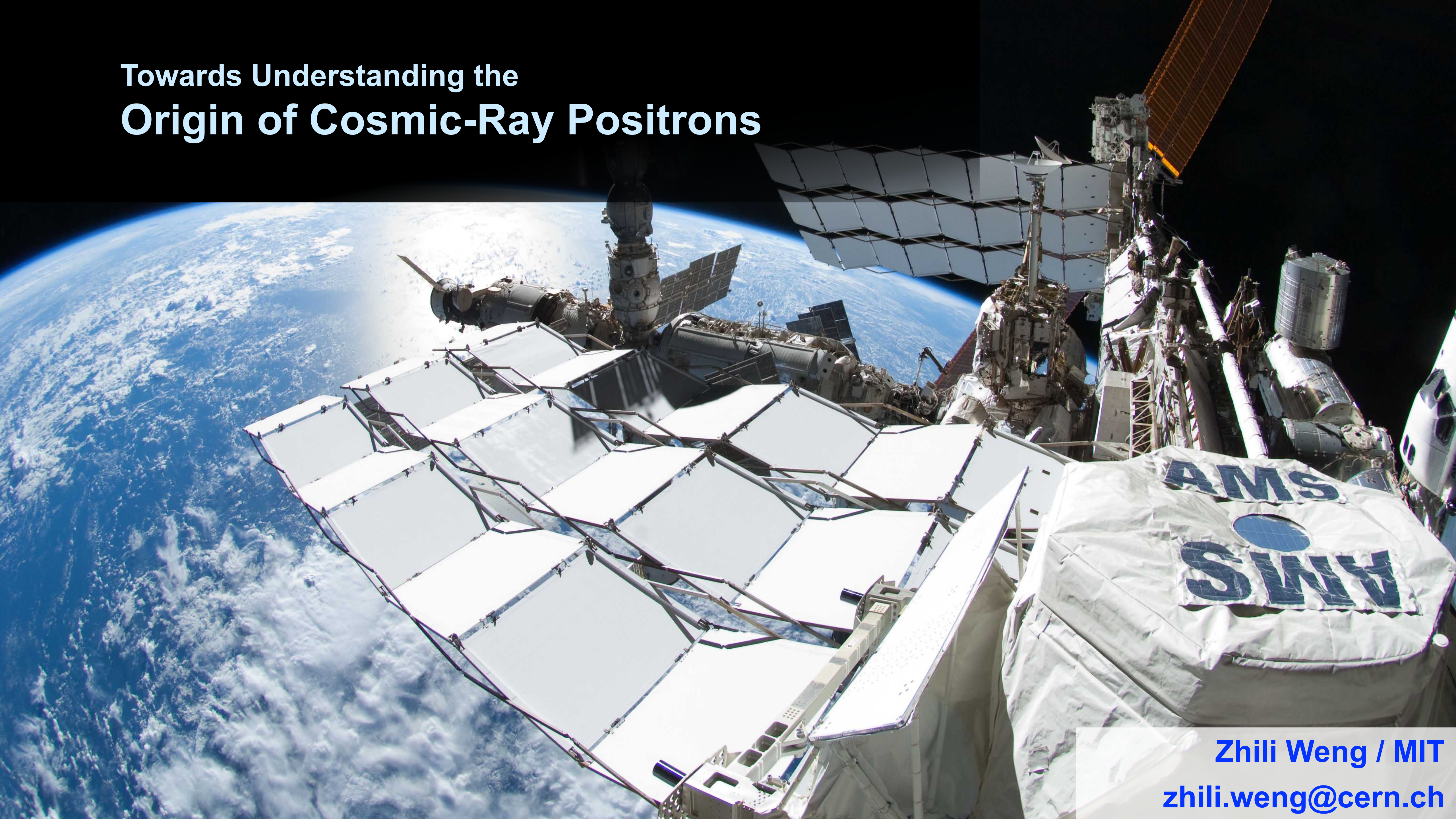
Towards Understanding the

Origin of Cosmic-Ray Positrons



Zhili Weng / MIT

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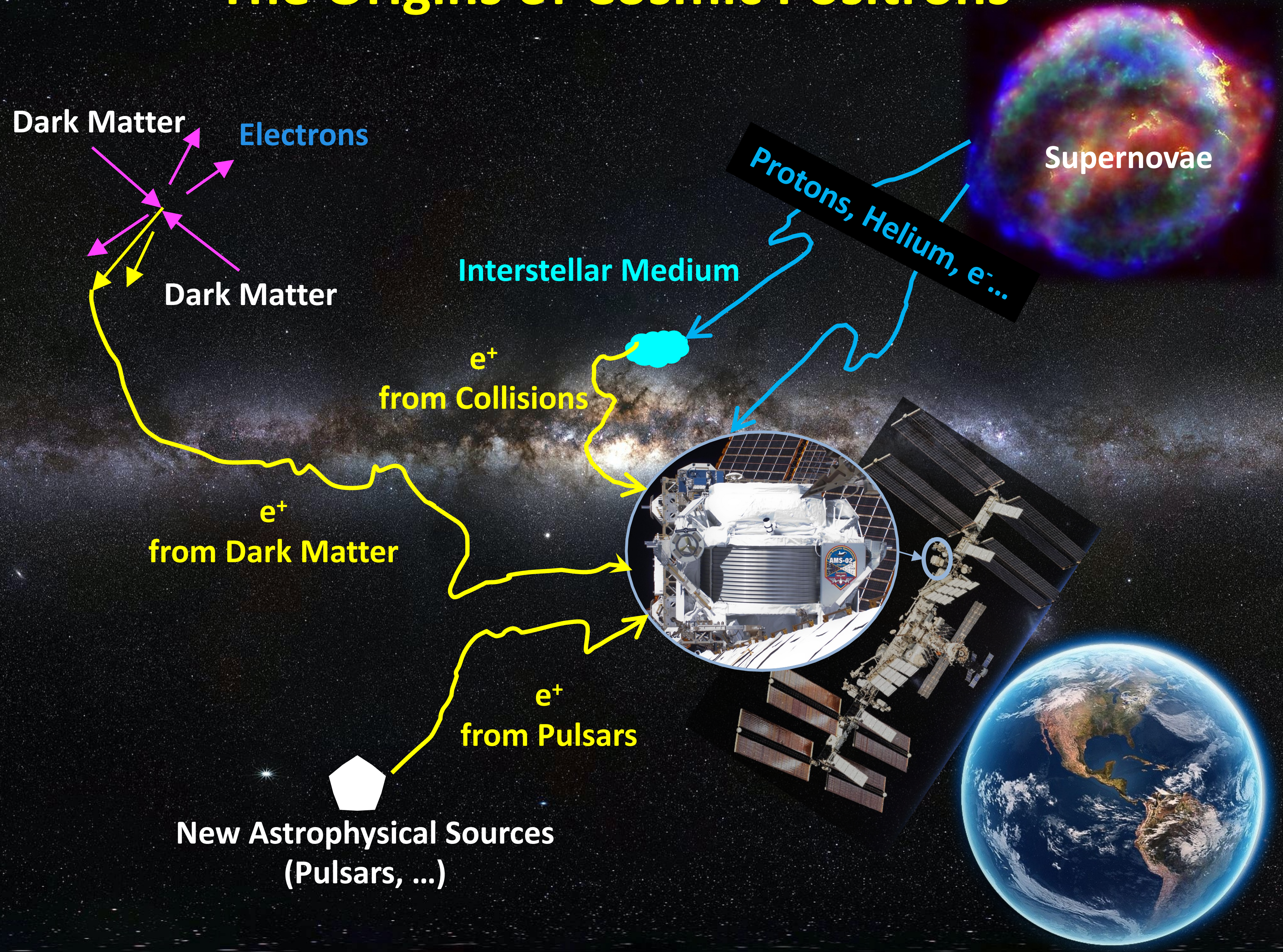
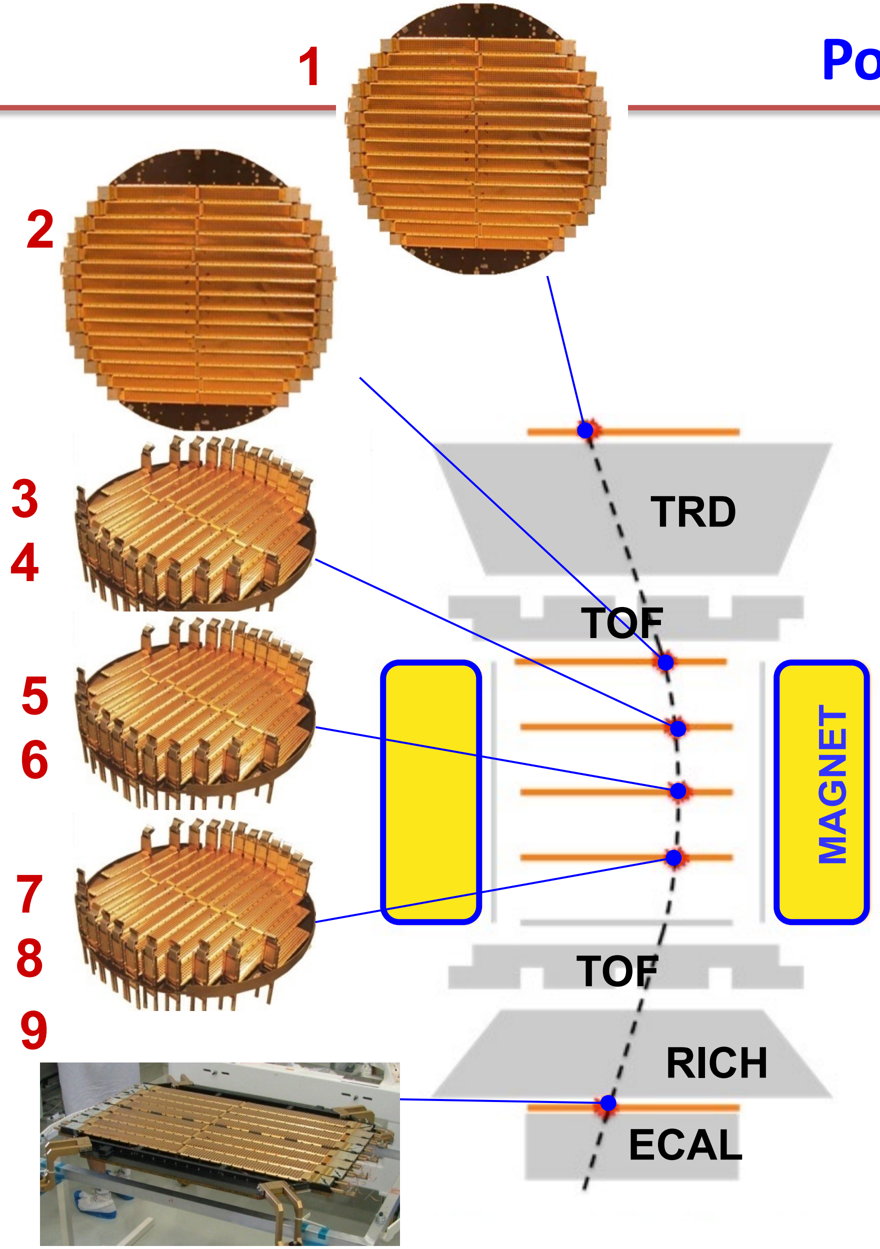
The Origins of Cosmic Positrons

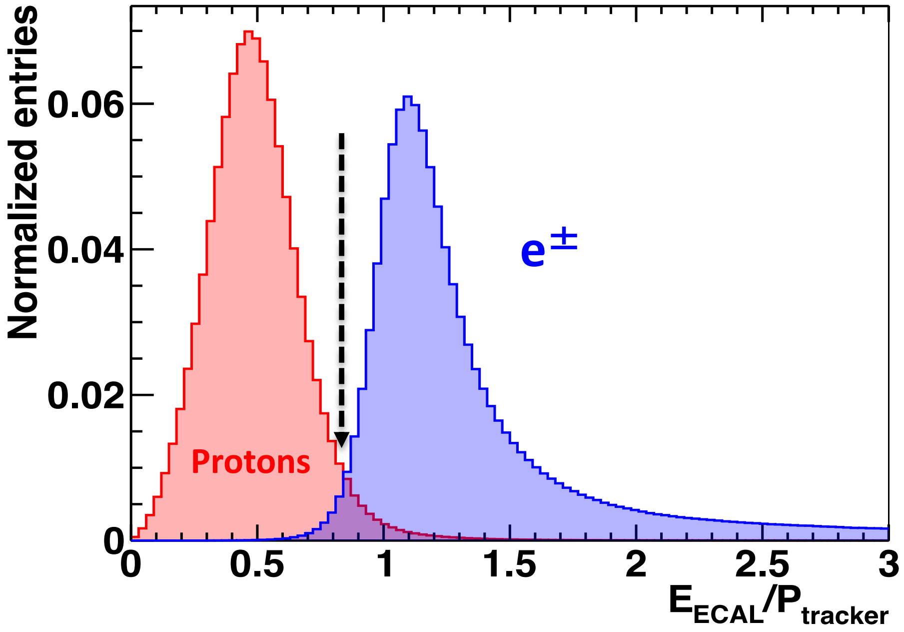


Positron Measurement in AMS



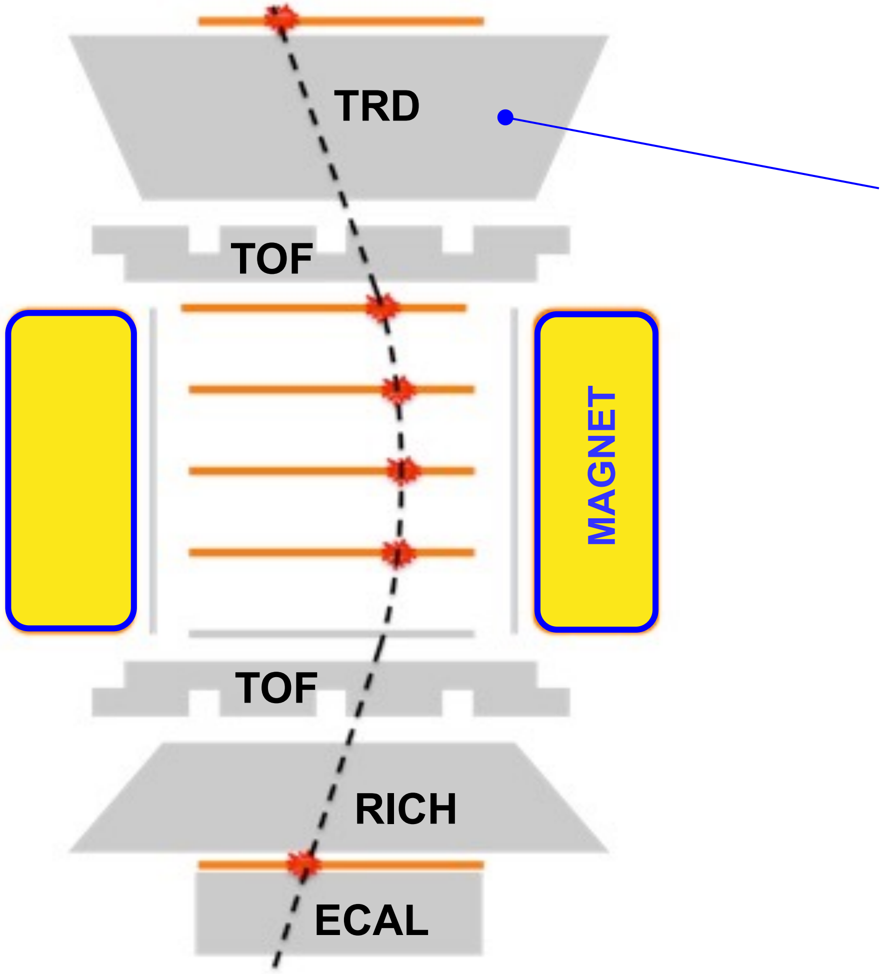
L1 to L9: 3m level arm;
single point resolution 10 μm;

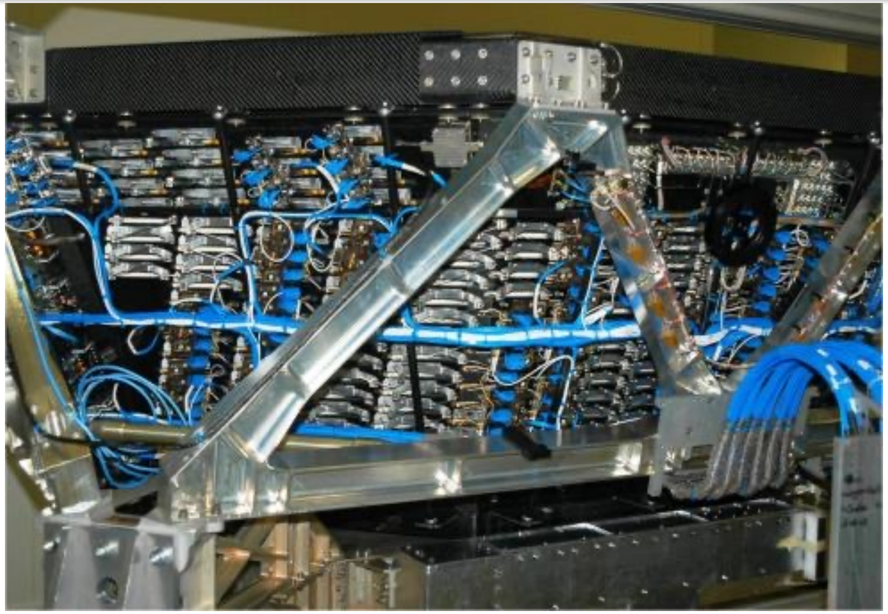
- Tracker and Magnet Measures the sign and magnitude of positrons and electrons to few TeV.
- Unique particle identification capability of AMS: Independent Momentum and Energy measurement



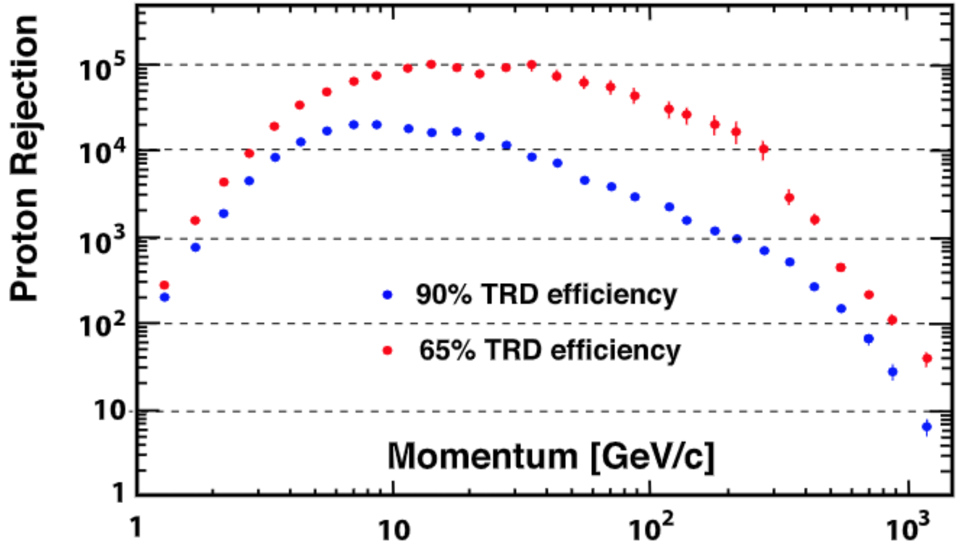
- Identify electron charge confusion:
  - Large angle scattering,
  - Interaction with detector materials.
  - Identified and measured from data using Charge confusion estimator Λ_{CC}

Positron Measurement in AMS



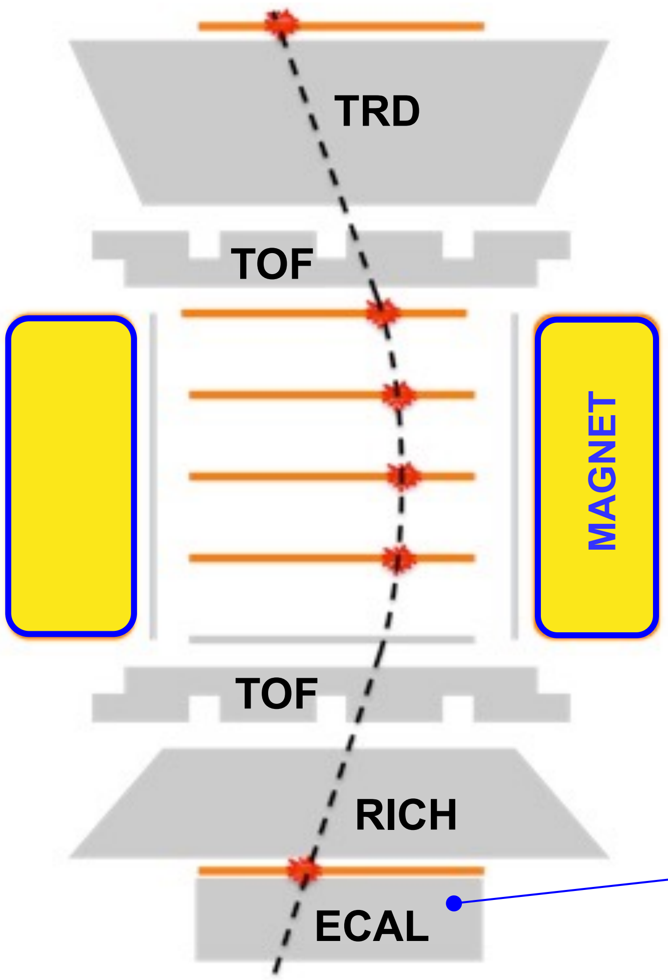


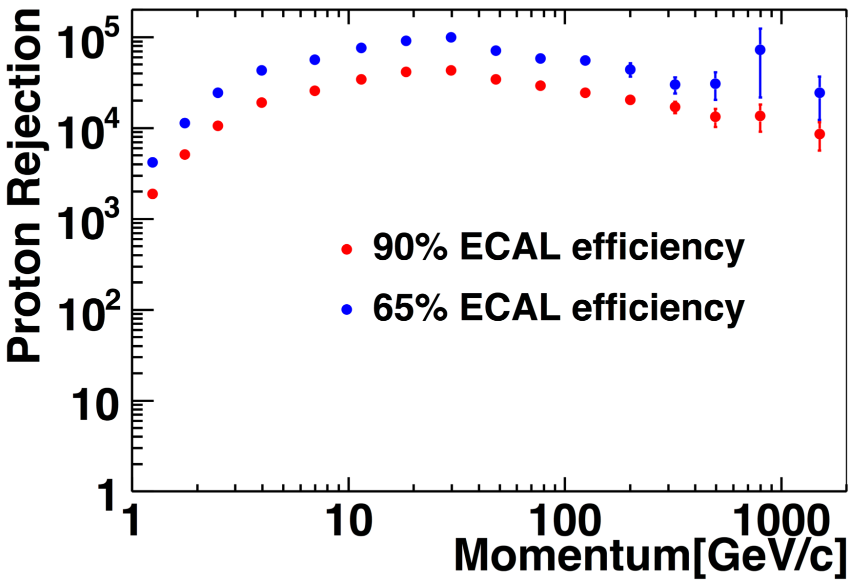
TRD proton separation at different $e^{\pm}$ efficiency



- TRD: Identify $e^{\pm}$ from protons using transition radiation. Combine 20 layers proportional tubes signal: Λ_{TRD} .

Positron Measurement in AMS

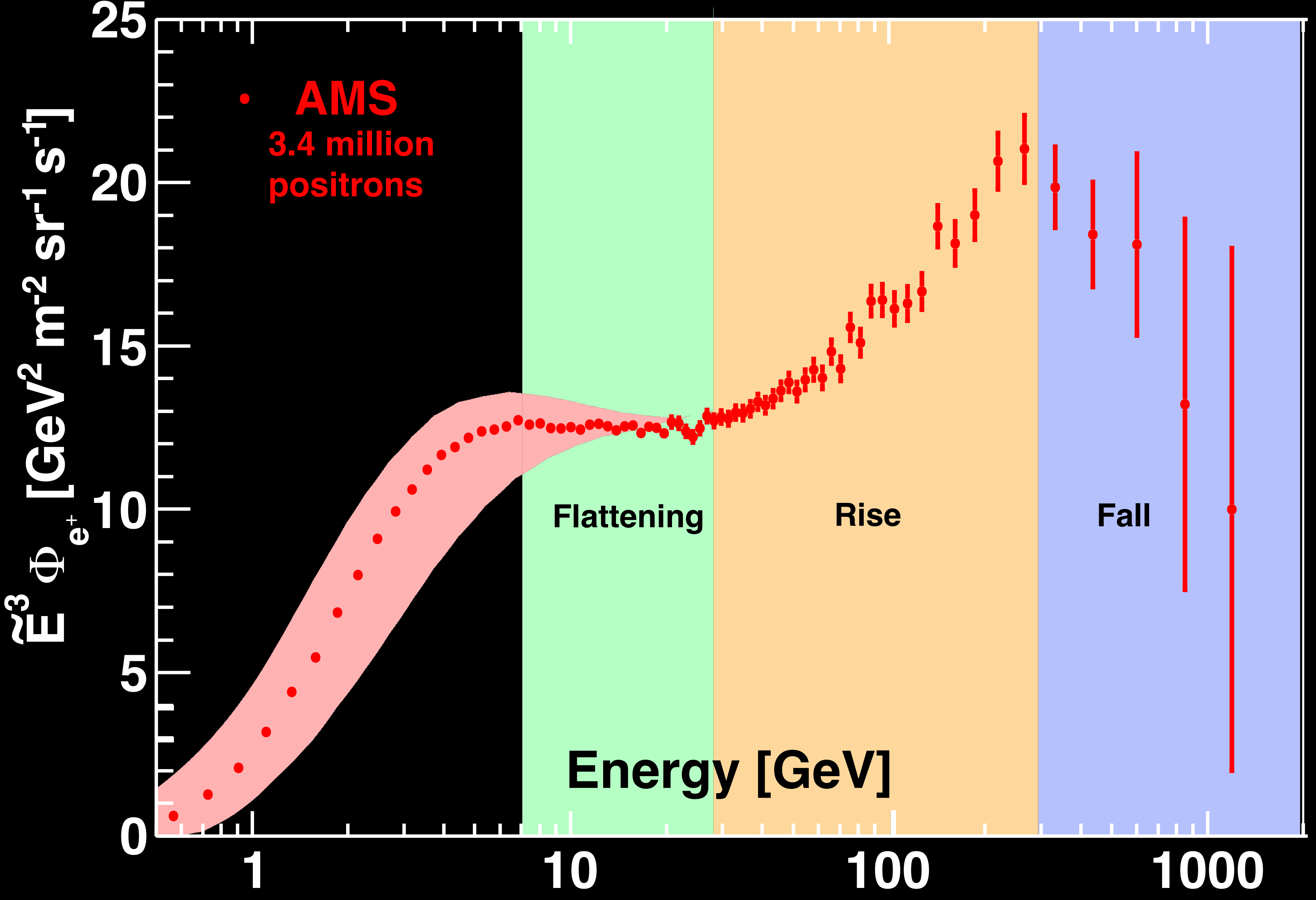




- ECAL : 17 X_0 , TeV Precision 3D measurement of the energy and shower development of electrons and positrons.

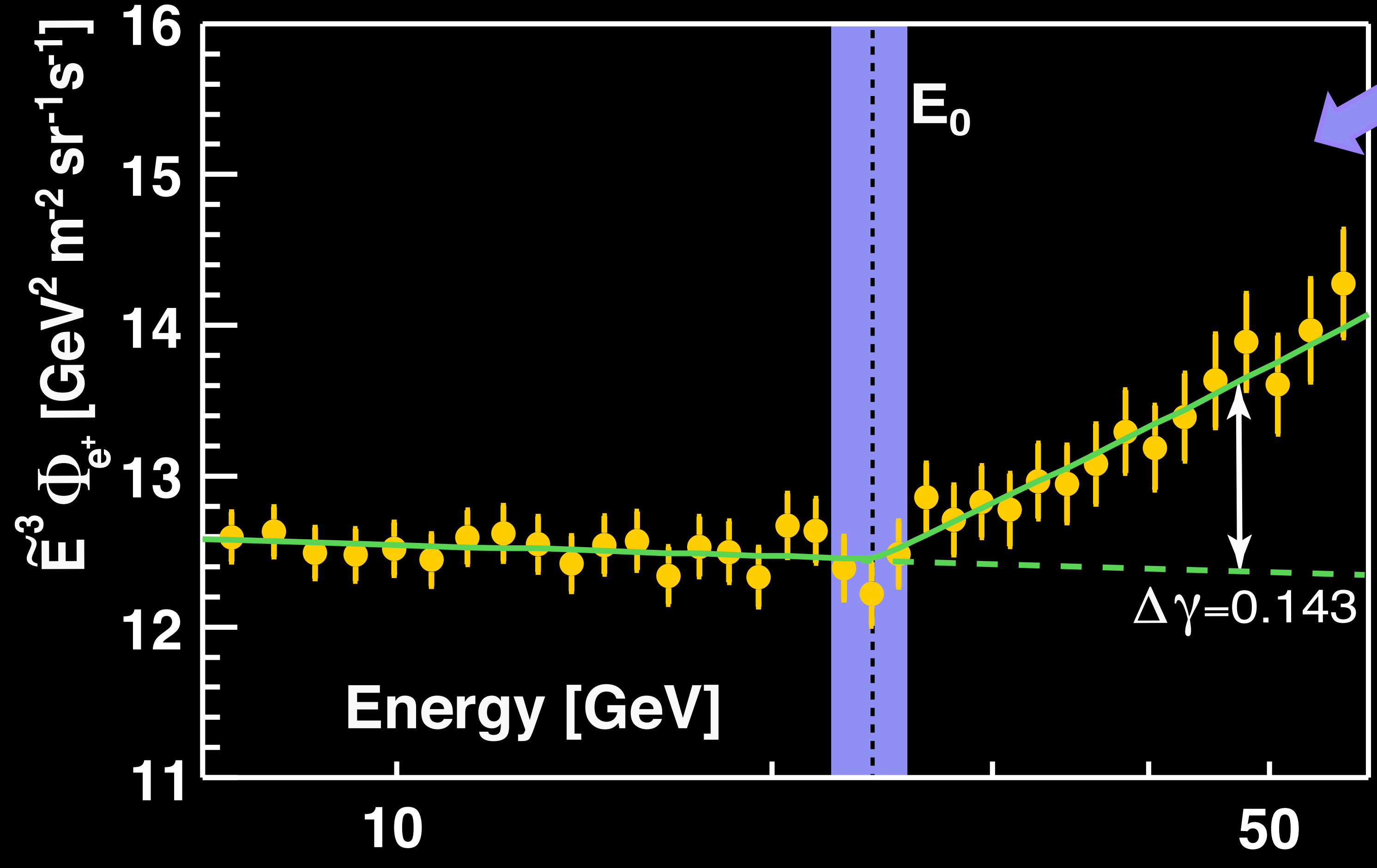
TRD and ECAL are separated by the Magnet
They have independent particle identification: combined rejection > 1 in 10^6

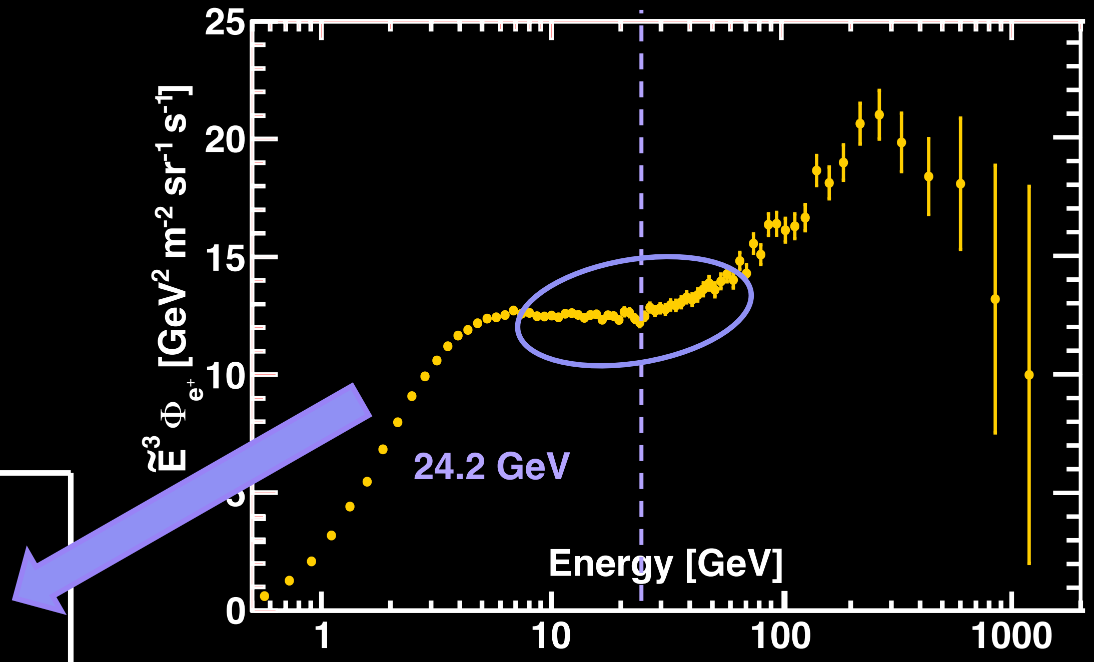
Latest AMS Results on Positron Flux



Fits of the data to

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





7.8σ excess above

$\boldsymbol{E_0 = 24.2 \pm 1.1}$ **GeV**

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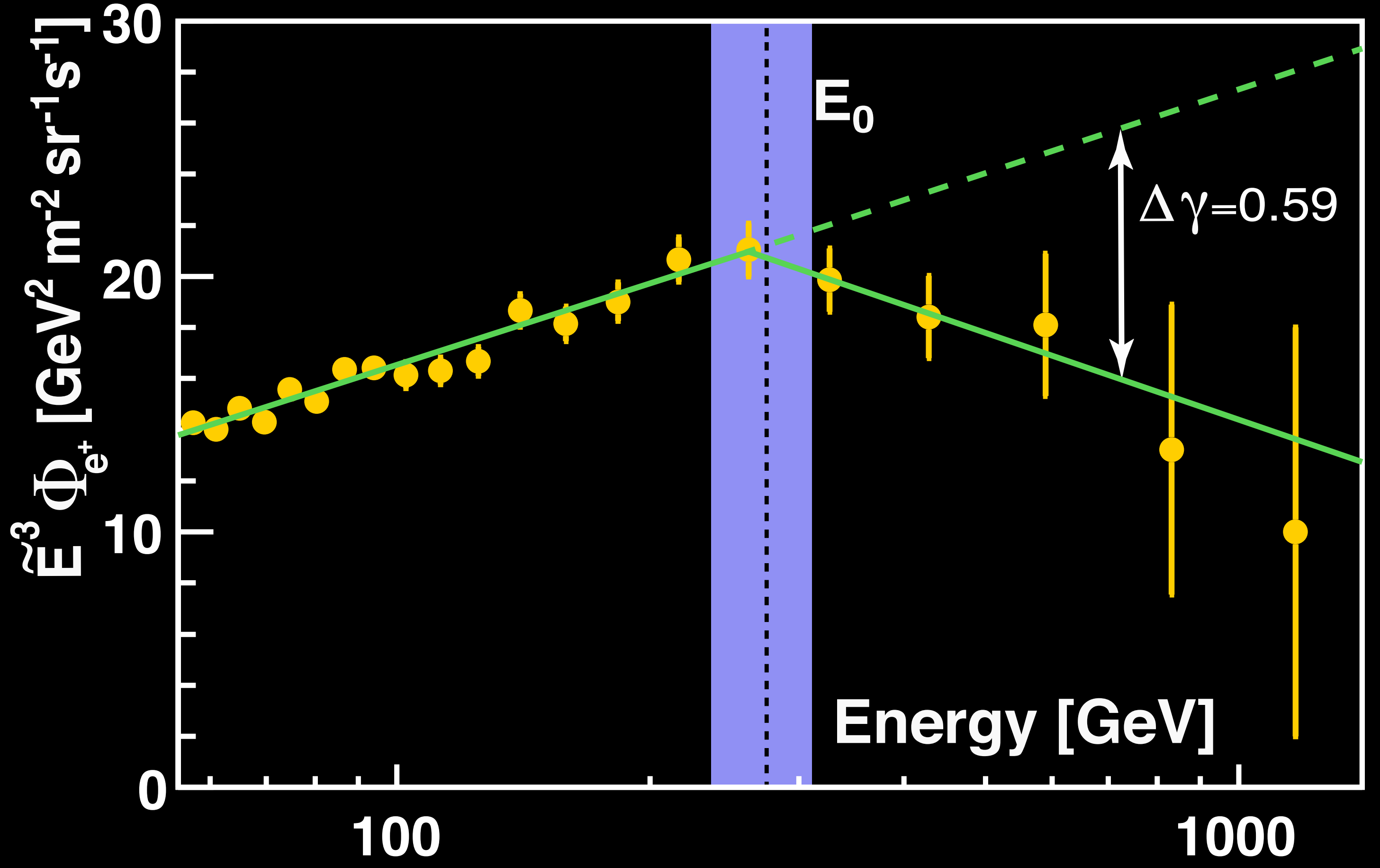
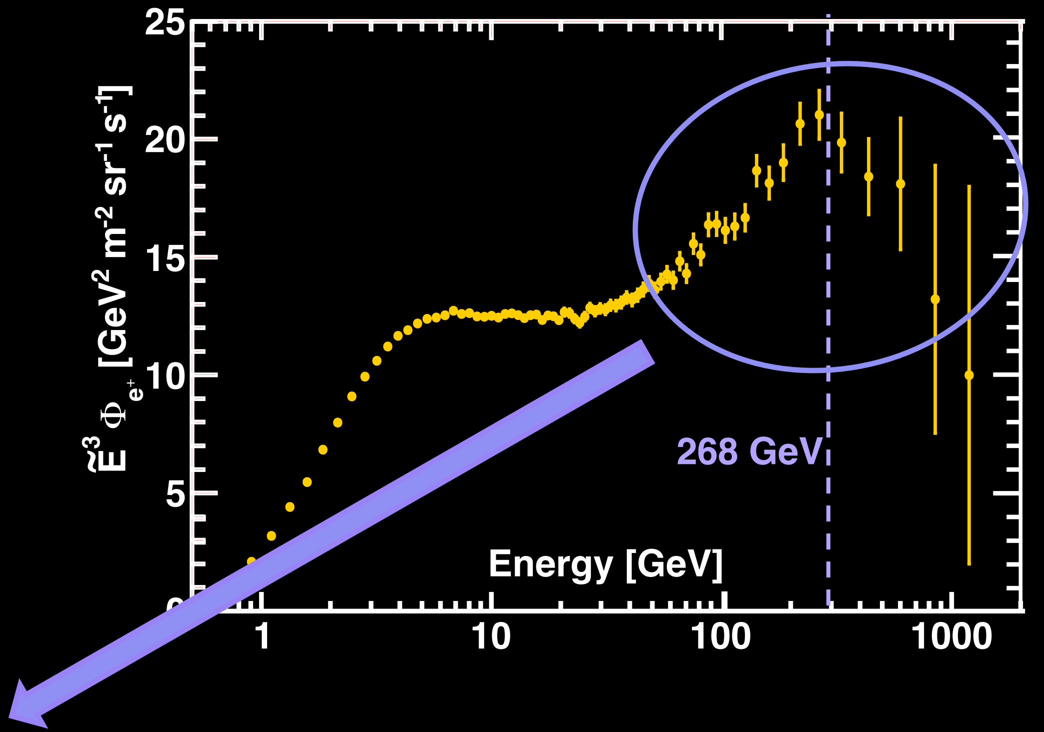
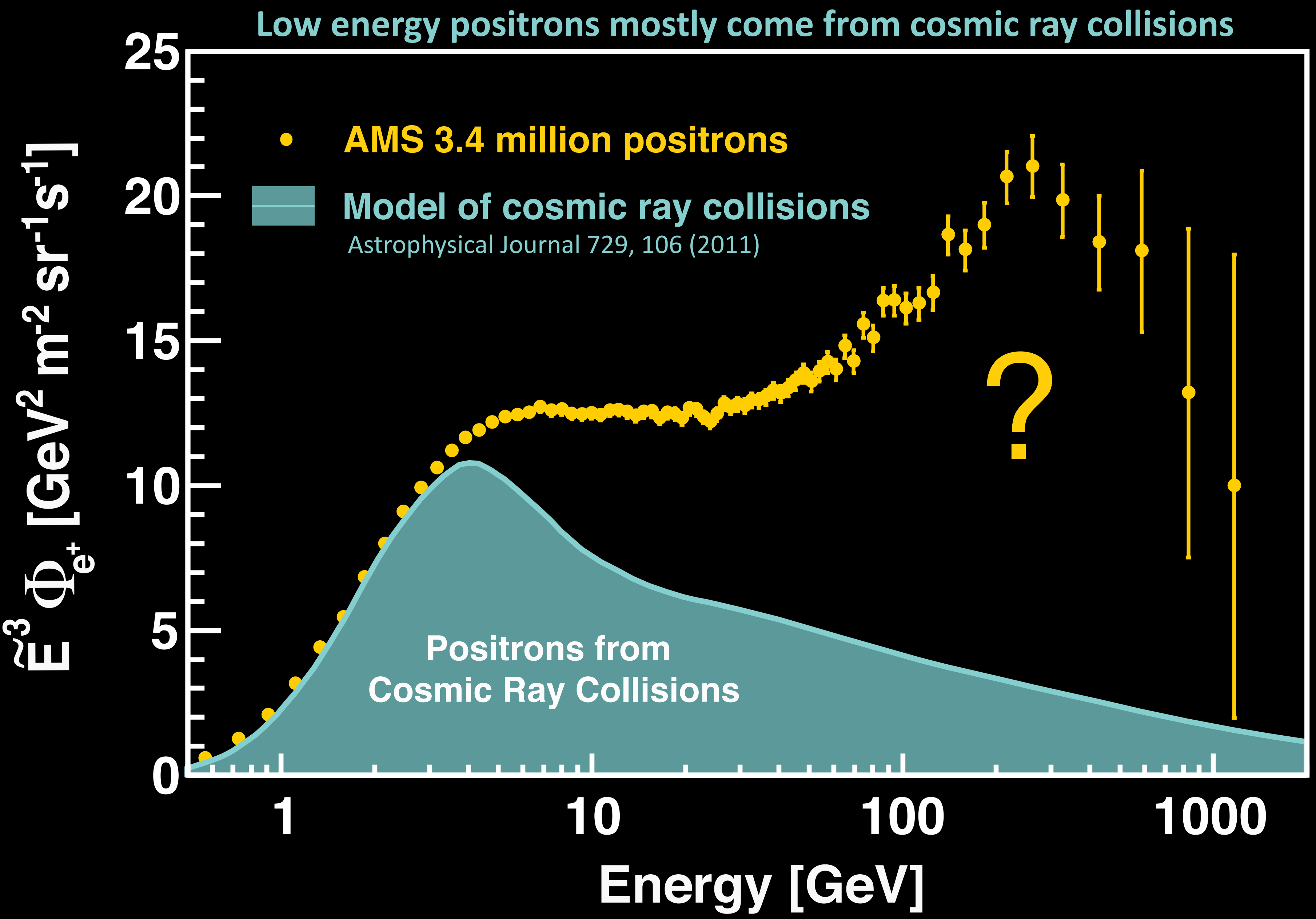




4.8σ sharp drop-off at

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

The Origin of Positrons

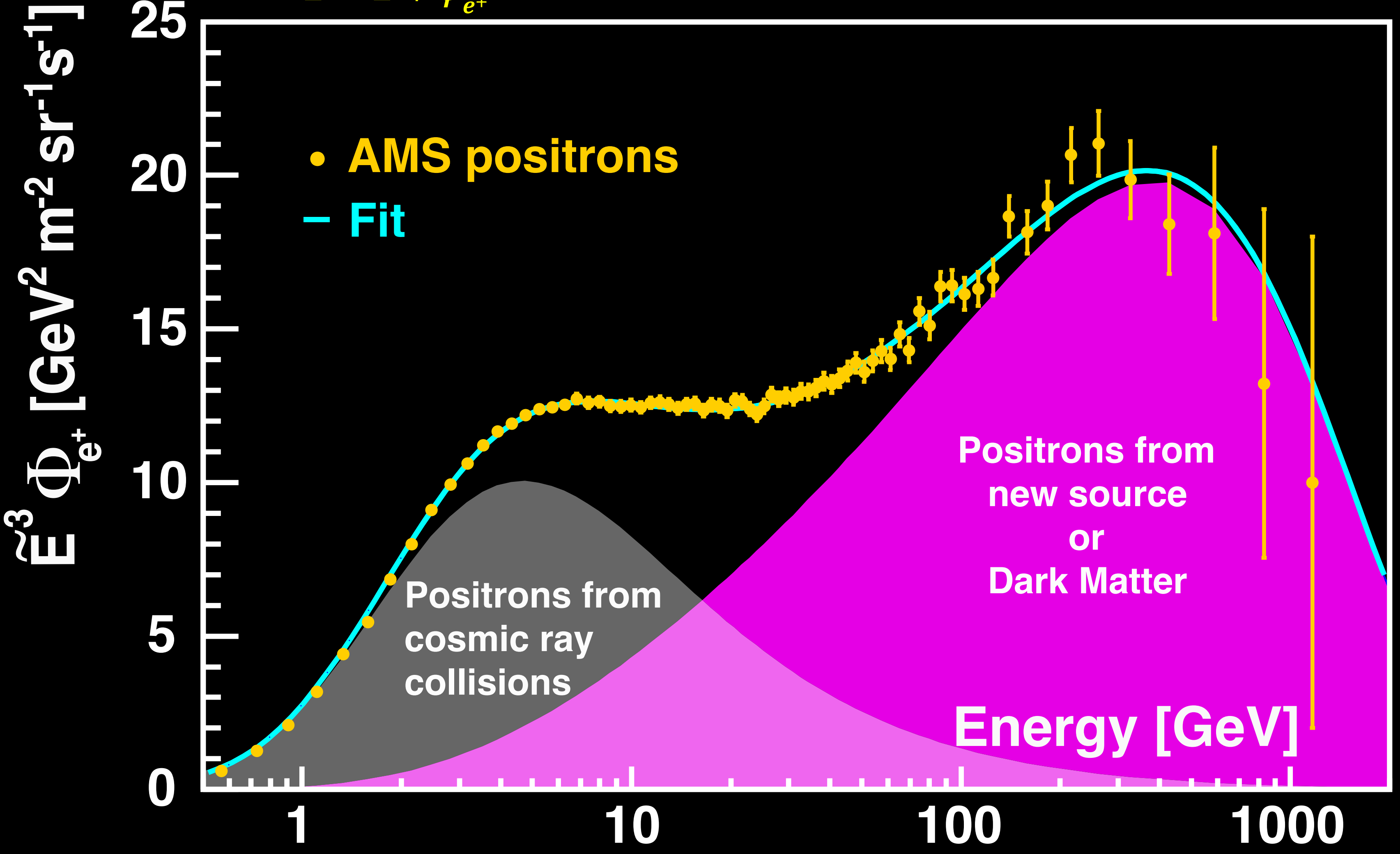


The positron flux is the sum of low-energy part from cosmic ray collisions plus a high-energy part from a new source or dark matter both with a cutoff energy E_S.

Collisions — New Source or Dark Matter

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

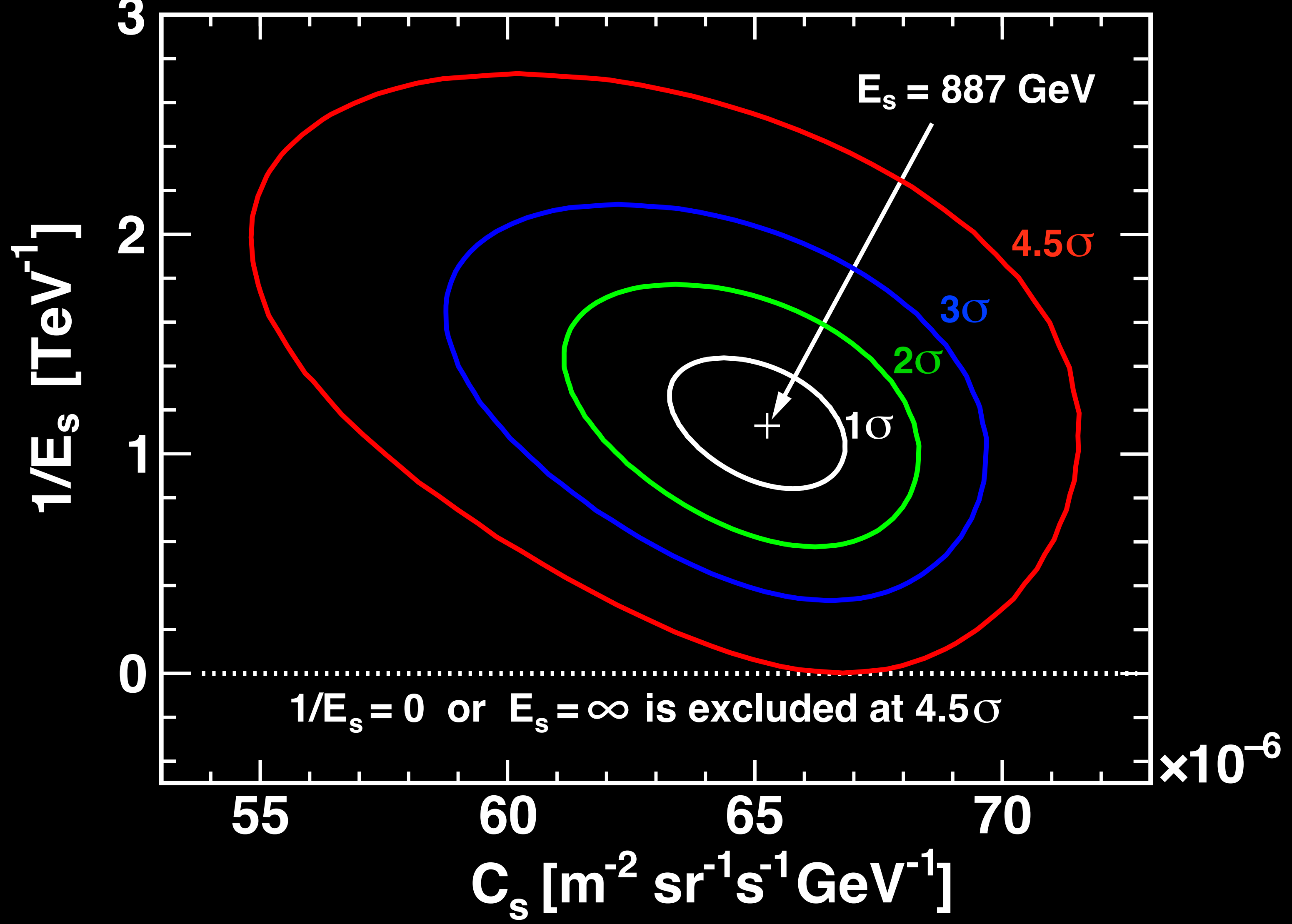
$$\hat{E} = E + \varphi_{e^+}$$



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

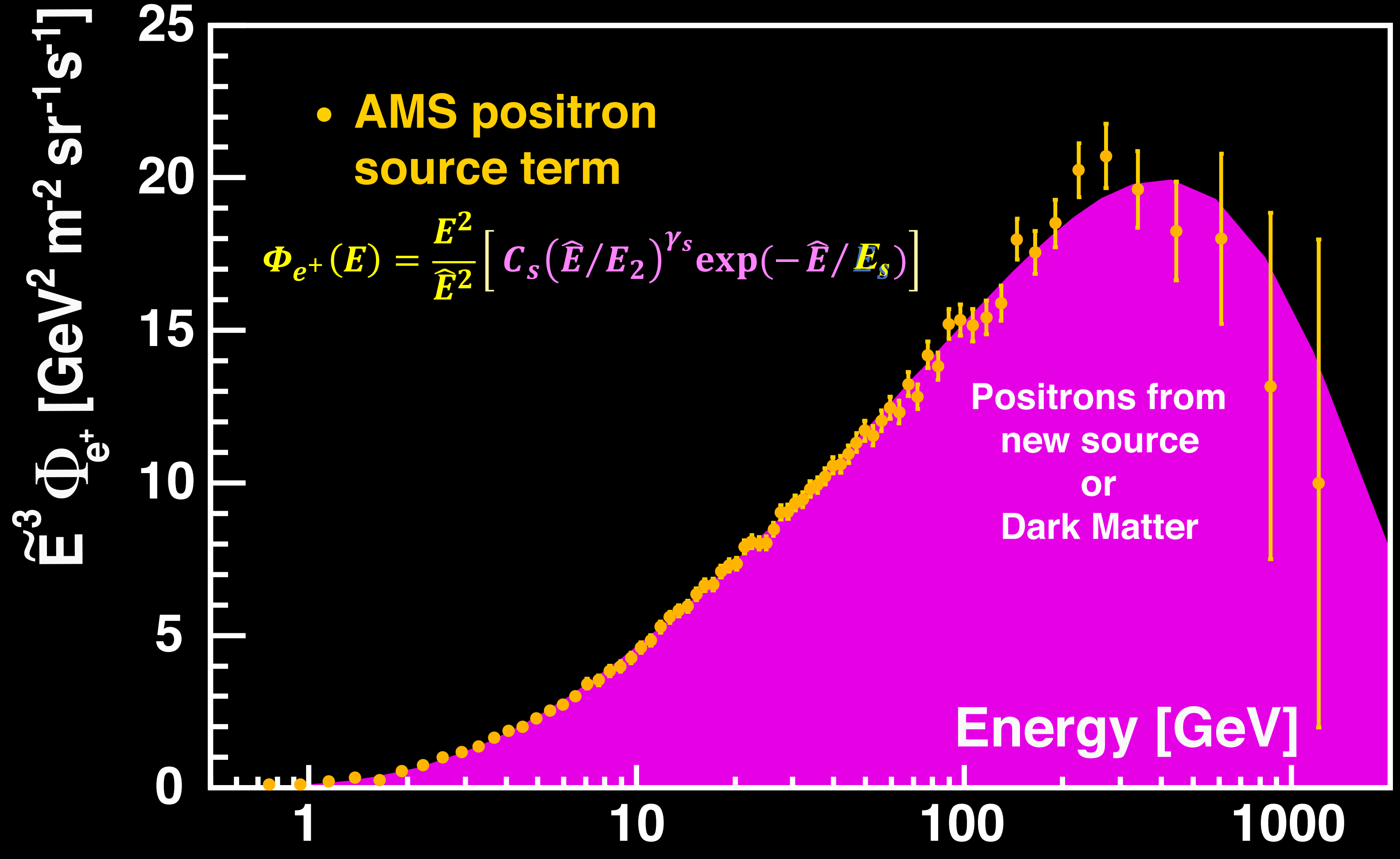
$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2}\left[C_d(\hat{E}/E_1)^{\gamma_d} + C_s(\hat{E}/E_2)^{\gamma_s}\exp(-\hat{E}/E_s)\right]$$

Collisions — New Source or Dark Matter



At high energies

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



New sources of high energy positrons, such as dark matter, may also produce an equal amount of high energy electrons.

See talk by V. Vagelli, DM #127

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 …

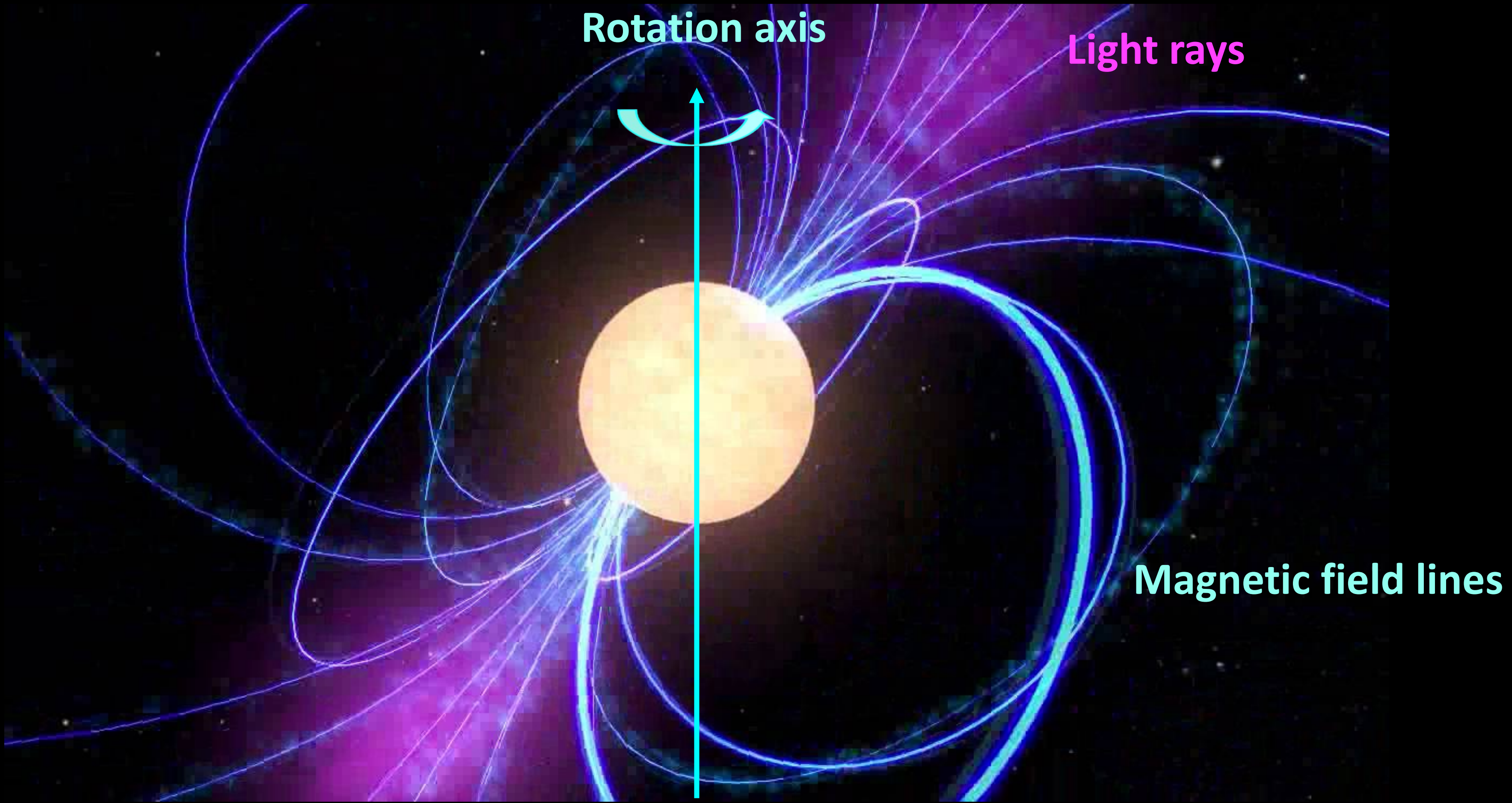
Propagation

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

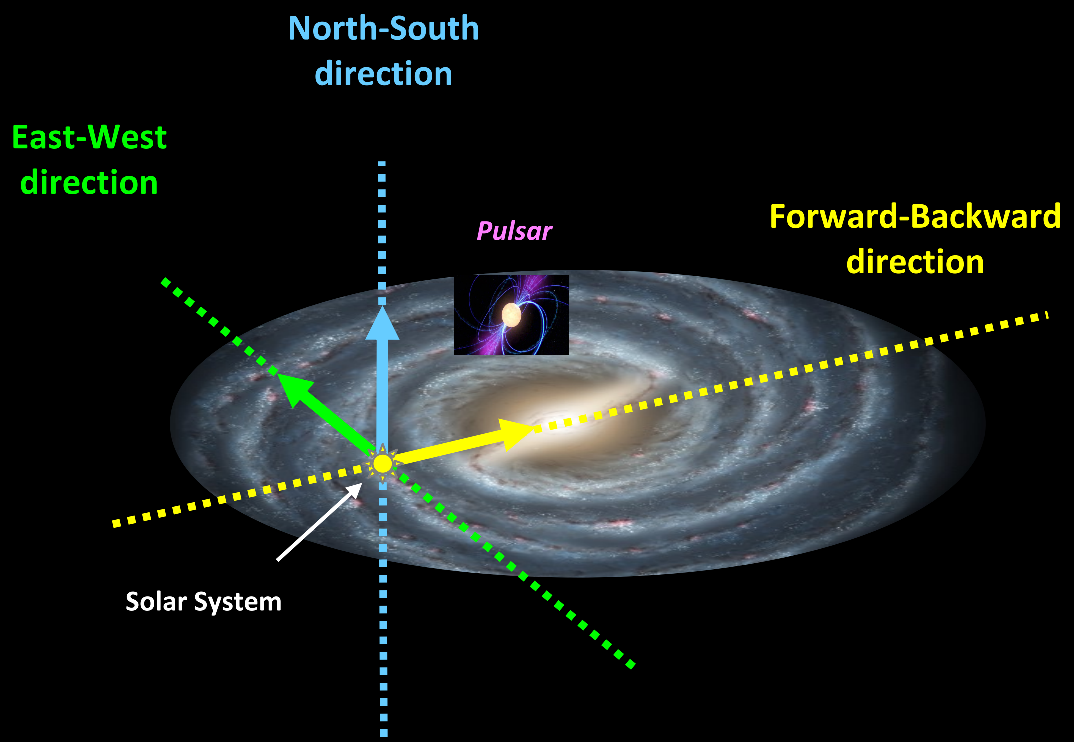
and many other excellent papers …

Positrons from Pulsars

- Pulsars produce and accelerate positrons to high energies.
- Pulsars will imprint a higher anisotropy on the arrival directions of positrons
- Pulsars do not produce antiprotons.



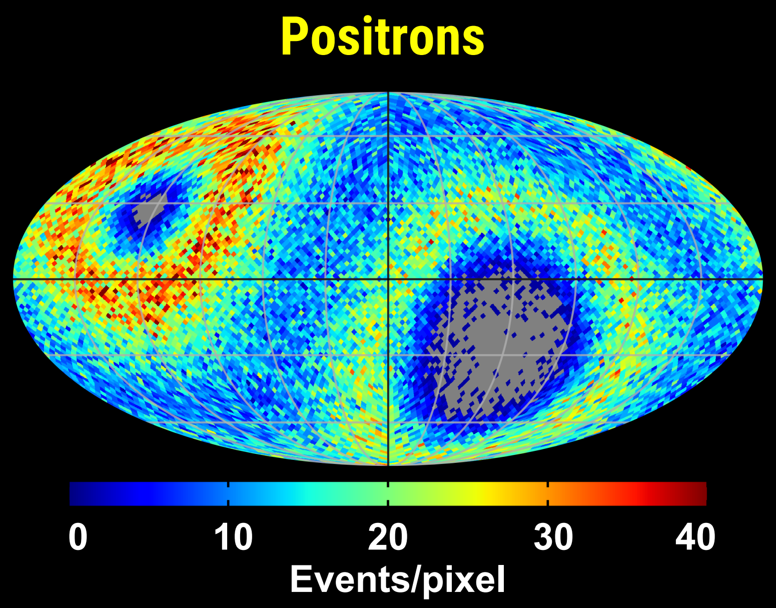
Positron Anisotropy

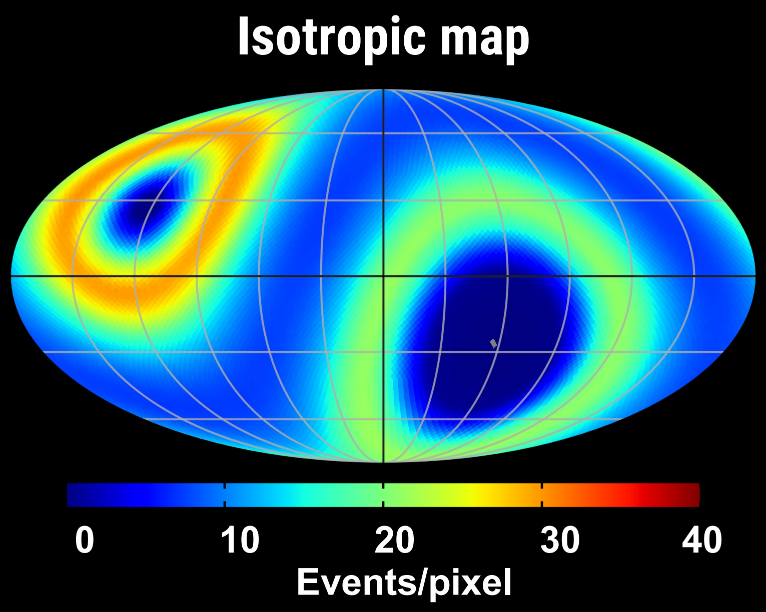


AMS measures cosmic ray fluxes as function of the arrival direction in **Galactic Coordinates**

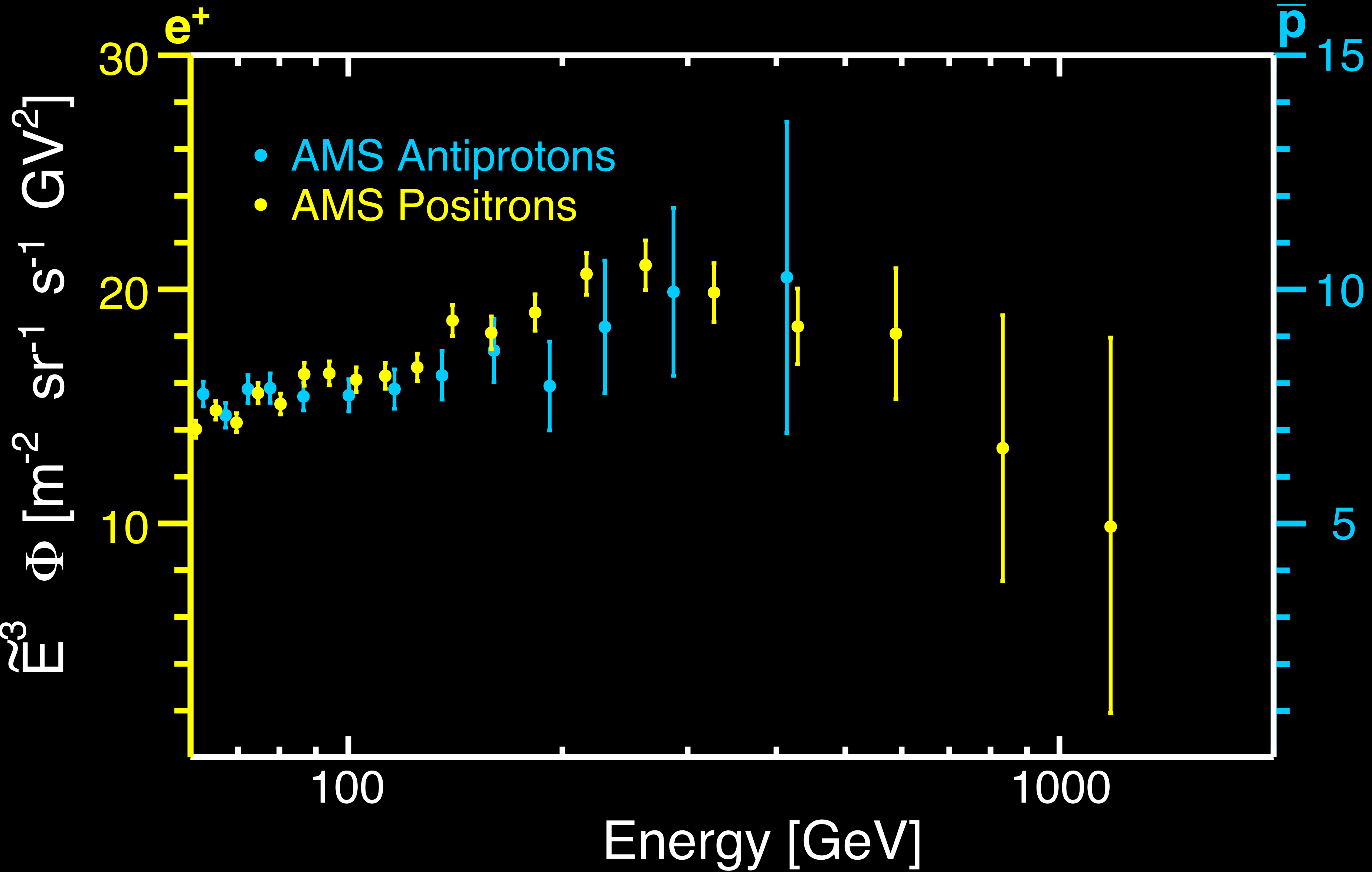
Results consistent with isotropy

Amplitude of the dipole anisotropy on e^+ for $16 < E < 500$ GeV $\delta < 1.5\%$ at the 95% C.L.





Positron and Antiproton have nearly identical rigidity dependence.



Examples of DM models discussed in the literature

DM annihilation

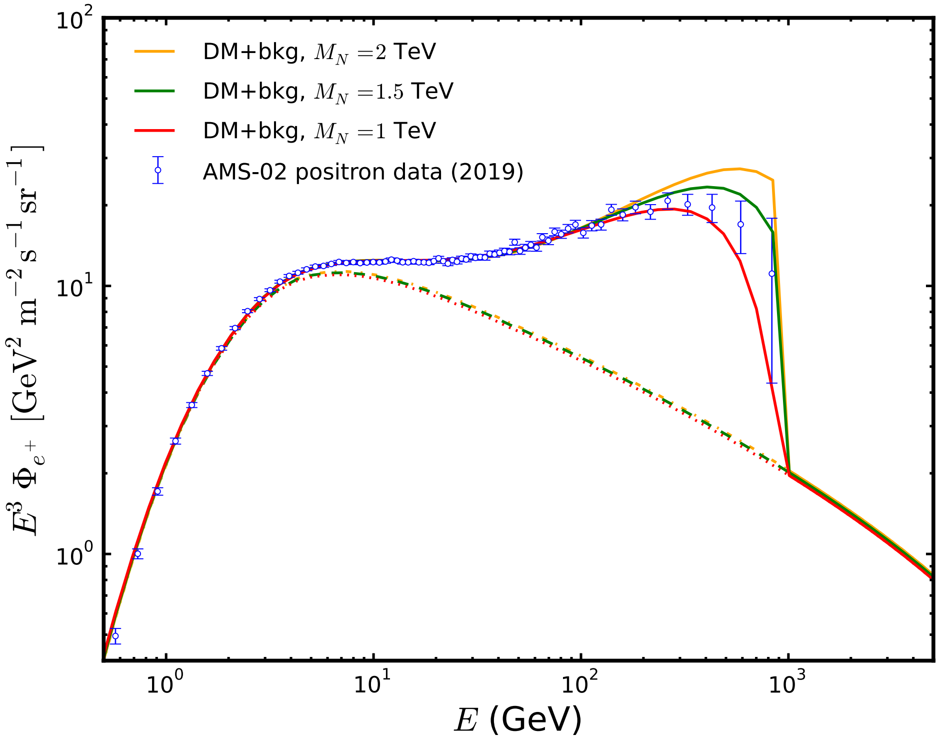
Z.L. Han, R. Ding, S.J. Lin, and B. Zhu,
Eur. Phys. J. C79 (2019) 12, 1007

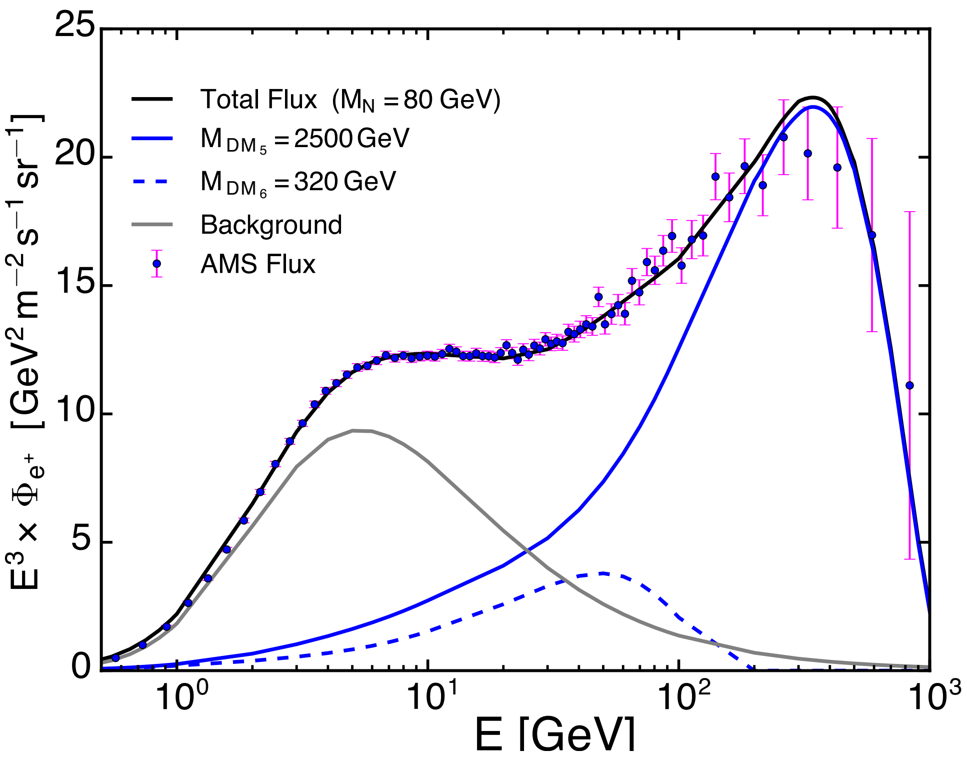
$NN \rightarrow Z' Z' \rightarrow e^+ + X$

DM decays

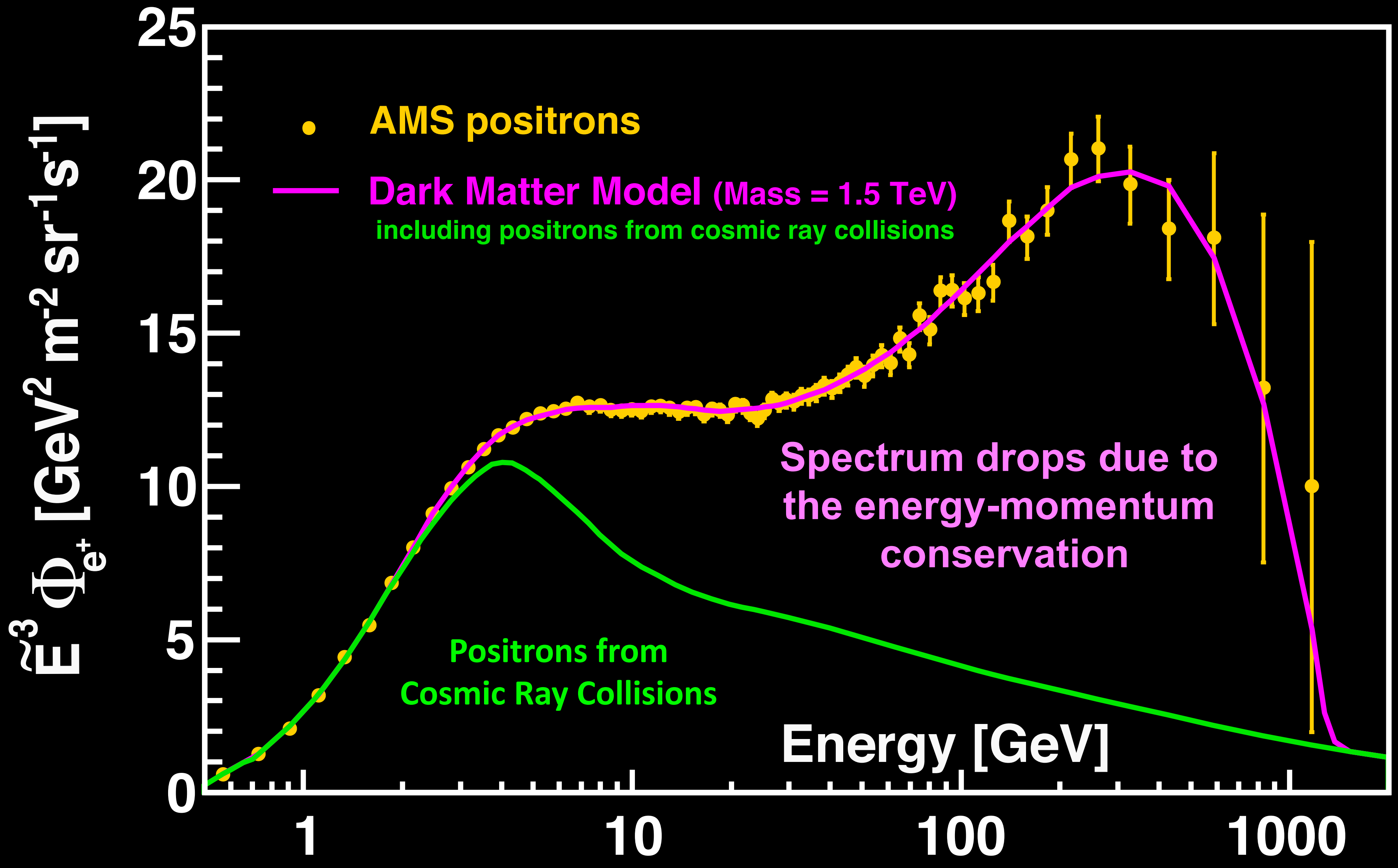
F. Queiroz and C. Siqueira,
Phys. Rev. D 101 (2020) 7, 075007

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





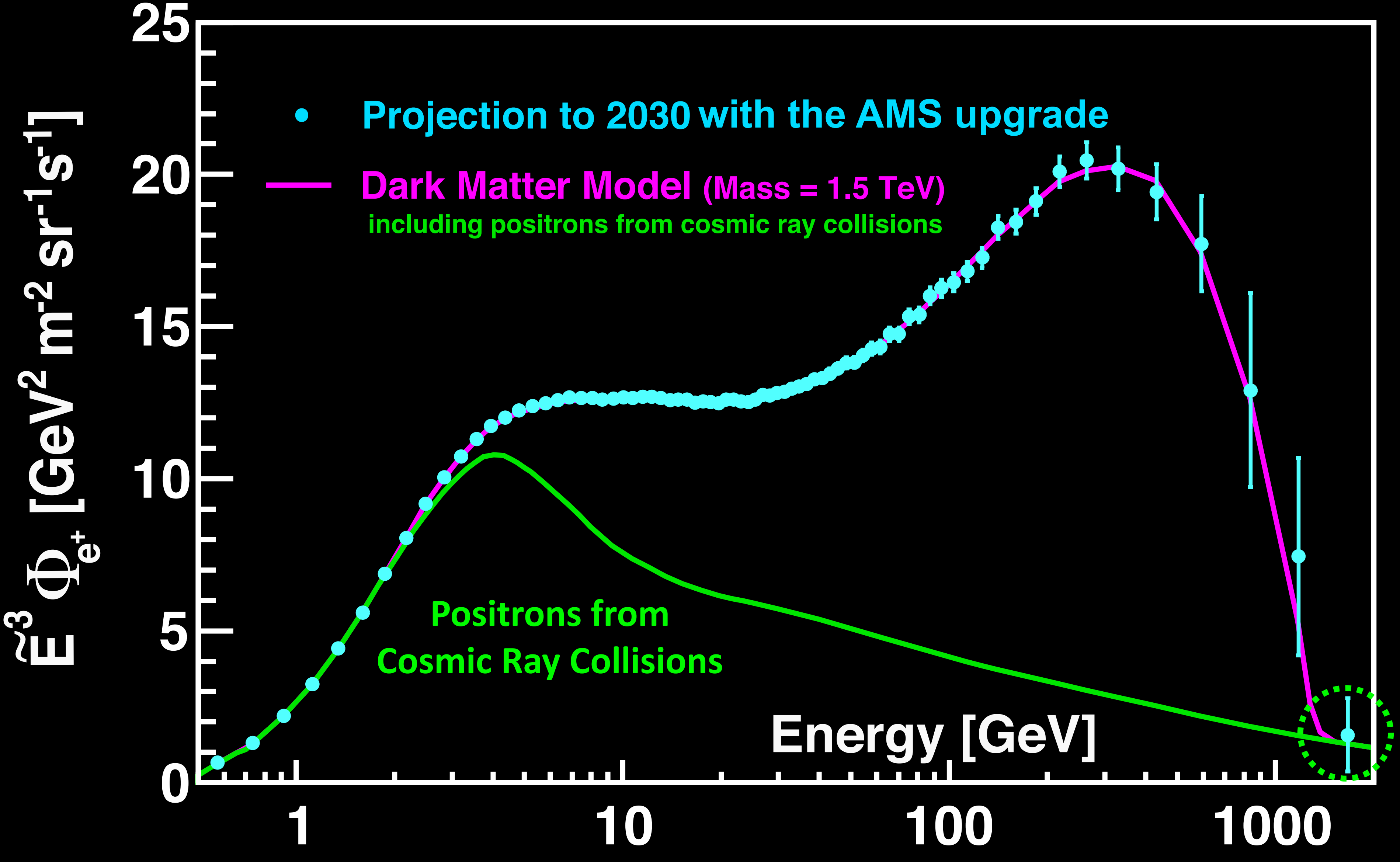
Positrons and a Dark Matter Model



Model based on J. Kopp, PRD 88, 076013 (2013)

Positrons and Dark Matter Model by 2030

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



Conclusion and Outlooks

- Precision measurements by AMS of the positron flux to 1.4 TeV.

- The positron flux shows distinctive energy dependence:
  (a) a significant excess starting from 24.2 GeV
  (b) a sharp drop-off above 268 GeV,

- The positron flux is well described by the sum of a diffuse term and a new source term with a finite energy cutoff at 887 GeV, with a significance of 4.5σ.

- These properties are not explained by traditional CR models:
  A primary source of high energy positrons.

- By continuing the measurement through the live time of the Space Station, we will be able to improve the accuracy and extend to higher energy, and determine the origin of high energy positrons.