A first result on axial coupling WIMPs with Xenon target at Gran Sasso

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A Xenon detector is running in the Gran Sasso National Laboratory. It has been operative filled both with liquid and gaseous Xenon. A first preliminary result on dark matter direct search is presented; the exclusion plot for axial vector coupling WIMPs is compared with previous ones obtained with different target nuclei. A new very low activity detector is under installation.

1. INTRODUCTION

Our investigation on Dark Matter particles by the detection of elastic scattering processes with scintillators [1,6-12] includes the study of Xenon target-detectors [1-6].

As we have already pointed out [5,6], Xenon is a very interesting material for dark matter search; in particular, it could allow to investigate both vector and axial coupling interactions by comparing measurements performed with the same set-up using Xenon enriched in even and odd spin isotopes.

Furthermore, the possibility to build efficient scintillators in liquid phase allows to obtain large mass detectors (to look for annual modulation signature or for candidates with extremely low expected rate) with well reduced dimensions. In addition, the scintillation properties of the Xenon in gaseous phase also allow to evaluate and subtract most of the residual environmental background.

2. EXPERIMENTAL SET-UP

The data presented here have been collected at Gran Sasso National Laboratory [13] with a $\simeq 3.5$ Kg LXe target-scintillator, whose performances have been described in detail elsewhere [5]. The

detector was calibrated at low energy using an X-ray ^{109}Cd source (22 and 88 keV lines): the energy resolution was $\sigma/E=0.05 + 1.63/\sqrt{E(\text{keV})}$. In ref. [5] the detector efficiency at low energy and the response versus the released energy in a WIMP-nucleus elastic scattering, i.e. the quenching factor, have been studied and discussed.

During the measurements presented here, the detector was shielded by 4 cm of steel and 10 cm of lead.

The scintillation light was collected by two EMI photomultipliers with MgF_2 windows (working in coincidence) through special cultured crystal quartz windows; for each event we record the ADC value and the pulse shape by a Lecroy transient digitizer, which allows a pulse shape analysis to reject photomultiplier noise. The comparison between the ADC value and the area of the pulse recorded by the transient digitizer allows to check the linearity of the ADC.

3. DATA ANALYSIS

Data have been collected both in the low and high energy range. The high and intermediate energy spectra allowed us to evaluate the U/Th and K contaminations as reported in ref. [5].

New measurements of the low energy part of the spectrum - between 15 and 50 keV - allow us

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to evaluate here a first exclusion plot for axially coupling WIMPs.

Figure 1. Response of the detector to a bare ^{109}Cd source a) LXe; b) 2.5 bar Xenon gas.

As we already pointed out [5] the detector used for these measurements was not yet optimized for low activity, therefore we measured independently the environmental background contribution to the low energy spectrum by filling the detector with Xenon gas at 2.5 bar. We subtracted

these data - by the procedure described in the following - from those collected when the detector is filled with liquid Xenon. The residual spectrum can be ascribed only to eventual WIMP-nucleus scatterings or contaminants present in the gas, whose rate depends on the mass, like e.g. ^{85}Kr and radon.

In fig. 1 we show - for comparison - the response of the detector to a bare ^{109}Cd source when it is filled with liquid Xenon (fig. 1 a) and the one when it is filled with 2.5 bar Xenon gas (fig. 1 b).

To obtain the residual rate from the low energy spectra - collected in the two experimental situations - we consider the background mainly due to environmental γ rays from the detector walls, being most of γ s coming from outside shielded by the external lead.

We have to consider that the observed energy spectra ($\frac{dR}{dE}$) in the two cases (gaseous and liquid Xenon measurements) can be written as the sum of two terms:

$$\left[\frac{dR}{dE}\right]_g = \int_0^\infty \epsilon_g(E, E') \frac{dB(E')}{dE'} dE' + \left[\frac{dR^{(M)}}{dE}\right]_g, \quad (1)$$

$$\left[\frac{dR}{dE}\right]_l = \int_0^\infty \epsilon_l(E, E') \frac{dB(E')}{dE'} dE' + \left[\frac{dR^{(M)}}{dE}\right]_l, \quad (2)$$

where we distinguish the contributions of the external γ rays background ($\frac{dB(E')}{dE'}$, equal in the two cases) from the contribution proportional to the target mass ($\frac{dR^{(M)}}{dE}$). Xenon contaminants and an eventual WIMP signal would be included in this latter term. In case of Xenon gas this contribution is negligible respect to the liquid one, being the ratio between the used masses $\simeq 1/140$.

We define $\epsilon(E, E')dE'$ as the probability that a γ ray of energy E' gives a contribution in the energy range $E, E+dE$. We can rewrite eq. 1,2 as in the following:

$$\left[\frac{dR}{dE}\right]_g \simeq \sum_i \epsilon_{ij}^g b_j, \quad (3)$$

$$\left[\frac{dR}{dE}\right]_l \simeq \sum_i \epsilon_{ij}^l b_j + \left[\frac{dR^{(M)}}{dE}\right]_l. \quad (4)$$

The ϵ_{ij} 's have been calculated using a MonteCarlo code for both gaseous and liquid cases.

Using the experimental values for $\left[\frac{dR}{dE}\right]_g$, we get from eq. 3, by best fit, the b_j values. Mainly the b_j values in the energy bins within 200-400 keV and 1300-1600 keV are considerably different from zero, pointing out the presence of Bi, U, Th and K contaminants in the stainless steel vessel. The obtained b_j values substituted in eq. 4 allowed us to evaluate the residual energy spectrum $\left[\frac{dR^{(M)}}{dE}\right]_i$ shown in fig. 2. The quoted errors are statistical only.

Figure 2. Residual low energy spectrum (see text). The quoted errors are statistical only.

4. RESULTS ON AXIAL COUPLING WIMPS

Following a conservative procedure similar to the one used in ref. [8], we evaluated the exclusion plot (2σ C.L.), for spin dependent interaction. To compare the result with some other nuclei the limit cross-sections have been renormalized to the ones that WIMPs would have on protons (see fig. 3). The assumptions were: a) local galactic halo density equal to 0.3 GeV/cm^3 ; b) orbital solar system velocity $\simeq 220 \text{ km/s}$; c) $v_{rms} = 300 \text{ km/s}$

and escape cut-off velocity of 600 km/s for the WIMP maxwellian velocity distribution; d) estimated quenching factor $\simeq 0.8$ for ^{129}Xe and ^{131}Xe recoil [5]; e) spin factors for ^{129}Xe and ^{131}Xe from ref. [14]; f) nuclear form factors from ref. [15]. The energy resolution and the efficiency of the detector have been considered.

In fig. 3 there are also shown for comparison results available on some other target nuclei [8,16].

Figure 3. Preliminary exclusion plot for spin dependent coupling WIMPs (2σ C.L.); some results on other target nuclei are shown for comparison.

We have to notice the favourable spin factor for ^{129}Xe and the improvement in the Lindhard quenching factor [17] due to the recombination effect present in LXe scintillators [5]. However, we have to stress that new measurements of the quenching factor are foreseen to properly verify the evaluation used here.

We have to consider that the residual low energy counting rate has to be attributed mainly to the gas background radioactivity, due to the possible presence of ^{85}Kr (β spectrum with 0.7 MeV endpoint) that could be created by cosmogenic activation at sea level and depends also on

the gas producing plans.

5. CONCLUDING REMARKS

Actually a new very low activity detector is under installation together with an improved shield. Kr-free gas will be used. Measurements are foreseen looking for annual modulation signature [6].

We will explore also the interesting possibility of the comparison between results obtained with Xenon enriched once in odd and once in even spin isotopes [6].

6. ACKNOWLEDGMENTS

We gratefully acknowledge Prof. S. d'Angelo for helpful discussions. We wish also to thank Mr. A. Bussolotti for his technical support and LNGS staff for the efficient assistance.

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