Directionality for nuclear recoils in a liquid argon Time Projection Chamber

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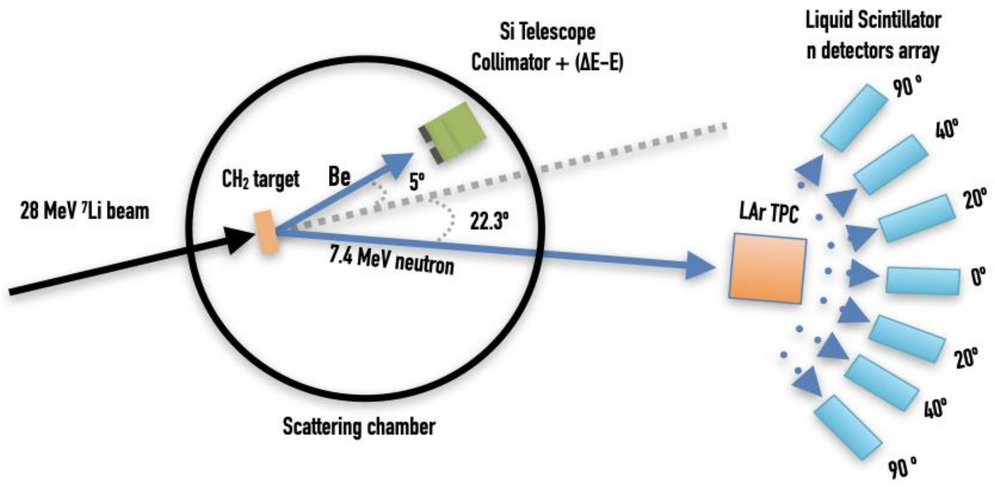
- Sensitivity to the **direction of nuclear recoil** (NR) would be a key asset for LAr-based detectors, as signal directionality **would be a "smoking gun" to support a discovery of WIMP dark matter.**
- Hints of such directional phenomena were reported by the SCENE experiment[1].
- The Recoil Directionality project (ReD) was designed and implemented within the Global Argon Dark Matter Collaboration in order to unambiguously verify the hint by SCENE and to provide information on the recombination mechanism in argon.

ReD directionality setup

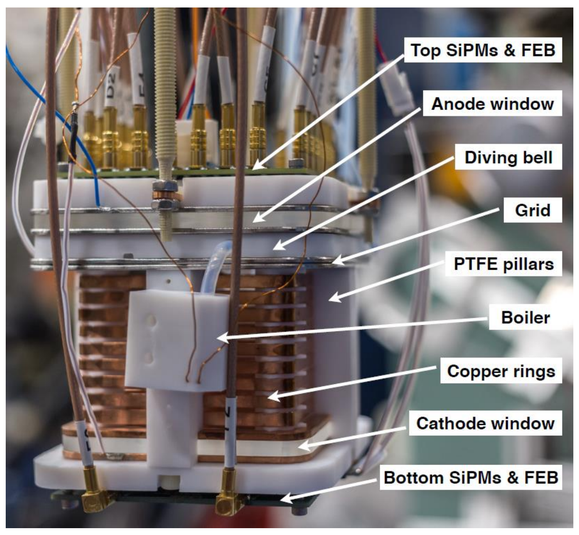
- The ReD measurement consisted of the **irradiation of a miniaturized LAr TPC with a neutron beam, producing Ar recoils of known energy and direction**.
- The neutron beam is generated via the p(^{7}Li,^{7}Be)n reaction using a ^{7}Li beam from LNS-INFN TANDEM accelerator.
- ^{7}Be identified with ΔE-E technique in Silicon detectors
- Neutrons elastically scattered off ^{40}Ar are tagged by a spectrometer constituted by an array of nine 3-inch liquid scintillator neutron detectors (LSci).
- The placement of the scintillators is such that they identify Ar recoils of the same energy, but at different angles Φ wrt the TPC drift field.
- Kinematics of (n,n') will fix energy and direction of the recoil.



Components

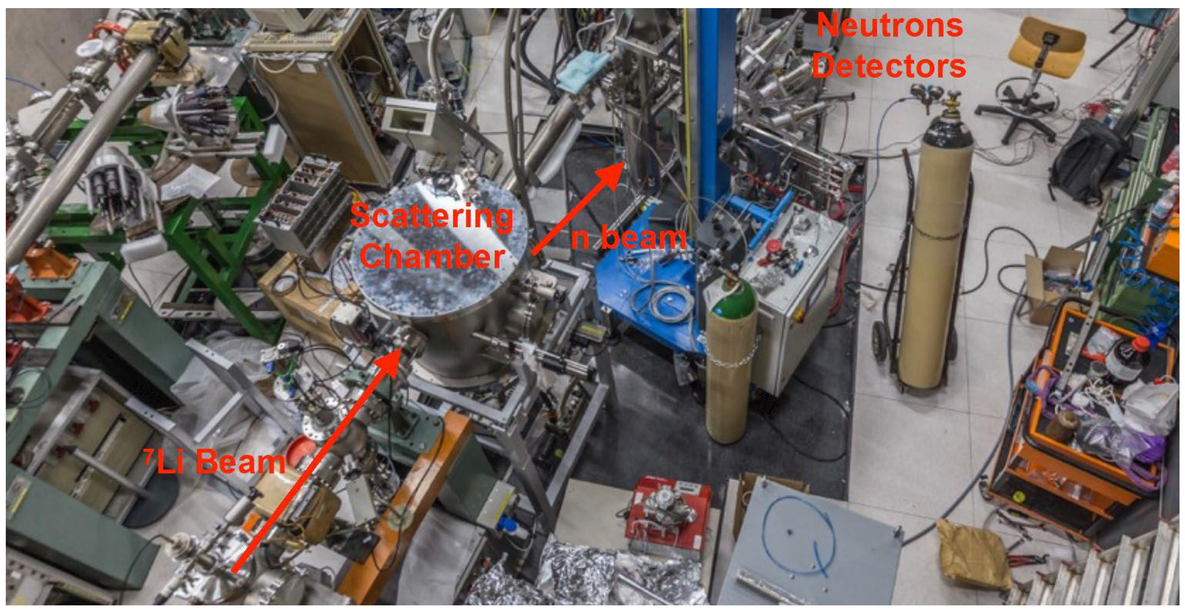
The ReD TPC:

- TPC has some key element of future DS-20k TPC (acrylic optical window, ESR reflectors, SiPM readout).
- Active volume: 5(L) x 5 (W) x 6 (H) cm
- Light readout: 5x5 cm² array made with 1 cm² SiPMs(as for DS-20k)
- ReD TPC is a valuable test bench of the technology which is being developed for DarkSide-20k and the future project Argo.
- Light Yield is ~10 PE/keV at null field[2]



Tagger detectors:

- The Si telescope measures the energy of the impinging particles and allows for Z separation (Li vs. Be).
- LSci are EJ-309 featuring n/γ discrimination.
- Arranged within a "ring" structure, in order to tag ^{40}Ar recoils in the TPC at 0°, ±20°, ±40°, ± 90° wrt $E_{drift.}$
- Energy/angles tuned to select ^{40}Ar recoils of ~70 keV in the TPC.

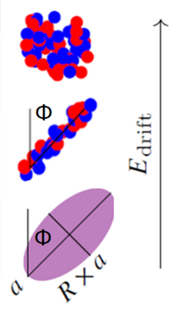


- Events are selected as **triple coincidence between Si, TPC and LSci**.
- Clean identification of events based on: ^{7}Be tagging, timing and PSD (TPC and LSci).
- Small dimensions of the TPC minimize double scattering probability

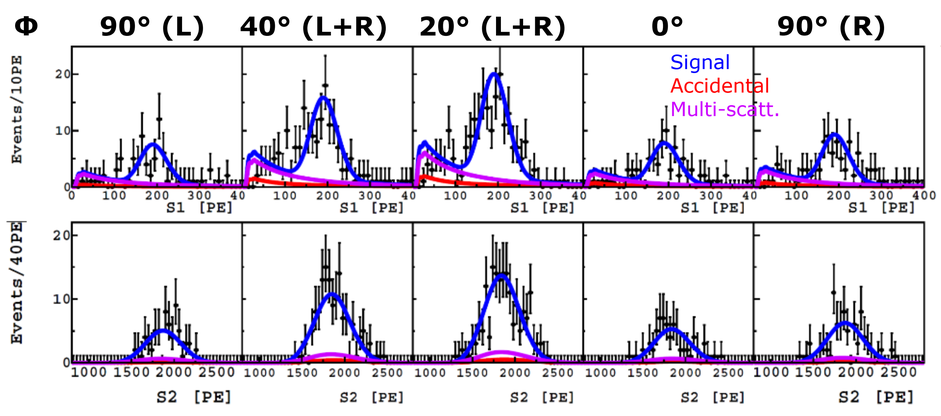
Data analysis

- The correlation of the ionization and scintillation signals is a possible handle to measure the recoil direction of nuclei.
- A model based on directional modulation in charge recombination was developed to describe the correlation[3].
- **The model depends on a single parameter R, which measures the non-sphericity of the initial electron cloud.**

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

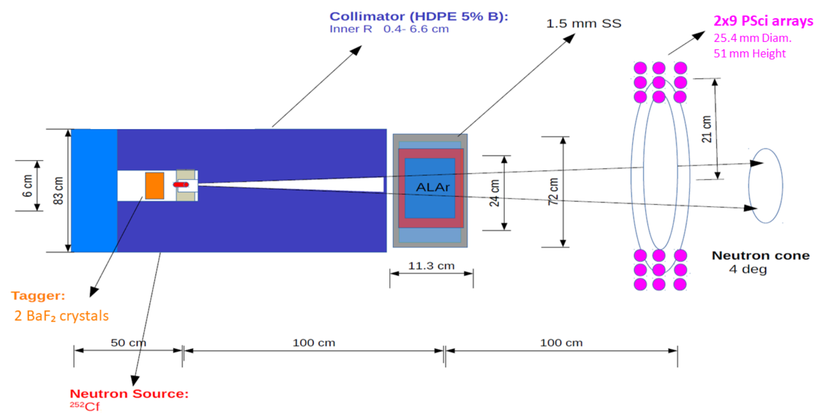


- **If R > 1 there is a net directional effect** → the ratio of ionization (S2) over scintillation (S1) signals will depend on the angle Φ between the NR momentum and the drift field.
- **If R = 1 → no directional effect.**
- **Preliminary results R = 1.036 ±0.024 → No effect.**

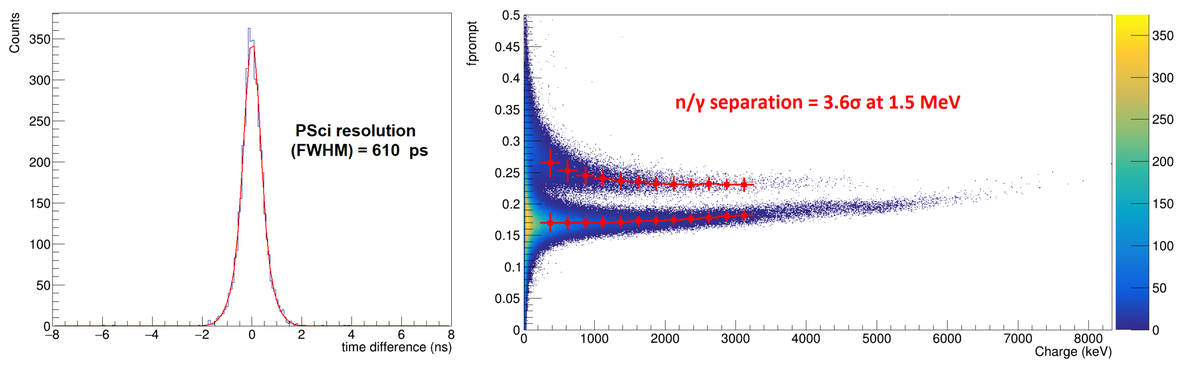


ReD future

- A dedicated measurement tailored to characterize **the response of the TPC to very low-energy nuclear recoils (< 10 keV)** is being currently performed at INFN Sezione di Catania, using neutrons produced by an intense ^{252}Cf fission source.



- **BaF_2 crystals and Plastic scintillators (Psci) (EJ-276) have been characterized**[4]
- PScis are 1-inch diameter and 2-inch height coupled to 1-inch PMT.
- **PSci time resolution** has been measured, resulting to be **610 ps**
- PSci PSD has been optimized resulting in a **n/γ separation** of 3.6σ at 1.5 MeV



References

1)SCENE, Cao et al., PRD 91 (2015) 092007
2)ReD, Agnes et al., EPJ C 81, 1014 (2021)
3)Cataudella et al., JINST 12(2017) P12002
4)Cesarano R., Master thesis (2022)