CAPTAIN: Current Neutron and Future Stopped Pion Neutrino Measurements

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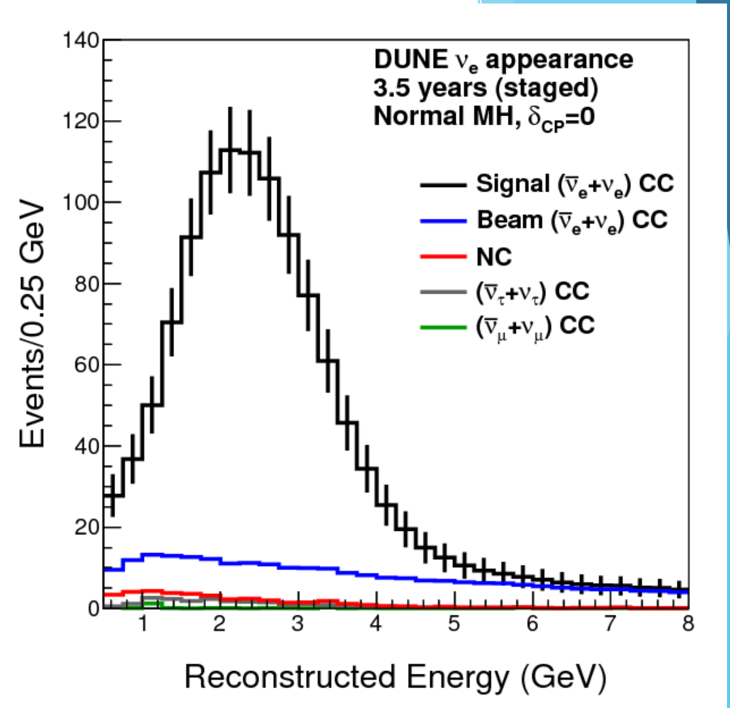
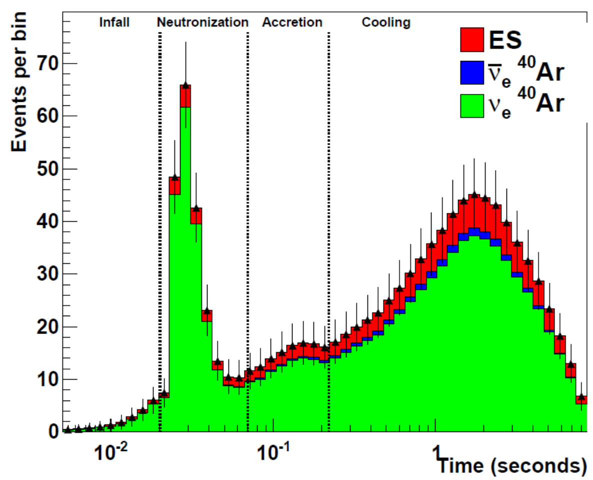
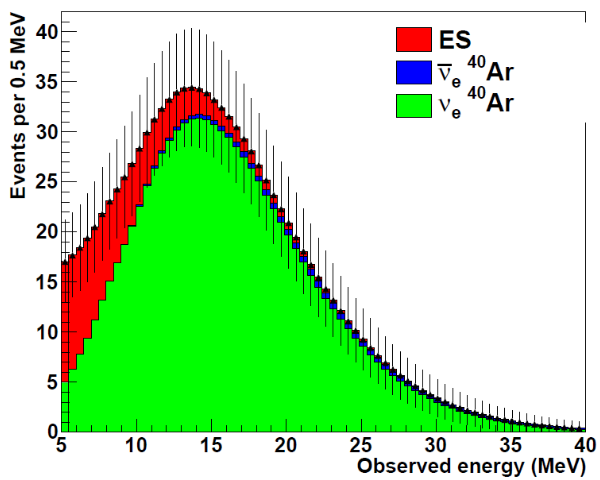
Introduction

- CAPTAIN is a liquid argon TPC (LArTPC) designed to make measurements relevant for the DUNE experiment
- DUNE will use a LArTPC to study neutrino oscillations, search for proton decay, and detect neutrinos from a core-collapse supernova in our galaxy should one occur







arXiv:1512.06148

The CAPTAIN Physics Program

Neutron Beam Low-Energy Neutrino Beam

- Medium-energy neutrino physics
  - Measure neutron interactions and event signatures to constrain the number and energy of emitted neutrons in neutrino interactions
  - Measure higher-energy neutron-induced processes that could be backgrounds to electron neutrino appearance, e.g. $^{40}Ar(n,\pi^0)^{40}Ar^{(*)}$
- Low-energy neutrino physics
  - Measure neutron production of spallation products
  - Benchmark simulations of spallation production
  - Measure CC and NC cross sections in the neutrino energy range relevant for supernova neutrino detection
  - Measure the correlation between true neutrino energy and visible energy for events in the neutrino energy range relevant for supernova neutrino detection

The CAPTAIN Detectors

- CAPTAIN
  - 5 tons of instrumented LAr
  - Hexagonal TPC with 1 m vertical upward drift
  - 3 mm wire pitch
  - Laser calibration system
  - Photon detection system
- Mini-CAPTAIN
  - 0.4 tons of instrumented LAr
  - Hexagonal TPC with 32 cm of vertical upward drift
  - 3 mm wire pitch
  - Photon detection system (24 PMTs)
- Both use same cold electronics chain as MicroBooNE

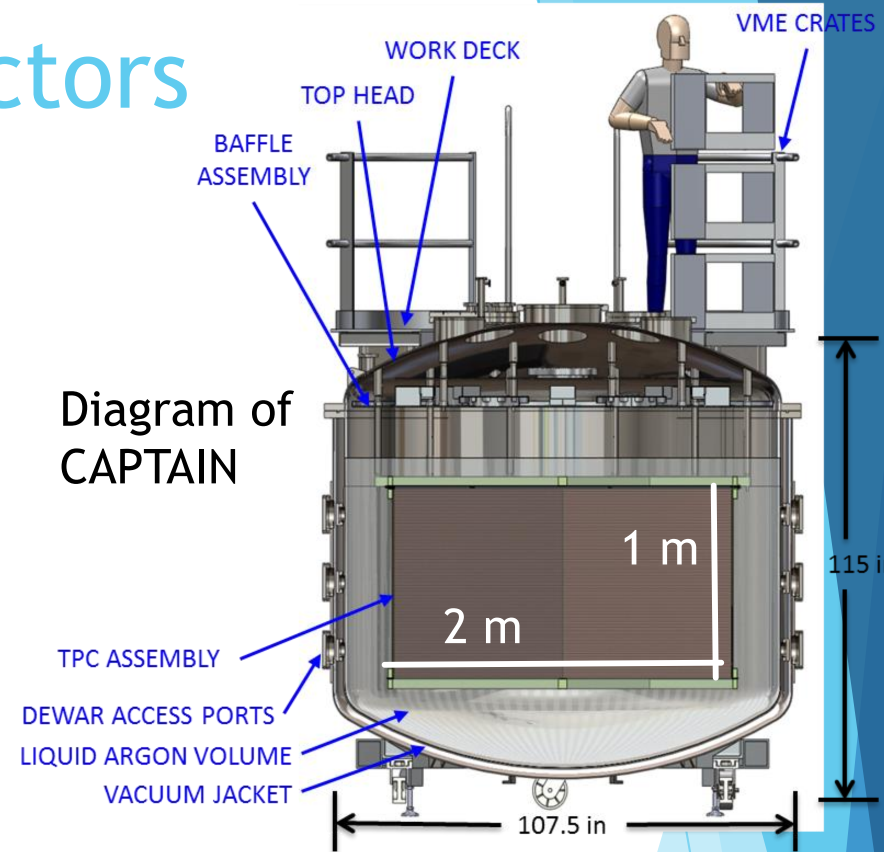


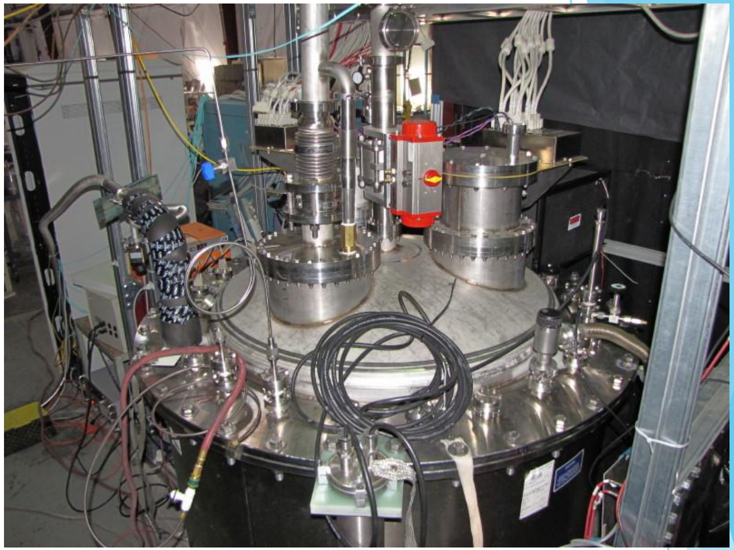
Diagram of CAPTAIN

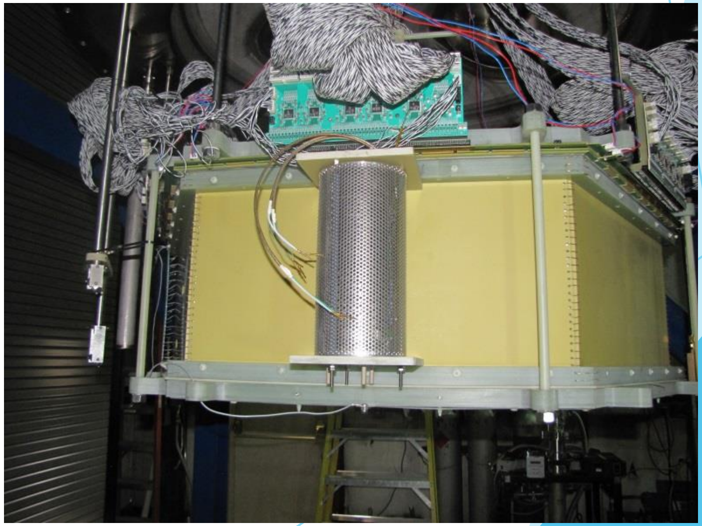
CAPTAIN Cryostat

Mini-CAPTAIN

TPC being pulled out after liquid nitrogen run

Fall 2014 LAr run



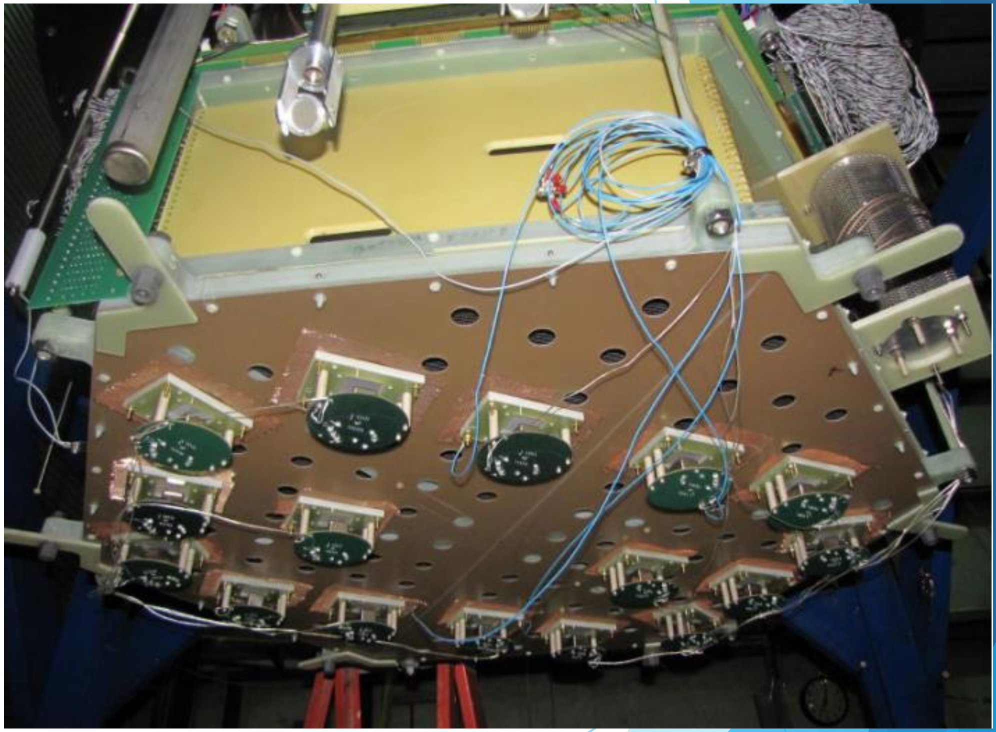


Purity monitoring system

Mini-CAPTAIN

TPC

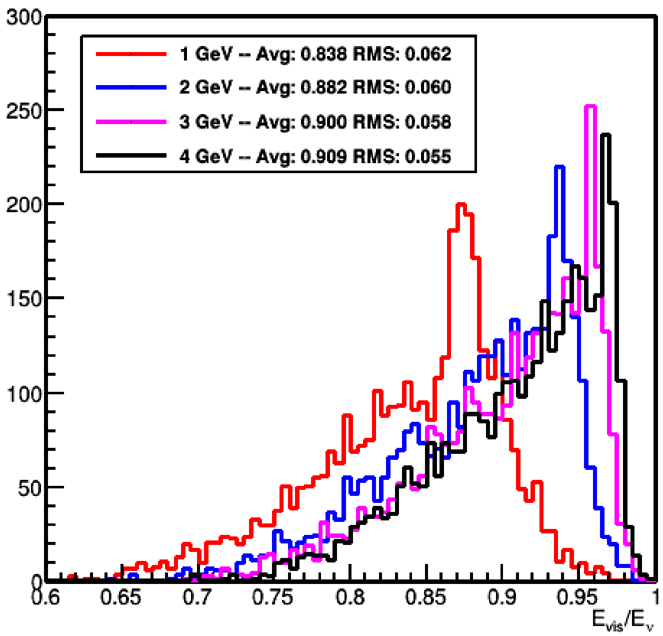
Photon detection system



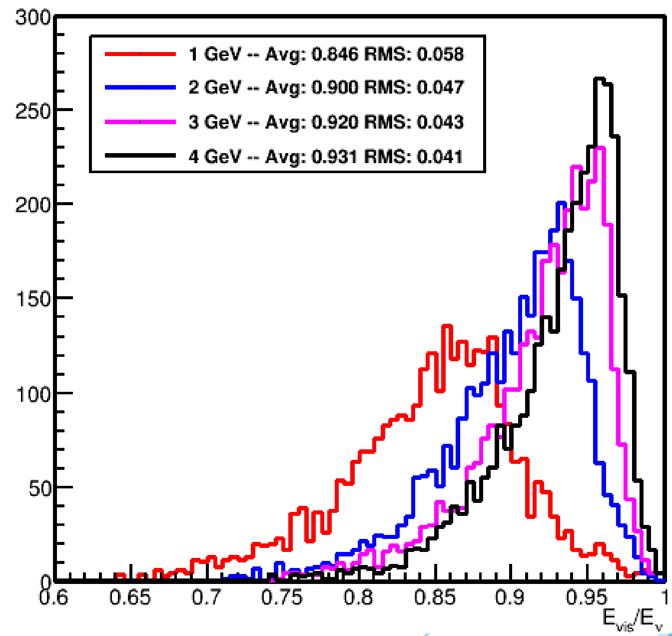
Visible Energy in ν Interactions

- DUNE will see mixture of QE, RES, and DIS interactions
- Neutrino energy reconstruction via calorimetry (over kinematic reconstruction)
- Missing visible energy depends upon neutrino energy and is different for neutrino and antineutrino interactions

Muon Neutrino

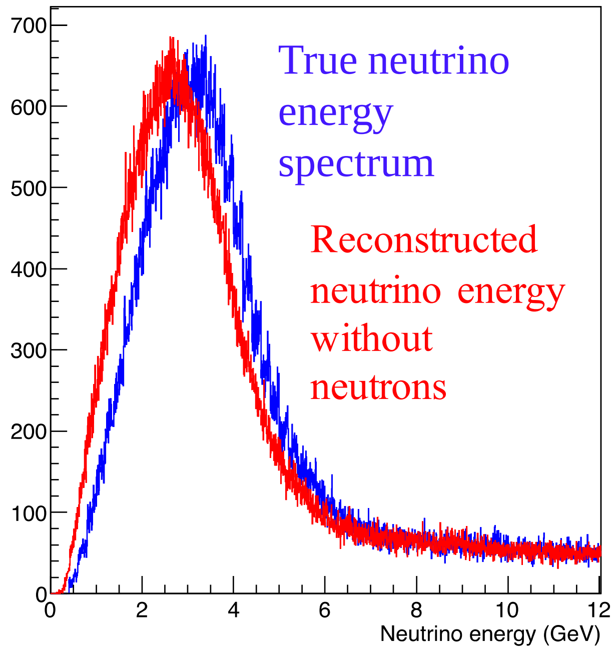


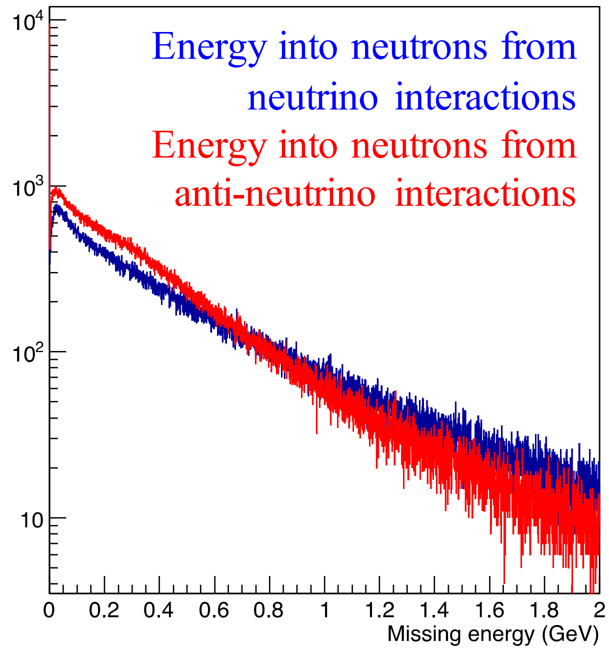
Muon Anti-neutrino



Neutrons and Neutrino Energy Reconstruction

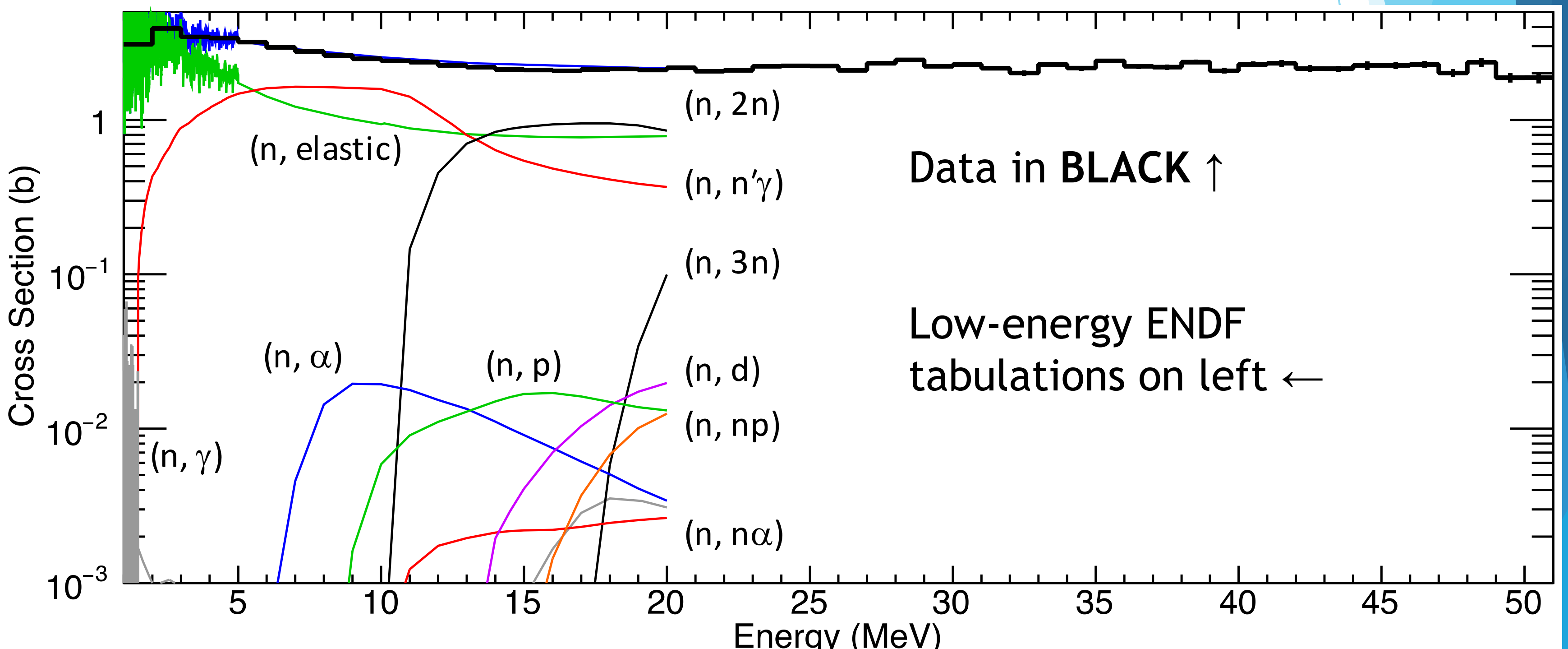
- The neutrino energy in DUNE will be reconstructed based on the total visible energy in the detector
- Models must be used to correct for the missing energy, including neutrons





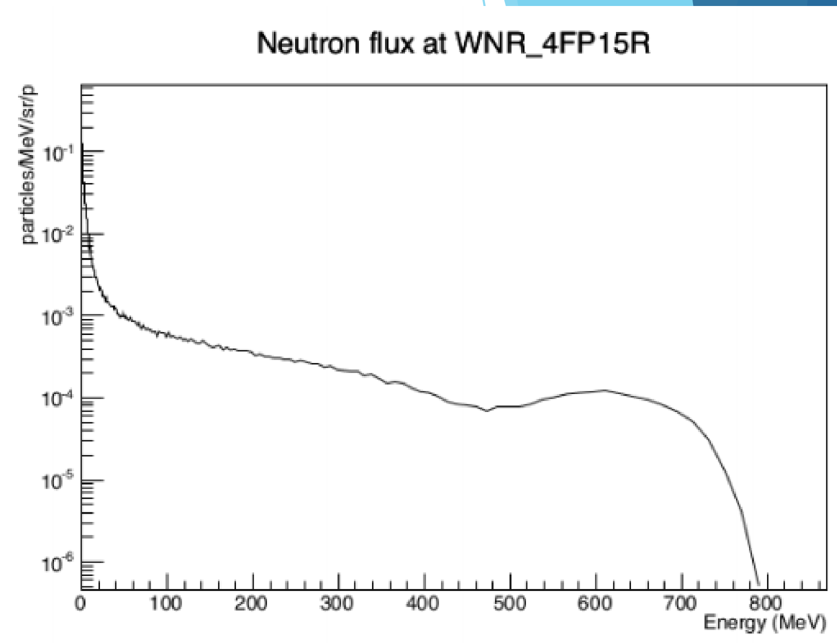
Existing Neutron-Argon Data

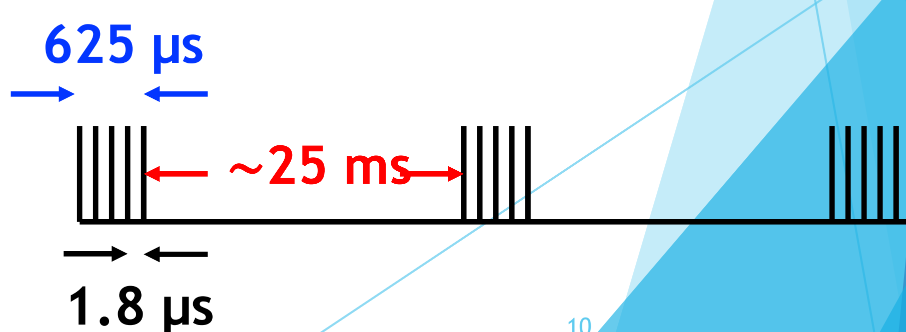
- Cross-section data only published up to 50 MeV kinetic energy
- Existing data is from R.R. Winters et al., Phys. Rev. C43, 492 (1991) – www.nndc.bnl.gov
- We will measure the cross-section up to 800 MeV with Mini-CAPTAIN



Mini-CAPTAIN Neutron Run

- 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
- We require reduced neutron occupancy
  - Clamp aperture → alters spectrum
- Time structure of the beam
  - sub-nanosecond micro pulses 1.8 μs apart within a 625 μs long macro pulse
  - Repetition rate: up to 120 Hz
- Engineering run last year
- **Physics run happening now!**



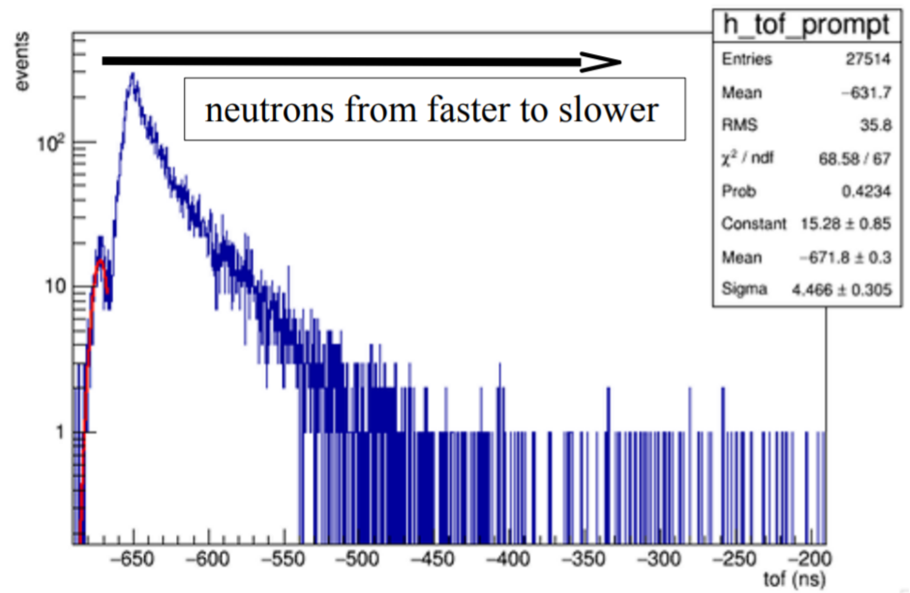


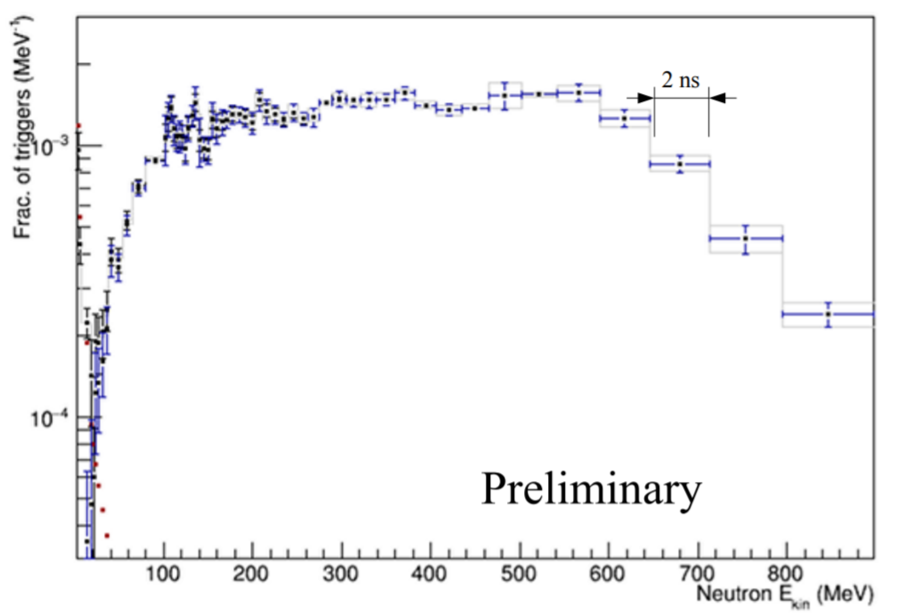
Mini-CAPTAIN Neutron Run

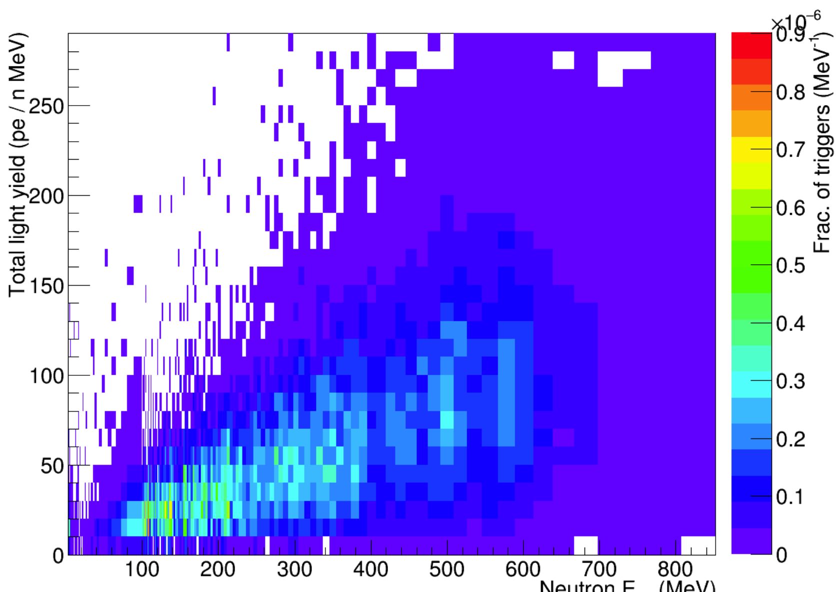
- **Physics run happening now!**

Results from 2016 Engineering Run

- Neutron time-of-flight (TOF) measured by argon scintillation in Mini-CAPTAIN using the photon detection system.
- Neutron energy is determined event-by-event using the time of flight (Not efficiency corrected; not flux normalized)
- Light output vs. TOF-tagged neutron energy



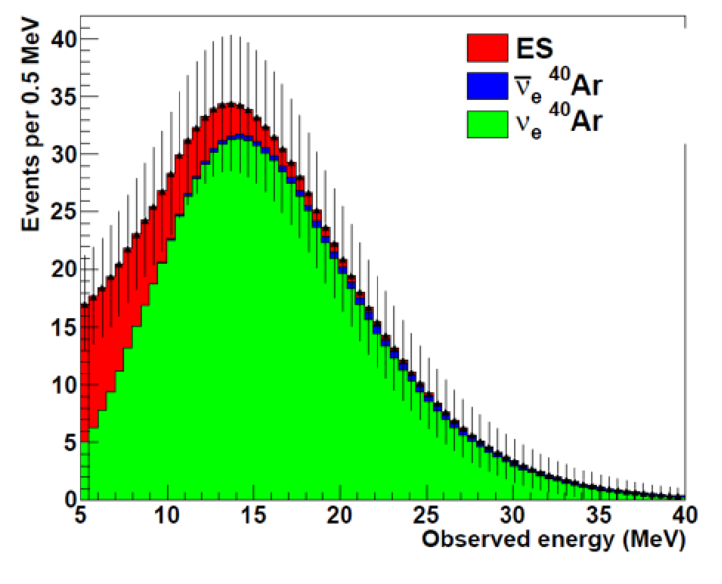




Low-energy Neutrinos

- Use CAPTAIN to study neutrino-argon interactions in the energy range relevant for supernova detection
  - Cross sections have never been measured in this energy range and have large theoretical uncertainties
- Possible source: Neutrinos from pion decay-at-rest at the Spallation Neutron Source (SNS)
  - ~1 GeV, ~1 MW primary proton beam
- Goals
  - Measure the neutrino-argon xsec to about 10% for neutrino energies of O(10) MeV
  - Test the ability of detecting SNe with LAr detectors (triggering, timing)

Observed energy spectrum in 40 kt of LAr for supernova at 10 kpc



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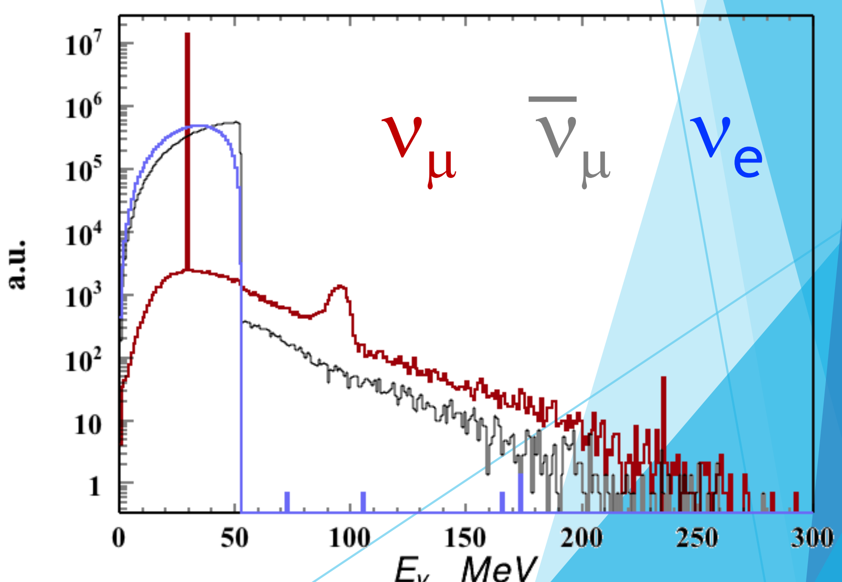


Summary

- CAPTAIN provides an ideal set of instruments to make crucial supporting measurements for DUNE physics program.
  - Neutrons and neutrino energy reconstruction
  - Neutrino cross sections at supernova energies
- The current CAPTAIN run plan includes several measurements
  - Neutrons on argon
    - Taking data with Mini-CAPTAIN at WNR now!
  - Low energy neutrino cross sections
    - Measured at a stopped pion neutrino source
- There are opportunities with CAPTAIN for new collaborators!

CAPTAIN Collaboration

- **Alabama**: Ion Stancu
- **LBL**: Craig Tull
- **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 Koerner
- **LANL**: Elena Guardincerri, Nicolas 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
- **Stony Brook**: Neha Dokania, Clark McGrew, Sergey Martynenko, Chiaki Yanagisawa

Spokesperson: Christopher Mauger

Deputy Spokesperson: Clark McGrew

Backup

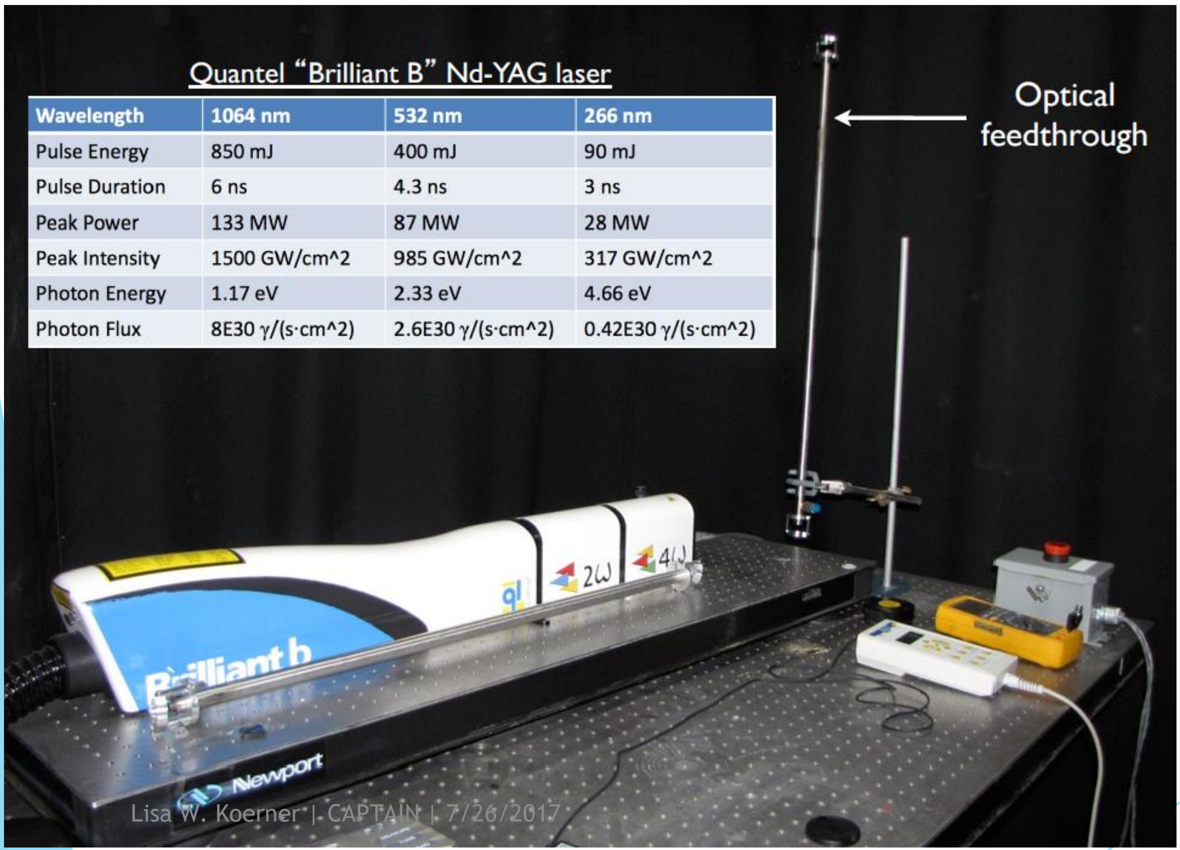
Mini-CAPTAIN

- Liquid nitrogen fill in Summer 2014: test electronics and TPC, test heat load
- 1st LAr engineering run in Fall 2014: development of filling procedure, test cryogenic and purification system, DAQ development, laser system testing
- 2nd LAr engineering run in March 2015: further development of above items plus installation of gas recirculation system, integration with muon system
- Commissioning run in Summer 2015: more development of electronics and recirculation system – achieved sufficient purity to see tracks

Liquid nitrogen run

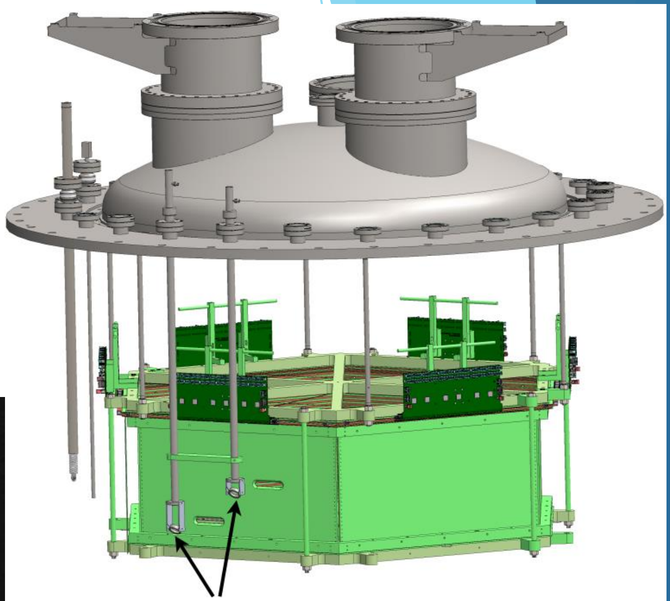
Laser System

- Nd-YAG laser
- Light is shown through a periscope and deflected by mirrors into the desired path

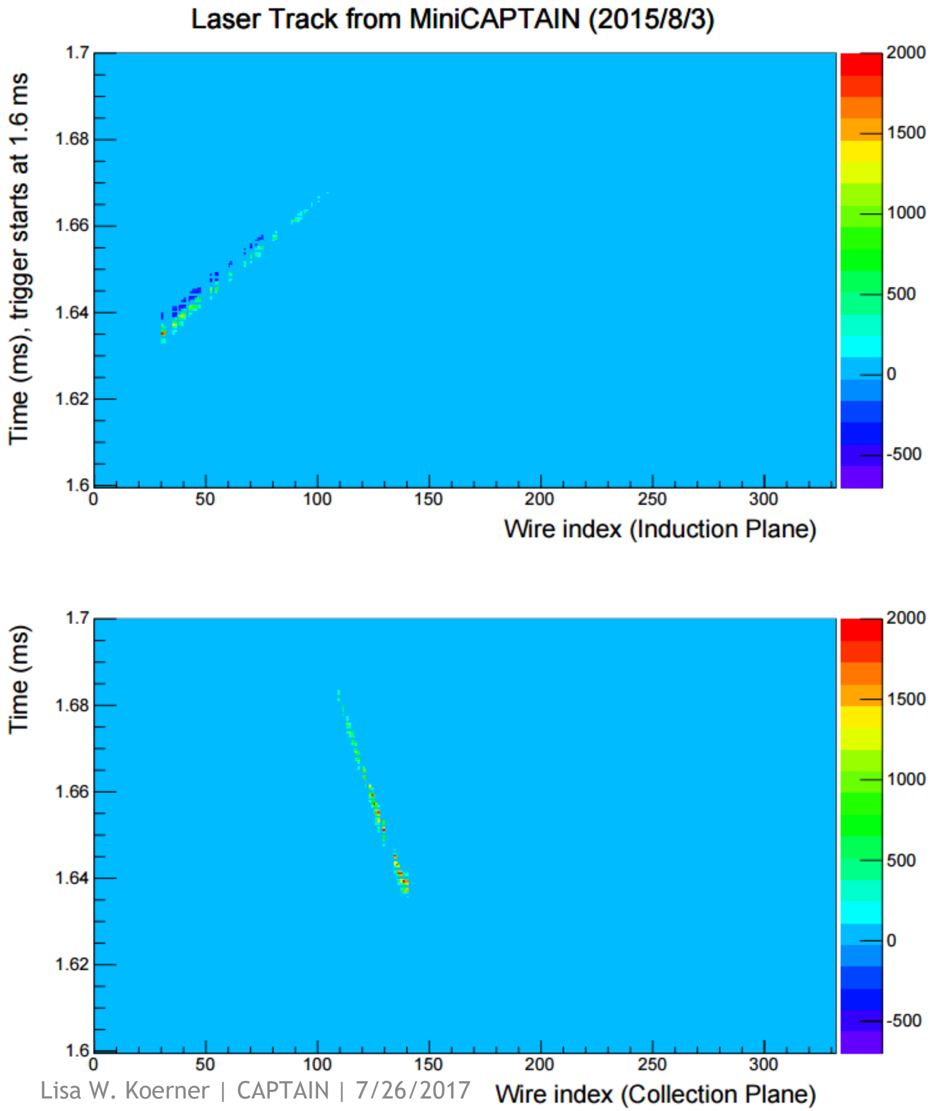


Quantel "Brilliant B" Nd-YAG laser

Wavelength	1064 nm	532 nm	266 nm
Pulse Energy	850 mJ	400 mJ	90 mJ
Pulse Duration	6 ns	4.3 ns	3 ns
Peak Power	133 MW	87 MW	28 MW
Peak Intensity	1500 GW/cm^2	985 GW/cm^2	317 GW/cm^2
Photon Energy	1.17 eV	2.33 eV	4.66 eV
Photon Flux	8E30 γ/(s·cm^2)	2.6E30 γ/(s·cm^2)	0.42E30 γ/(s·cm^2)



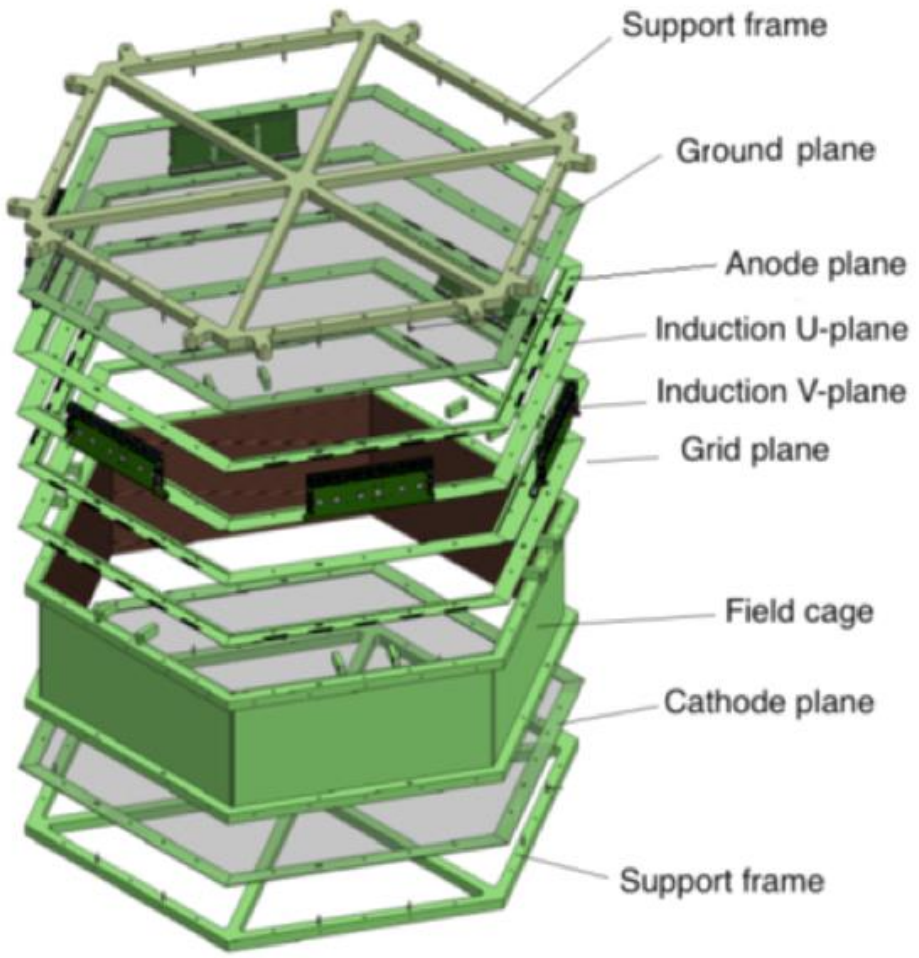
Laser Track in Mini-CAPTAIN



An ionization track from the laser calibration system in Mini-CAPTAIN. The data were collected on August 3, 2015 and were created with a high-intensity UV laser pulse traversing the TPC. The detector was running with one collection plane and one induction plane. The color represents ADC value.

More laser and cosmic-ray data is under analysis.

CAPTAIN TPC



Support frame
Ground plane
Anode plane
Induction U-plane
Induction V-plane
Grid plane
Field cage
Cathode plane
Support frame

Mini-CAPTAIN purity monitor