Distinctive Properties of Cosmic Electrons and Positrons Measured by AMS on ISS

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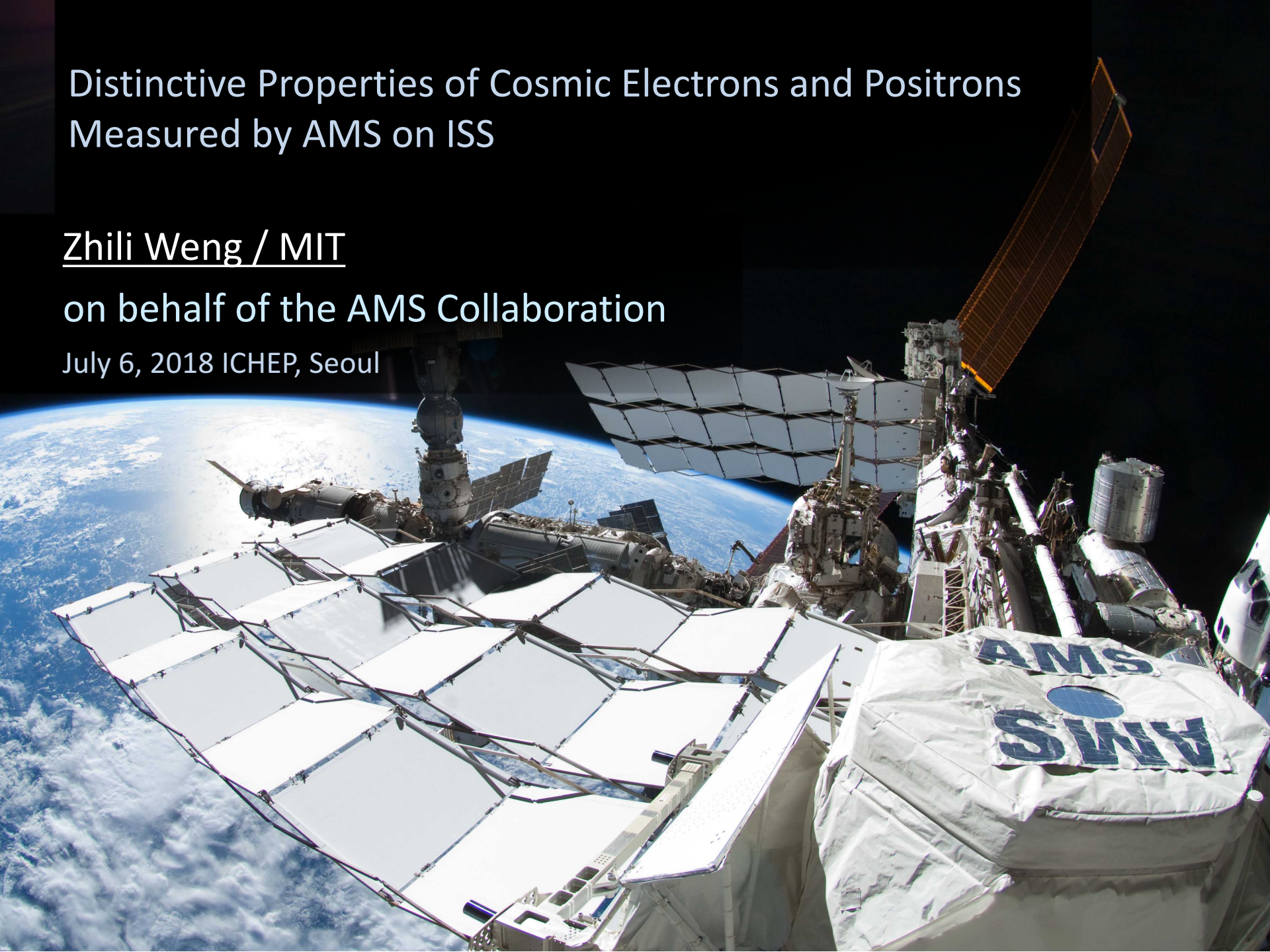
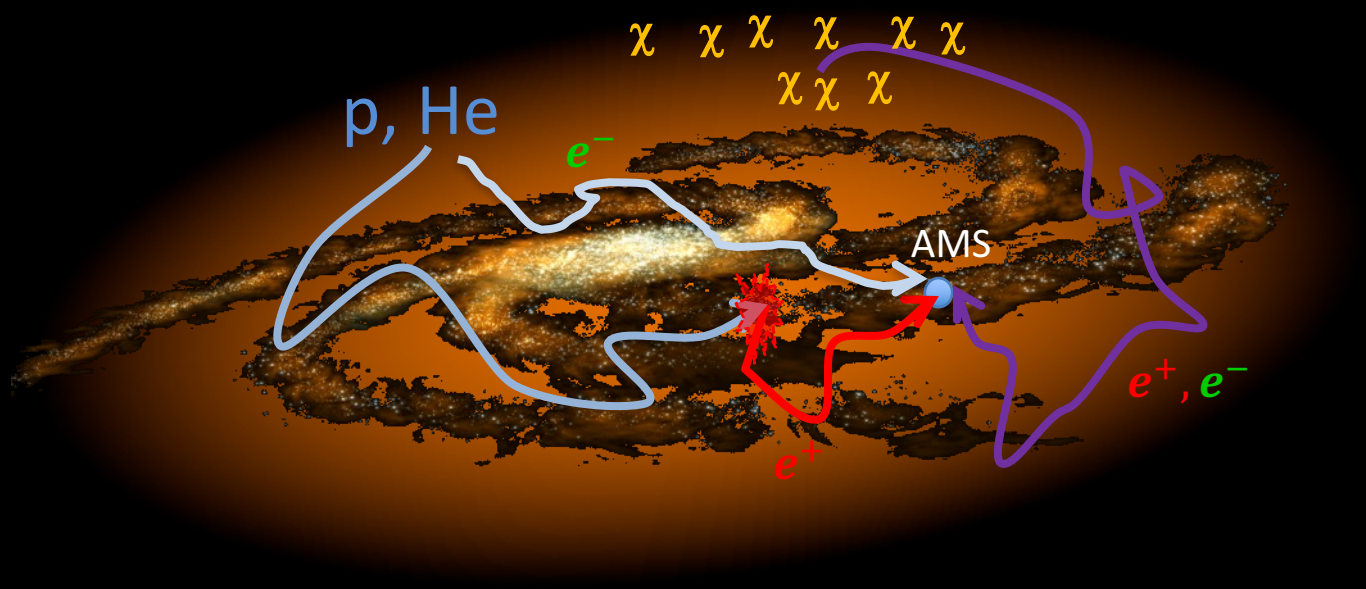
on behalf of the AMS Collaboration

July 6, 2018 ICHEP, Seoul



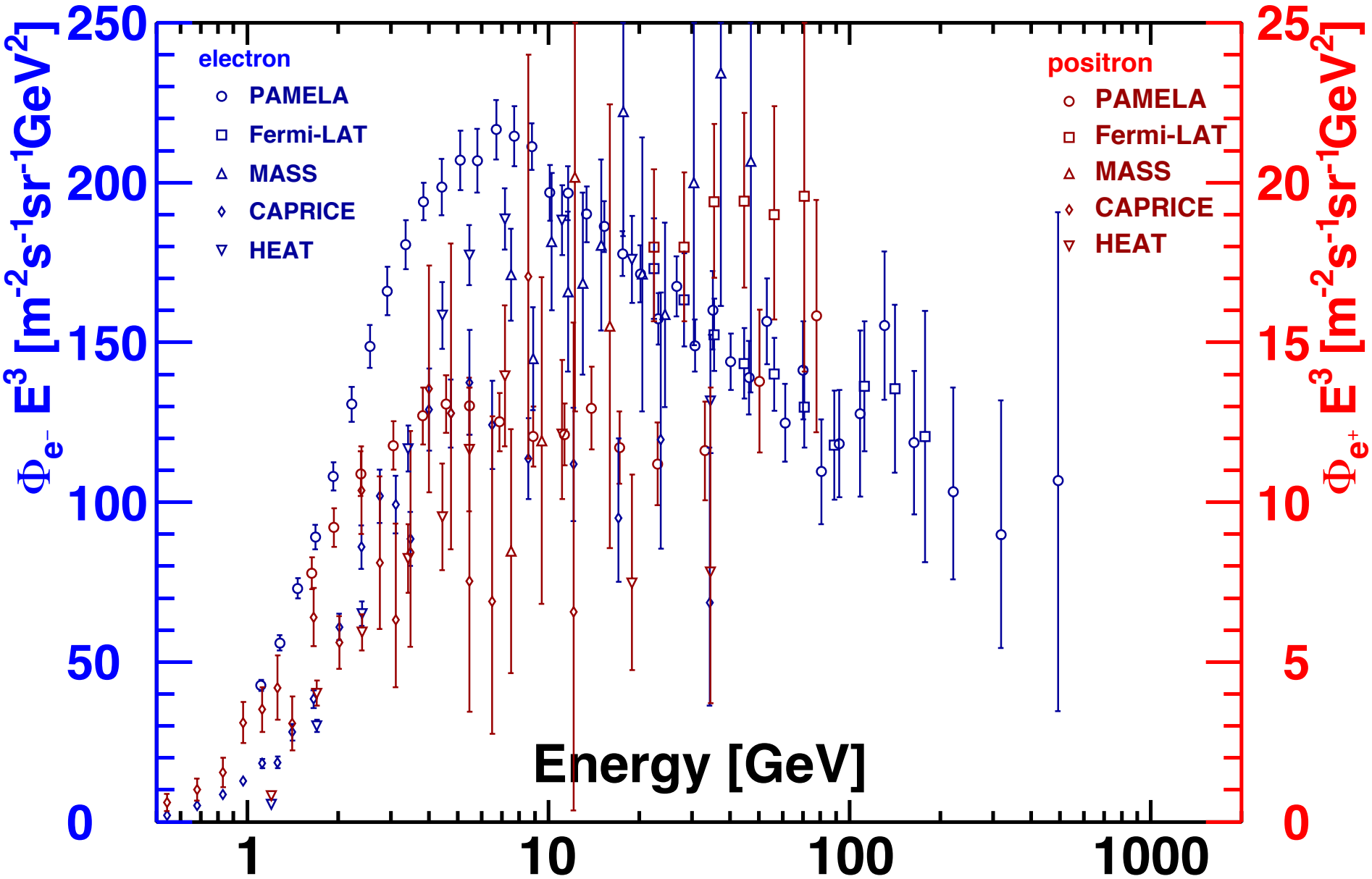
Electrons and Positrons in the Cosmos

- Electrons are produced and accelerated in SNR together with proton, Helium. They are primary cosmic rays that travel through the galaxy and detected by AMS.
- These particle interact with the interstellar matter and produce secondary source of anti-particle: positron, anti-protons etc. They are much less abundant in astrophysics process.
- New physics sources like Dark Matter produce both particles and antiparticles in equal amount.

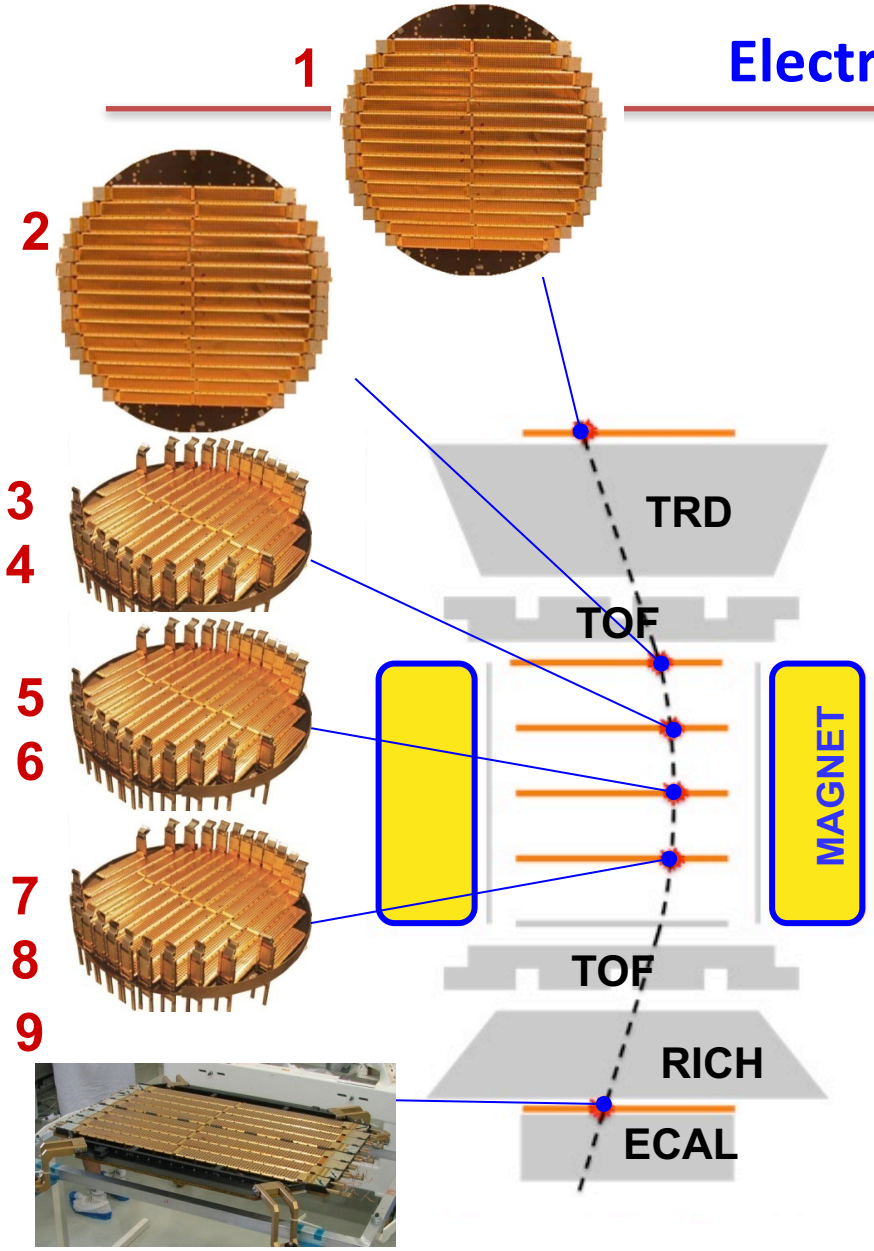


Measuring antiparticles are much more sensitive to Dark Matter

Positron and electron fluxes before AMS

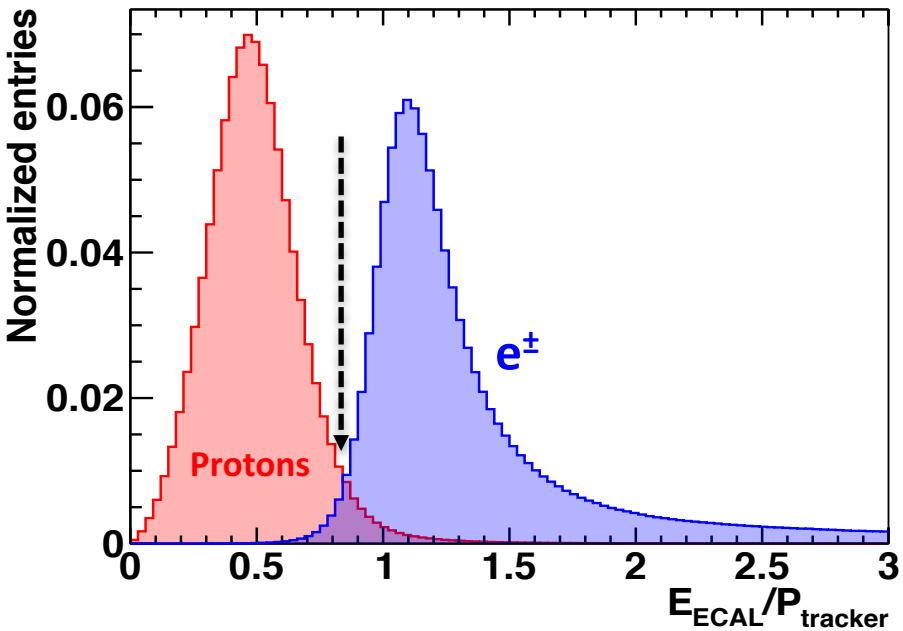


Electrons and Positrons Identification



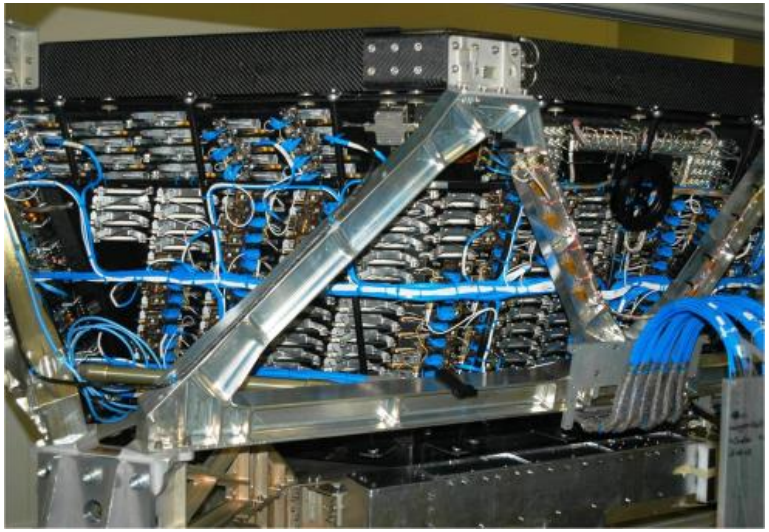
L1 to L9: 3 m level arm;
single point resolution 10 μm;

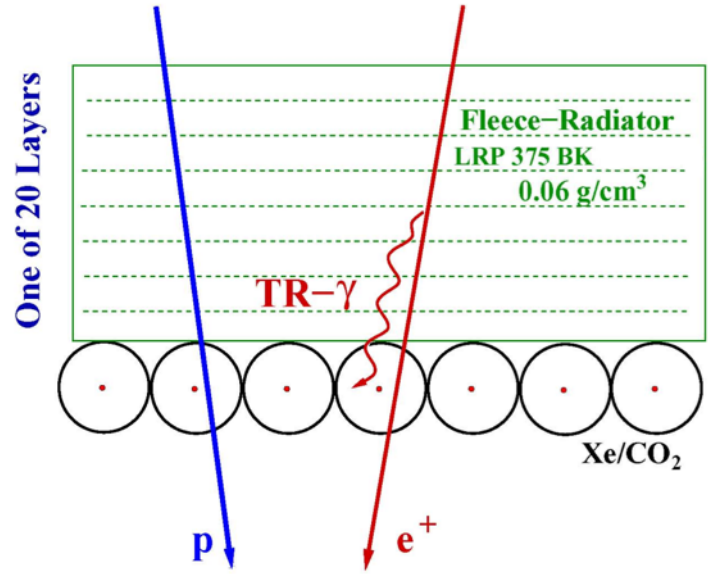
- Maximum Detectable Rigidity 2.0 TV for Z=1
- Independent Momentum and Energy measurement provide unique particle identification capability



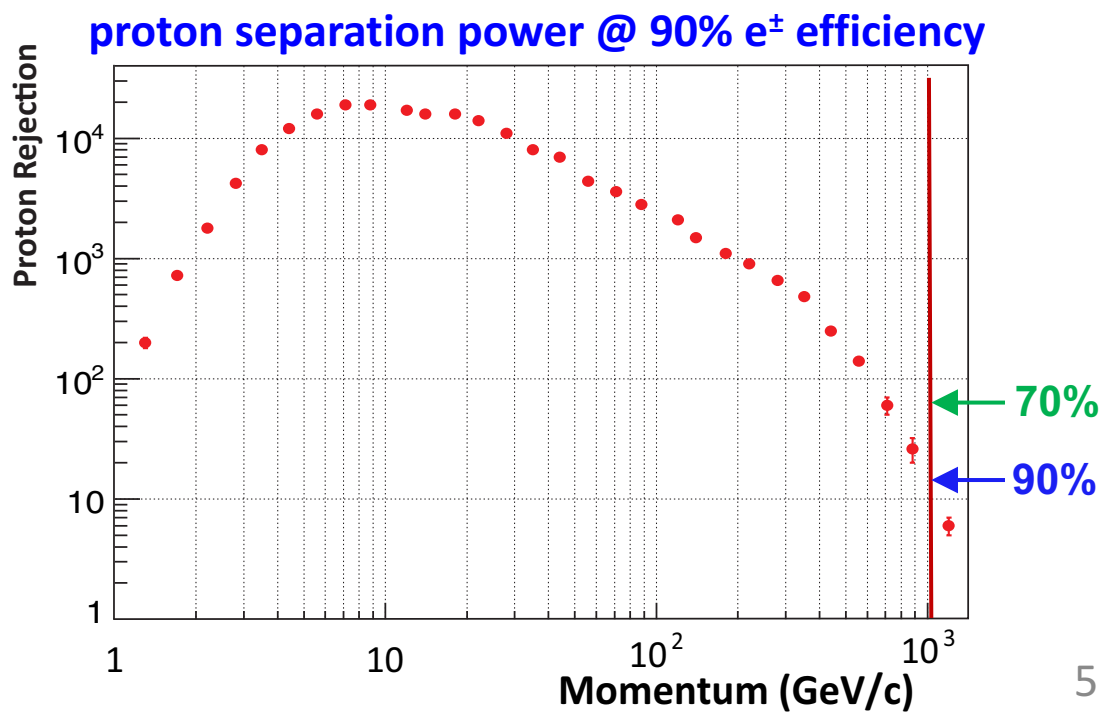
- Electron charge confusion:
  - Large angle scattering,
  - Interaction with detector materials.
  - Identified and measured from data using Charge confusion estimator Λ_{CC}

Electrons and Positrons Identification



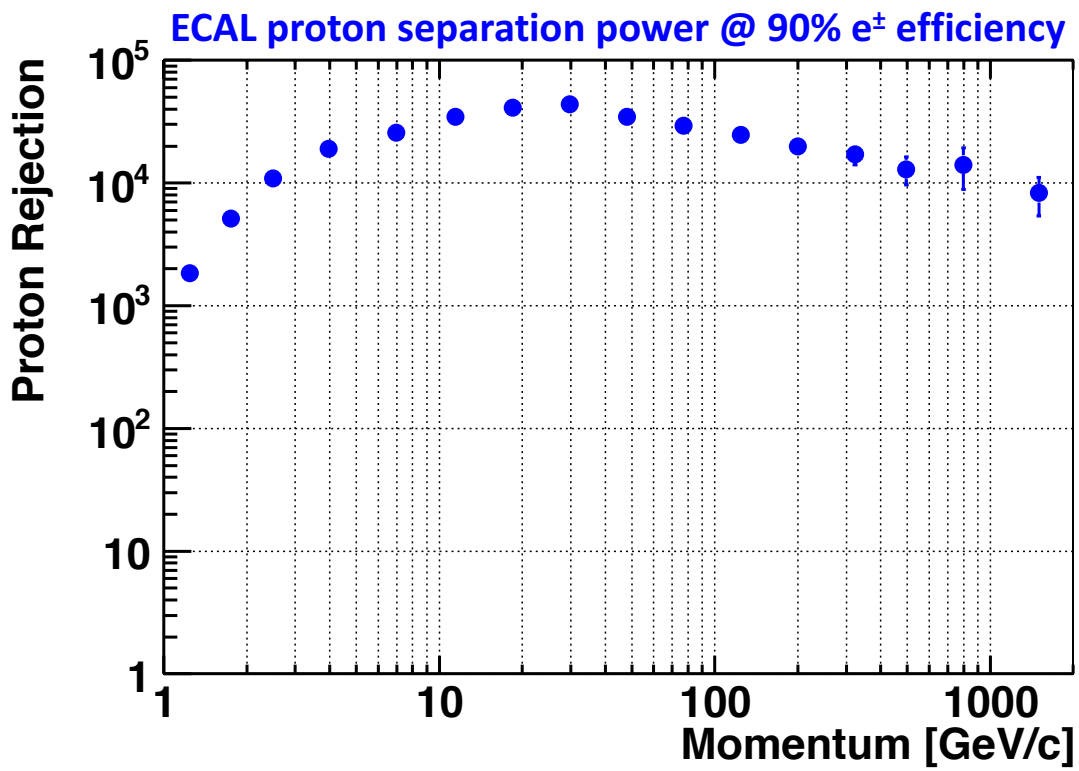


- Identify $e^{\pm}$ from protons using transition radiation
- Combine 20 layers proportional tubes signal into TRD estimator Λ_{TRD}
- Reject protons with high efficiency



Electrons and Positrons Identification

- ECAL : 17 X_0 , TeV Precision 3D measurement of the energy and shower development of electrons and positrons.
- ECAL proton separation power > 10^4 : remove majority of the proton backgrounds



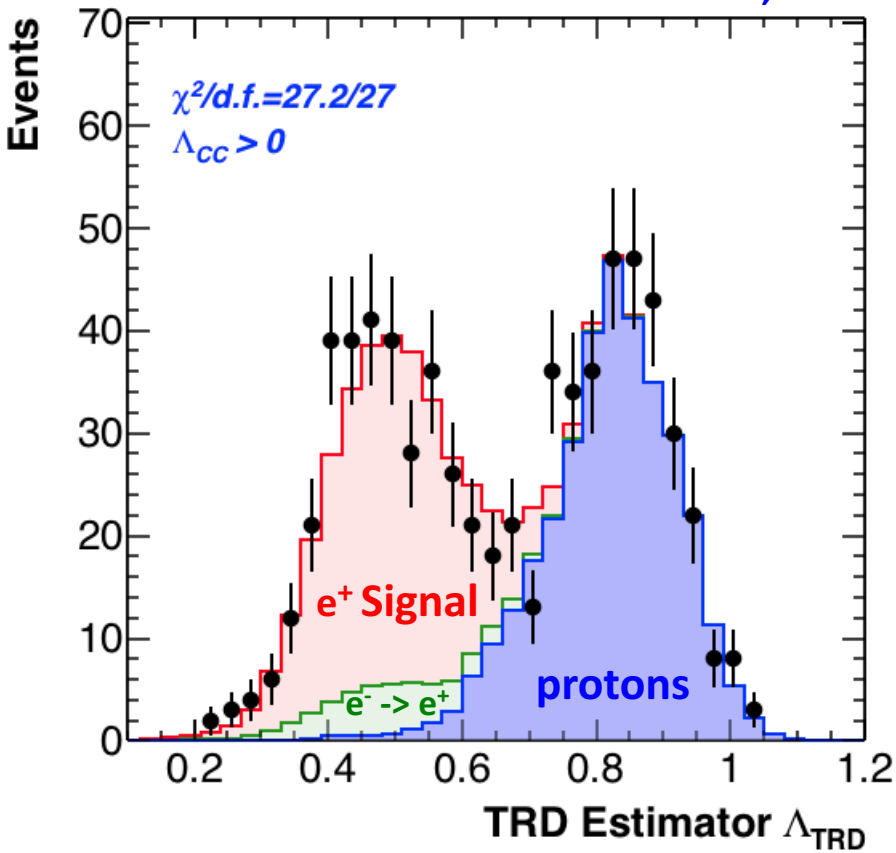
TRD and ECAL are separated by the Magnet

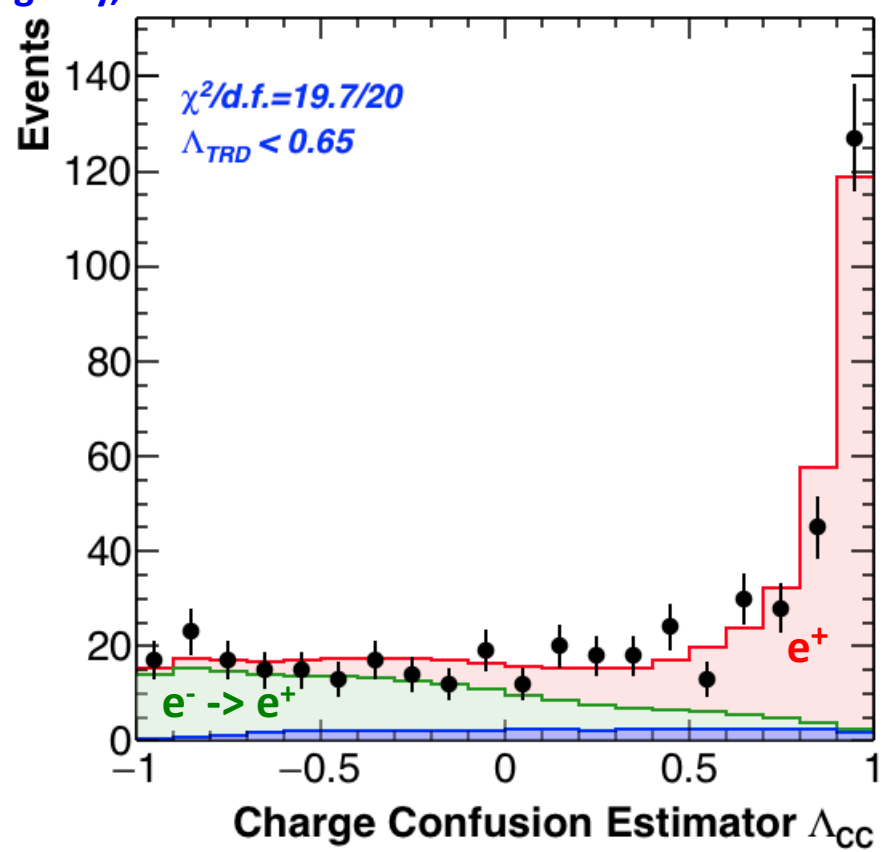
They have independent particle identification: combined rejection > 1 in 10^6

Measuring Positron and Electron

- For each bin, number of e^+ and e^- are obtained from a fit to data sample in $(\Lambda_{TRD} - \Lambda_{CC})$ plane
- Precision determination of Signal and Background from Data
  - Positron Signal are clearly identified in the signal region of Λ_{TRD} and Λ_{CC}
  - Proton : identified by TRD estimator Λ_{TRD}
  - Electron charge confusion measured from data using Charge confusion estimator Λ_{CC}

Fit to Data, Positive Rigidity, 237 – 290 GeV





In 6.5 Years: 28.1 million electrons, 1.9 million positrons

Electron, Positron Flux Measurement

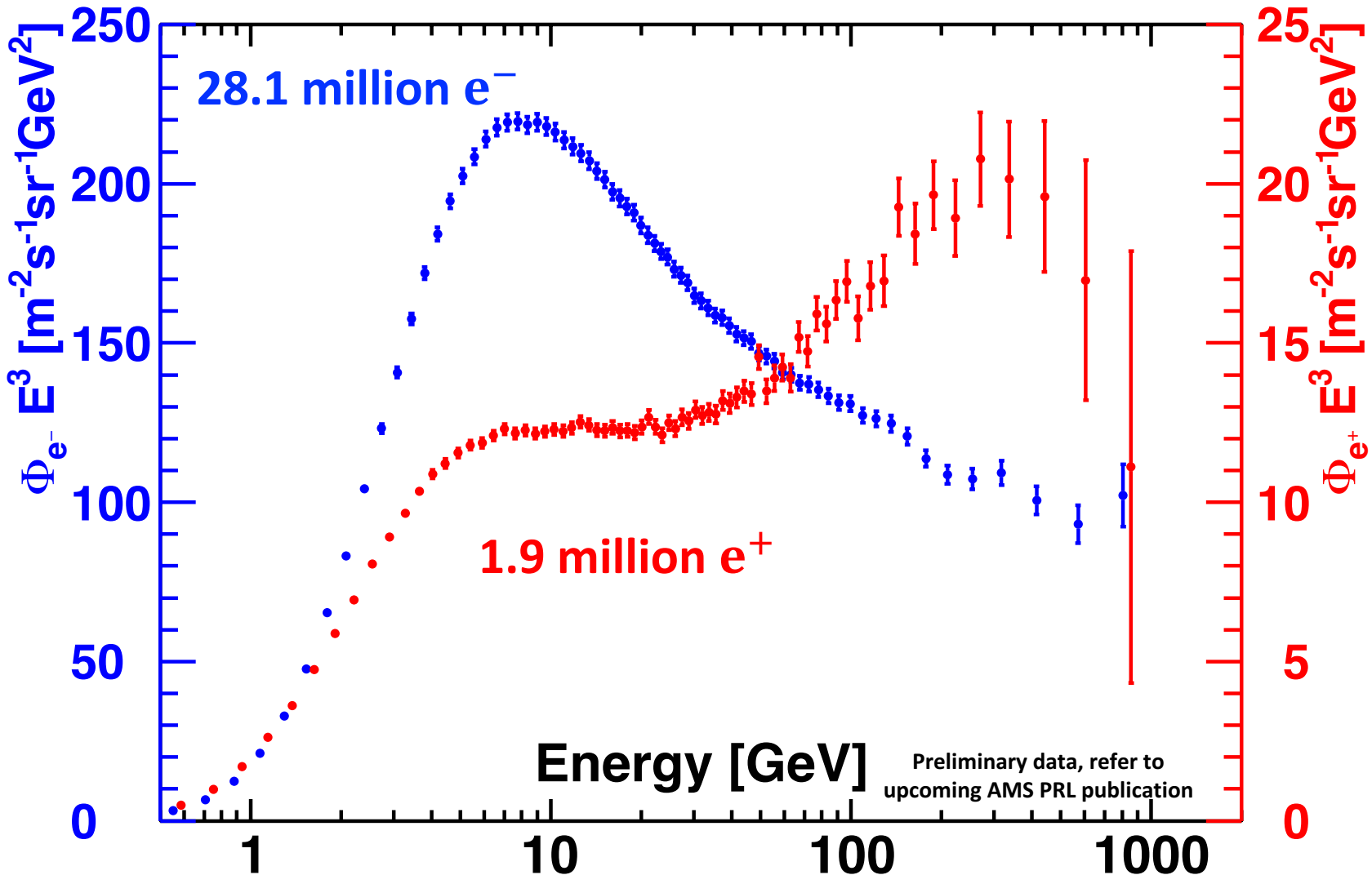
Isotropic flux: $$\Phi_{e^\pm}(E) = \frac{N_{e^\pm}(E)}{A_{eff}(E) \cdot \varepsilon_{trig}(E) \cdot T(E) \cdot \Delta E}$$

Major Systematic Errors:

- **Charge confusion:**
  - **Measured directly from data. Good agreement between data and Monte Carlo. The difference is taken as systematic error.**
- **Selection, Template definition:**
  - **The measurement is stable over wide ranges of the selections.**
- **Effective Acceptance:**
  - **Estimated from MC, Small correction applied based on efficiency measured from Data. Systematic uncertainties: 2% ~ 3%**
- **Energy Measurement:**
  - **Uncertainty in the absolute energy scale: ~2% at [10, 300] GeV, ~3% at 1TeV**

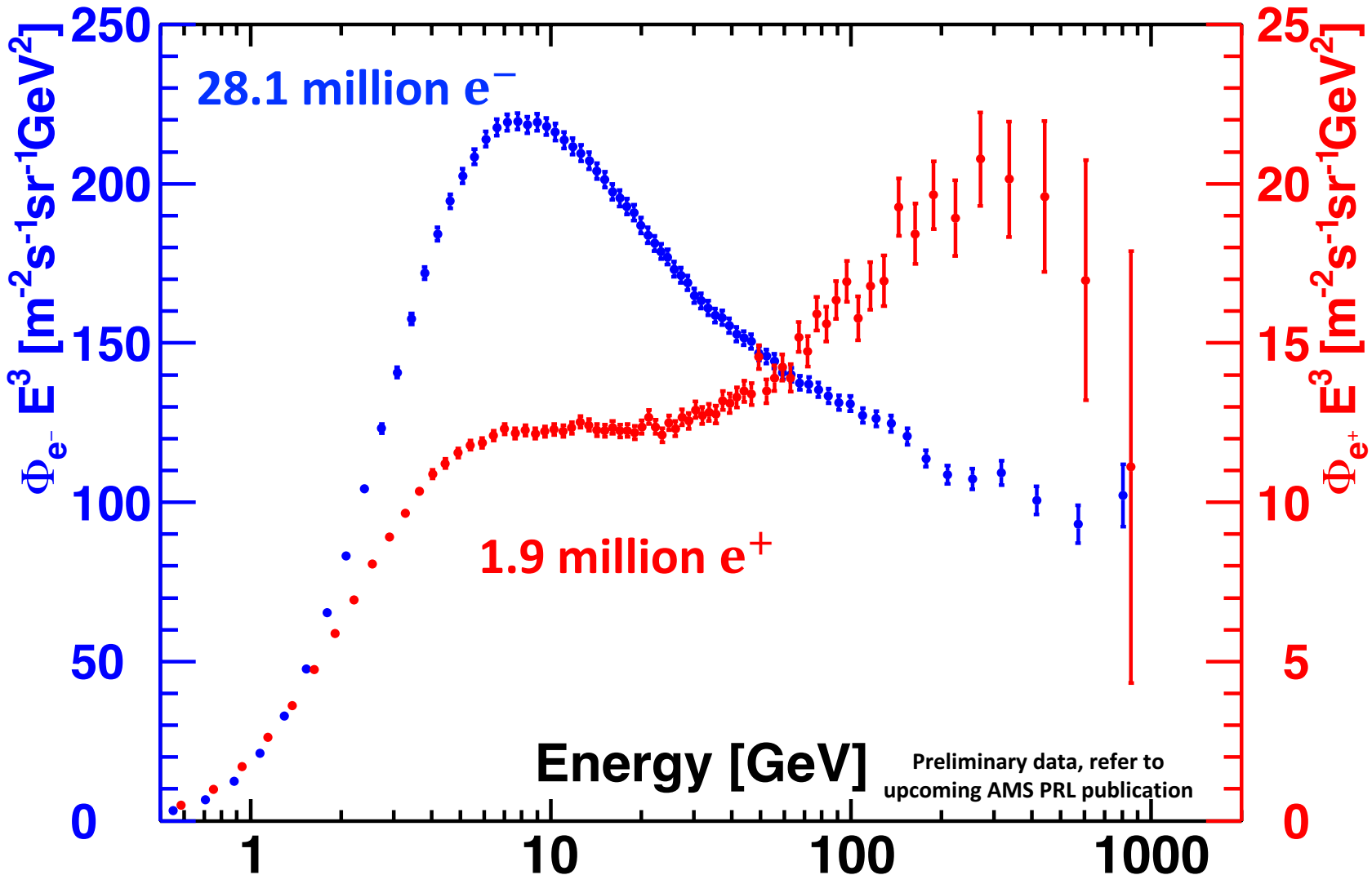
Statistical error are larger than systematic error (> 30 GeV for e^+, >200GeV for e^-)

Latest result based on 30 million e^+, e^-



- The electron flux and positron flux are different in amplitude and energy behavior.
- Both spectra show change of behavior at ~30GeV
- Positron shows drop-off at 300GeV

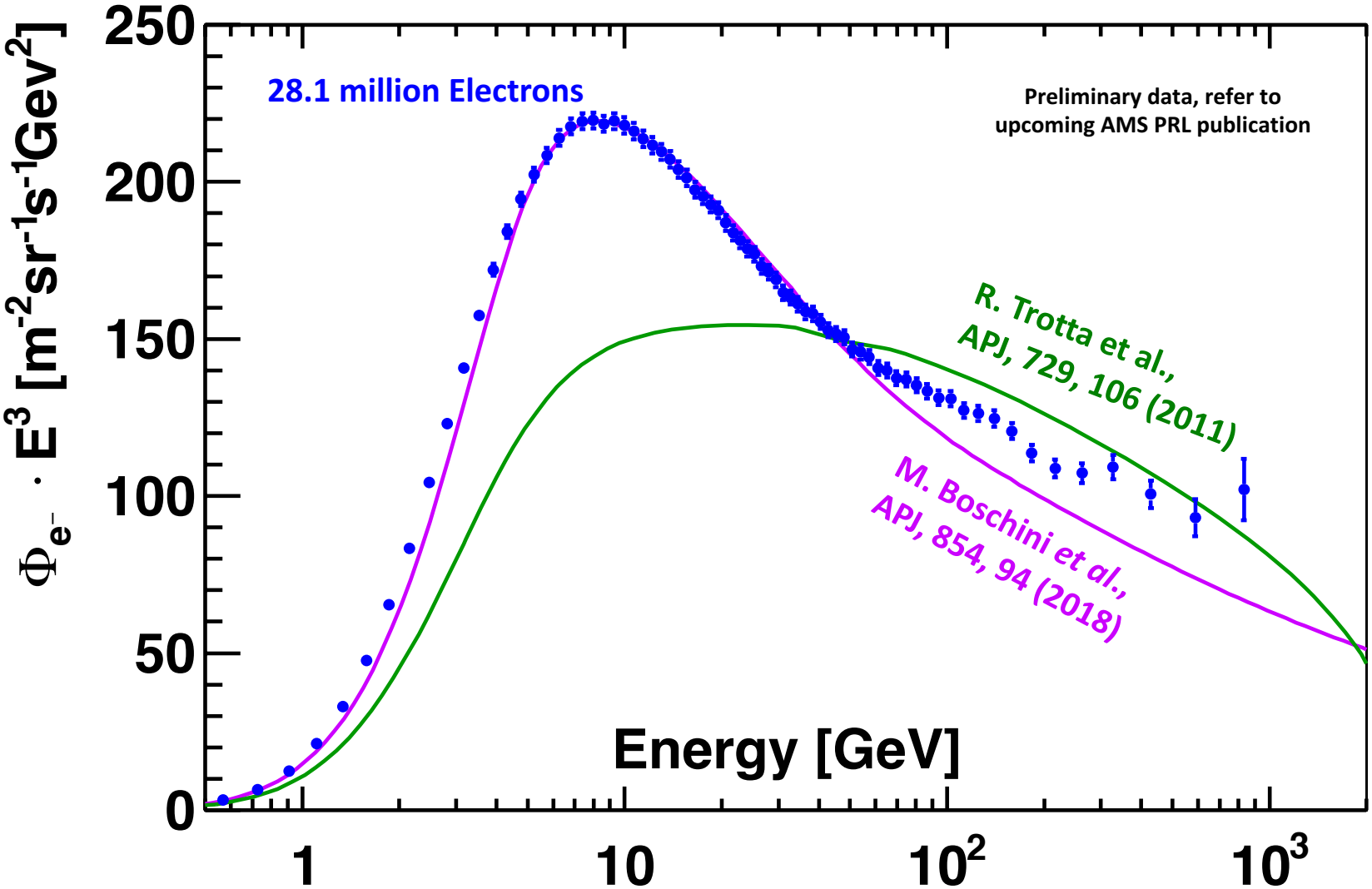
Latest result based on 30 million e^+, e^-



- Drop-off of e^+ at 300GeV does not correspond to the same behavior in e^-

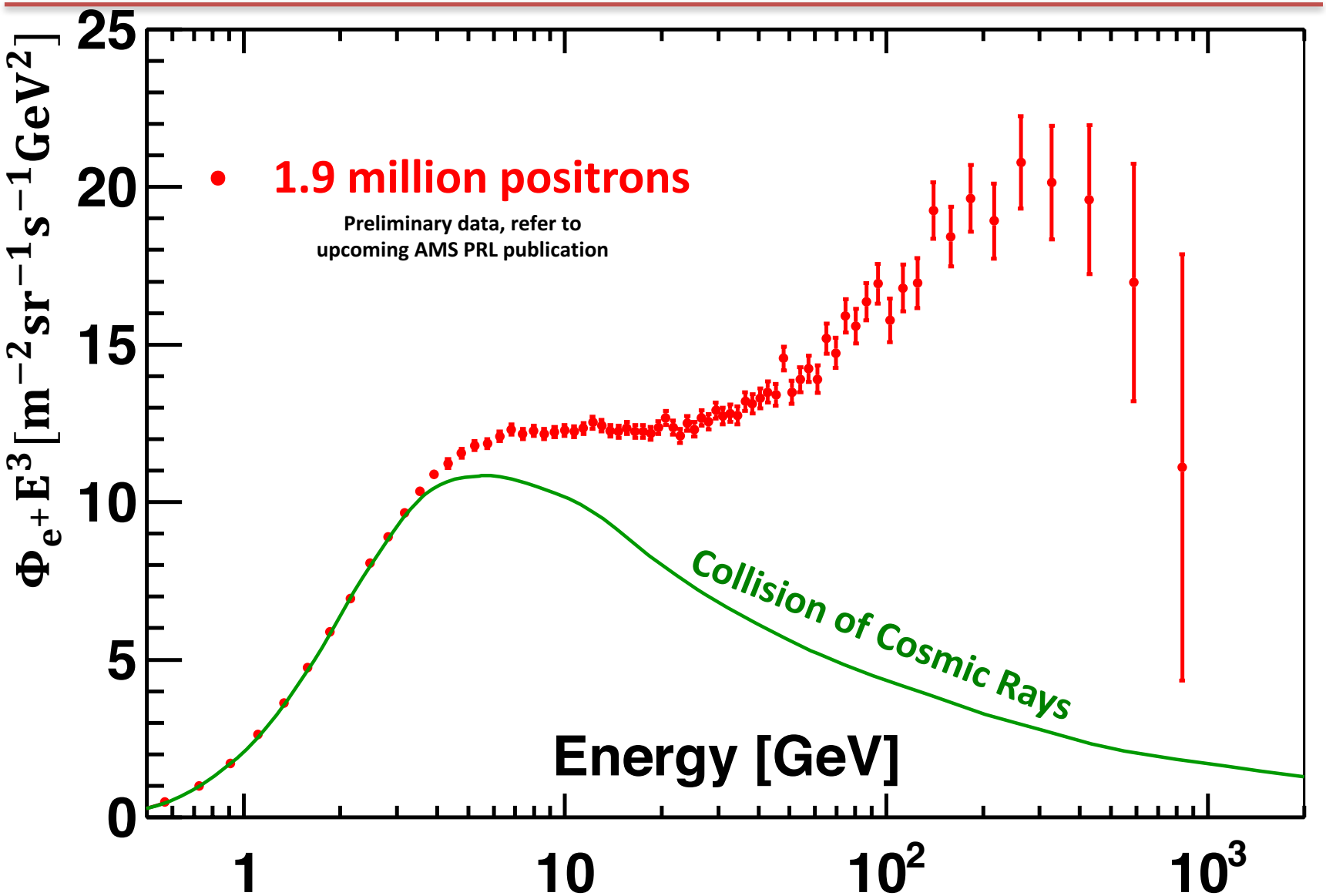
Not a propagation effect: Additional source of cosmic ray positron and electron

Additional source of cosmic ray Electron



AMS Electron flux disagree with conventional cosmic ray model expectation.
Indicates additional primary source of electron starting ~30GeV
However, due to large background and its uncertainties from conventional cosmic ray electron, it is difficult to extract source contribution from electron flux alone

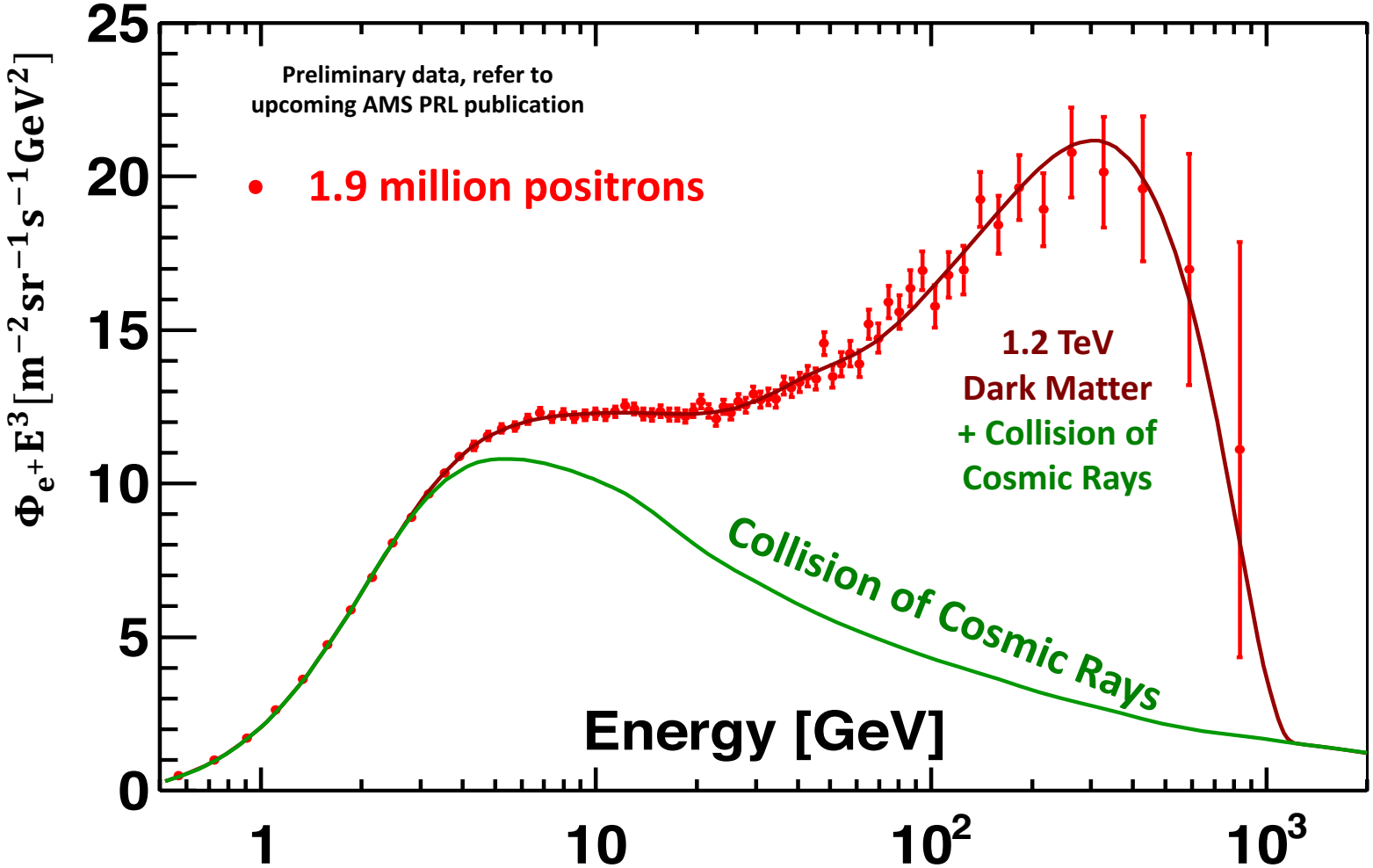
Primary source of cosmic ray Positron



The positron flux by far exceeds the prediction from collision of cosmic rays, requiring a primary source of e^+

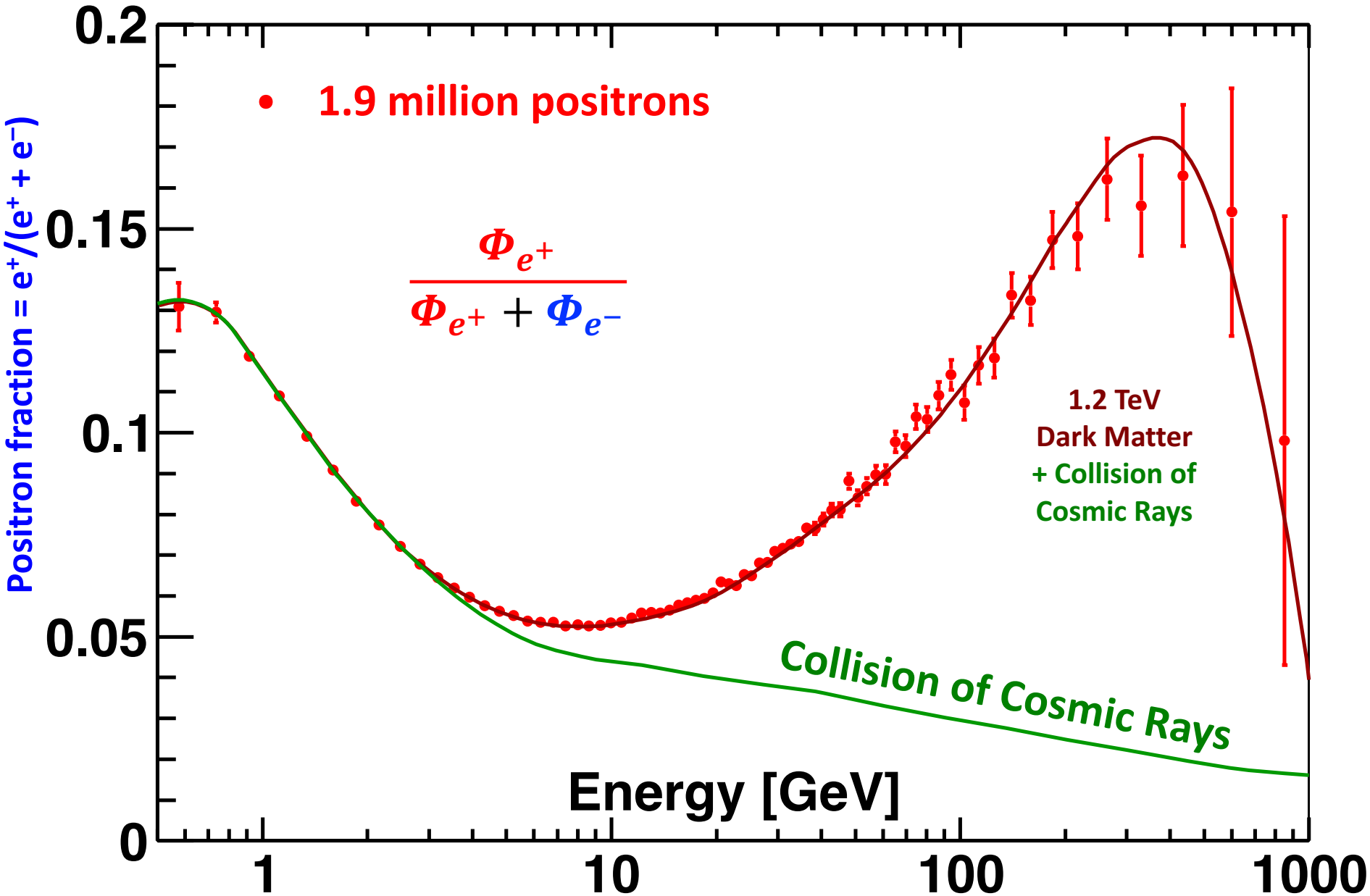
Models to explain the AMS Positron Flux

1) Particle origin: Dark Matter
2) Modified Propagation of Cosmic Rays
3) Astrophysics origin: Pulsars, SNRs



The AMS results appear to be in agreement 1.2 TeV Dark Matter Model

Positron excess also can be expressed in terms of the positron fraction



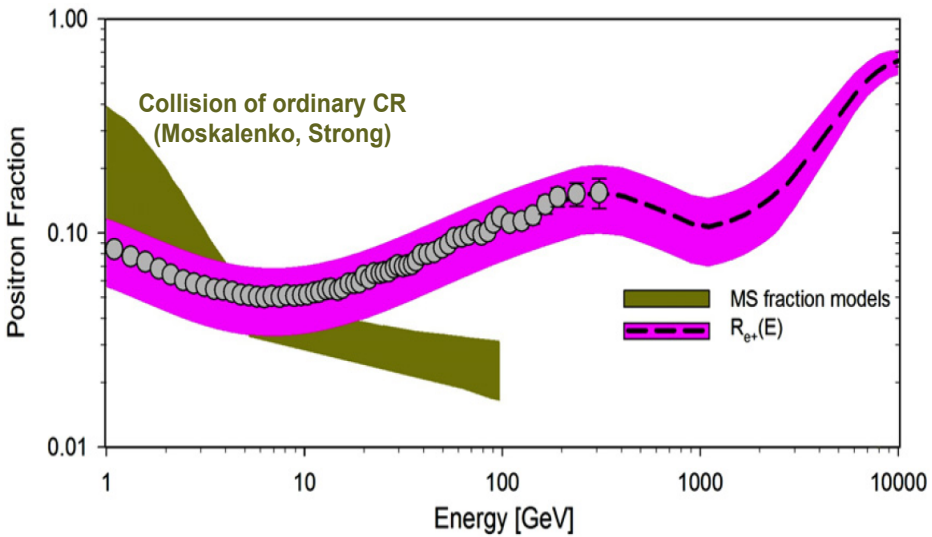
Dark Matter model based on J. Kopp, Phys. Rev. D 88, 076013 (2013).

Alternative Models to explain the AMS Measurements

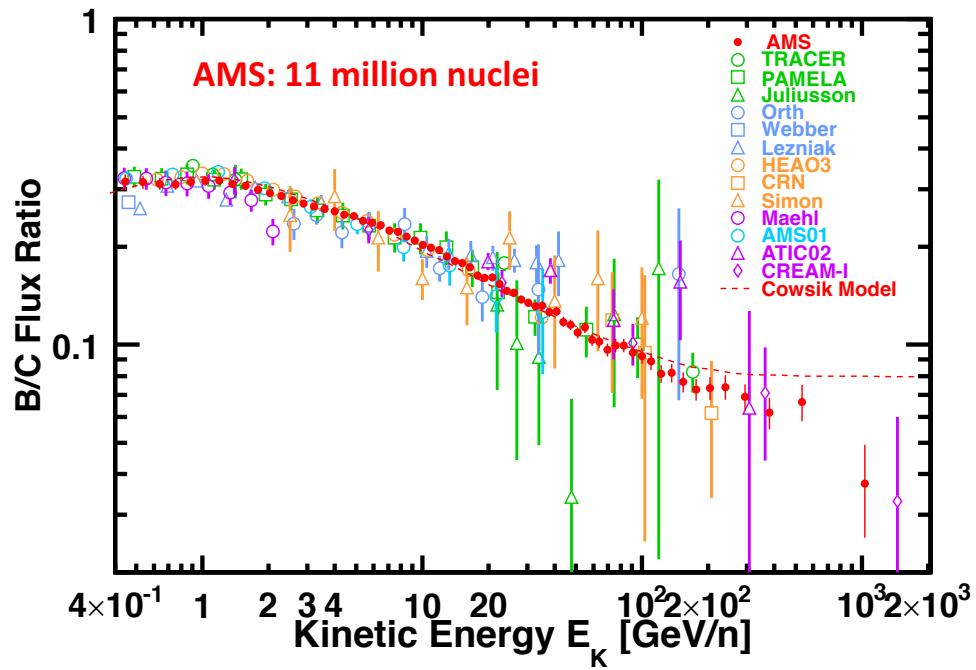
- **Modified Propagation of Cosmic Rays**

Examples:

R. Cowsik *et al.*, Ap. J. 786 (2014) 124, (pink band)
Explaining the AMS positron fraction(grey circle)
as propagation effects.



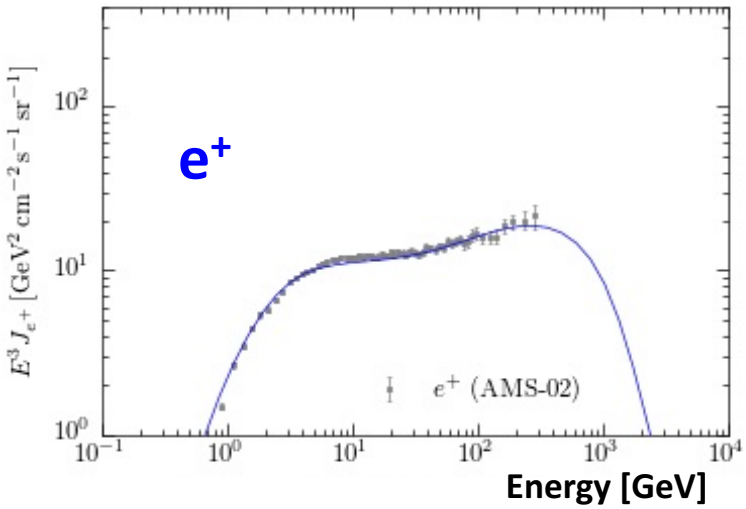
This requires a specific energy dependence of the B/C ratio
ruled out by AMS B/C measurement

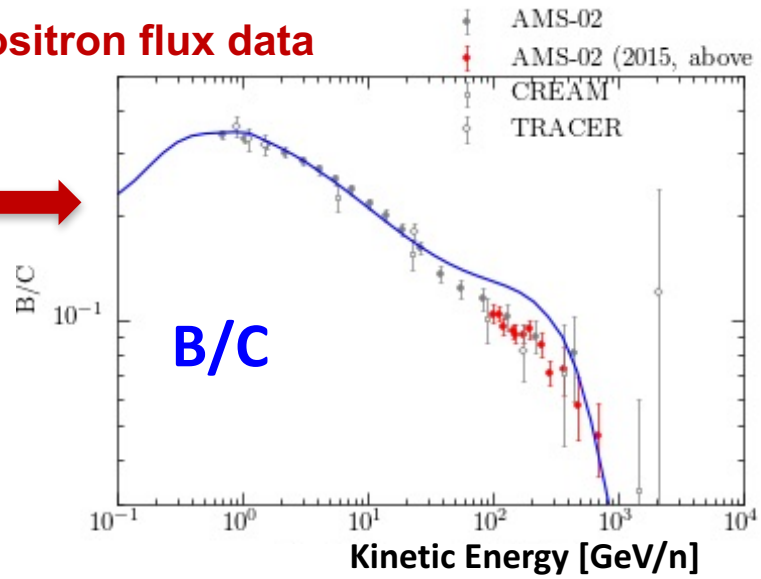


The observed features of the AMS data cannot be explained by propagation effects

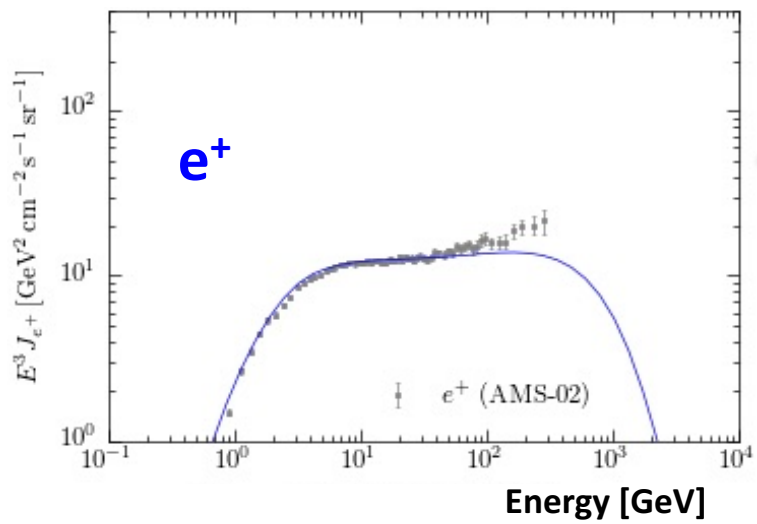
Alternative Models to explain the AMS Measurements
New Astrophysical sources (Supernova Remnants)

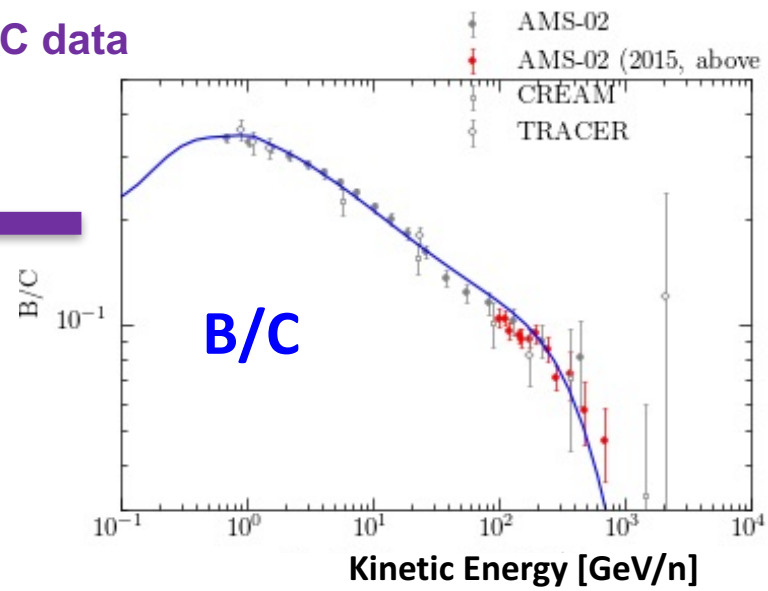
Model parameter tuned to fit the positron flux data





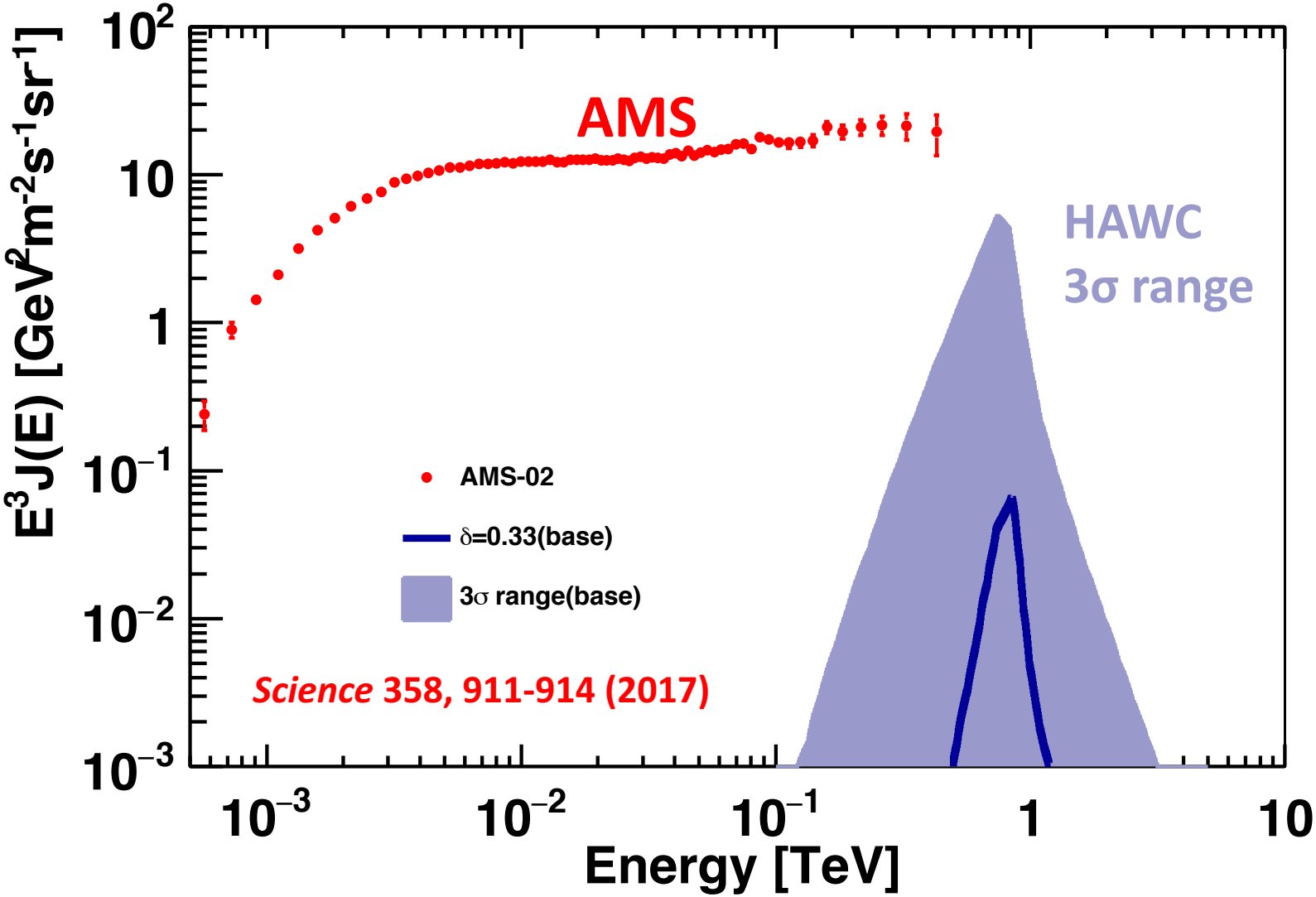
Model parameter tuned to fit the B/C data





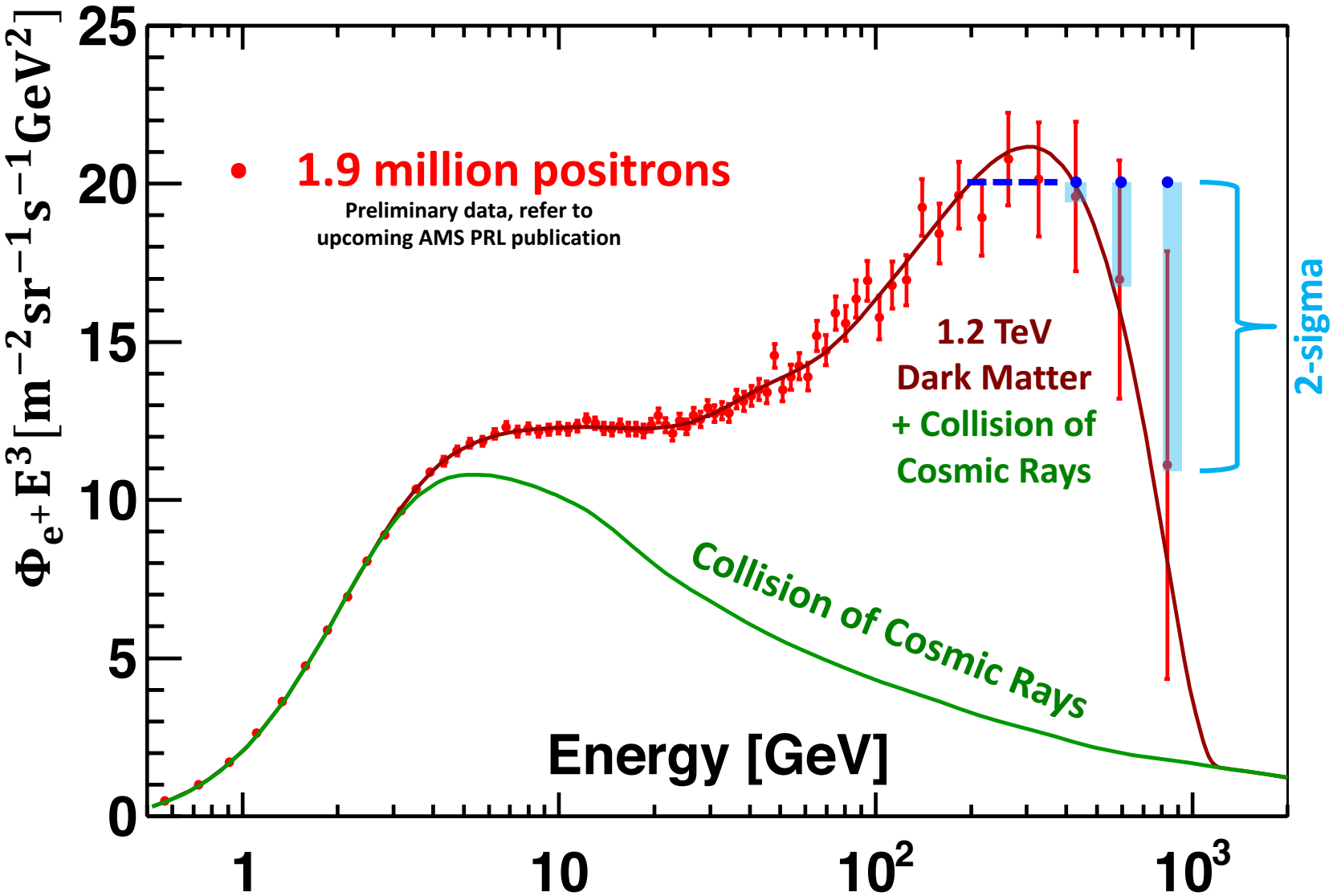
P. Mertsch and S. Sarkar, Phys.Rev. D 90 (2014) 061301

HAWC rules out that the positron excess is from nearby pulsars



In addition, AMS Measurement of positron, electron anisotropy will distinguish and constrain Pulsar origin of high energy $e^{\pm}$

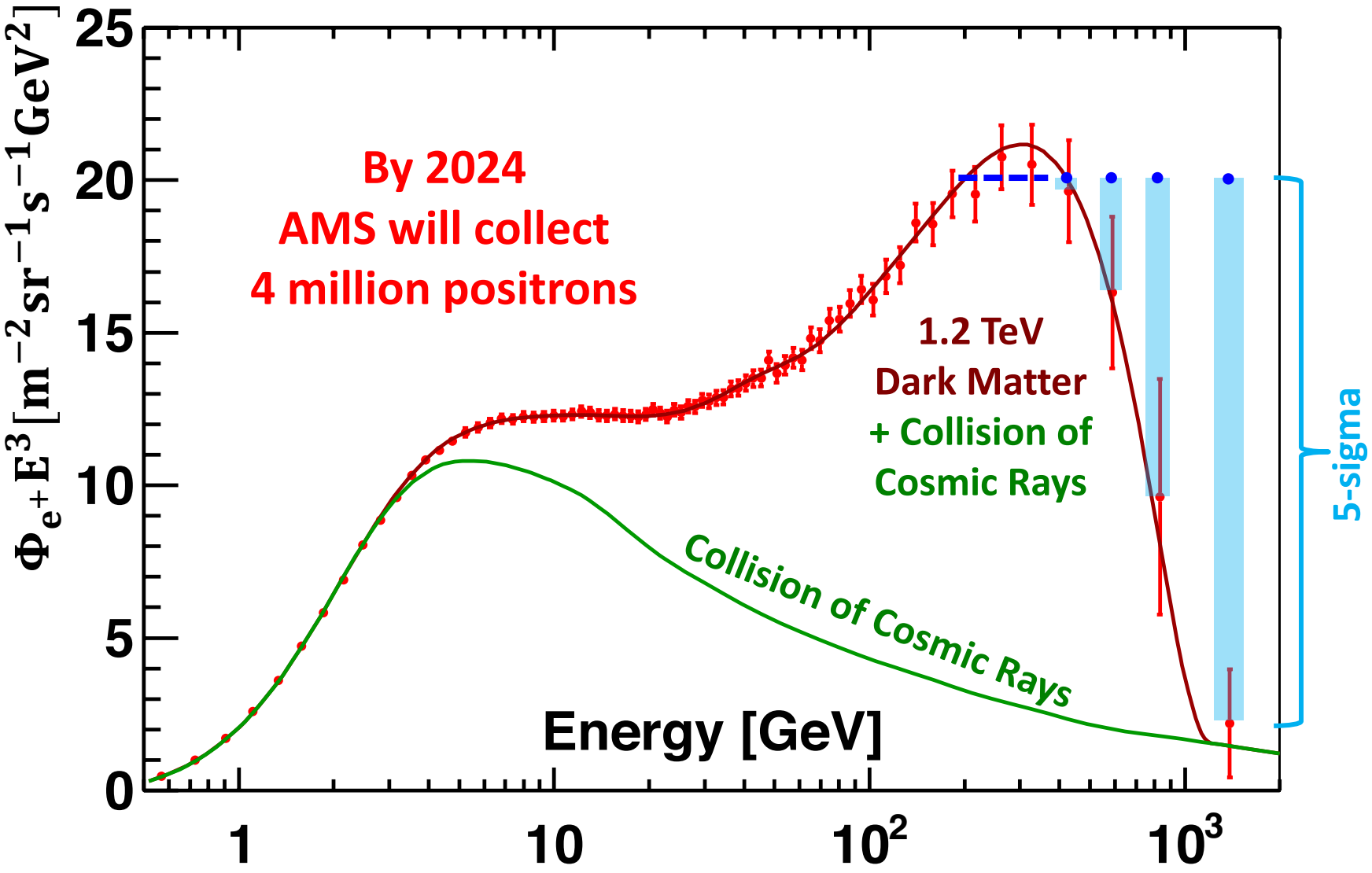
Positron spectrum beyond the turning point



Measuring positron flux behavior at high energy is key to understanding their origin

Combining last 3 points (E > 370 GeV), 2-sigma deviation from $\Phi \propto E^{-3}$

Positron spectrum beyond the turning point



By 2024, we will extend the measurements to 2 TeV and reaches 5 sigma significance

Conclusion

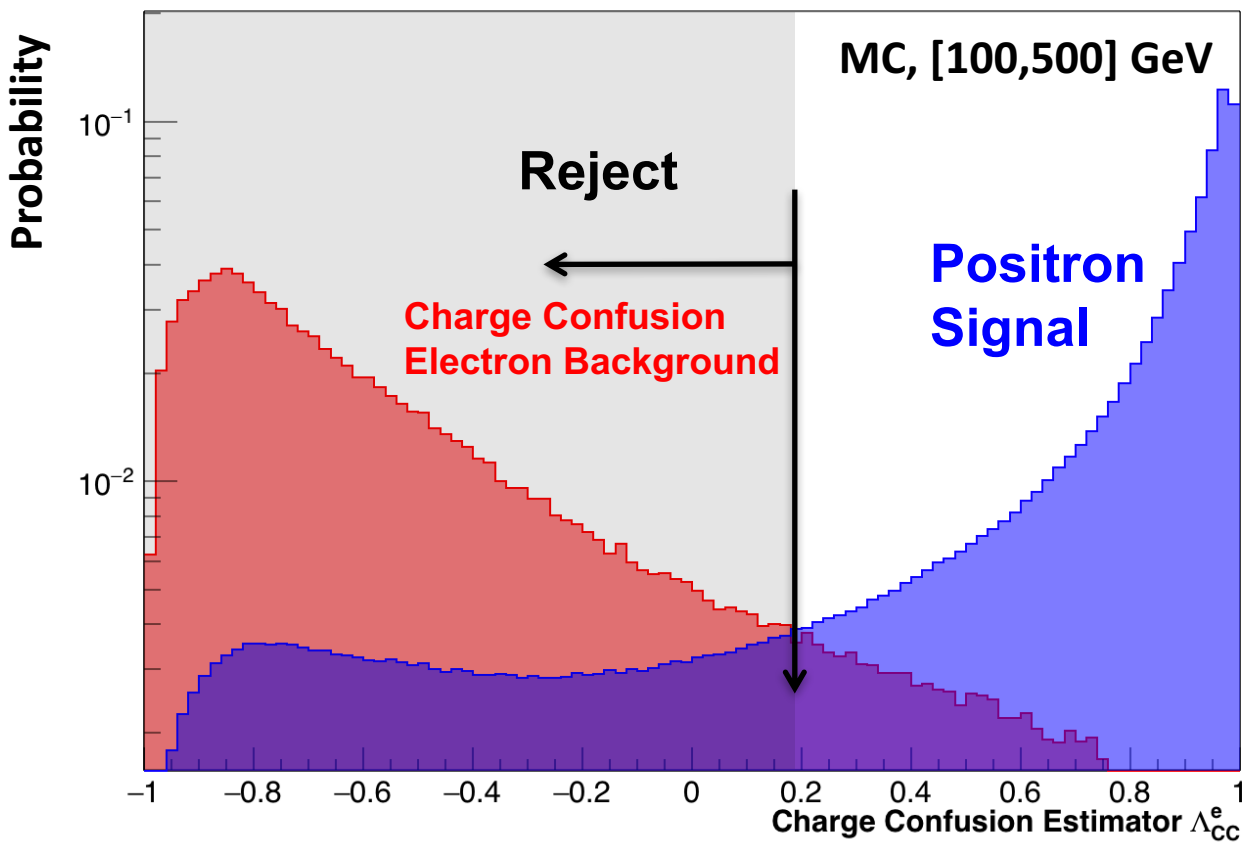
- **The individual positron and electron fluxes are measured to 1 TeV with 28.1 million electrons and 1.9 million positrons.**
- **The precision measurement indicates primary source of cosmic ray electron and positron**
- **Positron flux exhibits a cutoff at high energy: Above 370 GeV, Positron flux deviates from $\Phi \propto E^{-3}$ with 2 sigma significance.**
- **By continuing the measurement to 2024, we will be able to extend to higher energy and determine the origin of high energy positrons.**


AMS
AMS

Separation of positive and negative charges

- Electron charge confusion: Large angle scattering, interaction with detector materials. Well reproduced by the Monte Carlo.

- Identified and measured from data： Evaluate charge sign measurement at high energy using Charge confusion estimator: Information from Tracker, TOF and ECAL, including Energy-Momentum matching



A sample of papers on AMS data from more than 2000 publications

Dark Matter

1) J. Kopp, Phys. Rev. D 88, 076013 (2013);
2) L. Feng, R.Z. Yang, H.N. He, T.K. Dong, Y.Z. Fan and J. Chang Phys.Lett. B728 (2014) 250
3) M. Cirelli, M. Kadastik, M. Raidal and A. Strumia ,Nucl.Phys. B873 (2013) 530
4) M. Ibe, S. Iwamoto, T. Moroi and N. Yokozaki, JHEP 1308 (2013) 029
5) Y. Kajiyama and H. Okada, Eur.Phys.J. C74 (2014) 2722
6) K.R. Dienes and J. Kumar, Phys.Rev. D88 (2013) 10, 103509
7) L. Bergstrom, T. Bringmann, I. Cholis, D. Hooper and C. Weniger, PRL 111 (2013) 171101
8) K. Kohri and N. Sahu, Phys.Rev. D88 (2013) 10, 103001
9) A. Ibarra, A.S. Lamperstorfer and J. Silk, Phys.Rev. D89 (2014) 063539
10) Y. Zhao and K.M. Zurek, JHEP 1407 (2014) 017
11) C. H. Chen, C. W. Chiang, and T. Nomura, Phys. Lett. B 747, 495 (2015)
12) H. B. Jin, Y. L. Wu, and Y.-F. Zhou, Phys.Rev. D92, 055027 (2015)
13) A. Reinert and M. W. Winkler JCAP 01 (2018) 055

and many other excellent papers **…**

New Propagation Models

1) R.Cowsik, B.Burch, and T.Madziwa-Nussinov, Ap.J. 786 (2014) 124
2) K. Blum, B. Katz and E. Waxman, Phys.Rev.Lett. 111 (2013) 211101
3) R. Kappl and M. W. Winkler, J. Cosmol. Astropart. Phys. 09 (2014) 051
4) G.Giesen, M.Boudaud, Y.Gènolini, V.Poulin, M.Cirelli, P.Salati and P.D.Serpico, JCAP09 (2015) 023;
5) C.Evoli, D.Gaggero and D.Grasso, JCAP 12 (2015) 039.
6) R.Kappl, A.Reinert, and M.W.Winkler, arXiv:1506.04145 (2015)

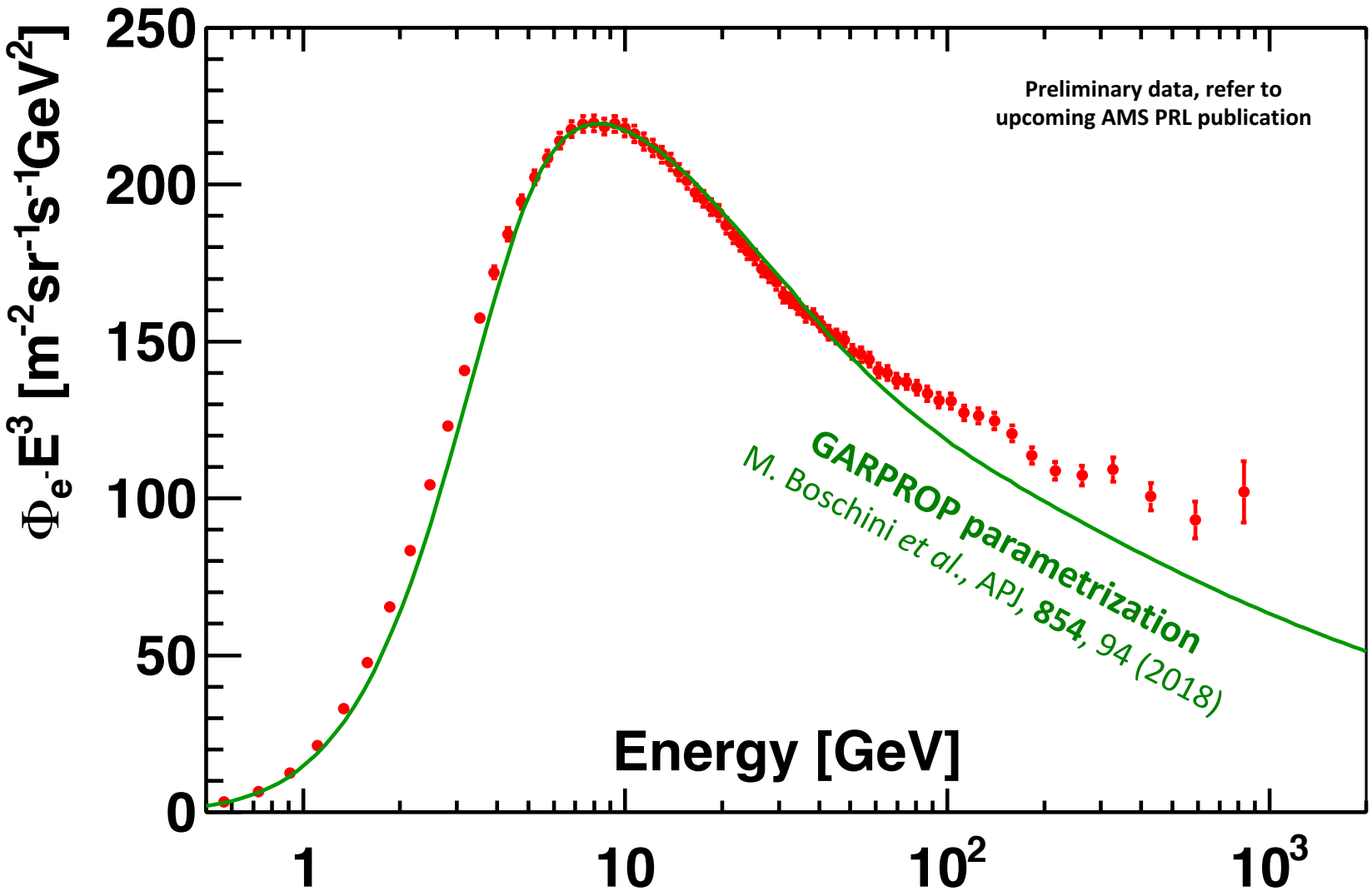
and many other excellent papers …

New Astrophysical Sources

1) T. Linden and S. Profumo, Astrophys.J. 772 (2013) 18
2) P. Mertsch and S. Sarkar, Phys.Rev. D 90 (2014) 061301
3) I. Cholis and D. Hooper, Phys.Rev. D88 (2013) 023013
4) A. Erlykin and A.W. Wolfendale, Astropart.Phys. 49 (2013) 23
5) P.F. Yin, Z.H. Yu, Q. Yuan and X.J. Bi, Phys.Rev. D88 (2013) 2, 023001
6) A.D. Erlykin and A.W. Wolfendale, Astropart.Phys. 50-52 (2013) 47
7) E. Amato, Int.J.Mod.Phys.Conf.Ser. 28 (2014) 1460160
8) P. Blasi, Braz.J.Phys. 44 (2014) 426
9) D. Gaggero, D. Grasso, L. Maccione, G. DiBernardo and C Evoli, Phys.Rev. D89 (2014) 083007
10) M. DiMauro, F. Donato, N. Fornengo, R. Lineros and A. Vittino, JCAP 1404 (2014) 006
11) K. Kohri, K. Ioka, Y. Fujita, and R. Yamazaki, Prog. Theor. Exp. Phys. 2016, 021E01 (2016)

and many other excellent papers …

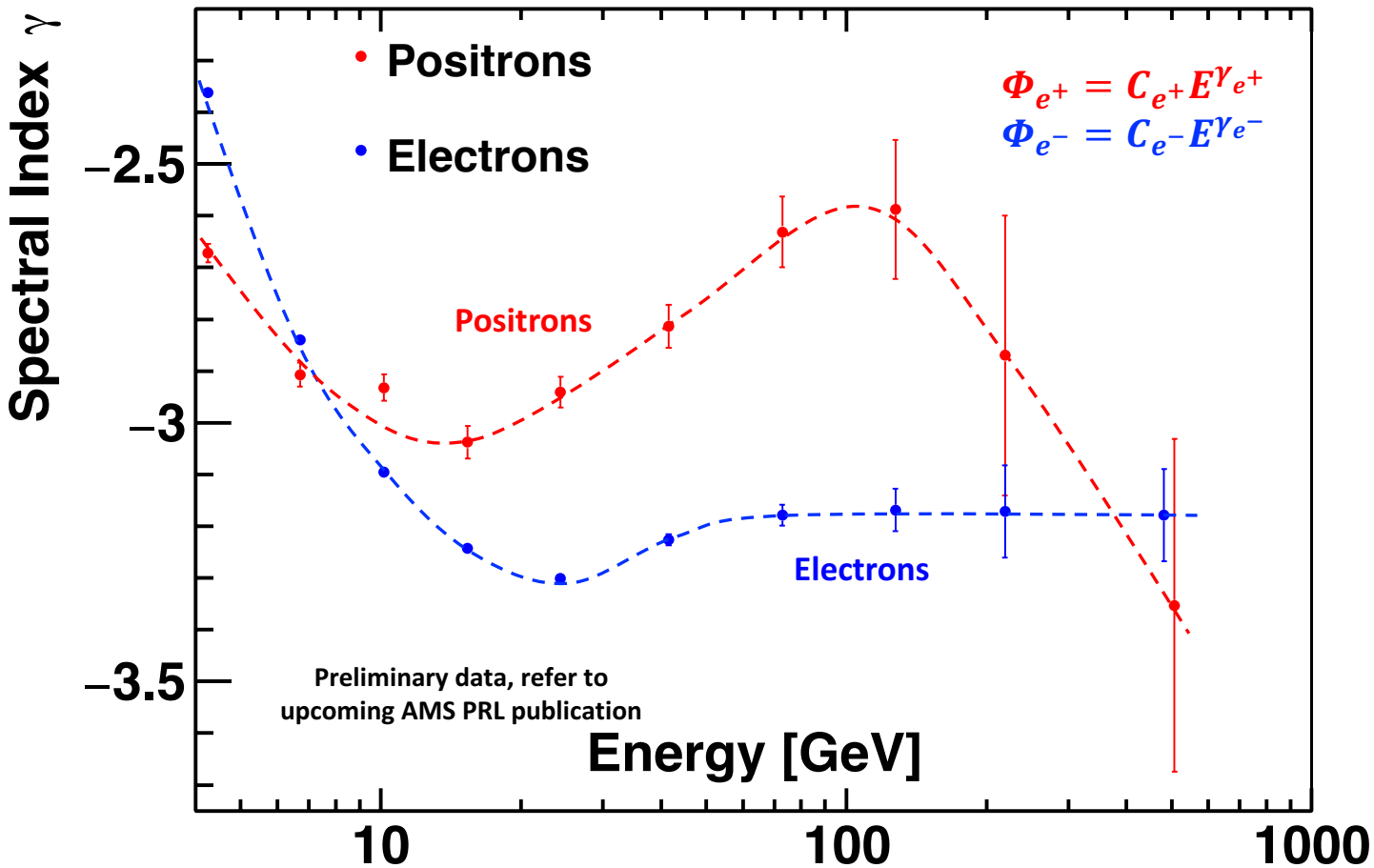
Additional source of cosmic ray Electron



Starting from 30 GeV, electron flux require additional primary source.

However, due to large background from conventional cosmic ray electron. It is difficult to extract source contribution from electron flux alone

The Electron and Positron spectral indices



- Positron and Electron both show hardening from ~30GeV
- Positron shows softening/cut-off effect at 300GeV
- Softening of e^+ does not correspond to softening in e^-: Not a propagation effect.

Additional source of cosmic ray positron and electron

Measurements of electrons and positrons in AMS

TOF:

- Down-going particle $\beta>0.8$

TRD:

- TRD estimator identified as $e^{\pm}$

Tracker and magnet:

- **Provide accurate momentum measurement**
- Charge $|Z|=1$ particle

ECAL:

- **Provide accurate energy measure**
- **Remove bulk of the proton.**

A 960 GeV positron