Zenith Alignment of the Milagro Data

1 Introduction

In the process of studying the difference between calibrations in Milagro it became obvious that the detector has not been properly aligned. I looked at the last years data (Jan 2,2002- Jan 5,2003). In this period we accumulated 2.7σ at the position of the crab. Examination of the map of the region leads one to believe that perhaps the lack of sensitivity in the rec data is due to inaccurate pointing. See figure 1 and decide for yourself. This inspired me to seek an independent method of re-pointing the rec data to properly align the Milagro detector and improve value of the reconstructed data.

2 x and y

I begin with the assumption that the highest rate of data should come from zenith. This assumption, although somewhat obvious, may not be always true. The earth's magnetic field breaks the azimuthal symmetry of the detector. Also, Milagro's rect-angular shape combined with the risetime trigger leads to an obvious 2 humped phi distribution, as was shown at the NYU collaboration meeting. The latter effect could not however lead to an average non-zenith pointing because the ϕ excess to the east is exactly countered by an equal excess to the west, likewise, the deficit in the north is countered by the deficit in the south. The magnetic field effect can be reduced by raising the energy threshold which can be easily achieved by applying a strong NHIT or NFIT cut to the events under consideration.

To evaluate the pointing I first plot the distributions x and y for one day of data. These variables are defined as,

$$x = sin\theta cos\phi$$
$$y = sin\theta sin\phi.$$

Figure 2 shows a plot of x and y for a single day of Milagro data. The region $[-0.25 : 0.25]$ was fit to a Gaussian. The means of the fits are displayed with errors on the plots. In the case of both x and y, the measured mean is inconsistent with zero (zenith). In figure 3 I have plotted the mean of the Gaussian fit from several nfit bands for a given day of data. Small nfit events produce different (x, y) values than large nfit events. This could be caused by magnetic field effects or by an artifact in the VME trigger. For data where $nfit > 75$ the fit values for x and y converge to constant values. I conclude that the inconsistence of the mean of x and y with 0 is due to mis-pointing of the detector.

I ran through all the rec data on disk and recorded x and y distributions for each day from turn on in June 1999 to January 2003. The mean of x and y for each day is plotted vs JD in figure 4. The abrupt shifts in x and y were identified with the help of the logbook. The table below lists each of the epoch in the x, y plots and identifies the reason for the change.

JD	$< x >$	$< y >$	difference from prior epoch
1340-1400	0.0048	-0.0061	Initial made up calibration
1401-1588	0.0001	-0.0057	1999 PMT repair
1589-1668	-0.0094	-0.0056	New Calibrations
1669-1708	-0.0201	0.0077	Bug added to code
1709-1812	-0.0092	-0.0063	Bug removed from code
1813-2067	-0.0062	-0.0061	2000 PMT repair
2068-2168	-0.0091	-0.0106	New Calibrations
2169-2350	-0.0076	-0.0110	2001 PMT repair
2351-2540	-0.0074	-0.0096	New trigger goes online
2541-2591	-0.0082	-0.0117	2002 PMT repair
2592-9999	-0.0106	-0.0095	New Calibrations

Table 1: List of Milagro data epochs.

Code was written to correct the pointing in Milagro Reconstructed data by applying a rotation to each event based on the measured x and y values derived for each epoch. The function works by first calculating the local coordinates θ and ϕ applying a rotation and then converting back to astronomical coordinates with $angle2astro()$ and $J2000()$. Figure 5 shows the mean x and y values after the correction is applied.

3 The Effect on the Crab

I run through all the online reconstructed data since x_2 was added to the DAQ event reconstruction, July 18, 2000 (JD 1775). A significance map of the region around the Crab is shown in figure 6. At the position of the Crab a 5.6σ excess is observed. This excess is as large as is observed through re-reconstruction offline with improved calibrations.

A function to apply the zenith alignment correction has been added to the CVS offline archive under the *zenith_align.c*. Instructions for use of this function can be found in the comments at the top of the file. Note that application of this function may significantly slow down analysis programs, because of the additional calculations required to convert from (RA, δ) to (θ,ϕ), perform the corrective rotation and then rotate back to (RA, δ).

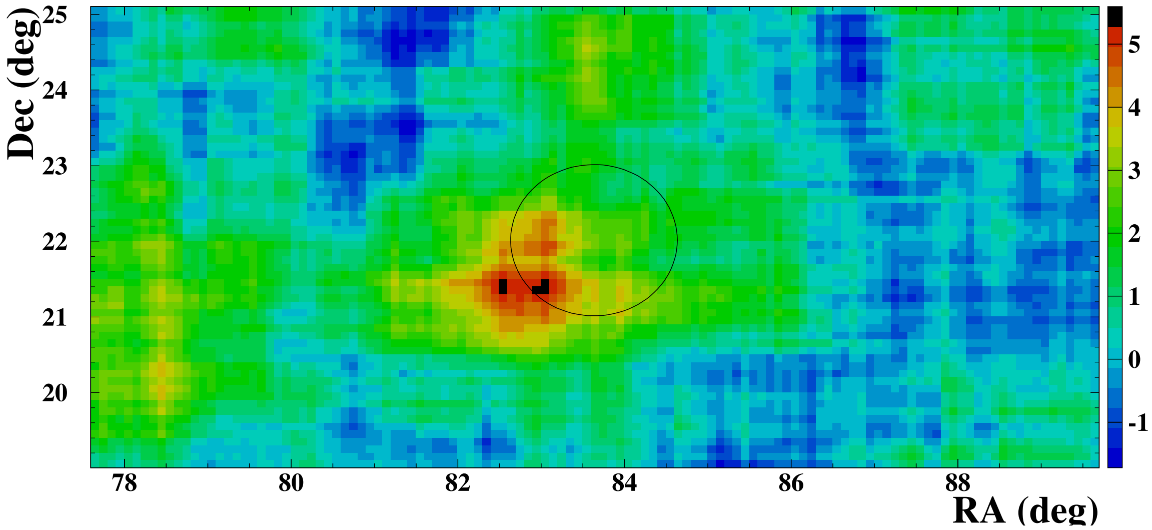

Figure 1: Significance map for the region around the Crab for data reconstructed online from the last year of Milagro data (Jan 2,2002 to Jan 1,2003). Standard cuts were applied ($NF \geq 20$, $x_2 > 2.5$, Binsize=2.1^o)

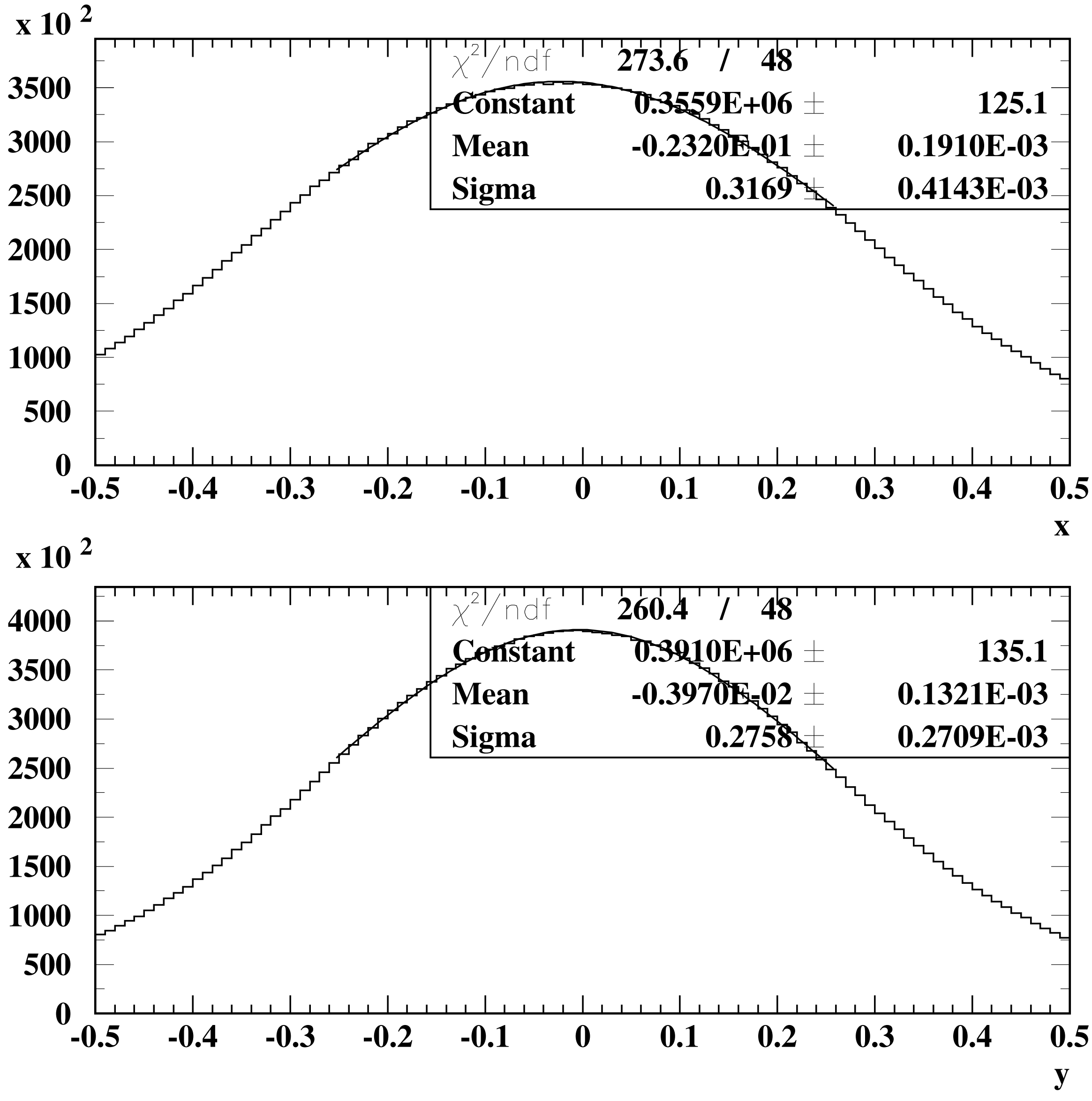

Figure 2: x and y plotted for a single day. A fit of the region $[-.25 : .25]$ was performed. In each case the mean is clearly inconsistent with 0.

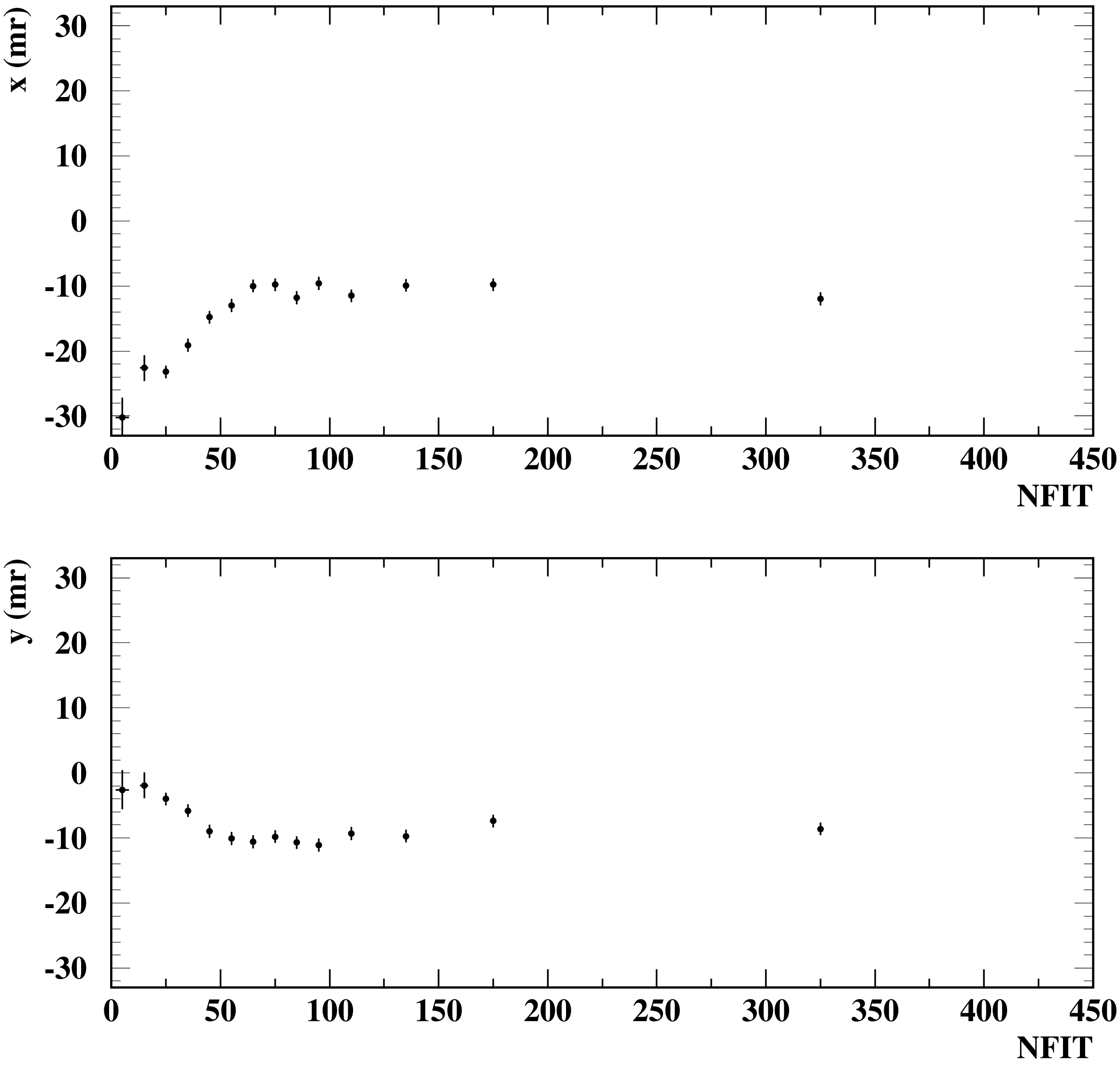

Figure 3: The mean of x and y derived from a Gaussian fit plotted for various NFIT bands.

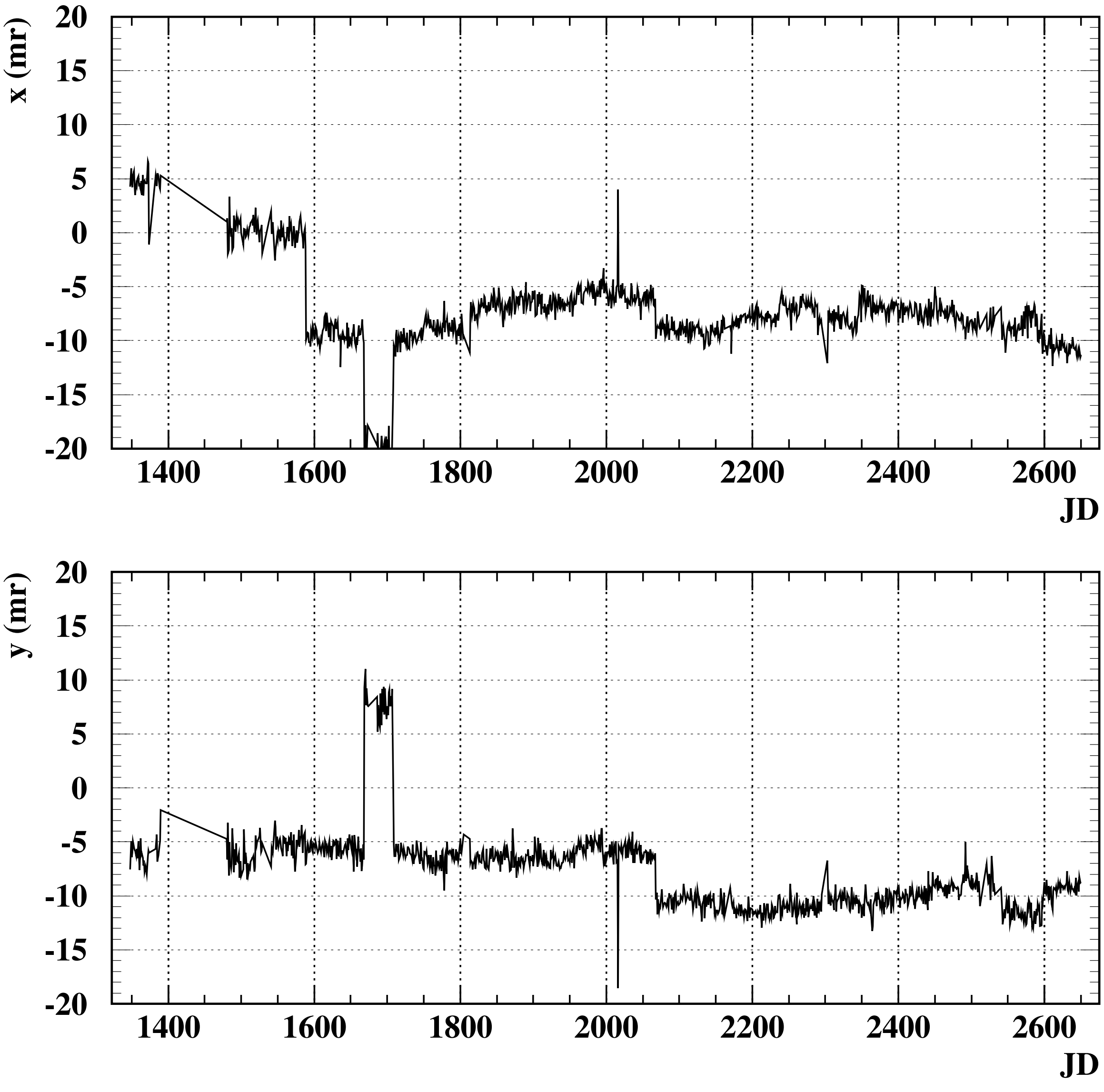

Figure 4: The mean of x and y derived from a Gaussian fit plotted vs Modified Julian Date.

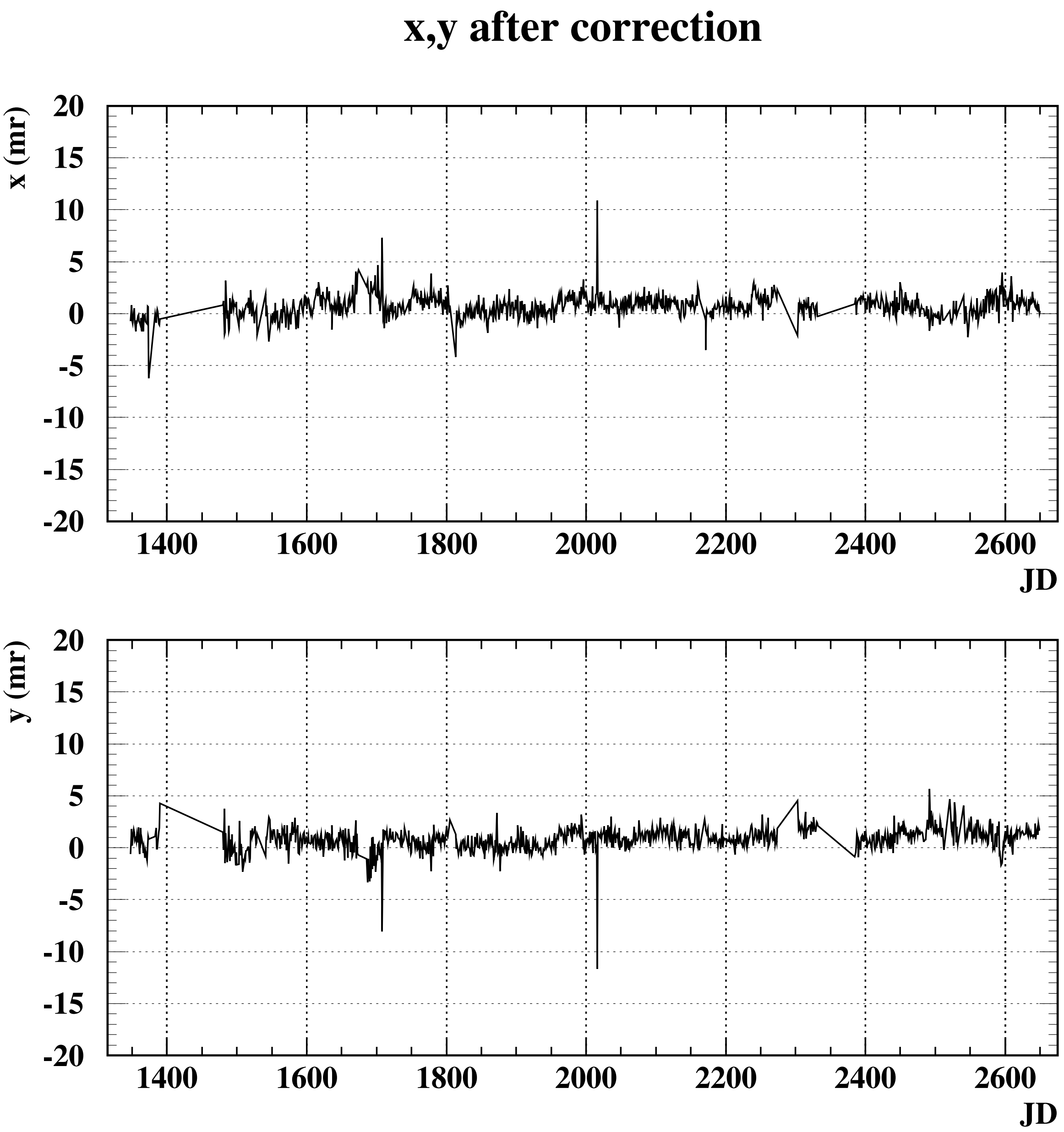

Figure 5: The mean of x and y derived from a Gaussian fit plotted vs Modified Julian Date after the alignment correction was applied.

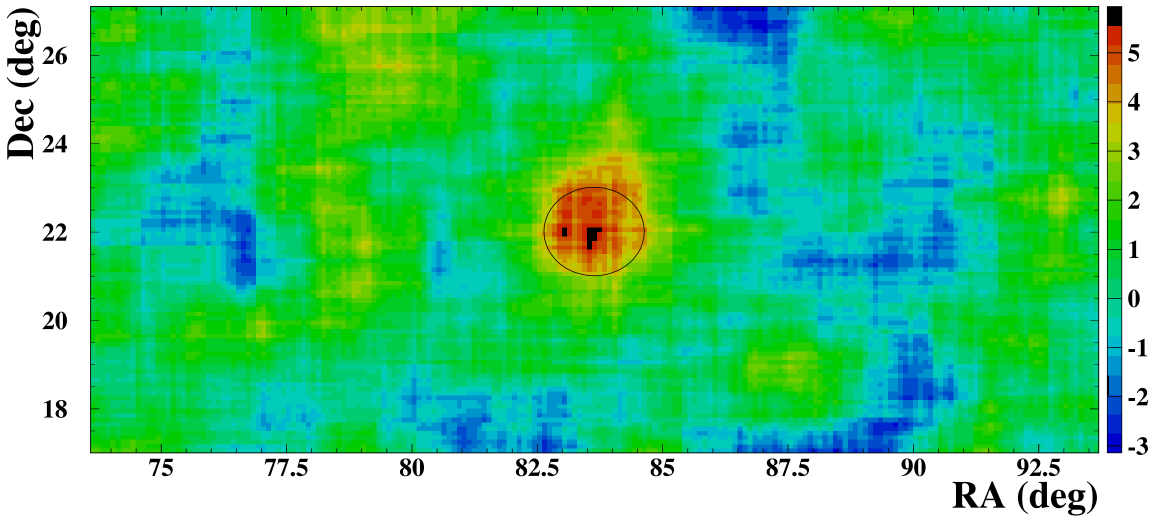

Figure 6: Significance map for the region around the Crab for data reconstructed online from July 18, 2000 to January 20, 2003 after alignment correction was applied. Standard cuts were applied ($NF \geq 20$, $x_2 > 2.5$, Binsize=2.1^o)