Highlights from the AMS Experiment: Properties of Elementary Particle Fluxes

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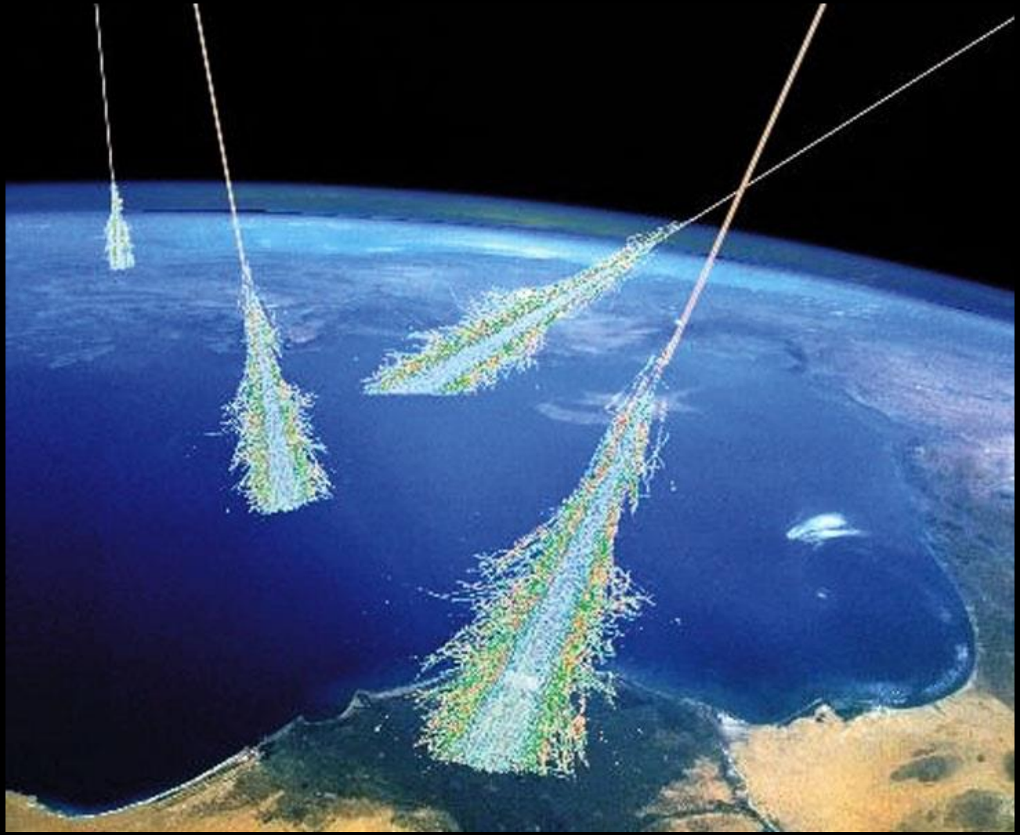
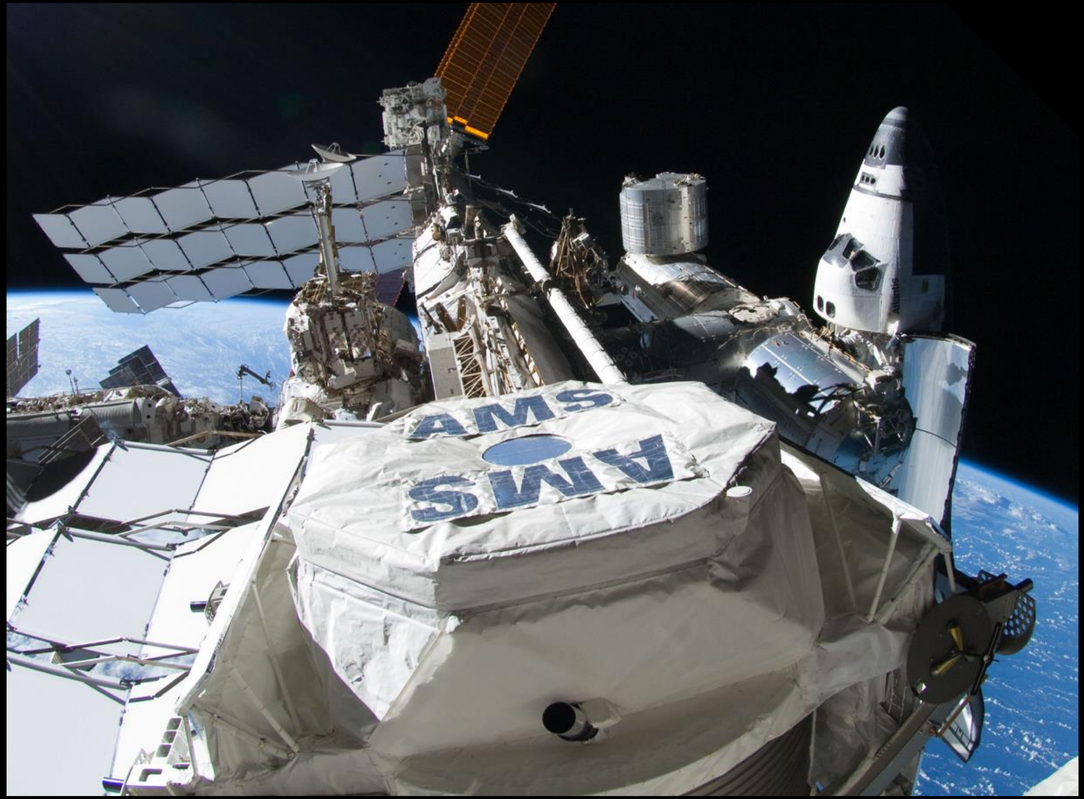
TEVPA2026, Tendo

The physics of Alpha Magnetic Spectrometer (AMS) on the Space Station: Study of Charged Cosmic Rays

Charged cosmic rays have mass.
They are absorbed by 100 km of Earth's atmosphere.

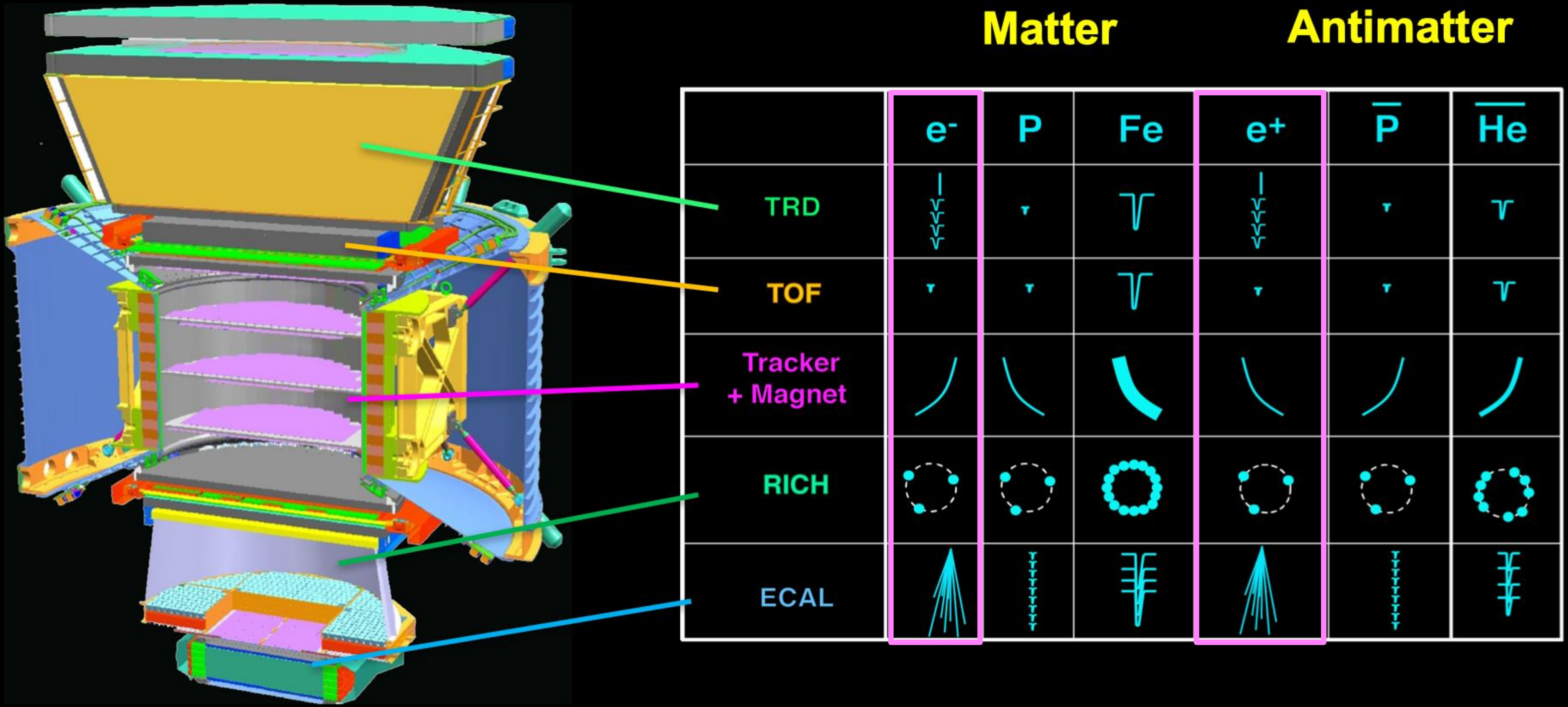
To measure their charge and momentum requires a magnetic spectrometer in space.





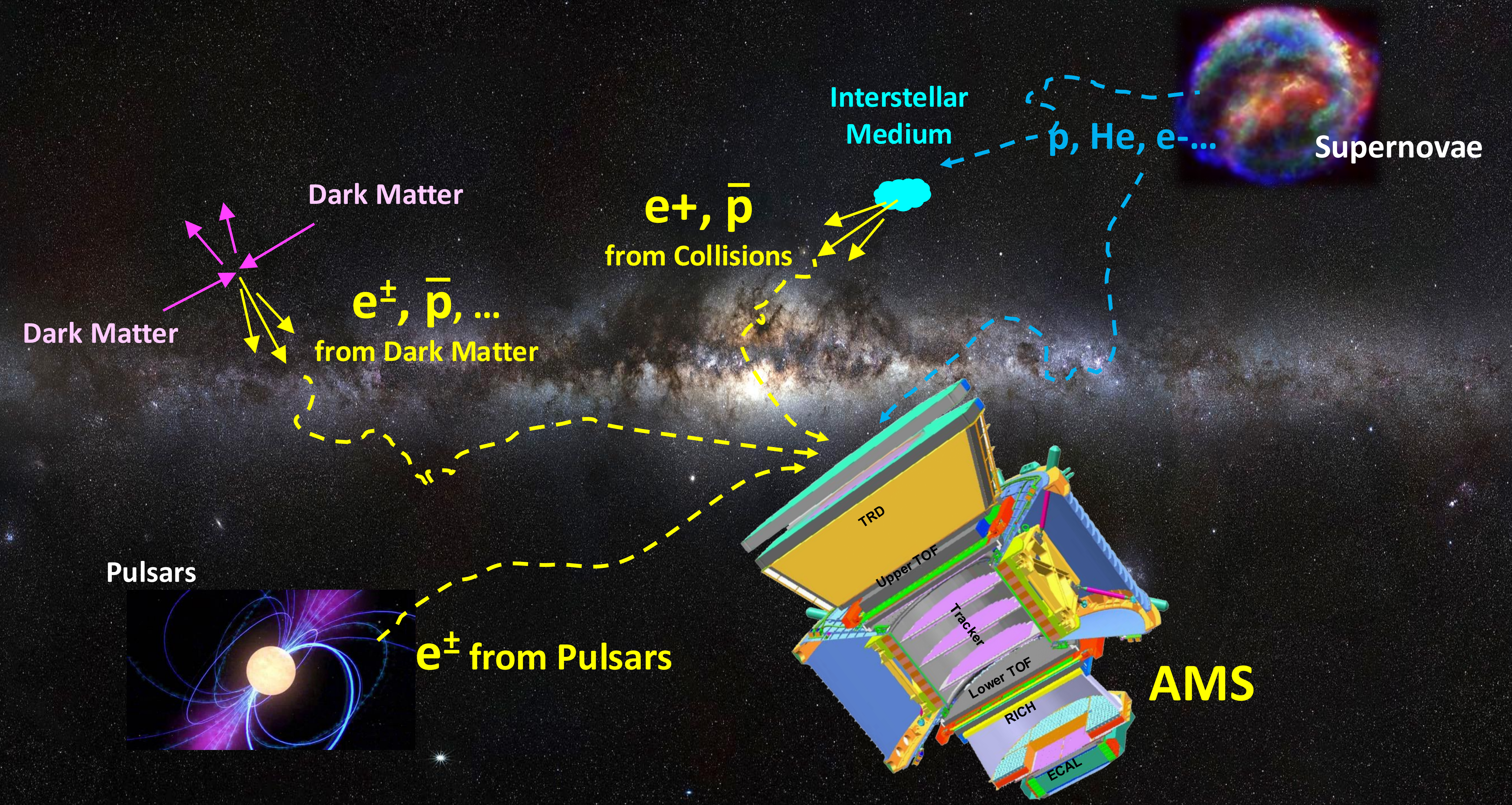
AMS on ISS provides long term precision measurements of charged cosmic rays.
Research topics: the Origin of Cosmic Rays, Physics of Dark Matter and Antimatter.

AMS is a unique magnetic spectrometer in space



In 14.5 years, the detectors have performed flawlessly. AMS is able to pick out 1 positron from 1,000,000 protons; unambiguously separate positrons from electrons up to a trillion eV; and accurately measure all cosmic rays to trillions of eV.

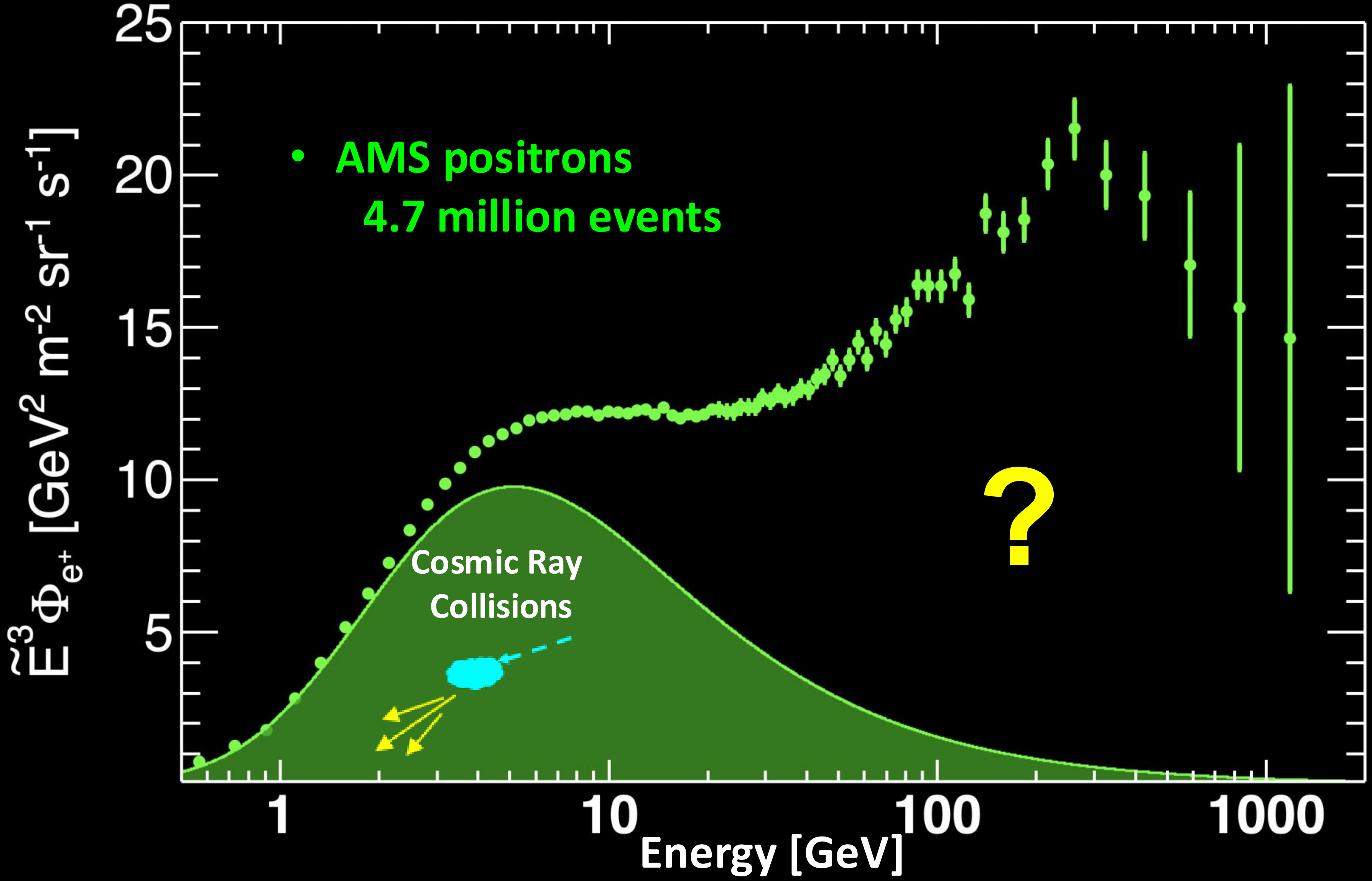
Latest Results on e+, e−, and $\bar{p}$



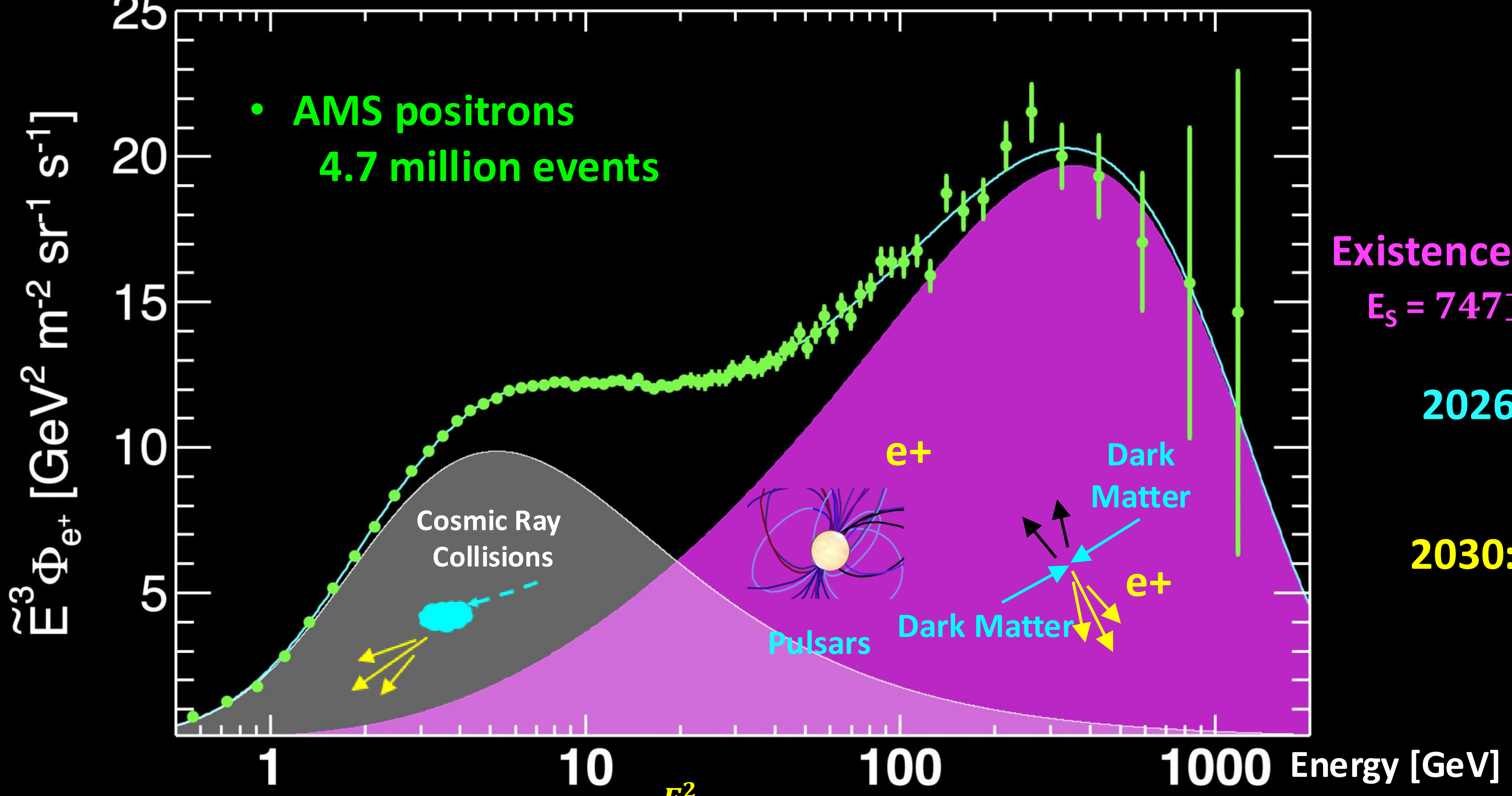
Latest Result on the positron spectrum

Low-energy positrons come from cosmic ray collisions

High-energy positrons must come from a new source



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



Existence of Cutoff

$E_S = 747^{+195}_{-128}$ GeV.

2026: 5-σ

2030: >6-σ

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

χ^2/dof = 36/66

Solar Collisions Pulsars or Dark Matter

Latest Result on the electron spectrum

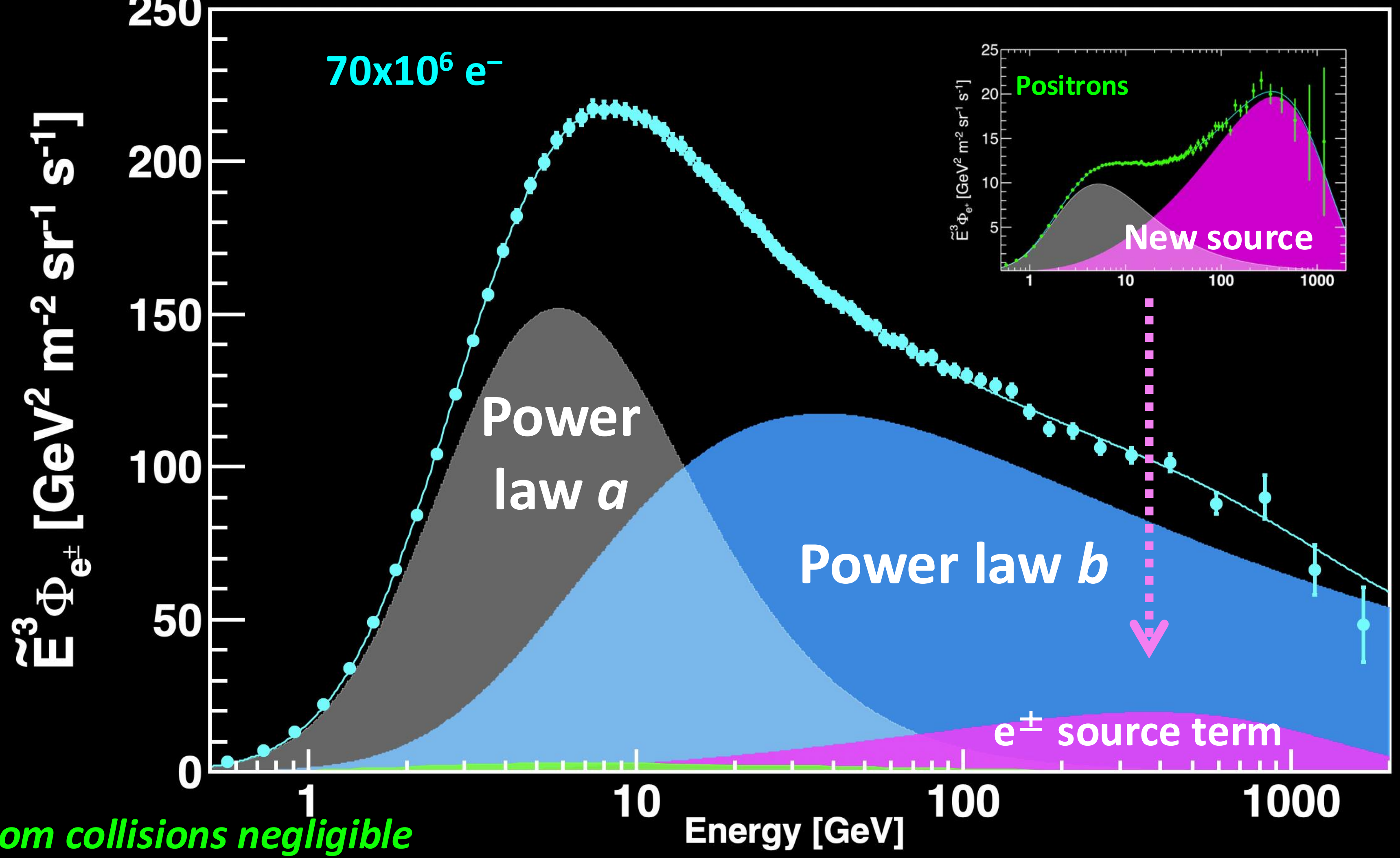
The spectrum fits well with two power laws (*a*, *b*) and the measured positron source term

Empirical model:

χ^2/dof = 42/67

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

Solar Power law *a* Power law *b*



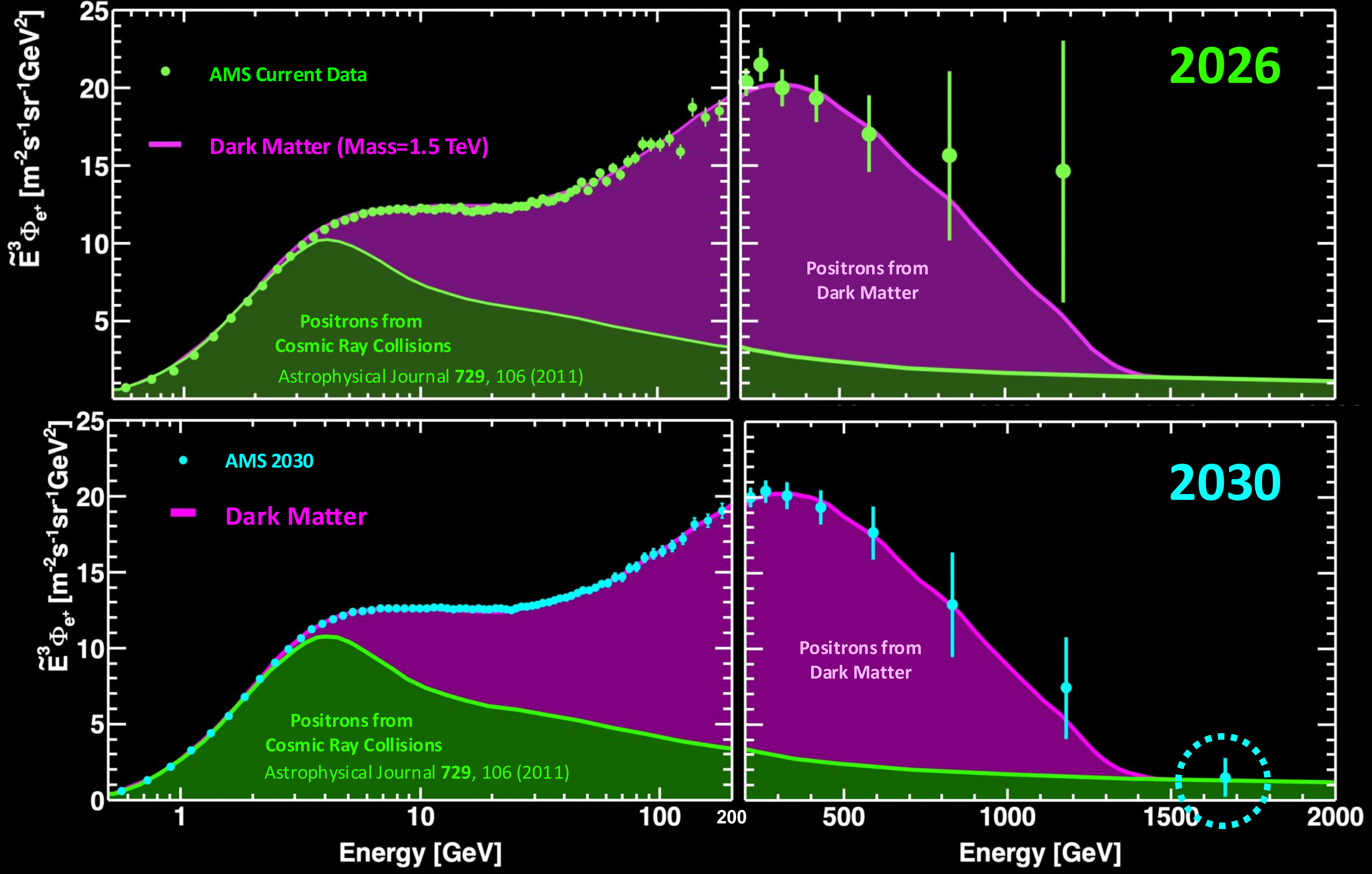
New sources, like Dark Matter or Pulsars, produce equal amounts of e+ and e–

2.7 σ

2030: >4σ

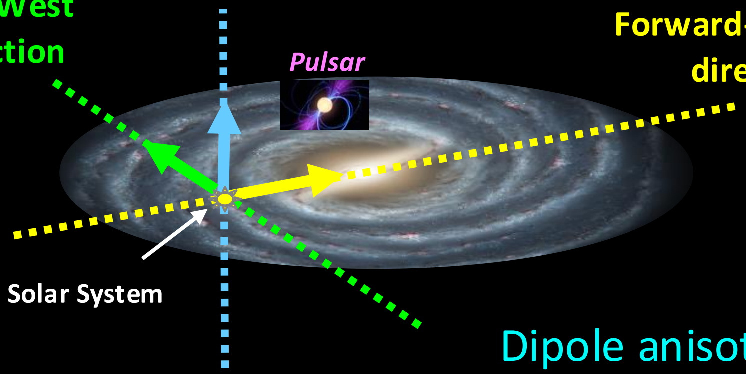
e⁻ from collisions negligible

Physics of Dark Matter: AMS Positron Spectrum through 2030



By 2030, AMS will ensure that the high energy positron spectrum drops off quickly in the 0.2-2 TeV region and the highest energy positrons only come from cosmic ray collisions as predicted in dark matter model

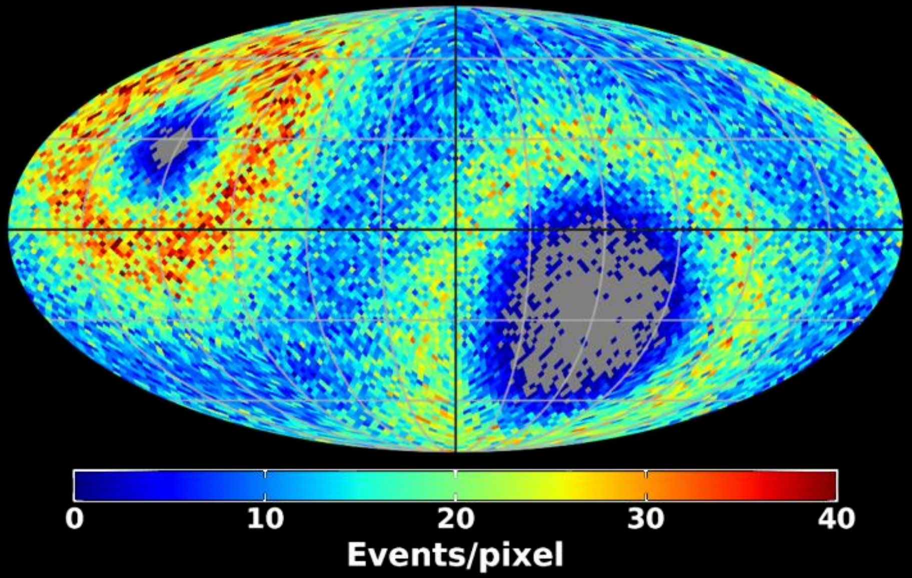
Positron Anisotropy



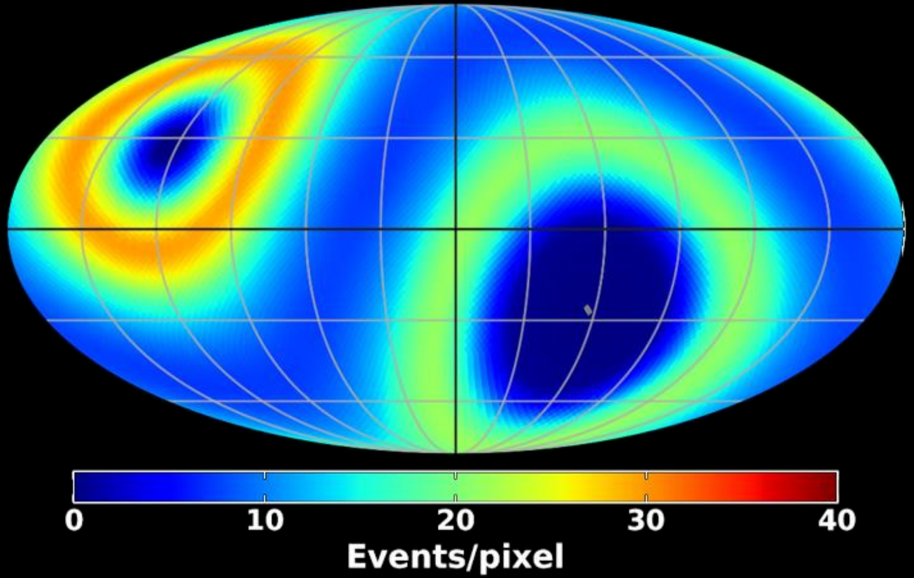
Astrophysical point sources will imprint a higher anisotropy on the arrival directions of energetic positrons than a smooth dark matter halo.

Dipole anisotropy: $\delta = 3\sqrt{C_1/4\pi}$ C_1 is the dipole moment

Positrons



Isotropic map



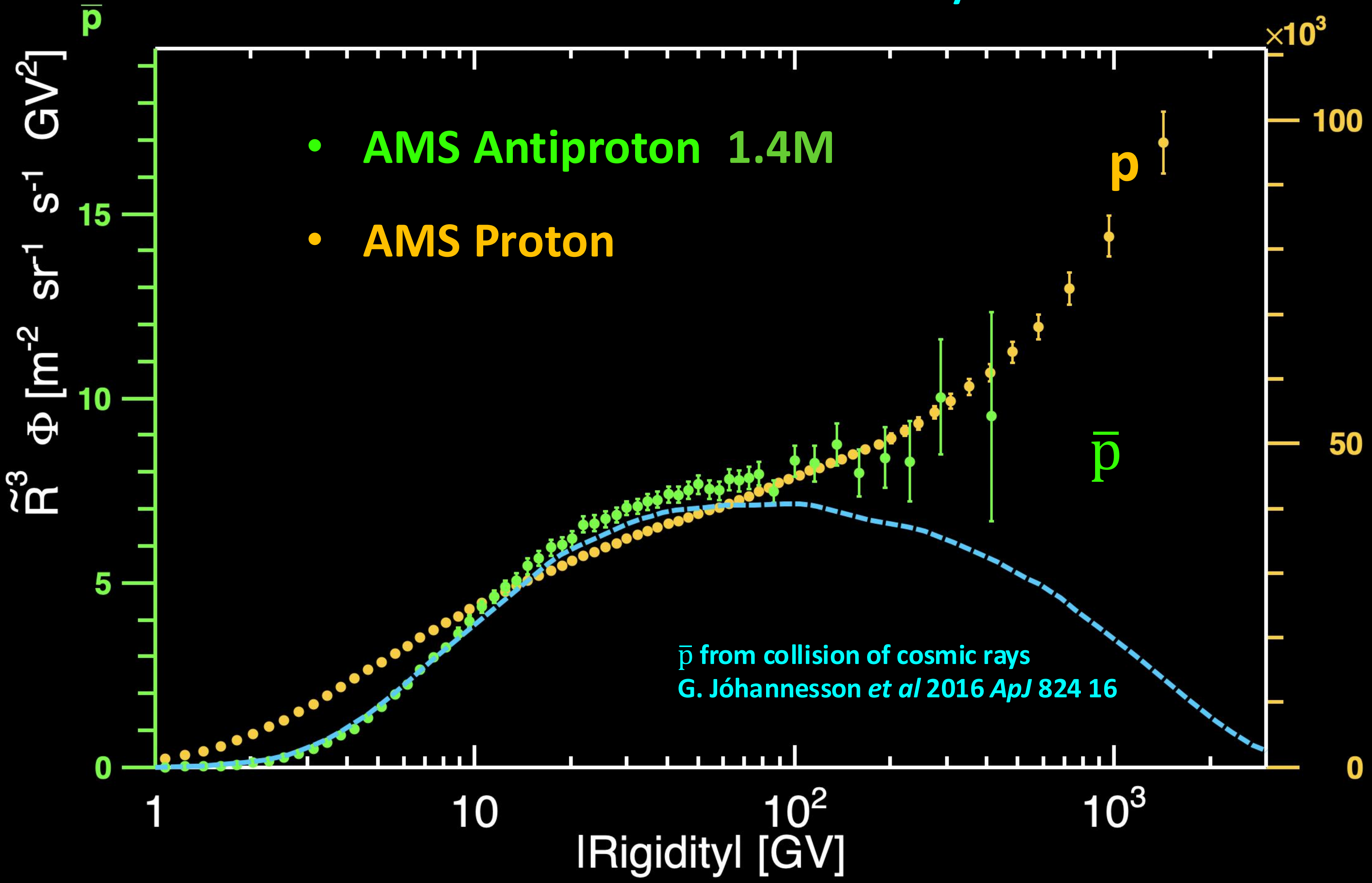
More details in
A. Stuzhin's talk on Monday

AMS **Currently at 95% C.I.:**
for 16 < E < 500 GeV

$\delta_{e+} < 1.27\%$

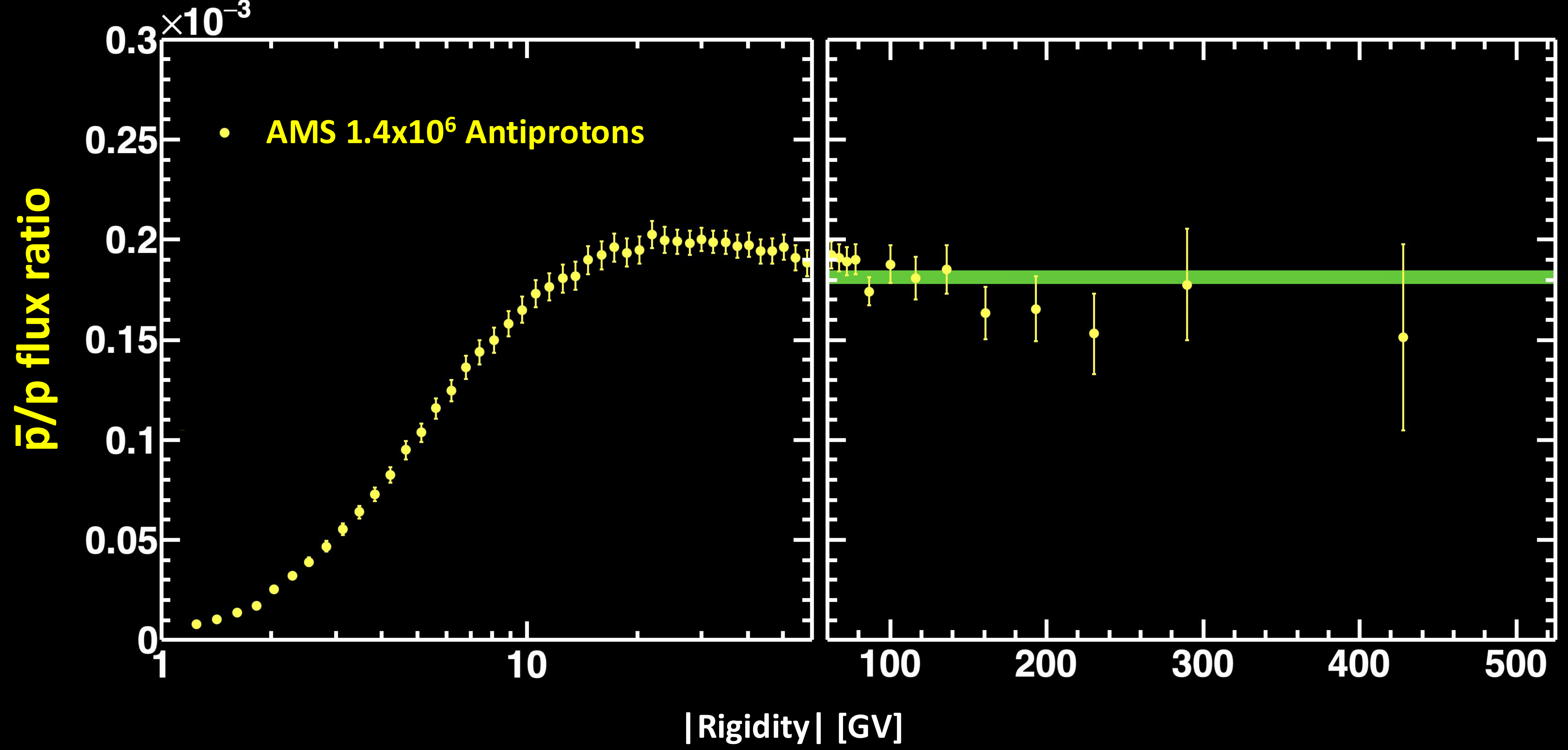
New Results on Cosmic Antiprotons

Does not agree with traditional cosmic ray model with only secondary $\bar{p}$ produced from collision of cosmic rays

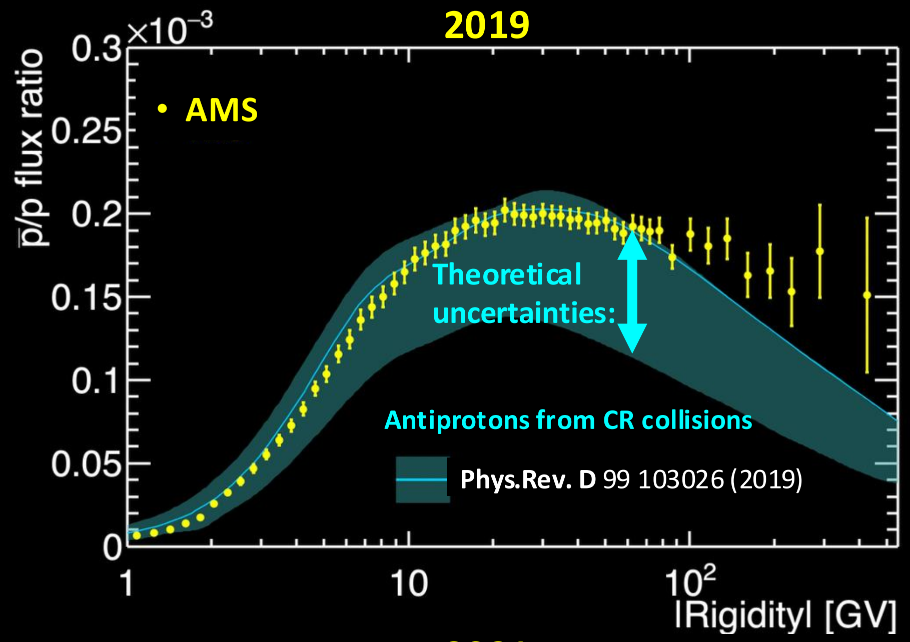


Properties of Cosmic Antiprotons

Above 60 GV, the antiproton-to-proton flux ratio is energy independent.



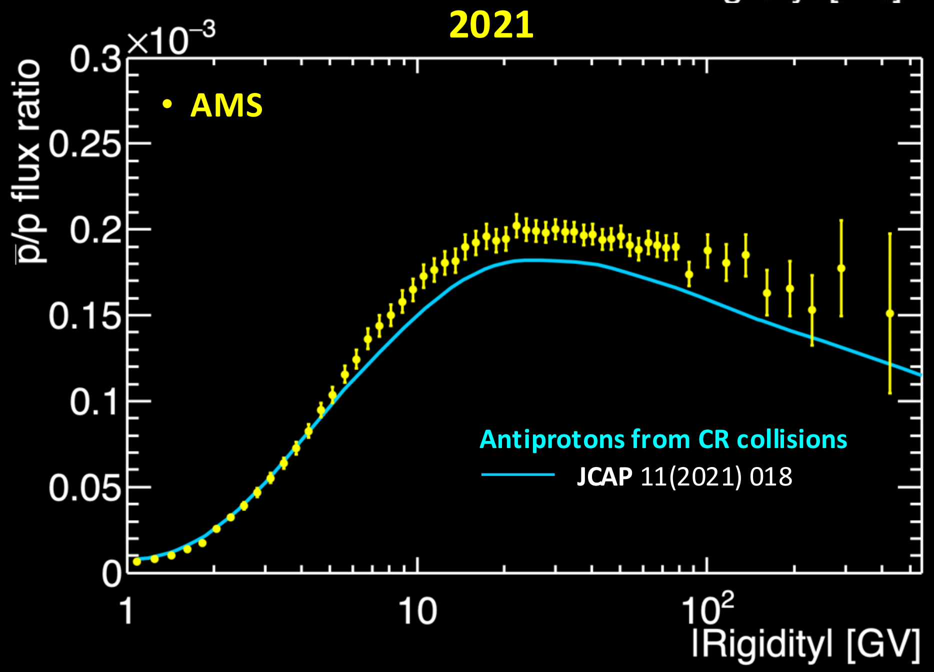
Model Examples: Antiprotons from Cosmic-Ray Collisions

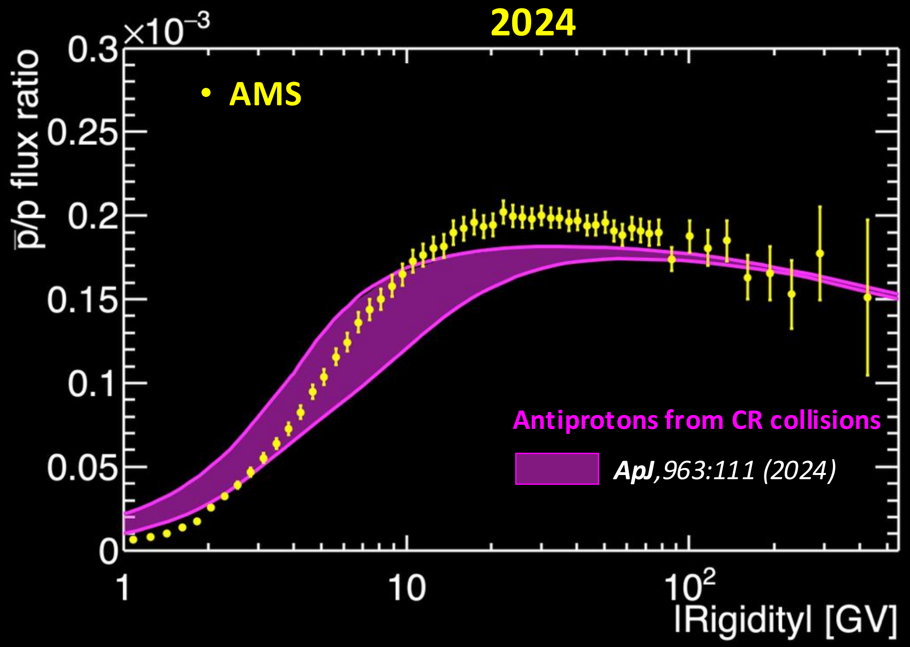


Theoretical uncertainties in Cosmic-Ray Collision Models:

- Cosmic ray acceleration and propagation
- Particle transportation in the heliosphere
- Antiproton production cross-section

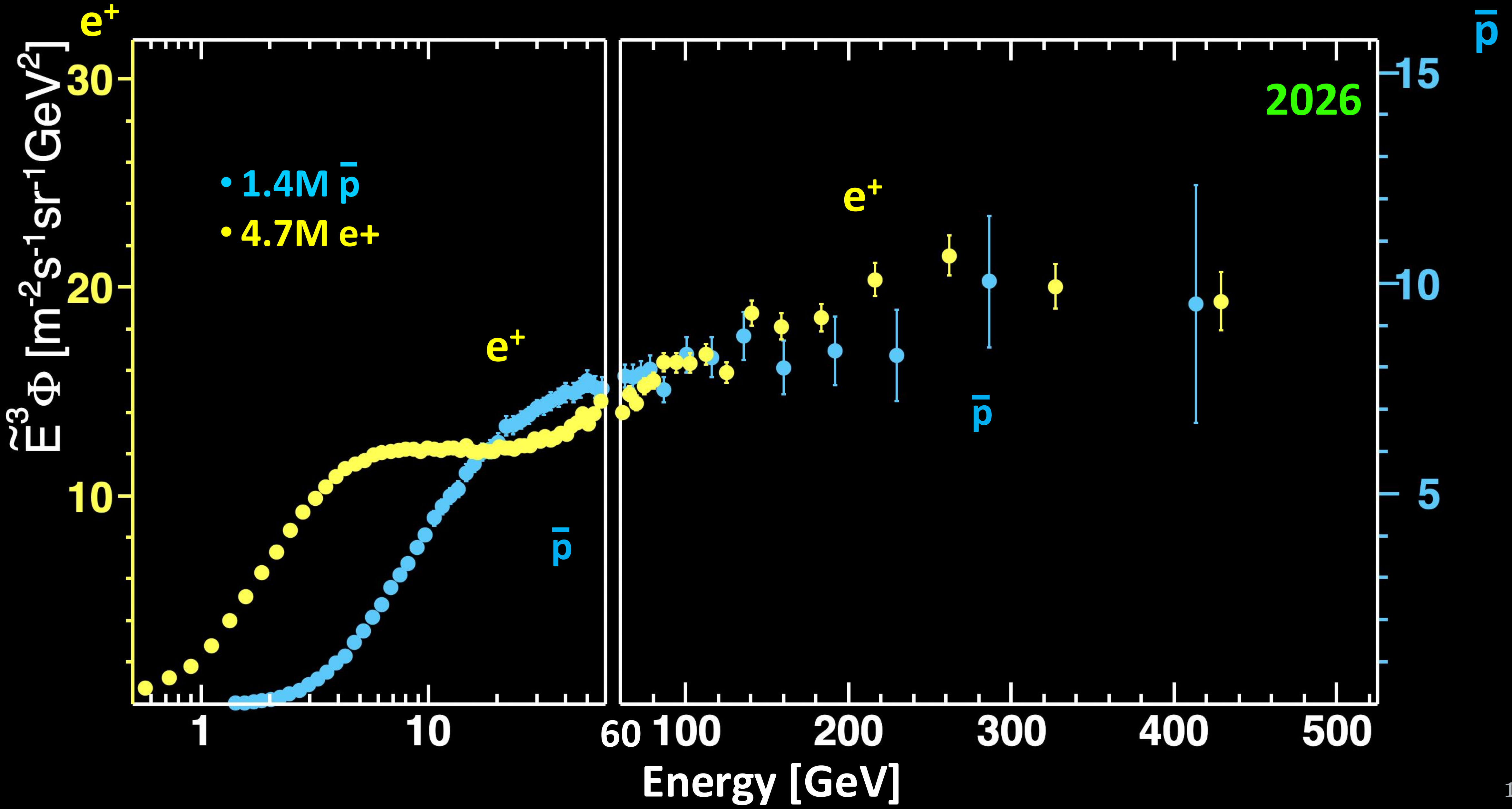
No models agree with AMS data





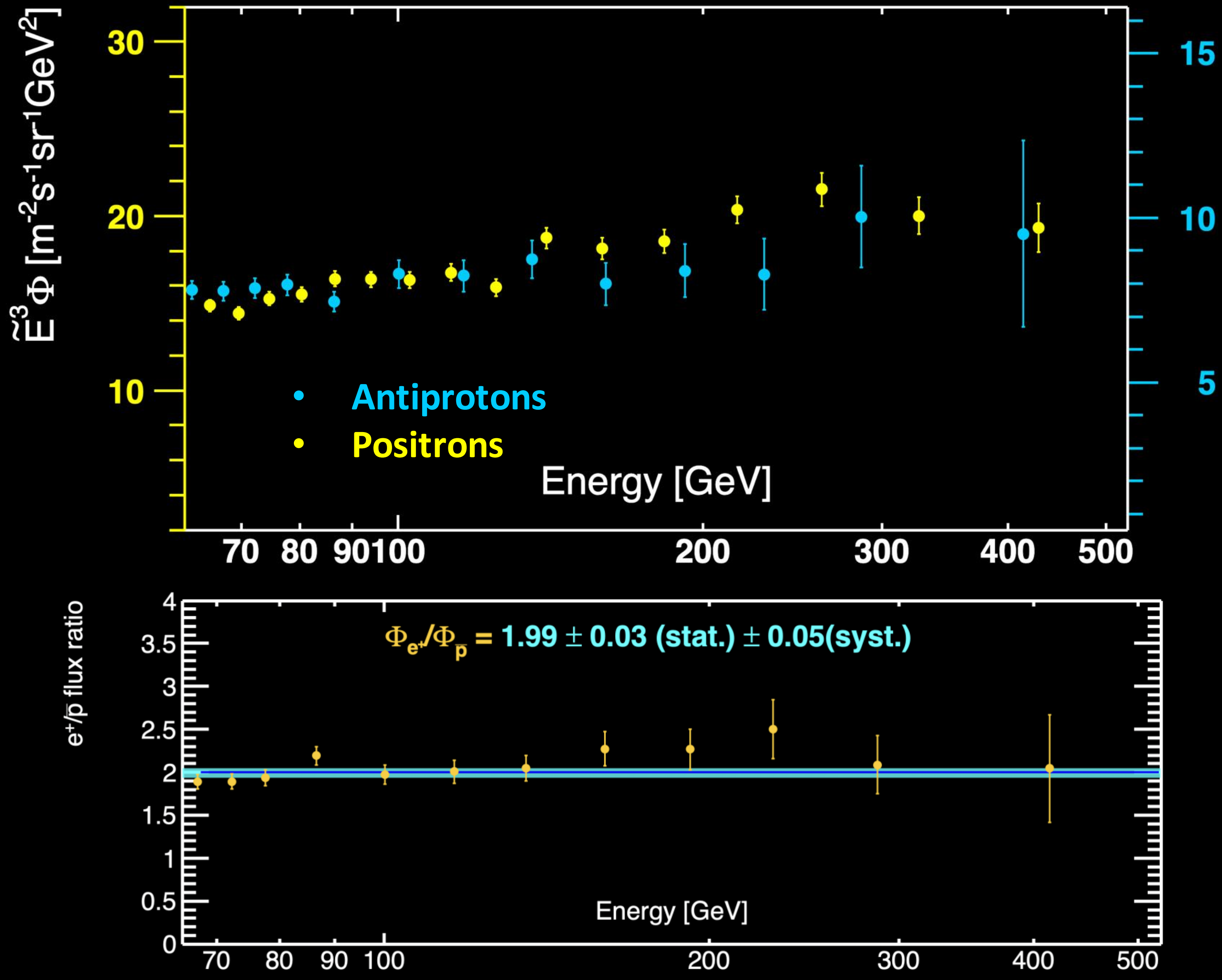
Cosmic Antiprotons and Positrons

Above 60 GeV, the $\bar{p}$ and e^+ fluxes have identical energy dependence



Antiprotons and Positrons

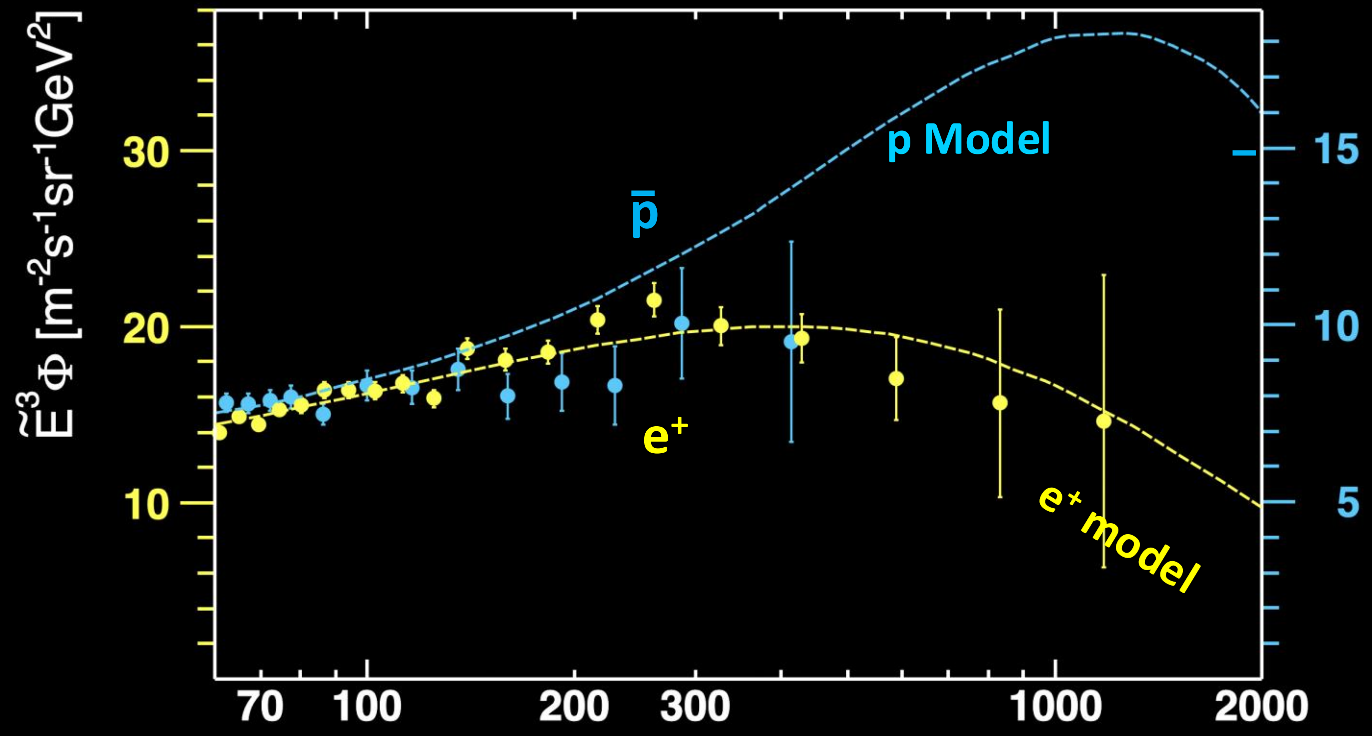
Above 60 GeV, the $\bar{p}$ and e^+ fluxes have identical rigidity dependence



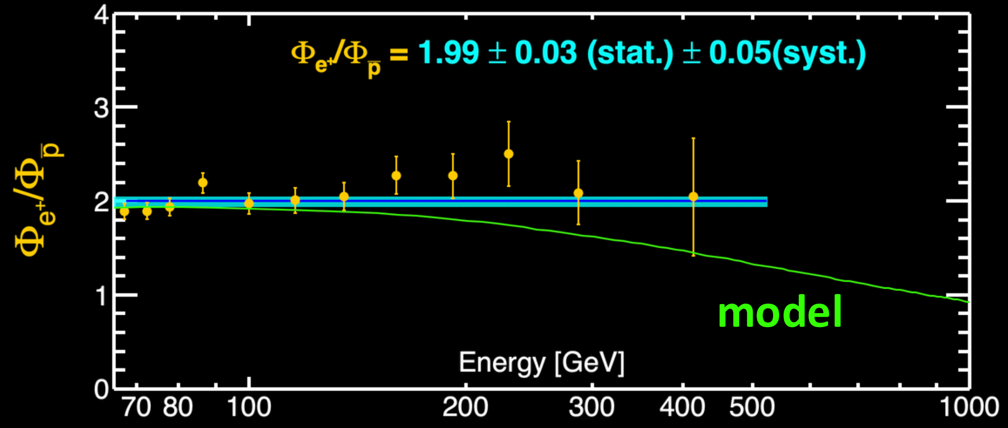
The identical behavior of positrons and antiprotons points toward a common source which disfavours the pulsar origin of positrons

Model Example: Explaining cosmic ray antimatter with secondaries from old supernova remnants

P. Mertsch, A. Vittino, S. Sarkar, PRD 104 (2021) 103029



Model describes both positron and antiproton production from supernova remnants



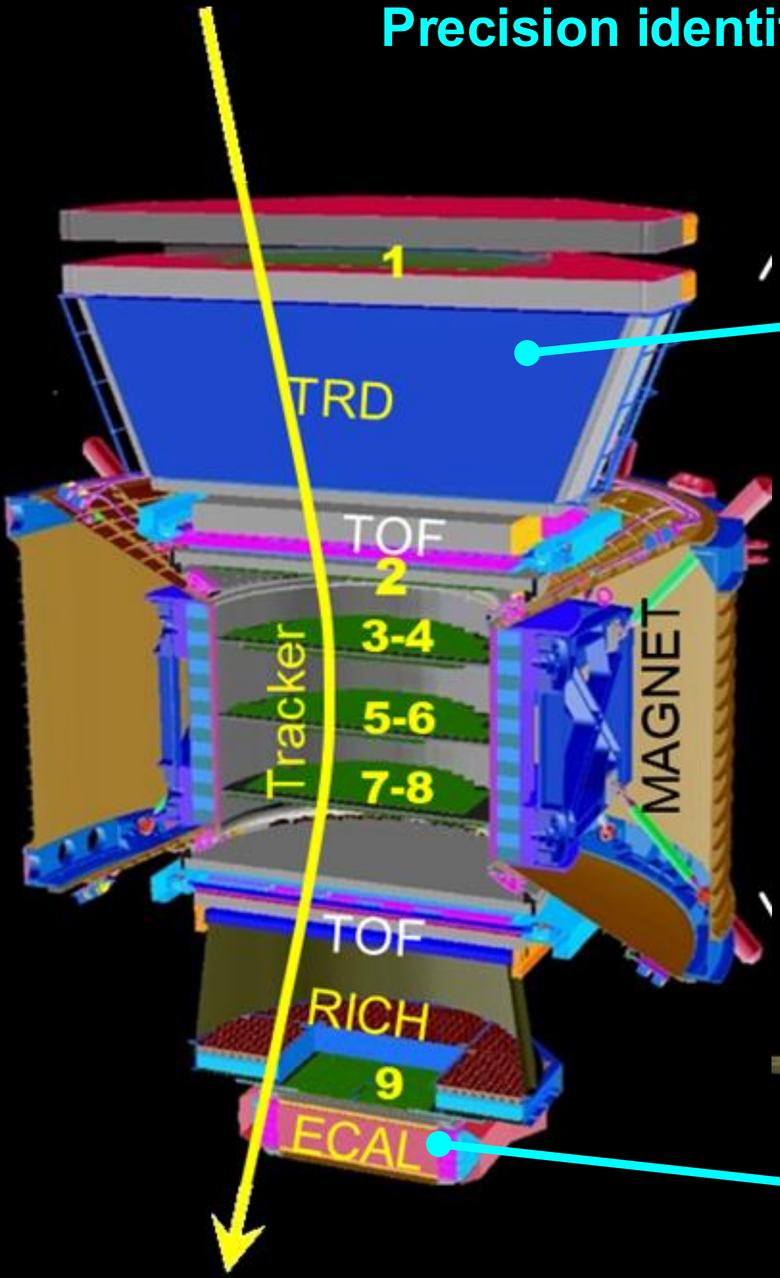
AMS data is not consistent with an origin of old supernova remnants

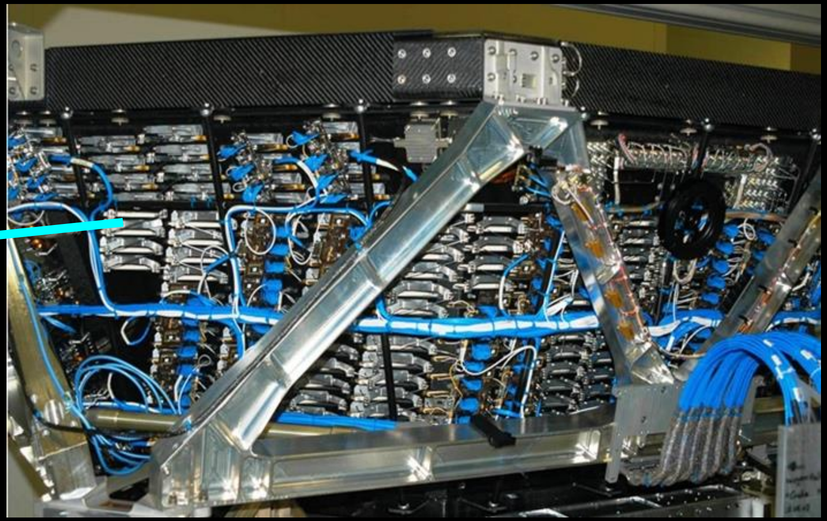
In 15 years on the ISS, AMS is providing cosmic ray information
with ~1% accuracy with energies up to multi-TeV.
The precision and characteristics of the data is providing new insights,
requiring the development of a new understanding of cosmic rays.

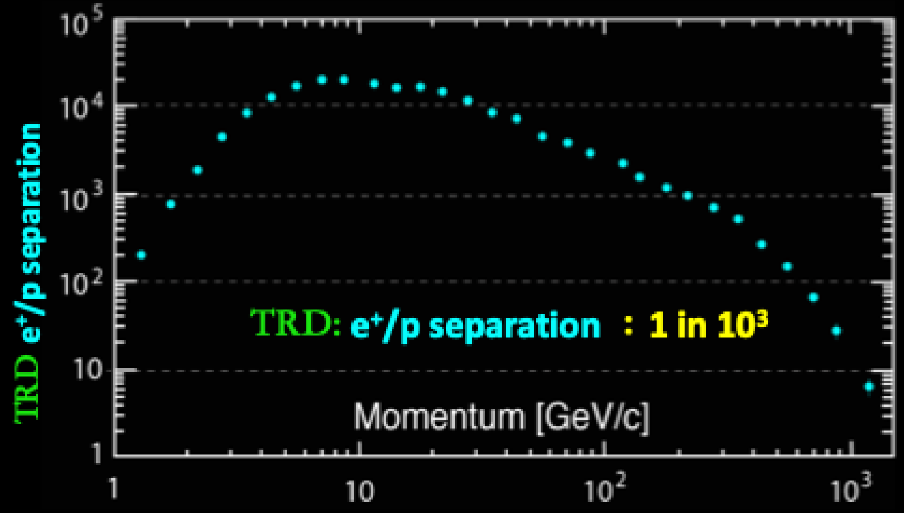
Backup

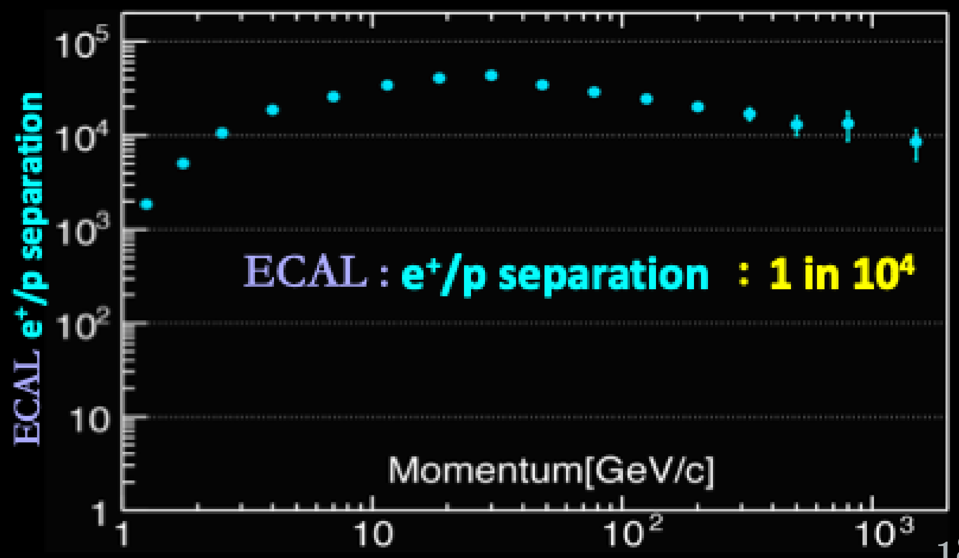
Transition Radiation Detector (TRD) and Electromagnetic Calorimeter (ECAL)

Precision identification and measurement of Positrons and Electrons



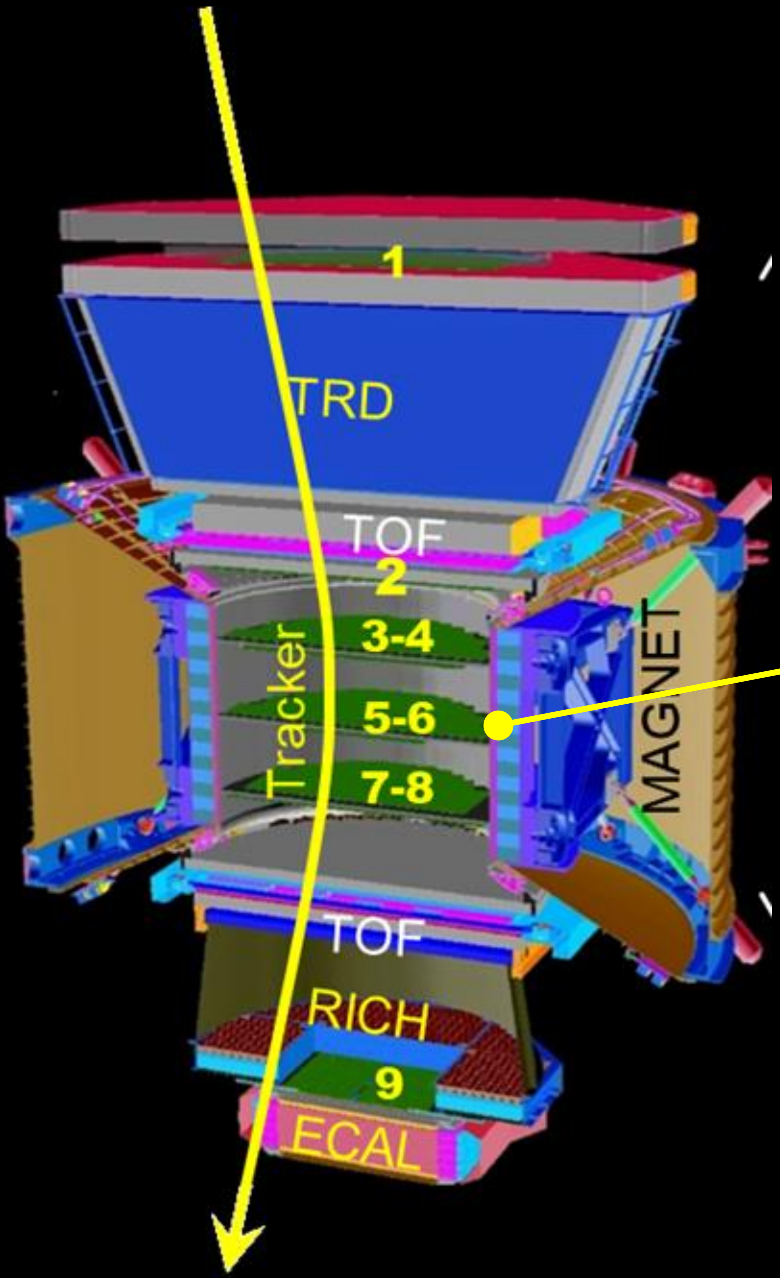


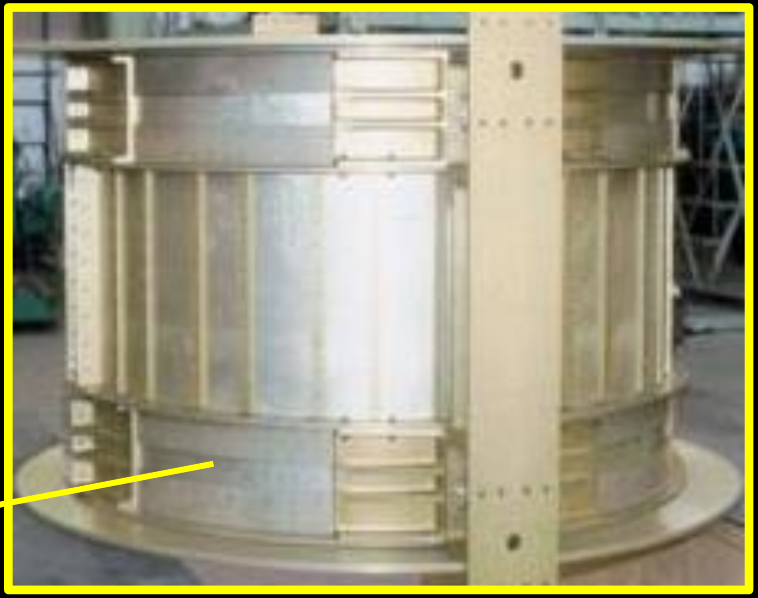


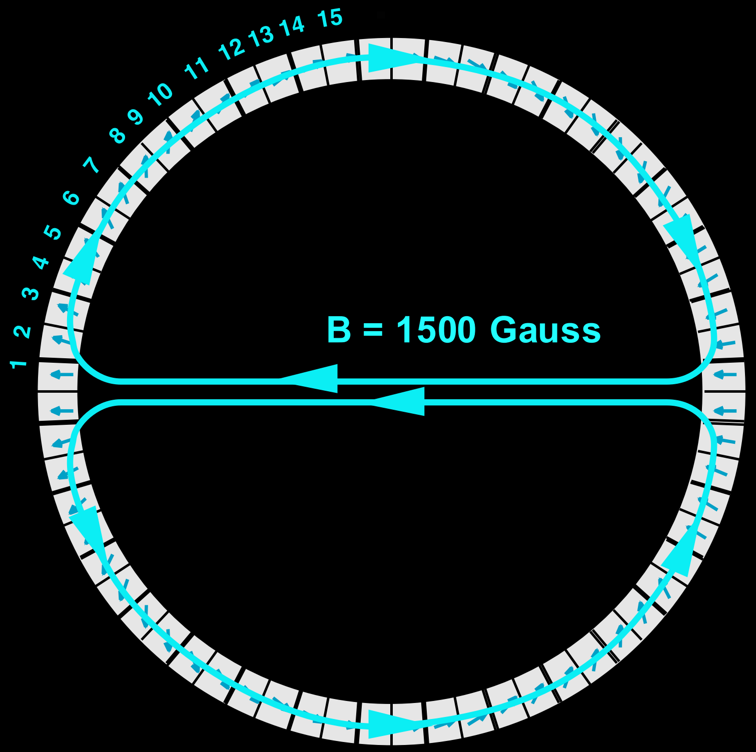


The Magnet

Identify $\pm Z$, P





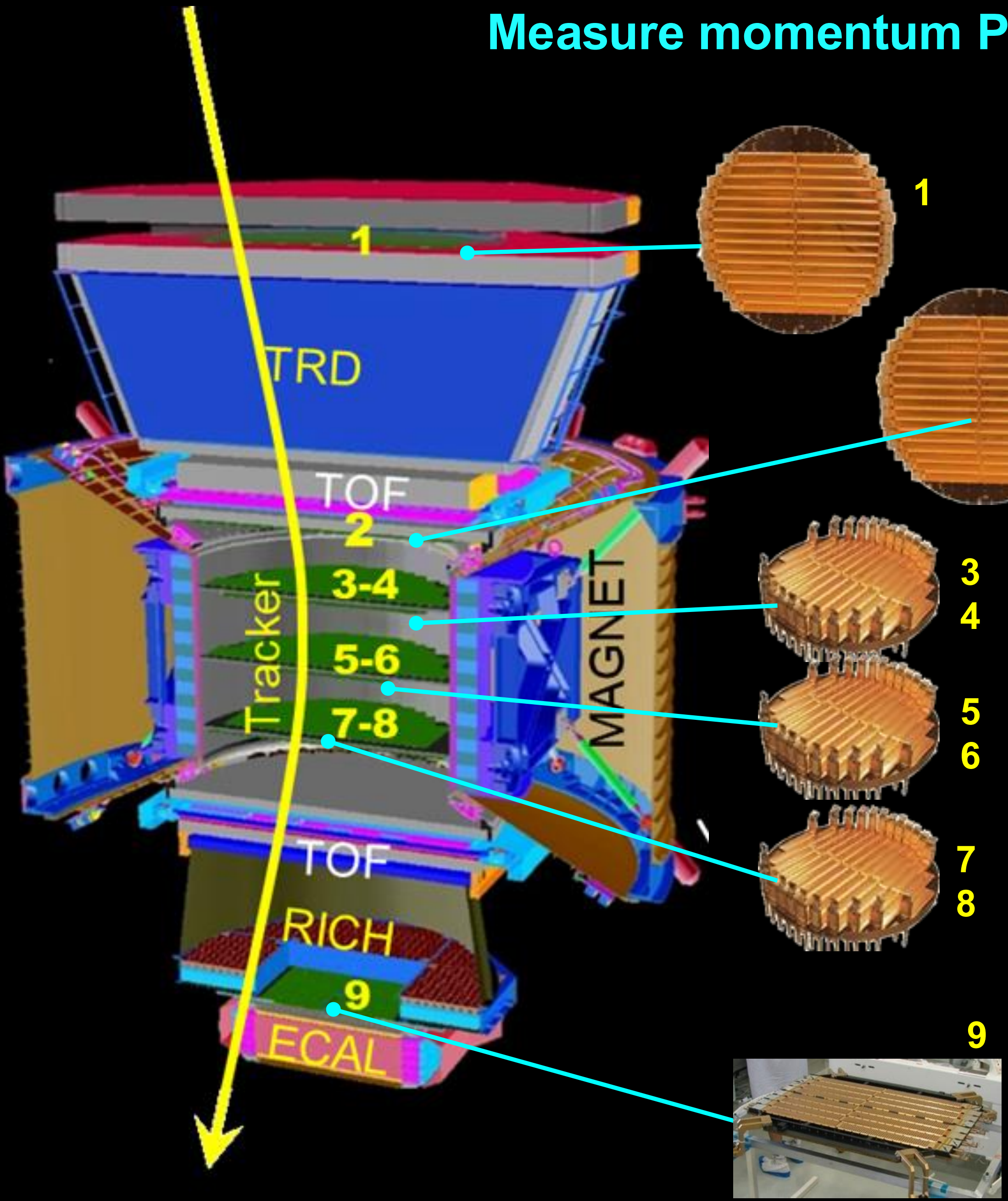


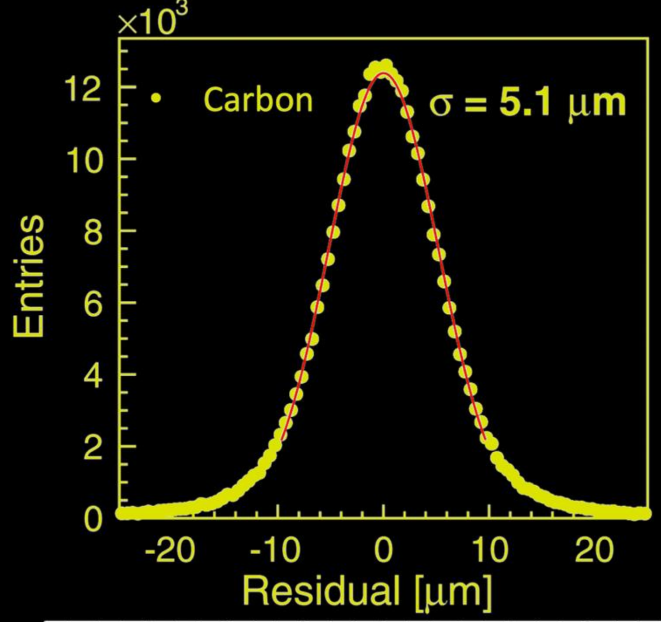
Low energy $e^{\pm}$ produced in TRD are swept away by the magnet and do not enter into ECAL:

Independent rejection of TRD and ECAL: e^{+}/p separation : > 10^{6}

Silicon Tracker

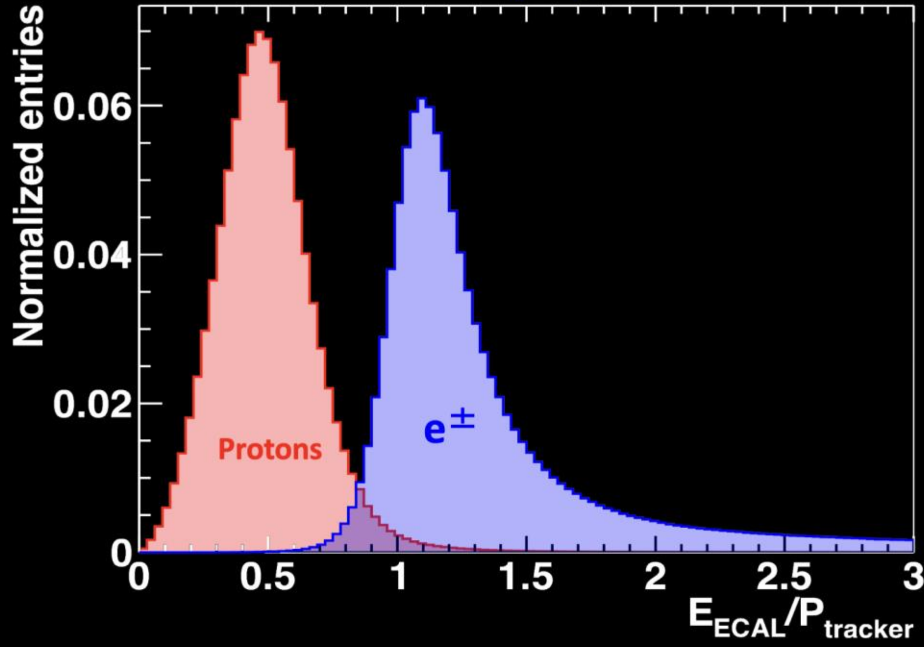
Measure momentum P and nuclear charge Z, Rigidity: P/Z





Spatial resolution: 5-10 μm in bending plane.

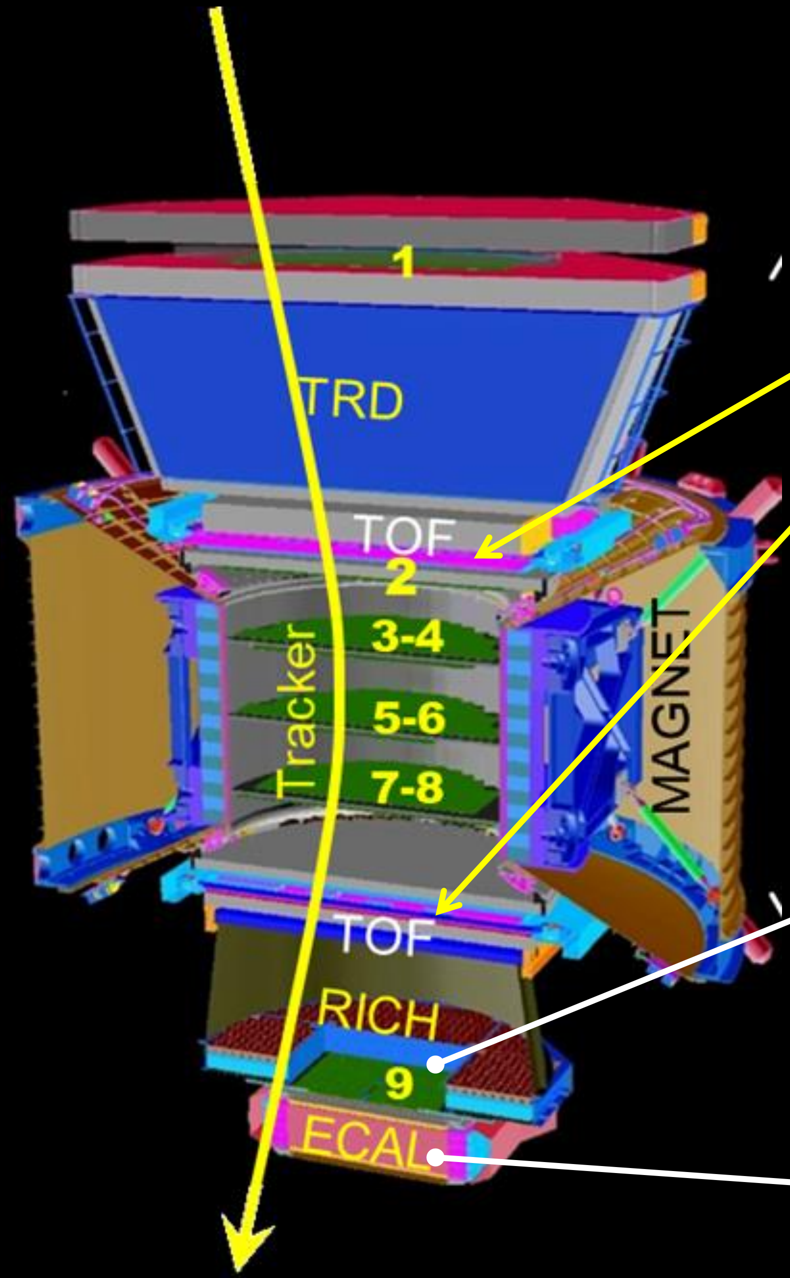
Maximum Detectable Rigidity:
~2TV for protons,
~3.7 TV for heavy nuclei



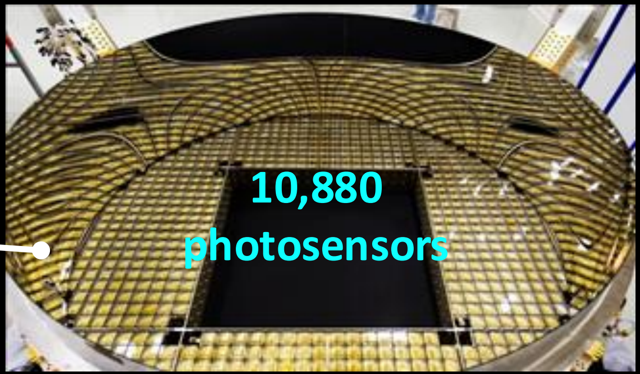
Independent Momentum and Energy measurement.
For electron and positron require: E=P

Time of Flight (TOF) and Ring Imaging CHerenkov (RICH)

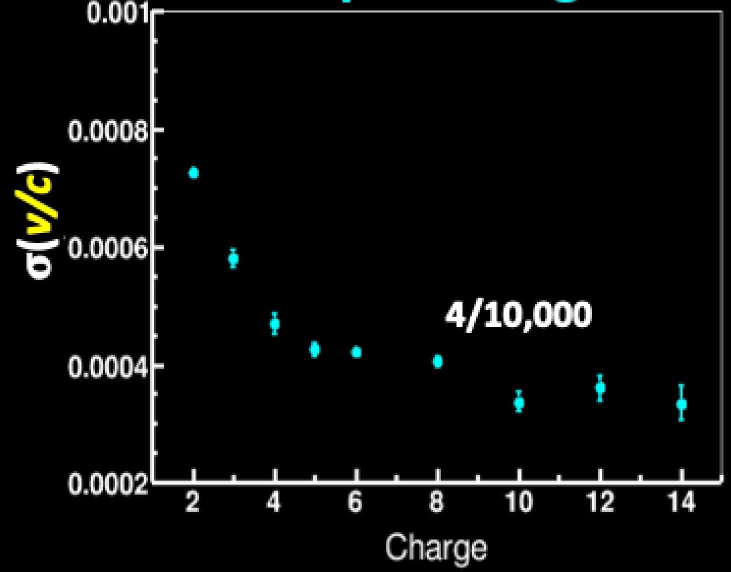
Measure velocity β , charge Z



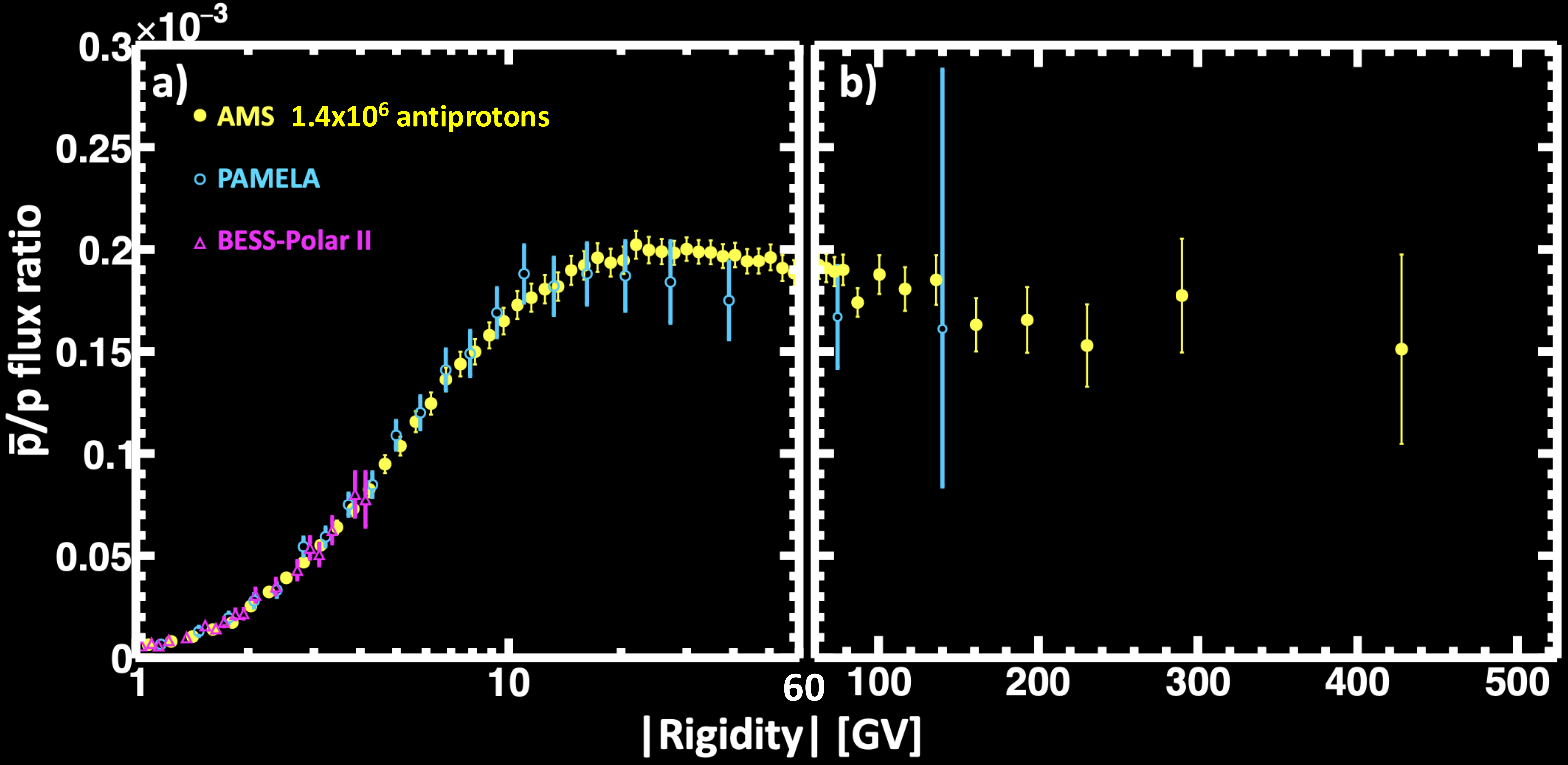
TOF: velocity, charge, direction, trigger.
Time resolution: ~50-160 ps
Velocity resolution: 1% (Z>6) to 4% (Z=1)



RICH velocity *v* resolution
at the speed of light *c*



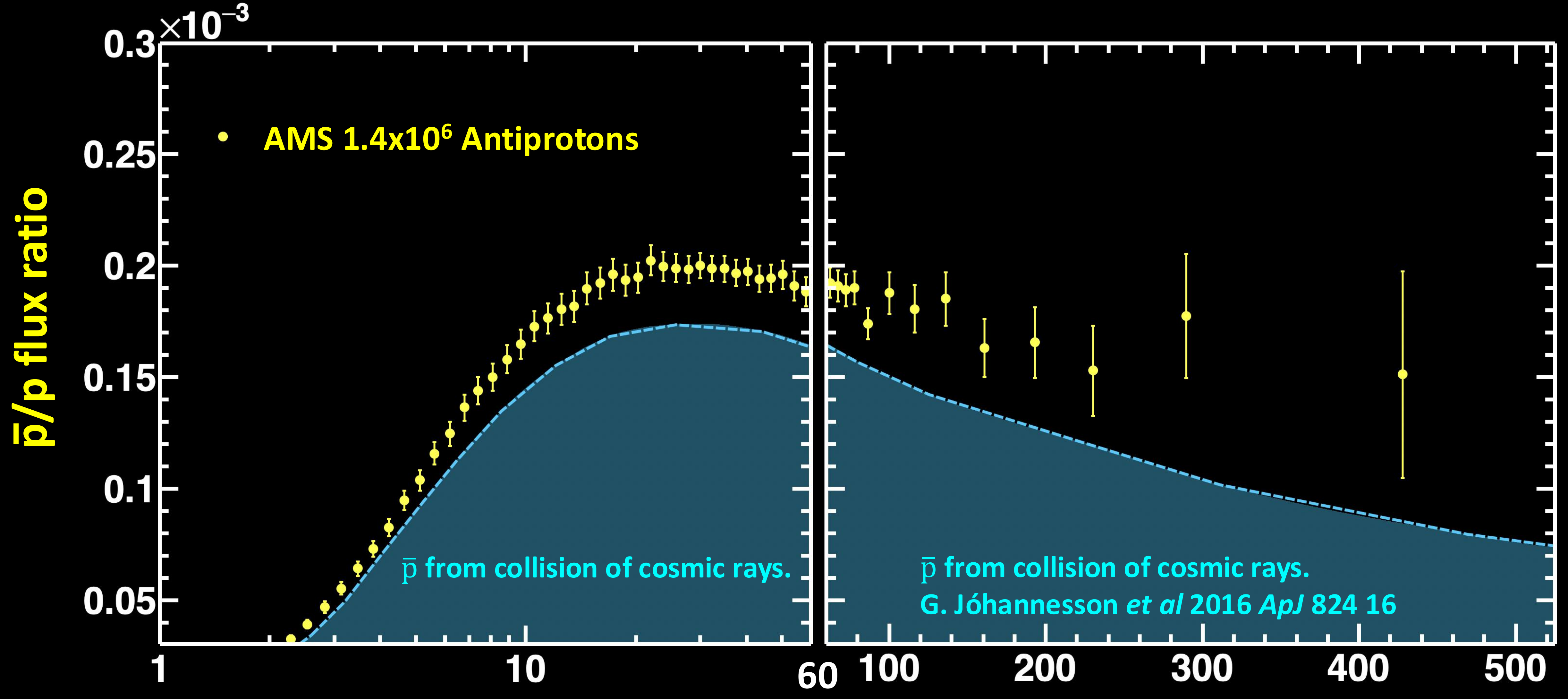
Precision study of the Properties of Cosmic Antiproton Flux



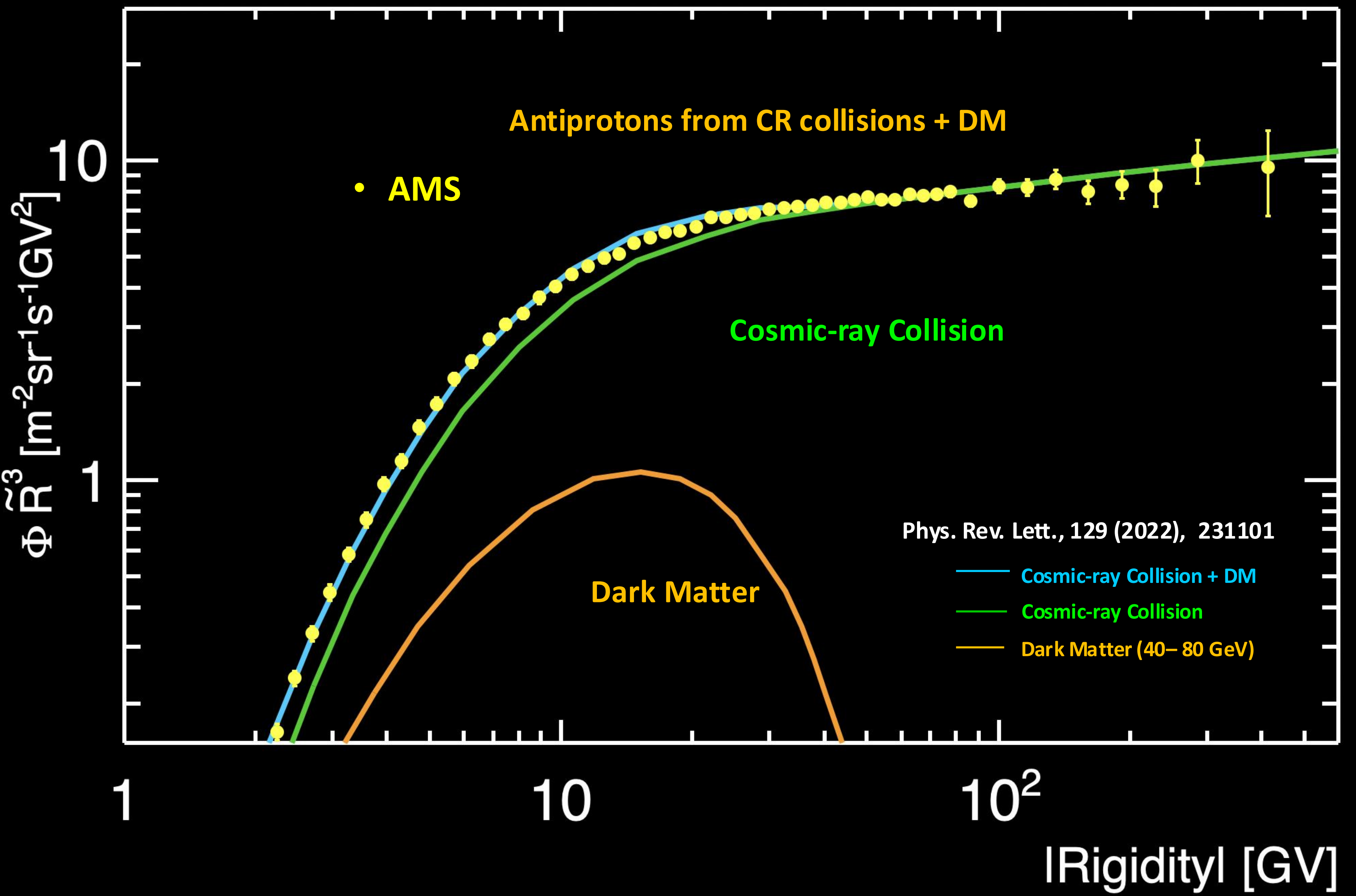
Model Example: Antiprotons from Cosmic Ray Collisions

The antiproton-to-proton flux ratio shows that above 60 GV the ratio is energy independent.

Not consistent with only secondary production of antiprotons



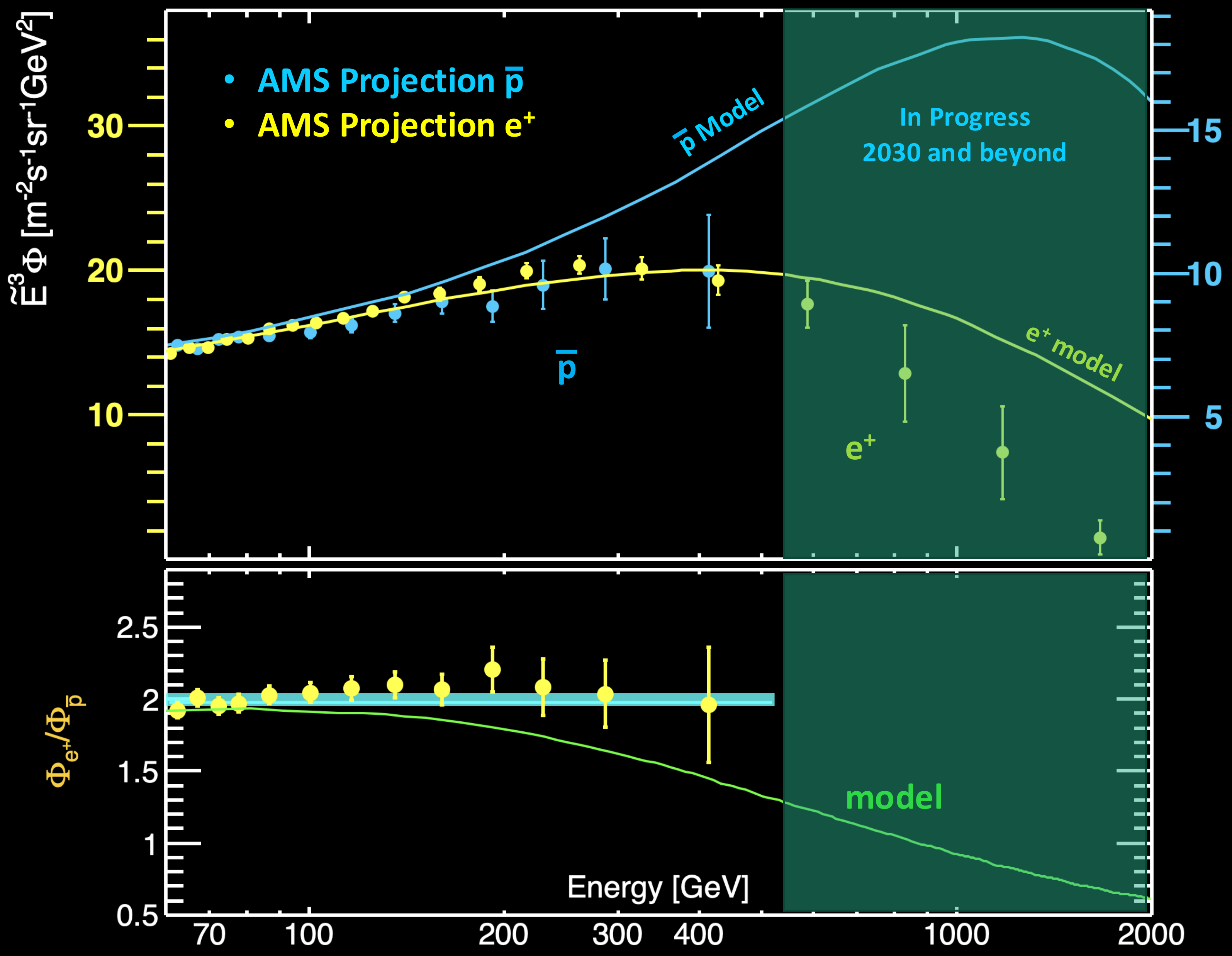
Model Example: Antiprotons from Cosmic-Ray Collisions and Dark Matter



Signal at low energy is subject to uncertainty in solar modulation

The accuracy of the models need to be improved with AMS Data

Future Measurement of Antiprotons and Positrons



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