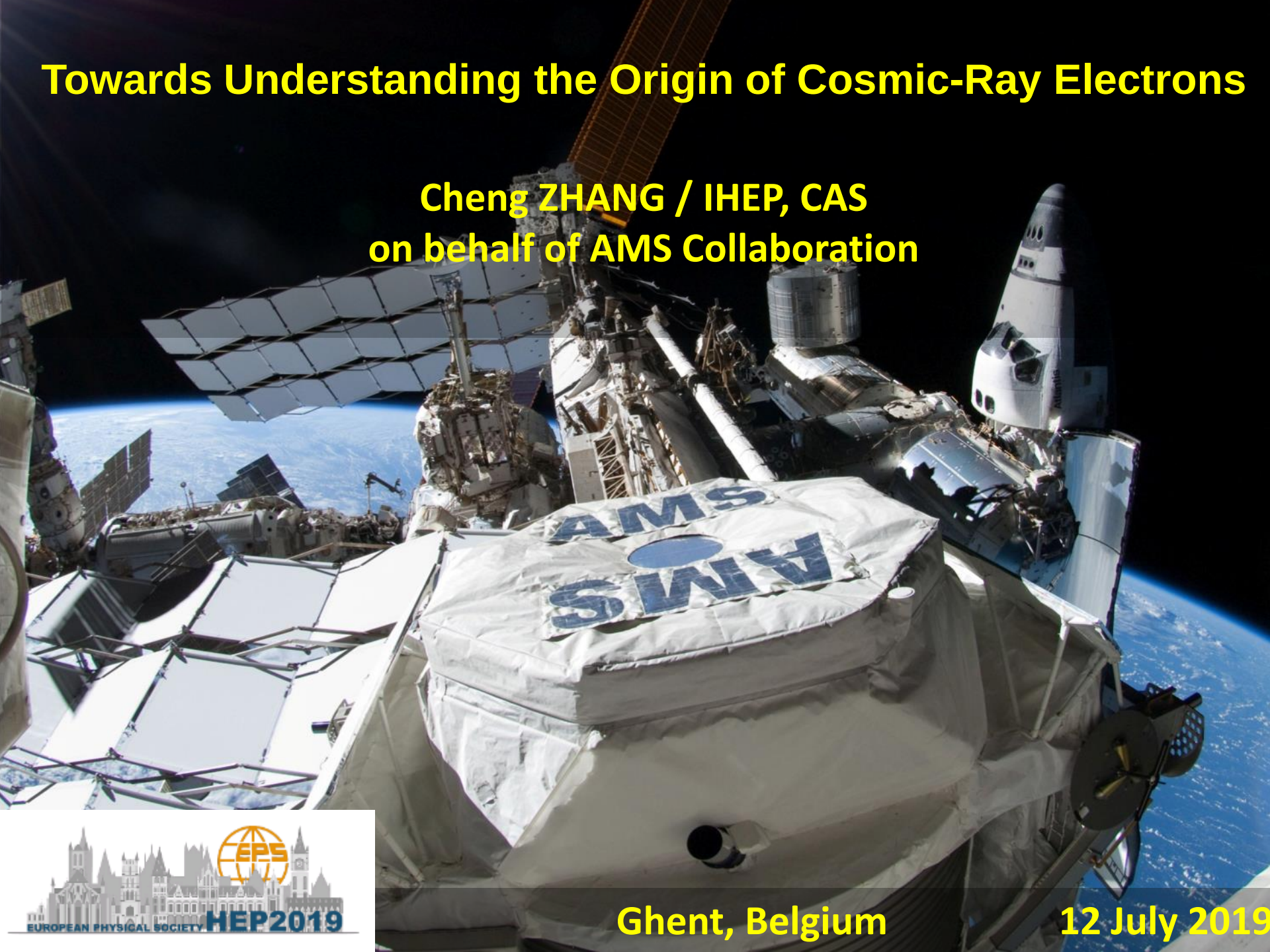
Towards Understanding the Origin of Cosmic-Ray Electrons

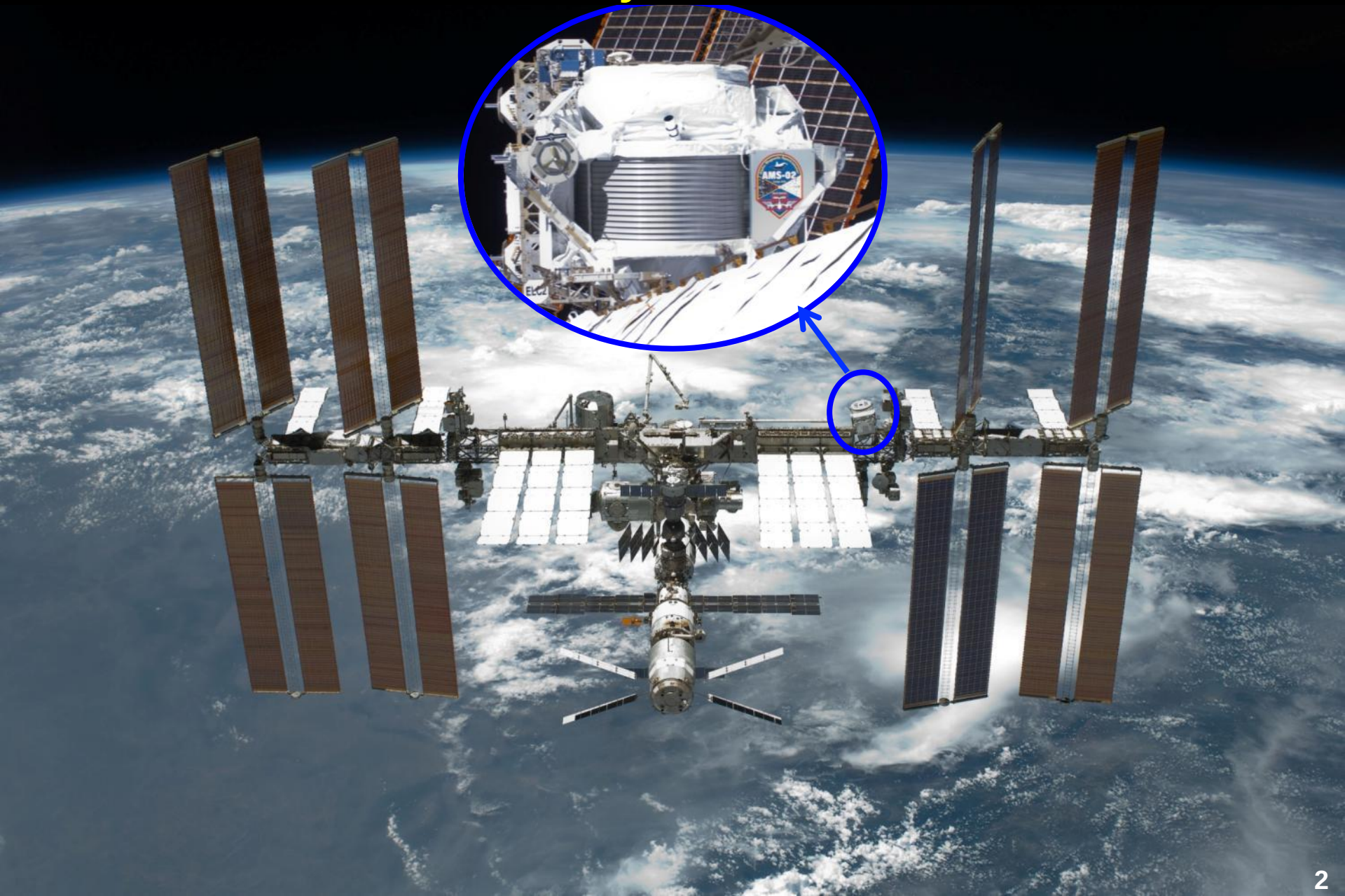
Cheng ZHANG / IHEP, CAS
on behalf of AMS Collaboration



EUROPEAN PHYSICAL SOCIETY HEP2019

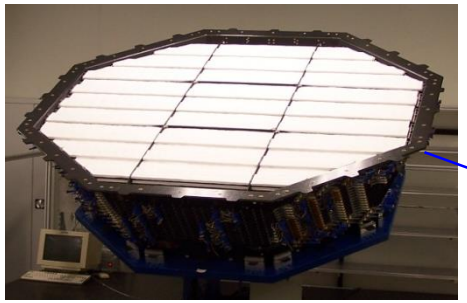
Ghent, Belgium 12 July 2019

In 8 years, 140 billion charged particles have been measured by AMS



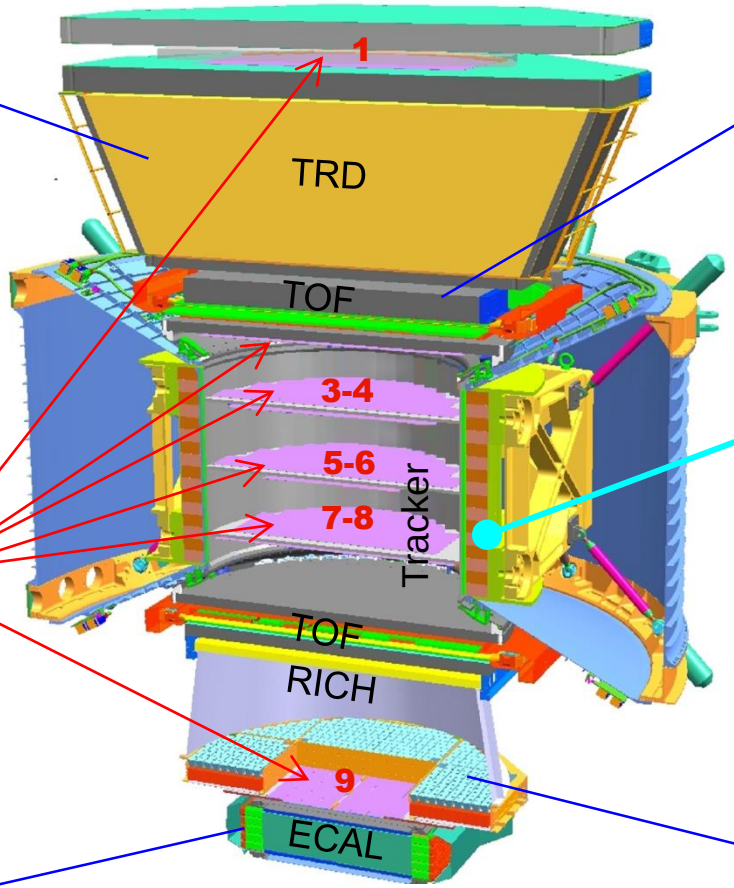
AMS is a space version of a precision detector used in accelerators

Transition Radiation Detector (TRD)

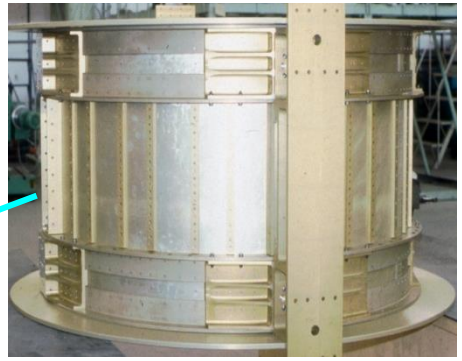


Particles and nuclei are defined by their charge (Z) and energy (E or P)

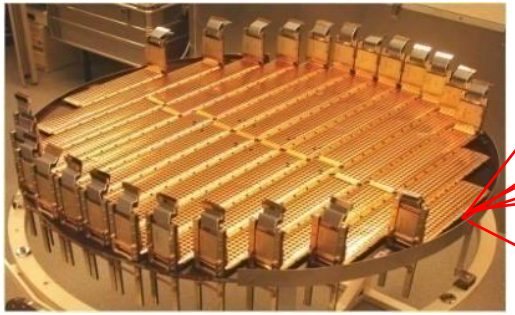
Time of Flight Detector (TOF)



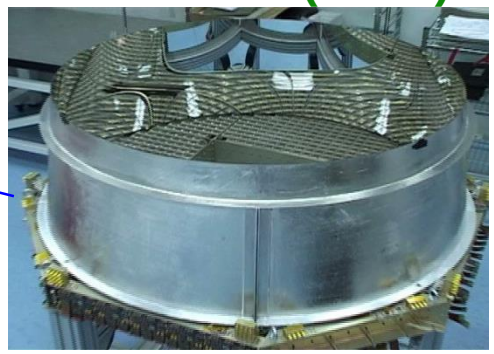
Magnet



Silicon Tracker



Ring Imaging Cherenkov (RICH)

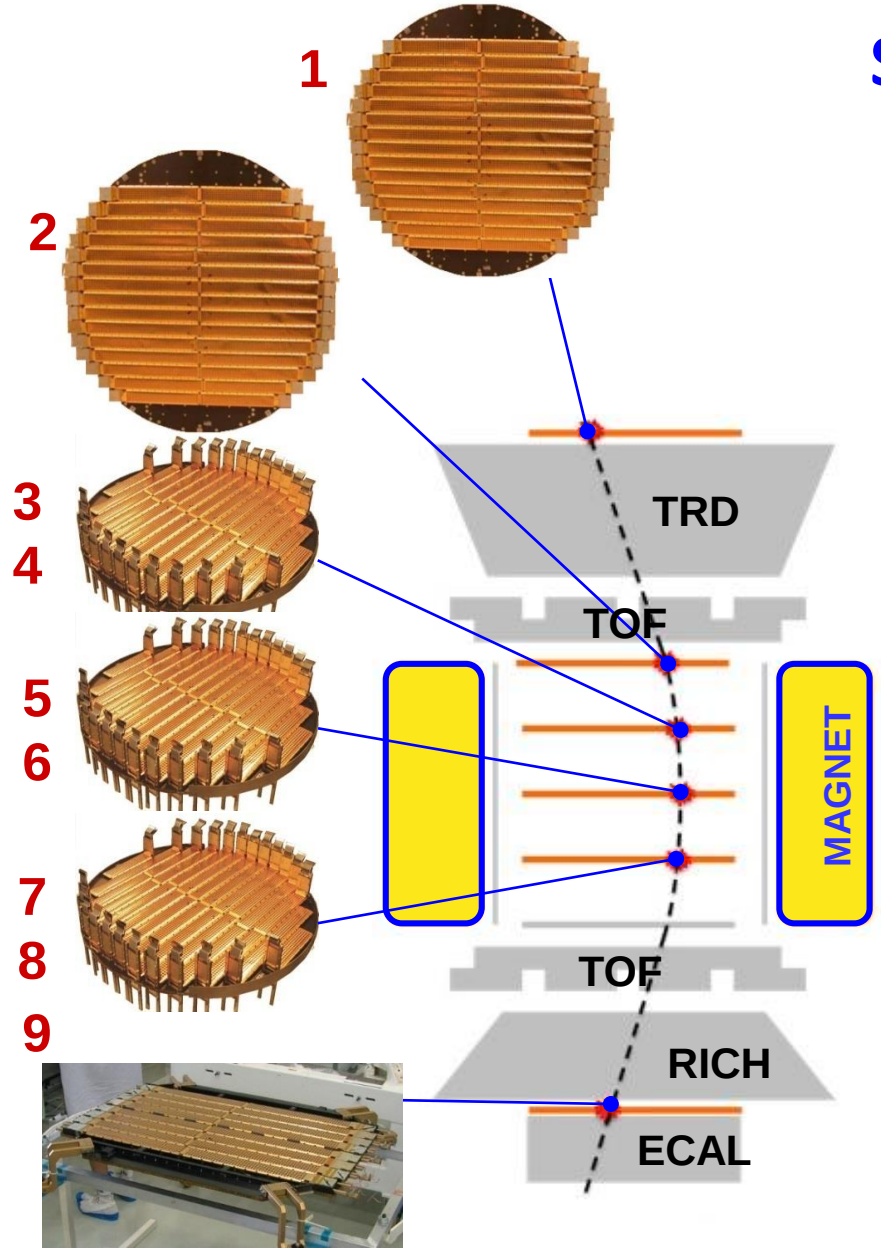


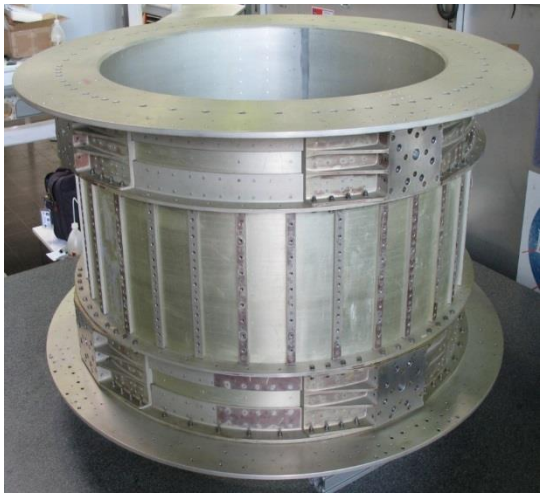
Electromagnetic Calorimeter (ECAL)

Z and P

are measured independently by the Tracker, RICH, TOF and ECAL

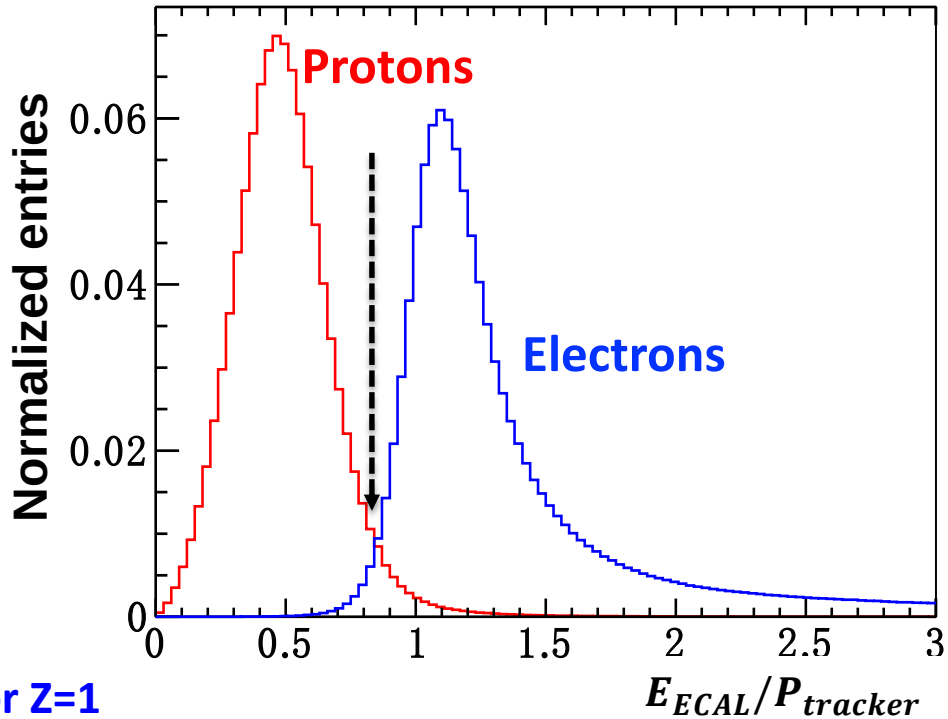
Silicon Tracker and Magnet





1.4 kG

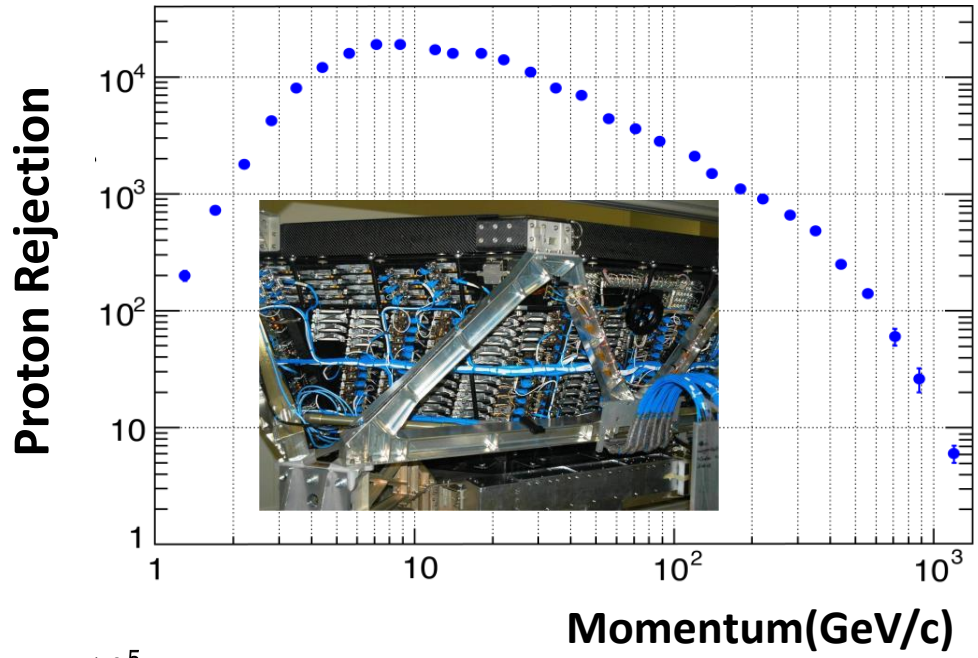
Unique feature of AMS: Energy-Momentum Match



L1 to L9: 3 m level arm;
single point resolution 10 μm;
Maximum Detectable Rigidity(MDR) 2.0 TV for Z=1

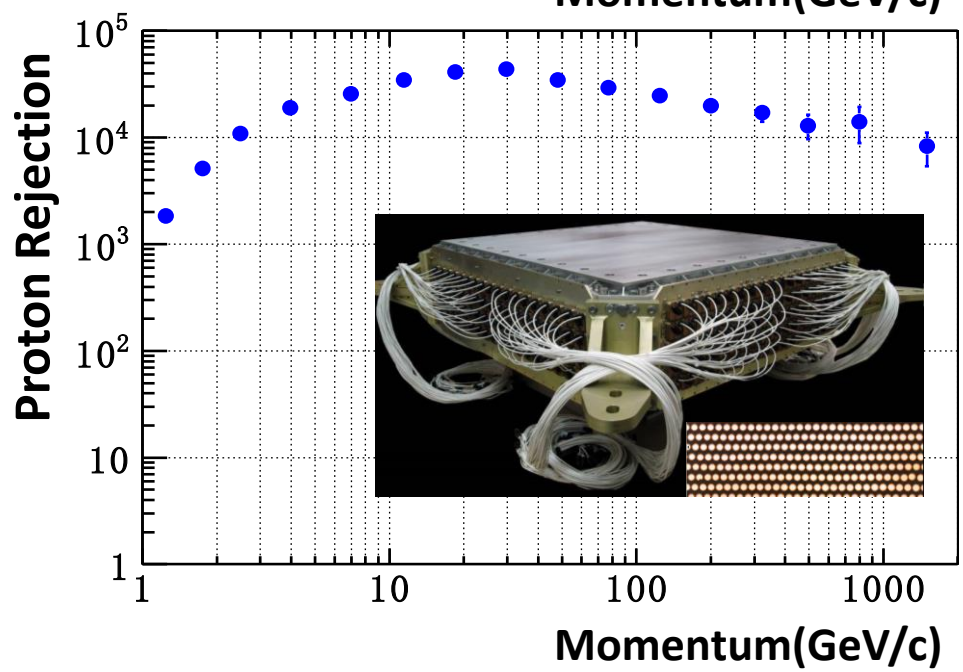
Positron and electron identification in AMS

- Proton rejection 10^3 to 10^4 with TRD



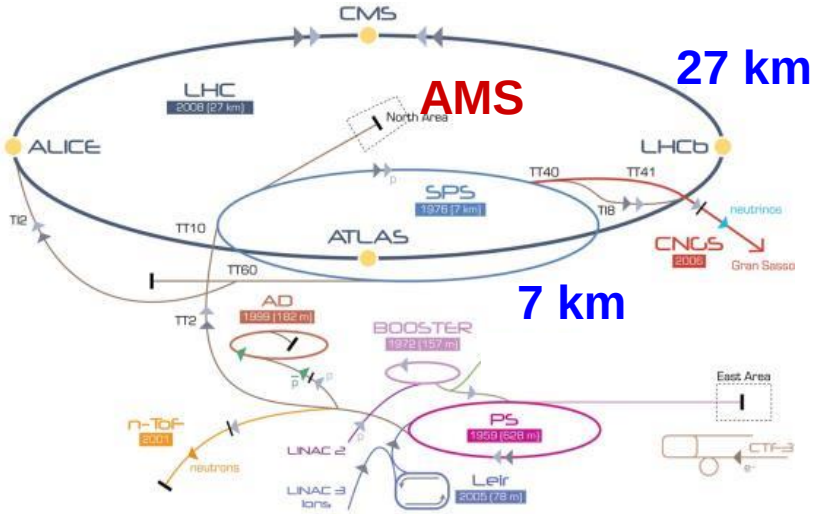
- Proton rejection is above 10^4 with ECAL and tracker

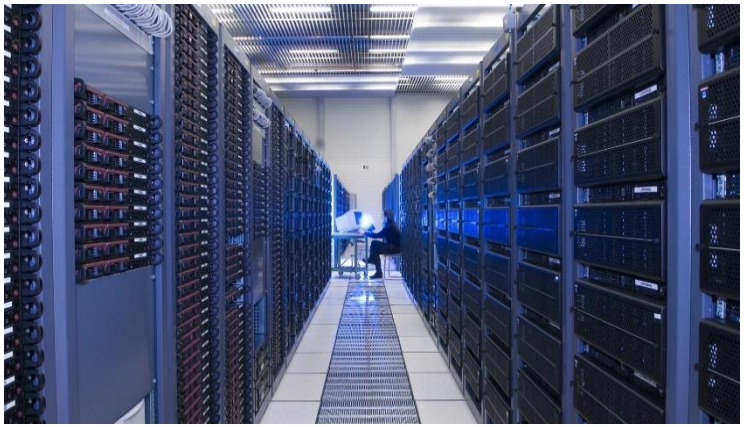
- TRD and ECAL is separated by magnet, they have independent proton rejection



Calibration of the AMS Detector

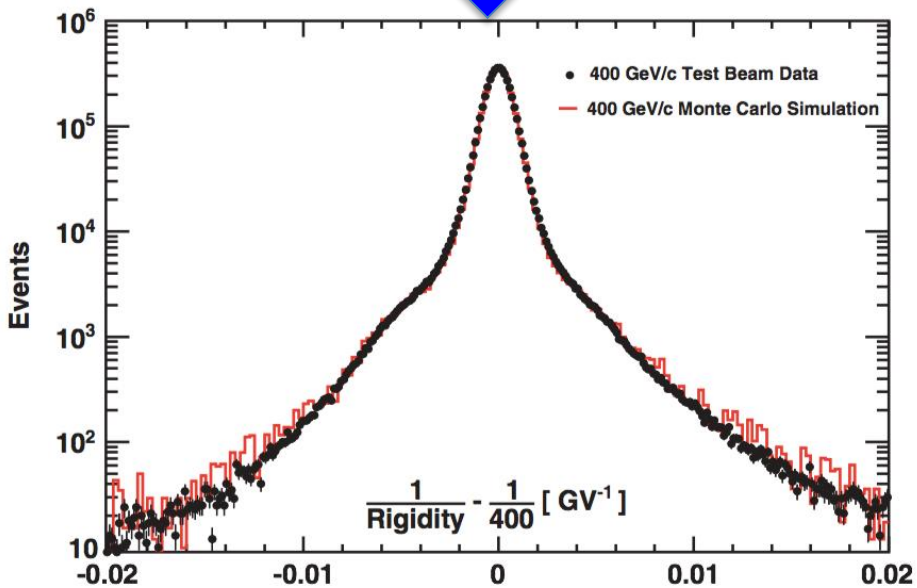
Test beam at CERN SPS:
p, $e^{\pm}$, $\pi^{\pm}$, 10–400 GeV





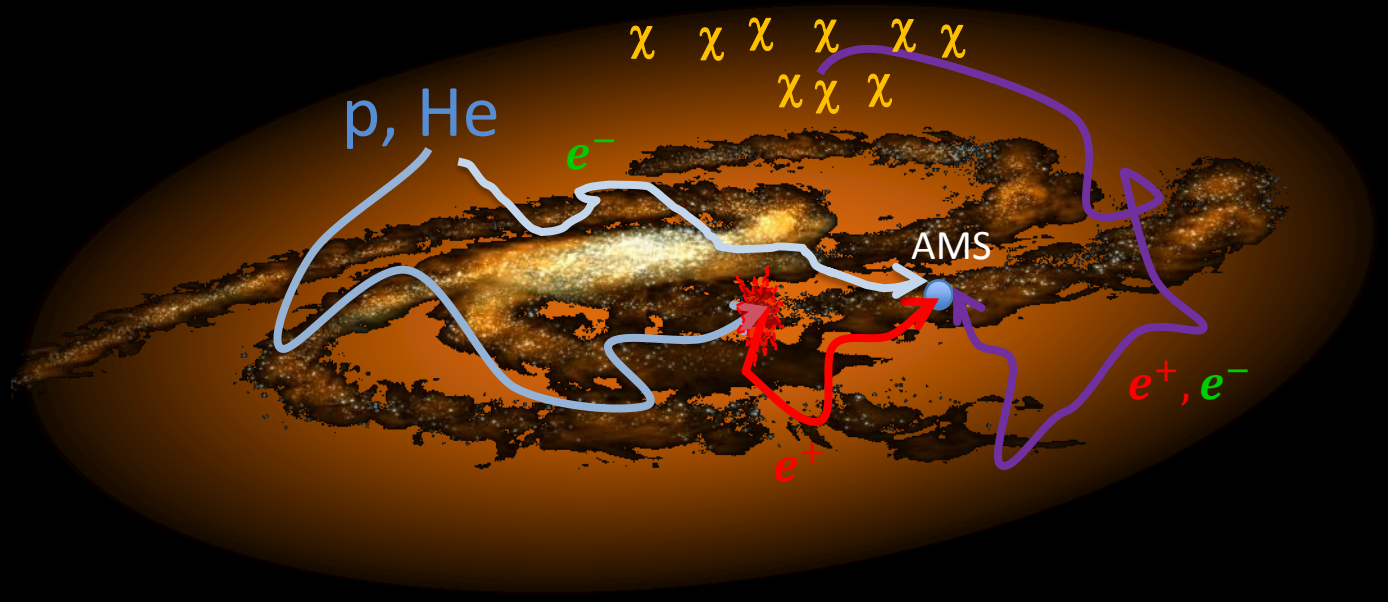
Computer simulation:
Interactions, Materials, Electronics

2000 positions

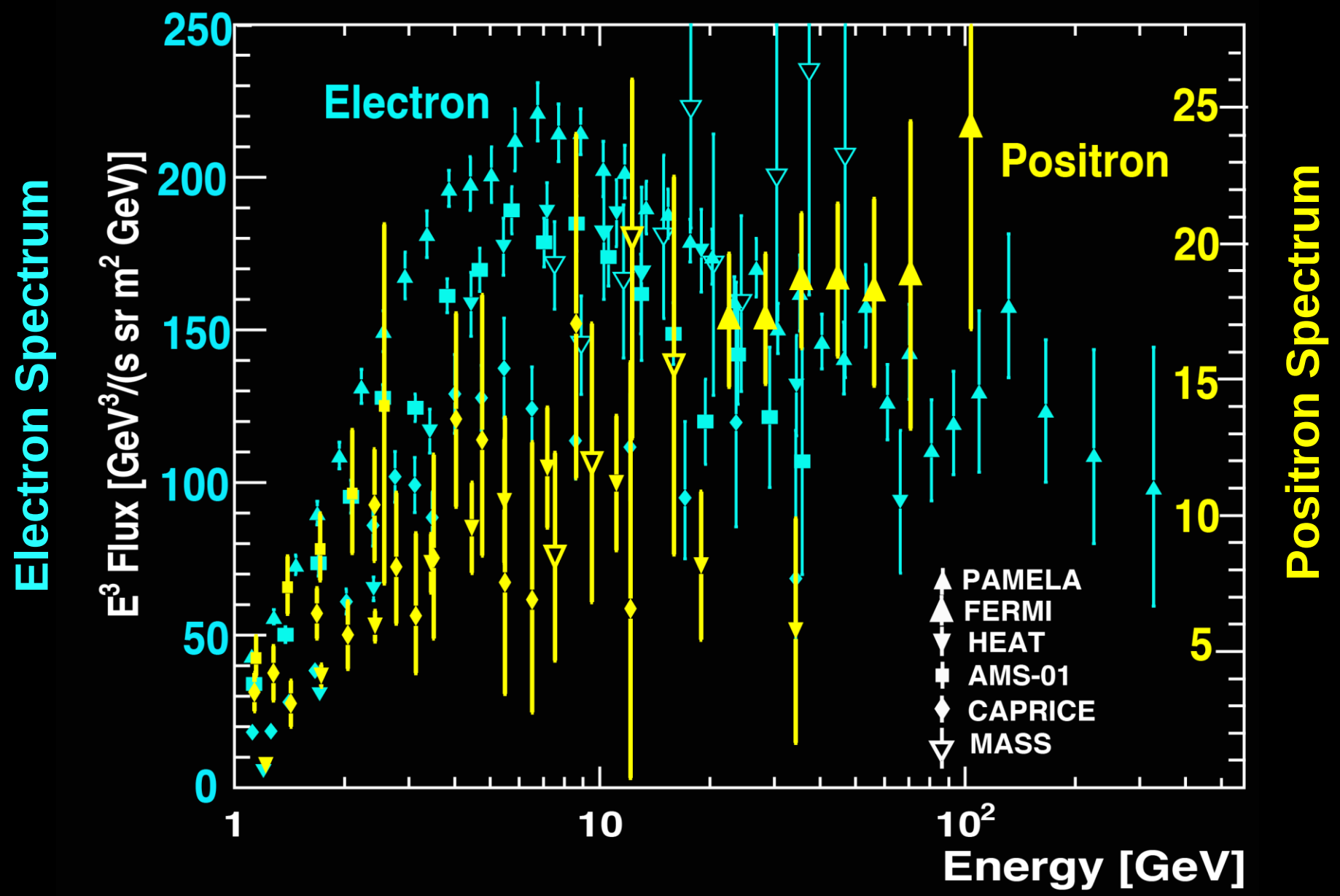


Electrons and Positrons in the Cosmos

- 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.



Electron and Positron spectra before AMS



The measurement of electrons and positrons in AMS

Primary cosmic ray particle:

- E>1.2·max cutoff

TOF:

- Down-going particle β>0.8
- Charge |Z|=1 particle

TRD:

- **Provide proton rejection Λ_{TRD}:**

The ratio of the log-likelihood probability of the $e^{\pm}$ hypothesis to that of proton hypothesis

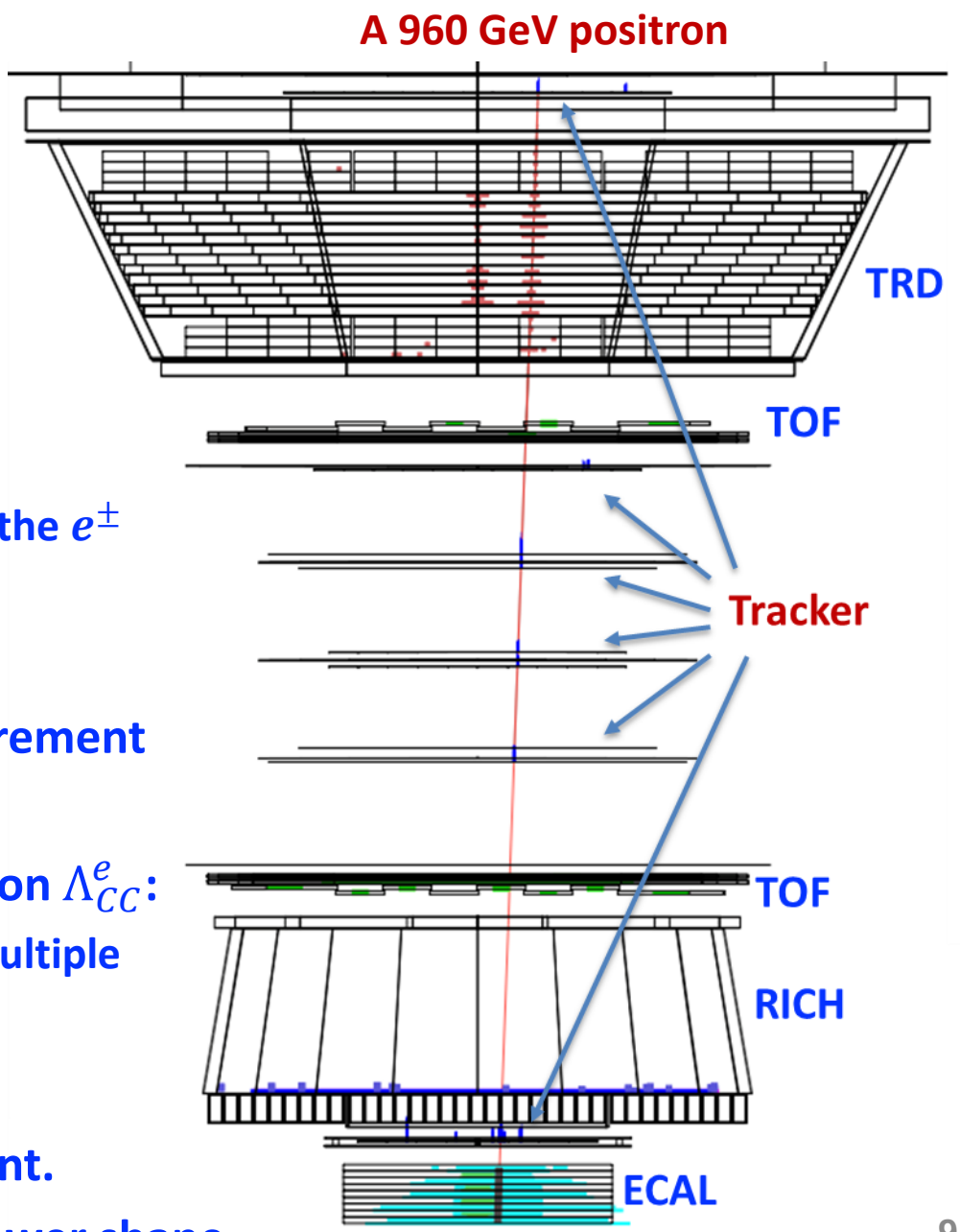
tracker and magnet:

- **Provide accurate momentum measurement**
- Charge |Z|=1 particle
- **Provide charge confusion identification Λ_{CC}^{e}:**

The boosted decision tree value combines multiple information from tracker and TOF

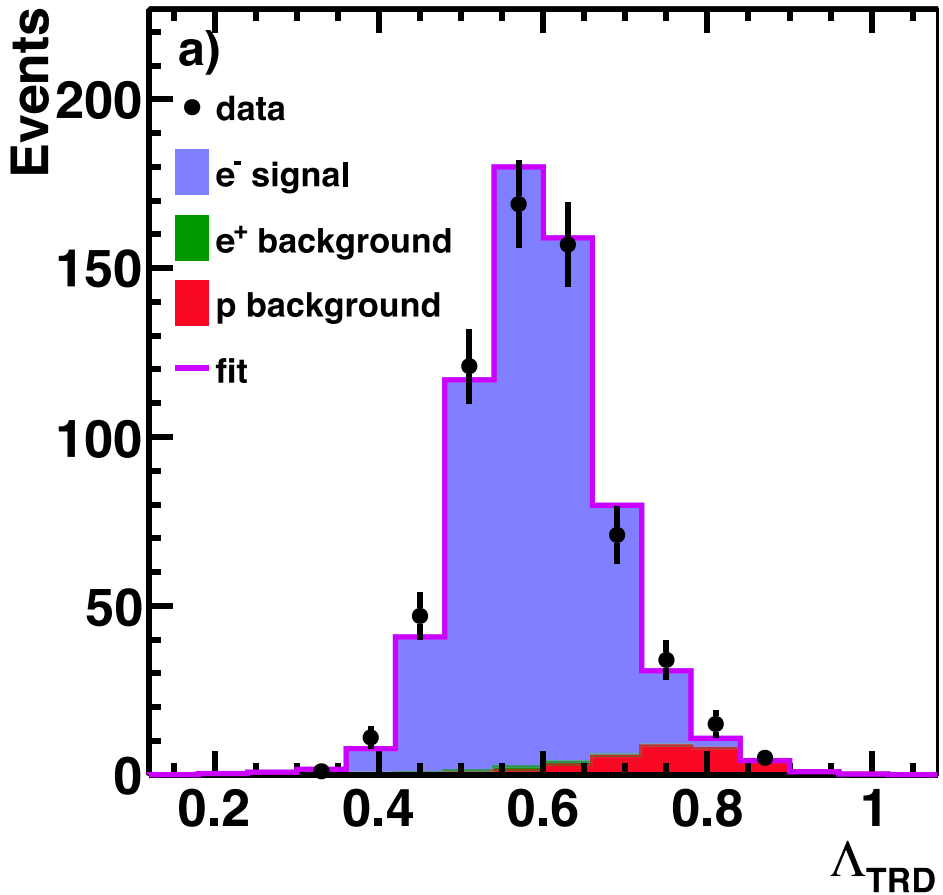
ECAL:

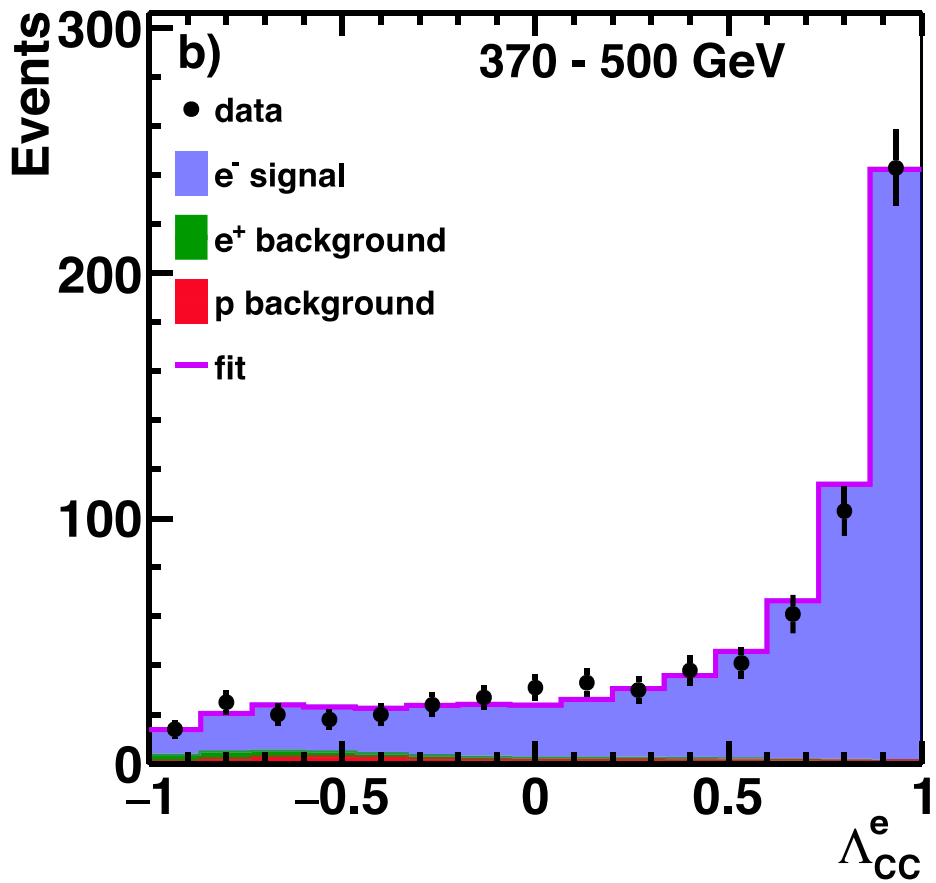
- **Provide accurate energy measurement.**
- **Provide proton rejection with 3D shower shape**



Analysis method to determine the number of e^-

- ECAL selection to remove bulk of the proton background.
- For each bin, fit templates to negative data sample in $(\Lambda_{\mathrm{TRD}} - \Lambda_{CC}^{e})$ plane





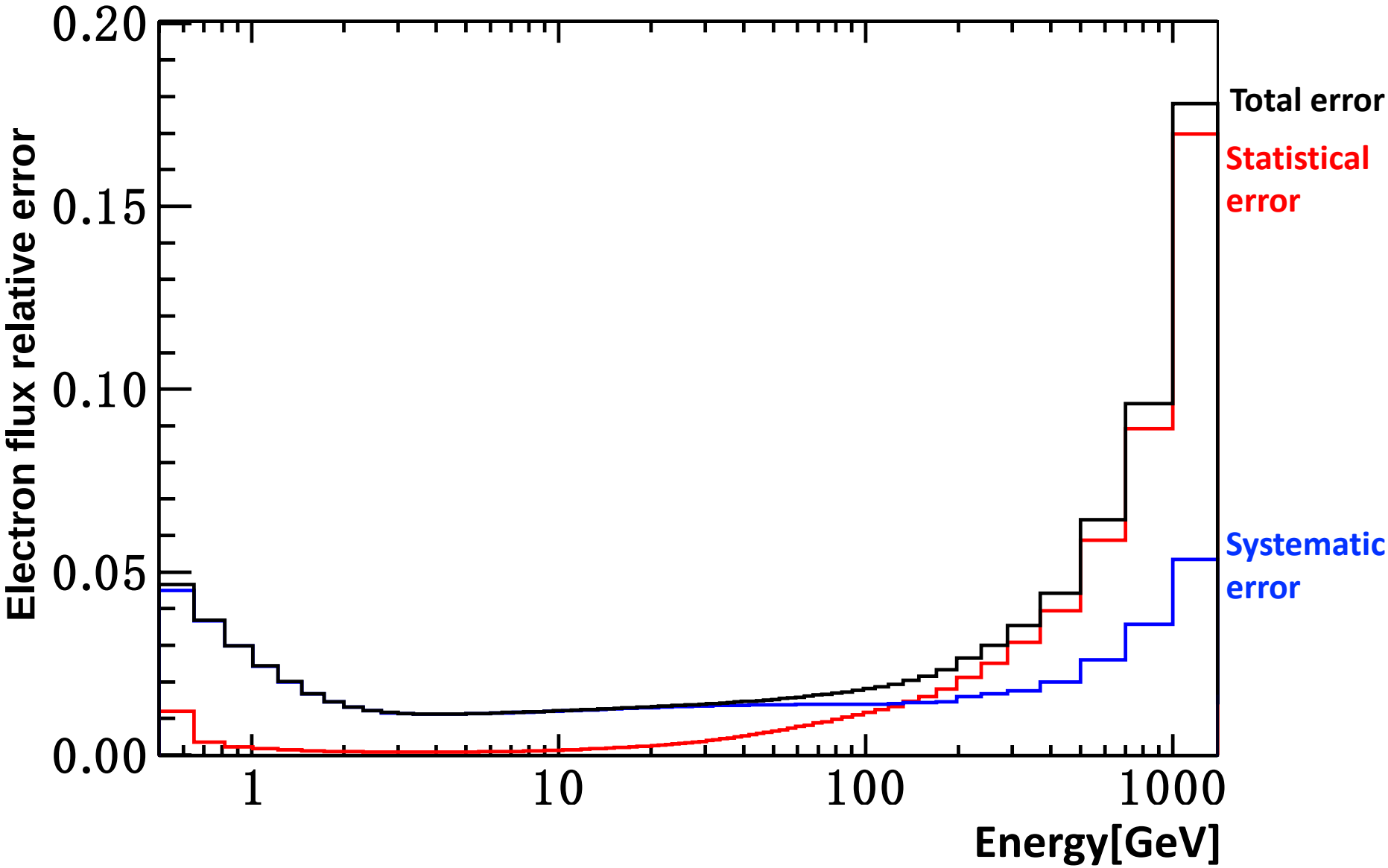
The background contribution is small comparing to the electron signal

In total, 28.1 million electrons are identified from 0.5 GeV to 1.4 TeV

Major Systematic Errors

- **Charge confusion:**
  - Measured directly from data. Good agreement between data and Monte Carlo. The difference is taken as systematic error
- **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.
- **Event bin-to-bin migration:**
  - Corresponding error is 2% of the flux at 0.5GeV and it decreases to < 0.2% above 10 GeV.
- **Energy Scale:**
  - Uncertainty in the absolute energy scale: 2% at [2, 300] GeV, 2.6% at 1.4TeV. Treated as the uncertainty of the energy bin boundaries.

The errors of the electron flux



Statistical error dominates above 200 GeV

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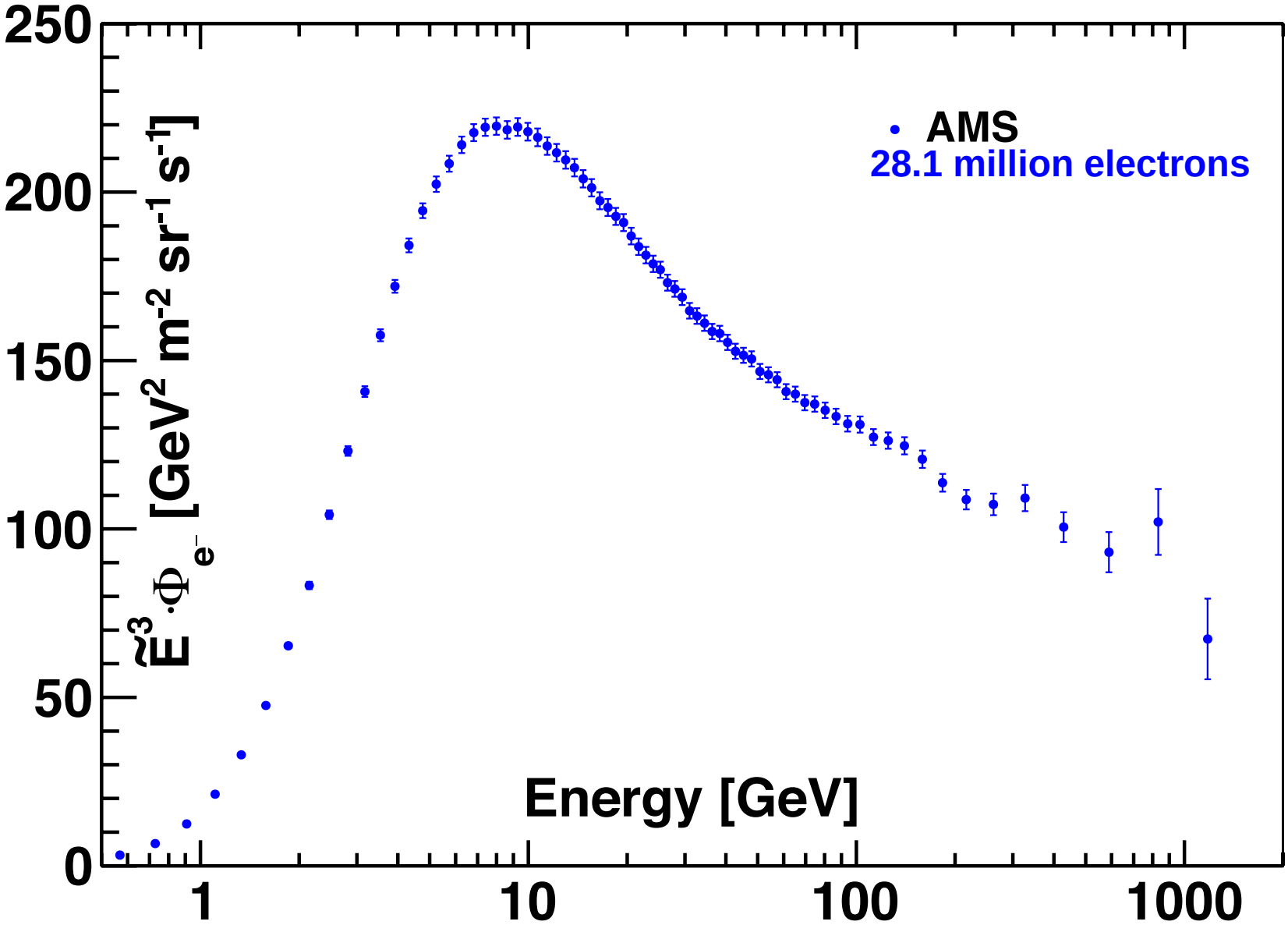
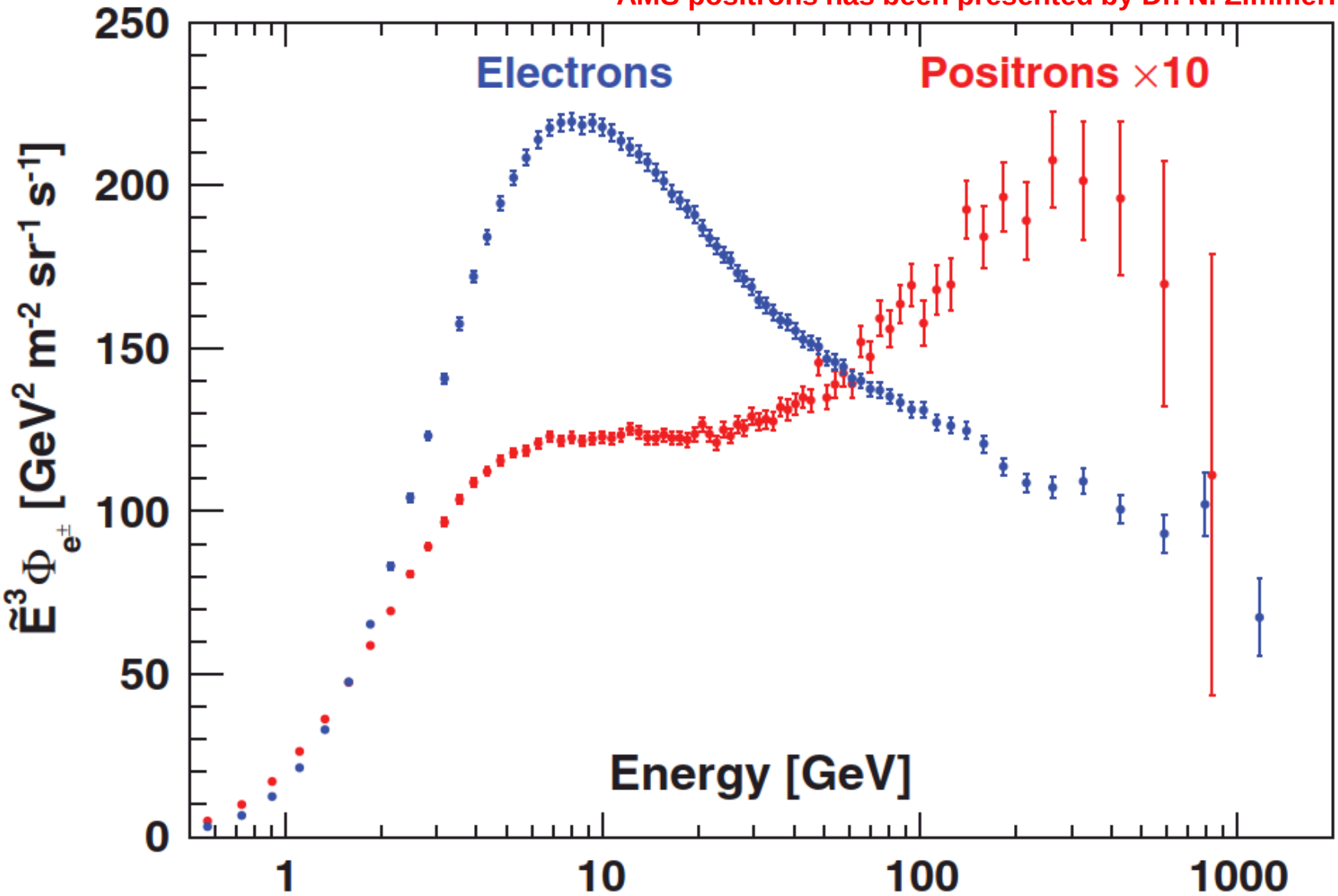
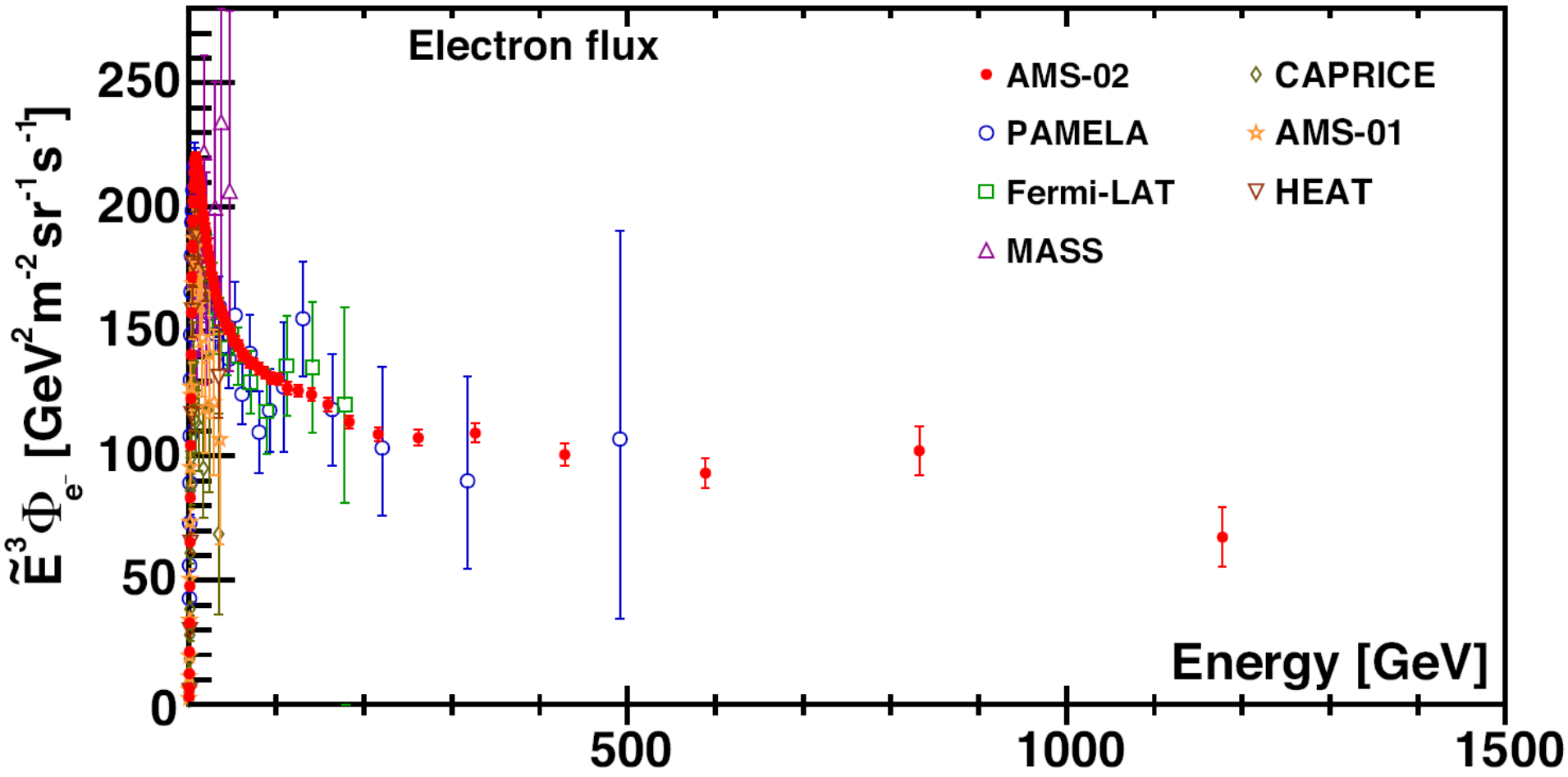


AMS Latest Electron and Positron spectra

AMS positrons has been presented by Dr. N. Zimmermann

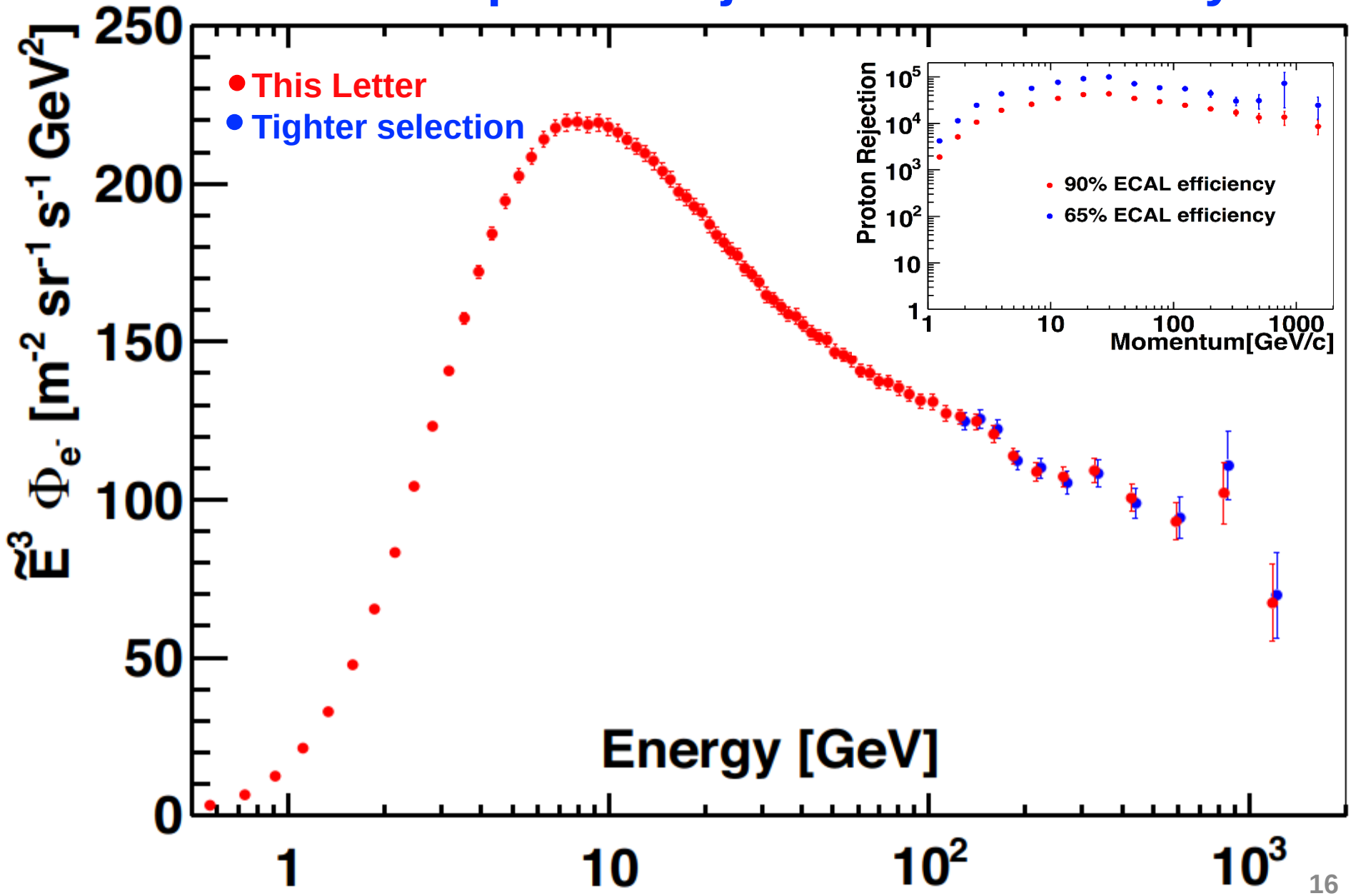


AMS Electron spectrum with earlier experiments



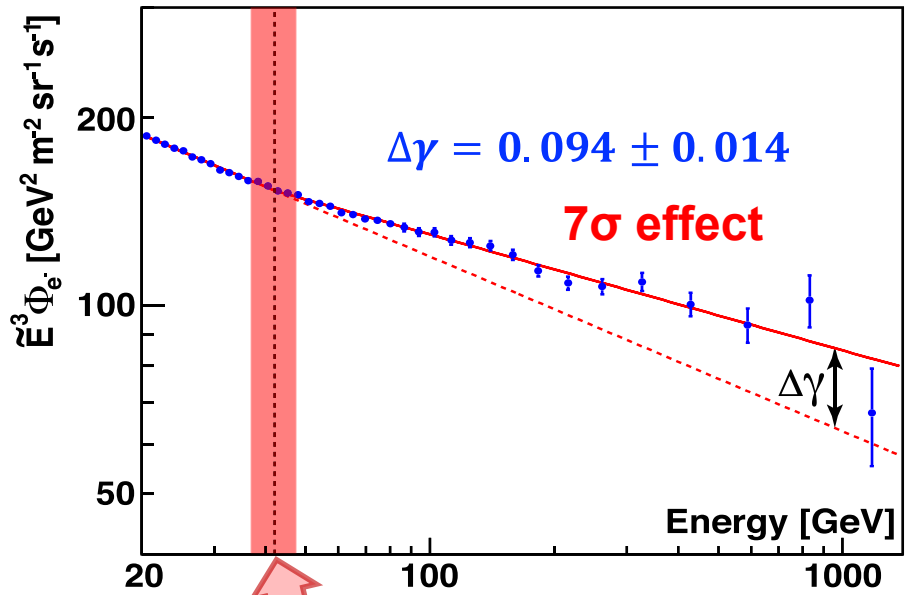
Consistency check:

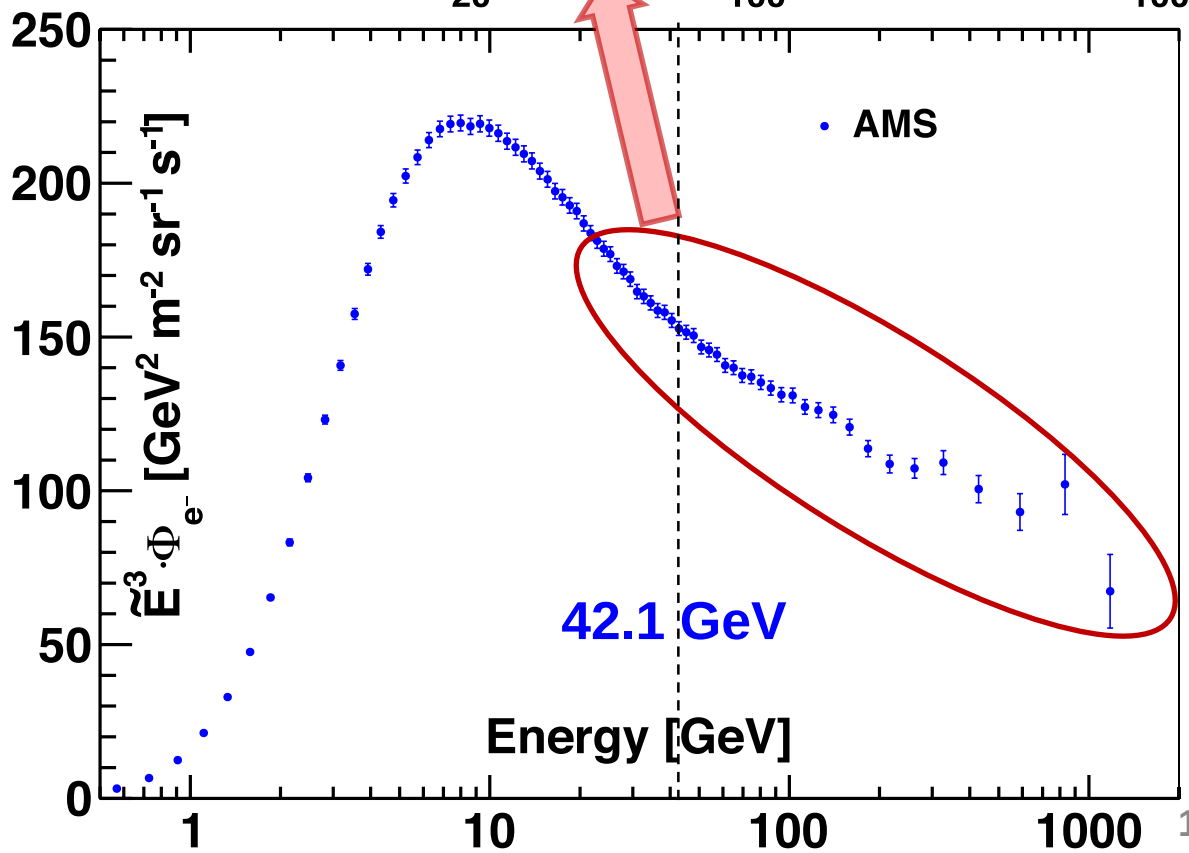
Electron flux with proton rejection increased by x3



Fit to the 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 above $42.1^{+5.4}_{-5.2}$ GeV

Solar modulation is negligible

The electron flux can be described by two power law functions.

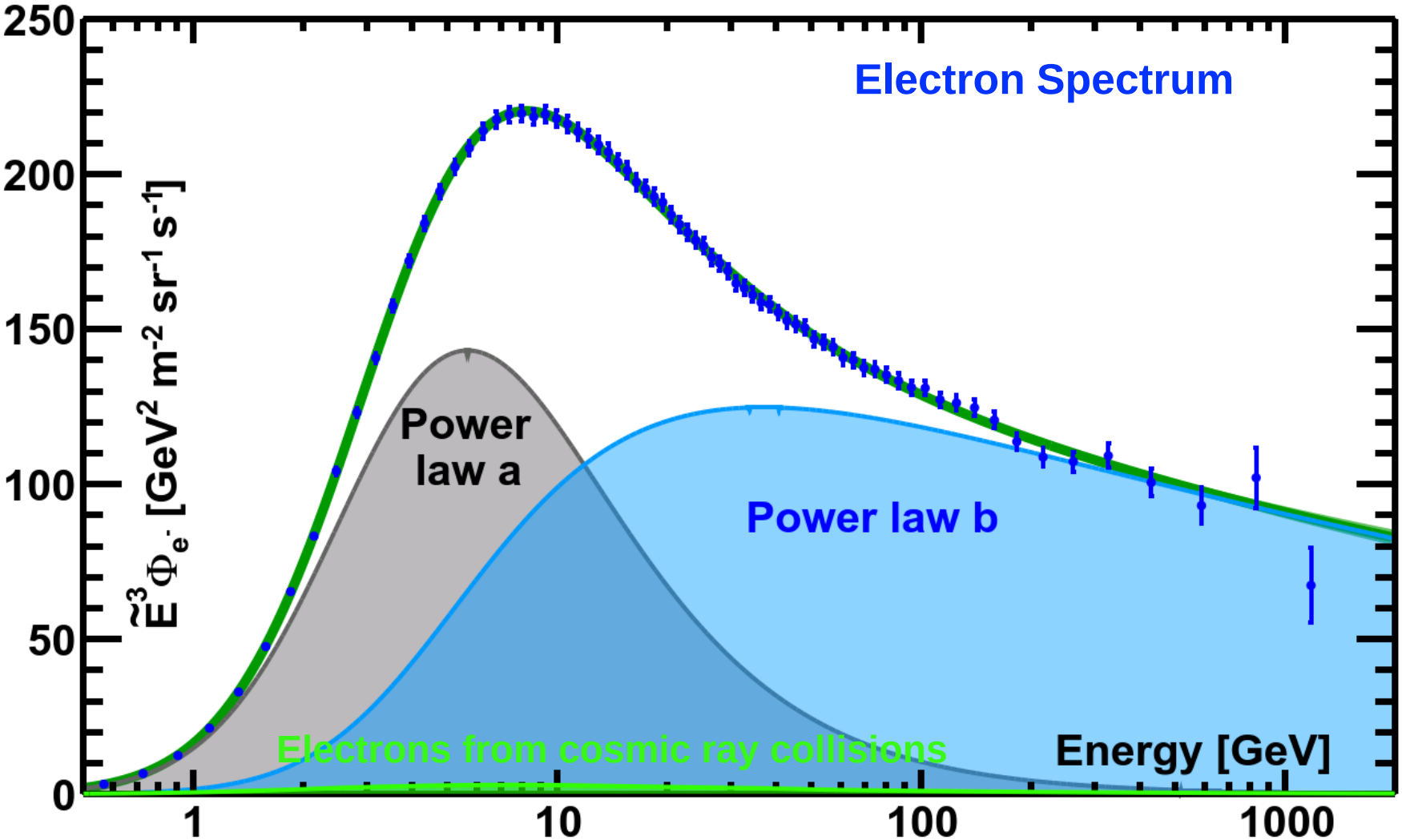
$$\Phi_{e^-}(E) = \frac{E^2}{\widehat{E}^2}\left[1 + \left(\widehat{E}/E_t\right)^{\Delta\gamma_t}\right]^{-1}\left[C_a\left(\widehat{E}/E_a\right)^{\gamma_a} + C_b\left(\widehat{E}/E_b\right)^{\gamma_b}\right]$$

Solar & low-energy

Power laws

a

b

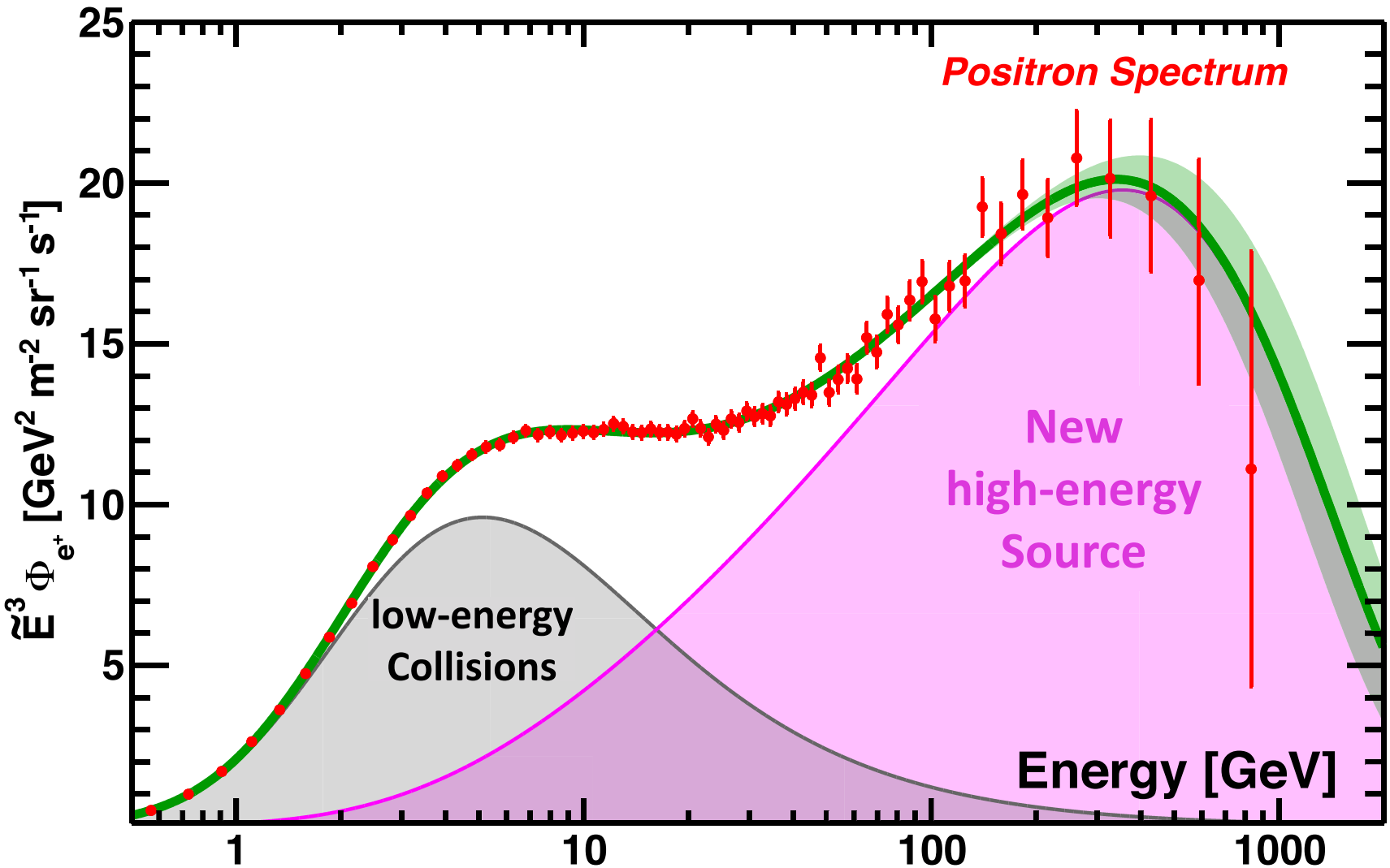


Electrons have neither source nor cutoff.

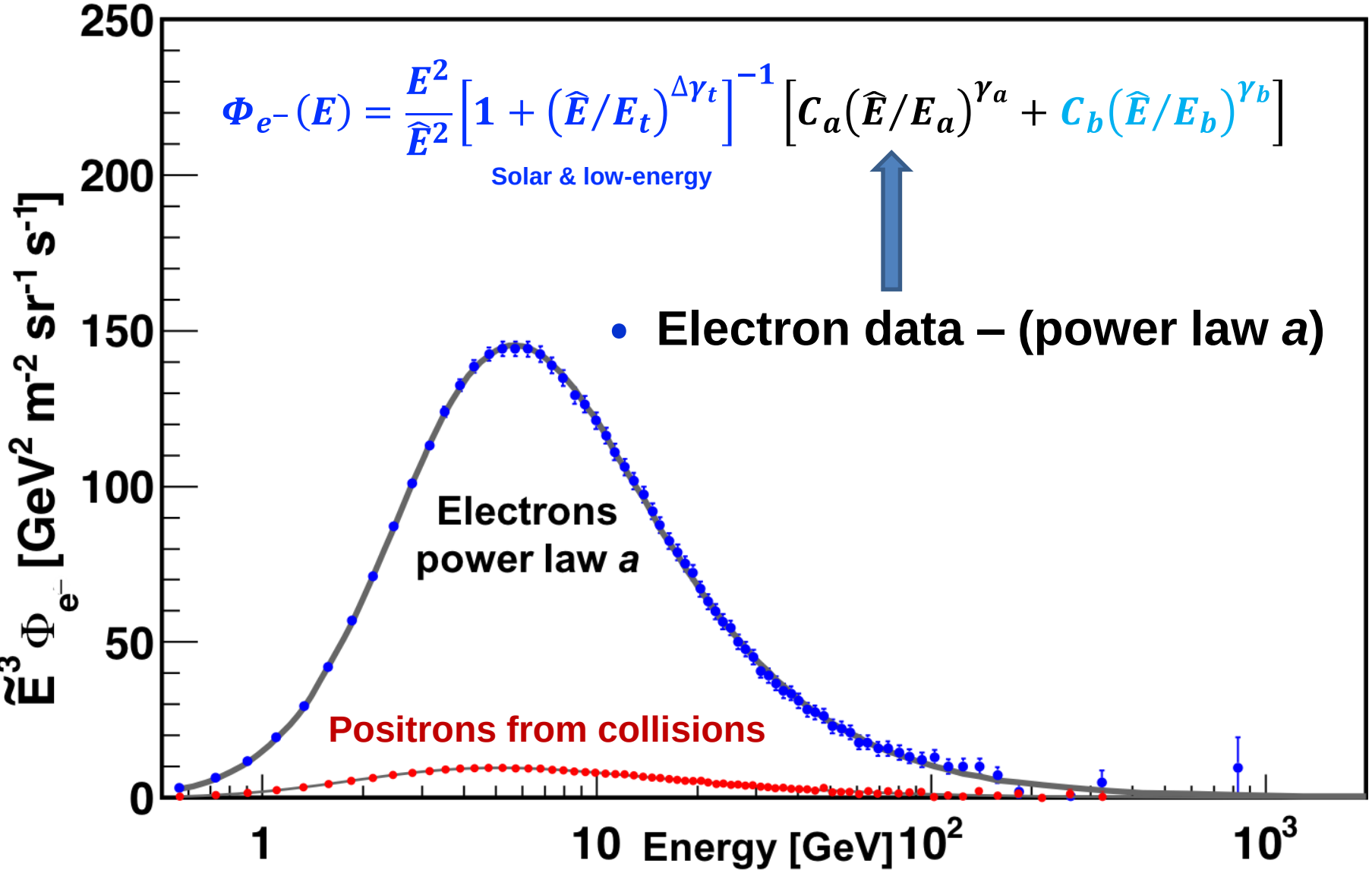
The positron flux is the sum of

low-energy e⁺ from collisions plus a new source of high-energy e⁺

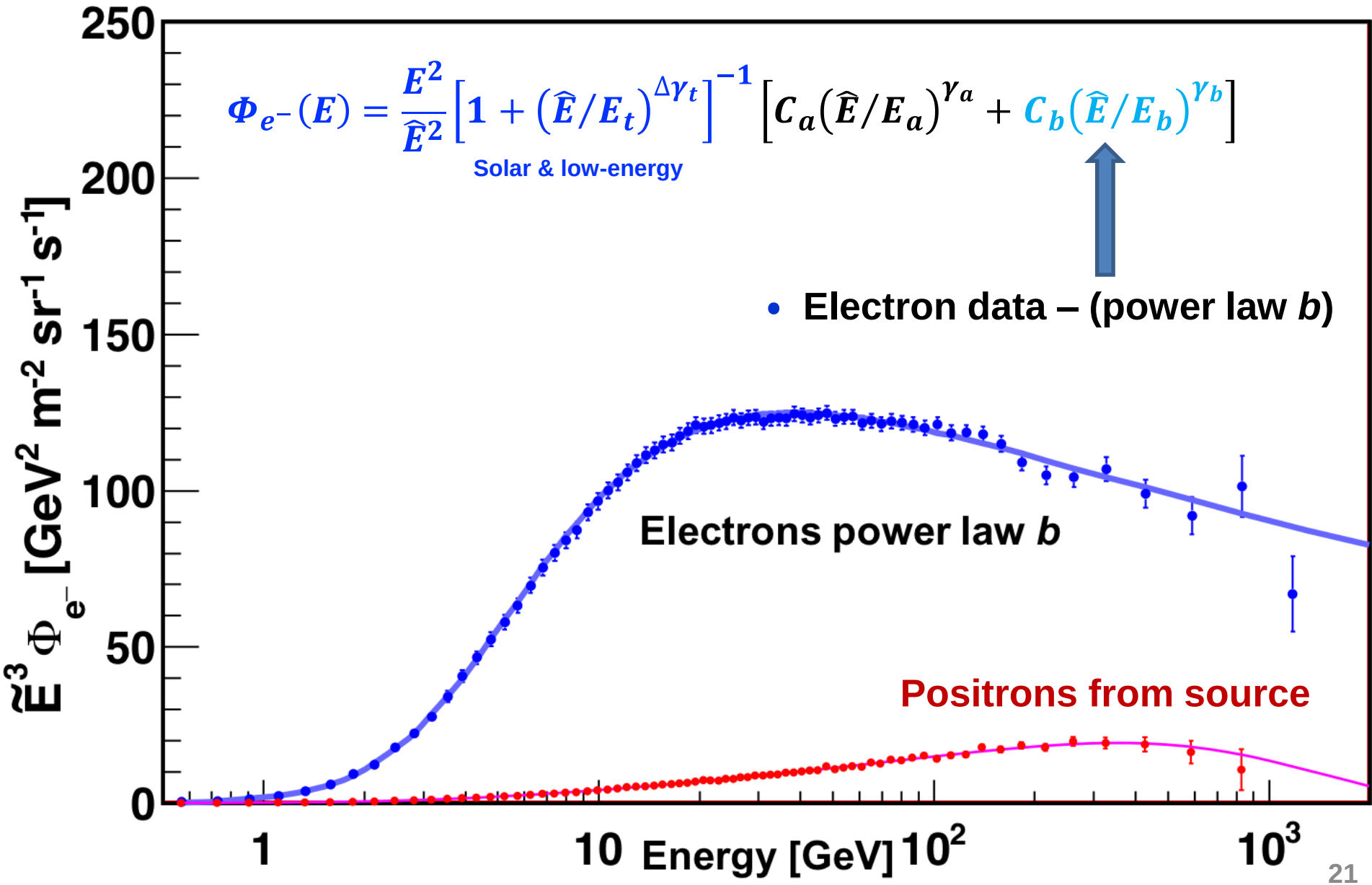
$$\Phi_{e^+}(E) = \frac{E^2}{\widehat{E}^2}\left[\overbrace{C_d(\widehat{E}/E_1)^{\gamma_d}}^{\text{Collisions}} + \overbrace{C_s\left(\widehat{E}/E_2\right)^{\gamma_s}\exp(-\widehat{E}/E_s)}^{\text{Source}}\right]$$



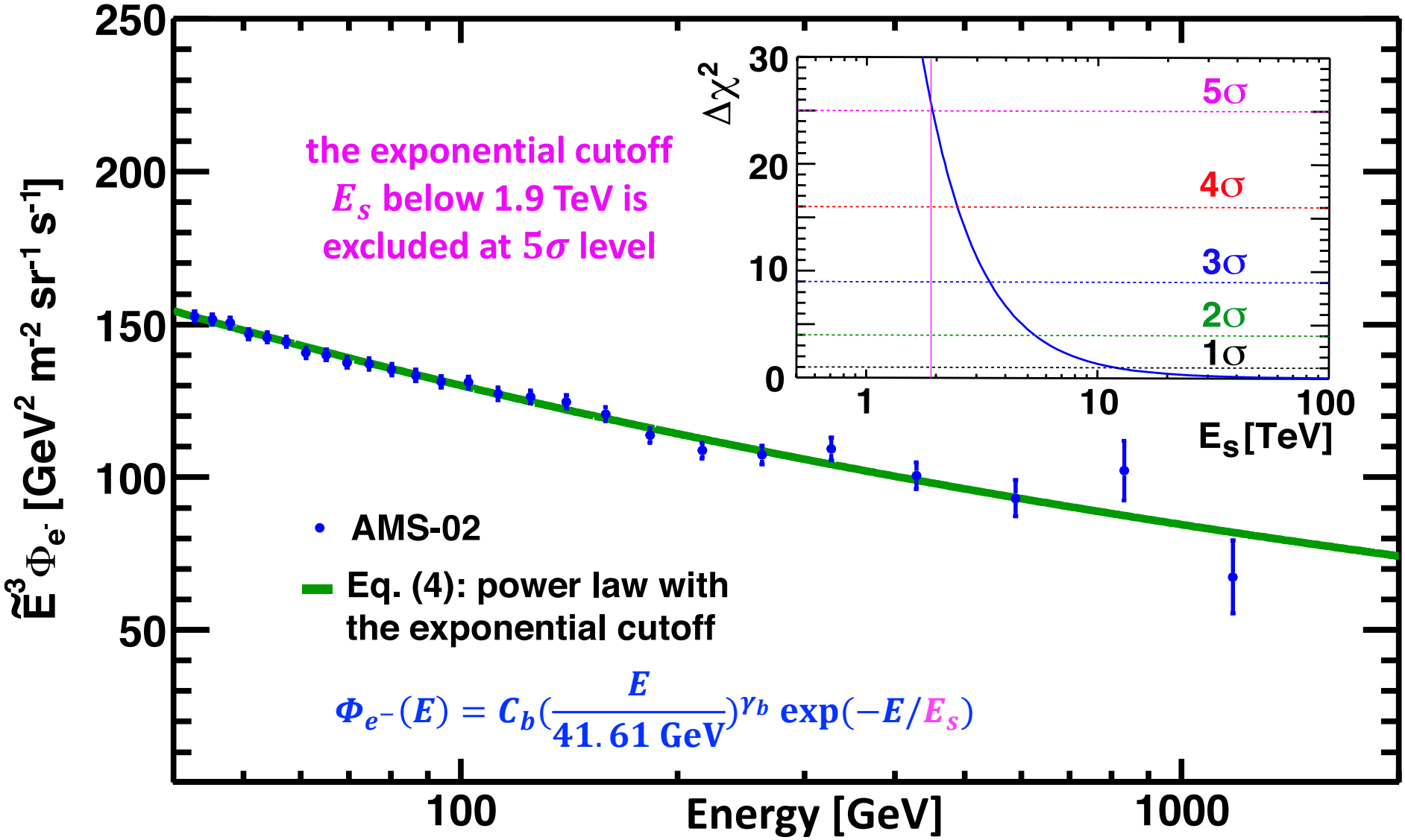
At low energies positrons come from cosmic ray collisions, electrons do not.



The positron source term has a cutoff, whereas electrons have neither source term nor the cutoff.



Study of high energy cutoff in the electron flux



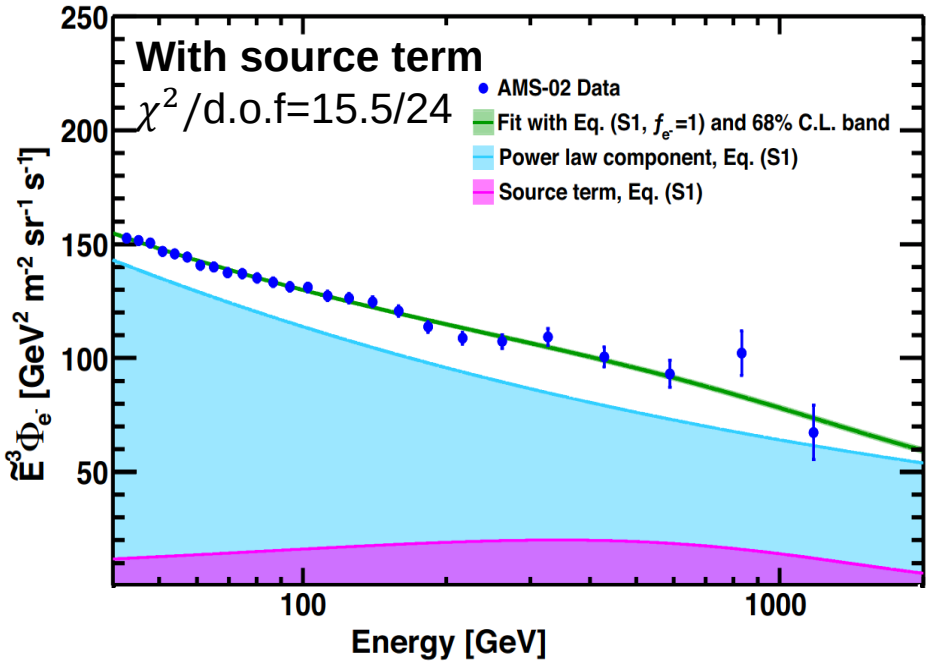
Contrary to 4σ exponential cutoff at 810^{+310}_{-180} GeV in the positron flux, the electron flux does not show a cutoff below 1.9 TeV.

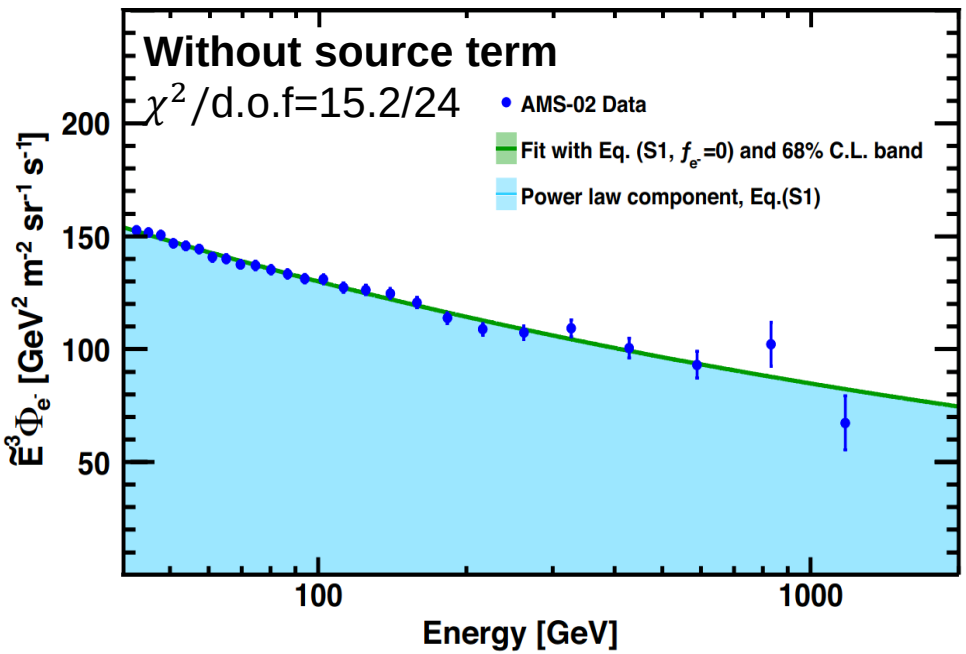
Electron flux fit with positron source term

$$\Phi_{e^-}(E) = C_{e^-}\,(E/E_1)^{\gamma_{e^-}} + f_{e^-}\,C_s^{e^+}(E/E_2)^{\gamma_s^{e^+}}\exp(-E/E_s^{e^+}).$$ (E > 41.16)

Electrons Power Law b

Positrons high energy source term

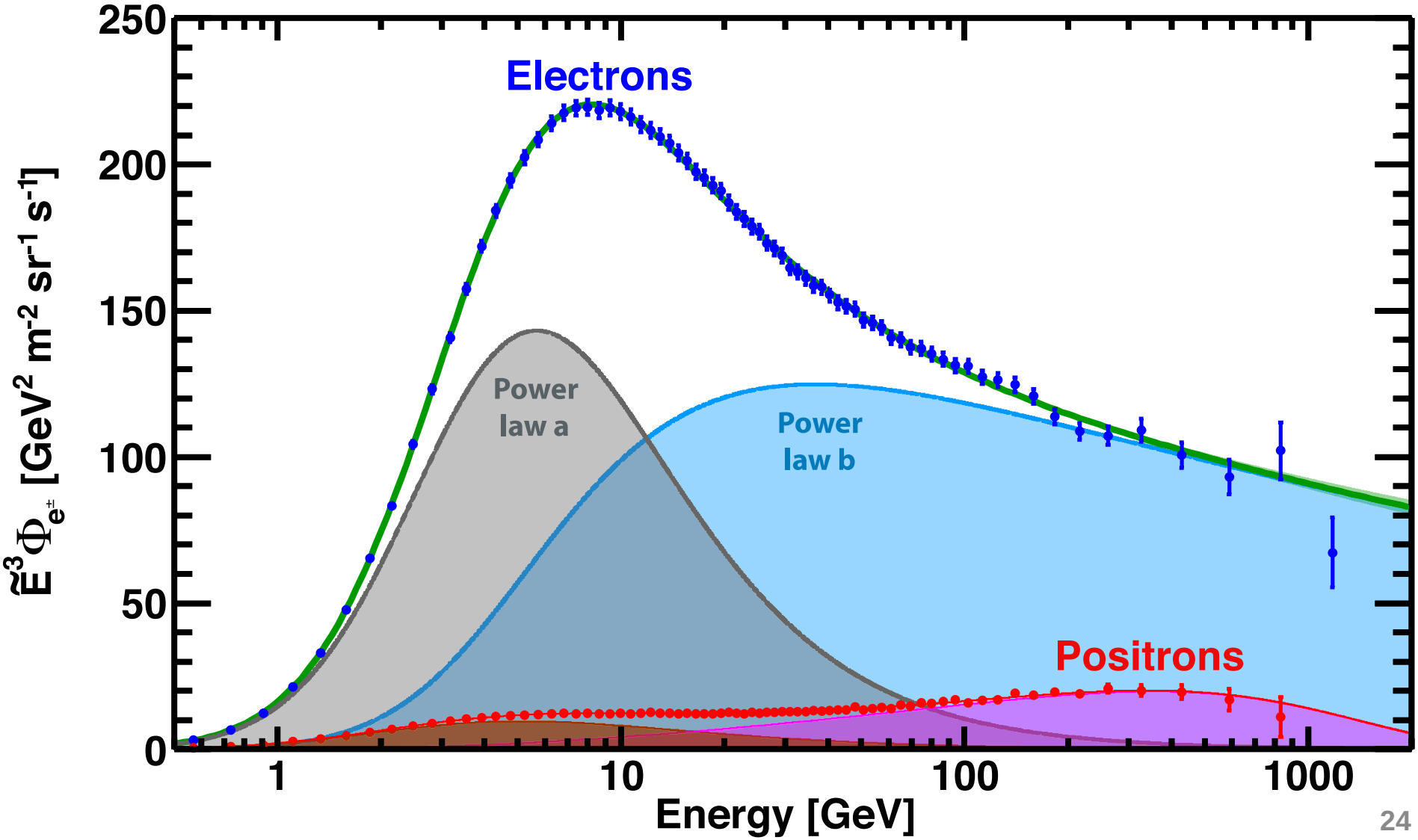




It's not possible to extract any additional information on the existence and properties of the source term using the electron flux alone.

Origins of Cosmic Electrons

The cosmic ray electrons originate from different sources than high energy positrons.



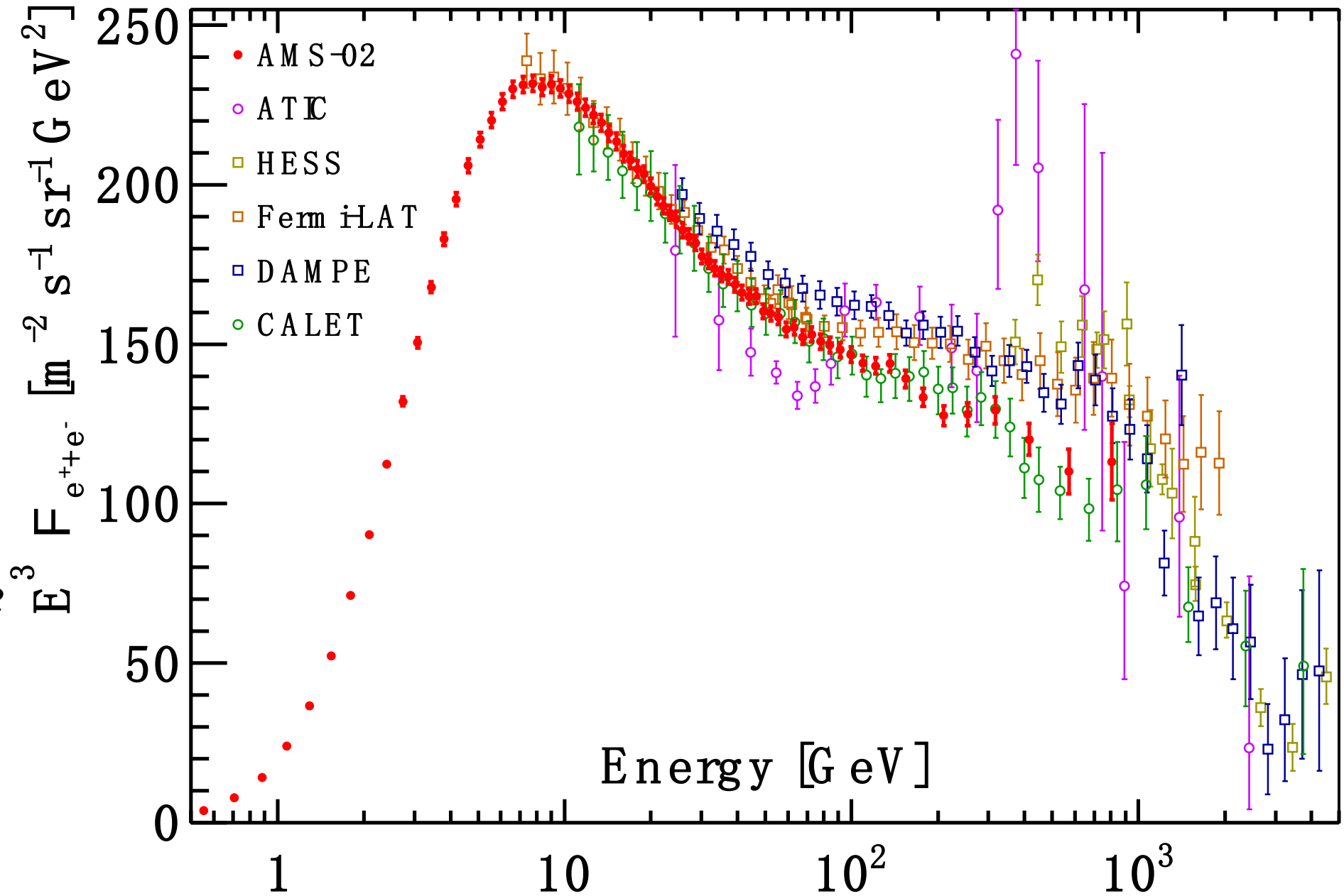
Conclusion

- **The high statistics precision measurements of the electron flux from 0.5GeV to 1.4TeV, with detailed study of systematic uncertainties based on a data sample of 28.1×10^{6} electrons is presented.**

- **The electron flux exhibits a significant excess starting from $42.1^{+5.4}_{-5.2}$GeV compared to the lower energy trends, and is well described by the sum of two power law component in the entire energy range.**

- **The different behavior of the cosmic-ray electrons and positrons measured by AMS is clear evidence that most high energy electrons originate from different sources than high energy positrons.**

AMS (electron + positron) spectrum with earlier measurements



AMS positron fraction together with earlier measurements