



## Recent results from DAMA/LIBRA-phase1 and perspectives

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### Abstract

The DAMA/LIBRA experiment, consisting of about 250 kg of highly radio-pure NaI(Tl) target, is running deep underground at the Gran Sasso National Laboratory (LNGS) of the I.N.F.N.; its main aim is the investigation of Dark Matter (DM) particles in the Galactic halo by means of the model independent DM annual modulation signature. In this paper we briefly summarize the results obtained in its first phase of measurements (DAMA/LIBRA–phase1) lasted for 7 annual cycles with a total exposure of 1.04 ton × yr. The DAMA/LIBRA–phase1 and the former DAMA/NaI data (cumulative exposure 1.33 ton × yr, corresponding to 14 annual cycles) give evidence at 9.3  $\sigma$  C.L. for the presence of DM particles in the galactic halo. No systematic or side reaction able to mimic the exploited DM signature has been found or suggested by anyone over more than a decade. At fall 2010 a relevant upgrade of the experiment has been performed: all the PMTs have been replaced by new ones having higher quantum efficiency. After some optimization periods, a new phase of measurement, DAMA/LIBRA–phase2, has began in this new configuration with increased sensitivity. Some of the perspectives of the presently running DAMA/LIBRA–phase2 are mentioned.

### 1. Introduction

The DAMA project is based on the development and use of low background scintillators. In particular, the second generation DAMA/LIBRA apparatus [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13], as the former DAMA/NaI (see for example Ref. [8, 14, 15] and references therein), is further investigating the presence of DM particles in the galactic halo by exploiting the model independent DM annual modulation signature, originally suggested in the mid 80's[16].

At present DAMA/LIBRA is running in its phase2. The detailed description of the DAMA/LIBRA set-up during the phase1 has been discussed in details in Ref. [1, 2, 3, 4, 8]. Briefly we remind that the sensitive part of this set-up is made of 25 highly radiop-

ure NaI(Tl) crystal scintillators (5-rows by 5-columns matrix) having 9.70 kg mass each one. The detectors are housed in a sealed low-radioactive copper box installed in the center of a low-radioactive Cu/Pb/Cd-foils/polyethylene/paraffin shield; moreover, about 1 m concrete (made from the Gran Sasso rock material) almost fully surrounds (mostly outside the barrack) this passive shield, acting as a further neutron moderator. A threefold-level sealing system prevents the detectors to be in contact with the environmental air of the underground laboratory. The light response of the detectors during phase1 typically ranges from 5.5 to 7.5 photoelectrons/keV, depending on the detector. The hardware threshold of each PMT is at single photoelectron, while a software energy threshold of 2 keV electron equivalent

(hereafter keV) has been used in the phase1.

The signature exploited by DAMA/LIBRA (the model independent DM annual modulation) is a consequence of the Earth's revolution around the Sun; in fact, the Earth should be crossed by a larger flux of DM particles around  $\approx 2$  June (when the projection of the Earth orbital velocity on the Sun velocity with respect to the Galaxy is maximum) and by a smaller one around  $\approx 2$  December (when the two velocities are opposite). This DM annual modulation signature is very effective since the effect induced by DM particles must simultaneously satisfy many requirements: the rate must contain a component modulated according to a cosine function (1) with one year period (2) and a phase peaked roughly  $\approx 2$  June (3); this modulation must only be found in a well-defined low energy range, where DM particle induced events can be present (4); it must apply only to those events in which just one detector of many actually “fires” (*single-hit* events), since the DM particle multi-interaction probability is negligible (5); the modulation amplitude in the region of maximal sensitivity must be  $\approx 7\%$  for usually adopted halo distributions (6), but it can be larger (even up to  $\approx 30\%$ ) in case of some possible scenarios such as e.g. those in Ref. [17, 18]. Thus this signature is model independent, very discriminating and, in addition, it allows the test of a large range of cross sections and of halo densities.

This DM signature might be mimicked only by systematic effects or side reactions able to account for the whole observed modulation amplitude and to simultaneously satisfy all the requirements given above. No one is available [1, 2, 3, 4, 7, 8, 12, 19, 14, 15, 13].

## 2. The results of DAMA/LIBRA–phase1 and DAMA/NaI

The total exposure of DAMA/LIBRA–phase1 is 1.04 ton  $\times$  yr in seven annual cycles; when including also that of the first generation DAMA/NaI experiment it is 1.33 ton  $\times$  yr, corresponding to 14 annual cycles [2, 3, 4, 8].

To point out the presence of the signal the time behaviour of the experimental residual rates of the *single-hit* scintillation events for DAMA/NaI and DAMA/LIBRA–phase1 in the (2–6) keV energy interval are plotted in Fig. 1. In the Figure the major upgrades of the experiment are also pointed out.

The  $\chi^2$  test excludes the hypothesis of absence of modulation in the data:  $\chi^2/\text{d.o.f.} = 83.1/50$  and the P-value is  $P = 2.2 \times 10^{-3}$  for the (2–6) keV energy interval. When fitting the *single-hit* residual rate of DAMA/LIBRA–phase1 together with the DAMA/NaI ones, with the function:  $A \cos \omega(t - t_0)$ , considering a

period  $T = \frac{2\pi}{\omega} = 1$  yr and a phase  $t_0 = 152.5$  day (June 2<sup>nd</sup>) as expected by the DM annual modulation signature, the following modulation amplitude is obtained:  $A = (0.0110 \pm 0.0012)$  cpd/kg/keV corresponding to  $9.2 \sigma$  C.L..

When the period, and the phase are kept free in the fitting procedure, the modulation amplitude is  $(0.0112 \pm 0.0012)$  cpd/kg/keV ( $9.3 \sigma$  C.L.), the period  $T = (0.998 \pm 0.002)$  year and the phase  $t_0 = (144 \pm 7)$  day, values well in agreement with expectations for a DM annual modulation signal. In particular, the phase is consistent with about June 2<sup>nd</sup> and is fully consistent with the value independently determined by Maximum Likelihood analysis (see later). For completeness, we recall that a slight energy dependence of the phase could be expected in case of possible contributions of non-thermalized DM components to the galactic halo, such as e.g. the SagDEG stream [20, 21, 22] and the caustics [23].

We stress that by performing the run test and the  $\chi^2$  test on the data, we have shown that the modulation amplitudes singularly calculated for each annual cycle of DAMA/NaI and DAMA/LIBRA–phase1 are normally fluctuating around their best fit values [2, 3, 4].

We have also performed a Fourier analysis on the data [8] in terms of the power spectrum of the *single-hit* residuals of DAMA/LIBRA–phase1 and DAMA/NaI by considering the Lomb-Scargle approach; the same analysis has been also performed in the energy interval just above the region where the signal is present, (6–14) keV. It has been obtained that the principal mode is present in the (2–6) keV energy interval at a frequency of  $2.737 \times 10^{-3} \text{ d}^{-1}$ , corresponding to a period of  $\approx 1$  year and that only alias peaks are present in the (6–14) keV energy interval where no modulation is observed.

Absence of any other significant background modulation in the energy spectrum has been verified in energy regions not of interest for DM; e.g. the measured rate integrated above 90 keV,  $R_{90}$ , as a function of the time has been analysed [4]. Similar result is obtained in other energy intervals. It is worth noting that the obtained results account of whatever kind of background and, in addition, no background process able to mimic the DM annual modulation signature (that is able to simultaneously satisfy all the peculiarities of the signature and to account for the whole measured modulation amplitude) is available (see also discussions e.g. in Ref. [1, 2, 3, 4, 7, 8, 12, 13]).

A further relevant investigation in the DAMA/LIBRA–phase1 data has been performed by applying the same hardware and software procedures, used to acquire and to analyse the *single-hit*

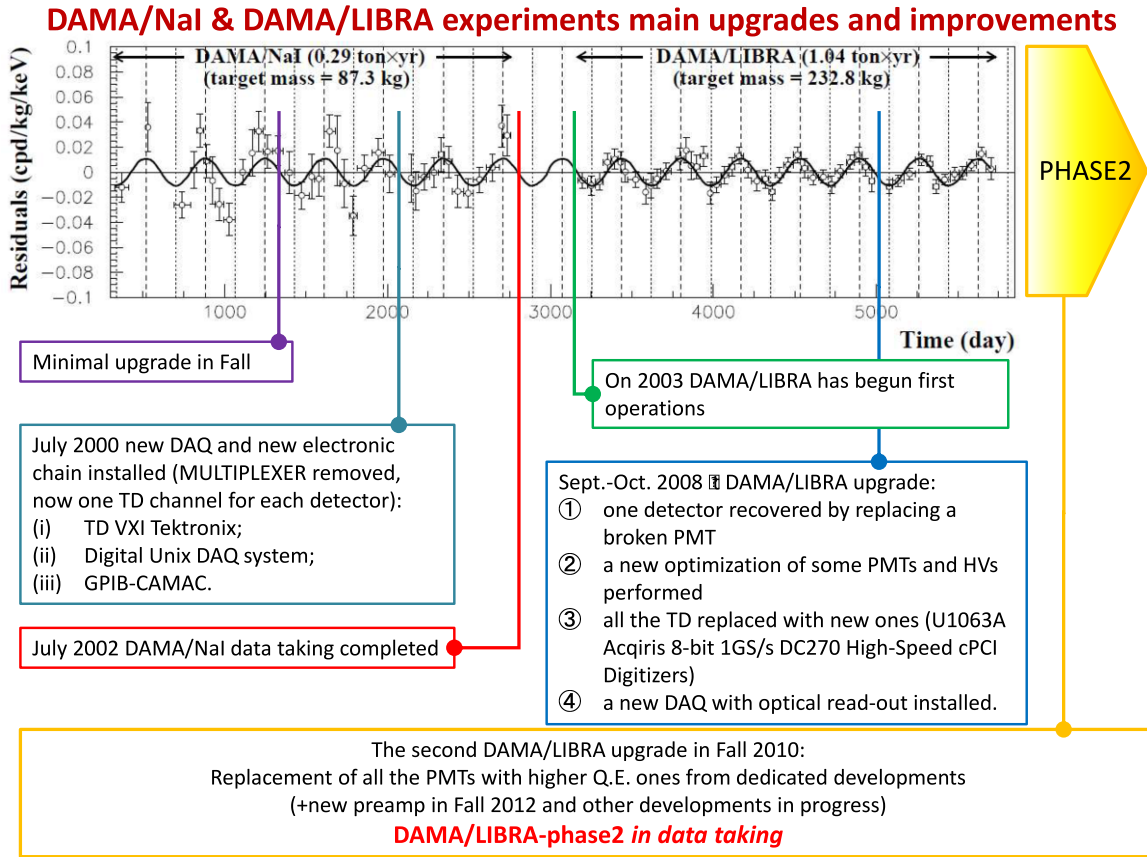


Figure 1: Experimental residual rate of the *single-hit* scintillation events measured by DAMA/NaI and DAMA/LIBRA–phase1 in the (2–6) keV energy interval as a function of the time. The data points present the experimental errors as vertical bars and the associated time bin width as horizontal bars. The superimposed curves are the cosinusoidal functions behaviors  $A \cos(\omega(t - t_0))$  with a period  $T = \frac{2\pi}{\omega} = 1$  yr, a phase  $t_0 = 152.5$  day (June 2<sup>nd</sup>) and modulation amplitudes,  $A$ , equal to the central values obtained by best fit on the data points. The dashed vertical lines correspond to the maximum expected for the DM signal (June 2<sup>nd</sup>), while the dotted vertical lines correspond to the minimum. The major upgrades of the experiment are also pointed out.

residual rate, to the *multiple-hit* one. In fact, since the probability that a DM particle interacts in more than one detector is negligible, a DM signal can be present just in the *single-hit* residual rate. Thus, the comparison of the results of the *single-hit* events with those of the *multiple-hit* ones corresponds practically to compare between them the cases of DM particles beam-on and beam-off. This procedure also allows an additional test of the background behaviour in the same energy interval where the positive effect is observed. In particular, the residual rates of the *single-hit* events measured over the DAMA/LIBRA–phase1 annual cycles are reported in Ref. [4], as collected in a single cycle, together with the residual rates of the *multiple-hit* events, in the (2–6)

keV energy interval. A clear modulation satisfying all the peculiarities of the DM annual modulation signature is present in the *single-hit* events, while the fitted modulation amplitude for the *multiple-hit* residual rate is well compatible with zero:  $-(0.0005 \pm 0.0004)$  cpd/kg/keV in the same energy region (2–6) keV. Thus, again evidence of annual modulation with the features required by the DM annual modulation signature is present in the *single-hit* residuals (events class to which the DM particle induced events belong), while it is absent in the *multiple-hit* residual rate (event class to which only background events belong). Similar results were also obtained for the last two annual cycles of the DAMA/NaI experiment [15], when the electronics

allowed it. Since the same identical hardware and the same identical software procedures have been used to analyse the two classes of events, the obtained result offers an additional strong support for the presence of a DM particle component in the galactic halo.

By performing a maximum-likelihood analysis it is possible to extract from the data the modulation amplitude,  $S_{m,k}$ , as a function of the energy considering  $T = 1$  yr and  $t_0 = 152.5$  day. For such purpose the likelihood function of the *single-hit* experimental data in the  $k$ -th

energy bin is defined as:  $\mathbf{L}_k = \prod_{ij} e^{-\mu_{ijk}} \frac{\mu_{ijk}^{N_{ijk}}}{N_{ijk}!}$ , where  $N_{ijk}$  is the number of events collected in the  $i$ -th time interval (hereafter 1 day), by the  $j$ -th detector and in the  $k$ -th energy bin.  $N_{ijk}$  follows a Poisson's distribution with expectation value  $\mu_{ijk} = [b_{jk} + S_{ik}] M_j \Delta t_i \Delta E \epsilon_{jk}$ . The  $b_{jk}$  are the background contributions,  $M_j$  is the mass of the  $j$ -th detector,  $\Delta t_i$  is the detector running time during the  $i$ -th time interval,  $\Delta E$  is the chosen energy bin,  $\epsilon_{jk}$  is the overall efficiency. Moreover, the signal can be written as  $S_{ik} = S_{0,k} + S_{m,k} \cdot \cos \omega(t_i - t_0)$ , where  $S_{0,k}$  is the constant part of the signal and  $S_{m,k}$  is the modulation amplitude. The usual procedure is to minimize the function  $y_k = -2 \ln(\mathbf{L}_k) - \text{const}$  for each energy bin; the free parameters of the fit are the  $(b_{jk} + S_{0,k})$  contributions and the  $S_{m,k}$  parameter. Hereafter, the index  $k$  is omitted for simplicity.

In Fig. 2 the obtained  $S_m$  are shown by considering energy bin of 0.5 keV obtained from the data of DAMA/NaI and DAMA/LIBRA-phase1. It can be inferred that positive signal is present in the (2–6) keV energy interval, while  $S_m$  values compatible with zero are present just above. In fact, the  $S_m$  values in the (6–20) keV energy interval have random fluctuations around zero with  $\chi^2$  equal to 35.8 for 28 degrees of freedom (upper tail probability of 15%). All this confirms the previous analyses.

As described in Ref. [2, 3, 4, 8], the observed annual modulation effect is well distributed in all the 25 detectors, the annual cycles and the energy bins at 95% C.L.

Further analyses have been performed. All of them confirm the evidence for the presence of an annual modulation in the data satisfying all the requirements for a DM signal.

Sometimes naive statements were put forwards as the fact that in nature several phenomena may show some kind of periodicity. The point is whether they might mimic the annual modulation signature in DAMA/LIBRA (and former DAMA/NaI), i.e. whether they might be not only quantitatively able to account for the observed modulation amplitude but also able to con-

temporaneously satisfy all the requirements of the DM annual modulation signature. The same is also for side reactions. This has already been deeply investigated in Ref. [1, 2, 3, 4] and references therein; the arguments and the quantitative conclusions, presented there, also apply to the entire DAMA/LIBRA-phase1 data. Additional arguments can be found in Ref. [7, 8, 12, 13].

No modulation has been found in any possible source of systematics or side reactions; thus, cautious upper limits on possible contributions to the DAMA/LIBRA measured modulation amplitude are summarized in Ref. [2, 3, 4]. It is worth noting that they do not quantitatively account for the measured modulation amplitudes, and also are not able to simultaneously satisfy all the many requirements of the signature. Similar analyses have also been done for the DAMA/NaI data [14, 15].

In particular, in Ref. [13] a simple and intuitive way why the neutrons, the muons and the solar neutrinos cannot give any significant contribution to the DAMA annual modulation results is outlined. Table 1 summarizes the safety upper limits on the contributions to the observed modulation amplitude due to the total neutron flux at LNGS, either from  $(\alpha, n)$  reactions, from fissions and from muons' and solar-neutrinos' interactions in the rocks and in the lead around the experimental set-up; the direct contributions of muons and solar neutrinos are also reported there. As seen in Table 1, they are all negligible and they cannot give any significant contribution to the observed modulation amplitude. In addition, neutrons, muons and solar neutrinos are not a competing background when the DM annual modulation signature is investigated since in no case they can mimic this signature. For details see Ref. [13] and references therein.

In conclusion, DAMA give model-independent evidence (at  $9.3\sigma$  C.L. over 14 independent annual cycles) for the presence of DM particles in the galactic halo.

This obtained model independent evidence is compatible with a wide set of scenarios regarding the nature of the DM candidate and related astrophysical, nuclear and particle Physics (see e.g. Ref. [14, 2, 8] and references therein).

### 3. On comparisons

Let us recall some arguments about the comparison between the DAMA result and the result obtained by other experiment in the field. No direct model independent comparison is possible in the field when different target materials and/or approaches are used; the same is for the strongly model dependent indirect searches.

In order to perform corollary investigations on the nature of the DM particles, model-dependent analyses are

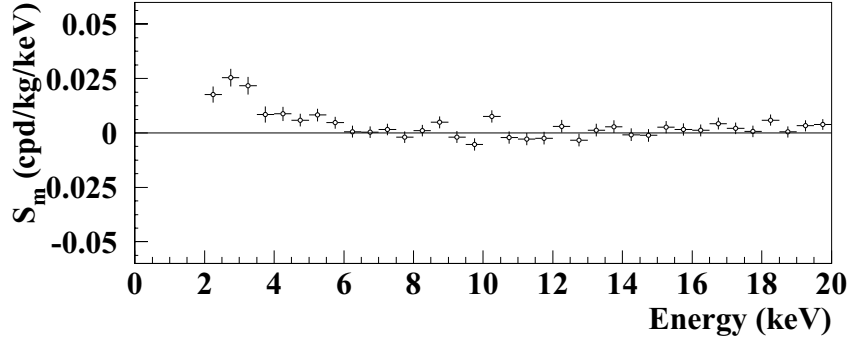


Figure 2: Energy distribution of the  $S_m$  variable for the total cumulative exposure 1.33 ton $\times$ yr. The energy bin is 0.5 keV. A clear modulation is present in the lowest energy region, while  $S_m$  values compatible with zero are present just above. In fact, the  $S_m$  values in the (6–20) keV energy interval have random fluctuations around zero with  $\chi^2$  equal to 35.8 for 28 degrees of freedom (upper tail probability of 15%).

Table 1: Summary of the contributions to the total neutron flux at LNGS; the value, the relative modulation amplitude, and the phase of each component is reported. It is also reported the counting rate in DAMA/LIBRA for *single-hit* events, in the (2 – 6) keV energy region induced by neutrons, muons and solar neutrinos, detailed for each component. The modulation amplitudes,  $A_k$ , are reported as well, while the last column shows the relative contribution to the annual modulation amplitude observed by DAMA/LIBRA,  $S_m^{exp} \simeq 0.0112$  cpd/kg/keV [4]. As can be seen, they are all negligible and they cannot give any significant contribution to the observed modulation amplitude. In addition, neutrons, muons and solar neutrinos are not a competing background when the DM annual modulation signature is investigated since in no case they can mimic this signature. For details see Ref. [13] and references therein.

Source	$\Phi_{0,k}^{(n)}$ (neutrons cm <sup>-2</sup> s <sup>-1</sup> )	$\eta_k$	$t_k$	$R_{0,k}$ (cpd/kg/keV)	$A_k = R_{0,k}\eta_k$ (cpd/kg/keV)	$A_k/S_m^{exp}$	
SLOW neutrons	thermal n (10 <sup>-2</sup> – 10 <sup>-1</sup> eV)	1.08 × 10 <sup>-6</sup>	≈ 0 however ≪ 0.1	–	< 8 × 10 <sup>-6</sup>	≪ 8 × 10 <sup>-7</sup>	≪ 7 × 10 <sup>-5</sup>
	epithermal n (eV-keV)	2 × 10 <sup>-6</sup>	≈ 0 however ≪ 0.1	–	< 3 × 10 <sup>-3</sup>	≪ 3 × 10 <sup>-4</sup>	≪ 0.03
FAST neutrons	fission, (α, n) → n (1-10 MeV)	≈ 0.9 × 10 <sup>-7</sup>	≈ 0 however ≪ 0.1	–	< 6 × 10 <sup>-4</sup>	≪ 6 × 10 <sup>-5</sup>	≪ 5 × 10 <sup>-3</sup>
	μ → n from rock (> 10 MeV)	≈ 3 × 10 <sup>-9</sup>	0.0129	end of June	≪ 7 × 10 <sup>-4</sup>	≪ 9 × 10 <sup>-6</sup>	≪ 8 × 10 <sup>-4</sup>
	μ → n from Pb shield (> 10 MeV)	≈ 6 × 10 <sup>-9</sup>	0.0129	end of June	≪ 1.4 × 10 <sup>-3</sup>	≪ 2 × 10 <sup>-5</sup>	≪ 1.6 × 10 <sup>-3</sup>
	ν → n (few MeV)	≈ 3 × 10 <sup>-10</sup>	0.03342*	Jan. 4th*	≪ 7 × 10 <sup>-5</sup>	≪ 2 × 10 <sup>-6</sup>	≪ 2 × 10 <sup>-4</sup>
	direct μ	Φ <sub>0</sub> <sup>(μ)</sup> ≈ 20 μ m <sup>-2</sup> d <sup>-1</sup>	0.0129	end of June	≈ 10 <sup>-7</sup>	≈ 10 <sup>-9</sup>	≈ 10 <sup>-7</sup>
	direct ν	Φ <sub>0</sub> <sup>(ν)</sup> ≈ 6 × 10 <sup>10</sup> ν cm <sup>-2</sup> s <sup>-1</sup>	0.03342*	Jan. 4th*	≈ 10 <sup>-5</sup>	3 × 10 <sup>-7</sup>	3 × 10 <sup>-5</sup>

\* The annual modulation of solar neutrino is due to the different Sun-Earth distance along the year; so the relative modulation amplitude is twice the eccentricity of the Earth orbit and the phase is given by the perihelion.

necessary<sup>1</sup>; thus, many theoretical and experimental parameters and models are possible and many hypotheses must also be exploited.

In particular many candidates, interactions, halo models, etc. are possible, while specific experimental

and theoretical assumptions are generally adopted in a single arbitrary scenario without accounting neither for existing uncertainties nor for alternative possible scenarios, interaction types, etc.

The obtained DAMA model independent evidence is compatible with a wide set of scenarios regarding the nature of the DM candidate and related astrophysical, nuclear and particle Physics. For examples some given scenarios and parameters are discussed e.g. in

<sup>1</sup>For completeness, we recall that it does not exist any approach to investigate the nature of the candidate in the direct and indirect DM searches, which can offer that information independently on assumed astrophysical, nuclear and particle Physics scenarios

Ref. [14, 2, 8]. Further large literature is available on the topics (see for example in the bibliography of Ref. [8]). Moreover, both the negative results and all the possible positive hints are compatible with the DAMA model-independent DM annual modulation results in various scenarios considering also the existing experimental and theoretical uncertainties; the same holds for strongly model dependent indirect approaches; see e.g. arguments in Ref. [8] and references therein.

#### 4. Search for second order effect and other rare processes with DAMA/LIBRA

By considering the data collected in DAMA/LIBRA–phase1 we have also investigated the possible diurnal effects in the *single-hit* low energy scintillation events. A diurnal effect with the sidereal time is expected for DM because of Earth rotation; this DM second-order effect is model-independent and has several peculiar requirements as the DM annual modulation effect does. At the present level of sensitivity the presence of any significant diurnal variation and of diurnal time structures in the data can be excluded for both the cases of solar and sidereal time [12]. In particular, the DM diurnal modulation amplitude expected, because of the Earth diurnal motion, on the basis of the DAMA DM annual modulation results is below the present sensitivity. It will be possible to investigate such a diurnal effect with adequate sensitivity only when a much larger exposure will be available. On the other hand, better sensitivities can also be achieved by lowering the software energy threshold; in fact an almost exponential rising of the signal rate is expected at lower energy for some DM candidates. This is one of the goals of the presently running DAMA/LIBRA–phase2.

As regard the search for rare processes we have performed an analysis considering the data collected irradiating DAMA/LIBRA detectors with  $^{241}\text{Am}$  source to search for correlated  $e^+e^-$  pairs in its  $\alpha$  decay [11]. The source experimental data show an excess of double coincidences of events with energy around 511 keV in faced pairs of detectors, which are not explained by known side reactions. This measured excess can be interpreted in terms of the Internal Pair Production (IPP). The observed effect gives a relative activity  $\lambda = (4.70 \pm 0.63) \times 10^{-9}$  for the Internal Pair Production (IPP) with respect to the  $\alpha$  decay of  $^{241}\text{Am}$  [11]. This value is of the same order of magnitude as the previous determinations obtained by using different set-ups, sources (with different features and producers) and experimental approaches. In a conservative approach the upper limit  $\lambda < 5.5 \times 10^{-9}$  (90% C.L.) can be derived. It is

worth noting that this is the first result on IPP obtained in an underground experiment, and that the  $\lambda$  value obtained is independent on the live-time estimate (which is difficult to estimate with very high accuracy in similar experiments because of the relatively high intensities of the  $^{241}\text{Am}$  sources).

Moreover we have also performed an analysis obtaining new lifetime limits on the charge non-conserving (CNC) electron capture with excitation of the 417.9 keV nuclear level in the  $^{127}\text{I}$  by using the coincidence technique on an exposure of  $0.87 \text{ ton} \times \text{yr}$ , collected by DAMA/LIBRA [10]. The considered approach is that each CNC electron capture decay produces an excited level and the relaxation of the atomic shells. In a multi-detector set-up the products of the atomic relaxation are contained in the source = detector releasing a total energy of 33.2 keV, considering only  $^{127}\text{I}$  K-shell electrons involved in the process. The  $\gamma$  quanta emitted in the nucleus de-excitation may escape from the source = detector and then interact with one of the surrounding detectors, giving events in coincidence with multiplicity two (two detectors fire). The search for events with multiplicity two – in the particular energy interval of interest for the process searched for – offers both a peculiar signature for this process and a significant reduction of the background. The analysis was focused on the case of the 417.9 keV excited level of  $^{127}\text{I}$ , since it offers the largest efficiency for the detection of double-coincidence from the CNC electron capture searched for, and the lowest background. The obtained limit on the mean life is  $\tau > 1.2 \times 10^{24} \text{ yr}$  (90 % C.L.), about one order of magnitude larger than those previously available for CNC electron capture involving nuclear level excitations of  $^{127}\text{I}$  [10].

Finally we recall that a new search for non-Paulian nuclear processes, i.e. processes normally forbidden by the Pauli Exclusion Principle (PEP) has also been performed [9].

#### 5. DAMA/LIBRA–phase2 and perspectives

After a first upgrade of the DAMA/LIBRA set-up in September 2008, a more important upgrade has been performed at the end of 2010 when all the PMTs have been replaced with new ones having higher Quantum Efficiency (Q.E.), realized with a special dedicated development by HAMAMATSU co.. Details on the developments and on the reached performances in the operative conditions are reported in Ref. [6] where the feasibility to decrease the software energy threshold below 2 keV in the new configuration has been also demonstrated.

Since the fulfillment of this upgrade, DAMA/LIBRA–phase2 – after optimization periods – is continuously running in order: (1) to increase the experimental sensitivity lowering the software energy threshold of the experiment; (2) to improve the corollary investigation on the nature of the DM particle and related astrophysical, nuclear and particle physics arguments; (3) to investigate other signal features. This requires long and heavy full time dedicated work for reliable collection and analysis of very large exposures.

Another upgrade at the end of 2012 was successfully concluded: new-concept preamplifiers were installed, with suitable operative and electronic features. Moreover, further improvements are planned; in particular, new trigger modules have been prepared and ready to be installed.

Finally, further improvements to increase the sensitivity of the set-up can be considered; in particular, the use of high Q.E. and ultra-low background PMTs directly coupled to the NaI(Tl) crystals is an interesting possibility. This possible configuration can allow a further large improvement in the light collection and a further lowering of the software energy threshold. Moreover, efforts towards a possible highly radiopure NaI(Tl) “general purpose” experiment (DAMA/1ton) having full sensitive mass of 1 ton (we already proposed in 1996 as a general purpose set-up) have been continued in various aspects.

## 6. Conclusions

The data of DAMA/LIBRA–phase1 have further confirmed the presence of a peculiar annual modulation of the *single-hit* events in the (2–6) keV energy region satisfying all the many requirements of the DM annual modulation signature; the cumulative exposure by the former DAMA/NaI and DAMA/LIBRA–phase1 is 1.33 ton  $\times$  yr. No systematic or side processes able to simultaneously satisfy all the many peculiarities of the signature and to account for the whole measured modulation amplitude is available.

DAMA/LIBRA is continuously running in its new phase of measurement (named DAMA/LIBRA–phase2) with a lower software energy threshold. The enhanced sensitivity will allow to improve the knowledge on corollary aspects regarding the signal and on second order effects as discussed e.g. in Ref. [8, 12]. Further efforts to increase the sensitivity of the set-up are also in progress, as well as efforts towards a possible highly radiopure NaI(Tl) “general purpose” DAMA/1ton experiment, with full sensitive mass of 1 ton.

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