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MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

cfp CIEMAT física de partículas

Determination of Anisotropy of Elementary Particles

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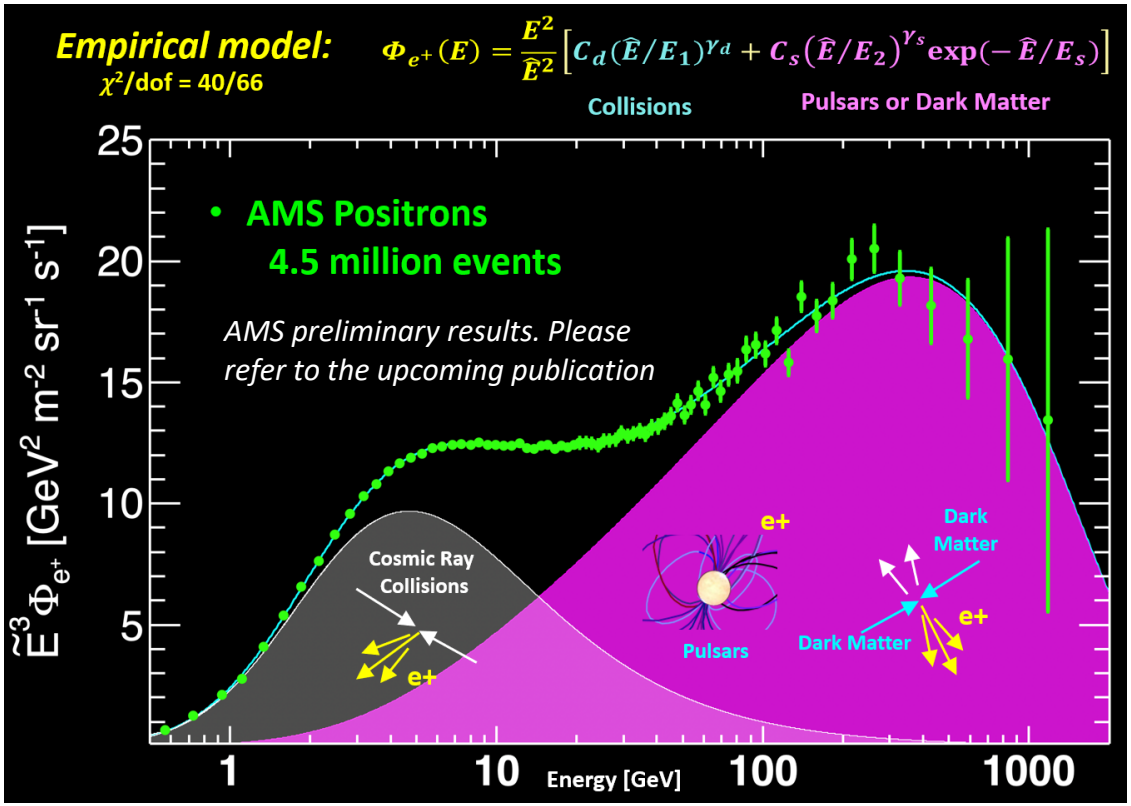
on behalf of the AMS Collaboration

EUROPEAN PHYSICAL SOCIETY
EPS
HEP2025
MARSEILLE

Origin of Cosmic Ray Positrons

See Dr. Dimitrii Krasnopevtsev's talk

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



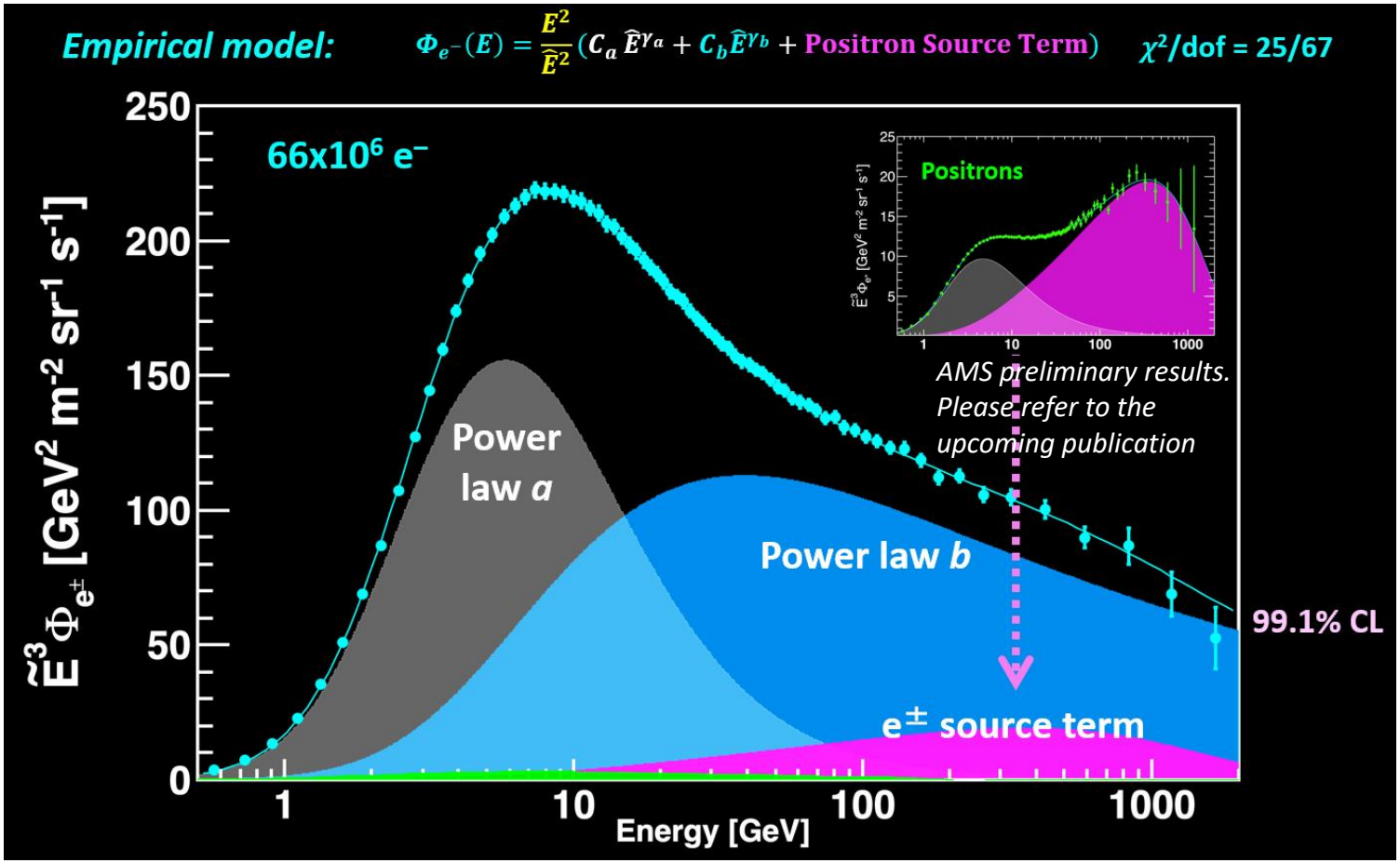
The observation requires the inclusion of primary sources whether from a particle physics or an astrophysical origin

Astrophysical point sources (like pulsars) of cosmic ray positrons may induce some degree of anisotropy on the measured positron flux

Origin of Cosmic Ray Electrons

See Dr. Dimitrii Krasnopevtsev's talk

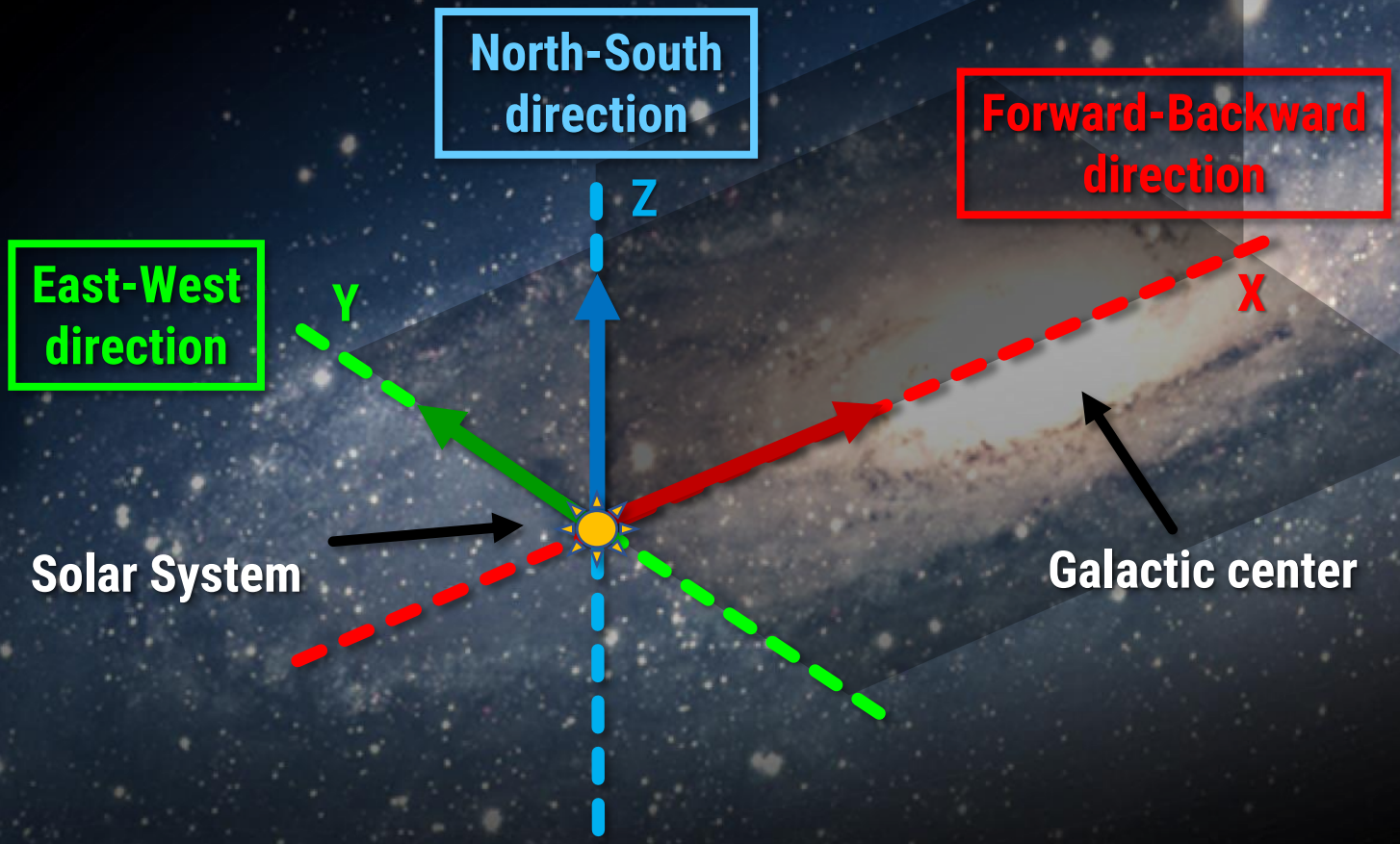
Electron spectrum is best described with a combination of two power laws (*a*, *b*) and a source term like positrons



Astrophysical nearby sources of cosmic ray electrons responsible of power law *b* may induce some degree of anisotropy on the measured electron flux

Analysis of the Anisotropy

Measurement of the cosmic ray fluxes as function of the arrival direction in Galactic Coordinates

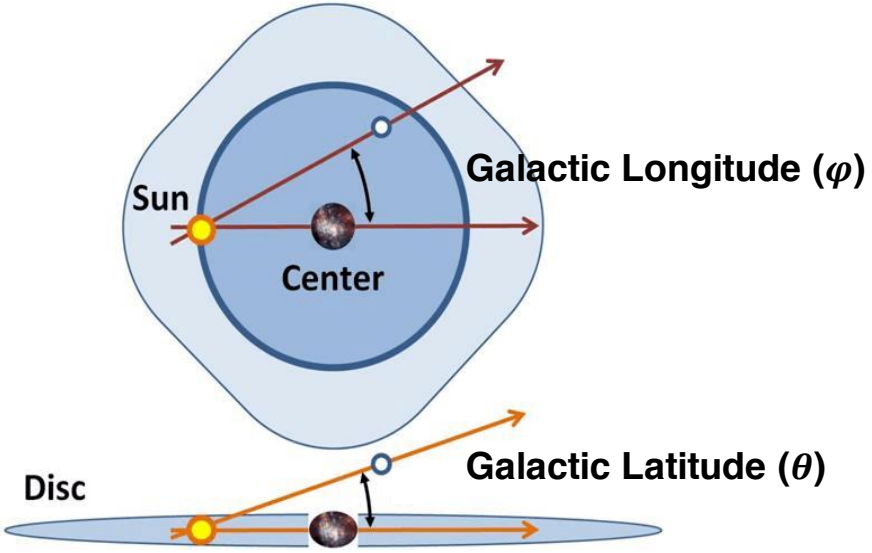


Spherical Harmonic Expansion of CR Fluxes

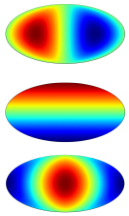
The directional dependence of the CR flux is described in terms of an expansion in spherical harmonics

Dipole anisotropy (ℓ=1)

$$\Phi(\theta,\varphi) = \Phi_0\,(1 + \rho_{\mathrm{EW}}\sin\theta\sin\varphi + \rho_{\mathrm{NS}}\cos\theta + \rho_{\mathrm{FB}}\sin\theta\cos\varphi)$$



Dipole components



ρ_{EW} **East-West**

ρ_{NS} **North-South**

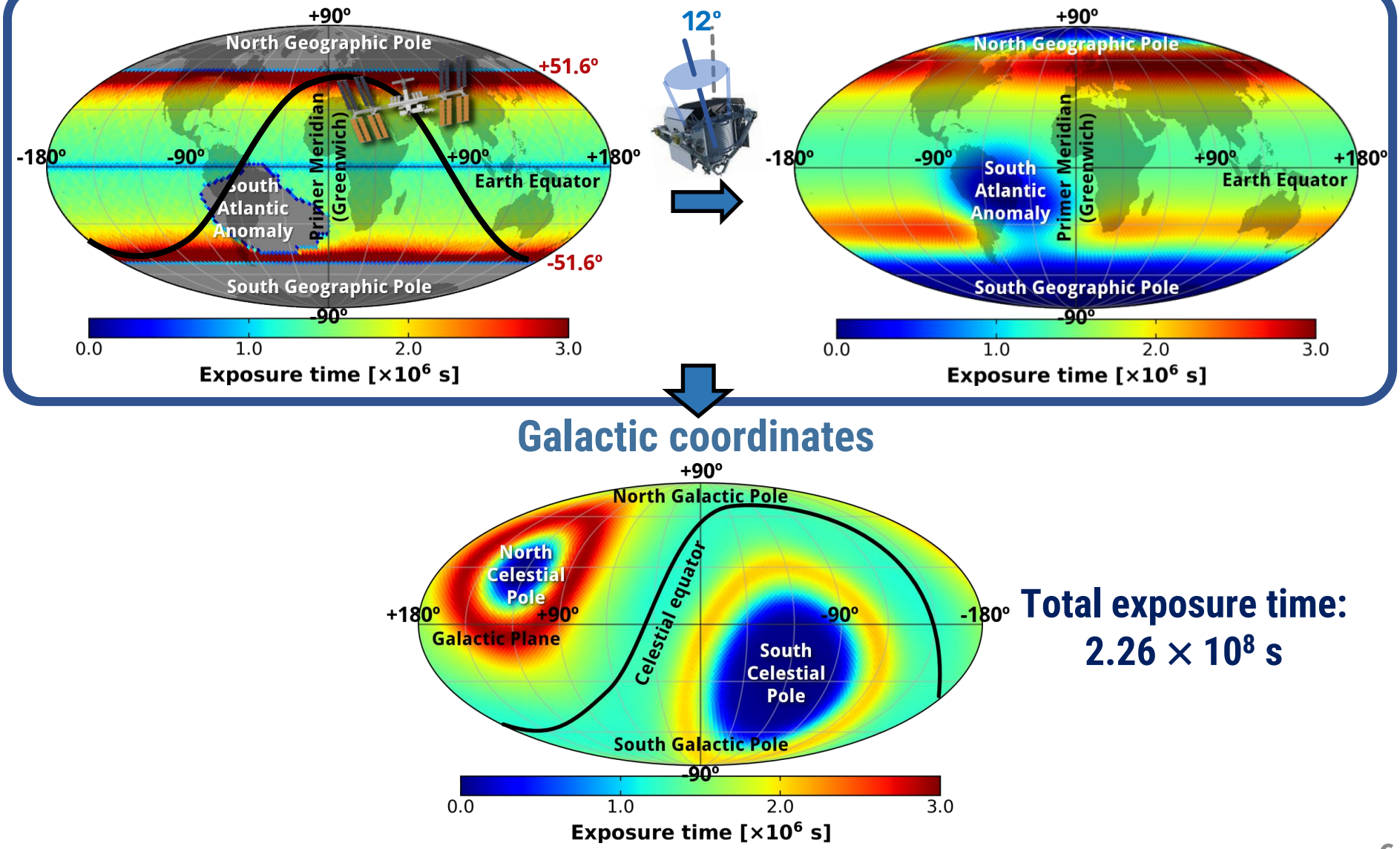
ρ_{FB} **Forward-Backward**

Dipole amplitude

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

AMS Sky Coverage

Position Geographic coordinates **Arrival directions**



Galactic coordinates

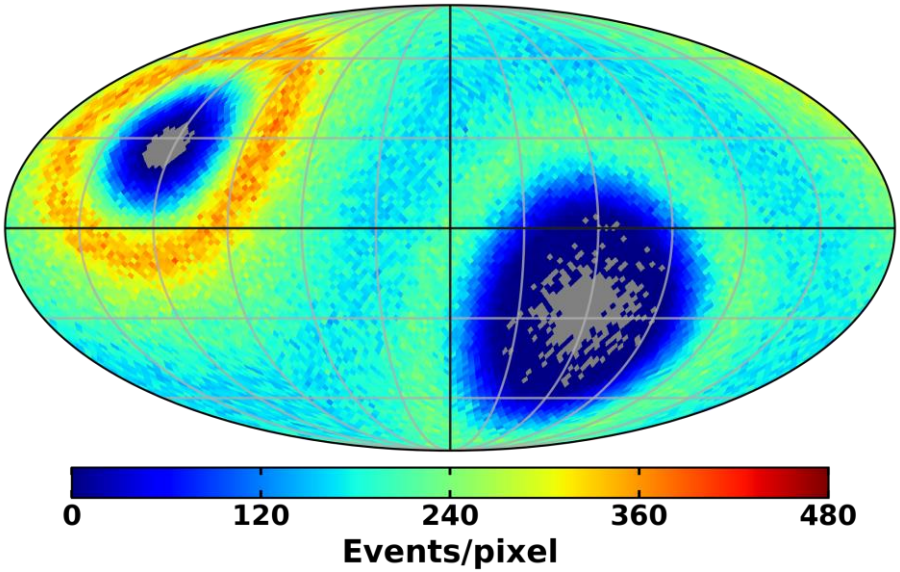
Total exposure time:
2.26×10^8 s

Determination of the Absolute Anisotropy

The absolute anisotropy is determined by comparing the observed map of arrival directions from data with the expected map for an isotropic flux in galactic coordinates

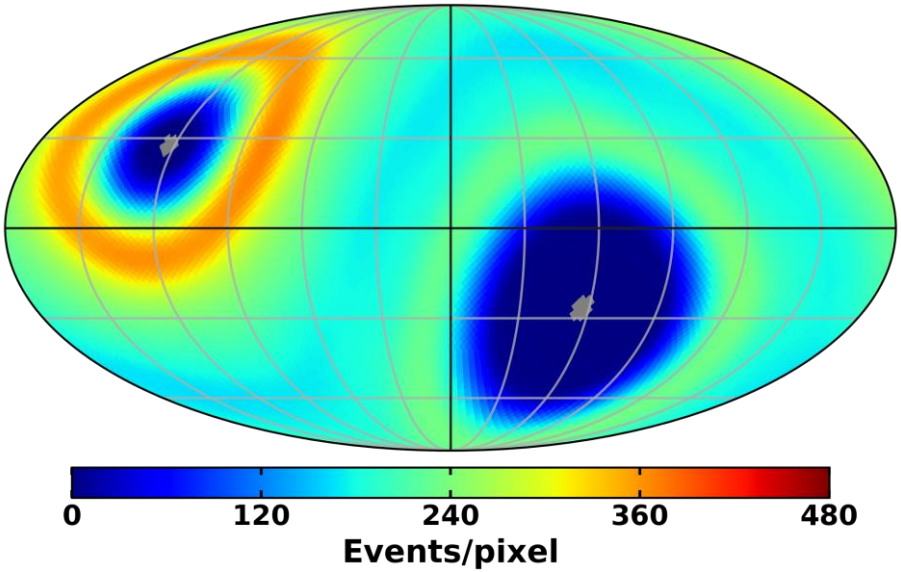
Galactic Coordinates

ISS data



Map of arrival directions of the measured events

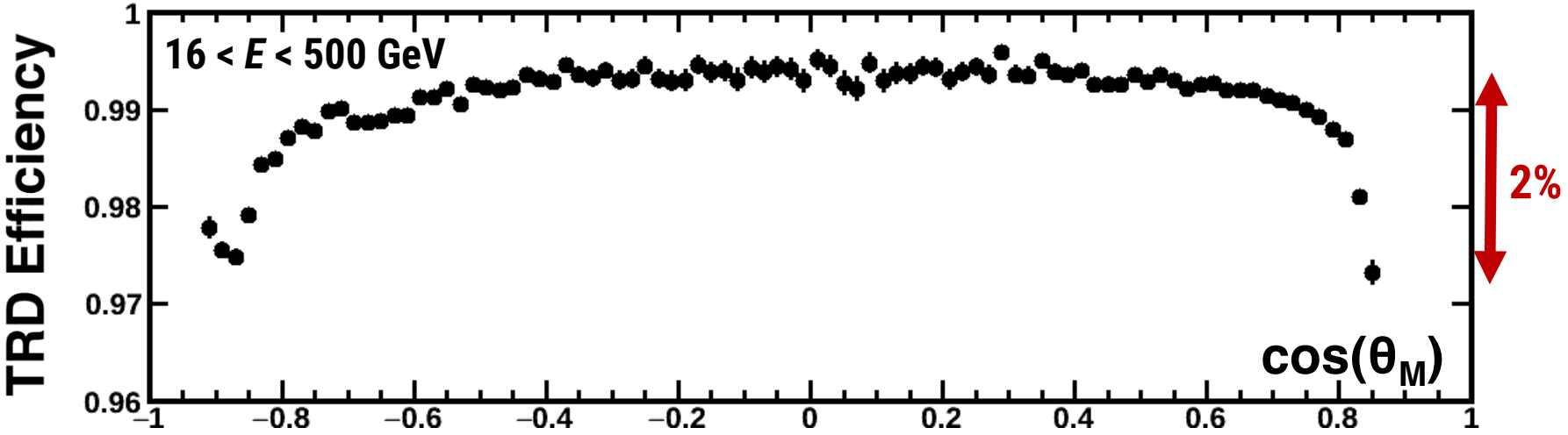
Isotropic map



Expected map of isotropic flux includes the exposure time and detector efficiencies

Absolute Anisotropy: Detector Efficiencies

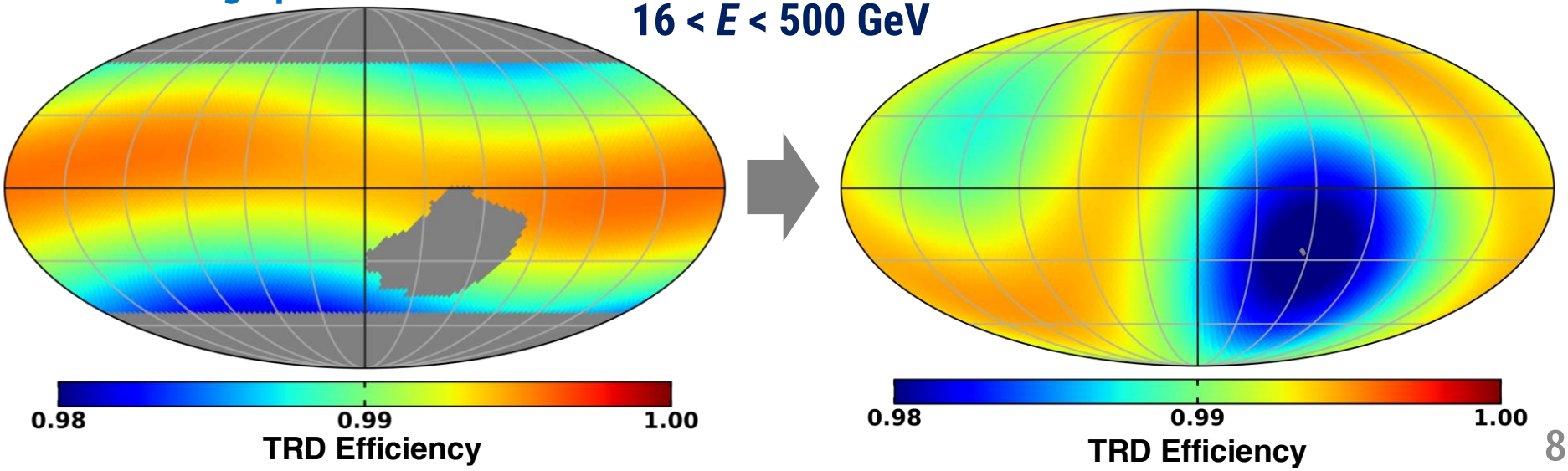
Computation of isotropic map requires detailed understanding of detector efficiencies at different geographical locations



Geographical Coordinates

16 < *E* < 500 GeV

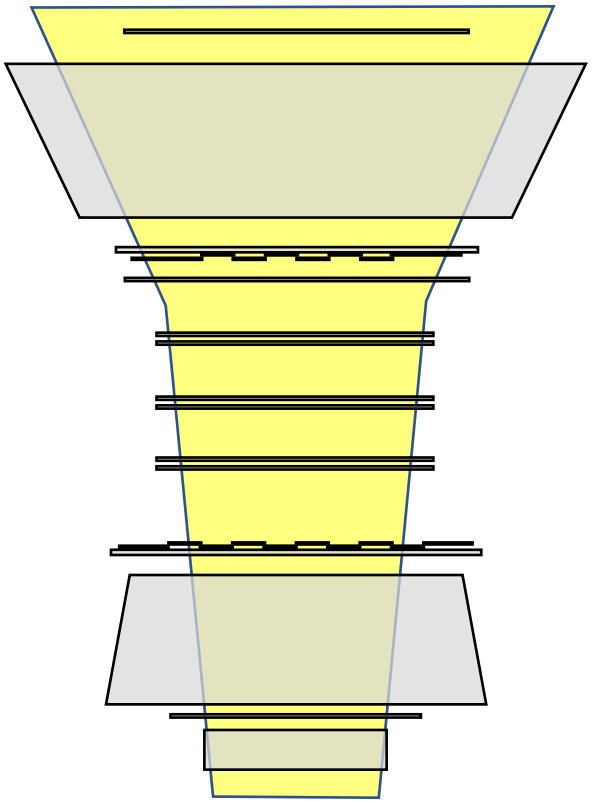
Galactic Coordinates



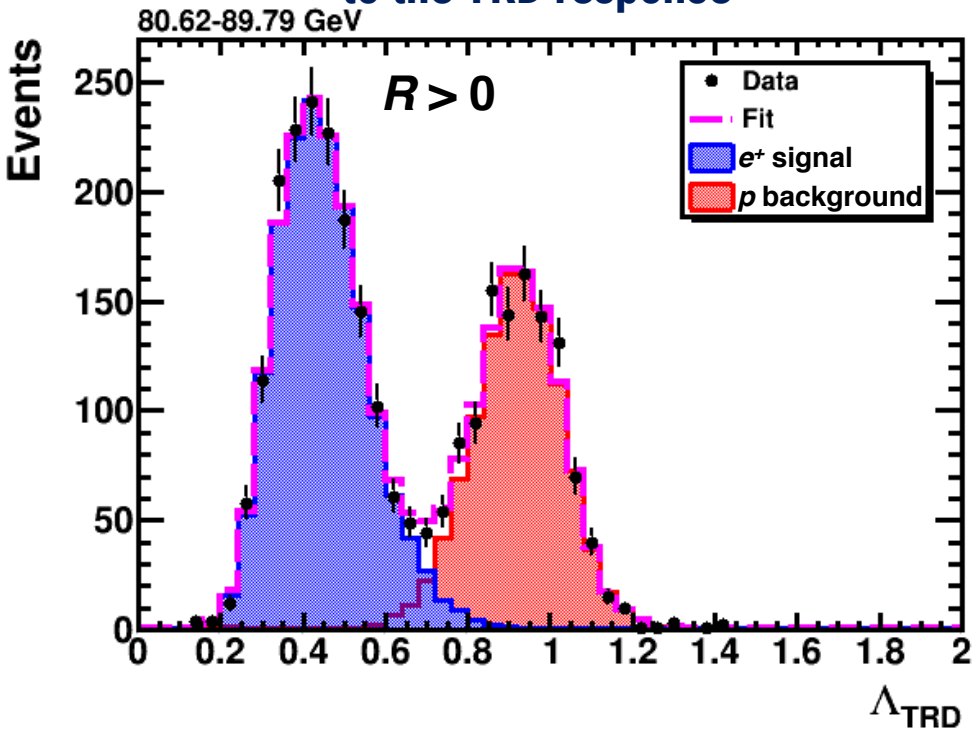
Positron & Electron Anisotropy Analysis

Current Analysis

Fiducial Volume: TRD - ECAL



Positron signal extraction from template fit to the TRD response



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

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

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

Electron Anisotropy

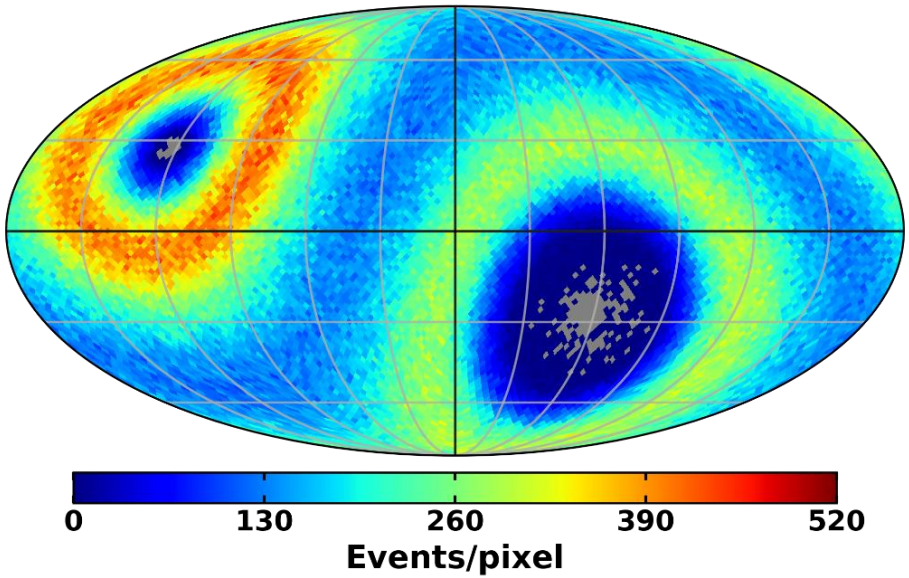
Selected events are grouped into 5 cumulative energy ranges:
***E* > 16, 25, 40, 65, and 100 GeV**

The arrival directions of electrons events are compared to the expected map for an isotropic flux in galactic coordinates

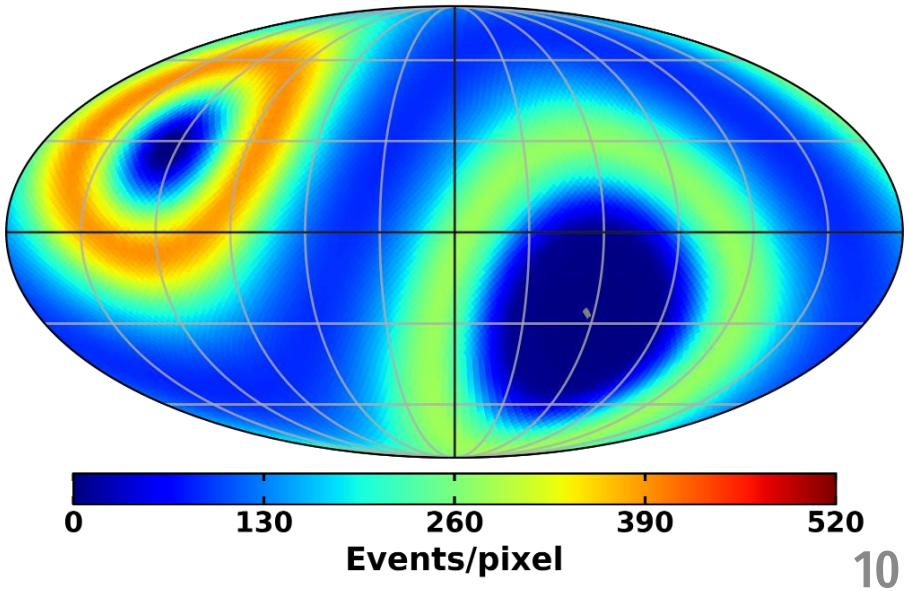
16 < *E*/GeV < 500
Galactic coordinates

Allows to investigate the origin of power law b in the electron flux

3.4×10^6 electrons



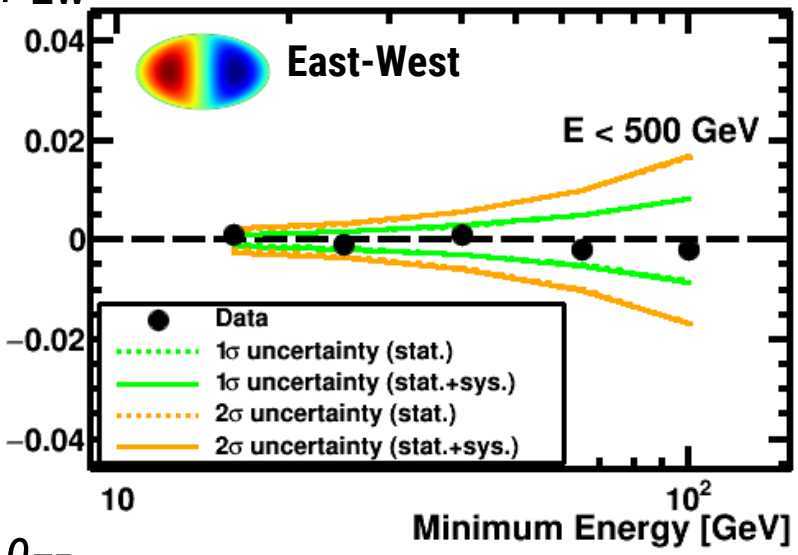
Isotropic map



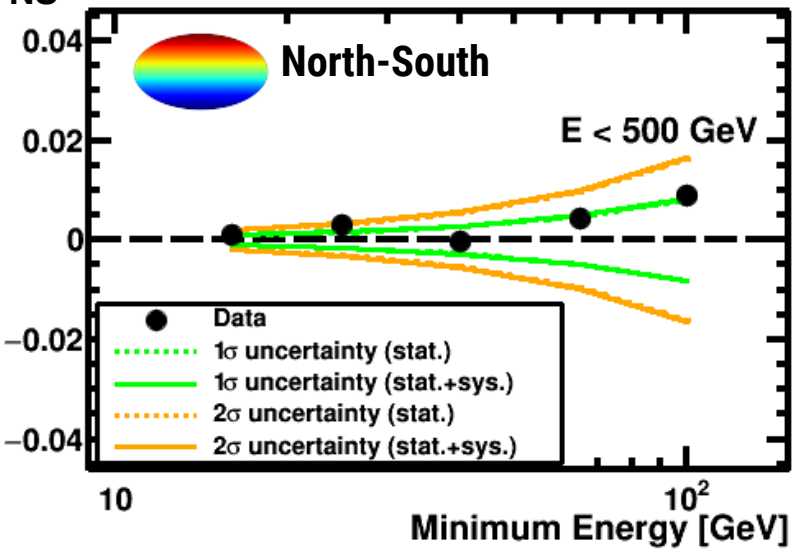
Electron Anisotropy: Dipole Components

Galactic Coordinates

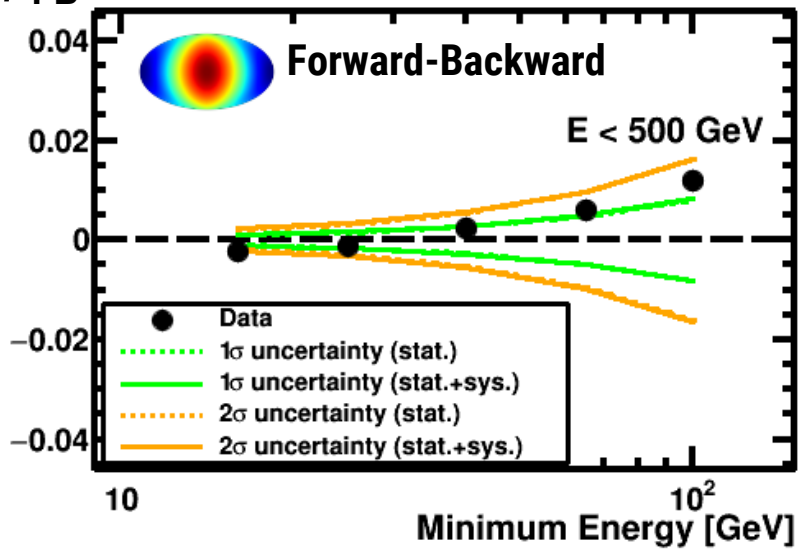
ρ_{EW}



ρ_{NS}



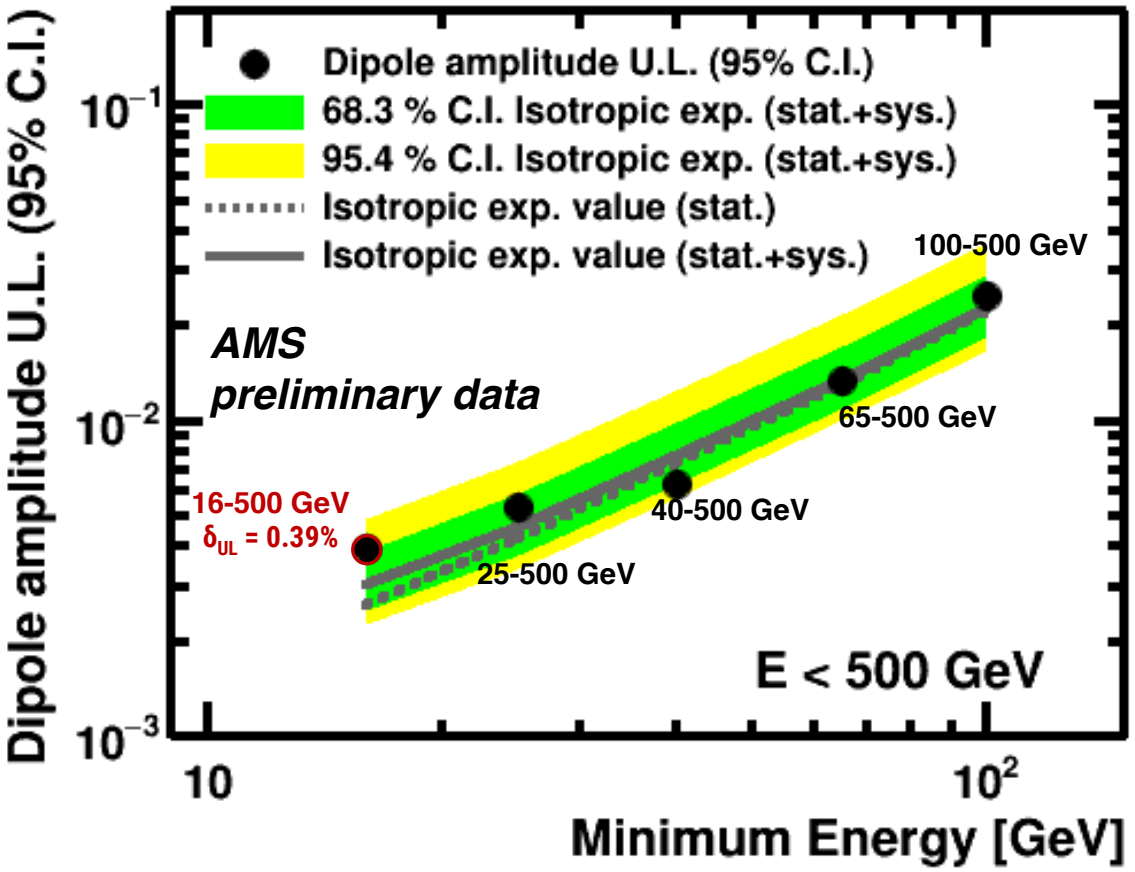
ρ_{FB}



Results consistent with isotropy in all the dipole components and energy ranges

ELECTRON ANISOTROPY: UPPER LIMITS

Upper limits to the electron dipole anisotropy in galactic coordinates



3.4×10^6 electron events
$16 < E/\text{GeV} < 500$

$\delta < 0.39\%$ at the 95% C.I.
for $16 < E/\text{GeV} < 500$
0.31% Iso. Exp. (stat.+sys.)

Positron Anisotropy

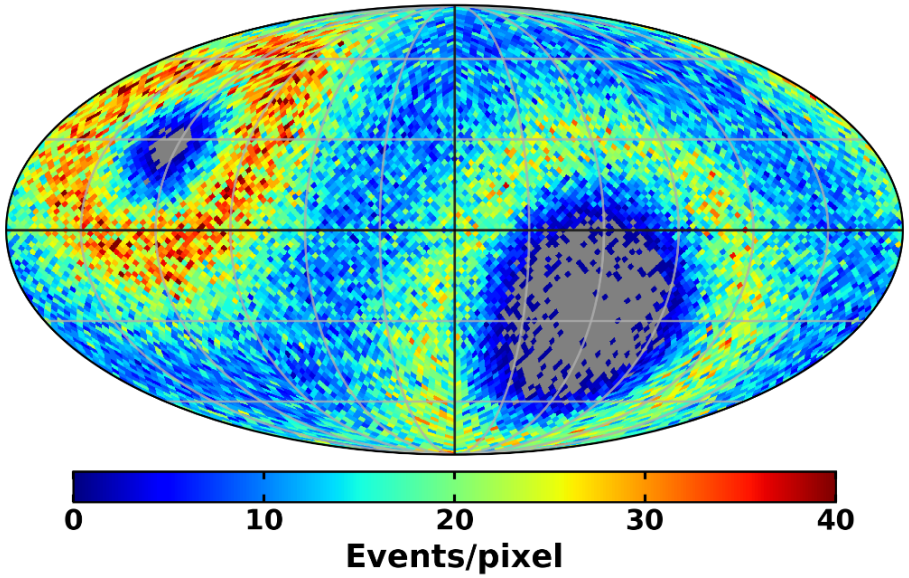
Selected events are grouped into 5 cumulative energy ranges:
E **> 16, 25, 40, 65, and 100 GeV**

The arrival directions of positrons events are compared to the expected map for an isotropic flux in galactic coordinates

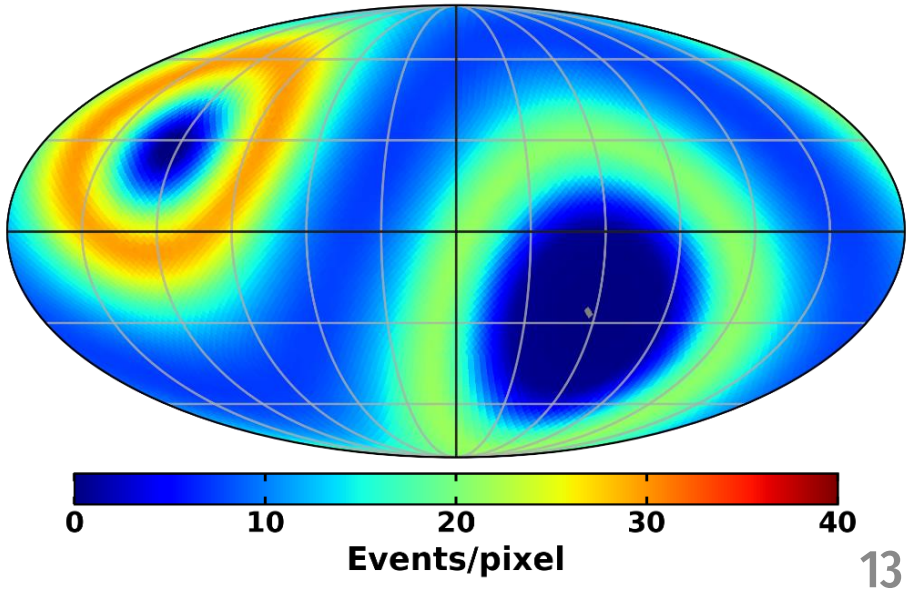
16 < *E*/GeV < 500
Galactic coordinates

Allows to investigate the origin of the positron source term

2.5×10^5 positrons



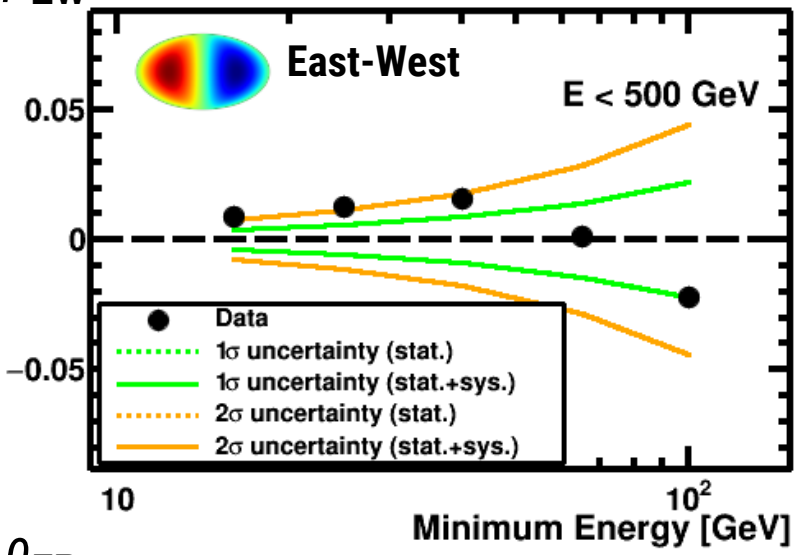
Isotropic map



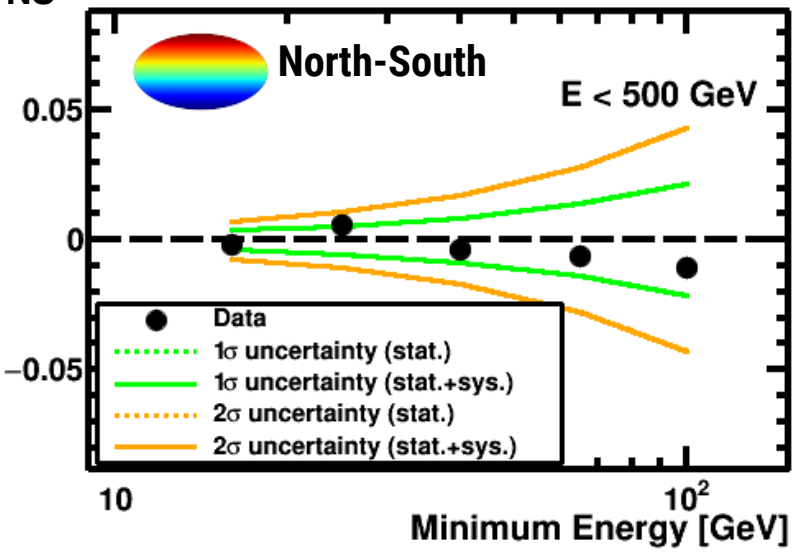
Positron Anisotropy: Dipole Components

Galactic Coordinates

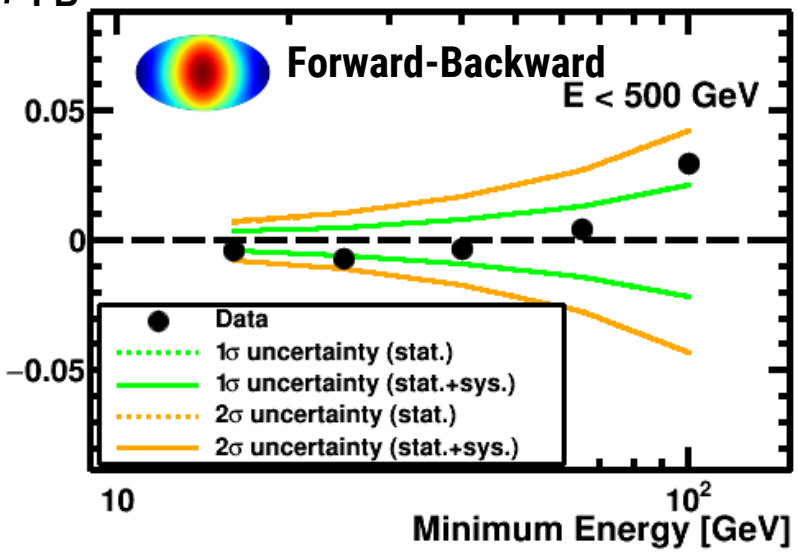
ρ_{EW}



ρ_{NS}



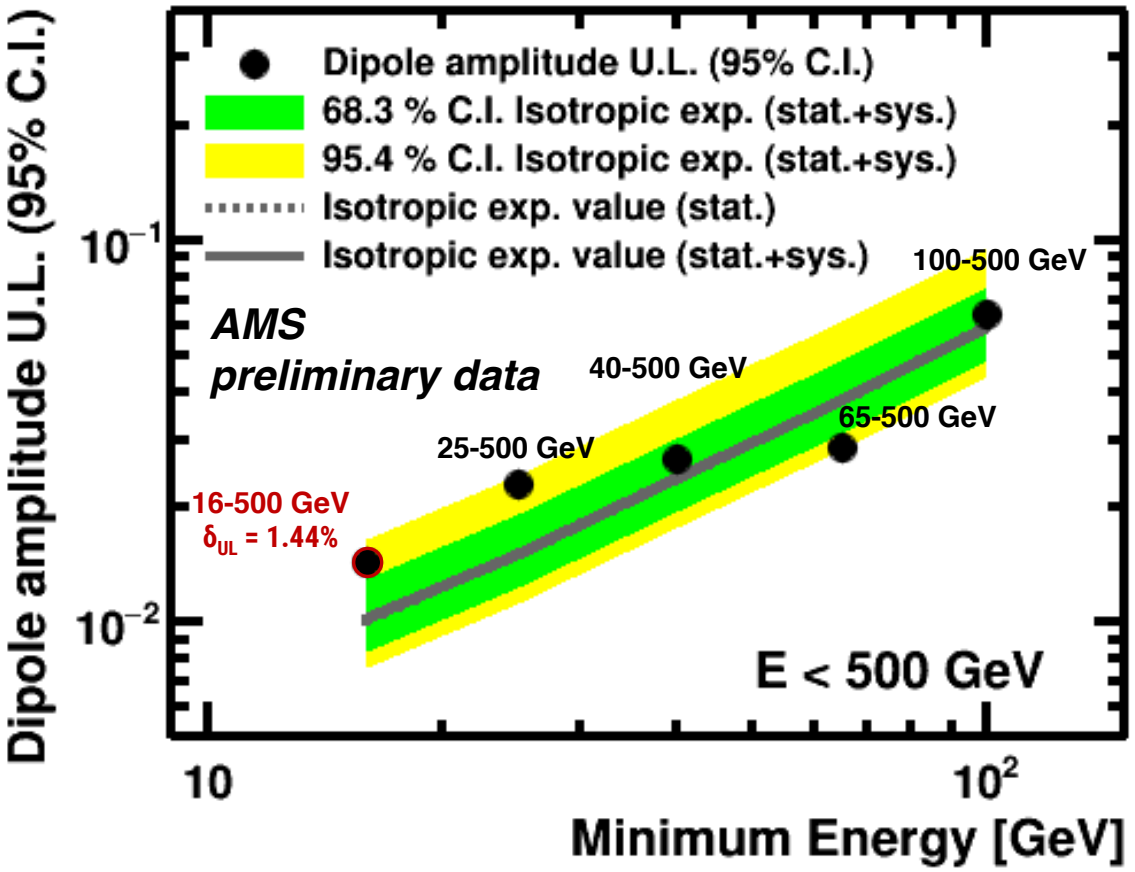
ρ_{FB}



Results consistent with isotropy in all the dipole components and energy ranges

Positron Anisotropy: Upper Limits

Upper limits to the positron dipole anisotropy in galactic coordinates



2.5×10^5 positron events
$16 < E/\text{GeV} < 500$

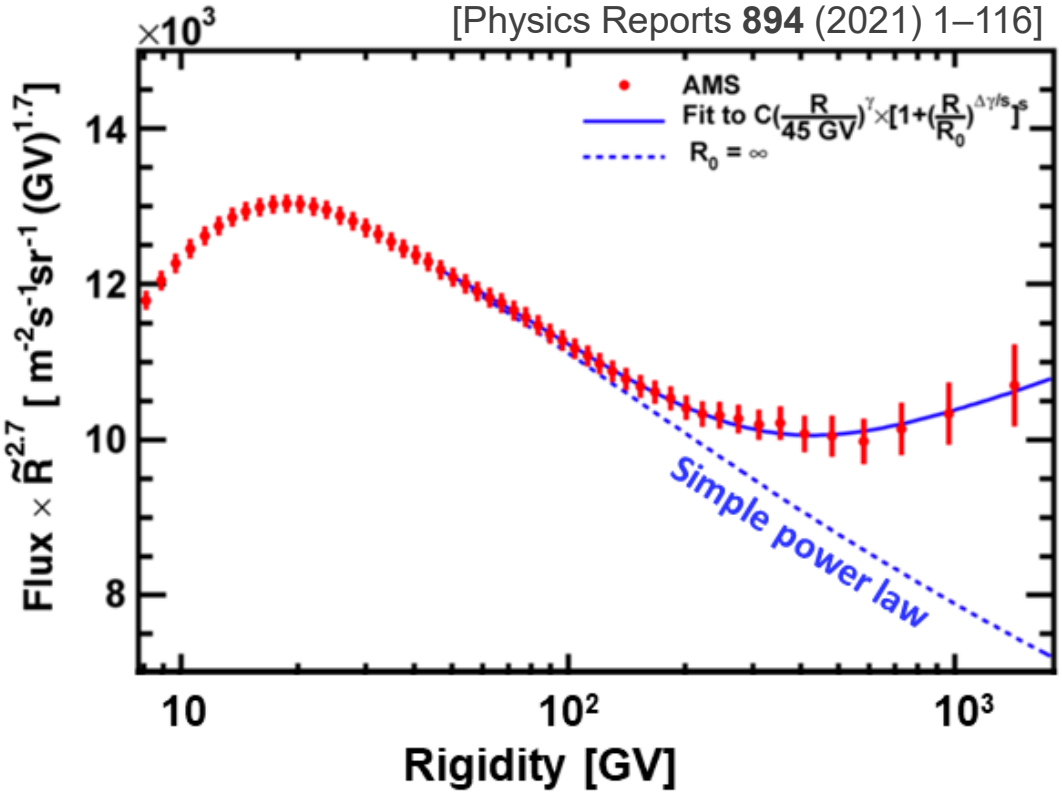
$\delta < 1.44\%$ at the 95% C.I.
for $16 < E/\text{GeV} < 500$
1.02% Iso. Exp. (stat.+sys.)

Analysis dominated by statistics
More data will allow to ascertain the origin of cosmic ray positrons

Origin of the Proton Flux Deviation

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

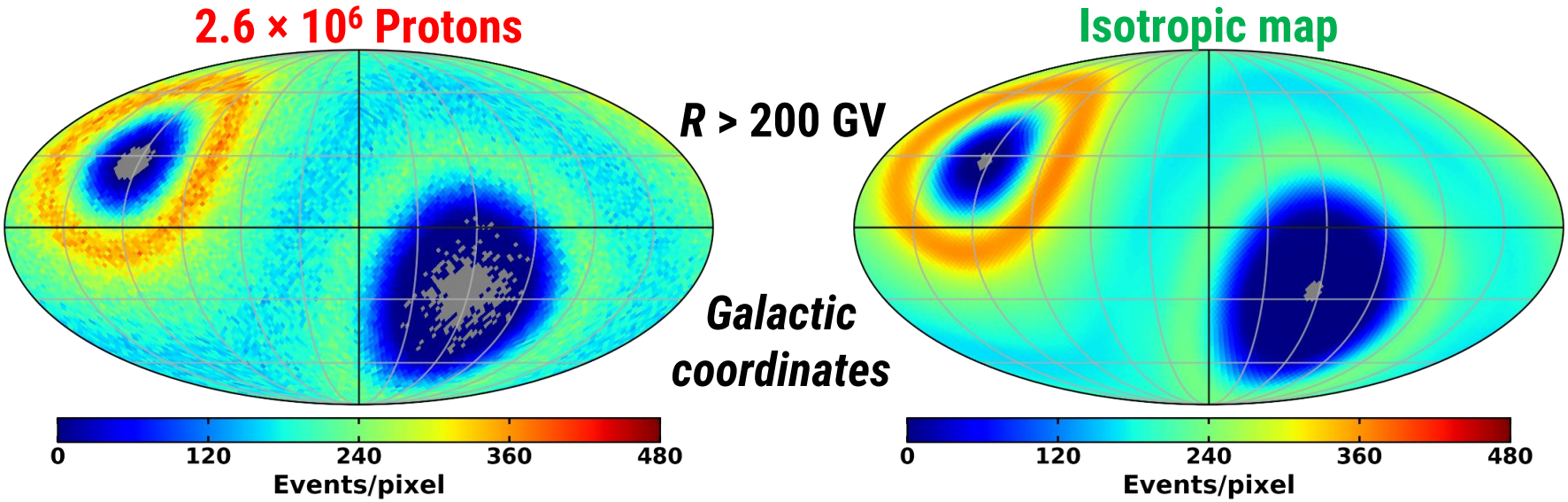
[Physics Reports **894** (2021) 1–116]

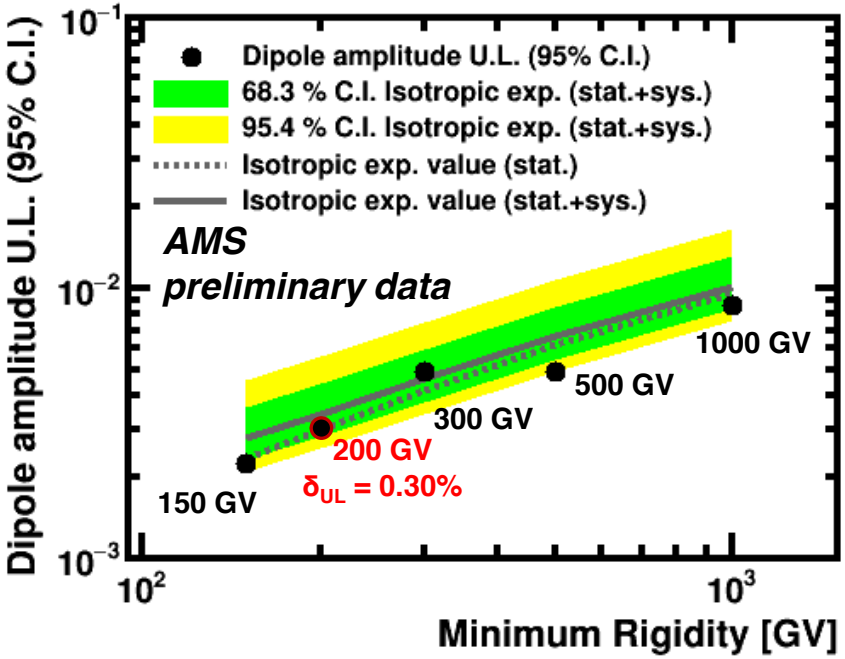


This observation may require modification of cosmic ray transport models or the inclusion of local sources of high rigidity events

A nearby source of cosmic ray protons may induce some degree of anisotropy in the high rigidity sample

Proton Anisotropy



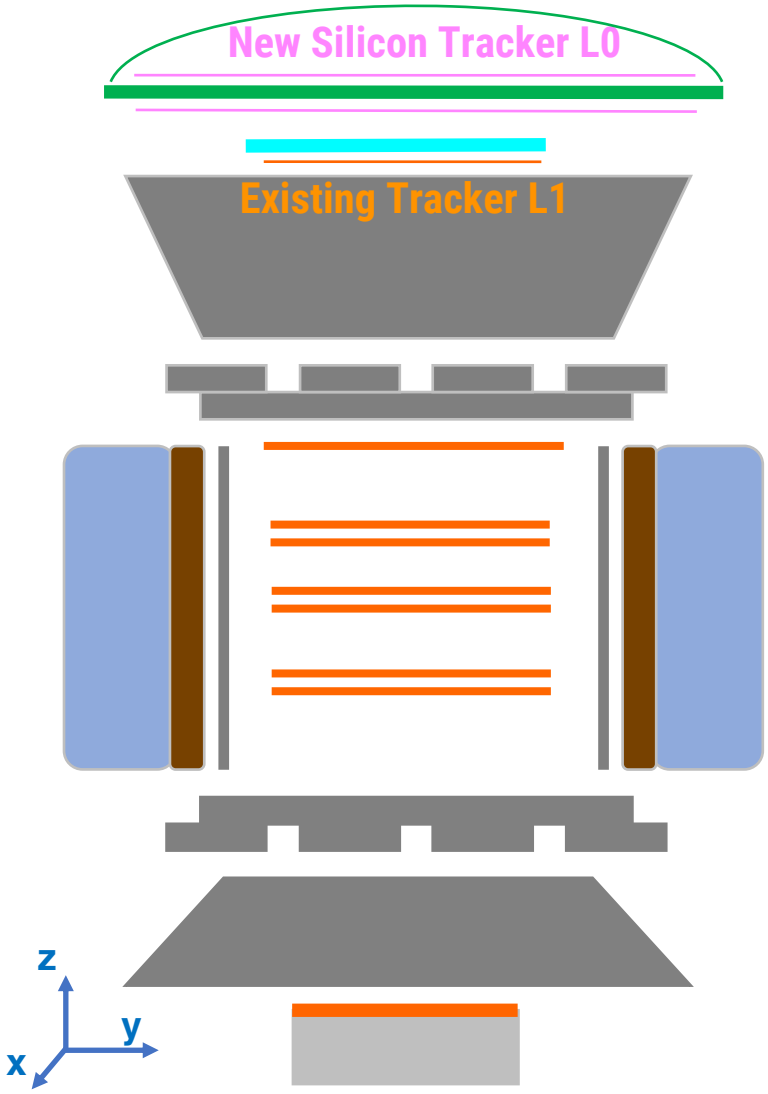


Results are consistent with isotropy and upper limit to the dipole amplitude is established

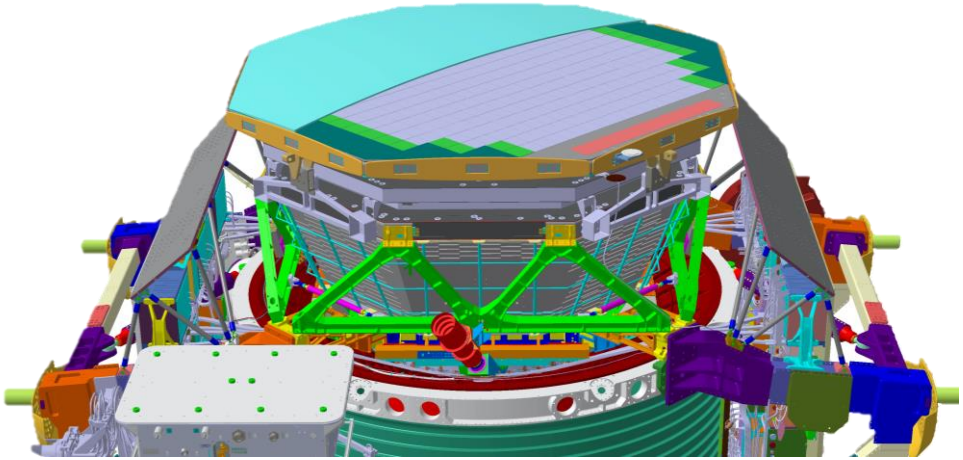
$\delta < 0.30\%$ at the 95% C.I. for $R > 200$ GV

0.34% Iso. Exp. (stat.+sys.)

AMS L0 Upgrade



With completion of L0 Upgrade AMS acceptance will be Increased by 300%



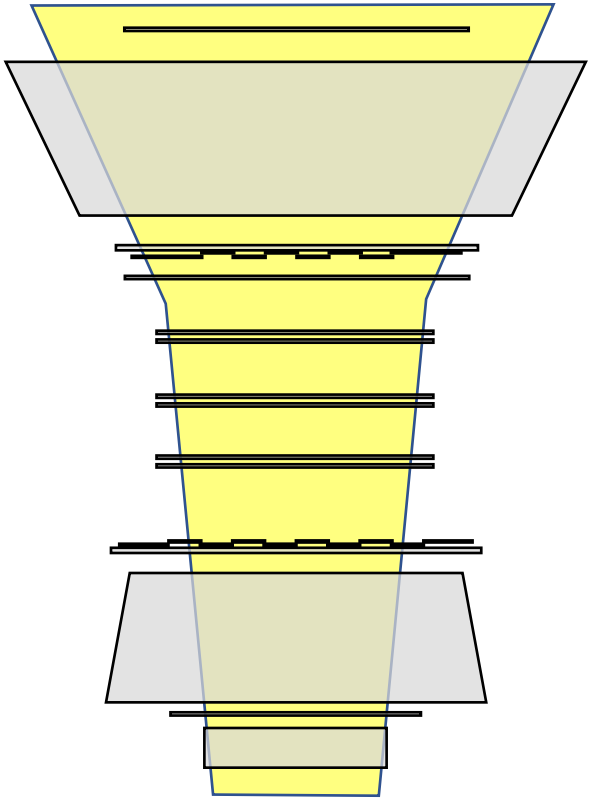
With the L0 upgrade, AMS will provide measurements of the spectra of positrons, electrons, antiproton and 14 high-Z elements, from P to Zn, due to large increase of the statistics and large reduction of the backgrounds.

This will allow accurate measurements at highest energies, there no data exist.

Future Positron & Electron Anisotropy Analysis

Current Analysis

Fiducial Volume: TRD - ECAL

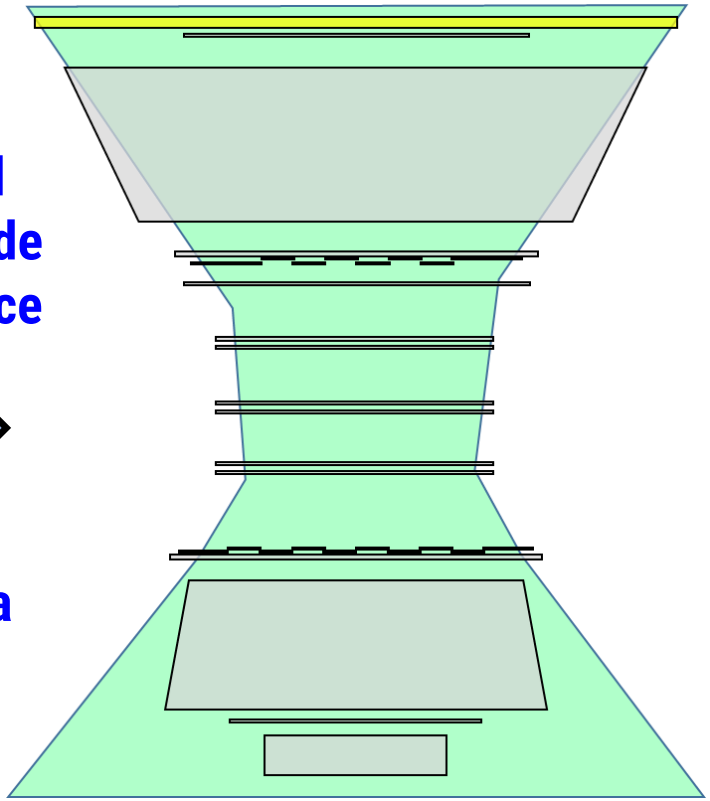


Positrons and electrons outside ECAL acceptance

Acceptance increases by a factor 3

Future Analysis

Fiducial Volume: TRD + L0



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

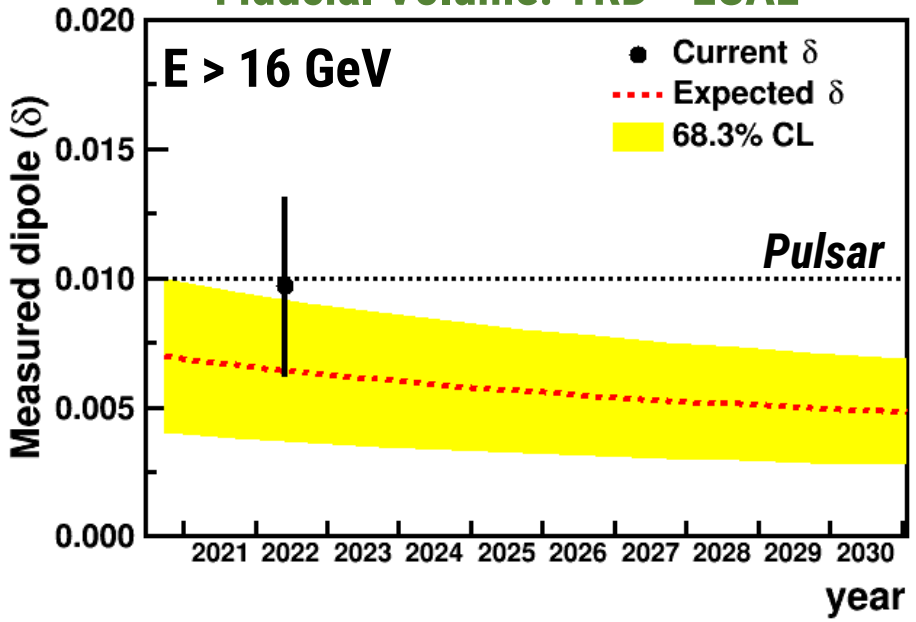
Positrons are separated from protons with a selection based on a template fit to the TRD response

Positron Anisotropy: Projection up to 2030

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

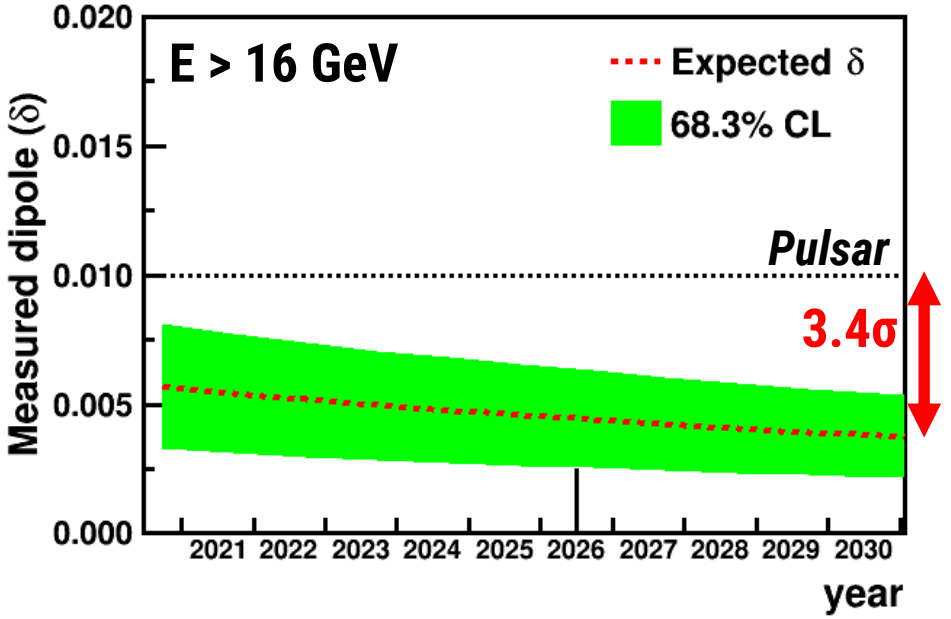
Current Analysis

Fiducial Volume: TRD - ECAL



Future Analysis

Fiducial Volume: TRD + L0



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

The measurement of the anisotropy of electrons, positrons and protons provides unique information to understand the origin of the unexpected features observed in their fluxes

AMS sensitivity to 1% level positron dipole anisotropy provides a test of the pulsar origin for the positron excess