Directionality for nuclear recoils in a liquid argon Time Projection Chamber

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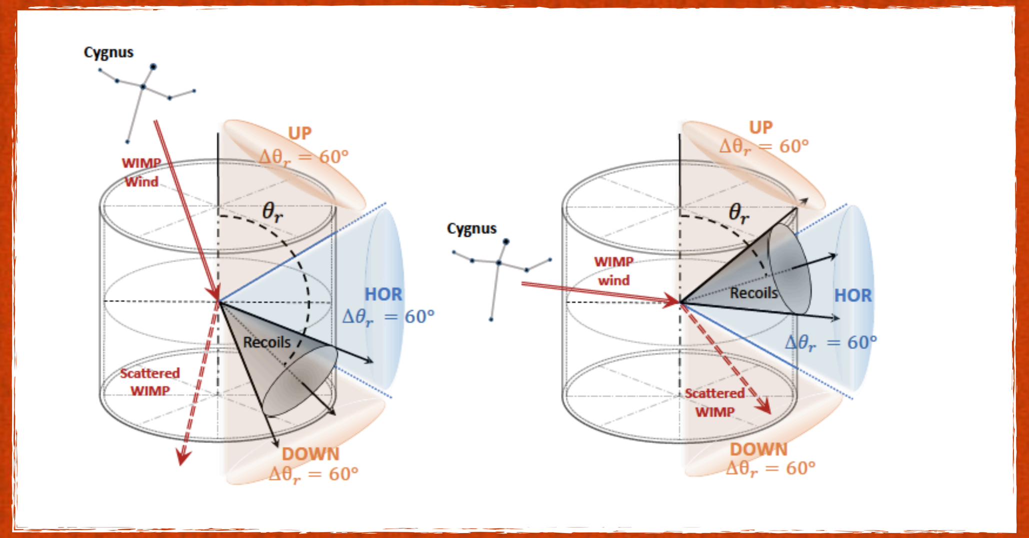
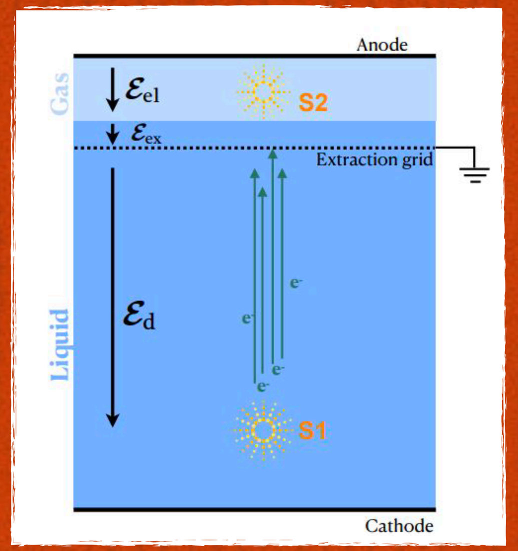
The goal

The expected WIMP events rate is strongly anisotropic, due to the motion of the solar system within our galaxy. The apparent WIMP wind should come from the Cygnus constellation direction.



A dark matter detector with sensitivity to the direction on the recoil would **open the possibility to make a unambiguous dark matter discovery.**
The goal of the ReD experiment is to investigate the potential sensitivity of a dual-phase argon TPC to the direction of nuclear recoils. The ReD TPC is a small scale version of the future DarkSide-20k TPC and shares with it some mechanical structures and the cryogenic Silicon Photomultipliers.

Dual phase Argon TPC working principle



Detection of two signals:

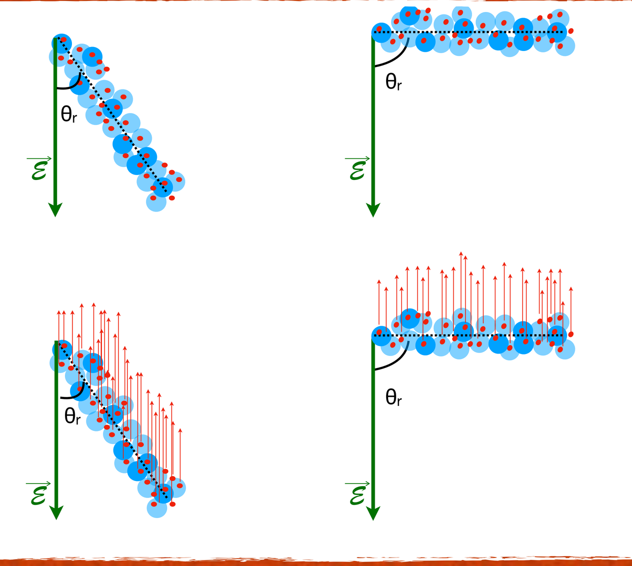
S1: produced in the liquid Ar by the scintillation light due to both the excited Ar atoms, and the recombined fraction of the ionized atoms.

S2: produced in the gas layer by the free electrons escaped from recombination and drifted up to the liquid surface.

Columnar recombination

If recoil track is almost parallel to the electric field

The free electron must pass through almost the whole column during the drift, maximizing the recombination probability.

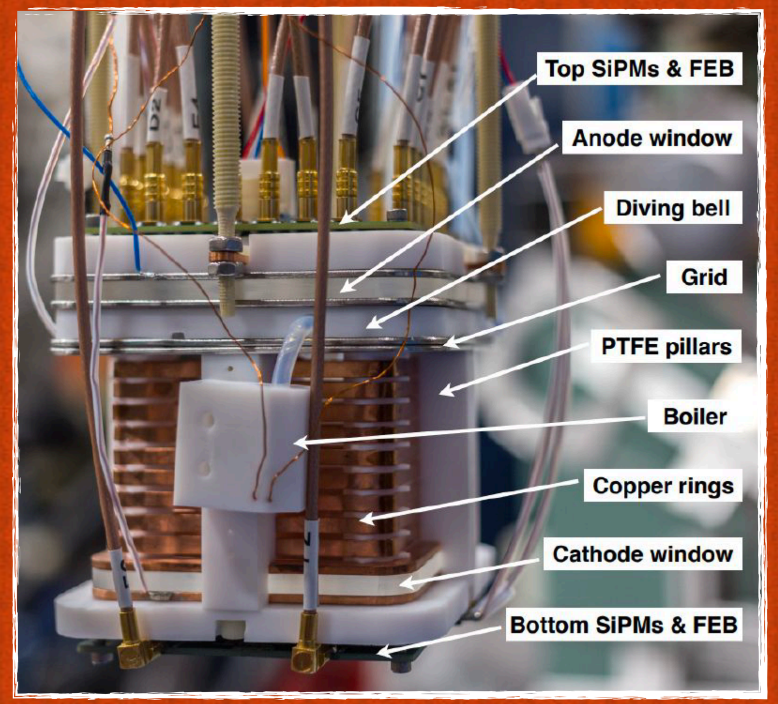


S1 and S2 signals expected to depend on $\mathcal{E}$ and θ_r

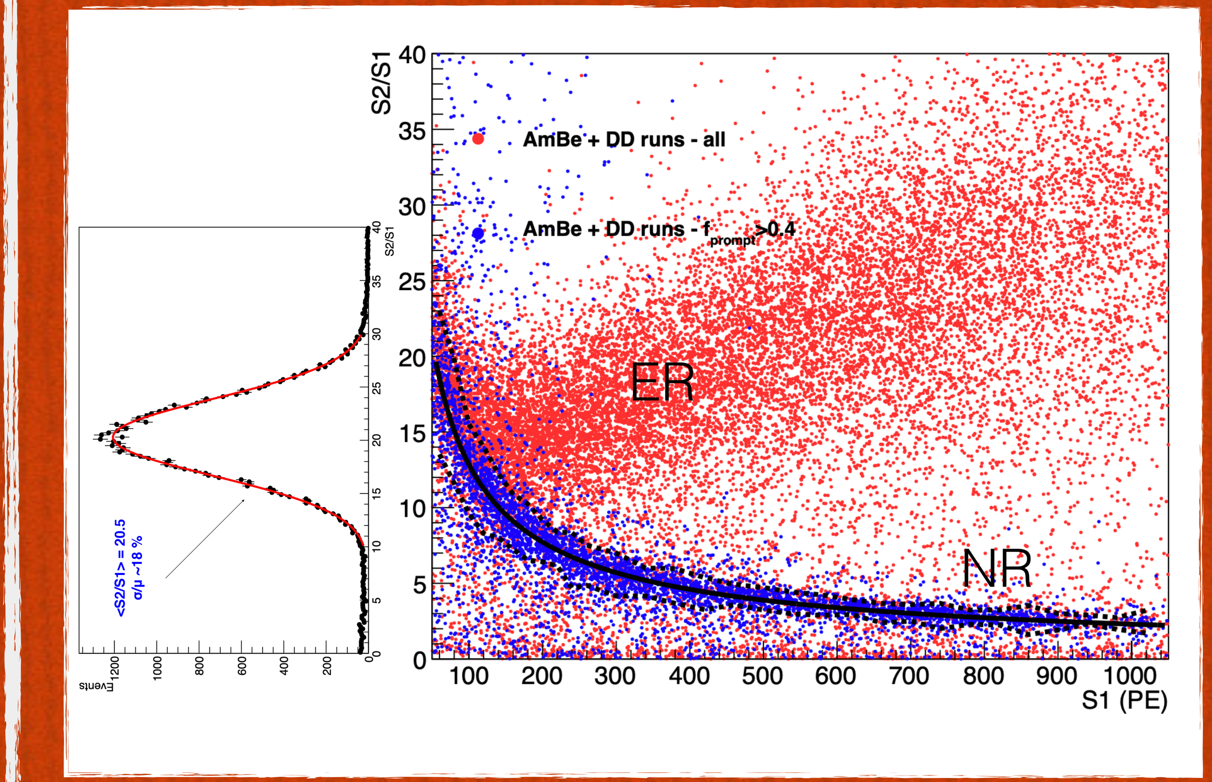
If recoil track is perpendicular to the electric field

Electrons will drift for a short distance inside the ionized particles cloud and then pass in region of neutral atoms, reducing the recombination probability.

The TPC design and performance



- **The dual-phase TPC** - designed at UCLA - has an active volume of 5 x 5 x 6 cm^3;
- The walls are made in by 3M reflector film, sandwiched by two 1.5 mm acrylic plates;
- **Anode and cathode** are made **in acrylic**, coated with a 25 nm ITO conductive layer on both sides;
- **Wavelength shifter** (TPB) is coated on the entire internal surfaces;
- Photosensors are made with **new cryogenic SiPMs**, developed by FBK Foundation;
- The SiPMs are grouped in two 5x5 cm^2 tiles, each containing 24 SiPMs;
- The tile located at the top of the TPC has a 24-channel readout board, the one at the bottom has a 4-channel readout board.

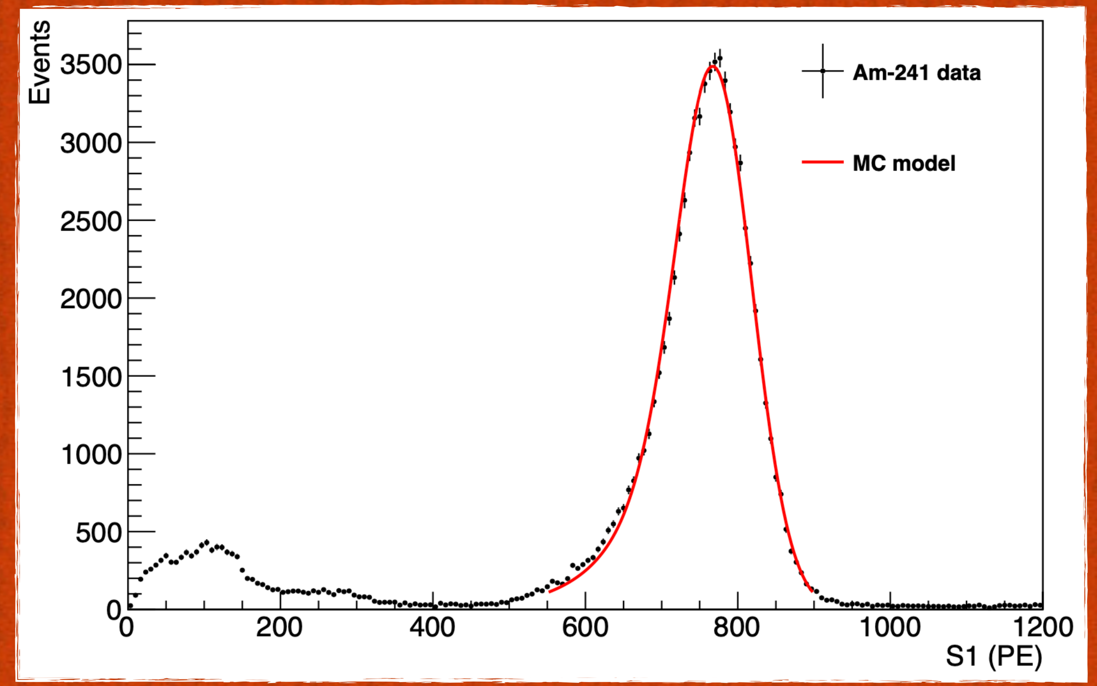


✳ $\mathcal{E}_{drift}$ and $\mathcal{E}_{elec}$ are set independently such to optimize scintillation (S1) and charge (S2) yield and resolution.
✳ **NR band is clearly separated from ER band above ~200 PE.**
✳ σ/μ(S2/S1) ~ 12% and 18% for NR and ER respectively, in the region between 150 and 250 PE
✳ **Good uniformity of S2/S1 response** ⟶ key performance parameter

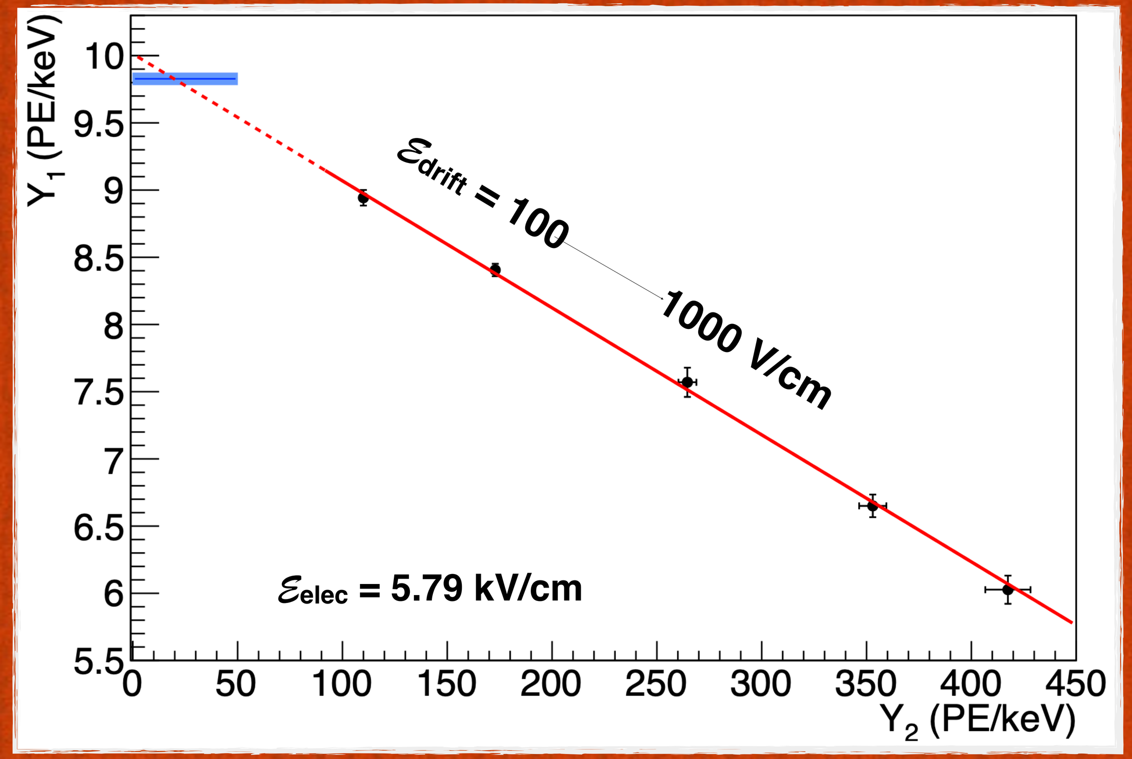
From the **S1 vs S2 yield anti-correlation**, due to the different ratio of recombined and drifted electrons at different $\mathcal{E}_{drift}$, we obtain:

- **g1 = 0.194 ± 0.013 PE/ph** (0.16 PE/ph, 0.11 PE/ph from DS50 and SCENE respectively)
- **g2 = 20.0 ± 0.9 PE/e-** (23 PE/e-, 3.1 PE/e- from DS50 and SCENE respectively)

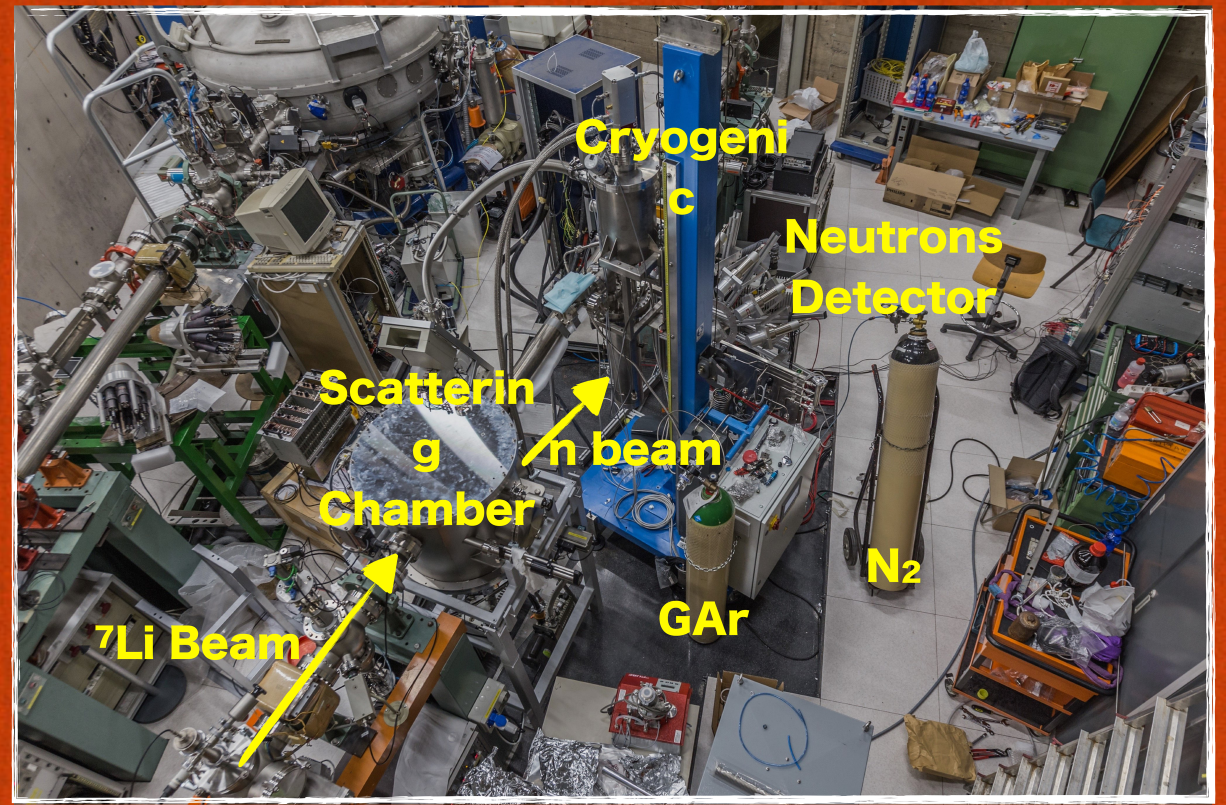
For details see :
https://arxiv.org/pdf/2106.13168.pdf



Calibration in sigle phase mode with ^{241}Am source.
Total light yield @ 59.5 keV accounting for cross talk and after pulse in the SiPMs at null field **~ 9.80 ± 0.13 PE/keV$_{ee}$** (stable within 2%)

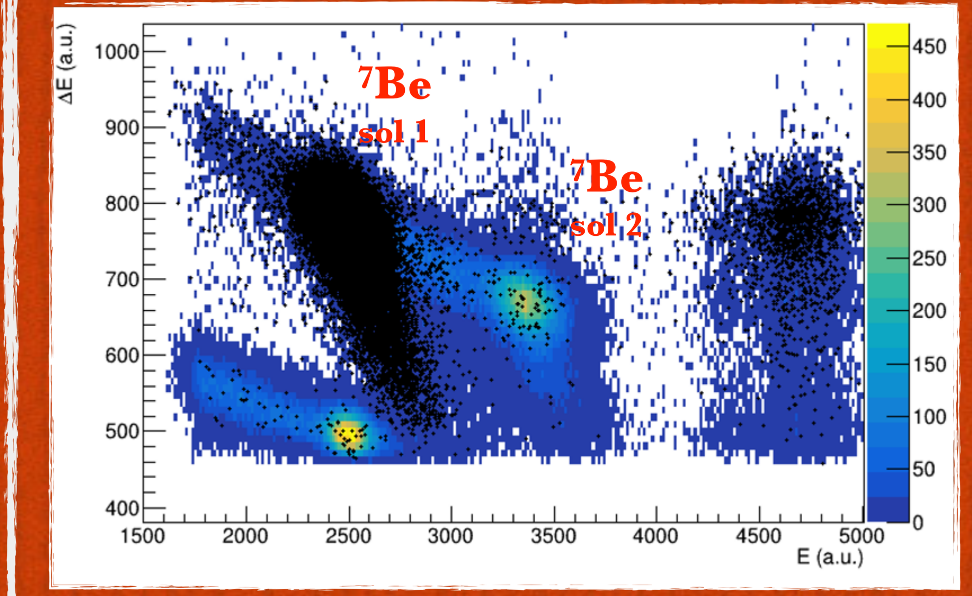


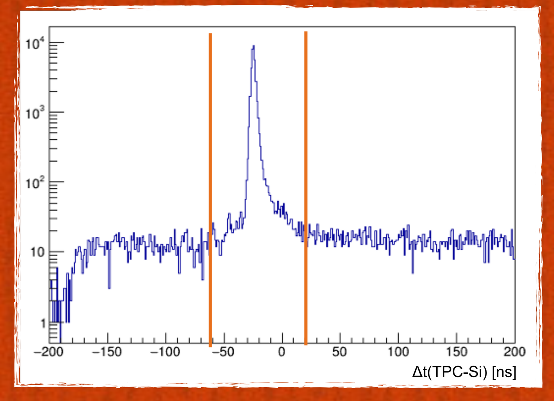
The full experiment setup and the first data



The key point is to **irradiate the TPC with neutrons** and produce parallel or orthogonal nuclear recoils, with respect to the $\mathcal{E}_{drift}$ field in order **to probe the directionality in liquid argon.**
The neutrons are generated through the **p(^{7}Li,n)^{7}Be reaction** with the 15 MV **Tandem accelerator** at the INFN Laboratori Nazionali del Sud, in Catania. **Neutrons scattered from the TPC are tagged** with a dedicated spectrometer constituted by an array of nine 3-inch liquid **scintillator neutron detectors (LSci).** This allows to **reconstruct the scattering angle** with respect to the electric field.

Two weeks beam run in February 2020





Neutrons are tagged individually by detecting the associated ^{7}Be nuclei by means of a ΔE/E telescope of silicon detectors.

The primary ^{7}Li energy and the positions of the TPC and of the LScis are tuned such to **select nuclear recoils of about 70 keV** in the TPC.

Events of interest are selected as triple coincidence between Si, TPC and LSci. The event sample is further cleaned by the identification of ^{7}Be in the Si telescope, the timing and the pulse shape discrimination, both in the TPC and LSci.