# CAPTAIN Update

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Los Alamos National Laboratory
9 July 2014

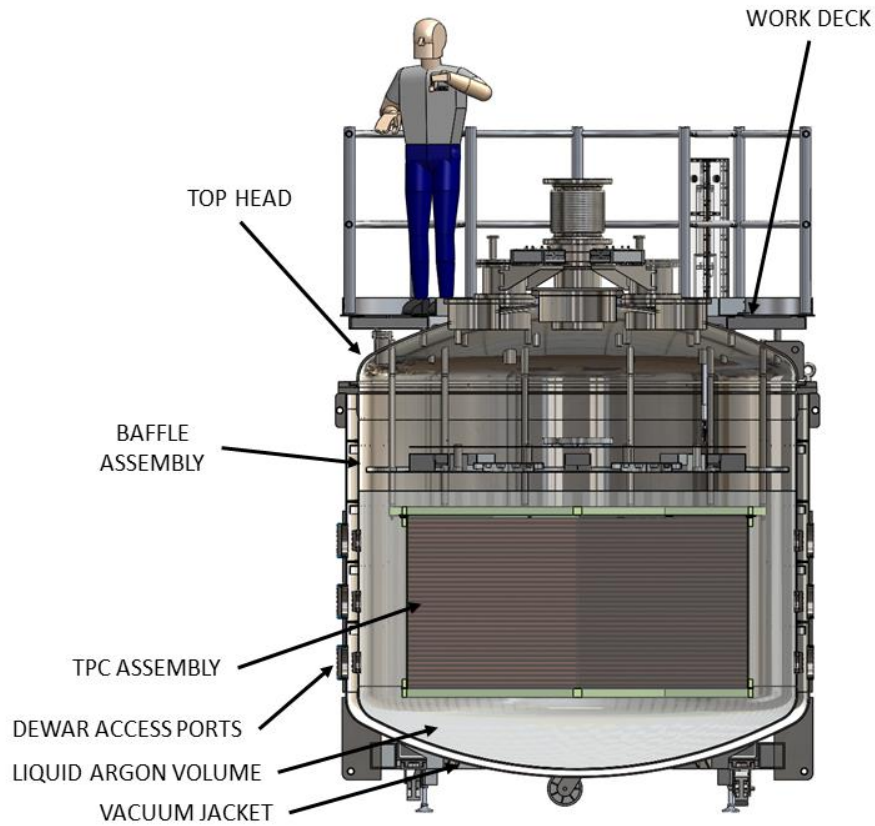
# Outline

- The CAPTAIN Program
  - Detector
  - CAPTAIN motivation
    - Neutron Running
    - Neutrino Running
  - Status: cold $N_2$ testing of mini-CAPTAIN
- Conclusions

# The CAPTAIN Program

CAPTAIN: Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos

- Liquid argon TPC
  - 5 instrumented tons
  - hexagonal TPC with 1 m vertical drift.
  - 2000 channels, 3mm pitch, 75 μm BeCu wire.
  - cryostat 7700 liter capacity, evacuable, portable
  - all cryogenic connections made through top head
  - indium seal – can be opened and closed
  - photon detection system and laser calibration system
  - using same cold electronics, readout electronics, and DAQ chain as MicroBooNE
- Designed to operate safely at multiple facilities
  - compliant with standard pressure safety regulations
  - compliant with electrical safety practices
  - can be loaded and shipped by truck
- Being constructed with internal Los Alamos National Laboratory funds (Laboratory Directed Research and Development)
- mini-CAPTAIN prototype, 1000 channels, 30cm drift, 400 instrumented kilograms



# CAPTAIN Collaboration

- Alabama: Ion Stancu
- ANL: Zelimir Djurcic
- LBL: Vic Gehman, Richard Kadel, Craig Tull
- BNL: Hucheng Chen, Veljko Radeka, Craig Thorn
- UC Davis: Hans Berns, Dan Danielson, Chris Grant, Aaron Manalaysay, Emilja Pantic, Robert Svoboda, Matthew Szydagis
- UC Irvine: Michael Smy
- UC Los Angeles: David Cline, Kevin Hickerson, Kevin Lee, Elwin Martin, Jasmin Shin, Artin Teymourian, Hanguo Wang, Lindley Winslow
- FNAL: Oleg Prokoviev, Jonghee Yoo
- Hawaii: Jelena Maricic
- Houston: Babu Bhandari, Lisa Whitehead
- Indiana: Stuart Mufson

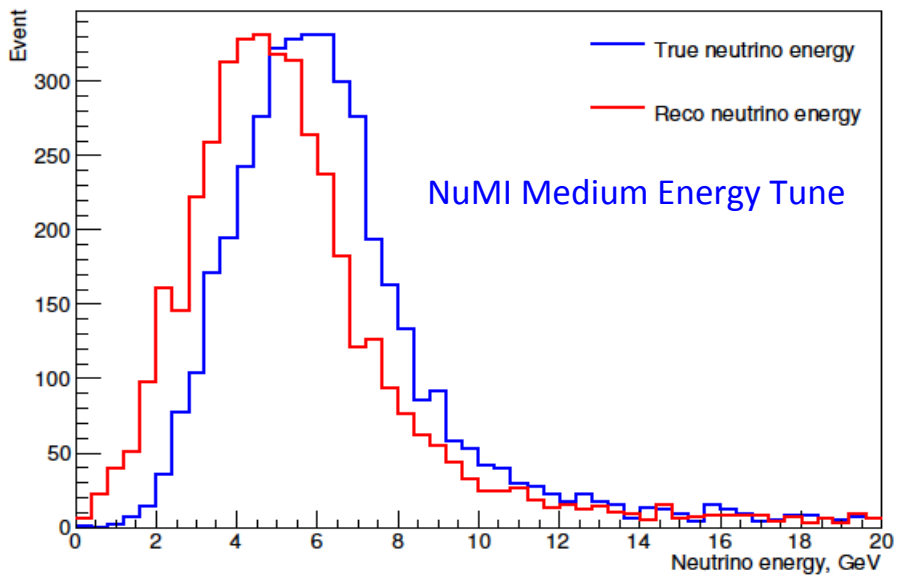
- LANL: Jeremy Danielson, Steven Elliott, Gerald Garvey, Elena Guardincerri, Todd Haines, Wesley Ketchum, David Lee, Qiuguang Liu, William Louis, Christopher Mauger, Geoff Mills, Jacqueline Mirabal-Martinez, John Ramsey, Keith Rielage, Constantine Sinnis, Walter Sondheim, Charles Taylor, Richard Van de Water, Kevin Yarritu
- Louisiana State University: Flor de Maria Blaszczyk, Thomas Kutter, William Metcalf, Martin Tzanov
- New Mexico: Franco Giuliani, Michael Gold
- South Dakota: Chao Zhang
- South Dakota State: Robert McTaggart
- Stony Brook: Clark McGrew, Chiaki Yanagisawa

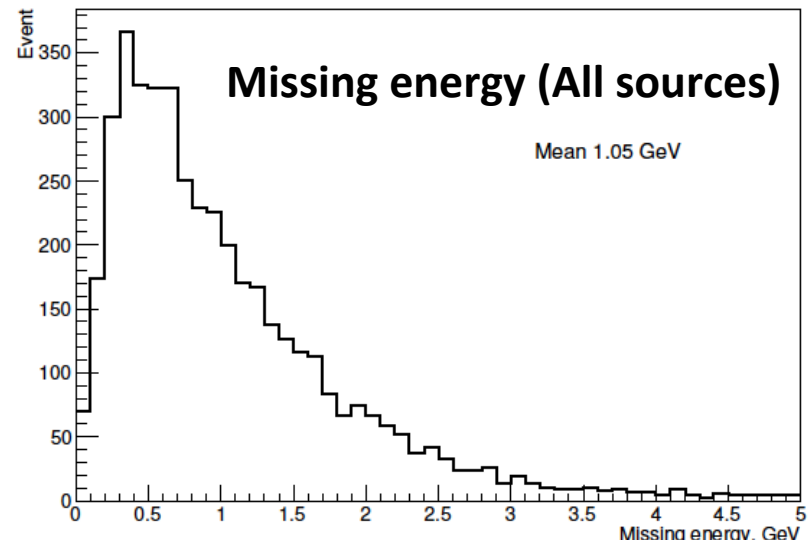
# CAPTAIN Physics Program

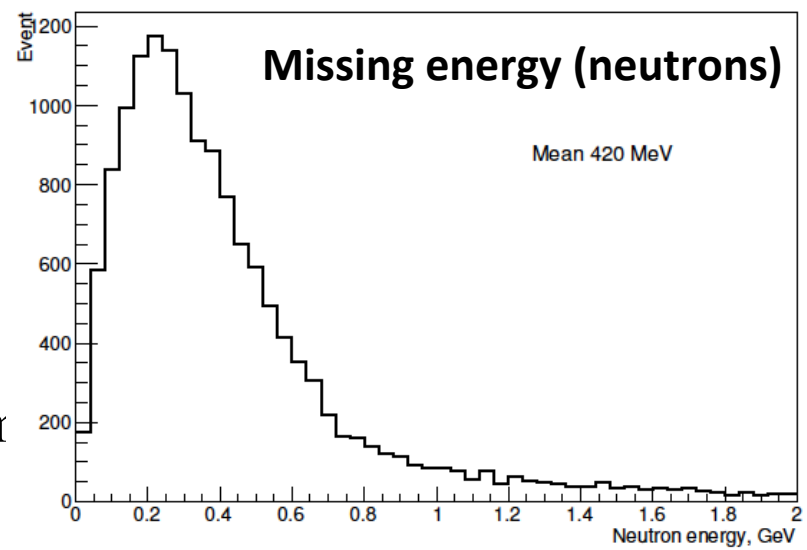
Neutron Beam
Low-Energy Neutrino Beam
Medium-Energy Neutrino Beam

- Low-energy neutrino physics related
  - Measure neutron production of spallation products
  - Benchmark simulations of spallation production
  - Measure the neutrino CC and NC cross-sections on argon in the same energy regime as supernova neutrinos
  - Measure the correlation between true neutrino energy and visible energy for events of supernova-neutrino energies
- Medium-energy neutrino physics related to SBN/LBNE
  - Measure neutron interactions and event signatures (e.g. pion production) to allow us to constrain number and energy of emitted neutrons in neutrino interactions
  - Measure higher-energy neutron-induced processes that could be backgrounds to $\nu_e$ appearance e.g. $^{40}Ar(n,\pi^0)^{40}Ar^{(*)}$
  - Measure inclusive and exclusive channels neutrino CC and NC cross-sections/ event rates in a neutrino beam of appropriate energy
  - Test methodologies of total neutrino energy reconstruction with neutron reconstruction

# Importance of Understanding Neutrons in LAr




- Neutrons can carry away significant energy
- Uncertainties also large
- We would like to determine how to use these neutrons
- Deploy CAPTAIN in a neutron beam

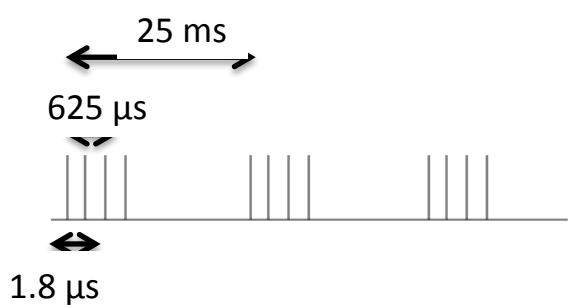
# Importance of Understanding Neutrons in LAr

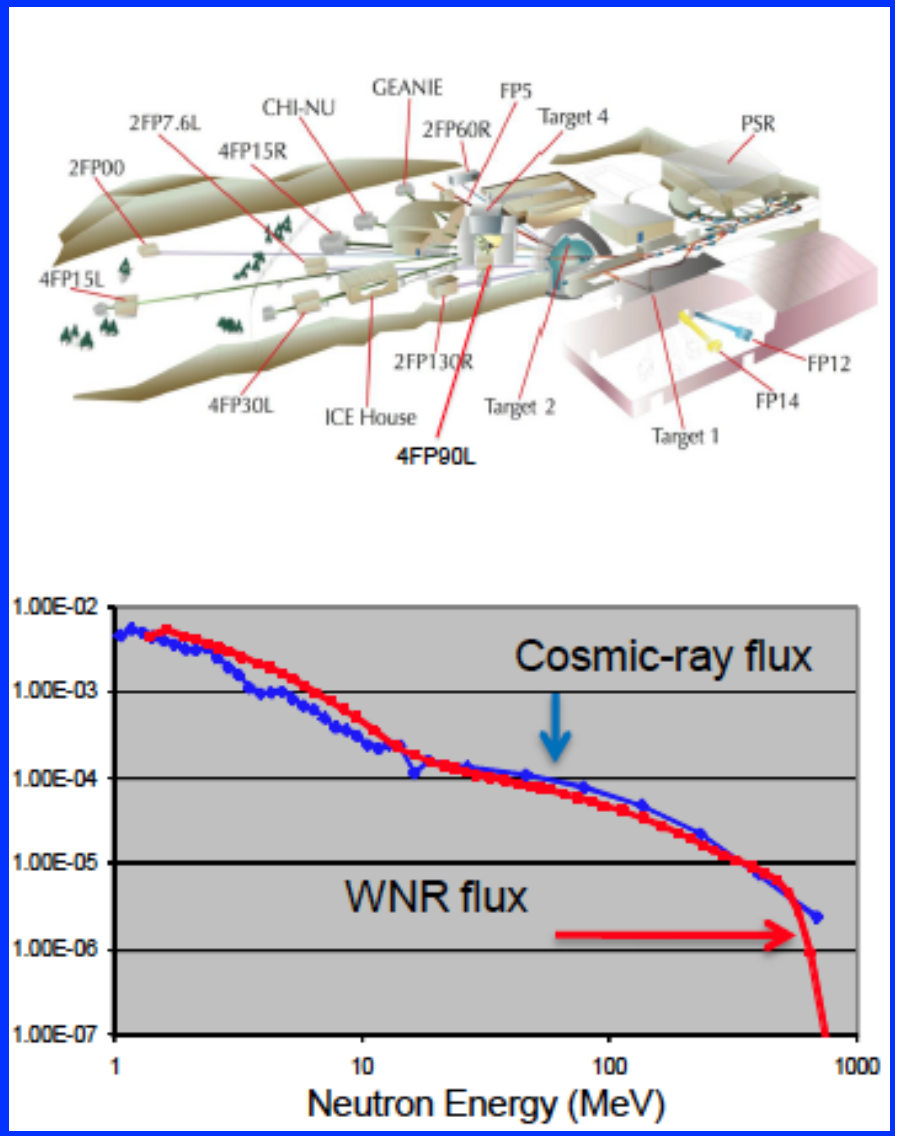
- For surface detectors, cosmic induced neutrons are a potential background.
- For both surface and underground detectors, neutrons induced by neutrinos in the rock (dirt events) are a potential background.
- Rates of both processes hard to model. **Cannot rely on MC!**
- With good neutron response calibrations can reconstruct these events in random triggers (cosmics) and spatially forward (dirt) events. **Provides data driven rate estimates!**
- Analysis most effected by neutron backgrounds are low energy neutrino neutral current and direct production/ detection Dark Matter measurements.

# Neutron Beam at LANL

- Los Alamos Neutron Science Center WNR facility provides a high flux neutron beam with a broad energy spectrum similar to the cosmic-ray spectrum at high altitude

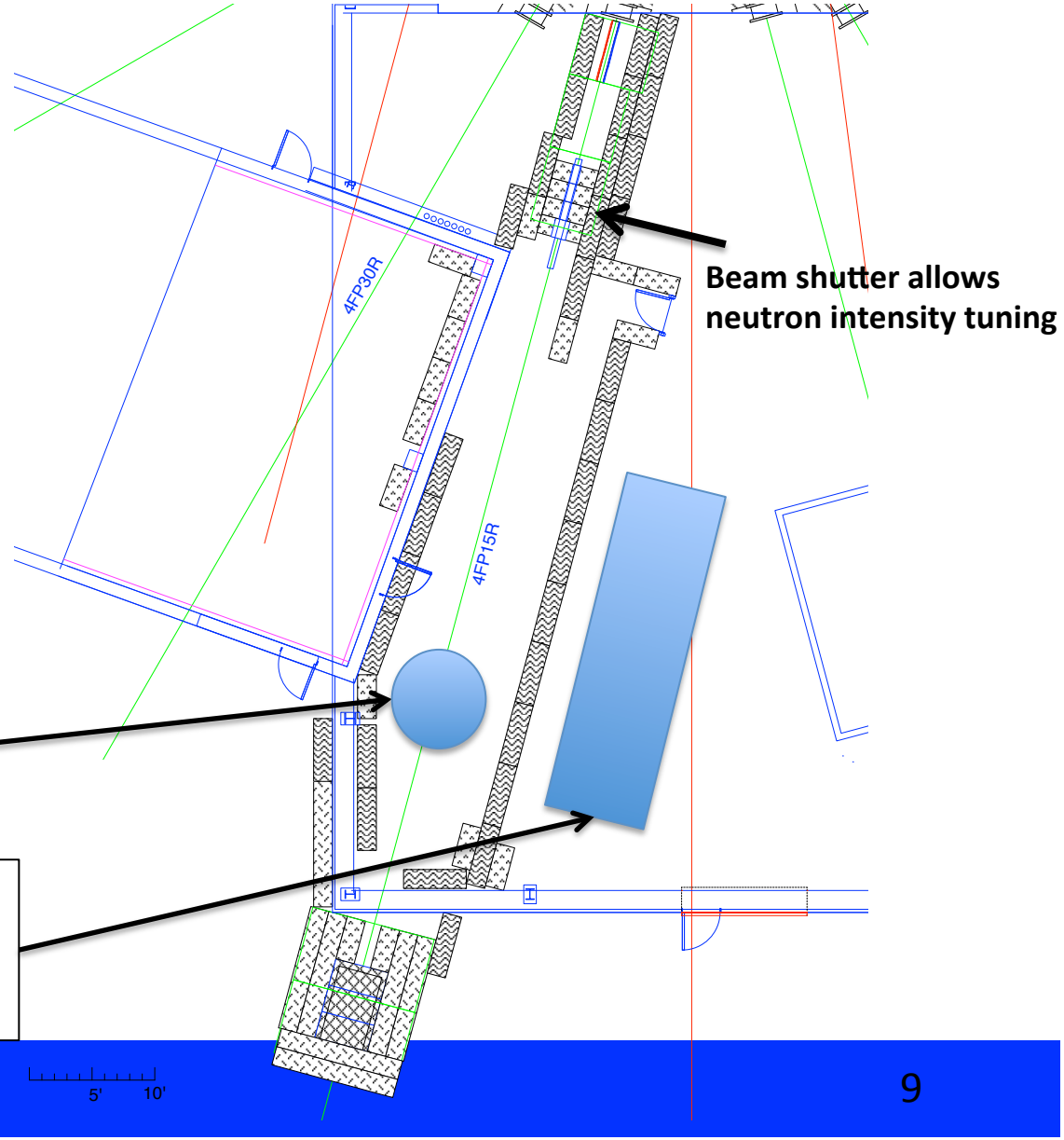
- Time structure of the beam
  - sub-nanosecond micro pulses 1.8 microseconds apart within a 625 μs long macro pulse
  - Repetition rate: 40 Hz



# Neutron Beamline

- Anticipate two run conditions:
  - High-intensity (normal) where we expose our detector to a high flux, close the shutter, identify produced spallation events
  - Low-intensity where we get one neutron event per macropulse
- Granted two low-intensity runs last autumn for engineering studies
- Anticipate Mini-CAPTIAN run in early 2015.
- **A one week run will generate millions of neutron interactions.**



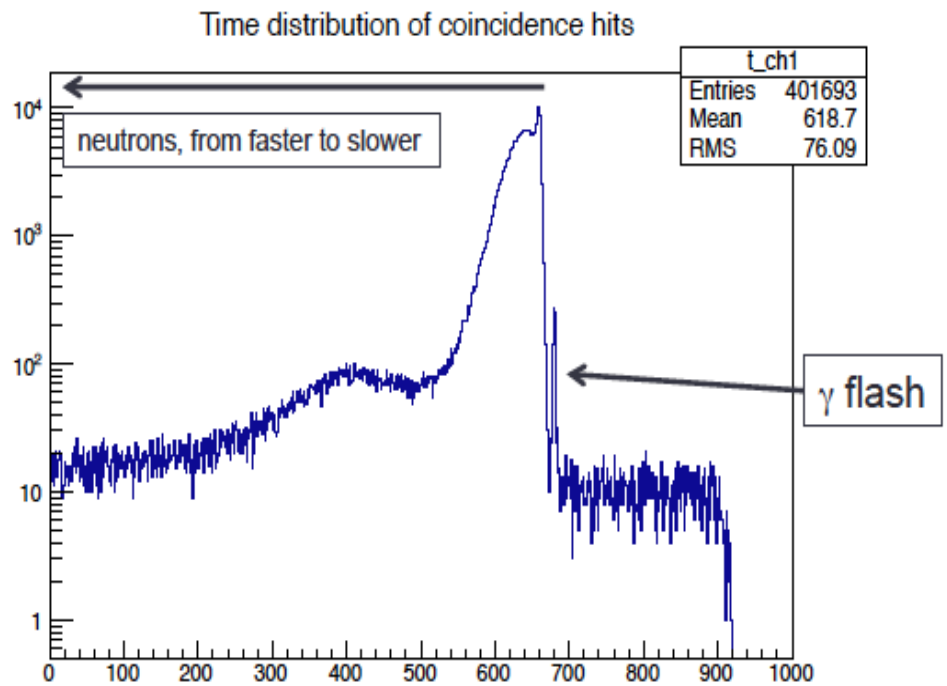

- Electronics and DAQ
- LAr purification system
- LAr cryogenic system

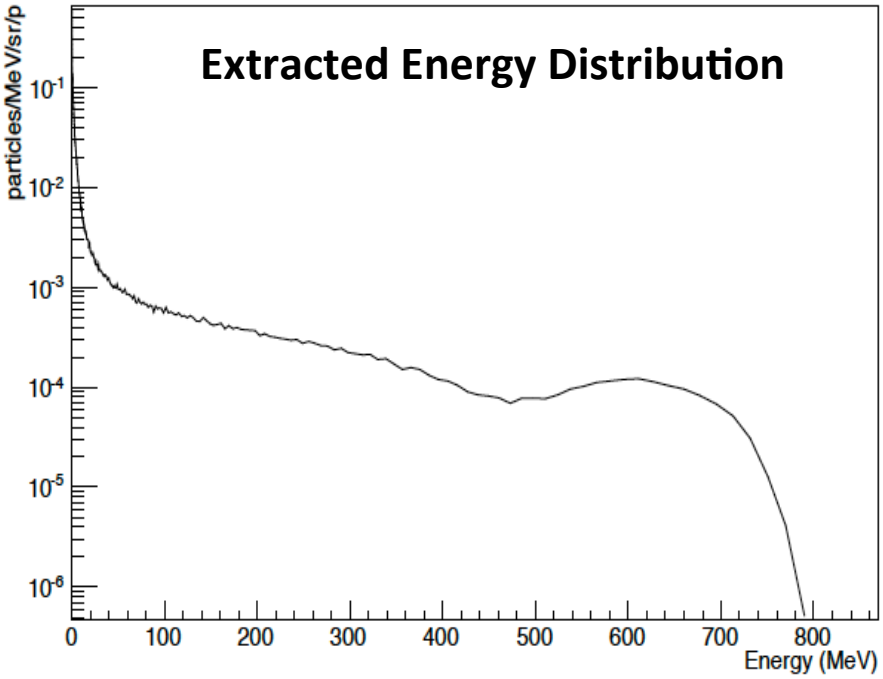
# Low-intensity neutron running

48 in long plastic scintillator with 2 PMTs at 25 m from production target

Effort led by Elena Guardincerri

# Test Neutron Data



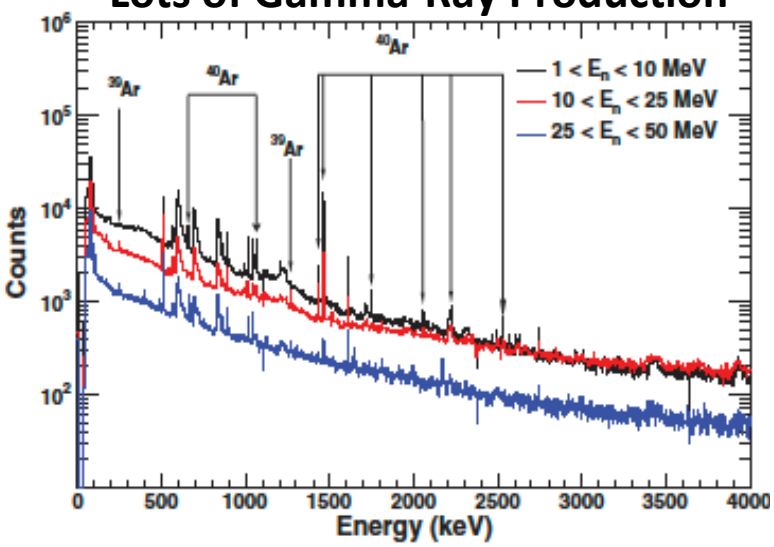




**Mini-CAPTAIN will have 16 1" PMT's which can measure the neutron time of flight (energy).**

# Expected Results from Neutron Run

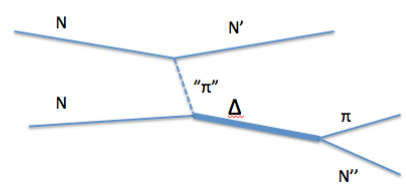
- Most neutrons reaching the detector will interact: At low energy < 3MeV the total cross section is ~3b and drops to about 2b at 20 MeV. Thus the MFP at 20 MeV is about 25 cm.
- Neutron interactions in LAr are complicated and not well understood…

**Lots of Gamma-Ray Production**




***π events estimated to be 5 to 10%, with very different charge multiplicities!***

N-N Pion Production via Delta




(Garvey)

| | | |
|---|---|---|
| $n-n$ | $\pi^-$ | $\frac{10}{12}$ |
| | $\pi^0$ | $\frac{2}{12}$ |
| | $\pi^+$ | 0 |
| $n-p$ | $\pi^-$ | $\frac{1}{12}$ |
| | $\pi^0$ | $\frac{4}{12}$ |
| | $\pi^+$ | $\frac{1}{12}$ |

*Ratios will be modified by FSI*

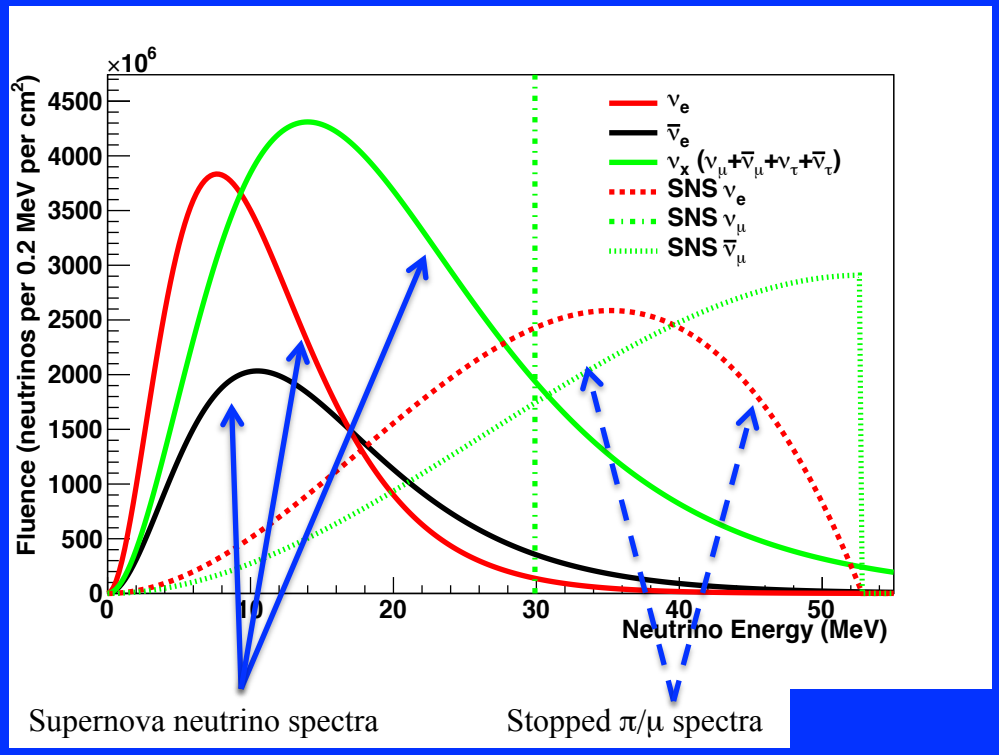
| | |
|---|---|
| $\pi^-$ | $\frac{11}{12}$ |
| $\pi^0$ | $\frac{6}{12}$ |
| $\pi^+$ | $\frac{1}{12}$ |

# Our proposal and goals

- Using time-of-flight techniques we can correlate a visible interaction in a liquid argon TPC with a neutron of a specific kinetic energy.
- Plan to study neutron interactions on LAr in terms of their topology, of the multiplicity and identity of the visible particles in the final state and of their kinematic properties
  - Focus in particular on primary neutron interactions (known incident neutron energy) and obtain a catalogue and a probability distribution of the possible topologies of events (and their properties) as a function of the incoming neutron energies

**Ultimate goal: use our catalogue to identify outgoing neutrons in neutrino interactions and obtain a PDF for their energy, to be used in neutron background measurements and the reconstruction of the incident neutrino energy.**

# Running at a stopped pion source



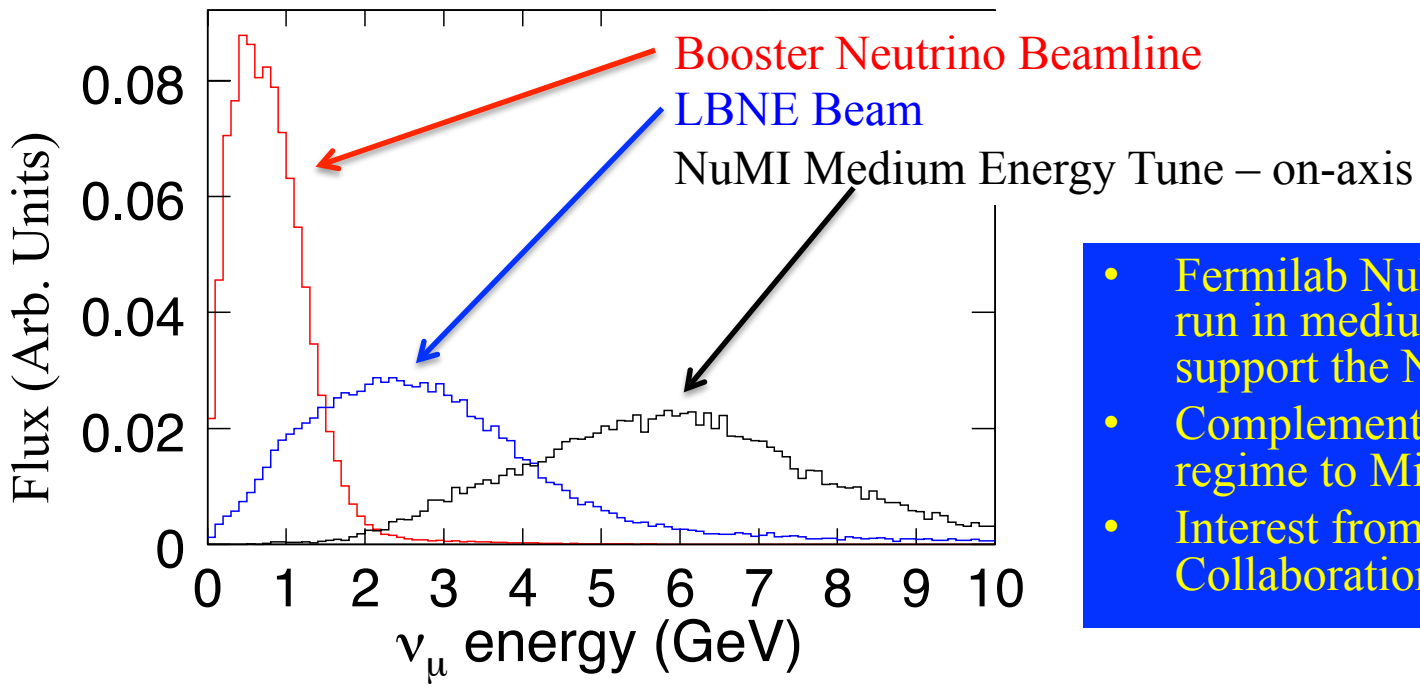

From:arXiv:1211.5199

Plot for SNS, but spectra are generic for a stopped π/μ source

- P5 report: ``The experiment (LBNE) should have demonstrated capability to search for supernova bursts''
- Neutrinos in the supernova energy regime have never been detected with a liquid argon TPC
- Cross-section uncertain
- Detection efficiencies unknown

- Exploring opportunities using the SNS or BNB as a stopped pion source

# Neutrino Spectra




- Fermilab NuMI beamline – will run in medium energy tune to support the Nova Experiment
- Complementary neutrino energy regime to MicroBooNE
- Interest from Minerva Collaboration

- Approximately 1 million contained events per year ($4 \times 10^{20}$ POT) (containing all but lepton)
  - detailed exploration of threshold region for multi-pion production, kaon production
  - high-statistics data for algorithm development required for LBNE
  - employment of methods for neutron energy reconstruction
  - early development of multi-interaction challenge – must solve if wish to usefully employ a near liquid argon TPC

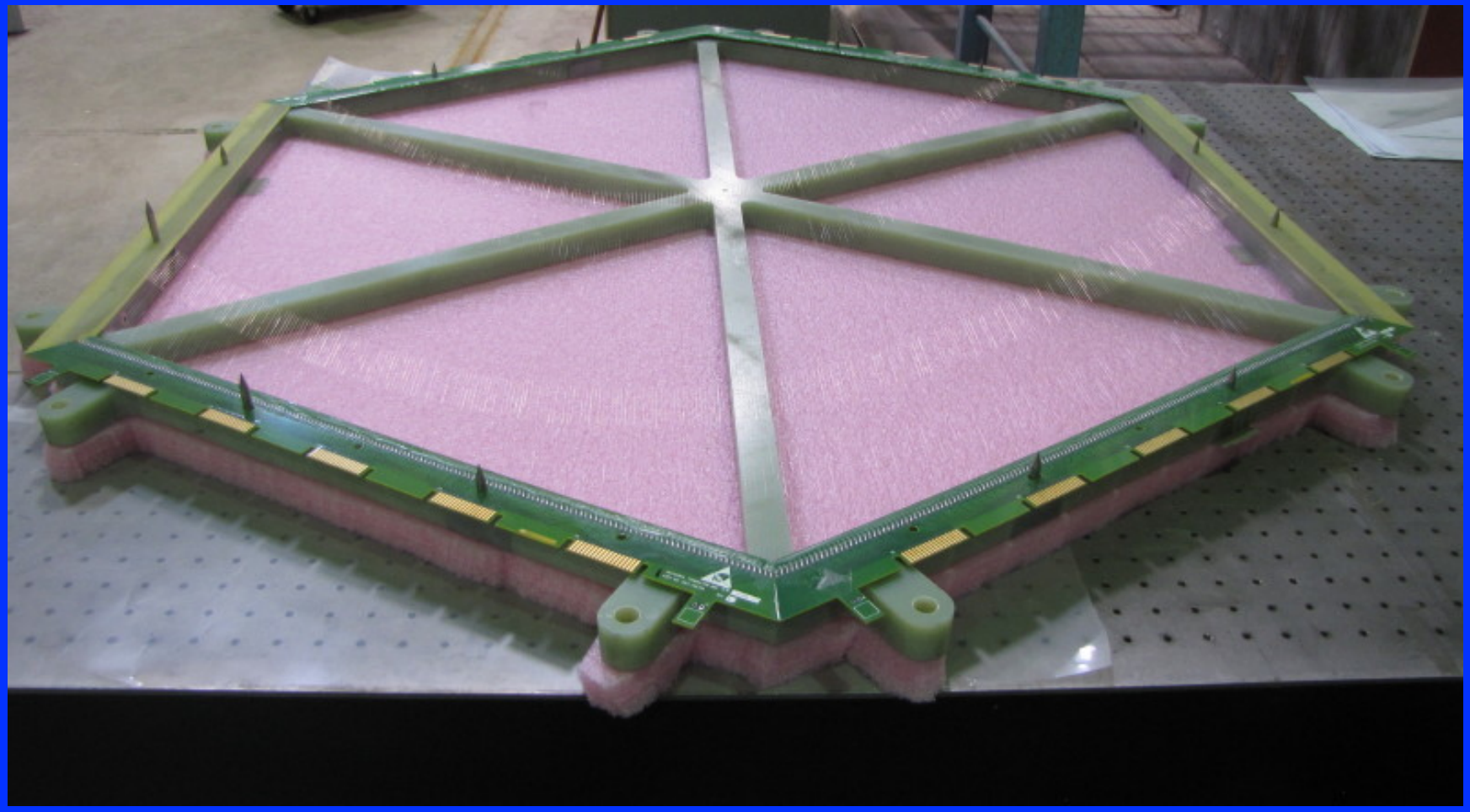
# CAPTAIN Current Status

- Electronics end-to-end acquired and tested for the prototype and for CAPTAIN
- DAQ tested
- Prototype TPC completed and tested
- LAr Cryogenic circulation and filter system being assembled
- First argon fill planned for August 2014
- Laser (see Gus Sinnus talk) and cosmic rays calibrations
- mini-CAPTAIN neutron run in 2015
- CAPTAIN cryostat delivery expected in October
- CAPTAIN purification skid expected in November
- CAPTAIN TPC assembled this summer at UCI

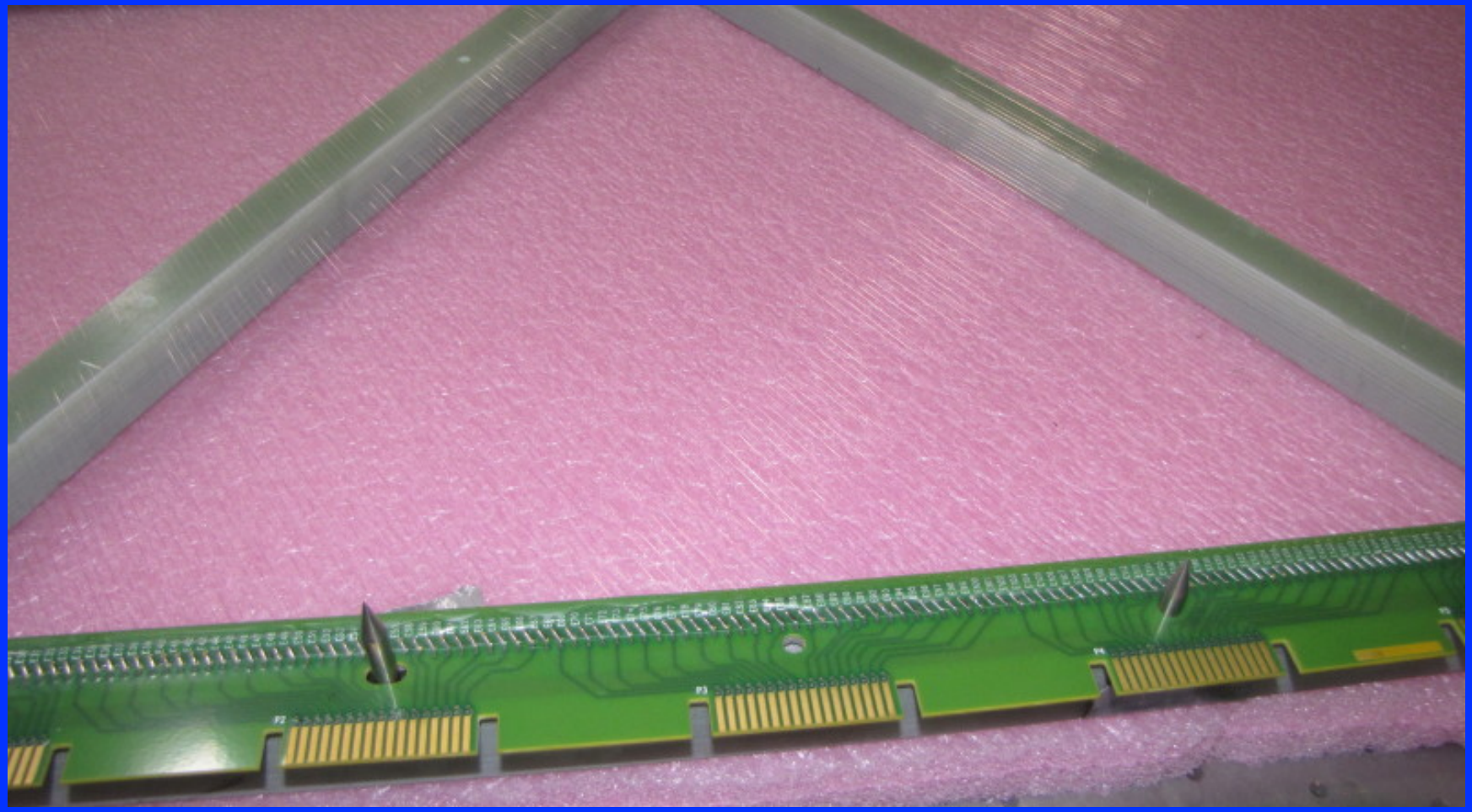
**mini-CAPTAIN $LN_2$ cold testing the last two weeks**

# Mini-CAPTAIN field cage

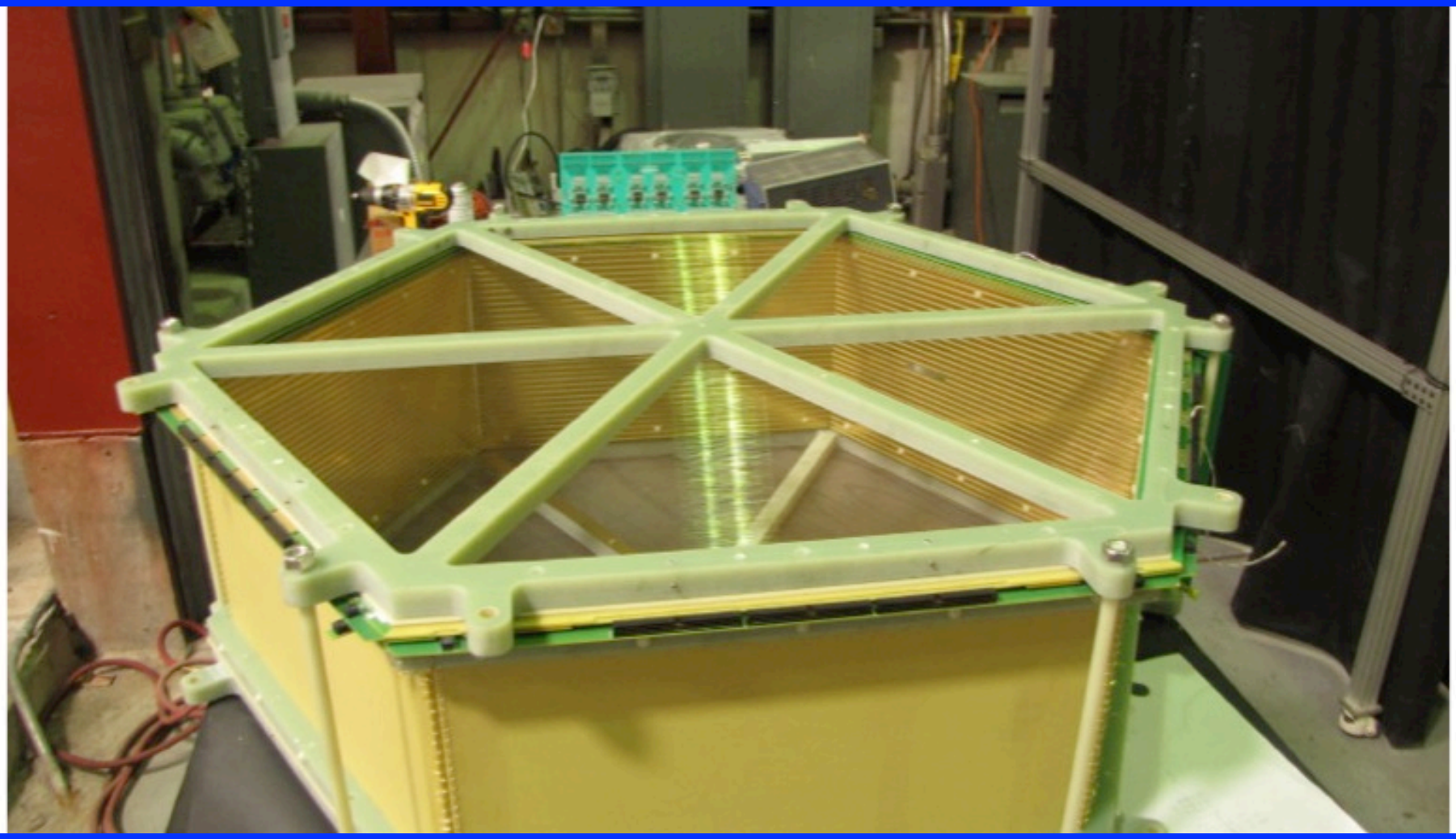
# Mini-CAPTAIN wire frame



# Wire-frame close-up

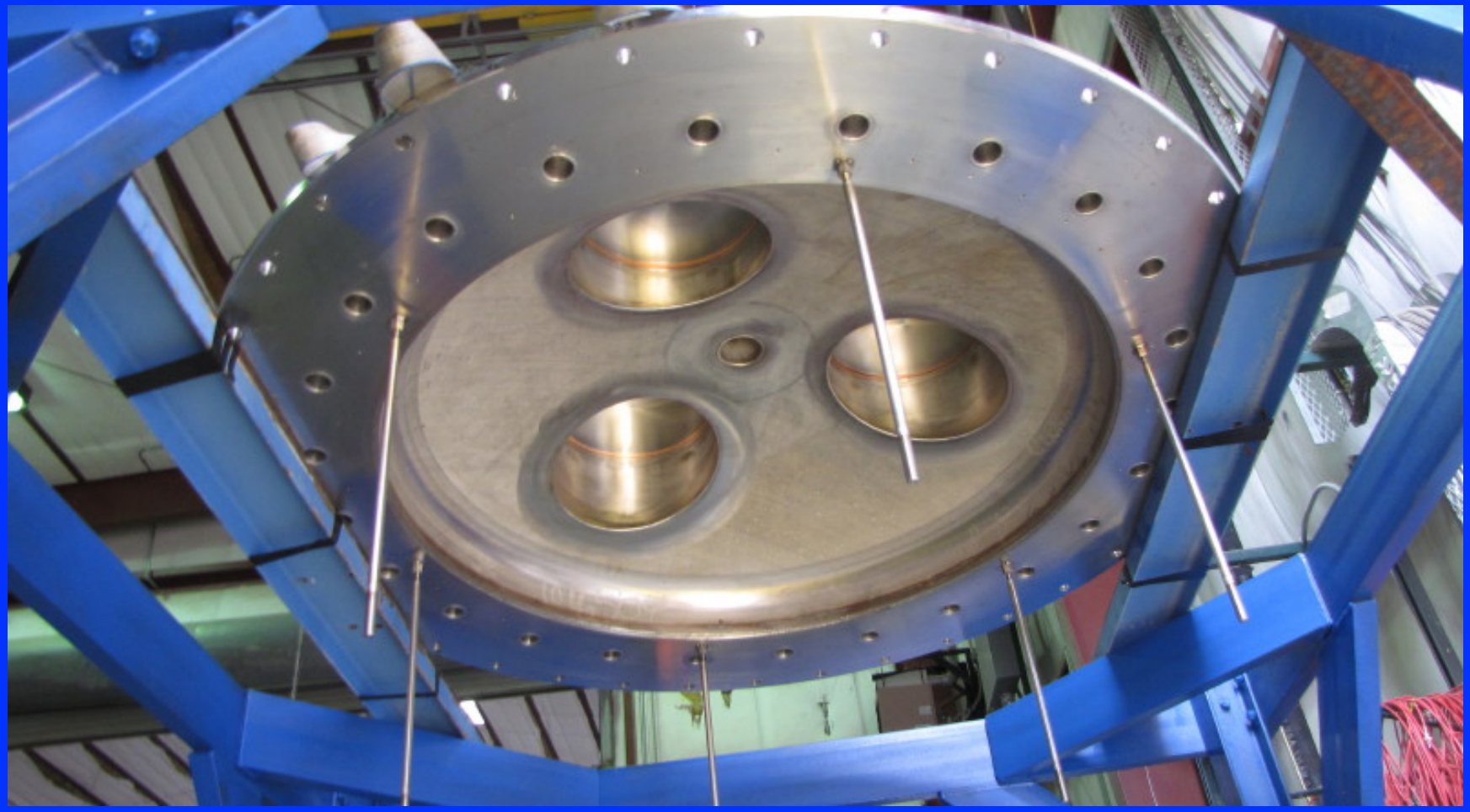


# Mini-CAPTAIN TPC assembled



# Mini-CAPTAIN cryostat

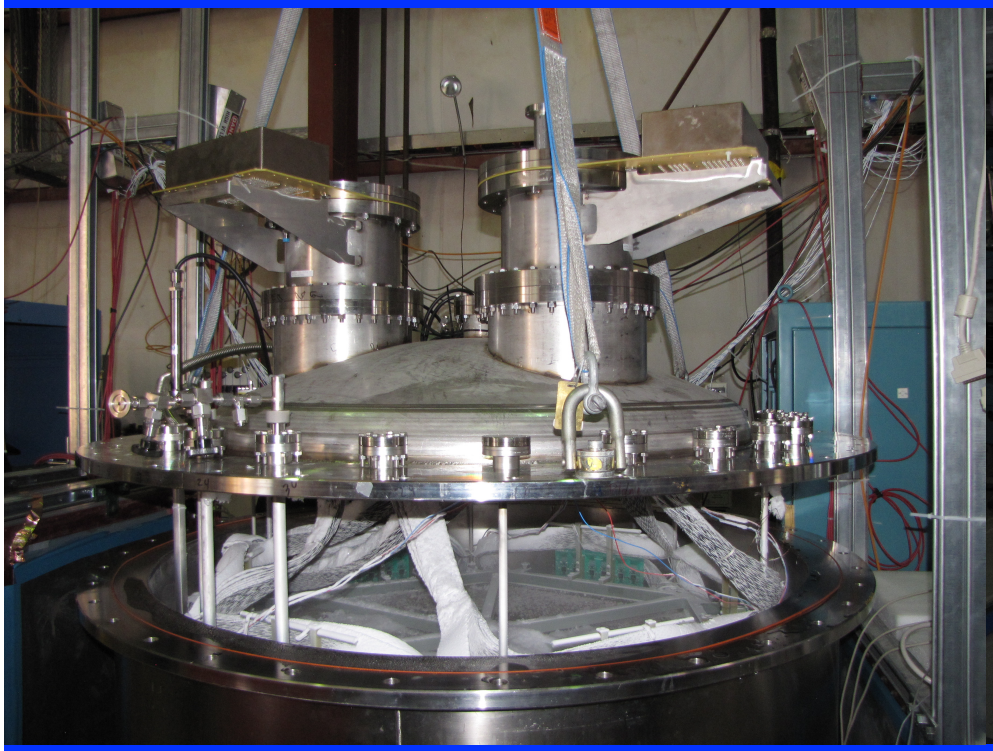
# Mini-CAPTAIN lid and support stand



# Prototype Detector: Tophat and TPC

LANL postdoc Charles Taylor prepares the prototype

# Prototype Detector TPC removed after First LN2 Cold Test

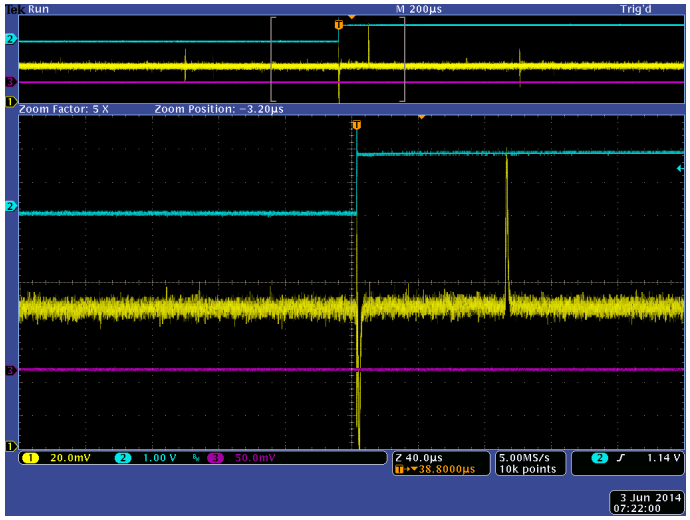


A very cold detector!  We are working to mitigate snow buildup next time.

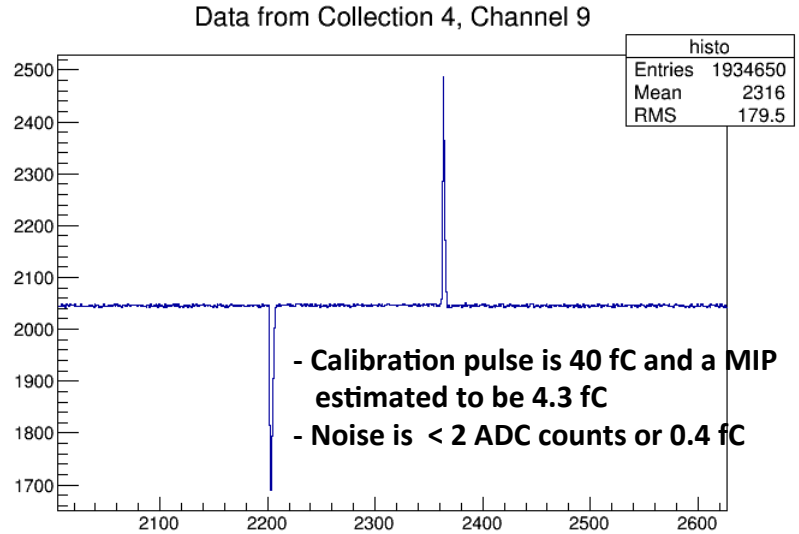
# Electronics/DAQ Testing

- Cold testing of mini-CAPTAIN 1000 channels front and back-end electronics (uBooNE design) shows good performance.
- Stable, with HV on, over two weeks of $LN_2$ testing. We have begun to carefully monitor channel health versus time.
- Have achieved designed S/N ~ 10:1 for most channels.

**With Scope…**

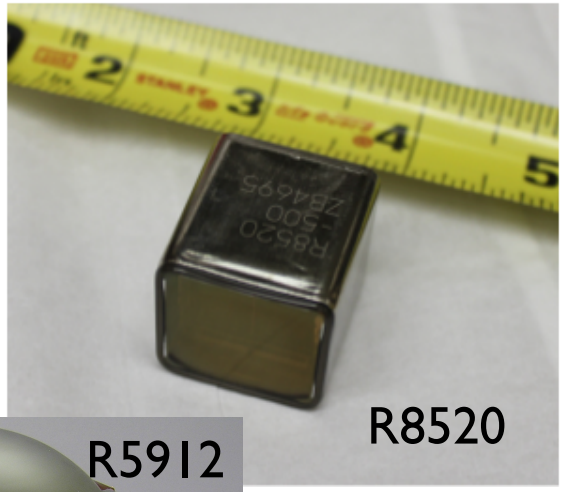



**With DAQ readout…**



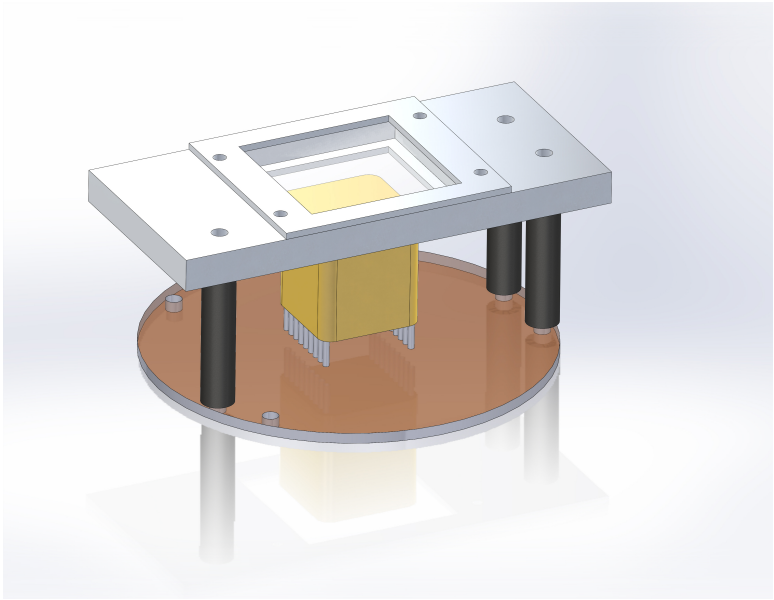
# Photon Detector Options

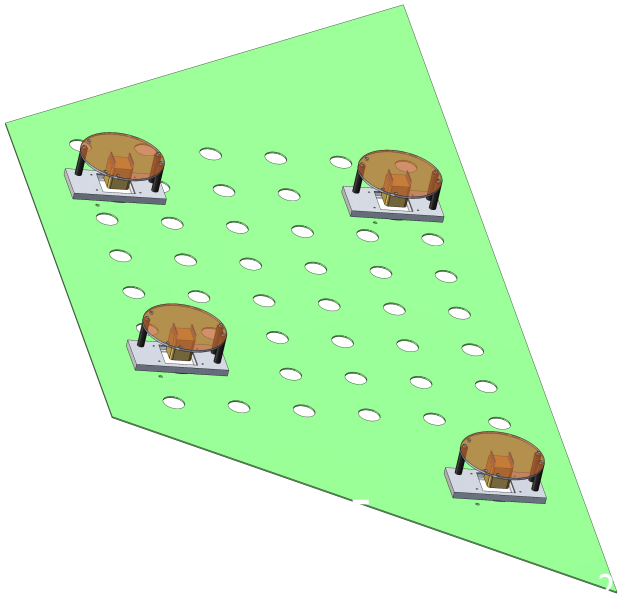
- Four LAr PMT options:
  - Hamamatsu R8520-500
    - 1” square, 25% QE at LAr temperature, special Bialkali LT
  - Hamamatsu R6041-506
    - 2” diameter, 25% QE at LAr temperature, special Bialkali LT
  - Hamamatus R11065
    - 3” diameter, 25% QE at LAr temperature, special Bialkali LT
    - Used by DarkSide
  - Hamamatsu R5912-02Mod
    - 8” hemispherical, 18% QE at LAr temp, regular Bialkali with Pt flash
    - Used by MiniCLEAN, microBooNE



# Photon Detectors for Mini-CAPTAIN

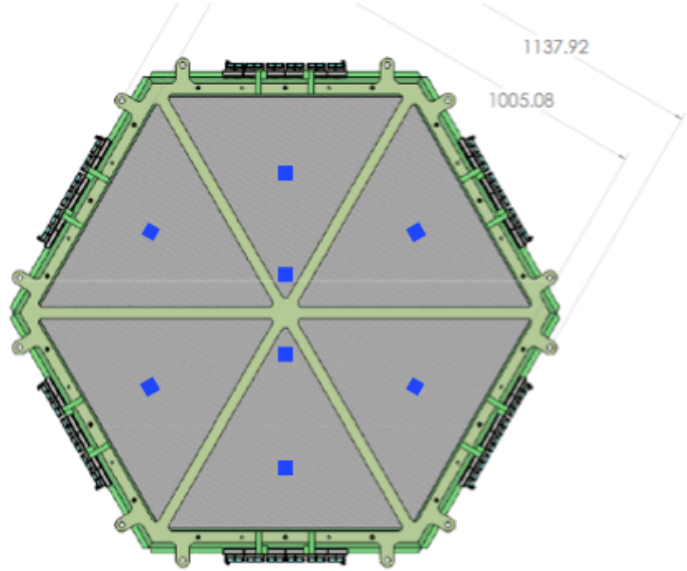
- Mini-CAPTAIN will use:
  - 16 -- 1” R8520 PMTs
  - TPB wavelength shifter on acrylic slide in front of PMT
    - Allows us to insert the TPB right before closing up to prevent degradation from UV and dust
- CAPTAIN will use:
  - 16 to 24 -- 1” R8520 PMTs
  - 2 to 4 -- 3” R11065 PMTs
- Will be mounted on top and bottom behind grounding plane

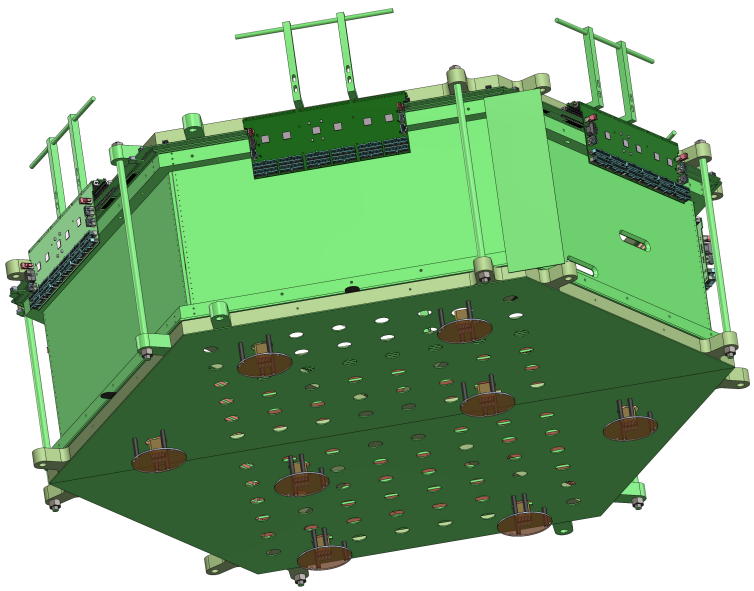


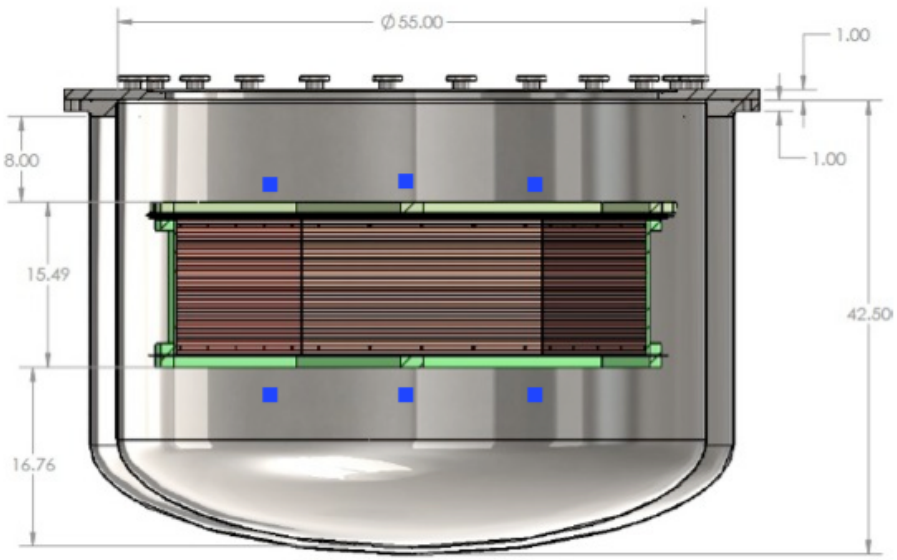


# Mini-CAPTAIN PMT Placement

- 16 R8520 PMTs:
- 8 top
- 8 bottom



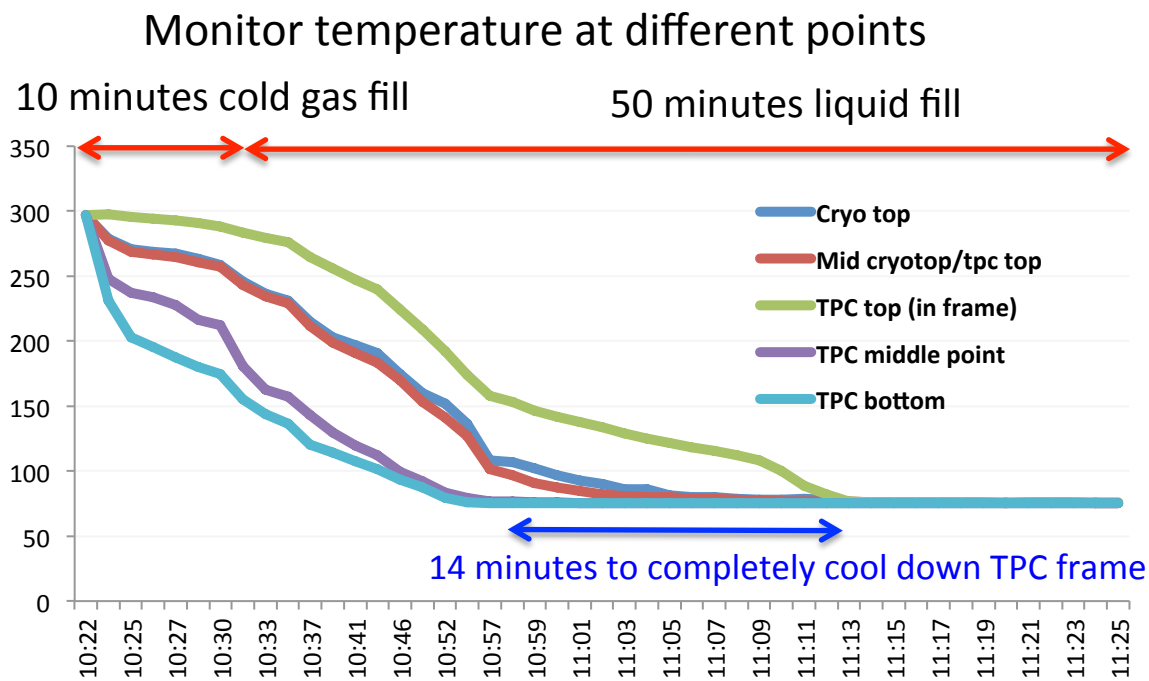


# $LN_2$ mini-CAPTAIN Test

Initial filling is from a $LN_2$ delivery truck
Then refilling is done by a low pressure Dewar

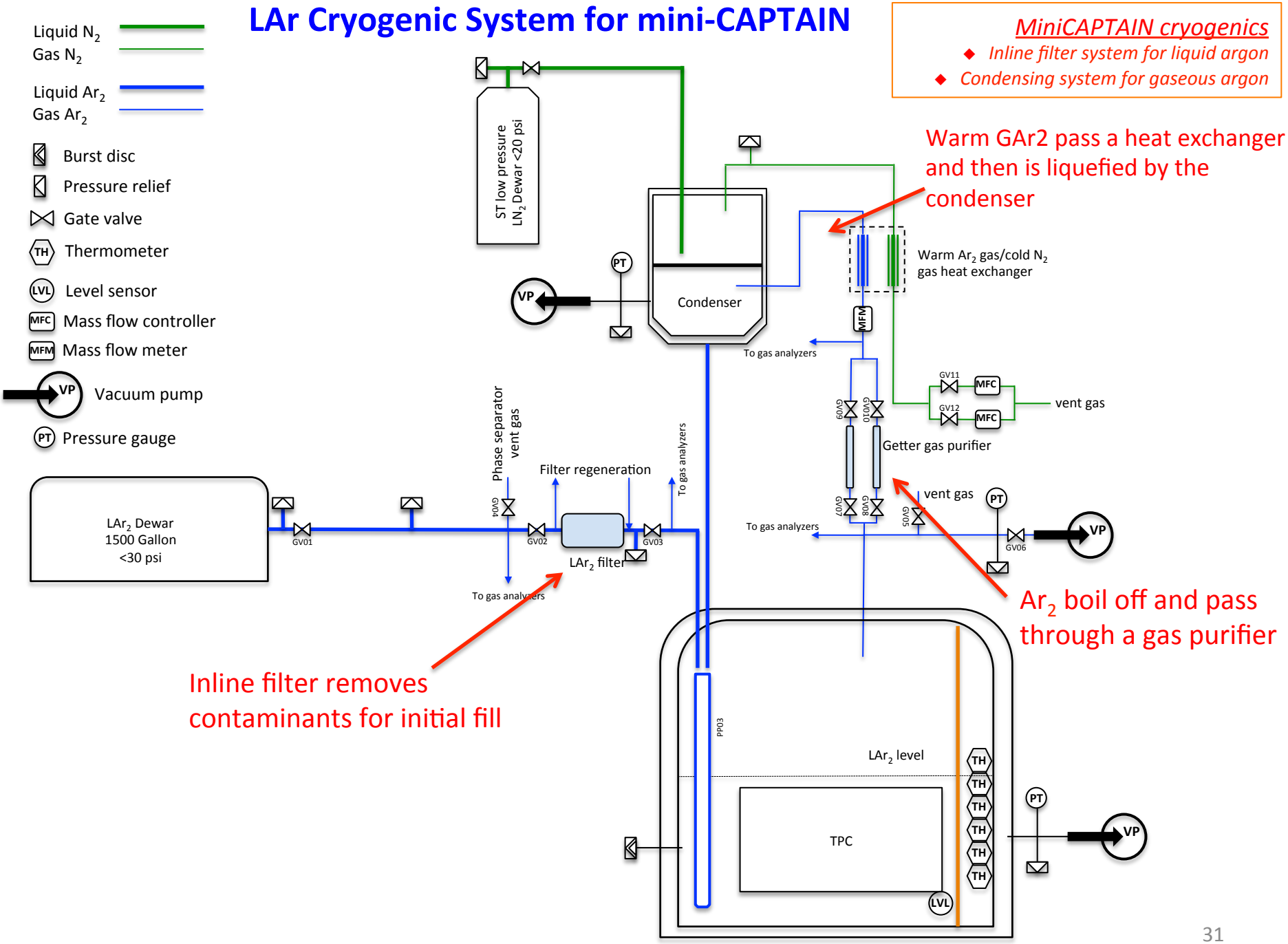
A temporary ventilation pipe for $N_2$ tests
A better constructed ventilation system will be implemented for $Ar_2$ runs

# $LN_2$ mini-CAPTAIN Test




- Takes less than an hour to fill it up to 1200 L level.
- Flow rate is maximize by the high pressure delivery line, flow rate is as high as 22-30 liters/min
- Loss about 50 L in initial filling to cool down the inner surface of the cryostat (~80 kg stainless steel)
- Liquid level drops 1 cm in every 3 hours
- Measured heat load is about 230 W (boil-off rate 3.7 liter/hour $LAr_2$)

# LAr Cryogenic System for mini-CAPTAIN




*MiniCAPTAIN cryogenics*

- *Inline filter system for liquid argon*
- *Condensing system for gaseous argon*

# Mini-CAPTAIN Inline filter system (Walt, LANL)

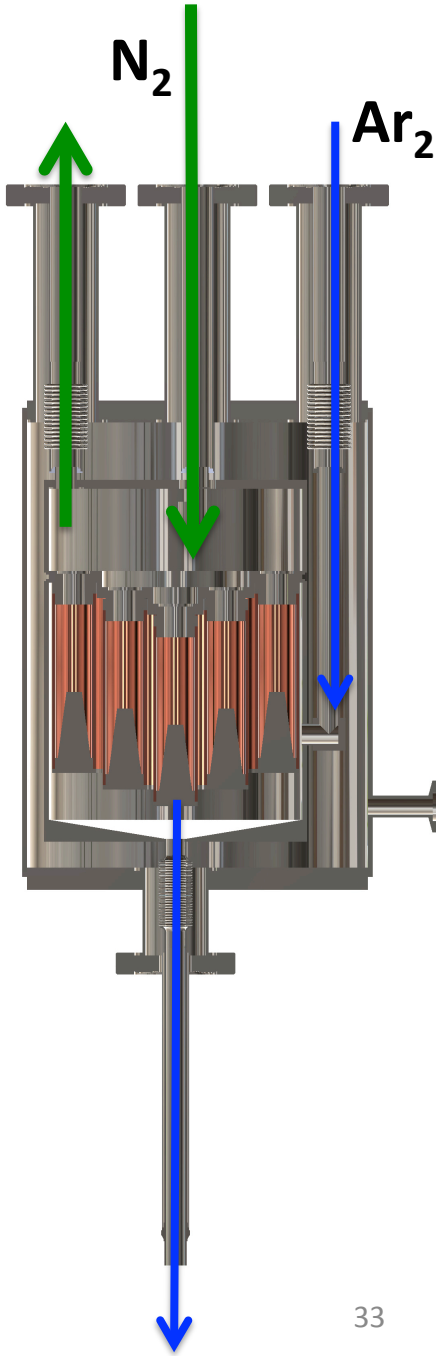
Two compartments holding filter material

Ports for thermocouples to monitor the gas temperature in regenerating filter material

Vacuum insulated container
And the stand of inline filter

# Mini-CAPTAIN Condensing system (Hanguo, UCLA)

Condensing gas $Ar_2$ with liquid $N_2$
Exchange heat with *copper stainless steel brazed* tube
Tubes are at different height – tunable cooling power up to 500 W



# Full CAPTAIN Cryostat last week

To be instrumented and completed in 2015.

# Conclusions

- Progress on the CAPTAIN detector construction at LANL is proceeding well:
  - CAPTAIN to be instrumented in 2015.
  - mini-CAPTAIN is 400 instrumented kilograms prototype test detector. LAr test run to begin later this summer.
- Mini-CAPTAIN will run in a neutron beamline in early 2015 and take neutron calibration data which will be valuable for SBN background studies.
- CAPTAIN is designed to address scientific questions of importance to two major LBNE missions: low-energy (supernova) neutrinos and medium-energy (long-baseline, atmospheric) neutrinos and will do so with neutron beam running and neutrino running