

RED: A SIPM BASED LAR TPC FOR DIRECTIONALITY STUDIES

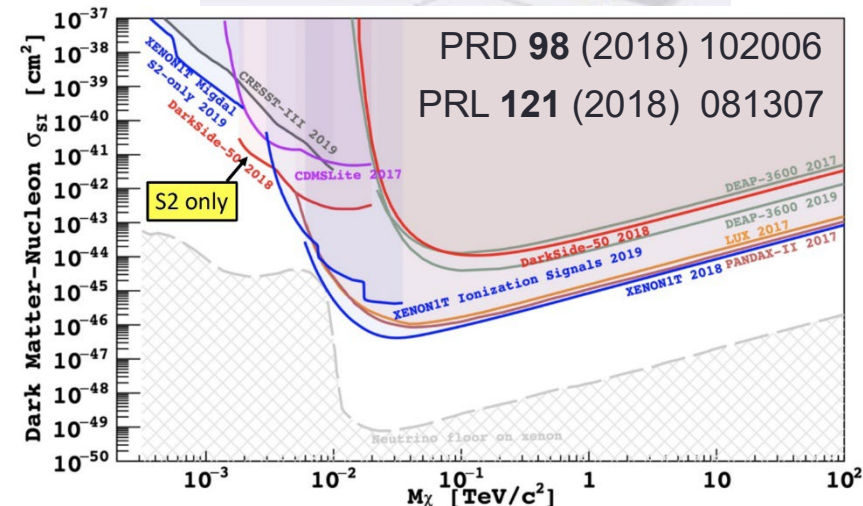
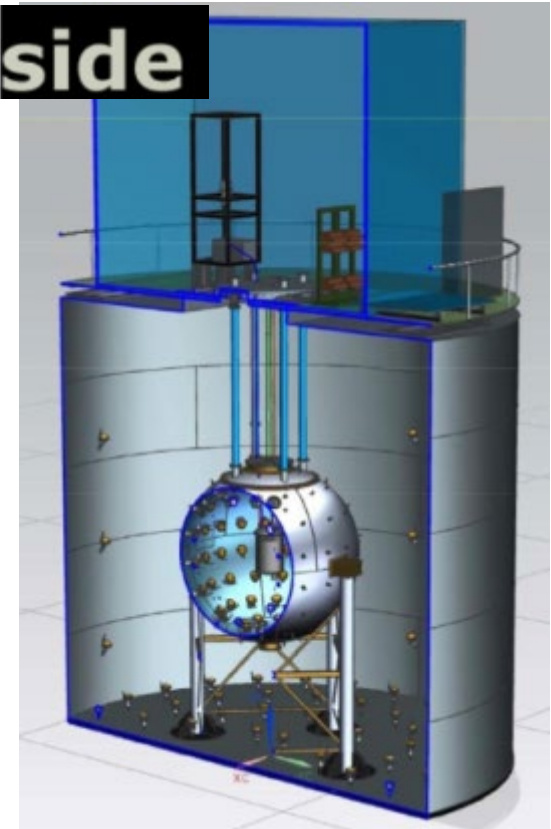
L. Pandola (LNS)

on behalf of the ReD Working Group
(DarkSide Collaboration)

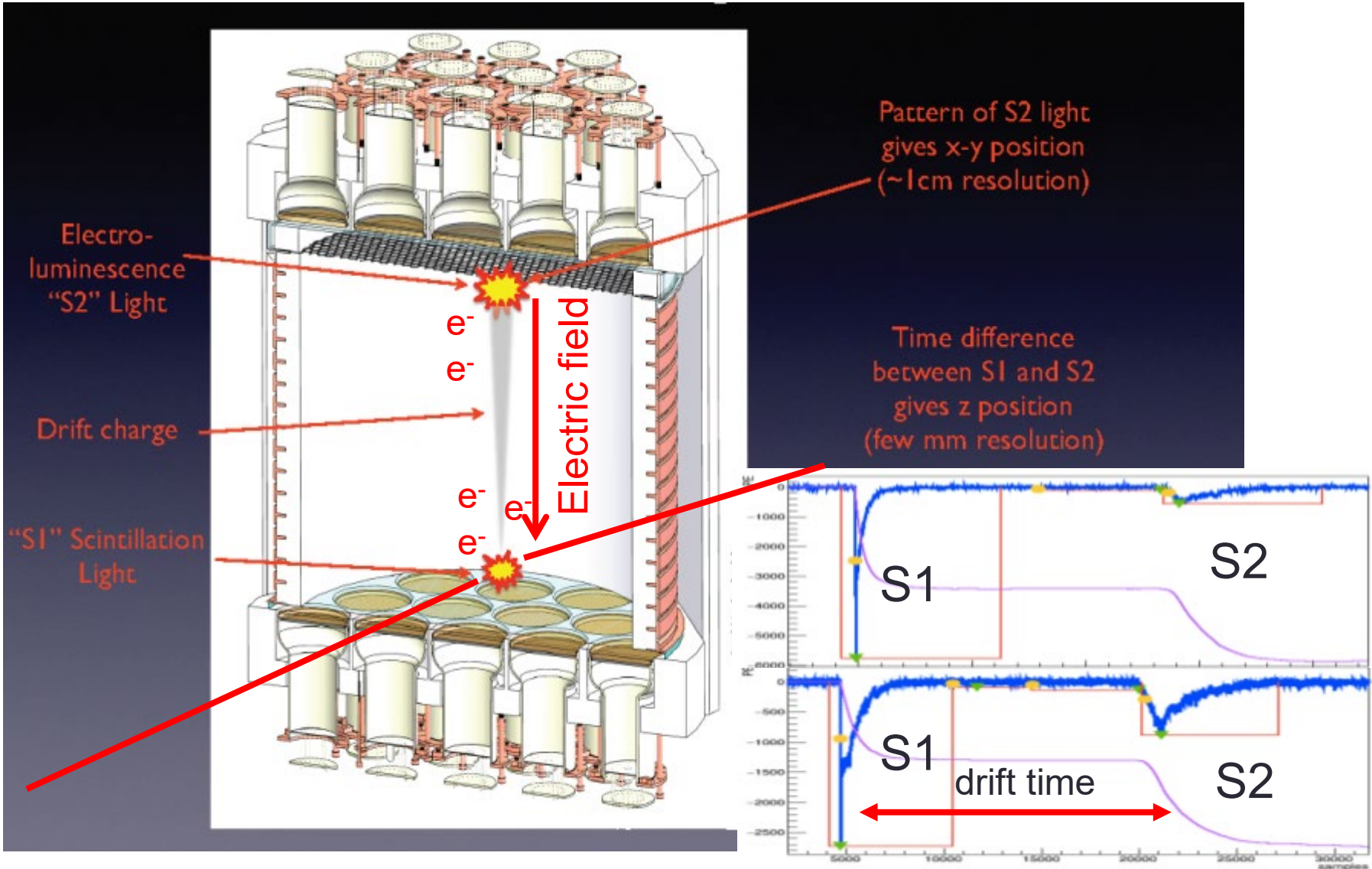
The logo for the DarkSide collaboration, with the word "darkside" in white lowercase letters. The "side" portion is set against a black rectangular background.

Physics background **darkside**

- **DarkSide** at Gran Sasso Laboratory, WIMPs using search using a **dual-phase TPC** with **low-radioactivity LAr**
 - Operated a **50 kg TPC** (DarkSide-50)
 - Next step: 20 ton LAr **TPC** (DarkSide-20k)
 - Novel light **readout** with **SiPM**
 - Getting ready for 2022, exposure $O(100)$ ton yr
 - Expected sensitivity $10^{-47} \text{ cm}^2 @ M_W = 1 \text{ TeV}/c^2$
 - Next-next step: global worldwide effort (ARGO, 300 ton LAr)
- More sensitive to **low-mass WIMP** than Xe, due to the **lighter target**

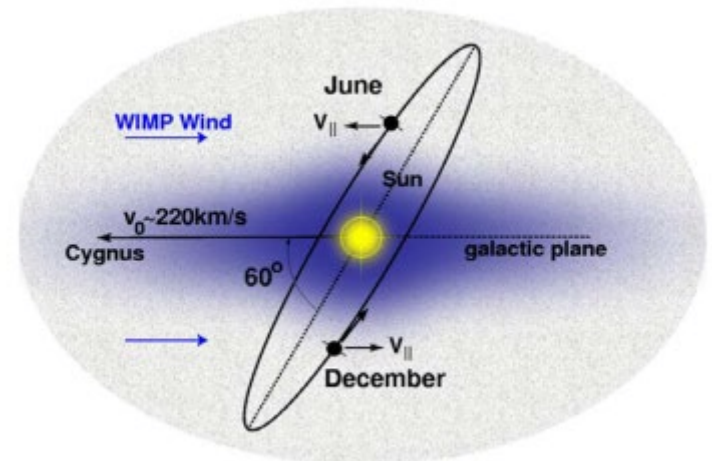


Working principle of the TPC in one slide



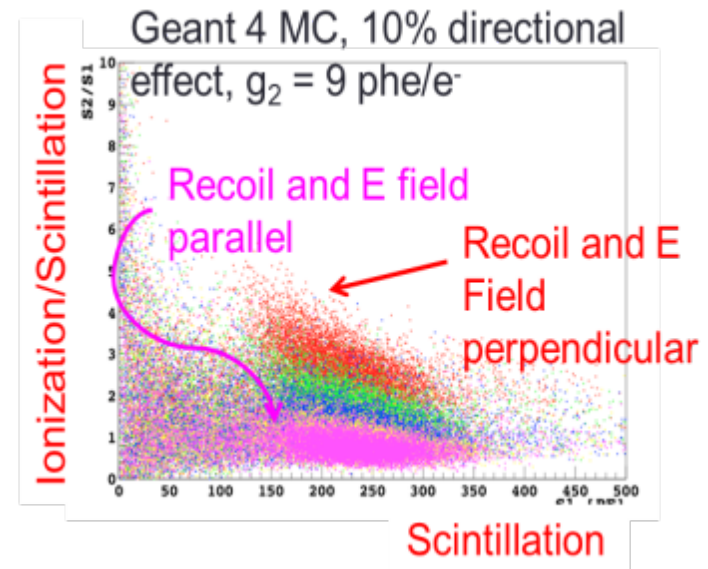
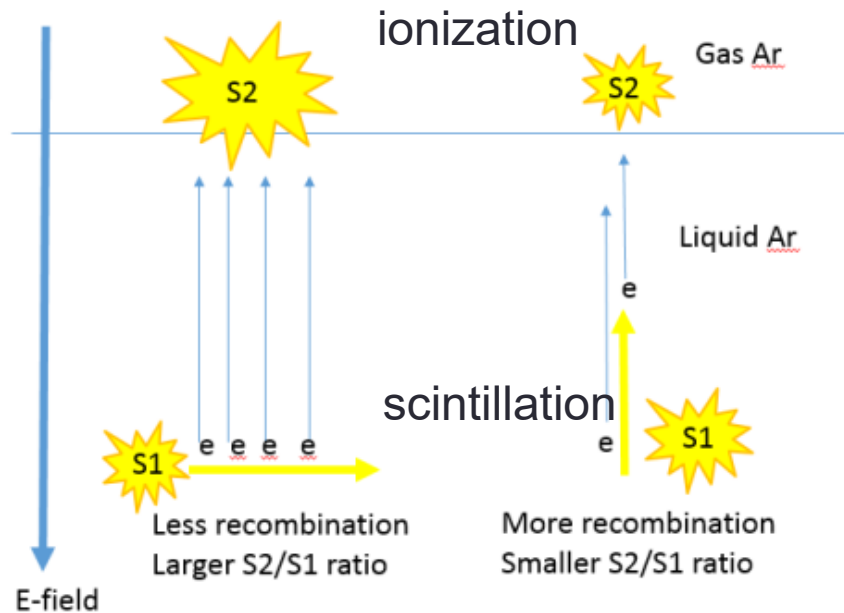
A smoking gun for dark matter discovery

- Correlation of **recoil direction** with the expected direction of the **WIMP galactic wind** would be a smoking gun
 - Much **more convincing** than a mere excess of recoil events



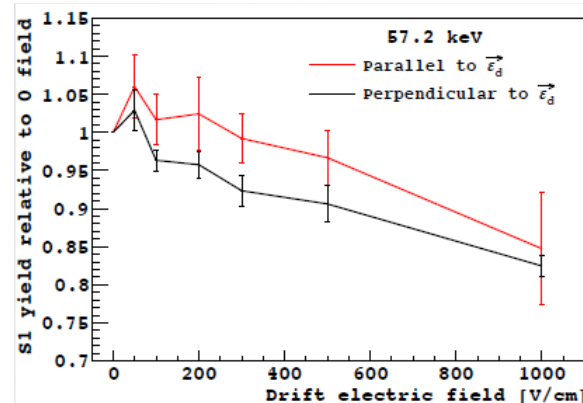
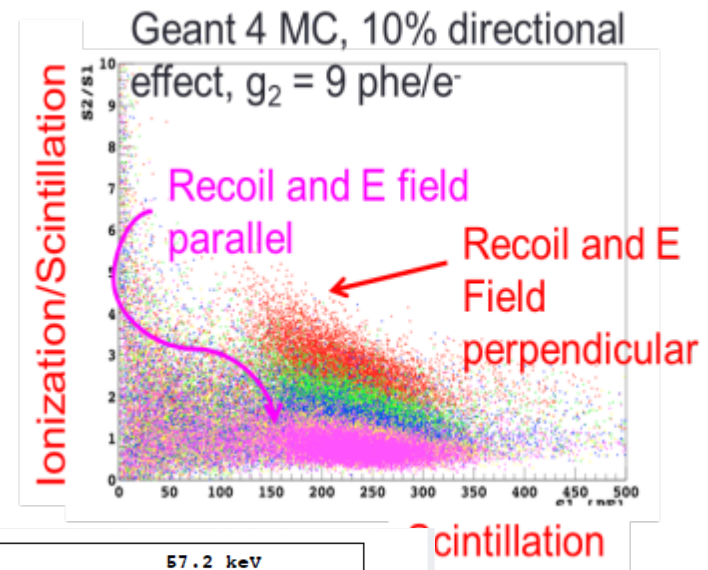
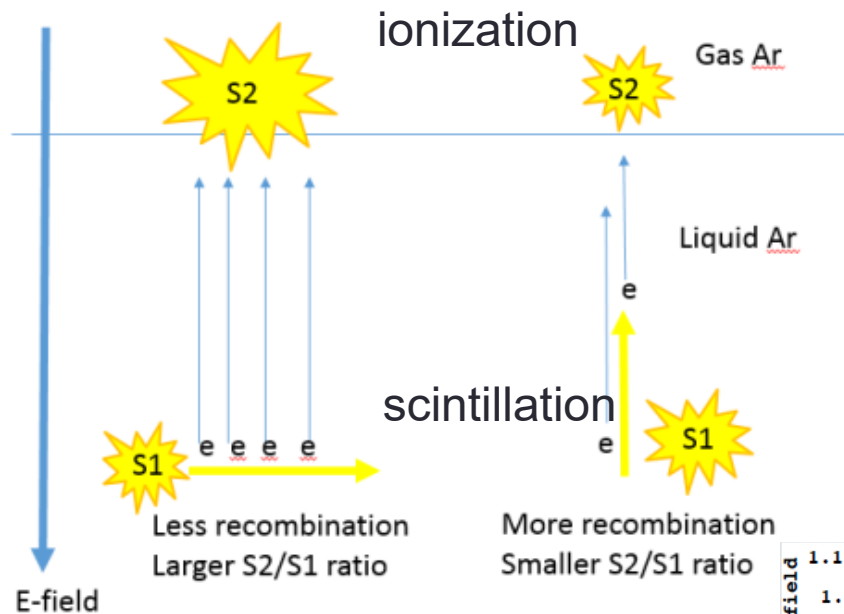
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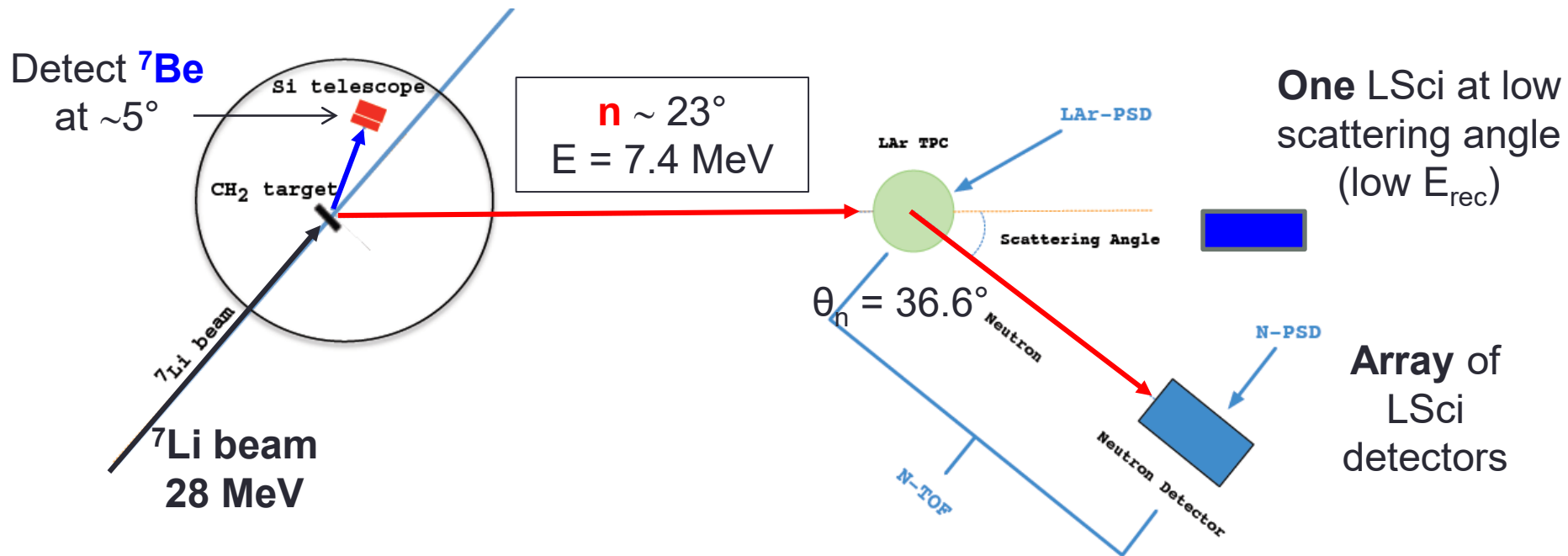


Just an **indication** →
to be confirmed

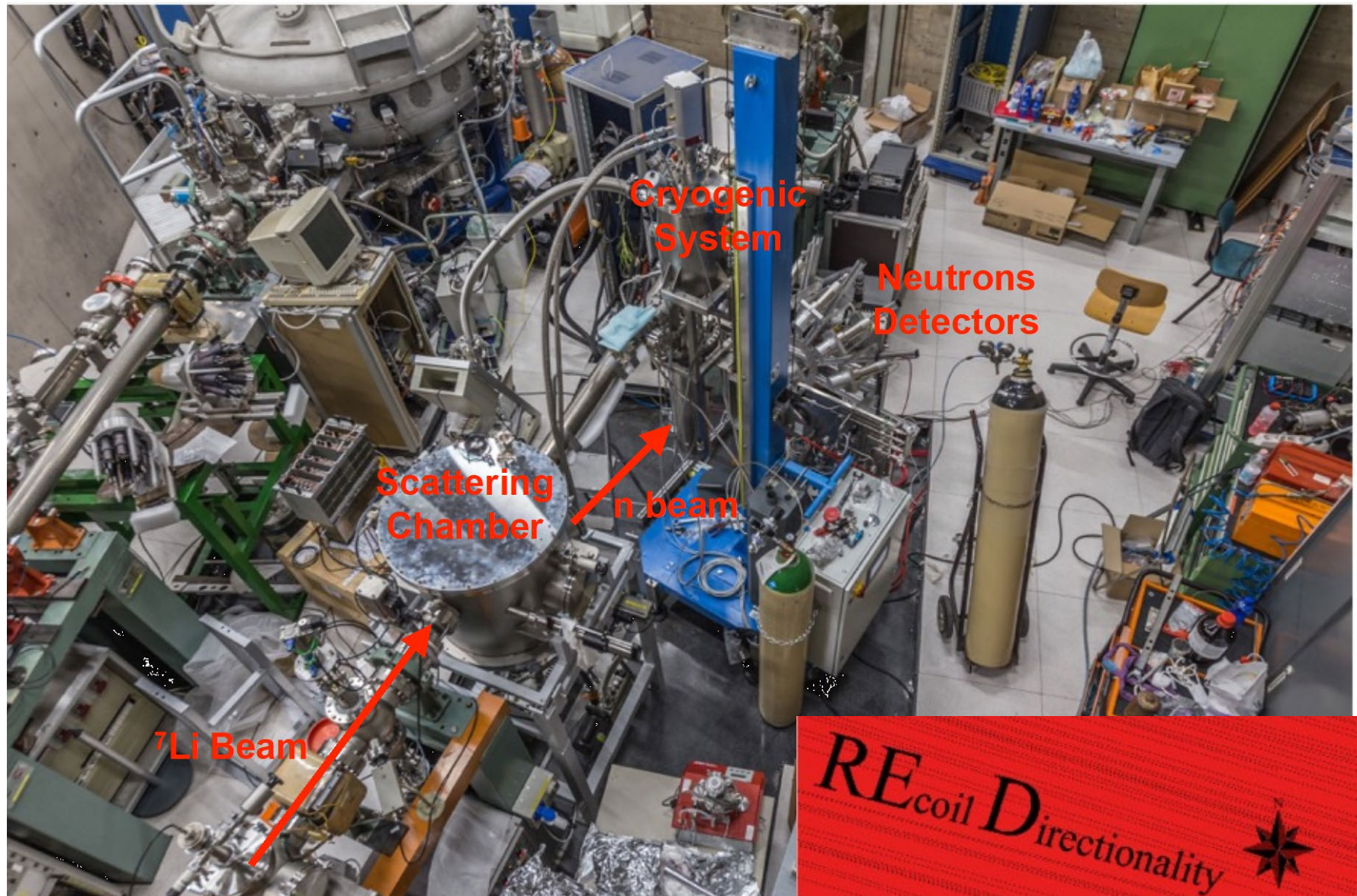
SCENE, Cao et al, PRD **91**
(2015) 092007

ReD conceptual design

- Produce **Ar recoils** by using a suitable **neutron beam**
 - Can be produced via $p(^7\text{Li}, ^7\text{Be})n$
 - ^7Li beam** from the TANDEM accelerator of INFN-LNS (Catania)
 - Detect the **associate particle** (^7Be) and **ToF** to **tag neutron energy** event by event (fixed by **two-body** kinematics)
- Detect neutrons **elastically scattered** off ^{40}Ar
 - Kinematics of (n, n') will fix **energy and direction** of the recoil
- Pay attention to **arrange the setup** such to tag nuclear recoils **\sim parallel** and **\sim perpendicular** to the E-field



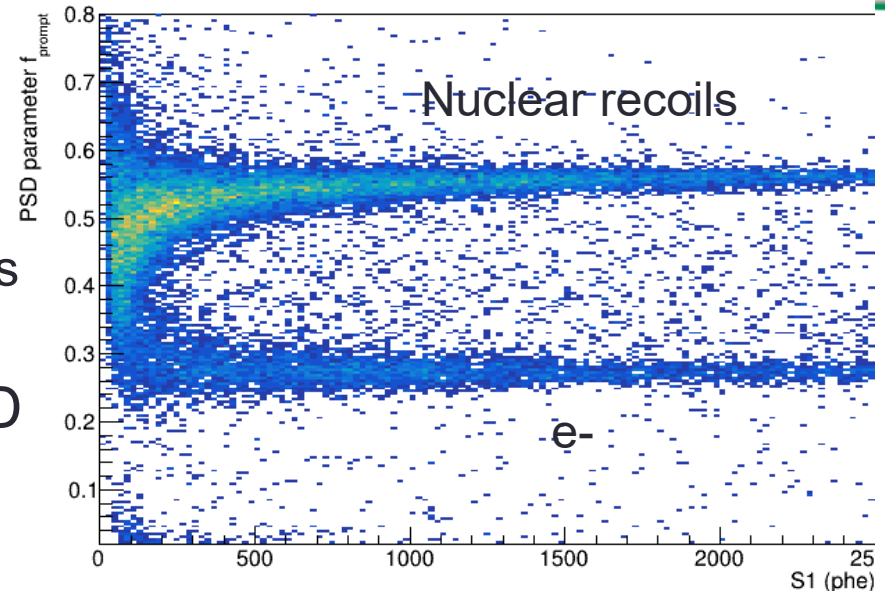
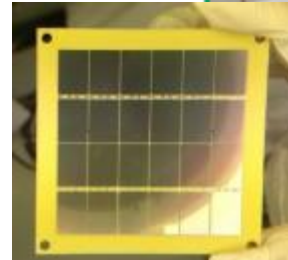
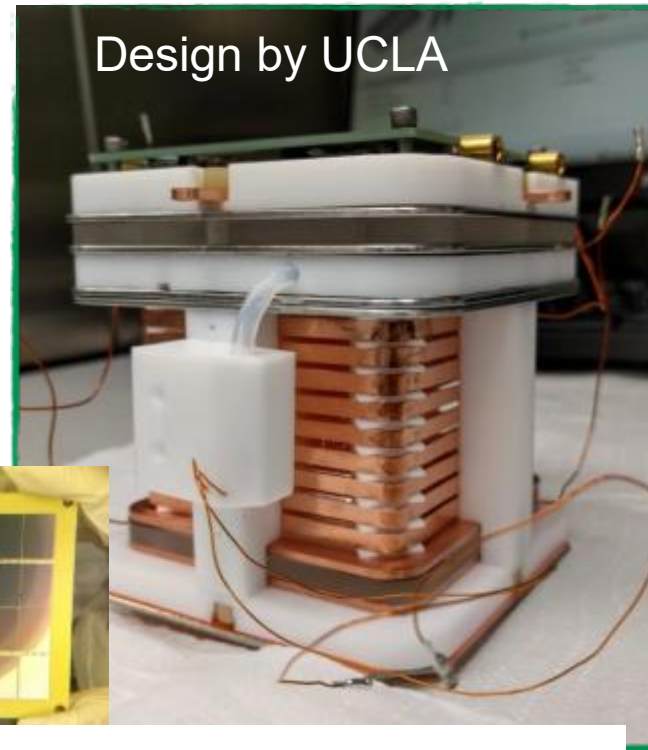
...and actual implementation at



THE INGREDIENTS

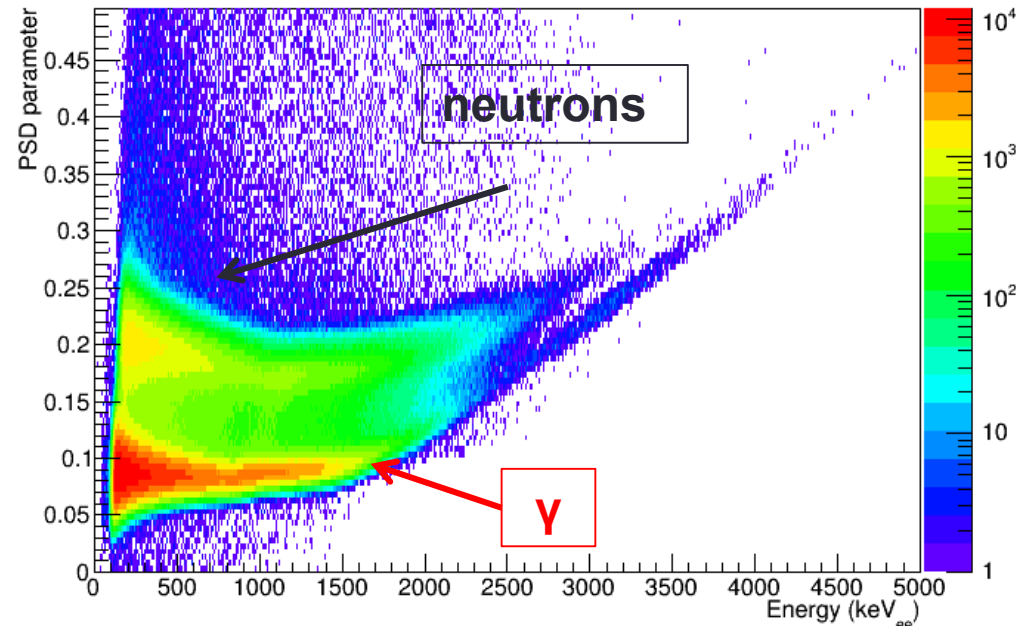
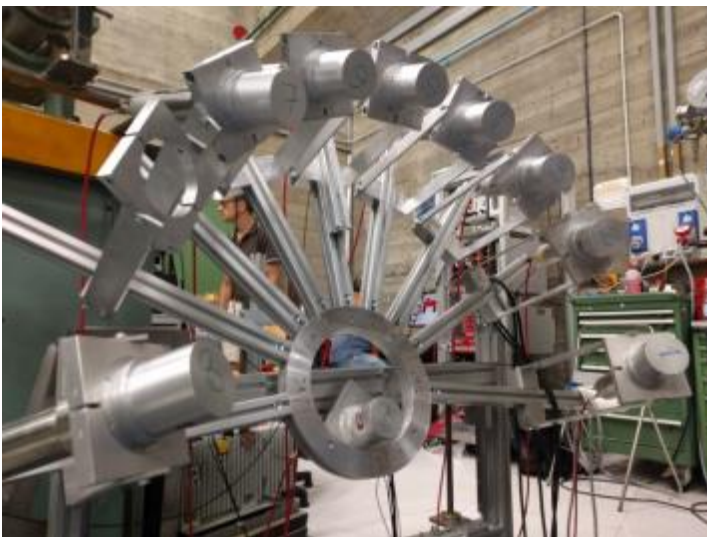
The TPC

- Miniaturized version of the DarkSide-20k TPC
 - Active volume: 5(L) x 5 (W) x 6 (H) cm
 - Gas pocket: 7 mm thick
 - TPB coating for wavelength shifting
- Light readout: 5x5 cm² SiPM (as for DS-20k)
 - 24x1cm² SiPM 24 ch readout (top), for increased (x,y) resolution
 - 24x1cm² SiPM, 4 ch readout (bottom)
- Front End from the DS-20k R&D
- 3D event reconstruction:
 - (x,y) from S2 pattern on the top SiPMs
 - z from drift time (up to ~60 μ s)
- ER/NR discrimination by using PSD parameter f_{prompt} on S1
 - Fast/total ratio



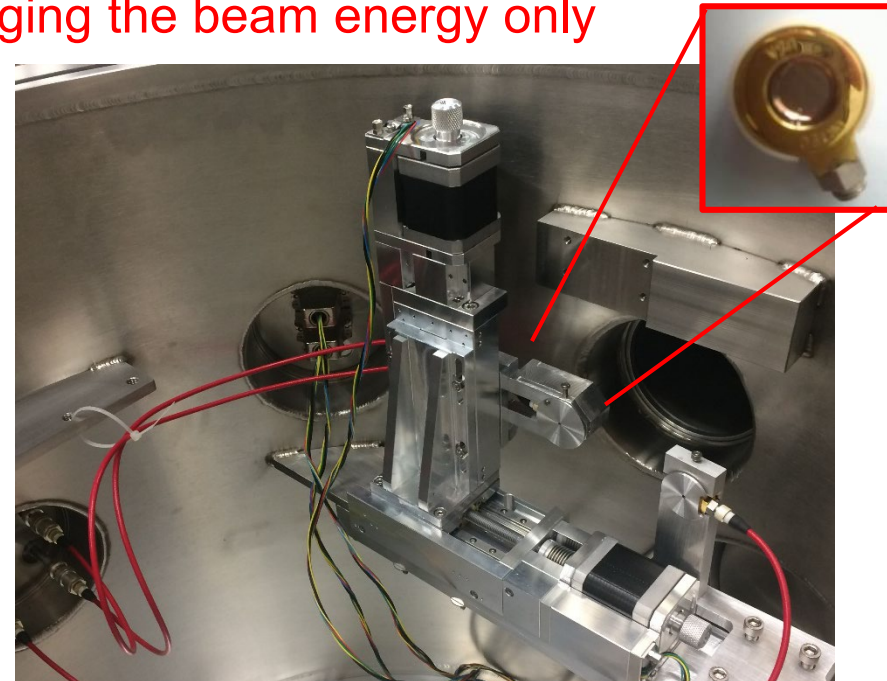
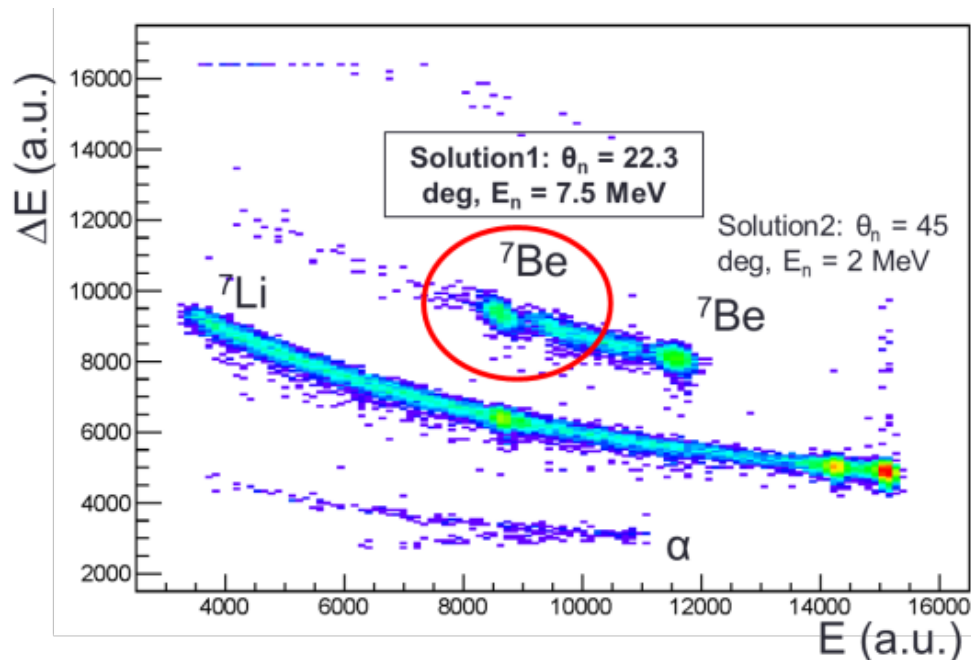
The Neutron Spectrometer

- Nine 3" Liquid Scintillators cells (EJ-309), readout by PMTs
 - Featuring **n/γ discrimination**
 - Absolute calibration with ^{252}Cf (@LNS), $\epsilon \sim 20\text{-}40\%$ for neutrons between 2 and 8 MeV
 - Time resolution **~ 0.5 ns rms**
- Arrangement within a "ring" structure



Si detectors and beam settings

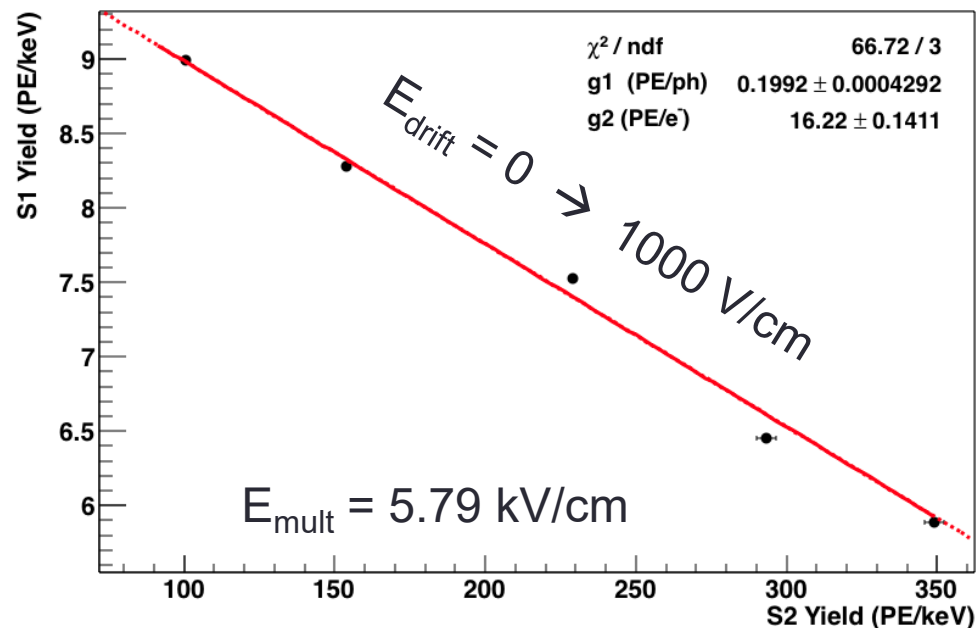
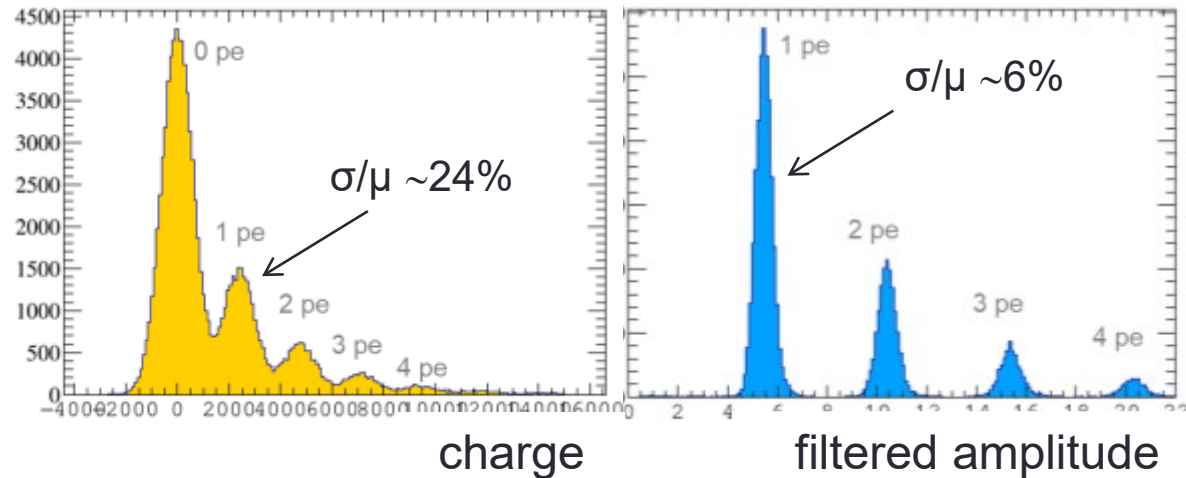
- ΔE -E telescope to tag ${}^7\text{Be}$ associated with neutrons
 - ΔE Si detector (25 μm), E Si detector (1000 μm)
 - Allows for Z separation (Li vs. Be)
 - Can be moved by a remotely-controlled stepper motor
- ${}^7\text{Li}$ beam delivered by LNS-TANDEM: 28 MeV, CH_2 target
 - Two solutions allowed from $\text{p}({}^7\text{Li}, {}^7\text{Be})\text{n}$ kinematics with $\theta_{\text{Be}} = 5^\circ$
 - $\theta_n = 22.3$ deg, $E_n = 7.4$ MeV \rightarrow TPC
- Energy/angles tuned to select ${}^{40}\text{Ar}$ recoils of 67 keV in the TPC
 - Other recoils energies selected by changing the beam energy only



PUTTING ALL
TOGETHER

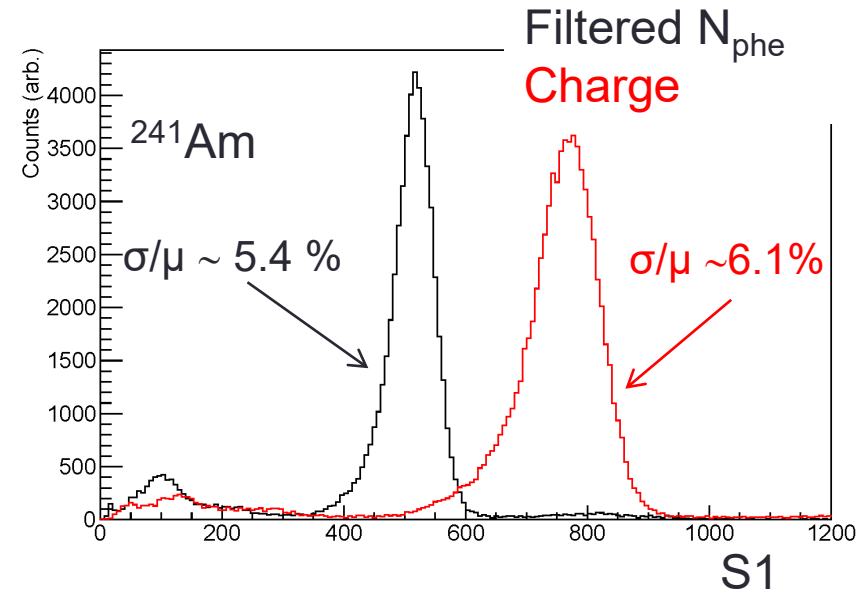
TPC Performance - 1

- **Single-phe spectrum** from laser
 - Single photons **nicely separated**
 - Effect of **after-pulses** and **x-talk**, $K_{\text{dup}} = 30\%$
 - **Digital filtering**
- **Light yield** at null field about **9 phe/keV**
 - Scintillation (S1) **anti-correlated** with charge (S2)
 - Relative balance **changes with electric field**, due to recombination
- **Electron lifetime** **> 1 ms**
 - Purity OK



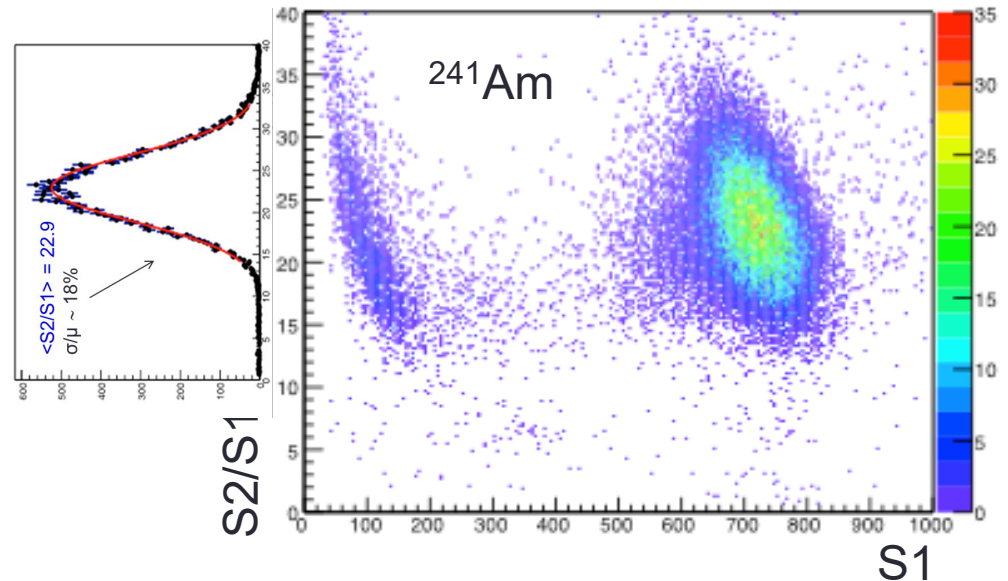
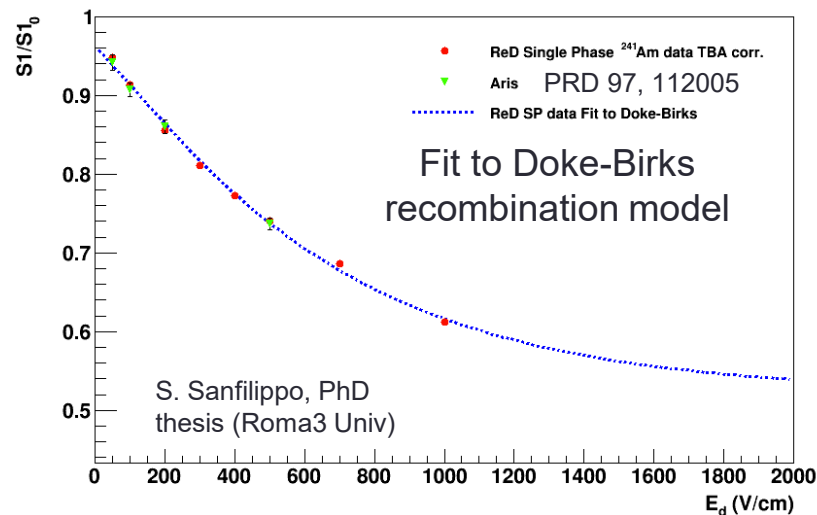
TPC Performance - 2

- Set E_{drift} and E_{mult} independently, such to optimize
 - S1 (light) and S2 (charge) yield
 - Resolution in S1 and S2
- S1 (energy) resolution further improved by digital filtering
- E-fields set to achieve $g_2 \sim 16$ phe/e-
- Calibrations with laser, ^{241}Am , $^{83\text{m}}\text{Kr}$ (diffused source) and neutron DD gun



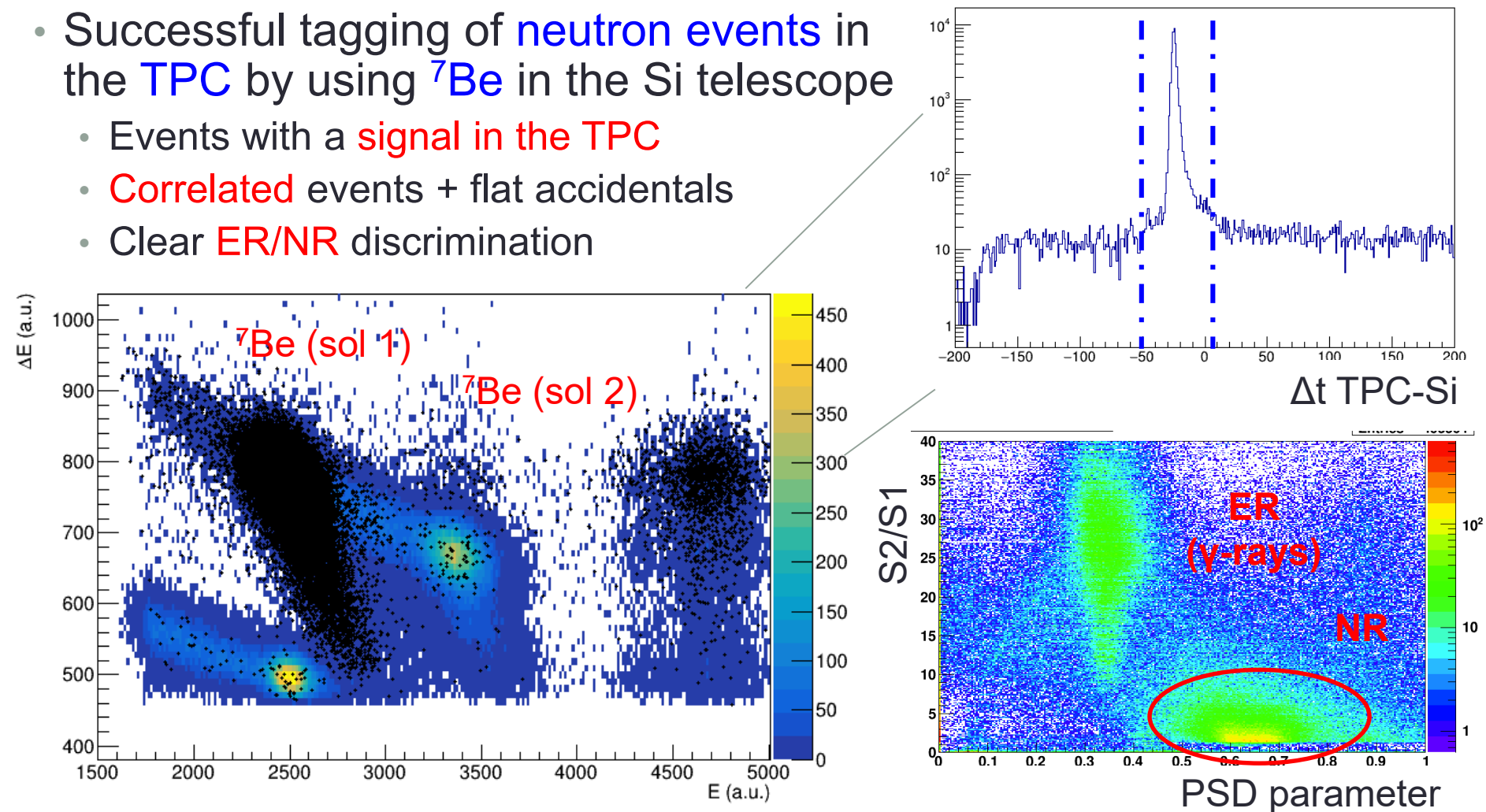
$$E_{\text{drift}} = 200 \text{ V/cm}, E_{\text{mult}} = 5.8 \text{ kV/cm}$$

Quenching



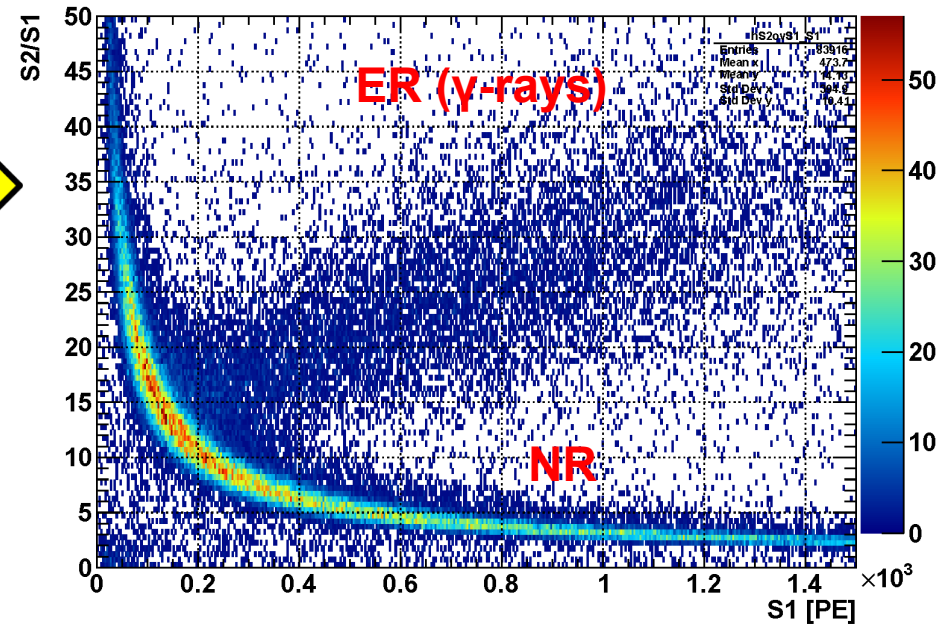
ReD run @ LNS

- Two-week run in February 2020
 - Several **test beams** in 2018-2019 for preparation and integration
- Successful tagging of **neutron events** in the **TPC** by using ^7Be in the Si telescope
 - Events with a **signal in the TPC**
 - **Correlated** events + flat accidentals
 - Clear **ER/NR** discrimination

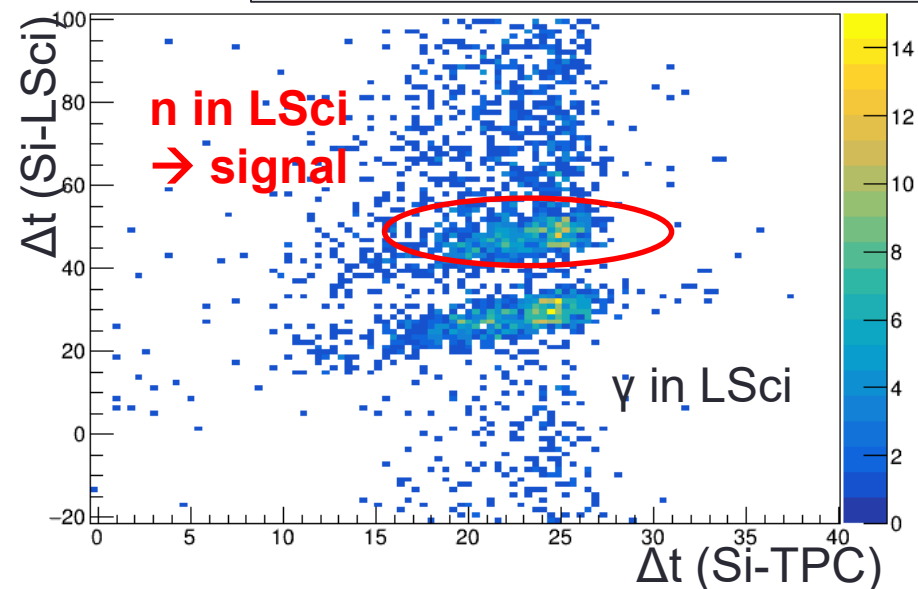


ReD run @ LNS

- Analysis in progress
 - S1 & S2 resolution
 - Correction for XY-Z dependence
 - pile-up, cuts
- Full three-fold coincidences (Si \wedge TPC \wedge n-Spectrometer)
 - About 150 events/day, from rough analysis
 - More, with scanning of digitized traces
- Very clean identification of events based on: ^7Be tagging, timing and PSD (TPC and LSci)
 - ToF resolution $\sim 1\text{-}2$ ns rms



Ar recoil events in the TPC



Conclusions and outlook



- ReD has a two-fold value as a **physics experiment** (**directionality**, and possibly **low-energy characterization**) and as **a test bench** for the DarkSide-20k new technologies
- Produce **nuclear recoils** by neutron scattering
 - Neutrons from **p(⁷Li,⁷Be)n** with a **⁷Li** beam of 18-30 MeV
- Two-week run in February 2020 at LNS, with **⁷Li beam**
 - Data analysis **in progress** → **STAY TUNED**
 - Run tailored to **directionality studies**
- Future studies focused to **low-energy response (< few keV)**
 - **Lower** neutron energy is more appropriate
 - LNS accelerators **switched off for 2 years** for major refurbishment
 - Approach based on intense **²⁵²Cf neutron source**
 - Allows tagging by the detection of **γ-rays from the fission**

