Anisotropy studies in cosmic ray electron - positron flux with the PAMELA

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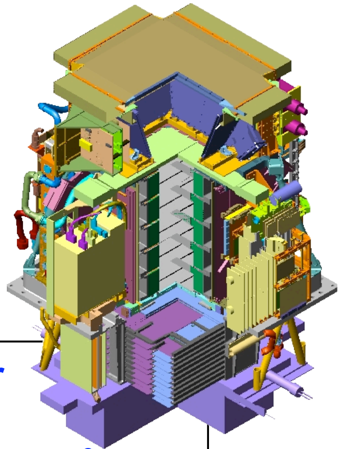
On behalf of the Pamela Collaboration

International Workshop on
Positrons in Astrophysics

20-23 March, 2012
Murren - Switzerland

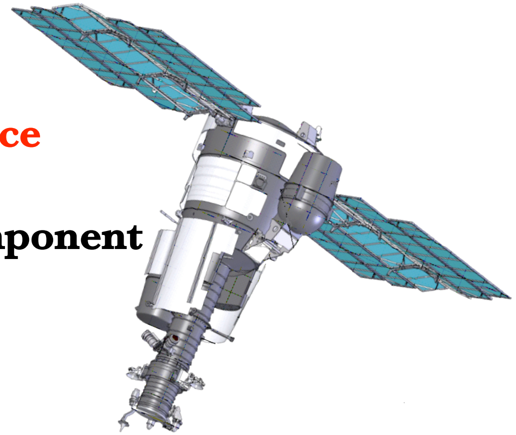
Payload for Antimatter/Matter Exploration and Light-nuclei Astrophysics



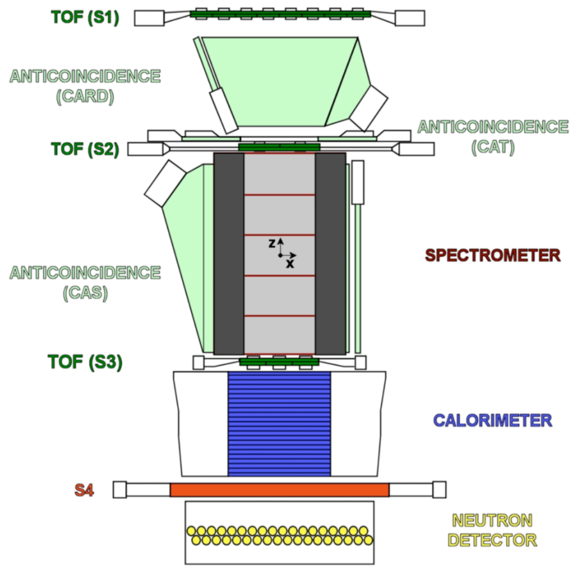
GF: 21.5 cm^2 sr
Mass: 470 kg
Size: 130x70x70 cm^3
Power Budget: 360W

⇒ **Direct detection of CRs in space**

⇒ **main focus on antimatter component**



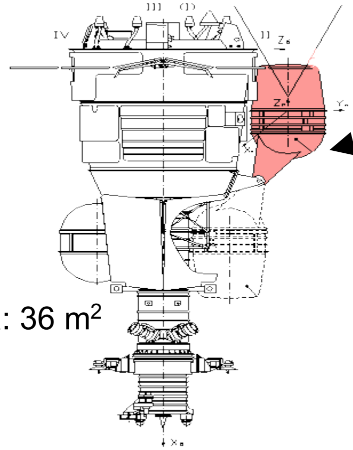
Pamela detector



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

(see E. Mocchiutti talk)

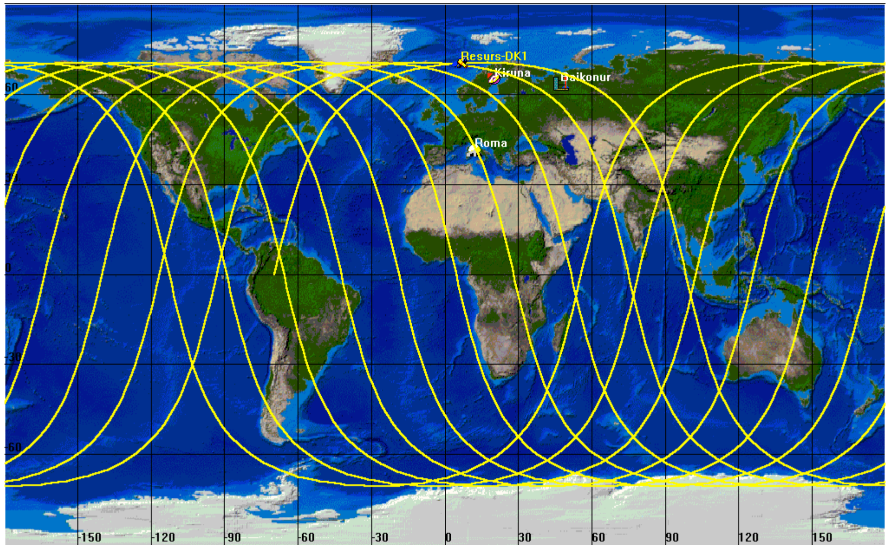
Satellite orbit



Mass: 6.7 tons
Height: 7.4 m
Solar array area: 36 m^2

PAMELA mounted inside a pressurized container of the Resurs DK-1 spacecraft

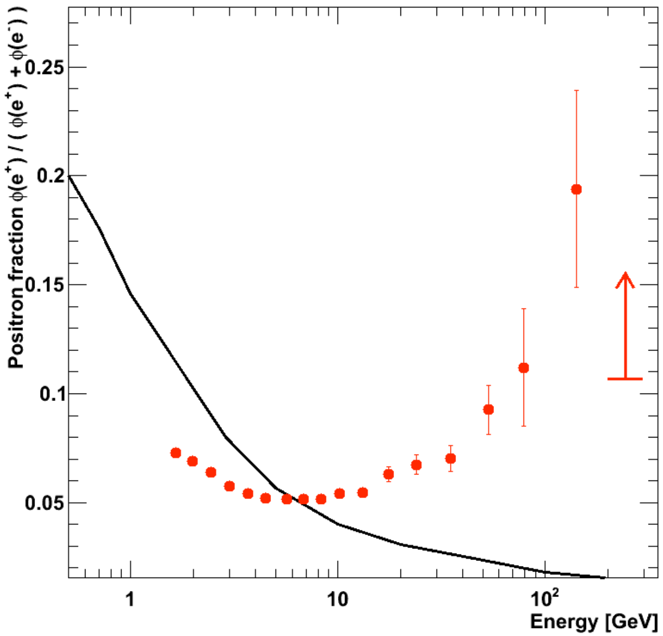
launched on 15th June 2006 and in continuous operation mode since then



- **Operational orbit parameters:**
  - **quasi polar and elliptical orbit inclination ~70°, altitude ~ 360-600 km**
  - **from 2010 circular orbit (~70.0°, ~600 km)**

Quasi polar orbit allows to perform a survey in each direction of the sky (coverage of the full sky)

Motivation



Pamela has measured the positron fraction
(see E. Mocchiutti talk)

$$\frac{\phi(e^+)}{\phi(e^+) + \phi(e^-)}$$

Anomaly $\Rightarrow$ positron excess above secondary production

Source of anomaly: Nearby pulsars?
Nearby SNRs ?
Dark Matter (DM)?

Study of e^++e^- (CREs) arrival directions could help to understand the nature of the positron excess

- If local nearby sources dominate the e^++e^- sky $\Rightarrow$ an anisotropy in the angular e^++e^- distribution even though the CREs are heavily deflected by the galactic magnetic field

- DM explanation could lead an anisotropy signal for the inhomogeneities in the dark matter spatial distribution (DM is dense towards the Galactic Center)

Anisotropy of CREs and data set

- arrival directions of e^+ and e^- (CREs) are isotropized by the action of the magnetic fields (galactic, heliosphere, geomegnetic)

  → information on the direction of CREs sources is lost

  → CREs flux could reveals structures spanning over the full sky **(large scale anisotropy)**

- Galactic Magnetic Field: higher CRE energy → smaller effect

- Heliospheric Field: affect direction of charge particle with energy in the ~GeV range

  heliospheric effects not well known → we decided to consider events with $E > 40$ GeV

- Geomagnetic Field: particle with rigidity larger than the geomagnetic rigidity cutoff in each position of the detector

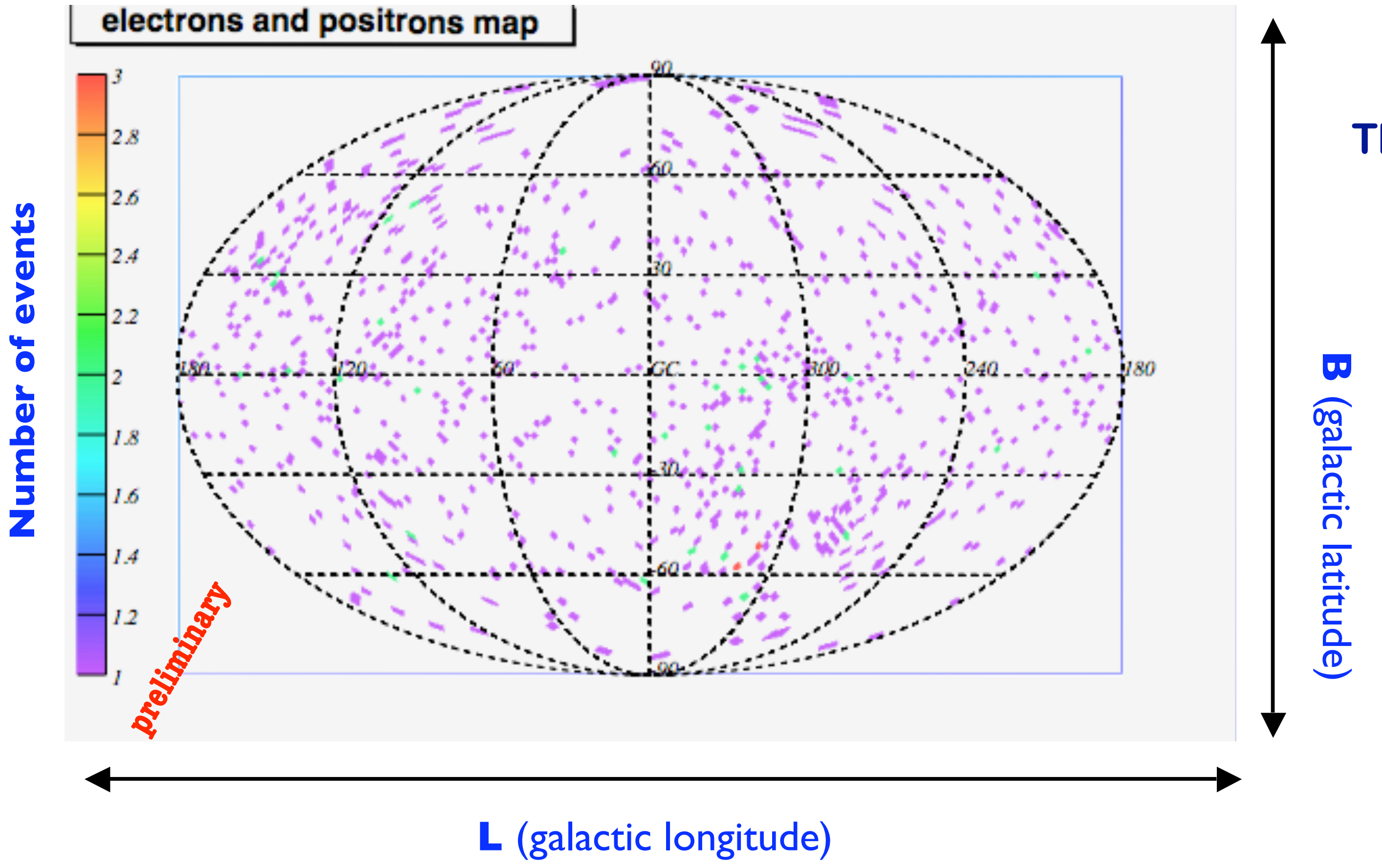
analyzed data July 2006 - January 2010 (~ 1200 days)

879 reconstructed e^+ and e^- with energy $E > 40$ GeV

good pointing information of the satellite

Event Map

Electron - positron sky map in galactic coordinated



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

The sky is visualized using the Healpix pixelization - each pixel same solid angle

sky divided in 12288 (N_{side} =32) equal are pixel (~10^{-3} sr)

Anisotropy Search

- observed events (real map) in each region of the sky (N_{on})

- calculate the expected number of events in each direction of the sky (background or coverage map) under the assumption of an isotropic CREs flux distribution

background map obtained with two different methods:
-) shuffling technique (NIM A 328, 570)
-) direct integration method (ApJ 595, 803)

- compare the real and the background map to study deviations from isotropy of the real map

statistical significance test adopted by Li & Ma (Astrophys. J. 272, 317)

Shuffling Technique

- the main idea of the shuffling technique is to produce an isotropic distribution of arrival directions using the real data

artificial data set is created combining the directions of each real event in local instrument coordinates with the arrival time of other randomly selected real event

local arrival direction distribution of the real events and the dead times of the detector are taken into account in the background map

- a large number of simulated data sets are created with this process, each data set is consistent with the case of an isotropic CREs arrival distribution

in this study the randomization process is repeated 10^4 times

- the final background map is then obtained from the average of the simulated data sets to obtain the expected number of events in each region of the sky

Direct Integration technique

Another way to calculate the background map is the direct integration technique

This method is based on the assumption that the proton cosmic ray create an isotropic background and that the detector acceptance is independent of the trigger rate over some period

The expected number (ΔN) of events in each direction (i) of the sky in a time interval [t, t+Δt] is given by:

$$\Delta N(i|t+\Delta t) = R_{allSky} P(i) \Delta t$$

- R_{allSky} (t) = event rate from all sky at time t
- P(i) = detection probability as a function of the celestial coordinates

• P(i) is obtained from the acceptance of the detector in celestial coordinates of the proton flux (proton selected in the same way as CREs in the same time window)

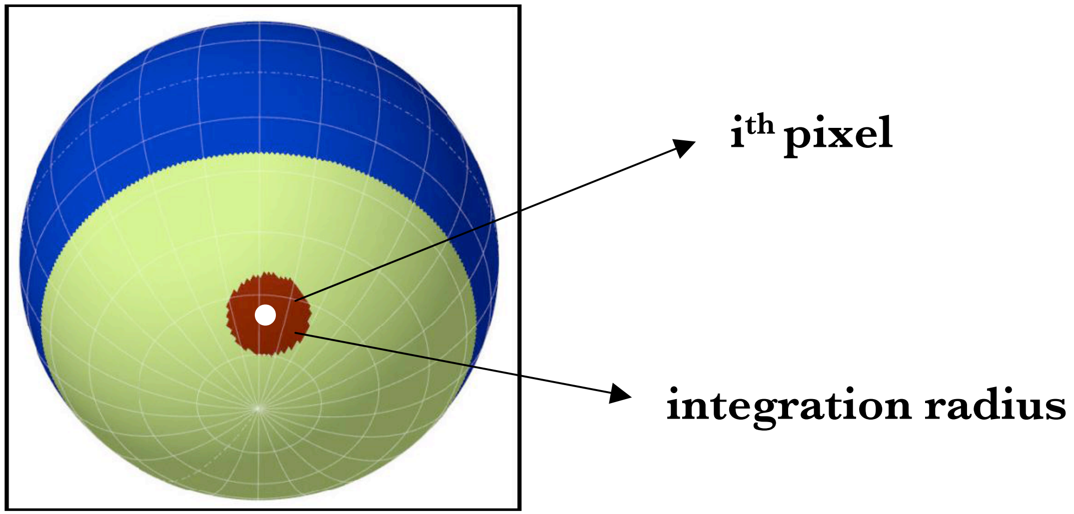
$\Rightarrow$ proton exposure ~ CREs exposure

• R_{allSky} (t) is the real CREs rate

Search for large structures anisotropies

Large scale anisotropy is expected for CREs
→ to avoid to divide a possible signal in adjacent bins use sky map consisting of a large number of correlated bins

Integrated sky map: the content of a bin is equal to the integrated number of events in a circular region around that bin ⇒ <u>adjacent bins are correlated</u>



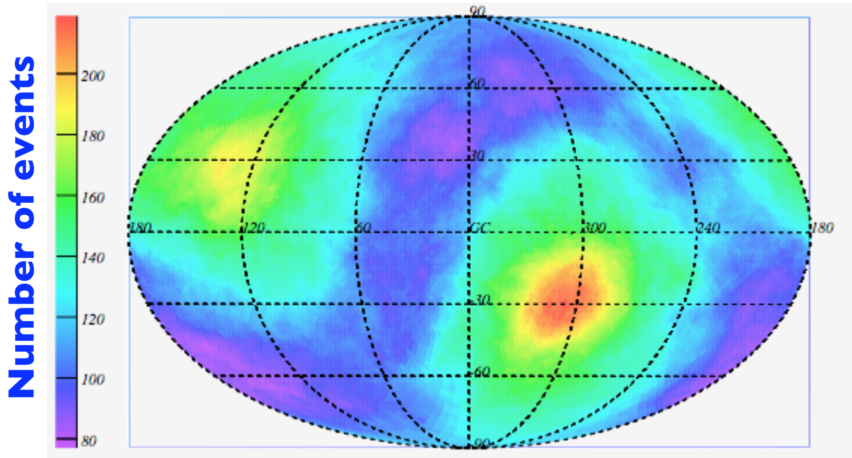
$$N_i = \sum_{p \in disc} N_p$$

Both real and background maps are treated in this way

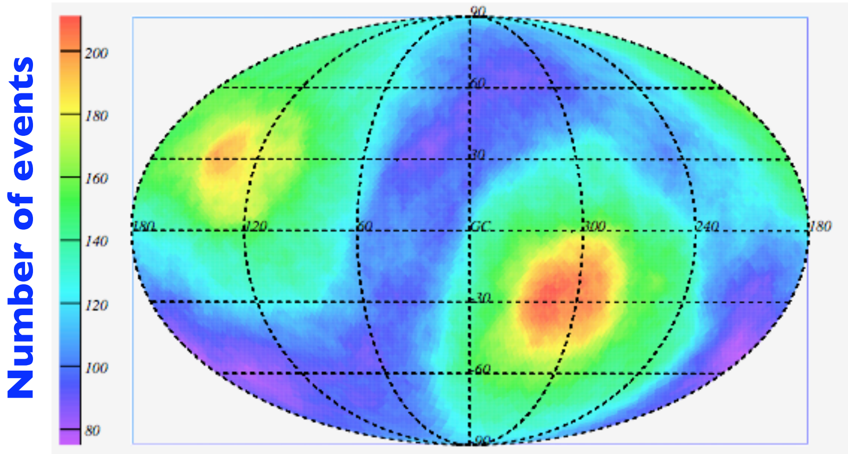
Integrated Sky Maps

Event and background maps integrated at an angular scale of 45°

Event map (in galactic coordinates)



Background map (in galactic coordinates) obtained with the shuffling method



Quasi polar orbit ⇒ longer exposure near the poles

Li & Ma Significance Test

Once obtained the coverage map the next step is to study the deviations from the isotropy of the real data map

We use statistical significance test using the method of Li-Ma

$$S = \sqrt{2}\left\{N_{on}\ln\left[\frac{1+\alpha}{\alpha}\left(\frac{N_{on}}{N_{on}+N_{off}}\right)\right] + N_{off}\ln\left[(1+\alpha)(\frac{N_{off}}{N_{on}+N_{off}})\right]\right\}^{1/2}$$

N_{on} : observed number of events in a given sky region w_{on} (on region)

N_{off} : backgound events in the same sky region w_{off} (off region)

$\alpha = w_{on} / w_{off}$ exposure weighted areas of the on and off source regions respectively

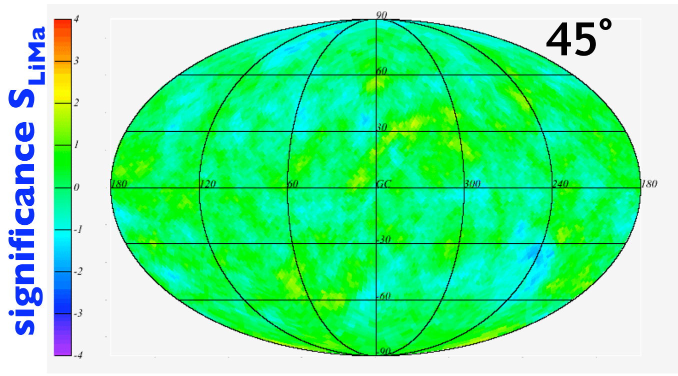
Li & Ma Significance Test

for a given integration radius compare in each sky direction the integrated event and background maps

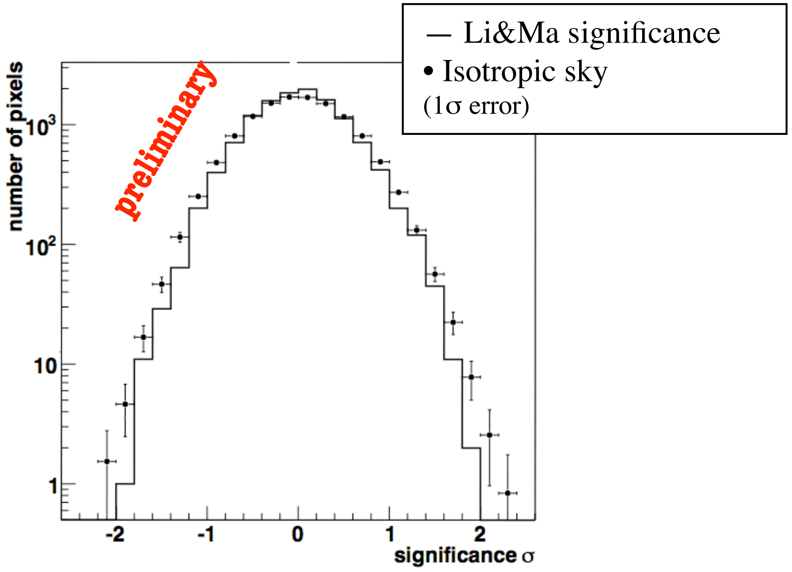
$\Rightarrow$ S_{LiMa} significance

in case of anisotropy
$\Rightarrow$ extended region
with high values of significance

Significance Map



Significance LiMa Distribution



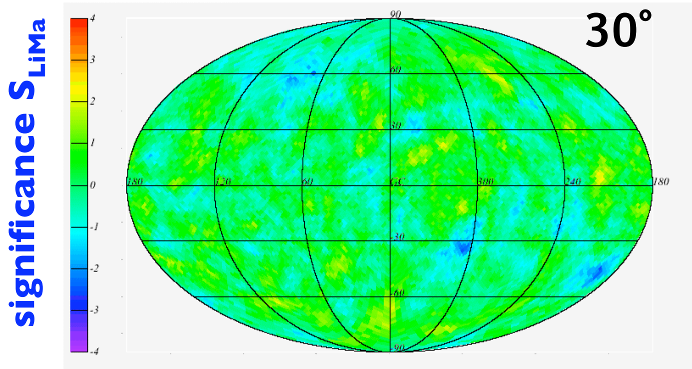
test the compatibility of the Significance Map with the statistical fluctuations of an isotropic sky

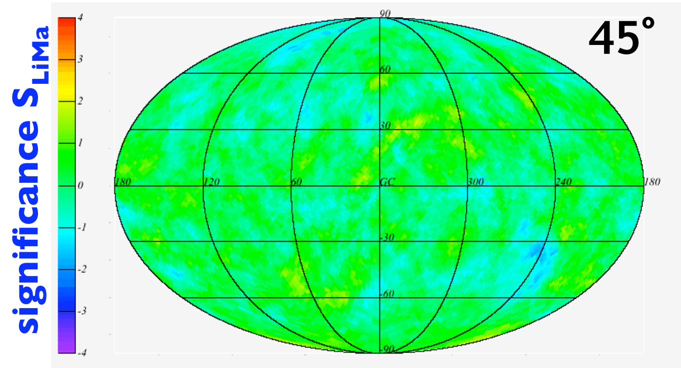
Expectation of an isotropic sky based on simulated data sets (10^3) obtained from shuffling method and analyzed like the real data

S_{LiMa} distribution consistent with the isotropic expectation

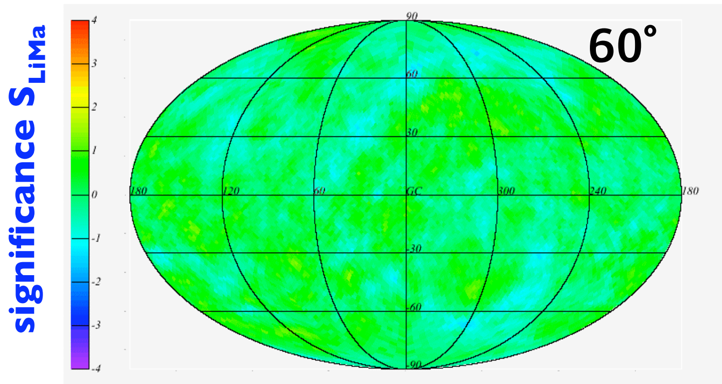
Sky Map of Statistical Significance

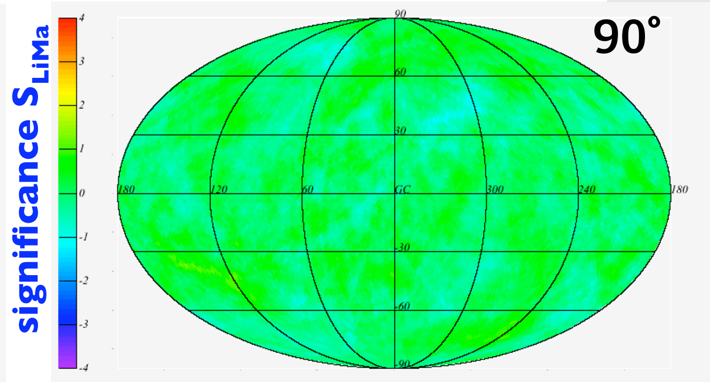
significance sky map as a function of the integration radius
(background - shuffling method)





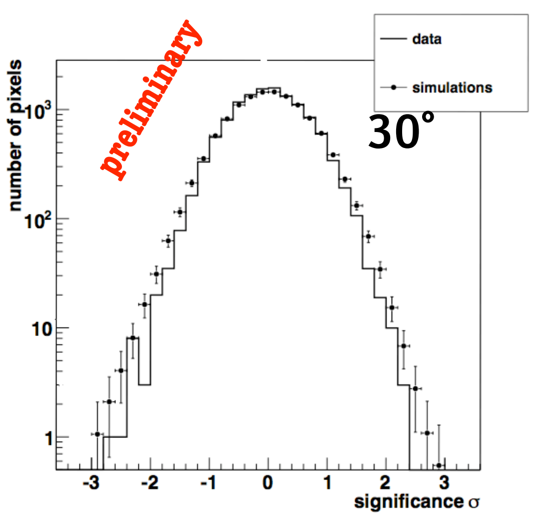
no significant departure from isotropy is observed

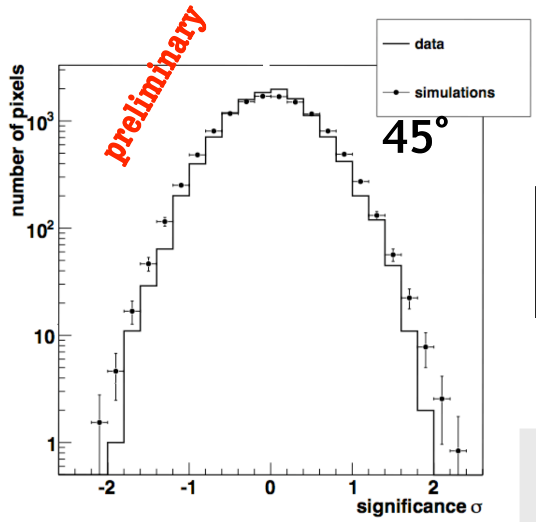




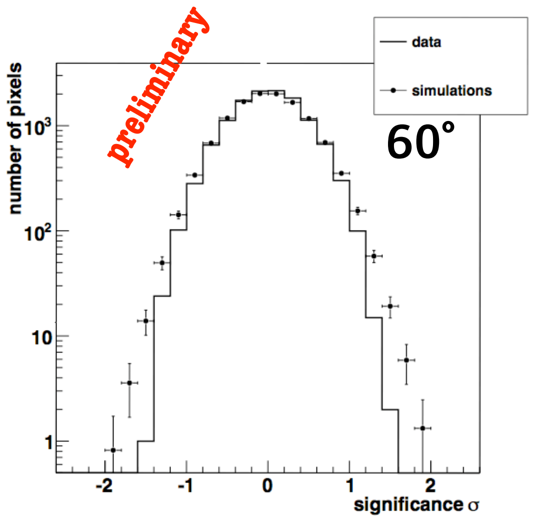
Li & Ma significance distribution

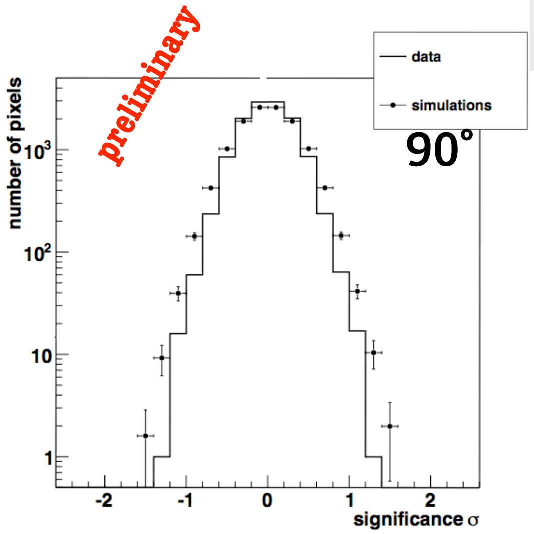
significance distribution as a function of the integration radius togheter with isotropic expectations (background - shuffling method)





— Li&Ma significance
• Isotropic sky
(1σ error)

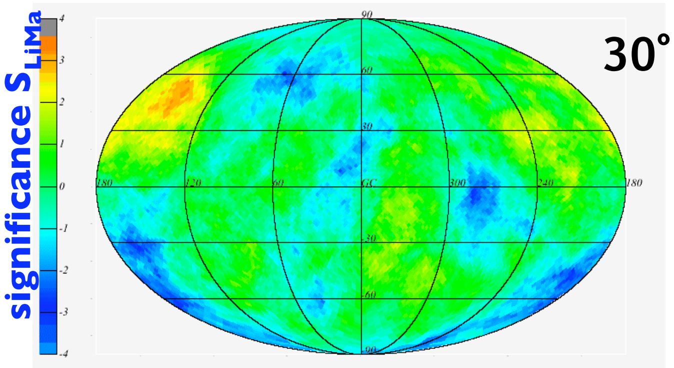


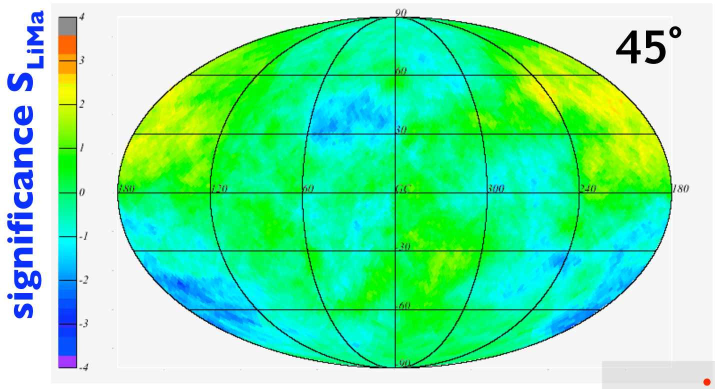


data consistent with the isotropic expectation for each angular scale

Sky map of statistical significance

significance sky map as a function of the integration radius
(background - direct integration method)





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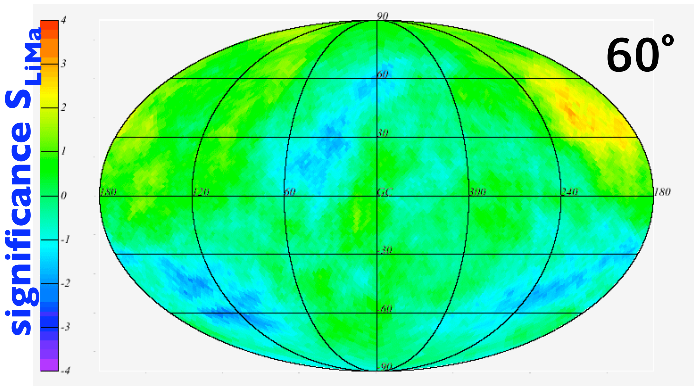
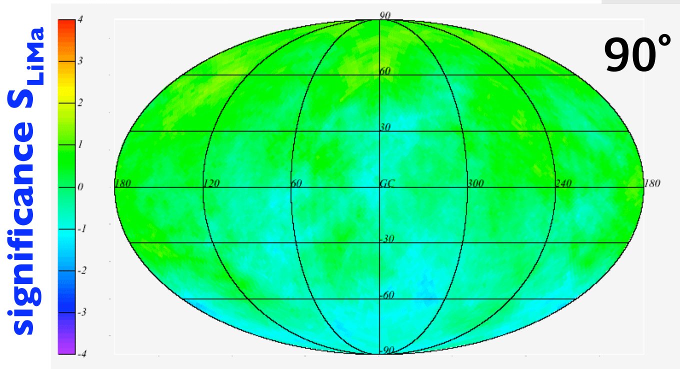
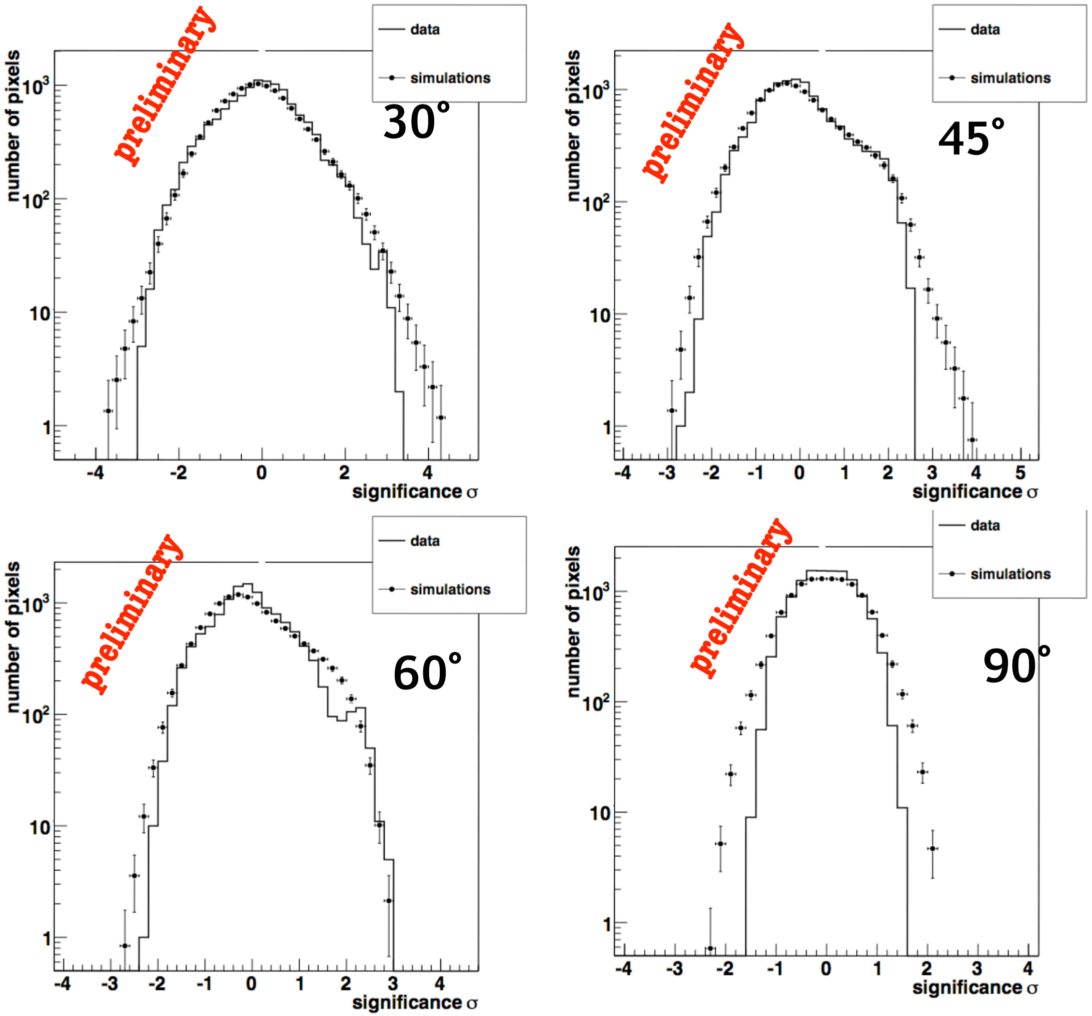




Li & Ma significance distribution

significance distribution as a function of the integration radius togheter with isotropic expectations (background - direct integration)

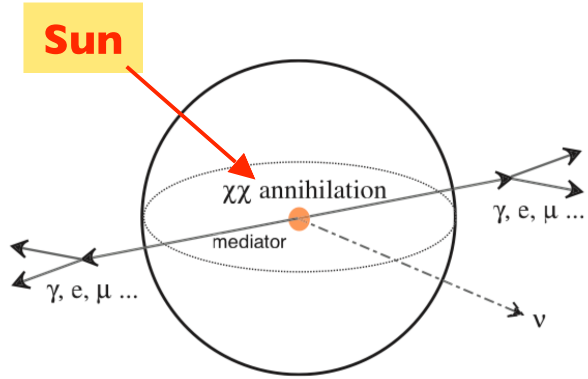


— Li&Ma significance
• Isotropic sky
(1σ error)

data consistent with the isotropic expectation for each angular scale

Anisotropy search in the Sun direction

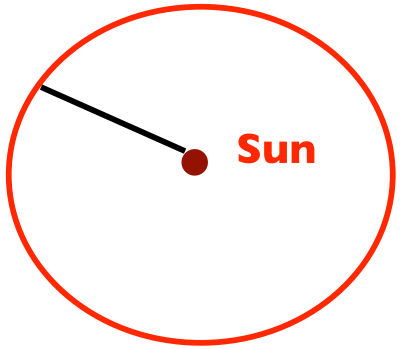
Some models predict a significant flux of e^+ and e^- around the Sun direction due to DM particles



to study an anisotropy signal around the Sun direction

- consider the events direction in the solar frame (ecliptical coordinates)

- calculate the number of events at a given angular distance from the Sun



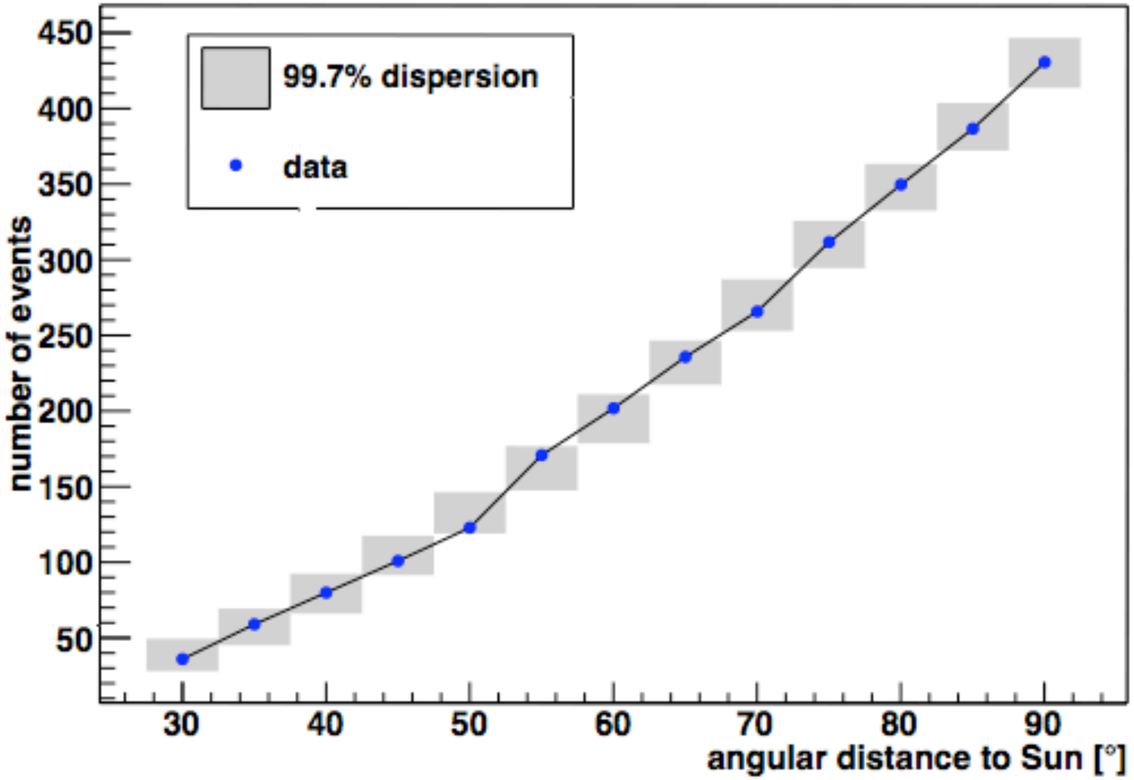
Region of interest:

Circle around Sun Position

- compare the observed events with the expected number of events from an isotropic flux (shuffling technique)

Anisotropy search in the Sun direction

cumulative number of events as a function of the angular distance from the Sun direction



comparison with the fluctuations of an isotropic sky

Expectation of an isotropic sky based on simulated data sets (10^3) obtained from shuffling method and analyzed like the real data

no significant excess is found at any angular distance from the Sun

conclusion

• search of anisotropy in all direction of the sky extending from 30° up to 90° using $e^+ + e^-$ with E > 40 GeV observed by Pamela has been presented

no significant evidence of anisotropies

• directional study around the Sun direction extending from 30° up to 90°

no excess from the Sun direction

improvements in the analysis ongoing

- use spherical harmonic analysis to put upper limit on dipole anisotropy
- set upper limit on the CREs flux from the Sun