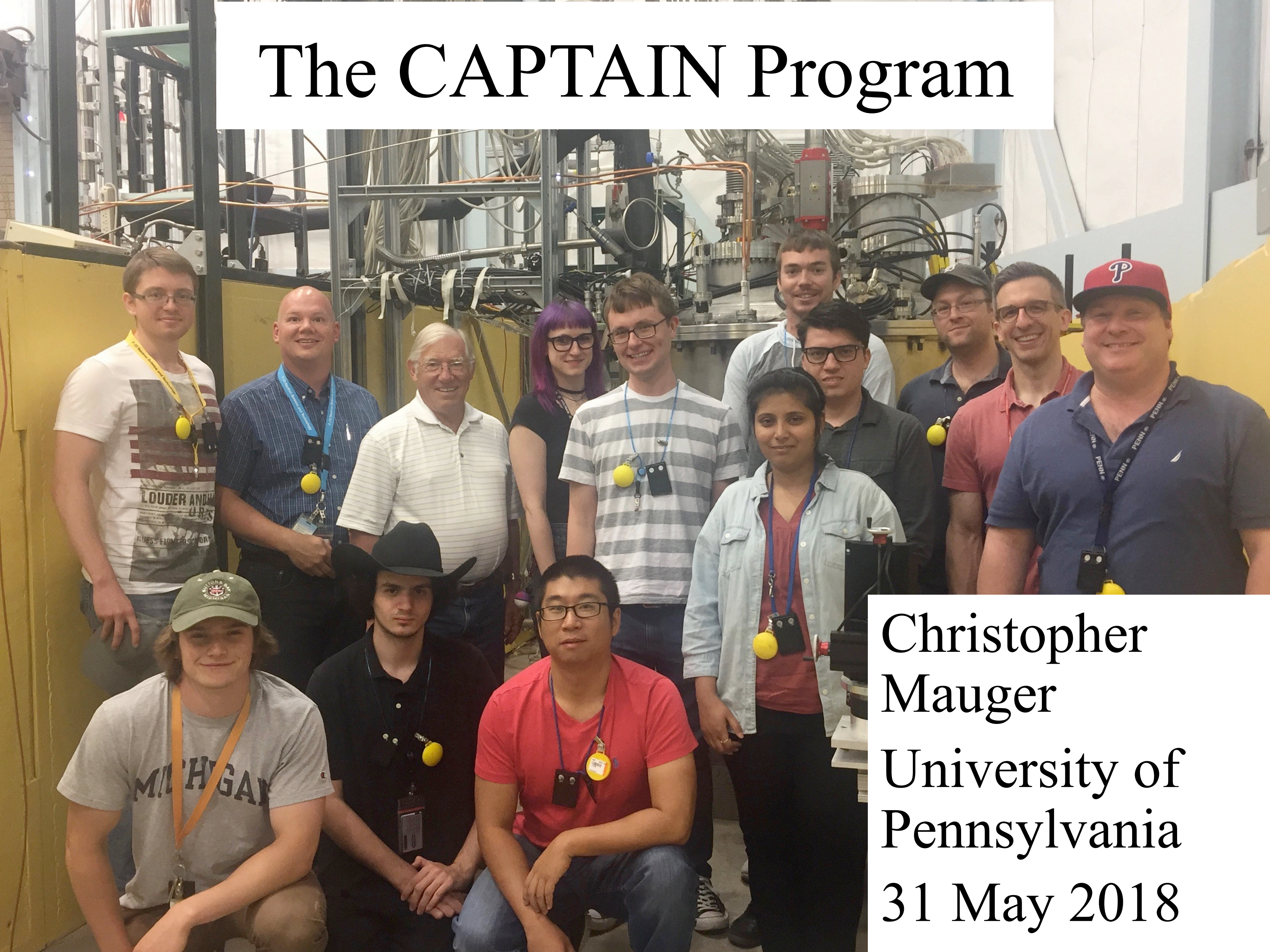
The CAPTAIN Program



Christopher Mauger
University of Pennsylvania

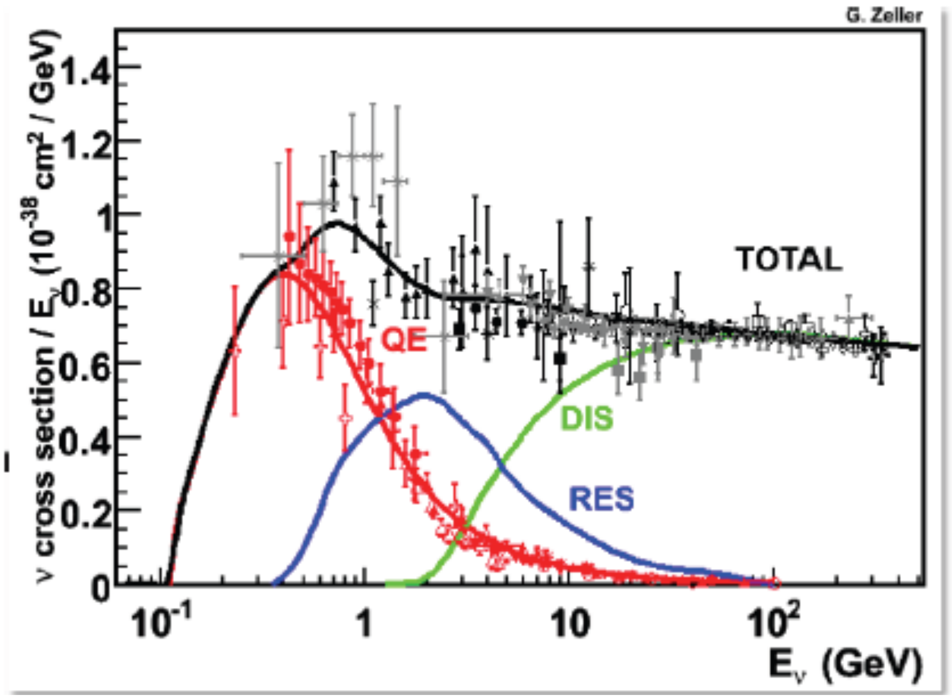
31 May 2018

Outline

- DUNE experiment – covered by Bian in this session
- Physics Challenges for DUNE
  - Long-baseline neutrinos (also atmospheric)
  - Supernova neutrinos
- The CAPTAIN program
- Current and future activities

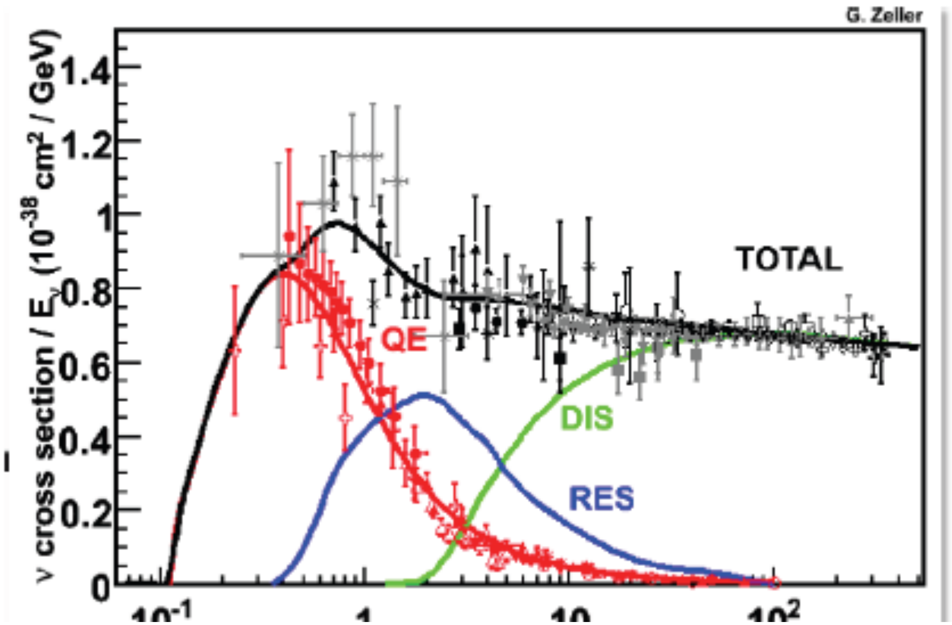
Physics Challenges for DUNE

DUNE Physics Challenges



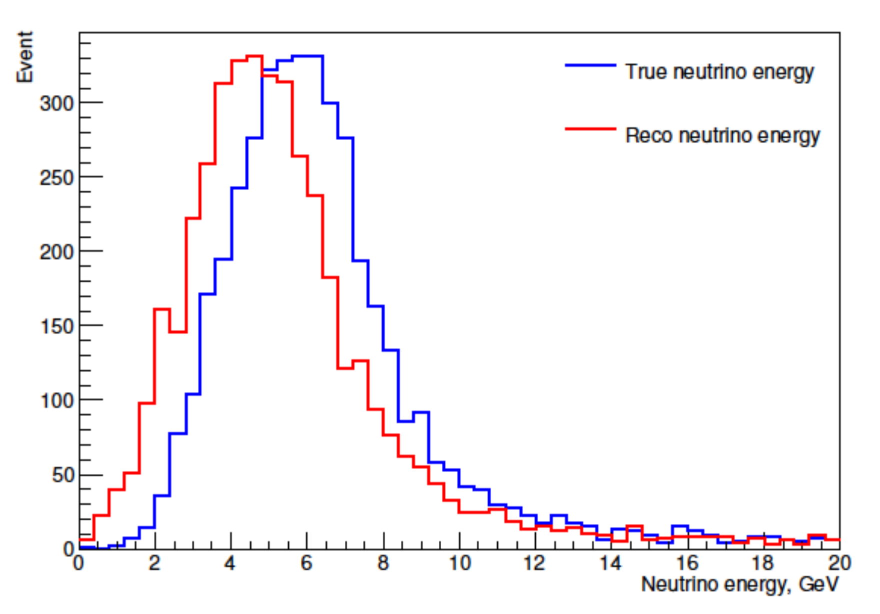
- DUNE will produce a conversion probability of muon neutrino to electron neutrino and muon anti-neutrino to electron anti-neutrino as a function of neutrino energy
- DUNE does long-baseline physics on earth (matter), so the experiment has a built in CP asymmetry
- Oscillation phenomena depend on mixing angles, masses, etc. and neutrino energy
- Critical to understand the correlation between true and reconstructed neutrino energy – especially any differences between neutrinos and anti-neutrinos

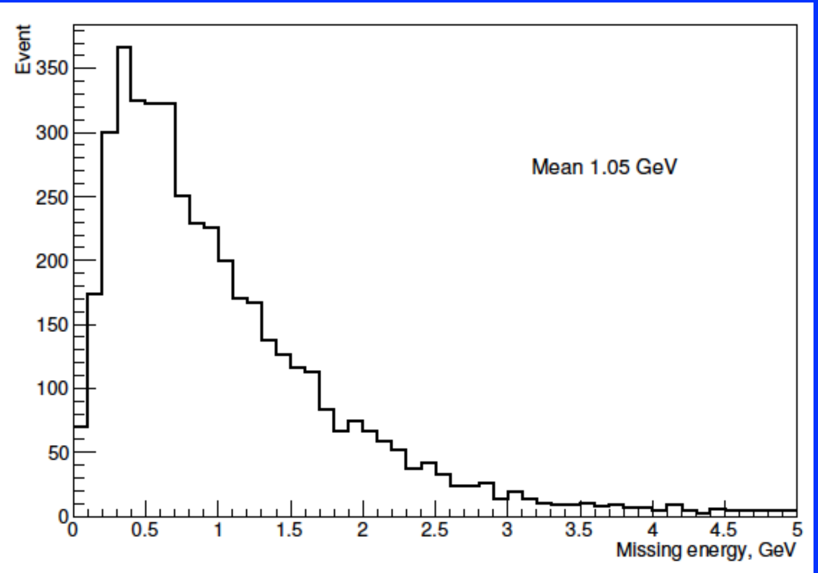
DUNE Physics Challenges

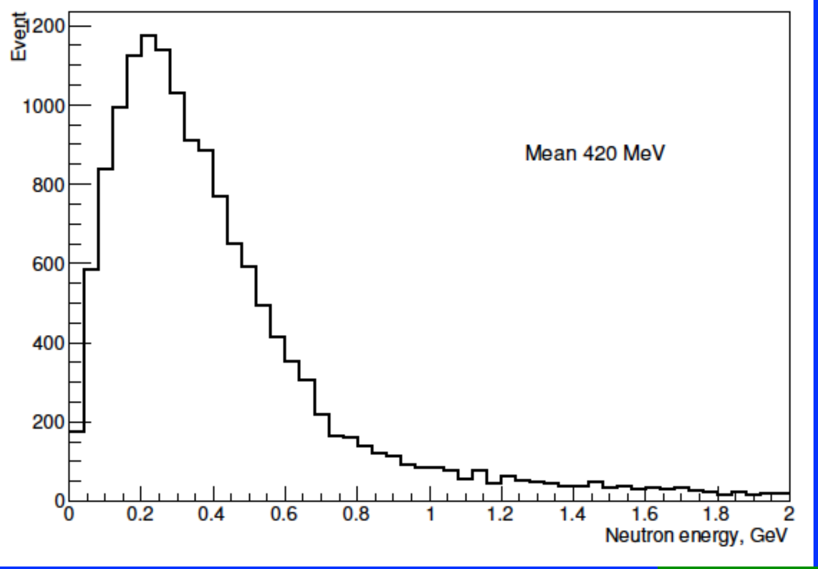


- The first oscillation maximum is at approximately 2.4 GeV
- Neutrino cross-sections are highly uncertain – talk by Marshall
- Most DUNE long-baseline neutrino interactions involve baryon resonance production
- Final state interactions of the outgoing hadronic system also uncertain
- Neutrons often part of the hadronic system emerging from the nucleus
- Typical kinetic energies - hundreds of MeV, so should account for them when reconstructing neutrino energies

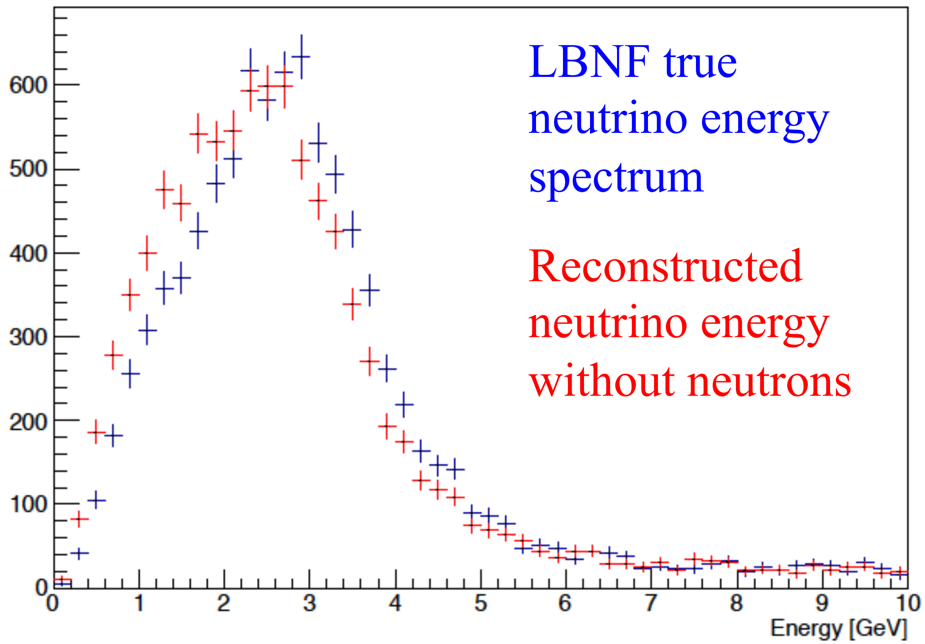
NuMI Medium Energy Tune

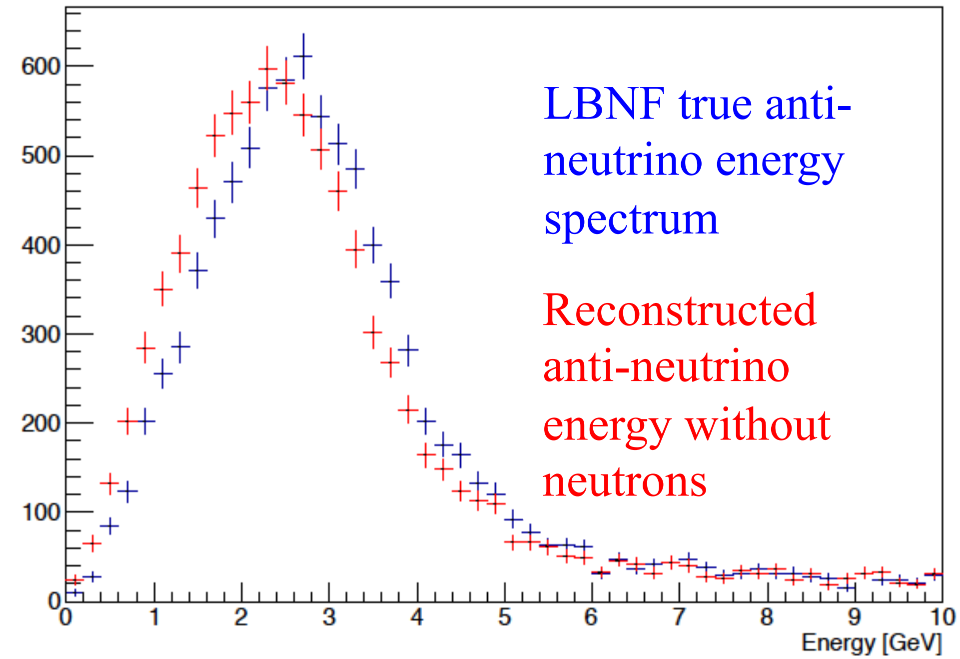




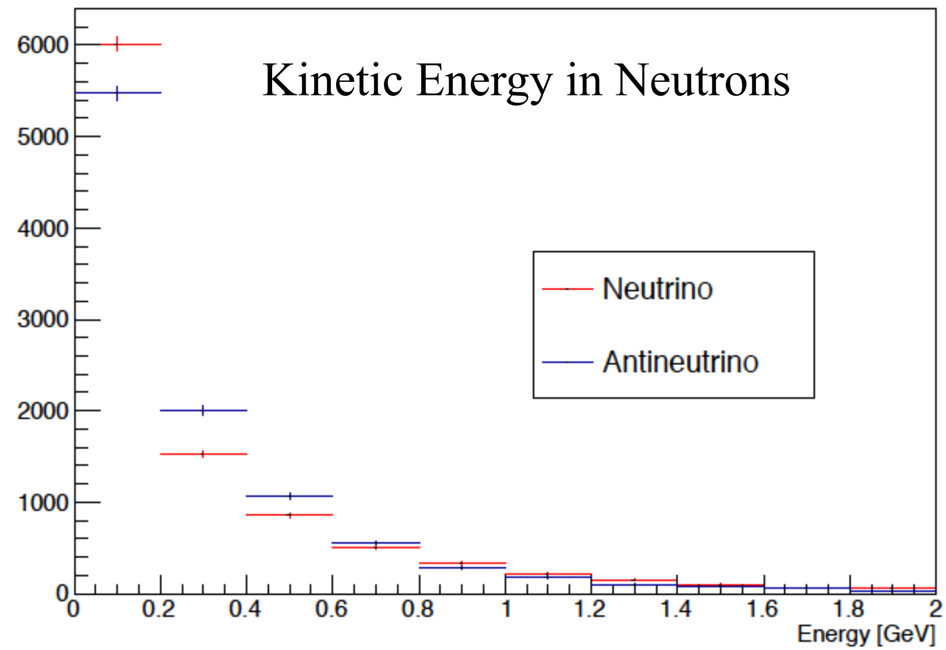


- Upper left: Blue is true neutrino energy; Red is reconstructed energy assuming no neutron reconstruction and perfect reconstruction of other particles
- Upper right: Total energy in neutrons. Note asymmetric distribution (and large uncertainties), so we cannot assume a constant ``offset'' to the neutrino energy reconstruction
- Lower right: Energy per neutrons
- All plots: NuMI medium energy tune, GENIE event generator ``out of the box''

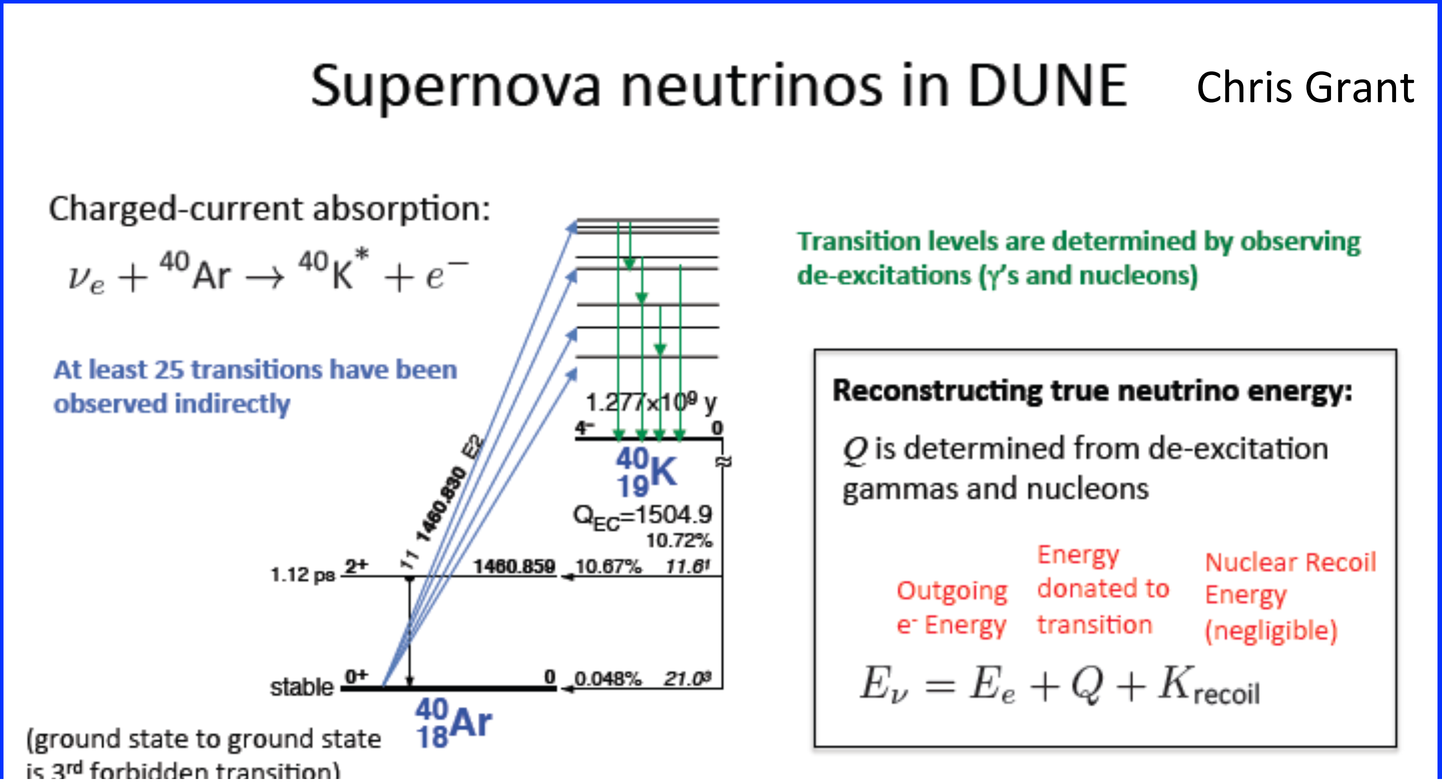




- At LBNF neutrino energies, neutrons can carry away significant energy
- Uncertainties on the energy carried away are large and unconstrained
- The energy carried away differs between neutrinos and anti-neutrinos
- Neutron interactions on argon are unmeasured above 20 MeV
- Let's measure what neutron interactions look like in a liquid argon detector!



Argon as a detection medium for supernova neutrinos

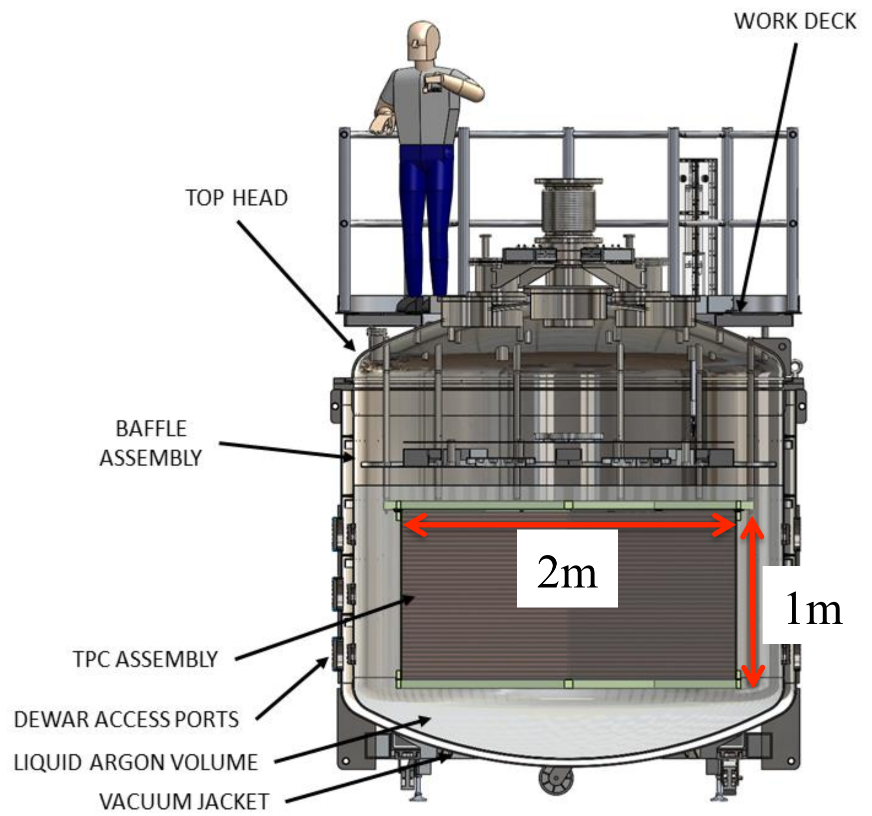


- Supernova neutrinos are a primary physics goal for DUNE (talks by Conley and Scholberg)
- Argon has a large, though uncertain, electron neutrino CC cross-section
- Need to know how much energy goes into gammas, protons and neutrons in order to reconstruct the total neutrino energy

The CAPTAIN Detector

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

- CAPTAIN Detector
  - hexagonal TPC with 1m vertical drift, 1m apothem, 2000 channels, 3mm pitch, 5 instrumented tons
  - indium seal – can be opened and closed
  - photon detection system and laser calibration system
  - cold front-end electronics – same as MicroBooNE
- Physics program focused on challenges to DUNE
  - Neutron running at LANL
  - Low-energy neutrino running

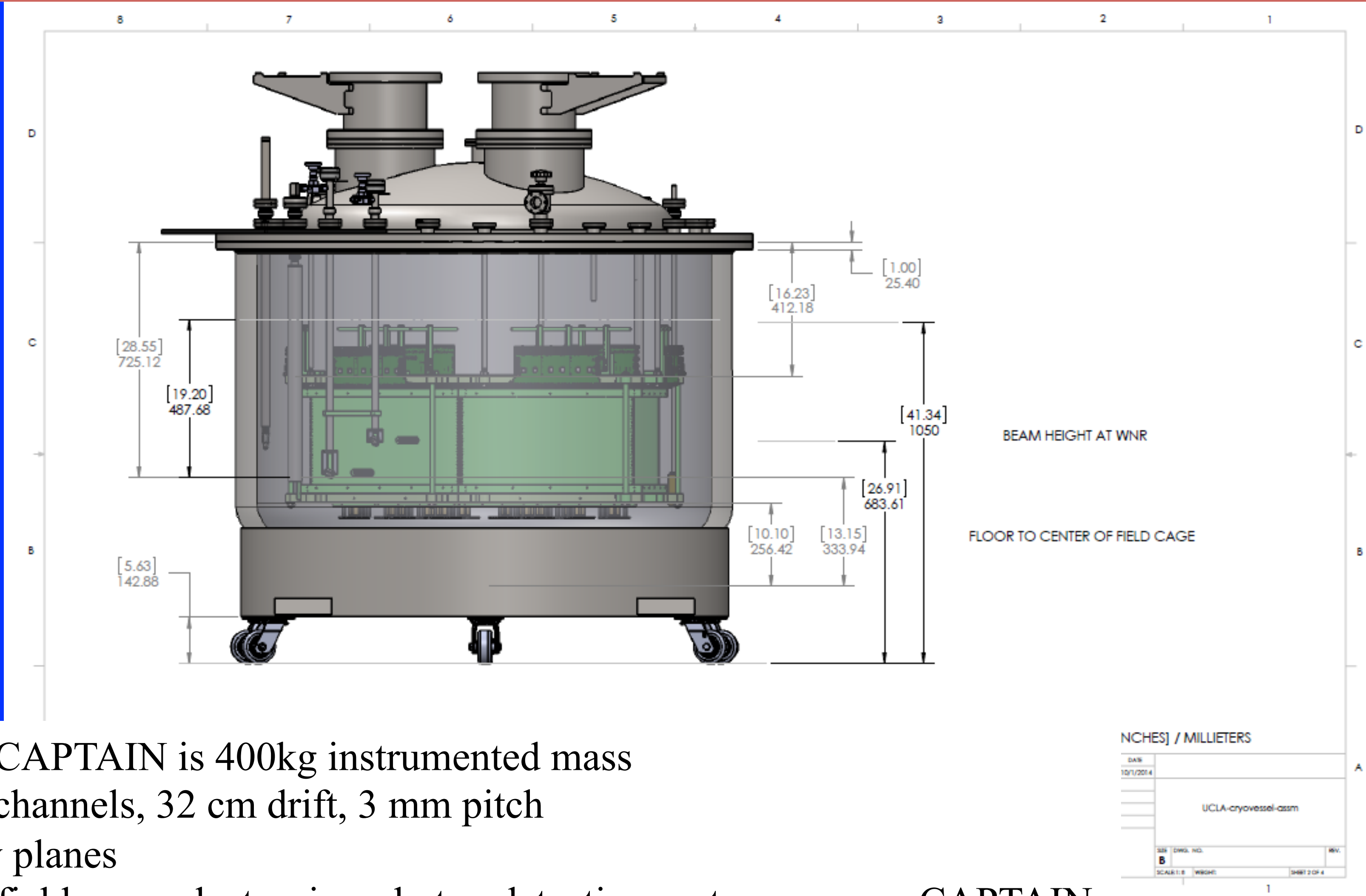


CAPTAIN Physics Program

Neutron Beam
Low-Energy Neutrino Beam

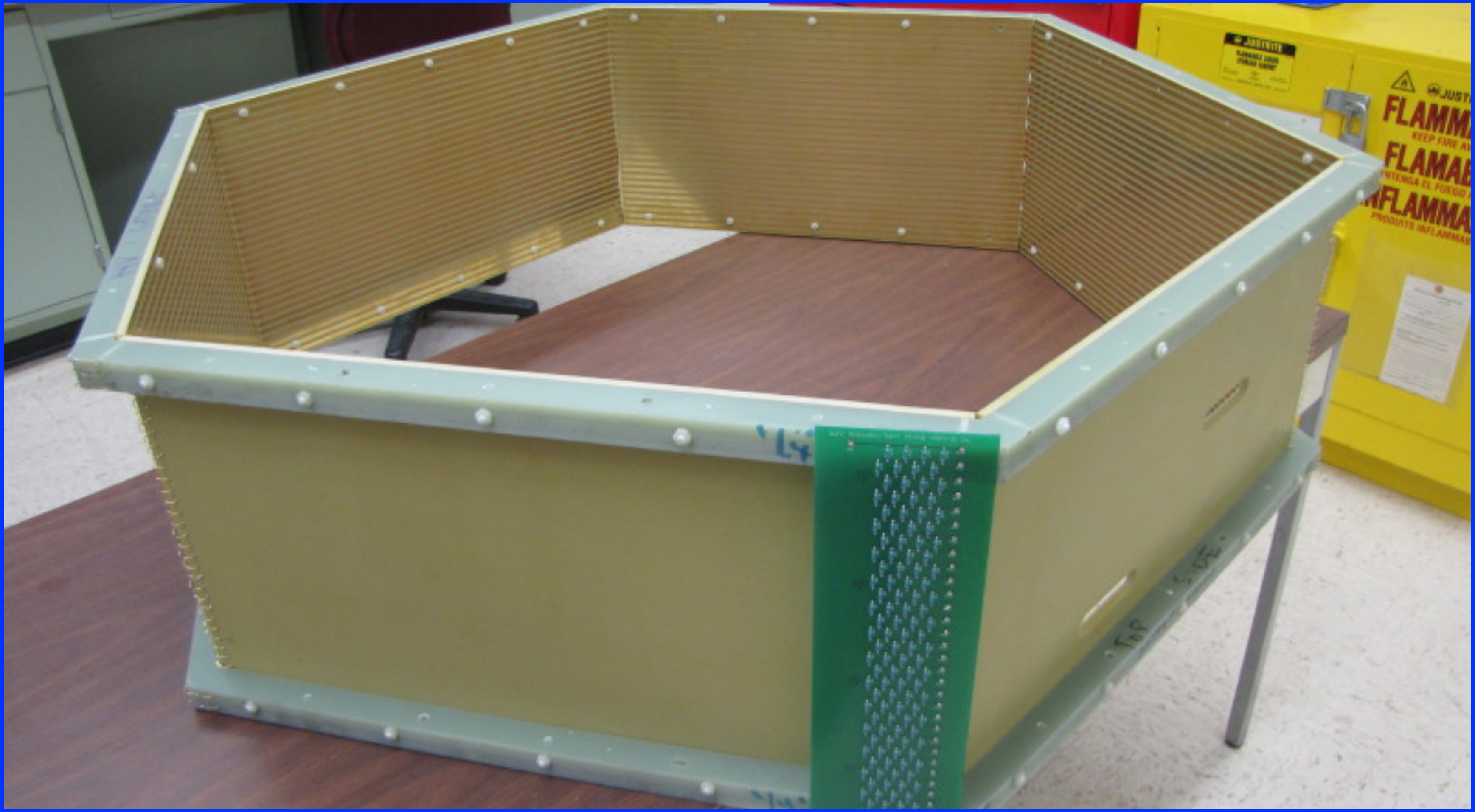
- Low-energy neutrino physics related
  - Measure the neutrino CC and NC cross-sections on argon in the same energy regime as supernova neutrinos
  - Measure the correlation between true neutrino energy and visible energy for events of supernova-neutrino energies
- Medium-energy neutrino physics related
  - Measure neutron interactions and event signatures (e.g. pion production) to allow us to constrain number and energy of emitted neutrons in neutrino interactions (at DUNE, mean neutron K.E. from the LBNF beam ~ 400 MeV)
  - Measure higher-energy neutron-induced processes that could be backgrounds to ν_e appearance e.g. $^{40}Ar(n,\pi^0)^{40}Ar^{(*)}$

Mini-CAPTAIN – prototype detector

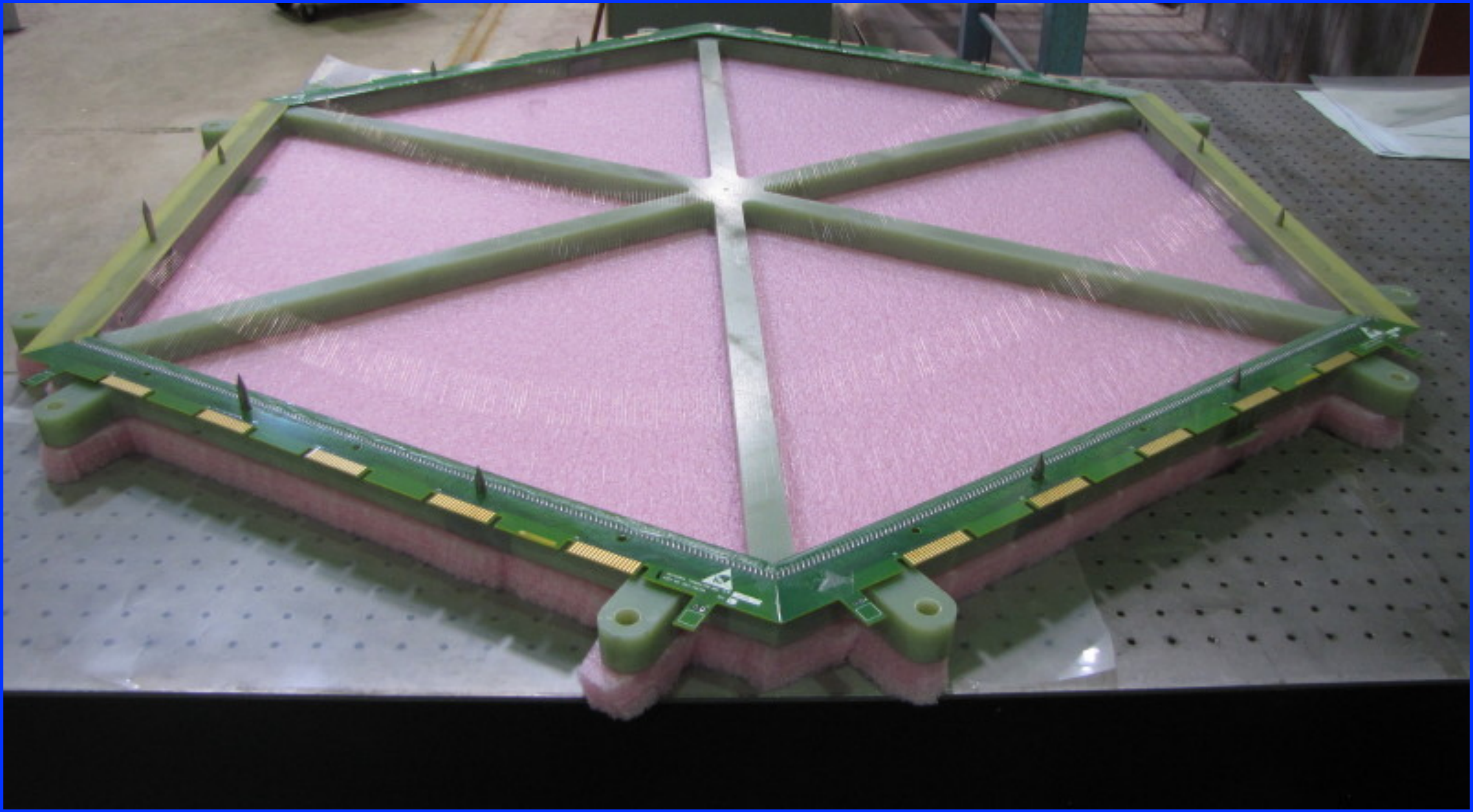


Mini-CAPTAIN is 400kg instrumented mass
1000 channels, 32 cm drift, 3 mm pitch
x, u, v planes
TPC, field cage, electronics, photon detection system same as CAPTAIN

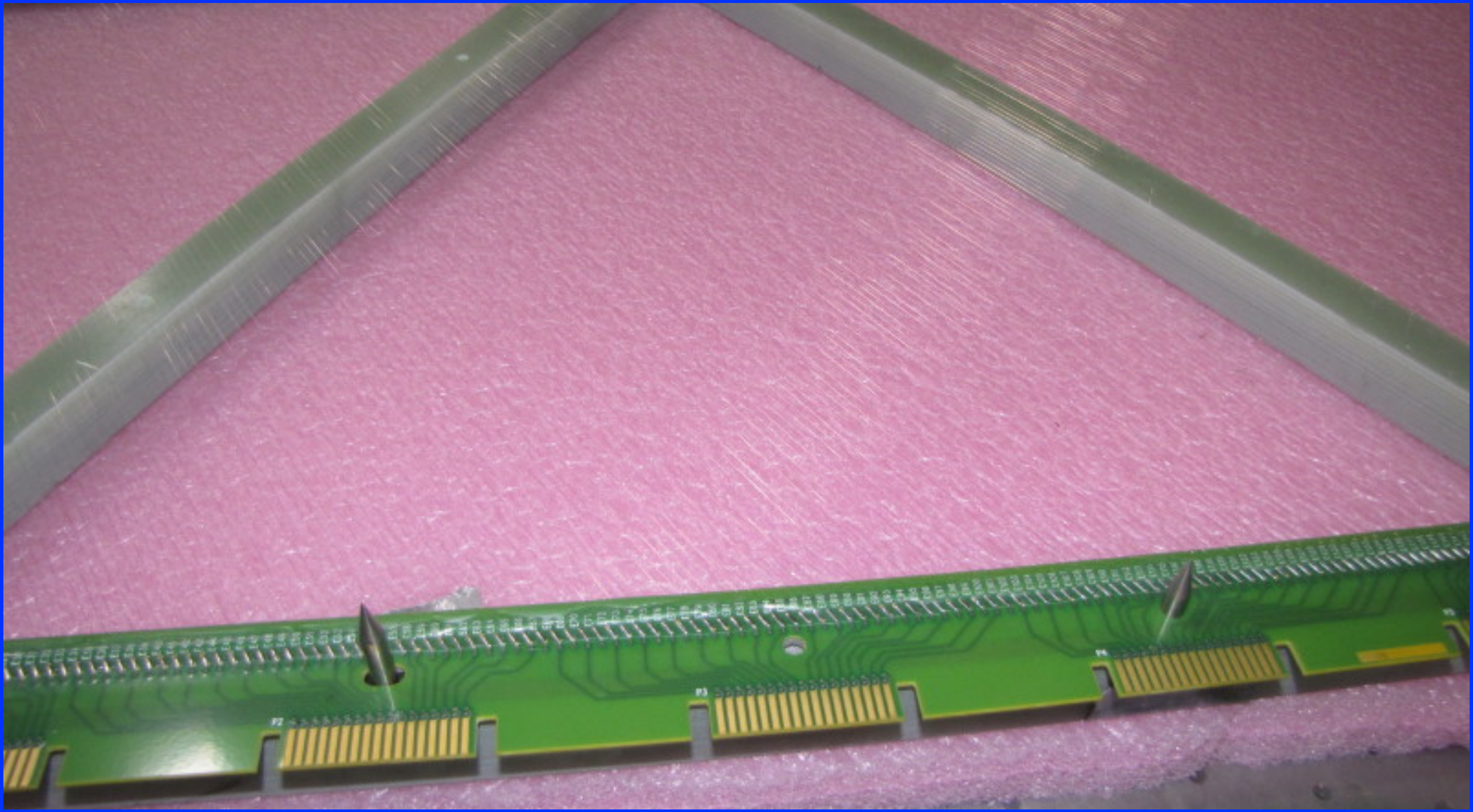
Mini-CAPTAIN field cage



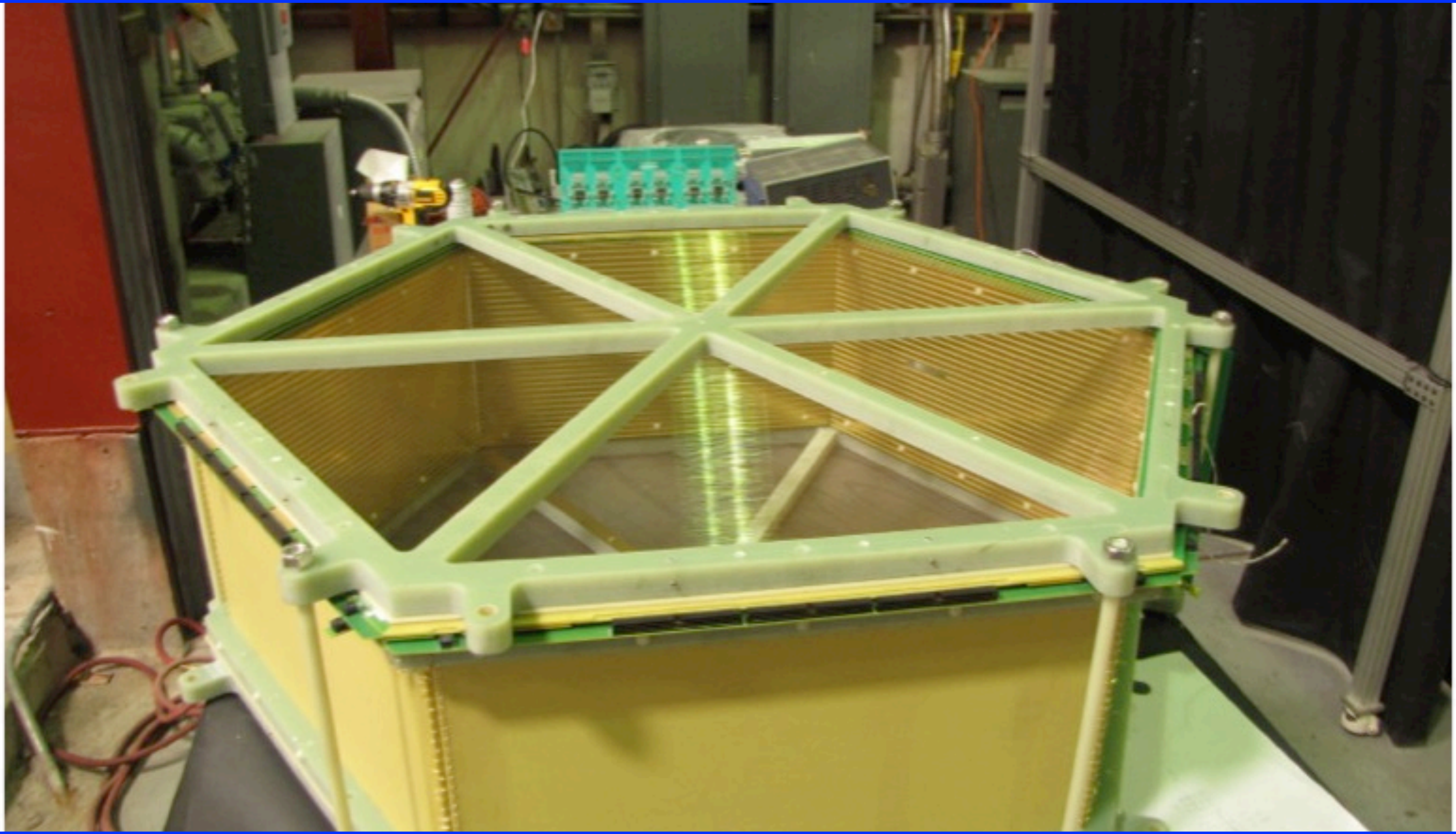
Mini-CAPTAIN wire frame



Wire-frame close-up



Mini-CAPTAIN TPC assembled

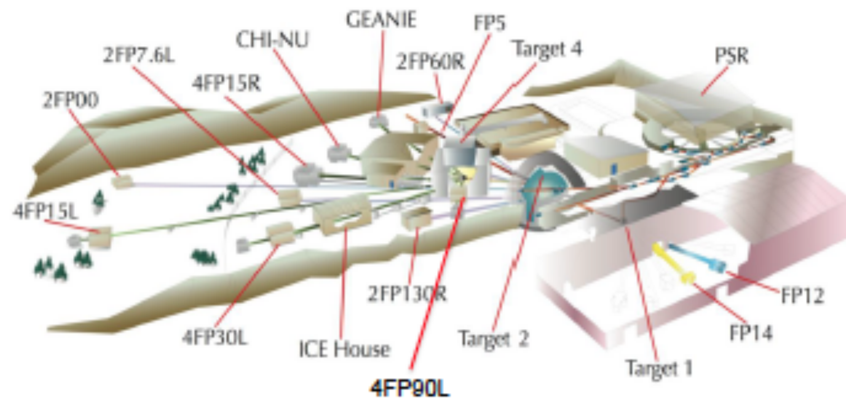


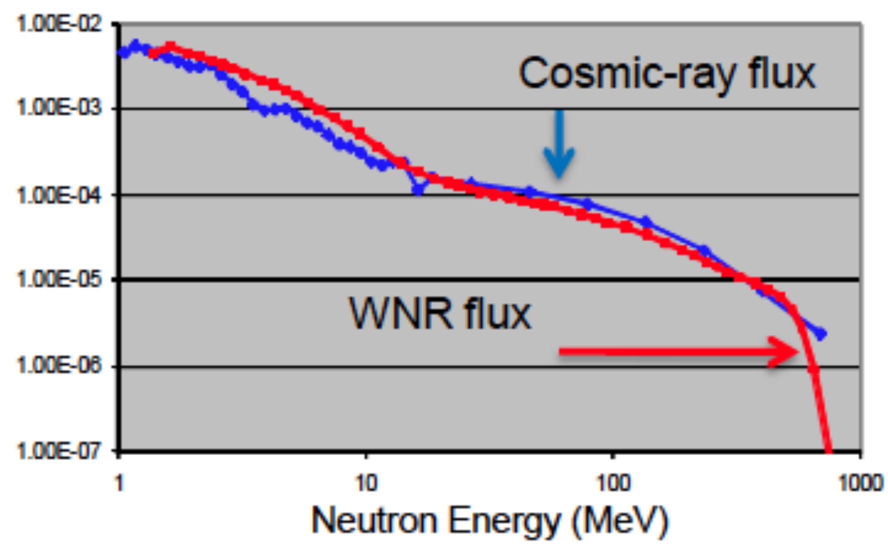
Mini-CAPTAIN Detector

Charles Taylor (PD in picture, now staff) prepares the detector

Neutron Beam at LANL

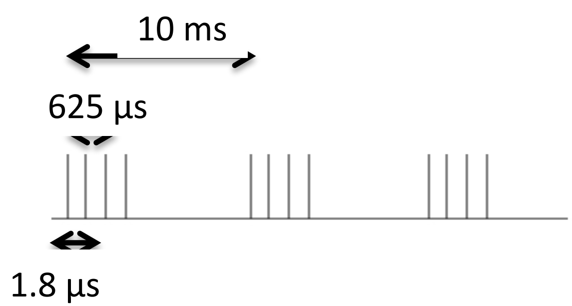
- Los Alamos Neutron Science Center WNR facility provides a high flux neutron beam with a broad energy spectrum similar to the cosmic-ray spectrum at high altitude
- Neutron run completed in August 2017 with our prototype detector (Mini-CAPTAIN, 400 kg)
- Neutron-argon interactions up to endpoint energy of 800 MeV
- protons, pions produced

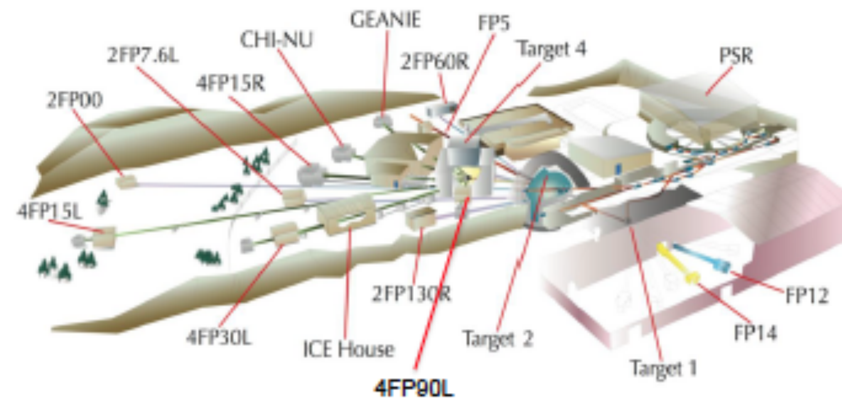


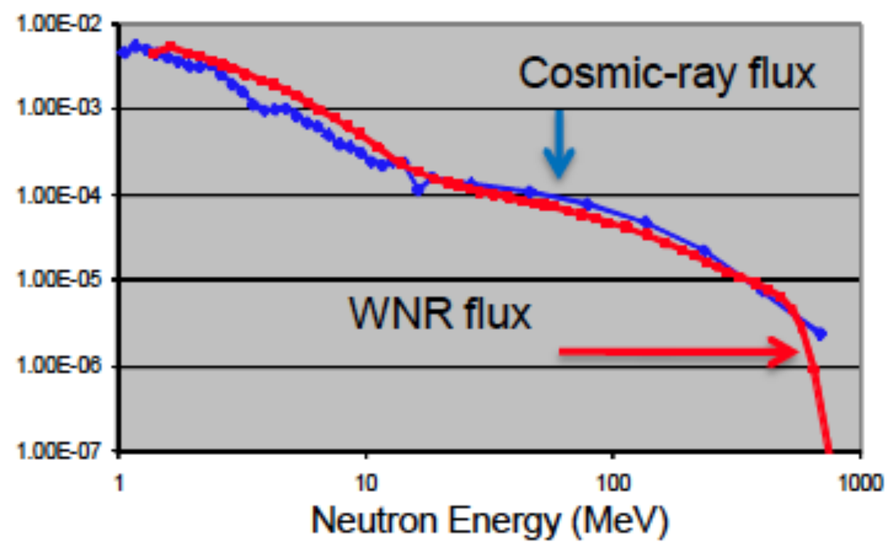


Neutron Beam at LANL

- Time structure of the beam
  - sub-nanosecond pulses 1.8 microseconds apart within a 625 μs long macro pulse
  - Repetition rate: 100 Hz

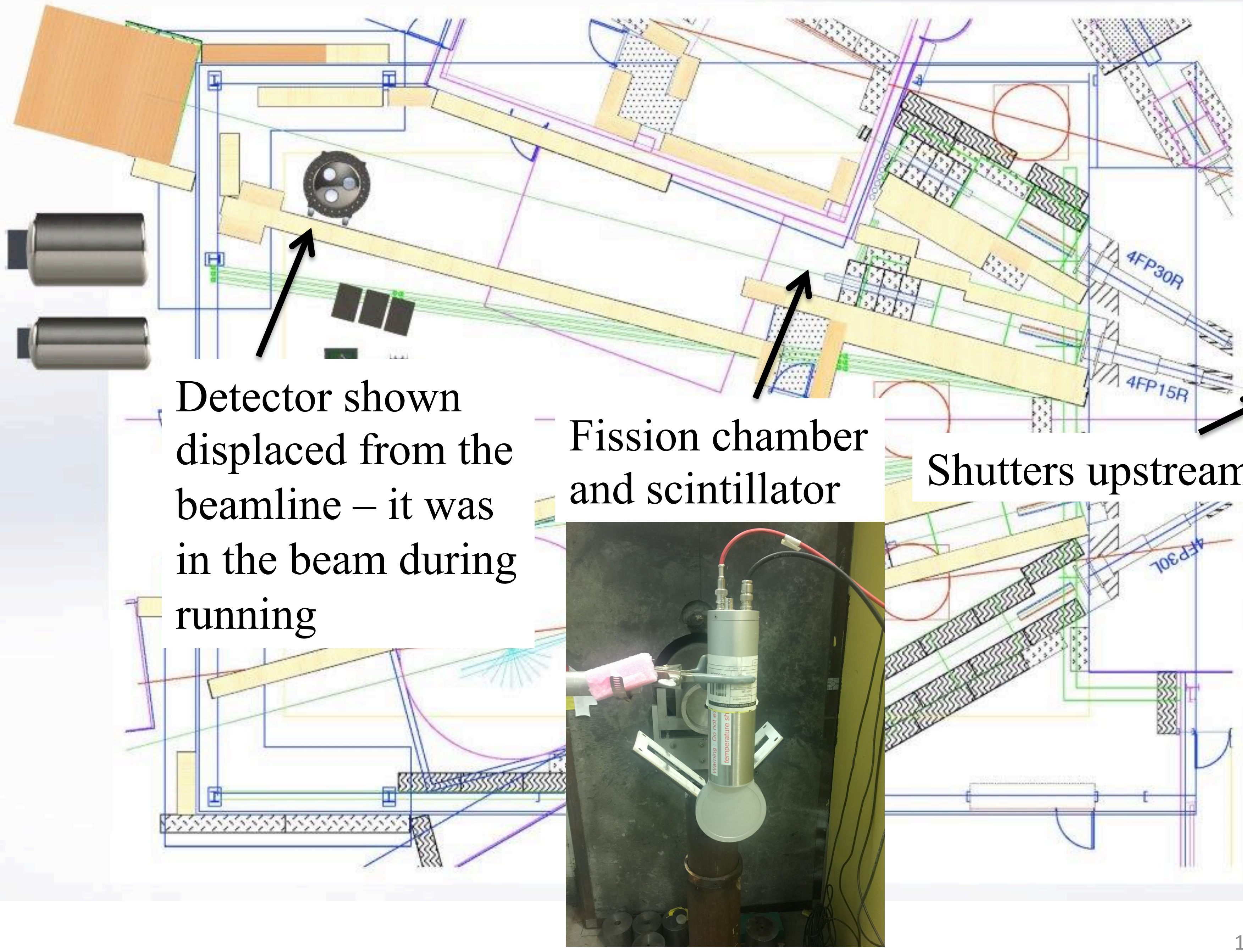






Special low-intensity run gives us a bunch spacing of 200 μs

We also constrain the shutters to achieve low intensity



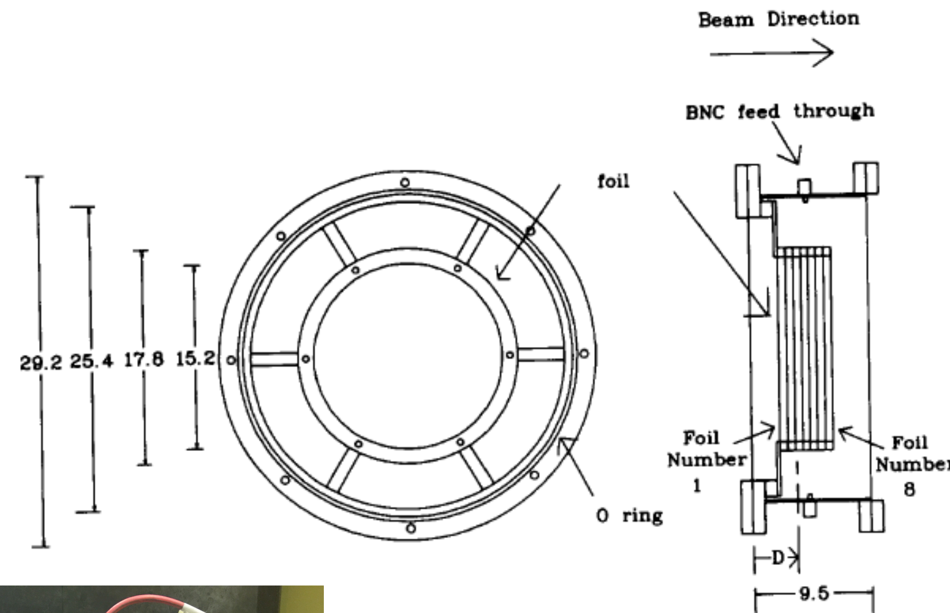
Detector shown displaced from the beamline – it was in the beam during running

Fission chamber and scintillator

Shutters upstream

Flux detectors and strategy

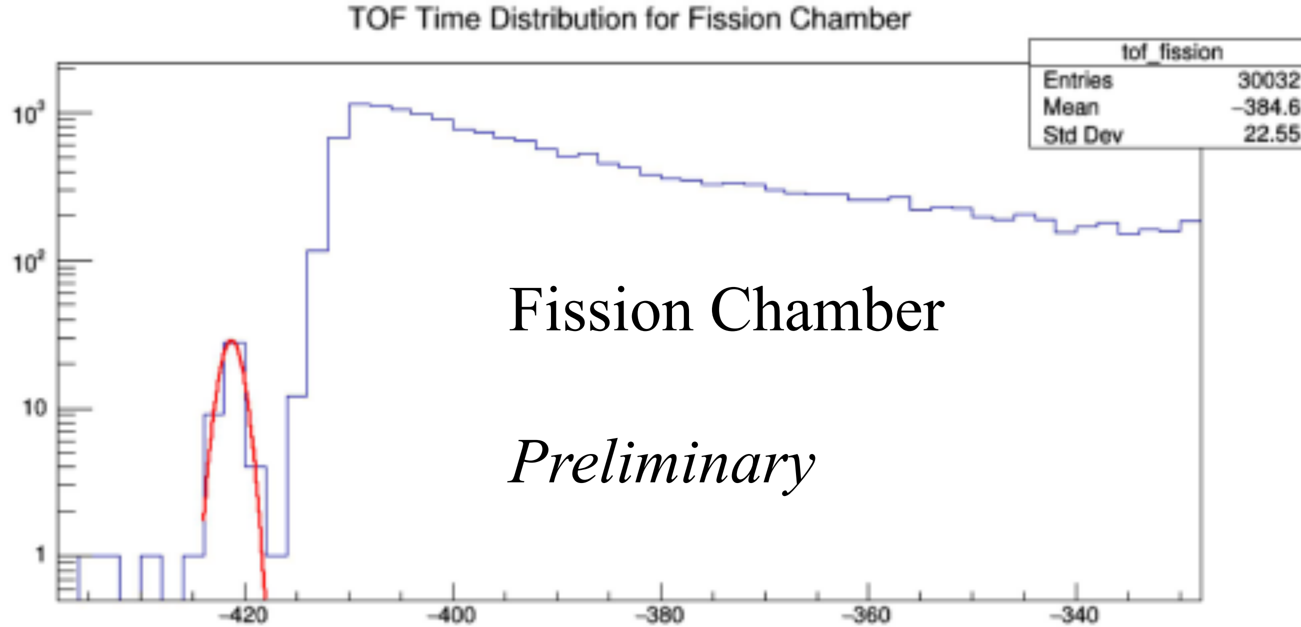
- Fission chamber – useful for high neutron fluxes ($\sim 10^{-5}$ interaction rate)
- Scintillator detector – useful for low neutron fluxes ($\sim 10^{-2}$ interaction rate)
- Cross-calibrate at moderately high flux

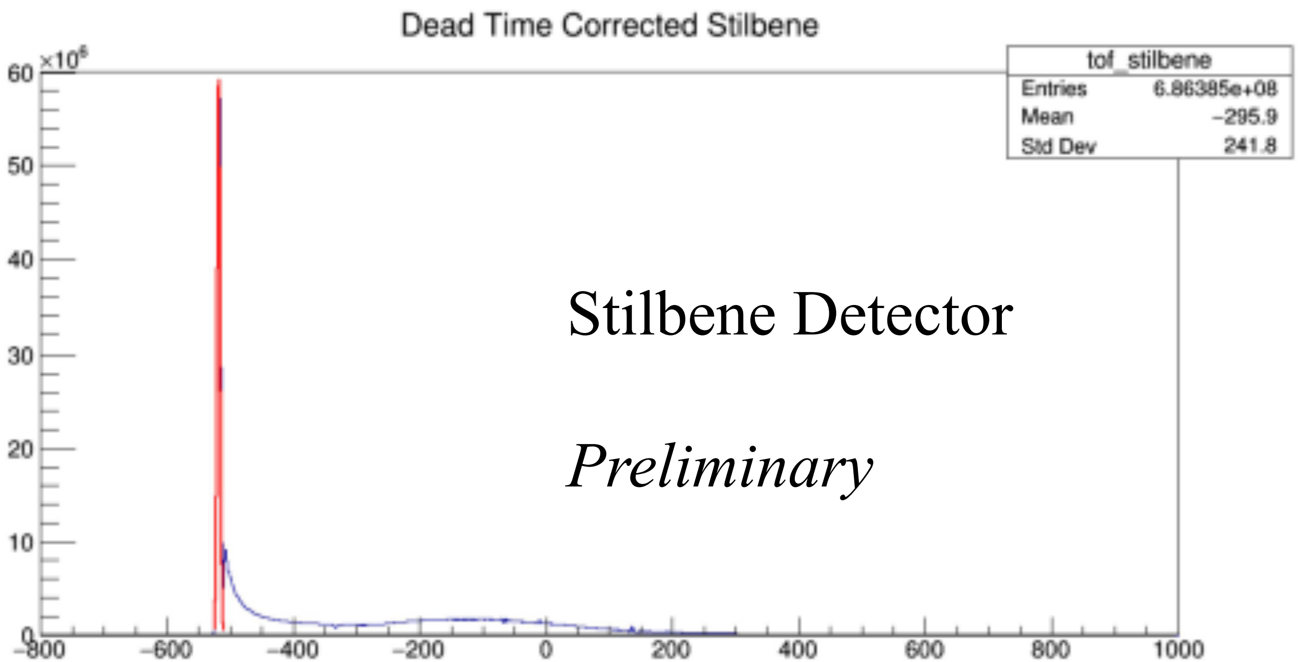


Wender et al. NIM A 336 (1993) 226-231

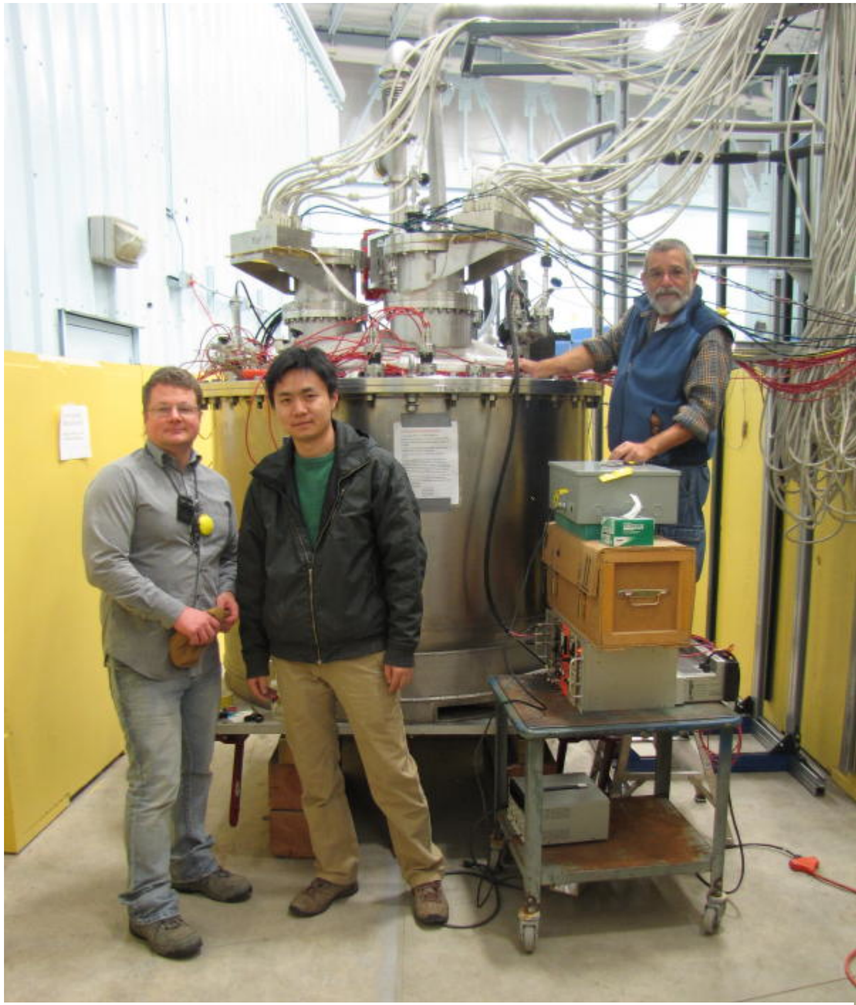
Flux detector data

Very preliminary results integrated over low and high intensity running



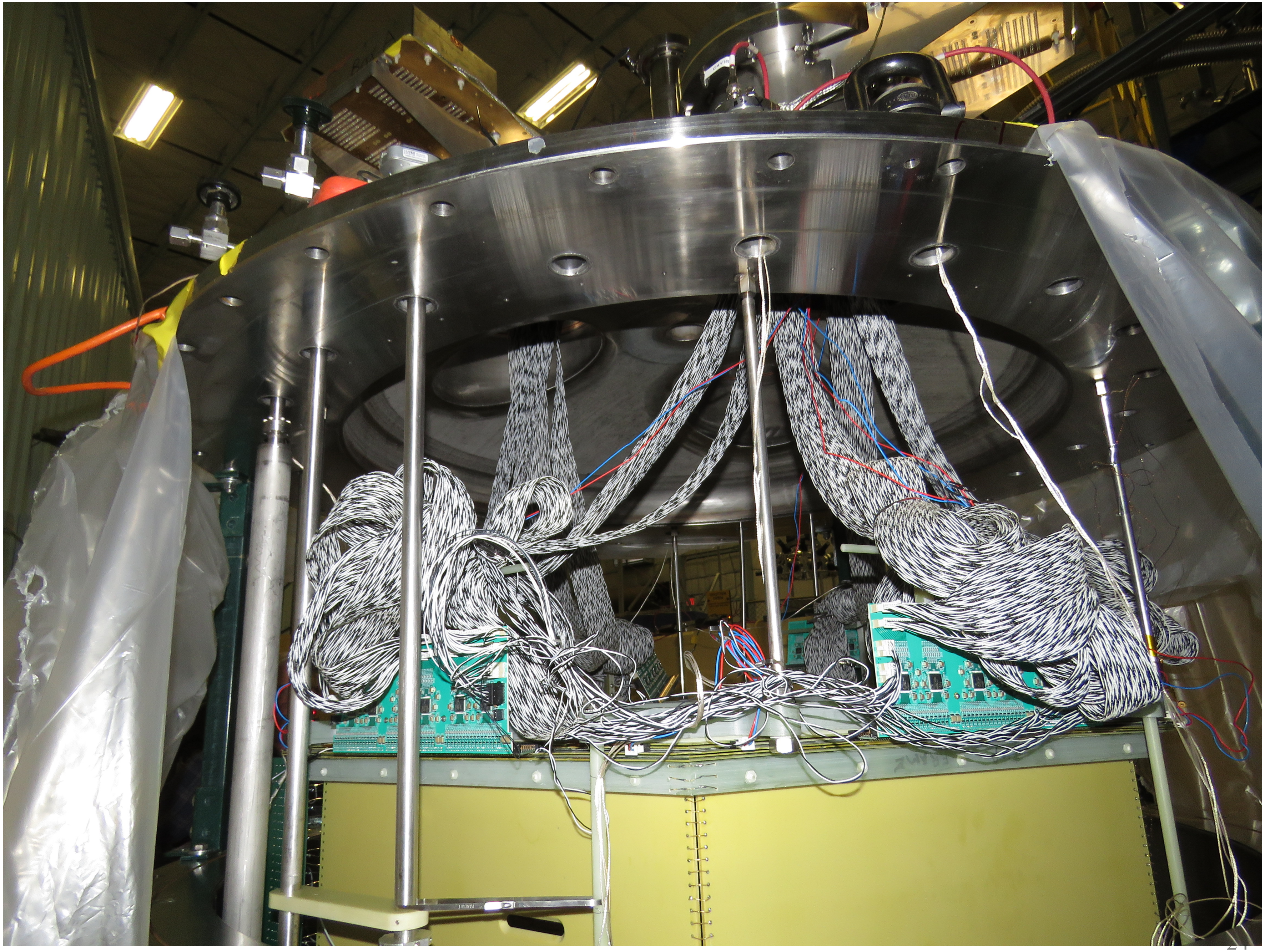


Mini-CAPTAIN at the neutron beamline



Chuck Taylor (LANL), Qiuguang Liu (LANL) and Marc Rosen (Hawaii)


March, 2017 at LANL



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DO NOT MOVE
SHIELD BLOCKS
WITHOUT APPROVAL OF

CAPTAIN Collaboration

- Alabama: Ion Stancu
- LBL: Craig Tull
- Boston University: Christopher Grant
- BNL: Hucheng Chen, Veljko Radeka, Craig Thorn
- UC Davis: Daine Danielson, Steven Gardiner, Emilja Pantic, Robert Svoboda
- UC Irvine: Jianming Bian, Scott Locke, Michael Smy
- UC Los Angeles: David Cline, Hanguo Wang
- UC San Diego: George Fuller
- Hawaii: Jelena Maricic, Marc Rosen, Yujing Sun
- Houston: Lisa Whitehead
- LANL: Elena Guardincerri, Nicholas Kamp, David Lee, William Louis, Geoff Mills, Jacqueline Mirabal-Martinez, Jason Medina, John Ramsey, Keith Rielage, Constantine Sinnis, Walter Sondheim, Charles Taylor, Richard Van de Water
- New Mexico: Michael Gold, Alexandre Mills, Brad Philipbar
- New Mexico State: Robert Cooper
- University of Pennsylvania: Connor Callahan, Jorge Chaves, Shannon Glavin, Avery Karlin, Christopher Mauger, Keith Wiley
- Stony Brook: Neha Dokania, Clark McGrew, Sergey Martynenko, Chiaki Yanagisawa

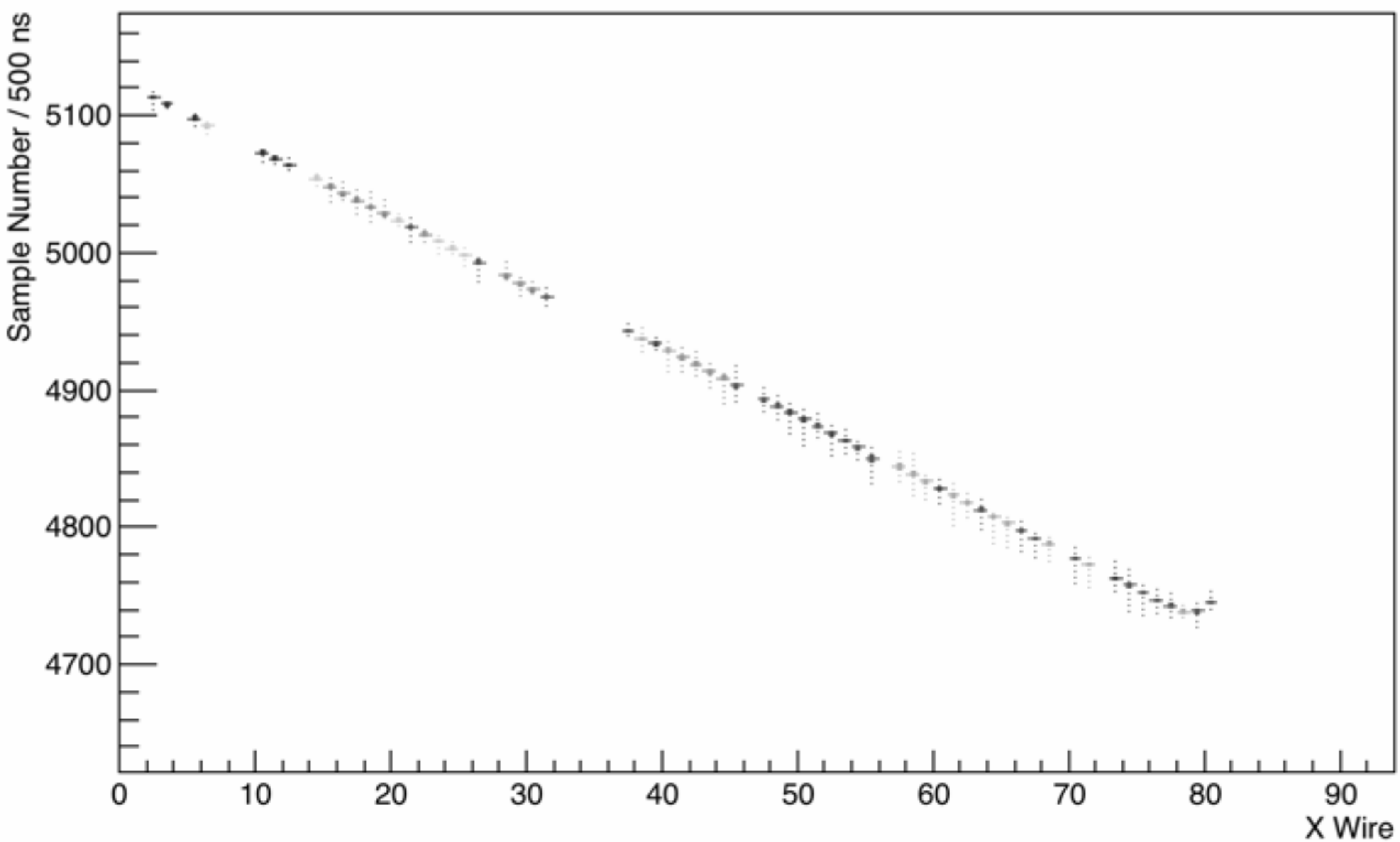
Spokesperson: Christopher Mauger; Deputy Spokesperson: Clark McGrew


PENN

Analysis Status

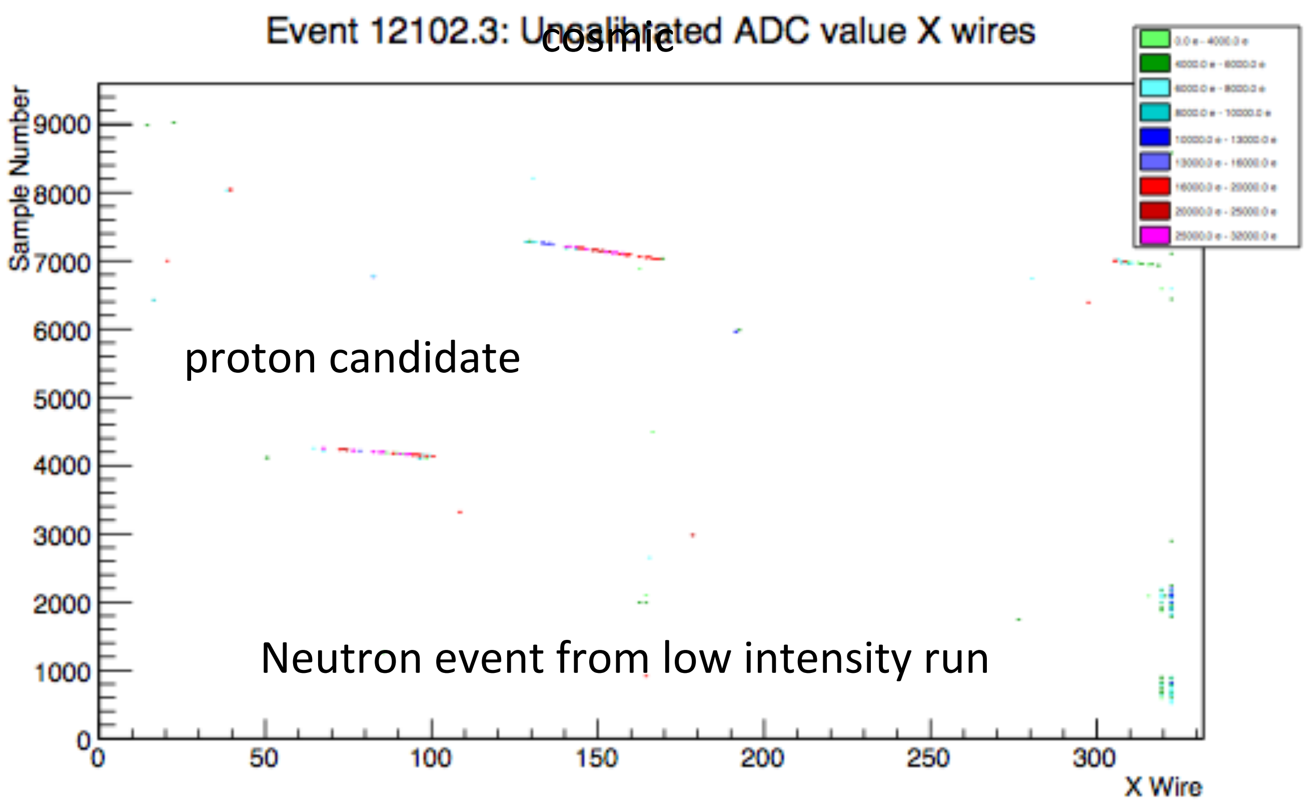
- Several hundred thousand beam triggers
- Currently analyzing our special low-intensity run sample (golden sample) – 3 bunches per macropulse
- Good purity
- Low electronics noise
- Can get absolute cross-sections
  - flux detector in place
  - rates vs depth in the detector
- Expect first physics results late this summer
- Integrate analysis into DUNE – between one and two years

Cosmic-ray muon event through the whole detector (collection-plane view)

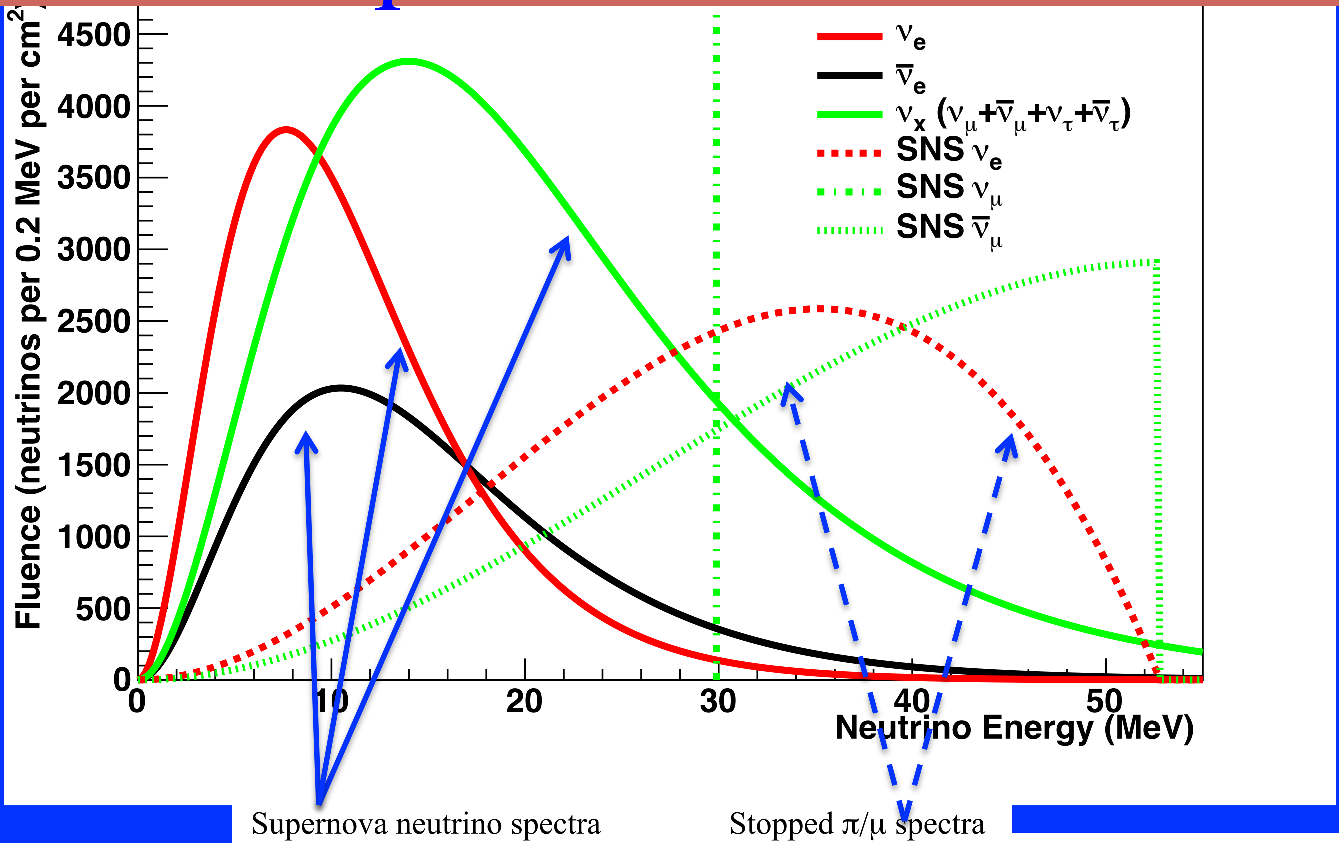


Proton candidate with cosmic candidate

Preliminary



Low-energy neutrino running at a stopped pion source



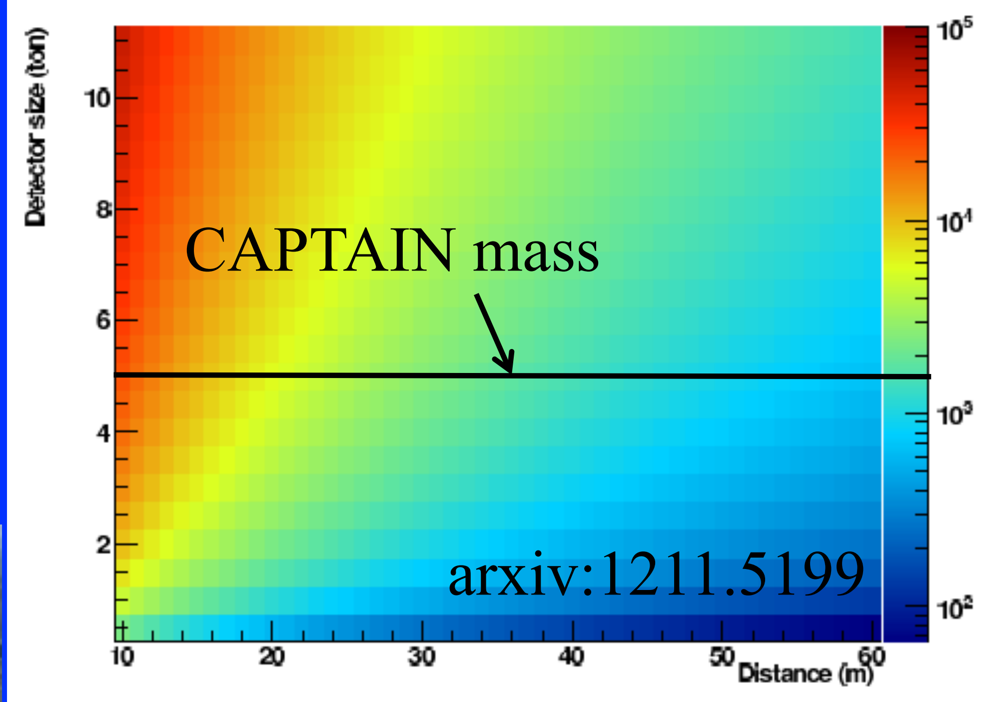
From:arXiv:1211.5199

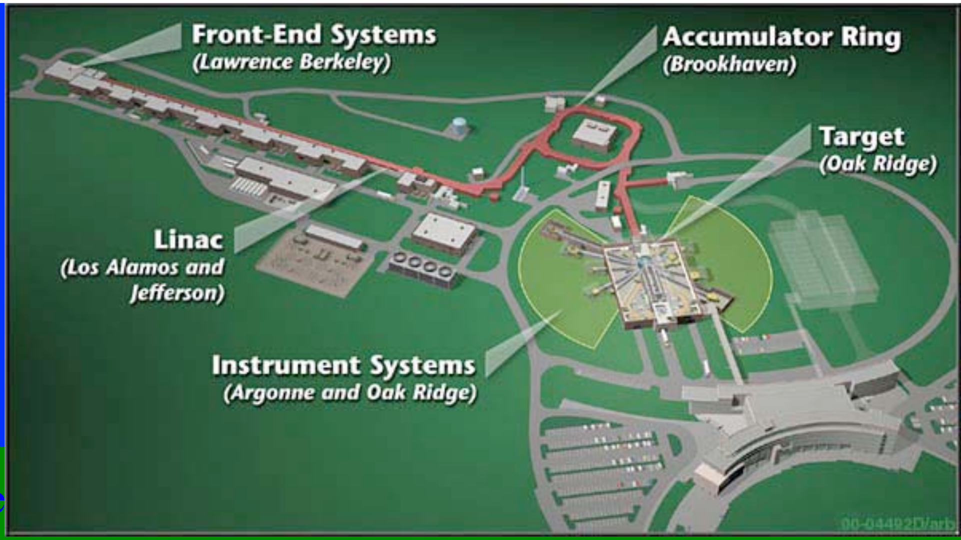
Source: $\pi^+ \to \mu^+ + \nu_\mu$, $\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu$

- Stopped pion source near ideal for cross-section measurement
- Well-known shape of neutrino energy spectrum

Low-energy neutrino running

- Spallation neutron sources like the SNS at ORNL are an ideal environment for these measurements
- High beam power, low duty cycle
- Running at SNS would generate a lot of exciting physics – thousands or tens of thousands of events

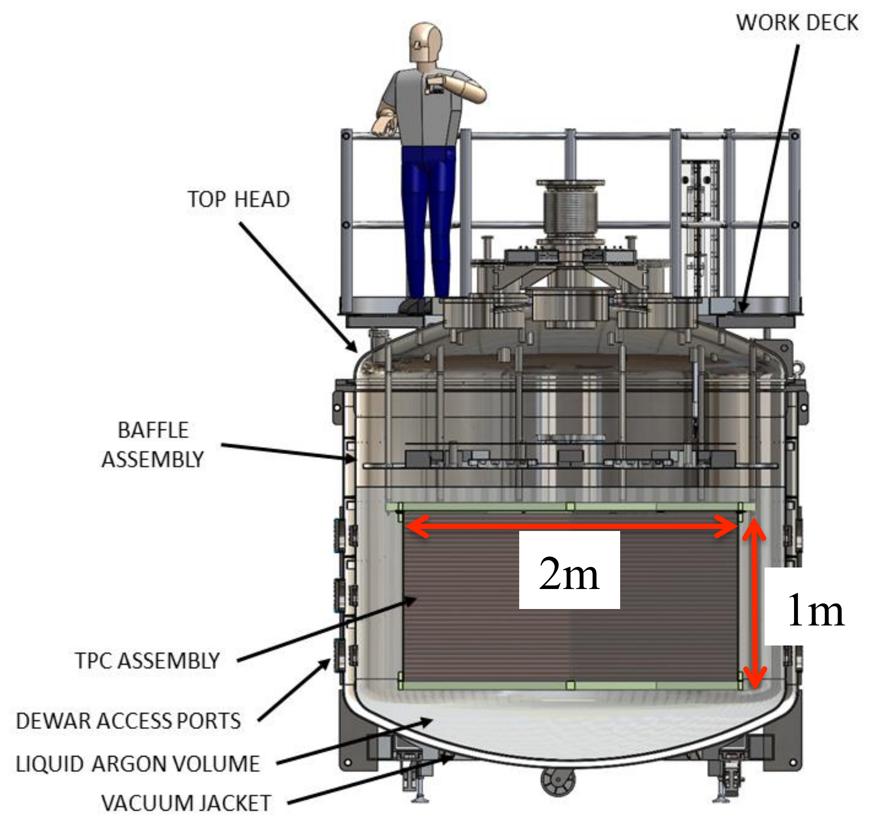




The CAPTAIN Detector

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

- CAPTAIN Detector
  - Photon detection system – up to 10% coverage with PMTs (better timing and coverage than DUNE)
- Low-energy neutrino running
  - Use both TPC and PDS to measure the true-reconstructed neutrino energy with Michel spectrum
  - What is the impact of only measuring electrons well?
  - What is the cost-benefit of improving DUNE's nominal PDS detector
- Running at SNS – synergy with ORNL physics program
- Also possibility of Mini-CAPTAIN deployment



Summary

- Much exciting physics to do to support the DUNE enterprise
  - neutron-argon interactions – first measured cross-section in this energy regime
  - integrate neutron ID and measurements into neutrino energy reconstruction for DUNE and SBN
- Next, we want to go to SNS and make electron neutrino cross-section measurements on argon with CAPTAIN