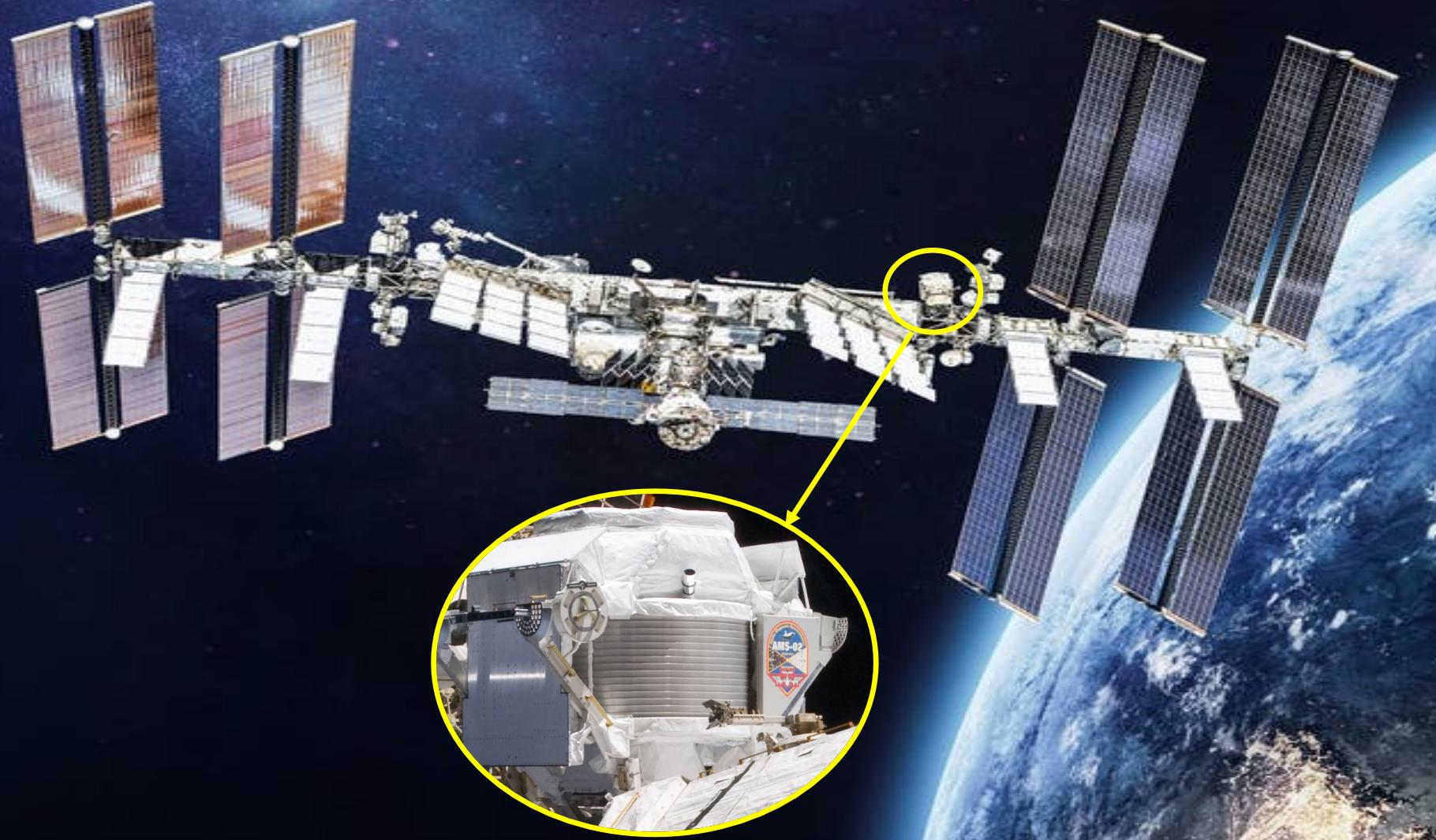


Understanding the Origins of Cosmic Electrons and Positrons



Zhili Weng / MIT

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

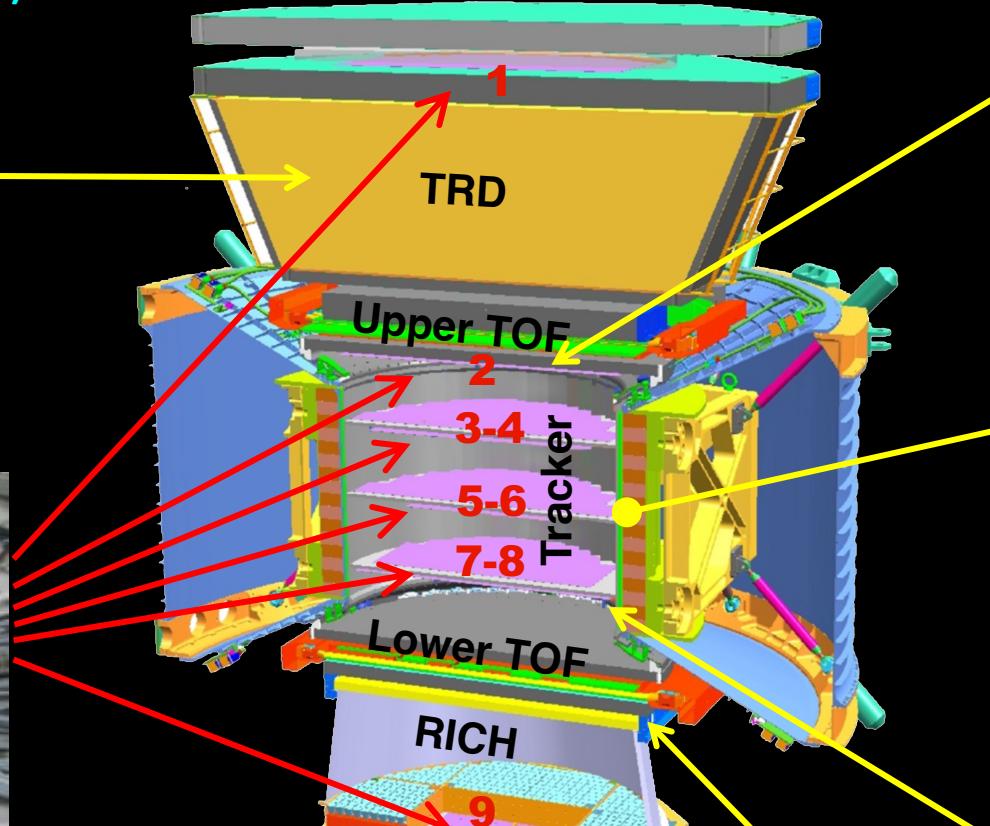
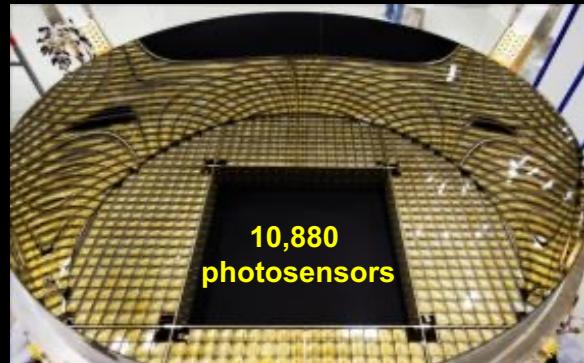
Transition Radiation Detector (TRD)
identify e^+ , e^-



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



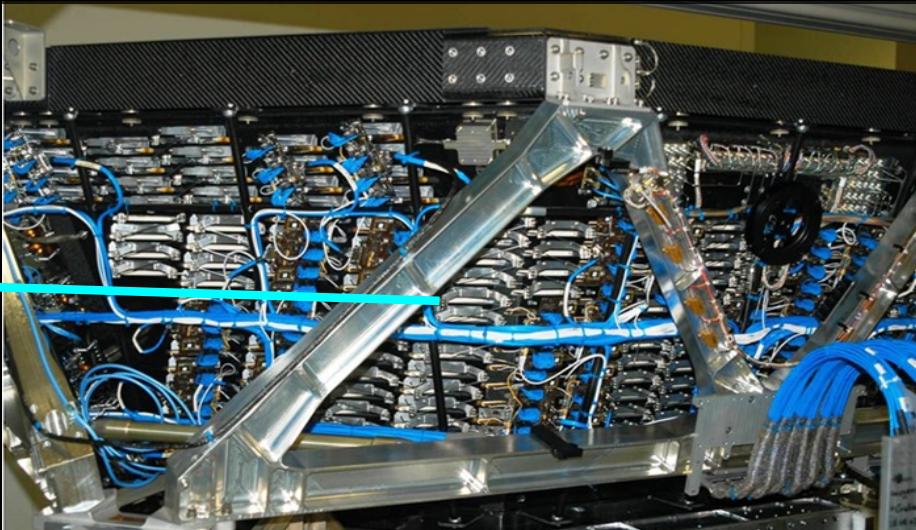
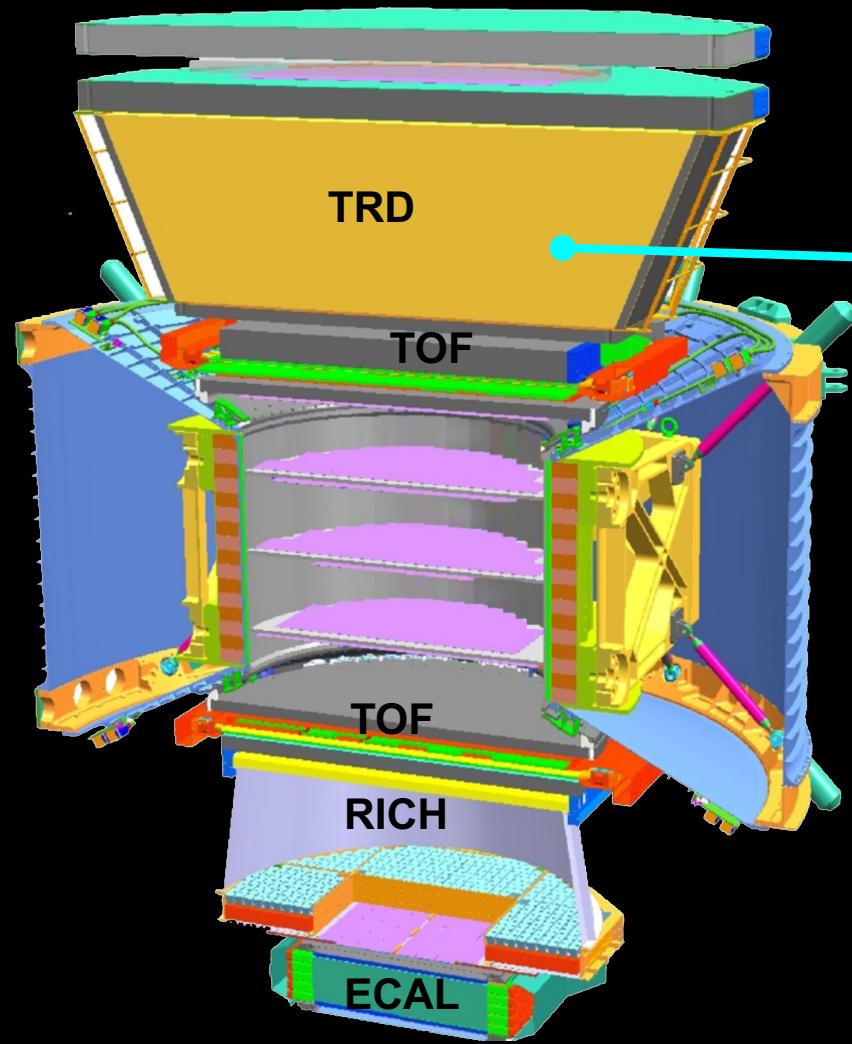
Lower TOF measure Z, E



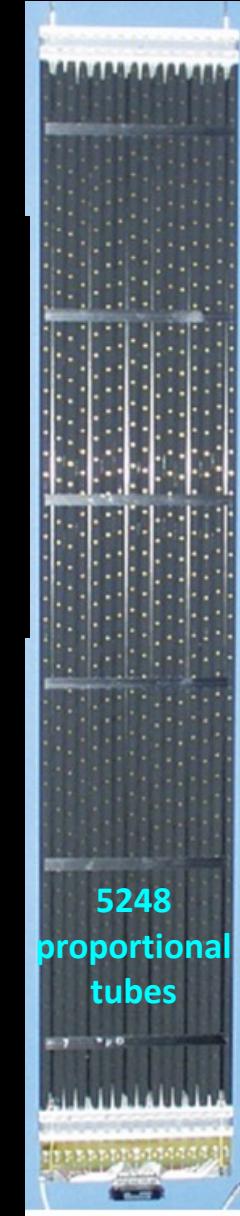
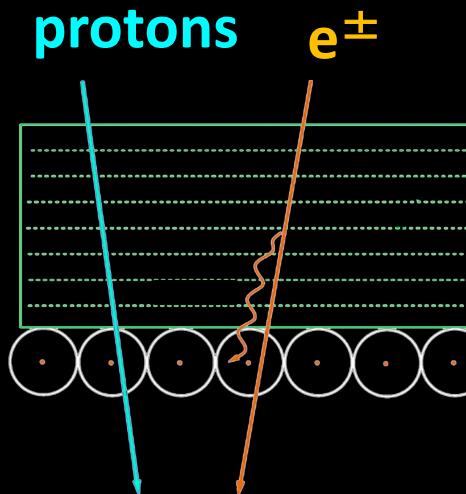
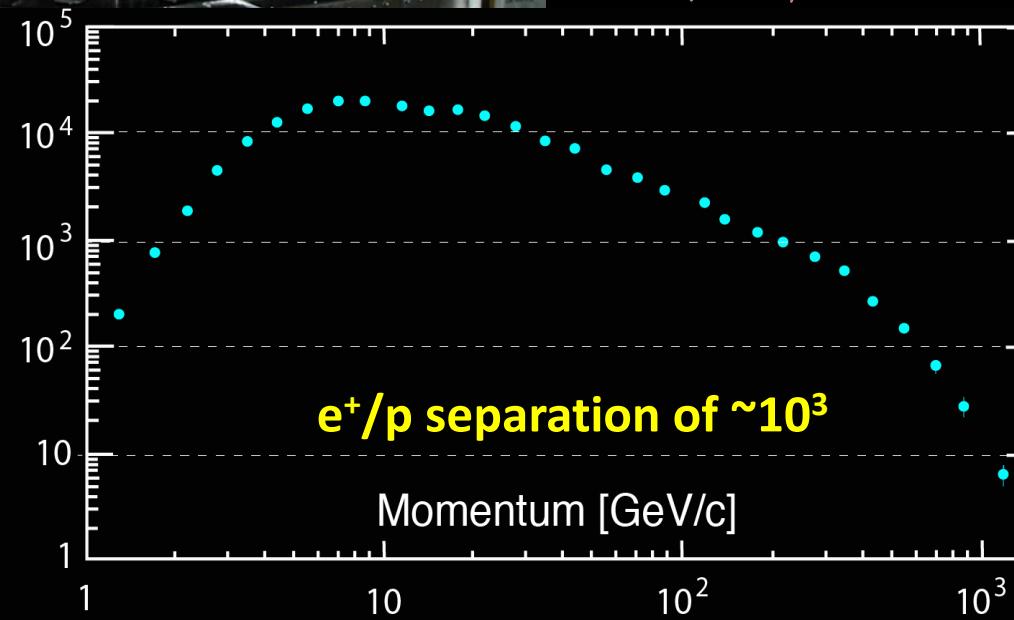
Accurate Measurement of Positrons and Electrons

For every cosmic positron there are 10,000 cosmic protons, a 1 % measurement requires a e^+/p separation of 10^6

Transition Radiation Detector (TRD)

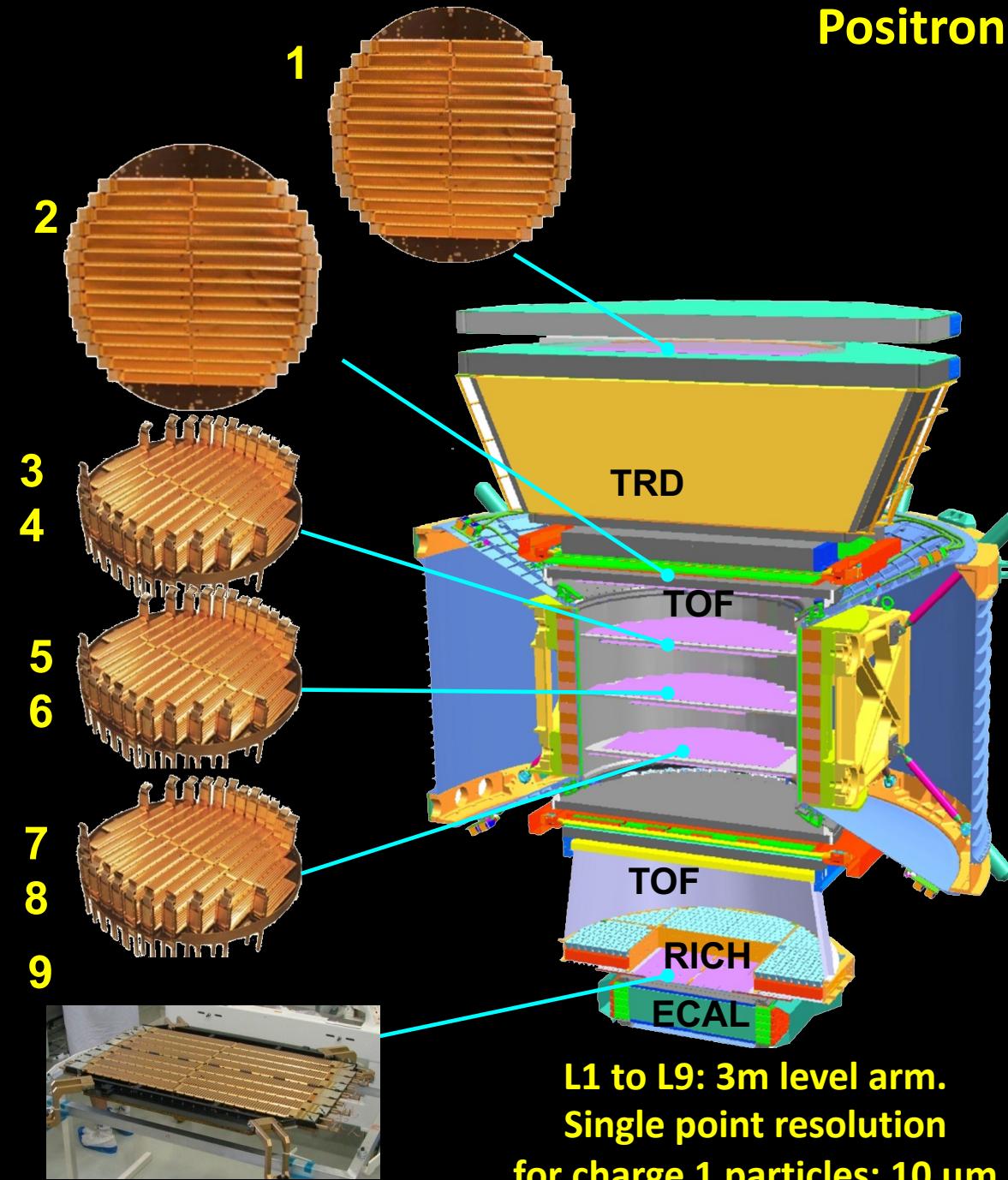


TRD Proton Rejection

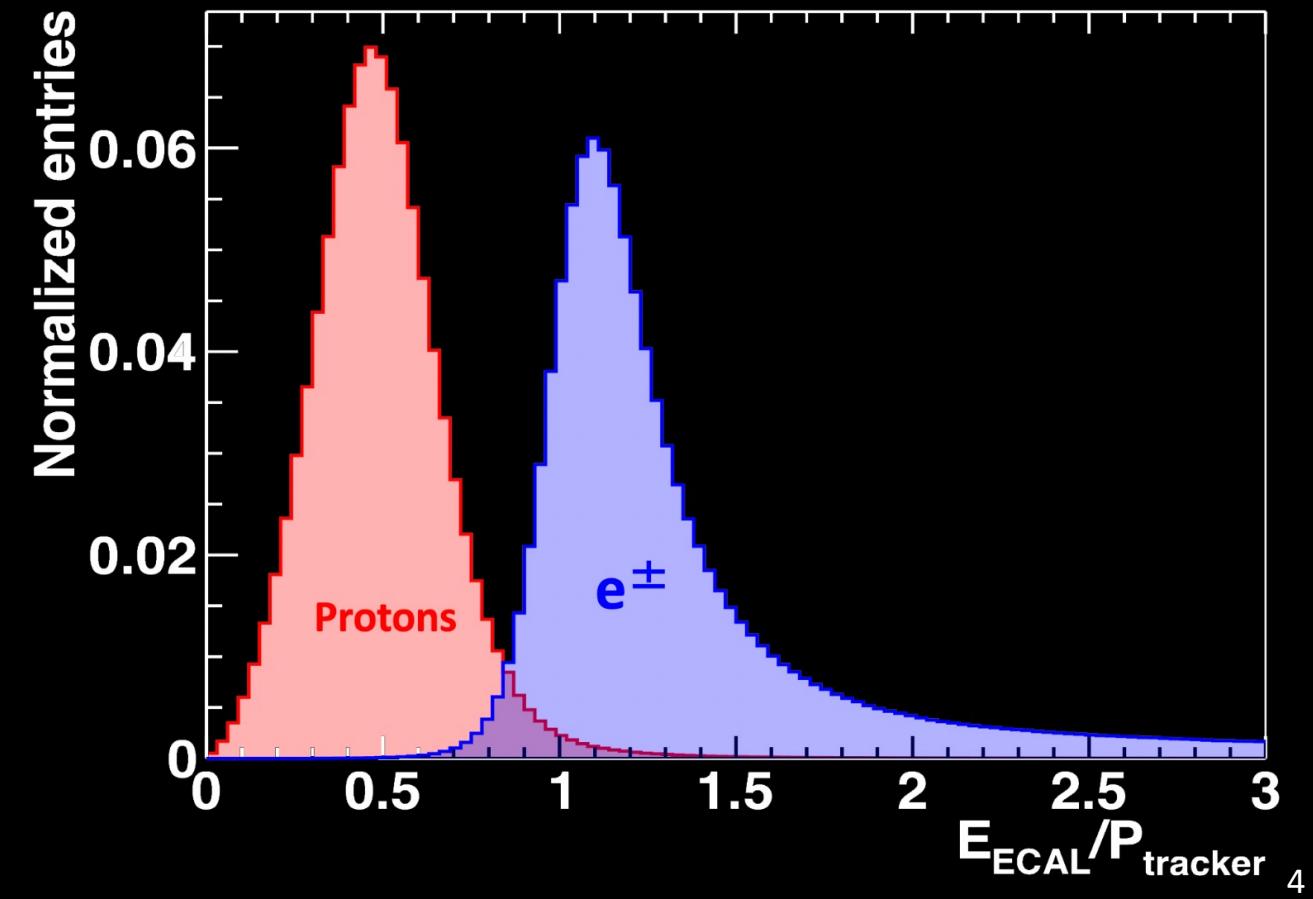


5248
proportional
tubes

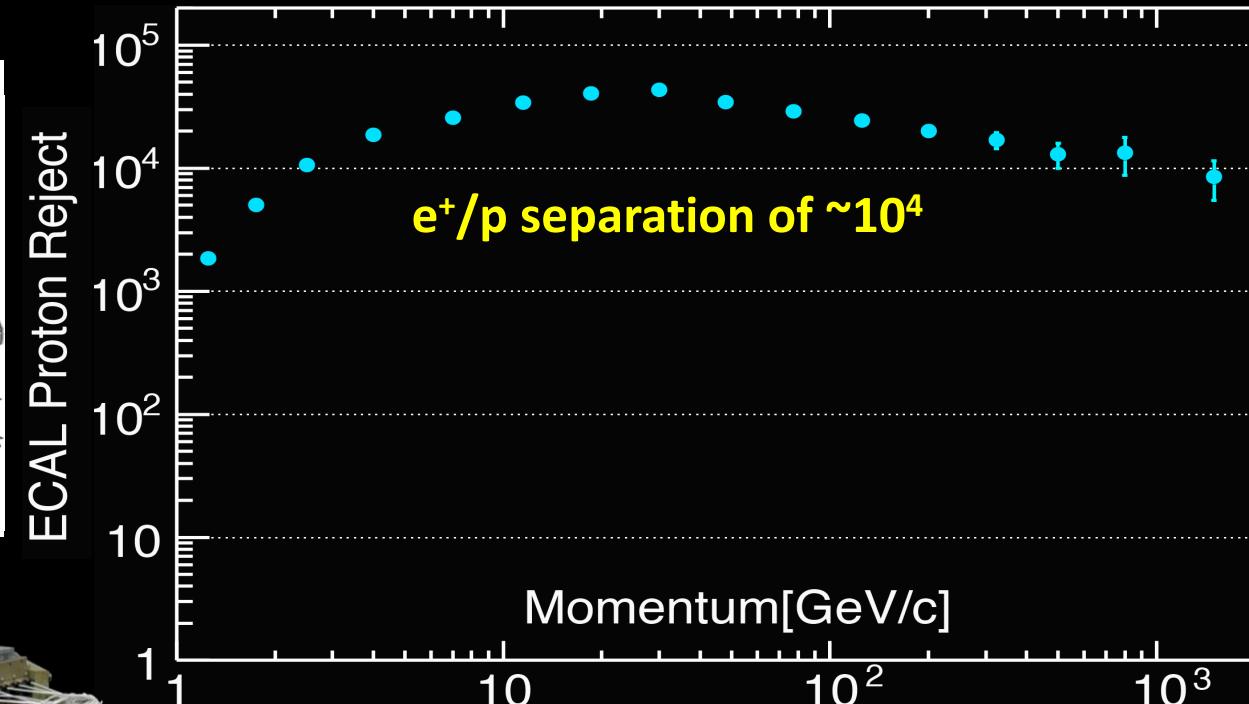
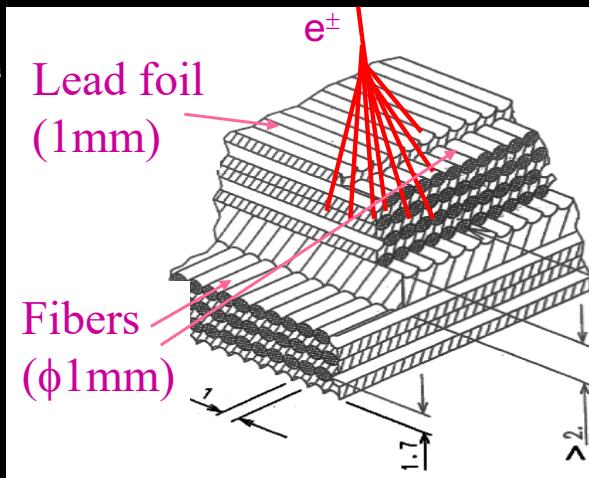
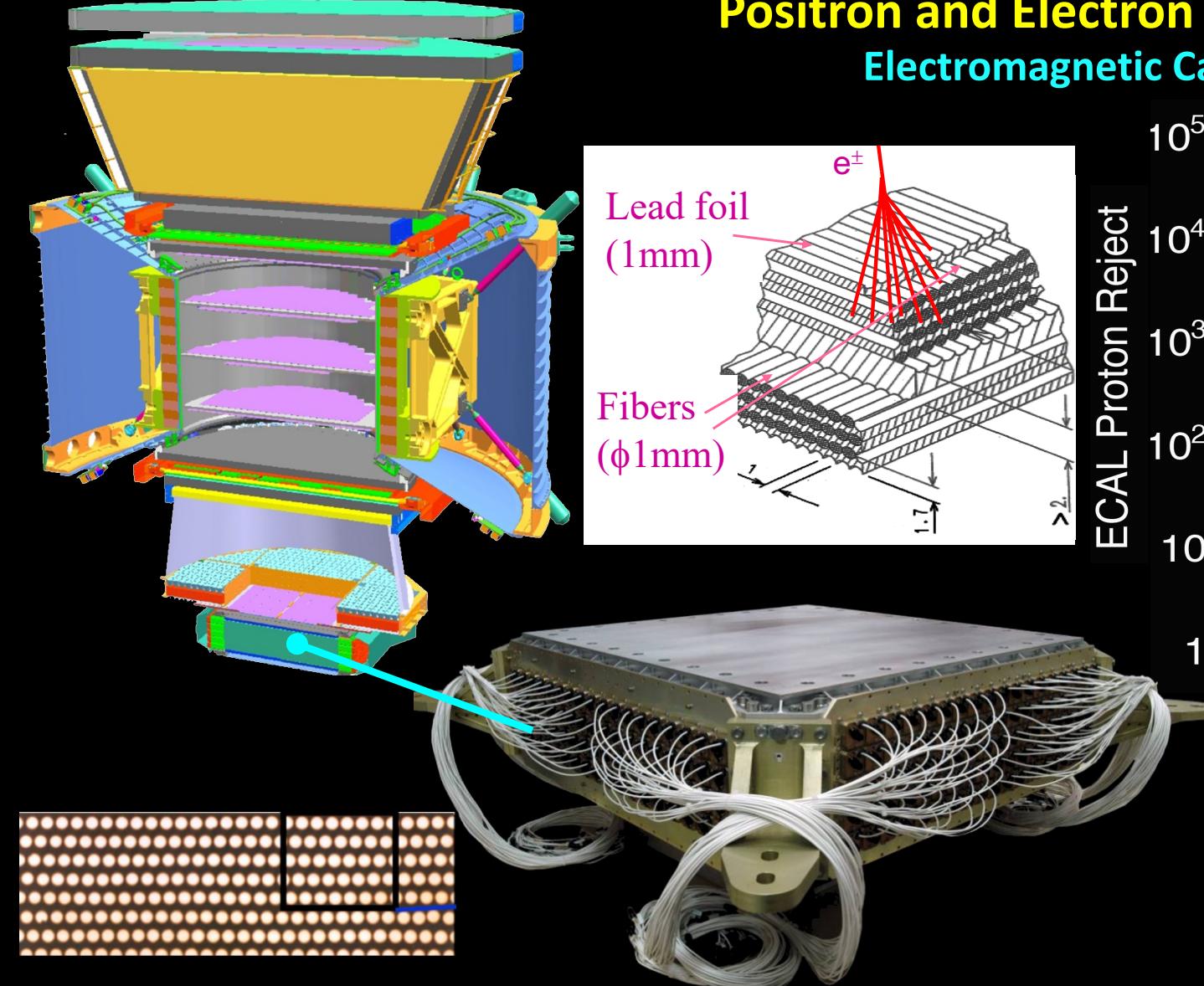
Positron and Electron Measurement in AMS



- Tracker and Magnet measures the sign and magnitude of momentum: separate electrons and positrons
- Unique particle identification capability of AMS: Independent Momentum and Energy measurement



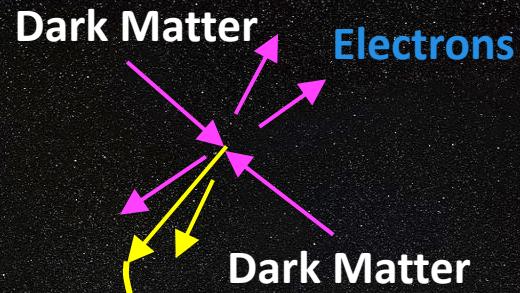
Positron and Electron Measurement in AMS Electromagnetic Calorimeter (ECAL)



ECAL measures the 3-D shower development over 17 radiation length of the directions and energies of electrons and positrons up to multi-TeV.

TRD and ECAL are separated by the magnet so that e^+ produced in the spectrometer do not enter the ECAL
 e^+/p separation of $> 10^6$

The Origins of Cosmic Positrons and Electrons



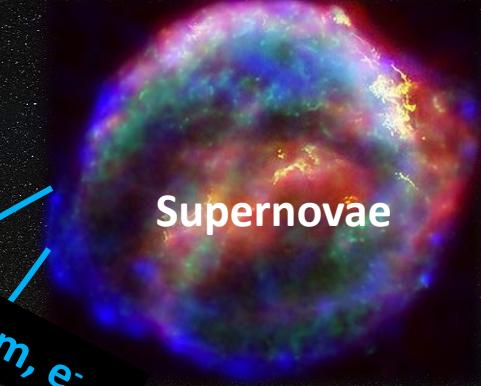
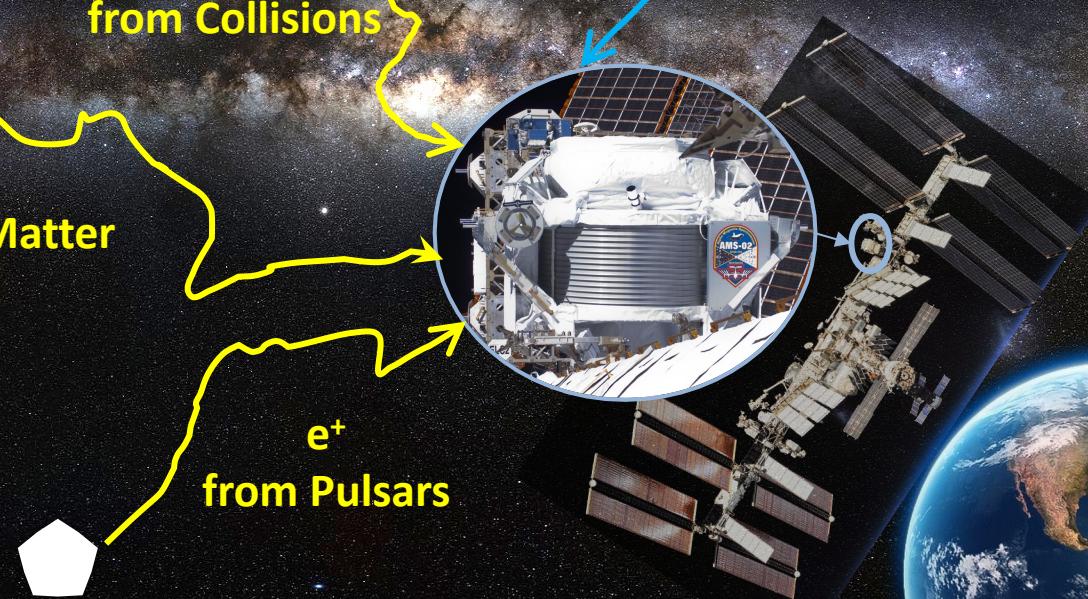
e^+
from Dark Matter

New Astrophysical Sources
(Pulsars, ...)

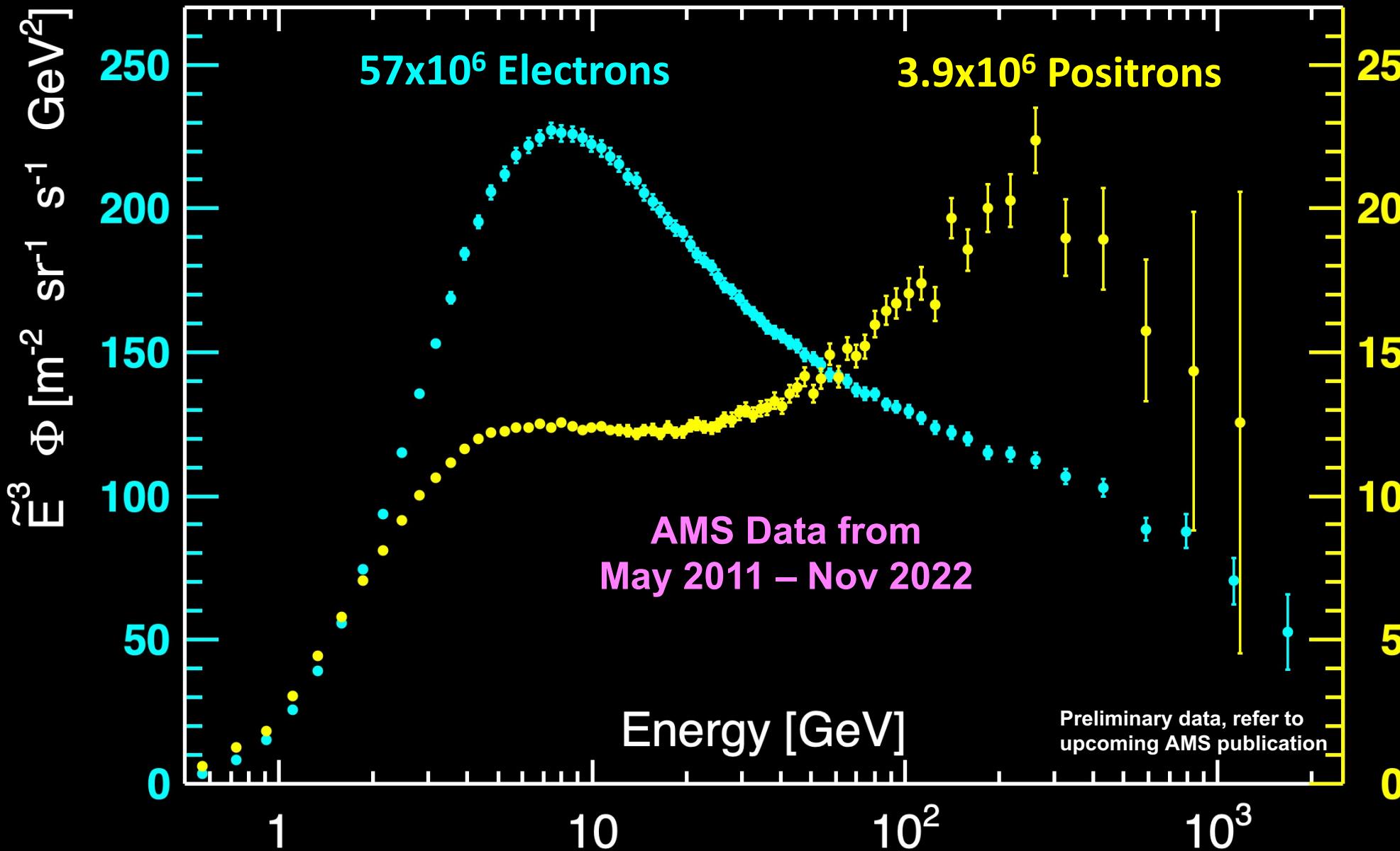


Interstellar Medium

e^+
from Collisions

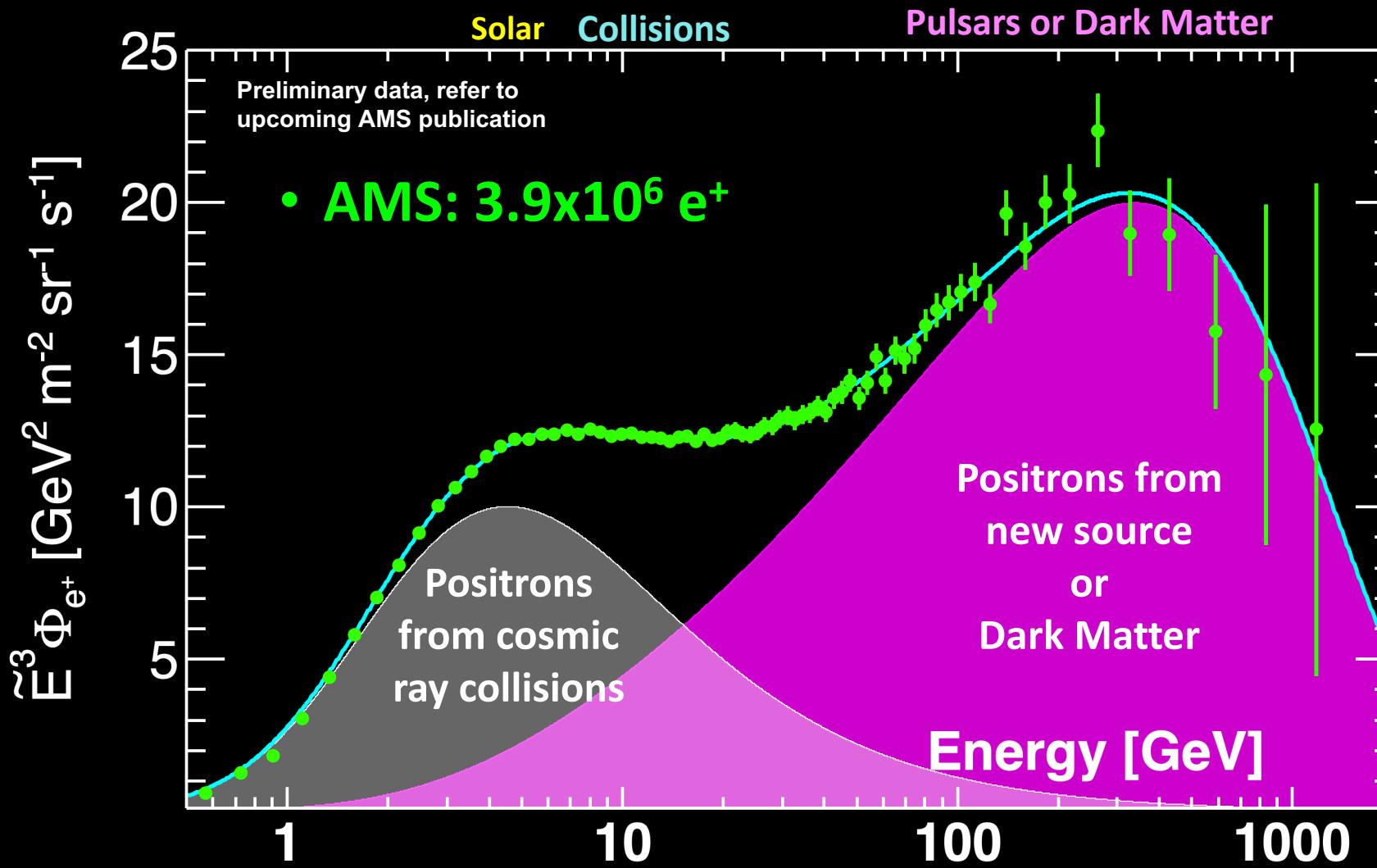


Latest Physics Results from AMS: Study of Positrons & Electrons



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 .

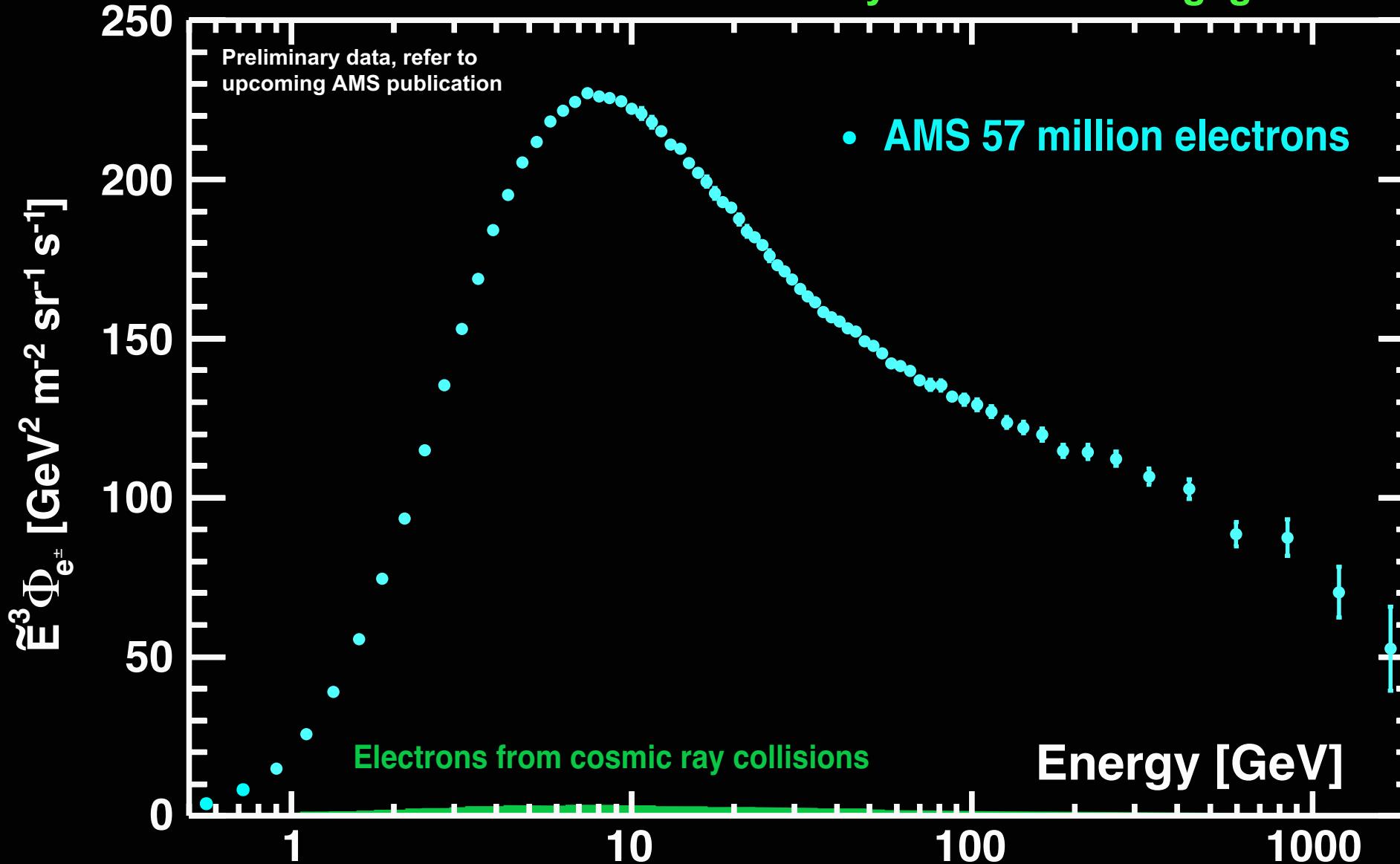
$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2} \left[C_d (\hat{E}/E_1)^{\gamma_d} + C_s (\hat{E}/E_2)^{\gamma_s} \exp(-\hat{E}/E_s) \right]$$



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

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

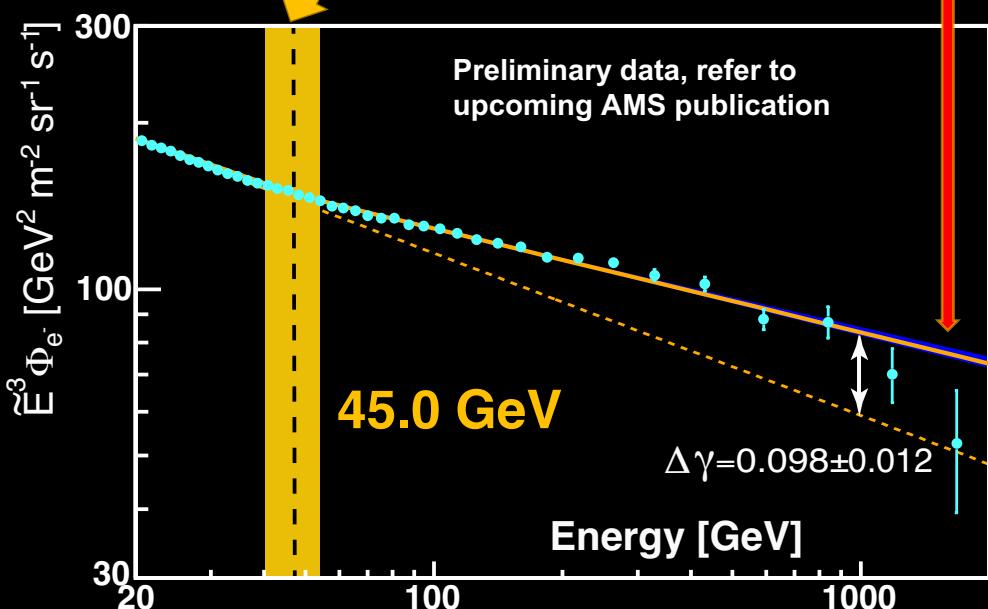
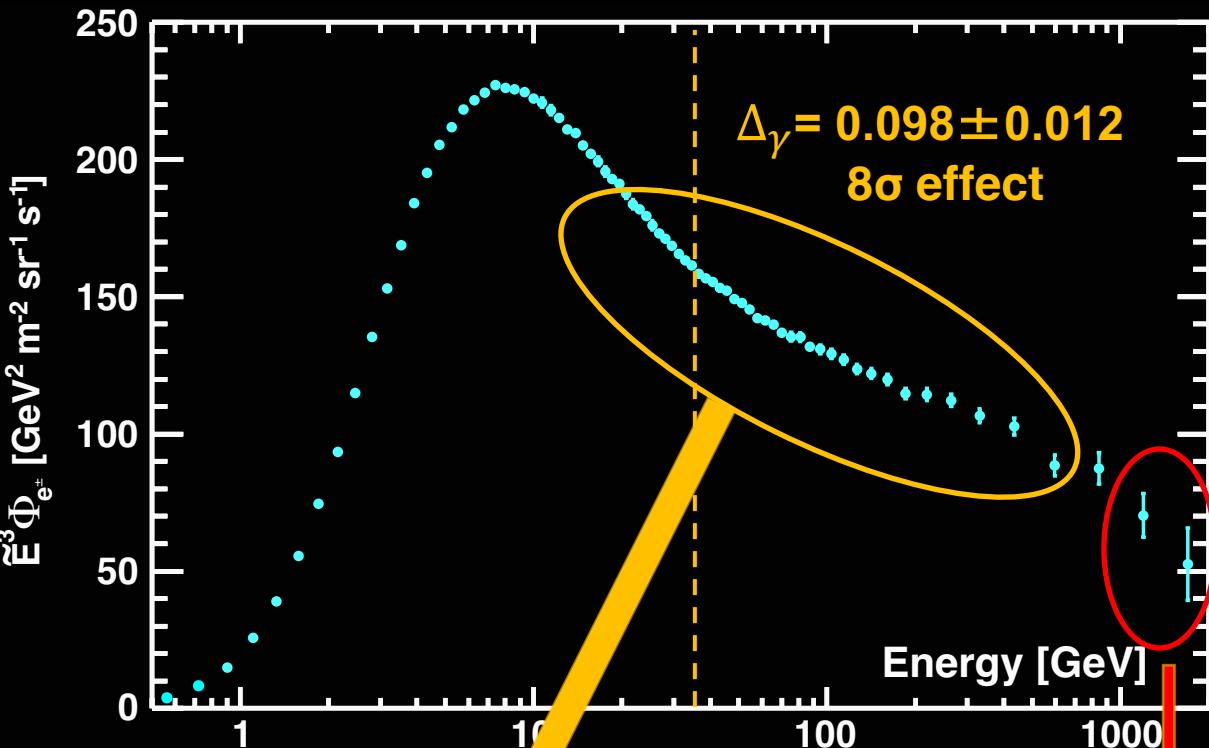
Change of the behavior at 45 GeV and at ~ 1 TeV

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

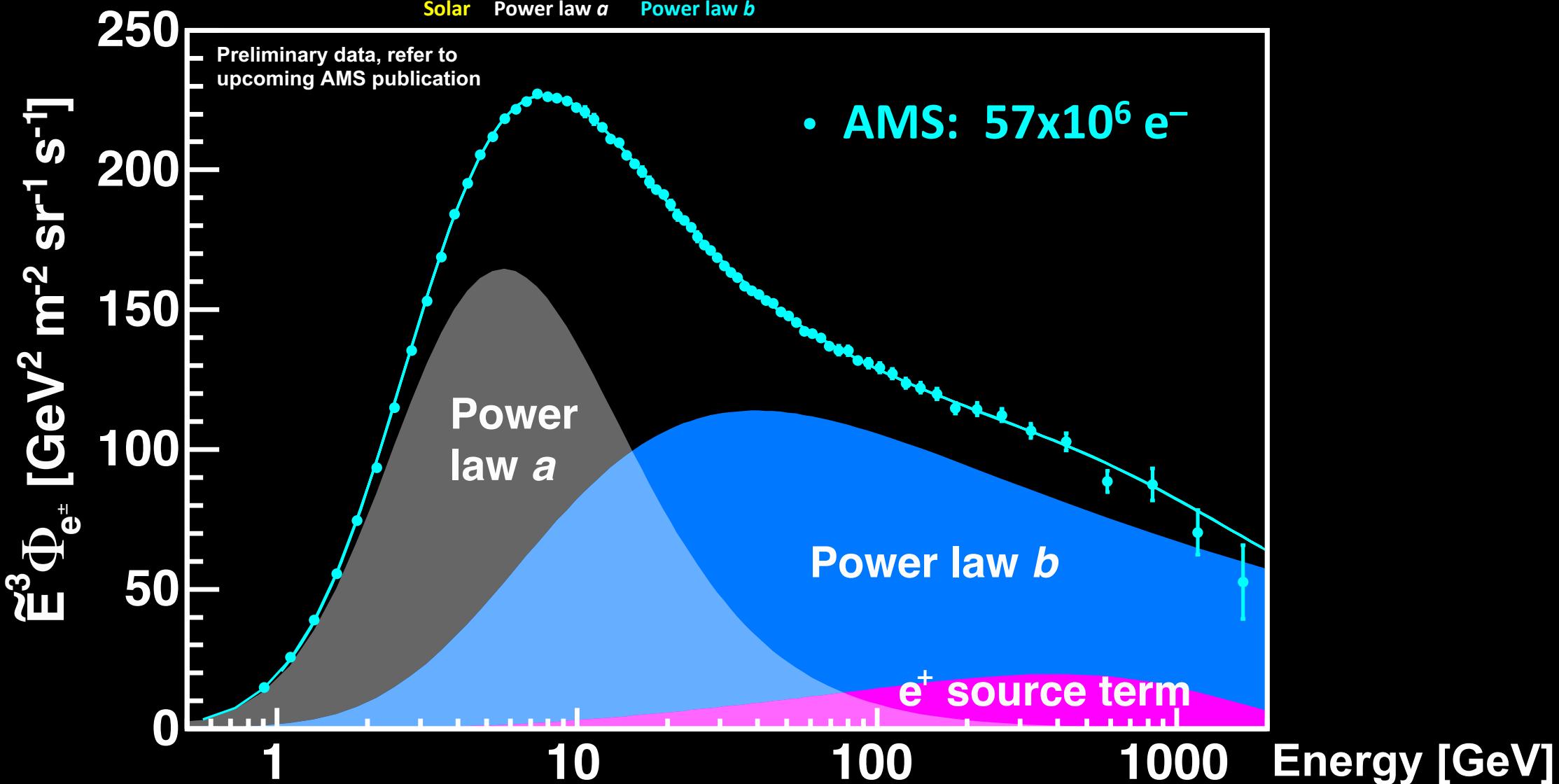
$$E_0 = 45.0 \pm 3.1 \text{ GeV}$$



AMS Result on the electron spectrum

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

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



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

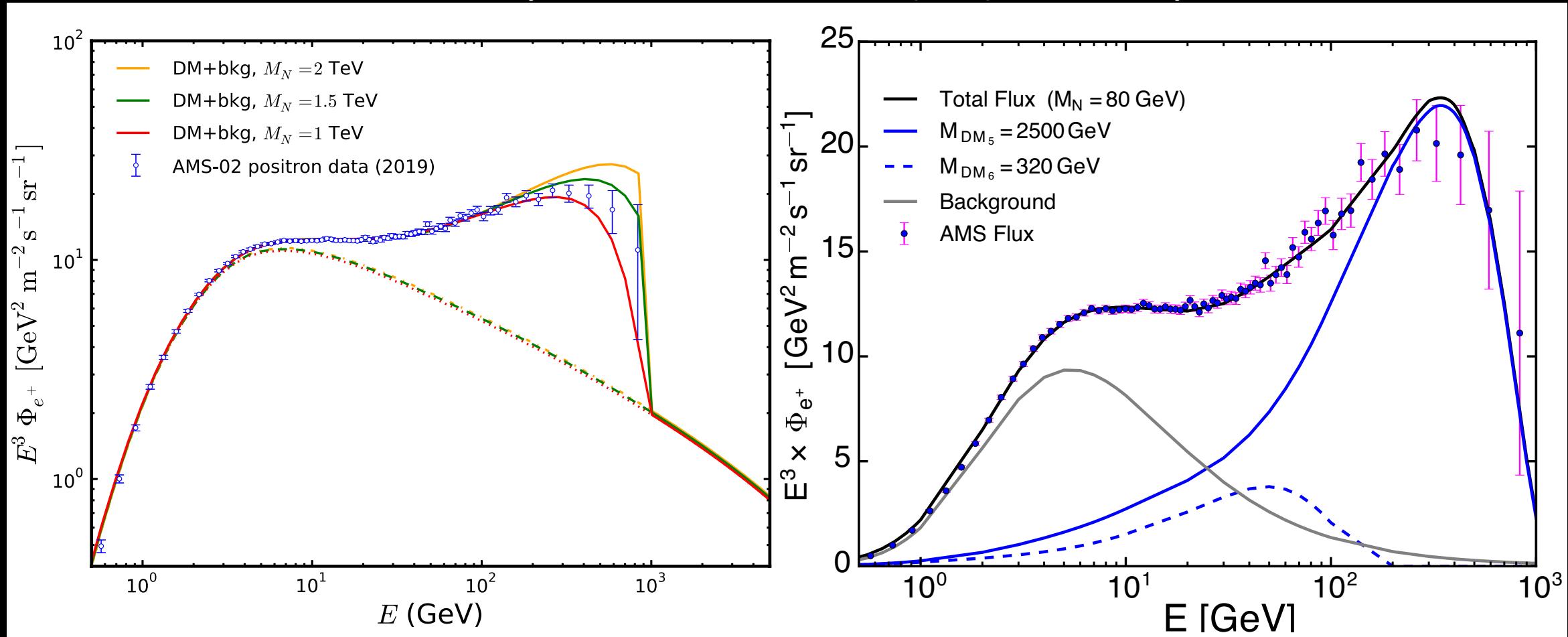
Examples of DM models discussed in the literature

DM annihilation

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

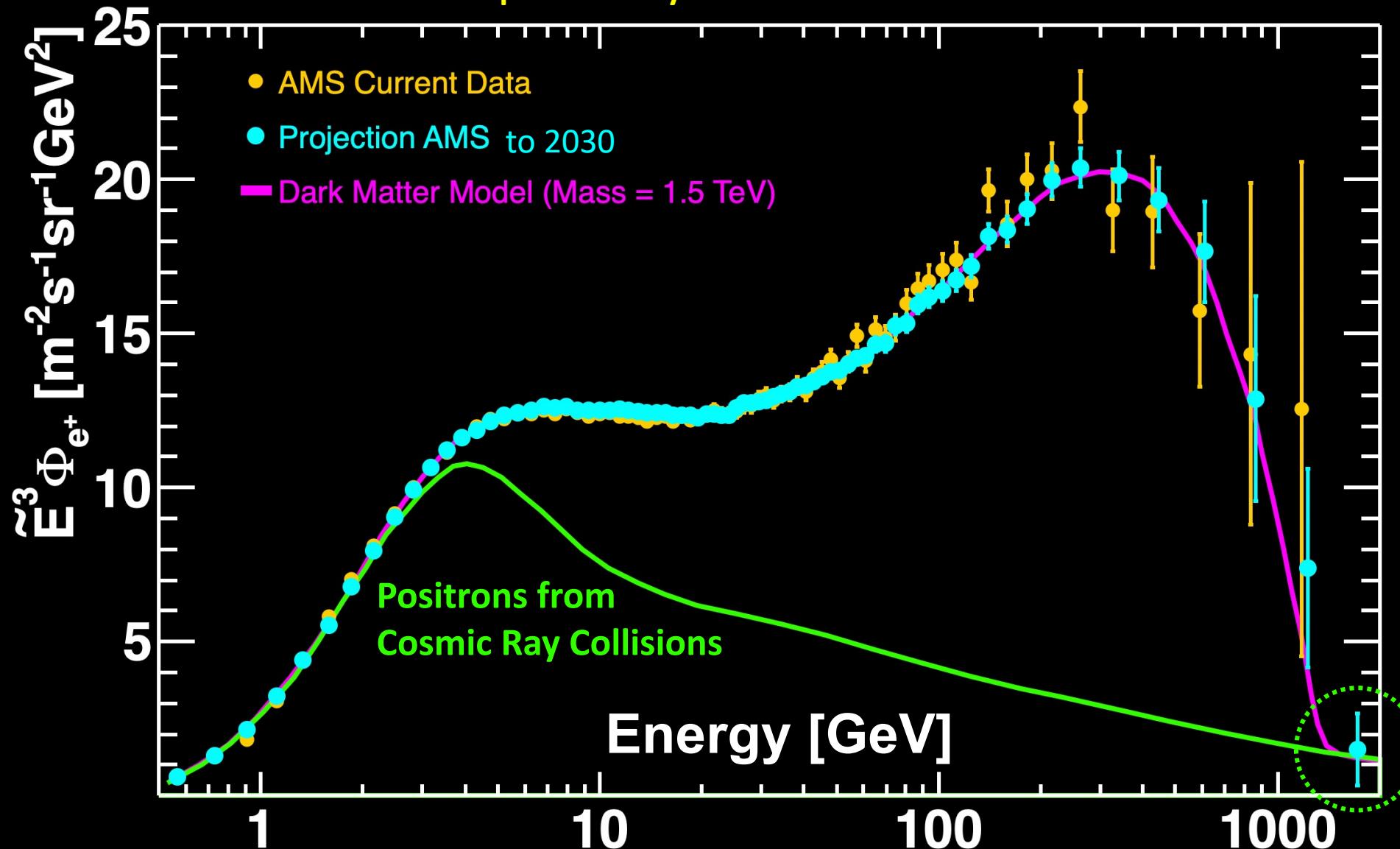
$$NN \rightarrow Z' Z' \rightarrow e^+ + X$$

Based on the AMS publication PRL 122, 041102 (2019) – 1.9 million positrons



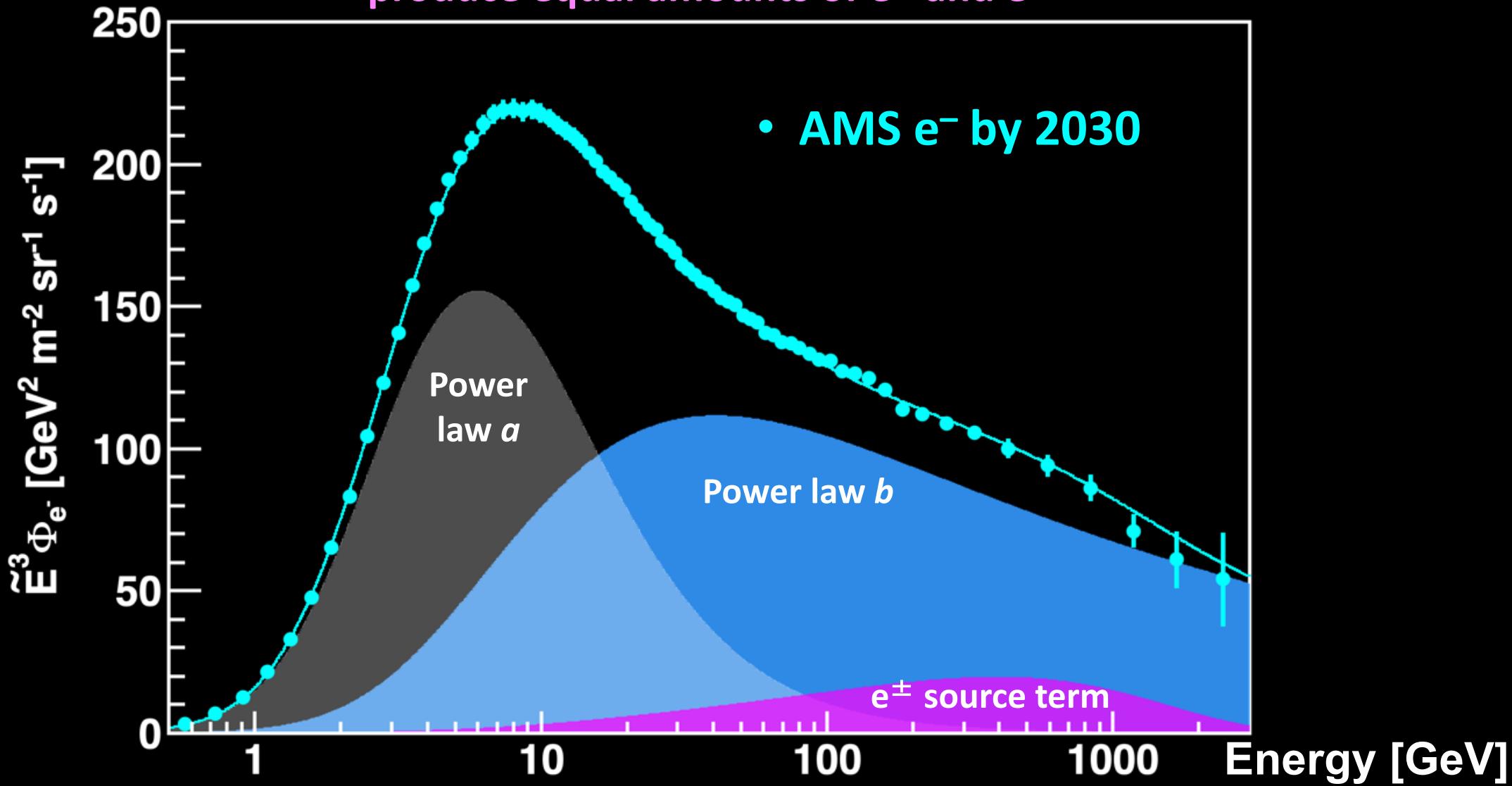
Determination of the Origin of Cosmic Positrons by 2030

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

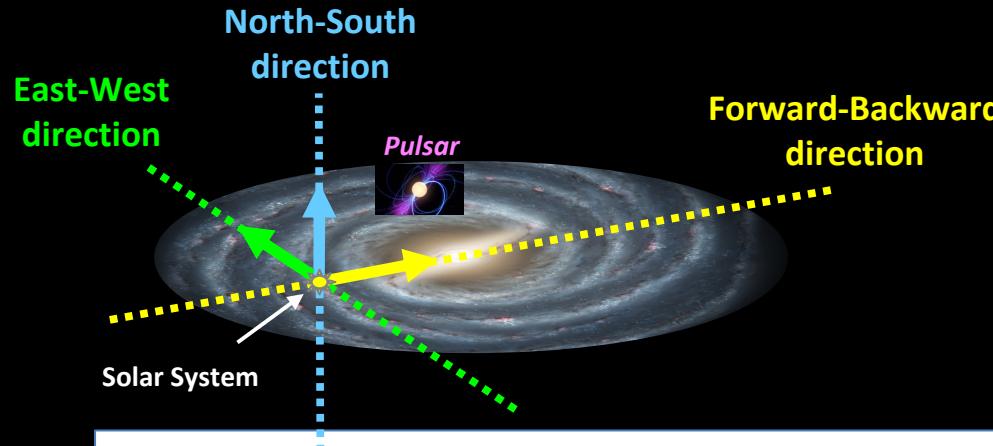


By 2030, the charge-symmetric nature of the high energy source
will be established at the 4σ level

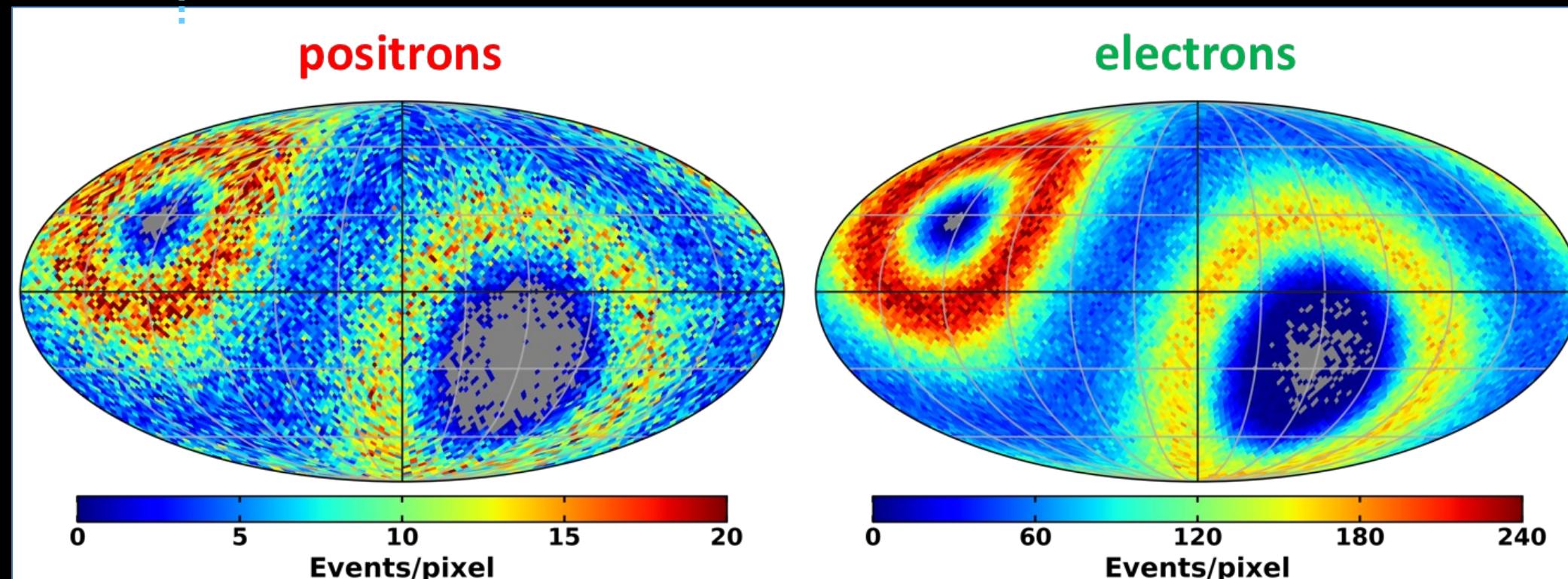
New sources, like Dark Matter or Pulsars,
produce equal amounts of e^+ and e^-



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.

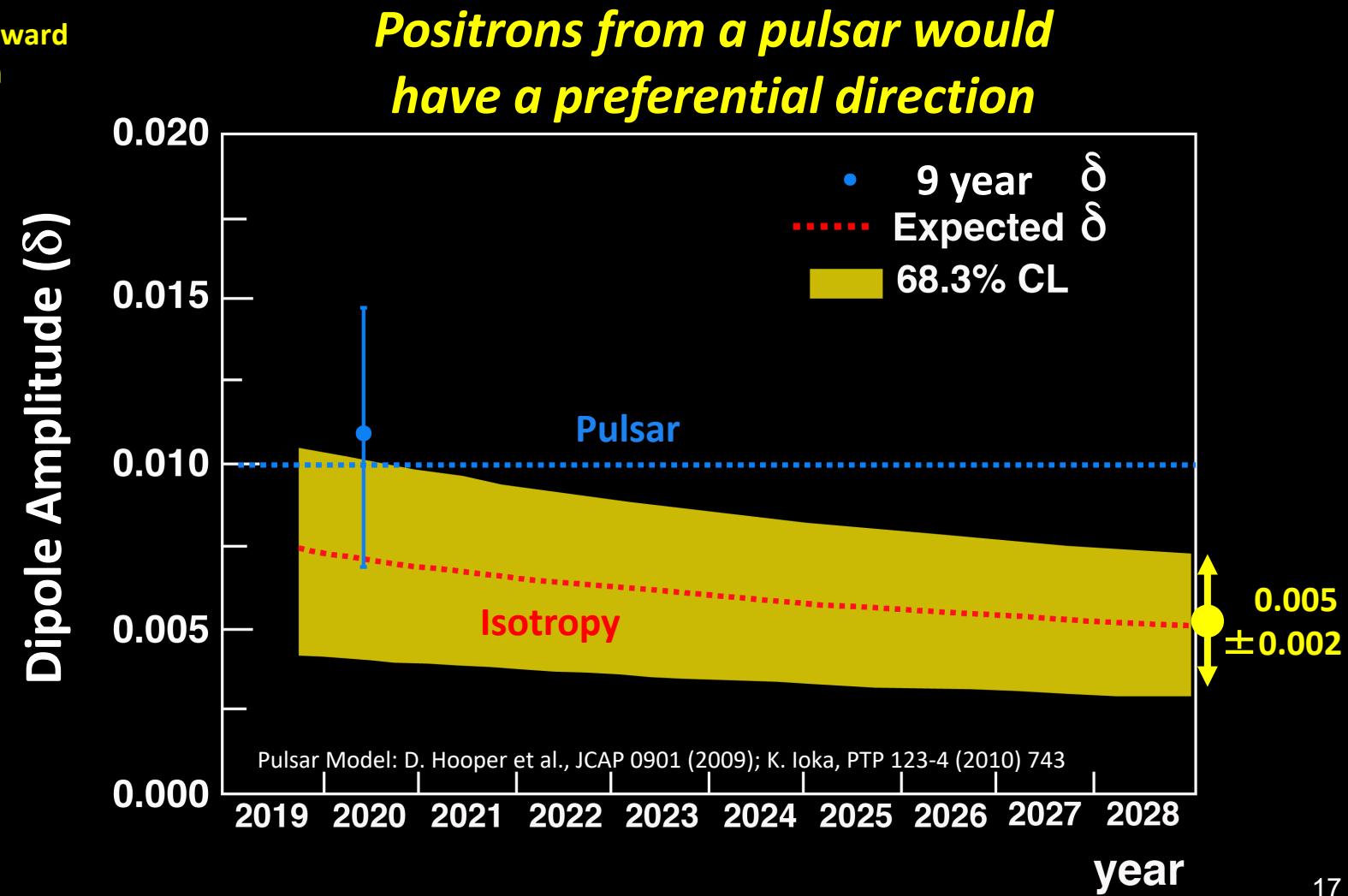
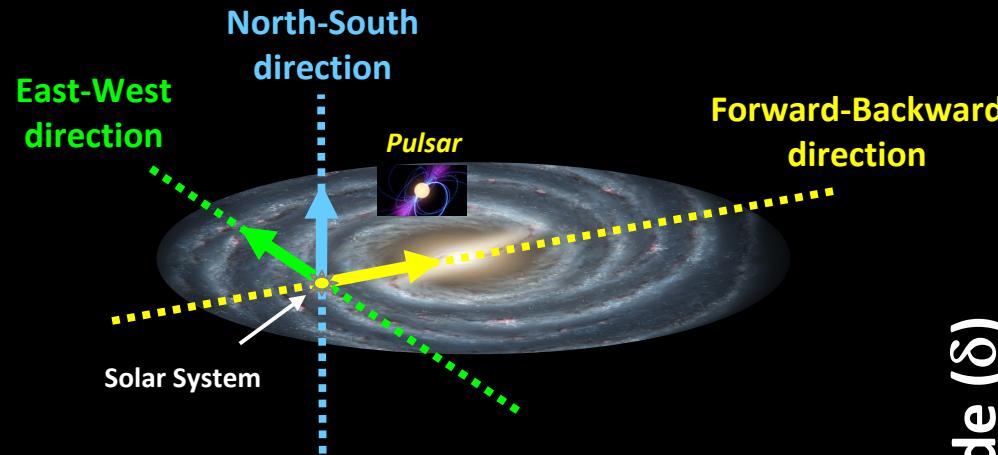


Dipole anisotropy:

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

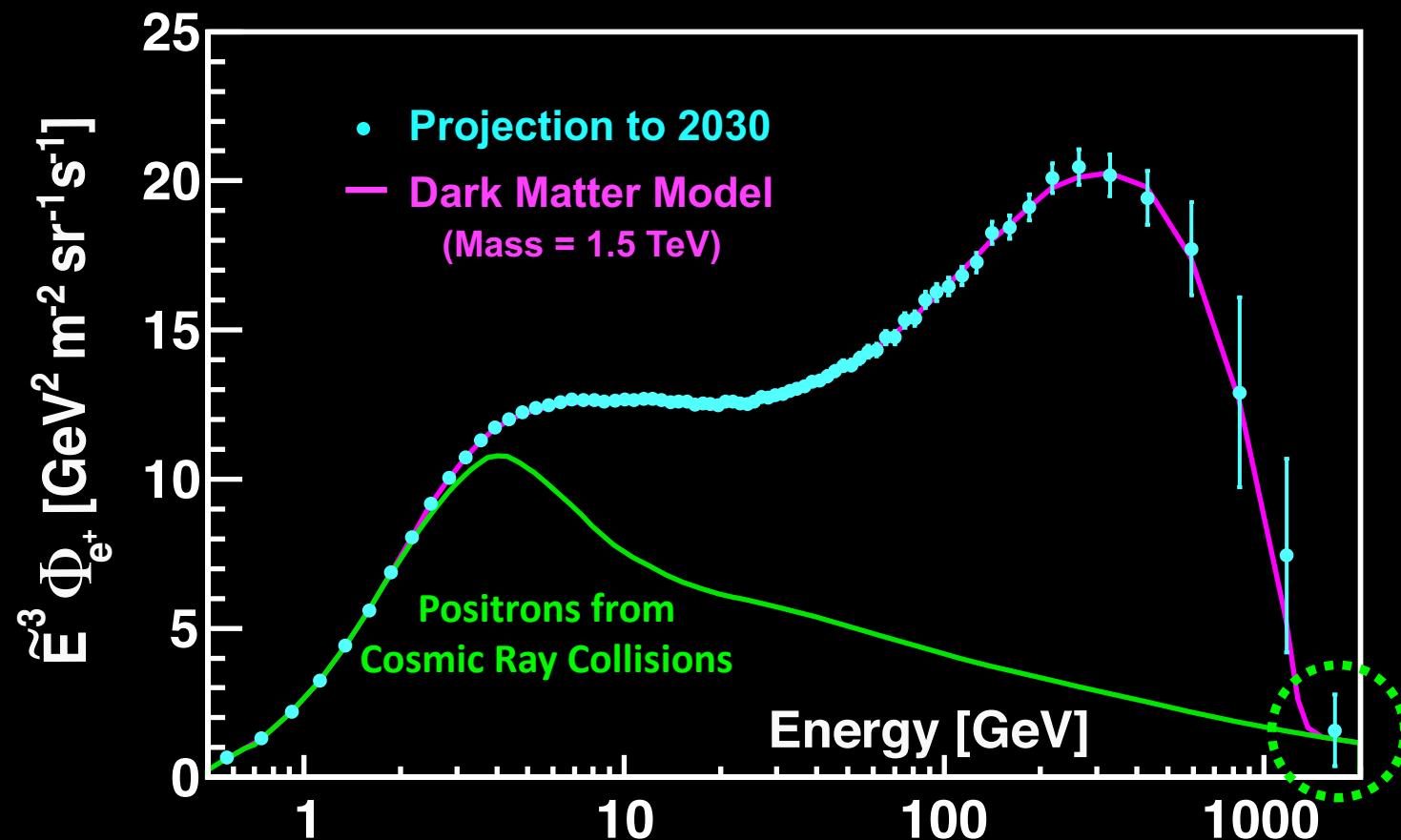
C_1 is the dipole moment

By 2030, the positron statistics will allow us to measure the anisotropy accurately, separation between dark matter and pulsars at the 99.93% C.L.



Conclusions

- **Positron spectrum requires an additional source of high energy positrons:**
 - can not be explained by the ordinary CR collisions
 - has an exponential cutoff with $E_s = 749 \text{ GeV}$;
 - AMS measurement to 2030 will enable us to determine the origin of the behavior of positrons at high energies



Conclusions

- 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.
- AMS measurement to 2030 will establish the existence of charge-symmetric positron-like source term at highest electron energies.

