LATEST RESULTS FROM THE AMS-02 EXPERIMENT

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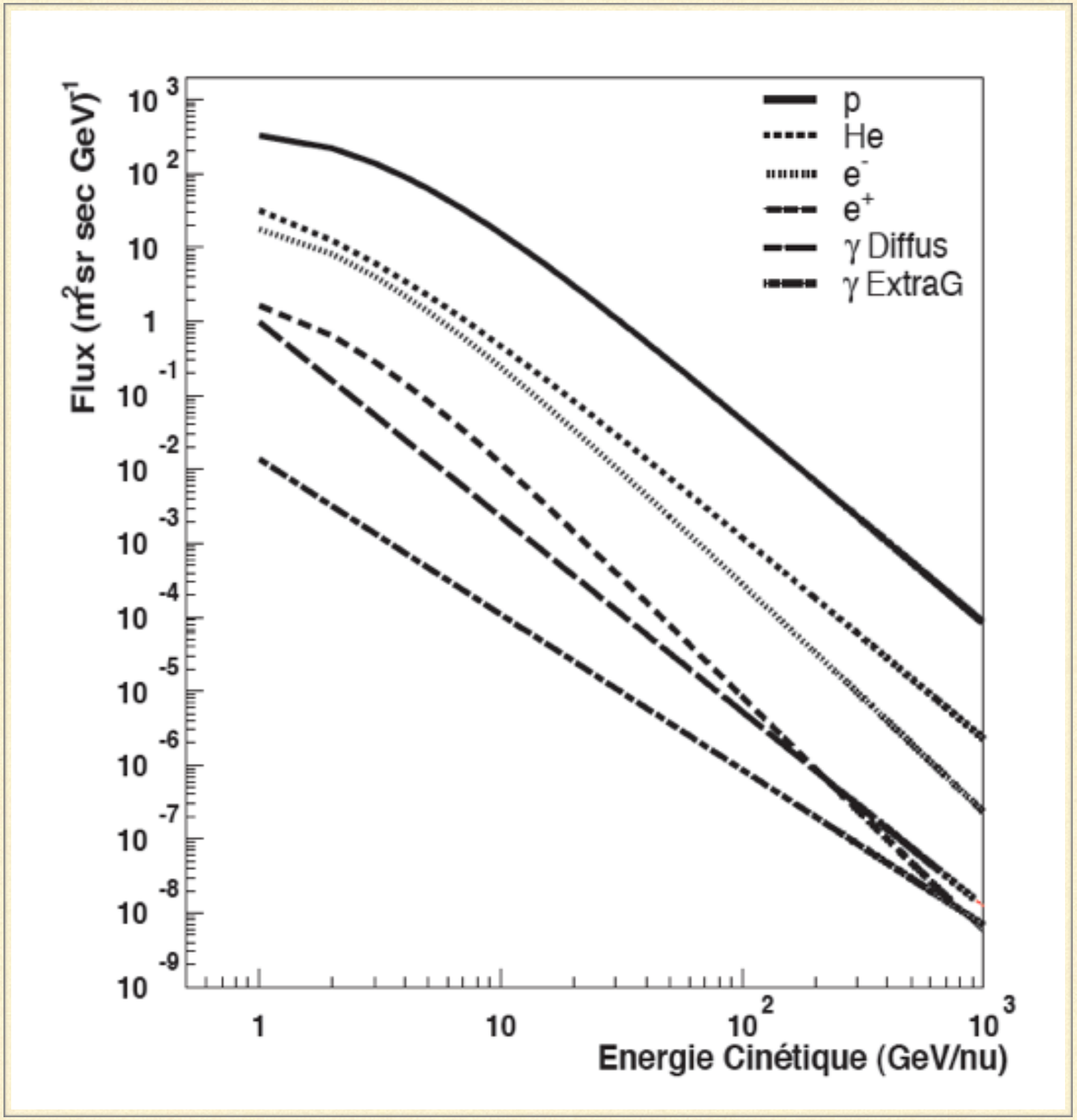
ON BEHALF OF THE AMS-02 COLLABORATION

Physicists from 15 countries in America, Europe and Asia

COSMIC RAYS COMPOSITION



- 99% nucleons
  - 89% protons,
  - 10% He,
  - 1% heavier nuclei
- 1% electrons (0.1% e+)

A WINDOW ON THE NEARBY UNIVERSE

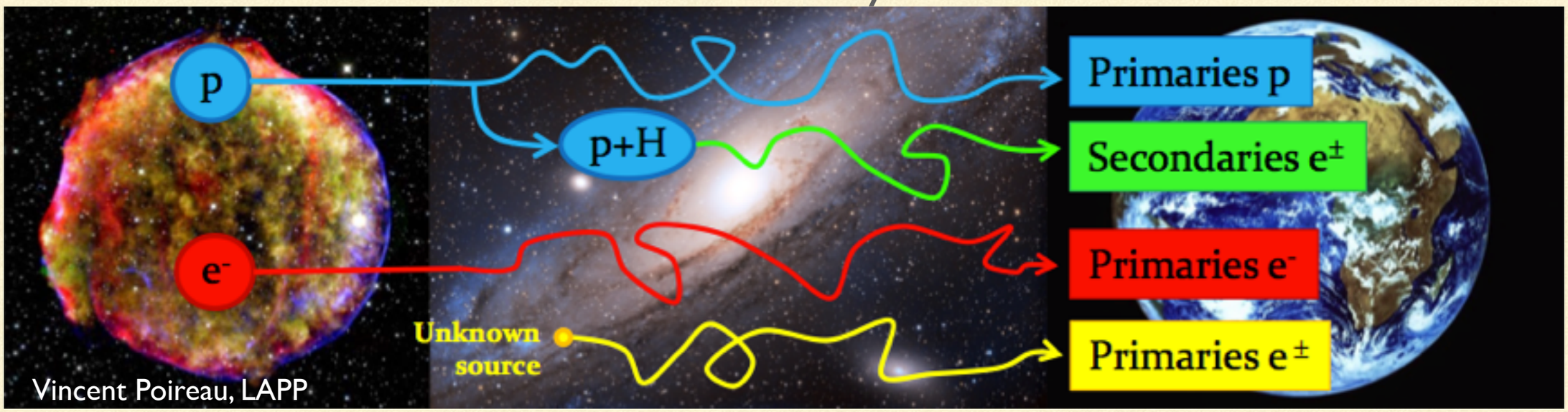
- Electrons (and e+) constitute only a tiny fraction (1%) of CRs
- Due their low mass, they loose their energy by synchrotron radiation and by inverse Compton scattering on the Interstellar radiation field.
- Their horizon is limited to few kpc: a window on nearby Universe!

COSMIC RAYS IN THE MILKY WAY

Production and acceleration

Propagation in our Galaxy

Detection



Primary cosmic rays:

- Produced directly in the source
- Known sources (E< 10^{16} eV): SNRs
- Primary cosmic rays include e^-, p, He, C, …

$$p + p_{\rm ism} \rightarrow \pi^+ + \dots$$
$$\hookrightarrow \mu^+ + \nu_\mu$$
$$\hookrightarrow e^+ + \nu_e + \overline{\nu}_\mu$$

Secondary cosmic rays:

- Produced in the interaction of primaries in the interstellar medium
- Secondary cosmic rays include e^-, e^+, anti-p, B, …

AMS-02 is a particle physics detector in outer space

Scientific goals:

- Cosmic ray fluxes in the GeV to TeV region
- Search for primordial antimatter
- Indirect search for dark matter
- Cosmic rays propagation

THE LAUNCH OF AMS-02

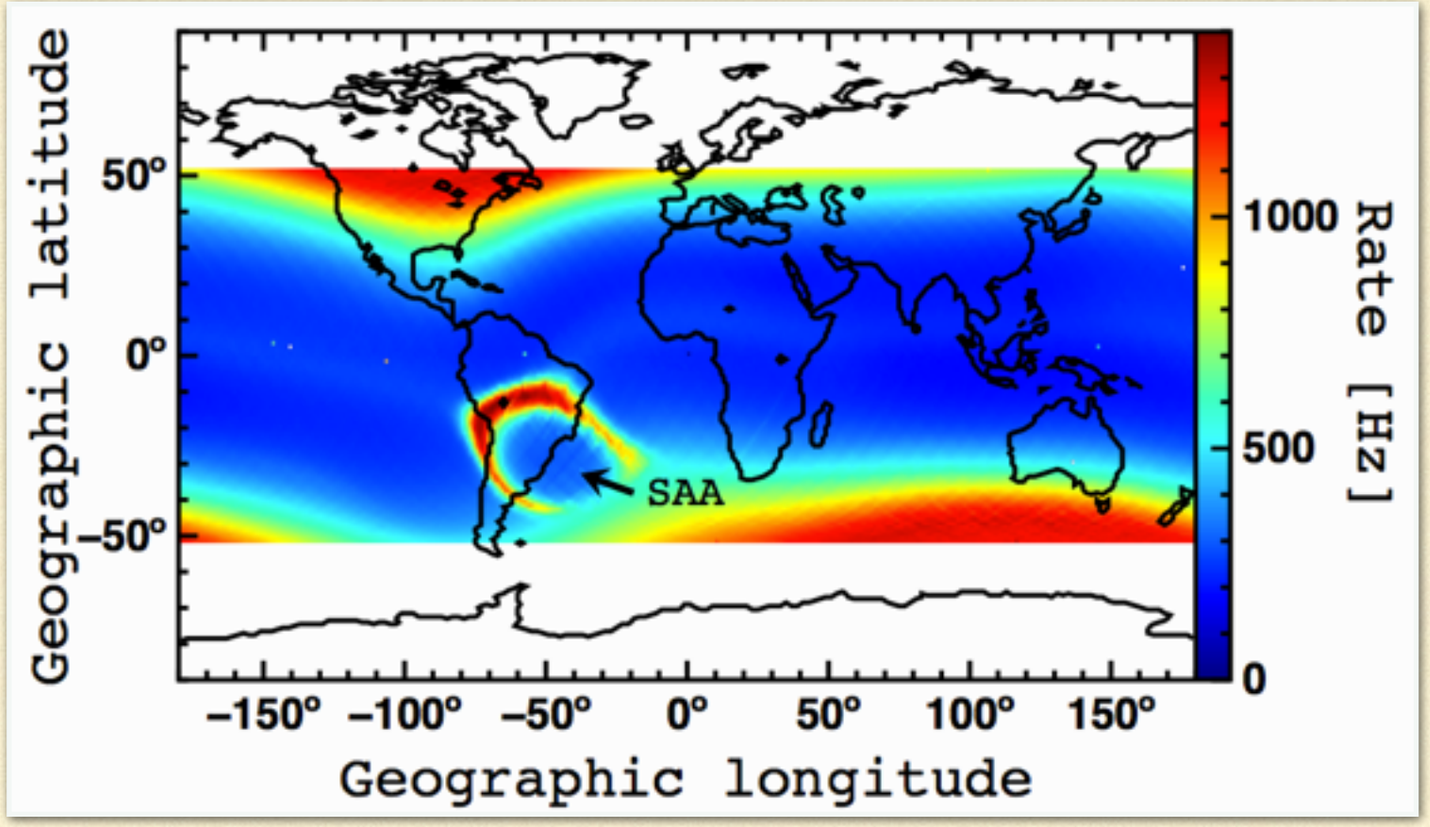
Cap Canaveral: May 16th 2011

AMS-02 ONBOARD THE ISS

- Orbiting at 400 km altitude
- Detect cosmic rays before they interact with the atmosphere

DETECTOR OPERATIONS

- Continuous operation 7d/7 24h/24
- 54 millions particles/day
- Detector operation until ~ 2024
- Data presented here up to November 2013

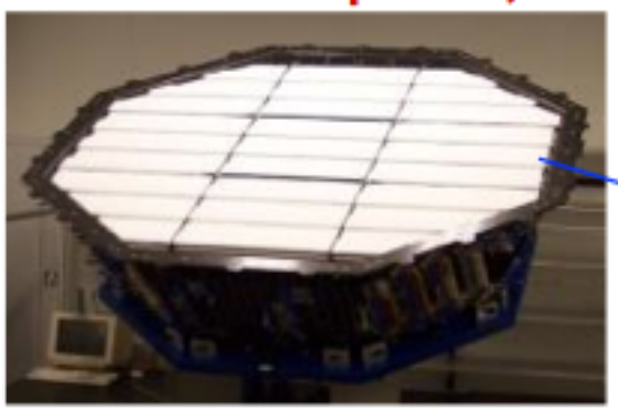


- Average rate ~ 700 Hz/orbit

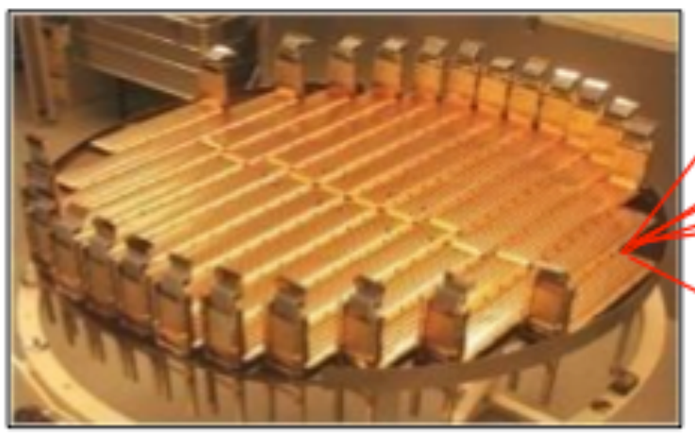
AMS: A TeV precision, multipurpose spectrometer

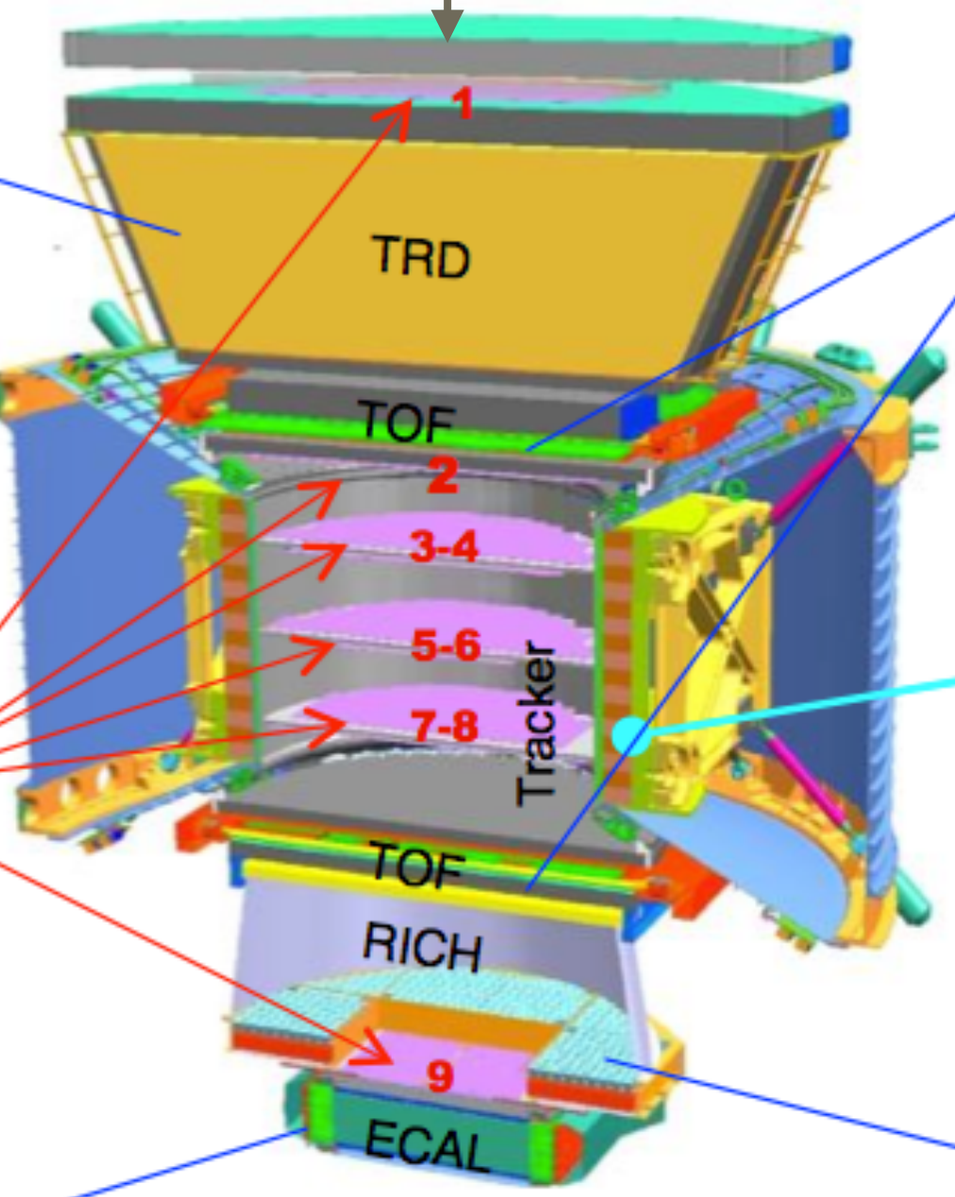
Incoming CRs

Transition Radiation Detector
Electron/proton, Z



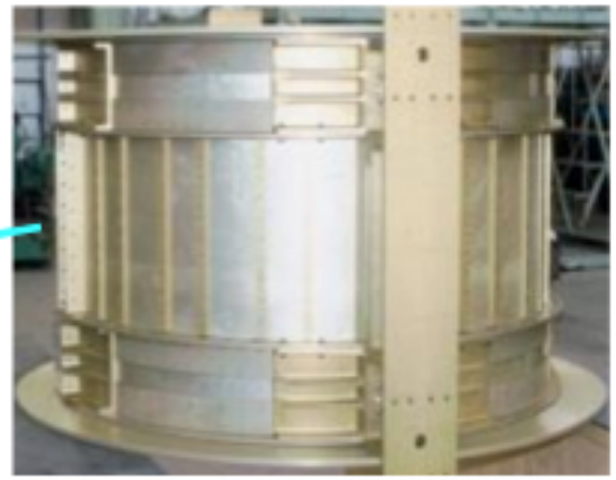
Silicon Tracker
Z, P



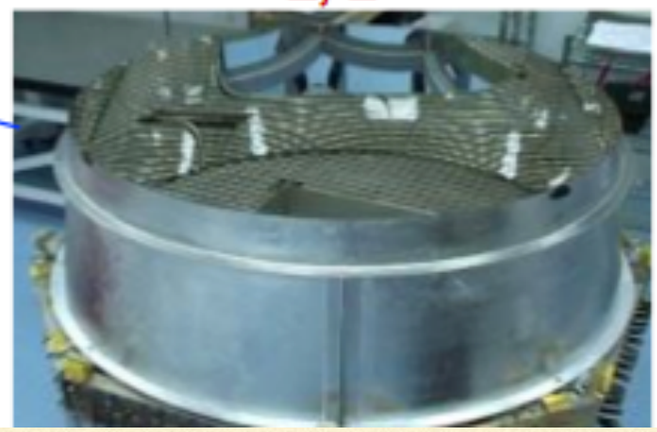


Time of Flight
Z, E

Magnet
±Z



Ring Imaging Cherenkov
Z, E



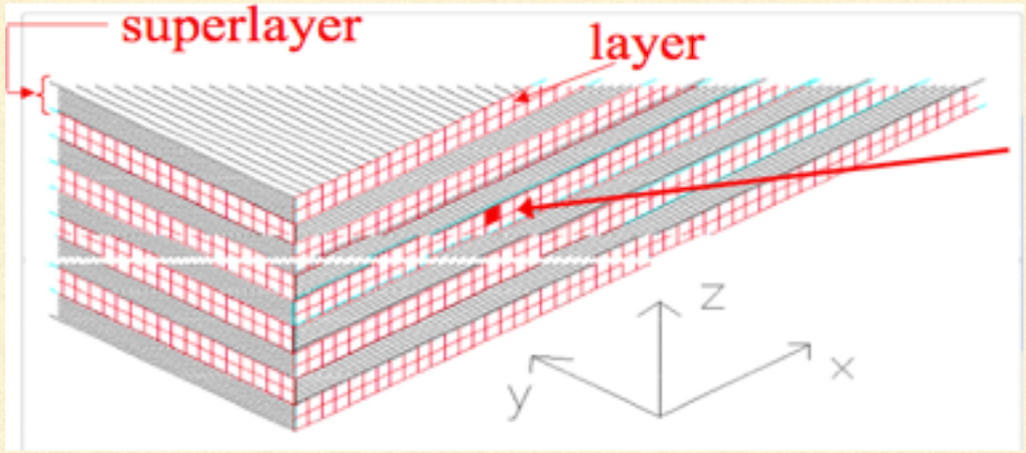
Electromagnetic Calorimeter
E of electrons

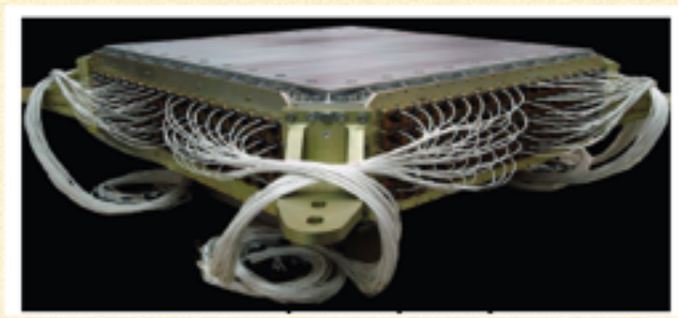
The Charge and Energy are measured independently by several detectors

ENERGY MEASUREMENT

The AMS-02 electromagnetic calorimeter:

a 3-D sampling calorimeter made out of lead and scintillating fibers



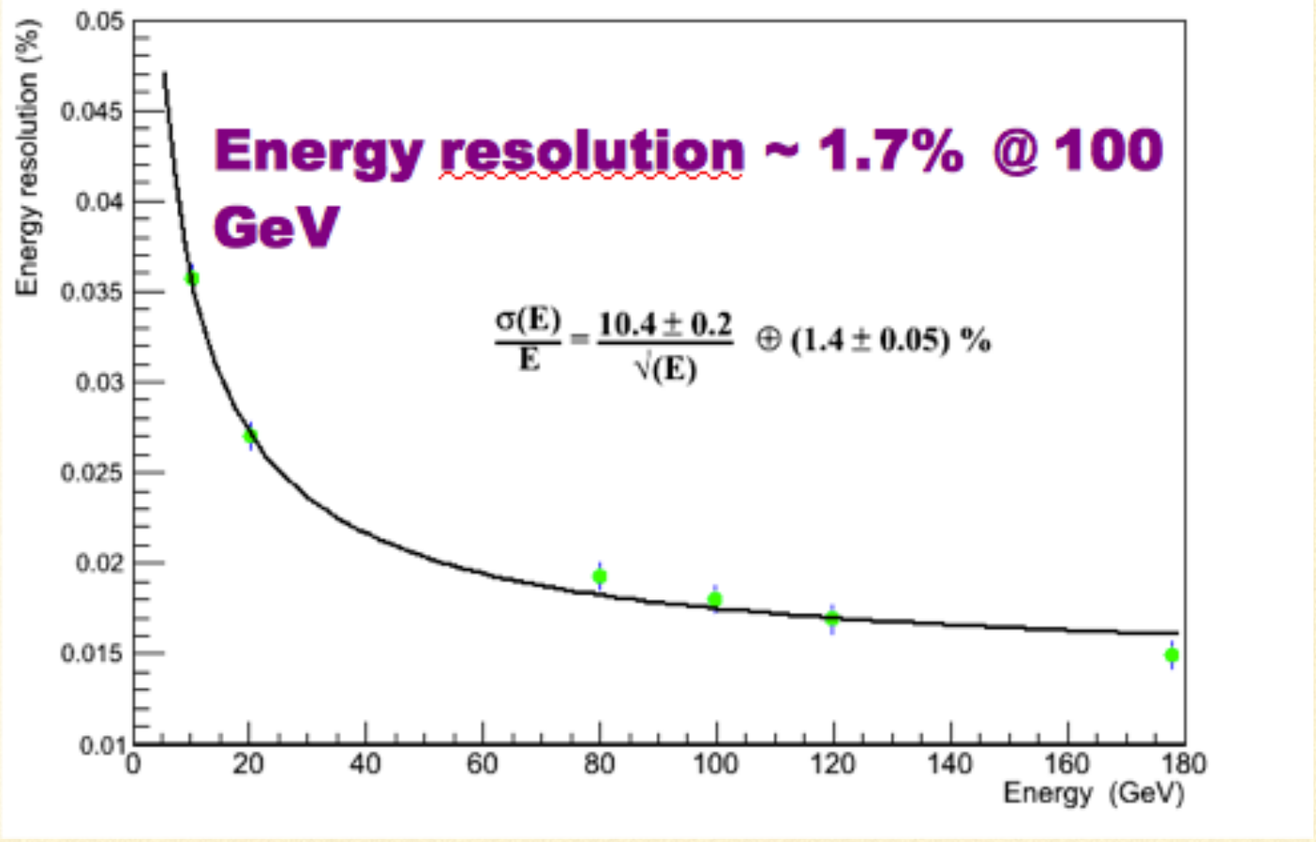


High granularity: ~ 0.9 x 0.9 cm

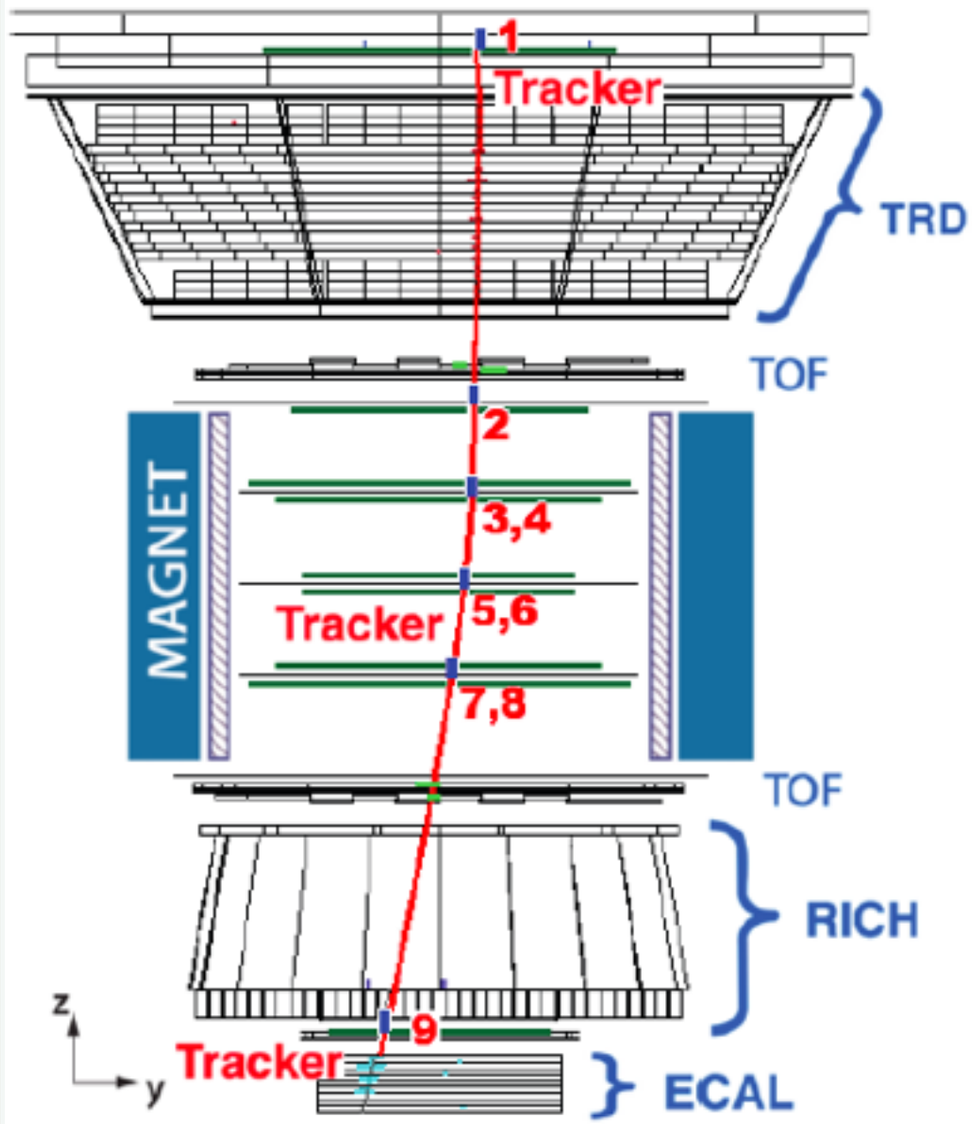
18 Longitudinal samplings

72 Lateral samplings

17 X_0, $\lambda_I / X_0 \sim 22$

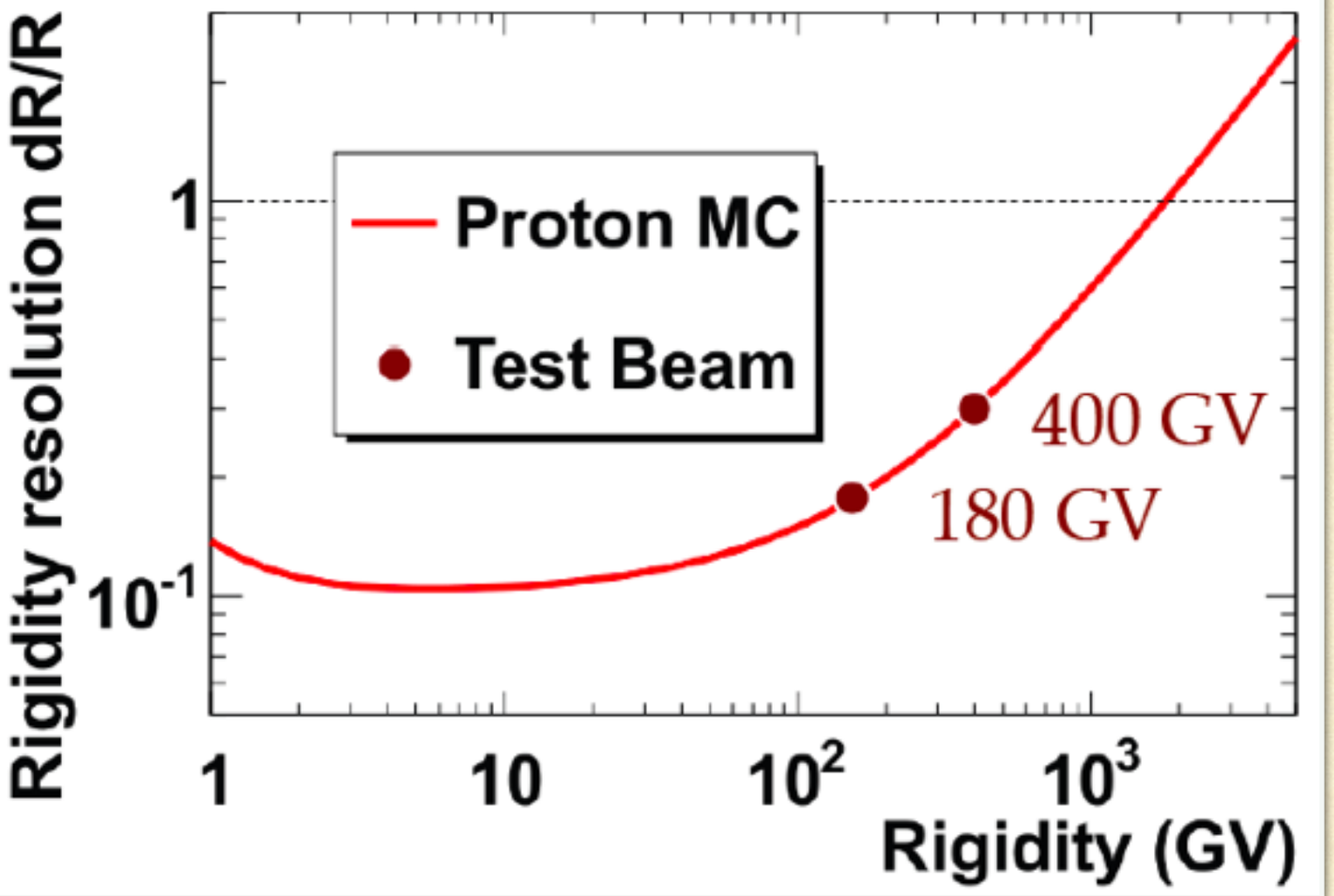


MOMENTUM MEASUREMENT

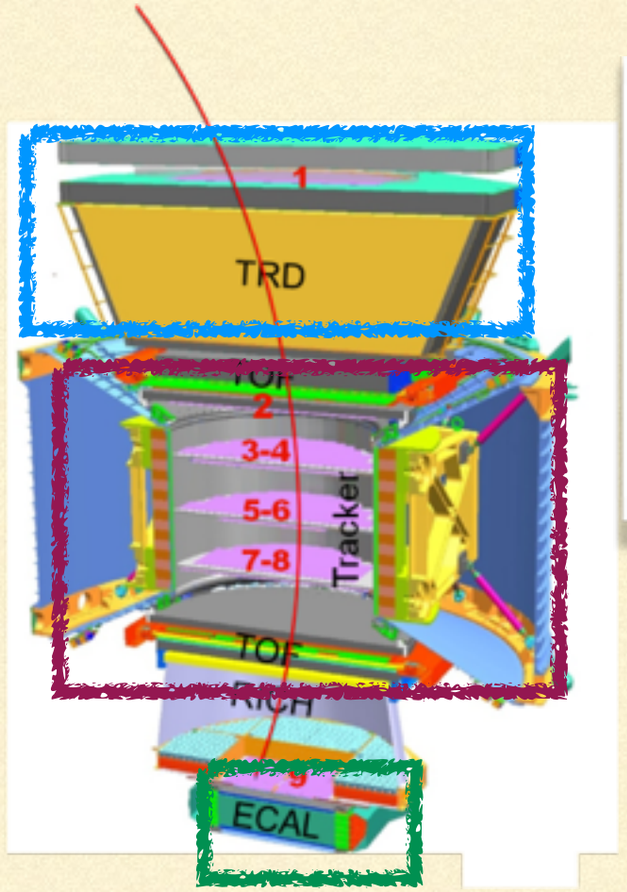


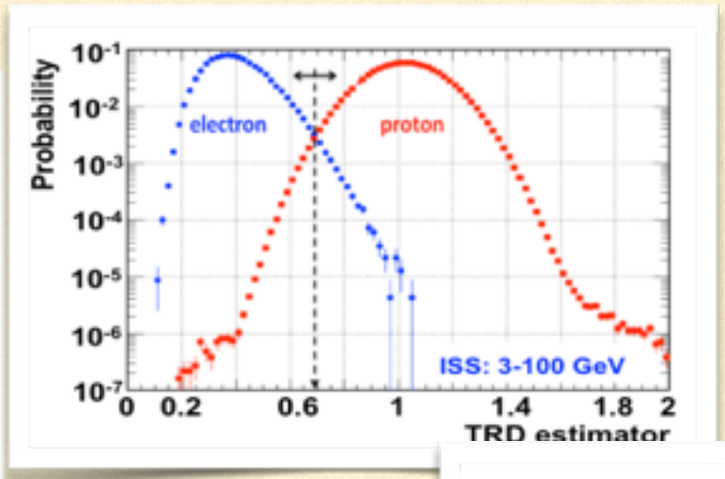
$B_x = \sim 0.14\ \mathrm{T}$ $L = \sim 3\mathrm{m}$

$\sigma_y = \sim 10\mu\mathrm{m}$ MDR : ~2TV

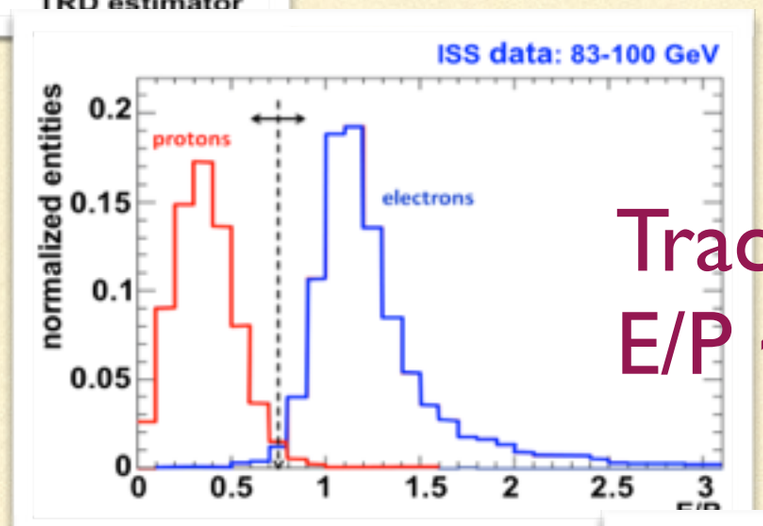


LEPTONS IDENTIFICATION



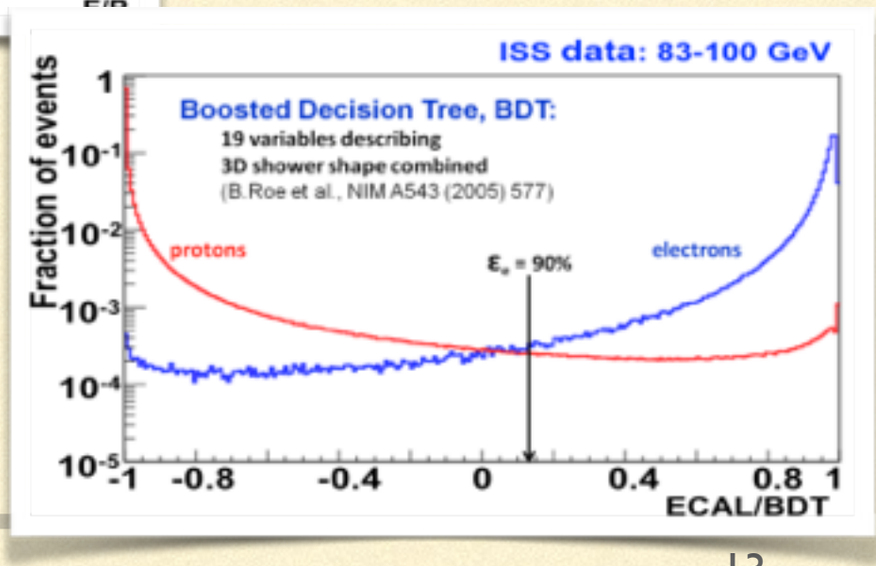


Transition Radiation Detector



Tracker:
E/P ~ 1 for e^+ and e^-

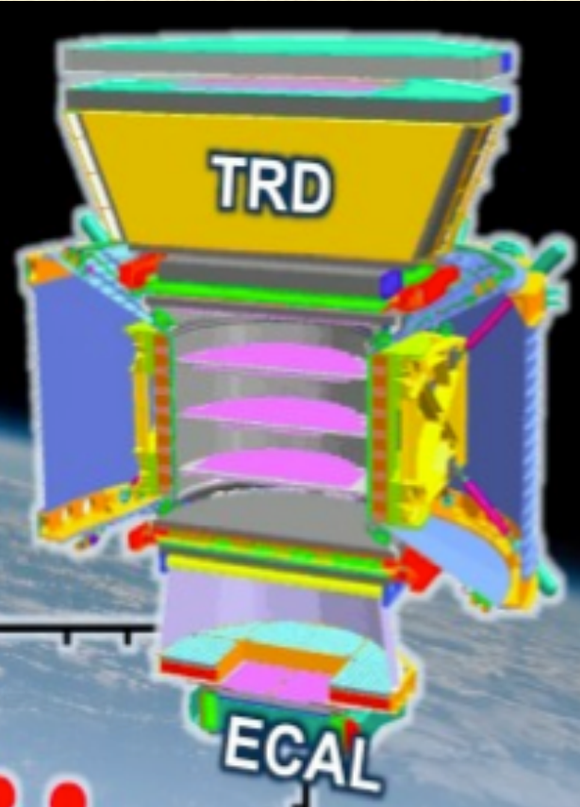
Acc(p) ~ 0.5 m^2sr
Acc(e) ~ 0.04 m^2sr

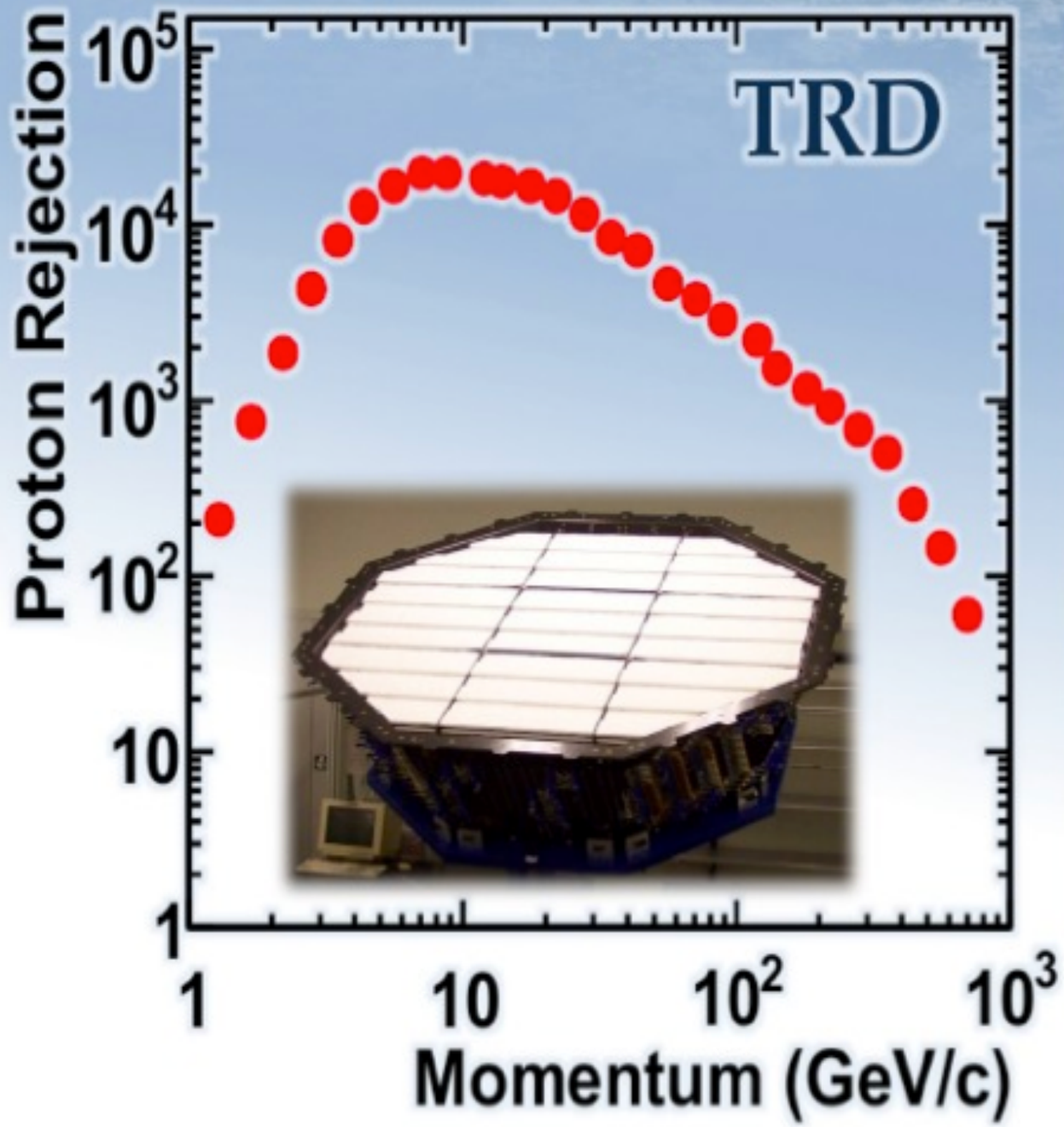


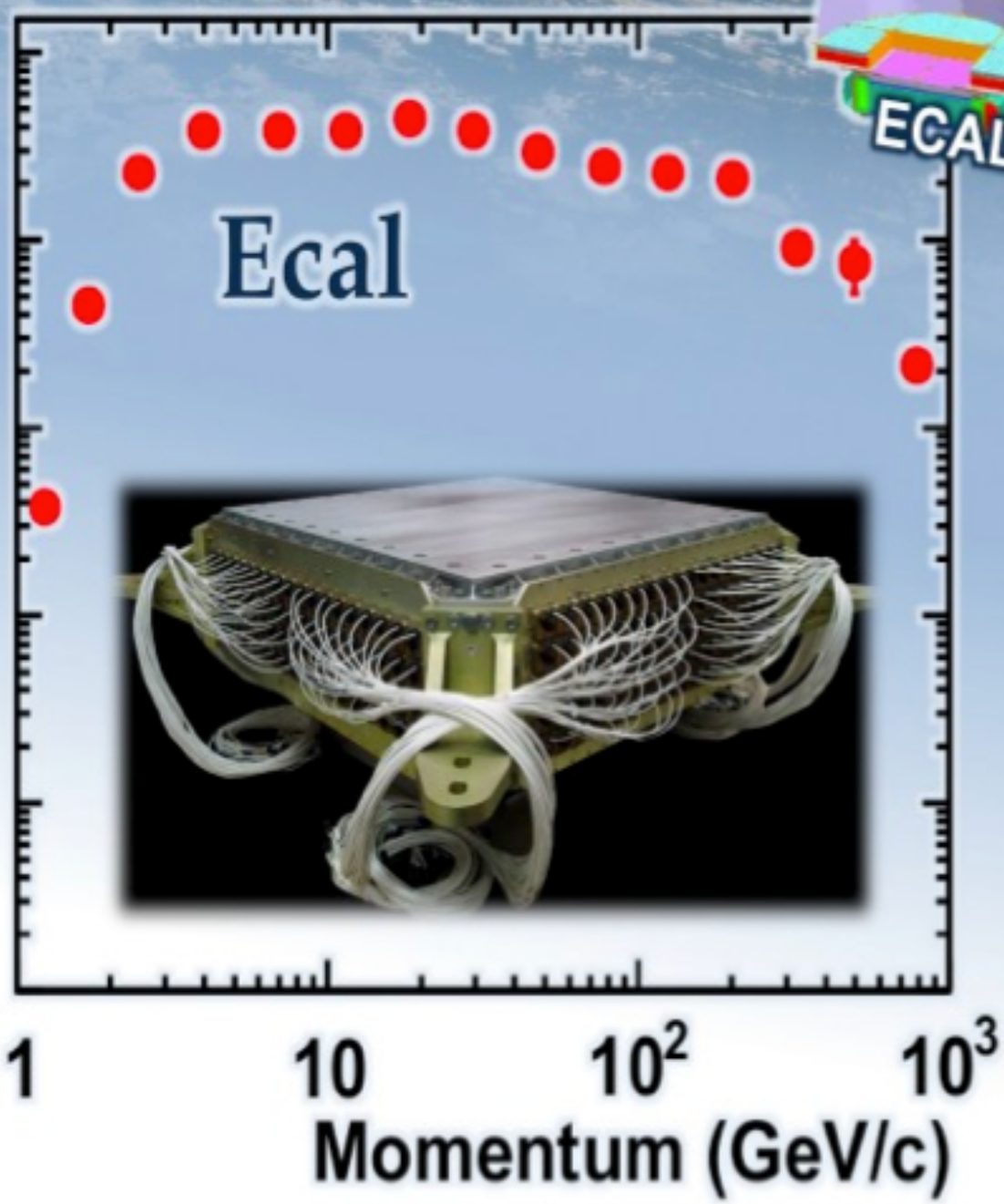
ECAL estimator: based on shower shape

Proton rejection

With 90 % e^+ efficiency







The positron fraction measurement

PHYSICAL REVIEW LETTERS

High Statistics Measurement of the Positron Fraction in Primary Cosmic rays of 0.5–500 GeV with the Alpha Magnetic Spectrometer on the International Space Station

Energy range from 0.5 to 500 GeV based on 10.9 million positron and electron events.

This measurement extends the energy range of our previous observation and increases its precision.

THE POSITRON FRACTION

Defined as : $$F = \frac{\Phi_{e+}}{\Phi_{e+} + \Phi_{e-}} = \frac{N_{e+}}{N_{e+} + N_{e-}}$$

- Acceptance and efficiencies simplify in the ratio
- A ratio of number of counts

Challenge :

- **Proton rejection of the order of 10^6 is required**

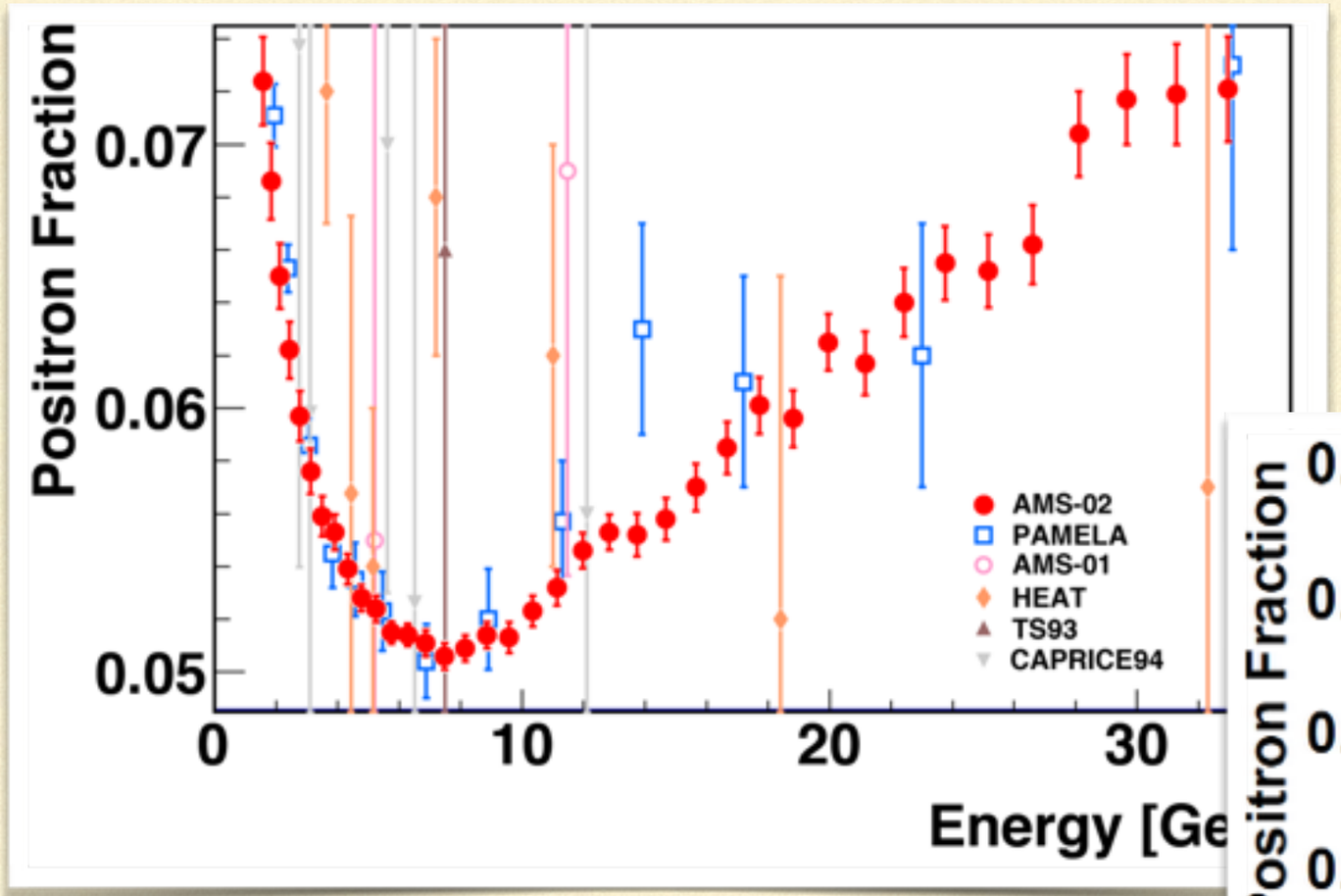
What we do expect :

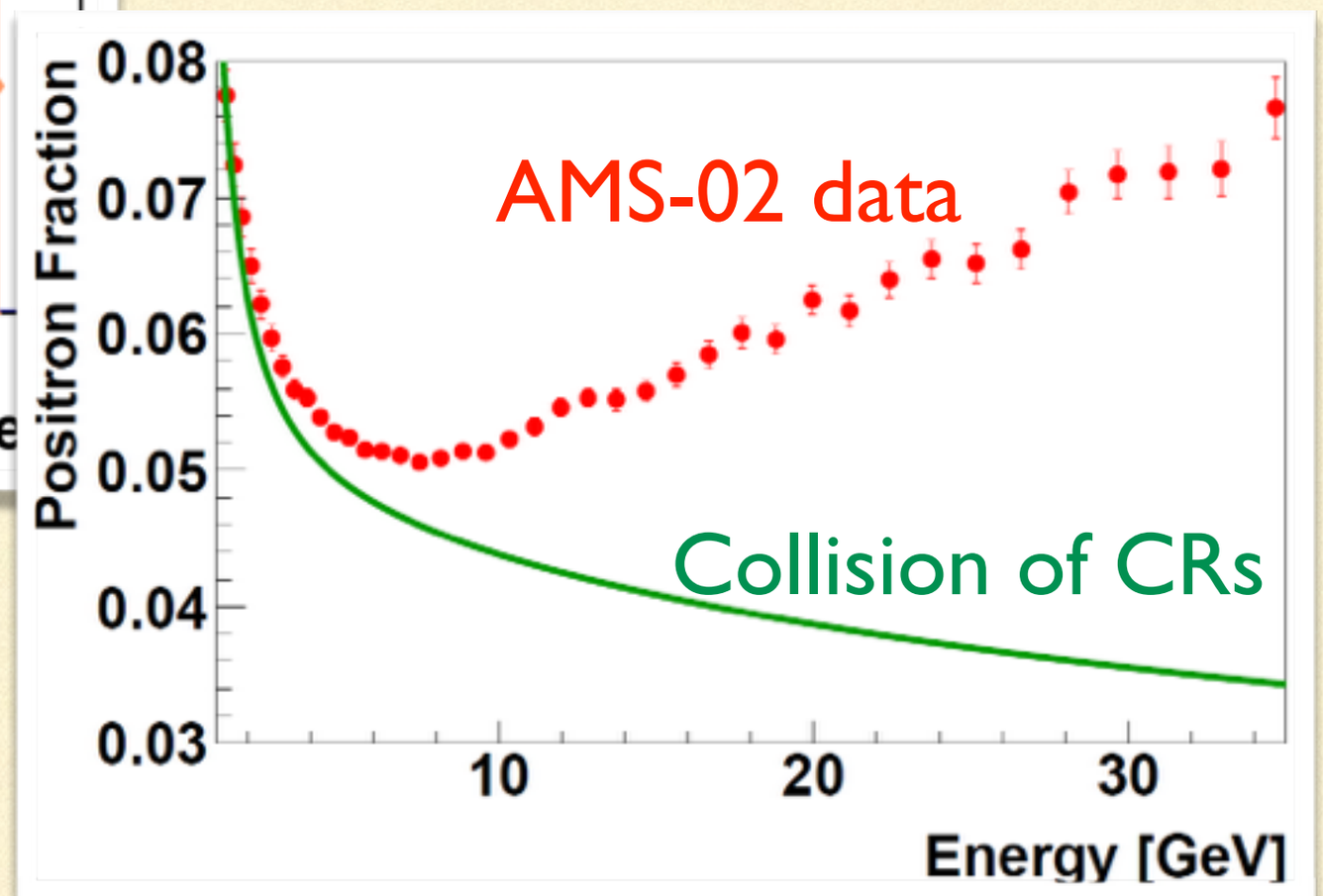
- Positrons are secondaries, produced in protons interactions with the Interstellar medium.

- **If positrons are ONLY secondaries, the positron fraction is expected to decrease with energy.**

LOW ENERGY POSITRON FRACTION

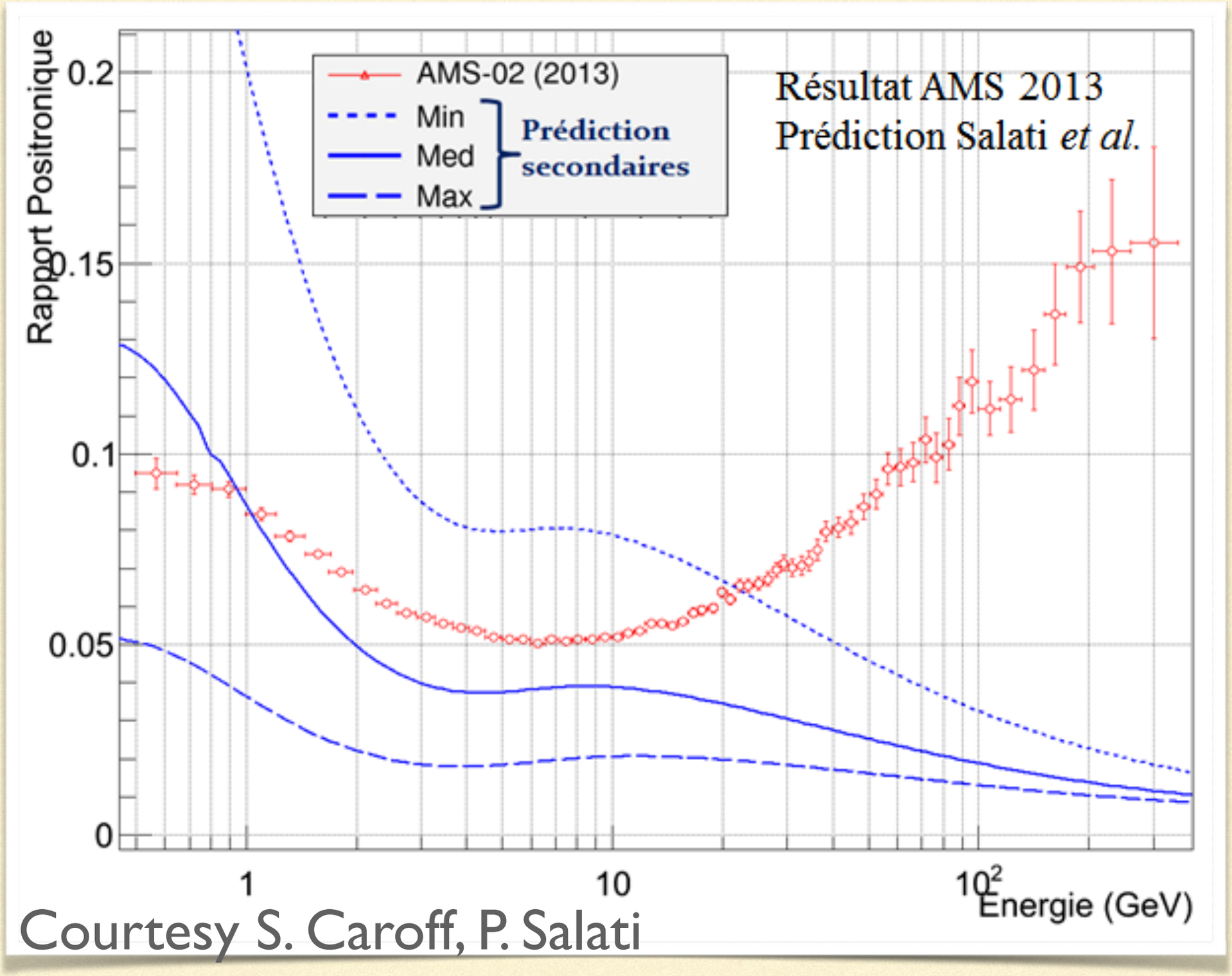
Fraction begins to increase above 10 GeV





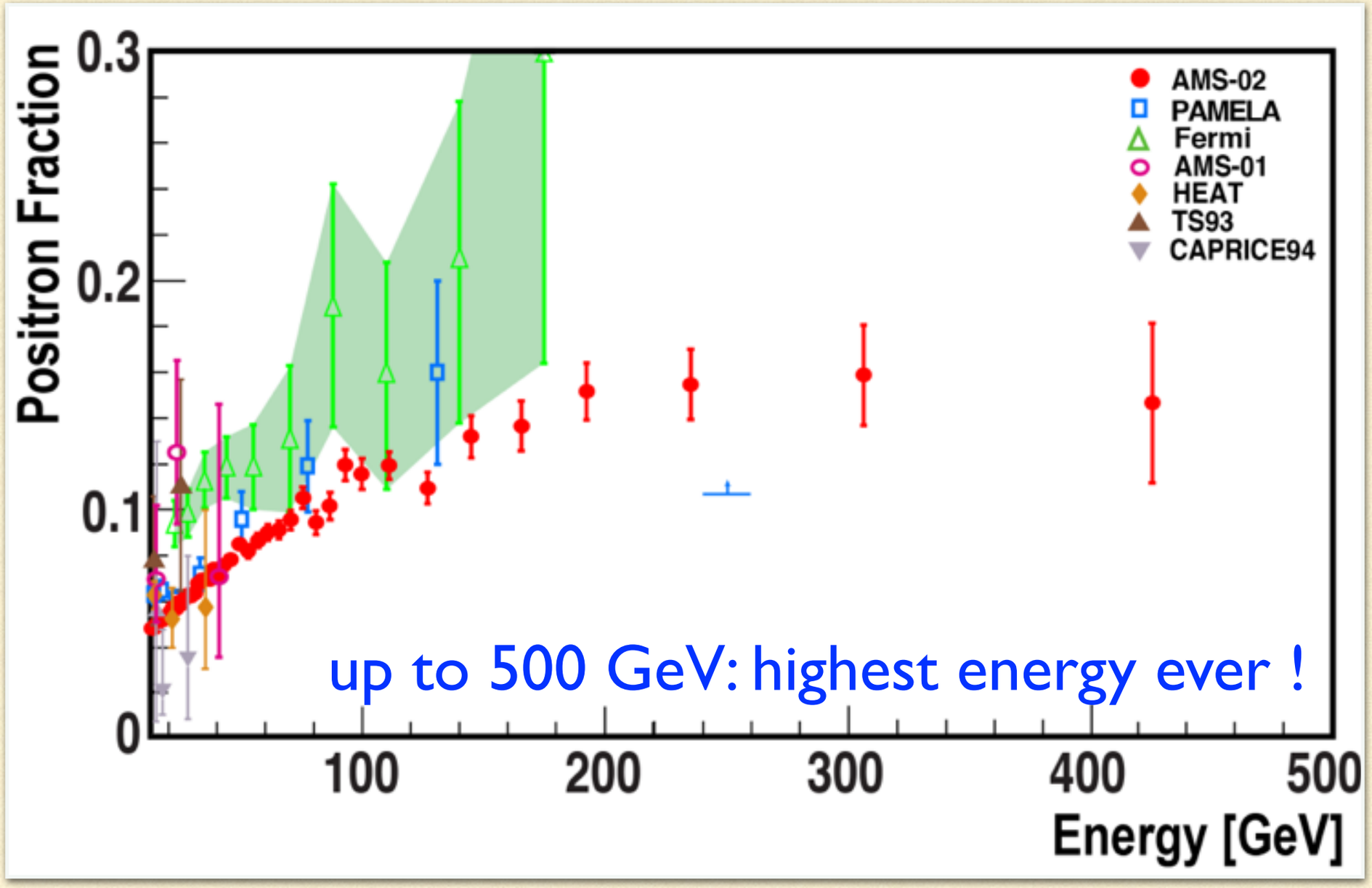
Incompatible with
pure secondary hypothesis

EFFECT OF COSMIC RAYS PROPAGATION



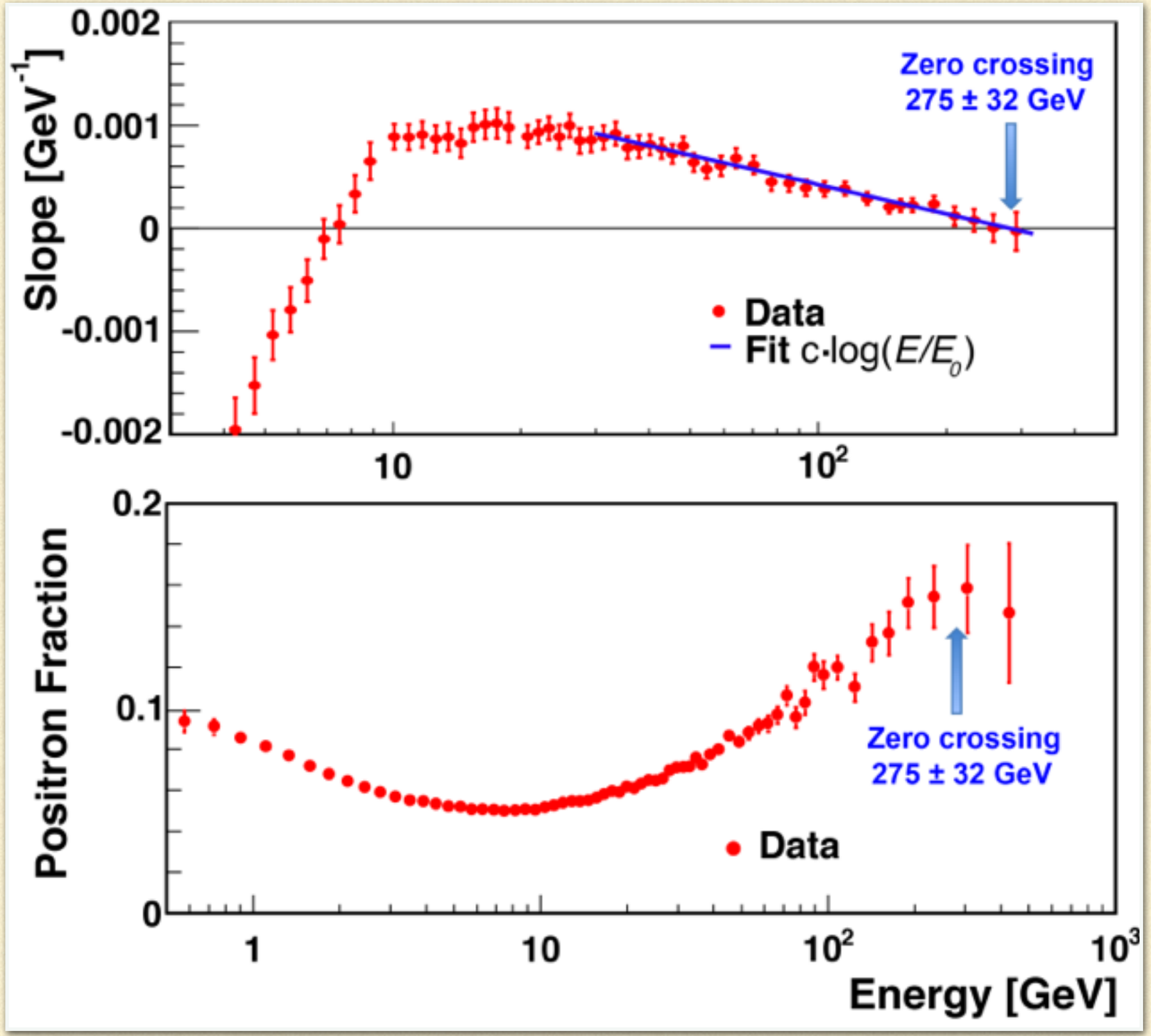
Courtesy S. Caroff, P. Salati

POSITRON FRACTION IN 2014



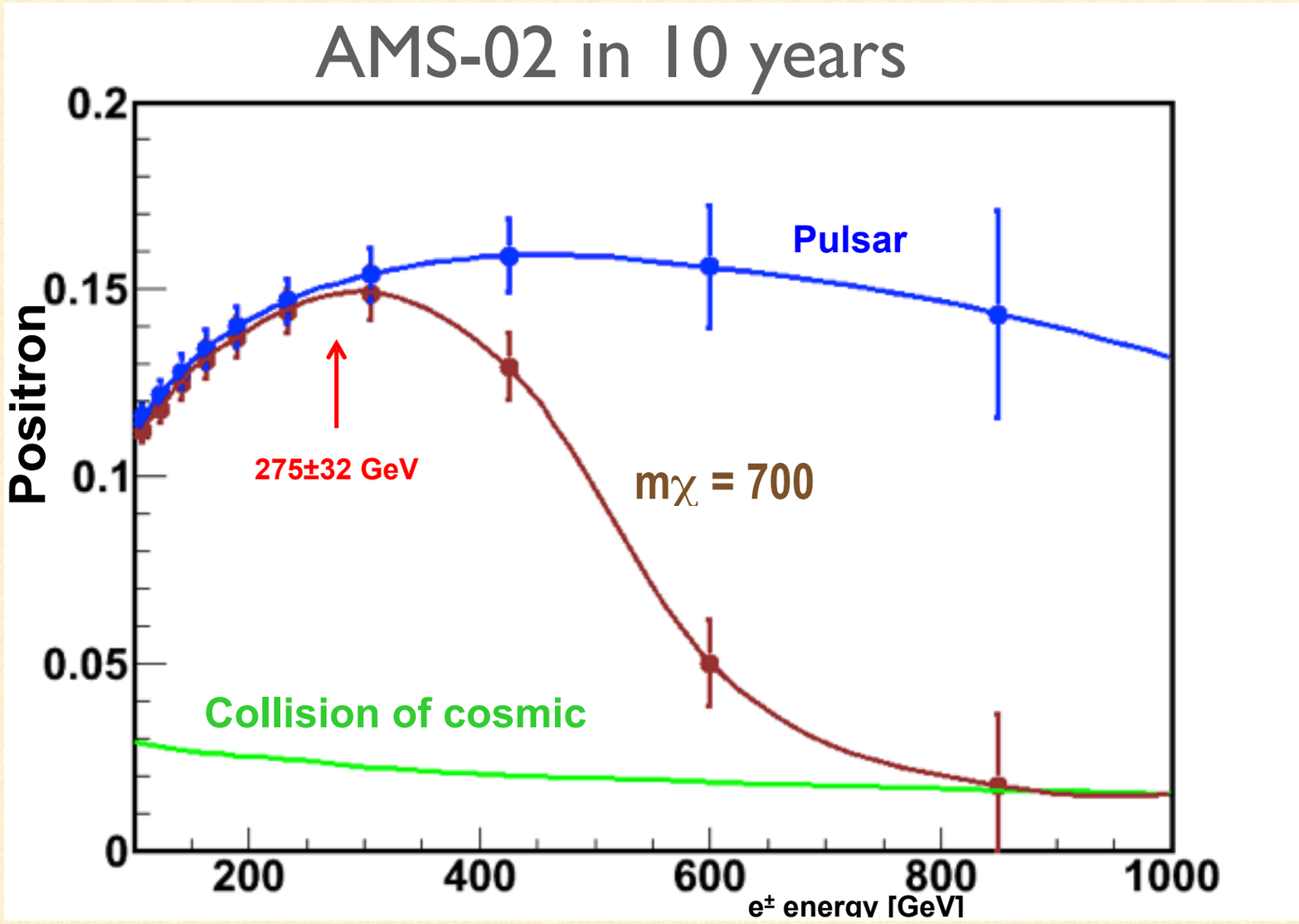
- No sharp structure
- With the current sensitivity, the flux is isotropic

THE POSITRON FRACTION SLOPE



EXPECTED SENSITIVITY

Current cosmic ray data suggest the existence of
an unknown nearby source of positrons and electrons



In the near future, AMS will extend its energy range, and will be able to discriminate between the dark matter and pulsar hypothesis

ELECTRONS AND POSITRONS FLUXES

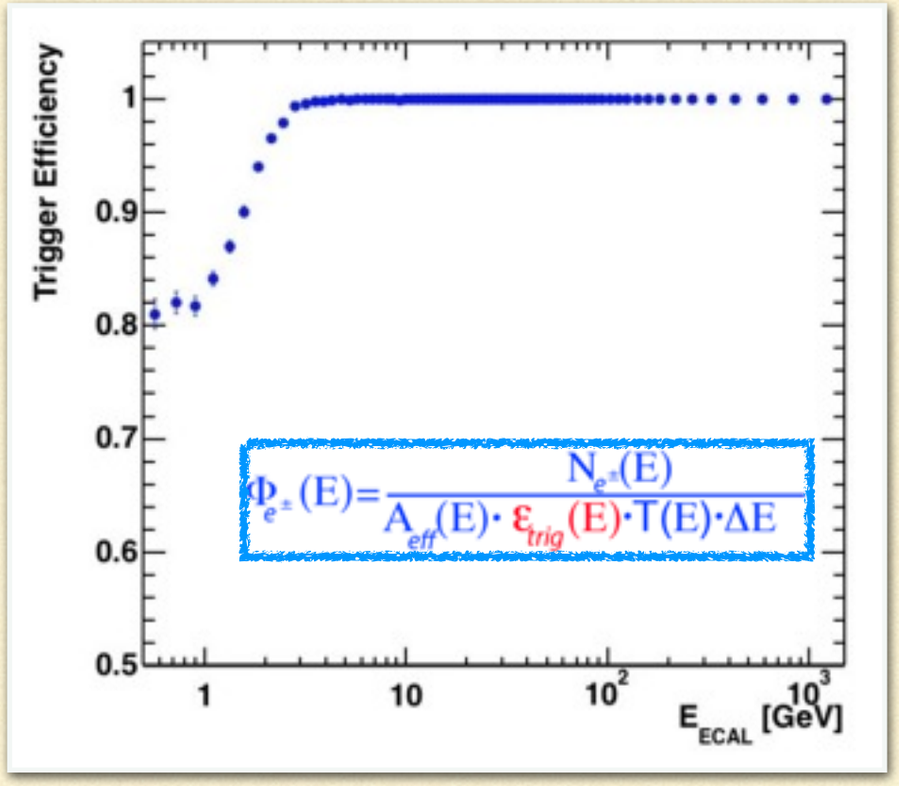
PHYSICAL REVIEW LETTERS

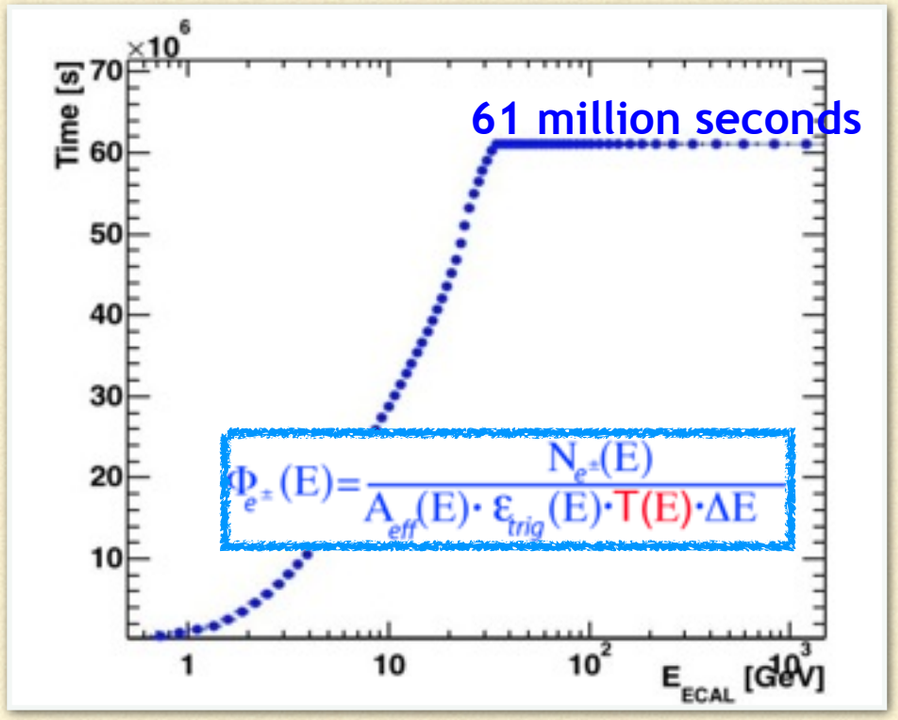
Electron and Positron Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the International Space Station

THE FLUX MEASUREMENT

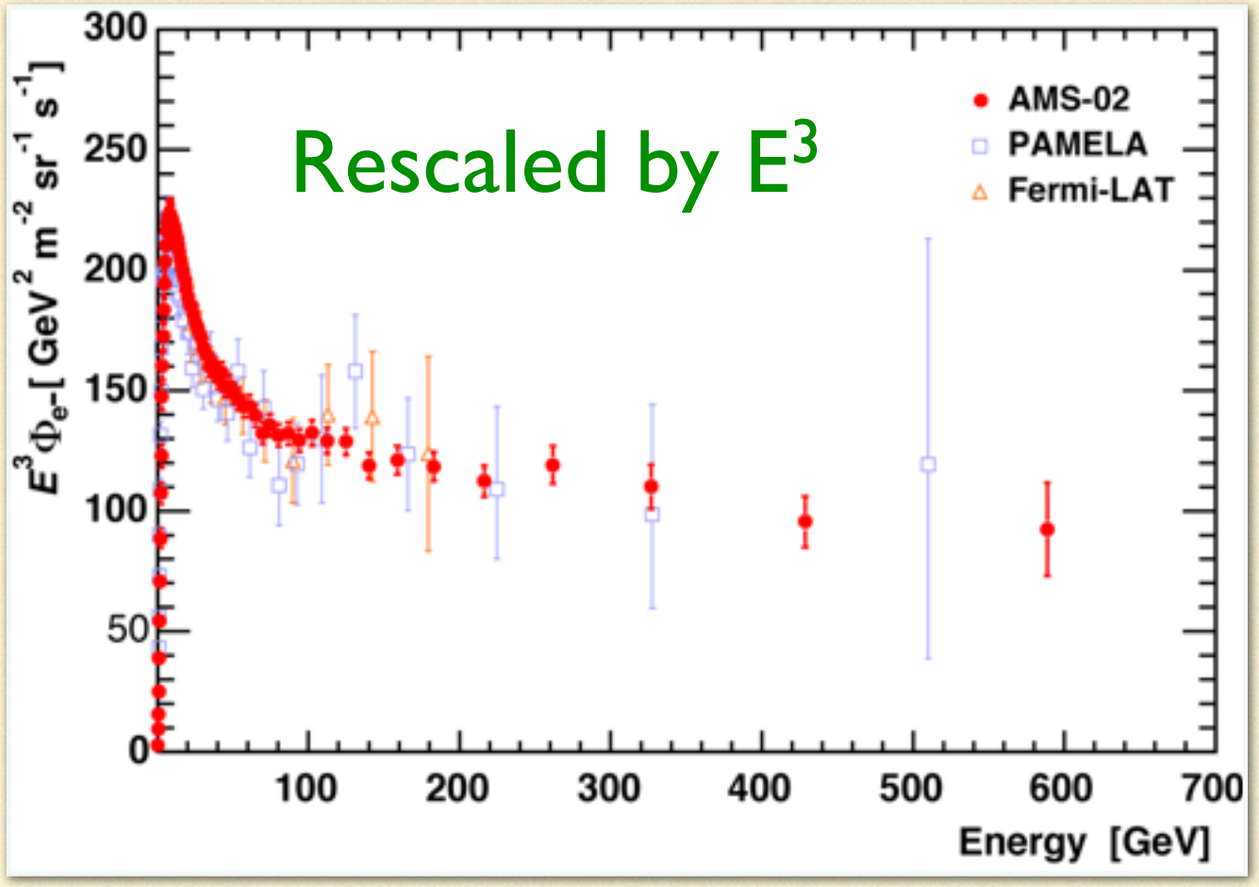
$$\Phi_{e^\pm}(E) = \frac{N_{e^\pm}(E)}{A_{eff}(E) \cdot \varepsilon_{trig}(E) \cdot T(E) \cdot \Delta E}$$

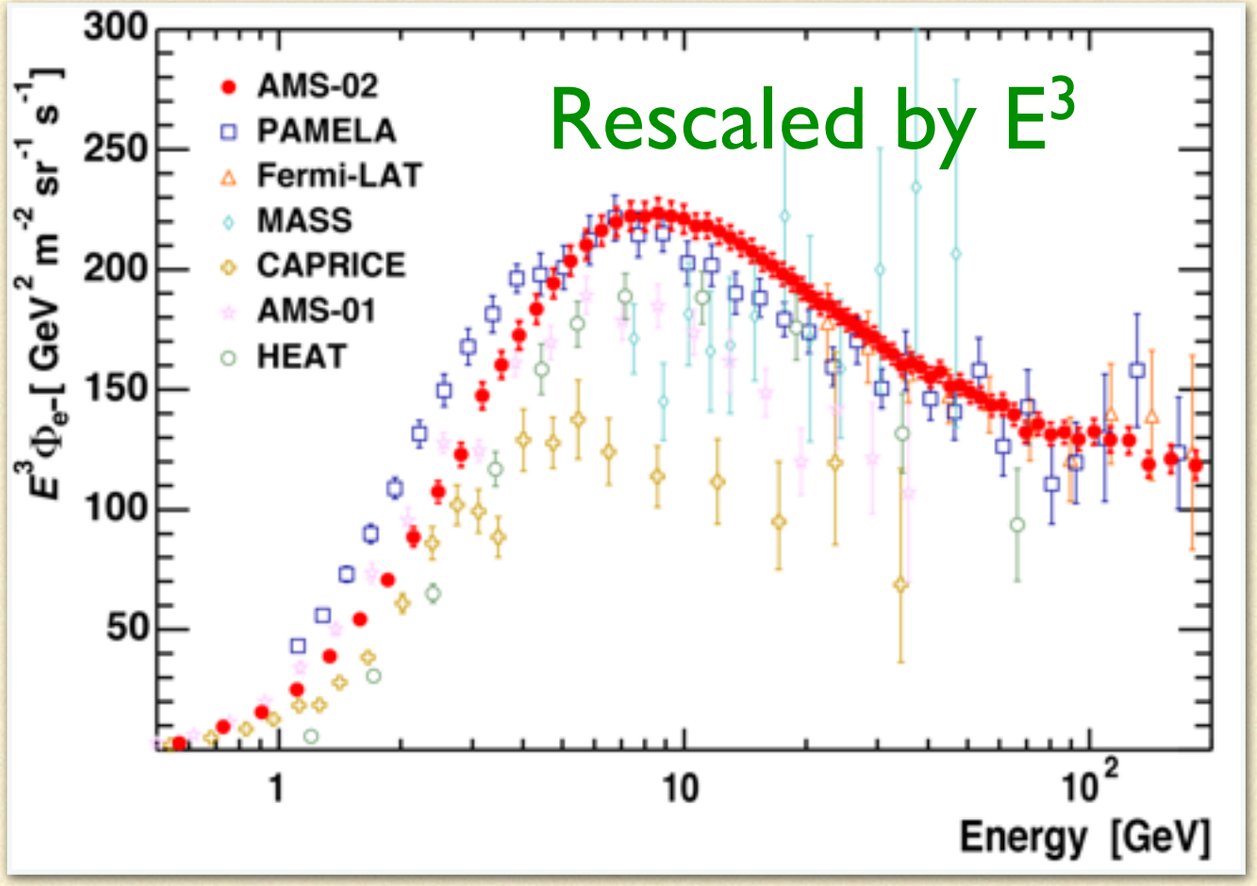
- $N_{e\pm}$ is the number of signal events
- ε_{trig} is the trigger efficiency
- T is the exposure time
- A_{eff} is the effective acceptance





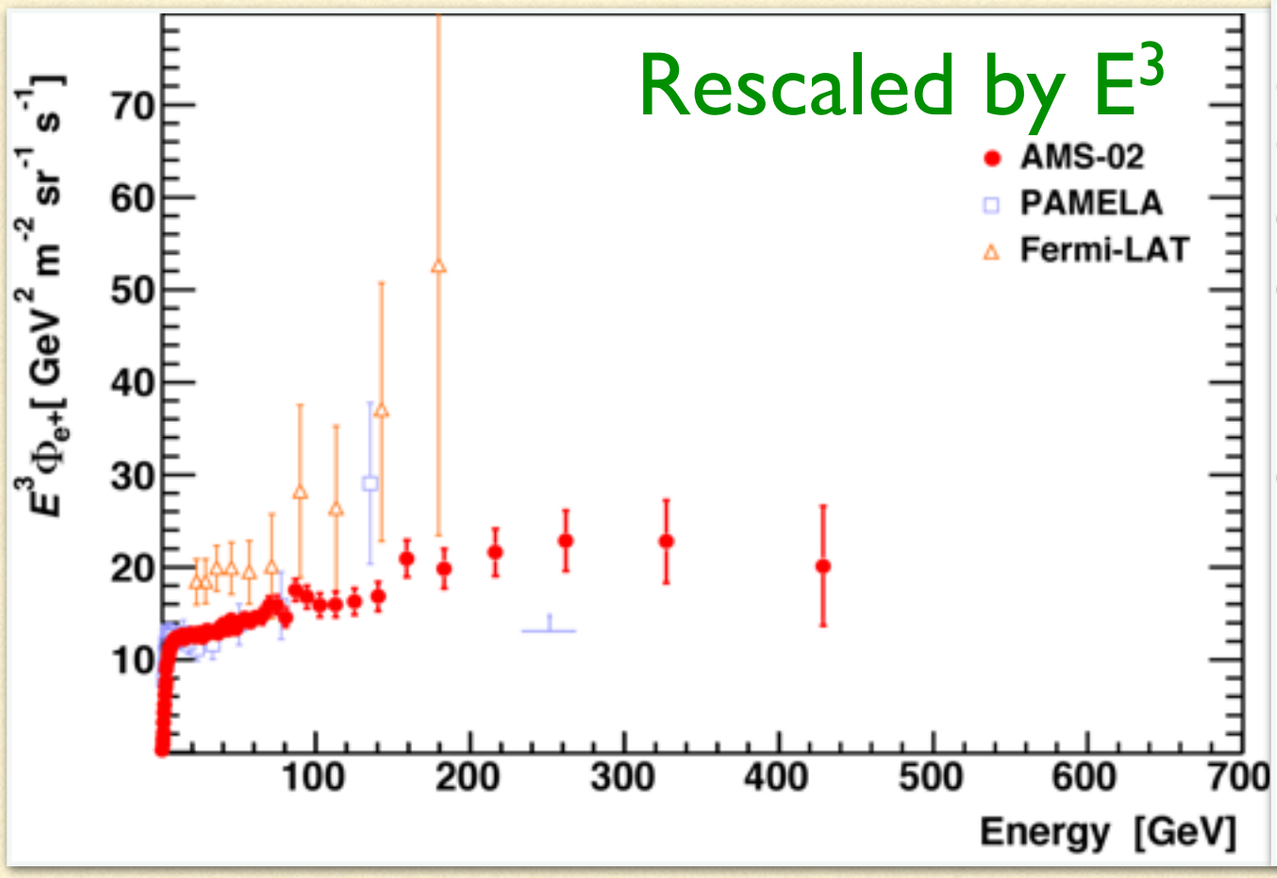
ELECTRON FLUX

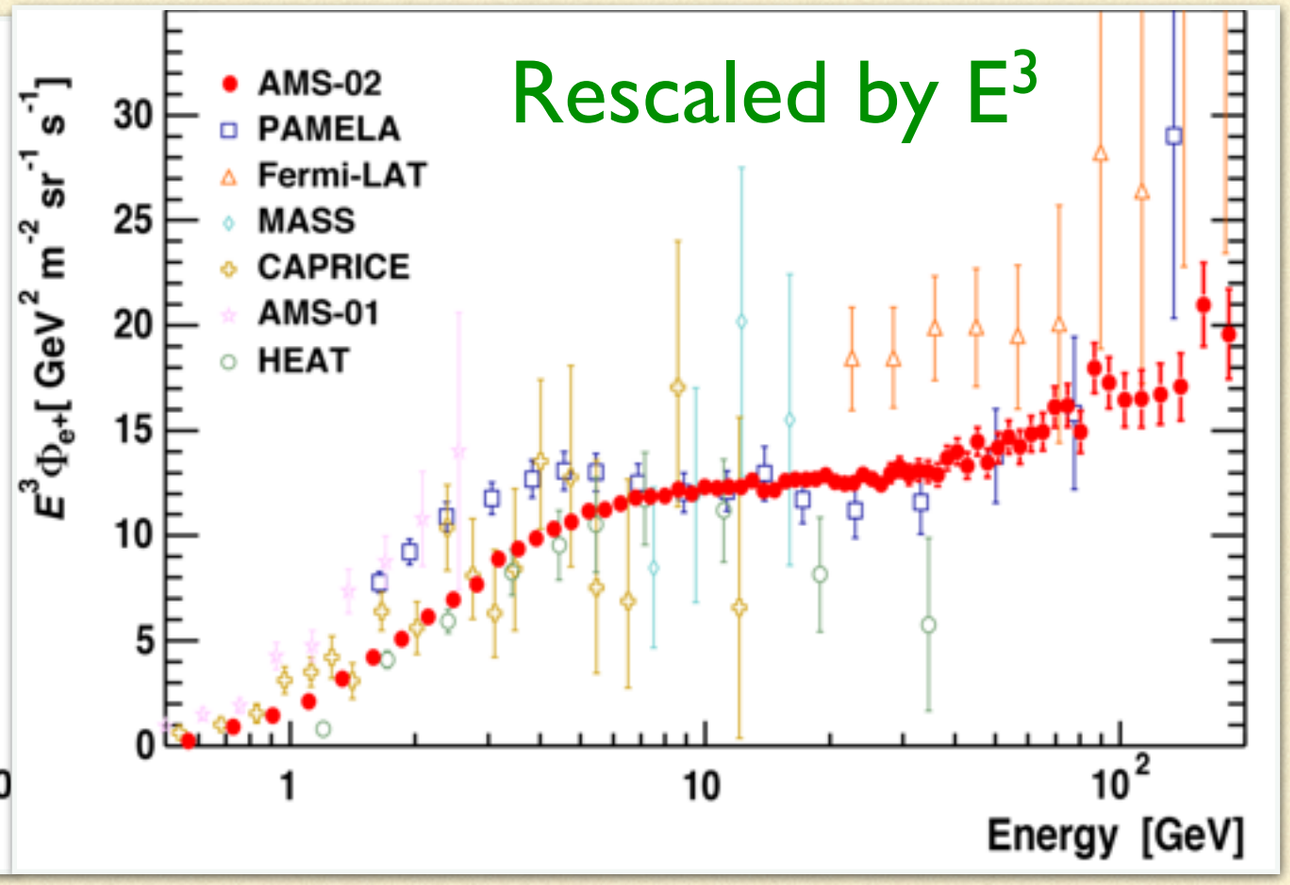




Above > 10 GeV:
spectral index > 3

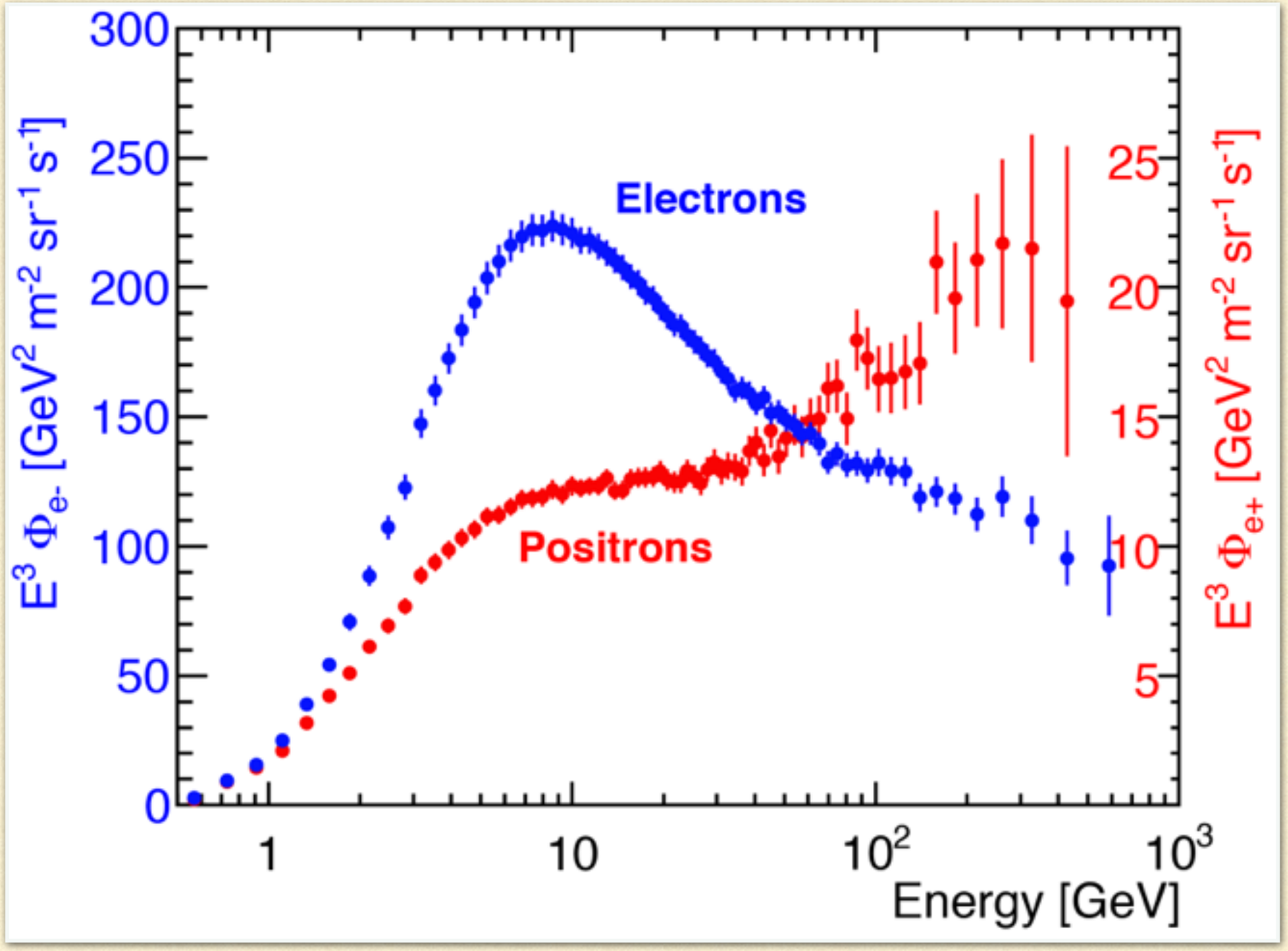
POSITRON FLUX





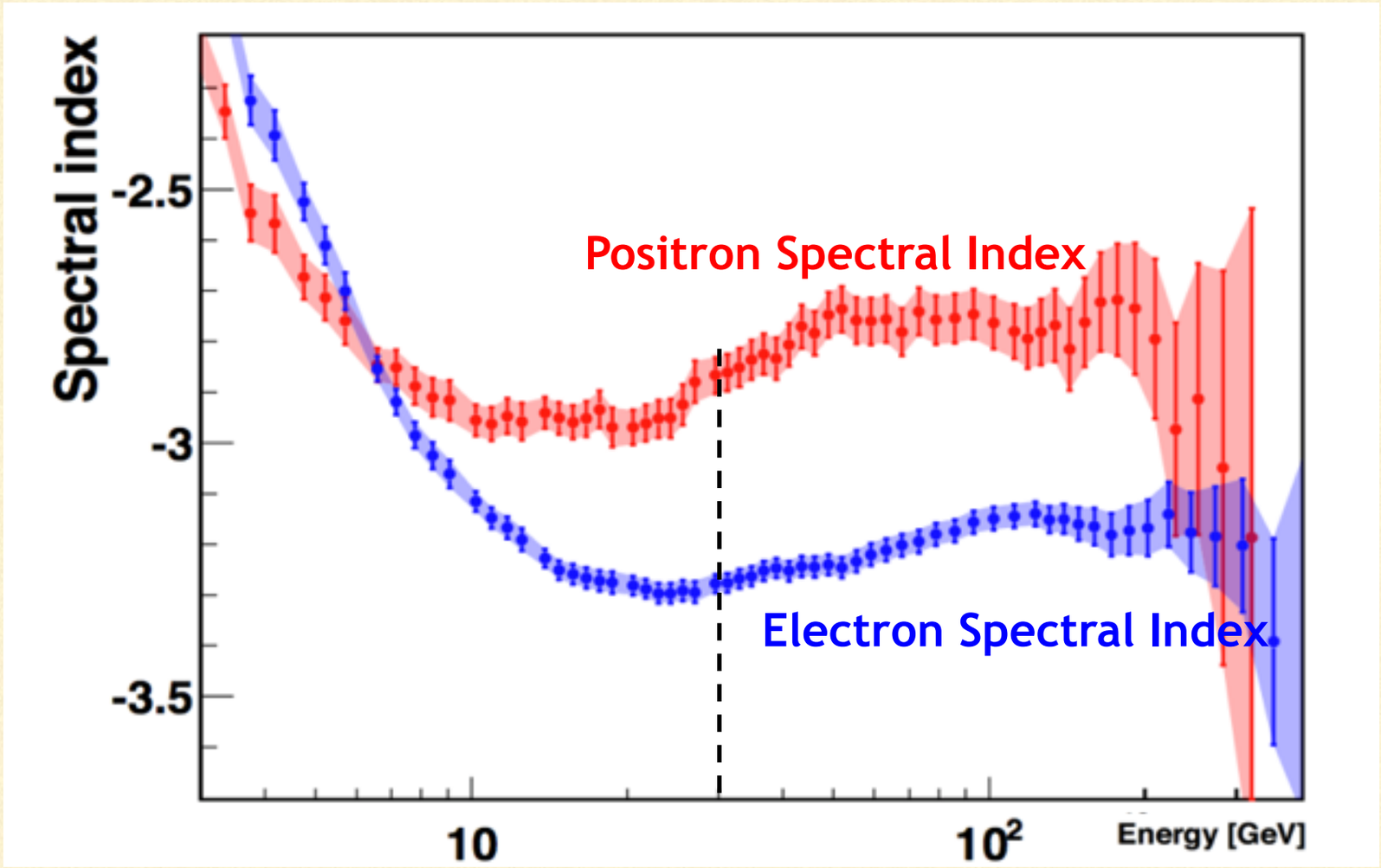
- Raising up to 10 GeV
- flat up to 30 GeV
- raising again

ELECTRONS AND POSITRONS COMPARED



The electron flux and the positron flux are different in their magnitude and energy dependence.

SPECTRAL INDEX

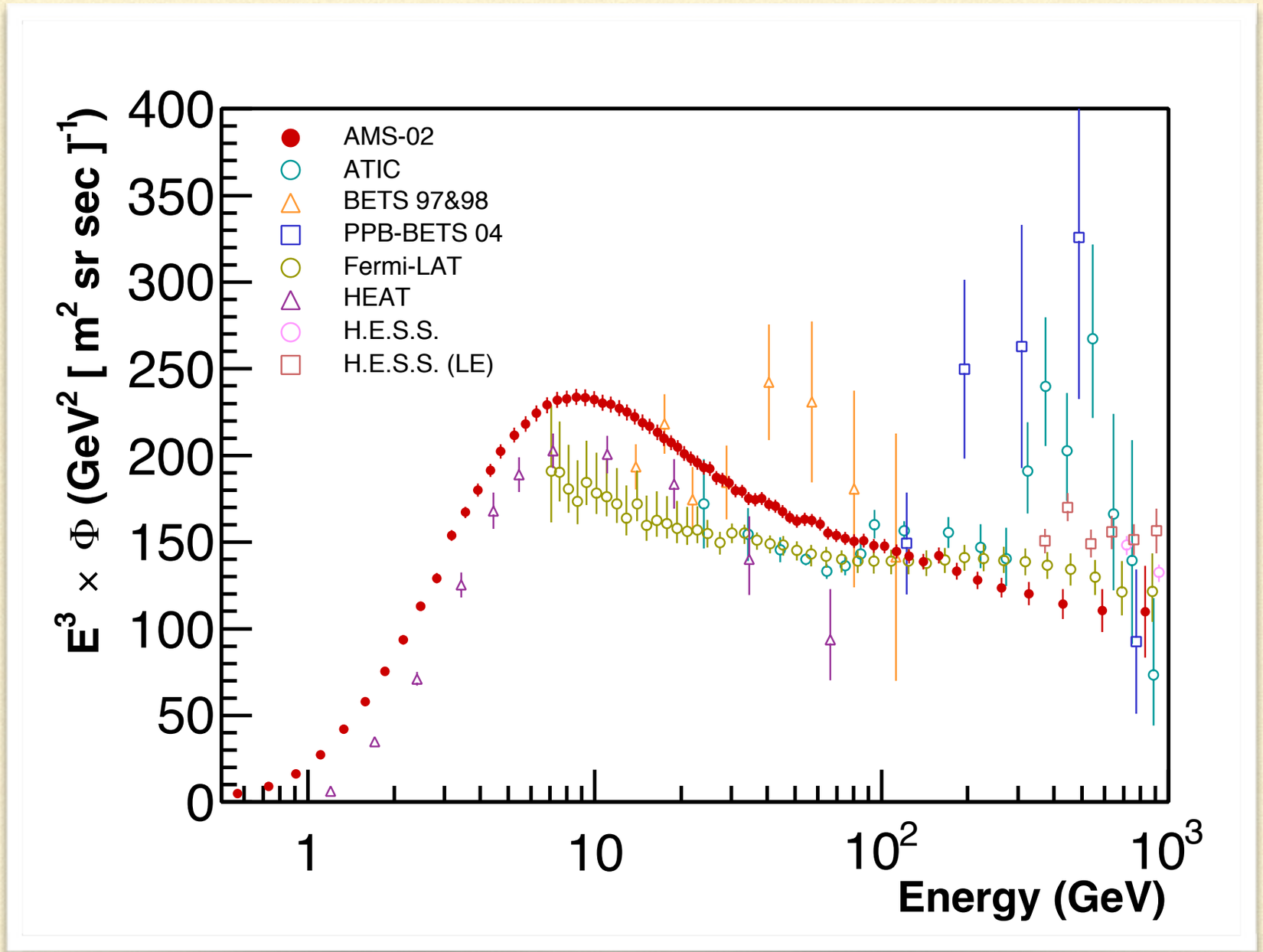


- The spectral indices of electrons and positrons are different
- Both spectra cannot be described by single power laws
- Change of behavior at ~30GeV

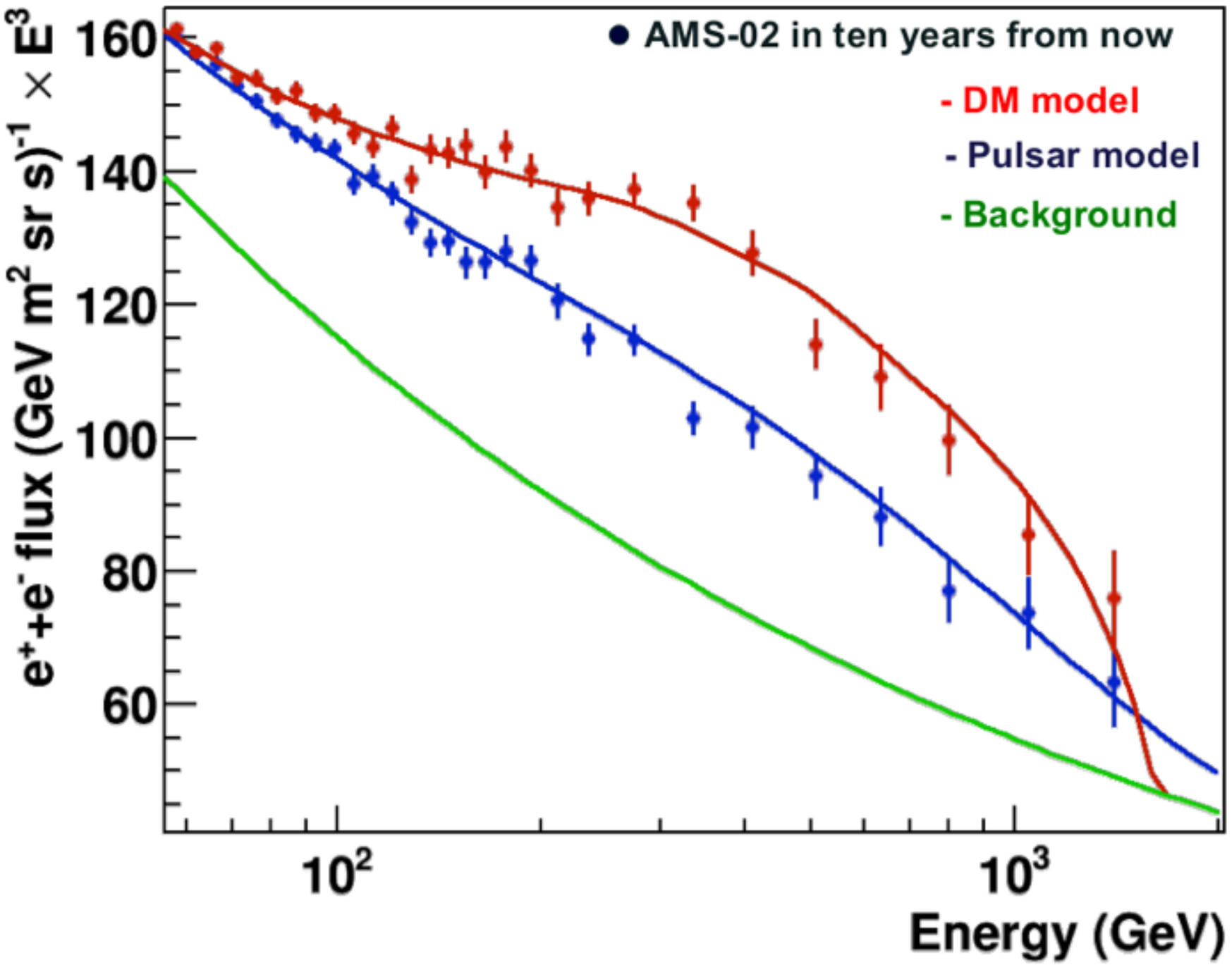
The rise in the positron fraction is actually due to an excess of positrons, not the loss of electrons (the positron flux is harder).

COMBINED FLUX

- TRD and ECAL are the key detectors in the (e^+ + e^-) measurement
- Independent of charge sign measurement (no charge confusion)
- High selection efficiency : 70% @ 1 TeV



AMS data and phenomenological models: what can we say in 10 years from now?"



MINIMAL MODEL TO FIT AMS DATA

Diffuse Term **Source Term**

$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

Positrons:

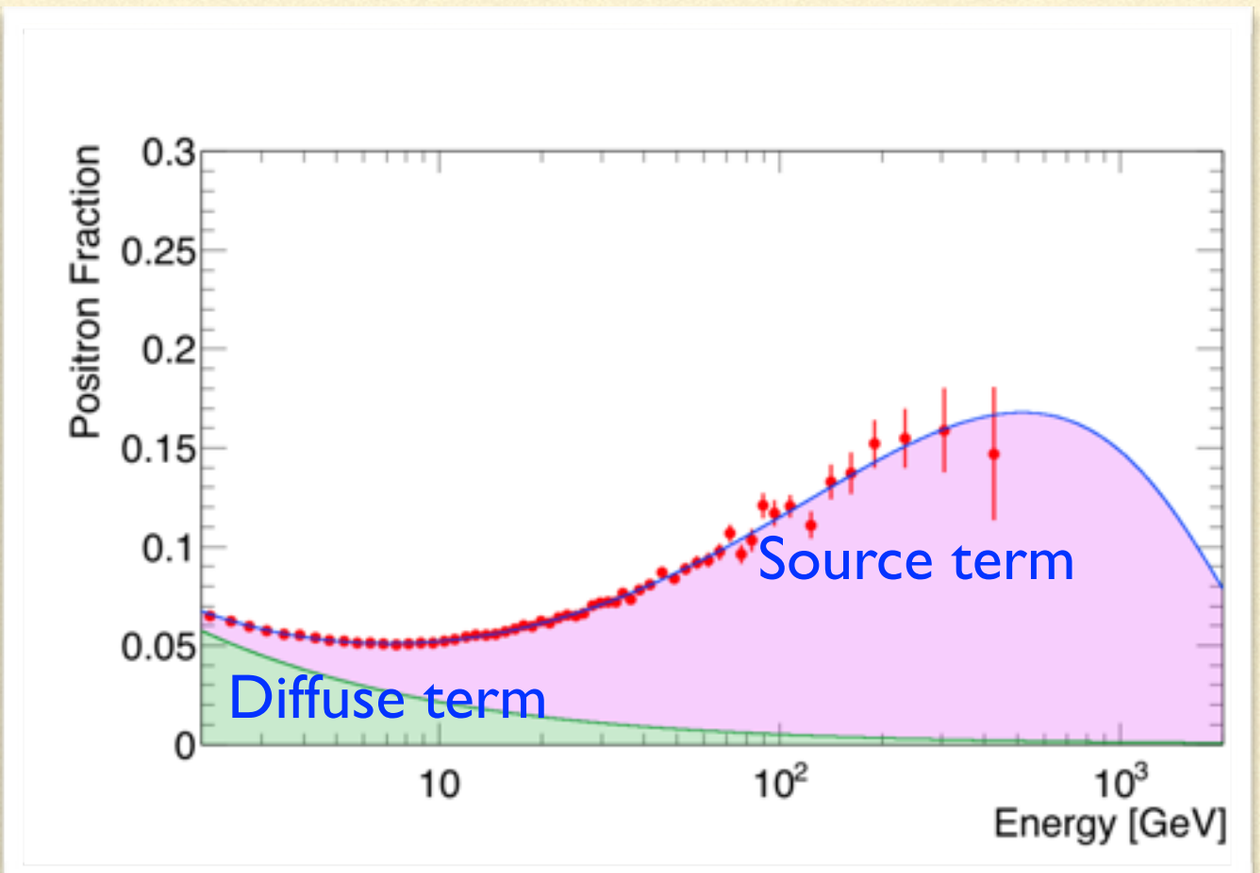
- Diffuse term: secondary production
- Source term

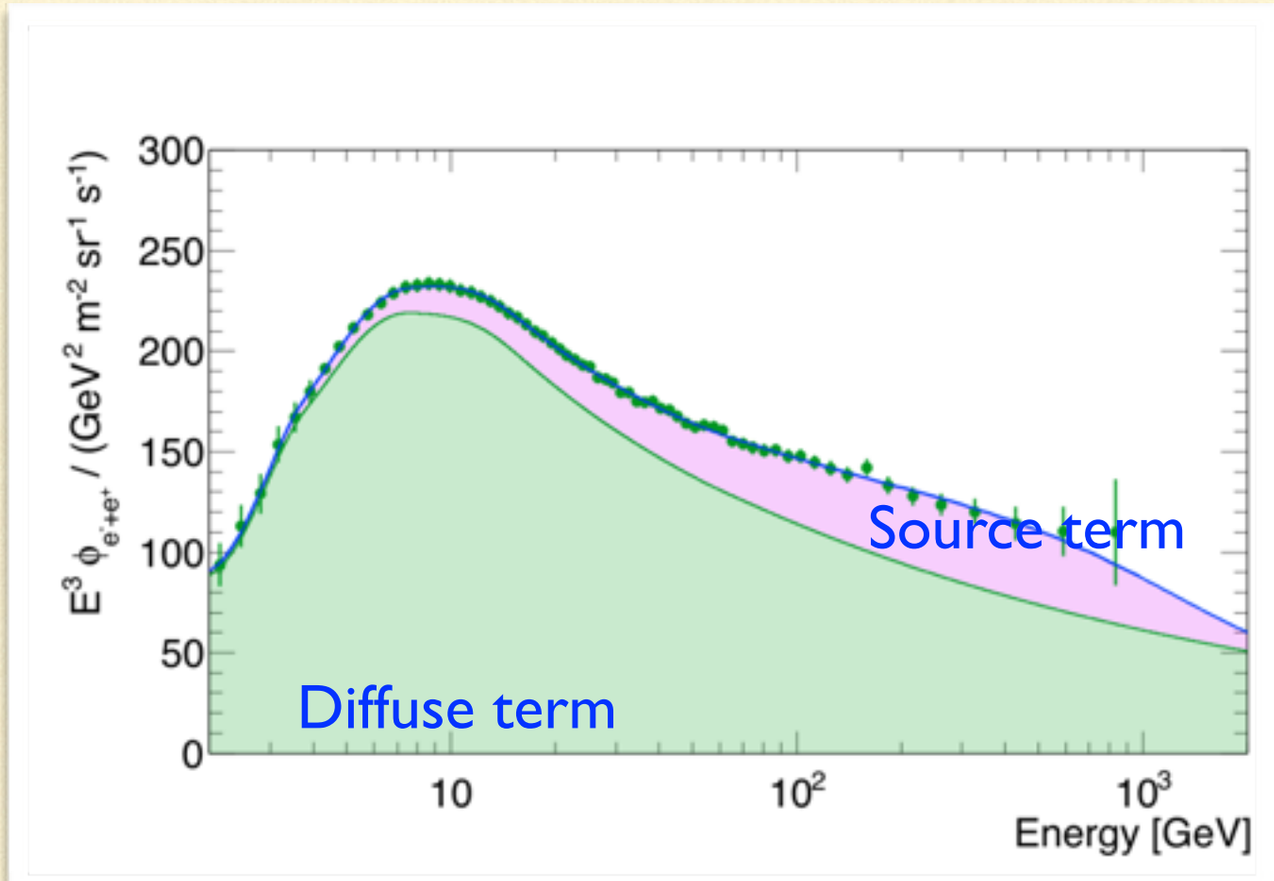
+

Electrons:

- Diffuse term: Primary and secondary production
- Source term

RESULTS FROM THE FIT



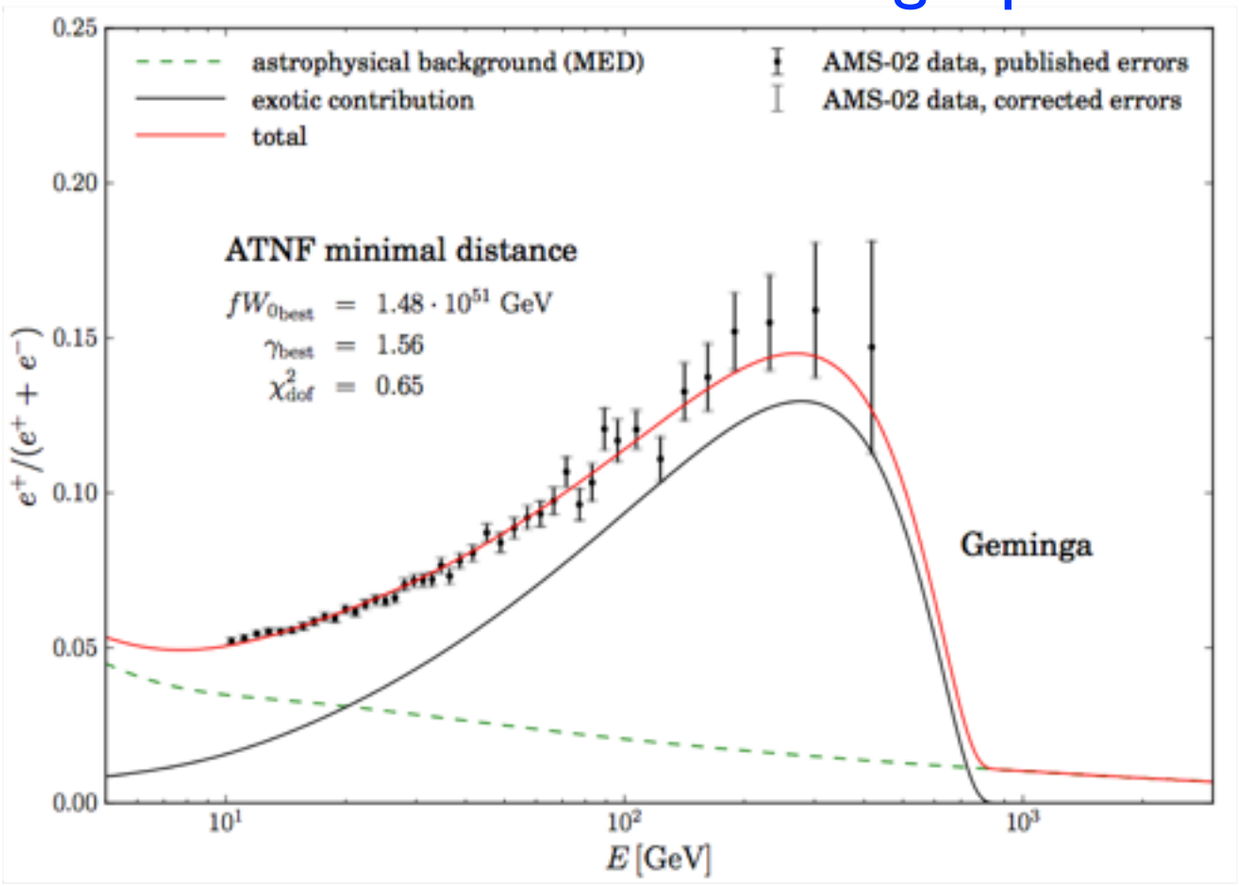


- Simultaneous fit to
  - Positron fraction from 2 GeV
  - Combined flux from 2 GeV
- Fits are satisfactory: data can be described by a common source of e^+ and e^-

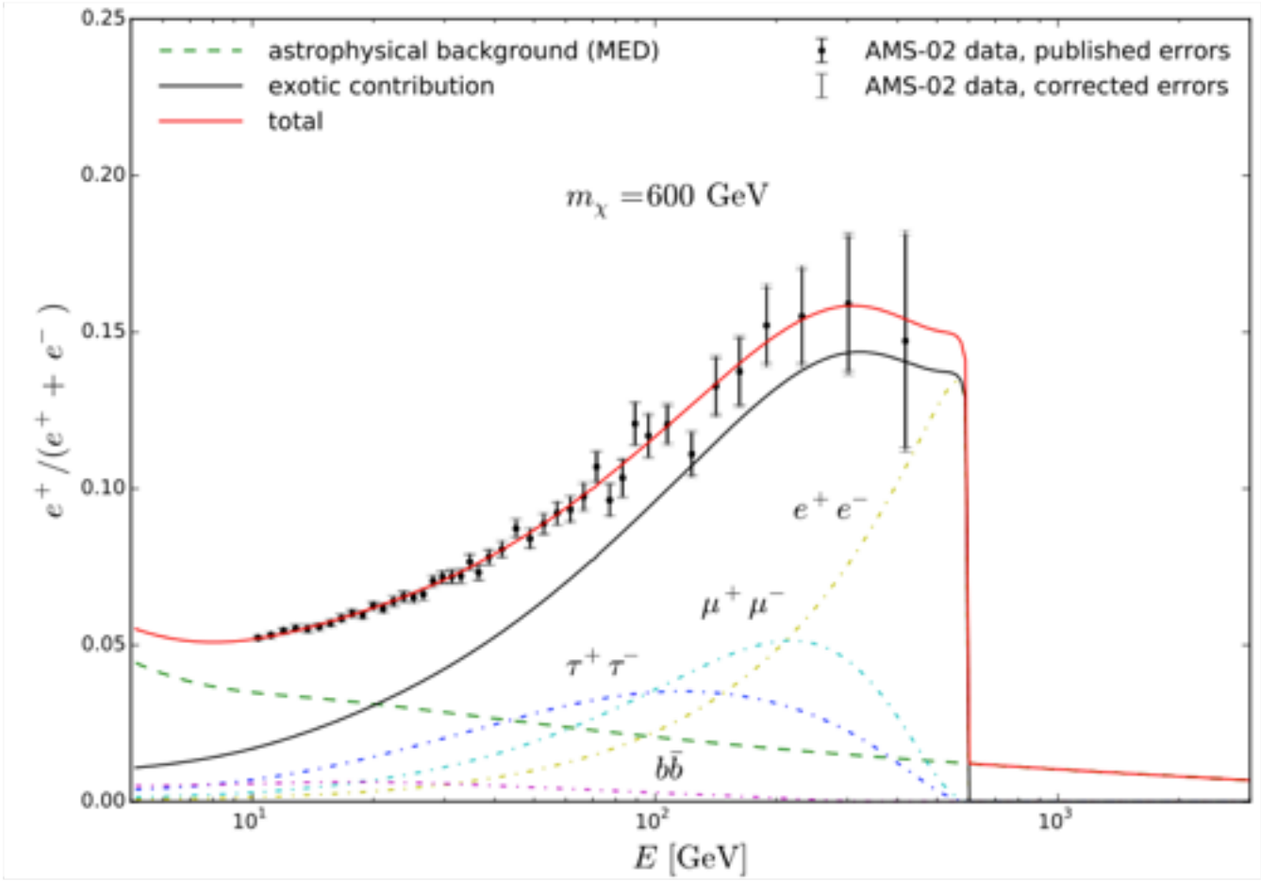
INTERPRETATION OF THE AMS-02 DATA

M. Boudaud et al, submitted to A&A [arXiv:1410.3799]

Positron fraction from a single pulsar



Positron fraction from DM annihilation



- A Dark Matter interpretation is consistent with the AMS-02 data, but requires:
  - A large enhancement of the annihilation cross section
  - A strong suppression of annihilation into p-pbar [PAMELA data].
- Young nearby pulsars can also fit the positron fraction

SUMMARY

- The AMS-02 experiment operates onboard the ISS since May 2011
  - All the detectors are working as expected
  - More than 54 billions events were recorded so far. This is much more than all the cosmic rays collected in the last 100 years.
- The AMS-02 Collaboration has published cosmic rays electrons and positron fuxes of *unprecedented quality and precision.*

- AMS-02 is expected to collect data at least until 2024
- Many important measurements are yet to come:
  - Protons, helium, B/C, antiproton, heavier nuclei, ….

THANK YOU FOR YOUR ATTENTION !