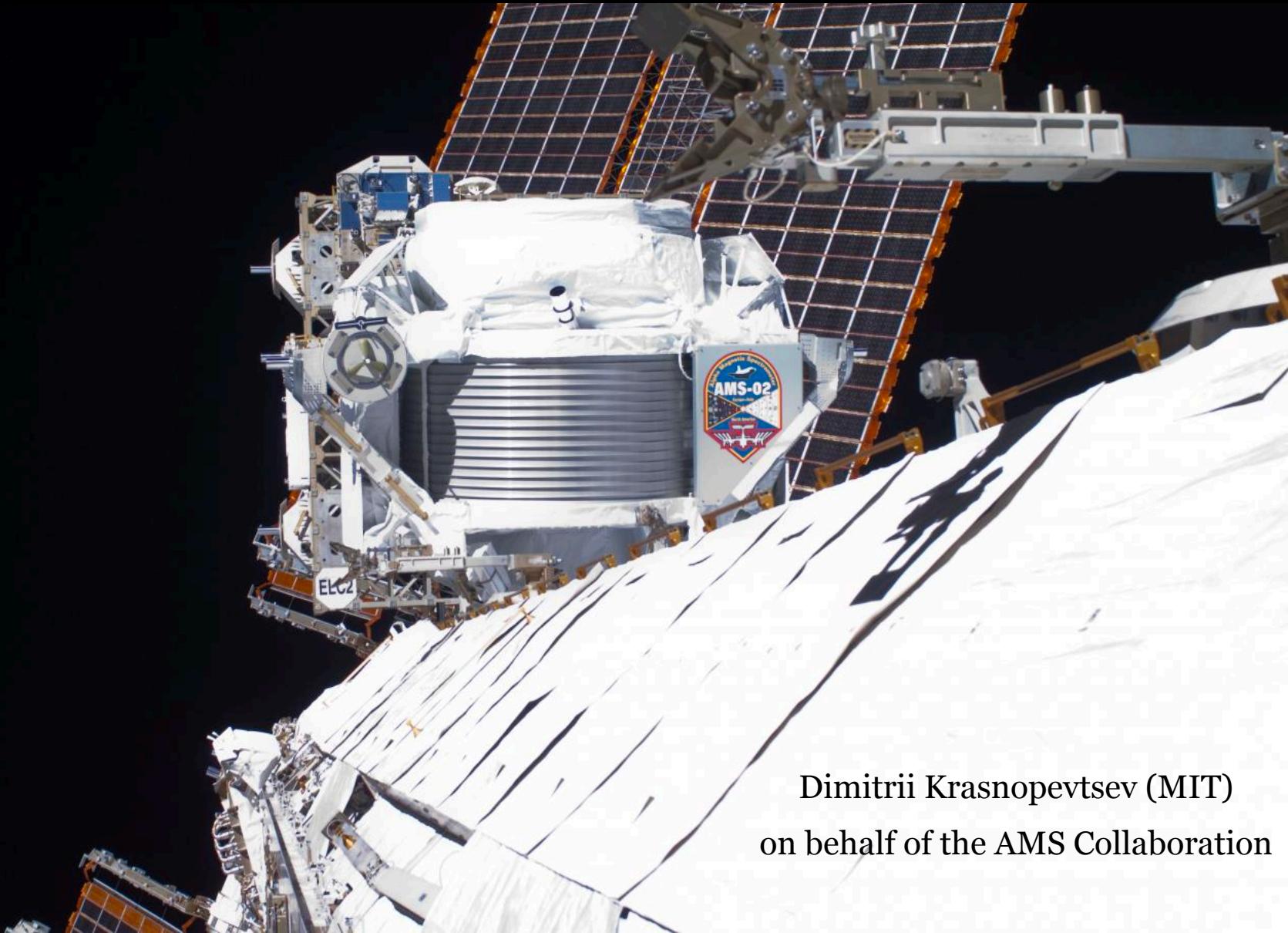
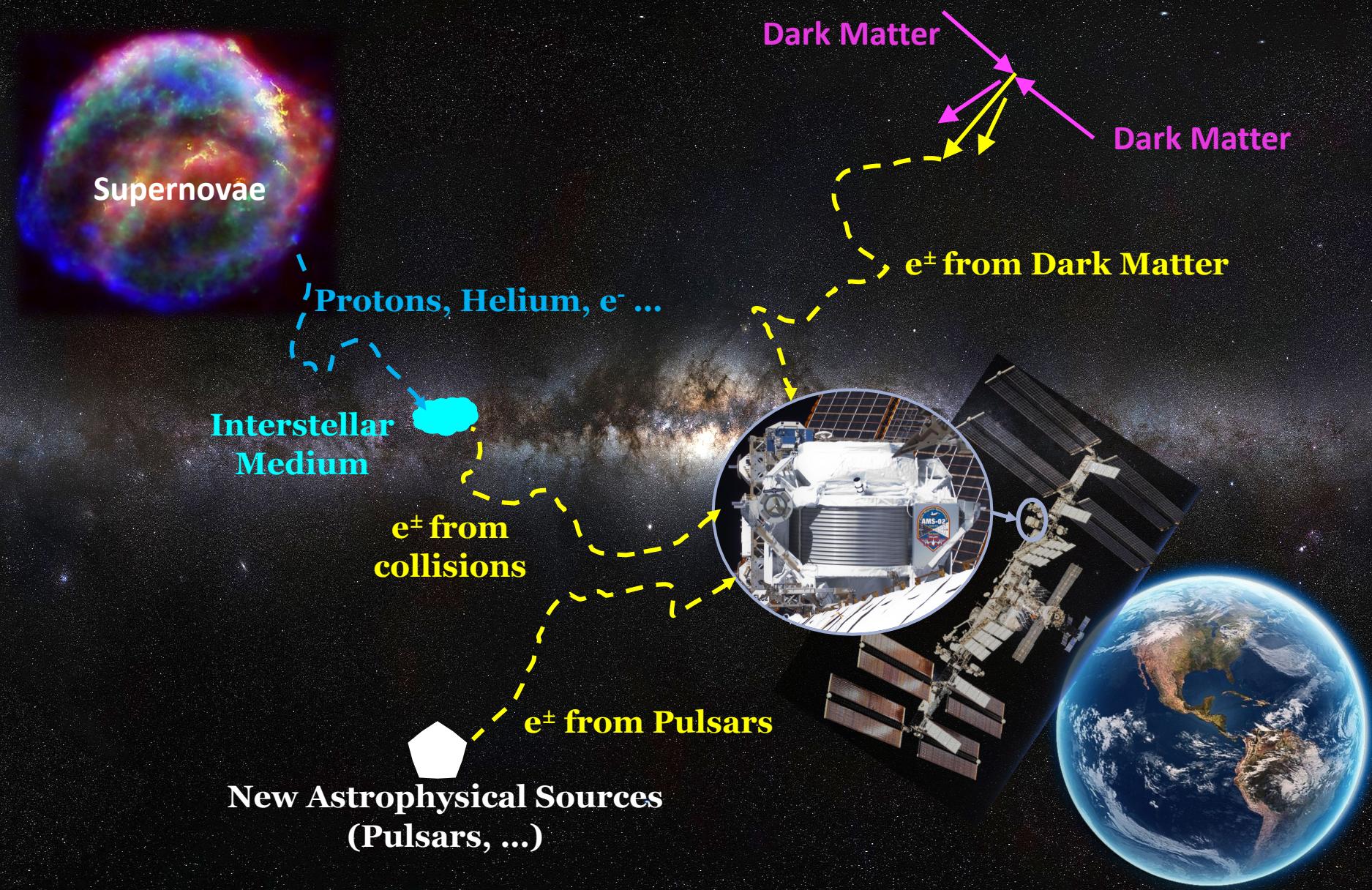


Towards Understanding the Origin of Cosmic-Ray Positrons



Dimitrii Krasnopevtsev (MIT)
on behalf of the AMS Collaboration

The origins of cosmic positrons



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

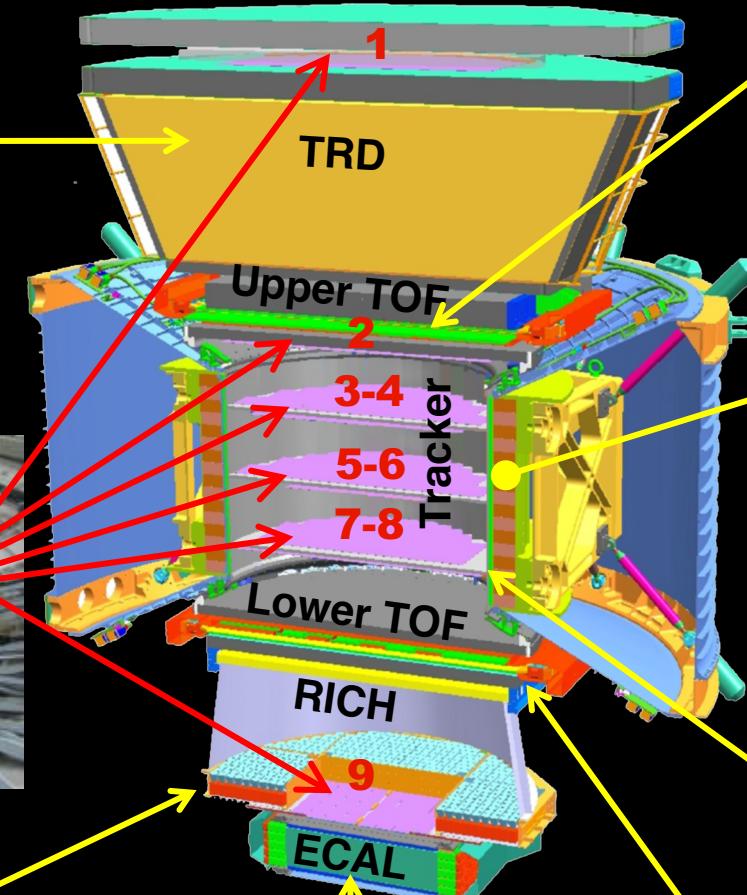
Transition Radiation Detector (TRD)
identify e^+ , e^-



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



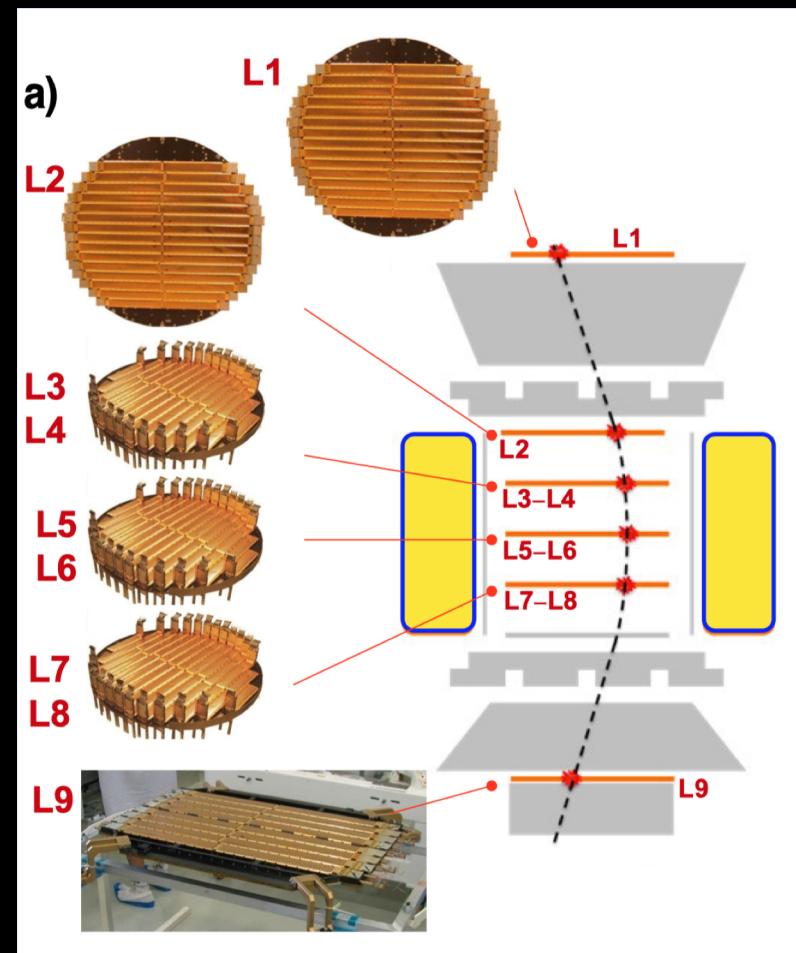
Anticoincidence Counters (ACC)
reject particles from the side



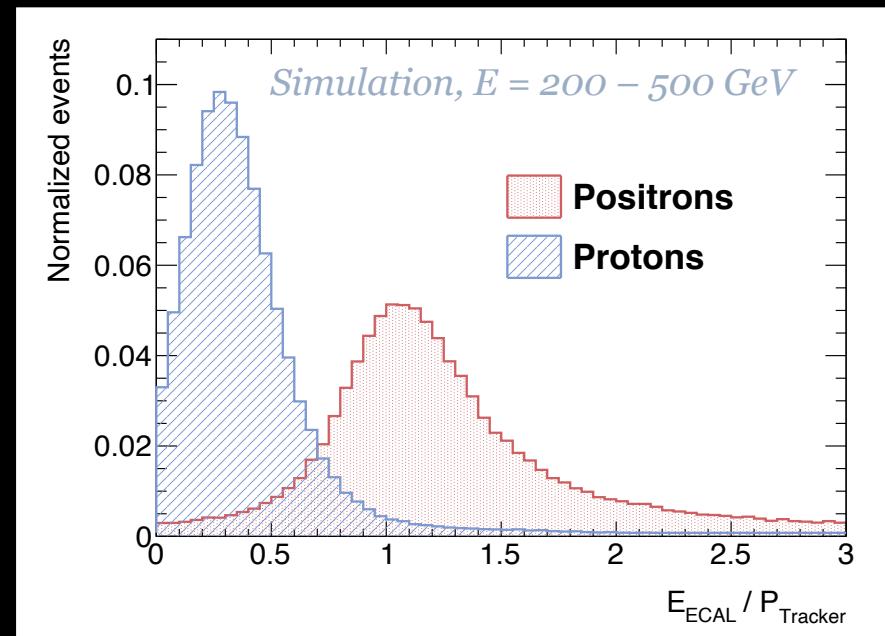
Lower TOF measure Z, E



Energy and momentum measurements



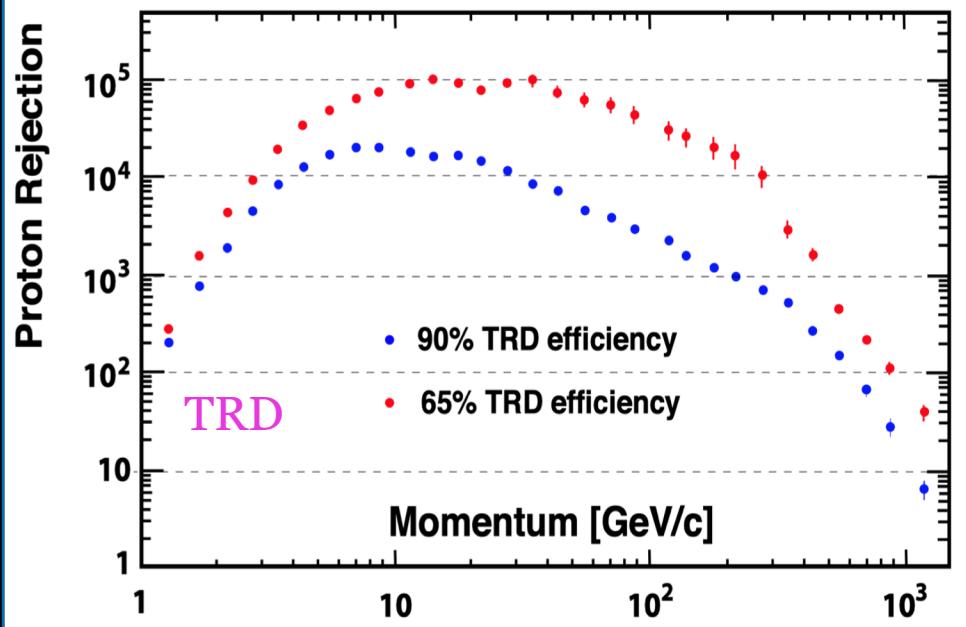
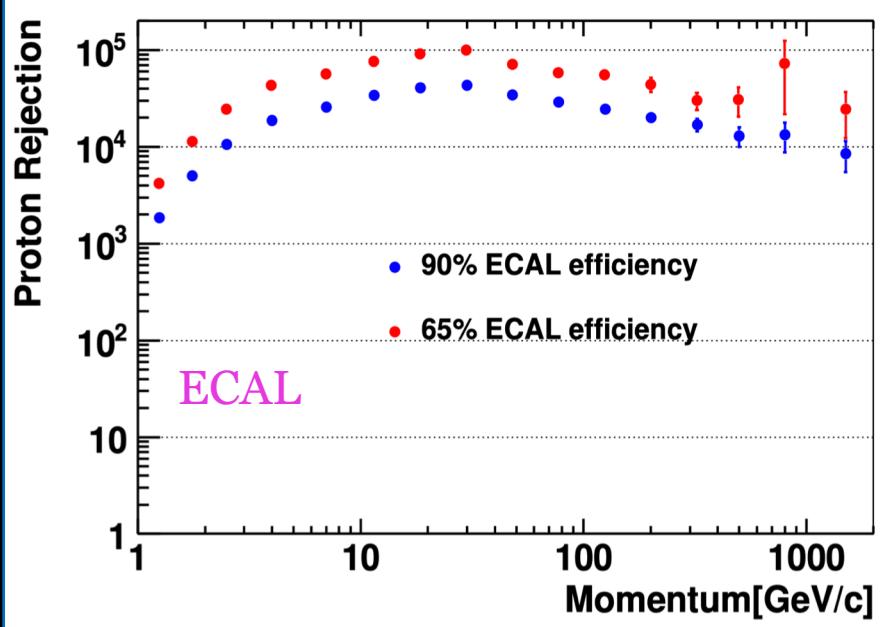
- Nine layers in AMS tracker forms 3 m lever arm
- For particle with $Z=1$:
 - Single point resolution is **10 μm**
 - The maximum detectable rigidity is **2 TeV**



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

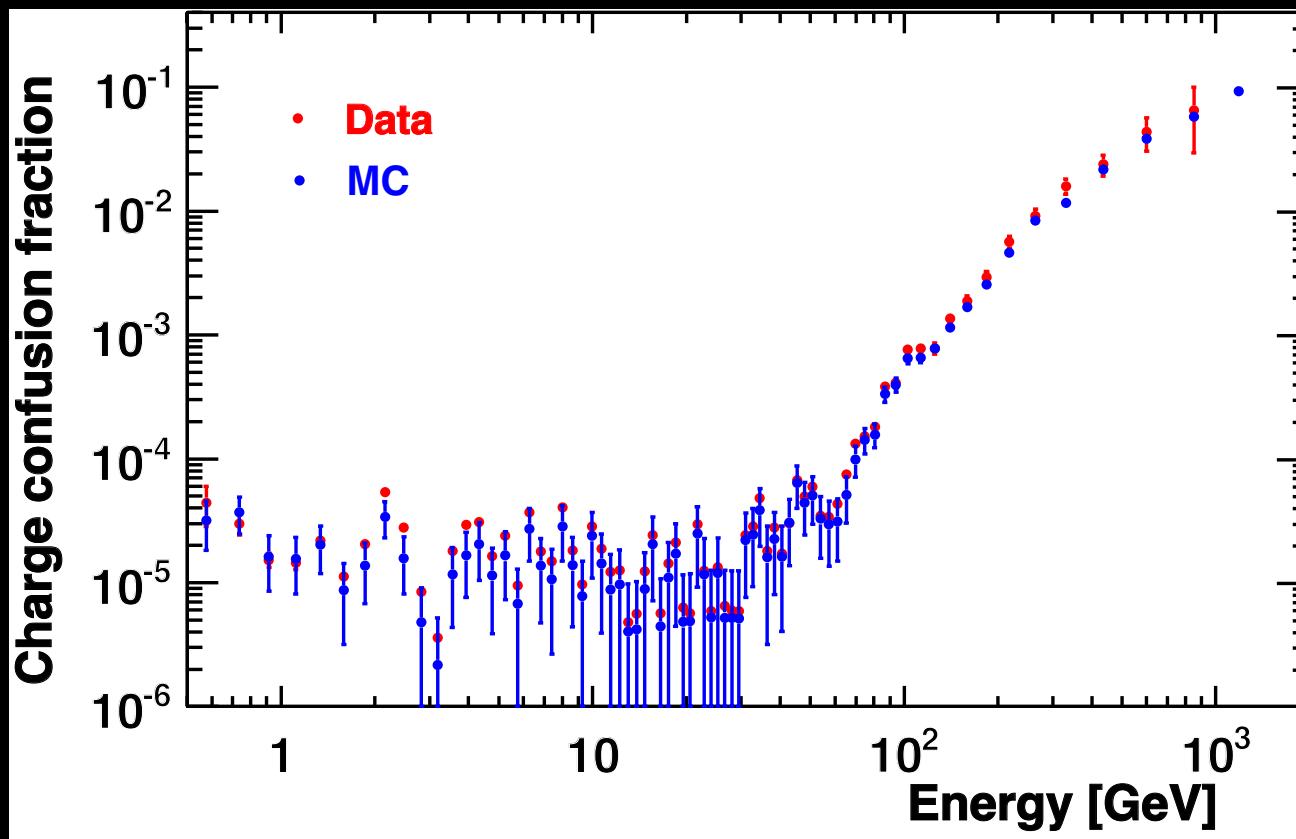
Proton rejection

- ECAL and TRD provides independent proton rejection
- Combined proton rejection power at 90% signal efficiency is $\sim 1 \text{ in } 10^6$



Charge sign confusion

Charge sign confusion events are identified using BDT based **Charge confusion estimator**. This estimator uses information from various detectors (tracker, TOF, ECAL) and is efficient up to with the highest measured energy.



Positron Selection

Primary cosmic ray particle:

- $E > 1.2$ Geomagnetic cutoff

TRD:

- Track identified in TRD

TOF:

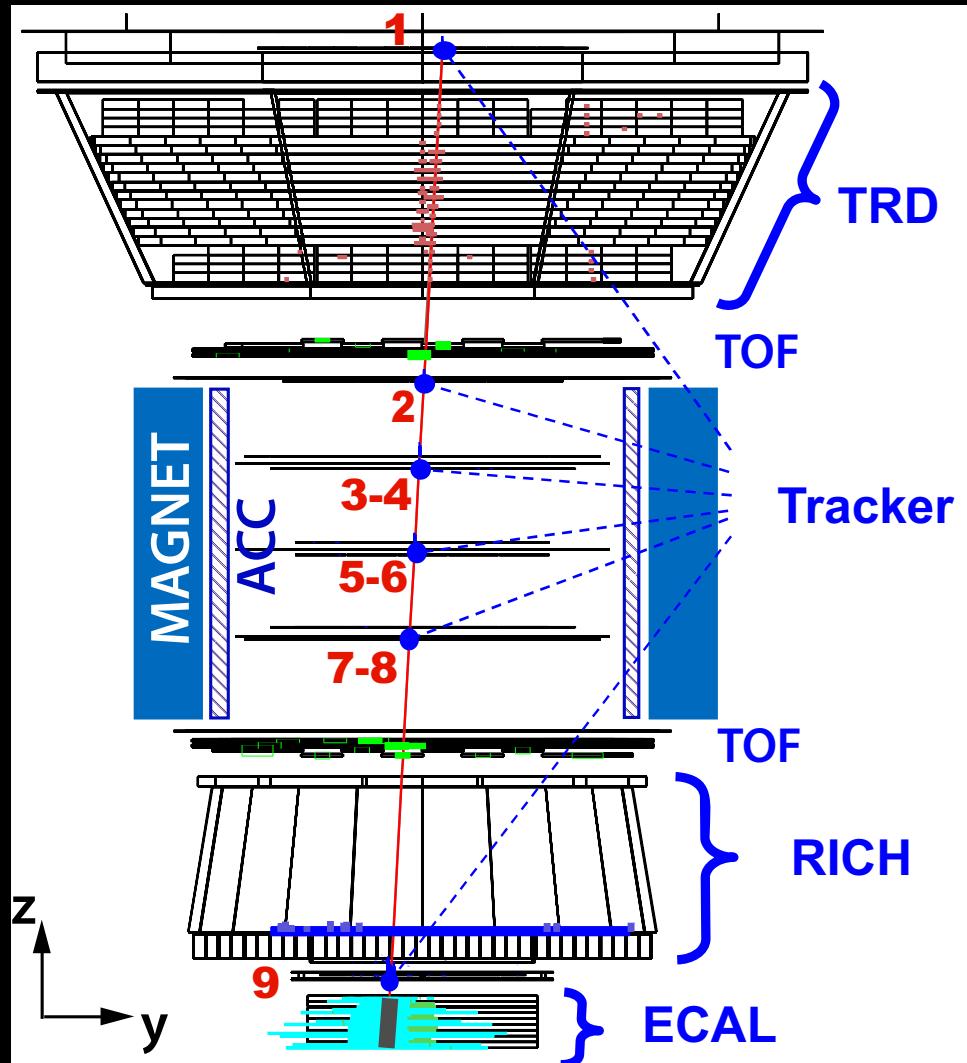
- Down-going particle $\beta > 0.8$
- Charge $|Z|=1$ particle

Tracker and magnet:

- Good quality track
- Charge $|Z|=1$ particle

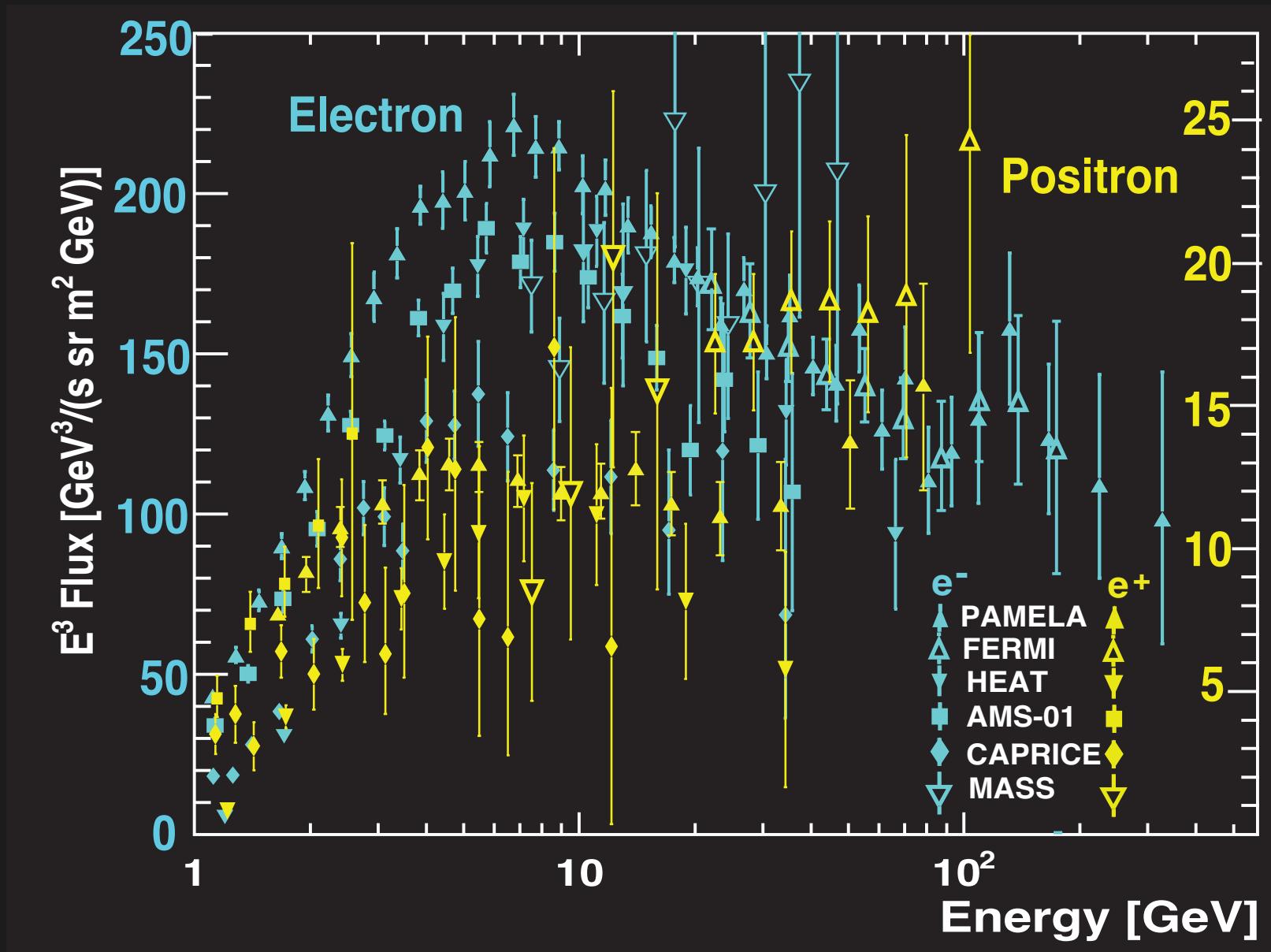
ECAL:

- EM shower is matched with track extrapolation

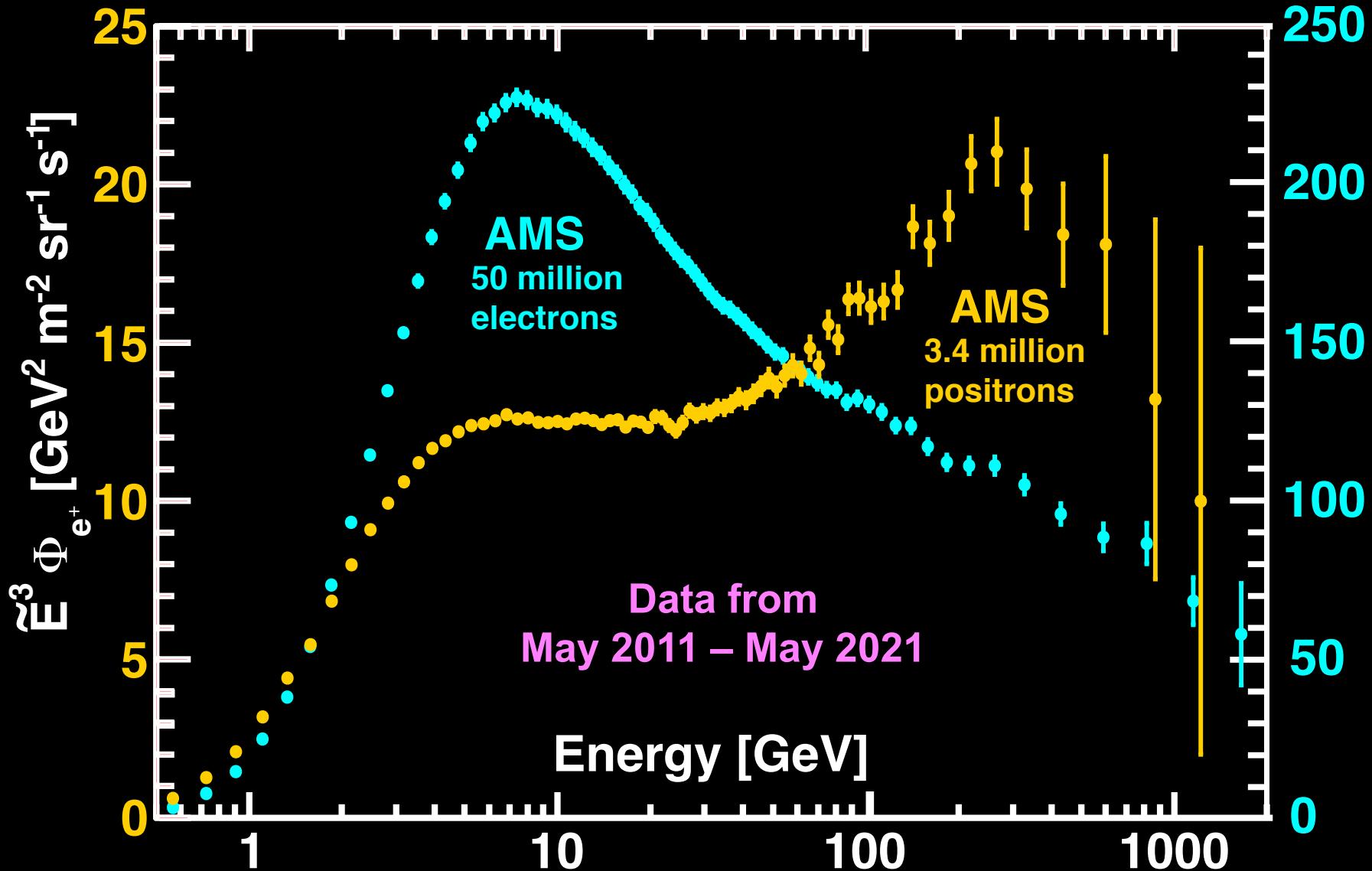


Positron candidate with $E = 1353$ GeV

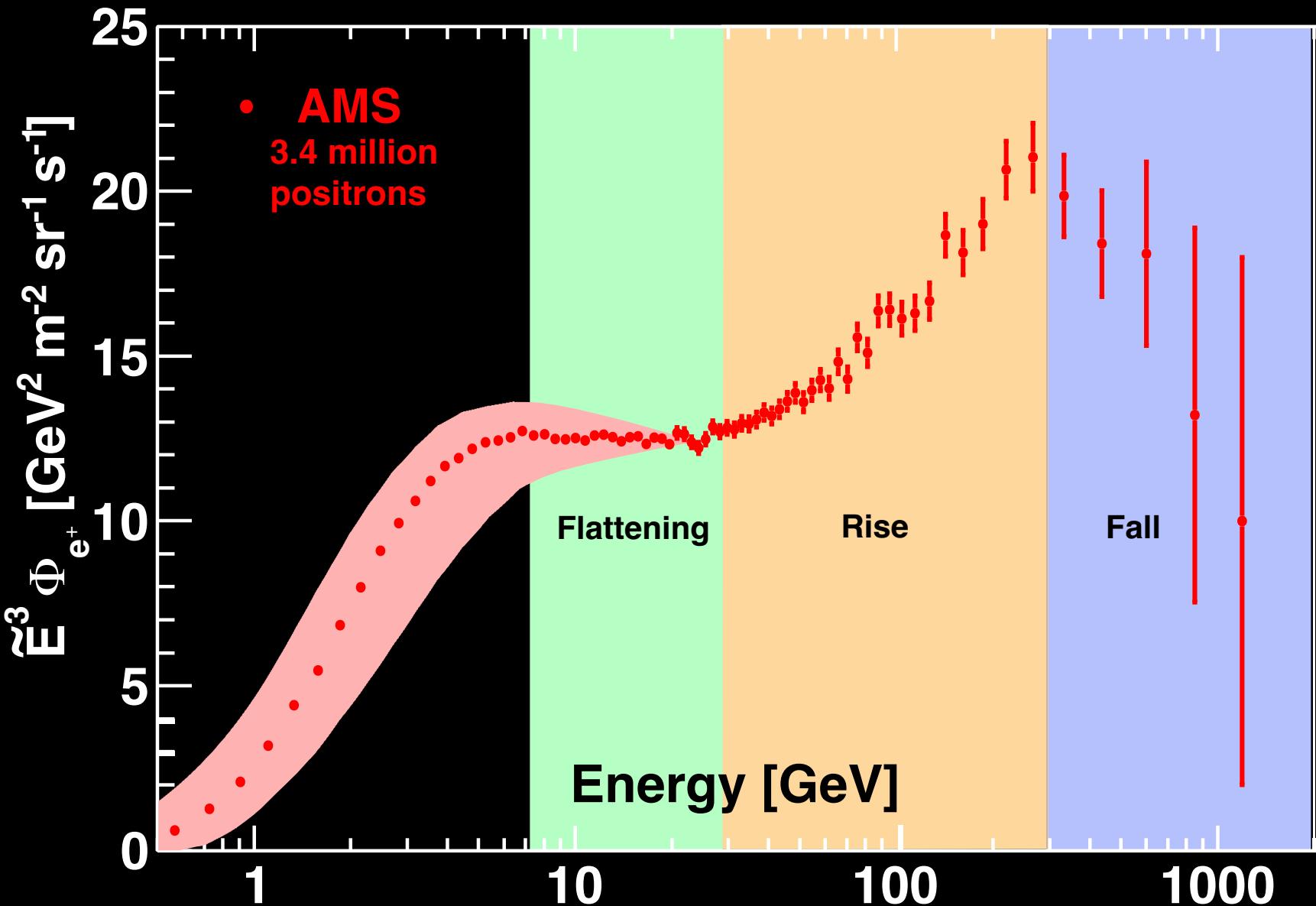
Measurements of positrons and electrons before AMS



Latest Physics Results from AMS



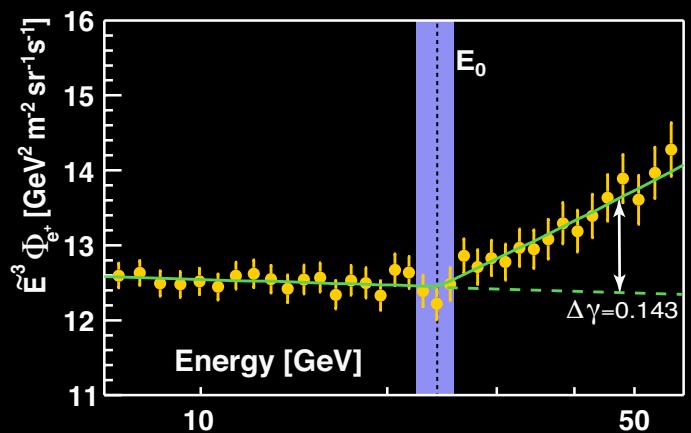
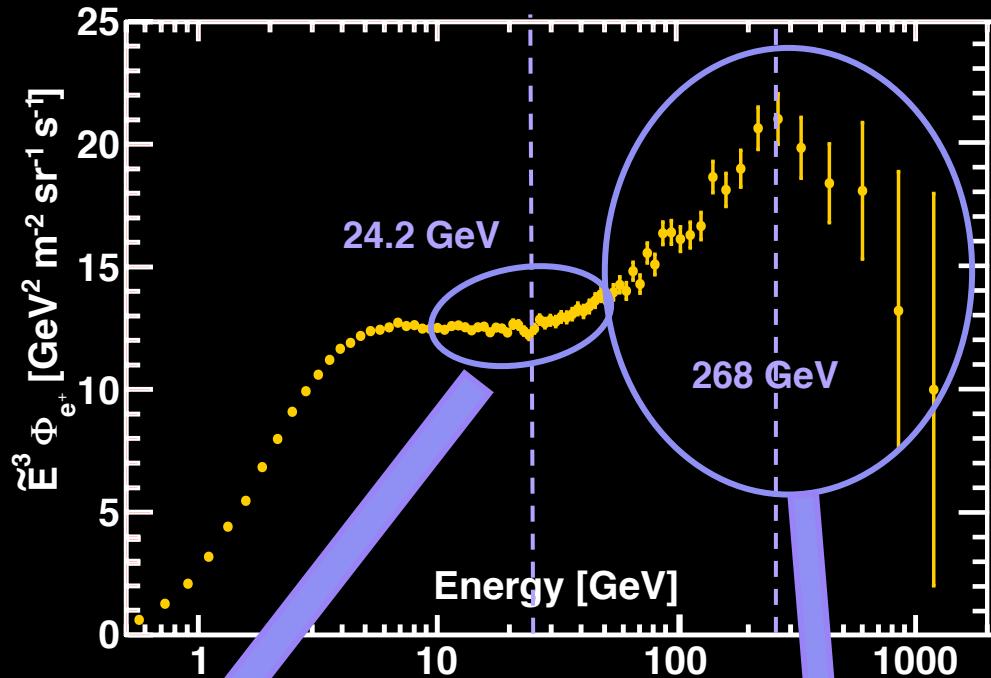
Towards understanding the origin of cosmic ray positrons



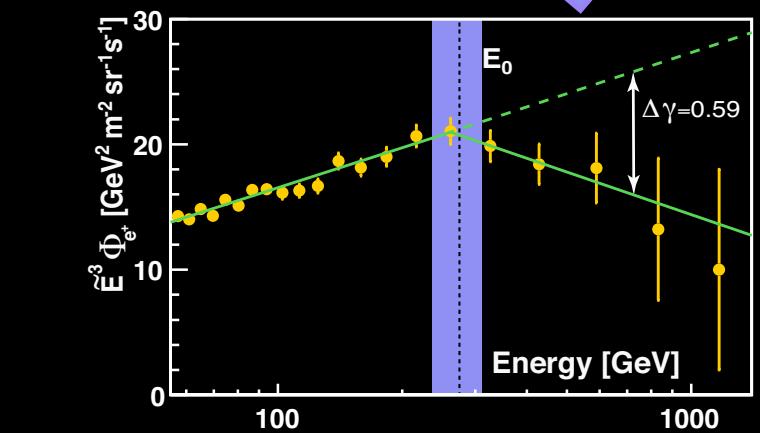
Transition energies

Fits of the data to

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



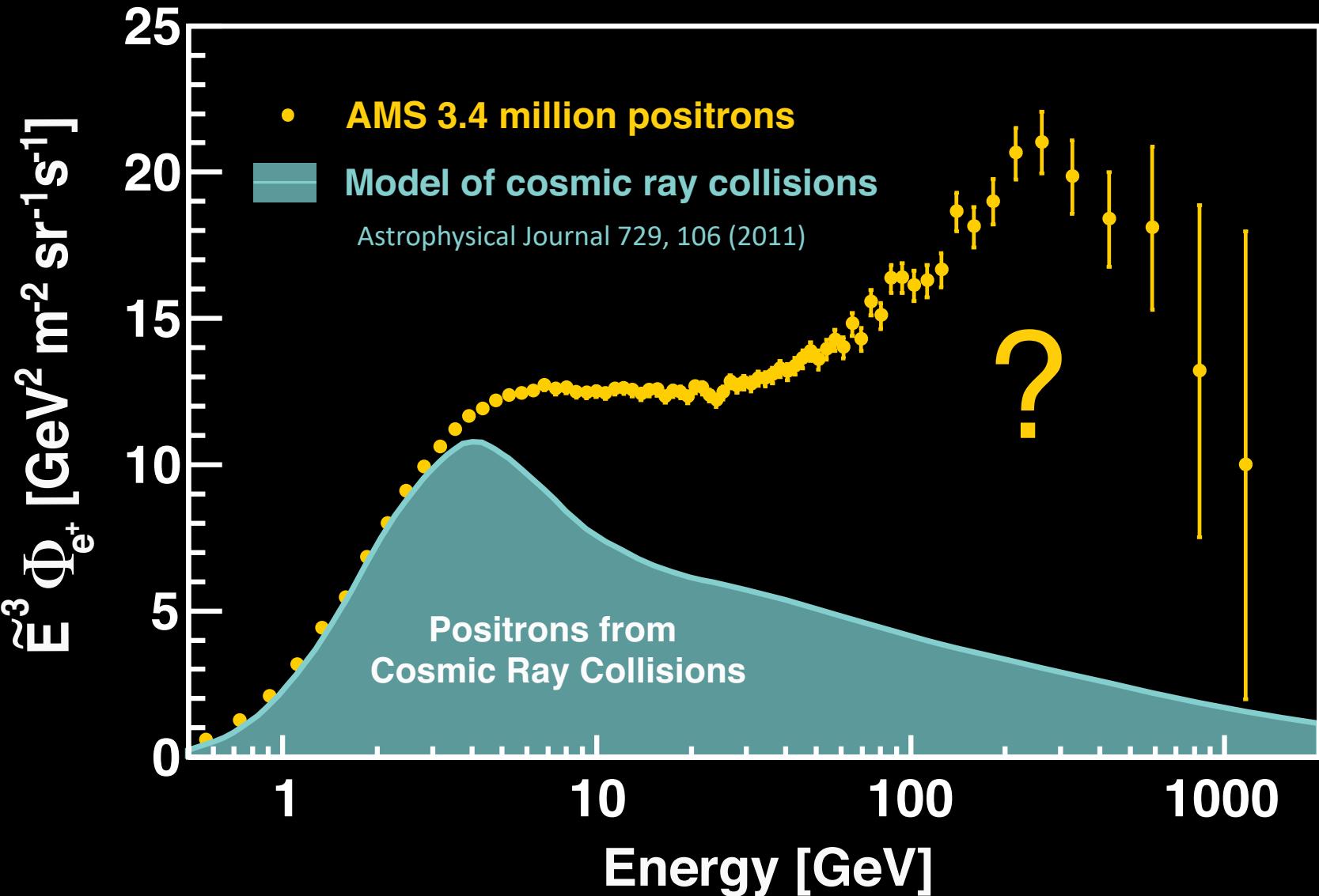
7.8 σ excess above $E_0 = 24.2 \pm 1.1 \text{ GeV}$



4.8 σ sharp drop-off at $E_0 = 268^{+35}_{-33} \text{ GeV}$

The Origin of Positrons

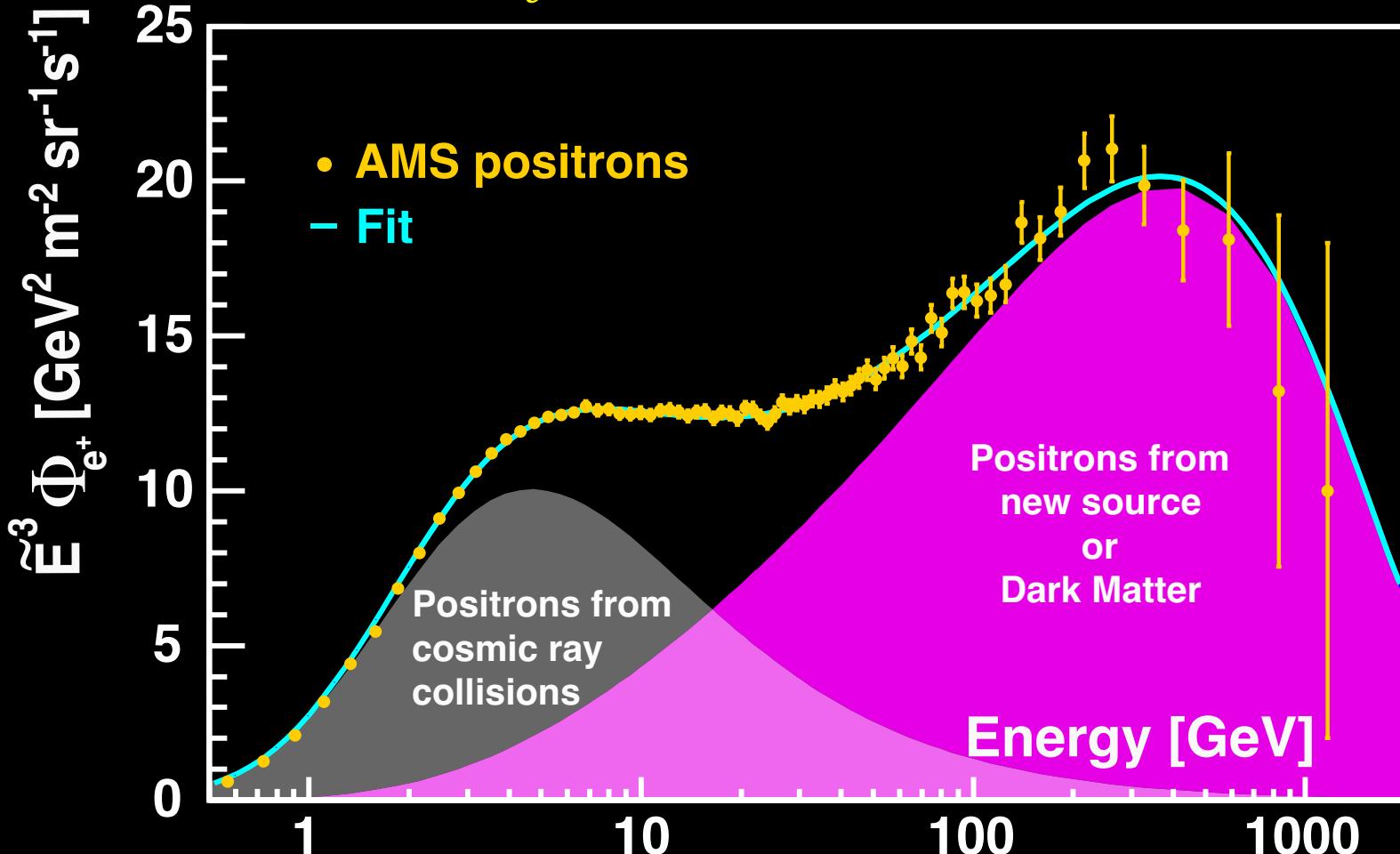
Low energy positrons mostly come from cosmic ray collisions



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 .

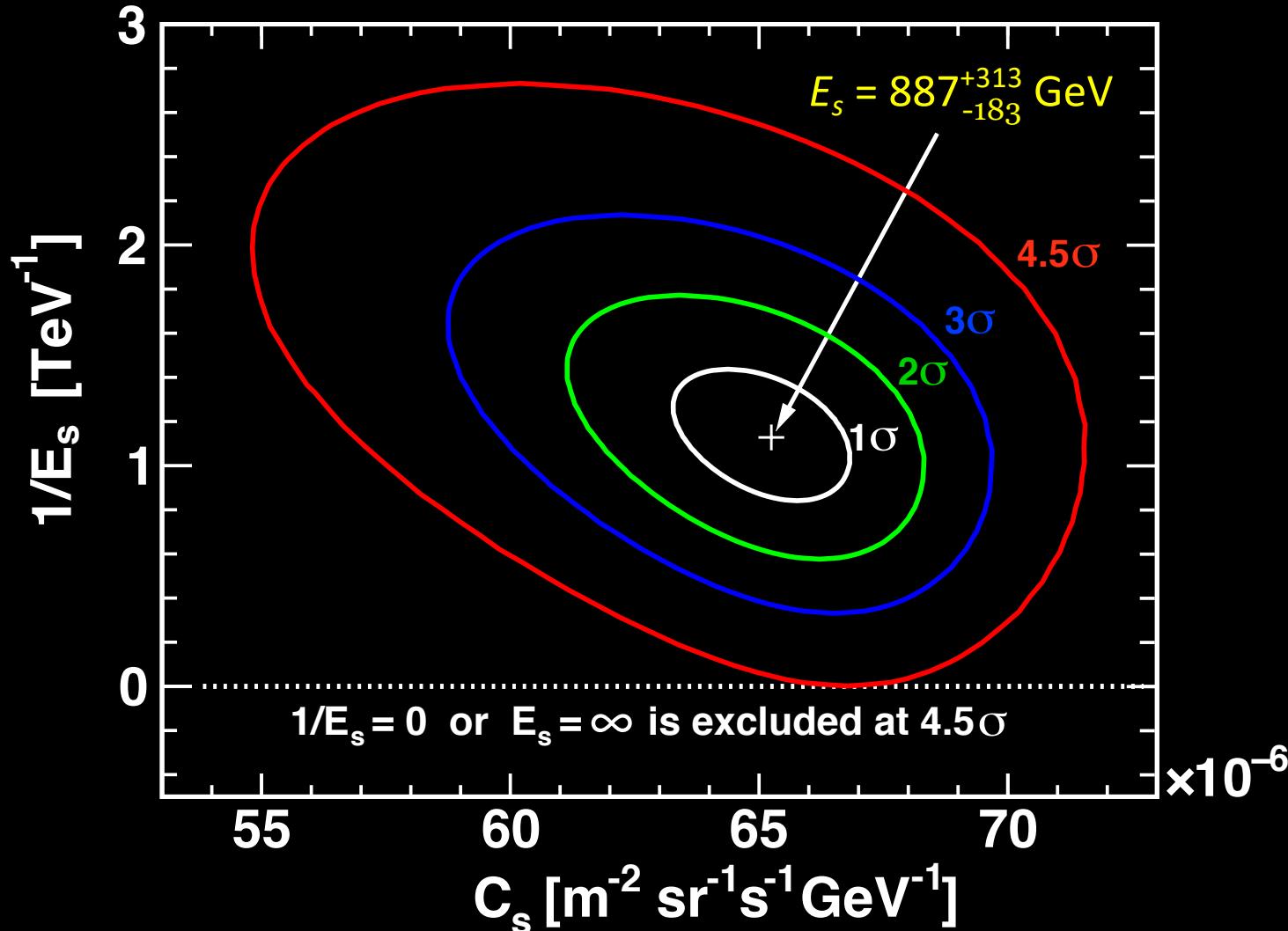
$$\Phi_{e^+}(E) = \frac{\text{Solar } E^2}{\widehat{E}^2} \left[C_d (\widehat{E}/E_1)^{\gamma_d} + C_s (\widehat{E}/E_2)^{\gamma_s} \exp(-\widehat{E}/E_s) \right]$$

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



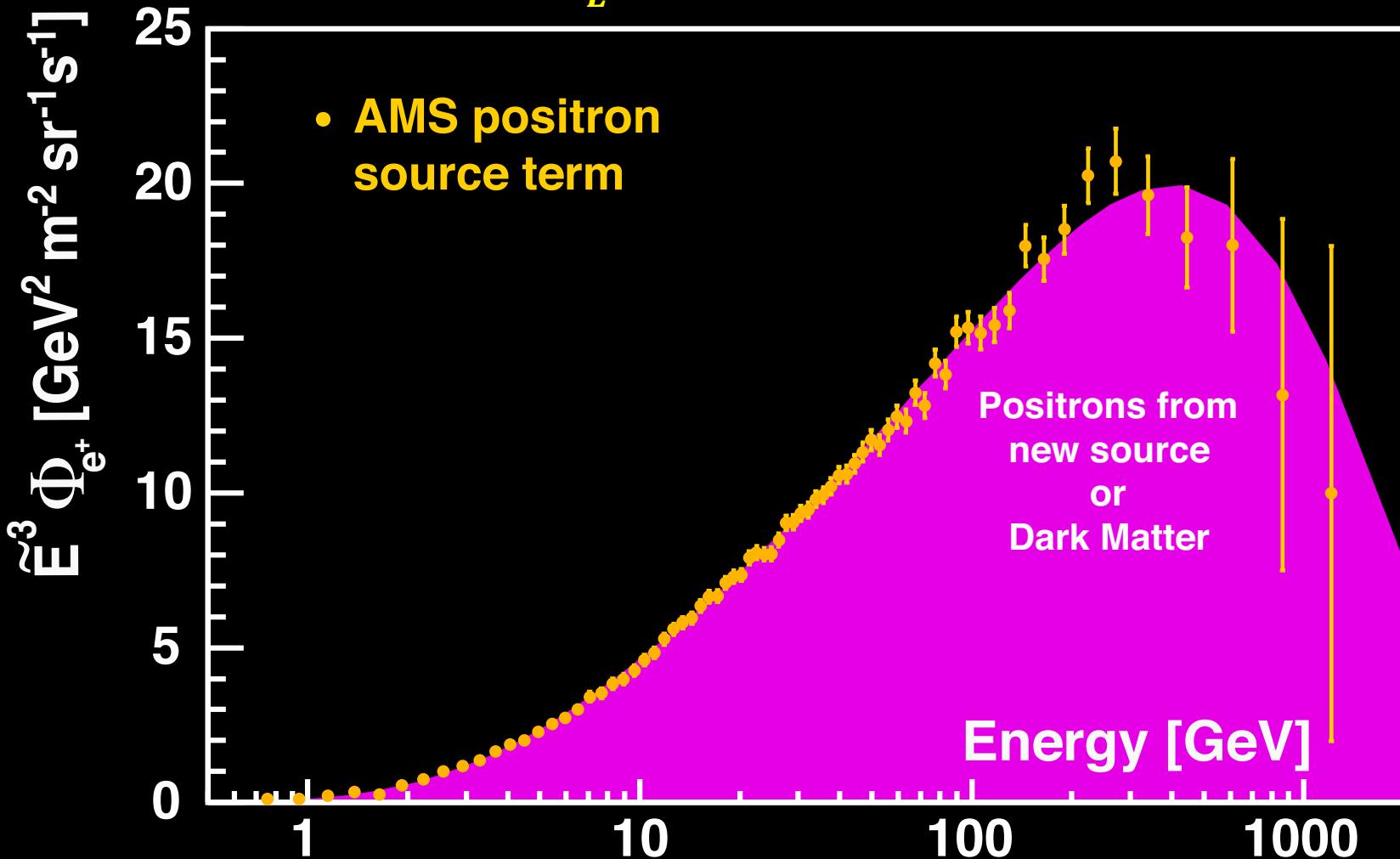
The finite cutoff energy E_S is established at 4.5σ C.L.

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



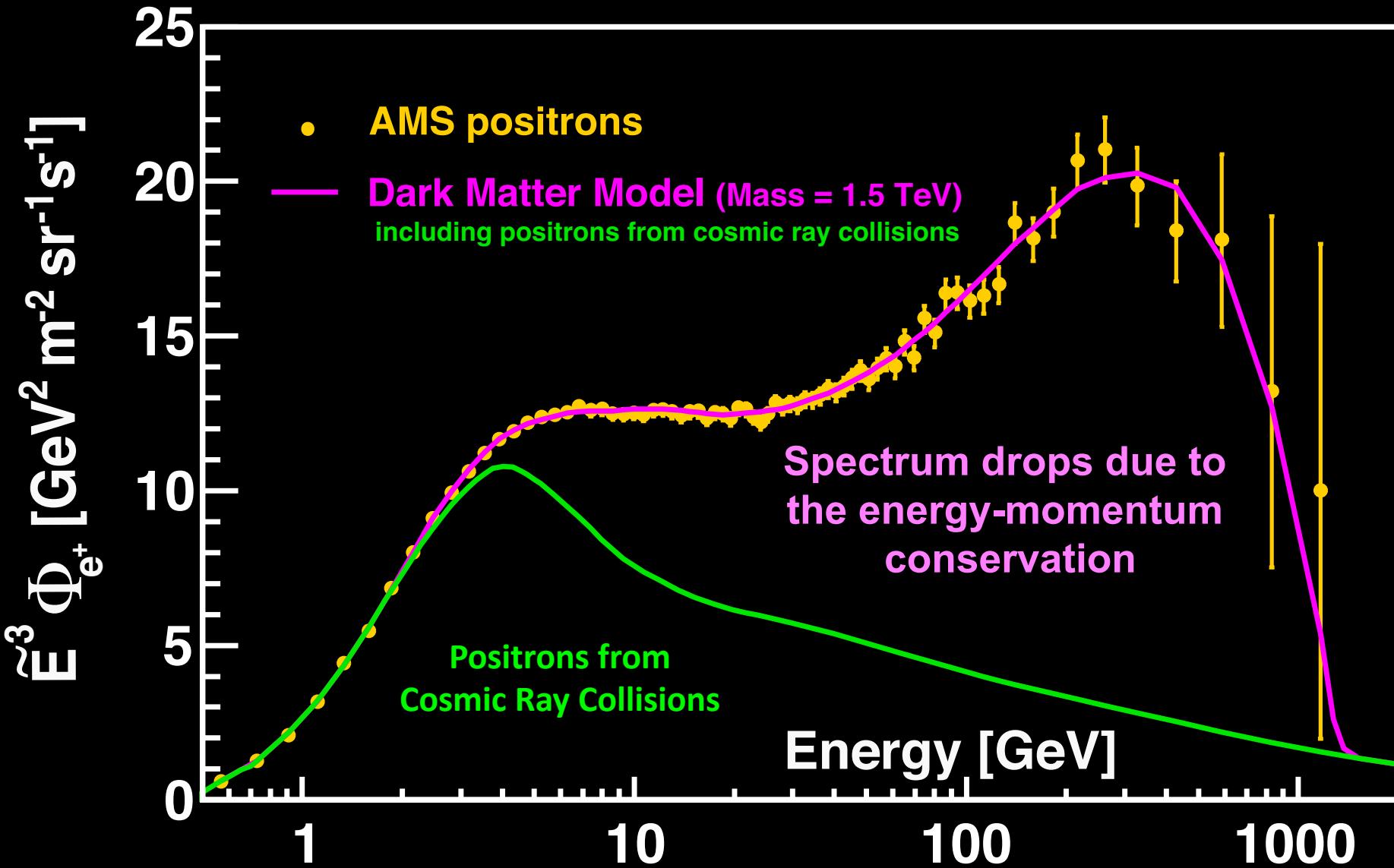
At high energies positrons come from dark matter or new astrophysical sources with a cutoff energy E_s .

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



For more details about contribution of positron source term to the electron flux see poster by Cheng Zhang

Positrons and a Dark Matter Model



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

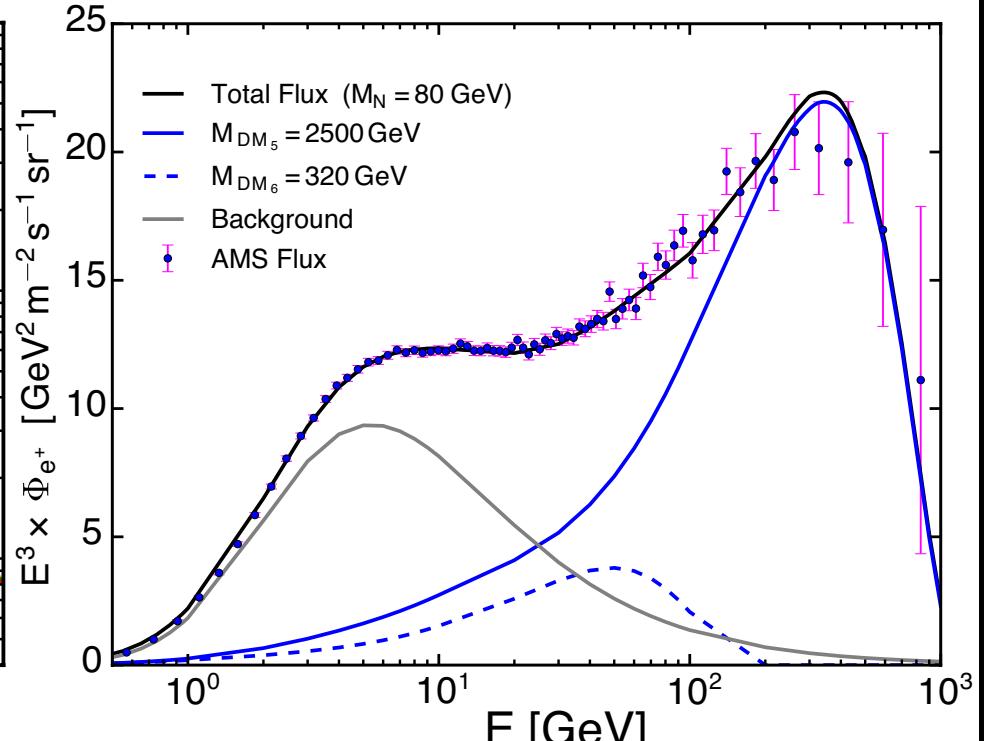
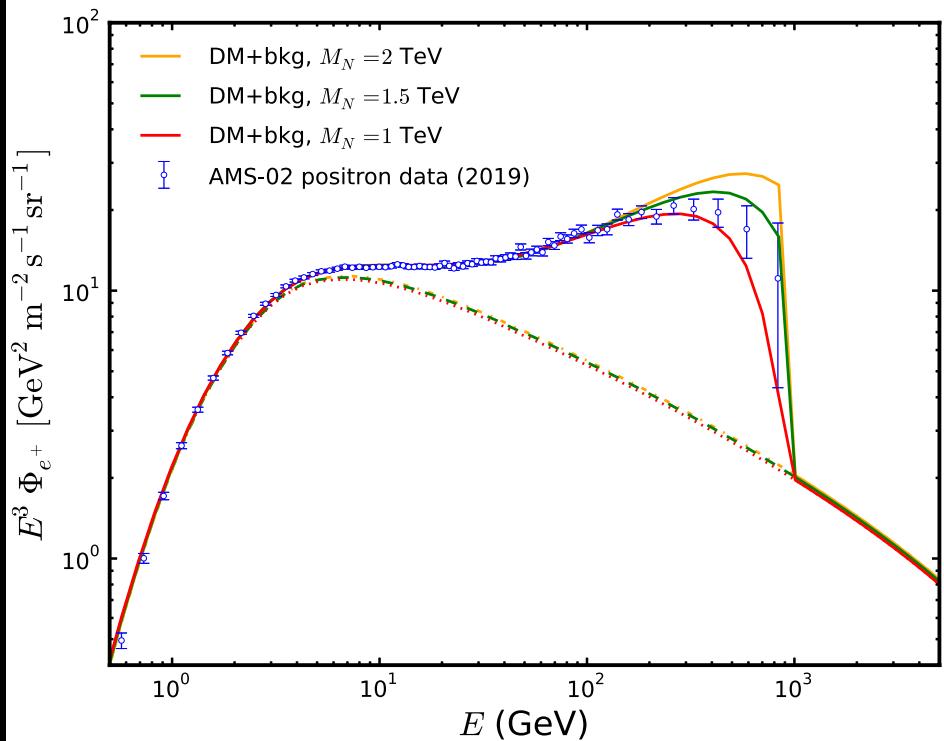
Z.L. Han, R. Ding, S.J. Lin, and B. Zhu,
Eur. Phys. J. C79 (2019) 12, 1007

$$\bar{N}N \rightarrow Z'Z' \rightarrow e^+ + X$$

DM decays

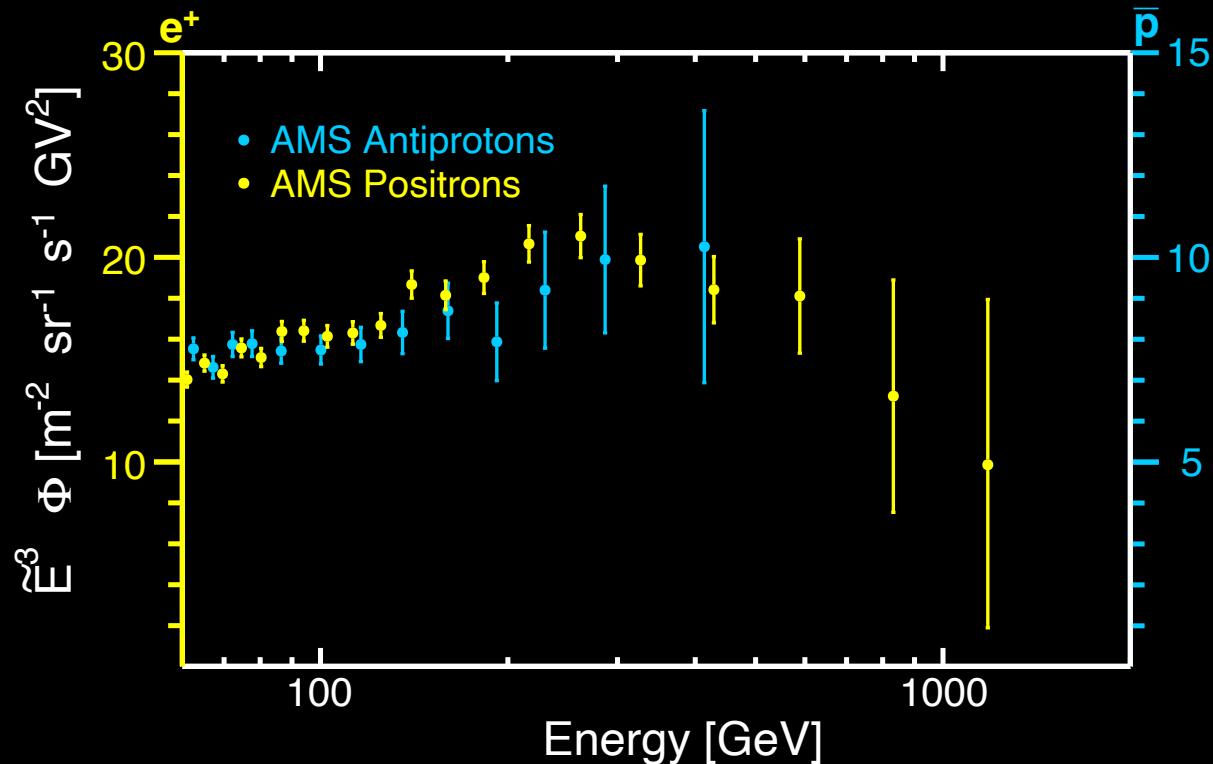
F. Queiroz and C. Siqueira,
Phys. Rev. D 101 (2020) 7, 075007

$$\chi \rightarrow \bar{N}N ; N \rightarrow e^+ + X$$



Positrons from Pulsars

- Pulsars produce and accelerate positrons to high energies.
- Antiprotons show a similar trend to positrons
- Pulsars do not produce antiprotons.

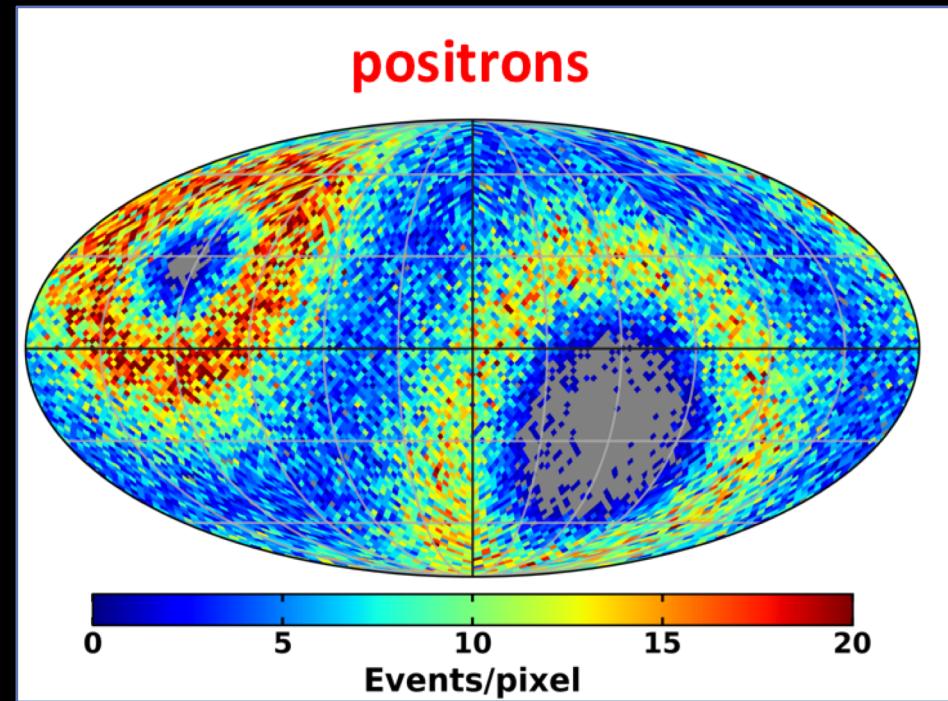
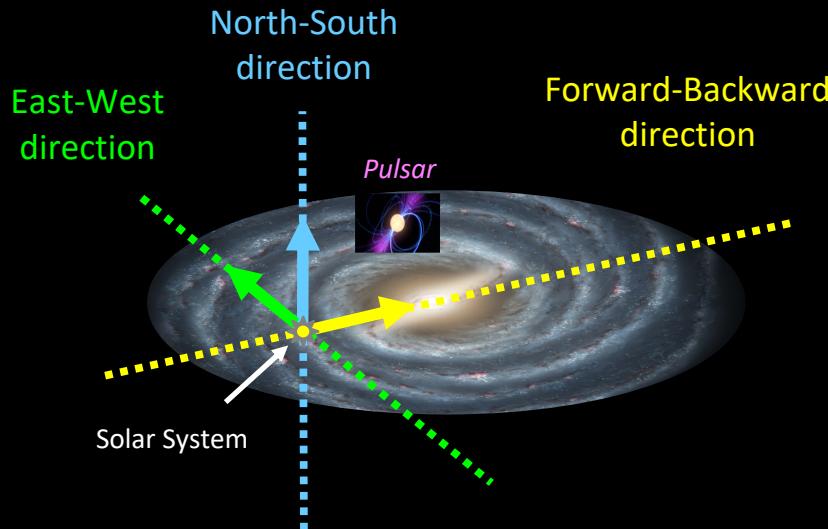


For more details about relation between positron and antiproton fluxes see next talk by Hsin-Yi Chou ID=845

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

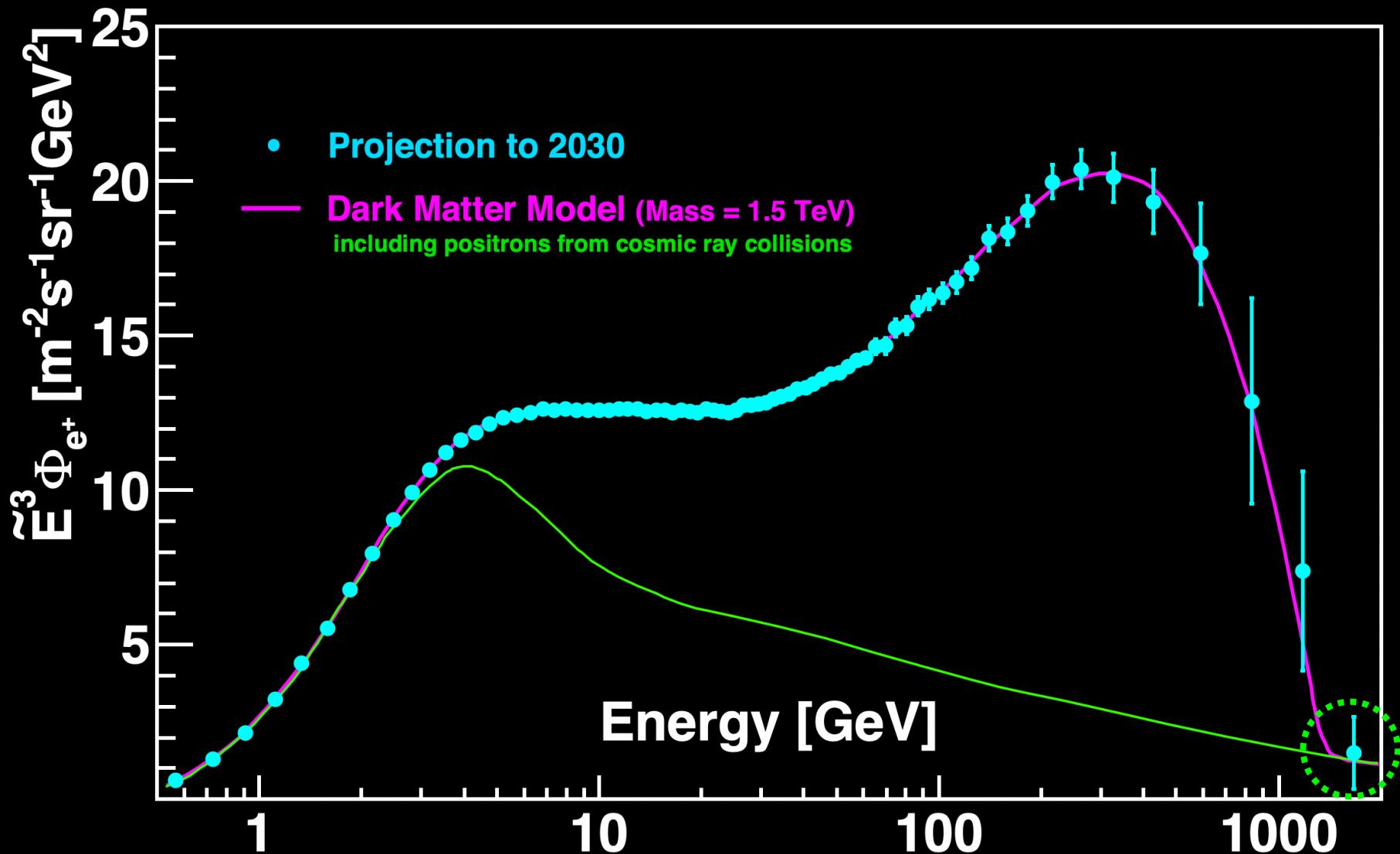


For $16 < E < 500$ GeV currently at 95% C.L.: $\delta < 0.0150$

*For more details about anisotropy studies please
see poster by Miguel Molero Gonzalez*

Positrons and Dark Matter Model by 2030

AMS will provide the definitive answer on the nature of dark matter

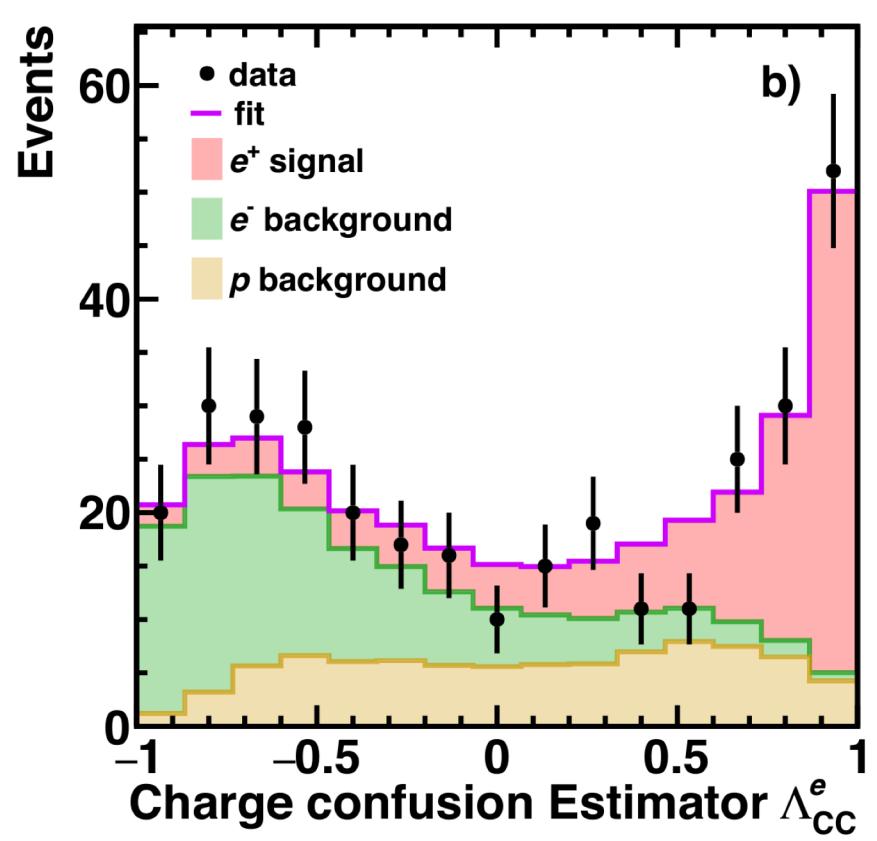
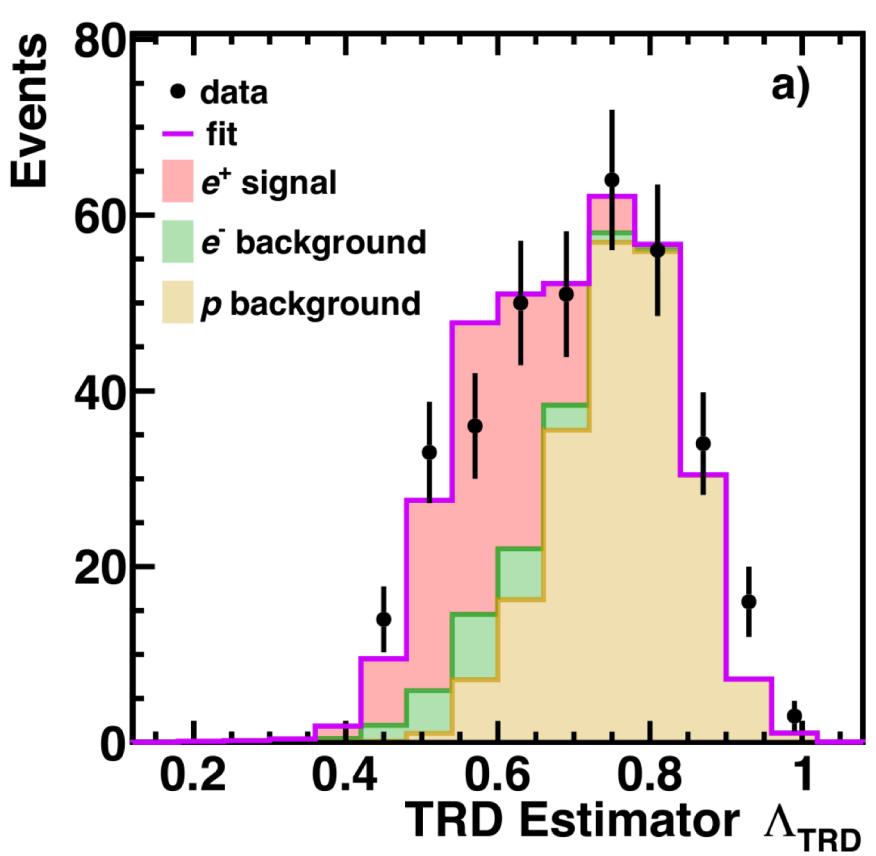


Summary

1. Sharp drop-off of the positron spectrum above 268^{+35}_{-33} 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 $E_s = 887^{+313}_{-183}$ GeV, established with 4.5 sigma significance;
 - measurement to 2030 will enable us to determine the origin of the behavior of positrons at high energies.

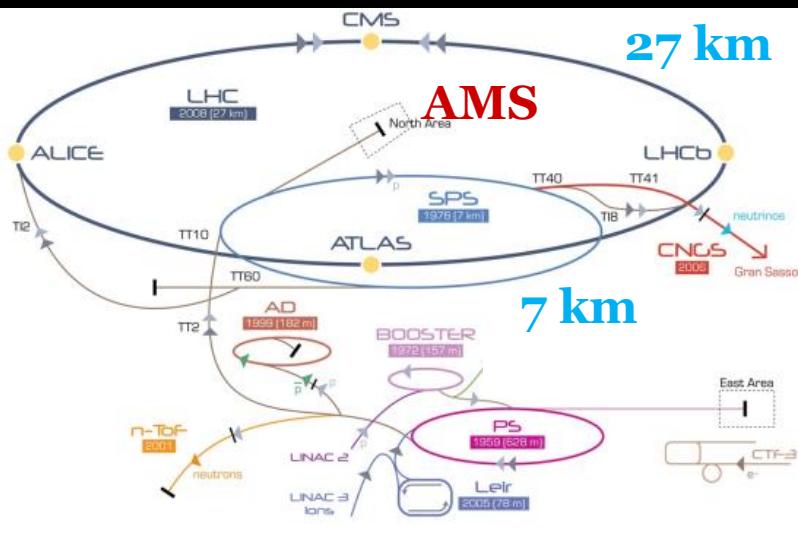
Backup

2D fit of TRD and CC estimators



Calibration of the AMS Detector

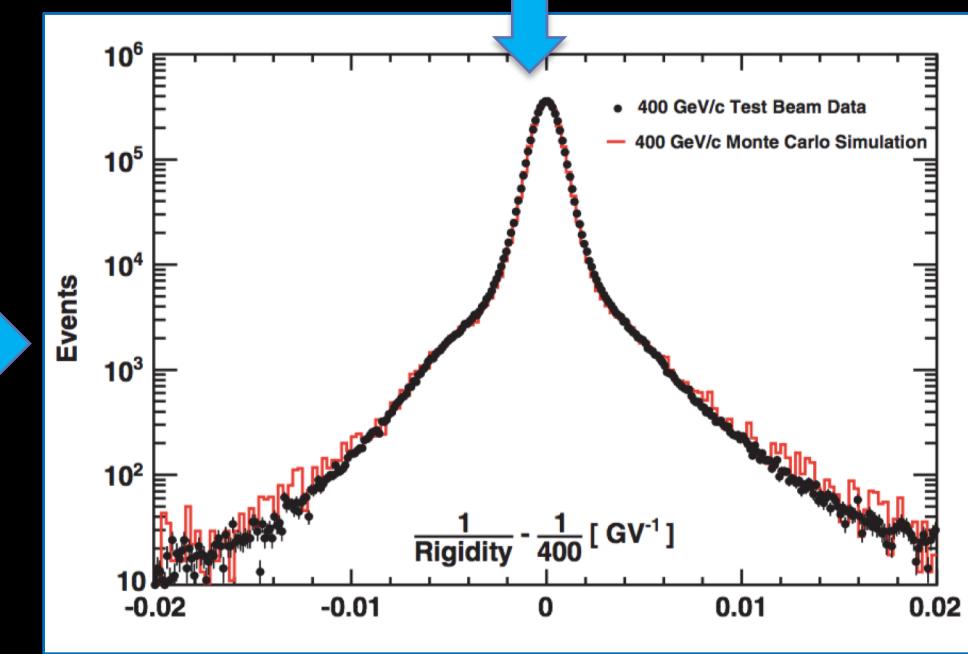
Test beam at CERN SPS:
 $p, e^\pm, \pi^\pm, 10\text{-}400 \text{ GeV}$



2000 positions

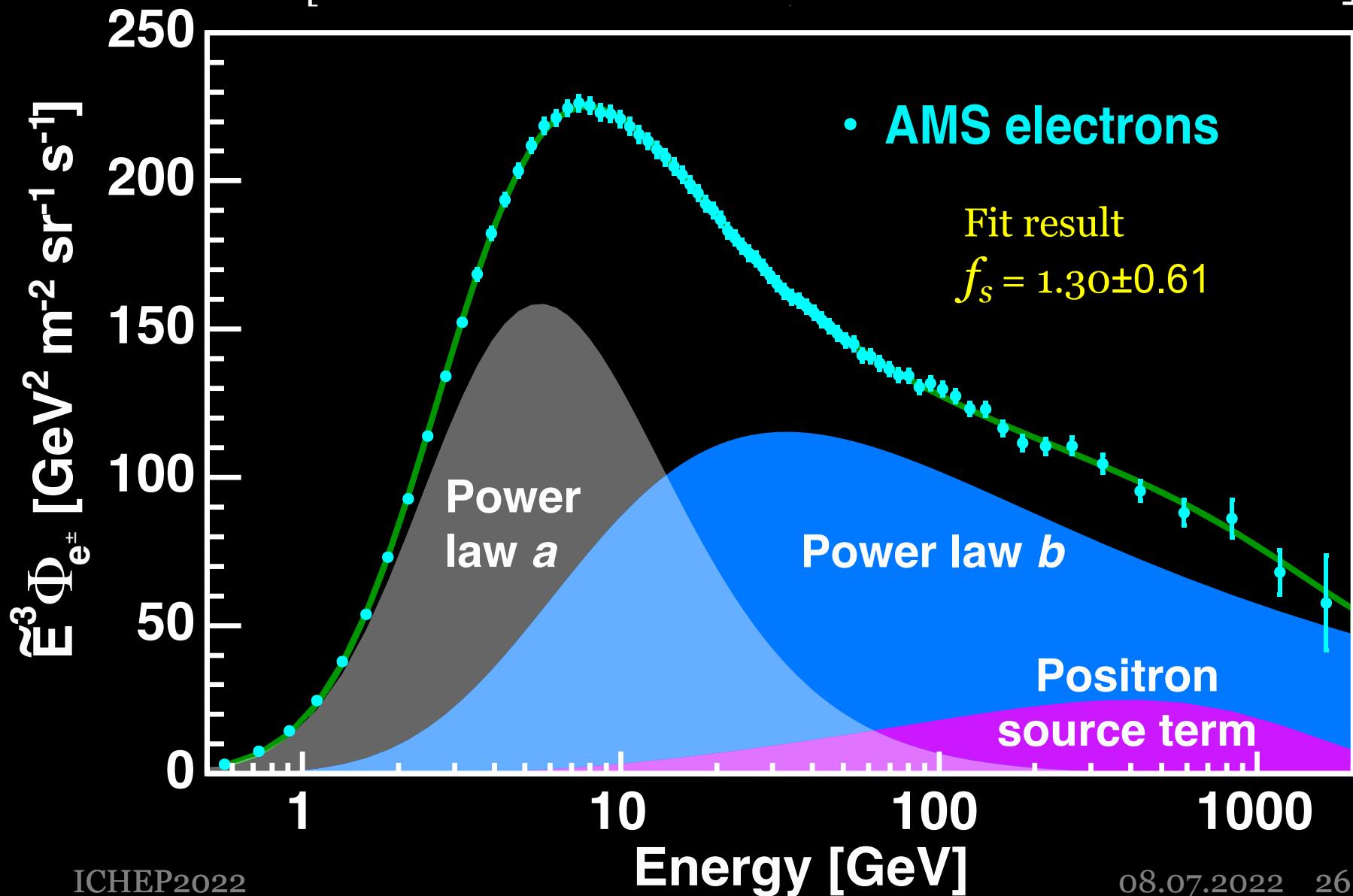


Computer simulation:
Interactions, Materials, Electronics

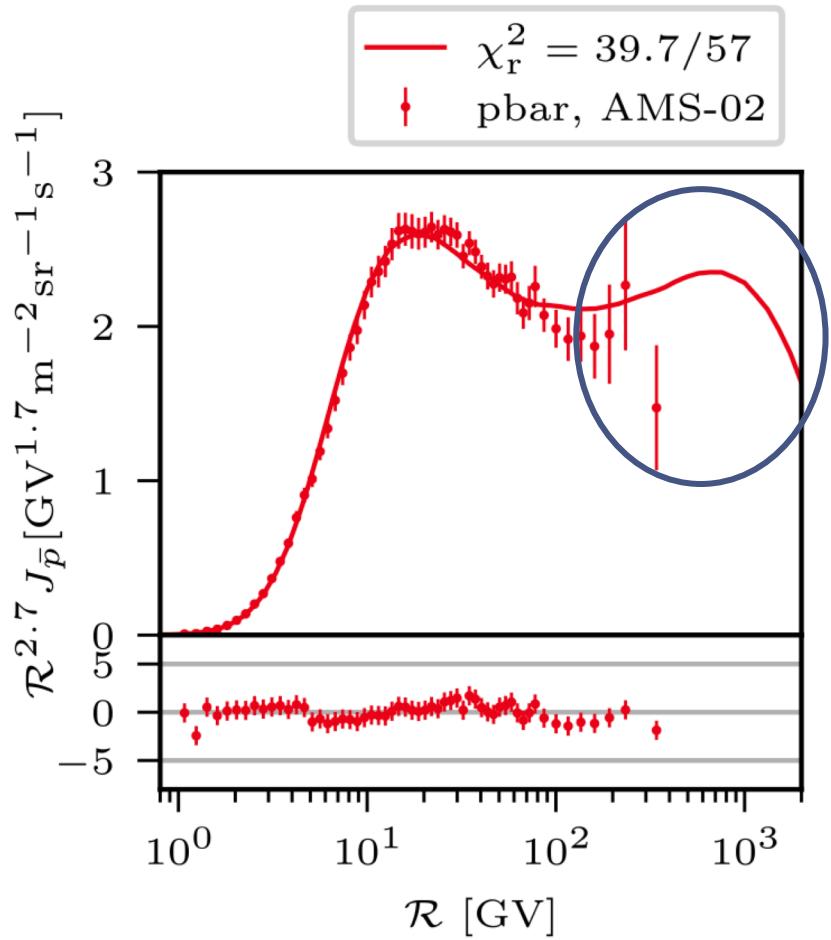
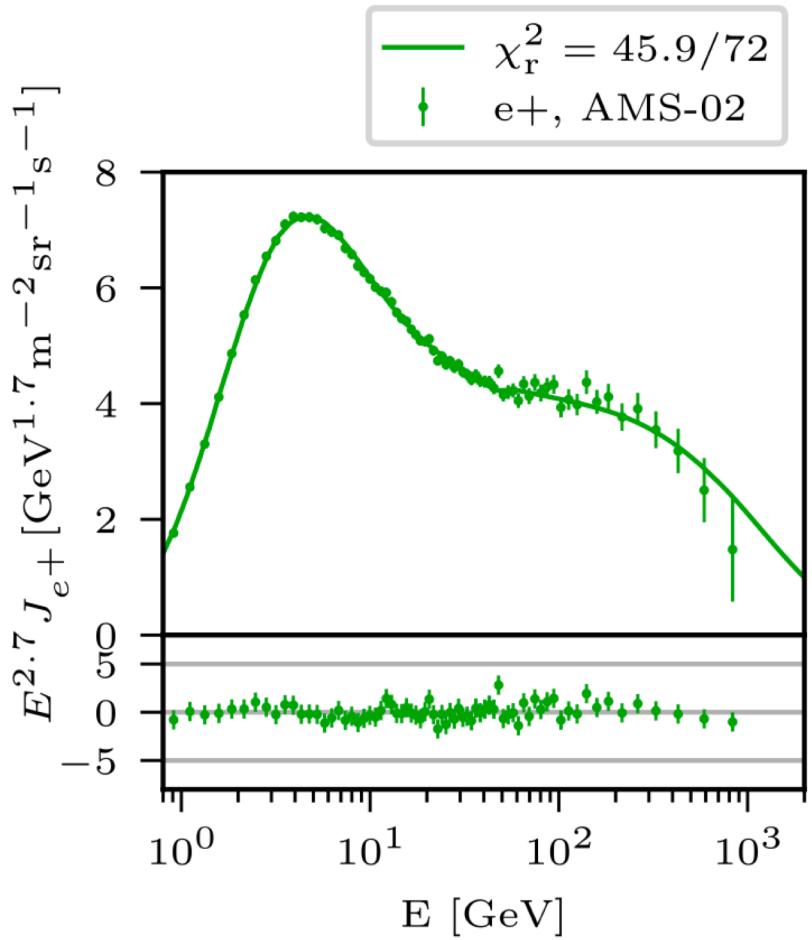


Electron spectrum favors the contribution of
the positron-like source term

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



Astrophysical sources



Astrophysical sources

