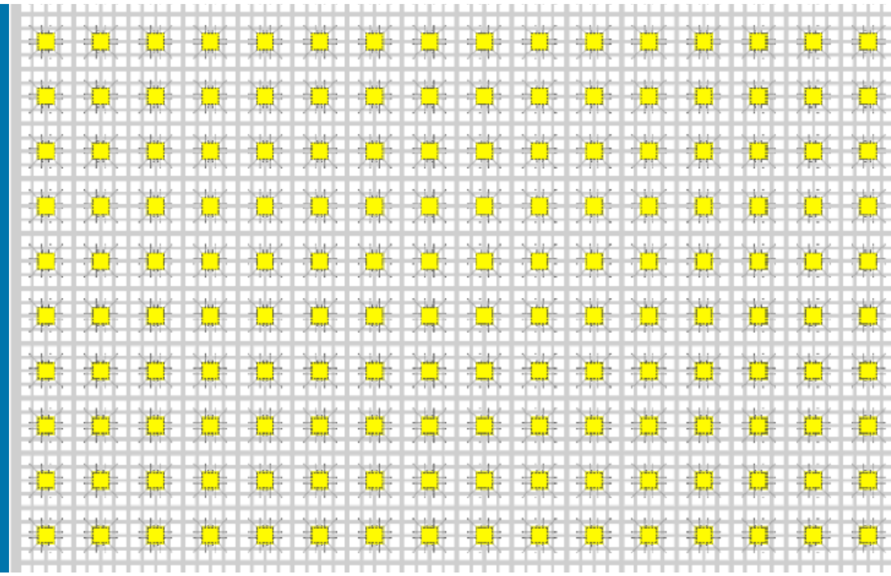
Q-PIX AT ARGONNE



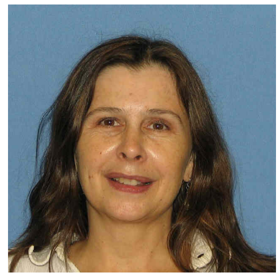
Zelimir Djurcic, Karen Byrum, Steve Magill, Vic Guarino, Bob Wagner, Alex Martinson

Argonne R&D, EOF, MSD and Neutrino Teams
High Energy Physics Division
Argonne National Laboratory

April 2-3, 2020

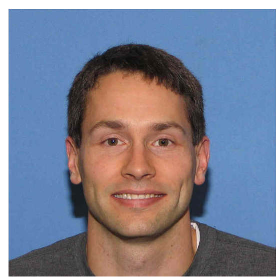
Argonne Q-pix Team


Zelimir Djurcic


Karen Byrum


Vic Guarino


Steve Magill


Alex Martinson


Bob Wagner

Content

- Argonne Focus on Q-pix

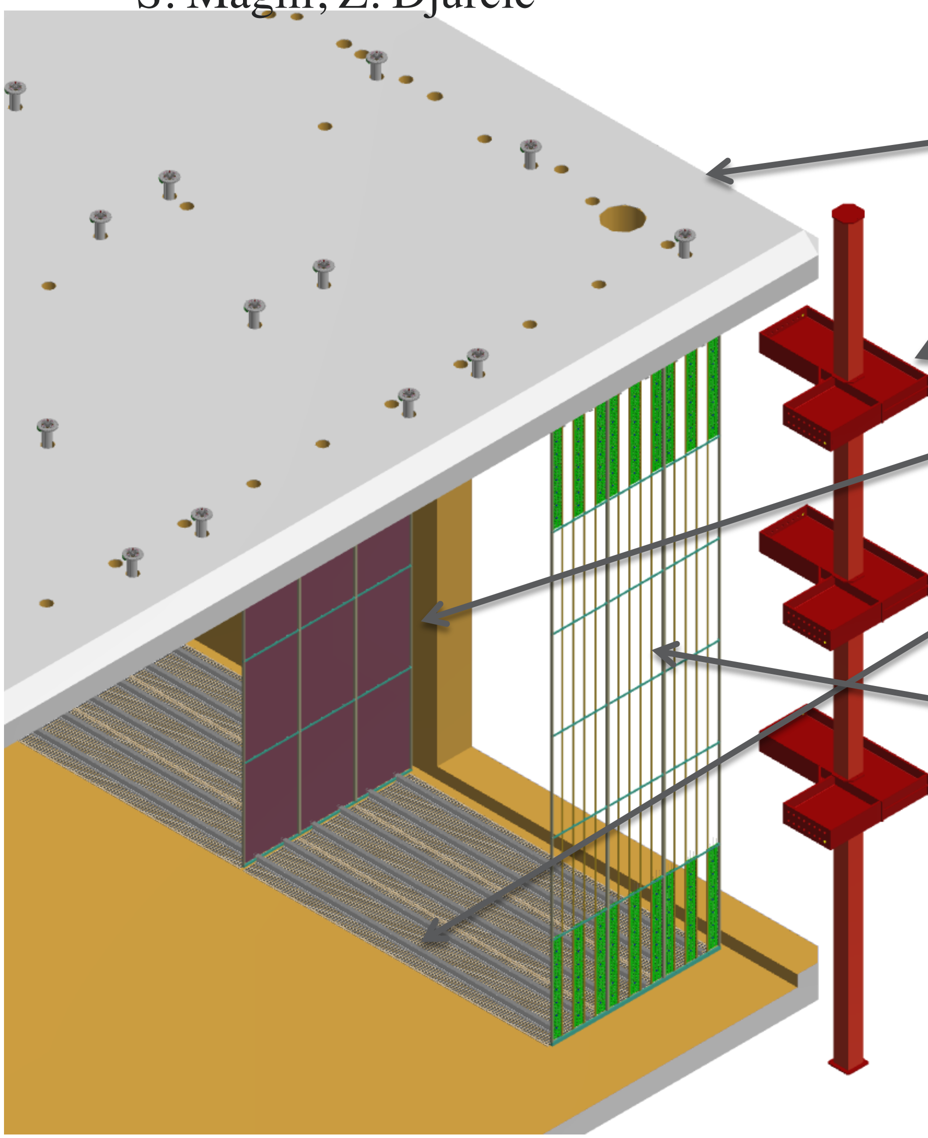
  - Mechanical and Electrical Engineering design of Q-Pix Pixel Board and Support Structure

  - Development of novel photo-detection techniques and materials for light detection

  - Science Interest and Opportunities

Engineering design of Q-Pix Pixel Board and Support Structure

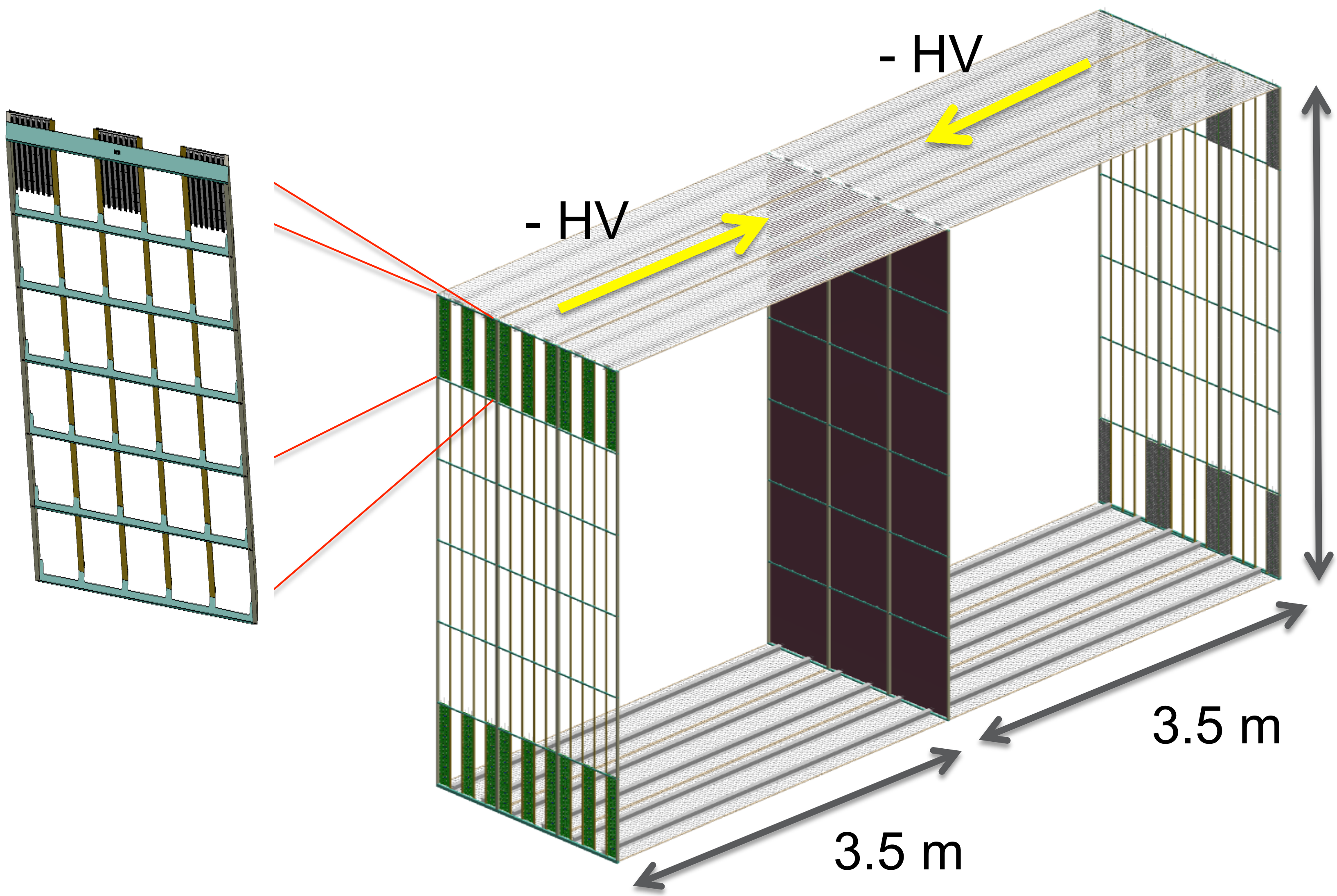
- Overview of Q-pix based DUNE Far Detector
  - -Led by Vic Guarino (Argonne EOF Division) and HEP scientists K. Byrum, S. Magill, Z. Djurcic



- Currently 3.5 m drift region between CPA and Q-pix planes; 12 m detector height → same as DUNE-SP wired APA TPC, could be different as needed.

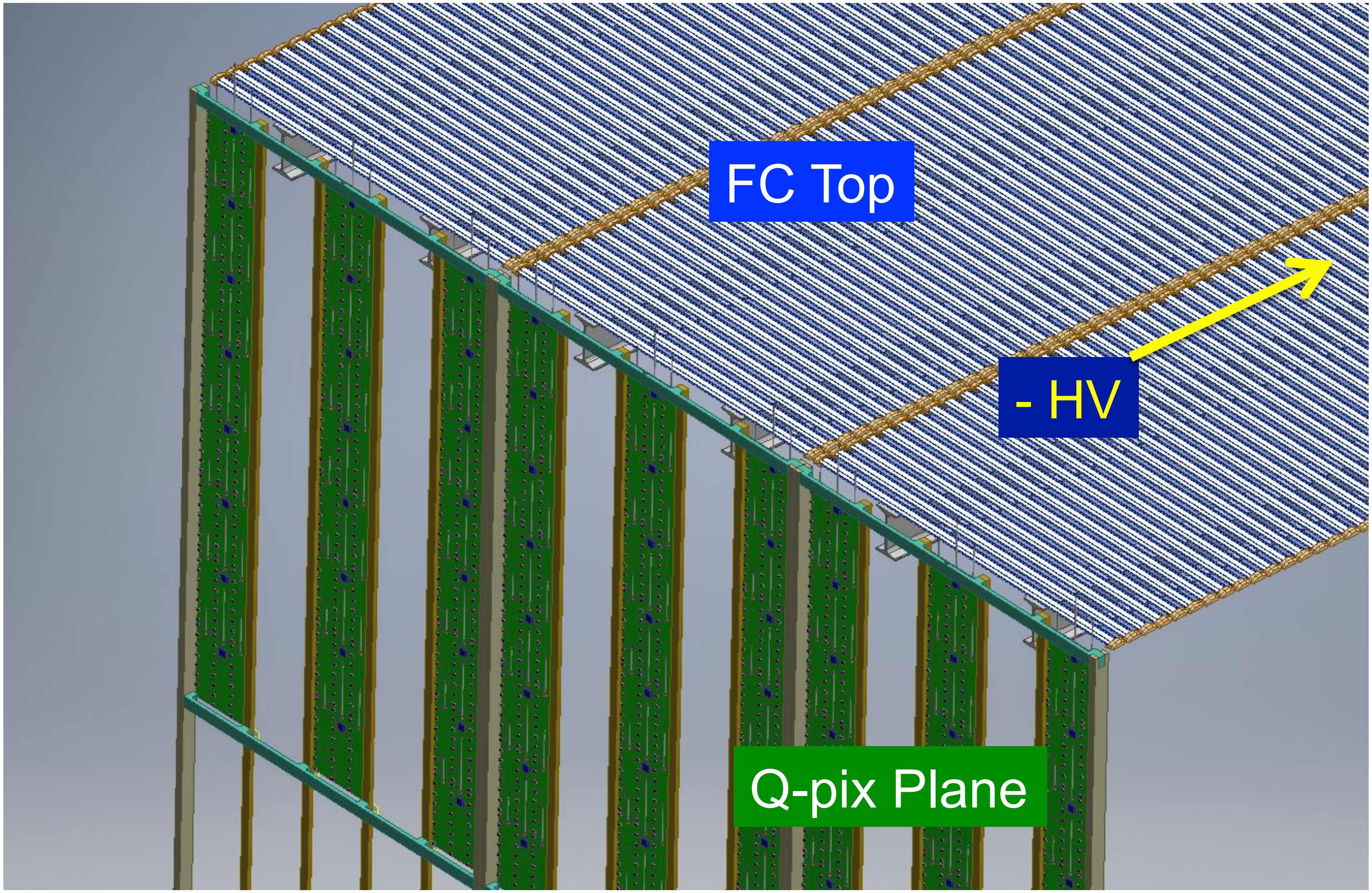
Engineering design of Q-Pix Pixel Board and Support Structure (cont.)

- Two drift volumes showing Top/Bottom Field Cage, CPA in middle and Q-pix planes at each end



Engineering design of Q-Pix Pixel Board and Support Structure (cont.)

- Field cage top with Q-pix plane



- 3/5 Qpix panels shown in the plane (Green)
  -Wires shown exiting top of Q-pix plane are examples (small subset of total!)

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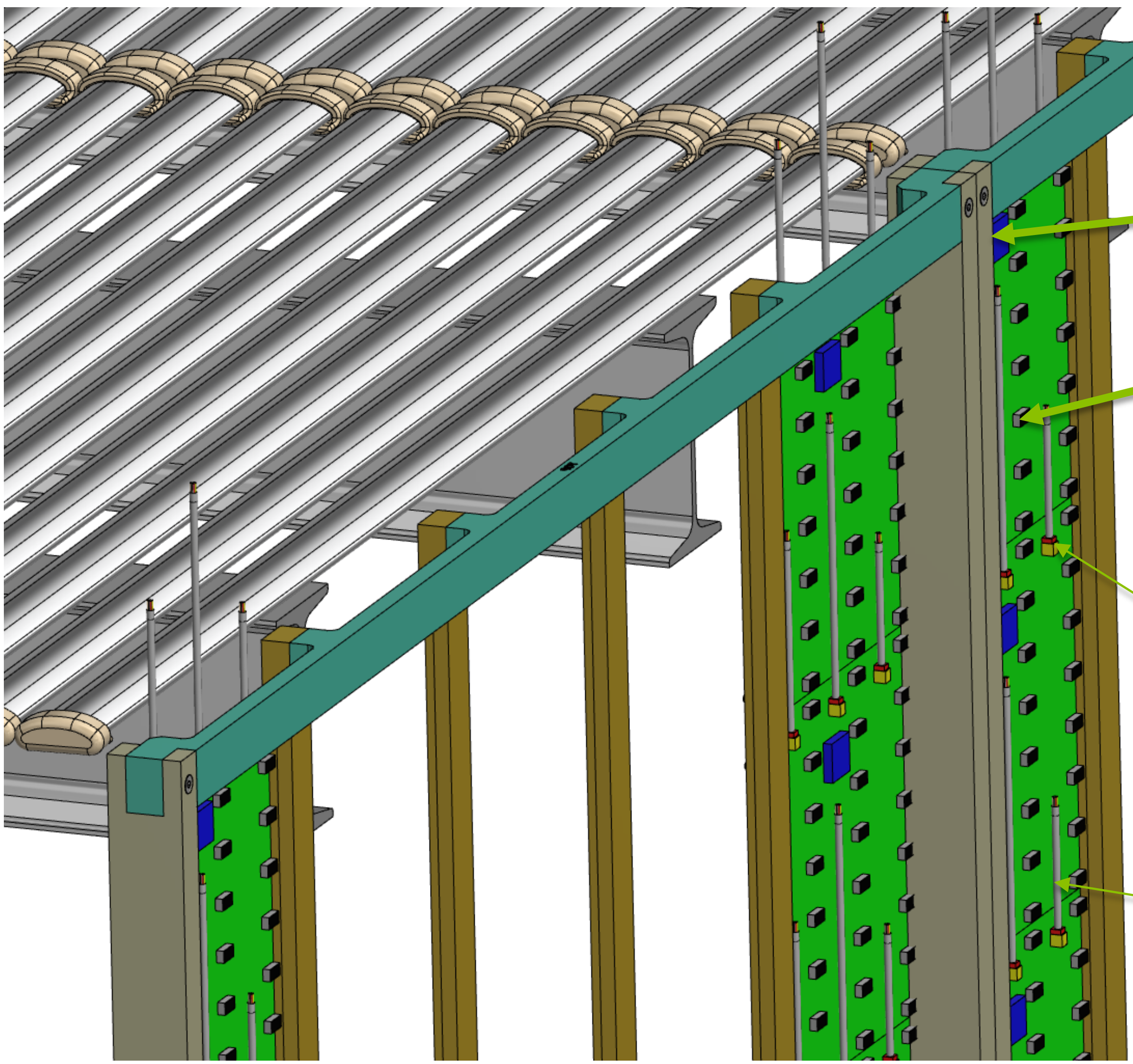
Engineering design of Q-Pix Pixel Board and Support Structure (cont.)

- Close-up view of the top of FC and Q-pix Plane
  -Cable lines, ASICs, Data Collector, Connectors and Cables



Engineering design of Q-Pix Pixel Board and Support Structure (cont.)

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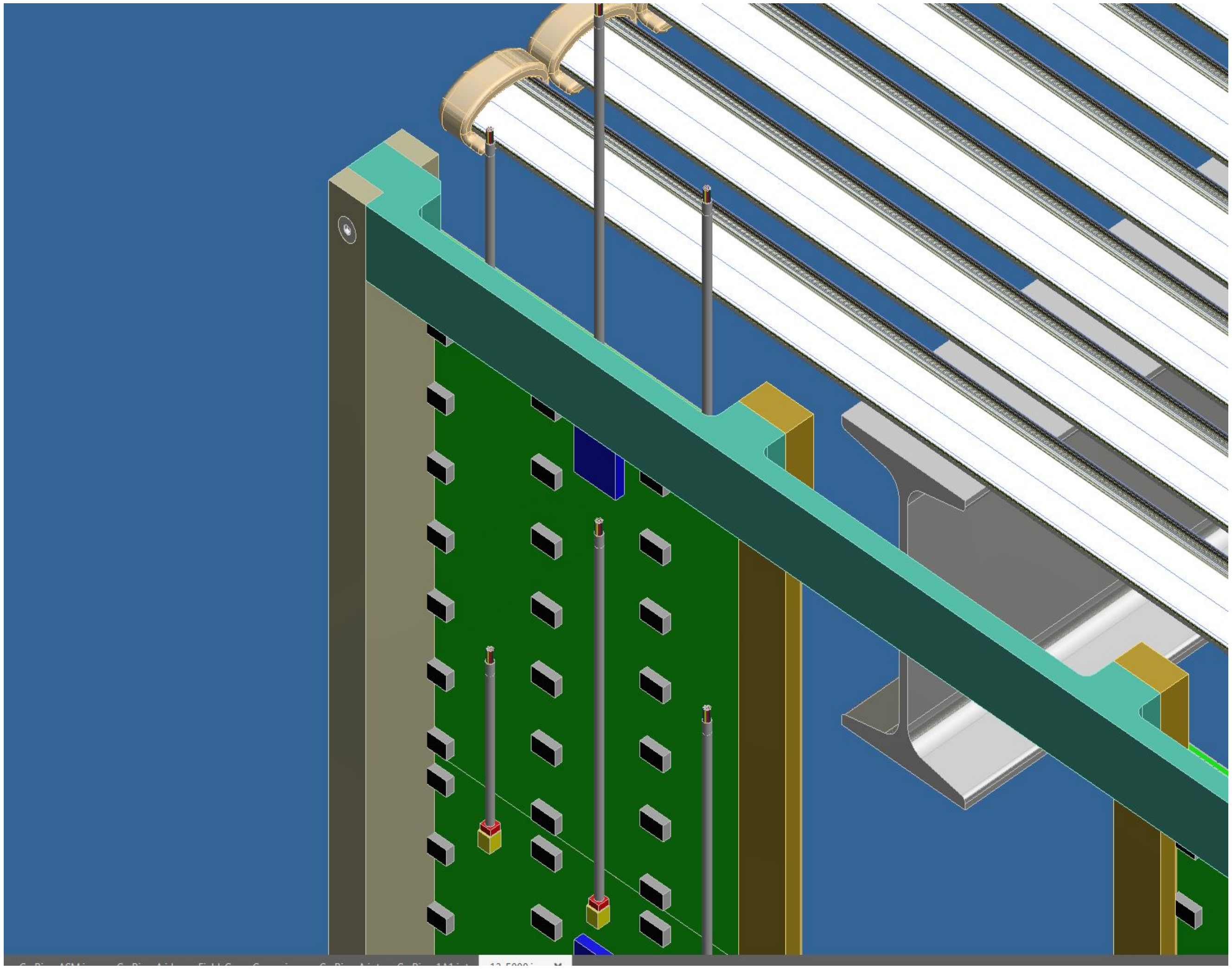


Engineering design of Q-Pix Pixel Board and Support Structure (cont.)

- Next Steps
  - Short-term
    - -Completion of Q-pix electro-mechanical design for the 10-kton DUNE Module of opportunity
    - -Electronics support from ANL Physics, TBD
    - -Initial cost estimate for 10-kton module
  - Longer-term
    - -Further refinement of Q-pix electro-mechanical design
    - -Electronics support within HEP
    - -Q-pix Prototype Design and Fabrication

Photon Detection

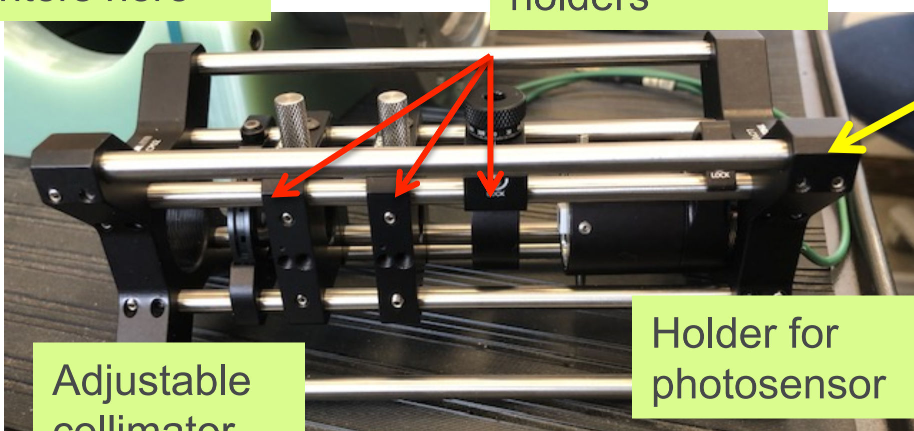
- ANL UV conversion material research
  - Ongoing program to develop nanoparticle wavelength shifters tuned to specific absorption wavelength and emission wavelength.
  - Goal: identify nanoparticle for detection of light at 128 nm and 175 nm (Argon & Xenon) and study applicability to both neutrino and DM experiments.
  - ANL role: test candidates and characterize in terms of absorption, wavelength-shift size, emission.
  - Research on materials for direct conversion of UV to electron/(holes) draws on expertise of Argonne Materials Science Division (MSD)

    -Alex Martinson (MSD) has experience in areas of solar conversion materials and optoelectronic processes; could provide 20% of his time researching materials and processes specific for liquid argon UV detection.
  - Steve Magill is leading a research on nanoparticle wavelength shifters for Ar and Xe light detection (SBIR grant with CapeSym, Inc).

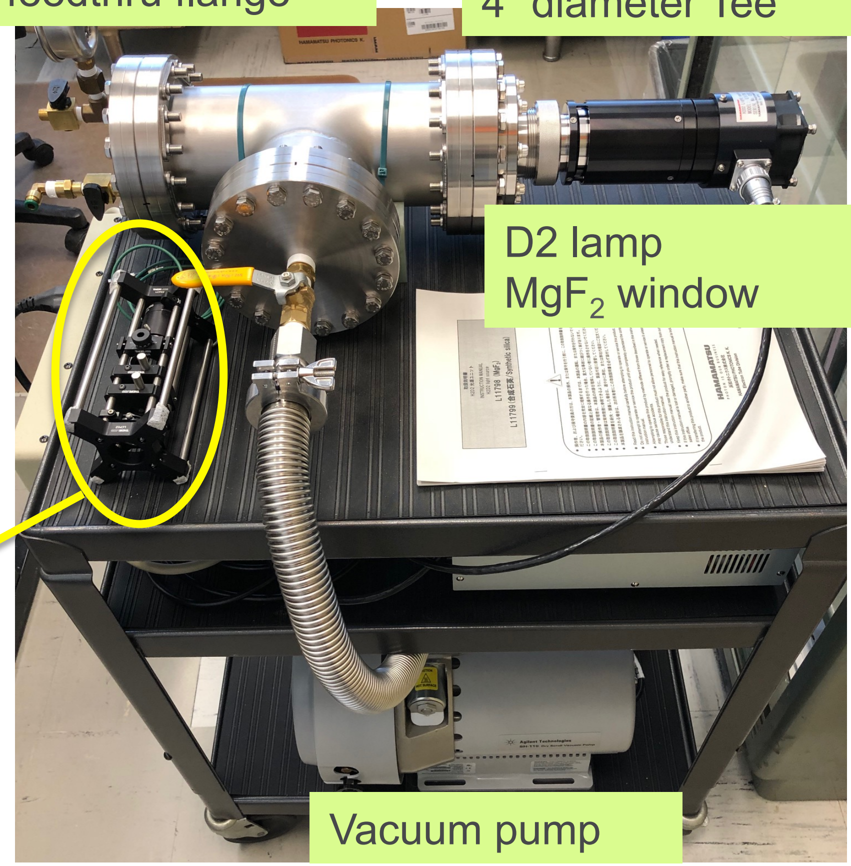
Photon Detection (cont.)

- Nanoparticle wavelength shifting research for detection of Argon and Xenon light (SBIR grant with CapeSym, Inc)

- Low Wavelength Filter Testing Device
  - Tests of UV absorption and visible emission by nanoparticles (SBIR)
  - Vacuum or gas flow operation
  - Transmission or reflection measurements



Insert fits inside Tee – aligned with lamp

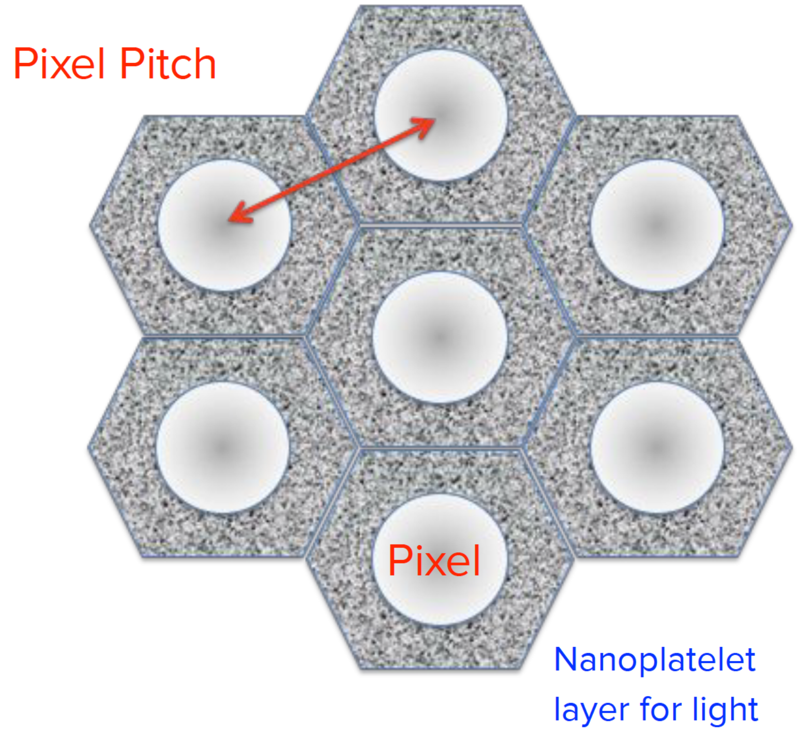


So far – 4 out of 9 samples from CapeSym tested – eager to get back to testing!

Photon Detection (cont.)

➢ Nanoplatelets Approach

- The charge collection pixels are isolated using the photon sensors.
- The pixel plane is made of a substrate material with nanoplatelets deposited on the substrate, readout on the back side (outside of TPC)
- Nanoplatelets absorb VUV photons, generate electrons: direct conversion of photons to current.
- Current SBIR grant with CapeSym, Inc. (8/19–4-20) to identify nano candidates sensitive to 128 nm and 175 nm form into nanoplatelets direct signal.
- Collaboration with Argonne Nano-Science and Technology (NST) Division



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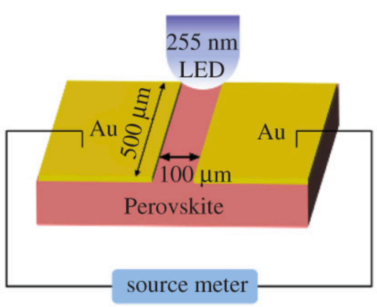
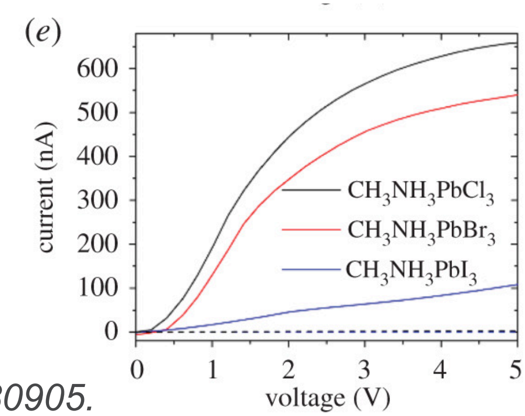
Photon Detection (cont.)

➢ Halide Perovskite Approach

- In addition to amorphous selenium, halide perovskites are a potentially very interesting candidate for UV photodetection.
- Perovskite: A generic term for any material with the same crystal structure at $CaTiO_3$.
- Base material for new high-efficiency solar photovoltaics. Methylammonium halides are being studied for their excellent charge carrier mobility and lifetime.
- Sensitivity to deepest UV (100-300 nm) is largely untested
- Low temperature operation untested
- Stability is a challenge (H_2O sensitivity)
- Low temperature stability untested





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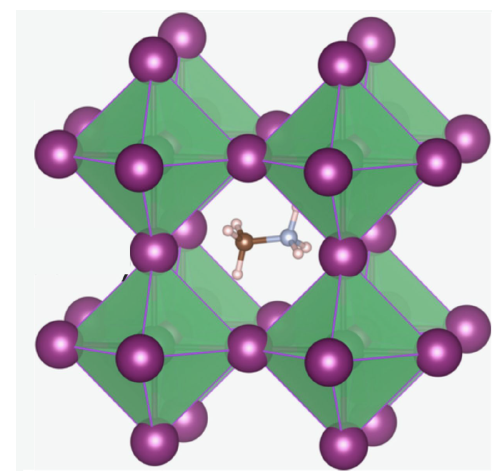

Methylammonium lead triiodide

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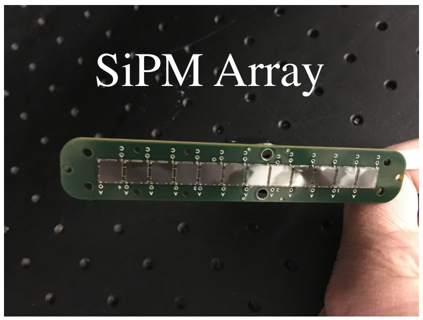
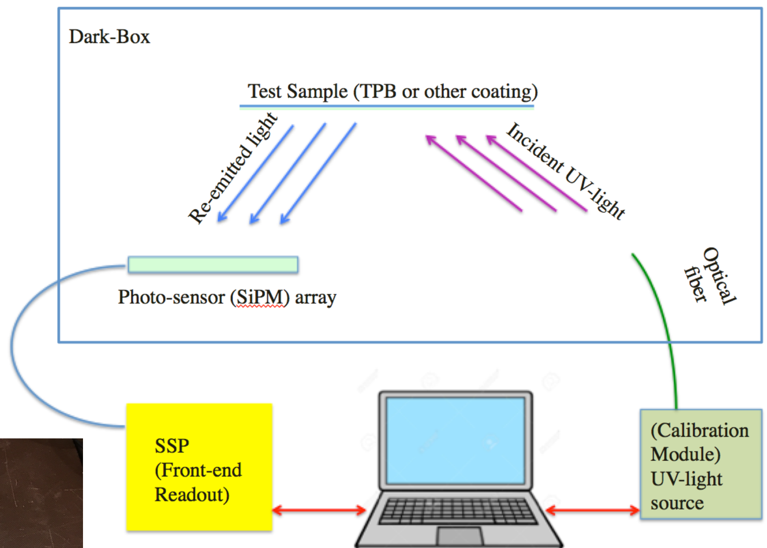
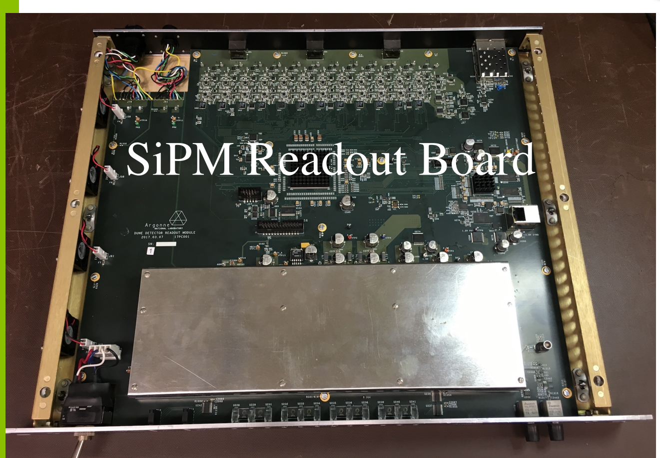
Photon Detection (cont.)

- Photon-Detector R&D test-stand for wavelength-shift materials and photo-sensor tests
  - -Ready for testing of new materials and SiPMs
  - -Expertise with photon readout systems and calibration
  - -To be used by Q-pix collaborators

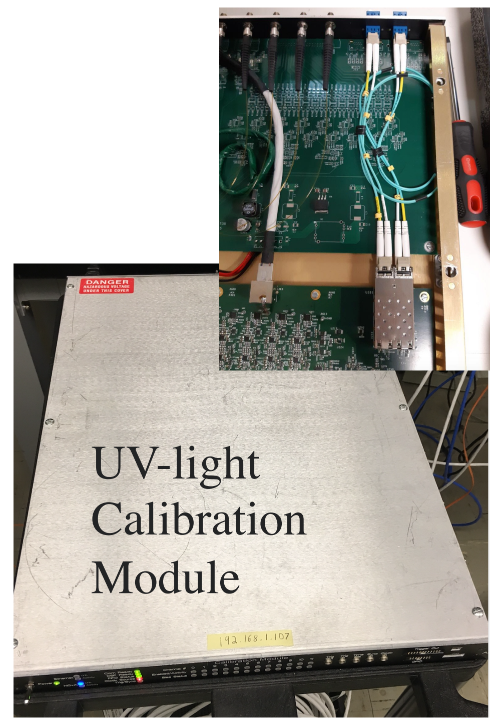






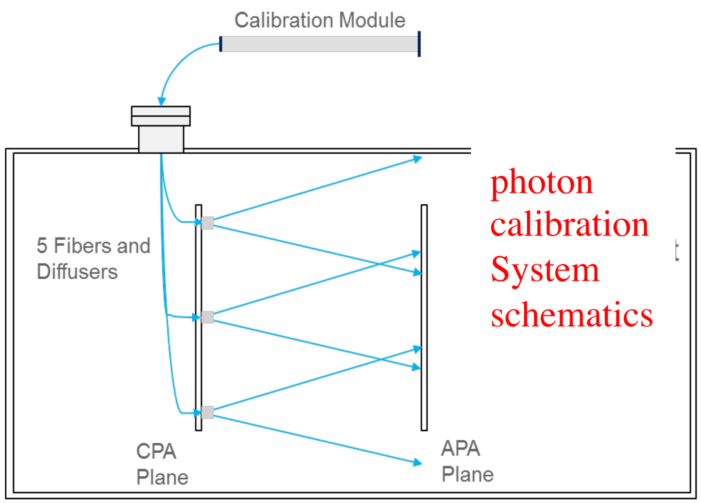
Built 288 readout channels for ProtoDUNE with SiPM photo-sensors

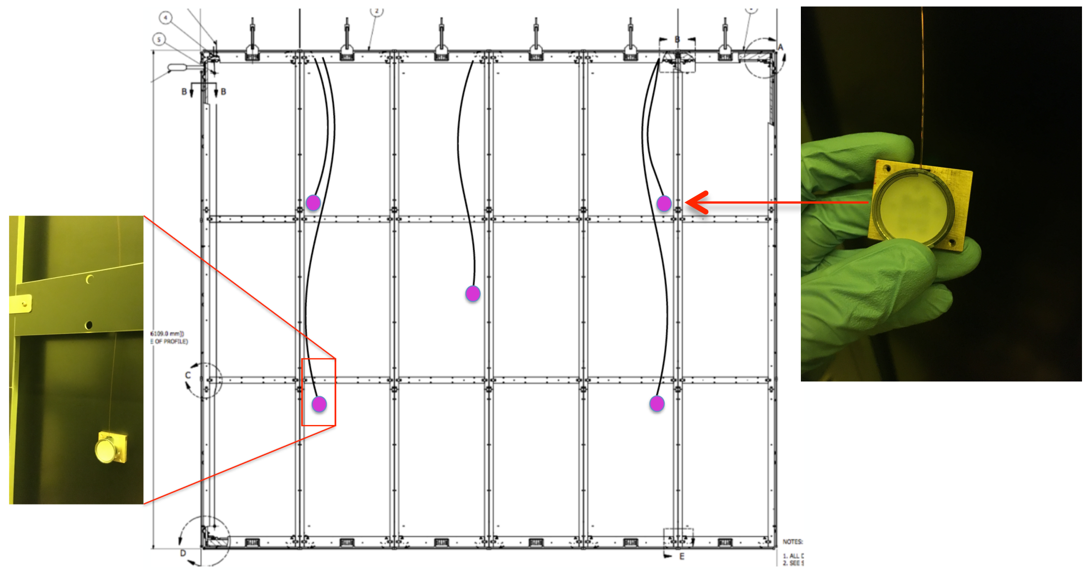
In addition we have LN, LAr dewars, and GN Box.

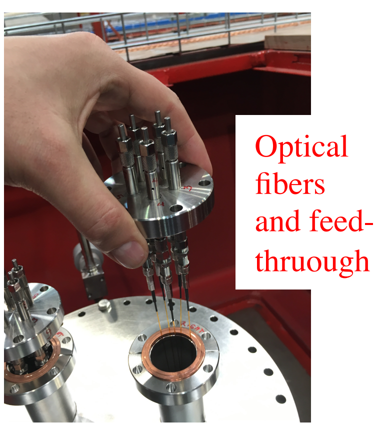


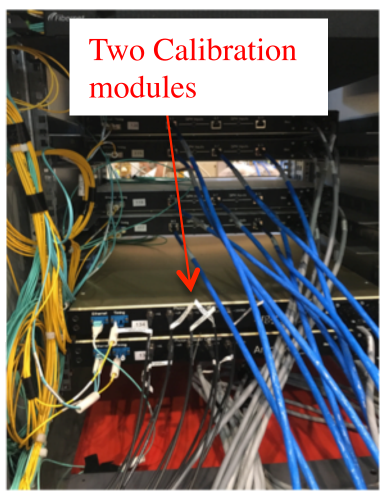
Photon Detection (cont.)

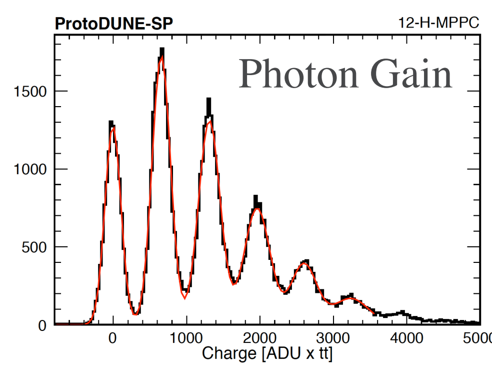
- Related photon-detection R&D at Argonne: DUNE photon-detector calibration system
  - The system emits UV-light: electronics module -> fiber (through cryostat) -> point-like diffusers
    - -Result: distribute UV light from cathode to photon detector at anode
    - -Fully integrated with DAQ/timing, emits light with desired intensity and repetition rate
    - -Full test and verification completed with ProtoDUNE => will equip full DUNE SP FD
  - Potential use for Q-pix photon system tests/prototypes/detectors

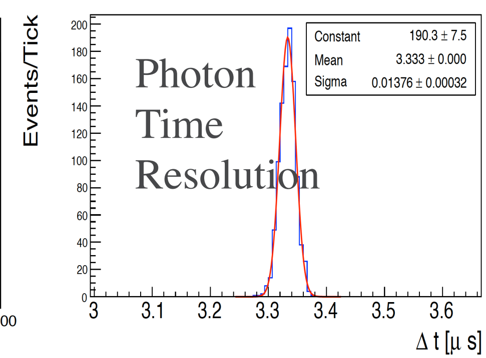












Photon Detection (cont.)

- Next Steps
  - Short term
    - -Identify and test promising perovskite materials
    - -Continued work to identify nanoparticle wavelength shifters for UV 128nm and 175nm
    - -Collaborative work with Argonne Nanoscience & Technology Division on nanoplatelet concept
    - -Research material candidates for direct UV➙electron conversion
    - -Optical test setups at Argonne (two existing setups) are available for material tests.
    - -Explore potential SiPM-based photon detector with Q-pix
  - Longer-term
    - -Continue exploring DUNE physics sensitivity with efficient photon-detectors (see next slides)
    - -Integrate UV➙electron candidate material into pixel board design. Produce and test actual prototype board
    - -Design the SiPM-based photo detector with Q-pix, if decided
    - -Incorporate prototype into ProtoDUNE or ArgonCUBE prototypes when needed.

Science Opportunities

- Ultimate science goal is to provide a definite measurement of CP-violation, and to enhance a sensitivity to other deep underground physics
  - -Capable additional Far Detector (Q-pix based) increasingly important to reach DUNE science goals
  - -Use advantages of pixelated readout: expected with a lower noise and a lower energy threshold compared to conventional wire-APA

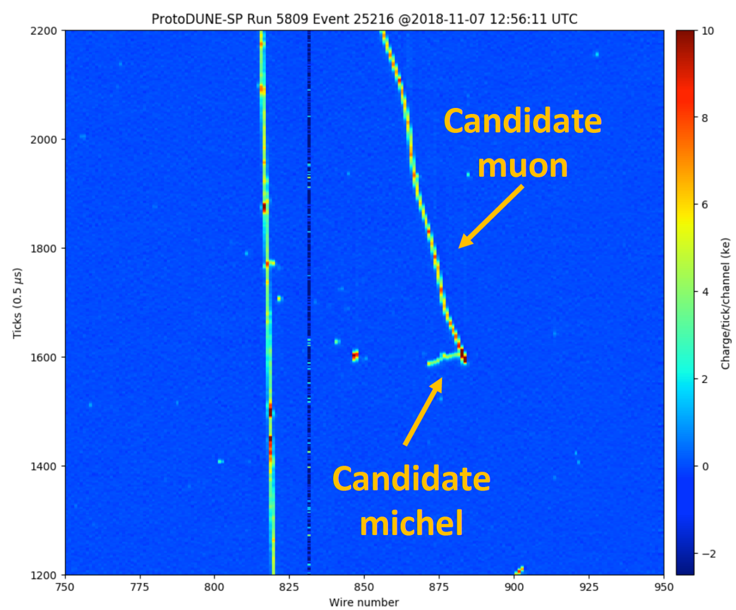
- Argonne is exploring several opportunities to improve physics sensitivity
  - -Low-energy physics
  - -Use LAr scintillation light information
  - -Improve energy resolution by charge + light information

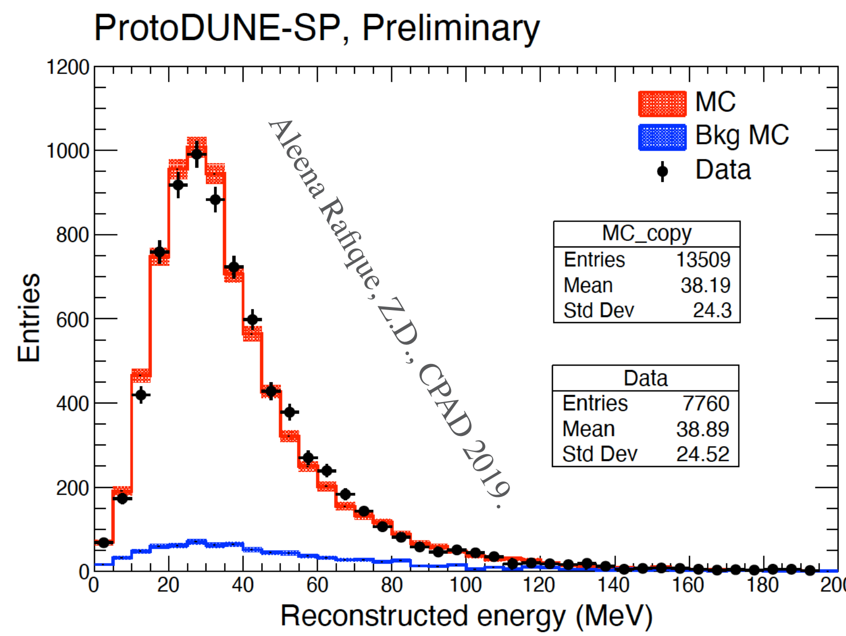
- We have started on these topics with the SP ProtoDUNE/DUNE
  - -Potential to carry these studies to Q-pix based detector
  - -Potential to add Argonne High-Performance Computing to development efforts

Science Opportunities

- Argonne group is addressing DUNE low-energy physics via Michel electron studies

  -Our goal is to provide reconstruction and calibration algorithm to be used from Far Detector day one





- Preliminary energy resolution of reconstructed Michel electrons ~28%

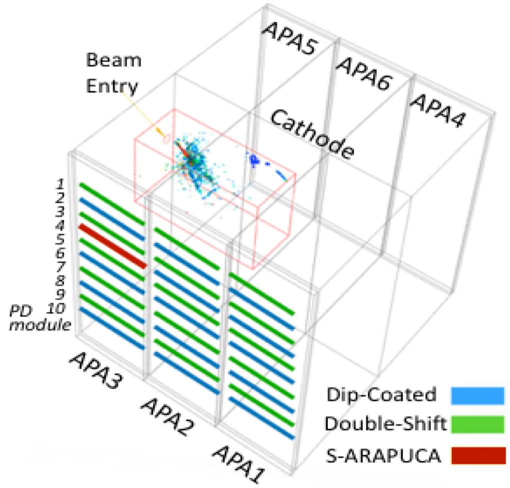
  -this is expected to improve with Q-pix readout (lower noise, low det. threshold)

- Potential to extend above studies to Q-pix detector and compare two technologies

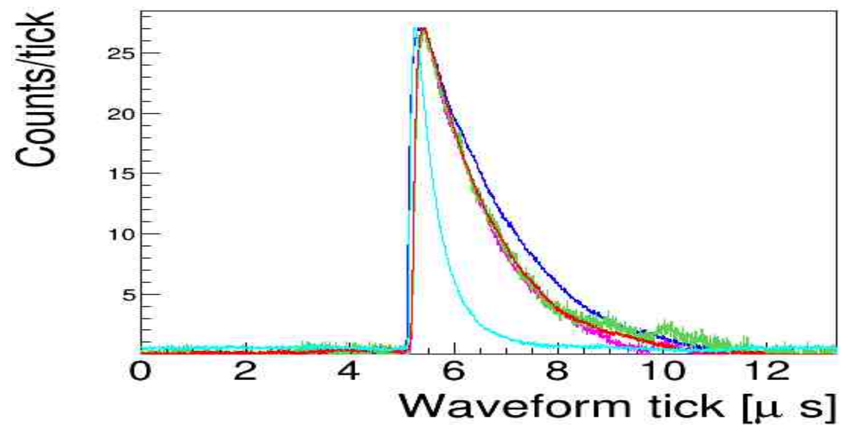
  -will need simulated data

Science Opportunities

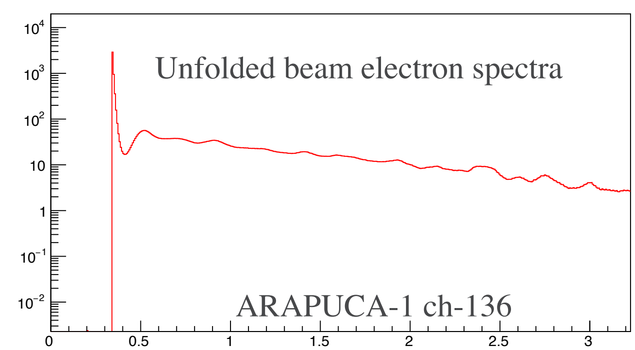
- LAr scintillation light information - contained in photon-detector signal waveforms
  - -Particle ID information contained in pulse-shape (singlet vs triplet light components)
  - -Aka prompt vs delayed light ratio: different for different particle species?



Example waveform from ProtoDUNE: cosmic muons, calibration light, beam electrons, beam protons, beam muon/pion candidates



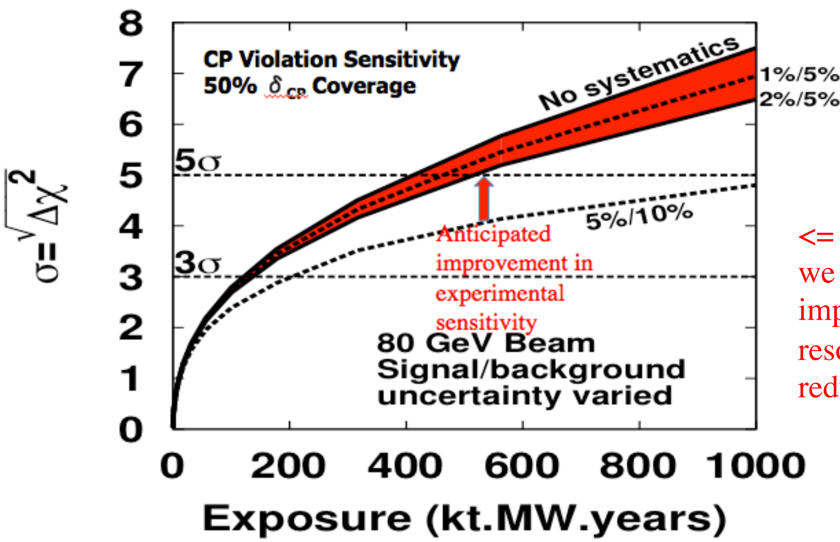
- We are currently studying this with an IMSA student
  - -Use collected ProtoDUNE-SP photon det. data
  - -Compare beam electrons vs cosmic-ray muons



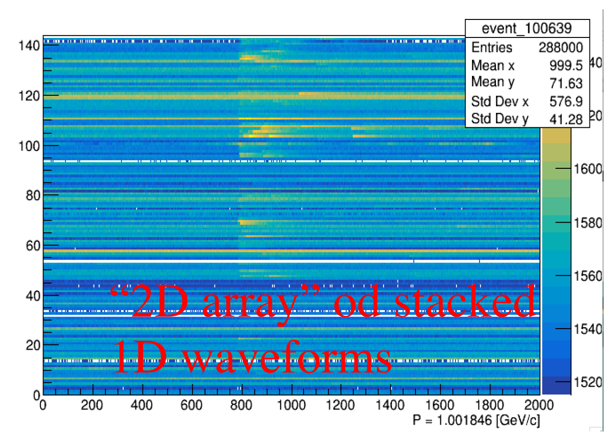
- Will this provide additional PID information?
  - -Can we separate electrons from muons?
  - -Is the late light important for Far Detector?

Science Opportunities

- We submitted an Exploratory AI/ML LDRD in March: “Achieving unprecedented sensitivity in DUNE neutrino experiment using raw data information”
  1) use Machine Learning to recognize light wave form (previous slide) and “learn” particle energy
  2) **understand how to combine light and charge to achieve unprecedented energy resolution (potential improvement in energy resolution ~50%, with event-by-event basis)**
- TPC data is 2D image data with a slow timescale, while the optical data is 1D time series data/channel
  -”Combining these datasets in a meaningful way is an important and unfilled challenge”.



<= An older sensitivity study we performed at ANL: assumed improvement in energy resolution and background reduction. Potential for Q-pix.

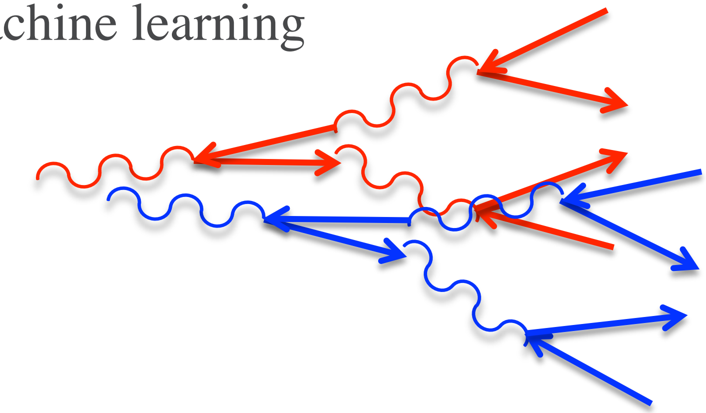


- Opportunities with ANL High Performance Computing for Q-pix (w Corey Adams et al.): simulation, reconstruction
  -Currently hold a sample of 10M simulated Geant4 events
  -Further discussion with Q-pix group is needed on how to synchronize simulation effort.
  We are interested to run simulation at Argonne “super” computers

Science Opportunities

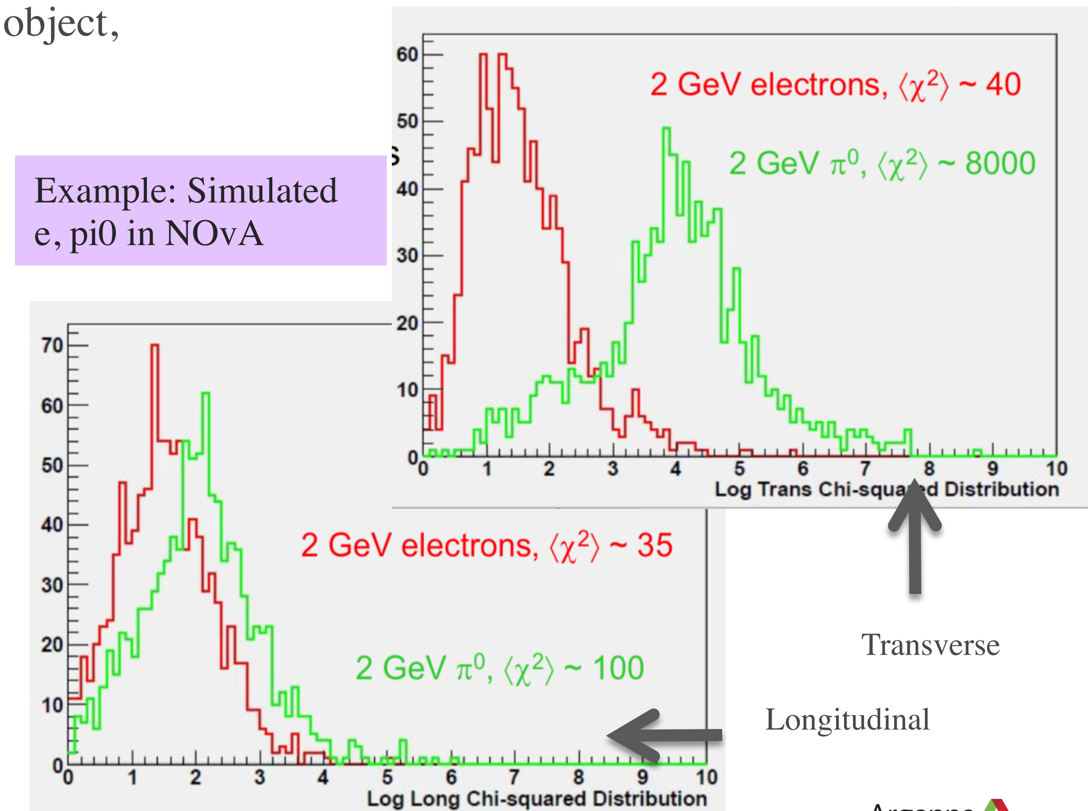
➢ Electron ID/pi0 rejection algorithm using machine learning

- Learning process
  - -Energy deposits in an electromagnetic shower are highly correlated
  - -Form a covariance matrix of the correlations between hits in an EM shower
  - -Matrix generated from MC ***or Data*** electrons
  - -Use inverted matrix to test hits in an object, forming a Chi2.



- Advantages of this method:
  - -Uses basic detector objects - starts with ***highest purity objects*** available in the event
  - -Relies on ***most basic correlations between objects*** to ID source of the objects
  - -Training can be done on MC ***or on real Data*** if available.

Example: Simulated e, pi0 in NOvA



Transverse

Longitudinal

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Science Opportunities

- Next Steps: we won't be able to do everything – these are opportunities we are looking at
  - Short-term
    - -Complete Michel electron studies with DUNE/protoDUNE-SP; publish
    - -Summarize ongoing waveform studies
    - -Start on exploratory Machine Learning LDRD on light and charge (if funded)
  - Longer-term
    - -Perform optimized energy resolution studies (charge + light)
    - -Run Michel electron reco algorithm with Q-pix simulation
    - -Use Argonne AI/ML/simulation capabilities in Q-pix simulation, reconstruction
    - -Perform Physics sensitivity studies with improvement above

Summary

- ANL group will continue to lead mechanical design of the pixelated anode and high-voltage systems, leveraging expertise from DUNE and ProtoDUNE efforts
  -Assuming availability of an electronics engineer at ANL, develop cost estimate for full Q-pix based Far Detector for DUNE

- ANL will collaborate with Q-pix groups to test novel ANL solutions (MSD, NST et al.) and schemes for light collection and detection
  -Test stands for tests of new materials are in place. This should support a development of baseline concept of a photon-detector system for DUNE Q-pix, with new materials and/or with SiPMs

- We will contribute to Q-pix white paper

- Contributions using ANL High Performance Computing (HPC) in support of pixelated detector simulation and AI/ML reconstruction
  -Leverage Argonne Leadership Computing Facility (ALCF), ALCF and HEP science teams

- Argonne participation of above roles will enhance prototyping and demonstration of Q-pix concept with either ProtoDUNE or ArgonCUBE prototypes.

THANK YOU!