Results from the AMS1 Precursor Flight
and
Prospects of AMS2

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- Data Taking
- AMS1 Detector
- Physics Results
  - Antimatter
  - Primary Spectra (p, $e^{\pm}$, He)
  - Second Spectra
- AMS2 Prospects
- Conclusions

New Worlds in Astroparticle Physics
September 2, 2000 (Algarve)

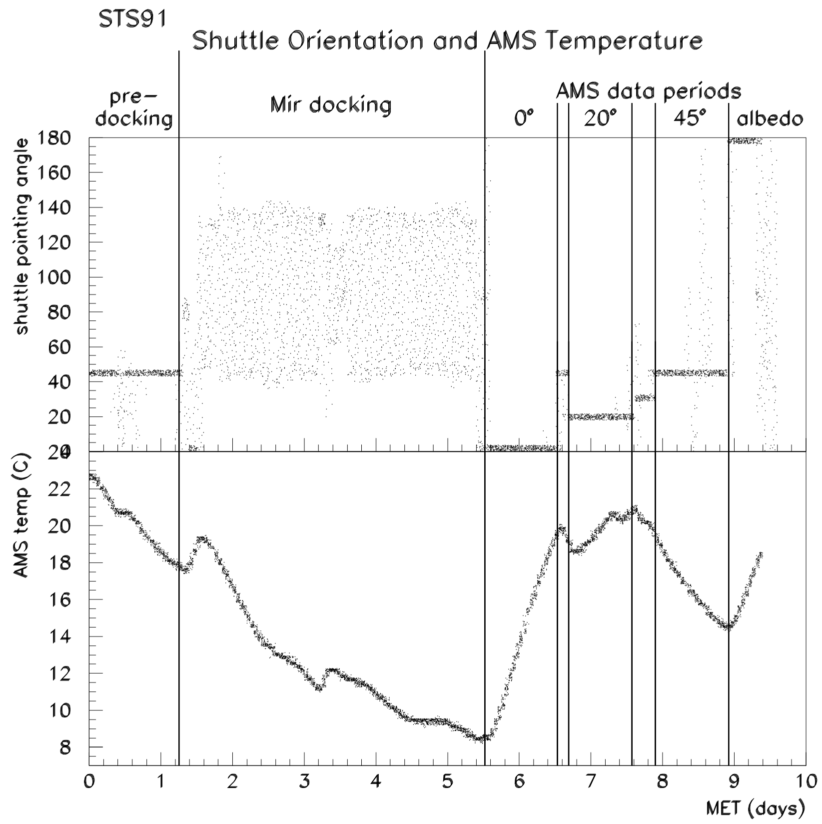
AMS Physics Aims

AMS is a precision magnetic spectrometer scheduled to be installed in the International Space Station (ISS) at the end of 2003, for three years, having as scientific objectives:

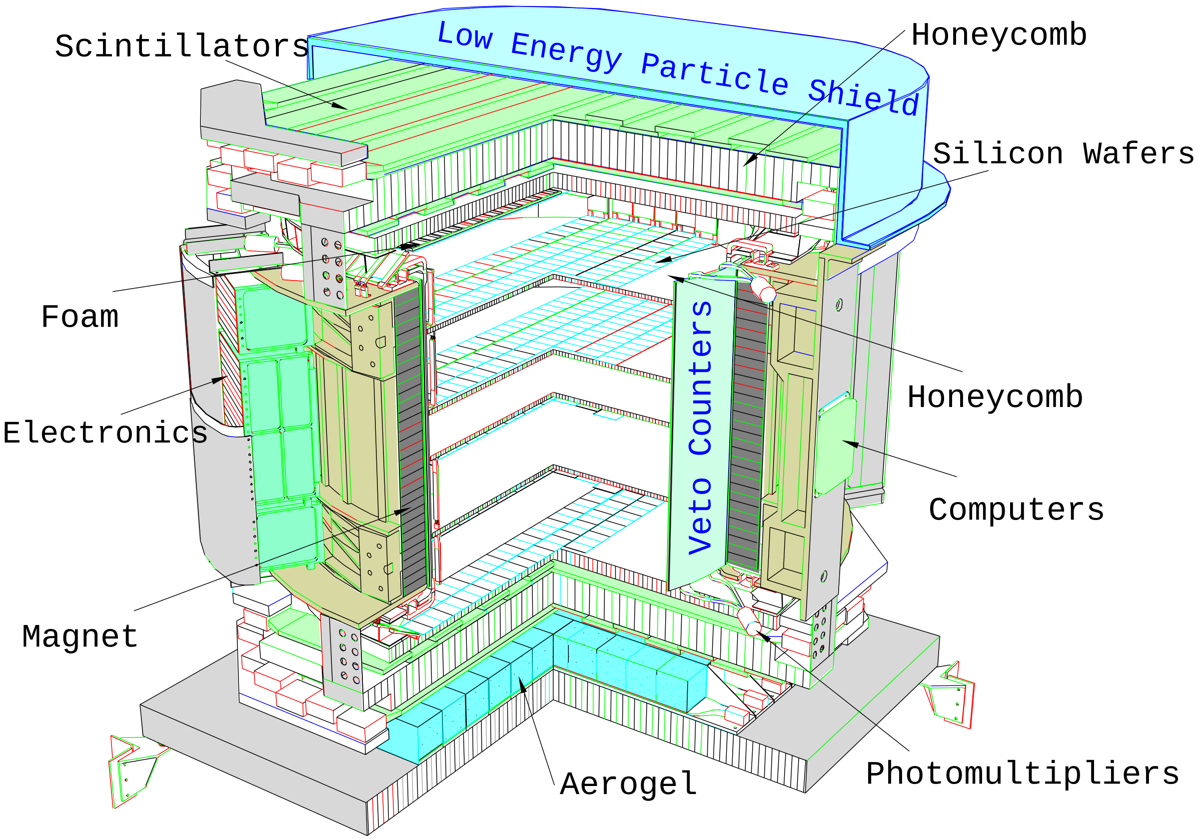
- Search for Cosmic Antimatter (anti-Helium or heavier elements)
- Search for DarkMatter
- Measurements on the relative abundance of Elements and Isotopes in primary cosmic rays

STS-91 Flight

- 2-11 June, 1998
  10 days flight on Shuttle Discovery
- mean altitude ∼ 370 Km
- 90 min orbit
  inclination of 51.7°
- around 100 hours of data taking
  100 million events
- event rate 100-700 Hz



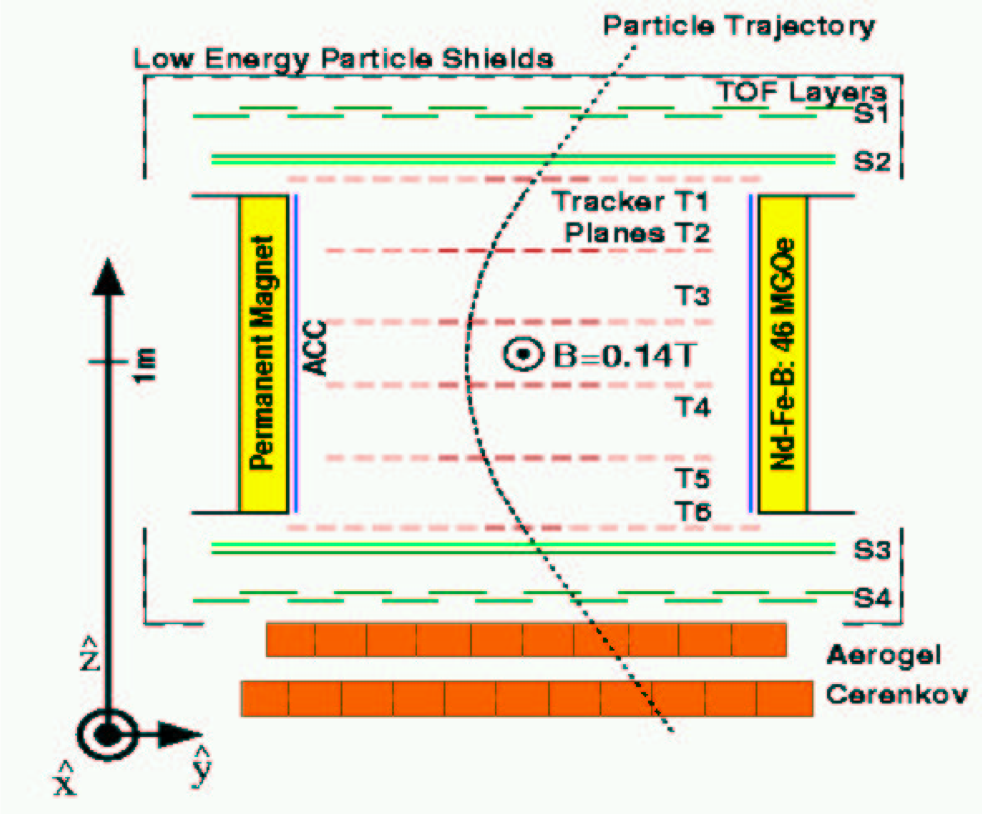
AMS1 Detector



AMS1: Spectrometer Capabilities

- particle bending
  Nd-Fe-B permanent magnet
  $BL^2 = 0.14\,Tm^2$
- particle direction of incidence
  Time-of-Flight detector
- Momentum (p)
  measured on silicon detector
- Velocity (β)
  measured on Time-of-Flight and Threshold Counter
- Charge (Q)
  measured on Silicon and Time-of-Flight detectors

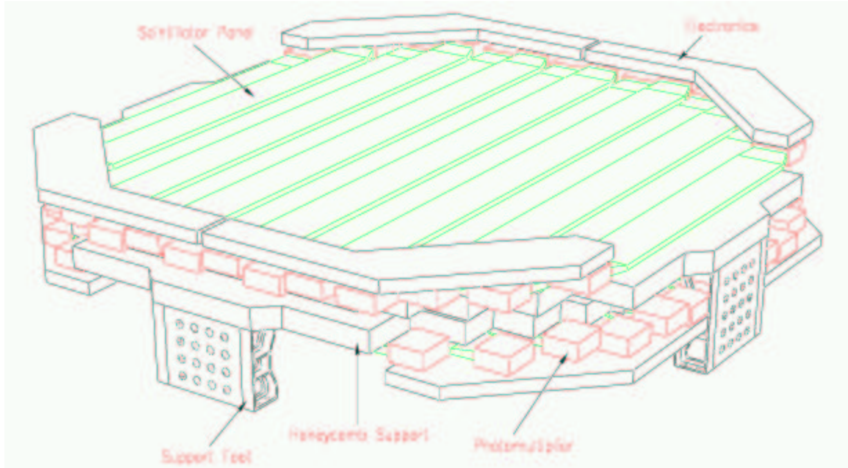
Acceptance $\sim 0.5\,m^2.sr$



Time-of-Flight (TOF)

The Time-of-Flight system consists of 4 scintillator planes with 14 bars large of 11 cm and provides:

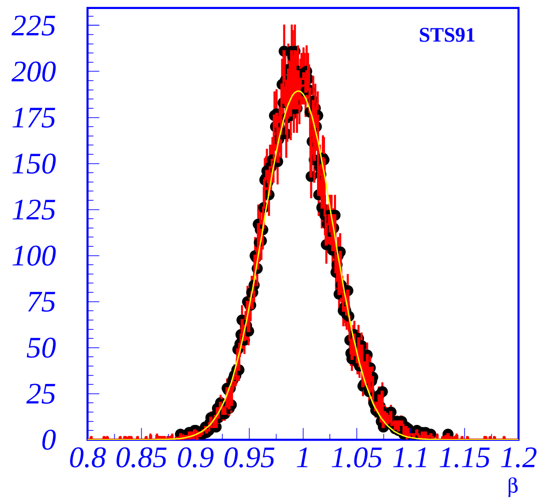
- fast trigger (4×4)
- velocity measurement
- absolute charge measurement
- upward/doward particle separation (10^{-8})



$\Delta t \simeq 125$ **psec**

$\Delta\beta/\beta \sim 3$ **%**

$\Delta x \simeq 2$ **cm**



Silicon Tracker (TRK)

The Silicon Tracker is assembled in 6 planes made of double sided microstrips detectors and placed inside the permanent magnet.

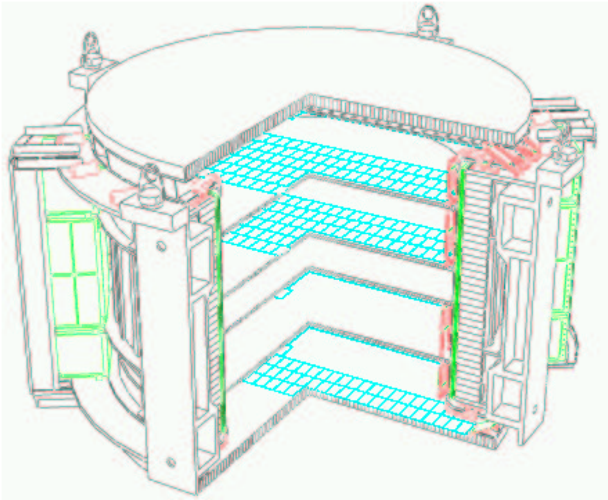
- 3rd level trigger
- rigidity ($R \equiv p/Z$) measurement (value and sign)
- absolute charge measurement

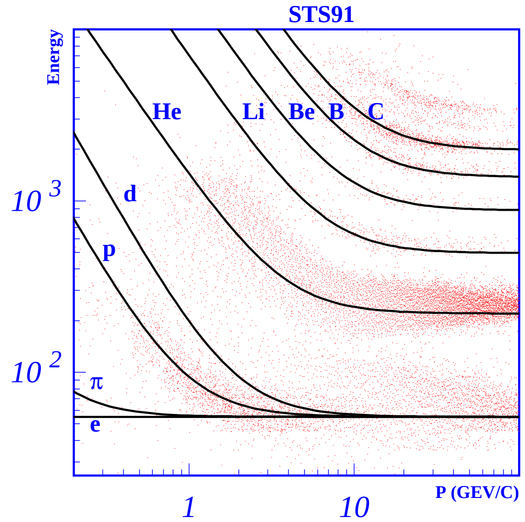
Silicon Area: $2.4\ m^2$

$\sigma_y = 10\ \mu m$ **(bending plane)**

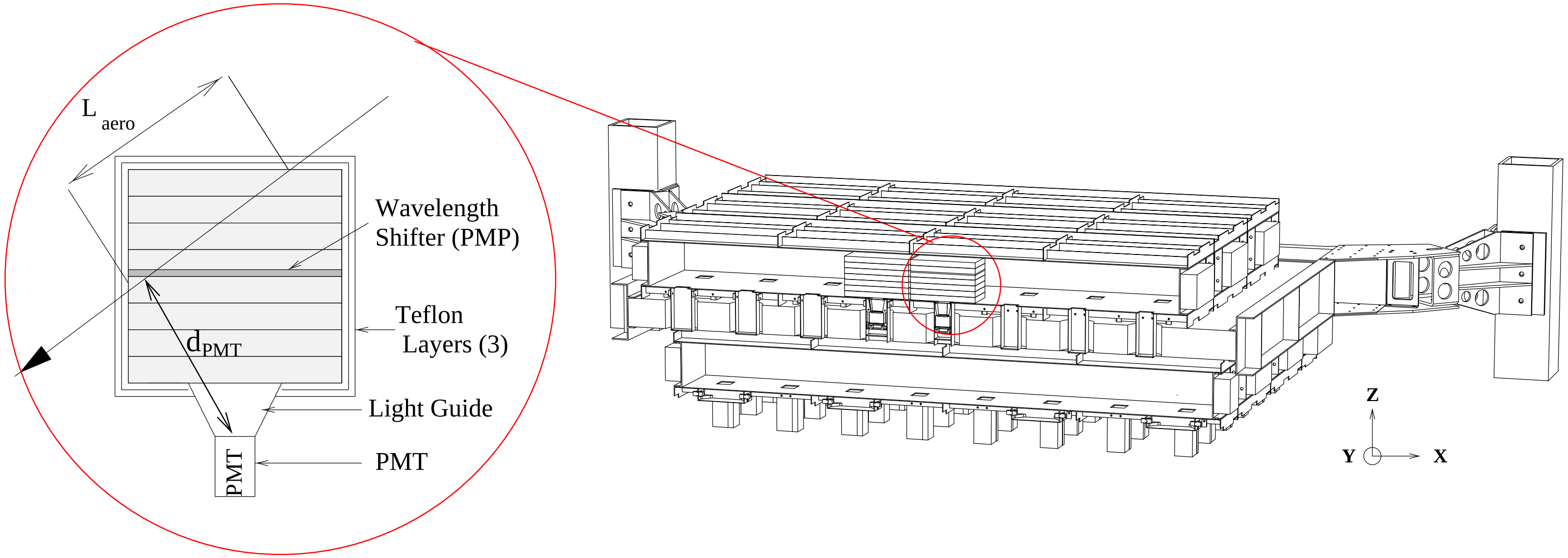
$\sigma_x = 30\ \mu m$ **(non-bending plane)**

$\frac{\Delta p}{p} \simeq 8\%$ **(2-10 GeV/c)**





Aerogel Threshold Counter (ATC)



Detector elements

- 2 planes
- 5 (up) and 6 (down) modules
- 168 aerogel cells
- low refractive index aerogel (n=1.035)

Contributions to

- antiproton identification
- positron selection
- sensitive to charge magnitude

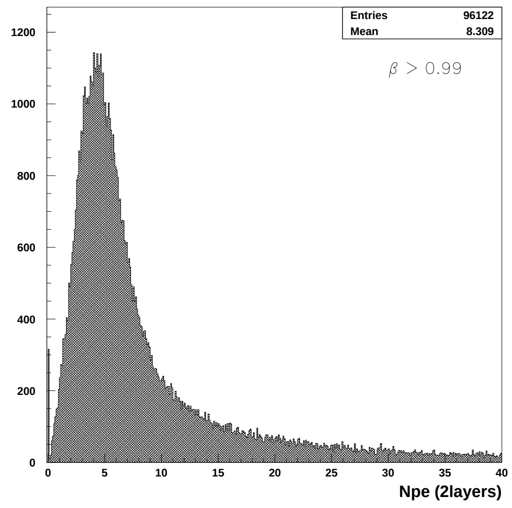
ATC: e^+ selection

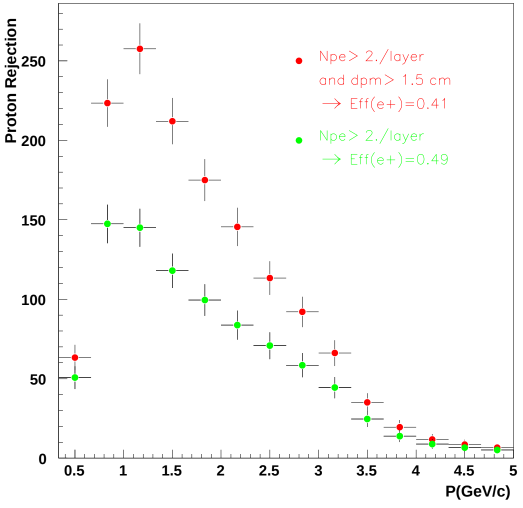
- The positron sample has potentially a strong contamination due to the very abundant proton statistics $(e^+/p \sim 10^{-3})$
- Separation relies on the fact that up to the threshold proton momentum $(\sim 3.5\ GeV/c)$ the positron provides a signal stronger than proton

$$\beta \simeq 1 \Rightarrow n_{p.e} \simeq 7$$

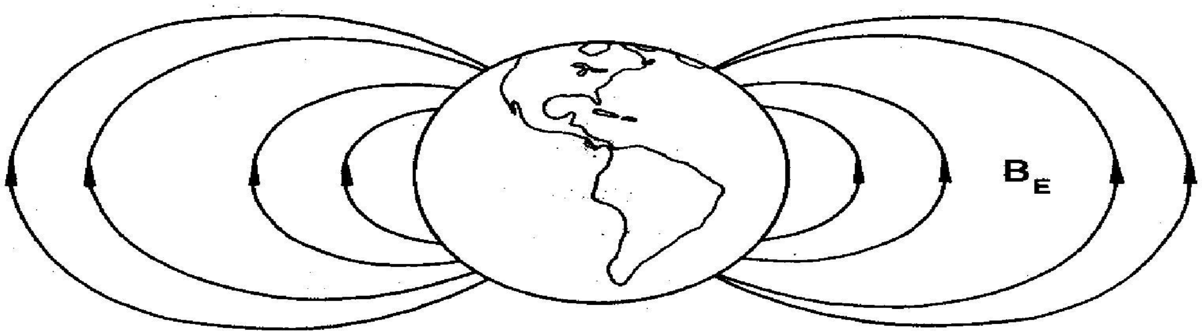
- positron selection
  - Aerogel thickness > 8 cm/plane
  - $n_{p.e} = 2/\text{plane}$
  - Impact par > 1.5 cm

$$\varepsilon_{e+} \simeq 41\%$$





Geomagnetic Field: dipole



- Magnetic field around Earth
  - Æ 1st approx. dipolar

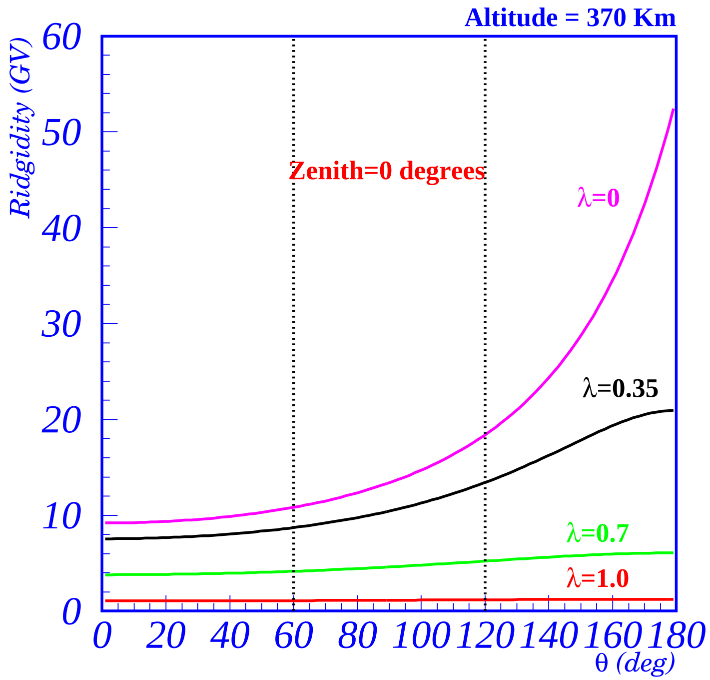
  $$B \simeq 0.26 \frac{\sqrt{1+sin^2\lambda}}{cos^6\lambda}\ G\ (at\ 370\ Km)$$

- Geomagnetic Cutoff
  - Æ minimal particle Ridgidity

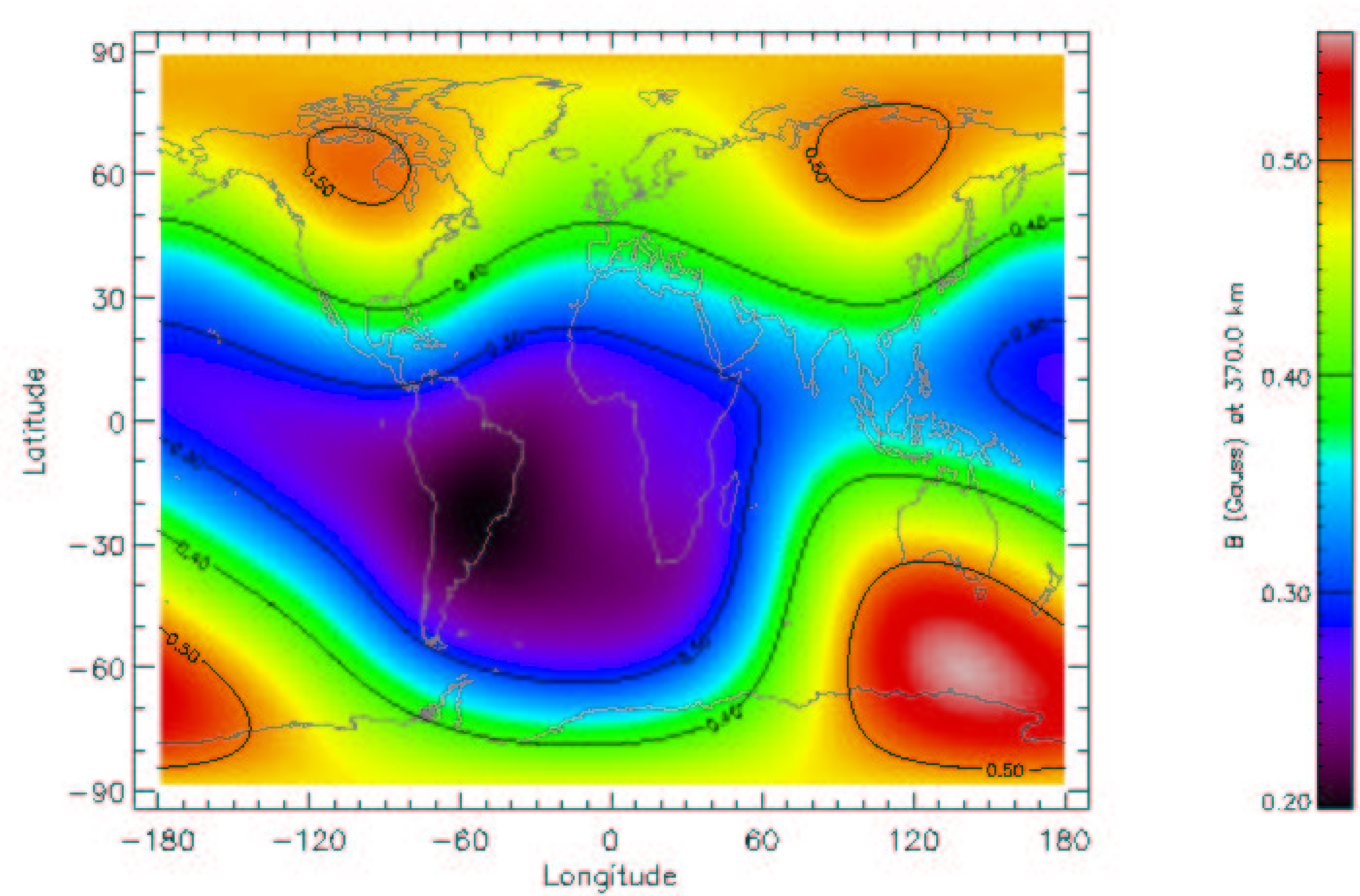
  $$R_{cut} = \frac{60}{\left(1+\frac{h}{R_E}\right)^2} \frac{cos^4\lambda}{\left[(1+cos\alpha cos^3\lambda)^{1/2}+1\right]^2}$$

East-West assymetry

maximal in magnetic equator



Geomagnetic Field

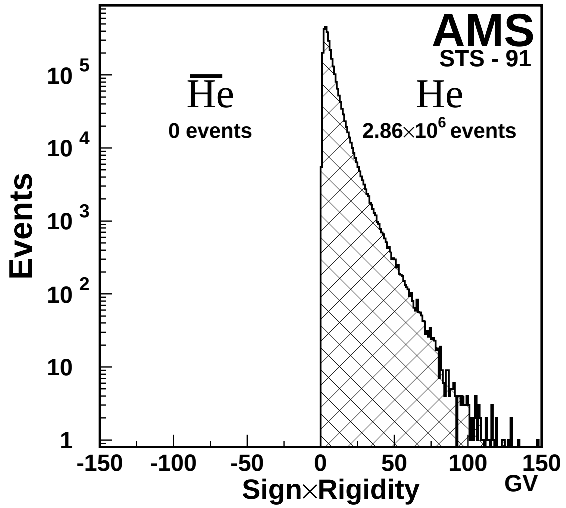


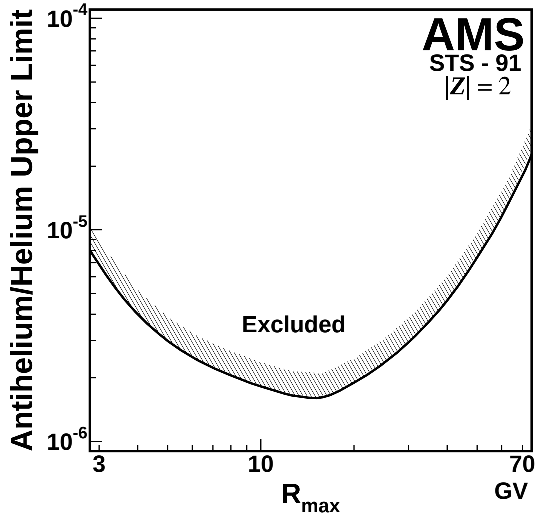
(Altitude = 370 km)

AntiMatter Search: AntiHelium

- Data Selection
  - $|Z| = 2$ events
  - Negative Charge
- Background
  - $|Z| = 1$ negligible (10^{-7})
  - He scattered on tracker planes
  - δ-rays
- Upper Limit
  - **No event found**
  - 95%CL signal: 3 events
  - $\frac{\bar{H}e}{He} = \frac{N_{\bar{H}e}(95\%CL)}{\varepsilon_{\bar{H}e} N_{He}}$

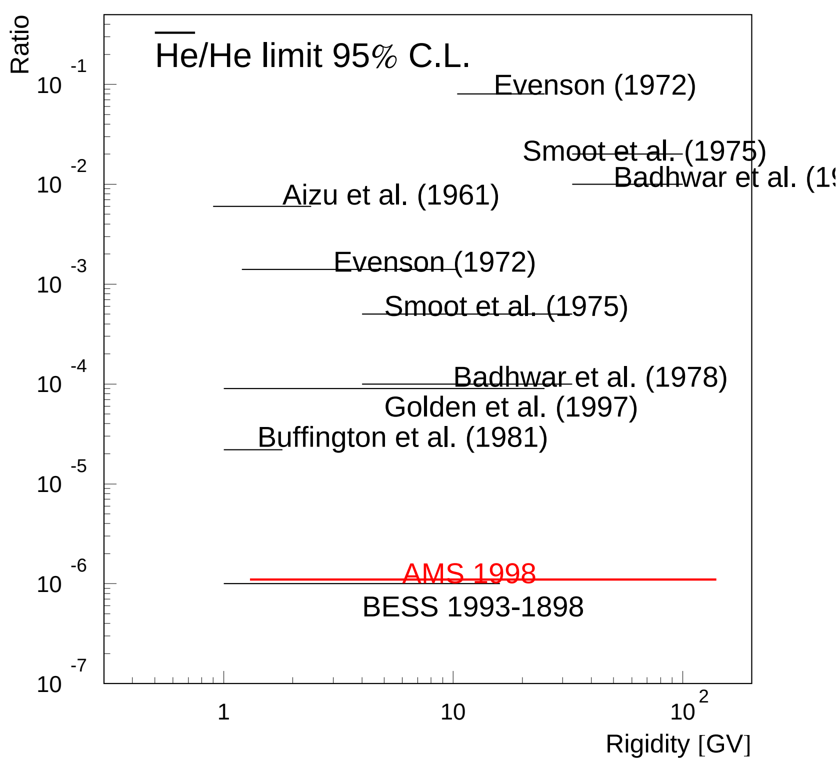
$$\frac{\bar{H}e}{He} < 1.1 \times 10^{-6} \quad (1 < R < 140\ GV)$$



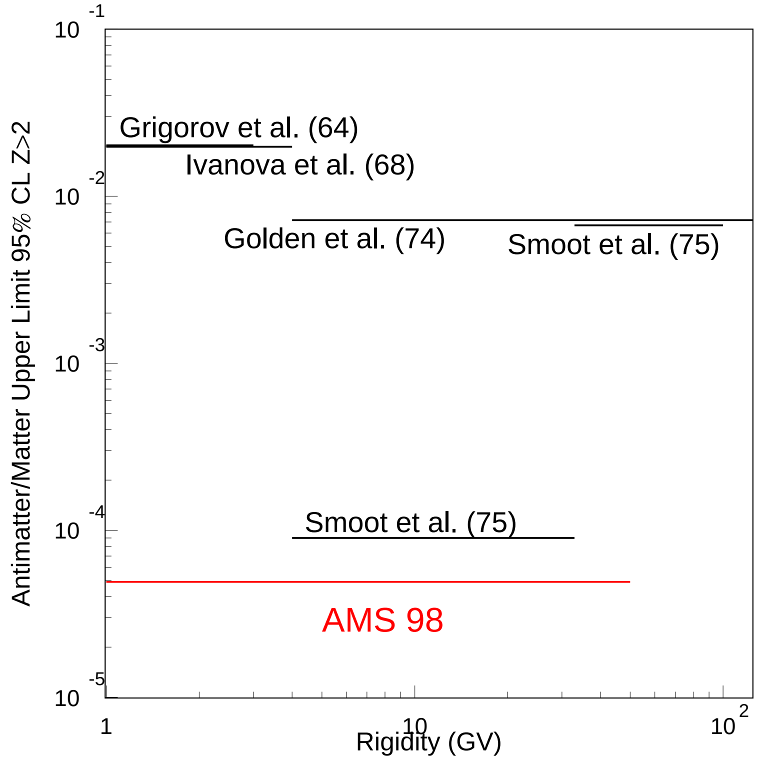


AntimatterSearch limits

AntiHelium $(Z = 2)$



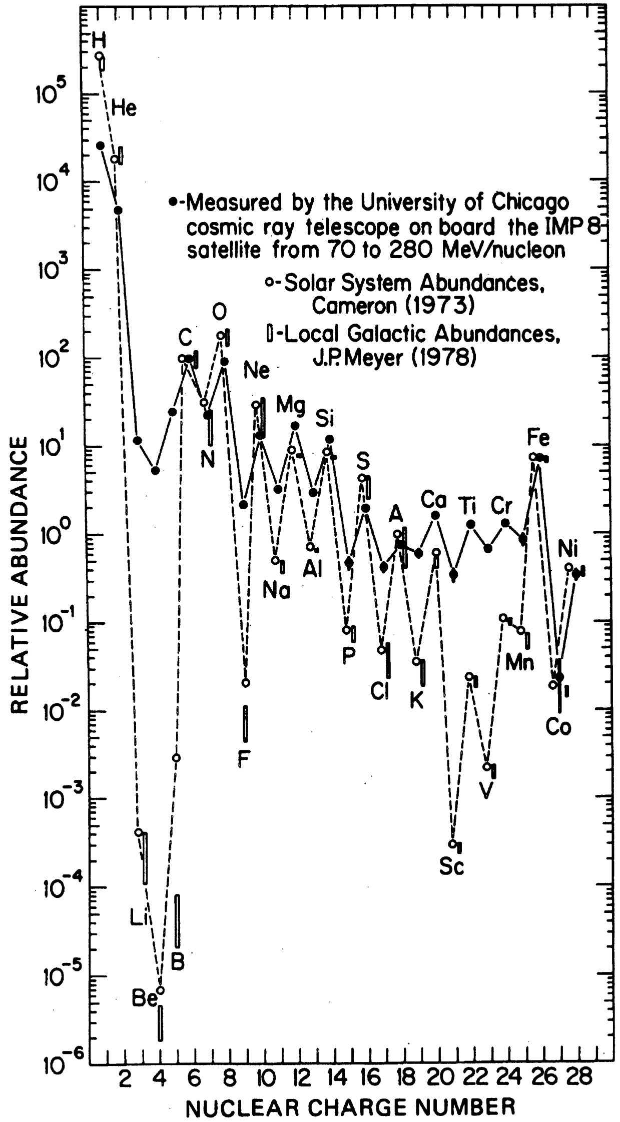
AntiNuclei $(Z > 2)$



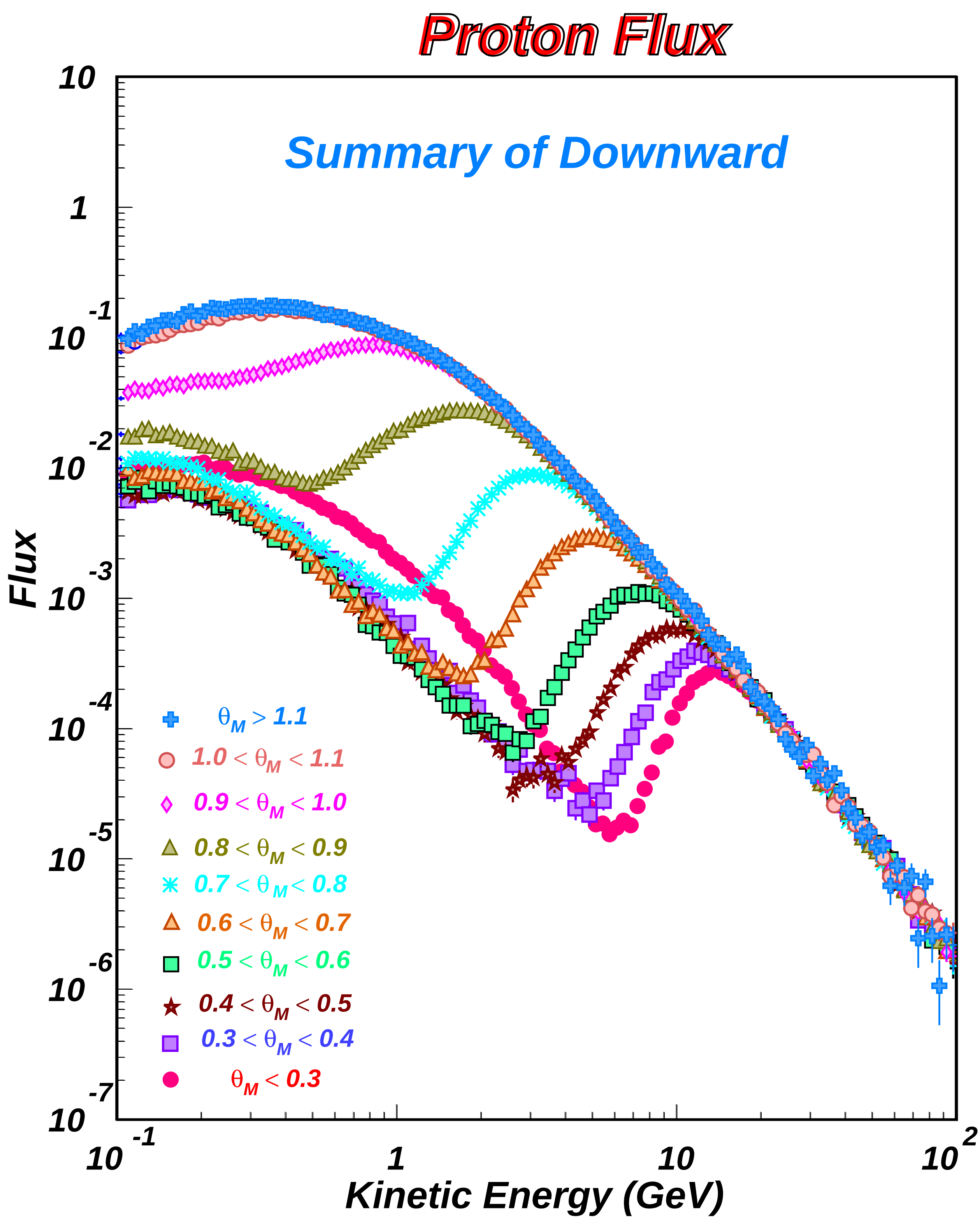
(Assuming similar spectra for Nuclei and antiNuclei)

Measurement of Primary Cosmic Rays

- Charged Cosmic Rays (mostly Protons and Heliums) are supposed to be produced in the galaxy (stellar explosions, stellar flares,...)
- Their energy is well described by a power law: $\Phi = \Phi_0 E^{-\gamma}$
- Low energy spectrum and abundance are modified by the solar wind (solar modulation)
- The measurement of the Proton and Helium fluxes are important
  - Œ secondary particles fluxes $(\bar{p}, e+)$
  - Œ atmospheric neutrino fluxes
- Flux: $\Phi(E) = \frac{\sum N_i(E,\theta,\phi)/\varepsilon_i^{Livetime}}{\varepsilon(E,\theta,\phi)\ Acc(E,\theta,\phi)\ \int t}$



Primary Proton Spectrum



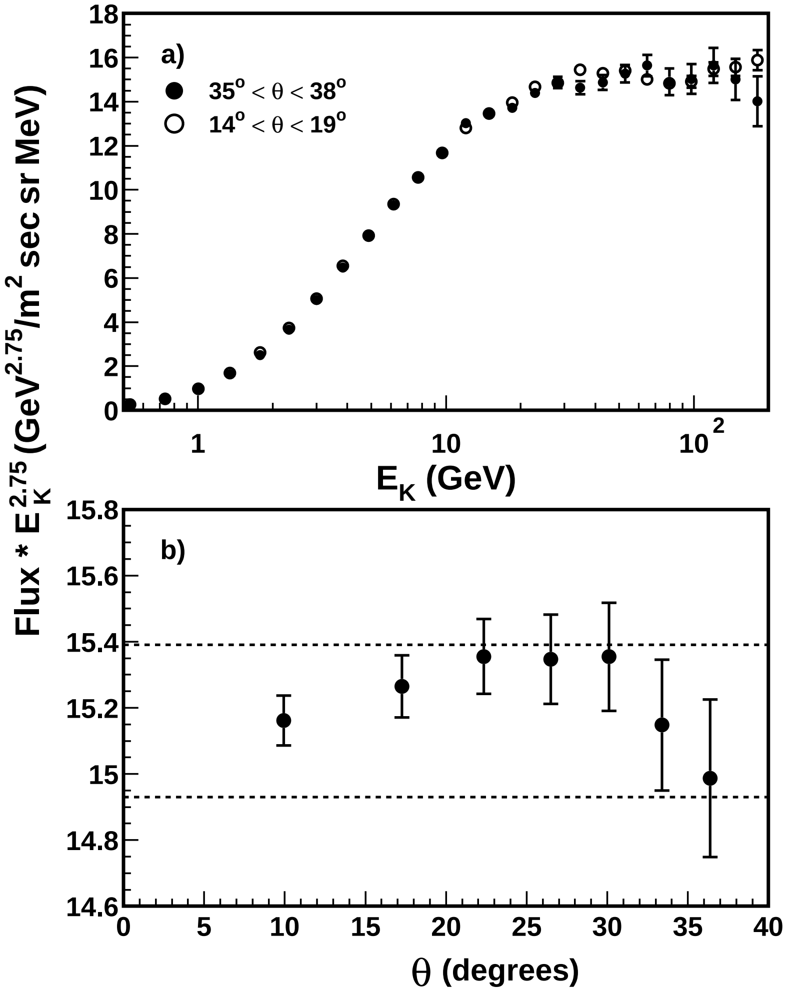
Primary Proton Spectrum

- Data Selection
  - Charge=+1
  - Quality cuts for tracks (χ^2)
  - Reconstructed mass within 3σ of m_p
  - Measured Rigidity above Cutoff
- Acceptance
  - $\sim 0.15\ m^2.sr$
- Data Sample
  - $5.6\ 10^6$ events
- Kinetic energy range
  - 0.2-200 GeV
- Power Law on Rigidity:

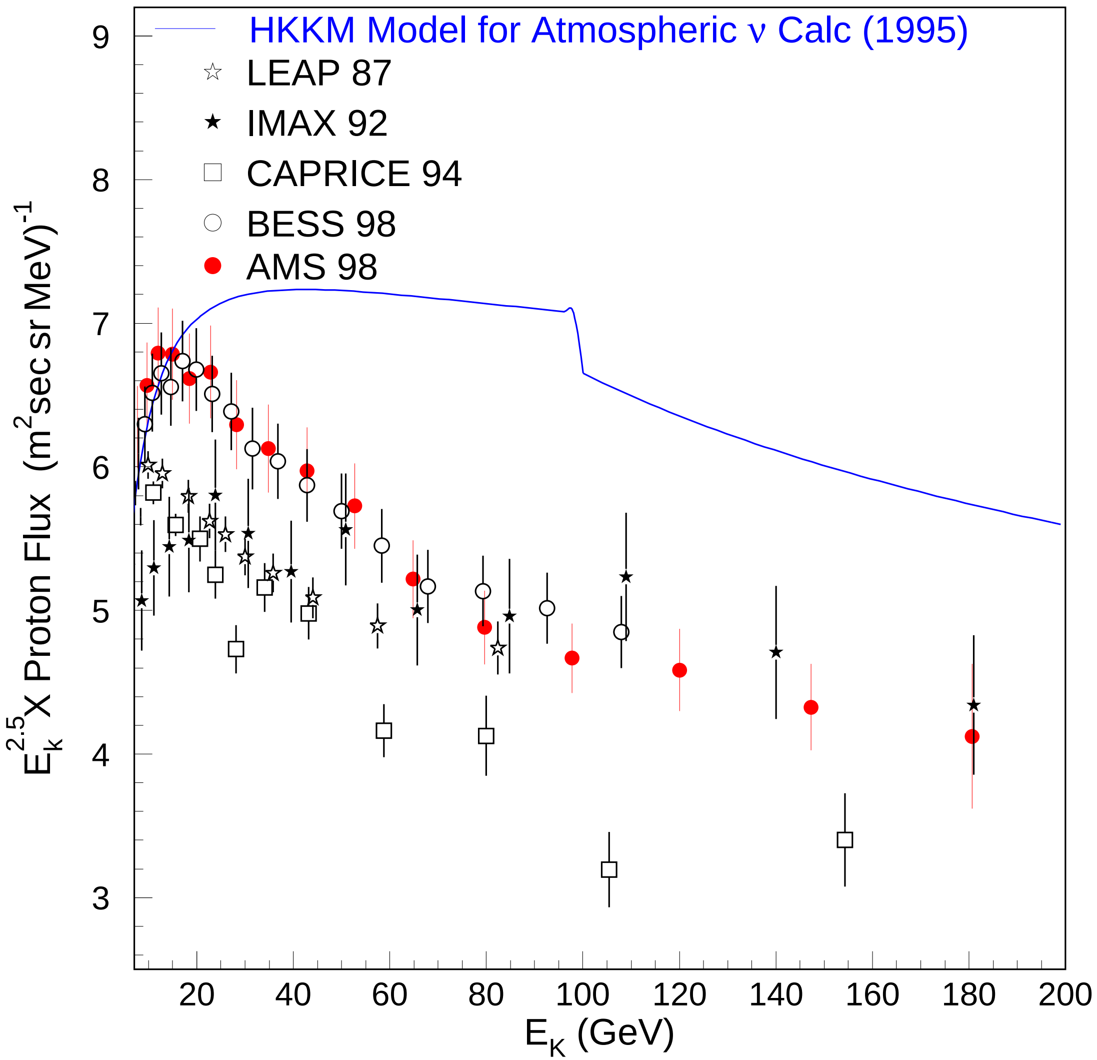
$$\Phi = \Phi_0\ R^{-\gamma}$$

fit ($10 < R < 200$ GV):

$$\gamma = 2.78 \pm 0.025$$



Primary Proton Spectrum



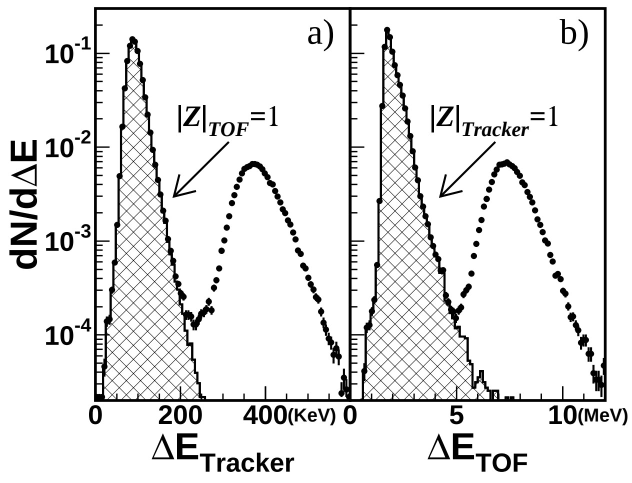
Primary Helium Spectrum

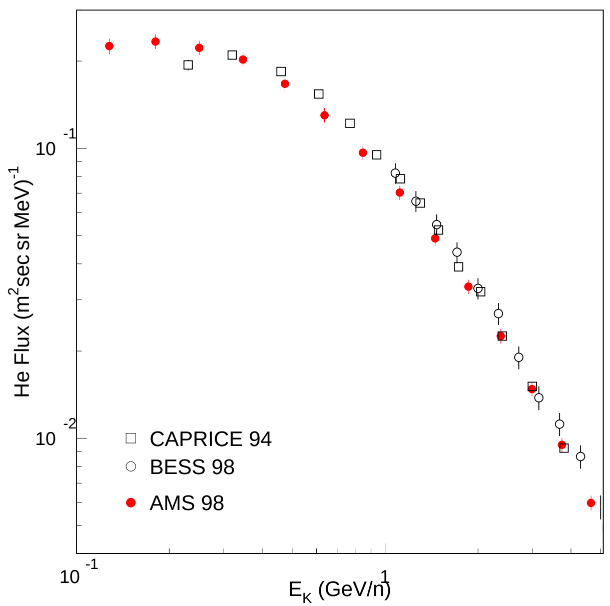
- Data Selection
  - Charge=+2
  - Quality cuts for tracks (χ^2)
  - Measured Rigidity above Cutoff
  - Backg: protons at the level 10^{-4}
- Acceptance
  - $\sim 0.10\ m^2.sr$
- Data Sample
  - 10^6 events
- Kinetic energy range
  - 0.1-100 GeV/nucleon
- Power Law on Rigidity:

  $\Phi = \Phi_0\ R^{-\gamma}$

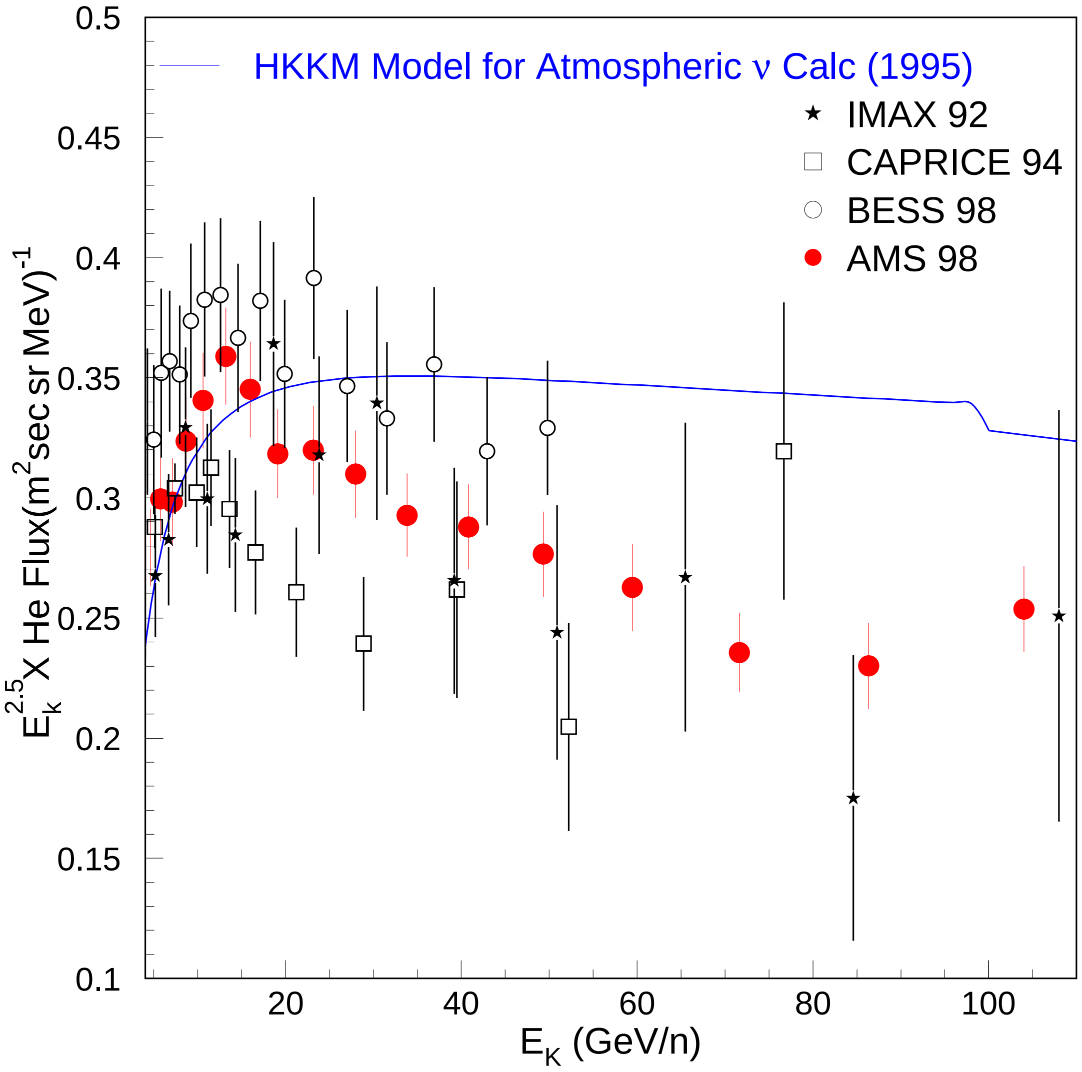
  fit ($20 < R < 200$ GV):

  $$\gamma = 2.74 \pm 0.02$$





Primary Helium Spectrum



Primary Lepton Spectrum

- e^- selection

  Charge=-1

  $\beta \sim 1$

  Cerenkov signal

  Quality cuts: χ^2_{fit}

  Kinetic energy range: 0.2-40 GeV

  – Background

    pions and bad reconst protons

- e^+ selection

  Charge=+1

  $\beta \sim 1$

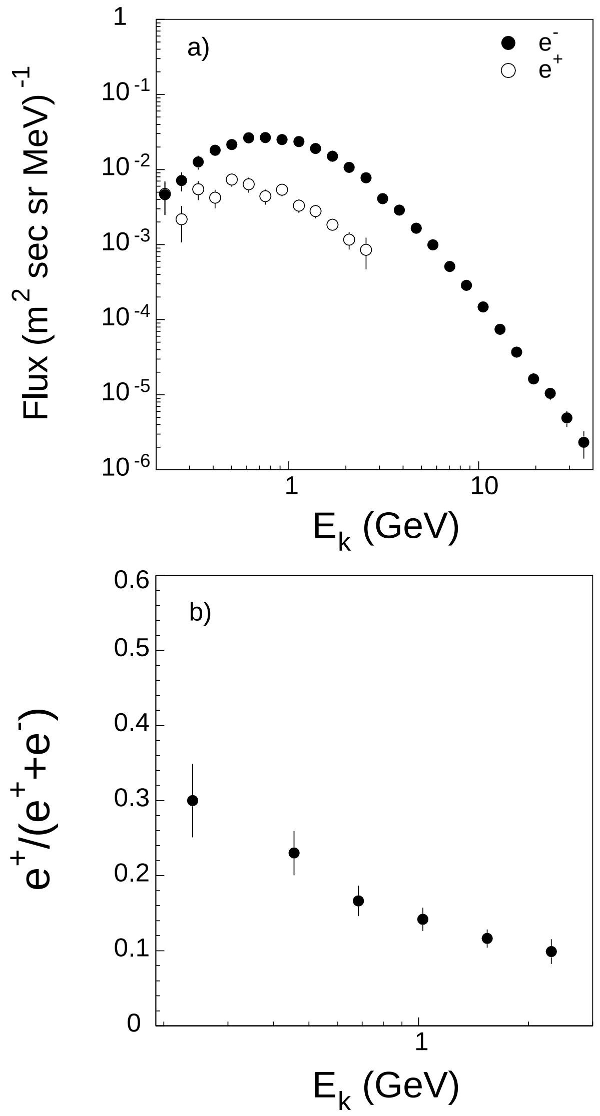
  Cerenkov signal

  Quality cuts: χ^2_{fit}

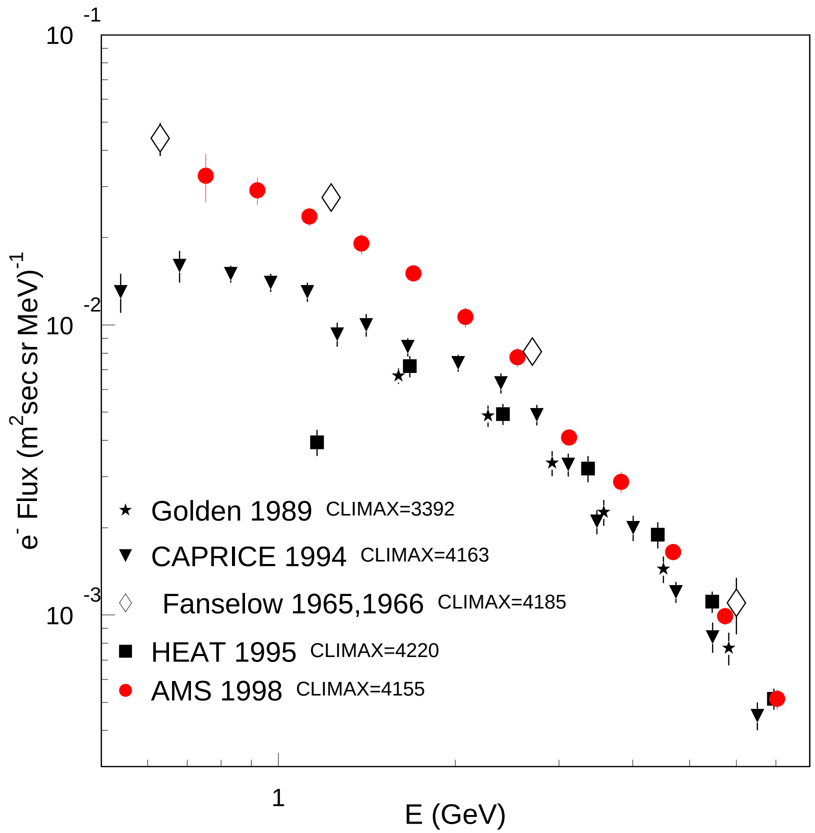
  Kinetic energy range: 0.2-3 GeV

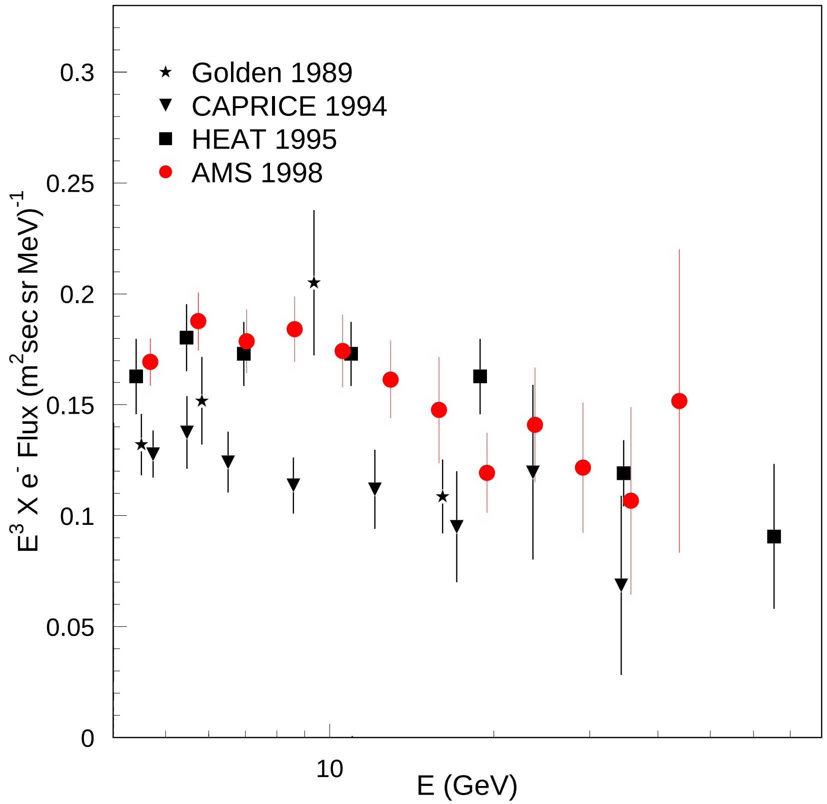
  – Background

    pions and protons with poorly measured β



Primary Lepton Spectrum

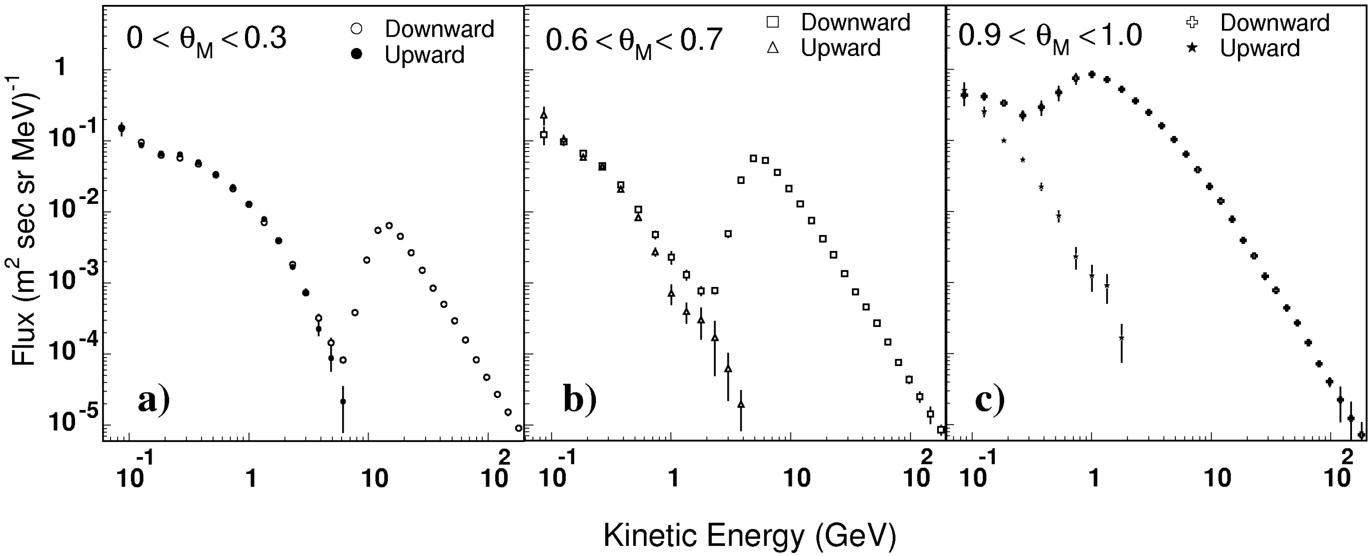




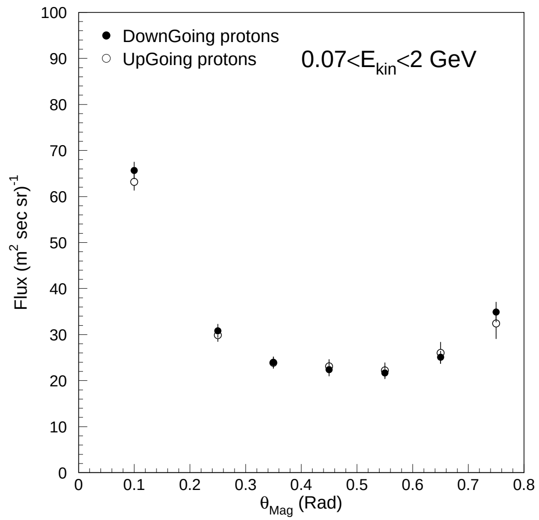
Cosmic Rays: AMS second spectra

- A substantial second spectra is observed by AMS for downward and upward going particles with rigidities below the geomagnetic cutoff
  - protons
  - leptons
  - helium
- Upward and Downward fluxes are very identical
- particles were traced back and forward from detection point

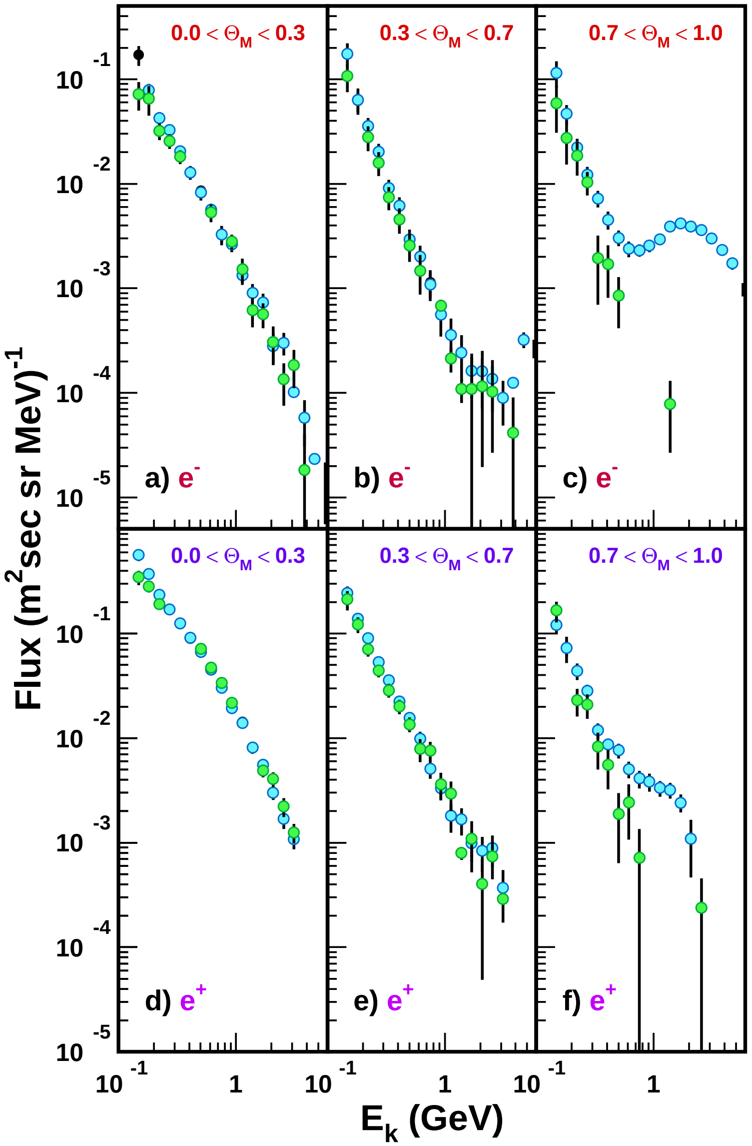
Proton second spectra

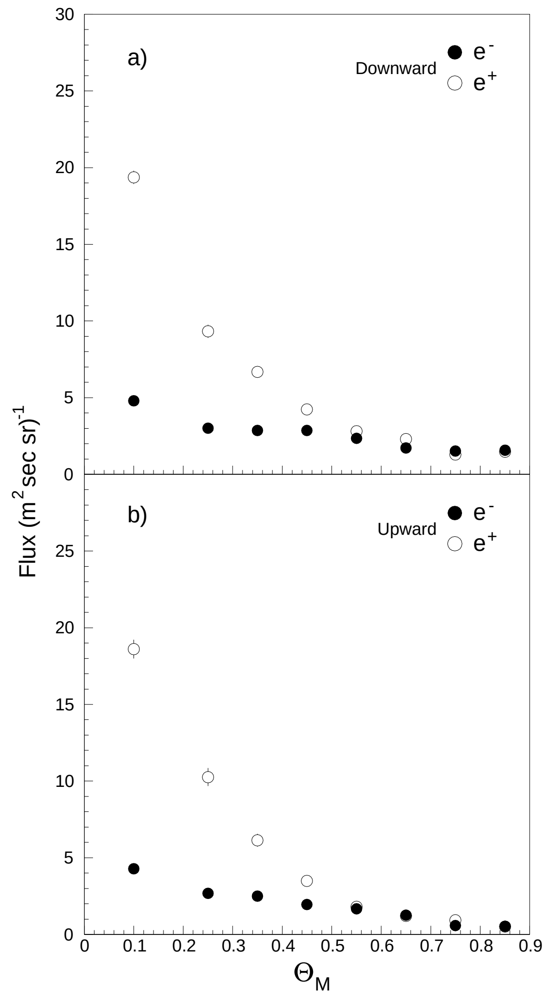


- Identical fluxes for downward and upward going particles (within 1%)
- Flux near geomagnetic equator ($\Theta_{Mag} \sim 0$) has a different structure
- Maximum flux near geomagnetic equator
  $\Phi \sim 70 (m^2 sr sec)^{-1}$
  essentially constant for $\Theta_{Mag} > 0.3$
  $\Phi \sim 20 (m^2 sr sec)^{-1}$



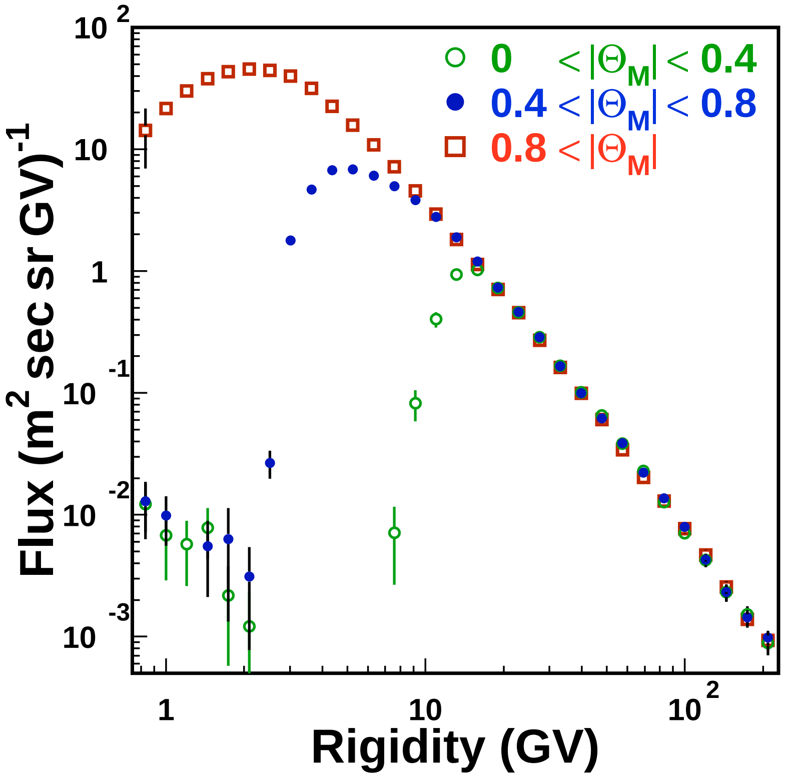
Lepton second spectra

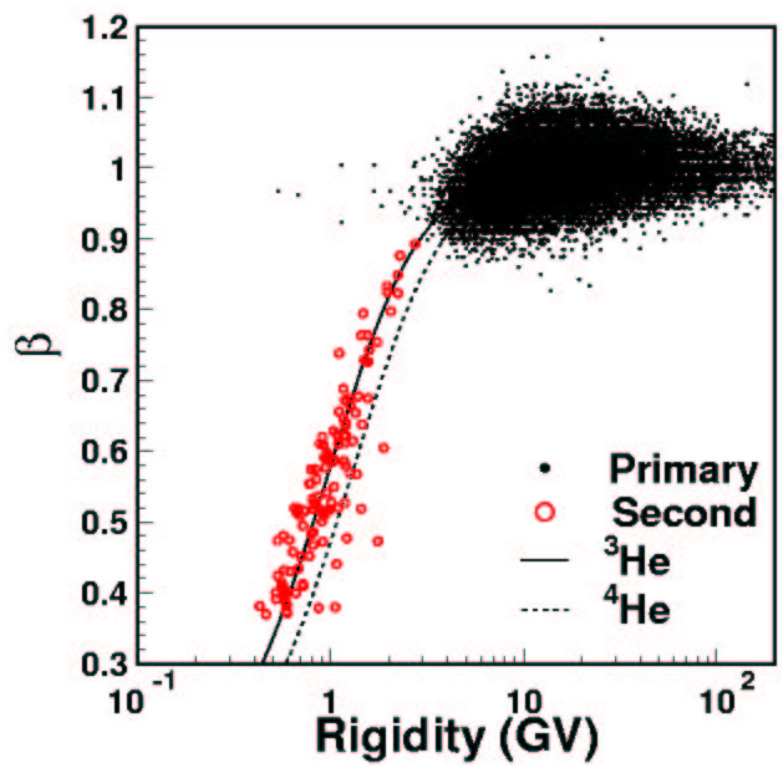




$0.2 < E_k < 2.5\ GeV$

Helium second spectra

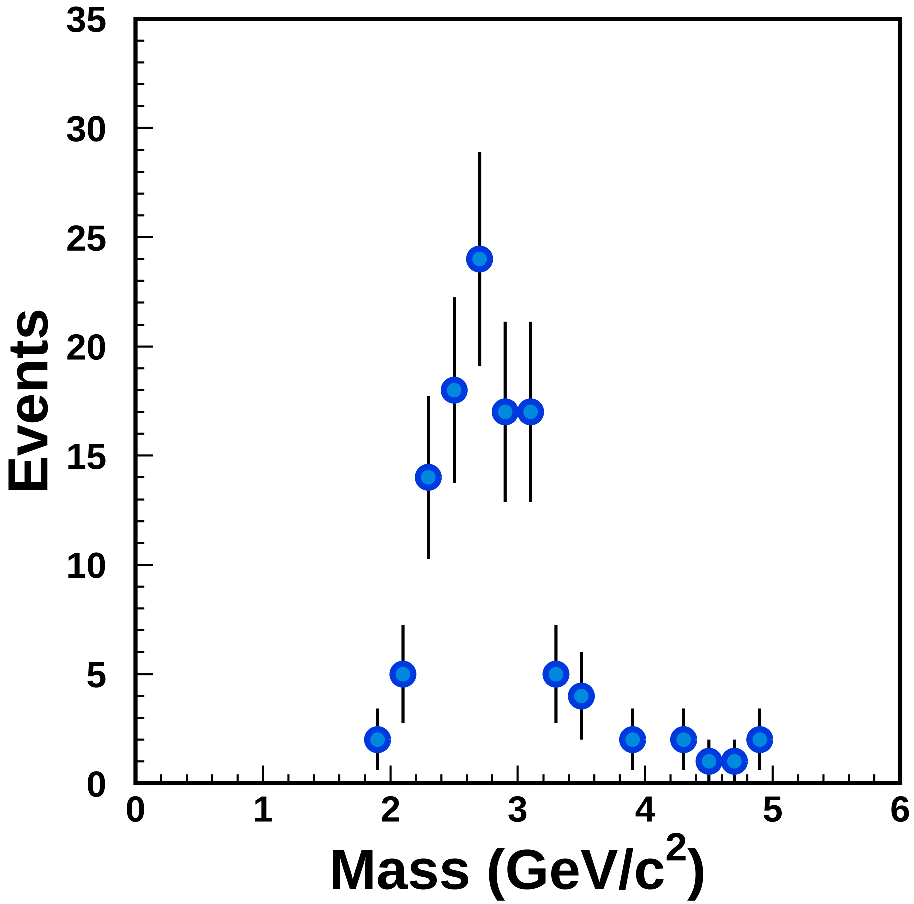




- second spectrum observed for $\Theta_M < 0.8$
- rigidity range: $0.8 \sim 3\ GV$
- Flux $\sim 10^{-3}\ (m^2.sec.sr)^{-1}$

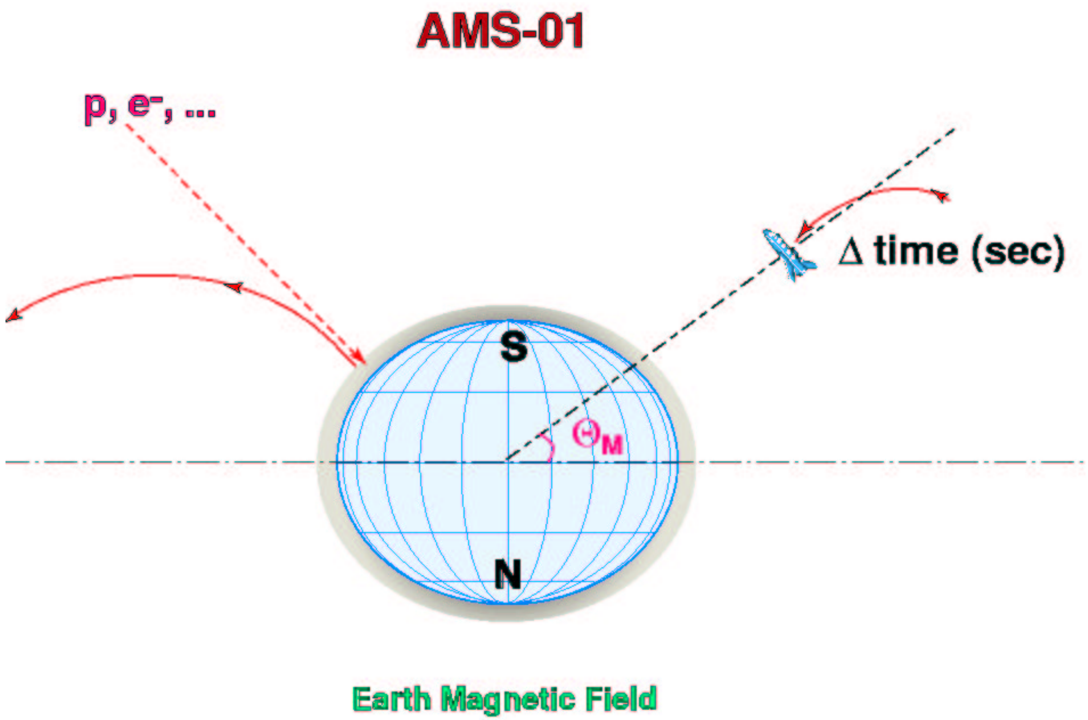
- 115 events observed with $\Theta_M < 0.6$ and below cutoff rigidity $\beta < 0.9 \quad Rig < 3\ GV$

Helium second spectra



More than 90% of the events are ^3He (90%CL)

AMS second spectra: flight time



- Charged Particles (p, , $e^{\pm}$, He) detected on AMS were traced backward and forward, defining so the Origin and Sink points

$$t_f = t_{forw} + t_{backw}$$

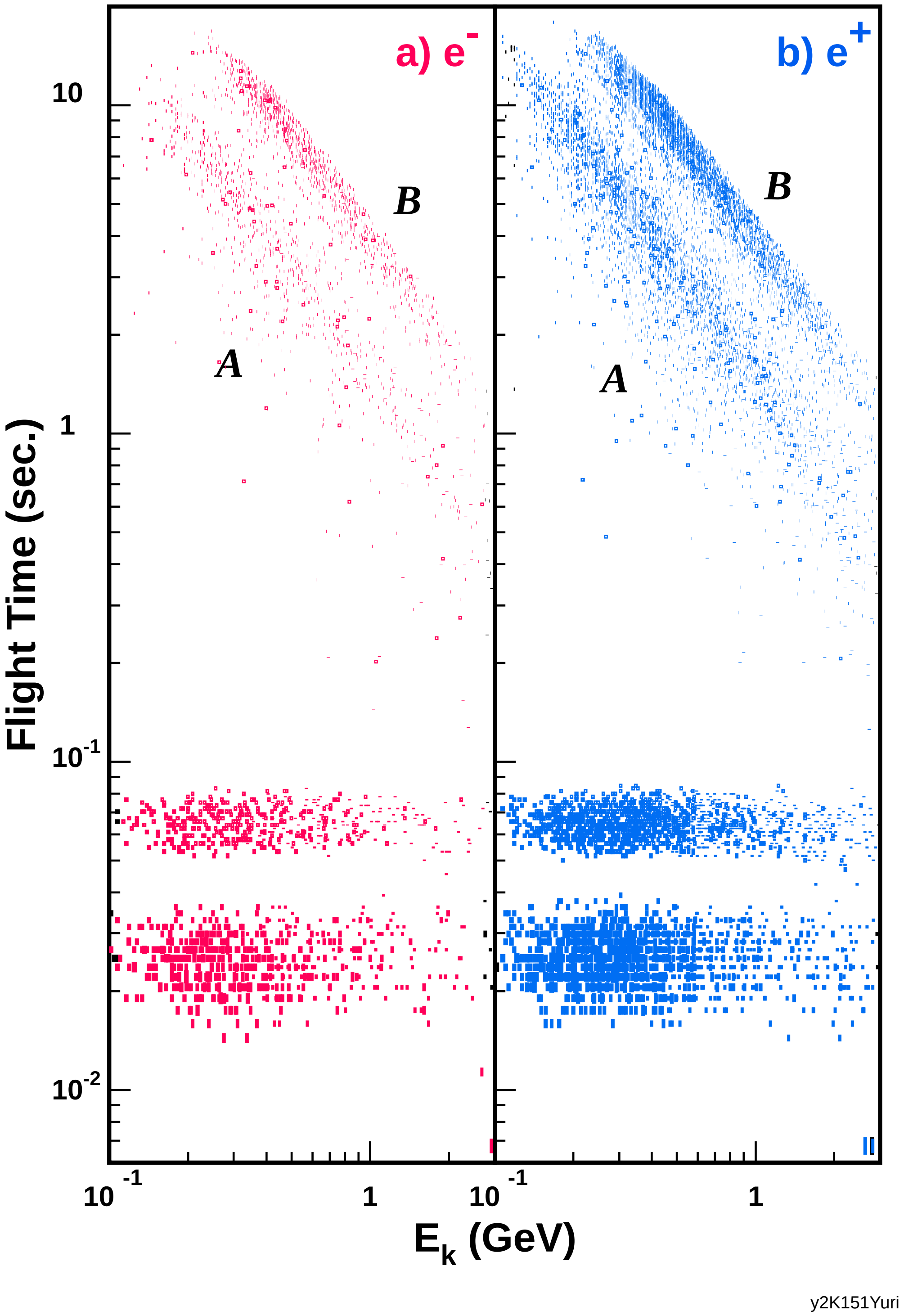
AMS second spectra characteristics

- The hypothetical intersection with the atmosphere was considered at 40 Km
- Depending on flight time, two populations were defined:

  - $t_{flight} < 0.2 - 0.3\ sec \Rightarrow$ ***Short-Lived***
  - $t_{flight} > 0.2 - 0.3\ sec \Rightarrow$ ***Long-Lived***

- **All second spectrum particles have their origin on atmosphere**
- **Around 70% of them are** *Long-Lived*
- ***long-lived* particles originate from well defined regions**
- ***long-lived* particles are reflected around equator many times**

Lepton second spectra: Flight Time

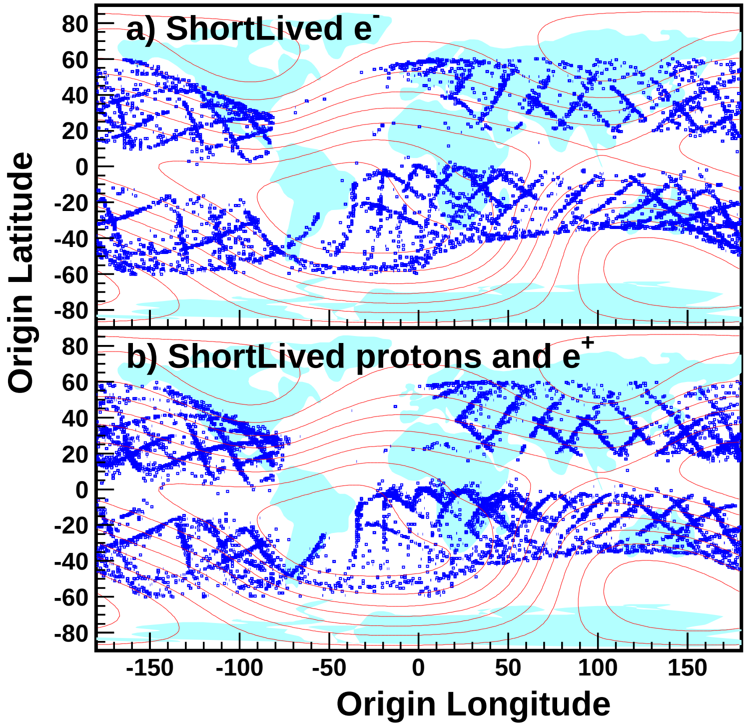


$\Theta_M < 0.3$

$R < 3\ GV$

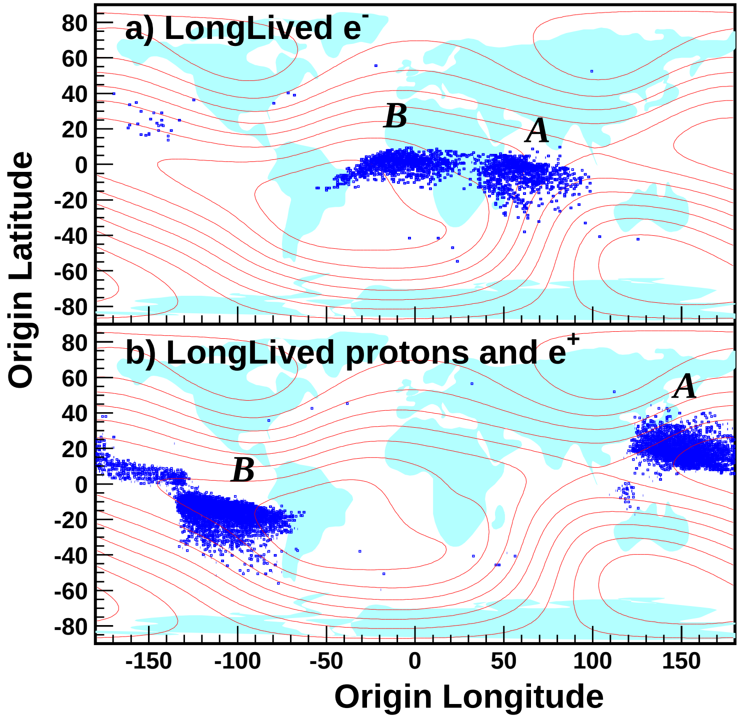
Second Spectra: Origin and Sink regions

Short-Lived



o flux roughly independent of geomagnetic latitude

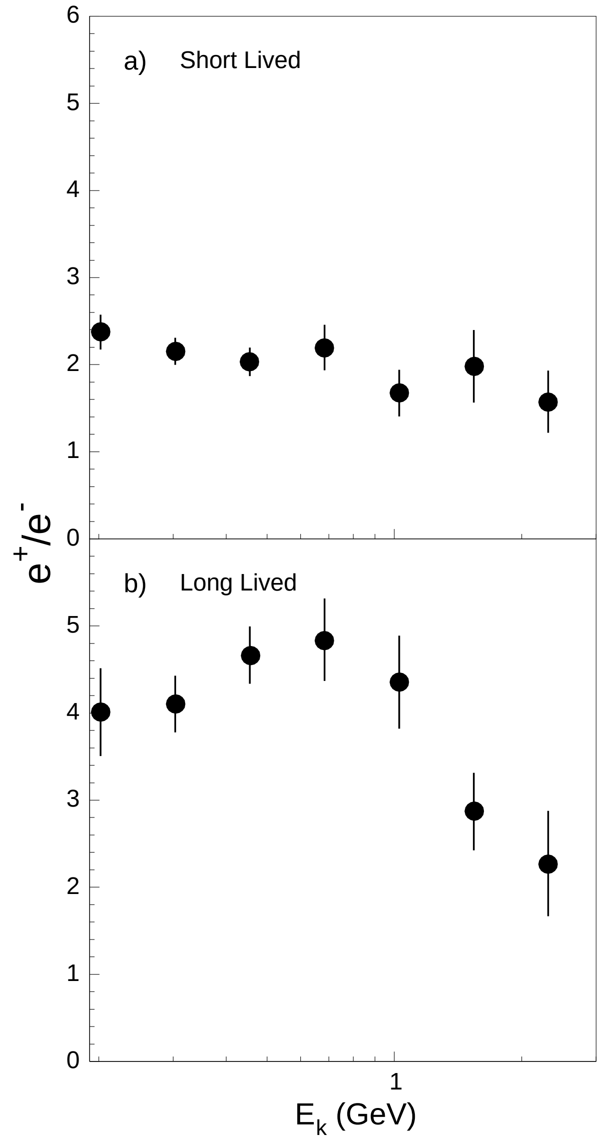
Long-Lived

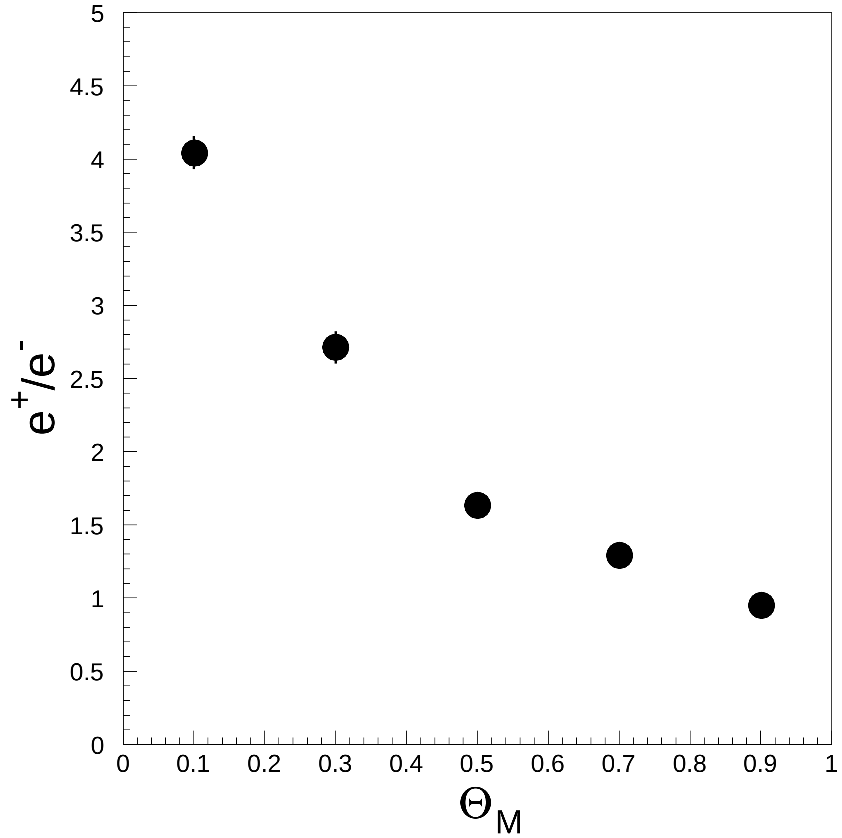


o flux is maximum in geomag equatorial region

o 99% of leptons detected for $\Theta_M < 0.4$ (Zenith attitude)

Lepton Second Spectra: e^+ excess



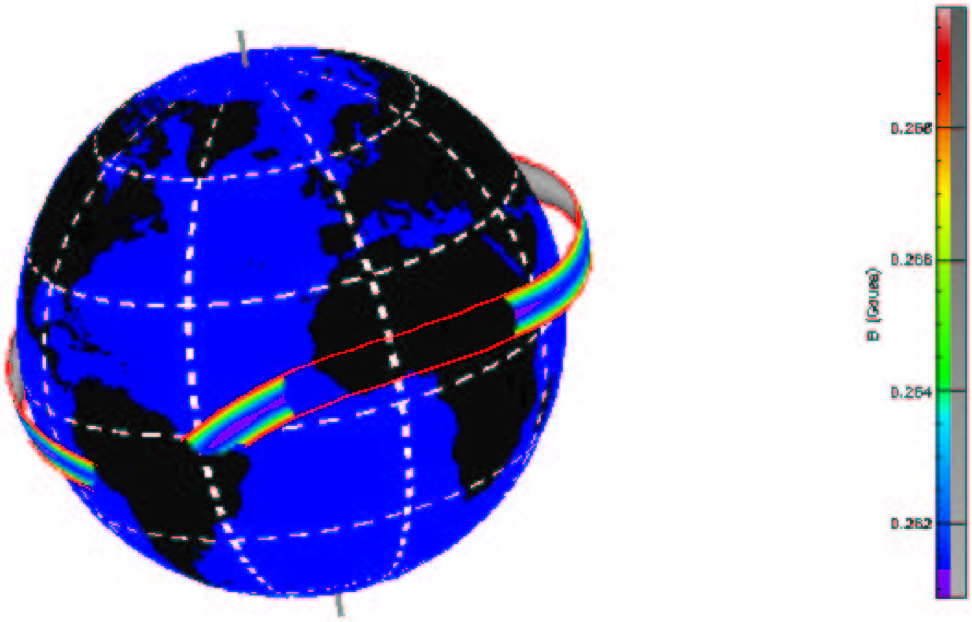


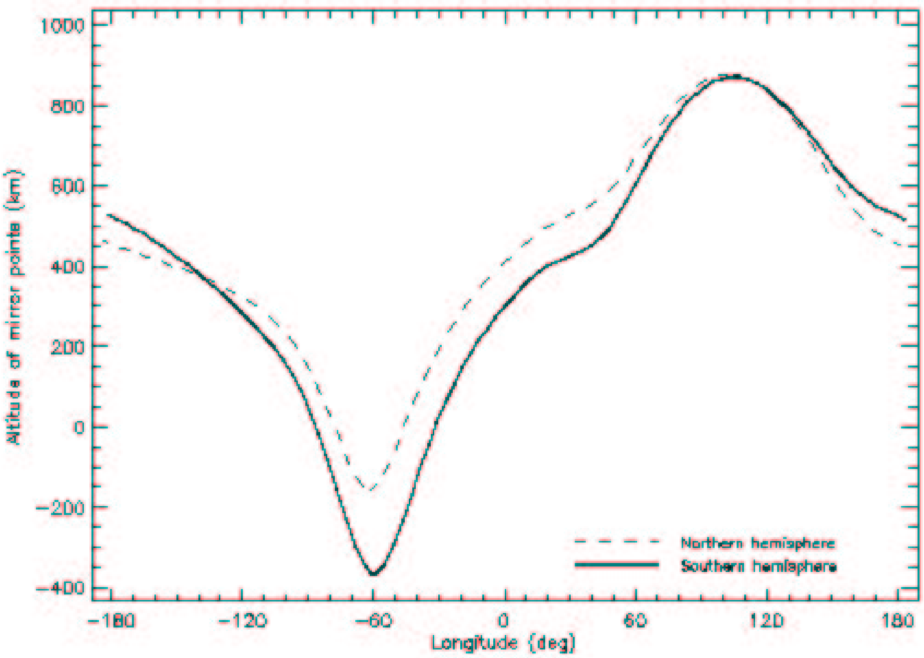
í e^+/e^- **ratio for** $0.2 < E_k < 2.5\ GeV$

í **excess of positrons over electrons**

Trapped particles in magnetic equator

$\alpha_{eq} \simeq 80^\circ \quad L = 1.06$





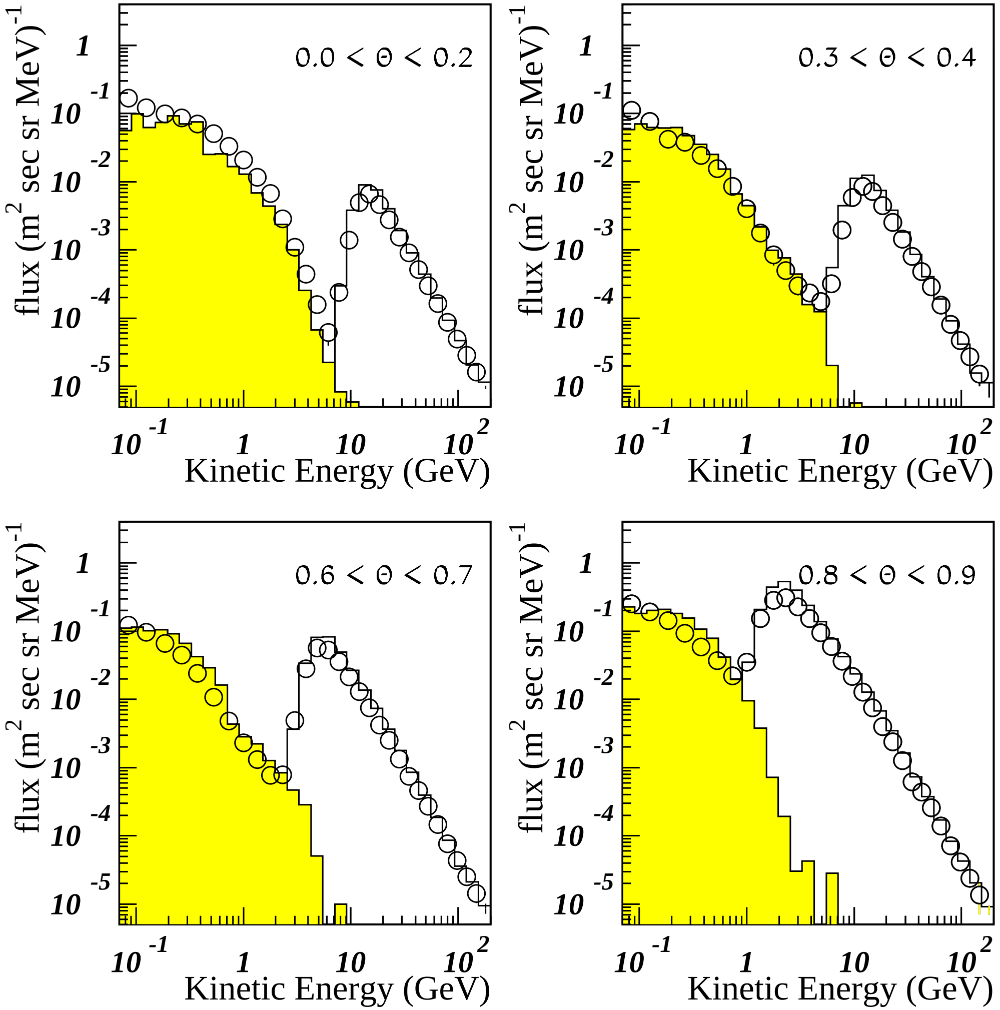
produced with SPENVIS

Simulation of proton second spectra

Reference: L.Derome et al, astro-ph/6160 (2000)

Collisions of primary cosmic protons with terrestrial atmosphere together with the geomagnetic field would explain second spectrum

$$p + N \rightarrow p + ...$$



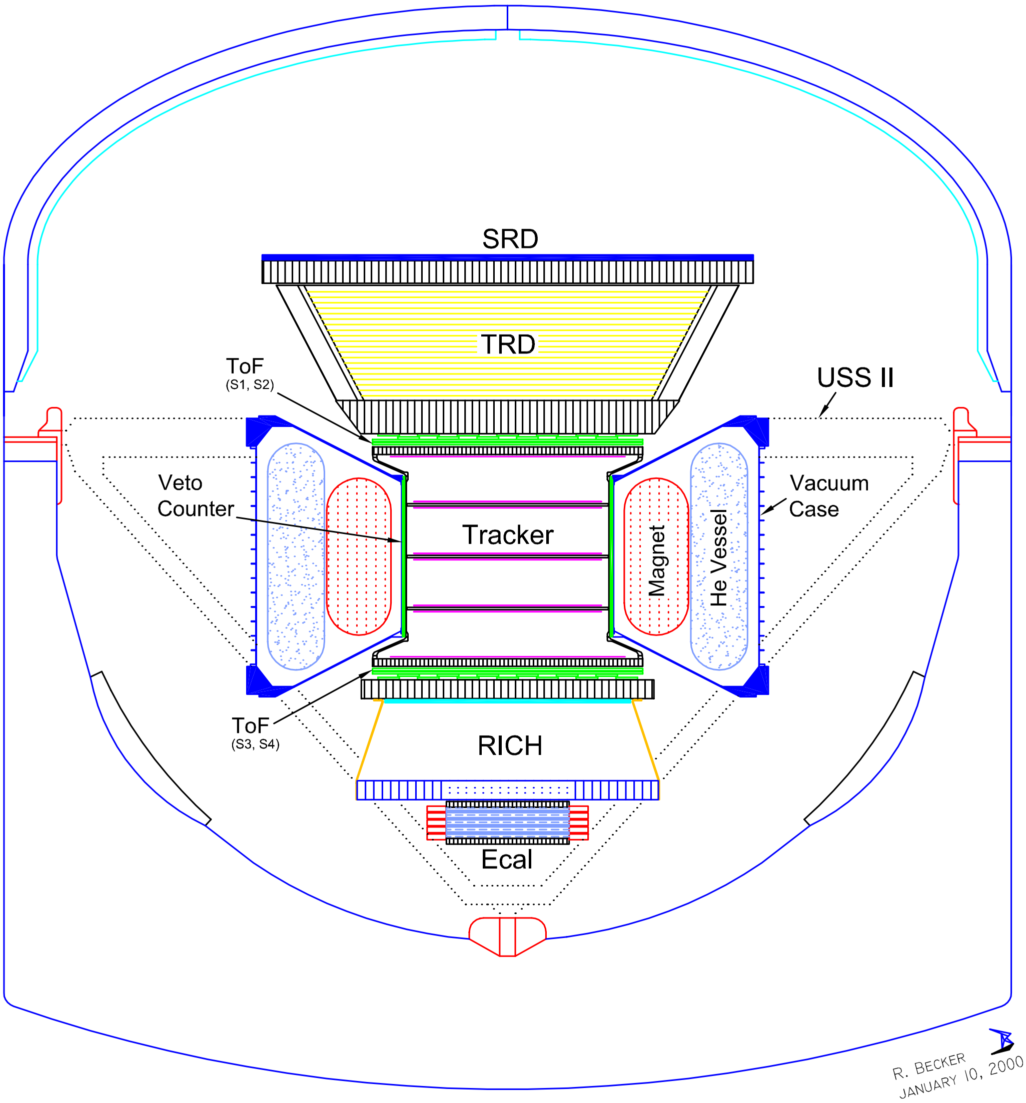
AMS2 Detector

- larger acceptance
  - $\sim 0.5\ m^2.sr$
- Superconducting magnet
  - $B \sim 0.9$ Tesla
- Tracker will be finished
  - 8 planes
  - 5.4 m^2 silicon
- New Detectors
  - Cerenkov Detector (RICH)
  - Electromagn. Calorimeter (ECAL)
  - Transition Radiation Detector (TRD)

AMS2 Detector

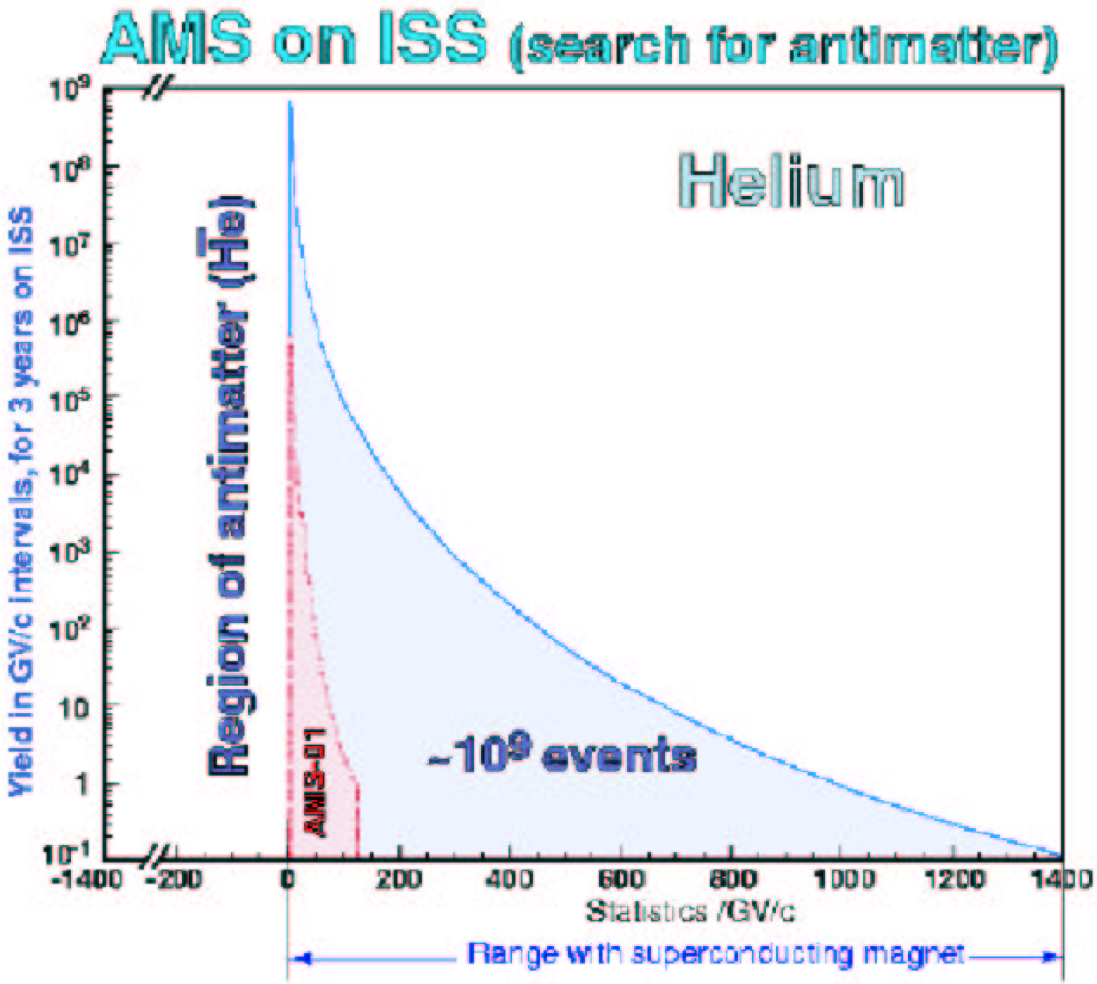
AMS 02

In Cargo Bay

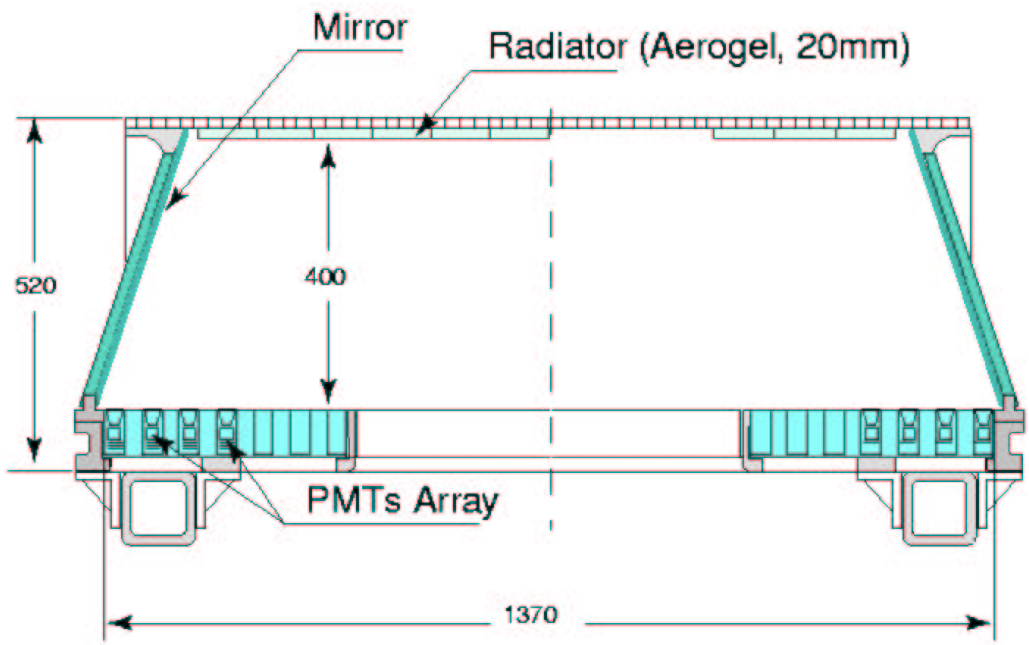


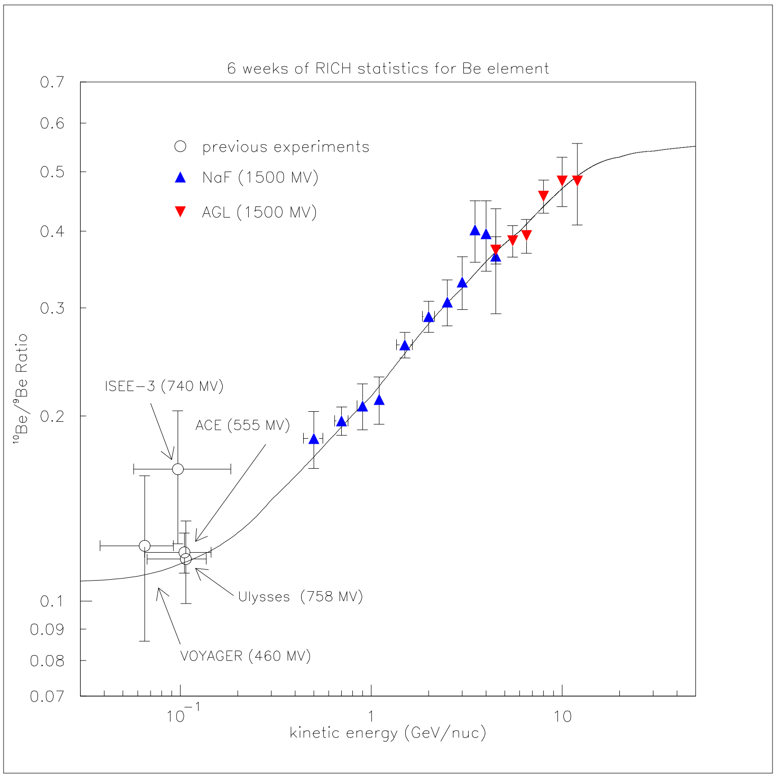
To be installed on ISS on September 2003 for three years

Search for Antimatter with AMS2



The RICH detector

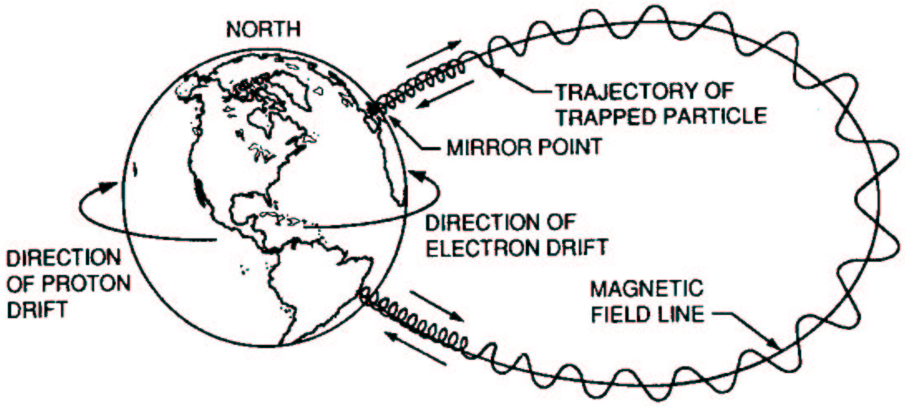


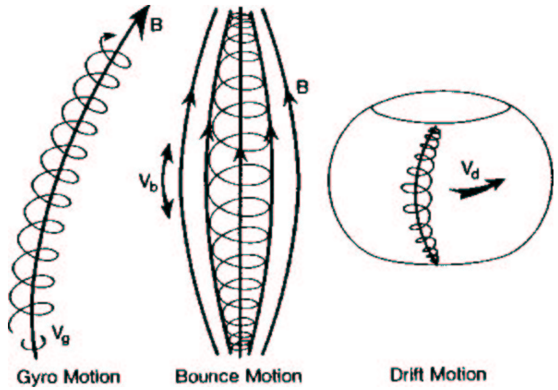


Conclusions

- AMS is a detector to be installed on ISS on year 2003 for three years of data taking
- The physics aims are:
  - Search for Antimatter
  - Search for Darkmatter
  - Measure relative abundances of nuclei and isotopes
- A precursor and very successfull flight aboard Shuttle Discovery was performed on June 1998 for 10 days
- Physics achievements:
  - Antimatter search limit of $\sim 10^{-6}$
  - Primary spectra of protons, leptons ($e^{\pm}$) and Heliums measured
  - A second spectra was detected

Geomagnetic Field: particle motion





- particle bouncing

  a charged particle spiraling in a magnetic field of variable strength feels a force towards the weaker field region

  $$\tau_B(s) \simeq 0.12\frac{L}{\beta}\left[1 - 0.46(\sin\alpha_{eq})^{3/4}\right]$$

  Ł $\beta \simeq 1$ equator trapped particles ($\alpha \sim 90°$)

  $$\tau_B \sim 6.10^{-2}\ L\ [s]$$

- particle drifting

  B variation with distance to earth ($B \propto 1/r^3$) causes particles to drift

  positive particles to **west**

  negative particles to **east**

  $$\tau_D(s) \simeq \frac{1}{L\beta}\frac{8}{E(GeV)}\left[1 - 0.33(\sin\alpha_{eq})^{0.6}\right]$$

  Ł $\beta \simeq 1$ equator trapped particles ($\alpha \sim 90°$)

  $$\tau_D \sim \frac{6}{LE(GeV)}\ [s]$$