First results from DAMA/LIBRA

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The highly radiopure $\simeq$ 250 kg NaI(Tl) DAMA/LIBRA set-up is running at the Gran Sasso National Laboratory of the I.N.F.N.. Here first results obtained by this second generation experiment exploiting the model-independent annual modulation signature for Dark Matter particles in the galactic halo are mentioned (exposure of 0.53 ton x yr). The DAMA/LIBRA data confirm the evidence for the presence of Dark Matter particles in the galactic halo as observed by the former DAMA/NaI experiment. The combined analysis of the data of the two experiments (total exposure 0.82 ton x yr) gives a C.L. at 8.2 sigma.

The former DAMA/NaI [1, 2, 3, 4, 5], and the present DAMA/LIBRA set-ups [6, 7], have been developed inside the DAMA project [1, 2, 3, 4, 5, 6, 7, 8] and both present unique features in order to investigate the presence of Dark Matter (DM) particle in the galactic halo by exploiting the model-independent annual modulation signature (originally suggested more than twenty years ago [9]).

In particular, this signature exploits the effect of the Earth revolution around the Sun on the number of events induced by DM particles in a suitable low background set-up placed deep underground. In fact, as a consequence of its annual revolution, the Earth should be crossed by a larger flux of DM particles around roughly June 2^{nd} (when its rotational velocity is summed to the one of the solar system with respect to the Galaxy) and by a smaller one around roughly December 2^{nd} (when the two velocities are subtracted). Thus, the contribution of the signal to the counting rate in the k–th energy interval can be written as [2]: $S_k = S_{0,k} + S_{m,k} \cos\omega(t-t_0)$, where: i) $S_{0,k}$ is the constant part of the signal; ii) $S_{m,k}$ is the modulation amplitude; iii) $\omega = \frac{2\pi}{T}$ with period T; iv) t_0 is the phase.

This signature is very distinctive since a seasonal effect induced by DM particles must satisfy all the following requirements: 1) the rate must contain a component modulated according to a cosine function; 2) with one year period; 3) with a phase roughly around June 2^{nd} in case of usually adopted halo models (slight variations may occur in case of presence of non thermalized DM components in the halo [3, 10]); 4) this modulation must be present only in a well-defined low energy range, where DM particles can induce signals; 5) it must be present only in those events where just a single detector, among all the available ones in the used set-up, actually "fires" (*single-hit* events), since the probability that DM particles experience multiple interactions is negligible; 6) the modulation amplitude in the region of maximal sensitivity has to be $\lesssim 7\%$ in case of usually adopted halo distributions, but it may be significantly larger in case of some particular scenarios such as *e.g.* those of reference [11]. To mimic such a signature spurious effects or side reactions should be able not only to account for the observed modulation amplitude but also to contemporaneously satisfy all the requirements of the signature [2, 7].

The DAMA/LIBRA set-up, its main features and radiopurity have been discussed in details in reference [6], while the model-independent experimental results obtained by DAMA/LIBRA (exposure of 0.53 ton$\times$yr over 4 annual cycles) and those combined with DAMA/NaI (exposure of 0.29 ton$\times$yr over 7 annual cycles), just mentioned in the following, are presented in details in reference [7]. In fact, a clear annual modulation of the *single-hit* events (i.e. events in which just one detector fires) satisfying all the several peculiarities expected for a dark matter particle induced effect has also been observed in DAMA/LIBRA [7]. A cumulative 8.2 σ C.L. is reached when considering the data of the two experiments all together. In particular, Figure 1 shows the time behaviour (over three energy intervals) of the model-independent experimental residual rates for *single-hit* events collected by the DAMA/NaI and the new DAMA/LIBRA experiments over eleven annual cycles (0.82 ton$\times$yr); when the phase and the period are free in the best fit procedure, an amplitude equal to (0.0131 ± 0.0016) cpd/kg/keV, a phase $t_0 = (144 \pm 8)$ days and a period $T = (0.998 \pm 0.003)$ year are measured in the (2-6) keV energy range [7], well in agreement with the expectations. The experimental data have been investigated by various analyses as reported in details in reference [7].

In order to verify absence of annual modulation in other energy regions and, thus, to also verify the absence of any significant background modulation, the energy distribution measured during the data taking periods has been investigated up to MeV region; in particular the analyses described in reference [7] exclude the presence of a background modulation in the whole energy spectrum at a level much lower than the effect found in the lowest energy region for the *single-hit* events.

A further investigation has also been performed on the *multiple-hits* events (i.e. events in which more than one detector fire). The *multiple-hits* events class – on the contrary of the *single-hit* one – does not include events induced by DM particles since the probability that a DM particle interacts in more than one detector is negligible. The fitted modulation amplitude is $A = -(4 \pm 6) \cdot 10^{-4}$ cpd/kg/keV for the *multiple-hits* residual rate in the (2-6) kV energy range [7]. Summarising, evidence of annual modulation with proper features is present in the *single-hit* residuals (events class to which the DM particle-induced signals belong), while it is absent in the *multiple-hits* residual rate (event class to which only background events belong). 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 DM particles in the galactic halo, further excluding any side effect either from hardware or from software procedures or from background. Details can be found in reference [7].

Obviously as previously done for DAMA/NaI [2], careful investigations on absence of any significant systematics or side reaction effect in DAMA/LIBRA have been quantitatively carried out. In fact, in order to continuously monitor the running conditions, several pieces of information are acquired with the production data and quantitatively investigated [7]. No modulation has been found in any possible source of systematics or side reactions for DAMA/LIBRA as well; thus, cautious upper limits (90% C.L.) on the possible contributions to the DAMA/LIBRA measured modulation amplitude have been estimated [7]. They cannot account for the measured modulation amplitude and contemporaneously satisfy all the requirements of the signature. For

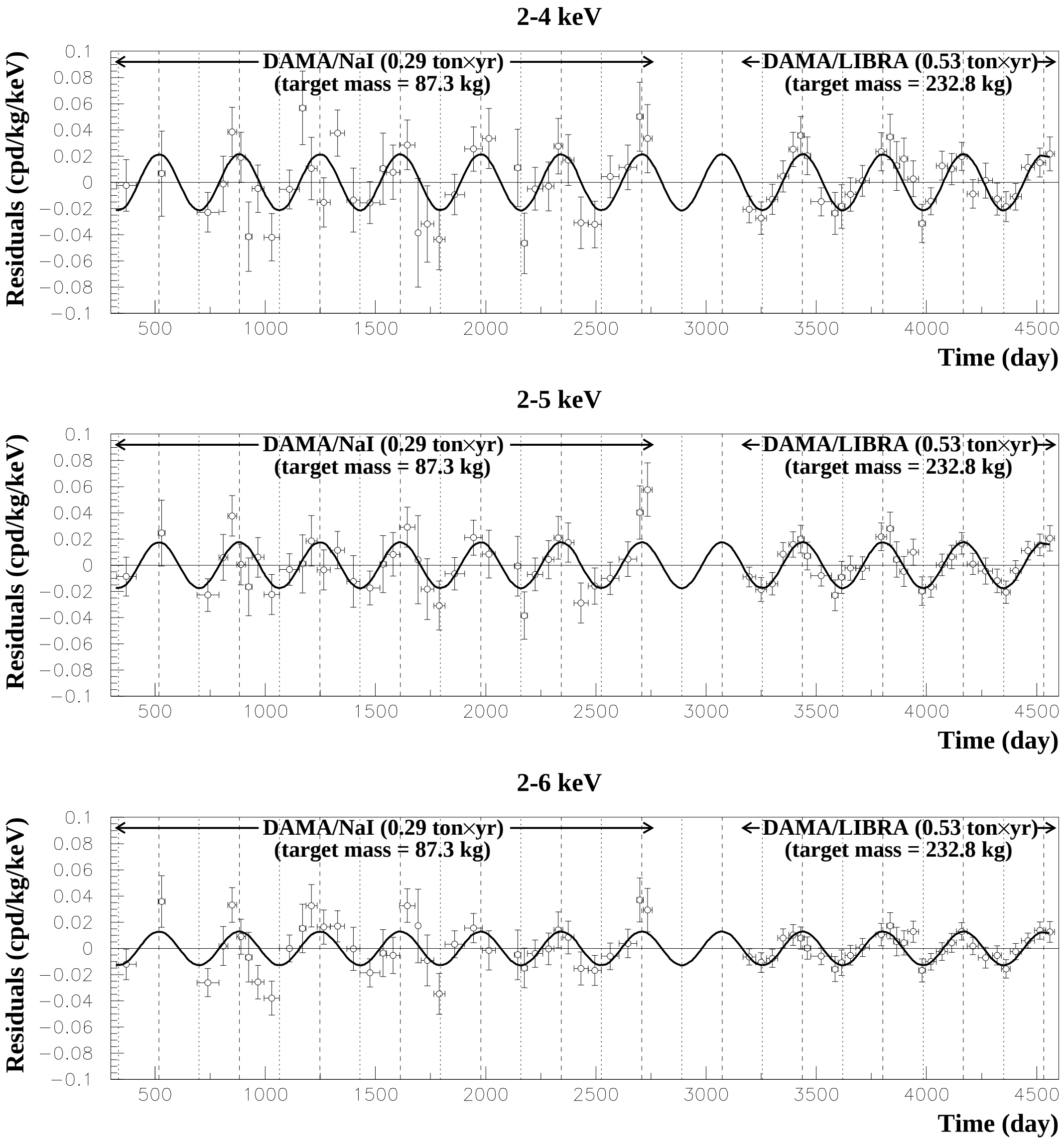

Figure 1: Model-independent experimental residual rate of the *single-hit* scintillation events, measured by DAMA/NaI and DAMA/LIBRA in the (2 – 4), (2 – 5) and (2 – 6) keV energy intervals as a function of the time. The zero of the time scale is January 1^{st} of the first year of data taking of the former DAMA/NaI experiment. The experimental points present the errors as vertical bars and the associated time bin width as horizontal bars. The superimposed curves represent the cosinusoidal function behaviours $A\cos\omega(t-t_0)$ with a period $T=\frac{2\pi}{\omega}=1$ yr, with a phase $t_0=152.5$ day (June 2^{nd}) and with modulation amplitudes, A, equal to the central values obtained by best fit over the whole data, that is: (0.0215 ± 0.0026) cpd/kg/keV, (0.0176 ± 0.0020) cpd/kg/keV and (0.0129 ± 0.0016) cpd/kg/keV for the (2 – 4) keV, for the (2 – 5) keV and for the (2 – 6) keV energy intervals, respectively. The dashed vertical lines correspond to the maximum of the signal (June 2^{nd}), the dotted vertical lines correspond to the minimum. The total exposure is 0.82 ton × yr. For details and for more results see reference [7].

detailed discussions on all the related topics and for results see the devoted paper [7]. In conclusion, also the data of the first four annual cycles of DAMA/LIBRA as previously those of DAMA/NaI, fulfil the requirements of the DM annual modulation signature.

The corollary question about the nature of the DM particle(s) detected by the annual modulation signature and the related astrophysical, nuclear and particle Physics scenarios requires subsequent model-dependent corollary analyses as those performed [2, 3, 4]; few examples have been given in reference [7], while an update of allowed volumes/regions in various scenarios is in preparation. One should stress that it does not exist any approach to investigate the nature of the candidate in the direct and indirect DM searches which can offer these information independently on astrophysical, nuclear and particle Physics assumptions. It is also worth noting that no experiment exists whose result can be directly compared in a model-independent way with the DAMA/NaI and DAMA/LIBRA experimental results; some related arguments have been addressed e.g. in references [2, 3, 4, 6, 7, 12].

Finally, the collection of a larger exposure with DAMA/LIBRA (and with the possible DAMA/1ton, which is at R&D stage) and the possible lowering of the energy threshold below 2 keV will allow further investigations on DM features and will offer higher sensitivities.

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