Trapped positrons and electrons in the inner radiation belt

Vladimir Mikhailov (MEPhI)

For PAMELA collaboration

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MEPHI, Moscow,

PAMELA Collaboration

Bari Florence Frascati Naples Rome Trieste CNR, Florence

Russia:

Moscow
St. Petersburg

Universität Gesamthochschule Siegen

Sweden:

KTH, Stockholm

Electron halo around the Earth

N. Grigorov

Possibility of existence of a radiation belt around the earth consisting of electrons with energies of 100 MeV and above. Soviet Physics Doklady, Vol. 22, p.305, 1977

- Production of charged pions in CR protons interaction with residual atmosphere

  $\pi^{\pm} \rightarrow \mu^{\pm} \rightarrow e^{\pm}$

- Trapping of secondary particles by the Earth magnetic field

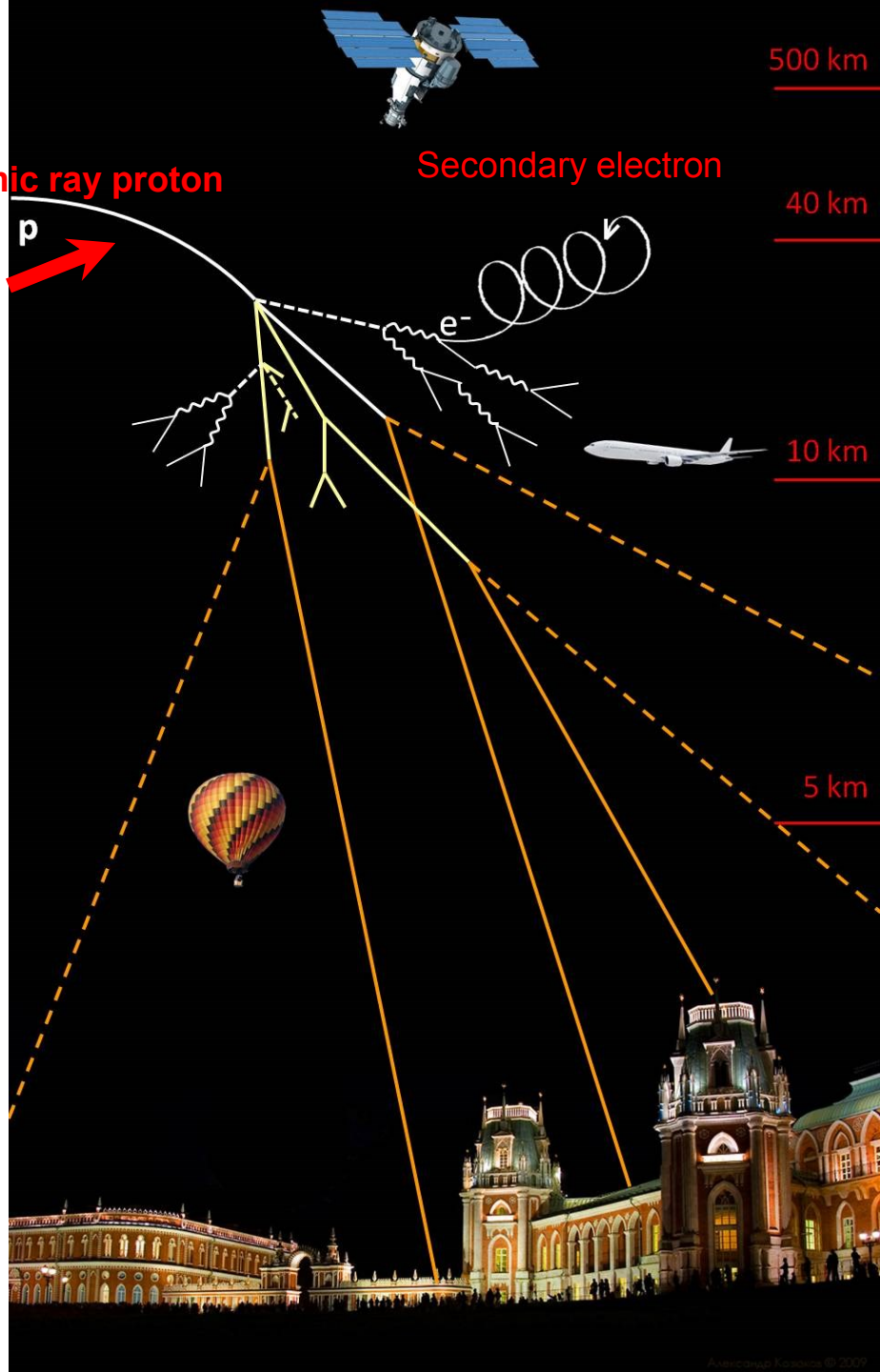
  livetime $T(h) \sim 1/\rho(h)$

  Intensity :

$I_e(h) \propto I_{cr} \times \rho(h) \times T(h) \propto \rho/\rho \approx$ constant (h)

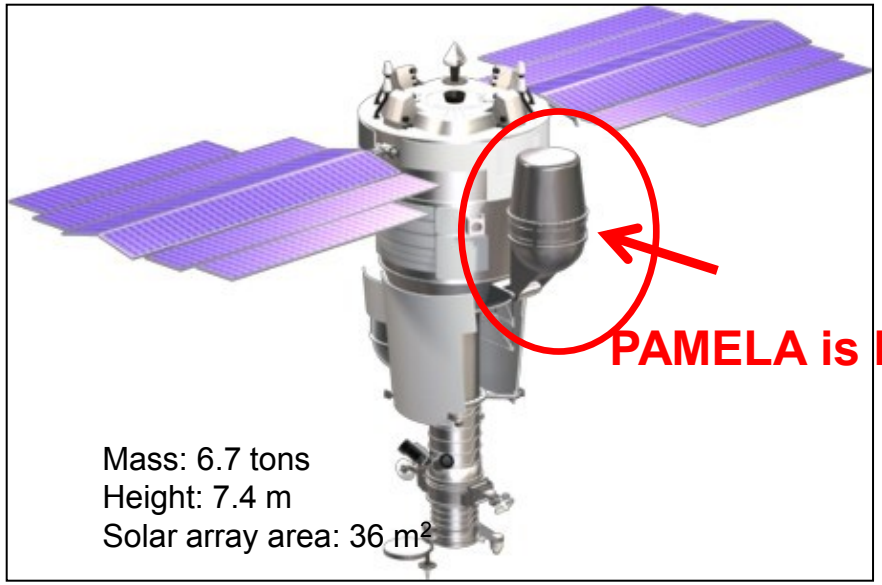
from ~100 to ~1000км

Basilova et al. 1978 &
Kurnosova et al.1979: first measurements
Galper et al 1983 : electron excess in SAA

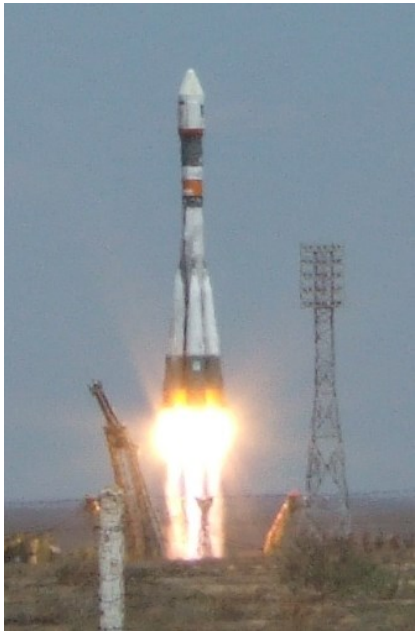


The PAMELA Experiment

Resurs DK satellite built by
the Space factory «TsSKB Progress»
in Samara (Russia)



Trigger rate **~25Hz** (outside radiation belts)
Event size (compressed mode) ~ **5kB**
25 Hz x 5 kB/ev → **~ 10 GB/day**

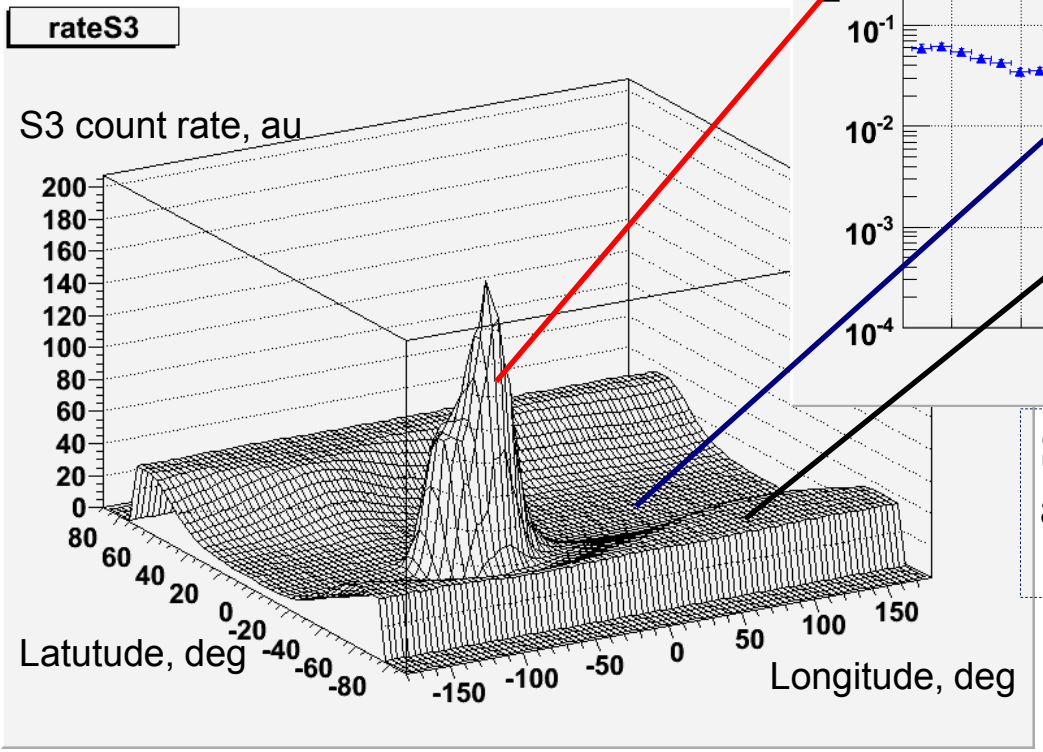


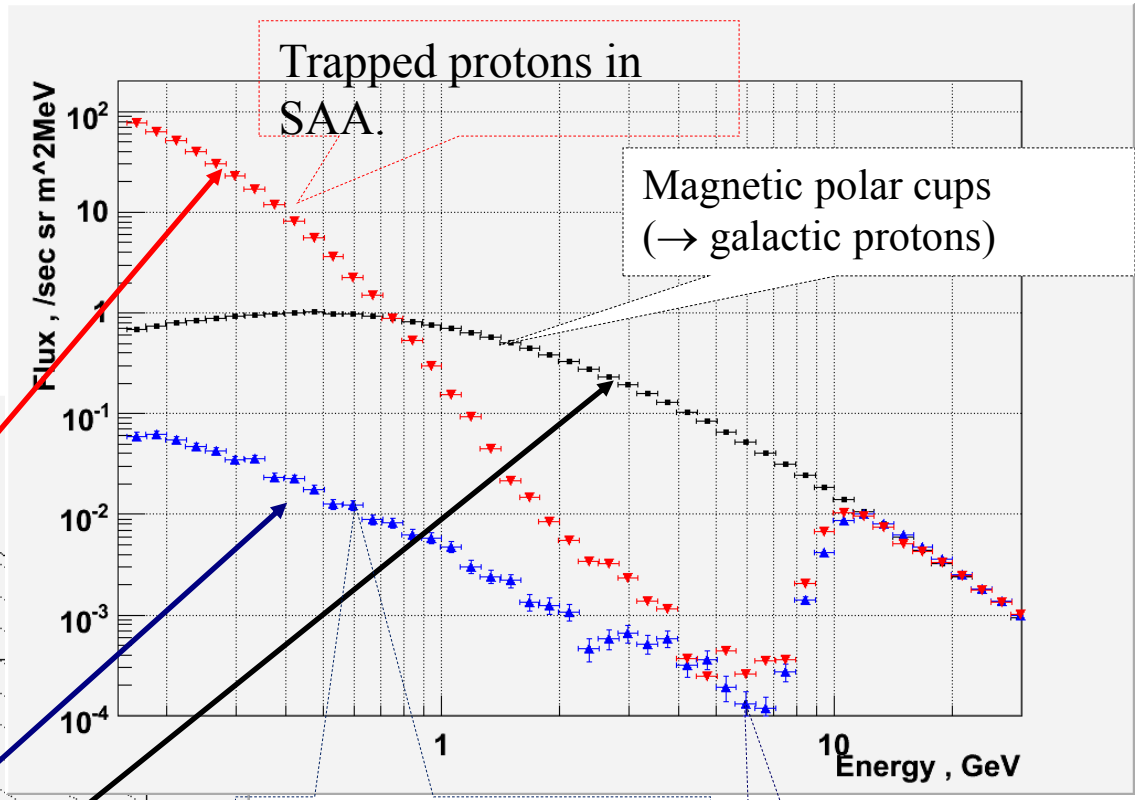
Satellite was launched 15.06.2006 on elliptical polar orbit with inclination 70^0, altitude 350-610km. Circular orbit with altitude ~570km from September 2010

Since July 2006 till Junuary 2016:
~3200 days of data taking
~50 TByte of raw data downlinked
~$9 \cdot 10^9$ triggers recorded and analyzed

Spectra in different parts of magnetosphere

- Analyzed data July 2006 – January 2016 (~3400 days)
- Identified **~ more then 1× 10^6 electrons** and **~ 1× 10^5 positrons** between 50 MeV and 100 GeV





Trapped protons in SAA.

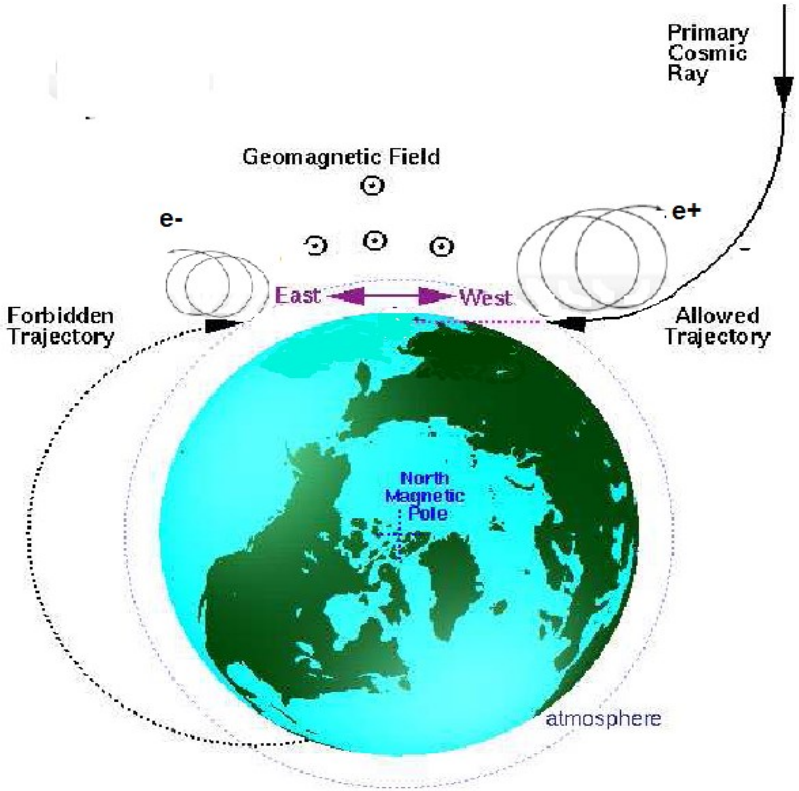
Magnetic polar cups (→ galactic protons)

Secondary re-entrant-albedo protons

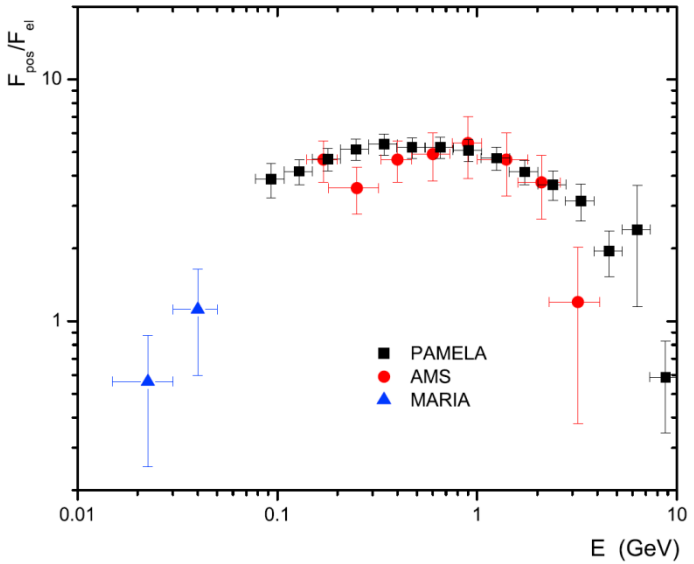
Geomagnetic cutoff

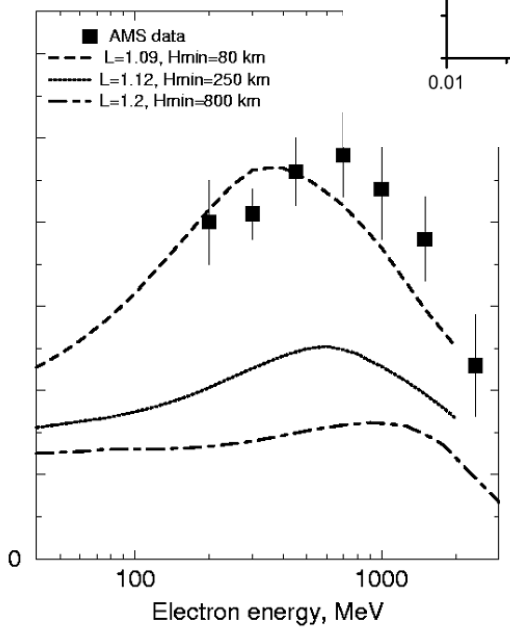
Positron to electron ratio for quasitrapped particles

AMS-01 experiment (1998):
Due to East-West effect
ratio e+/e- is about ~5 at E~1GeV
in near equatorial region



Result of AMS-01 confirmed by PAMELA
Adriani et al , JGR ,2009





Gusev et al, 2001, 2004 :
Cosmic ray interaction with residual atmosphere explains AMS-01 results

Data analysis

Trajectories of positrons and electrons were tracing back in the Earth's magnetic field.

IGRF field model was used (http:/nssdcftp.gsfc.nasa.gov)

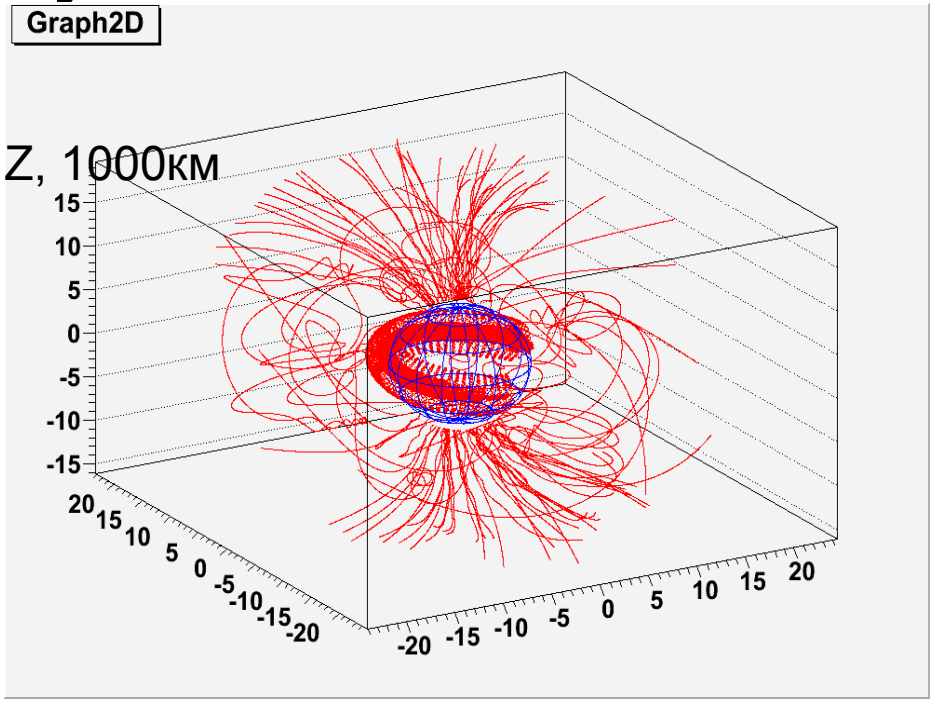
Boundary :

Losses in atmosphere Hmin=30 km,

Escaping Hmax=20000 km

Time of tracing Tmax=50 s

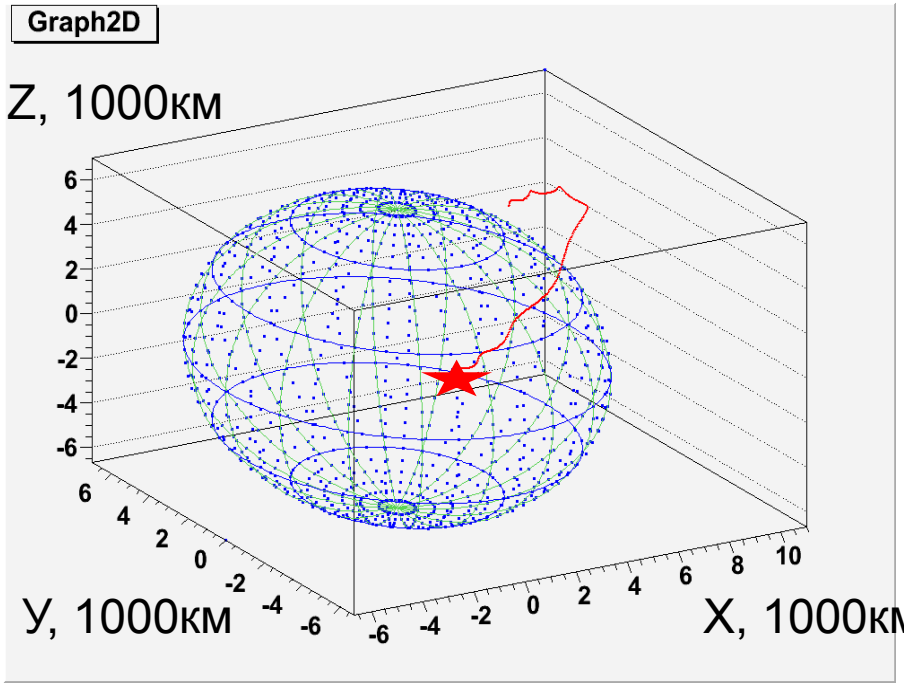
it is drift time around the Earth for particles with energy E~70 MeV



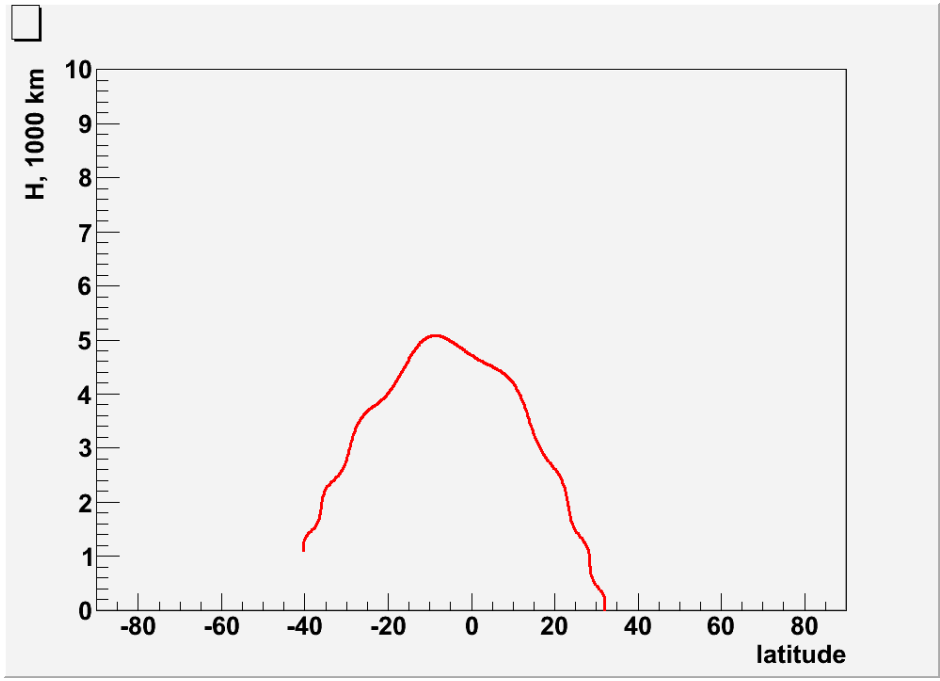
Reconstructed trajectories of electrons and positrons detected by PAMELA during several orbits

Samples of particles trajectories:

Simple reentrant albedo:



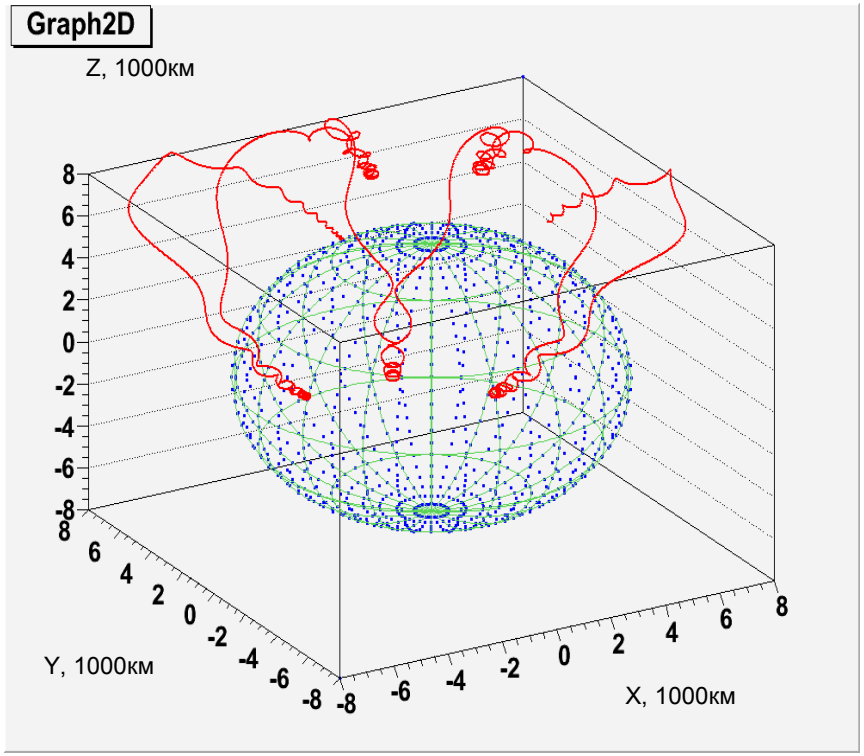
Altitude vs latitude

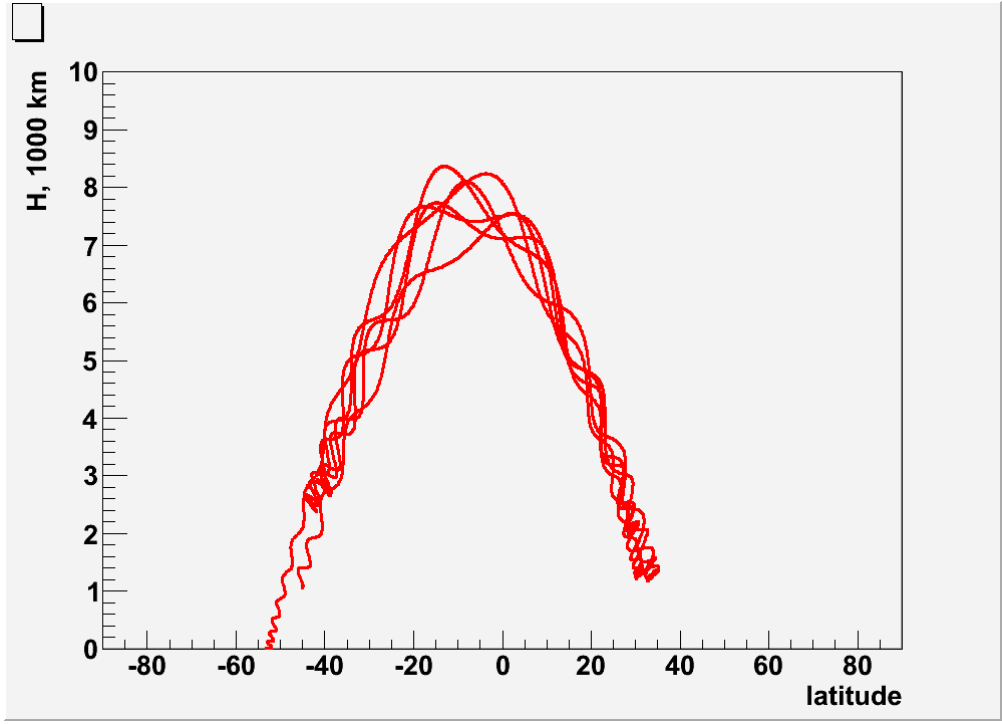


Trajectory of **re-entrant albedo** positrons with rigidity R=1.24 GV

Time of flight ~0.1 s

Quasi-trapped particles:



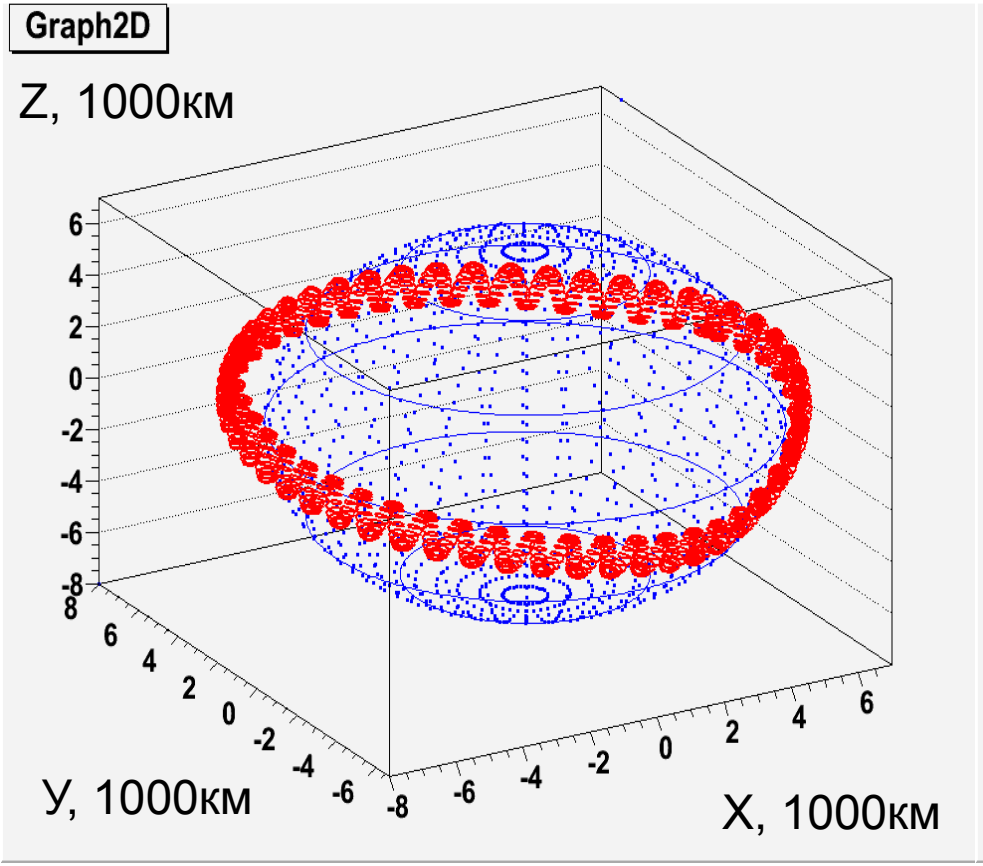


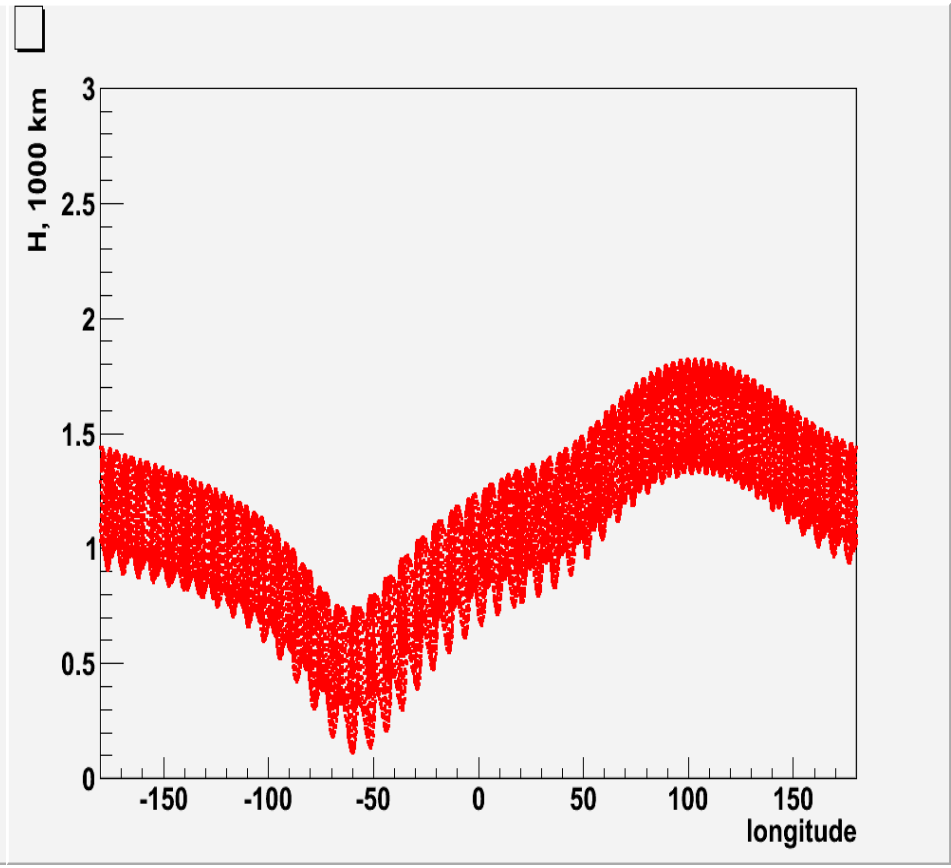
Positron trajectory with rigidity R~1.2 GV,

Altitude vs latitude

Time of flight >>0.1 s at R<1GV.

Trapped positron



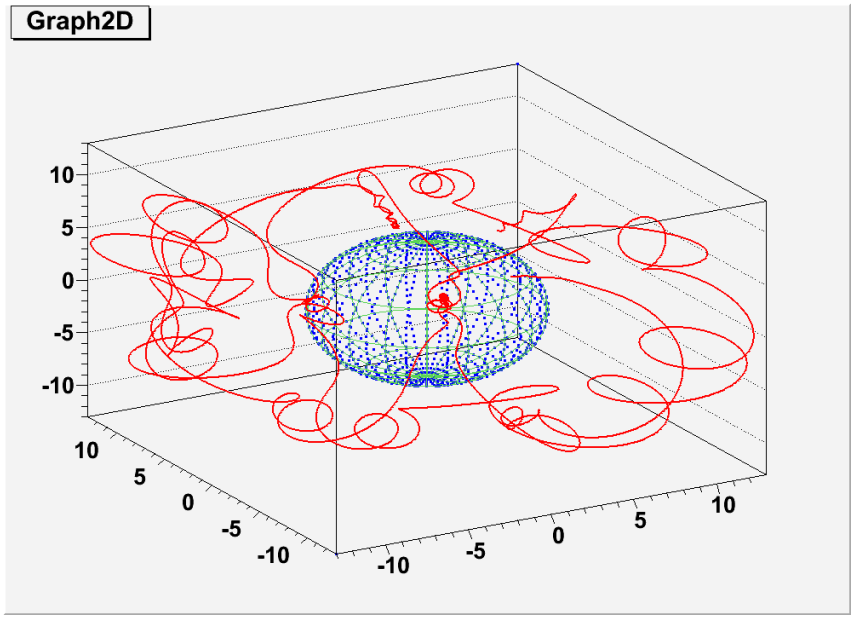


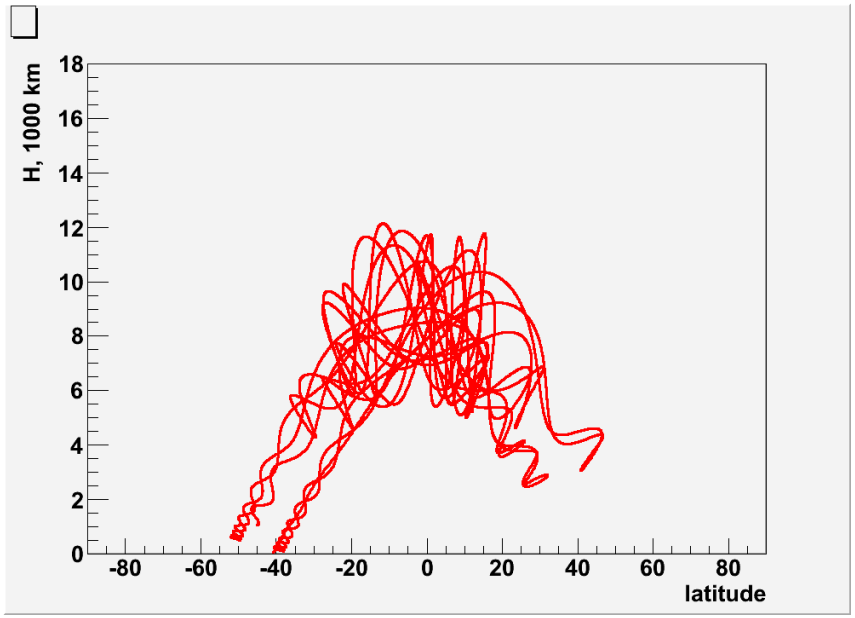
Positron trajectory with rigidity R~1 GV, pitch-angle about 90 °.

Altitude vs longitude. Minimal trajectory altitude is in South Atlantic Anomaly region.

Quasi-trapped particle near geomagnetic cut-off

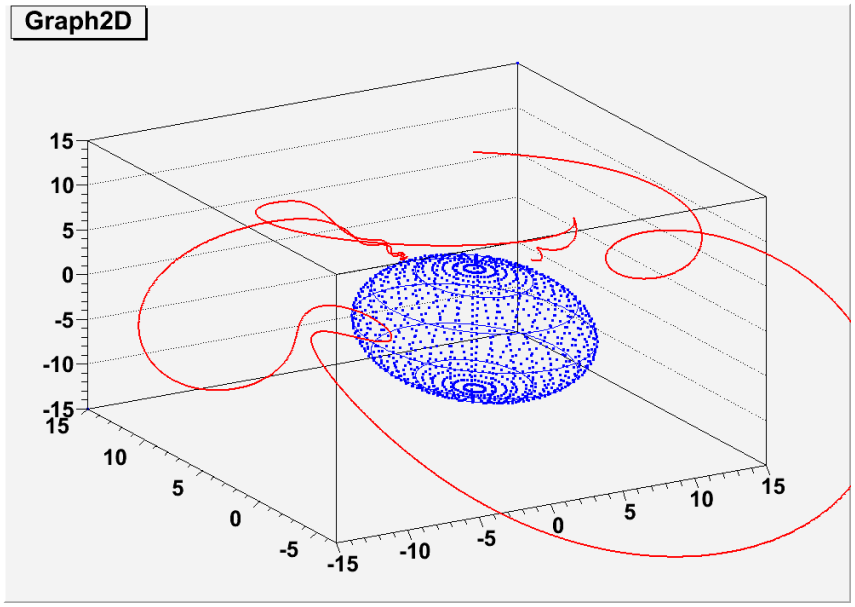
Altitude vs latitude

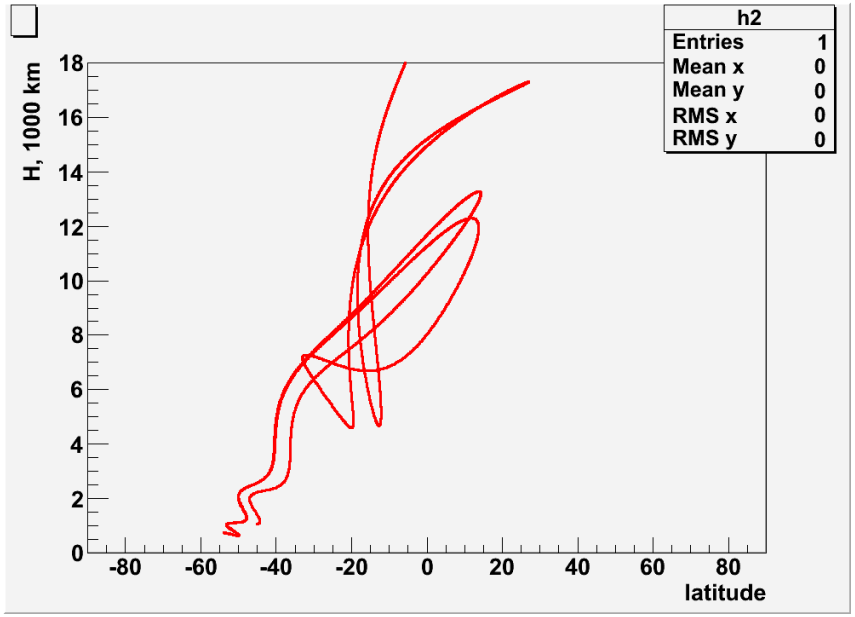




Positron trajectory with rigidity R=2.24 GV, with small pitch-angle

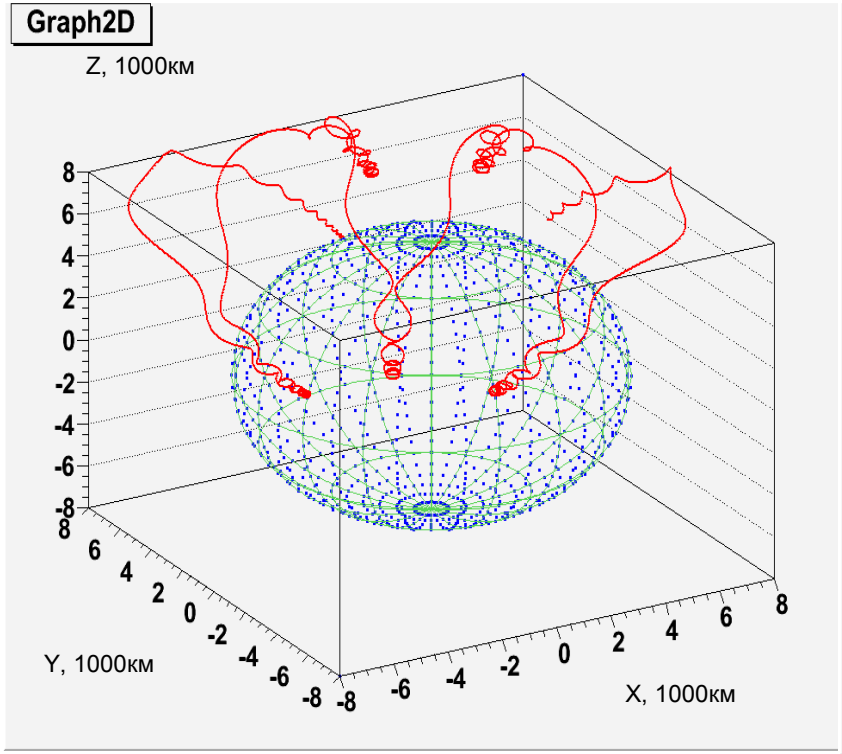
Cosmic ray trajectory near geomagnetic cut-off

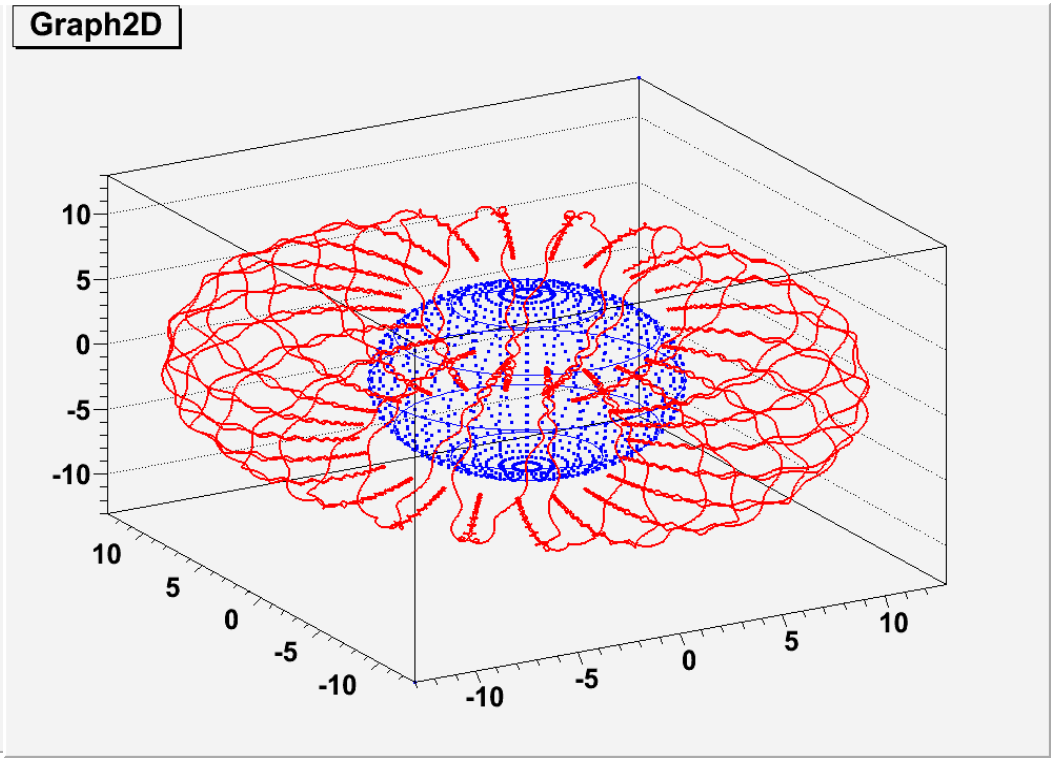




Chaotic trajectory of non-adiabatic type .

Quasi-trapped particles:



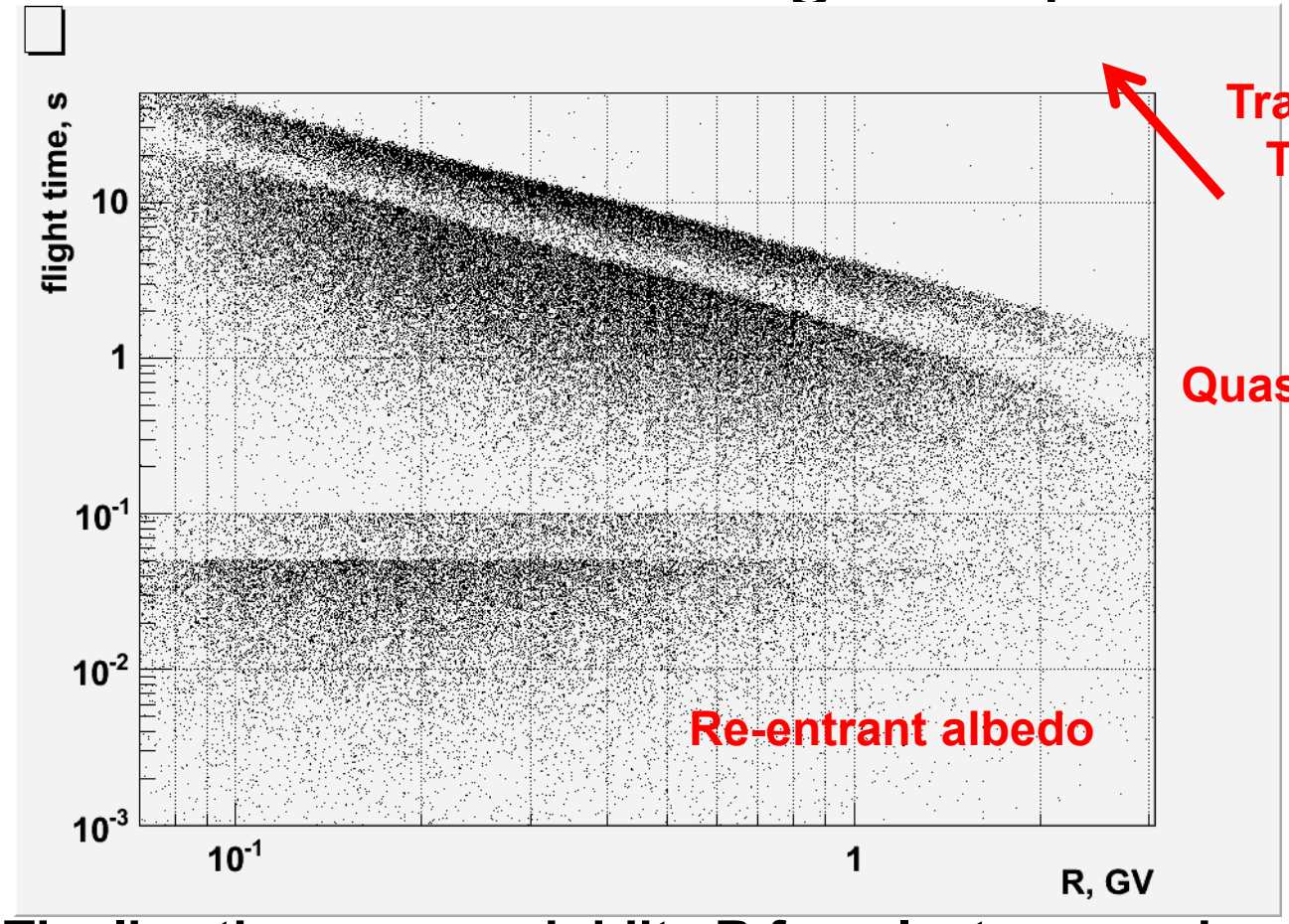


Positron trajectory with rigidity R~1.2 GV,

Positron trajectory with rigidity R~0.5 GV

Time of flight >>0.1 s at R<1GV. Drift time is decreasing with R increasing

Electron and positron live time in magnetosphere

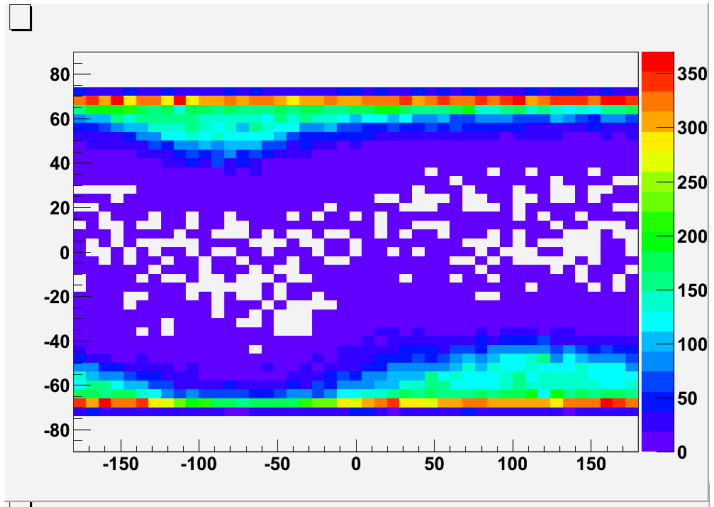


The live time versus rigidity R for electrons and positrons Max time of tracing was 50 sec. It corresponds drift time of ~70MeV electrons around the Earth.

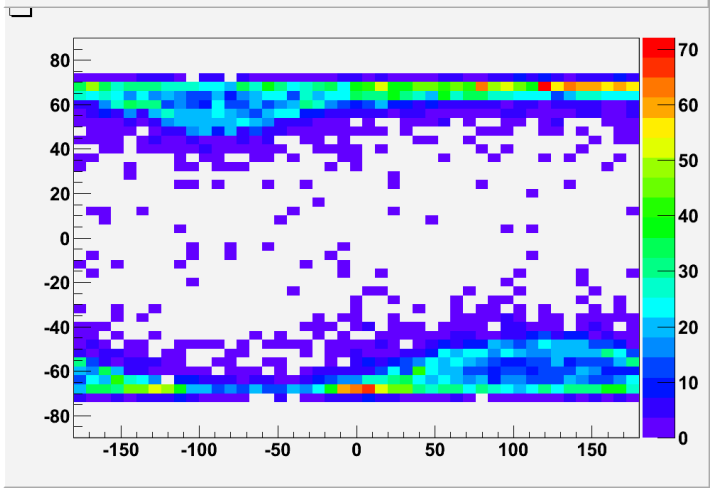
There is trapped component with very long flight time >> minute

Galactic CR

Detection region



- electrons

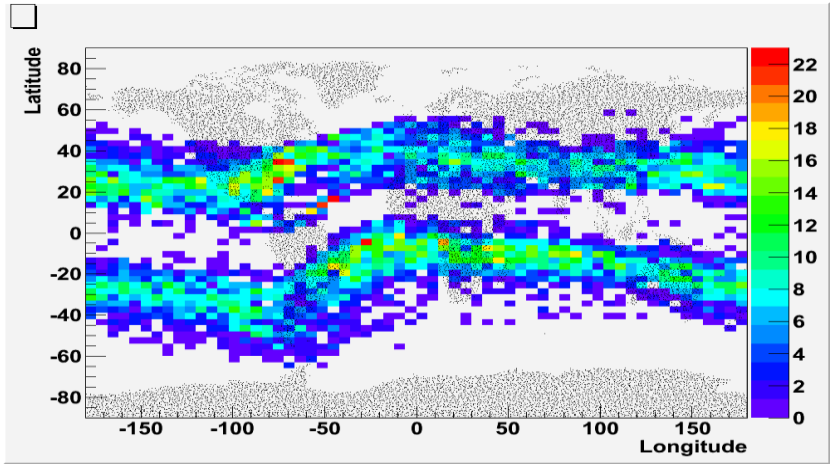


- positrons

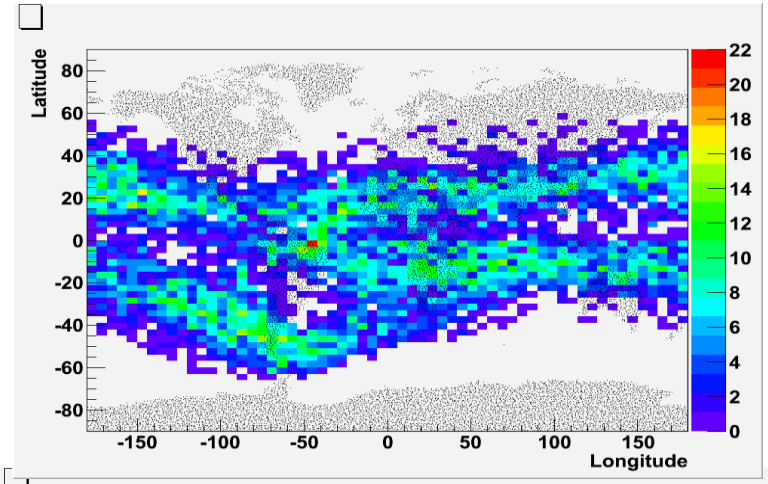
Re-entrant albedo (time <0.1s)

electrons

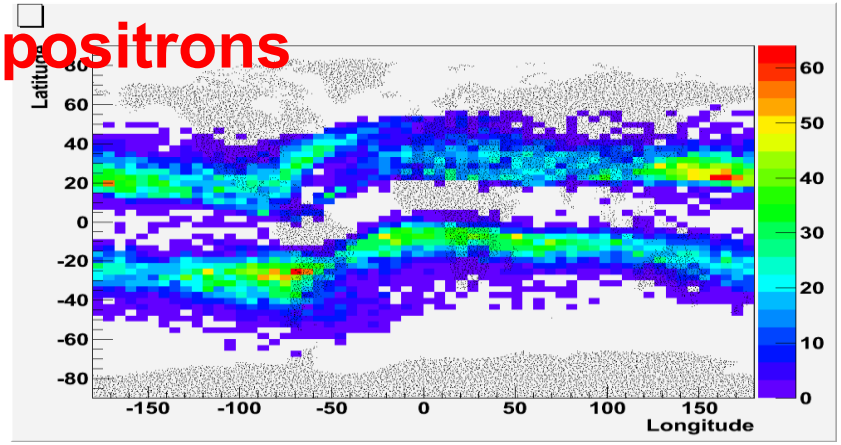
points of origin

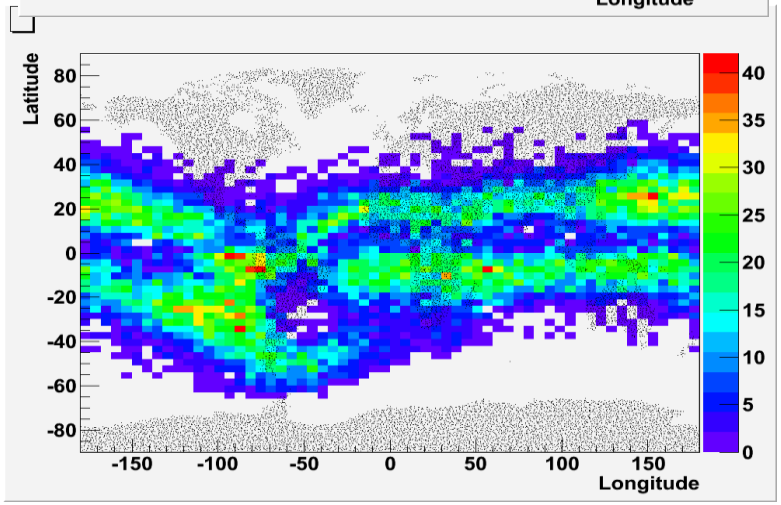


points of detection



positrons



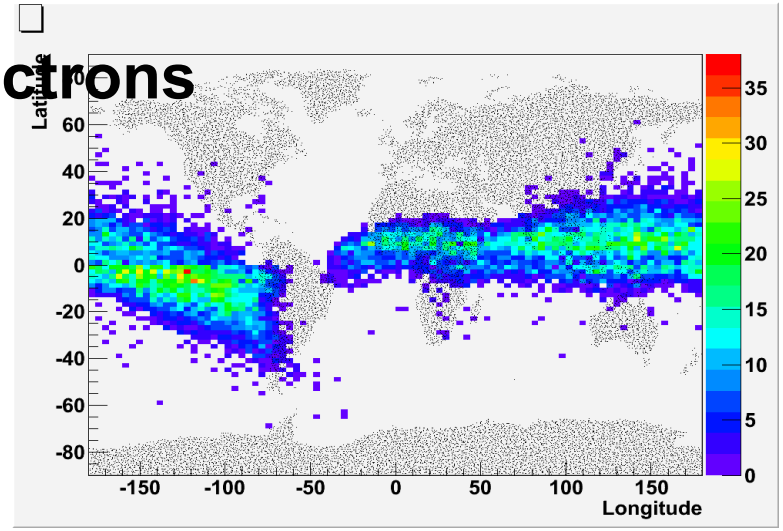


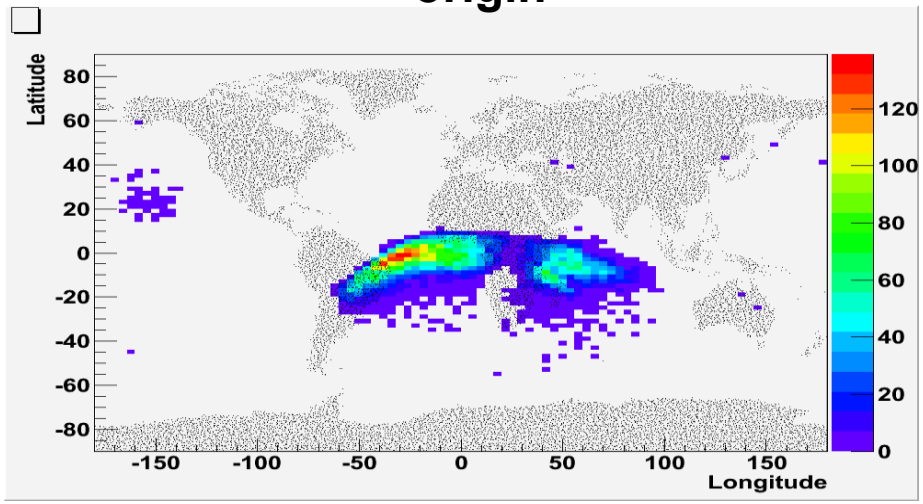
Quasi-trapped albedo (time>>0.1s)

detection

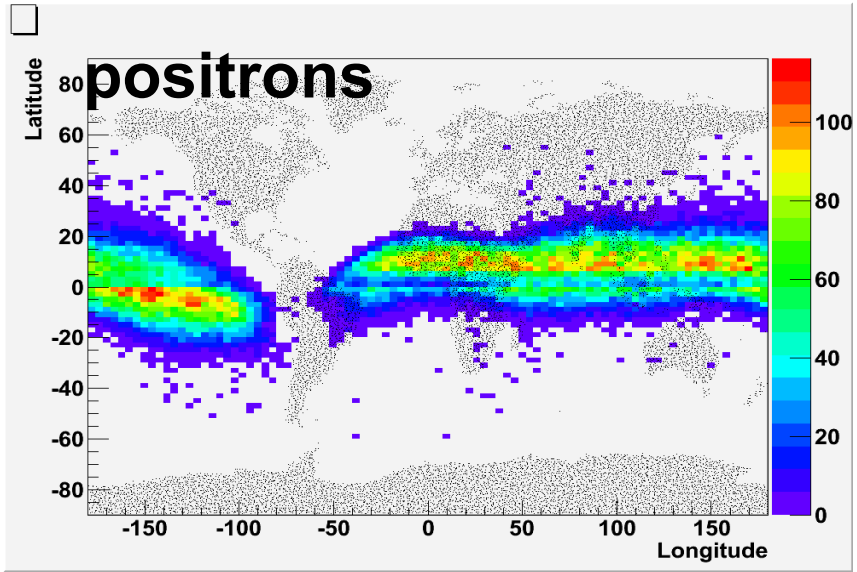
origin

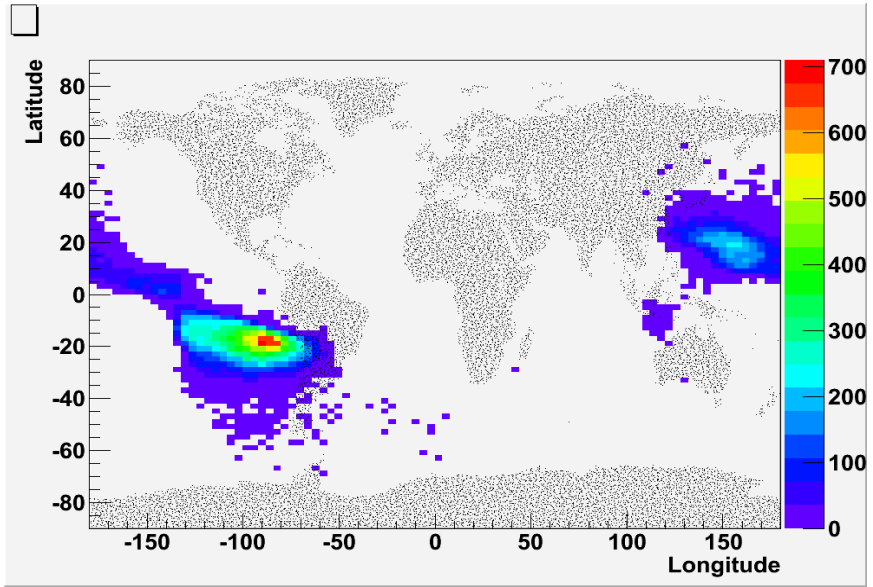
electrons



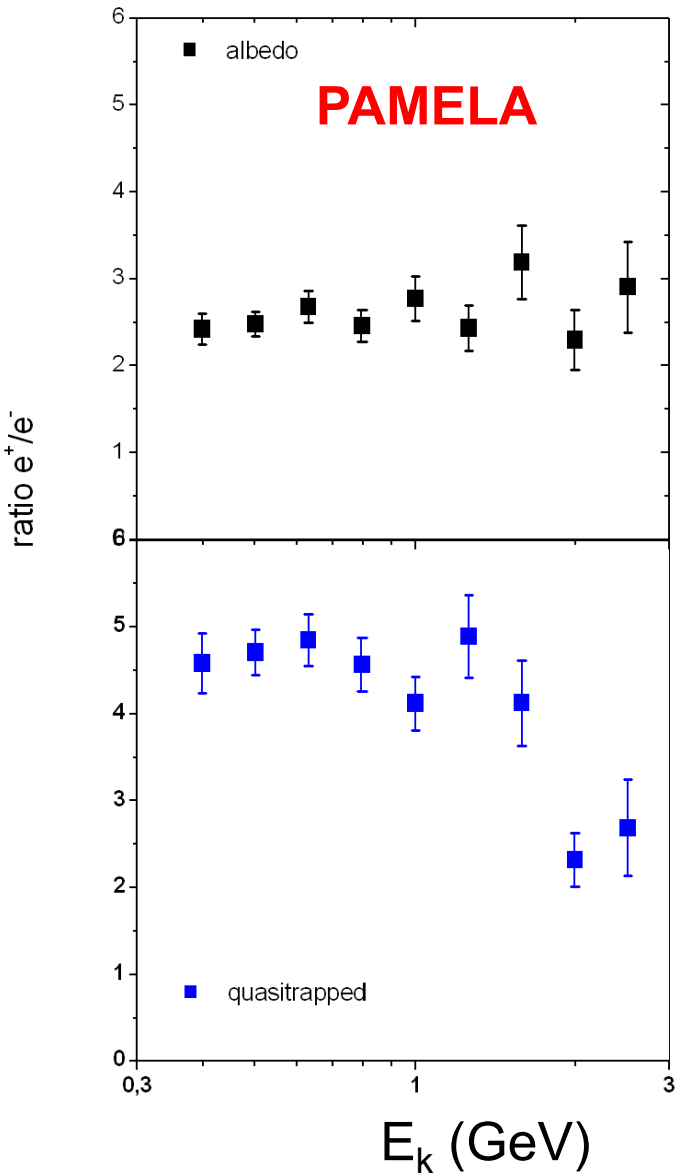


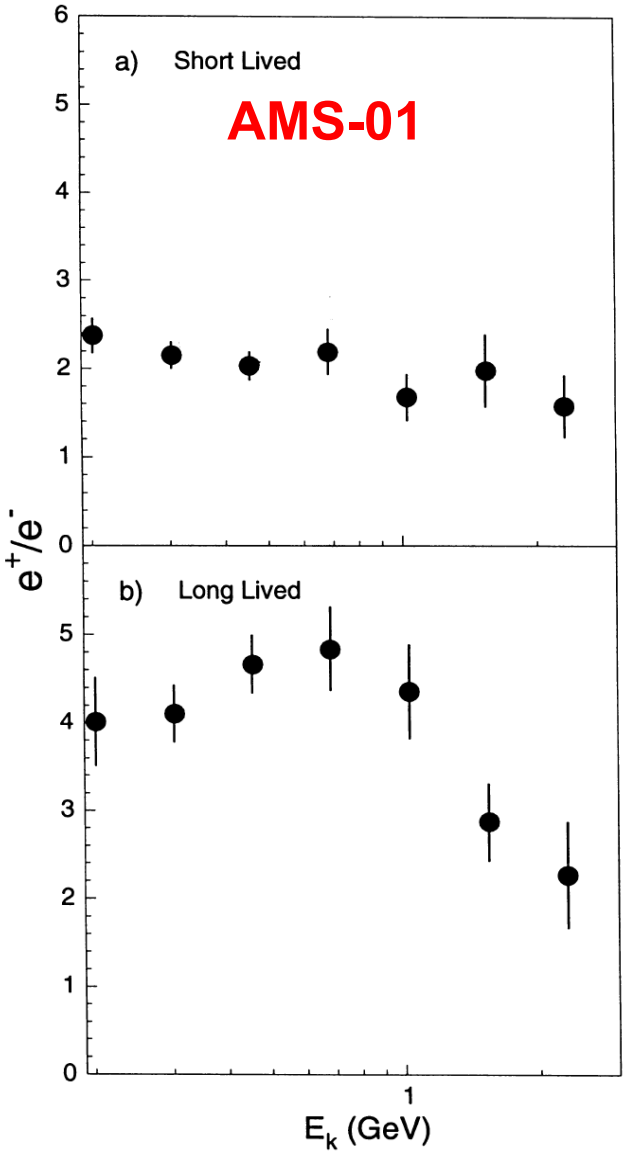
positrons





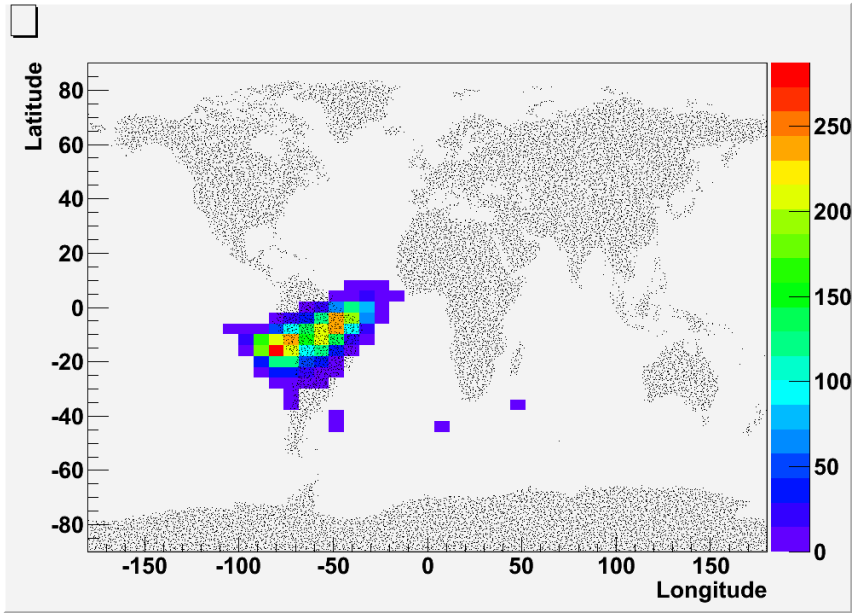
Positron to electron ratio vs energy



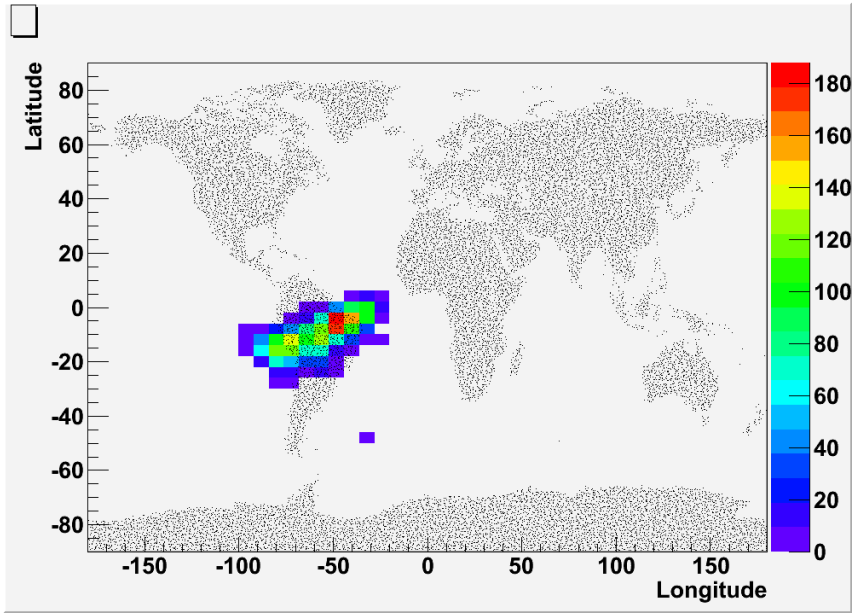


Stably trapped particles: points of detection

positrons

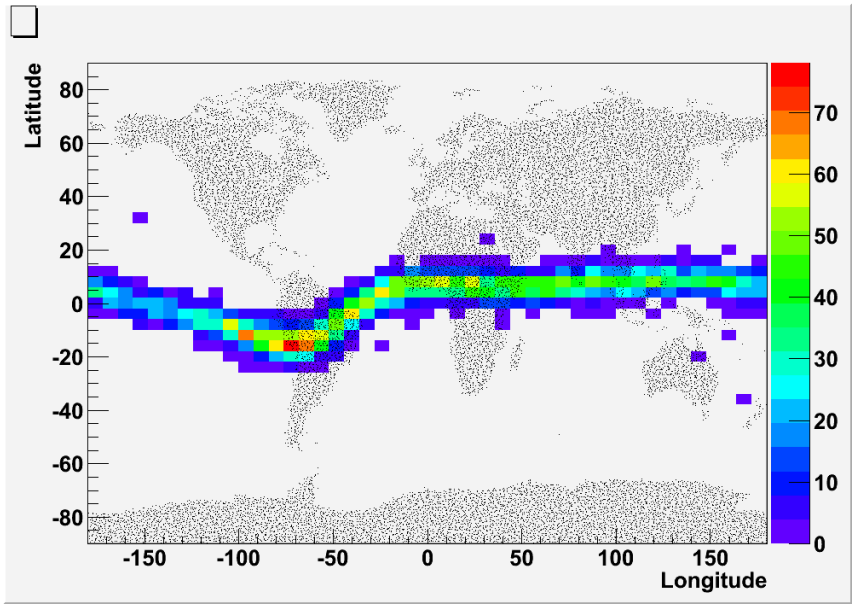


electrons

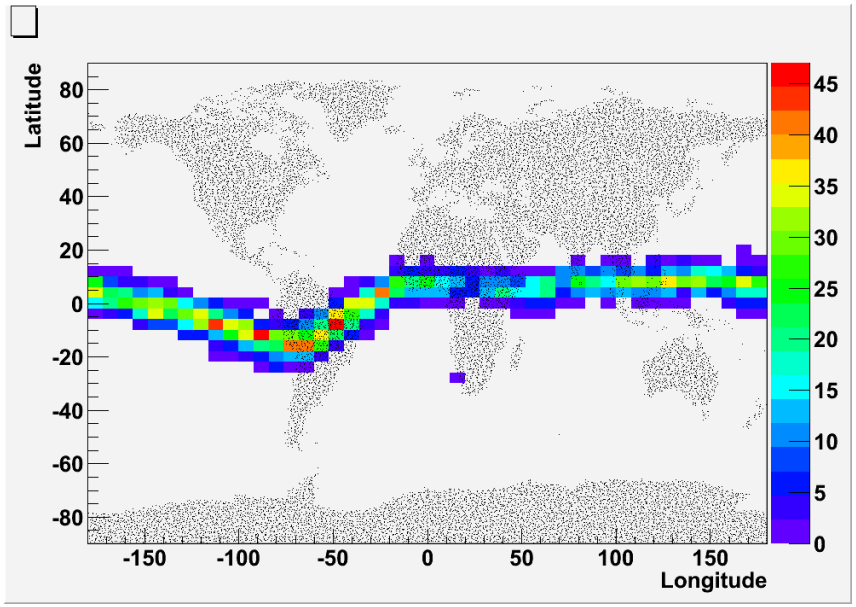


Space distribution of trapped particles

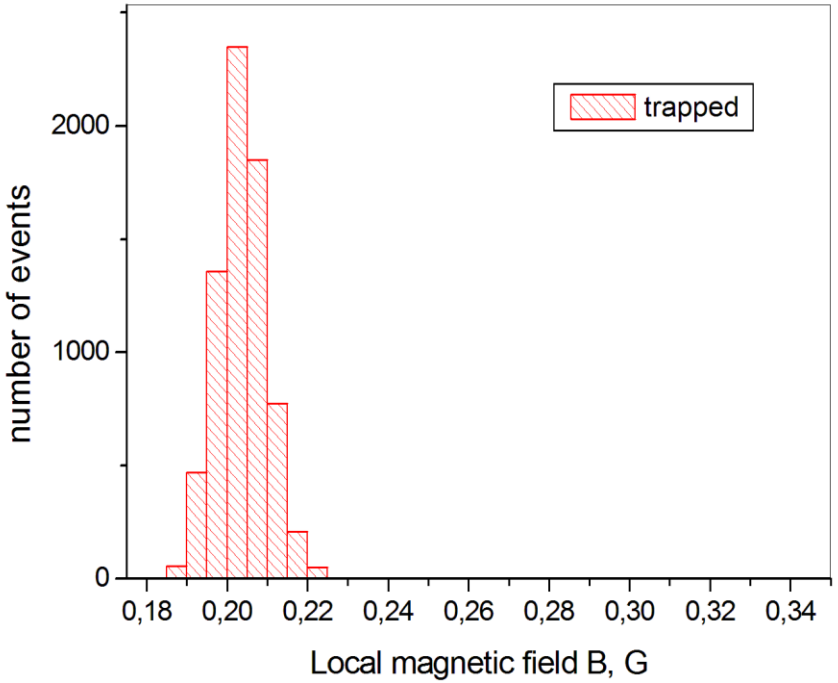
positrons

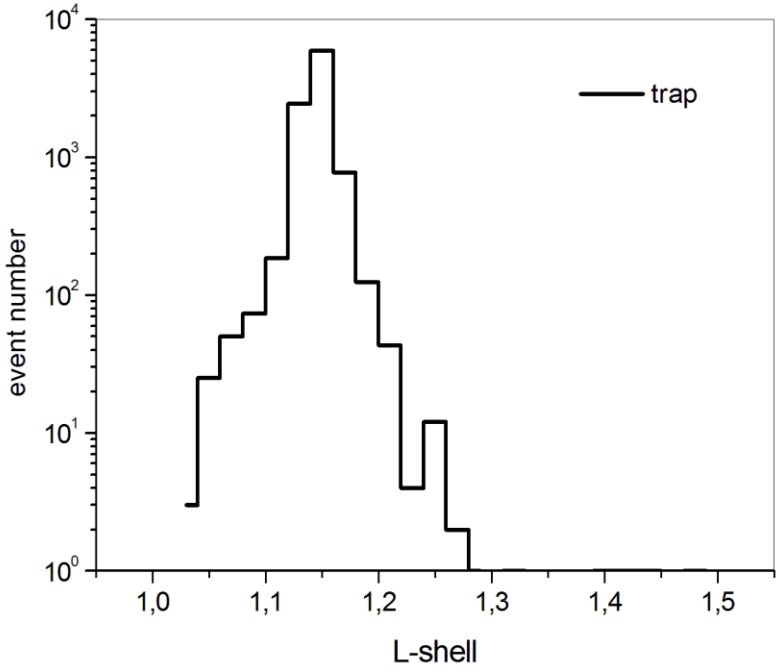


electrons

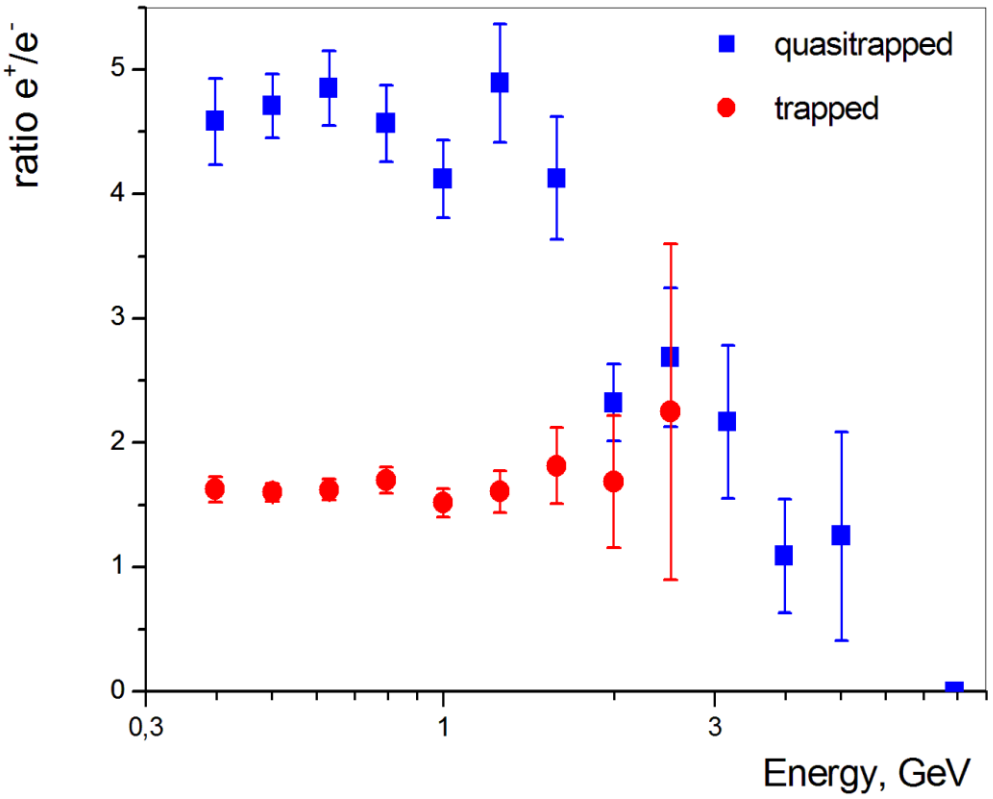


Geomagnetic coordinates L-B of detected trapped particles

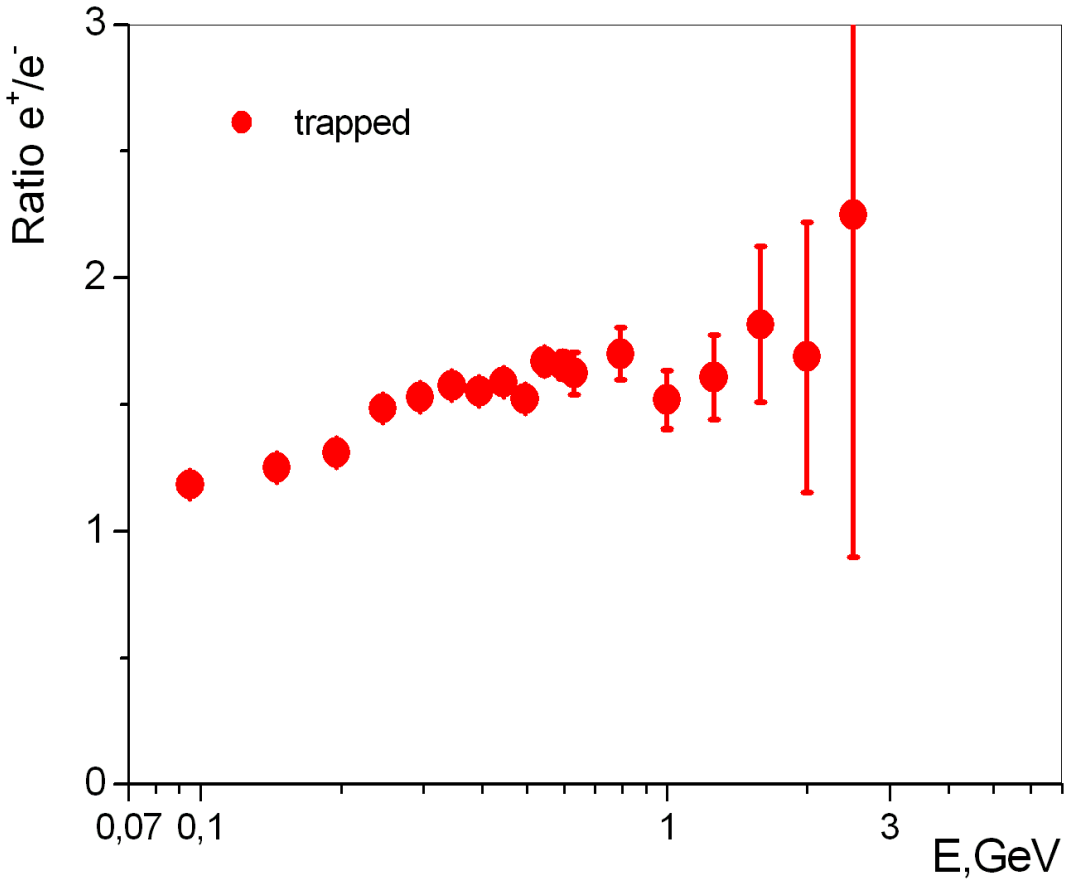




Positron to electron ratio



Positron to electron ratio for trapped particles (time >50 sec)



Sources of trapped electrons and positrons with E>10 MeV

$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu; \quad \mu^{\pm} \rightarrow e^{\pm} + \nu + \tilde{\nu}$$

$$\pi^{0} \rightarrow 2\gamma \rightarrow 2e^{+} + 2e^{-} \ .$$

Gusev et al, 2001, 2004 :TP source are limited in spatial distribution at around L=1.2± 0.1 with the energy spectrum showing a steep cutoff at energy of about ~ 300 MeV. The calculated e+/e- flux ratios in the belt due to this source are high and attain values of ≥7 in the energy range of 10 to 500 MeV. The simulated results for the CR source, at the center of the positron belt, are about 100 times lower than the positron fluxes of the TP origin at L=1.2.

Trapped proton (TR) interactions

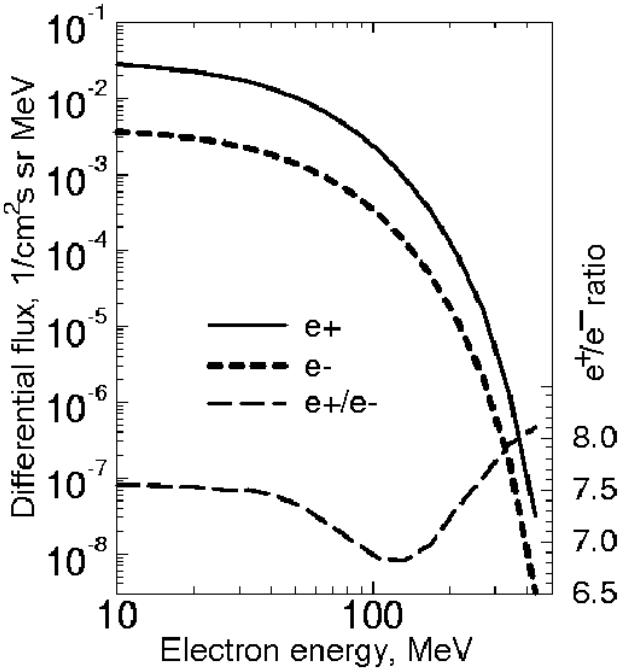


Fig. 4. Spectra of the trapped positrons and electrons produced by trapped proton source.

CR interaction with residual atmosphere

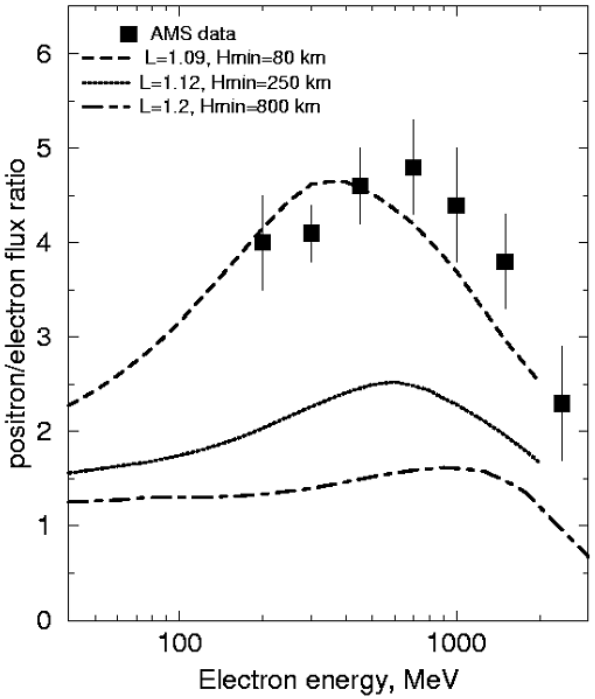
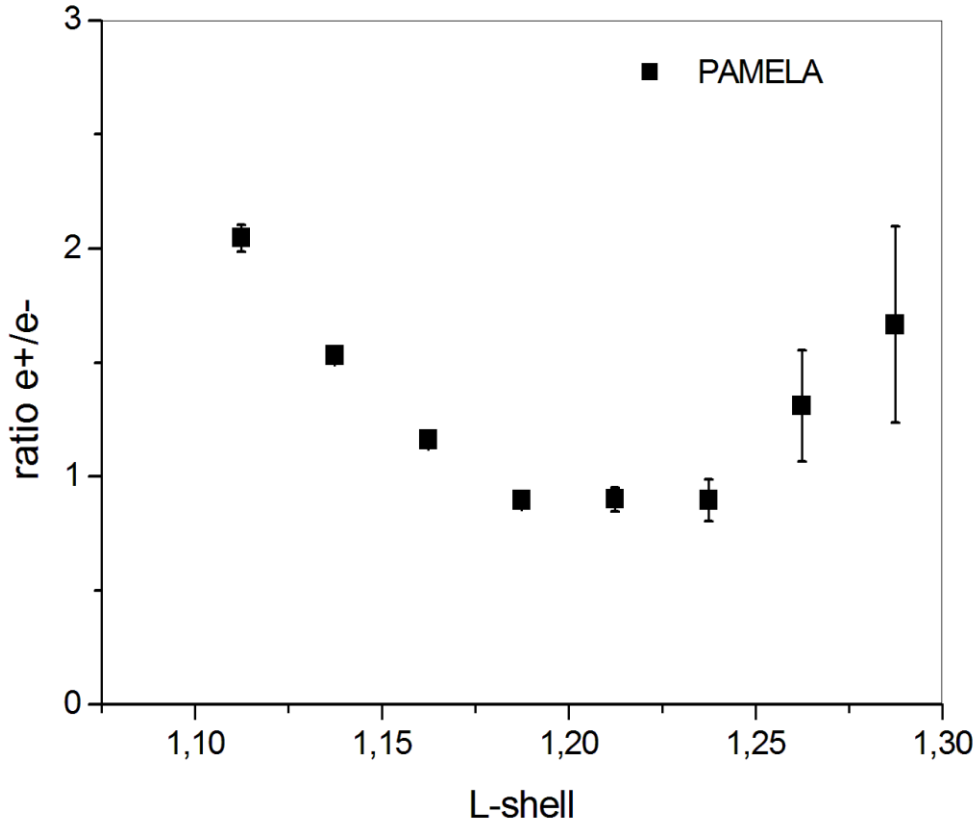
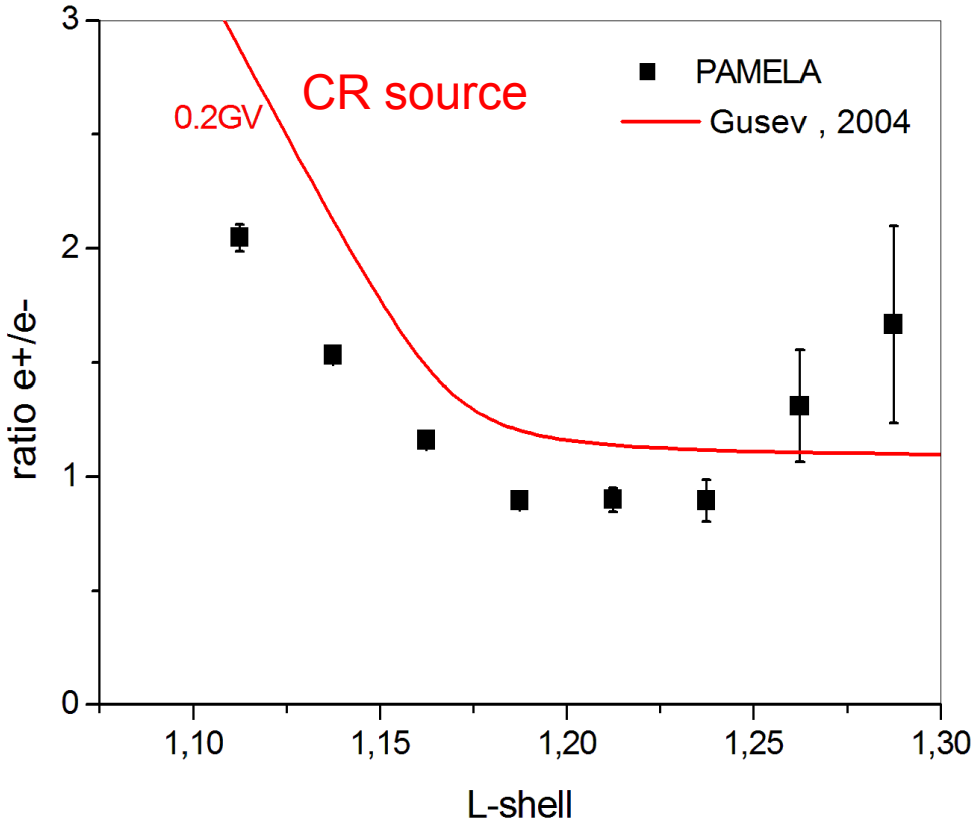


Fig. 11. Positron/electron flux ratio for CR source; circles are data of AMS experiment.

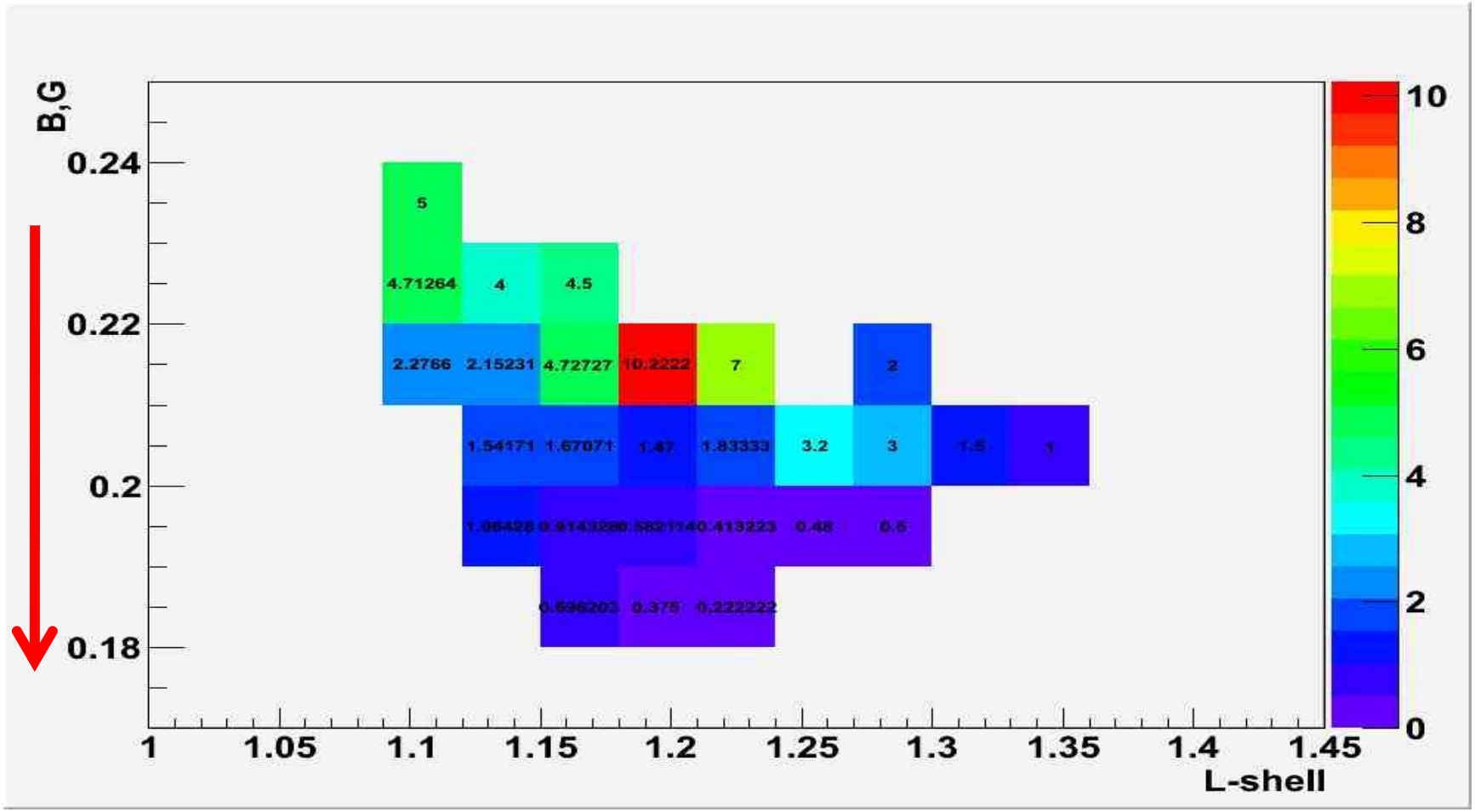
Ratio of positrons to electrons vs L-shell for trapped particles



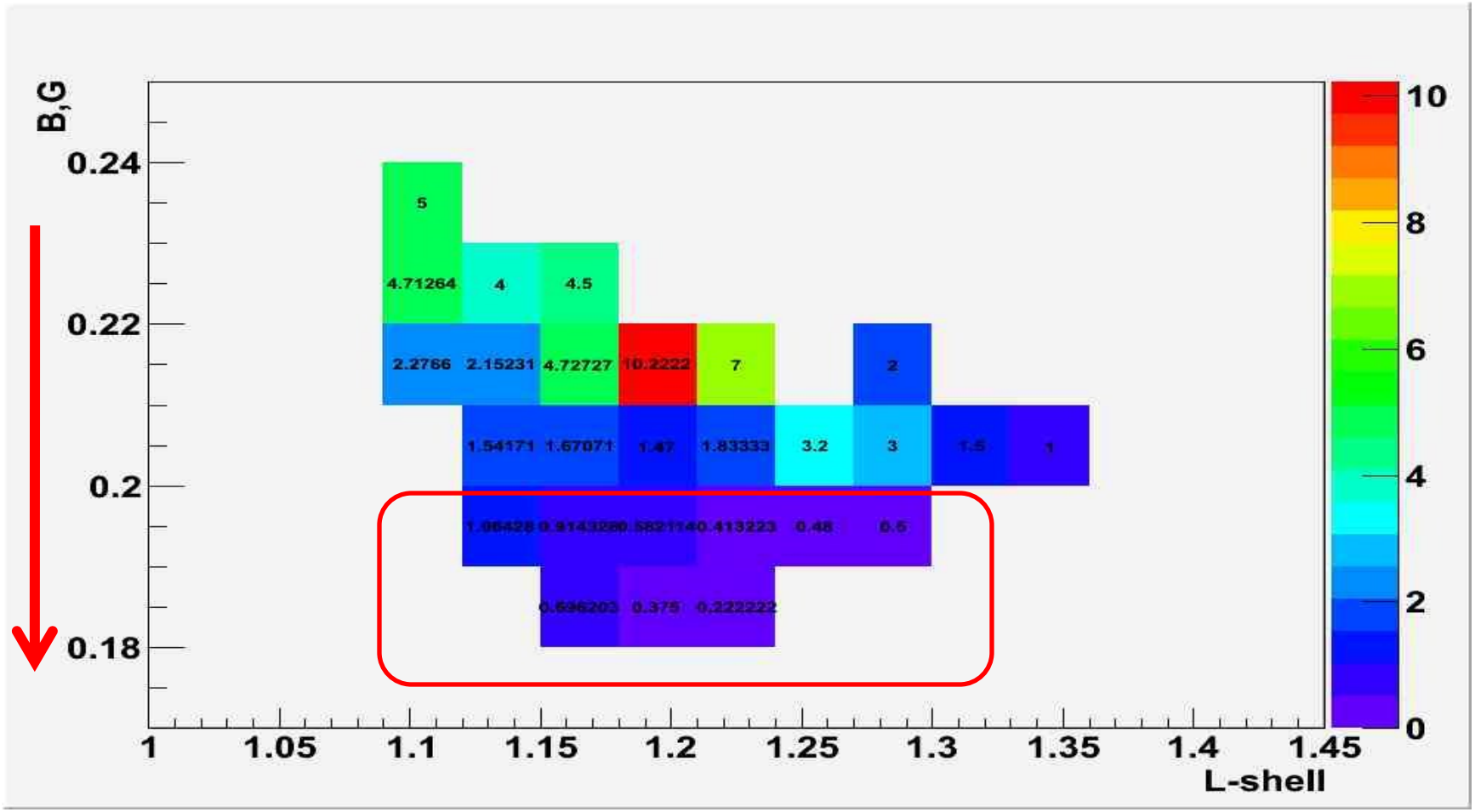
Ratio of positrons to electrons vs L-shell for trapped particles



ratio e+/e- in LB coordinates for trapped particles



ratio e+/e- in LB coordinates for trapped particles



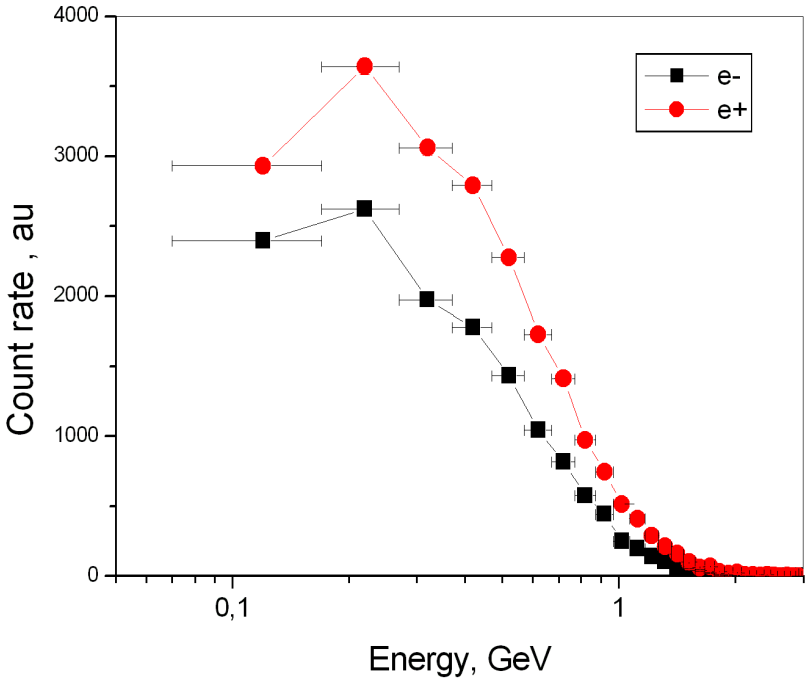
Altitude increasing

0.18<B<0.2 G , 1.12<L<1.3

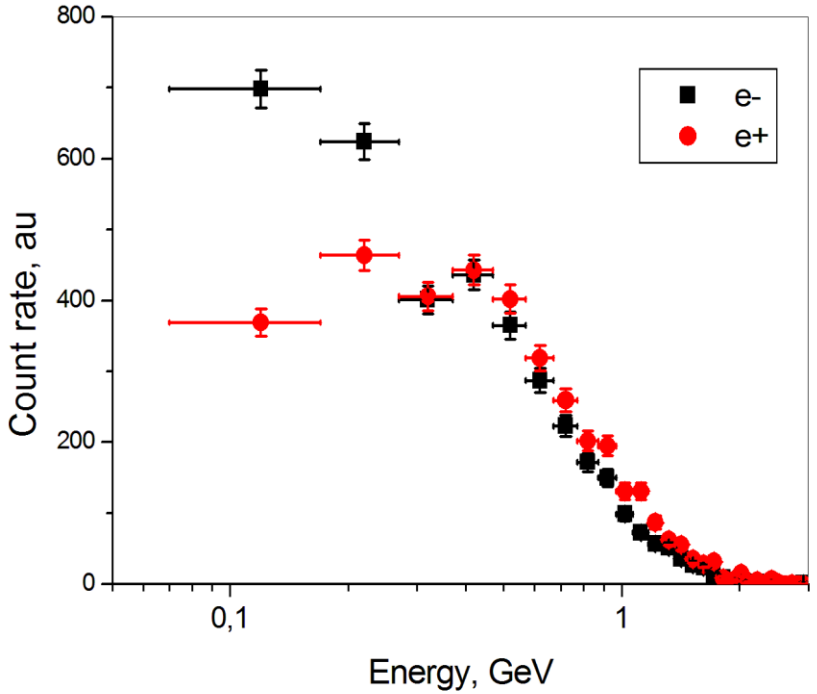
Energy distribution of trapped particles

L-shell 1.12-1.3

0.20<B<0.23 G



0.18<B<0.20 G

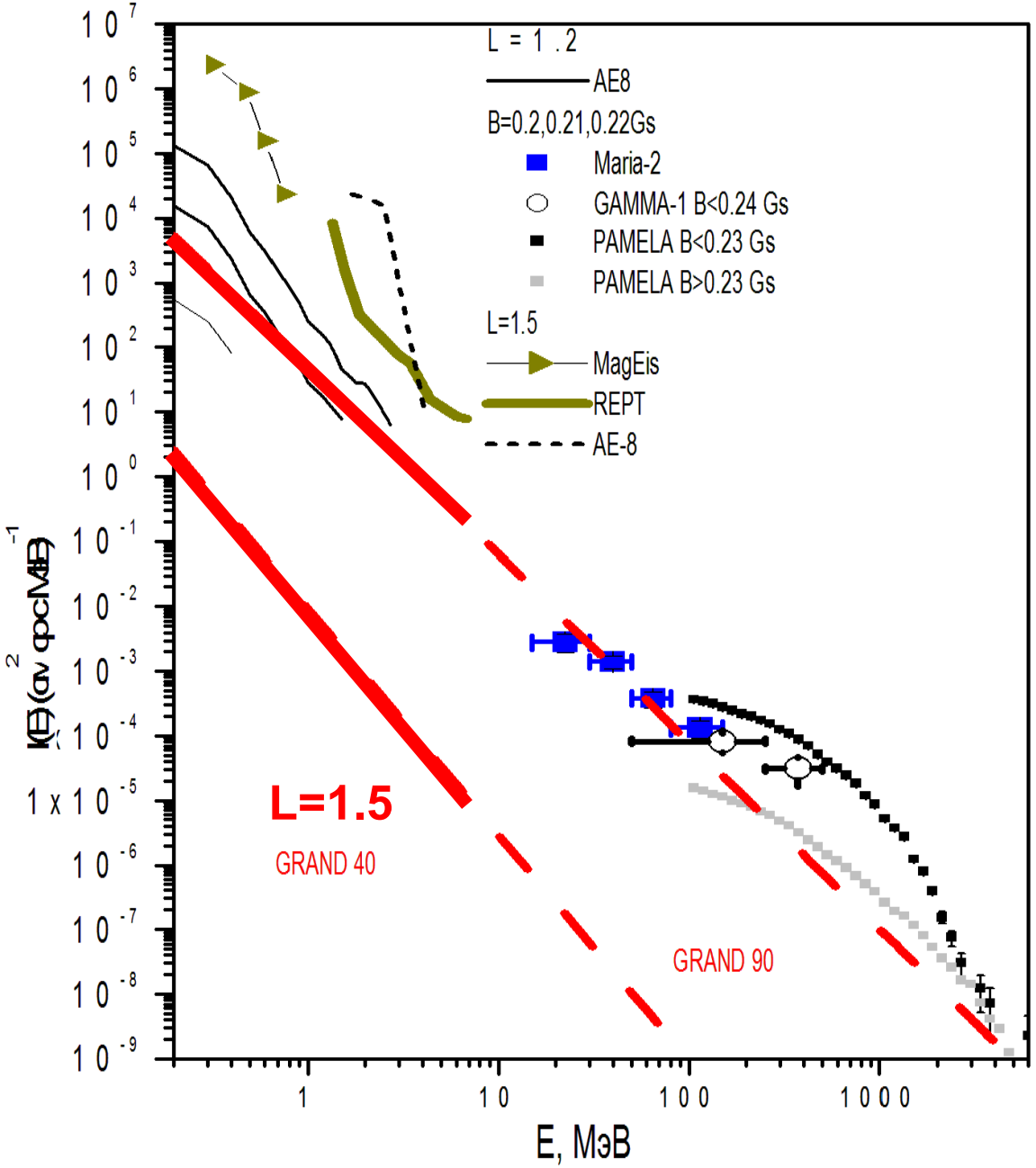


Spectra of trapped electrons from keVs to GeVs

Постер 46

CRAND model,
New calculations
L=1.5

R. Selecnick
J. Geophys. Res.
2015



Conclusion

1. Particle tracing in magnetosphere selects
   - cosmic ray
   - re-entrant albedo
   - quasitrapped
   - trapped

electron and positron

2. Charge composition of stably trapped particles in radiation belt differs from longlived quasitrapped component

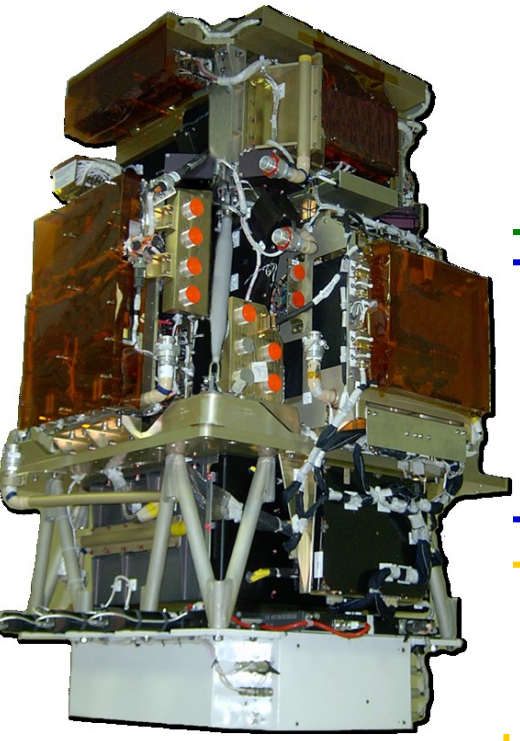
3. PAMELA detects more electrons then positrons on boundary of radiation belt at E <0.5 GeV

Thank you!

SPARE SLIDES

PAMELA detectors

Main requirements → high-sensitivity antiparticle identification and precise momentum measure

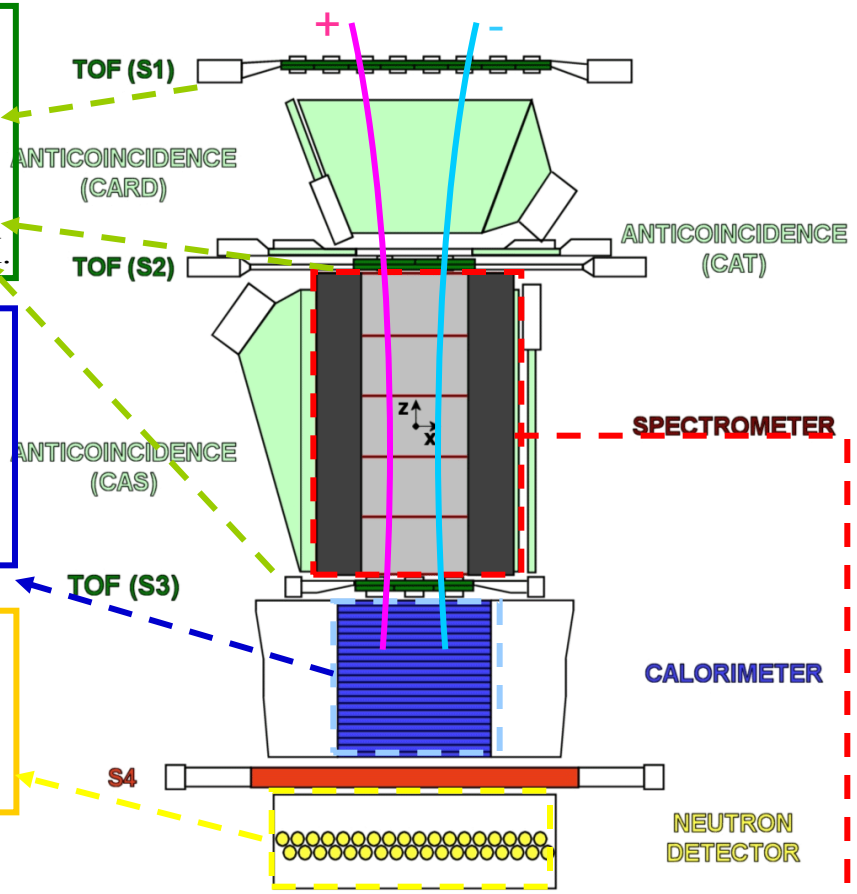


GF: 21.5 cm^2 sr
Mass: 470 kg
Size: 130x70x70 cm^3
Power Budget: 360W

Time-Of-Flight
plastic scintillators + PMT:
- Trigger
- Albedo rejection;
- Mass identification up to 1 GeV;
- Charge identification from dE/dX.

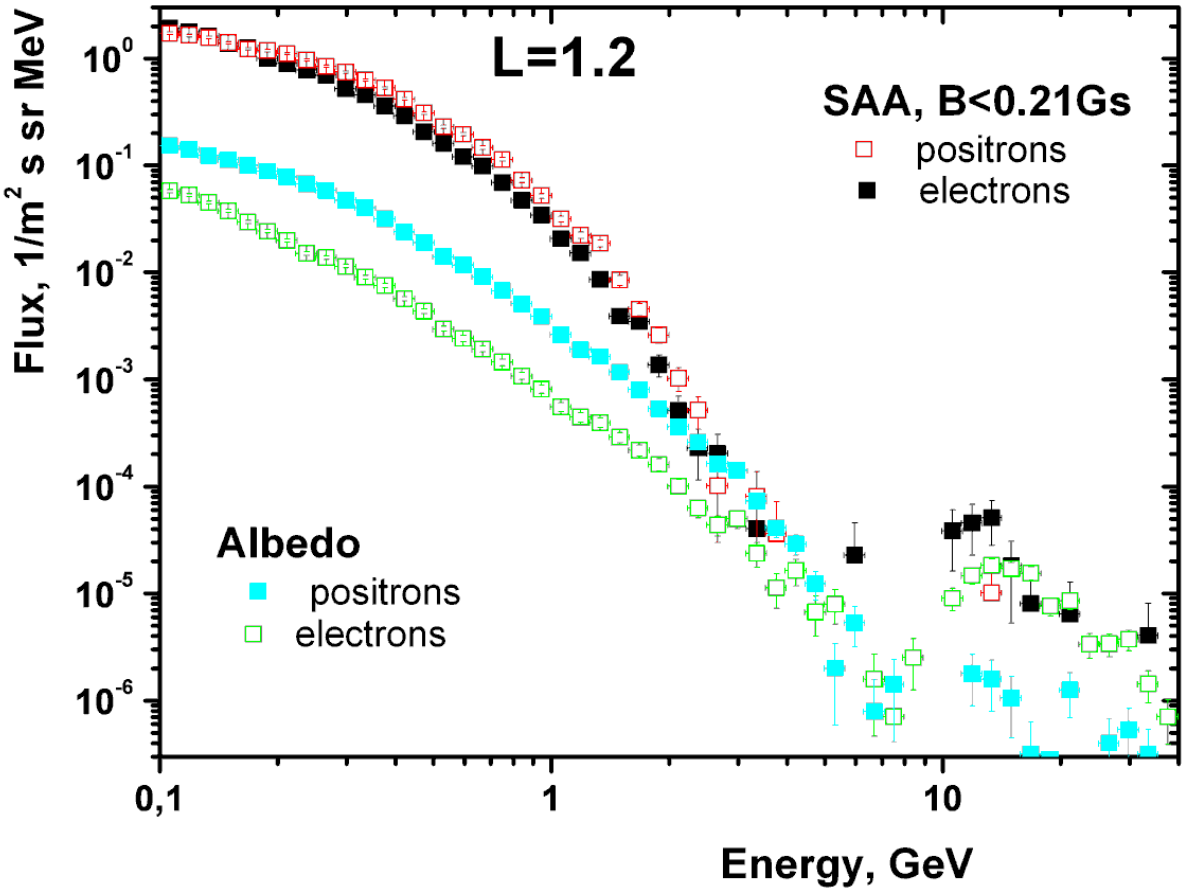
Electromagnetic calorimeter
W/Si sampling (16.3 X_0, 0.6 λI)
- Discrimination e+ / p, anti-p / e^- (shower topology)
- Direct E measurement for e^-

Neutron detector
^{3}He tubes + polyethylene moderator:
- High-energy e/h discrimination

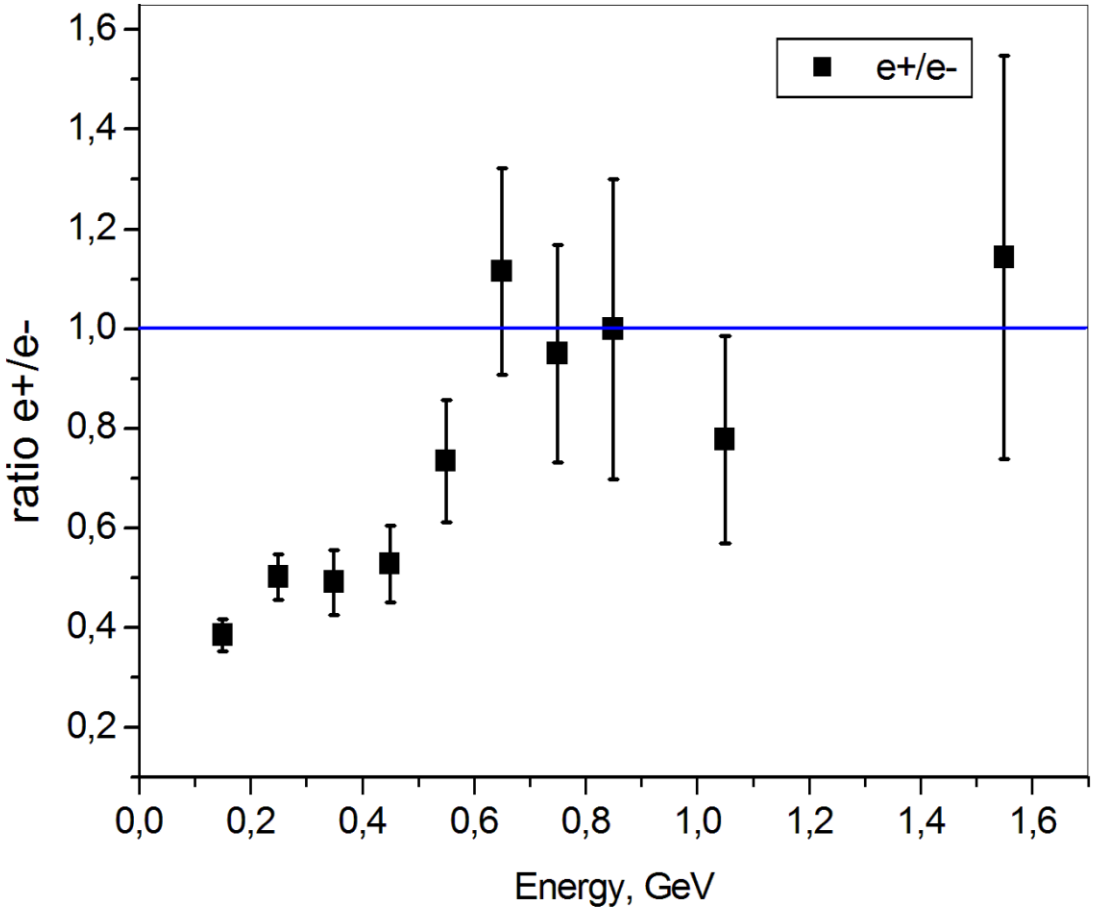


Spectrometer
microstrip silicon tracking system + permanent magnet
It provides:
- *Magnetic rigidity* → R = pc/Ze
- *Charge sign*
- *Charge value from dE/dx*

Electron and positron spectra in SAA



Отношение e+/e- для 0.18<B<0.2 , 1.18<L<1.13



Energy distributions of trapped electrons and positrons

0.18<B<0.2 G , 1.12<L<1.3