Search for Annual Modulation of WIMPs with the Large NaI(Tl) Scintillators of ELEGANT V

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The cold dark matter such as Weakly Interacting Massive Particles(WIMPs) hypothetically forms a large fraction of our galaxy[1]. WIMPs could be directly detected through the nuclear recoil induced by their elastic and inelastic scattering with detector target[1]. The expected recoil energy spectrum has a exponential shape with a characteristic energy less than 100keV. The event rate of the WIMPs signals, which depends on the model of WIMPs, is the order of 1event/kg/day. Thus the measurement with the low energy threshold and with extremely low background condition is required for WIMPs search. The purpose of this work is to look for the annual modulation[1] of the WIMPs signal.

The data considered here has been collected at Oto Cosmo Observatory from the middle of May,1999 to the beginning of July,2000. The modules, to be taken into account the analysis, were selected as the conditions(see Ref.[4]). After the selections, 9 modules were selected for the analysis at the energy bin of 4 - 5keV, and 11 modules at the energy higher than 5keV.

The procedure used to extract the periodic component follows the method in Ref.[2]. The observed event rate is expressed, in first order, as $S_{obs}(t) = \langle B \rangle + \langle S_0 \rangle + S_m \cos(\omega t)$, where brackets mean the average of Poisson distributed variables, ω is inverse modulation period, t is the day from June 2nd when the maximum is expected. S_0 and S_m are the unmodulated and modulated components of WIMPs signal, respectively. The analyses were carried out for each energy bin between 4 to 10keV, and also for higher energy region to check the stability of systematics. The obtained values are given in Table 1. No significant deviation above the statistical fluctuation was found in the data. Consequently, the exclusion plots can be obtained by comparing the experimental upper limits on the modulation components with expected ones. The expected values were calculated with the assumptions of astrophysical parameters(local density, velocities of WIMPs model[2]), nuclear physics parameters(spin matrix elements[2], nuclear form factors) and experimental conditions(energy threshold, resolution and light output responses[4]). The parameters used for the calculation are summarized in Table 2.

The form factors used here for the spin independent interaction are Helm form factors[2]. For the spin dependent case, form factors are more complex ones[2]. For the comparison of the results obtained with different nuclei, the exclusion plots were represented by the cross section for proton. They are shown in Fig.1 for the interactions of both spin independent and dependent.

In case of the spin independent interaction, the cross section is scaled according to A^2. Nuclear recoils occur mostly on iodine, the expected differential energy spectrum forms steeply decreasing and most of the signals below 4keV(threshold). The sensitivity comes from the event rate at the lowest energy. The present work was not sensitive enough to neither to exclude nor prove the claimed candidate of DAMA/NaI experiment[3]. The detector with much low background and/or the lower energy threshold are required to improve the sensitivity for the spin independent interaction.

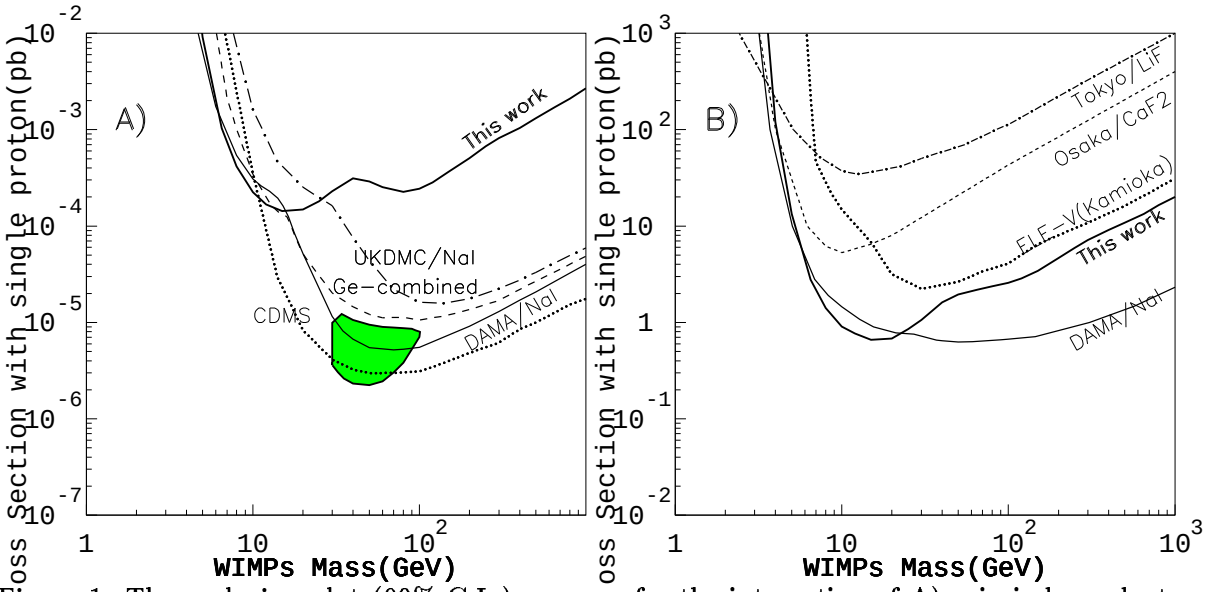

Figure 1: The exclusion plots(90% C.L.) on $\sigma_{p-\chi}$ for the interaction of A) spin independent and B) dependent from this work and other experiments, including the positive result of DAMA/NaI experiment

On the other hand, the most stringent limit was obtained for the spin dependent interaction with the low WIMPs mass. The quenching factor of Na nucleus in the NaI scintillator is larger than that of Iodine nucleus. In addition, the spin form factor of ^{23}Na is the two orders of magnitude larger than that of ^{127}I at the characteristic recoil energy of 100keV. Thus, the sensitivity for spin dependent interaction is efficient to improve the published limits.

Table 1: The modulation amplitudes and their dispersions for the cosine modulation analysis.

Energy bin (keV)	Exposure (kg × day)	S_m (/day/kg/keV)	$\sigma(S_m)$ (/day/kg/keV)
4-5	328.5 × 340.5	0.009	0.019
5-6		-0.007	0.014
6-7		0.009	0.011
7-8		0.003	0.011
8-9	401.5 × 340.5	-0.005	0.010
9-10		0.004	0.010
(keV)		(/day/kg)	
10-15		-0.011	0.021
15-20		0.014	0.020

Table 2: List of parameters used for the calculation of WIMPs spectra.

Parameter	Value
WIMPs local density	0.3GeV/cc
WIMPs mean velocity	220km/sec
Escape velocity	600km/sec
Earth velocity	230±15km/sec
Spin factor ^{23}Na	0.089
^{127}I	0.126
Quenching factor ^{23}Na	0.40
^{127}I	0.05

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