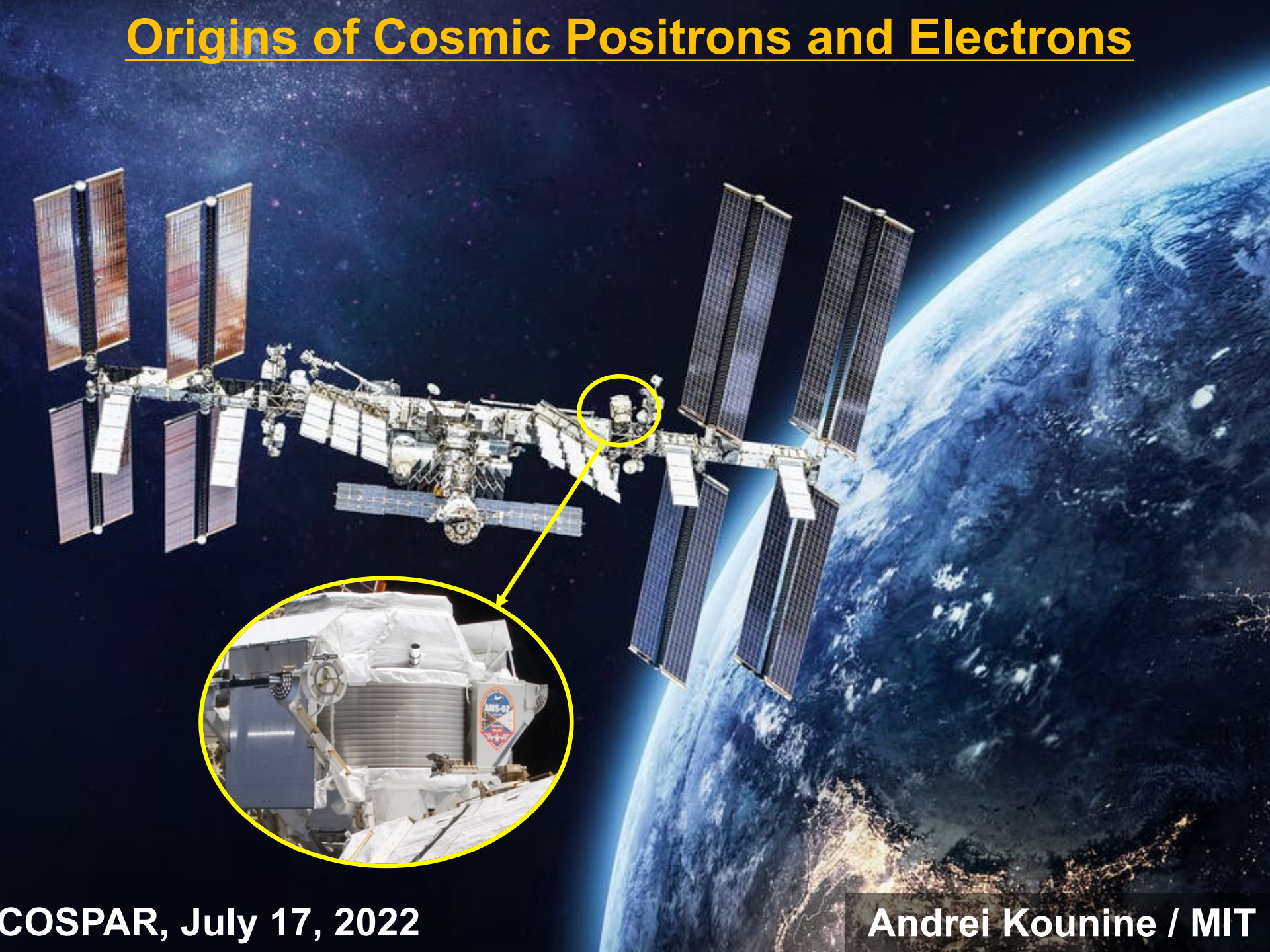


Origins of Cosmic Positrons and Electrons



COSPAR, July 17, 2022

Andrei Kounine / MIT

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

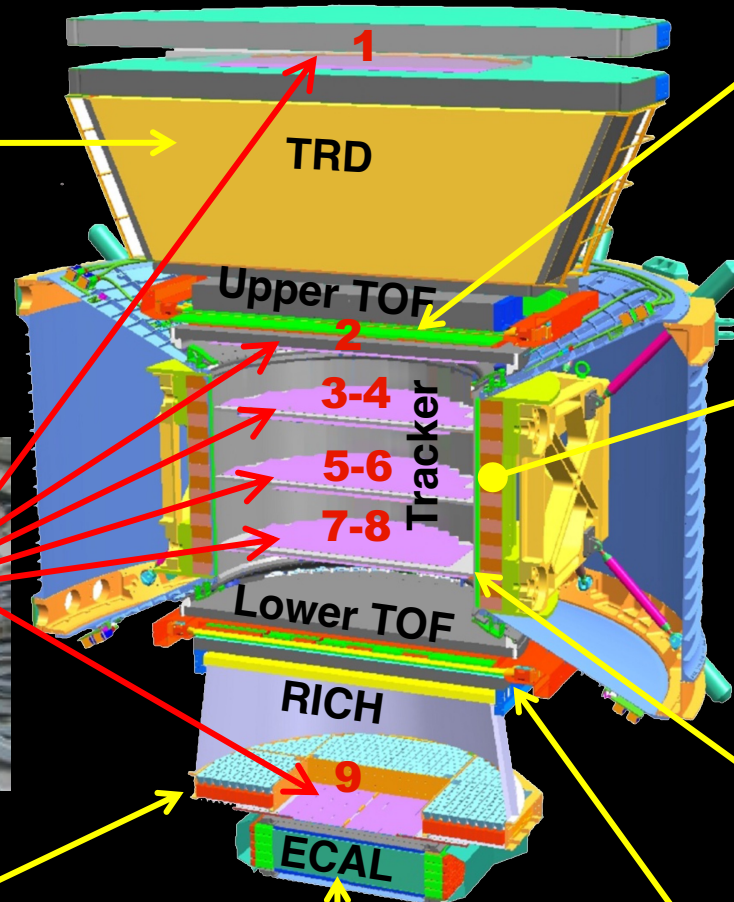
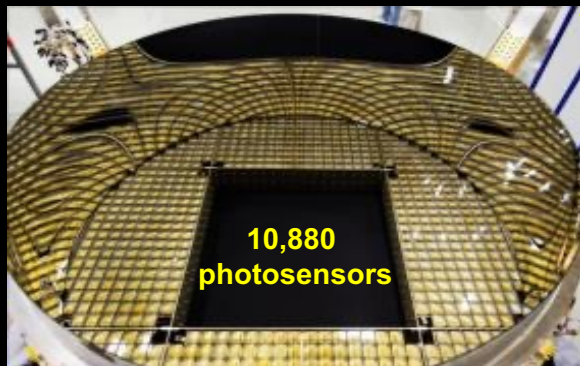
Transition Radiation Detector (TRD)
identify e^+ , e^-



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 $\pm Z$, P



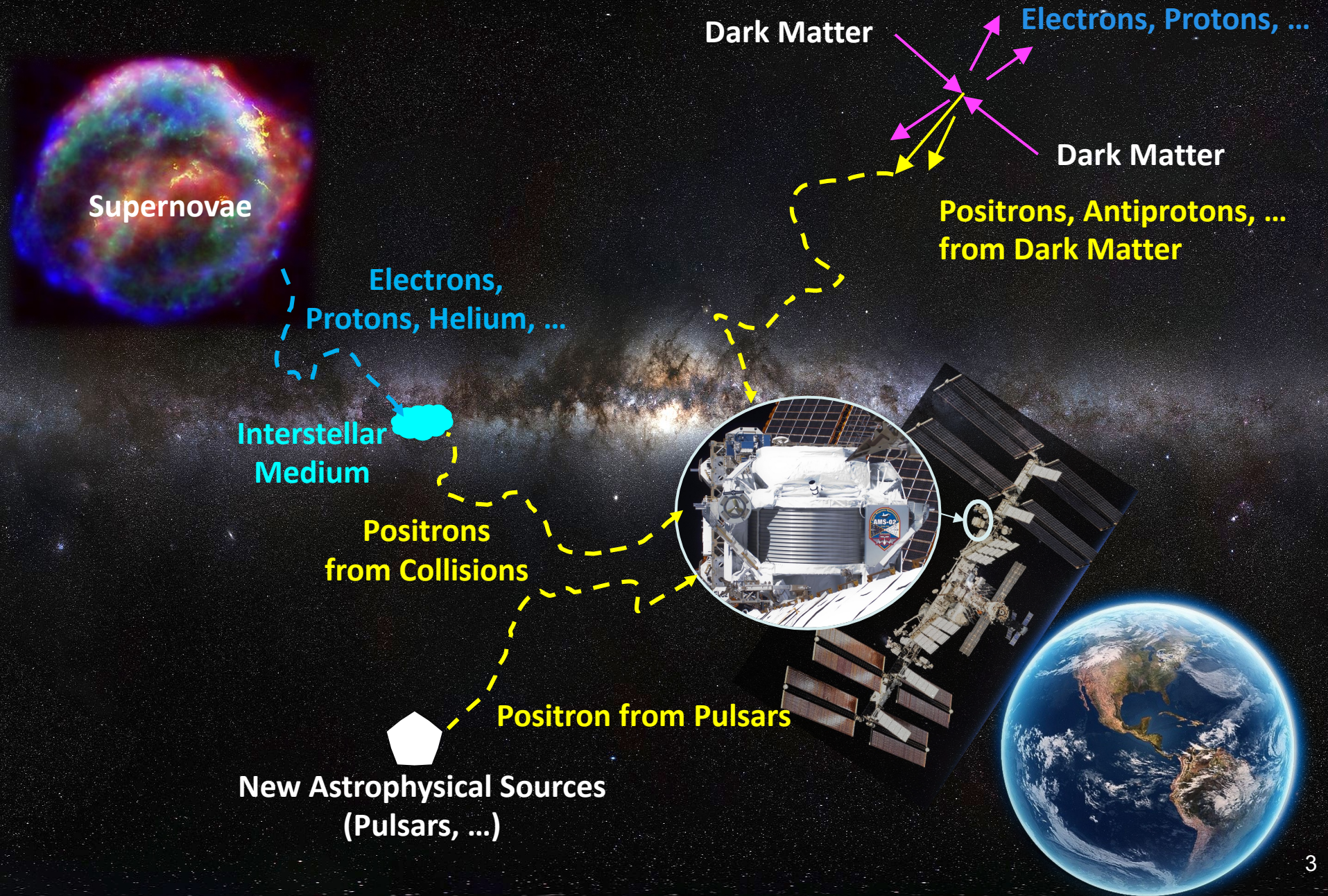
Anticoincidence Counters (ACC)
reject particles from the side



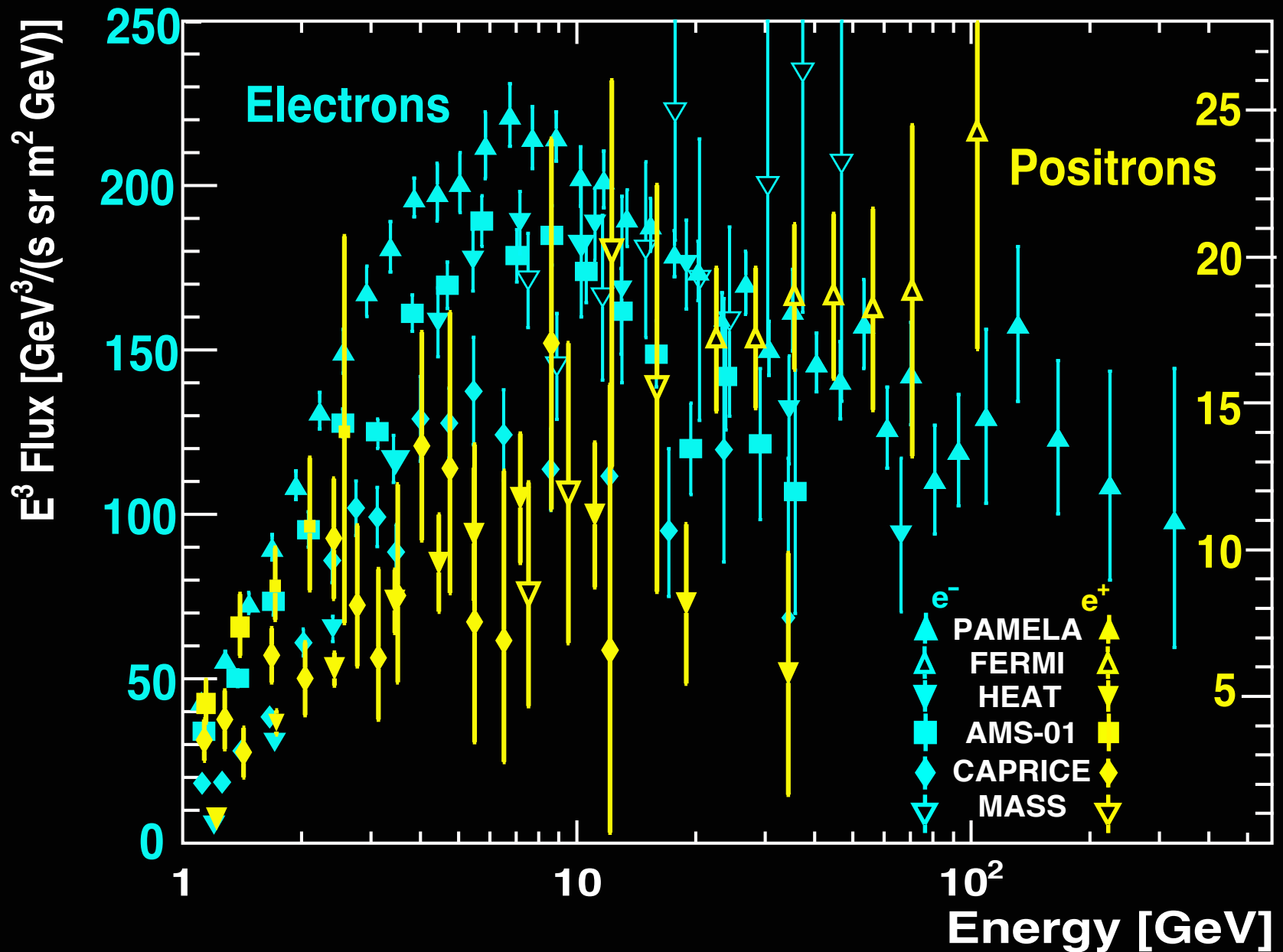
Lower TOF measure Z , E



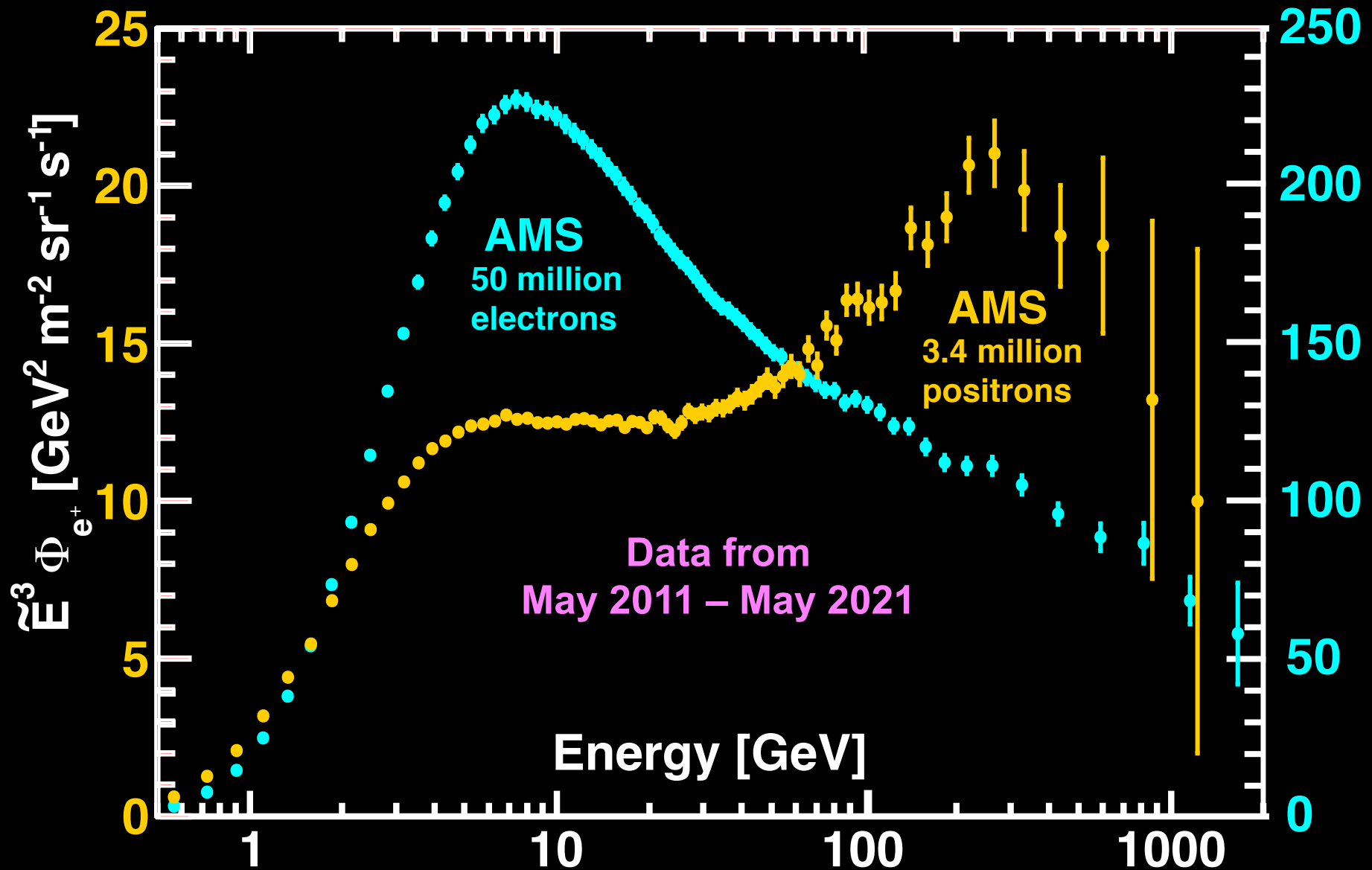
Latest Physics Results from AMS: Study of Positrons & Electrons



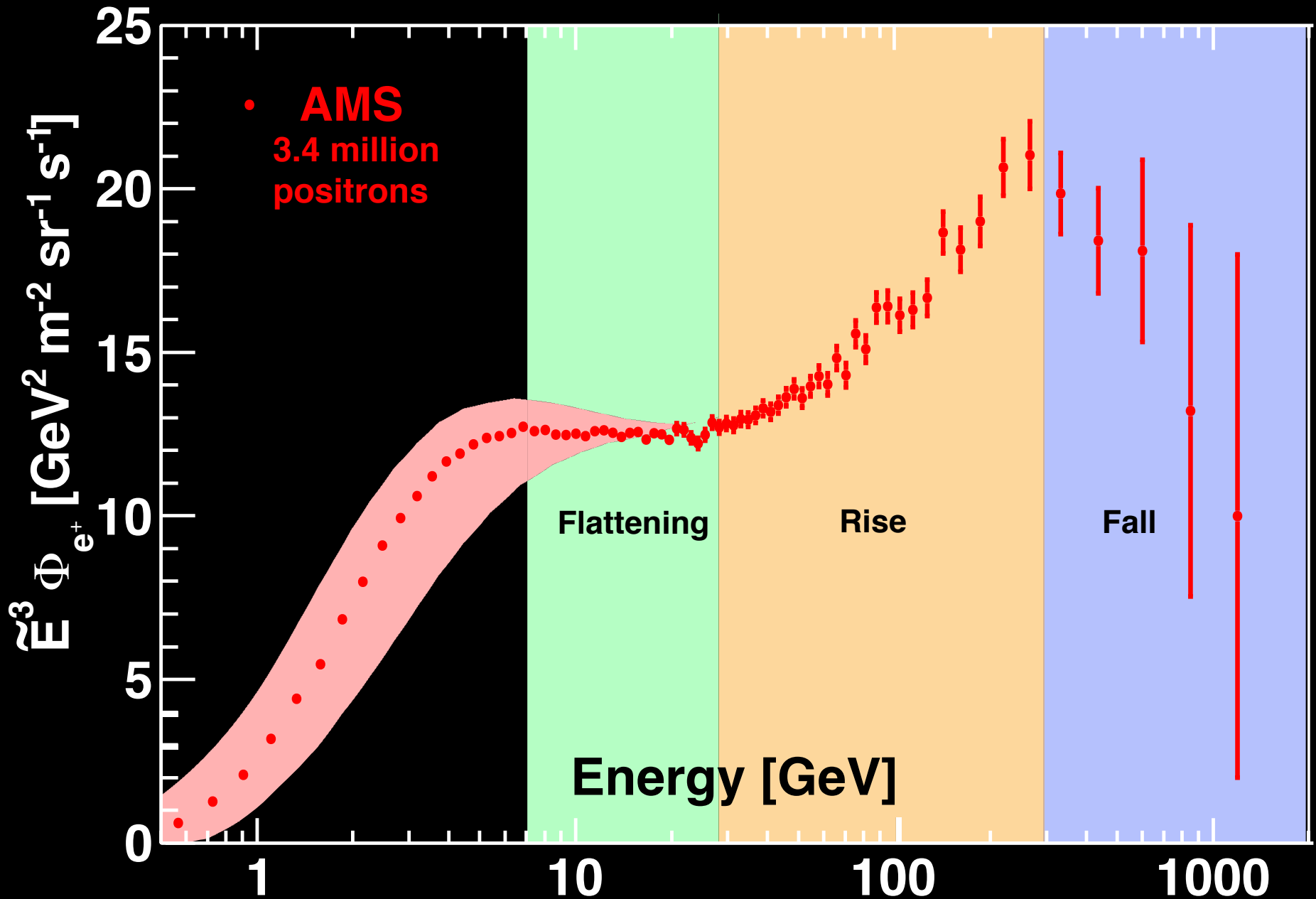
Measurements of positrons and electrons before AMS



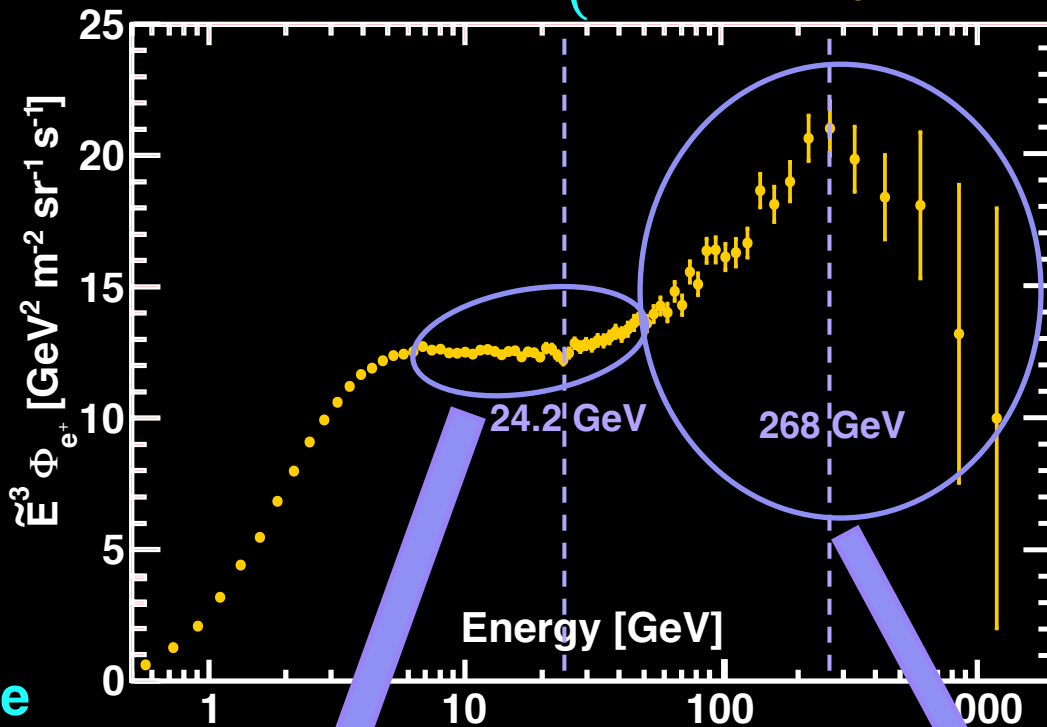
Latest Physics Results from AMS: Study of Positrons & Electrons



Towards understanding the origin of cosmic ray positrons



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



7.8 σ

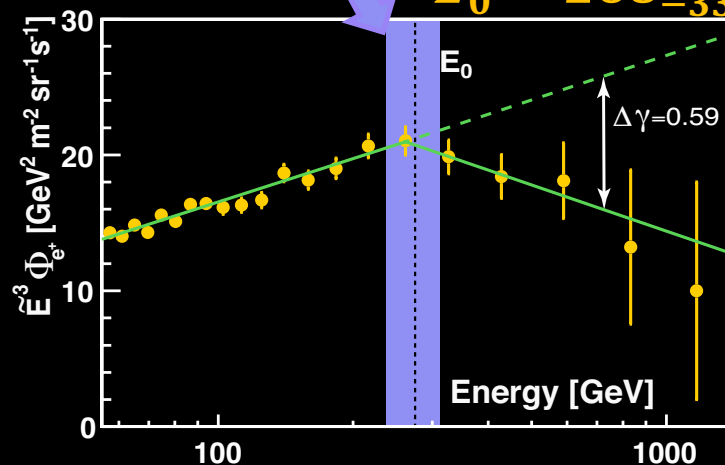
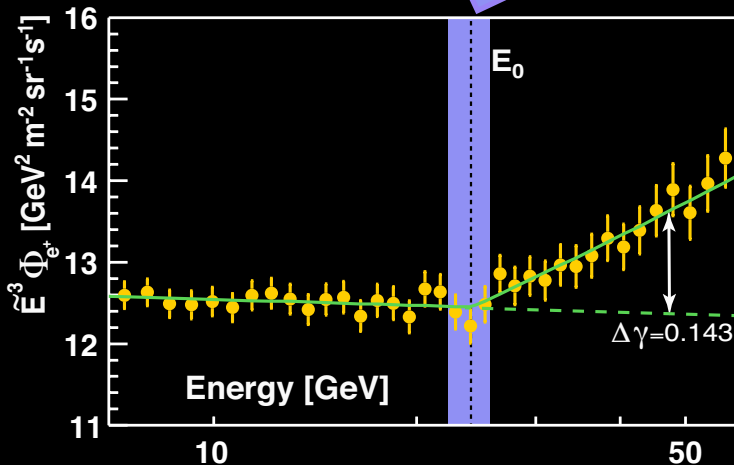
excess above

$E_0 = 24.2 \pm 1.1$ GeV

4.8 σ

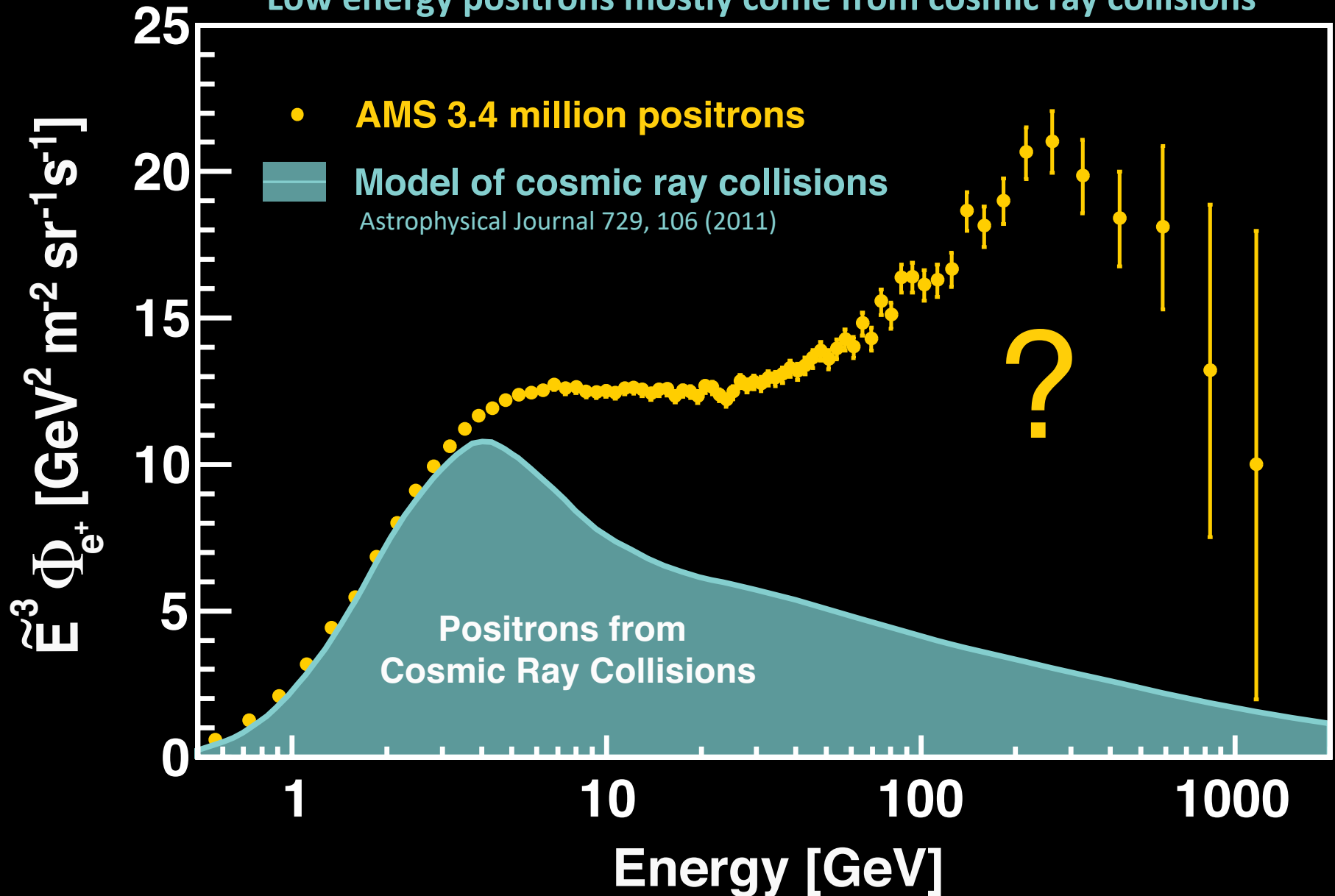
sharp drop-off at

$E_0 = 268^{+35}_{-33}$ GeV



The Origin of Positrons

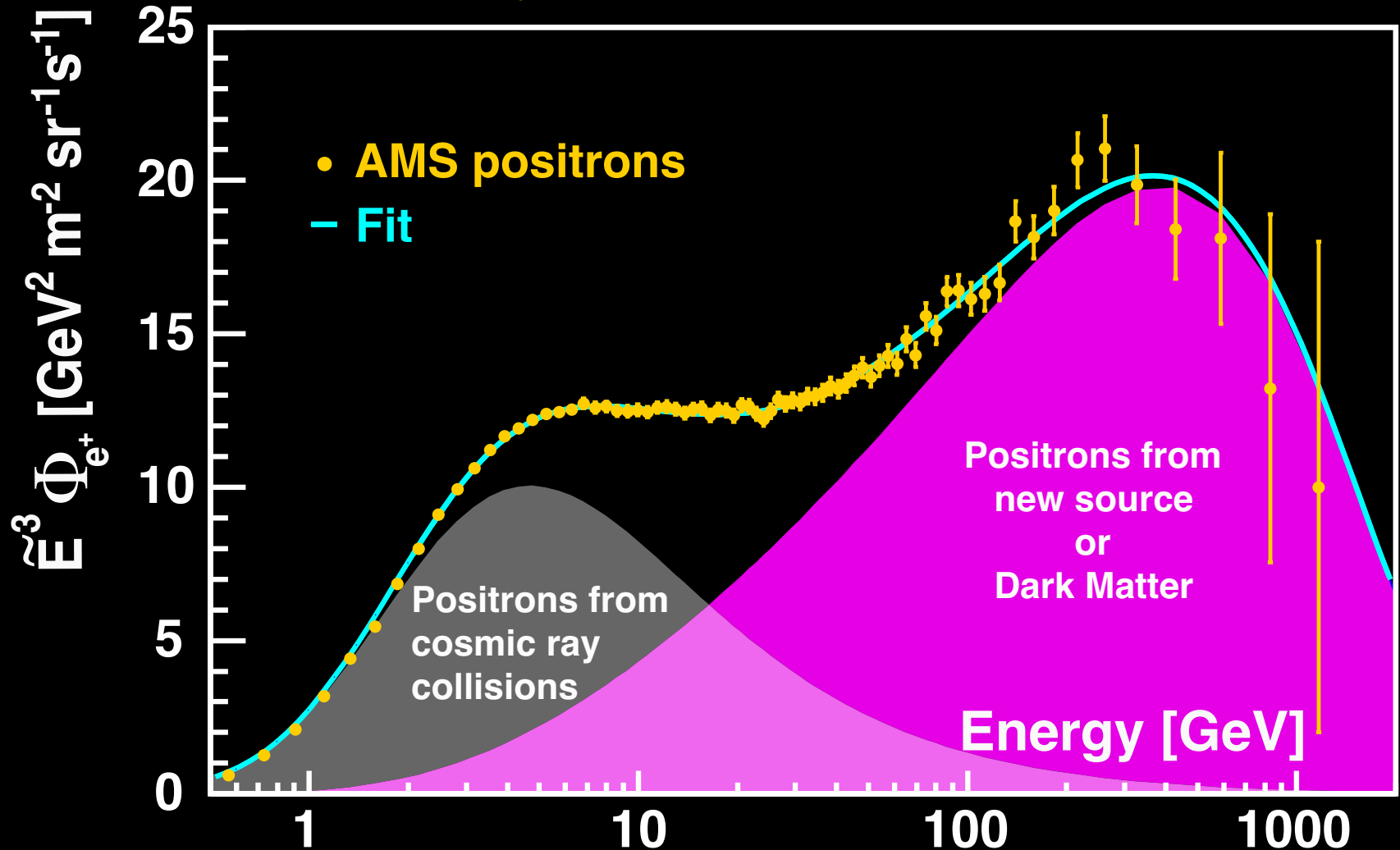
Low energy positrons mostly come from cosmic ray collisions



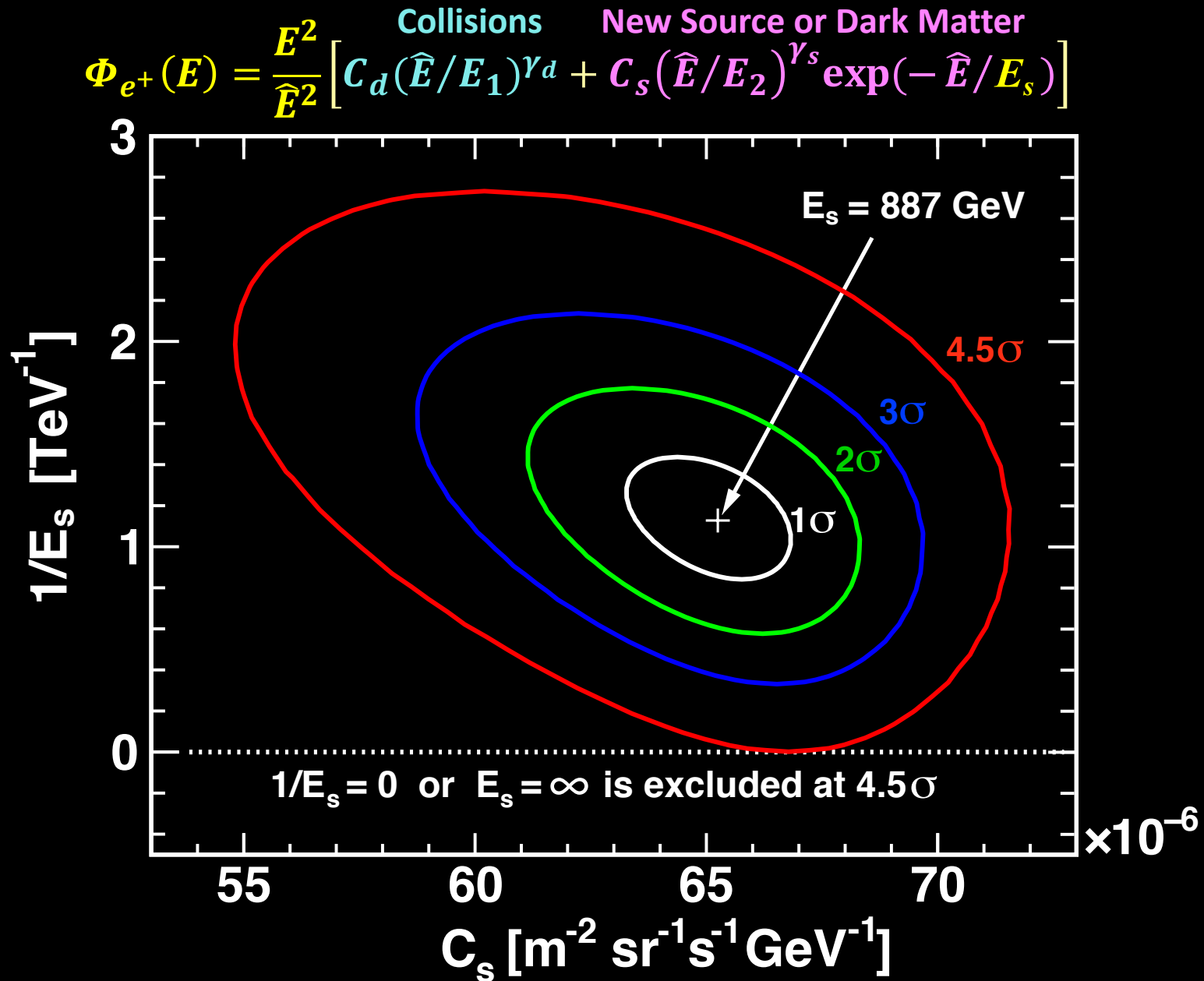
The positron flux is the sum of low-energy part from cosmic ray collisions plus a high-energy part from a new source or dark matter both with a cutoff energy E_s .

$$\Phi_{e^+}(E) = \frac{\text{Solar } E^2}{\hat{E}^2} \left[\overset{\text{Collisions}}{C_d (\hat{E}/E_1)^{\gamma_d}} + \overset{\text{New Source or Dark Matter}}{C_s (\hat{E}/E_2)^{\gamma_s} \exp(-\hat{E}/E_s)} \right]$$

$$\hat{E} = E + \varphi_{e^+}$$



The finite cutoff energy E_s is established at 4.5σ C.L.

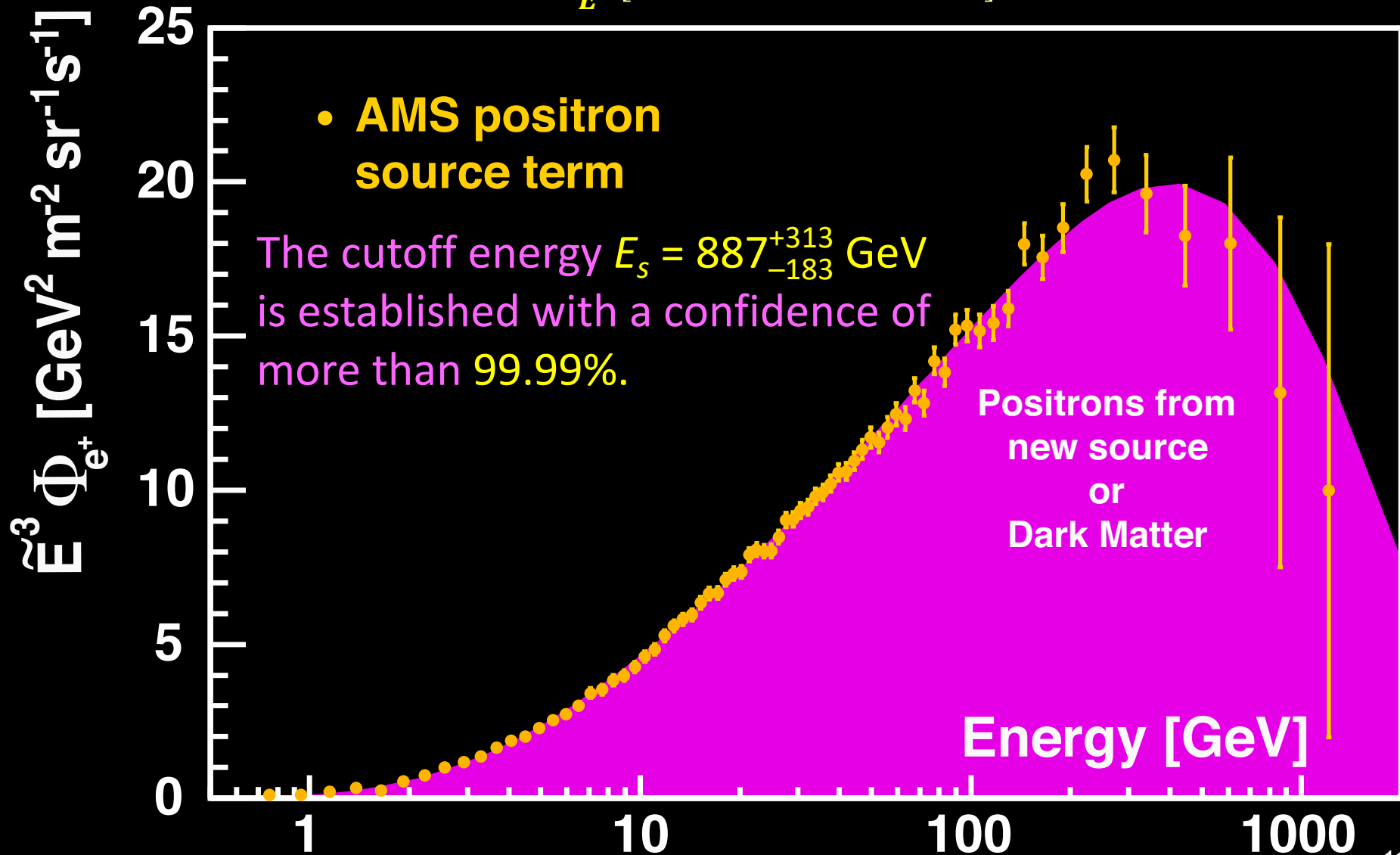


At high energies positrons come from
dark matter or new astrophysical sources with a cutoff energy E_s .

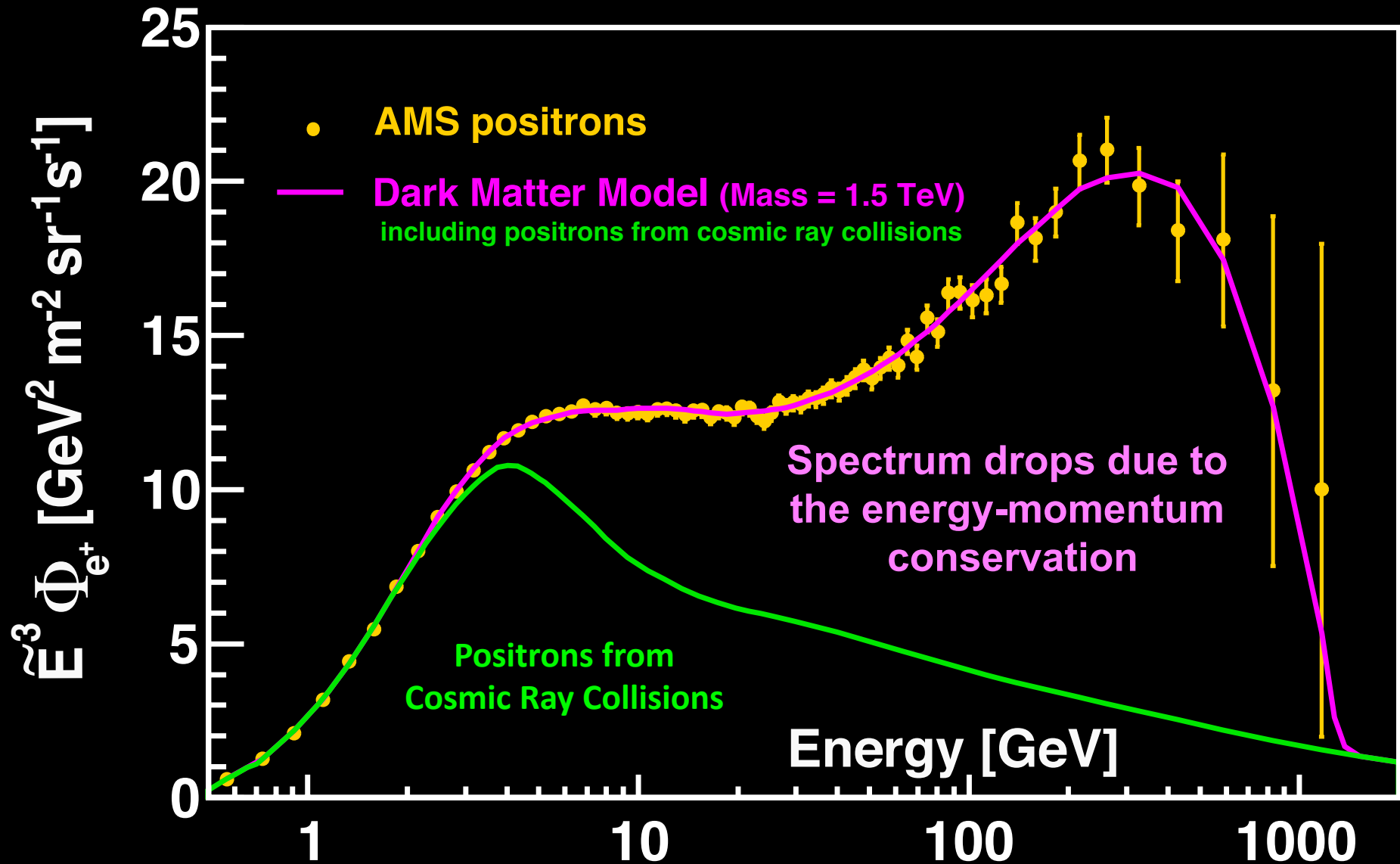
$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2} \left[C_s (\hat{E}/E_2)^{\gamma_s} \exp(-\hat{E}/E_s) \right]$$

- AMS positron source term

The cutoff energy $E_s = 887^{+313}_{-183}$ GeV
is established with a confidence of
more than 99.99%.

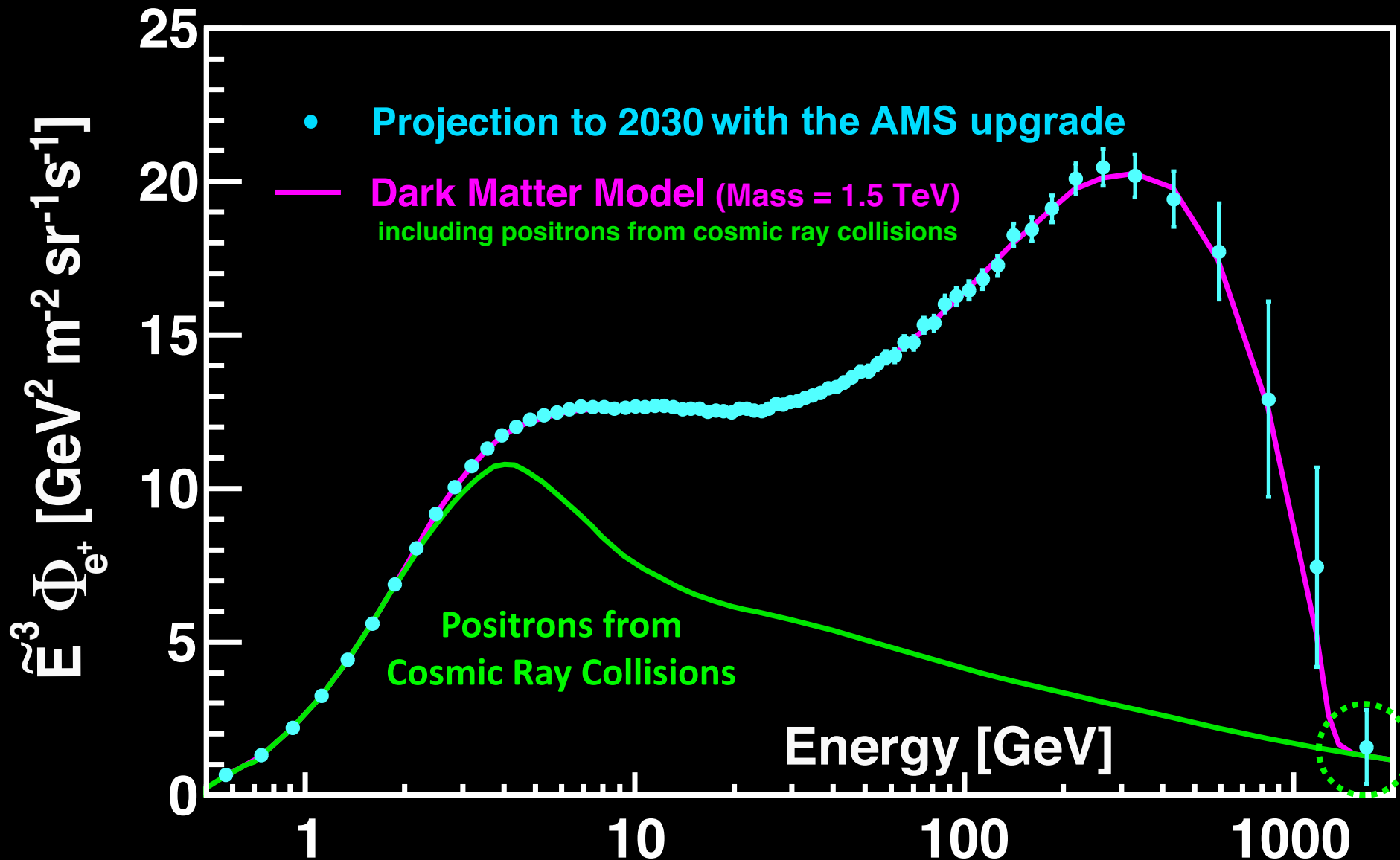


Positrons and a Dark Matter Model



Positrons and Dark Matter Model by 2030

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



A sample of recent theoretical models explaining AMS positron and electron data (overall >3000 citations)

- 1) H. Motz, H. Okada, Y. Asaoka, and K. Kohri, Phys.Rev. D102 (2020) 8, 083019
 - 2) Z.Q. Huang, R.Y. Liu, J.C. Joshi, X.Y. Wang, Astrophys.J. 895 (2020) 1, 53
 - 3) R. Diesing and D. Caprioli, Phys.Rev. D101 (2020) 10
 - 4) A. Das, B. Dasgupta, and A. Ray, Phys.Rev. D101 (2020) 6
 - 5) F. S. Queiroz and C. Siqueira, Phys.Rev. D101 (2020) 7, 075007
 - 6) Z.L. Han, R. Ding, S.J. Lin, and B. Zhu, Eur.Phys.J. C79 (2019) 12, 1007
 - 7) C.Q. Geng, D. Huang, and L. Yin, Nucl.Phys. B959 (2020) 115153
 - 8) S. Profumo, F. Queiroz, C. Siqueira, J.Phys.G 48 (2020) 1, 015006
 - 9) D. Kim, J.C. Park, S. Shin, JHEP 04 (2018) 093
- and many other excellent papers ...

- 1) P. Mertsch, A. Vittino, and S. Sarkar, Phys.Rev. D 104 (2021) 103029
 - 2) P. Zhang et al., JCAP 05 (2021) 012
 - 3) C. Evoli, E. Amato, P. Blasi, and R. Aloisio, Phys.Rev. D103 (2021) 8, 083010
 - 4) K. Fang, X.J. Bi, S.J. Lin, and Q. Yuan, Chin.Phys.Lett. 38 (2021) 3, 039801
 - 5) C. Evoli, P. Blasi, E. Amato, and R. Aloisio, Phys.Rev.Lett. 125 (2020) 5, 051101
 - 6) O. Fornieri, D. Gaggero, and D. Grasso, JCAP 02 (2020) 009
 - 7) P. Cristofari and P. Blasi, Mon.Not.Roy.Astron.Soc. 489 (2019) 1, 108
 - 8) K. Fang, X.J. Bi, and P.F Yin, Astrophys.J. 884 (2019) 124
 - 9) S. Recchia, S. Gabici, F.A. Aharonian, and J. Vink, Phys.Rev. D99 (2019) 10, 103022
- and many other excellent papers ...

- 1) E. Amato and S. Casanova, J.Plasma Phys. 87 (2021) 1, 845870101
 - 2) Z. Tian et al., Chin.Phys. C44 (2020) 8, 085102
 - 3) W. Zhu, P. Liu, J. Ruan, and F. Wang, Astrophys.J. 889 (2020) 127
 - 4) P. Liu and J. Ruan, Int.J.Mod.Phys. E28 (2019) 09, 1950073
 - 5) R. Diesing and D. Caprioli, Phys.Rev.Lett. 123 (2019) 7, 071101
 - 6) W. Zhu, J. S. Lan and J. H. Ruan, Int. J. Mod. Phys. E27 (2018) 1850073
- and many other excellent papers ...

AMS Publications on electrons and positrons

- 1) M. Aguilar et. al., Phys. Rev. Lett. 110 (2013) 141102.
APS Highlight of the Year 2013
10-year Retrospective of Editors' Suggestions
- 2) L. Accardo et al., Phys. Rev. Lett. 113 (2014) 121101.
Editor's Suggestion
- 3) M. Aguilar et. al., Phys. Rev. Lett. 113 (2014) 121102.
Editor's Suggestion
- 4) M. Aguilar et. al., Phys. Rev. Lett. 113 (2014) 221102.
- 5) M. Aguilar et. al., Phys. Rev. Lett. 122 (2019) 041102.
Editor's Suggestion
- 6) M. Aguilar et. al., Phys. Rev. Lett. 122 (2019) 101101.
- 7) M. Aguilar et. al., Physics Reports, 894 (2021) 1.

Dark Matter

Astrophysical sources

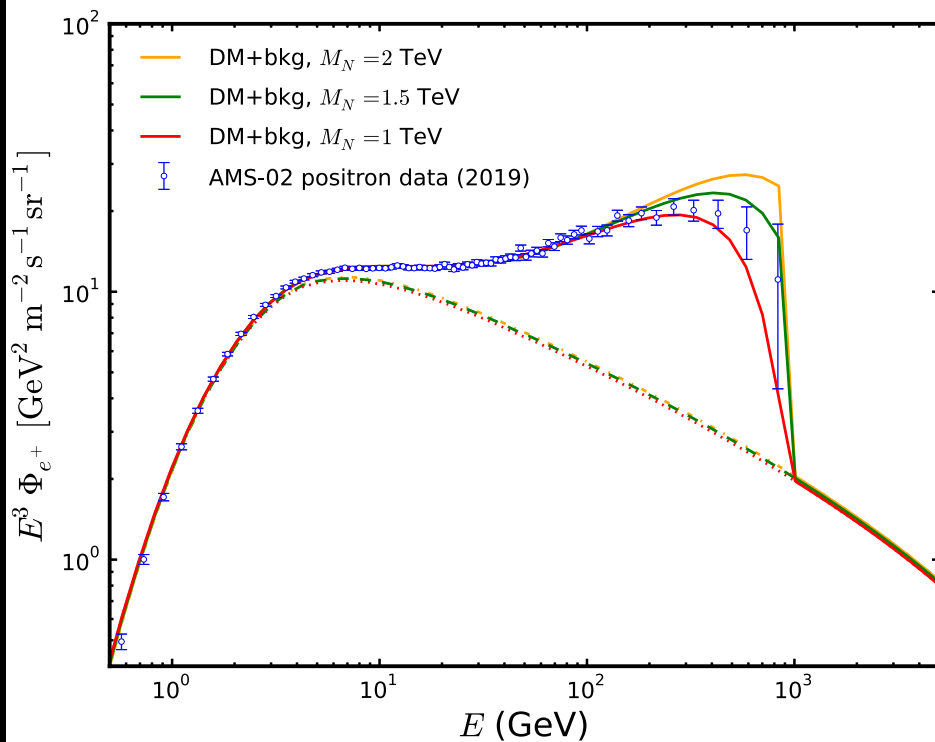
Propagation

Examples of DM models discussed in the literature

DM annihilation

Z.L. Han, R. Ding, S.J. Lin, and B. Zhu,
Eur. Phys. J. C79 (2019) 12, 1007

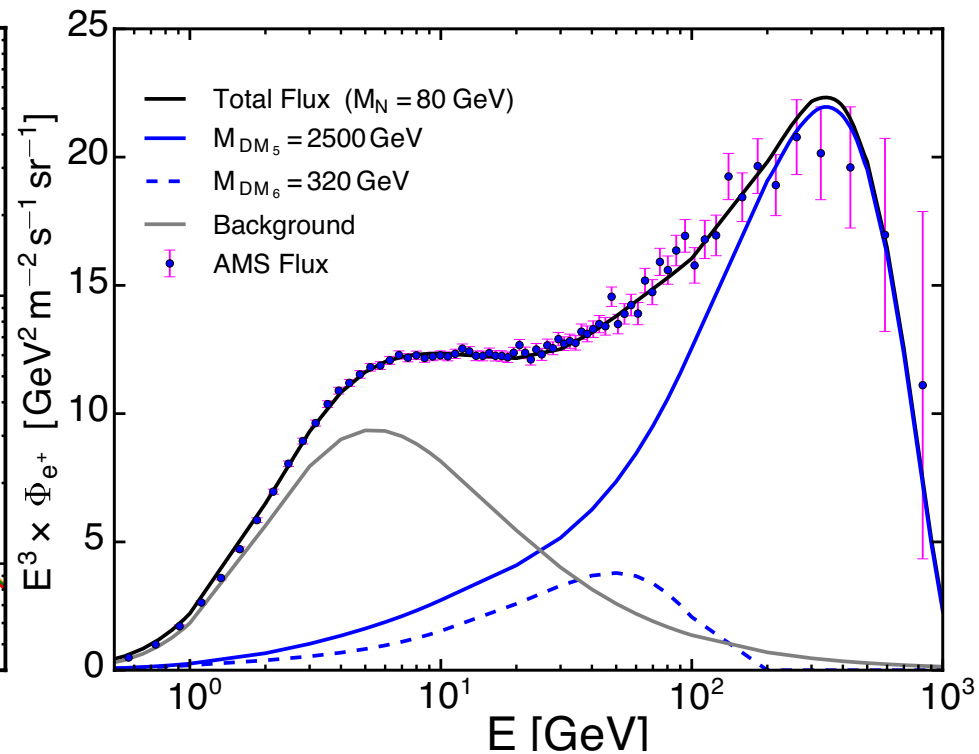
$$NN \rightarrow Z' Z' \rightarrow e^+ + X$$



DM decays

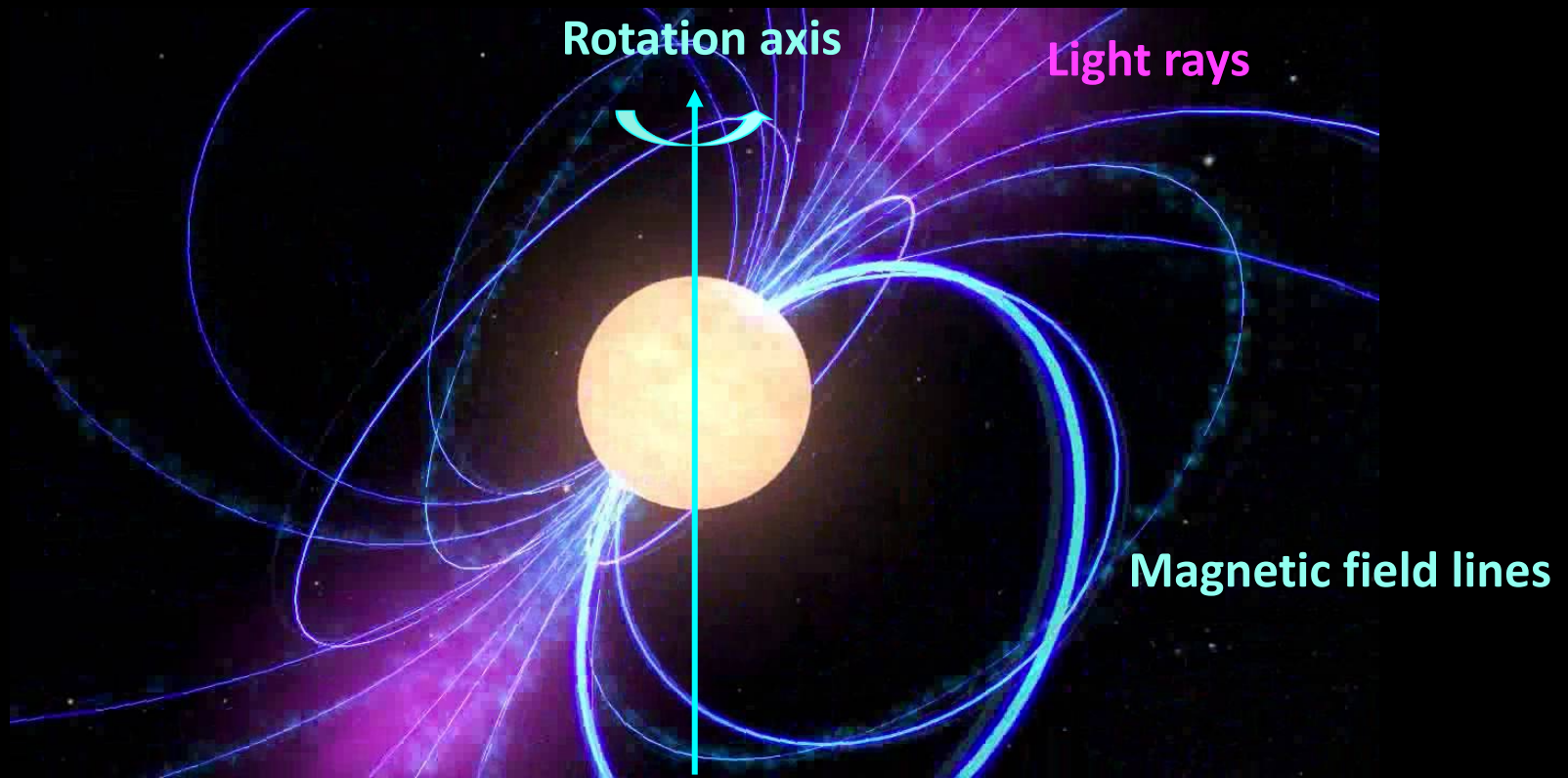
F. Queiroz and C. Siqueira,
Phys. Rev. D 101 (2020) 7, 075007

$$\chi \rightarrow N \rightarrow e^+ + X$$



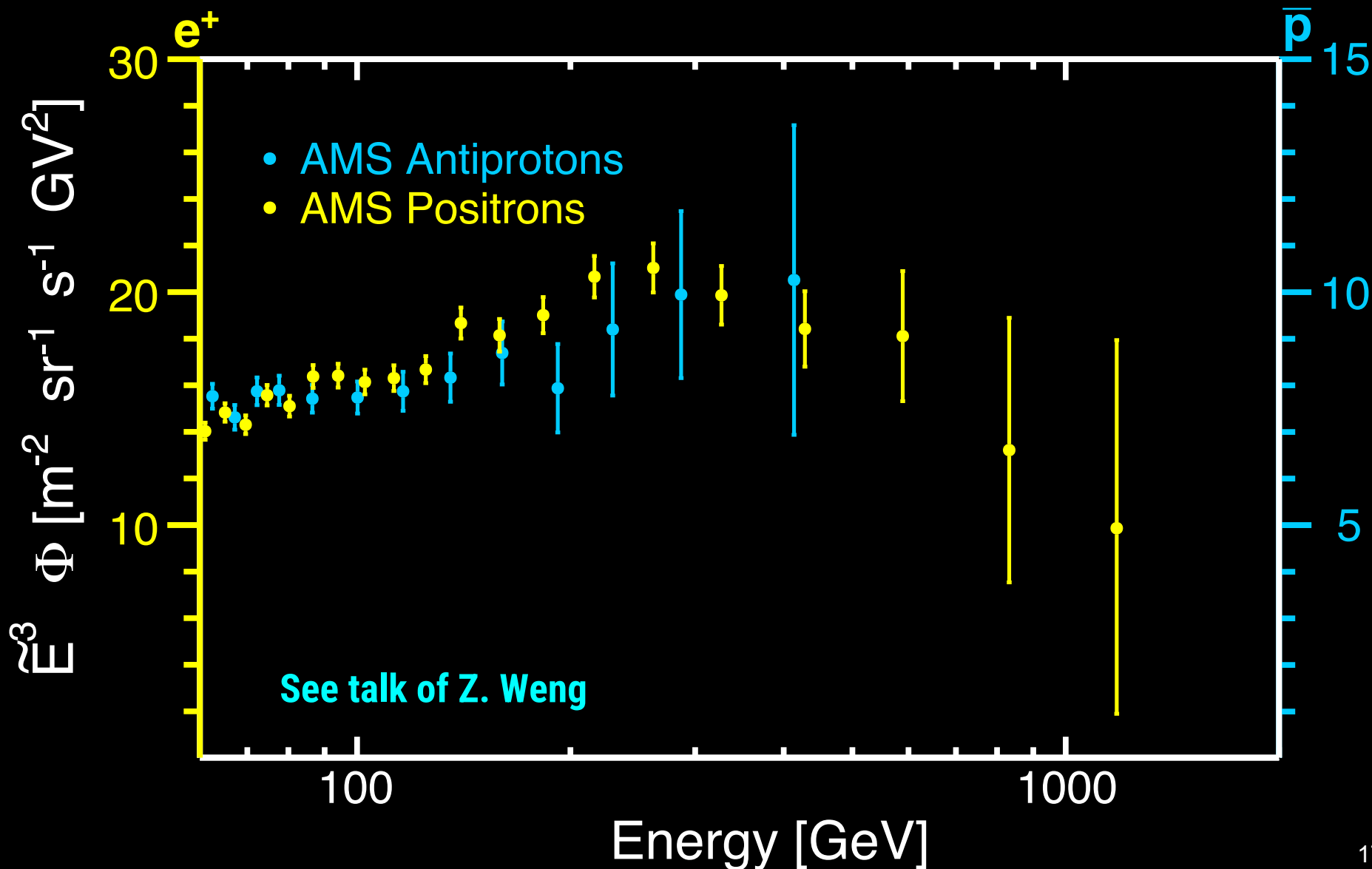
Positrons from Pulsars

1. Pulsars produce and accelerate positrons to high energies.
2. Pulsars do not produce antiprotons.

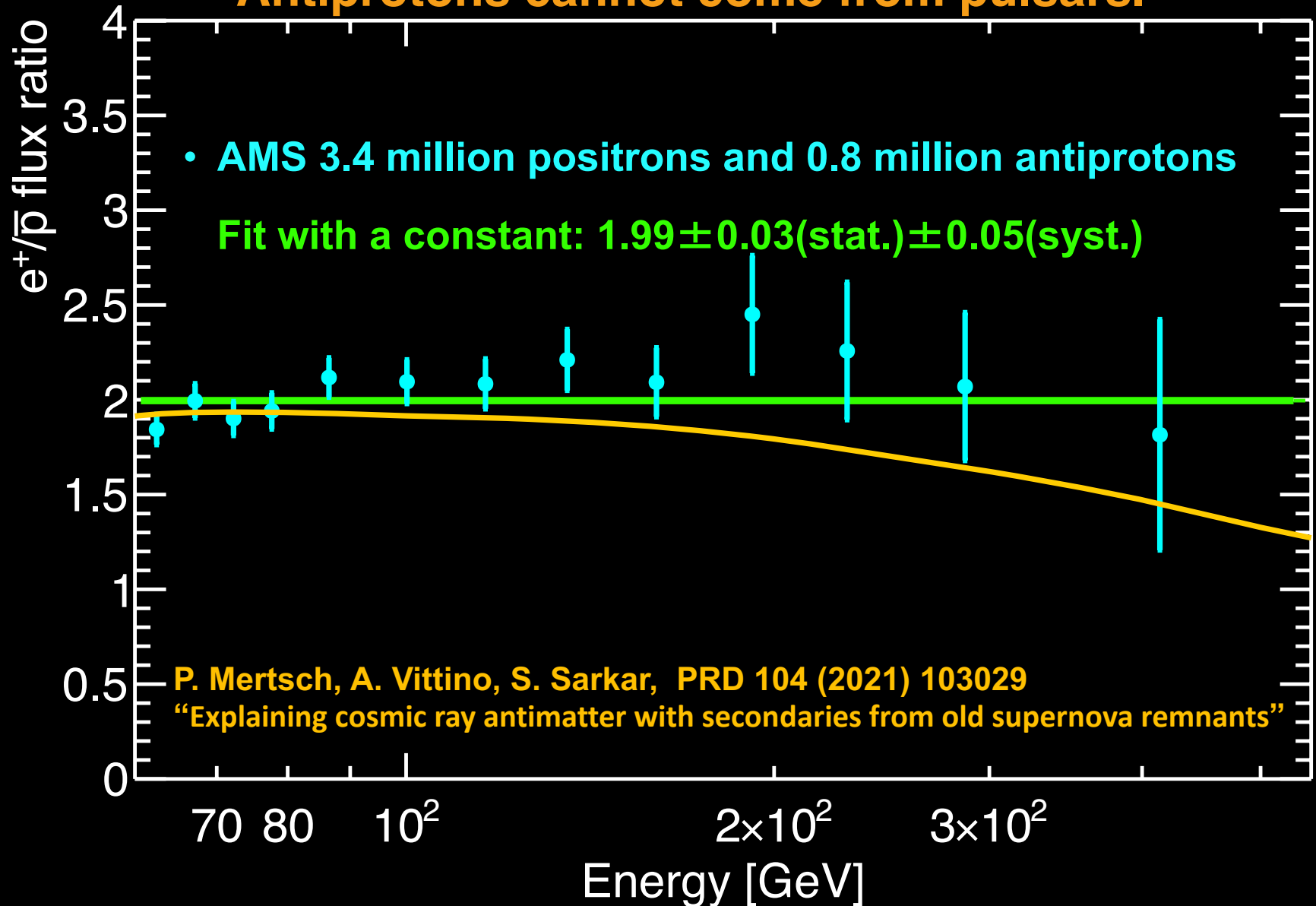


Latest Physics Results from AMS: Study of Antiprotons

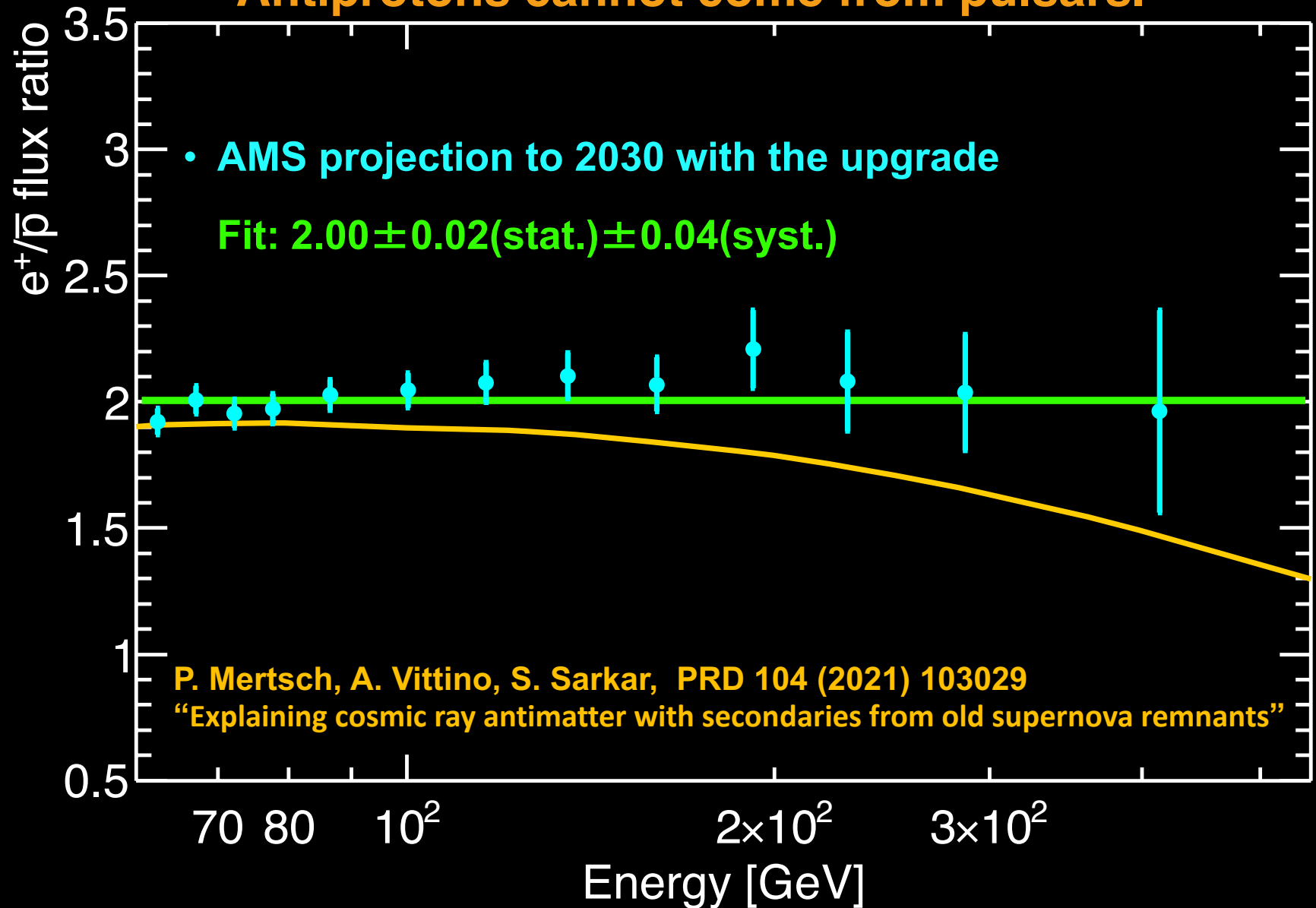
Antiprotons show a similar trend to positrons.



**The positron-to-antiproton flux ratio is
constant independent of energy.
Antiprotons cannot come from pulsars.**

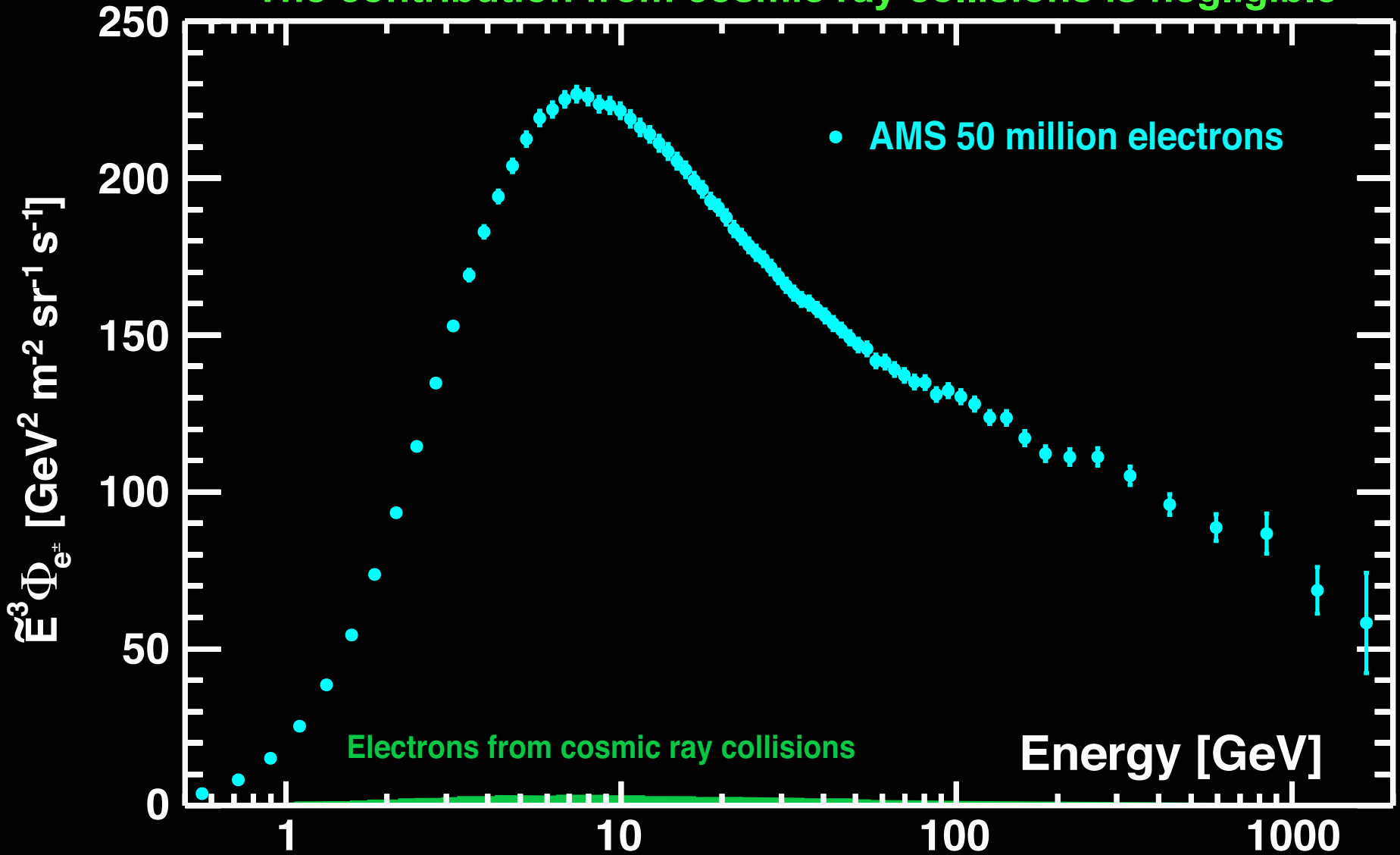


**The positron-to-antiproton flux ratio is
constant independent of energy.
Antiprotons cannot come from pulsars.**



Origins of Cosmic Electrons

The contribution from cosmic ray collisions is negligible



Origins of Cosmic Electrons

Traditionally, Cosmic Ray spectrum is described by a power law function

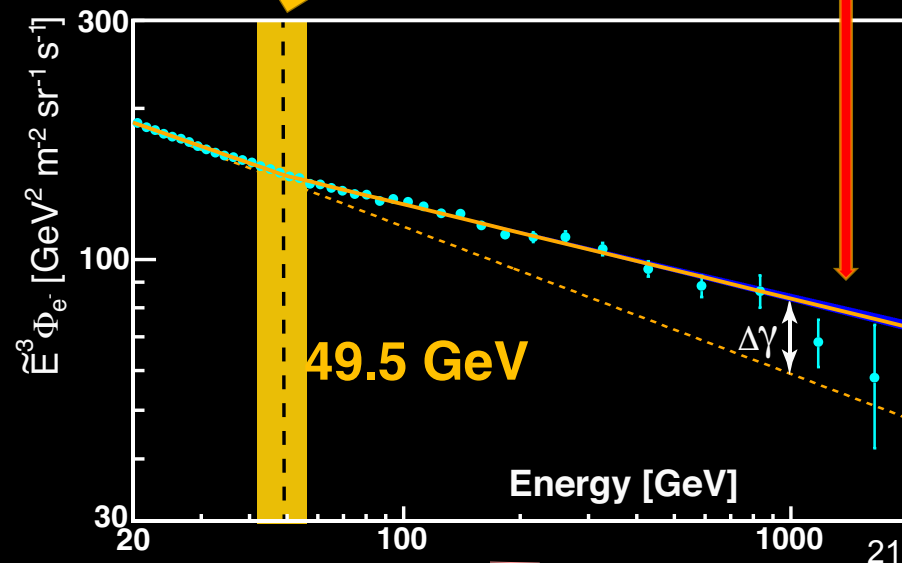
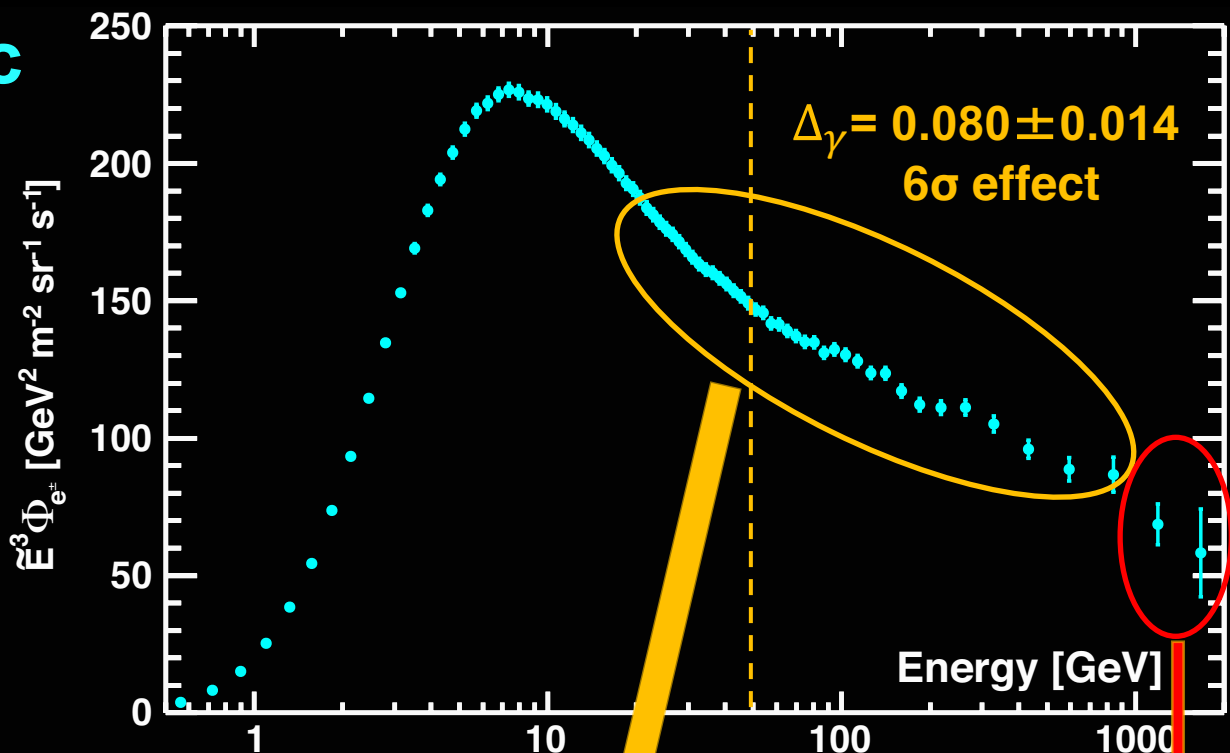
Change of the behavior at ~ 50 GeV and at ~ 1 TeV

Fit to data

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

A significant excess at

$$E_0 = 49.5 \pm 5.6 \text{ GeV}$$



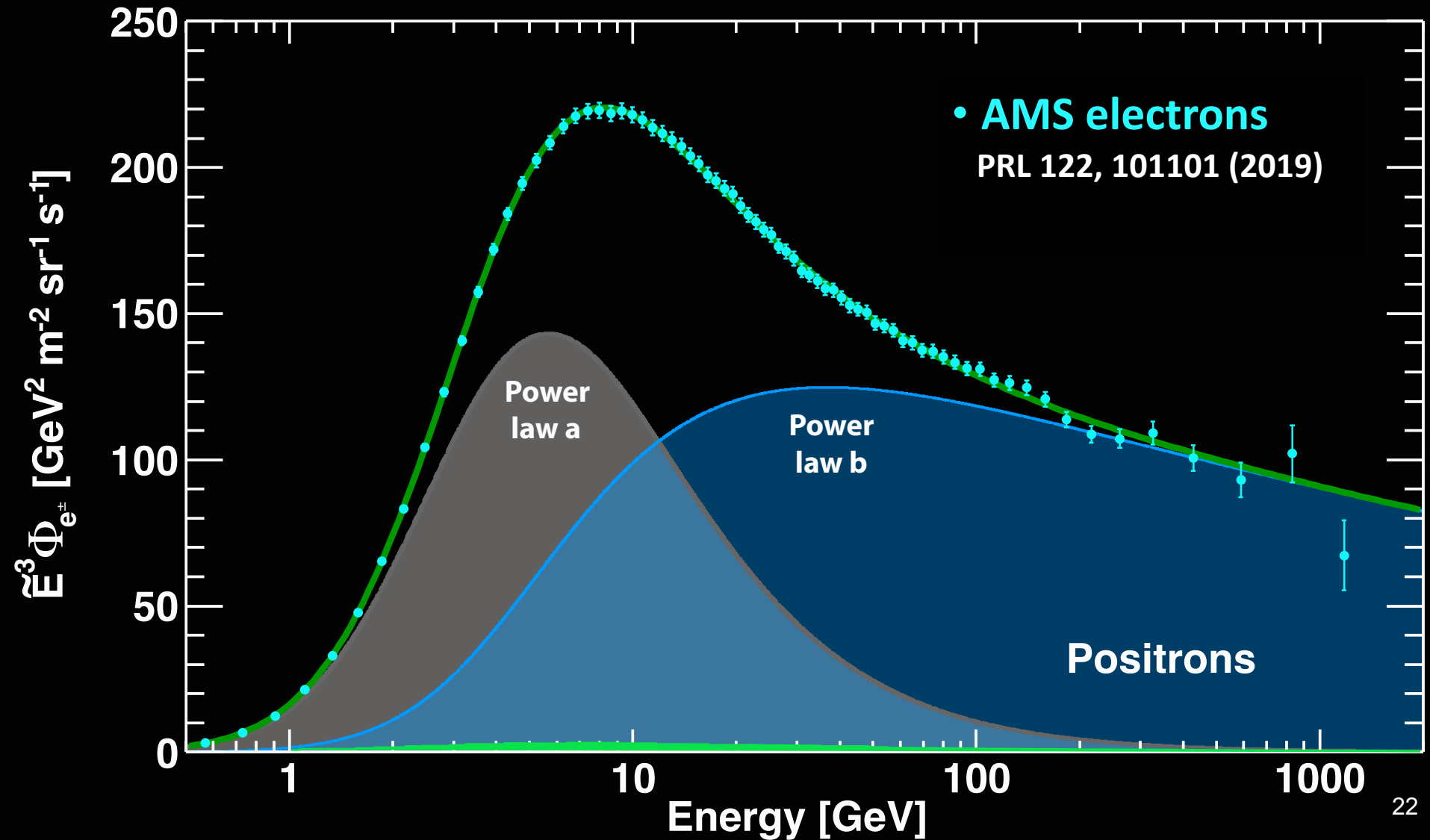
The electron flux description by two power law functions is disfavored:

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

Solar &
low-energy

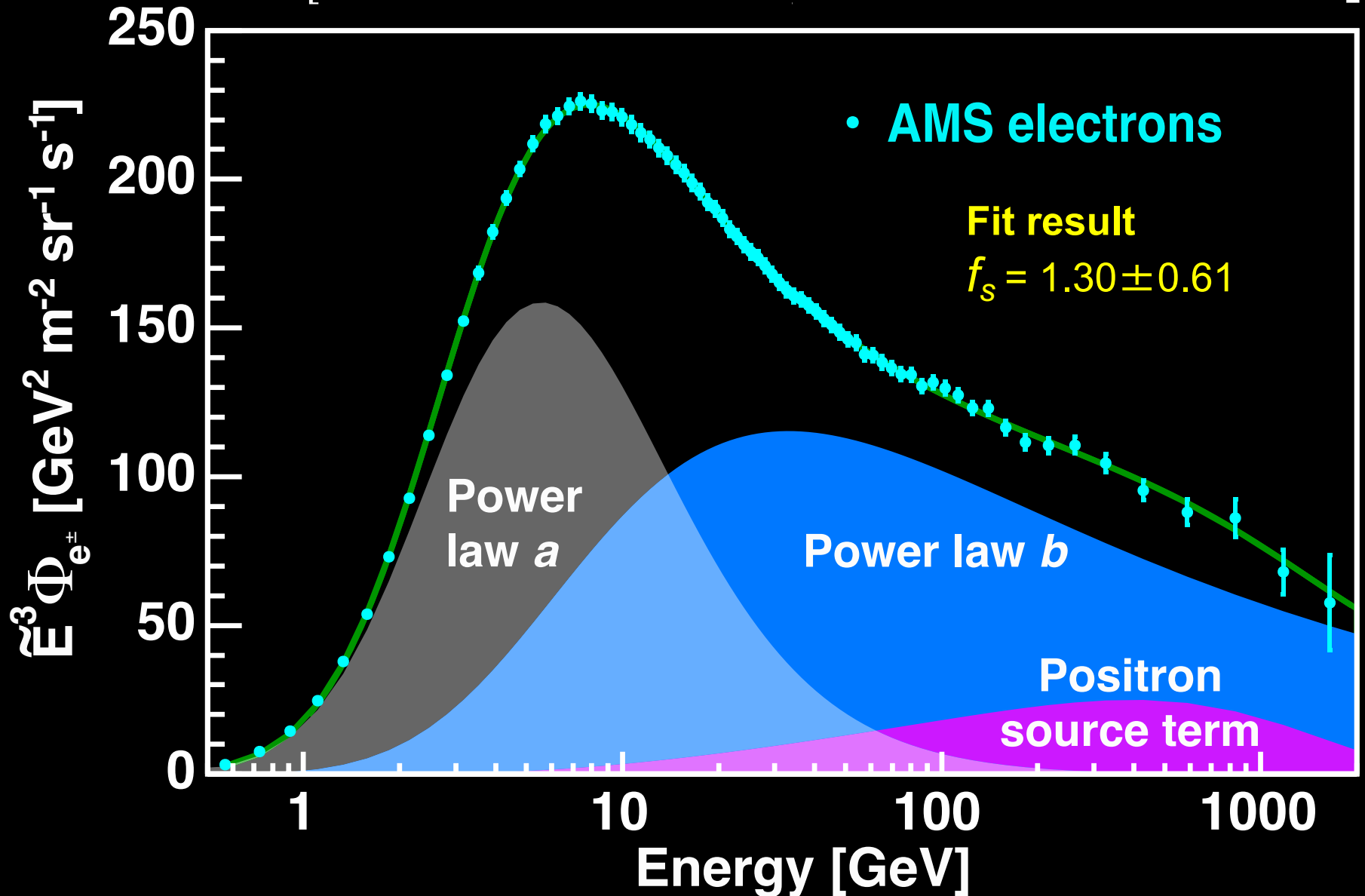
Power
law a

Power
law b



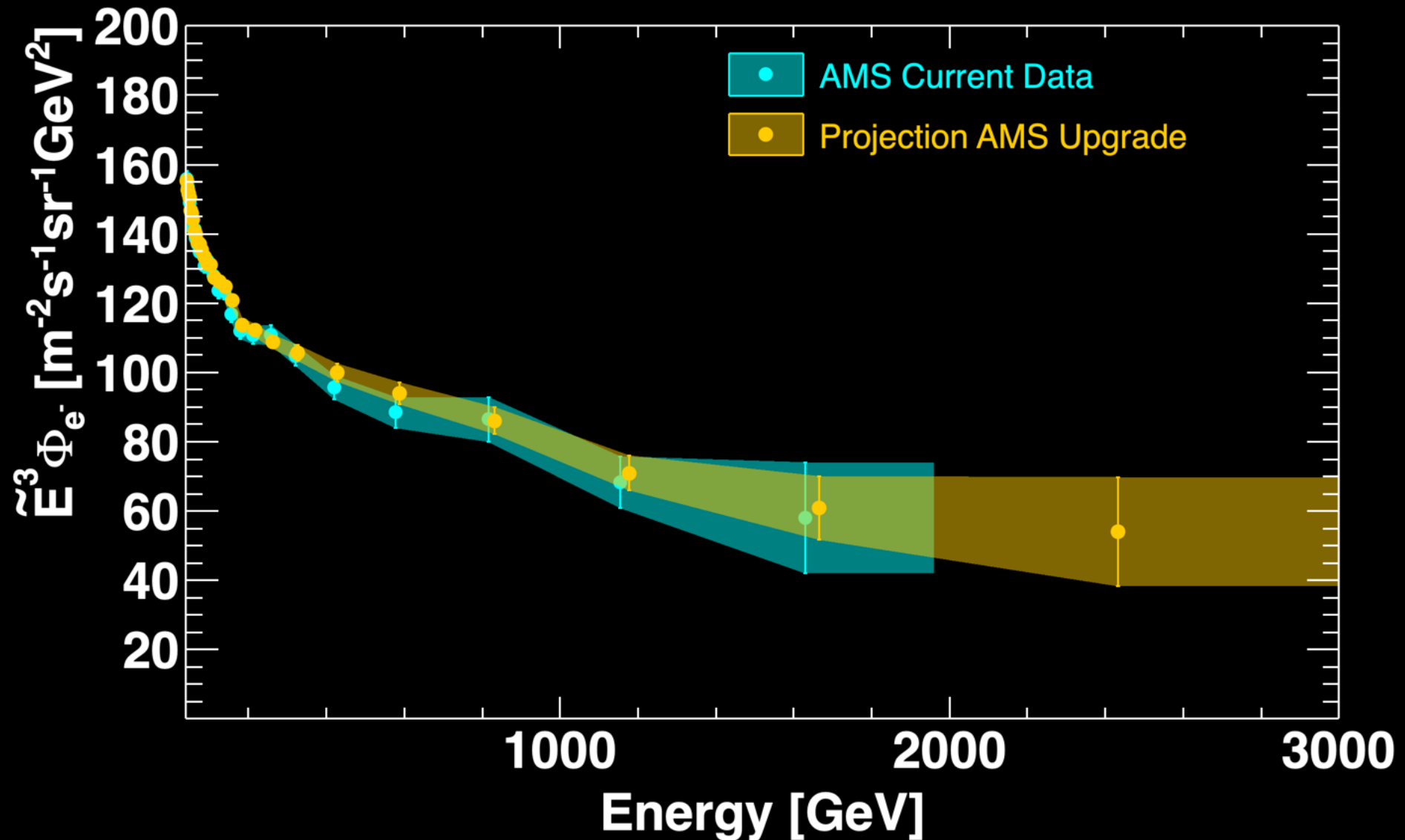
Electron spectrum favors the contribution of the positron-like source term

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

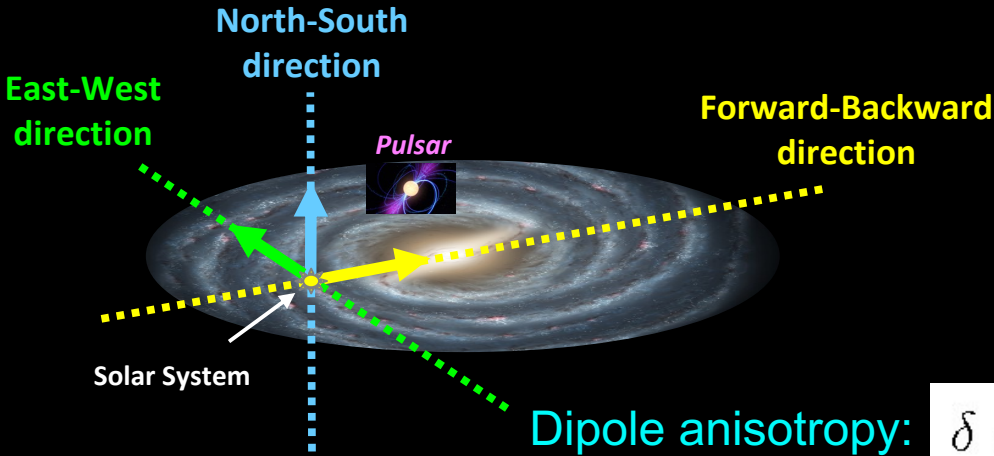


Physics of cosmic electrons to 2030

Establish the existence of the positron-like source term at highest energies at 4σ CL



Positron Anisotropy and Dark Matter



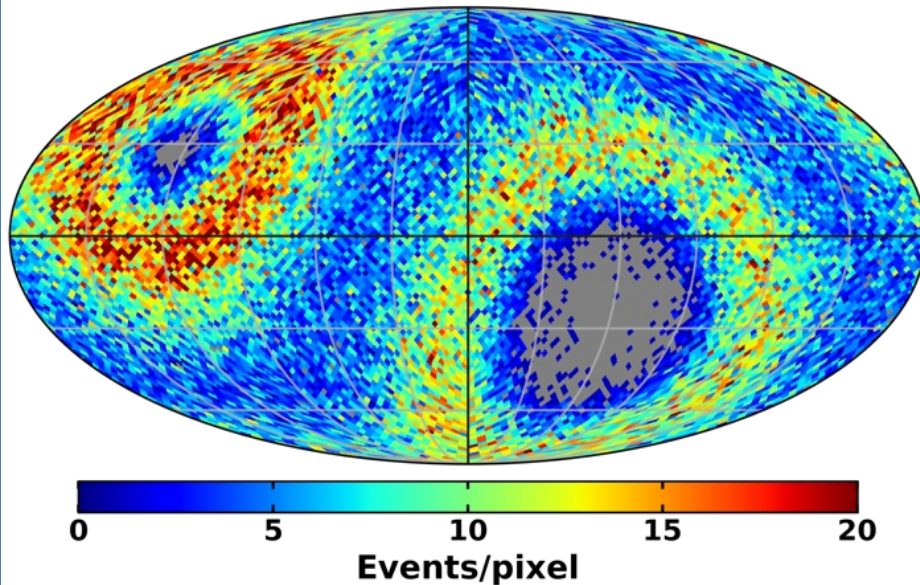
Astrophysical point sources will imprint a higher anisotropy on the arrival directions of energetic positrons than a smooth dark matter halo.

Dipole anisotropy:

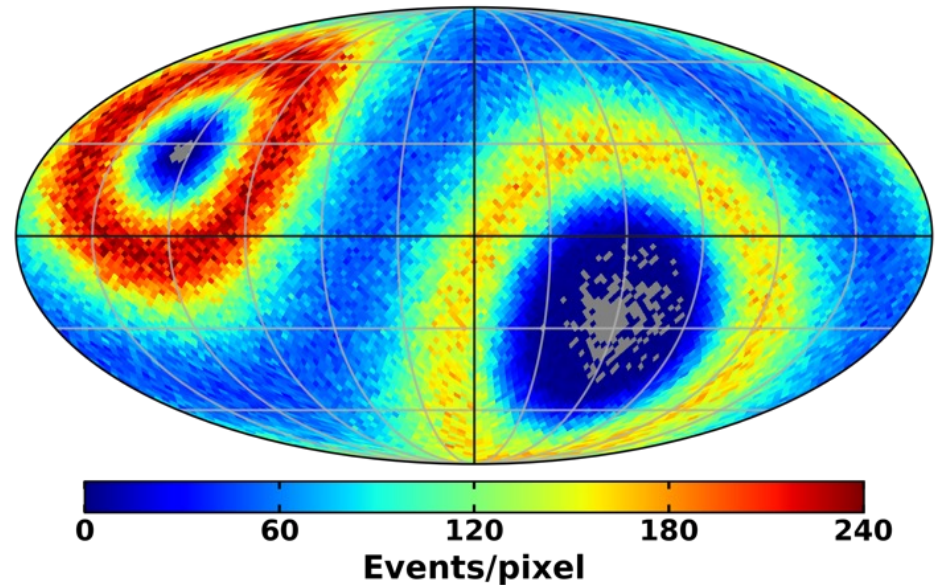
$$\delta = 3\sqrt{C_1/4\pi}$$

C_1 is the dipole moment

positrons



electrons

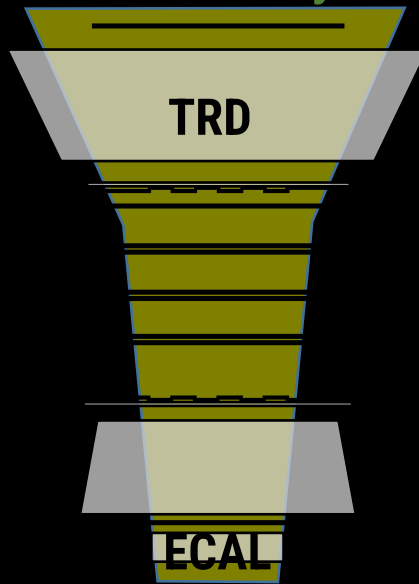


Currently at 95% C.L.:
for $16 < E < 500$ GeV

positrons: $\delta < 0.0150$
electrons: $\delta < 0.0034$

Analysis of Anisotropies

Current Analysis

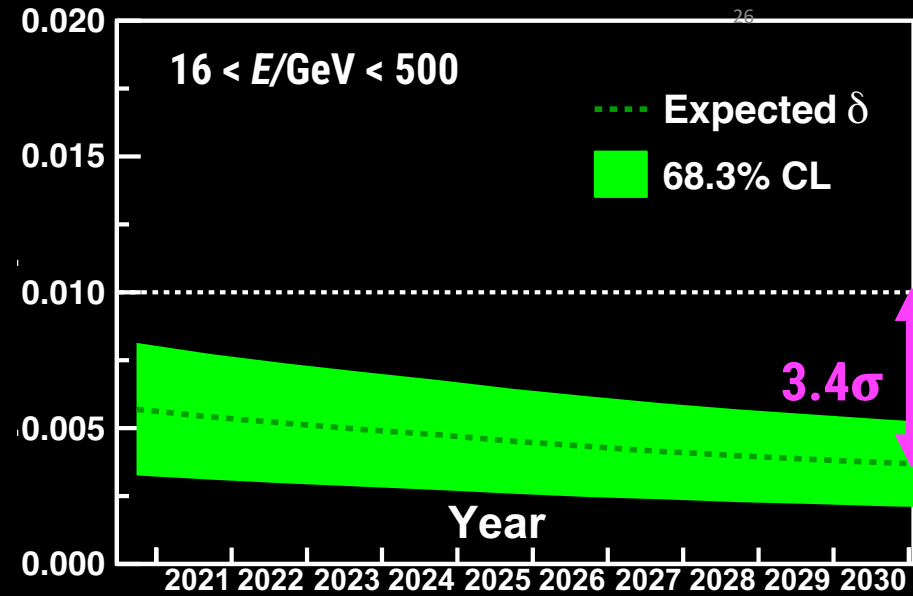
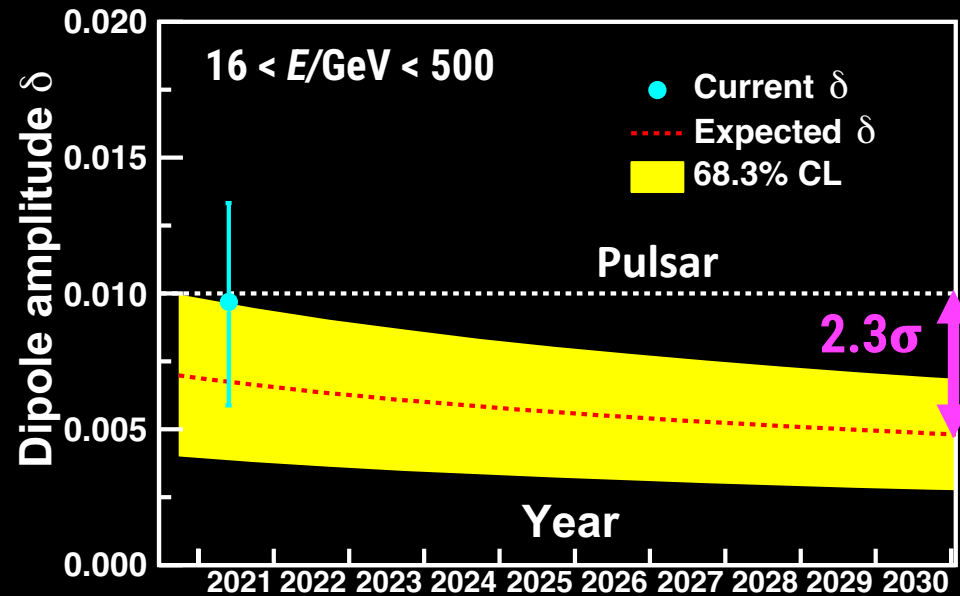
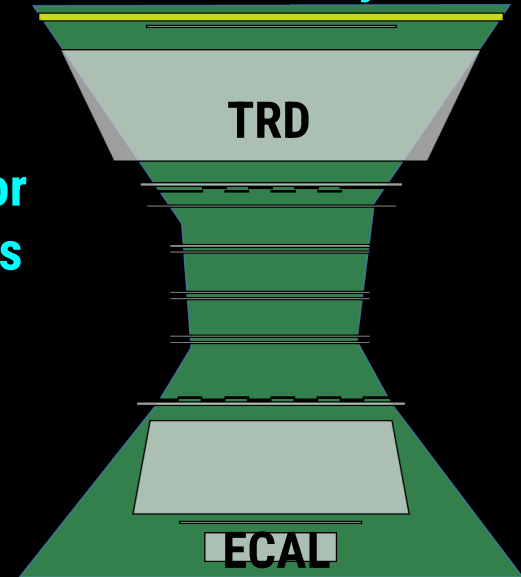


Increase acceptance for
positrons and electrons



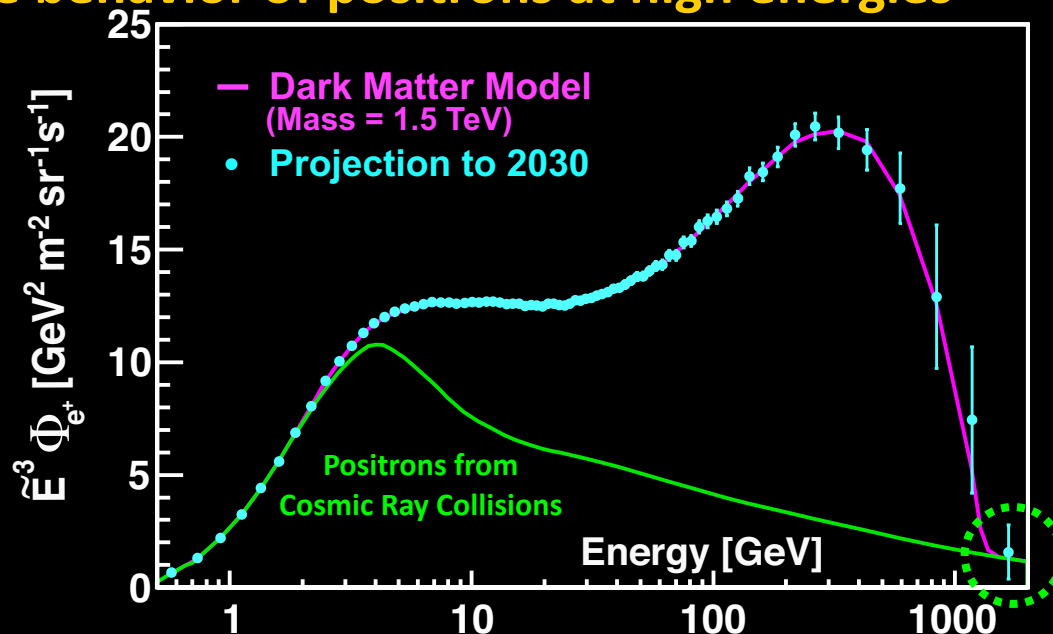
See talk of
M.A. Velasco

Future Analysis



Conclusions

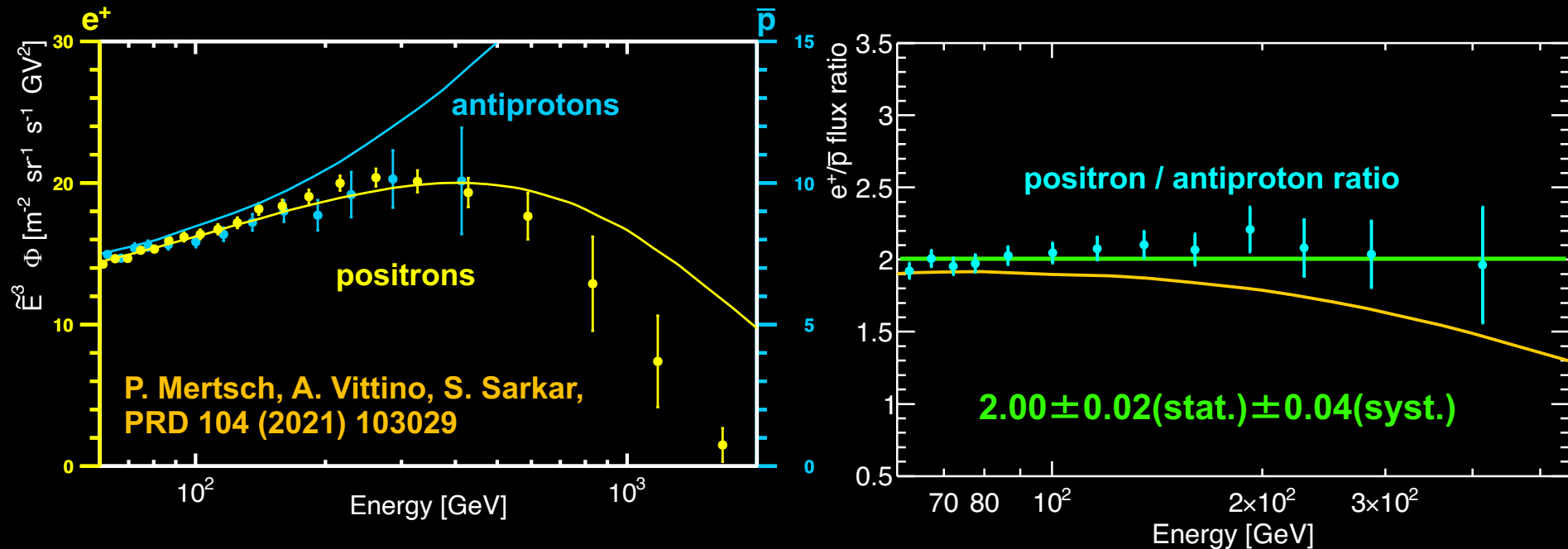
1. Sharp drop-off of the positron spectrum above 268_{-33}^{+35} GeV is established with 4.8 sigma significance;
2. Positron spectrum requires an additional source of high energy positrons (e.g. DM models):
 - can't be explained by the ordinary CR collisions
 - has an exponential cutoff with $E_s=887$ GeV;
 - measurement to 2030 will enable us to determine the origin of the behavior of positrons at high energies



Conclusions

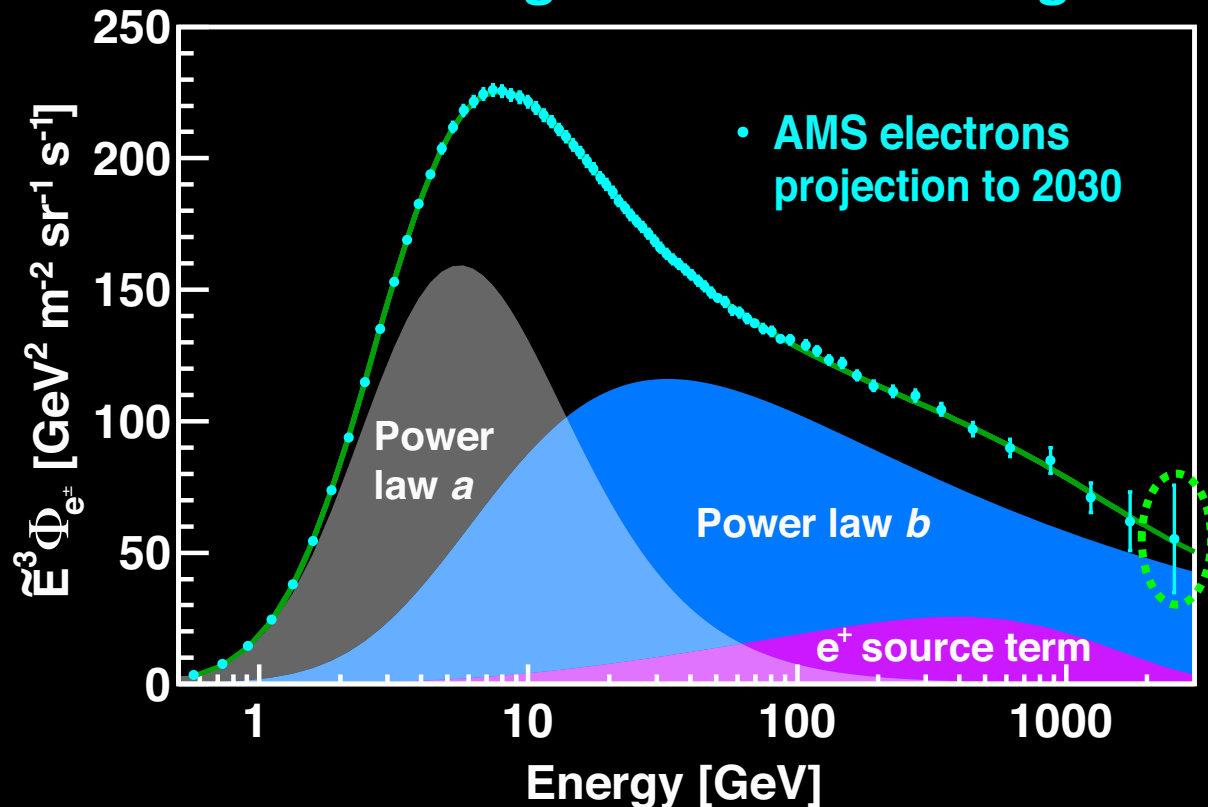
3. Comparison of the antiproton and positron spectra shows strikingly similar behavior of the two spectra above 60 GeV. This points to the common source of high energy antiprotons and positrons and disfavors pulsars as the origin of high energy positrons.

AMS projections to 2030

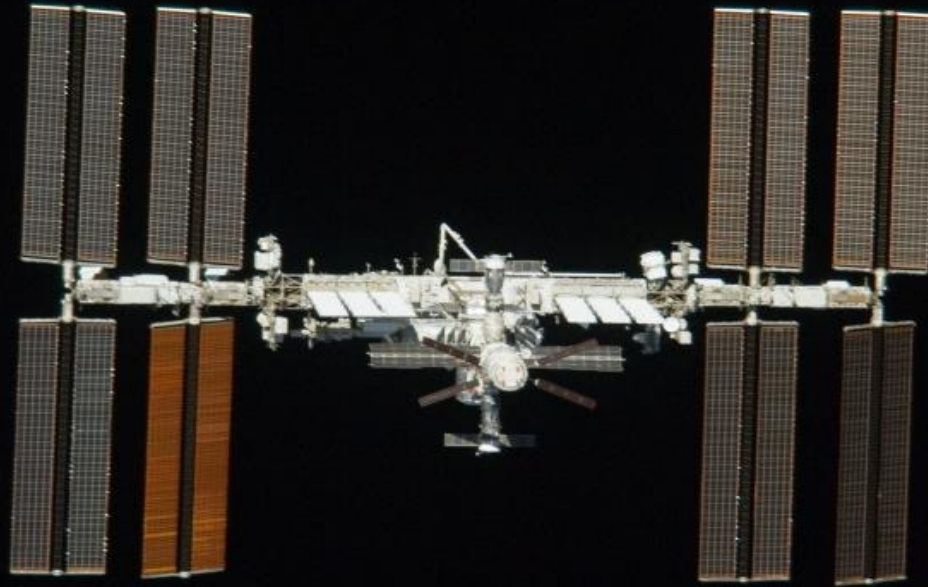


Conclusions

4. 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.
5. Significance of this observation is 2σ at present. With 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.**