# Characterization of electroluminescence signal in the Liquid Argon TPC of the ReD experiment

*Noemi* Pino[1,2,*] *on behalf of the ReD working group* (DarkSide-20k Collaboration)

[1]University of Catania, Catania, Italy
[2]INFN, Sezione of Catania, Catania, Italy

**Abstract.** Dark Matter as a Weakly Interactive Massive Particle (WIMP) has been directly searched in the past decade at a mass scale from 100 GeV/c$^2$ up to 1 TeV/c$^2$. Double-phase argon Time Projection Chambers (LAr TPC) recently explored the possibility of inspecting also the GeV/c$^2$ scale looking for a lighter WIMP using the ionization signal only. These studies are limited by the fact that the ionization response of argon is scarcely described for recoil energies of a few keV. The ReD experiment within the DarkSide-20k Collaboration aims to investigate the liquid argon ionization response at 2-5 keV to cover the current gap.

## 1 Introduction

In a LAr TPC, interactions produce prompt scintillation (S1) and delayed electroluminescence (S2) from ionization electrons drifting toward the gas layer and amplifying within it. WIMPs are expected to cause single nuclear recoils (tens of keV). The distinct S1 response in Ar for nuclear vs electron recoils enables strong pulse shape discrimination for background rejection [1]. In the low-mass WIMPs scenario (< 10 GeV/c$^2$), WIMP-nucleon interaction yield a few keV recoil energy ($E_{Ar}$), which may hinder the detection of S1 signals, reducing the typical discrimination capability of argon. Nevertheless, near-complete efficiency in extracting single ionization electrons enables low-mass WIMP recoils to be detected with great sensitivity. DarkSide-50 (DS-50) has set a 90% CL exclusion limit for spin-independent WIMPs with mass in [1.2, 3.6] GeV/c$^2$ [2]. The ionization response of argon at a few-keV scale remains largely uncharacterized, with only two direct points in the literature: 6.7 keV (ARIS [3]) and 7.1 keV (Joshi et al. [4]). The model in [5] uses calibration data of the DS-50 detector taken with neutron sources alongside Monte Carlo simulations but requires further refinement with external two-body kinematic calibration datasets. The Recoil Directionality (ReD) experiment aims to collect nuclear recoil events in a two-body-kinematic approach to constrain better the DS-50 model.

## 2 The ReD experiment

The ReD LAr TPC [6] was exposed to fission neutrons from a $^{252}$Cf source to collect nuclear recoil events in a controlled two-body kinematic setup (Fig. 1). The recoil energy is calculated as

$$E_{Ar} = 2K_n \frac{m_n m_{Ar}}{(m_n + m_{Ar})^2}(1 - \cos\theta_{scatt}), \tag{1}$$

where $K_n$ is the kinetic energy of the neutron, which is calculated event per event by time-of-flight (ToF) measurement over a known path, and $m_n$ and $m_{Ar}$ are the neutron and argon masses. The scattering

*e-mail: noemi.pino@dfa.unict.it

angle $\theta_{scatt}$ is fixed by geometry (12°-17°). The source is contained in a collimator shield that allows only a 2° exit cone directed toward the TPC. Two $BaF_2$ scintillators, positioned close to the source, detect accompanying radiation from fission events, providing the start time signal for ToF, while the stop is given by a neutron spectrometer downstream. It consists of two 3×3 arrays of EJ-276 plastic scintillators (Pscis) arranged to detect scattered neutrons for precise kinematic closure. The Pscis arrays are positioned outside the collimator cone to avoid direct flux. Signals in the TPC are seen by two tiles of cryogenic Silicon Photomultipliers placed on the top and bottom of the detector.

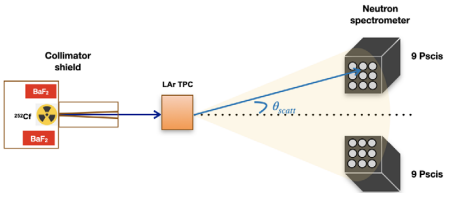


**Figure 1.** Sketch of the ReD experimental setup. The arrows in blue trace the neutron path.

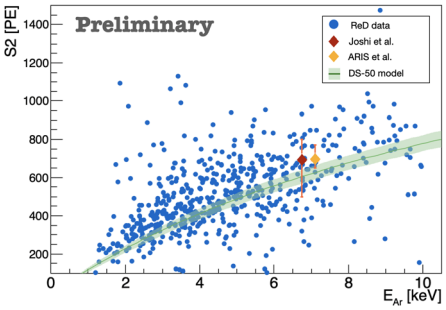


**Figure 2.** Preliminary result of the ReD campaign.

## 3 Data taking and analysis

ReD operated at INFN Sezione of Catania and collected data in winter 2023. The trigger logic required (any $BaF_2$) ∧ (any Psci), with the TPC running in follower mode. Candidate neutron events were selected offline by identifying Psci scintillation signals within the expected neutron ToF. For these events, the TPC was checked for an S2 signal in single-scattering events. The preliminary dataset contains approximately 600 S2-only events after cuts [7]. The scatter plot of S2 vs $E_{Ar}$ for the individual S2-only events is displayed in Fig.2, superimposed with the data points from [3, 4] and with the DS-50 model prediction [5] [1].

## 4 Preliminary results and future perspectives

ReD successfully collected data within the target energy range, as shown in Fig. 2. ReD experiences will be transferred to the upcoming ReD+ project at INFN Laboratori Nazionali del Sud will extend measurement coverage down to 0.4 keV. This will be achieved with a larger TPC and the added advantage of using a deuterium-deuterium neutron generator.

## References

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[1] For direct comparisons with the literature, S2 signals in photoelectrons should be converted to the number of electrons, $N_{e^-}$, via the scaling parameter $g_2$, which is the ionization amplification, detector-specific parameter. A preliminary $g_2$ value of 17.7 PE/$e^-$ was derived through cross-calibration with DS-50 data.