# R&D on Liquid Argon TPC for neutrino physics

# - Large scale challenges

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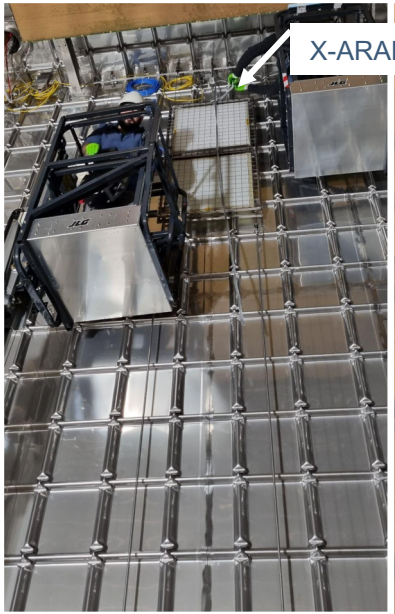
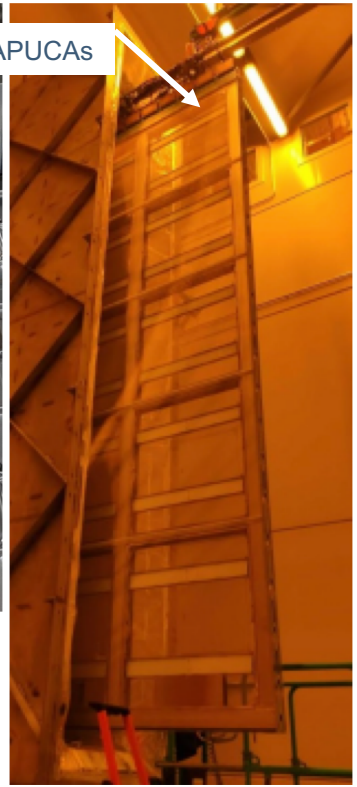
# Large scale challenges

R&D proposed to address the scaling challenges of light detection in kton LArTPCs for neutrino physics:

1. **Cryogenic infrastructures** at Spanish labs for massive photosensor assembly and characterization prior to installation.
2. **Photon detection efficiency** measurement as a key parameter for photon detector optimization and light simulation.
3. **VUV photosensors** able to cover large areas.
4. **Large scale** R&D at CERN.
5. **Electronics** and readout.
6. **Simulation** of light propagation and reconstruction that is computational intensive.
7. **Light and charge** combined readout as a solution for DUNE far detector phase II.



*ProtoDUNE-VD*




*ProtoDUNE-HD*

# 1. Cryogenic infrastructures

- Development of cryogenic infrastructures at CIEMAT, IFIC, UGR for cryogenic photosensor characterization, validation, and massive testing

  → Validation measurements in $LN_2$: gain, dark current rate, signal to noise ratio.

  → Photon detection efficiency measurement in LAr.

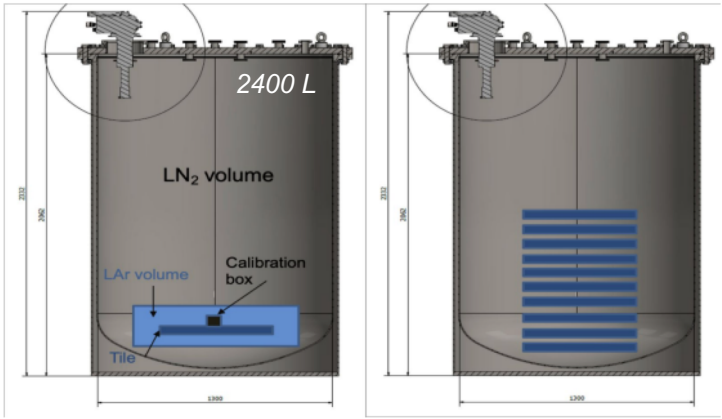
- **Previous activities**: Characterization and validation of ProtoDUNE-DP PMTs [JINST13(2018)T10006; JINST15(2020)P09023] and ProtoDUNE-HD X-ARAPUCAs [ISSN: 2695-8864(2022)].

*ProtoDUNE-HD X-ARAPUCAs massive testing at CIEMAT*

# 1. Cryogenic infrastructures

- Spain will be an assembly and qualification center for the DUNE FD2-VD X-ARAPUCAs.
- The 352 membrane VD X-ARAPUCAs will be assembled and characterized at CIEMAT and UGR labs in 2025-2027.
- This requires dedicated installations for the characterization of the membrane VD X-ARAPUCAs with new cryogenic infrastructures.


*CIEMAT cryogenic lab*

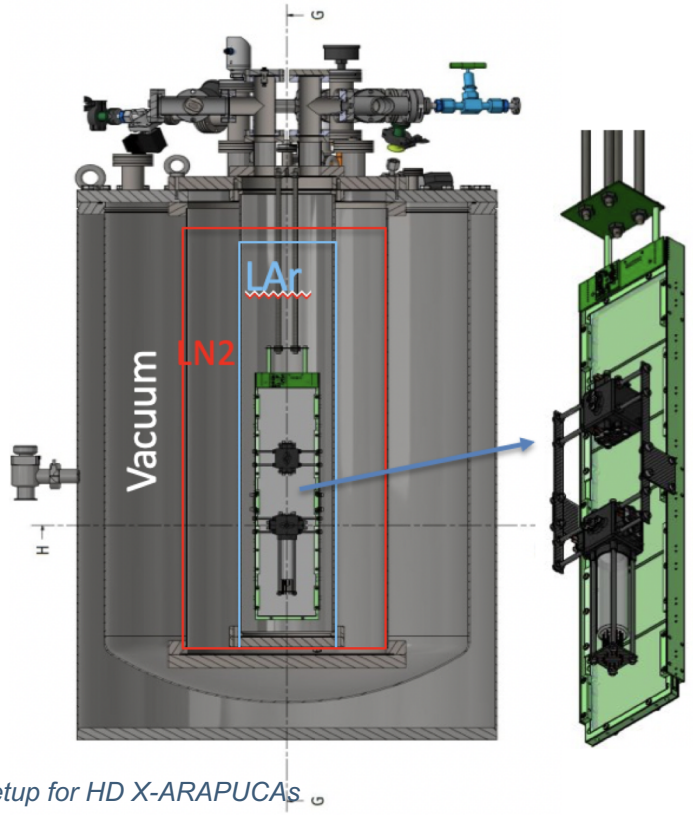



*Setup diagrams for* VD X-ARAPUCAs characterization

*Cryogenic vessel at CIEMAT*

# 2. Photon detection efficiency

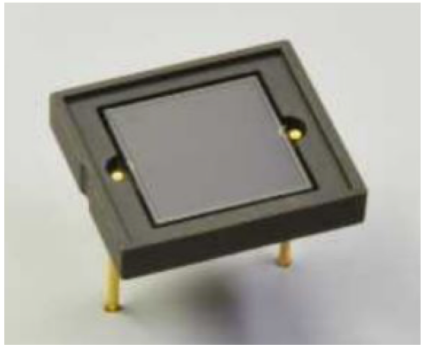
- Reference parameter for:
  → X-ARAPUCA design optimization
  → DUNE FD data-MC comparisons
- **Difficult** measurement: VUV light, cryogenics. Not measured before.
- **Previous experience**: first measured for X-ARAPUCAs of ProtoDUNE-HD (2-3% [ISSN: 2695-8864]) and SBND (on-going).
- Low-activity electrodeposited $^{241}$Am alpha source used to produced scintillation light
- Future upgrade to VUV light source + monochromator.
- VD X-ARAPUCAs to be measured




*CIEMAT setup for HD X-ARAPUCAs*

# 3. VUV cryogenic photosensors

- R&D on VUV SiPM to avoid the use of wavelength shifters.
  Needs:
  → cryogenic operation.
  → large arrays (signal ganging).
  → Sensitive to 128 nm (vacuum ultraviolet, VUV).
  → industrial collaboration (Hamamatsu, FBK)



*Hamamatsu VUV4 SiPM*

- Experience at CIEMAT testing VUV SiPMs
  → SiPM: Hamamatsu VUV4 SiPMs, S13370 – 6075CN)
  → Used as reference sensors in photon detection efficiency measurements.
  → Measured absolute photon detection efficiency at CIEMAT at 128nm ~25% at 300K.
- Need new setup with VUV light source + monochromator and cryogenic operation for direct measurements.
- Possible use of VUV light collectors with R&D needed. Will explore the use of light collectors used in the solar energy industry.

# 4. Large scale R&D at CERN

Certain R&D needs of specific infrastructure not available in local labs: **CERN Neutrino Platform.**

- Operation of **light readout systems in HV environment** as the TPC field cage or cathode (with the goal of increasing the coverage).
- **Large-scale calibrations** → new methods to ensure calibration capabilities at large-scale.
- Light and charge readout integration.
- **Xe doping** performance.
- Long-term operation and stability of the readout systems.

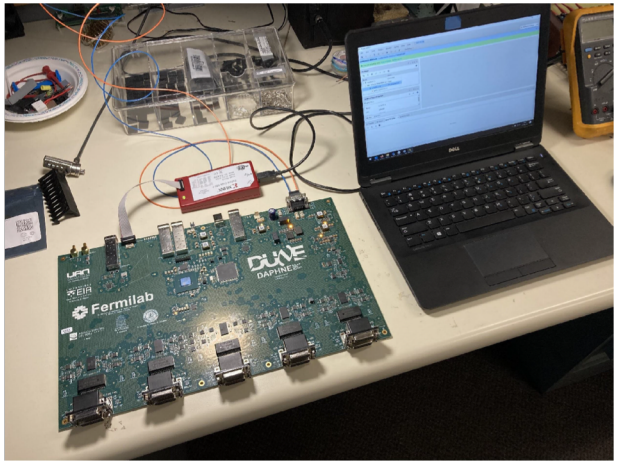

*ProtoDUNEs at CERN*

# 5. Electronics and signal processing

SiPM array → Cold front-end electronics amplification → Warm electronics (DAPHNE) → DAQ

Future/on-going R&D plans:

- Developments of digital electronics in the readout electronics of DUNE: DAPHNE (Detector electronics for Acquiring Photons from Neutrinos)* in collaboration with FNAL, Milano-Bicocca, APC.
- Implement photon detection system trigger in DAPHNE.
- Develop a trigger algorithm based on the photon detection system for low energy events (supernova burst and solar neutrinos).

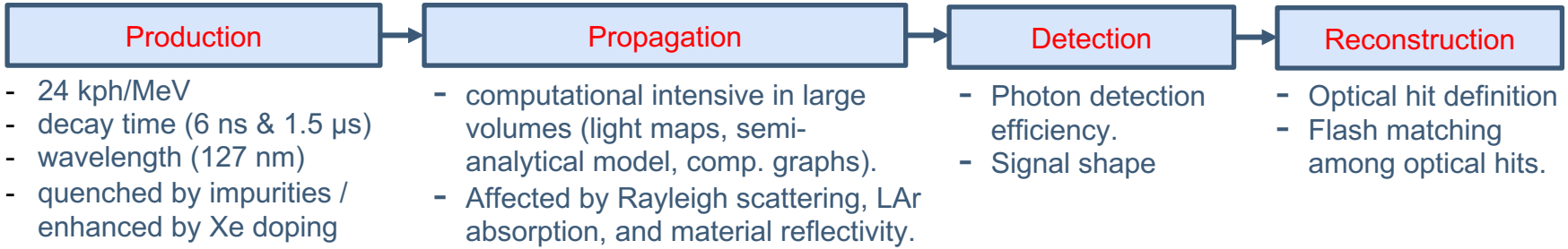



*DAPHNE board*

* DAPHNE:
- 40 channels/ 14 bits
- Bias-trim voltage supply
- Cold electronics power supply
- Link to DAQ
- DUNE Timing interface

# 6. Light reconstruction

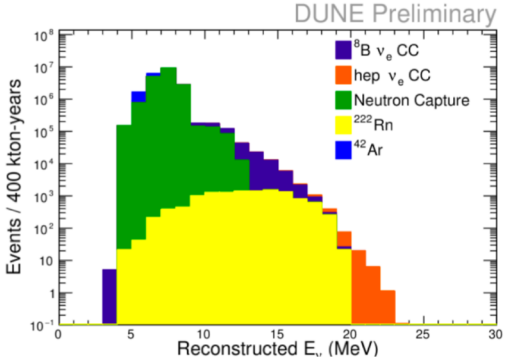
- Development of simulation tools for the study of scintillating light in large LArTPCs:



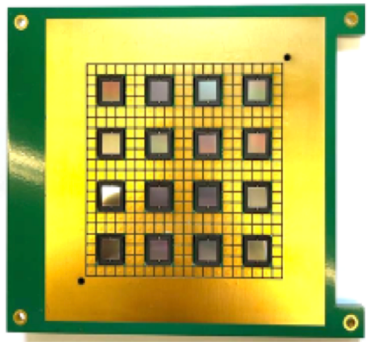

- Pulse shape discrimination**, machine learning techniques** for signal/background discrimination in supernova and solar neutrino studies.
- **Previous experience** in WA105 3x1x1 demonstrator [JINST16(2021)P03007] and ProtoDUNE-DP [EPJC 82 (2022) 618] → 3 PhD Thesis at CIEMAT.

# 7. Light + charge combined readout

- Special focus on low energy physics in LAr for DUNE phase II:
  → **Solar and supernova neutrinos** (5 MeV threshold)
  → Challenges: background, energy resolution, energy reconstruction
- The SoLAr concept [arXiv:2203.07501]
  → Combining **light and charge**
  → Integrate developing technologies:
  - Charge readout **pixels**
  - **VUV SiPMs**
- SoLAr collaborators from U. Bern, CIEMAT, U. Edinburgh, Fermilab, U. Genova,U. Manchester, U. Milano Bicoca, U. Naples, INFN.
- UGR interest in amorphous selenium based photodetector [JINST18(2023)P01029]




*Solar neutrino spectrum in DUNE simulations*

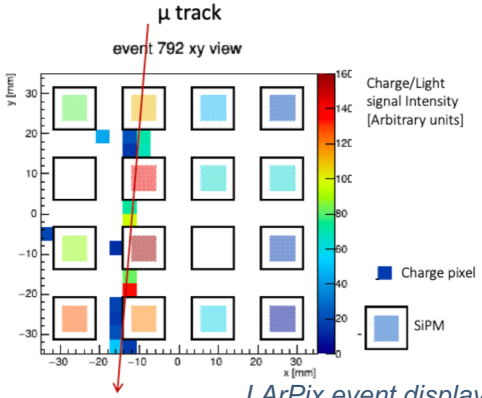


*LArPix prototype for SoLAr*

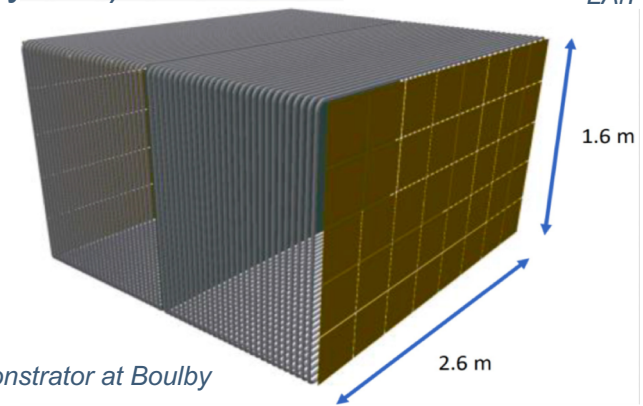
# 7. Light + charge combined readout

Possible timeline:

- Small scale, **SoLAr prototype at Bern** (2022-2023)
  → 7 x 7 $cm^2$ anode plane
  → 16 VUV SiPMs
  → 4 LArPix-v2a chips (R&D also on QPix)
- **Mid scale, SoLAr Demonstrator at Bulby** (~2025-2030)
  → Few-ton scale detector underground (Boulby, UK).
  → 32 × 32 $cm^2$ anode tiles (≈ 6400 pixels/tile).
  → First measurement of solar neutrinos.
- **DUNE Phase II?**




*LArPix event display*




*SoLAr Demonstrator at Boulby*

# Summary

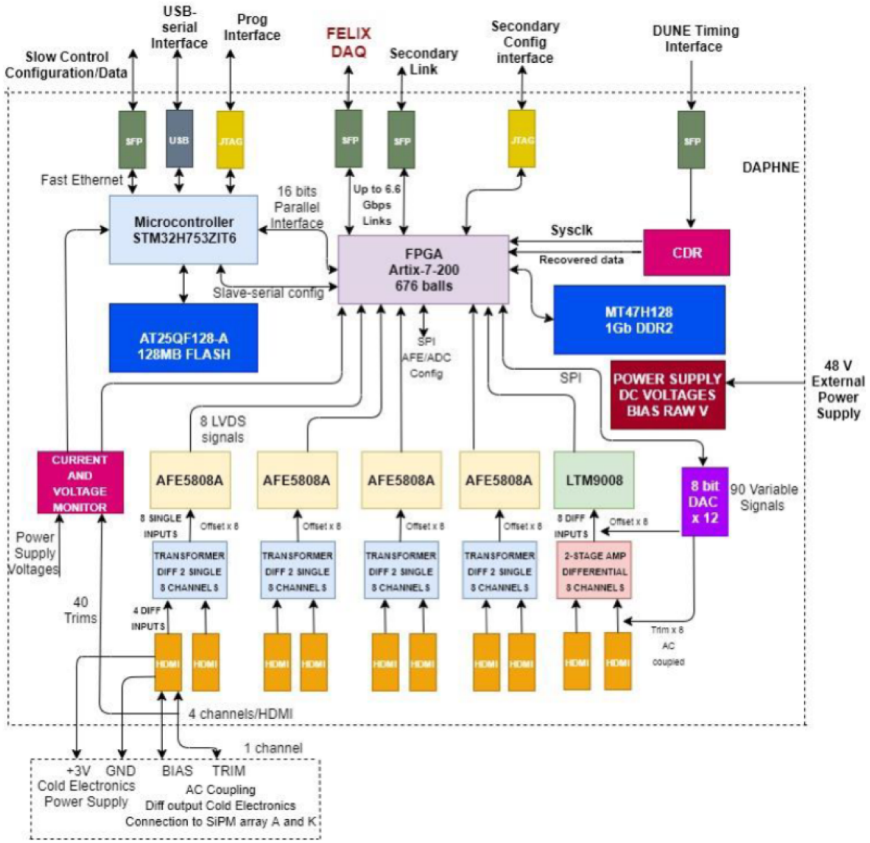
Efficient light detection is challenging in kton LArTPCs and we propose R&D to assess it:

- **Cryogenic infrastructures** for massive photosensor assembly and characterization prior to installation.
- Development of dedicated cryogenic setups for **photon detection efficiency** measurement as a key parameter for photon detector optimization and light simulation.
- **R&D on VUV photosensors** able to cover large areas.
- Developments of cold and warm **electronics** and readout.
- **Simulation** of light propagation and reconstruction that is computational intensive.
- **Light and charge** combined readout to improve energy and spatial resolution in LAr TPCs and, as a result, expand low-energy physics in LArTPCs.


Thanks


Backup

# Daphne general block diagram




**DAPHNE (Detector electronics for Acquiring PHotons from NEutrinos)**

- 40 channels/65 Msps/14 bits
- Bias-Trim Voltage supply
- Cold Electronics power supply + 3V
- Gigabit link up to 6.6 Gb/s to FELIX DAQ/full-mode protocol
- DUNE Timing interface