RED: A SIPM BASED LAR TPC FOR DIRECTIONALITY STUDIES

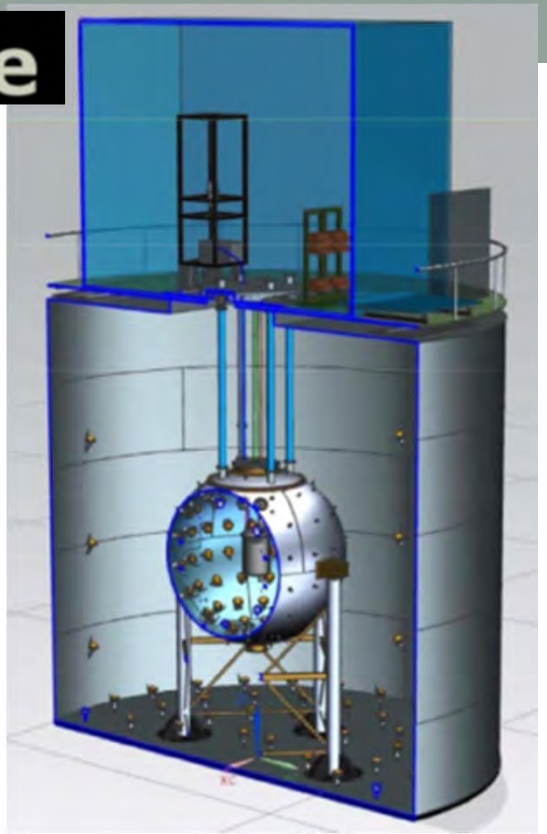
L. Pandola (LNS)

on behalf of the ReD Working Group

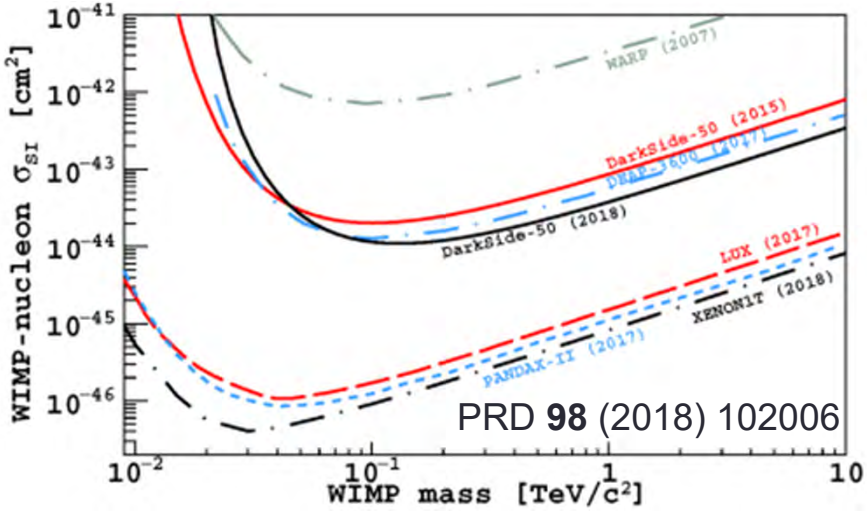
(DarkSide Collaboration)

Physics background

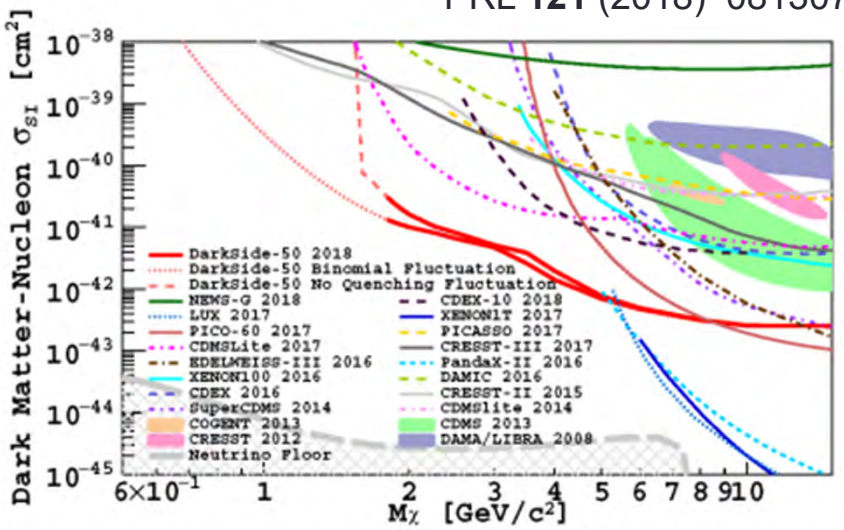
- **DarkSide** at Gran Sasso Laboratory, WIMPs using search using a dual-phase TPC with low-radioactivity LAr
  - Operated a **50 kg TPC** (DarkSide-50)
  - Next step: 20 ton LAr **TPC** (DarkSide-20k)
    - Novel light readout with SiPM
    - Getting ready for 2022, exposure O(100) ton yr
    - Expected sensitivity 10^{-47} cm^2 @ M_W =1 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



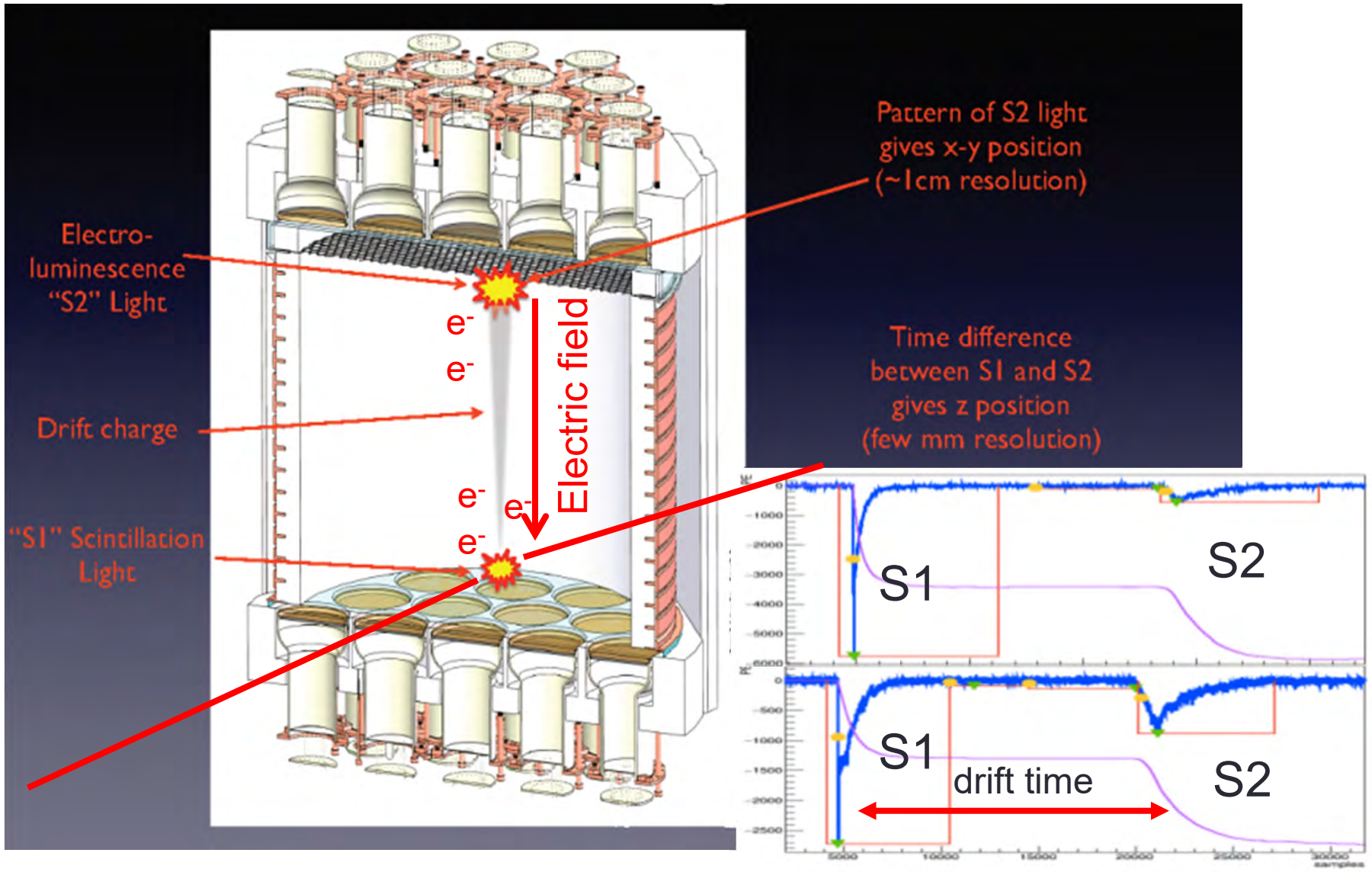
PRL **121** (2018) 081307



PRD **98** (2018) 102006

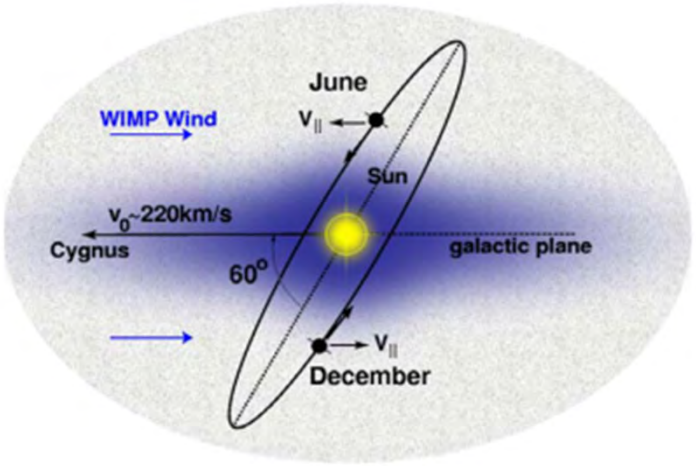


Working principle of the TPC in one slide



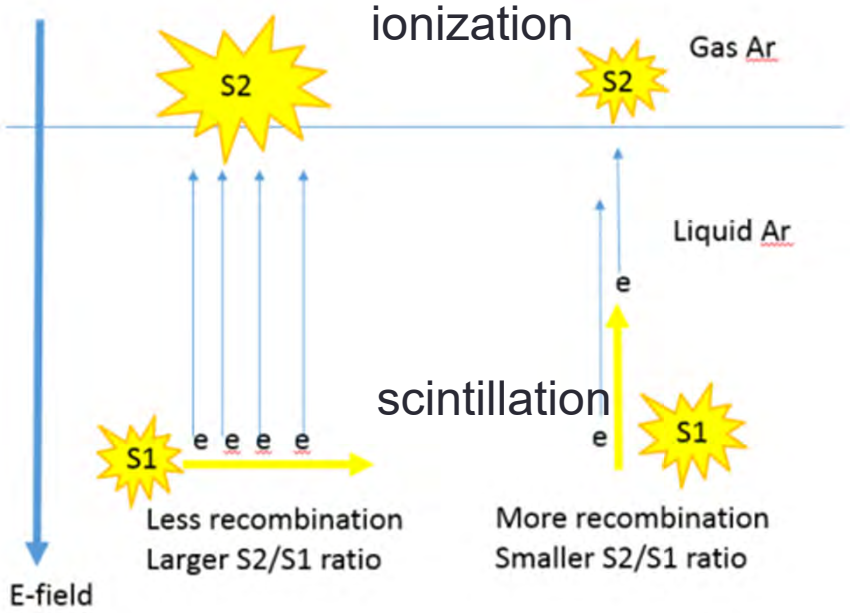
A smoking gun for dark matter discovery

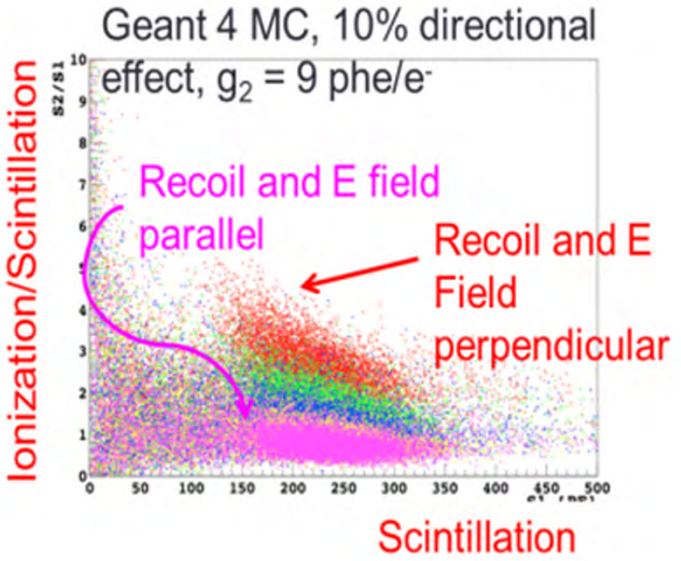
- Correlation of **recoil direction** with the expected direction of the WIMP galactic wind would be a smoking gun
  - Much more convincing than a mere excess of recoil events



A smoking gun for dark matter discovery

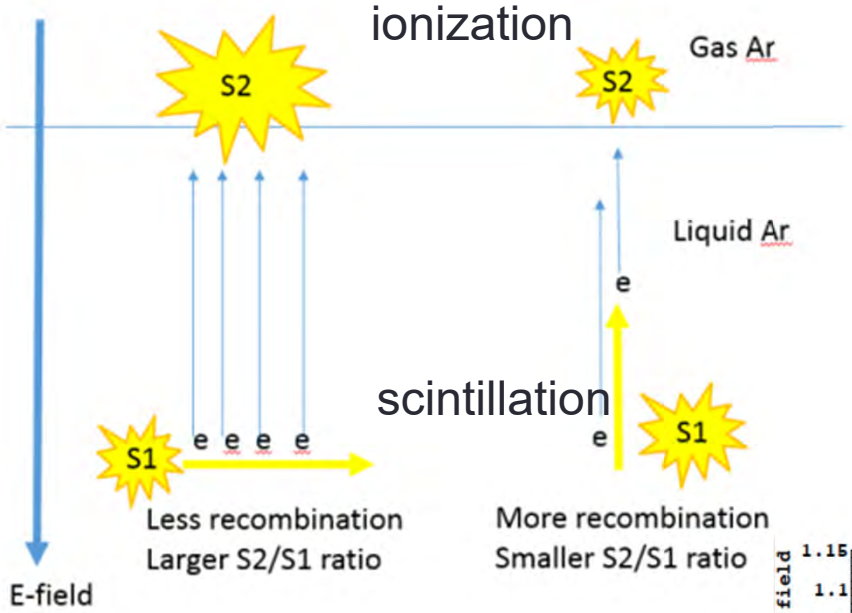
- Correlation of **recoil direction** with the expected direction of the WIMP galactic wind would be a smoking gun
  - Much more convincing than a mere excess of recoil events

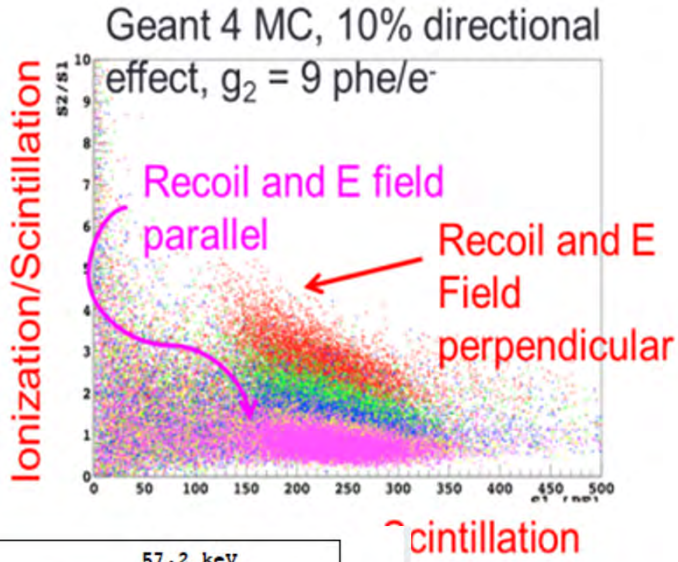




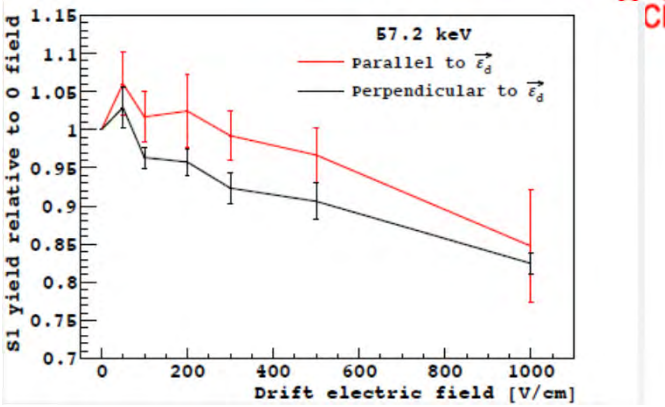
A smoking gun for dark matter discovery

- 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



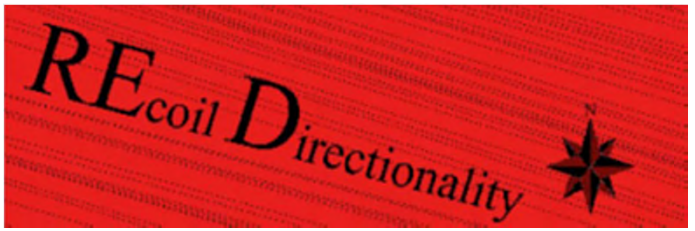


Just an **indication** → to be confirmed



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

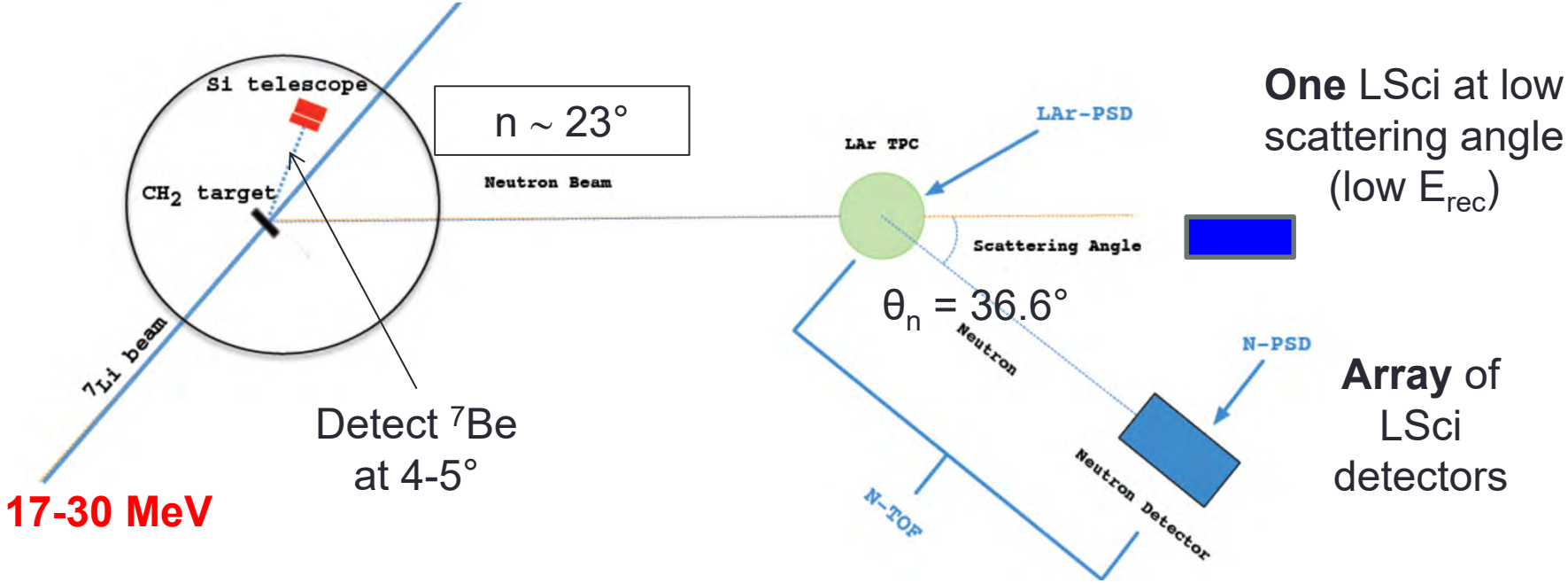
The ReD project



- **ReD** is a project within the DarkSide collaboration, aiming to characterize the response of a TPC to neutron-induced Ar recoils
  - Scrutinize the directionality effect
    - Confirm that the TPC response is different for different recoil directions with respect to the electric field
  - Measure the response to very low-energy nuclear recoils (< few keV)
    - Not part of the original project, but quickly became a **hot topic**
  - Be a test bench for optoelectronics of DarkSide-20k (SiPM readout)
    - The ReD TPC is a **miniaturized version** (5 x 5 x 5 cm^3) of the DarkSide-20k TPC and features all technical solution developed so far
    - Check performance within a **realistic situation**, early identification of problems
- Produce Ar recoils by using a suitable **neutron beam**
  - Two-body **closed kinematics (n,n')**, such to determine energy and direction of ^{40}Ar recoils

ReD conceptual design

- Use a neutron beam produced via **p(^{7}Li,^{7}Be)n**
  - ^{7}Li beam from the TANDEM accelerator of INFN-LNS (Catania)
  - Detect the associate particle (^{7}Be) and ToF to **tag neutron energy** event by event (fixed by kinematics)
- Detect neutrons elastically scattered off ^{40}Ar
- Pay attention to arrange the setup such to tag nuclear recoils ~parallel and ~perpendicular to the E-field



...and actual implementation at

Cryogenic System

Neutrons Detectors

Scattering Chamber

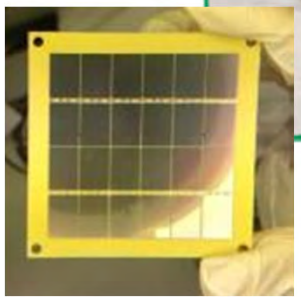
n beam

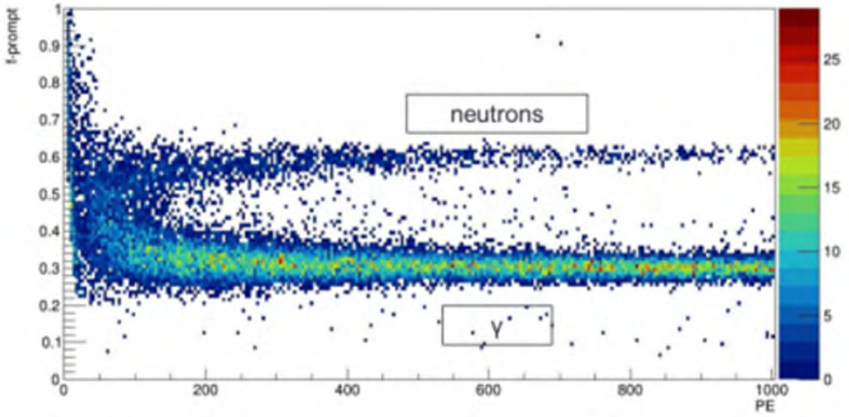
^{7}Li Beam

THE INGREDIENTS

The TPC

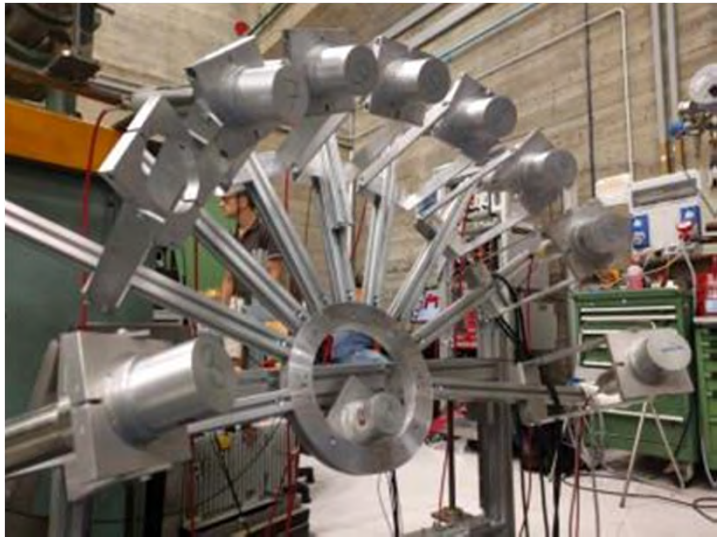
- Miniaturized version of the DarkSide-20k TPC
  - Active volume: 5(L) x 5 (W) x 6 (H) cm
  - Gas pocket: 7 mm thick
  - TPB coating for wavelength shifting
- Light readout: 5x5 cm^2 SiPM (as for DS-20k)
  - 24x1cm^2 SiPM 24 ch readout (top), for increased (x,y) resolution
  - 24x1cm^2 SiPM, 4 ch readout (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 μs)
- ER/NR discrimination by using PSD parameter f_{prompt} on S1
  - Fast/total ratio

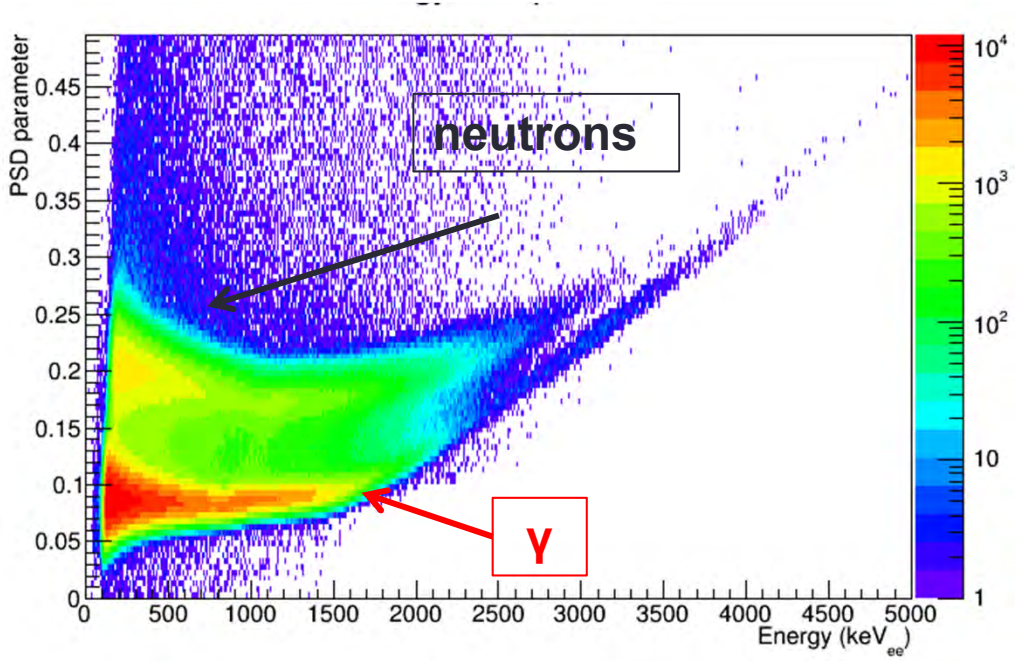




The Neutron Spectrometer

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

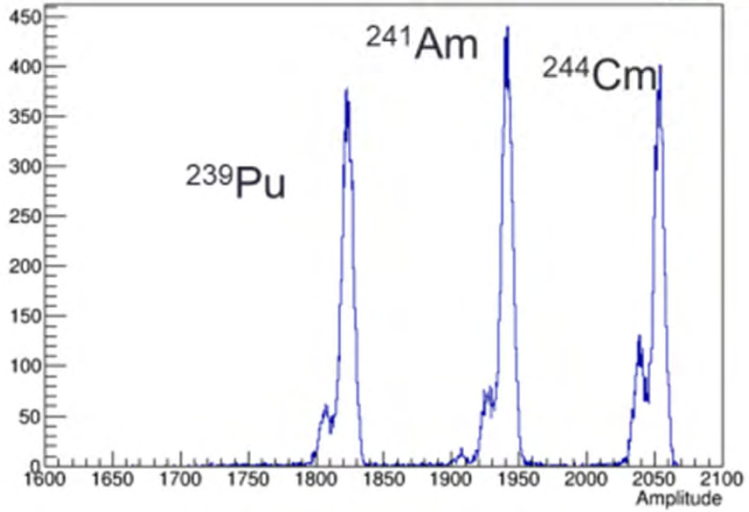




Inside the scattering chamber

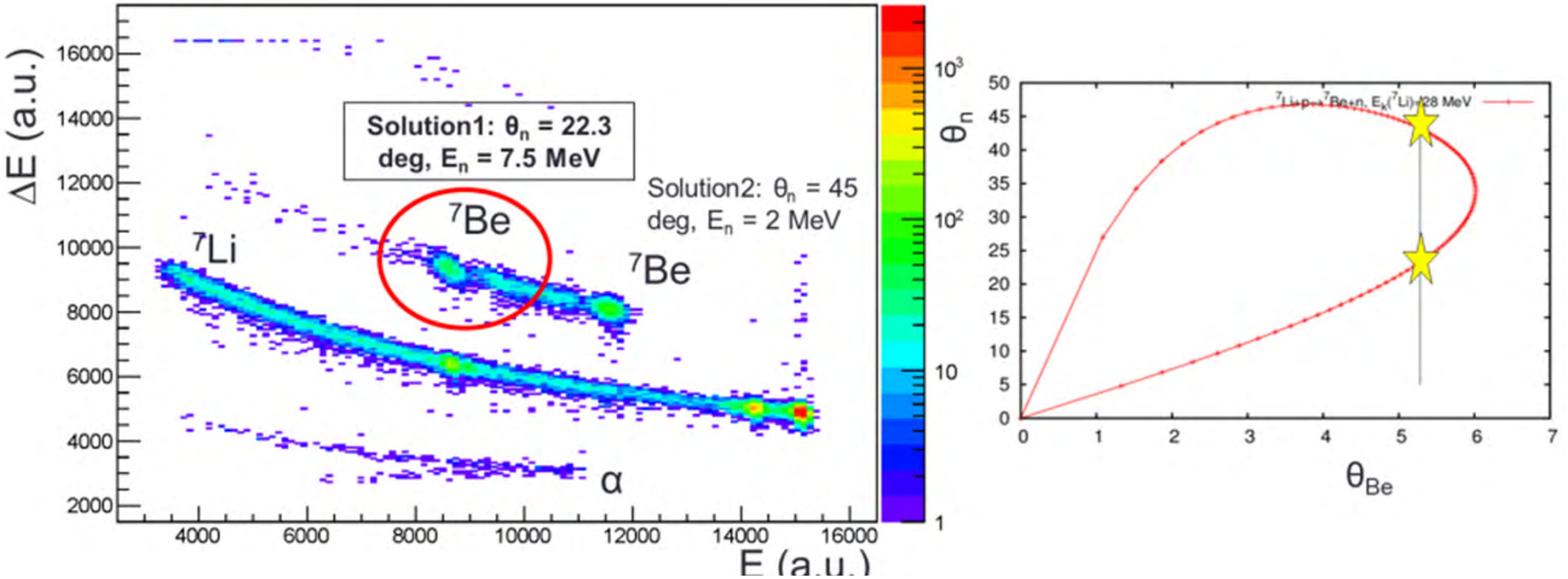
- Si telescope to detect ^{7}Be associated with neutron
  - **ΔE Si** detector (20 μm), **E Si** detector (500 μm)
  - Placed at 5 deg
- Targets
  - CH_2, 250-400 μg/cm^2

α sources



Beam & geometry settings

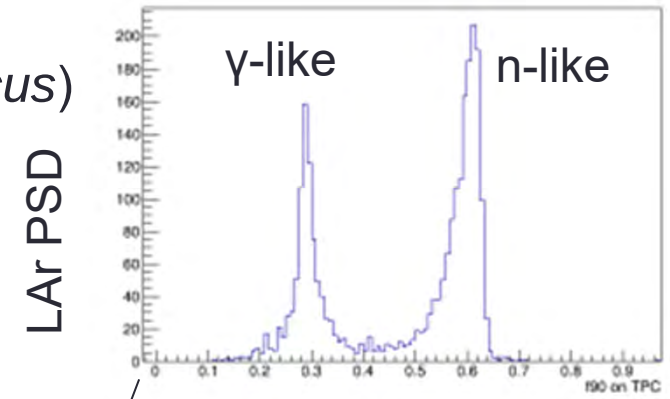
- ^{7}Li beam delivered by LNS-TANDEM: 28 MeV, CH_2 target
  - Two solutions allowed from kinematics with θ_{Be}=5°
    - **θ_n=22.3 deg, E_n=7.4 MeV → TPC**
- ΔE-E telescope allows for a clear Z separation (Li vs. Be)
- Energy/angles tuned to select ^{40}Ar recoils of 66 keV in the TPC
  - Other recoils energies selected by changing the beam energy only

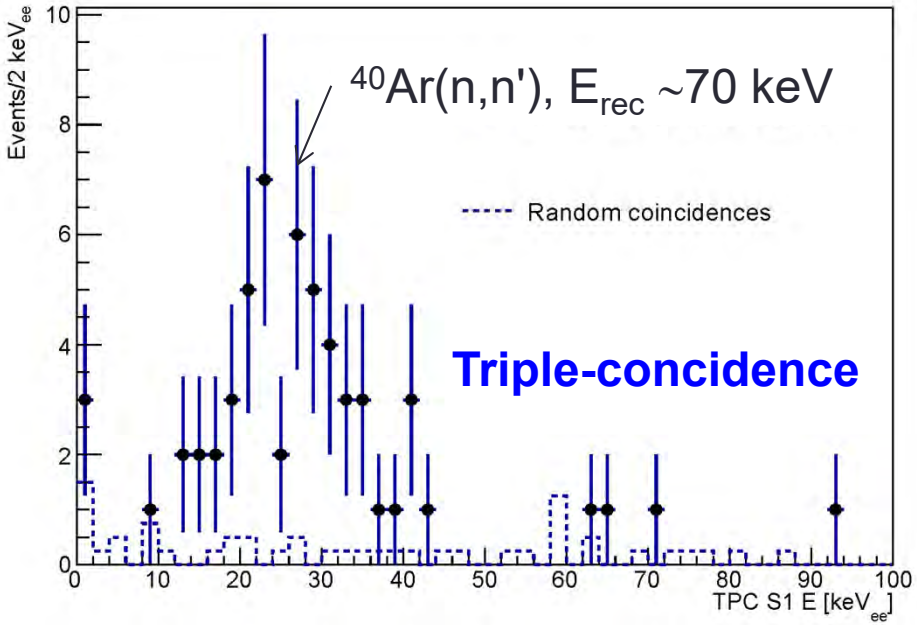


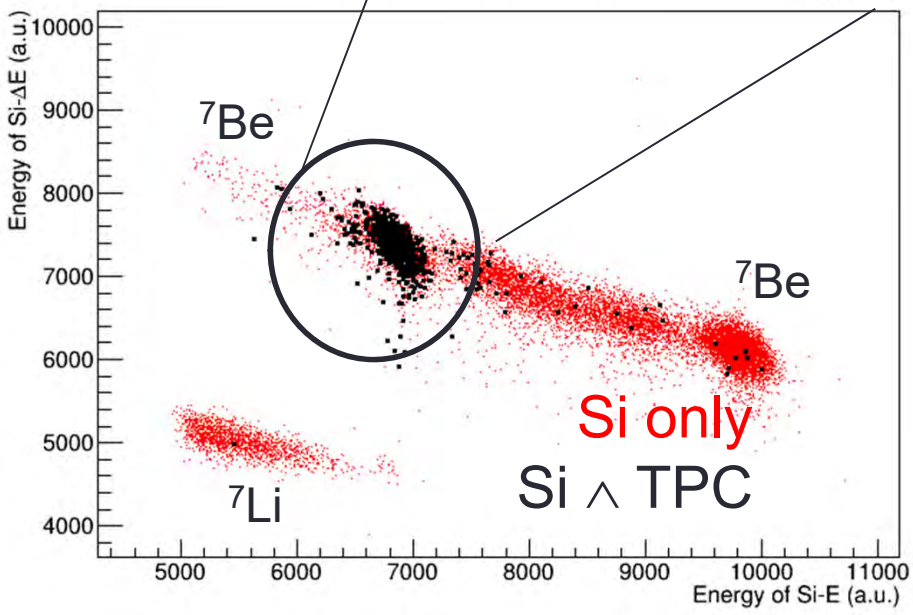
PUTTING ALL TOGETHER

Two test beams@LNS in 2018

- Commission and integrate the full system with "real" neutrons
  - **Alignment**: mechanical procedure, need O(mm's) precision
  - E_{beam} = 28 MeV (E_{rec} = 66 keV)
- Found events with the **proper signature**
  1. ^{7}Be in the Si telescope (and in the proper *locus*)
  2. neutron in the TPC (PSD & ToF)
  3. neutron in the LSci's (PSD & ToF)
- **Rate lower than expected**
  - Mis-alignment, beam divergence

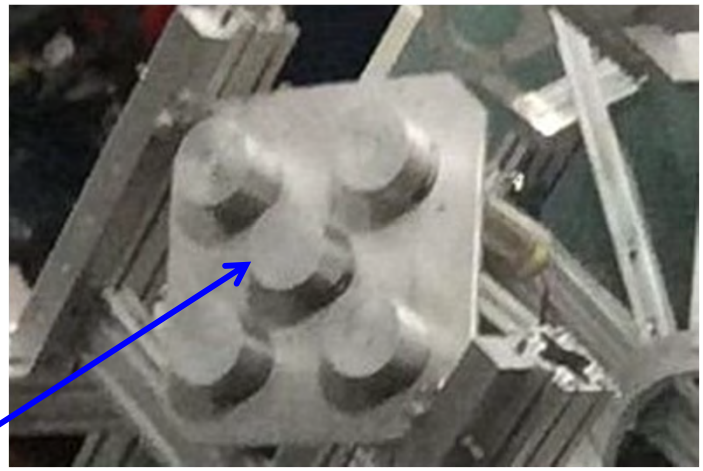


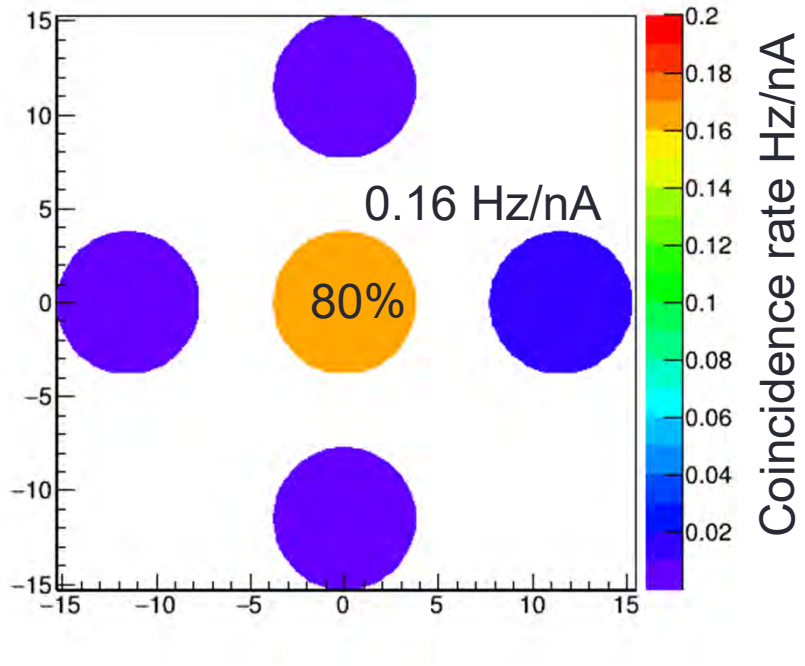




Beam optimization (May 2019)

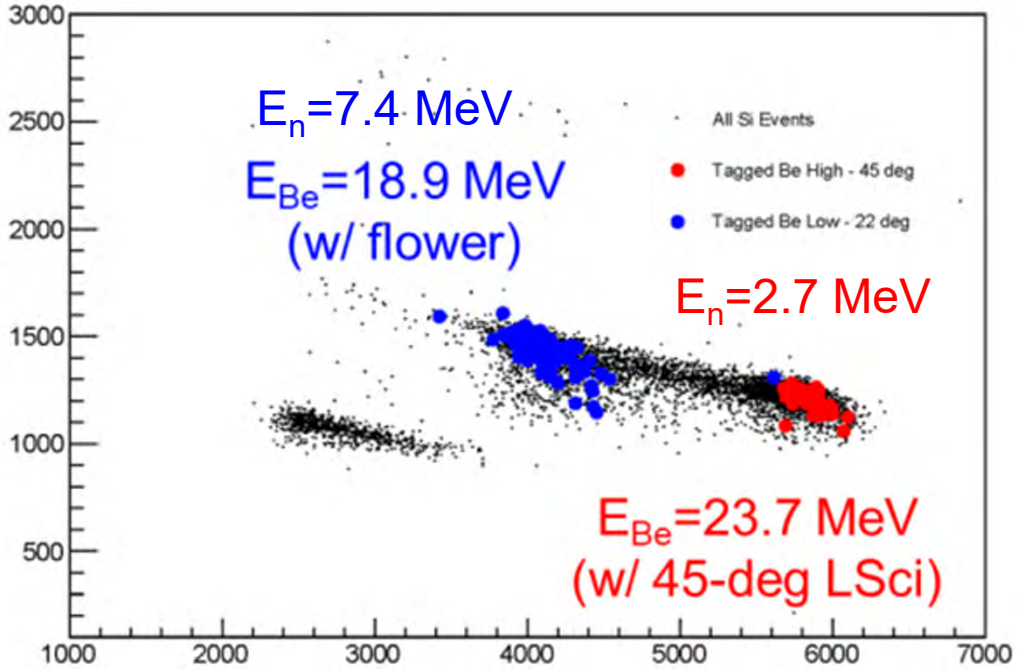
- 3-day test beam to implement & check **beam improvements**
  - New beam diagnostics, thicker target
  - **Without TPC**
- "Flower" neutron camera made with LSci to study the neutron spot
  - Center of the central petal at the position of the TPC
- Look for LSci events in coincidence with ^{7}Be in Si
- Much **higher beam current** and **better focusing** than in 2018
  - **10 enA** current routinely achieved
  - **>80%** of the tagged beam within 0.3 msr from the target
  - **O(5 n/s)** on central petal (**ΔE < 200 keV**)

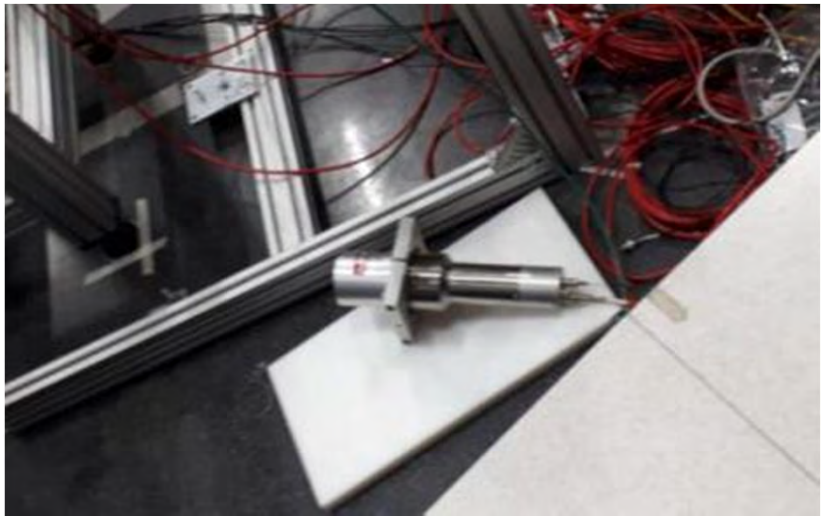




Neutron beam characterization - 1

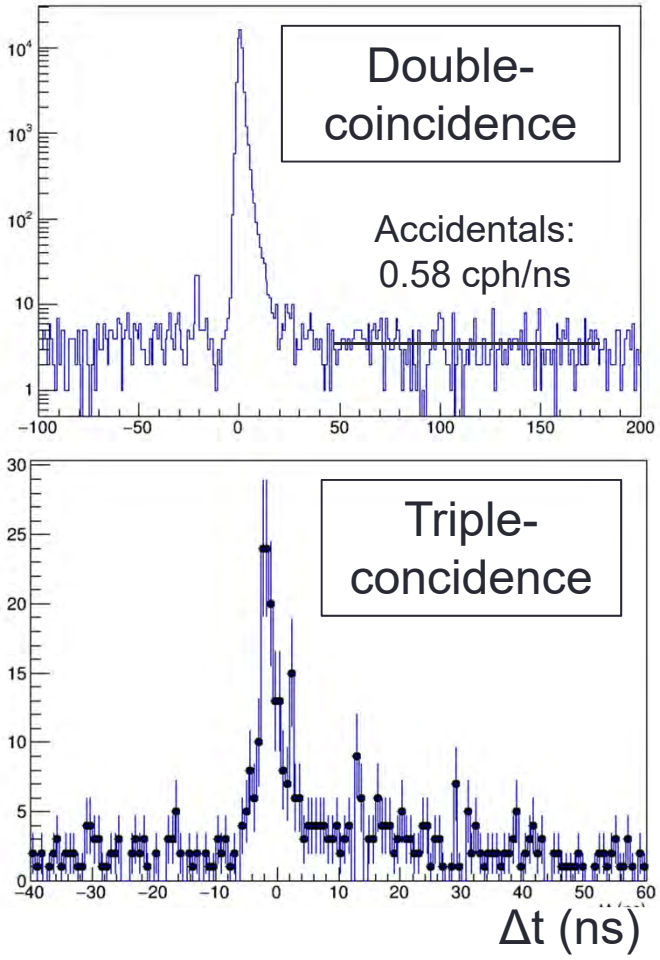
- Kinematics: *two* solutions with ^{7}Be at the same angle
- For the low-energy recoils studies, smaller energy neutrons are more appropriate → look for the other solution, at θ_n ~45°
- Basically, tag **two neutron beams at the same time**
  - Different neutron angle, different neutron energy

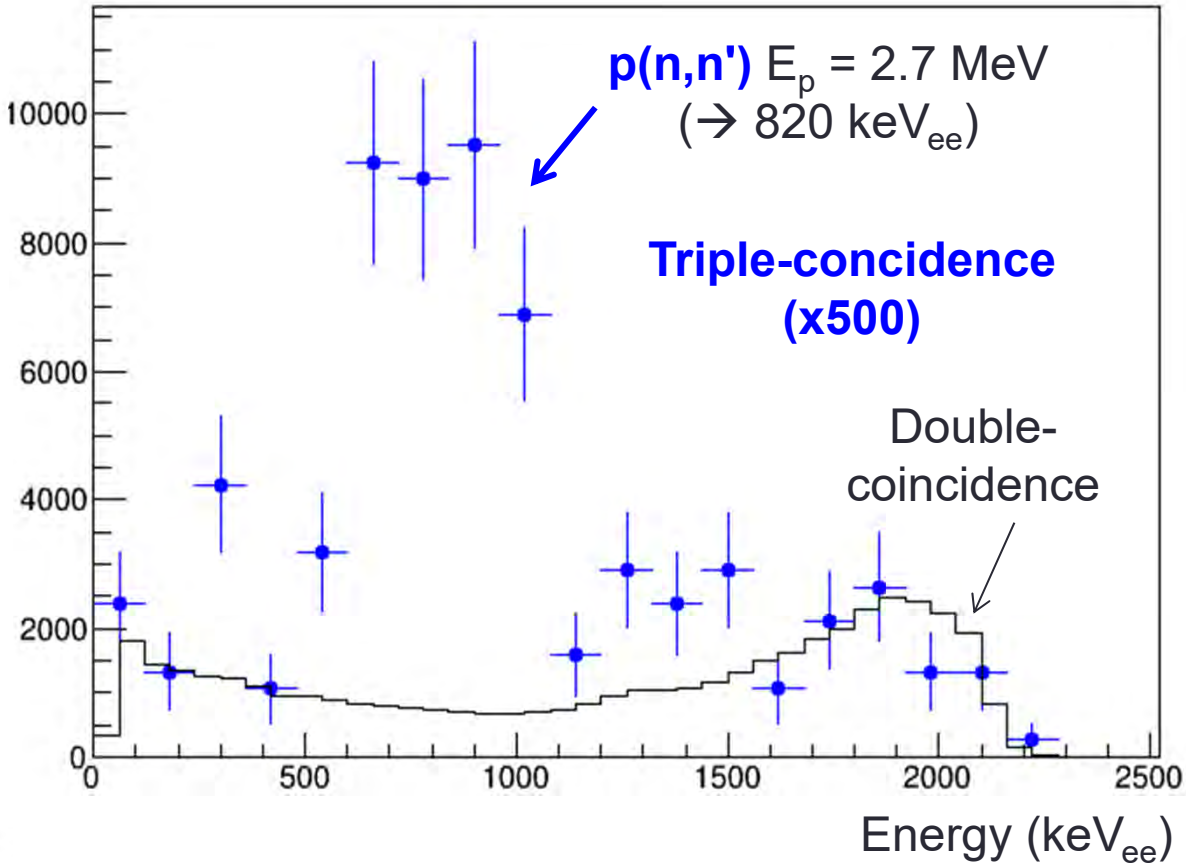




Neutron beam characterization - 2

- **Triple-coincidences (10h run)**
  - **ReD configuration**, with the central LSci playing as the TPC
  - Rate of "good" events x10 than in 2018 (~**4 cph** per detector)

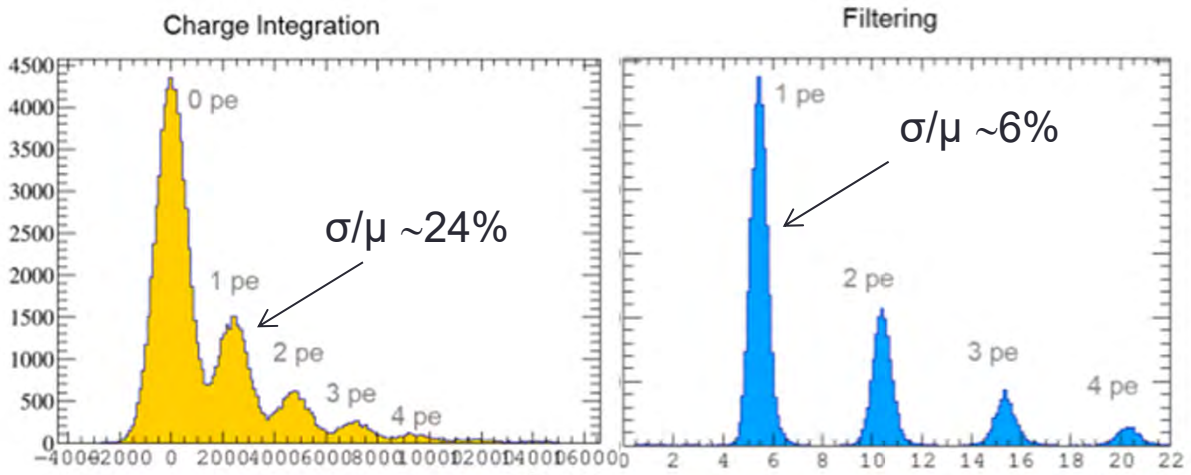




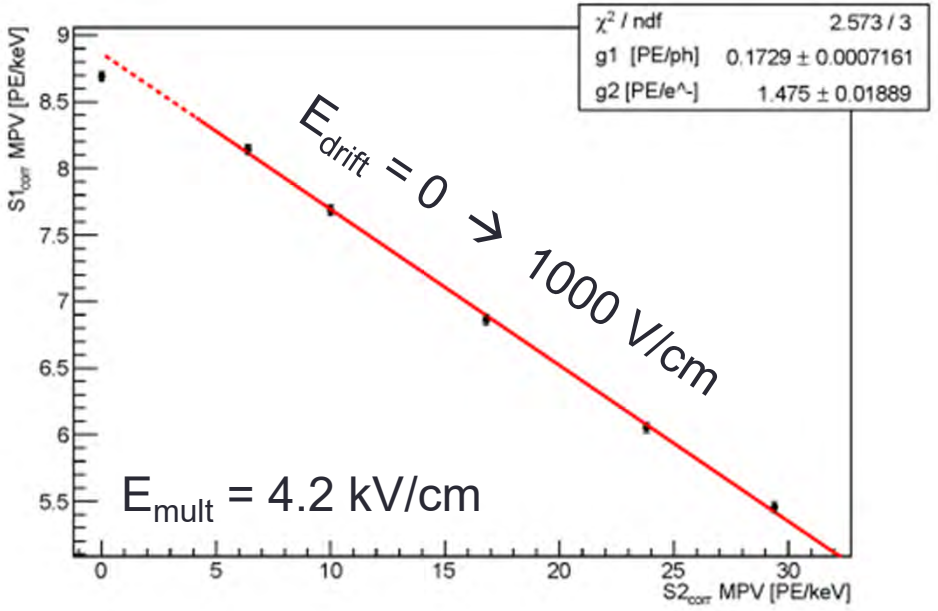
TPC Optimization - 1

Two reconstruction codes
(C++ and python)

- Single-phe spectrum from laser
  - Single photons nicely separated
  - Effect of after-pulses and cross-talk observed, K_{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

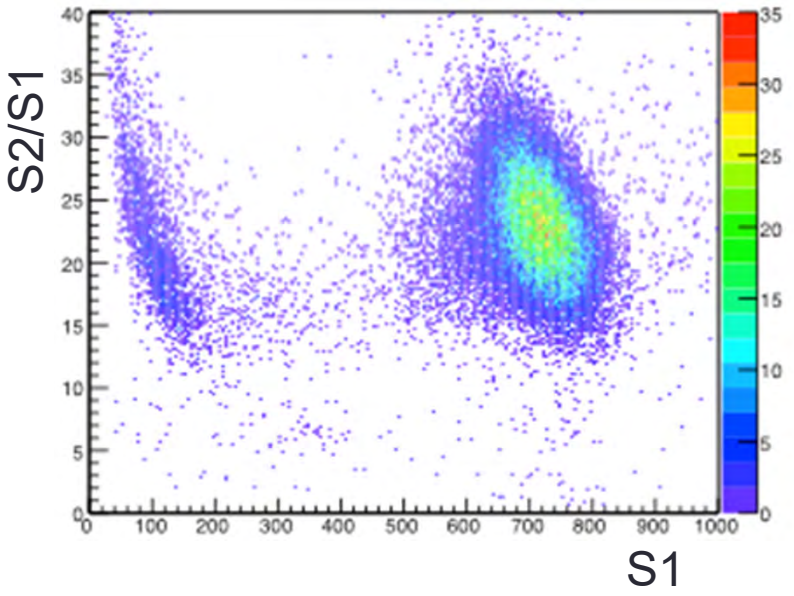


charge filtered amplitude

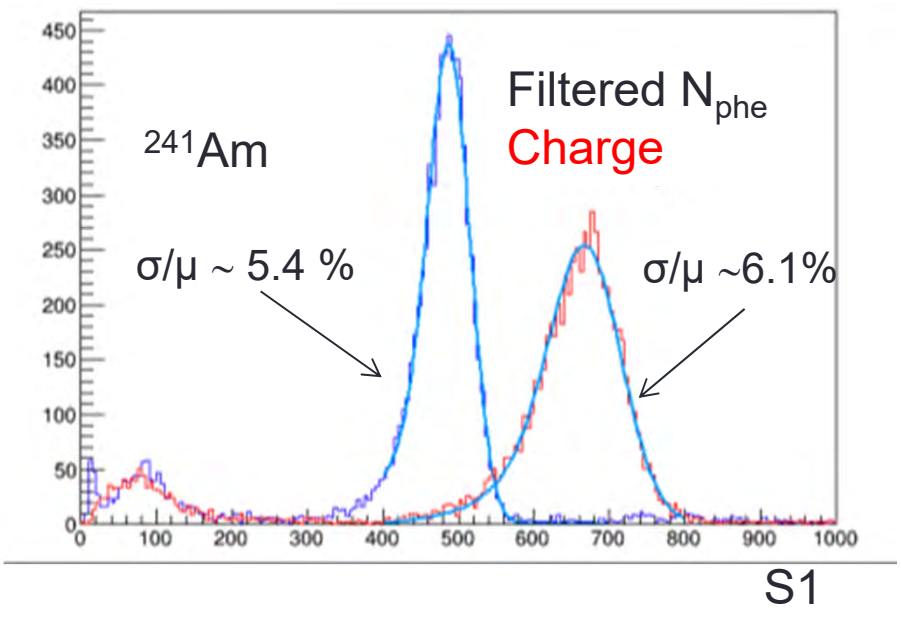


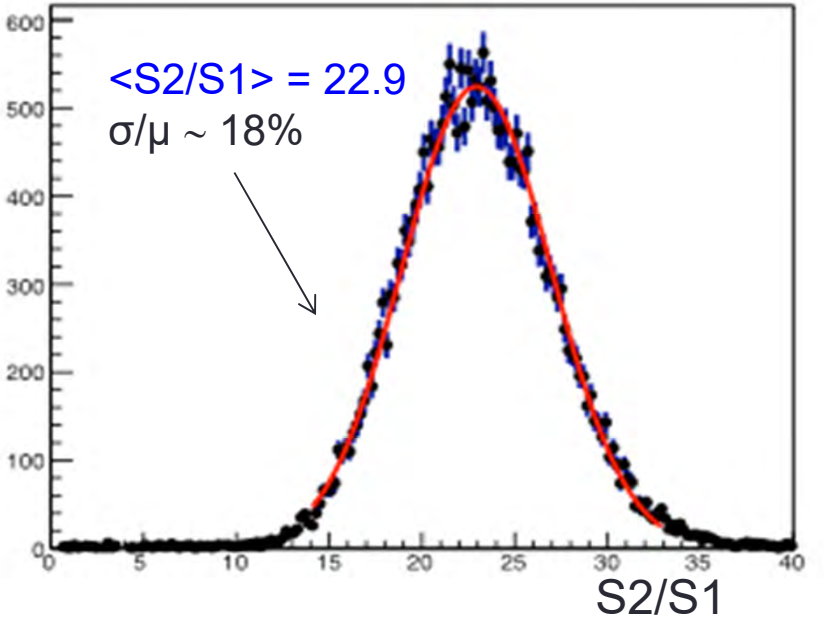
TPC Optimization - 2

- 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
- Set the configuration of the electric fields such to achieve g_2 ~ 14 phe/e-
- TPC performance suitable for the measurement!



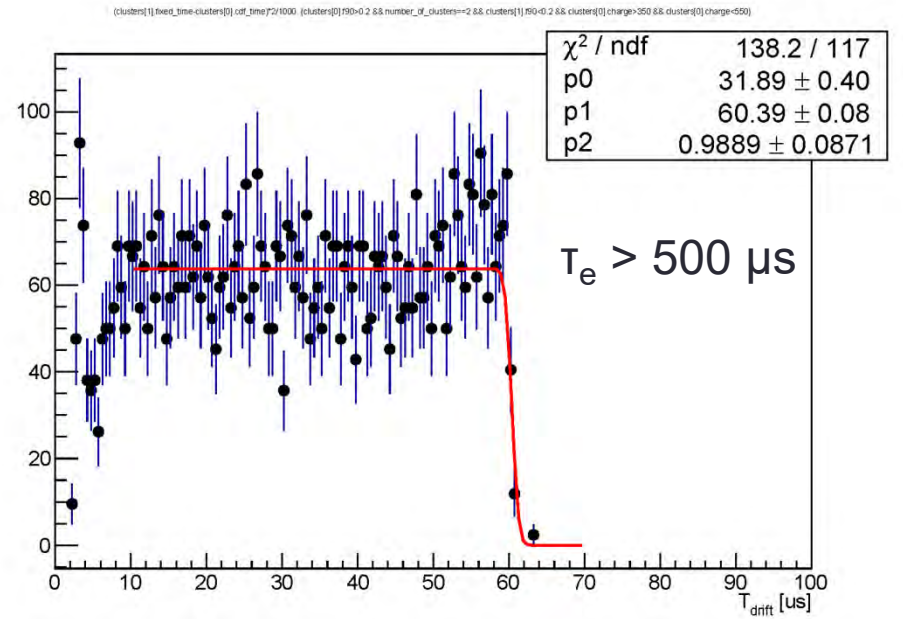
E_{drift} = 200 V/cm, E_{mult} = 5.8 kV/cm

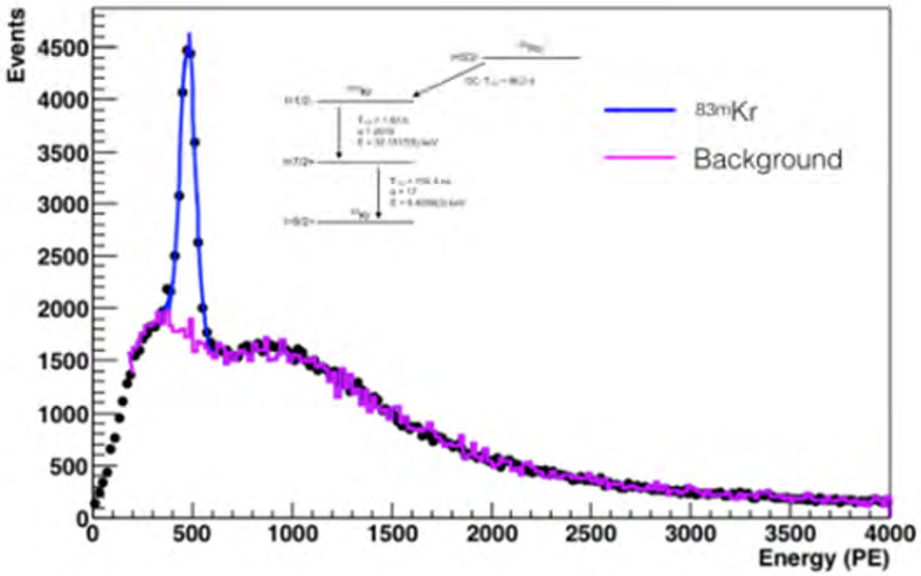


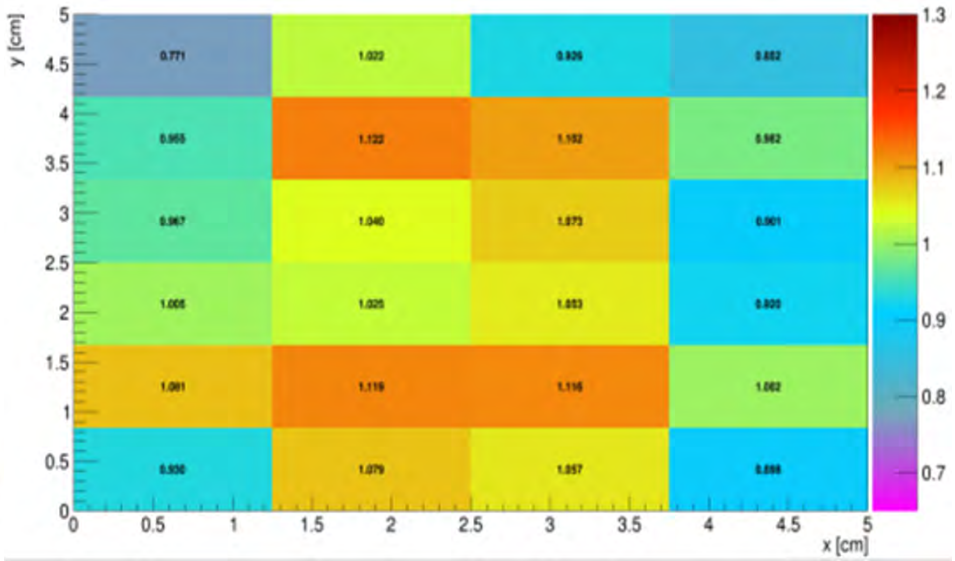


TPC Optimization - 3

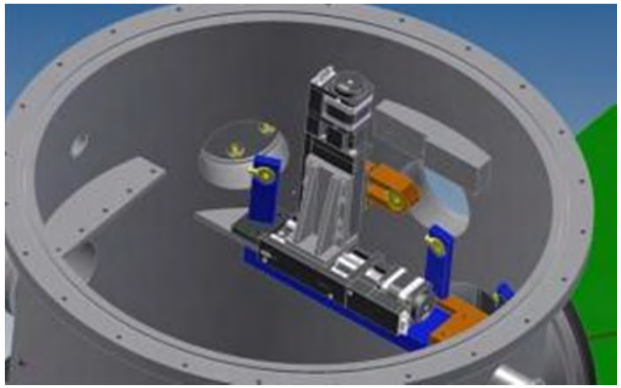
- Calibration with a diffused ^{83m}Kr source (32+9 keV)
  - Nice uniformity in z (T_{drift})
  - Within 15% in xy (central SiPMs see more light)
  - Total light yield compatible with previous estimates based on ^{241}Am







Planning for 2019-2020



- One more test beam in July
  - Implement possibility of a **fine adjustment** the position of the Si telescope by a dedicated motor
- Re-deploy the TPC
- **Take data**: physics run (7-10 days) with the full system in Fall 2019
  - One single beam energy (E_{Li}= 28 MeV → E_{rec} = 66 keV)
  - Milestone: prove the performance of the system
- (Following): take more runs (~7 days) each with different beam energy (up to Spring 2020)
  - Explore directional sensitivity in the range 20-100 keV_{rec}
  - Take more data points for low-energy recoils
    - Consider to use an array of smaller LSci detectors (1-in), in order to improve sensitivity by a better 3D neutron tracking

Conclusions

- ReD has a two-fold value as a physics experiment (directionality, low-energy characterization) and as a test bench for the DarkSide-20k new technologies
- Produce nuclear recoils by neutron scattering
  - Neutrons from p(^{7}Li,^{7}Be)n with a ^{7}Li beam of 18-30 MeV
  - TANDEM accelerator at LNS
  - Two-body kinematics
- Components have been tested, characterized and debugged individually
- Commissioning and integration of the *full system* within several test beams in 2018-2019
  - Experiment made by three different kind of detectors
  - Beam intensity and divergence achieved
  - Performance of all systems good enough for the measurement
- Getting ready for the "physics run" within this year
- **Stay tuned!**