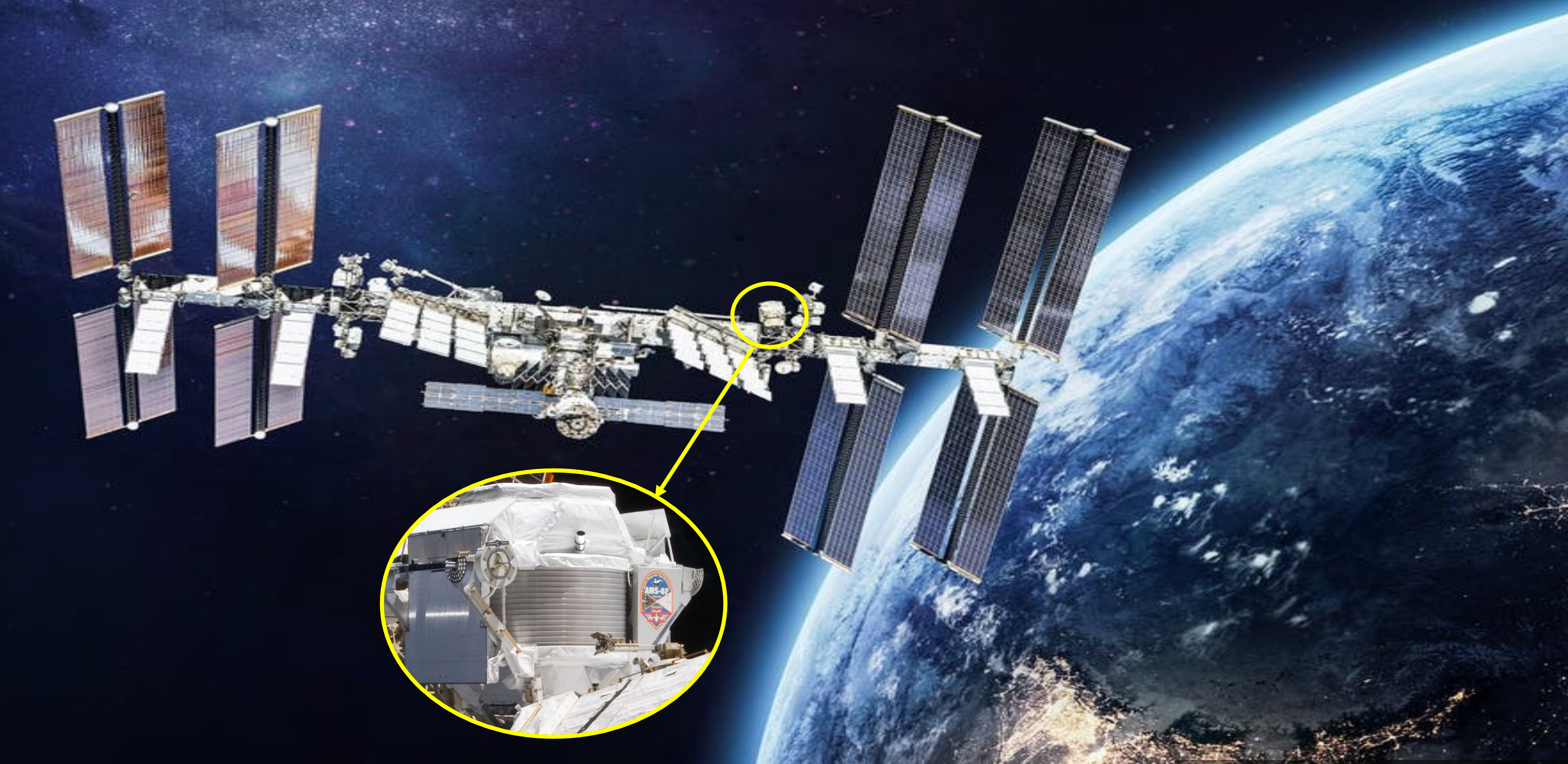
Latest AMS Results on Cosmic Light Antimatter Particles



PAW’24 Workshop

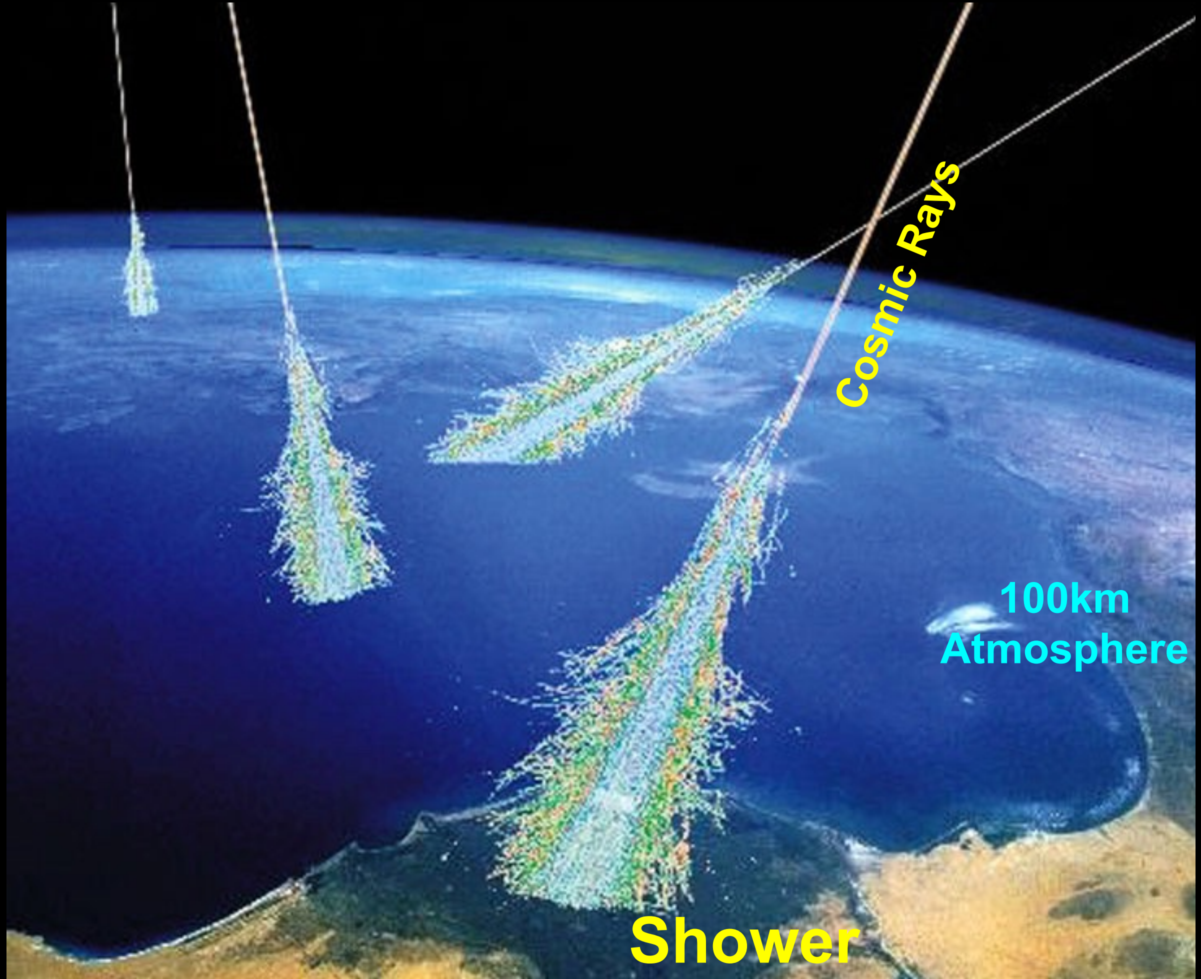
March 18, 2023

Andrei Kounine / MIT

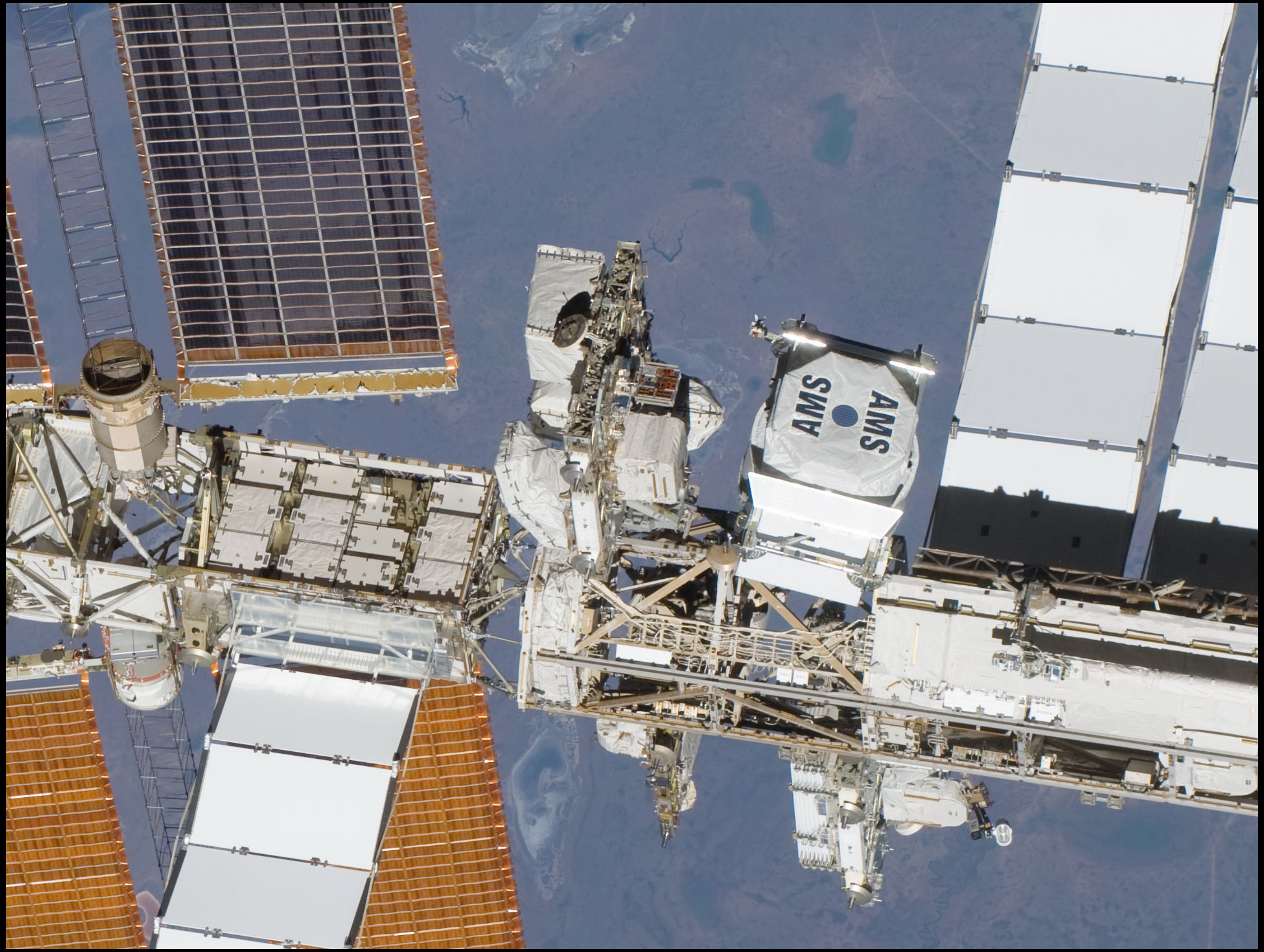
AMS on the Space Station:

Provides precision, long-duration measurements of charged cosmic rays to study the Origin of the Cosmic Rays, the physics of Dark Matter and Antimatter

Charged cosmic are absorbed by the 100 km of Earth's atmosphere (10m of water).



To measure cosmic ray charge and momentum requires a magnetic spectrometer in space

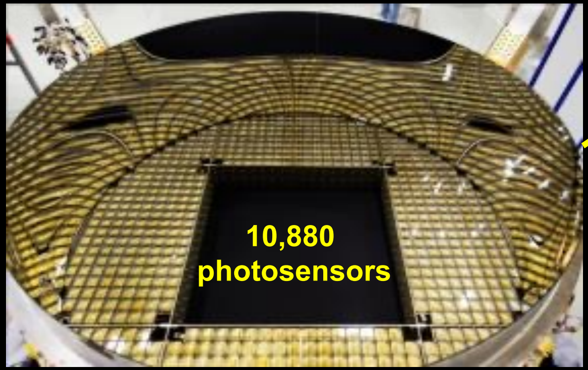


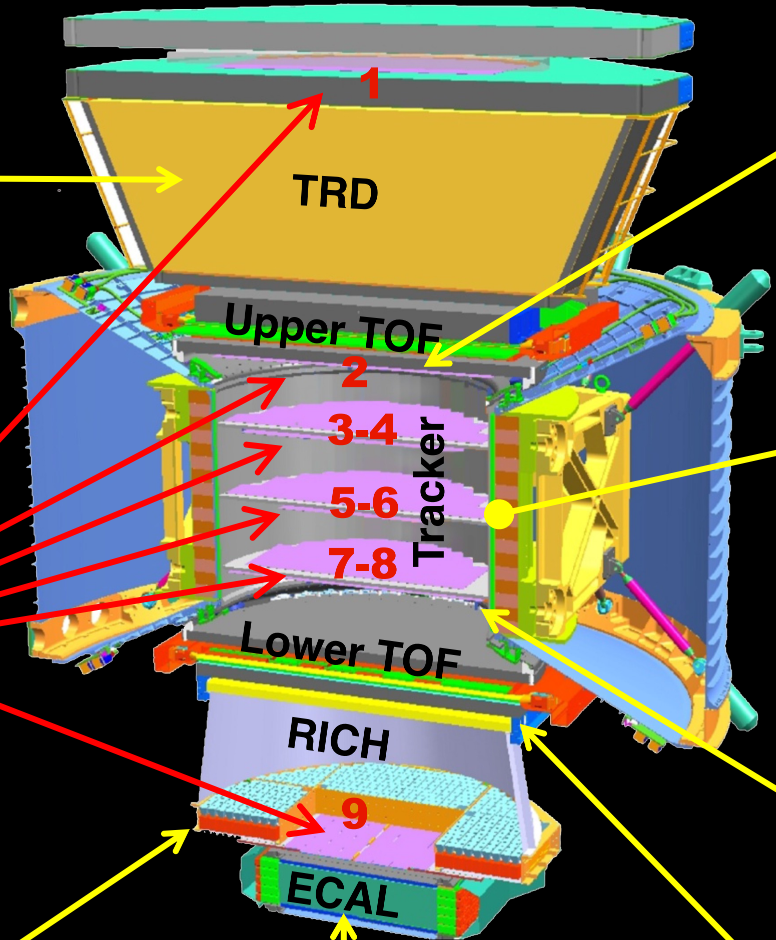
AMS is a space version of a precision detector used in accelerators

Transition Radiation Detector (TRD)
identify e^+, e^-

Silicon Tracker
measure Z, P

Ring Imaging Cerenkov (RICH)
measure Z, E





Electromagnetic Calorimeter (ECAL)
measure E of e^+, e^-

Upper TOF measure Z, E

Magnet identify ±Z, P

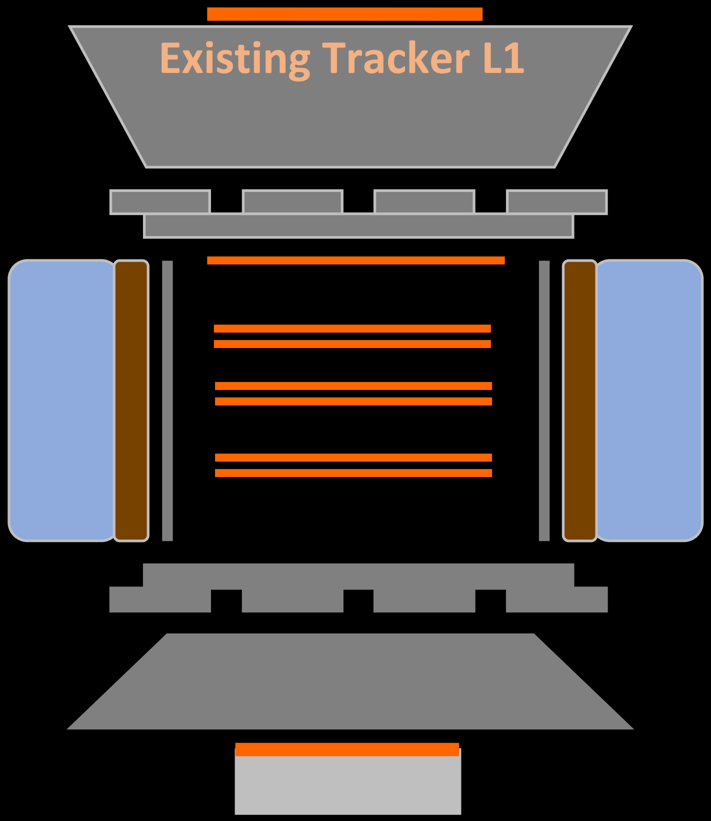
Anticoincidence Counters (ACC)
reject particles from the side

Lower TOF measure Z, E

AMS on ISS

AMS 2011-2025

Continuous data-taking

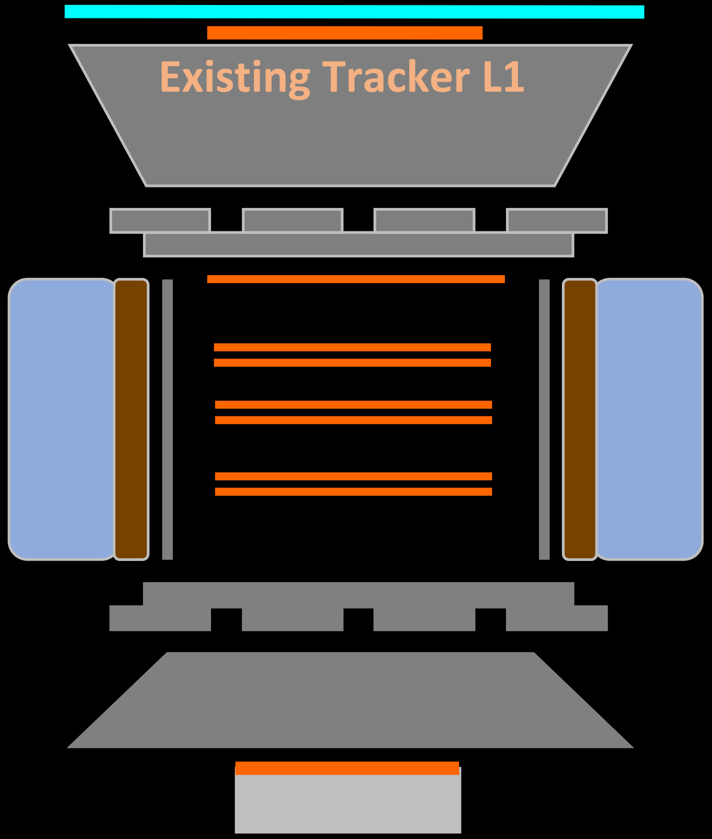


Latest Results: 2011-2023

AMS 2025-2030

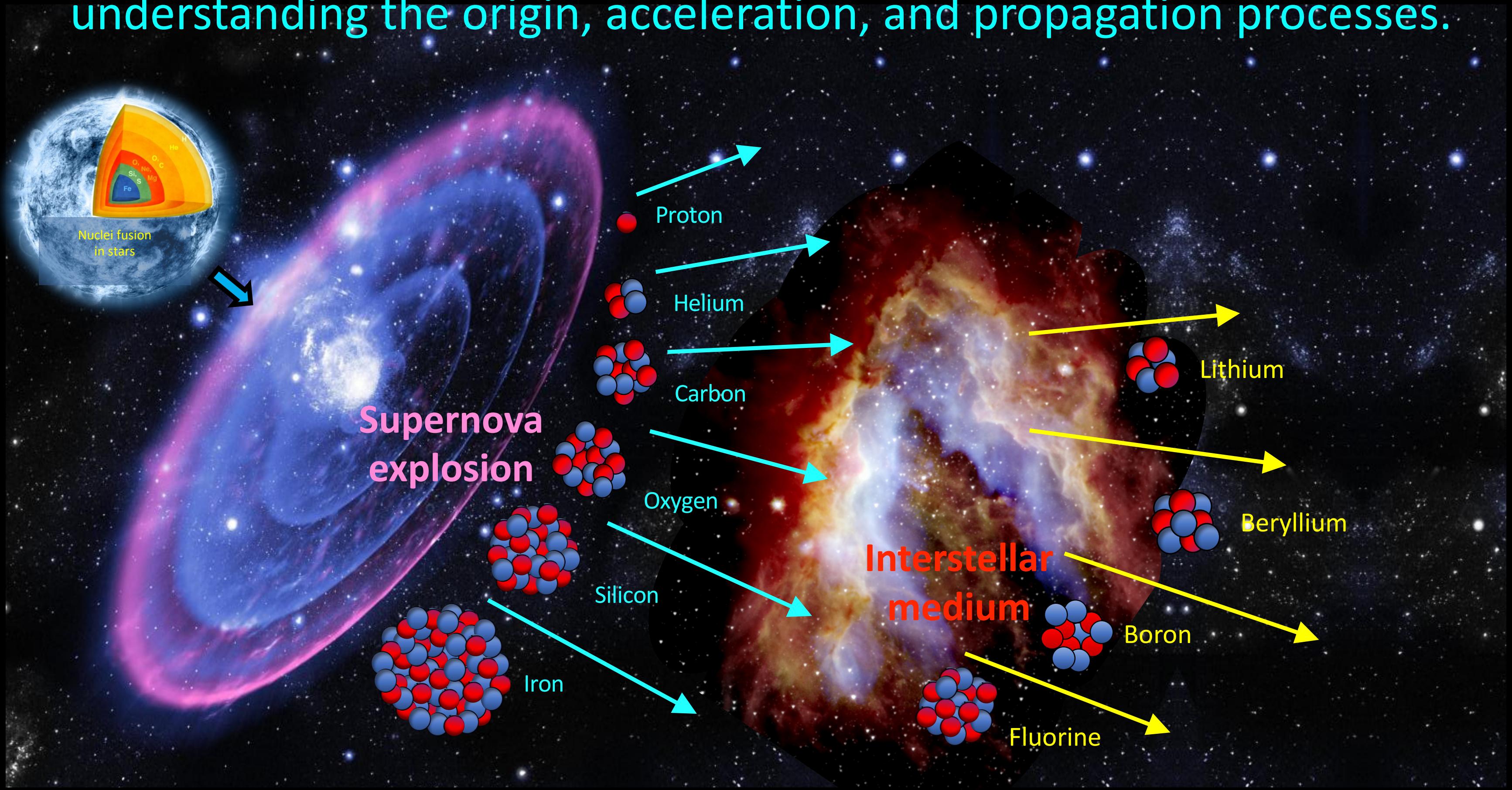
New 4+4m^2 Silicon Tracker Planes

Acceptance increased to 300%



Projections to 2030

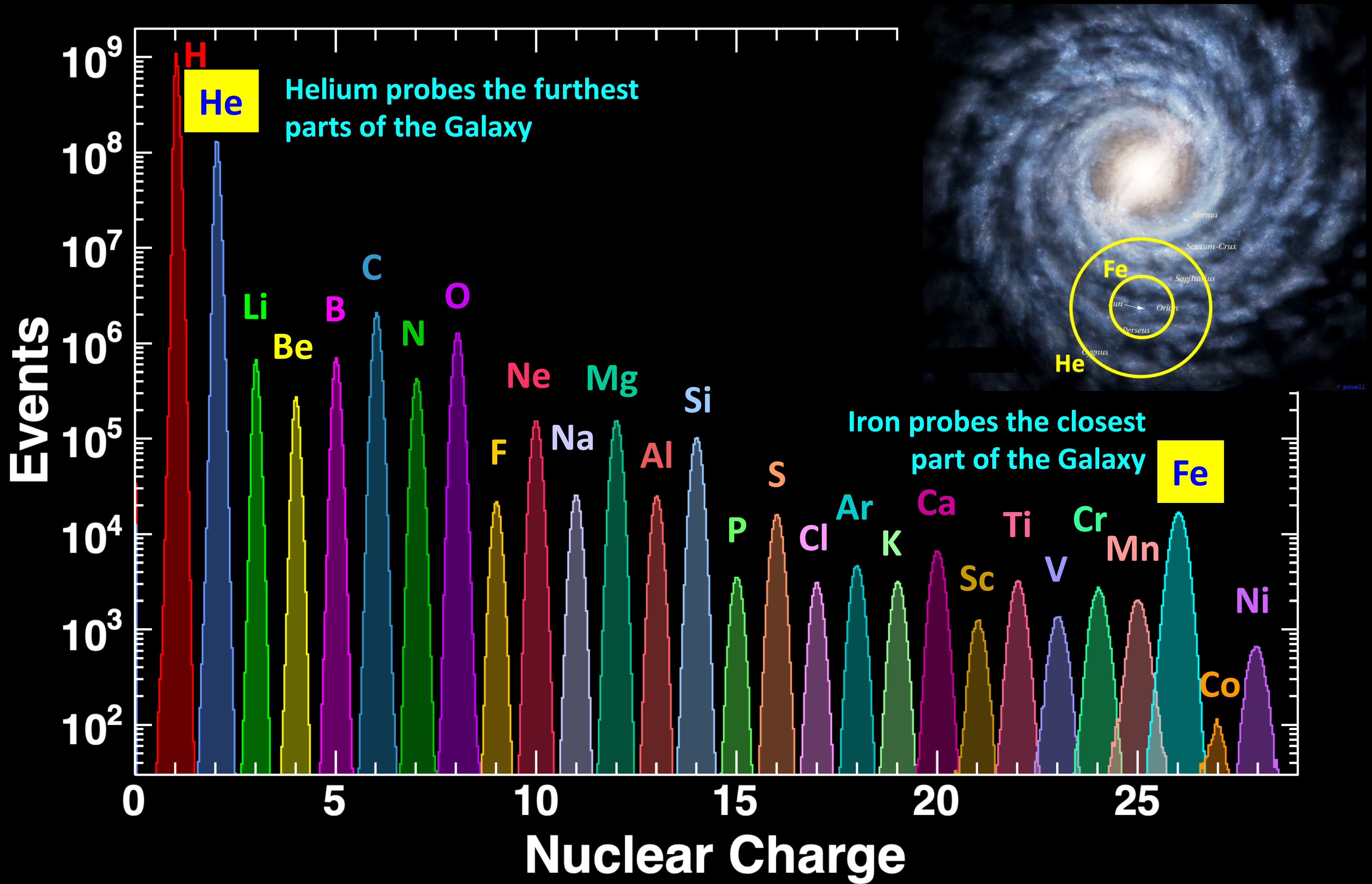
Primary cosmic rays p, He, C, O, ..., Si, ..., Fe
are produced during the lifetime of stars and accelerated by supernovae.
Measurements of primary cosmic ray fluxes are fundamental to
understanding the origin, acceleration, and propagation processes.



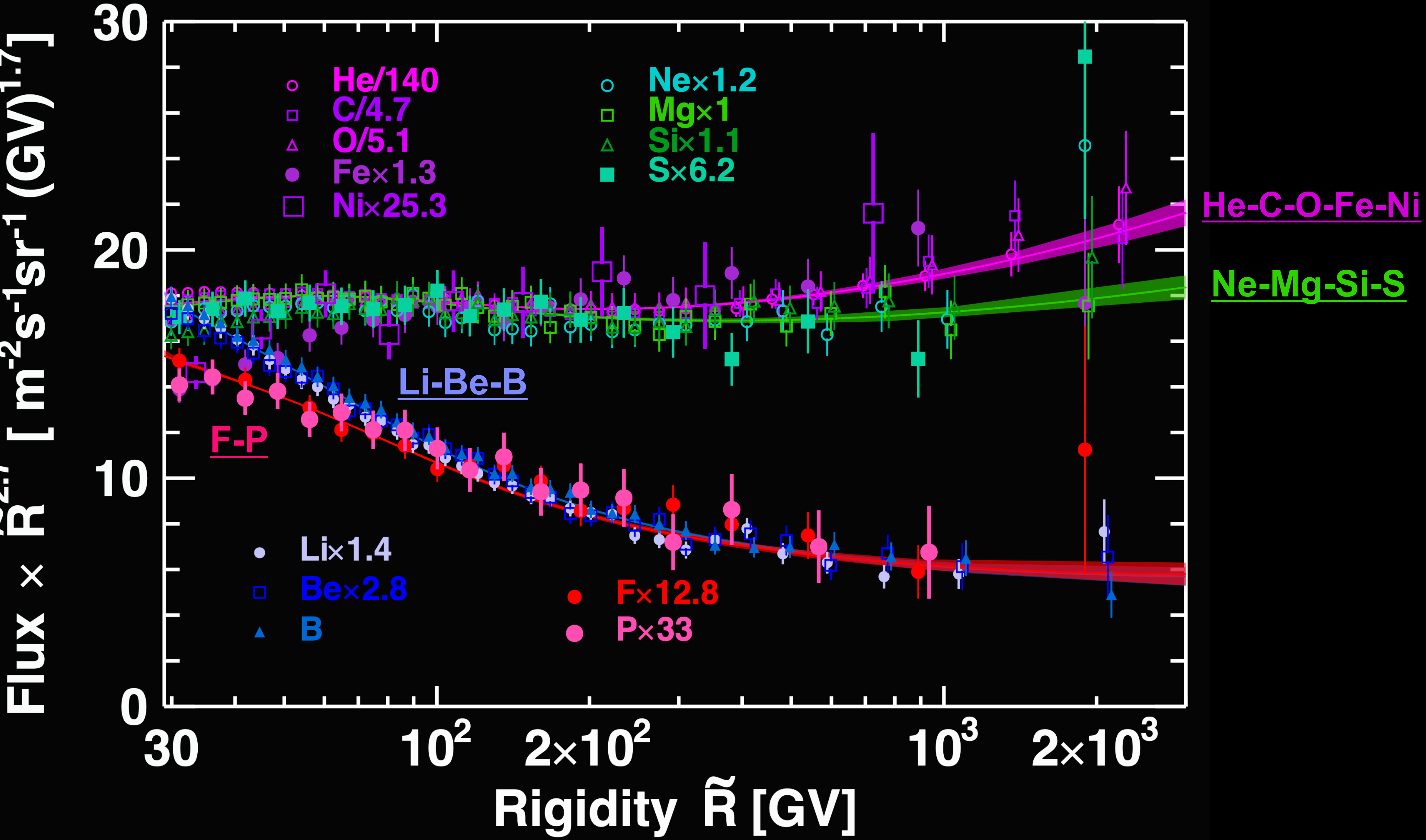
Where light cosmic antimatter (e^+, $\bar{p}$, $\bar{D}$) belongs to?

Secondary Li, Be, B, and F nuclei in cosmic rays are produced by the collision of primary cosmic rays C, O, Ne, Mg, Si, ..., Fe with the interstellar medium.
Measurements of the secondary cosmic ray nuclei fluxes are important in understanding the propagation of cosmic rays in the Galaxy.

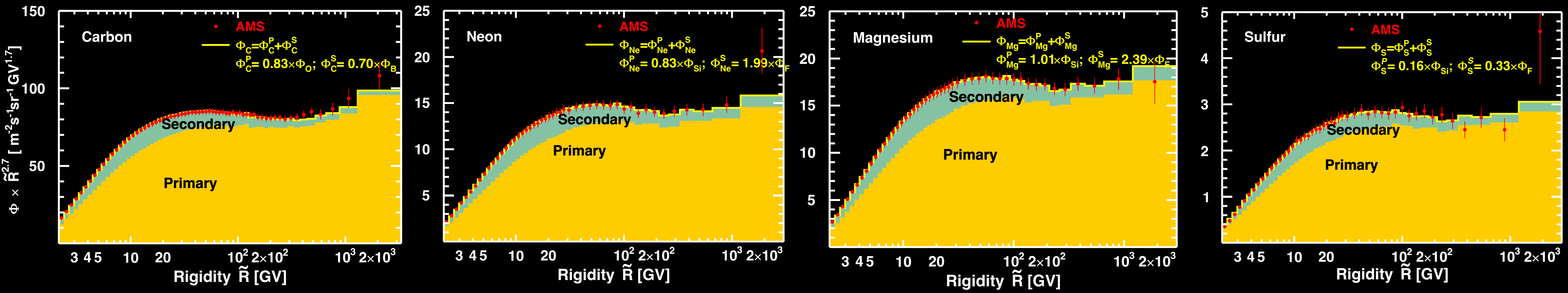
Measurements of cosmic ray nuclei



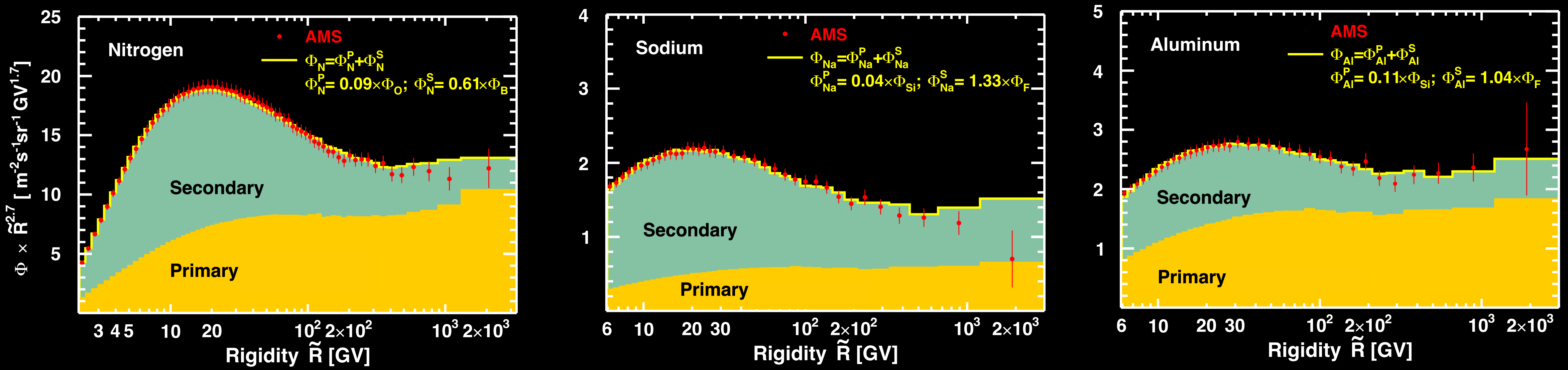
Primary and Secondary cosmic rays: each has two distinct classes



Even-Z nuclei and Odd-Z nuclei have distinctly different primary and secondary composition

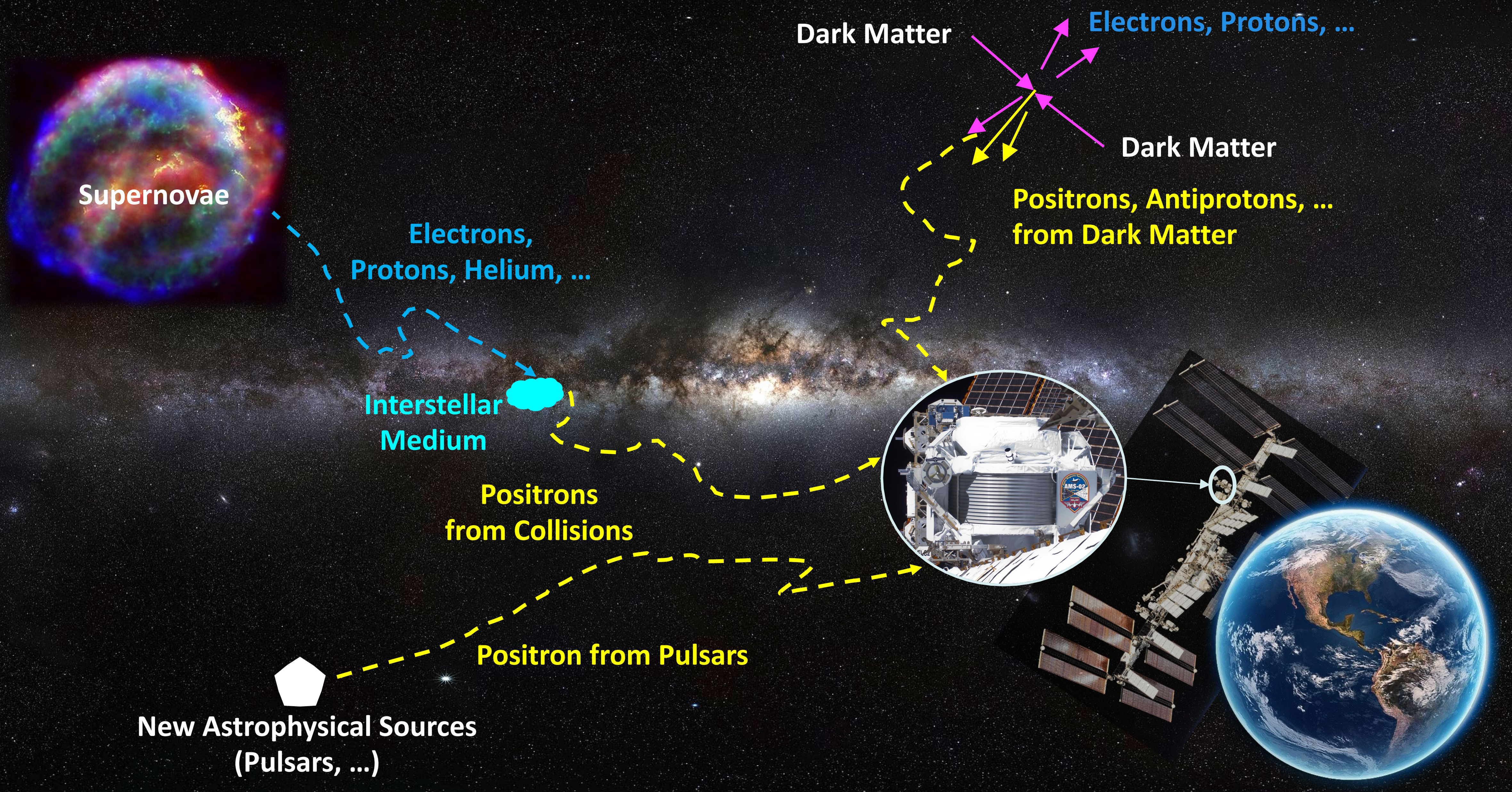


Even-Z nuclei are dominated by primaries



Odd-Z nuclei have more secondaries than even-Z

Study of Light Antimatter cosmic rays



The p̄/p ratio is sensitive to new physics

Black Holes:

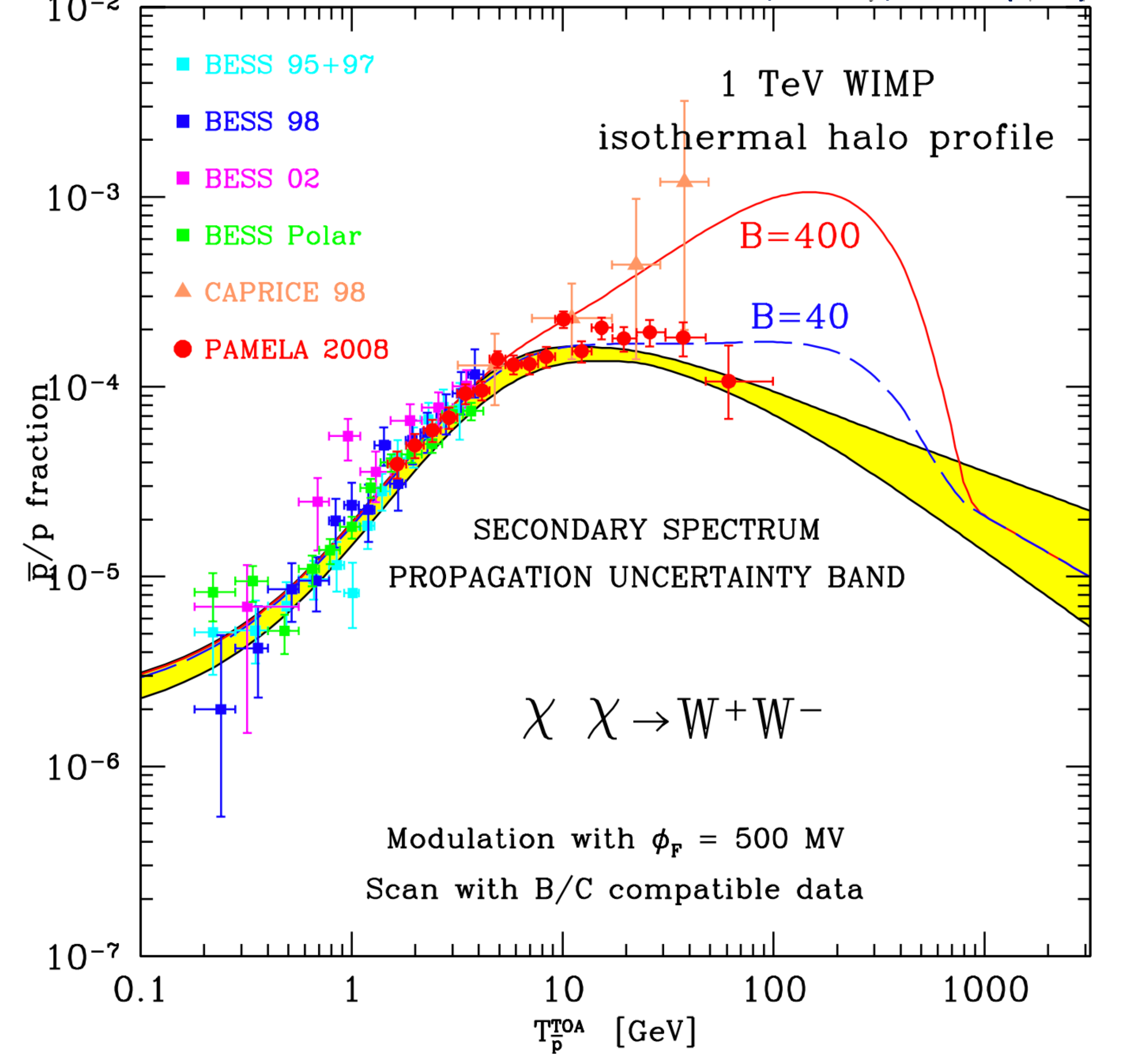
S. W. Hawking,
Nature (London) 248 (1974) 30

WIMPs:

J. Ellis et al.,
Phys. Lett. B 214 (1988) 403

M. Turner and F. Wilczek,
Phys. Rev. D 42 (1990) 1001

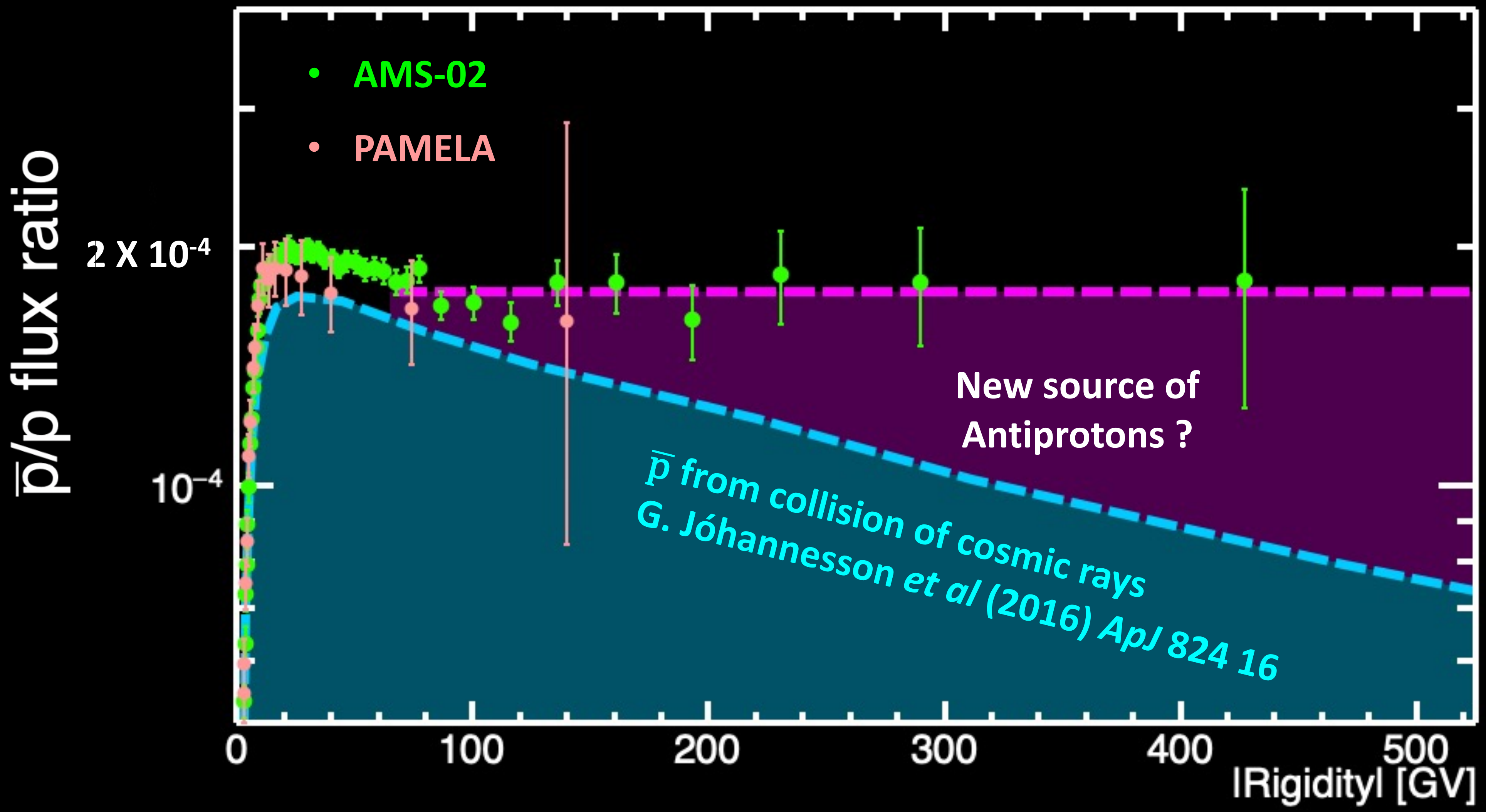
F. Donato et al., PRL 102, 071301 (2009)



Antiproton-to-Proton flux ratio

The antiproton-to-proton flux ratio shows unexpected energy dependence

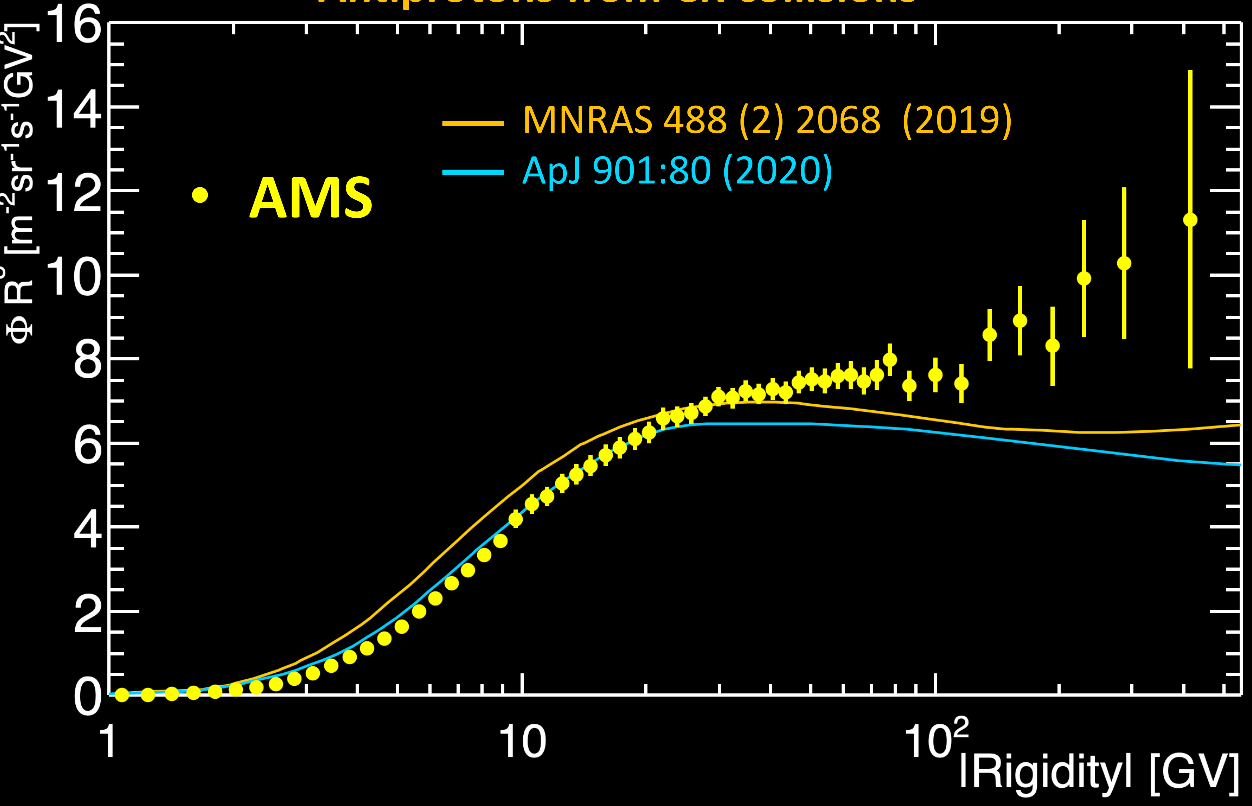
Distinctly different from antiprotons from collision of cosmic rays



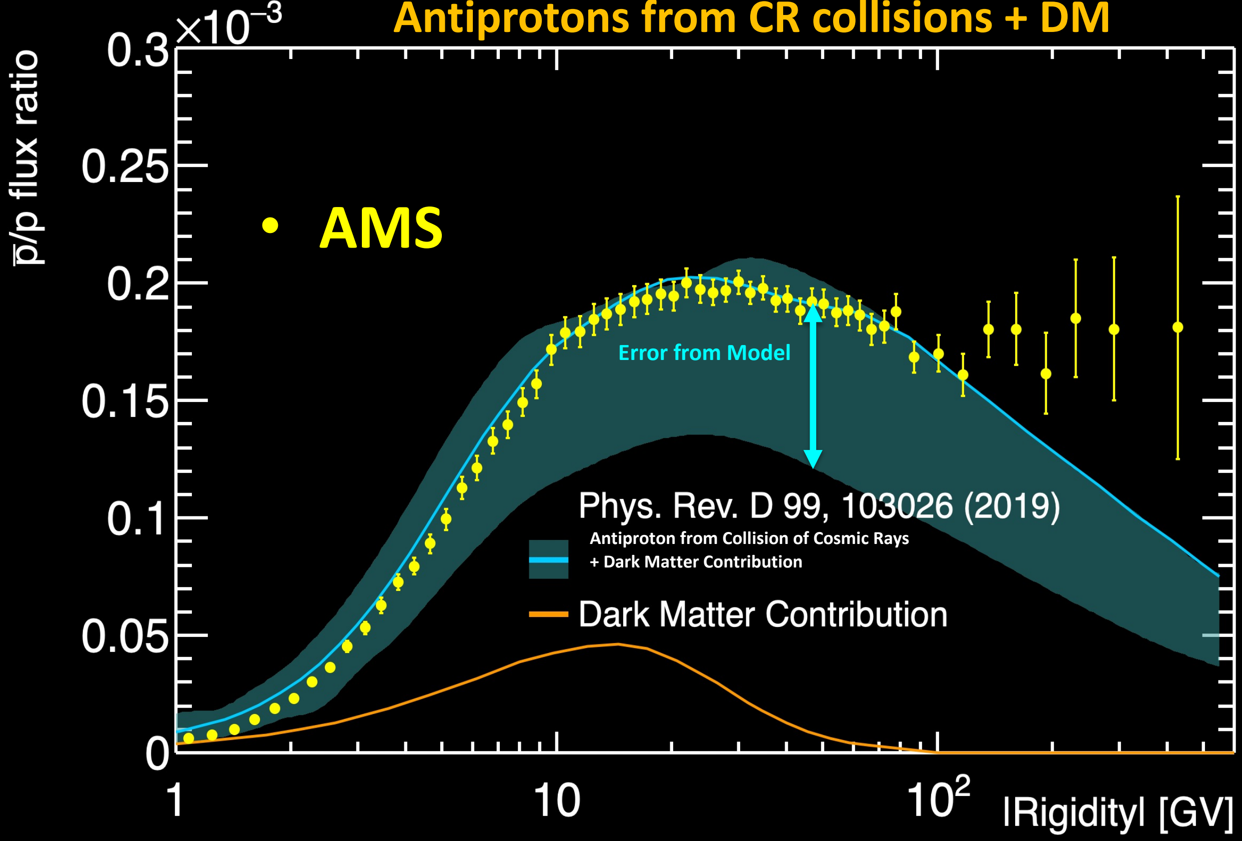
New Development in Understanding Cosmic Ray Antiprotons

- Secondary Antiprotons from CR collisions
- Primary antiprotons from (Dark Matter)

Antiprotons from CR collisions



Antiprotons from CR collisions + DM

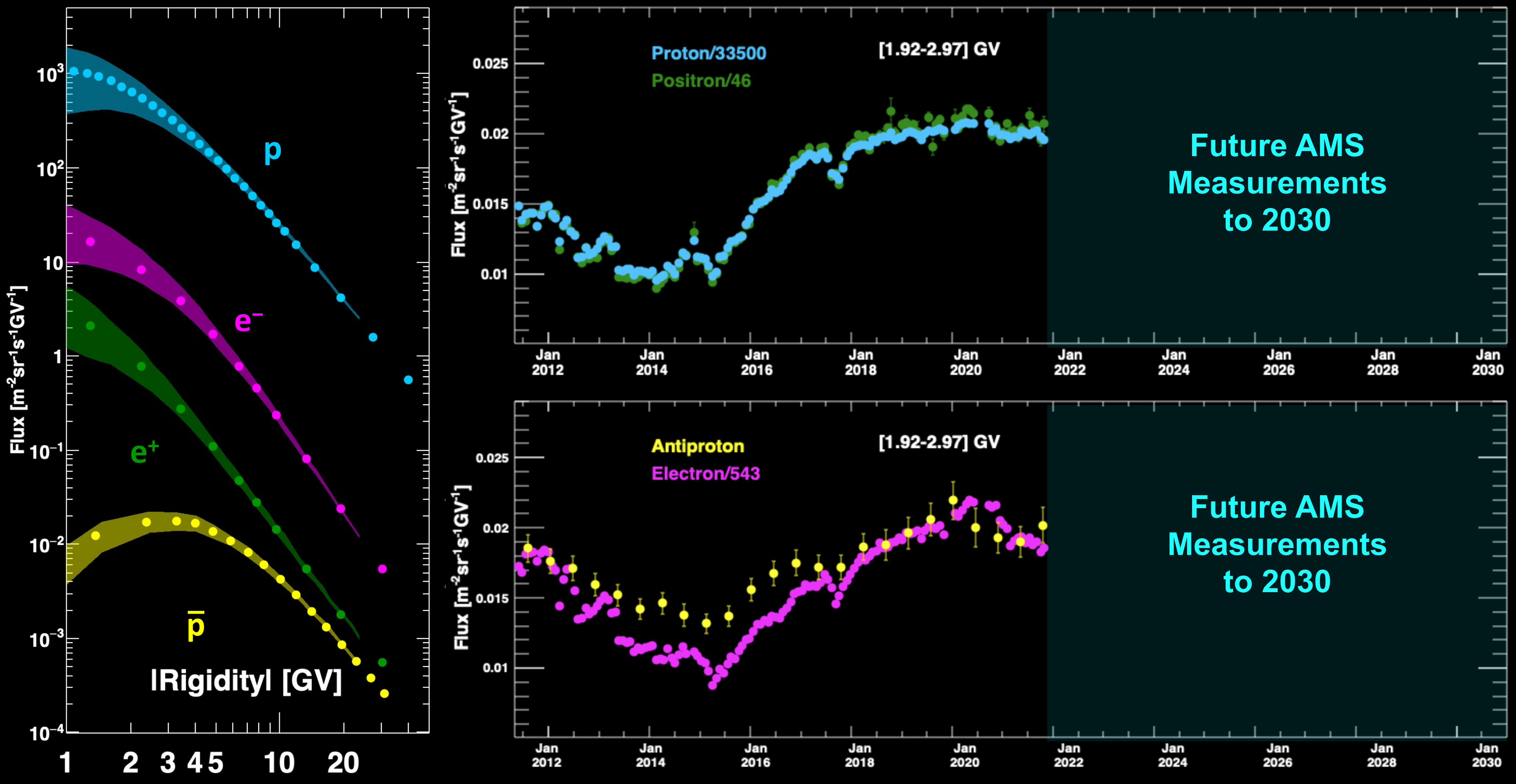


Modelling uncertainties:

- Production cross section
- Propagation
- Solar effects

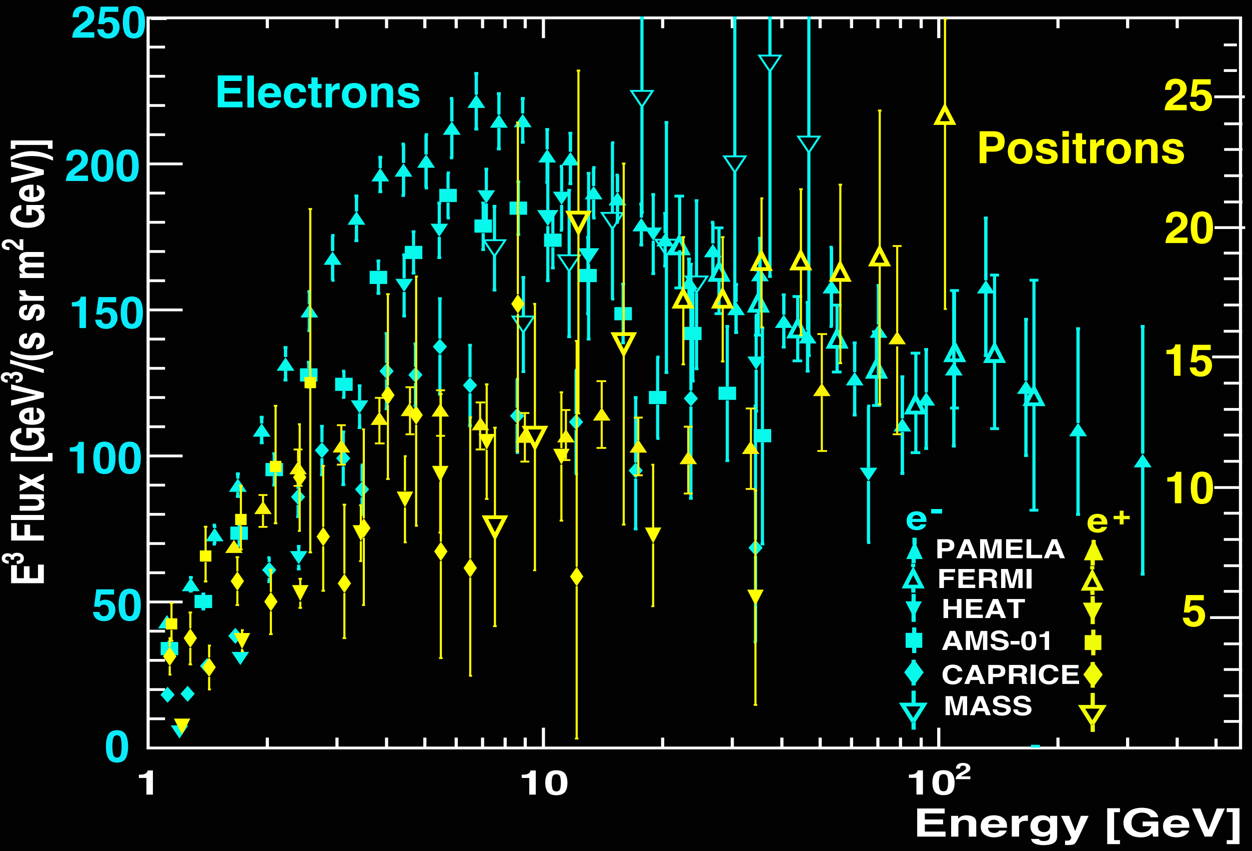
Understanding Antiprotons with AMS Measurements

For the first time, the time dependence of 4 elementary (e^+, e^-, p, $\bar{p}$, …) are studied in detailed with the same experiment in a long duration

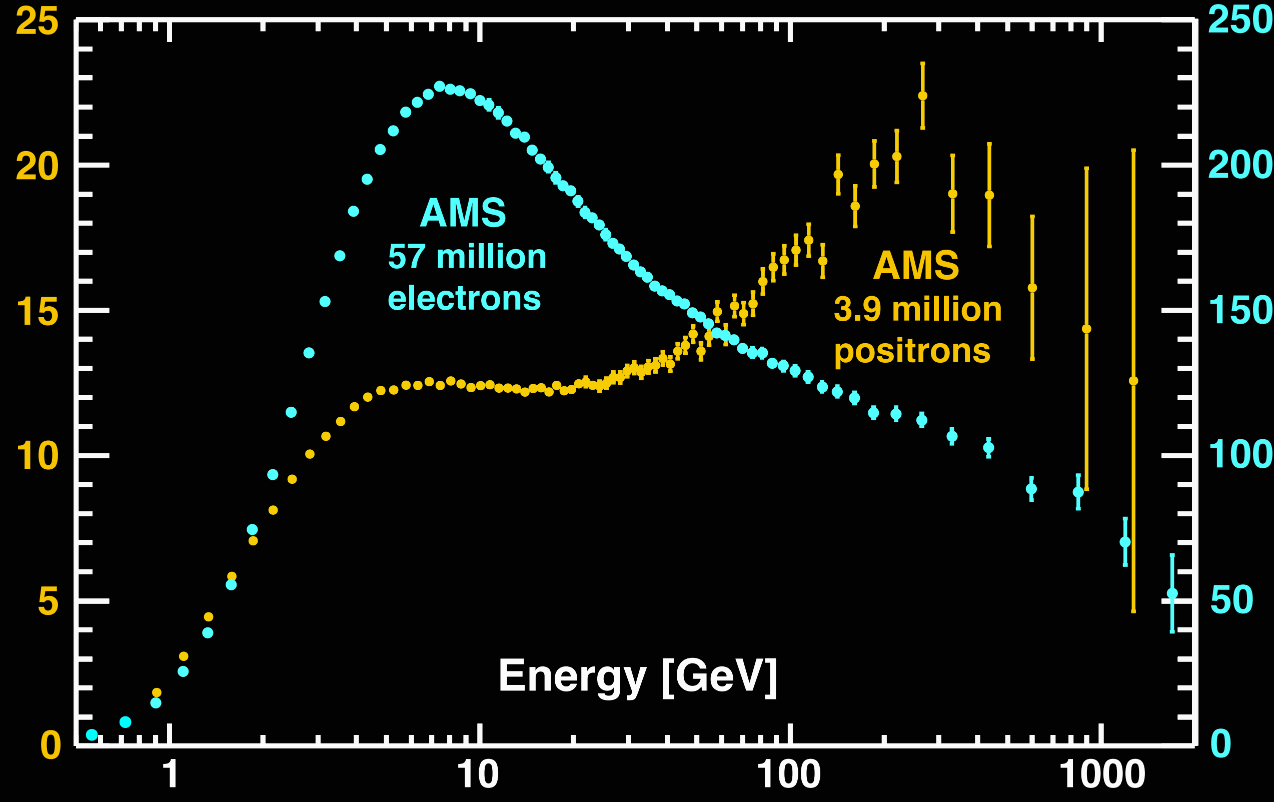


Study of Positrons & Electrons

Measurements before AMS



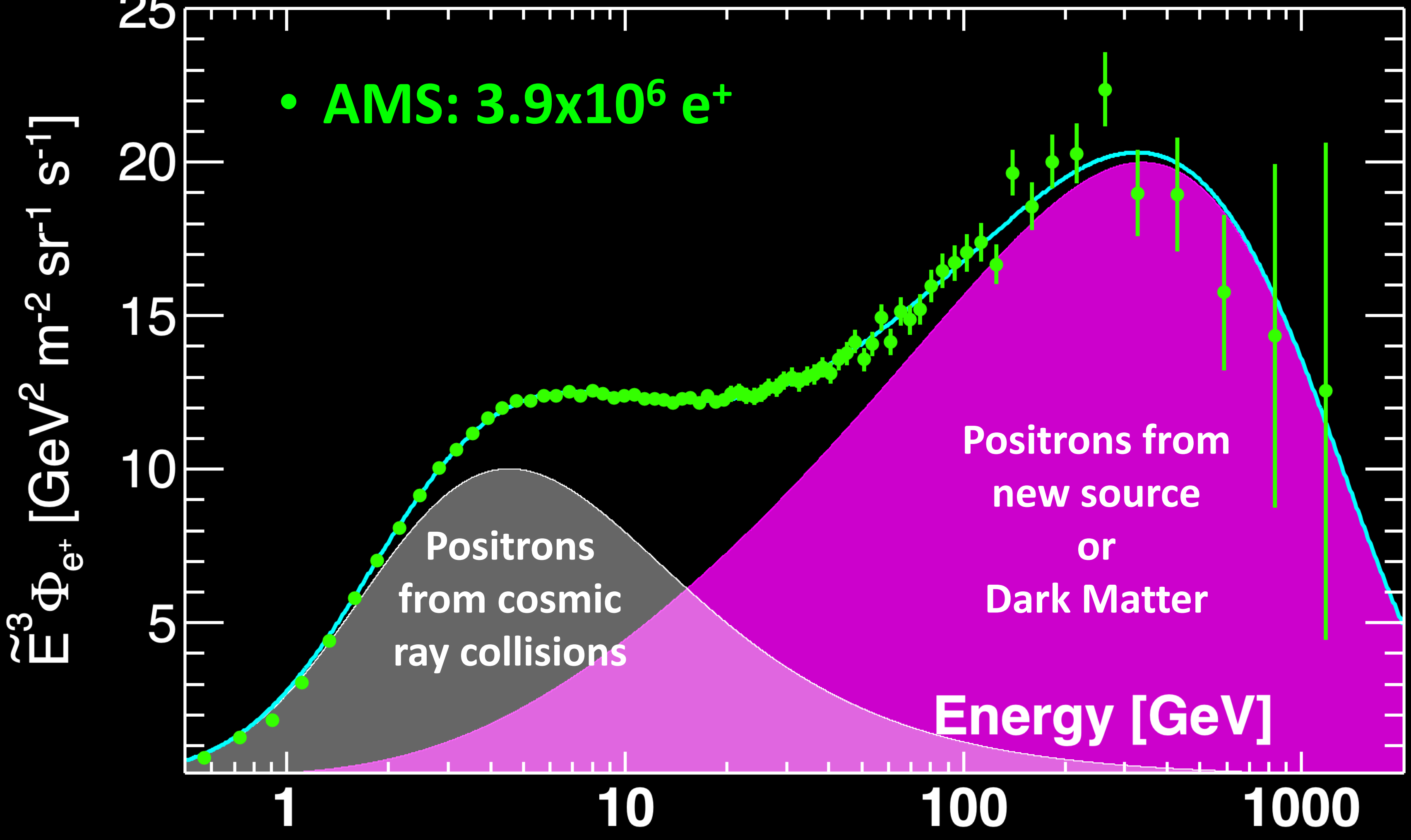
AMS measurements



The positron flux is the sum of low-energy part from cosmic ray collisions plus a high-energy part from pulsars or dark matter both with a cutoff energy E_S.

$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2}\left[C_d(\hat{E}/E_1)^{\gamma_d} + C_s(\hat{E}/E_2)^{\gamma_s}\exp(-\hat{E}/E_s)\right]$$

Solar Collisions Pulsars or Dark Matter

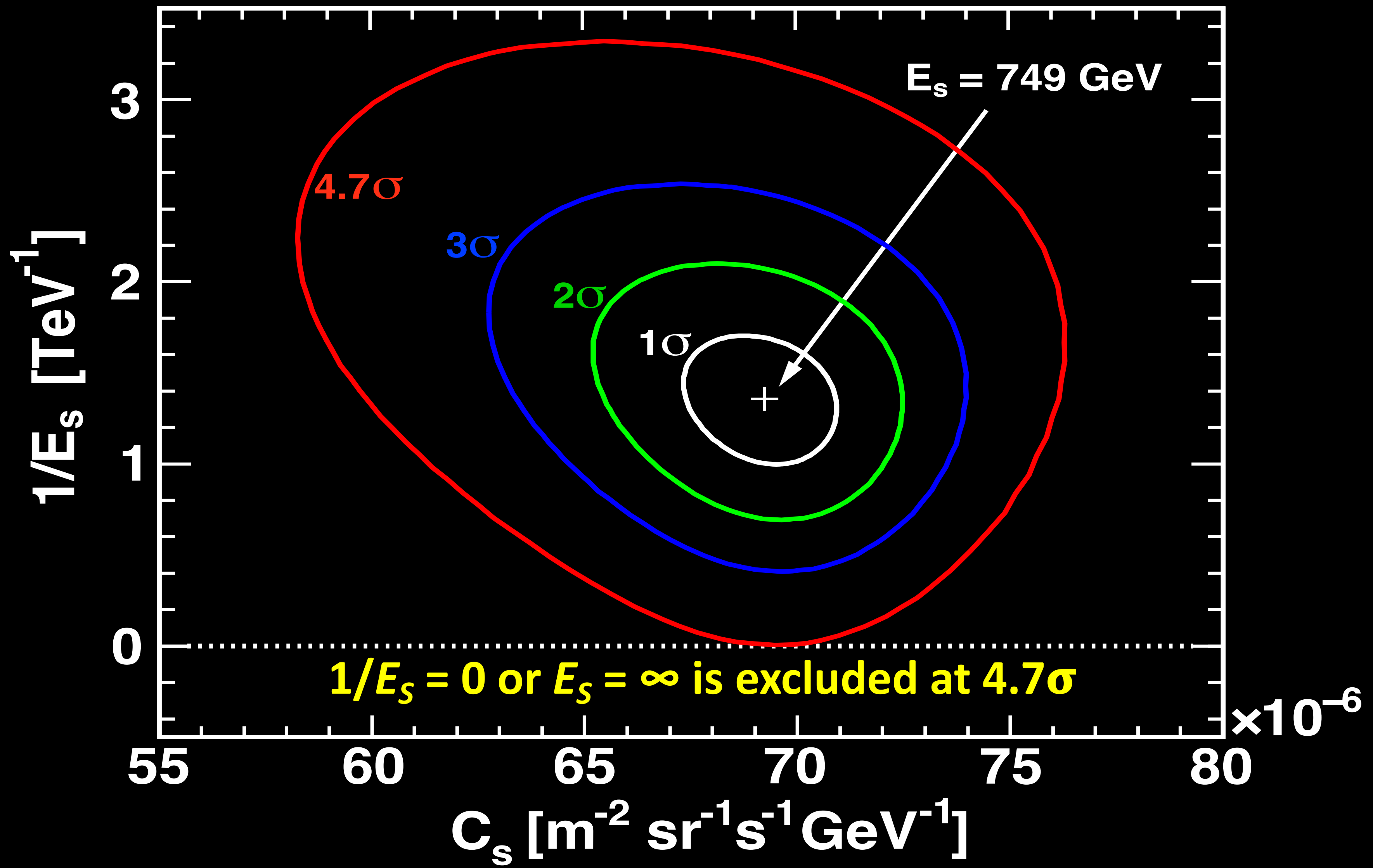


The existence of the finite cutoff energy (4.7σ) is a new and unexpected observation

Determination of the cutoff energy E_S

Collisions New Source or Dark Matter

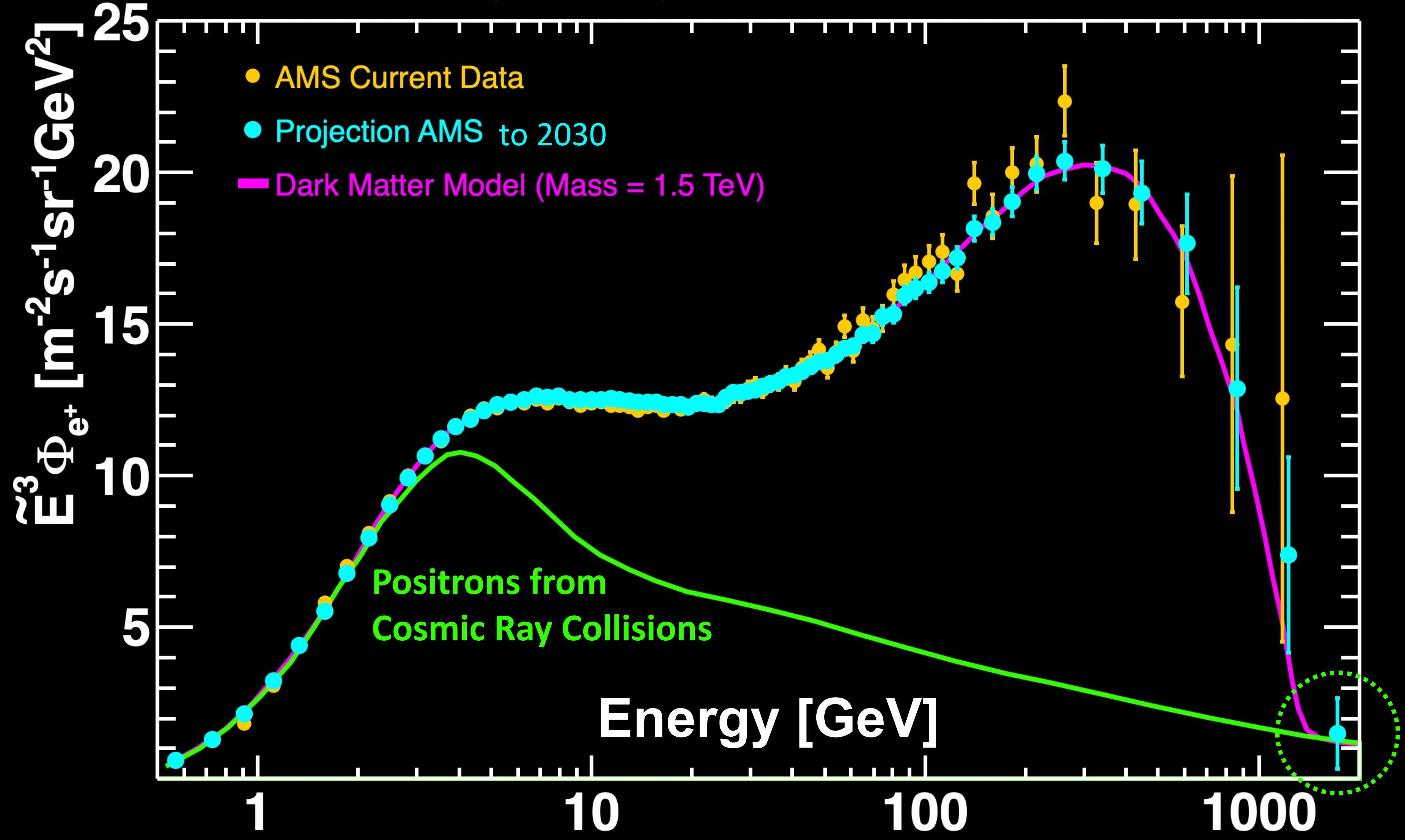
$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2}\left[C_d(\hat{E}/E_1)^{\gamma_d} + C_s(\hat{E}/E_2)^{\gamma_s}\exp(-\hat{E}/E_s)\right]$$



$1/E_S = 0$ or $E_S = \infty$ is excluded at 4.7σ

Determination of the Origin of Cosmic Positrons by 2030

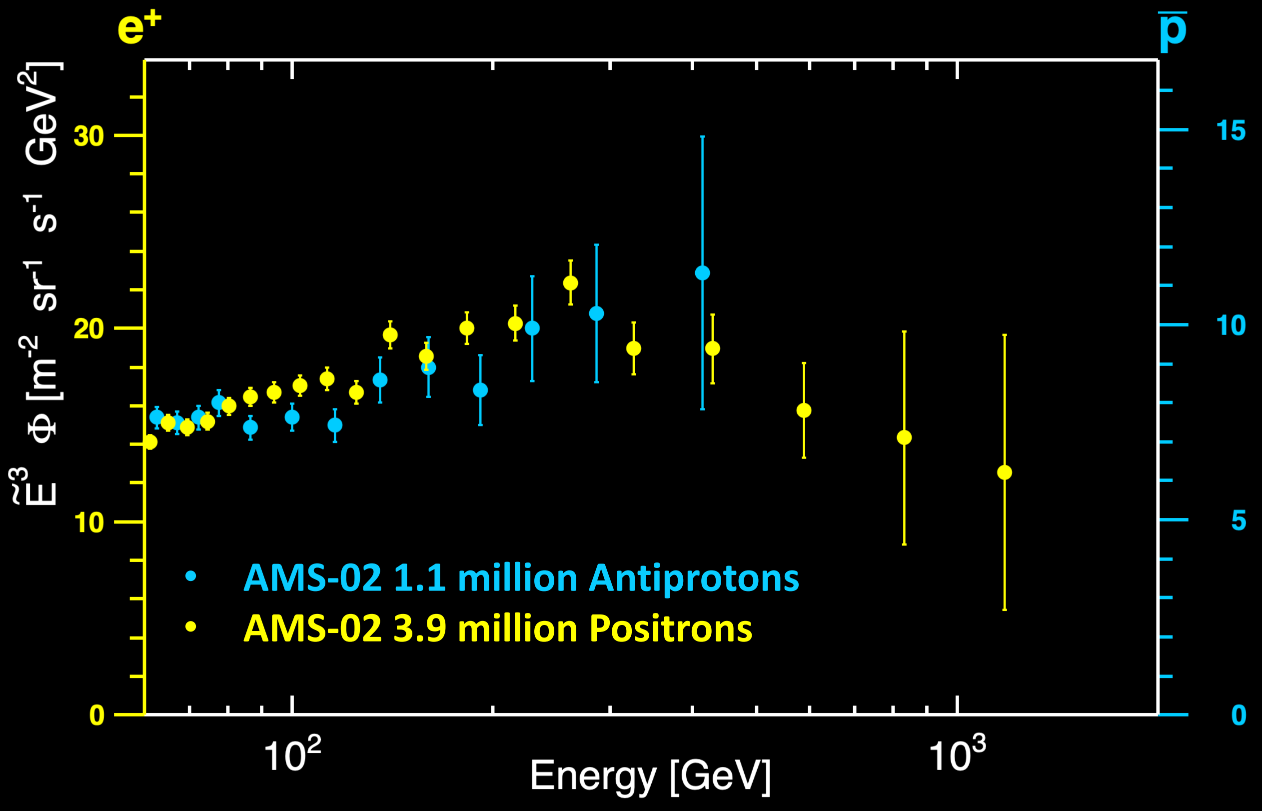
AMS will ensure that the measured high energy positron spectrum indeed drops off quickly and, at the highest energies, the positrons only come from cosmic ray collisions as predicted by dark matter models

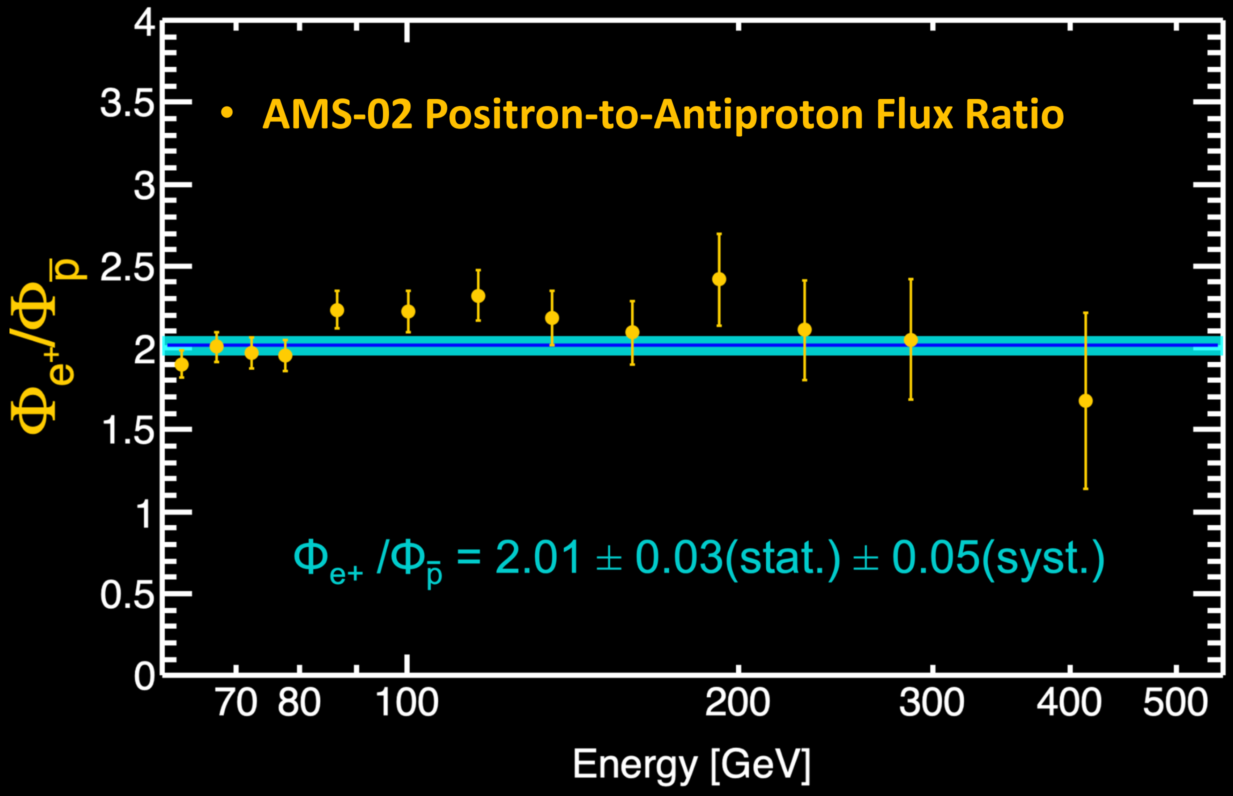


Unique Observation from AMS:

Positron and Antiproton have nearly identical energy dependence

The positron-to-antiproton flux ratio is independent of energy.

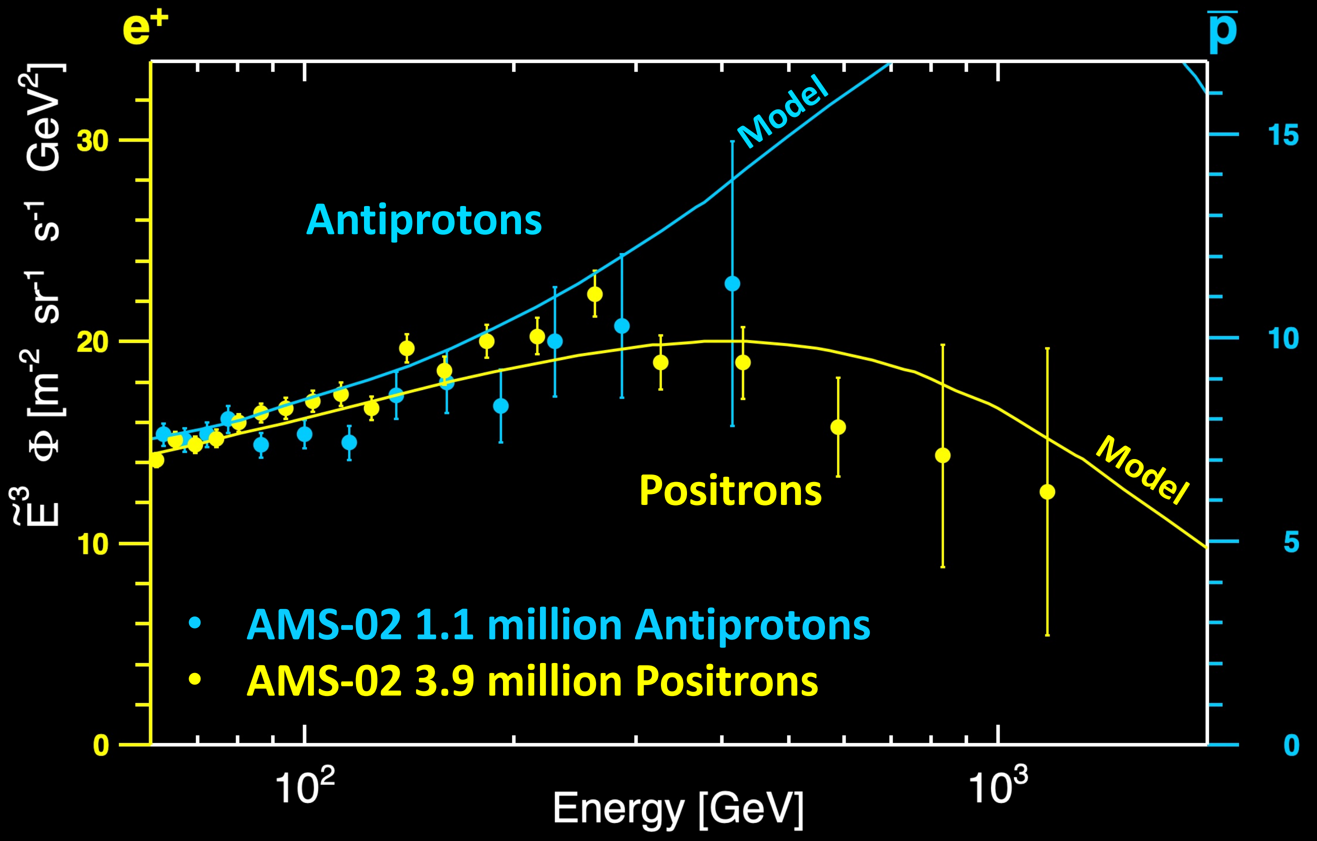


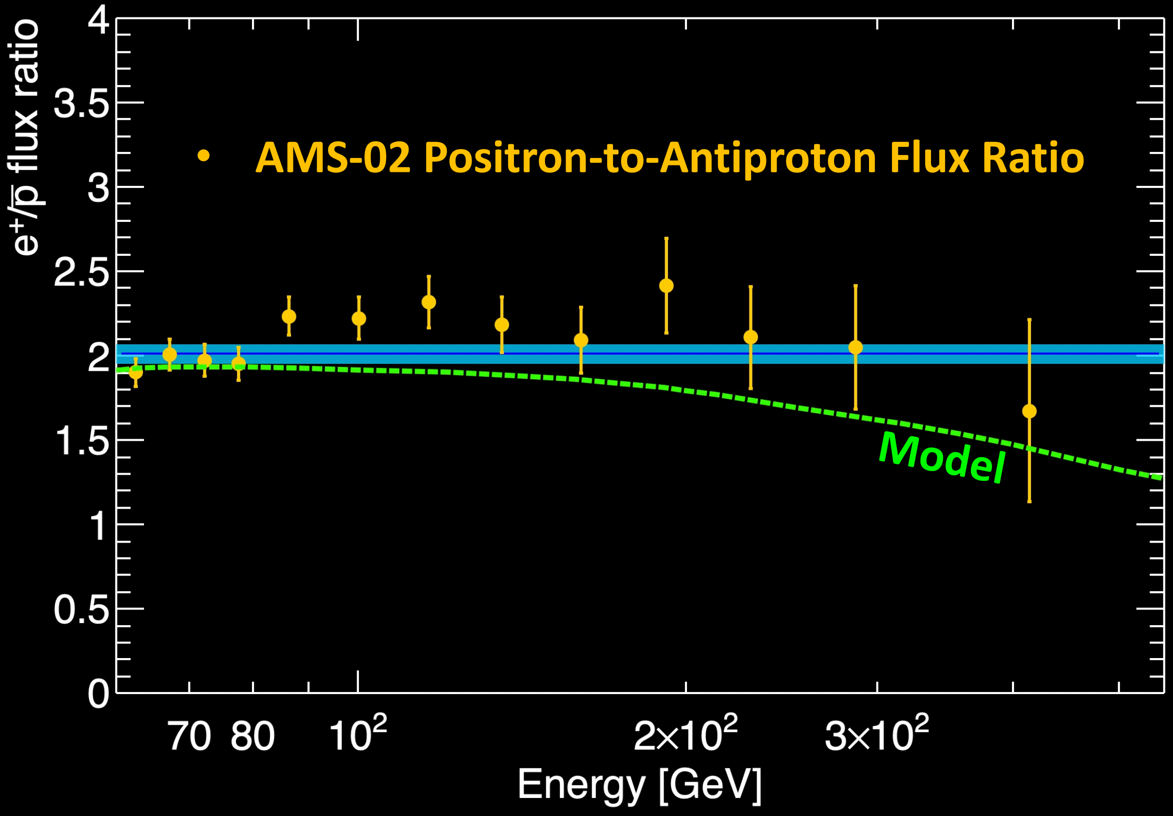


Antiprotons are not produced by pulsars.

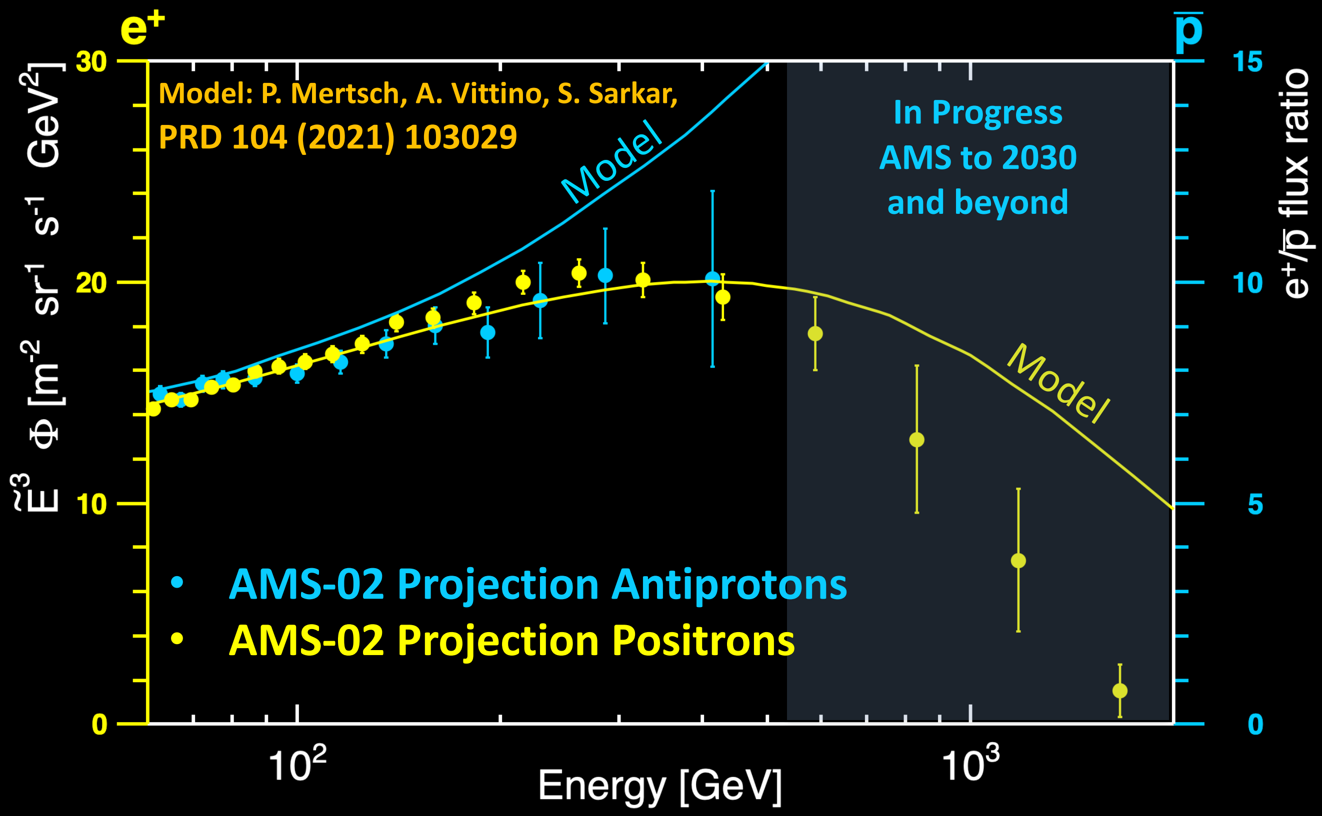
Example: Positron and Antiproton spectra compared with recent model

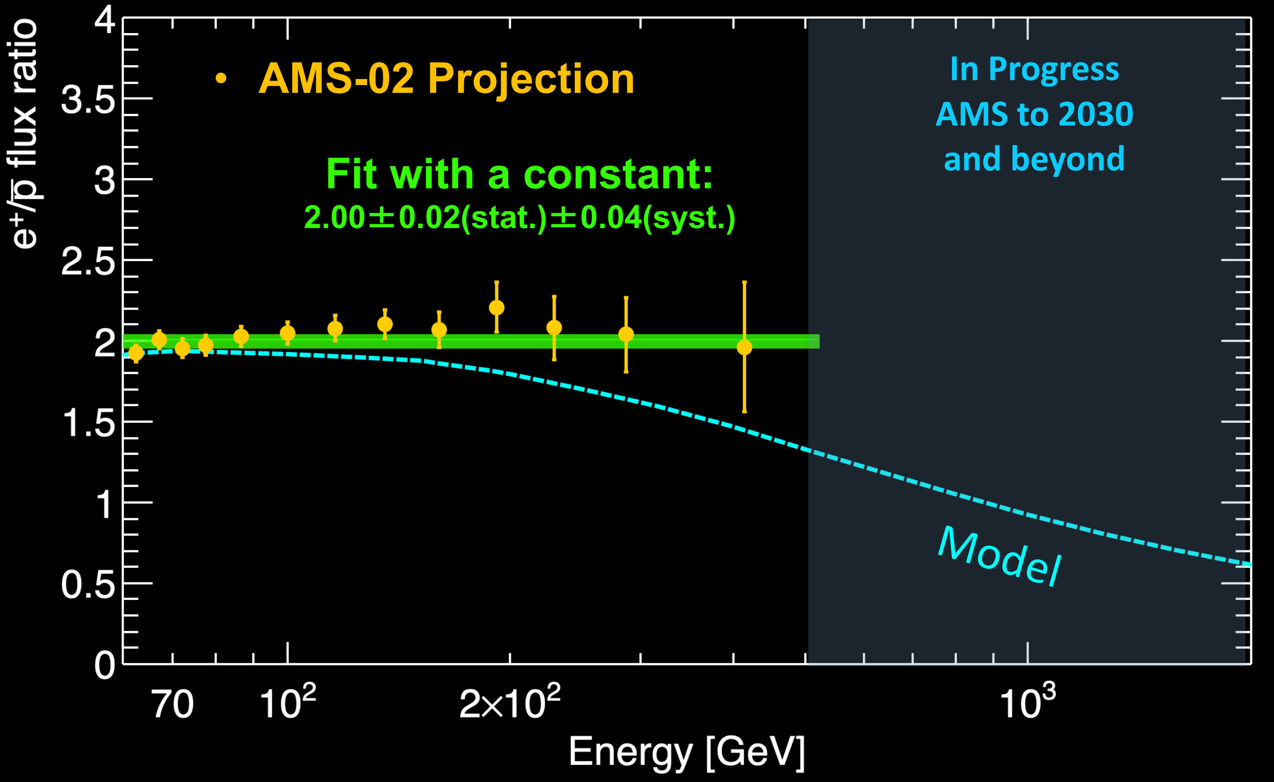
Model Example: "Explaining cosmic ray antimatter with secondaries from old supernova remnants"
P. Mertsch, A. Vittino, S. Sarkar, PRD 104 (2021) 103029





Future Measurement of Antiproton and Positrons with AMS Upgrade

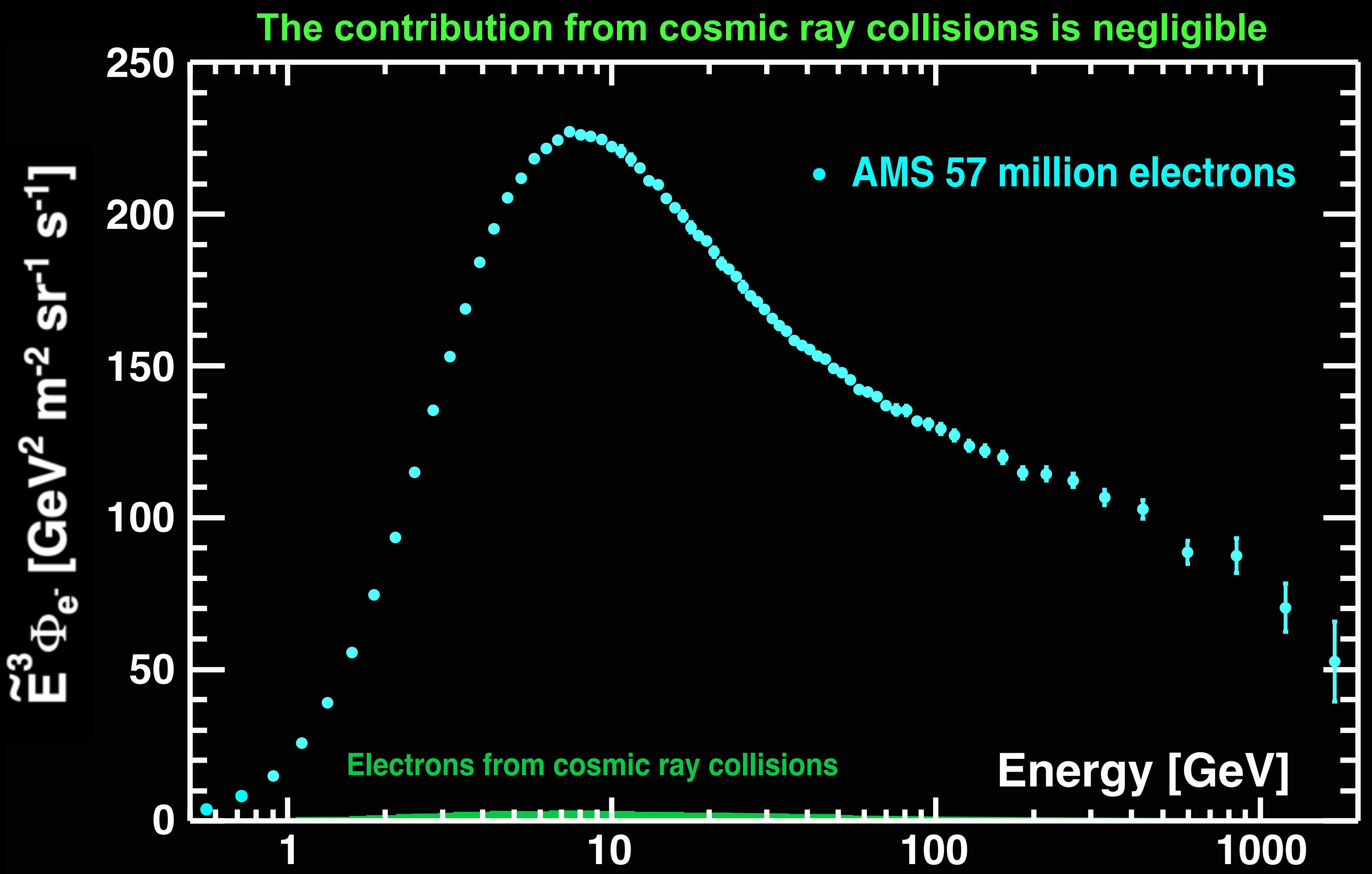




AMS will significantly improve the measurement of the positrons and antiprotons

The identical behaviour of positrons and antiprotons disfavours the pulsar origin of positrons

Origins of Cosmic Electrons

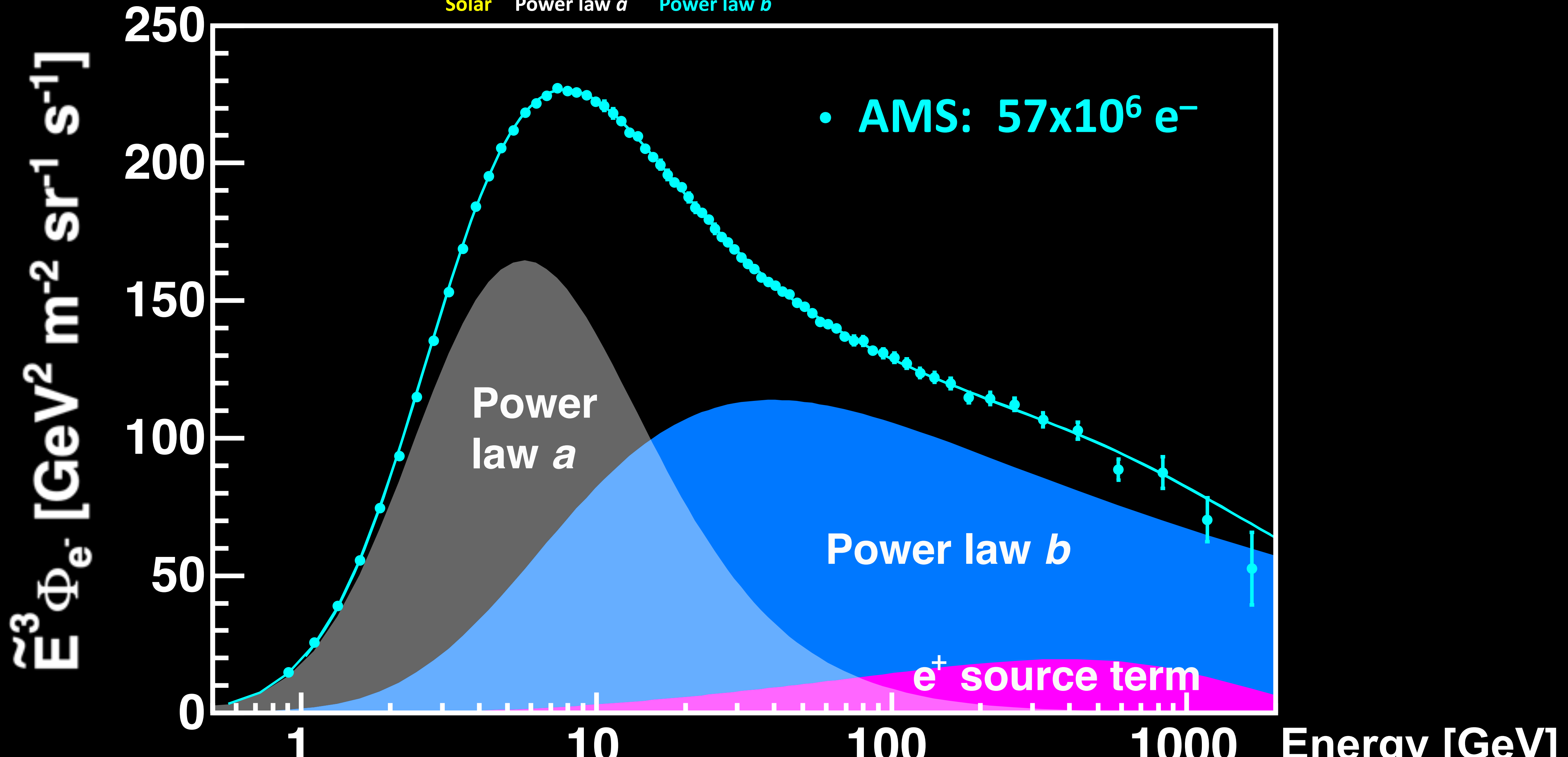


AMS Result on the electron spectrum

The spectrum fits well with two power laws (*a*, *b*) and a source term like positrons (2.6σ significance)

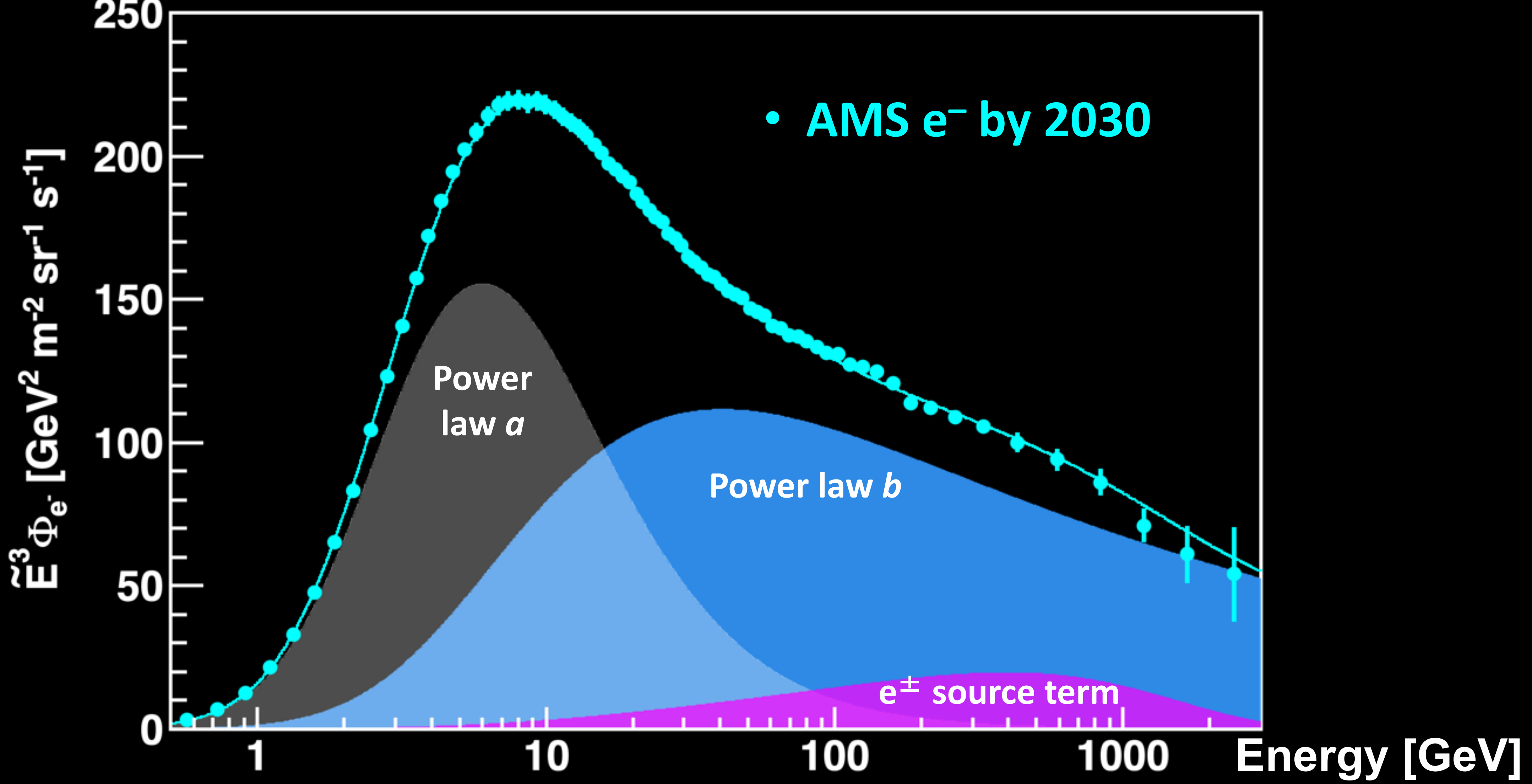
$$\Phi_{e^-}(E) = \frac{E^2}{\widehat{E}^2}\left(C_a \widehat{E}^{\gamma_a} + C_b \widehat{E}^{\gamma_b} + \text{Positron Source Term}\right)$$

Solar Power law *a* Power law *b*



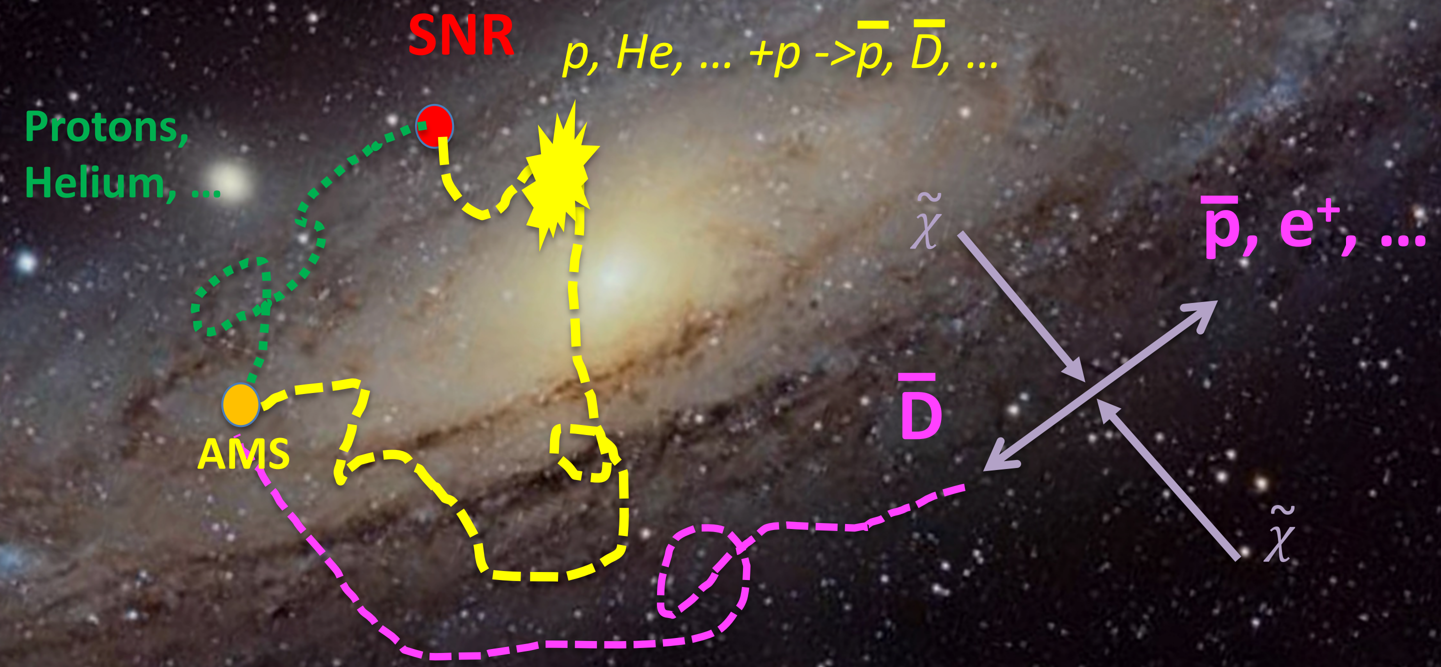
By 2030, the charge-symmetric nature of the high energy source will be established at the 4σ level

New sources, like Dark Matter or Pulsars, produce equal amounts of e+ and e–



Antideuterons in the Cosmos

Anti-deuterons have never been observed in space

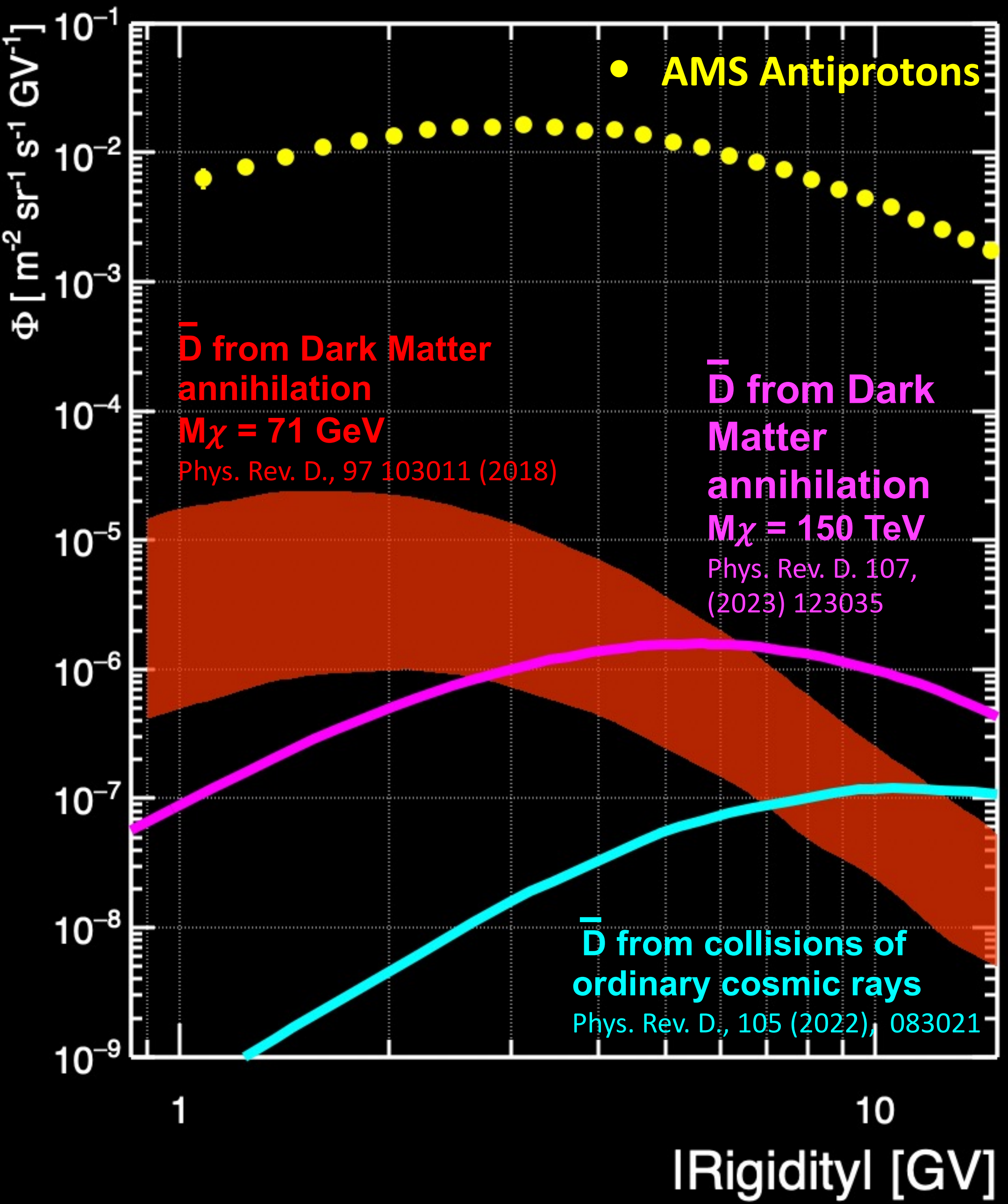


For the last 11 years, AMS has collected ~10 billion protons, ~100 million deuterons, and 1.1 million antiprotons

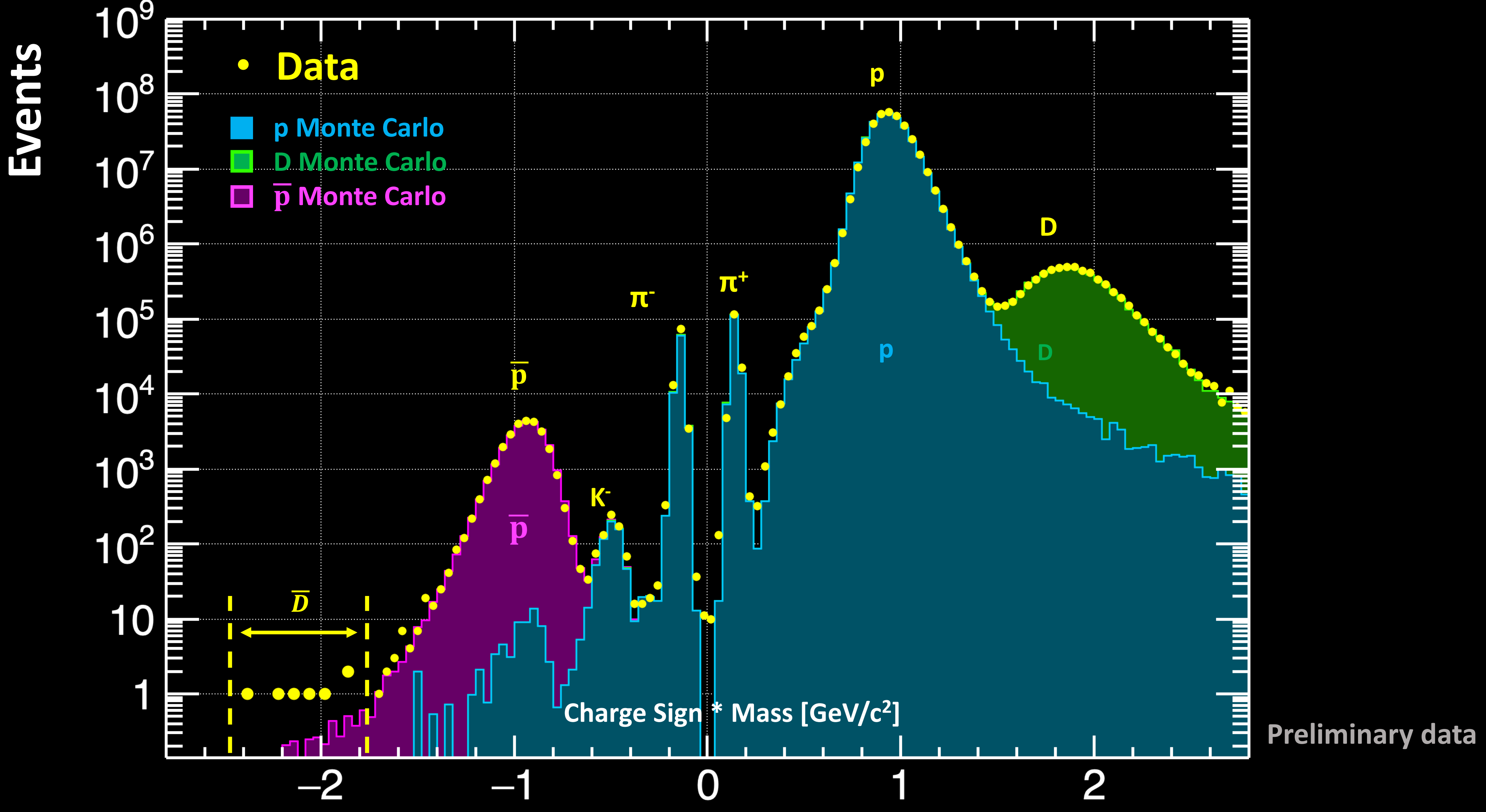
AMS provides a unique opportunity to measure cosmic anti-deuterons

Antideuterons in the Cosmos

- **Simultaneous measurement from AMS of $\overline{p}$ and $\overline{D}$ will provide precise and consistent information on their origin.**

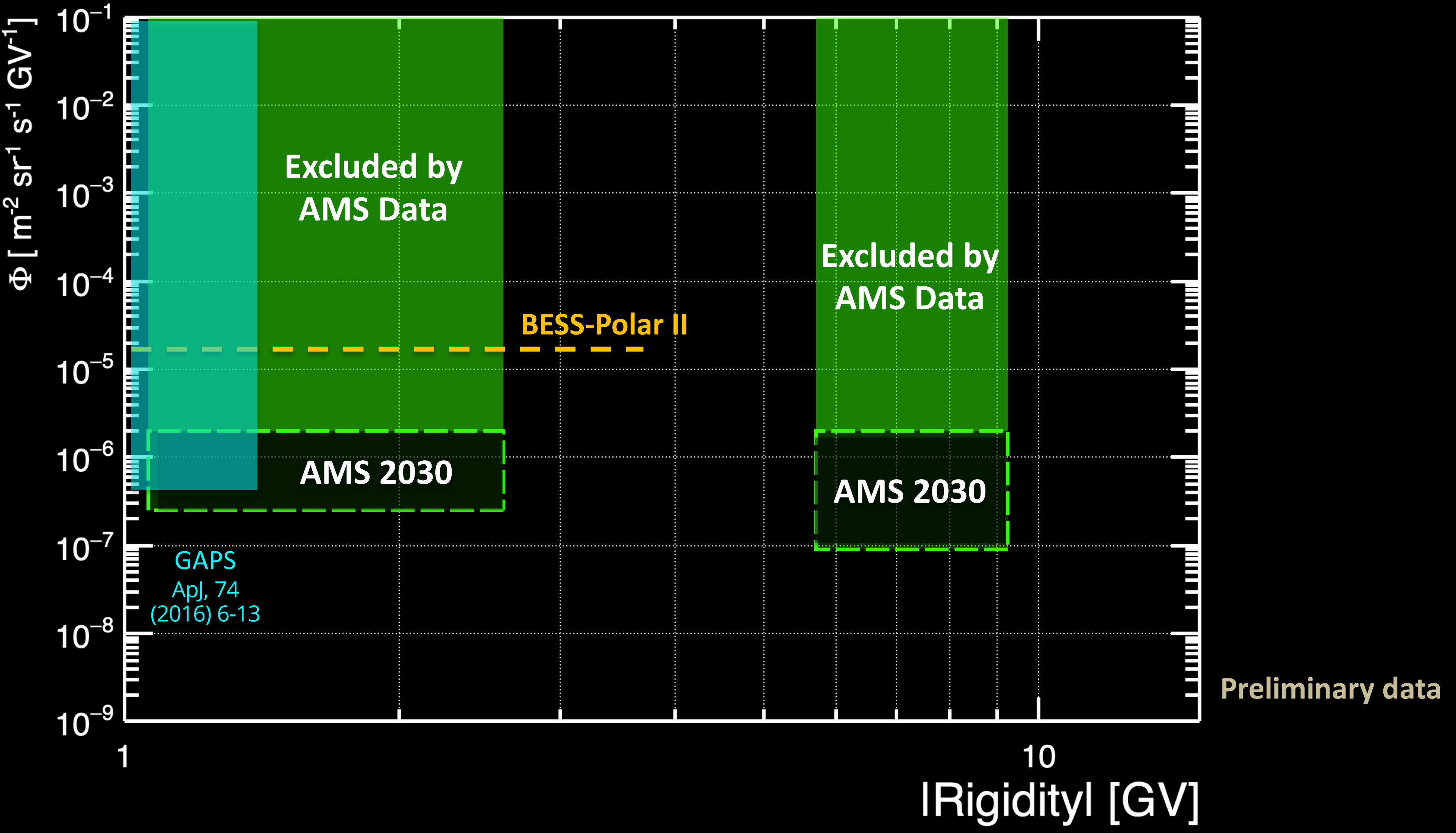


Current Status with 11 Years of AMS Data: Antideuterons in 5.7<|R|<9.3 GV



- **Future AMS upgrade will provide additional measurement point to antideuterons.**
- **Improve analysis techniques, further MC study to better understand the background.**

Future Measurement of Antideuteron with AMS Upgrade



AMS provide a unique opportunity to look for antideuterons in the cosmos.

AMS has recorded over 230 billion cosmic rays. Many interesting and unexpected observations were made that require the development of a new comprehensive theory of cosmic rays.

AMS will continue to collect and analyze data for the lifetime of the Space Station.

More new and exciting results are expected.