Recent updates in the Cosmic Ray Anisotropy measurement by AMS

Giuseppe La Vacca
Università & INFN Milano-Bicocca

Outline:
- Motivations, Strategies, Methology
- Relative anisotropy
- Absolute anisotropy
- The case of the GSE “signal”

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Motivations for anisotropy search

AMS-02 observes structures in the spectra of e+, e-, p, He that cannot be fully explained within the current physical knowledge. These features may be connected to new phenomena which could induce some degree of anisotropy in their fluxes:

- Local environment (e.g., galactic magnetic field, effects due to the solar activity at low rigidity)
- Local sources (e.g., pulsars for e+ and e-, local SNRs)

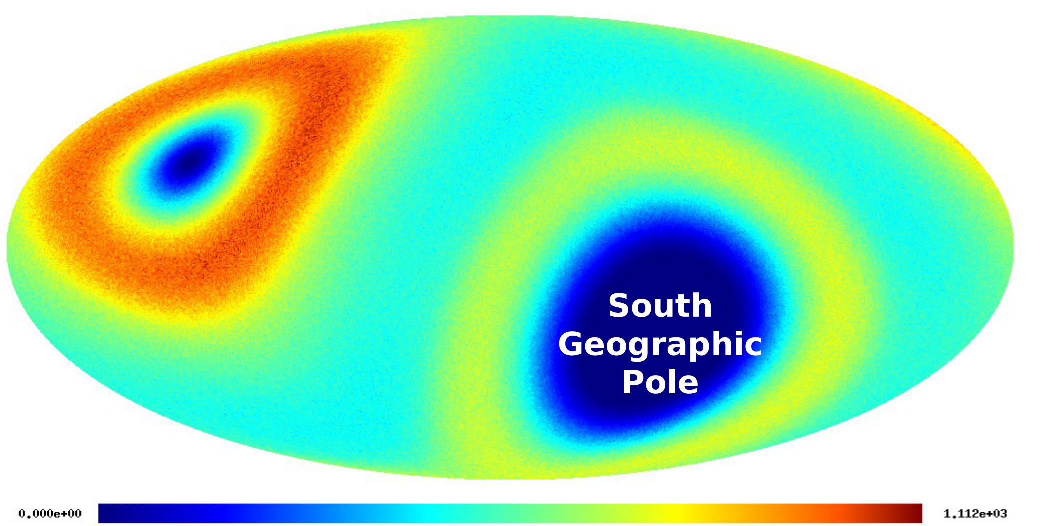
BEING IN SPACE:

Pro:

- A *long term*, (nearly) *full-sky* observation and a three-dimensional measurement of the tiny CR anisotropy signals;
- Primary CR detected before interacting with the atmosphere;

Con:

- In LEO's, the presence of the magnetosphere: CR directions after trajectory reconstruction in magnetosphere, rigidity cut-off;
- Not uniform exposure.



AMS-02 exposure in Galactic cordinates

Strategies for anisotropy search

Reference maps: best guess for an image of an isotropic sky measured by AMS-02 in the respective data taking period. Any deviation from this reference map might be detected as a signal.

Choices for reference maps:

I) other cosmic ray species (e.g. protons used for leptons)

II) same cosmic ray species (at different energy)

III) simulation of an isotropic sky from data

Absolute Anisotropy
Topic of the analysis efforts at the moment

Relative Anisotropy
No significant deviation from isotropy is found!

Methodology

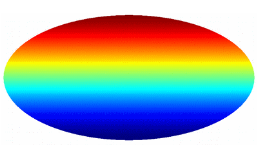
for anisotropy search

A **likelihood fit** procedure has been set up to compare the species under study to the reference sky map. It takes into account the differences in the exposure for different rigidities. A spherical harmonics expansion of the relative anisotropy is obtained:

$$\Phi(\vartheta,\varphi)=\sum_{l=0}^{\infty}\sum_{m=-l}^{l}a_{l,m}Y_{l,m}(\vartheta,\varphi)$$

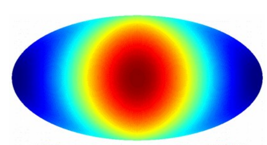
For the **three dipole components** (l=1)

North-South



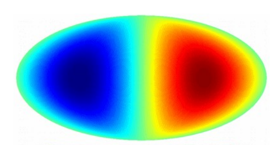
$$\rho_{NS}=\sqrt{\frac{3}{4\pi}}a_{10}$$

Forward-Backward



$$\rho_{FB}=\sqrt{\frac{3}{4\pi}}a_{11}$$

East-West



$$\rho_{EW}=\sqrt{\frac{3}{4\pi}}a_{1-1}$$

Dipole amplitude: $\delta=\sqrt{\rho_{NS}{}^{2}+\rho_{FB}{}^{2}+\rho_{EW}{}^{2}}$

Relative anisotropy

Results based on 5-year sample, up to November 2016:
10^6 electrons, 80000 positrons, 6×10^6 protons (>150GV)

Other CR species as reference for detector exposure:

• **other cosmic ray species:** e+/e- and e+/p, e-/p also at magnetosphere border. Protons to normalize for exposure.

In galactic coordinate, for [16,350]GeV:

$$\delta_{e^+/p}(95\%\,C.L.) < 2\%$$

$$\delta_{e^+/e^-}(95\%\,C.L.) < 2\%$$

$$\delta_{e^-/p}(95\%\,C.L.) < 0.6\%$$

PAMELA published:
δe+/e-(95% C.L.) < 17%
at R>10GeV [ApJ 811, 21, **2015**]

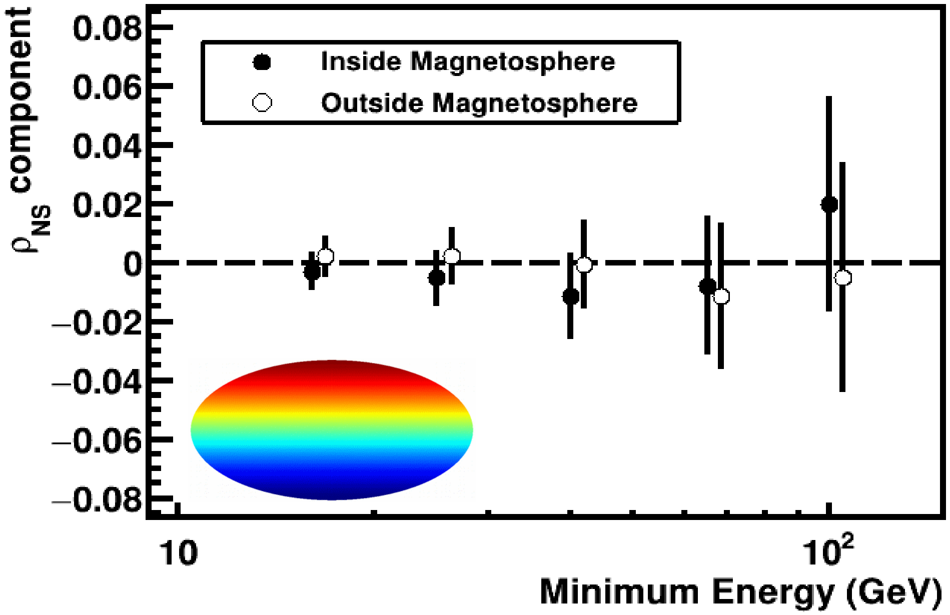
• **same cosmic ray species at different energy:** high energy p vs. low energy p. Low energy (before break) protons to normalize for exposure.

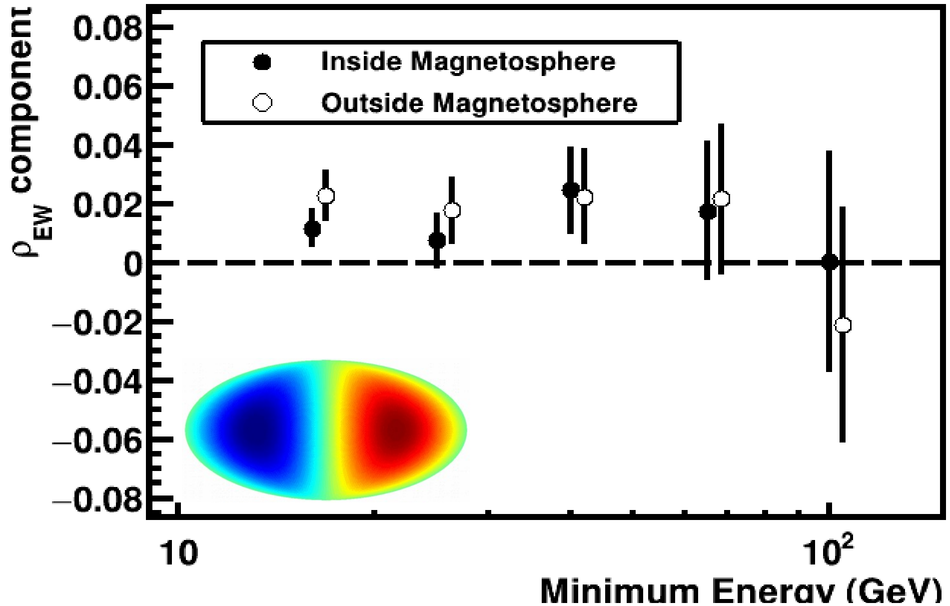
In galactic coordinate, for R>150GV (full span)

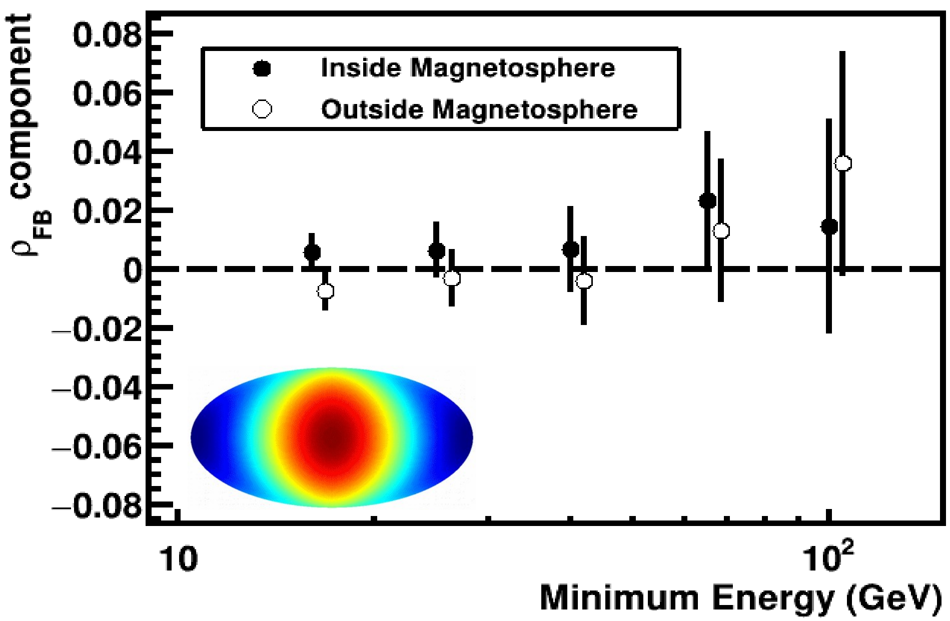
$$\delta_{pH/pL}(95\%\,C.L.) < 0.2\%$$

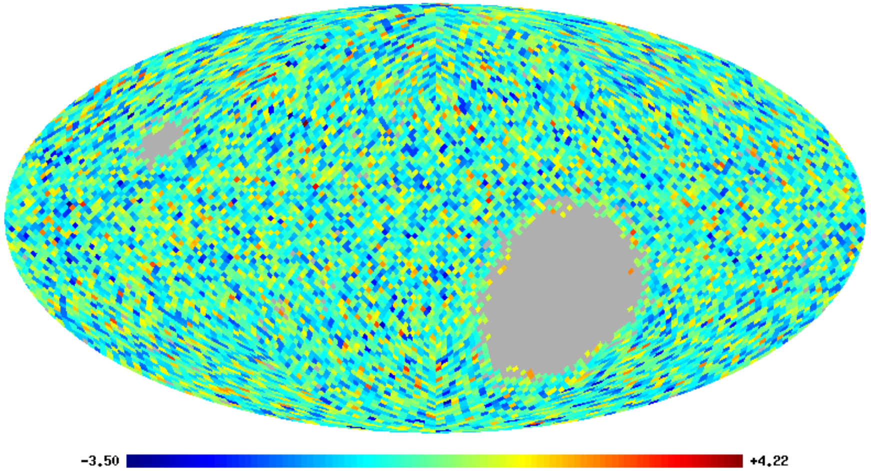
Positrons vs. protons

Dipole components in galactic coordinates







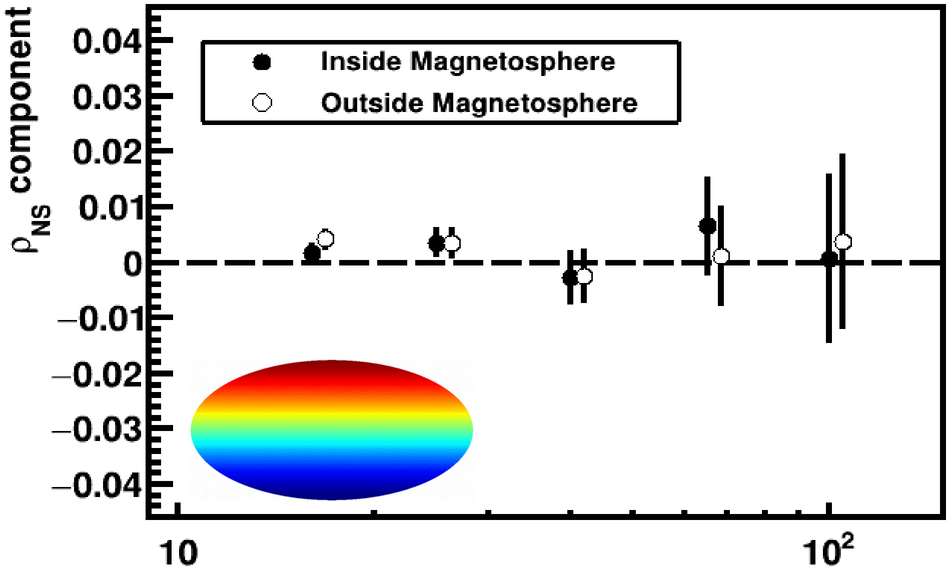


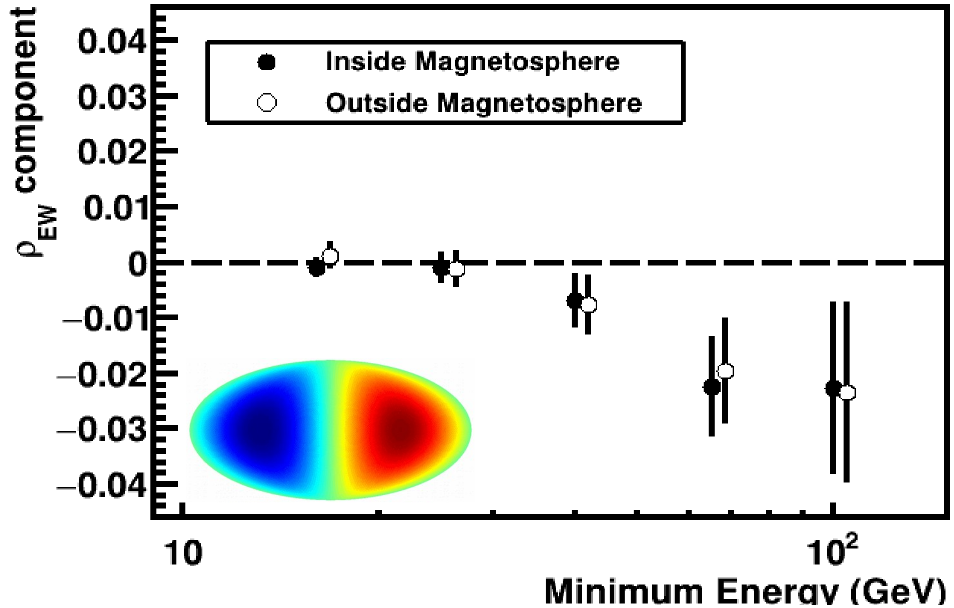
No significant deviation from isotropy is found

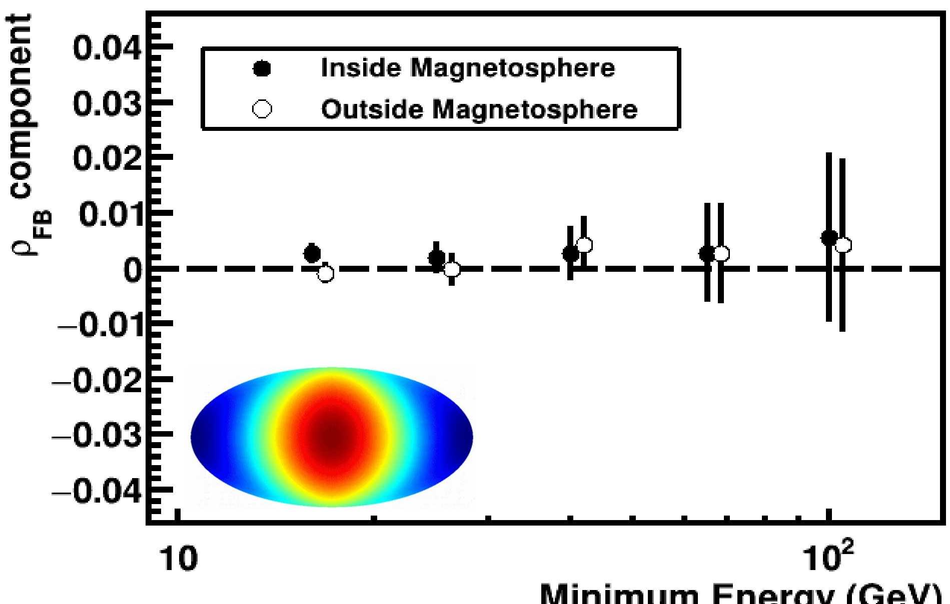
Electrons vs. protons*

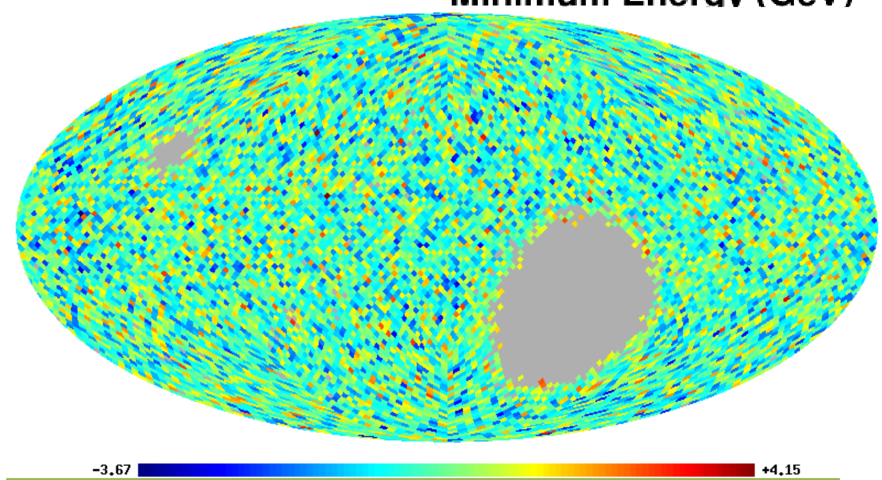
Dipole components in galactic coordinates

*Protons back-traced with negative charge





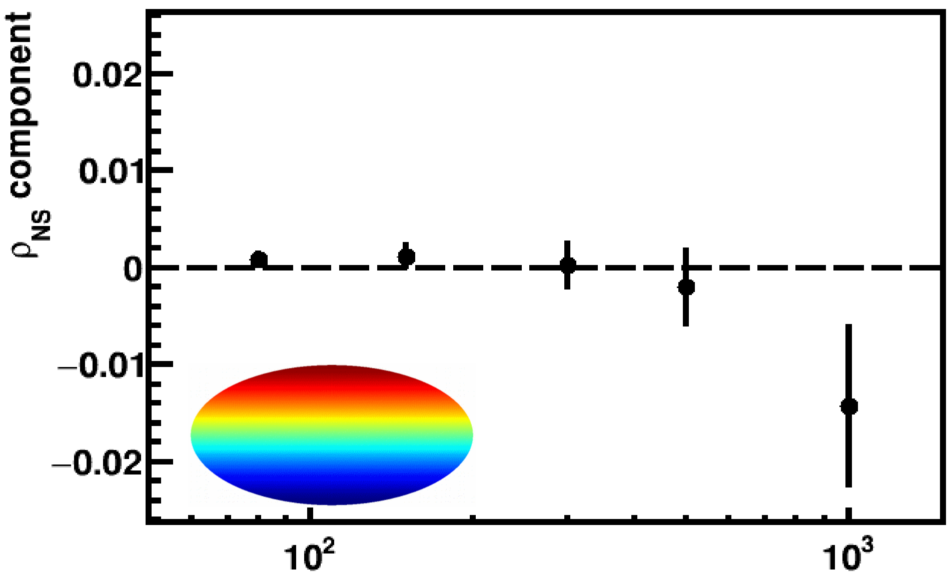


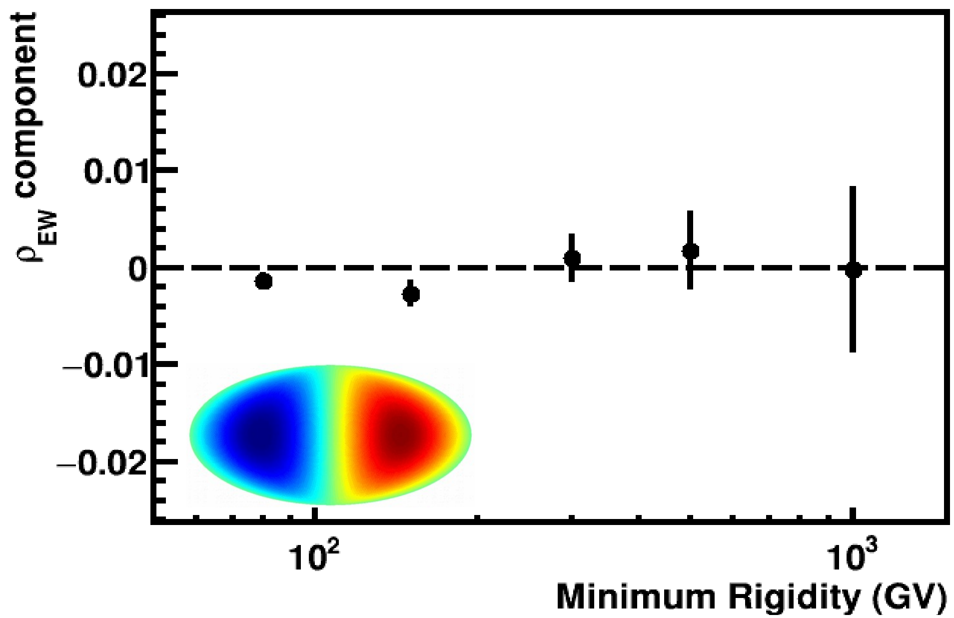


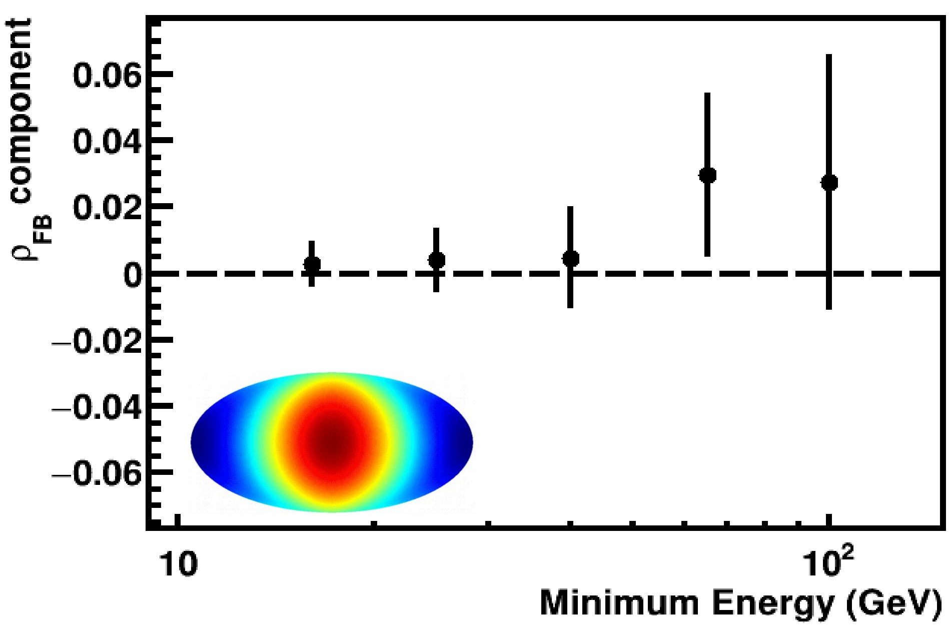
No significant deviation from isotropy is found

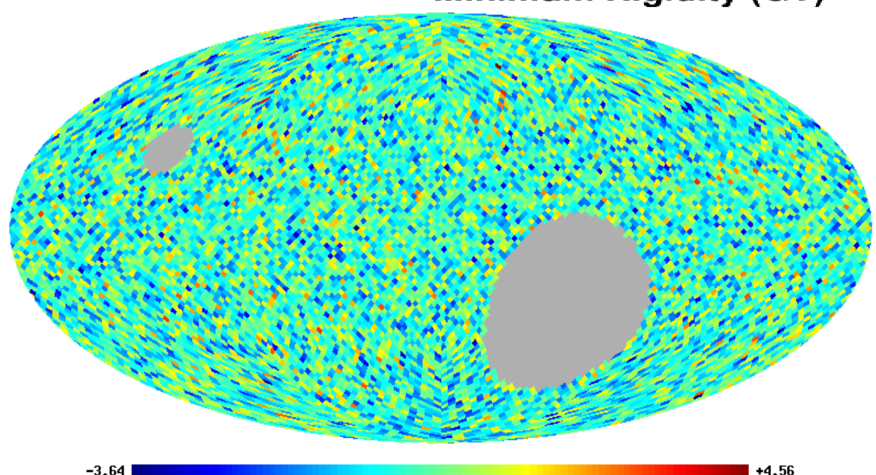
Protons High vs. Protons Low

Dipole components in galactic coordinates









No significant deviation from isotropy is found

Absolute Anisotropy

Reference maps: an accurate MC generation of the isotropic sky is need. The usual method consists in generation of events proportionally to the exposure time and to the detector acceptance.

Efficiency corrections as a function of detector position are required to prevent non-physical signals, with a precision better than 10^{-4} (expected signal), but:
- limited in statistics
- statistics different for each detector position

In galactic coordinate, for R>16GeV:

$$\delta_{e^+}(95\%\,C.L.)<2\%$$

$$\delta_p(95\%\,C.L.)<0.1\%$$

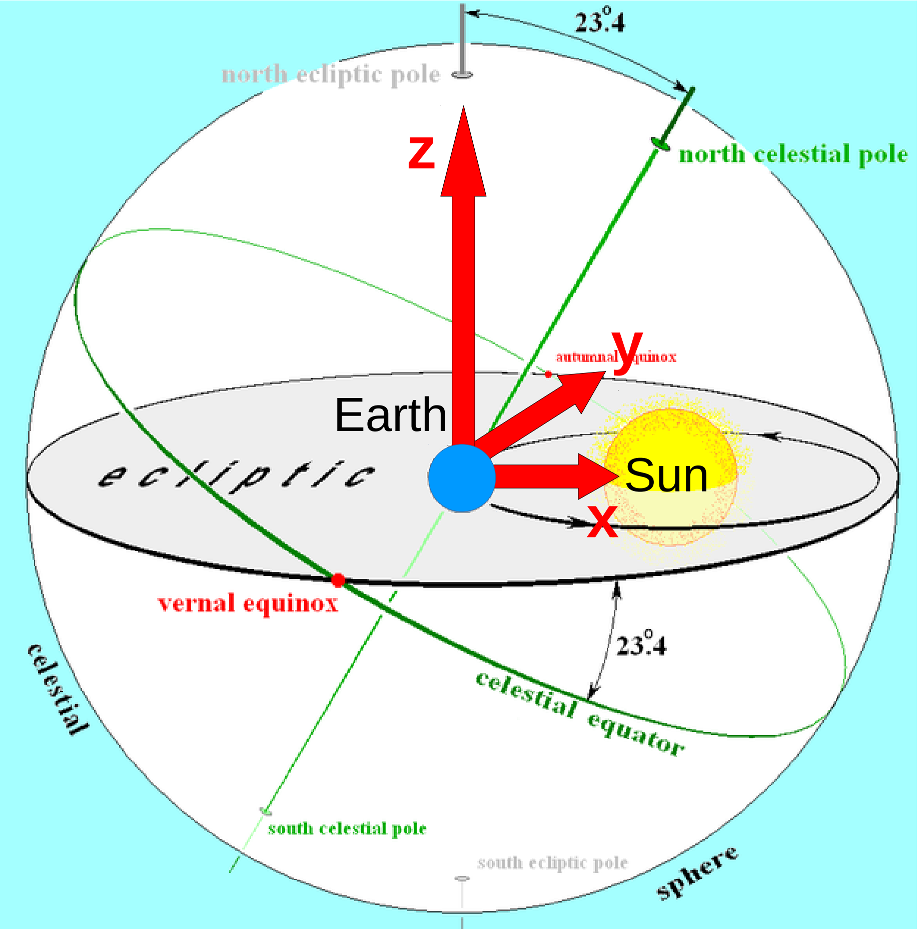
$$\delta_{e^-}(95\%\,C.L.)<0.5\%$$

The case of GSE “signal”

X axis pointing from Earth to Sun
Y axis in ecliptic plane opposing Earth motion
Z axis perpendicular to Ecliptic plane

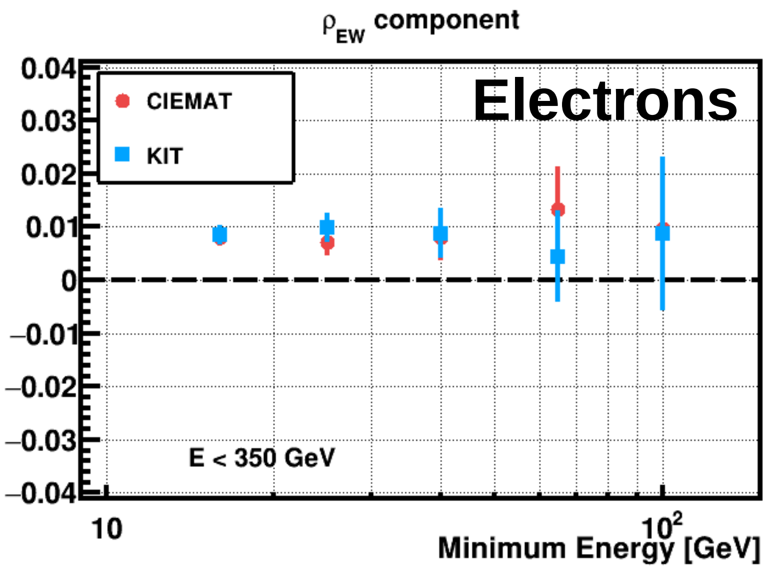
This coordinate system allows investigating night-day effects which can be averaged out over a complete year revolution in inertial systems, e.g. galactic

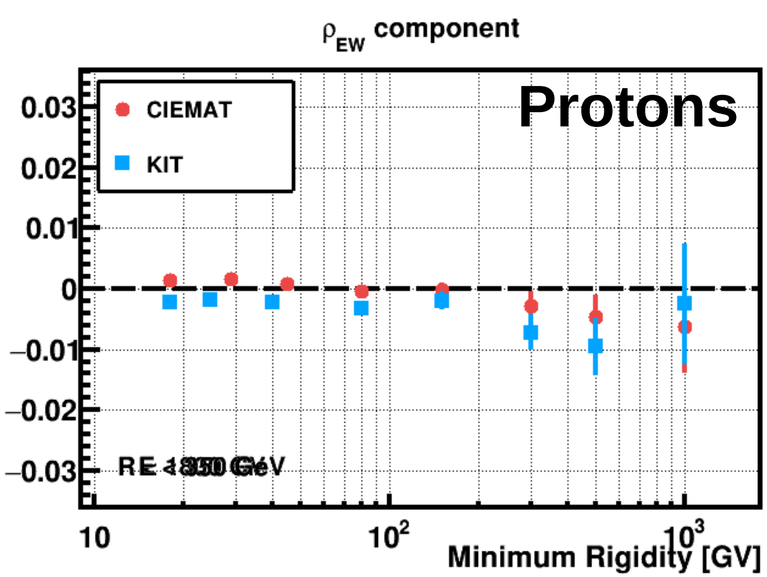
-180°

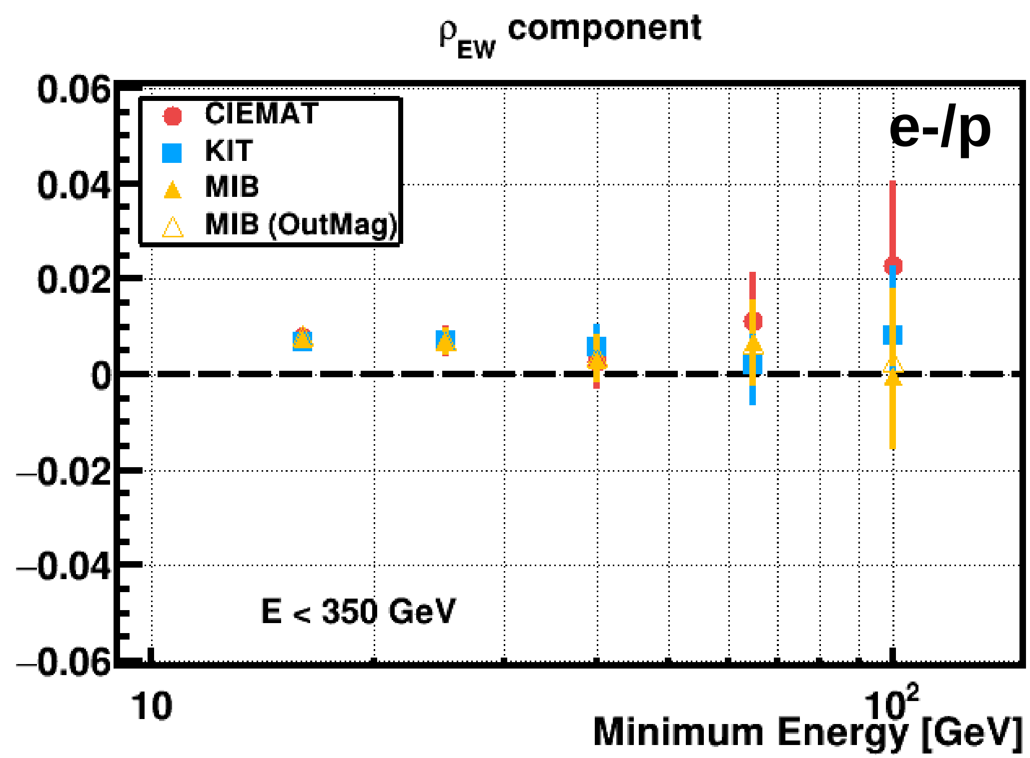


The case of GSE “signal”

A significant **EW component** (but also a smaller FB component) appears in proton and electron anisotropy, after efficiency corrections, already present in relative anisotropy studies...







The case of GSE “signal”

M. Velasco, AMS General Meeting 31.05.2017

Only visible in GSE

Proton relative anisotropy

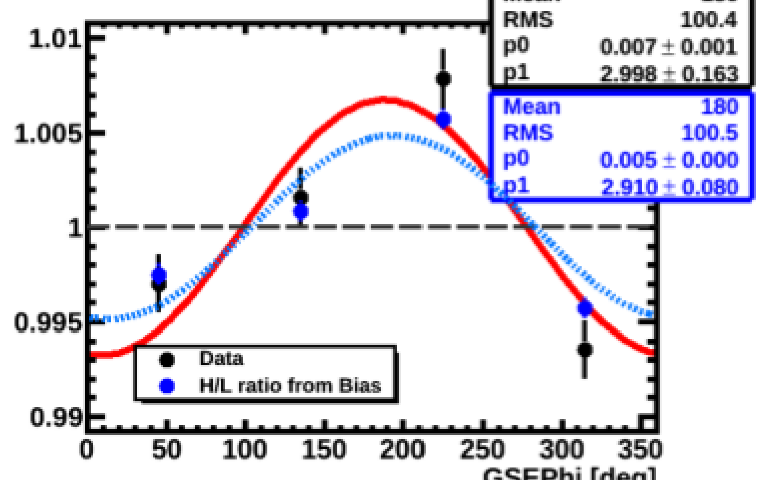
Harmonic analysis of the diff. rigidity scale effect

Full Span protons

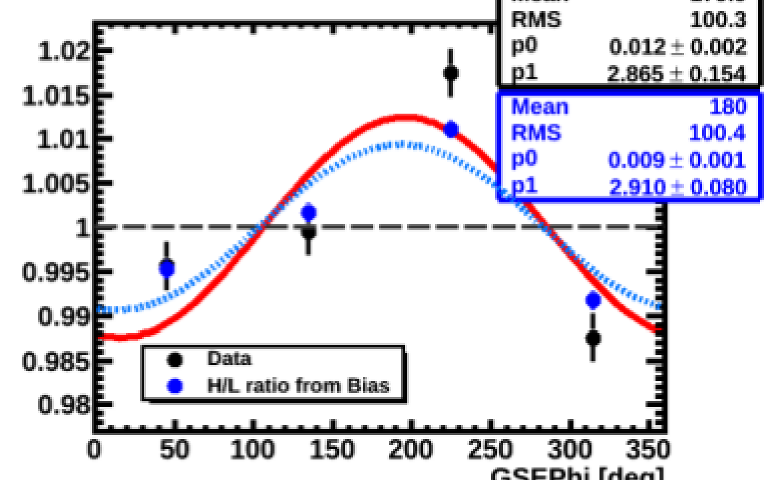
In GSE, a differential rigidity scale with an amplitude below 1/25 TV^{-1} induces a modulation of the H/L ratio in the ecliptic plane

The effect of this differential rigidity scale can be seen as a correction we need to take into account in our analysis

Rmin: 150 GV



Rmin: 300 GV



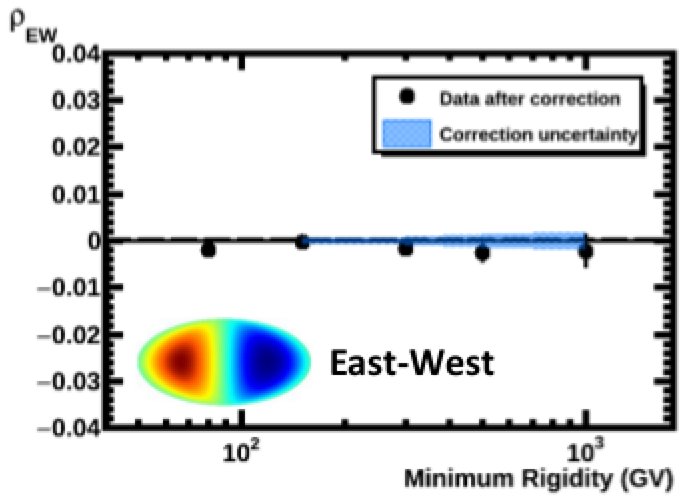
The case of GSE “signal”

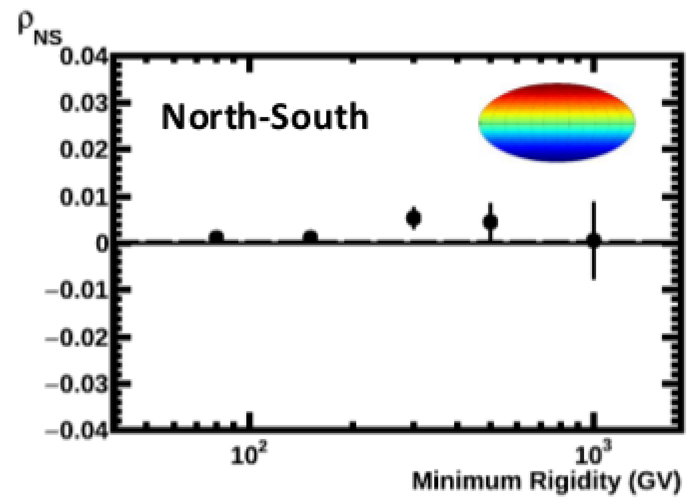
M. Velasco, AMS General Meeting 31.05.2017

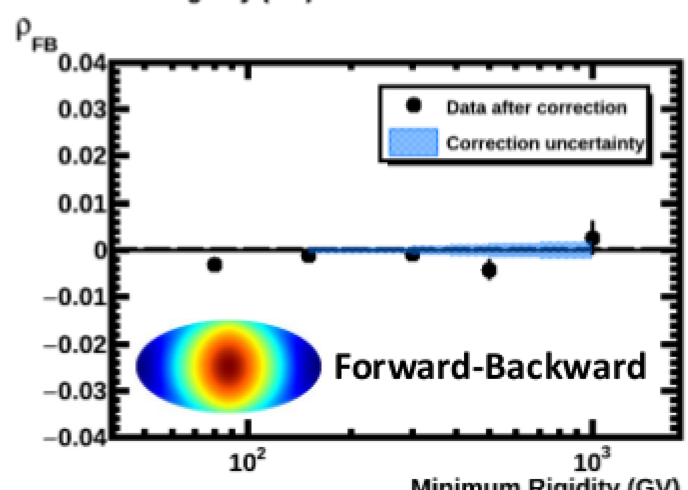
Proton relative anisotropy

Dipole components: GSE coordinates

Full Span protons







No significant deviation found after taking into account rigidity scale correction

MIB Analysis status

Before CNAF flooding:

After Summer 2017, analysis efforts were mainly directed to the systematic study of the **absolute anisotropy**:
- New procedure for exposure time and counting maps
- New procedure for trigger efficiency maps
- New procedure for rate maps
  in differential rigidity bins
  with monthly time binning
  for different coordinate systems (GAL, GTOD, ECI, GSE, GeoMag)

Codes local backup
Data completely lost (except few periods at CERN)

Time to CNAF problem resolution apparently too short for scheduling a new complete data selection

MIB Analysis status

After CNAF restoring:

- Complete the absolute anisotropy analysis:
    - compare with the most updated data selection available
    - full efficiency correction studies

- Perform the analysis at the magnetosphere border:
    - determine the exposure outside magnetosphere
    - optimize the FoV determination with back-tracing
    - compute efficiency corrections at the magnetosphere border
    - determine systematics due to back-tracing