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Recoil Directionality Experiment

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Abstract. Directional sensitivity to nuclear recoils could provide a smoking gun for a possible discovery of dark matter in the form of WIMPs. A hint of directional dependence of the response of a dual-phase liquid argon Time Projection Chamber was found in the SCENE experiment. Given the potential importance of such a capability in the frame-

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work of dark matter searches, a new dedicated experiment, ReD (Recoil Directionality), was designed in the framework of the DarkSide Collaboration, in order to scrutinize this hint. This contribution will describe the performance of the detectors achieved during the first test-beam, the current status of ReD and the perspectives for physics measurements during the forthcoming beam-time.

1 Introduction

The hypothesis of dark matter was introduced more than 80 years ago to explain anomalous motions of galaxies gravitationally bound in clusters. Observational evidences had continued to accumulate since then, including rotation curves of galaxies and their clusters and discrepancies in the distributions of galaxy cluster mass estimated from luminosity vs. gravitational lensing. One of the most favored dark matter candidate is the Weakly Interacting Massive Particle (WIMP) [1, 2], which explains the current abundance of dark matter as a thermal relic of the big bang. Most models predict dark matter WIMP masses near the electroweak scale of 100's of GeV/c^2. However, dark matter particle masses $\leq$ 10 GeV/c^2 can also be compatible with experimental constraints if a significant asymmetry between dark matter and their anti-particles existed in the early universe.

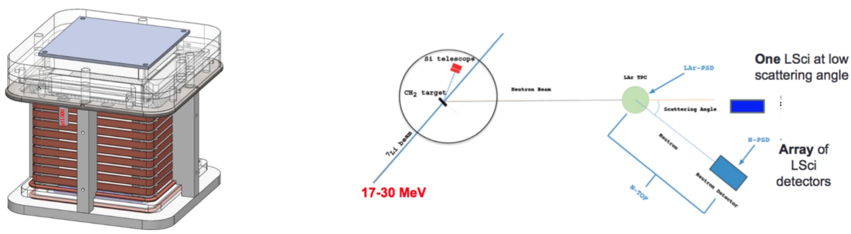
2 The DarkSide program

DarkSide-50 (DS-50) is an experiment for the direct detection of WIMPs currently running at INFN Laboratori Nazionali del Gran Sasso (LNGS, Italy), at a depth of 3800 m.w.e. [3, 4]. The DarkSide Collaboration has recently published WIMP search results from about 500 days of data taking of DS-50. The results lead to the best WIMP-Argon cross section exclusion limits at present day, in a wide range of WIMP masses [5–7]. In order to further increase the sensitivity on WIMP-nucleus cross section with an argon based experiment, an enlarged DarkSide Collaboration (Global Argon Dark Matter Collaboration - GADMC) proposed a long term program for dark matter searches. The DarkSide-20k experiment (about 40 tonnes of active mass), in particular, aims at a significant improvement in the sensitivity for the direct detection of WIMPs in the mass range above a few hundred GeV/c^2, forecasting $\sigma = 1.2 \times 10^{-47}$ cm^2 for WIMPs of 1 TeV/c^2 mass [8]. Beyond this limit, however, demonstrating that a putative signal is due to WIMPs, is a major challenge. Several studies [9] show that the identification of recoil events due to particles coming from the galactic halo would give, for any WIMP model, a powerful tool to discriminate the signal from an isotropic, or fixed-location in the laboratory, background source. Direction-sensitivity is therefore a highly desirable characteristic for a direct detection experiment, which will become of paramount interest in case evidence is found for nuclear recoils that cannot be explained by any known backgrounds.

3 Recoil Directionality Experiment (ReD)

WIMP directional information is potentially available in a dual-phase Liquid Argon Time Projection Chamber (LAr TPC) by exploiting the recombination effect. Columnar recombination models [10] suggest that the magnitude of the recombination effect should vary with the angle between the field and the track direction. A difference in the electron-ion recombination effect is expected when the ionizing track is either parallel or perpendicular to the electric field. Such an effect were explored by the SCENE experiment [11], where a monoenergetic neutron beam were used to irradiate a small dual-phase LAr TPC with and without the application of an electric field. The collaboration achieved,

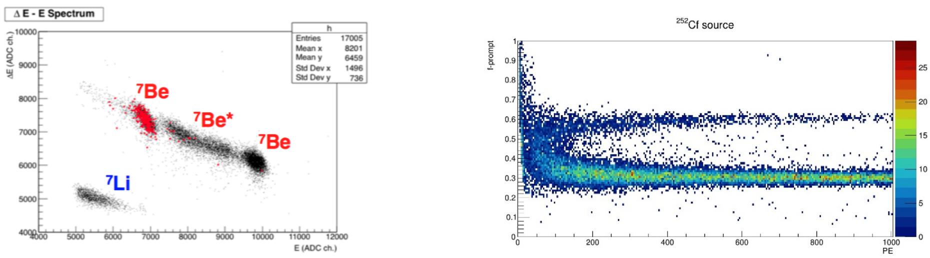
for the first time, the comparison of the light and charge yield of recoils parallel and perpendicular with respect to the electric field (directional sensitivity), in case of a S1 signal due to scintillation (S1, [11]). Unfortunately the same was not found for ionization signals (S2, [11]). The ReD experiment was proposed with the aim to improve the SCENE measurements as part of the DarkSide program, so it may provide a fully scalable technology to bring the future dark matter experiments based on LAr to the multi-ton scale, i.e. DarkSide-20k.
The main goal of the ReD experiment is to demonstrate the WIMP directional sensitivity by using a small scale, dual-phase LAr TPC explicitly designed for this purpose at University of California, Los Angeles (UCLA), in which the information is collected in form of optical signals by means of newly developed silicon photomultipliers (SiPMs), working at cryogenic temperature [12, 13]. The TPC



(a) (b)

Figure 1. (a) Schematic drawing of the ReD dual-phase LAr TPC. (b) The ReD experimental setup (drawing) at INFN Laboratori Nazionali del Sud (LNS).

has the dimensions of 5×5×6 cm^3 in the inner part, and is enclosed by vertical acrylic-ESR sandwich reflection panels, and by two acrylic windows ITO and TPB coated, on the top (anode) and bottom (cathode) (fig. 1(a)). It is equipped with an array of 24x1 cm^2 FBK (Fondazione Bruno Kessler) SiPM with a 24 channels front-end board readout (custom-made for ReD by INFN Naples, in collaboration with INFN Bologna and INFN LNGS) on the top, and a 24x1 cm^2 FBK tile with a 4 channels front-end board readout on the bottom. Neutrons are produced by $p(^7Li,n)^7Be$ reaction, available thanks to the 15 MV TANDEM accelerator of the INFN Laboratori Nazionali del Sud (LNS) in Catania, Italy, with energy of about 7 MeV and at a specific angle with respect to the beam line, in the direction of the LAr TPC. Neutron interactions producing 20-100 keV nuclear recoils in argon, were then recorded in the TPC, while the scattered neutrons were intercepted by a set of nine 3-inches neutron detectors (LSci) placed in coincidence with the TPC, allowing to close the kinematics and estimate the argon recoil direction (fig. 1(b)). All LSci are placed such to tag recoils having the same energy, i.e the same scattering angle with respect to the incident neutron, but different angle with respect to the drift field of the LAr TPC. One LSci detector is at small scattering angle and is devoted to the study of low-energy recoils. If a directional effect on recombination is present in LAr, it is expected to measure different scintillation and ionization responses for nuclear recoils of the same energy, but with tagged initial momentum in the parallel and perpendicular directions to the TPC electric drift field. The directional effect should also be dependent on the electric field, whose variation will provide a further signature to model the directionality [10]. The scatter plot of the amplitudes of a ΔE - E telescope, able to identify the charged particles (^7Be) which accompany the neutrons emitted towards the TPC, is displayed in fig. 2(a): it shows the ability of the detector to discriminate the charged products of the beam-target reactions, i.e. the main ^7Li band due to elastic scattering and the two ^7Be *loci* corresponding to the two solutions allowed by kinematics. As expected, coincident events between Si and TPC are mostly associated to one ^7Be *locus*. Prior to the beam start, the detectors were commissioned and tested



(a) (b)

Figure 2. (a) Scatter plot of the amplitudes of the ΔE and E Si detectors, placed at 5 deg with respect to the beam axis. The red markers are events having a coincident signal in the TPC. (b) The fraction of prompt light in the scintillation pulse (f-prompt) versus the total charge collected by the two SiPM arrays, expressed in units of photoelectrons (PE): are clearly visible the two different bands of neutrons (upper band) and γ-rays (lower band) that leave a signal inside the TPC.

individually, by using the laser and radioactive sources. Light yield and timing were checked by using ^{241}Am and ^{22}Na, respectively; a ^{252}Cf (fig. 2(b)) fission neutron source was used to characterize the pulse shape discrimination performance of the LAr TPC and the LSci.

4 Conclusions

Directional sensitivity to nuclear recoils would provide a smoking gun for a possible discovery of dark matter in the form of WIMPs. A hint of directional dependence of the response of a dual-phase LAr TPC was found in the SCENE experiment. Given the potential importance of such a capability in the framework of dark matter searches, a new dedicated experiment, ReD (Recoil Directionality), was designed in the framework of the DarkSide Collaboration, in order to scrutinize this hint. Here we gave a preliminary look on the potentiality of such a technology by the successful installation and running of the ReD Experiment at INFN Laboratori Nazionali del Sud in Catania (Italy).

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