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Dark Matter search with directional sensitivity

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Summary. — The perspectives of an argon Dark Matter detector with directional information located at Laboratori Nazionali del Gran Sasso are discussed. Columnar recombination combined with a dual-phase Liquid Argon Time Projection Chamber looks a promising approach in view of a directional detector. Even for a minimal angular resolution, a very clear WIMP signature is expected.

1. – Introduction

A plausible explanation of the nature of Dark Matter (DM) is that it is constituted by Weakly Interacting Massive Particles (WIMPs). The standard non-directional direct detection is very challenging in particular for what concerns background rejection, leaving doubts on the authenticity of the few DM observation claims existing [1]. If detectors were able to distinguish the recoil direction of the scattered nucleus, the signal would have an unambiguous daily angular variation. As a consequence of the Earth's rotation around its axis, the WIMP apparent direction should in fact change during the day. Thus, the angular distribution of the recoil nuclei should vary with time. The most promising approach is a detector based on the so-called Columnar Recombination (CR) effect on a Noble Liquid [2]. In this detector, recoiling nuclei cause argon excitation and ionization. Each event is detected using argon de-excitation prompt scintillation light, S1, and the signal from free ionization electrons drifted by an electric field towards the top of the TPC, S2. A fraction of free electrons, however, recombine with ions. Models of CR suggest that the recombination probability should vary with the angle between the field and the track direction, modifying the amount of S1 and S2 events. A measurement of S1 and S2 may provide informations on the WIMP directionality. The RED experiment, which is under construction at Naples University, aim to measure the effect of CR on the S1 and S2 signals in a dual-phase Lar TPC optimized for this purpose. The results shown here are obtained considering an Earth-based detector, located at Laboratori Nazionali del Gran Sasso (LNGS), with a 100 tonne target mass of argon. This detector is assumed to discriminate only between tracks with different inclination relative to the vertical (electric field) direction. For this reason, the only measurable angle is the polar angle, θ_r, while the azimuthal angle is integrated out.

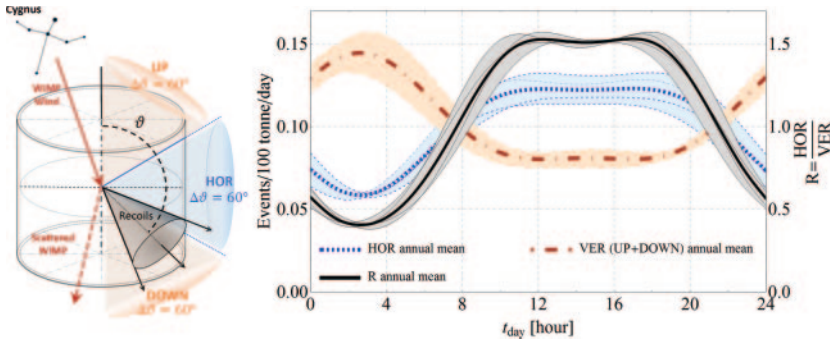

Fig. 1. – Left: Schematic representation of the recoils distribution between horizontal (HOR) and vertical (VER) events in a LAr TPC. Right: Daily variation of HOR (VER) event rate in blue dashed (orange dot-dashed) lines for different sidereal days of the year. See text for details.

2. – Results

Here the clean advantage of a directional detection capability is highlighted. Events are divided in two classes. Horizontal events (HOR), defined by $|\cos\theta_r| < 0.5$, and vertical events (VER = UP + DOWN), defined by $|\cos\theta_r| > 0.5$, as shown in the left panel of fig. 1. The ratio, R, of HOR and VER events is defined, which should be constant and equal to one for an isotropic signal. On the right panel of fig. 1 the time dependence of this ratio and of the single components is shown. The thin lines represent the daily variation of the HOR and VER event rates, and their ratio, R, for four equidistant sidereal days, while the corresponding blue (orange) bands represent the overall variation registered in the HOR (VER) component among different sidereal days of the year. The thick curves represent the averages over different sidereal days. Considering the annual mean, the variation of the single component is of the order of 35% (29%), with respect to the average daily value. For comparison, the seasonal modulation of the events that can be observed under the same assumptions, for the case of a non-directional WIMP detection is only about 8%.

To conclude, in these proceedings it is discussed how a directional detector located at LNGS could provide a very clear signature for WIMP signal. This signature is sizeable even for a minimal angular resolution. In particular, the daily modulation shown in fig. 1 is an order of magnitude larger than the annual modulation obtained ignoring the angular information. Thus, a realistic detector able to use the angular information to reject the background would provide a strong evidence of DM, the latter due to the fact that no known background is correlated with the sidereal period.

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