Stony Brook University

APS | DIVISION OF PARTICLES & FIELDS
DPF 2017

CAPTAIN : Current Neutron and Future Stopped Pion Neutrino Measurements

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(for CAPTAIN collaboration)
Stony Brook University

(C)ryogenic (A)pparatus for (P)recision (T)ests of (A)rgon (I)nteractions with (N)eutrinos

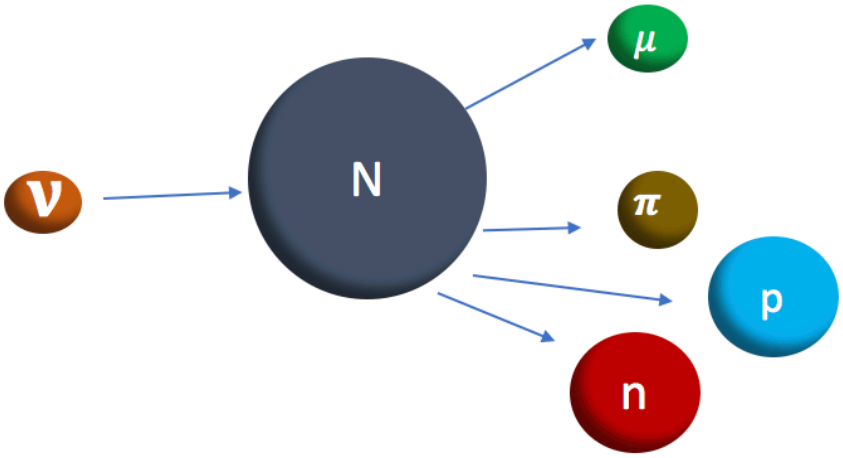
CAPTAIN Physics Program

CAPTAIN is a 1m-long drift liquid argon TPC designed to make measurements relevant for the DUNE experiment

Neutron Beam

Medium-energy neutrino physics

- Neutron interactions and event signatures to constrain the no. and energy of emitted neutrons in ν-Ar interactions
- Higher-energy n-induced processes e.g. $^{40}Ar(n,\pi^0)^{40}Ar^{(*)}$: backgrounds to ν_e appearance



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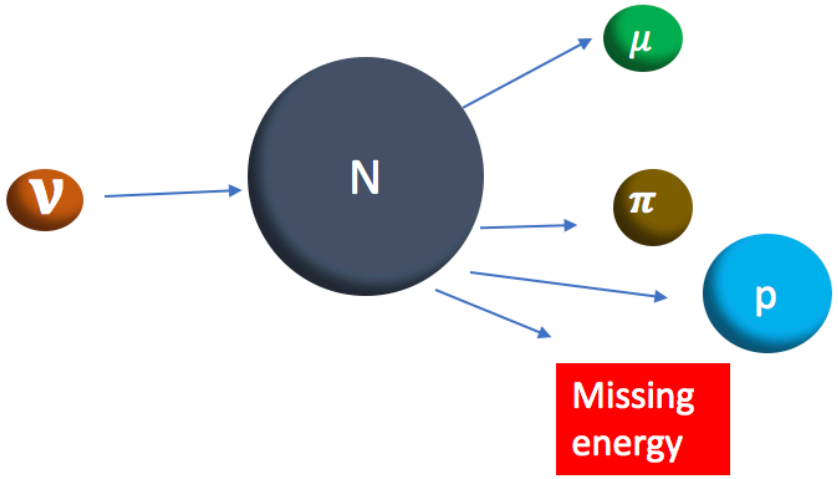

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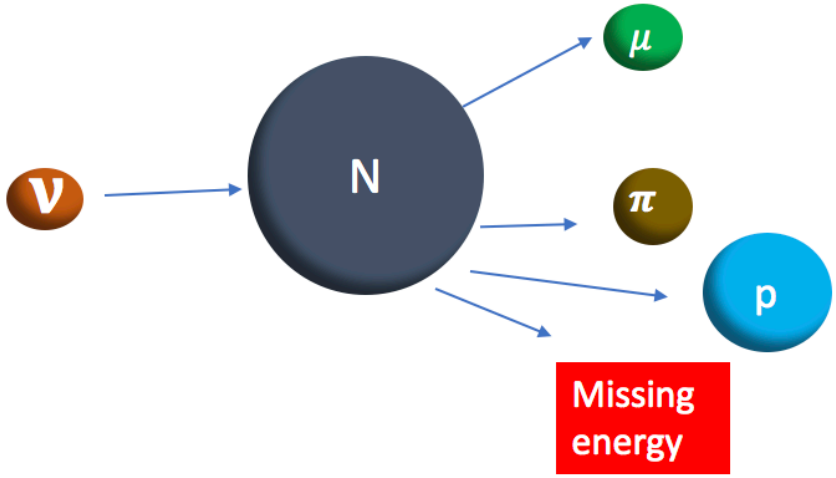


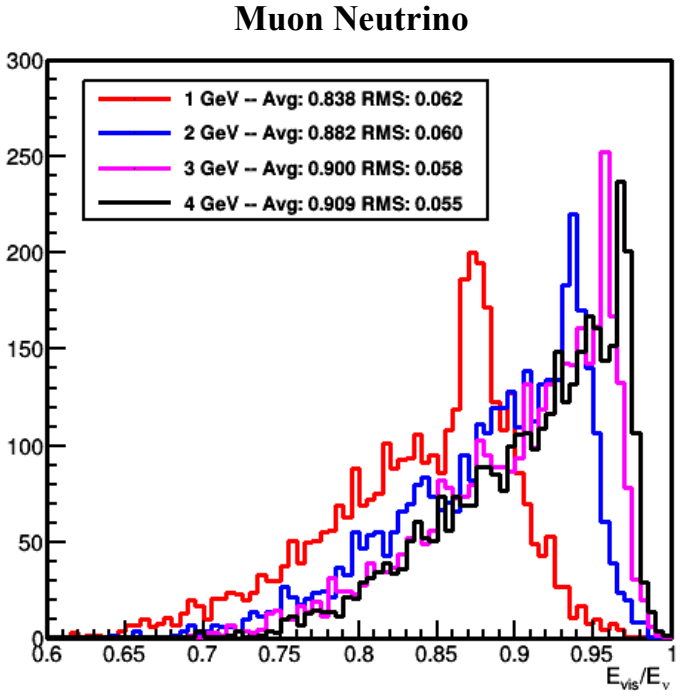
Low-energy neutrino physics

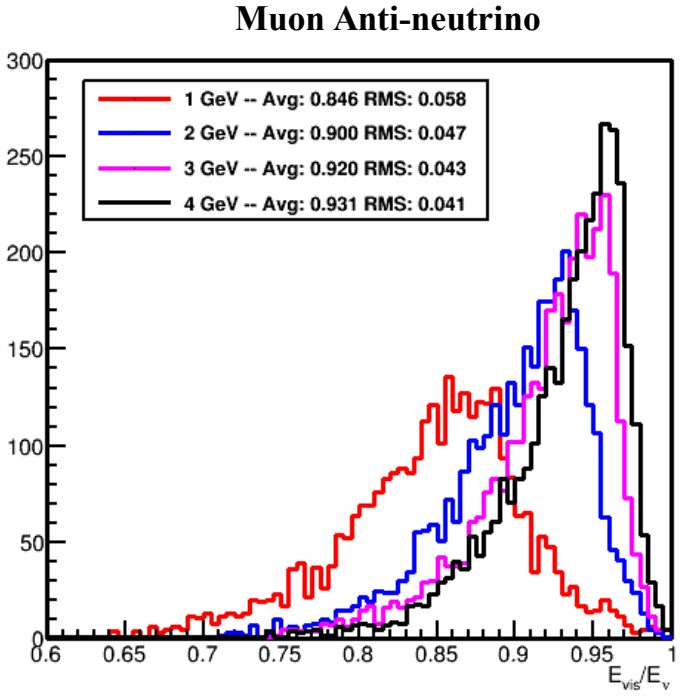
Neutrino Beam

- Cross sections in the ν energy range relevant for SN neutrino detection
- Correlation between true ν energy and visible energy for events in the ν energy range relevant for SN neutrino detection

Visible Energy in ν Interactions

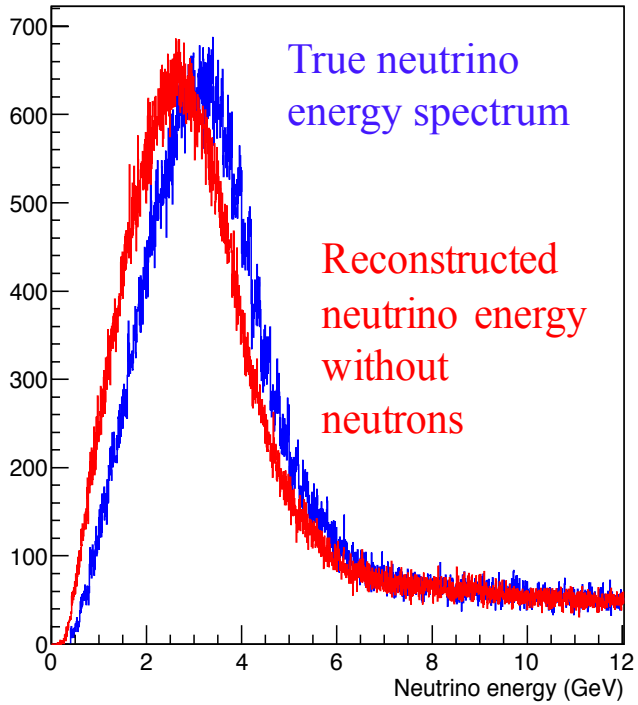
- DUNE will see mixture of QE, RES, and DIS interactions
- Neutrino energy reconstruction via calorimetry (over kinematic reconstruction)
- Missing energy depends upon neutrino energy and is different for neutrino and antineutrino interactions
- Bias in the neutrino energy reconstruction translates into a bias in the determined δ_{CP} value, *PHYS. REV. D 92, 091301 (2015)*

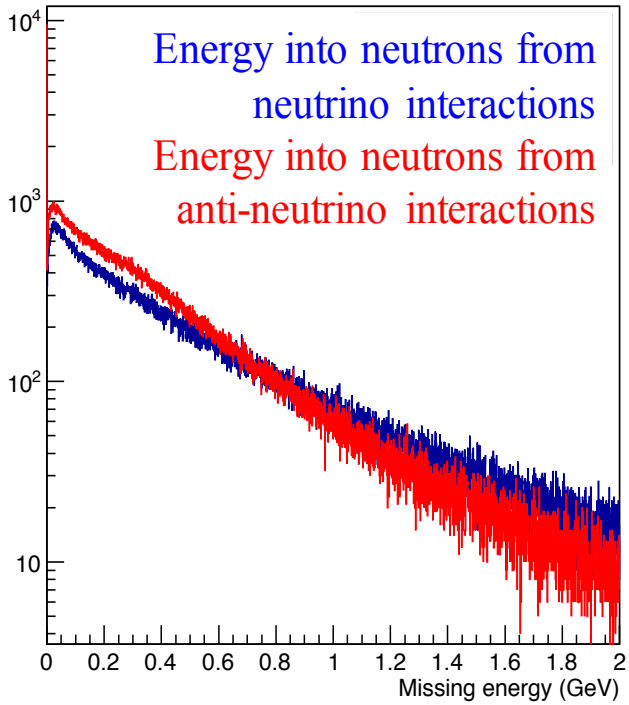




Neutrons and Neutrino Energy Reconstruction

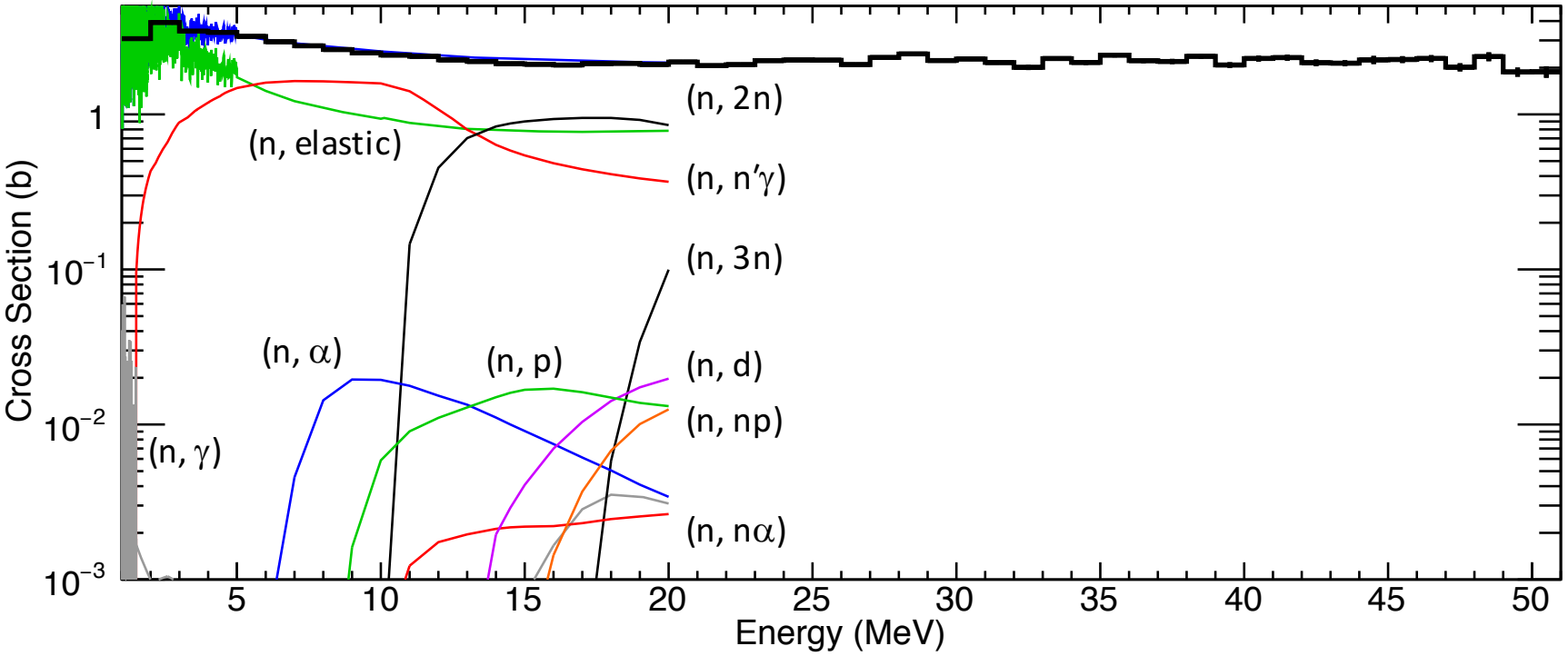
- The neutrino energy in DUNE will be reconstructed based on the total visible energy in the detector
- Models used to correct for the missing energy, including neutrons, have large and unconstrained uncertainties





Existing Neutron-Argon Data

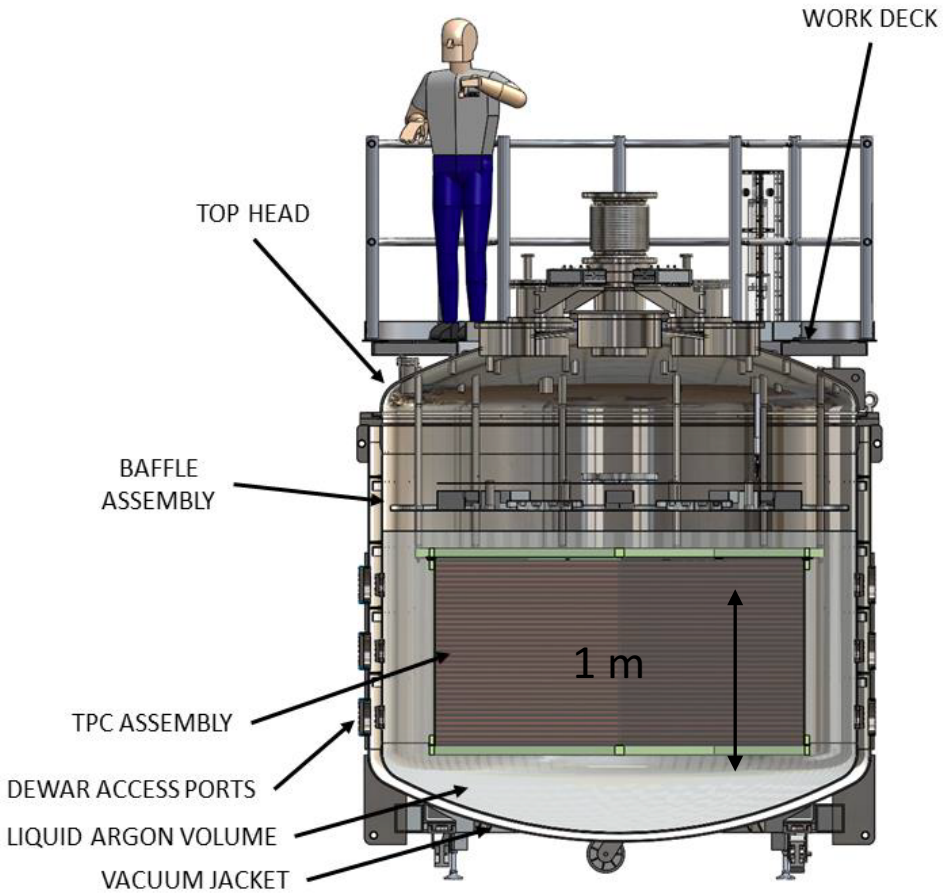
- Cross-section data only published up to 50 MeV kinetic energy
- Existing data is from R.R. Winters et al., *Phys. Rev. C* ***43****, 492 (1991)* – www.nndc.bnl.gov
- We will measure the cross-section as a function of neutron energy up to 800 MeV with Mini-CAPTAIN



The CAPTAIN Detectors

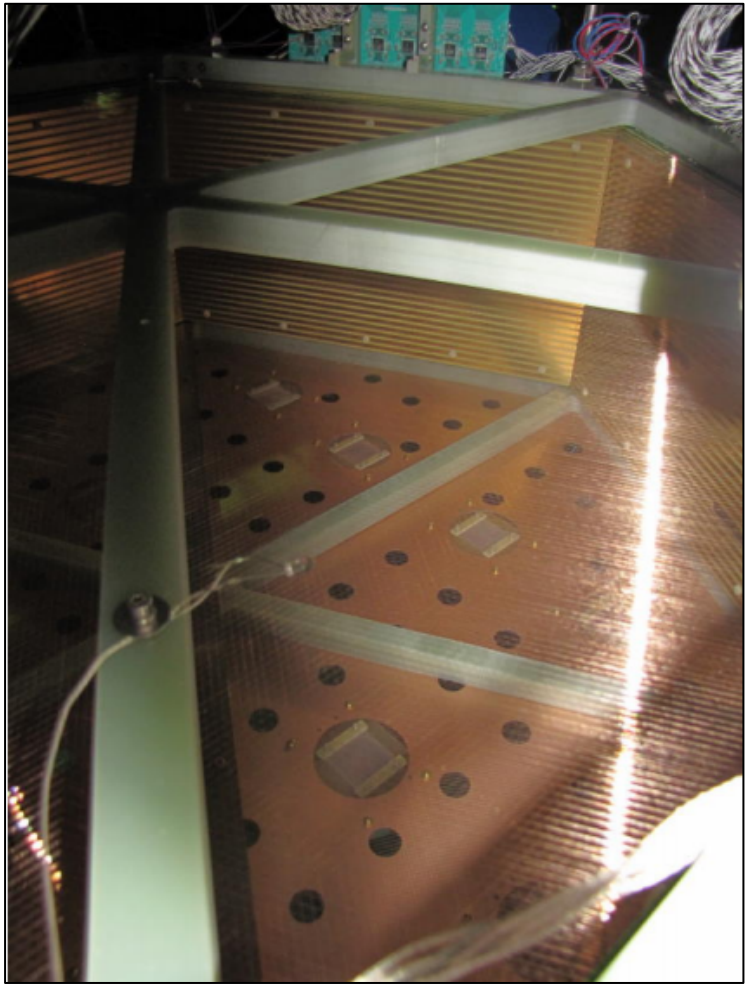
- **CAPTAIN**
  - 5 instrumented tons hexagonal TPC with 1 m vertical drift, 1 m apothem,
  - ~2000 channels, 3 mm wire pitch
  - Photon detection system
  - Laser calibration system
  - Moving toward commissioning in ’18

- **Mini-CAPTAIN (Prototype)**
  - 400 kg instrumented hexagonal TPC with 32 cm drift, 50 cm apothem,
  - ~1000 channels, 3 mm wire pitch
  - 24 x 6 cm^2 PMTs : below and above drift region
  - Same cold electronics and electronics chain as MicroBooNE

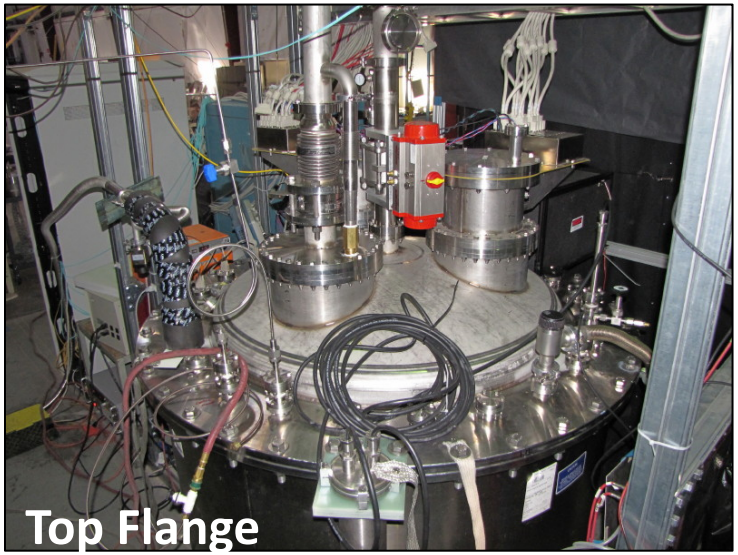


The CAPTAIN Detector

Mini-CAPTAIN Detector



The wire plane assembly



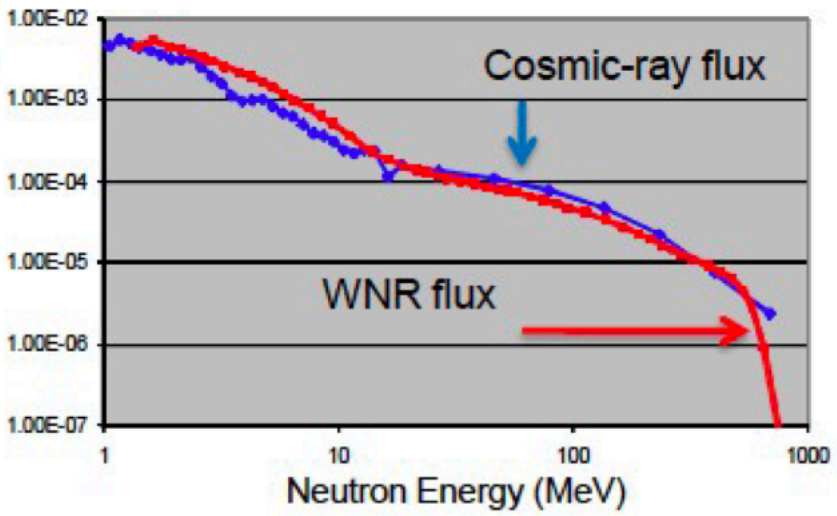
Neutron Flux at LANSCE

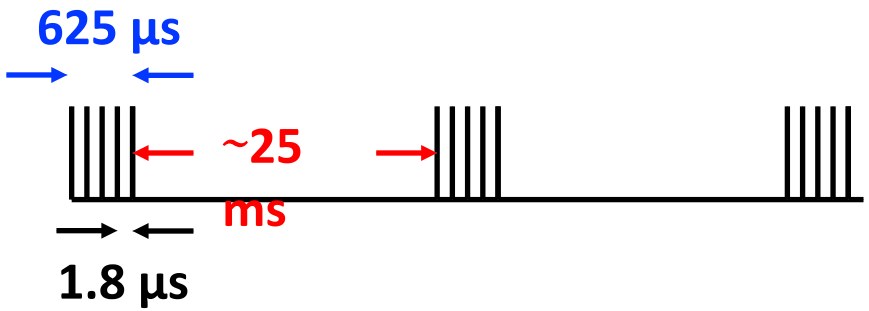
- Los Alamos Neutron Science Center WNR facility provides a high flux neutron beam with a broad energy spectrum similar to the cosmic-ray spectrum at high altitude
- We require reduced neutron occupancy

  Clamp aperture → alters spectrum
- Time structure of the beam

  sub-ns micro pulses 1.8 μs apart within a 625 μs long macro pulse

  Repetition rate: up to 120 Hz
- Engineering run in 2016

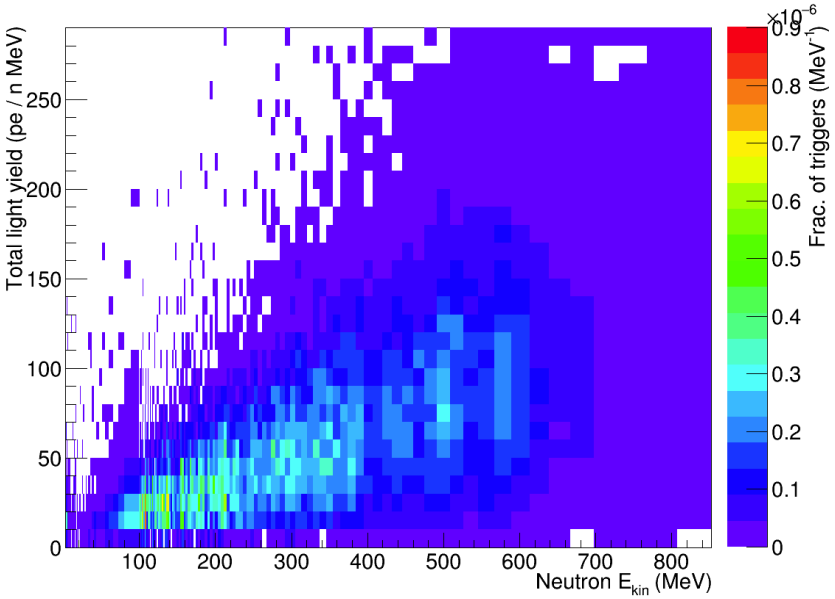




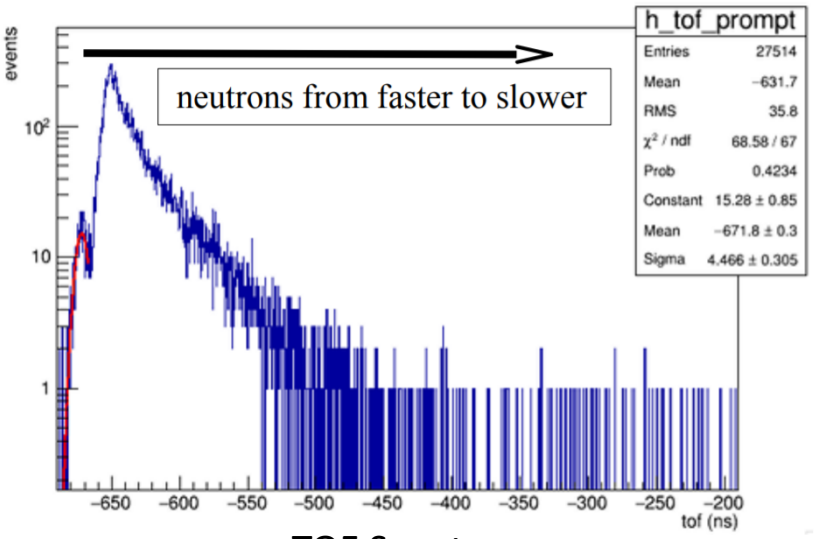
Physics run : July 23 – Aug 05, 2017

Results from 2016 Engineering Run

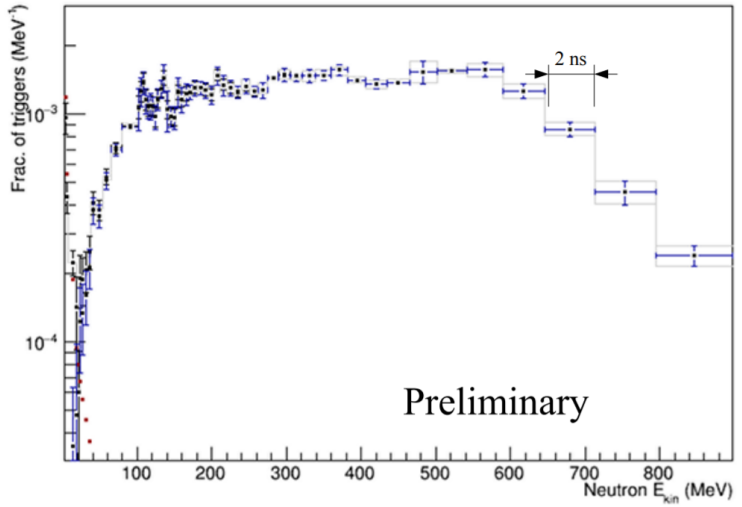
- Neutron time-of-flight (TOF) measured by Ar scintillation in Mini-CAPTAIN using the photon detection system.
- Neutron energy is determined event-by-event using the TOF (Not efficiency corrected; not flux normalized)



Light output vs. TOF-tagged neutron energy



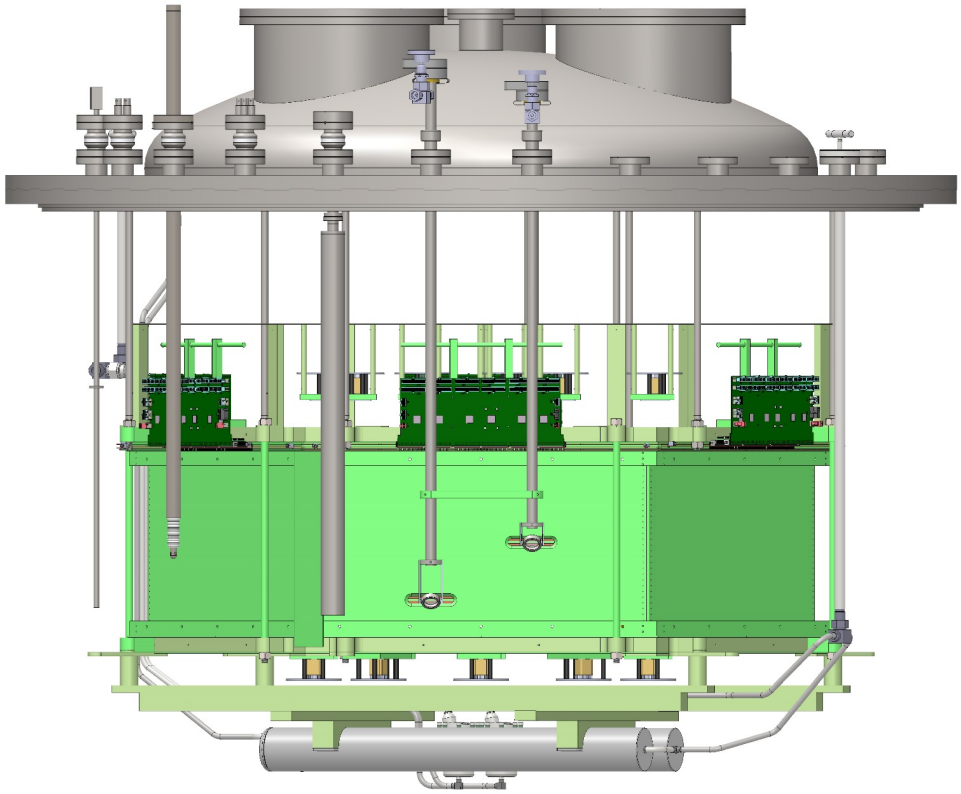
TOF Spectrum

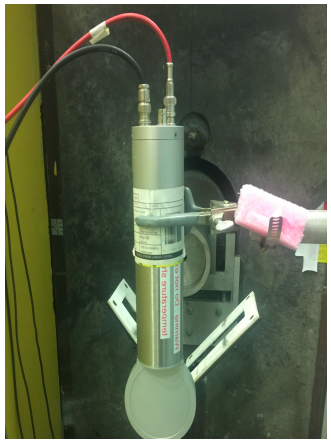


Reconstructed Neutron Energy

Mini-CAPTAIN WNR Neutron Run

- Significant improvement in LAr purification system before the 2017 Physics Run
- Criotec liquid purification and recirculation system (similar to that used on ARGONTUBE arXiv:1304.6961)
- Thin Stilbene scintillator implemented as a neutron flux monitor (cross-calibrated with the fission chamber)



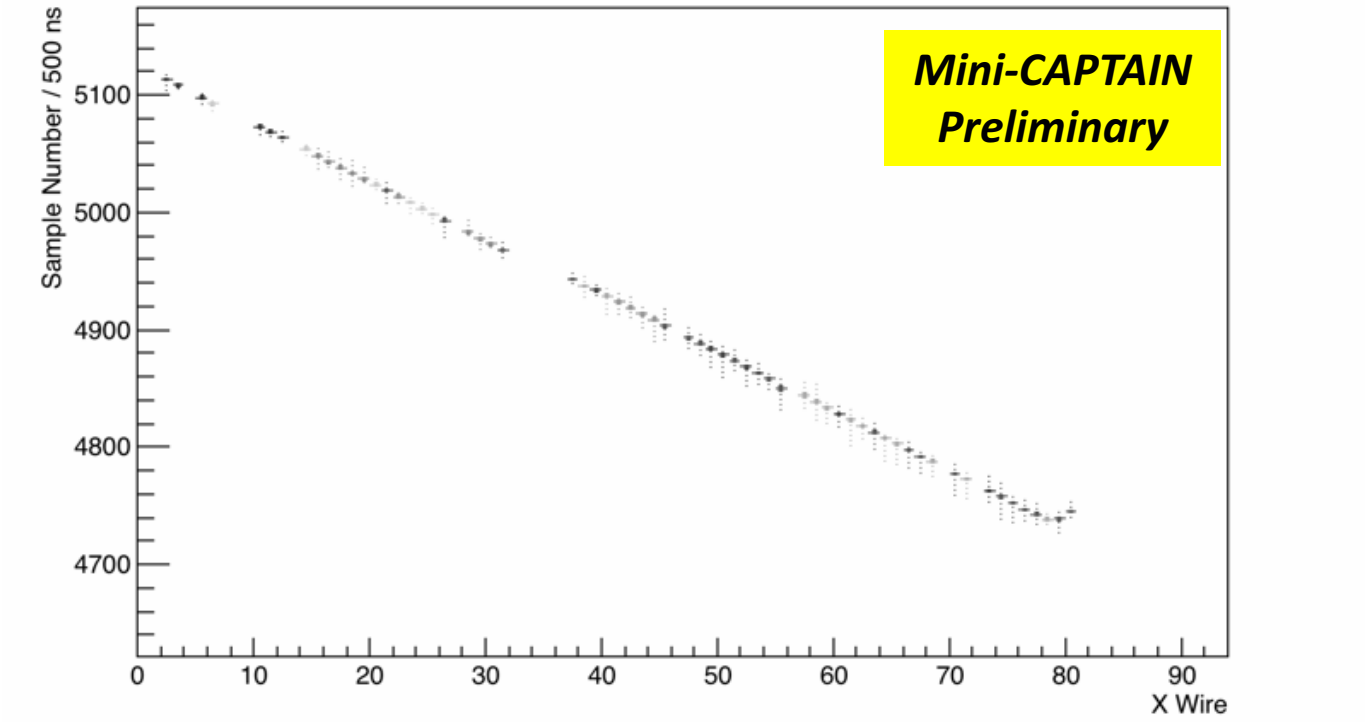


Mini-CAPTAIN WNR Neutron Run

Criotec Liquid Recirculation system attached to the bottom of the TPC frame

TPC being lowered into the Mini-CAPTAIN cryostat before filling in May 2017

First tracks from 2017 Run



Cosmic Muon Track with a drift distance of 30 cm
(Data taken on July 30th)

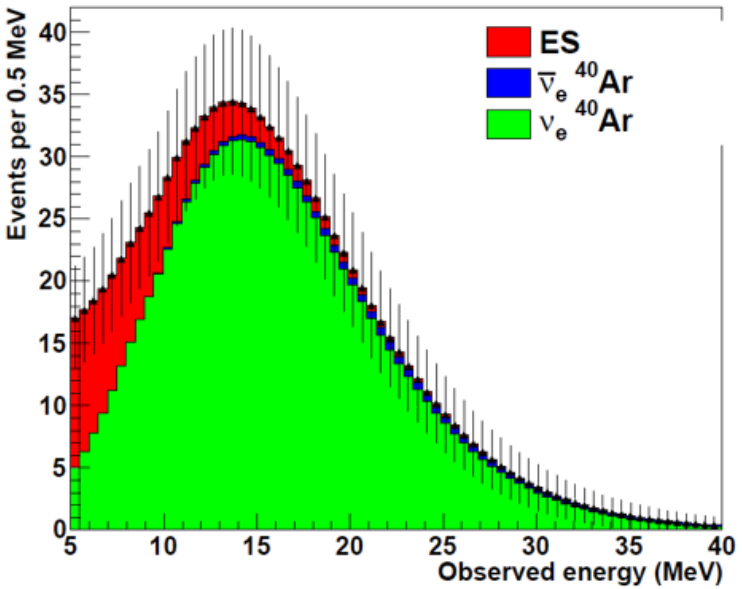
- Full TPC and PDS used in the 2017 Physics Run : July 23 – Aug. 05
- 2017 Physics Goals
  - Cross-sections as a function neutron energy
    - Differential partial cross-section on Ar, e.g. π^0, p, $\pi^{\pm}$ production

Low-energy Neutrinos

- Use CAPTAIN to study ν-Ar interactions in the energy range relevant for SN detection
- Cross sections have never been measured in this energy range and have large theoretical uncertainties

<u>Goals</u>

- Measure the ν-Ar cross-section to about 10% for neutrino energies of O(10) MeV
- Dominantly CC ν_e interactions
- Test the ability of detecting SN neutrinos with LAr detectors (triggering, timing)

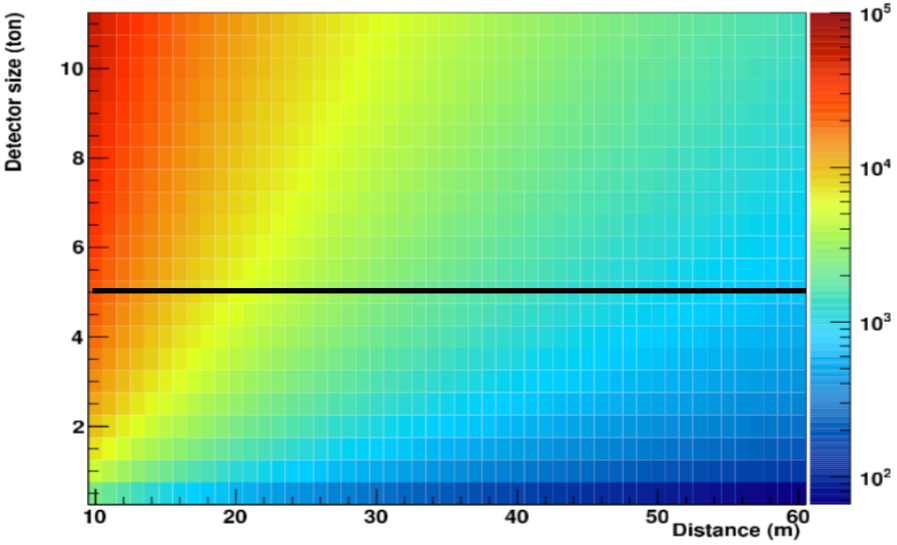


Observed energy spectrum in 40 kt of LAr for supernova at 10 kpc

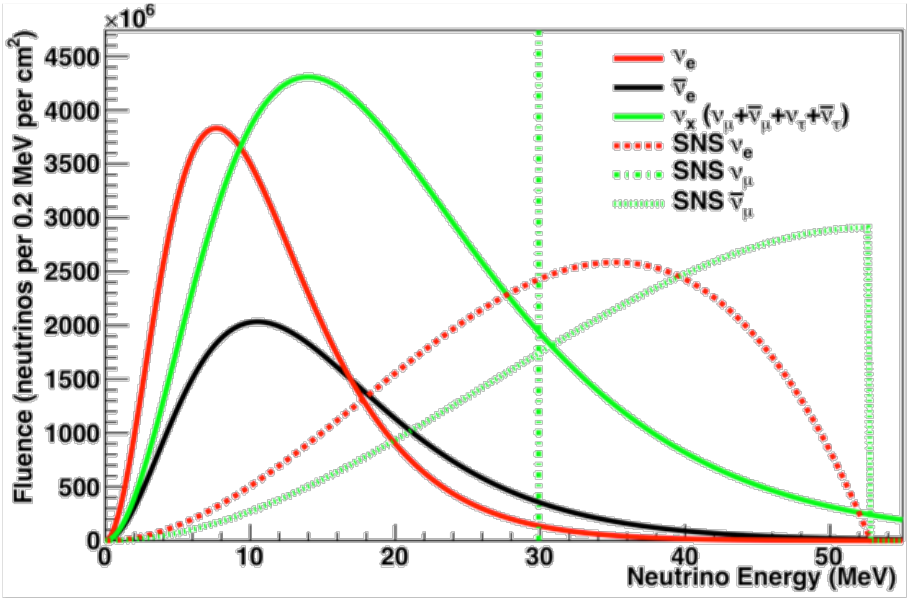
arXiv:1512.06148

CAPTAIN at Spallation Neutron Source

- Source: Neutrinos from pion decay-at-rest at the ORNL Spallation Neutron Source (SNS)
- ~1 GeV, ~1 MW primary proton beam on liquid Hg target at 60 Hz
- 1000s events anticipated in full CAPTAIN detector



Expected counts per year in LAr at ORNL SNS



Typical expected supernova spectrum for different flavors; SNS spectrum : integrated fluence for one day at 30 m from the SNS target.

A. Bolozdynya et al. arXiv:1211.5199

CAPTAIN Collaboration

CAPTAIN collaborators in front of the Mini-CAPTAIN cryostat installed in the WNR 15R flight path at LANL

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

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

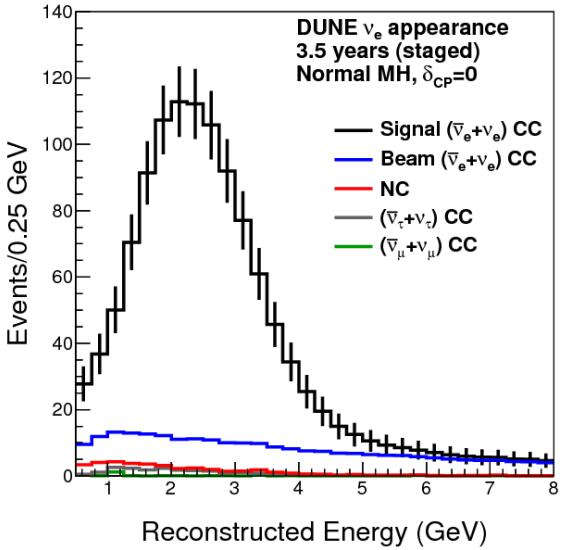
- The current CAPTAIN run plan includes several measurements
  - Neutrons on argon
    - Data taken with Mini-CAPTAIN at WNR from July 23- Aug 05, 2017
    - Under Analysis – ***Stay Tuned !!***
  - Low energy neutrino cross sections
    - Future Measurements : At a stopped-pion neutrino source

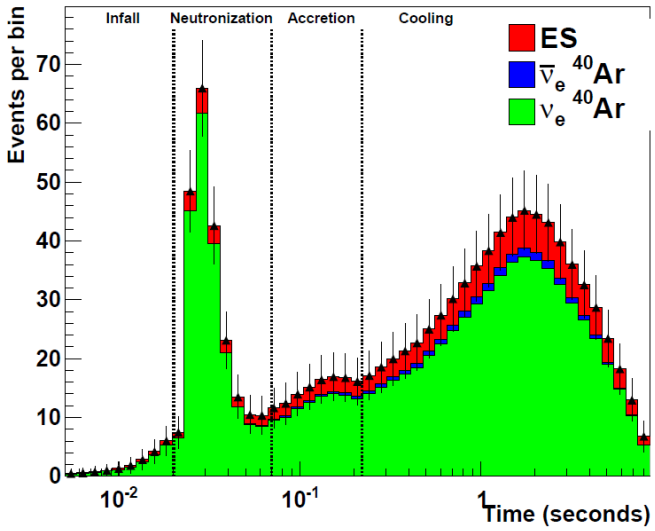
Opportunities with CAPTAIN for new collaborators !!

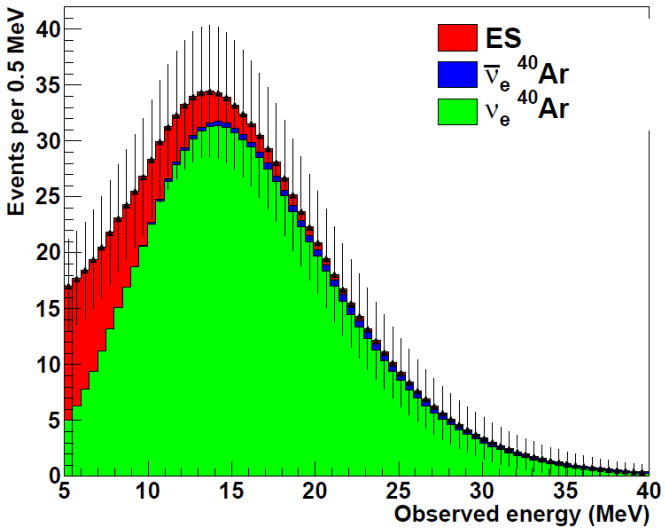
BackUP

- DUNE will use a LArTPC to study neutrino oscillations, search for proton decay and detect supernova neutrinos

arXiv:1512.06148



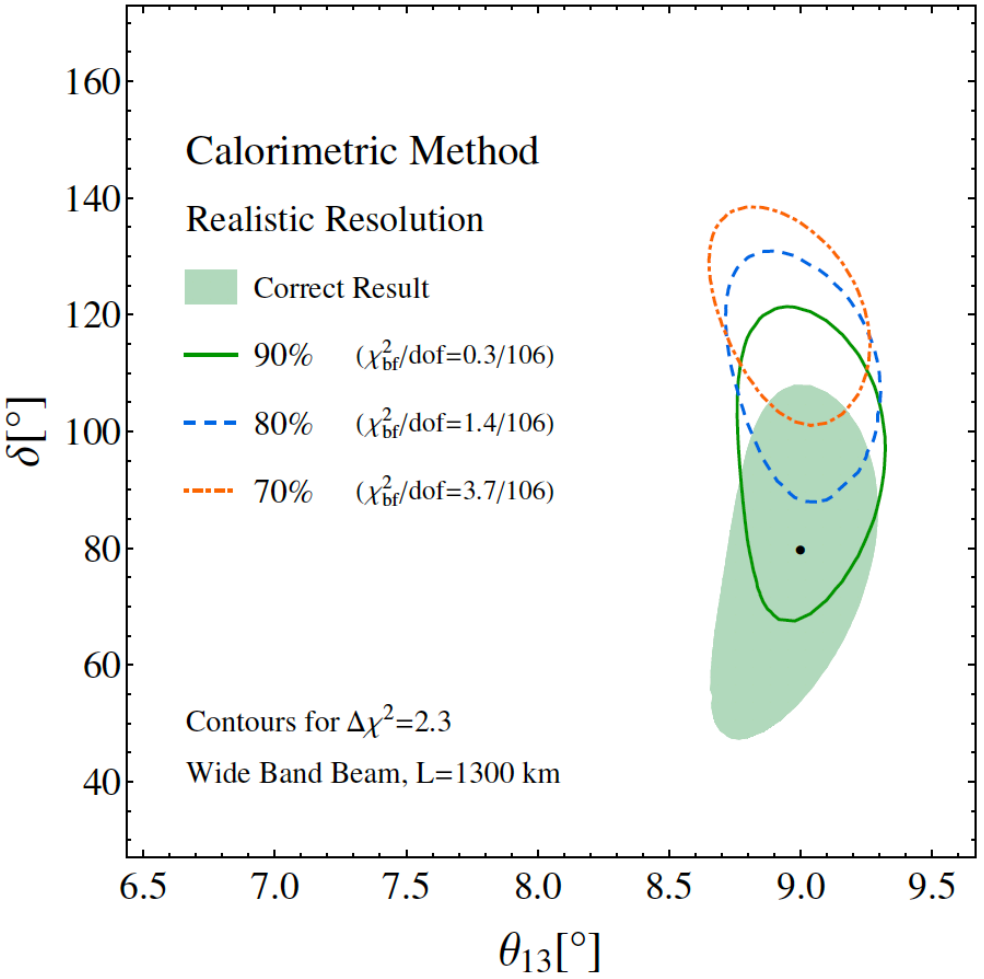




Delta-CP Biased by Missing Energy

It does not take "too much" neutron missing energy to significantly bias the reconstructed delta-CP

PHYS. REV. D 92, 091301 (2015)



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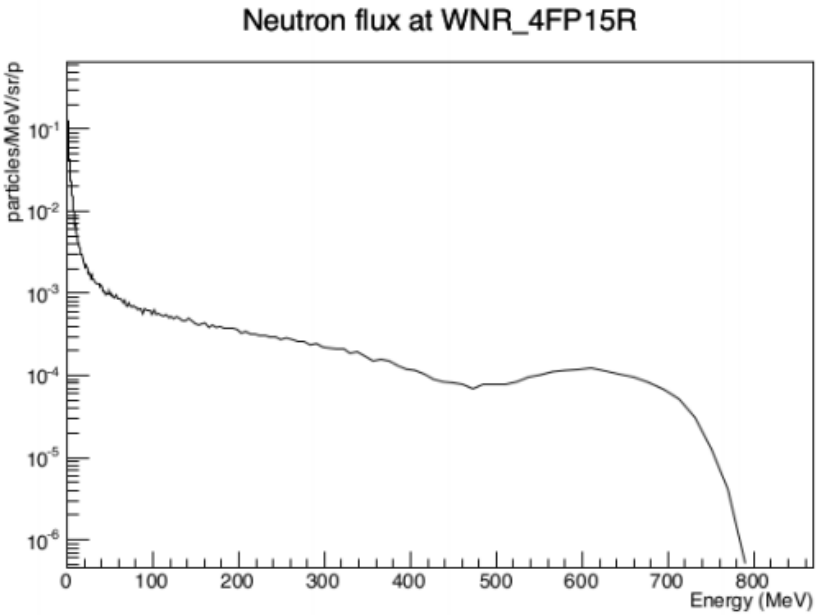
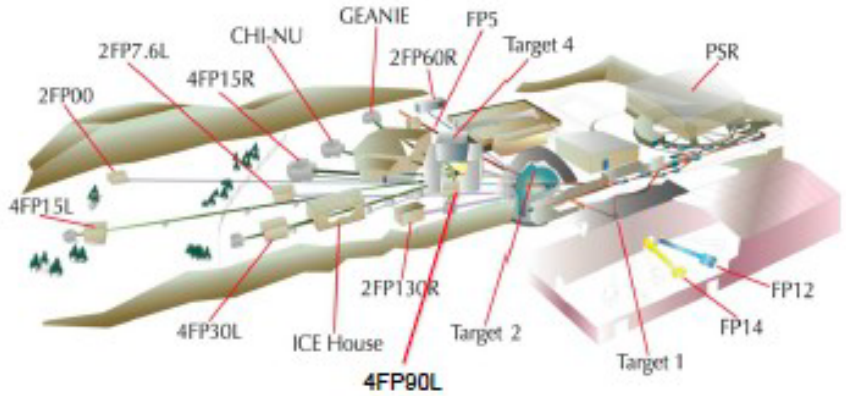
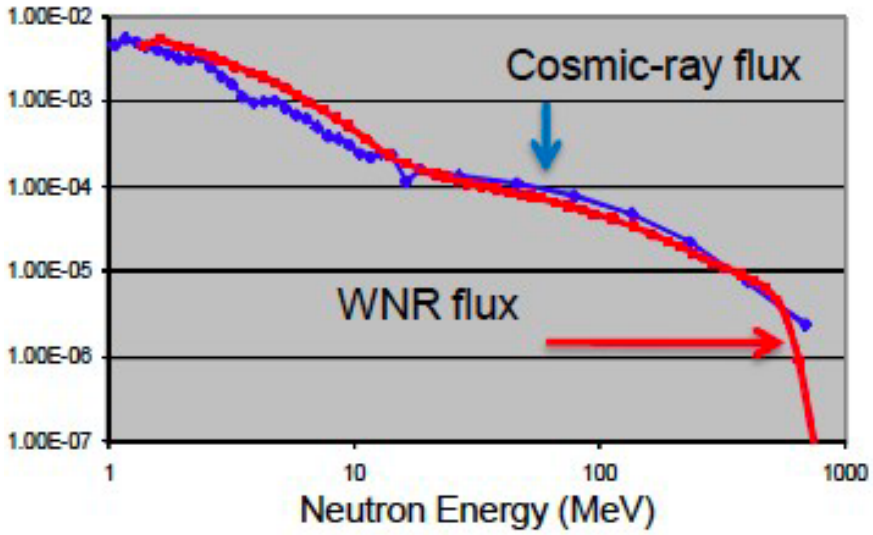
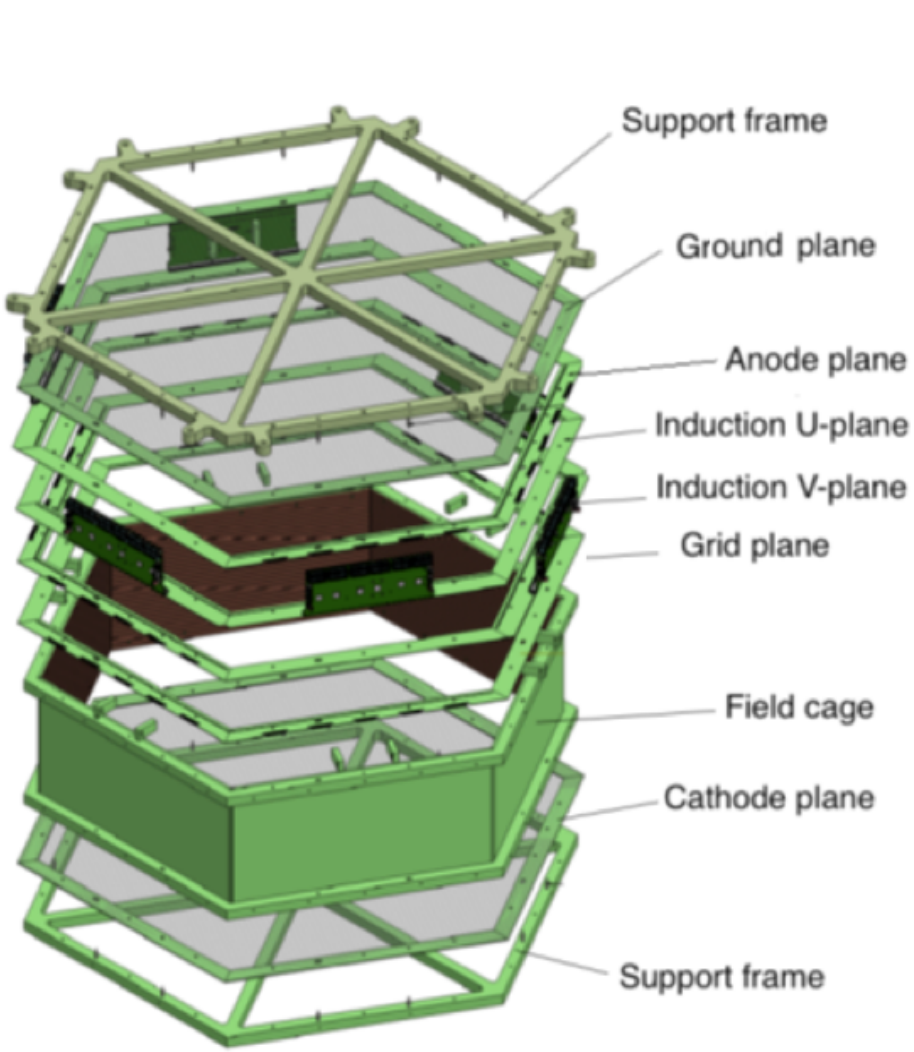
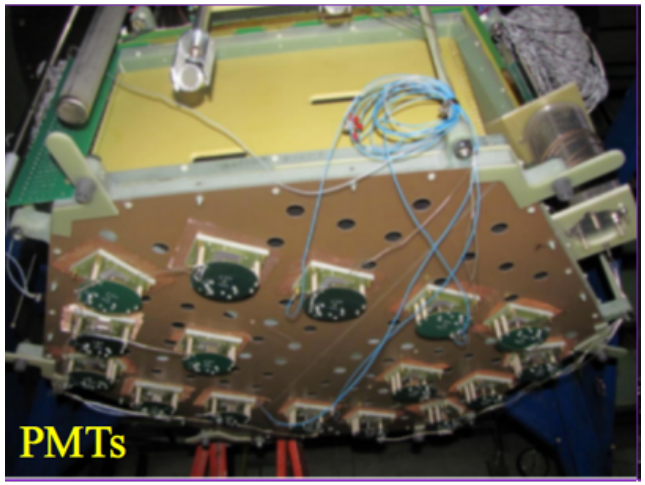






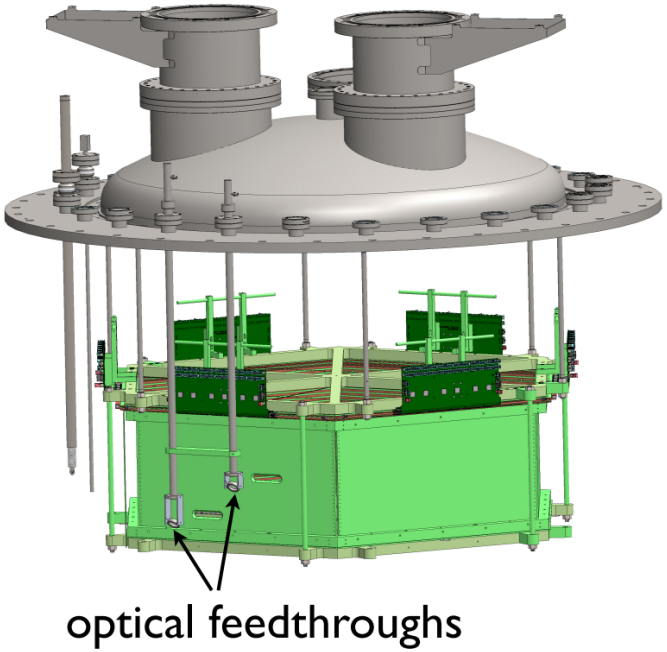
Backup

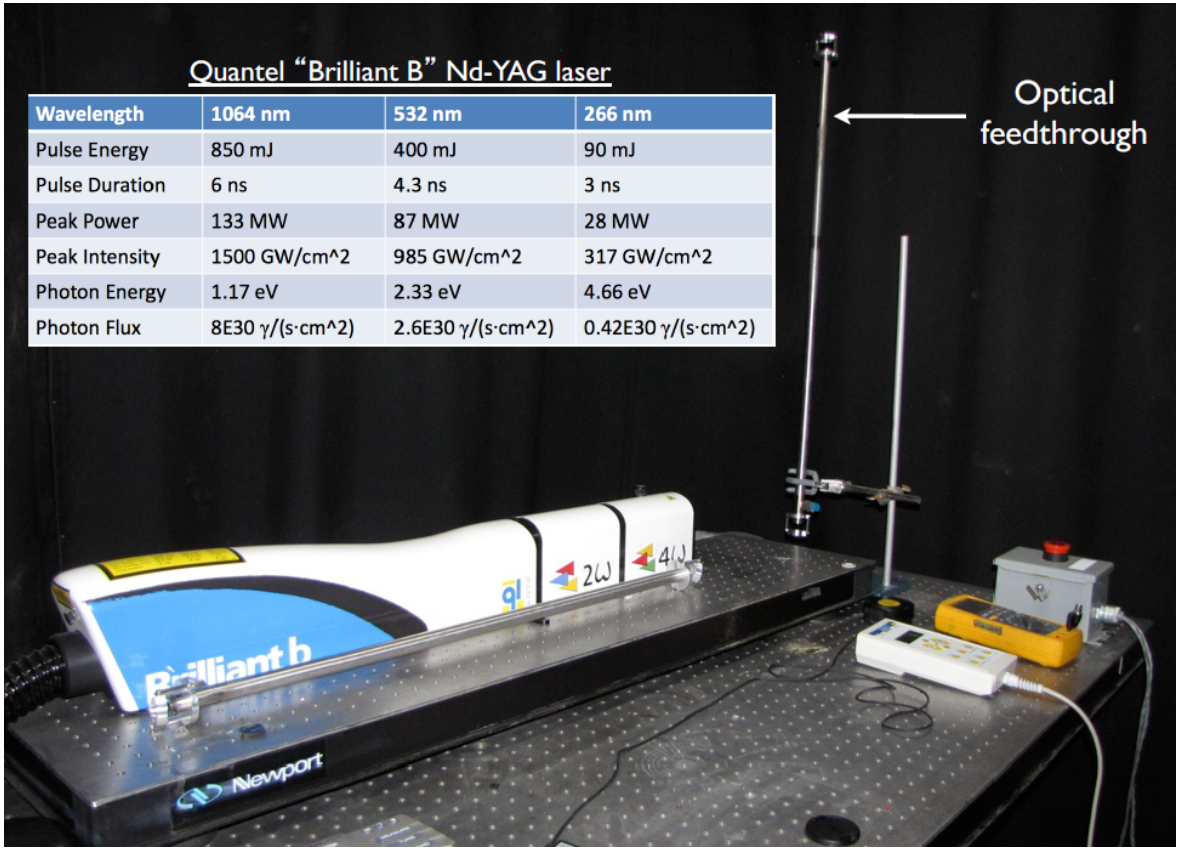

Support frame
Ground plane
Anode plane
Induction U-plane
Induction V-plane
Grid plane
Field cage
Cathode plane
Support frame

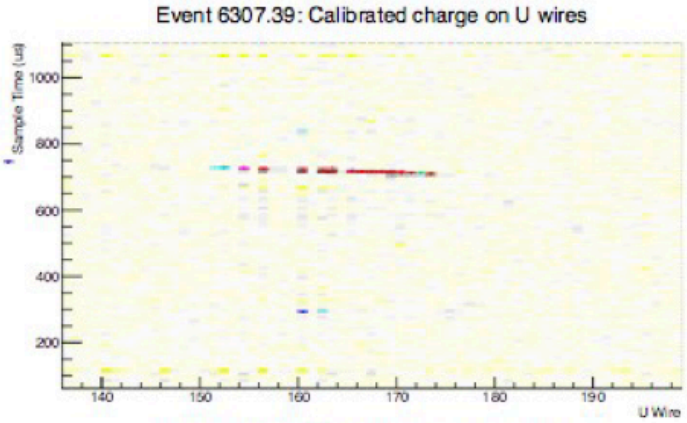

PMTs

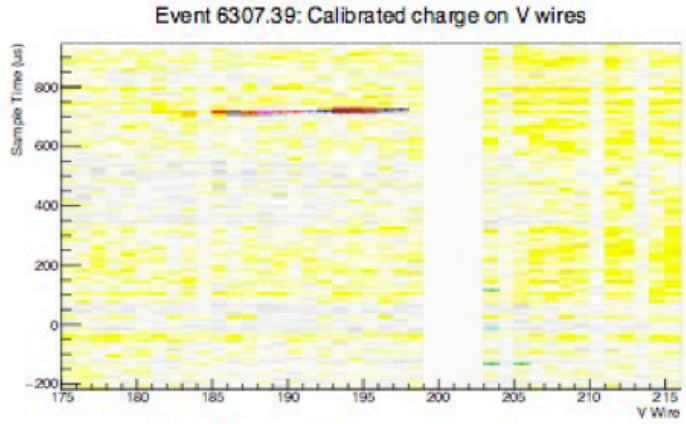
Laser System

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






Event 6307.39: Calibrated charge on U wires
Sample Time (μs)
1000
800
600
400
200
140
150
160
170
180
190
U Wire


Event 6307.39: Calibrated charge on V wires
Sample Time (μs)
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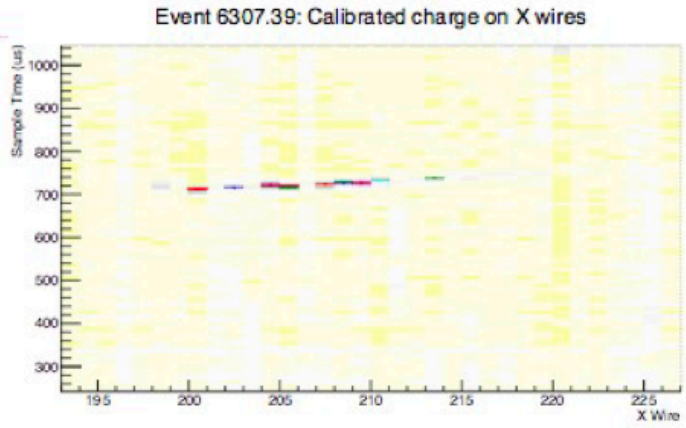
600
400
200
0
−200
175
180
185
190
195
200
205
210
215
V Wire


Event 6307.39: Calibrated charge on X wires
Sample Time (μs)
1000
900
800
700
600
500
400
300
195
200
205
210
215
220
225
X Wire