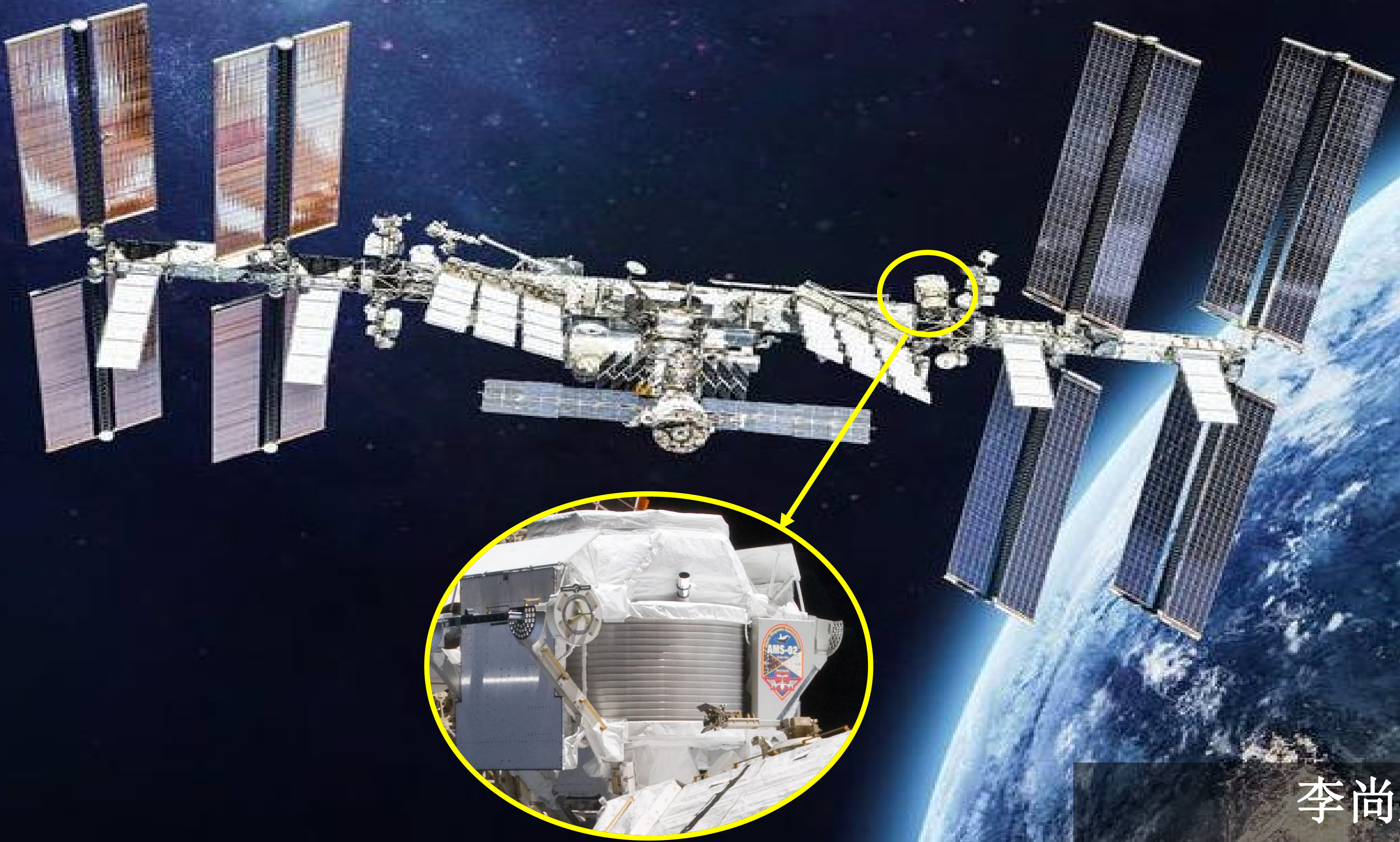
Understanding the Origin of Cosmic-Ray Electrons



李尚霖 / IHEP, CAS

on behalf of the AMS Collaboration

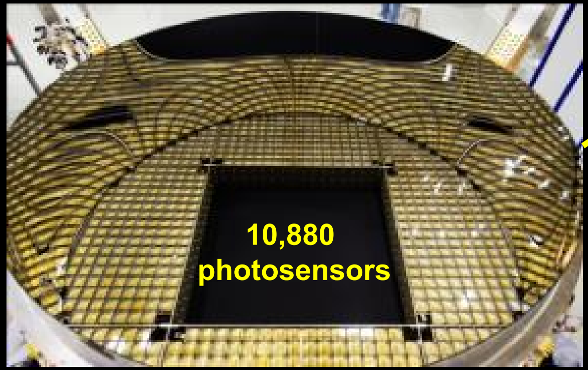
2024年5月8日

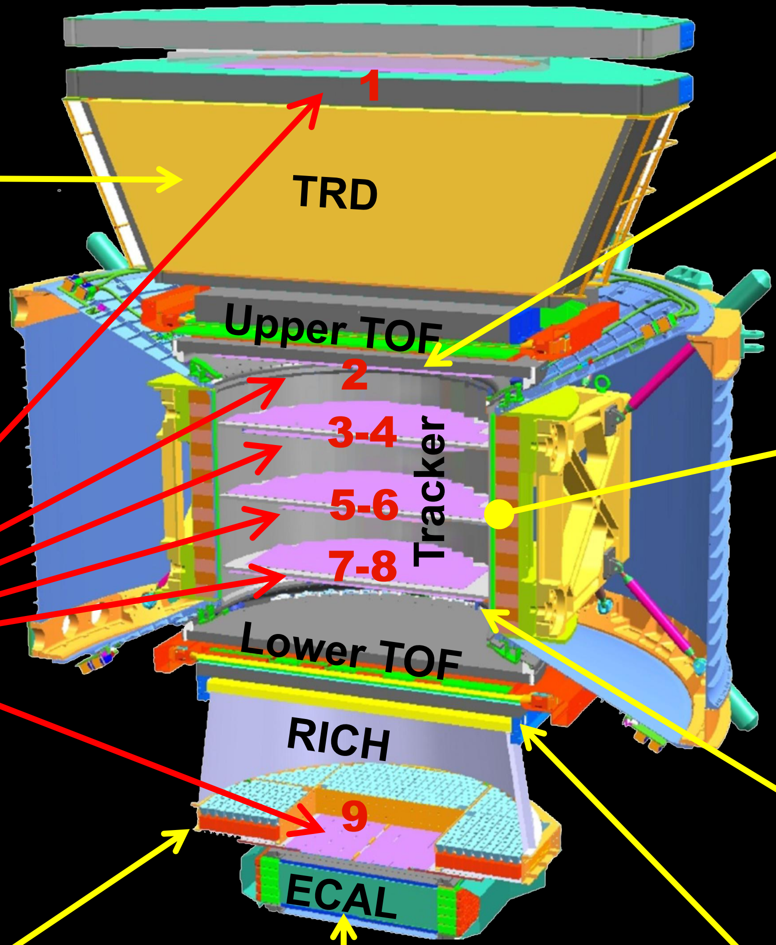
AMS is a space version of a precision detector used in accelerators

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^-

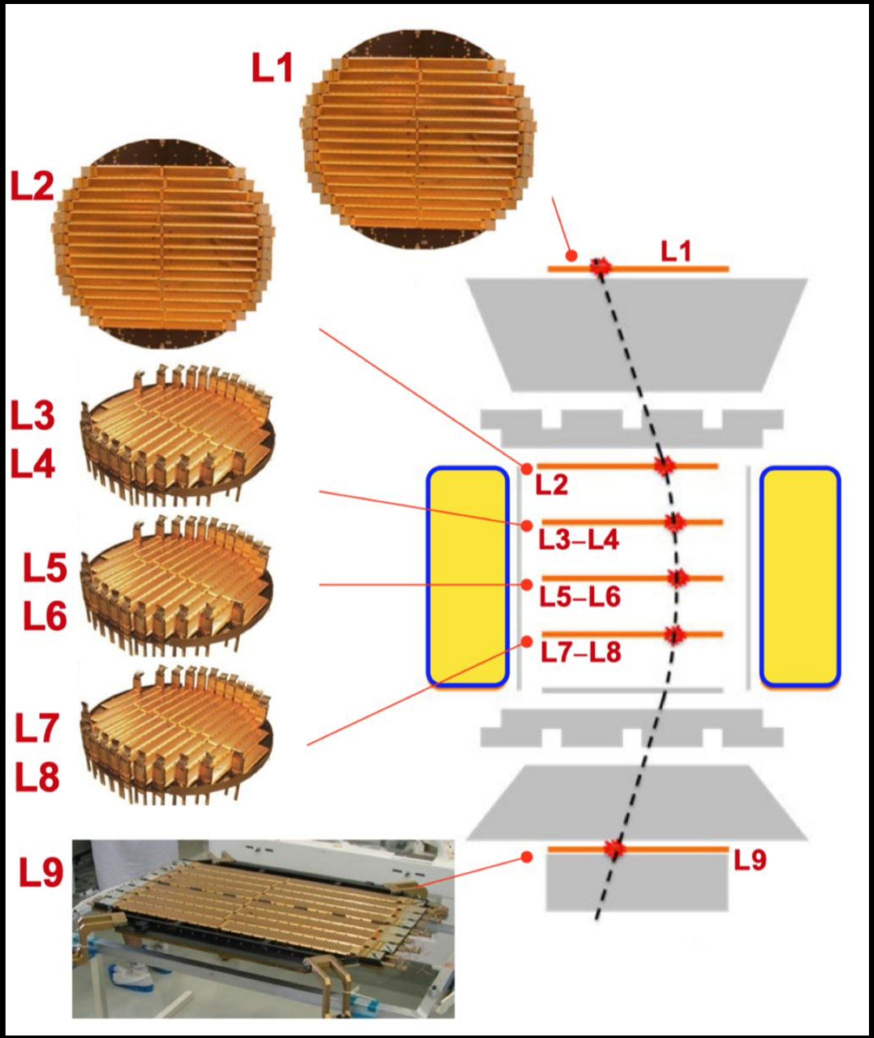
Upper TOF measure Z, E

Magnet identify ±Z, P

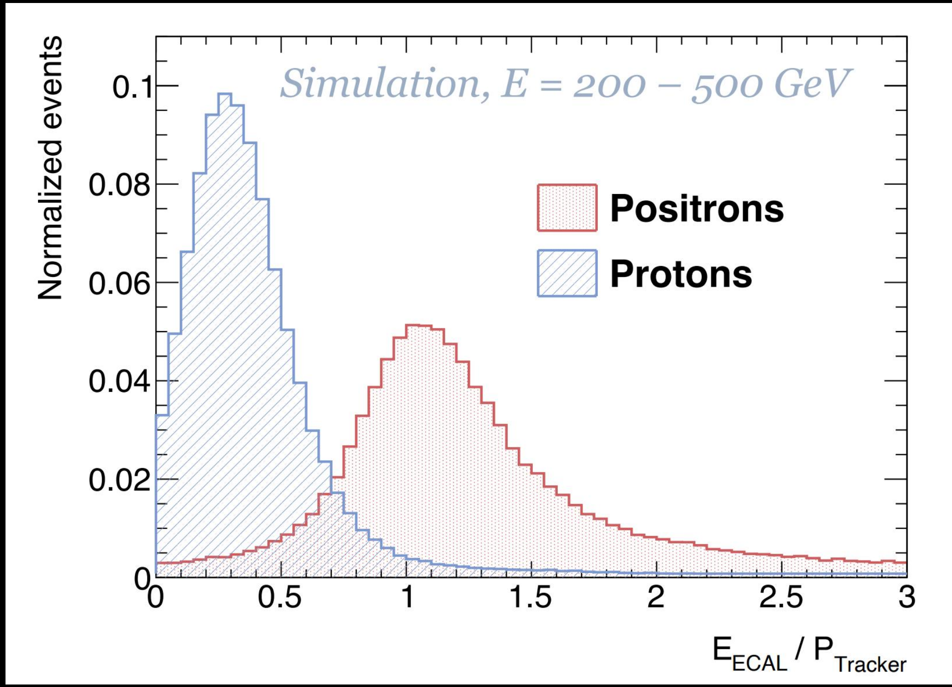
Anticoincidence Counters (ACC)
reject particles from the side

Lower TOF measure Z, E

Energy and momentum measurements



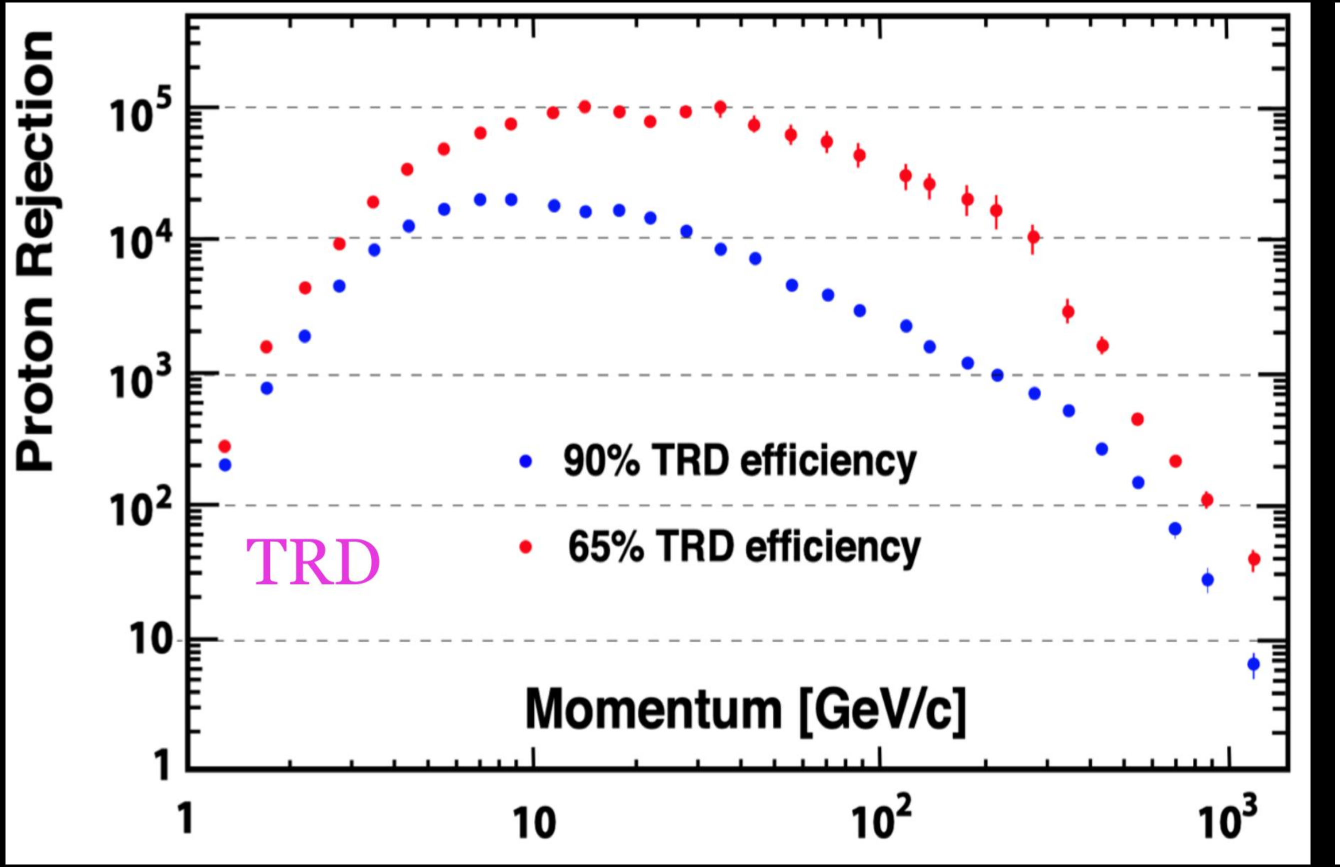
- Nine layers in AMS tracker forms 3 m lever arm
- For particle with Z=1:
  - Single point resolution is 10 um
  - The maximum detectable rigidity is 2 TV

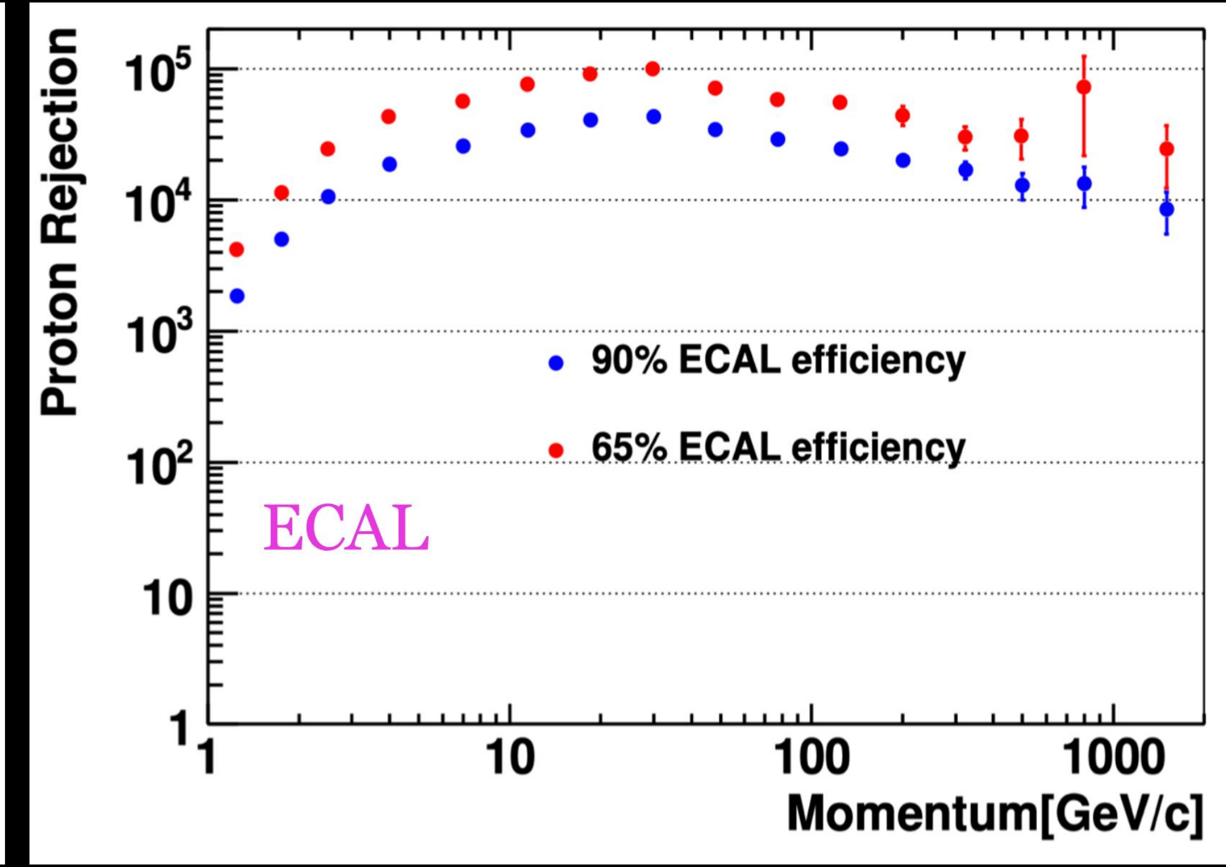


Independent momentum(by tracker) and energy(by calorimeter) measurements allows to distinguish $e^{\pm}$ from protons

Proton rejection

- TRD and ECAL provides independent proton rejection
- Combined proton rejection power at 90% signal efficiency is ~1 in 10^6





AMS on ISS

AMS 2011-2025

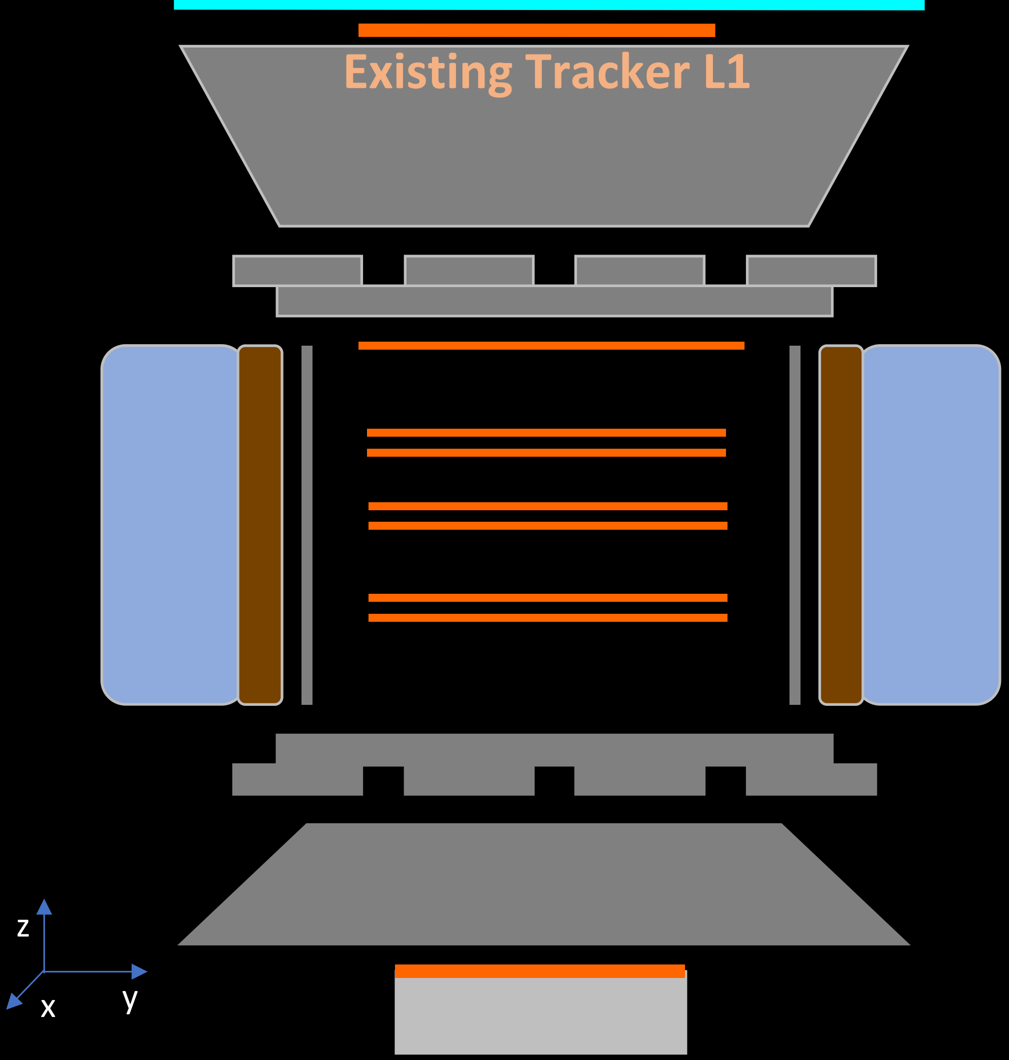
Continuous data-taking

Latest Results: 2011-2022

AMS 2025-2030

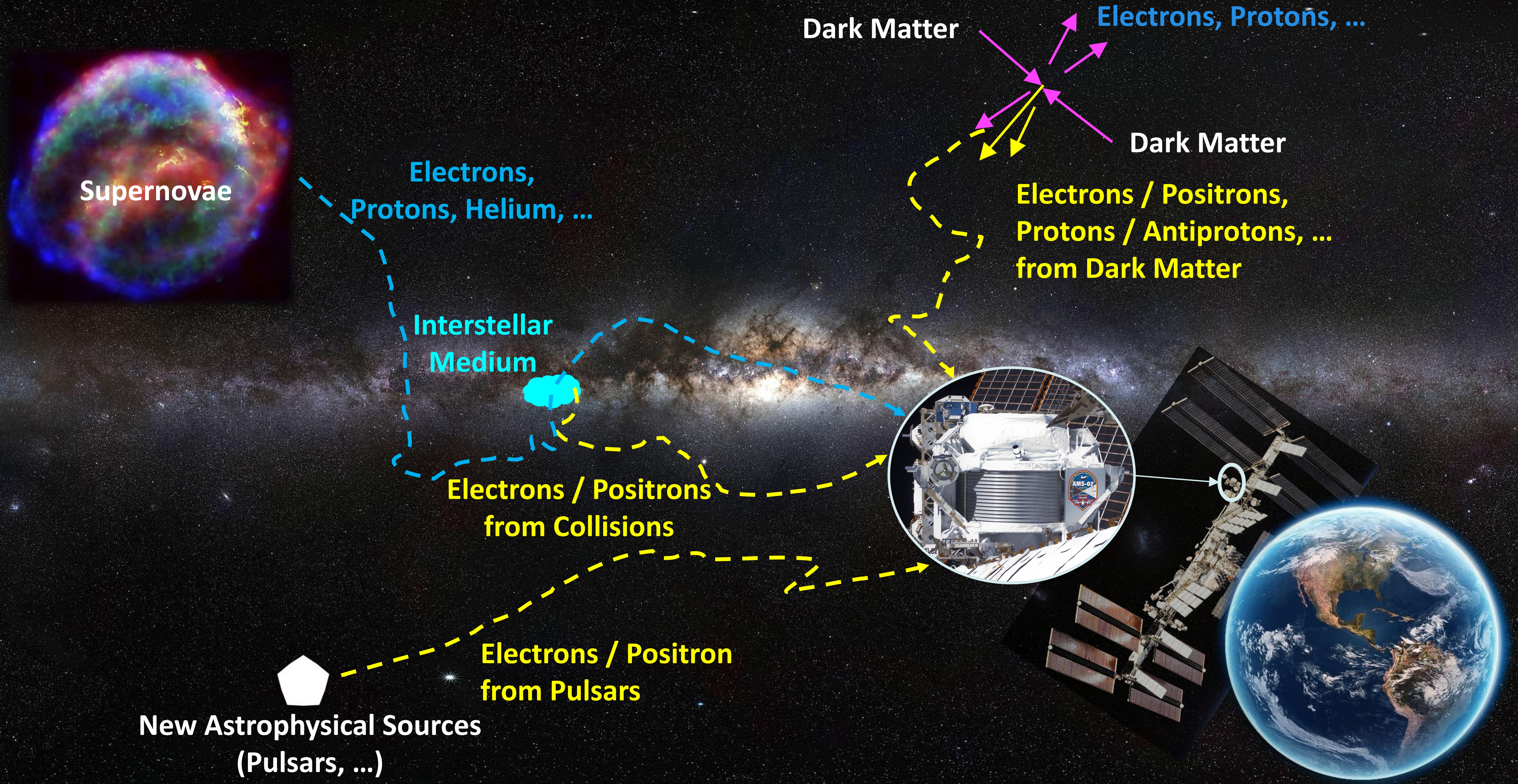
New $8m^2$ Silicon Tracker Layer

Acceptance increased to 300%



and Projections to 2030

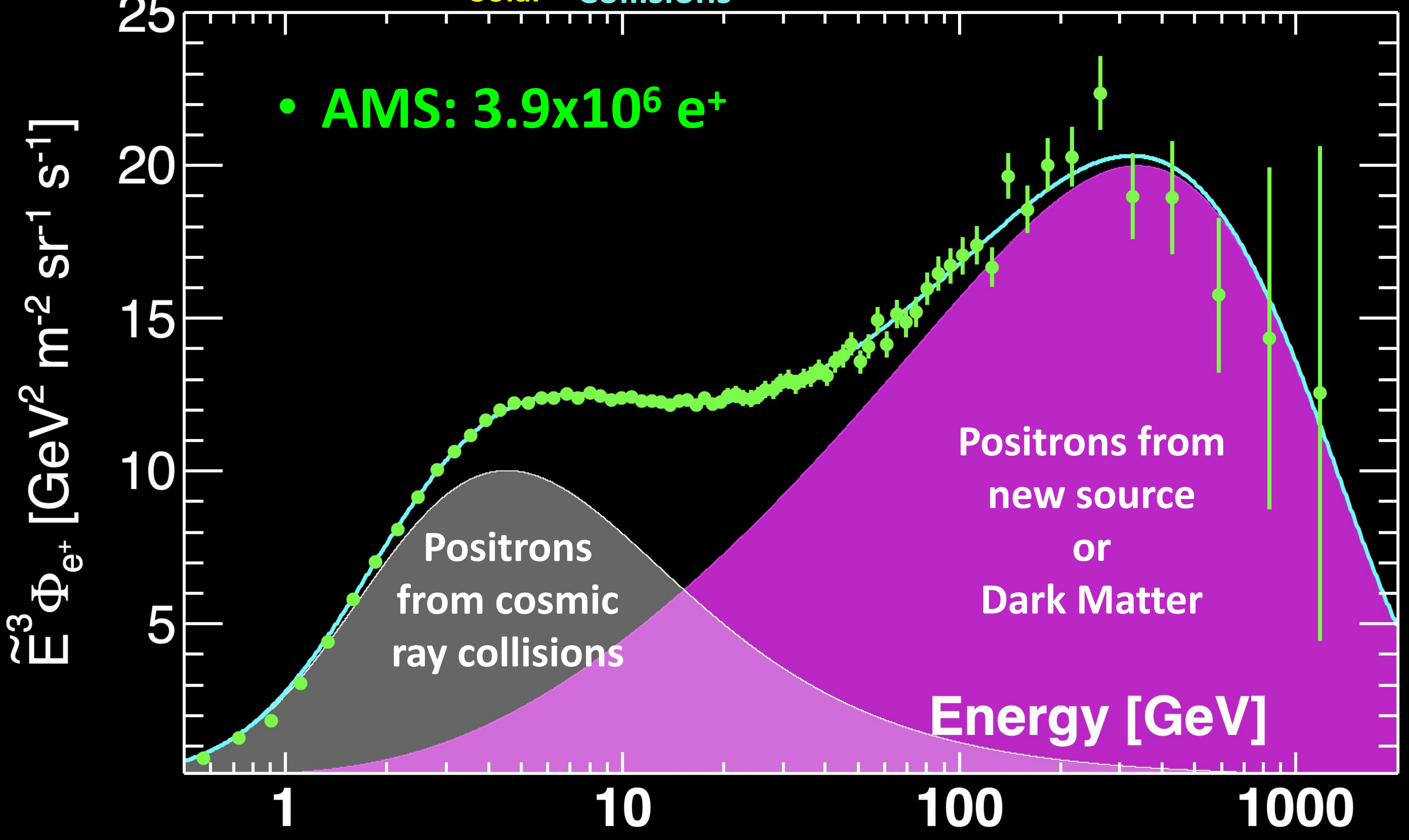
Latest Physics Results from AMS: Study of Positrons & Electrons



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.

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

Solar Collisions Pulsars or Dark Matter



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

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

Dark Matter

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 …

Astrophysical sources

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 …

Propagation

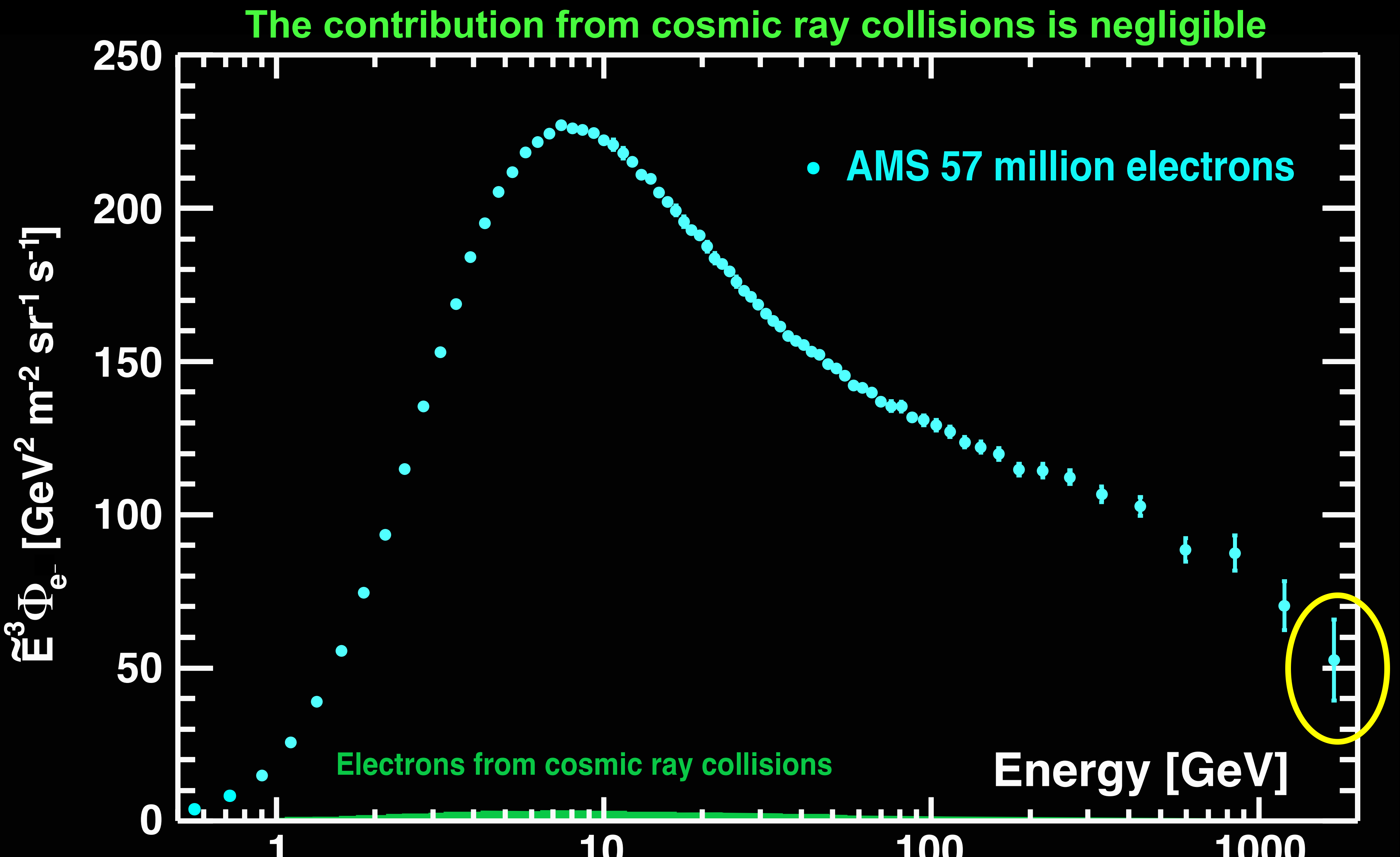
1) E. Amato and S. Casanova, J.Plasma Phys. 87 (2021) 1, 845870101
2) Z. Tian et al., Chin.Phys. C44 (2020) 8, 085102
3) W. Zhu, P. Liu, J. Ruan, and F. Wang, Astrophys.J. 889 (2020) 127
4) P. Liu and J. Ruan, Int.J.Mod.Phys. E28 (2019) 09, 1950073
5) R. Diesing and D. Caprioli, Phys.Rev.Lett. 123 (2019)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

Origins of Cosmic Electrons



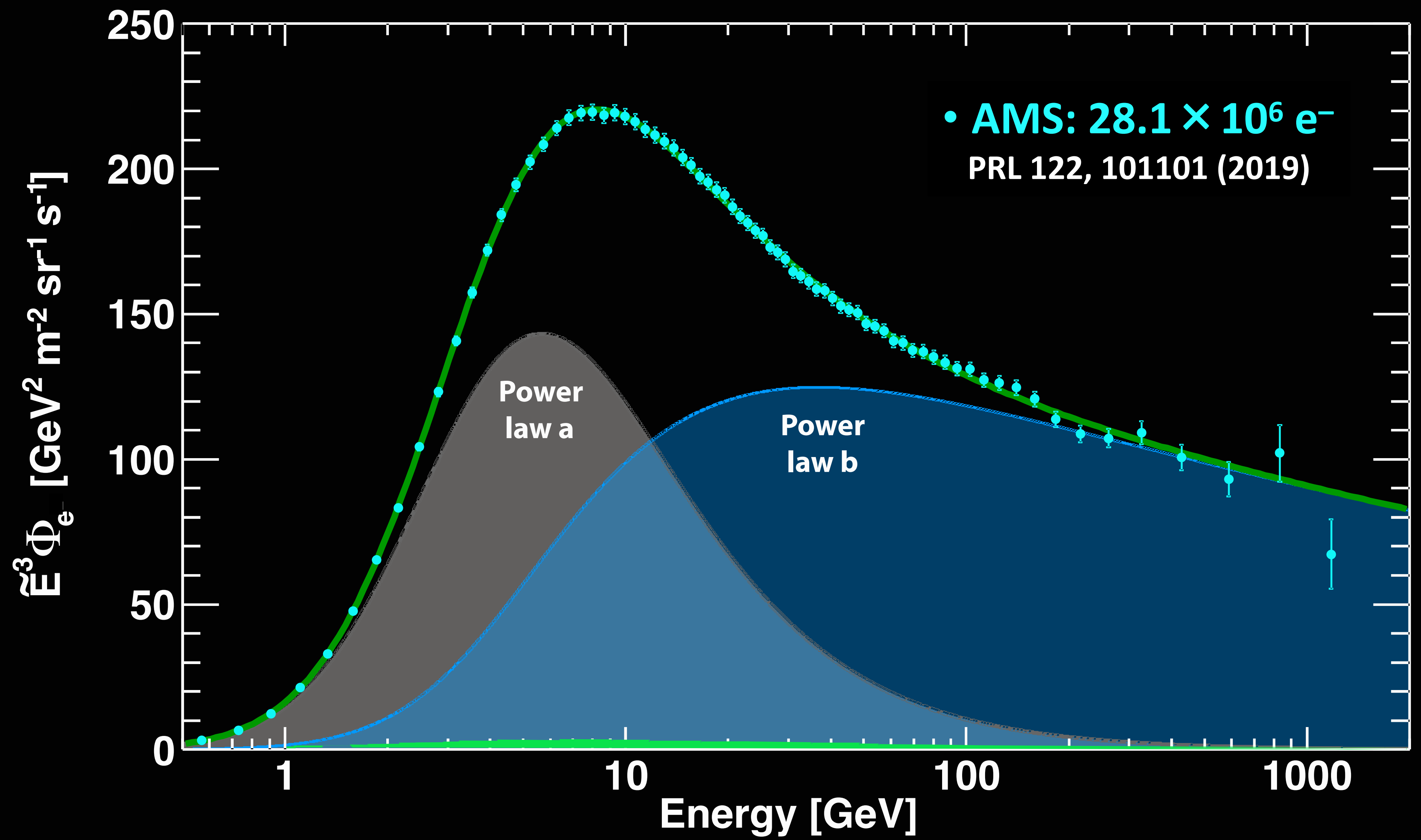
The electron flux description by two power law functions is disfavored:

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

Solar & low-energy

Power law *a*

Power law *b*



Origins of Cosmic Electrons

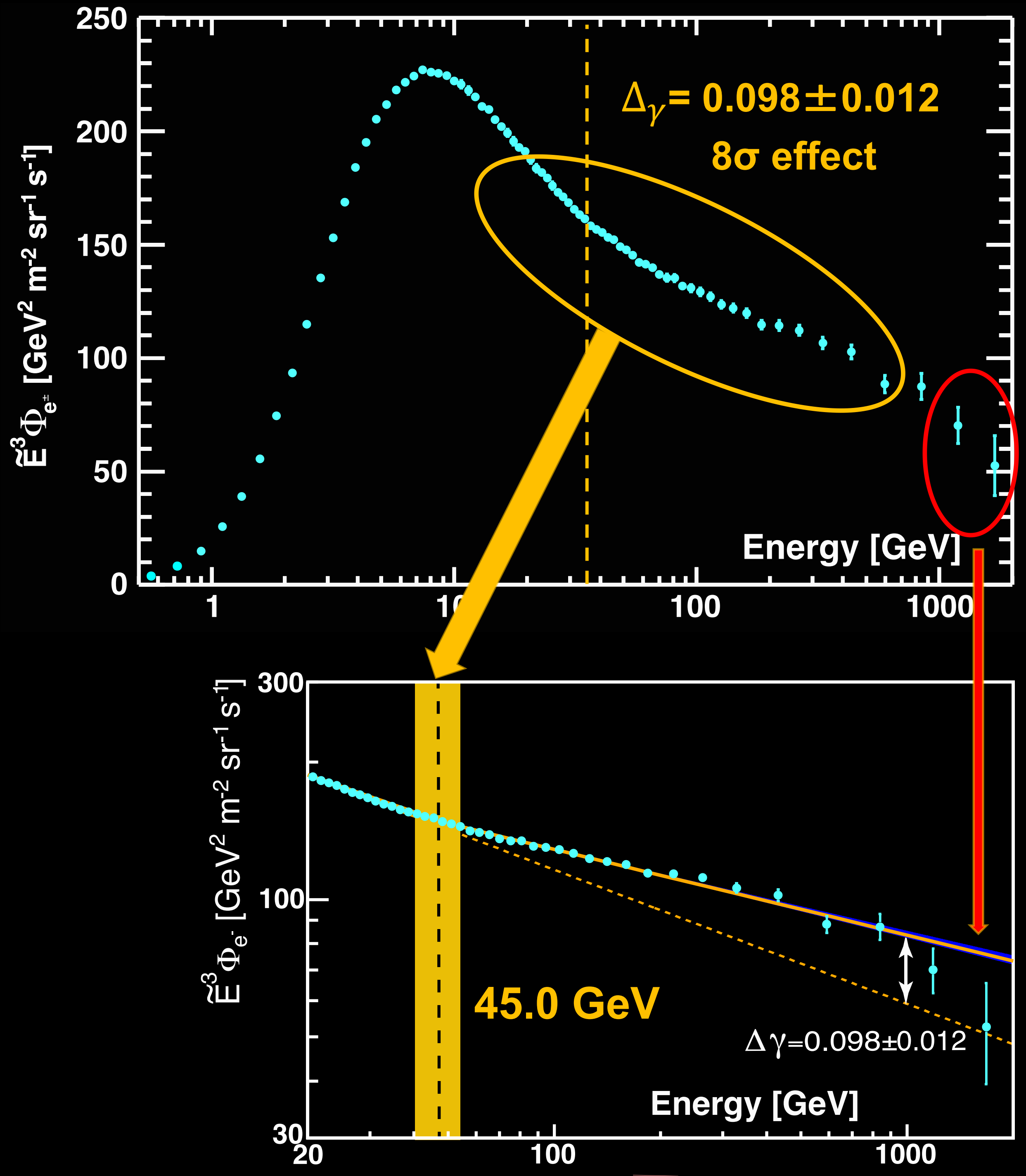
Traditionally, Cosmic Ray spectrum is described by a power law function

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

Fit to data

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

A significant excess at E_0 = 45.0±3.1 GeV

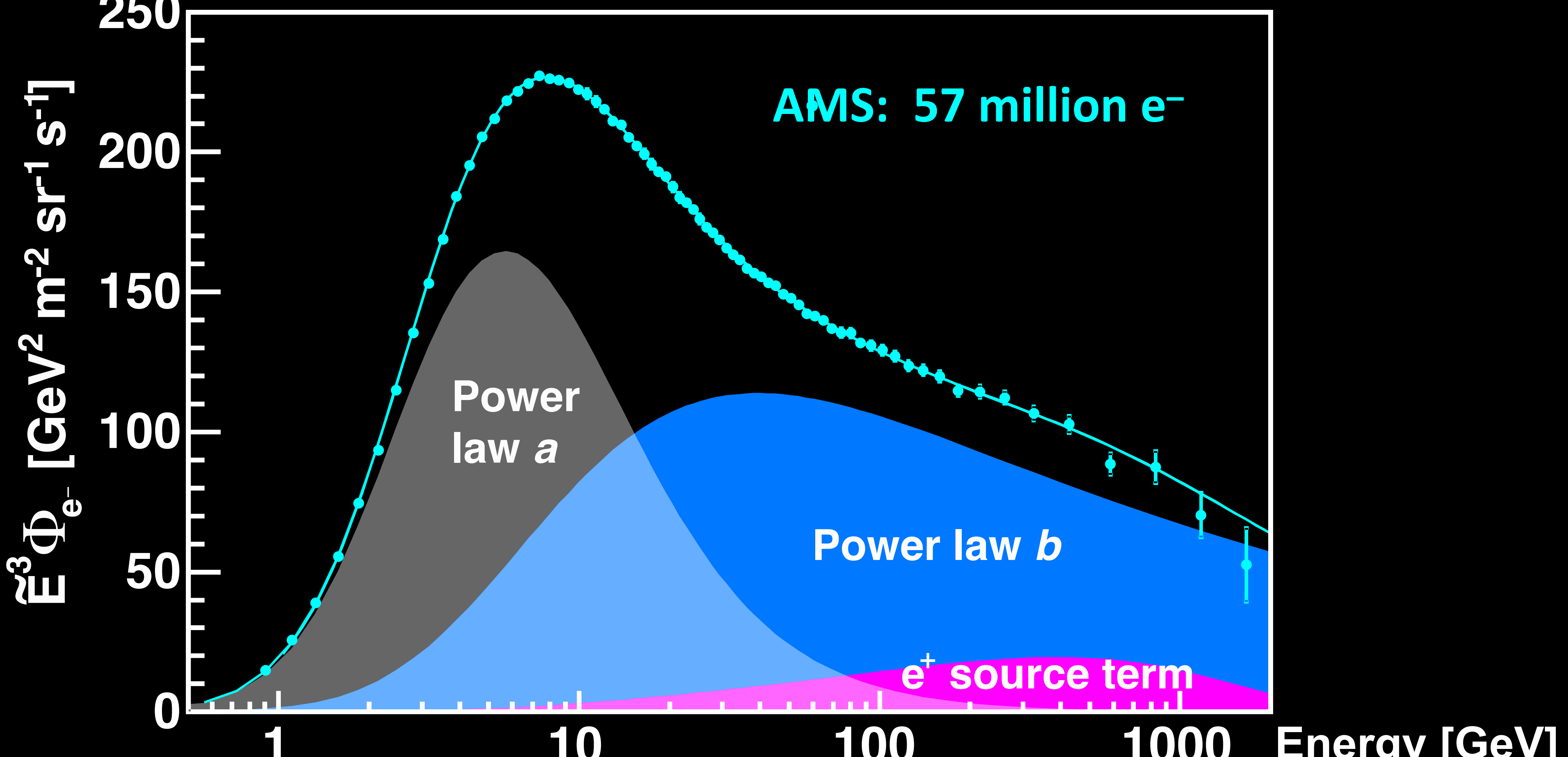


AMS Result on the electron spectrum

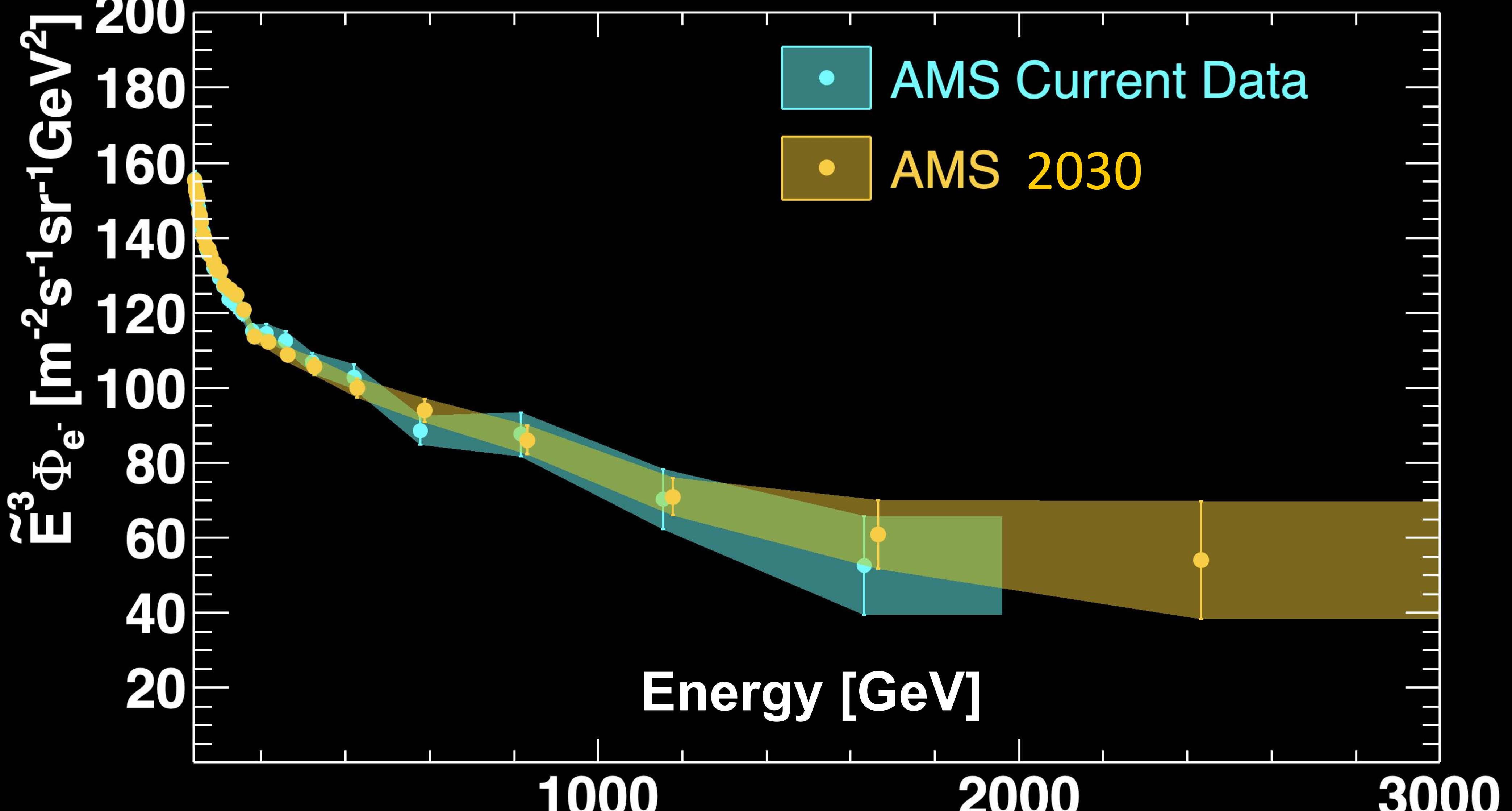
The spectrum fits well with two power laws (a, b) and a source term like positrons

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

Solar Power law *a* Power law *b*

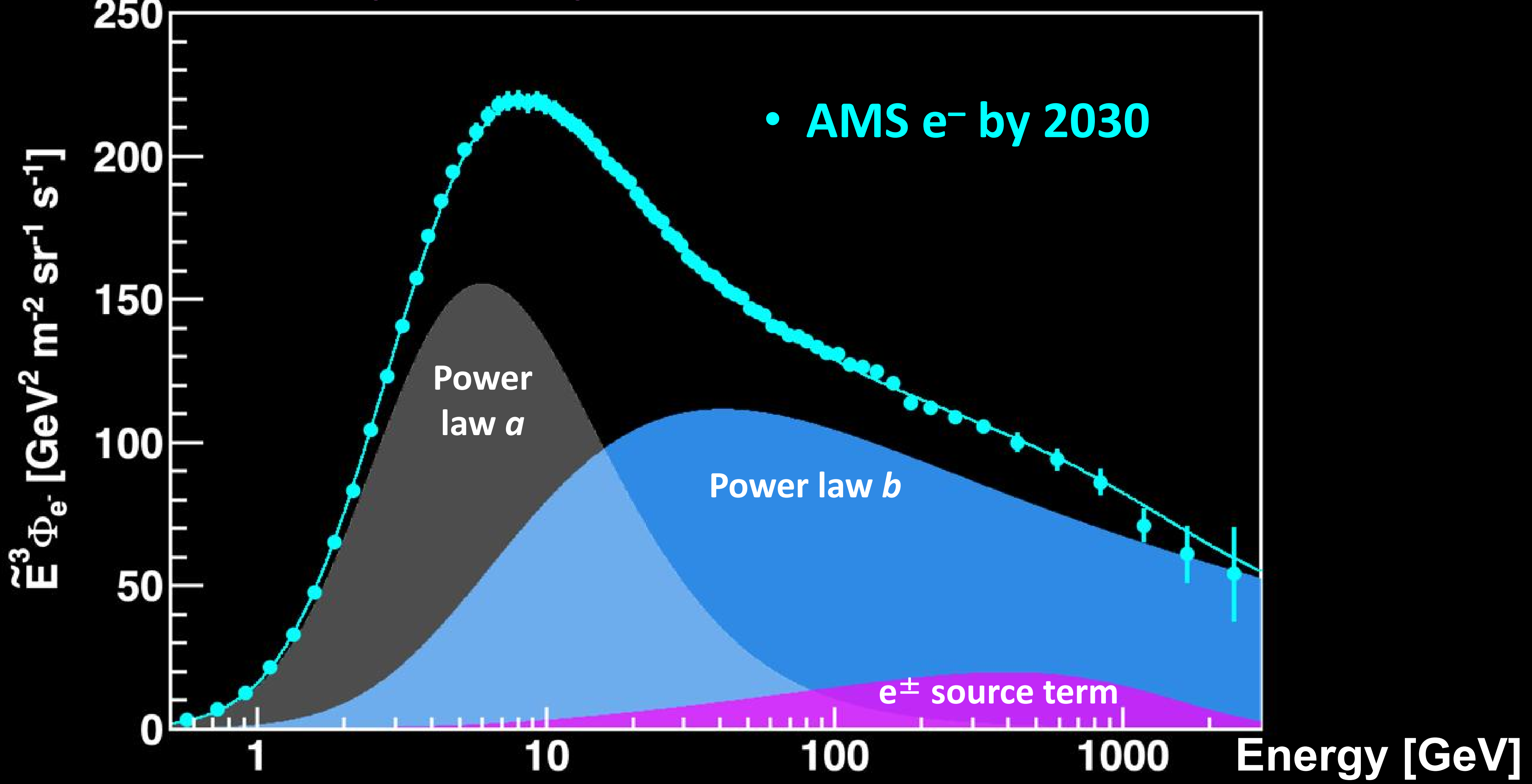


By 2030, AMS will extend the energy range of the electron flux measurement from 2 to 3 TeV and reduce the error by a factor of two compared to current data



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–



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.

Significance of this observation is 2.6σ at present. With More data is needed to establish the existence of charge-symmetric positron-like source term at highest electron energies.