Understanding the Origin of Cosmic-Ray Positrons

TEVPA 2023
Napoli

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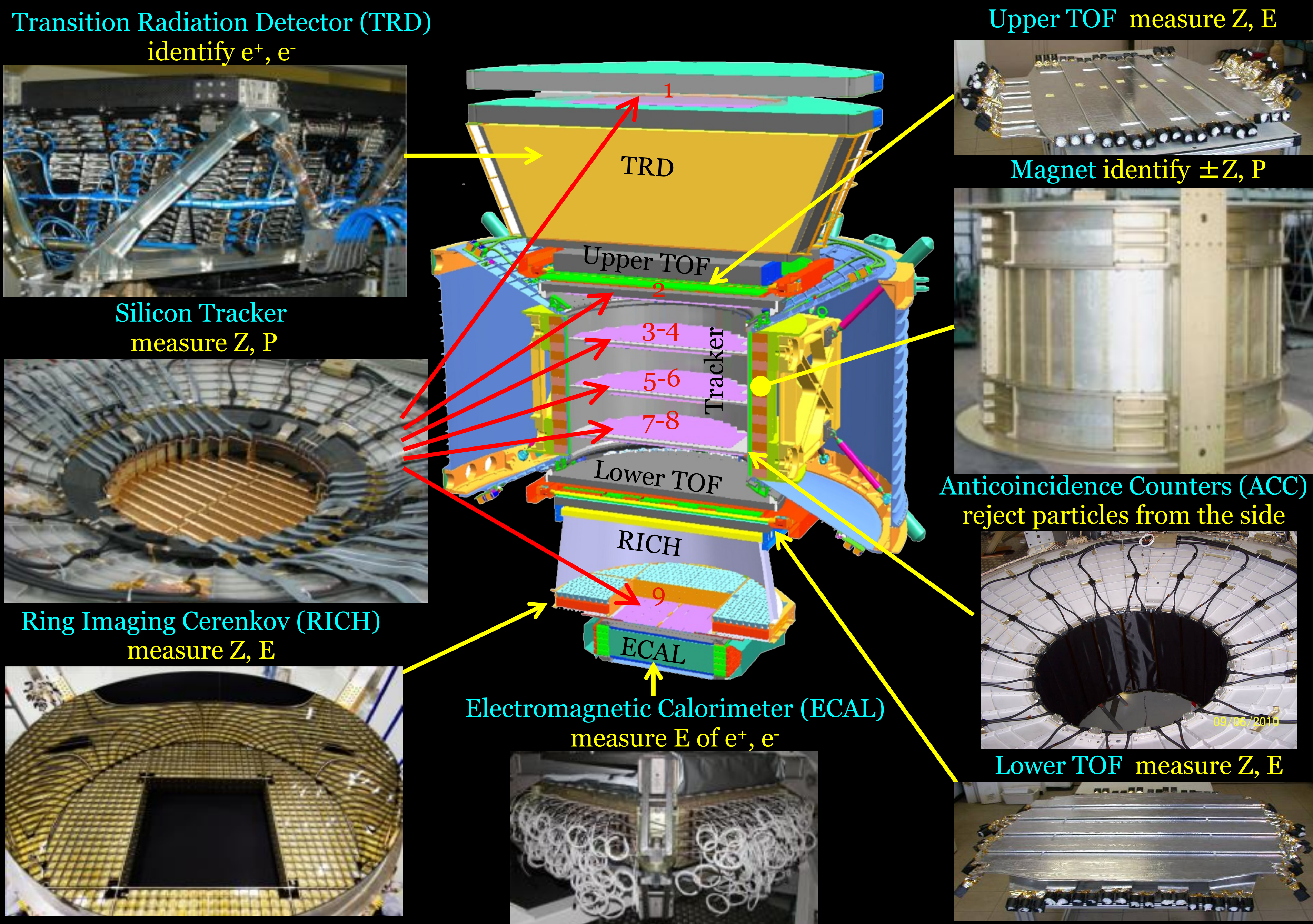
on behalf of the AMS Collaboration

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



AMS on ISS

AMS 2011-2025

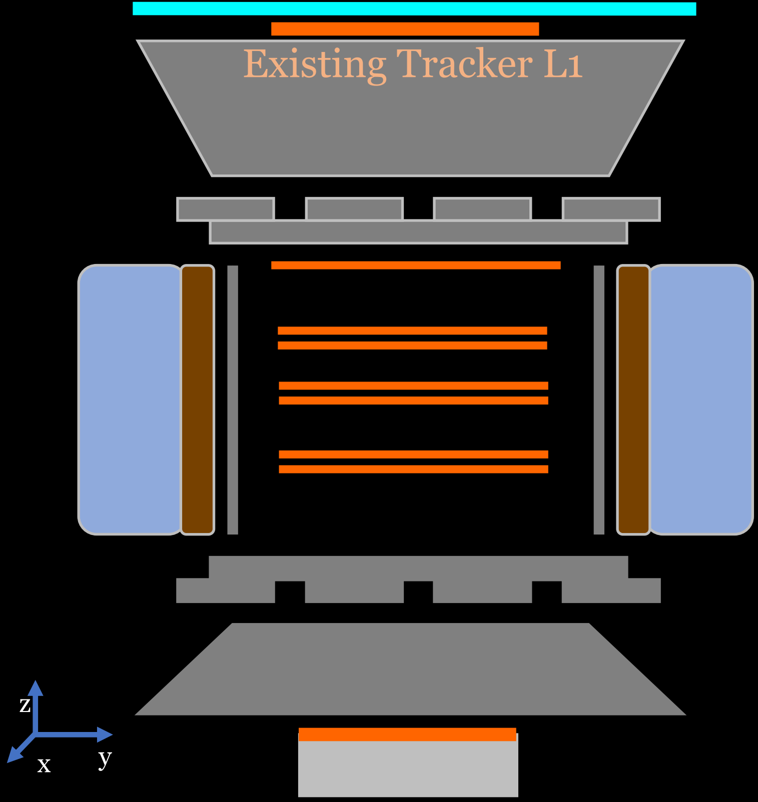
Continuous data-taking

Latest Results: 2011-2022

AMS 2025-2030

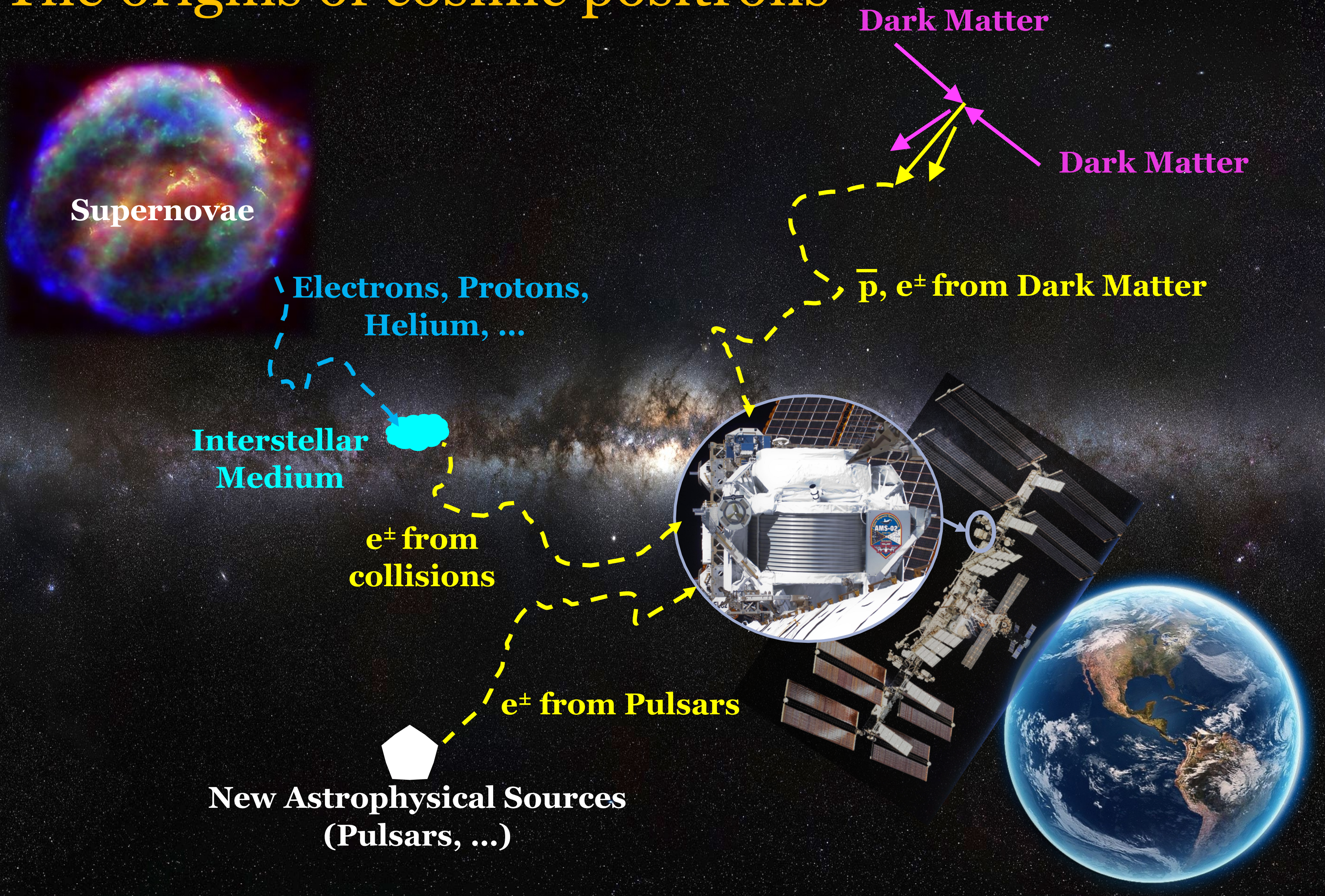
New 8m² Silicon Tracker Layer

Acceptance increased to 300%

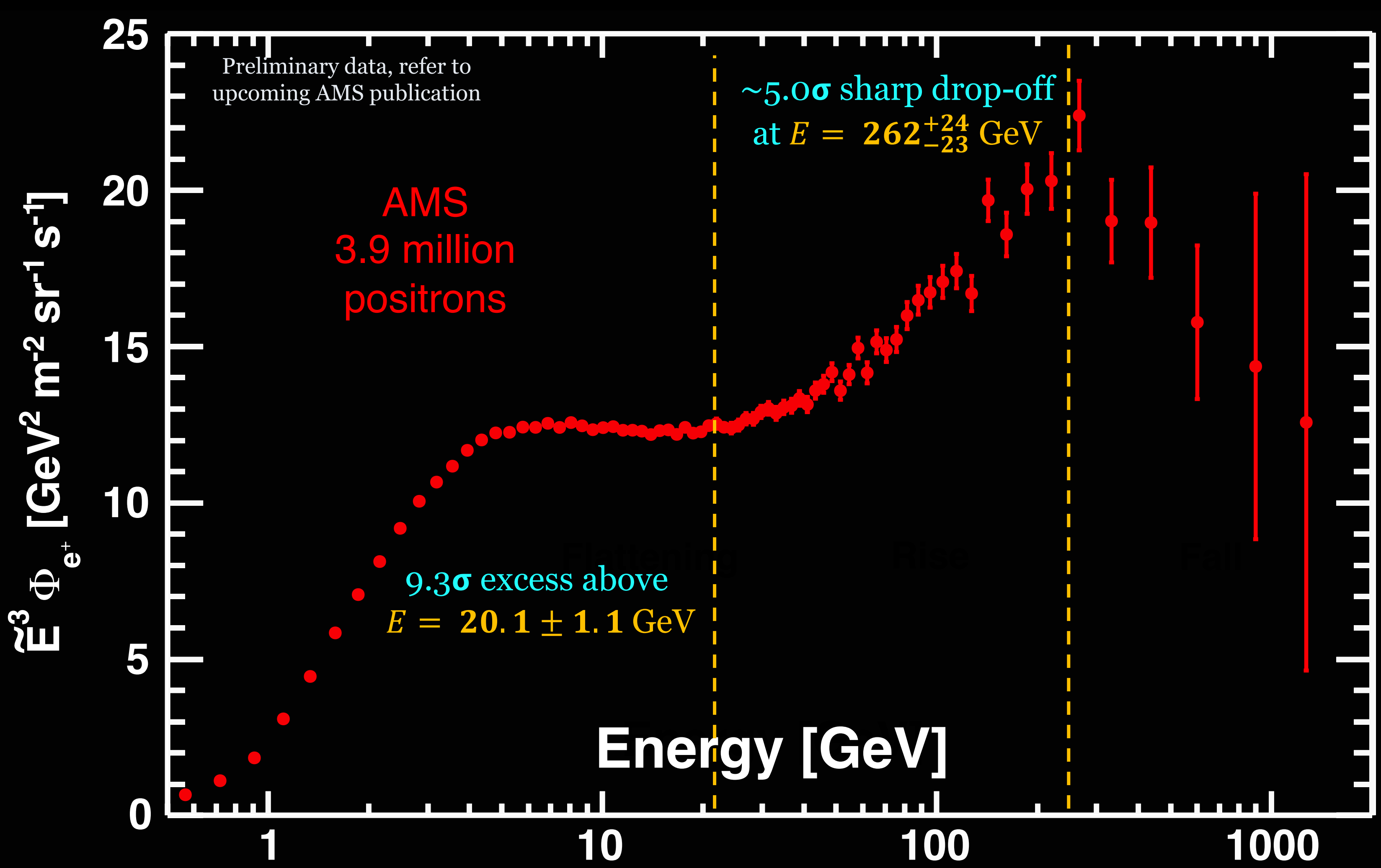


Projections to 2030

The origins of cosmic positrons

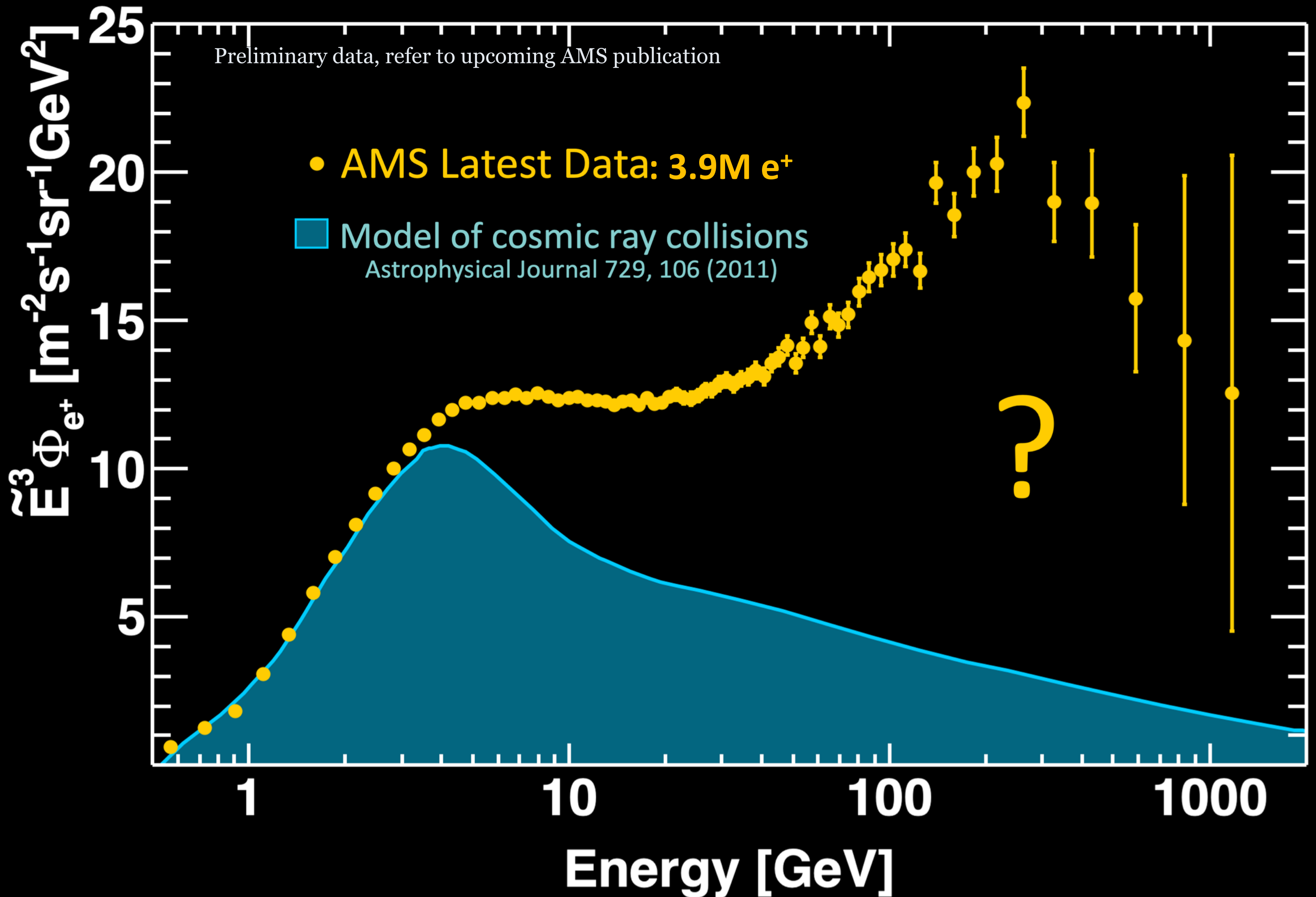


Towards understanding the origin of cosmic ray positrons



The Origin of Positrons

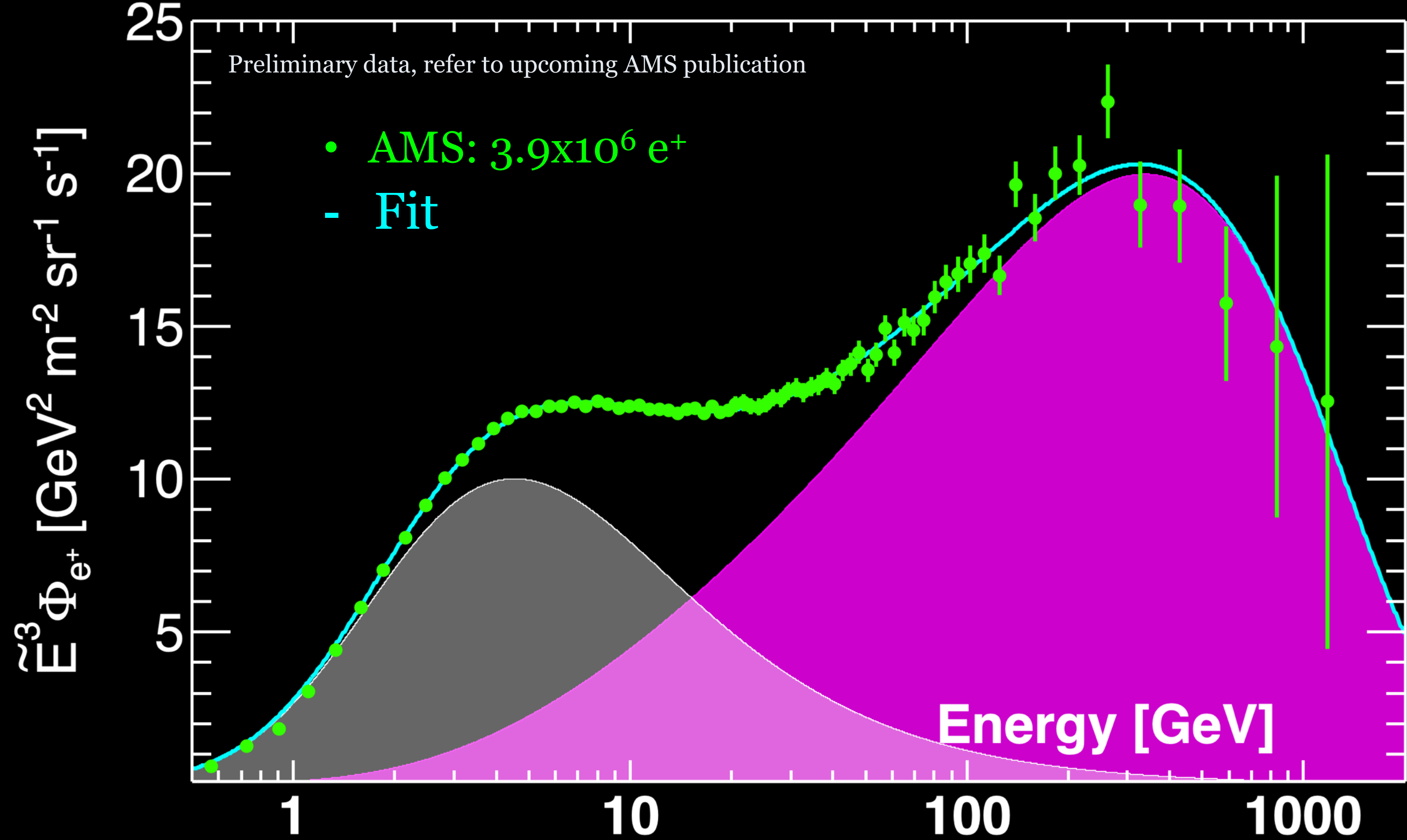
Low energy positrons mostly come from cosmic ray collisions



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.

Solar Collisions New Source or Dark Matter

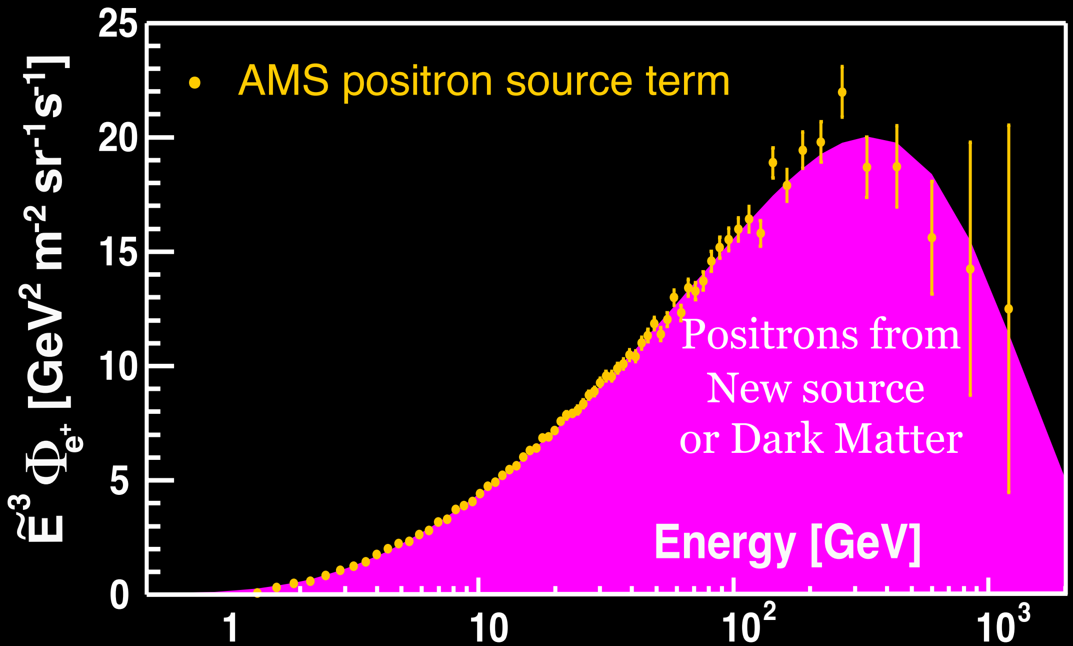
$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2}\left[C_d(\hat{E}/E_1)^{\gamma_d} + C_s(\hat{E}/E_2)^{\gamma_s}\exp(-\hat{E}/E_s)\right]$$

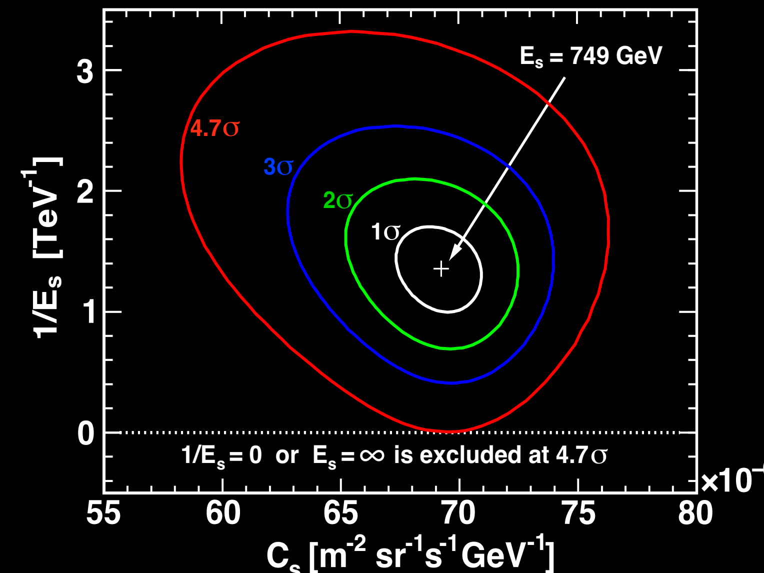


The existence of the finite cutoff energy is a new and unexpected observation

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

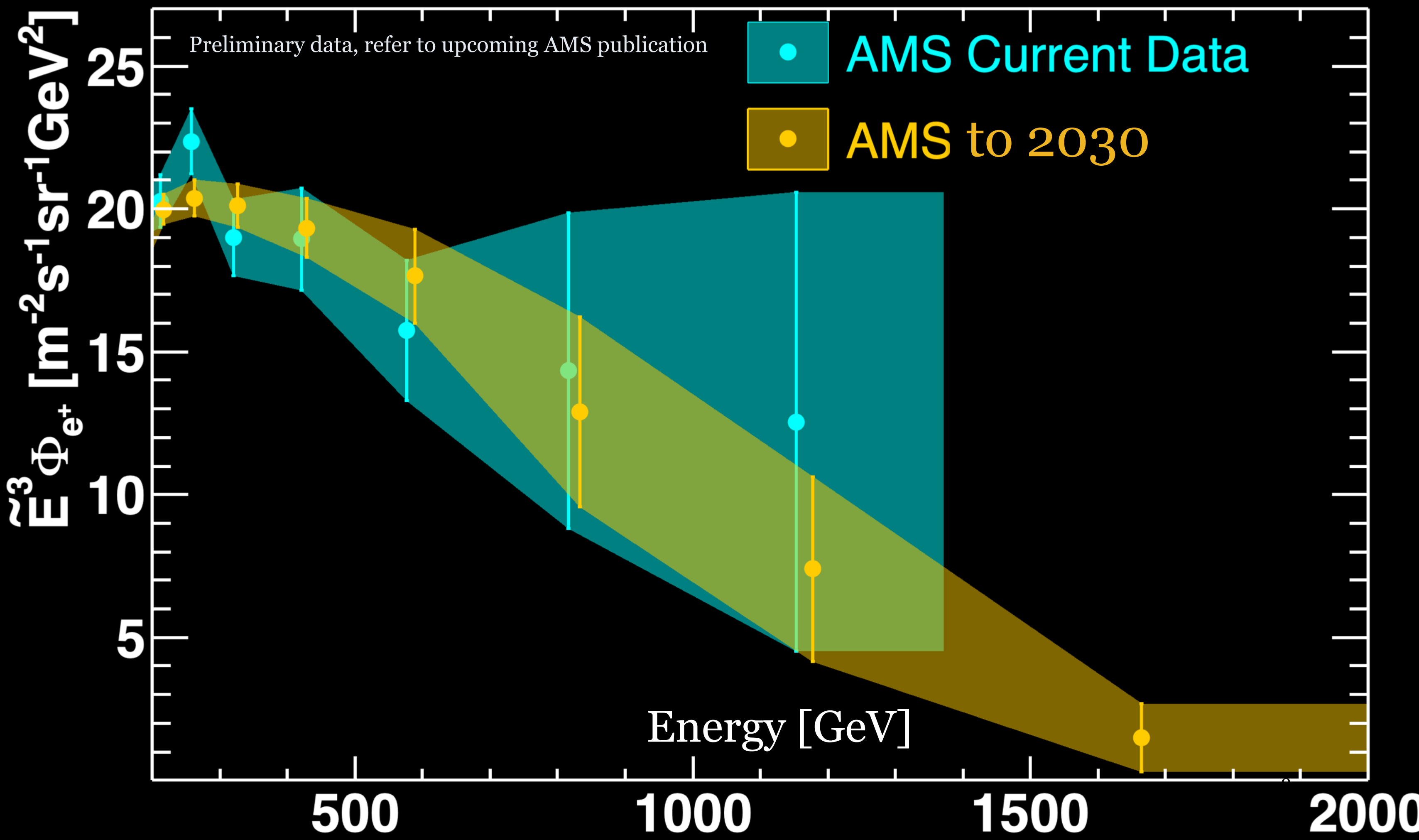
$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2}\left[C_s(\hat{E}/E_2)^{\gamma_s}\exp(-\hat{E}/E_s)\right]$$





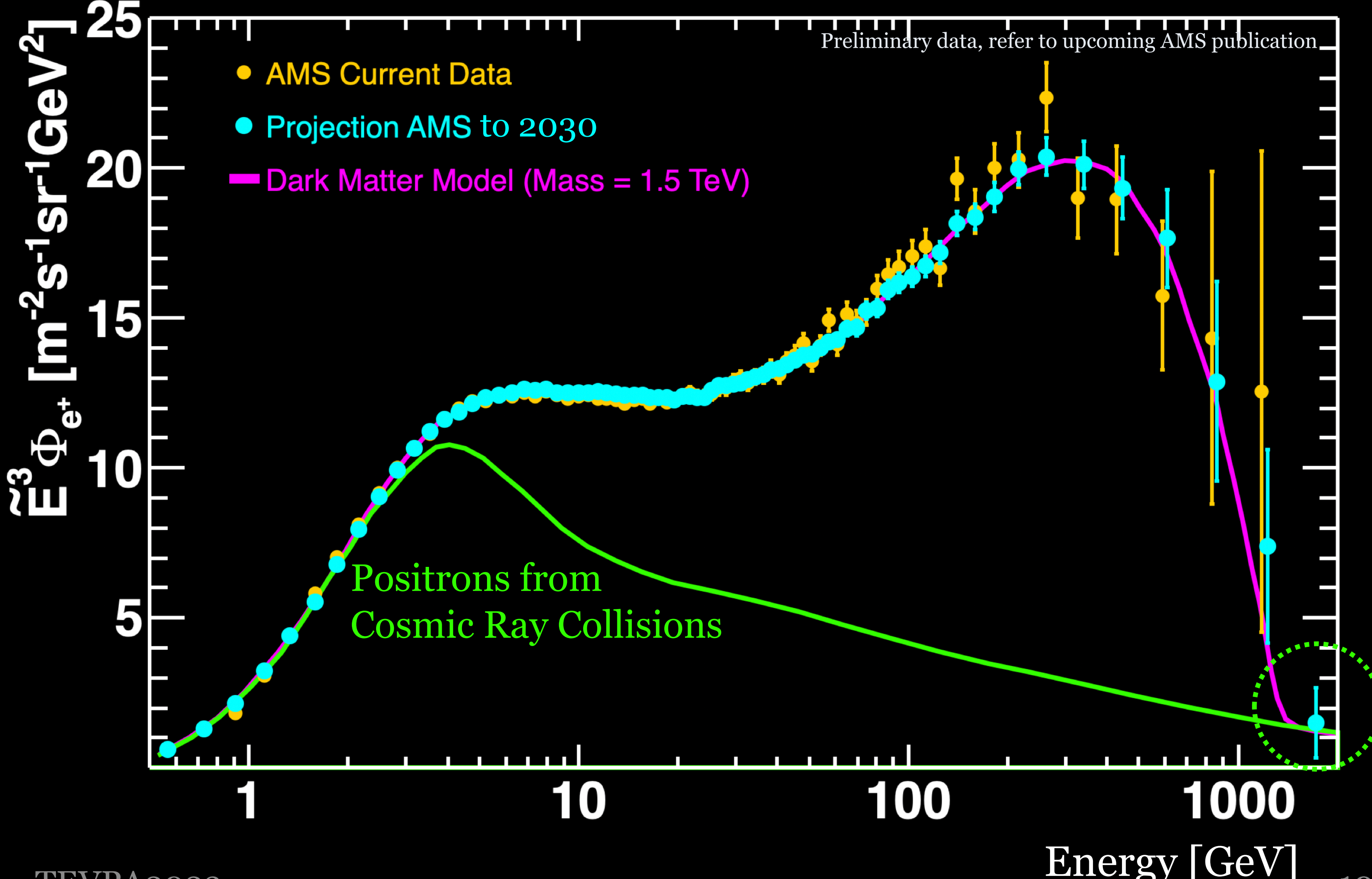
The cutoff energy $E_s = 749^{+308}_{-137}$ GeV is established with a confidence of more than 99.99%.

By 2030, AMS will extend the energy range of the positron flux measurement from 1.4 to 2 TeV and reduce the error by a factor of two compared to current data



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



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

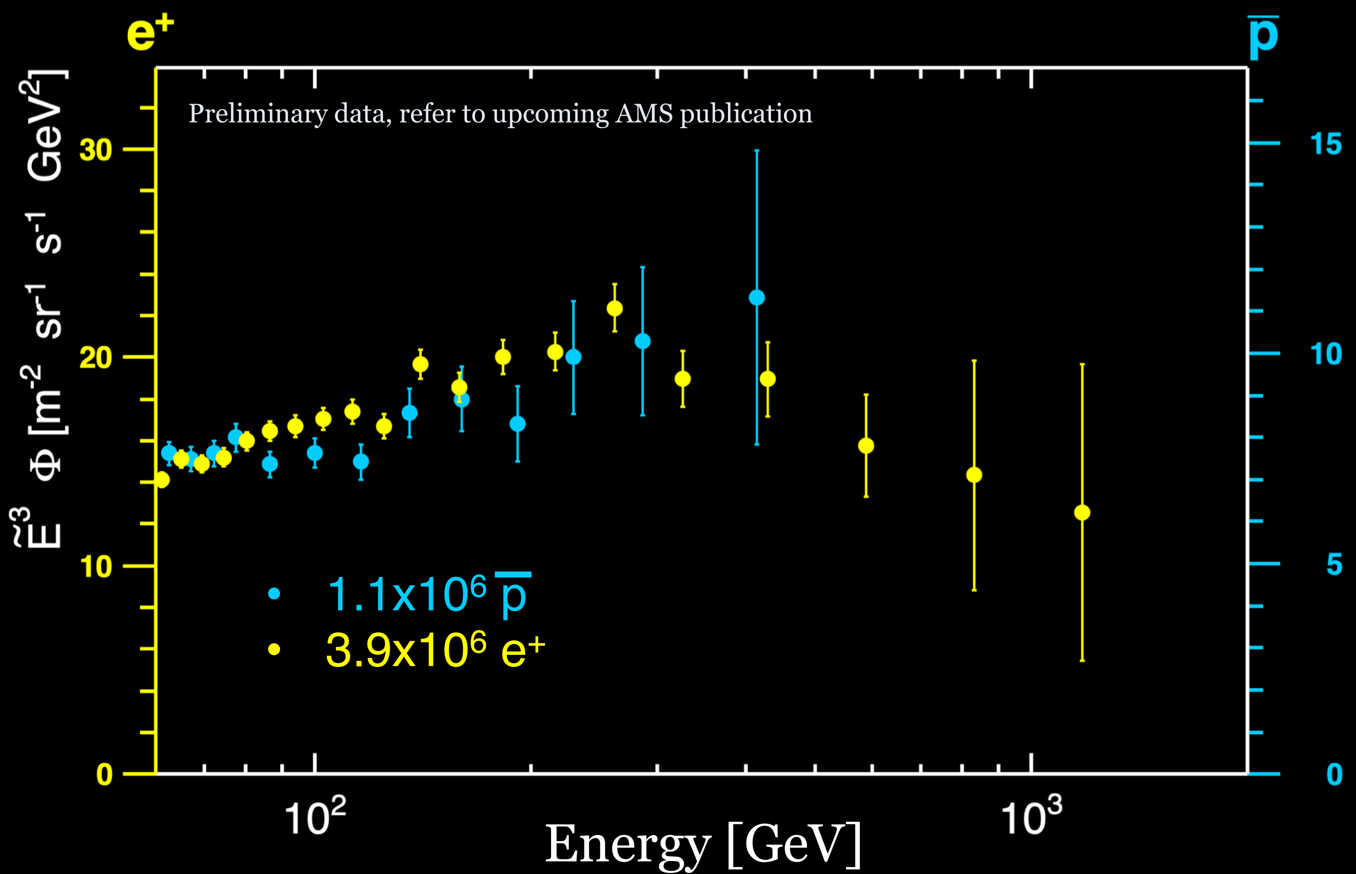
and many other excellent papers …

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.

Properties of Cosmic Antiprotons

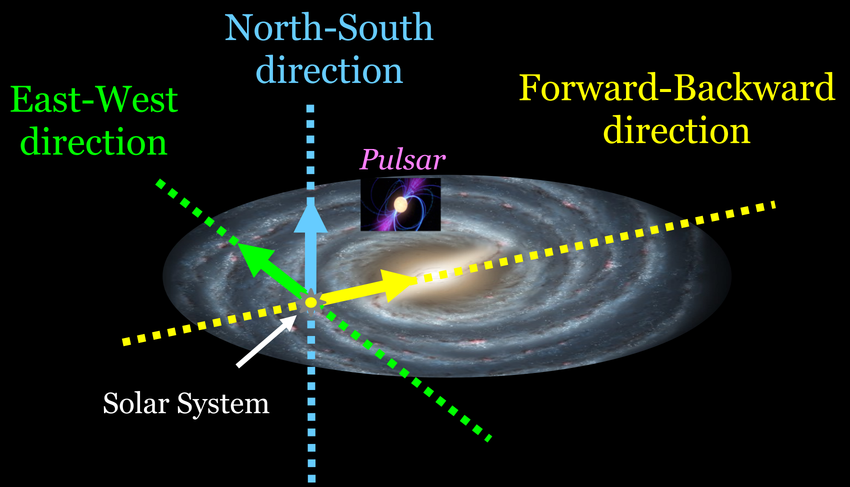
The $\bar{p}$ and e^+ fluxes have identical rigidity dependence.
$\bar{p}$ are not produced by pulsars.



For more details about relation between positron and antiproton fluxes see next talk by Zhicheng Tang

Positron Anisotropy and Dark Matter

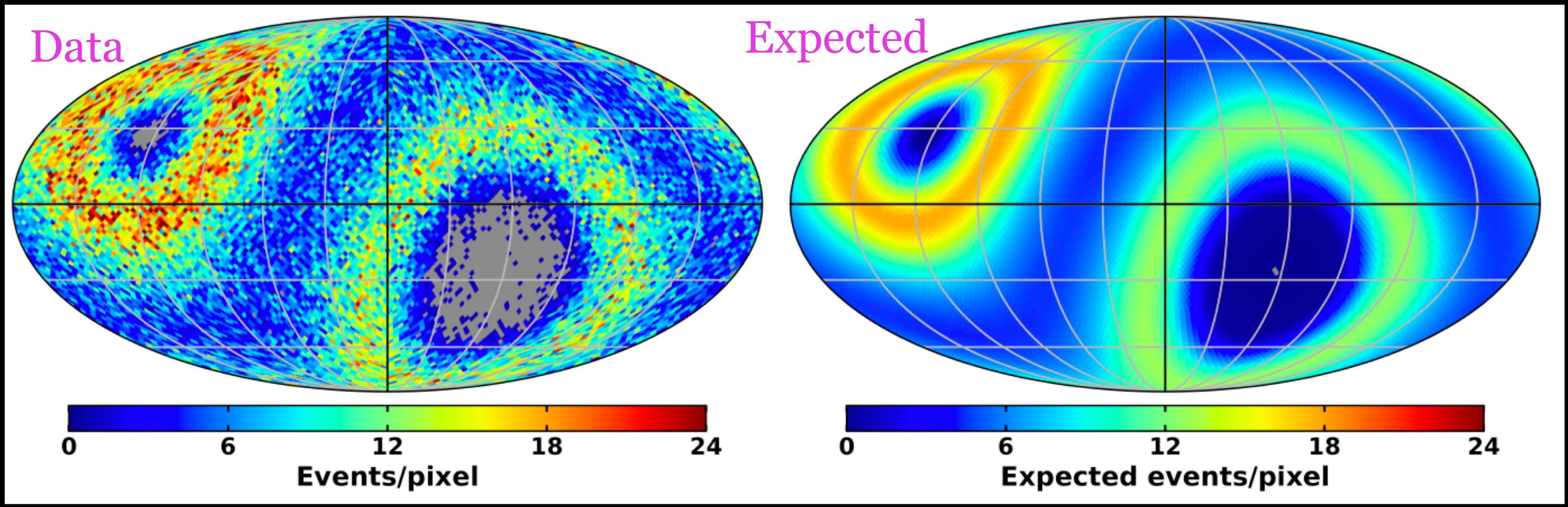
Astrophysical point sources will imprint a higher anisotropy on the arrival directions of energetic positrons than a smooth dark matter halo.



Dipole anisotropy:

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

C_1 is the dipole moment



Summary

- Positron spectrum requires an additional source of high energy positrons (e.g. DM models):
  - can't be explained by the ordinary cosmic ray collisions;
  - has an exponential cutoff with E_s=749 GeV;
  - measurement to 2030 will enable us to determine the origin of the behavior of positrons at high energies.

- 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.

- By 2030, the positron statistics will allow us to measure the anisotropy accurately to permit a separation between different positrons origins.