Characterization of light signal in the Liquid Argon TPC of the ReD experiment

N.Pino[1,2], on behalf of the ReD group within DarkSide-20k experiment

1) Università degli Studi di Catania, 2) Istituto Nazionale di Fisica Nucleare (INFN) – Sezione di Catania

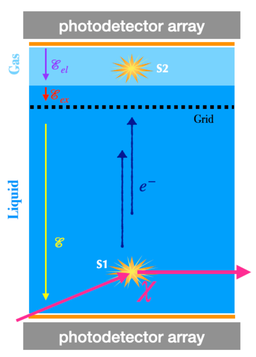
[noemi.pino@dfa.unict.it]

Direct searches in dual-phase TPC

Liquid Argon Time Projection Chambers (**LAr TPC**) are one of the leading technologies in the direct searches for **Weakly Interacting Massive Particles** (**WIMP**) as dark matter candidate [1]

WIMP elastic scatters on Ar → the signature of the Nuclear Recoil (NR):

- prompt **scintillation** signal **S1**
- delayed electroluminescence signal **S2** due to drifted electrons formed by **ionization**, which are extracted in the gaseous layer



How heavy are WIMPs? Possible scenarios:

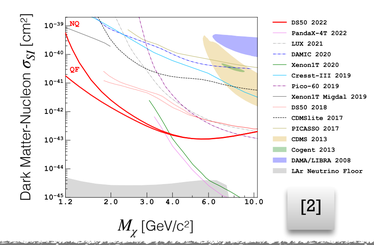
- mass $\mathcal{O}(100)$ GeV/c² → NR energy of tens of keV$_{nr}$ (detectable S1+S2)
- Low mass $\mathcal{O}(1)$ GeV/c² → NR energy of ***a few*** keV$_{nr}$ (detectable S2)

The detection challenge of low-mass WIMPs

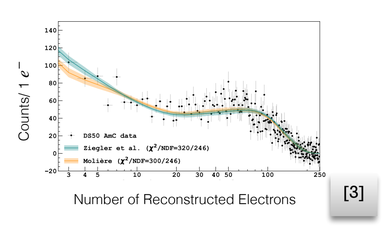
Due to the *feeble S1* signal, detection relies exclusively on the **ionization channel**
→at the corresponding recoil energy range the literature is scarce in data

In 2018 DarkSide-50 set a 90% CL exclusion limit for spin-independent WIMPs with mass in [1.2, 3.6] GeV/c² [2]

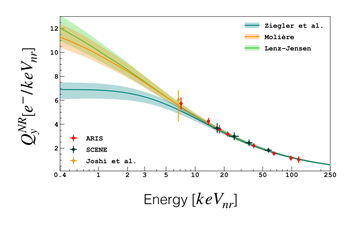
Dedicated model for the ionization response in argon [3] → need to be further improved with a calibration dataset collected in a two-body kinematics approach at the keV scale



[2]



[3]

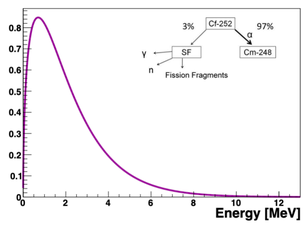


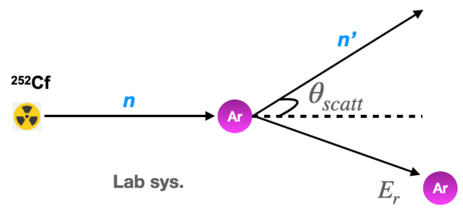
[3]

The ReD experiment: conceptual design

The ***Recoil Directionality (ReD)*** experiment, within the **Global Argon Dark Matter Collaboration** (**GADMC**), aims to study the low energy region (2-5 keV) for NRs using neutrons from a ^{252}Cf source and directed toward a small LAr TPC [4]

^{252}Cf emits neutrons in spontaneous fission (SF) events with a continuous energy spectrum → interact in the TPC via *(n, n')* → scattered *n'* detected by a neutron spectrometer



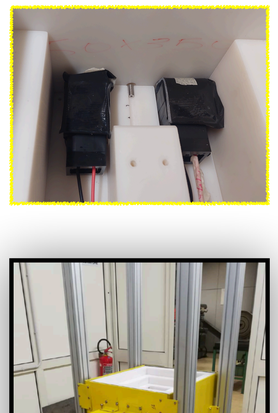


The recoil energy E_r is calculated event-by-event in a purely kinematic approach from **geometry** and **time-of-flight measurement** (**ToF**)

$$E_r = 2E_n \frac{m_n m_{Ar}}{(m_n + m_{Ar})^2}(1 - \cos\theta_{scatt})$$

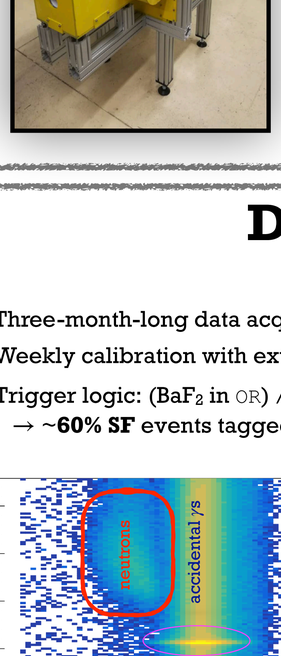
NR candidate events are selected firstly by applying ToF and Pulse Shape Discrimination (PSD) from the neutron spectrometer →among these S2-only events are searched offline in the TPC

Experimental setup @ INFN CT



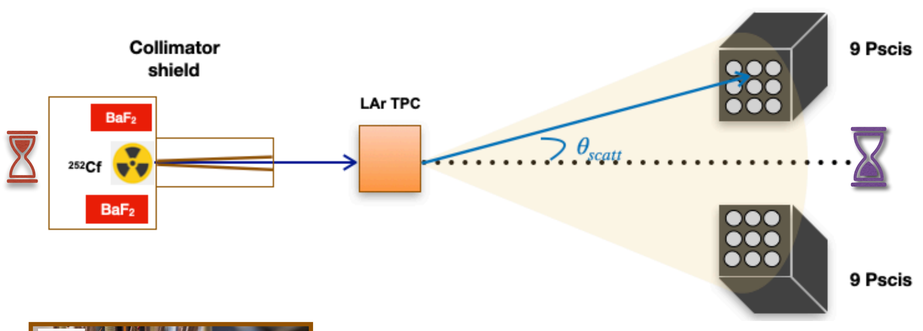
1. ^{252}Cf source

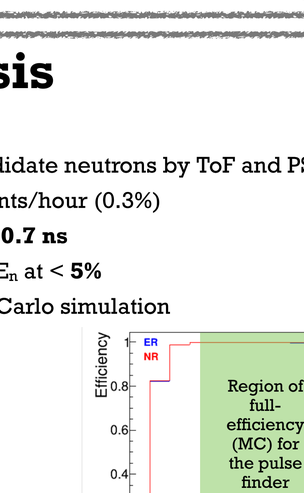
- **1.0 MBq** (1/1/2023)
- **26 kBq** SF
- Shield made of B-loaded PE (15 cm), Fe and Pb
- Collimator "nose": 50 cm of B-loaded PE, opening angle ~2°
- Irradiate the entire TPC at 1 m distance



2. BaF_2

- Coupled with Hamamatsu PMT
- Fast scintillation (0.8 ns but @220 nm)
- Featuring n/γ discrimination
- Detect the accompanying radiation of the SF
- Provide the **START** time for the ToF





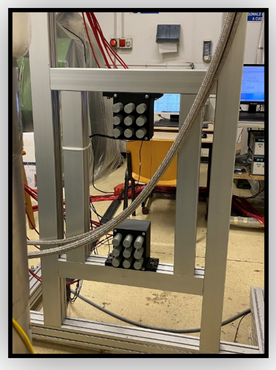
Read more about it

3. TPC

- Active volume of **5(l)** x **5(w)** x **6(h)** cm³
- Liquid Argon bulk + *7-mm-thick gas layer*
- Conductive layer of **ITO** on Anode and Cathode windows
- **TBP** as a wavelength shifter
- Cryogenic **SiPM** readout: two 5x5 cm² tiles with 24 devices
- Follower acquisition mode→ offline analysis

4. Neutron spectrometer

- **18** 1-in **EJ-276** Plastic Scintillators (**Pscis**) + PMTs
- Two matrices **3x3** placed at θ_{scatt} ~ **12°-17°** wrt the TPC position in the cryostat
- Fast timing (**1 ns rms**)
- Featuring n/γ discrimination
- Provide the **STOP** time for ToF



Data taking and analysis

- Three-month-long data acquisition
- Weekly calibration with external sources
- Trigger logic: (BaF_2 in OR) ∧ (Pscis in OR)
  → ~**60% SF** events tagged

- Selection of candidate neutrons by ToF and PSD
  - About 28 events/hour (0.3%)
- ToF resolution ~ **0.7 ns**
- Event-by-event E_n at < **5%**
- Detailed Monte Carlo simulation

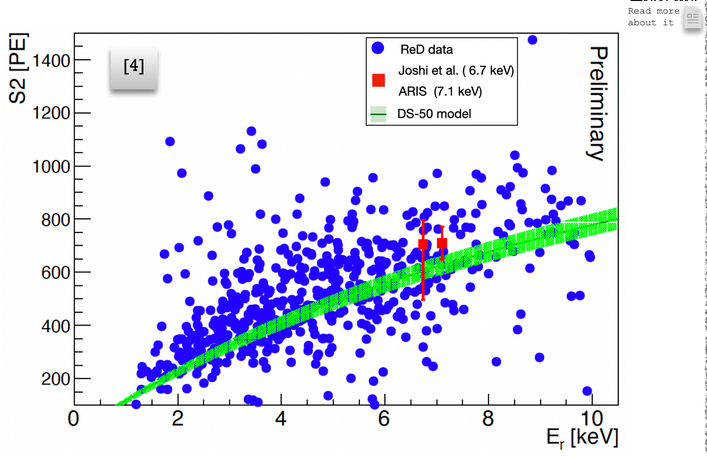
Preliminary results

E_r down to 1-2 keV$_{nr}$!!

- Compare against the prediction of the **DarkSide-50 model** and **literature data** using the S2 gain g_2 (*photoelectrons per electron*)
- Preliminary g_2 = **17.2 PE/e-**, based on cross-calibration with DarkSide-50
- Work in progress to infer g_2 directly from ReD data

→evaluate absolute charge yield and constrain model

Read more about it



ReD+: innovating and moving forward

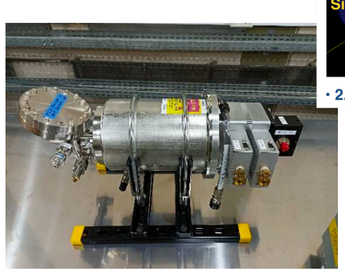
Future project ReD+, funded as a 2-year PRIN project at INFN, Laboratori Nazionali del Sud

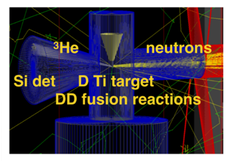
Timeline: *Oct 2023-Oct 2025*
GOAL: improve and extend the coverage of ReD down to **0.4 keV** using the same approach (^{252}Cf source)

Optimized components:

- *New TPC* → bigger than the ReD one
- *Larger neutron spectrometer* (18 more Pscis!)

In addition, irradiating the TPC with **2.4-MeV mono-energetic neutrons** from a **DD generator**
Joint project with the University of São Paulo (FAPESP grant)
Delivered to USP in June 2024: it will be commissioned and shipped to LNS





• 2.4 kHz trigger rate at Si Det

References

[1] P. Agnes et al. PRD 98 (2018), 102006

[2] Agnes et al. PRD 107 (2023) 063001

[3] Agnes et al. PRD 104 (2021) 082005

[4] I. Ahmad et al, PoS(TAUP2023) 052

[5] Agnes et al. EPJ C 81, 1014 (2021)

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