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The Recoil Directionality Experiment

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Summary. — 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 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.

In the framework of the DarkSide program [1, 2], the R&D project ReD (Recoil Directionality) aims to operate a Liquid Argon Time Projection Chamber (LAr TPC) to look for a possible directionality signature in the energy range of the expected WIMP-nucleus scattering recoils (up to 100 keV). The goal of the project is to irradiate a small LAr TPC with a neutron beam of known energy and direction by using the 15 MV Tandem accelerator of the INFN Laboratori Nazionali del Sud (LNS) in Catania, Italy. Neutrons are produced by means of the p(^{7}Li,^{7}Be)n two-body reaction in inverse kinematics, and then, thanks to the closed kinematics of the reaction, directed towards the TPC. Columnar recombination models suggest that the magnitude of the recombination effect between electrons and ions should vary with the applied electric field. Differences in the electrons-ions cloud are, in fact, expected for different ionization track orientations (parallel or perpendicular with respect to the electric field) [3]. Those effects can be explored by a deep characterization of both scintillation (S1) and ionization (S2) signals. Since most of the technological solutions adopted in ReD will be part of the future DarkSide-20k detector [4] it was crucial to have a complete characterization of the whole apparatus, in particular of the TPC. The detector has the dimensions of $5 \times 5 \times 6\,\mathrm{cm}^3$ in the inner part, and is enclosed by vertical acrylic-ESR sandwich reflection panels, and

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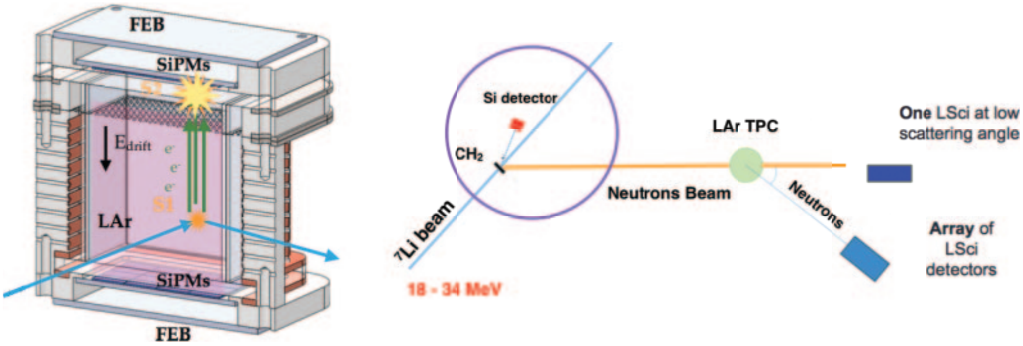

(a) (b)

Fig. 1. – (a) Drawing of the ReD TPC with a representation of its working principle. (b) Drawing of the ReD geometrical scheme at LNS in Catania. Together with the scattering chamber (the circle on the left part of the sketch), the neutron spectrometer and the low mass detector position are also represented.

by two ITO- and TPB-coated acrylic windows, on the top (anode) and bottom (cathode). It is equipped with an array of $24 \times 1\,\mathrm{cm}^2$ FBK (Fondazione Bruno Kessler) silicon photomultipliers (SiPM), working at cryogenic temperature [5, 6], 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 $24 \times 1\,\mathrm{cm}^2$ FBK tile with a 4 channels front-end board readout on the bottom. Neutron interactions producing 20–100 keV nuclear recoils in argon were recorded in the TPC, while the scattered ones are intercepted by a set of nine 3 inch neutrons detectors (LScis) placed in coincidence with the TPC, allowing to determine the direction of the argon recoil (fig. 1). All LScis 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, ReD expects 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 [3]. A representation of the TPC working principle together with the geometrical setup adopted in Catania are displayed in fig. 1. A preliminary analysis reports a light output yield of about 8.4 PE/keV at 200 V/cm from single phase ^{241}Am runs, confirmed also from ^{83m}Kr and ^{133}Ba measurements. The double phase runs analysis gave a value for the yield of extracted ionization electrons per unit of deposited energy at an extraction field of 5.79 kV/cm that can be compared with the ones reported from other experiments like SCENE [7], confirming also the capability of the system to extract electrons with high efficiency. The physics run with the complete apparatus in Catania is scheduled for early 2021.

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