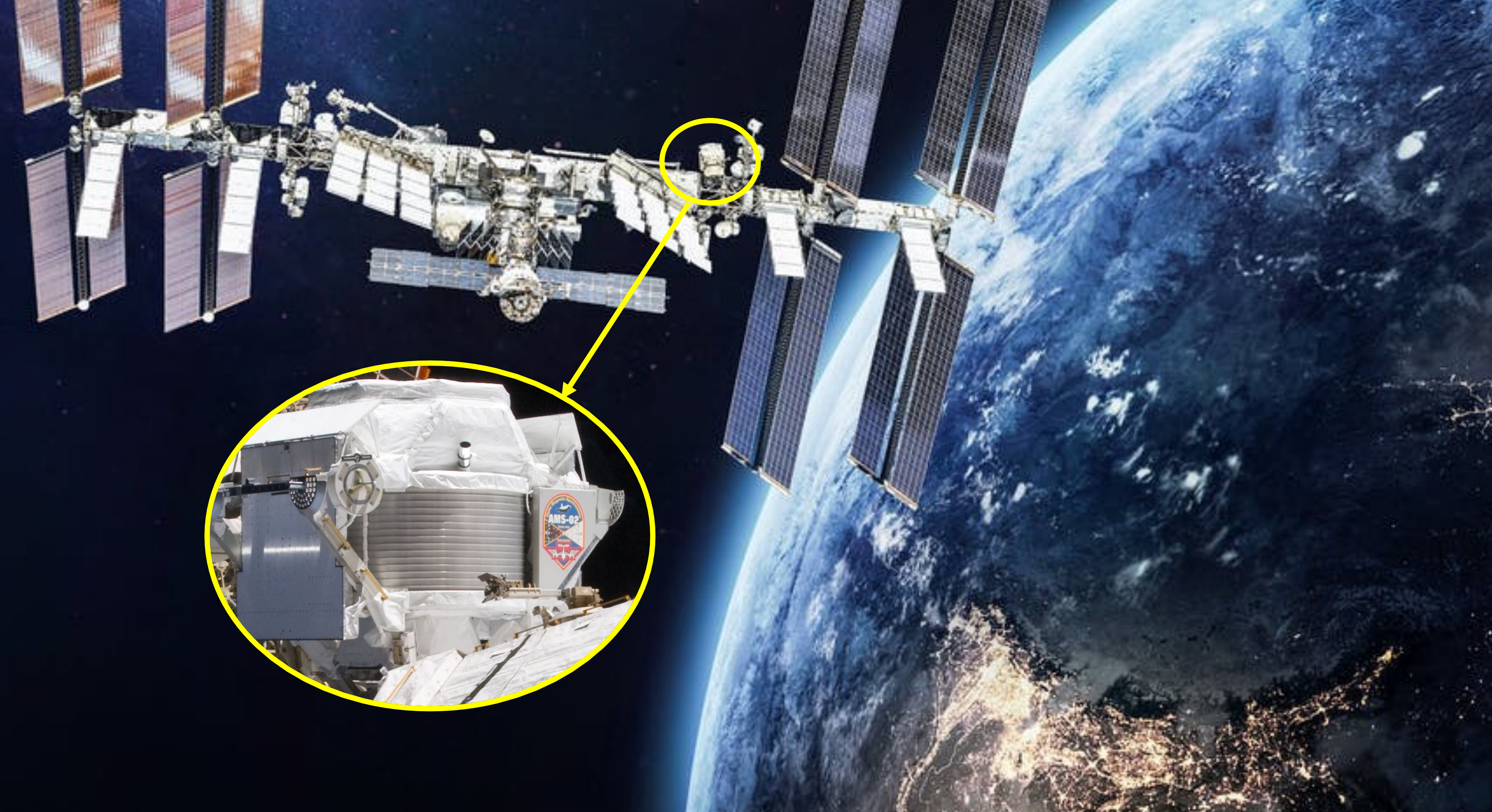
Towards Understanding the Origin of Cosmic-Ray Electrons

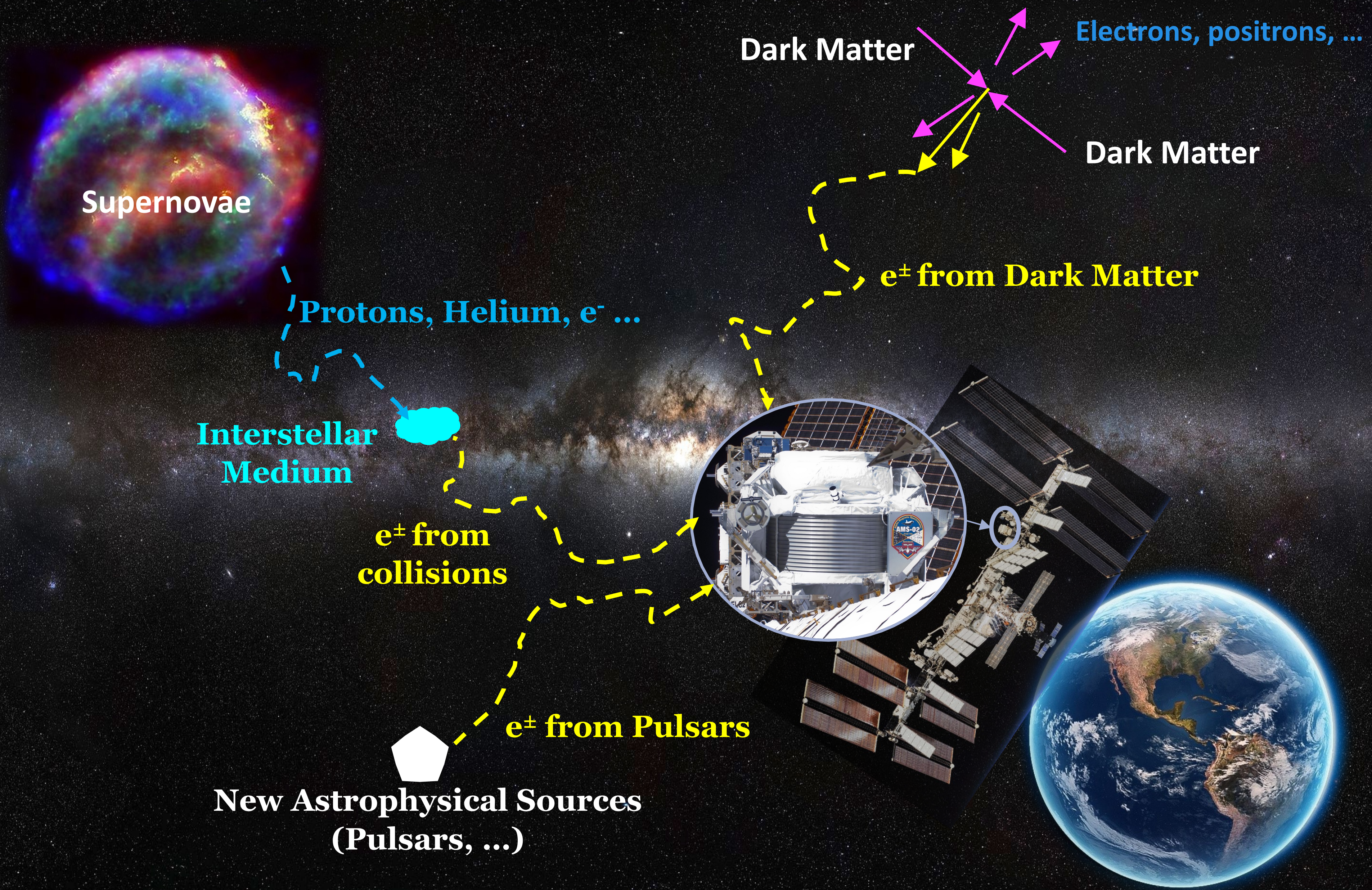
TeVPA, Aug 2022

Valerio Vagelli (ASI and INFN)

on behalf of the AMS Collaboration



The origins of cosmic electrons

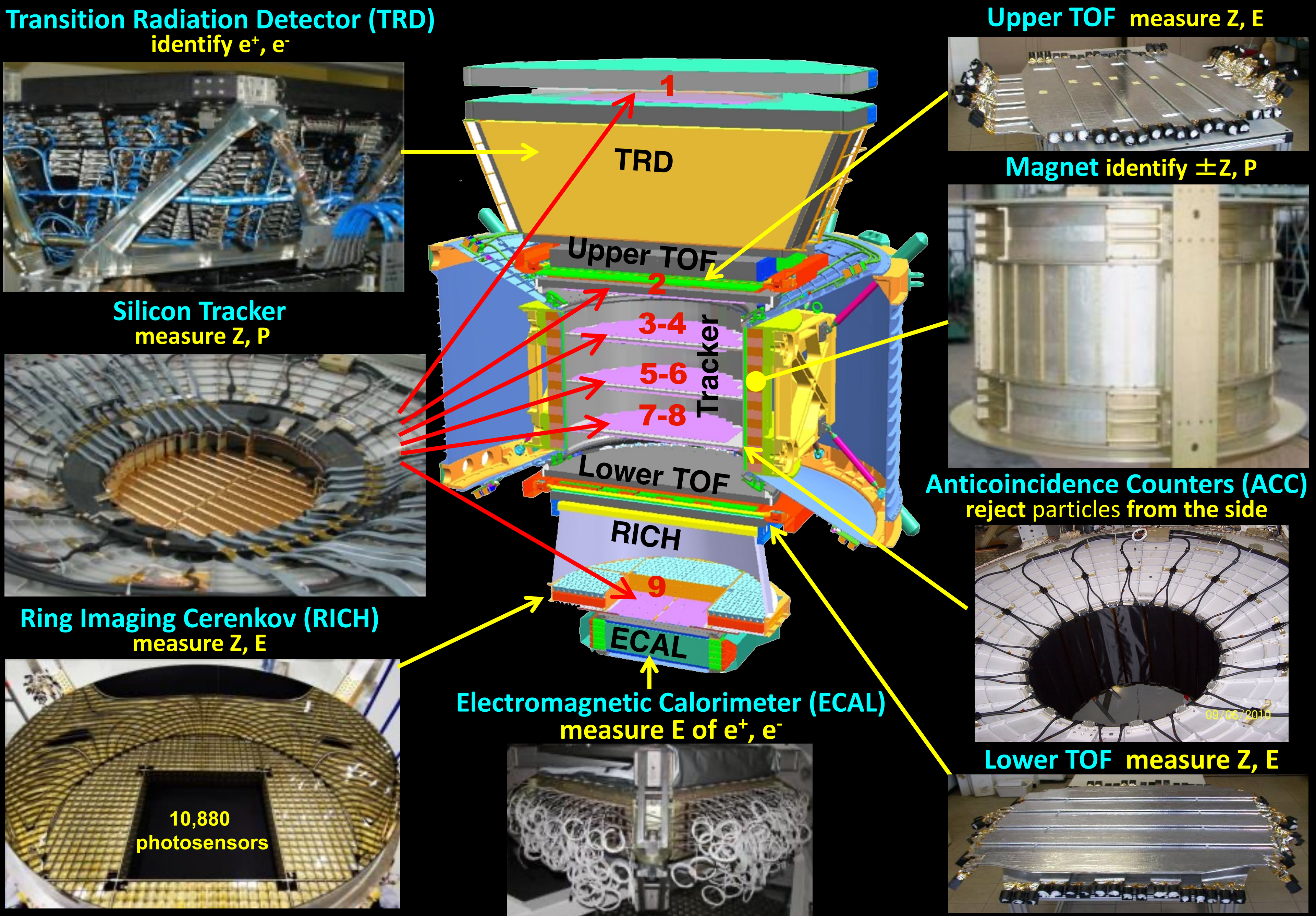


The AMS-02 detector on the ISS

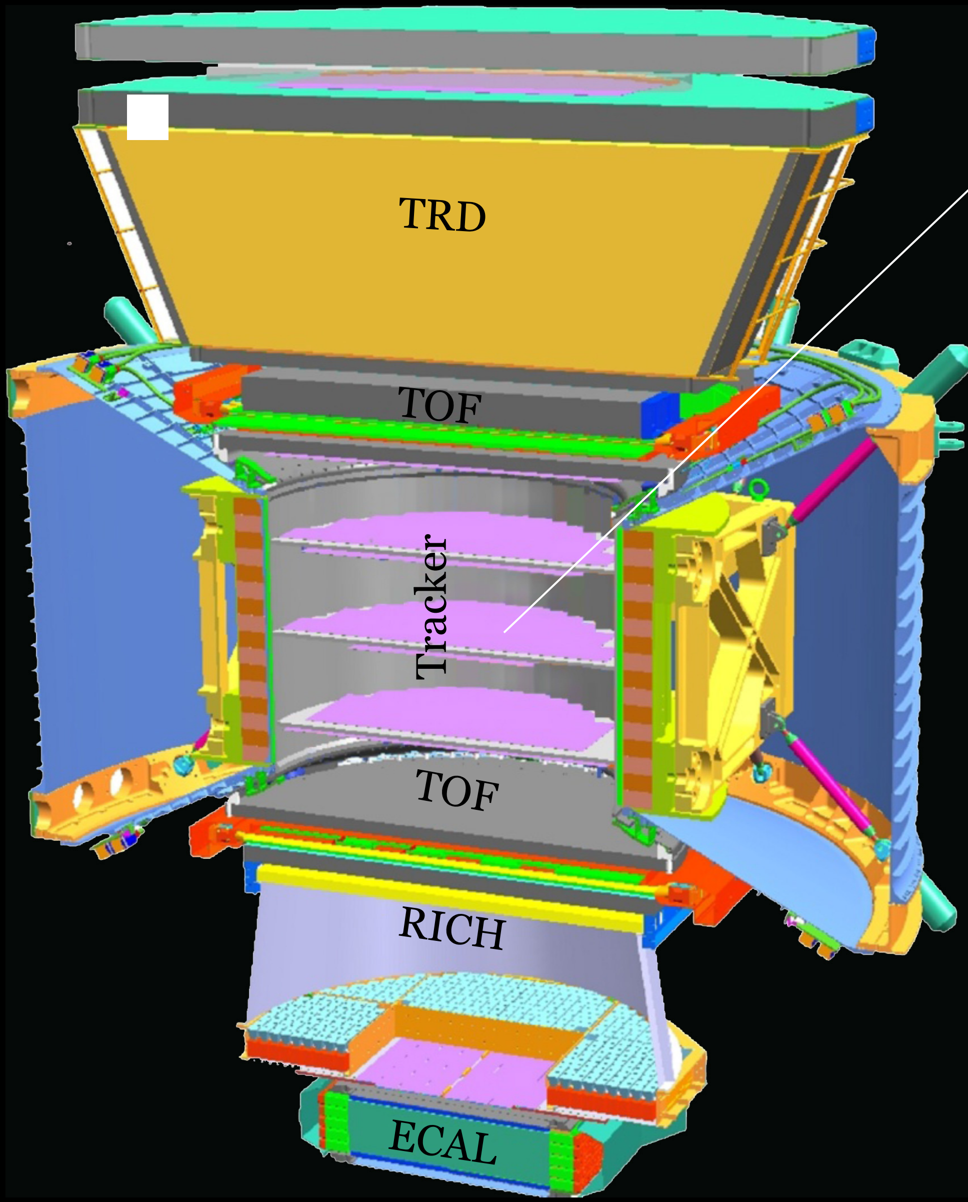
To-date >200 billion cosmic. rays have been measured by AMS: e^+, e^-, p, $\bar{p}$, nuclei, γ,...

Y. Jia, F. Donnini, Y. Chen, J. Wei, V. Formato,
F. Giovacchini, Z. Weng
Cosmic Ray session
@ TeVPA 2022

AMS-02 detector

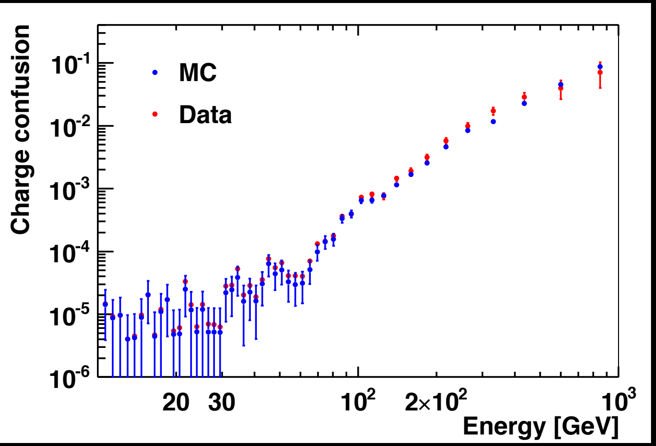


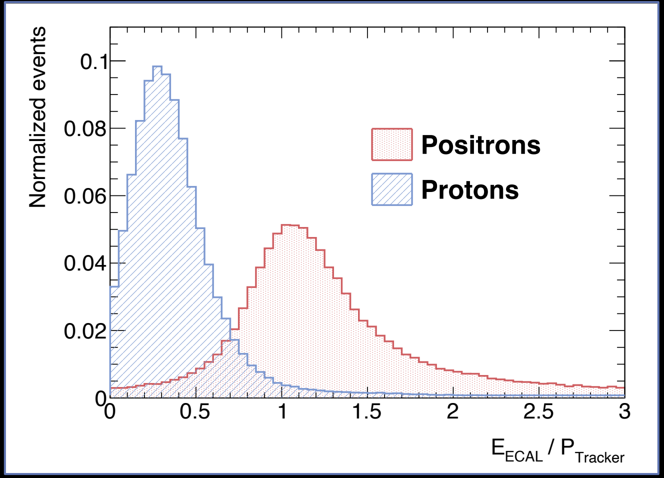
Electron measurements with AMS-02



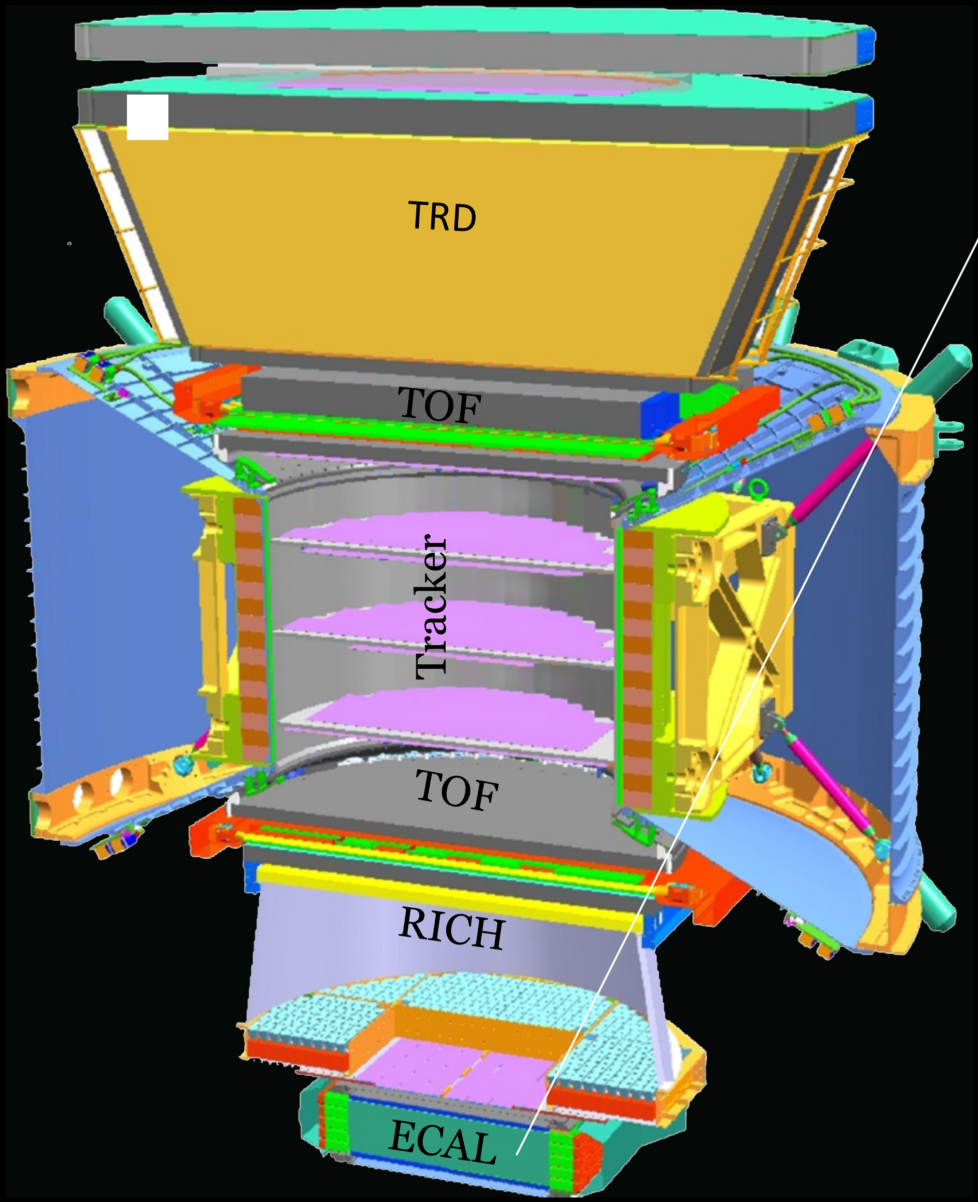
Silicon tracker and magnet distinguish between e^- and e^+ up to a few TeV using 9 layers over 3 m lever of arm

Δx: 10 μm, MDR 2 TV

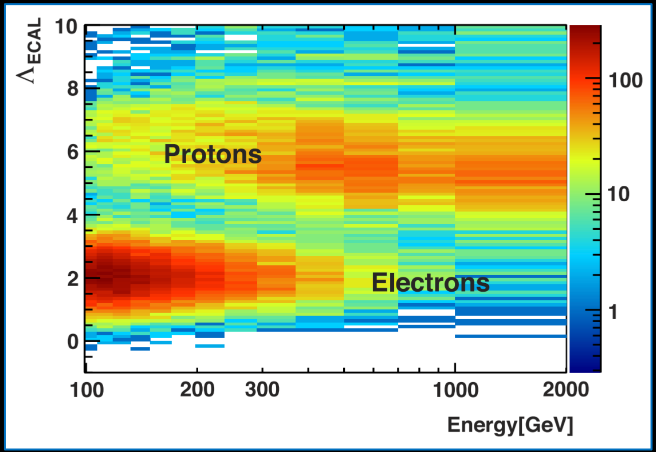


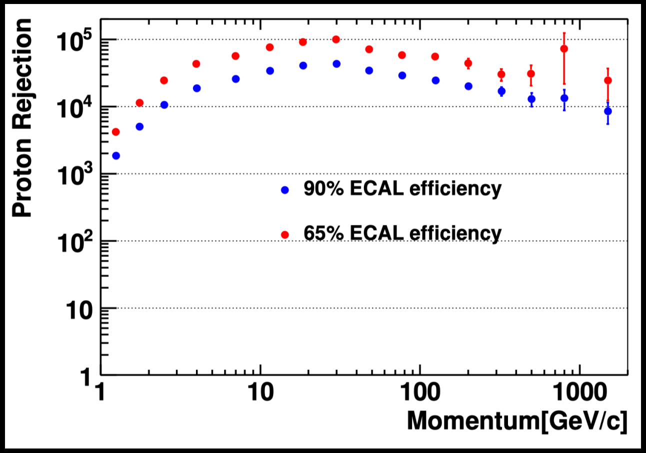


Electron measurements with AMS-02

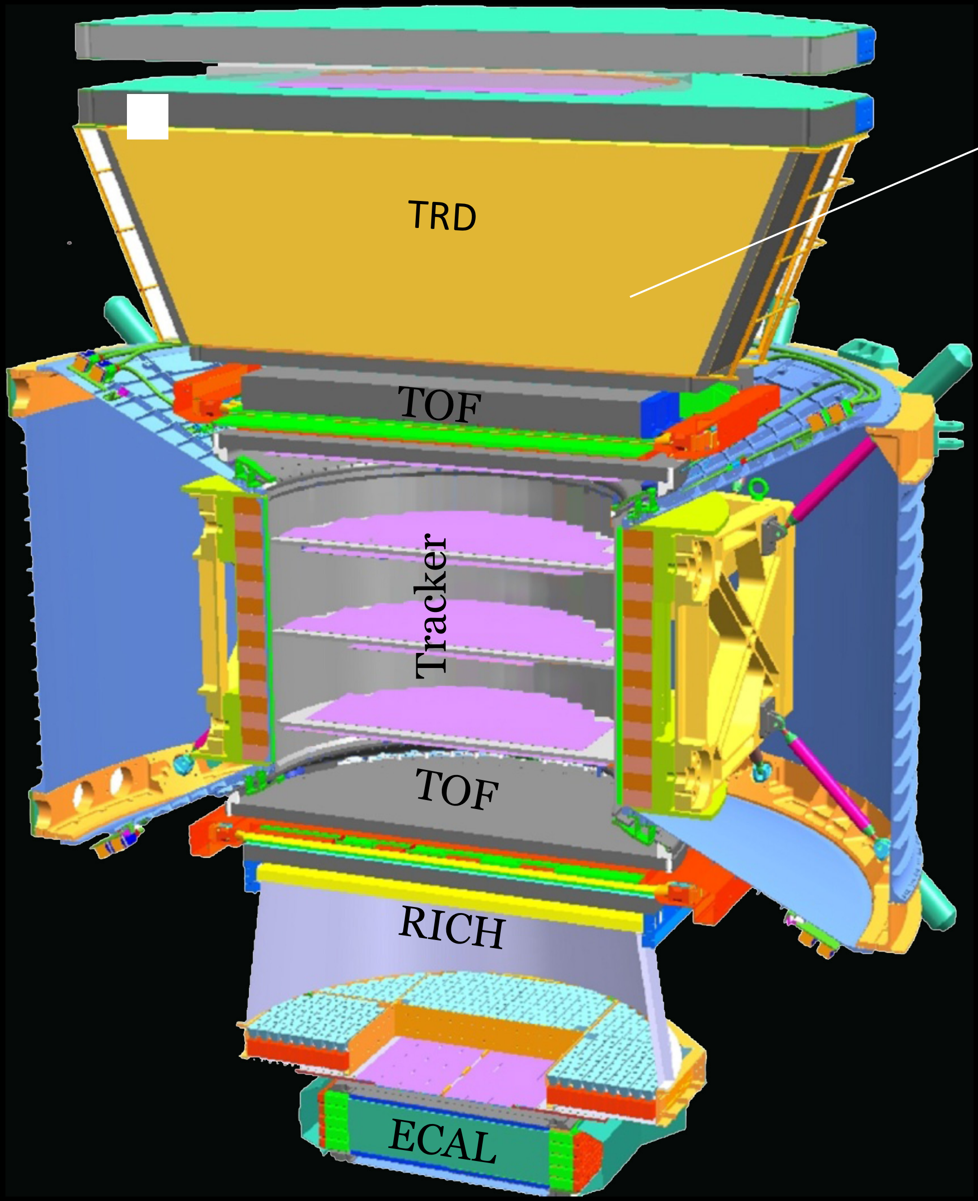


Electromagnetic Calorimeter (ECAL) provides a precision 3D measurement of energy and shower development over $17X_0$

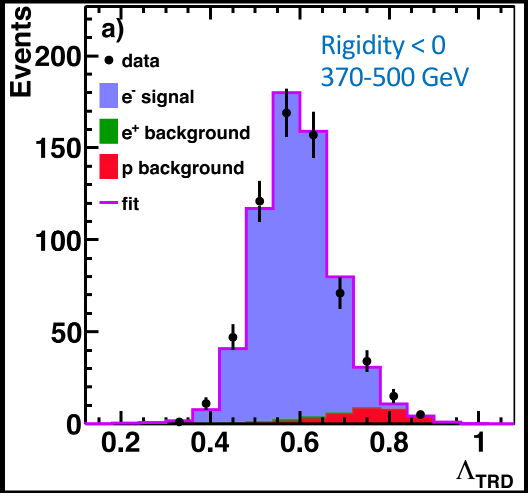


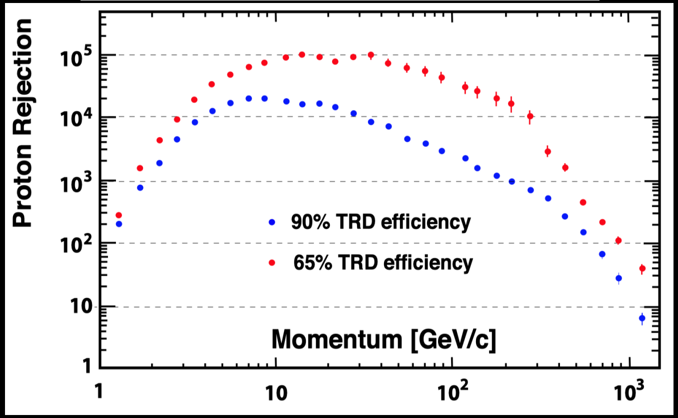


Electron measurements with AMS-02

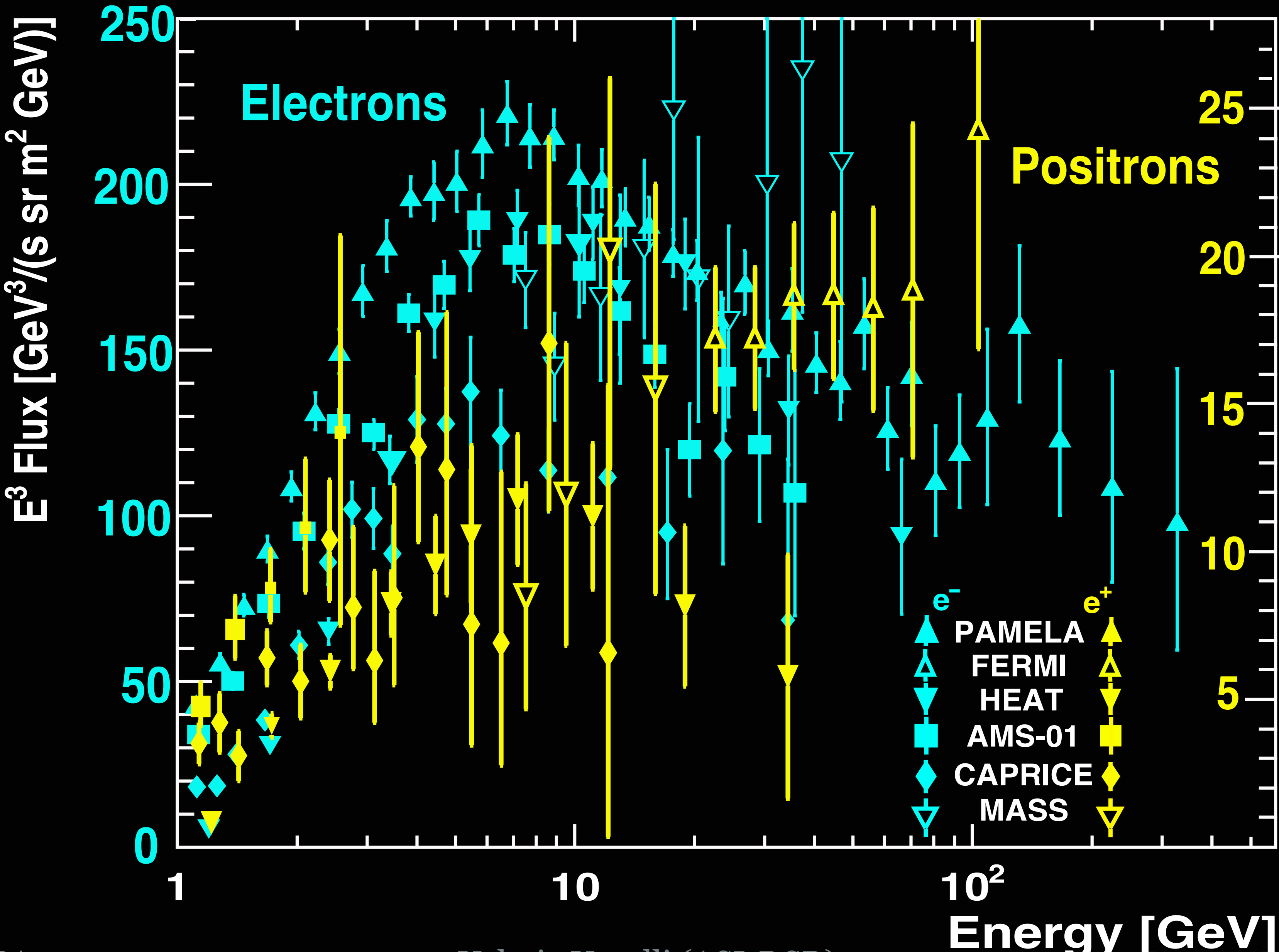


Transition Radiation Detector (TRD) separates $e^{\pm}$ from protons using transition radiation measured in 20 layers of proportional tubes.

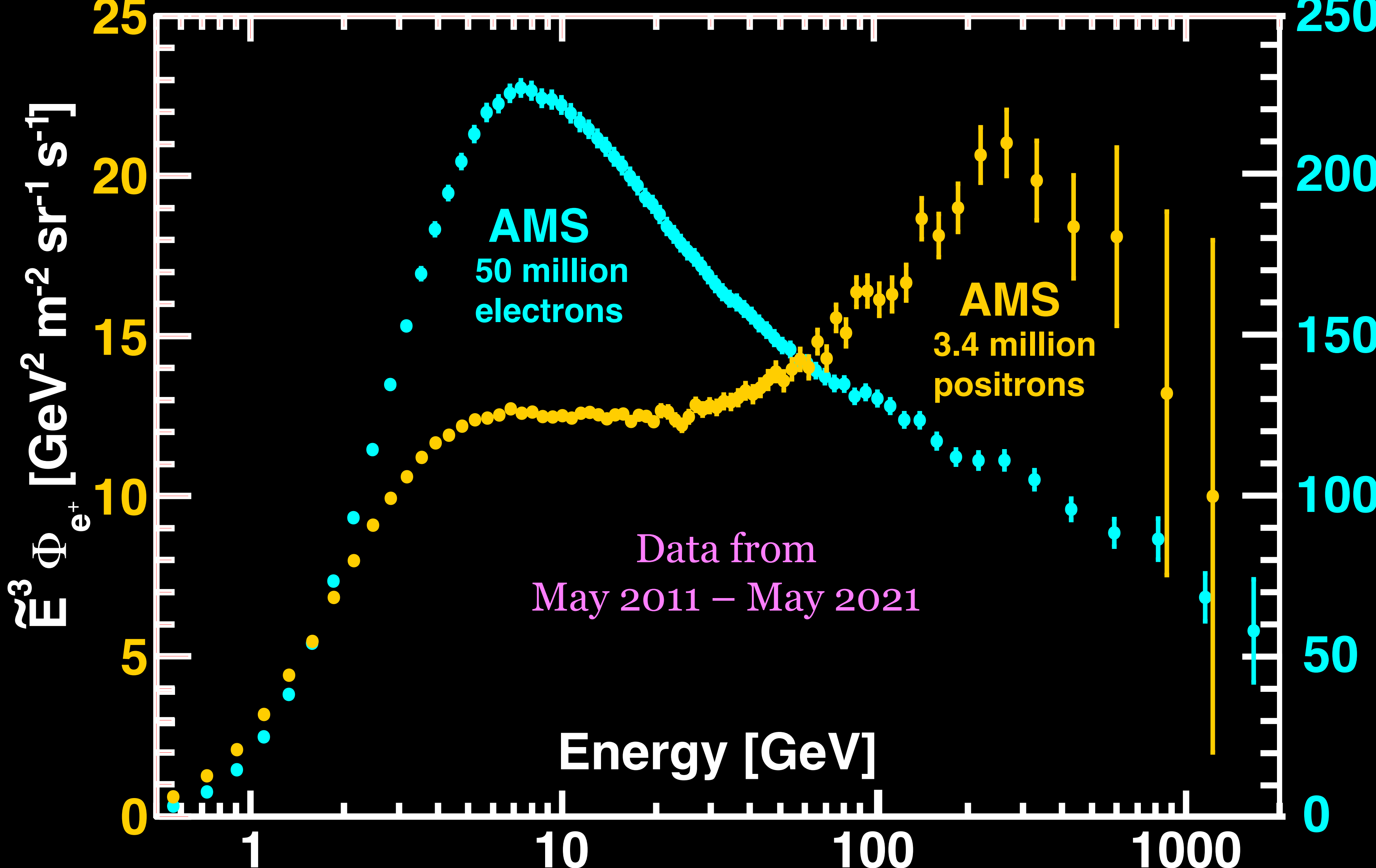




Measurements of e+/- before AMS-02



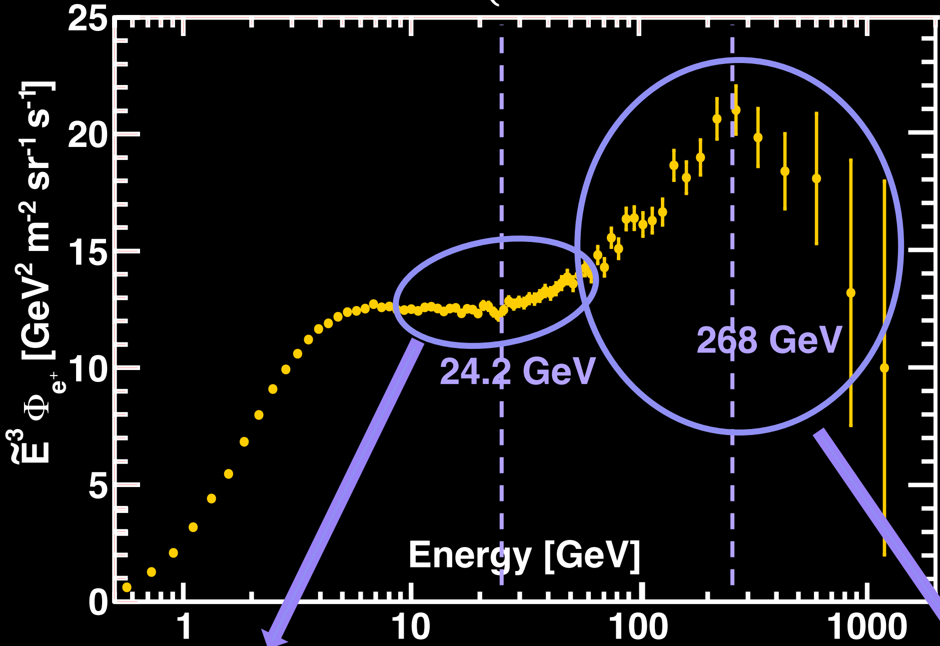
Measurements of $e^{+/-}$ with AMS-02



AMS measurement of cosmic ray positrons

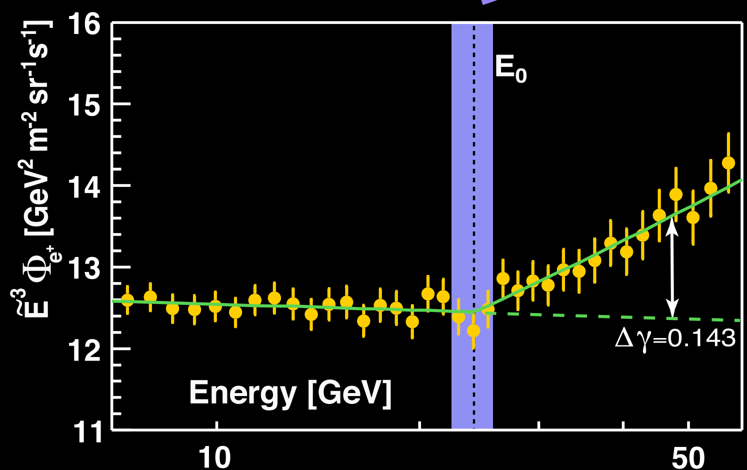
Fits of the data to $\Phi_{e^+}(E) = \begin{cases} C\boldsymbol{E}^{\gamma}, & E \le E_0; \\ C\boldsymbol{E}^{\gamma}(E/E_0)^{\Delta\gamma}, & E > E_0. \end{cases}$

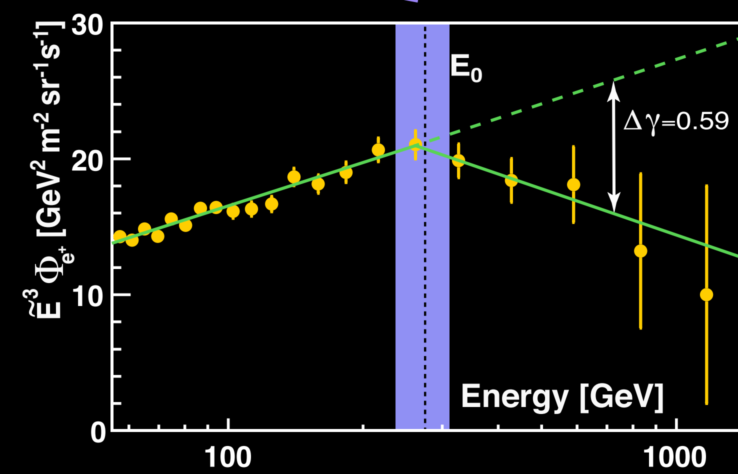
See Z. Weng,
Cosmic Ray session
@ TeVPA 2022



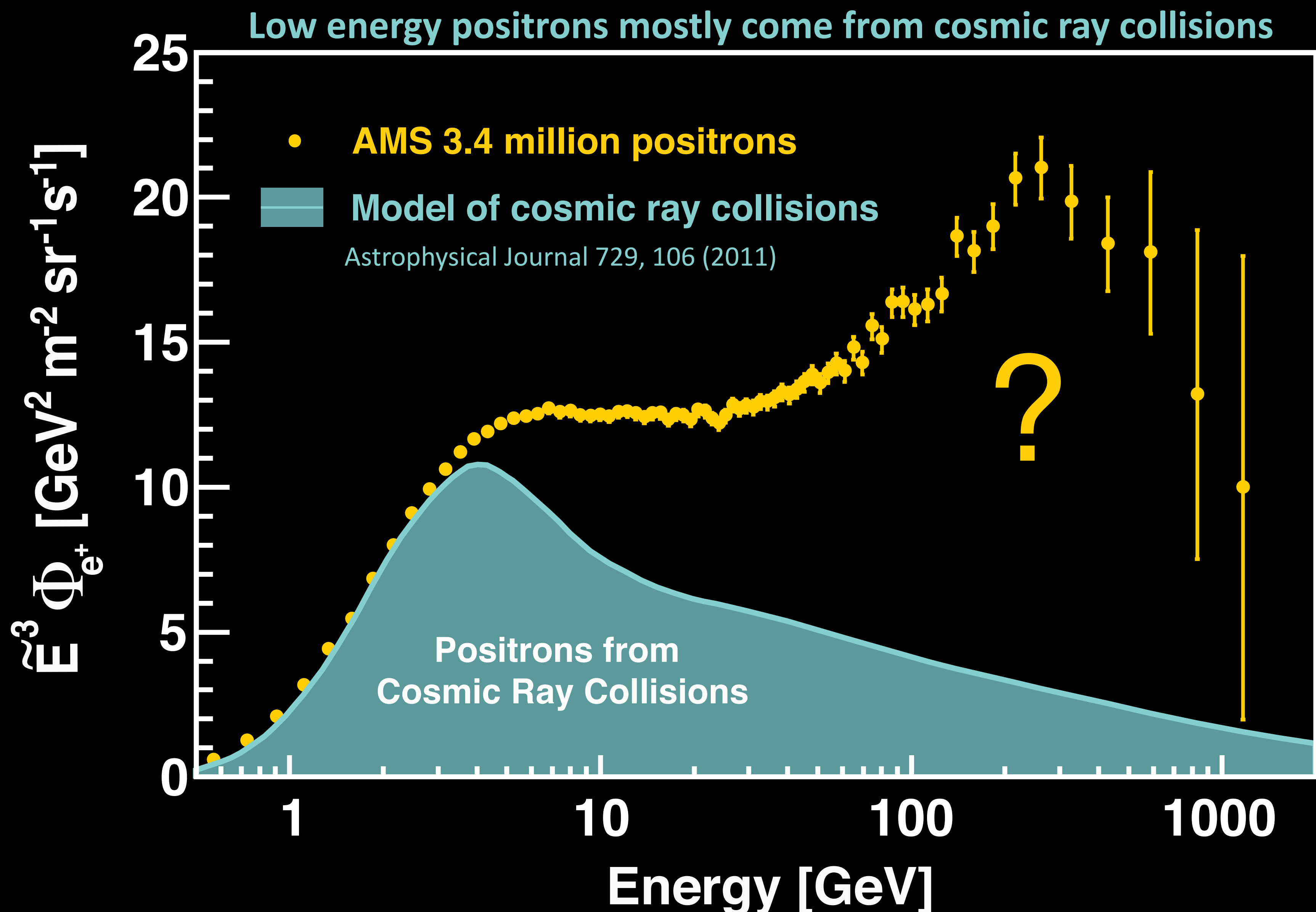
7.8σ
excess above
$E_0 = 24.2 \pm 1.1$ GeV

4.8σ
sharp drop-off at
$E_0 = 268^{+35}_{-33}$ GeV





Origin of cosmic ray positrons

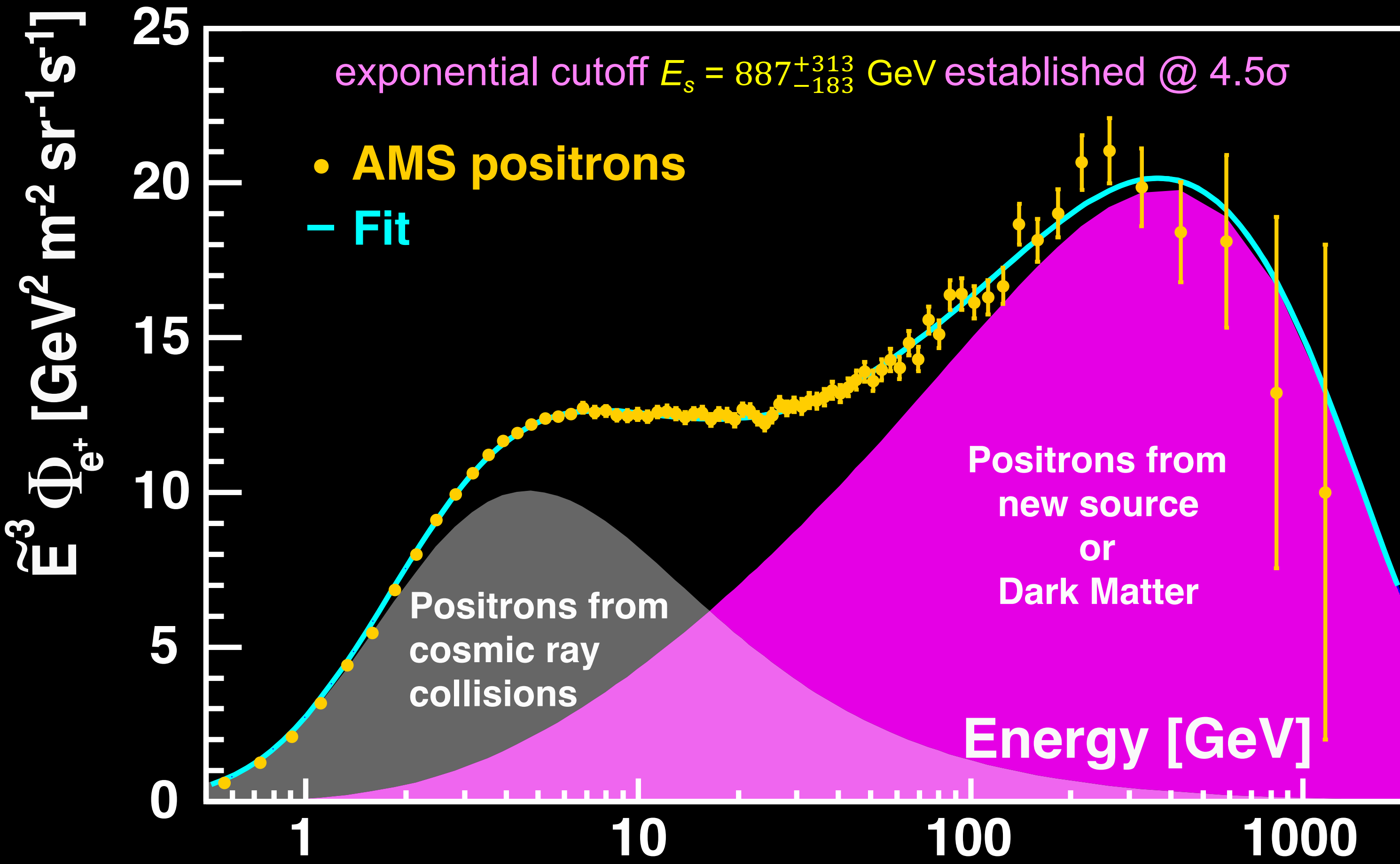


Origin of cosmic ray positrons

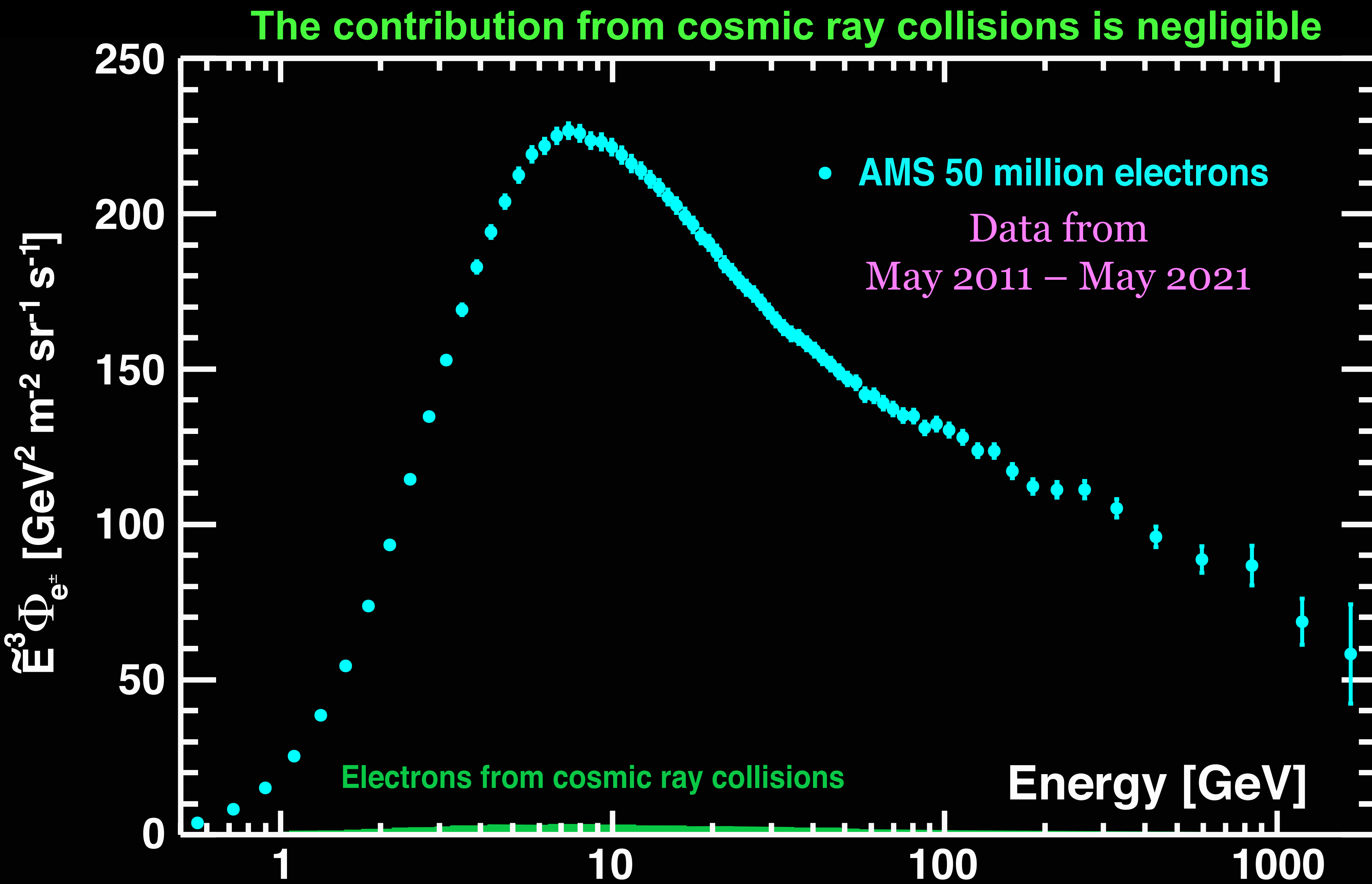
The positron flux is the sum of low-energy part from cosmic ray collisions plus a high-energy part from a new source or dark matter both with a cutoff energy E_s.

Solar — Collisions — New Source or Dark Matter

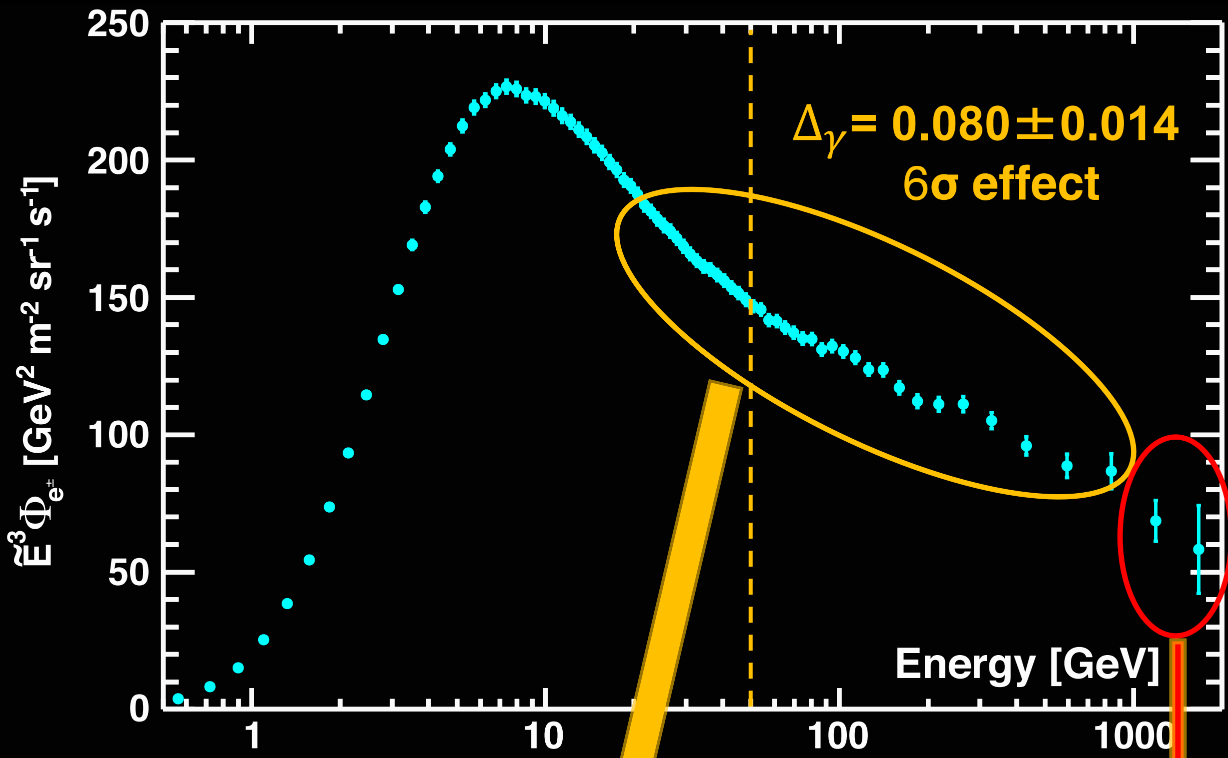
$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2}\left[C_d(\hat{E}/E_1)^{\gamma_d} + C_s(\hat{E}/E_2)^{\gamma_s}\exp(-\hat{E}/E_s)\right] \quad \hat{E} = E + \varphi_{e^+}$$



Origin of cosmic ray electrons



Origins of Cosmic Electrons



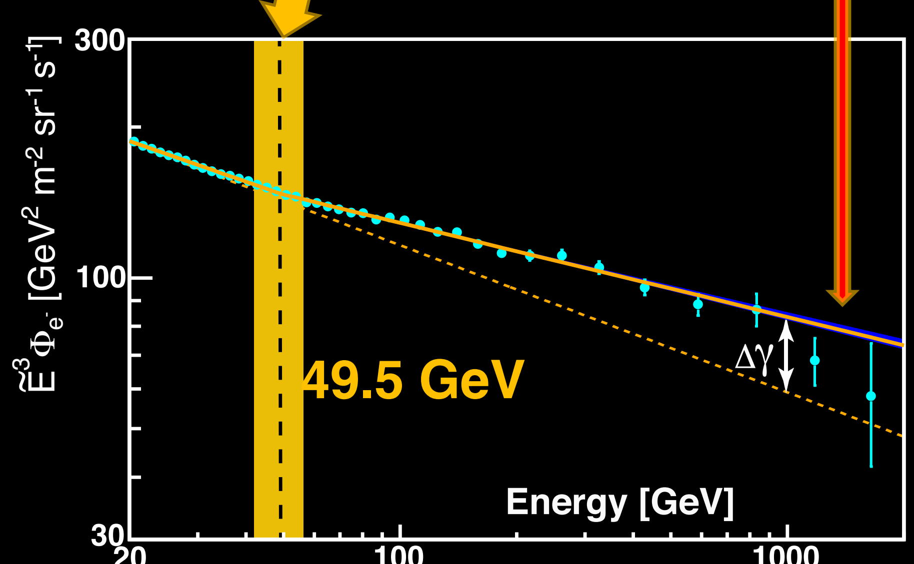
Change of behavior at ~50 GeV and at ~1 TeV

Fit to data

$$\Phi_{e^-}(E) = \begin{cases} C\boldsymbol{E}^{\gamma}, & E \leq E_0; \\ C\boldsymbol{E}^{\gamma}(E/E_0)^{\Delta_\gamma}, & E > E_0. \end{cases}$$

significant excess at

E_0 = 49.5 ± 5.6 GeV

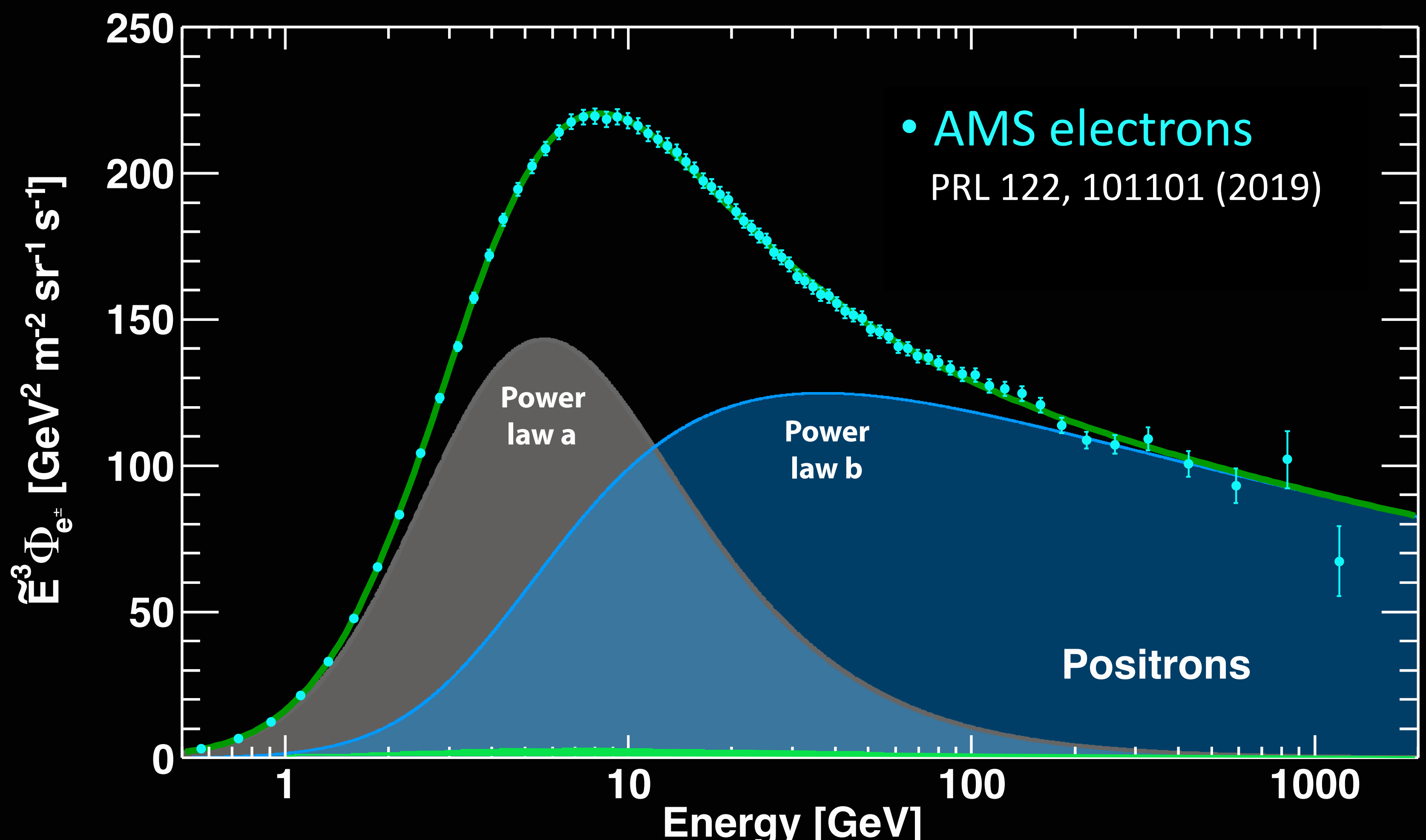


Origin of cosmic ray electrons

The electron flux description by two power law functions is disfavored:

$$\Phi_{e^-}(E) = S(E)\left[C_a(\hat{E}/E_a)^{\gamma_a} + C_b(\hat{E}/E_b)^{\gamma_b}\right]$$

Solar & low-energy | Power law *a* | Power law *b*

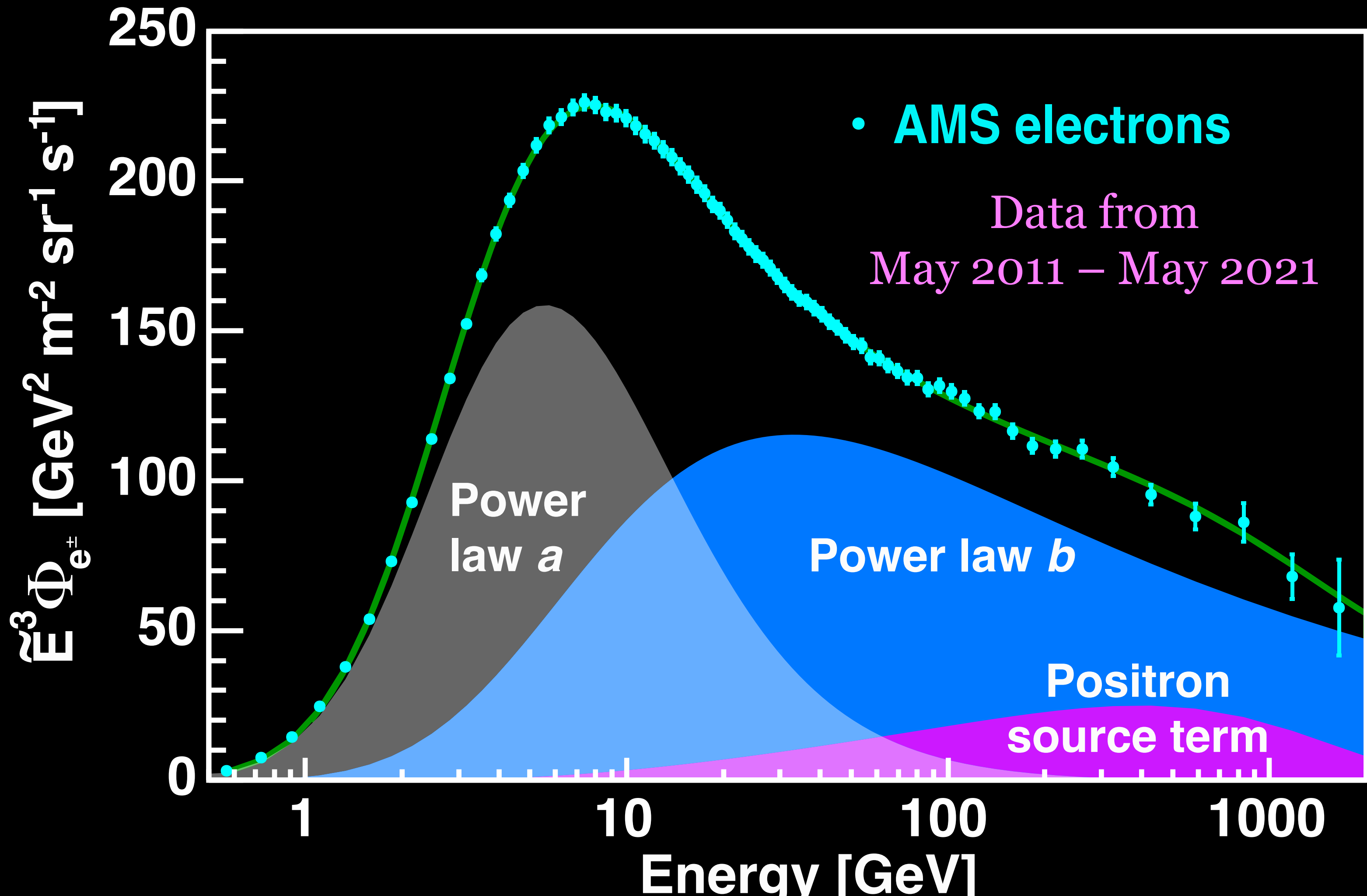


Origin of cosmic ray electrons

$$\Phi_{e^-}(E) = S(E)\left[C_a(\hat{E}/E_a)^{\gamma_a} + C_b(\hat{E}/E_b)^{\gamma_b} + f_s\, C_s^{e^+}(\hat{E}/E_2)^{\gamma_s^{e^+}} \exp(-E/E_s^{e^+})\right]$$

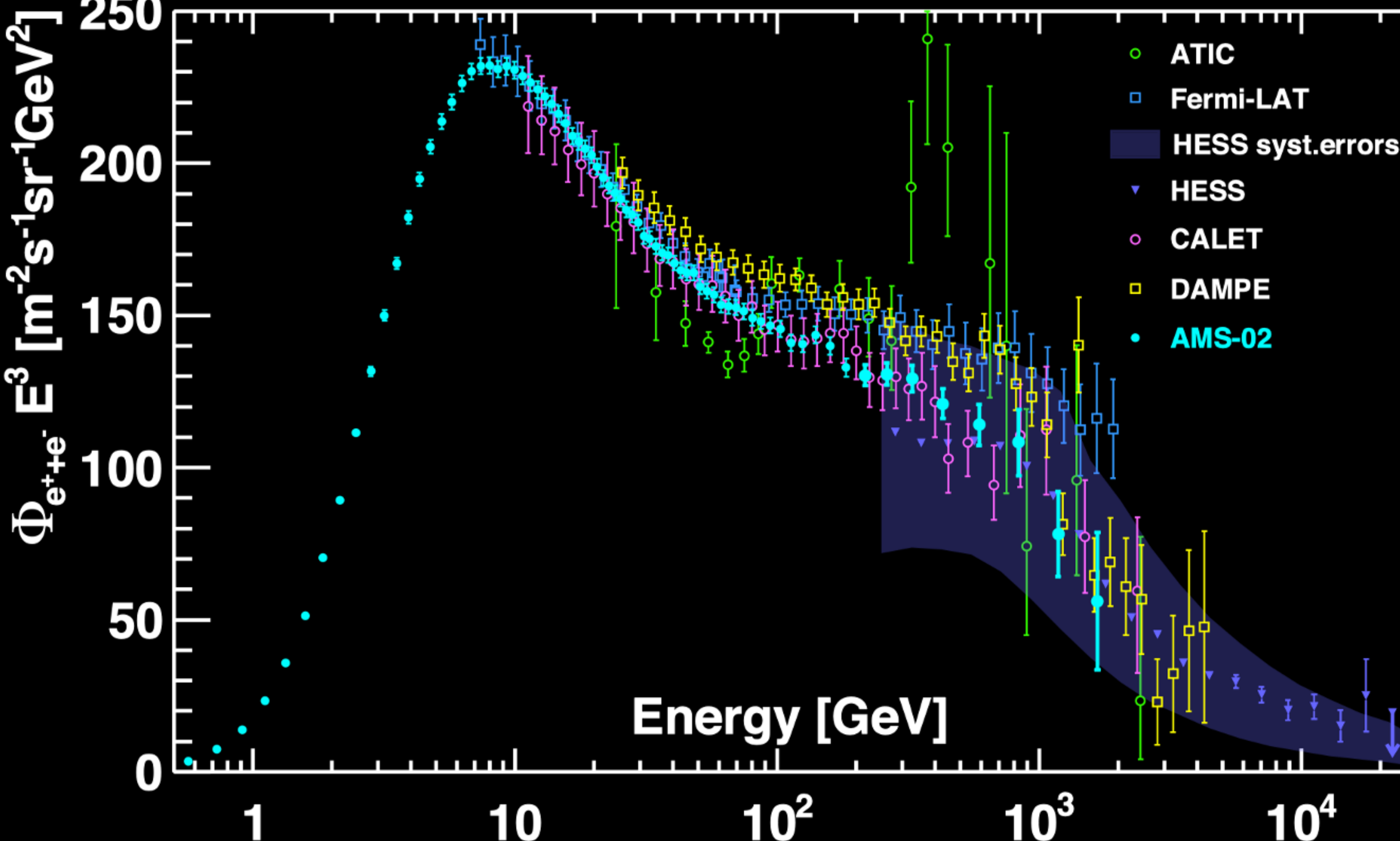
Fit result $f_s = 1.30 \pm 0.61$

Electron spectrum favors the contribution of the **positron-like source term (@95%C.L.)**



Comparison with other space and ground experiments

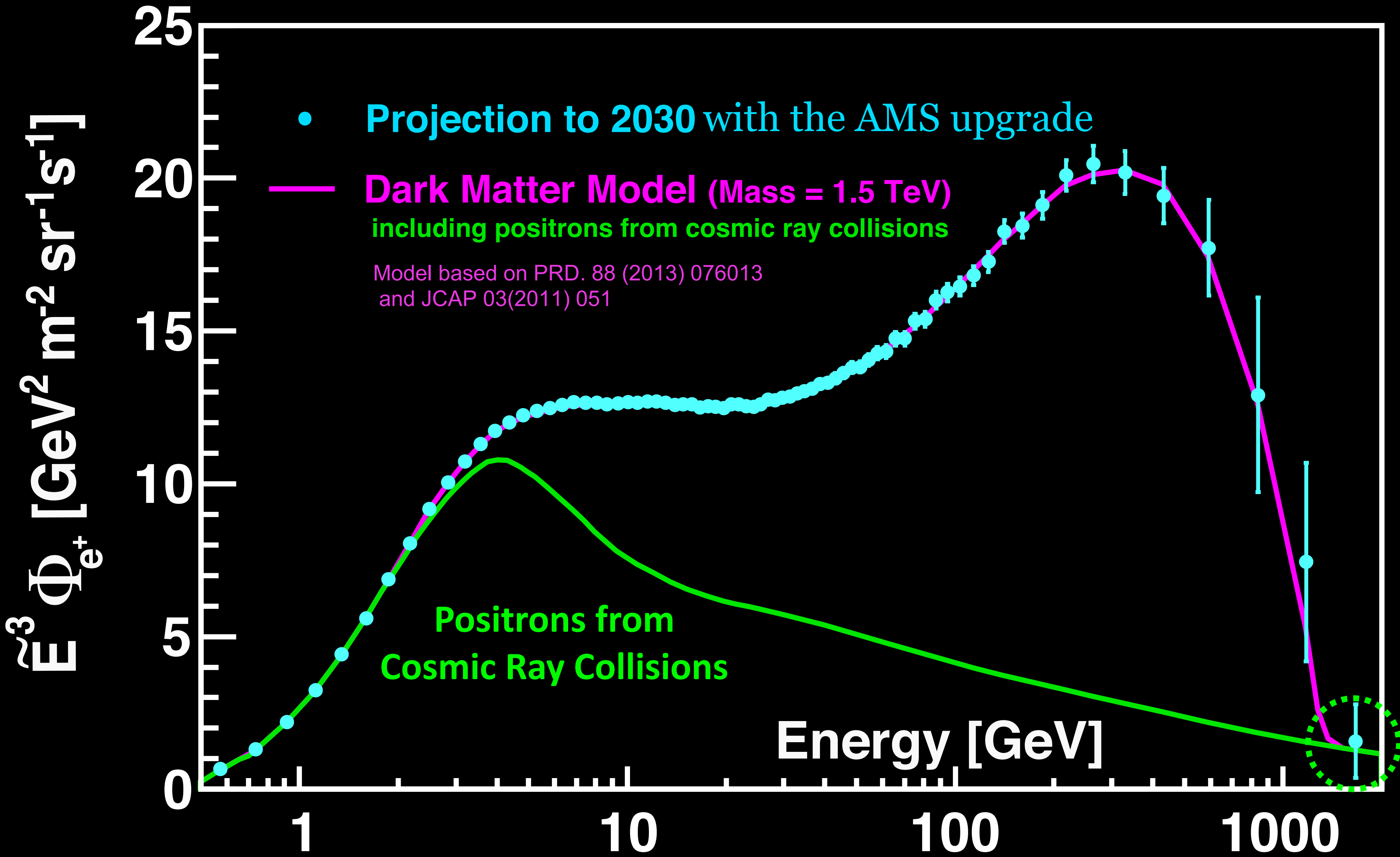
Phys.Rept. 894 (2021) 1-116, 7 years of data



CALET and HESS results are in agreement with the AMS measurements

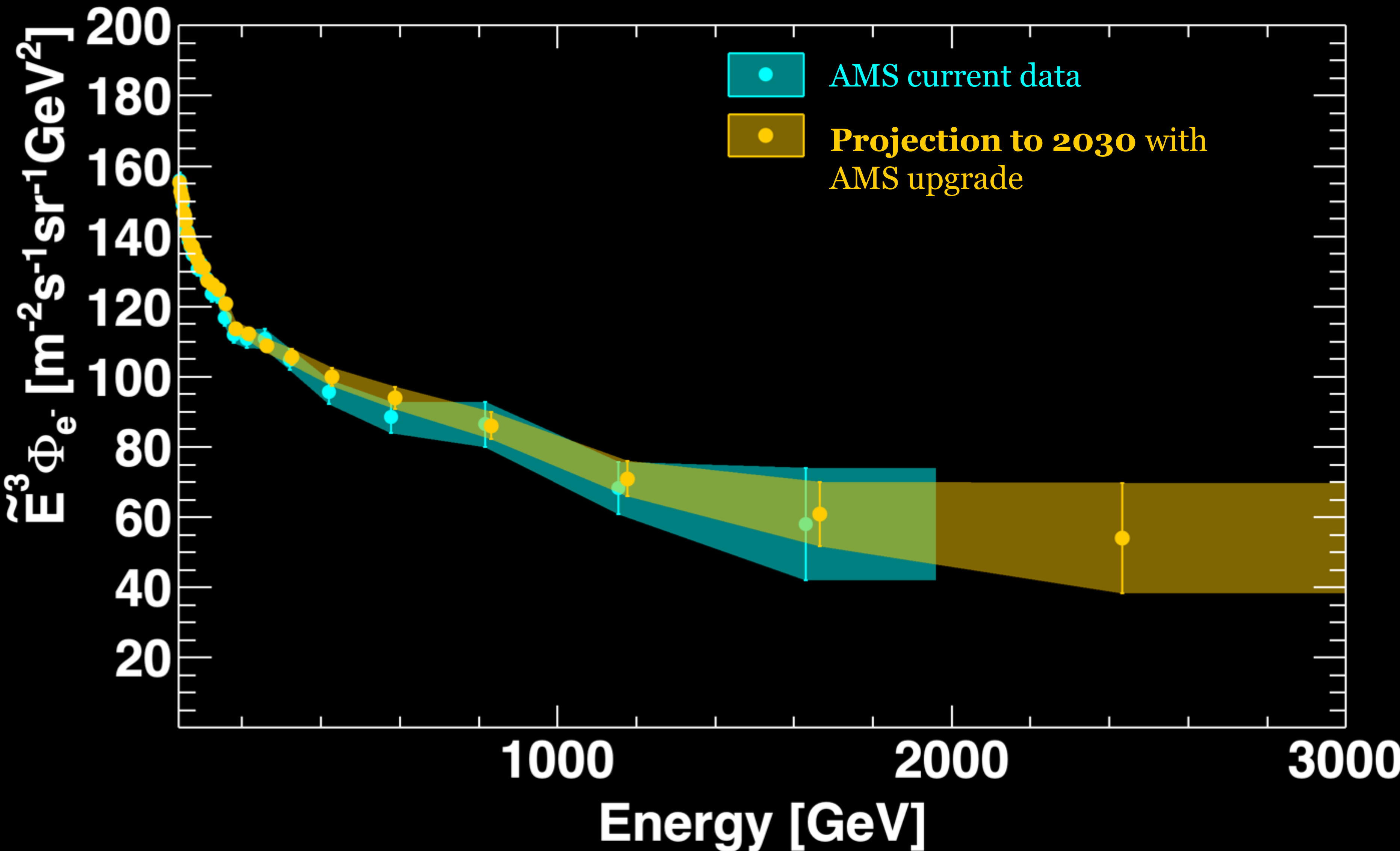
Physics of cosmic ray positrons to 2030

AMS will provide the definitive answer on the nature of the excess

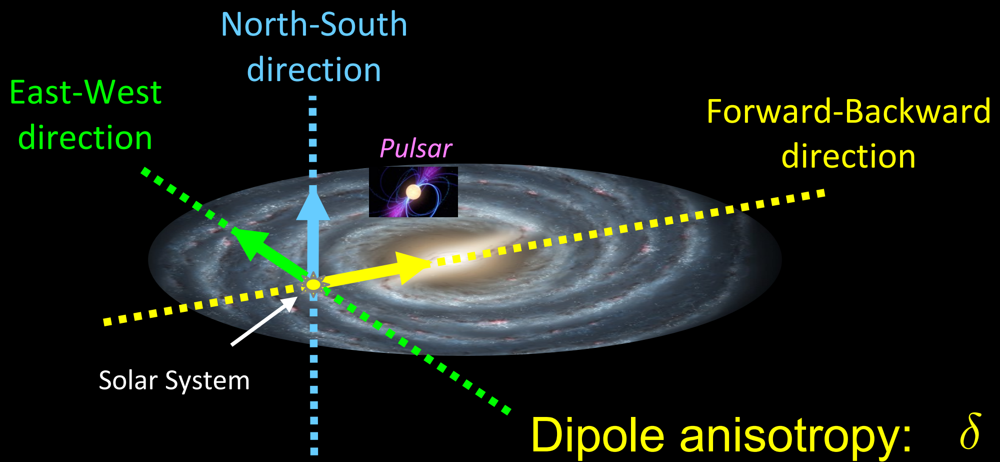


Physics of cosmic ray electrons to 2030

Establish the existence of the charge symmetric source term at high energies at 4σ CL

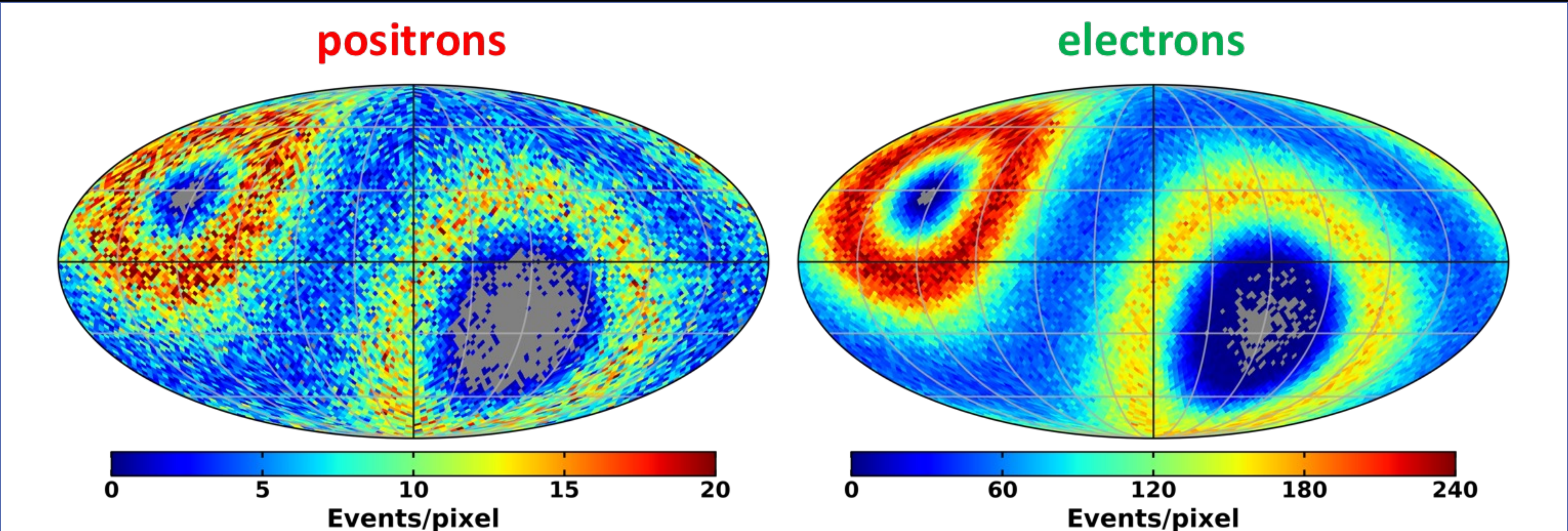


Electron and Positron Anisotropies



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



Currently at 95% C.L.: positrons: $\delta < 0.0150$

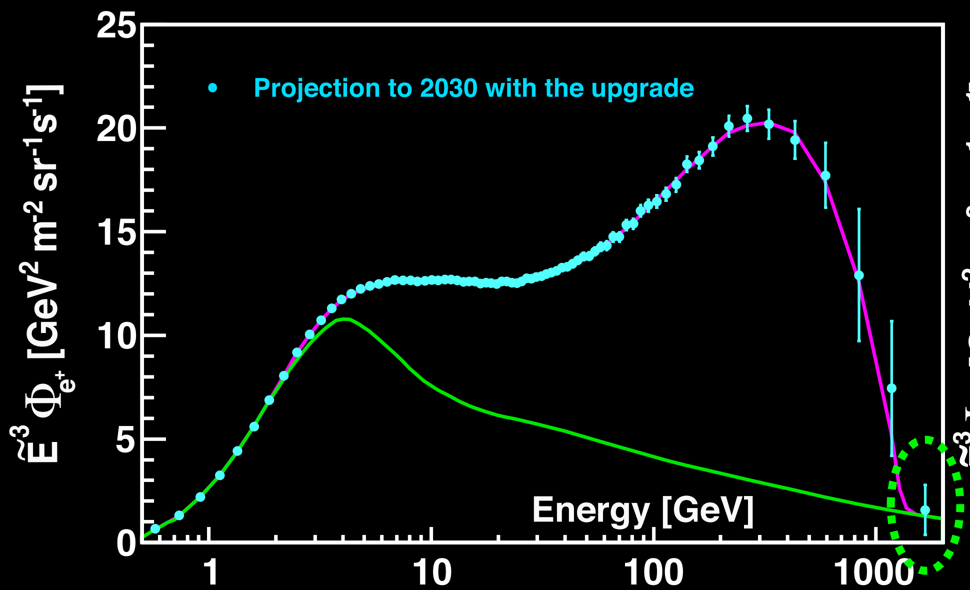
for $16<E<500$ GeV electrons: $\delta < 0.0034$

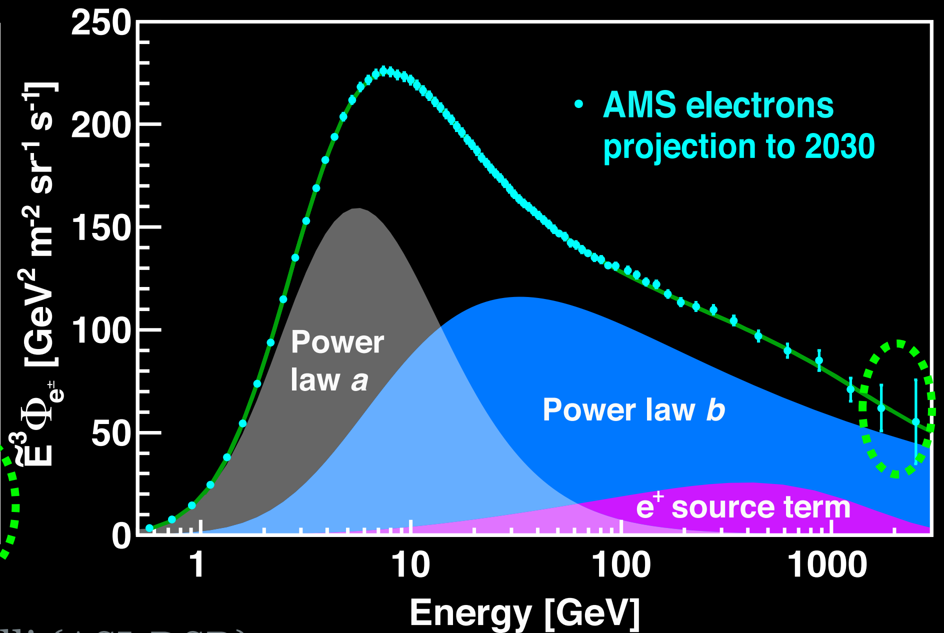
Conclusions

Positron spectrum requires an additional source of high energy positrons, not explained by ordinary CR collisions.

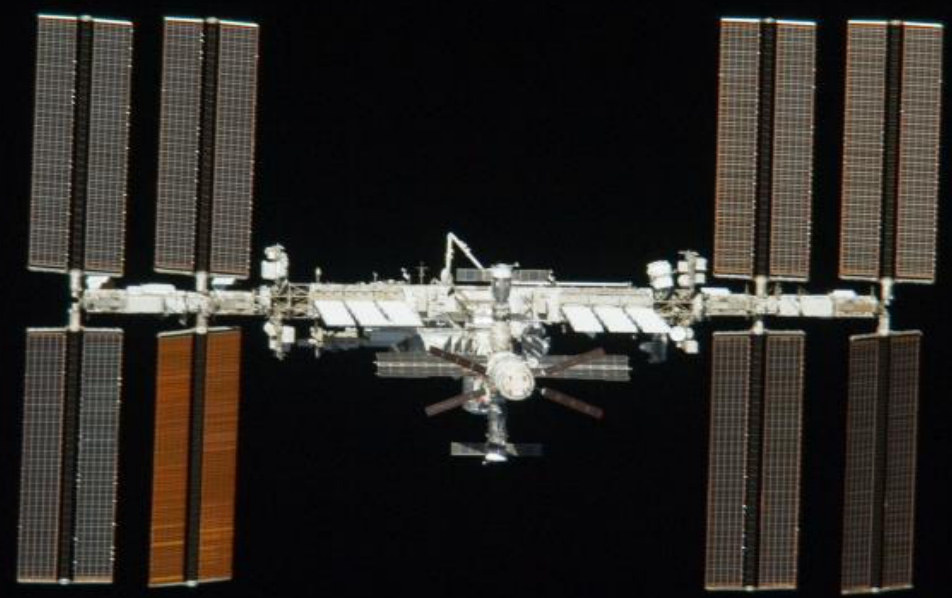
Electron spectrum shows complex behavior that can be best described by the sum of two power law functions and the contribution of the positron-like source term.

Significance of this observation is 2σ at present. More data is needed to establish the existence of charge-symmetric positron-like source term at highest electron energies





There is no other magnetic spectrometer in space in the foreseeable future.



By collecting data through the lifetime of ISS AMS should be able to determine the origin of the observed unexpected phenomena.