Journal of Radiation and Nuclear Applications
An International Journal

http://dx.doi.org/10.18576/jrna/040109

Verifying the Relationship between Solar Neutrinos and Solar Wind for Solar Cycle 23

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Received: 2 Nov. 2018, Revised: 2 Dec. 2018, Accepted: 20 Dec. 2018.
Published online: 1 Jan. 2019.

Abstract: The major solar energetic events of solar cycle (23) for the years (1996 -2007) are analysed by using the Energetic and Relativistic Nucleus and Electrons (ERNE) detectors, the Large Angle Spectroscopic Coronagraph experiments (LASCO) on board SOHO and the Geostationary Operational Environmental Satellite system (GOES) that is operated by the U.S. National Oceanic and Atmospheric Administration (NOAA). The number of Coronal Mass Ejection (CME) which satisfies the required conditions by testing their intensity – time profile provided by ERNE detector is 212 events, as well as the 100 solar energetic particle (SEP) events that are detected by GOES and 23176 flares has been held in this study. The captured flare by GOES are classified according to their strength include only 1339 flares of class M and X. 2313 neutrino events of energy (E_{ν}=233 keV to 15 MeV) are taken from the Soviet American Gallium Experiment (SAGE) for the same period of time of the investigated solar wind. All the extracted results are statistically analysed using the statistical program SPSS (version 20), these results indicate to a linear relationship between CME and the neutrino events for the down phase of the solar cycle 23.

Keywords: Solar Neutrinos, Solar flare; Coronal Mass Ejection (CME); Solar Energetic Particle (SEP); SOHO-LASCO-ERNE: Data base.

1 Introduction

The Sun is a magnetically unstable star of spectral type G2V that indicate to the solar activity including the solar wind. The solar wind consists of electrons, protons and electromagnetic spectrum and it is divided into Solar flares, Coronal Mass Ejections (CME) and Solar Energetic Particles (SEP) [1].

Solar flares are sudden and rapid phenomena that last from few minutes to few hours emitting high speed particles and electromagnetic radiation. The CME is a giant cloud of solar plasma confined by frozen magnetic field that expand away from the Sun into the interplanetary space during strong long-duration solar flares and filament eruptions in the corona. However, not every event has a CME accompanied with it, and SEPs are high energy particles that consists of electrons, protons, and heavy ions of very high speeds (80% of the speed of flares). Their energy varies from few keV to Gev. Complex magnetic field of the Sun are created by a mechanism of solar dynamo, and are stored as magnetic energy in the solar corona and are released through reconnection, which is the source of the solar activity [1].

Neutrino is a fermion that - according to standard model SM- belongs to leptons family with intrinsic angular momentum of (1/2). There are three generations of neutrino associated respectively with the three charged leptons: the electron (e), the muon (μ) and the tau (τ) [2]. These particles can travel at speeds relative to the speed of light [3]. The main source of the solar neutrino is the pp-chain and CNO cycle from nuclear reactions at the core of the Sun. Another source of the solar neutrino is from nuclear reactions in the solar Corona, in which the decay of the charged pion(π) particles will produce the electron neutrinos, anti-electron neutrinos, muon neutrinos and anti-muon neutrinos as in equations from Figure (1)[4,5]. This type of neutrino is known as flare neutrino and confirmed through its energy spectrum diagram shown in Figure (2) in Ref. [6] the Spectrum of core generated solar neutrinos including the neutrinos from solar flares.

The SAGE was built to measure the capture rate of solar neutrinos by the reaction, $^{71}Ga + \nu_e \rightarrow ^{71}Ge + e^-$.The feature that distinguishes the Ga experiment (and prefers it for the current study) from all other solar neutrino experiments,

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$$p + p \quad \text{or} \quad p + \alpha \longrightarrow \begin{cases} \pi^+ + X \\ \pi^0 + X \\ \pi^- + X \end{cases}$$

$$\pi^+ \longrightarrow \mu^+ + \nu_\mu \qquad \mu^+ \longrightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

$$\pi^0 \longrightarrow 2\gamma$$

$$\pi^- \longrightarrow \mu^- + \bar{\nu}_\mu \qquad \mu^- \longrightarrow e^- + \bar{\nu}_e + \nu_\mu$$

Fig. 1. Nuclear reaction of the generation of flare neutrinos on the solar Corona [4].

that it has the lowest threshold energy of 233 keV. So, even the low energetic neutrinos from the Sun are detected. This detector (i.e., experiment) is only sensitive to electron neutrinos (ν_e) [7], and it can detect the most of solar neutrino spectrum including those (ν_e) associated directly with solar flares. The reaction transforms a stable gallium atom into a radioactive isotope of germanium. Exposures used in the experiments lasted for 4 to 6 weeks. Then, the 71Ge atoms produced are chemically extracted together with the germanium carrier from gallium [7]. This fact led to the monthly extracted data in the current study. SAGE operated till 2010, which limited the time period of this study.
The "IBM SPSS statistics" is used to investigate the relationship between the solar wind and the solar neutrino events.
The main goal of this study is to track the solar neutrino and to investigate its relationship with the solar energetic events such as the solar wind. The importance of this study lies in that since the neutrinos are the most penetrating particles and it can be travel huge distances without losing information. Neutrino provides all the information about the Sun, its interior, activity, magnetic field and solar reactions, as well as for the other stars.
Other studies are performed to search for a relation between the solar neutrino and any of the solar activities. Erofeeva and et.al, in 1987, calculated neutrinos and photons of energies > 10 MeV that are generated in large solar flares. Then by measuring photons of energies > 10 MeV they proved the theory [8]. Fukugita et. al, in 1989 found; by estimating the neutrino Reaction cross section with Cl-37 and O-16 targets; that the total number of neutrino events was rather small, and only few events, in a few hours, could have been counted as " anomalous" (i.e. associated with large solar flares) [9]. Aharmim et. al, in 2013, from Sudbury Neutrino Observatory (SNO) experiment searched for neutrinos associated with sources other than the solar core, such as solar flares. They concluded that No correlations were found between neutrinos detected in SNO and such astrophysical sources [10]. From Ice-cube detector Wasseige et.al, found direct relation between solar neutrino and solar flare events by time profile analysis using the Geant4 toolkit [4]. Recently in 2017, Fargion and Oliva tracked solar flare and their sudden neutrino (or anti-neutrino) flare that made by proton scattering and pion decays via Delta resonance production. According to them these signals might be observable at largest flare by Hyper-Kamiokande HK through soft spectra up to tens-hundred MeV energy and by IceCube-PINGU at higher, GeV up to hundred GeV, energies. And the existence of solar flare neutrinos was archived [11].

2 Data Handling

-The Neutrino Candidate Events counted per unit of time (i.e., month), for neutrino energy (E_ν=233 keV to 15 MeV) and 2293 candidate events are taken from the SAGE for a period of time from May 1996 to December 2007 [12].
-The13094 CMEs observed by SOHO/LASCO for the years 1996-2007. These data are filtered according to radial speed of $\left(\vartheta \geq 450 \frac{km}{s}\right)$ and angular width($AW \geq 50°$), 2012 CME are to be left over as result of this filtration [13].
-From the logarithmic intensity- time profile of proton for resolution time of 1 hour from ERNE detector the CMEs events has been extracted and they were 112 events [14].
-The major SEP events that observed by GOES were 100 events [15].
-The investigated Solar flares in this study for the solar cycle (23) were extracted from GOES satellite and they were 23178 events. All of the captured flares were filtered in order to separate and classify them according to flare classes (A, B, C, M and X) which determine the flare strength. Only the strongest flares of power per unit area of 10^{-5} – 10^{-4} watts/m^{2}class (M) were 1229 events, and for class (X) power per unit area of ≥ 10^{-4} watts/m^2 were 114 events.

Later each of the nominated CME events, SEP events and flares are added separately to give monthly data for the years (1996-2007) [16].
All the mentioned data ahead are statistically analysed to investigate the relation between the solar neutrino and the solar wind observations for the solar cycle (23).

3 Statistical Analysis

Statistical approaches are an important process to detect the correlation between data sets. All observation has been statistically analysed by means of the statistical software (SPSS) program to find correlations between neutrino candidate events and the solar wind as measured from SOHO/ERNE and GOES of solar cycle (23)
The Pearson's coefficient that varies between 1 and -1 indicates the strength and direction of the relation, the positive sign indicates a positive correlation and vice versa. To test the hypothesis, the significance of the correlation should be equal or less than (0.01 or 0.05), for the Nell hypothesis (i.e. there is no statistically significant relationship between the two data sets) to be rejected and the alternative hypotheses (there is a statistically significant relation) accepted. The number of variables included in the analysis is given as N.

4 Results and Discussion

Figures (2) to (6) shows the variation in the number of neutrino candidate events (blue coloured) with time, along with each of the Solar flares, SEPs and CMEs (red coloured) separately. The red rectangular shapes surround the related peaks of the two data sets. Some neutrino events peaks are related to solar wind peaks; the other peaks are light. According to this, a small shift in the peaks between each of neutrino events in one hand and CME and SEPs in the other hand, will be true for periods of time in seconds, hours or even days. But since the period of time in the current study is in months this shift should not appear.

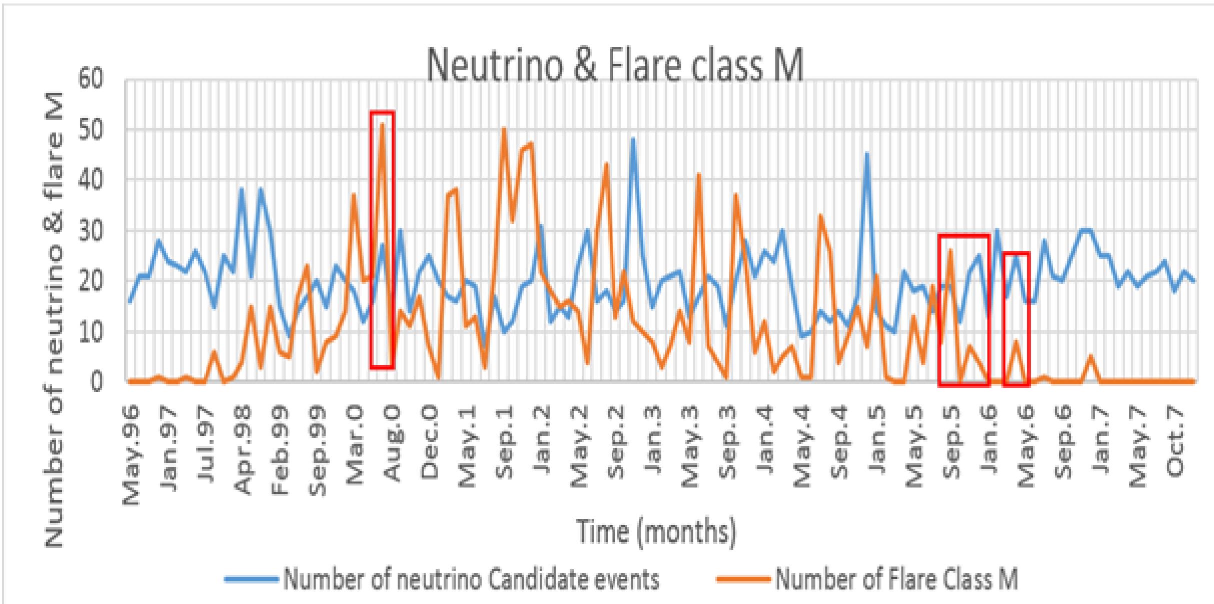

Fig. 2:The variation in the number of Candidate Neutrino Events and solar flare of class M.

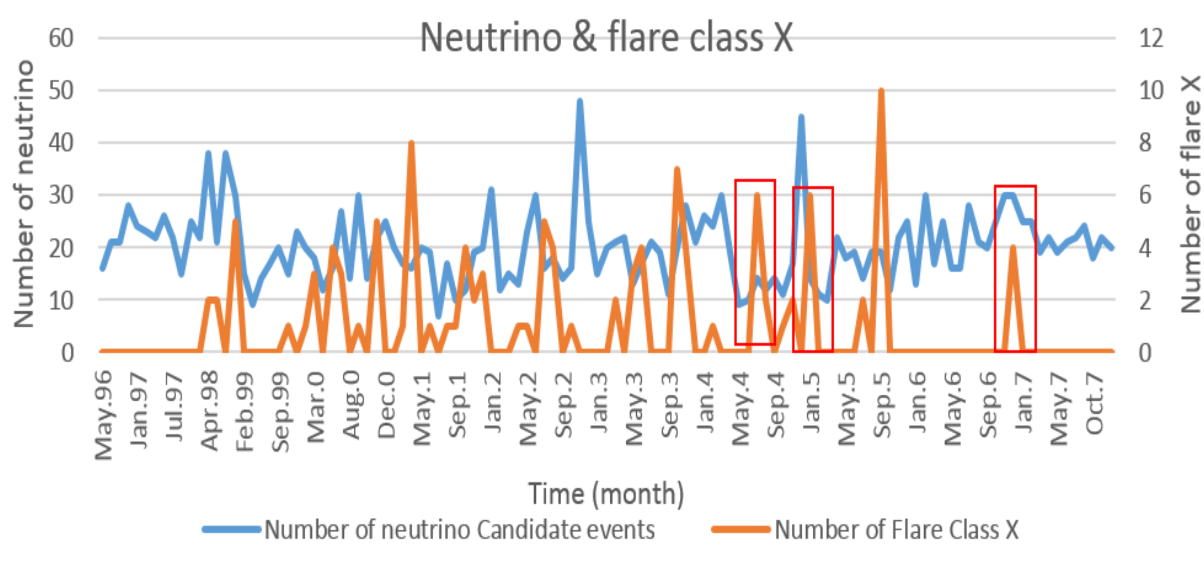

Fig. 3: The variation in the number of Candidate Neutrino Events and solar flare of class X.

Neutrino particles travel at speeds close to that of light - regardless of the density of the medium it passes through due to its very small interaction cross-section-, whereas the speed of the CME and SEPs are not close to the speed of

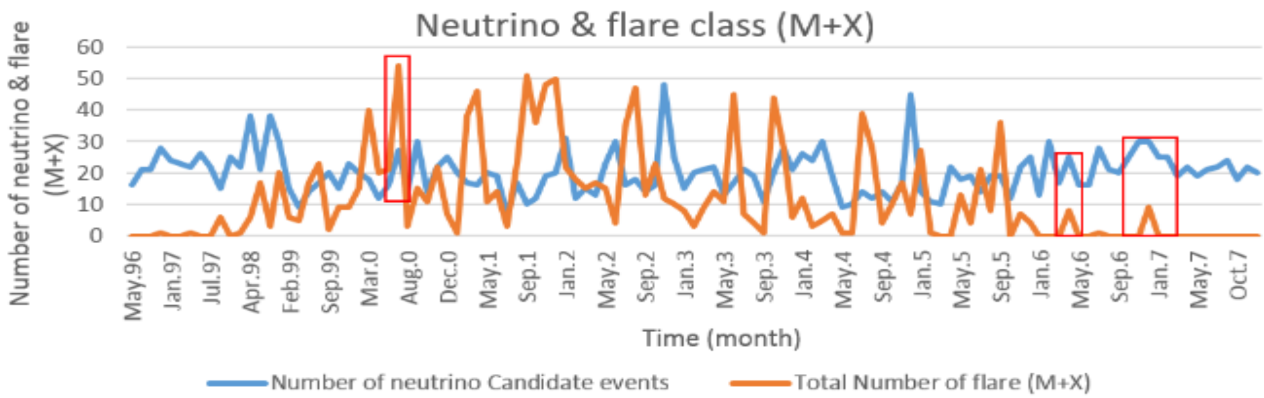

Fig. 4: The variation in the number of Candidate Neutrino Events and solar flare (M+X).

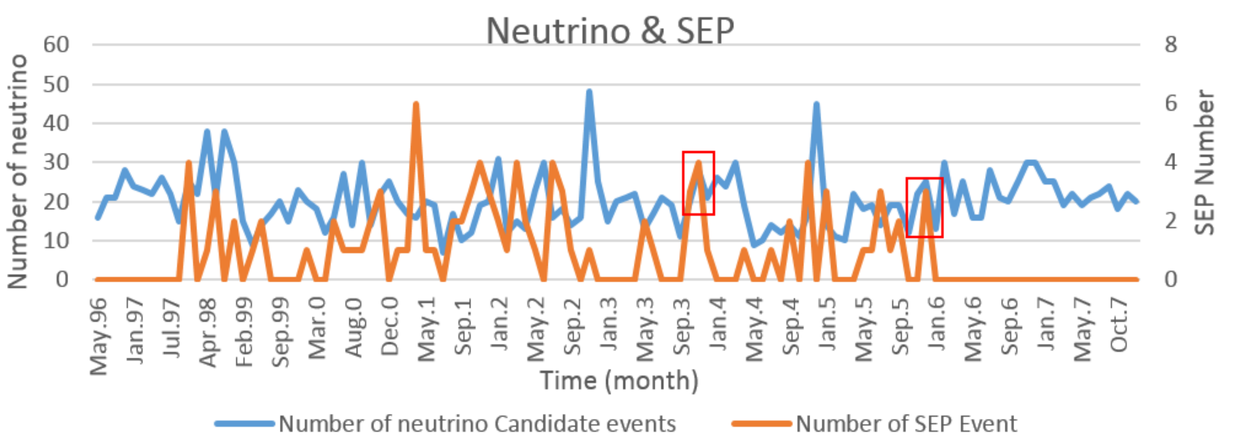

Fig. 5: The variation in the number of Candidate Neutrino Events and SEP events with time.

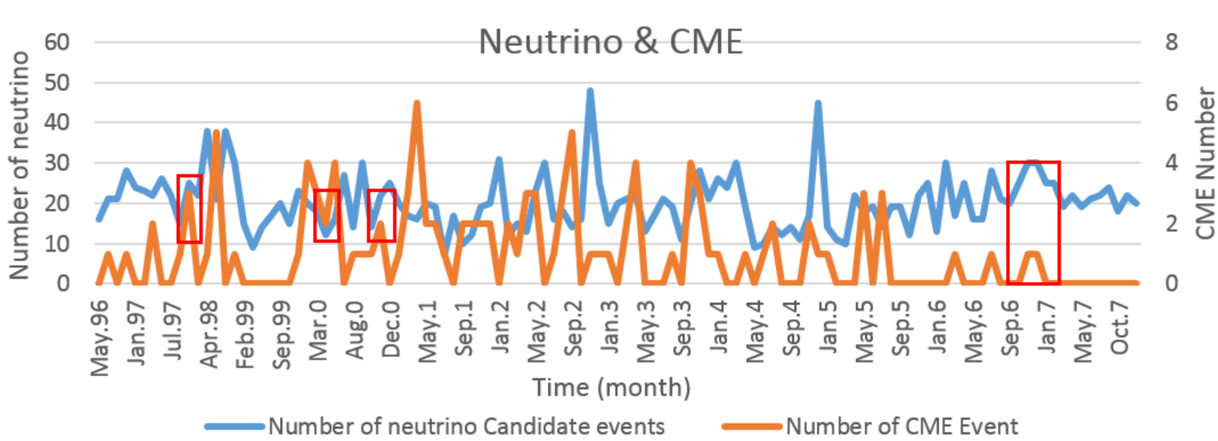

Fig. 6: The variation in the number of Candidate Neutrino Events and CME events with time.

class M, flare class X, flare (X+M), SEP events and CME events with the monthly neutrino candidate events as detected from SAGE for the years 1996-2007 have no statistically significant relation, table (1).

The three main regions (rising phase, peak and down phase) of the 23rd solar cycle were investigated, for a short period the presence of a relation between any of the high energetic solar flares, SEP events and CME events with the number of candidate neutrino events, as in tables (2), (3) and (4). Again despite of the existing Pearson's coefficient values, the P values indicates no statistically significant relationship. Then noticeably for down phase a statistically significant relation does exist between the neutrino candidate events and the CME, r(23) = 0.414 as in table (4).After that, a further step was applied to estimate the describing equation through regression. From table (5), the linear regression equation is given in Equation (1), Figure (7) shows the relation graphically.

$N_v = 21.211 + (5.039 \times N_{CME})$ .... (1)

Where

N_v: is the number of neutrino candidate events

N_{CME} : is the number of CME events

Table 1: The correlation relation between number of Neutrino candidate events and the energetic events of the years (1996- 2007).

		Flare Class M	Flare Class X	Total flare	SEP Event	CME Event
Number of Candidate events	Pearson Correlation	-.156	-.073	-.150	-.114	-.085
	Sig. (2-tailed)	.096	.438	.110	.225	.366
	N	115	115	115	115	115

Table 2: The correlation relation between number of Neutrino candidate events and the energetic events of the years (1996 & 1997).

		Flare Class M	Flare Class X	Total flare	SEP Event	CME Event
Number of Candidate events	Pearson Cor-relation	-.523	.[a]	-.523	.246	.157
	Sig. (2-tailed)	.081	.	.081	.440	.626
	N	12	12	12	12	12

a. Cannot be computed because at least one of the variables is constant.

Table 3: The correlation relation between number of Neutrino candidate events and the energetic events of the year 2000.

	Flare Class M		Flare Class X	Total flare	SEP Event	CME Event
Number of Candidate events	Pearson Correlation	.210	.160	.234	-.068	-.417
	Sig. (2-tailed)	.536	.639	.489	.842	.201
	N	11	11	11	11	11

Table 4: The correlation relation between number of Neutrino candidate events and the energetic events of the yeas (2006-2007).

		Flare Class M	Flare Class X	Total flare	SEP Event	CME Event
Number of Candidate events	Pearson Correlation	.344	.366	.395	.[a]	.414*
	Sig. (2-tailed)	.108	.086	.062	.	.050
	N	23	23	23	23	23

a.Cannot be computed because at least one of the variables is constant.

Table 5: The coefficients table of the linear regression equation for the number of candidate neutrino events as the dependents variable and number of CME events as the independent variable.

	Unstandardized Coefficients		Standardized Coeffic-ients	t	Sig.
	B	Std. Error	Beta		
CME Event	5.039	2.419	.414	2.084	.050
(Constant)	21.211	1.009		21.029	.000

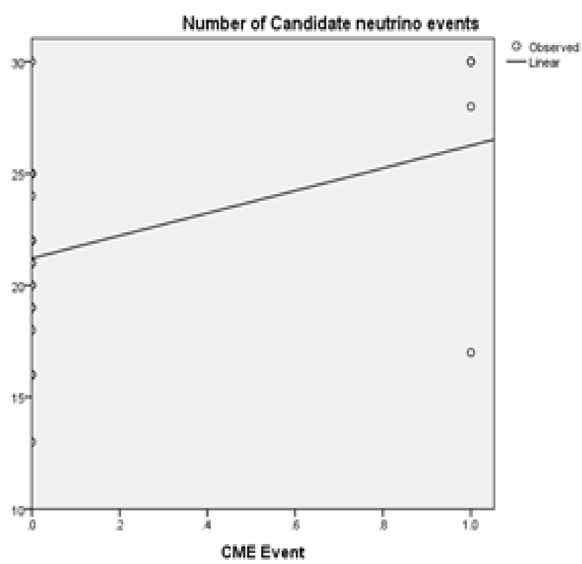

Fig. 7: The linear relation between the number of Candidate Neutrino Events (dependent variable) and CME events (independent variable).

Related studies searched for neutrino events of ($E_v > \sim 50\ MeV$) in the KAMIOKANDE II detector is correlated with the solar flare, by observing great solar flares in march 1989 and no evidence could be obtained [17]. Another study was provided the same result by observing the large flares for the period of July 1983–July 1988, giving a limit on the time-integrated solar flare which are comparative to the final results of the current study [18].

Erofeeva et.al , Wasseige et.al and Fargion and Oliva in their studies took into account individual flares of specific energy and class. They proved that these flares are associated with solar neutrino events. The current study included all the energetic solar activities that believed to reach the Earth in a time profile simultaneous to the captured neutrino particles by SAGE experiment. The present study used the time scale of months for two reasons. First: to escape the complexity of time shift between the solar neutrino, and solar flare neutrino (which are undistinguishable yet by SAGE and many other underground detectors) in one hand and solar flares, CME and SEPs in other hand. Second: Gallium experiments do not directly count the neutrino events, but the exposure lasts for 4 to 6 weeks then the Germanium atoms are extracted and processed to know the final number of the candidate neutrino events for that period of time. Since the present study included both core and solar surface neutrinos, the current results were varied from theirs.

The data analysis of the current study differs from the previous studies in

- Using statistical analysis to find the correlation, then the regression equation is used on the most correlated data to estimate the most descriptive equation in tracking neutrinos generated from solar activities.
- Searching for a relation for a long period of time (1996-2007), by taking the monthly summation for each of SEPs, CMEs and strong solar flares. While in the other studied the comparison was done for shorter periods and single flare (i.e. each flare separately)

5 Conclusions

The outcome results lead to the following conclusions:

For long period of time (1996-2007), no significant relation was found between the solar wind and the solar neutrino events, For periods of time of two years and less, and by comparing the three main regions of the solar cycle (the peak and both rising and down phase) with the neutrino events evident no significant relation could be found. Except for the CME for years (2006-2007) a weak positive significant linear correlation exists, Big factors affected the out coming result, they are The very small number of neutrinos detected by the neutrino detectors, has a great impact on the outcome result. Since the majority of neutrino particles pass through the detector unnoticeably,

Neutrino data for longer periods of time (i.e. at least for two or three solar cycles) is required to estimate accurate results,The Solar flares detected from GOES and the counted SEP and CME events covers a wide range of area as they could be detected by satellites. In the other hand, the neutrino experiment is located underground, limiting the range of area for the detected solar neutrinos, The SAGE is only sensitive to electron neutrino. Despite of the fact that it should be able to sense almost all of the solar core neutrino ν_e (i.e. if they weren't oscillating into the other flavours), it can only detect ¼ of the solar flare neutrinos, because ν_e is only ¼ of flare neutrinos, referring back to equations in Figure (1).

This study focused on the total summation of monthly data instead of single events comparison, this was done to exclude the complexity of the shift in time among the different solar events.

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