The CAPTAIN Experiment

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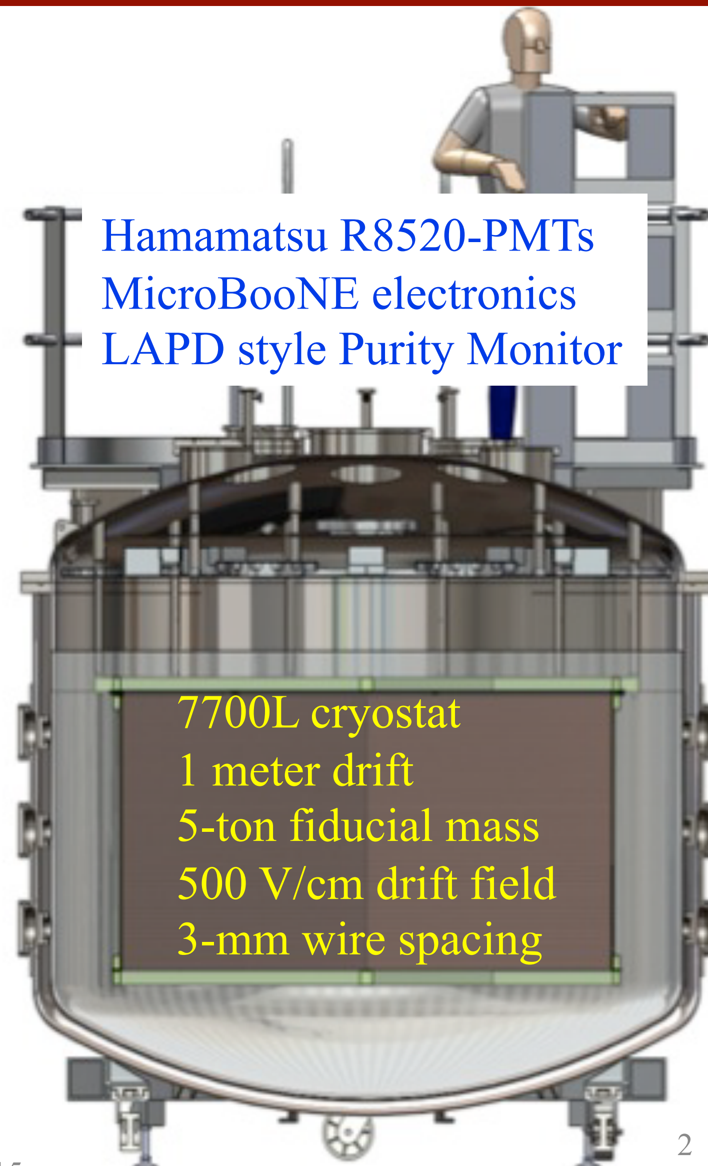
08-04-2015

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

- Funded by Los Alamos National Lab (LANL) Laboratory Director Research & Development (LDRD). Now a multi-instituitional collaboration.
- A portable full-scale liquid argon TPC (CAPTAIN) and a prototype (Mini-CAPTAIN).
- Study interactions in liquid argon with neutron source at LANL and neutrino beams at Fermilab.



CAPTAIN Collaboration

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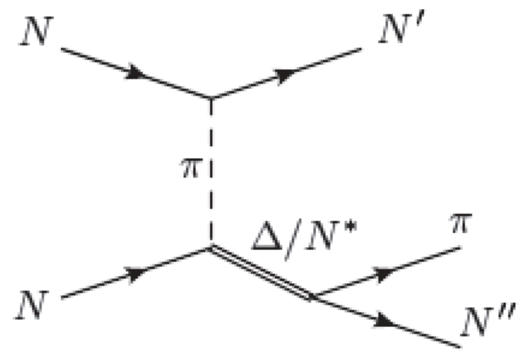
Neutron studies at the Weapons Neutron Research Facility

Mini-CAPTAIN positioned in the WNR neutron beam at LANL and will characterize neutron interactions in argon.

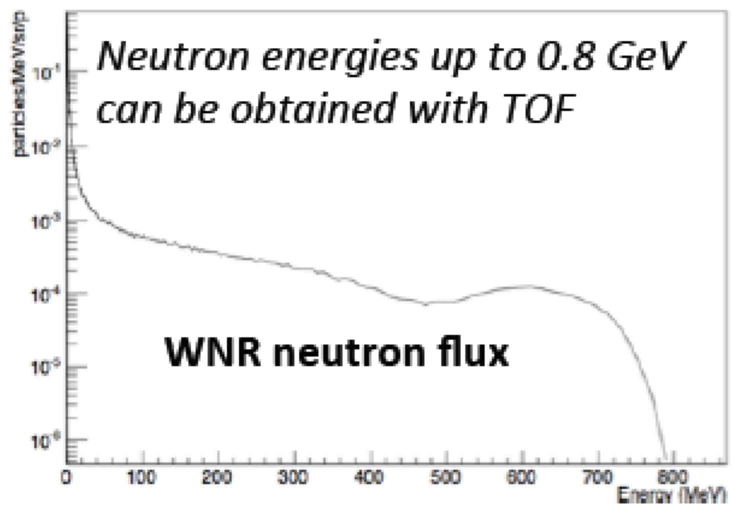


- **High-energy neutrons** will produce pions and can be used to develop techniques to identify neutron interactions in Argon that will later help with neutrino energy reconstruction

- **Low energy** neutrons can be used to study the neutrino-like argon reaction:

$$n + {}^{40}\mathrm{Ar} \rightarrow {}^{40}\mathrm{Ar}^{*} + n$$

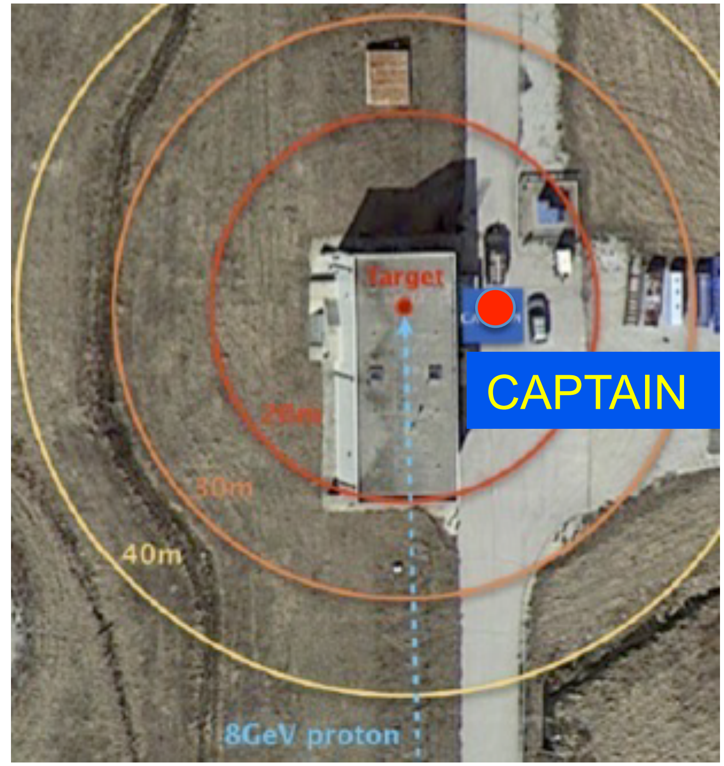
Important for identifying NC scattering from supernova neutrinos in argon.



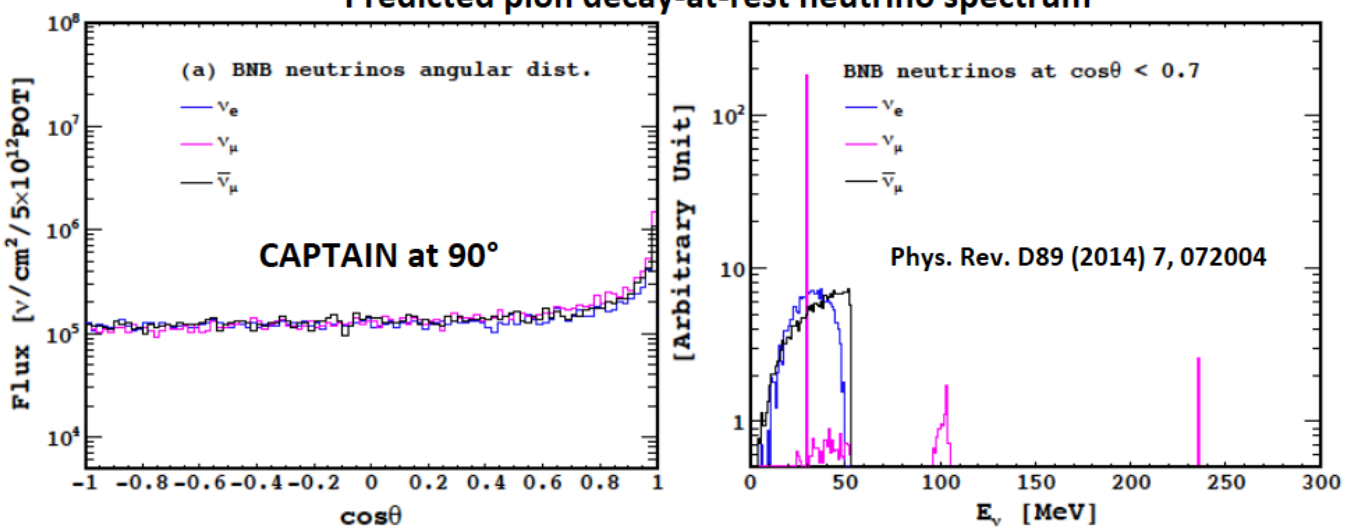
Help DUNE to understand neutrons better, benefit both energy reconstruction and background rejection.

CAPTAIN in the Booster Neutrino Beam

- Expected CC neutrino absorption event rates of about 200 / year for $2x10^{20}$ POT
- Neutron backgrounds have to be mitigated - plan to measure with SciBath detector during the fall of 2015
- Could get 3x the event rate with lower neutron backgrounds if the beam is run in off-target mode (for the current MiniBooNE dark matter search)



Predicted pion decay-at-rest neutrino spectrum

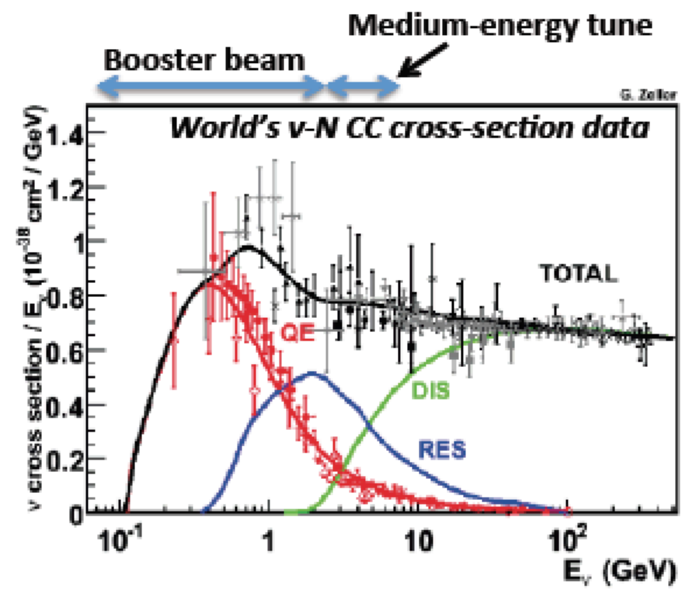


Close enough to collect low energy neutrino produced by pion decay at rest. First time LAr run for lowE neutrino, great help for DUNE supernova study.

CAPTAIN-MINERvA in the NuMI Beam

- Running CAPTAIN-MINERvA in NuMI beamline (on-axis with medium energy tune) will probe cross-section data between 1.5 – 5 GeV

Complementary measurements to MicroBooNE for the full DUNE energy spectrum



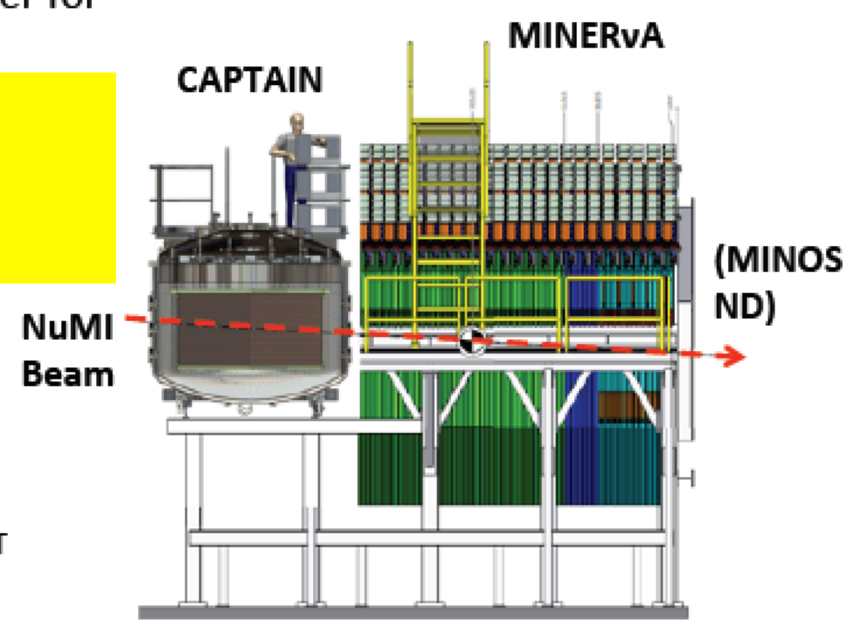
- MINERvA(+MINOS ND) will act as a calorimeter for the final state particles that exit CAPTAIN

Great improvement for flux/cross-section mesurements that benefit existed NuMI experiments like NOvA

Predictions for CAPTAIN-MINERvA(+MINOS ND)

	Events w/ reco μ	Events w/ reco μ and charge
CCQE-like	915900	783600
$CC1\pi^{\pm}$	1952700	966000
$CC1\pi^{0}$	1553100	596700

Assuming 6×10^{20} POT



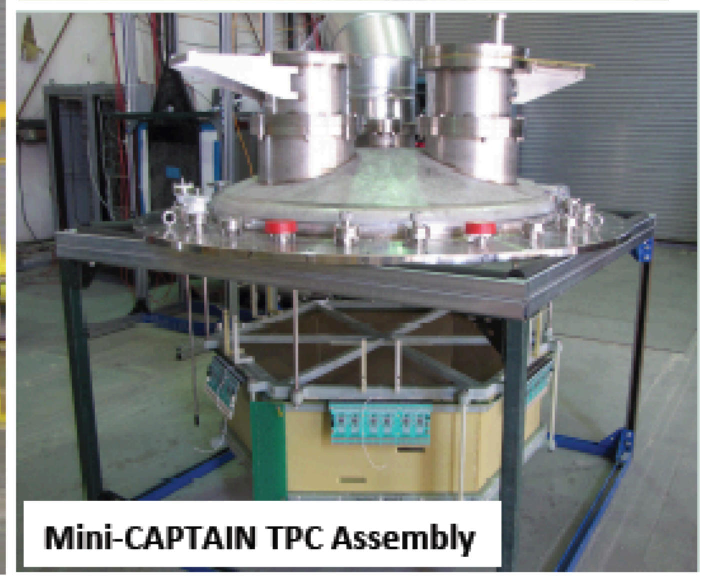
Mini-CAPTAIN (protoype) constructed and started testing

- A Cryostat – 1700 L of liquid argon.
- TPC has 1000 wires (3planes) and a max. drift length of 32 cm (1 m diameter)
- 16-1'' PMTs facing the TPC volume
- Purity monitor attached to the side of the TPC


Mini-CAPTAIN + Muon Tracker


Purification and Recirculation

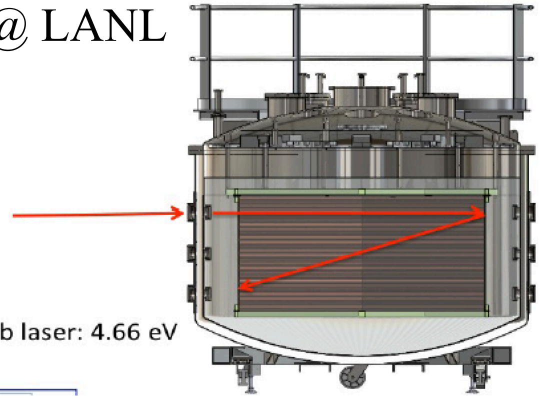

Mini-CAPTAIN Cryostat


Mini-CAPTAIN TPC Assembly

Other systems/detectors

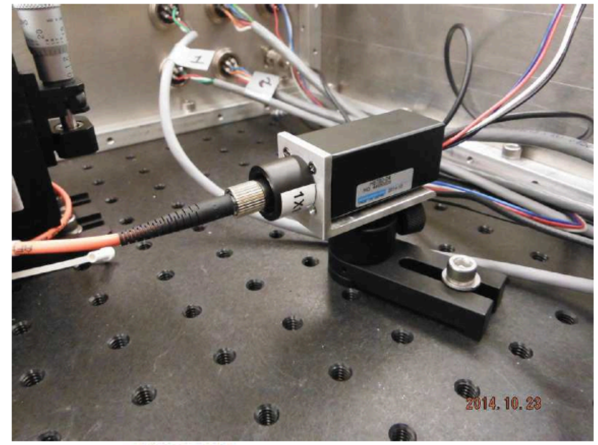
Laser Calibration System @ LANL

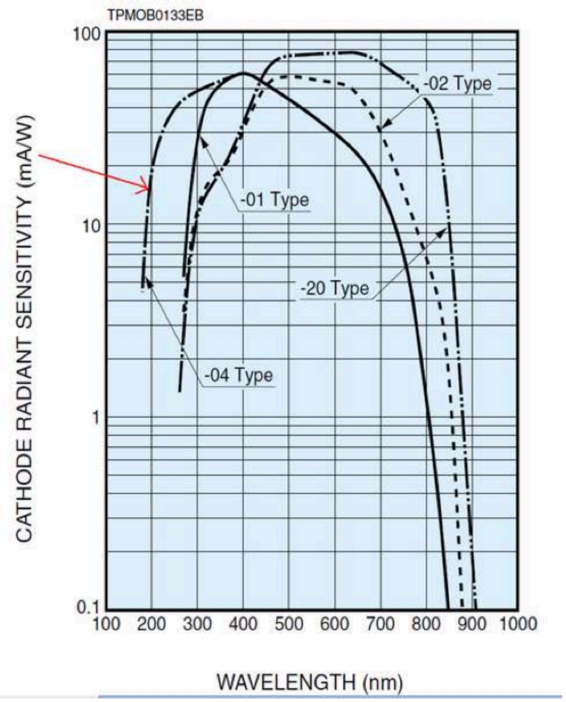
266 nm, 90 mJ, 3 ns pulse



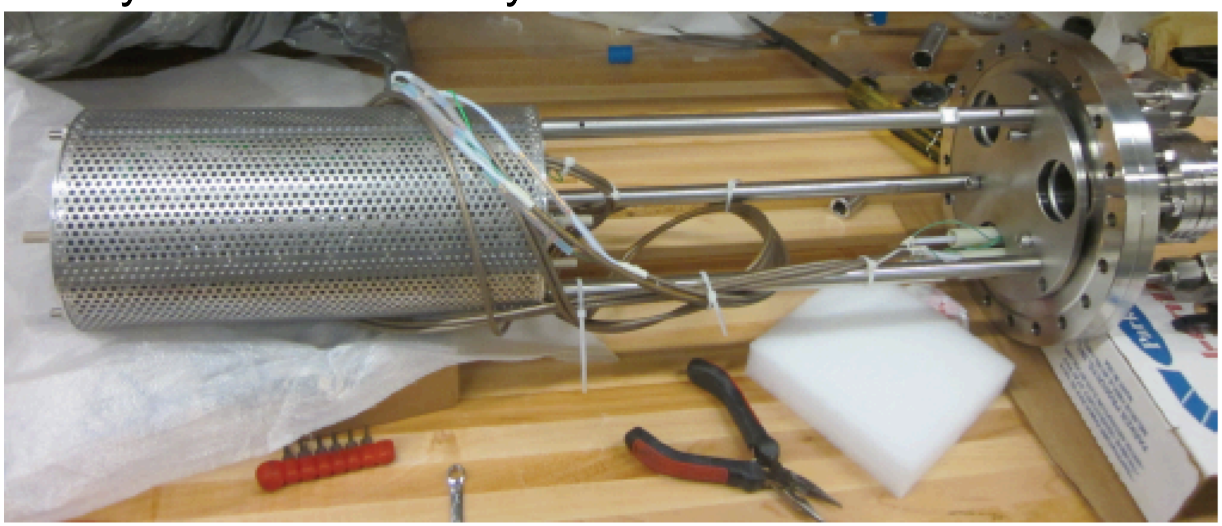
Nd-YAG frequency quadrupled Quantel Brilliant-b laser: 4.66 eV
LAr ionization potential: 13.78 eV (3 photons)

PMT test

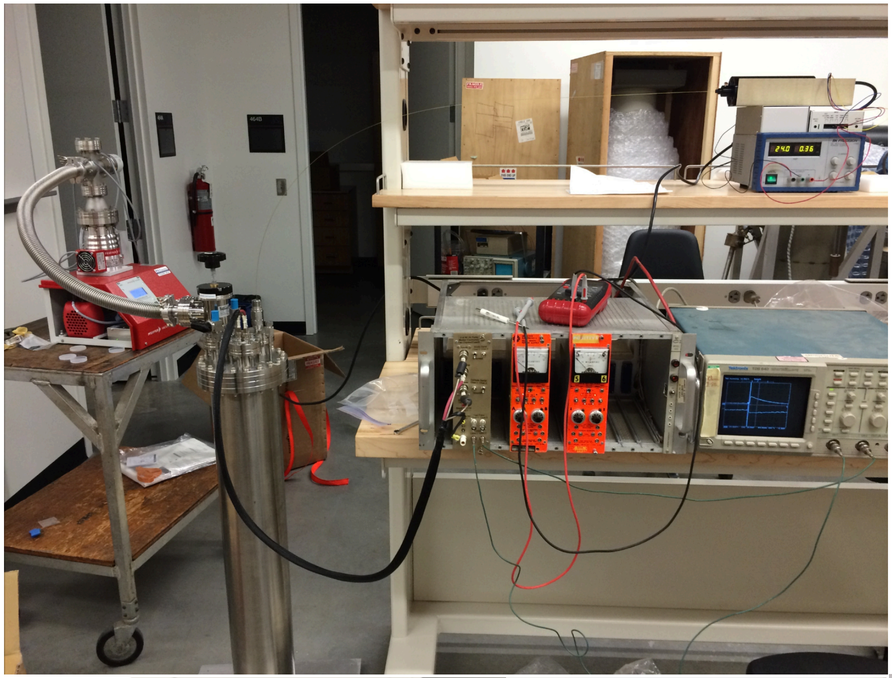


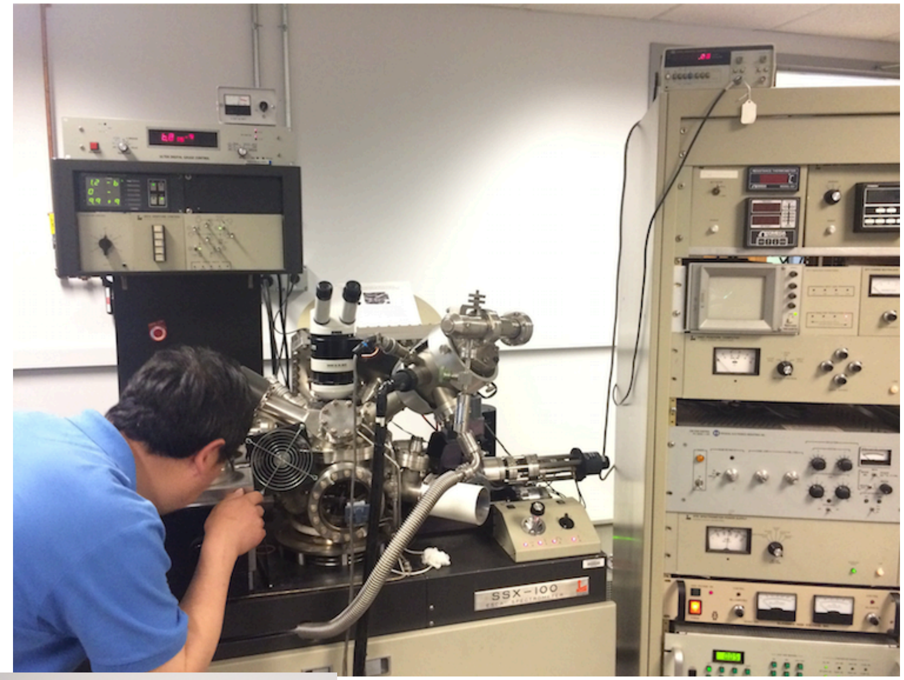


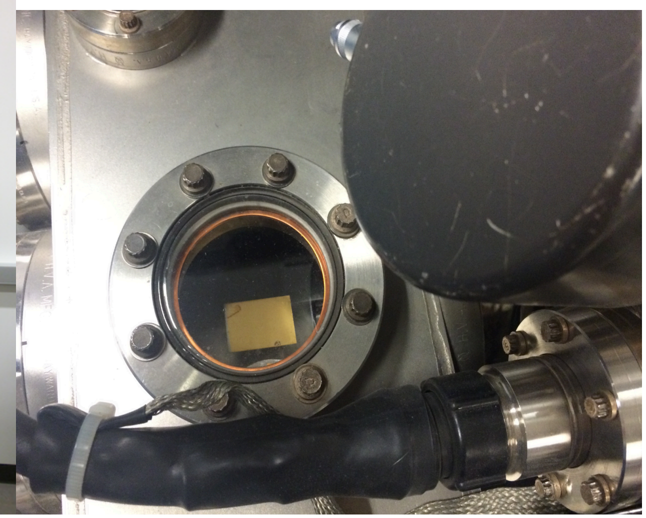
Purity Monitor assembly



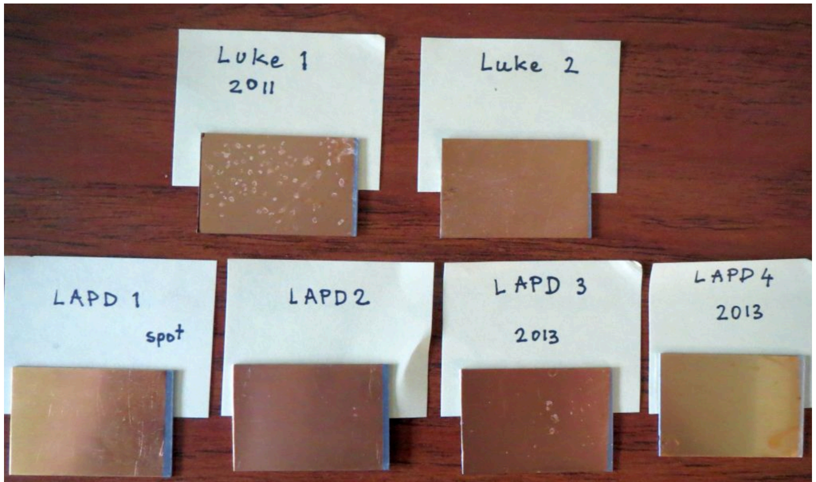
Minnesota lab for purification and material study



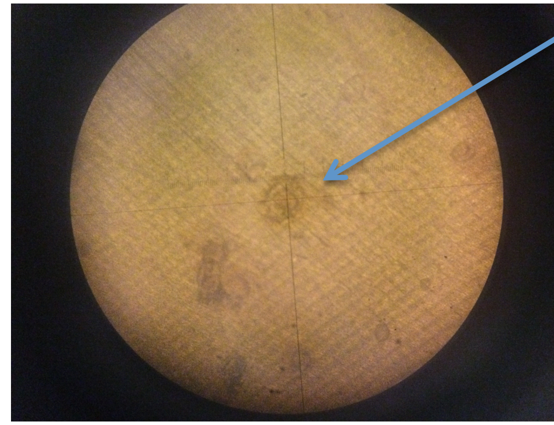


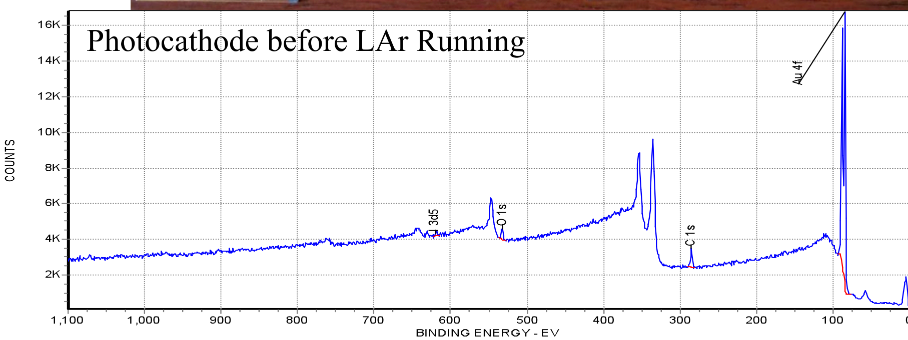


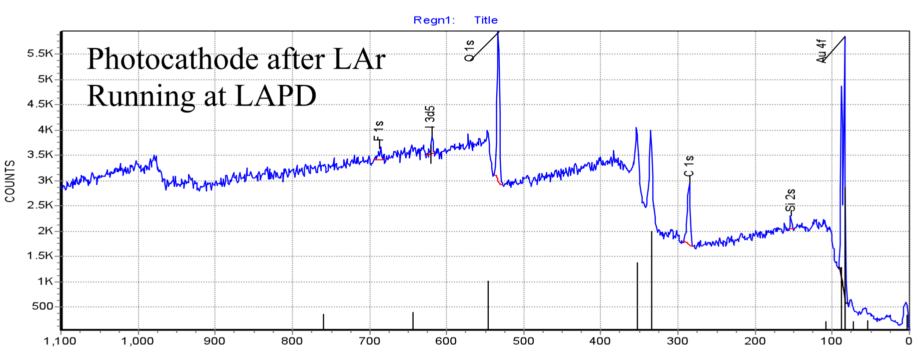
X-ray Photoelectron Spectroscopy (XPS) test at UMN for photocathodes degraded in LAPD/Luke @ Fermilab



organic compound?





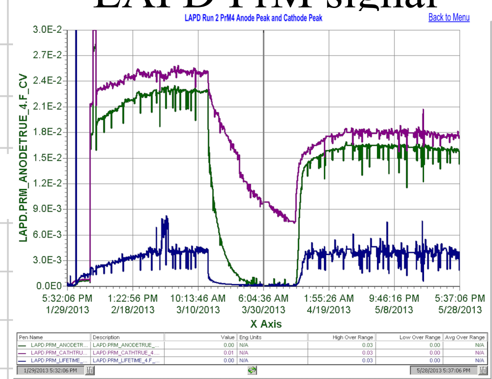


Elements on the surface of photocathodes

XPS Line	Atom %
Au 4f	51.299
C 1s	37.623
O 1s	10.716
I 3d5	0.361

XPS Line	Atom %
Au 4f	9.048
Si 2s	3.932
C 1s	45.279
O 1s	38.326
I 3d5	0.535
F 1s	2.88

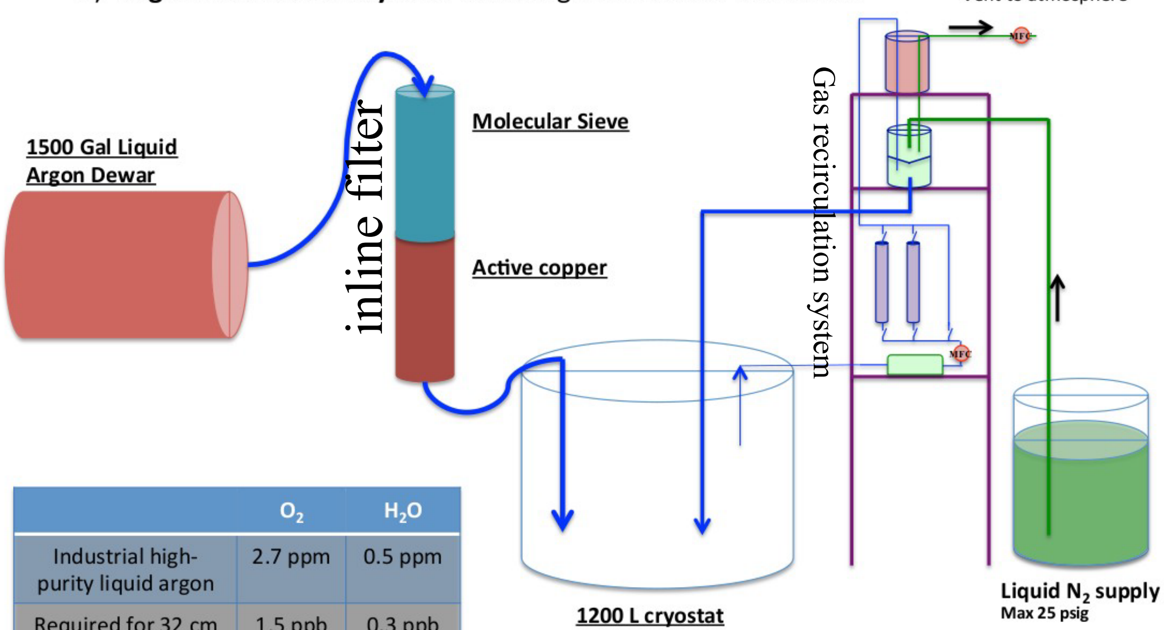
LAPD PrM signal



Purification test for Mini-CAPTAIN with H_2O/O_2 analyzers

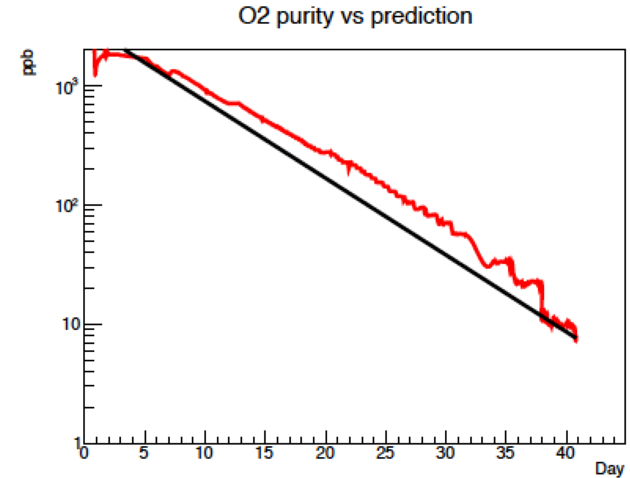
MiniCAPTAIN Cryogenics and Purification system consists of:

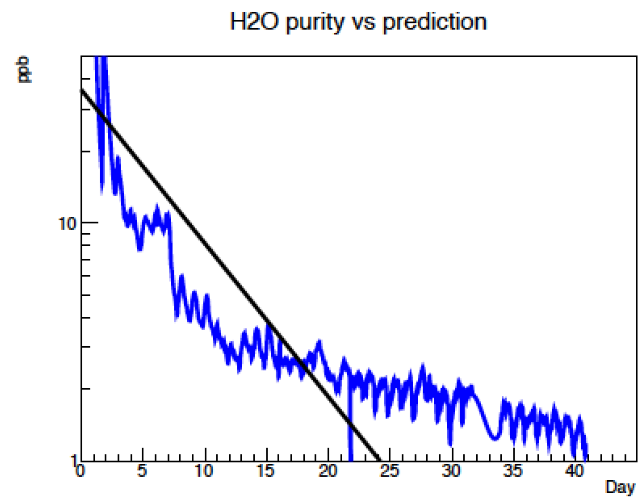
1) An inline **liquid argon filter**
2) A **gas recirculation system** including a condenser and filters



	O_2	H_2O
Industrial high-purity liquid argon	2.7 ppm	0.5 ppm
Required for 32 cm drift distance	1.5 ppb	0.3 ppb

Courtesy of Q. Liu





From Qiuguang Liu @ LANL

CAPTAIN construction is underway


CAPTAIN Cryostat


CAPTAIN Cryostat


Pressure Testing


After arriving at LANL

- Cryostat and electronics are in hand
- TPC wiring will take place soon
- Purification system is at the vendor

Conclusions

The CAPTAIN physics program will navigate the neutrino detection uncertainties related to DUNE in two critical energy regimes:

Low-energy neutrinos and neutrons (< 100 MeV)

- Measure and characterize, for the first time ever, the CC and NC interactions relevant for supernova neutrino detection in argon
- Directly identify the most intense transitions to bound excited states and measure the unbound states

High-energy Neutrinos (1.5 – 5 GeV) and neutrons (0.4 – 0.8 GeV)

- Measure the inclusive and exclusive CC and NC cross-sections from neutrino interactions in the few GeV energy range – joint collaboration with MINERvA
- Develop ways to identify and tag neutrons produced in FSI and improve the neutrino energy reconstruction

Neutron beam running will take place in January 2016 using the Mini-captain detector system.

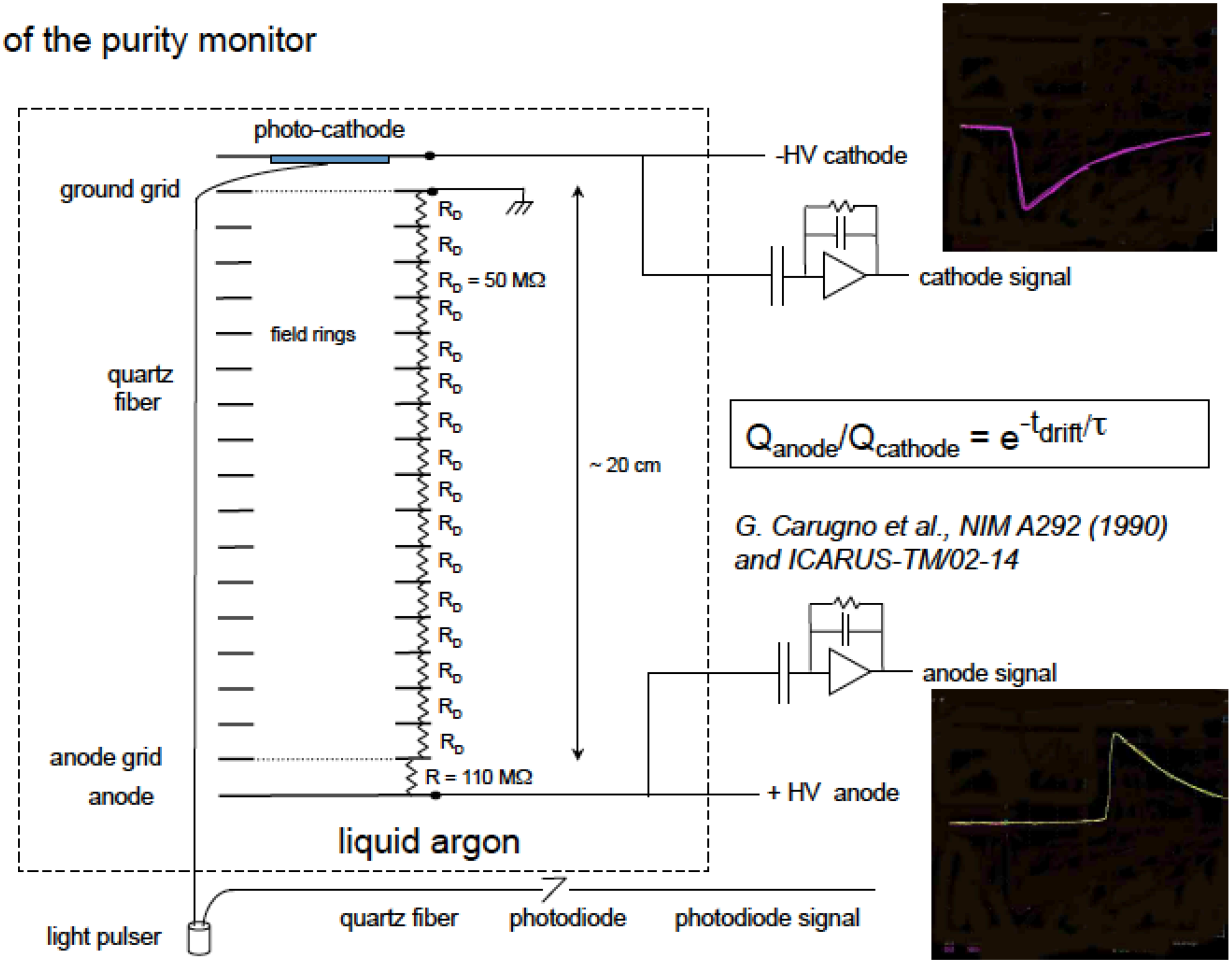
Two LOIs for Fermilab PAC:

1) **Run CAPTAIN at the BNB for supernova-like neutrinos**
2) **Run CAPTAIN-MINERvA in the NuMI beam for long-baseline neutrinos**

We submitted a full proposal to the Fermilab PAC and received Stage 1 approval for CAPTAIN-MINERvA from the Fermilab director.

Backup

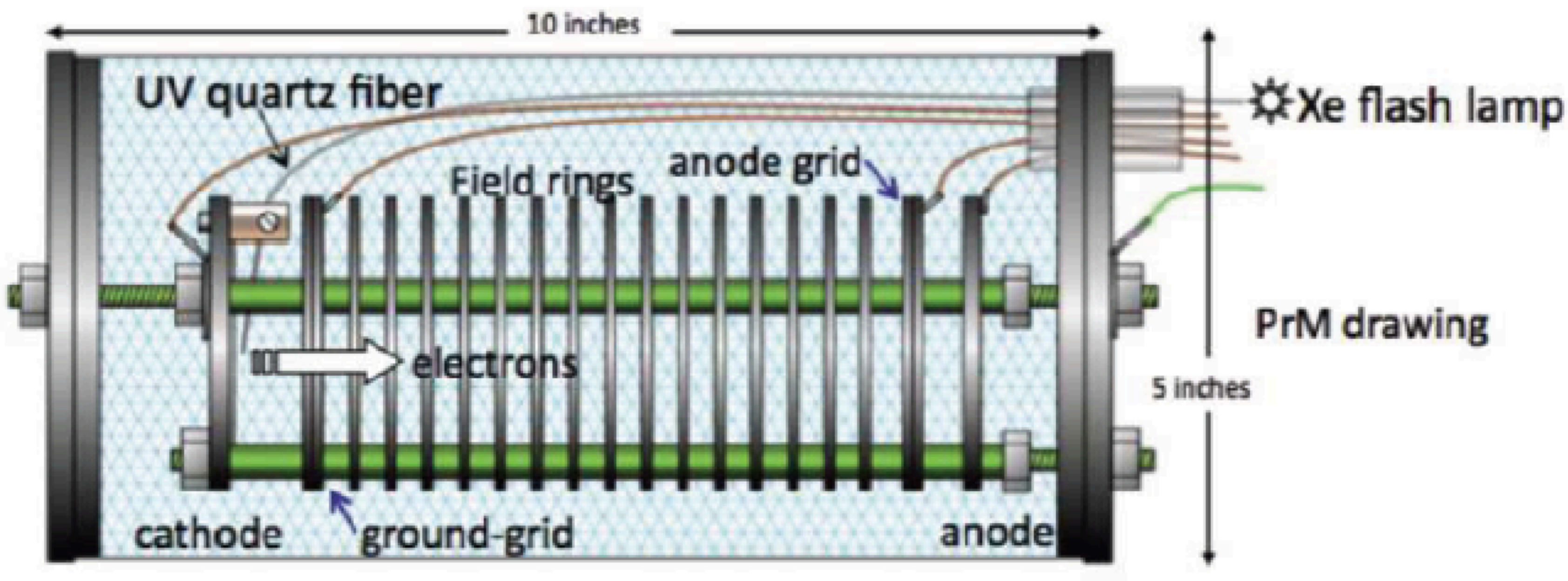
Diagram of the purity monitor



$$Q_{anode}/Q_{cathode} = e^{-t_{drift}/\tau}$$

G. Carugno et al., NIM A292 (1990) and ICARUS-TM/02-14

The purity monitor



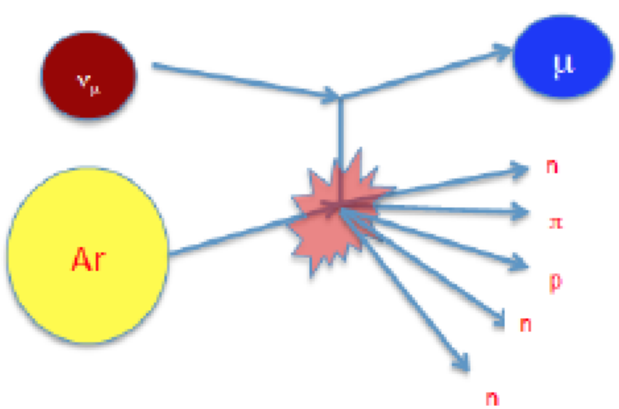
Long-Baseline Neutrino Event Reconstruction

At 1300 km, DUNE will measure neutrino interactions between 1.5 – 5 GeV (near first oscillation maximum), where neutrino-nucleus interactions are poorly understood:

- **ArgoNEUT** has the first and only inclusive cross-section measurement at these energies **(~3200 ν and anti-ν events) from NuMI beam**

- In the 1.5 – 5 GeV energy window, rich and complex neutrino-nuclei interactions will take place - **more than half of neutrino interaction events will occur in the baryon resonance channel**

- **Neutrons produced in neutrino interactions will complicate energy reconstruction of incoming neutrinos (missing energy = uncertainty in L/E)**



Understand neutrons better to improve neutrino Energy reconstruction.

Supernova Neutrino Event Reconstruction

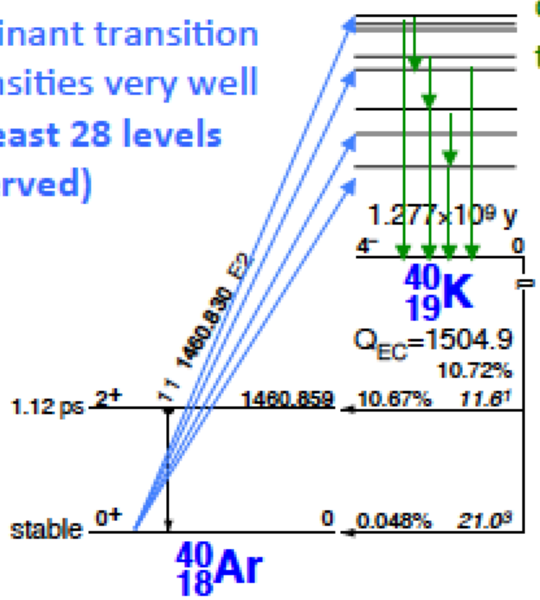
A supernova burst will result in a continuous spectrum of neutrino energies < 100 MeV.
Neutrinos in this energy regime have **NEVER** been detected in a liquid argon TPC.

Extracting physics from supernova neutrinos requires reconstructing true neutrino energy.

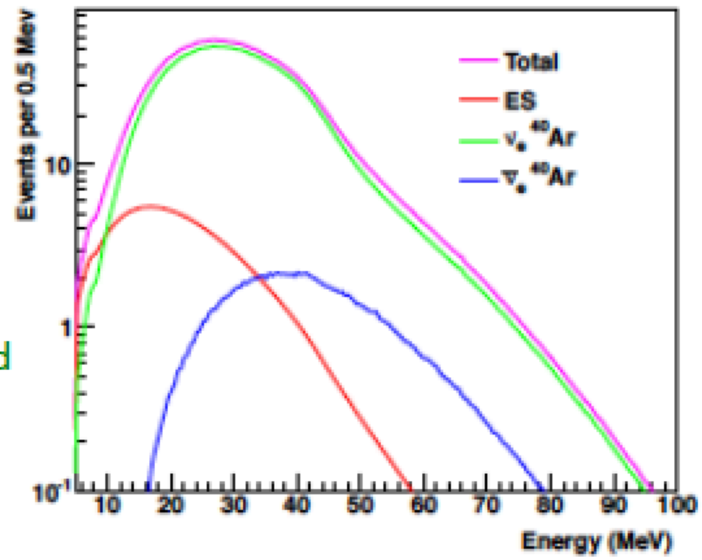
Neutrino Energy | Outgoing Electron Energy | Q-value of Transition | Recoil Energy of Nucleus

CC reaction: $E_\nu = E_e + Q + K_{\text{recoil}}$

We need to know dominant transition intensities very well **(at least 28 levels observed)**



Also need to know all the de-excitation gammas and their branching fractions

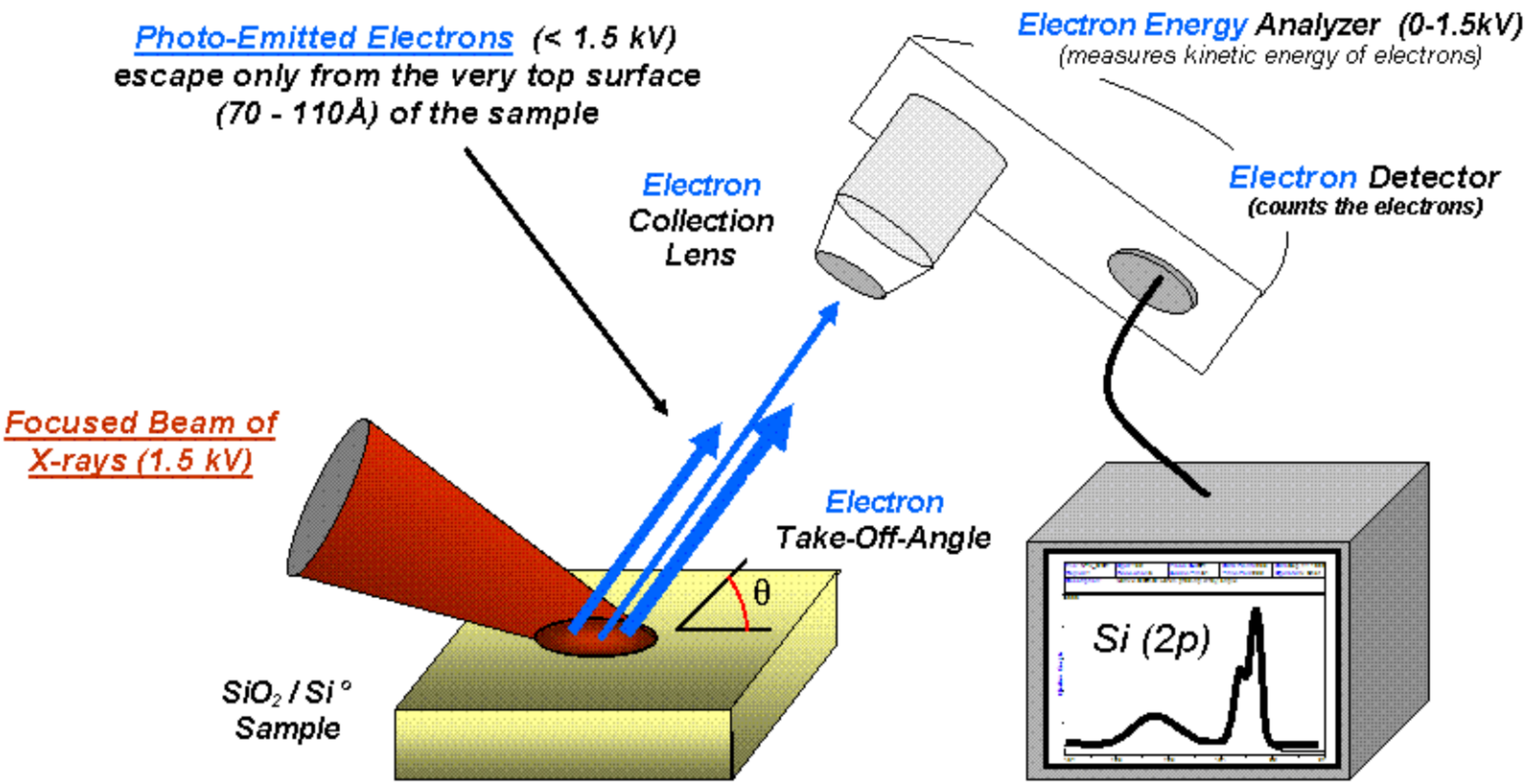


[1] K. Scholberg
[2] A. Hayes

Reaction Type	Events / 10 kt
(CC) $\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$	~700 [1]
(CC) $\bar{\nu}_e + {}^{40}\mathrm{Ar} \rightarrow e^+ + {}^{40}\mathrm{Cl}^*$	~60 [1]
(ES) $\nu_x + e^- \rightarrow \nu_x + e^-$	~85 [1]
(NC) $\nu_x + {}^{40}\mathrm{Ar} \rightarrow \nu_x + {}^{40}\mathrm{Ar}^*$	~90 [2]

(SN at 10 kpc)

X-ray Photoelectron Spectroscopy (XPS) test at UMN for photocathodes degraded in LAPD/Luke @ Fermilab



Samples are usually solid because XPS requires ultra-high vacuum (<10^{-8} torr)

Si (2p) XPS signals from a Silicon Wafer

Inline filter and condenser