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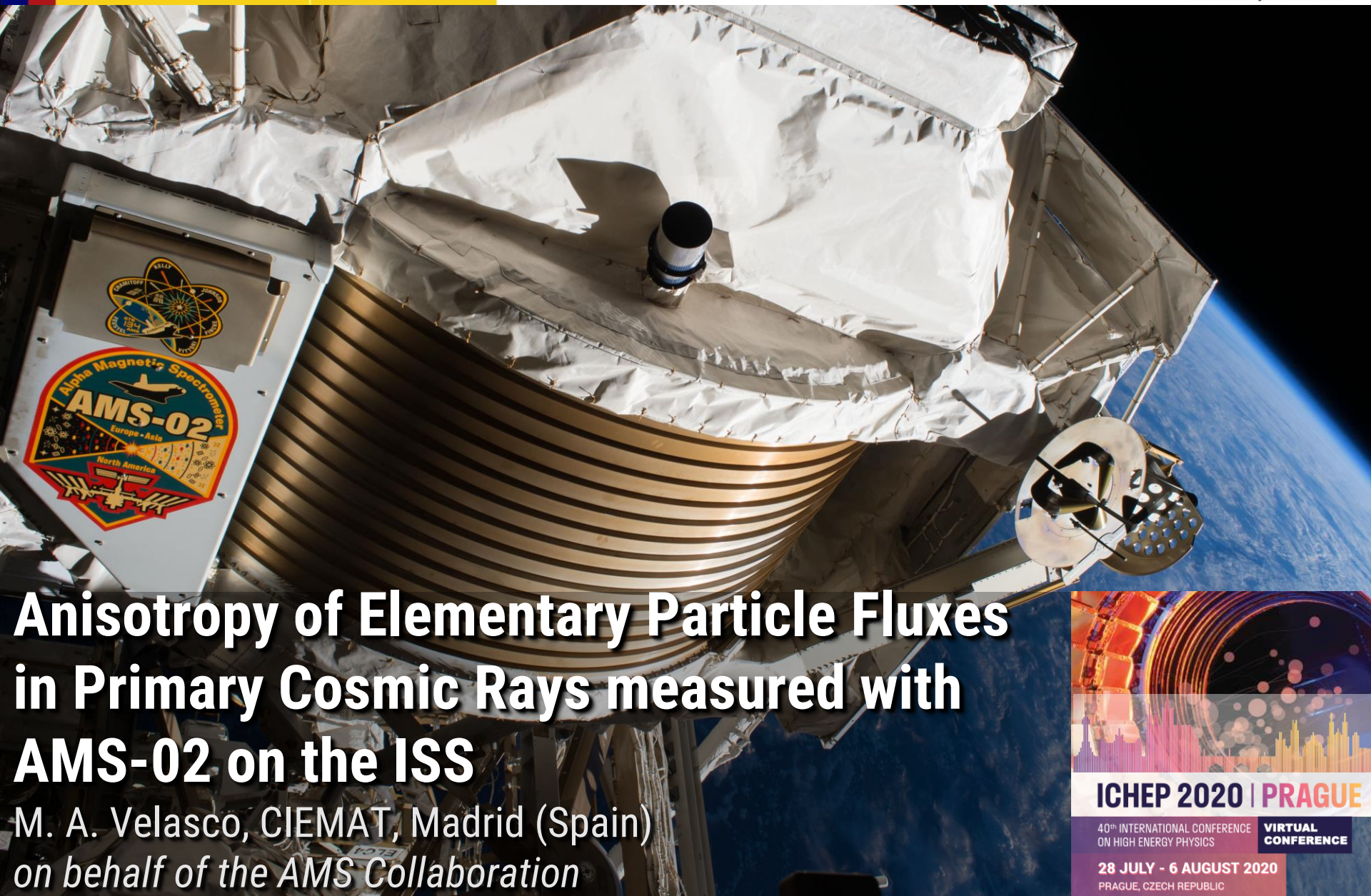


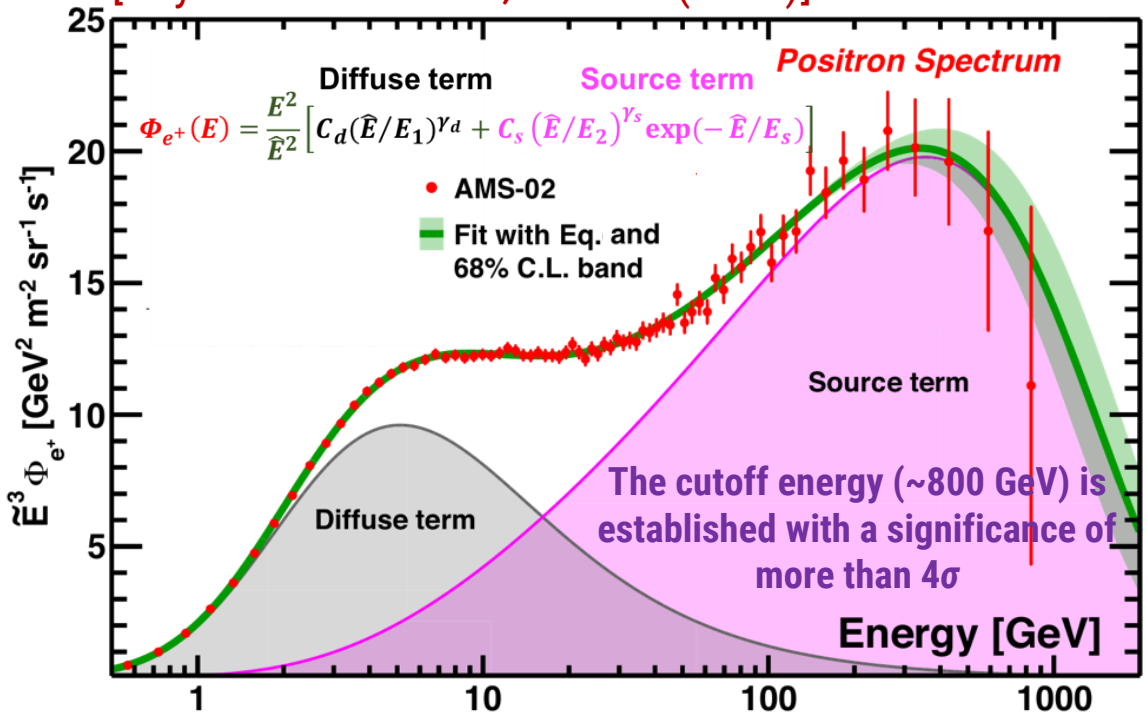
Anisotropy of Elementary Particle Fluxes in Primary Cosmic Rays measured with AMS-02 on the ISS

M. A. Velasco, CIEMAT, Madrid (Spain)
on behalf of the AMS Collaboration

Origin of the Positron Excess

Positron spectrum shows a significant excess above 25 GeV that is not consistent with only the secondary production of positrons

[Phys. Rev. Lett. **122**, 041102 (2019)]



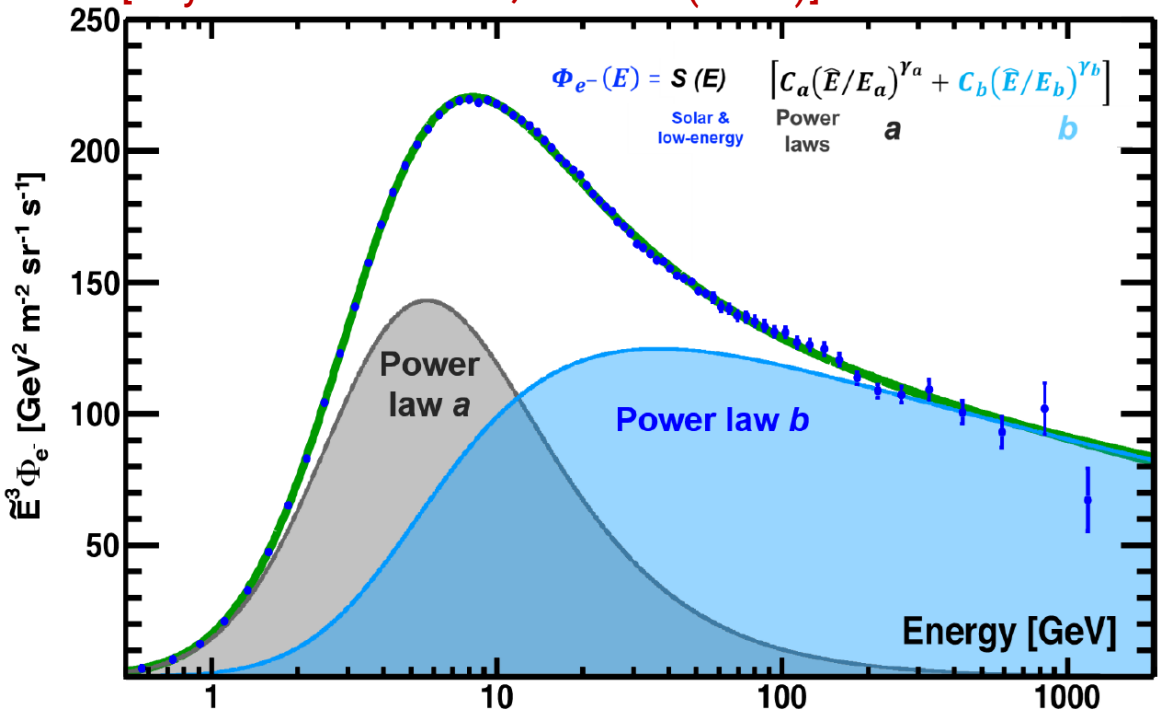
The observation requires the inclusion of primary sources whether from a particle physics or an astrophysical origin

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

Origin of the Electron Excess

Electron spectrum shows a significant excess above 42 GeV that is not consistent with lower energy trends

[Phys. Rev. Lett. **122**, 101101 (2019)]

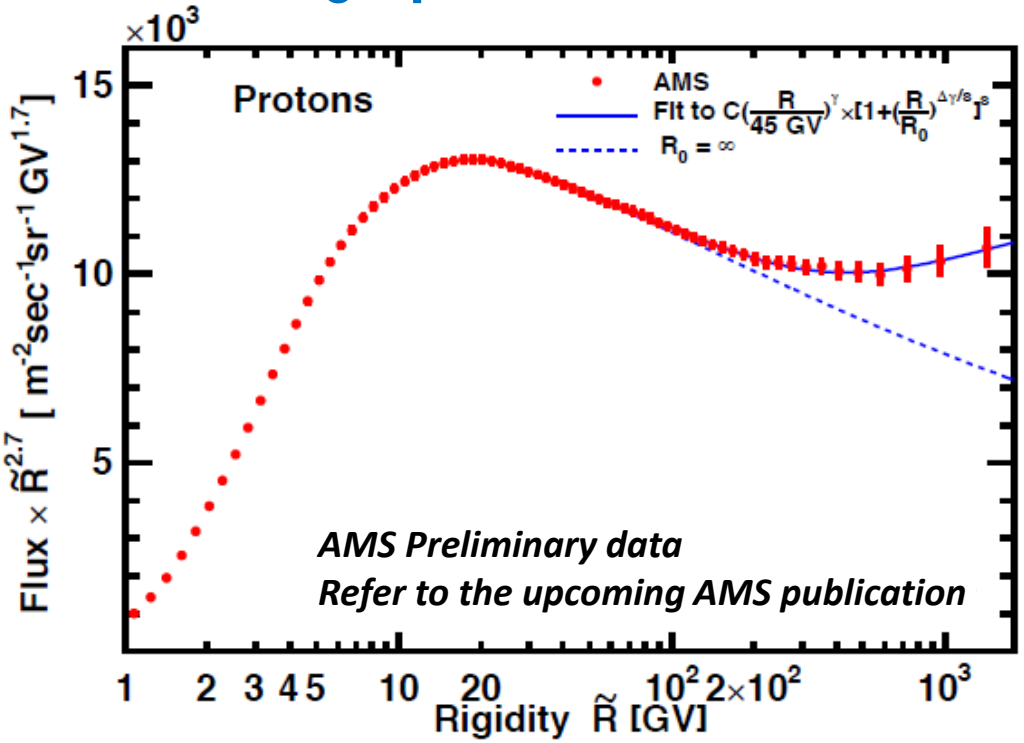


The electron flux does not have an energy cutoff below 1.9 TeV, i.e. high energy electrons originate from different sources that positrons

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

Origin of the Proton Flux Deviation

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

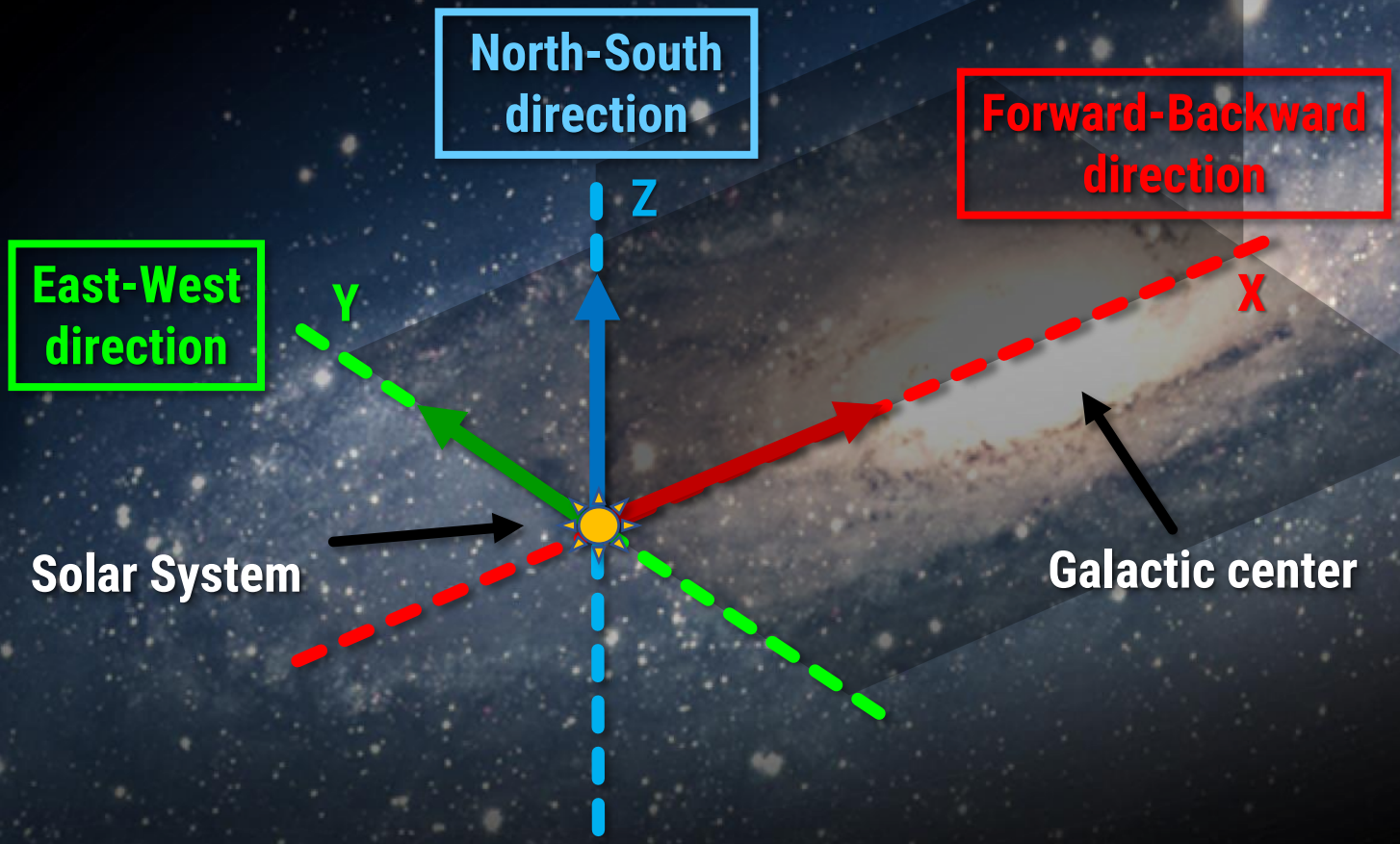


This observation may require modification of cosmic ray transport models or the inclusion of local sources of high rigidity events

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

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

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

Multipolar components

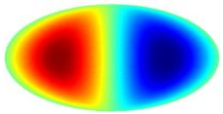
Real spherical harmonics basis

Dipole anisotropy (ℓ=1)

Dipole amplitude

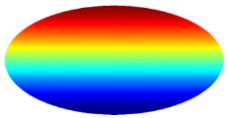
$$\delta = \frac{\Phi_{\max} - \Phi_{\min}}{\Phi_{\max} + \Phi_{\min}}$$

Dipole components



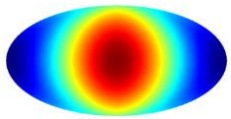
East-West

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



North-South

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



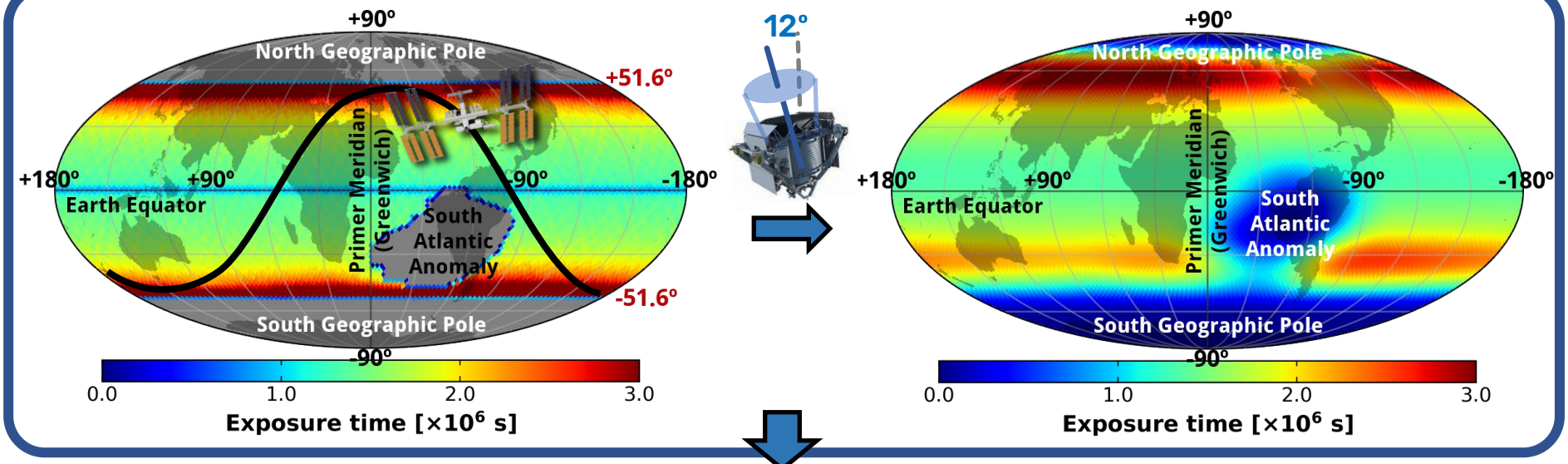
Forward-Backward

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

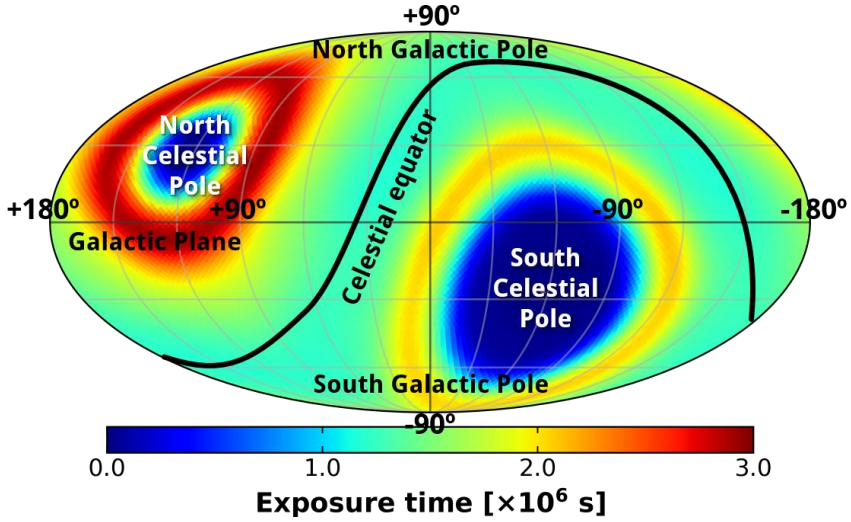
$$\delta = \sqrt{\rho_{\mathrm{EW}}^2 + \rho_{\mathrm{NS}}^2 + \rho_{\mathrm{FB}}^2}$$

AMS Sky Coverage

Position — Geographic coordinates — **Direction**



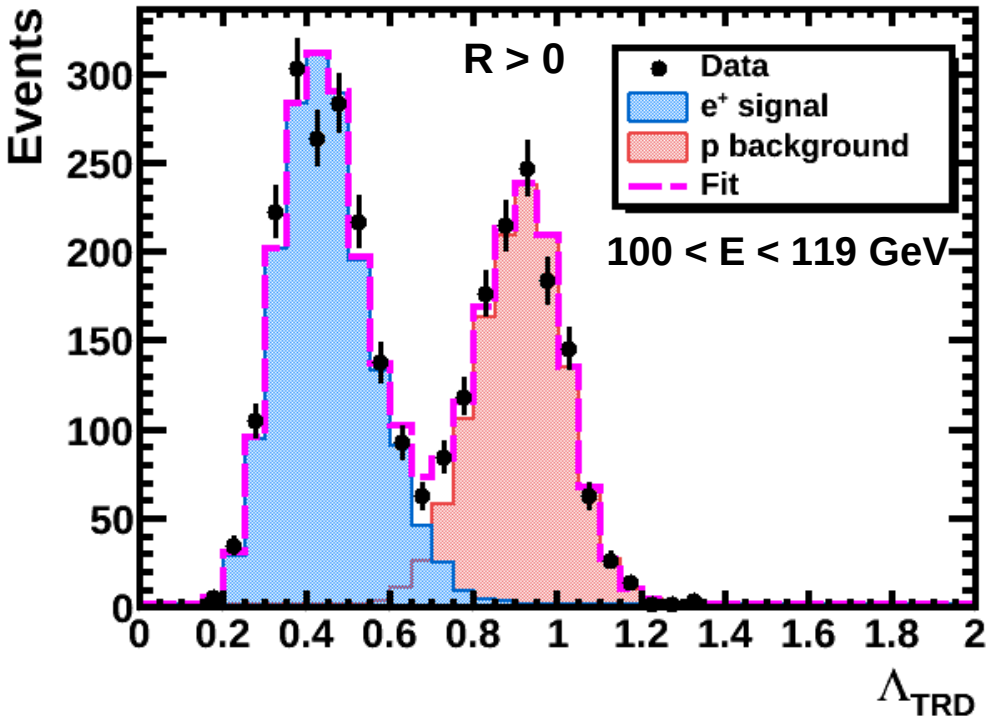
Galactic coordinates



Positron Anisotropy

Sample selection

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



For the anisotropy analysis, selected events are grouped into 5 cumulative energy ranges:

E **> 16, 25, 40, 65, and 100 GeV**

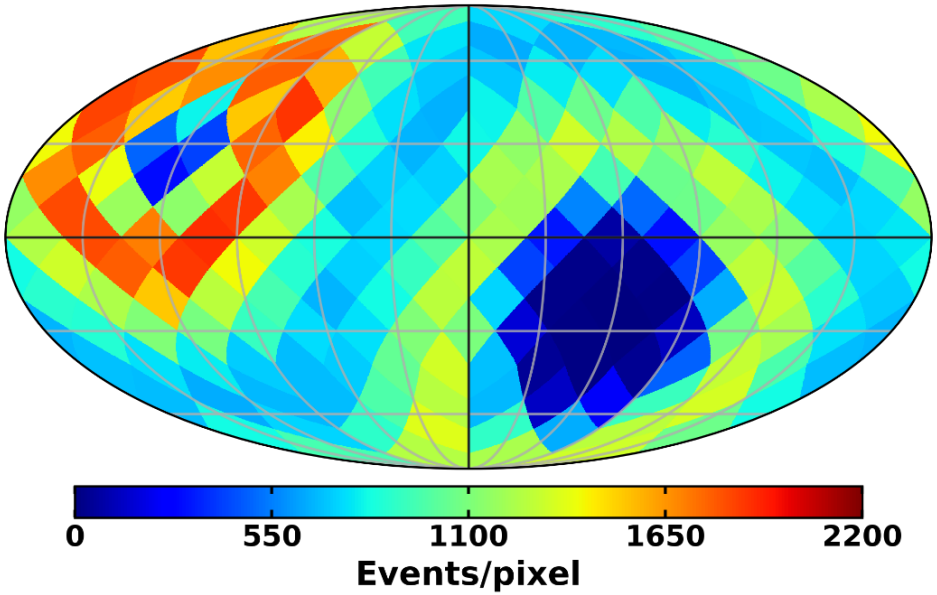
Event Sample: AMS 8.5 years
1.7×10^5 e^+ ($16 < E < 500$ GeV)

Positron Anisotropy

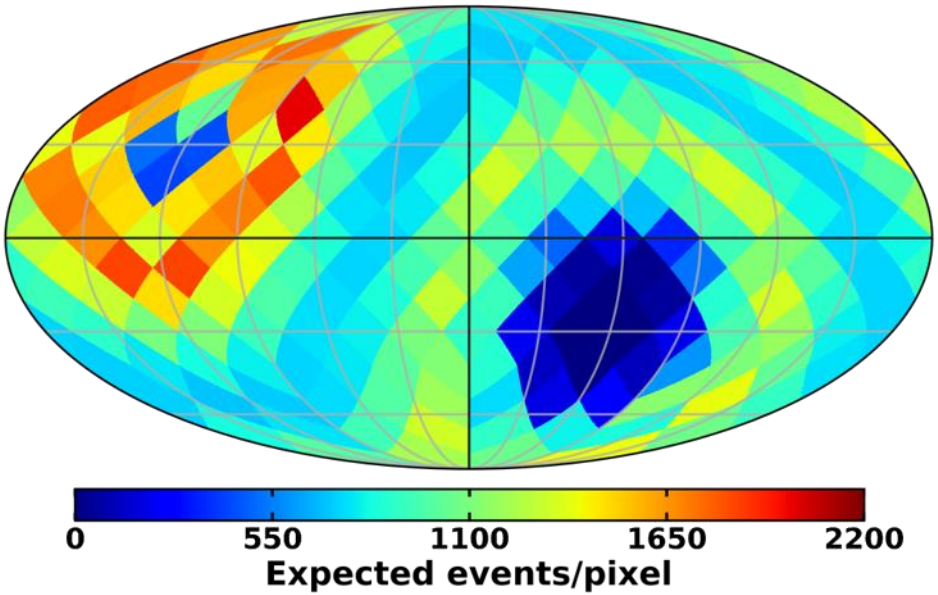
The arrival directions of positron events are compared to the expected map for an isotropic flux in Galactic coordinates

$16 < E < 500$ GeV

1.7×10^5 positrons

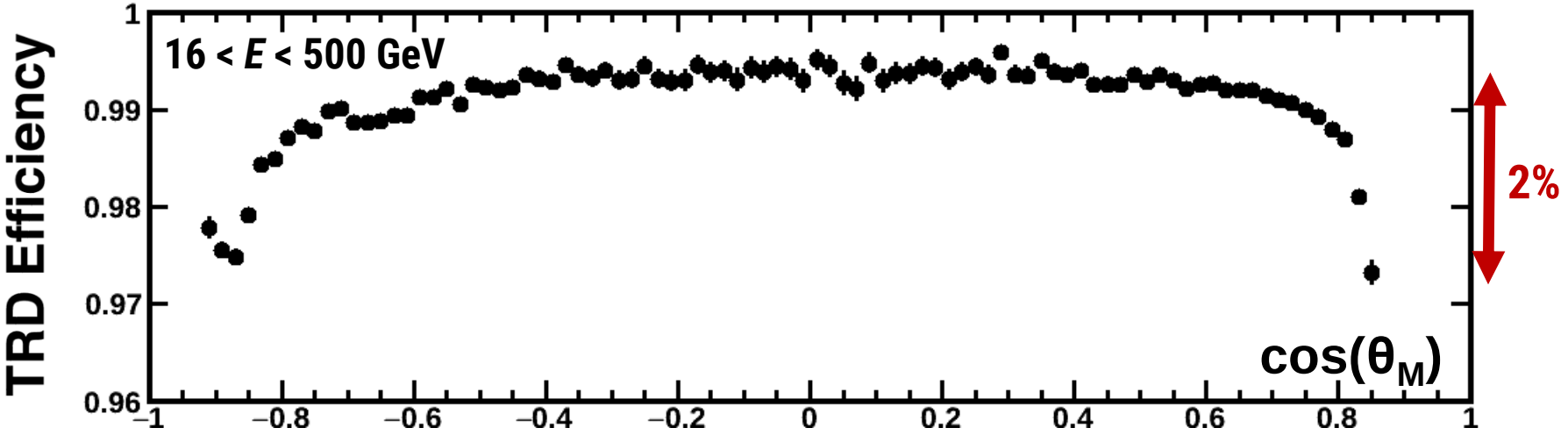


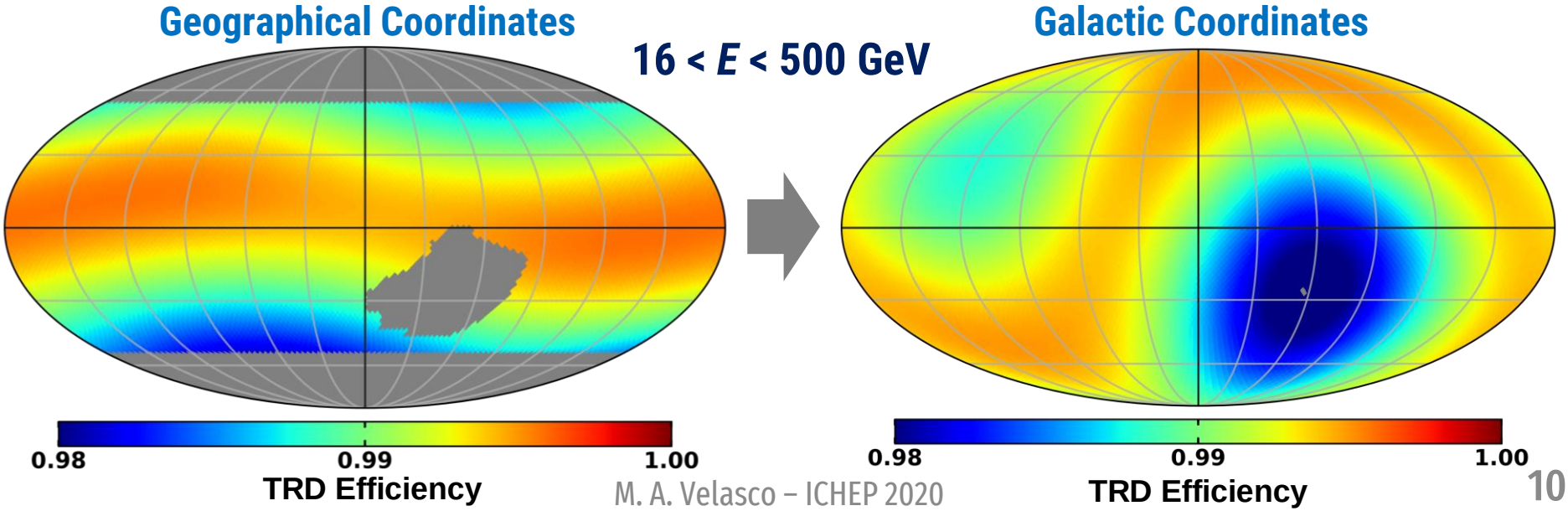
Isotropic map



Positron Anisotropy: Detector Efficiencies

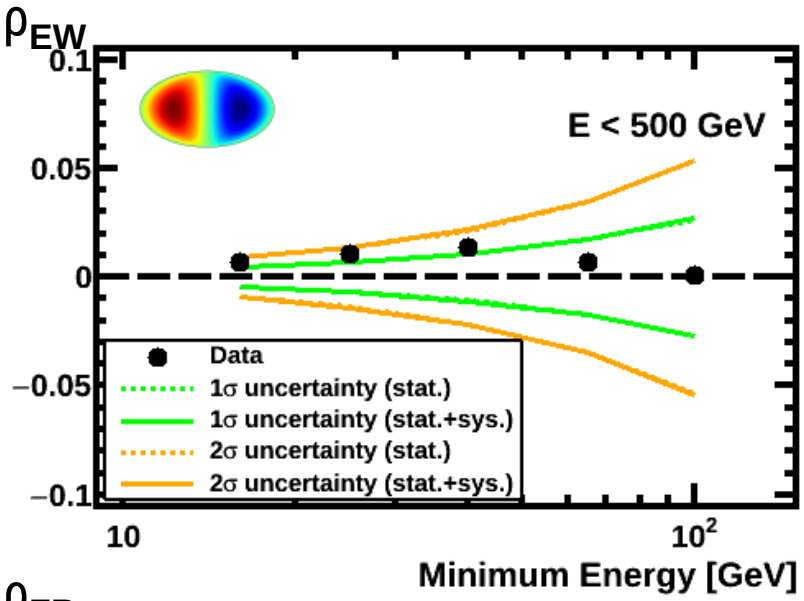
Computation of isotropic map requires detailed understanding of detector efficiencies at different geographical locations

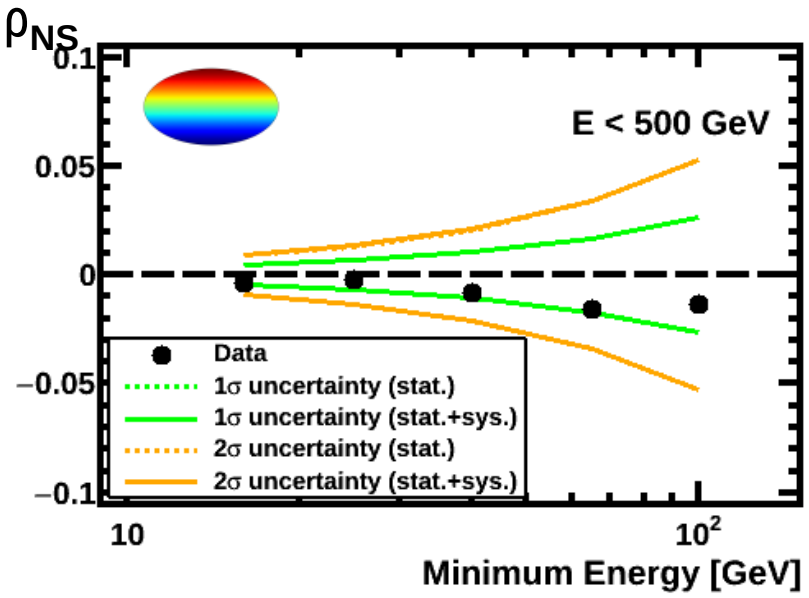


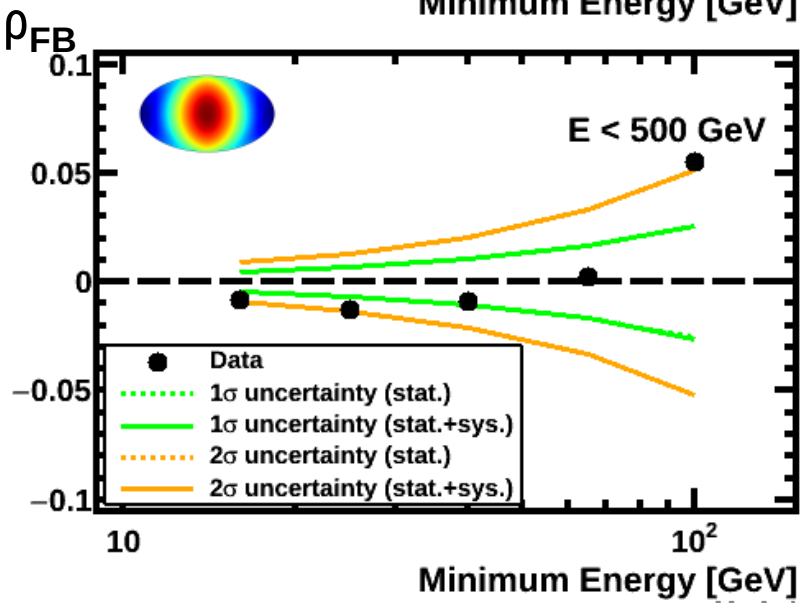


Positron Anisotropy: Dipole Components

Galactic Coordinates







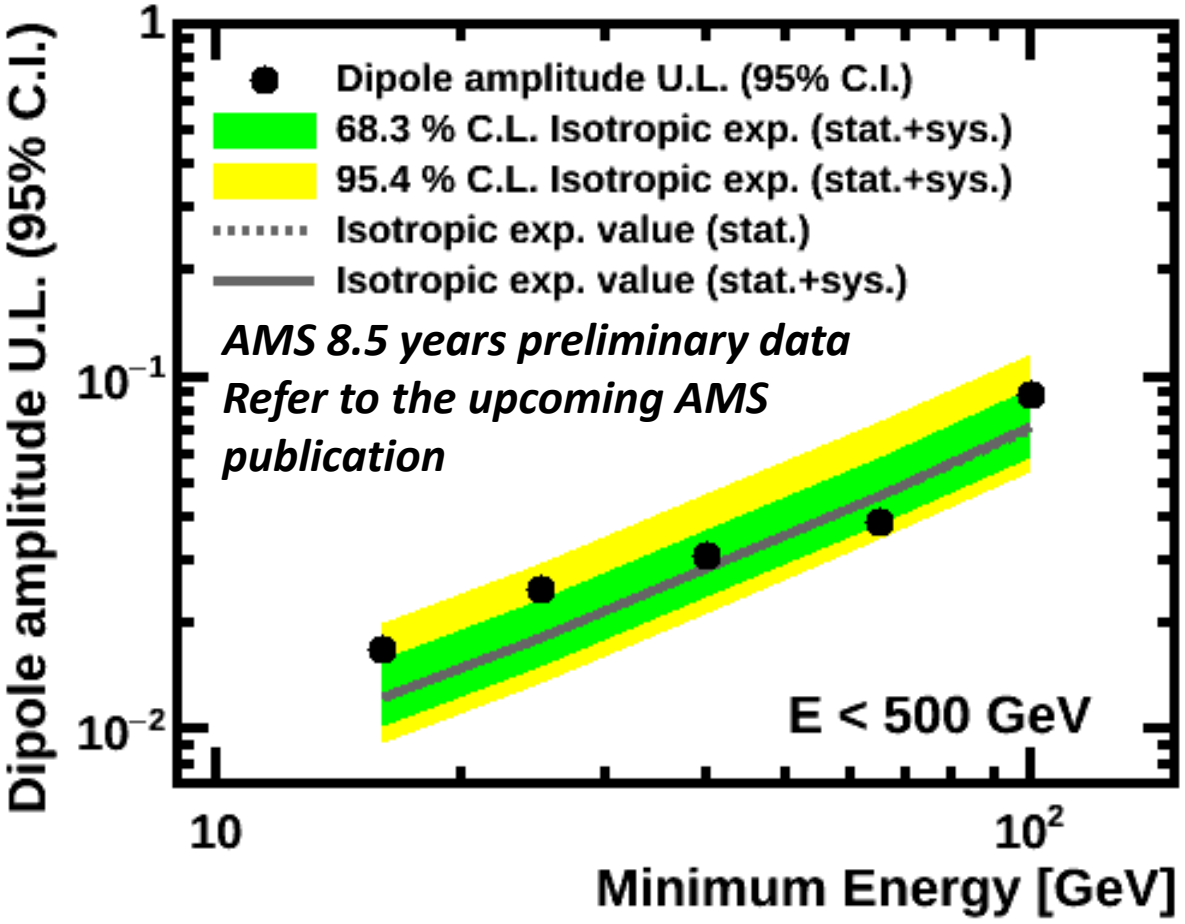
Results consistent with isotropy in all the dipole components and energy ranges

POSITRON ANISOTROPY: DIPOLE UPPER LIMITS

Upper limits are set for each energy range

Amplitude of the dipole anisotropy on e^+ for $16 < E < 500$ GeV

$\delta < 1.7\%$ at the 95% C.I.

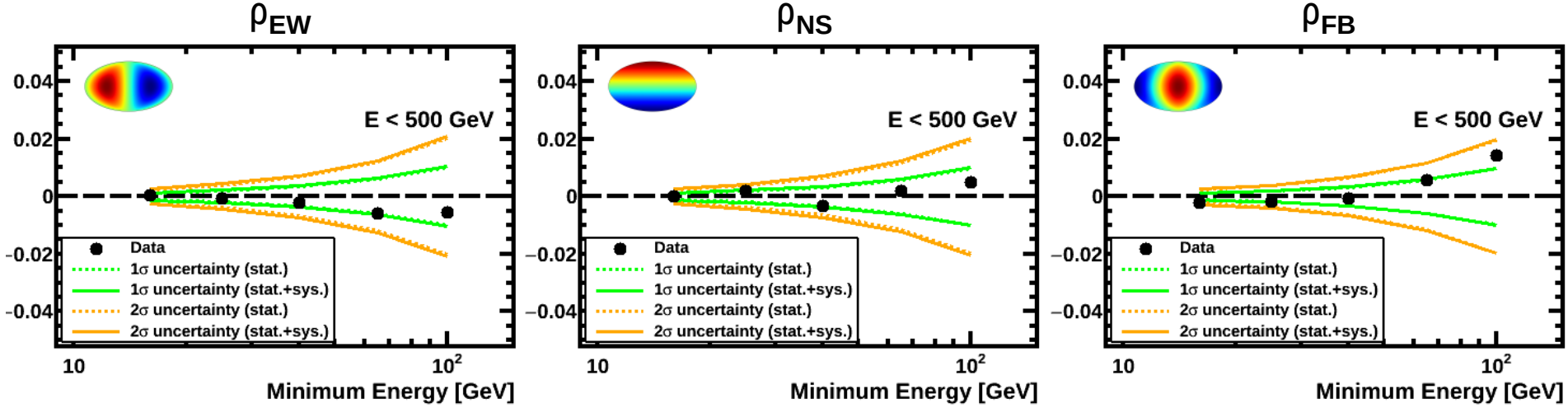


Electron Anisotropy

In addition to the sensitivity to nearby astrophysical sources, the measurement of electron anisotropy provides a test of systematics for the positron analysis

Electron sample AMS 8.5 years: 2.3×10^6 events ($16 < E < 500$ GeV)

Dipole components – Galactic Coordinates



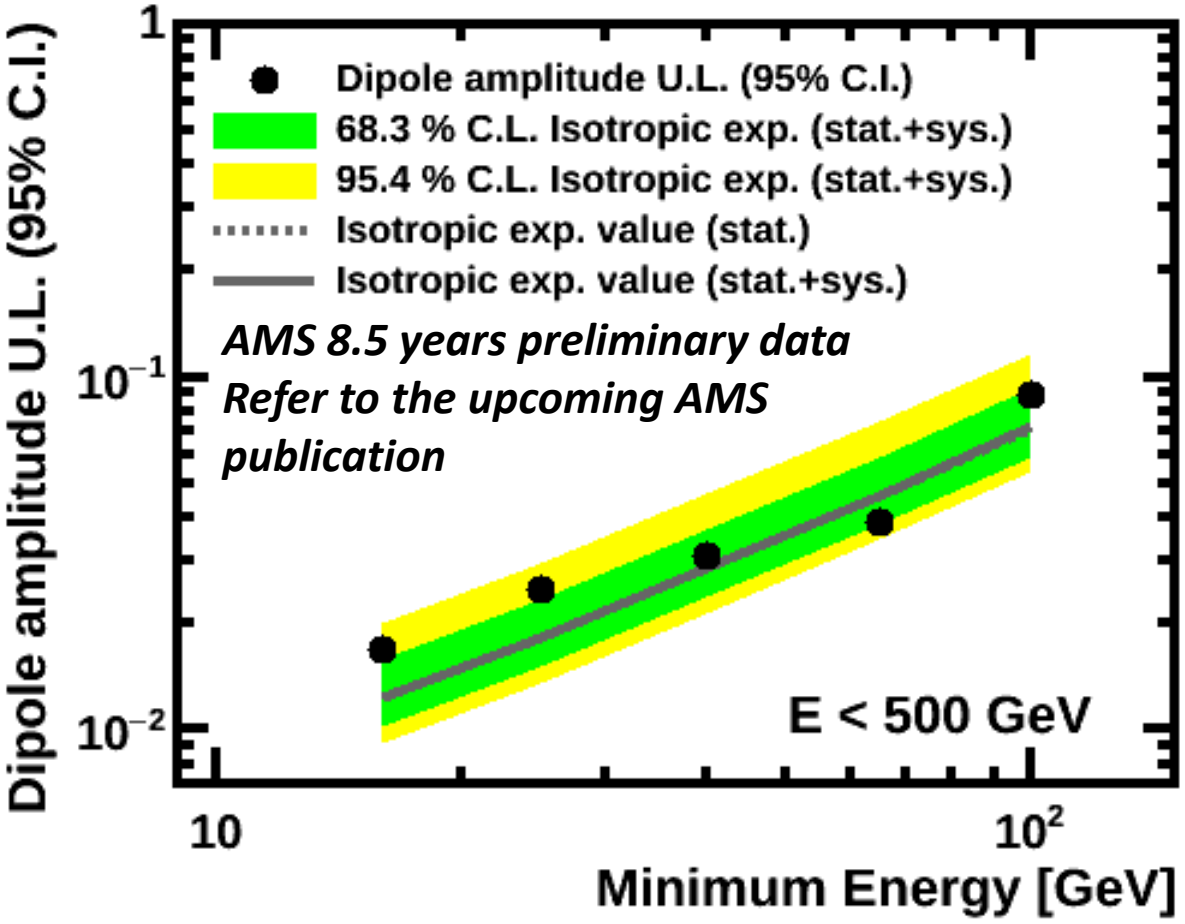
Results consistent with isotropy in all the dipole components and energy ranges

ELECTRON ANISOTROPY: DIPOLE UPPER LIMITS

Upper limits are set for each energy range

Amplitude of the dipole anisotropy on e^- for $16 < E < 500$ GeV

$\delta < 0.37\%$ at the 95% C.I.



Proton Anisotropy

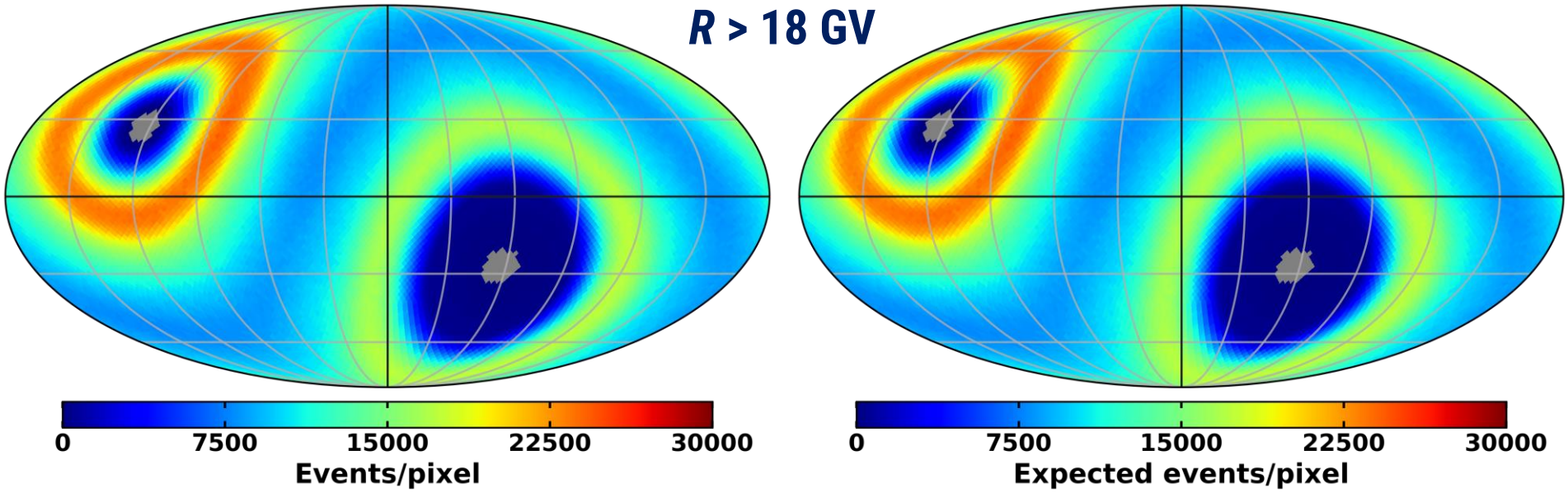
The arrival directions of proton events collected in the first 8.5 years are compared to the expected map for an isotropic flux in Galactic coordinates

Selected events are grouped into 9 cumulative rigidity ranges with R > 18, 30, 45, 80, 150, 200, 300, 500 and 1000 GV

1.4×10^8 protons

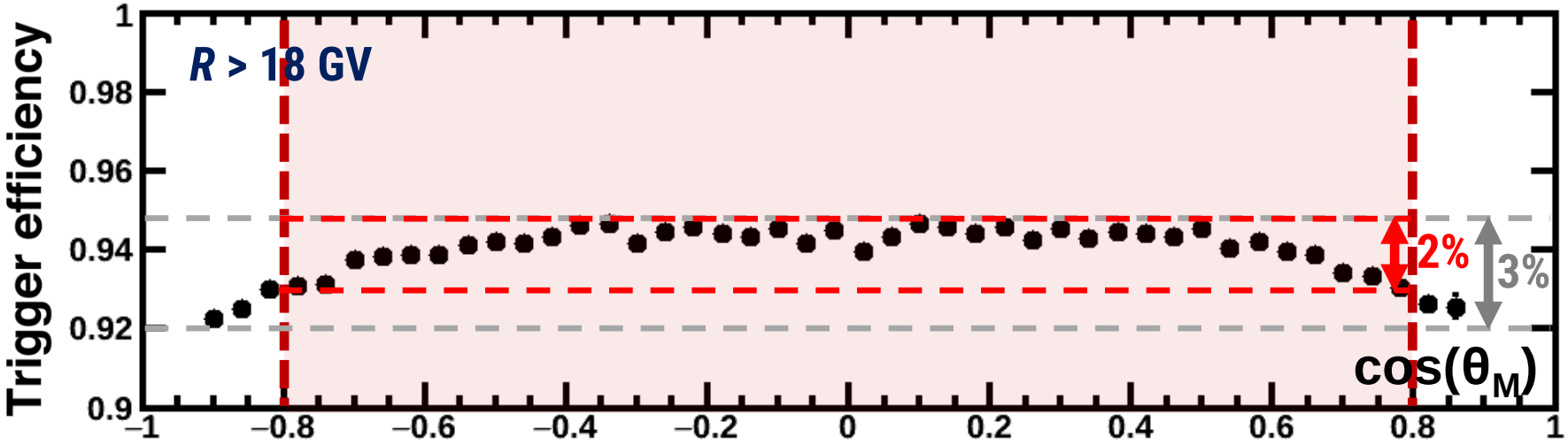
Isotropic map

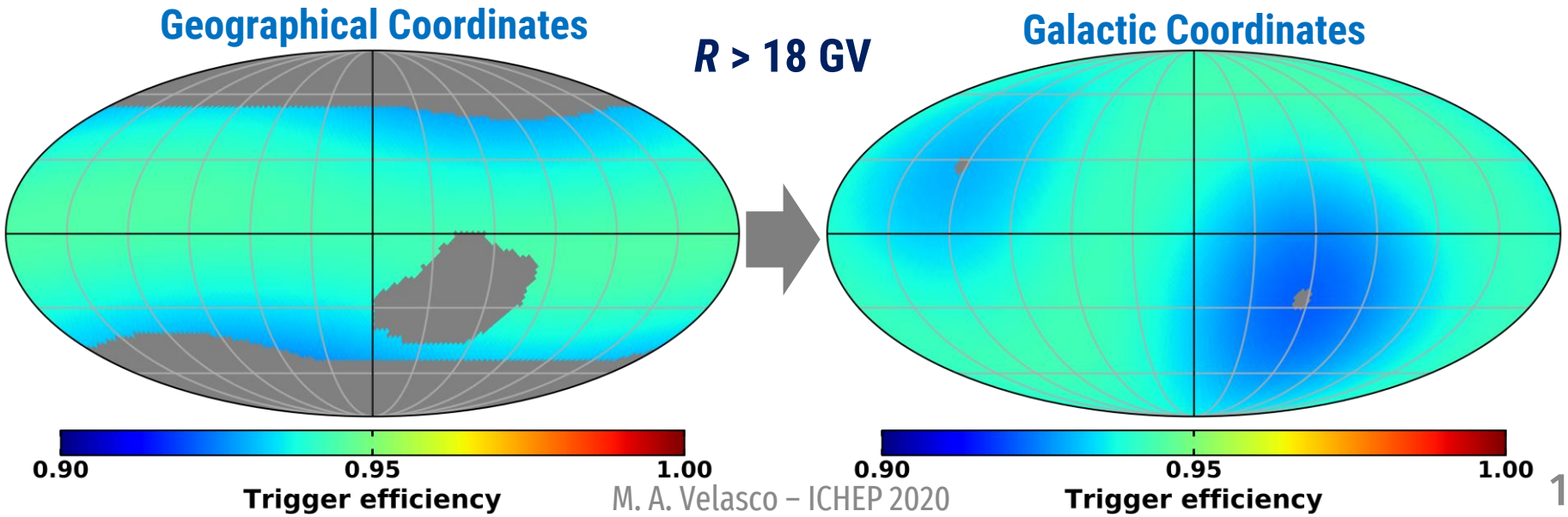
R > 18 GV



PROTON ANISOTROPY: DETECTOR EFFICIENCIES

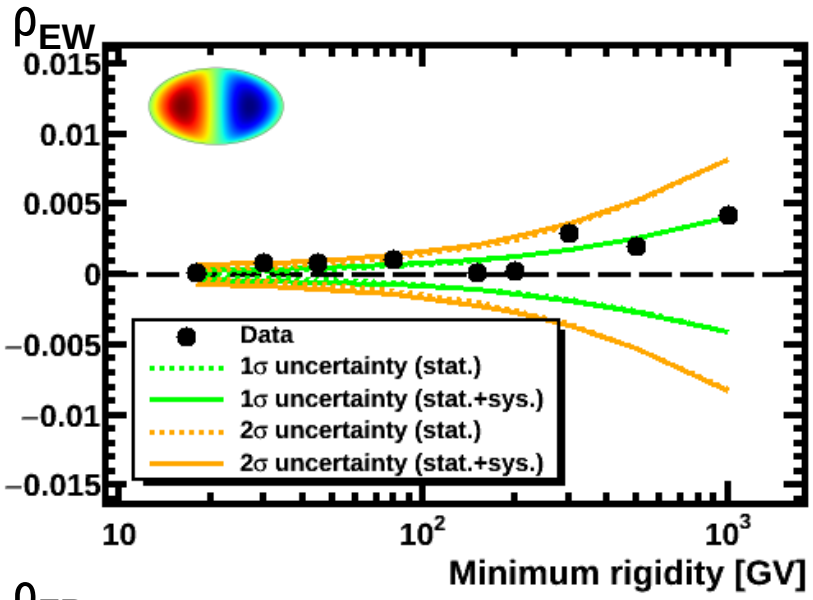
Computation of the isotropic map requires detailed understanding of detector efficiencies at different geographical locations

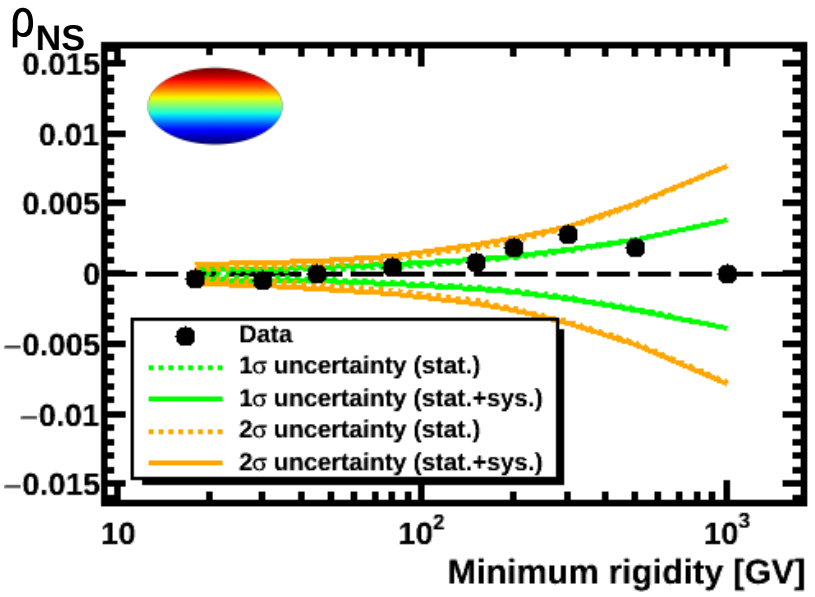


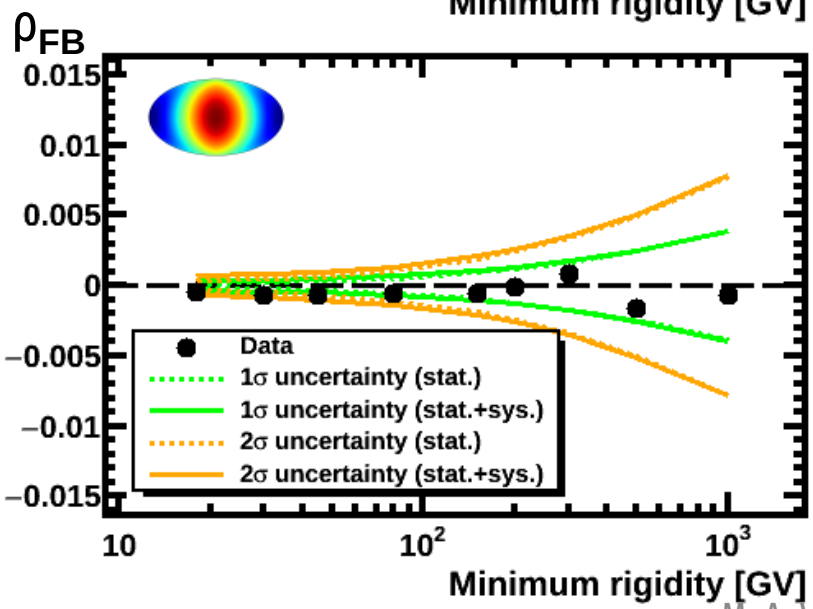


Proton Anisotropy: Dipole Components

Galactic Coordinates







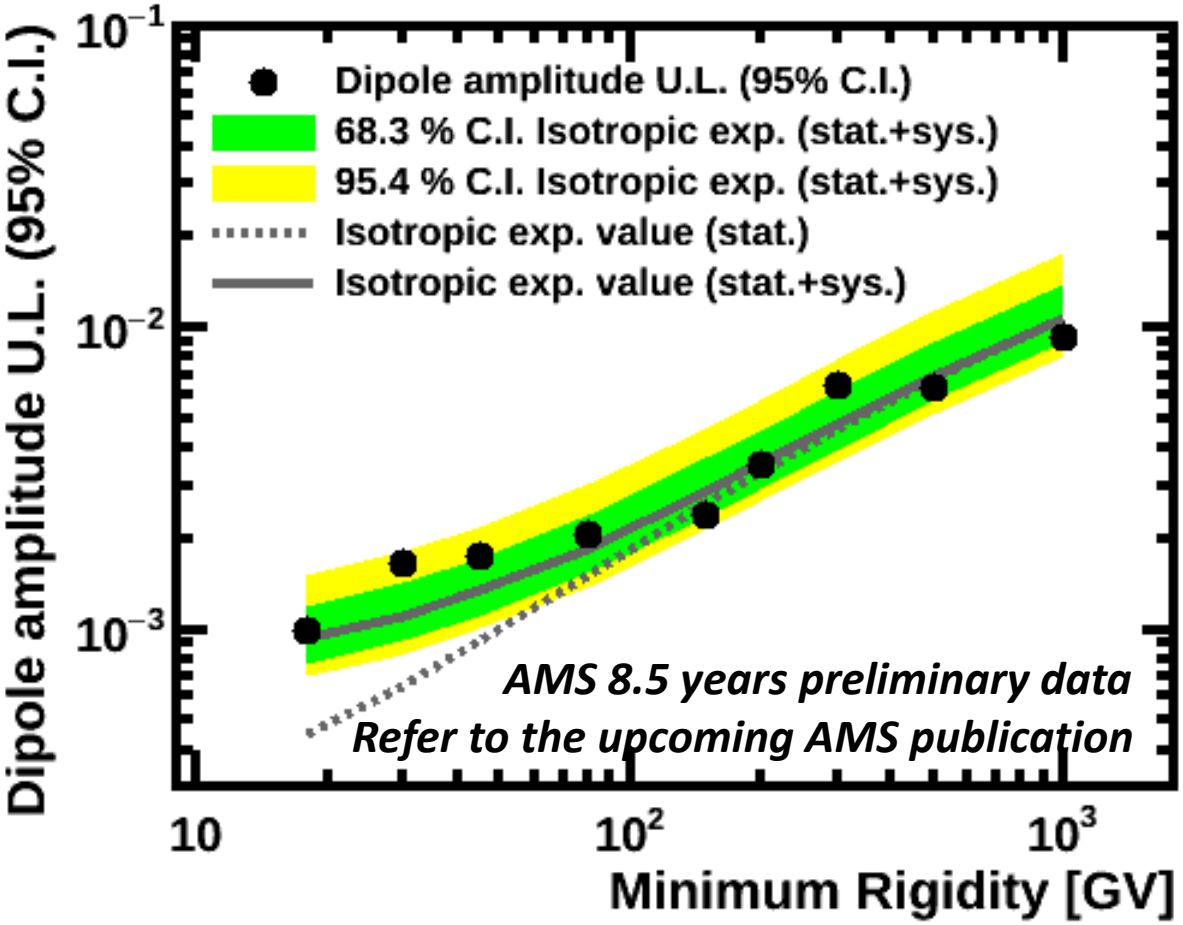
Results consistent with isotropy in all the dipole components and rigidity ranges

PROTON ANISOTROPY: DIPOLE UPPER LIMITS

Upper limits are set for each rigidity range

Amplitude of the dipole anisotropy on protons for $R > 200$ GV (2.1×10^6 events)

$\delta < 0.35\%$ at the 95% C.I.



SUMMARY

1. The precise measurements performed by AMS on positron, electron, and proton fluxes show unexpected features that challenge the traditional paradigm of cosmic rays
2. The study of the directionality of cosmic rays, i.e. the anisotropy, provides complementary information to the spectra and may help to understand the origin of these features
3. A measurement of the anisotropy in the arrival directions of cosmic ray positrons, electrons and protons has been performed in galactic coordinates
   - ► No deviation from isotropy has been observed and upper limits to the dipole amplitude have been established
4. AMS will continue taking data until the end of ISS operation, currently 2028. By that time positron statistics will allow us to reach the 1% level predicted by pulsar models