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AGENCIA ESTATAL DE INVESTIGACIÓN
INSTITUTO DE ASTROFÍSICA DE CANARIAS · IAC
EXCELENCIA SEVERO OCHOA

DETERMINATION OF ANISOTROPIES OF ELEMENTARY PARTICLES

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on behalf of the AMS-02 collaboration

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PRAGUE
ichep2024.org
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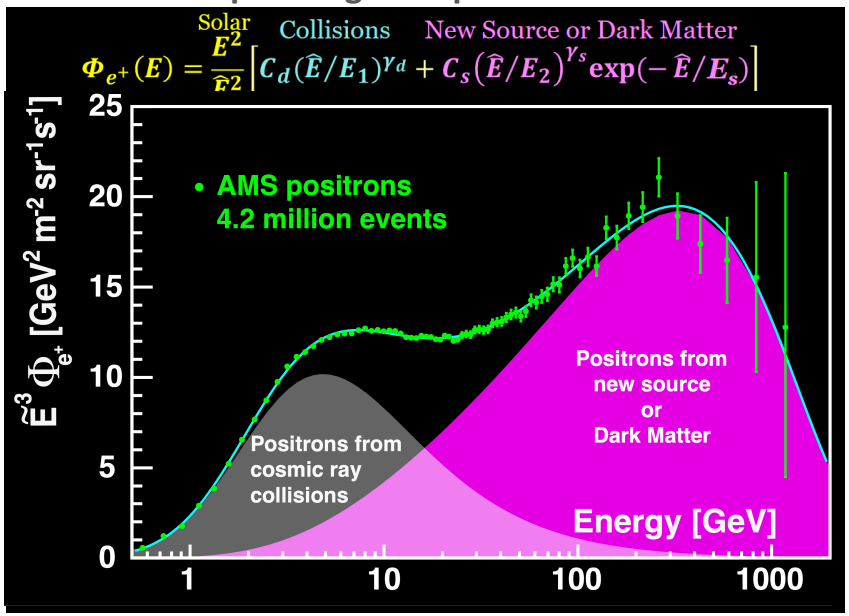
Motivation: Positrons

- The **positron** flux shows an excess at high energies that is not consistent with purely secondary production
- The excess is consistent with the existence of a **source term** of high-energy **positrons** with a characteristic cutoff energy

AMS 12.5 years preliminary data
Refer to the upcoming AMS publication



Typically, the **source term** is classified in two scenarios: **astrophysical sources** and **dark matter**

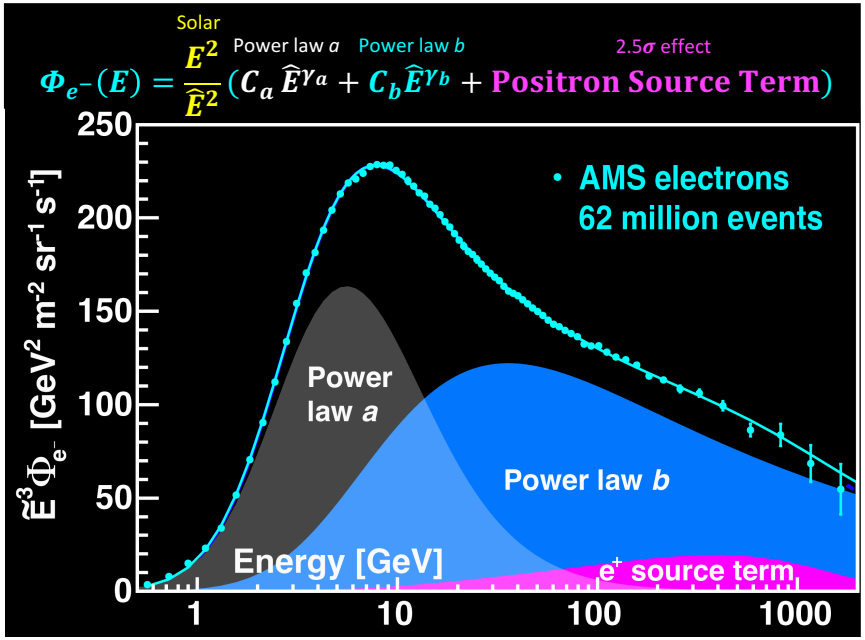
See also: Origin of Cosmic Positrons and Electrons in the TeV Region by A. Kounine

A local source of CR **positrons** may induce some degree of **anisotropy**

Motivation: Electrons

- The **electron** flux shows an excess above ~ 45 GeV that is not consistent with low energy trends
- The **electron** spectrum can be best described by the **sum of 2 power law functions** and the **contribution of a positron-like source term**

AMS 12.5 years preliminary data
Refer to the upcoming AMS publication

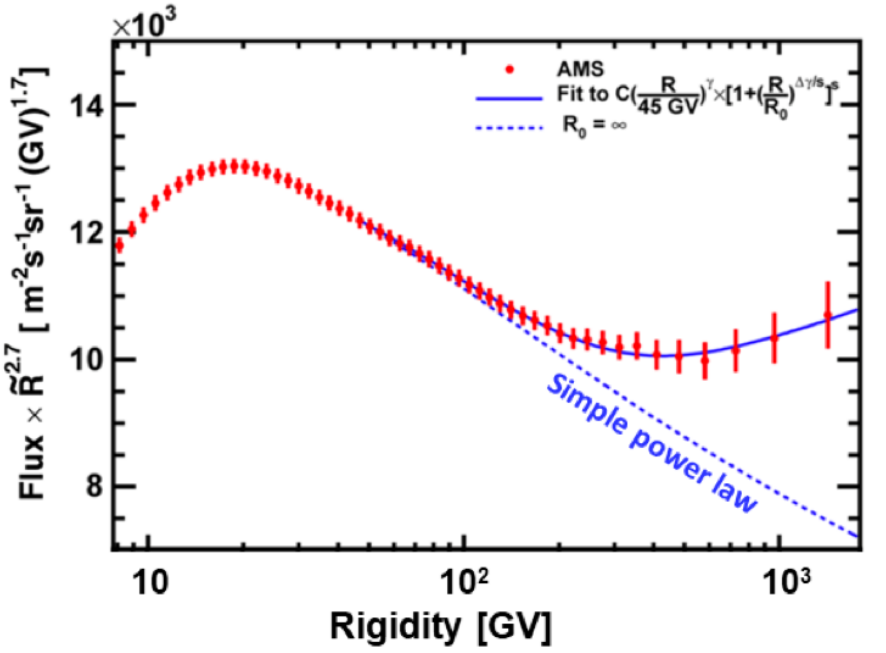


See also: Origin of Cosmic Positrons and Electrons in the TeV Region by A. Kounine

A local source of CR **electrons** may induce some degree of **anisotropy**

Proton Anisotropy

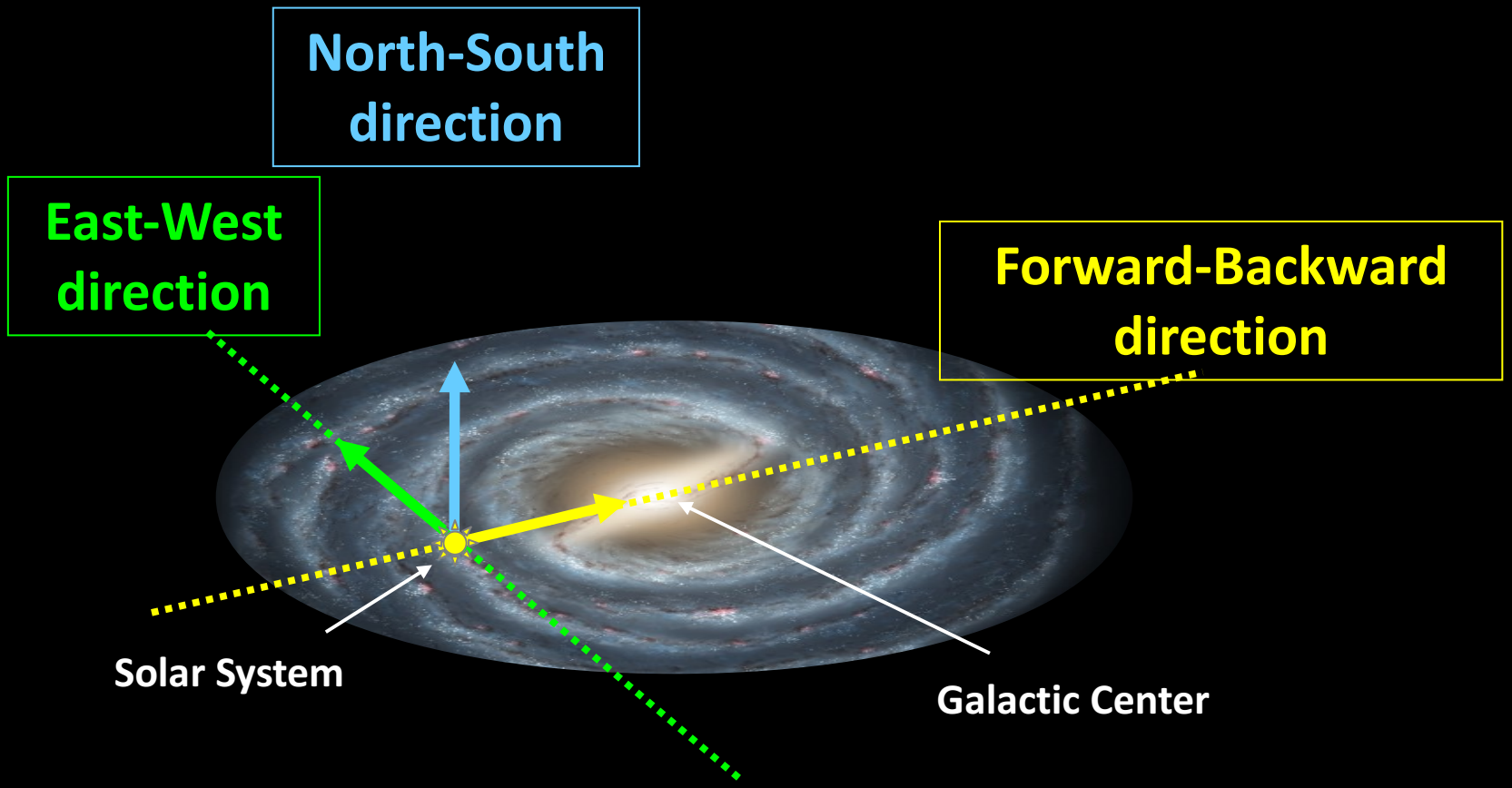
- Proton flux shows a **deviation from a single power law** above 200 GV
- This observation may require **modification** of cosmic ray **transport models** or the inclusion of **local sources** of high rigidity events



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

Coordinate System of Analysis

Galactic Coordinates



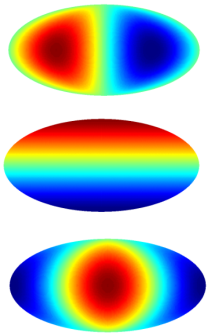
Expansion of the CRs Flux

$$\Phi(\theta,\varphi) = \Phi_0 \left(1 + \sum_{\ell=1} \sum_{m=-\ell}^{m=+\ell} a_{\ell m} Y_{\ell m}(\theta,\varphi)\right)$$

Multipolar Components

Real basis of spherical harmonics

Dipole Components



East-West

North-South

Forward-Backward

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

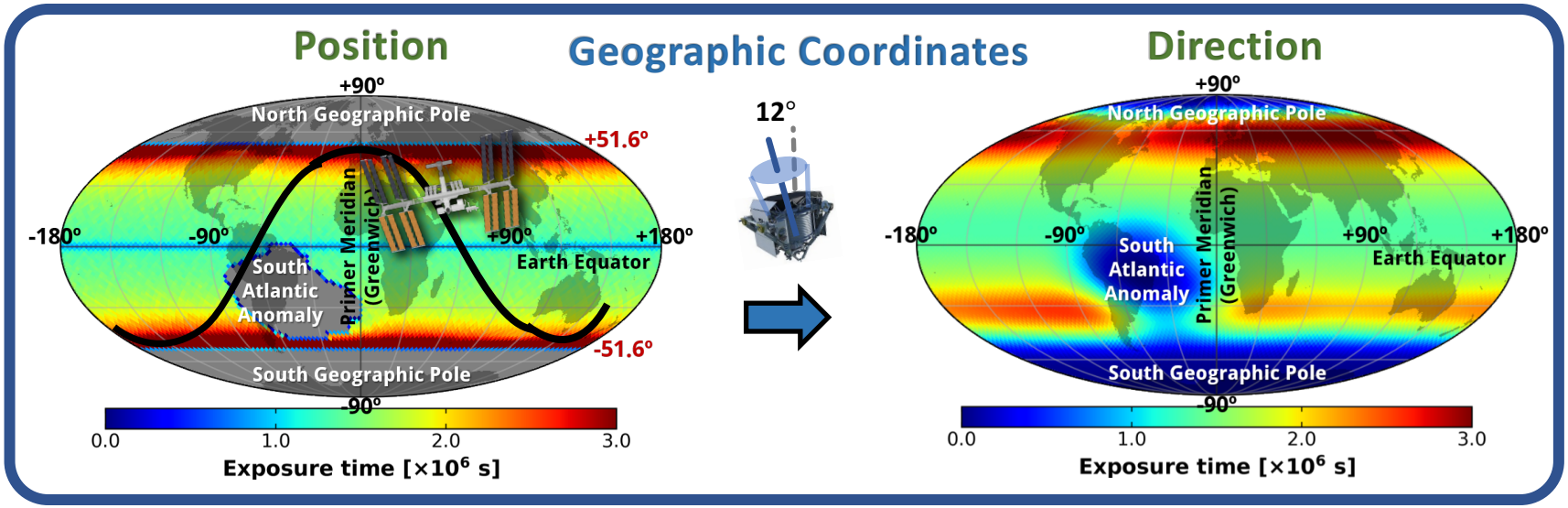
$$\rho_{\mathrm{NS}} = \sqrt{\frac{3}{4\pi}} a_{1+0}$$

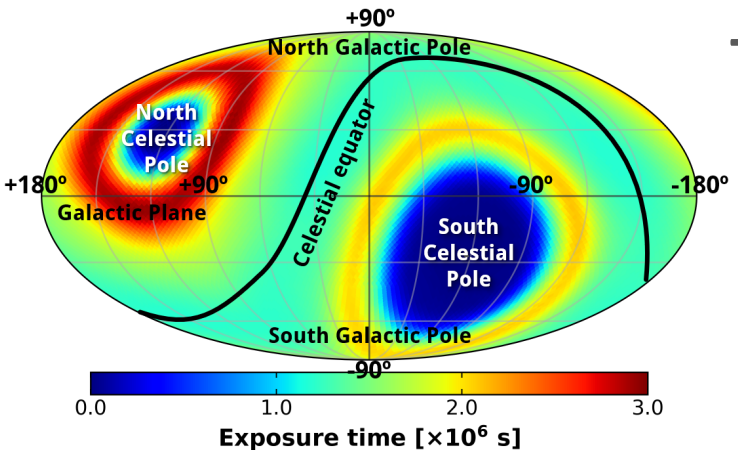
$$\rho_{\mathrm{FB}} = \sqrt{\frac{3}{4\pi}} a_{1+1}$$

Dipole Amplitude

$$\delta = \frac{\Phi_{\max} - \Phi_{\min}}{\Phi_{\max} + \Phi_{\min}} = \sqrt{\rho_{\mathrm{EW}}^2 + \rho_{\mathrm{NS}}^2 + \rho_{\mathrm{FB}}^2}$$

Exposure of AMS-02



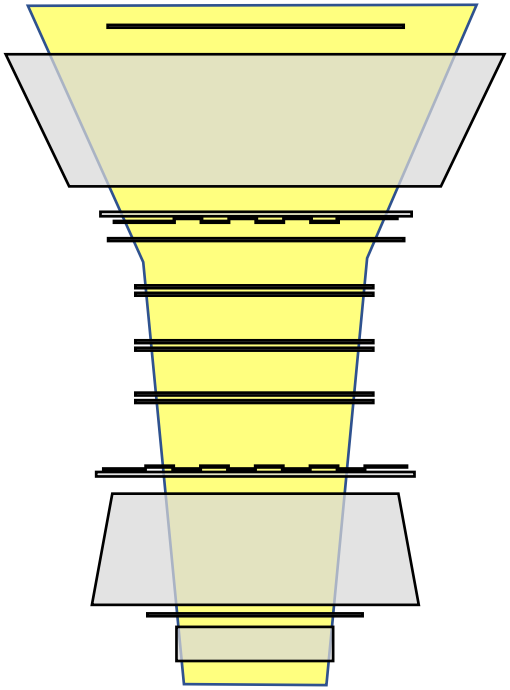


Total exposure time:
2.26×10^8 s
(AMS 11 years)

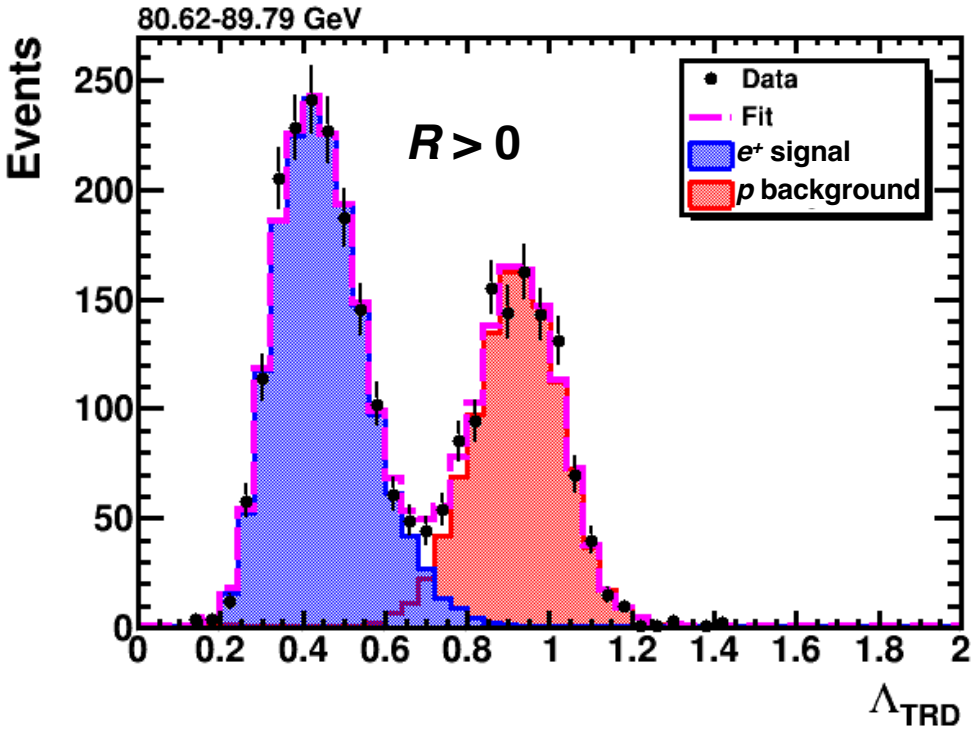
Positron & Electron Anisotropy Analysis

- **Positrons and electrons** 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

Fiducial Volume ECAL-TRD



Template fit to the TRD response



Electron Anisotropy

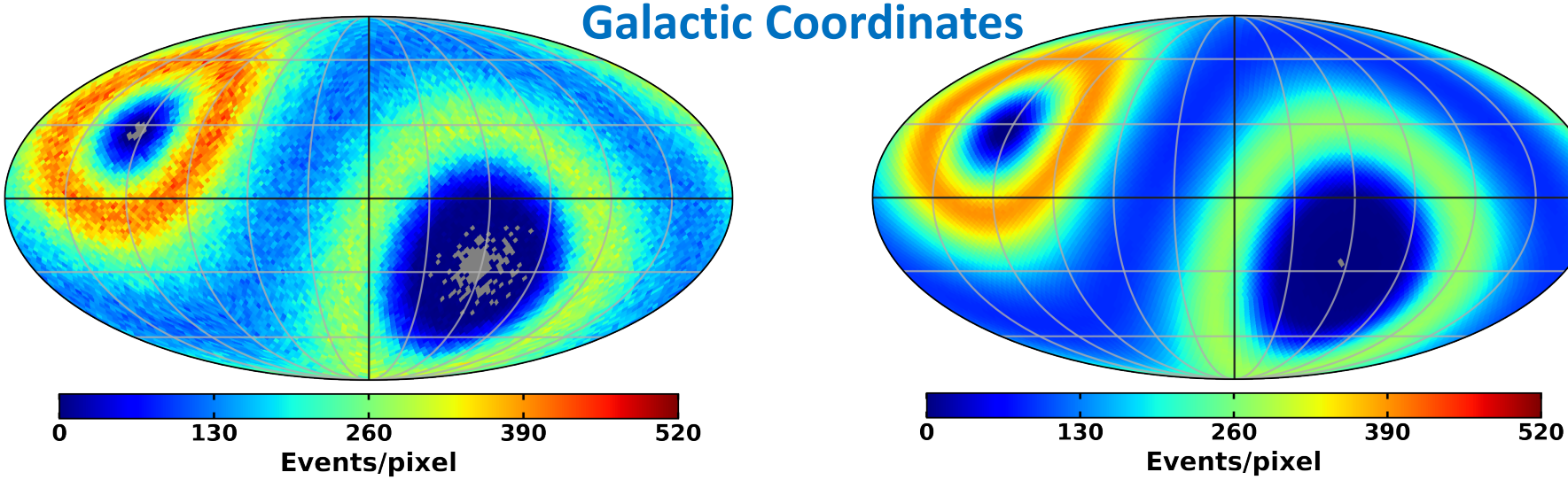
Selected events are grouped into 5 cumulative energy ranges:
E **> 16, 25, 40, 65, and 100 GeV**

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

3.4×10^6 electrons

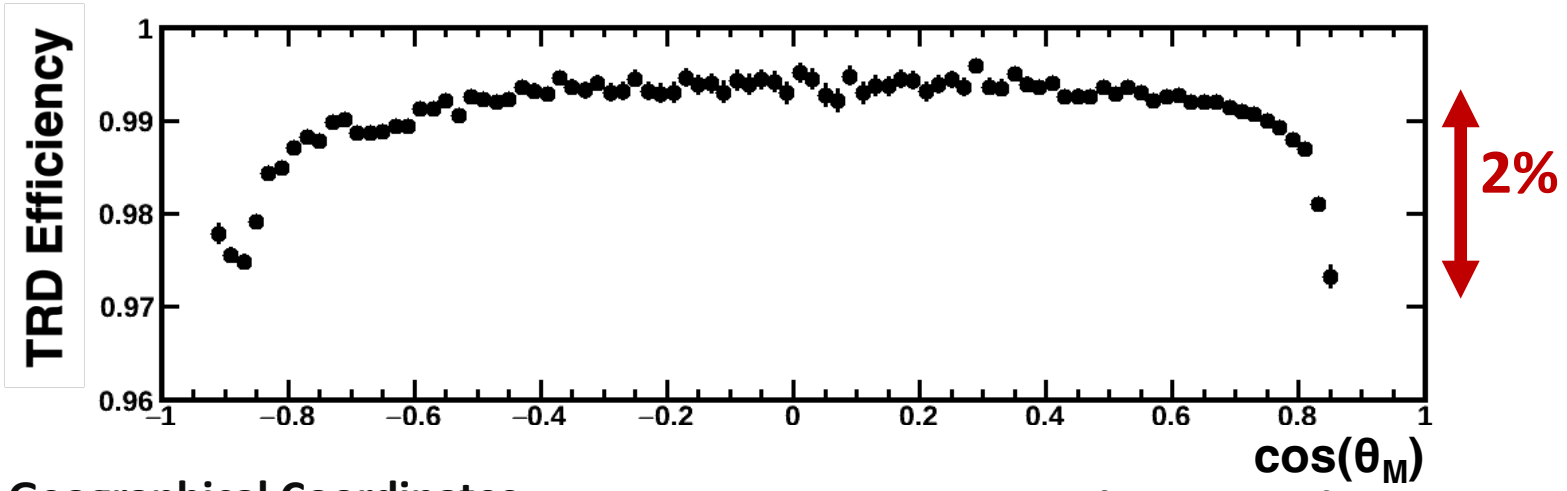
$16 < E/GeV < 500$
Galactic Coordinates

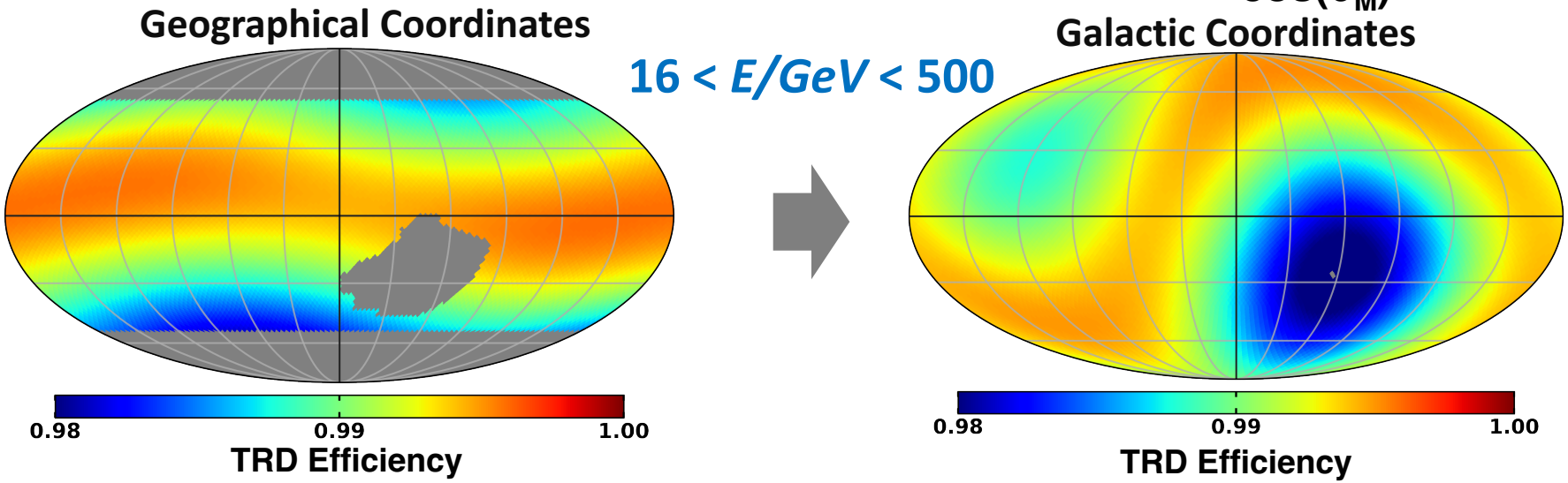
Isotropic map



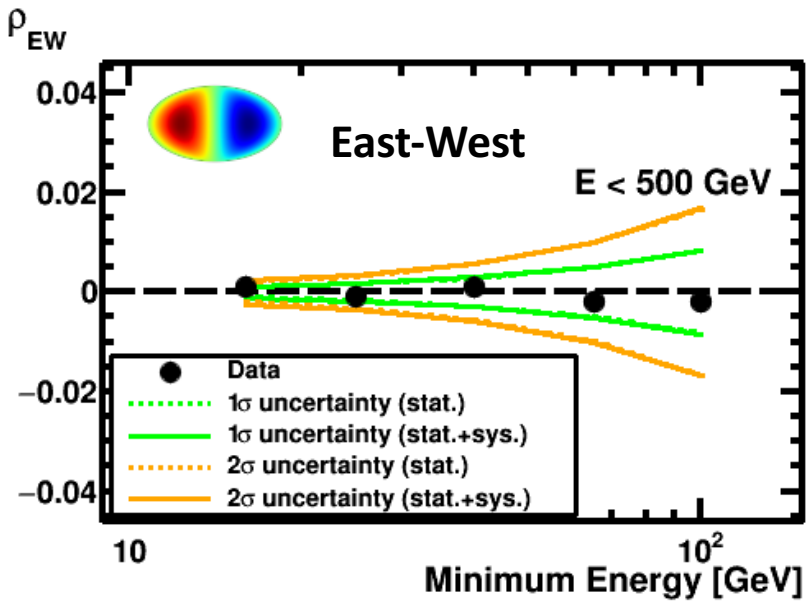
Electron Anisotropy: Detector Efficiencies

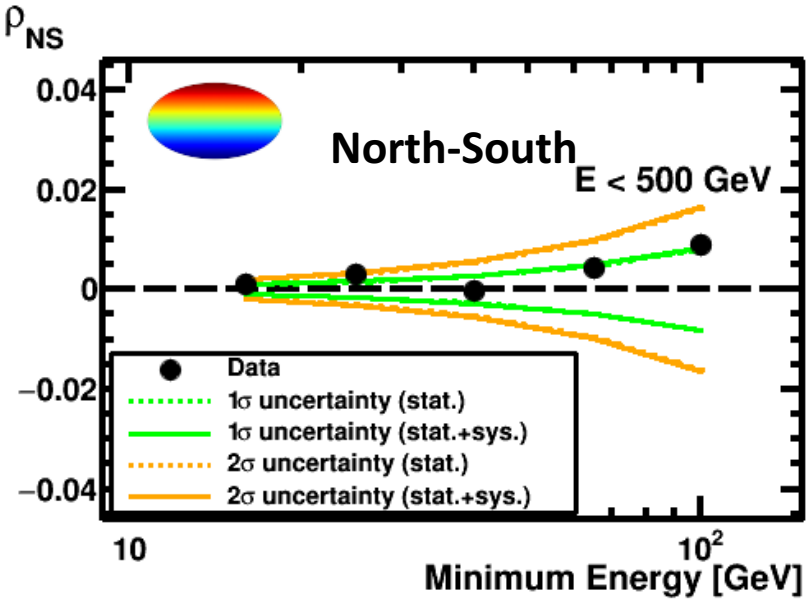
Computation of isotropic map requires detailed understanding of detector efficiencies at different geographical locations

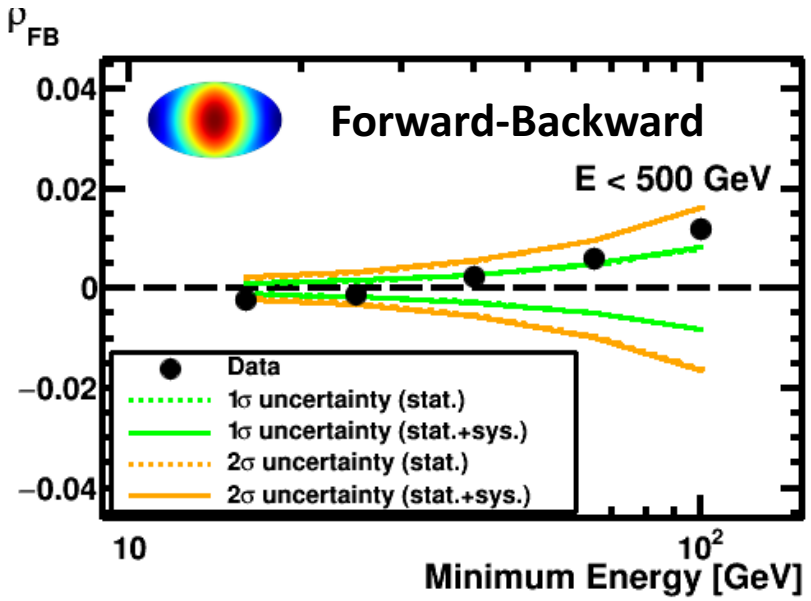




Electron Anisotropy: Dipole Components



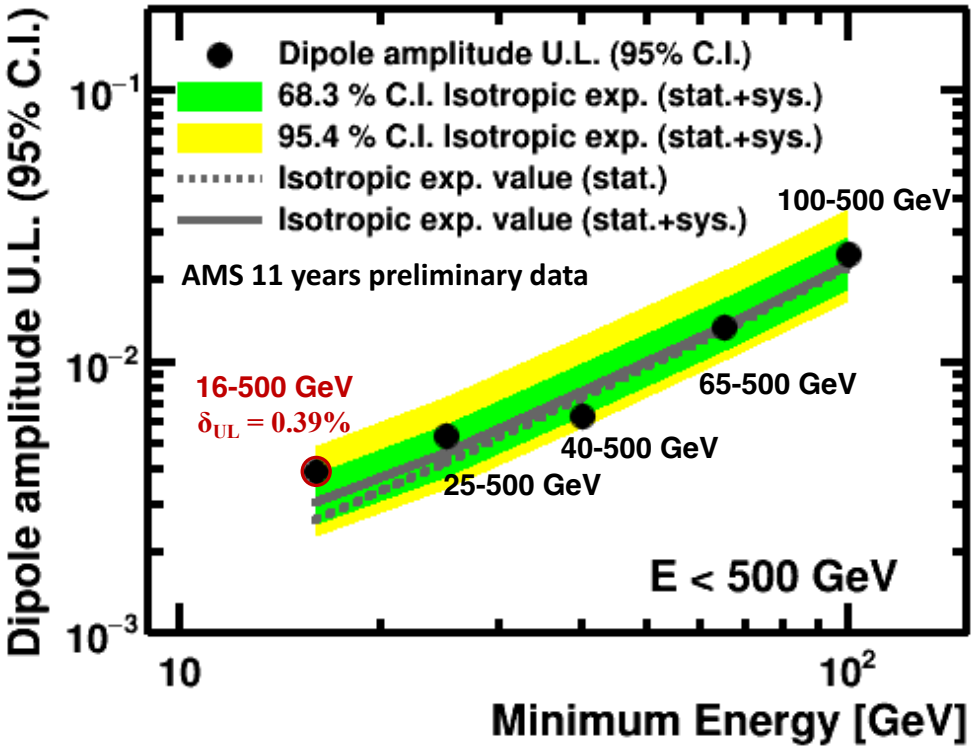




Electron dipole components in galactic coordinates are consistent with **isotropy**

Electron Anisotropy: δ_{UL}

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



3.4×10^6 electron events
$16 < E/\text{GeV} < 500$
(AMS 11 years)

$\delta_{UL} = 0.39\%$ at the 95% C.I.
for $16 < E/\text{GeV} < 500$

0.31% Isotropic Expectation
(stat.+sys.)

Positron Anisotropy

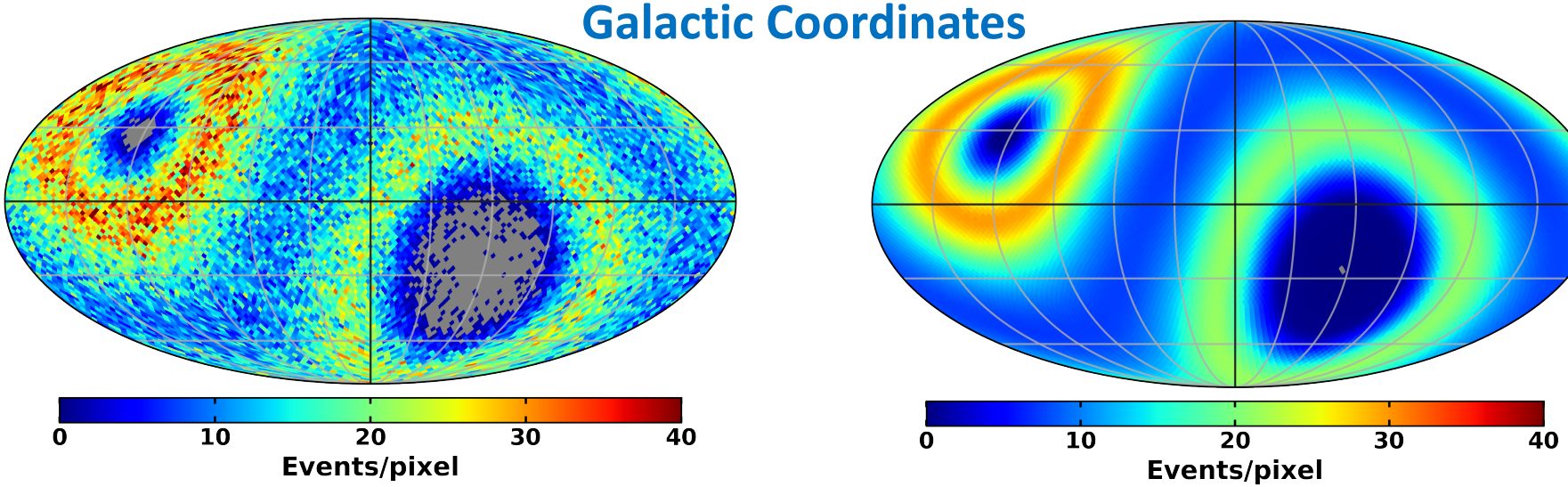
The arrival directions of positron events are compared to the expected map for an isotropic flux in galactic coordinates

2.5×10^5 positrons

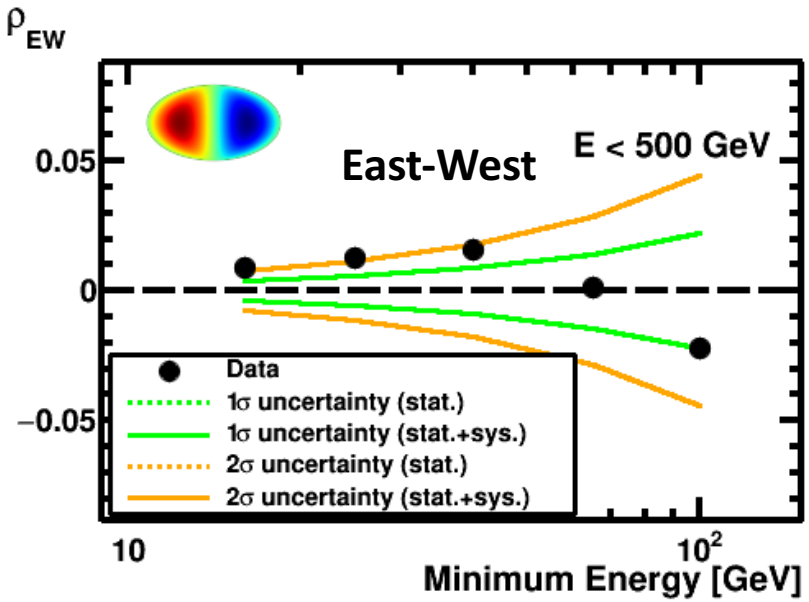
16 < *E/GeV* < 500

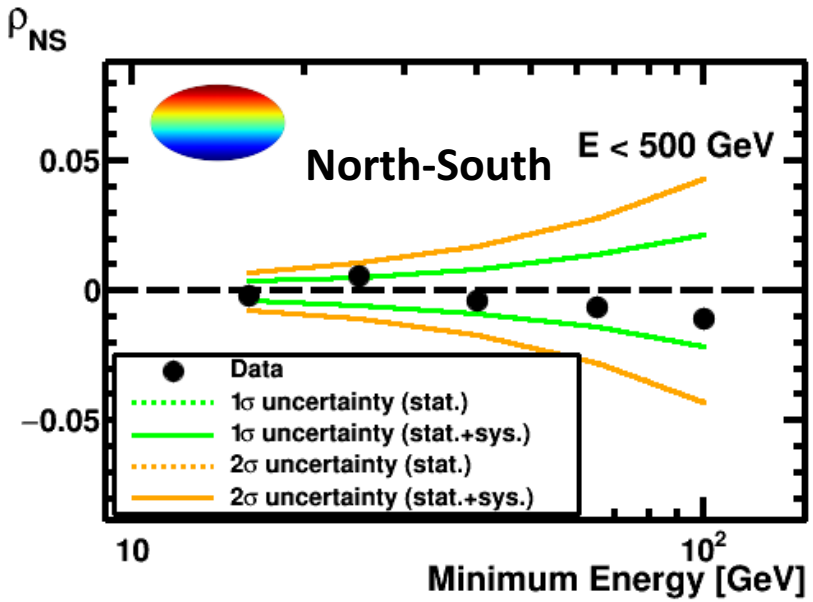
Galactic Coordinates

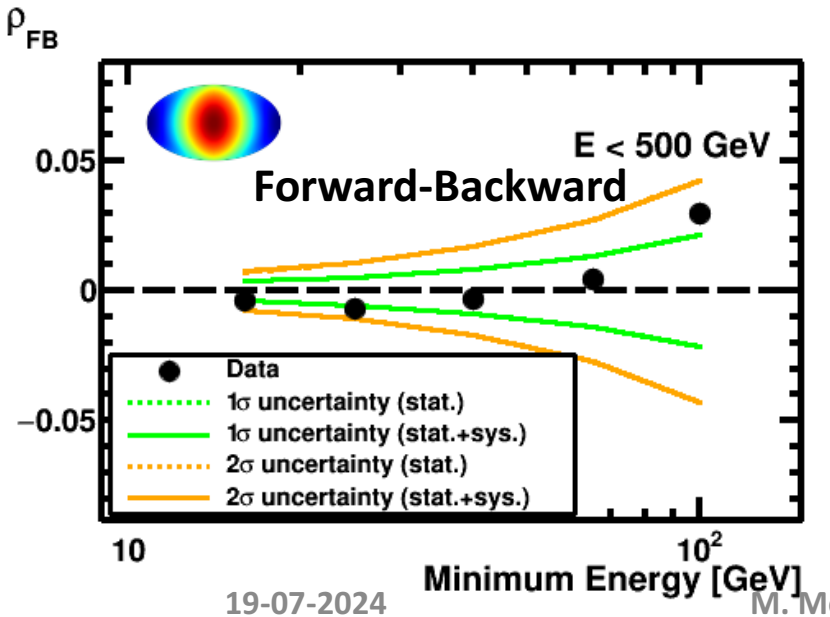
Isotropic map



Positron Anisotropy: Dipole Components



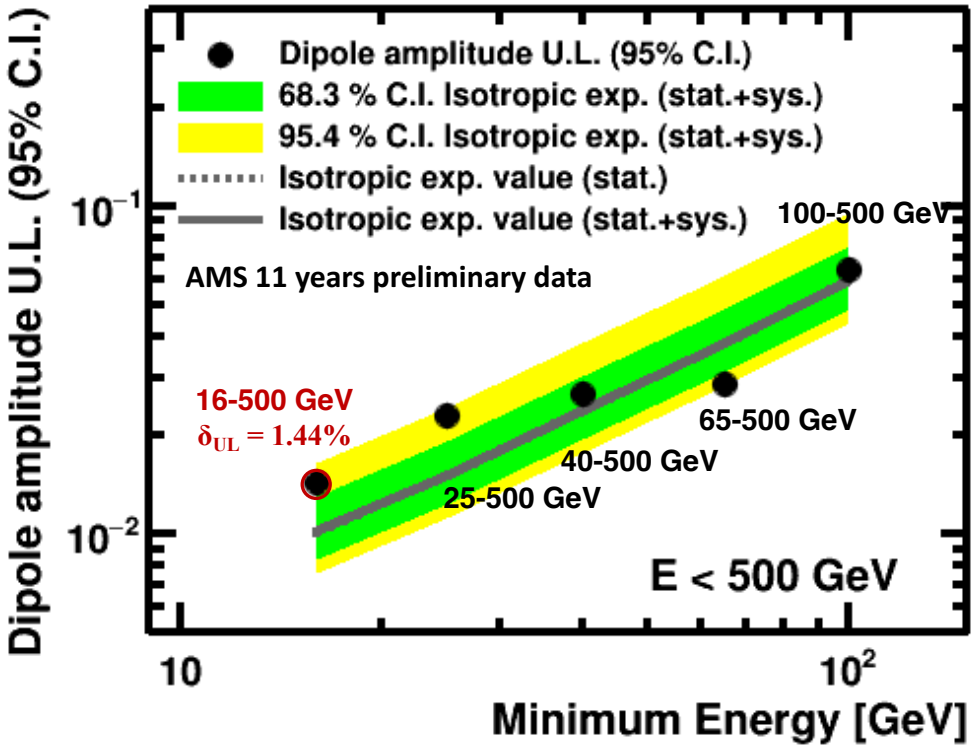




Positron dipole components in galactic coordinates are consistent with **isotropy**

Positron Anisotropy: δ_{UL}

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



2.5×10^5 positron events
$16 < E/\text{GeV} < 500$
(AMS 11 years)

$\delta_{UL} = 1.44\%$ at the 95% C.I.
for $16 < E/\text{GeV} < 500$

1.02% Isotropic Expectation
(stat.+sys.)

For the first time, the expected upper limit is at the 1% level

Proton Anisotropy

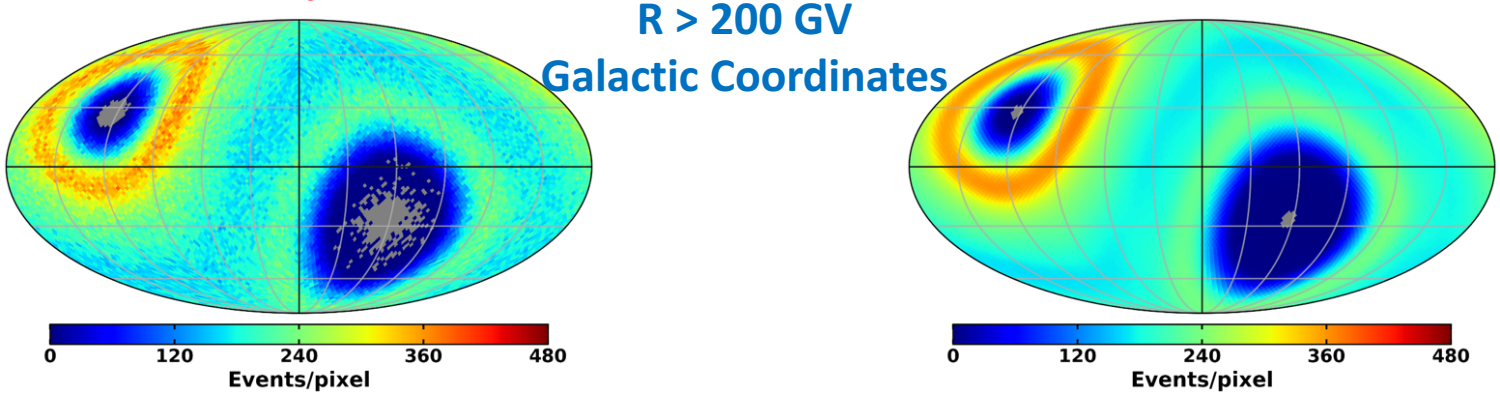
Proton Anisotropy

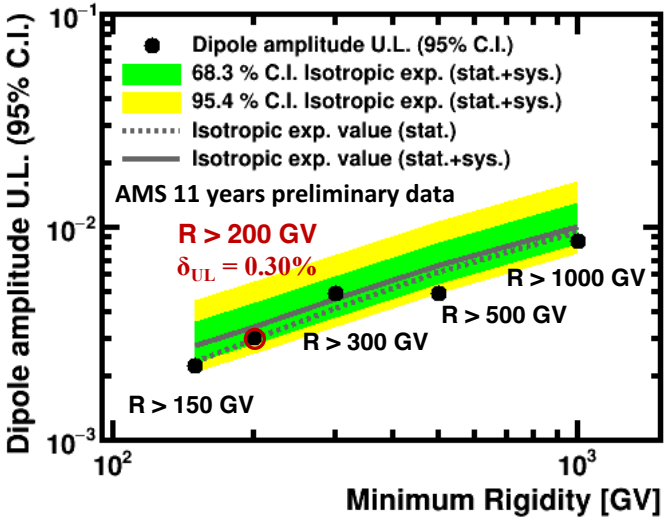
2.6×10^6 protons

R > 200 GV

Galactic Coordinates

Isotropic map



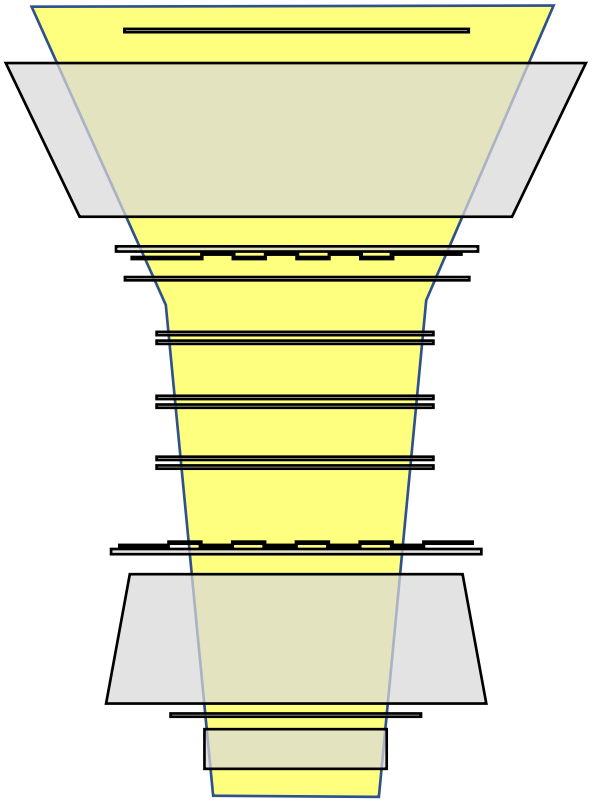


Results are consistent with isotropy and upper limit to the dipole amplitude is established:

$\delta_{UL} = 0.30\%$ at the 95% C.I. for R > 200 GV

Future Positron & Electron Anisotropy Analysis

Current Analysis
Fiducial Volume ECAL-TRD

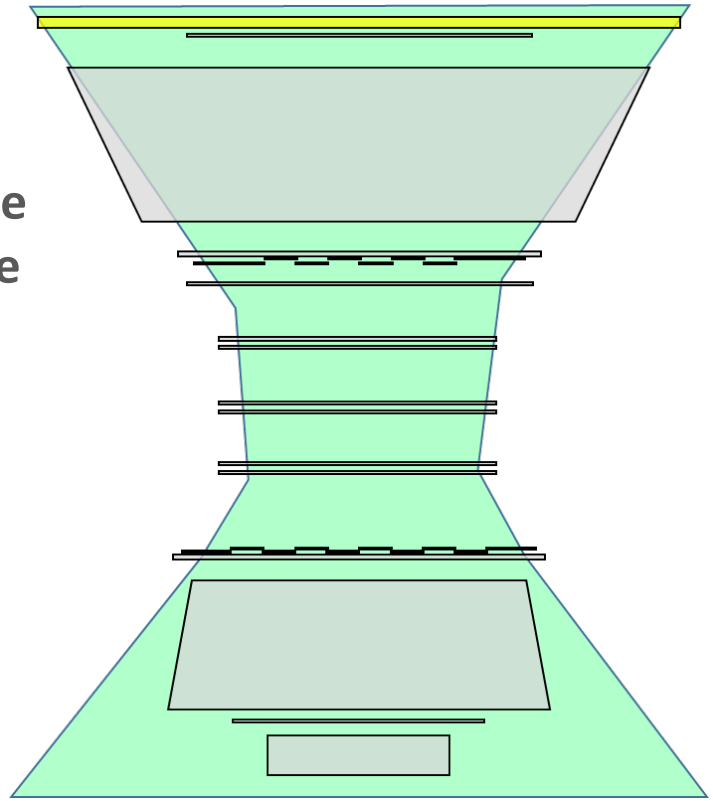


Positrons are separated from protons with a selection based on a cut on the ECAL estimator and a template fit to the TRD response

Positrons and electrons outside ECAL acceptance

Acceptance increases by a factor 3

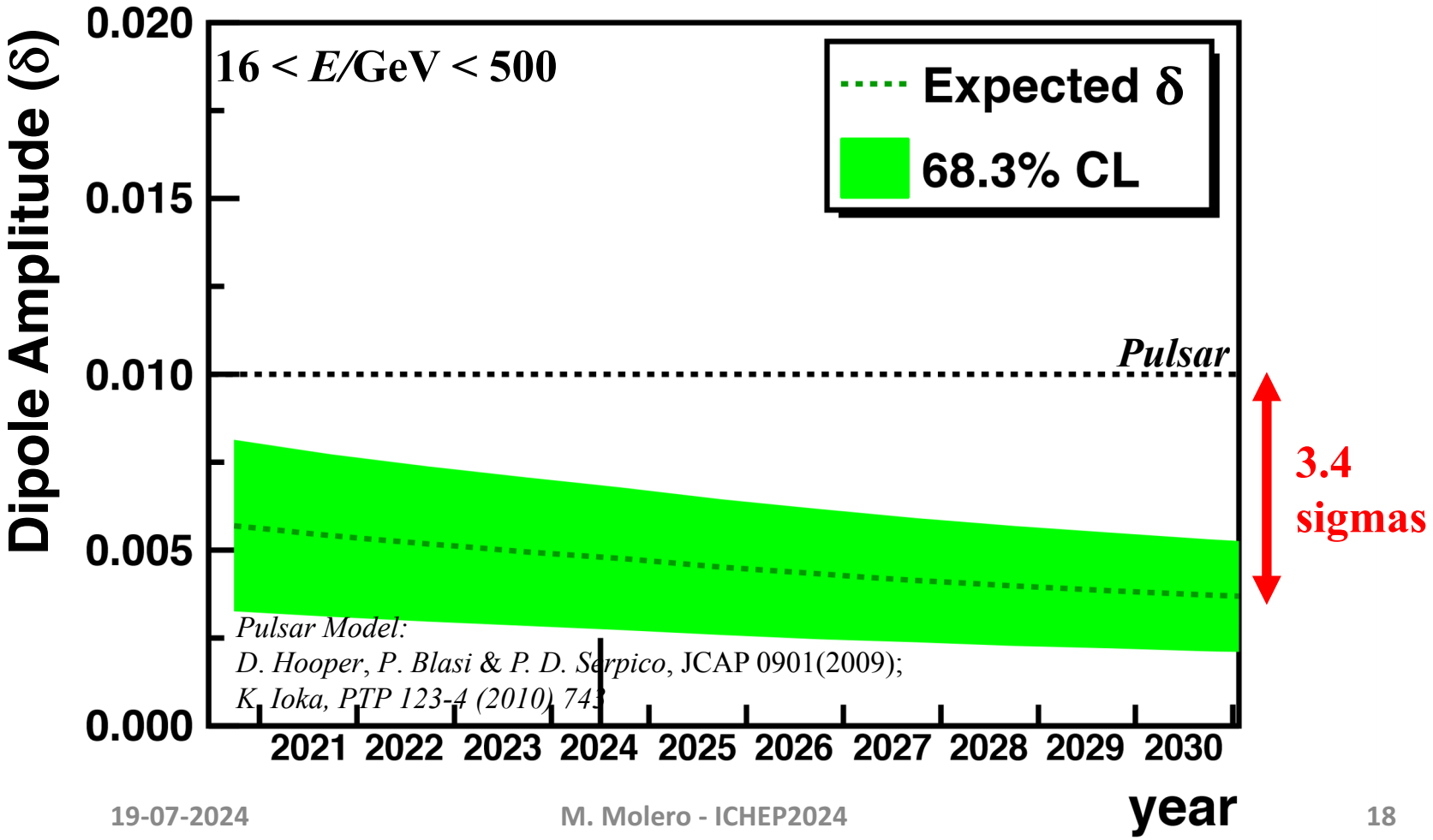
Future Analysis
Fiducial Volume TRD+L0



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

Positron Anisotropy: 2030 Projection

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



Conclusions

- **AMS measurements have shown new features in the positron, electron and proton fluxes that challenge the traditional models**
- **The study of the directionality of the cosmic rays provides additional information to the energy dependence of the fluxes and, in particular, it may help to understand the origin of the observations**
- **A measurement of the anisotropy in the arrival directions of positrons, electrons and protons in galactic coordinates has been performed**
- **Positrons and electrons in the energy range of 16-500 GeV are consistent with isotropy and upper limits to the dipole amplitude at the 95% C.I. are obtained**
- **Protons for R > 200 GV are also consistent with isotropy and upper limits to the dipole amplitude at the 95% C.I. are established**
- **AMS will continue taking data until the end of the ISS operation. AMS sensitivity to 1% level for positrons provides a test of the pulsar origin for the positron excess.**