LBNE style detector R&D overview

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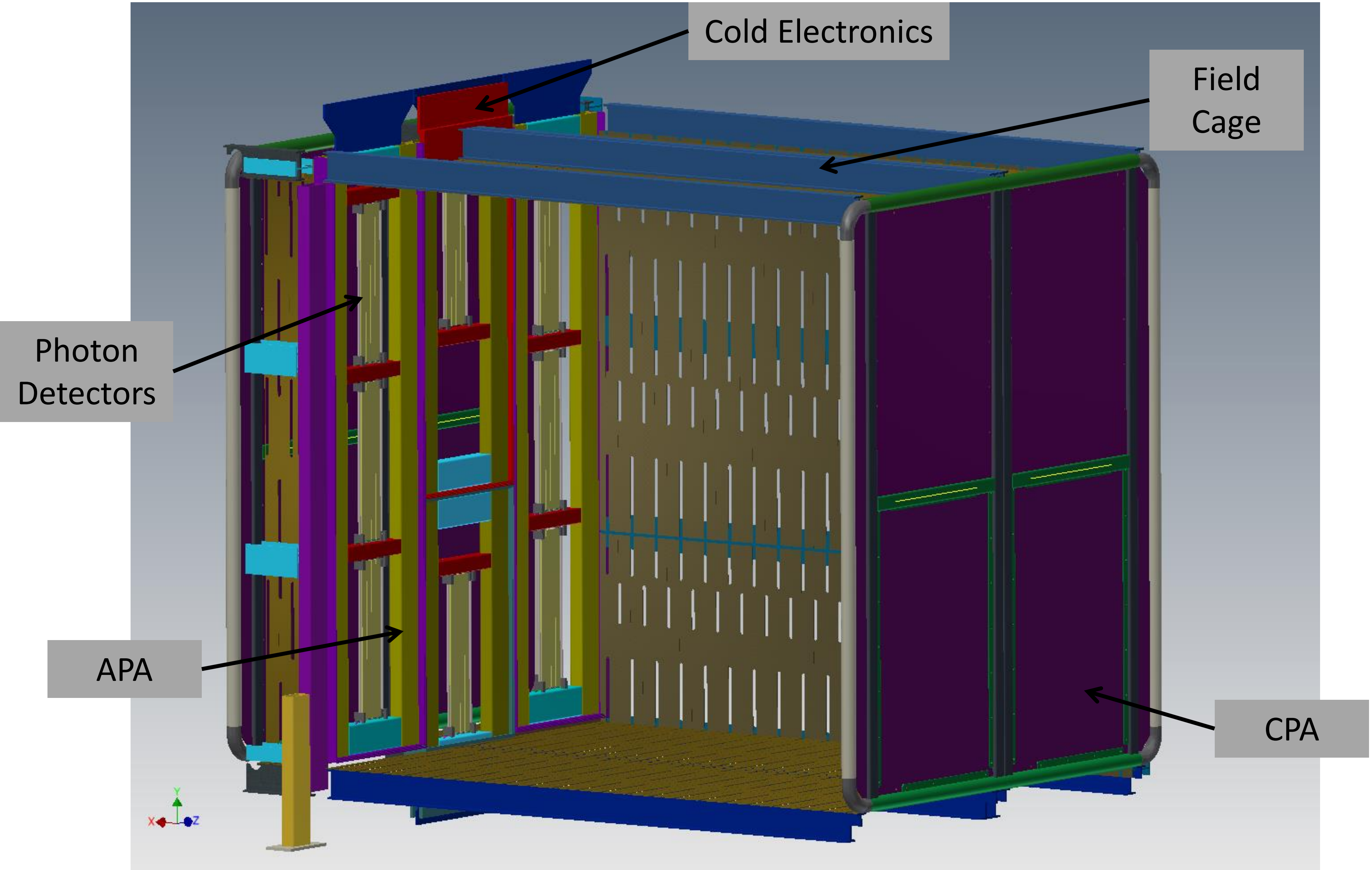
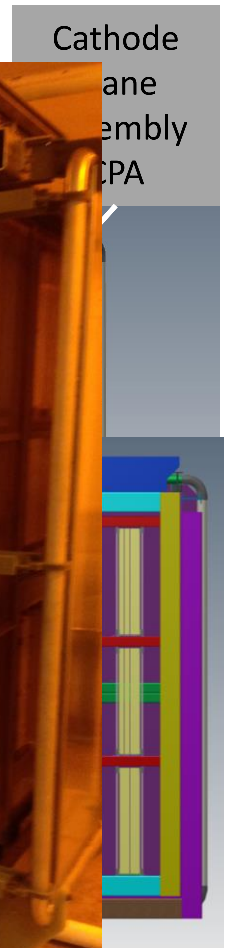
October 20 2014

35t Phase II Prototype TPC



35t Phase II Prototype TPC

- Construct a device with as close as possible to the final construction techniques and configuration as possible.



- Wrapped wires with end only readout.
- Cold pre-amp and cold ADC readout.
- APA frames with small gaps between planes.
- One bottom APA hung from a top APA.
- Copper clad G-10 field cage
- Tube and Sheet CPA construction

Parameters:

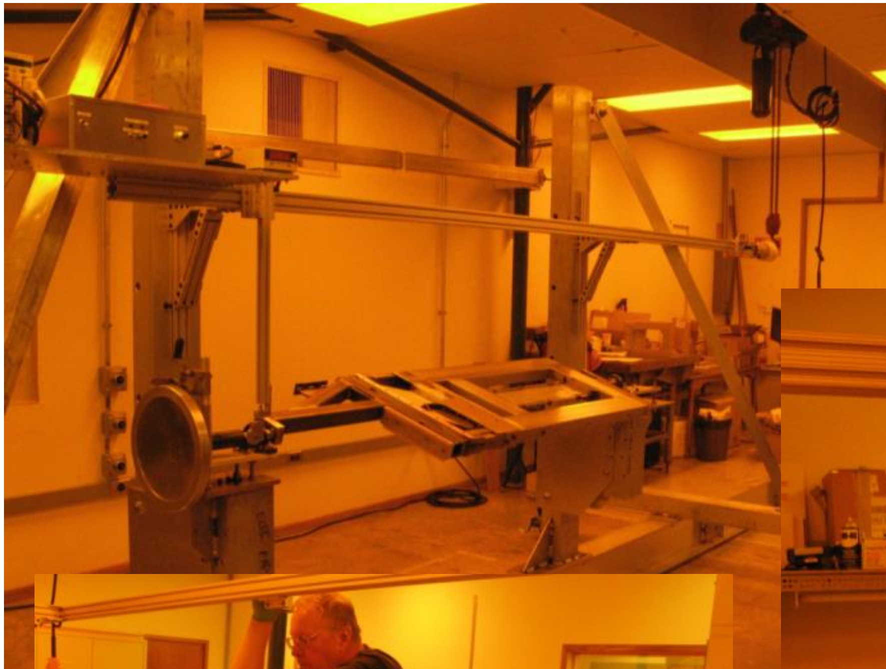
- 0.27 m and 2.27 m max drifts
- 1.5 m wide and 2 m tall
- 1.1 t and 9.3 t active mass.

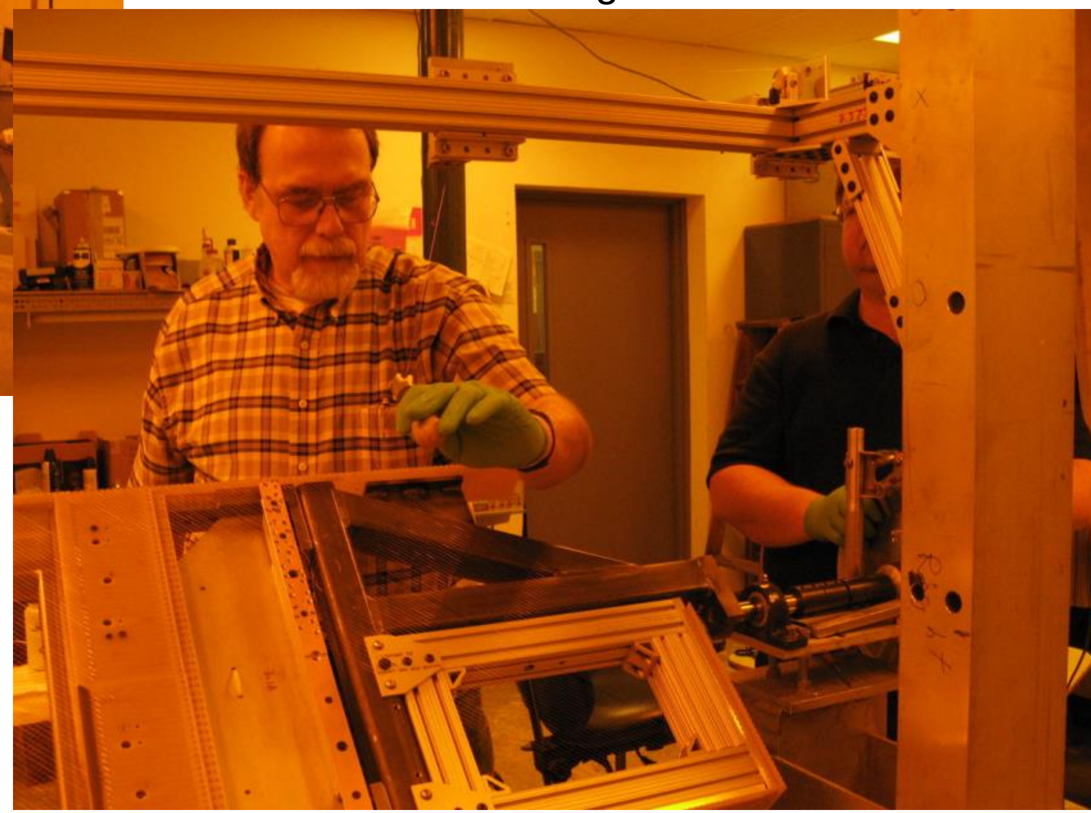
- **Status:**
- **APA construction finished in July**
- **Test assembly complete**
- **Installation starting November**
- **Start taking data Spring**
- **End data collection in Summer**

Fabrication - winding

The APA is rotated in a gantry to wind wire onto the frame. It is manually guided into the slots in the edge boards.

A tensioner on the wire spool maintains wire tension at any speed and in either direction. Wires are at 1/6 breaking load.





Next Steps

- Most work done till now on small scale prototypes
  - Need to re-start designing full scale planes.
- Quality assurance and testing plans are needed.
  - Testing equipment and procedures.
- Full scale winding setup for manual winding is needed.
- Mounting motion and tolerances need defined.

- Need to understand discharge and mitigation.

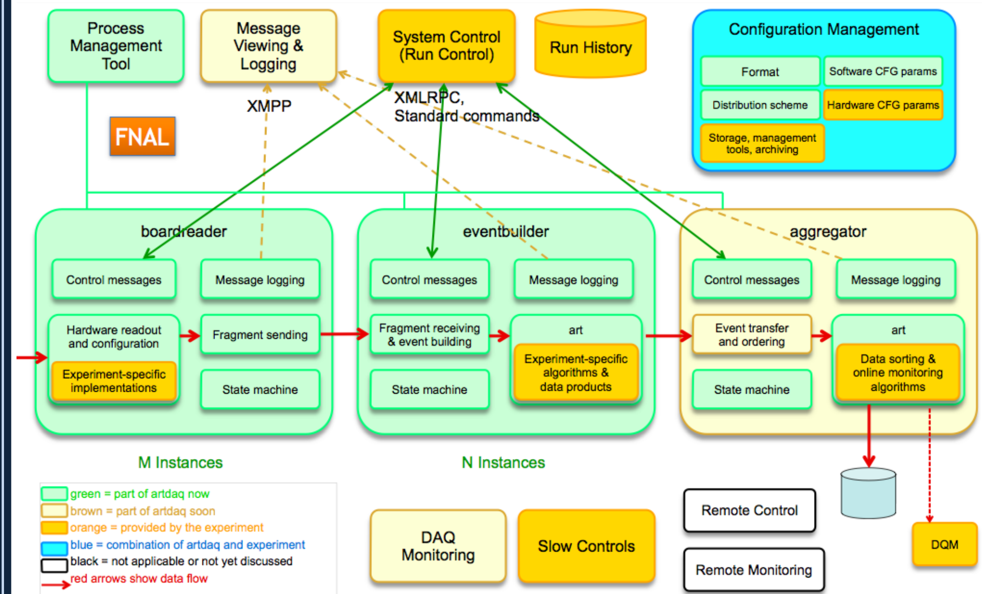
Triggering and DAQ for Liquid Argon

ANL, BNL, Fermilab, LANL, Maryland, Oxford, Penn, RAL, SLAC, Sussex., UTArlington, Warwick

35t Main DAQ goals:

- Collect all the events.
- Only cut out (zero suppress) parts of events which are unimportant.
- Zero dead time, 100% efficiency:
  - Process signals from L-Ar continuously, in real time to identify interesting time windows.
  - Also select windows from PD, calib triggers, beam spill.

Most physics events (Beam-ν, ATM-ν PDK, etc.) similar trigger; supernova (>10s live) requires more careful buffering design.

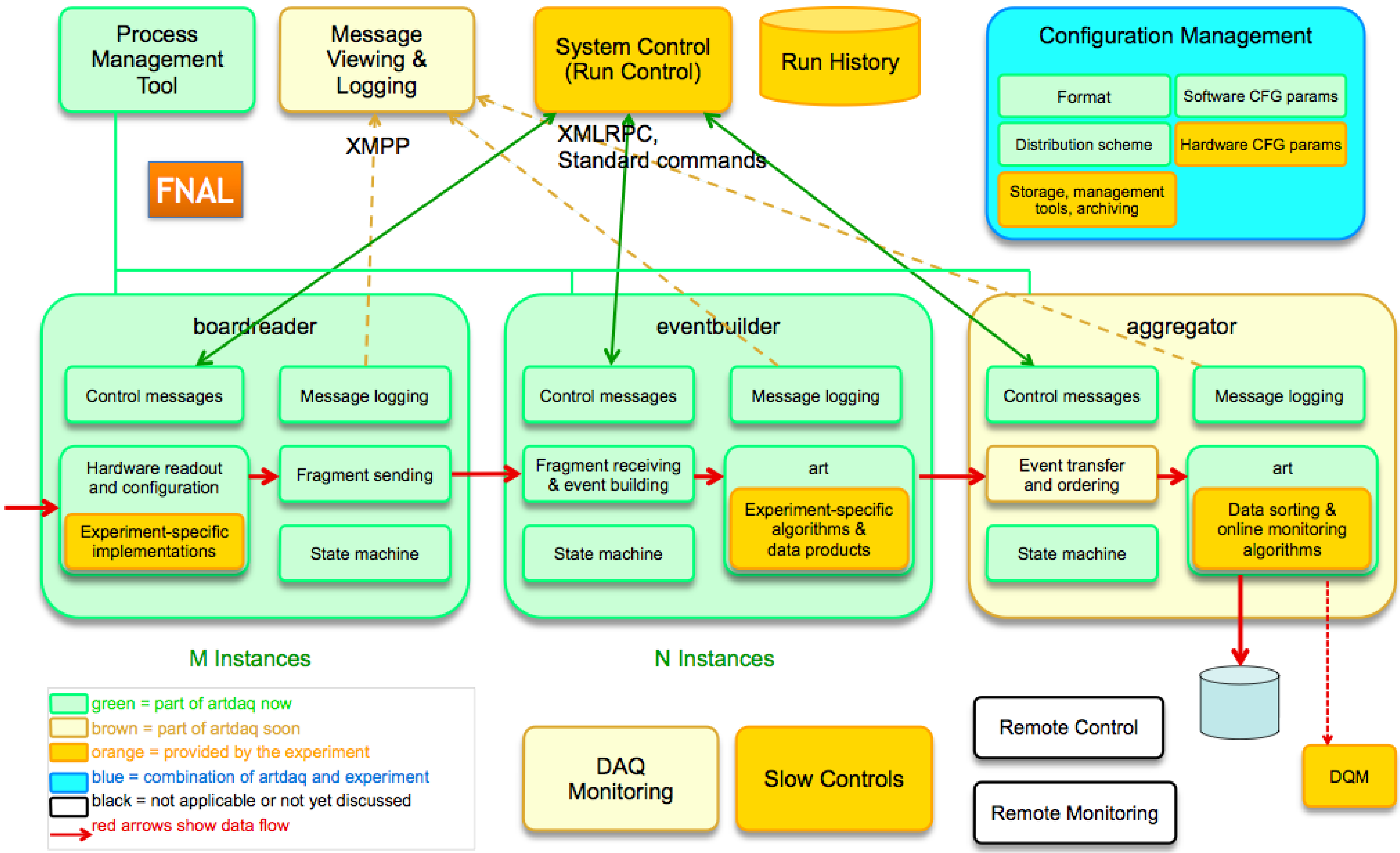


35t tests:

DAQ is a 'service' for primary 35t goals (test APA layout, PDs, cold electronics), but

- Chance to use modern DAQ techniques, and see them working together.
- Include special data taking to investigate/optimize triggering, zero suppression, compression and data transport options.

ARTDAQ based DAQ



Preparations for 35t test

Hardware: Most individual system designs and construction are well under way:

L-Ar (SLAC): COBs, RCEs, RTM, hardware well tested through two design cycles. Now designing firmware and waiting for full final production run

PD (ANL): SSP module well established with firmware, and readout on USB interface. Will add Ethernet interface.

Trigger board (Penn): Specified, design underway, coming in September

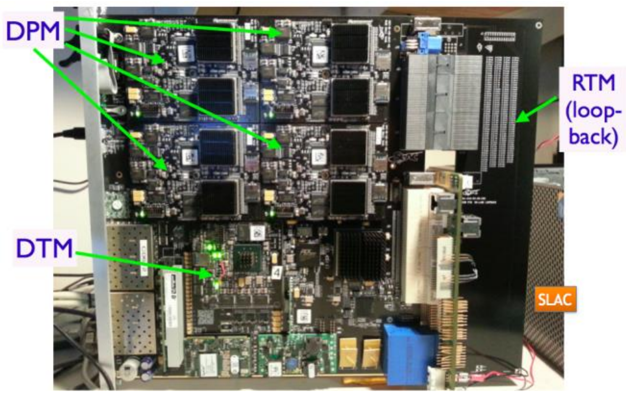
NOvA timing: Ready

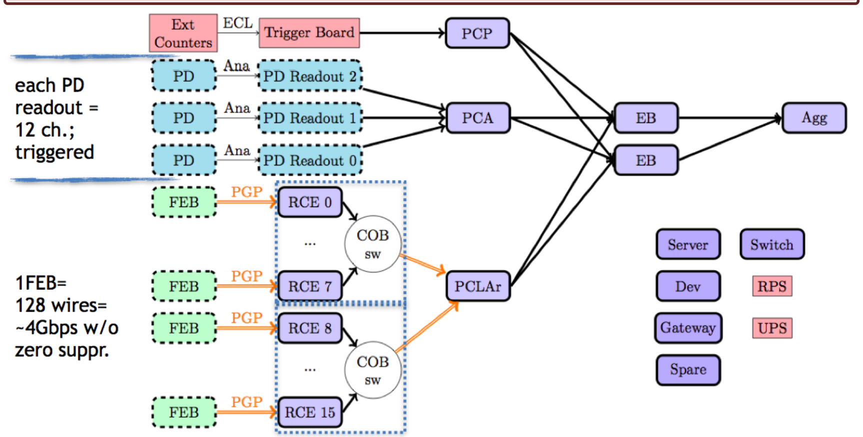
Flange board + cold electronics interface: Underway

Software: Main DAQ software (artDAQ from FNAL) in use on several other recent experiments (DarkSide50, mu2e) . Many of the 35t interfaces to it now exist.

Now existing: Run control, Configuration management, Board reading software for L-Ar and PD, framework for online monitoring and event display.

To come shortly: Trigger board reader, DAQ data testing packages, interface to offline



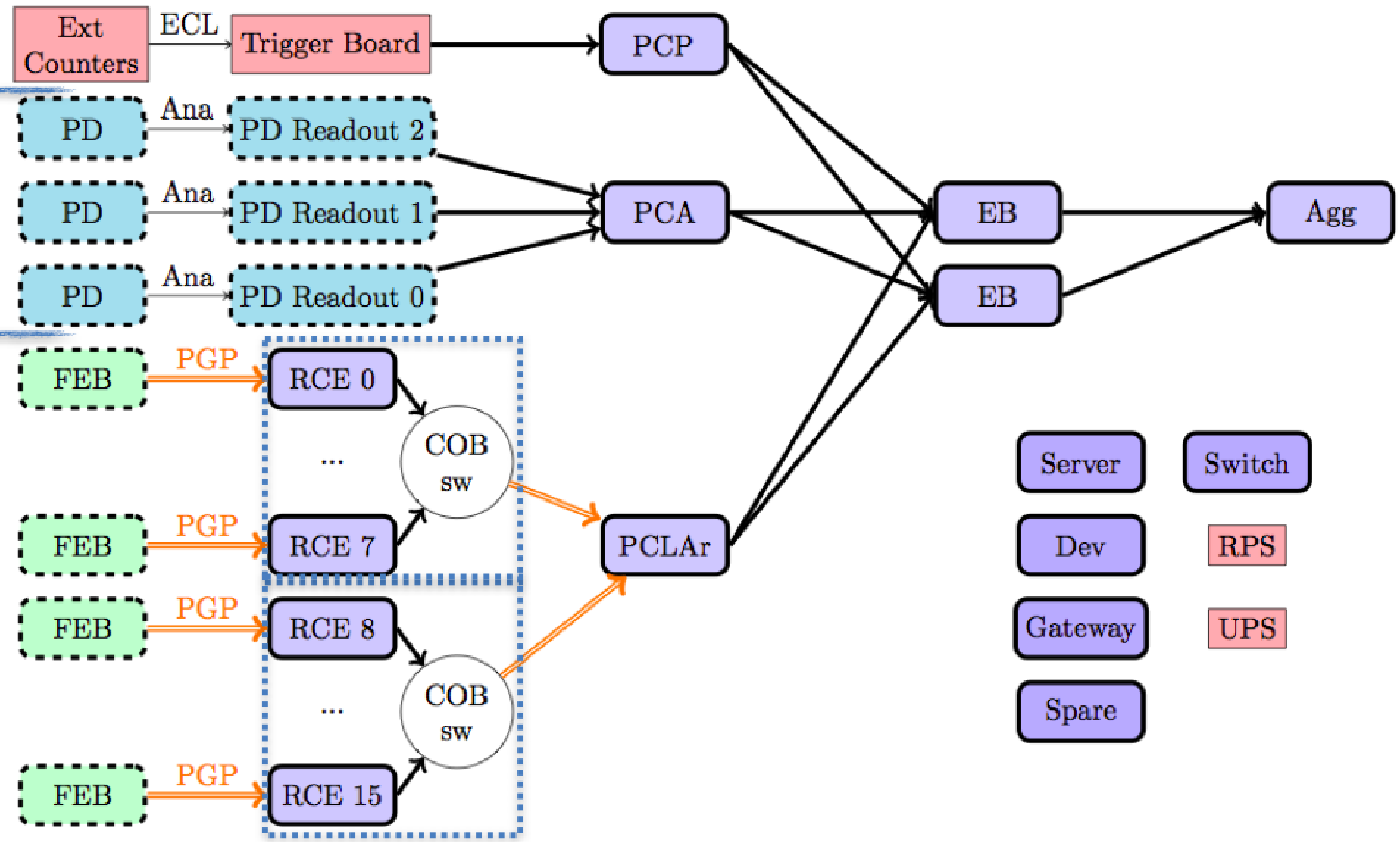


Recent Tests:

- Test PD boards with artDAQ, with NOvA timing, producing data through to offline files, synchronized between two boards
- Test chain from emulated L-Ar data through board reader into artDAQ and to offline files.
- Test software chain: RC, artDAQ, board readers
- Develop a consistent plan between sub-systems for run-starts, trigger window definition etc.
- Start rack build-up and ORC. Start operating a software test bench for use remotely.

each PD readout = 12 ch.; triggered

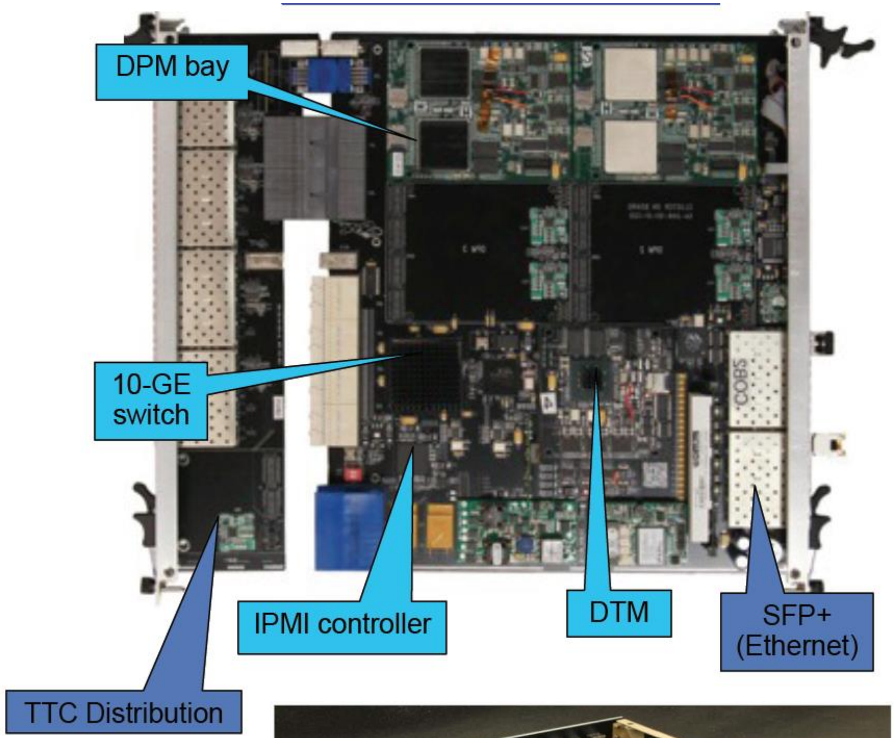
1FEB= 128 wires= ~4Gbps w/o zero suppr.



Data Flow

DAQ Hardware

- TPC readout hardware is based on SLAC RCE module.
  - High-speed DAQ (64 channels at 10 Gbit/s per module)
  - Can capture full data rate and zero suppress
  - 2 boards read out one APA
  - Half the electronics for the CERN test is available
- 35t uses the NOVA timing system to interface to the FNAL accelerator.
  - What is needed for CERN?
- SiPM readout electronics constructed by Argonne
  - Read out 12 SiPM
  - See single photoelectrons
  - Designed for Nova timing synchronization
- Plan to use the 35t cold electronics but only have enough for half the detector.



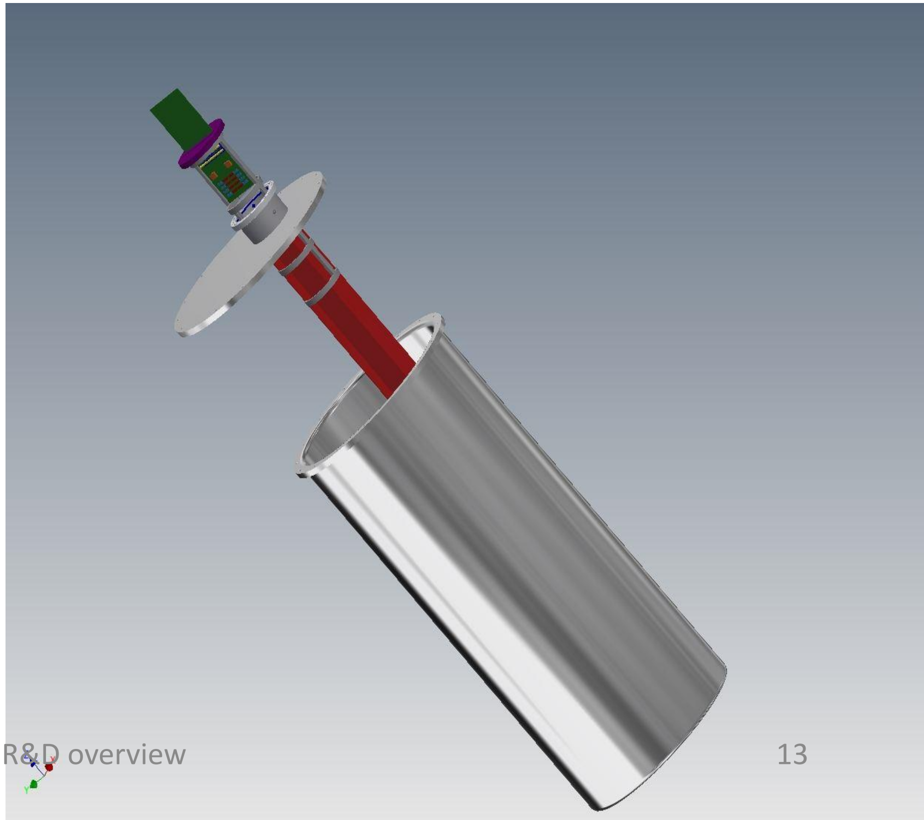
MOVING BEYOND THE 35T TEST

Contamination (e-lifetime)

- The test of the 35t cryostat achieved 2ms lifetime.
  - ICARUS has achieved 15 ms which demonstrates large improvements are possible.
  - Material test stand sees no impact on electron lifetime by any material under the Ar liquid.
- Need to identify the sources of contamination in the detector and propose changes to eliminate them.
  - A strong contamination working group is needed.
  - Extensive studies by ICARUS over the years
  - Can ICARUS, LAPD, 35t, LAr1-ND and the CERN cryostats be modeled?
- Possible measures and studies
  - Cooling the materials in the ullage
  - Careful hatch design
  - Cold Feedthrus
  - More 35t studies?

Cold Feedthru Design

- Development is time critical. It impacts the cable count and thus the cold digital requirements (Speed and multiplexing).
- A highly reliable and high speed feedthru is needed.
- Possible a joint endeavor LAr1ND others?
- Need a test stand large enough for the feedthru.
- Need a good engineering design and testing plan.

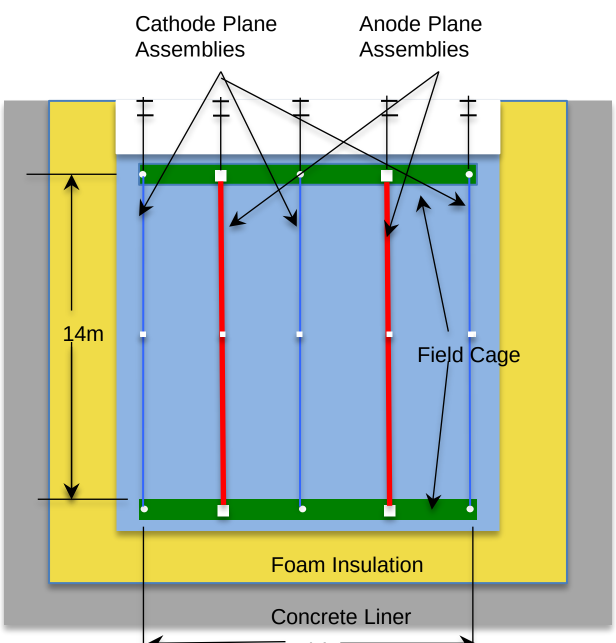


HV Design (cathodes and field cage)

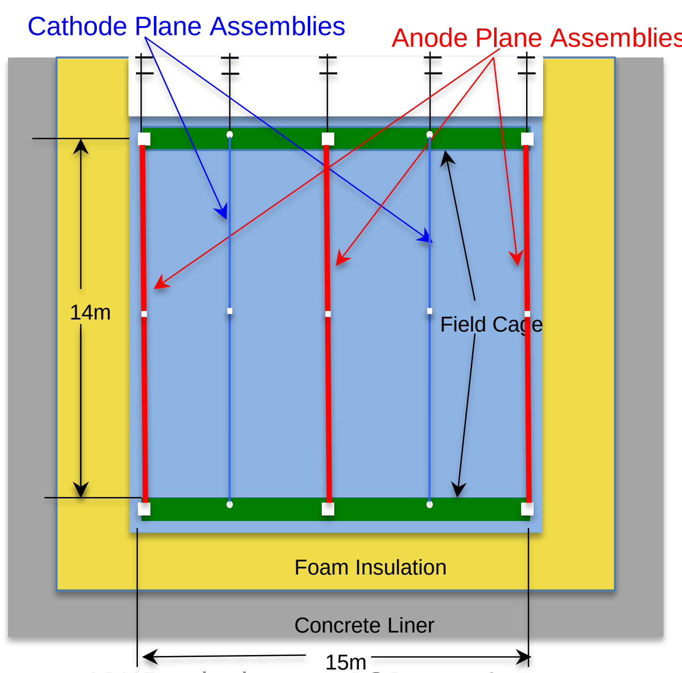
- Extensive work done through MicroBooNE.
  - FNAL has an LDRD dedicated to this.
- LBNE has a prototype feedthru which is tested at 200kV (175 kV required). More QA is needed.
- Very large detectors have a large stored energy.
  - Need to ensure that a discharge does not damage any equipment.
  - Thermal effects, over-voltages of components, or ground shifts that can damage electronics
- Need to slow down the discharge, prevent overvoltage, and manage the stored energy
- Will work on electrical model this year.

Cathode Plane Stored Energy

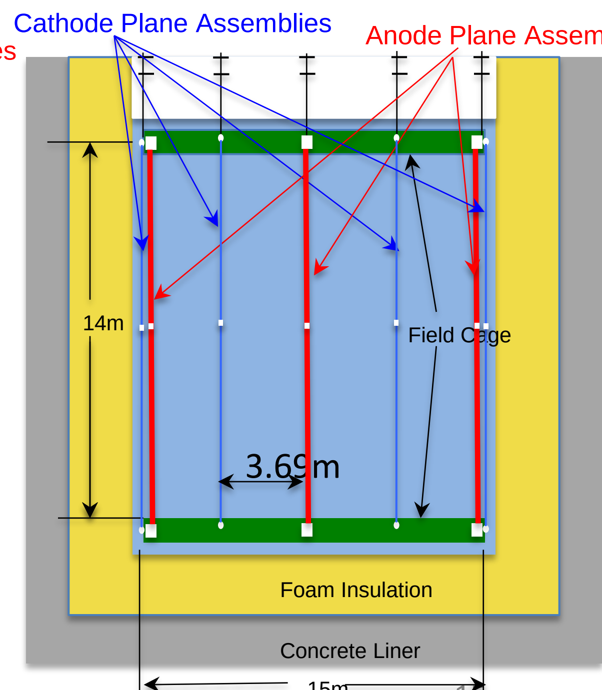
Configuration	Arrangement	d, Wall to CPA (mm)	V, Cathode voltage (kV)	Energy on Cathode Plane (Joules)	Temperature Rise of 2mm SS tube (K)
Design on April 1, 2014	C A C A C	850	-173	85	2700
Design for 5 kv/cm nom	C A C A C	525	-181	150	4793
Anode planes on outsid	A C A C A	4074	-186	20	651
Short 10cm drift at outs	C A C A C A C	4129	-183	20	625



CACAC configuration
Reference Design

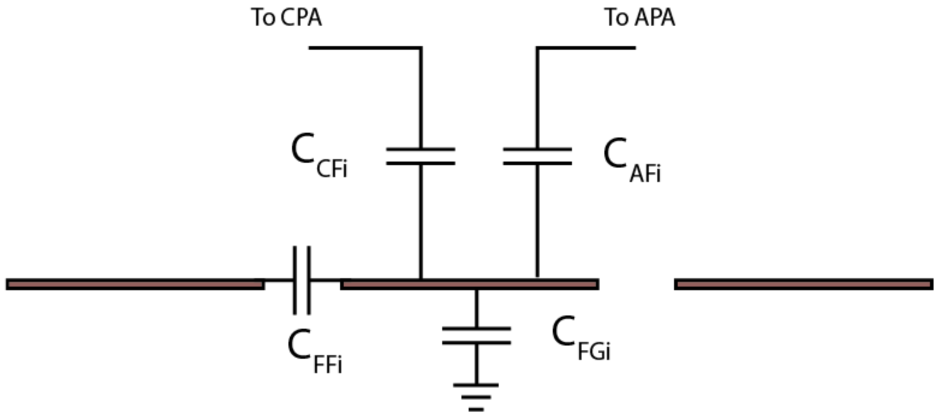


ACACA configuration



CACACAC configuration

Field Cage

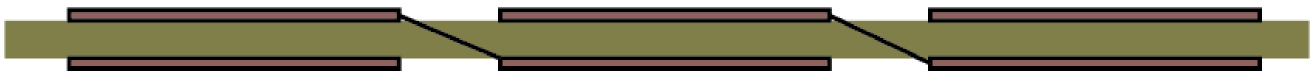


The field cage are constructed of copper strips on FR4 panels.

Recent MicroBooNE studies has shown that an effective method to minimize over voltage conditions between the CPA and field cage strips in the event of CPA or field cage discharge to ground is to increase the inter-strip capacitance.

$$E_{FC} = \frac{1}{2}\sum_{i=1}^{N} C_{CFi} V_{CFi}^{2} + \frac{1}{2}\sum_{i=1}^{N} C_{AFi} V_{AFi}^{2} + \frac{1}{2}\sum_{i=1}^{N} C_{FGi} V_{FGi}^{2} + \frac{N}{2} C_{FF} V_{FF}^{2}$$

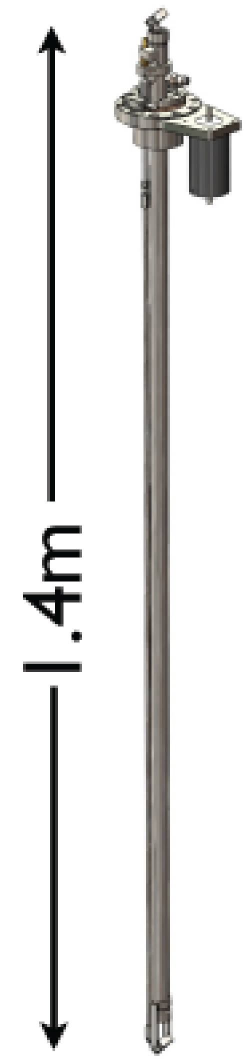
Double sided FR4 panel used to increase the inter-strip capacitance



Need resistive elements in the filed cage to slow discharge

Calibration

- Limitations and capabilities of cosmic rays?
- How to determine the drift velocity?
- How to measure the electron recombination and with what precision?
- How to measure the fiducial volume?
  - What needs to be the survey capability?
- Measuring the filed shape with tracks?
- Laser calibration – How to use the data best?
- How to get the energy scale?
  - Are sources useful?
- Do background sources help in calibration?
  - Ar39 endpoint at 500 keV
  - Look for channels relevant to proton decay?



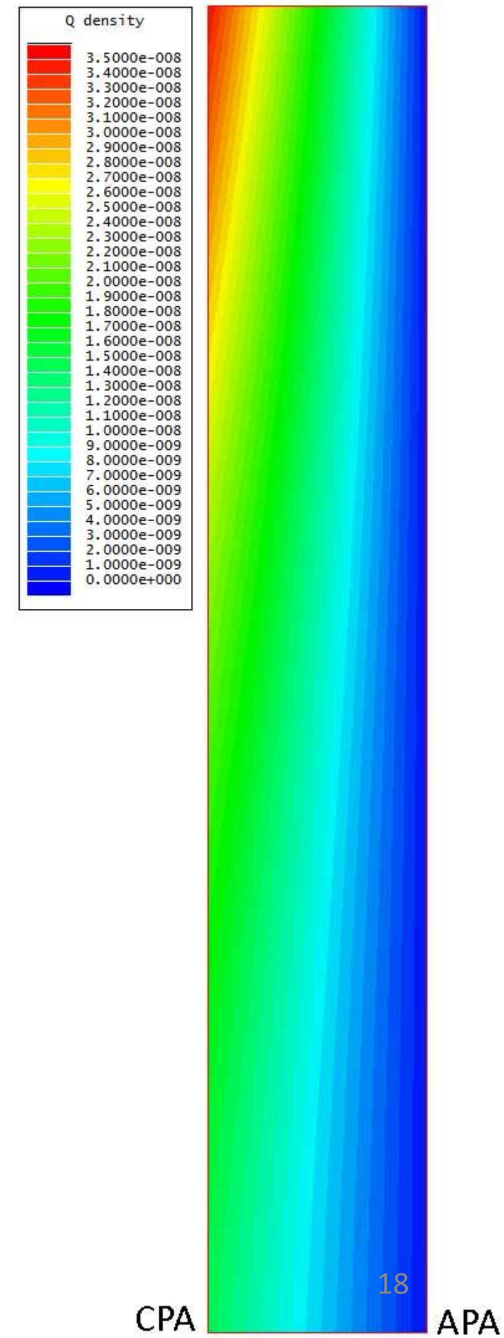
A lot of synergy with MicroBooNE should be possible!

How would the data impact the SBN program?

Space Charge

- Initial studies on surface running Bo Yu 6299
- What impact will this have on the CERN test?
- What impact will this have on MicroBooNE?
  - Accuracy of corrections?
  - Can we measure quantities that will help MicroBooNE?
- What is the ultimate accuracy of surface calibration experiments?

Charge distribution



Trigger development

- External Trigger counters? (Work with LBNO on options?)
- The 35t DAQ is state of the art. All the raw data exists in the warm FPGAs.
  - No work has gone into advanced features.
  - Can an algorithm to identify decaying particles be developed?
  - How would one code a low threshold trigger (4 consecutive hits)?
    - Define the low energy threshold and then measure it?
- Advanced noise analysis and correction?
  - Common mode, vibration, microphonics?

Near-Term LBNF LArTPC Simulation Task List

- Finalize 35t Geometry (we have workable preliminary geometries)
  - wire segments
  - photon detectors
  - scintillator paddles
- Modify signal response for charge drifting in and near gaps
- Add space charge model parameterization
- Check and optimize the NEST electron and photon model
- Develop GGD as a tool for specifying geometries
- Develop photon detector response functions (We are working on this)
- Analyze test-stand photon detectors and understand acceptance and efficiency
- Add modeling of dead wires
- Interface to calibration database
- Simulation data file handling – automatically extract metadata from generated MC files
- Automatically store MC in SAM
- Exercise web-based MC file cataloging

Medium-Term LBNF Simulation Task List

- Make/Validate Geometry for alternate FD's
  - 10 kt, 24 kt, 34 kt, larger (have 10 kt, 34 kt preliminary designs already)
  - APA's on the outside
  - Wire angle variations (already have 36 and 45. Other designs from engineers – 33 degrees)
  - Update 4-APA simpler geometry with new wire angle (33 degrees)
- Make/Validate Geometry for CERN Test-Beam test
- Model two-phase detector in LArSoft
- Make/Validate Geometry for ICARUS re-simulation (have a preliminary geometry)
- Make radiological generator aware of geometry
- Tune simulation of field response and electronics response functions to the 35t prototype data
- Interface with LArIAT data tuning
- Optimize memory and CPU usage and convenience of LArSoft simulations
  - large detectors can easily take lots of memory in simulation programs, but the detector is largely empty

Near-Term LBNF Reconstruction Tasks

- Need to write an input module for the offline to read in DAQ-formatted data
  - Several issues – an "event" is not necessarily the same online and offline
  - Working with the art team on defining a new input module
  - Several 35t run modes to support. Not all are reconstructible and their data can best be analyzed with standalone programs

- Need urgently: disambiguation algorithm for 35t
  - have one that is fairly efficient and pure (but not enough) for the 10 kt APA's but the 35t wires wrap more and are thus more challenging

- Map zero-suppressed data onto offline ROI's (regions of interest) so we don't have to un-zero-suppress

- Characterize hit finder performance and optimize

- Event Display improvements
  - More responsive for online use, show all TPC's at once in real time
  - Write specific displays for different detectors:
    - Small detectors: see all the data at once
    - Large detectors: zoom and drill down
    - Show raw and reconstructed objects. 2D and 3D

Near-Term LBNF Reconstruction Tasks

- Characterize PANDORA performance on tracks and showers
  - Efficiency
  - Energy Resolution
  - Particle ID performance (efficiency, misidentification probabilities)
  - As functions of particle type, containment, energy, angle, and environment

- Characterize competing reconstruction algorithms (FuzzyCluster, DBCluster, Kalman Filter, Bezier tracks, other algoritms) for performance

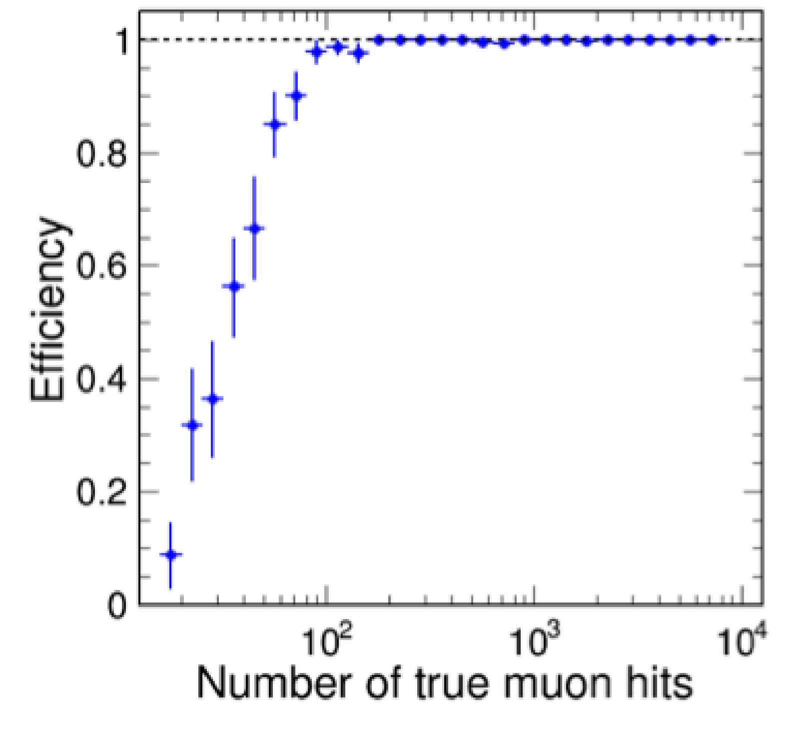
- Incorporate the new MCShower data product to see what the efficiency and purity is for showers (very near term to include this but need it to characterize performance)

- Optimize noise filtering

- Optimize e-gamma/pizero separation
  - ionization at the start of a shower
  - event topology

- Algorithm to measure non-contained muon (and pion) momentum from multiple scattering. Calibrate with stopping muons. Test with LArIAT

Pandora Performance with Cosmic Rays



$$\text{Efficiency} = \frac{\text{True muons with Reco particles}}{\text{True muons}}$$

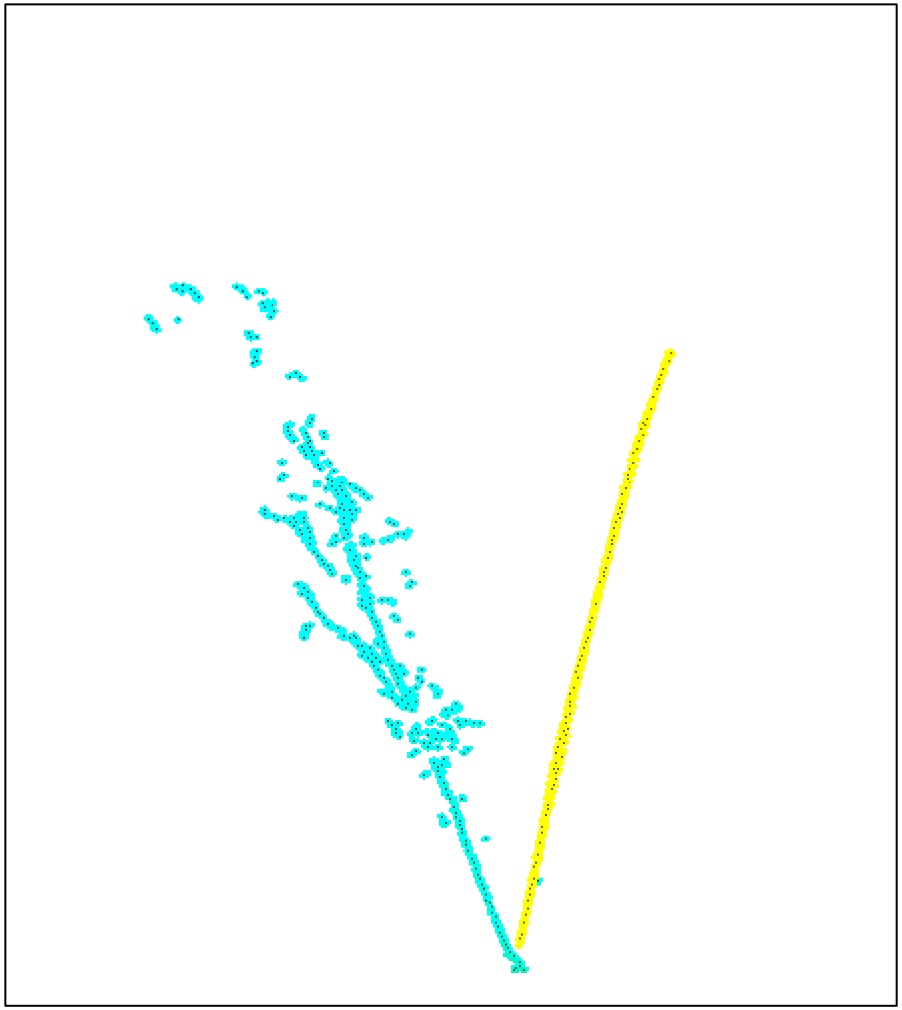
Current performance very good:
Efficiency close to 100% above approximately100 hits.

Significant improvement over past three months:
Aggregation of marginal gains.

A few remaining failures:

- Short tracks (<100 hits).
- Tracks within large showers, where 2D reconstruction is wrong in two views.
- Other assorted mistakes.

3D Particles Reconstructed with Pandora



Animated gif, displaying reconstructed 3D particles, containing 3D hits, for a typical ν_e CC event in the MicroBooNE detector.

All code is available in LArSoft. The Pandora Client App will soon output instances of recob::Particles, a new addition to the LArSoft EDM.

Expect to be able to start systematic studies in ~6 mo

35t Analysis Task List

- Measure Detector signal response by channel for TPC's and Photon Detectors using triggered muons
  - MIP normalization
  - signal shape – field response convoluted with electronics – check model with data and improve it
  - Photon detector absolute efficiency and purity
  - Photon detector timing resolution and stability
  - Photon detector acceptance vs. position of emitted light
- Measure noise – mean, RMS, frequency spectrum
- Measure electron lifetime with cosmic-ray tracks
- Measure t_0 offsets between TPC, Photon Detectors, and Paddles
- Measure drift velocity
- Select and reconstruct straight tracks. Calibrate efficiency in data using triggers
- Characterize performance of charge collection in gaps and through APA wire planes

35t Analysis Task List

- Define and Measure detector alignment constants
- Test space charge models. Measure space charge distribution if possible.
- Select a sample of stopping muons.
  - Online filter
  - Offline selection
- Stopping particle analysis
  - dE/dx vs. residual range calibration
  - PID optimization and validation
    - muons, (both signs separately) protons, charged pions, kaons
  - Michel electron analysis and calibration of electron response
- pizero selection and analysis
  - EM energy scale measurement
- Neutron selection and analysis
- Spallation products
- Measurement of Radiological event rates and spectra

Detector Optimization Tasks

Propagate to impacts on physics sensitivity. Fast MC provides the last step, at least for beam physics.

- Supernova Burst and Nucleon Decay analyses have different demands on the detector. Even down to the optimal definition of an "event"
- Wire angle optimization
  - Effects on resolution, efficiency, and PID. Correct hit assignment and disambiguation issues
- Wire spacing optimization:
  - signal/noise vs. spatial resolution vs. cost
- Test the geometry choice with APA's on the outside vs. APA's on the inside
- Backgrounds for SNB and nucleon decay analyses may be the most important issue here
- Just three wire planes? Additional wire planes at different angles?
- Optimize fiducial volume cuts (analysis dependent, and breaking events into contained and non-contained categoreies)

BACKUP

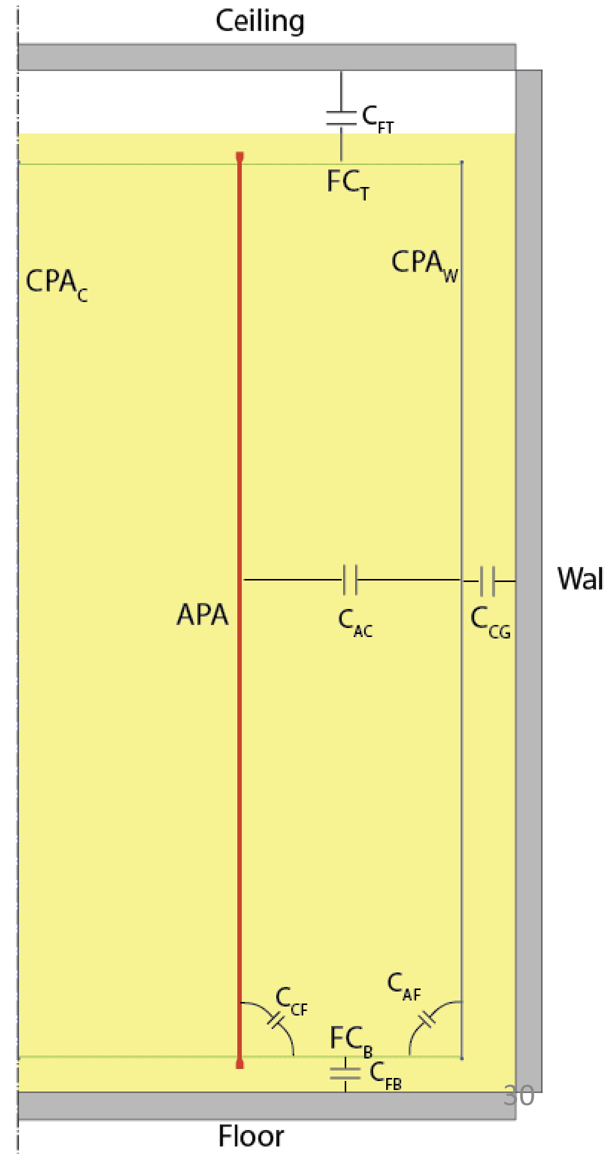
2D Model of the TPC

A 2D model of the TPC is used to calculate the capacitance matrix of all major components in the TPC. The following tables shows a few elements related to the CPA_W (outside CPA):

	CPA_W
wall	2.276E-10
floor	9.355E-12
ceiling	1.772E-12
APA	4.221E-11

Unit: F/m

$$E = \sum \frac{1}{2} C_{ij} V_{ij}^{2}$$



Detector Design and MC validation

- Identify necessary detector improvements!
- Data/MC comparison to tune the MC.
- Define projected performance parameters!
- Study impact of changing the detector design.
  - Different wire pitch
  - Different wire angle
  - Different plane ordering
- Refine Requirements
- Most the plots for CD3.