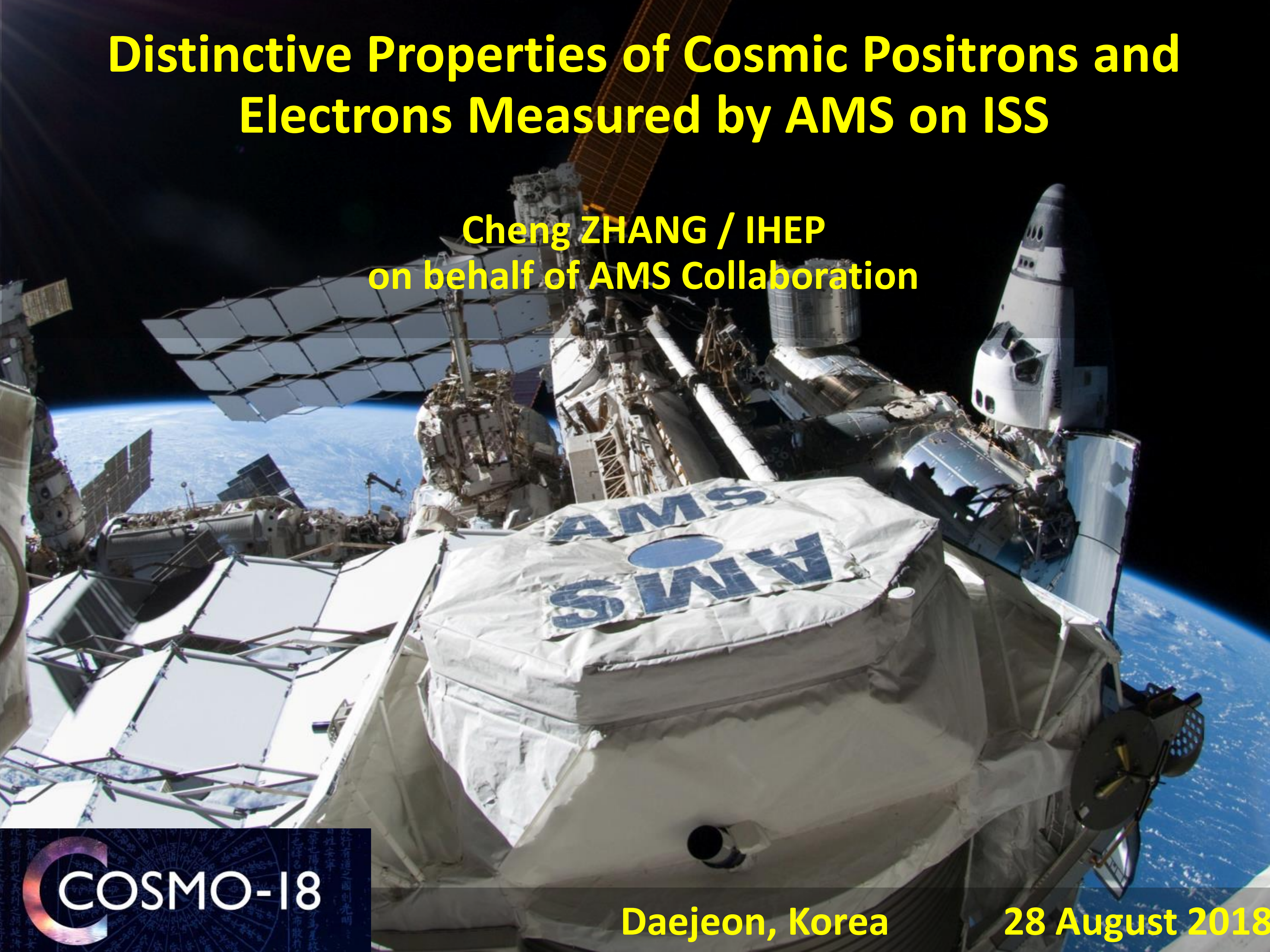
Distinctive Properties of Cosmic Positrons and Electrons Measured by AMS on ISS

Cheng ZHANG / IHEP
on behalf of AMS Collaboration

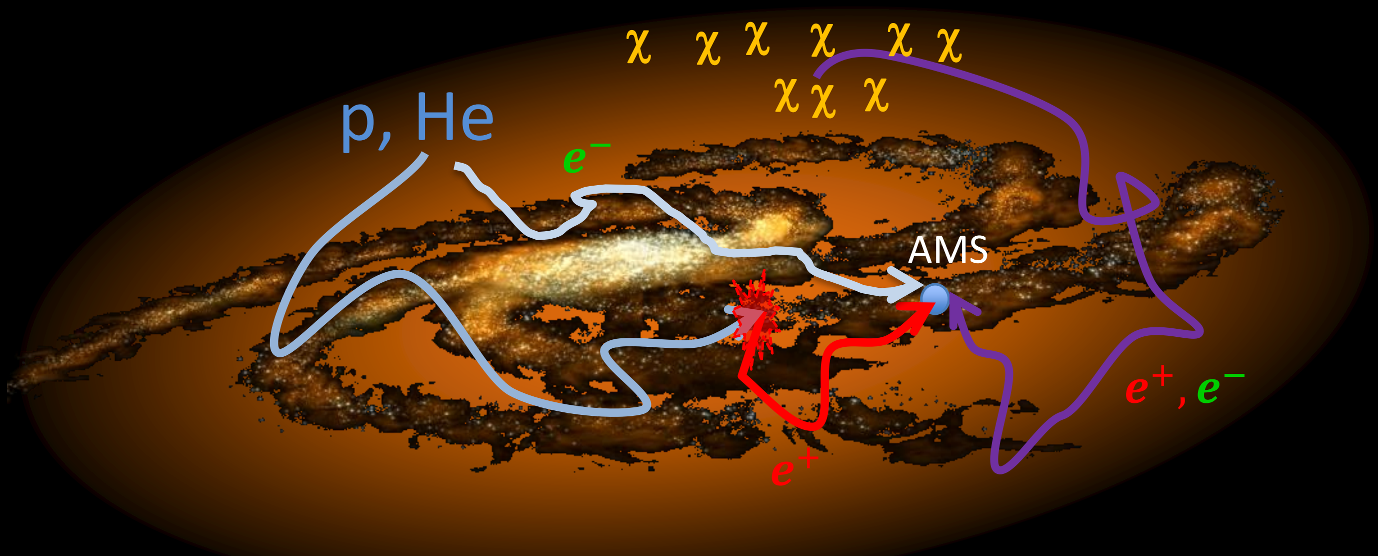


COSMO-18

Daejeon, Korea **28 August 2018**

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 particles interact with the interstellar matter and produce secondary source of anti-particle: positrons etc. They are much less abundant in astrophysics process.
- New physics sources like Dark Matter produce both particles and antiparticles.



M. Turner and F. Wilczek, Phys. Rev. D42 (1990) 1001; J. Ellis, 26th ICRC (1999)

Measuring antiparticles are much more sensitive to Dark Matter

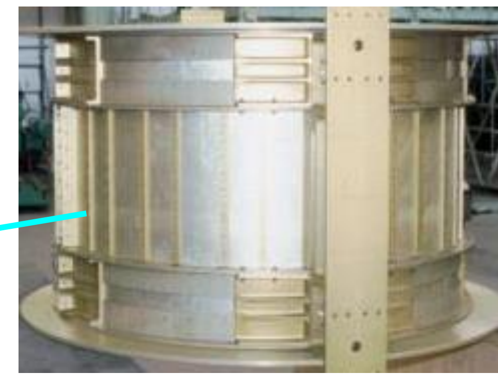
AMS: a unique TeV precision, magnetic spectrometer in space

TRD: Identify e^+, e^-, Z

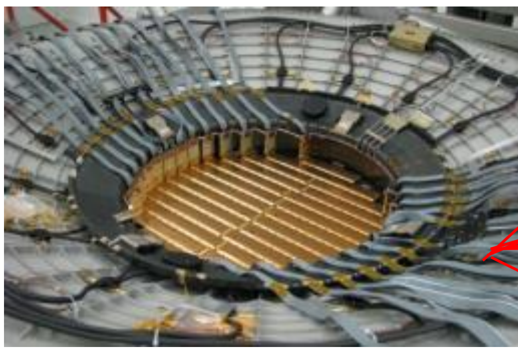
Particles and nuclei are defined by their charge (Z) and energy (E or P)

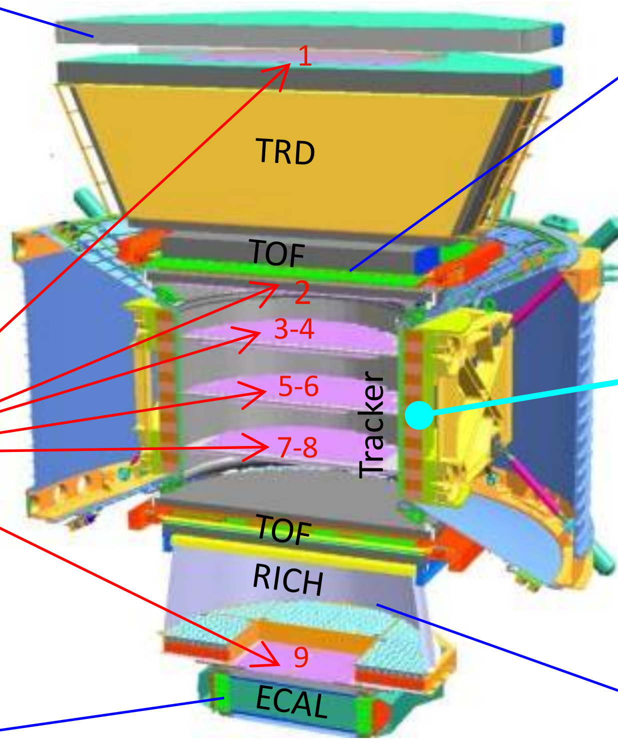
TOF: Z, E

Magnet: ±Z

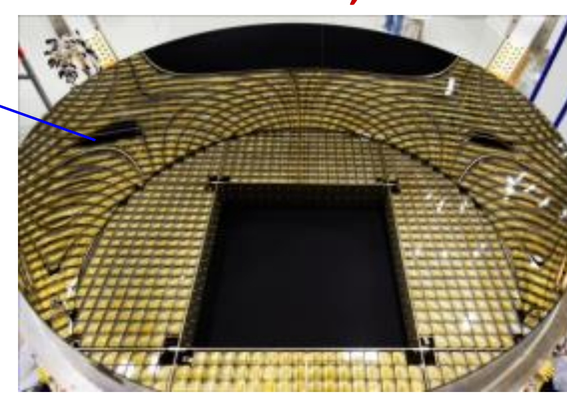


Silicon Tracker: Z, P

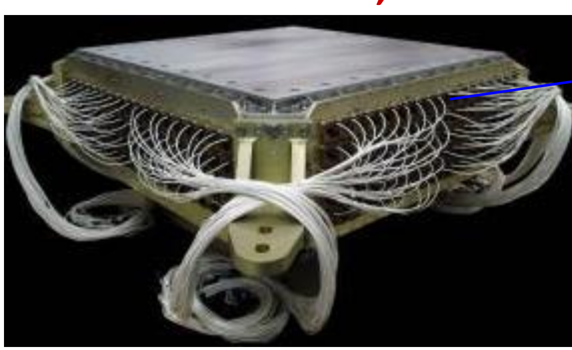




RICH: Z, E



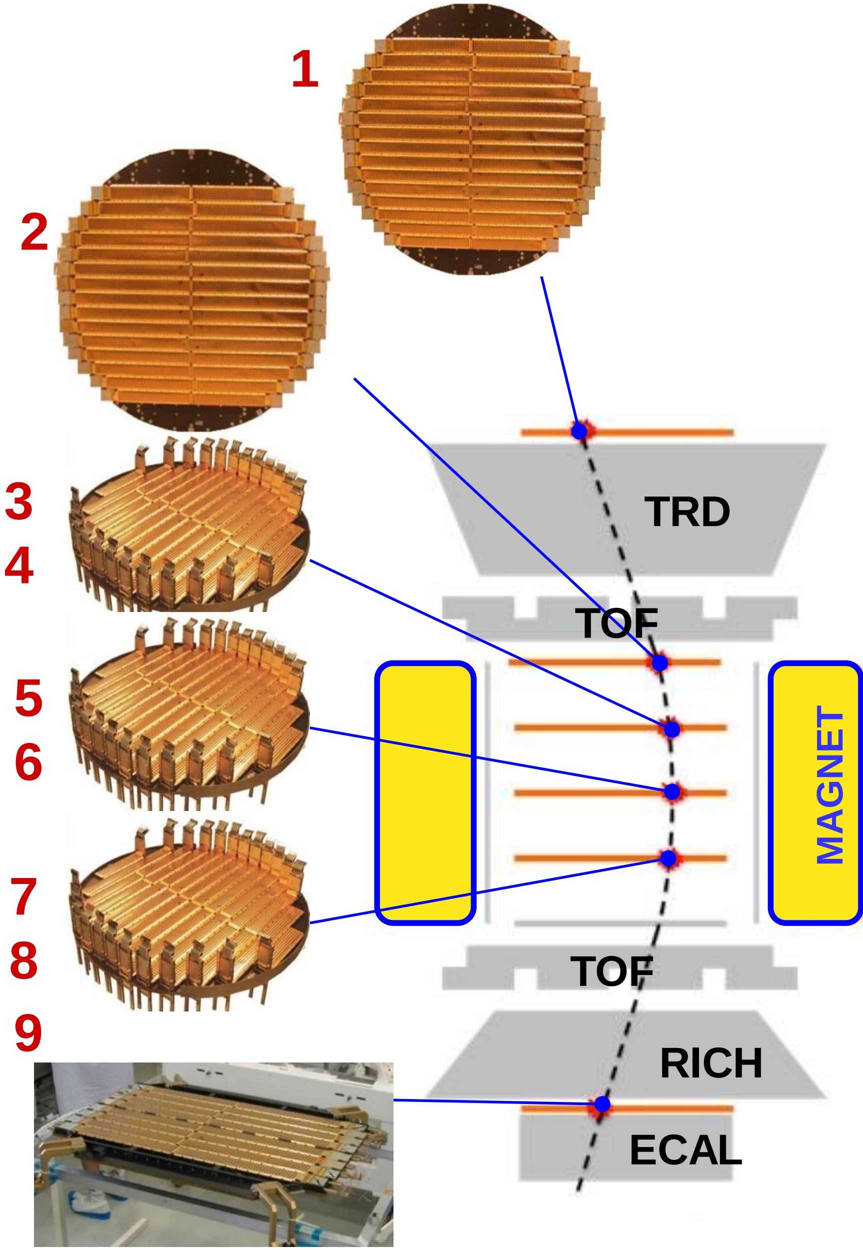
ECAL: E of e^+, e^-

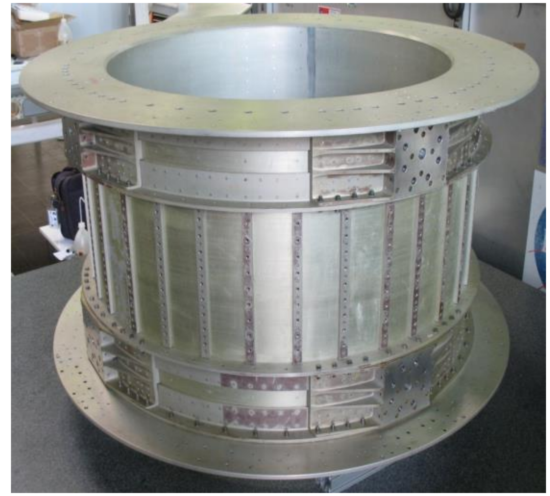


Z and P

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

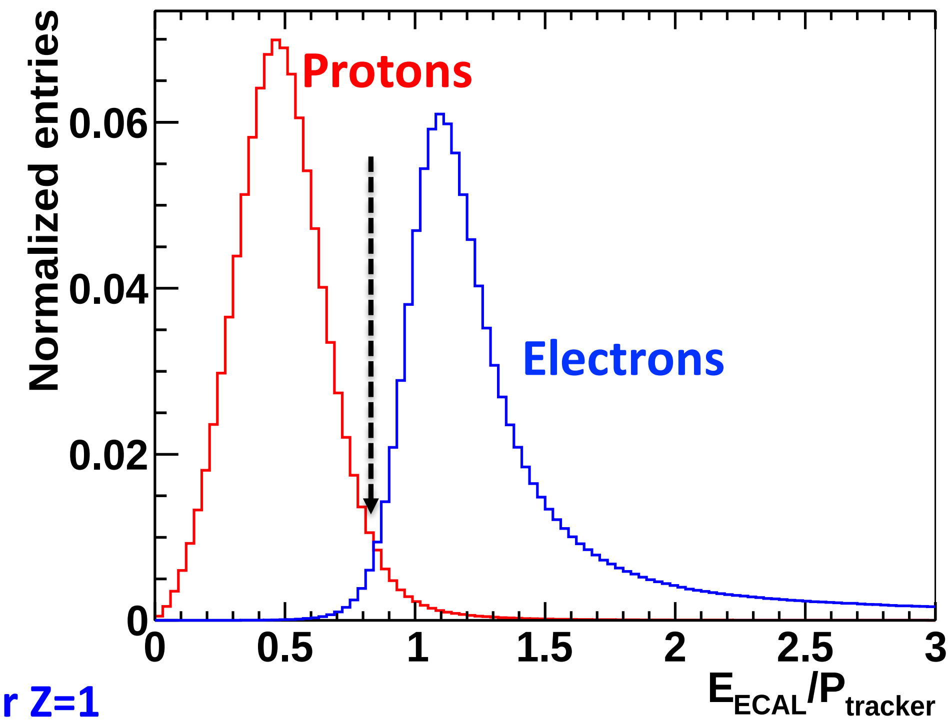
Silicon Tracker and Magnet





1.4 kG

Unique feature of AMS



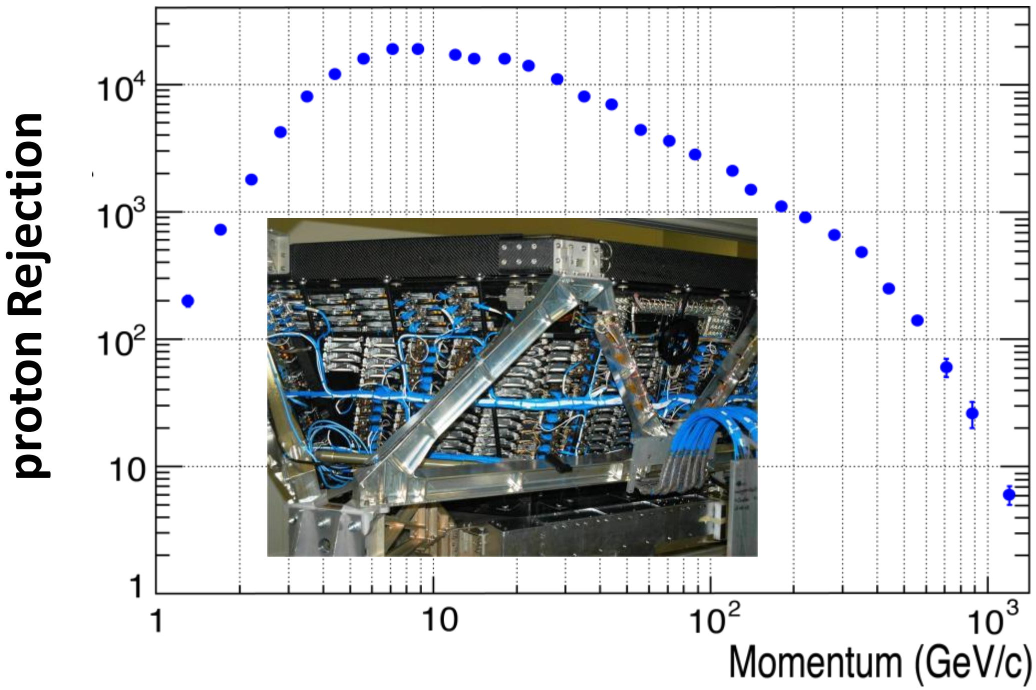
L1 to L9: 3 m level arm;

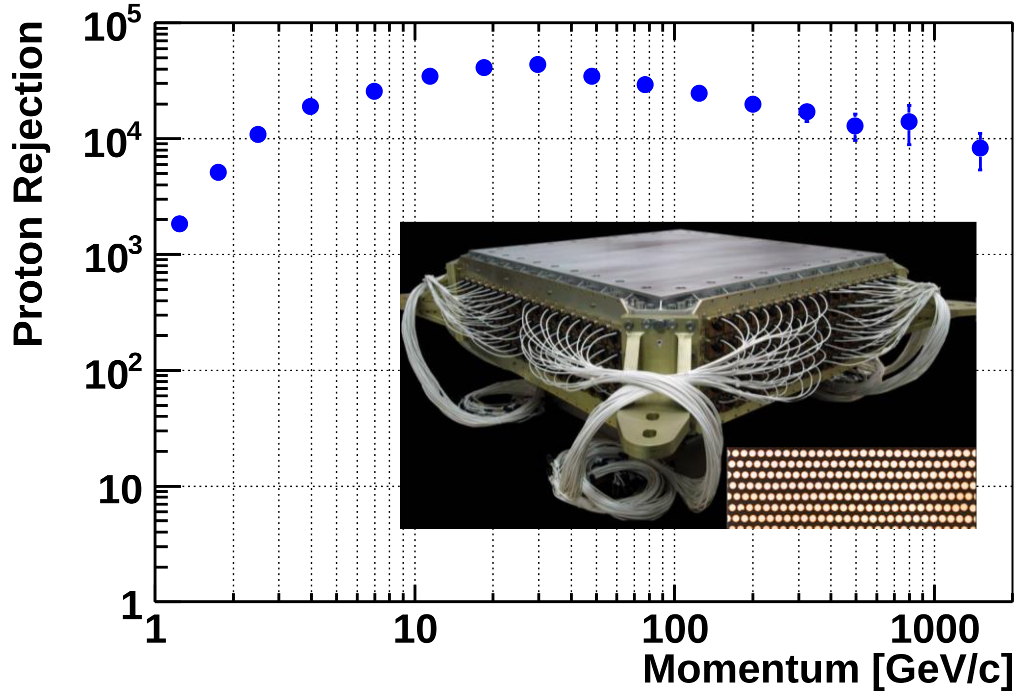
single point resolution 10 μm;

Maximum Detectable Rigidity(MDR) 2.0 TV for Z=1

Positron identification in AMS

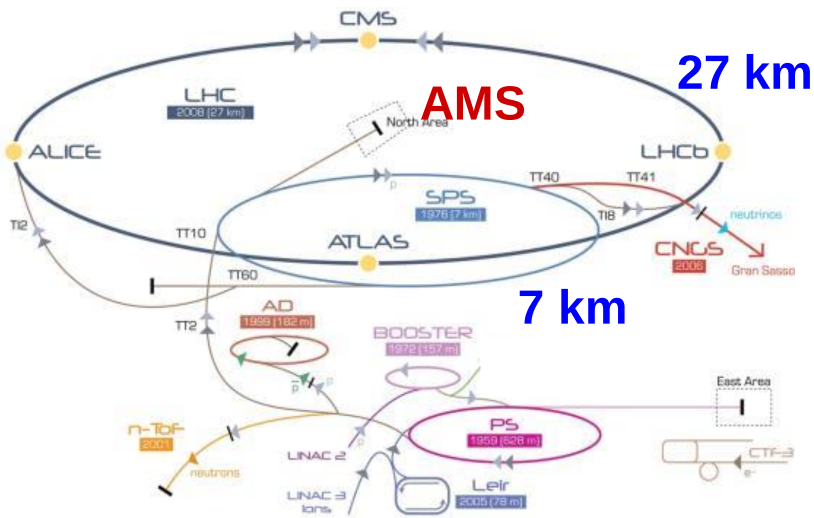
- Proton rejection 10^3 to 10^4 with TRD
- Proton rejection is above 10^4 with ECAL and tracker
- TRD and ECAL is separated by magnet, they have independent proton rejection



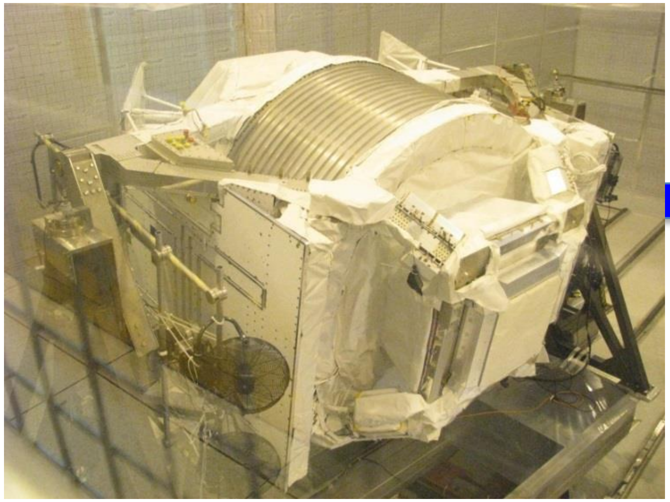


Calibration of the AMS Detector

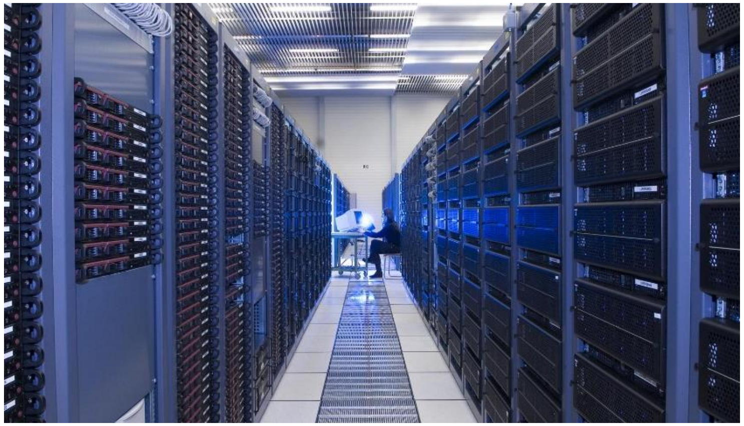
Test beam at CERN SPS:
p, e$^{\pm}$, $\pi^{\pm}$, 10–400 GeV



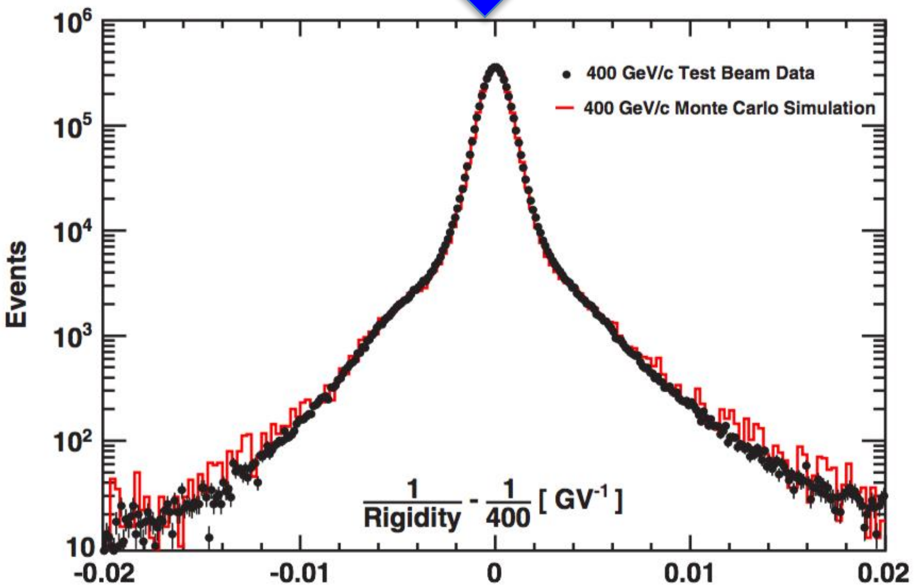
2000 positions



12,000 CPU cores at CERN



Computer simulation:
Interactions, Materials, Electronics



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:

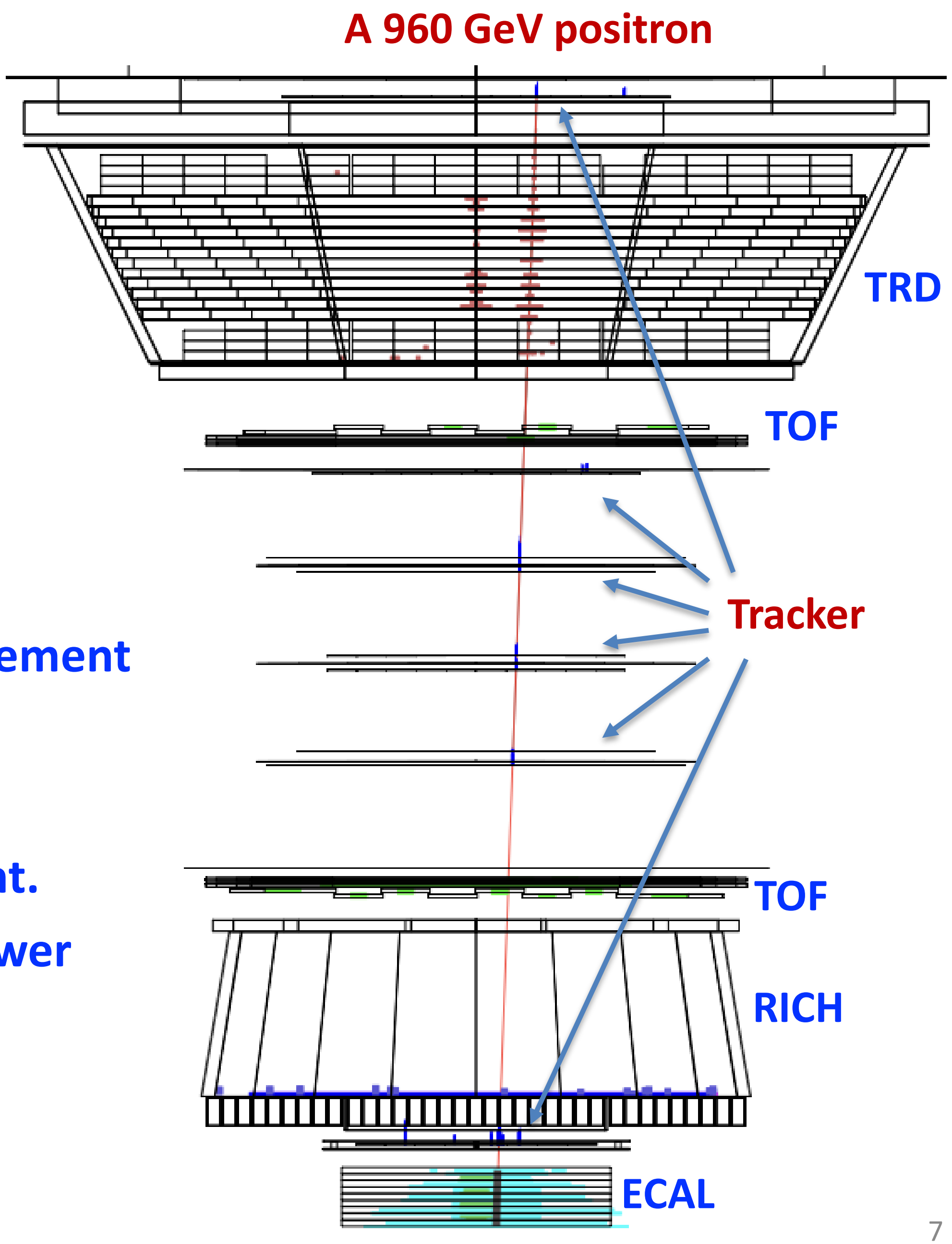
- **Provide proton rejection**

tracker and magnet:

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

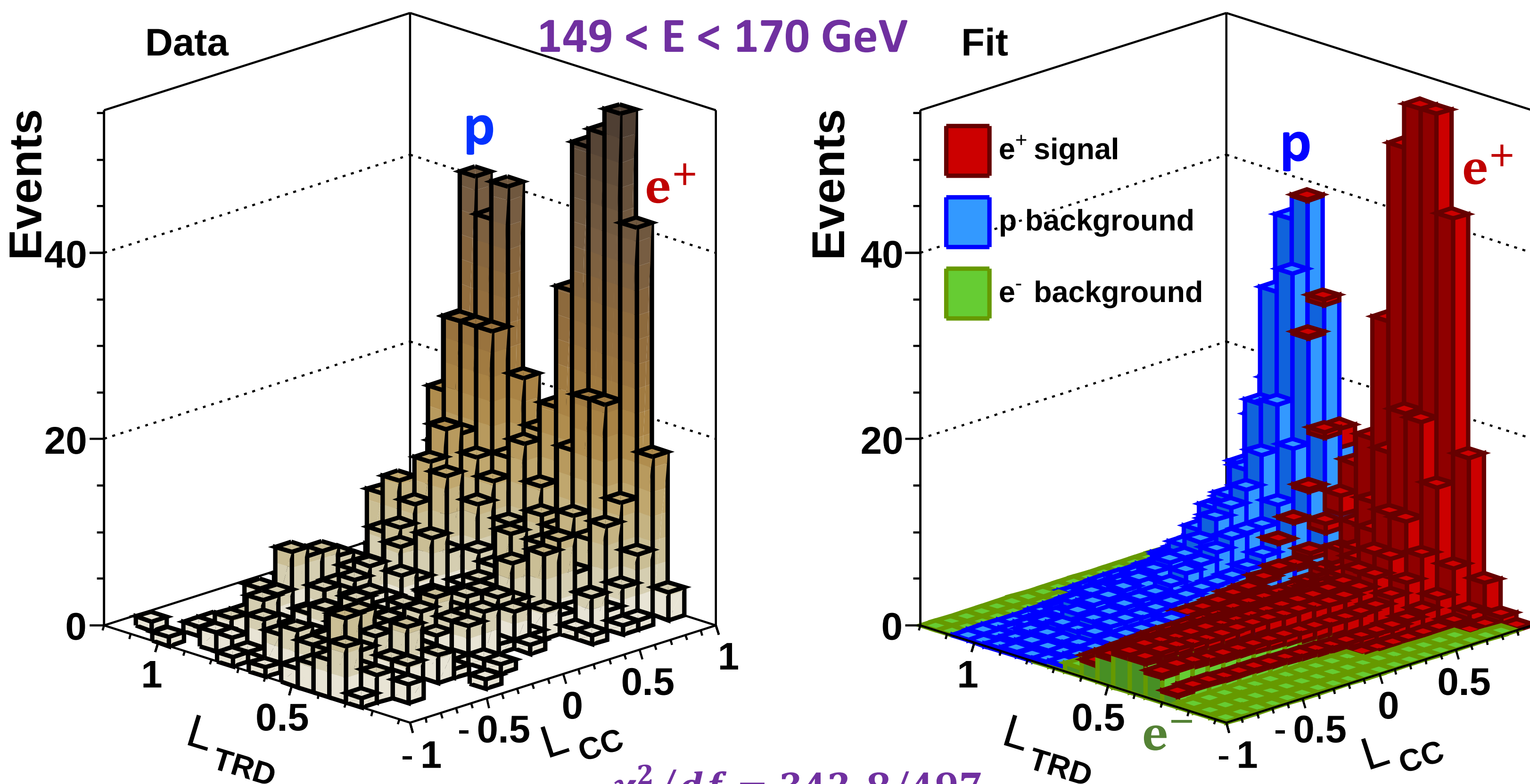
ECAL:

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



Analysis method to determine the number of e^+

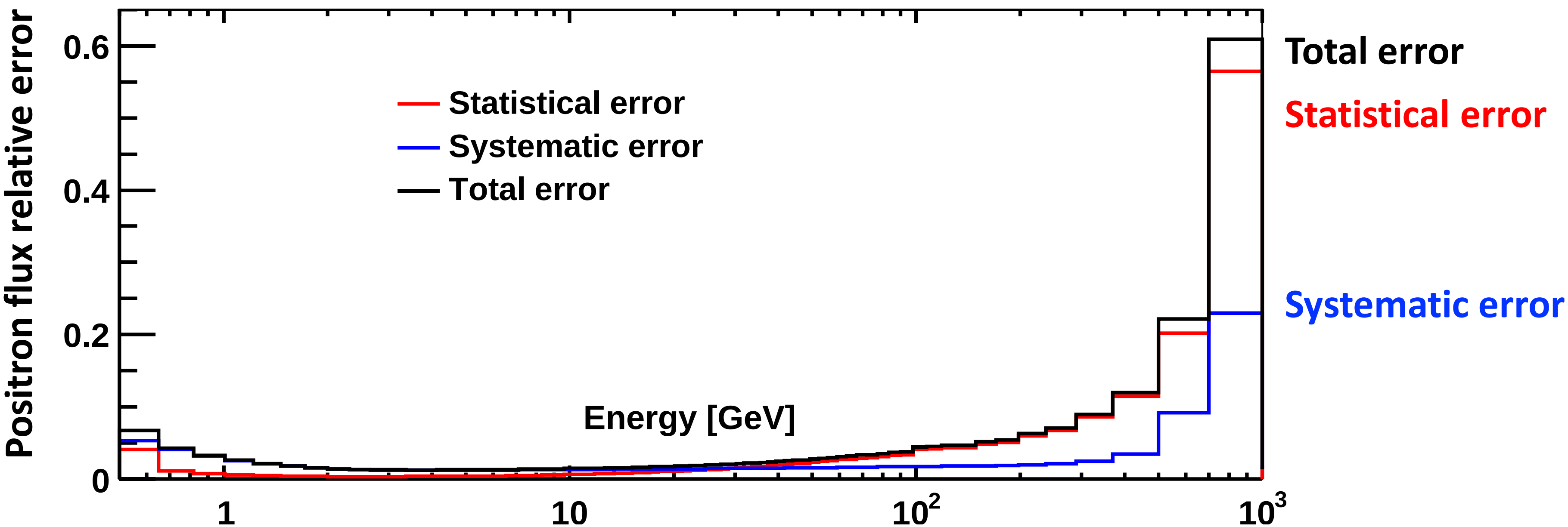
- ECAL selection to remove bulk of the proton background.
- For each bin, fit templates to positive data sample in $(\Lambda_{TRD} - \Lambda_{CC})$ plane
- **Positron signal template** from data using electrons
- **Proton background template** from proton data
- **Charge confusion electron** template from electron MC



With 28.1 million electrons and 1.9 million positrons,

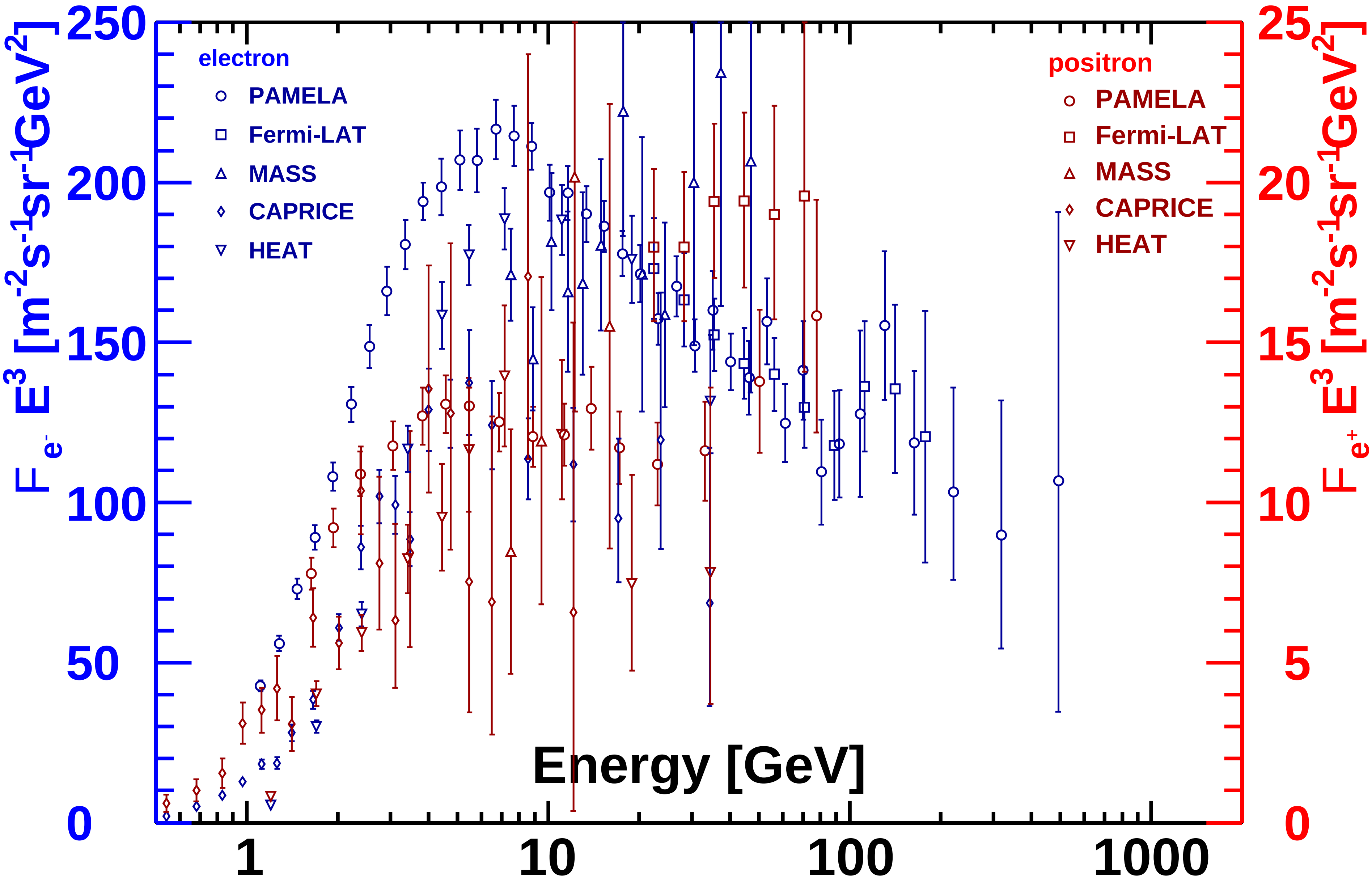
the study of systematic errors is crucial

1. Charge confusion
2. Template selection
3. Template statistical fluctuation
4. Acceptance(cancelled for positron fraction analysis)
    1) Data/MC efficiency correction
    2) ECAL selection efficiency



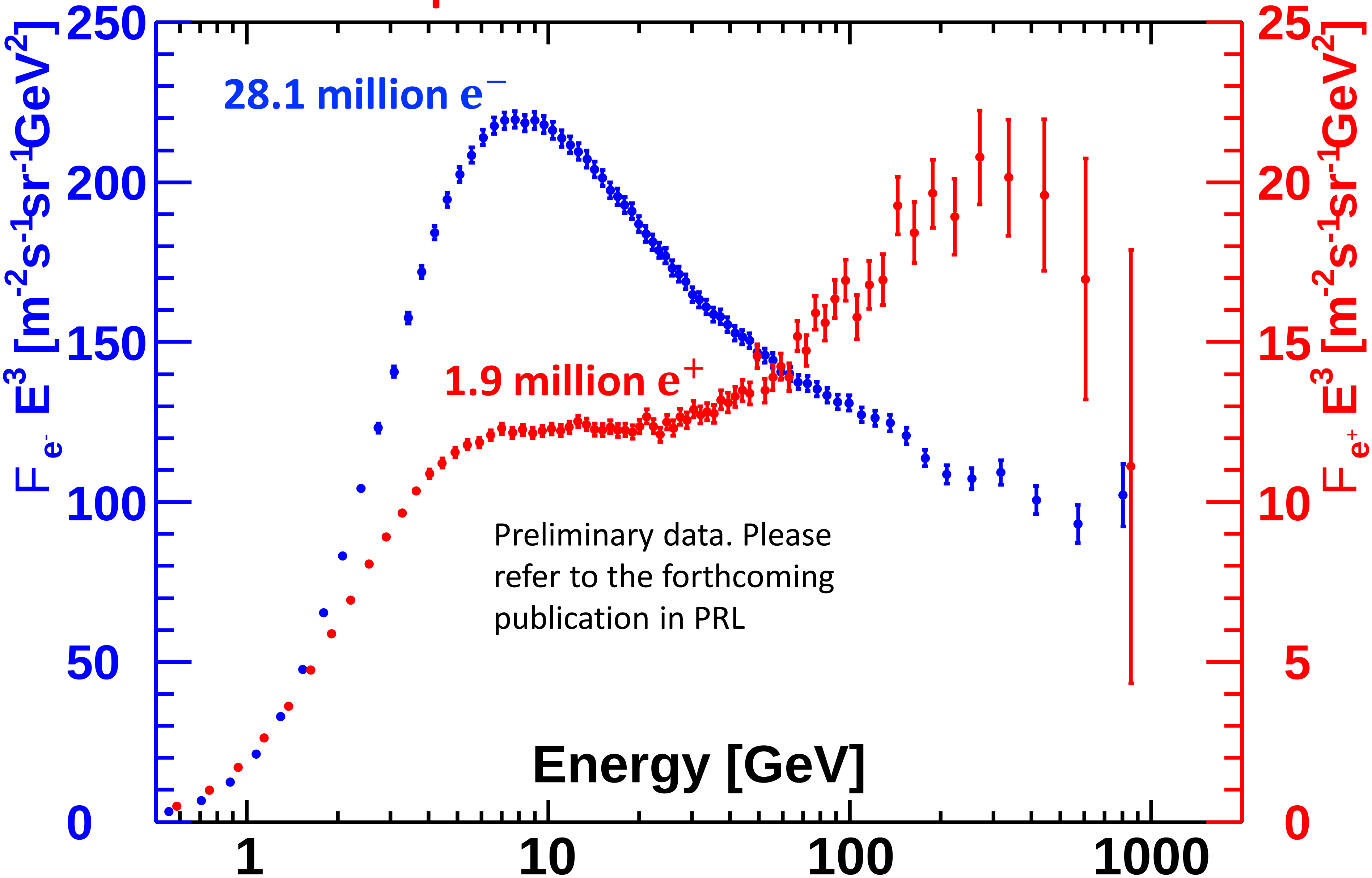
Statistical errors dominates above 60 GeV for positron flux

Positron and electron fluxes before AMS



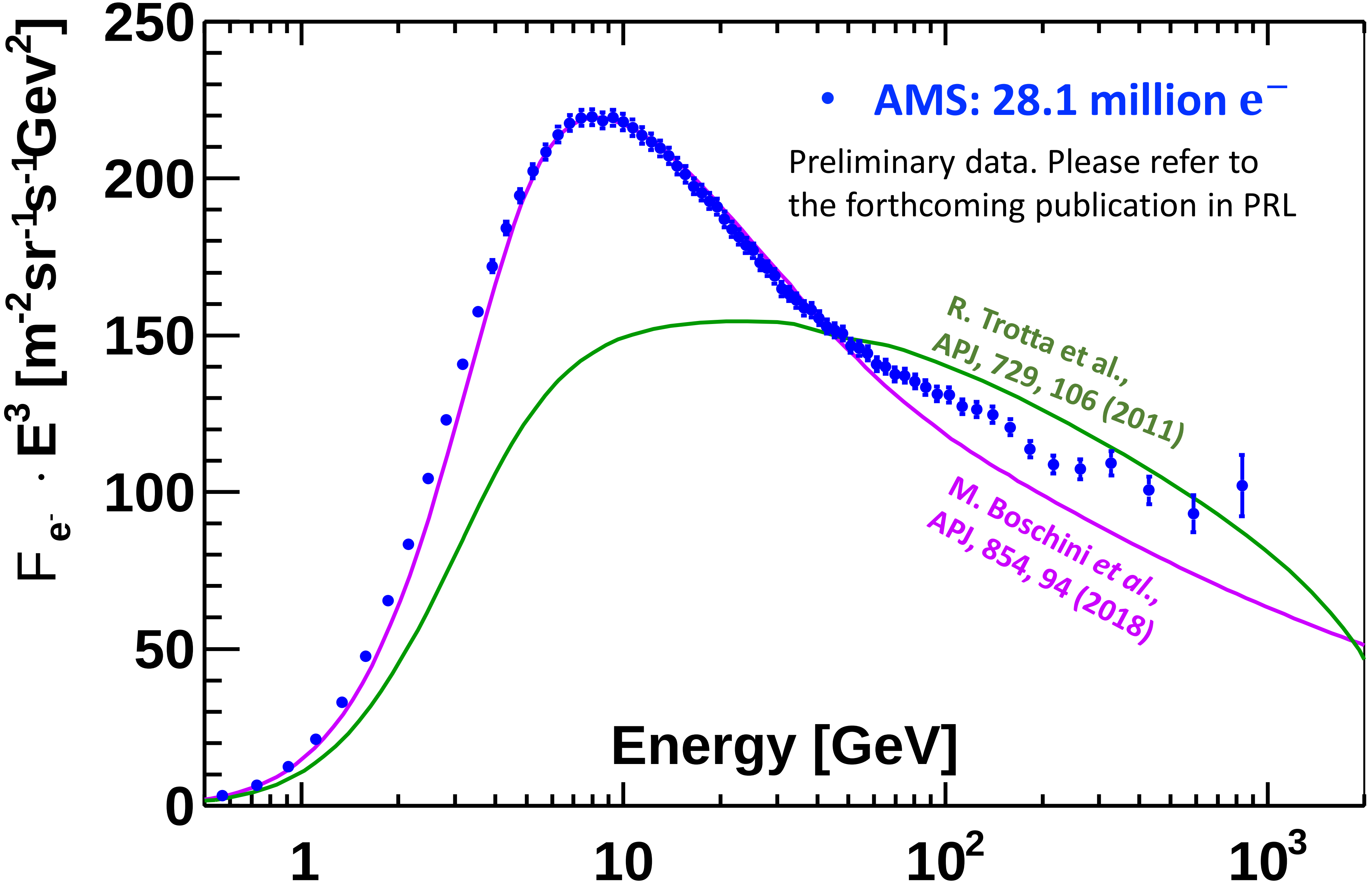
These are very difficult measurements

AMS positron and electron fluxes



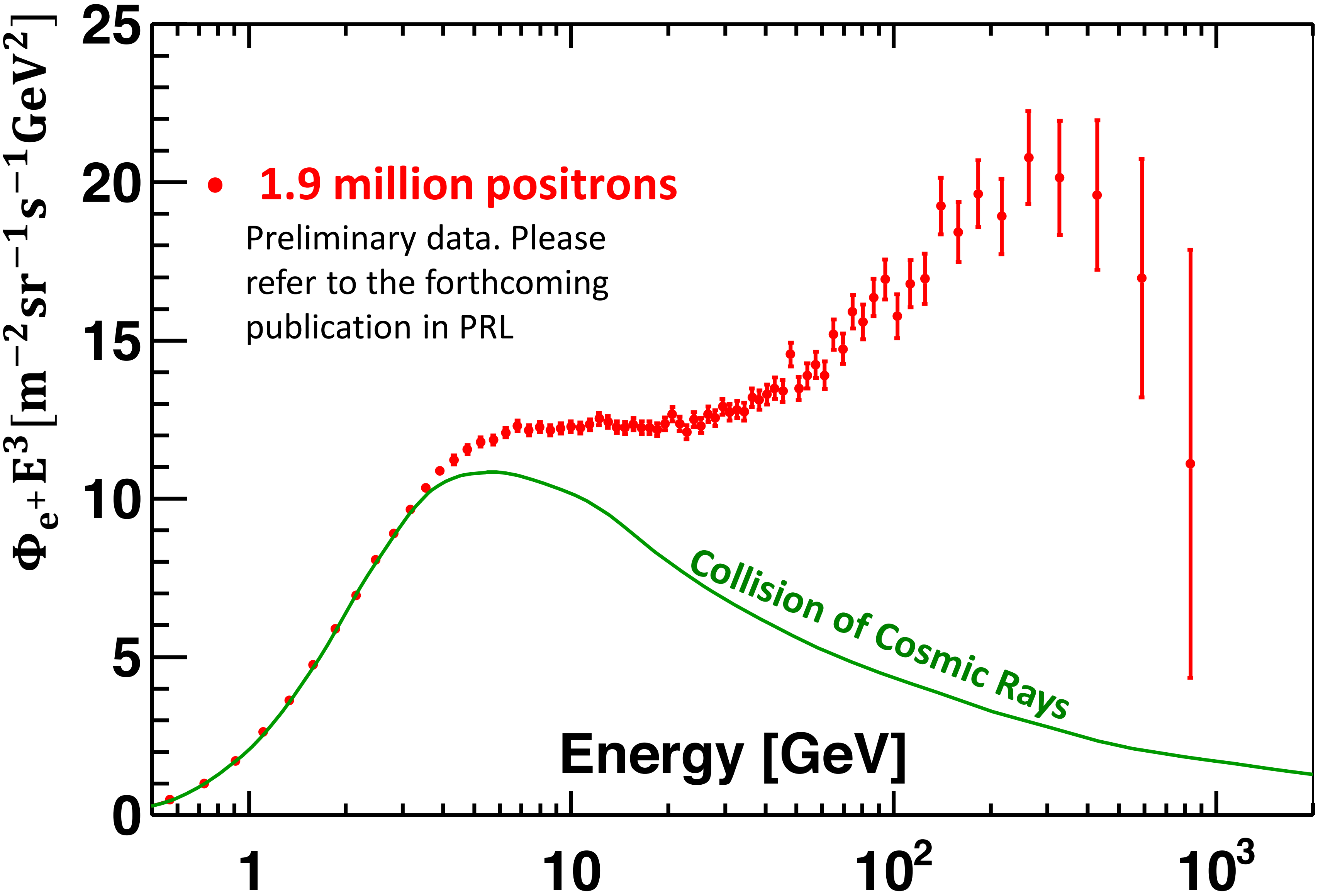
The magnitude and energy dependence are distinctly different between positrons and electrons

The origin of cosmic electrons



The AMS accurate data can not be explained by current models

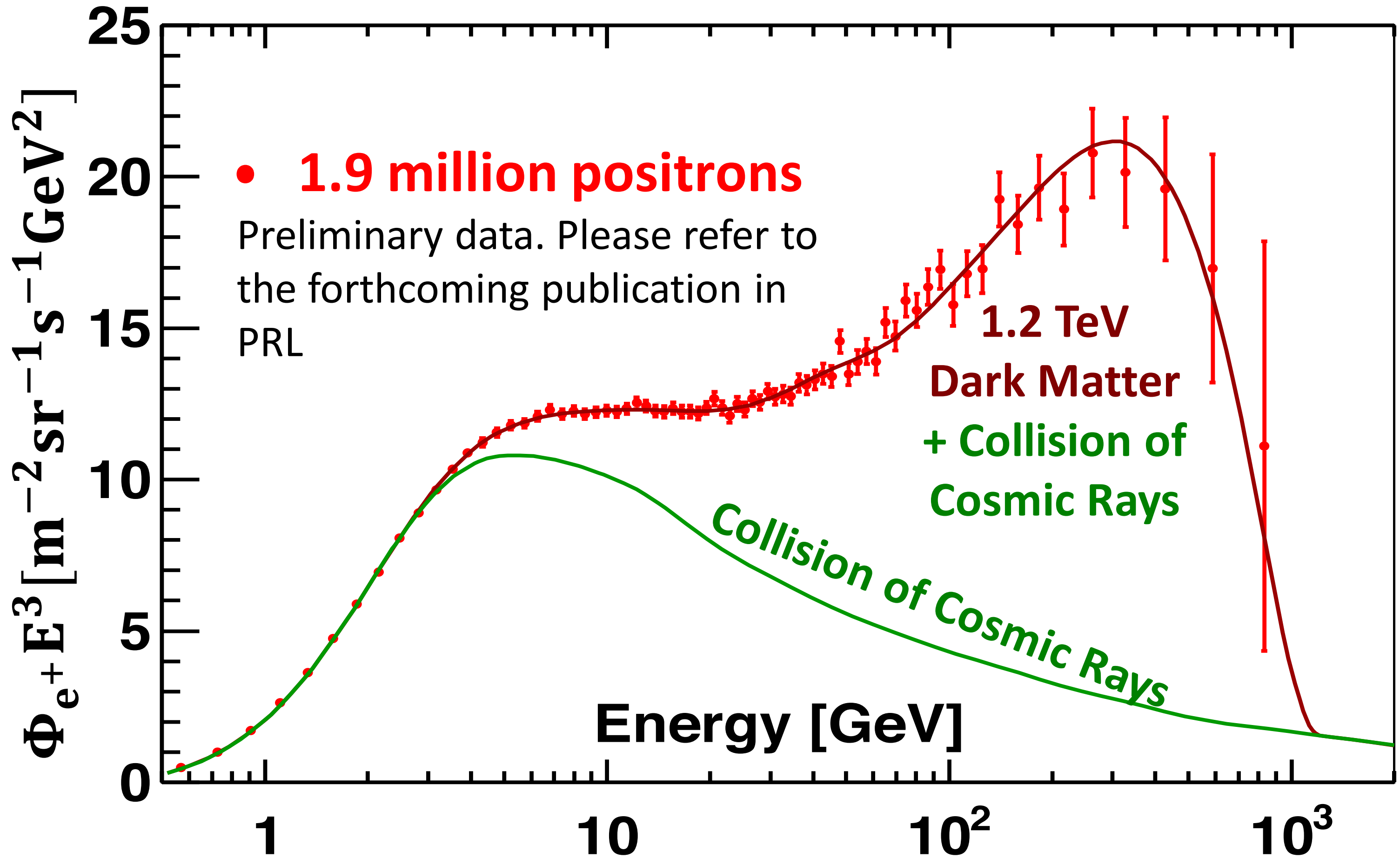
The origin of cosmic positrons



The AMS positron flux exceeds the prediction from collision of cosmic rays, requiring a new source of high energy positrons

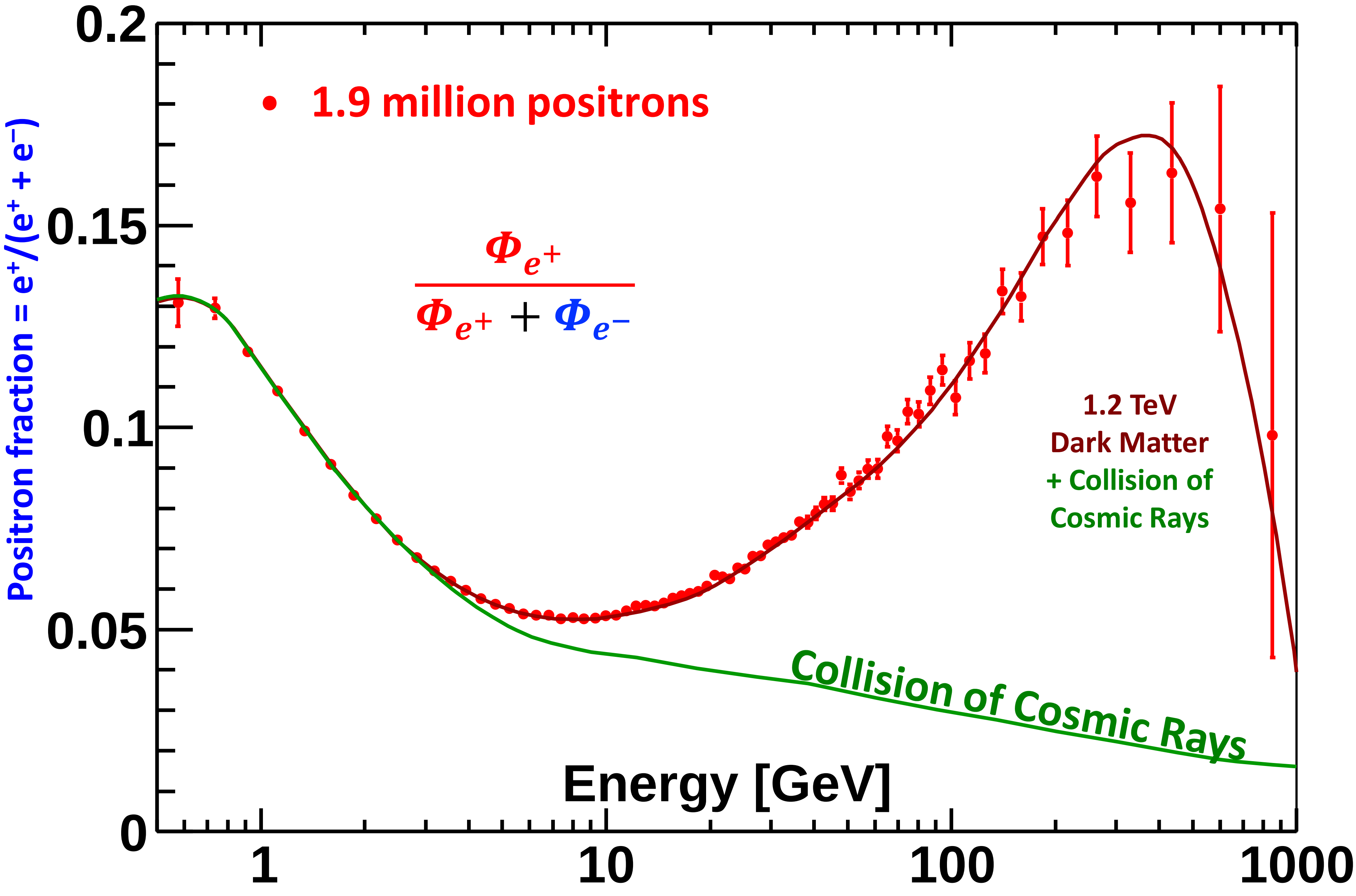
Models to explain the AMS Positron Flux

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



AMS data appears to be in excellent agreement with the predictions from a 1.2 TeV Dark Matter model (J. Kopp, Phys. Rev. D 88, 076013 (2013))

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



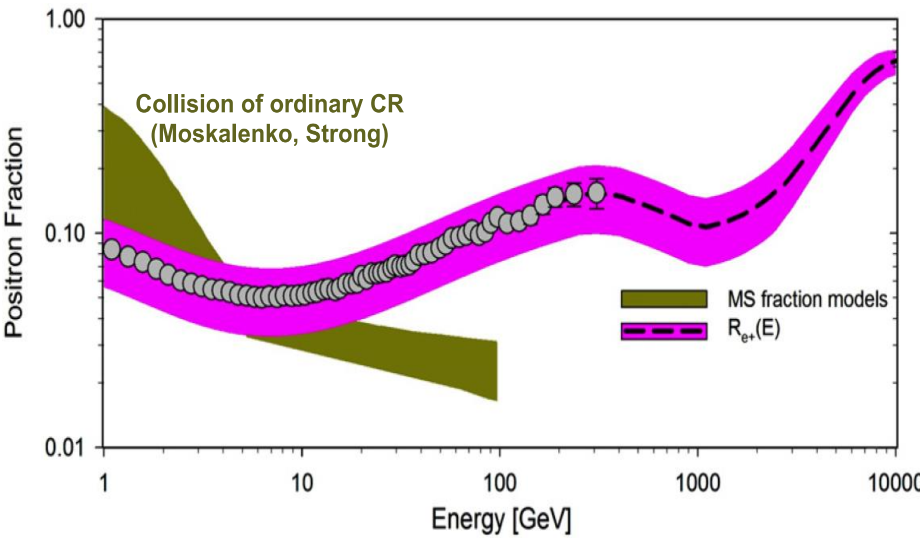
Dark Matter model based on J. Kopp, Phys. Rev. D 88, 076013 (2013).

Alternative Models to explain the AMS Measurements

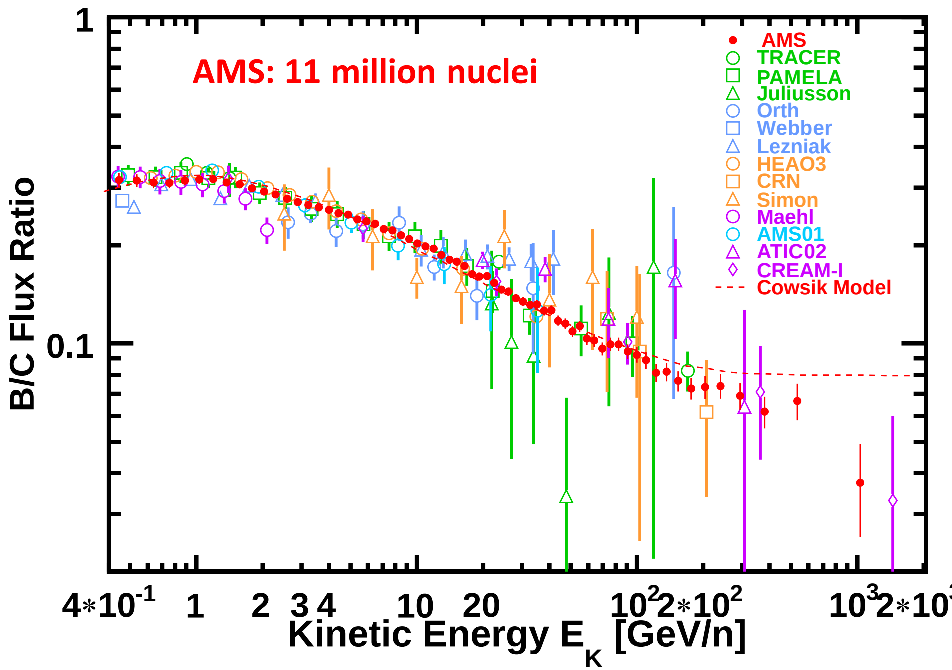
- **Modified Propagation of cosmic Rays**

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

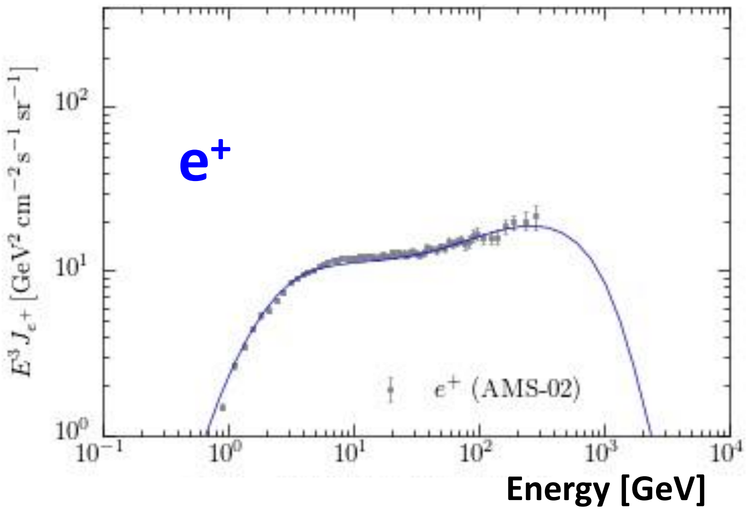


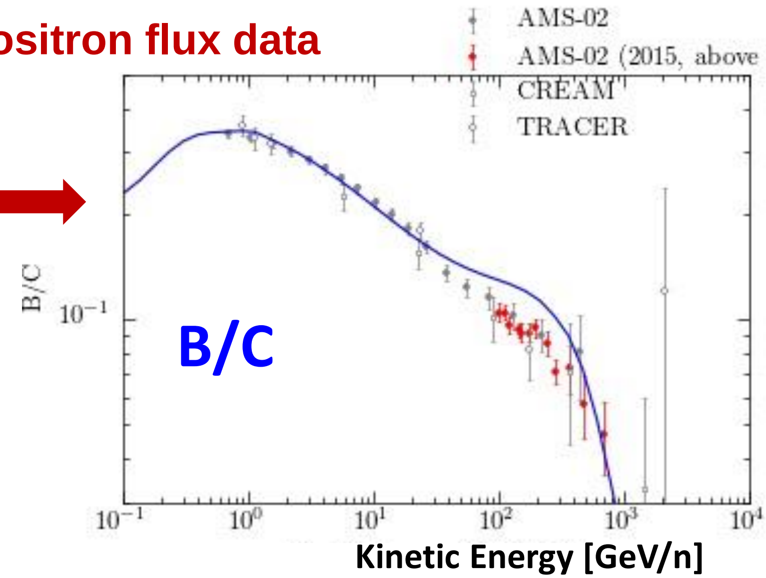
The observed features of the AMS data cannot be explained by propagation effects

Alternative Models to explain the AMS Measurements

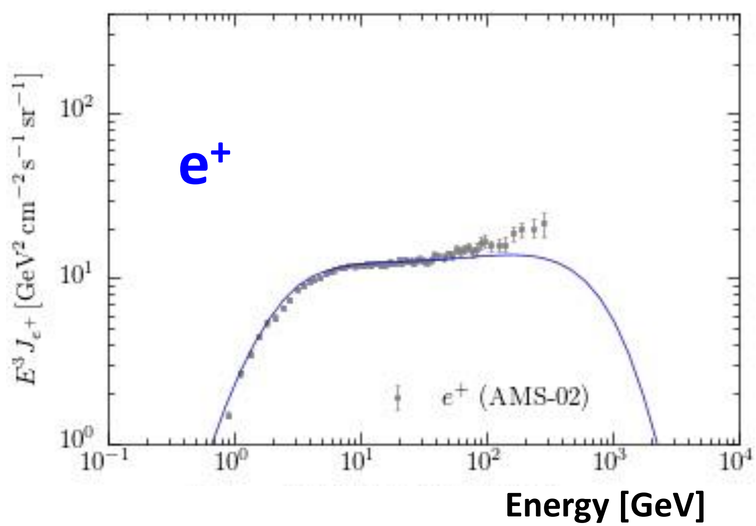
New Astrophysical sources (Supernova Remnants)

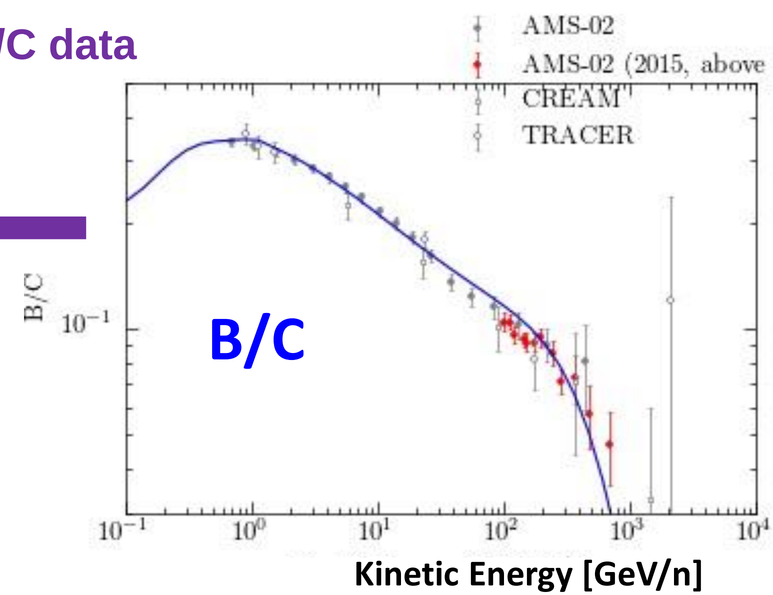
Model parameter tuned to fit the positron flux data





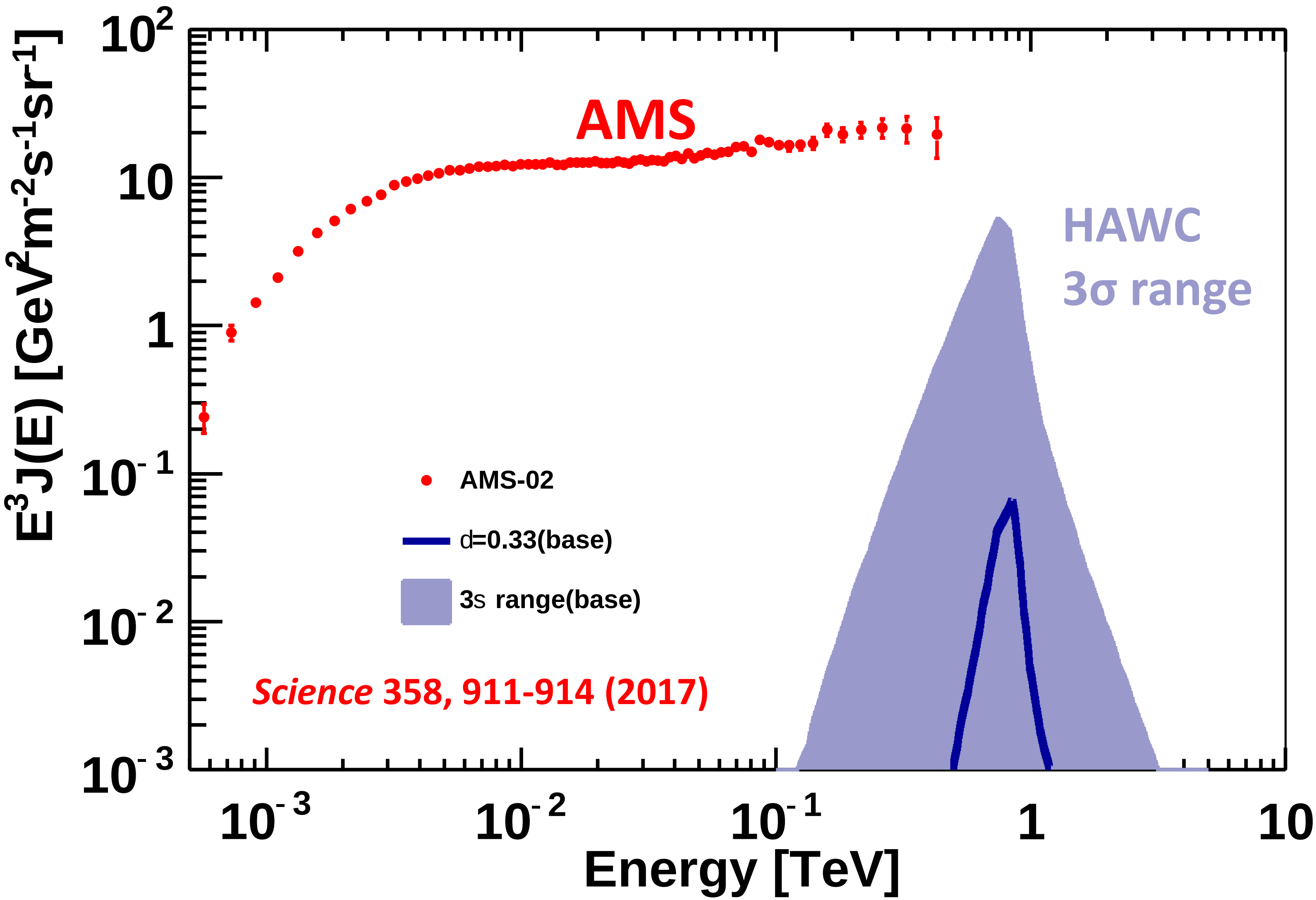
Model parameter tuned to fit the B/C data





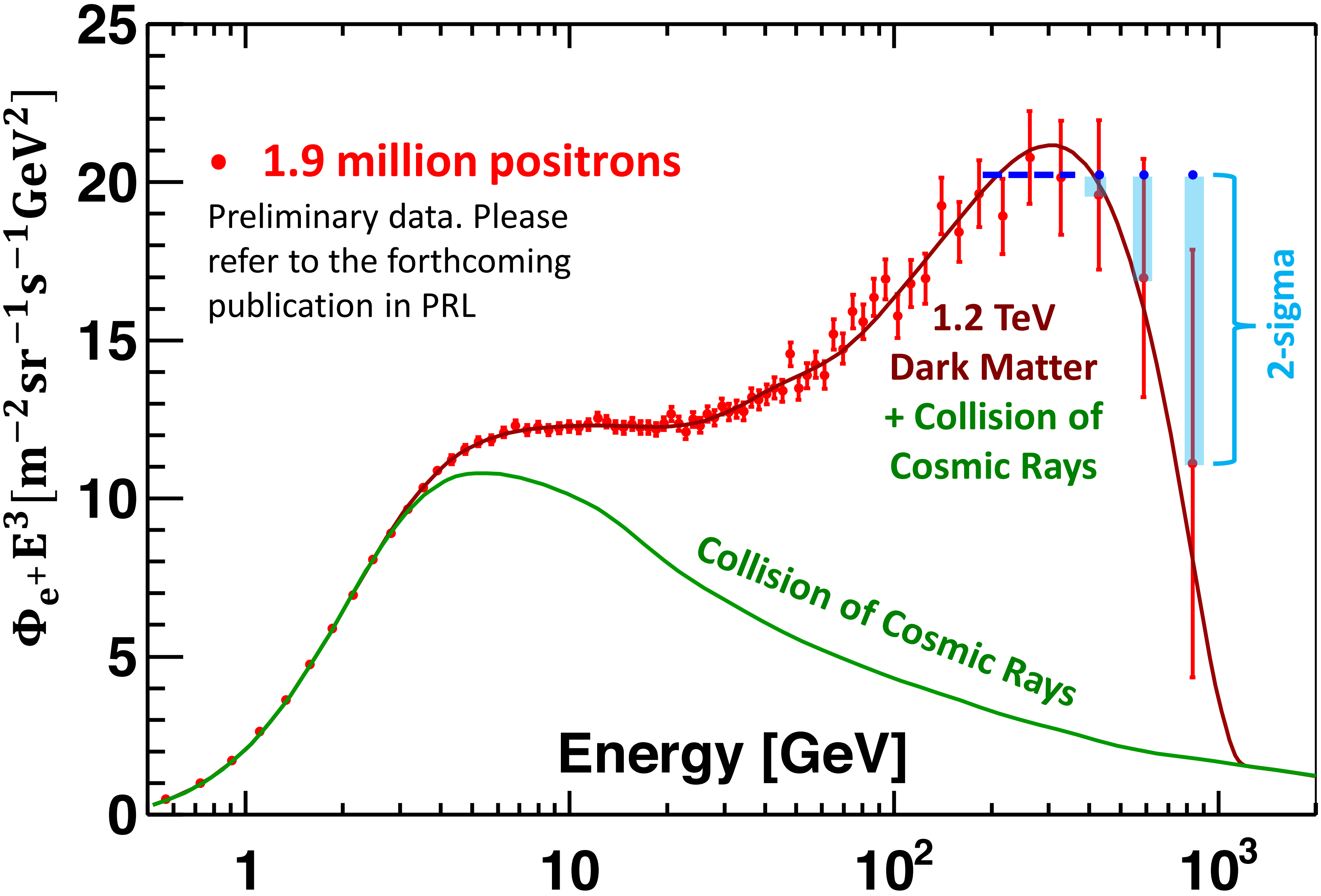
P. Mertsch and S. Sarkar, Phys.Rev. D 90 (2014) 061301

HAWC rules out that the positron excess is from nearby pulsars



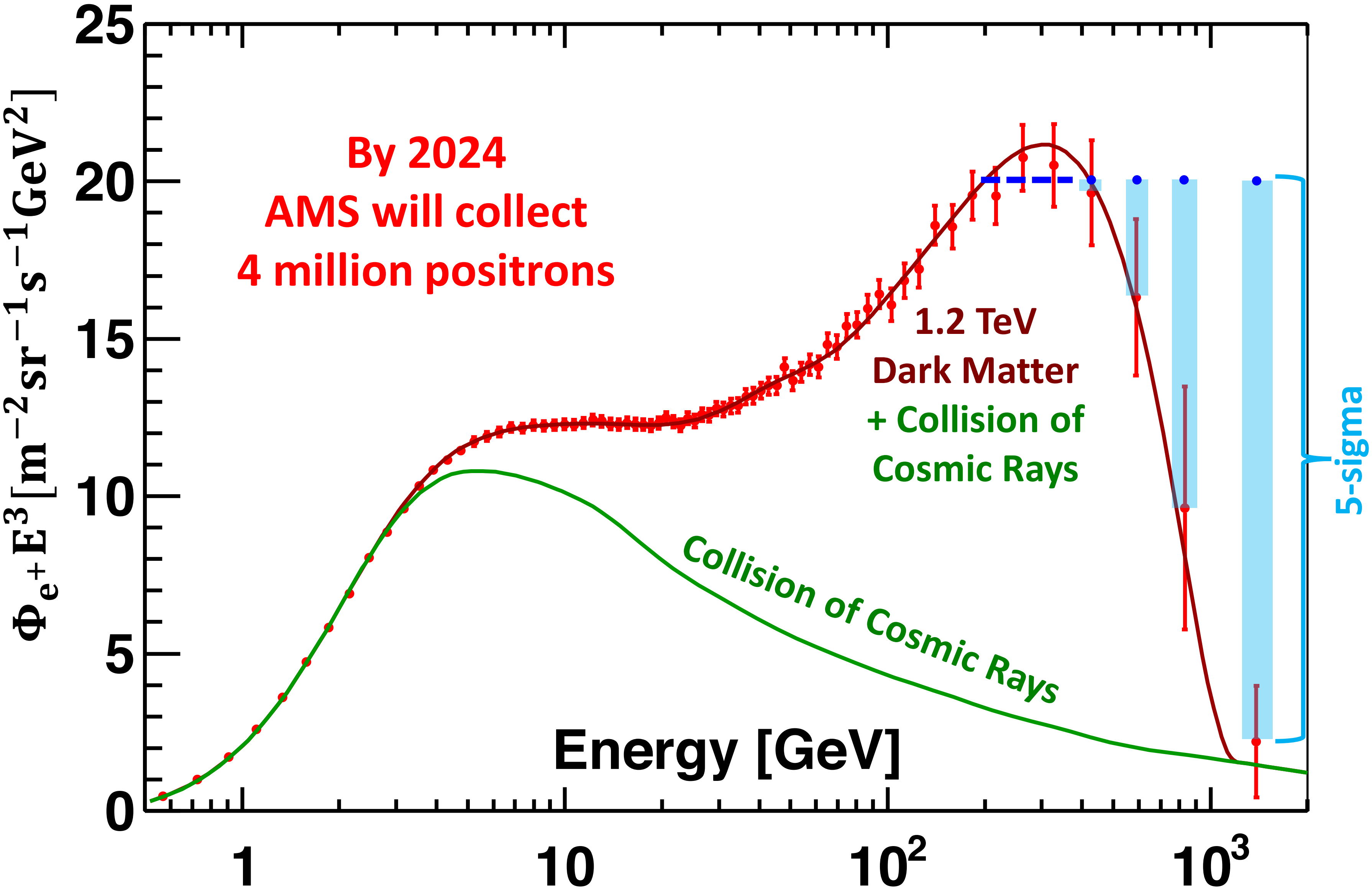
In addition, AMS Measurement of positron, electron anisotropy will distinguish and constrain Pulsar origin of high energy $e^{\pm}$

Positron spectrum beyond the turning point



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

Positron spectrum beyond the turning point

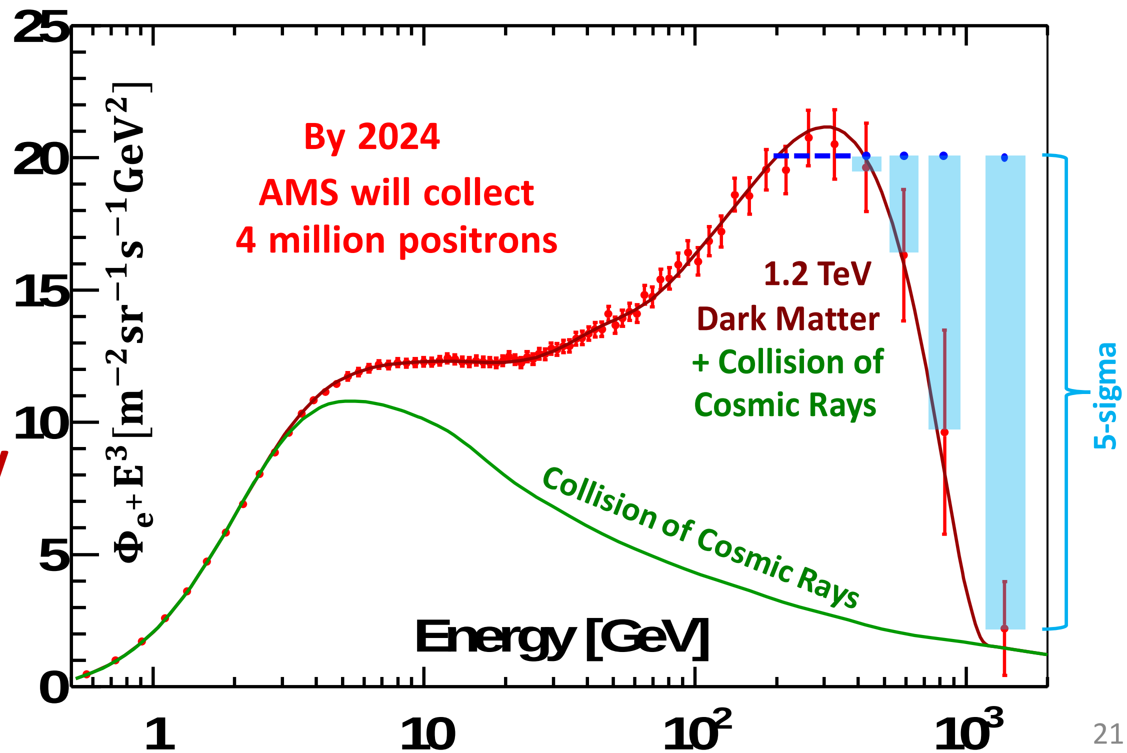


By 2024, we will extend the measurements to 2 TeV and reach 5 sigma significance

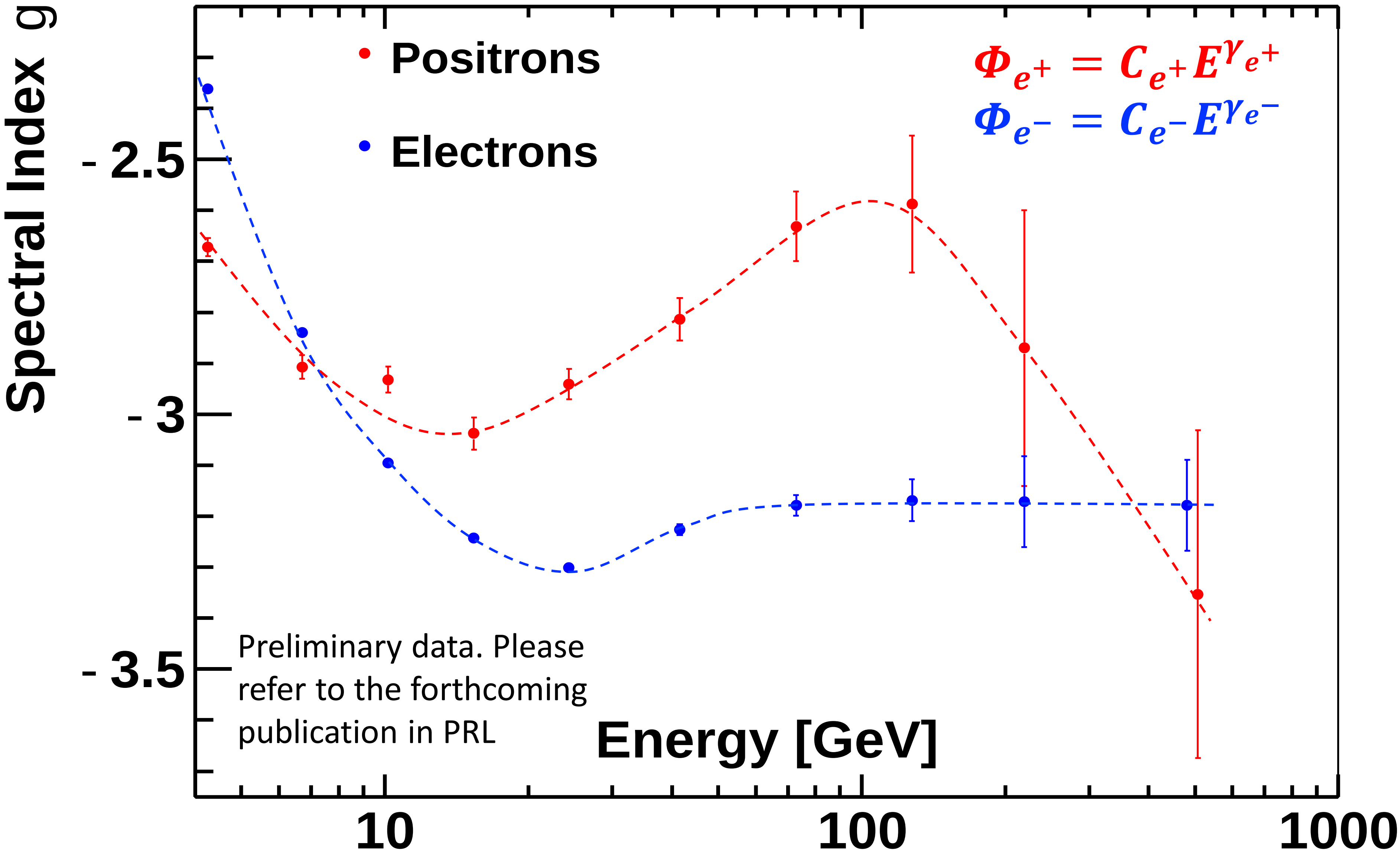
Conclusion

- The individual positron and electron fluxes are measured to 1 TeV with 28.1 million electrons and 1.9 million positrons.
- Both the amplitude and energy dependence are distinctly different between positron flux and electron flux.

- Positron flux hardens from 20 GeV and exhibits a cutoff at high energy.
- Above 370 GeV, Positron flux deviates from $\Phi \propto E^{-3}$ with 2 sigma significance. By 2024 we will reach 5 sigma.



Complex energy dependence of positron and electron fluxes



The spectral indices and their energy dependence are distinctly different between positrons and electrons