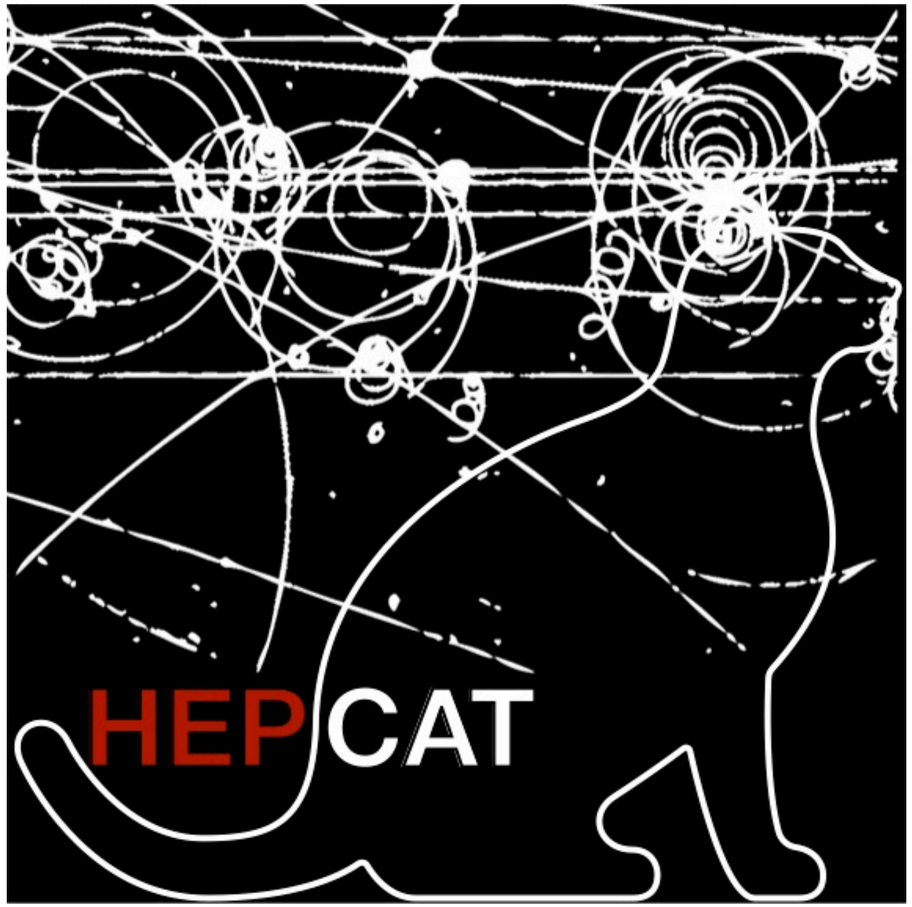
# High Energy Physics Consortium for Advanced Training

Maxwell Chertok, UC Davis
Director, HEPCAT

CPAD, UW Seattle
10/22/26



# Outline

FOA

Overview

Topical Groups

Cohorts

Summer schools / Seminars

Examples of fellow research

Assessment

Summary

# DOE Traineeship in HEP Instrumentation (DE-FOA-0002496, April 2021)




Sponsor: DOE Office of Science, High Energy Physics (HEP) program

Purpose: Address critical workforce shortages by training graduate students (Ph.D. and terminal Master's) in the physics and technology of detectors and instrumentation for HEP

Three targeted areas of need:

- Advanced sensors for particle and radiation detection, including quantum devices
- Application-specific front-end electronics and data acquisition (ASICs, interconnects, high-speed data, real-time processing)
- Systems design and engineering for complex instrumentation in extreme radiation, temperature, or low-background environments

# HEPCAT :
# High Energy Physics Consortium for Advanced Training



*UC Davis*
*UC Berkeley*
*Caltech*
*Stanford*
*UC Irvine*
*UCLA*
*UC Riverside*
*UC Santa Barbara*
*UC Santa Cruz*
*UC San Diego*
*Berkeley Lab*
*LLNL*
*LANL (NM)*
*Sandia*
*SLAC*




- 5 year DOE funded training grant for particle physics instrumentation
  - *Topics: Rad hardness, Noble liquid detectors, Photosensors, Quantum devices, Scintillators, Silicon detectors, AI/ML, Electronics*
  - *28 HEPCAT Fellows; 2 years each*
- 8 UC campuses plus Caltech and Stanford, 5 DOE labs
  - *UC Davis is host institution*

*https://hepcat.ucsd.edu/*

*DOE Grant DE-SC0022313*

# Organization

## Director (Chertok, UC Davis)

## Exec. Committee (Chair: Lankford, UC Irvine)

- One member from each of the 15 institutions

## Topical Area Coordination

- Selection of fellows

## Program coordination

- Summer schools, curricular development, seminar series

## Assessment

- Some results provided

# Topical Groups

At proposal stage, created TGs that aligned with consortium member research:

- Radiation Hardness
- Noble Liquid Detectors
- UV/VUV Photosensors
- Quantum Devices
- Optical Scintillators/Crystals
- Silicon Detectors
- AI/ML for Detectors
- Programmable Electronics/DAQ

# Cohort overview

HEPCAT: 4 cohorts with a total of 28 fellows

UC student strikes caused significant perturbation in budget

Focus on institutional distribution; secondary focus on topical group numbers

| Topical Group | # |
|---|---|
| 1: Rad Hard | 1 |
| 2: Noble Liq | 7 |
| 3: Photosensors | 2 |
| 4: Q Devices | 5 |
| 5: Scintillators | 4 |
| 6: Si Detectors | 2 |
| 7: AI/ML | 2 |
| 8: Electronics | 5 |
| TOTAL | 28 |

# HEPCAT Fellow Projects by Topical Group




## TG1 Radiation Hardness — 1

- Diamond detectors for XFEL beam diagnostics *Padilla*

## TG2 Noble Liquid Detectors — 7

- LArCADe: CEvNS detector R&D *Antonakis*
- Delayed photons in Xe TPCs *Gibbons*
- DarkSide-20k outer-veto design *Peck*
- LXe scintillation counter & CHILLAX *Qi*
- CHILLAX experiment *Kingston*
- ★ VUV SiPMs for rare events *Hood*
- ★ DarkSide-20k SiPMs & materials *Repond*

## TG3 UV/VUV Photosensors — 2

- ★ Inorganic crystal scintillators (BaF2, CsI) *Borrel*
- ★ GNN shower reconstruction for SiPM-on-tile calorimeters *Milton*

## TG4 Quantum Devices — 5

- Radio-frequency quantum upconverter *Corbin*
- Kinetic inductance phonon-mediated (KIPM) detectors *Sandoval*
- Superconducting MKIDs for meV-scale dark matter *Z. Smith*
- TES bolometers for Simons Observatory & PANOSETI *Johnson*
- ★ Dark E-Field Radio dark-photon search *Levine*

## TG5 Optical Scintillators/Crystals — 4

- Organic scintillator electron-recoil response *McGuire*
- TCSPC timing of organic scintillators *Sebastian*
- SiPM-on-tile calorimeter insert for the EIC *Preins*
- ★ FLAME millicharged-particle search & TINMAN *Kelly*

## TG6 Silicon Detectors — 2

- InP:Fe thin-film charged-particle trackers *Almazan*
- LGAD active target for PIONEER *Molnar*

## TG7 AI/ML for Detectors — 2

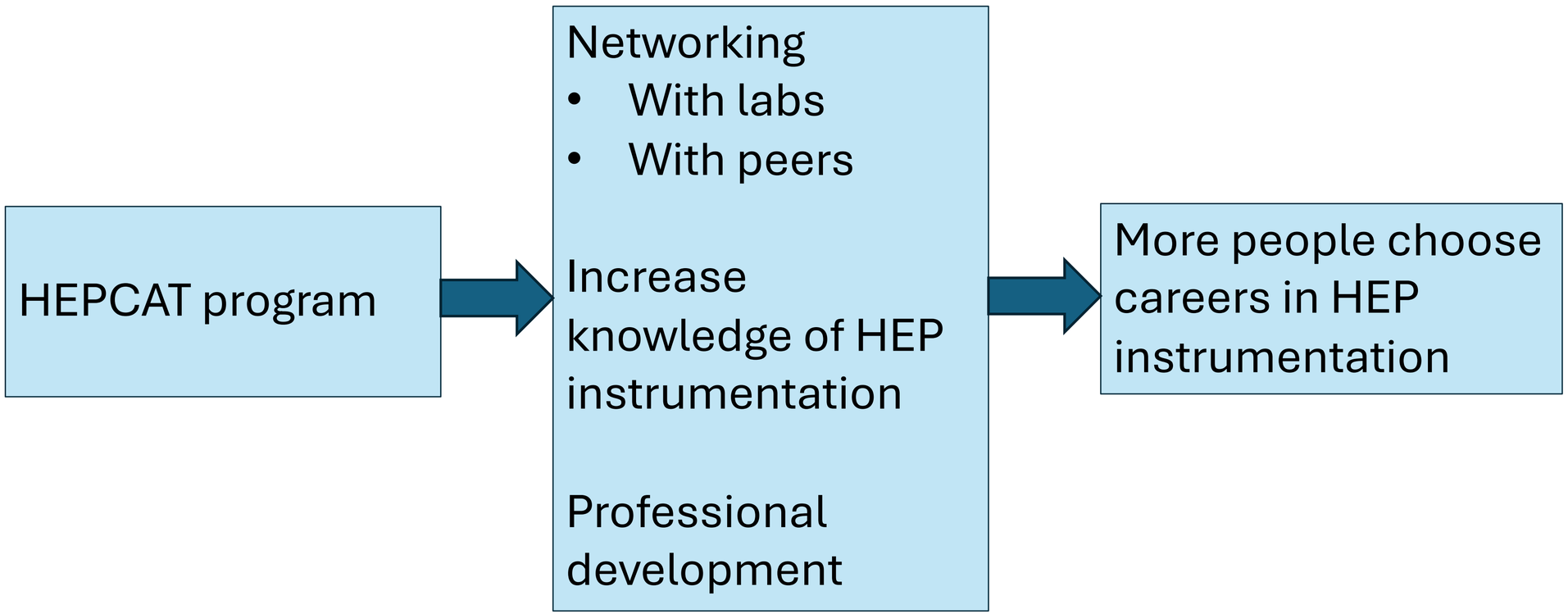
- ★ Jet-tagging neural nets in the CMS L1 trigger *Aportela*
- Fast ML simulation for future calorimeters *D. Smith*

## TG8 Electronics/DAQ — 5

- CMS L1 muon trigger board (Kraken) *Avila*
- Tracker muons for the CMS Phase-2 L1 trigger *Ancelin*
- ATLAS L0 MDT trigger *Gleason*
- Firmware for LDMX trigger scintillator & S30XL *O'Dwyer*
- ★ MAPS characterization for future colliders *Vassilev*

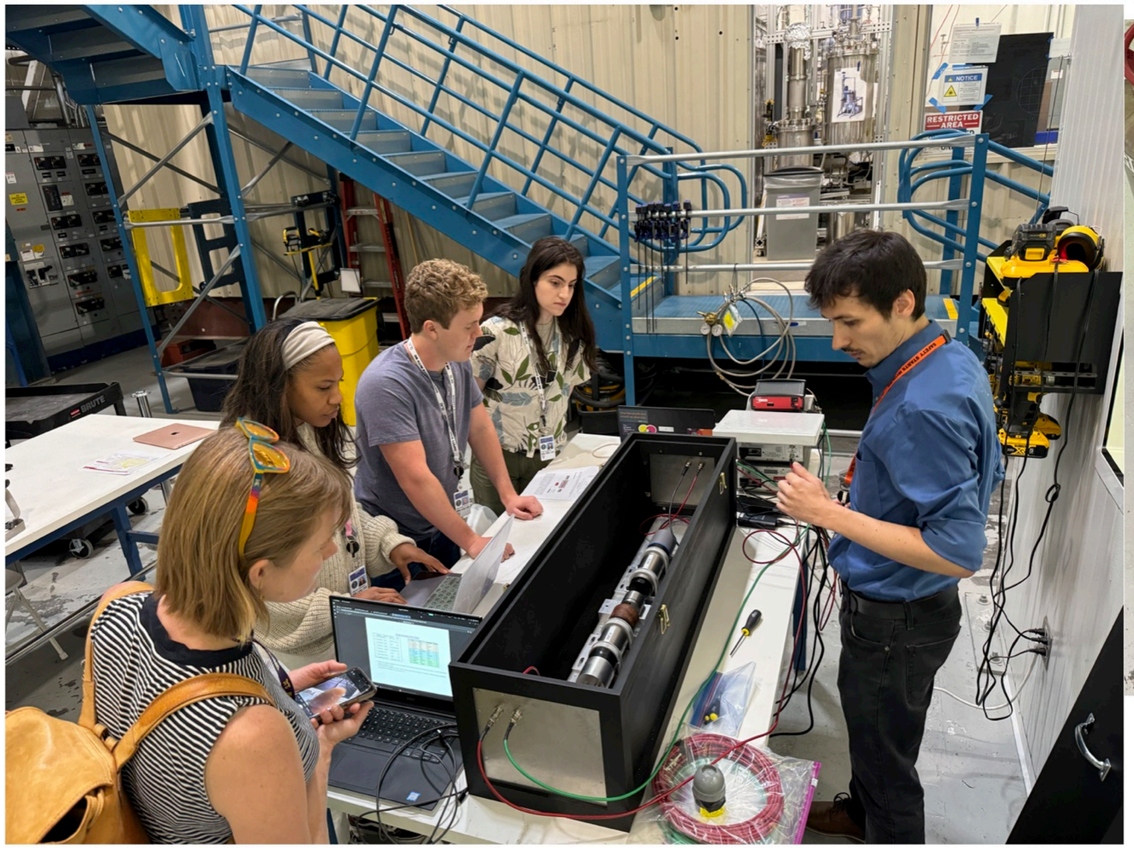
★ Project also overlaps another topical group

# The HEPCAT model

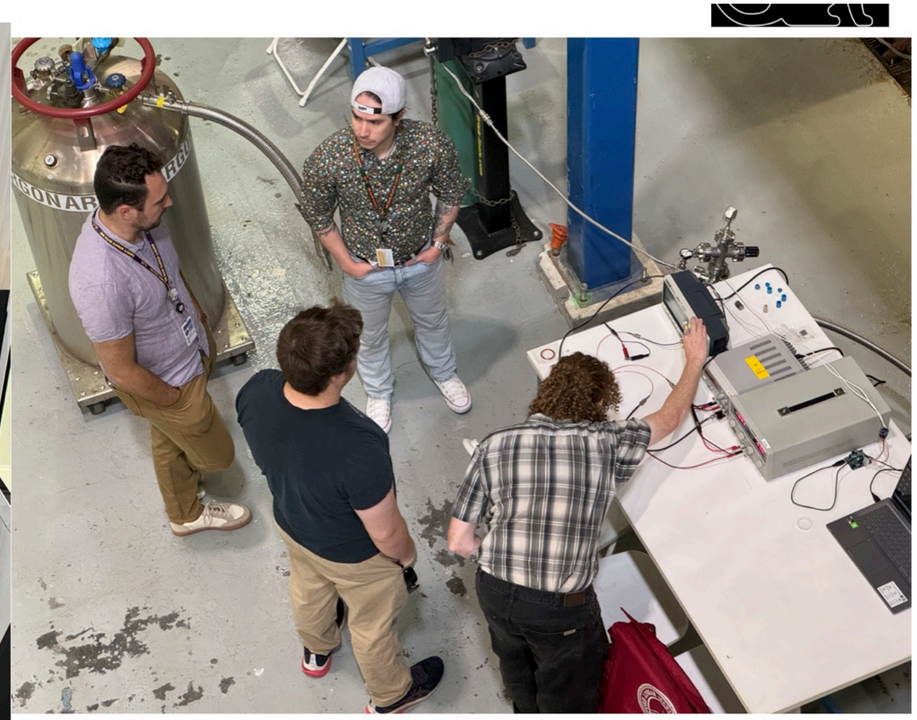


# 2024 Summer School @ SLAC

*Summer school each year:*
*mix lectures with labs, 2nd year fellows serve as "TAs"*



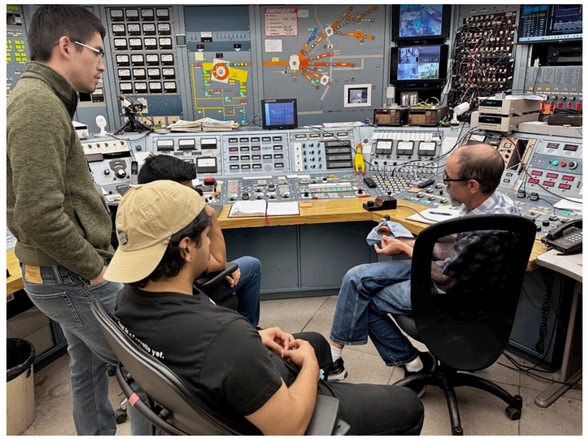
*Ultrafast $BaF_2$*



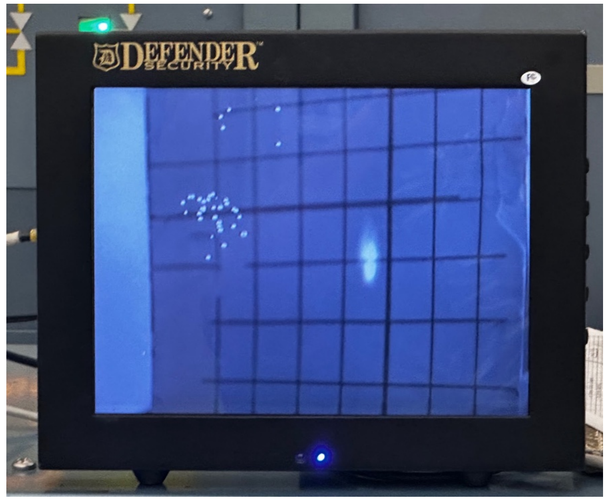
*LAr SiPM*

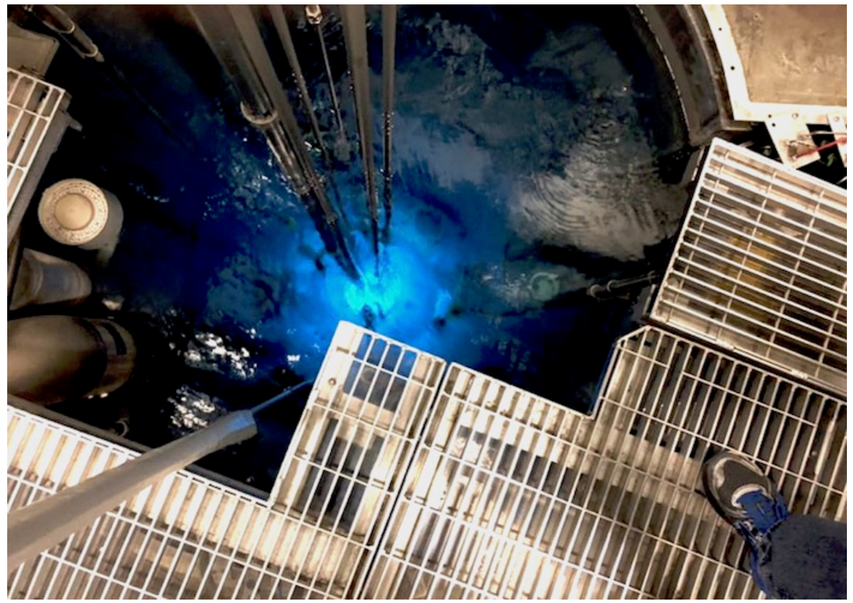
# 2025 Summer School @ UC Davis

## Hands on experience with the Crocker cyclotron





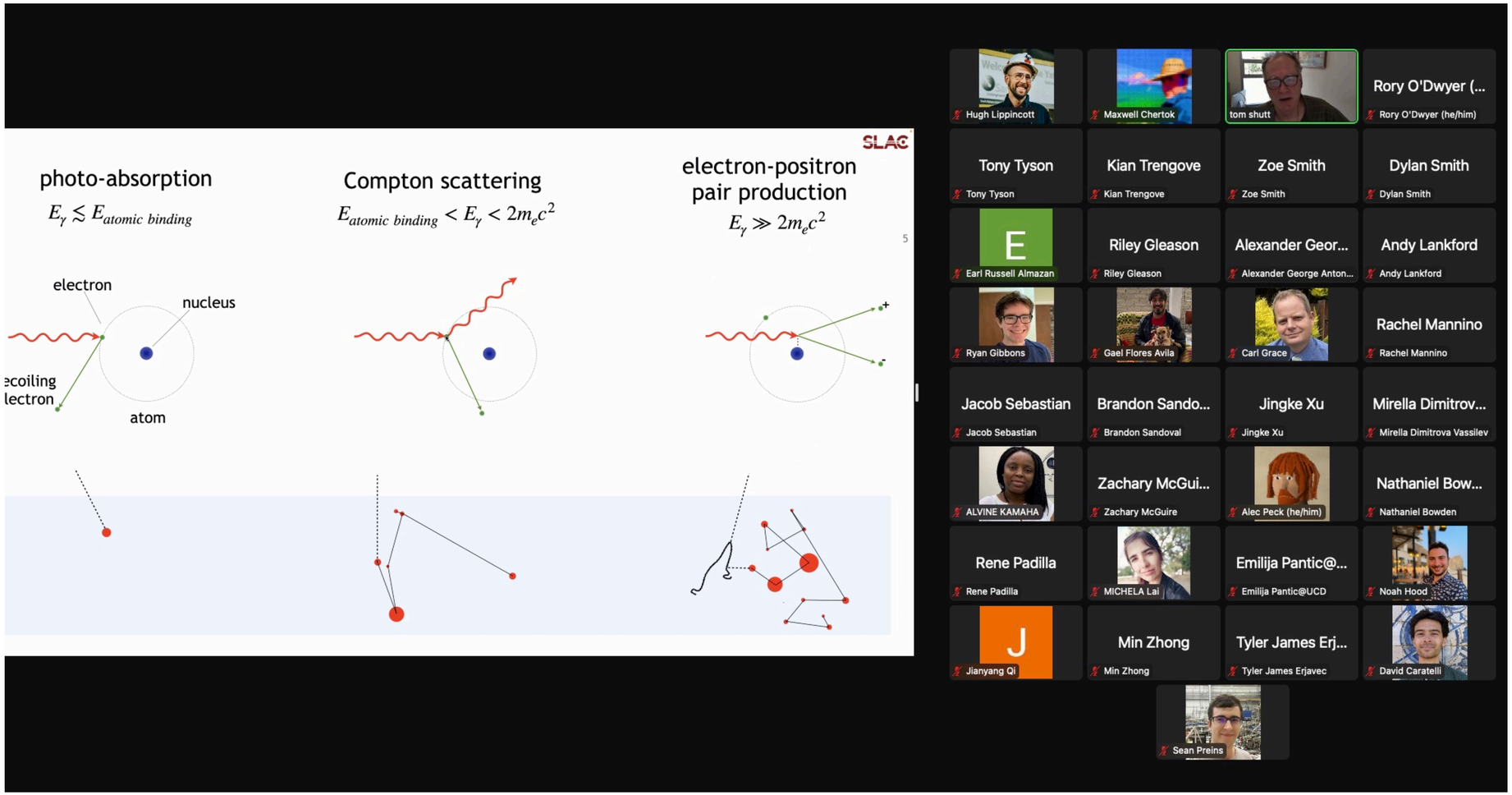


Visit to McClellan Reactor: Neutron activation and gamma ray spectroscopy based analysis

# Annual Seminar Series

*Example: T. Shutt, SLAC*




## Additionally:

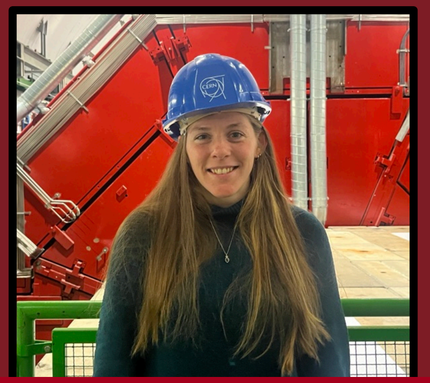
- UCSD opened grad-level detector course to HEPCAT fellows over zoom.

# Examples of Fellow Research

# HEPCAT Fellow: Mirella Vassilev

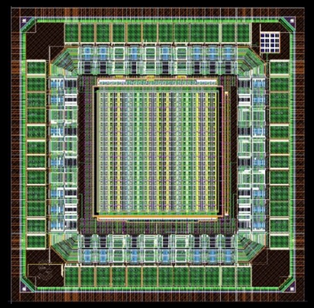
## Stanford University/SLAC

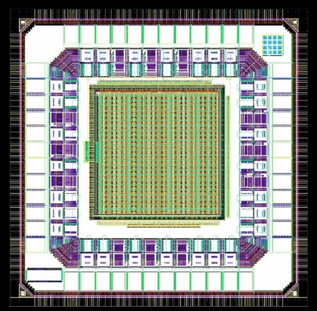
NAPA: nanosecond timing pixel for future colliders



**PhD Student:** Graduating Spring 2027
**Next Steps:** Looking for postdoc in physics+instrumentation

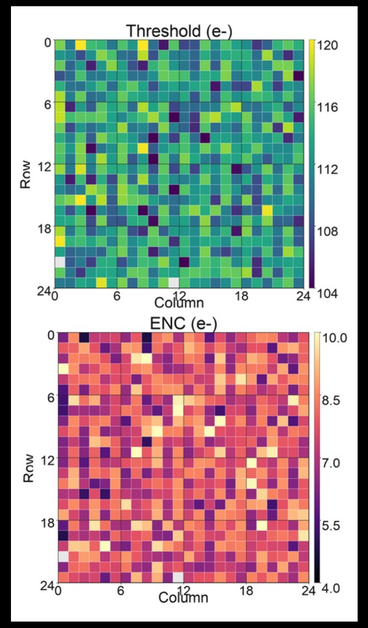


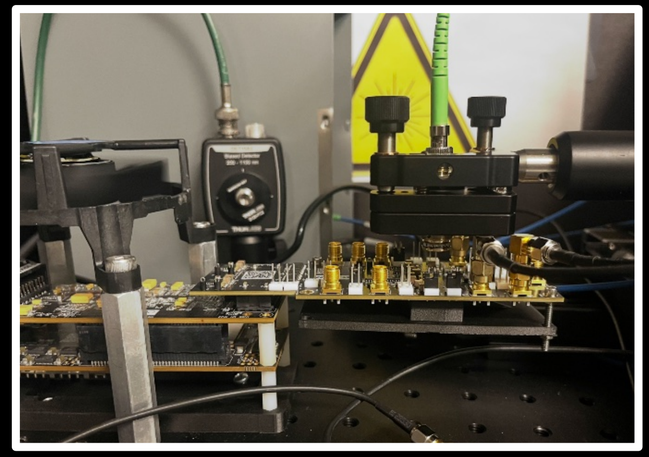





NAPA-p1/ NAPA-p2 layout

Electrical Testing



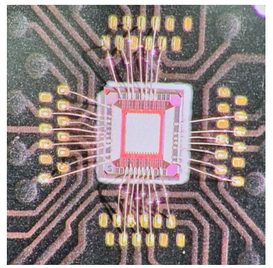
Laser Testing

U.S. DEPARTMENT OF ENERGY
Office of Science

ATLAS EXPERIMENT

SLAC NATIONAL ACCELERATOR LABORATORY

# NAPA Research and Instrumentation



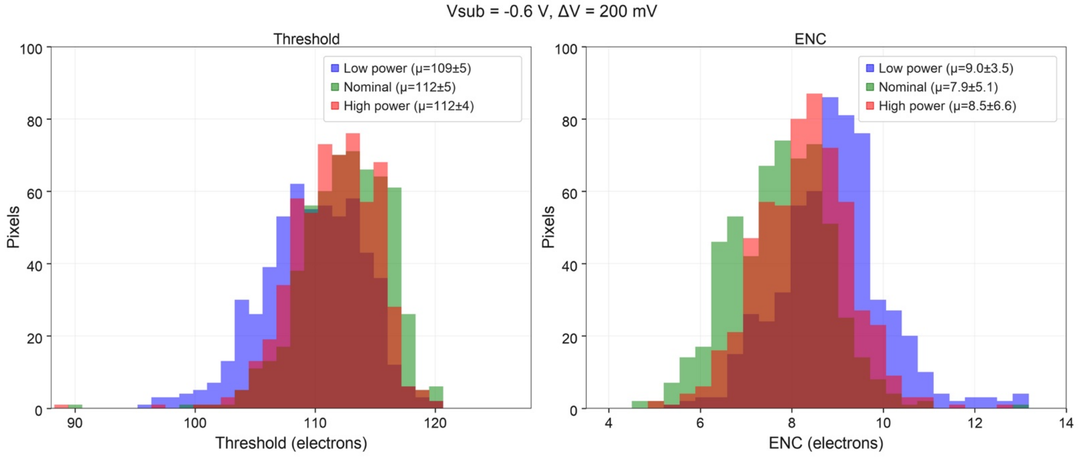
24 x 24 matrix of pixels with 25 um pitch

**Motivation:** Focus on long term R&D targeting requirements at $e^+e^-$ colliders, in particular:

- **O(ns) timing resolution** for whole readout chain
- **Power consumption compatible with gas cooling** for large area, low material budget detectors

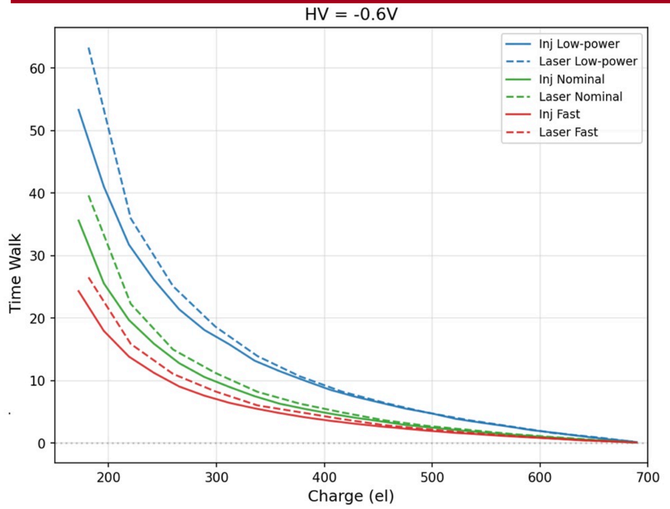
**NAPA-p2:** systematic electrical and optical characterization, using the developed laser setup. Includes Vernier delay cell TDC test structures






Uniform response, consistent with auto-zero comparator design

- Set up a 1080 nm picosecond pulsed laser system for NAPA testing




Low Power mode: 32 mW/cm$^2$

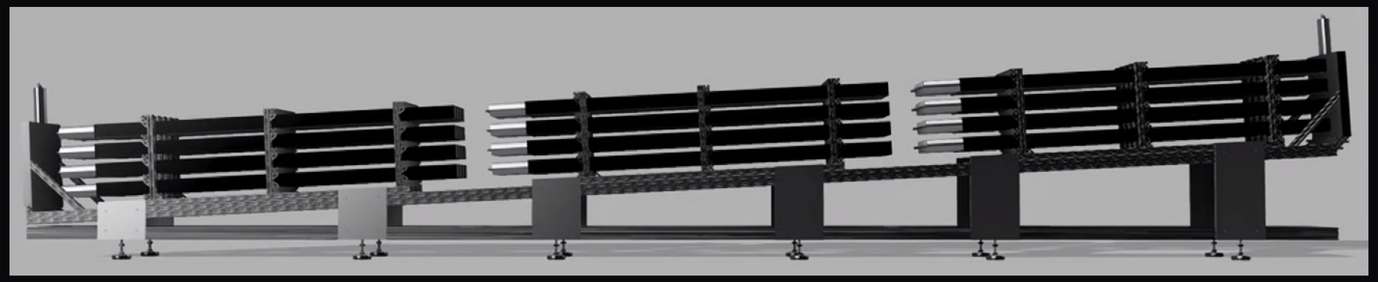
- Nominally achieves <300 ps jitter with injection and laser measurements
- Higher front-end power improves time-walk/jitter

Samantha Kelly, UC Davis

# FLAME: Fermilab-Los Alamos Millicharged Experiment



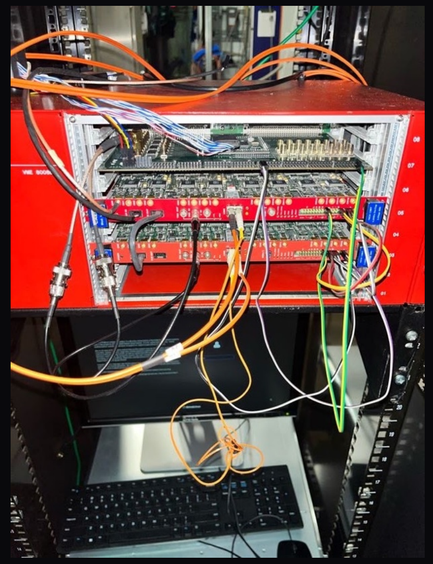
- Particle physics experiment searching for millicharged particles (mCPs)
- Three-layer detector made of coupled PMTs and plastic scintillator bars intended to detect small energy deposits
- Multi-layer coincidence triggering to distinguish mCP signals from background noise like PMT dark rate and cosmics





# Current work on FLAME

- Detector layers are installed and cabled in the MINOS access tunnel at FNAL
- 2/4 digitizers + trigger board cabled
- SurgeX and smoke detectors installed
- PC OS updated and cleared for use
- ORC submitted to get safety clearance



# Next steps

- Cable remaining digitizers and connect BNCs from PMTs
- Confirm DAQ firmware is functioning properly
- Take data ☺
- Decommission in Jan 2027

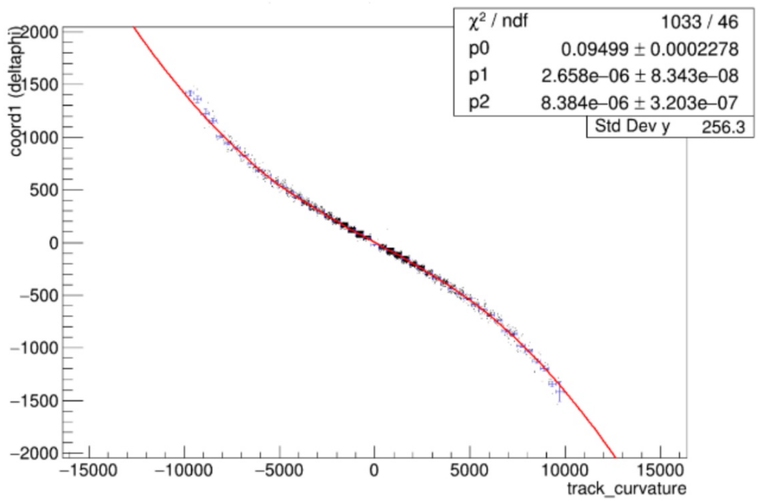


# The CMS Global Muon Trigger in HL-LHC

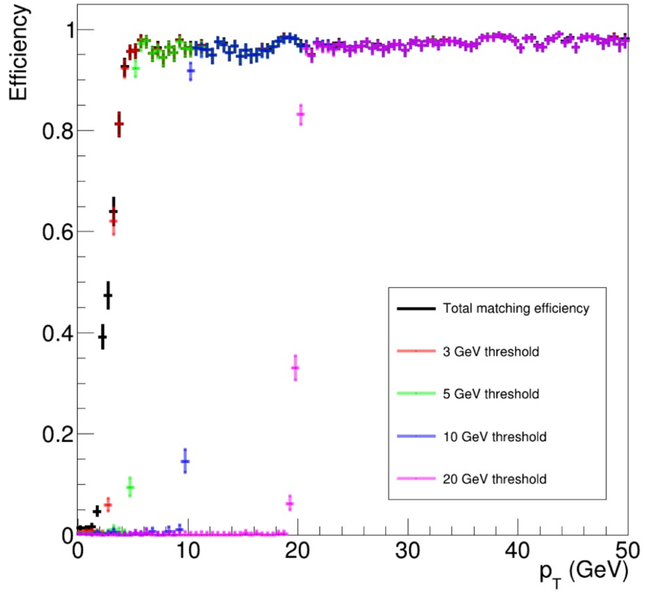


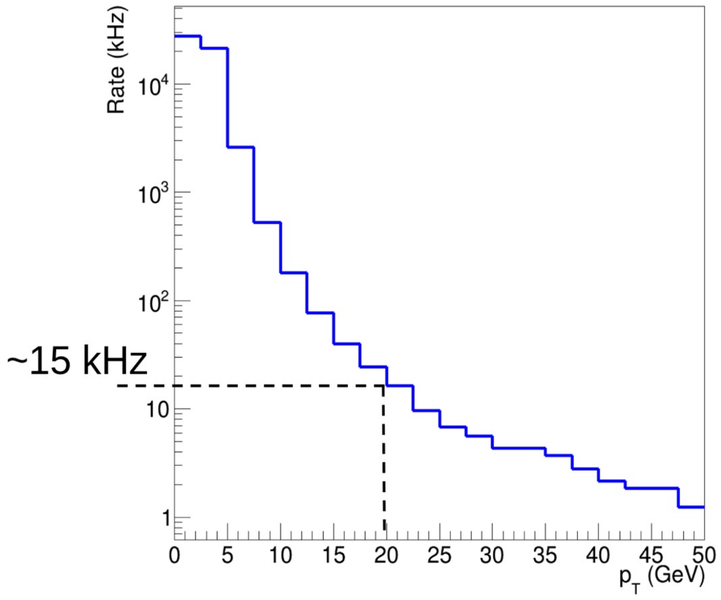
Fellow: Havyn Ancelin
Advisor: Michalis Bachtis
Institution: UCLA

- CMS needs a hardware-based trigger to only record interesting events and lower event rate from 40 MHz to ~1 MHz
- HL-LHC: combine silicon tracks and muon station hits to reconstruct “tracker muons” (as opposed to standalone muons which only use muon station hits) in the L1 trigger
- **My work: Calibration and implementation of tracker muon reconstruction and implementation of the whole chain in FPGA firmware and hardware**




Fit of mean $\Delta\phi$ vs k within a small window of pseudorapidity

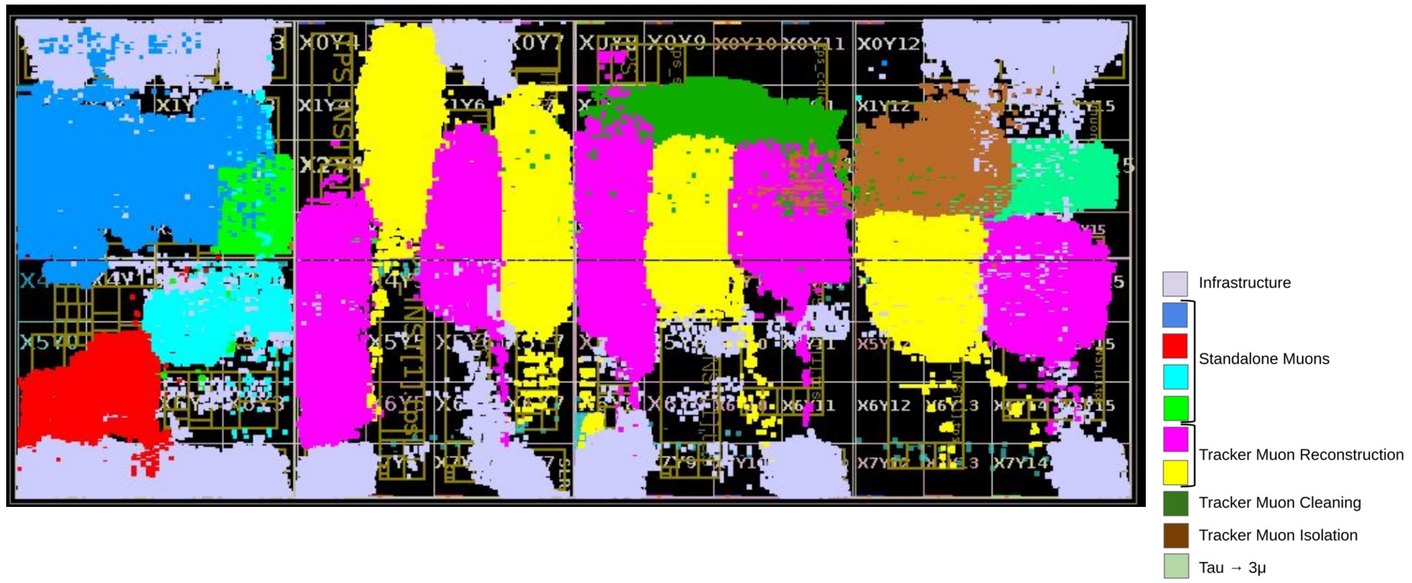


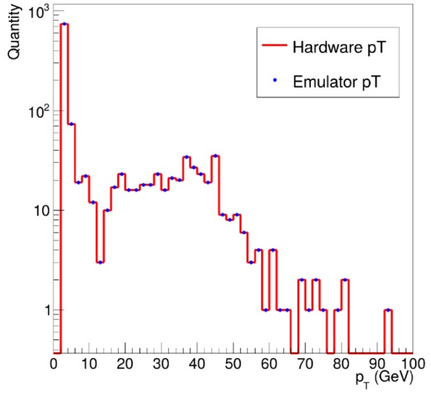



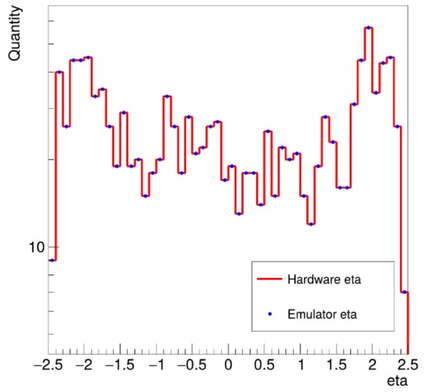
# Firmware and hardware implementation

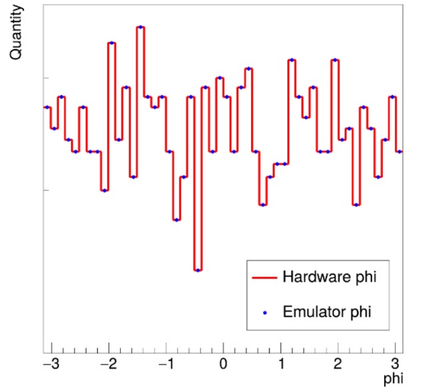
- GMT is divided into 18 slices, each running an X2O board
- After verifying firmware-emulator agreement using Vivado behavioral simulation and closing timing at 360 MHz, we have built a realistic slice of the GMT at UCLA
- Future work
  - Upgrade GMT to run on more powerful Versal FPGA
  - Perform integration tests with other subsystems at CERN

## FPGA Floorplan and Utilization

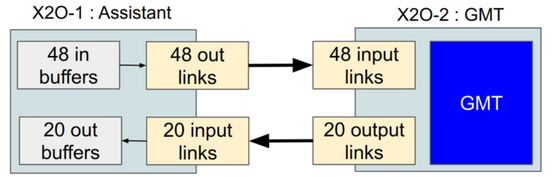


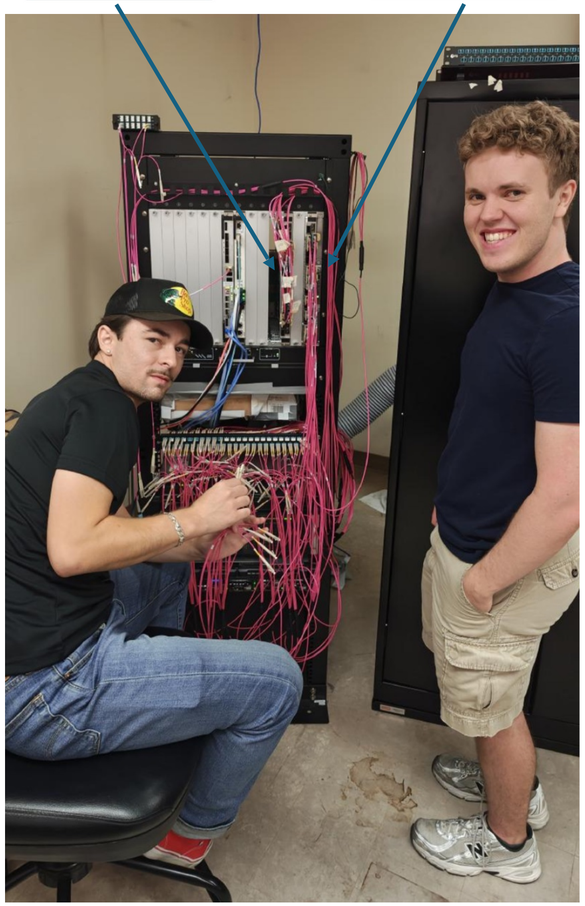




## Hardware slice implementation



Havyn and Delano (another UCLA graduate student) wiring the hardware slice

# PANORAMIC SETI

## Research overview

**Developing and characterizing fast optical detectors for PANOSETI's search for optical technosignatures and astrophysical transients.**




**Alyssa Johnson, PhD Candidate**

University of California, San Diego


**FALL 2024 HEPCAT FELLOW**

Panoramic SETI (**PANOSETI**) is a wide-field optical observatory designed to detect nanosecond-to-second optical transients. Using fast silicon photomultiplier (SiPM) detectors and multiple telescope sites, **PANOSETI searches for optical technosignatures, astrophysical transients**, and **atmospheric Cherenkov events**.

*I anticipate completing my Ph.D. in May 2028 and hope to continue pursuing research in astronomical instrumentation and observational astrophysics.*
*Dream job: Staff Astronomer at Keck Observatory :D*

**FUTURE**

- 0.5 m f/1.32 Fresnel lens with 32×32 pixel SiPM array
- Wide 9.9° × 9.9° FoV





Backend electronics & telescope module

UCSD OIR LAB · HARVARD · UC · CALTECH · UNIVERSITY OF DELAWARE · RUB · BERKELEY SETI RESEARCH CENTER

# Assessment: Fellow Survey 2025

*Survey responses:*

*"I have been able to travel to National Labs and work on things I would probably not have access to otherwise"*

*"I found both participating in and TAing for the summer schools to be immensely interesting and beneficial"*

*"[I appreciated] Having a chance to present my research to people outside of my main field"*

*92% of respondents thought that HEPCAT was very or somewhat useful*
*100% of respondents are very or somewhat likely to recommend HEPCAT*
*69% very or somewhat likely to pursue a career in HEP instrumentation*

# Summary

This work is supported by DOE grant DE-SC0022313

HEPCAT's goal: train the next generation of detector researchers

In the 5-year period, 28 HEPCAT fellows have received two years support for research in particle physics instrumentation throughout the state of California

Tie-ins with national labs, annual summer schools and seminar series have provided additional training and educational experiences for the fellows

Thanks to Mani Tripathi, creator and founding director of HEPCAT!

# Backup

# Lab Modules

## FPGA Lab

- In this lab, the students performed a number of activities using the Xilinx Artix-7 chip on the Digilent Basys 3 development board.  Configuration was done by editing Verilog code and then synthesizing it using the standard Xilinx Vivado IDE.

## SiPM Lab

- This activity involves the use of a tabletop test bed that utilizes Silicon PhotoMultipliers (SiPMs) and scintillators to assess the Pulse Shape Discrimination (PSD) capabilities of the scintillator using a mixed neutron and gamma source.
  - Understanding of data collection using a digitizer.
  - Fitting models to data using lmfit (python library).
  - Understanding of metrics used to assess PSD

# Lab Modules (continued)

## Liquid Argon Lab

- Build a photon detector using a cryogenic chamber housing a SiPM
- Read out liquid argon (LAr) scintillation light using the detector.
- Get hands on experience with vacuum and cryogenic systems.
- Be familiar with noble liquid scintillators and photodetectors.
- Deal with signal readout and preliminary processing (LabView).
- Data analysis of the amplitude/area spectra of SiPM signals.

## LGADs

- Learn to use LGADs in conjunction with radioactive source
- Measure timing jitter

## Geant 4

- Learn how G4 is structured
- Set up a liquid xenon detector in Geant4 with photosensors
- Analyze the output of an optical simulation
- Bonus: simulate neutron scattering from Cf252

# Lab Modules (continued)

## CCDs

- simulate astronomical observing in a controlled daytime environment. We will use a CCD camera to image a simulated galaxy with a telescopic lens.

## Fast ML on FPGA

- learn how to train an ML algorithm for an experimental physics task and then consider its latency, throughput, and resource usage.  Use of AUP PYNQ-Z2 board.

## Dark Radio

- learn how to use a spectrum analyzer in a search for low-mass dark matter

## Ultra Fast Inorganic Scintillators

- This module will compare two crystals, cesium iodide (CsI) and barium fluoride (BaF2), exploring their characteristics by measuring MeV gamma rays.

## CaloGAN

- Multi-layber calorimeter simulation using GANs