Поиск анизотропии позитронов галактических космических лучей по данным эксперимента ПАМЕЛА

Donatella Compagna*, Виталий Малахов**, Владимир Михайлов**,
Emiliano Mocchutti*, Beatrice Panico* , Ugo Giaccari *

*INFN
** НИЯУ МИФИ

PAMELA collaboration

ВККЛ, 13/08/2014, Дубна

PAMELA Collaboration

Italy:

Bari, Florence, Frascati, Naples, Rome, Trieste, CNR, Florence

Russia:

Moscow
St. Petersburg

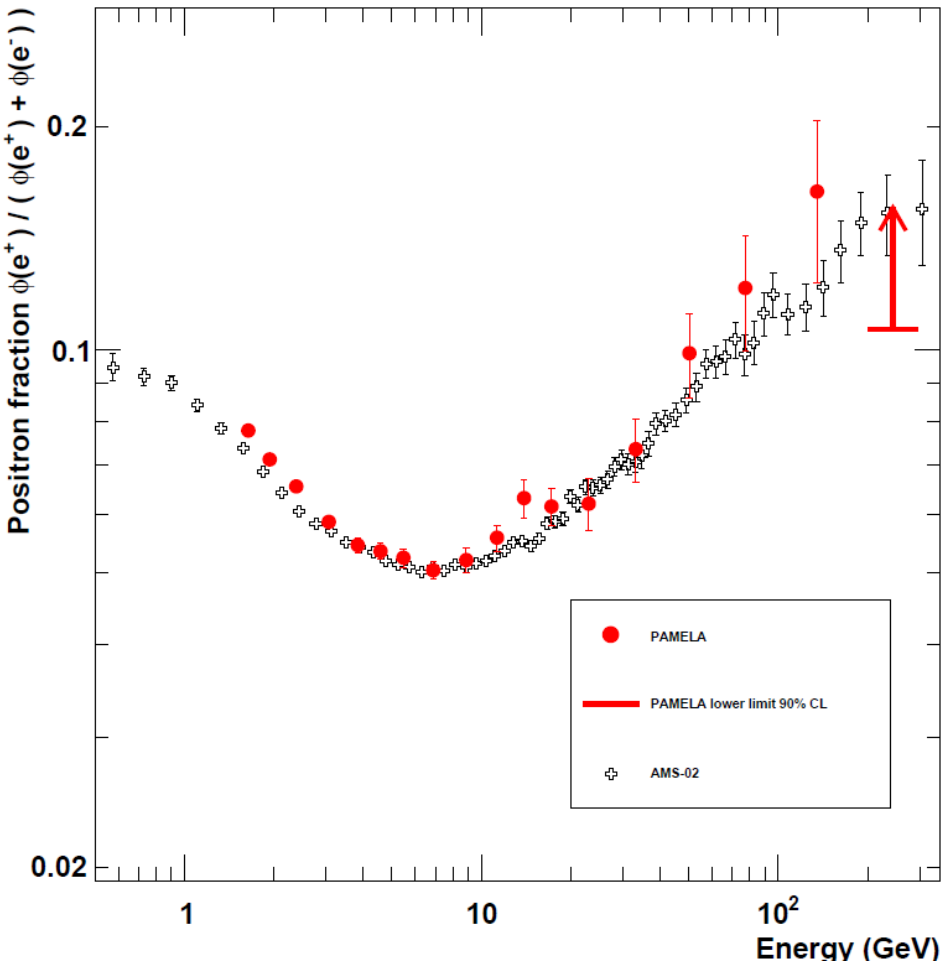
Germany

Siegen

Sweden:

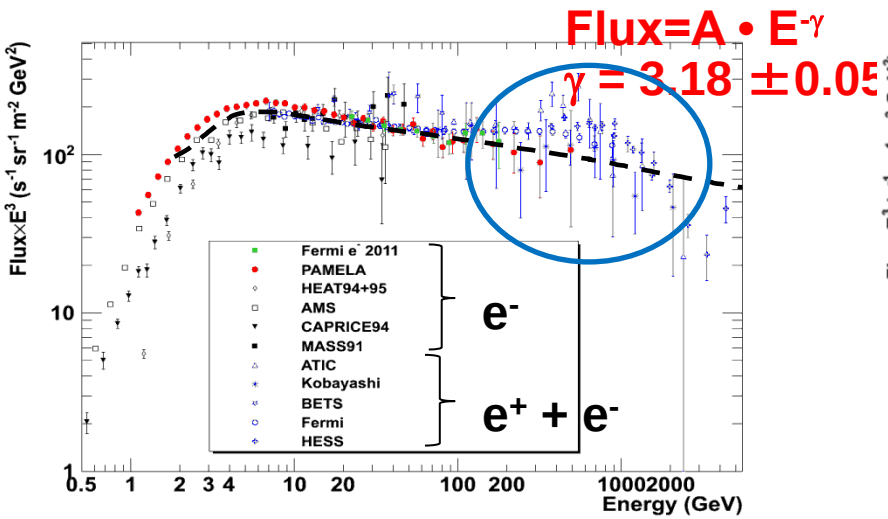
KTH, Stockholm

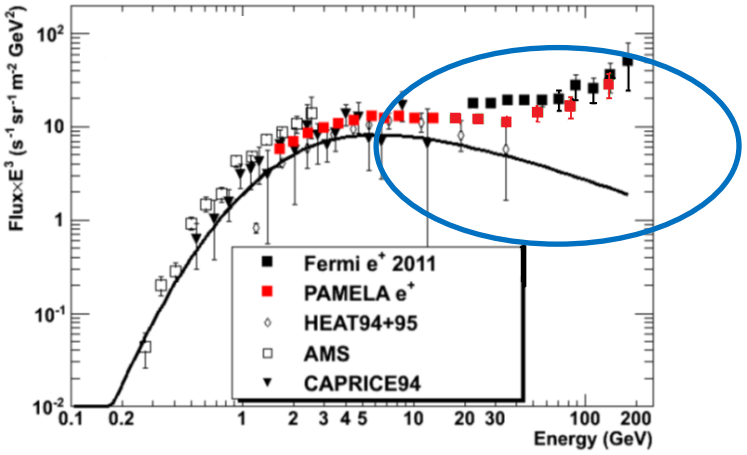
Отношение $e^+/(e^+ + e^-)$



M. Aguilar, et al., Phys. Rev. Lett. 110 (2013) 141102

Новые результаты по спектрам электронов и позитронов КЛ





Измерения электронного спектра

PRL, 102, 181101, 2009

Измерения позитронного спектра
PRL, 111, 081102, 2013

- ***Избыток электронов выше 200 ГэВ по сравнению с диффузионной моделью наблюдался Fermi-LAT , ATIC и PPB-BETS, PAMELA и AMS-02***
- ***PAMELA,FERMI, AMS-02 : избыток позитронов выше ~ 5 ГэВ***

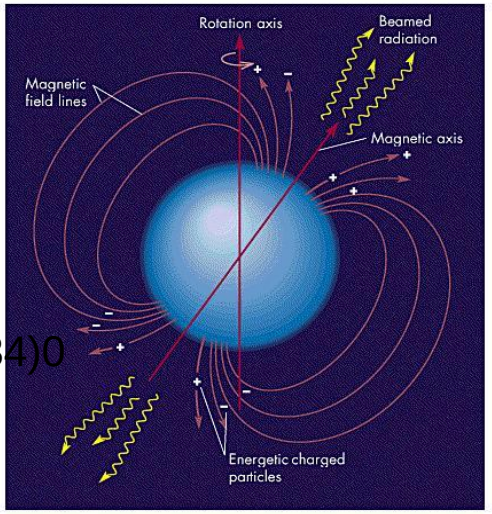
Локальные источники, пульсары или темная материя?

Search for anisotropy of high energy $e^+ + e^-$

$$A = \frac{I_{max} - I_{min}}{I_{min} + I_{max}} = \sum_i \frac{I_i(\vec{n}_{max}, \vec{r}_i/r_i)\delta_i}{I_i}$$

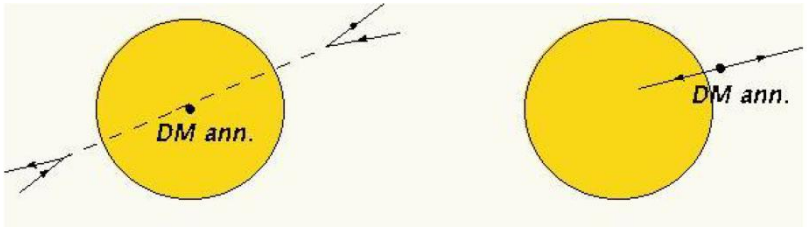
Expected anisotropy from nearest pulsars is $\delta_i = \frac{3}{c}\frac{r_i}{t_i}$

~10% for Vela, ~3% for B0656+14, ~0.25% for Geminga
(astro-ph 0804.0220) , ~13% for Vela at ~1 TeV (APJ 2004, 601, 340)



Pulsars are possible source of HE electrons & positrons.

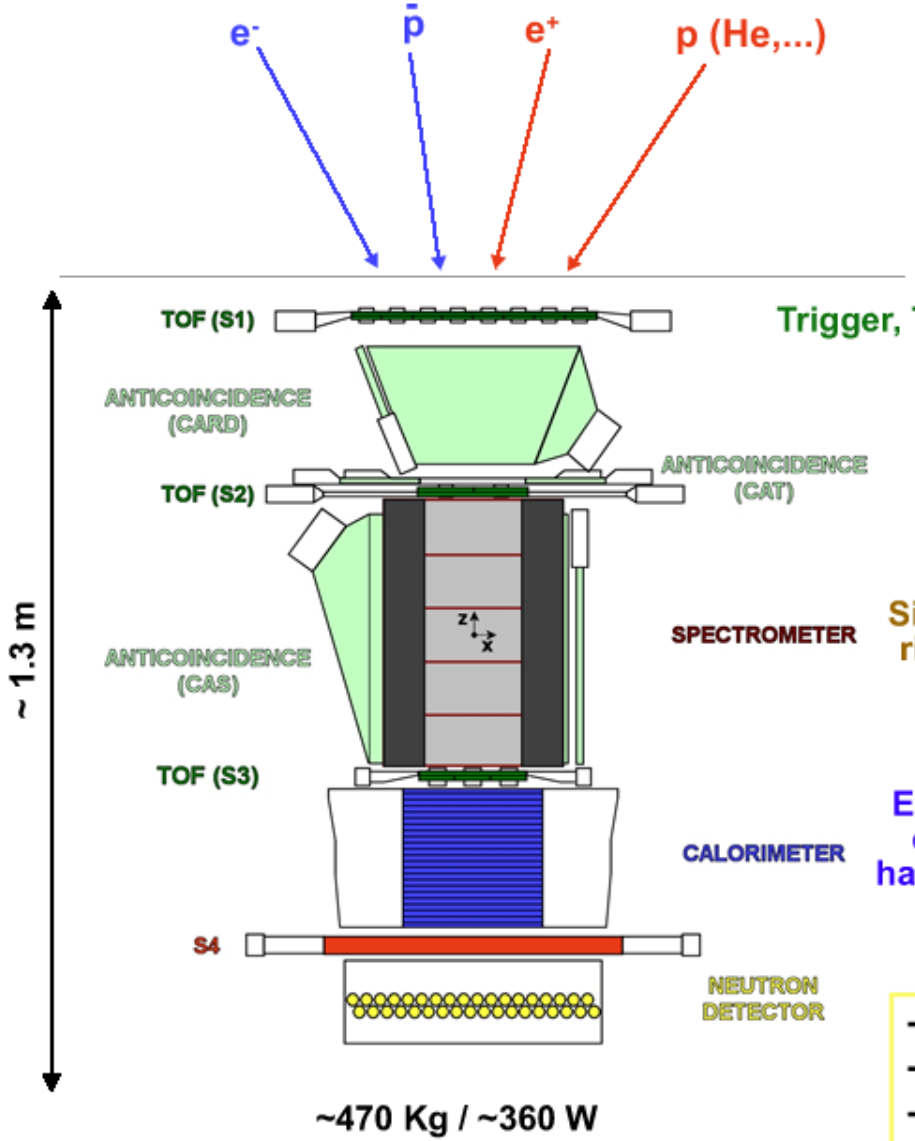
Dark Matter on the Sun as a source of e^+,e^-:



Two possible escape mechanism of positrons from the Sun.
Figure from astro-ph 0910.1838.

Search anisotropy from the Sun for electrons was performed in
Ajello M. et al.[Fermi collaboration]Physical Review D 84 (2011) Issue 3, id. 032007
Campana D. et al [PAMELA collaboration]2013 J. Phys.: Conf. Ser. 409 012055

PAMELA instrument



~470 Kg / ~360 W

Trigger, ToF, dE/dx

- S1, S2, S3; double layers, x-y
- plastic scintillator (8mm)
- ToF resolution ~300 ps (S1-3 ToF >3 ns)
- lepton-hadron separation < 1 GeV/c
- S1.S2.S3 (low rate) / S2.S3 (high rate)

Sign of charge, rigidity, dE/dx

- Permanent magnet, 0.43 T
- 21.5 cm^2 sr
- 6 planes double-sided silicon strip detectors (300 μm)
- 3 μm resolution in bending view → MDR

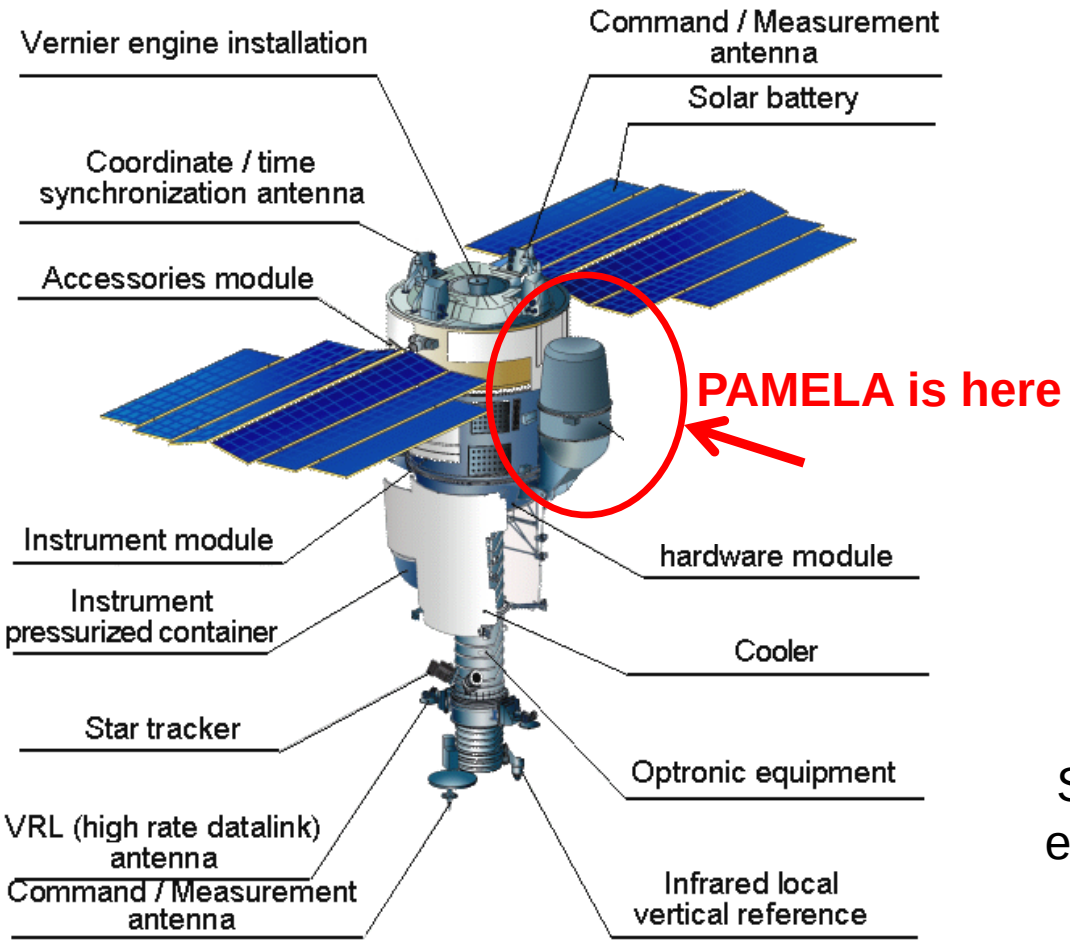
MDR 1.2 TeV

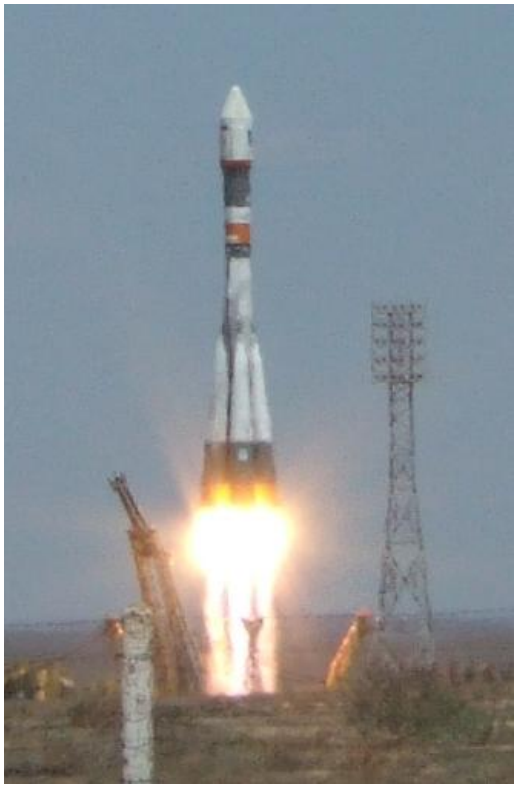
Electron energy, dE/dx, lepton-hadron separation

- 44 Si-x / W / Si-y planes (380)
- 16.3 X0 / 0.6 L
- dE/E ~5.5 % (10 - 300 GeV)
- Self trigger > 300 GeV / 600 cm^2 sr

- 36 ^{3}He counters
- ^{3}He(n,p)T; E_p = 780 keV
- 1 cm thick poly + Cd moderator
- 200 μs collection

The PAMELA experiment



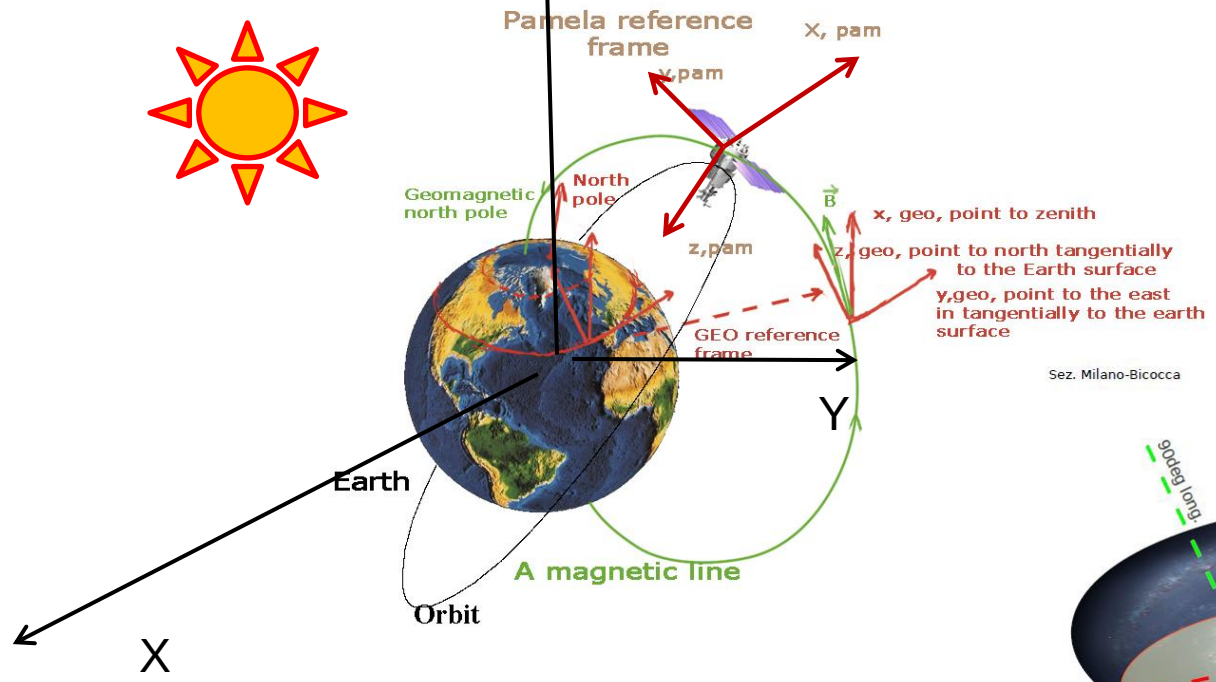


Satellite was launched 15.06.2006 on elliptical polar orbit with inclination 70^0, altitude 350-610 km.
About 20 GB data per day

Coordinate systems

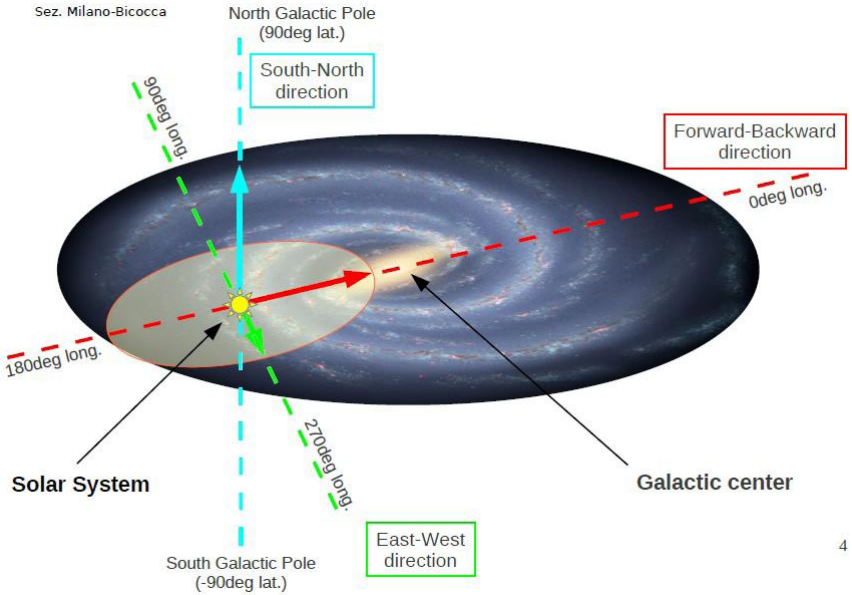
ECI (Earth-Centered Inertial) reference frame X,Y,Z was used to the satellite orbiting

Z, pointed to north pole

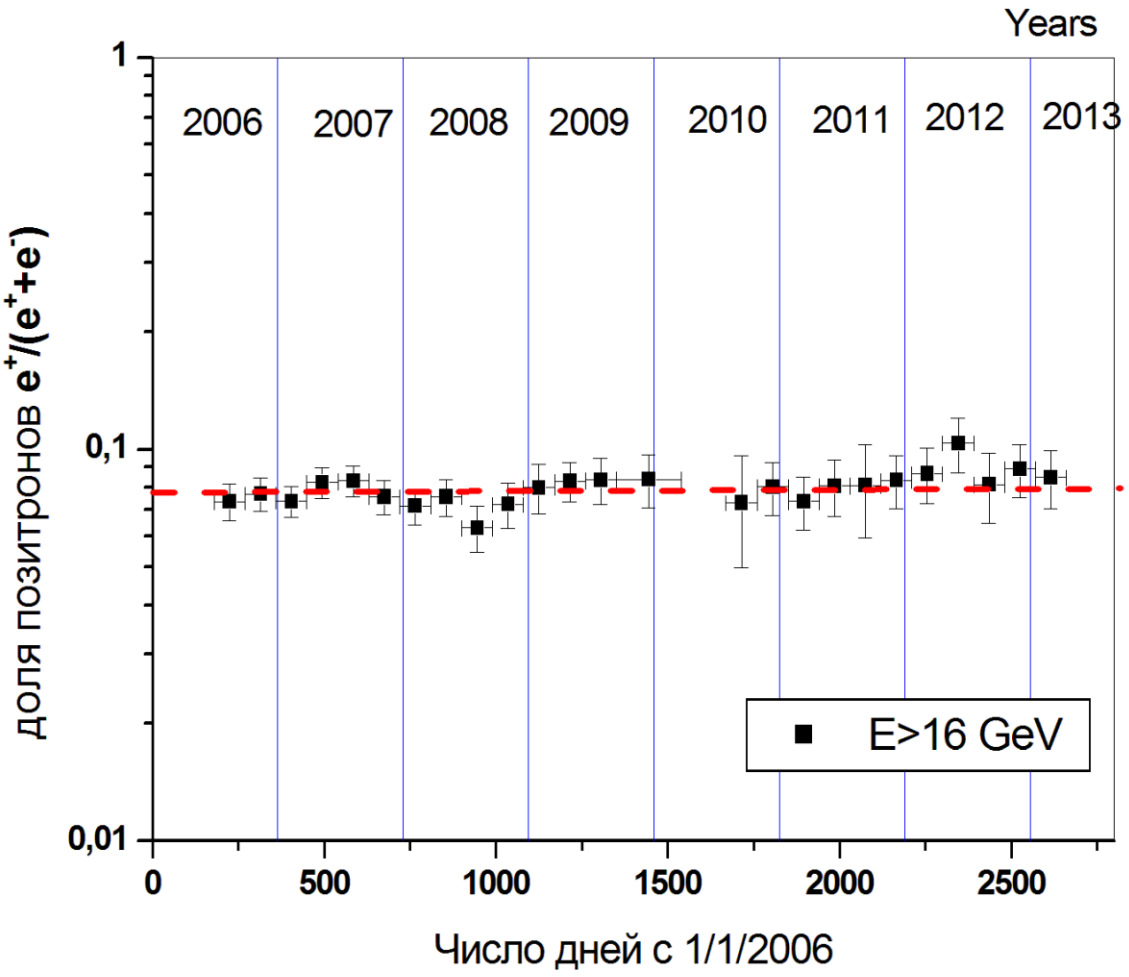


pointed to the verbal equinox

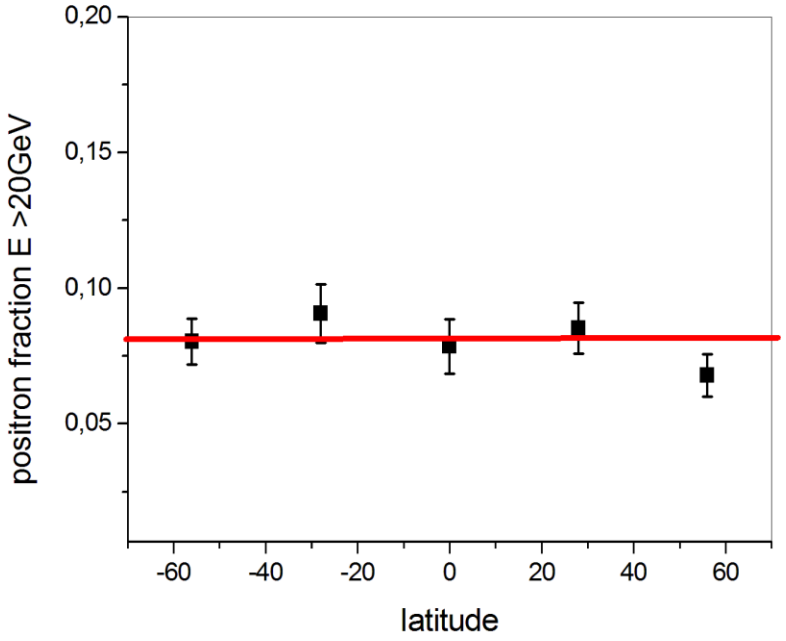
Galactic reference frame

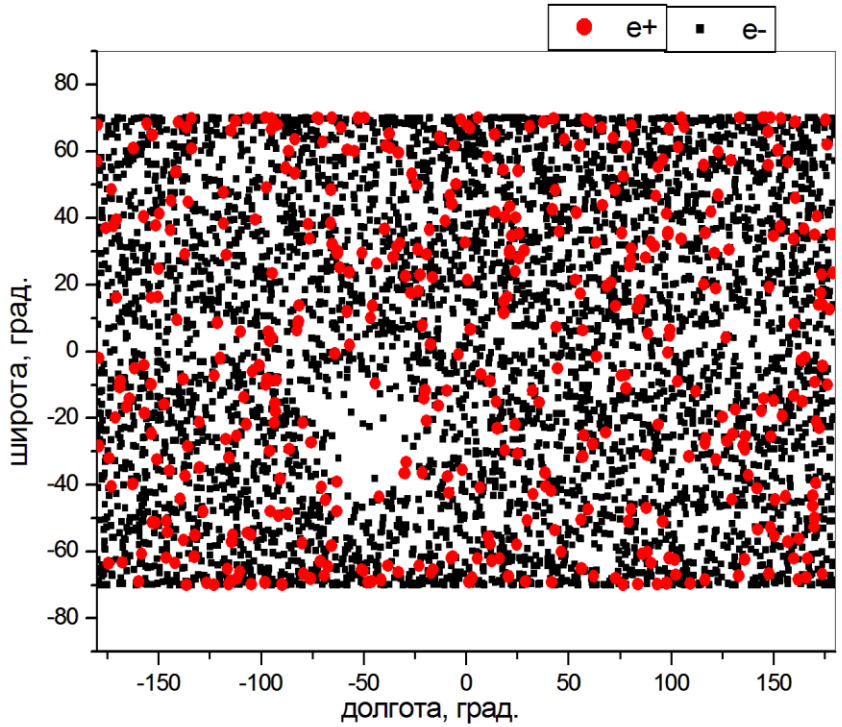


Поиск временных вариаций в 2006-2013



Географическое распределение событий





Метод анализа данных

- Определение направлений зарегистрированных частиц
- Определение направлений частиц за пределами магнитосферы
- Построение карты событий и определение числа зарегистрированных частиц N_s для всех направлений
- Построение карты событий для изотропного потока , вычисление ожидаемого фонового числа частиц N_b для каждого направления
- Сравнение реального и фонового распределений

сигнал⇒ N = Ns – Nb, <N>=0 – нет источника

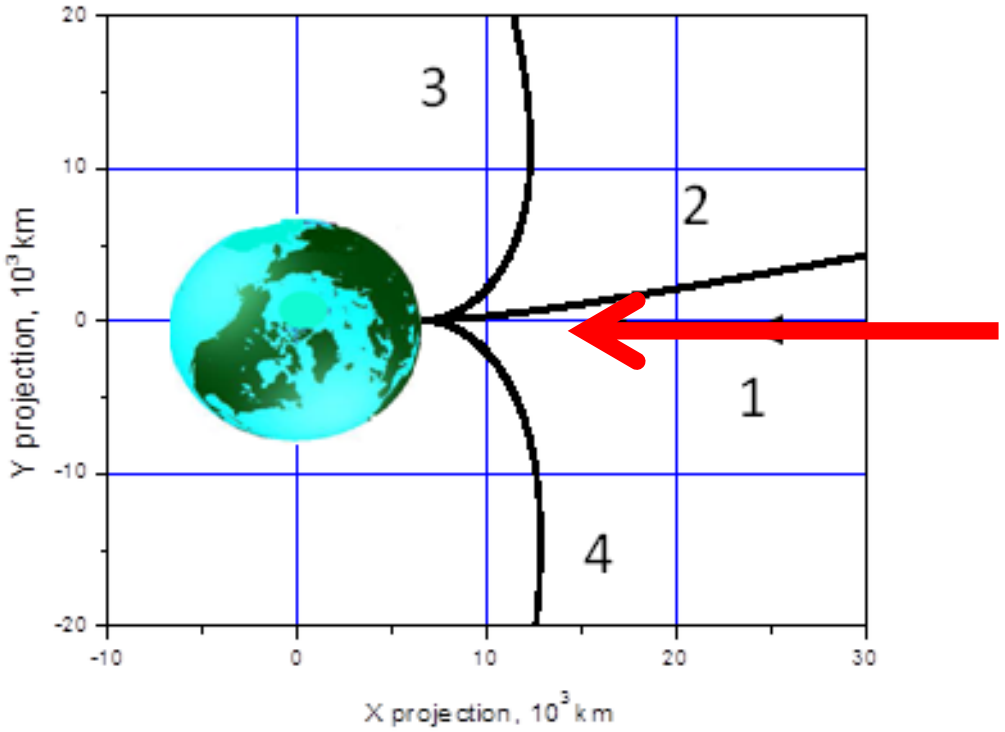
Значимость $S=\Delta N/\sigma$

$$S^2 = 2\{N_s\{\ln[\frac{1+\alpha}{\alpha}]\frac{N_s}{Ntot}] + N_b\{\ln[(1+\alpha)\frac{N_b}{Ntot}\}$$

S дает доверительный интервал для оценки сигнала в σ

T.-P. Li & Y.-Q. Ma, Astrophysical Journal 272 (1983)317-324.

Учет магнитного поля Земли

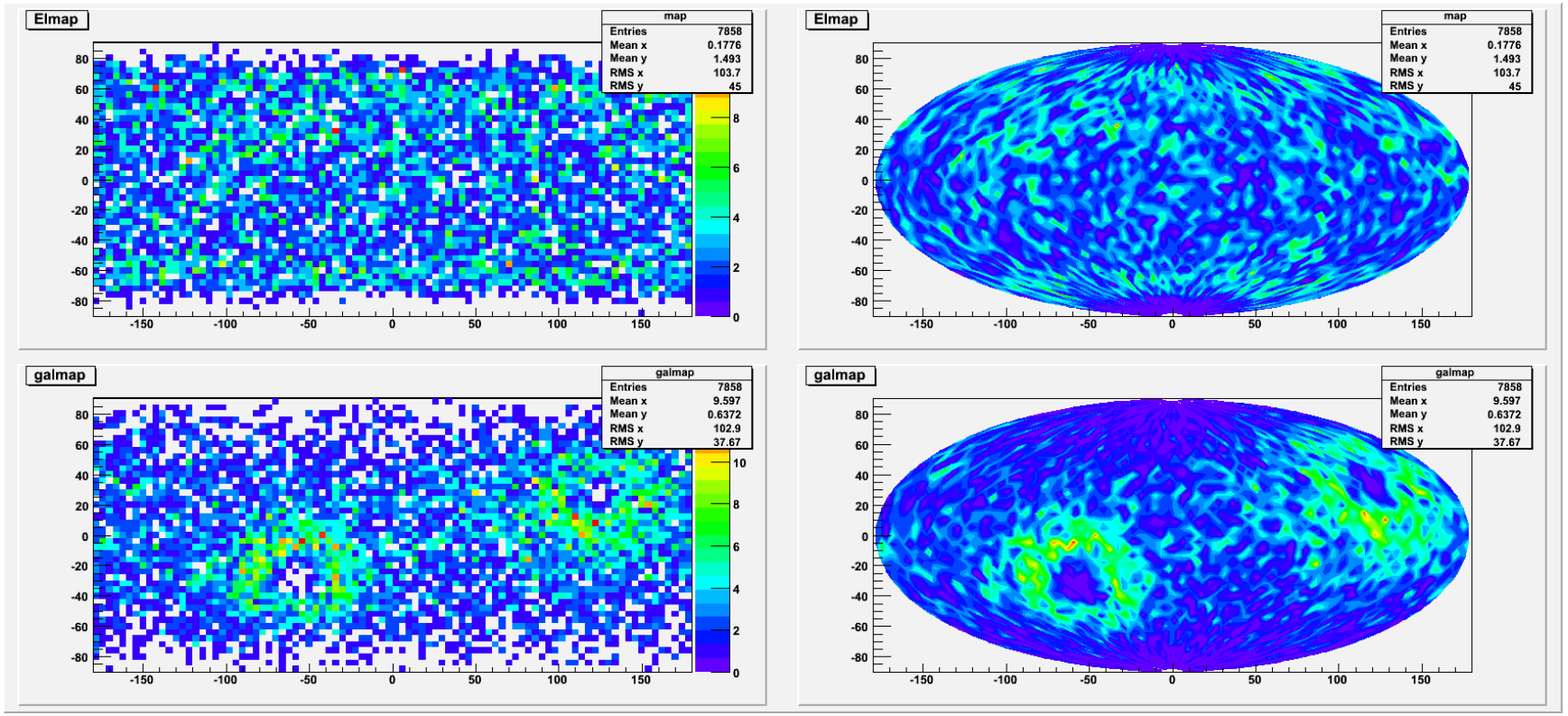


1 – measured direction in near equatorial plane
2 - positron E=90GeV
3- positron E=15 GeV
4- electron E=15 GeV

Карта для электронов

~8000 событий с энергией E>20 ГэВ

ECI reference frame



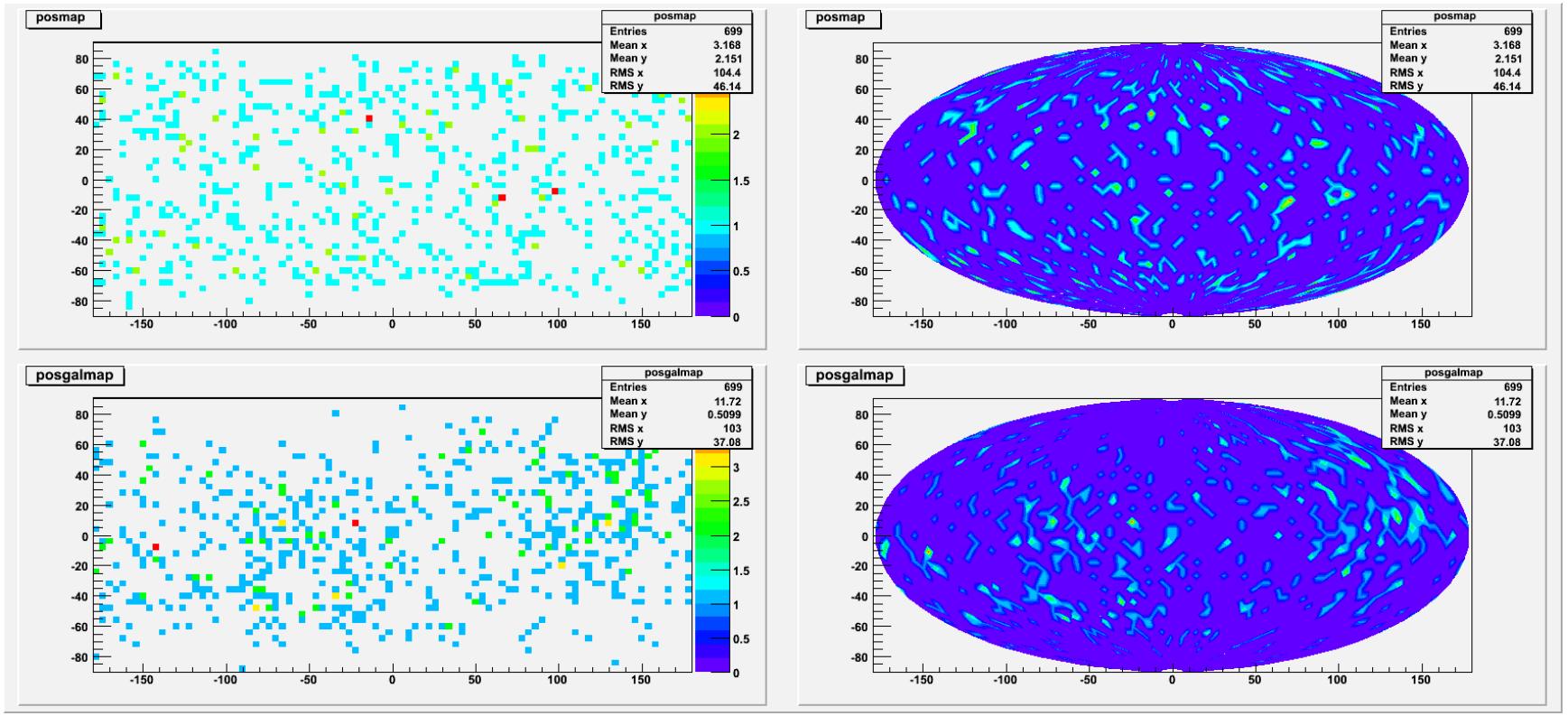
Galactic reference frame

the Galactic Center (l,b) =(0,0)
is in the middle of this map

Карта для позитронов

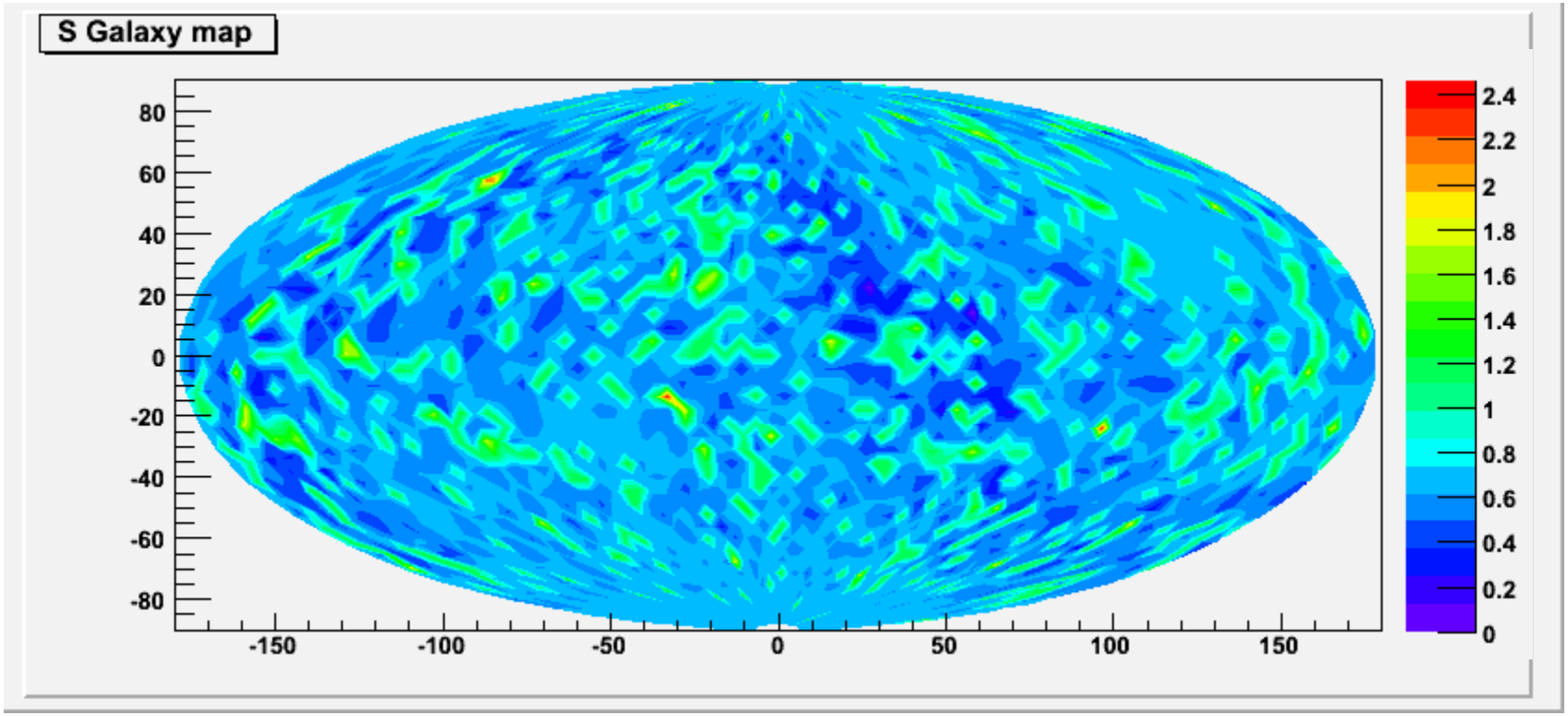
~700 событий с энергией E>20 ГэВ

ECI reference frame



Galactic reference frame

Распределение «S» для позитронов в галактической системе координат



Map Projection

HEALPix *- **H**ierarchical **E**qual **A**rea iso-**L**atitude **P**ixelization*

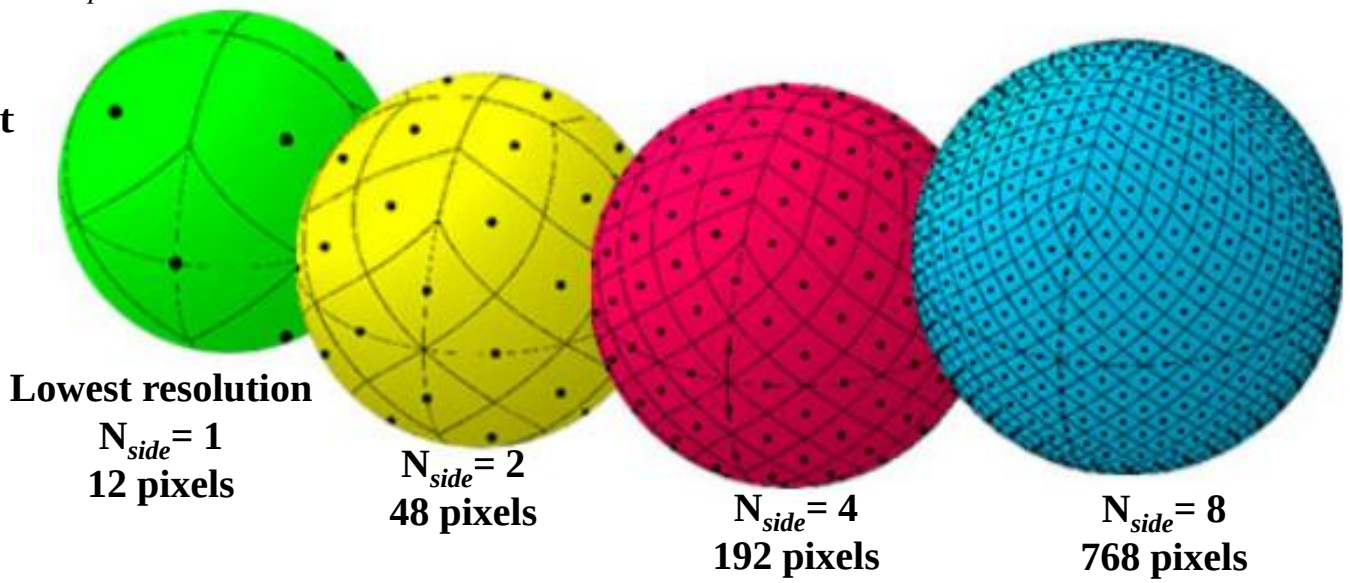
http://healpix.jpl.nasa.gov/

Gives a pixelization that produces a subdivision of a spherical surface in which each pixel covers the same surface area as every other pixel.

The resolution of the grid is expressed by the parameter *Nside* which defines the number of divisions along the side of a base-resolution pixel that is needed to reach a desired high-resolution partition

The total number of pixels is $N_{pixel} = 12\ N^2_{side}$

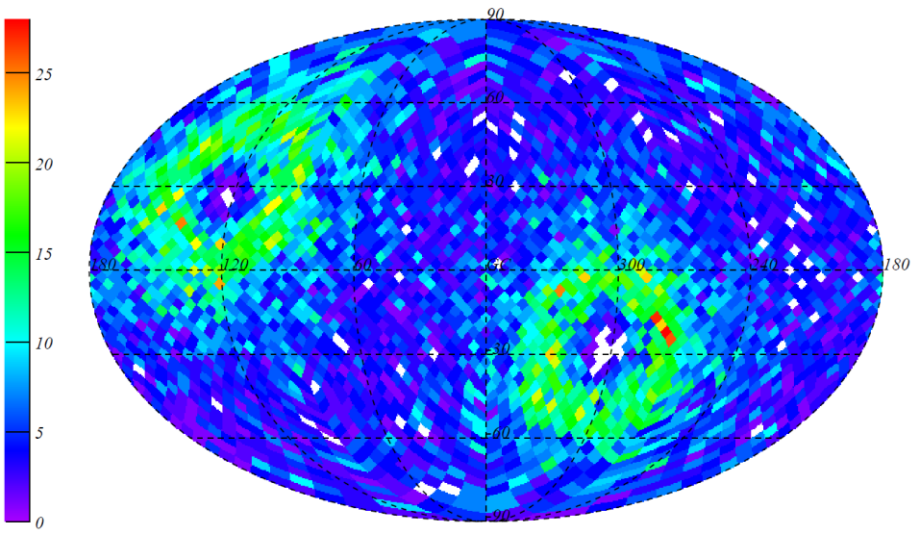
Partitioning of a sphere at progressively higher resolution



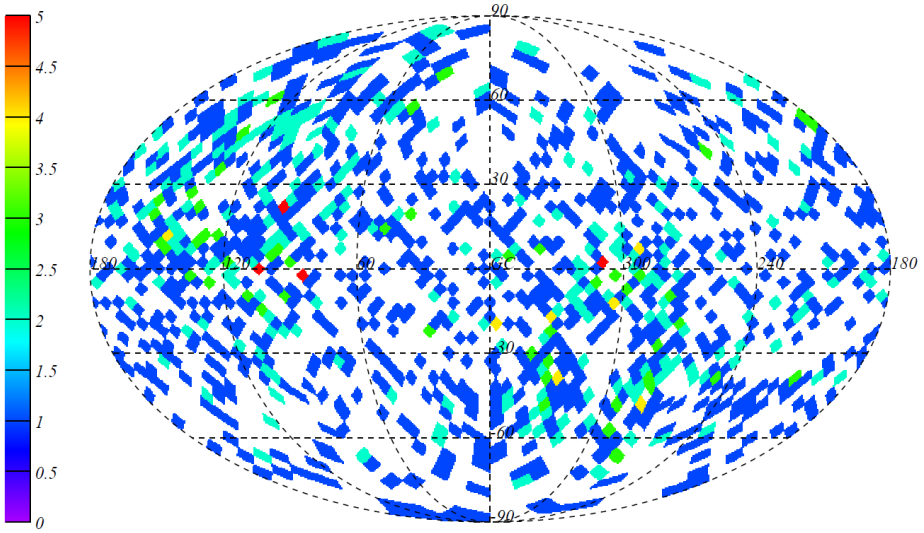
Event Map

Selected e^+ and e^- with energy E > 10 GeV

Electron map



Positron map



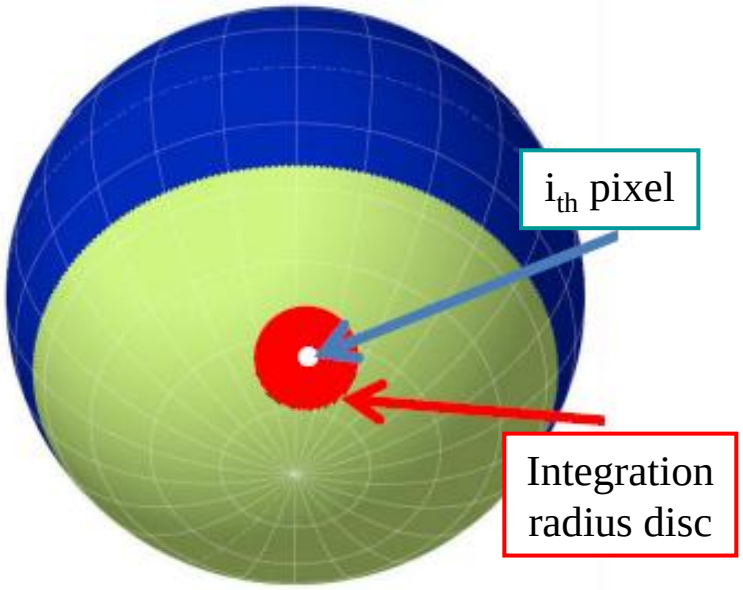
The palette colors indicate the number of events in each pixel

N_{side} =16 → Pixels Number = 3072
Angular scale ~3°

Integrated Maps

Need to use sky maps with bin size similar to the angular scale of the anisotropy under search

If the excess/deficit is too weak in a single bin? → ***Integrated sky map***



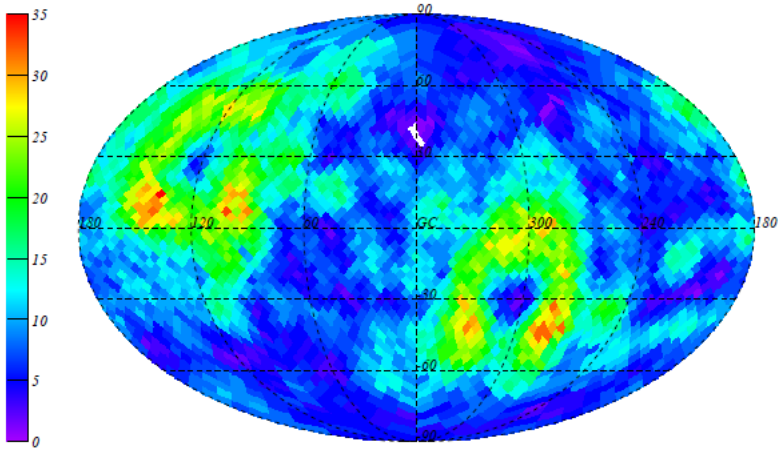
- ✓ The content of a correlated bin is equal to the integrated number of events in a circular region around that bin.
- ✓ In general, the sensitivity for detecting an anisotropy of given angular scale is greater when an integration radius close to that scale is chosen.

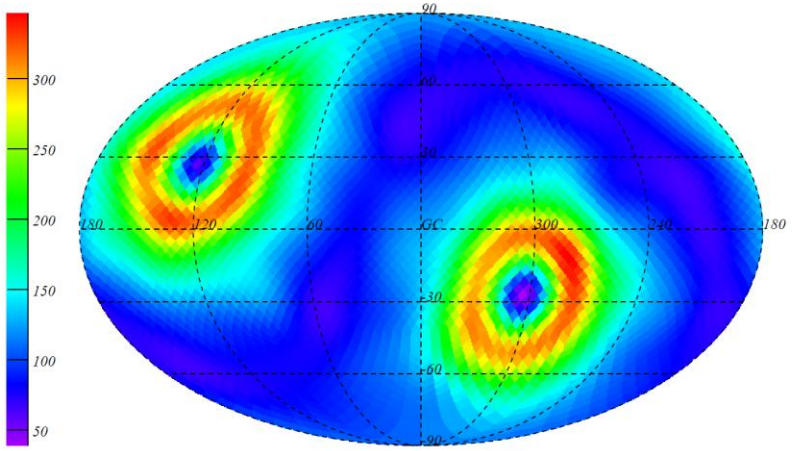
If the integration radius is too small or too large compared to the angular scale of the prospective anisotropy, the sensitivity becomes suboptimal since either the signal can be split among several adjacent bins or there can be too much "background" (isotropic signal) contamination.

Integrated Maps

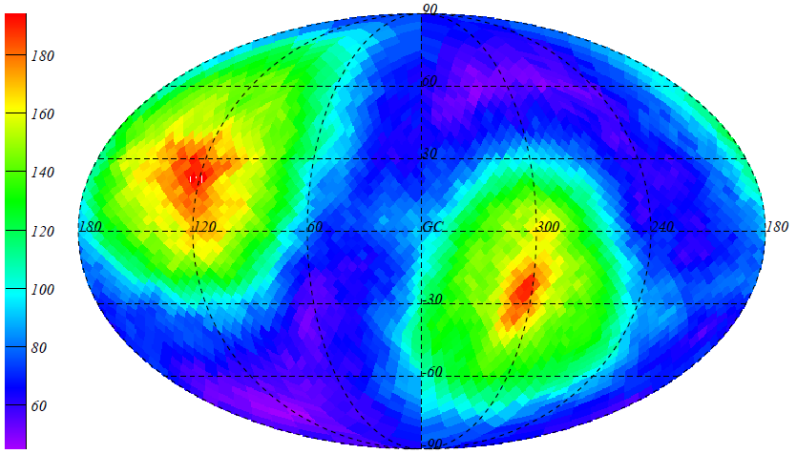
Event map **Background map**

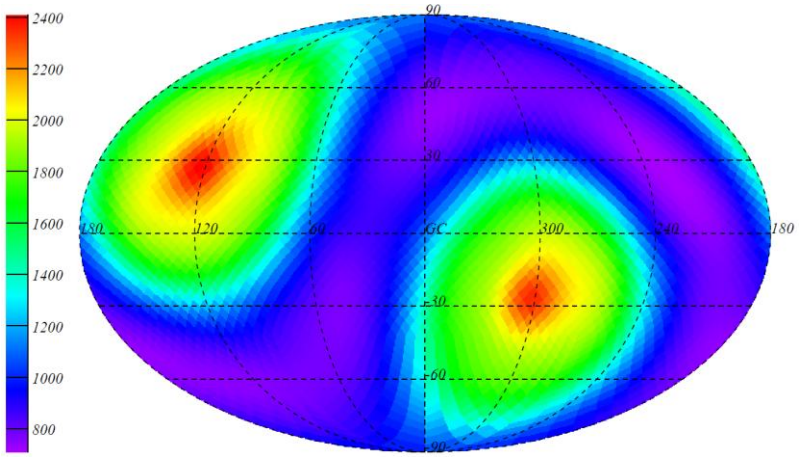
Angular scale 10°





Angular scale 30°



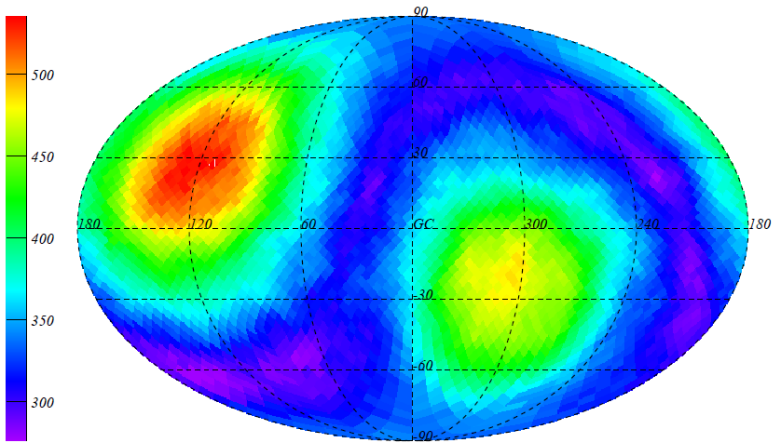


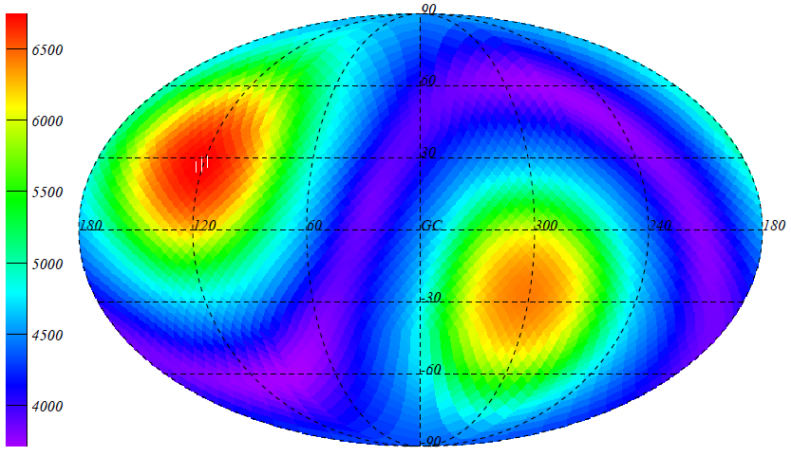
Integrated Maps

Event map

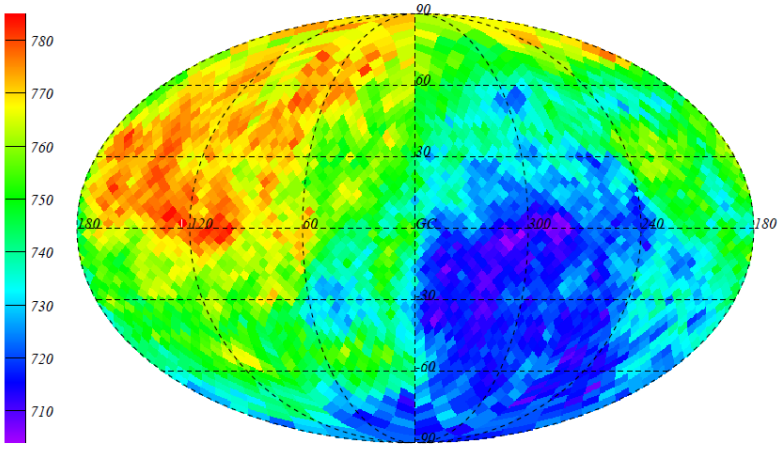
Background map

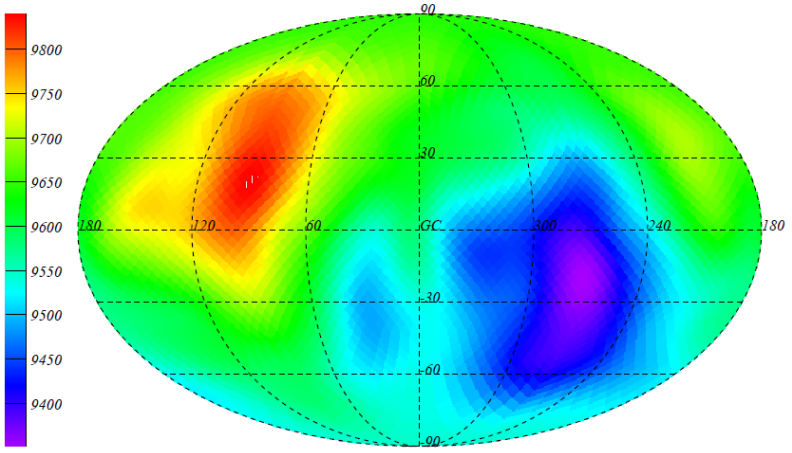
Angular scale 60°



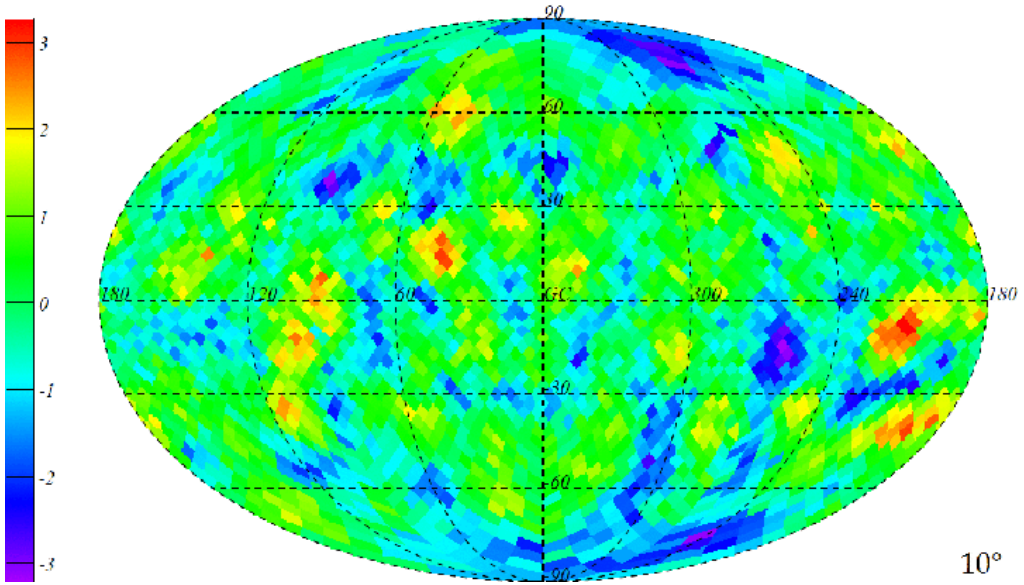


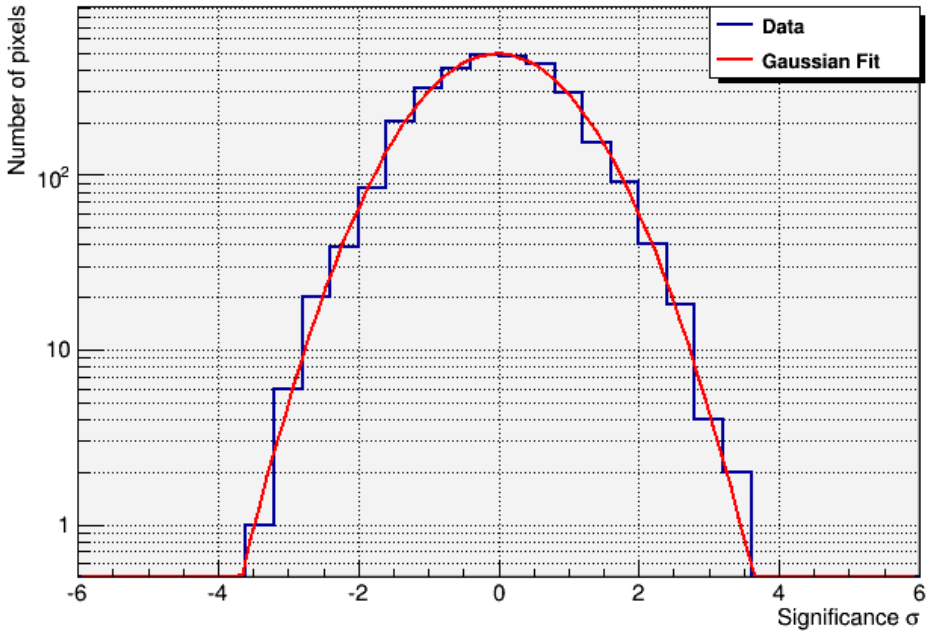
Angular scale 90°





Significance maps





Significance sky maps as a function of the integration radius

Increasing angular scale:
10° - 30° - 60° - 90°

In case of anisotropy we expect extended regions with high values of significance:

- no evidence of excess
- variance decreases with larger integration angles

Spherical armonic analysis

- **Relative intensity map**

$$I(l,b) = \frac{N(l,b) - < N(l,b) >}{< N(l,b) >}$$

$N(l,b)$ observed events

$< N(l,b) >$ expected events in each angular bin

- **Relative map in the basis of spherical harmonics**

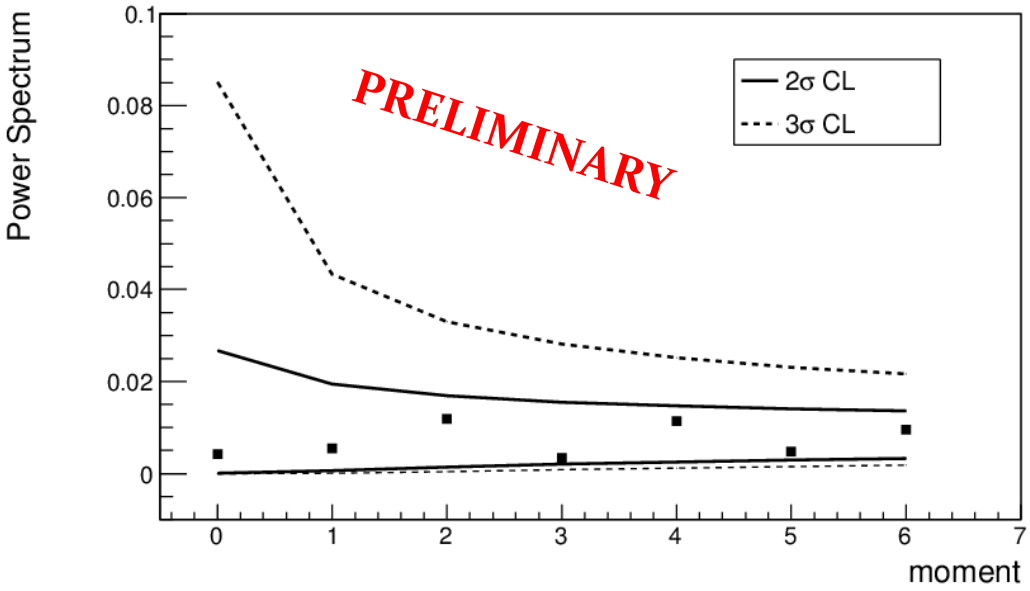
$$I(l,b) = \sum_{l=1}^{\infty} \sum_{m=-l}^{m=l} a_{lm} Y_{lm}$$

- **Angular power spectrum obtained**

$$C(l) = \frac{1}{2l+1} \sum_{m=-l}^{m=l} a_{lm}^2$$

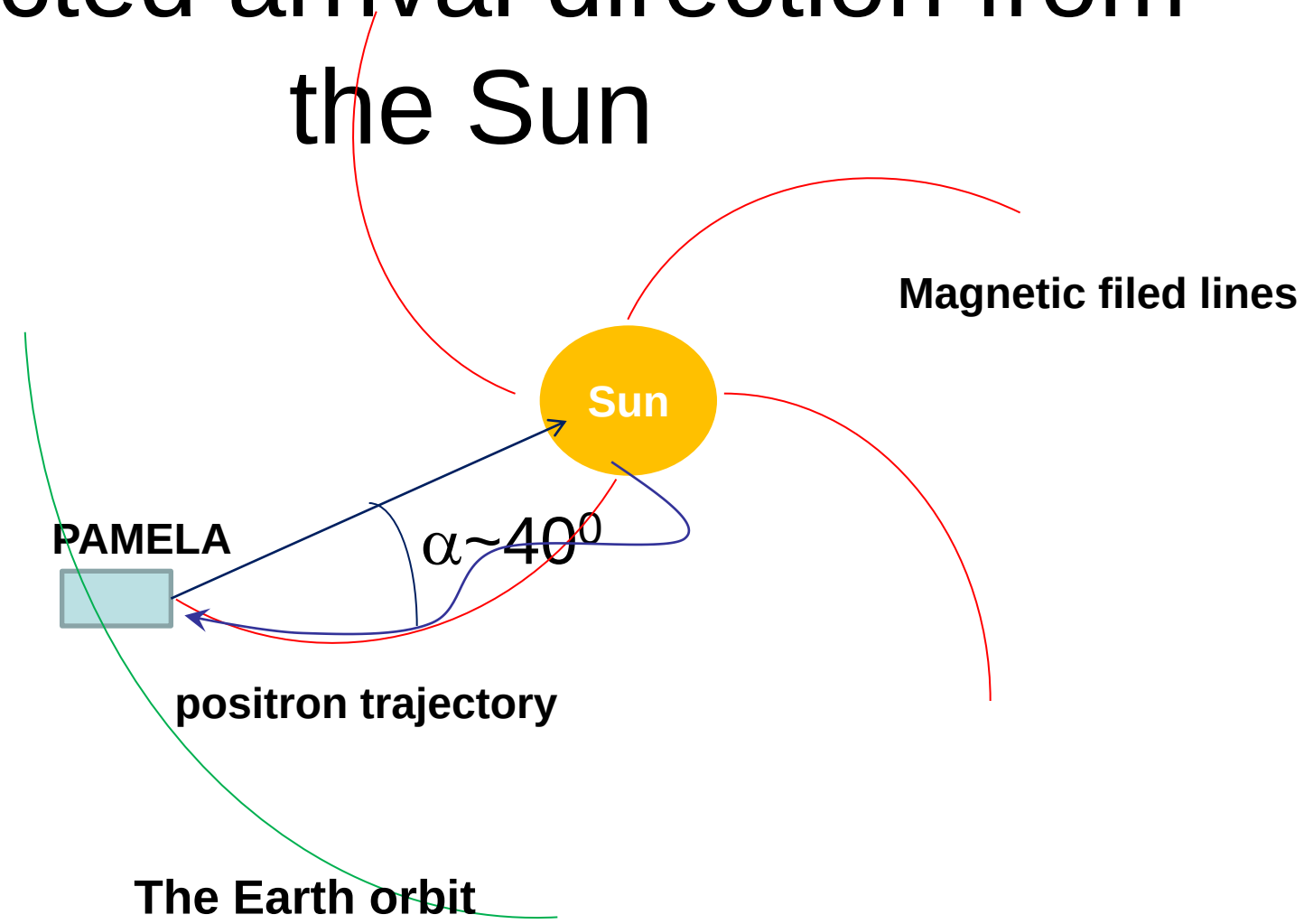
Structures on sky at angular scale 180°/ l

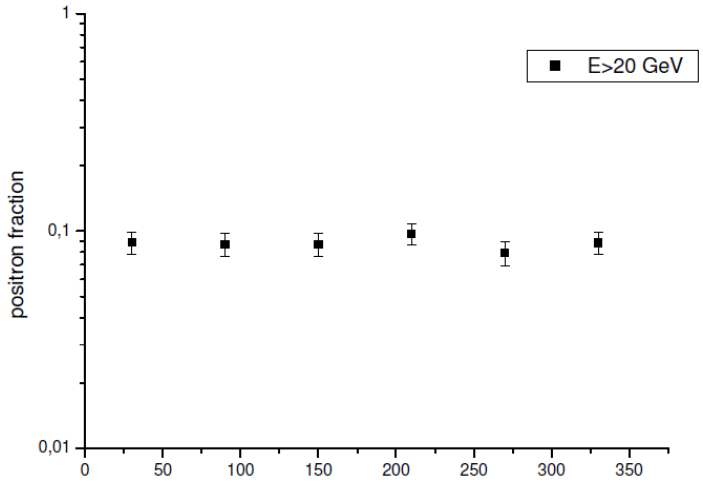
The power spectrum is calculated with Anafast Code in Healpix framework



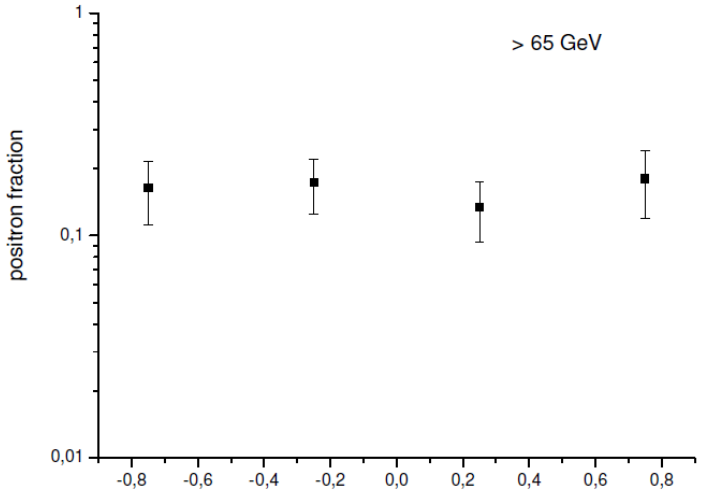
The continuous and dotted lines represent respectively 2-3 σ fluctuation respect to an isotropic sky

Expected arrival direction from the Sun





λ-λ_{sun}

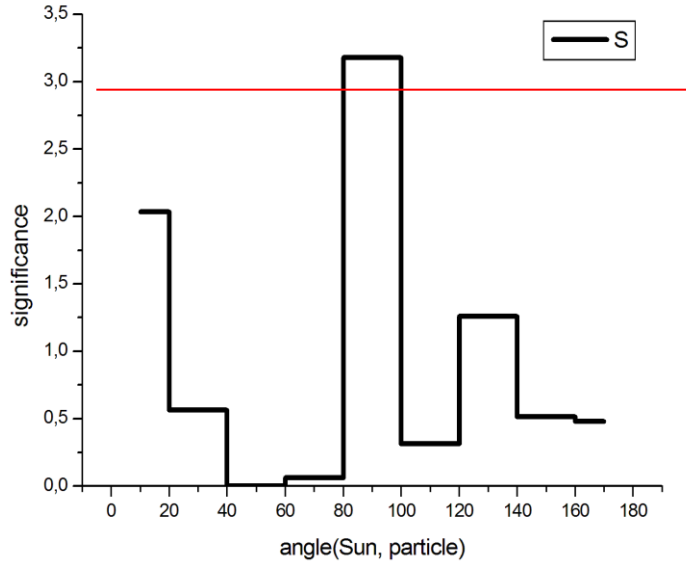


cos(α)

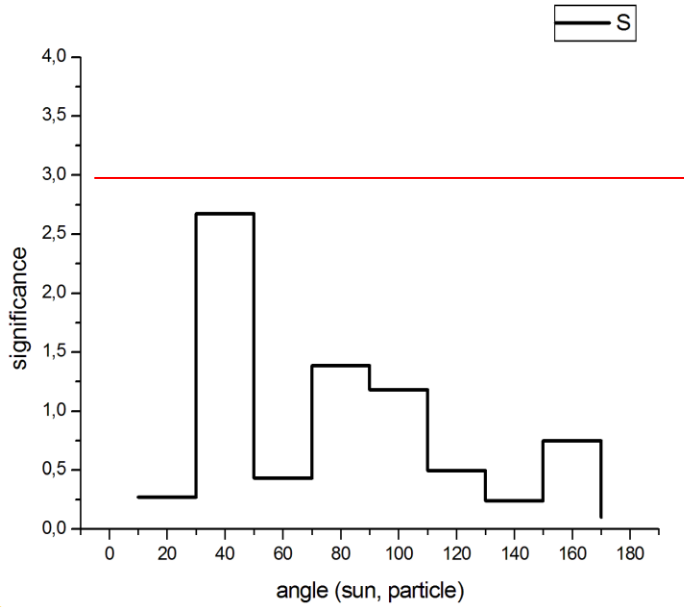
СПАСИБО!

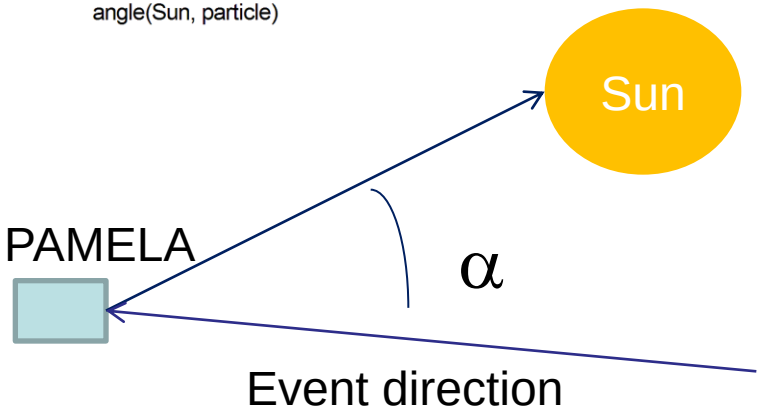
Anisotropy in the Sun direction

30-70 GeV

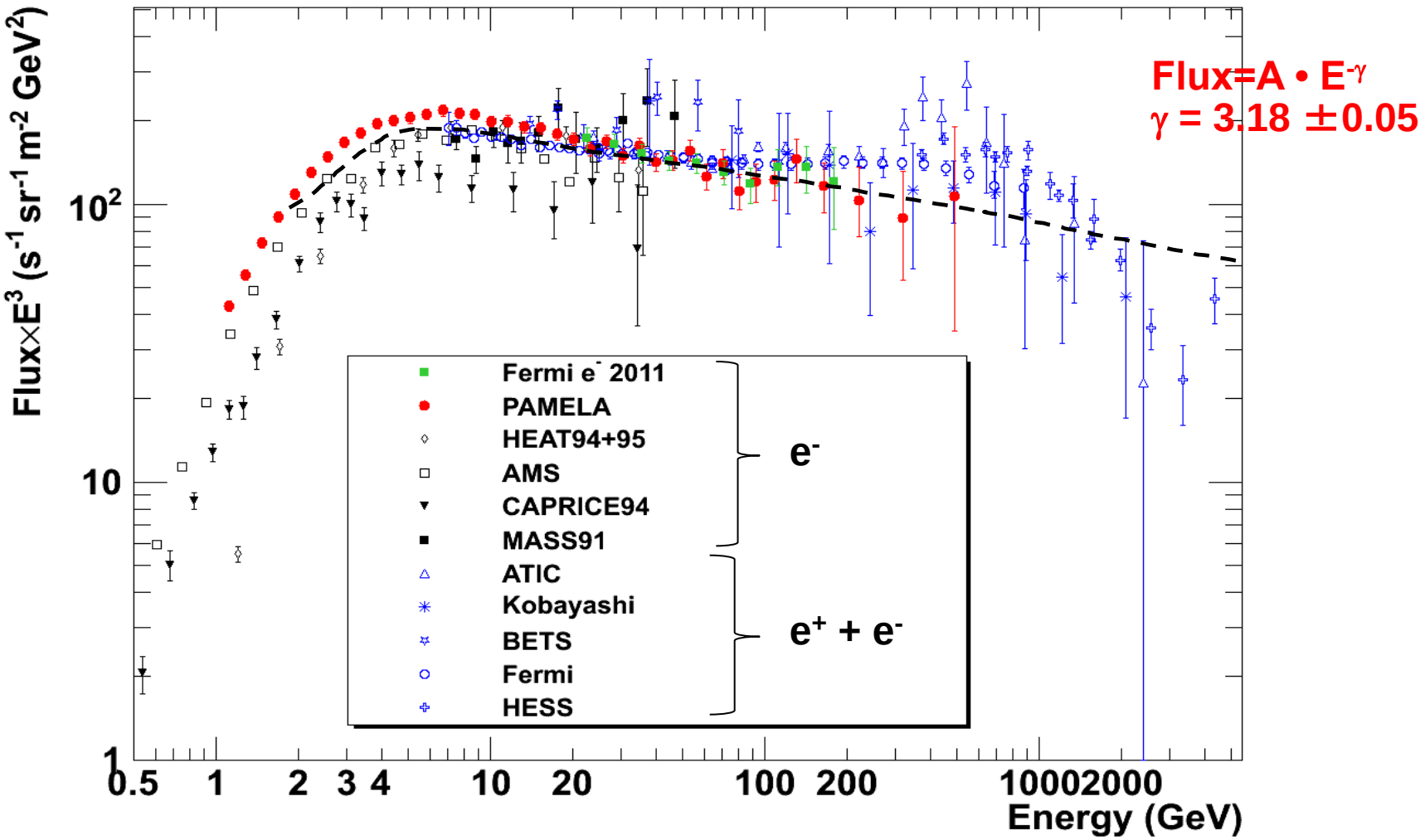


70-100GeV

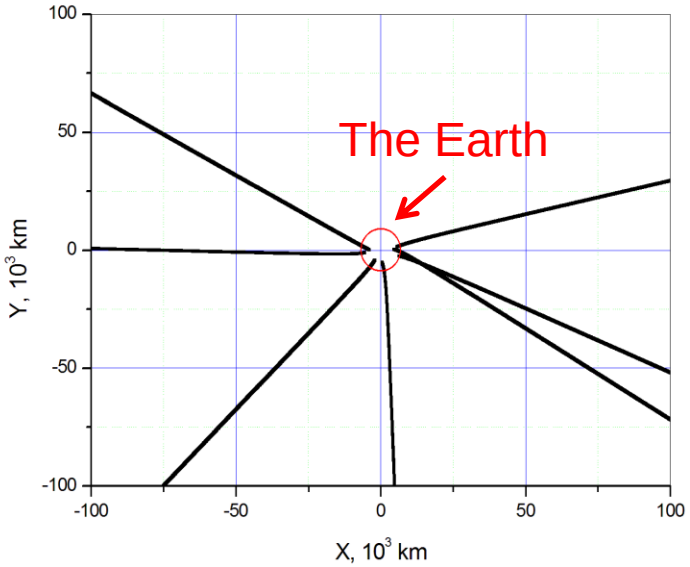


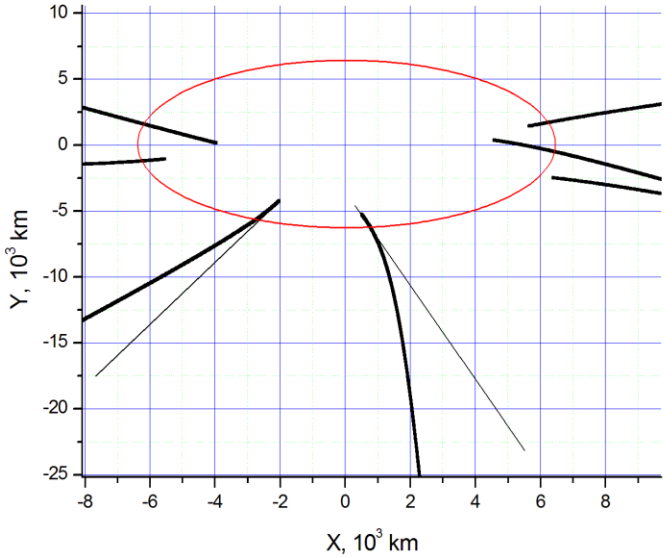


Electron Spectrum



Samples of trajectories

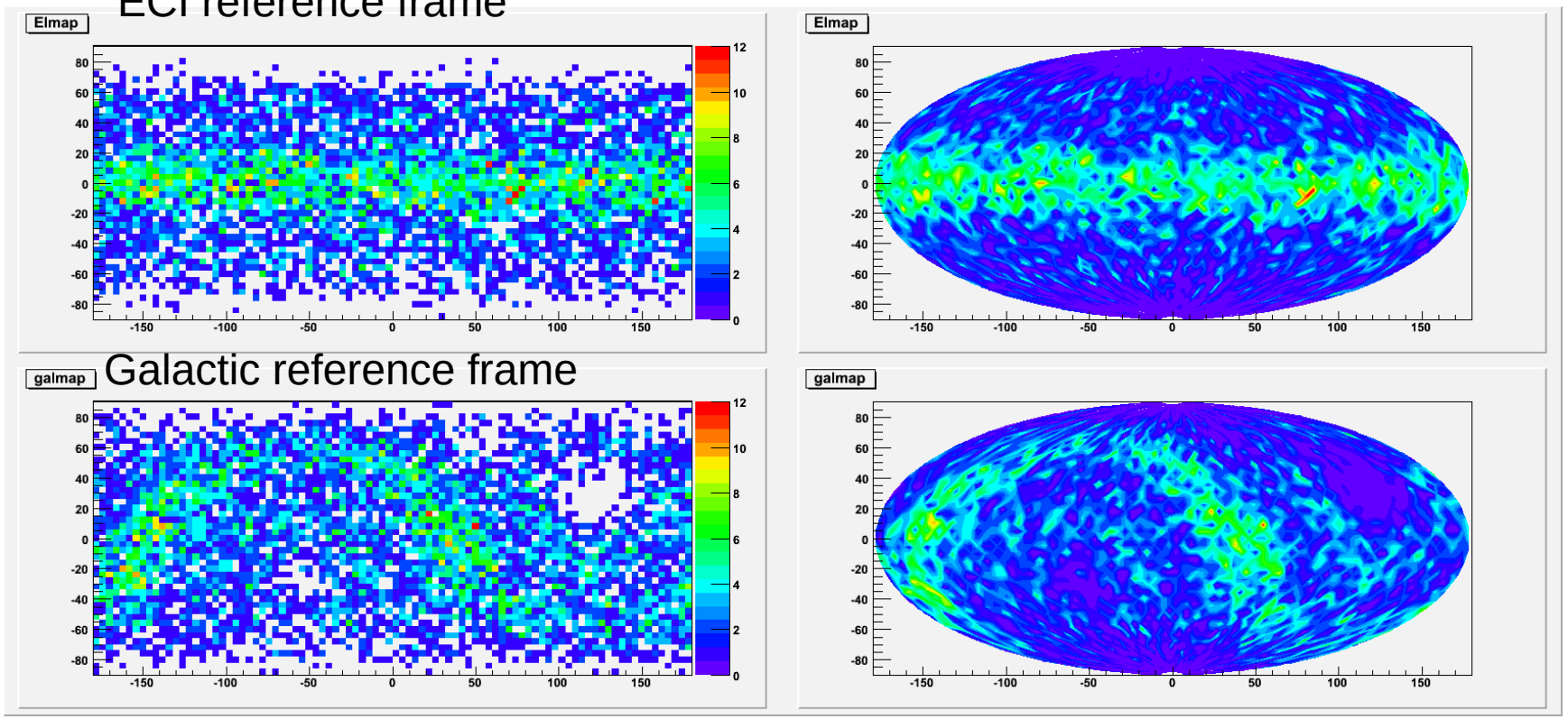




Trajectories of positrons and electrons were calculated in geomagnetic field for all selected events

Карта для электронов после коррекции направлений за пределы магнитосферы

ECI reference frame



Galactic reference frame

Распределение «S» для позитронов в “ECI” системе координат