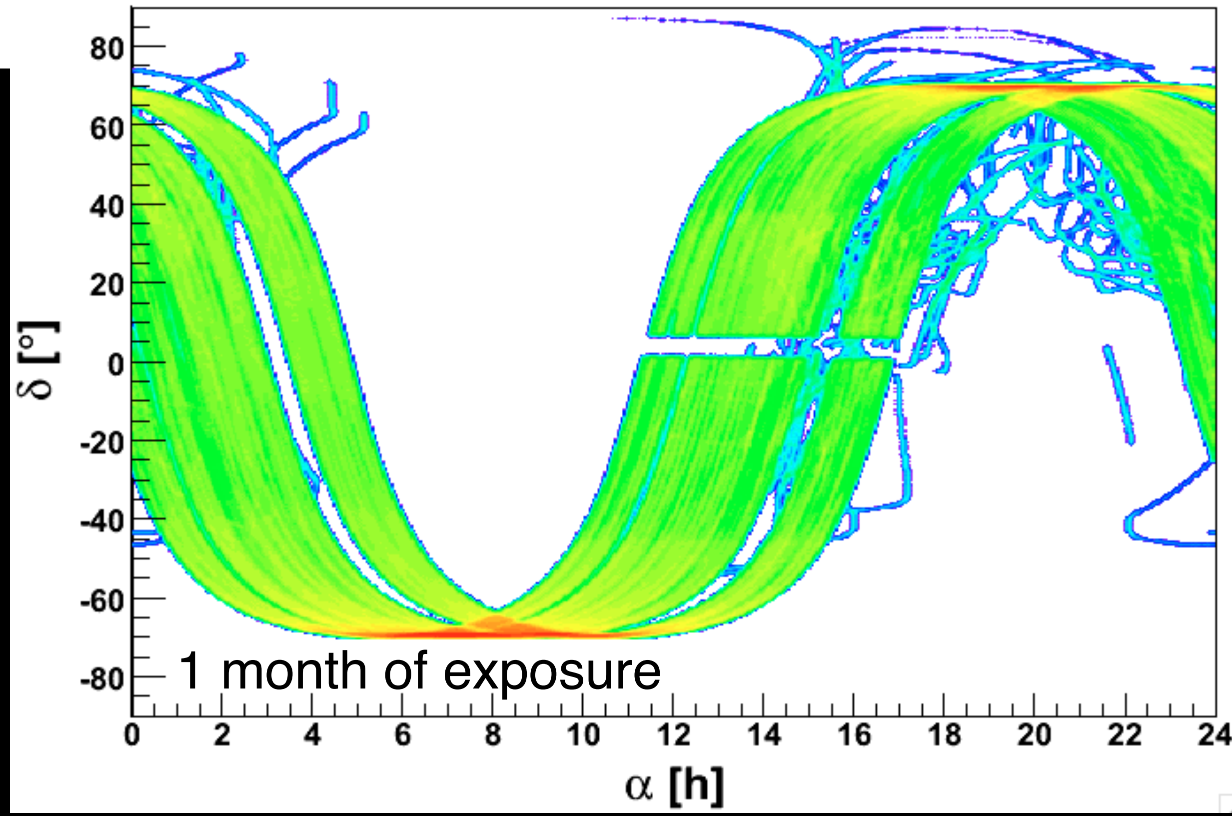
Anisotropy



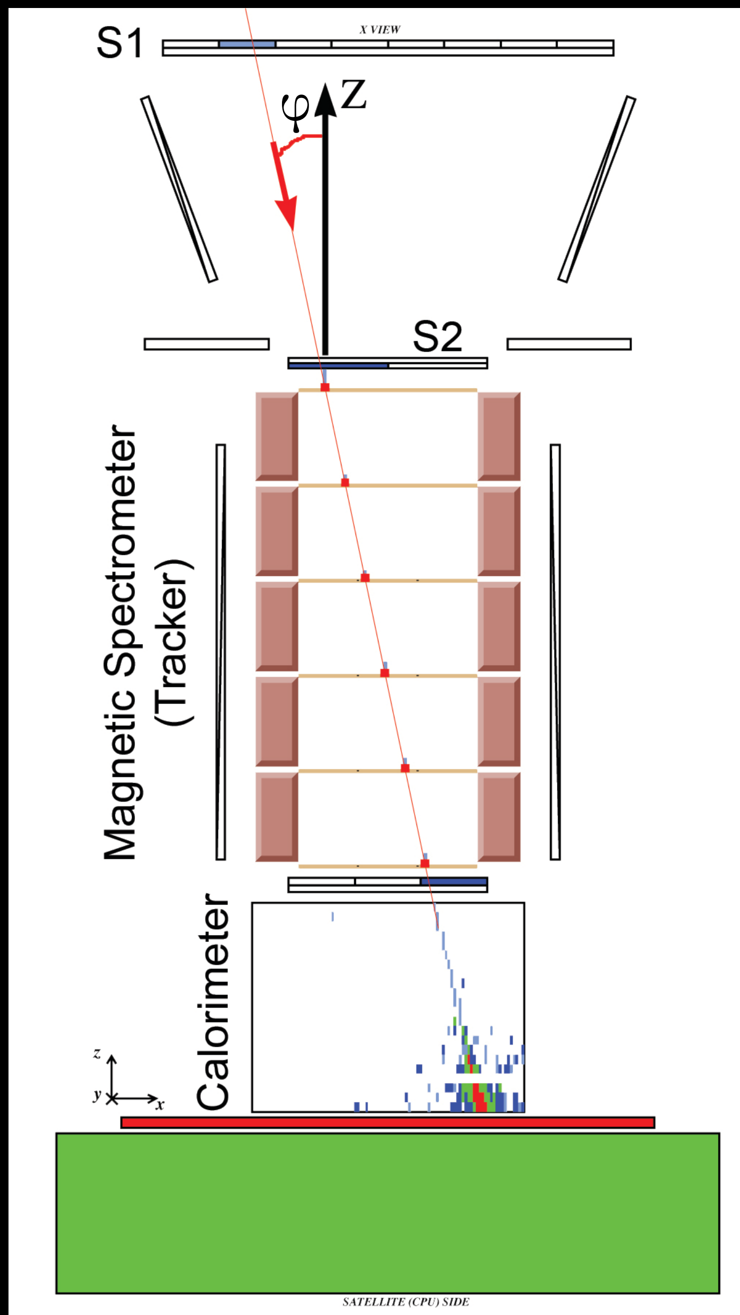
Interlude

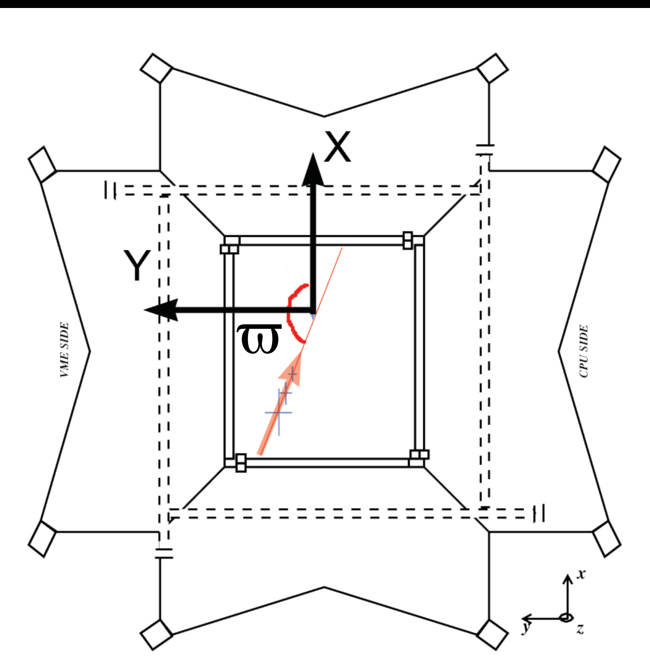


The effective vertical rigidity cutoffs [Cooke et al., 1991]



Cosmic Ray Mapping





The particle direction vector (red arrow) is estimated from the reconstructed track. φ is the angle between the particle direction vector and the PAMELA Z axis (also the PAMELA pointing direction). ϖ is the angle between the projection of the particle direction vector onto the (X,Y) plane and the PAMELA X axis.

The celestial coordinates are then deduce from rotation transformation from PAMELA rest frame to the Equatorial Coordinate system, tacking into account position and inclination of the satellite.

Anisotropy investigations

Anisotropy : Excesses or deficits from expectations from an isotropic sky.

The measured distribution is therefore the sum of an isotropic background plus an “additional signal”

Our first step in the search of anisotropies consist in modelling the isotropic background sky ➠ *Use of the Time flushing technique*

➊ At the time of each detected event, I randomly associate a particle rigidity according to the measured rigidity distribution.

➋ At the time of each detected event, I randomly associate a sky coordinate according to :

$$\mathrm{PDF} = \underbrace{H(20^\circ - \alpha_0, 20^\circ - \delta_0)}_{\text{Heaviside function representing FoV}} \otimes \underbrace{f(\alpha,\delta)}_{\text{Distribution function 4 different method}}$$

Heaviside function representing FoV

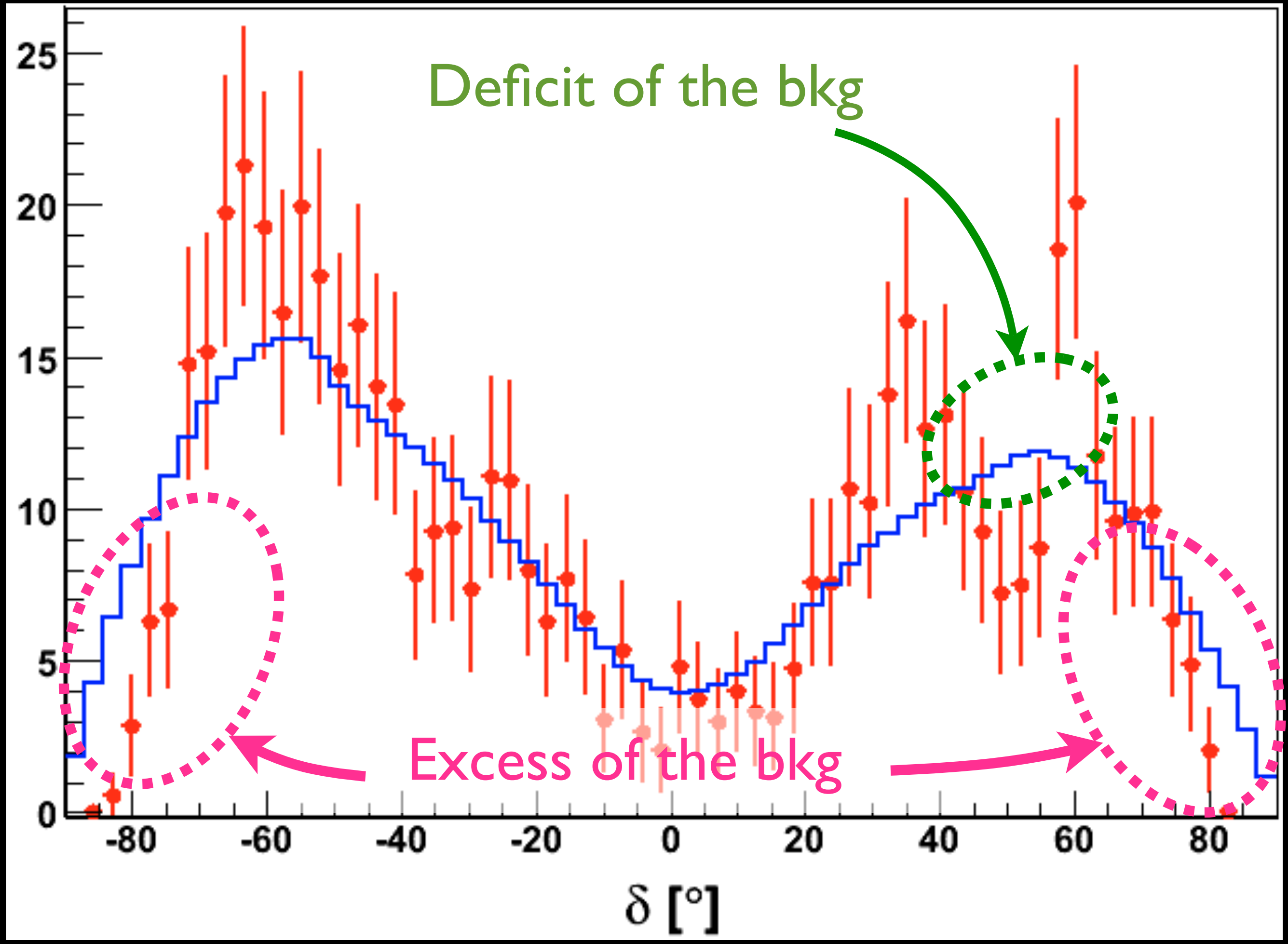
Distribution function 4 different method

➌ Process repeated 500 times to obtain an averaged isotropic background and reduce statistical fluctuation due to Monté-Carlo simulations.

Anisotropy investigations

① From an isotropic distribution: $f(\alpha,\delta) = C^{te}$

- ✓ Construct, by definition, an isotropic sky.
- ✓ Fluctuations of the simulated sky are due to exposure variation.
- ✗ Does not account for the effect of the Earth magnetic field
  - ➠ More accurate at high energy.

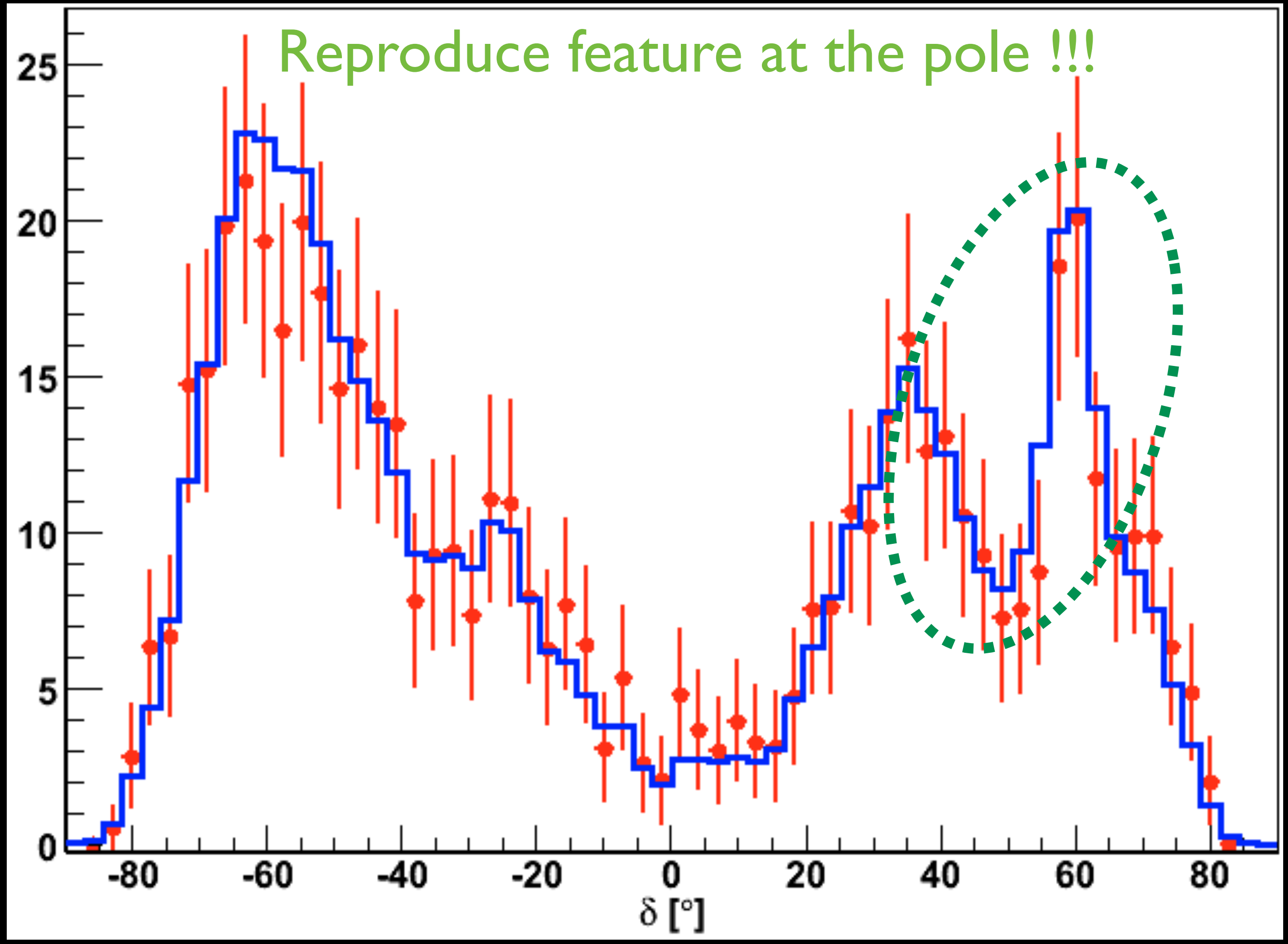


Comparison between the distributions of the measured positrons events (**red circle**) and of the simulated isotropic sky (**blue line**) as function of the declination.

Anisotropy investigations

② From the measured distribution: $f(\alpha,\delta)$ = measured (α,δ)

- ✓ Same exposure **and** efficiency between data and bkg.
- ✓ Account for the effect of the Earth magnetic field.
- ✗ For anisotropy with scales ≥ PAMELA field of view ➠ simulate an anisotropic background. Better for point like source anisotropy



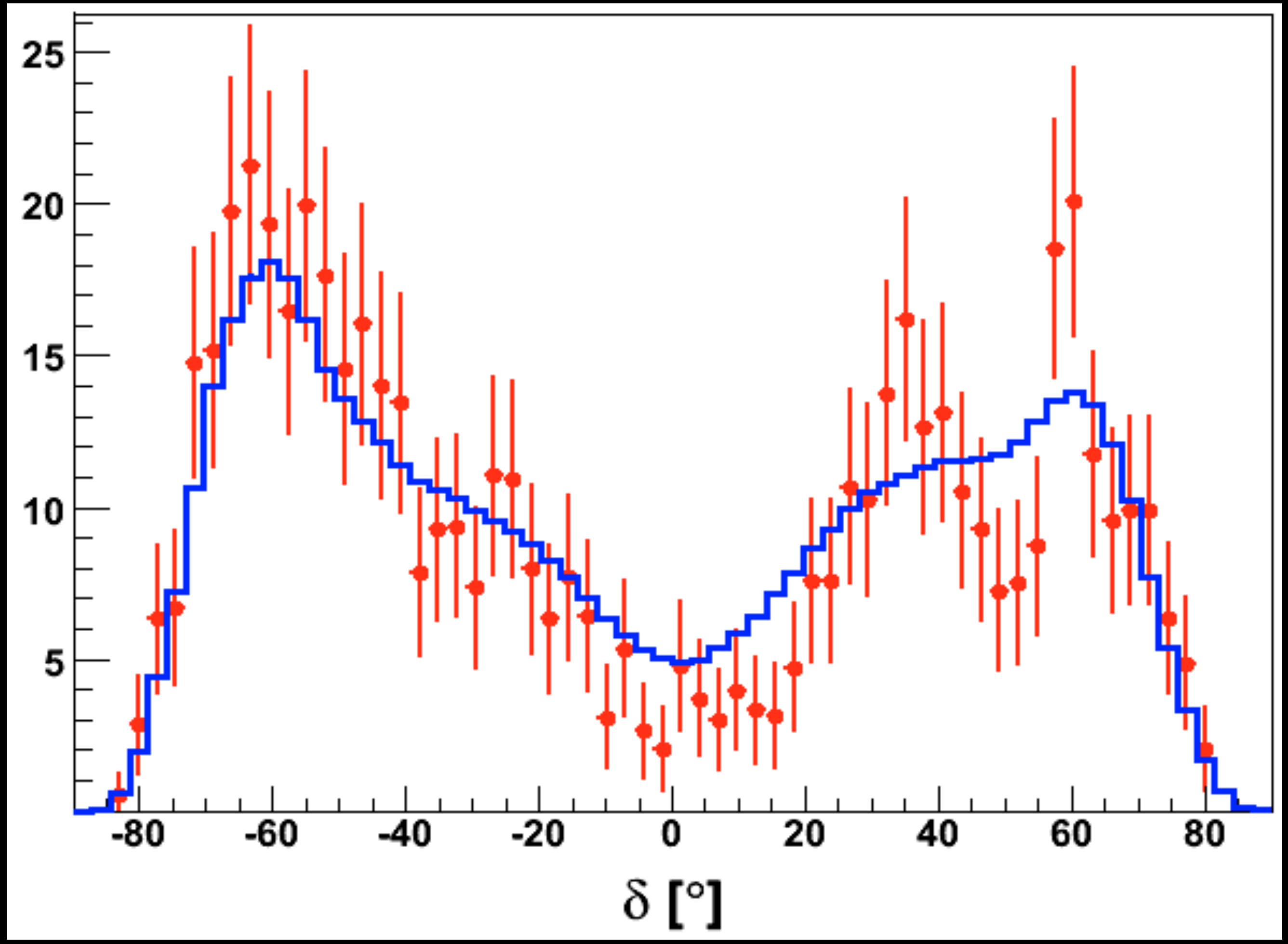
Comparison between the distributions of the measured positrons events (**red circle**) and of the simulated isotropic sky (**blue line**) as function of the declination.

Anisotropy investigations

Resurs-DK1
Magneto-sphere
CR Mapping
Anisotropy
background
Significance
Results

③ From the measured distribution of proton: $f(\alpha,\delta)$ = proton sky map

- ✓ Proton distribution is expected to be nearly isotropic.
- ✓ At similar rigidity, effect of the Earth magnetic field on proton and positron should be the same.
- ✗ Proton and positron efficiency are different.
- ✗ Proton sky-map is not perfectly isotropic

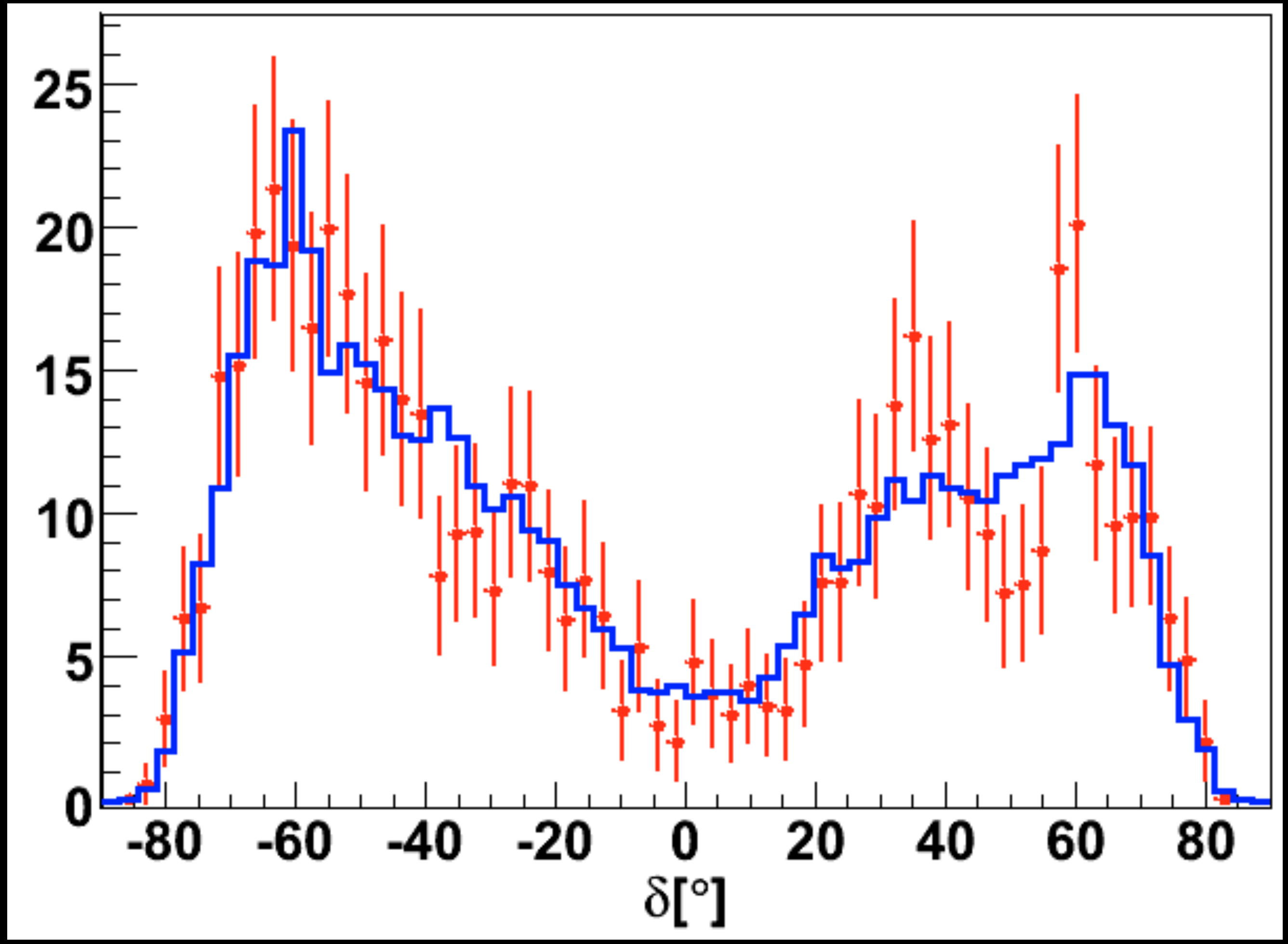


Comparison between the distributions of the measured positrons events (**red circle**) and of the measured proton events (**blue line**) as function of the declination.
The total number of detected protons has been scaled to the total number of detected positrons.

Anisotropy investigations

④ From the measured distribution of electron: $f(\alpha,\delta) = e^{-}$ sky map

- ✓ Account for the Earth magnetic field.
- ✓ Deflection of positron and electron goes in opposite direction.
- ✗ More sensitive at low energy



Comparison between the distributions of the measured positrons events (**red circle**) and of the measured electron events (**blue line**) as function of the declination.
The total number of detected electron has been scaled to the total number of detected positrons.

Anisotropy investigations

Our second step in the search of anisotropies consist in comparing the measured sky map and the simulated background

Estimate the number of standard deviation (S) the measured distribution deviate from expectation (simulated isotropic sky)

$$\begin{aligned} S(\alpha,\delta) &= \mathrm{sgn}\left[N_0(\alpha,\delta) - b(\alpha,\delta)\right]\sqrt{2} \\ &\times \left\{ N_0(\alpha,\delta)\ln\left(2\frac{N_0(\alpha,\delta)}{N_0(\alpha,\delta)+b(\alpha,\delta)}\right) + b(\alpha,\delta)\ln\left[2\frac{b(\alpha,\delta)}{N_0(\alpha,\delta)+b(\alpha,\delta)}\right]\right\}^{1/2} , \end{aligned}$$

Application to positrons produced by DM annihilating into the Sun

Solar Gamma Rays Powered by Secluded DM

Batell et al. ArXiv(0910.1567)

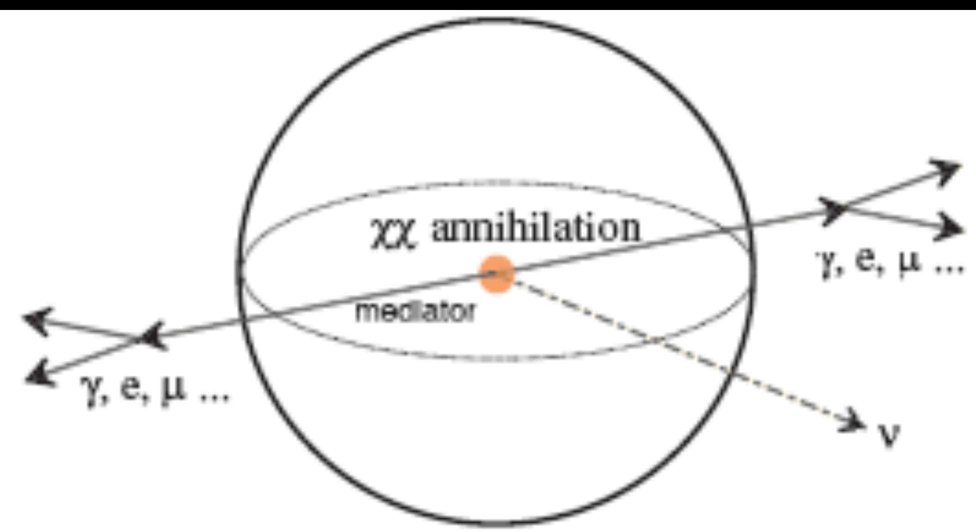
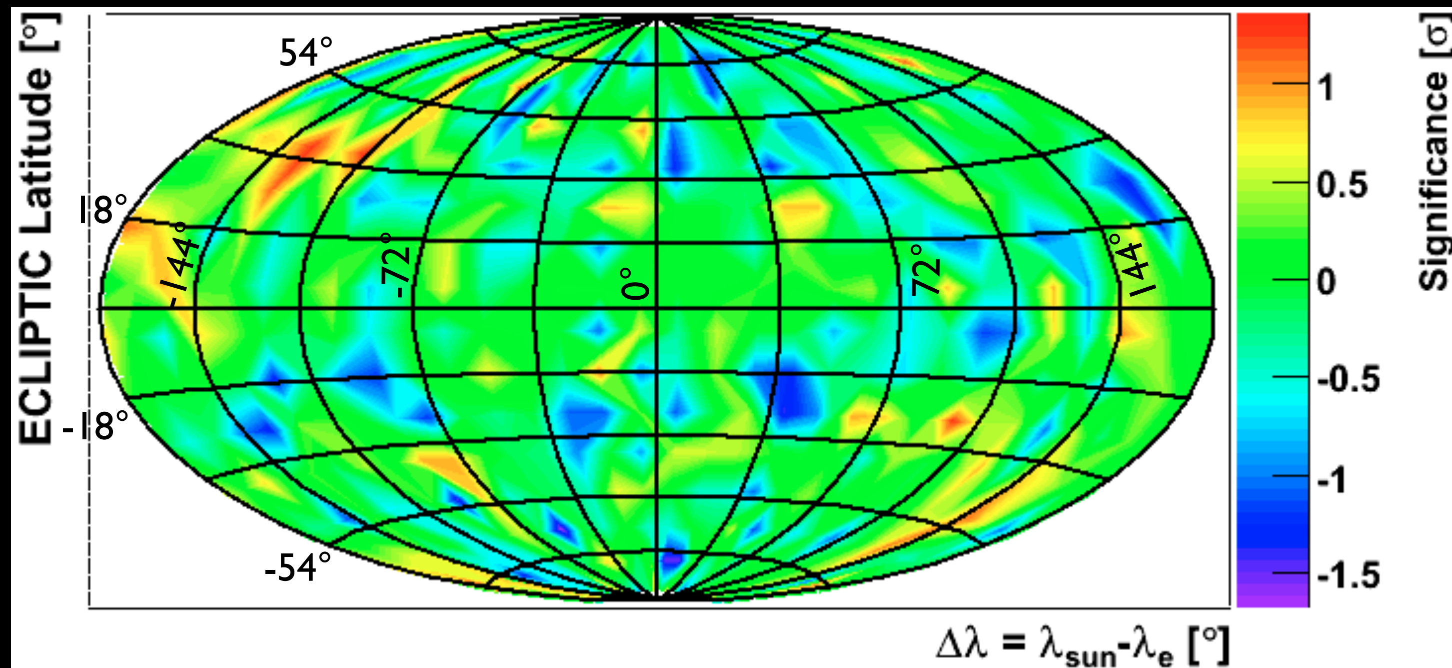
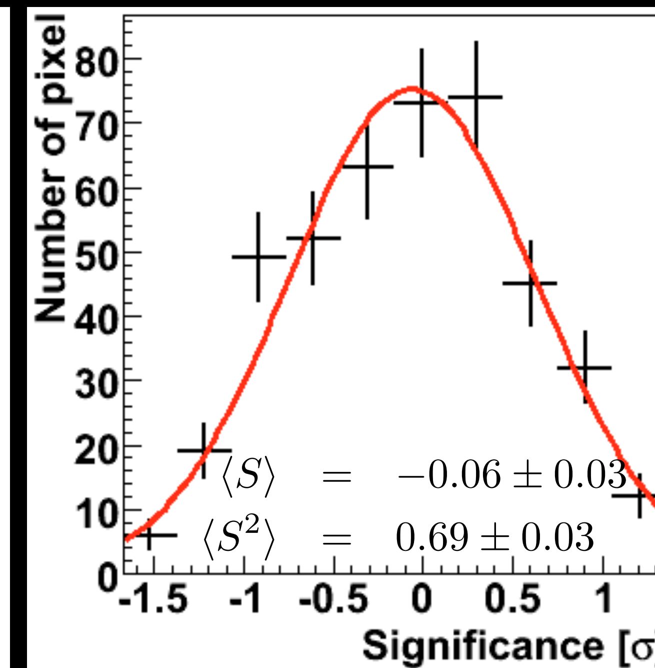


Figure 1: A schematic illustration of the new indirect detection signature of secluded WIMPs captured in the solar core, annihilating to metastable mediators and leading to an electromagnetic flux: $\gamma, e^{\pm}, \mu^{\pm}, \cdots$. Sensitivity to conventional WIMPs arises only through annihilation to neutrinos.

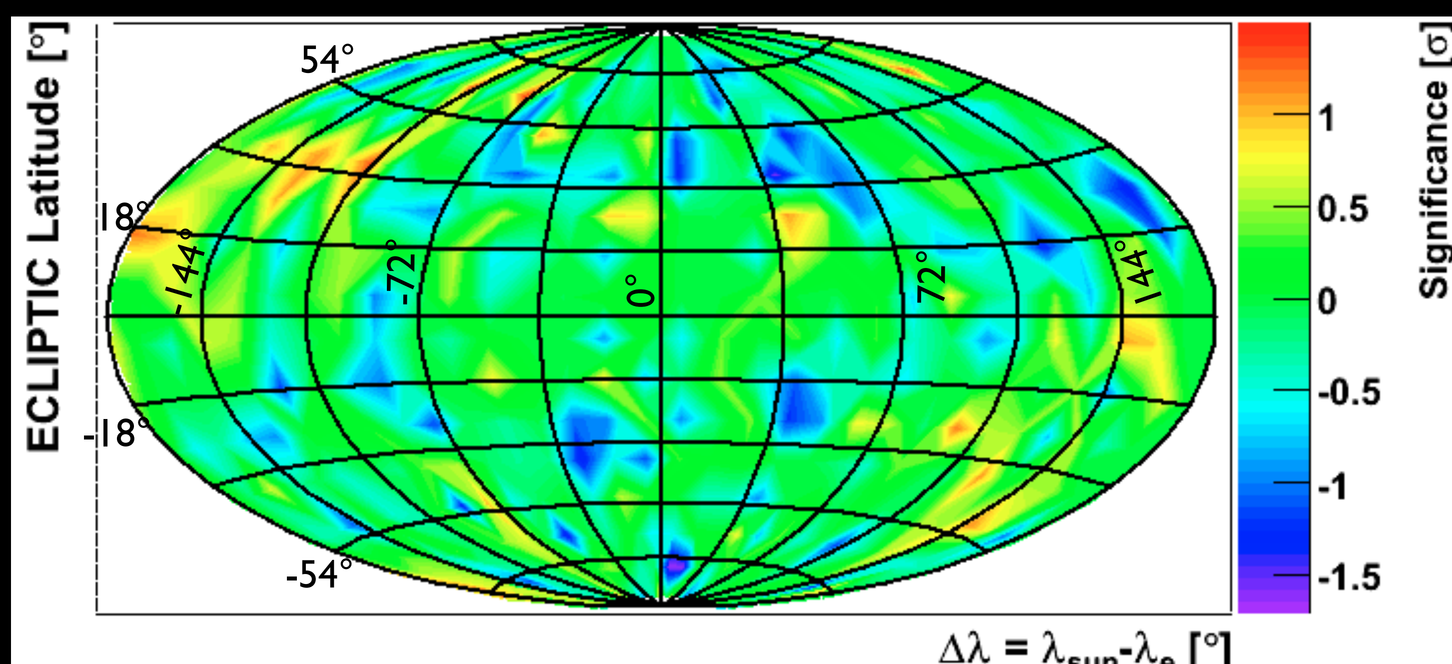
Anisotropy investigations

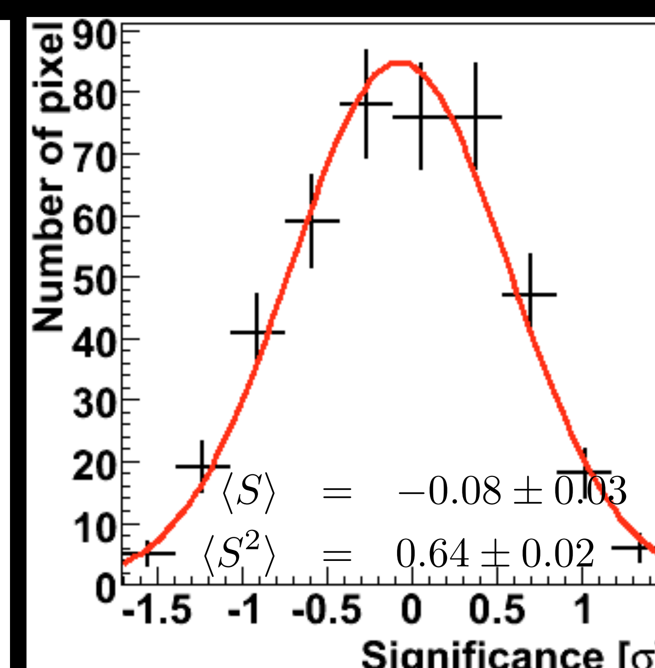
① From an isotropic distribution: $f(\alpha,\delta) = C^{te}$





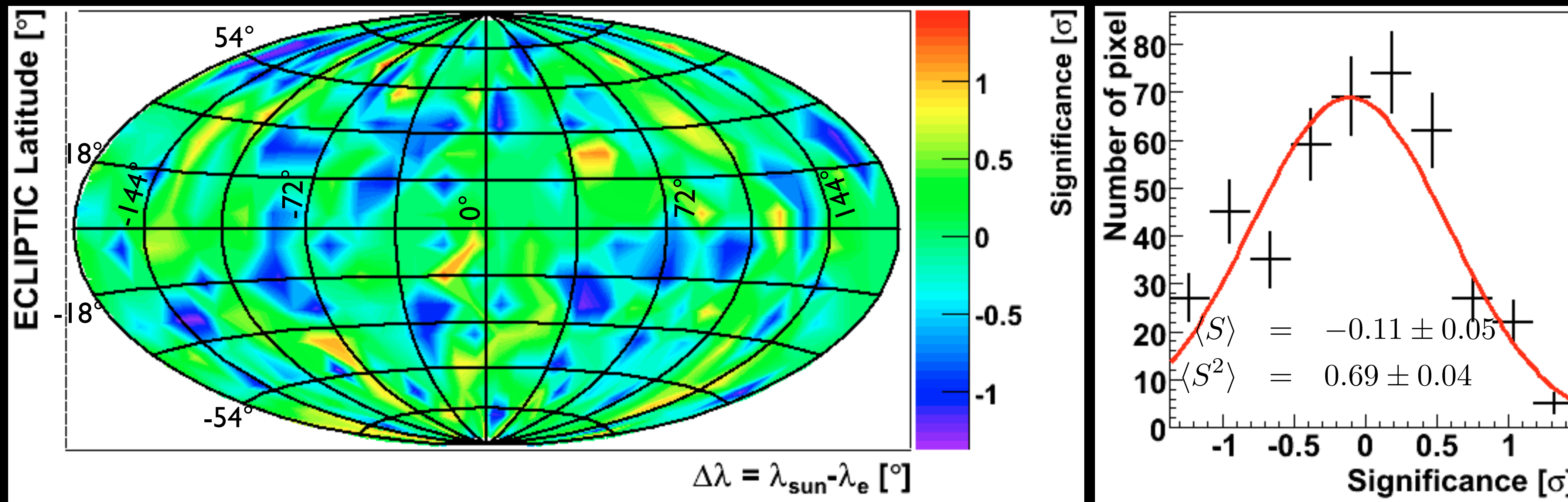
② From the measured distribution: $f(\alpha,\delta)$ = measured (α,δ)



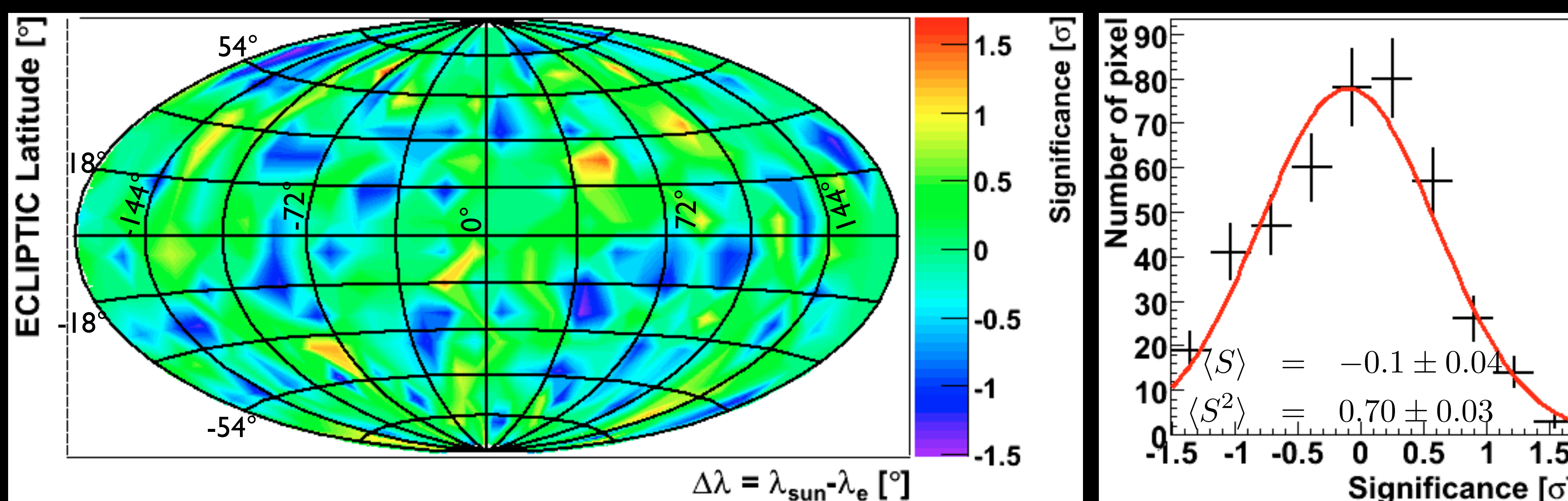


Anisotropy investigations

③ From the measured distribution of proton: $f(\alpha,\delta)$ = proton sky map



④ From the measured distribution of electron: $f(\alpha,\delta)$ = e^- sky map



Conclusion

i) We can reconstruct CR spatial distribution from PAMELA measurements

ii) We constructed isotropic backgrounds based on the measured efficiency and exposure of PAMELA.

iii) Measured e^+/e^- sky maps with respect to the Sun are compatible with an isotropic sky.

Next Step :

iv) Back trace particles into Earth's magnetosphere

v) Increase statistic with next data set (up to 2011) and using neural network for e^+/e^- selection