Studying Observation of EGRET Sources by an Array of Water Cherenkov Detectors

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Contents

Abstract 9

1 introduction 11

2 Detecting Extensive Air Showers by Cherenkov Detectors 15
   2.1 Water Cherenkov Detector ............................... 15
   2.2 Test measurements on Water Cherenkov detectors .......... 16
   2.3 Electronic circuit of the array ............................ 17
   2.4 Coincidence time between detectors of the array .......... 18
   2.5 Correction of EASs arrival time .......................... 18
   2.6 Distinguishing EASs from background noises .............. 19
   2.7 Scintillation detectors .................................. 22

3 Employing LI-Ma method in finding energy spectrum of EGRET sources 25
   3.1 Finding direction of arrived WCD array ...................... 25
   3.2 Zenith angle distribution ................................ 25
   3.3 Azimuth angle distribution ................................ 26
   3.4 Angular distributions in celestial and galactic coordinates 27
   3.5 Li-Ma method and finding discrete gamma ray sources ........ 29
   3.6 Calculating angular error for WCDS ........................ 29
   3.7 Investigating EGRET sources and evaluation of their statistical significance 30
   3.8 Analyzing data taken from schintillator array by Li-Ma method .... 32
   3.9 Results of using Li-Ma method .............................. 32

4 Analysis of the data according to poisson distributions of counts in time windows 35
   4.1 Pressure correction ....................................... 35
   4.2 Separating one year into six two months .................... 35
   4.3 Mean count rate change in each two-month .................. 37
   4.4 Separating the data into subintervals in another way ........ 39
   4.5 A test on the certainty of finding probable gamma ray events .... 40
   4.6 Considering another time windows .......................... 44

5 Concluding remarks 47

Bibliography 49
<table>
<thead>
<tr>
<th>Publications</th>
<th>51</th>
</tr>
</thead>
<tbody>
<tr>
<td>document</td>
<td></td>
</tr>
</tbody>
</table>


List of Figures

1.1 Energy spectrum of primary cosmic rays. .................. 12
2.1 A Water Cherenkov Detector sample. ..................... 16
2.2 Schematic view and electronic circuit of an experiment to measure time coincidence between a Cherenkov tank and a Scintillator. .................. 16
2.3 Electronic circuit of the Water Cherenkov array. ............ 17
2.4 Schematic view of an arrived EAS event to the WCDs array. .... 18
2.5 A part of main file as raw data providing by Mulpar software. ... 19
2.6 Coincident time distribution between each two Cherenkov detectors. .... 20
2.7 Time coincidence spectrum between three Cherenkov detectors and a Scintillator. ................. 21
2.8 A plot of time lag distributions, $T_{34}$ vs $T_{14}$, $T_{32}$ vs $T_{34}$. .............. 22
2.9 4 Scintillator array and its electronic circuit. .................. 23
3.1 Zenith angle distribution which is fitted with related equation. ........ 26
3.2 Top and side effective surface of the tank for arrived EAS. ........... 26
3.3 Azimuth angle distribution, direction of magnetic field is also shown. .... 27
3.4 Distribution of components of celestial coordinate (Right ascension and Declination angle) of the data. .................. 28
3.5 Galactic map of recorded EASs. ............................. 28
3.6 Simulated Galactic exposure map. ............................ 31
3.7 Division of the data map to the exposure map after removing extra pixels. .......... 31
3.8 Map of EGRET sources with statistical significance (>1σ) found by scintillators in galactic coordinate. .................. 33
3.9 Location of sources> 1σ in Galactic map. .................... 33
3.10 Location of sources> 1σ in Galactic map found in the Cherenkov array data. .................. 34
4.1 Event rates per half an hour as a function of atmospheric pressure. .......... 36
4.2 Counts in each time-window distribution for the first two-month. ............ 38
4.3 Distribution of event time-spacing. .......................... 39
4.4 Change in count rate during one year. ........................ 39
4.5 Change in count rate during one year, points in highlight area (the 3rd and 4th two-month) are mean count rate for any main file in this interval, four points are marked to be put away from analysis because of their low count rate. .................. 40
4.6 Counts in each time-window distribution for the first part. .................. 41
4.7 count rate (count in each time window) distributions which contain 17 probable gamma ray events. red bars at the end of distributions are related windows containing 17 events in all three time window scale (300sec, 1000sec and 3000sec) and blue bars refer to the peaks and similar events in three blue regions in three time window scale would be counted to be compared with similar events number in red regions. 42

4.8 In this figure counts in adjacent windows in three time window scales (300sec, 1000sec and 3000sec) are presented and in any scale a window is signed which contains 17 probable gamma ray events. 43

4.9 17 found events on Galactic map (green points) and EGRET sources, located near to them. 43

4.10 Location of 12 found events after changing time windows scale. 44
List of Tables

3.1 Characteristics of sources (> 1σ). Two colored sources are those also found in scitillator arrays analysis. ................................. 34

4.1 Derived parameters from fitting equation 4.1 on count rate dependance on pressure plot. ......................................................... 35
4.2 results and similar events from the first separation. ......................... 37
4.3 results from the second separation according to stable count rate in each part. ................................................................. 40
4.4 direction of all 17 events in Galactic, celestial and local coordinate and their time of detection. .................................................. 44
4.5 12 events of 17 ones, viewed in another time window scale of 180sec. . . 45
Abstract

Looking for electromagnetic air showers that are produced by initial gamma ray photons, a small flat square array of Water Cherenkov Detectors (WCDs) was used to reach this aim. This array contains 4 WCDs, is located in Physics Department of Sharif University of Technology, Tehran, Iran. We obtained angular distributions and Galactic map of recorded EAS events. Applying Li-Ma method, we found a few prominent points on galactic map and compared their location with EGRET sources’ locations. A few of those prominences had distinguishable statistical significances. To check out the acquired results, we divided our data into 4 parts and repeated all previous steps. But this time we found different sources with important statistical significance. It means that the eminent sources we obtained as our results are in the order of statistical fluctuations, in the other word, with this amount of data and poor angular resolution of our detectors we cannot observe any gamma ray source. Then, in the next step we planned to find rare or non-random gamma ray events belong to special windows of time, naturally stood on the outskirts of distributions of our mean count rate (count in subintervals of time or time-windows) which is expected to be Poisson distributions, since we are detecting EASs as almost random events. Amongst provided data, 17 of them were much probable to be gamma ray events. 12 of them are the most probable ones and they are accumulated in a circle region around plausible that these events are from EGRET sources 3EG J0010+7309, 3EG J0239+2816, 3EG J2016+3657, 3EG J2020+4017, 3EG J2021+3716, 3EG J2022+4317, 3EG 2033+4118, 3EG J2036+1132, 3EG J2227+6122, 3EG J2248+1745 and 3EG J2254+1601.
1 introduction

Cosmic rays are energetic particles originating from outer space that impinge on Earth’s atmosphere. Almost 90 percent of all the incoming cosmic ray particles are simple protons, with nearly 10 percent being helium nuclei (alpha particles), and slightly under 1 percent are heavier elements, electrons (beta particles), or gamma ray photons.

Cosmic rays include a wide range of energy from $10^7$ eV to $10^{20}$ eV. The variety of particle energies reflects the wide variety of sources. Figure 1.1 shows change in cosmic rays flux for a wide range of energy. The graph is logarithmic; a straight line indicates that the number of cosmic rays is proportional to the energy to some power, called the spectral index. In the case of cosmic rays, there are fewer particles at higher energies (the numbers go DOWN as the energy goes UP) so the spectral index is negative. Flux change with energy is presented is stated in equation (1.1).

$$\frac{dN}{dE}(m^{-2} sr^{-2} s^{-1} GeV^{-1} \approx 1.8 E^{-\gamma})$$

(1.1)

Up to $E_{10^6}$ GeV, $\gamma = 2.7$ and more than this $\gamma = 3$. Particles with lower energies cannot reach to the surface of the ground, so detecting them directly from ground level is impossible. Cosmic ray flux in the range of 100 MeV to 1 GeV has its maximum amount. Detection in this range of energy is operated by detectors installed on balloons and satellites, which best data are achieved in this energy range and flux.

When cosmic ray particles enter the Earth’s atmosphere they collide with molecules, mainly oxygen and nitrogen, to produce a cascade of lighter particles, a so-called air shower. The number of particles created in an air shower event can reach in the billions, depending on the energy and chemical environment (i.e. atmospheric) of the primary particle. Dominant interactions in the atmosphere are (1),

- $\pi^\pm \rightarrow \mu^\pm + \nu_\mu (\bar{\nu}_\mu)(\sim 100\%)$
- $\pi^0 \rightarrow 2 \gamma$
- $K^\pm \rightarrow \mu^\pm + \nu_\mu (\bar{\nu}_\mu)$
- $\mu^\pm \rightarrow e^\pm + \nu_e (\bar{\nu}_e) + \nu_\mu (\bar{\nu}_\mu)$

In higher energies measurements are based on analyzing extensive air showers that are produced by interactions between primary cosmic ray and atmospheric particles. Ground-based arrays are employed to detect cosmic rays indirectly in very high energies. This detection of energy is done in higher energy threshold (>100 TeV) and of course with very low flux of extensive air shower and we are about to distinguish if they are electromagnetic or not. So there are a lot of instruments which cover the detection of cosmic rays in variety of energy ranges.

- **Cherenkov Detectors**: A Cherenkov detector is a particle detector. A particle passing through a material at a velocity greater than that at which light can travel through the ma-
material emits light. This light is emitted in a cone about the direction in which the particle
is moving. The angle of the cone, $\theta_c$, is a direct measure of the particle’s velocity through
the formula,

$$\cos \theta_c = \frac{c}{nv}$$

(1.2)

Where $c$ is the speed of light, and $n$ is the refractive index of the medium. A cascade of charged particles ensues which, due to its extreme energy, produces a flash of Cherenkov radiation lasting between 5 and 20 ns. The total area on the ground illuminated by this flash corresponds too many hundreds of square meters, which is why the effective area of IACT telescopes is so large. On the other hand recent observations with atmospheric Cherenkov telescope system such as H.E.S.S and MAGIC have revealed sources with higher energies (VHE) gamma rays from 100GeV to 100TeV, but with lower flux, most of them from galactic plane (2).

- Ground-based array of detectors: in the case of arriving a primary cosmic ray with high energy to top of the atmosphere, an extensive air shower (EAS) would develop near to the earth and is detectable by ground-based detectors. This shower of charged particles, known as an EAS is initiated at an altitude of 10-20 km. Studying on observed EASs leads us to find out s.th about primaries. The Pierre Auger Observatory is a very large array of detectors in Argentina. Its aim is the study of the most energetic particles in the Universe.

- Each charged particle of the shower excites the nitrogen in the air and creates fluorescent light. The rule of thumb is that an electron creates four photons per meter path-length. This number depends on the atmospheric density and temperature, and on the electron energy, although the variation is not very strong. Optical air shower detectors are built at locations where the atmospheric quality is good and the absorption low. Because of the isotropic light emission, fluorescent detection becomes possible only at very high energy. The exact energy threshold depends of course on the design of the detector and is generally in the vicinity of $10^{17}$-$10^{18}$eV. Dugway is an experiment consist of Fluorescent detectors.

- Gamma ray observatory: our gamma-ray vision would peer into the hearts of solar flares, supernovae, neutron stars, black holes, and active galaxies. Gamma-ray astronomy presents unique opportunities to explore these exotic objects and the most energetic phenomena they produce. The energy band of gamma-ray astronomy extends over more
than seven orders of magnitude, from typically 500 KeV to more than 1 TeV. It is thus not surprising that a wide variety of detectors are used to study smaller sub-ranges. Most gamma-rays are absorbed by the Earth’s atmosphere. Thus, cosmic gamma-rays are typically observed from high-altitude balloons and satellites. EGRET as a satellite-based instrument on Compton Gamma Ray Observatory (CGRO) has the ability to detect sources with energies 100MeV to 10GeV. In this range of energy, 271 diffuse and discrete sources have been gathered in EGRET 3rd catalog (3).

Our small array of water Cherenkov detectors is utilized to detect extensive air showers at high energy range ($>10^{14}$eV) and consists of 4 detectors which have been designed in square shape with each side of 608cm. This is a prototype of a larger EAS array that is going to be built at ALBORZ observatory. The prototype was installed on the roof of physics department of Sharif University of Technology in Tehran ($35^\circ \ 43' \ N, \ 51^\circ \ 20' \ E$) with an altitude of 1200m 890gcm$^{-2}$ above sea level. In comparison with Scintillators, Cherenkov detectors are preferred to use in our array, because they are easy to access and more economic and their structure is too simple. Another advantage of such detectors is their noticeable height respect to their diameter, so in higher Azimuth angle effective surface area of detection would reduce less. Among logged events that are fractions of charged secondary particles arriving to our ground level array we are seeking for those that are related to electromagnetic showers or in other word, primary gamma ray photons which are directed from Very High Energy sources (VHE). We used EGRET 3rd catalog consists of 271 gamma ray sources to compare the location of our discovered sources in higher energy ($>10^{14}$eV) with the sources in the catalog; this work is in the continuum of finding TeV gamma ray sources among EGRET catalog which related data was acquired from a 4-small array of scintillation detectors (4).
2 Detecting Extensive Air Showers by Cherenkov Detectors

Scintillators and Cherenkov detectors are main detectors using in proto-type of Alborz Observatory located in Sharif University of Technology. Alborz Observatory is going to be constructed in distance 40km away from Tehran, Iran (51° 5.9’E, 35° 48.31’N, 2540m a.s.l). Till now some arrays including these detectors and their combination have been arranged to follow scientific objective of Cosmic ray laboratory group in Sharif University (5). One of these arrays is a flat small array of Cherenkov detectors contains 4 tank of Cherenkov in physics department of Sharif University that is placed 1200m above sea level. This array has collected more than 600000 events during one year. In this thesis, analyzing obtained data for the sake of investigating angular distribution of EGRET sources is the main purpose.

2.1 Water Cherenkov Detector

The water-Cherenkov detectors used in the array are home-made consisting of a metallic cylindrical tank 64 cm in diameter and 130 cm height filled up to a height of 120 cm with 382 liters of distilled water. It is coated with white diffuse paint inside to reflect radiated Cherenkov light in the best way. Each PMT with diameter of 5cm is located at the top of the water level along the cylinder axis. It should be considered to align it in an appropriate place to prevent reaching extra lights to the PMT and distinguish if detected photons are related to secondary cosmic rays or not, therefore we could admit to reduce background noises and environmental effects as much as possible. Special arrangements are made to situate just the end of the PMT in the water and at the same time avoiding extra reflection and dispersal of light reaching the PMT. The tanks are filled with distilled water of very low conductance using water distillation with solar energy. The tank has a facet near bottom edge for simple drain and cleaning of the tank. The top lid and the PMT going through it has been secured tightly with black tape to avoid the leakage of outside light into the tank and each of the whole Water-Cherenkov detectors have been firmly covered with a water protective tarpaulin cloth cover to insure proper performance of the detector in the open air (e.g. rain and sunlight etc.). The tests described below preformed on each detector have been carried out with the detector in the open air and the data acquisition electronic is indoor. Figure 2.1 shows a Cherenkov detector deployed in our array with view of its inside. The array is a flat square one with each side of 608cm (51° 20’ E, 35° 43’ N, 1200m a.s.l 890g/cm²).
2.2 Test measurements on Water Cherenkov detectors

In order to test the proper accuracy of each water Cherenkov detector to be used in the EAS array and to compare their detection performance with each other and with scintillator-light-enclosure detectors commonly used in EAS arrays, we are supposed to execute an experiment. To test the detectors response to the passage of a secondary cosmic ray (CR) and measure their detection efficiency, a plastic scintillator(15cm × 15cm) with an EMI 9813KB PMT connected to its 15×1cm² side via a regular plastic light guide was placed directly upon the water-Cherenkov detector. The passage of a CR is recorded by having signals from these two PMTs (the one at the end of plastic scintillator and the one viewing water in the Cherenkov tank) within less than 200ns. The circuit diagram for the tests carried out in this part is shown in Figure 2.2. identical electronic settings (gates, thresholds, TAC range, etc.) and duration time of experiment were used for each of the four home-made water-Cherenkov detectors used in the present small array. Running the experiment we have time coincidence spectrum (time difference of detecting an event by two detectors) that is expected to be Gaussian. Half Width of Half Maximum is equivalent to time error of reaching secondary cosmic rays into our array, this amount is $\Delta t_{\text{scin}} = 9.3\text{ns}$ for scintillation detectors and $\Delta t_{\text{cher}} = 9.6\text{ns}$ for Cherenkov detectors. As you can see, this error is greater amount for Cherenkov detectors (6).
2.3 Electronic circuit of the array

Figure 2.3 shows schematic view of Cherenkov array and its electronic circuit. If at least one particle arrives at a Cherenkov detector, the PMT above the detector makes a signal with a pulse height proportional to the direction and the number of secondary particles. The output signals from the PMTs are amplified (×10) with an 8-fold fast amplifier (CAEN N412) and then they reach into 8-fold fast discriminator (CAEN N413A) which its threshold is fixed on 100mV. The next unit is Time to Amplitude Convertors (TACs) which are set on 200ns. Since the third Cherenkov is regarded as the reference detector, the start input of cher3 connects to the start of TAC1 and TAC2 and TAC3. The stop inputs of TAC1, TAC2 and TAC3 are fed into by orderly cher1, cher2 and cher3. Then the outputs of these three TACs are fed into a multi-parameter Multi Channel Analyzer (MCA) via an Analogue to Digital Convertor (ADC) unit. With this electronic circuit the coincidence times, $T_{31}$, $T_{32}$ and $T_{34}$ would obtain, which leads us to find logged showers directions. Coincidence times between (cher1, cher3), (cher2, cher3) and (cher3, cher4) is recorded in a main file which time interval between two sequent records in this file is 0.05 sec. If an EAS event arrives to our array, three coincidence times would record.
Figure 2.4: Schematic view of an arrived EAS event to the WCDs array.

### 2.4 Coincidence time between detectors of the array

As it is seen in Figure 2.4 when a shower arrives at the array, detectors don’t start recording at the same time. Time difference in registering events between each two detectors, leads us to find the angle of lagged event as representative of an extensive air shower of secondary cosmic rays. Raw data are located in main files by Mulpar Software. Present numbers in main files are recorded each 0.05s sequentially, which is more than dead-time of PMTs. If an event is viewed by the array (all four detectors), would be registered as an arrived extensive air shower, so three figures in main file stand for three difference times between each two detector as $T_{31}$, $T_{32}$ and $T_{34}$. Figure 2.5 is an example of a raw main file. Detecting no event is presented by zero and when an event or more are observed by our array three time coincidences related to each event are shown. These numbers are in channel unit. Our window of detection is 200ns, this means if time differences are more than 200ns, it will not be considered. This window is divided into 1024 channels and reported digits in main files should be converted to time (ns). If we draw time coincidences distribution, as we expected, we find a Gaussian distribution that shows extensive air showers arrive randomly. Figure 2.6 shows such three distributions. We expect the peaks happen at zero which means most of EASs reach vertically and cause no time difference in being viewed by four Cherenkov detectors, but we can find that the peaks are shifted to the positive direction of the diagrams. These amounts of shifting are made by extra-long wire positioning in the electronic circuit in order to provide delay between START and STOP of TAC unit. For each meter of wire we have 5ns delay in time. During analysis it should be regarded to subtract man-made delays in time from time coincidences.

### 2.5 Correction of EASs arrival time

Since time differences between each two detectors show us in which angle an EAS arrives, we should care about measuring pulse height between start and stop in TAC Unit very accurately. Some errors are inevitable and are related to different efficiency of detectors and PMTs using in the array, this is a systematic error which should be considered in
2.6 Distinguishing EASs from background noises

According to Figure 2.8, positions of the first WCD to the fourth one are (d,0), (d,d), (0,0) and (0,d), respectively. Calculating local coordinate of detected showers, we assume that shower front is a flat surface and perpendicular to moving direction of the front shower (n).

\[ \hat{n} = -(\sin \theta \cos \phi \hat{i} + \sin \theta \sin \phi \hat{j} + \cos \theta \hat{k}) \]  

(2.1)

Here is the way time differences are linked with direction of arrived EASs. \( r_{3i} \) is the placement vector of the first, second and the fourth detectors respect to the third one.

\[ t_{3i} = \frac{1}{c} \cdot \frac{\hat{n}}{r_{3i}} \]  

(2.2)

As an assumption, shower front travels with speed of the light c. expanding equation 2.2 to reach to the three time differences we have,

\[ t_{31} = \frac{d}{c} \sin \theta \cos \phi \]  

(2.3)
Figure 2.6: Coincident time distribution between each two Cherenkov detectors.
2.6 Distinguishing EASs from background noises

![Figure 2.7: time coincidence spectrum between three Cherenkov detectors and a Scintillator.](image)

We can relate each time difference to the other one and derive other three relations as equation (2.6), (2.7) and (2.8)

\[
t_{32} = \frac{d}{c} \sin \theta (\cos \phi + \sin \phi)
\]

\[
t_{34} = \frac{d}{c} \sin \theta \sin \phi
\]

\[
t_{31}^2 + t_{34}^2 = \left(\frac{d}{c} \sin \theta\right)^2
\]

\[
(t_{31} - \frac{1}{2} t_{32})^2 + \frac{1}{4} (t_{32})^2 = \frac{1}{2} \left(\frac{d}{c} \sin \theta\right)^2
\]

\[
(t_{34} - \frac{1}{2} t_{32})^2 + \frac{1}{4} (t_{32})^2 = \frac{1}{2} \left(\frac{d}{c} \sin \theta\right)^2
\]

With arrangement of four Cherenkov detectors as a square array, we measure the time lag between the detectors (3,1), (3,2), and (3,4) for each shower. Figure 2.8 shows a plot of $T_{34}$ vs. $T_{31}$ for a large number of showers. Since three detectors 1, 3 and 4 have been placed at the vertices of a right triangle, the experimental points representing showers are distributed in a circular region whose center of gravity corresponds to a vertical shower. Also in Figure 2.8 we see a plot of $T_{32}$ vs. $T_{31}$, which shows a gathering of showers in a cylindrical region. The points distributed uniformly represent random coincidence events. While plotting these diagrams some points are out of these regions which are related to those events that are counted as background noises and should be removed from the analysis to find real EASs.
After passing all steps mentioned in this chapter, we finally found more than 600000 EAS events from raw data that were taken by the WCD array during about one year (2006-2007).

### 2.7 Scintillation detectors

In addition to WCDs array, we had previously arrays of Scintillators. Two of them were flat square, the first one with side of 8.30m which worked upon 8days with total detected EAS events of 53907 and the second one with side of 11m which after 40days viewing the sky, recorded 173765 EAS events. Figure 2.9 is prepared example of such array with its electronic. Scintillation detectors applied in these two arrays were plastic Scintillators with dimension of $100 \times 100 \times 3$ cm$^3$, covered with a pyramidal chamber and PMTs are located at the top of this figure.
Figure 2.9: 4 Scintillator array and its electronic circuit.
3 Employing LI-Ma method in finding energy spectrum of EGRET sources

3.1 Finding direction of arrived WCD array

Having three time differences between couples of WCDs, directions of logged EASs are measurable. Here Least Square Method is put on. Details of the calculation is presented in (8)

\[ X = c \left( \frac{\sum \alpha_j T_{3j} \sum \alpha_j \beta_j}{\sum \beta_j T_{4j} \sum \beta_j^2} \right) / \left( \frac{\sum \alpha_j^2 \sum \alpha_j \beta_j}{\sum \alpha_j \beta_j \sum \beta_j^2} \right) \] (3.1)

\[ Y = c \left( \frac{\sum \beta_j T_{3j} \sum \alpha_j \beta_j}{\sum \alpha_j T_{4j} \sum \alpha_j^2} \right) / \left( \frac{\sum \alpha_j^2 \sum \alpha_j \beta_j}{\sum \alpha_j \beta_j \sum \beta_j^2} \right) \] (3.2)

Then the local coordinate, Azimuth(\(\theta\)) and Azimuth angle (\(\phi\)) can be calculated.

\[ \theta = \tan^{-1} \sqrt{\frac{X^2 + Y^2}{1 - X^2 - Y^2}}, \phi = \tan^{-1} \left( \frac{Y}{X} \right) \] (3.3)

3.2 Zenith angle distribution

According to the method pointed out in the previous part, Azimuth angle is derived and so, Azimuth angle distribution comes up in Figure 3.1. This distribution is fitted with following relation,

\[ \frac{dN}{d\theta} = A_0(B_1 \cos \theta + B_2 \sin \theta) \sin \theta \cos^2 \theta \] (3.4)

In this equation, the first sentence is linked to those EASs enter from the top surface of the detector and the second sentence is related to those come from the sides. Performing a simulation for this size of detectors, we have, \(B_2/B_1=2.1\) ratio (7). Figure3.2 shows effective detection area for top and side of the detector. After fitting equ3.4 on obtained distribution now we have an amount for \(n=6.14\pm0.04\). in greater Azimuth angle, detected EASs is less, because secondary particles must pass thicker path in the atmosphere. As it is clear from the distribution, after Azimuth angle of 60, detection rate is not considerable.
3 Employing LI-Ma method in finding energy spectrum of EGRET sources

Figure 3.1: Zenith angle distribution which is fitted with related equation.

Figure 3.2: Top and side effective surface of the tank for arrived EAS.

3.3 Azimuth angle distribution

Angular distribution of Azimuth for all Azimuth angles is shown in Figure3.3. We can fit this distribution with coming equation,

\[
\frac{dN}{d\phi} = A_0[1 + \cos(\phi - \phi_1) + A_2\cos(2\phi) - \phi_2]
\]  

(3.5)

There is a anisotropy in north-south direction that is referred to magnetic field of the earth which affect charged comic ray particles. More investigations have been done on this effect in (9, 10). We put x axis in the line connecting the second and the fourth Cherenkov detectors. North-south direction is deviated from the x axis with 15 degrees which should be regarded as a displacement of azimuth angle.
After finding components of local coordinate we are about to obtain components of galactic and celestial coordinates. In order to reach to this aim we apply trigonometry relations and here we write down just necessary formulae we used to do these conversions. For the first step, converting local to celestial coordinate we have,

$$\cos(90 - \delta) = \cos(90 - \lambda) \cos \theta + \sin(90 - \lambda) \sin \theta \cos \phi$$  \hspace{1cm} (3.6)

$$\frac{\sin H}{\sin \theta} = \frac{\sin(360 - \phi)}{\sin(90 - \delta)}$$  \hspace{1cm} (3.7)

where $\delta$ is declination angle ($^\circ$) and $\lambda$ is geometrical latitude of Tehran ($^\circ$). H is Hour Angle. To deduce another components of this coordinate we need to know Local Sidereal Time that is derived by a software called "Astronomy Clock".

$$LST = LST_0 + \alpha(T - T_0)$$  \hspace{1cm} (3.8)

where $\alpha=1.00273790935$. $(T - T_0)$ is the difference in time, between an arrived EAS and start time of the experiment.

$$RA = LST - H$$  \hspace{1cm} (3.9)

Moving to Galactic coordinate we have,

$$sin b = sin \delta sin \delta_{NGP} + cos \delta cos (RA - A_0) cos \delta_{NGP}$$  \hspace{1cm} (3.10)

$$sin(l - l_0) = (sin \delta cos \delta_{NGP} - cos \delta sin \delta_{NGP} cos (RA - A_0))/cos$$  \hspace{1cm} (3.11)
3 Employing LI-Ma method in finding energy spectrum of EGRET sources

\[ \cos(\ell - \ell_0) = \cos \delta \sin(\text{RA} - a_0) \]  

(3.12)

\( \delta_{\text{NGP}} = 27^\circ 7.8' \) is declination angle of North Galactic Pole. \( a_0 = 192^\circ \), is Right Ascension of Galactic Center and lastly, \( \ell_0 = 32.93^\circ \), Galactic Longitude of Galactic Center. Angular distribution for celestial coordinate components can be found in Figure 3.4. Furthermore a galactic map in companion with galactic latitude and longitude is viewed in Figure 3.5.
3.5 Li-Ma method and finding discrete gamma ray sources

Evaluation of statistical reliability of positive results in searching discrete gamma ray sources is an important problem in gamma ray astronomy. Since both the signal to background ratio and detector sensitivity are generally limited in such high energy range, one must carefully analyze the observed data to determine the confidence level of a candidate source, that is the probability that the count rate excess is due to a genuine source rather than to a spurious background function, even though all systematic effects are believed to have been removed. Then we can estimate the number of background photons included on the on-source counts Non to reach to the number of photons originate from gamma ray sources. $N_{on}$ is the number of counts under a peak in count rate distribution in the source place, and the peak is taken to $n_s$ channels wide. $N_{off}$ is the number of counts in $n_b$ channels adjacent to the peak. Then $\alpha = n_s/n_b$.

\[ \hat{N}_B = \alpha N_{off} \]  (3.13)

In the former relation $N_B$ is background photon count. The observed signal, the probable number of photons bring by the source, is

\[ N_s = N_{on} - \hat{N}_B \]  (3.14)

Calculating the variance of $N_s$ from the above relation,

\[ \sigma^2(N_s) = \sigma^2(N_{on}) + \alpha^2 \sigma^2(N_{off}) \]  (3.15)

And then standard deviation,

\[ \hat{\sigma}(N_s) = \sqrt{\sigma^2(N_{on}) + \alpha^2 \sigma^2(N_{off})} \]  (3.16)

Defining the significance S as a ratio of the excess counts above background to its standard deviation, we have,

\[ S = \frac{N_s}{\hat{\sigma}(N_s)} = \frac{N_{on} - \alpha N_{off}}{\sqrt{N_{on} + \alpha^2 N_{off}}} \]  (3.17)

Li-Ma method in details can be seen in (11)

3.6 Calculating angular error for WCDS

In the first step we find angular errors of local coordinate components and then using trigonometry relations lead us to calculate angular errors in other coordinate systems, analytically. The way $\Delta \theta$ is estimated for scintillators is completely explained in (9), but to apply whole method for WCDs, some small changes are supposed to be counted. Dispersion of random instrumental error is calculated in this way,

\[ D(\tau) = \frac{1}{6} D(T_{31} + T_{32}) - D(t) \]  (3.18)

Where we define $T_{31}$ to be the time lag between pulses and $T_{32}$ between pulses 3 and 2. $D(t)$ is the dispersion of times of first electron arrival, averaged over distances from shower axis.

\[ \sqrt{D(T_{31} + T_{32})} = 9.6 ns \]  (3.19)
Using CORSIKA simulation gives this amount for $D(t)$,

$$\sqrt{D(t)} = 3.2\text{ns} \quad (3.20)$$

If the time of arrival of the first shower particles detected in two adjacent detectors of an EAS array separated by a distance $d$ are $s_3$ and $s_2$, the direction of the two parallel shower particles is obtained from the following simple relation,

$$\sin \theta \sin \phi = \frac{c}{d} (s_3 - s_2) \quad (3.21)$$

Assuming that the errors in $\theta$ and $\phi$ are equal, we can therefore write the errors in $\theta$ as,

$$\Delta \theta = \sqrt{2 \left[ \frac{2c}{d} \Delta s \right]^2 + \frac{1}{2} \left( \frac{\Delta d}{d} \right)^2 \sin^2 \theta \right]^{1/2} \quad (3.22)$$

The error in arrival time can be written as,

$$\Delta s = (\sigma_i^2 + \sigma_{sh}^2)^{1/2} \quad (3.23)$$

Where $\sigma_i = (D(\tau))^{1/2} = 2.2\text{ns}$ is in the inherent uncertainty in time measurement and $\sigma_{sh}$ is the variance in time of arrival of shower particles of a given detector due to the thickness of the EAS disk (12).

$$\sigma_{sh} = (1.6\text{ns})(1 + \frac{r}{30})^{1.65} / \sqrt{n(r, \theta)} \quad (3.24)$$

Where $r$ is in meter and $n(r, \theta)$ is the number of shower particles crossing the detector located at a distance $r$ from the core of a shower with zenith angle $\theta$. So we have,

$$\Delta \theta = \sqrt{2 \left[ 2c \left( \frac{\Delta s}{d} \right)^2 \sigma_i^2 + 2.56(1 + r/30)^{3.3} / n(r) \right] + \frac{1}{2} \left( \frac{\Delta d}{d} \right)^2 \sin^2 \theta} \right]^{1/2} \quad (3.25)$$

Now after finding this amount for $\Delta \theta$, $\Delta l$ and $\Delta b$ are going to be estimated. If we have a generic function like $A(x,y,z)$ we have,

$$A = A(x,y,z) \rightarrow \Delta A = \sqrt{\left( \frac{dA}{dx} \right)^2 (\Delta x)^2 + \left( \frac{dA}{dy} \right)^2 (\Delta y)^2 + \left( \frac{dA}{dz} \right)^2 (\Delta z)^2} \quad (3.26)$$

The error in the observed solid angle of each source is $\Delta \Omega = \cos b \Delta b \Delta l$ and the equivalent error in the angular radius is $r_e \equiv \Delta \Omega / \pi (r_e \ll 1)$.

### 3.7 Investigating EGRET sources and evaluation of their statistical significance

The energy range of the EAS events logged by the array is in the range of 40 to 10000 TeV. In this energy range the distribution of cosmic rays is completely isotropic and homogeneous in the galaxy. After correcting for the exposure effects, we looked for excess emission that could be from gamma ray sources (16). We used the third EGRET catalogue as a reference. But some of EGRET sources do not have acceptable events in the FOV of our array or out of energy range. At the same time we produce a random exposure map by
3.7 Investigating EGRET sources and evaluation of their statistical significance

Monte Carlo method that is provided in the base of angular distribution of our taken data. We counted the number of events and the number of pixels and then calculated the count per pixel related to each source. We note that the mean count per pixel in the data map is 14. In the first step we divided the data map Figure 3.5 by the exposure map Figure 3.6 pixel by pixel. In the obtained map, most non-zero pixels are around 1 except probable source pixels and pixels with higher fluctuations in the data map, which are probably due to the small size of the data set. To eliminate the fluctuating pixels we multiplied the new map by mean count for each pixel, 14 to obtain a raw exposure-corrected map. In this step we added counts of all pixels of the raw corrected map. The number must be very near to 604000 which is the total number of collected data, so with this restriction we obtained a lower limit 0.3 for putting away pixels with lower count in the exposure map, and the final exposure corrected map was obtained; it is shown in Figure 3.7.

The obtained map was fairly uniform in the FOV of our array in galactic coordinates. Next we investigated the remaining faint inhomogeneity in the corrected map that could
be conditionally attributed to the existence of gamma-ray sources. To estimate the significance of an individual source we added all corrected EAS events, \( N_{on} \), within a radius \( \sqrt{2}r_e=7.98^\circ \) from the source position. The number of pixels, \( n_s \), within this region was also counted. The total number of background counts, \( N_{off} \), was found from the pixels that fall within an outer radius of \( 2r_e=11.4^\circ \) and an inner radius \( \sqrt{2}r_e \) from the source position. The number of background pixels, \( n_b \), was also counted too. The statistical significance of the source was obtained using the Li and Ma method (Li and Ma 1983). On-source circular region radius and surrounded off-source region thickness have arranged in a way that both of them have the same area. Using equation 3.17 directs to obtain individual statistical significance of EGRET sources. After employing related equation for all 271 gamma ray sources existed in EGRET catalog, it was considerable that some acquired numbers for their statistical significances were unusually very great, 13 and 14 were such strange numbers. More precise investigation presented that points with these amounts of significances are settled in the edge of galactic data map. Since our detectors have poor angular resolution so the effective angle \( r_e \) have a large amount, in employing Li-Ma method the areas of on-region and off-region would increase consequently, and if a source is located in the edge of our map off-region may extend to a place with no events there which leads to a considerable drop in counts and the number of full pixels. According to equation 3.17, decreasing \( N_{off} \) and \( n_b \) relative to \( N_{on} \) and \( n_s \) causes growth in statistical significance, which we should pay more attention to these kinds of sources, because we have no enough accuracy to calculate their significances.

3.8 Analyzing data taken from scintillator array by Li-Ma method

The same analysis that was explained in the previous section has been applied for accumulated data from two arrays of scintillation detectors (4). In the earlier chapter we have remarked characteristics of both of such arrays. Working with WCDs array data, we analyzed scintillator arrays data, simultaneously. some sources with noticeable statistical significance \( > 1\sigma \) were found that Figure3.8 shows their location in Galactic map.

3.9 Results of using Li-Ma method

In studying Chrenkov data, we consider sources \( > 1\sigma \). Figure3.9 displays location of these sources in galactic map of data collected by WCD array.

We have found 2 sources joint in scintillators and WCD array which have considerable statistical significances in both studying. The first source has 1.65\( \sigma \) in WCD and with 1.07\( \sigma \) in scintillator arrays analysis. The second one presents 1.21\( \sigma \) in WCD and 1.60\( \sigma \) for scintillator arrays studying. These two sources are called in this manner in 3rd EGRET catalog, respectively, 3EG J0239+2816 and 3EG J2021+3716.

Because of having great amount of error for our detectors, now it is time to make a survey to find out how much our final outcomes can be trustworthy. To prove the results, we separate total collected data in one year into four equal parts. (random or non-random)
3.9 Results of using Li-Ma method

Figure 3.8: Map of EGRET sources with statistical significance (>1σ) found by scintillators in galactic coordinate.

Figure 3.9: Location of sources > 1σ in Galactic map.

to make sure whether we can observe those important sources in any of these gained parts or not. Then we repeat all steps we did for the whole data for 4 sets of divided data. For each part there are some points with appreciable statistical significances. When we compare obtained final results with each other, no similar source is detectable among them, in other word important sources of any part are completely different from those from another parts. Although separating total data causes reducing in our statistics, but wholly for the sake of large amount of array error and lacking enough data we cannot trust on the two acquired sources and much precise investigation is needed to approve the final results. In Figure3.10 you can see four galactic data map in with highlight points are related to important statistical significances.
3 Employing LI-Ma method in finding energy spectrum of EGRET sources

Table 3.1: Characteristics of sources (> 1σ). Two colored sources are those also found in scintillator arrays analysis.

<table>
<thead>
<tr>
<th>Name</th>
<th>l</th>
<th>b</th>
<th>ID</th>
<th>(\sigma_{\text{cher}})</th>
<th>(\sigma_{\text{scin}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>3EG J0239+2816</td>
<td>150.21</td>
<td>-28.8</td>
<td>a</td>
<td>1.215</td>
<td>1.606</td>
</tr>
<tr>
<td>3EG J0416+3650</td>
<td>162.22</td>
<td>-9.97</td>
<td>a</td>
<td>2.558</td>
<td>-0.682</td>
</tr>
<tr>
<td>3EG J0433+2908</td>
<td>170.48</td>
<td>-12.58</td>
<td>A</td>
<td>1.245</td>
<td>0.097</td>
</tr>
<tr>
<td>3EG J0459+3352</td>
<td>170.3</td>
<td>-5.38</td>
<td></td>
<td>1.319</td>
<td>-0.226</td>
</tr>
<tr>
<td>3EG J0542+2610</td>
<td>182.02</td>
<td>-1.99</td>
<td></td>
<td>1.245</td>
<td>-0.288</td>
</tr>
<tr>
<td>3EG J1824+3441</td>
<td>62.49</td>
<td>20.14</td>
<td></td>
<td>1.560</td>
<td>1.436</td>
</tr>
<tr>
<td>3EG J1825+2854</td>
<td>56.79</td>
<td>18.03</td>
<td></td>
<td>2.562</td>
<td>0.225</td>
</tr>
<tr>
<td>3EG J1958+2909</td>
<td>66.23</td>
<td>-0.16</td>
<td></td>
<td>1.284</td>
<td>-1.293</td>
</tr>
<tr>
<td>3EG J2020+4017</td>
<td>78.05</td>
<td>20.08</td>
<td></td>
<td>1.962</td>
<td>0.479</td>
</tr>
<tr>
<td>3EG J2021+3716</td>
<td>75.58</td>
<td>0.33</td>
<td></td>
<td>2.822</td>
<td>1.079</td>
</tr>
<tr>
<td>3EG J2027+3429</td>
<td>74.08</td>
<td>-2.36</td>
<td></td>
<td>2.949</td>
<td>0.225</td>
</tr>
<tr>
<td>3EG J2033+4118</td>
<td>80.27</td>
<td>0.73</td>
<td></td>
<td>1.657</td>
<td>-0.970</td>
</tr>
<tr>
<td>3EG J2035+4441</td>
<td>83.17</td>
<td>2.5</td>
<td></td>
<td>1.724</td>
<td>0.068</td>
</tr>
<tr>
<td>3EG J2352+3752</td>
<td>10.26</td>
<td>-23.54</td>
<td>A</td>
<td>2.423</td>
<td>-0.802</td>
</tr>
<tr>
<td>3EG J2358+4604</td>
<td>113.39</td>
<td>-15.82</td>
<td>A</td>
<td>1.790</td>
<td>0.590</td>
</tr>
</tbody>
</table>

Figure 3.10: Location of sources > 1σ in Galactic map found in the Cherenkov array data.
4 Analysis of the data according to poisson distributions of counts in time windows

4.1 Pressure correction

The rate of shower detections depends on a number of factors. Various methods are used in order to study the dependence of the event rate on atmospheric ground pressure $p$ and temperature $T$ (15). The temperature effect is found to be statistically insignificant, in another word in a range that the temperature alters; counts are not sensitive to change in temperature. However any increase in pressure of atmosphere causes decreasing in count rate of observed EASs, since particle must pass through larger amount of matter and interact more which leads to less expected rate of count, and vice versa. The CR intensity dependence on barometric pressures in half-hour intervals is shown in Figure 4.1. We can describe the dependence by the following function (16)

$$R = R_0 \exp \left( \frac{P_0 - P}{P_1} \right)$$

(4.1)

If we divide one year into 6 equal parts in time, Depending half-hour rate of EASs to the pressure for the sixth part can be seen in Figure 4.1. In table 4.1, unknown parameters in equation 4.1 are derived for each six parts. From table 4.1 it is remarkable that in the third and fourth two-month, there is a drop in parameter $R_0$. In the next section we will consider such downfall more precisely.

Table 4.1: Derived parameters from fitting equation 4.1 on count rate dependence on pressure plot.

<table>
<thead>
<tr>
<th></th>
<th>1st 2-month</th>
<th>2nd 2-month</th>
<th>3rd 2-month</th>
<th>4th 2-month</th>
<th>5th 2-month</th>
<th>6th 2-month</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_0$</td>
<td>64</td>
<td>62</td>
<td>45</td>
<td>58</td>
<td>39</td>
<td>39</td>
</tr>
<tr>
<td>$P_0$</td>
<td>880</td>
<td>861</td>
<td>861.2</td>
<td>860</td>
<td>860.3</td>
<td>885.4</td>
</tr>
<tr>
<td>$P_1$</td>
<td>140</td>
<td>105</td>
<td>105.2</td>
<td>105.2</td>
<td>105</td>
<td>140</td>
</tr>
</tbody>
</table>

4.2 Separating one year into six two months

By employing Li-Ma method we couldn’t reach to a determined conclusion in observing gamma ray sources in EGRET catalog, so in the following we changed analyzing method.
In the new method, instead of looking for a discrete source of gamma ray which is a gathering of EAS events observed by our WCD array, we seek for individual EAS events that might be referred to a special source. Since primary cosmic ray particles are affected by magnetic fields they pass through, they arrive almost random at the top of the atmosphere and cannot point out to a certain source they are coming from. Amongst them there are few numbers of primary photons which direct toward special sources, originated from, but entirely we can claim that primaries reach randomly, so we expect to detect EASs to be observed by ground-based arrays, uniformly. The study of the flux of underground Muons generated by primaries with energy higher than 20 TeV confirmed the random feature of the arrival times (13, 14). Hence especial distributions of count rate of EASs are poisson distribution. Recorded events which are far from Poisson distributions can be related to those events initiate from discrete sources. The data set have been collected in one year. We separate this time period into time intervals in two ways, and for each period we consider subintervals or time windows: 10, 30, 100, 300, 1000 and 3000 seconds. We obtain count in subinterval distributions for any time intervals. As we expect, the majority of recorded extensive air showers arrive randomly to our array and if we acquire count in time intervals distributions, they are Poissonian. The poisons distribution is a Discrete probability distribution that expresses the probability of number of events occurring in a fixed period of time, if these events occur with a known average rate and independently of the time since the last event. Therefore according to our count rate variation we should choose fixed period which the mean count rate stays almost steady. We provide distributions for each subinterval of time for any different time windows and fit them out with Poisson function,

\[ P(x) = N_0 \frac{e^{-\lambda} \lambda^x}{x!} \]  

(4.2)

\( \lambda \) is the most probable count in an especial time window and \( x \) is count in each time window. When distributions are in a good agreement with Poisson function it means that commonly most of detected EASs are random and if a non-random event -which maybe belong to a point source of gamma ray- in a particular subinterval of time would contribute to extra counts and does not agree with Poisson distribution. These excesses in counts are out of distribution and we should distinguish them. It is possible that these events belong

Figure 4.1: Event rates per half an hour as a function of atmospheric pressure.
4.3 Mean count rate change in each two-month

to the counts in time windows which show good agreement with Poisson distribution but we are not able to separate them as special events like gamma ray ones, so we emphasis on those which are not in the skirt of Poisson distribution. If such events discover in another time-windows it could be an achievement in finding electromagnetic EAS which originate from a primary gamma photon. Dividing one year to 6 identical time intervals is the first way in separating one year into appropriate intervals, because in one side, two month is an appropriate time that mean count rate stay uniform and on the other hand, is not such a small interval which we encounter with lack of data in analyzing. After finding count in each time window distribution, we fit them with Poisson distribution as we can see in Figure 4.2. There are few points in the outskirt of the distributions in high counts in each time window (points related to lower counts in each time window which are not in a good accordance with Poisson distribution are not regarded to be studied because these excesses show lack of counts or data in some windows of time, while we are looking for excesses in higher counts), maybe related to events that are not adaptable with random spectrum and they must be investigated as nonrandom events such as electromagnetic showers. Table 4.2 shows some of these events that have been observed in two or more time windows.

Table 4.2: results and similar events from the first separation.

<table>
<thead>
<tr>
<th></th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
<th>6th</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean count rate</td>
<td>0.00673</td>
<td>0.00617</td>
<td>0.00544</td>
<td>0.00405</td>
<td>0.00385</td>
<td>0.0035</td>
</tr>
<tr>
<td>similar events in</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>two time windows</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>time windows</td>
<td>12</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>55</td>
<td>41</td>
</tr>
<tr>
<td>related to row 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>similar events in</td>
<td>30,300,1000</td>
<td>100,300</td>
<td>——</td>
<td>——</td>
<td>30,100,300,1000,3000</td>
<td>10,30,300,</td>
</tr>
<tr>
<td>three time windows</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>time windows</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>24</td>
<td>0</td>
</tr>
<tr>
<td>related to row 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.3 Mean count rate change in each two-month

In this stage, we are needed to gain exact measure of mean count rate for each two-month. Figure 4.3 shows the event time-spacing distribution. Since events arrive randomly in time, it is expected that this will follow an exponential distribution, which index of this exponential function is mean count rate (count per second),

\[ N = N_0 e^{-\frac{b}{\Delta t}} \]  \hspace{1cm} (4.3)

The event rate can be obtained by fitting this function on the event time-spacing distribution. Figure 4.3 shows that our observed distribution is in good agreement with the exponential function. Parameter \(b\) is a representative of mean count rate. For all parts we obtain such distribution and so the mean count rate amounts. Figure 4.4 is the feature of changing mean count rates during one year.
It is obvious that in passing from the third two-month to the fourth one there is a descending part in count rate. After that in the 5th and 6th two-month the mean count rate is almost steady. The collapse in count rate may be related to the systematic problems of array and its electronics. Our whole data is consisting of 60 main files, therefore to understand which files are responsible for this collapse, we find mean count rate for any file which is situated in this time interval which mean count rate descends suddenly. Figure 4.5 present mean count rate for all files in highlight regions which is referred to the 3rd and 4th two-months.

As we get from Figure 4.5, 4 files shown in highlight area (in 4th two-month) have such low mean count rates that we prefer to remove them from our analysis. Eliminating these files results in lack of enough data in this time interval in order to have a reliable study. So we concentrate on the 1st, 2nd, 5th and the 6th time intervals. We can see
in table 4.2 in the columns related to 3rd and 4th two-months nothing has been written. Because of the slope in count rate variation, analysis in these regions causes poor quality results.

### 4.4 Separating the data into subintervals in another way

While separating one year into 6 subintervals of time, we were concerned about keeping count rate at a steady amount. This time, according to changing in count rate up to just 10 percent, we will have new divisions, three parts that with a good accuracy we can claim count rate in each parts is stable. Durations of new parts are equal. All steps we did for the previous 6 subintervals are repeated for new three parts. Figure 4.6 shows counts in each time window for the first part of the separation. Results are also written down in
4 Analysis of the data according to poisson distributions of counts in time windows

Figure 4.5: Change in count rate during one year, points in highlight area (the 3rd and 4th two-month) are mean count rate for any main file in this interval, four points are marked to be put away from analysis because of their low count rate.

table 4.3.

Table 4.3: results from the second separation according to stable count rate in each part.

<table>
<thead>
<tr>
<th></th>
<th>1st part</th>
<th>2nd part</th>
<th>3rd part</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean count rate</td>
<td>0.00617</td>
<td>0.00570</td>
<td>0.00370</td>
</tr>
<tr>
<td>similar events in two time windows</td>
<td>59</td>
<td>85</td>
<td>84</td>
</tr>
<tr>
<td>time windows related to row 2</td>
<td>1000,3000</td>
<td>300,1000,3000</td>
<td>30,100,300,1000</td>
</tr>
<tr>
<td>similar events in three time windows</td>
<td>0</td>
<td>17</td>
<td>7</td>
</tr>
<tr>
<td>time windows related to row 4</td>
<td>——</td>
<td>300,1000,3000</td>
<td>100,300,1000</td>
</tr>
<tr>
<td>time interval of each part</td>
<td>06/11/19-07/02/14</td>
<td>07/02/10-07/04/16</td>
<td>07/05/19-07/11/20</td>
</tr>
</tbody>
</table>

4.5 A test on the certainty of finding probable gamma ray events

Considering events related to those windows which are out of Poisson distribution, leads us to find few sets of similar events in two or three time windows. Studying on such sets of events especially those ones that are the same in three time windows, is a great deal in this stage. We perform a test to become more certain that these events are electromagnetic events. We apply this test for all sets of events have been observed in three time windows but we present result of this test for a set with 17 events in 5th two-month, figure.10. They have been found in three time windows 300, 1000 and 3000 seconds, because the outcome of this test for these events was desirable (the result shows that 17 events have the probability of being related to electromagnetic events among detected EASs); but for other discovered events did not. In figure4.7 we see count in each time window distributions for the 17 events. For each diagram there have been shown two regions, one in the end of each one where 17 events have been discovered, and the other one on the distribution peak.
4.5 A test on the certainty of finding probable gamma ray events

We obtain the ratio of found events in three time windows to total events at the end of the distribution and then compare it with the ratio of common similar events in the peak and in three time windows to total events existed there. In choosing these two regions for any time window, we are supposed to have in mind some details. Firstly, more than one interval or region around the peak are needed to be compared with the end of distribution, outskirt of that. By this way we have swept almost entire area of the distribution, finally we obtain some ratios for different comparison results and then an average of these amounts is going to be acquired. Further 7 regions or intervals -except one shown in our distributions in Figure 4.7- have been selected. The average for the ratio of joint events to the total events number in 300seconds time-window is 0.025±0.008, in 1000seconds time window 0.028±0.005 and in 3000second time-window is 0.032±0.001. The second point is that the mean count rate, \( \bar{c} \), in different time windows should conform with each other, for example, when a time window is broader than the other one, consequently its mean count rate would be three times greater, and if in 300seconds time-window scale we choose mean counts rate=7 count/300sec, so in the 1000seconds time-window scale which is about three times wider, a region around mean count rate=21count/1000sec is expected to be considered. Furthermore, when we sweep from the peak toward the skirts.

Figure 4.6: Counts in each time-window distribution for the first part.
Analysis of the data according to poisson distributions of counts in time windows

Figure 4.7: count rate (count in each time window) distributions which contain 17 probable gamma ray events. red bars at the end of distributions are related windows containing 17 events in all three time window scale (300sec, 1000sec and 3000sec) and blue bars refer to the peaks and similar events in three blue regions in three time window scale would be counted to be compared with similar events number in red regions.

In order to choose regions and doing comparison, we should be careful that the number of events decreases with a steady rate to have a much precise outcome. For 300sec and 1000sec time windows, comparison of these ratios shows that 17 events in these windows can be counted non-random, but in 3000sec time windows there is not any evidence to confirm the previous state. We can deduce that maybe 3000sec time window is not compatible with mean count rate or in other word it is too long for our analysis and for the 17 events, counts are in fluctuation in count order. Moreover, because of low count rate
4.5 A test on the certainty of finding probable gamma ray events

Figure 4.8: In this figure counts in adjacent windows in three time window scales (300sec, 1000sec and 3000sec) are presented and in any scale a window is signed which contains 17 probable gamma ray events.

we have, 10 and 30sec time-windows are too small for our analysis and so no remarkable events they would contain. Figure4.8 shows a comparison between counts in the time window which 17 events located in, and counts in adjacent time windows and this figure confirm the previous state that 3000sec time window is not appropriate for our analysis, furthermore 10sec time windows is also very small. We repeated this test for all similar events in three time-windows and are seen in table 4.3 and 4.2. Figure4.9 shows location of the 17 events in Galactic map in companion with EGRET sources placed near to them. Denoting table4.4, it is obvious that all the 17 events in all time-windows scale are referred to an individual time; it shows they are all the same events which have been appeared in three different time-windows as excesses in related time-window.
4 Analysis of the data according to poisson distributions of counts in time windows

Table 4.4: direction of all 17 events in Galactic, celestial and local coordinate and their time of detection.

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Figure 4.10: Location of 12 found events after changing time windows scale.

4.6 Considering another time windows

The next step to test certainty of these 17 events as non-random events, is to regard another time windows such as 180sec, 600sec and 800sec. in 180sec time window we observed 12 of those 17 events but in other both windows we did not. All 17 events are shown in Figure4.10 and 12 discovered events in the other time window are demonstrated with black. Around each event a region has been defined. The radius of these regions is equal to angular resolution $\Delta l \sim \Delta b \approx 13^\circ$. EGRET sources which are situated in these areas, are the most probable sources related to the 17 events. These sources are presented in table 4.5 and 4.6.
4.6 Considering another time windows

Table 4.5: 12 events of 17 ones, viewed in another time window scale of 180sec.

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5 Concluding remarks

By employing Li-Ma method, we observed some prominent sources probably related to some EGRET sources, but with this small amount of data and poor angular resolution we can’t firmly claim that these prominences are referred to any EGRET source. Another problem with our array is lacking enough space to arrange this array. Our detectors are placed on the roof of Physics Department in Sharif University of Technology. Therefore distance between two detectors is very small, as a Cherenkov tank dimension is remarkable respect to this distance, since a high amount of angular error would appear in our array. Then we preferred to apply another method to observe any EAS event pointing out a gamma ray source. Among our data 17 of the EAS events were more probable to belong to a gamma ray source. These events in galactic map are concentrated in an area broader than angular error of our WCD array. We can compare these events’ locations with the place of EGRET sources around them. In order to remove these problems, two simulations were performed to find an optimum size for Cherenkov detectors, used in the next array. In the first simulation height of 60 and diameter of 40 is an optimum size for our detector. The next simulation and data from experiments approve this size to be the optimum. We expect to arrange an array with this detector and more amounts of data to analyze.
Bibliography


Publications


