GOBIERNO DE ESPAÑA

MINISTERIO DE CIENCIA E INNOVACIÓN

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

cfp CIEMAT física de partículas

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

M. A. Velasco, CIEMAT, Madrid (Spain)

on behalf of the AMS Collaboration

ICRC 2021

THE ASTROPARTICLE PHYSICS CONFERENCE

Berlin | Germany

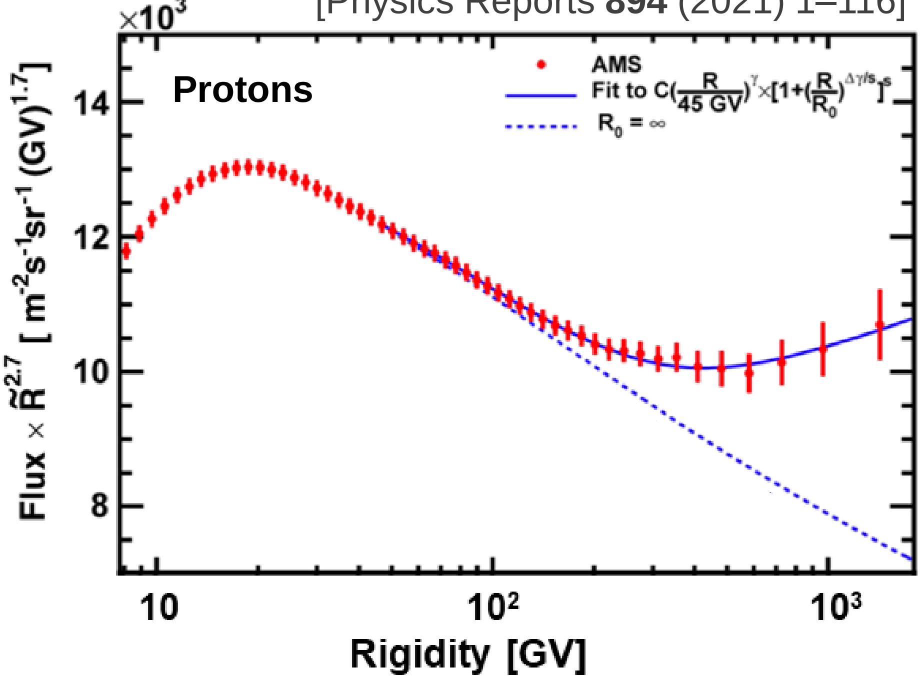
37th International Cosmic Ray Conference

12–23 July 2021

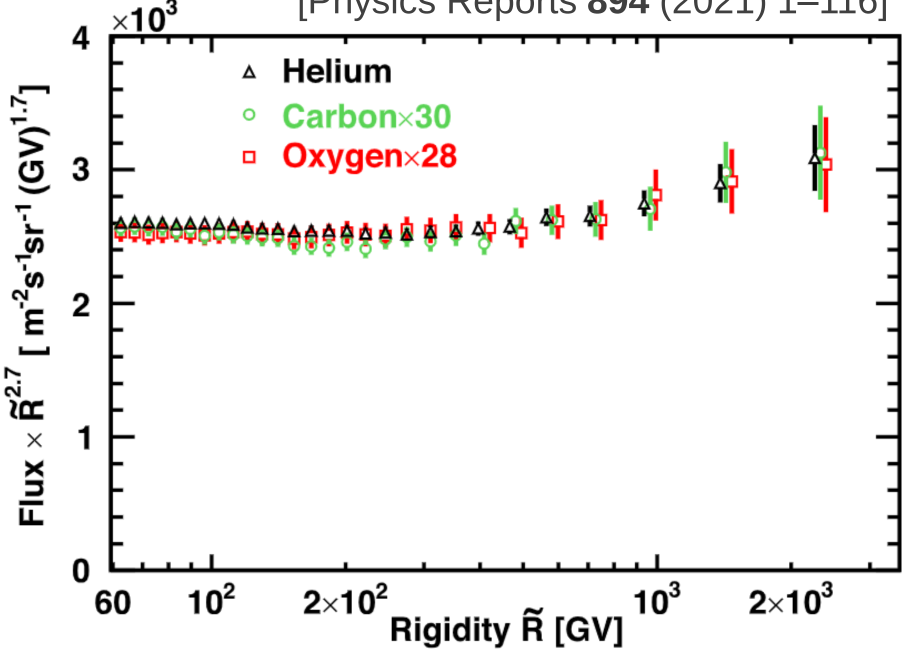
Origin of Proton & Light Nuclei Flux Deviation

Proton and light nuclei fluxes measured by AMS show a deviation from a single power law above 200 GV

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



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

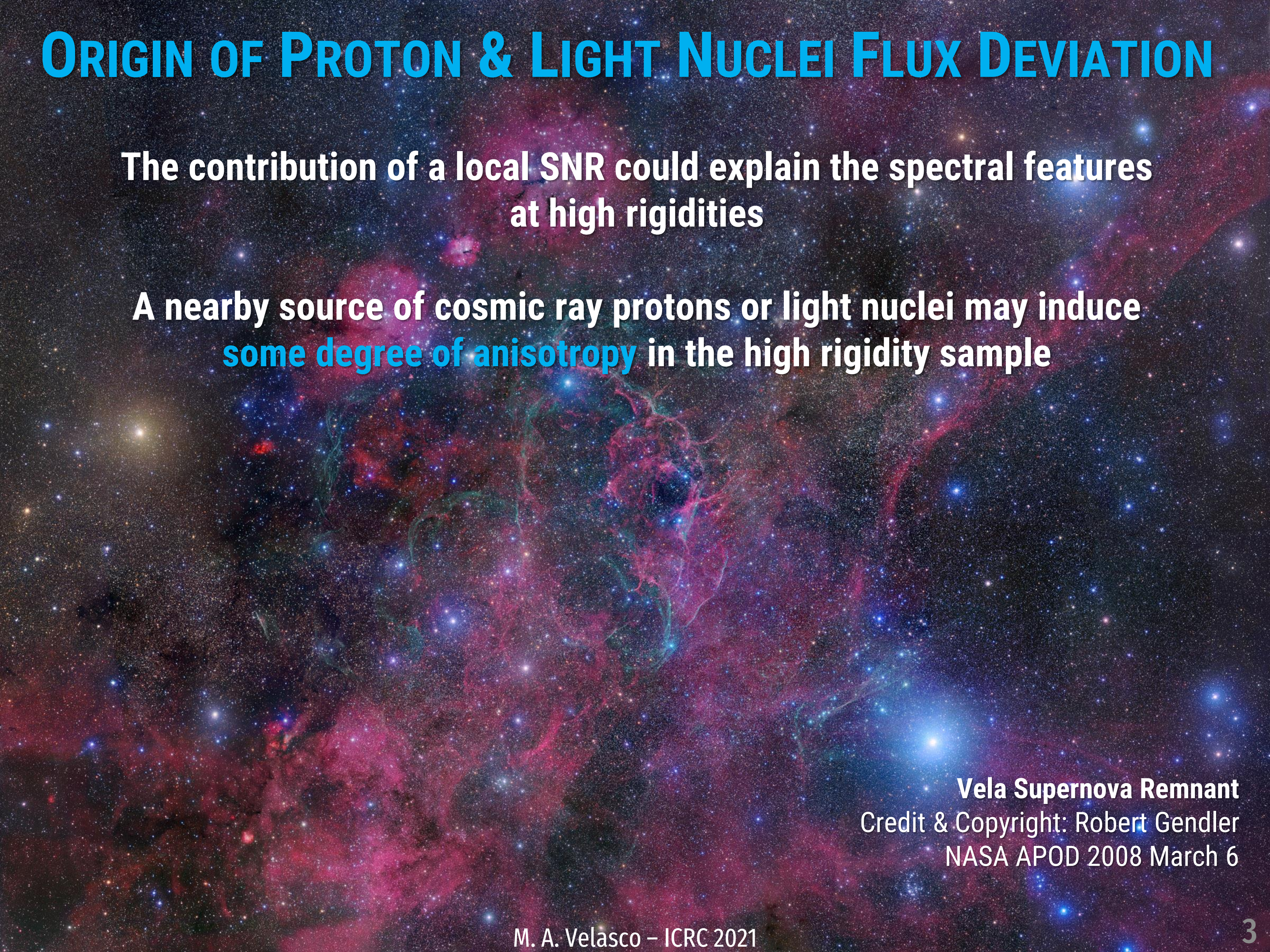


This observation may require modification of cosmic ray transport models or the inclusion of local sources of high rigidity events

Origin of Proton & Light Nuclei Flux Deviation

The contribution of a local SNR could explain the spectral features at high rigidities

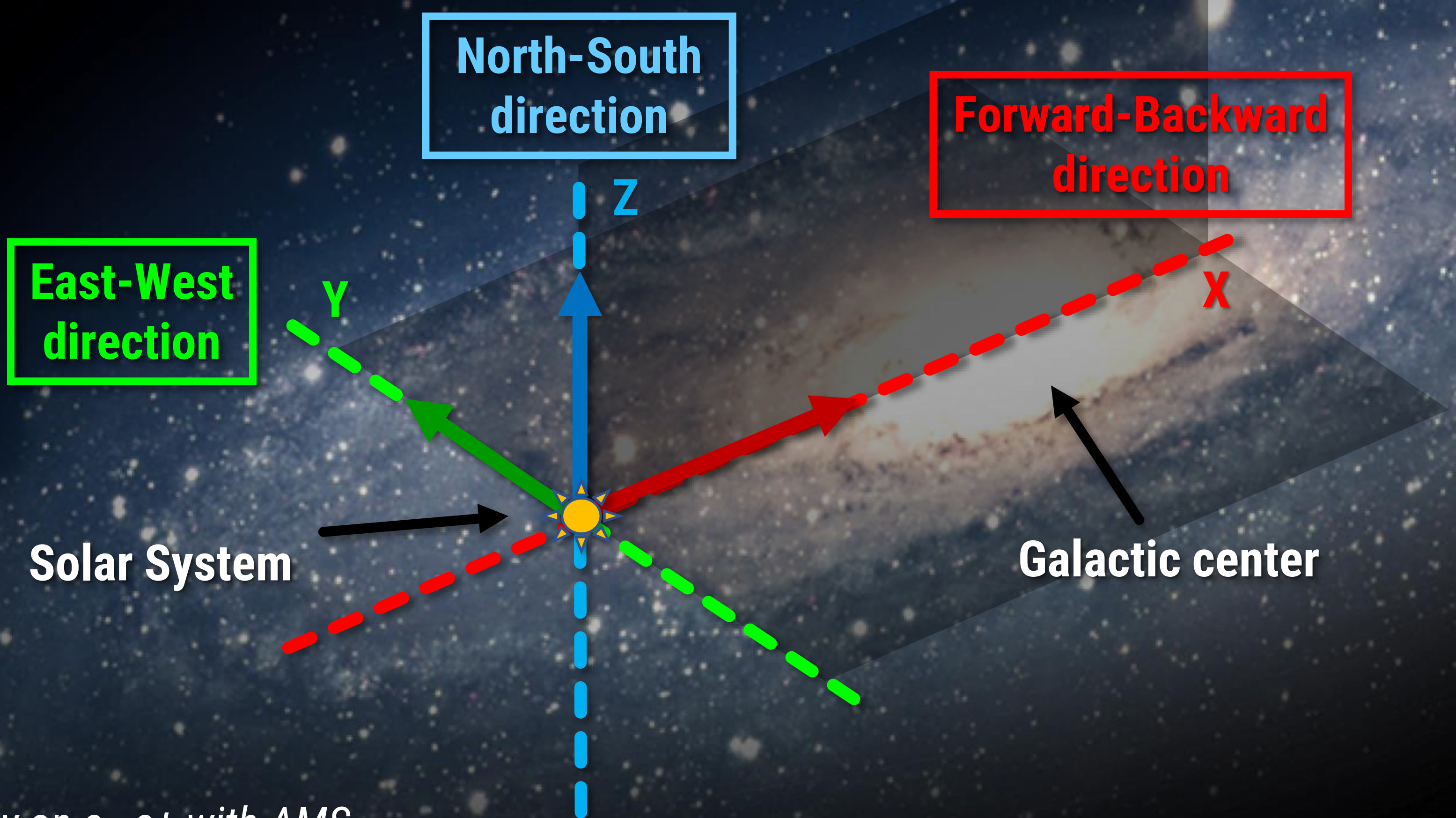
A nearby source of cosmic ray protons or light nuclei may induce some degree of anisotropy in the high rigidity sample



Vela Supernova Remnant
Credit & Copyright: Robert Gendler
NASA APOD 2008 March 6

ANALYSIS OF THE ANISOTROPY

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



See also:
#995 Anisotropy on e-, e+ with AMS
by M. Molero

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 ($a_{\ell m}$)

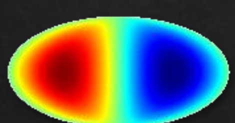
Real spherical harmonics basis ($Y_{\ell m}(\theta,\varphi)$)

Dipole anisotropy (ℓ=1)

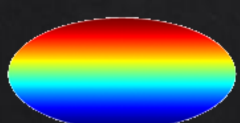
Dipole amplitude

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

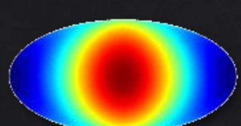
Dipole components



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



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

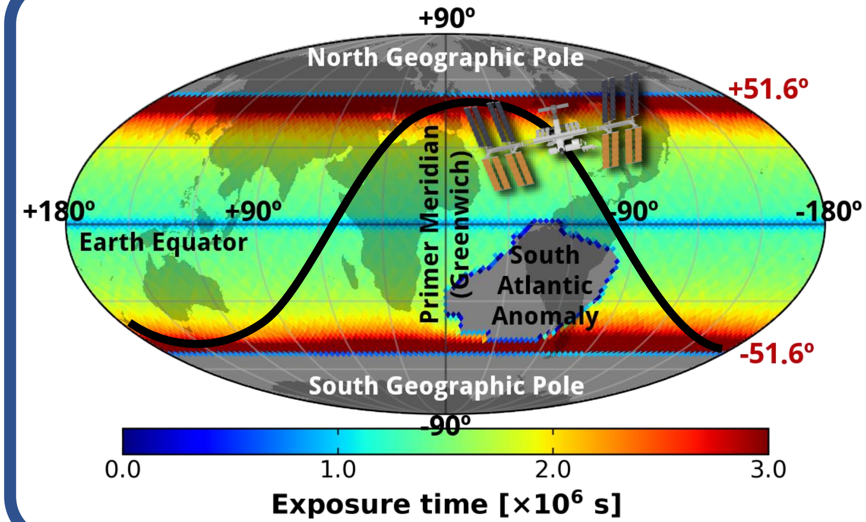


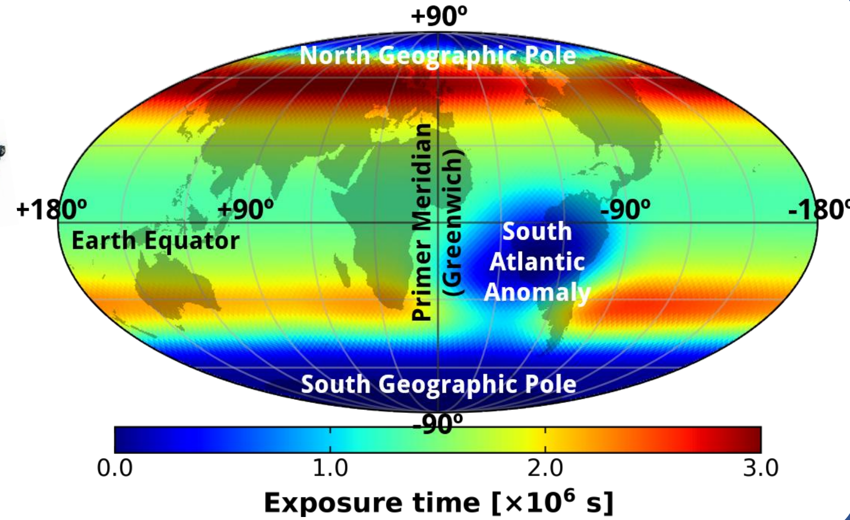
Forward-Backward $\rho_{\mathrm{FB}} = \sqrt{\frac{3}{4\pi}} a_{1+1}$

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

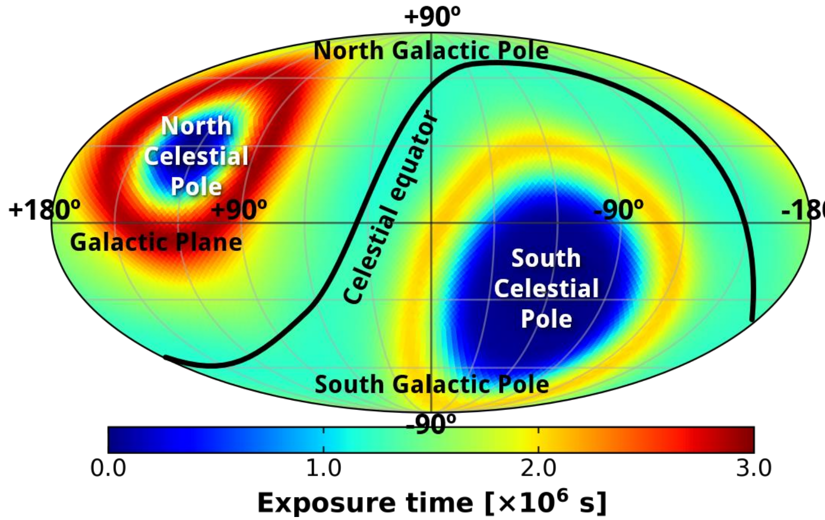
AMS Sky Coverage

Position **Geographic coordinates** **Direction**





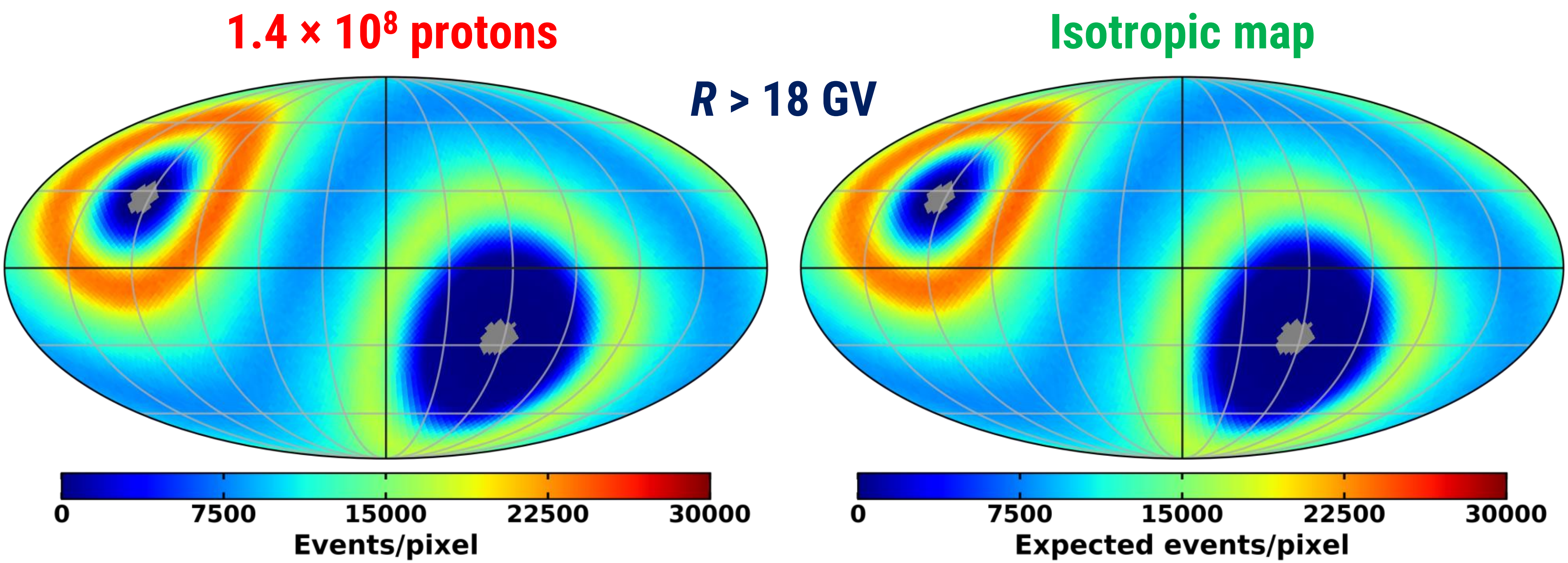
Galactic coordinates



PROTON ANISOTROPY

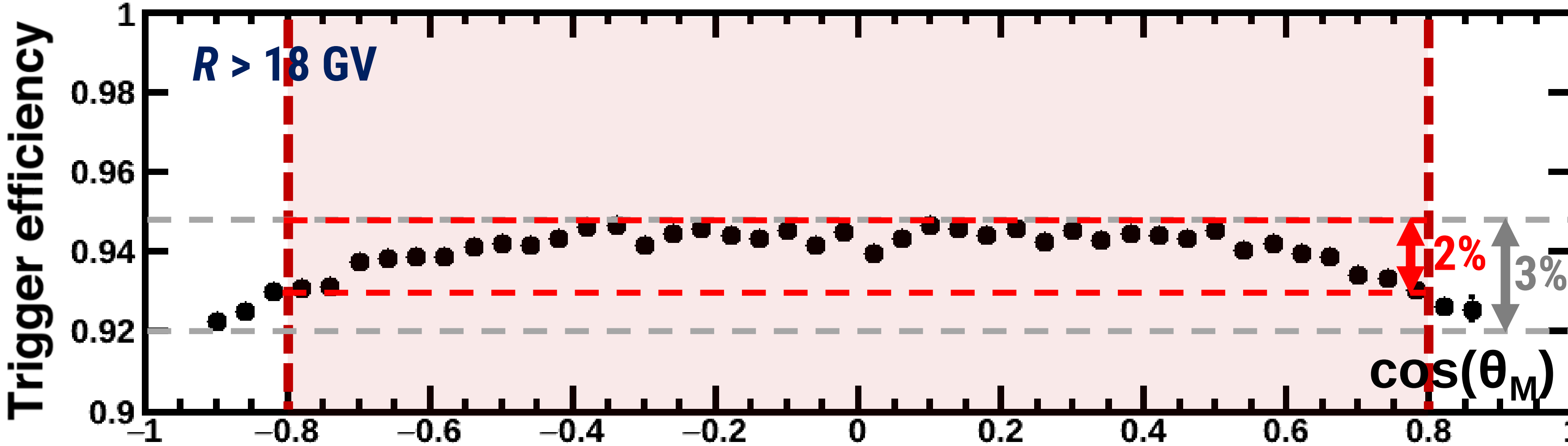
The arrival directions of proton events collected in the first 9 years are compared to the expected map for an isotropic flux in Galactic coordinates

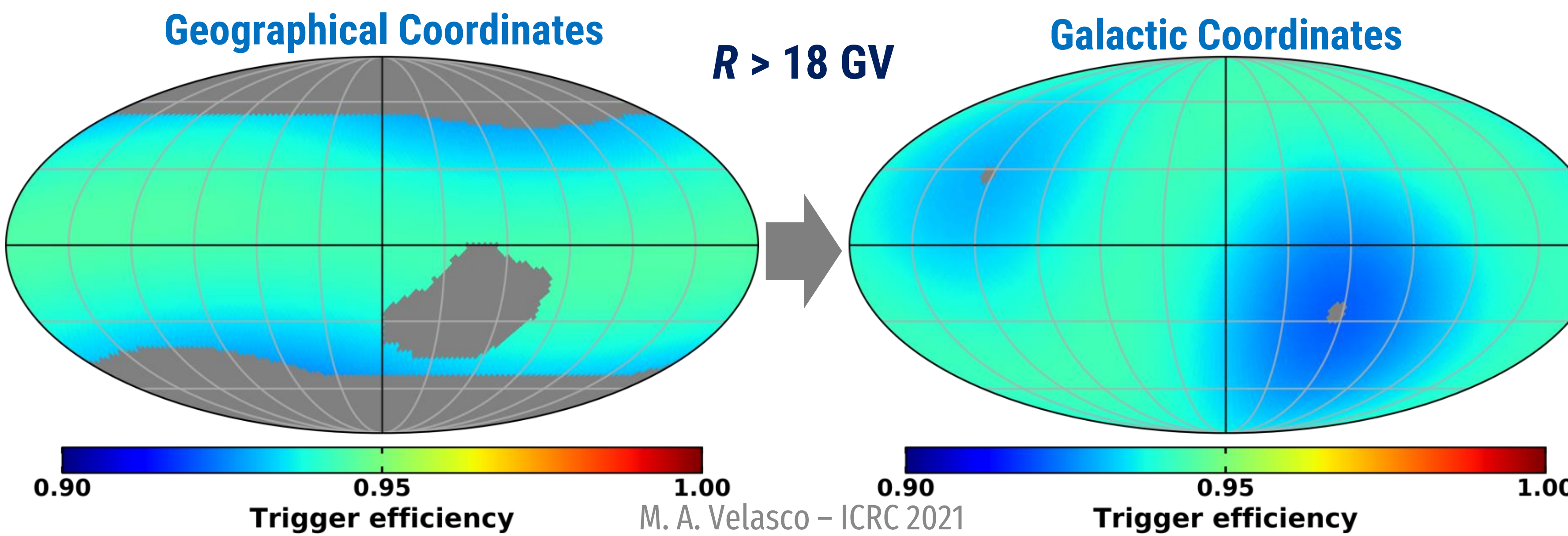
Selected events are grouped into 9 cumulative rigidity ranges with *R* > 18, 30, 45, 80, 150, 200, 300, 500 and 1000 GV



PROTON ANISOTROPY: DETECTOR EFFICIENCIES

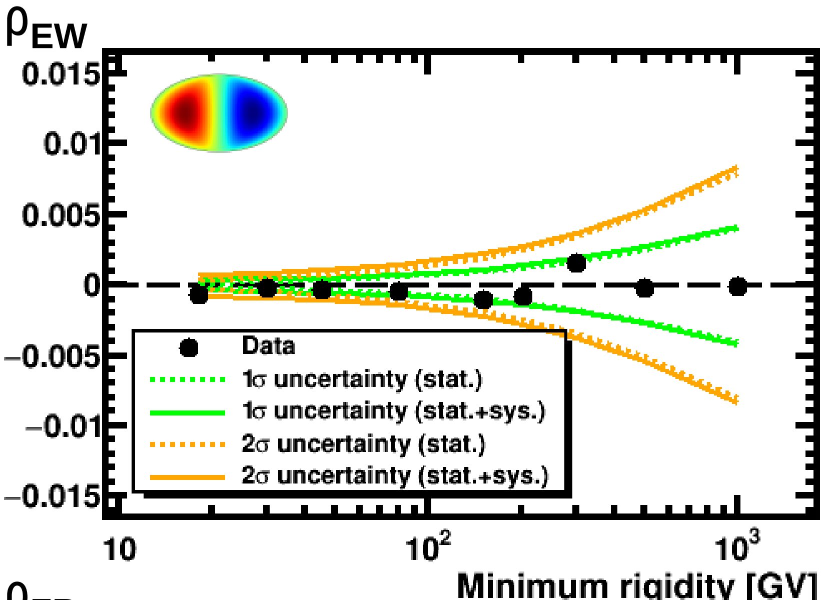
Computation of the isotropic map requires detailed understanding of detector effects at different geographical locations

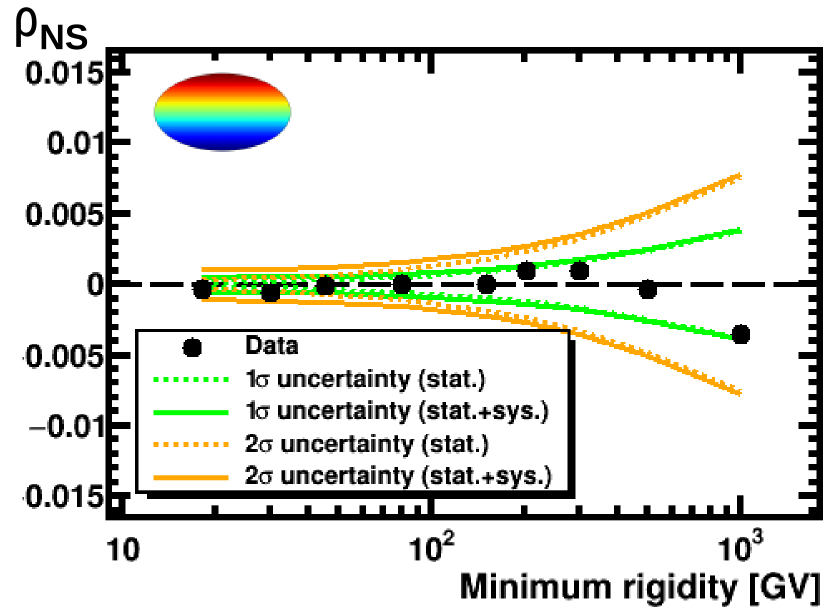


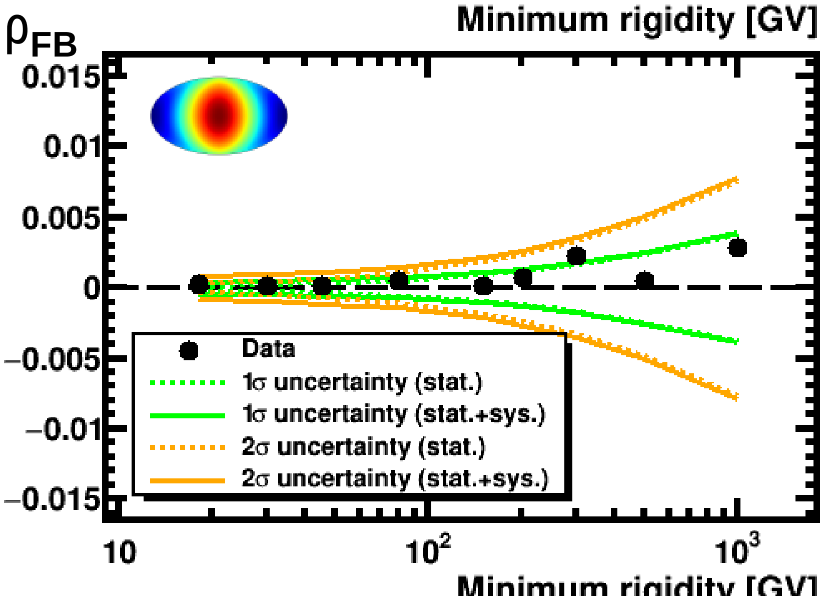


PROTON ANISOTROPY: DIPOLE COMPONENTS

Galactic Coordinates





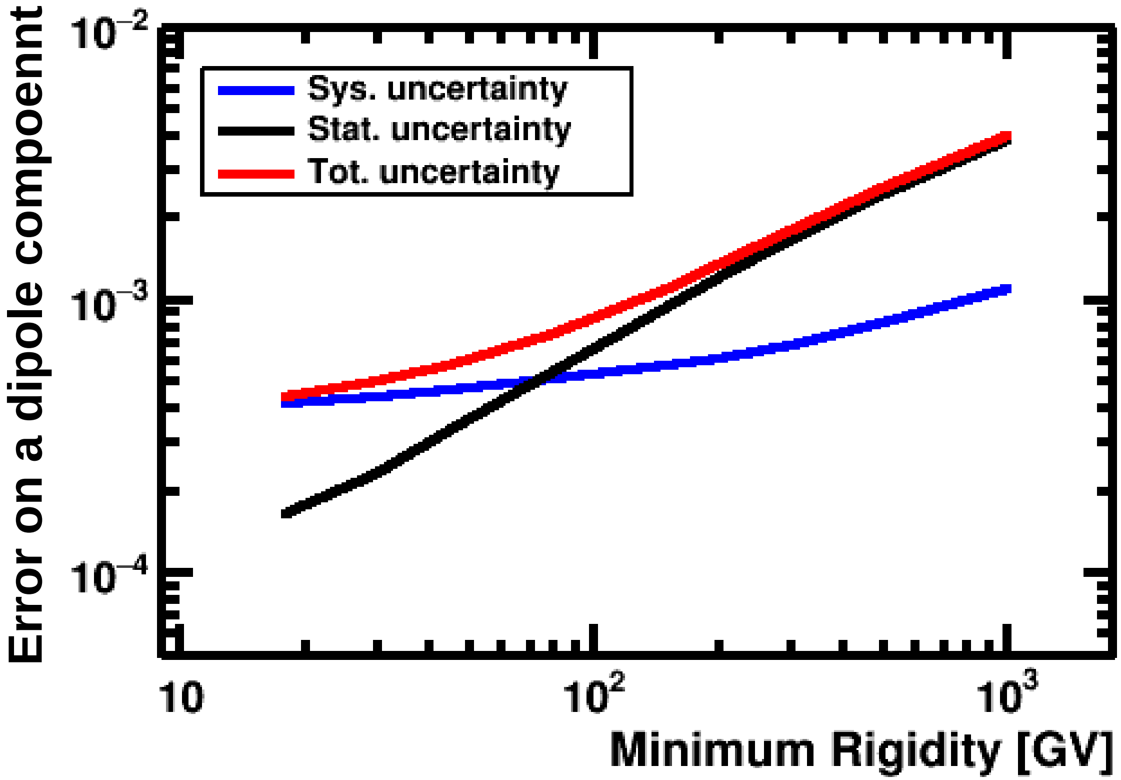


Results consistent with isotropy in all the dipole components and rigidity ranges

PROTON ANISOTROPY: UNCERTAINTIES

The measurement of the proton anisotropy requires a knowledge of the detector effects at the permille level

The analysis is dominated by statistics for *R* > 70 GV

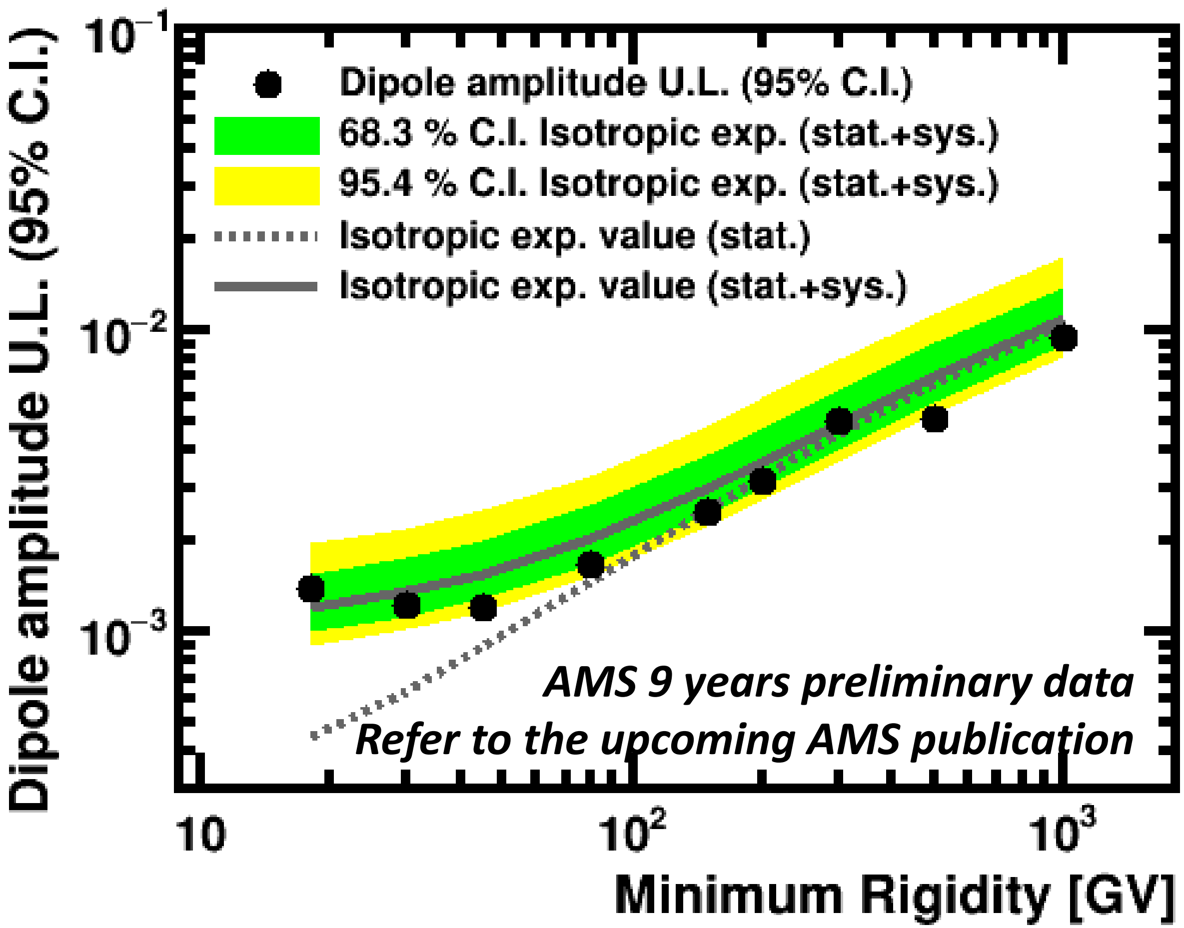


Proton Anisotropy: Dipole Upper Limits

Upper limits are set for each rigidity range

Amplitude of the dipole anisotropy on protons for *R* > 200 GV (2.2×10^6 events)

δ < 0.32% at the 95% C.I.



Helium Anisotropy

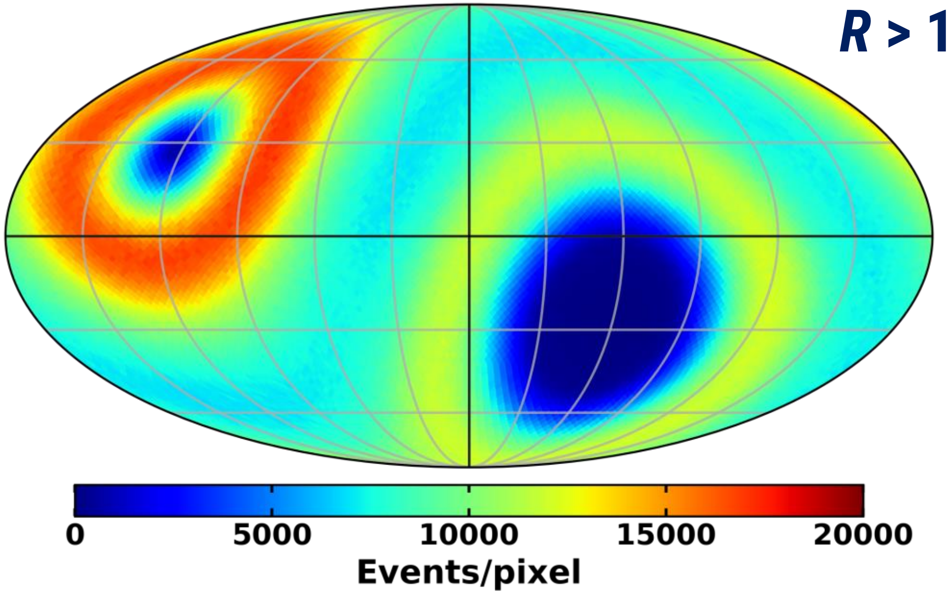
The arrival directions of helium events collected in the first 9 years are compared to the expected map for an isotropic flux in Galactic coordinates

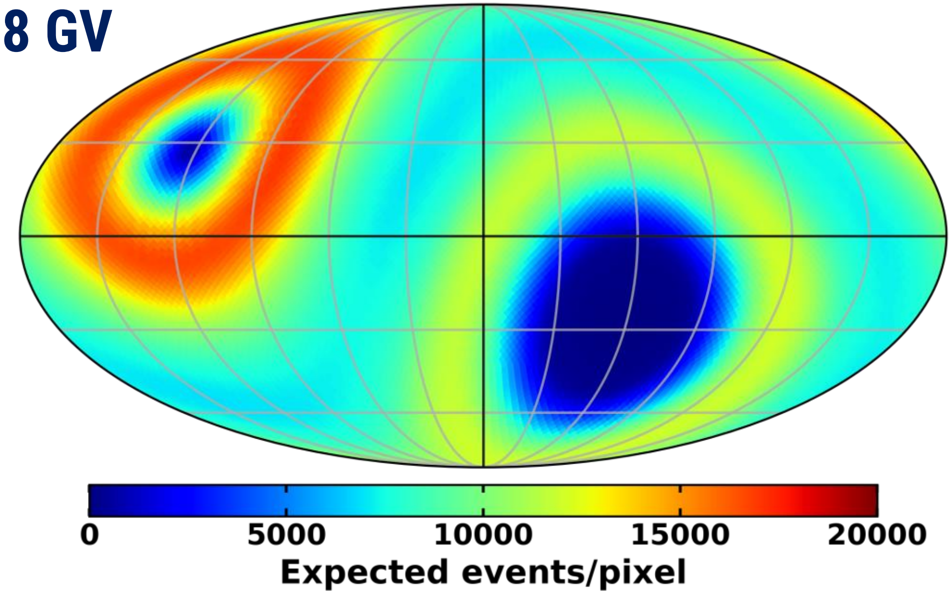
Selected events are grouped into 9 cumulative rigidity ranges with R > 18, 30, 45, 80, 150, 200, 300, 500 and 1000 GV

1.2×10^8 helium events

Isotropic map

R > 18 GV

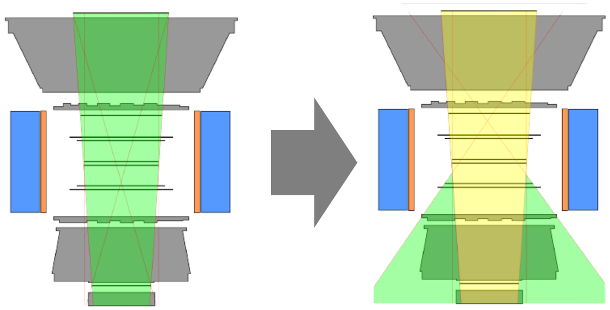


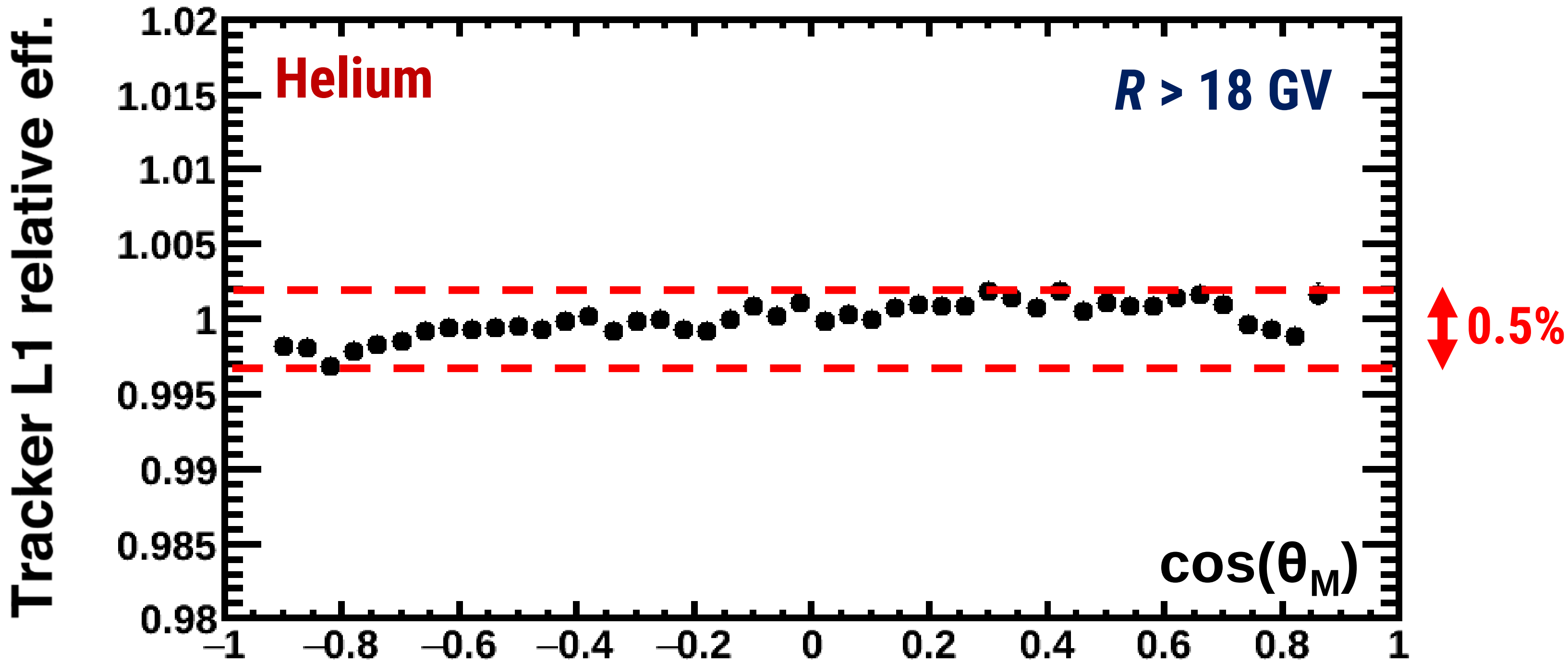


HELIUM ANISOTROPY: DETECTOR EFFICIENCIES

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

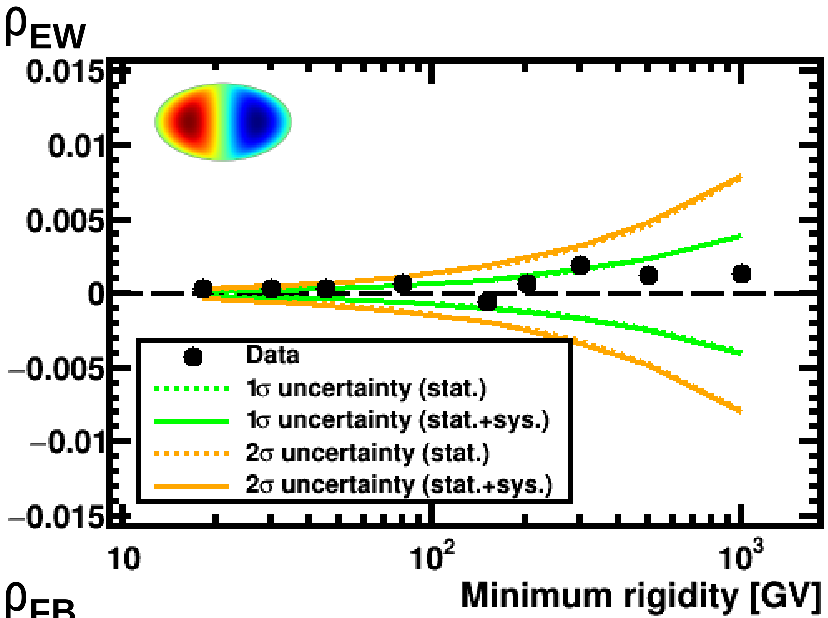
- **Reduced amplitude of the geographical dependence of the detector efficiencies allows to use extended detector acceptance**

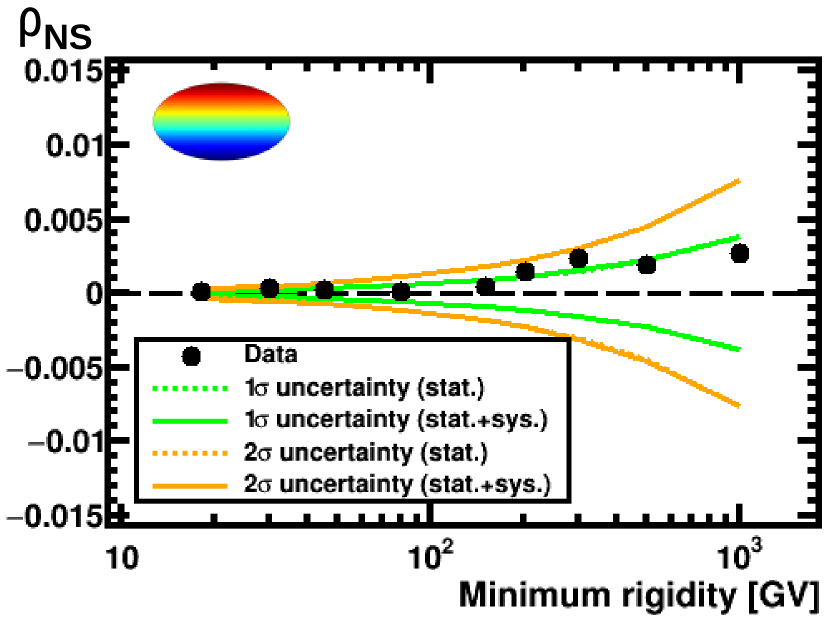


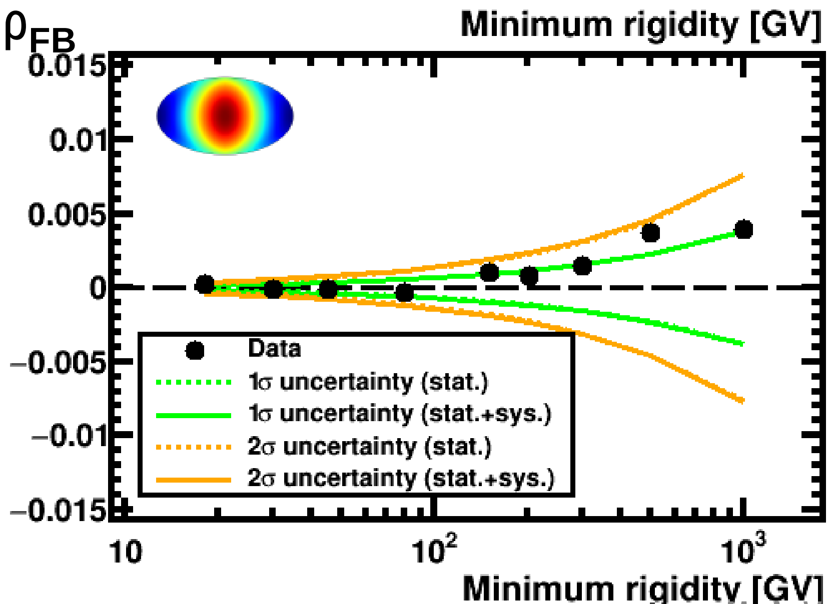


Helium Anisotropy: Dipole Components

Galactic Coordinates







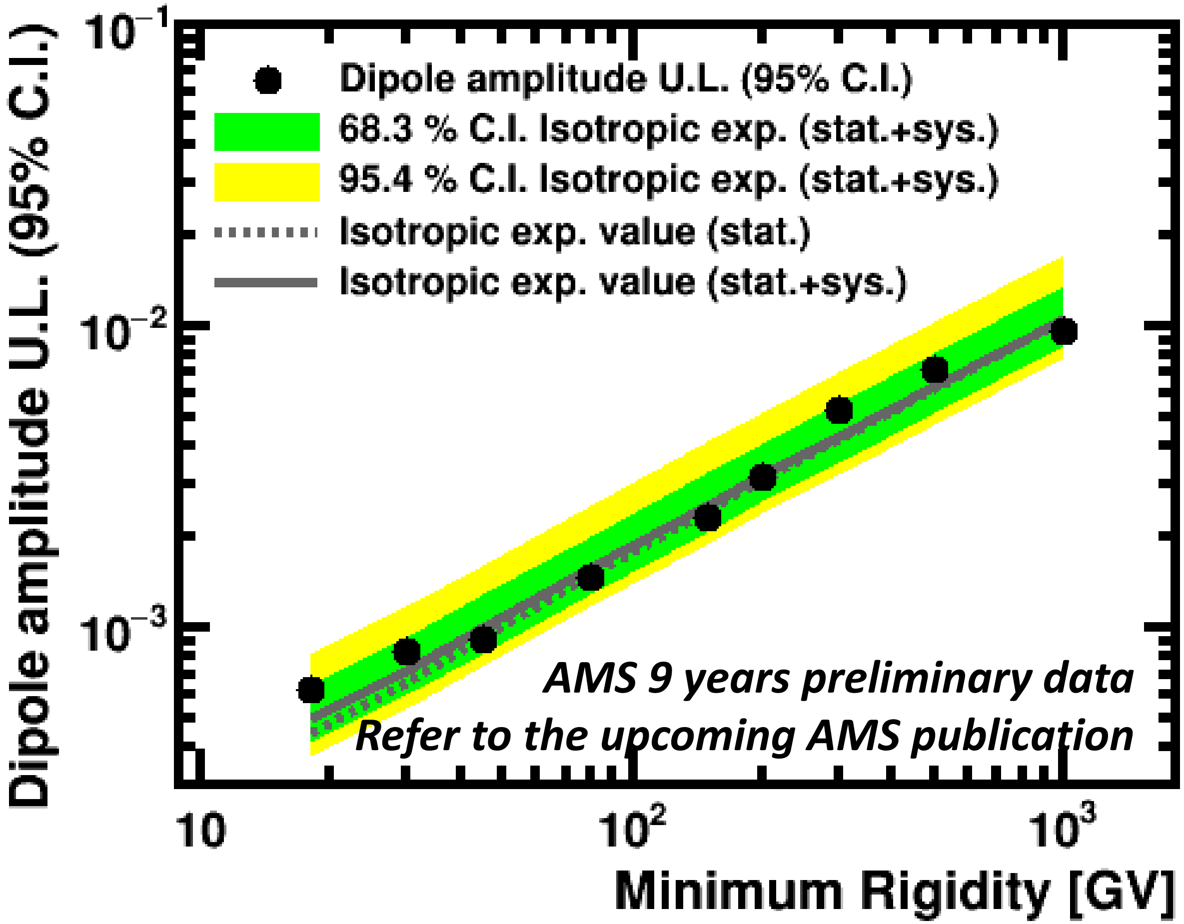
Results consistent with isotropy in all the dipole components and rigidity ranges

HELIUM ANISOTROPY: DIPOLE UPPER LIMITS

Upper limits are set for each rigidity range

Amplitude of the dipole anisotropy on helium for *R* > 200 GV (2.4×10^6 events)

$\delta < 0.32\%$ at the 95% C.I.



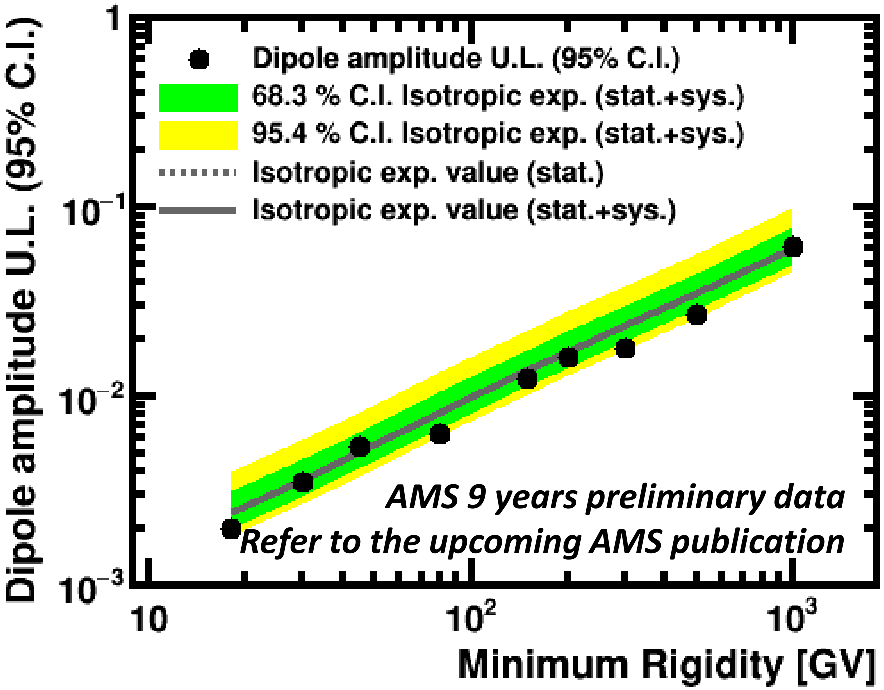
Carbon & Oxygen Anisotropy: Dipole Upper Limits

Similar analysis applied to the carbon and oxygen samples collected in the first 9 years

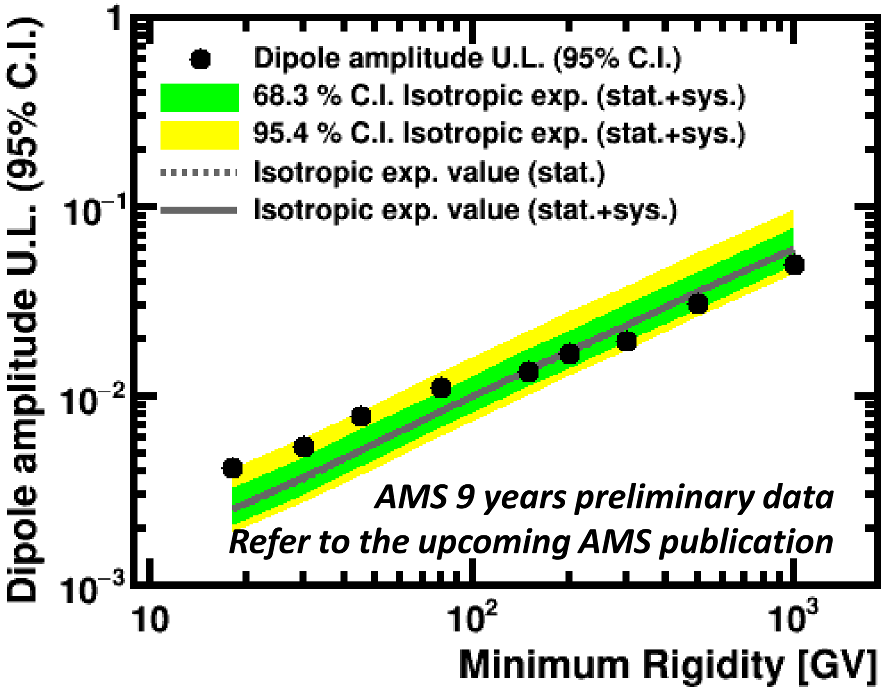
Carbon and oxygen results are consistent with isotropy

Upper limits are set for each rigidity range and particle species

Carbon: δ < 1.62% for *R* > 200 GV (7.7×10^4 events)



Oxygen: δ < 1.69% for *R* > 200 GV (7.6×10^4 events)



Summary

1. The precise measurements performed by AMS on proton and light nuclei 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 protons, helium, carbon and oxygen 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 is a unique experiment to perform anisotropy measurements on the individual species of the galactic cosmic rays