AMS01 -- Antimatter in Space

Daniel Haas
DPNC Genève
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- The AMS01 Detector
- Results from AMS01
  - Search for Antimatter
  - Flux Measurements
  - Geomagnetic Effects
- Outlook to AMS02

Motivation

The creation of the universe is well described by the Big Bang Model. Experimental proofs are e.g.

- Recession of the galaxies
- Existence of the cosmological background-radiation
- the relative quantities of the light isotopes in the universe

In principal, matter and antimatter should exist in equal quantities BUT till now, no trace of antimatter in the universe:

- neither close to our planet
- nor in the sun system
- nor in our galaxy

$\Longrightarrow$

Where did the antimatter go?

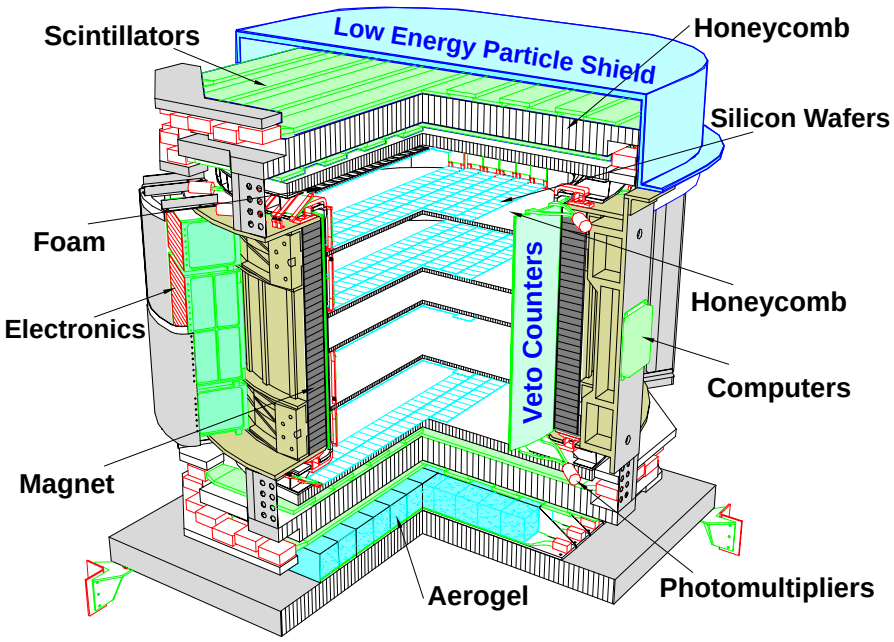
Motivation

Two possible scenarios:

- Did the antimatter disappear completely?
  Baryogenesis (Sakharov 1967):
  - Direct violation of baryon number conservation
  - C and CP-violation
  - Period out of thermal equilibrium
- The universe consists of domains of matter and antimatter
  - But: No annihilation photons discovered yet
  - $\Rightarrow$ Size and distance $>$ 15 Mpc

The AMS Experiment is designed to search for antimatter ($Z \geq 2$) with high sensitivity

The AMS-01 Detector



- Nd-Fe-B alloy permanent magnet $BL^2 = 0.14$ Tm^2
- LEPS: against low energy particles
- TOF: 4 planes, velocity β ($\Delta\beta/\beta \approx 2.4\%$) & Z
- Tracker: 2.1 m^2, 6 planes of double sided silicon microstrip detectors: sign(Z), Z and R
- Aerogel Threshold Cerenkov: additional β measurement
- ACC: reject multiparticle events

Once we know from where the particle came (TOF), matter and antimatter are identified by the bending in the magnetic field

The STS-91 Mission

2-12 June 1998

NASA-DOE Memorandum of Understanding, 20 Sep 1995

"Primarily a test flight that would enable the AMS team to gather data on background sources, adjust operating parameters and verify the detector's performance under actual space flight conditions"

- Total data taking: 184 hours
- Flight attitudes: 1°, 20°, 40°, 180° w.r.t. Zenith
- Flight altitude: 320-390 km
- Orbit: 51.7°, all longitudes (SAA excluded)

A complete success!!

- Detector was performing in space as during tests on ground
- 100 million events recorded on disk
- Trigger rates 0.1-1 kHz, DAQ livetime 90-40 %

AMS-01 gives already accurate results on the search for antimatter and charged cosmic ray spectra incl. geomagnetic effects

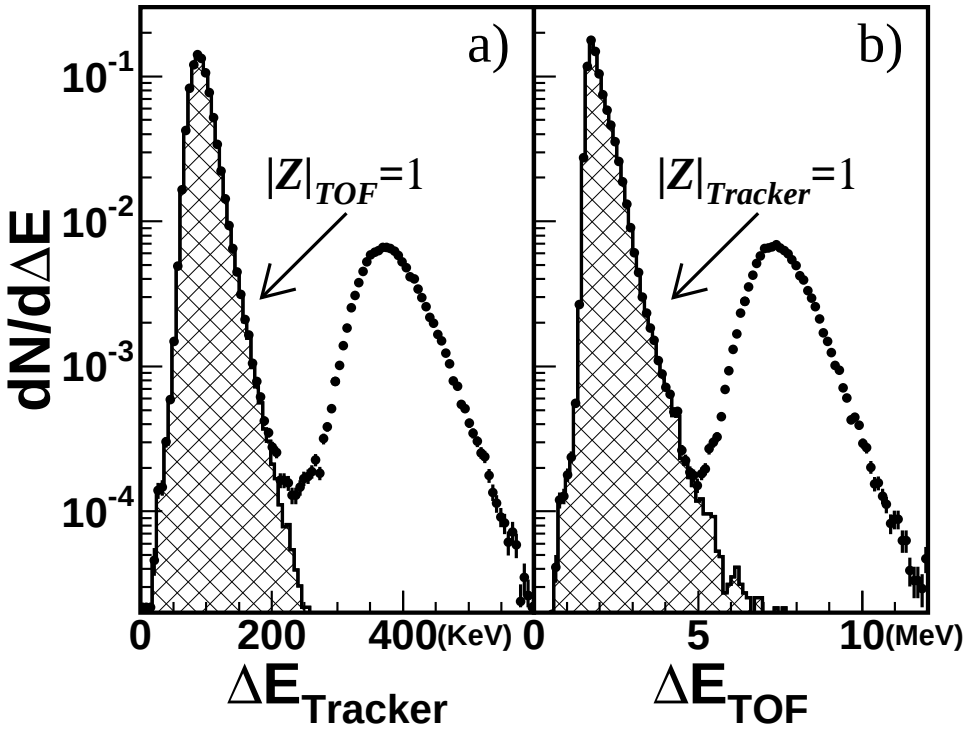
Search for Antimatter

What Parameters enter in the Data Analysis?

- Rigidity (p/Z): Measured by the Tracker from the deflection of the trajectory
- Velocity and Direction of the particle from the TOF
- Charge Magnitude is taken by the dE/dx measurement in the Scintillators and Tracker
- From these, the sign of the charge and particle mass are derived
- Major Background for antimatter search: p, e^- and He

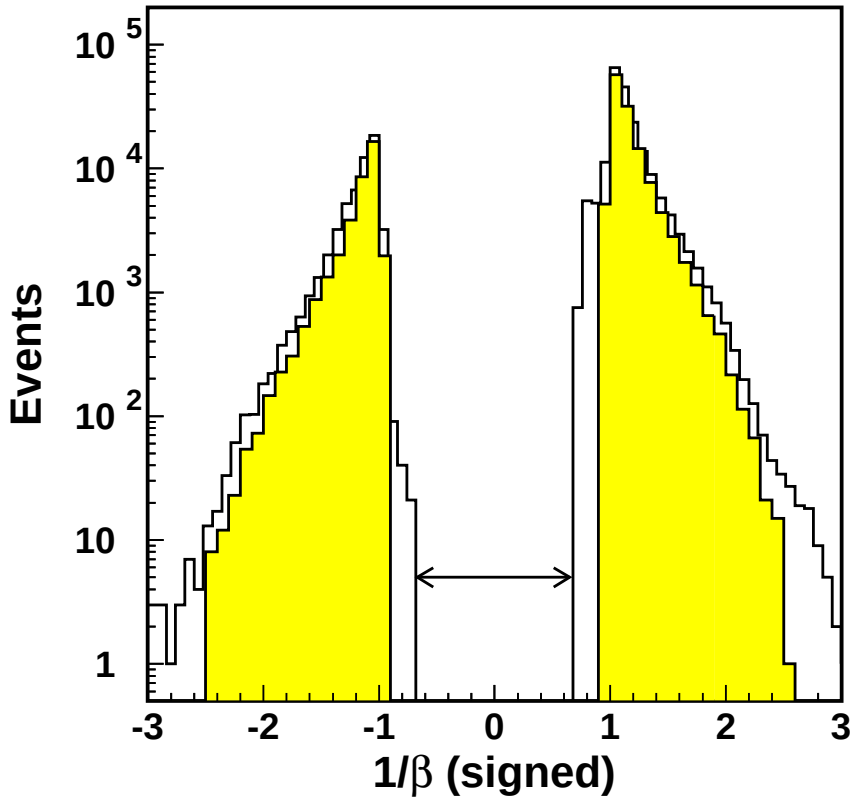
Search for Antimatter

Z=2 Event Selection



Very precise TOF system (105 ps)

$\Rightarrow$ always correct assigned direction

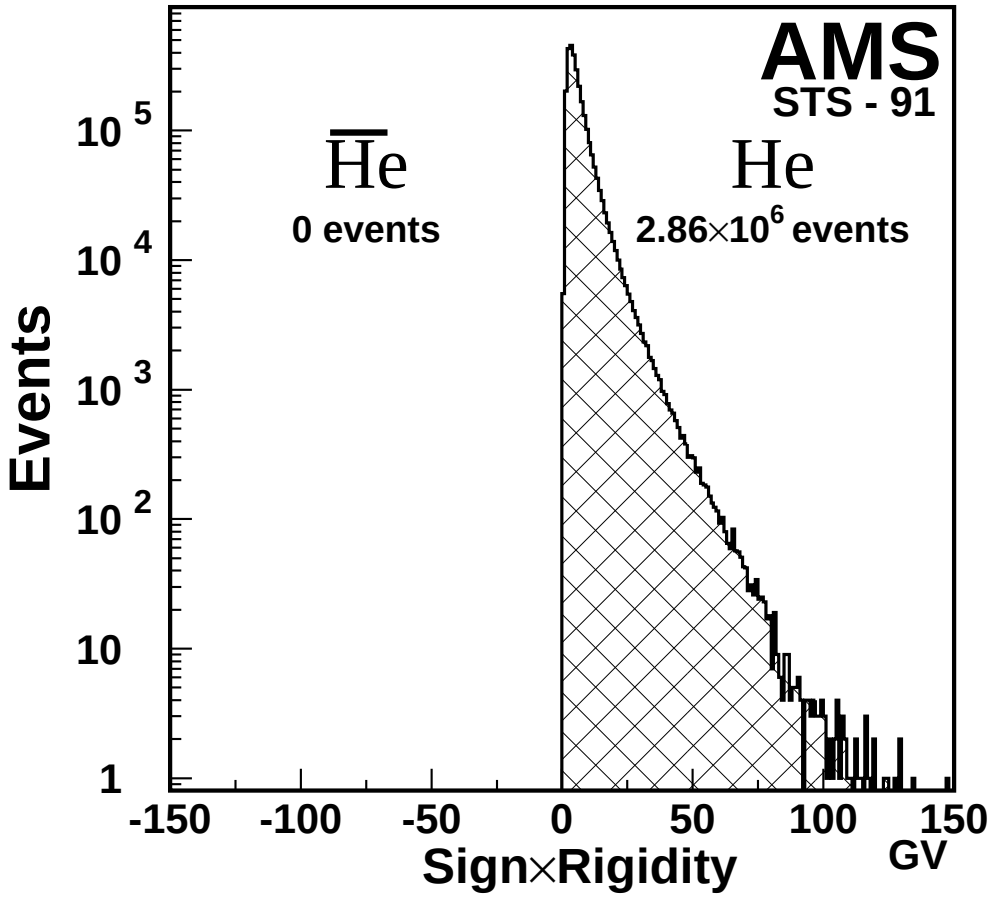


Energy loss is measured in two independent ways

$\Rightarrow$ Background $< 10^{-7}$

Search for Antimatter

Result for |Z|=2



No Anti-Helium events were found at any rigidity

Assumption:

incident $\overline{\mathrm{He}}$-spectrum the same as He

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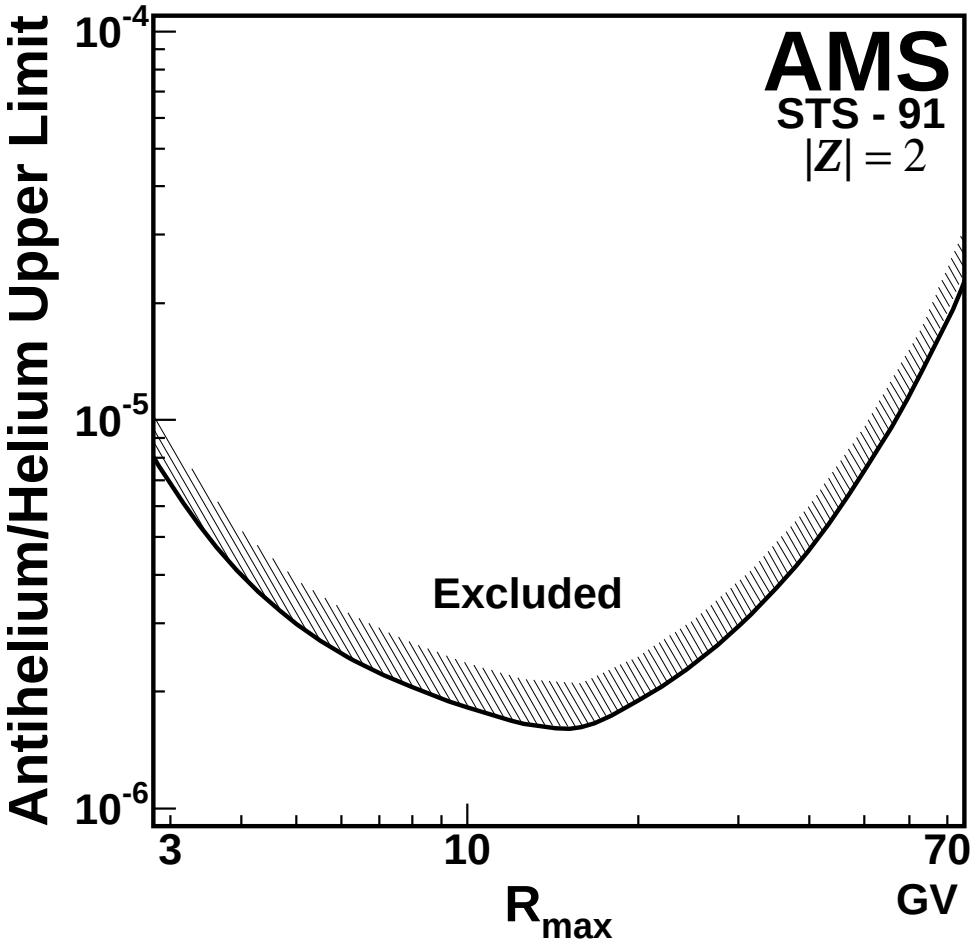
$$\frac{N_{\overline{\mathrm{He}}}}{N_{\mathrm{He}}} < 1.1 \times 10^{-6} \text{ at 95\% C.L.}$$

Search for Antimatter

Model Independent Result for |Z|=2



Corrections to raw spectrum for:

- Livetime (Θ_m)
- rigidity resolution
- inelastic cross sections

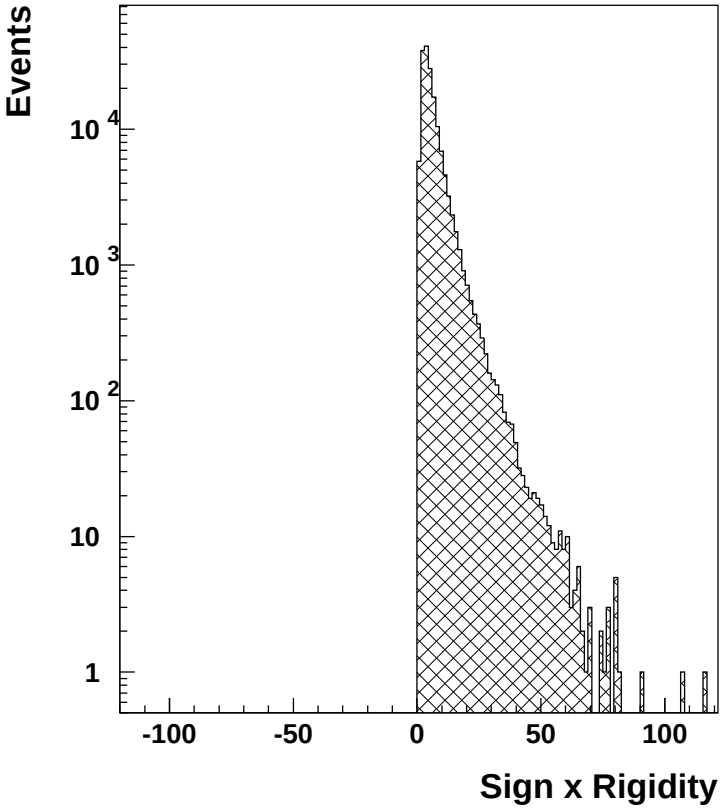
Upper limit on the flux ratio as a function of the rigidity interval

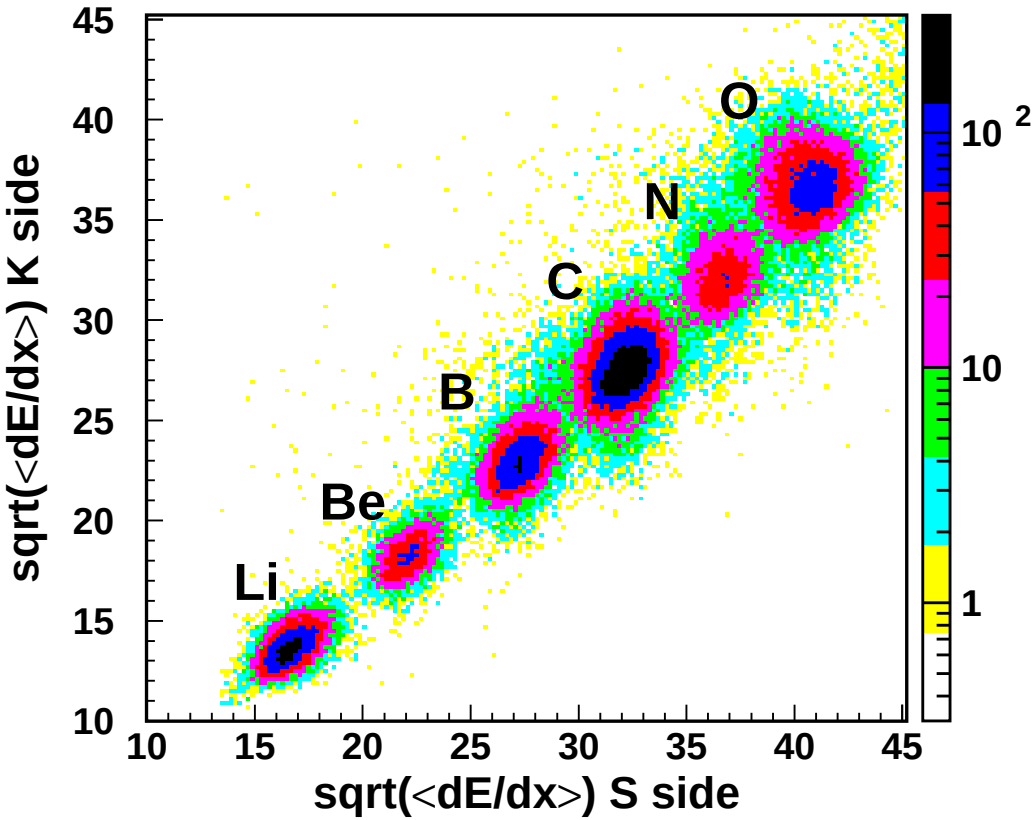
$$\mathrm{R_{min}} = 1.6\ \mathrm{GV} \ldots \mathrm{R_{max}}$$

Result is independent of the incident $\overline{\mathrm{He}}$-spectrum!

Search for Antimatter

Search for Heavier Antinuclei





1.65×10^5 heavy ions have been identified

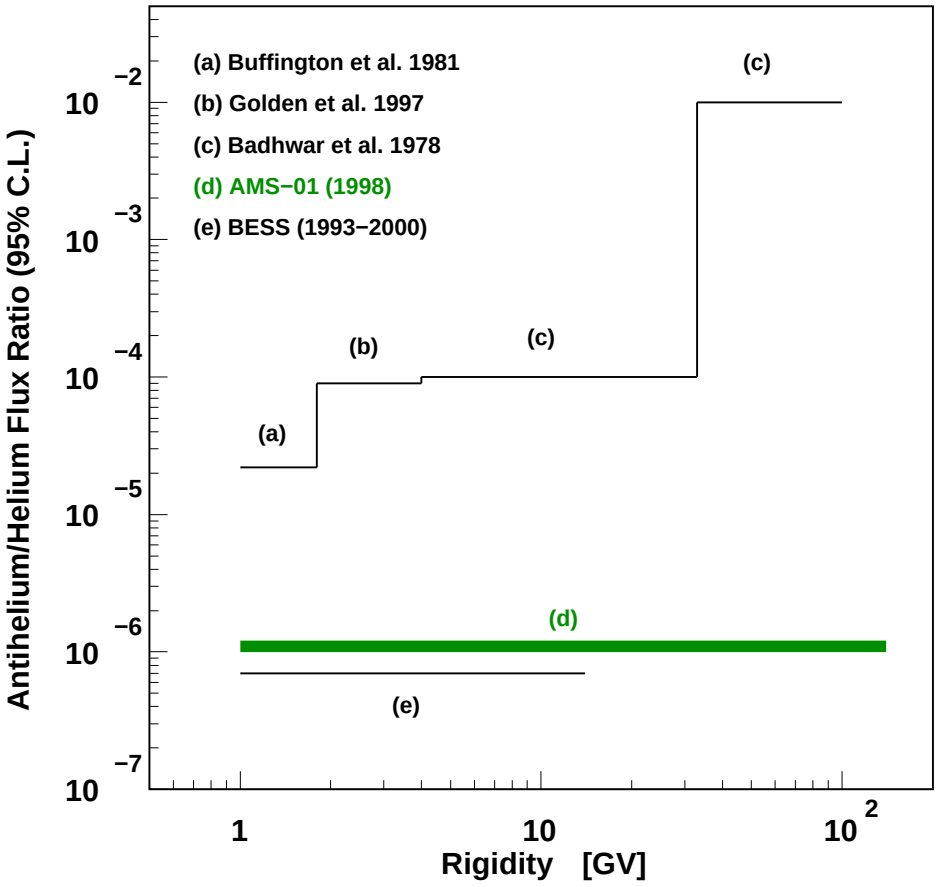
No antinucleus was found

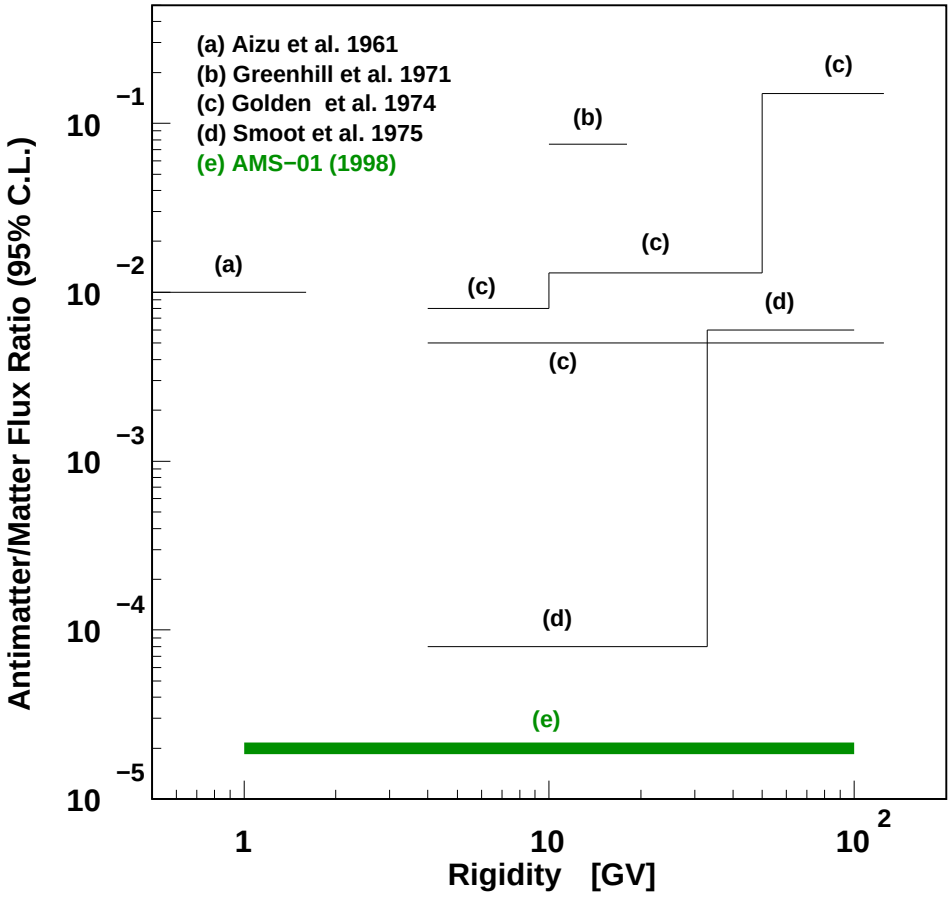
Nuclei range from lithium to oxygen in the rigidity interval

1 GV to 100 GV

Search for Antimatter

Comparison with Other Results





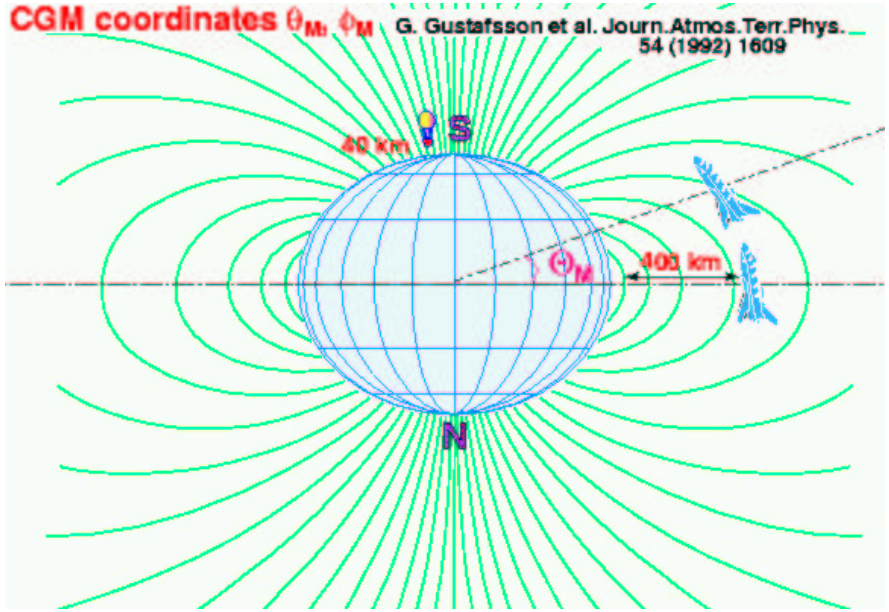
AMS-01 test flight produced competitive limits on an extended rigidity range, that are compatible or even better than previous results

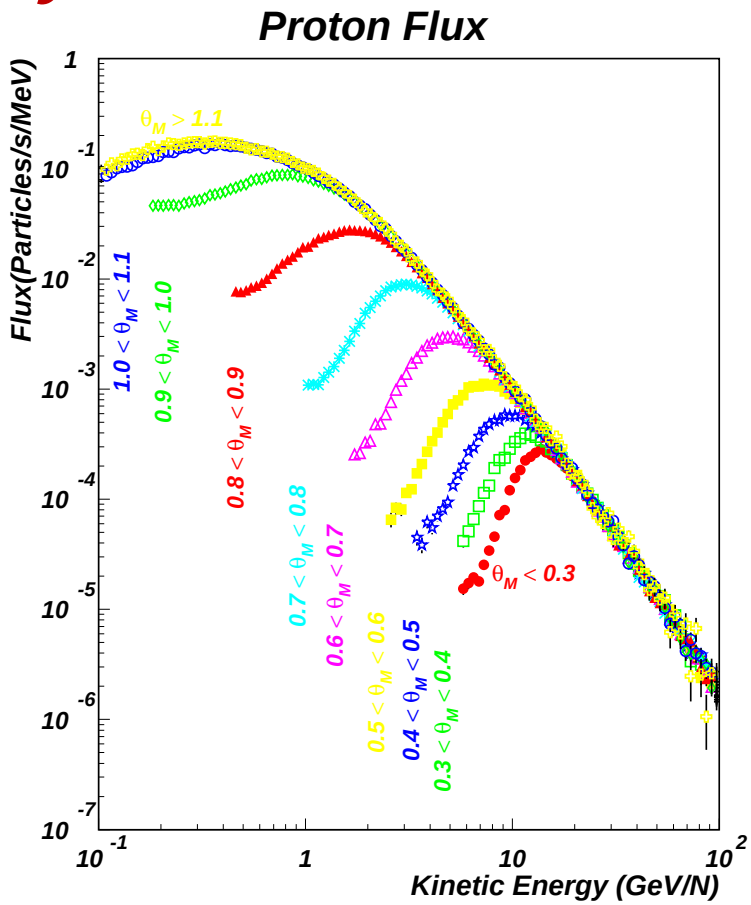
Flux Measurements

- No Antimatter found $\Rightarrow$ Study Properties of Matter
- Studies performed on:
  - protons
    To understand interstellar propagation and
    acceleration of cosmic rays
  - electrons
    coming from supernova explosions and interstellar gas
  - Helium
- Observed spectra show a primary and secondary spectrum
  - Primary spectrum: cosmic particles
  - Secondary spectrum: geomagnetic effects

Flux Measurements

Geomagnetic rigidity cut-off





Minimum rigidity (p/Z) depends on magnetic latitude

$\Rightarrow$ cutoff in the spectrum of cosmic particles

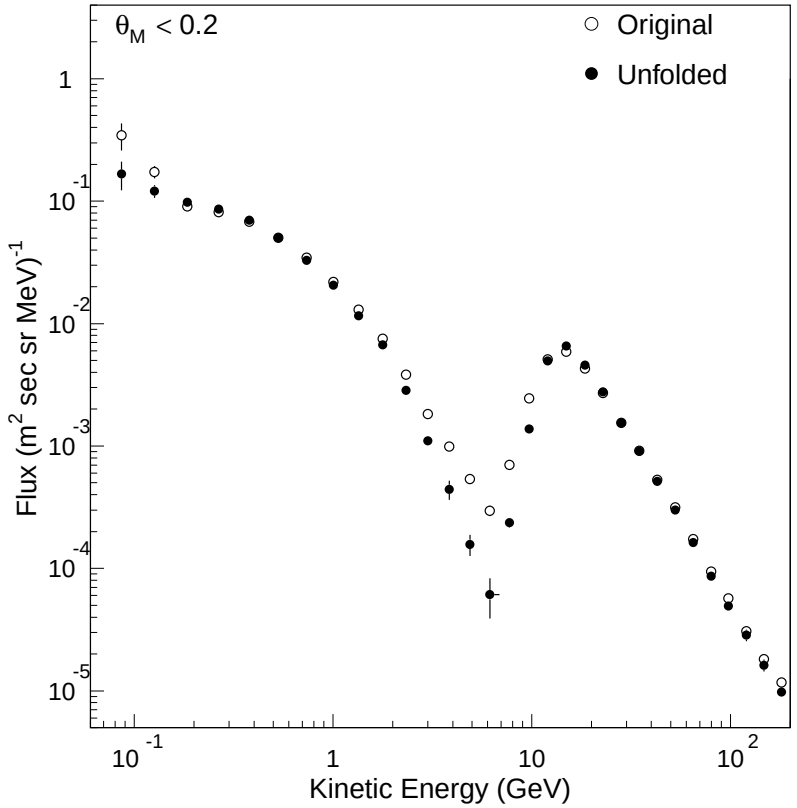
Flux Measurements

Protons

Protons are the most abundant charged particles in space, studied at:

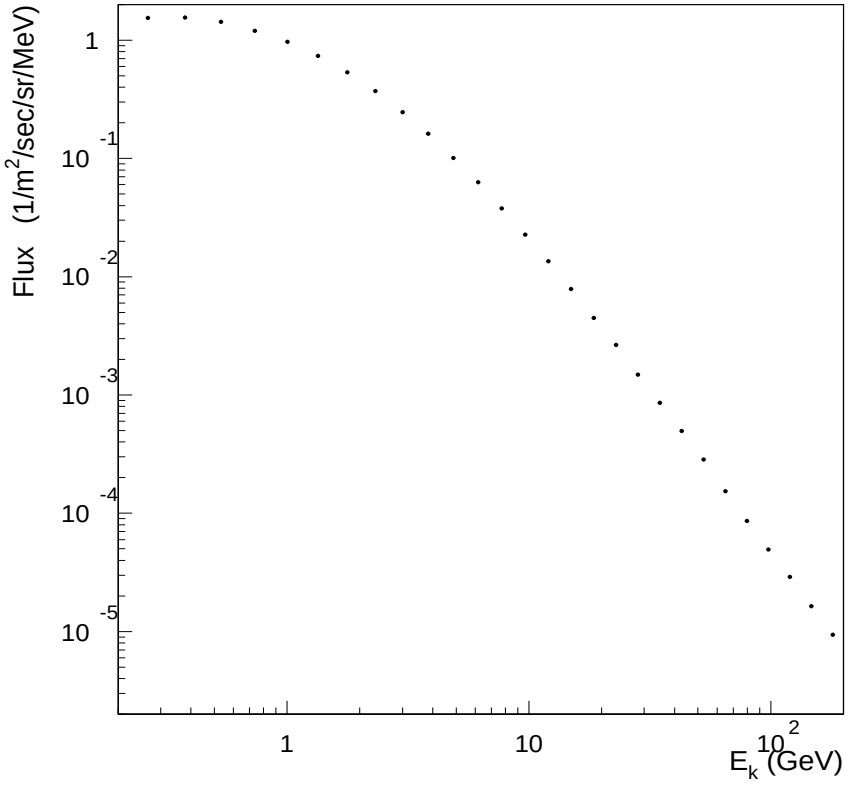
- Altitudes 30-40 km: Balloon measurements $\Rightarrow$ atmospheric secondaries
- Inner and outer radiation belts from 1000 km: small size satellite detectors $\Rightarrow$ high intensity cosmics
- Intermediate region by AMS-01 $\Rightarrow$ both spectra!

- Background: $\pi^{\pm}$ and d
- Acceptance and Resolution are taken into account $\Rightarrow$ Unfolding



Flux Measurements

Protons - Primary Spectrum



Fitting the spectrum over all latitudes at energies above the geomagnetic cutoff ($E > 10$ GeV) to

$$\Phi_0 \times R^{-\gamma}$$

we obtain

$$\gamma = 2.79 \pm 0.012_{\text{stat}} \pm 0.019_{\text{sys}}$$

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$$\Phi_0 = 16.9 \pm 0.2_{\text{stat}} \pm 1.3_{\text{sys}} \pm 1.5_{\gamma} \frac{\text{GV}^{2.79}}{\text{m}^2 \text{sec sr MeV}}$$

Flux Measurements

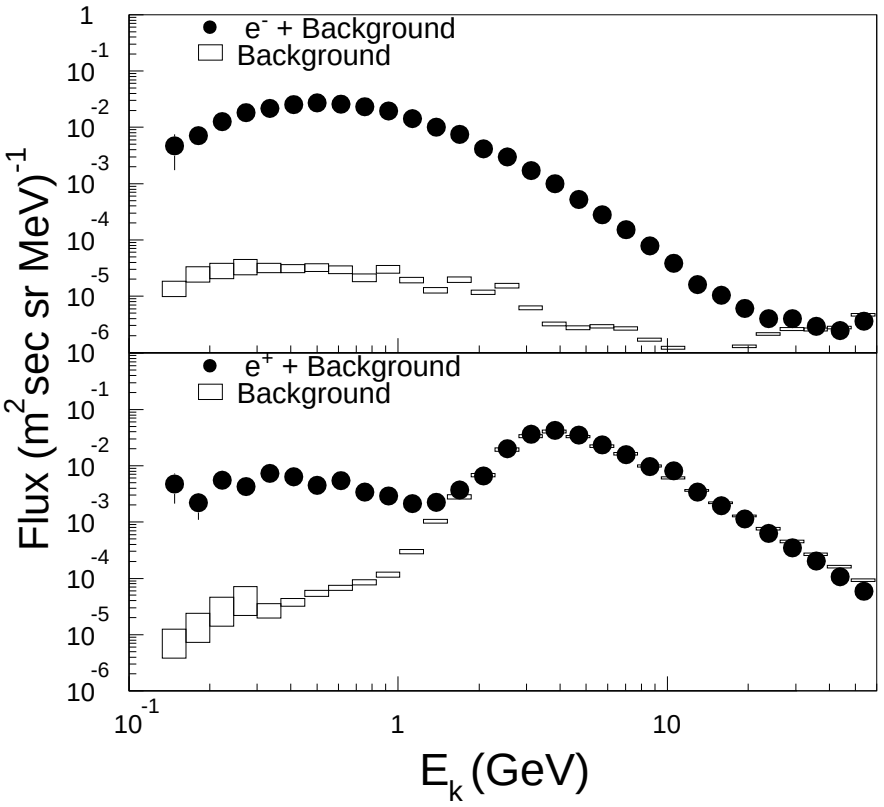
Electrons/Positrons

Electron spectrum from 0.2 - 30 GeV

- background: protons with bad p, secondary pions: $\mathcal{O}(10^{-4})$
- Cerenkov-signal required (independent β measurement)
- Efficiency: 39%

Positron spectrum from 0.2 - 3 GeV

- background: protons with bad p
- at low energy: tenfold dE/dx of scintillator and tracker
- at higher energy: additional cuts on Cerenkov
- Efficiency: 28%



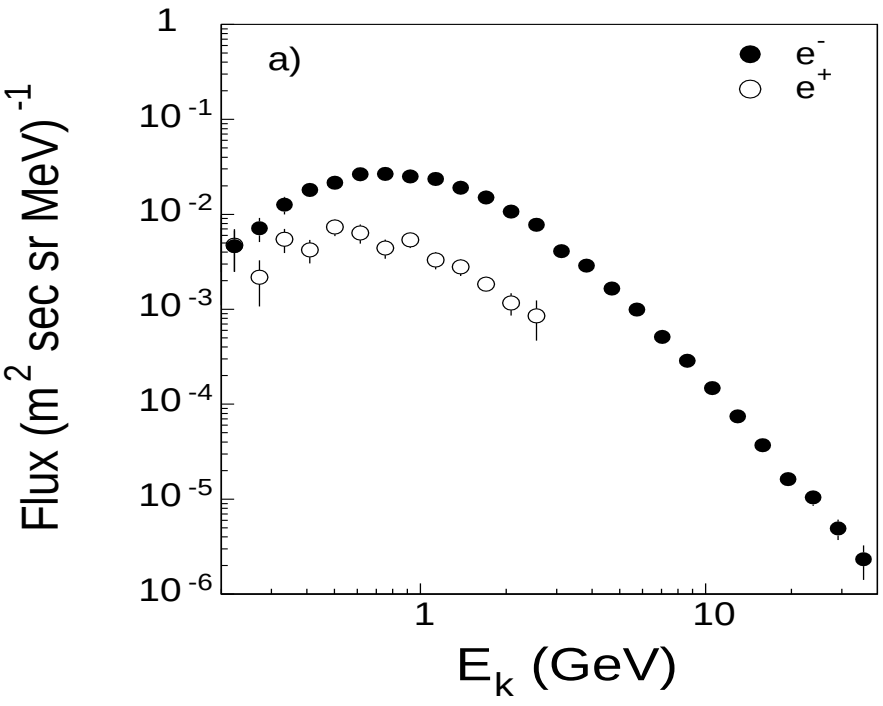
Background subtraction
⇒ Systematic error of 5%

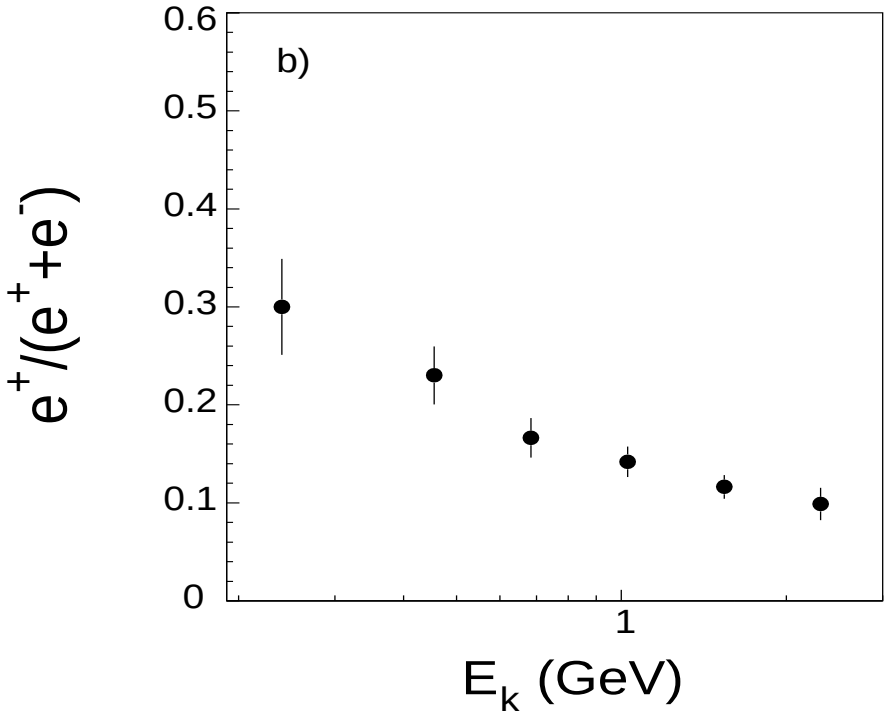
Flux Measurements

Primary Electrons/Positrons

- high energy electrons originate from primary acceleration sites (supernova explosions)
- high energy electron-positron pairs are produced from collisons of hadrons and gamma rays with interstellar gas

$\Rightarrow$ more e^- than e^+ expected

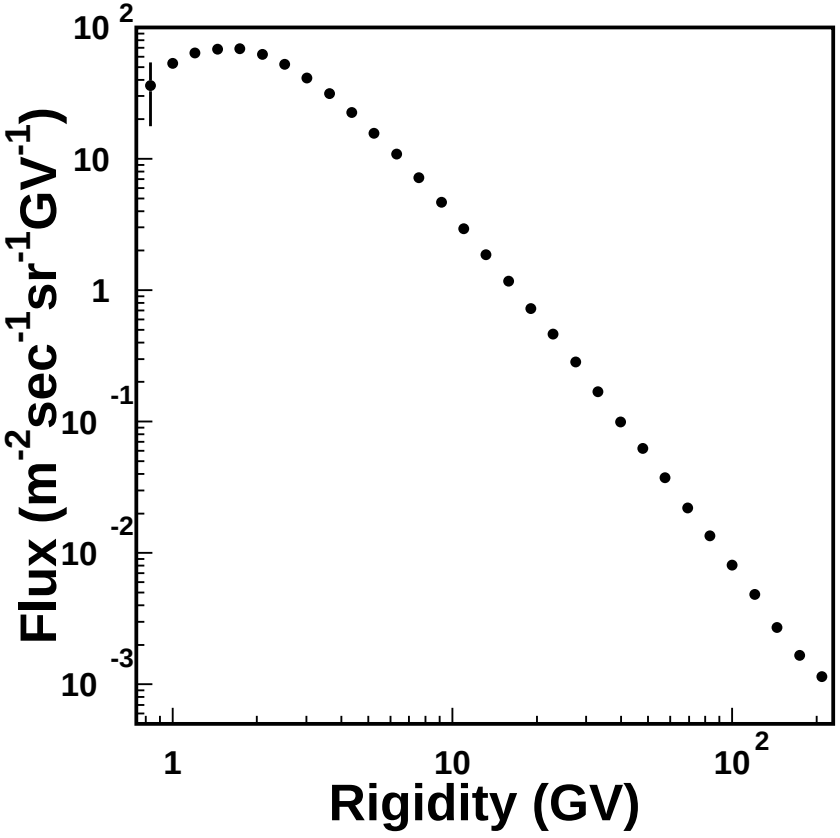




Flux Measurements

Helium

- Helium nuclei are second most abundant element in cosmic rays
- balloon experiments: helium and proton spectra show no difference $\Rightarrow$ same source
- But not yet confirmed above 10 GeV $\Rightarrow$ AMS-01 10^6 nuclei from 0.1 - 100 GeV/n



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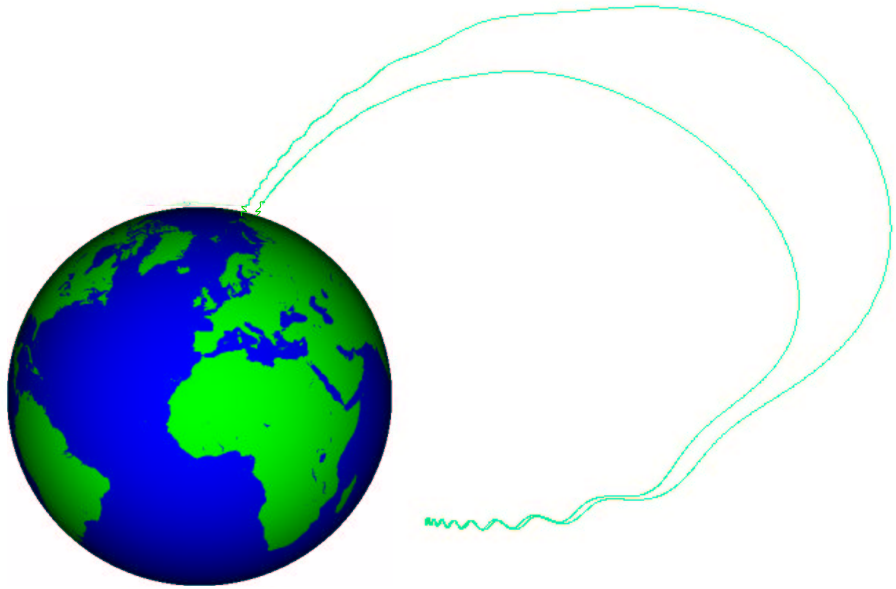
$$\gamma = 2.74 \pm 0.010_{\text{stat}} \pm 0.016_{\text{sys}}$$

$$\Phi_0 = 2.49 \pm 0.09_{\text{stat}} \pm 0.14_{\text{sys}} \pm 0.14_{\gamma} \frac{\text{GV}^{2.74}}{\text{m}^2 \text{sec sr MeV}}$$

Geomagnetic Effects

A large flux of particles is detected for rigidities lower than the geomagnetic cutoff $\Rightarrow$ Where do they come from?



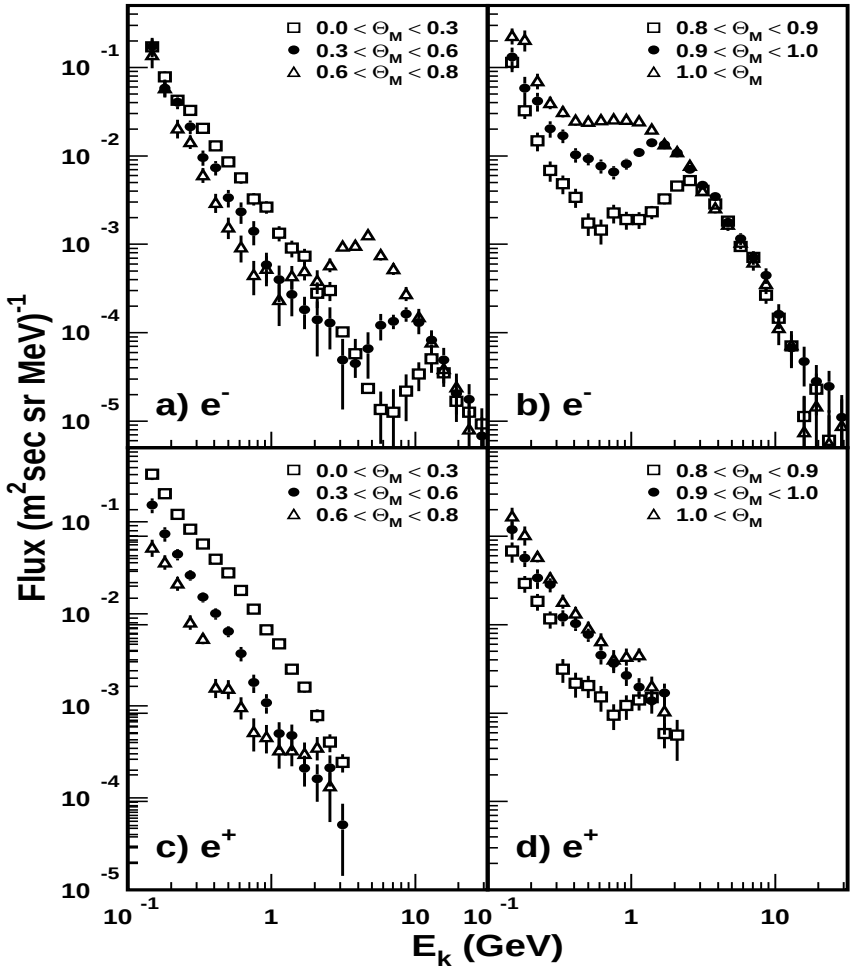
To determine their origin, detected particle trajectories have been backtraced through the Earth magnetic field

Backtracing has been done (for max 10 sec) until:

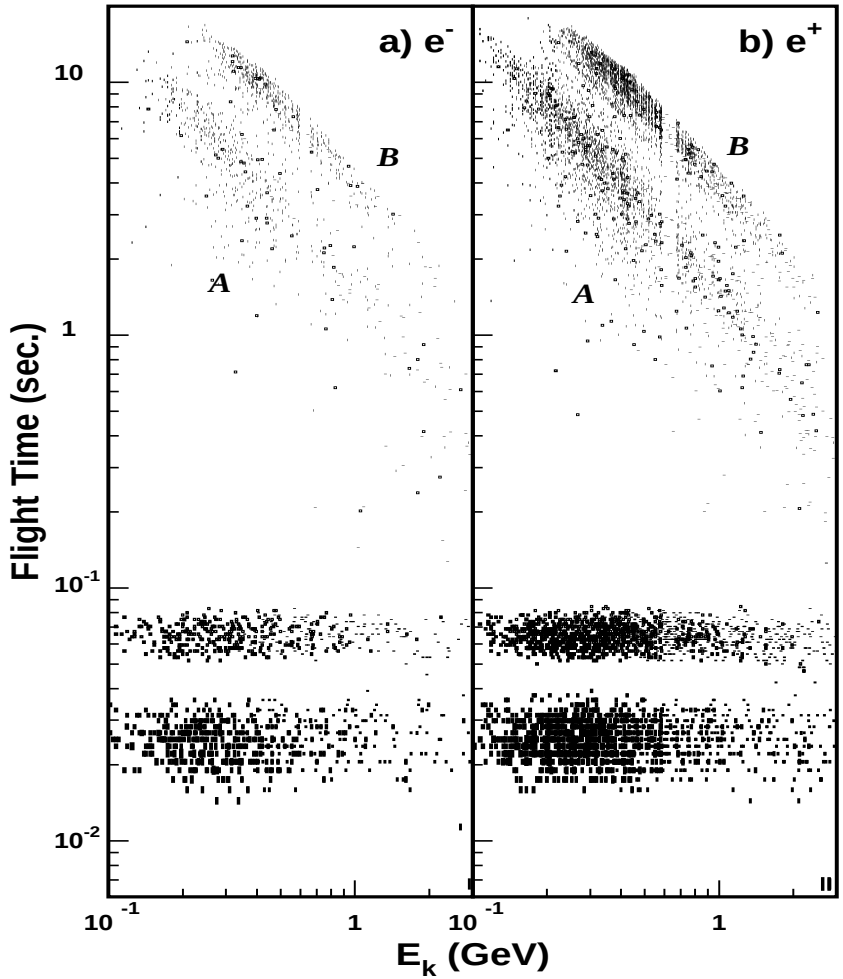
- The trajectory reached outside the magnetosphere
- it reached the atmosphere (altitude 40 km)
  for this, two components
  - $t < 200$ msec: short lived
  - $t > 200$ msec: long lived

Geomagnetic Effects

Secondary spectrum of $e^{\pm}$



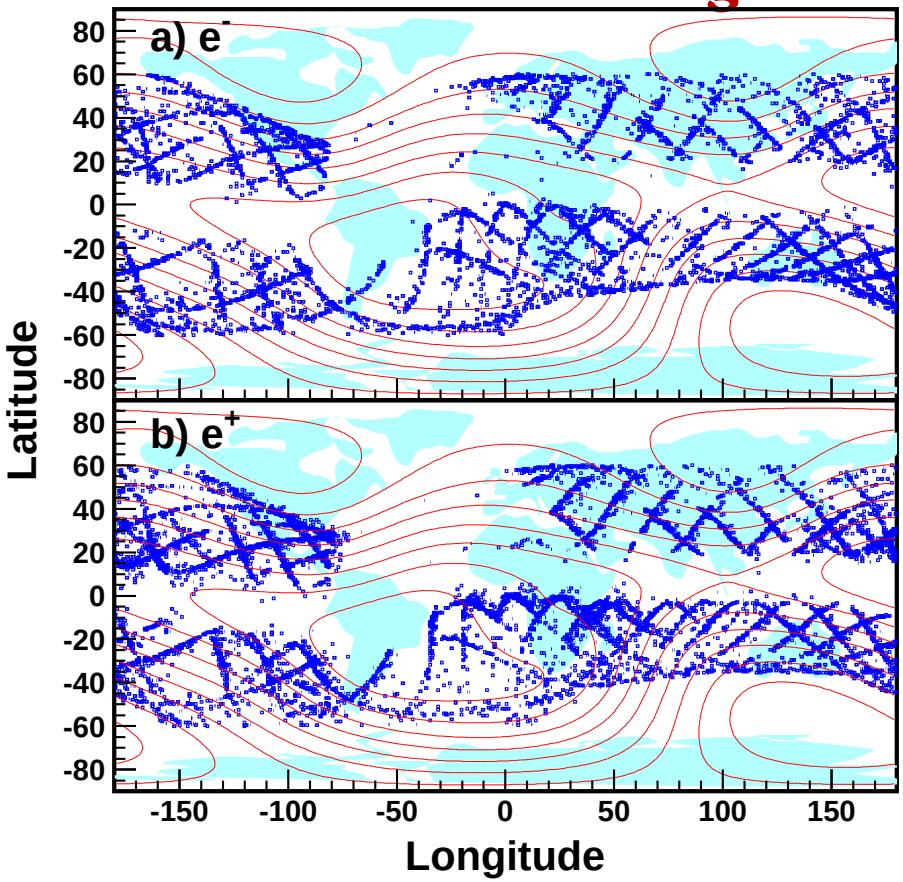
Substantial secondary spectrum under geomagnetic cutoff



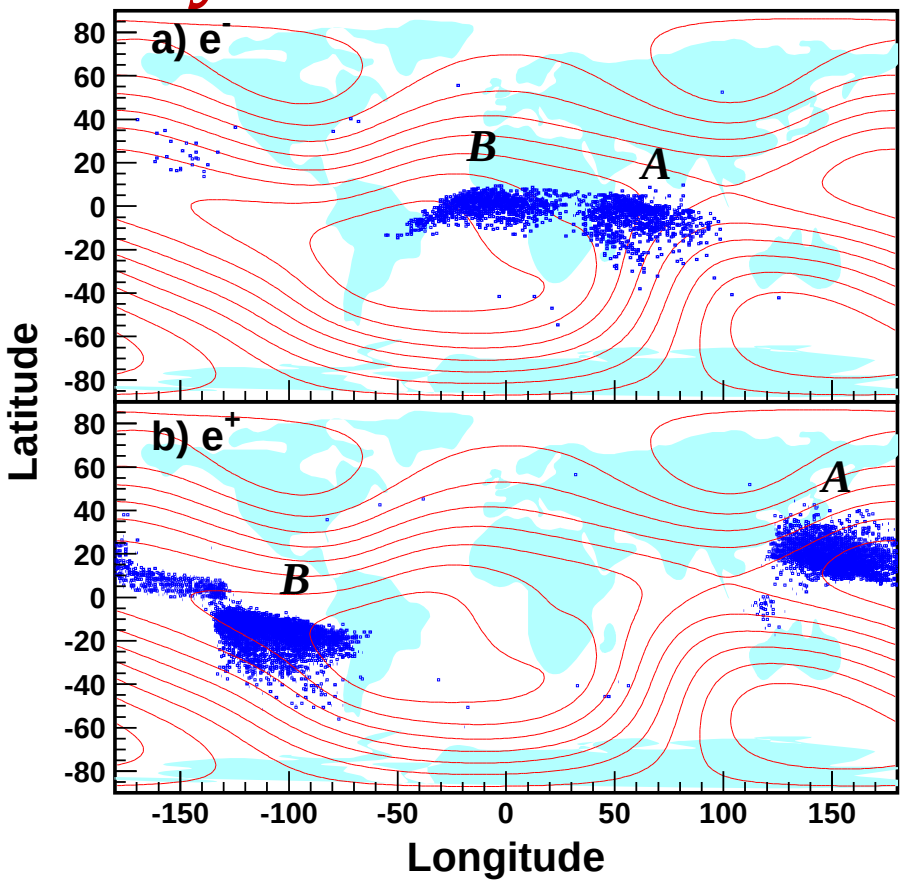
Short flight times show no energy dependence

Geomagnetic Effects

Origin of secondary $e^{\pm}$



- origin show no longitude dependence
- flux independent on attitude and isotropic



- origin for $e^{\pm}$ are from well-defined, complementary regions
- flux depends on attitude

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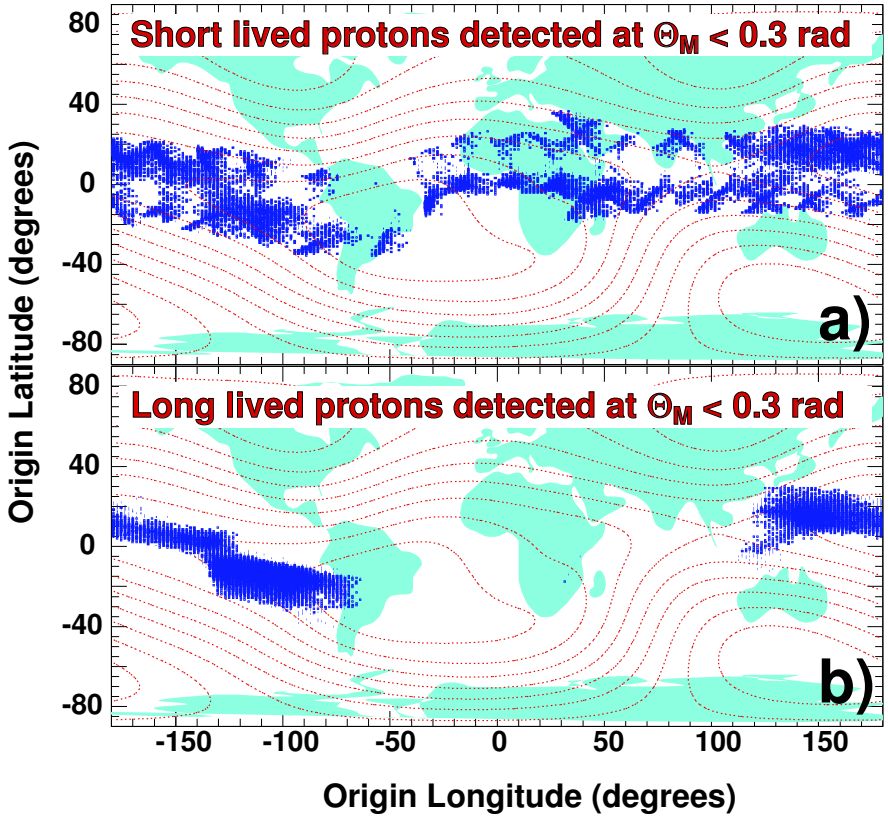
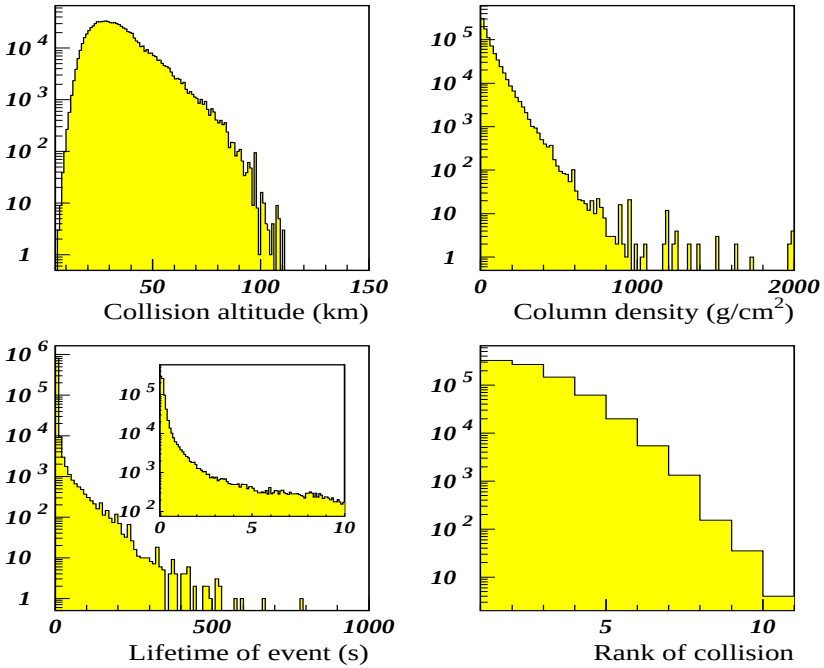
Geomagnetic Effects

Secondary spectrum of protons



Similar analysis for protons



Understanding of the origin requires full simulation of proton-nuclei in the atmosphere and their propagation in the magnetosphere

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Conclusions

Outlook to AMS-02

AMS-01 Results

- Best limit on antimatter flux up to 140 GV
- Primary spectra of protons, helium and leptons with excellent accuracy
- Geomagnetic effects on cosmic rays studied in detail
- Not bad for

  "Primarily a test flight [...] to adjust operating parameters and verify the detector's performance [...]"

What's next? ⇒ AMS-02

- Take data during 3 years on ISS
- First superconducting magnet in space
- Better Tracking System than AMS-01
- Additional ECAL energy measurement up to 1 TeV

Exciting challenge for coming years!