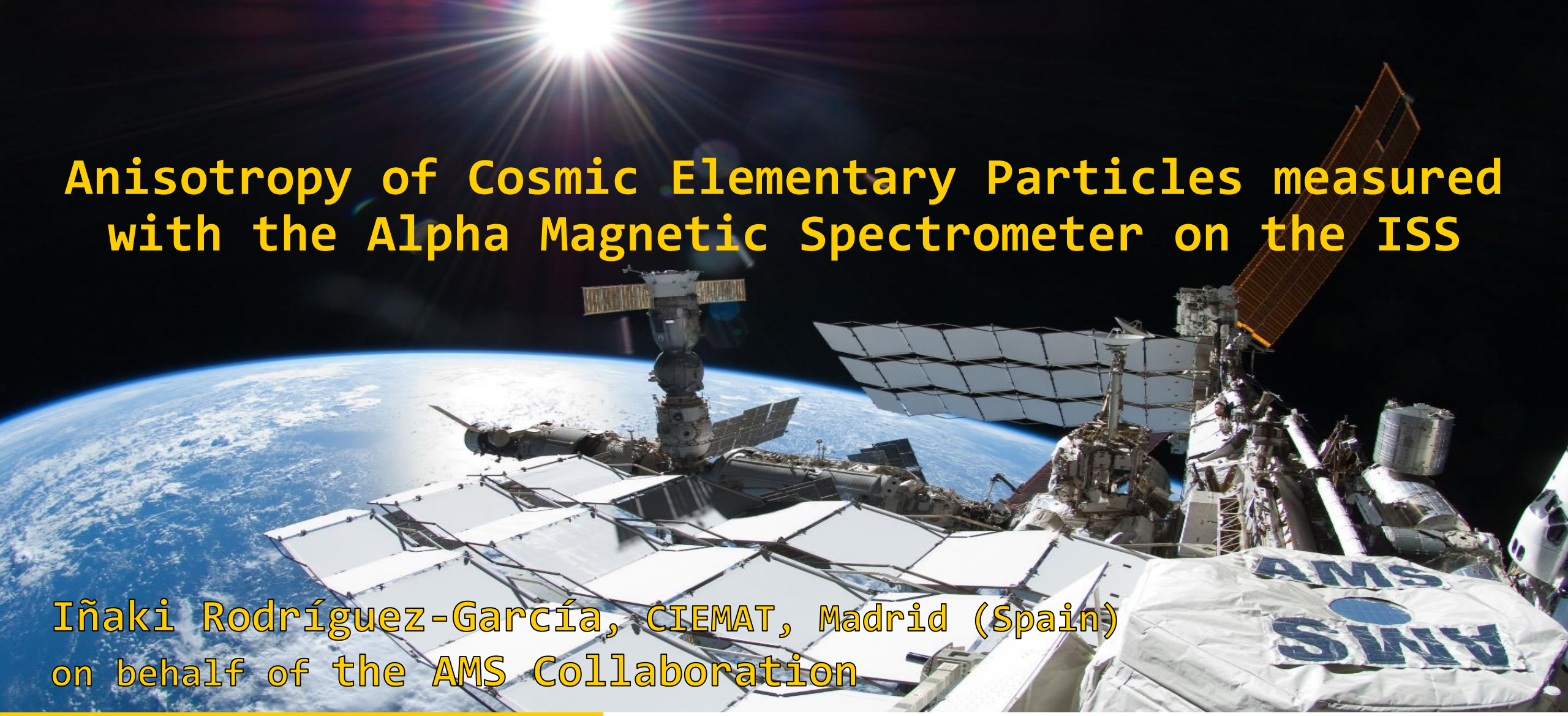
Anisotropy of Cosmic Elementary Particles measured with the Alpha Magnetic Spectrometer on the ISS



Iñaki Rodríguez-García, CIEMAT, Madrid (Spain)
on behalf of the AMS Collaboration

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Ciemat
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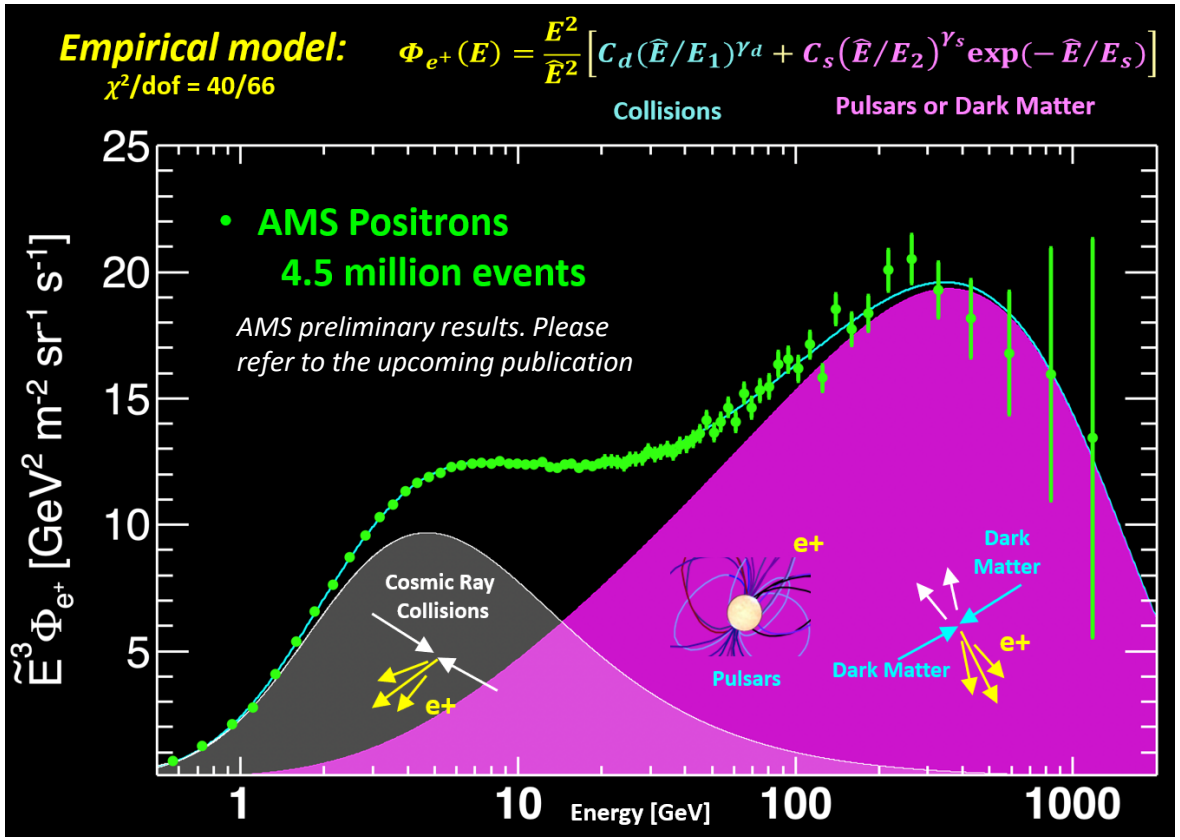
TeV Particle Astrophysics TeVPA Valencia 2025

Origin of Cosmic Ray Positrons

Positron spectrum shows a significant excess above ~23 GeV that is not consistent with only the secondary production of positrons

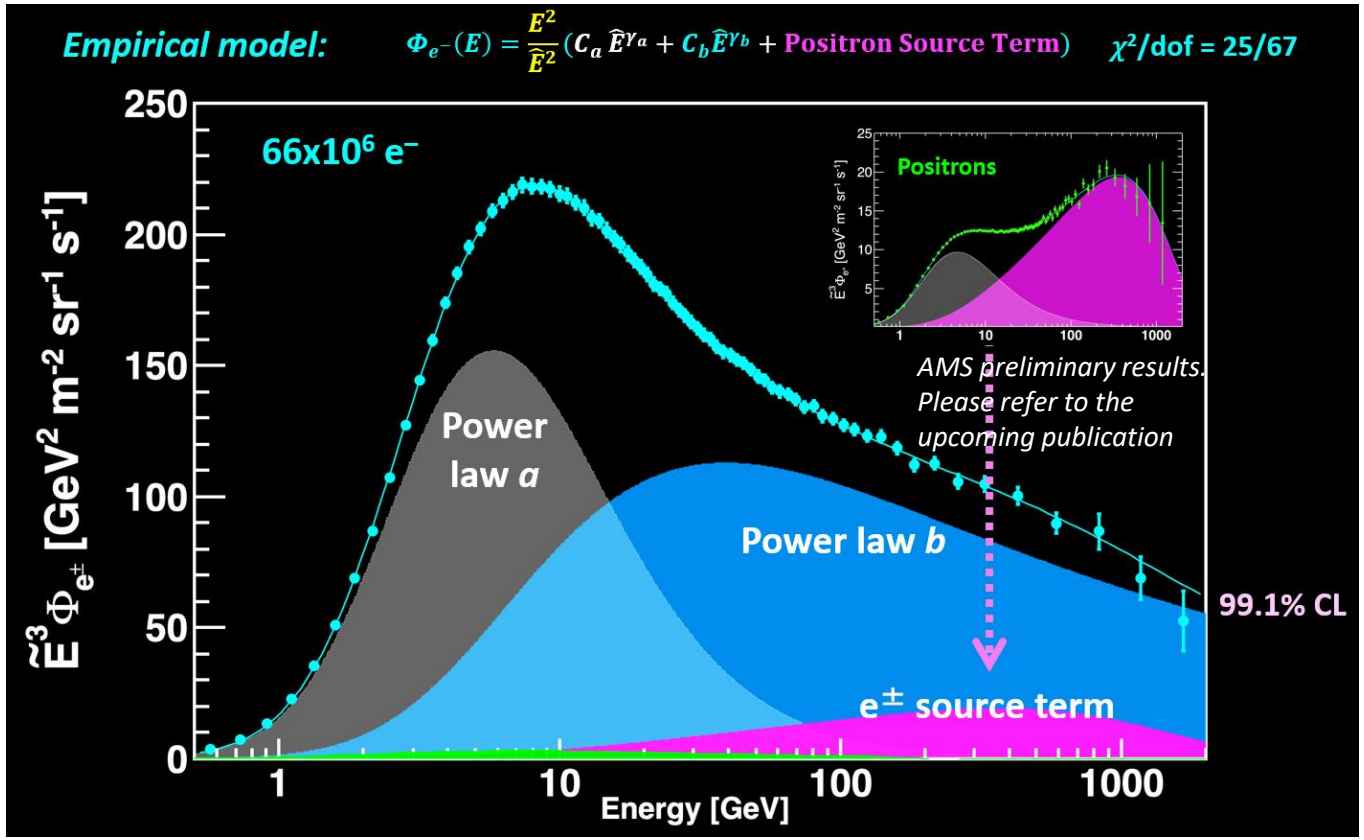


This excess can be explained with Dark Matter or astrophysical sources such as pulsars

An astrophysical point source may induce privileged direction (anisotropy) in the measured flux.

Origin of Cosmic Ray Electrons

Electron spectrum is described with two power laws (a, b) and the same source term for positrons

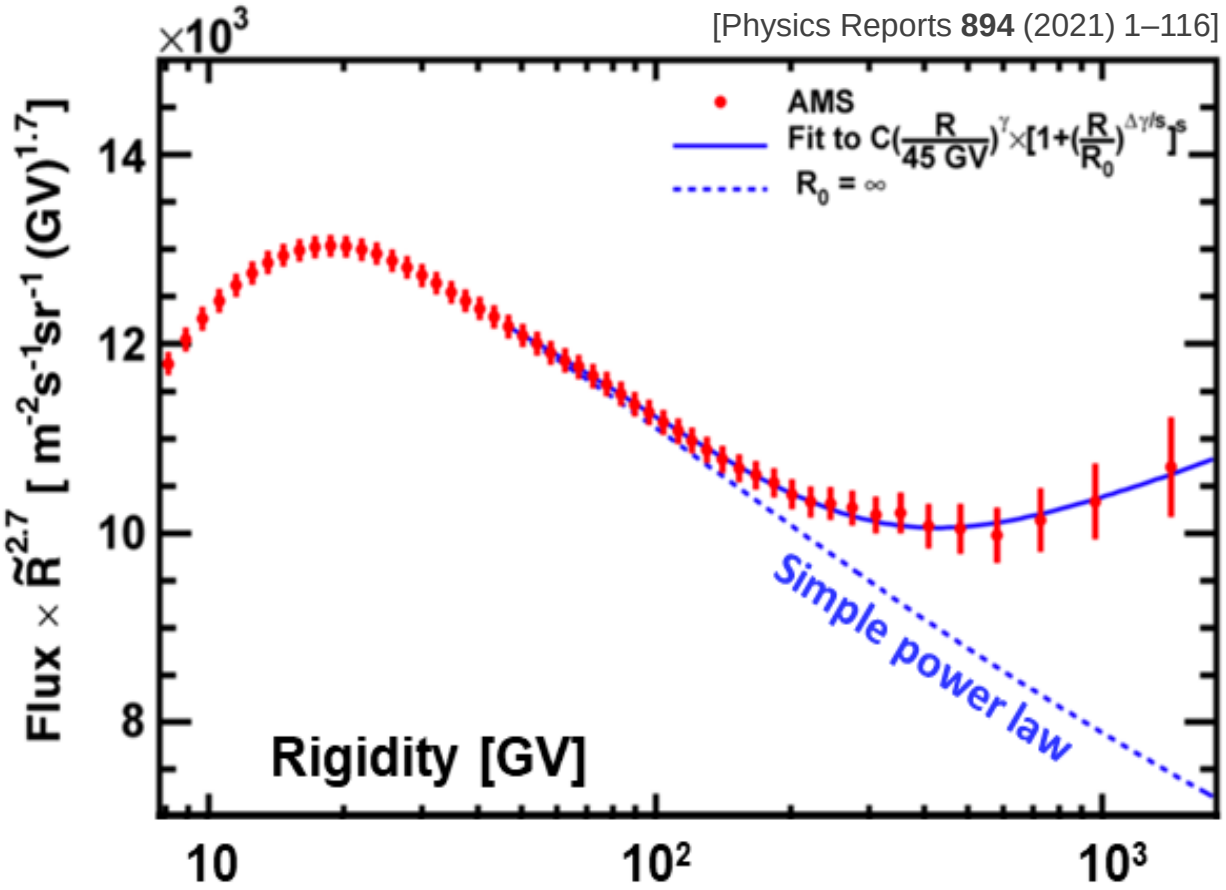


Astrophysical nearby sources of cosmic ray electrons may induce some degree of anisotropy on the measured electron flux

Origin of Cosmic Ray Protons

Proton flux shows a deviation from a single power law above 200 GV

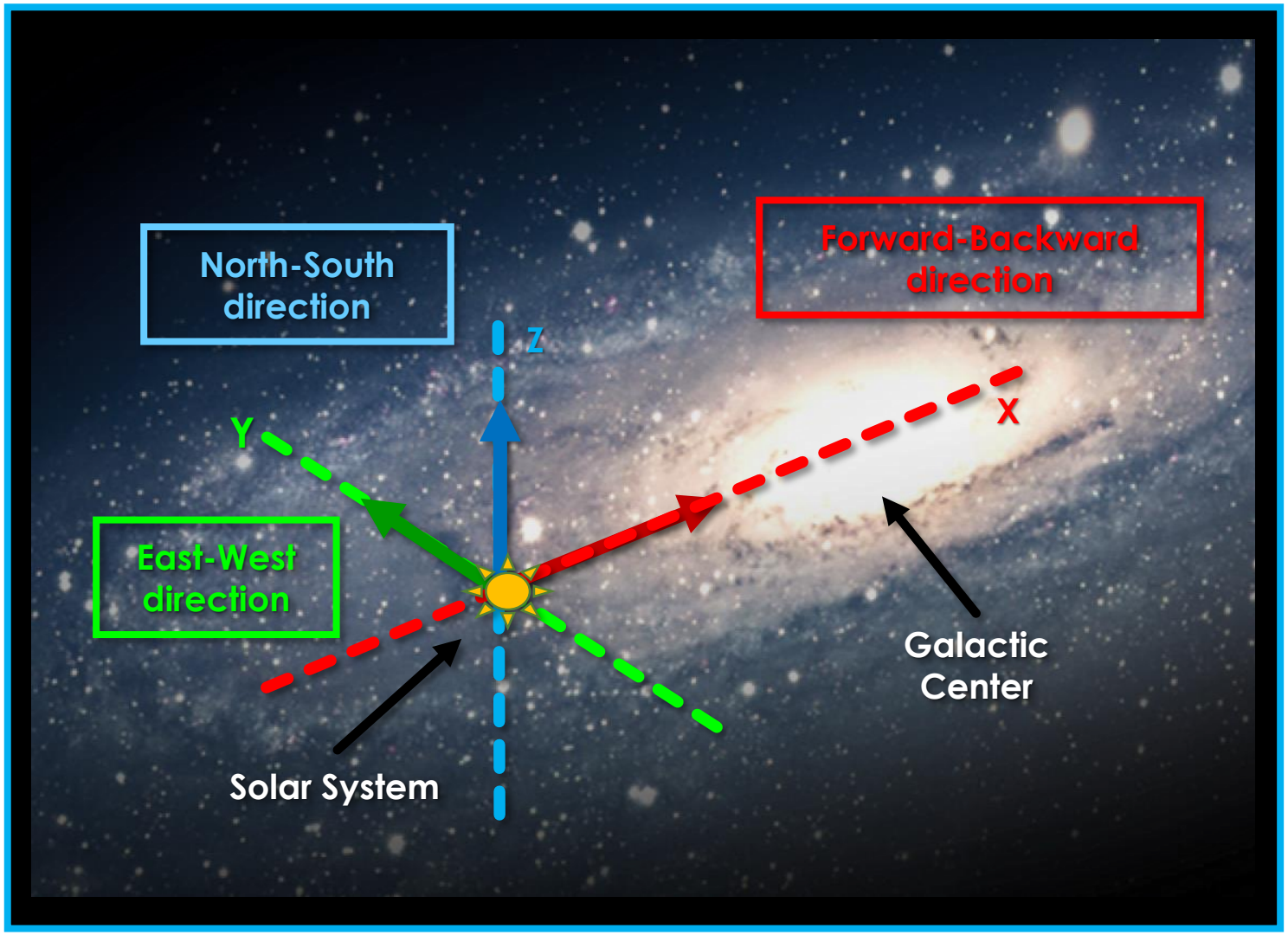
[Physics Reports **894** (2021) 1–116]



Possible explanations are related with propagation effects or local sources of cosmic protons.
The observation of privileged directions in the proton flux may favor the existence of nearby sources.

Galactic Coordinates

Analysis is performed in the Galactic Coordinate System defined as:

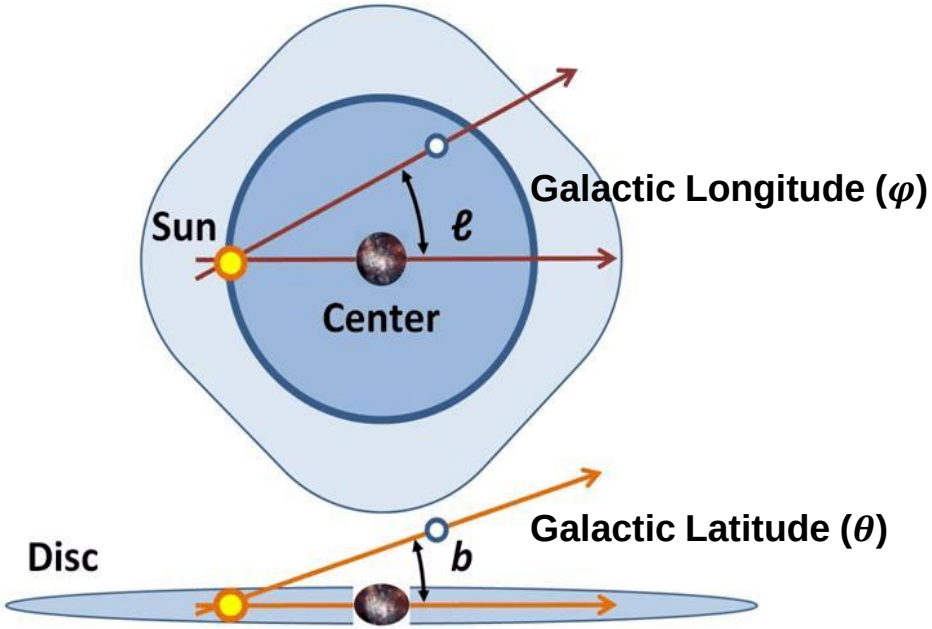


Spherical Harmonic Expansion

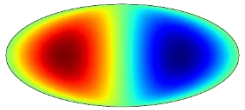
The directional dependence of the CR fluxes is described in terms of a spherical harmonic expansion

At first order ($\ell = 1$) it is described by a dipole:

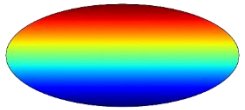
$$\Phi(\theta,\varphi) = \Phi_o(1 + \boldsymbol{\rho_{EW}}\ \sin\theta\sin\varphi + \boldsymbol{\rho_{NS}}\ \cos\theta + \boldsymbol{\rho_{FB}}\ sin\theta cos\varphi)$$



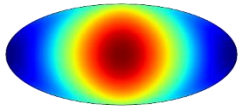
Dipole components



ρ_{EW} East-West



ρ_{NS} North-South



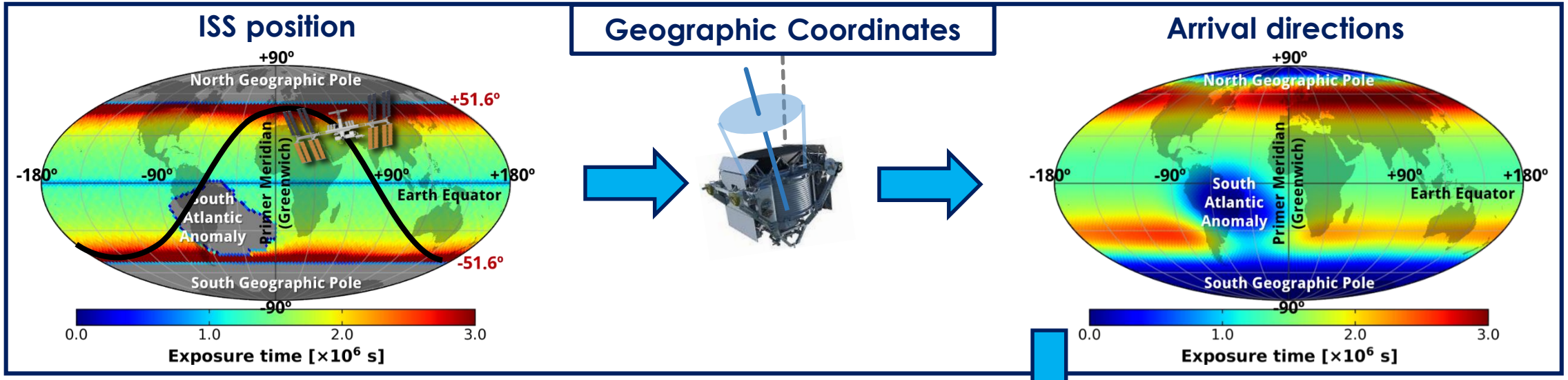
ρ_{FB} Forward-Backward

Dipole amplitude

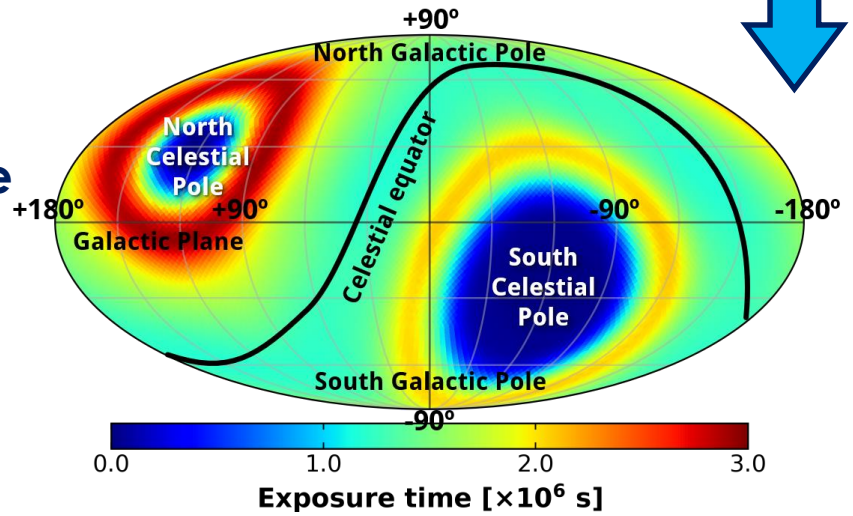
$$\delta^2 = \rho_{EW}^2 + \rho_{NS}^2 + \rho_{FB}^2$$

AMS Sky Coverage

Sky maps are built taking into account the ISS orbit, the inclination with respect to the local zenith and the AMS field of view

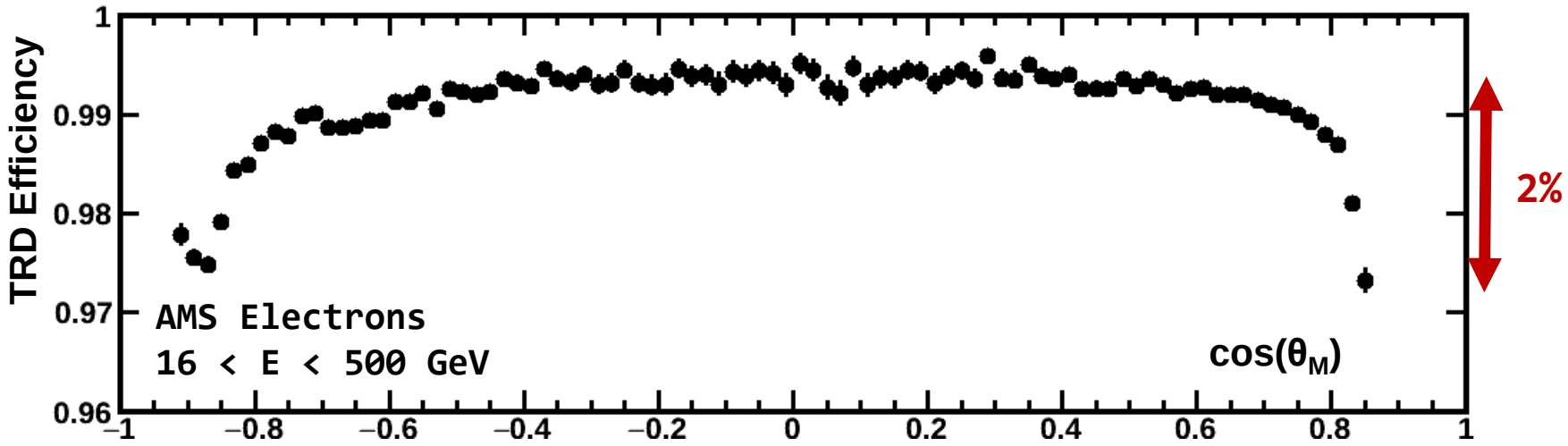


Sky map in Galactic Coordinate System for AMS exposure time

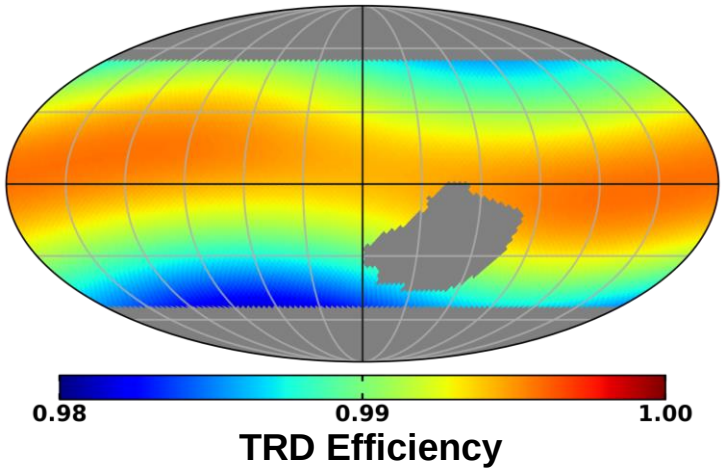


Geographical Dependence of Detector Efficiencies

Computation of isotropic map requires detailed understanding of detector efficiencies at different geographical locations

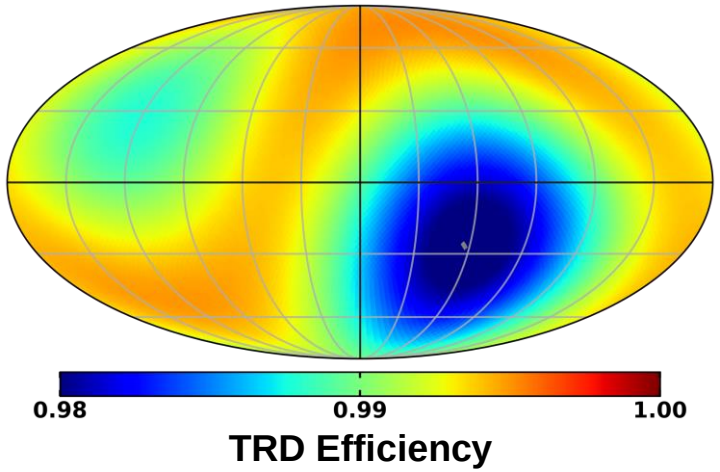


Geographic Coordinates



16 < E < 500 GeV

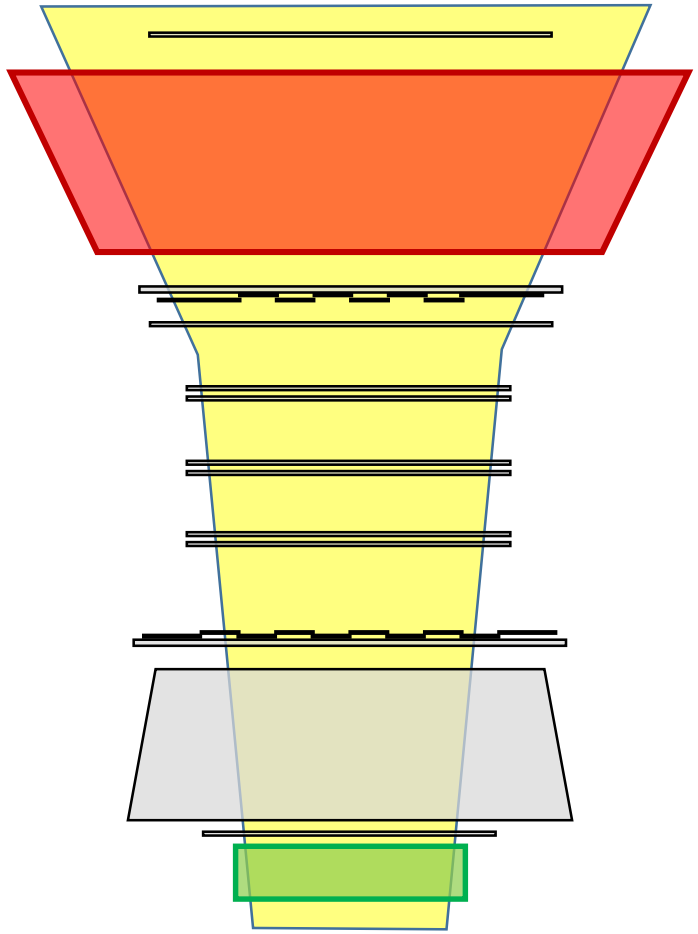
Galactic Coordinates



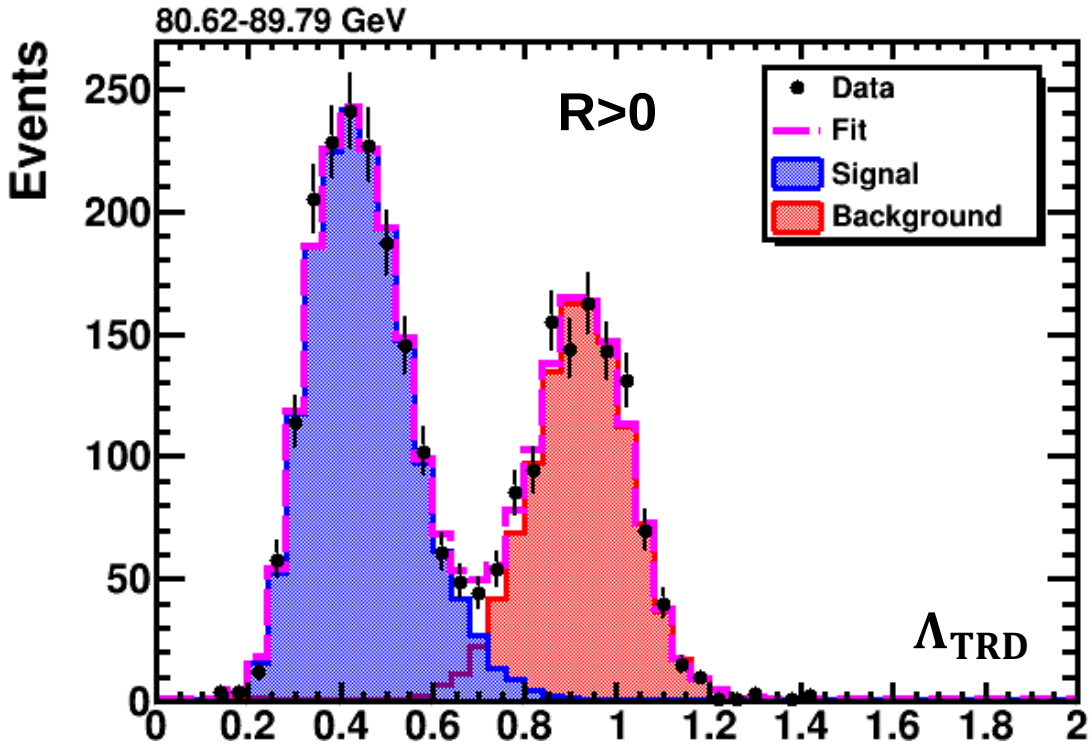
Positron Identification in AMS

Current Analysis

Fiducial Volume: TRD - ECAL



Positrons are separated from protons with a selection based on a cut on the ECAL estimator and a template fit to the TRD response



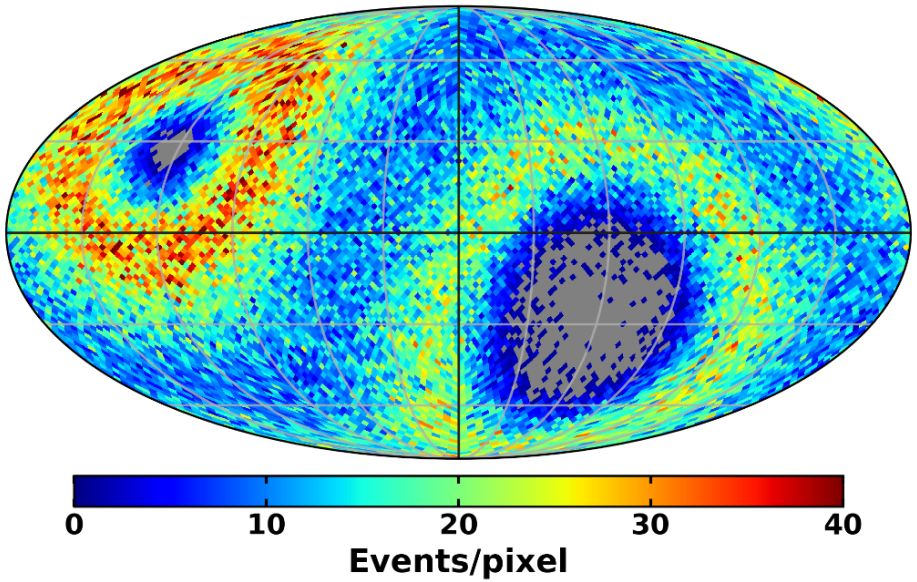
TRD templates obtained from data for both signal (e^+) as for background (p)

Charge confusion (CC) electrons are reduced to percent level by means of a cut on a CC estimator that combines information from TRD, TOF and Tracker

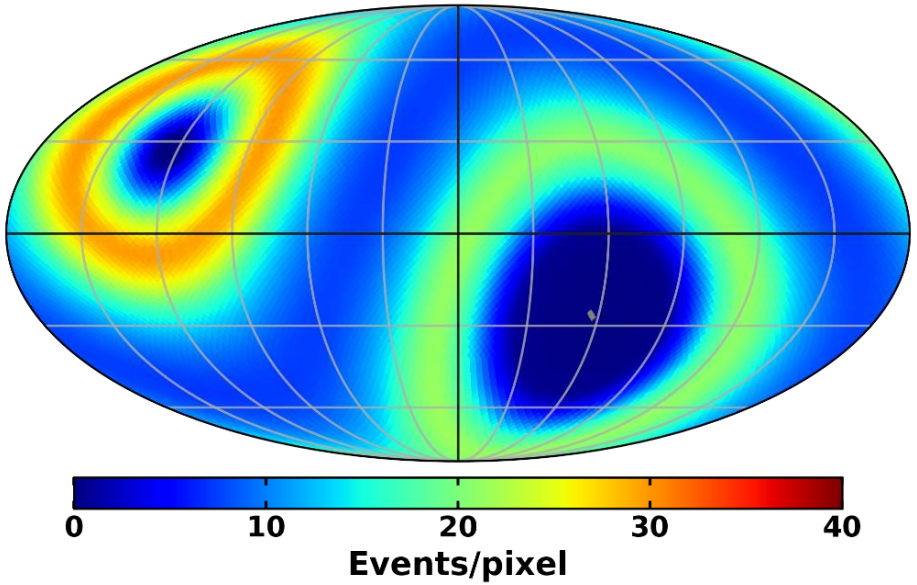
Positron Absolute Anisotropy: Sky Maps

The arrival directions of positrons are compared to the expected map for an isotropic flux in Galactic Coordinates in the range from 16 to 500 GeV

2.5×10^5 positrons (16< E/GeV <500)



Isotropic map
(with exposure time and efficiencies)



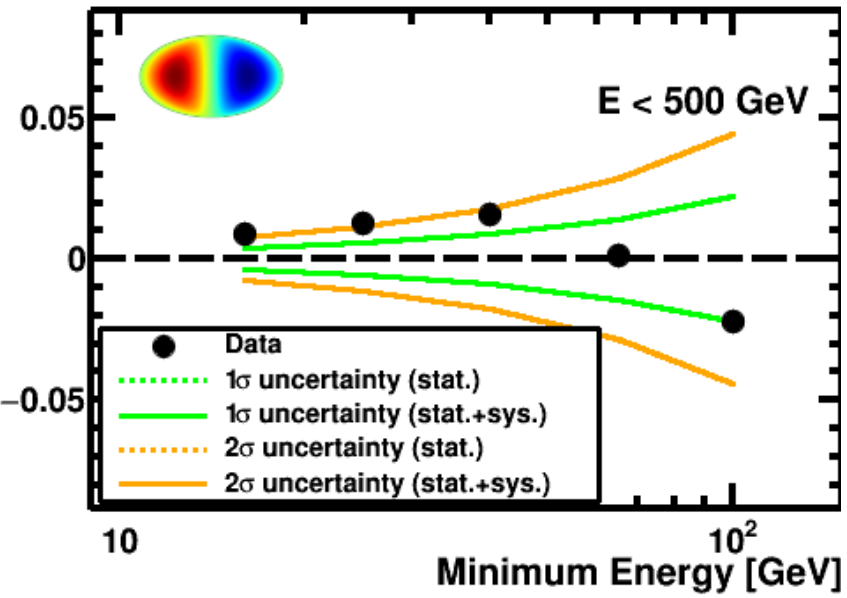
Similar sky maps are built in 5 cumulative energy ranges from 16, 25, 40, 65, 100 up to 500 GeV.

For each energy range, the dipole components are obtained.

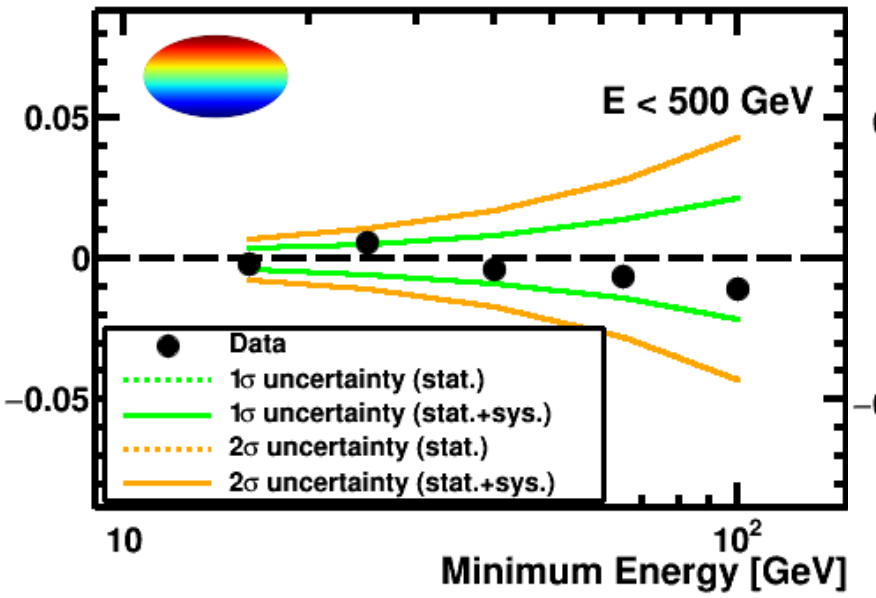
Positron Absolute Anisotropy: Dipole Components

The dipole components of the positron absolute anisotropy in Galactic Coordinates are obtained for each energy range

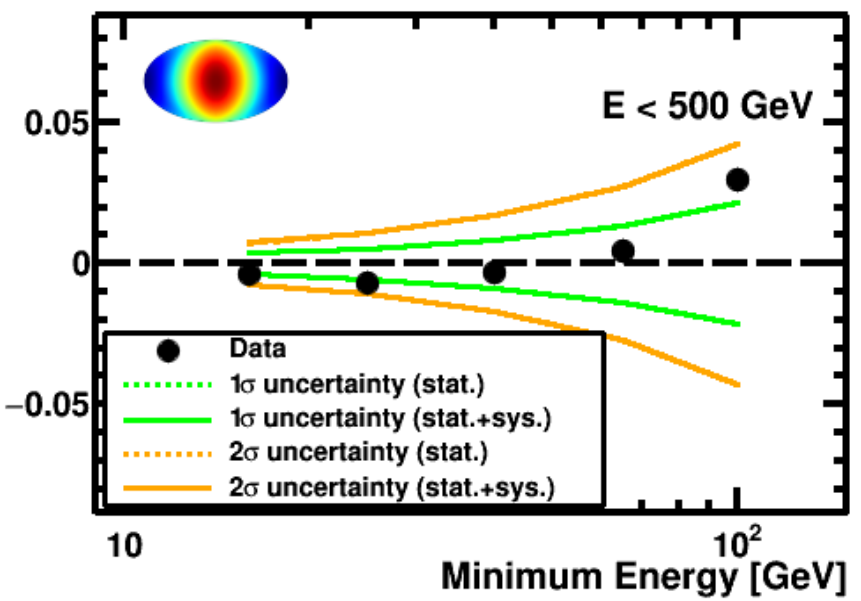
ρ_{EW} East-West



ρ_{NS} North-South



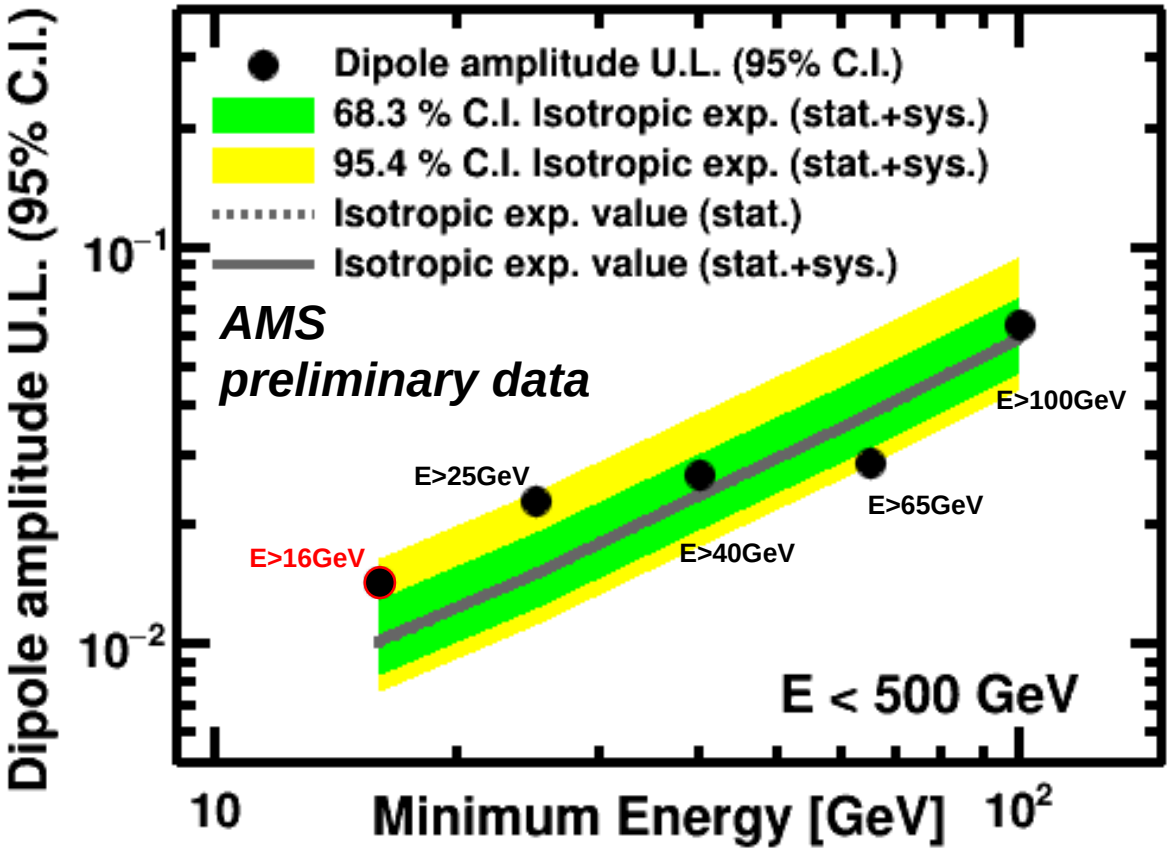
ρ_{FB} Forward-Backward



Results are consistent with isotropy for the three dipole components in all energy ranges

Positron Absolute Anisotropy: Upper Limits

Upper limits to the dipole amplitude are obtained from the measured components.



For the data sample of

2.5×10^5 positrons (16< E/GeV <500)

The upper limit to the positron dipole anisotropy in Galactic Coordinates is

δ <1.44 % at the 95% C.I. for 16< E/GeV <500

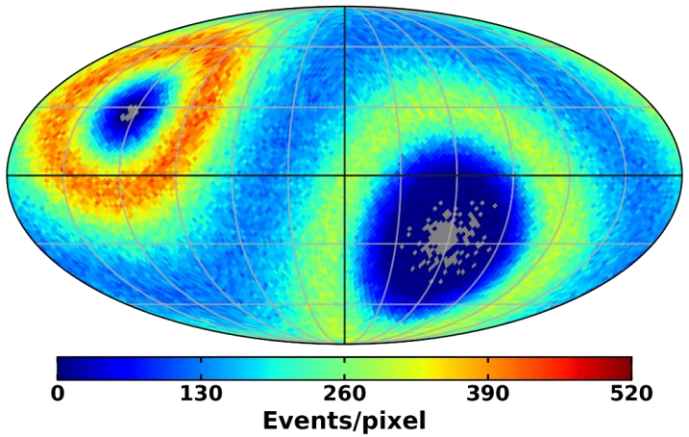
1.02 % Iso. Exp. (stat.+sys.)

The positron analysis is dominated by statistics.
More data will allow to ascertain the origin of cosmic ray positrons.

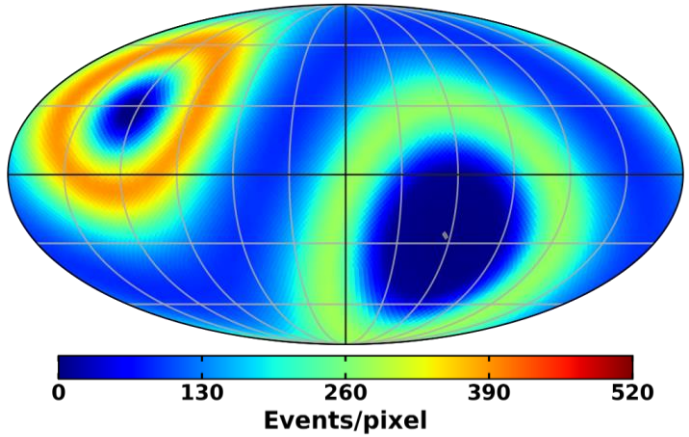
Electron Absolute Anisotropy

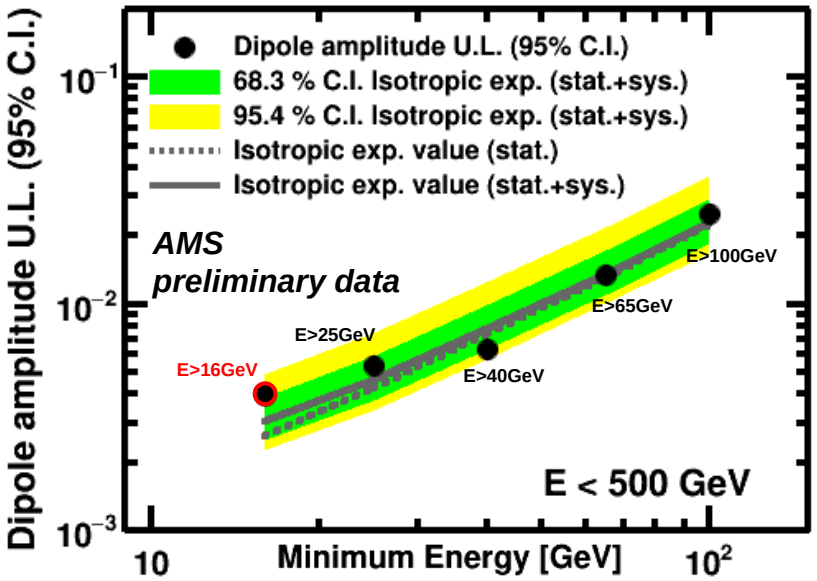
The arrival directions of electrons are compared to the expected map for an isotropic flux in Galactic Coordinates in the range from 16 to 500 GeV

3.4 × 10^6 electrons (16< E/GeV <500)



Isotropic map
(with exposure time and efficiencies)





Results are consistent with isotropy and upper limits to the dipole amplitude are established.

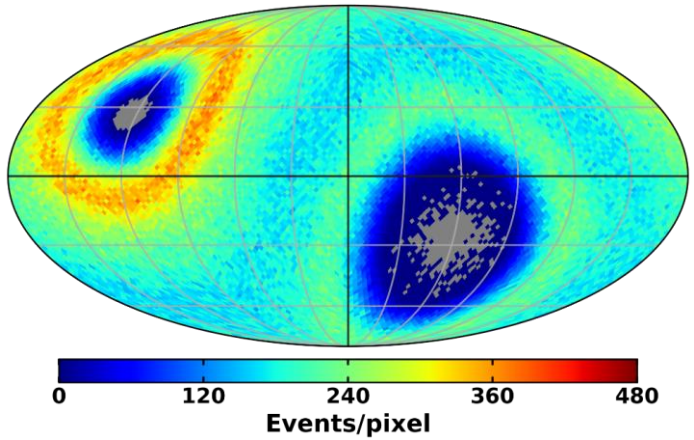
For the sample with E>16 GeV
The upper limit to the electron dipole anisotropy is

δ <0.39 % at the 95% C.I.
for 16< E/GeV <500
0.31 % Iso. Exp. (stat.+sys.)

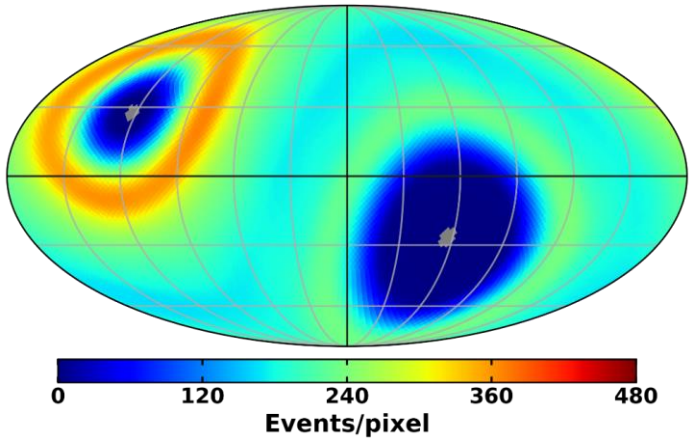
Proton Absolute Anisotropy

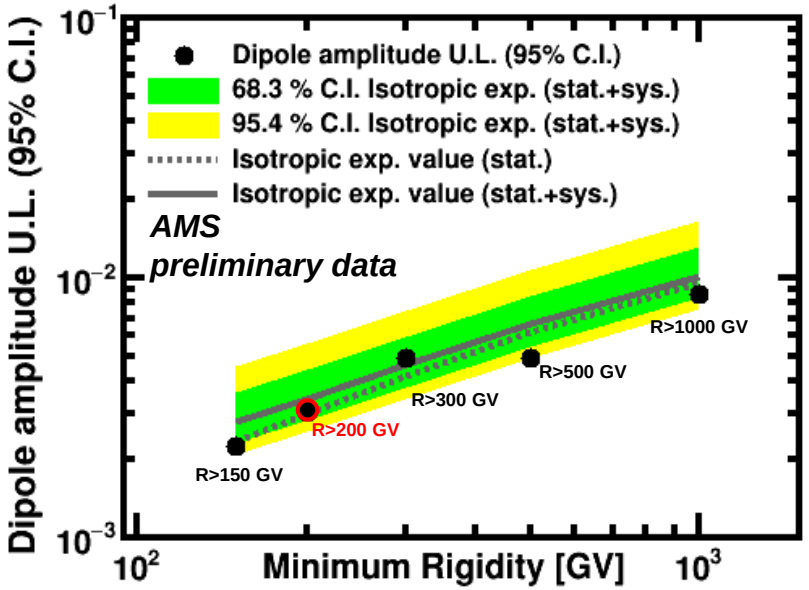
The arrival directions of protons are compared to the expected map for an isotropic flux in Galactic Coordinates for rigidities above 200 GV

2.6 × 10^6 protons (R > 200 GV)



Isotropic map
(with exposure time and efficiencies)





Results are consistent with isotropy and upper limits to the dipole amplitude are established.

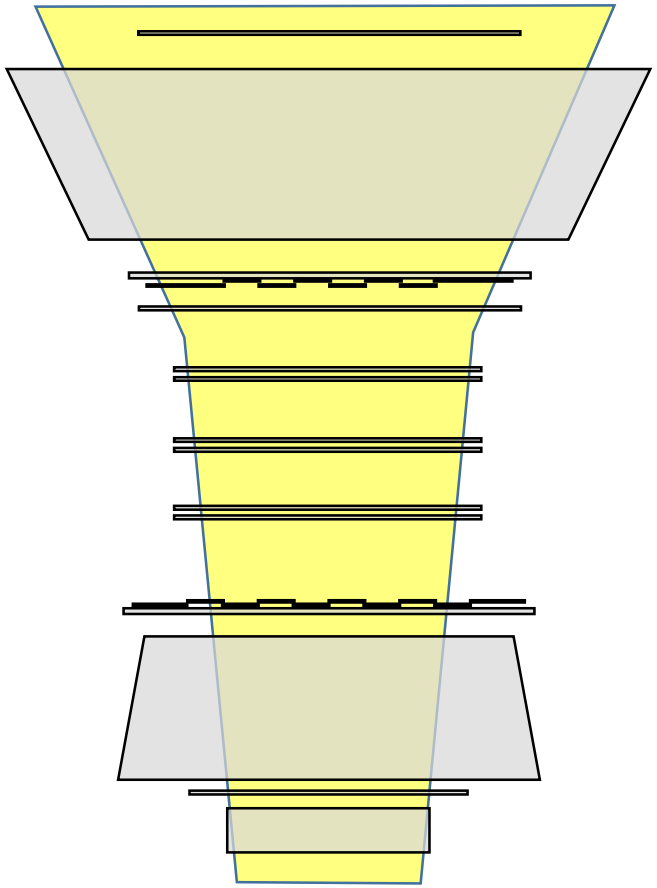
For the sample with R>200 GV
The upper limit to the proton dipole anisotropy is

δ <0.30 % at the 95% C.I.
for R > 200 GV
0.34 % Iso. Exp. (stat.+sys.)

Future Improvements in the e^+ & e^- Anisotropy Analysis

Current Analysis

Fiducial Volume: TRD - ECAL



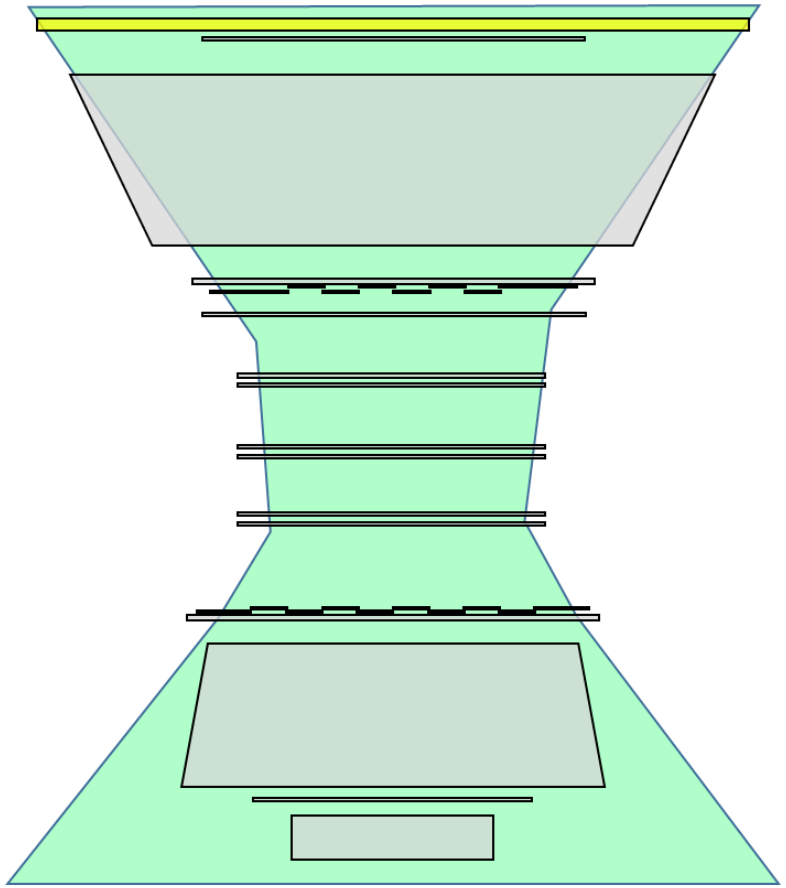
Positrons are separated from protons with a selection based on a cut on the ECAL estimator and a template fit to the TRD response

Positrons and electrons outside ECAL acceptance

Acceptance increases by a factor 3

Future Analysis

Fiducial Volume: TRD + L0



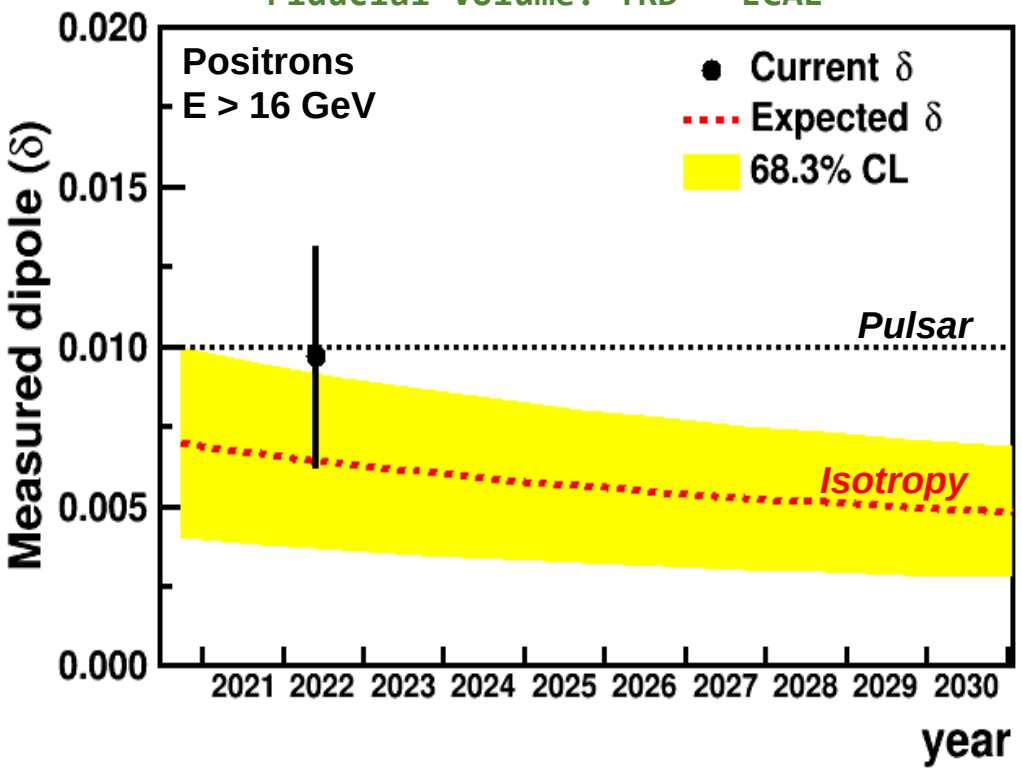
Positrons are separated from protons with a selection based on a template fit to the TRD response

Future Improvements in the e^+ & e^- Anisotropy Analysis

By 2030, the improved analysis with the L0 upgrade will allow AMS to be sensitive to anisotropies below the 1% level, as predicted by pulsar models that reproduce the positron excess

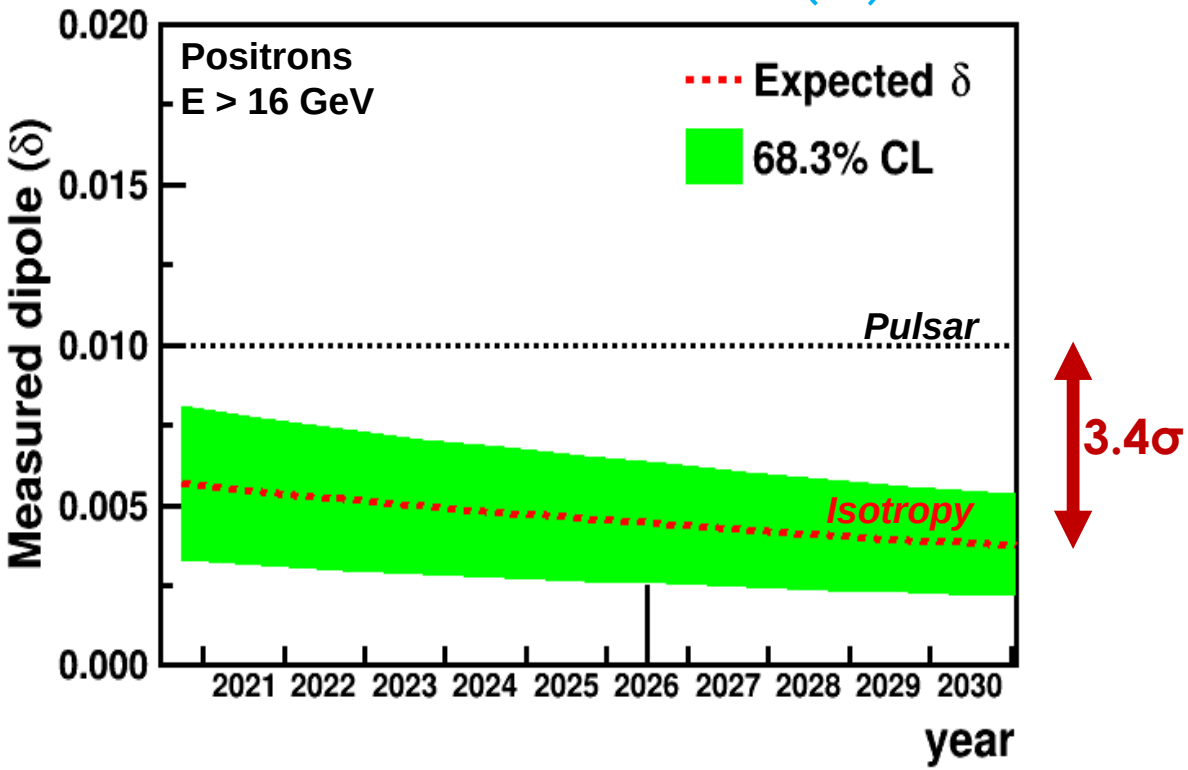
Current Analysis

Fiducial Volume: TRD - ECAL



Future Analysis

Fiducial Volume: TRD + L1 (L0)



Pulsar Model from:
D. Hooper, P. Blasi & P. D. Serpico, JCAP 0901(2009);
K. Ioka, PTP 123-4 (2010) 743

Conclusions

- The analysis of the arrival directions of cosmic rays provide useful information about their origin, which may explain the observed features in their spectra:
  - The positron excess at high energies.
  - The origin of the two power laws in the electron flux.
  - The spectral hardening in the proton flux.

- Measurements of anisotropies of positron, electron and proton fluxes have been performed in galactic coordinates. The three fluxes are compatible with isotropy.

- Upper limits to the dipole amplitudes have been established at 95% C.I.:

$\delta < 1.44\%$ for positrons (16< E/GeV<500)
$\delta < 0.39\%$ for electrons (16< E/GeV<500)
$\delta < 0.30\%$ for protons (R > 200 GV)

- By 2030, AMS sensitivity to 1% level positron dipole anisotropy will constrain the pulsar origin for the positron excess.