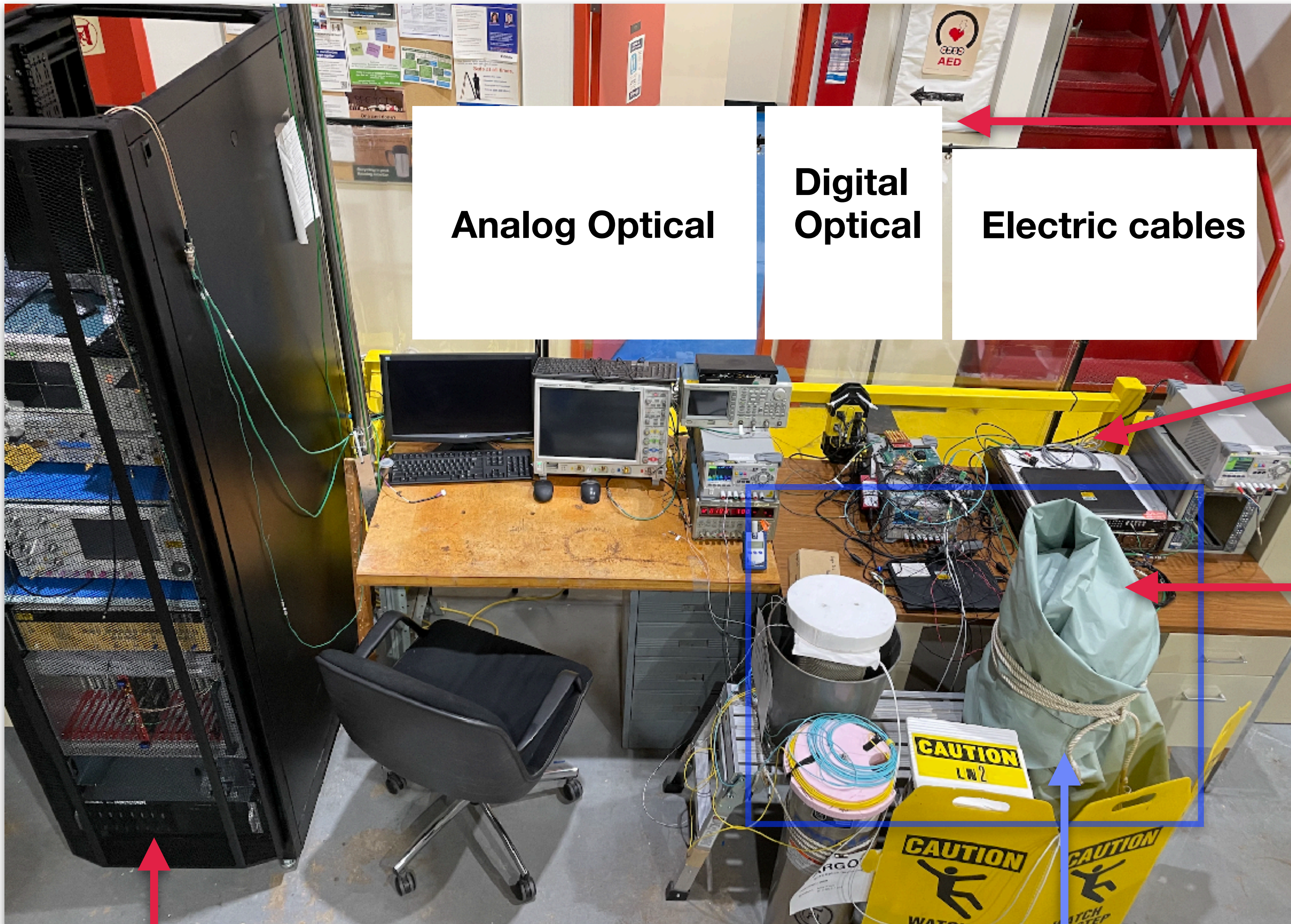
Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Noble Liquid Test Facility at Fermilab (PAB)

Alexander Kish

DUNE FD3 Workshop
June 27, 2023
Stony Brook University

DUNE VD PDS Cold Electronics Test stand



(D) DAQ2 (FPGA at room temperature, ADC in LAr)

(C) DAQ1 (differential input, SiPM direct measurements)

(B) SiPM board in dark environment with LED pulser (400 Hz)

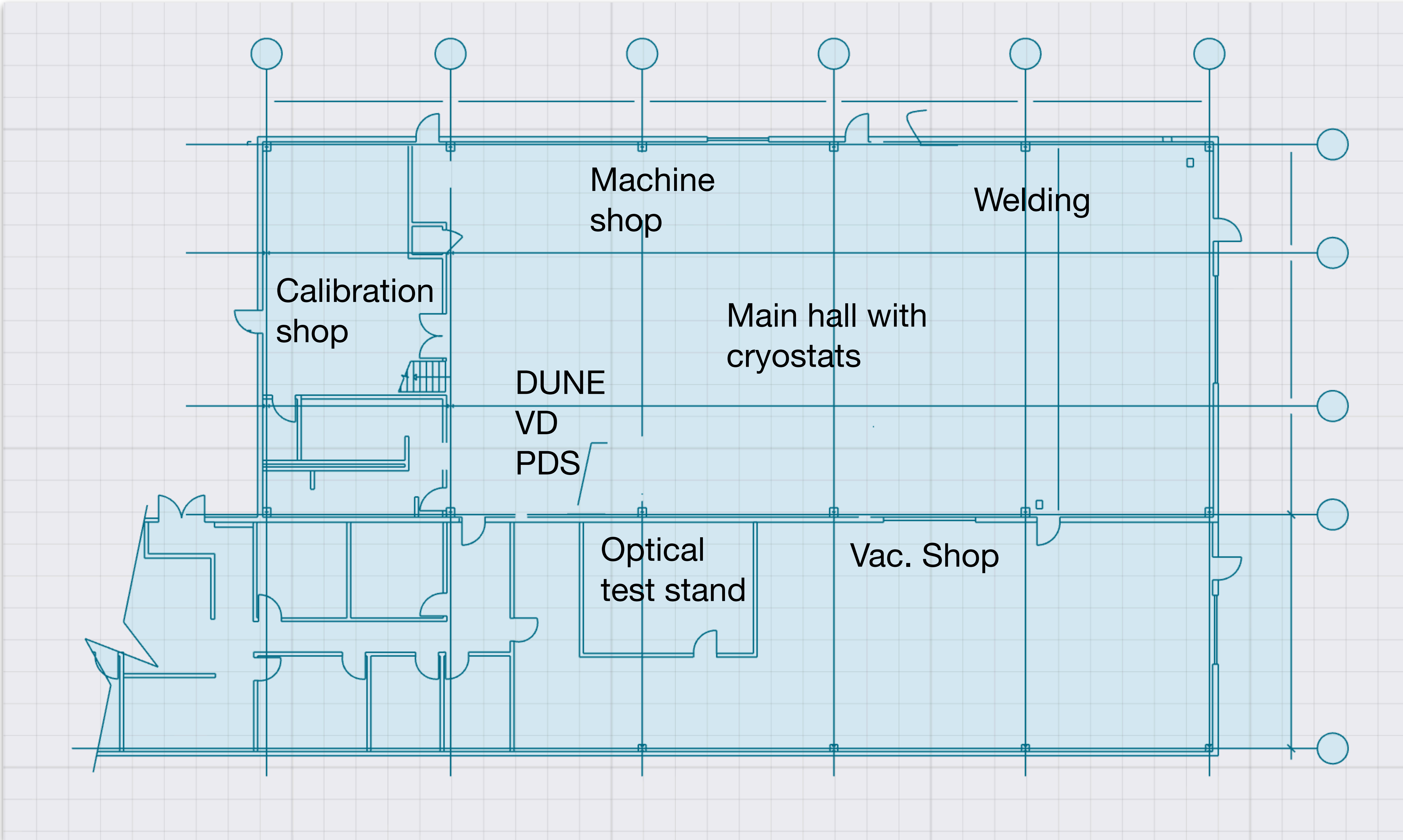
(E) DAQ3 (single-ended input, measurements with optical receiver)
Data storage and analysis server

(A) open-mouth dewars with LAr and LN2
– two shallow, two tall (up to 25” of cryogenic liquid)
– fast turn-around and iteration, side-by-side tests

*** Open-neck dewars from 1 to ~100 L capacity**

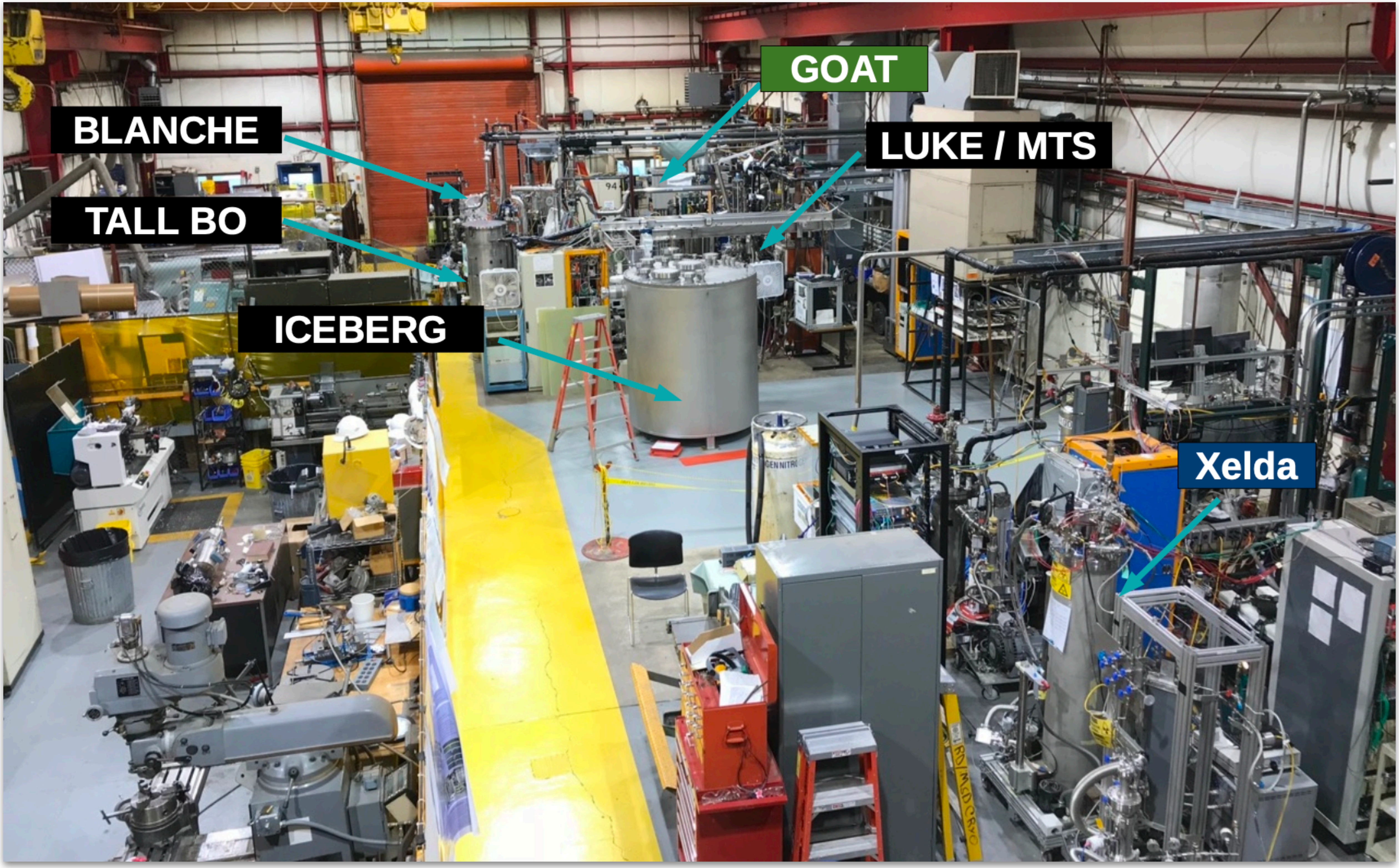
*** LAr delivery and external storage in 180L/350PSI cylinders, transfer walking with a 2-gallon insulated bottle**

Laboratory Layout



Noble Liquid Test Facility (NLTF)

Proton Assembly Building (PAB): noble liquid R&D, test facility, mechanical support, vacuum shop and pumps service, pressure calibrations and pressure tests



Cryogen Supply

The cryogenic system at NLTF is based on liquid nitrogen condensers

Argon is supplied from external tank with capacity 3000 L

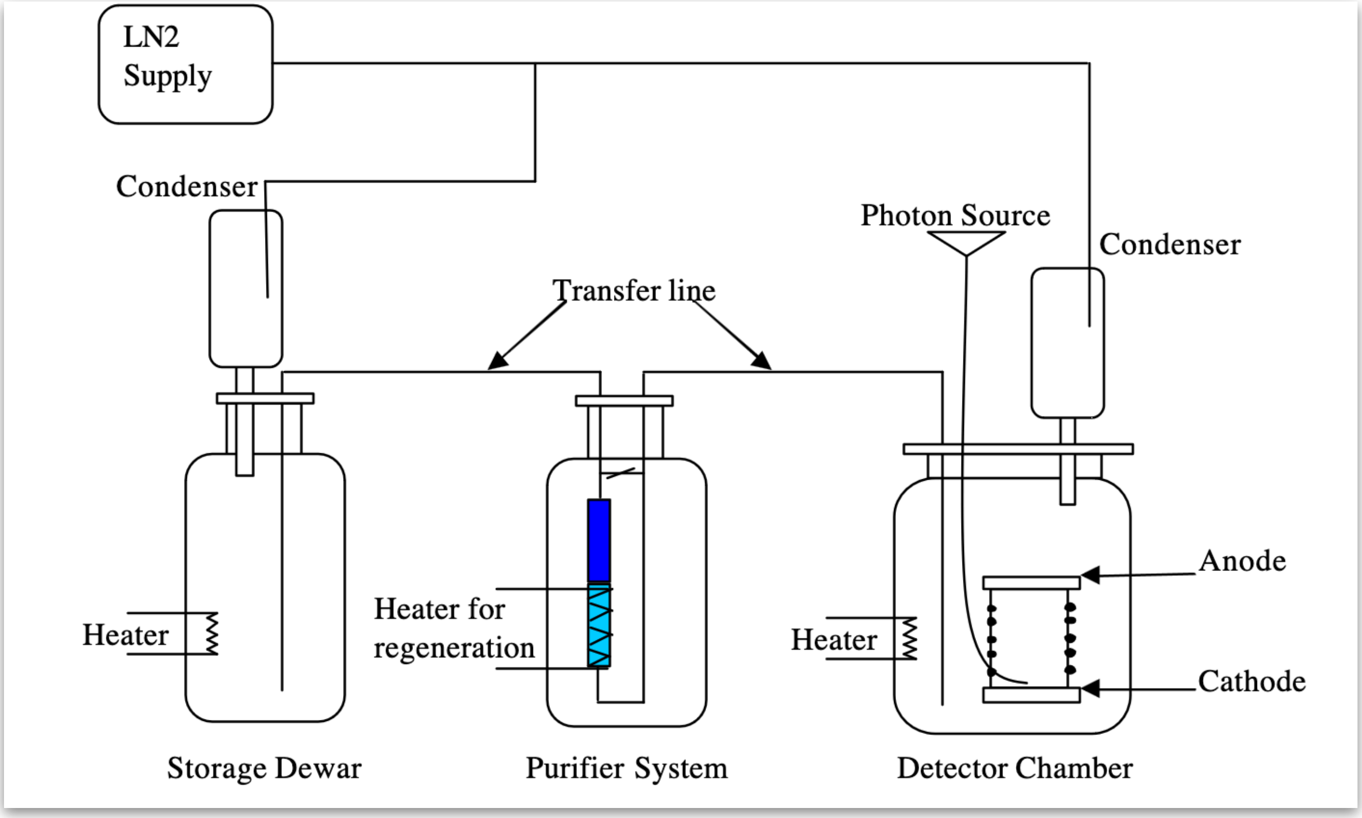
Nitrogen is stored in a 2000 L tank

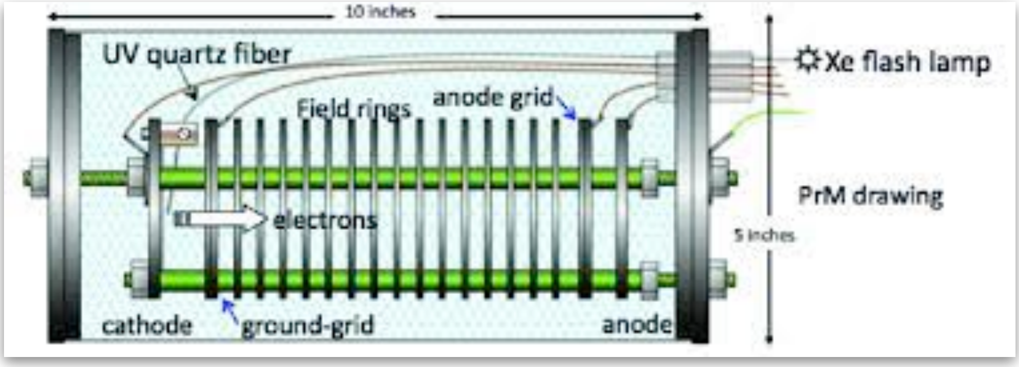
Liquid Argon Purification

Purity of liquid argon is measured before each tank fill

LAr is purified before entering the cryostats with molecular sieves

Purity (O_2, H_2O, N_2) is monitored with gas analyzers and liquid purity monitors





Cryostats: LUKE / Material Test Stand

Capacity 250 L

Features:

– Purity monitor

– internal filter

– airlock mechanism to insert materials into the cryostat

– elevator to lower the materials into the gas and liquid space

– 10 retractable cables that can be used to provide power or readout to devices inserted through the airlock

Mainly used for testing materials in GAr or LAr (impact on electron lifetime).

Can be used to test small setups (they must fit in the airlock basket).

Cryostats: TallBo

Capacity 450 L

Special feature: manual elevator platform (travel to various points in liquid and gas)
Is mainly used for photon detector studies

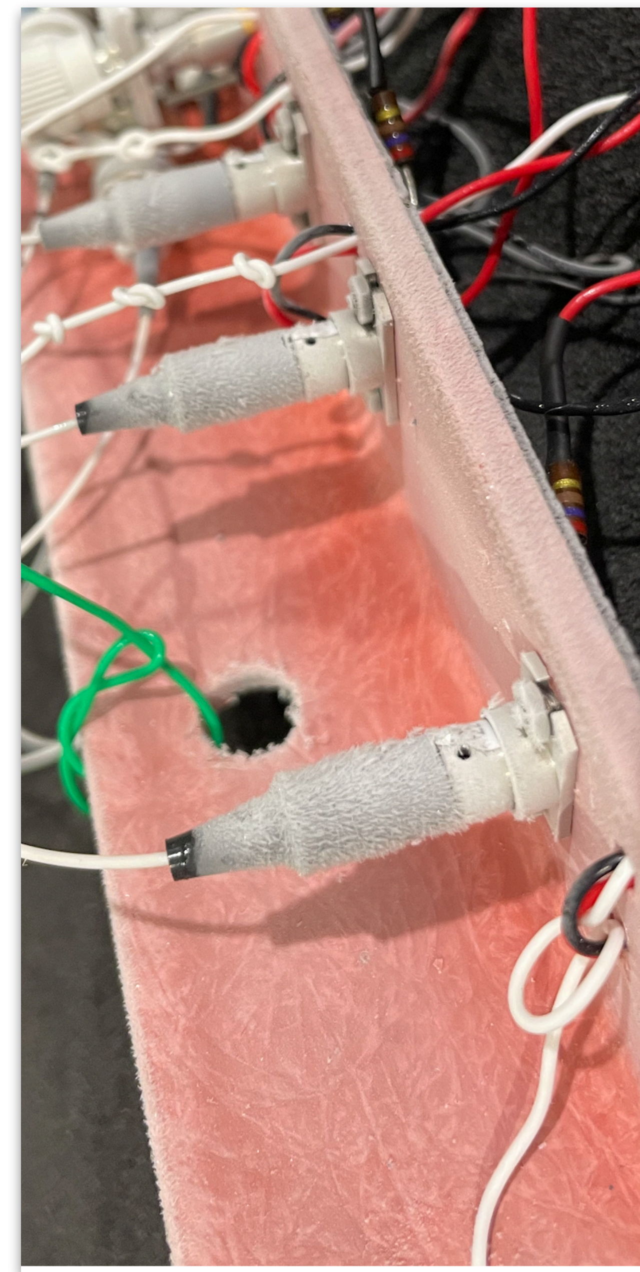
Cryostats: Blanche

Capacity 450 L

Features: purity monitor (depending on setup), internal filter

Originally designed for HV tests but multipurpose cryostat: laser diode tests for DUNE FD2, charge amplification and doping studies, pixel TPC, LLP calorimeter, etc.

Currently planning a long-term (~6months) test of 48 laser diodes



Cryostats: Iceberg

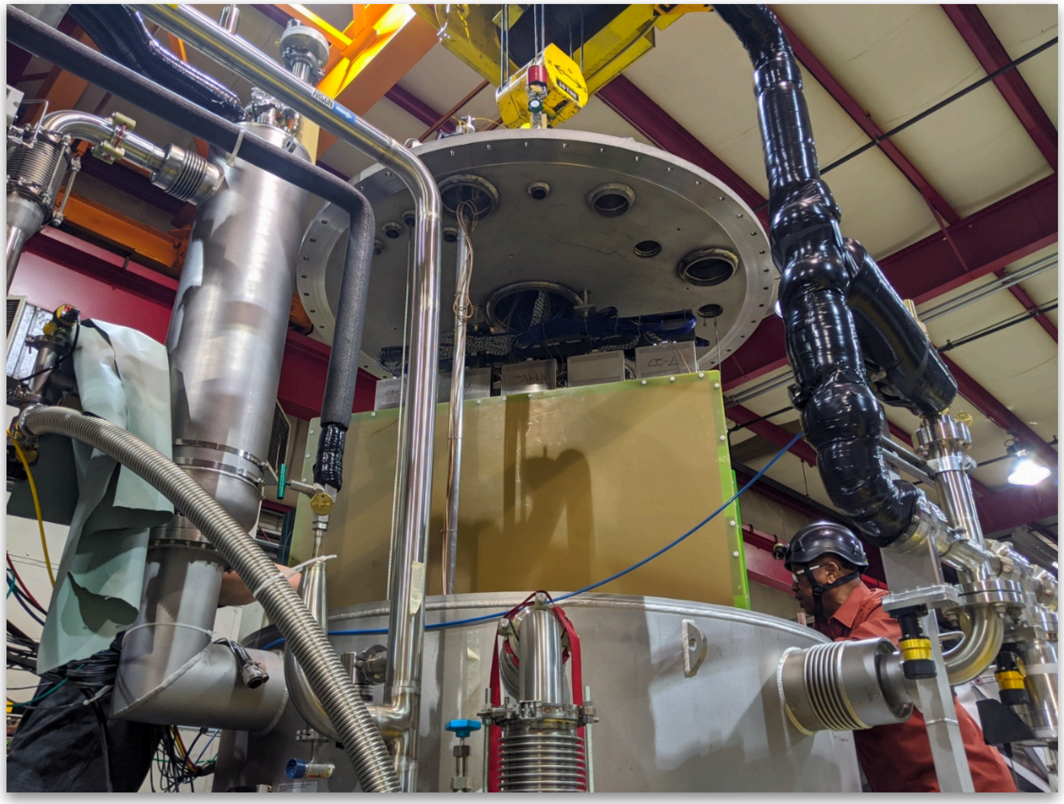
Capacity: 3000 L (4.2 ton LAr)

Features: Purity monitor, internal filter, full TPC (2 cathodes, central anode)

Dedicated to DUNE tests, DAQ development, edge-ML signal processing

Max dimensions: 152 cm diameter x 183 cm height

Vessel can accommodate Arapuca (tested one in summer 2022), possible combined run with the TPC



Optical Test Stand

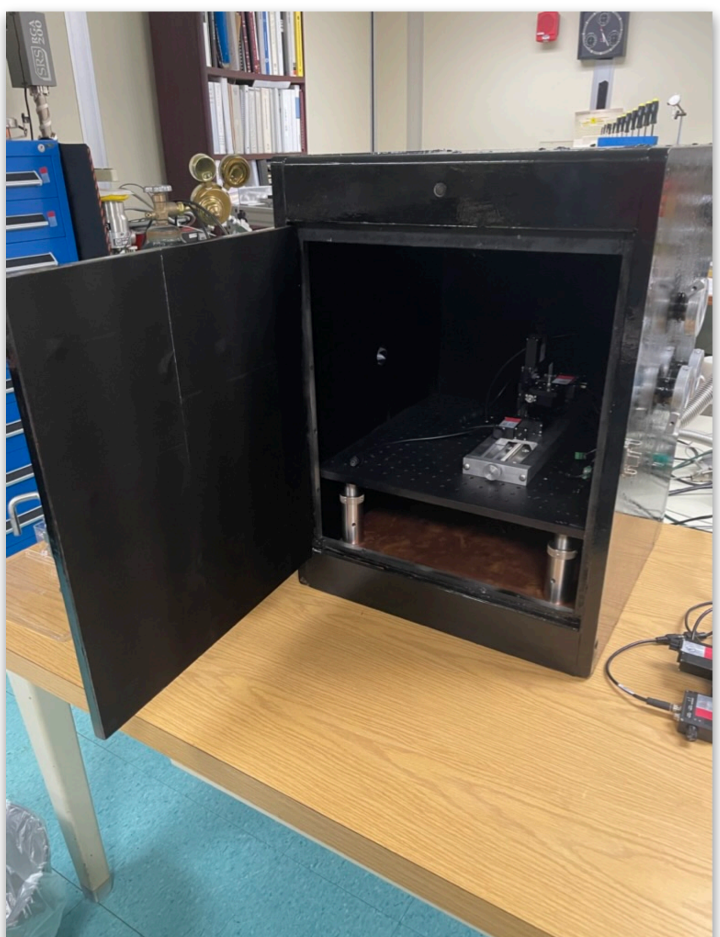
New test stand for optical characterization of materials (first project VUV-metasurfaces characterization)

Dark box with gas (N_2 or Ar) purge and VUV monochromator

Light sources: deuterium lamp, mercury-argon lamp, hydrogen glow-discharge lamp.

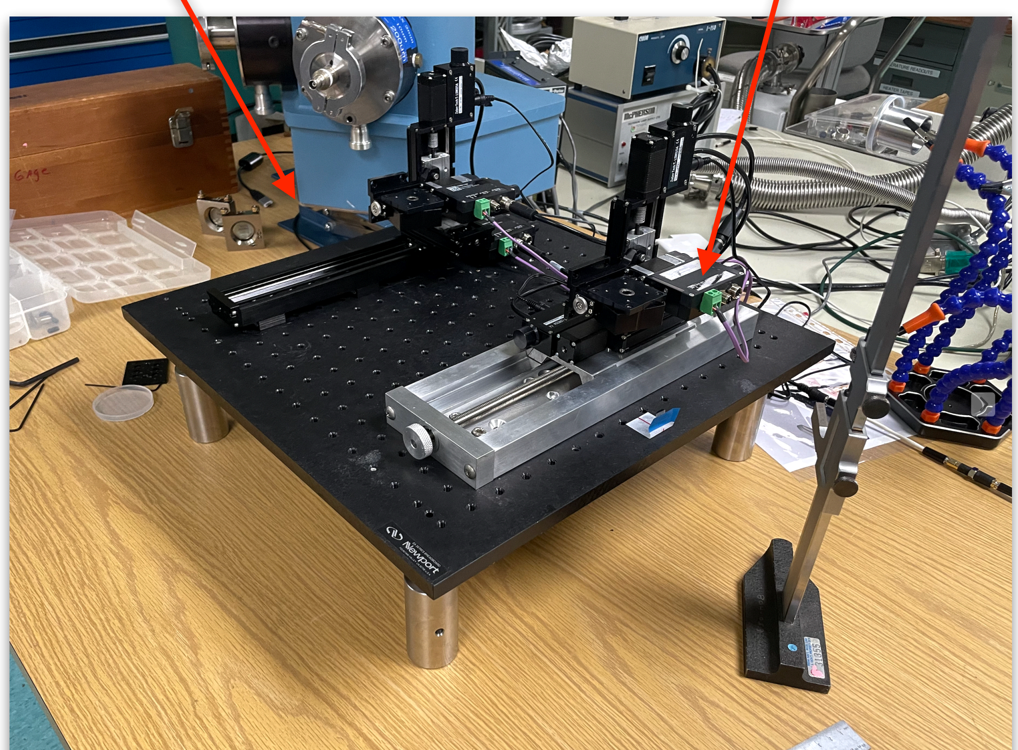
Seven motorized stages on the 18” optical breadboard, scan precision few micrometers

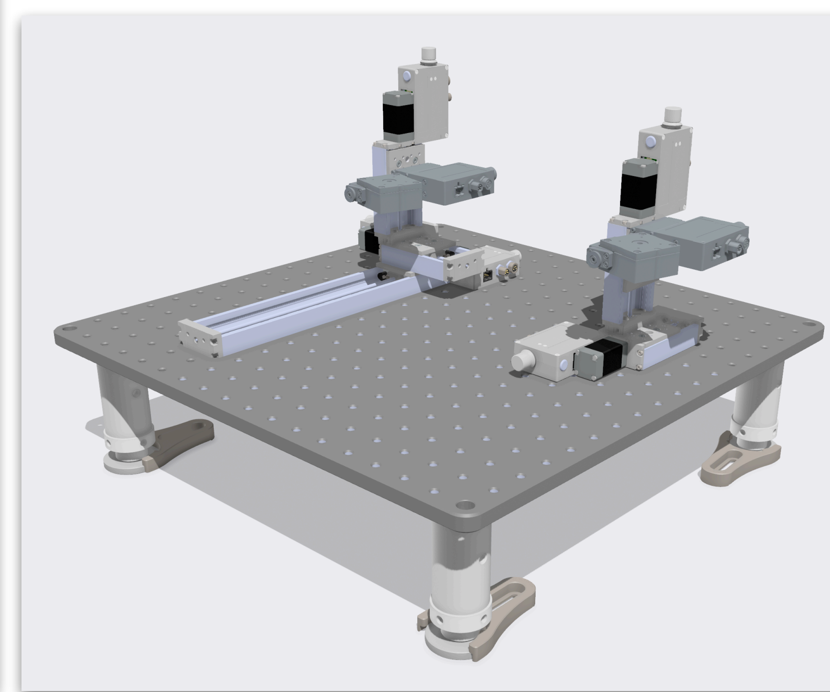
Enable various optical measurements: sensor PDE, transmission, reflectivity, WLS-efficiency



XYZ-R stage with photodetector

XZ-R stage with test object





Metalenses

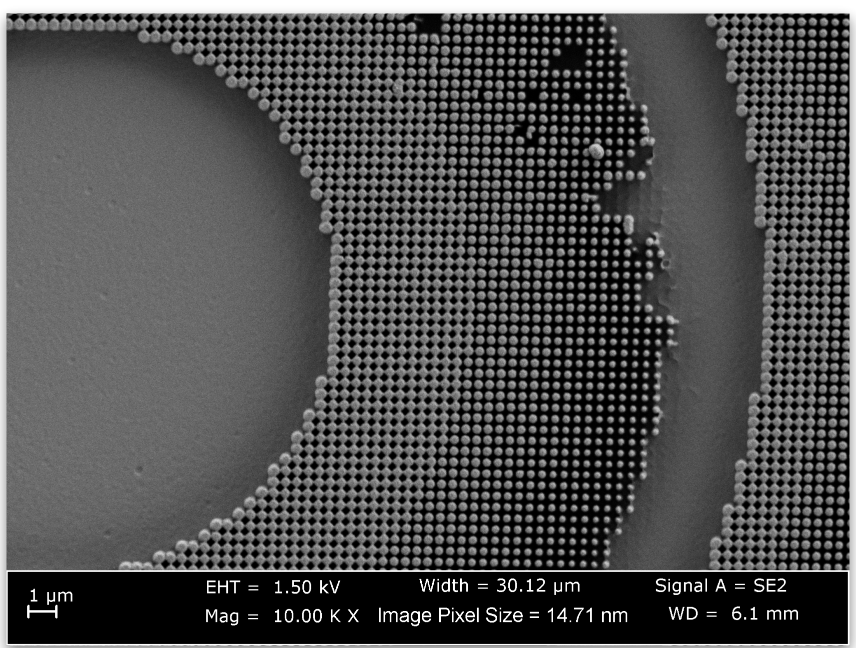
Carlos Escobar

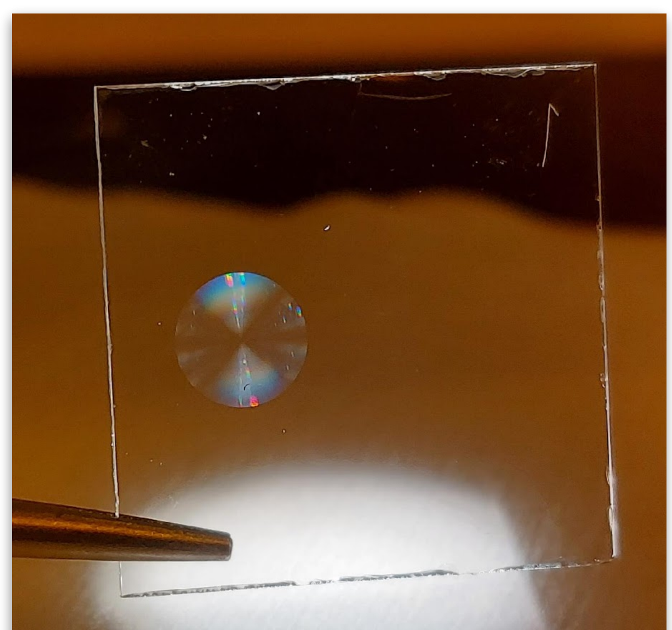
Application of metalenses for enhancement of VUV light collection in scintillation detectors based on noble elements. Collaboration with Manchester and York (formerly Harvard group)

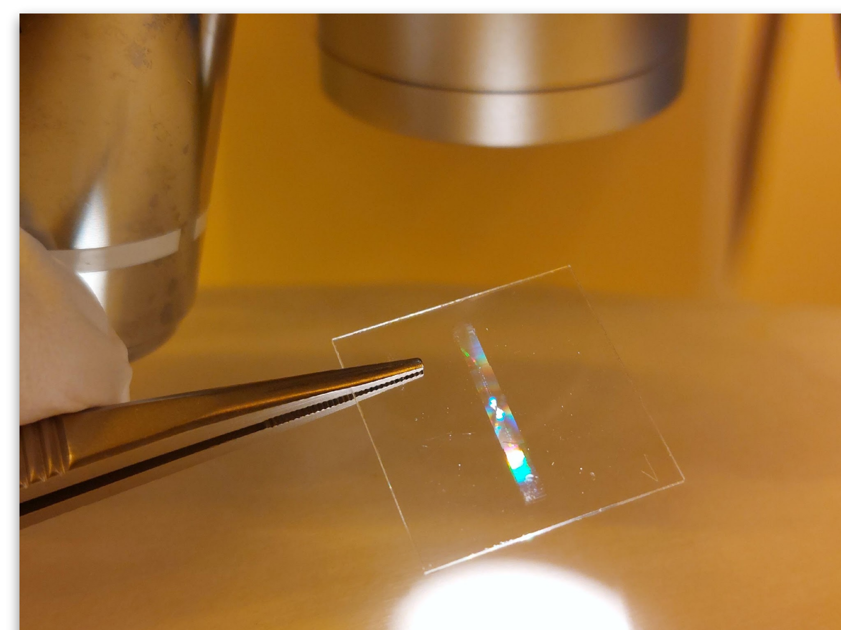
Designed and fabricated metalenses for visible and VUV light. Characterization of the lenses designed for VUV is ongoing at NLTF and Valencia

Metalens is shown to work in gas but not in liquid due to index of refraction
Small numerical aperture makes them ineffective to be used as light concentrator

Currently working on resonant metasurfaces to wavelength-shift the incident light and control emission direction. First results are encouraging







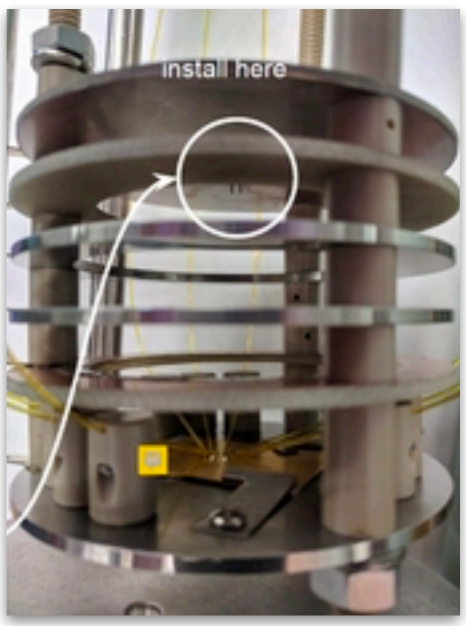
Current projects

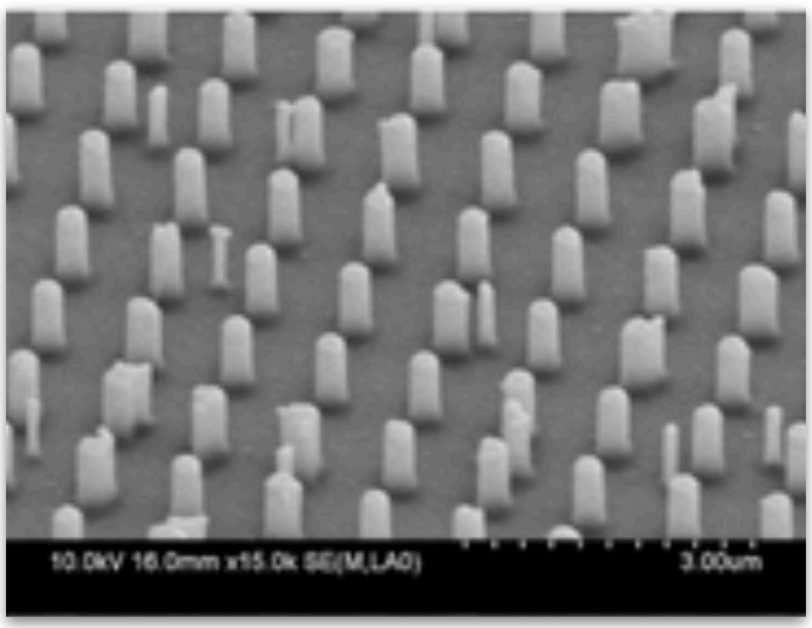
LArCADe
Angela Fava

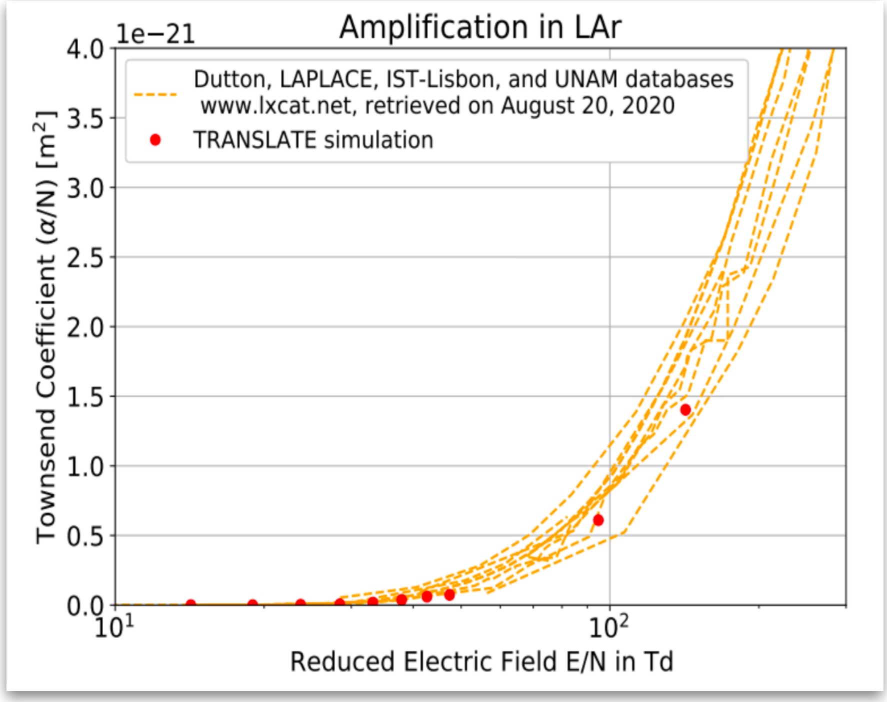
Studies of electron amplification in liquid argon with a nano tip array (100nm radius, 10–100µm height) for low-energy nuclear recoil signals

Microphysics simulations of electron drift in liquid and gaseous argon

Negative-ion TPCs for dark sector exploration with a possible beam-dump facility at Fermilab's PIP=II Linac







arXiv > physics > arXiv:2211.12645

Physics > Instrumentation and Detectors

[Submitted on 23 Nov 2022 (v1), last revised 8 Jan 2023 (this version, v2)]

TRANSLATE -- A Monte Carlo Simulation of Electron Transport in Liquid Argon

Zach Beever, David Caratelli, Angela Fava, Francesco Pietropaolo, Francesca Stocker, Jacob Zettlemoyer

The microphysics of electron and photon propagation in liquid argon is a key component of detector design and calibrations needed to construct and perform measurements within a wide range of particle physics experiments. As experiments grow in scale and complexity, and as the precision of their intended measurements increases, the development of tools to investigate important microphysics effects impacting such detectors becomes necessary. In this paper we present a new time-domain Monte Carlo simulation of electron transport in liquid argon. The simulation models the TRANSport in Liquid Argon of near-Thermal Electrons (TRANSLATE) with the aim of providing a multi-purpose software package for the study and optimization of detector environments, with a particular focus on ongoing and next generation liquid argon neutrino experiments utilizing the time projection chamber technology. TRANSLATE builds on previous work of Wojcik and Tachiya, amongst others, introducing additional cross-section processes up to ionization, thus modeling the full range of drift electron scattering interactions. The simulation is validated by benchmarking its performance with swarm parameters from data collected in experimental setups operating in gas and liquid.

arXiv > hep-ex > arXiv:2203.08079

High Energy Physics - Experiment

[Submitted on 15 Mar 2022 (v1), last revised 23 Sep 2022 (this version, v2)]

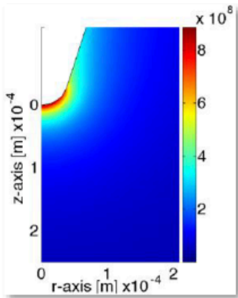
PIP2-BD: GeV Proton Beam Dump at Fermilab's PIP-II Linac

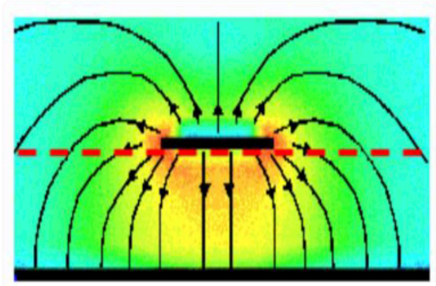
M. Toups, R.G. Van de Water, Brian Batell, S.J. Brice, Patrick deNiverville, Bhaskar Dutta, Jeff Eldred, Timothy Hapitas, Roni Harnik, Aparajitha Karthikeyan, Kevin J. Kelly, Doojin Kim, Tom Kobilarcik, Gordan Krnjaic, B. R. Littlejohn, Bill Louis, Pedro A. N. Machado, Nityasa Mishra, V. Pandey, Z. Pavlovic, William Pellico, Michael Shaevitz, P. Snopok, Rex Tayloe, Adrian Thompson, R. T. Thornton, Douglas Tucker, Jaehoon Yu, Jacob Zettlemoyer, Bob Zwaska

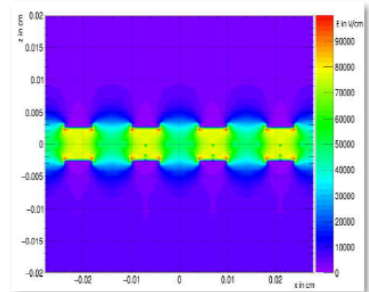
The PIP-II superconducting RF linac is currently under construction at Fermilab and is expected to be completed by the end of 2028. PIP-II is capable of operating in a continuous-wave mode and can concurrently supply 800 MeV protons to a mega-watt, GeV-scale beam dump facility and to LBNF/DUNE. Designs for proton accumulator rings are being studied to bunch the PIP-II protons into the short pulses needed for neutrino and low-mass dark matter experiments. PIP2-BD is a proposed 100-ton LAr scintillation-only experiment, whose detector design is inspired by CENNS-10 and CCM, that would have world-leading sensitivities to BSM physics, including low-mass dark matter produced in the PIP-II proton beam dump.

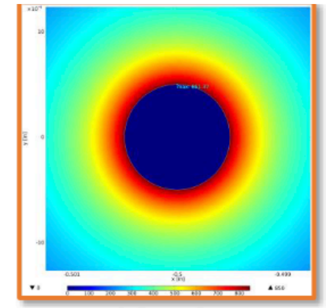
Proportional scintillation with thin wire in liquid argon

Wei Mu

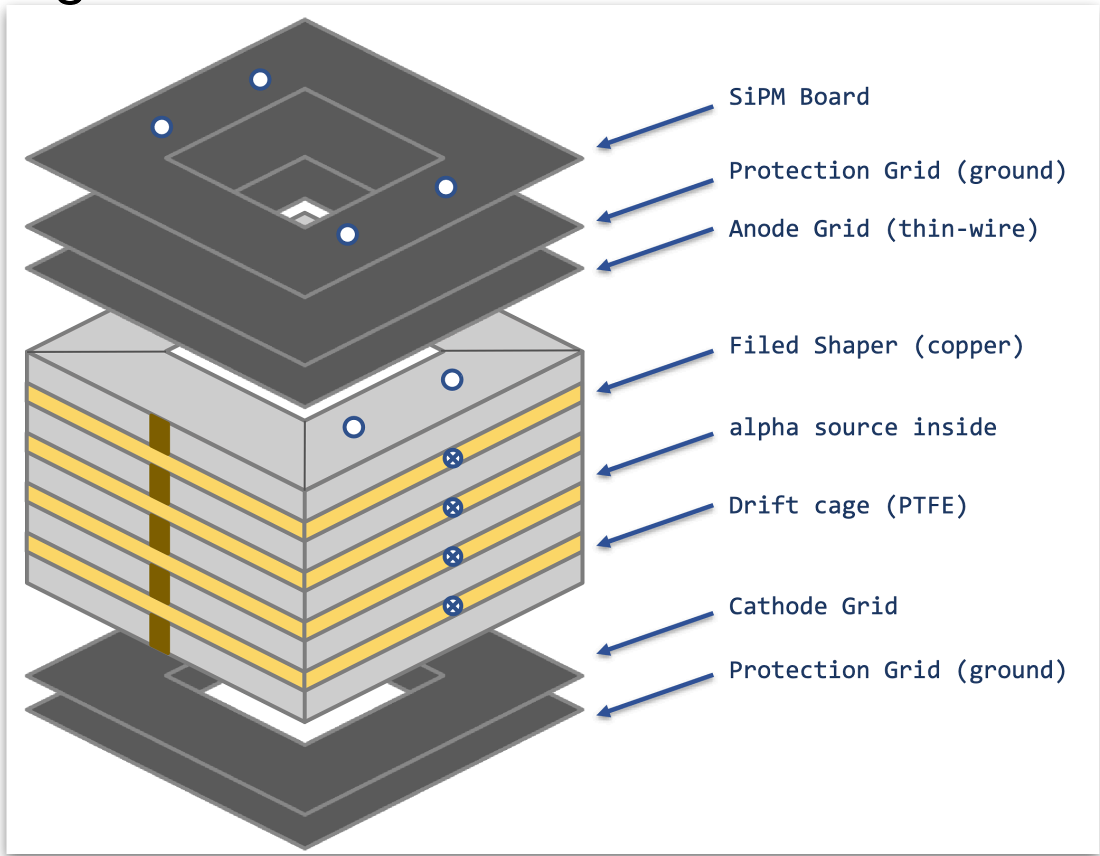

Needle Tip

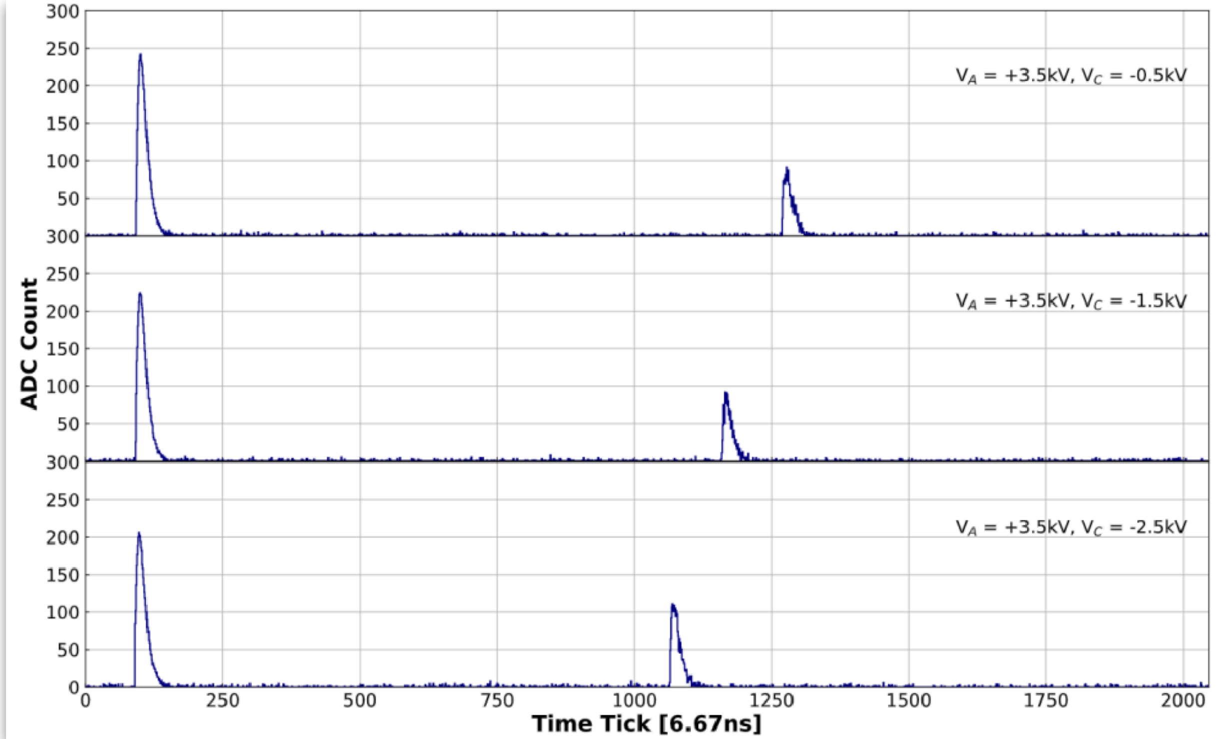

Microstrip


(Thick) GEM


Thin Wire

Observed propoprtional scintillation with a thin (10μm) wire in pure liquid argon with the yield of 30 photons/electron. Measurements will be extended and will include a study with xenon-doped argon





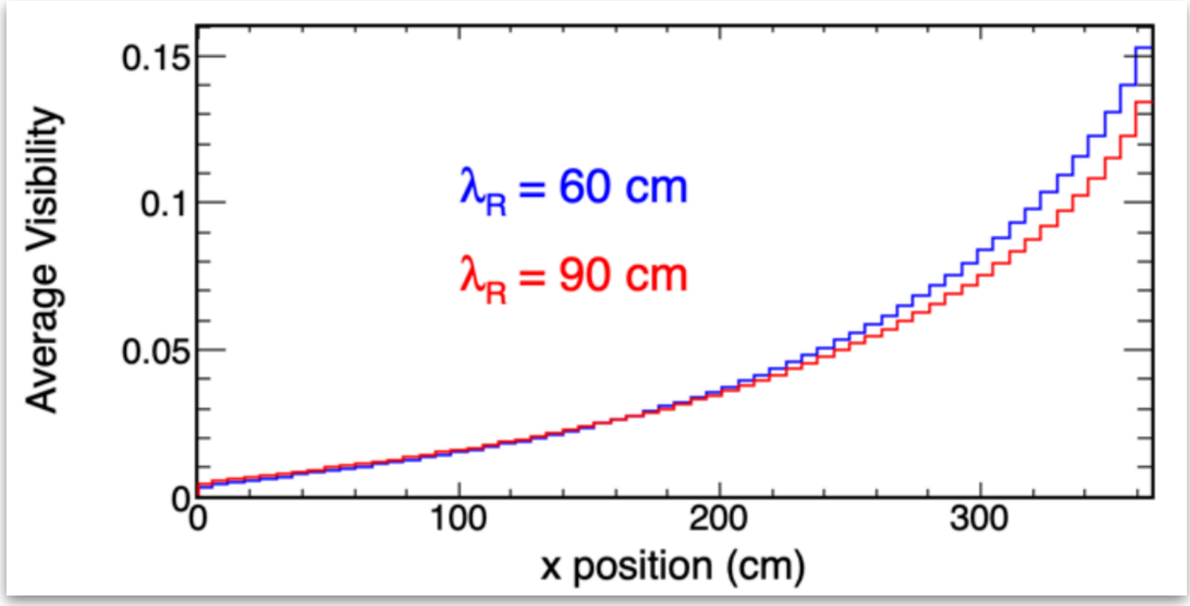
LArS (Liquid argon scattering)

Alexander Himmel

Direct measurement of the Rayleigh scattering in liquid argon

VUV light source (deuterium lamp) with a monochromator

TallBo cryostat with Hamamatsu VUV4 SiPMs at different depth

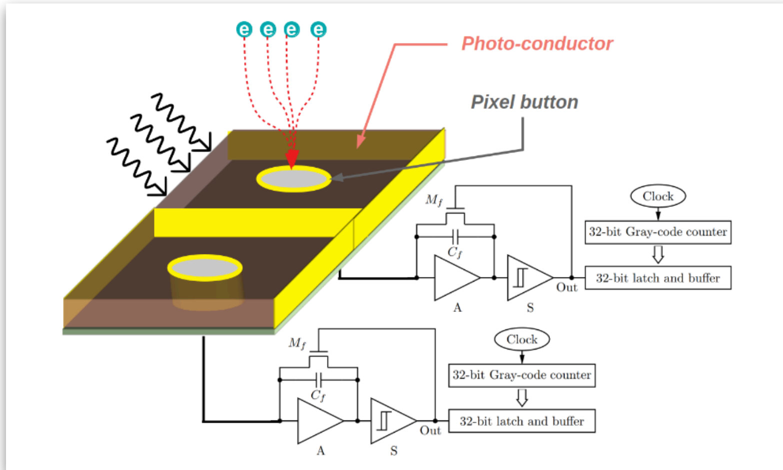


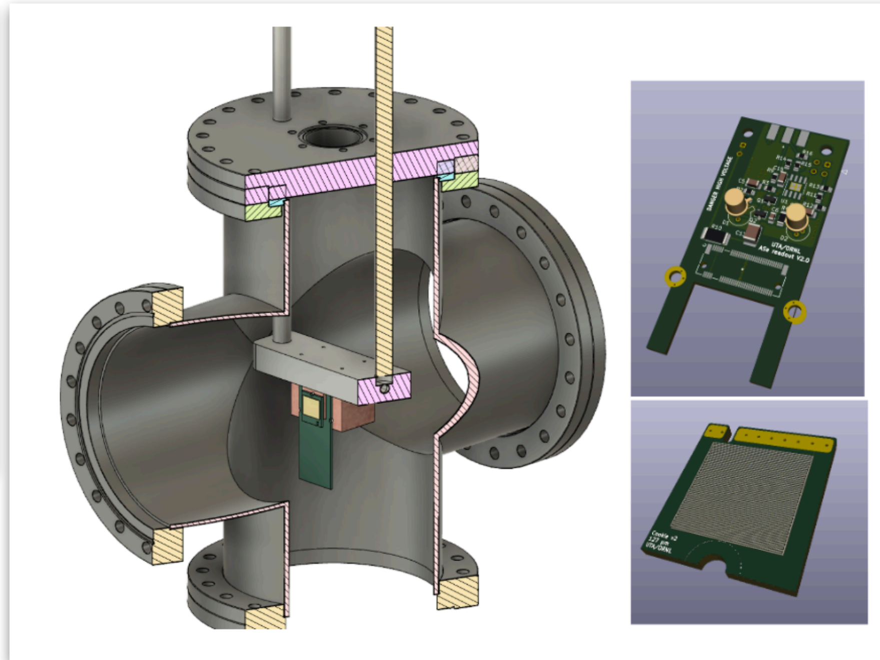
Current projects

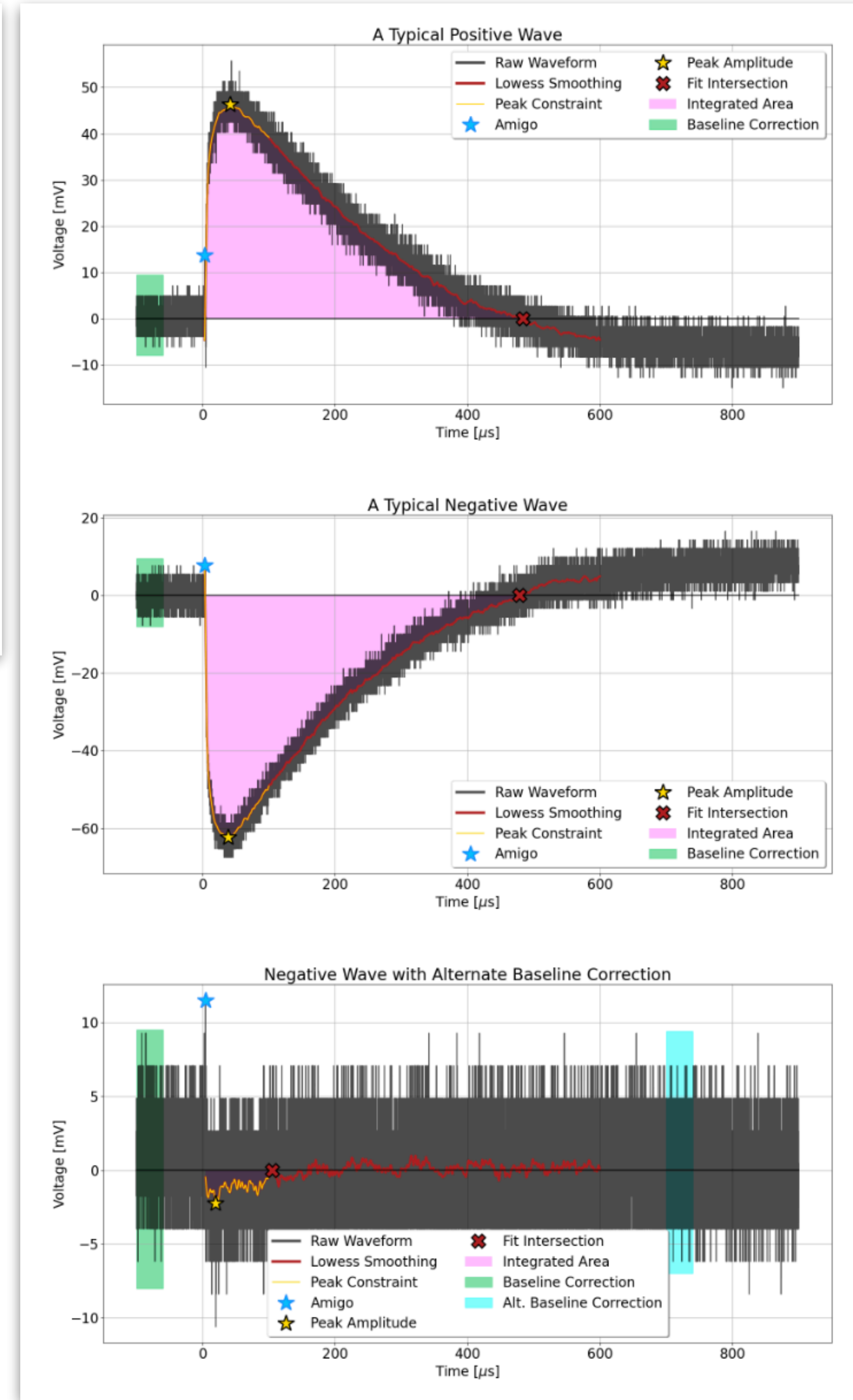
LiLAr

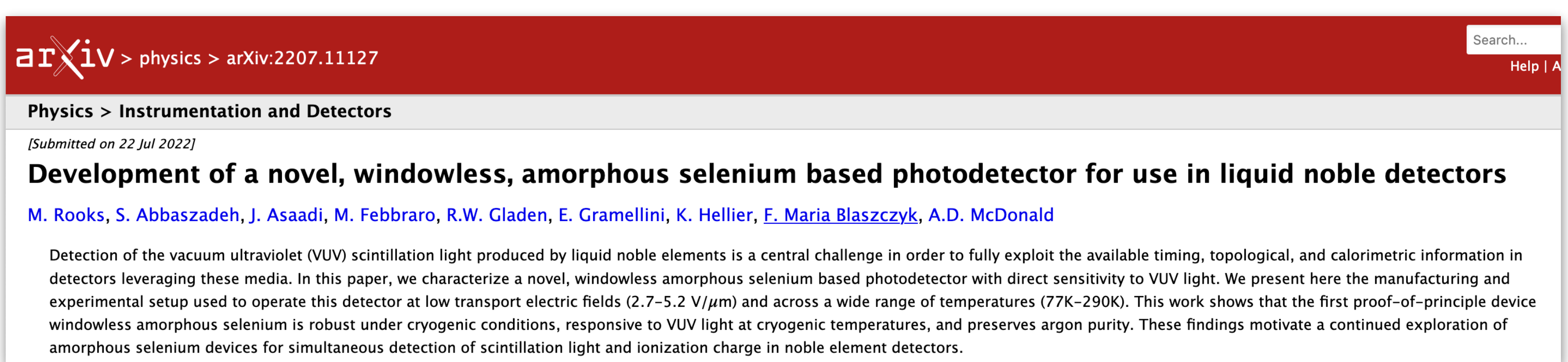
Elena Gramellini

Application of amorphous selenium for combined detection of scintillation light and ionization charge signals in a pixelated








arXiv > physics > arXiv:2207.11127

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Physics > Instrumentation and Detectors

[Submitted on 22 Jul 2022]

Development of a novel, windowless, amorphous selenium based photodetector for use in liquid noble detectors

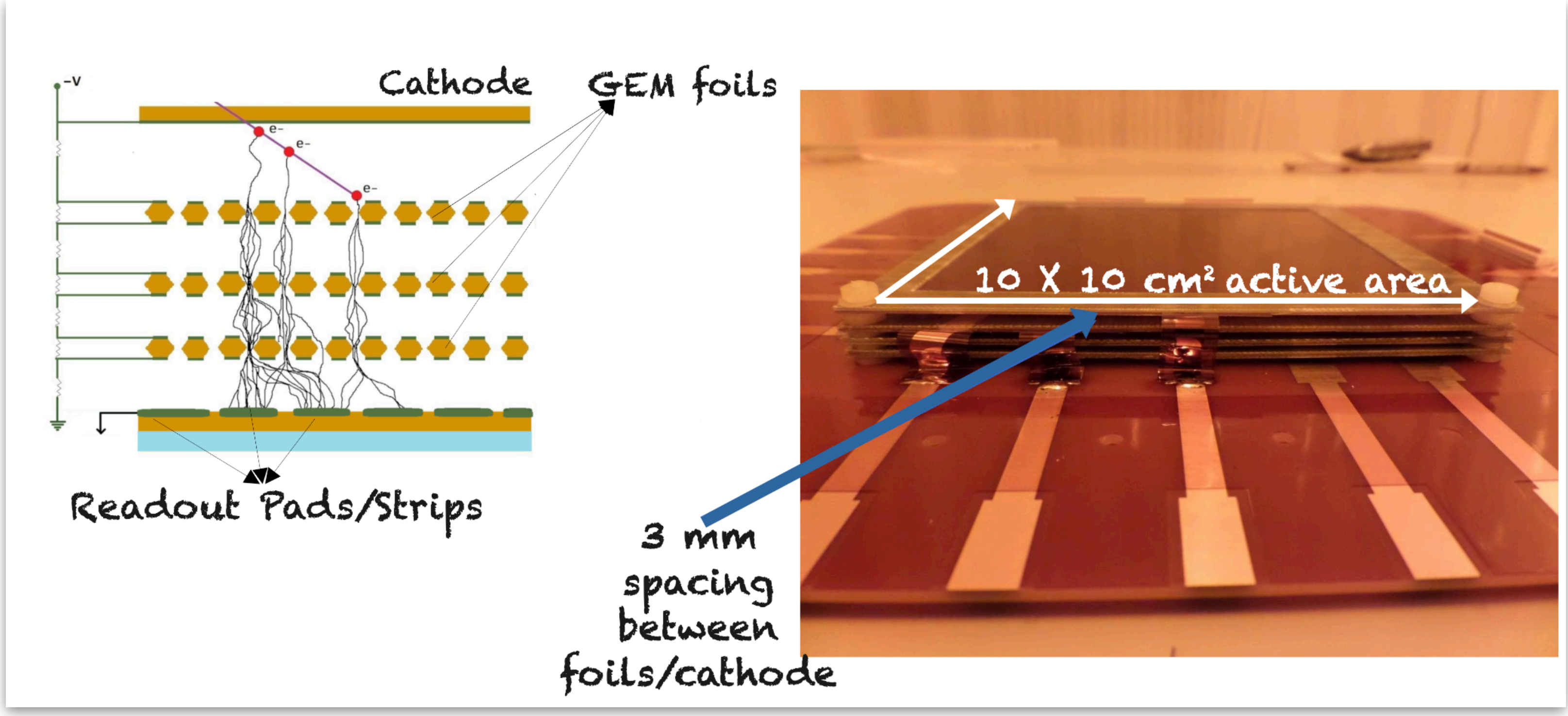
M. Rooks, S. Abbaszadeh, J. Asaadi, M. Febbraro, R.W. Gladen, E. Gramellini, K. Hellier, F. Maria Blaszczyk, A.D. McDonald

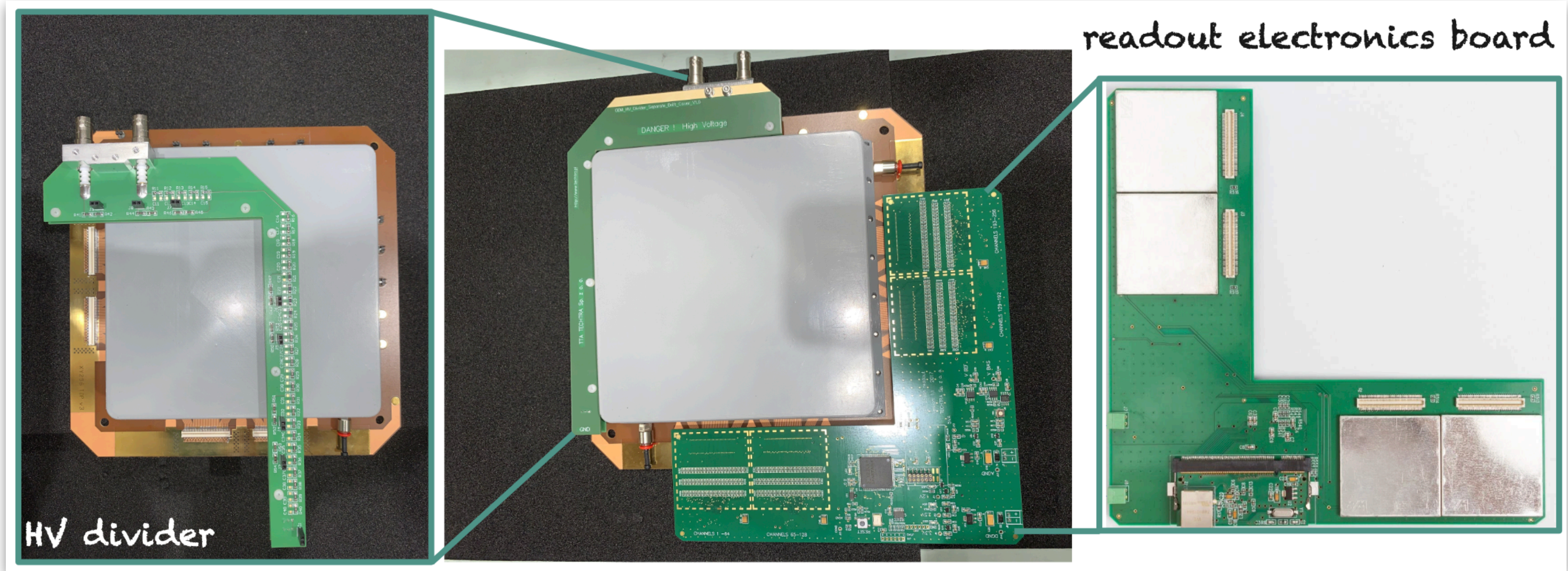
Detection of the vacuum ultraviolet (VUV) scintillation light produced by liquid noble elements is a central challenge in order to fully exploit the available timing, topological, and calorimetric information in detectors leveraging these media. In this paper, we characterize a novel, windowless amorphous selenium based photodetector with direct sensitivity to VUV light. We present here the manufacturing and experimental setup used to operate this detector at low transport electric fields (2.7–5.2 V/μm) and across a wide range of temperatures (77K–290K). This work shows that the first proof-of-principle device windowless amorphous selenium is robust under cryogenic conditions, responsive to VUV light at cryogenic temperatures, and preserves argon purity. These findings motivate a continued exploration of amorphous selenium devices for simultaneous detection of scintillation light and ionization charge in noble element detectors.

GORG (Optimizing the DUNE HPgTPC design)

Tanaz Mohayai

Optimization of a TPC gas gain with respect to electronics noise with a GEM-based TPC for reconstruction of low-energy signals from hadron interactions on argon





Current projects

Non-VUV light studies
Carlos Escobar

Spectrophotometry studies of argon scintillation light in visible and near-infrared range

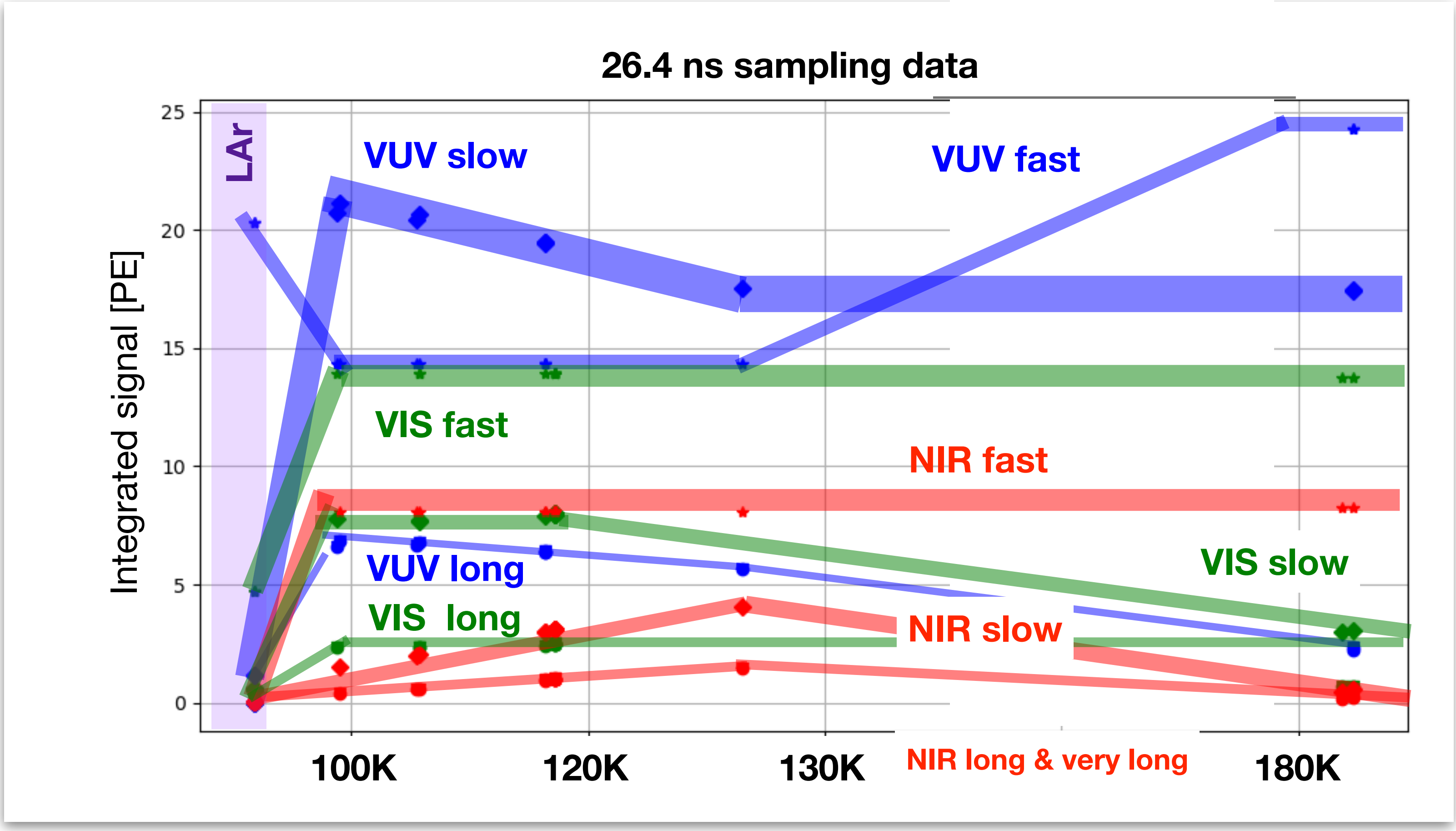
There are slow and long NIR components that increase with the temperature of cold gas

Signal is present in the visible VIS range, consisting of fast, slow, long and very long components in cold gas, and only fast and slow in warm gas

It is important to expand these studies for xenon-doped argon and investigate strong ~1200nm emission line reported so far only by one German group

VUV: <200nm
VIS: <700nm
NIR: <900nm

Fast component: < 1.5 μs
Slow component: 1.5–8 μs
Long component: 8–12 μs
Very long: 12-24 μs



Current projects

Liquid argon calorimeter with metal electrodes for LLP searches at LHC

A. Kish

Developing a demonstrator for proposed two-step strategy to search for long-lived particles (LLPs):

Physics beyond SM (SUSY), new hidden sectors at and below weak scale, e.g. sleptons, gluinos

Searches for LLPs with ATLAS, CMS, LHCb, FASER, milliQan, CODEX-b

LLPs can be trapped in detector material and decay much later

PHYSICAL REVIEW D
covering particles, fields, gravitation, and cosmology

Detecting long-lived particles trapped in detector material at the LHC

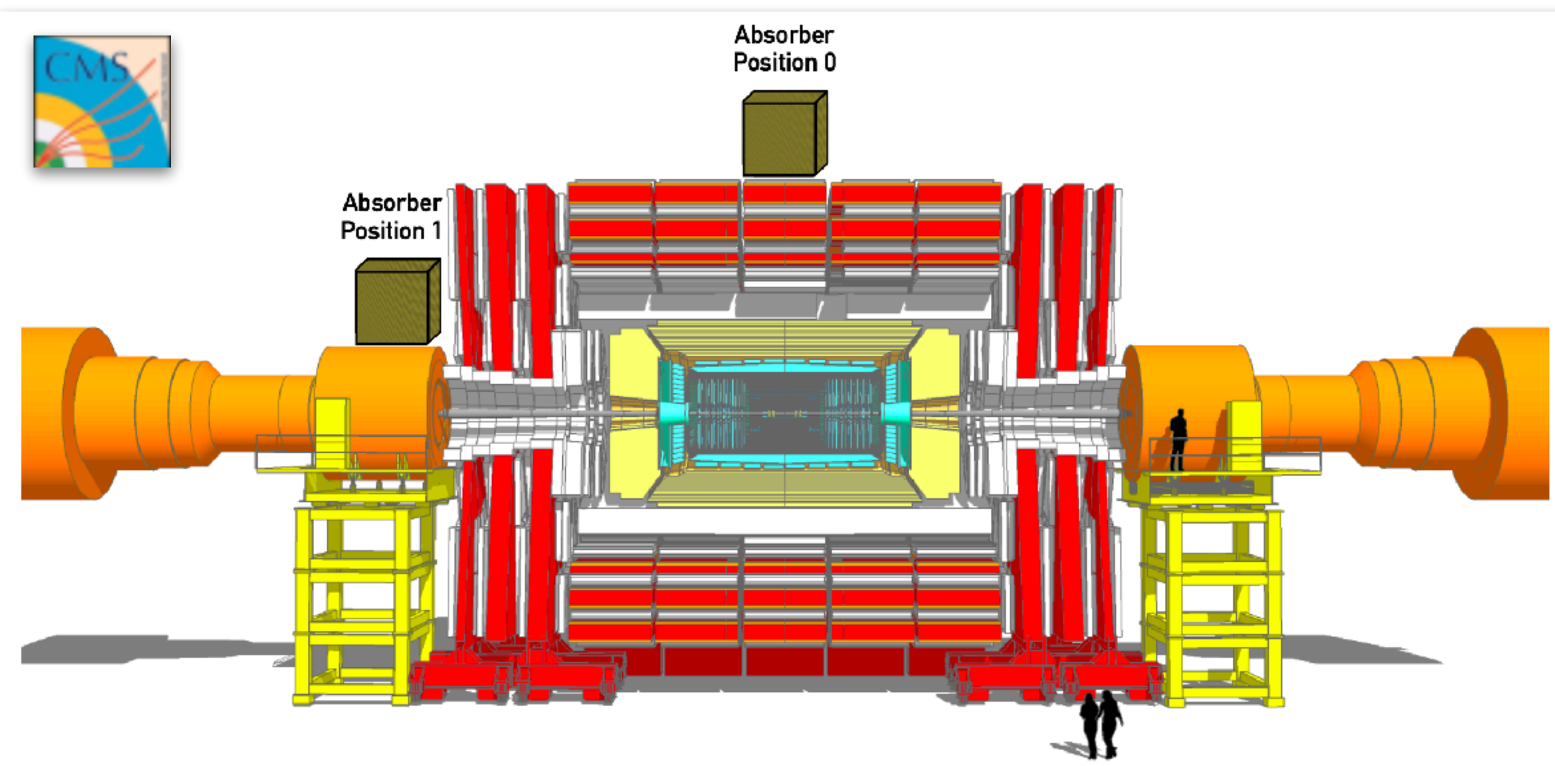
Jan Kieseler, Juliette Alimena, Jasmine Simms, Thea Aarrestad, Maurizio Pierini, and Alexander Kish
Phys. Rev. D **105**, L051701 – Published 4 March 2022

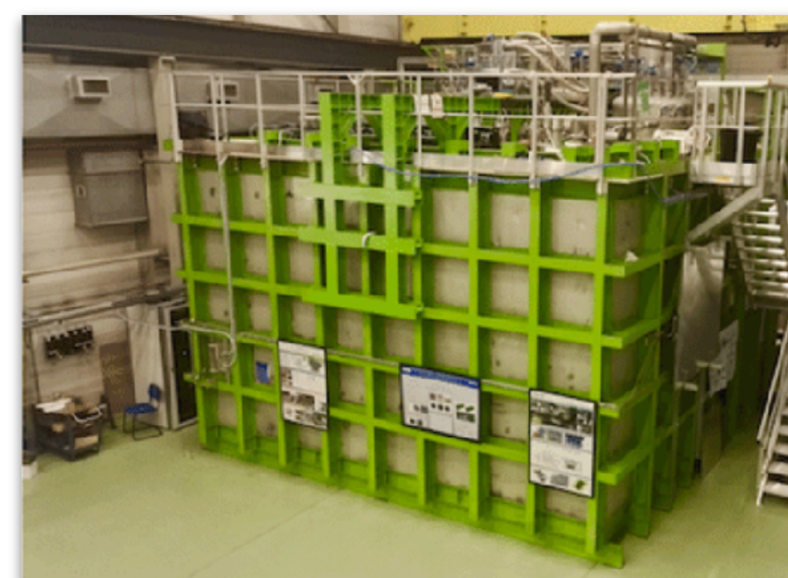
Step 1: Trap

Densely packed metal rods are a target exposed at an accelerator beam interaction point

Step 2: Detect

Metal rods are individually immersed in liquid argon and serve as electrodes to detect ionization charge from jets following LLP decay





SUMMARY

NLTF at FNAL is a very capable lab for research with condensed noble gases (perhaps the largest in the world)

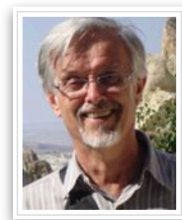
Many projects are currently in progress

Funding for R&D:
– DOE Early Career Awards (ECA)
– Fermilab Laboratory Directed Research and Development (LDRD) program
– FNAL Detector R&D New Initiatives program
– DOE Advanced Technology R&D program (KA25)

Multiple dewars and cryostats are available to the collaboration and for developments of the FD3 PDS components

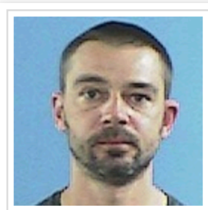
Flor Blaszczyk
Title: Group Leader/Applications Physicist
Department/Group: DUNE/DUNE Slow Controls HV & Cryo
Project/Experiment: DUNE/Liquid Argon R&D

Alan Hahn
Title: Group Leader/Scientist
Department/Group: DUNE/DUNE Slow Controls HV & Cryo
Project/Experiment: DUNE/Liquid Argon R&D



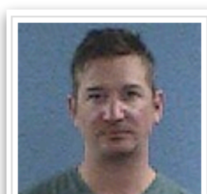
Carlos Escobar
Title: Guest Scientist
Department/Group: DUNE/DUNE Electronics, APAs & Light Collection
Project/Experiment: DUNE/Liquid Argon R&D

Sergey Koshelev
Title: Senior Engineer
Department/Group: Technical Support/Cryo
Project/Experiment: Cryo Engineering



Alexander Kish
Title: Application Physicist
Department/Group: DUNE/DUNE Slow Controls HV & Cryo
Project/Experiment: DUNE/Liquid Argon R&D

Nick Unold
Title: Technician
Department/Group: Technical Support
Project/Experiment: Technician Support



Robert Mrowca
Title: Technician
Department/Group: DUNE/DUNE Slow Controls HV & Cryo
Project/Experiment: DUNE/Liquid Argon R&D