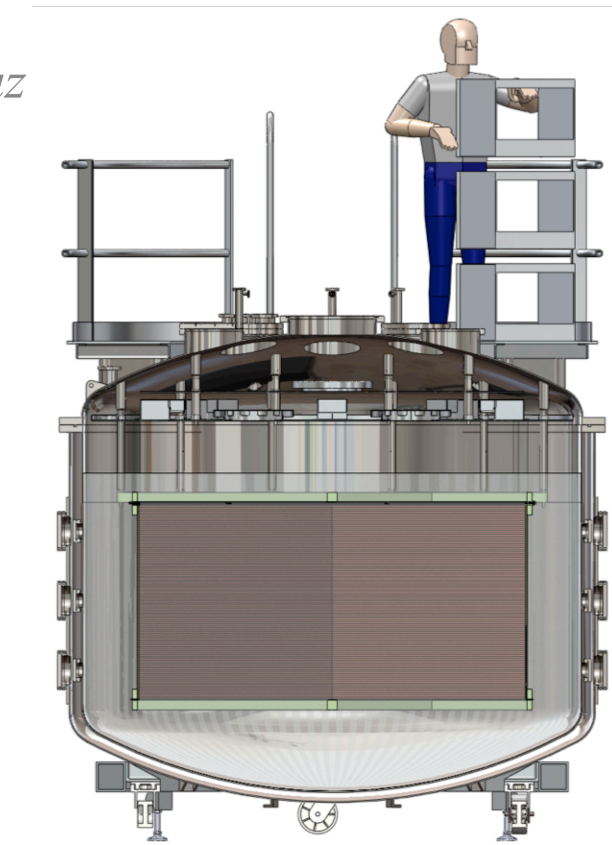
The CAPTAIN Detector and Physics Program

Christopher Grant
UC Davis

DPF 2013 – UC Santa Cruz
August 15, 2013

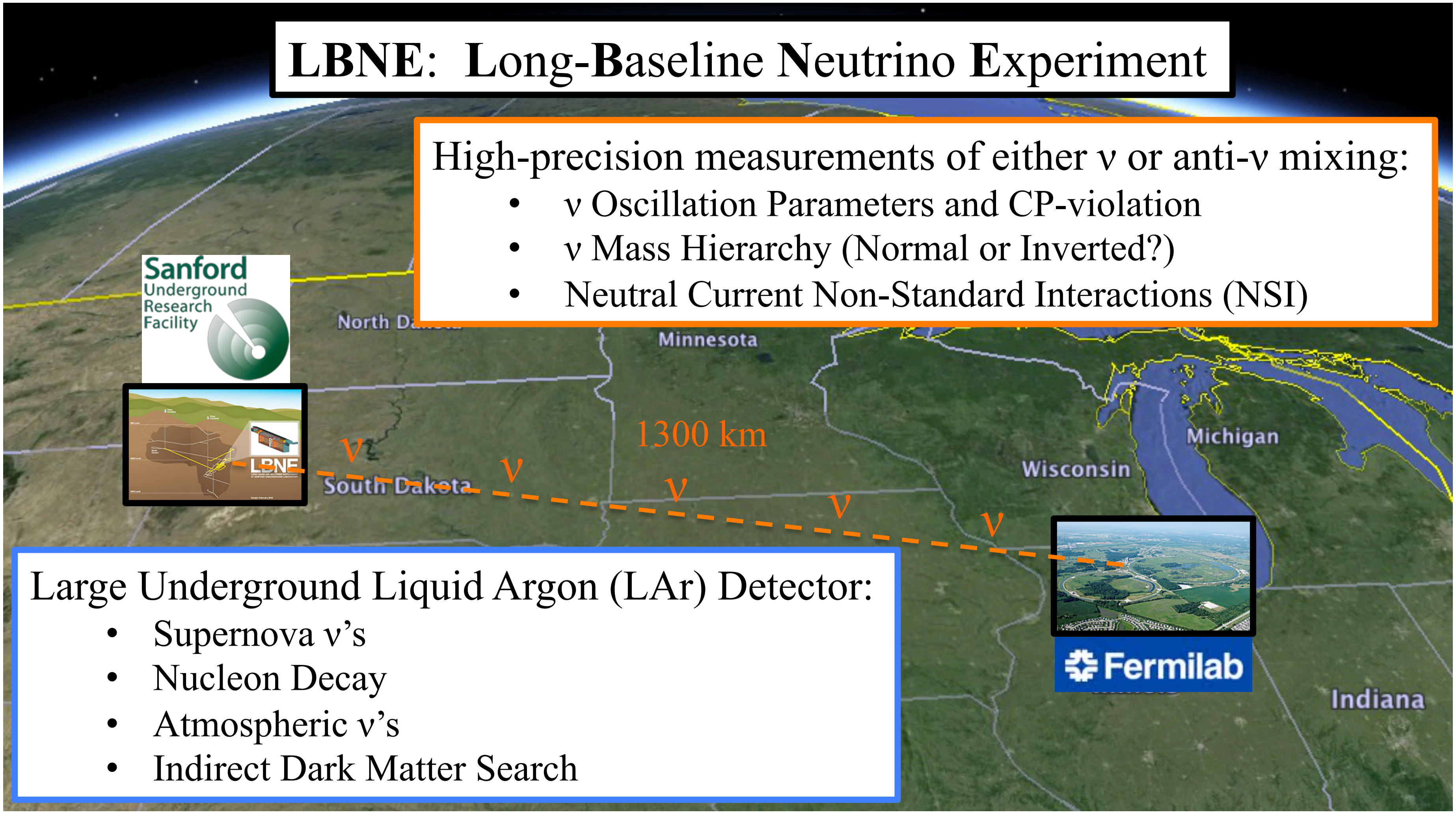
Los Alamos NATIONAL LABORATORY EST. 1943



LBNE: Long-Baseline Neutrino Experiment

High-precision measurements of either ν or anti-ν mixing:

- ν Oscillation Parameters and CP-violation
- ν Mass Hierarchy (Normal or Inverted?)
- Neutral Current Non-Standard Interactions (NSI)



Large Underground Liquid Argon (LAr) Detector:

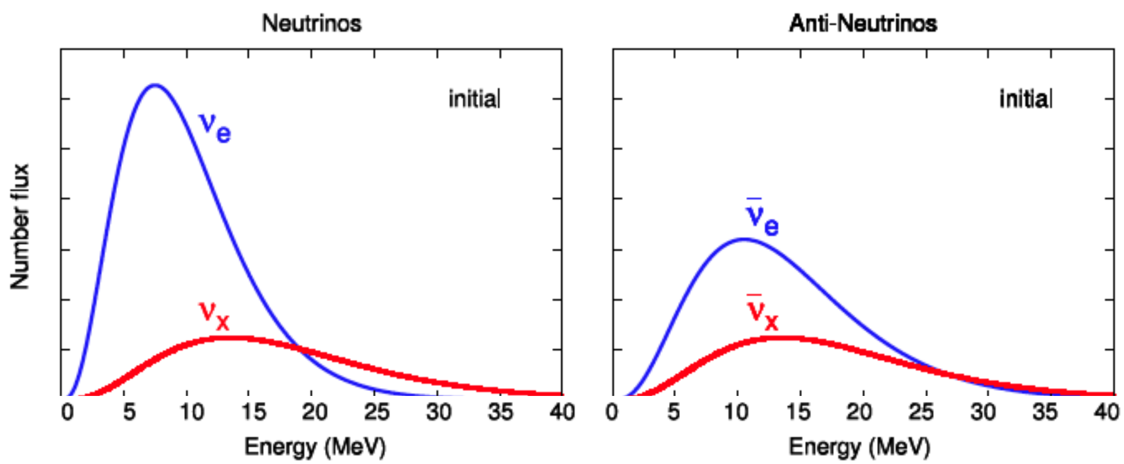
- Supernova ν's
- Nucleon Decay
- Atmospheric ν's
- Indirect Dark Matter Search

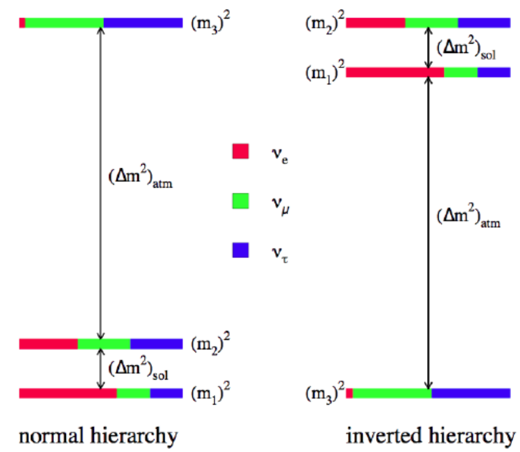
Scientific scope of LBNE is very broad

R&D at LANL will focus on the challenges involved with detecting neutrino interactions in LAr at "low" and "medium" energies

Supernova Neutrino Physics

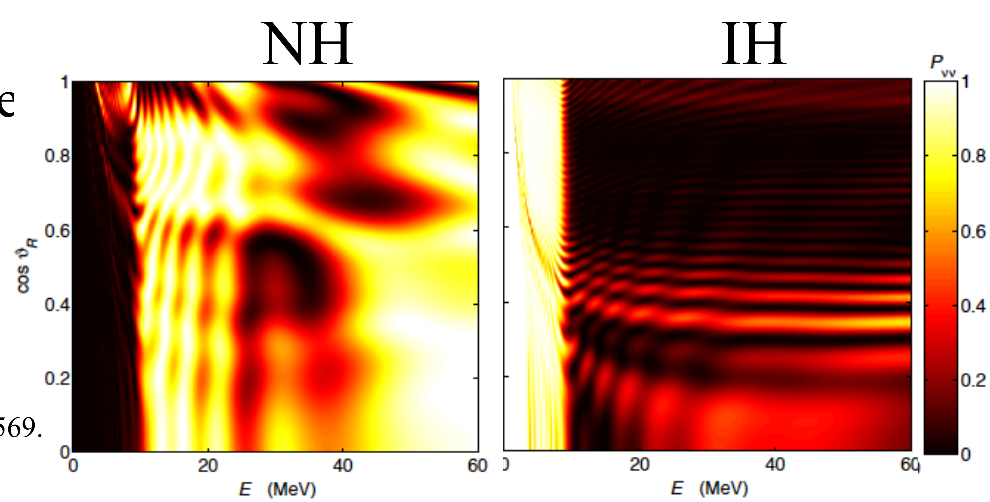
A supernova neutrino burst will result in a continuous spectrum of neutrino energies < 60 MeV





Collective neutrino oscillations may cause a “swap” in the spectrum[3]:

- NH = ν_x flavor change **below** 10 MeV
- IH = ν_x flavor change **above** 10 MeV



[3] H. Duan, G. M. Fuller, and Y. Quan Ann. Rev. Nucl. Part. Sci. 60 (2010) 569.

Supernova Neutrino Physics

	Reaction Type	Events / 10 kton
Majority of signal →	(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]
SN direction →	(ES) $\nu_x + e^- \rightarrow \nu_x + e^-$	~85 [1]
SN-ν total energy →	(NC) $\nu_x + {}^{40}\mathrm{Ar} \rightarrow \nu_x + {}^{40}\mathrm{Ar}^*$	~90 [2]

(at 10 kpc)

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

Measurements of CC and NC cross-sections don't exist for energies important for supernova neutrinos and theorists estimate uncertainties are at least 15%

The follow items are critical for supernova physics with a LAr TPC:

- Accurate measurements of the CC and NC cross-sections
- Ability to clearly tag excited states ${}^{40}\mathrm{K}^*$ and ${}^{40}\mathrm{Ar}^*$ using de-excitation γ's
- Ability to reject backgrounds such as neutron spallation and events that mimic electron neutrino interactions (can you operate on the surface?)
- Adequate energy resolution in a LAr TPC

Neutrino Oscillation Physics

Critical for oscillation studies:
Need neutrino flavor (l), neutrino energy (E_ν), baseline (L) and flux at source

Simple example (2-neutrino mixing): $$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2 2\theta \sin^2\left(\frac{\Delta m^2 L}{4E_\nu}\right)$$

At 1300 km, LBNE will measure neutrino oscillations using neutrino energies between 1.5 – 5 GeV (near the first oscillation maximum)…an energy regime where neutrino-nucleus interactions are poorly understood:

- ArgoNEUT has the first and only inclusive cross-section measurement at these energies (379 events) from NuMI low-energy tune
- 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)

CAPTAIN aims to study the following uncertainties:

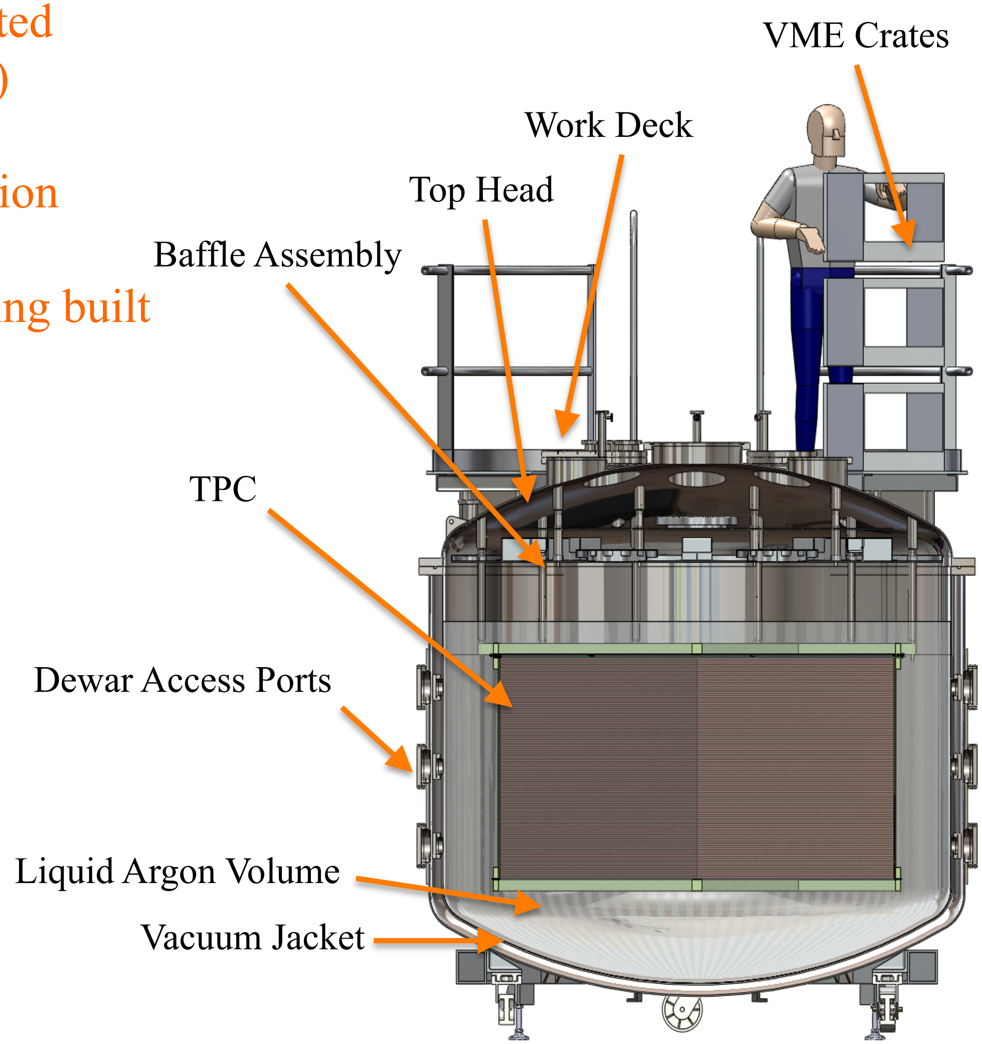
- Cross-section measurements at energies relevant for supernova neutrinos (< 60 MeV) and neutrino oscillation studies (1.5– 5 GeV)

- Neutron tagging and reconstruction relevant for long-baseline neutrinos

- Cosmic spallation backgrounds relevant for supernova neutrinos

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

- Funded by LANL Laboratory Directed Research and Development (LDRD)
- Now a multi-institutional collaboration
- “Portable” Liquid Argon TPC(s) being built at LANL
- 500 V/cm drift field
- 3-mm wire spacing
- Photon detection system (Hamamatsu R8520-500 PMTs)
- Laser system for calibration
- Uses MicroBooNE electronics



CAPTAIN Collaboration

I. Stancu
University of Alabama

Z. Djurcic
Argonne National Laboratory

V. Gehman, R. Kadel, C. Tull
Lawrence Berkeley 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. Termourian
University of California, Los Angeles

O. Prokofiev
Fermi National Accelerator Laboratory

J. Danielson, S. Elliot, G. Garvey, E. Guardincerri, D. Lee,
Q. Liu, W. Louis, C. Mauger, J. Medina, G. Mills,
J. Mirabal, J. Ramsay, K. Rielage, G. 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 Brooke

C. Zhang
University of South Dakota

R. McTaggart
South Dakota State University

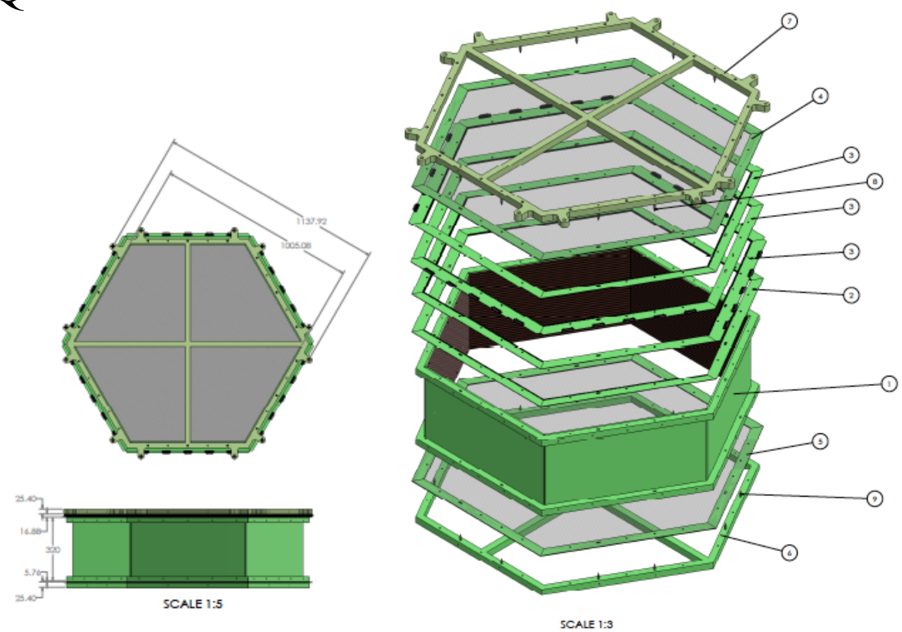
The Detector (2 phases)

Prototype (Mini-CAPTAIN)

- Cryostat from UCLA holds 1700 L of LAr (Diameter = 1.5 m; Height = 1.64 m)
- TPC has a total of about 1000 wires (3 planes) and a max. drift length of 32 cm
- Will allow for early development of DAQ software and provide much needed operational experience

Full-scale (CAPTAIN)

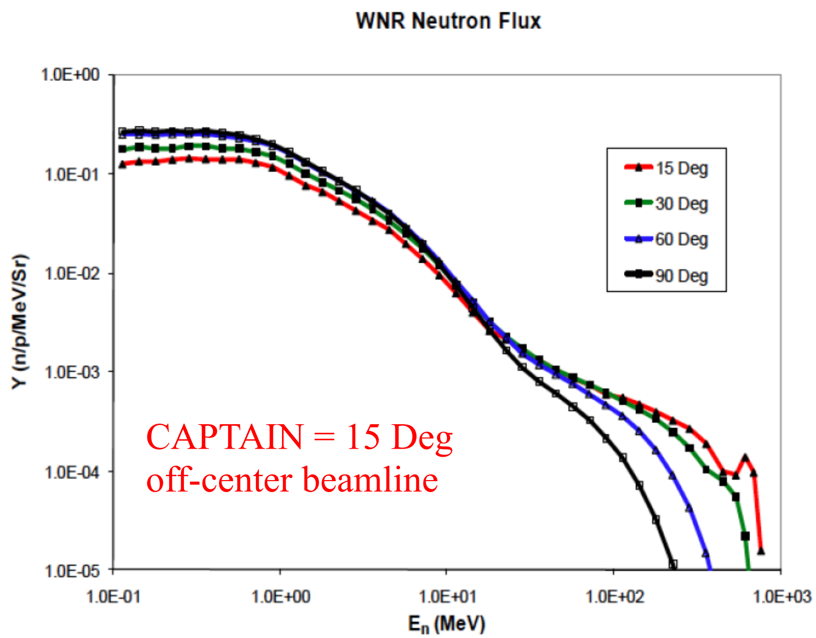
- 7,700 L cryostat (Diameter = 2.72 m; Height = 2.92 m)
- TPC has about 2000 wires and a max. drift length of 100 cm



Neutron Beam Run

The CAPTAIN program will take advantage of the LANSCE WNR neutron beam at LANL:

- Spallation neutron background studies for a detector on the surface (ex: ^{40}Cl production)
- Study neutrino-like Argon excitations via: $n + {}^{40}\mathrm{Ar} \rightarrow n + {}^{40}\mathrm{Ar}^{*}$ with de-excitation γ's
- Study π-production in liquid Argon (for neutron energy > 400 MeV)
- Develop techniques to identify neutron interactions in Argon that will later help with neutrino energy reconstruction



Neutron energies up to 0.8 GeV obtained with TOF

We anticipate a neutron beam run in the August 2014 – Early 2015 time period.

Neutrino Beam Run I – NuMI Beamline

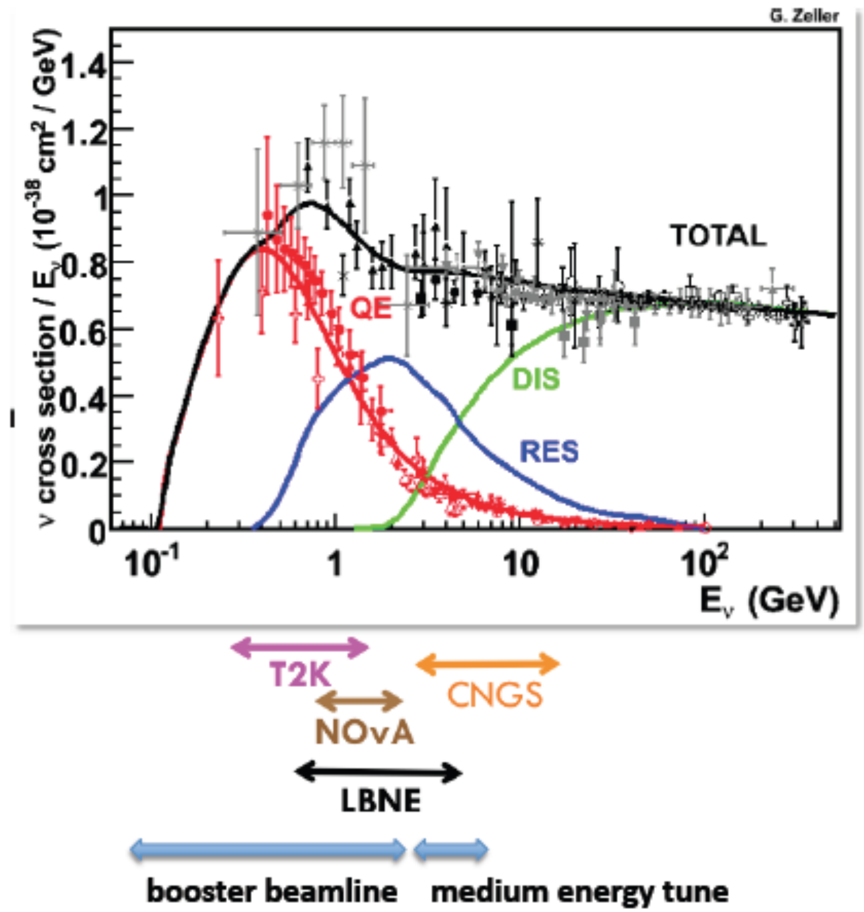
- Running CAPTAIN in NuMI beamline (on-axis with medium energy tune) will shed light on lack of cross-section data between 1 – 10 GeV

- Complimentary measurements to MicroBooNE (booster beamline) = total sampling of LBNE energy spectrum

- CAPTAIN is about 20 times larger than ArgoNEUT = higher statistics

- Monte Carlo studies show about 10% of all neutrino events will be contained (everything but the lepton and neutrons) = 3.7×10^5 contained CC events / year

  (Assuming 4×10^{20} POT)



Neutrino Beam Run II – SNS

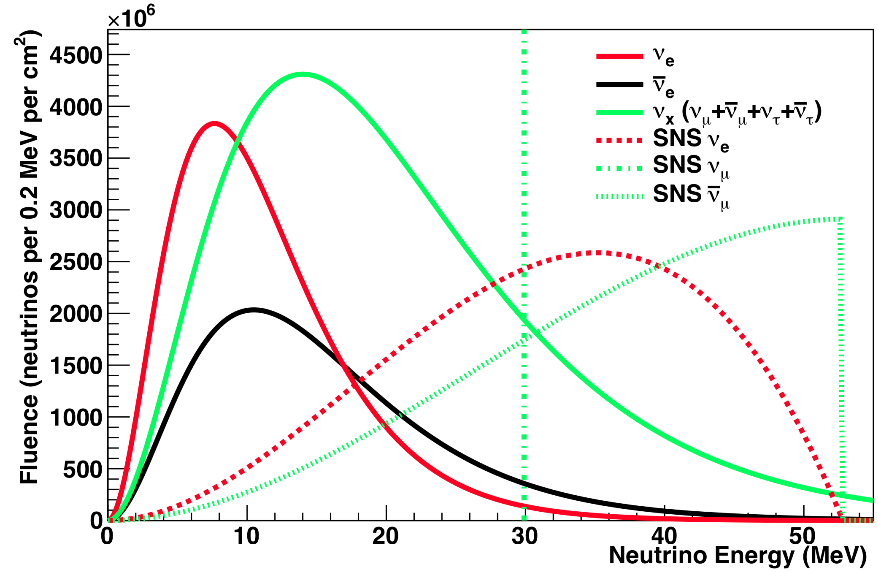
Neutrino beam from stopped pion source at Oak Ridge National Laboratory covers the energy range relevant for supernova neutrinos

~1 GeV protons bombard Hg to produce pions:

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$\downarrow$$

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



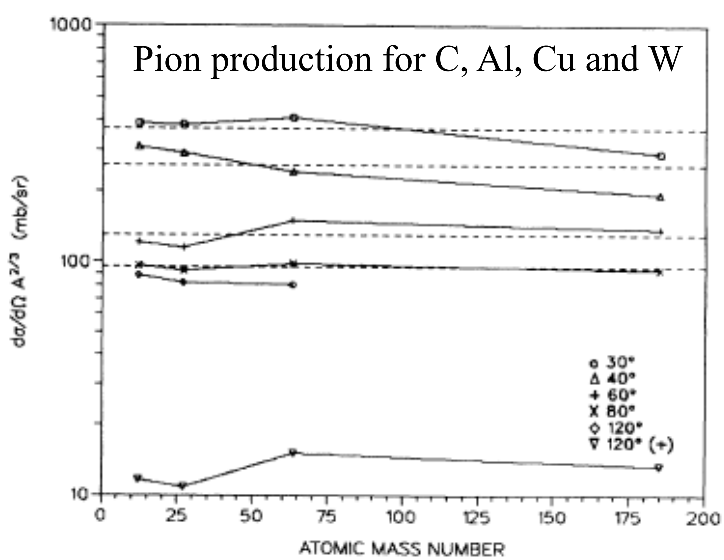
- CAPTAIN positioned at ~50 m from the SNS amounts to about one supernova / day exposure
- Allows for neutrino cross-section measurements and TPC performance studies

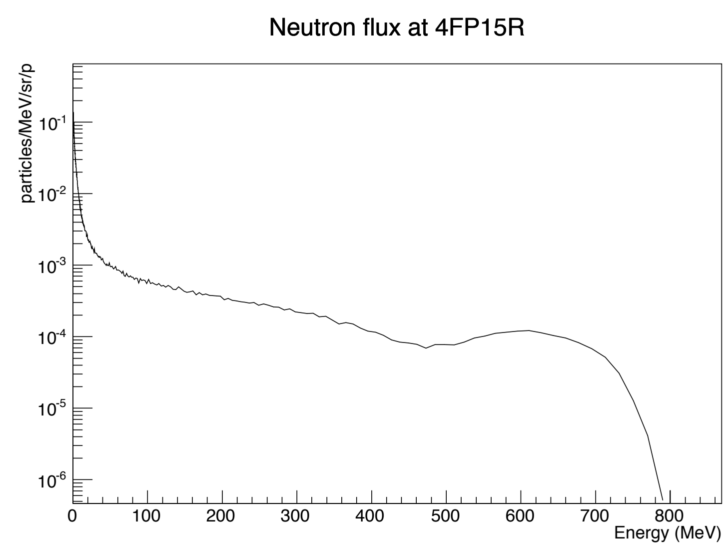
Near-future CAPTAIN Outlook:

- Initial fabrication of the Mini-CAPTAIN has already begun and construction/assembly will continue throughout the fall 2013

- Start commissioning and testing of Mini-CAPTAIN at the end of 2013 to prepare for LANSCE neutron beam exposure in 2014

Measure pion production and neutron interactions in CAPTAIN





Conclusions

The CAPTAIN physics program will attempt to shed-light on the following:

- CC and NC cross-sections relevant for supernova neutrino detection
- Cross-sections from long-baseline neutrino interactions in the few GeV energy range where resonance dominates
- Spallation neutron backgrounds and event reconstruction relative to supernova neutrinos
- Neutron event tagging related to neutrino energy reconstruction for oscillation studies