

L. Pandola (LNS) on behalf of the ReD Working Group

Gruppo 2 Local Meeting, June 30th 2022

Physics background

- Search for dark matter in the form of Weakly Interacting Massive Particles (WIMPs)
 - WIMP is a favourite candidate, but there are many others
- <u>Signature</u>: low energy (< 100 keV) nuclear recoil produced by WIMP elastic scattering
 - <u>Backgrounds</u>: e⁻ recoils, neutron-induced recoils
- Global effort worldwide:
 - Rates in the range from 10⁻¹ to 10⁻⁶ events / (kg·day)
 - next generation experiments should eventually reach exposures in the range of ktonday
 - Need very low background level (and underground site)



Physics background darkside

- DarkSide at Gran Sasso
 Laboratory, WIMPs using search using a dual-phase TPC with lowradioactivity LAr
 - Operated a 50 kg TPC (DarkSide-50)
 - <u>Next step</u>: 30 ton LAr **TPC** (DarkSide-20k)
 - Novel light readout with SiPM
 - Getting ready for data in 2025, exposure O(100) ton yr
 - Expected sensitivity 10⁻⁴⁷ cm² @ M_W =1 TeV/c²
 - <u>Next-next step</u>: global worldwide effort (ARGO, 300 ton LAr)
- More sensitive to low-mass WIMP than Xe, due to the lighter target





DarkSide/ReD activities @ LNS

- Main involvement is within the **ReD project**, three-fold goal:
 - check if a dual phase LAr TPC has sensitivity to the direction of Ar recoil
 - characterize the response of the LAr TPC to very low-energy recoils (< few keV) → recently became a hot topic (S2-only)
 - act as a test bench of the technical solutions for DarkSide-20k TPC
 - <u>Phase 1 (Napoli)</u> Characterization of the TPC
 - Stability over time scale of months
 - Check that performance OK for phase 2
- Phase 2 (LNS) Directionality run
 - TANDEM beam LNS (February 2020)
 - No indication for directionality
- <u>Phase 3 (Sez. Catania)</u> Low-energy run with ²⁵²Cf
 - In preparation (up to 2-5 keV)
 - Complemented with low-energy ERs



Directionality for nuclear recoils in a liquid argon Time Projection Chamber | Xinran Li | TAUP2021

EPJ C 81 (2021) 1014

ReD-directionality conceptual design

- Produce Ar recoils of known energy and direction in a TPC by using a suitable neutron beam
 - Can be done via p(⁷Li,⁷Be)n
 - ⁷Li beam from the TANDEM accelerator of INFN-LNS (Catania)
 - Detect the associate particle (⁷Be) to tag neutron energy event by event
- Detect neutrons elastically scattered off ⁴⁰Ar
 - Kinematics of (n,n') will fix energy and direction of the recoil



Riunione Gr2-LNS

6

...and actual implementation at









Phase 2– Directionality run (LNS)

- Neutron beam run at LNS, shortly before the lockdown (Feb 1st to Feb 14th)
- Total time of analysis runs : 241.7 h (= 10.07 days)



INGRESSO VIETATO



- <u>Signal</u>: single Ar recoils, of same energy but different φ
- Full three-fold coincidences (Si ^ TPC ^ n-Spectrometer)
 - About 150 events/day
- Very clean identification of events based on:
 ⁷Be tagging, timing and PSD (TPC and LSci)
 - ToF resolution ~1-2 ns rms

The directional model

Data intepretation needs a model for the directional effect

Model	Directional dependence	84	
Thomas-Imel, Box ("short track") Phys. Rev. A 36 (1987) 614	None		
Jaffé-Birks ("infinitely long track") Ann Phys 347 (1913) 303	$[\sin \phi]^{-1}$	Santa	E_{drift}
Cataudella et al. JINST 12 (2017) P12002	$\left[\sqrt{\sin^2\phi + \cos^2\phi/R^2}\right]^{-1}$	θ	



- Single parameter R → aspect ratio of the e⁻-ion cloud
 - R=1 → no directional effect (Thomas-Imel)

R+'

The directional model

Data intepretation needs a model for the directional effect

Model	Directional dependence	844
Thomas-Imel, Box ("short track") Phys. Rev. A 36 (1987) 614	None	
Jaffé-Birks ("infinitely long track") Ann Phys 347 (1913) 303	$[\sin \phi]^{-1}$	State -
Cataudella et al. JINST 12 (2017) P12002	$\left[\sqrt{\sin^2\phi + \cos^2\phi/R^2}\right]^{-1}$	θ



- Single parameter R → aspect ratio of the e⁻-ion cloud
 - R=1 → no directional effect (Thomas-Imel)
- Impact on detector response → change S1 vs. S2 balance

Analysis and results



- Unbinned maximum likelihood fit
 - Nuclear recoil sample (Si ^ TPC) and triple coincidence data
 - <u>Components</u>: signal, multi-scattering, random coincidences
 - PDF from Geant4 simulations and/or data-driven (side bands)
 - Nuisance parameters (e.g. g₁, g₂,) constrained with pull terms
- R is the only parameter of interest

R = 1.036 ± 0.024 No effect (Preliminary!)



- Results presented in conferences, since Aug 2021
- **Paper** draft available (currently under Collaboration's Review)

Phase 3 – Low-energy phase (INFN-Ct)

- Low-energy recoil measurements (< few keV) by using neutrons from a ²⁵²Cf fission source
 - Neutrons O(2 MeV), more appropriate for E_{rec} ~ few keV
 - Use close fission tagger (BaF₂) and time of flight
 - Neutron spectrometer to detect neutrons scattered off-Ar
 - Use 1-inch plastic scintillators
 - Conceptual design from USP group
 - Sensitivity down to







Preparation at INFN-Ct

- Refurbishment and equipment of the host site at INFN-Ct recently completed
- All hardware available:
 - Shielding (B-loaded PE, Pb, Fe) ✓
 - 1.5 MBq ²⁵²Cf source ✓
 - Neutron spectrometer (18 1-in EJ-276) and support structure
 - Fission taggers: BaF (available in-house) ✓
 - ⁸³Rb/^{83m}Kr ordered, ³⁷Ar from ⁴⁰Ca(n, α) \checkmark
- Re-commissioning:
 - Slow control & DAQ ☑
 - Cryogenic system
 - First cooldown
 - March 2022
 - Test of SiPMs
 ☑
 - Problem with the TPC fields ⊠









Workplan – low-energy run

- TPC windows replaced (May 22) to fix the field issue
- Next cooldown: July 22
- Data taking with ²⁵²Cf: Sep 22
 - About four weeks
- Data taking with (env) background
 - Two or three months
- Calibration of low-energy ERs with ^{83m}Kr and ³⁷Ar
 - Early 2023
- Decommissioning and data analysis







URANIA Facility

- The URANIA plant will extract and purify the underground Ar (low in ³⁹Ar) from the CO₂ wells at the Kinder Morgan Doe Canyon Facility, Colorado
 - Plant built & commissioned at the Company site
 - Ready for shipment to Colorado
- Expected production: 50 tons
 - To be purified and further depleted by distillation in the ARIA facility
- LNS actively involved in the design and construction of the plant (G. Schillaci)





15

Attività e richieste 2023 – gruppo LNS

- Il progetto ReD è in conclusione e non sono previste richieste finanziarie nel 2023, se non per il decommissioning
 - Trasporto del sistema criogenico a Napoli
 - Collaborazione concentrata sulla costruzione del rivelatore DarkSide-20k
- Attività di ReD nel 2023:
 - Completamento presa dati e coordinamento delle attività on-site (L. Pandola, L1 manager)
 - Finalizzazione presa e analisi dati, preparazione pubblicazione
 - Decommissioning
- Trasporto dell'impianto URANIA per l'estrazione di Ar depleto in ³⁹Ar in Doe-Canyon (Colorado)
- Contributo all'attività sperimentale di Proto-0 a Napoli, test SiPM e sviluppo software (offline, Monte Carlo, analisi) per DarkSide-20k
 - Da definire in dettaglio nell'ambito della Collaborazione
- Richieste finanziarie ridottissime
 - Missioni per meeting ed attività a Napoli
 - Decommissioning del sistema

Richieste 2023 – gruppo LNS

Fielinna		
		Drolimino
TOTALE		2.0 FTE (1.5 nel 2022)
S. Sanfilippo	Assegnista di Ricerca	80%
G. Schillaci	Tecnologo II	20%
L. Pandola	Ricercatore II	60% (RespLoc)
M. Gulino	Associato (UniKore)	40%

Trasporti	 Decommissioning del sistema criogenico codice WBS item: DS- 180600 	5 k€
Missioni	 Contatti con altri gruppi e meeting di Collaborazione 	6 k€
TOTALE		11 k€

(Ideas for) future next steps [DETOUR]

- ReD follow-up, always tailored to low-energy NRs
 - PRIN project ReD+
 - bigger TPC, ²⁵²Cf source
 - Irradiation with DD gun (application through Brazilian FAPESP)
 - Same (or bigger TPC), DD neutron gun

Non-ReD ideas

- Dedicated measurement of the poorly-known cross section of ⁴⁰Ar(α,n)
 - Of interest for Ar-based DM searches \rightarrow background from ²²²Rn progeny
- Re-use of the ²⁵²Cf setup (source, shielding and possibly spectrometer) for other measurements
 - NAA for cultural heritage and others