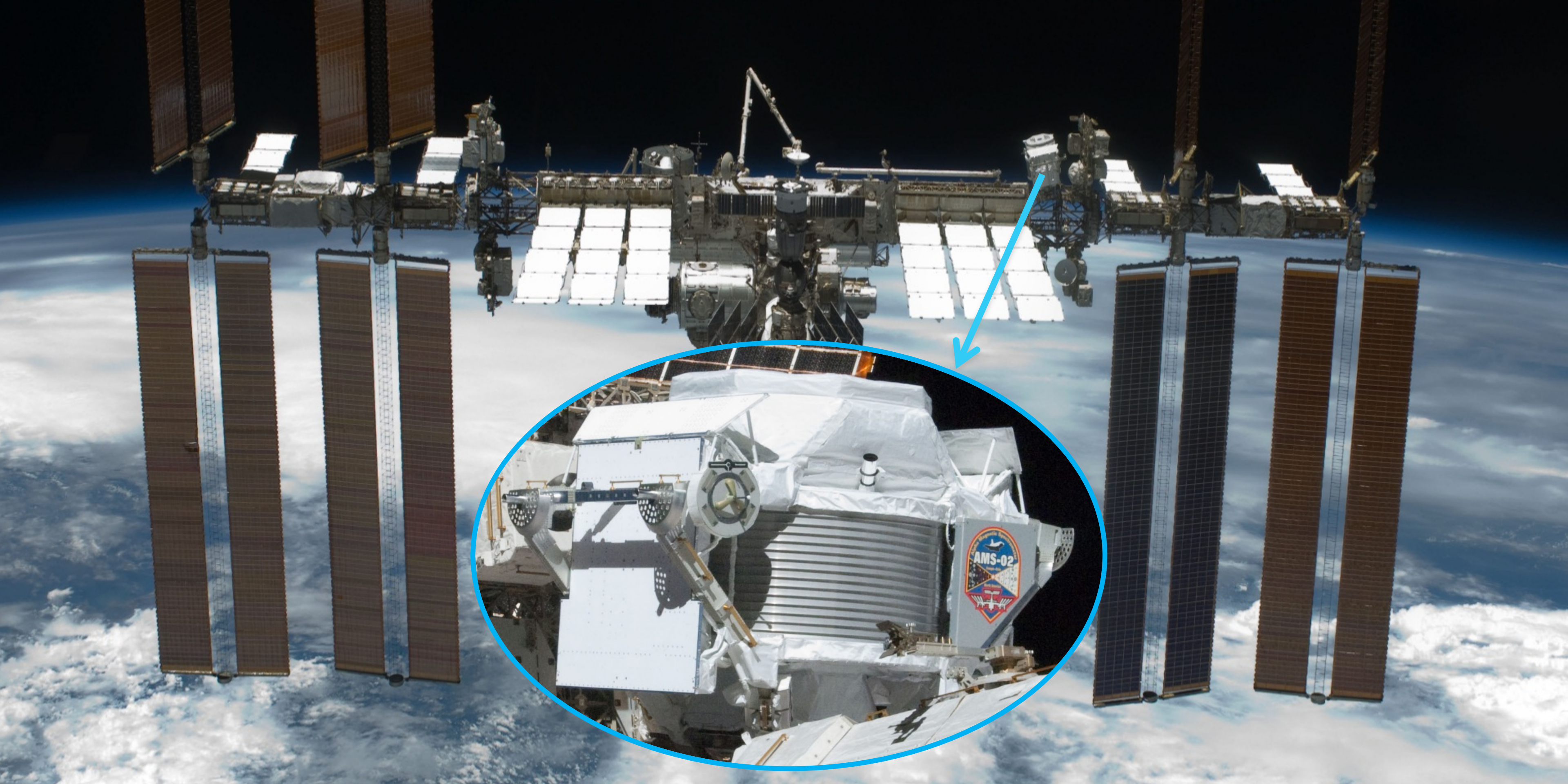
Latest Results from AMS-02

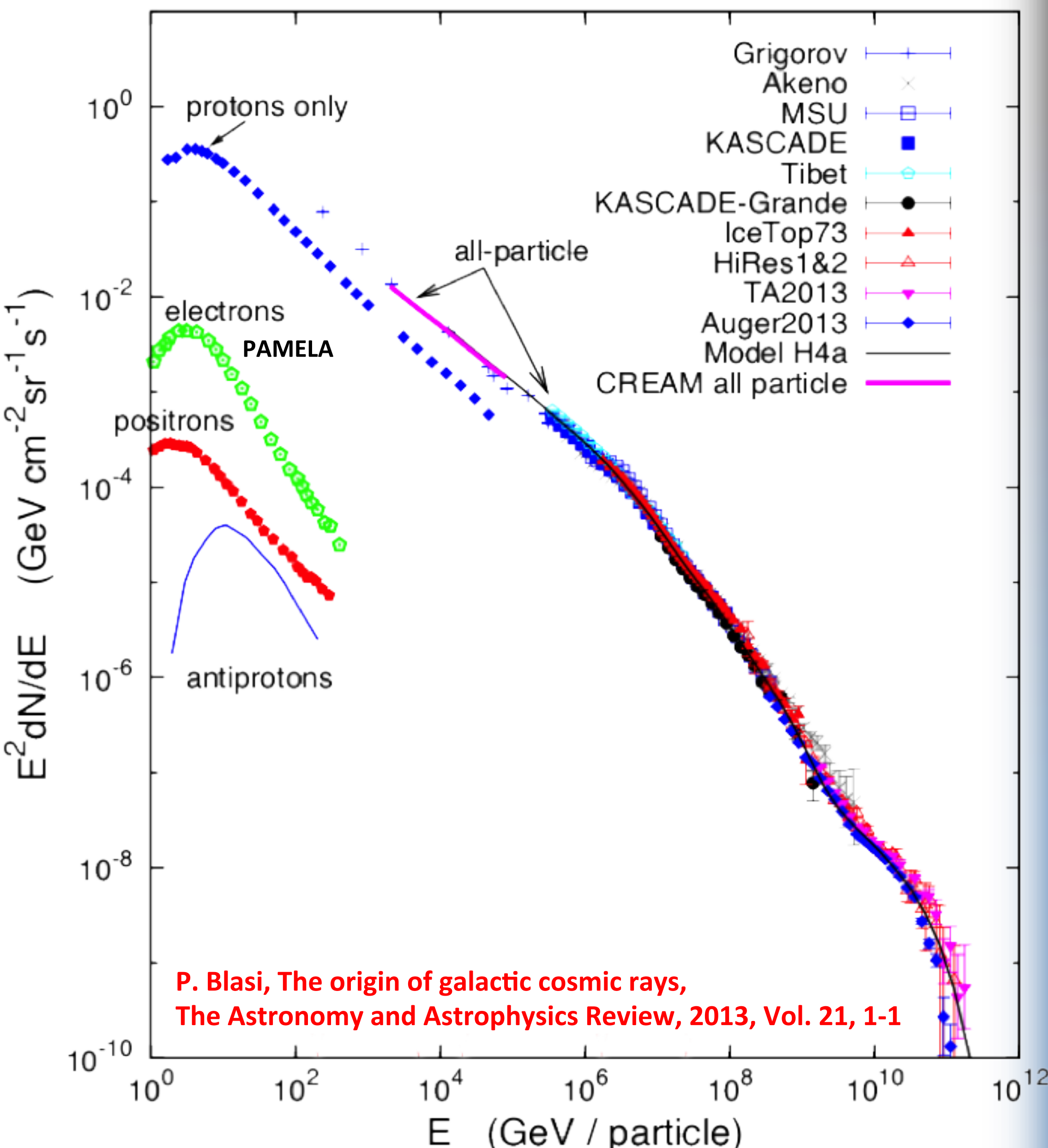


Zhili Weng (MIT, Cambridge)
On behalf of the AMS Collaboration

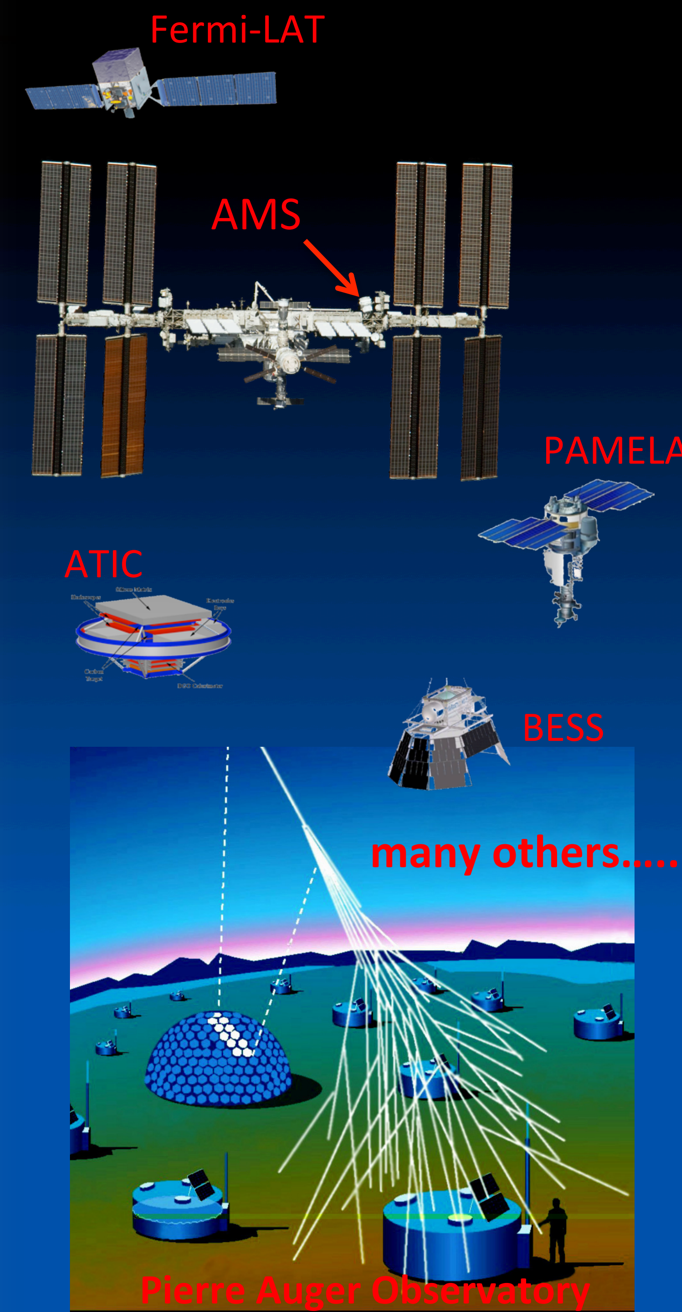
Invisible 2015, Madrid, 26 June 2015

Charged Cosmic Ray Particles

*not to scale

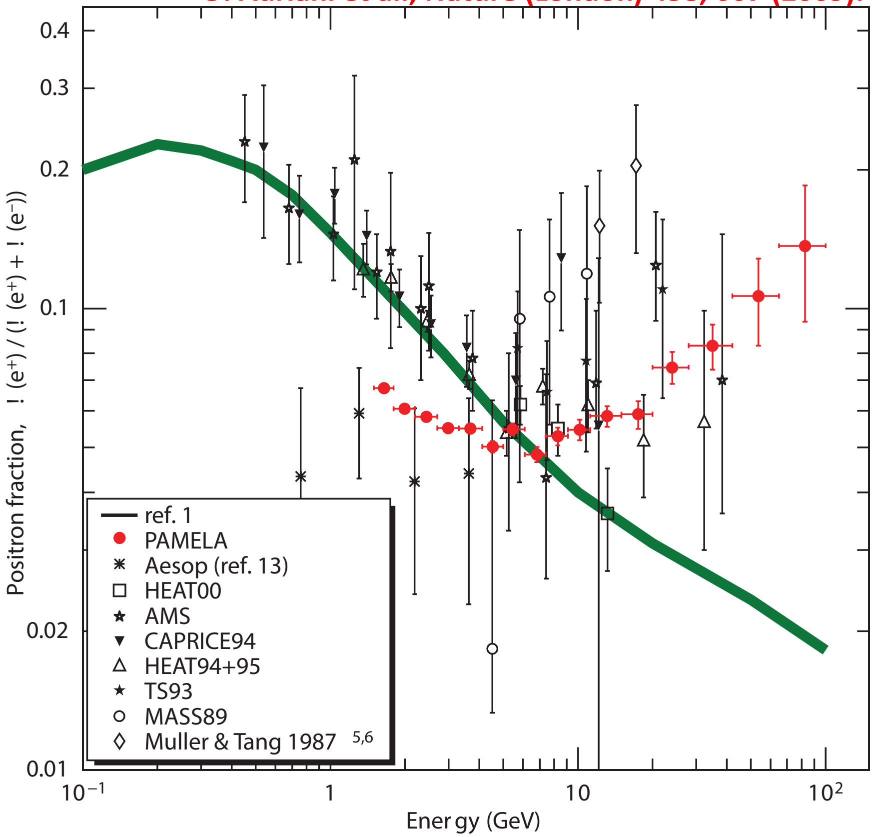


P. Blasi, The origin of galactic cosmic rays,
The Astronomy and Astrophysics Review, 2013, Vol. 21, 1-1



Charged Cosmic Ray Particles

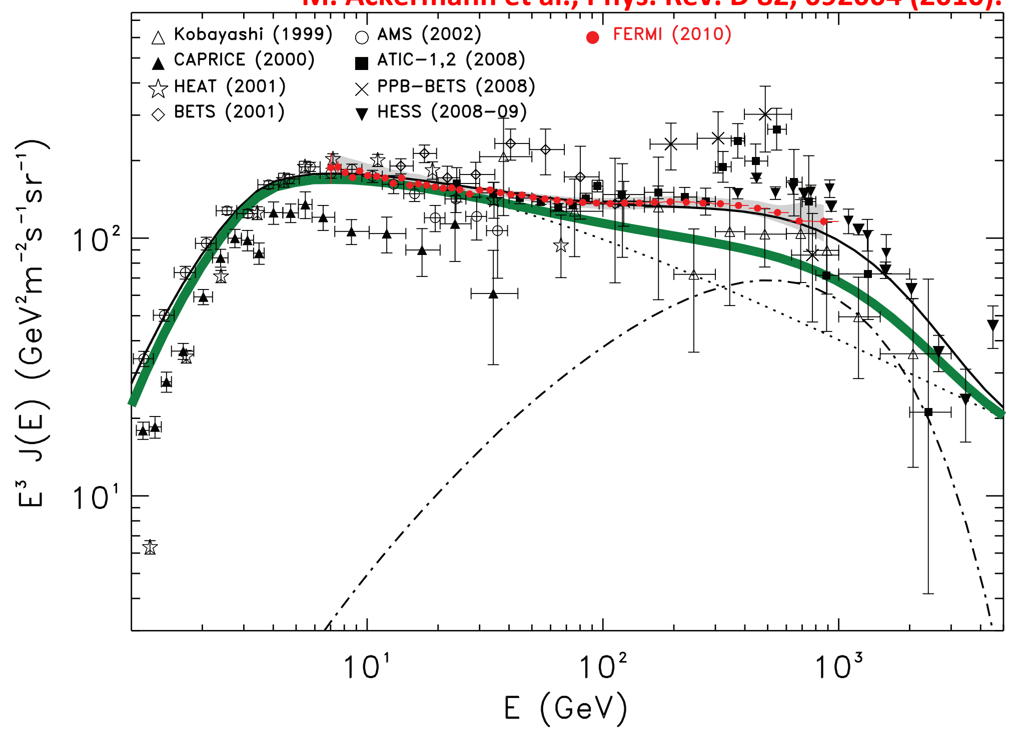
O. Adriani et al., Nature (London) 458, 607 (2009).



There are observed "anomaly" in cosmic ray that may link to dark matter:

- **Rise in positron fraction**
- **Possible excess on combined positron and electron spectrum**

M. Ackermann et al., Phys. Rev. D 82, 092004 (2010).



AMS Physics Program

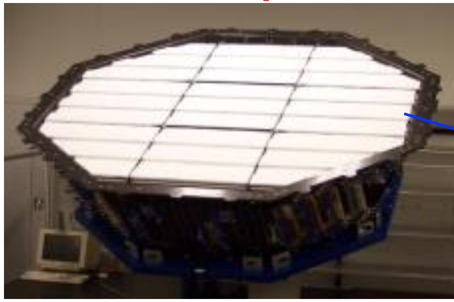
A long duration mission for precision cosmic rays measurement:

- **Searches for primordial antimatter:**
  - **Anti-nuclei: He, …**
- **Indirect Dark Matter searches:**
  - **simultaneous observation of several signal channels: e^+ , e-, antiproton , …**
- **Understanding of CR propagation and local CR sources**
- **Searches for new forms of matter**
- **Effects of solar modulation**

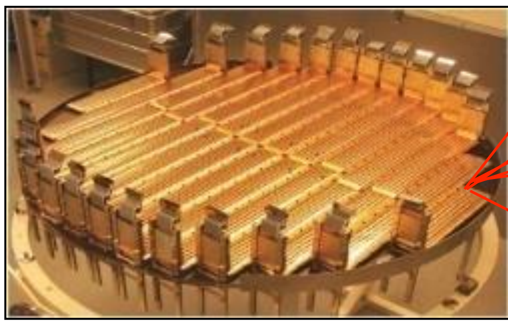

AMS
300,000 electronic channels
650 processors
5m x 4m x 3m
7.5 tons

Alpha Magnetic Spectrometer

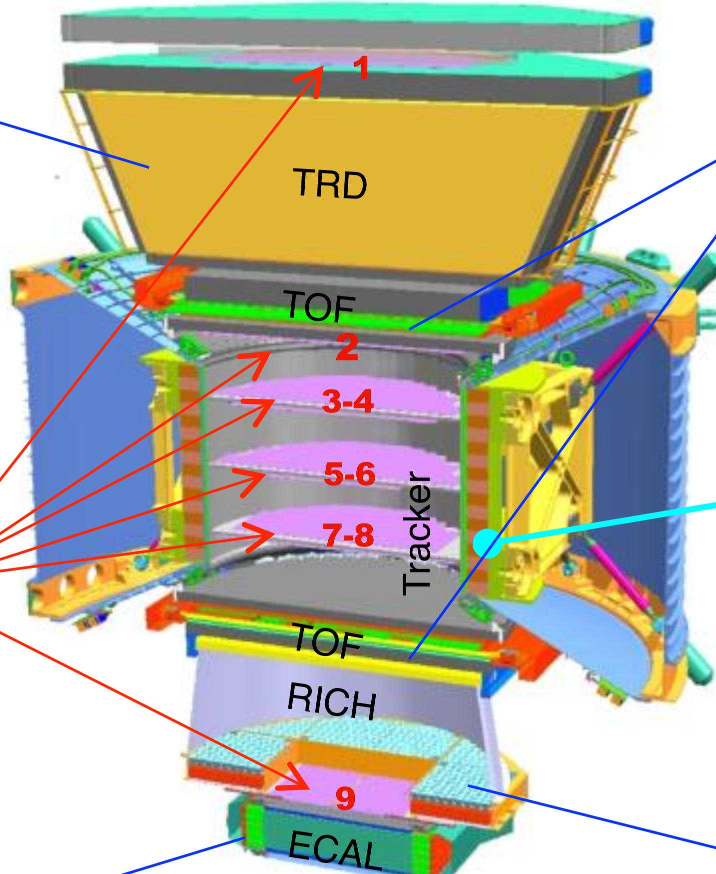
Transition Radiation Detector
Electron/proton, Z



Silicon Tracker
Z, P

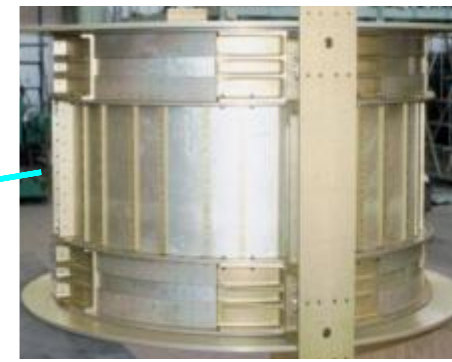


Electromagnetic Calorimeter
E of electrons



Time of Flight
Z, E

Magnet
±Z

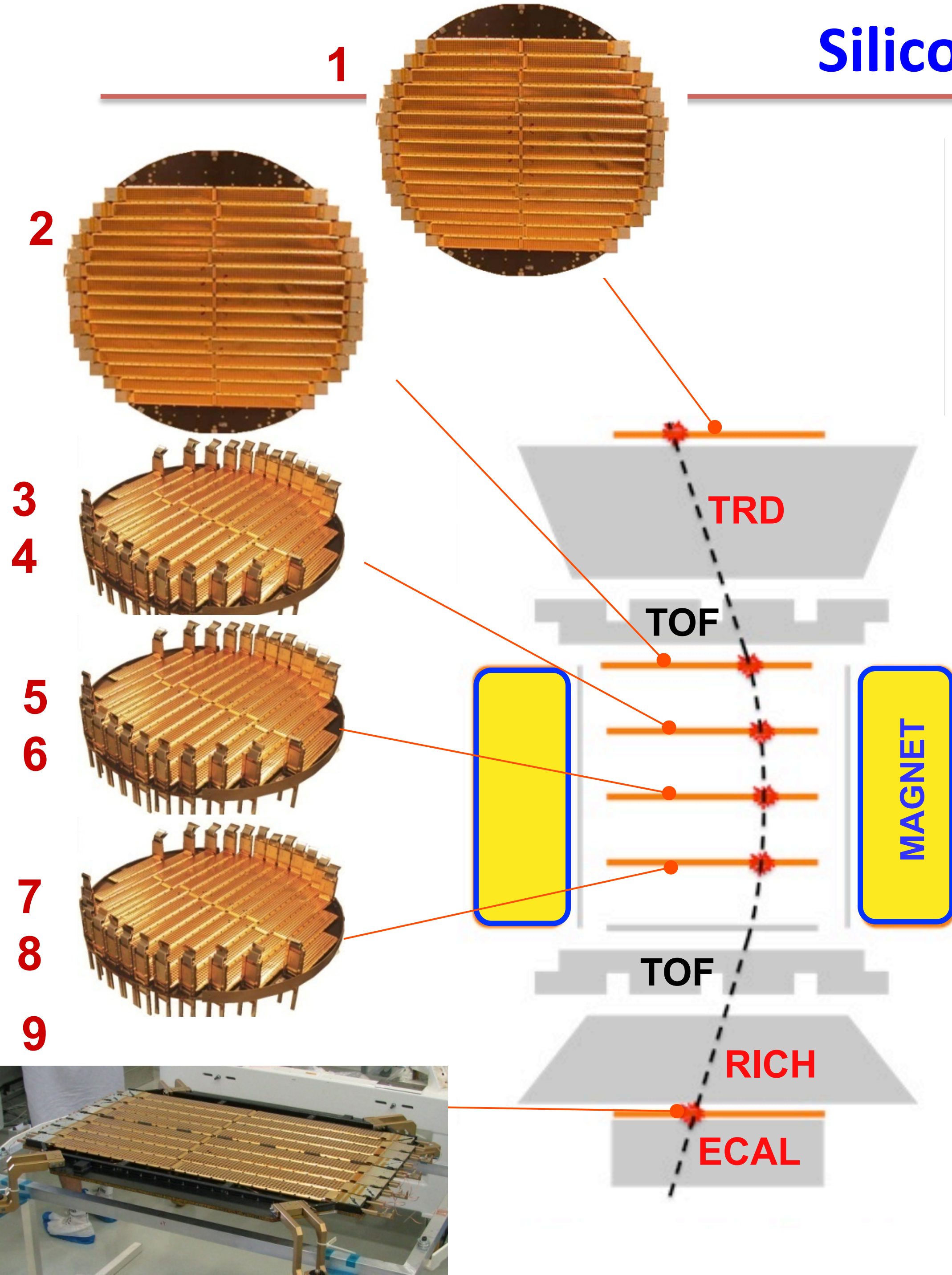


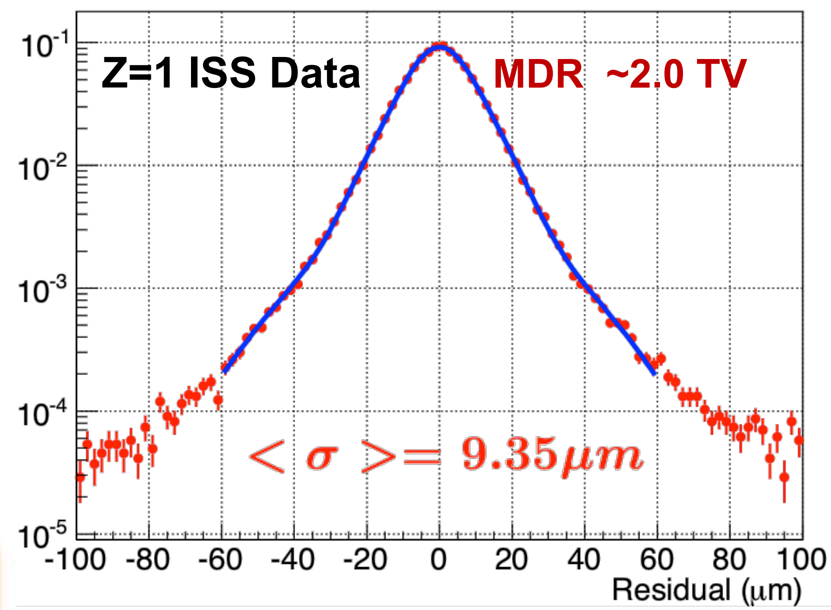
Ring Imaging Cherenkov
Z, E

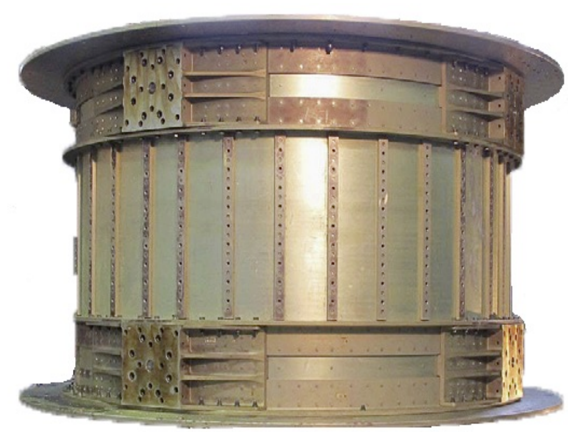
The Charge and Energy are measured independently by several detectors

Precise identification of particle species

Silicon Tracker and Magnet

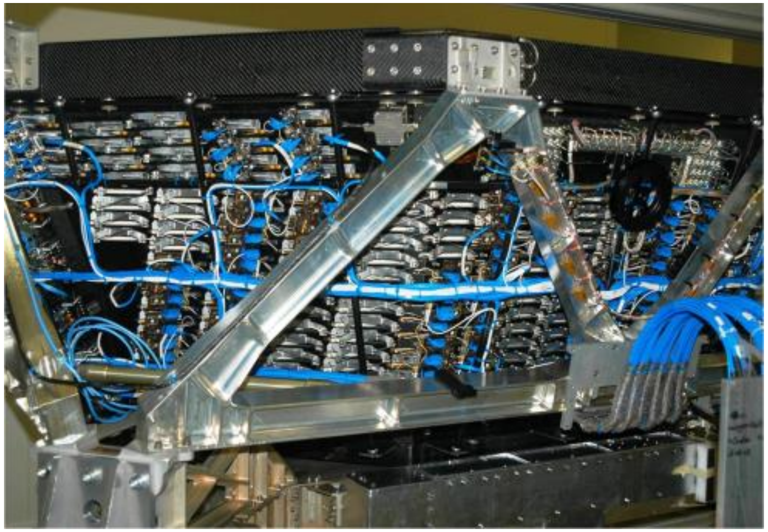


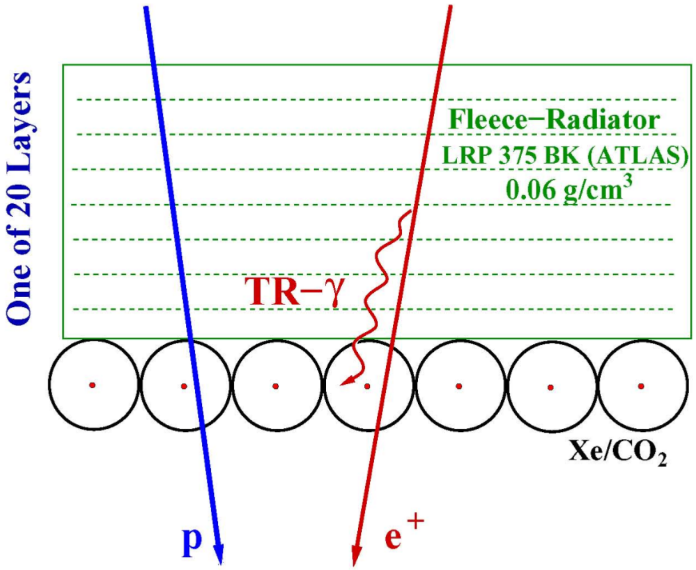


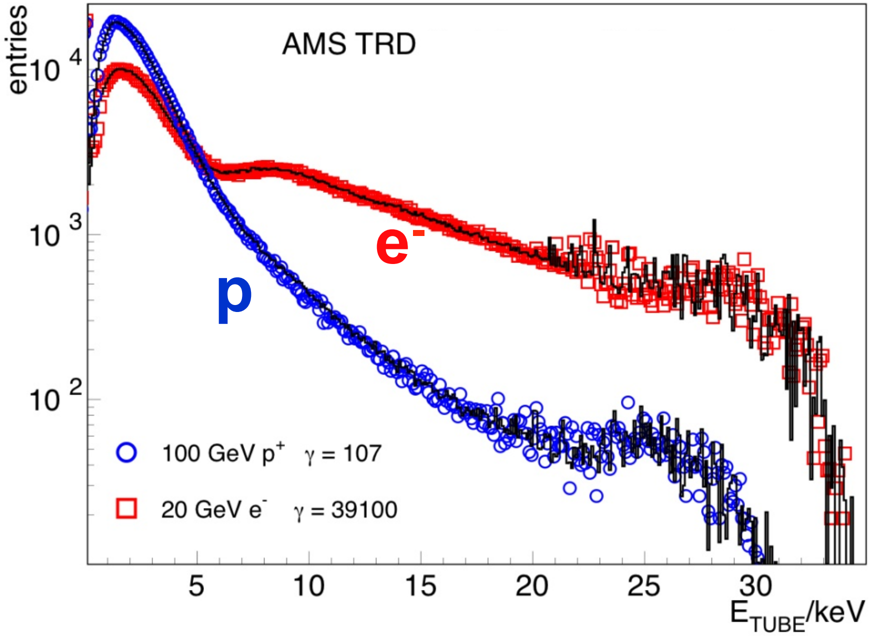


Permanent magnet: 1.4kG

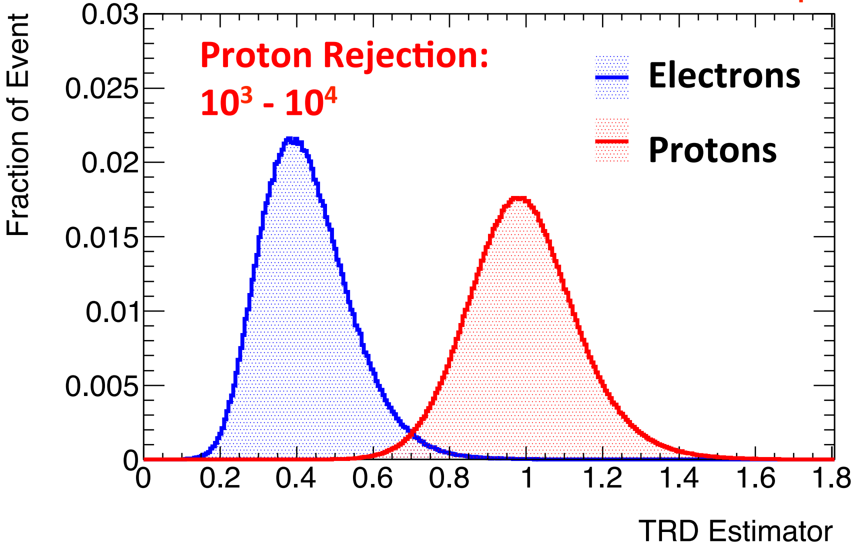
Transition Radiation Detector (TRD)







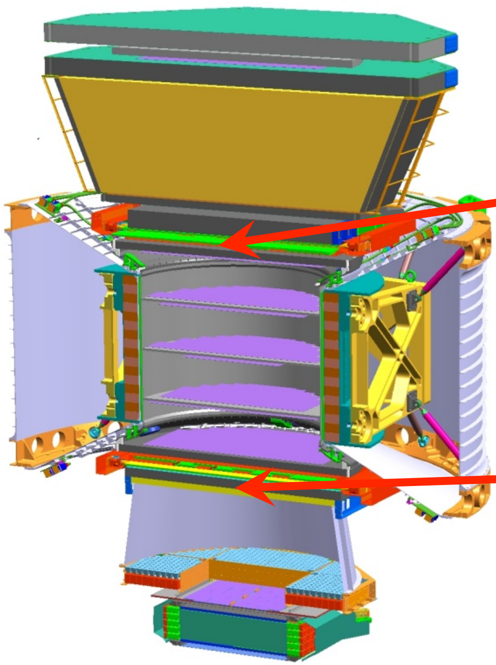
TRD estimator = $-\ln(P_e/(P_e+P_p))$

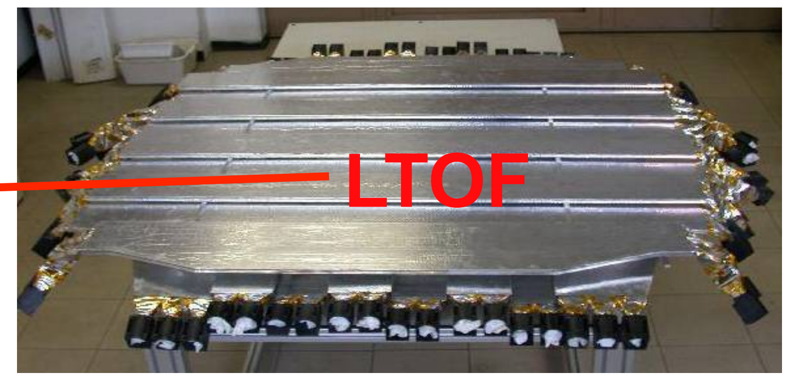


Time of Flight (TOF)

4 scintillator planes

Provides trigger for charged particles

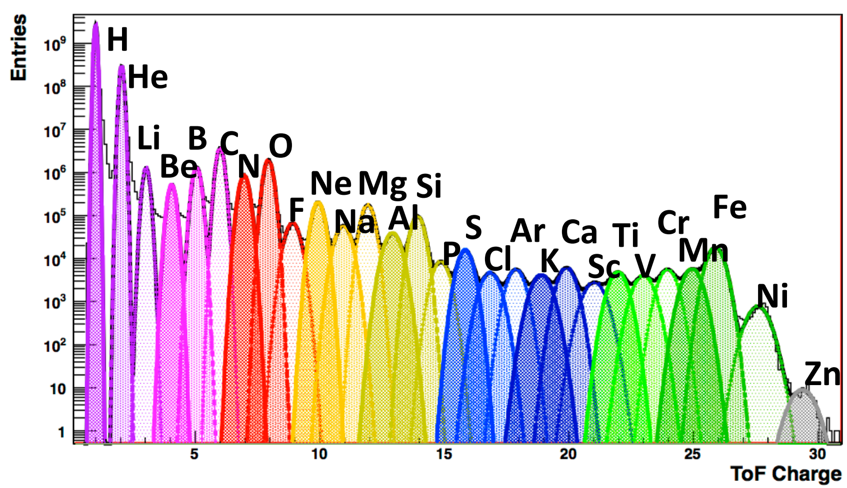




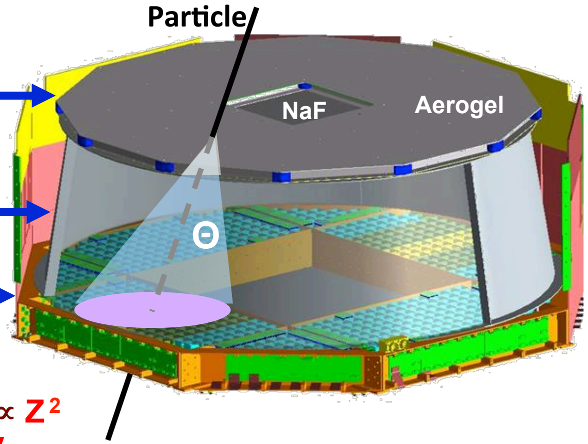
Measures direction and velocity

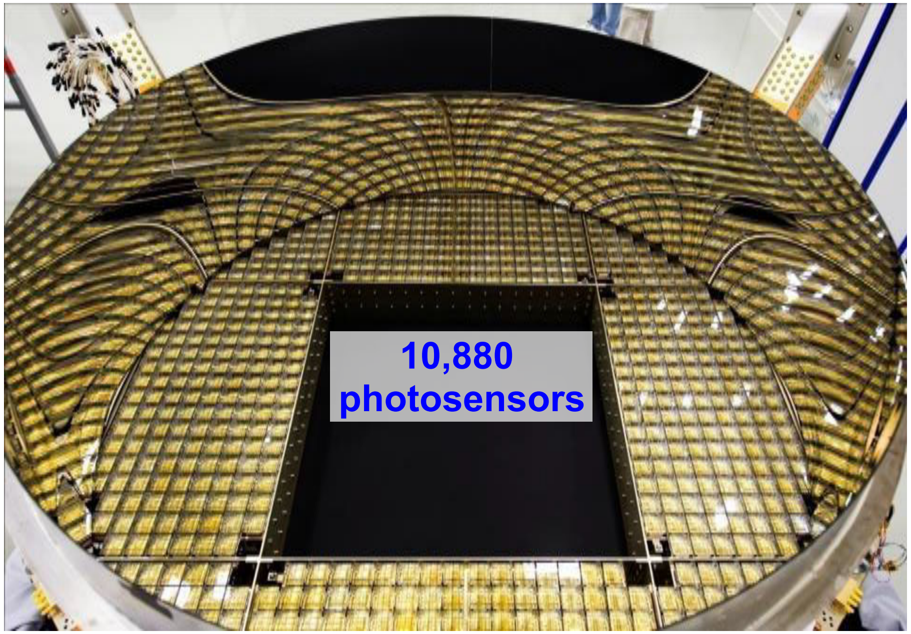
Time resolution 160 picoseconds(Z=1)

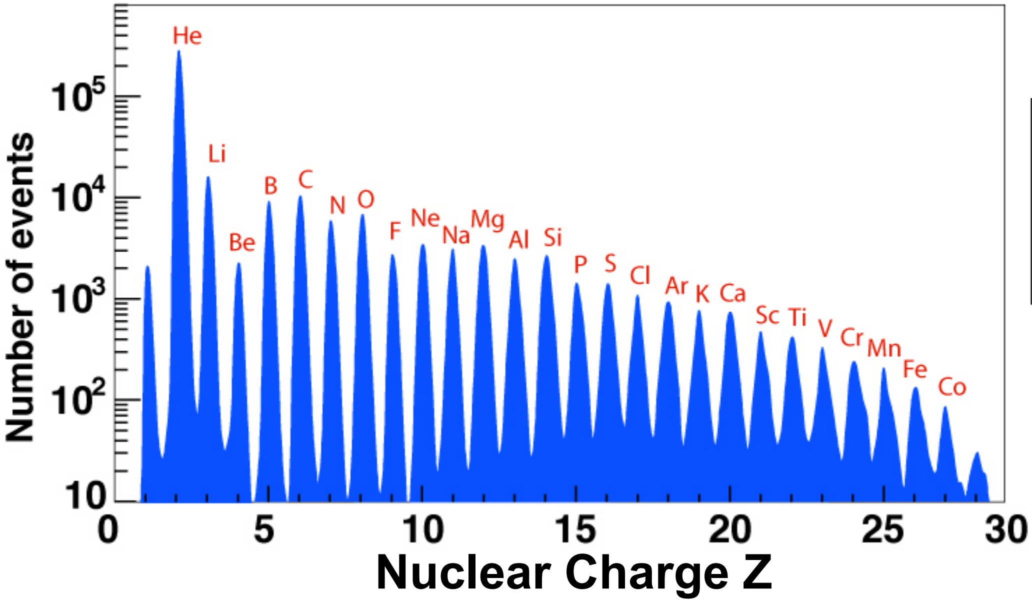
Measures absolute charge

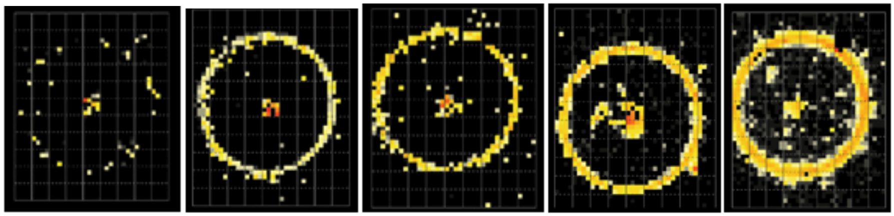


Ring Imaging Cherenkov Detector (RICH)







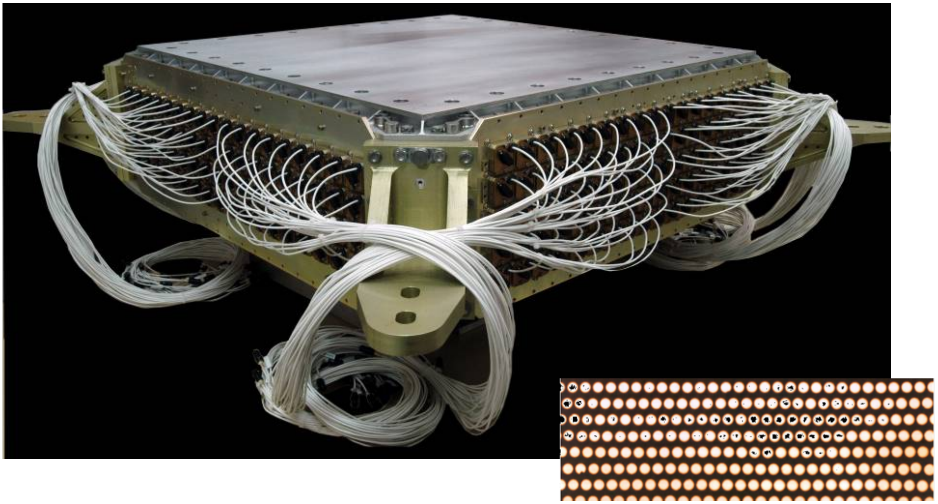


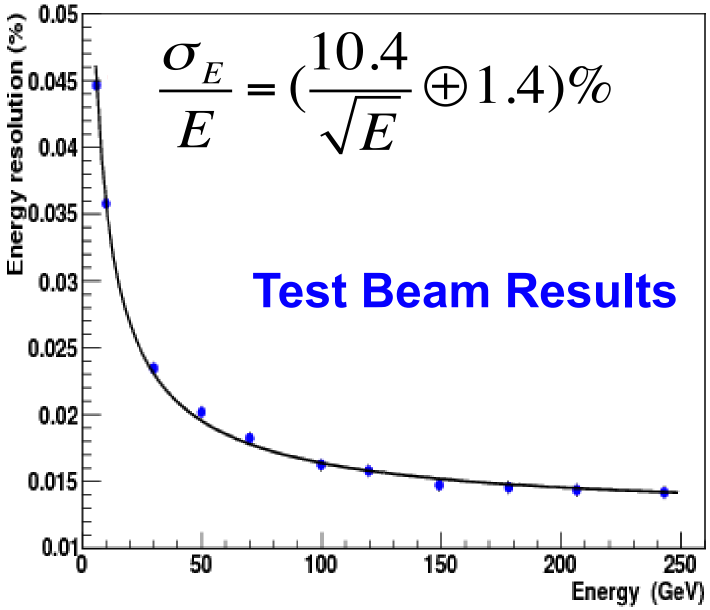
Single Event Displays

RICH test beam E=158 GeV/n

Electromagnetic Calorimeter

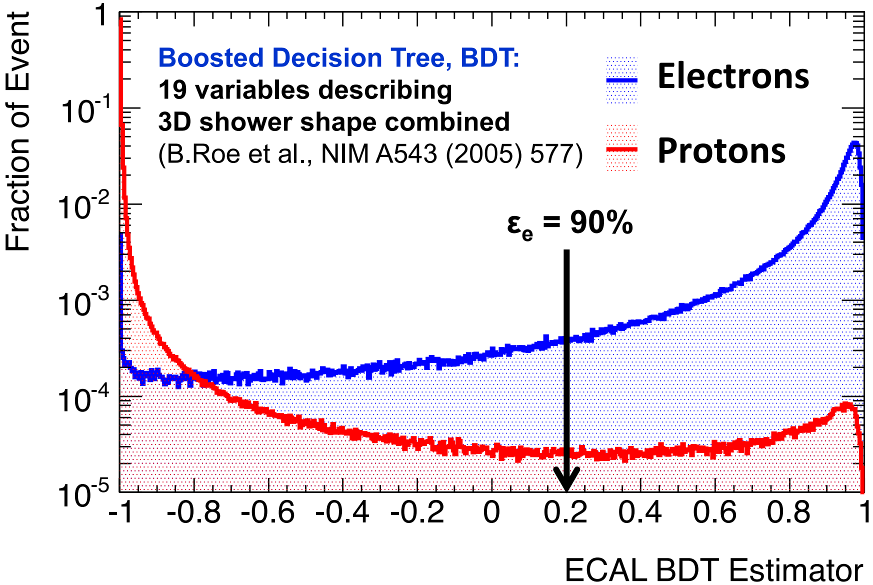
A precision, 17 X_0, TeV, 3D measurement of the directions and energies of light rays and electrons





50 000 fibers, $\phi = 1$ mm distributed uniformly inside 600 kg of lead

Energy scale and energy resolution measured using Test Beam



May 19, 2011: AMS installation completed.
In 4 years we have collected 67 billion events.

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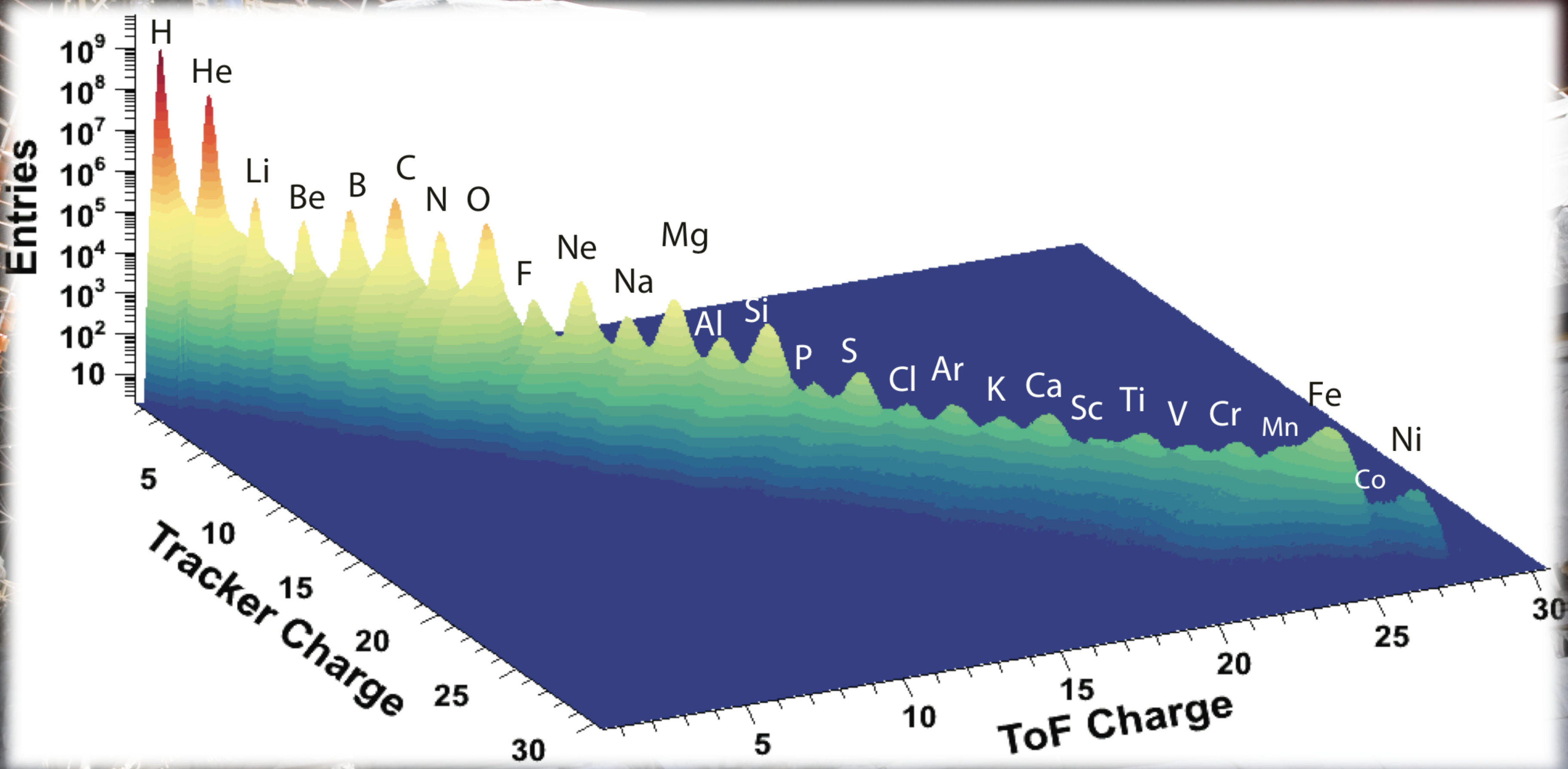
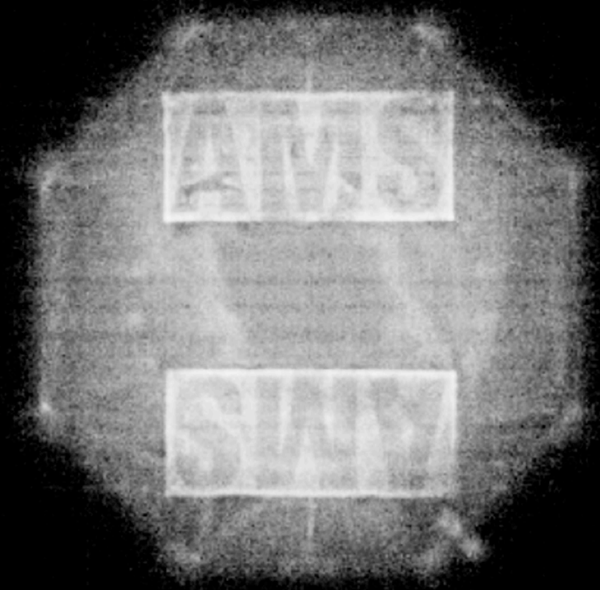
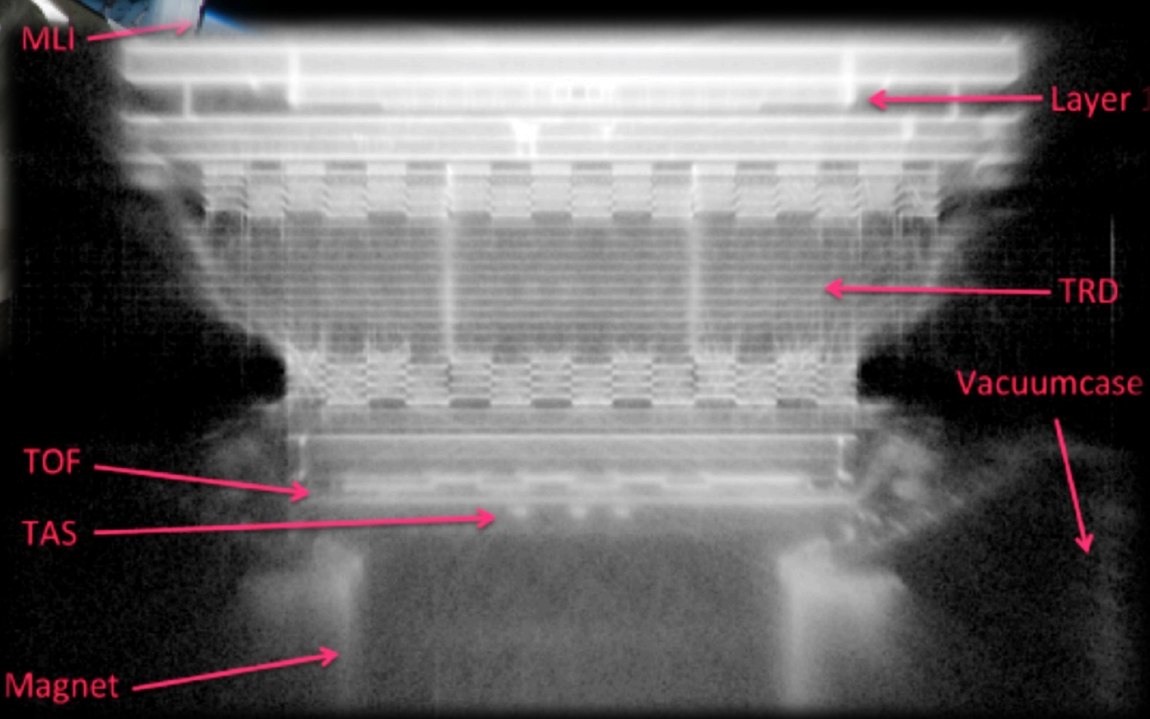
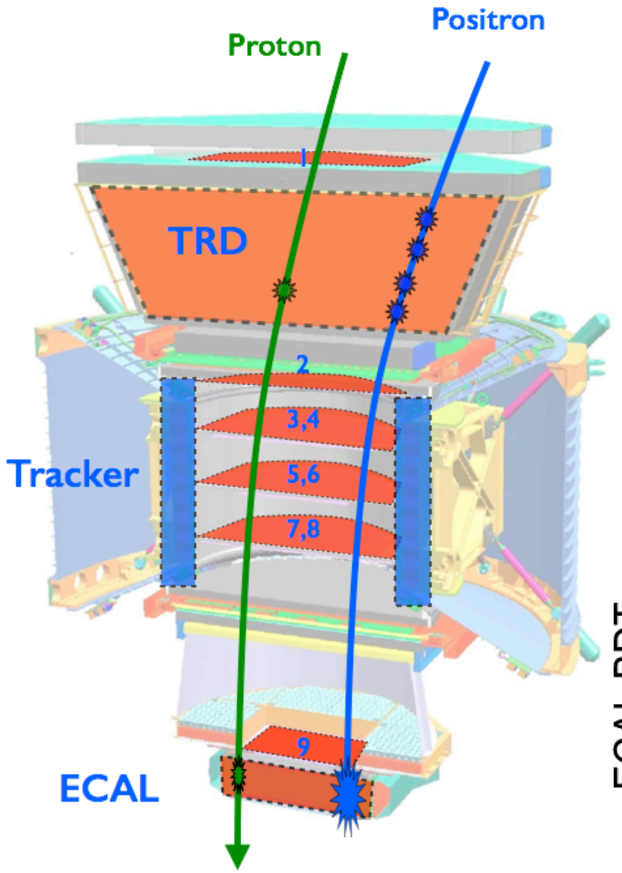


Tomography with vertices

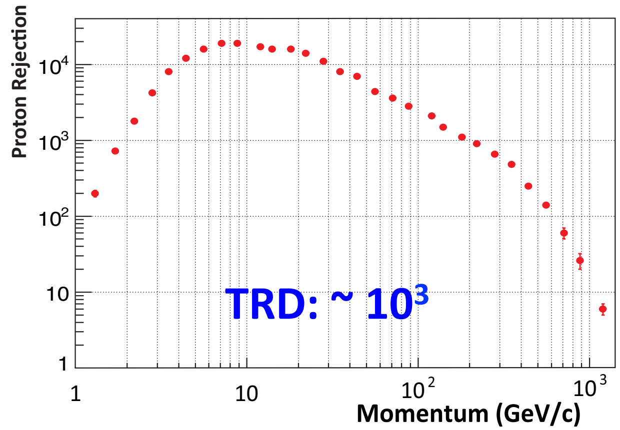


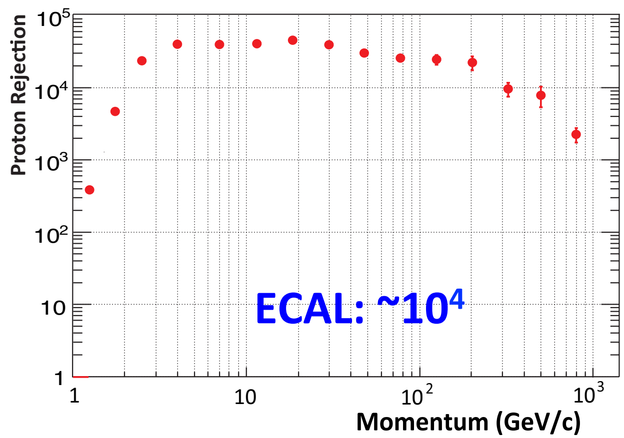


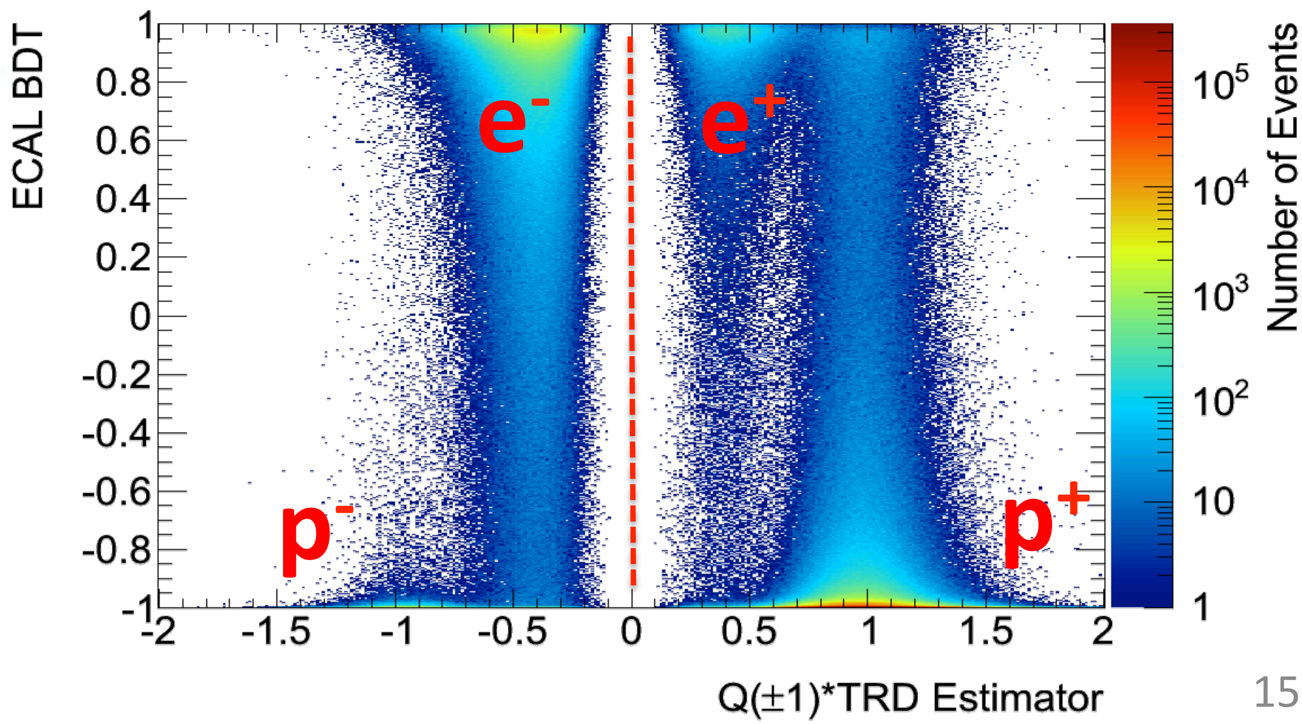
Particle Identification



Separation power @ 90% efficiency







Origin of CR Positron and Electron

e^- are produced and accelerated from SNR

Collision of "ordinary" Cosmic Rays produce secondary e^+, e^-

Among many possible mechanisms:

Collisions of Dark Matter will produce additional e^+,e^-

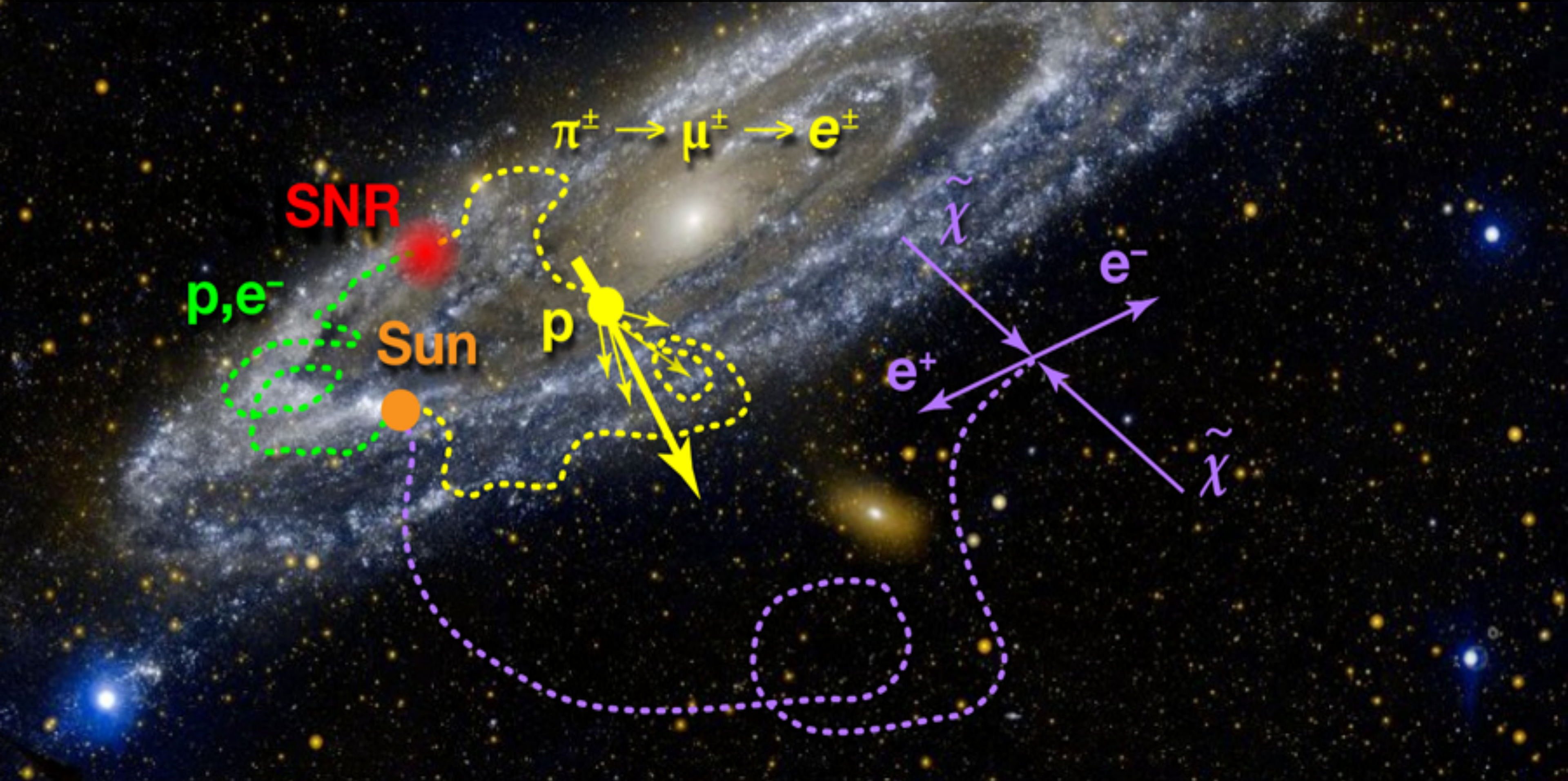


Image: GALEX, JPL-Caltech, NASA; Drawing: APS/Alan Stonebraker

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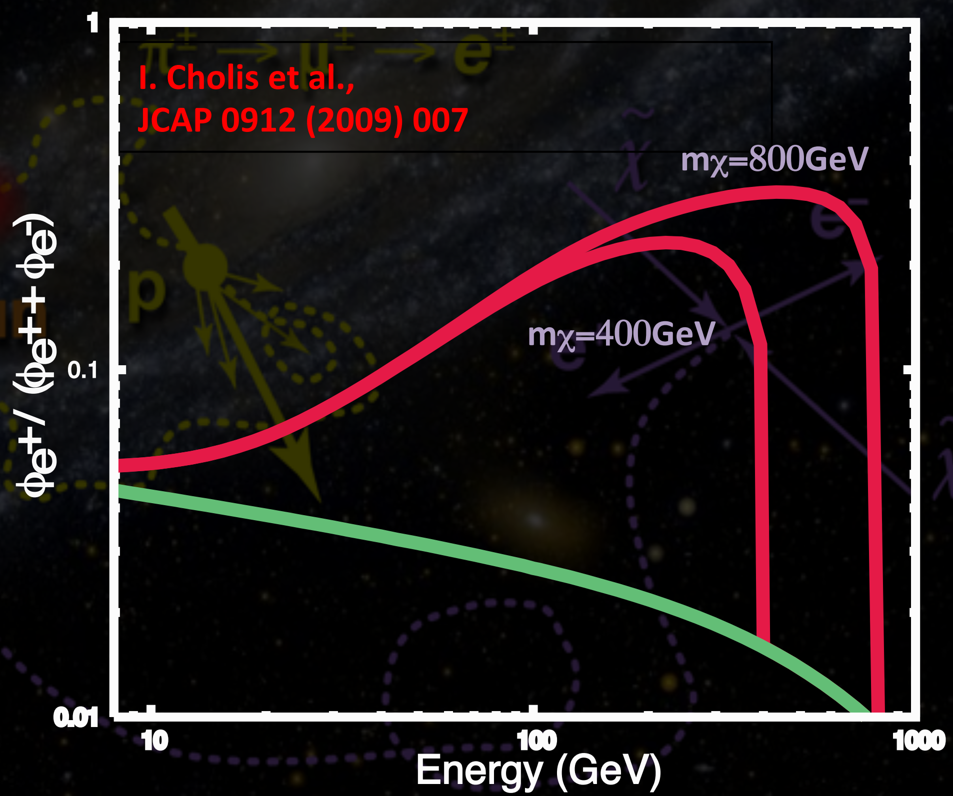


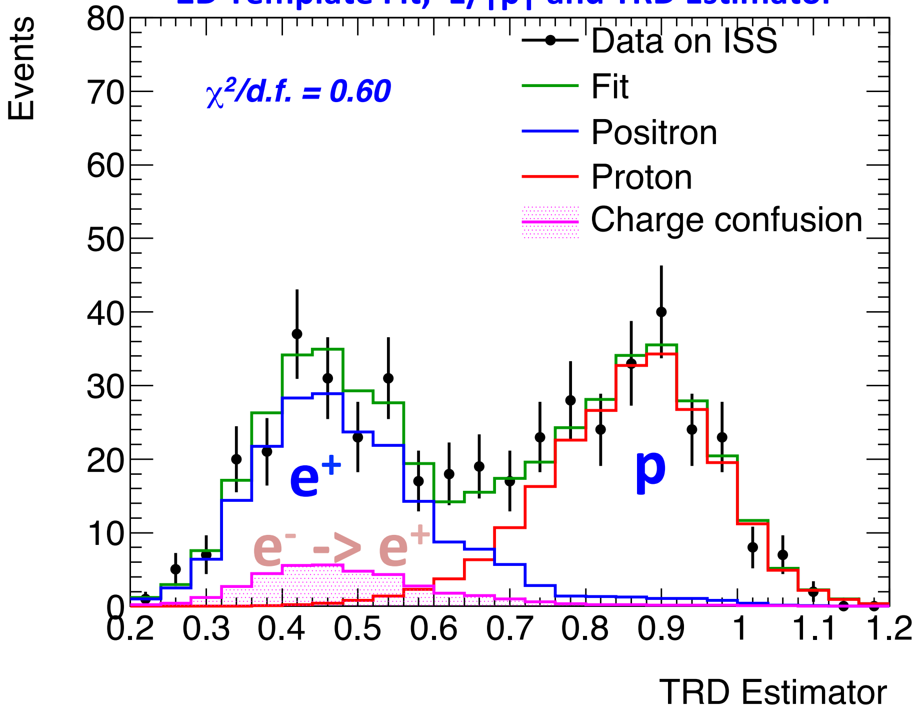
Image: GALEX, JPL-Caltech, NASA; Drawing: APS/Alan Stonebraker

Positron Fraction

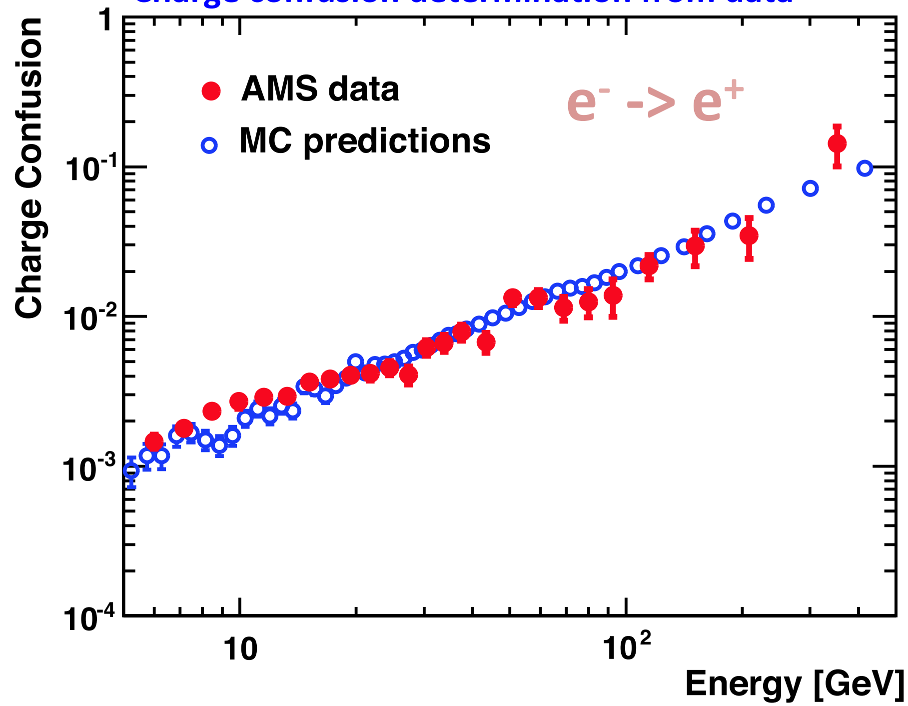
Positron Fraction:

$$f_{e^+} = \frac{\Phi_{e^+}}{\Phi_{e^+} + \Phi_{e^-}} \approx \frac{N_{e^+}}{N_{e^+} + N_{e^-}}$$

2D Template Fit, E/|p| and TRD Estimator



Charge confusion determination from data

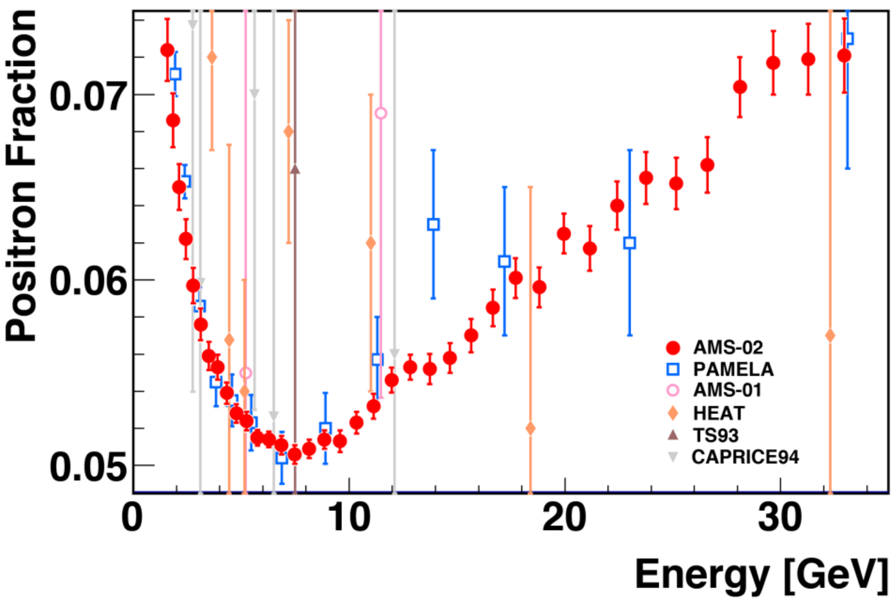


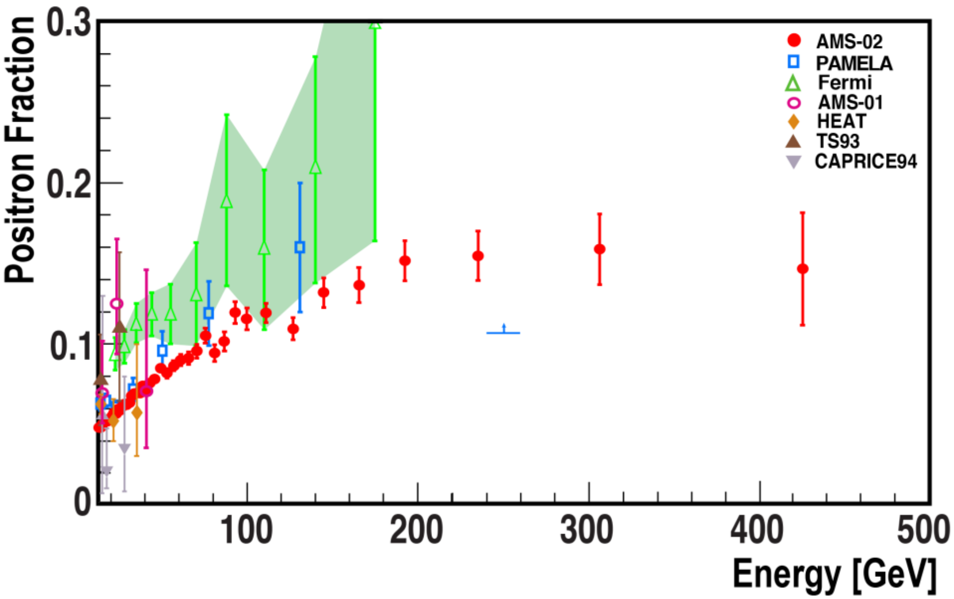
- **Main Systematic Errors:**

  Charge confusion, Selection dependence, Template definition;

- **Systematic error are smaller than statistical ones**

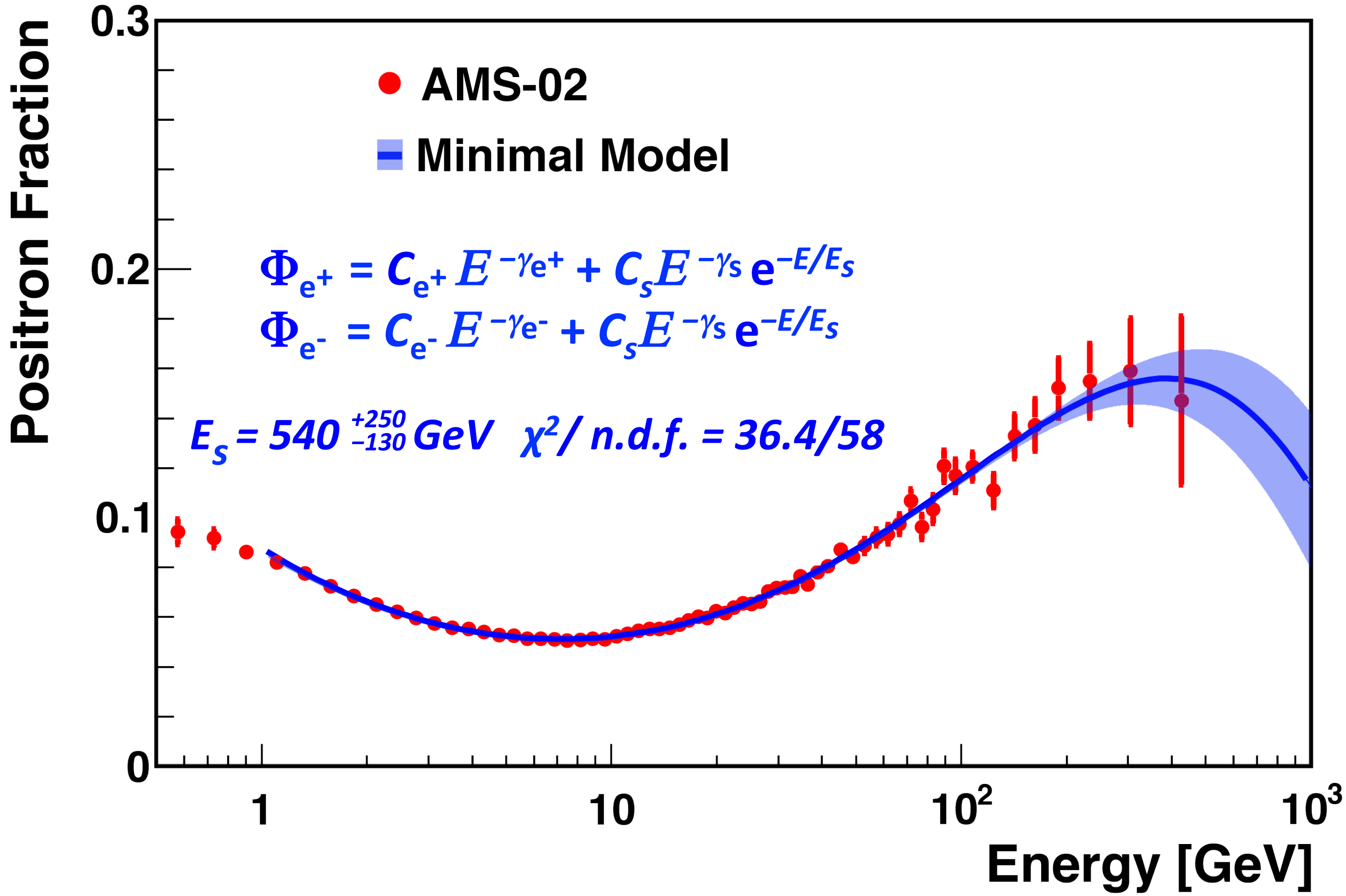
Positron Fraction





- Energy range 0.5 to 500 GeV
- Positron fraction begins to rise at ~9 GeV
- Positron fraction becomes energy independent above ~206 GeV
- Not compatible with only secondary production

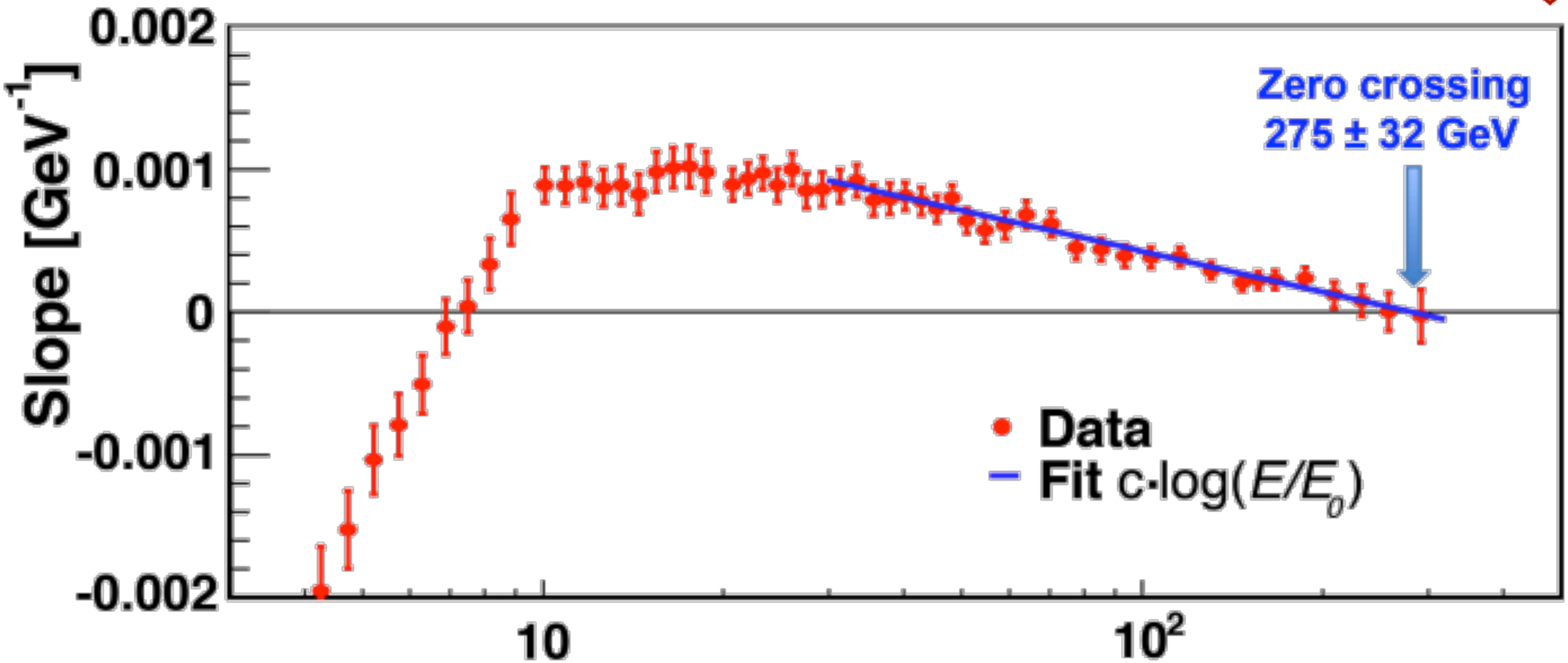
Minimal Model: Fit to the data



- **Positron fraction is smooth without *spectra features***
- Tight limits on DM annihilation cross-section based on “smoothness”:

  e.g. L. Bergstrom et.al. PhysRevLett.111.171101

Positron Fraction Slopes



- From 10 to 206 GeV, the Positron fraction are steadily rising, with a decreasing slope.
- With more data, AMS will determine the exact behavior at and beyond the crossing point

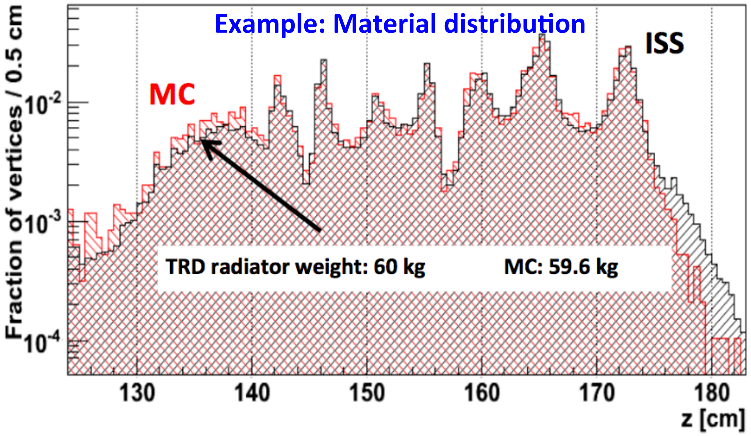
Electron/Positron Flux Measurement

Isotropic flux:

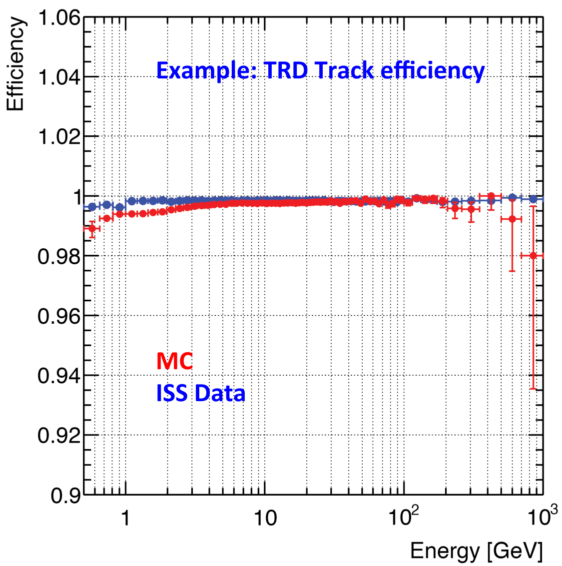
$$\Phi_{e^\pm}(E) = \frac{N_{e^\pm}(E)}{A_{eff}(E)\cdot \varepsilon_{trig}(E)\cdot T(E)\cdot \Delta E}$$

Additional systematic uncertainties:

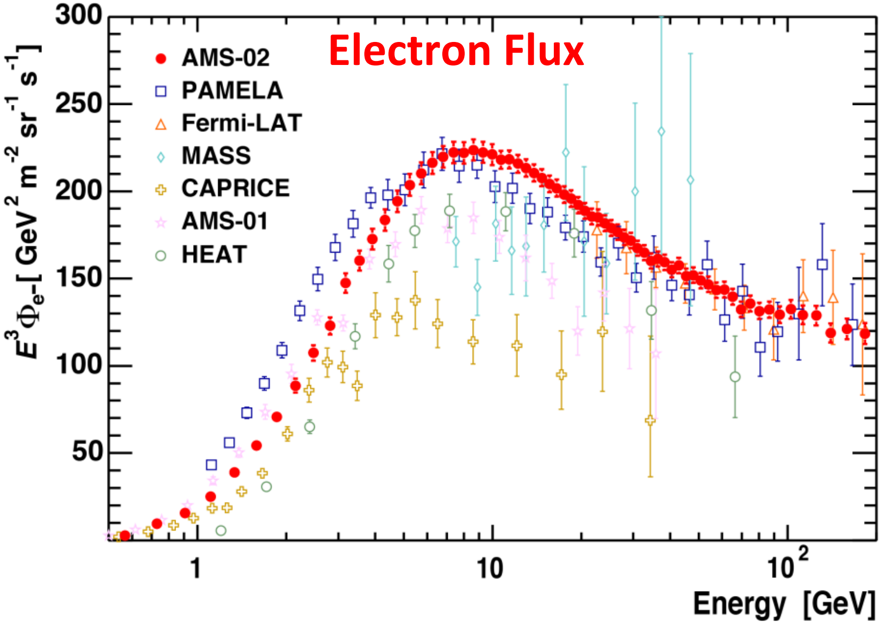
- **Effective Acceptance** $A_{eff} = A_{geom}\cdot \varepsilon_{sel}\cdot \varepsilon_{id}\cdot (1+\delta)$
  - Estimated from MC
  - Correction obtained based on efficiency measured from Data
  - Systematic uncertainties: 2% ~ 3%

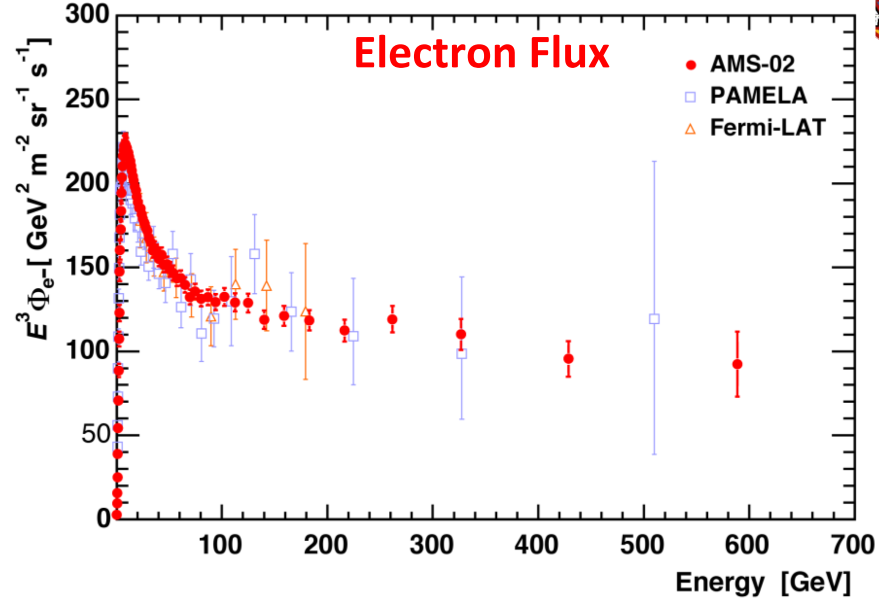


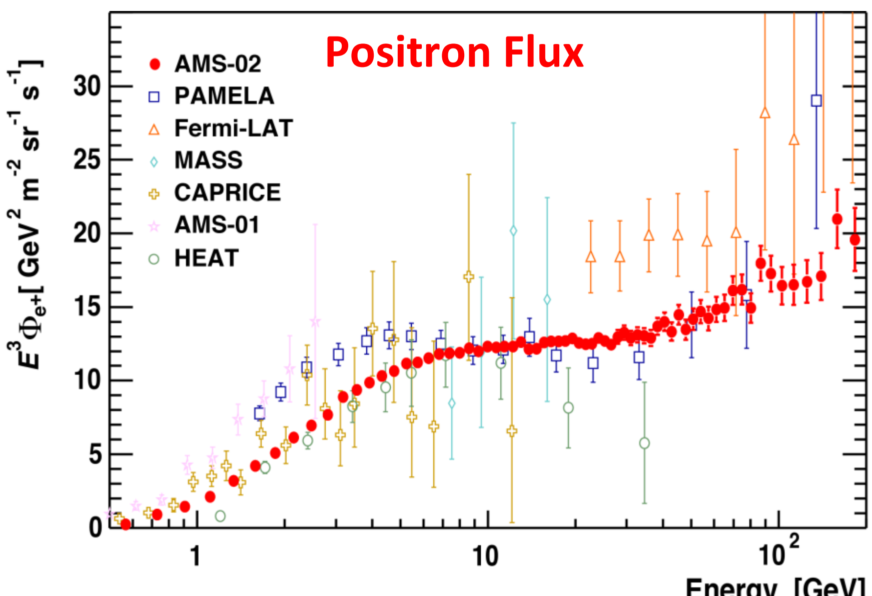
- **Energy Measurement**
  - **Minimum effect from resolution**
  - **Uncertainty in the absolute energy scale: ~2% as verified by TB**

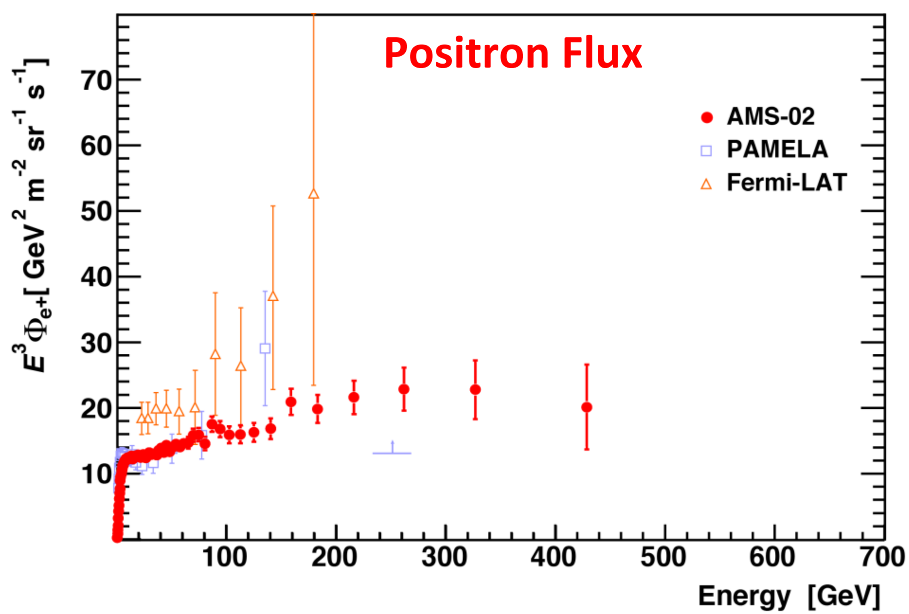


Electron Flux and Positron Flux



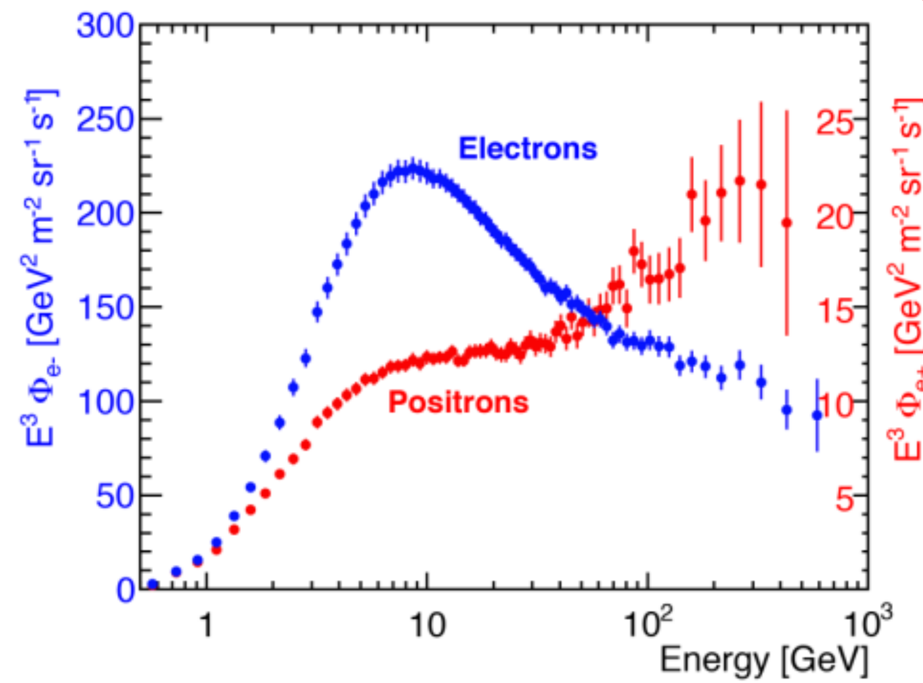


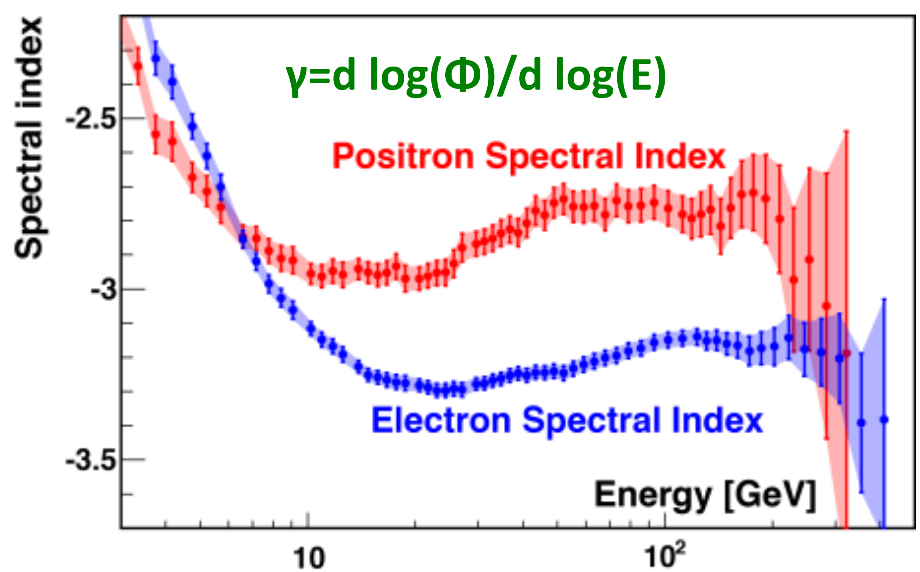




Flux Index

- The electron flux and positron flux are different in amplitude and energy behavior.
- Both spectra can not be described by a single power law .
- Spectra hardening from ~30GeV
- May indicates additional sources
- Rise of positron fraction from 20GeV is due to excess of positron and not loss of electron

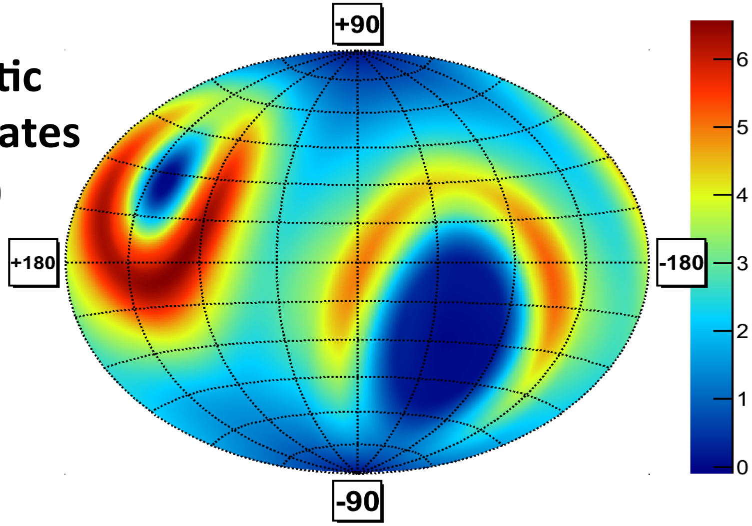




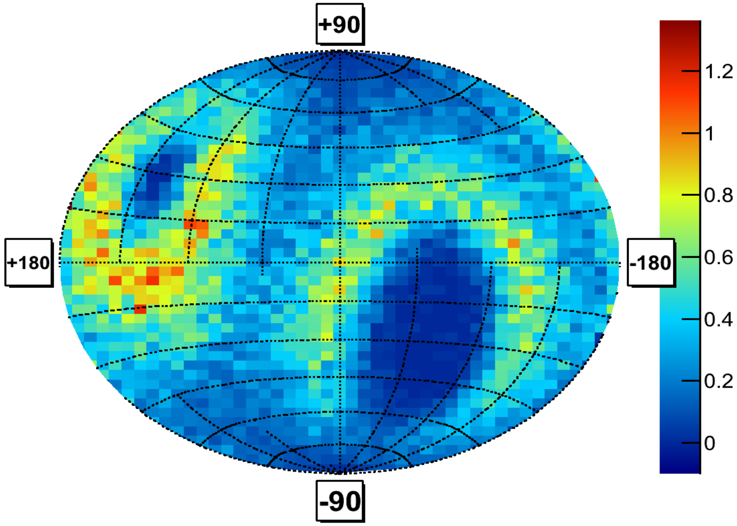
Positron and Electron Anisotropy

- Additional source of cosmic ray positrons and electrons may induce some degree of anisotropy on their arrival direction
- AMS measures the level of anisotropy for positrons and electrons independently
- Source term: **Spherical harmonic expansion , dipole amplitude: δ**

Galactic coordinates (b,l)



Expected exposure



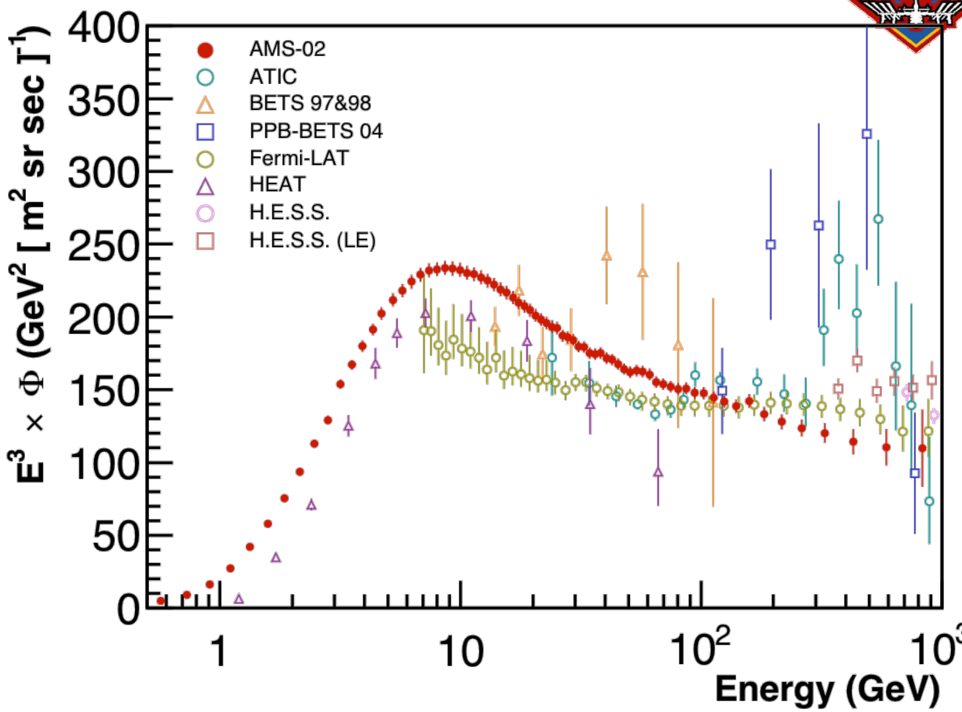
Measured Positron

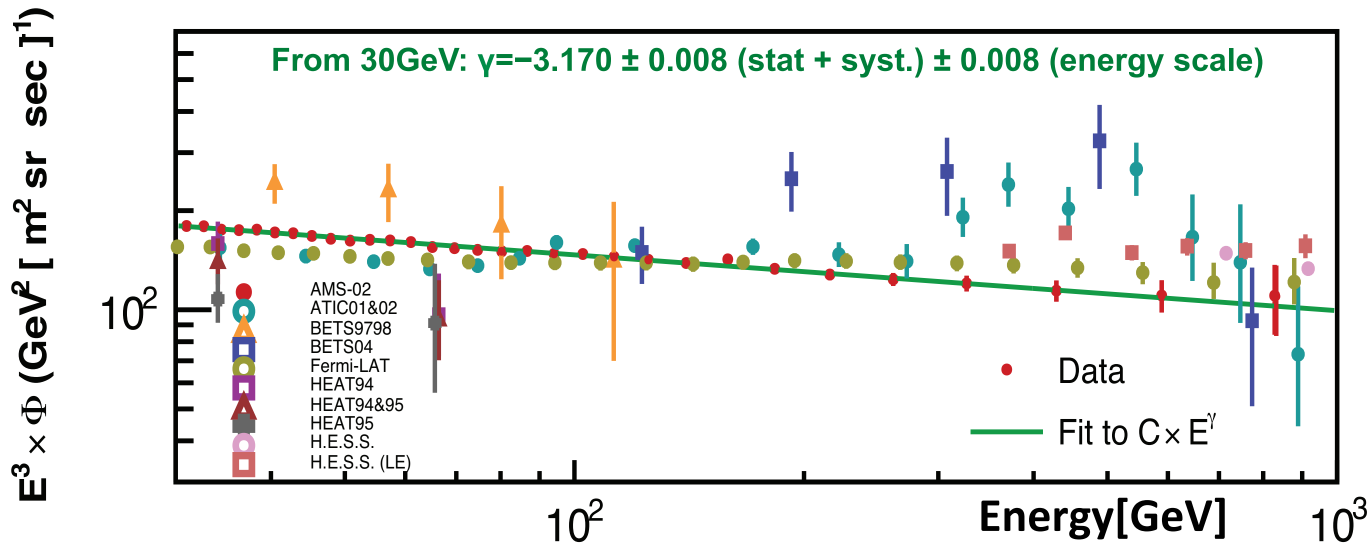
The incoming direction of positrons above 16 GeV in galactic coordinates yields δ ≤ 0.03 at the 95% confidence level

Combined (Electron + Positron) flux

- Independent analysis
- Maximize statistic with reduced normalization uncertainties

- Flux is smooth, without spectra feature
- Above 30GeV, the combined flux can be described by a single power law: **Significant implications on dark matter searches with e^-, e^+ channel**





Proton and Antiproton

Protons are produced and accelerated by SNR, they contribute ~90% of CR particles

Collision of proton, helium with ISM produce antiproton (~0.01%)

Collisions of Dark Matter will produce additional antiproton

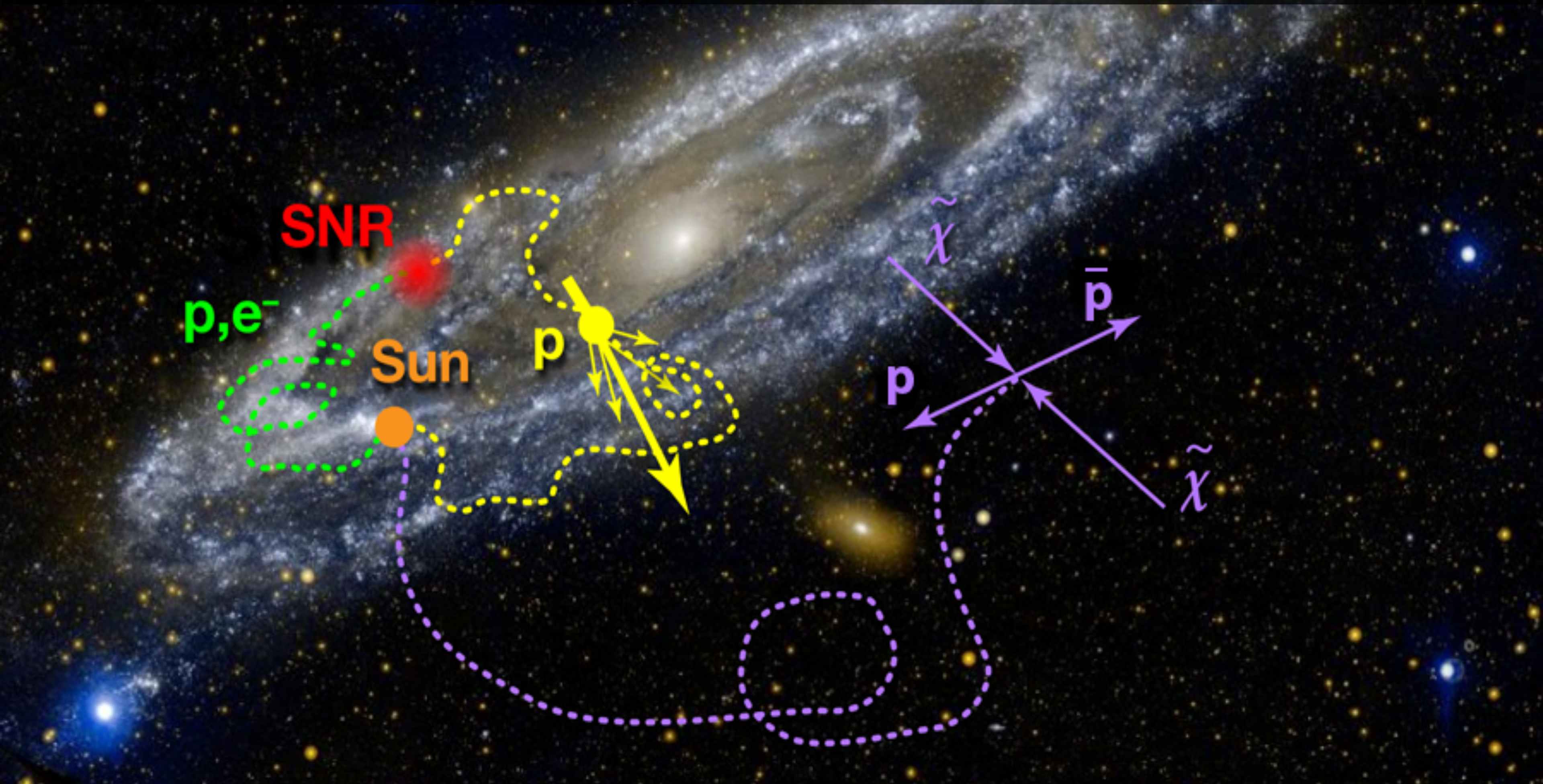


Image: GALEX, JPL-Caltech, NASA; Drawing: APS/Alan Stonebraker, adapted

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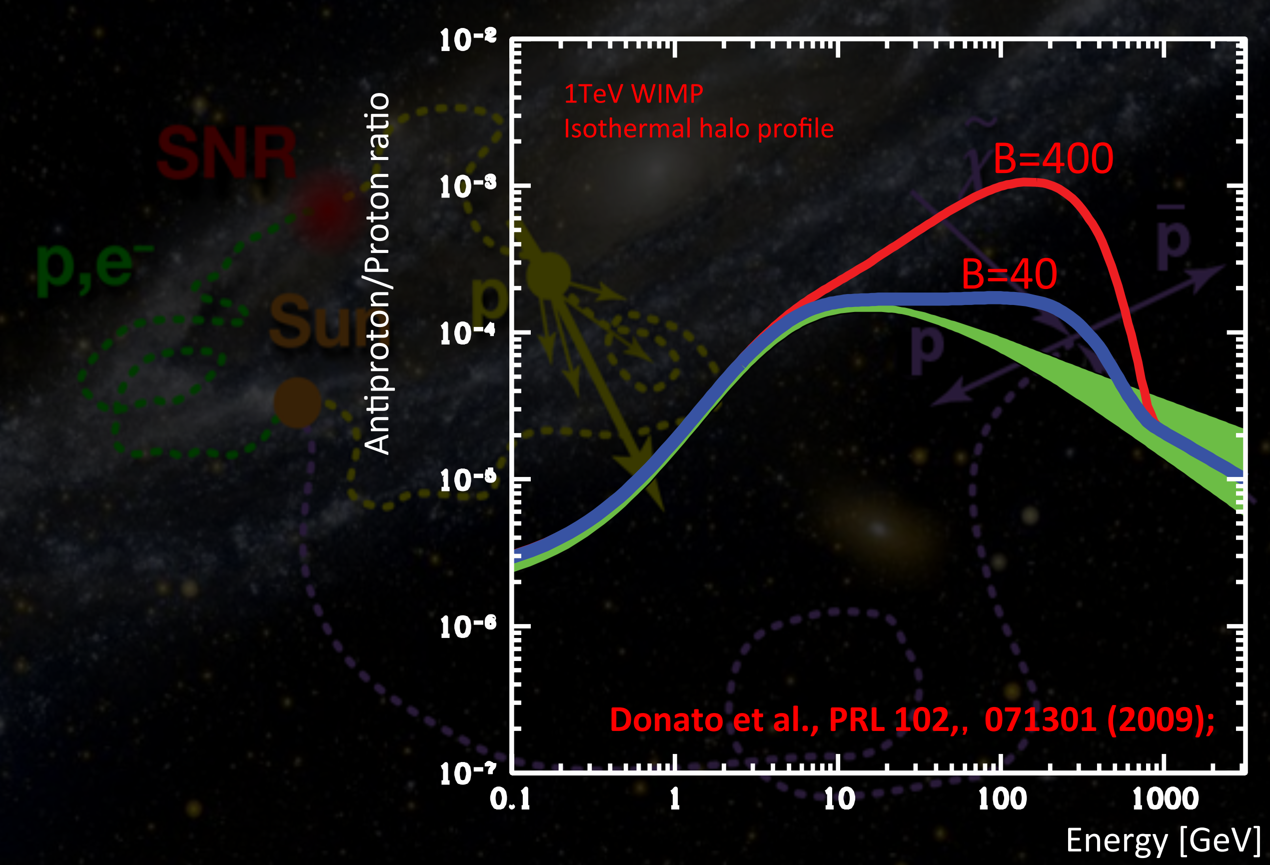
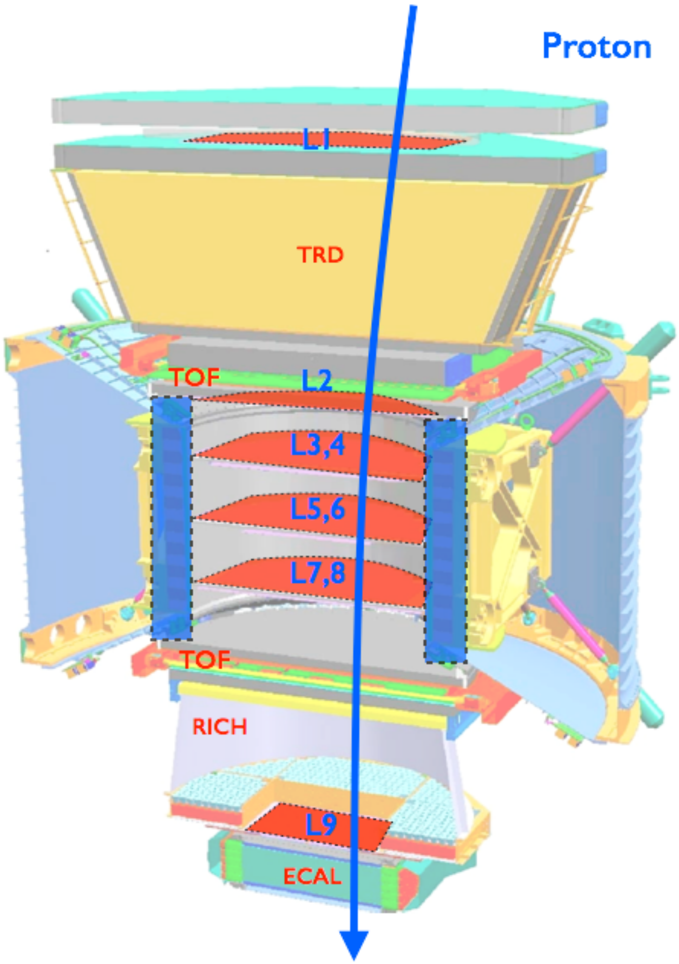


Image: GALEX, JPL-Caltech, NASA; Drawing: APS/Alan Stonebraker, adapted

Proton Flux Measurement

- **Knowledge of the precise behavior of the proton spectrum is important in understanding the origin, acceleration, and propagation of cosmic rays.**
- **Recent experiments showed deviations of the proton flux from a single power law and has generated many theoretical interest.**



- Tracker(9 Layers) + Magnet: Rigidity
- TOF (4 Layers): Velocity and Direction
- TRD, Tracker, RIGH, TOF, ECAL: Charge magnitude

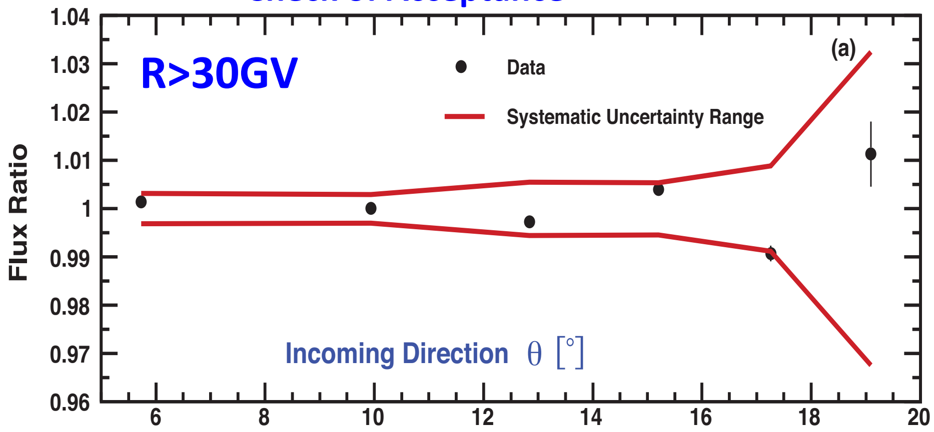
Proton flux systematic error:

- Unfolding systematic errors on the rigidity resolution function
- Absolute rigidity scale
- Acceptance and event selection
- Trigger efficiency
- Background contamination at low energy
- Geomagnetic cutoff

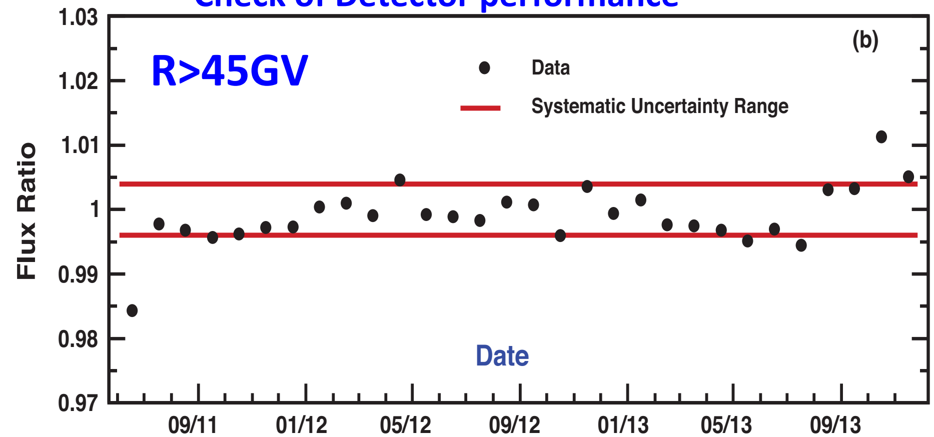
Validation of Proton Flux Systematic Error

Independent verification of systematic error:

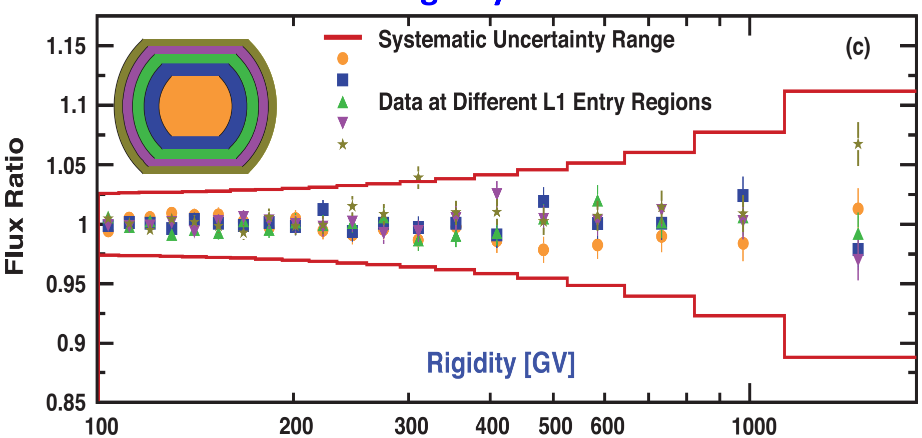
Check of Acceptance



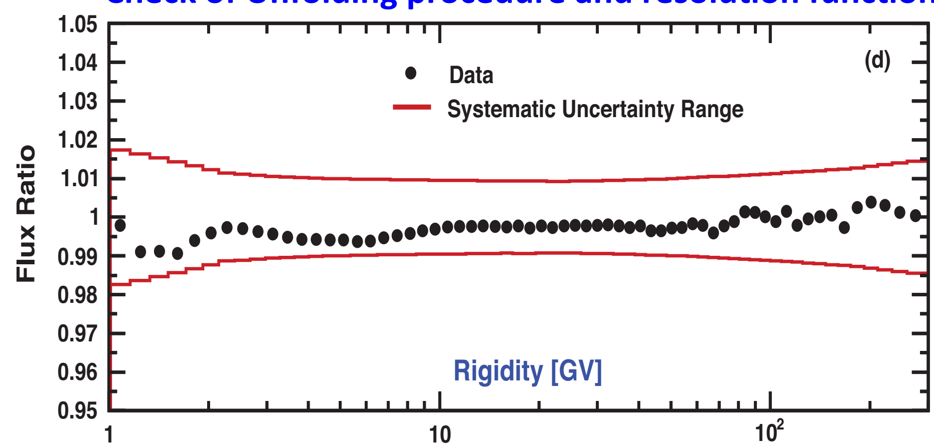
Check of Detector performance



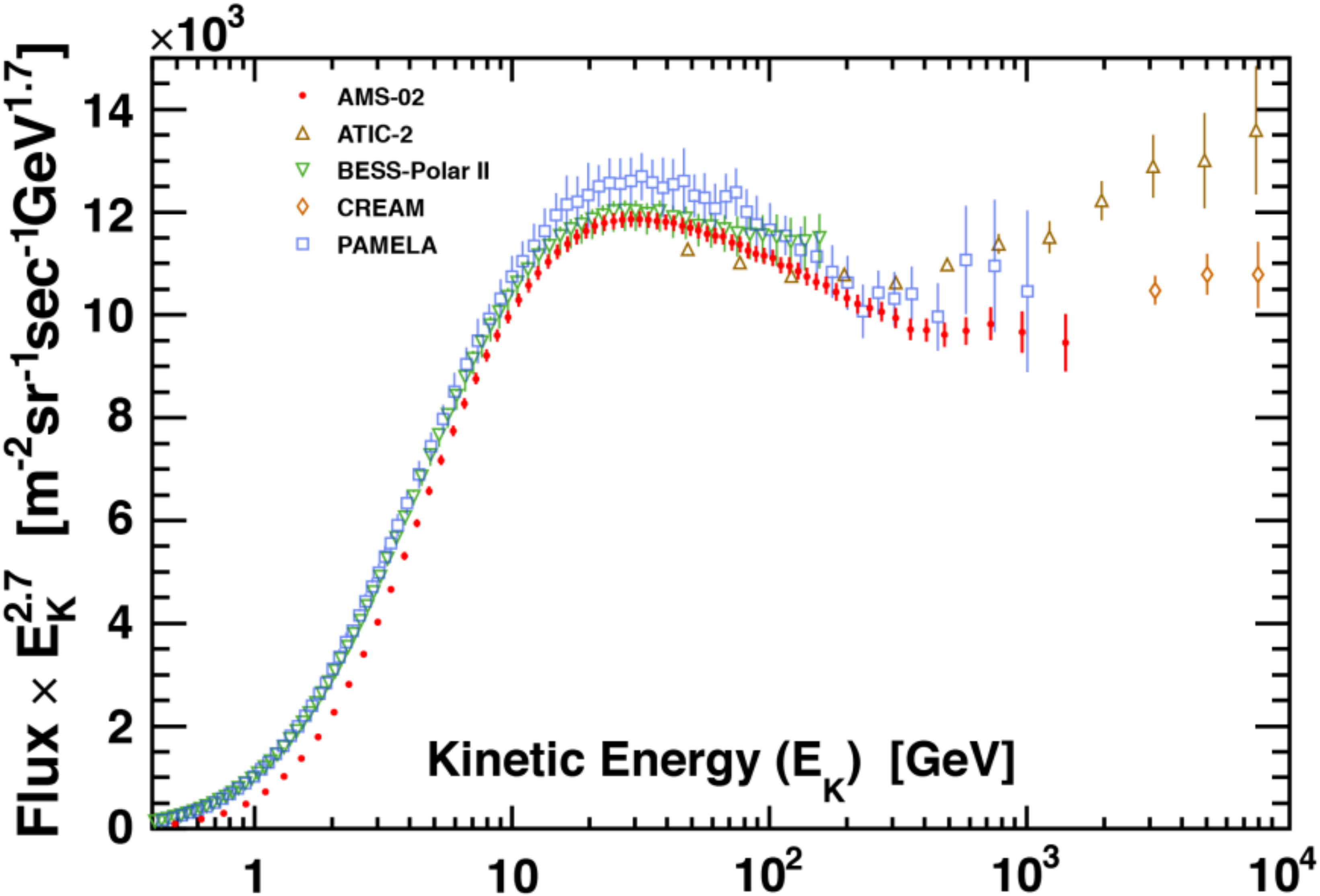
Check of Rigidity Scale



Check of Unfolding procedure and resolution function

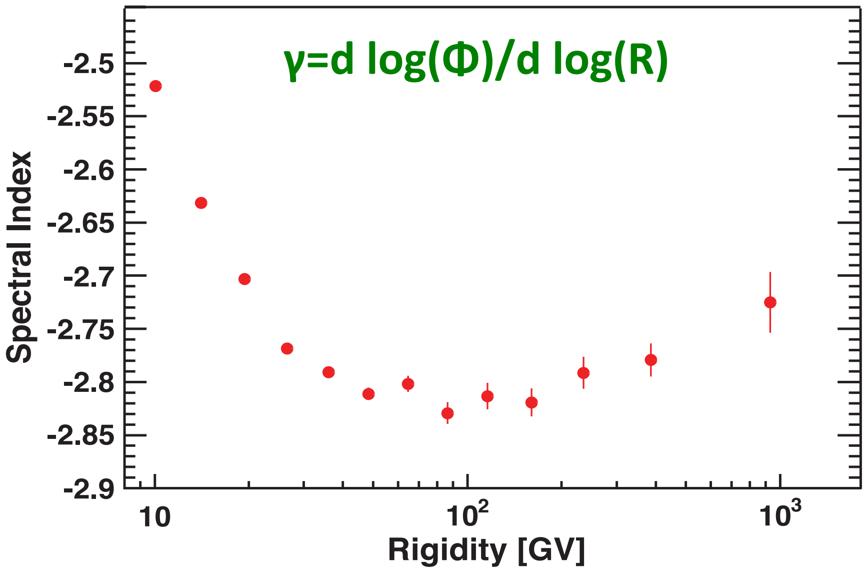


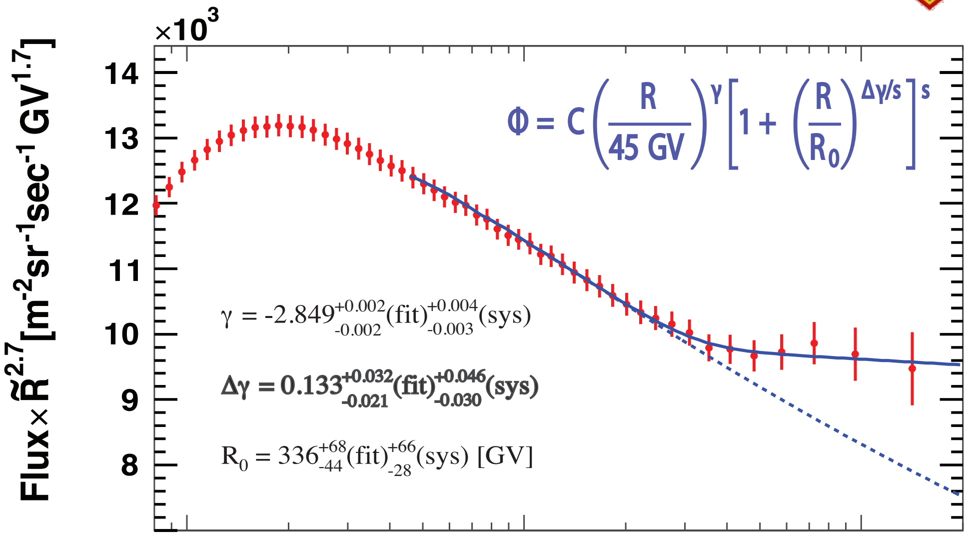
Proton Flux



×10^3
14
12
10
8
6
4
2
0
Flux × E_K^2.7 [m^-2sr^-1sec^-1GeV^1.7]
AMS-02
ATIC-2
BESS-Polar II
CREAM
PAMELA
Kinetic Energy (E_K) [GeV]
1
10
10^2
10^3
10^4

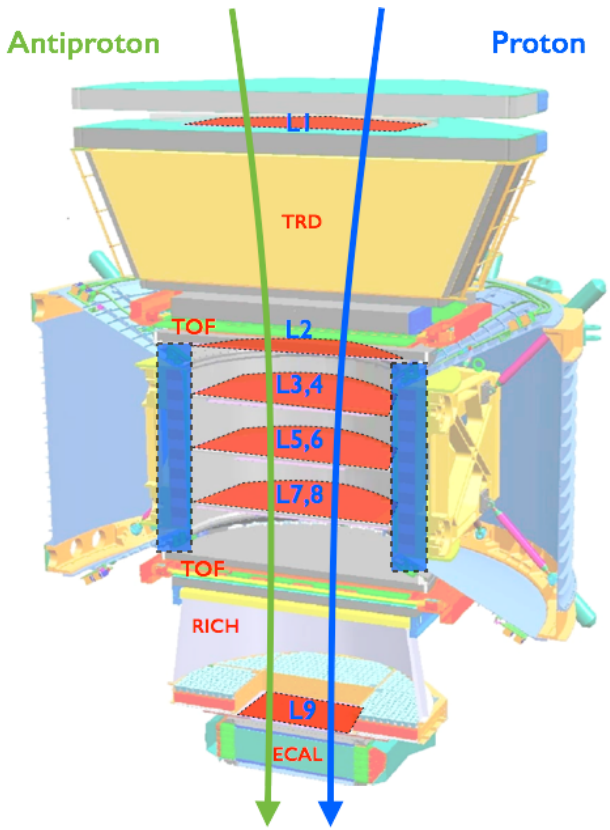
Proton Flux

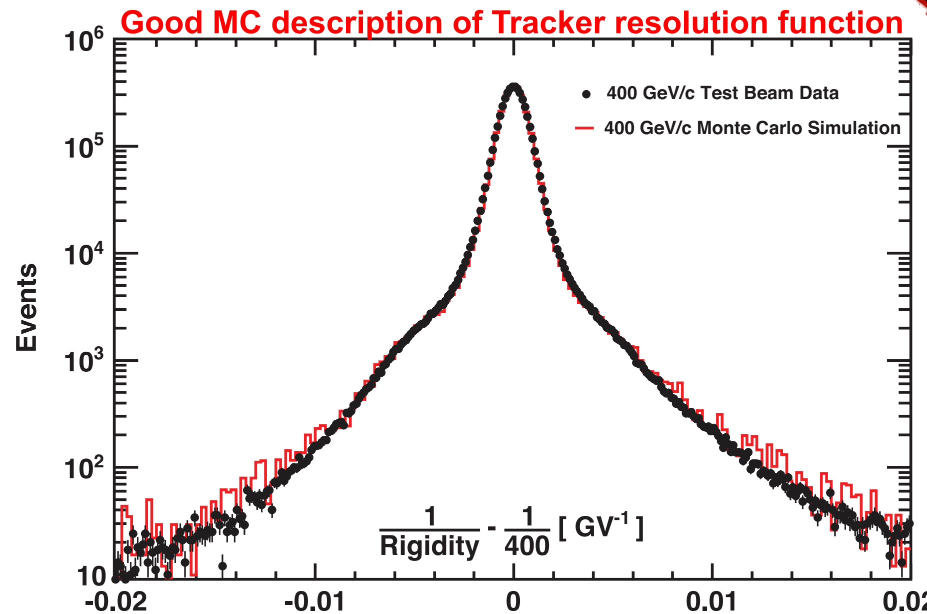




- **The spectra index is progressively hardening with rigidity above 100GV**
- **Spectra difference by 0.133, with over 3 sigma significance**
- **Requires more sophisticated CR acceleration/propagation modeling**

Antiproton Identification with AMS

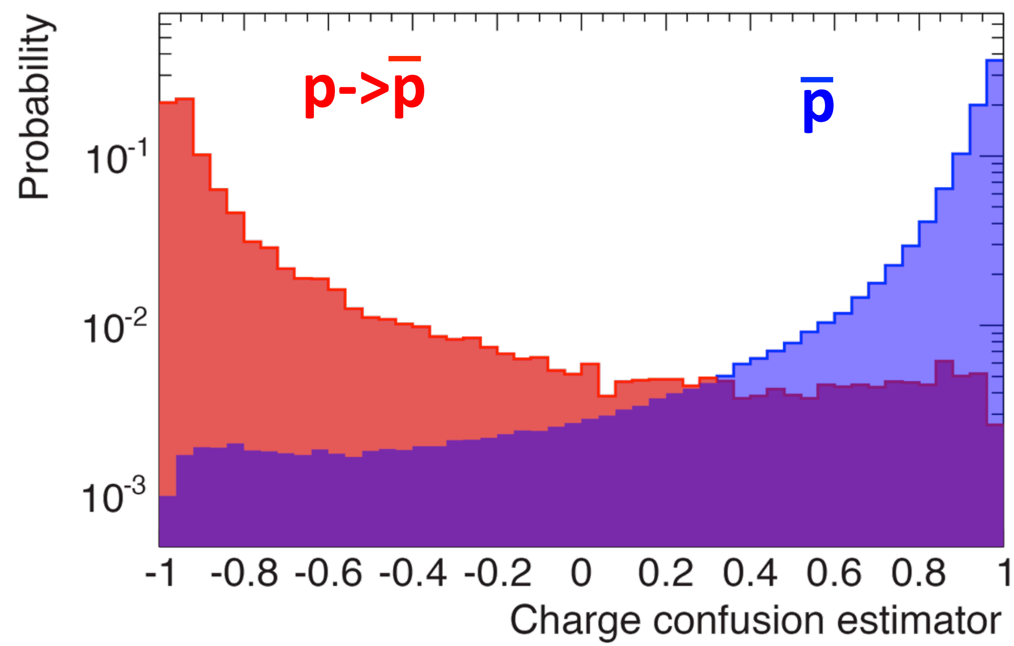




Charge confusion estimator:

BDT based on 10 variables:

- Track fit quality
- Rigidity measurements
- Charge measurements

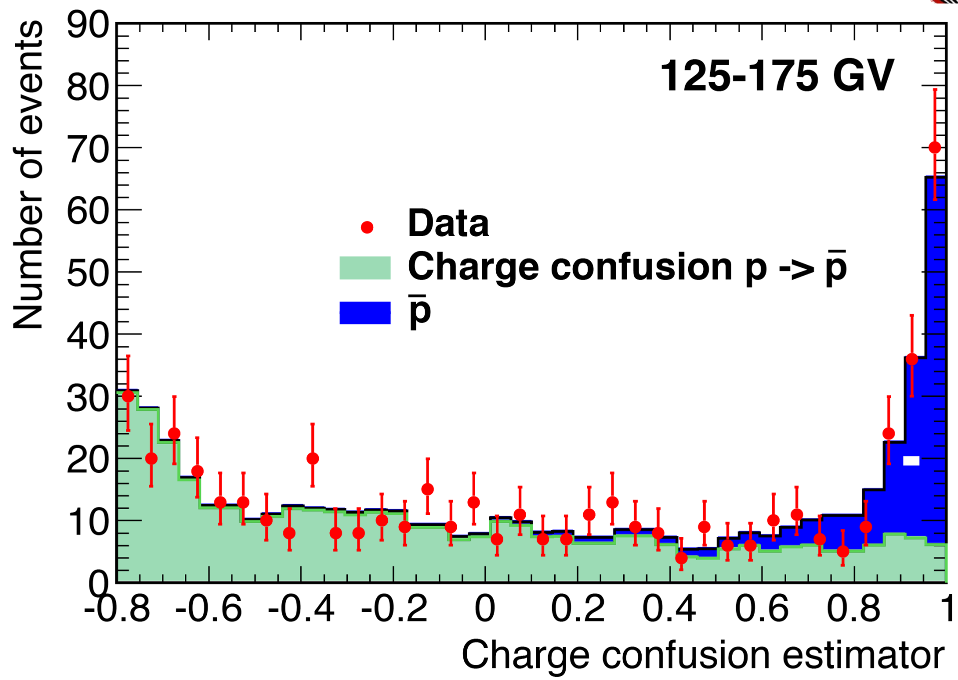


Antiproton Measurement and Systematics

Antiproton ratio:

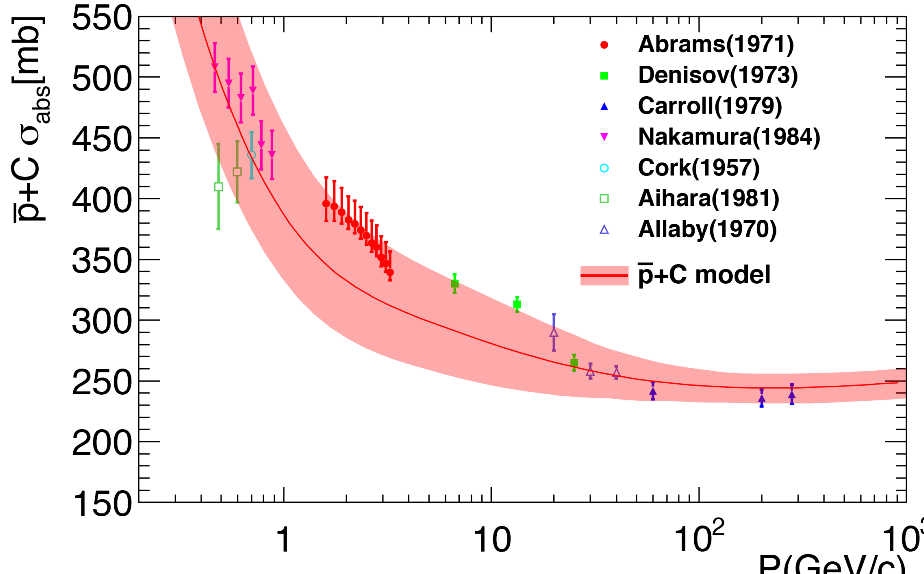
$$R_{\bar{p}} = \frac{\Phi_{\bar{p}}}{\Phi_p} \approx \frac{N_{\bar{p}}}{N_p}$$

*N Corrected for Acceptance difference



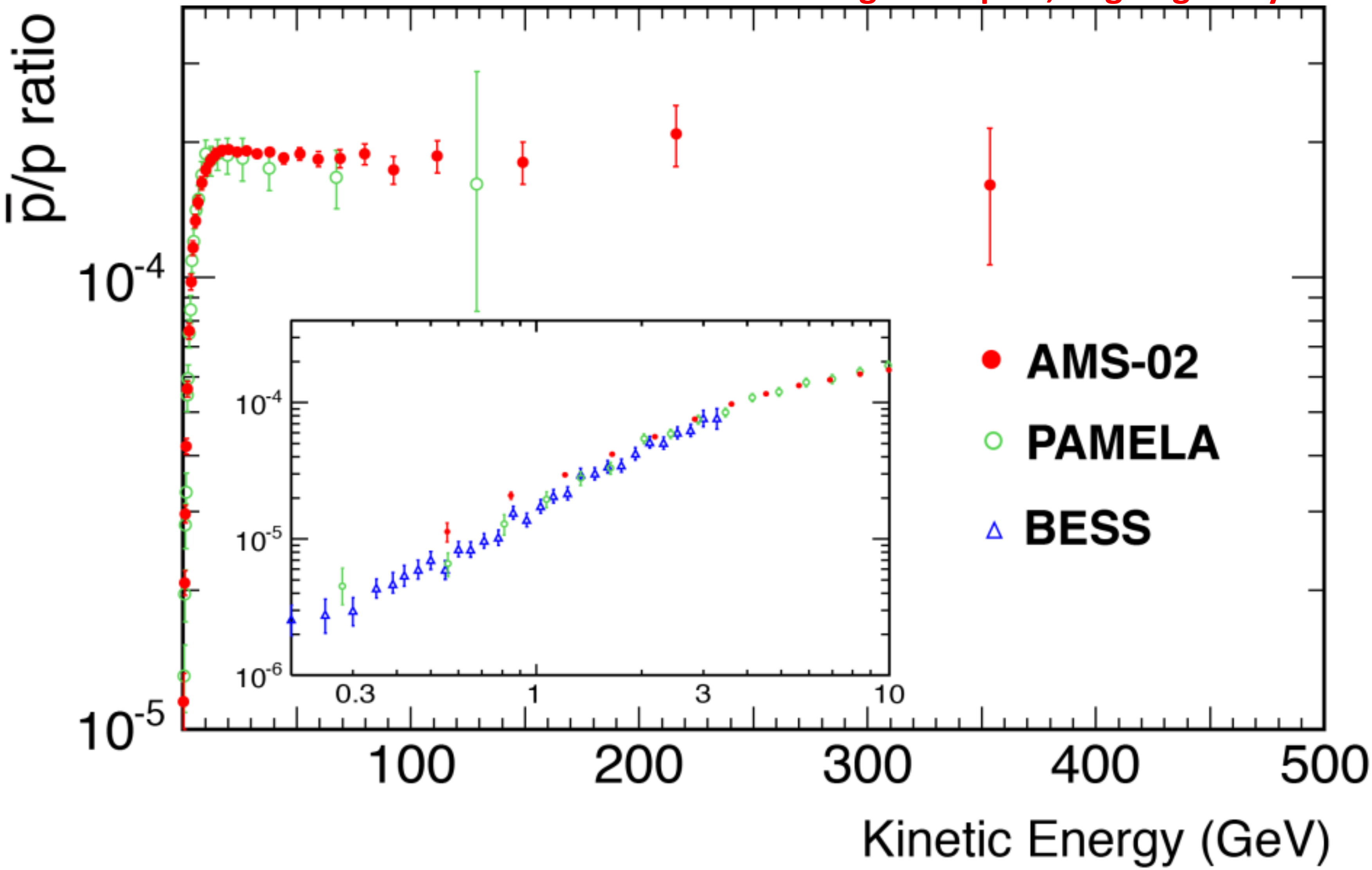
Major systematic error

- Charge confusion determination, uncertainty in the selection and template definition
- Acceptance asymmetry, limited by available antiproton cross section measurement.



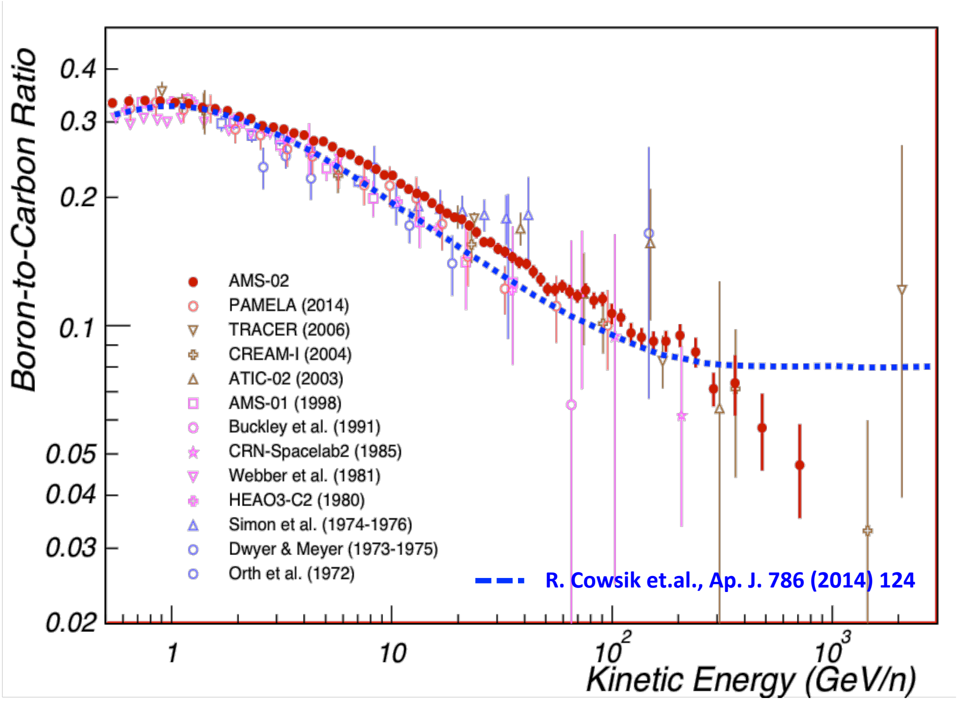
Antiproton Ratio

Progress report, ongoing analysis



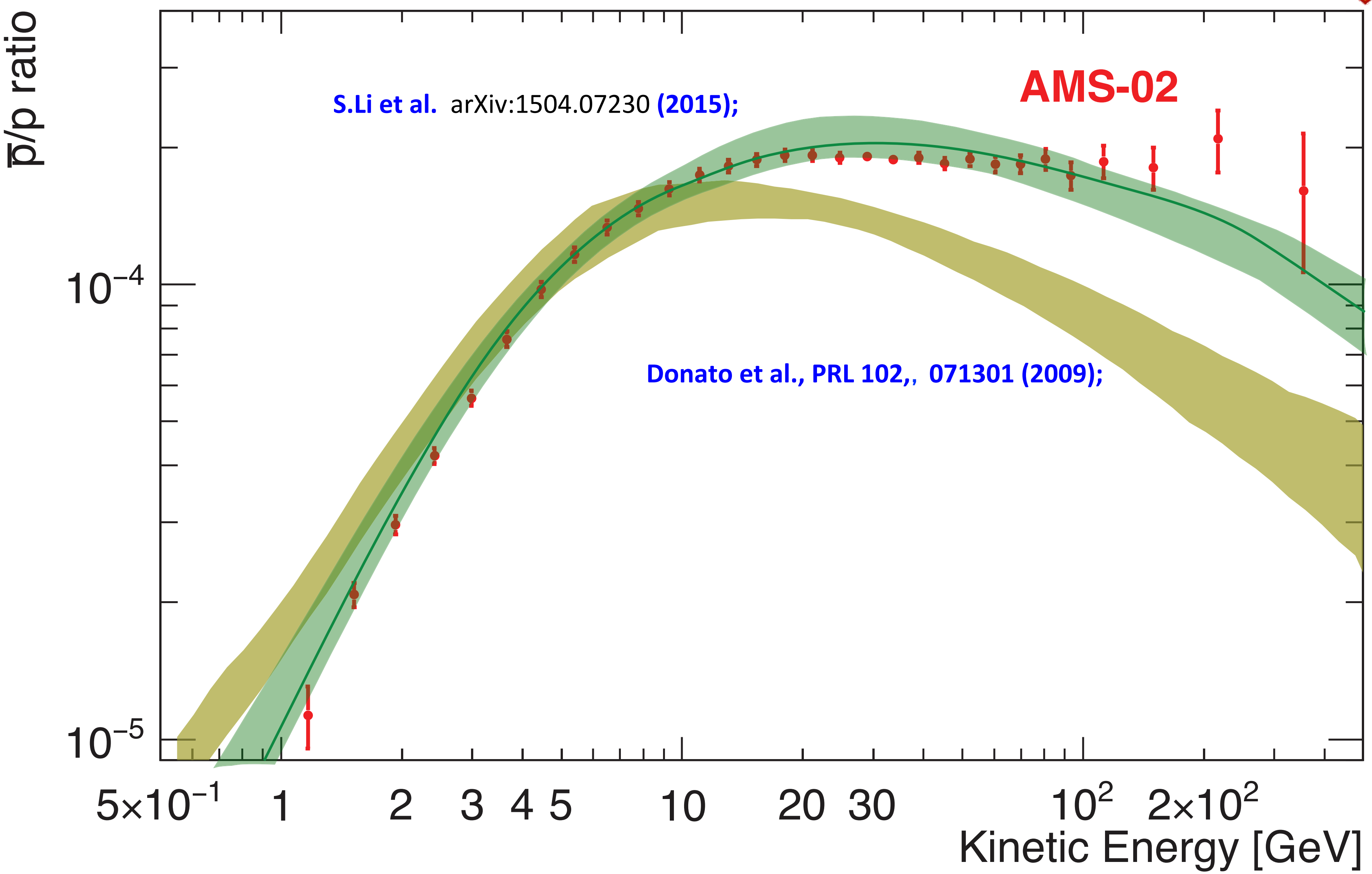
AMS CR Nuclei measurements: Constrain propagation models

- To explore new physics, we need to understand the background first.
  - Precise knowledge of the cosmic ray fluxes
  - Precision modeling of propagation and acceleration
- AMS Measurement of CR nuclei(Li, B, C, …) will greatly improve the CR modeling
  - Determine diffusive propagation parameters
  - Constrain on "exotic" propagation/production models

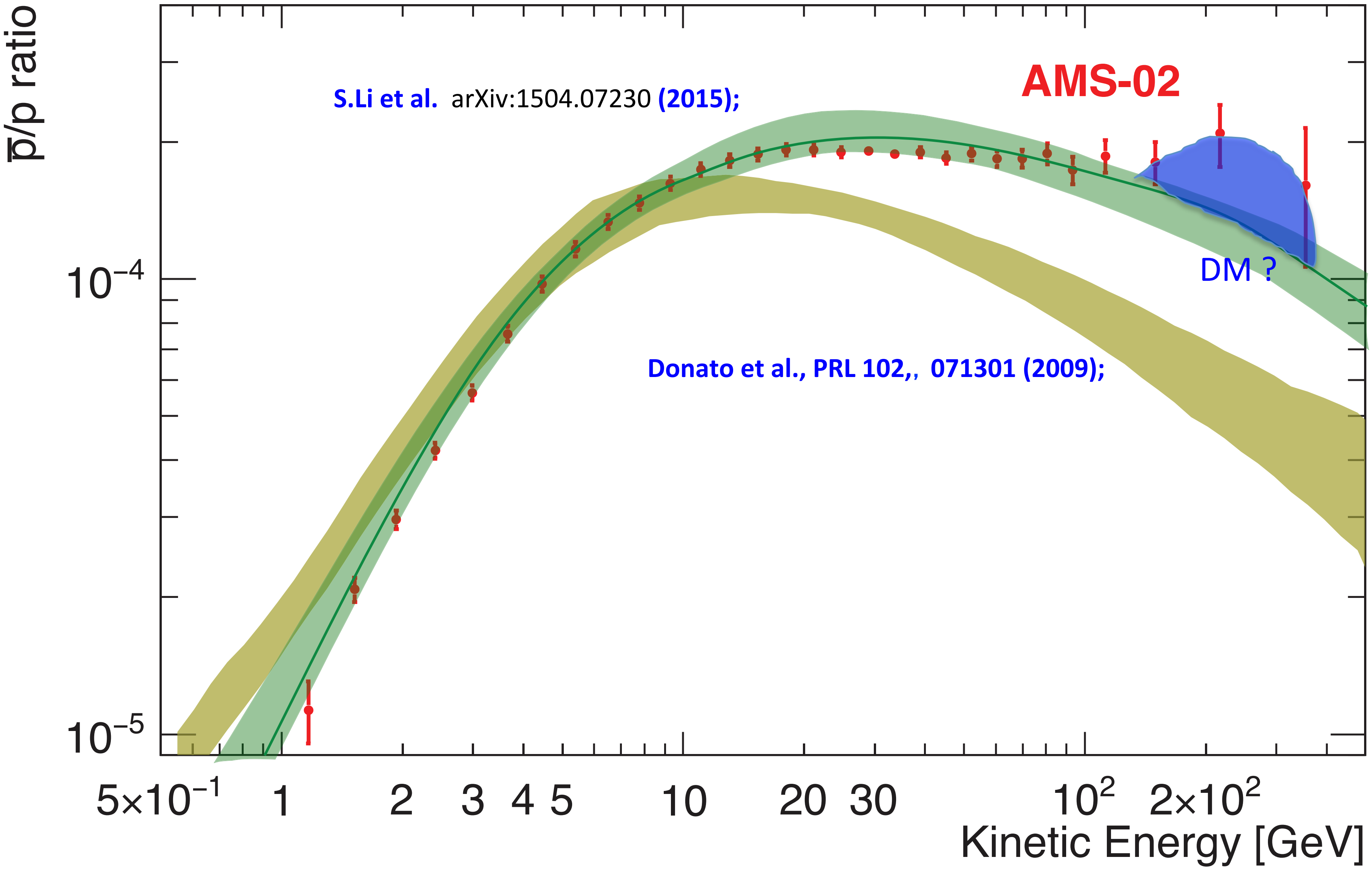


- Directly improve background prediction for indirect DM searches

AMS CR Nuclei measurements: Improve background prediction



AMS CR Nuclei measurements: Improve background prediction



The latest AMS measurements of the positron fraction, the antiproton/proton ratio, the behavior of the fluxes of electrons, positrons, protons, and other nuclei provide precise information.

The accuracy of the data from many different types of cosmic rays, require a comprehensive model to ascertain if their origin is from dark matter, astrophysical sources, acceleration mechanisms or a combination.