# Large-scale WLS tests at CERN

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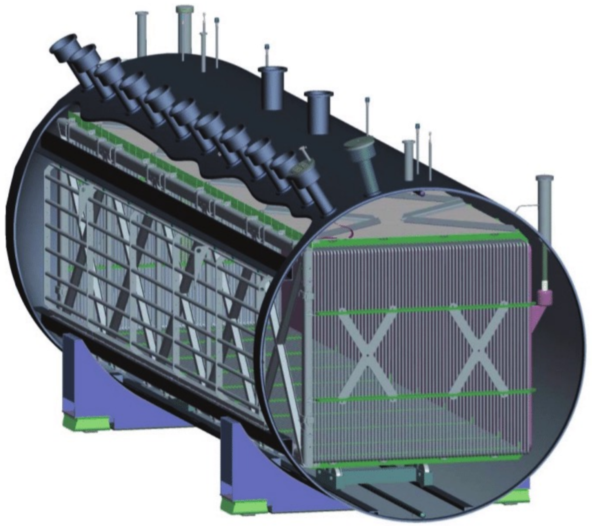
# Plan for presentation

1. Introduction to Wavelength Shifting Materials (WLS) and their Applications
2. Overview of polyethylene naphthlate (PEN) as a WLS
3. CERN Campaign: Experimental Setup and Data Acquisition
4. Discussion of the Analysis in Progress

# Background: LArTPCs

- Liquid argon (LAr) is a scintillator used in neutrino and dark matter detection experiments
  - scintillation light used as a trigger to determine interaction time
  - two light components (fast and slow) allows background rejection in DM experiments



*MicroBooNE (above) and ICARUS (below), both LArTPC detectors*


- Argon scintillation peak is at 128 nm (VUV)
  - PMTs respond optimally to green and blue visible light; effectively blind to VUV
  - VUV sensors still in development; typically have an efficiency of ≈ 15 % but hard to use with reflective materials
  - Solution: **use a wavelength shifter**

# Background: wavelength shifters (WLS)

- **wavelength shifter (WLS)**: material that can absorb light of one wavelength and emit light of a different wavelength
  - needs good quantum efficiency and fluorescence lifetime short enough to maintain pulse shape discrimination
- fluorescence spectrum has a longer wavelength than the absorption spectrum
  - VUV argon scintillation light 'shifted' to visible light that can be efficiently detected by PMTs

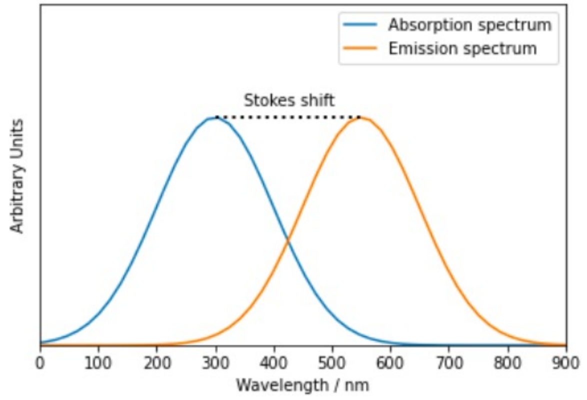
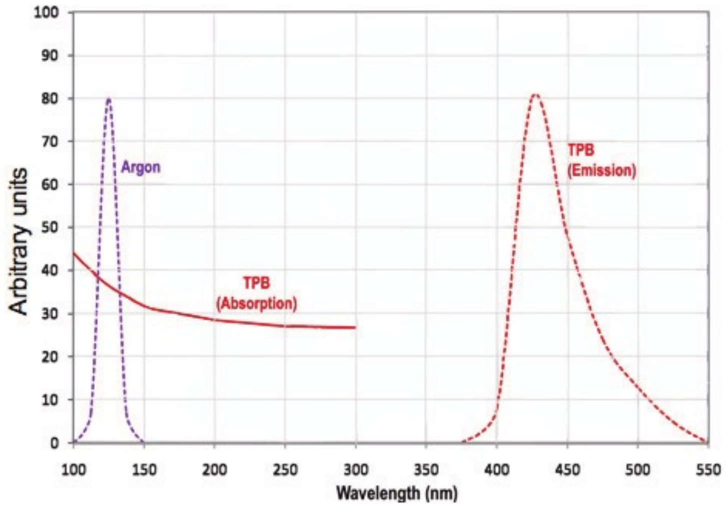


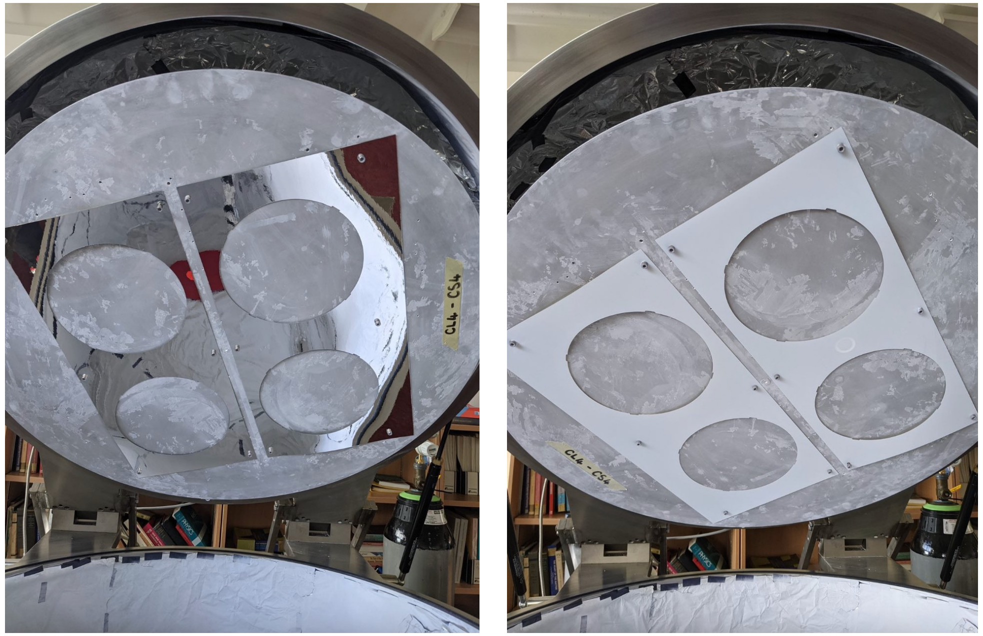

*Diagram showing an emission and absorption spectra and the gap between their peaks (Stokes shift)*




*TPB emission and absorption spectra and argon scintillation peak [1]*

# WLS in LArTPCs

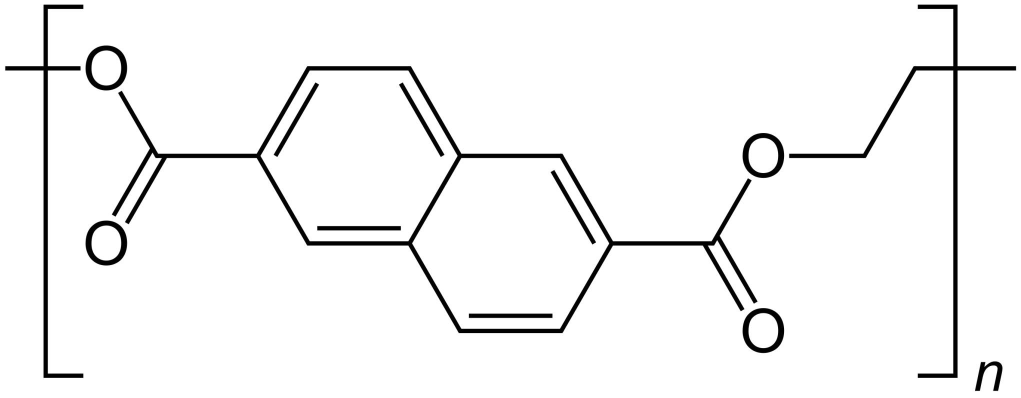
- WLS can be used in detectors to coat surfaces
  - often used in front of photon detectors or as reflective coating on passive surfaces
- TPB (tetraphenyl butadiene) is commonly used
  - expensive to use
  - difficult to scale up to large sizes (evaporative coating most efficient)
  - light yield reduced when TPB is painted on



*ESR before (left) and after (right) evaporative coating with TPB, for application around PMTs at the CCM argon scintillator experiment (credit: Andrzej Szelc)*

# PEN (polyethylene naphthalate)

- main emission component at 430 nm (blue)
- fluorescence lifetime $\sim$ 20 ns, less than argon triplet lifetime (1.3 µs)
- thermoplastic polymer
  - can be made into sheets to coat large surfaces fairly cheaply
- response of PEN could be competitive to that of TPB *Kuzniak et al, Eur. Phys. J. C (2019*)
  - PEN efficiency typically lower than that of TPB (49% and 67% respectively at 87 K: *Araujo et al, Eur. Phys. J. C (2022)* )

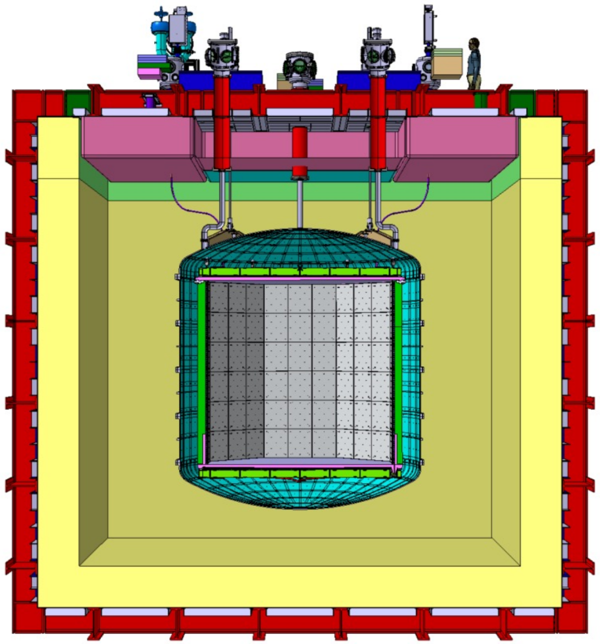



*Above: PEN molecule; below: PEN sheets*

# PEN (polyethylene naphthalate)

- PEN tests have been carried out on a small scale
  - *Y Abraham et al, arXiv:2103.03232 (2021)*

- Larger scale PEN-reflector tests and tests of PEN stability are needed
  - PEN chosen as the WLS for the **DarkSide-20k** LAr veto
  - **LEGEND-1000** experiment plans to use PEN WLS for instrumented LAr scintillation medium

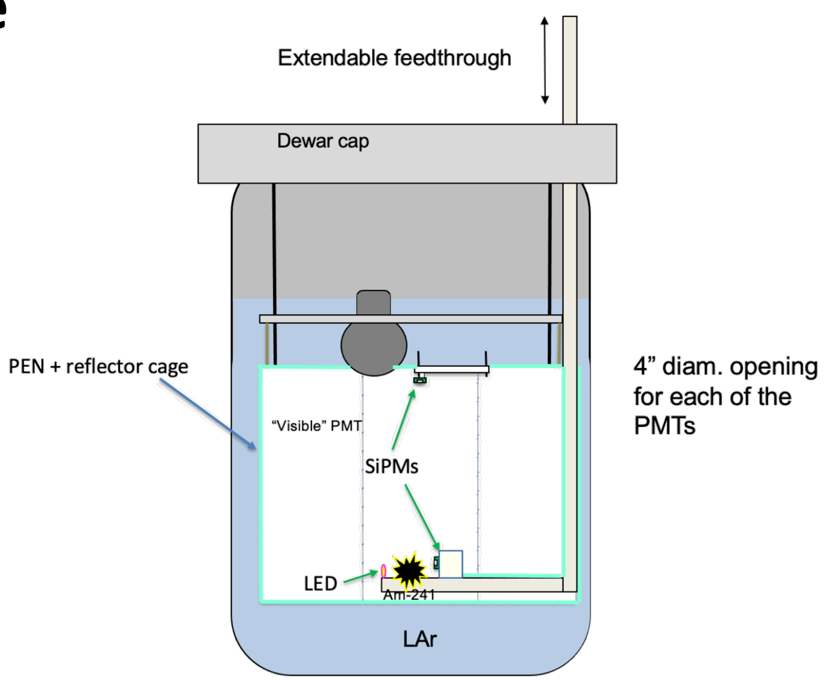


*DarkSide-20k (credit: DarkSide Collaboration)*

# Goals of campaign

**"Test the performance of PEN as a WLS over a large surface"**

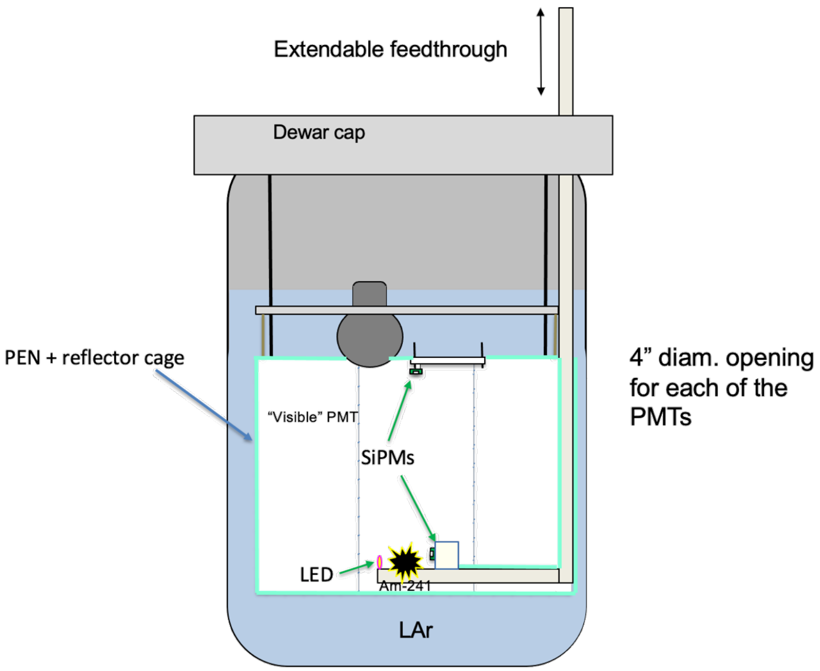
- large scale PEN wavelength shifter (with ESR) reflector test campaign at CERN Neutrino Platform test facility
- CERN, January – February 2023
  - use sheets of PEN mounted to lightweight support structure immersed in LAr
- investigate stability of light yield over 2-3 weeks
- moveable alpha source
  - measurement of LAr scintillation light properties




*Schematic of experimental setup*

# Experimental Setup

- 1500 litre double-walled cryostat
- PMT attached to PMT plane
  - not coated with WLS; only sensitive to visible light (8 in. R5912-MOD Hamamatsu)
- 2 SiPMs (S13370-3050CN / S13370-3075CN Hamamatsu)
  - 1 at alpha source, 1 near PMT
- alpha source used to create scintillation light
  - mounted on manipulator to allow raising and lowering; pressure to be carefully monitored during source movement
- white LED used for calibration; installed next to alpha source

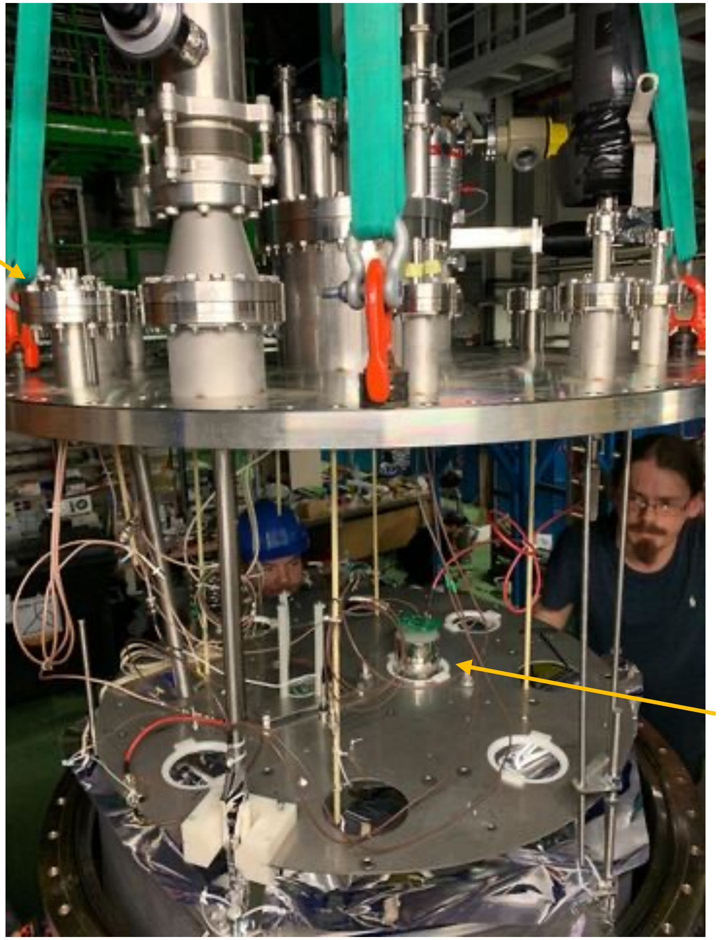



*Schematic of experimental setup*

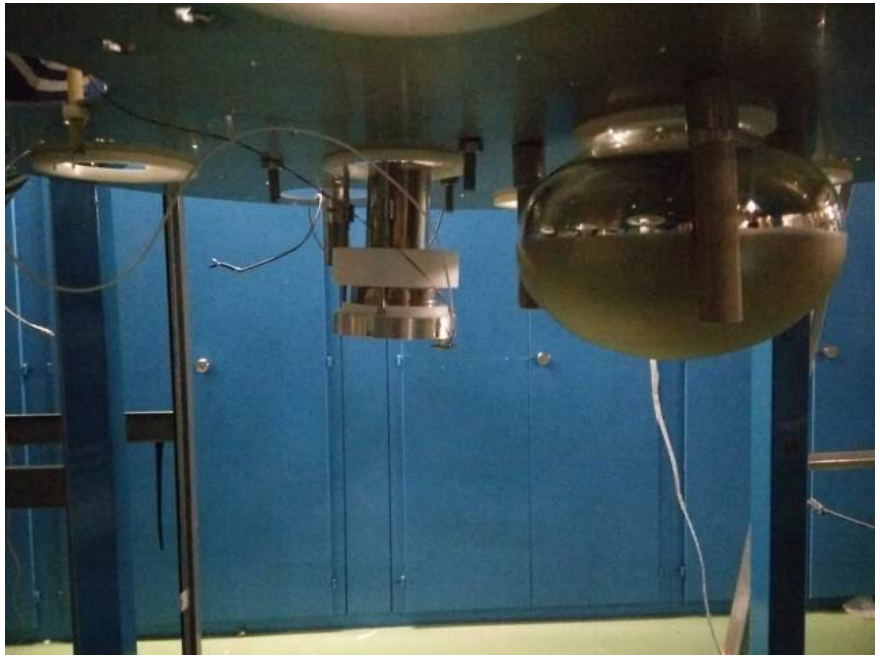
# Experimental Setup

- 25 μm thickness PEN and ESR mounted to hexagonal reflector cage, inserted into cryostat
  - area of 4.3 $m^2$
- detector filled with LAr; 50 – 150 mbar overpressure
  - regularly refilled (every ~ 3 days) to maintain LAr fill level
  - level monitored by capacitance probe
  - no active cooling
  - LAr purified in-line with filling

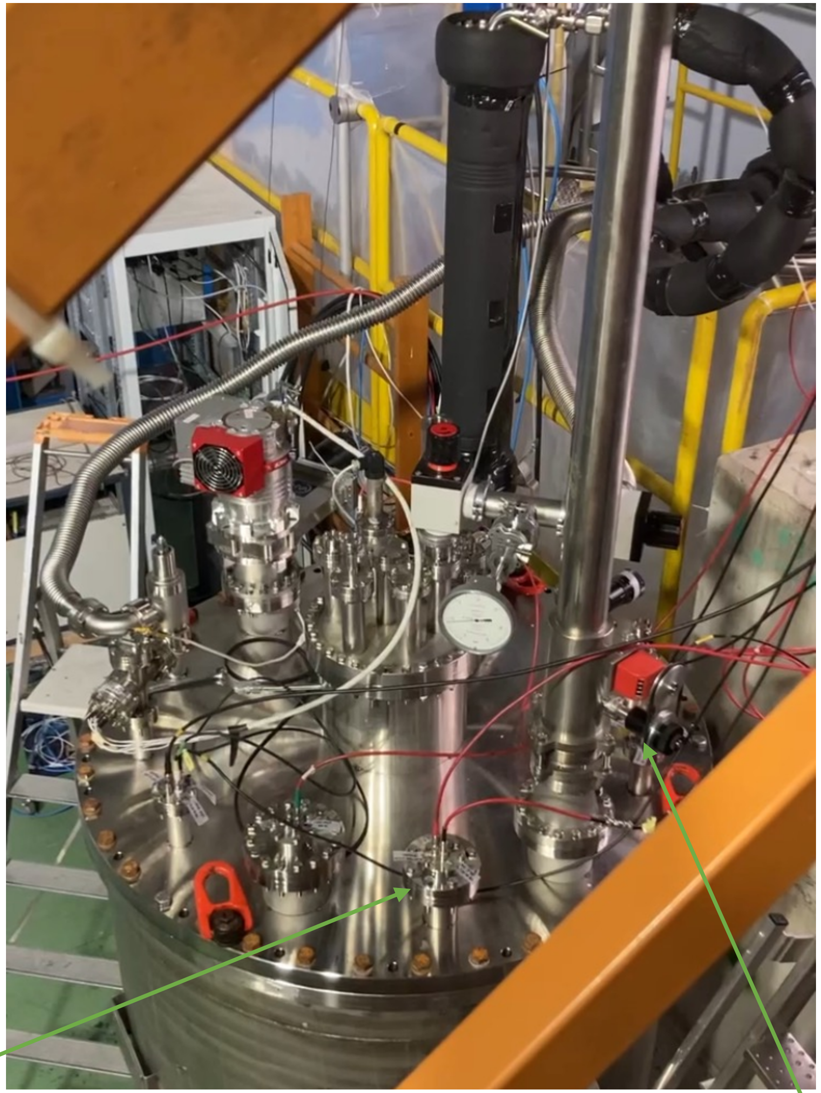
*1: filling with liquid argon; 2: the hexagonal reflector cage is lowered into the detector; 3: inside the reflector cage*




*Dewar flange is lowered*



*Alpha source mounted to manipulator to allow raising and lowering within the detector*

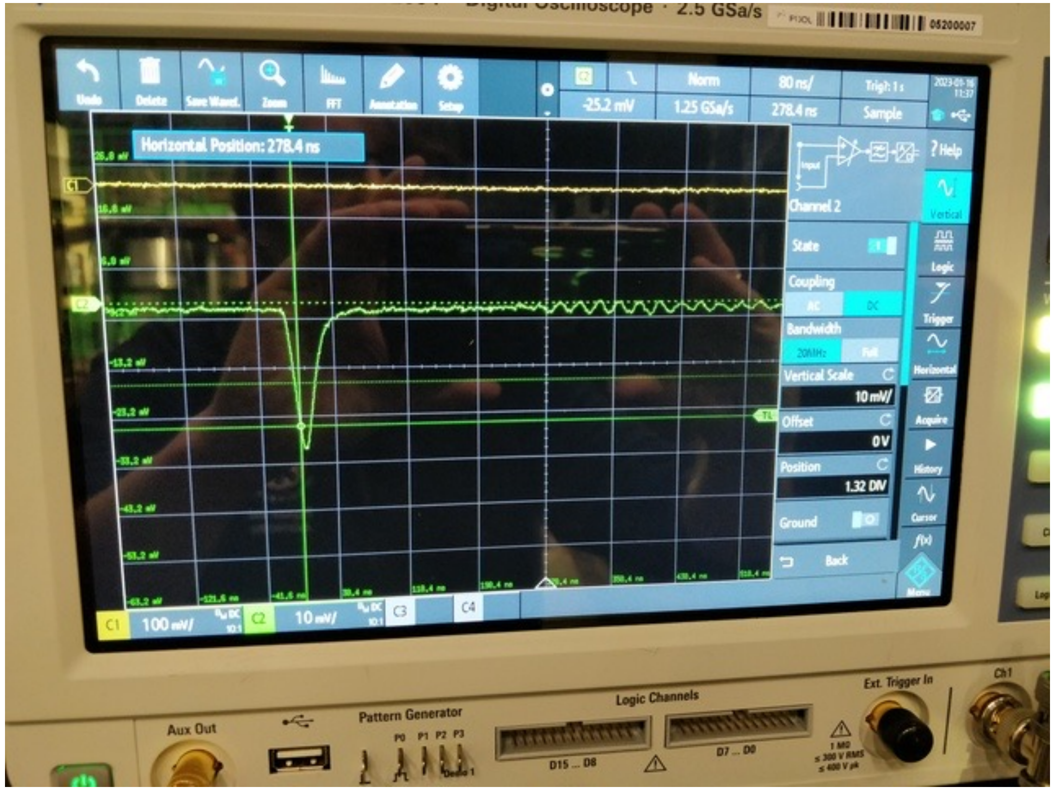


feedthroughs

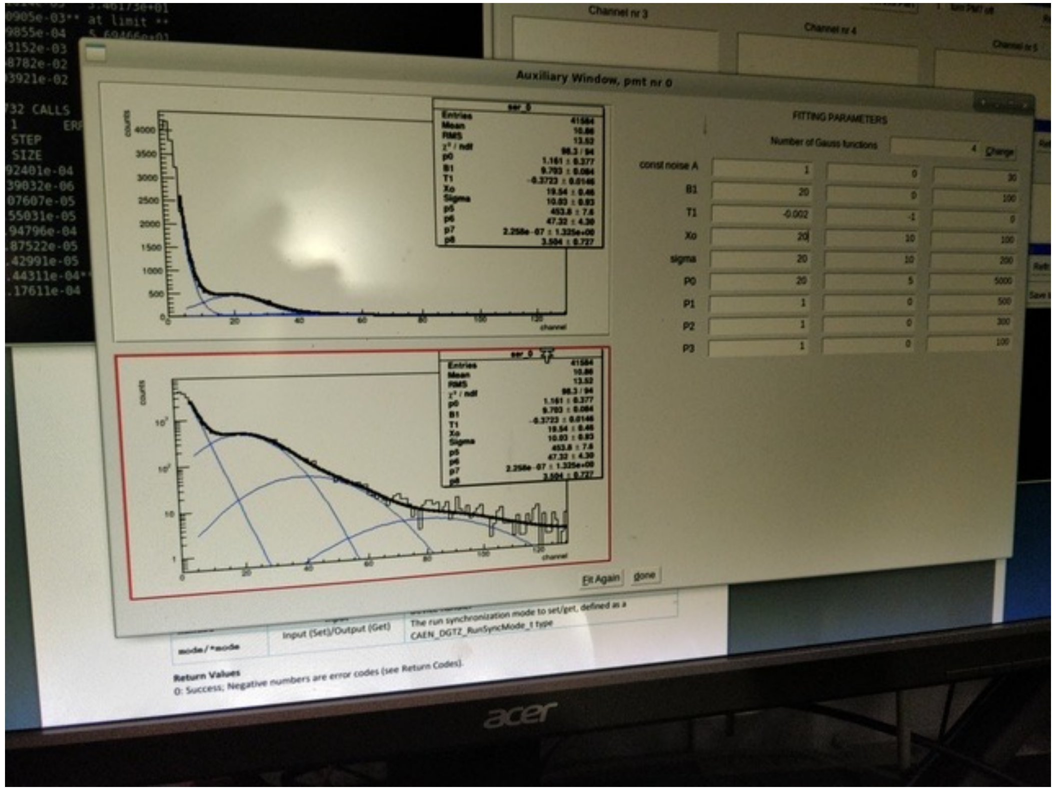
source manipulator

# Data taking

- **DAQ**: CAEN Digitizer V1751, CAEN A3818 PCI Express card, Rohde & Schwarz RTB2004 and LeCroy oscilloscopes, custom written C++ DAQ
  - can be triggered on input (PMT, SiPM) or external trigger (LED)
  - DAQ settings: number of events, acquisition window, bin width, dynamic range, baseline



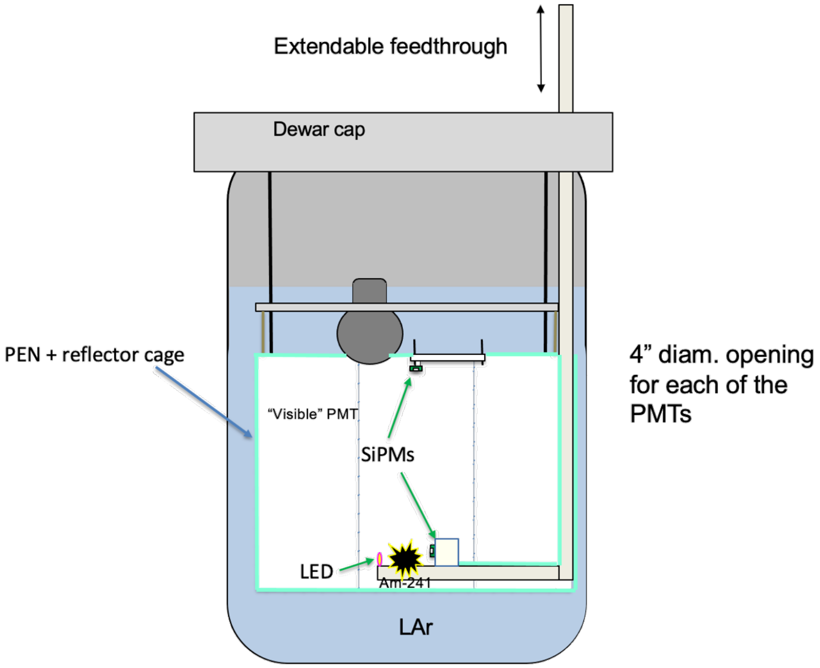

*First oscilloscope signals after setting up PMTs*




*First SER spectra obtained with DAQ*

# Data taking

- LED voltage between 2.38 – 2.63 V; PMT voltage 1100 – 1750 V
- z-positions of the alpha source: 0 cm ('top'), 37.5 cm ('middle'), 75 cm ('bottom')
  - angular 'left and right' manipulator positions also used (± 75º)
- 99 data runs taken over 19 days
  - 88 with alpha source; 6 with gamma source in addition
  - 26 with LED
  - initial issues with DAQ equipment meant first 25 runs had waveforms recorded using the oscilloscope, not the DAQ (1 – 6 with Rohde and Schwarz, 7 – 25 with LeCroy)




*Schematic of experimental setup*

# Example data taking log

## R90 (Alpha, top)

**Manipulator position:** z=0 (top)

**Trigger:** on alpha with PMT with trigger level 85 mV

**PMT Bias Voltage:** 1750 V

**TOP Bias Voltage:** 45.5 V

**Waveforms recorded:** 20 000 000 PMT & events with CDAQ

**DAQ Settings:** 10 us (1000 bins) acquisition window; 100 MS/s (10 ns bin width); 2250 mV dynamic range; baseline: 100 mV (15656 samples) (PMT) from top, 1007 samples ( SiPM ) from bottom

**Run started:** 08.02.2023, 18:39 CET

**Run ended:** 09.02.2023, 10:34 CET

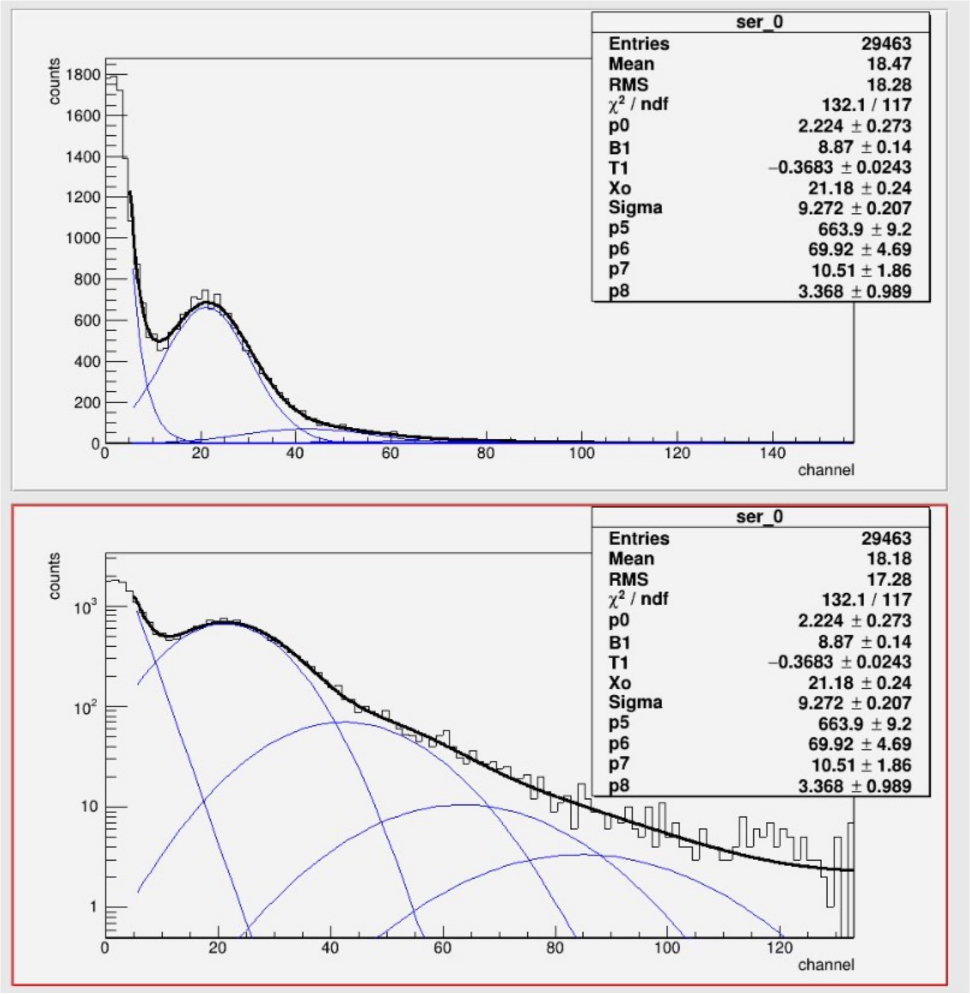
**Filename:** 230208_1840

**CERNBox Link:** https://cernbox.cern.ch/files/spaces/eos/user/m/mkuzniak/DataDWArF/all_runs/R90?sort-by=name&sort-dir=asc&items-per-page=100

**Comments:** rate ~ 270 Hz; stopped at 14.5 M

**Entry made by:** Holly

# Example waveform fitting: vacuum SER spectrum




Single Electron Response (SER): at low light levels, single photoelectrons can produce individual output pulses

Run details: LED light source, triggering on VUV PMT (not used in further data taking); visible PMT at 1100 V in channel 0 and VUV PMT at 1300 V in channel 1

x0 corresponds to the mean photoelectron charge in ADC*ns

FITTING PARAMETERS

Number of Gauss functions: 4 Change

| | | | |
|---|---|---|---|
| const noise A | 1 | 0 | 30 |
| B1 | 20 | 0 | 100 |
| T1 | -0.002 | -1 | 0 |
| Xo | 20 | 10 | 40 |
| sigma | 20 | 6 | 30 |
| P0 | 20 | 5 | 5000 |
| P1 | 1 | 0 | 500 |
| P2 | 1 | 0 | 300 |
| P3 | 1 | 0 | 100 |

# Analysis is in progress

- Code developed at UZH to process DAQ data into root files and clean up/parameterise into data structure
  - analysis of PMT and SiPM traces is currently in progress, based on existing expertise with developed algorithms

- Plan is to make a ‘Z-scan’
  - investigation into the effect of source height z on peak position, after SPE calibration
  - compare the light yield from the alpha source at different positions of z, and compare to simulation prediction to determine PEN efficiency

**Other ongoing studies**: investigating triplet lifetime stability; plot light yield vs time to investigate stability of PEN

# Conclusions

- a dedicated test has been performed at the CERN neutrino platform test facility to measure the performance of large-area PEN sheets as a WLS
- 99 runs of data have been acquired over 19 days in January – February 2023
- Data quality is good and analysis is ongoing
- Stay tuned for results soon

# All Contributors

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# References

[1] "A Demonstration of Light Guides for Light Detection in Liquid Argon TPCs", C. M. Ignarra, Physics Procedia (2012)