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Centro de Investigaciones
Energéticas, Medioambientales
y Tecnológicas



Determination of Anisotropy of Elementary Particles

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on behalf of the AMS Collaboration



COSPAR 2022

44th SCIENTIFIC ASSEMBLY

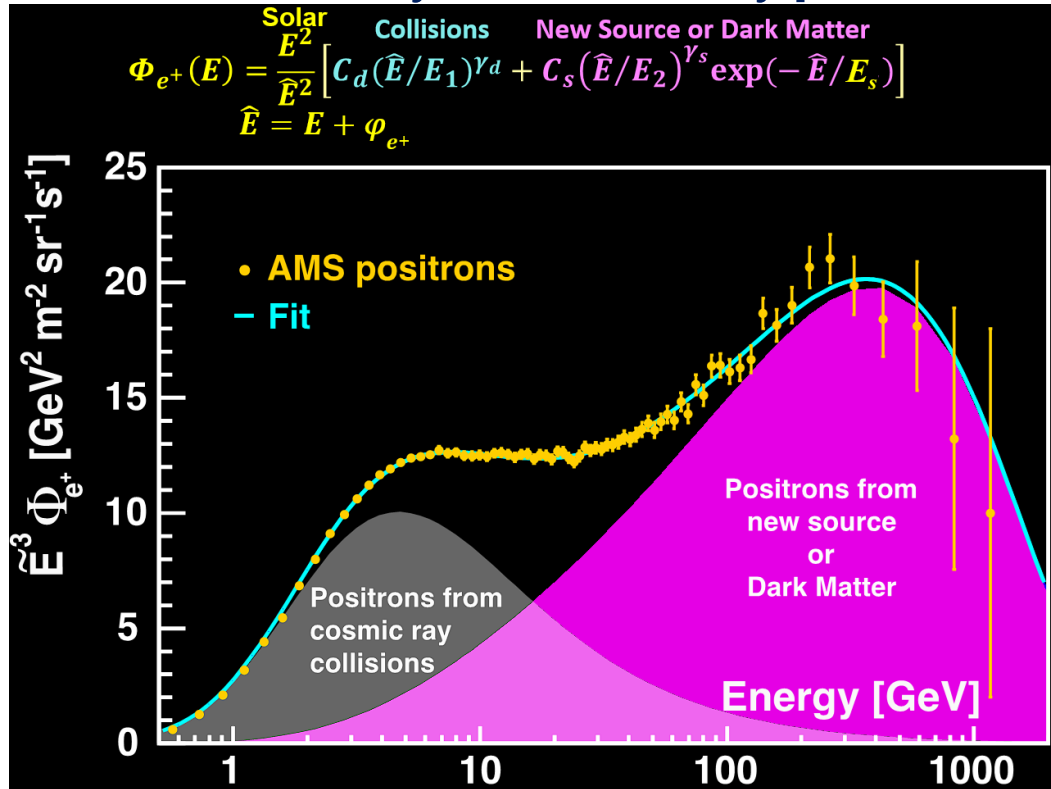
16-24 July 2022, Athens, Greece

aMUSED by the Athenian URANIA

*Ten Years of AMS on the
International Space Station
17 July 2022*

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

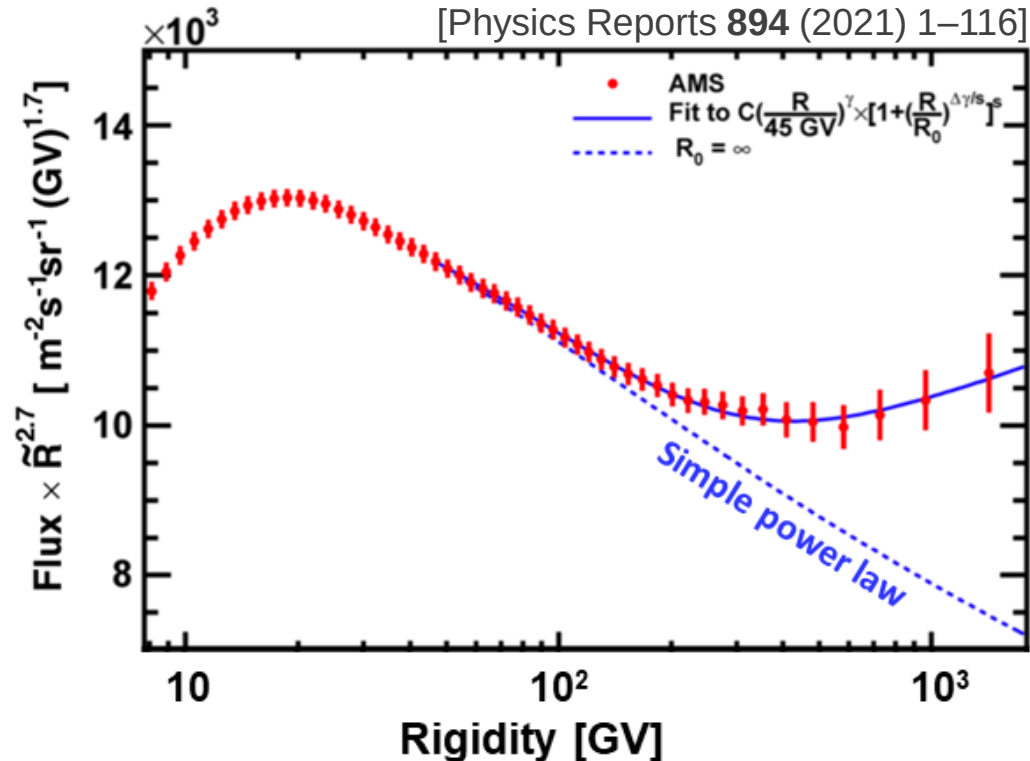


The observation requires the inclusion of **primary sources** whether from a **particle physics** or an **astrophysical** origin

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

ORIGIN OF THE PROTON FLUX DEVIATION

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

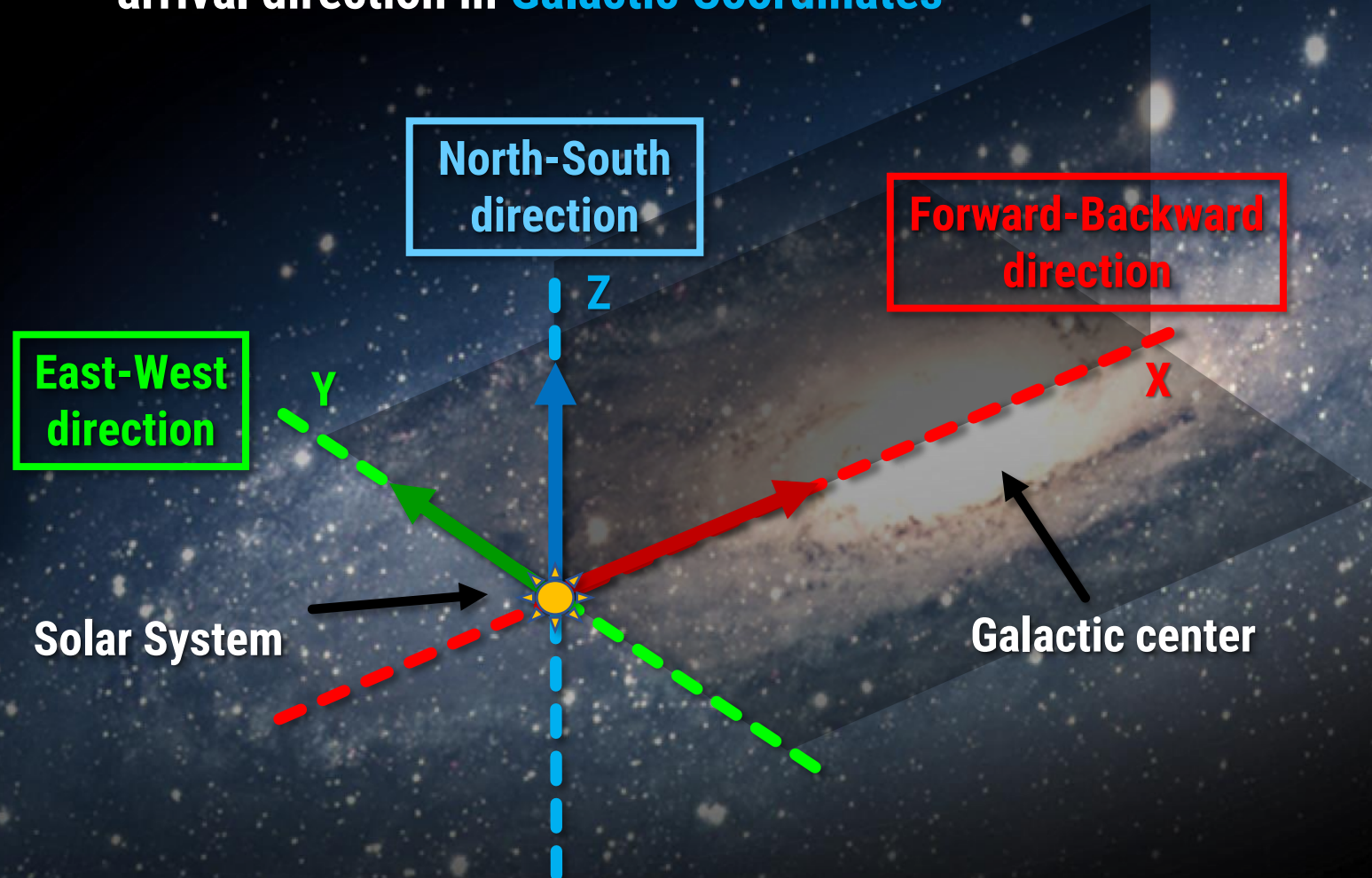


This observation may require modification of cosmic ray transport models or the inclusion of local sources of high rigidity events

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**

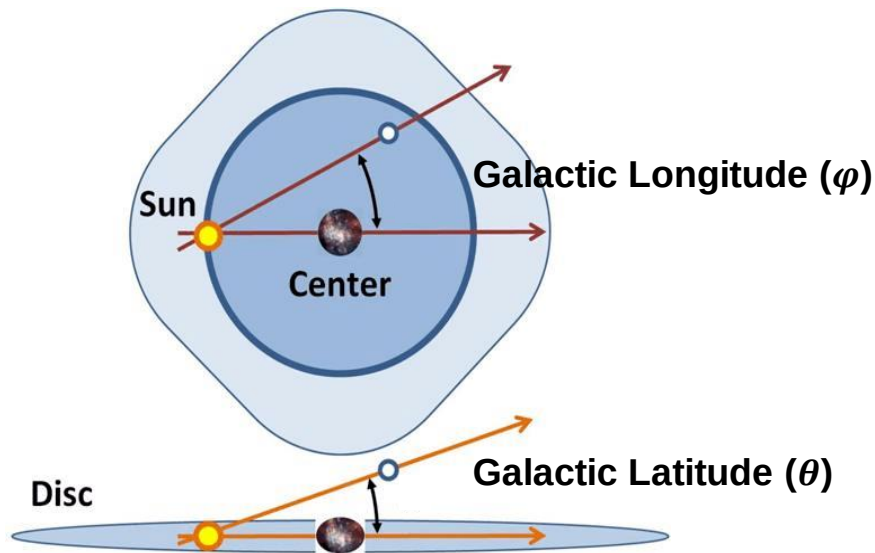


SPHERICAL HARMONIC EXPANSION OF CR FLUXES

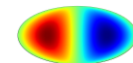
The directional dependence of the CR flux is described in terms of an expansion in spherical harmonics

Dipole anisotropy ($\ell=1$)

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

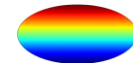


Dipole components



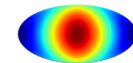
ρ_{EW}

East-West



ρ_{NS}

North-South



ρ_{FB}

Forward-Backward

Dipole amplitude

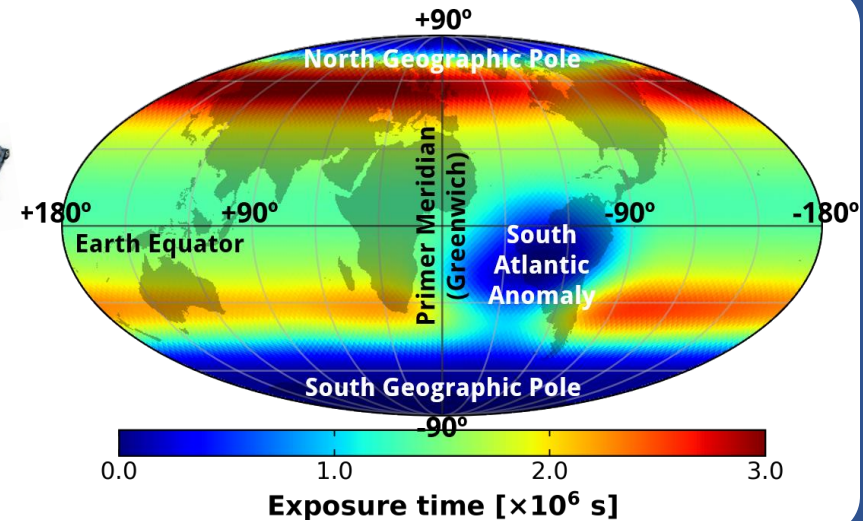
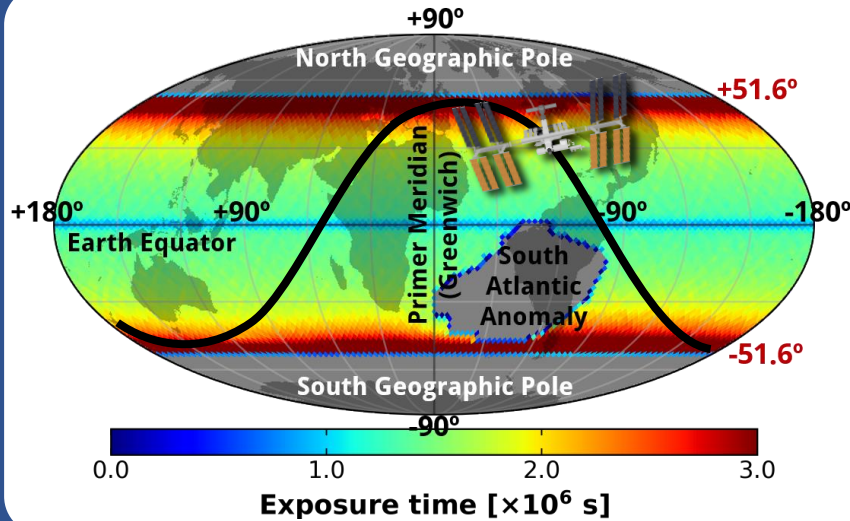
$$\delta = \sqrt{\rho_{EW}^2 + \rho_{NS}^2 + \rho_{FB}^2}$$

AMS SKY COVERAGE

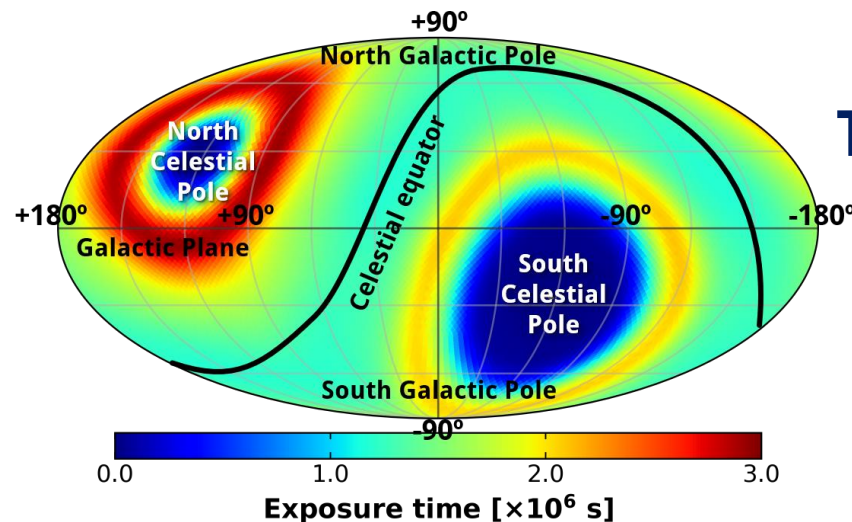
Position

Geographic coordinates

Arrival directions



Galactic coordinates

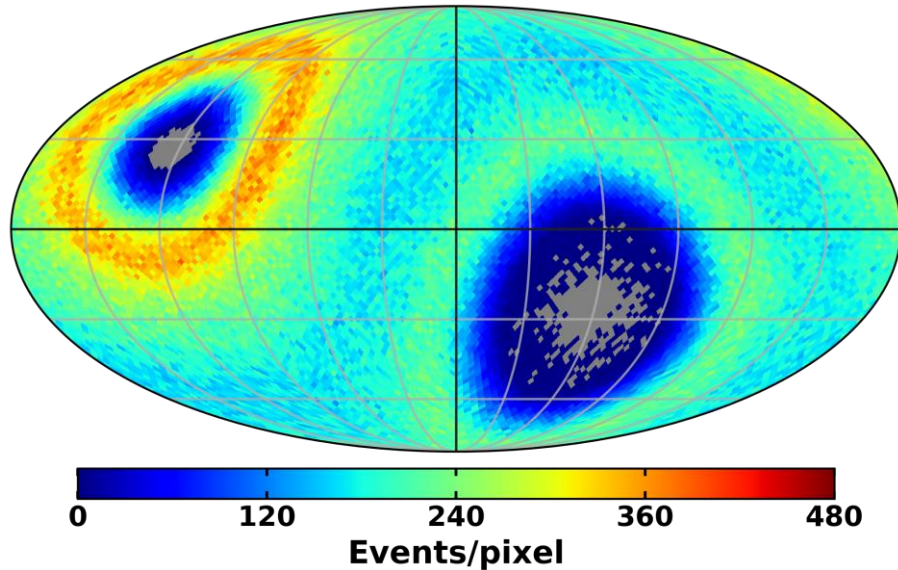


Total exposure time:
 2.03×10^8 s
(from May 2011 to May 2021)

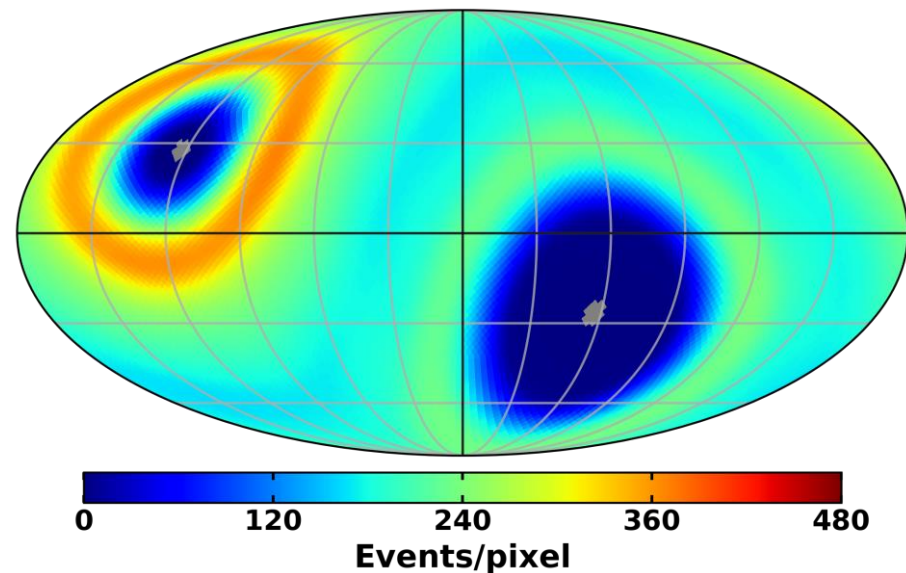
DETERMINATION OF THE ABSOLUTE ANISOTROPY

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

ISS data **Galactic Coordinates** **Isotropic map**



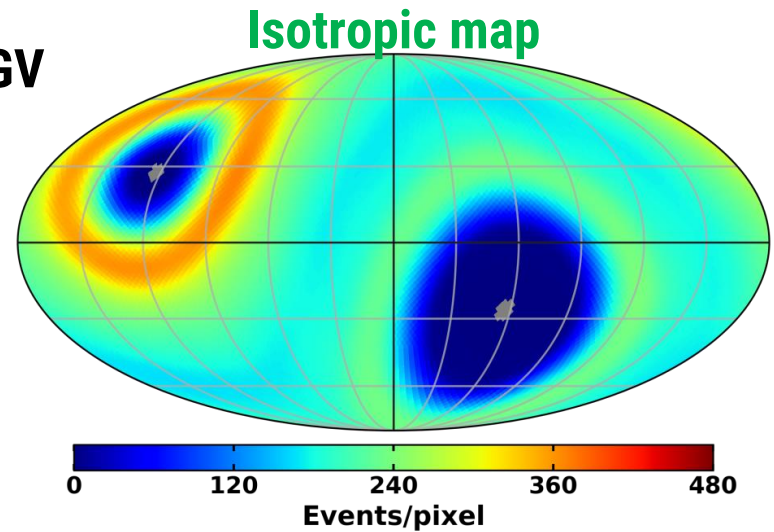
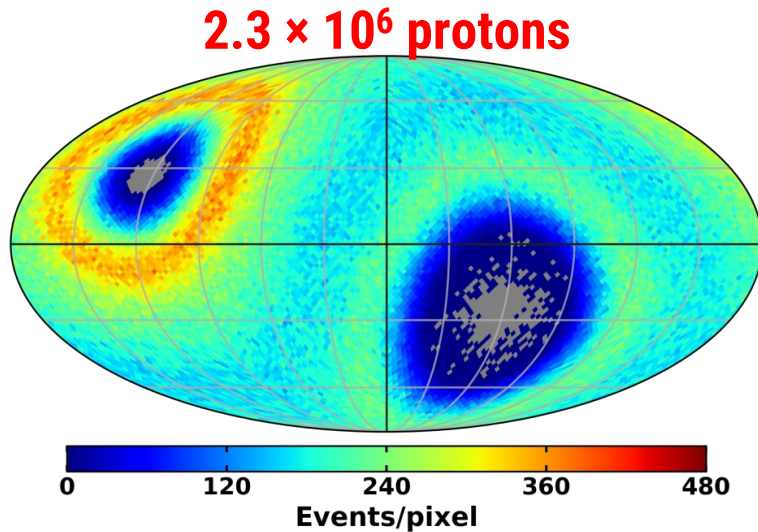
Map of arrival directions of the measured events



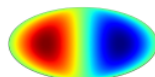
Expected map of isotropic flux includes the exposure time and detector efficiencies

PROTON ABSOLUTE ANISOTROPY

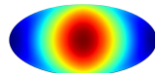
The map of arrival directions for **protons** is compared with the expected map from **isotropy**



Dipole components


$$\rho_{EW} = (-0.027 \pm 0.138) \times 10^{-2}$$


$$\rho_{NS} = (+0.114 \pm 0.133) \times 10^{-2}$$


$$\rho_{FW} = (+0.038 \pm 0.130) \times 10^{-2}$$

Dipole amplitude

$$\delta_M = 0.12^{+0.16}_{-0.02} \%$$

(Isotropy Expected: $\delta_{ISO} = 0.21\%$)

Results are consistent with isotropy and an upper limit to the dipole amplitude is established:
 $\delta_{UL} = 0.30\%$ at the 95% C.I. ($R > 200$ GV)

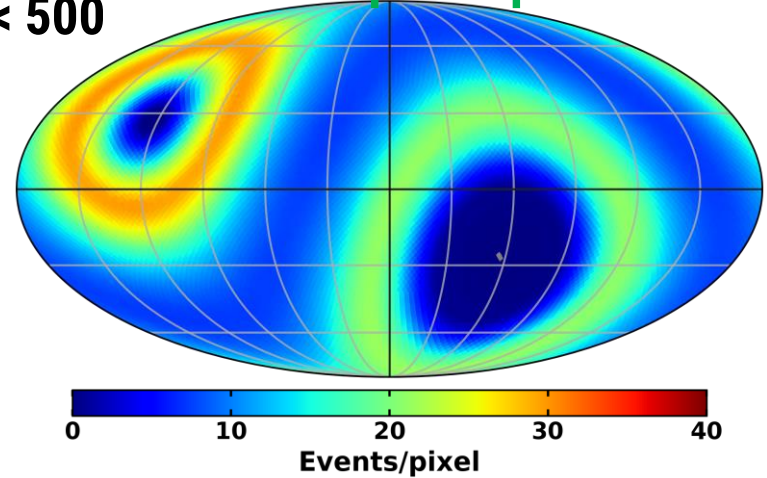
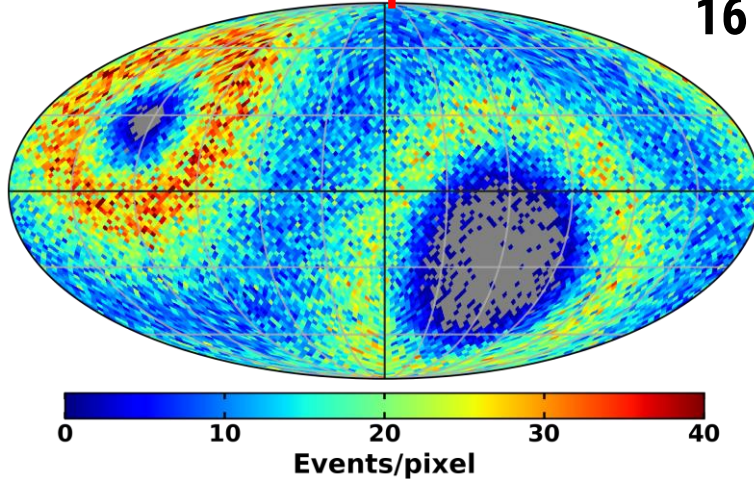
POSITRON ABSOLUTE ANISOTROPY

The map of arrival directions for **positrons** is compared with the expected map from **isotropy**

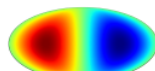
1.9×10^5 positrons

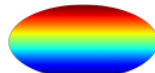
$16 < E/\text{GeV} < 500$

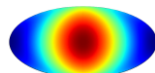
Isotropic map



Dipole components

 $\rho_{\text{EW}} = (+0.616 \pm 0.437) \times 10^{-2}$

 $\rho_{\text{NS}} = (-0.393 \pm 0.430) \times 10^{-2}$

 $\rho_{\text{FW}} = (-0.636 \pm 0.430) \times 10^{-2}$

Dipole amplitude

$$\delta_{\text{M}} = 0.97^{+0.36}_{-0.38} \%$$

(Isotropy Expected: $\delta_{\text{ISO}} = 0.69\%$)

Results are consistent with isotropy and an
upper limit to the dipole amplitude is established:
 $\delta_{\text{UL}} = 1.50\%$ at the 95% C.I. ($16 < E/\text{GeV} < 500$)

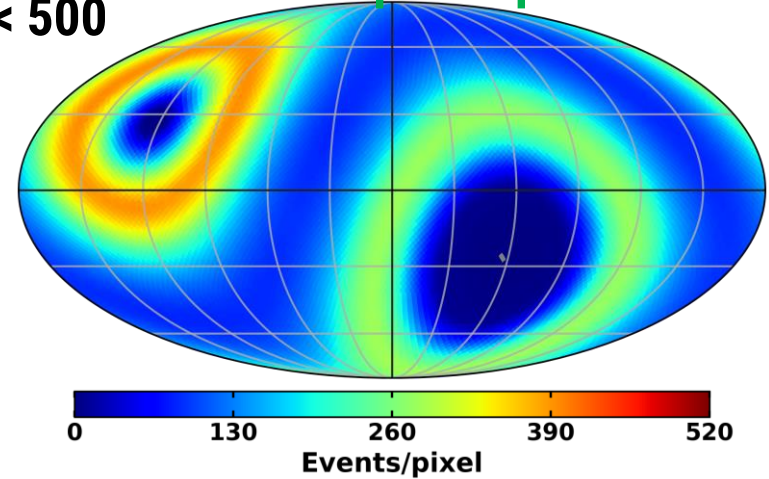
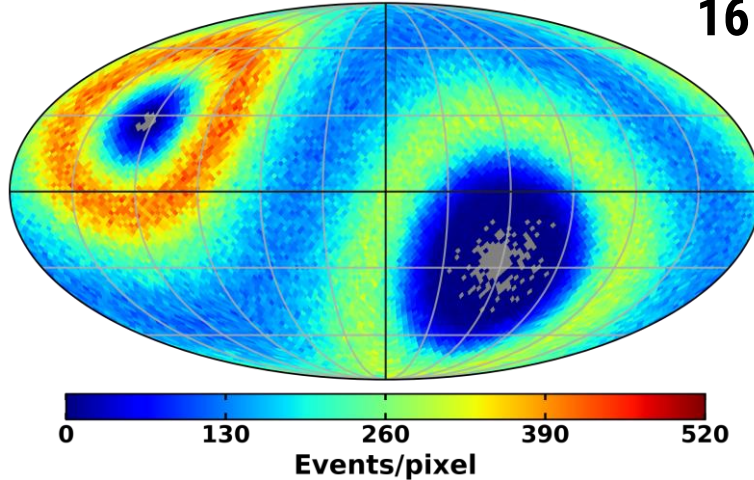
ELECTRON ABSOLUTE ANISOTROPY

The map of arrival directions for **electrons** is compared with the expected map from **isotropy**

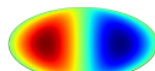
2.5×10^6 electrons

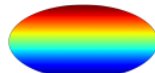
$16 < E/\text{GeV} < 500$

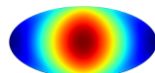
Isotropic map



Dipole components

 $\rho_{EW} = (+0.077 \pm 0.128) \times 10^{-2}$

 $\rho_{NS} = (+0.023 \pm 0.128) \times 10^{-2}$

 $\rho_{FW} = (-0.170 \pm 0.131) \times 10^{-2}$

Dipole amplitude

$$\delta_M = 0.19^{+0.09}_{-0.09} \%$$

(Isotropy Expected: $\delta_{ISO} = 0.21\%$)

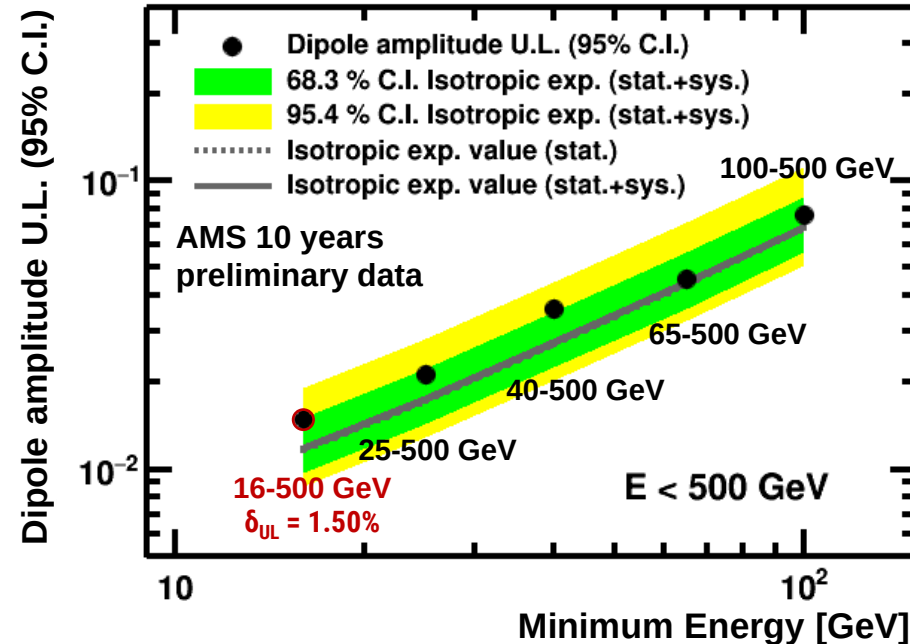
Results are consistent with isotropy and an upper limit to the dipole amplitude is established:
 $\delta_{UL} = 0.34\%$ at the 95% C.I. ($16 < E/\text{GeV} < 500$)

POSITRON & ELECTRON ABSOLUTE ANISOTROPY

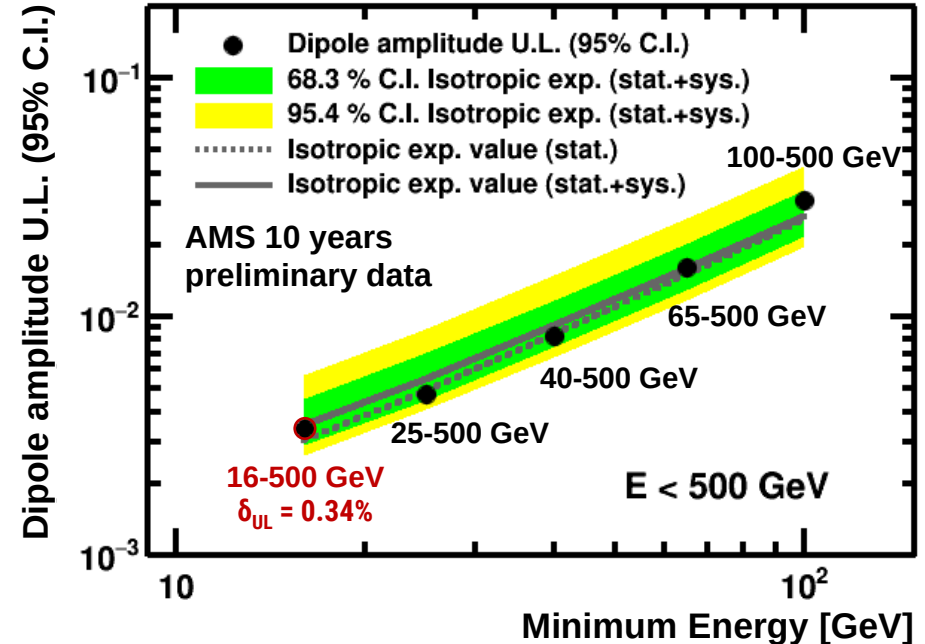
The measurement of the **absolute anisotropy** on **positrons** and **electrons** has been repeated for higher energy ranges

No deviations from isotropy have been observed and upper limits to the dipole amplitude are established

Positron upper limits to the dipole anisotropy



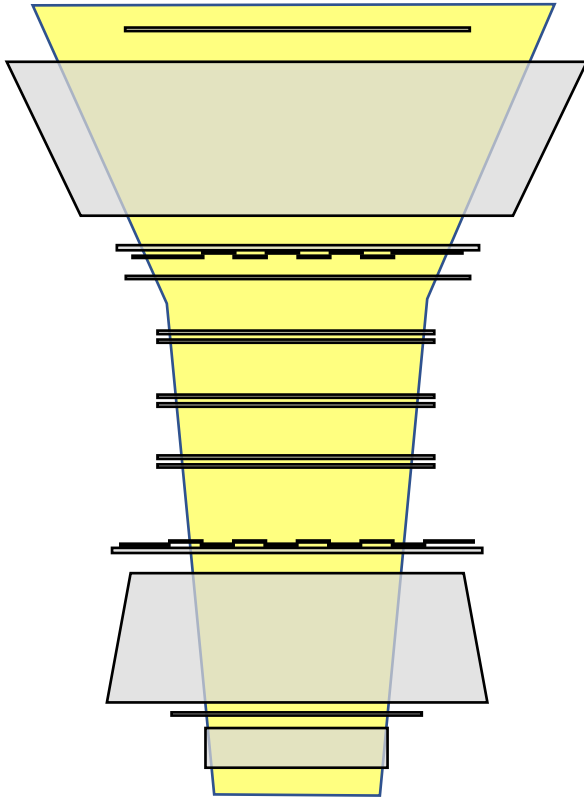
Electron upper limits to the dipole anisotropy



POSITRON & ELECTRON ANISOTROPY ANALYSIS

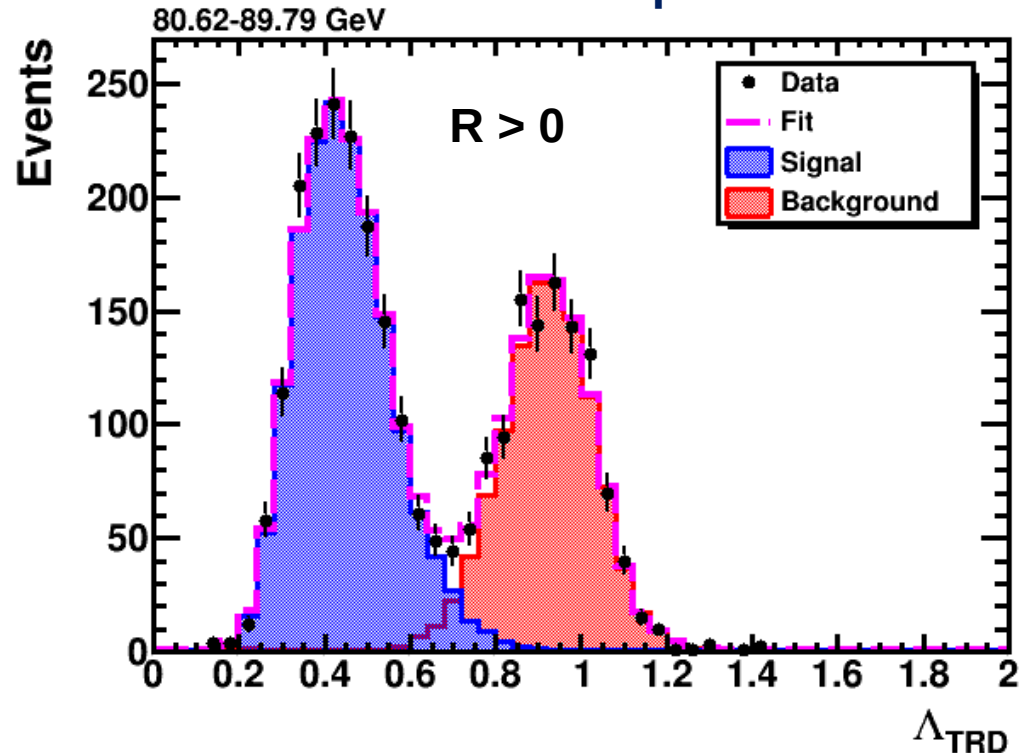
Current Analysis

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**

Positron signal extraction from template fit to the TRD response

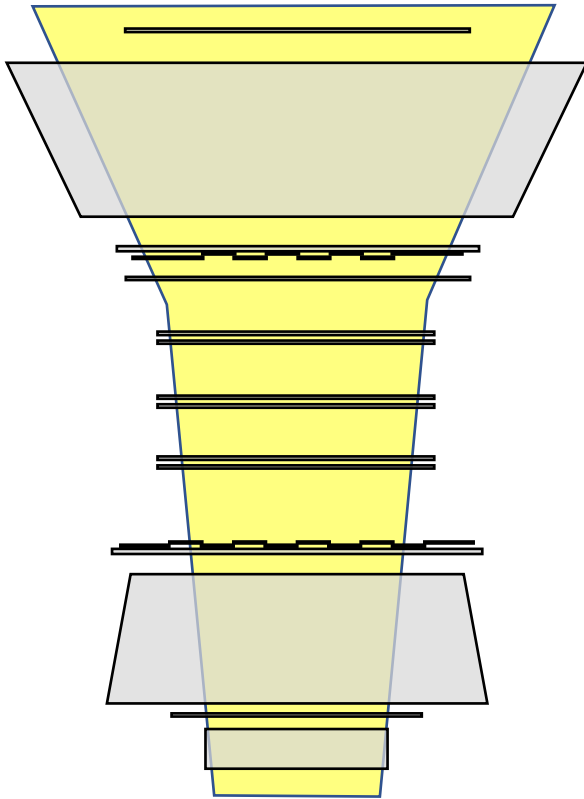


TRD templates obtained from data for both **signal** (e^+) as for **background** (protons)

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**

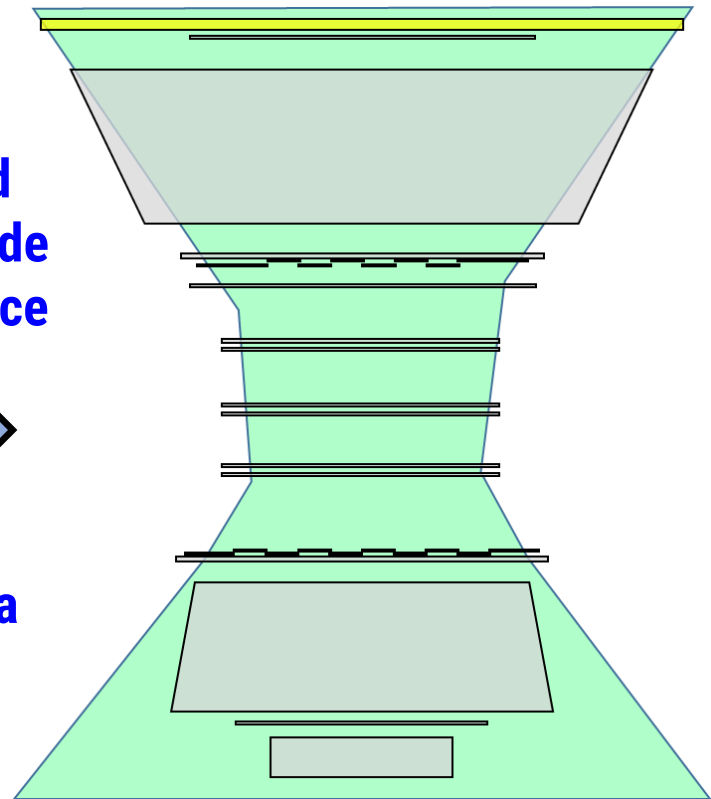
Positrons and electrons outside ECAL acceptance



Acceptance increases by a factor 3

Future Analysis

Fiducial Volume: TRD + L0

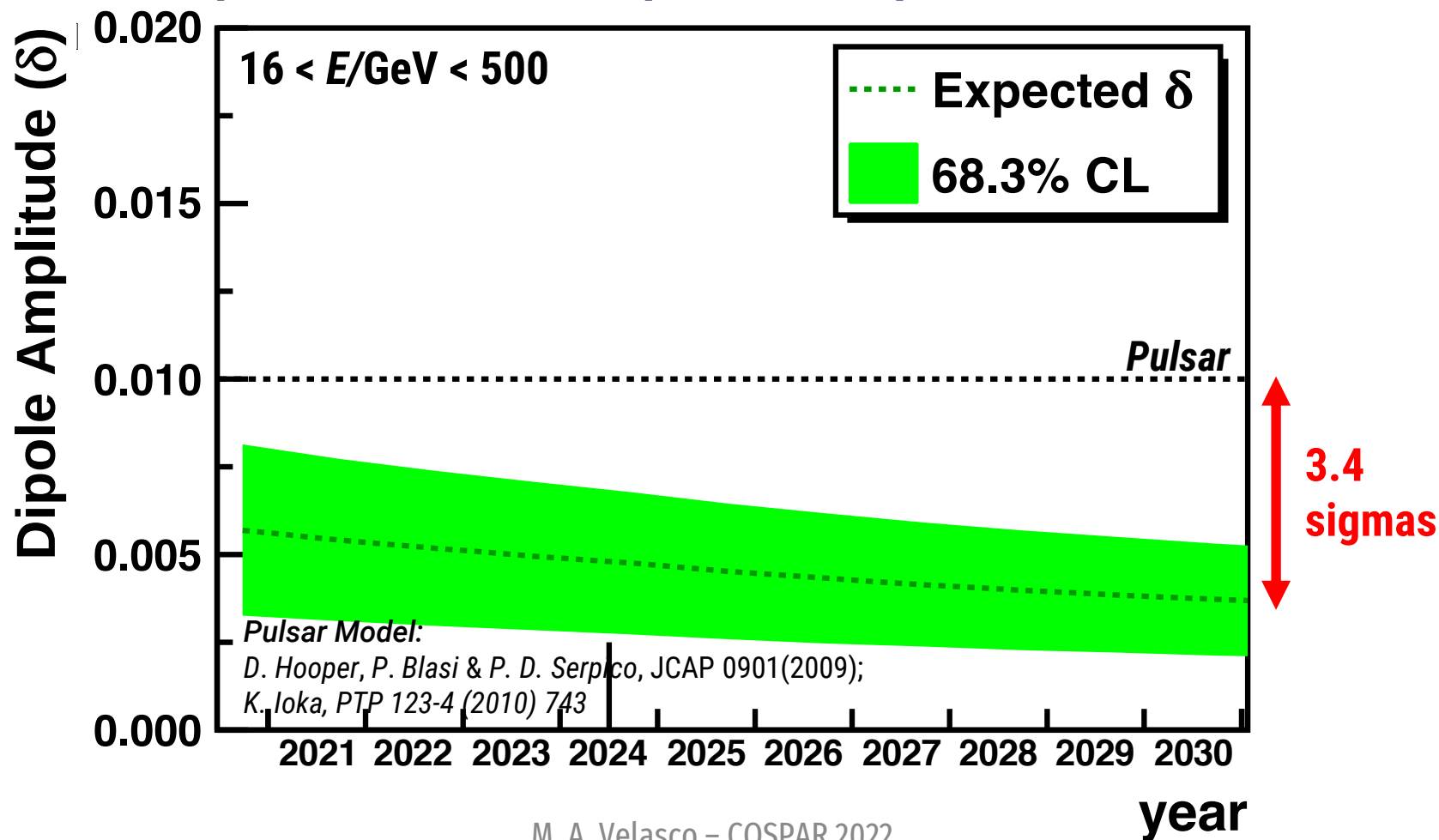


Positrons are separated from protons with a selection based on a **template fit to the TRD response**

POSITRON ANISOTROPY: PROJECTION UP TO 2030

By 2030, the improved analysis with the L0 upgrade will allow us to measure the positron anisotropy parameter δ to an accuracy of $\pm 0.16\%$

AMS will be sensitive to anisotropies below the 1% level, as predicted by pulsar models that reproduce the positron excess



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 collected by **AMS** in the first **10 years** of data taking 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 in 2030. By that time **positron statistics** will allow us to explore anisotropies below the **1% level** predicted by **pulsar models**