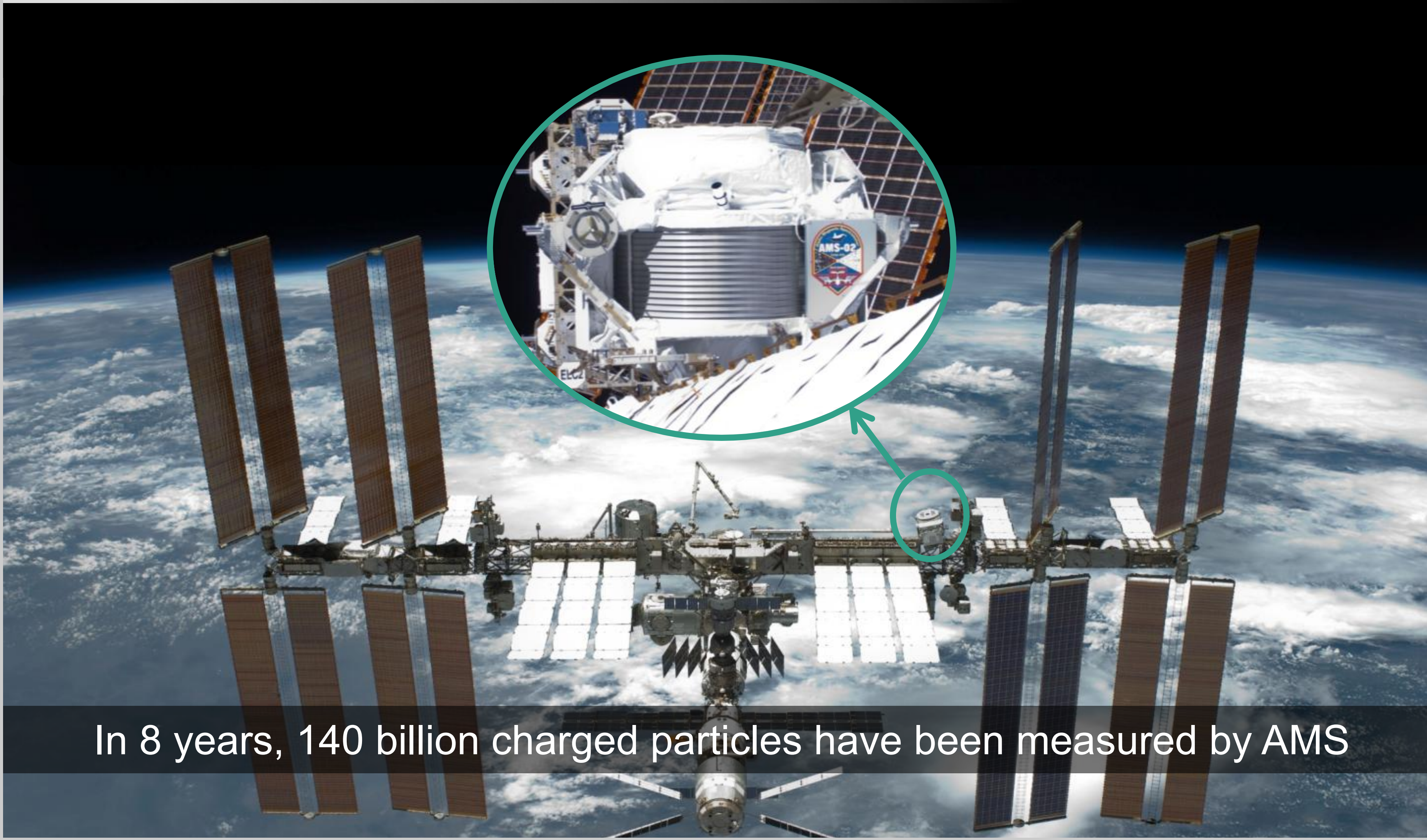
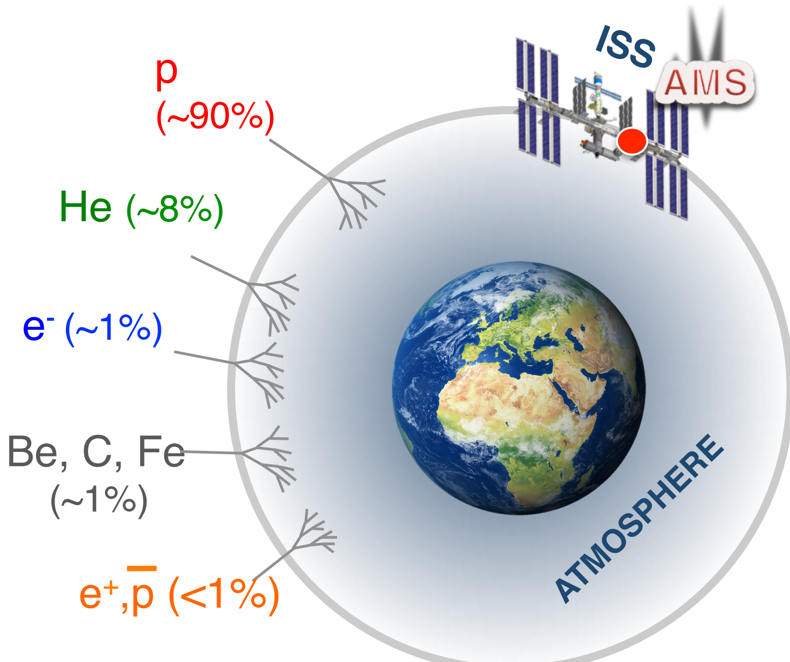
Karlsruher Institut für Technologie

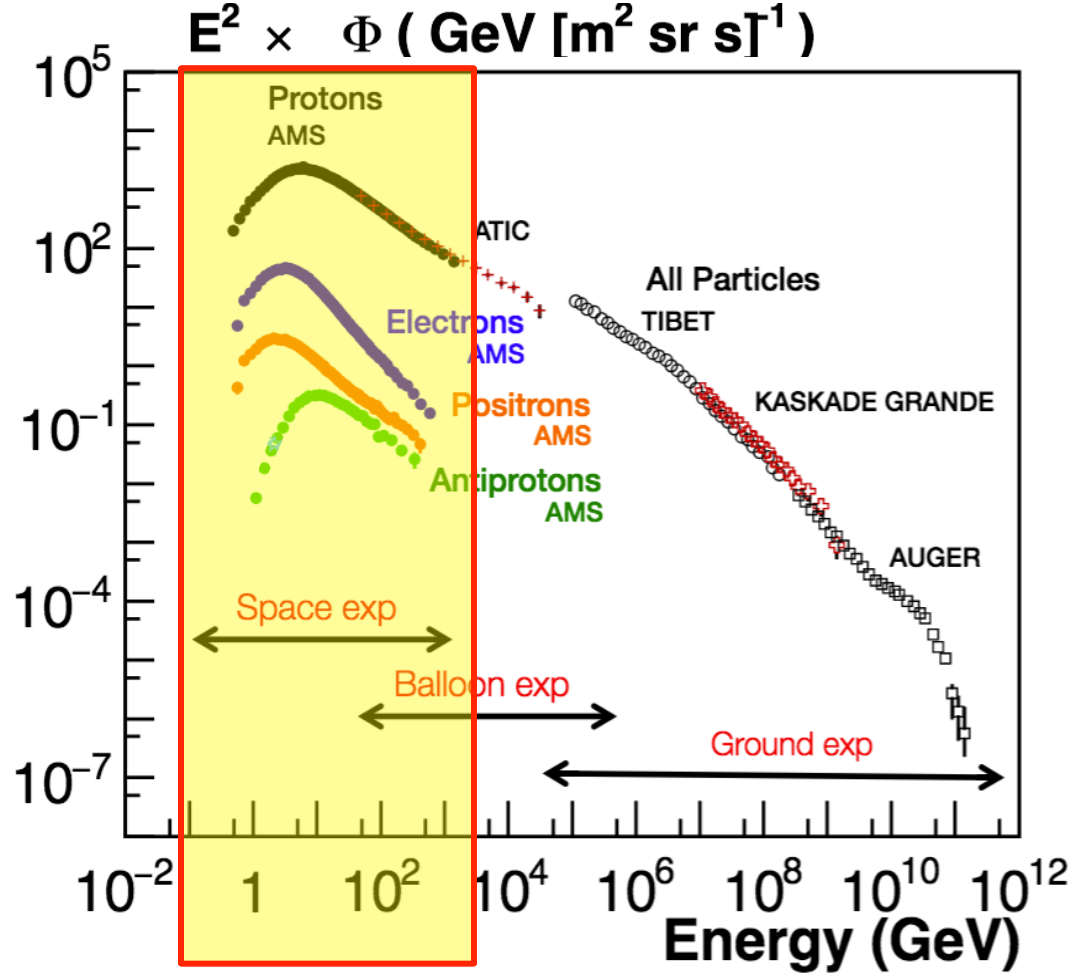
# Precision measurement of electrons and positrons with AMS-02 on the International Space Station




M.Graziani/Karsruhe Institute of Technology

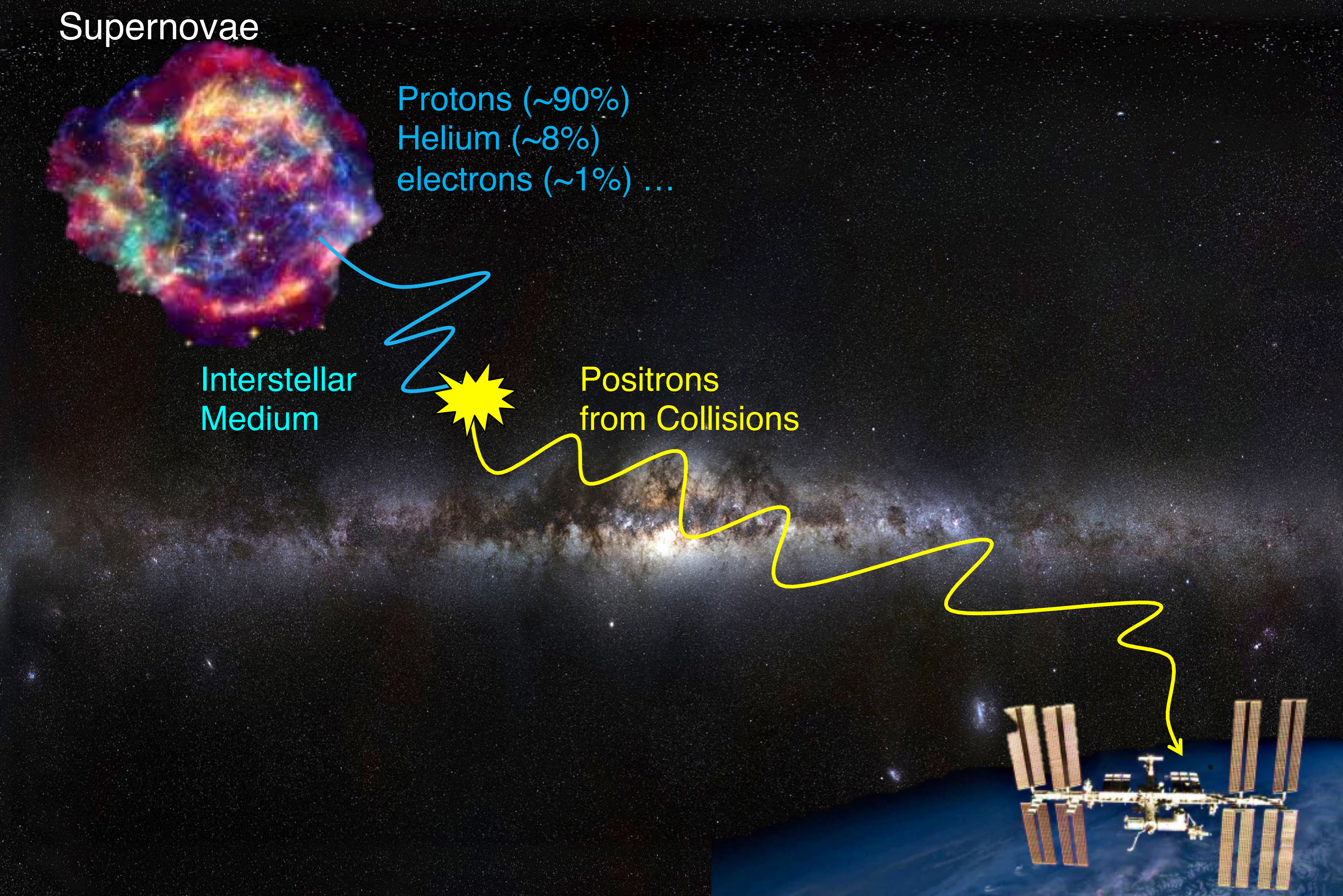
# THE PHYSICS OF AMS-02: COSMIC RAYS



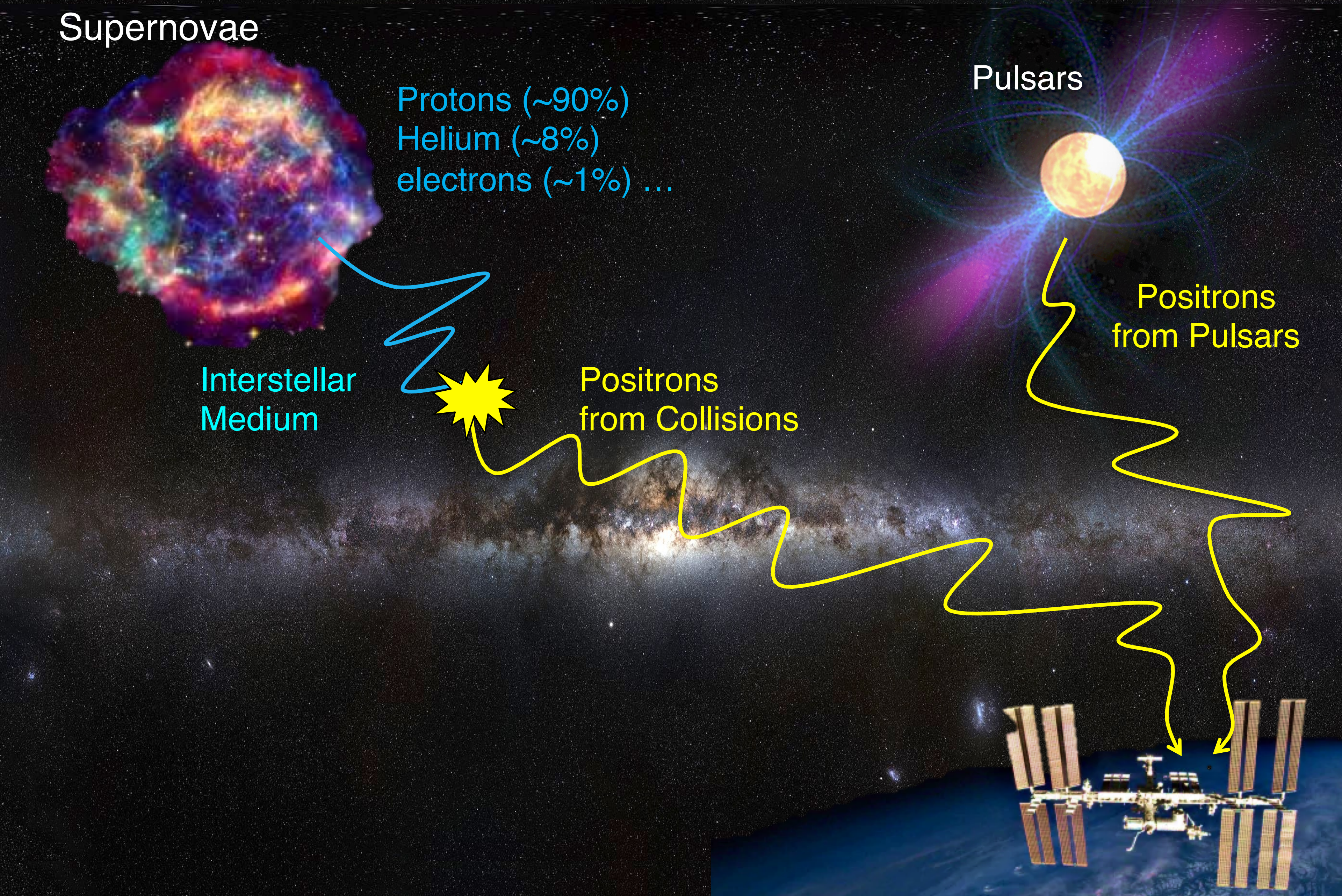




AMS-02 range: GV-TV

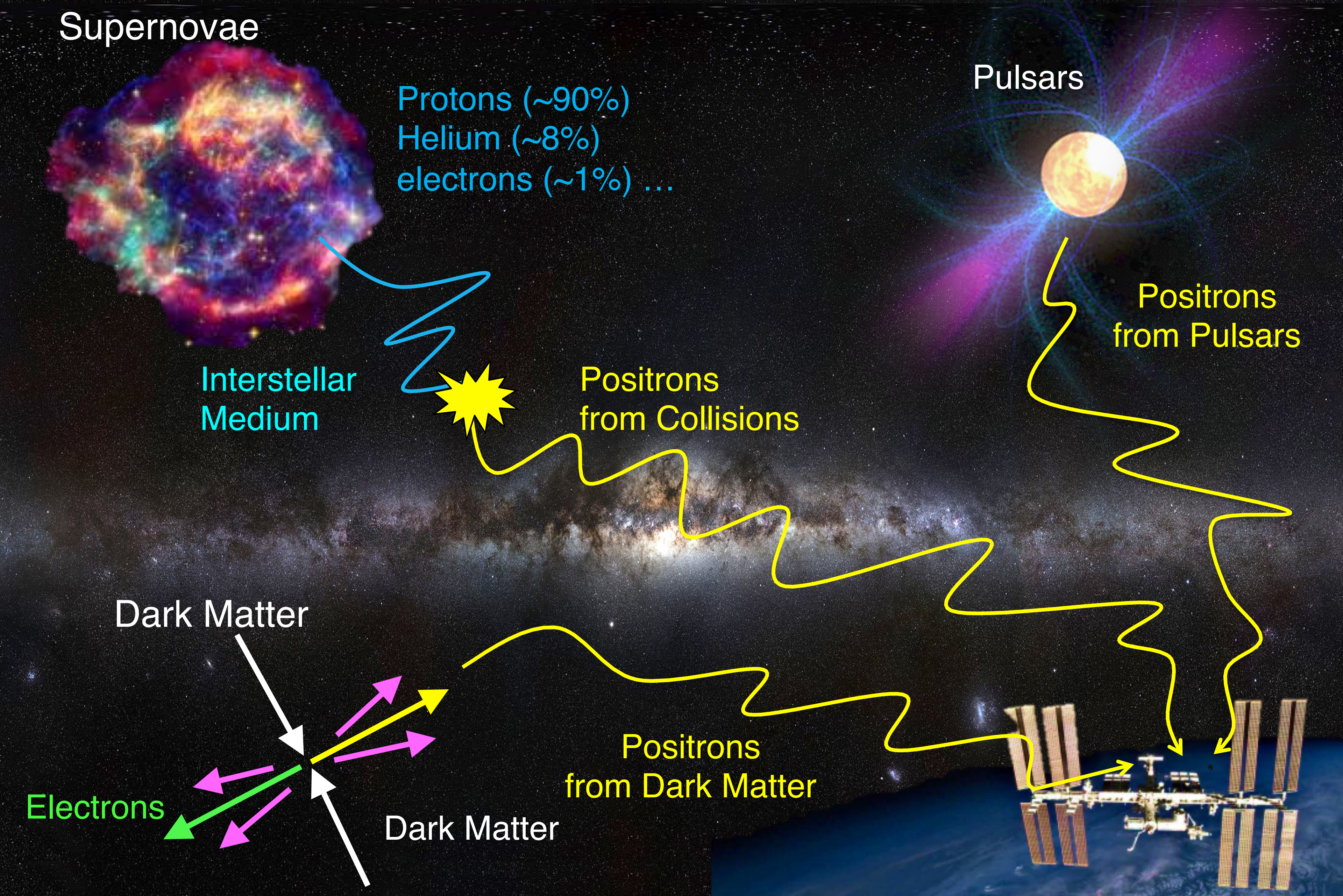
# On the Origins of Cosmic Positrons



# On the Origins of Cosmic Positrons



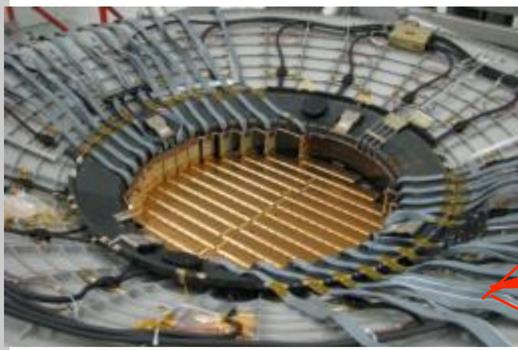
# On the Origins of Cosmic Positrons



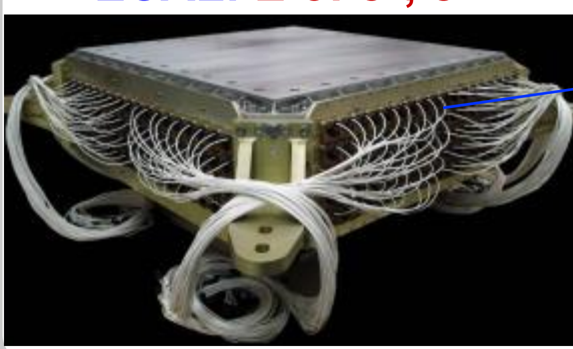
# AMS: a unique TeV precision, accelerator-type spectrometer in space

## TRD: Identify $e^+$, $e^-$, Z

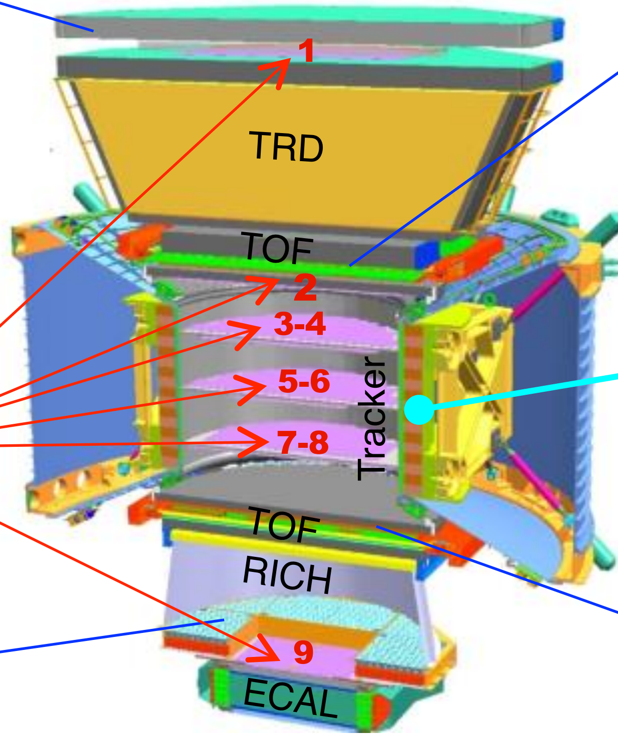
## Silicon Tracker: Z, P



## ECAL: E of $e^+$, $e^-$



**Particles and nuclei are measured by their charge (Z), energy (E), momentum (P) or Rigidity R = P/Z**

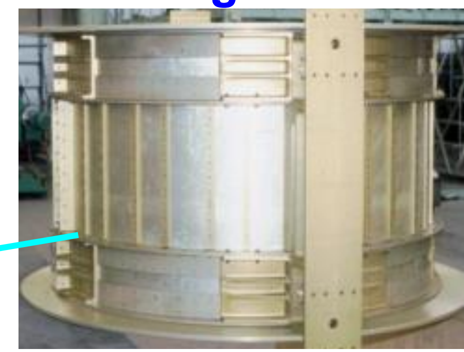



# Z and P

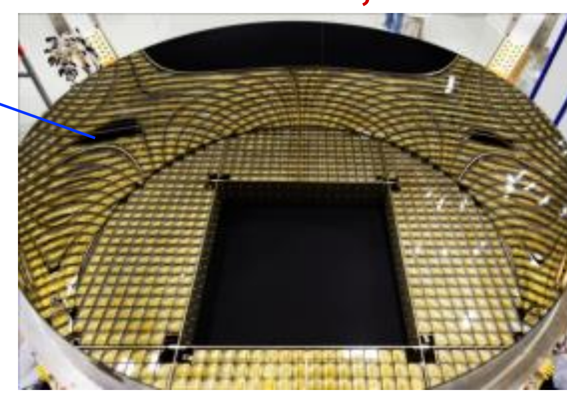
**are measured independently by the Tracker, RICH, TOF and ECAL**

## TOF: Z, E

## Magnet: ±Z



## RICH: Z, E

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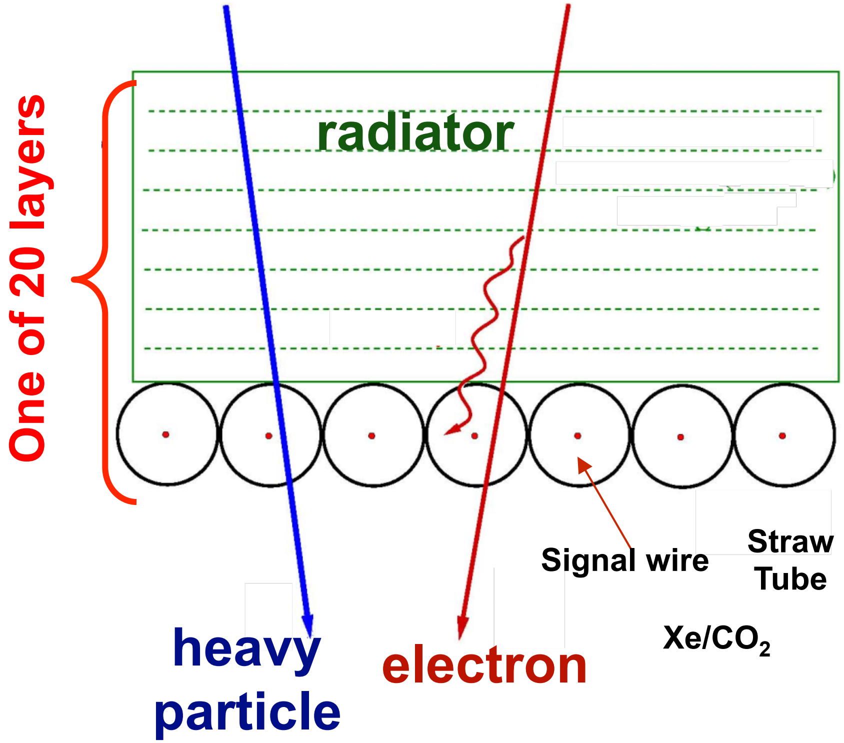
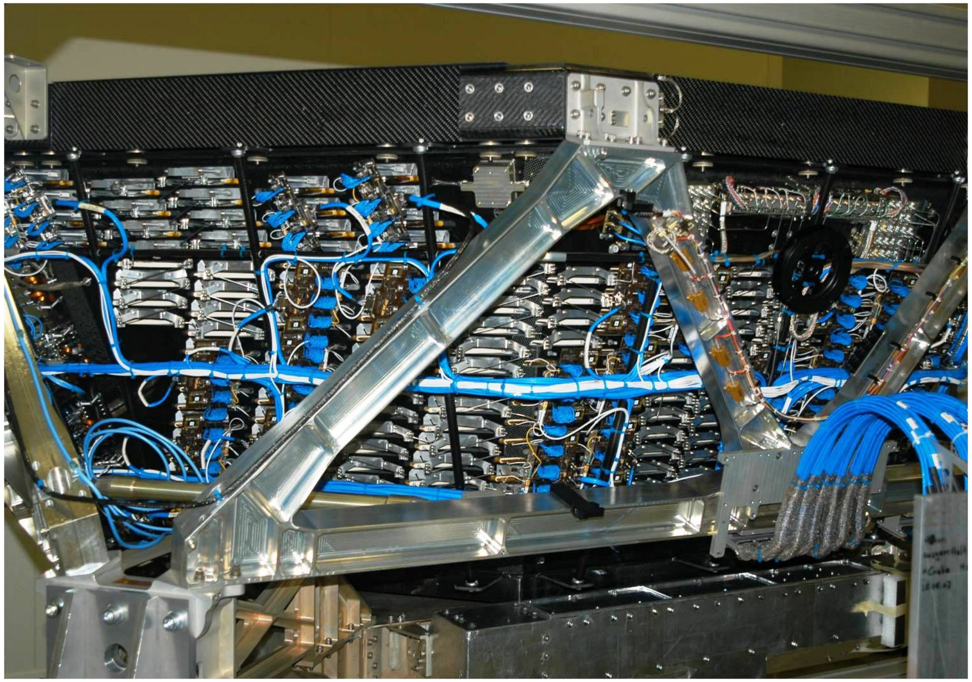
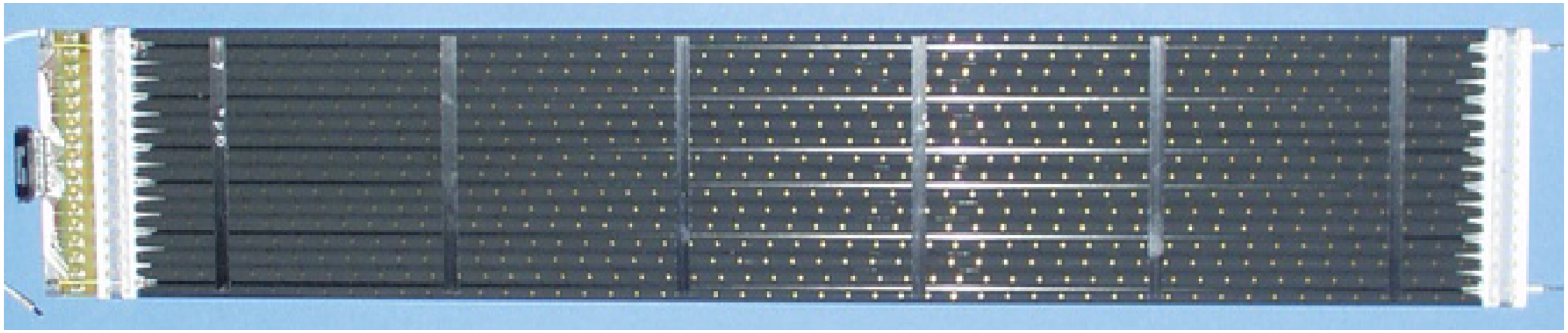
# Transition Radiation Detector (TRD)







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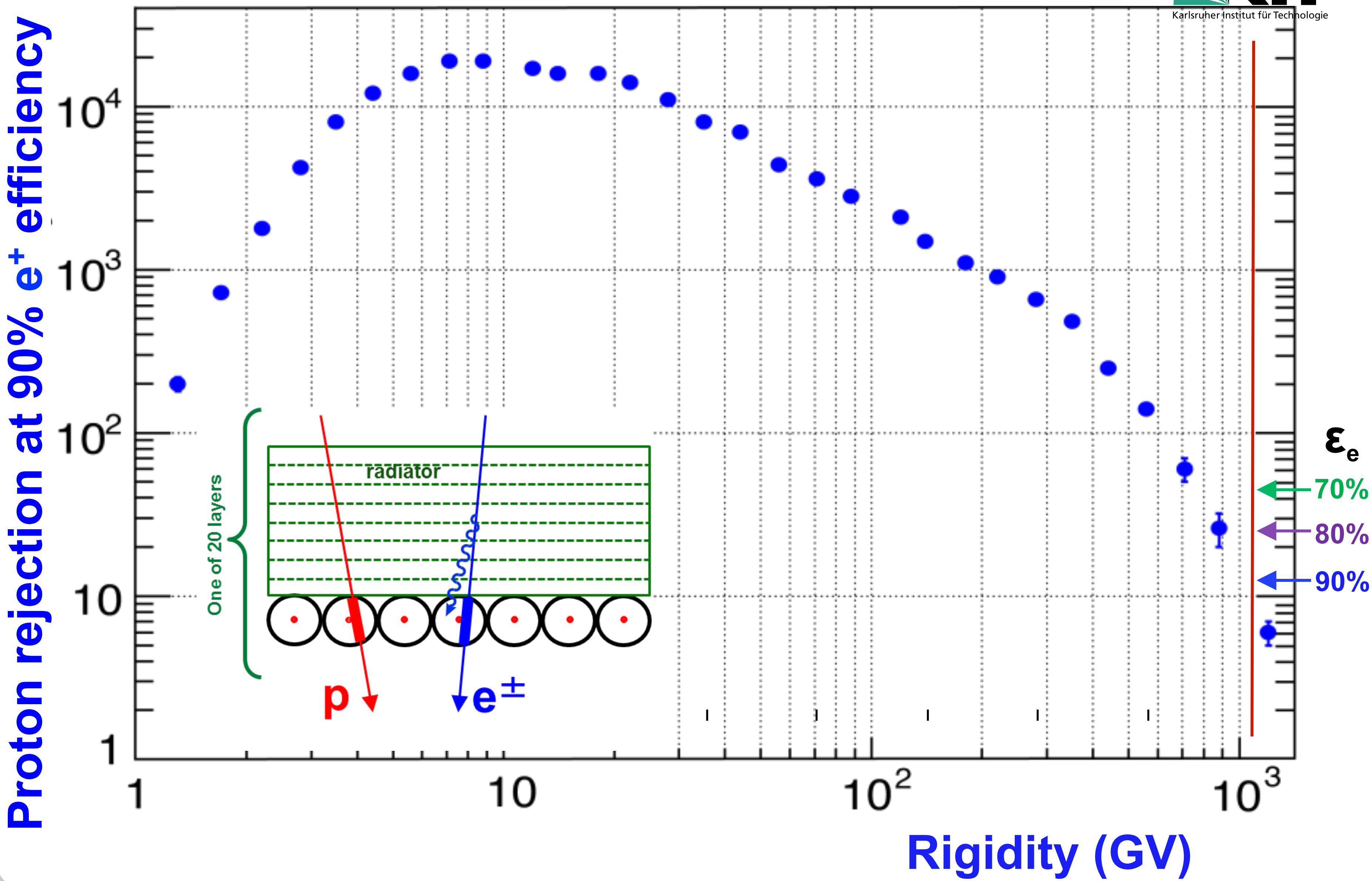
# TRD performance on ISS





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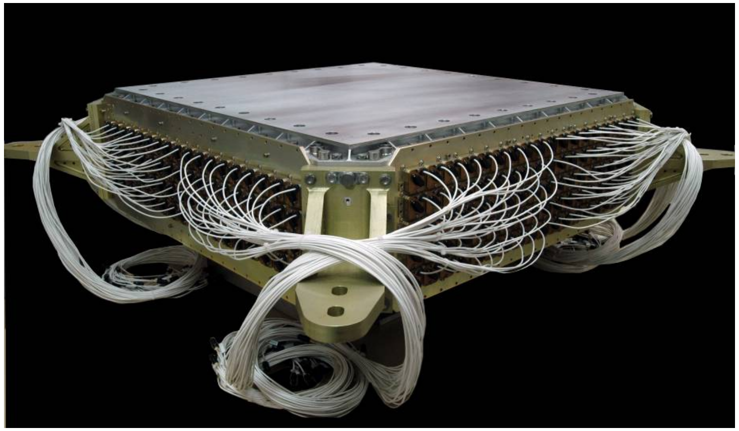
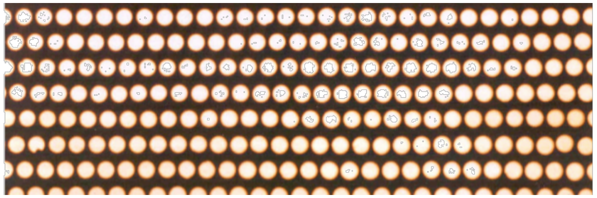
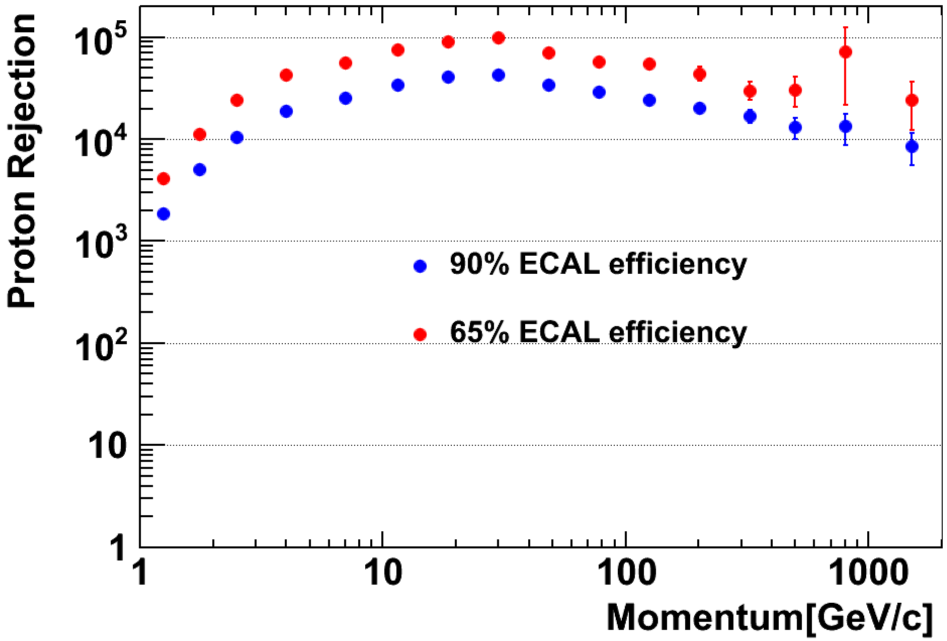
# Electromagnetic Calorimeter

provides a 17 $X_0$, TeV, 3-dimensional measurement of $e^+$, $e^-$, and gamma ray:



1. the directions to ± 1 degree
2. the energy resolution of 2%
3. Distinguishes electrons and positrons from protons, helium, …by a factor of 10,000

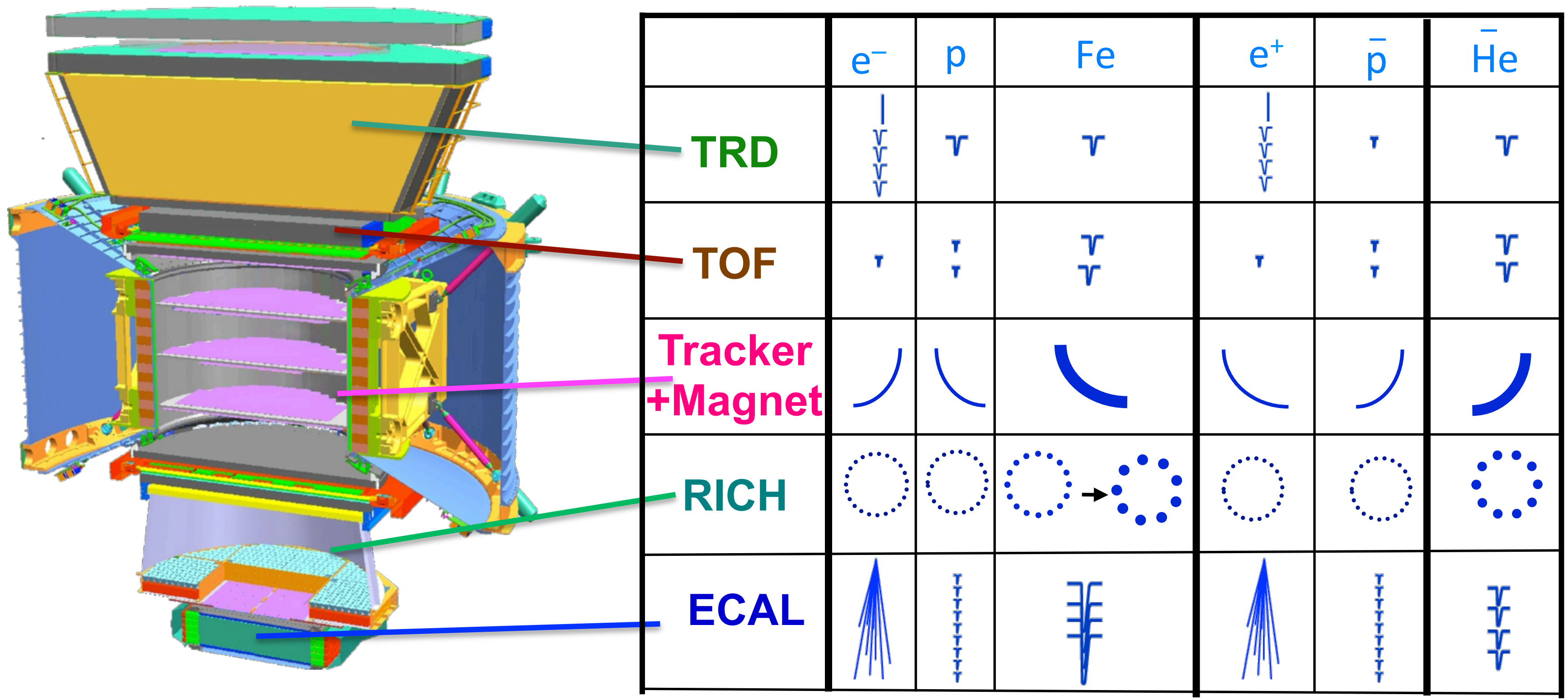





50 000 fibers, $\phi = 1$ mm distributed uniformly inside 600 Kg of lead

# AMS is a unique magnetic spectrometer in space

Karlsruher Institut für Technologie



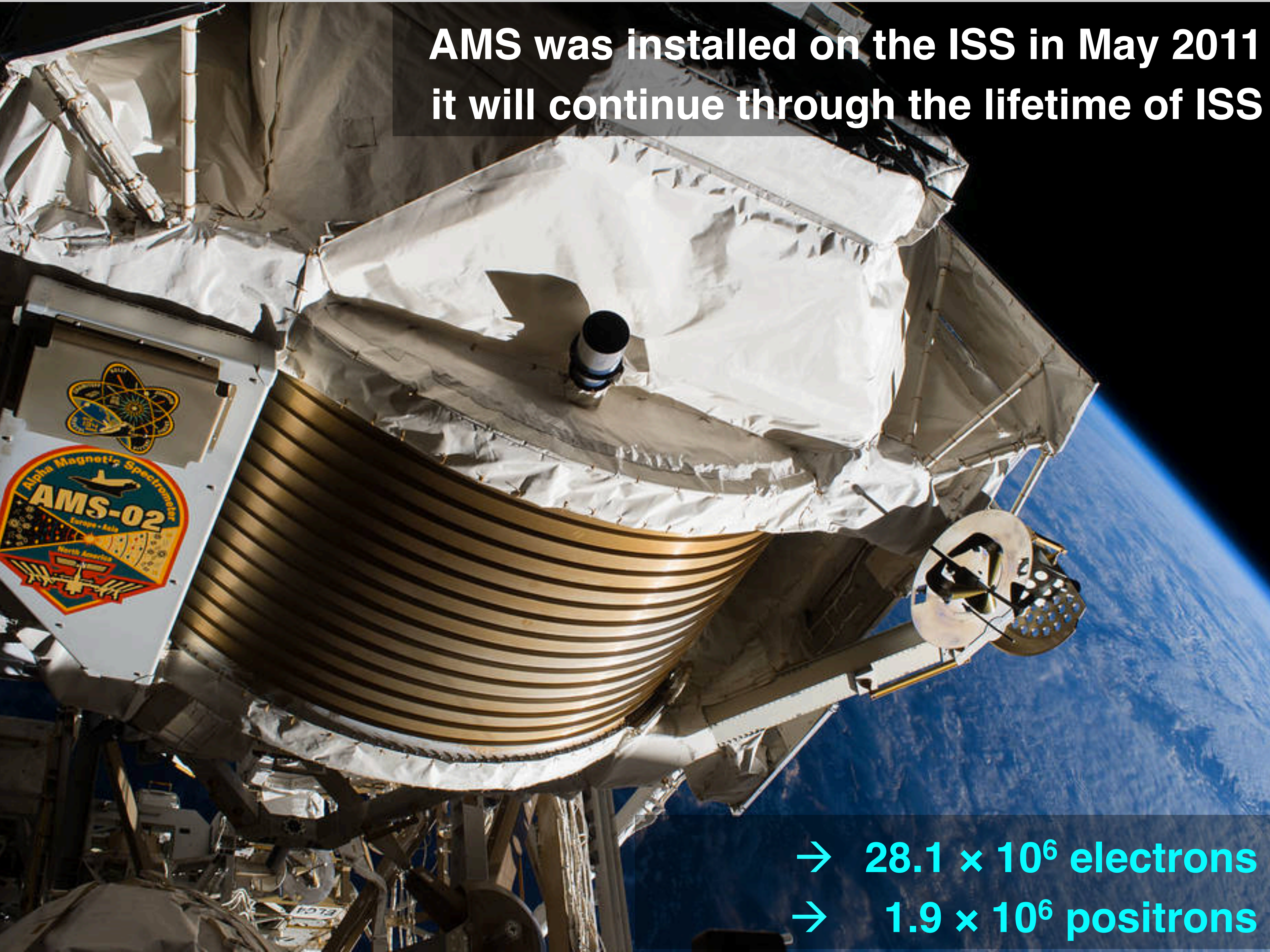

In 8 years, the detectors have performed flawlessly.

AMS is able to pick out 1 positron from 1,000,000 protons;

unambiguously separate positrons from electrons up to a trillion eV;

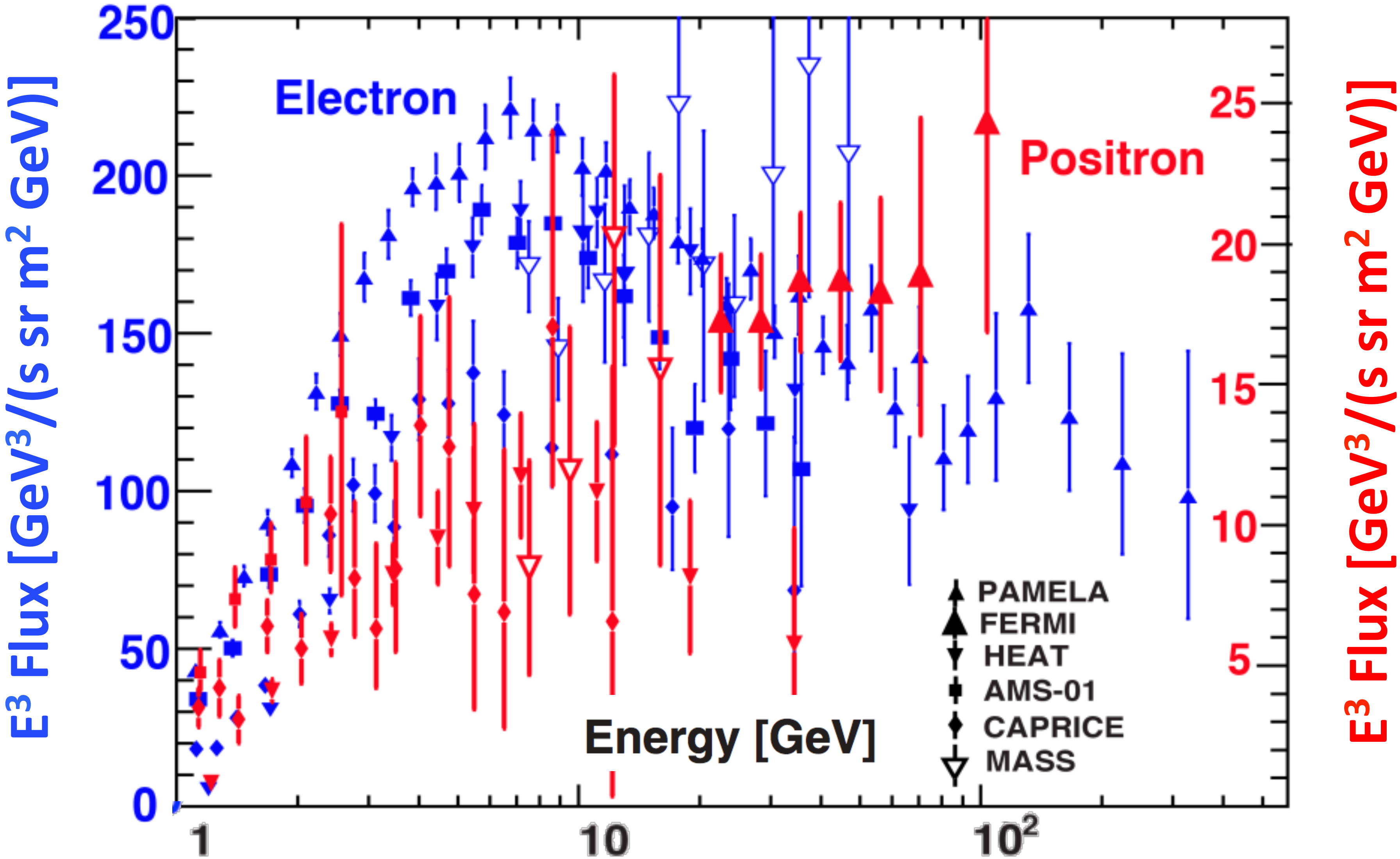
and accurately measure all cosmic rays to trillions of eV.

AMS was installed on the ISS in May 2011
it will continue through the lifetime of ISS

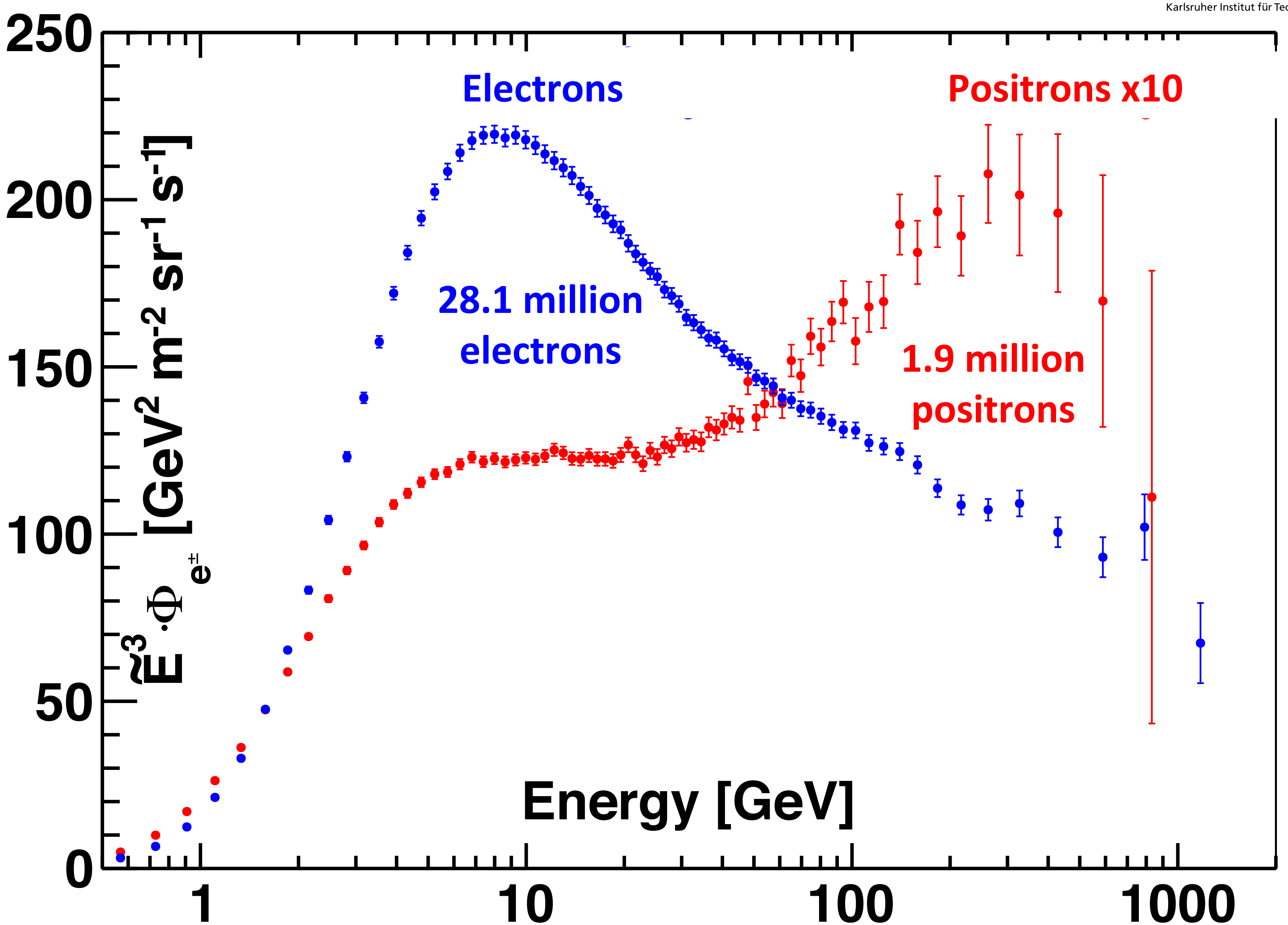



→ $28.1 \times 10^6$ electrons
→ $1.9 \times 10^6$ positrons

# Electron and Positron spectra before AMS



# Electron and Positron spectra after AMS



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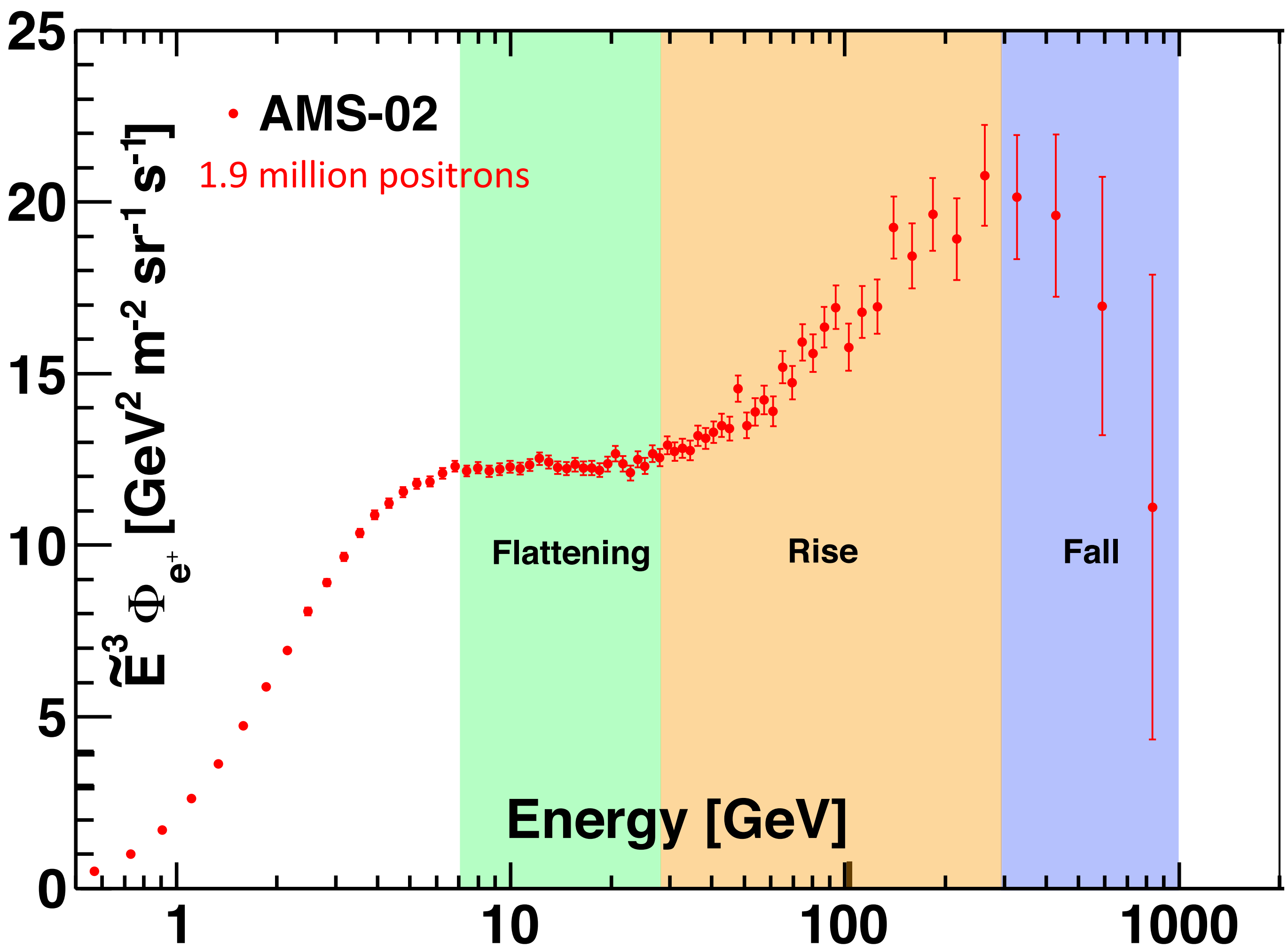
PHYSICAL REVIEW LETTERS 122, 041102 (2019)

Editors' Suggestion

# Towards Understanding the Origin of Cosmic-Ray Positrons



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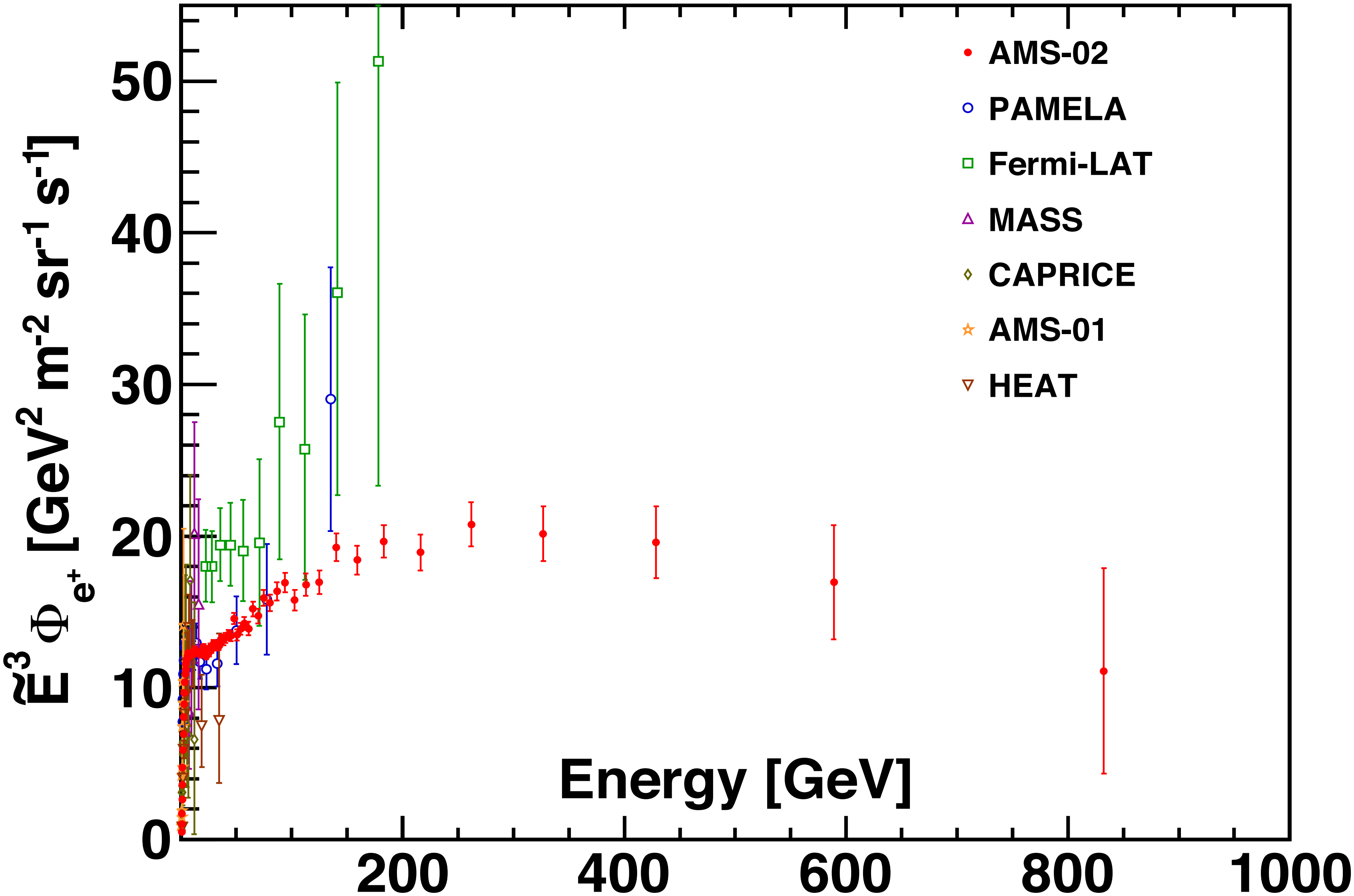
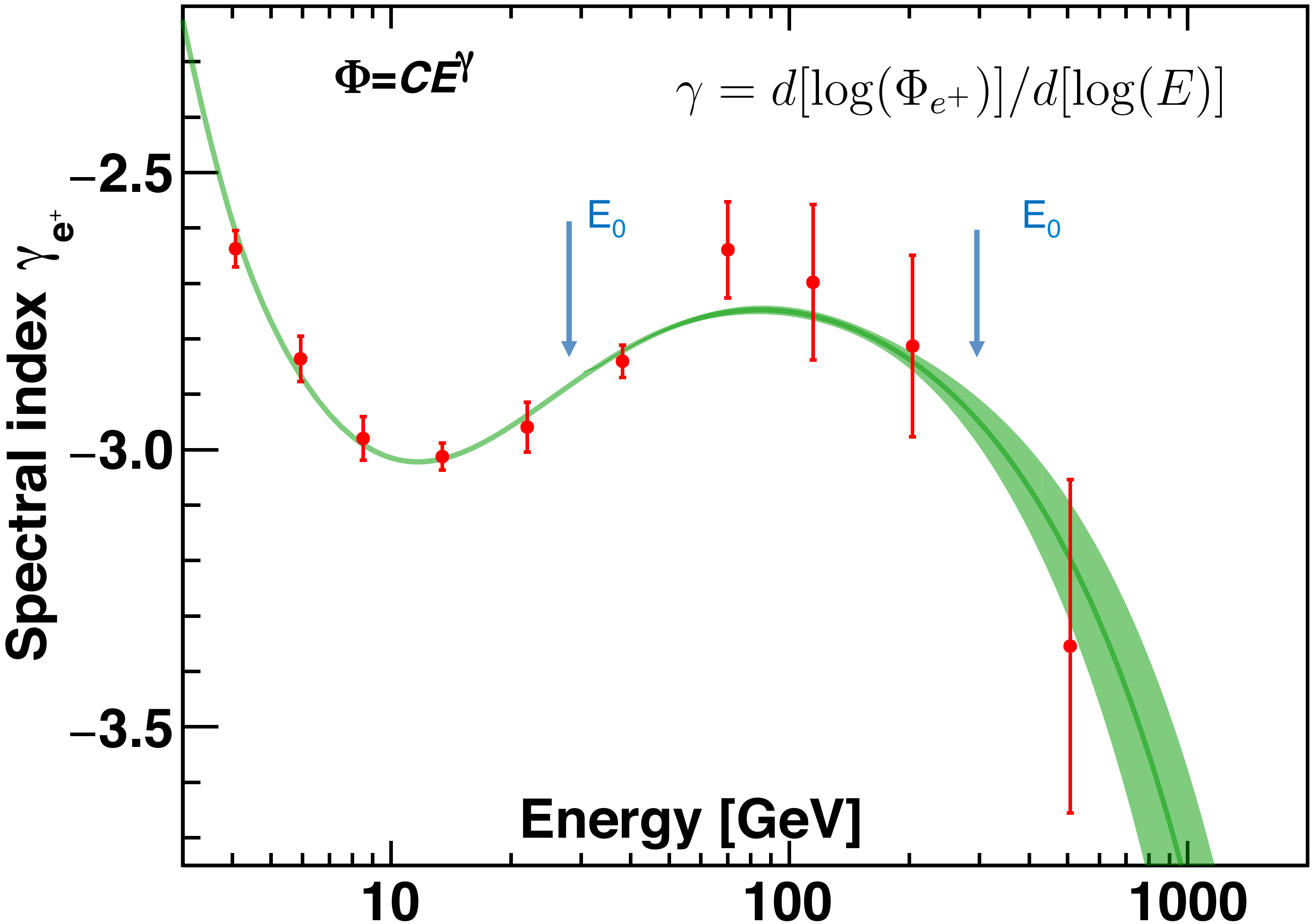
# AMS-02 positron flux at high energies



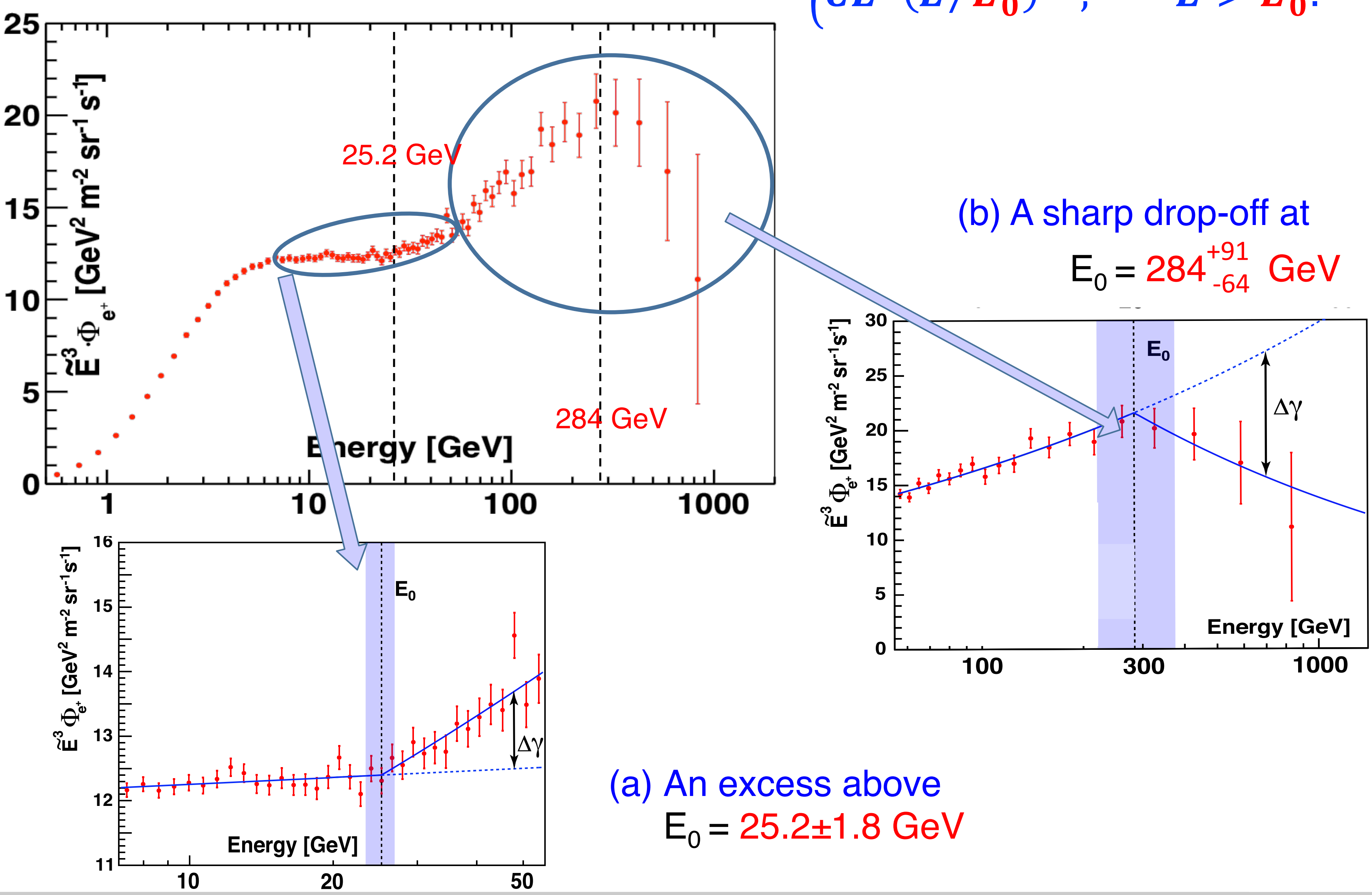
# The Spectral Index of the Positron Flux as a function of energy




The spectral index has complex energy dependence with a significant decrease towards higher energies.

## Fits of the data to

$$\Phi_{e^+}(E) = \begin{cases} CE^{\gamma}, & E \le E_0; \\ CE^{\gamma}(E/E_0)^{\Delta\gamma}, & E > E_0. \end{cases}$$




(b) A sharp drop-off at

$E_0 = 284^{+91}_{-64}$ GeV

(a) An excess above

$E_0 = 25.2 \pm 1.8$ GeV



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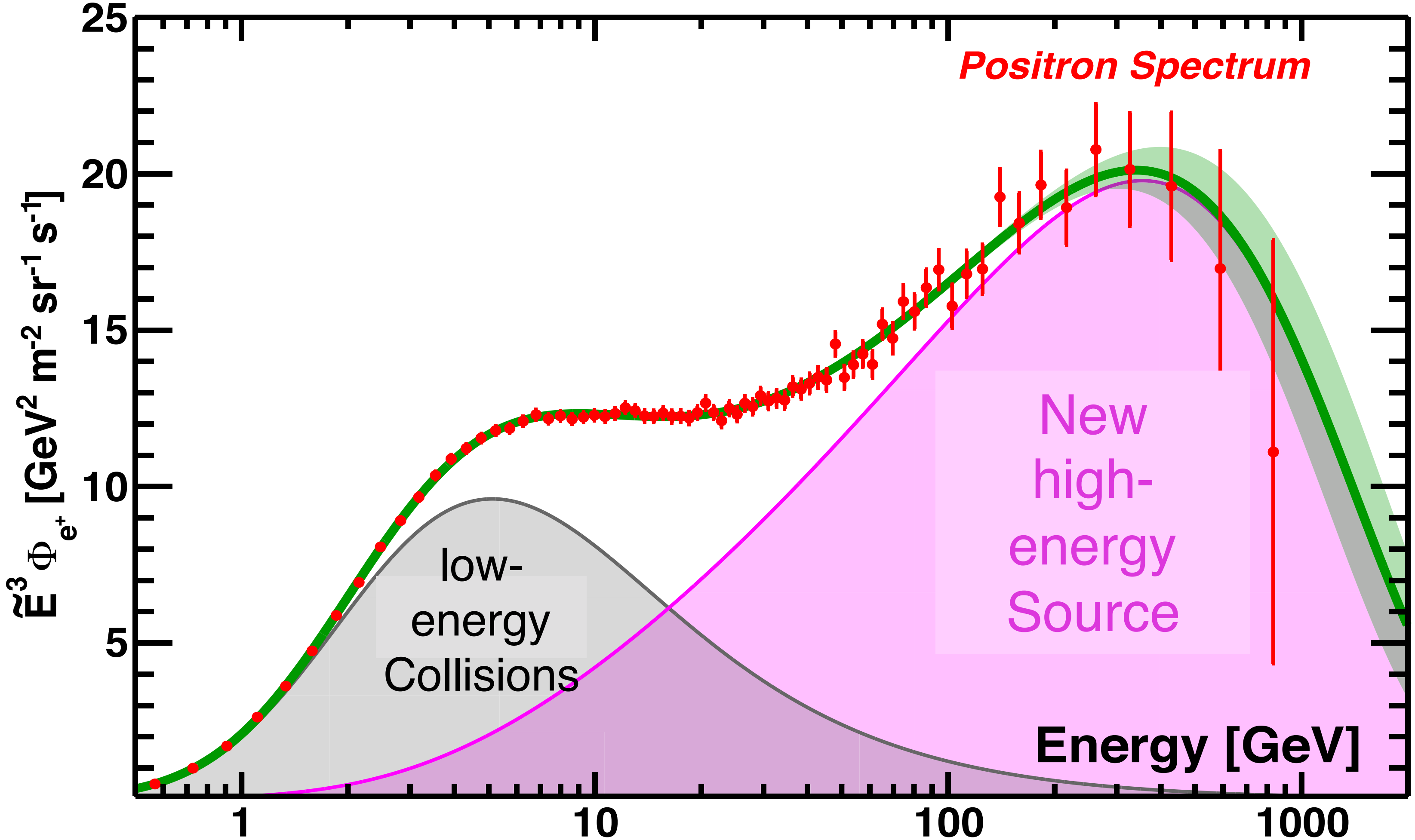
The positron flux is the sum of

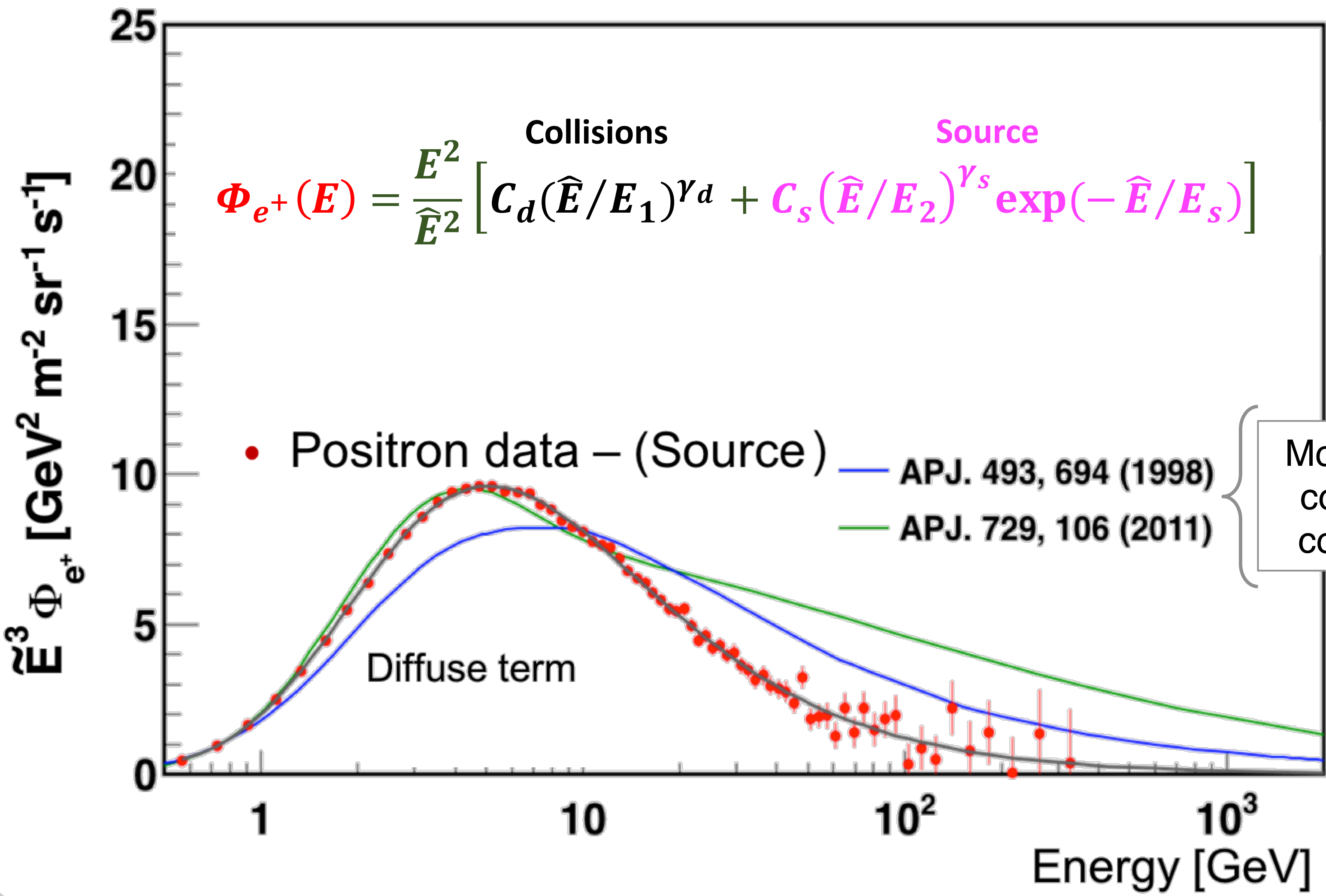
low-energy e⁺ from collisions plus a new source of high-energy e⁺

$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2}\Big[\underbrace{C_d(\hat{E}/E_1)^{\gamma_d}}_{\text{Collisions}} + \underbrace{C_s(\hat{E}/E_2)^{\gamma_s}\exp(-\hat{E}/E_s)}_{\text{Source}}\Big]$$



# Origins of Cosmic Positrons

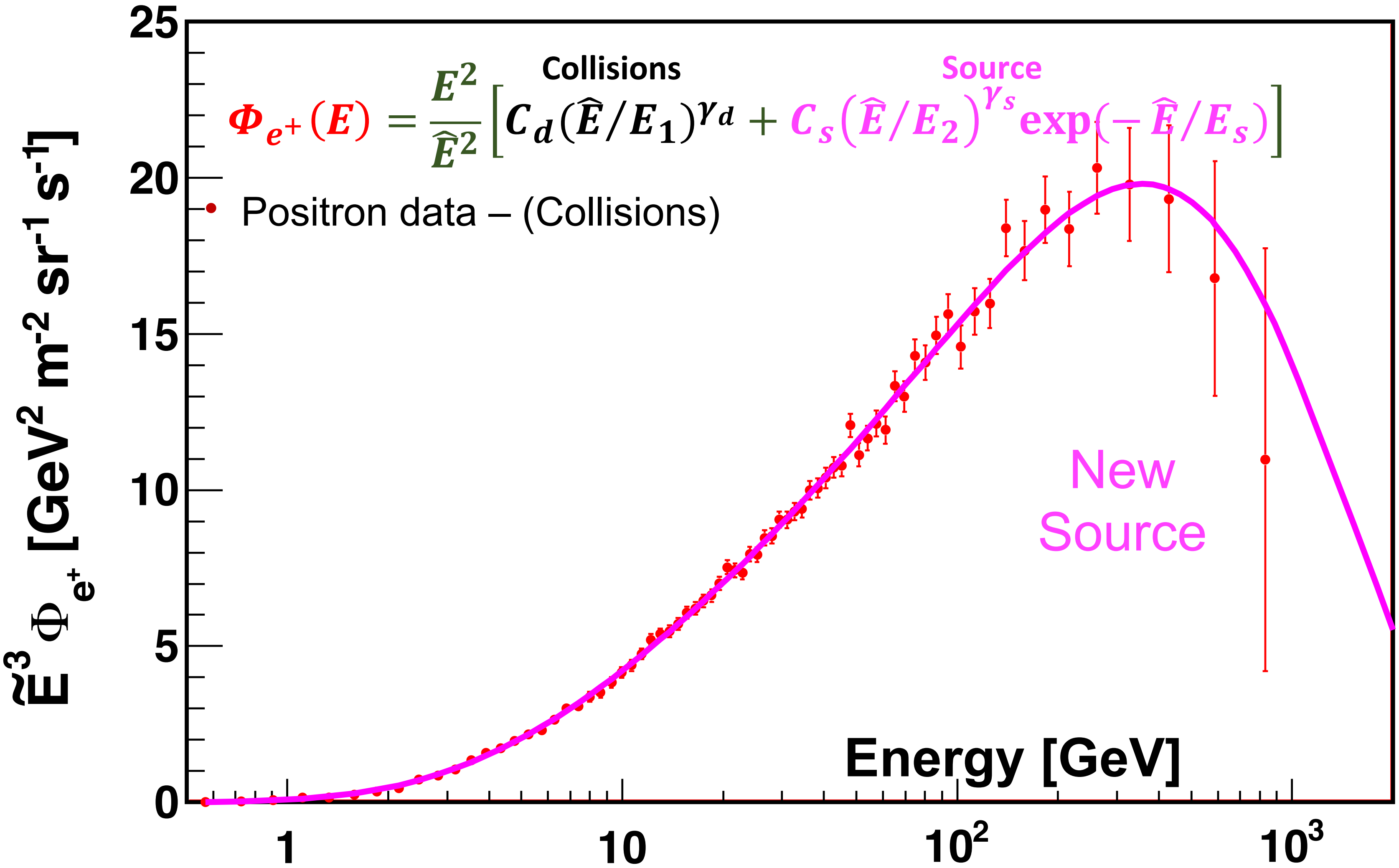
The low energy positron data can be explained by the collision of cosmic rays.




Models of the collisions of cosmic rays

# Origins of Cosmic Positrons

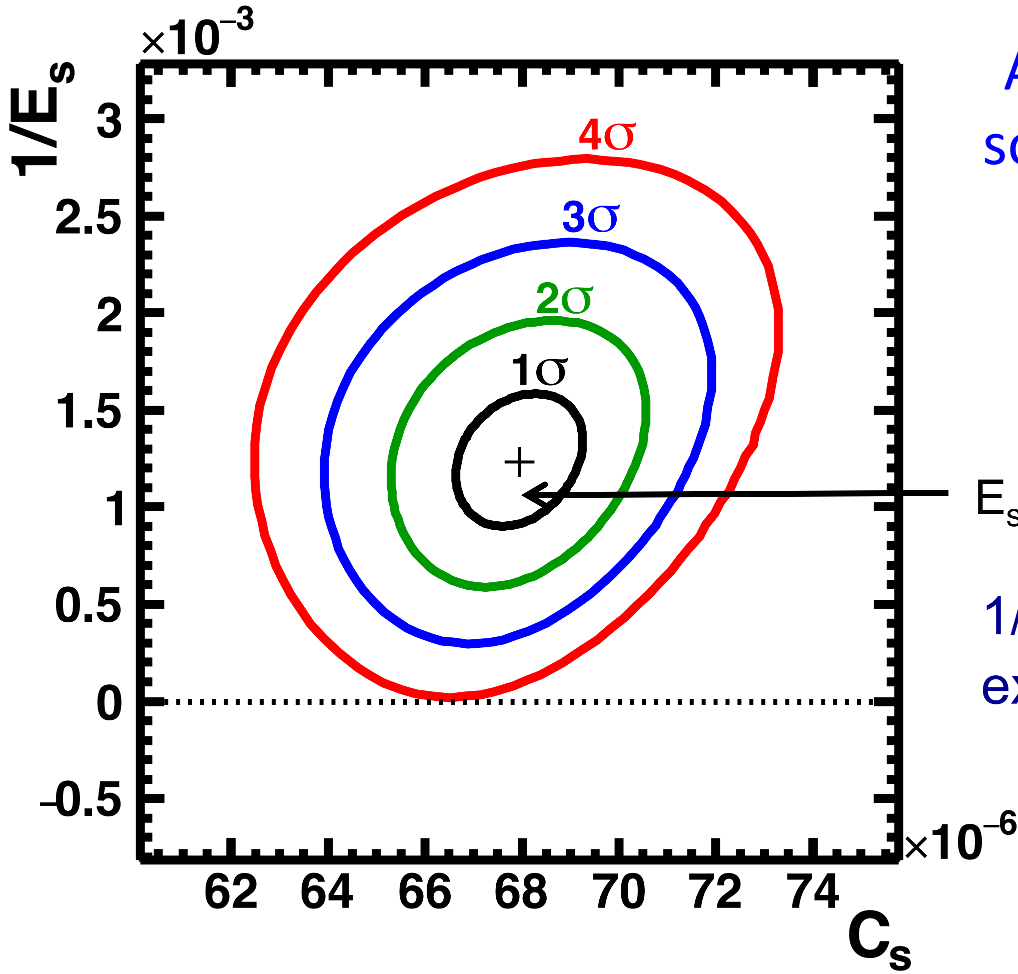
At high energies $e^+$ come from dark matter or new astrophysical sources



# Origins of Cosmic Positrons

Collisions Source

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



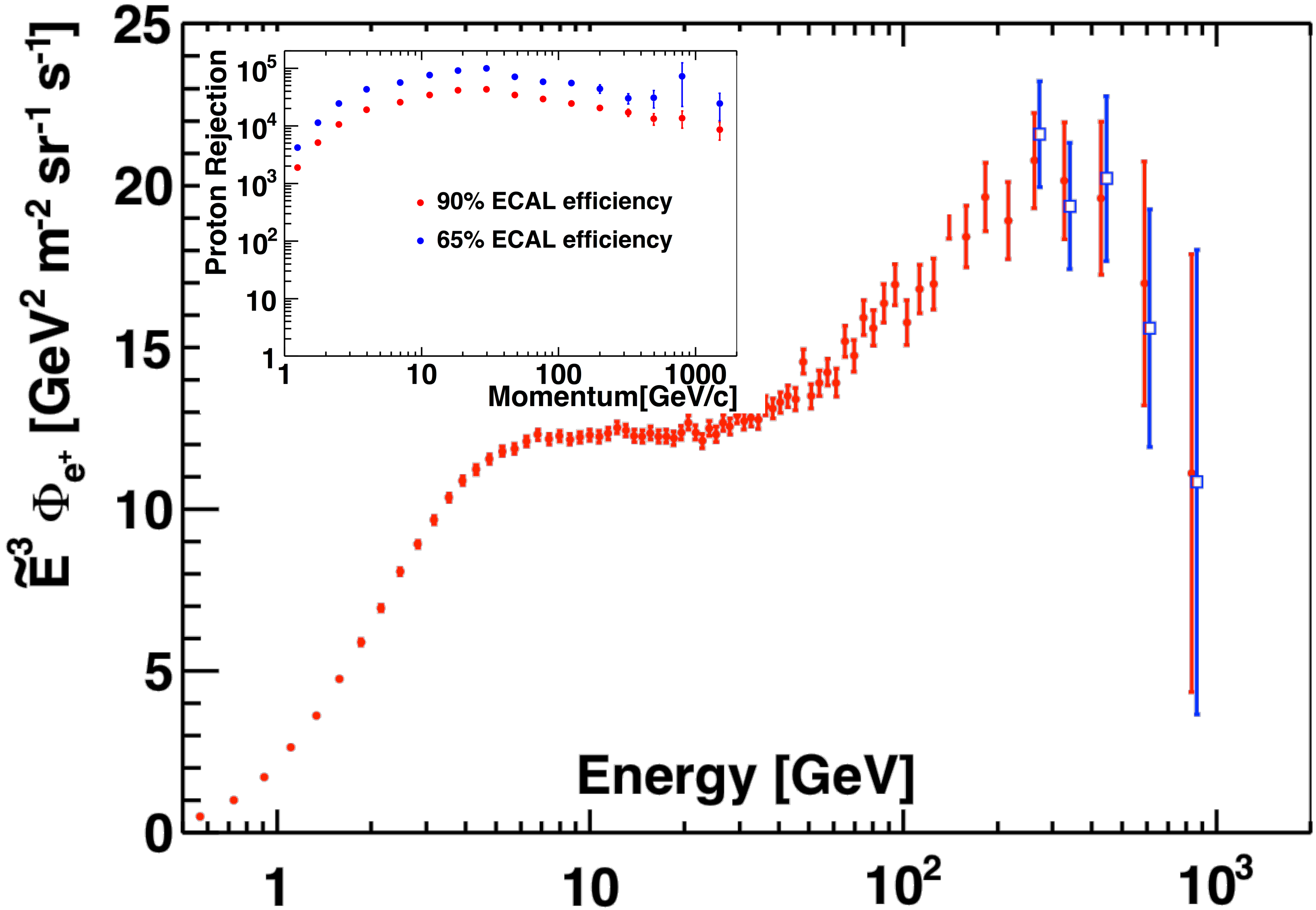

A finite energy cutoff of the source term $E_s = 810^{+310}_{-180}$ GeV, is established with a significance more than 4**σ**.

$E_s$ = 810 GeV

$1/E_s = 0$ or $E_s = \infty$ excluded at 4.07σ

Consistency check:

# Positron flux with proton rejection increased by x3



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PHYSICAL REVIEW LETTERS **122,** 101101 (2019)

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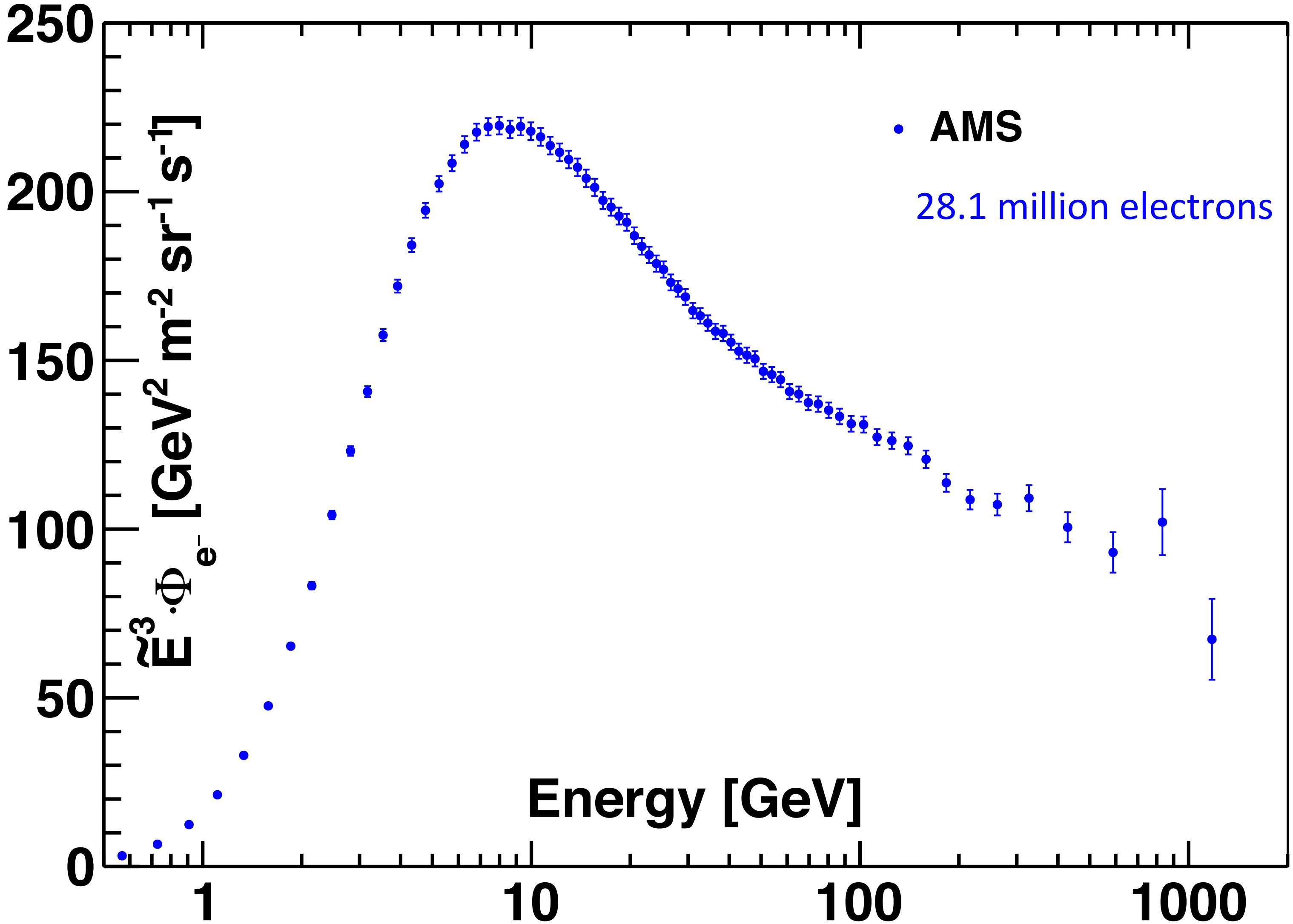
## Towards Understanding the Origin of Cosmic-Ray Electrons



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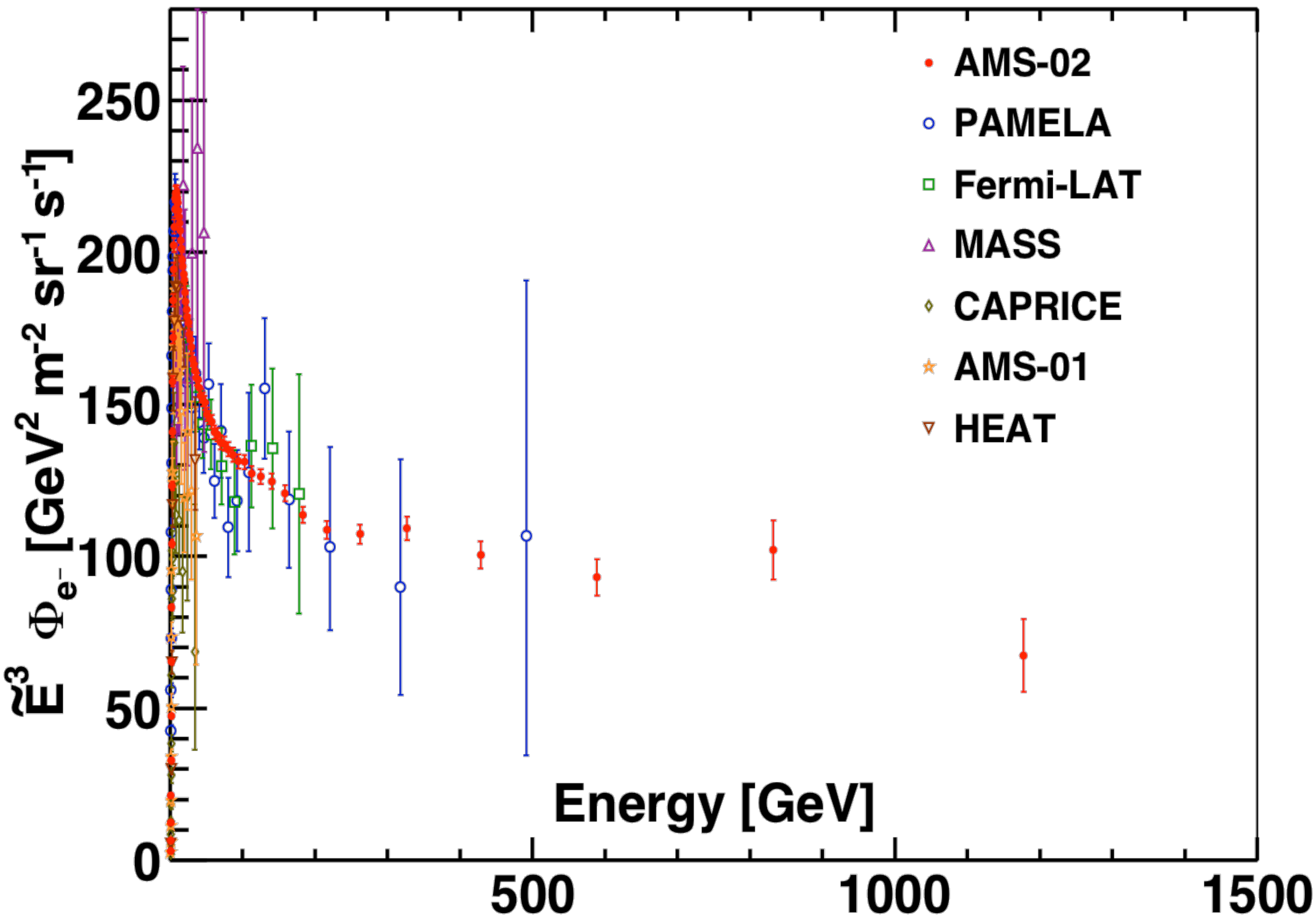
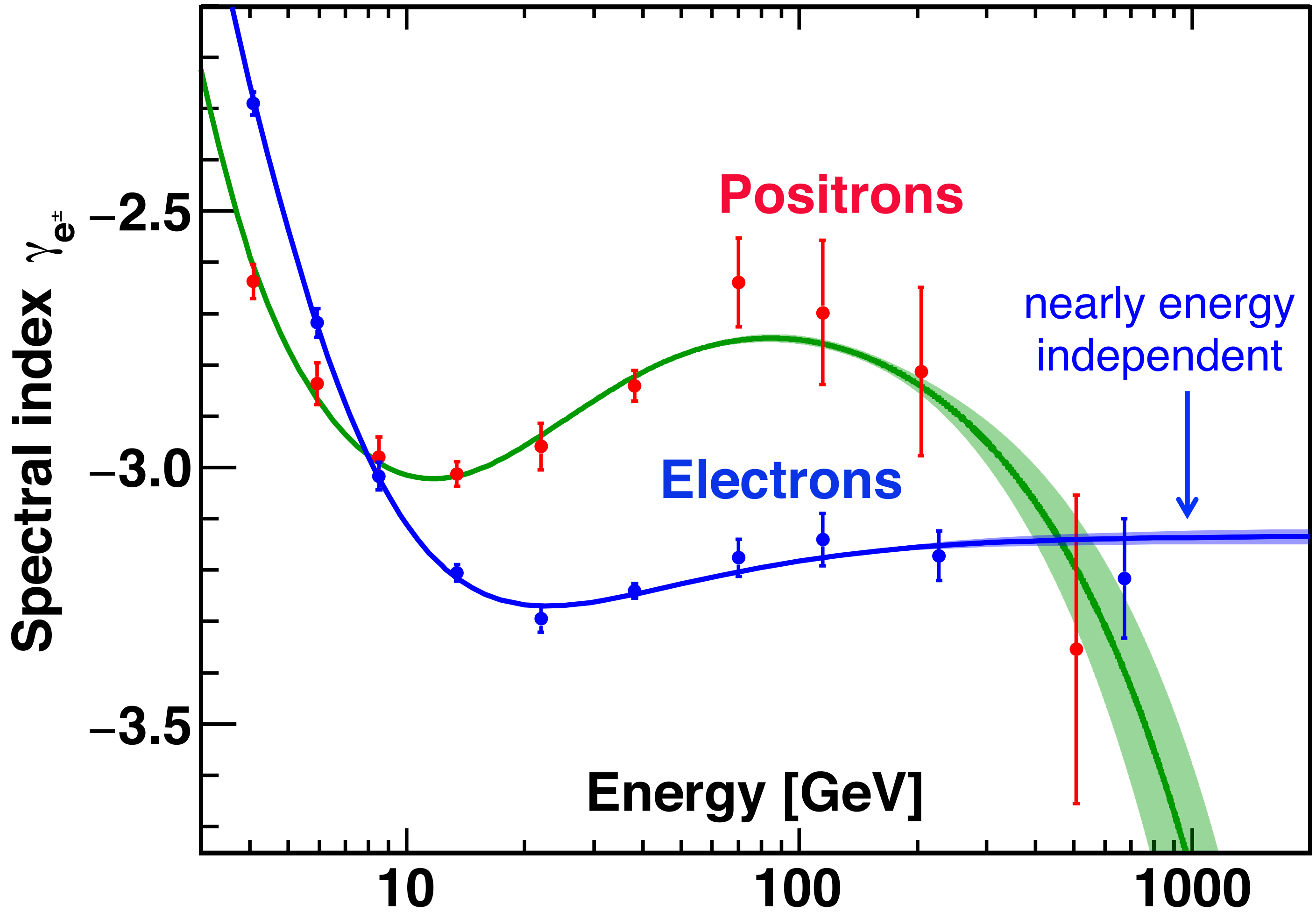
# AMS-02 electron flux at high energies



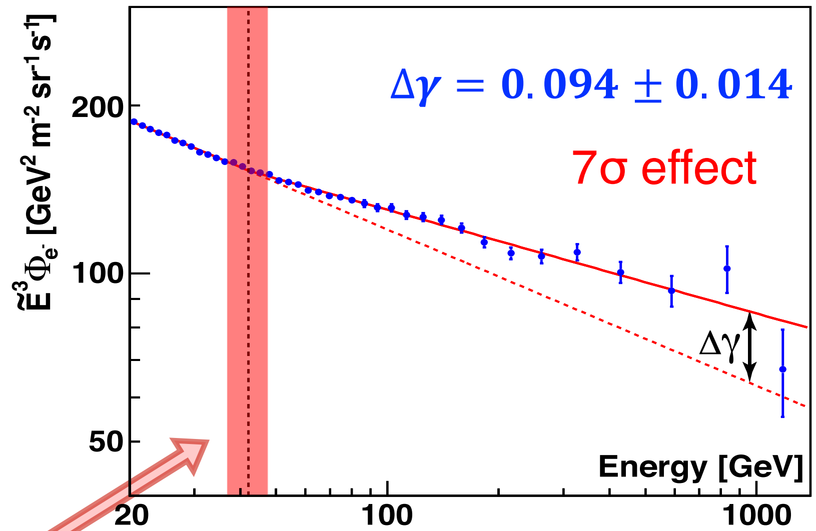
# Comparison of the behavior of the cosmic ray electrons and positrons

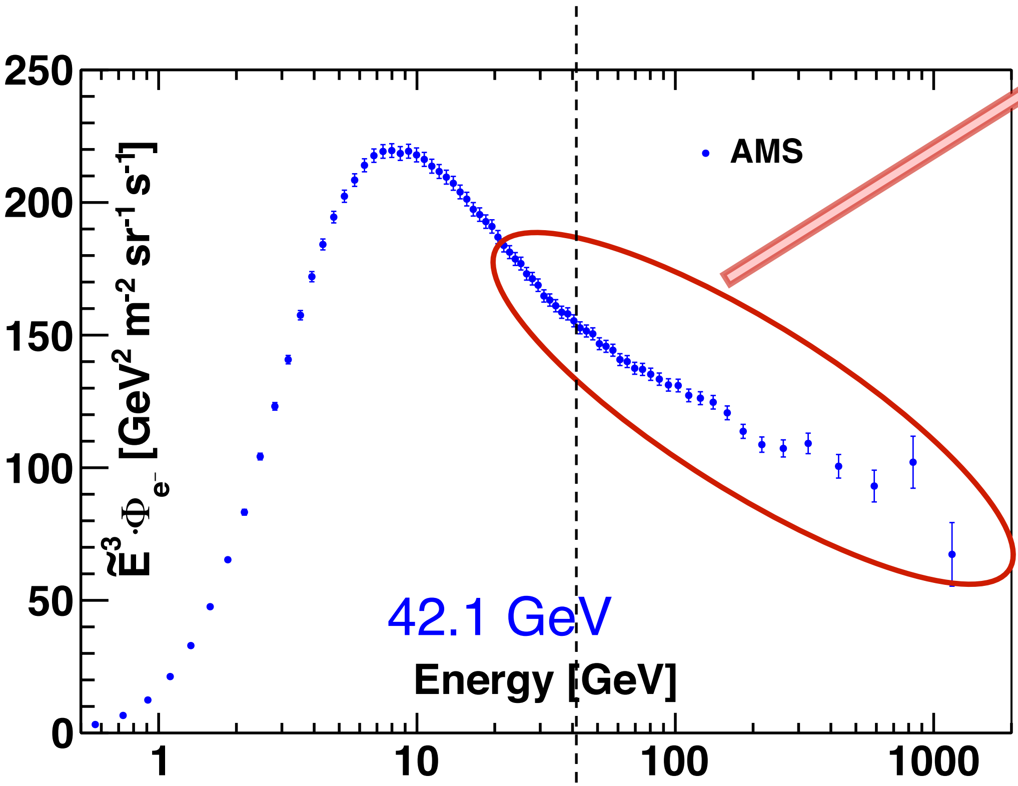
$$\gamma = d[\log(\Phi)]/d[\log(E)]$$



## Fits of the data to

$$\Phi_{e^-}(E) = \begin{cases} CE^{\gamma}, & E \le E_0; \\ CE^{\gamma}(E/E_0)^{\Delta\gamma}, & E > E_0. \end{cases}$$




A significant excess above

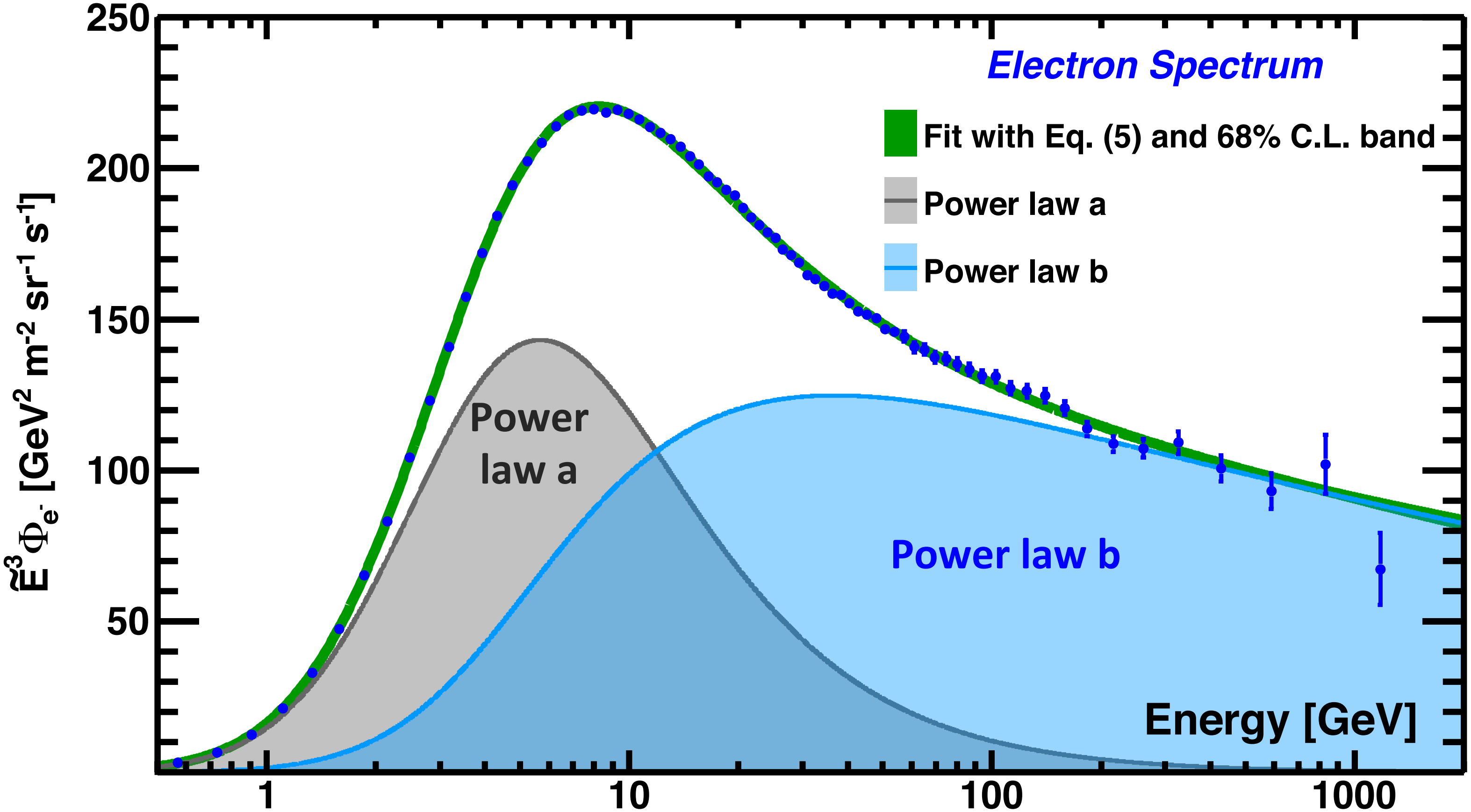
$E_0 = 42^{+5.4}_{-5.2}$ GeV

# The electron flux is the sum of two power law

$$\Phi_{e^-}(E) = \frac{E^2}{\widehat{E}^2}\left[1 + \left(\widehat{E}/E_t\right)^{\Delta\gamma_t}\right]^{-1}\left[C_a\left(\widehat{E}/E_a\right)^{\gamma_a} + C_b\left(\widehat{E}/E_b\right)^{\gamma_b}\right]$$

Solar & low-energy

Power laws **a** **b**




Electrons have neither source nor cutoff.



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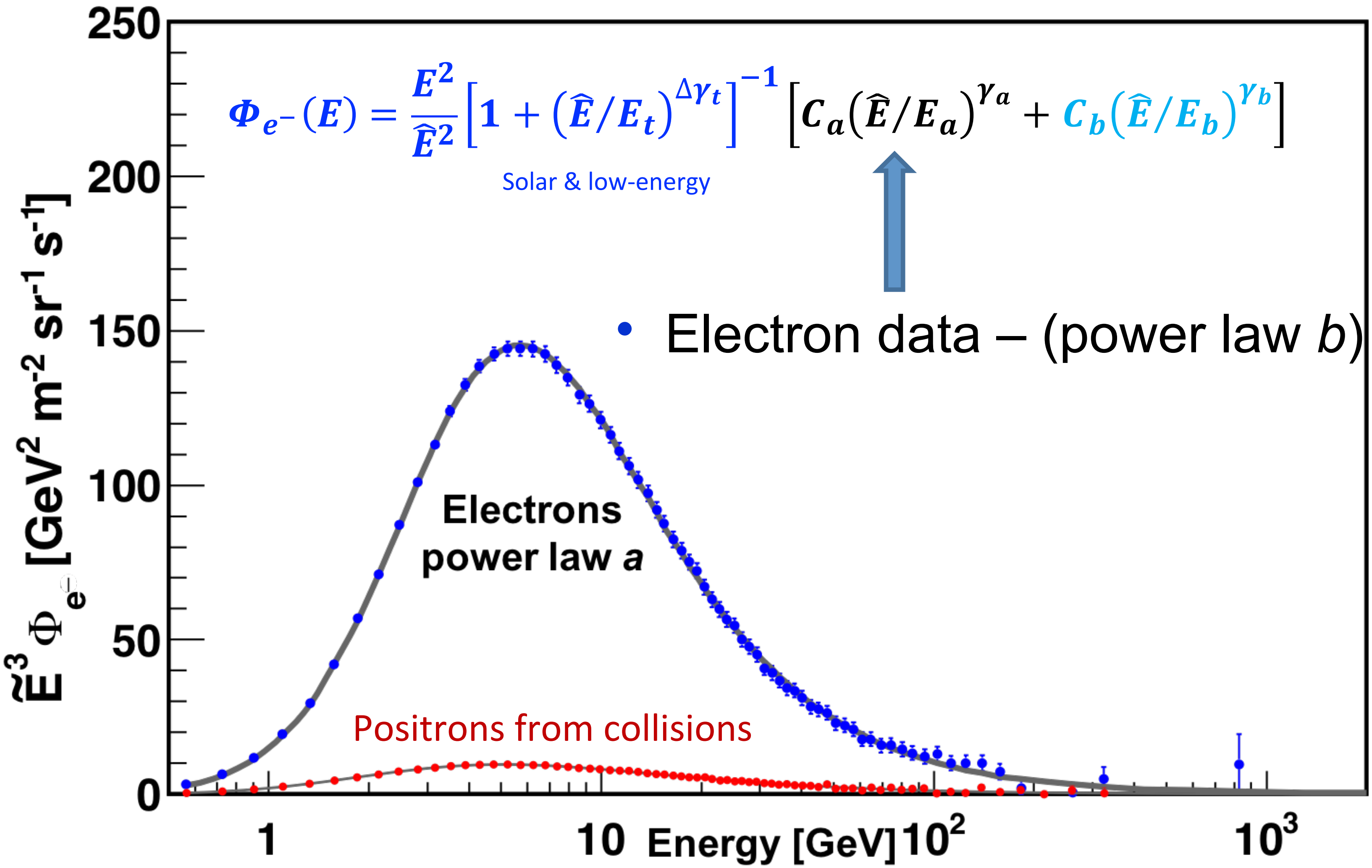
# Origins of Cosmic Electrons

At low energies positrons come from cosmic ray collisions, electrons do not.

$$\Phi_{e^-}(E) = \frac{E^2}{\hat{E}^2}\left[1 + \left(\hat{E}/E_t\right)^{\Delta\gamma_t}\right]^{-1}\left[C_a\left(\hat{E}/E_a\right)^{\gamma_a} + C_b\left(\hat{E}/E_b\right)^{\gamma_b}\right]$$

Solar & low-energy



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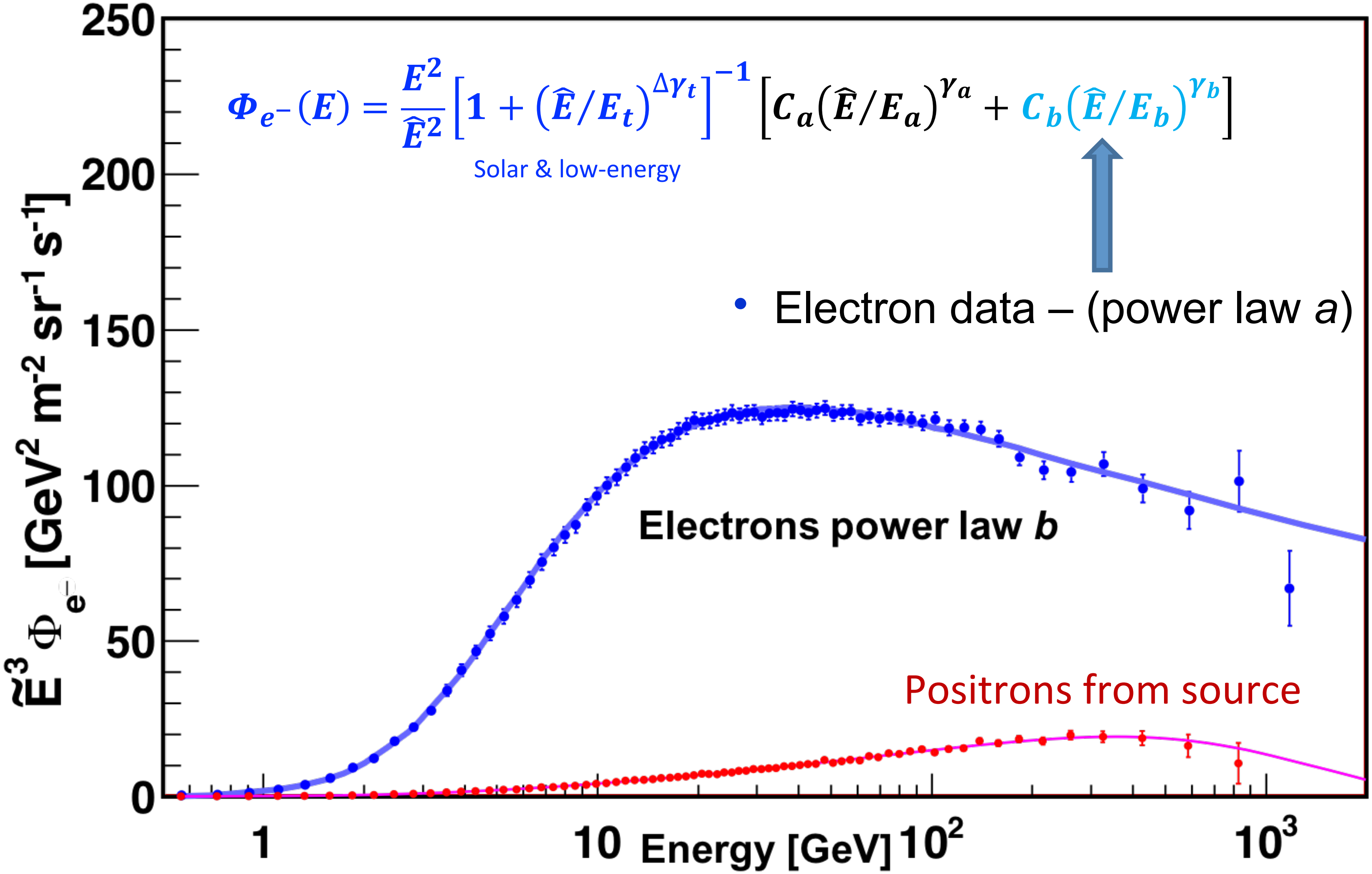
# Origins of Cosmic Electrons

The positron source term has a cutoff,

whereas electrons have neither source term nor the cutoff.







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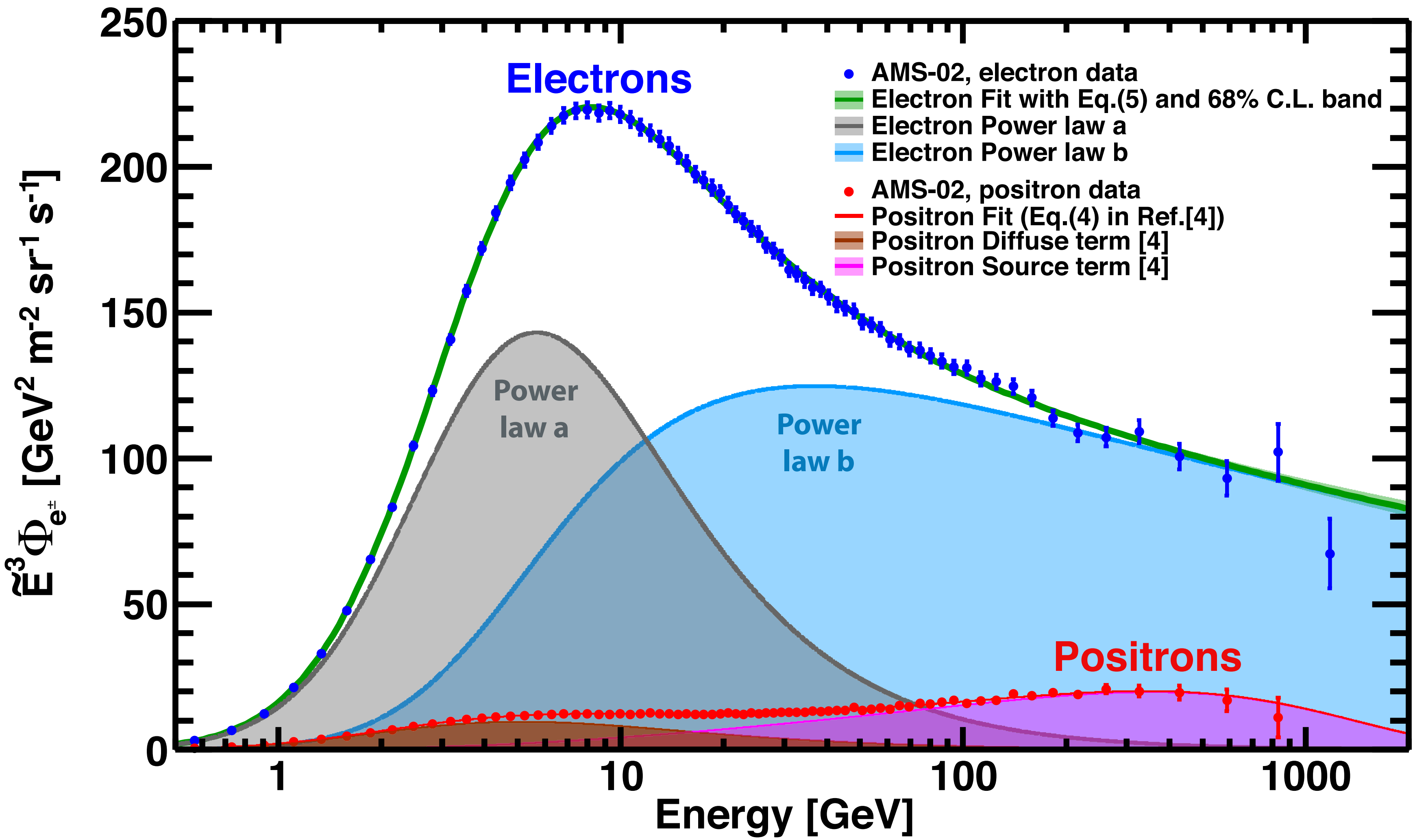
# Origins of Cosmic Electrons

The cosmic ray electrons originate from different sources than high energy positrons.



# Conclusions

- the measurement of the **$e^-$ flux from 0.5 GeV to 1.4 TeV** based on $28.1 \times 10^6$ events and of the **$e^+$ flux from 0.4 to 1 TeV** based on $1.9 \times 10^6$ event have been presented.

- **The positron flux:**
  - significant **excess starting** from ~25.2 GeV and a sharp **dropoff** above 284 GeV
  - is well described by the **sum of a diffuse term** associated with the secondary positrons production **and a new source** term of positrons, which dominates at high energies
  - shows a finite **energy cutoff** of the source term of E~ 810 GeV (significance > $4\sigma$)

- **The electron flux:**
  - significant **excess** starting from ~42 GeV but the nature of this excess is **different from the positron** flux excess above ~25.2 GeV.
  - is well described by the **sum of two power law** components.
  - The electron flux does **not have an energy cutoff** below 1.9 TeV.

- In the entire energy range the **electron and positron spectra have distinctly different magnitudes and energy dependences.**

  → most high energy electrons originate from different sources than high energy positrons.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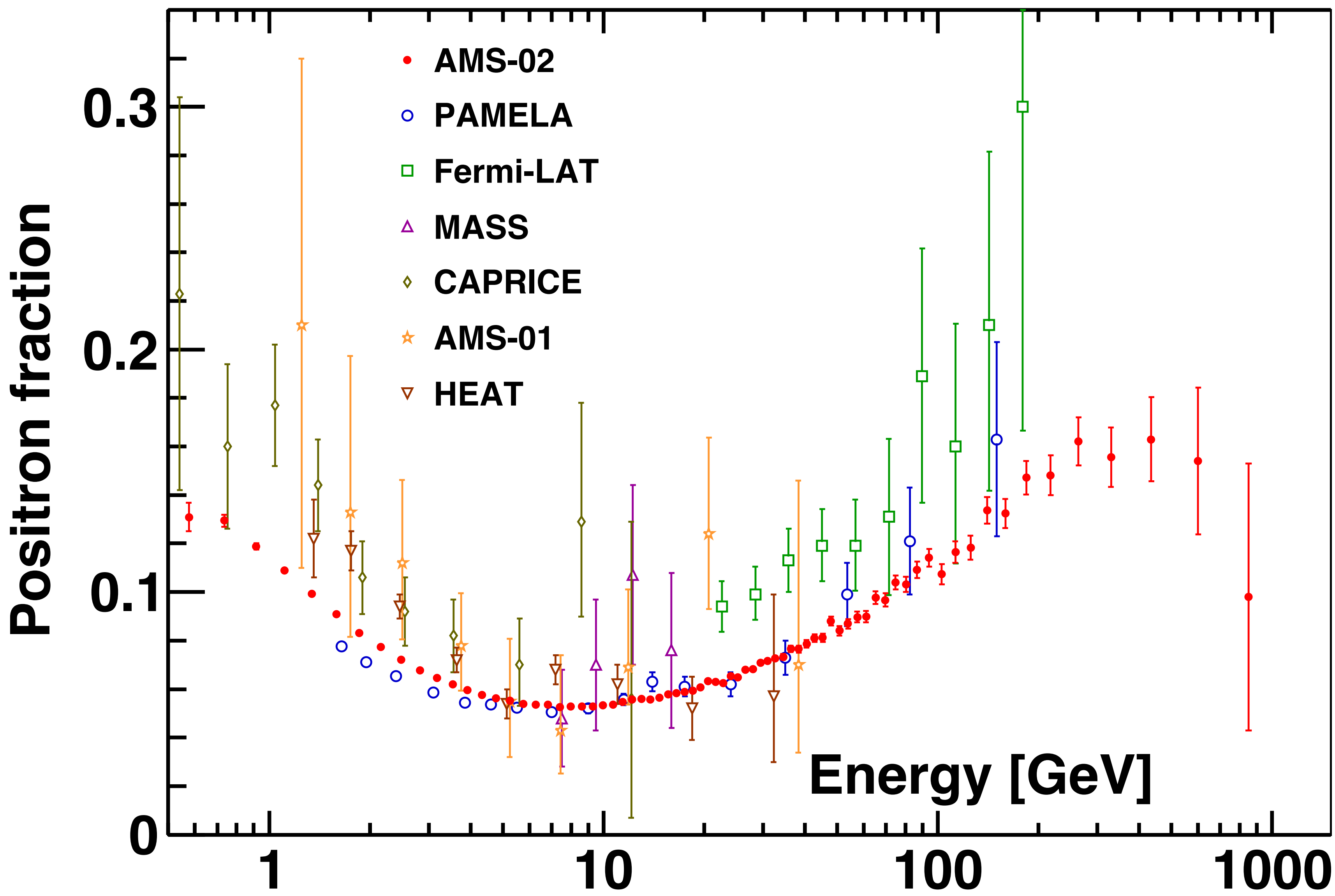
# Back up

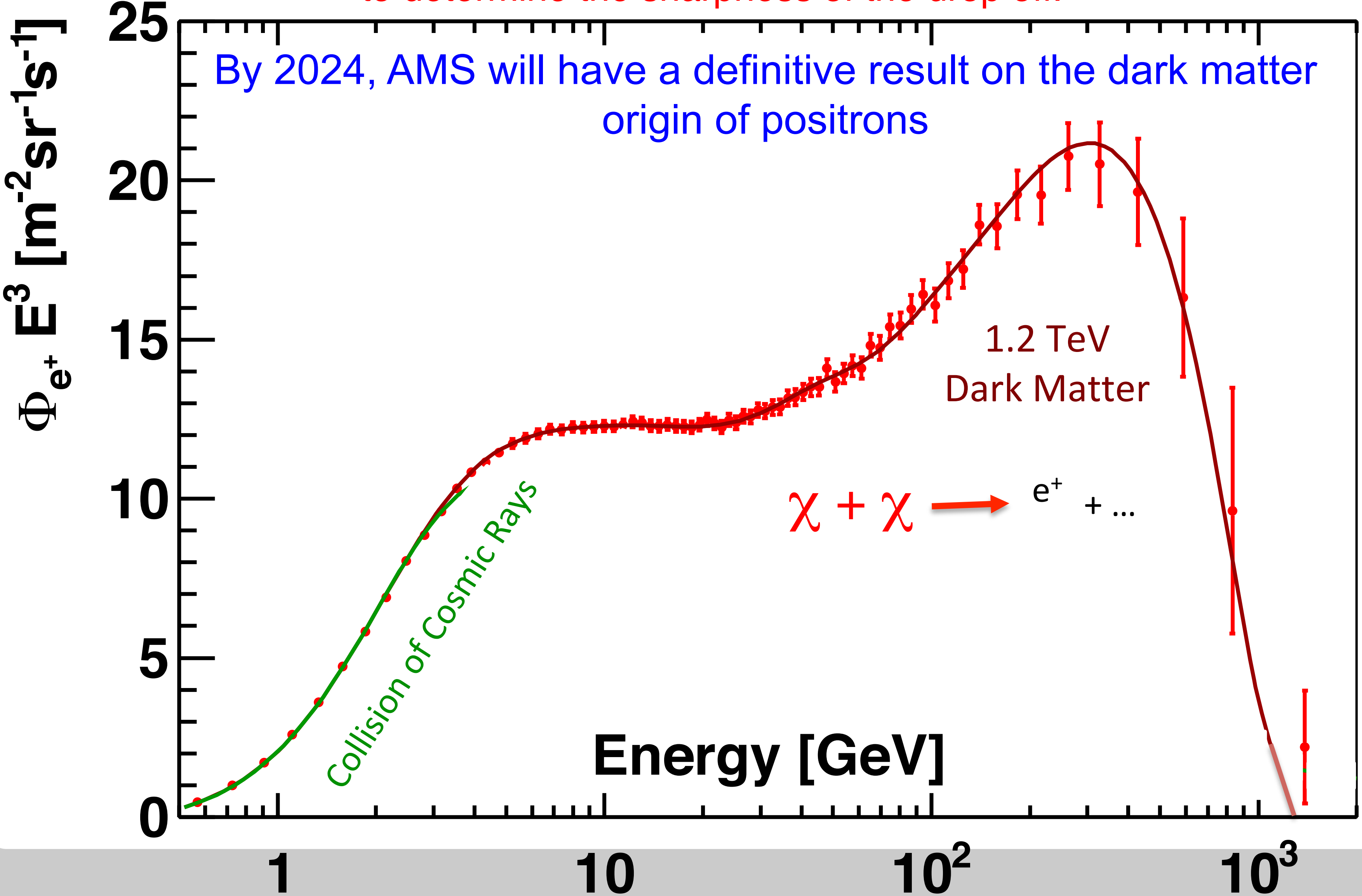
# AMS Positron Fraction



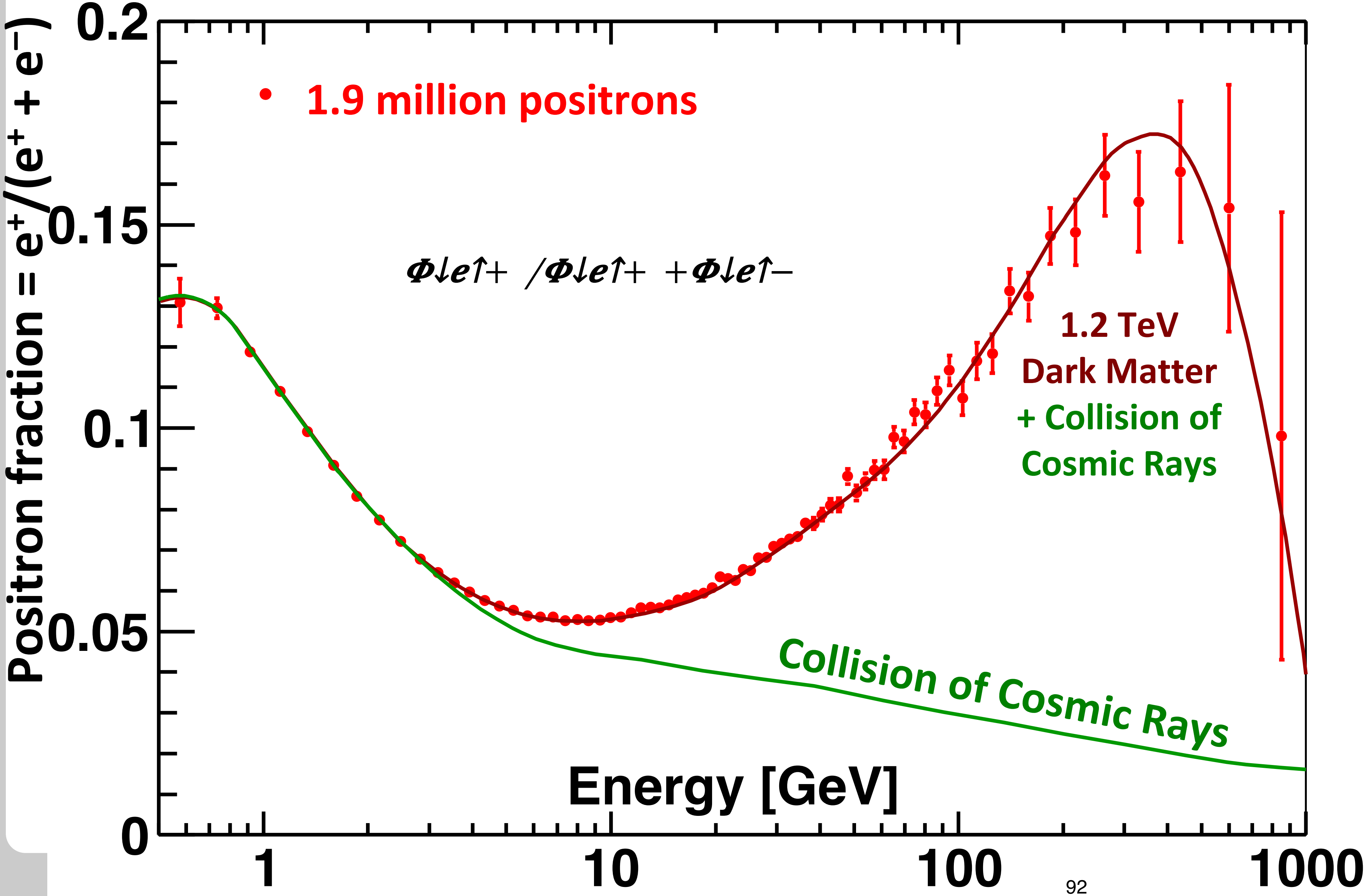
# The Positron Flux through 2024

Extend the measurements to 2 TeV and double the current statistics

to determine the sharpness of the drop off.



## Positron excess also can be expressed in terms of the positron fraction, which explores the same physics

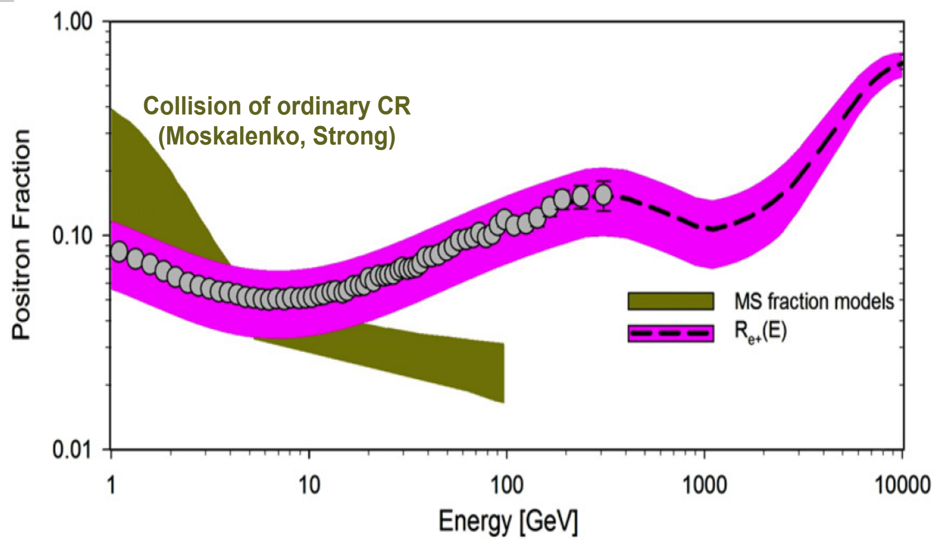




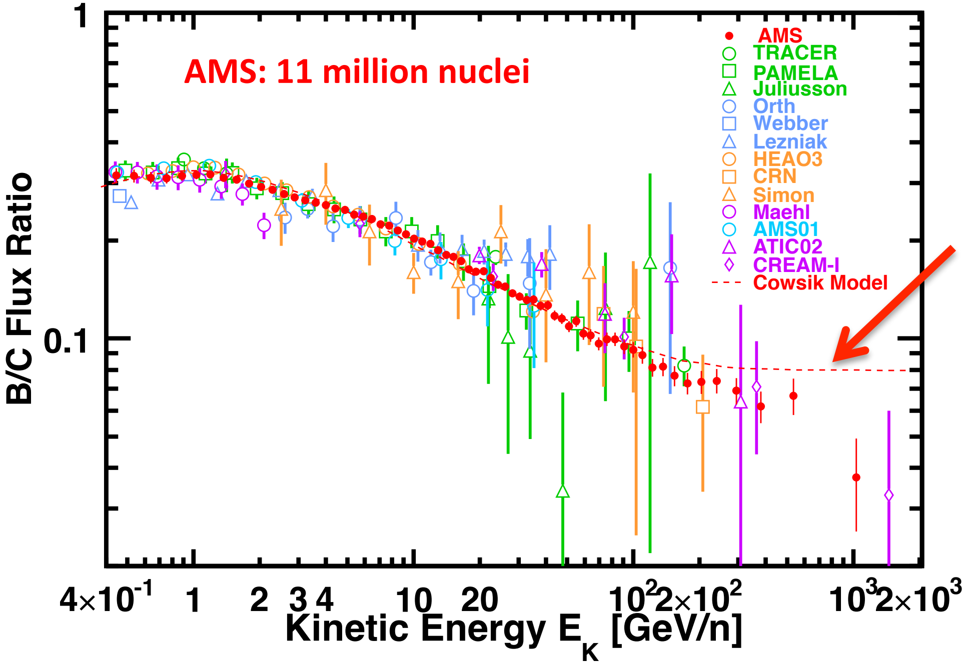

Dark Matter model is based on J. Kopp, Phys. Rev. D 88, 076013 (2013).

# New Propagation Models explaining the AMS e+ data

Explaining the AMS positron fraction (gray circles) is due to propagation effects.
R. Cowsik *et al.*, Ap. J. 786 (2014) 124, (pink band)

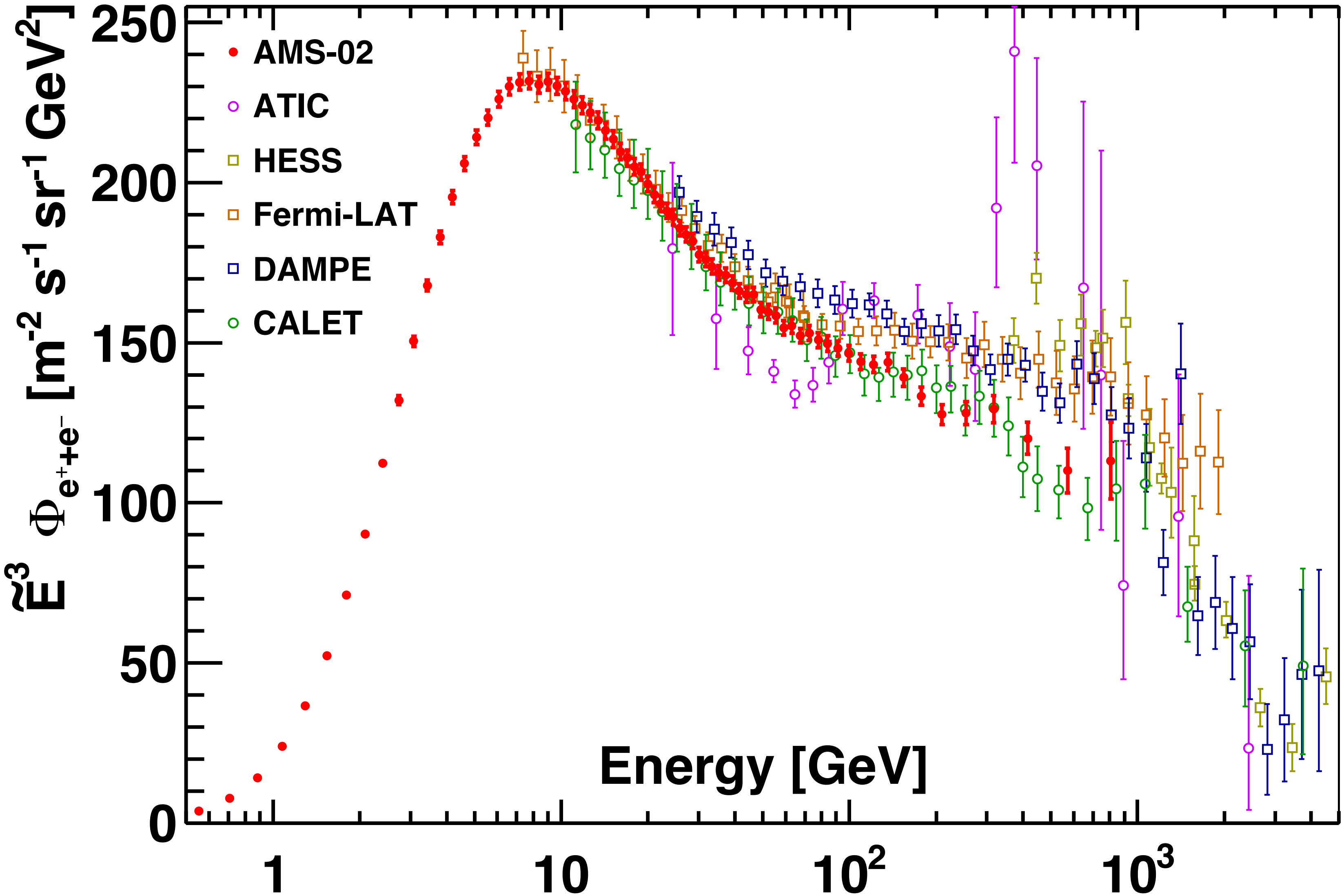



This requires a specific energy dependence of the B/C ratio




**The observed features of the AMS e+ data cannot be explained by standard propagation models**

# AMS Combined positron + electron flux



# HAWC rules out that the AMS positron excess is from nearby pulsars

*Science* 358, 911-914 (2017)