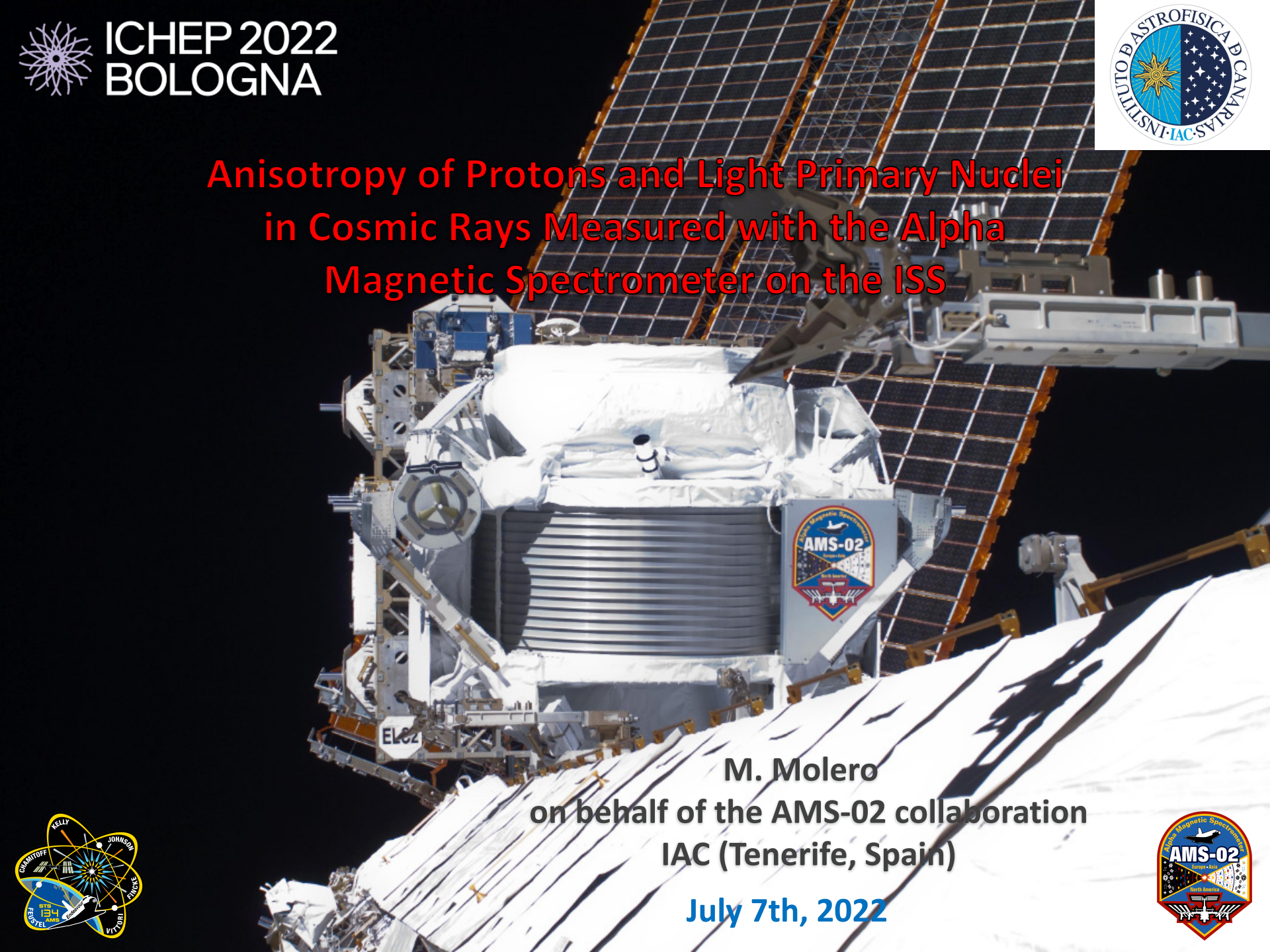
ICHEP 2022
BOLOGNA

Anisotropy of Protons and Light Primary Nuclei in Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the ISS



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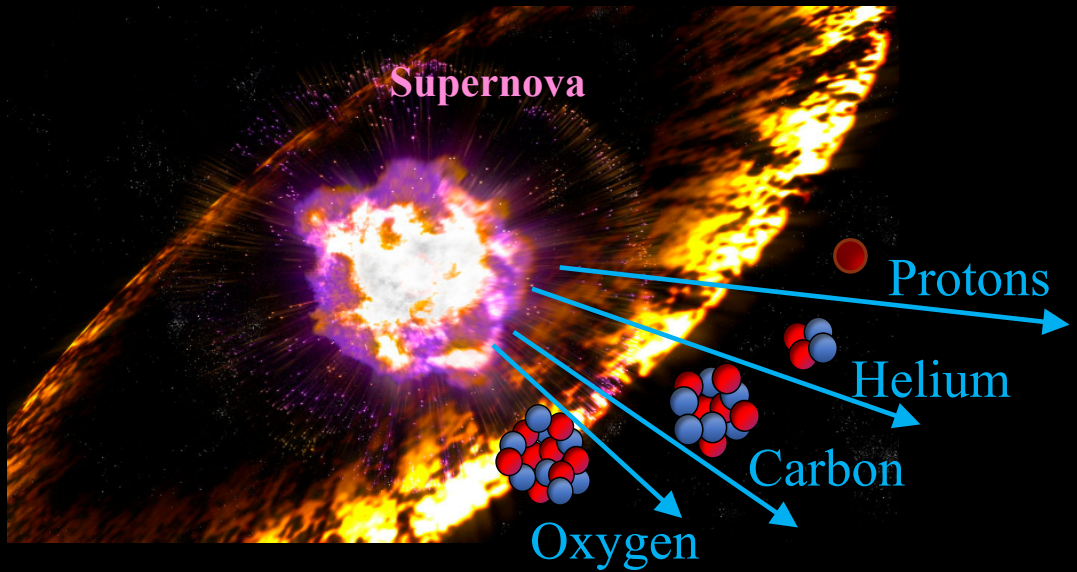
on behalf of the AMS-02 collaboration
IAC (Tenerife, Spain)

July 7th, 2022

Motivation: Proton and Light Nuclei Fluxes

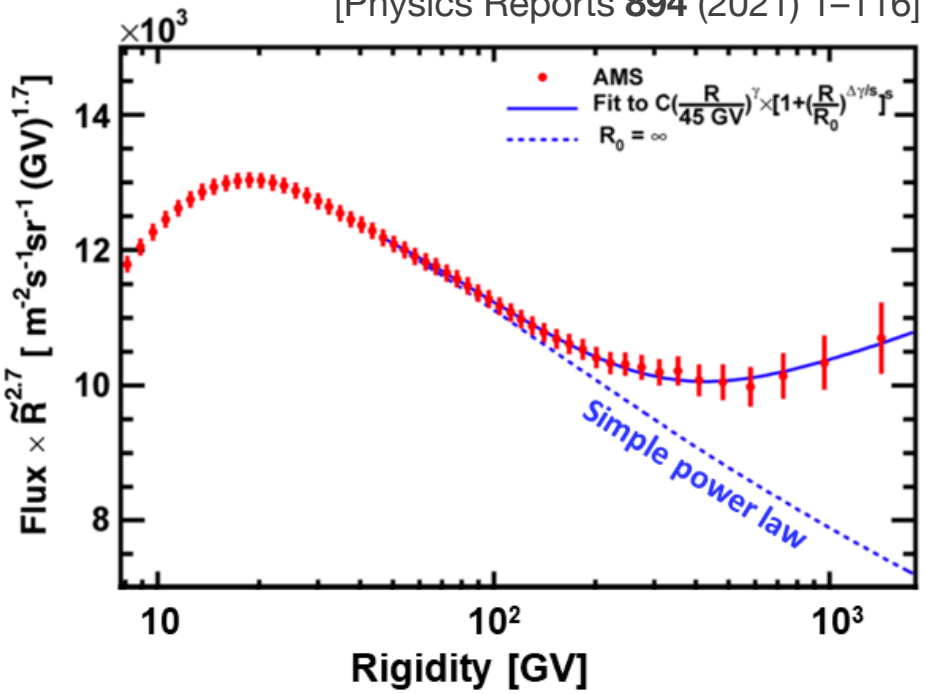
Protons and light primary nuclei are originated and accelerated in SNR. Then they travel through space and, finally, arrive to the Earth



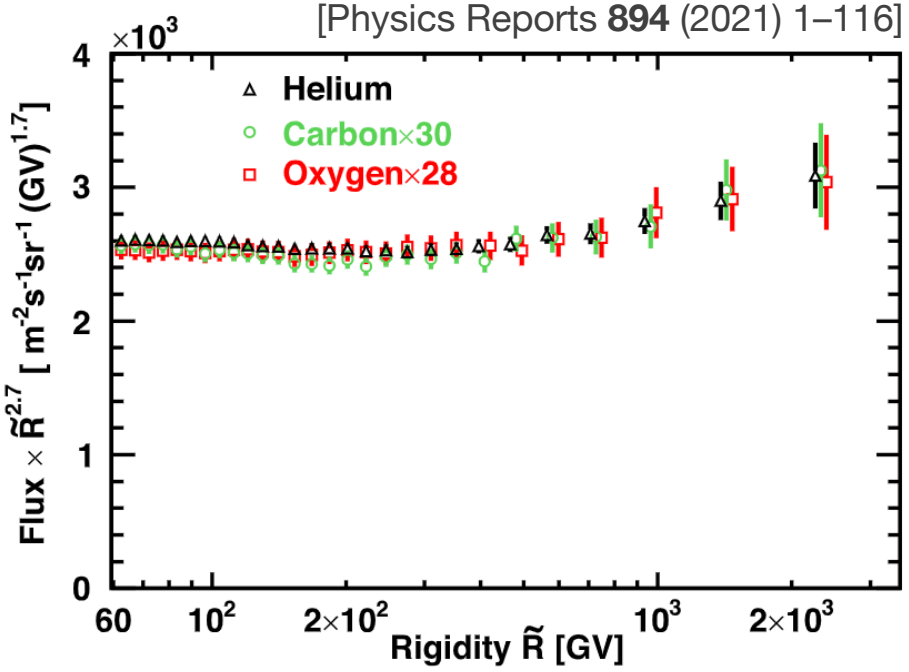
Motivation: Proton and Light Nuclei Fluxes

The **proton** and **light primary nuclei fluxes** progressively deviate from a single power law above 200 GV

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



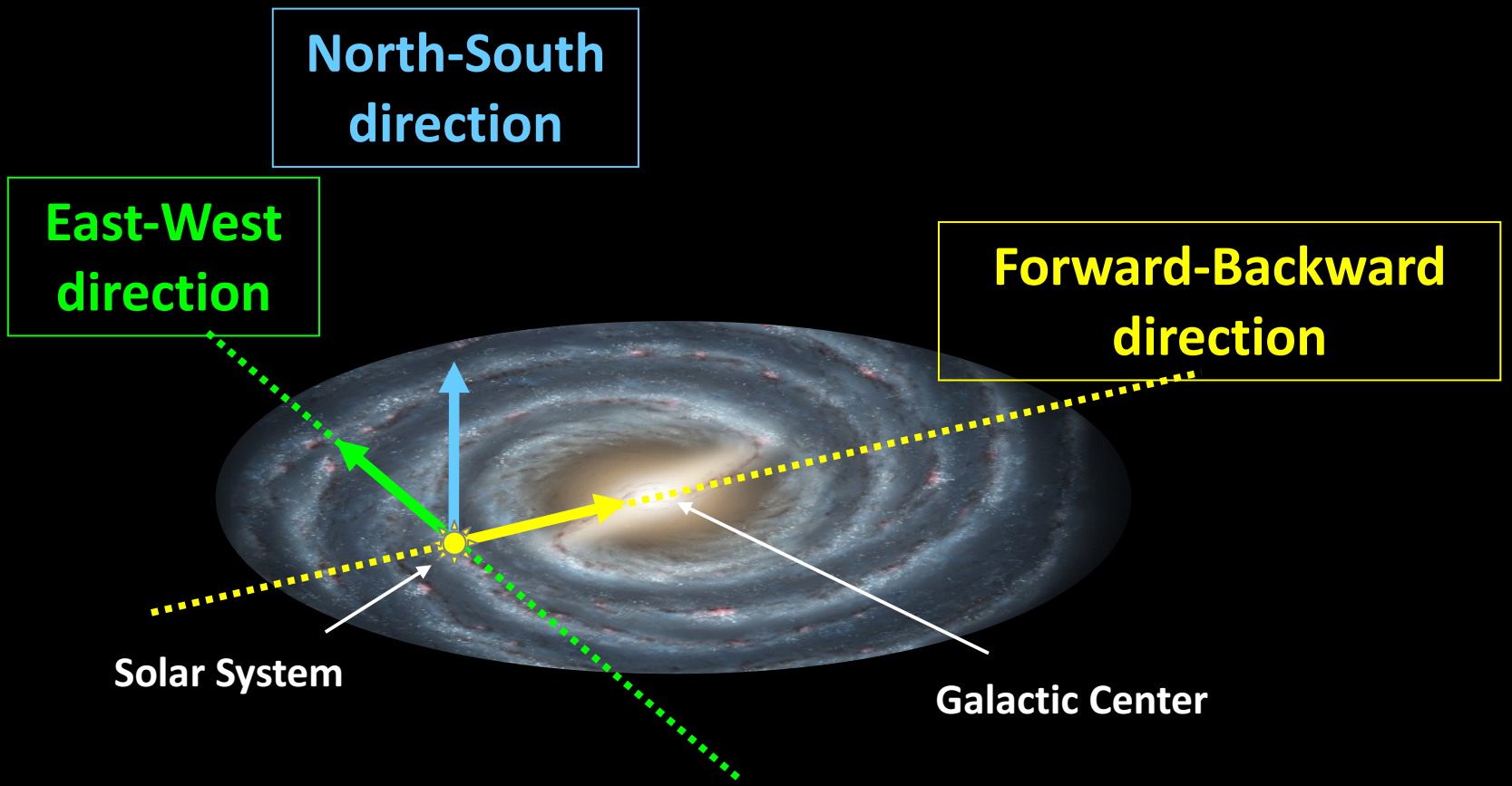
[Physics Reports **894** (2021) 1–116]



- These observations require the modification of cosmic rays **transport models** or the inclusion of **nearby sources of high rigidity events**
- The existence of **nearby sources** of cosmic rays may induce some degree of **anisotropy** in the high rigidity sample

Coordinate System of Analysis

Galactic Coordinates



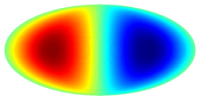
Expansion of the CRs Flux

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

Multipolar Components

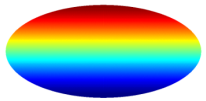
Real basis of spherical harmonics

Dipole Components



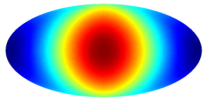
East-West

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



North-South

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



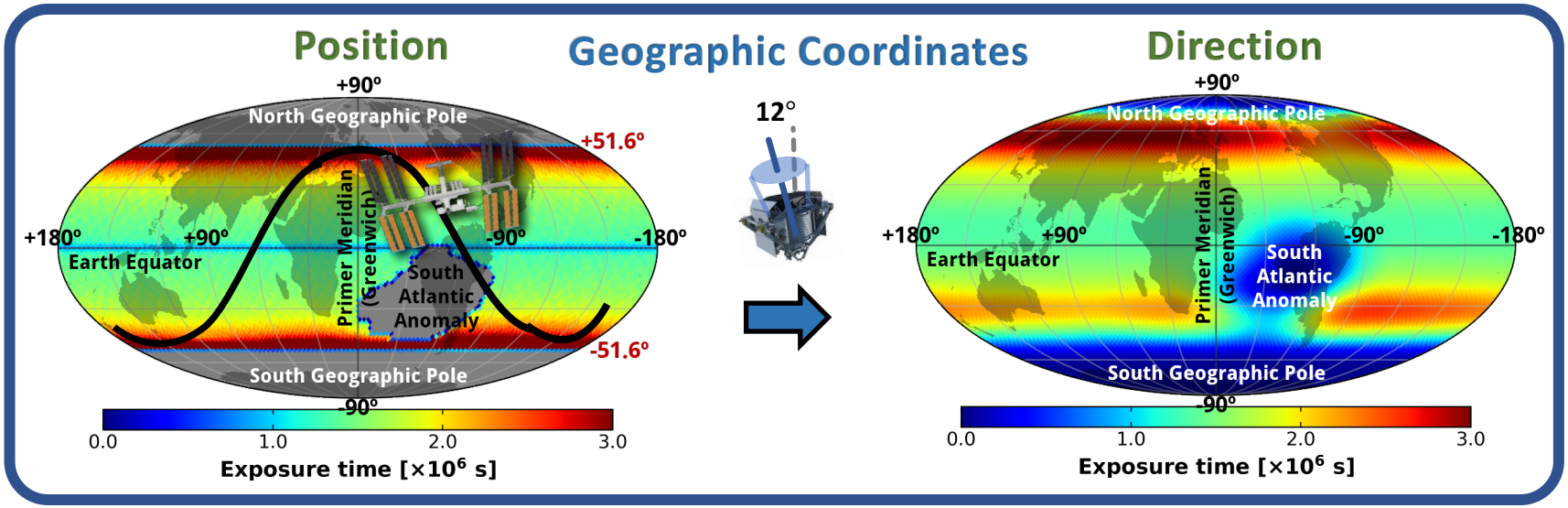
Forward-Backward

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

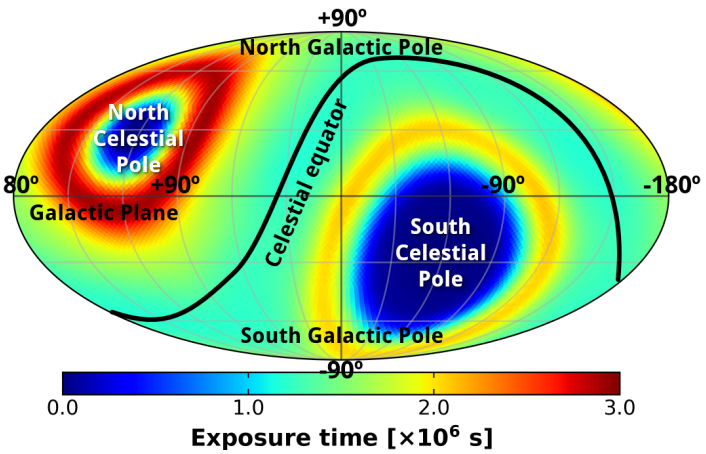
Dipole Amplitude

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

Exposure of AMS-02



Galactic Coordinates



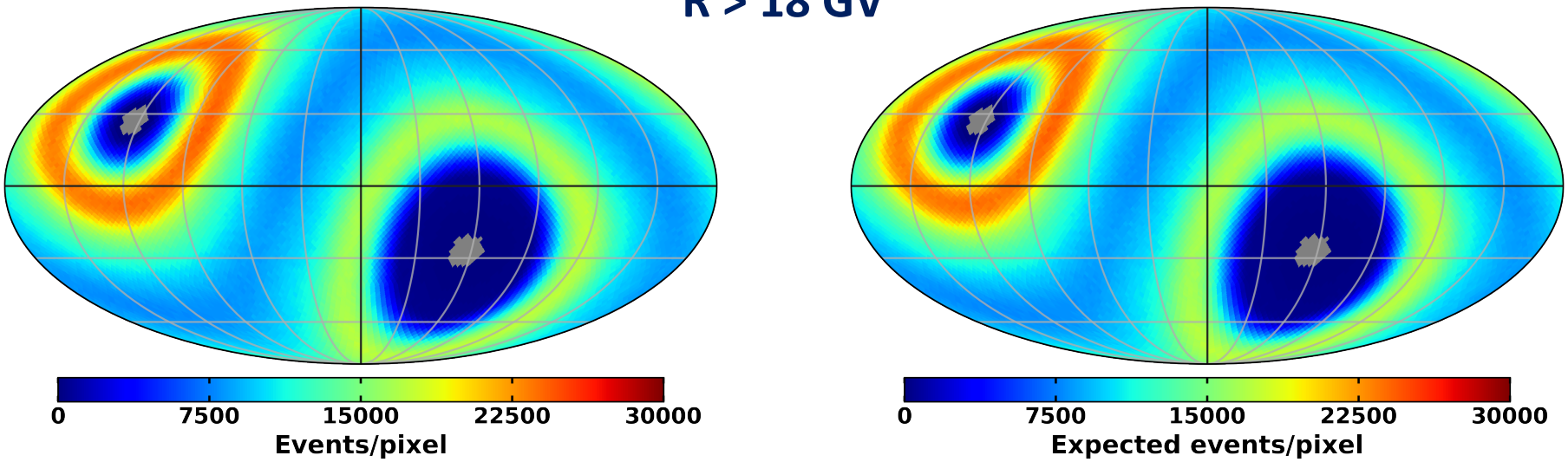
Results are presented for **10 years of data taking**

Proton Anisotropy

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

1.40×10^{8} protons | **Isotropic map**

R > 18 GV

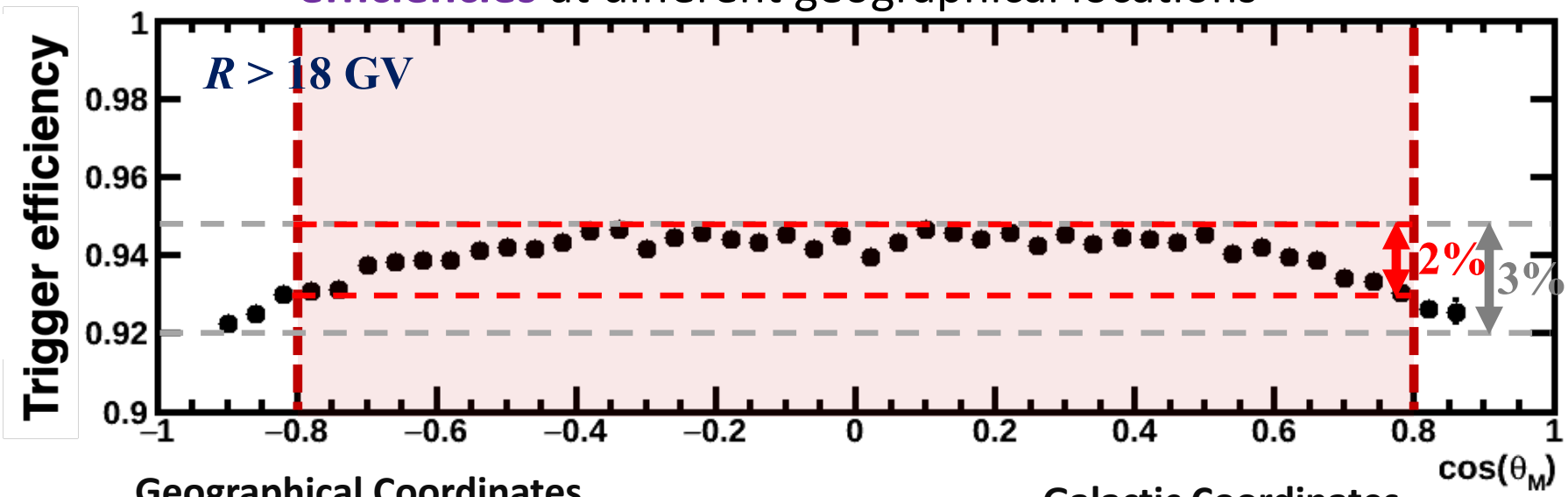


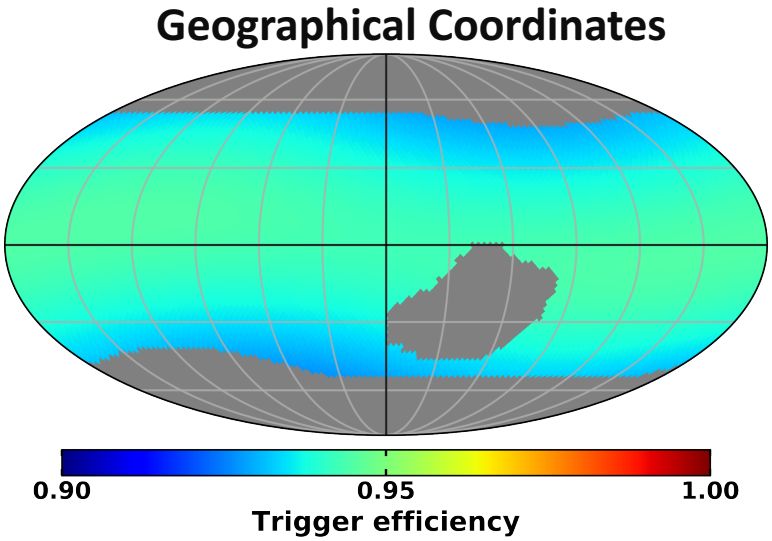
For the anisotropy analysis, selected events are grouped in **9 cumulative rigidity ranges**:

$R_{min} > 18, 30, 45, 80, 150, 200, 300, 500$ and 1000 GV

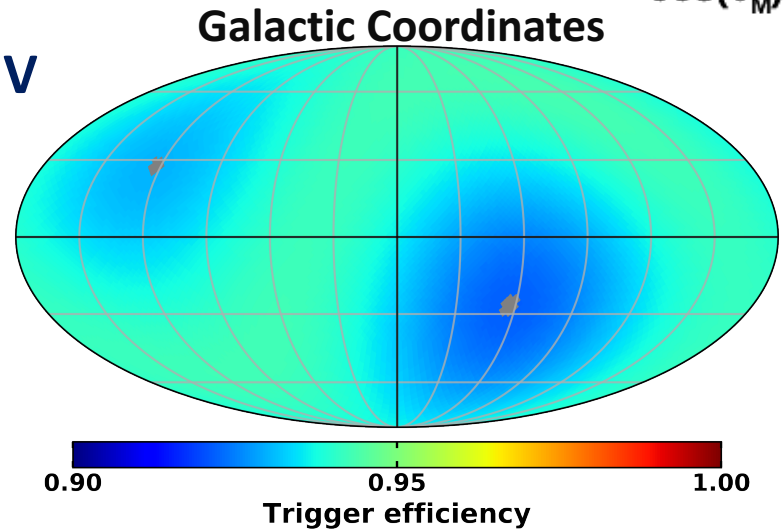
Proton Anisotropy: Detector Efficiencies

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

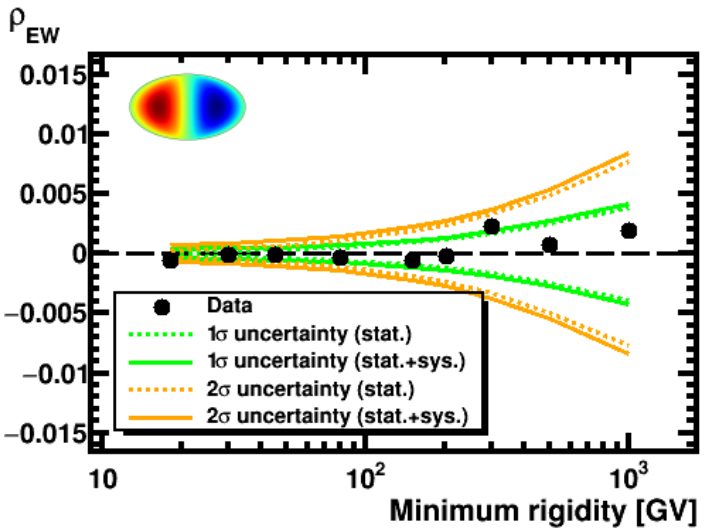


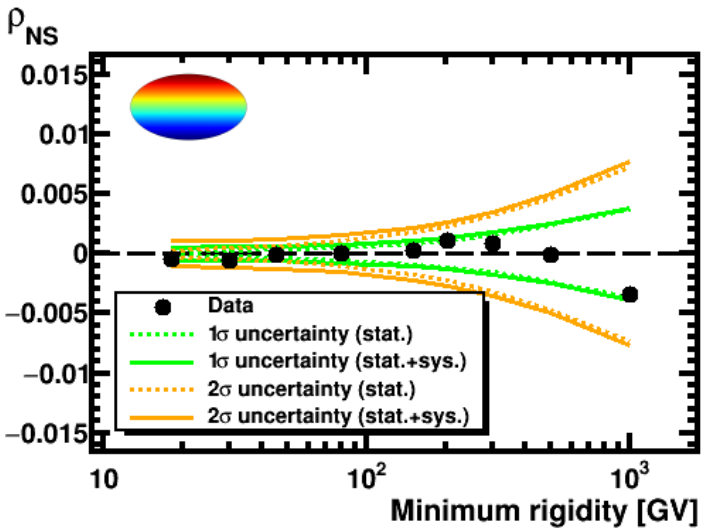


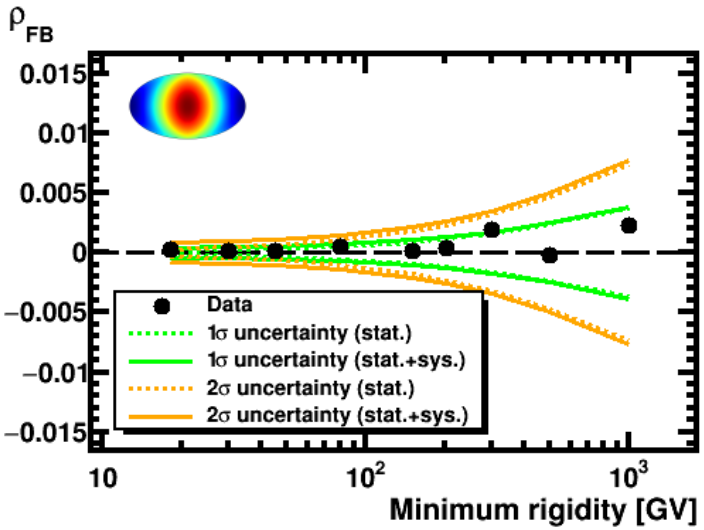
R > 18 GV



Proton Anisotropy: Dipole Components



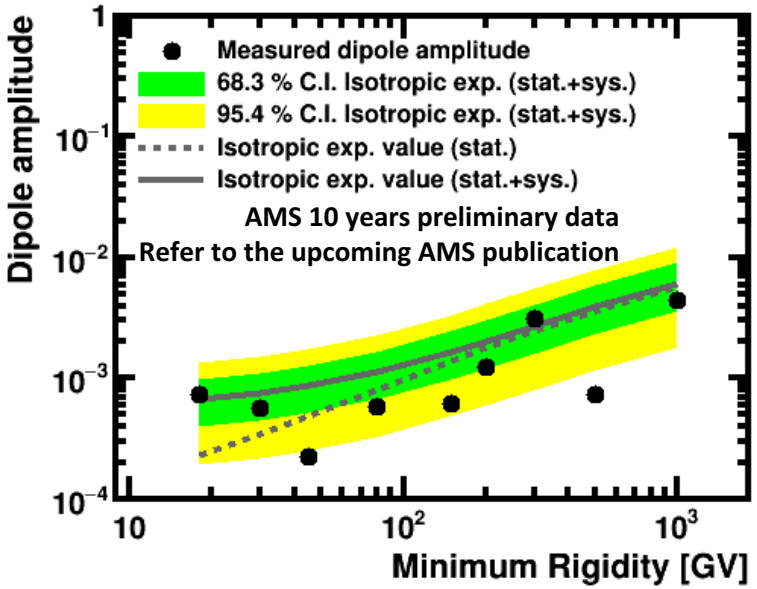


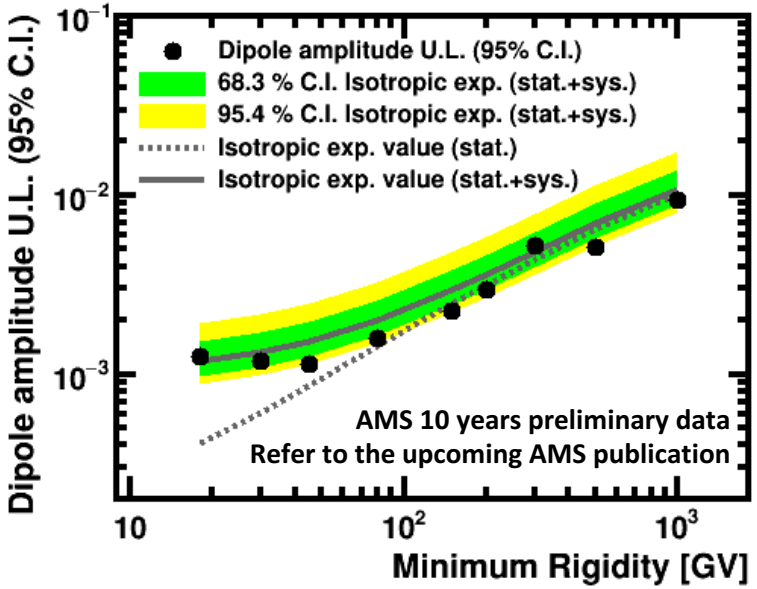


Proton dipole components in galactic coordinates are consistent with **isotropy**

Proton Anisotropy: δ_M and δ_{UL}

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





δ_M = 0.12% (R > 200 GV)

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

2.30×10^6 proton events (R > 200 GV)

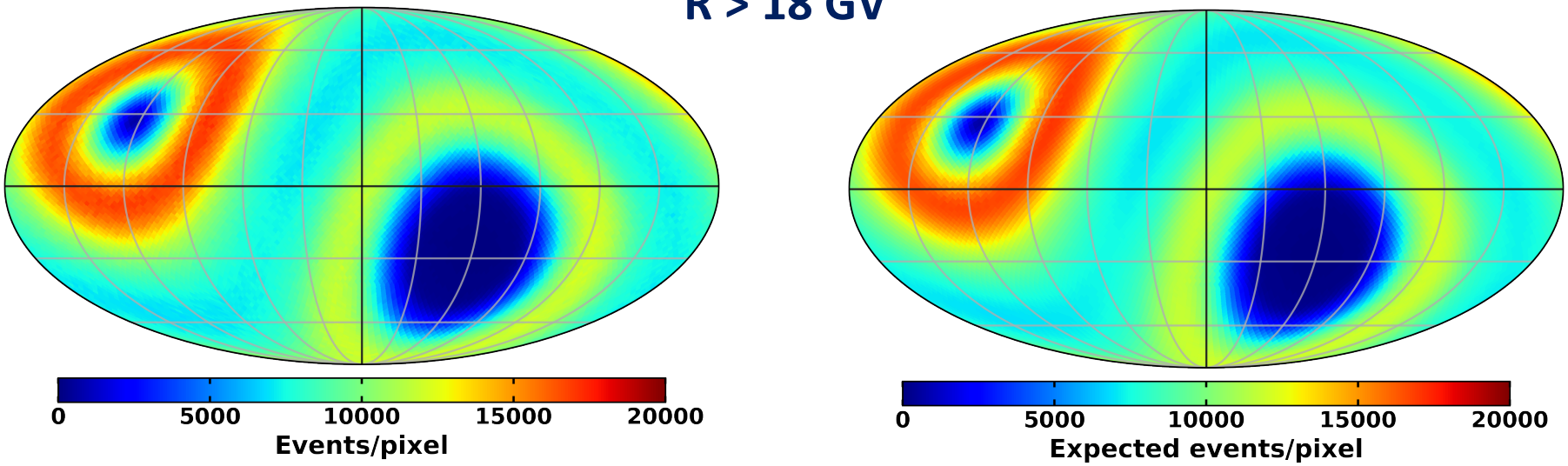
Helium Anisotropy

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

1.24×10^{8} helium

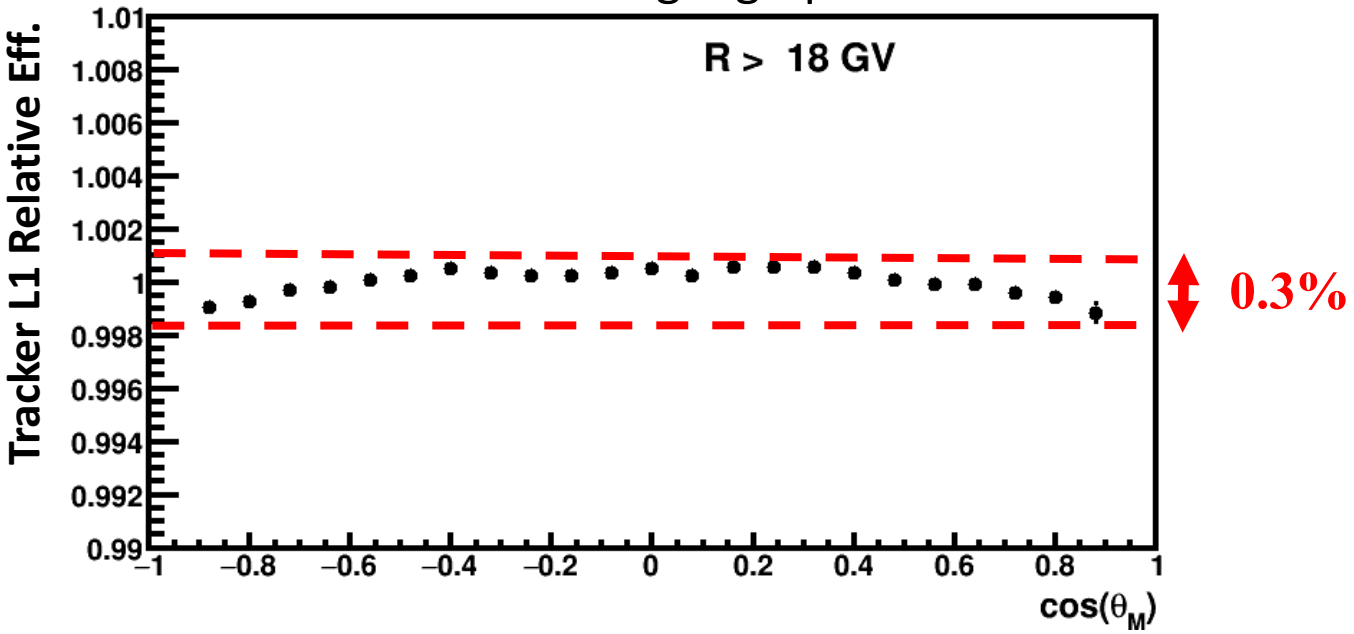
Isotropic map

R > 18 GV



Helium Anisotropy: Detector Efficiencies

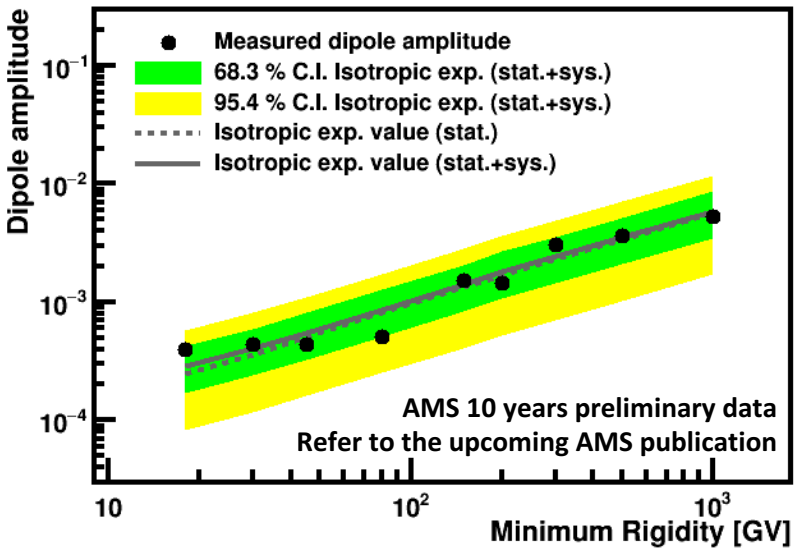
Computation of **isotropic map** requires detailed understanding of **detector efficiencies** at different geographical locations

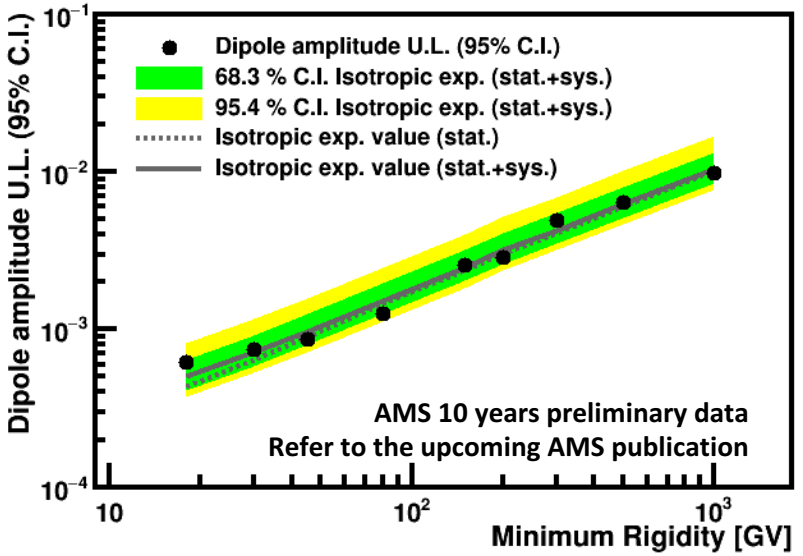


Reduced amplitude of the geographical dependence of the detector efficiencies allows to use **extended detector acceptance**

Helium Anisotropy: δ_M and δ_{UL}

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





δ_M = 0.17% (R > 200 GV)

δ_{UL} = 0.30% at the 95% C.I. (R > 200 GV)

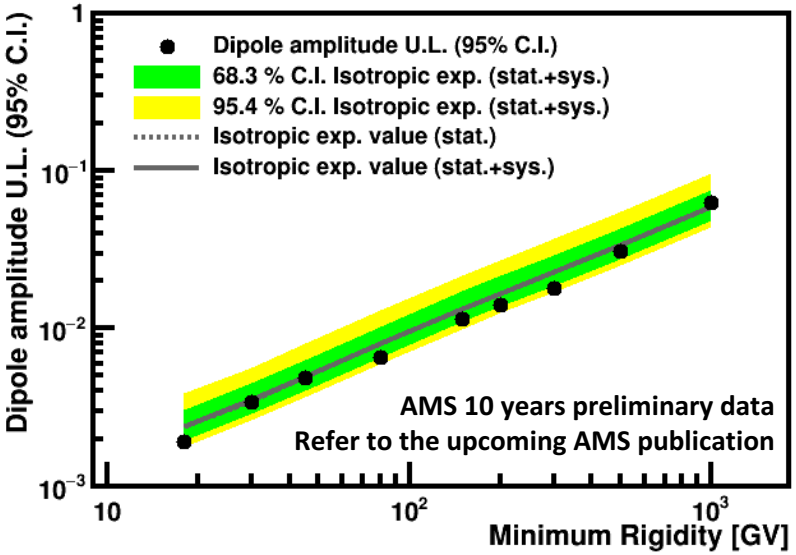
2.54×10^6 helium events (R > 200 GV)

Carbon and Oxygen Anisotropy: δ_{UL}

- Similar analysis is applied to carbon and oxygen samples
- Results are **consistent with isotropy** and **upper limits** to the dipole amplitude are established

Carbon Events:

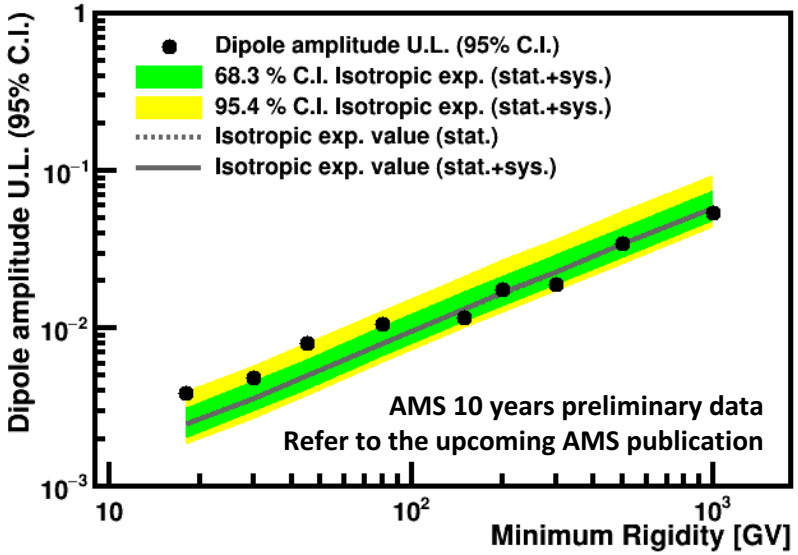
8.18×10^4 (R > 200 GV)



δ_{UL} = 1.41% at the 95% C.I. (R > 200 GV)

Oxygen Events:

8.00×10^4 (R > 200 GV)

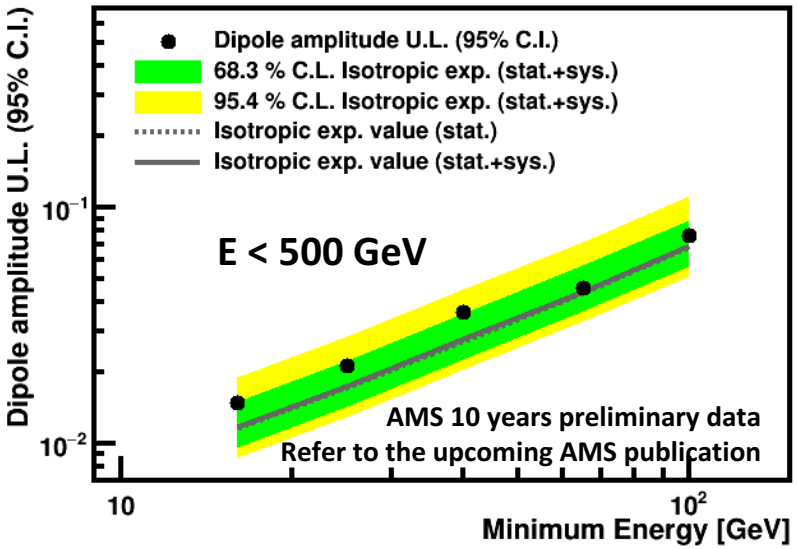


δ_{UL} = 1.73% at the 95% C.I. (R > 200 GV)

Positron and Electron Anisotropy: δ_{UL}

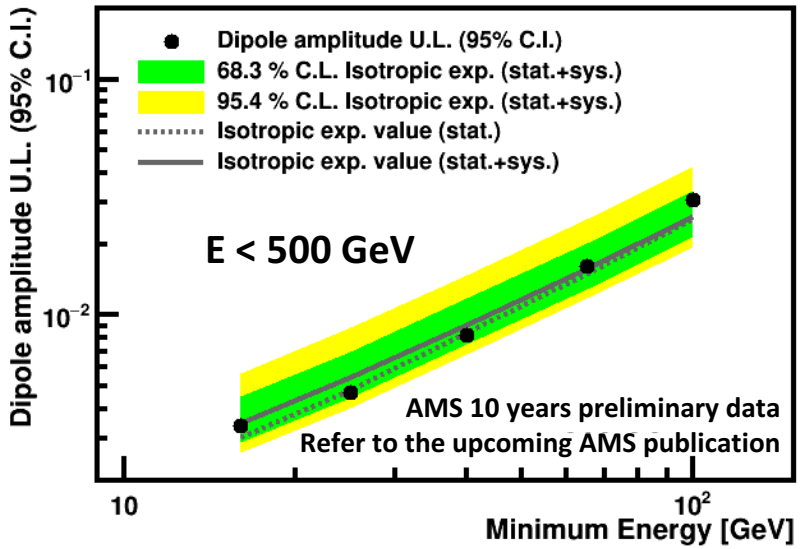
More Details in the Poster Section on July 8th:
Anisotropy on positron and electron fluxes with AMS

Positron Events:
1.70×10^5 (E > 16 GeV)



δ_{UL} = 1.50% at the 95% C.I.
(R > 200 GV)

Electron Events:
2.52×10^6 (E > 16 GeV)



δ_{UL} = 0.33% at the 95% C.I.
(R > 200 GV)

Conclusions

- AMS measurements have shown new features in the proton and light primary nuclei fluxes that challenge the traditional models

- The study of the directionality of the cosmic rays provides additional information to the rigidity 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 proton, helium, carbon and oxygen in galactic coordinates has been performed

- AMS measurements on the dipole components for rigidities R > 200 GV are consistent with isotropy and upper limits to the dipole amplitude at the 95% C.I. are obtained:
  - Proton: δ_{UL} = 0.30%
  - Helium: δ_{UL} = 0.30%
  - Carbon: δ_{UL} = 1.41%
  - Oxygen: δ_{UL} = 1.73%