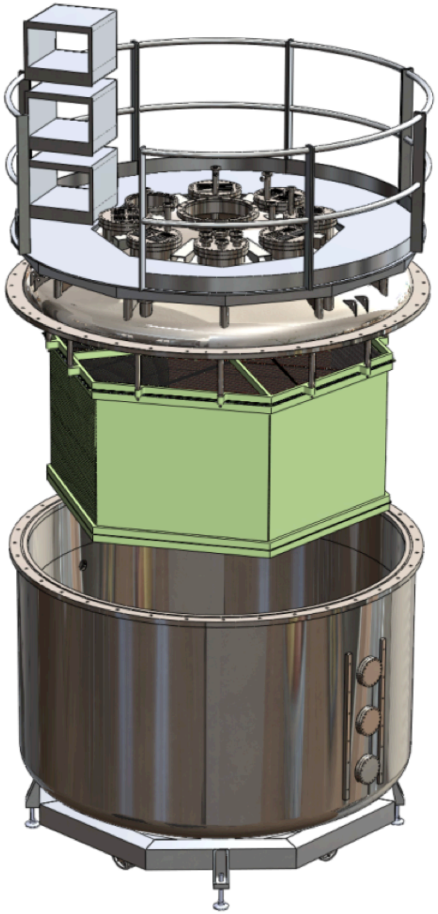


The CAPTAIN LAr TPC

Charles E. Taylor

NuFact 2013

IHEP, Beijing, August 21st 2013

Overview

- Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos (CAPTAIN)
- A 5-ton liquid Argon TPC is being built at Los Alamos
- System is designed for "mobility"
- Perform physics investigation for future neutrino experiments
  - Develop laser calibration system
  - Neutron beam run
  - SNS stopped pion neutrino run (10-50 MeV)
  - NuMI neutrino beam run (wide-band on-axis beam, broad peak between 1 and 10 GeV)
- Two prototype systems designed for preliminary testing for configuration changes

Collaboration

I. Stancu
University of Alabama

Z. Djurcic
Argonne National Laboratory

V. Gehman, R. Kadel, C. Tull
Lawrence Berkeley Laboratory

H. Chen, V. Radeka, C. Thorn
Brookhaven National Laboratory

H. Berns, C. Grant, E. Pantic, R. Svoboda, M. Szydagis
University of California, Davis

M. Smy
University of California, Irvine

D. Cline, K. Lee, H. Wang, A. Teymourian
University of California, Los Angeles

O. Prokofiev
Fermi National Accelerator Laboratory

J. Danielson, S. Elliott, G. Garvey, E. Guardincerri, D. Lee, Q. Liu, W. Louis, C. Mauger, J. Medina, G. Mills, J. Mirabal, J. Ramsey, K. Rielage, C. Sinnis, W. Sondheim, C. Taylor, R. Van de Water, A. Yarritu
Los Alamos National Laboratory

S. Mufson
Indiana University

T. Kutter, W. Metcalf, M. Tzanov
Louisiana State University

C. McGrew, C. Yanagisawa
State University of New York at Stony Brook

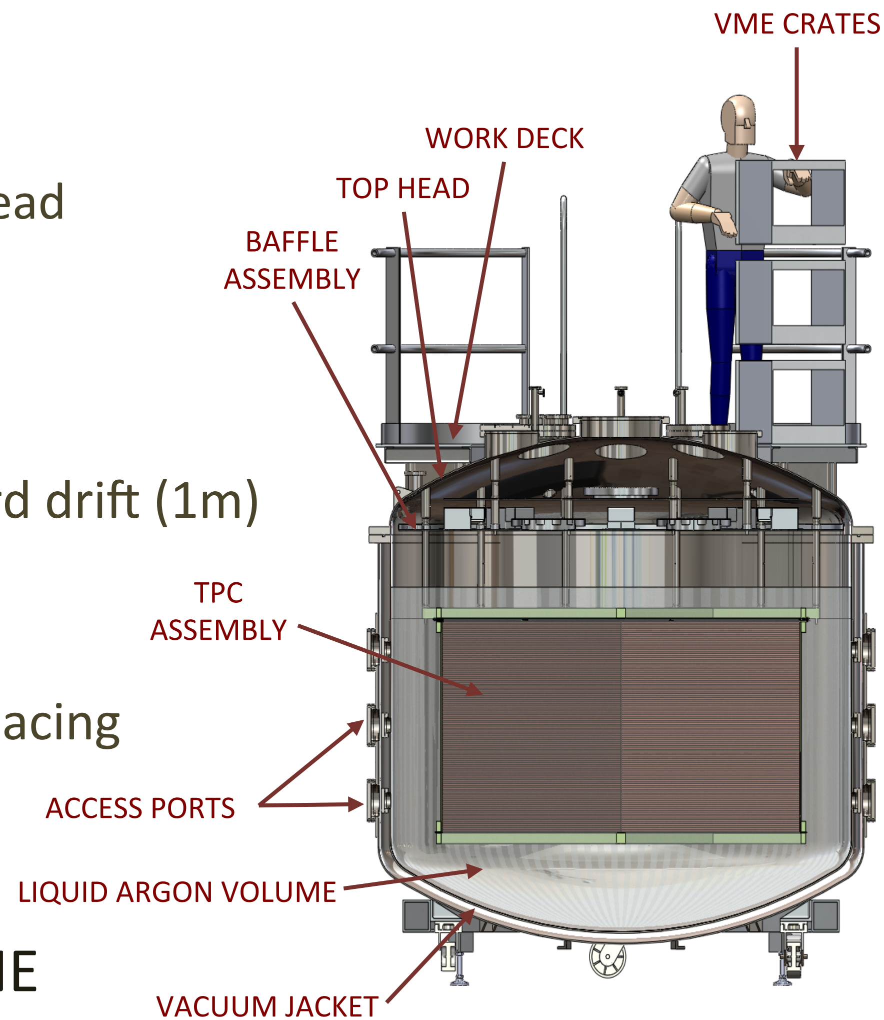
C. Zhang
University of South Dakota

R. McTaggart
South Dakota State University

Christopher Mauger (cmauger@lanl.gov)

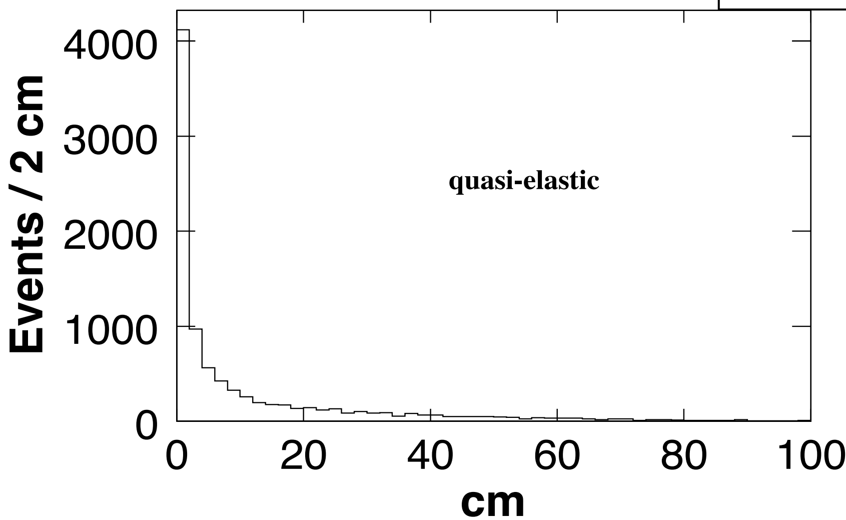
The CAPTAIN Detector

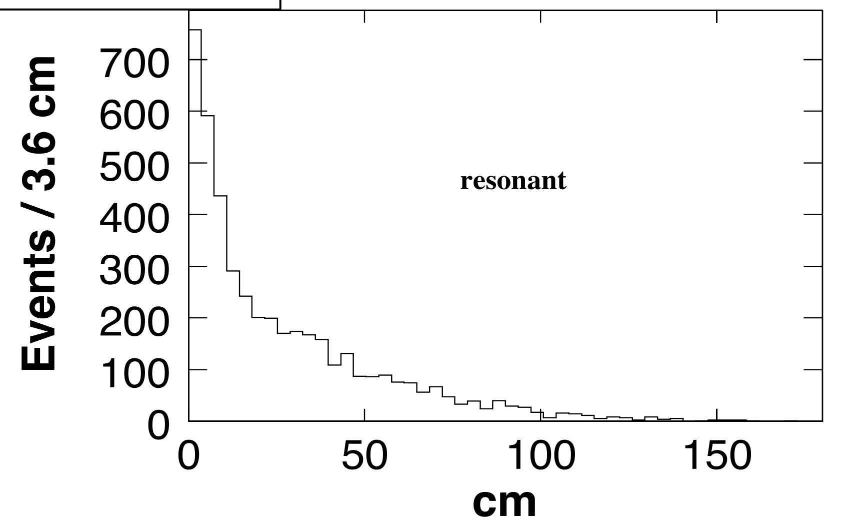
- Cryostat
  - Capacity: ~7700 L
  - All cryogenic and instrumentation connections made through top head
  - Work deck for worker safety and convenience
- TPC
  - Hexagonal prism, vertical upward drift (1m)
  - 500 V/cm drift field
  - 667 wire/plane (3 planes)
  - ~2k channels with **3 mm** wire spacing
- Laser calibration system
- Photon detection system
- Same electronics as MicroBooNE



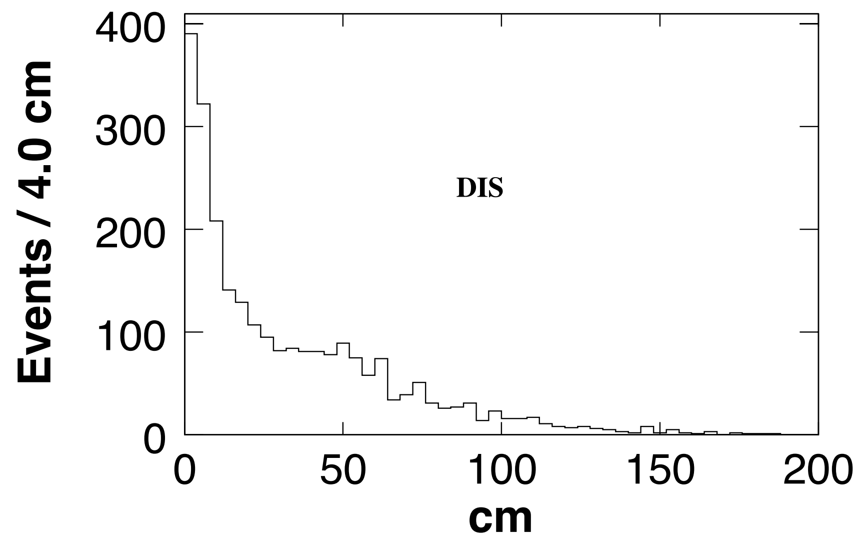
Cryostat Size from Simulations

Kevin Yarritu - LANL



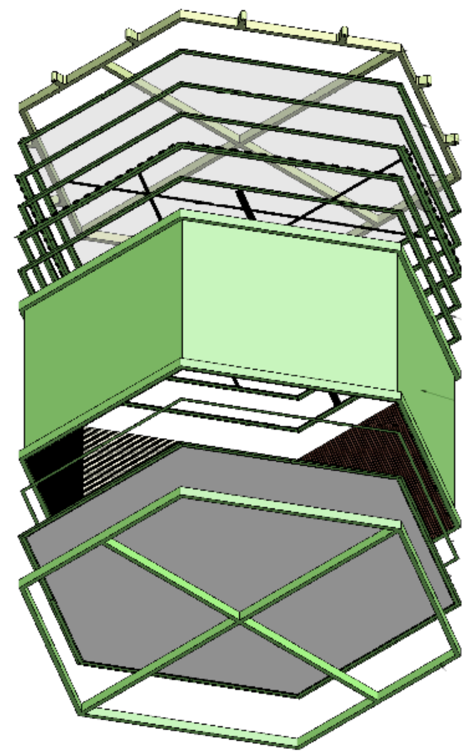


- Plots show the distance from the vertex to the endpoint of the longest track in the event for contained events
- Contained event: everything contained except the muons and neutrons
- 10% containment with the chosen size
- 10^6 neutrino interaction per 10^{20} POT for NUMI ME tune
- Anticipate 4 x 10^{20} POT per year
- Would get 370,000 contained CC events per year during a NUMI ME run



Electron drift-time and drift-distance

- Electron attachment process: $e^{-} + O_2 \rightarrow O_2^{-}$
- A purity of 100 parts per trillion (ppt) of electronegative oxygen equivalent gives electron lifetimes of ~2 ms, which will allow meters of drift distance
- Contamination received from industry
  - 1 ppm = 0.3 μs = 0.48 mm
  - 3 ppm = 0.1 μs = 0.16 mm
- Ideal specs for UCLA prototype and CAPTAIN
  - Prototype: 2x32 = 0.4 ms = 750 ppt
  - Captain: 2X100 cm = 1.25 ms = 240 ppt

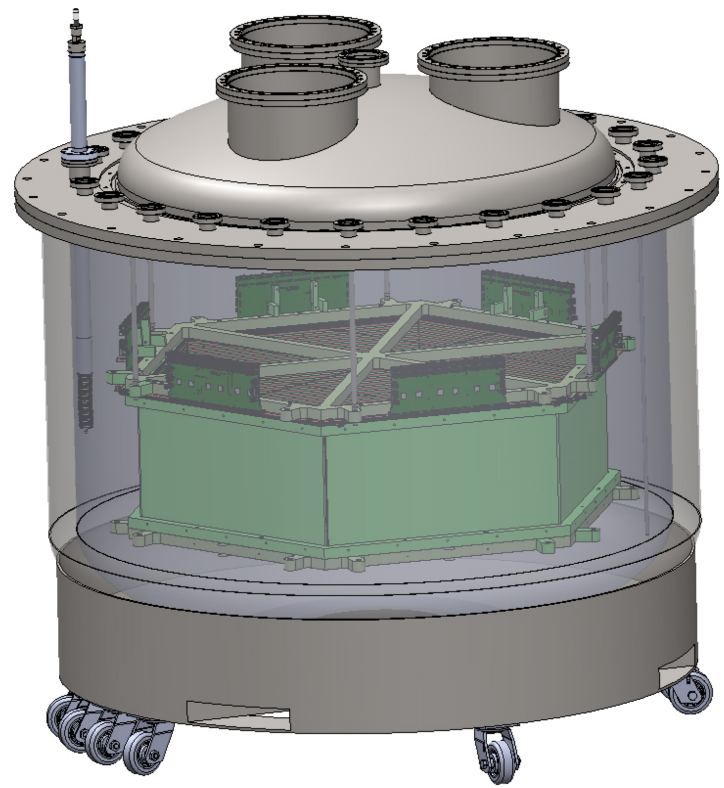


Photon Detection System

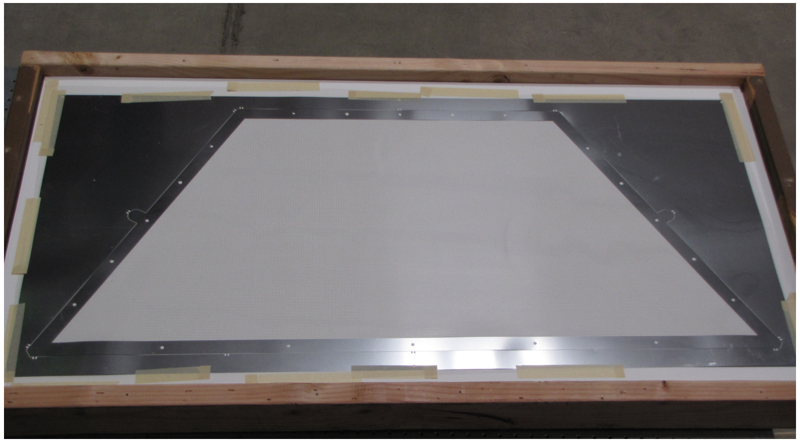
- Improves the projected energy resolution of the detector by 10-20%
- The scintillation light can be used to determine the energy of neutrons from the time-of-flight
- Liquid argon scintillates at 128 nm (same as the photodetector window)
  - Tetraphenyl butadiene (TPB) will be initially used as a wavelength shifter
  - Has a conversion efficiency of 120% as a thin film
  - Has a re-emission spectrum that peaks at 420 nm
- The CAPTAIN detector will serve as a test bench for alternate photon detection systems

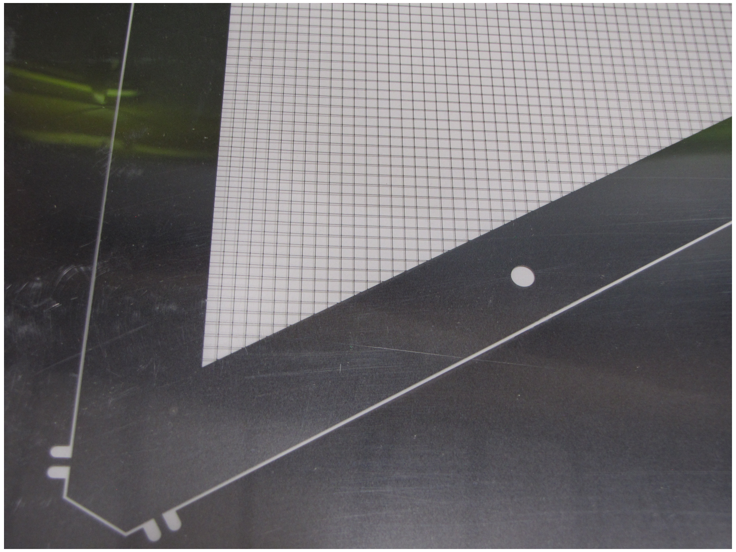
Prototype UCLA Cryostat

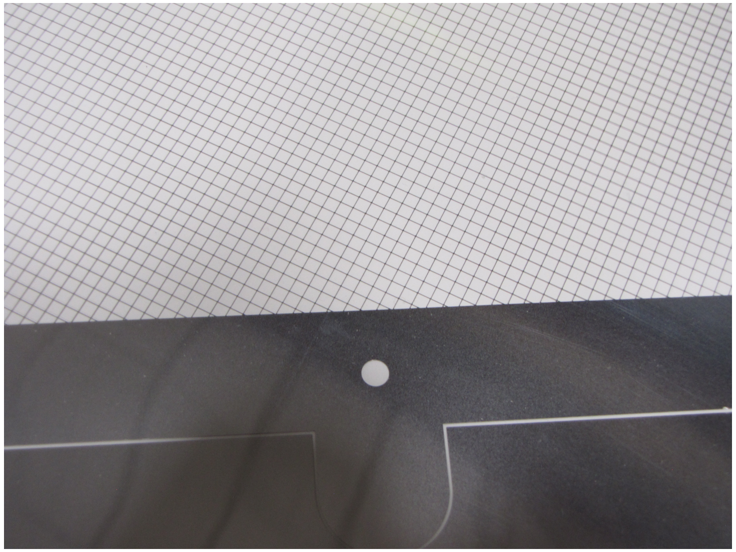
- Field cage is 1/4" thick FR 4, double sided, with 1.0 oz. copper, strip to strip spacing 1 cm centers.
- Wire planes are standard MWPC style with 3 mm spacing.
- All wires will be 75 um CuBe.
- The wire planes and field cage are separate modules that are pinned together. A stiff frame will hold all the wire planes under tension using precision alignment pins.
- The cathode and ground will be a etched wire mesh.
- The planes of wires will be, as the electrons see them, a grid, u, v and anode. All wire plane construction will be identical.



Etched Wire Mesh







Physics Goals by end of FY 2014

Within the scope of the LANL LDRD (Laboratory Directed Research & Development program)

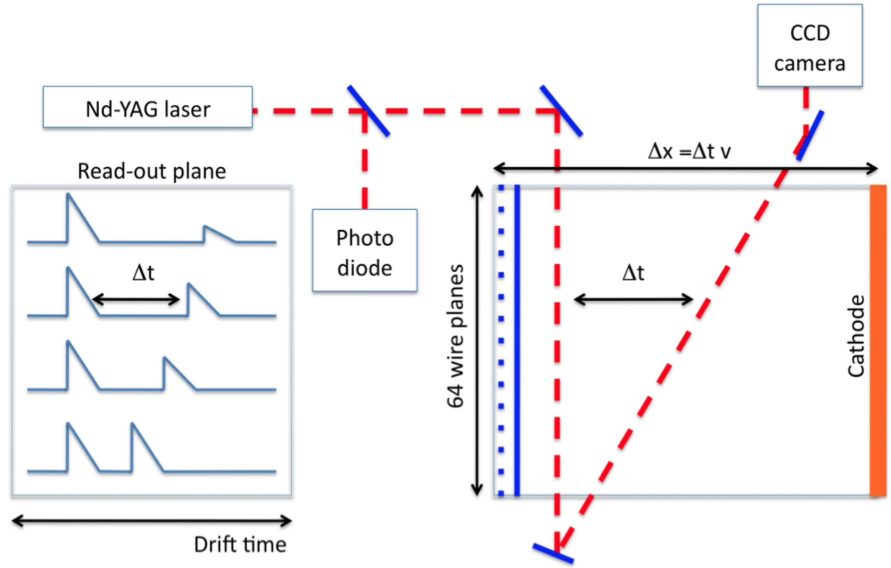
- Muon studies
  - Studies for future CP violation experiments (e.g. LBNE)
  - Supernova-related studies
- Laser calibration system development
  - Measure drift field and electron lifetime in-situ
  - Study laser calibration issues for LBNE far detector
- Run in a neutron beam
  - spallation studies
  - surface running backgrounds
  - neutrino energy reconstruction
  - beam-induced backgrounds for the near detector

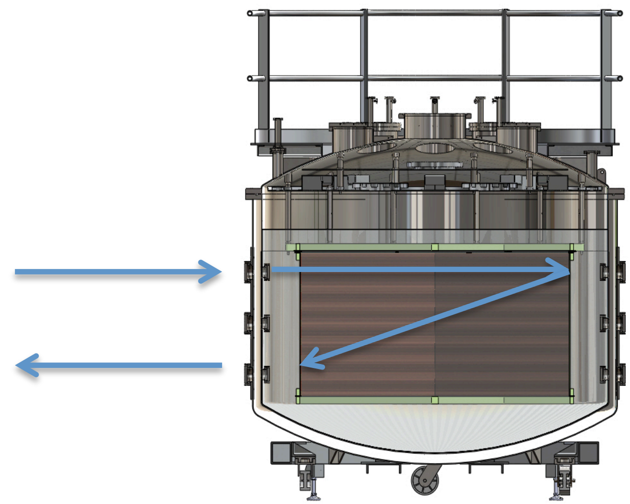
Muon Studies

- Studies for future CP violation experiments (e.g. LBNE)
  - The LBNE far detector will not be magnetized, cannot do μ^+/μ^- separation by track curvature
  - Approximately 75% of μ^- are captured by the argon nuclei
    - Gamma and neutron cascade
  - All μ^+ will decay
    - some positive muons can be captured in flight, leading to 2 protons, which can be useful for identification
  - If we can identify the captures with high purity and with reasonable and quantifiable efficiency, we can do neutrino/anti-neutrino separation
  - This allows CP studies of long-baseline and atmospheric neutrinos
- Supernova-related studies
  - spallation backgrounds
  - low energy particle identification, e.g. β/γ

Laser Calibration System

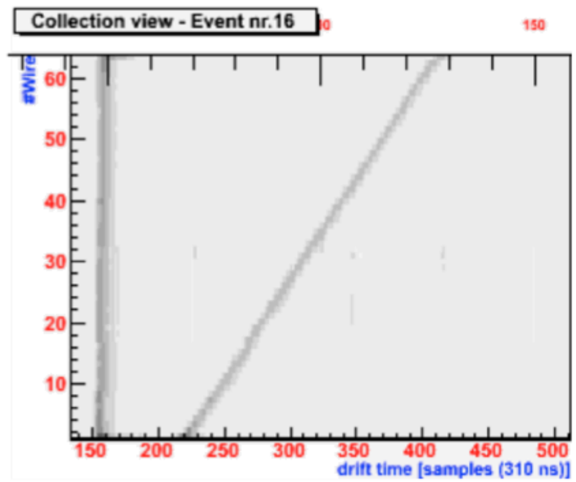
- Based on a recent work by the University of Bern
  - B. Rossi et al., JINST 4 P07011 (2009) arXiv:0906.3437
- Ionization potential of LAr 13.78 eV
- Nd-YAG laser
  - Frequency quadrupled 4.66 eV
  - Quantel Laser 90 mJ/pulse
- 4 optical ports
  - 2 set 15cm from anode
  - 2 set 15 cm from cathode

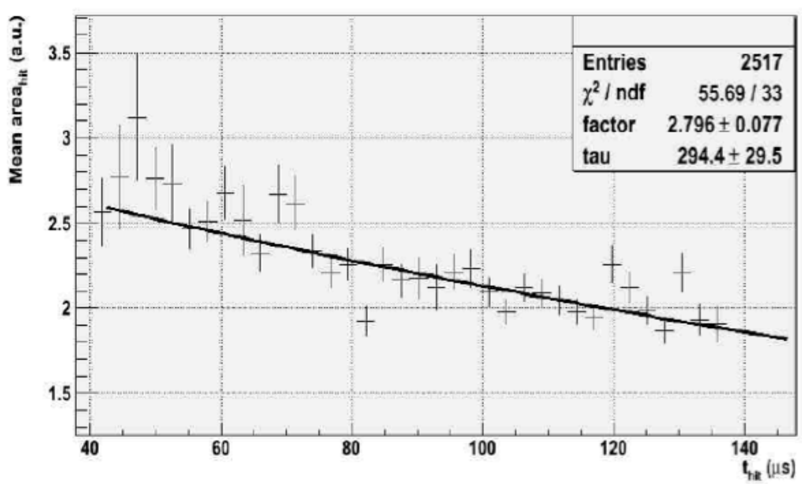




Laser Calibration System

- Measure drift field in-situ (drift velocity)
  - high muon rate leads to space charge buildup (~5% effect B.Yu BNL)
  - potential hardware problems
- Measure electron lifetime in-situ
  - Current LBNE spec. τ > 0.85ms
  - At 1.5ms drift time (max) ~20% electron survival





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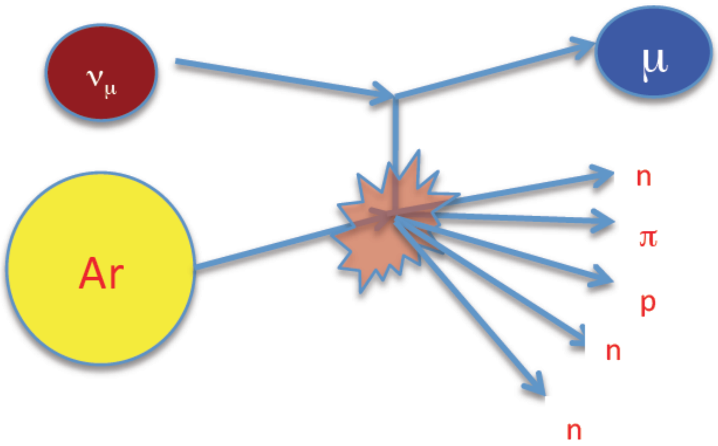
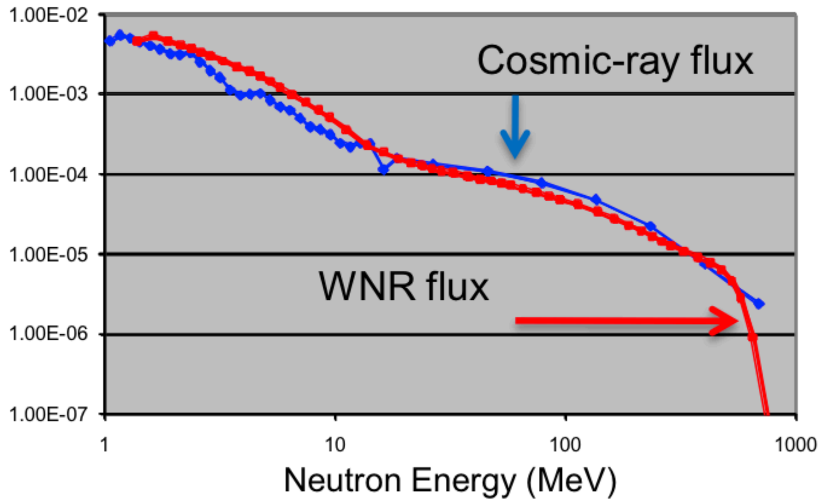
Neutron Running at LANSCE

- Characterize neutron interactions to understand energy carried by neutrons in neutrino interactions with Argon
- Measure response of LArTPC to neutrons
  - multi-particle events in high-energy regime
  - characterize reconstruction efficiency of these events
- Measure cosmogenic production of radioactive isotopes
  - validate simulations of spallation
  - background for neutrino interactions
- Want neutron beam with cosmic-ray energy spectrum
- Ability to know neutron energy, event- by-event



Neutron Running at LANSCE



- WNR at LANL provides a high flux neutron beam with an energy spectrum similar to the cosmic-ray neutron spectrum
- Measure production of backgrounds to low energy neutrino events

- Measure processes that could be background to ν_e appearance, e.g. $^{40}Ar(n,\pi^0)^{40}Ar^{(*)}$ that may be important for near-surface running of the LBNE far detector
  - the outgoing π^0 could be miss-reconstructed as an electron
- Validate spallation simulations with production as a function of neutron energy measured by TOF

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Physics Goals: post FY 2014

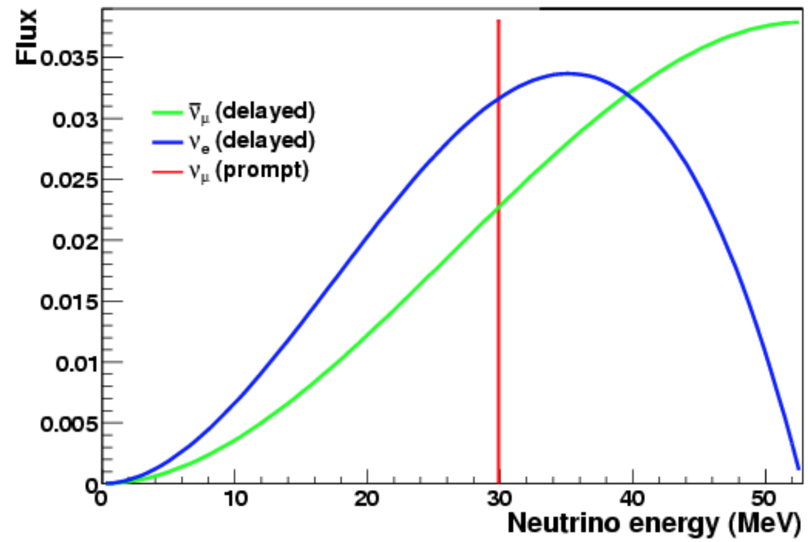
- SNS neutrino running – energies relevant to supernova
  - Neutrino cross-sections
  - Demonstration of event reconstruction with real data

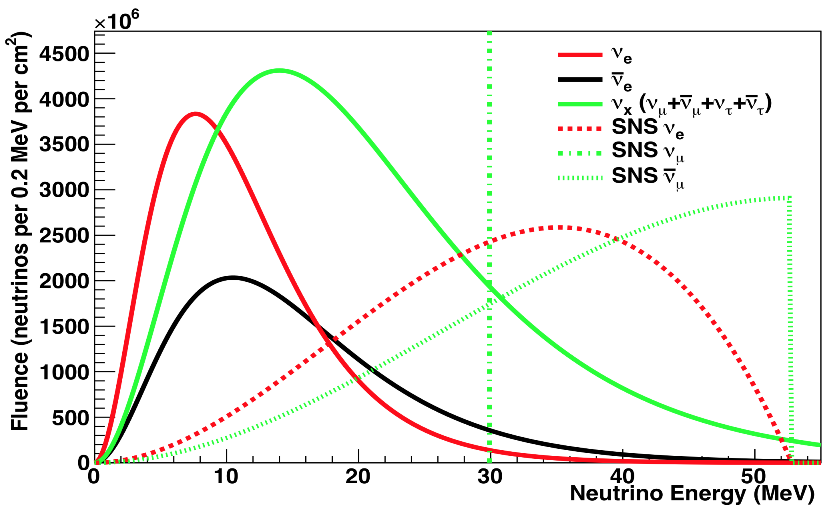
- NUMI neutrino running – energies relevant to long-baseline oscillations
  - Exclusive and inclusive neutrino interaction in resonance and DIS region
  - Explicit experience with neutrino energy reconstruction

Spallation Neutron Source (SNS)

- Neutrino beam from stopped π available at the OakRidge National Laboratory

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\downarrow$$
$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

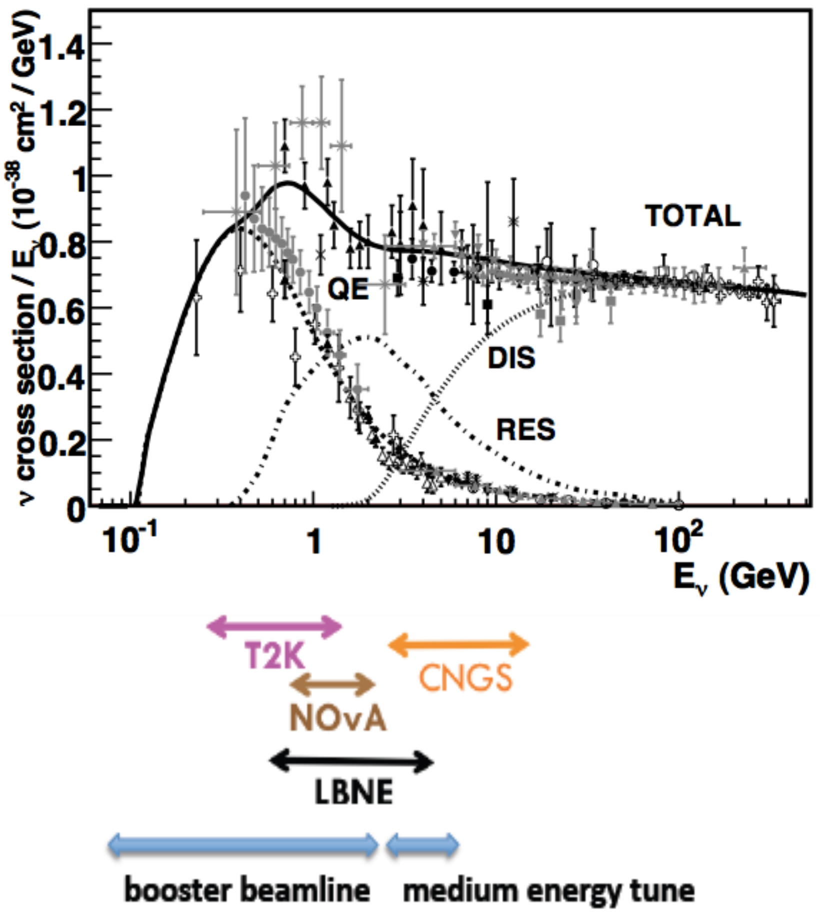




- Supernova neutrino spectrum overlaps with stopped π neutrino spectrum
- Fluence at ~ 50 m from the SNS amounts to ~ <u>a supernova a day</u>
  - K. Scholberg at https://indico.fnal.gov/contributionDisplay.py?sessionId=6&contribId=67&confId=6122

pictures by K. Scholberg

Neutrinos at Main Injector (NuMI)



J. Formaggio and G.P. Zeller, ArXiv: 1305.7513

- LBNE will detect neutrino with few GeV energy
  - rich and complex energy range
- Run in on-axis position in NUMI
- Energy regime complementary to MicroBooNE (booster)
  - booster + on-axis NUMI running covers entire LBNE energy regime
- 10% containment of all but muons and neutrons
  - 370,000 “contained” CC events per year
- Measure exclusive and inclusive cross sections
  - cover the threshold region for pion production
  - cover the resonance regime
- Reconstruction experience with higher energy neutrino interactions

Conclusion

- A prototype LAr TPC will be built at Los Alamos National Laboratory in the next months and will start operating at the end of 2013
- The 5 tons LAr TPC will be running by the middle of 2014
- It will be used to study different problems and topics
  - Experience in LAr TPC calibration
  - μ^+/μ^- discrimination for CP searches
  - Supernovae related studies (SNS)
  - Physics relevant to long-baseline oscillations (NuMI)
    - Neutron interactions in LAr (LANSCE)
- Numerous possibilities
  - Christopher Mauger (cmauger@lanl.gov)

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Backup Slides

Neutrino Reactions

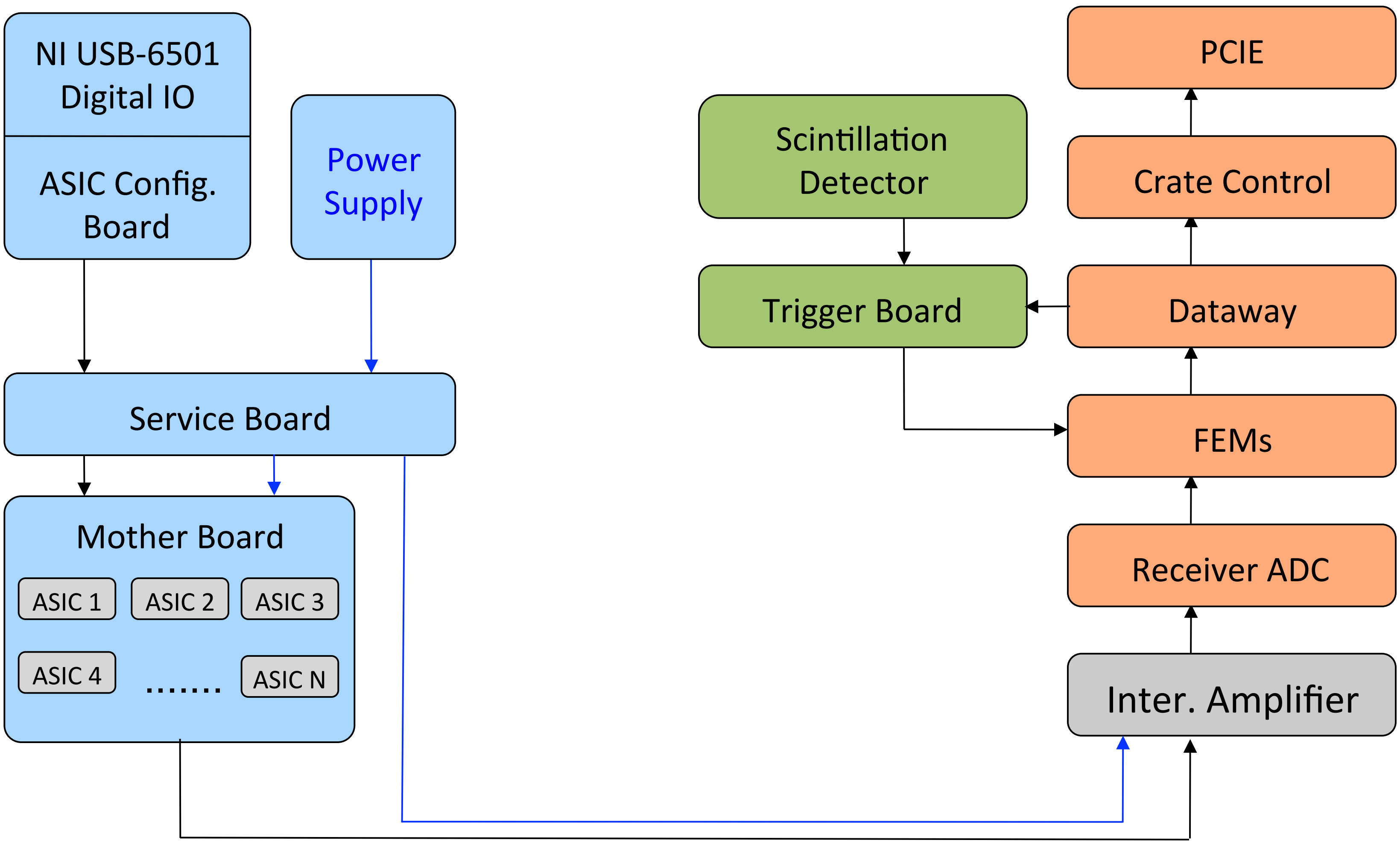
- Dominant channels for low energy neutrino interactions in Argon:

$$\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$$

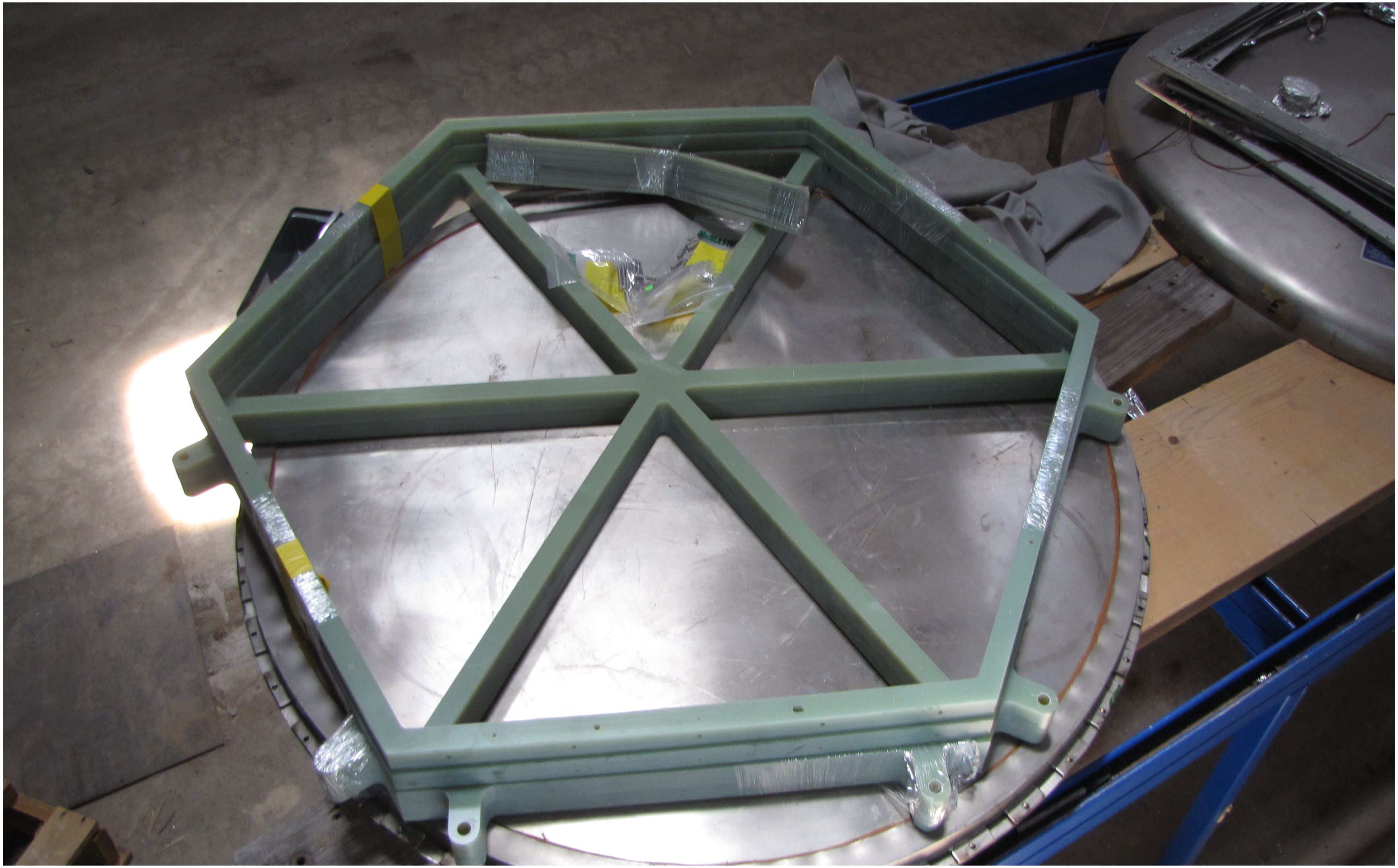
$$\bar{\nu}^e + {}^{40}Ar \rightarrow e^+ + {}^{40}Cl^*$$

- Expected ~ 3 events/s/kt over ~ 30 s for a SN @ 10kpc
- Measure cross sections for ν-Ar interactions at low energy (esp. νs from supernovae)
- Study CC and NC interactions below 50 MeV
- Study a realistic LAr detector response:
  - efficiency, resolution, event tagging

System Integration Layout



Prototype TPC parts



Wire Plane Transparency

The GRID, U, and V wire planes must be transparent to the drifting electrons so the electrons can be collected on the anode wires. This requires a bias to be used on each wire plane.

The equation for transparency is,

$$E_a/E_b > 1+x/1-x \quad x= 2\pi r/d$$

Where r = wire radius and d = wire pitch

This gives the following biases for each plane

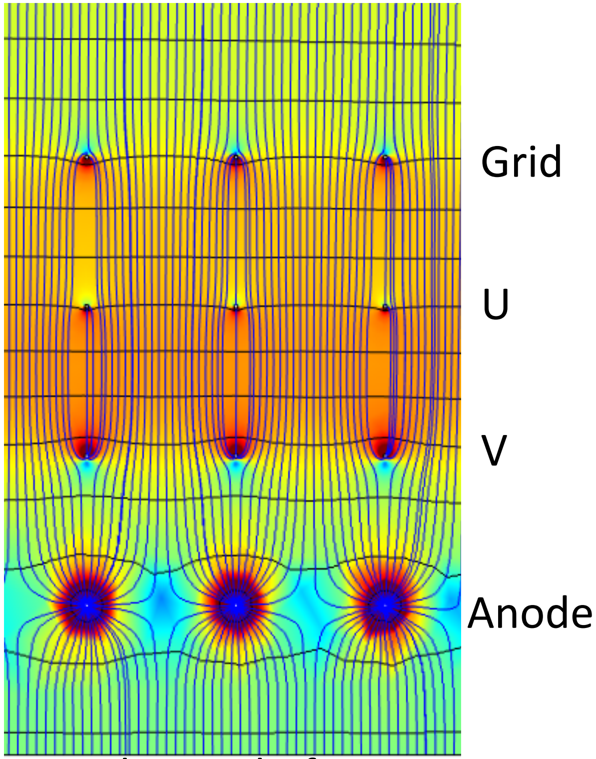
Grid = -495V

U = -290V

V = 0V

Anode= 290V

CAPTAIN 4 planes



Oleg Prokofiev

UCLA Cryostat

- Active area – 1m diameter x 32 cm electron drift
- Drift field – 500 V/cm
- Electron drift velocity – 1.6 mm/µs
- Wire spacing – 3mm
- plane separation – 3.175 mm
- Wires per plane – 338
- Mother boards per plane – 2