Results of a CEvNS Search with the CENNS-10 Liquid Argon Detector

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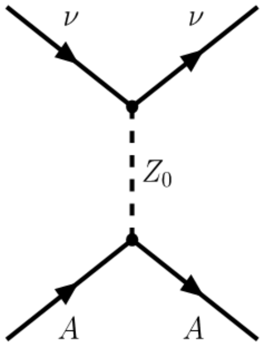
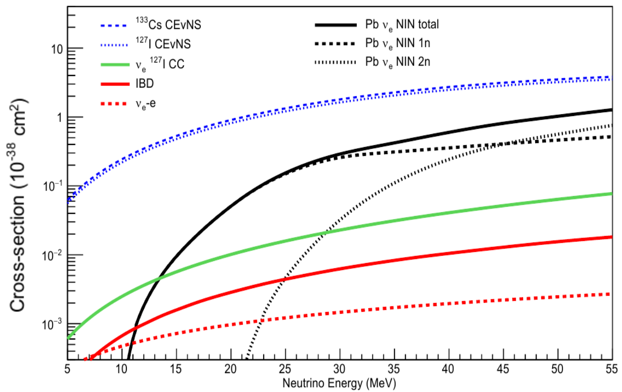
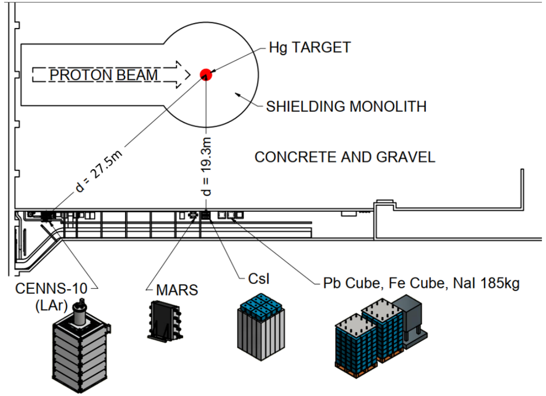
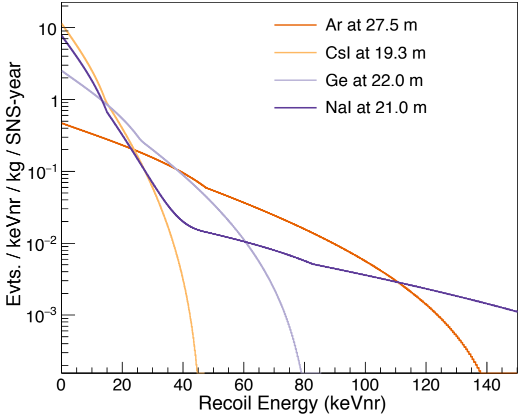
The COHERENT Experiment

- Suite of detectors to measure Coherent Elastic Neutrino-Nucleus Scattering (CEvNS) at ORNL
  - First predicted in 1974, first measured in 2017 on CsI target by COHERENT
    - Largest low-energy neutrino (<50 MeV) cross section
    - Low energy nuclear recoil, need low-background and low-threshold detectors
  - N^2 dependence of cross section
    - Measure on CsI, Ar, NaI, Ge
  - Physics accessible includes supernova neutrinos, nuclear physics, sterile neutrinos, reactor monitoring, nu magnetic moment



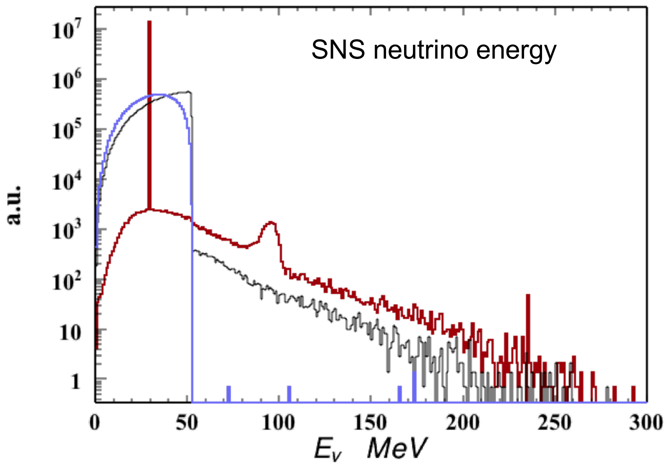


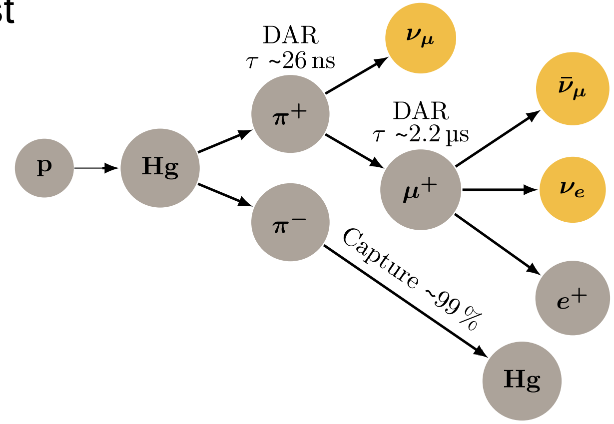


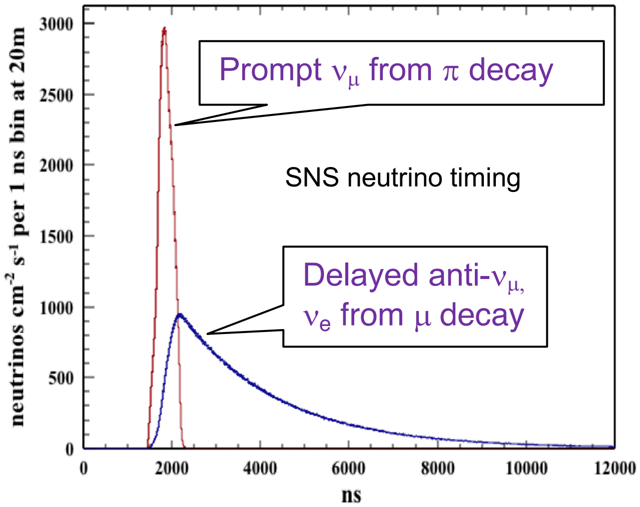


Neutrinos at the SNS

- Pulsed proton beam
  - 1.4 MW
  - 5000 MWhr/yr (1.5E23 POT/yr)
  - ~350 ns FWHM, 60 Hz
- Liquid mercury target
  - Neutrinos produced through p + Hg collisions and pi-decay at rest

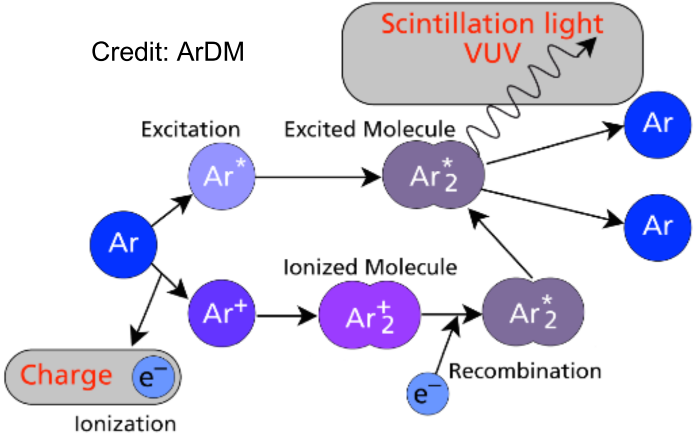




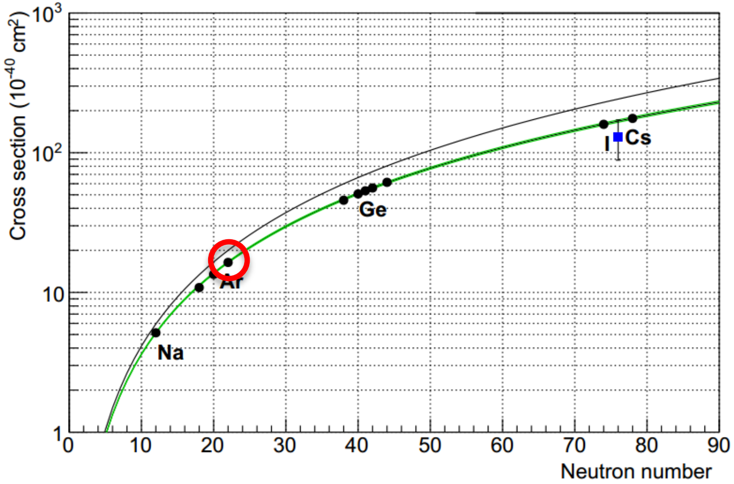


Liquid Argon (LAr) for CEvNS

Credit: ArDM

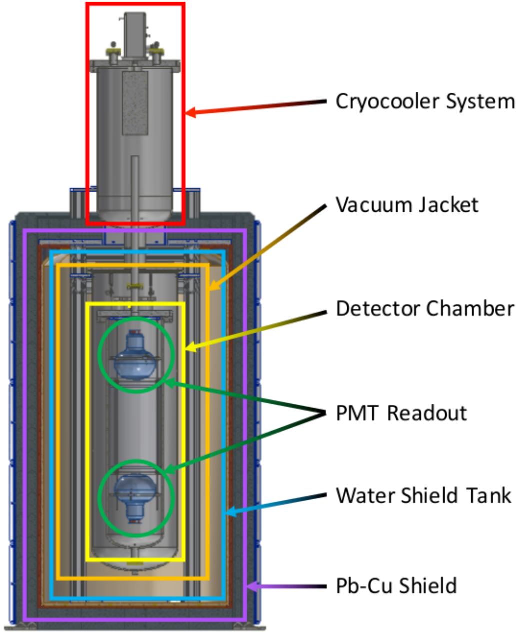


- Low N nucleus for CEvNS measurement
  - Map out N^2 dependence of CEvNS cross section after CsI measurement
- Large scintillation yield of 40 photons/keVee
- Well-measured quenching factor
- Pulse shape discrimination (PSD) capabilities for nuclear/electron recoil separation
  - Two scintillation time constants
    - ~6 ns singlet light
    - ~1.6 μs triplet light
  - Electron recoil (ER) events mostly triplet light, Nuclear recoil (NR) events mostly singlet light



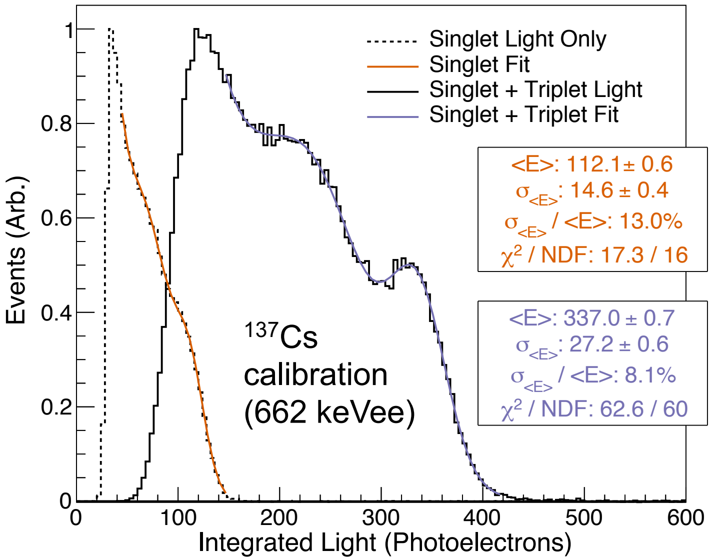
The CENNS-10 Detector

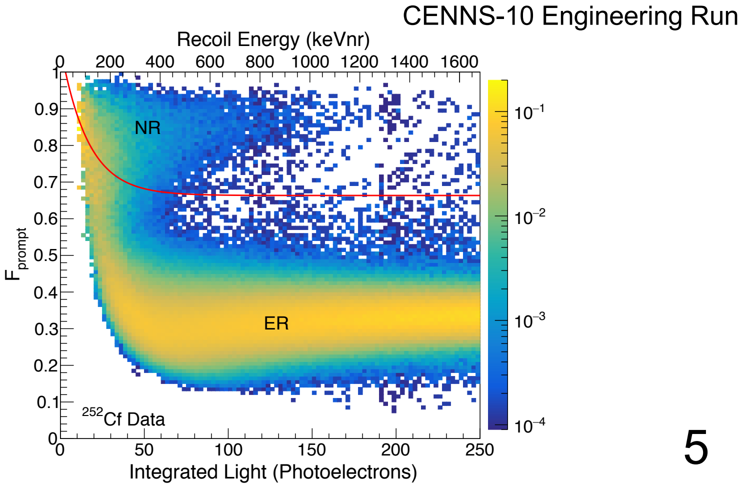
- Originally built in 2012 by J. Yoo et al. at FNAL for CENNS effort at FNAL
- ~24 kg fiducial volume
- 2x 8" Hamamatsu PMTs, 18% QE at 400 nm
- Tetraphenyl butadiene (TPB) coated side reflectors/PMTs
- 10 cm Pb/ 1.25 cm Cu/ 20 cm H_2O shielding
- SAES MonoTorr Zr getter for LAr purity management
- Moved to SNS for use in COHERENT late 2016
  - Engineering Run (early 2017) with TPB coated acrylic parts, ~80 keVnr threshold, no lead shielding, blind analysis finished (1.8 GWhr), published results (arXiv:1909:05913 [hep-ex], accepted to Phys. Rev. D)
  - Production Run (July 2017-present) after upgrade to TPB coated Teflon/PMTs, ~20 keVnr threshold, expect ~140 CEvNS events/SNS-yr, blind analysis with two parallel groups in end stages (6.12 GWhr)



CENNS-10 Analysis

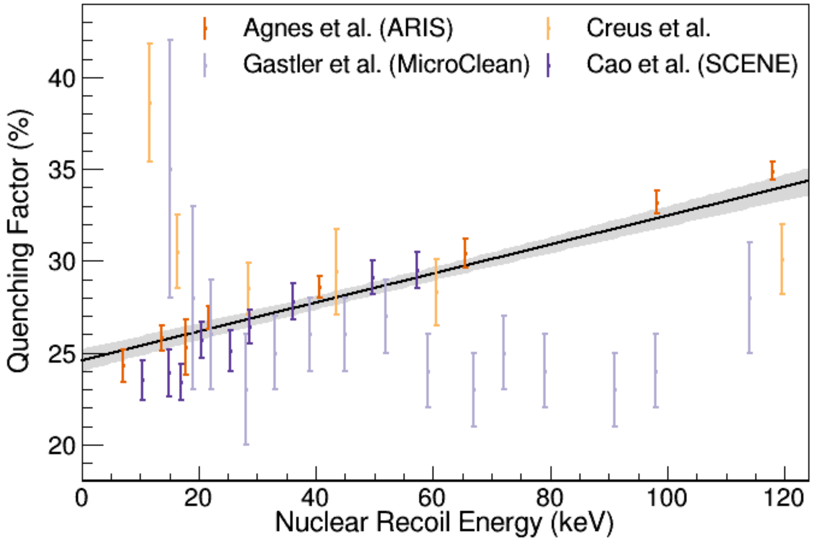
- Read out 33 μs around each beam spill
  - Pulse finding algorithm to find events
- Calibrate detector with variety of sources
- Characterize backgrounds
  - Measure and subtract beam unrelated backgrounds with beam-off trigger
  - Measure beam related neutrons with no-water shielding runs
- Optimize cuts using signal/noise in energy, pulse shape (PSD), and time
- Analysis consists of two steps
  - Counting experiment, “prompt”, and “delayed”
  - Full likelihood analysis





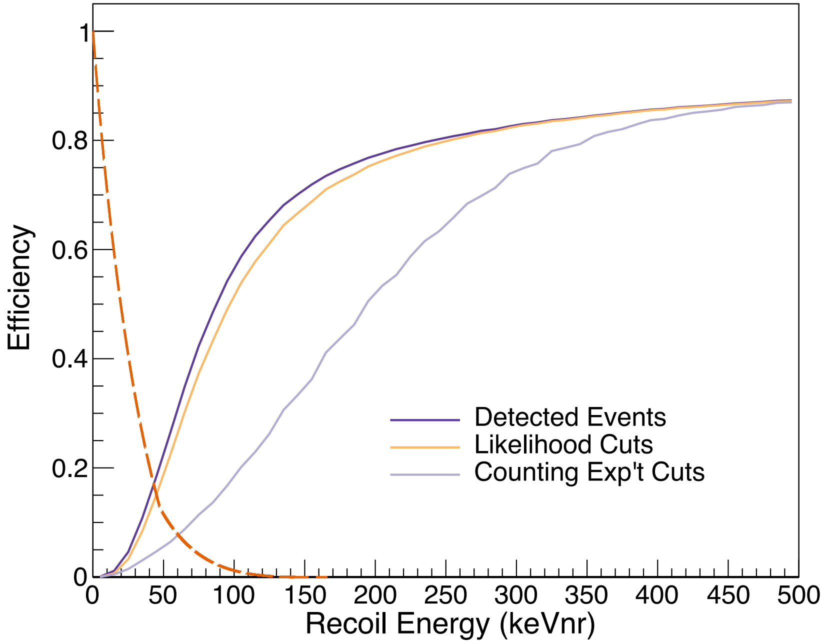
LAr Quenching Factor

- Multiple measurements of LAr quenching factor in CEvNS region of interest
- Analysis performed within collaboration to fit quenching factor model
  - Use linear fit model to describe quenching factor
    - χ^2/ndf = 138.1/36
    - Scale error band such that χ^2/ndf = 1
  - 2% average uncertainty on quenching factor value in ROI
  - O(1%) uncertainty on predicted CEvNS counts



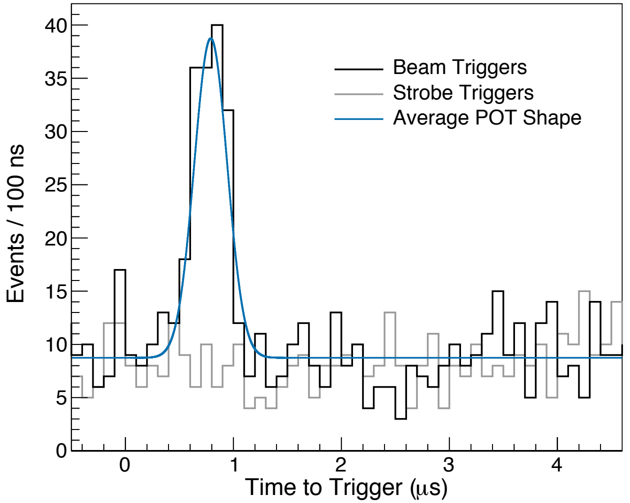
Engineering Run Cuts

- Cuts to waveforms include
  - Saturation, baseline
    - > 99% of waveforms pass
  - Event specific cuts
    - Pile-up, etc.
      - > 98% events pass
  - Beam-related events
    - Threshold and pulse shape discrimination cuts

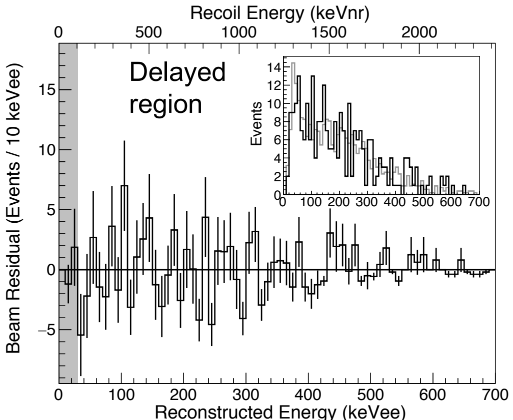


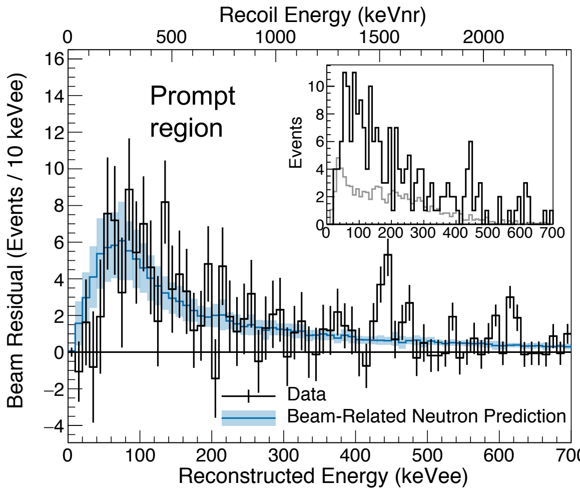
Engineering Run Results

- Threshold not low enough for sensitive CEvNS search
  - Understand beam related neutron (BRN) backgrounds
- Counting experiment results
  - Optimized cuts based on signal/noise
- Excess after cuts seen in time with beam consistent with prompt beam related neutron (BRN) rate
  - Delayed window excess consistent with zero
    - Place limit on CEvNS cross section
  - Place constraint on beam related neutrons for Production Run



Engineering Run Results, arXiv:1909:05913 [hep-ex], M. R. Heath (IU PhD Thesis) (2019) http://inspirehep.net/record/1744690?ln=en
Accepted to Phys. Rev. D





Engineering Run Results

- Full likelihood analysis
  - New limits on CEvNS cross section
    - SM predicted cross section of 1.8 x 10^{-39} cm^2
  - Non-standard interaction (NSI) constraints
    - Confirms constraints from 2017 COHERENT CsI result

sample size	4663
beam-unrelated background	4700 ± 34
fit BRN	$126 \pm 18(\text{stat.}) \pm 28(\text{syst})$
1σ (68 % C.L.) CEvNS events	< 7.4
1σ cross section	$< 3.4 \times 10^{-39}$ cm^2
1σ cross section sensitivity	$< 7.1 \times 10^{-39}$ cm^2

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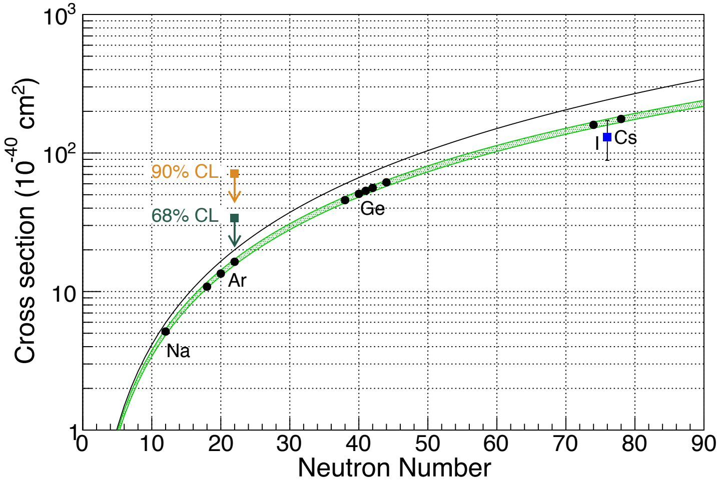
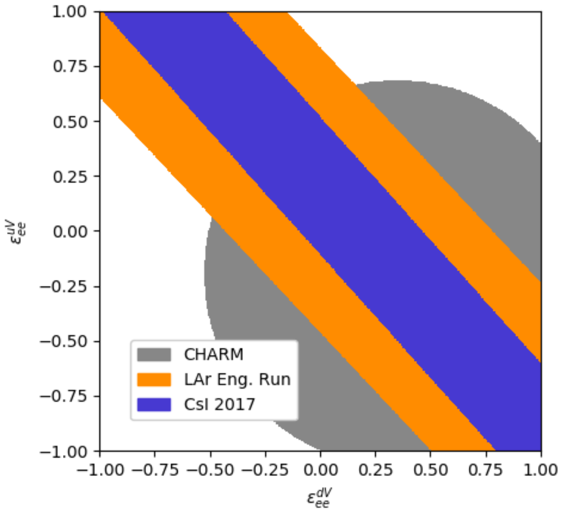
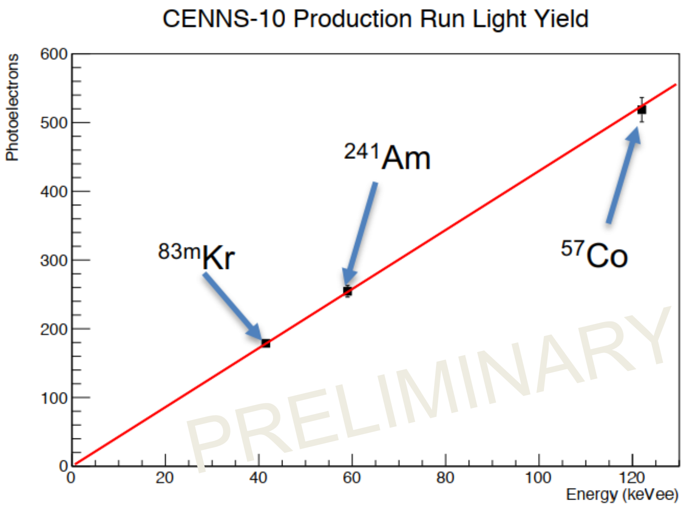
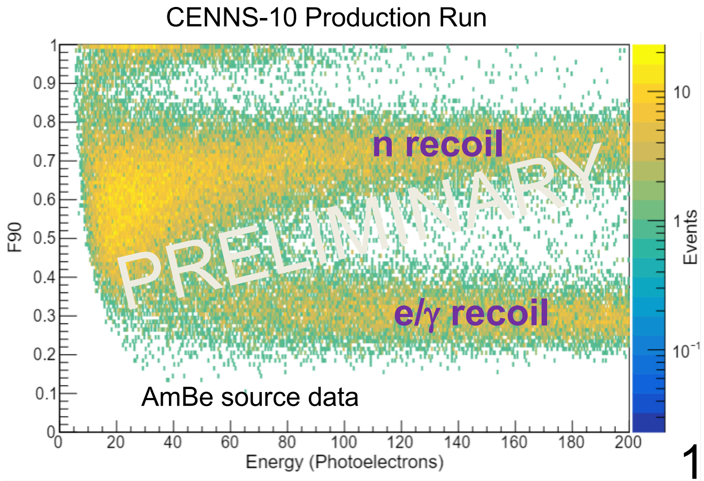




Production Run Analysis

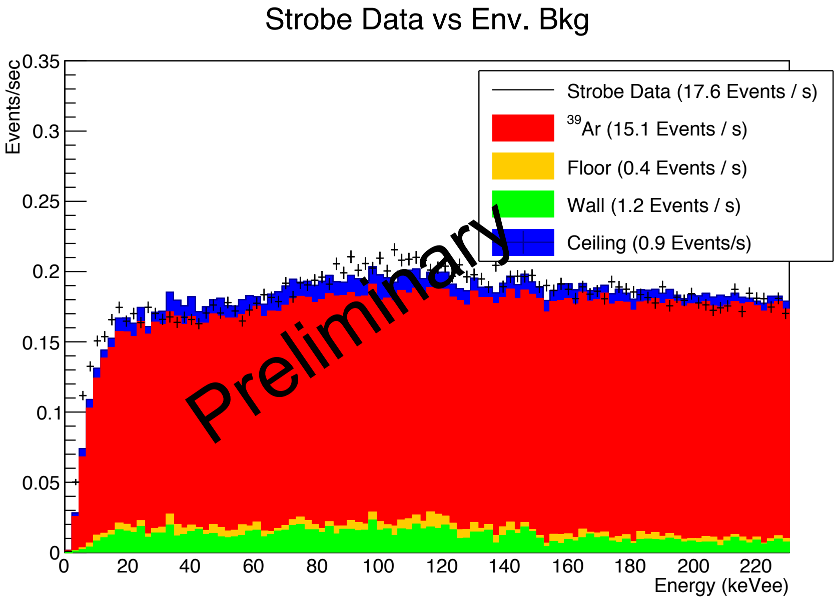
- Detector upgraded to TPB coated Teflon/PMTs
- Same strategy as Engineering Run
  - Measure and subtract beam unrelated backgrounds
  - Measure beam related neutrons with no-water shielding runs
  - Counting experiment, likelihood analysis
- Calibration determined light yield as ~4.5 photoelectrons/keVee
- Improved nuclear recoil pulse shape discrimination (PSD)
- Pulse shape discrimination, background rates, energy resolution, threshold (~20 keVnr) sufficient for measurement of CEvNS in ^{40}Ar
- SM prediction of ~130 CEvNS events in 6.12 GWhr Production Run dataset
- Results soon!





Beam-Unrelated Background

- With addition of lead shielding, largest background is ^{39}Ar
  - Cosmogenic background in atmospheric Ar at ~1 Bq/kg
  - CENNS-10 simulations ran of beam-unrelated background
- Other components measurable are naturally occurring U/Th backgrounds
- ^{39}Ar backgrounds reduced via extraction of ^{40}Ar from underground
  - Idea for future COHERENT LAr operation, see talk by R. Tayloe tomorrow

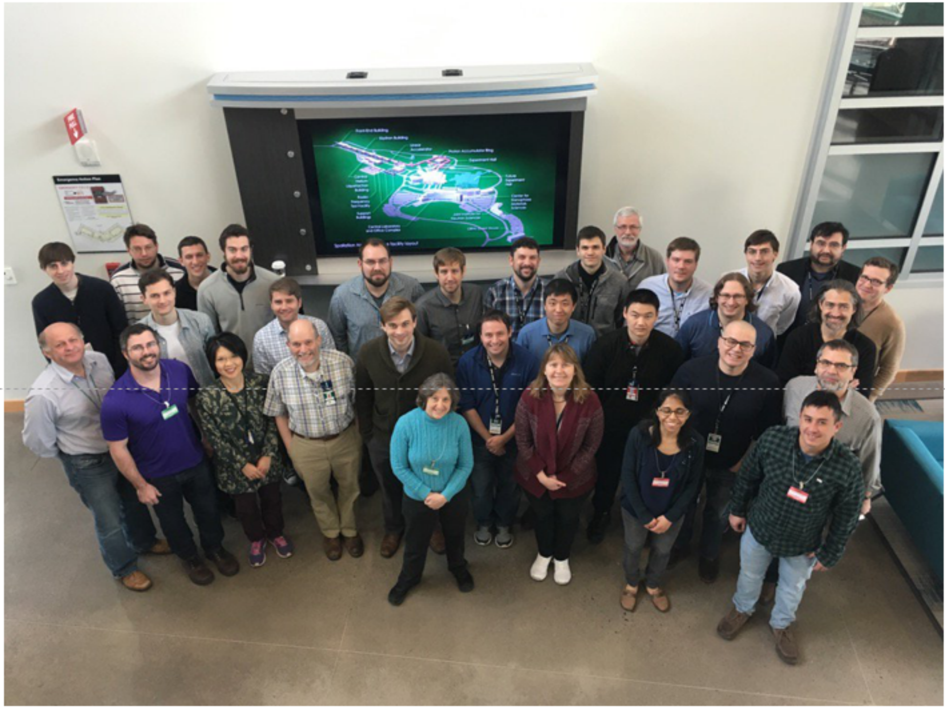


CENNS-10 Production Run

Summary

- Liquid Argon is low N target for CEvNS measurement due to high scintillation yield and PSD capabilities
- CENNS-10 detector built at FNAL and moved to SNS for COHERENT measurement of CEvNS on ^{40}Ar
- Engineering Run placed new limits on CEvNS cross section on ^{40}Ar and confirms CsI constraints for non-standard interactions
- CENNS-10 upgraded, production data taking continues, results from first physics run soon!
    - For future COHERENT LAr program, see talk by R. Tayloe

Thank you! Questions?



https://coherent.ornl.gov arXiv:1803.09183v2

COHERENT

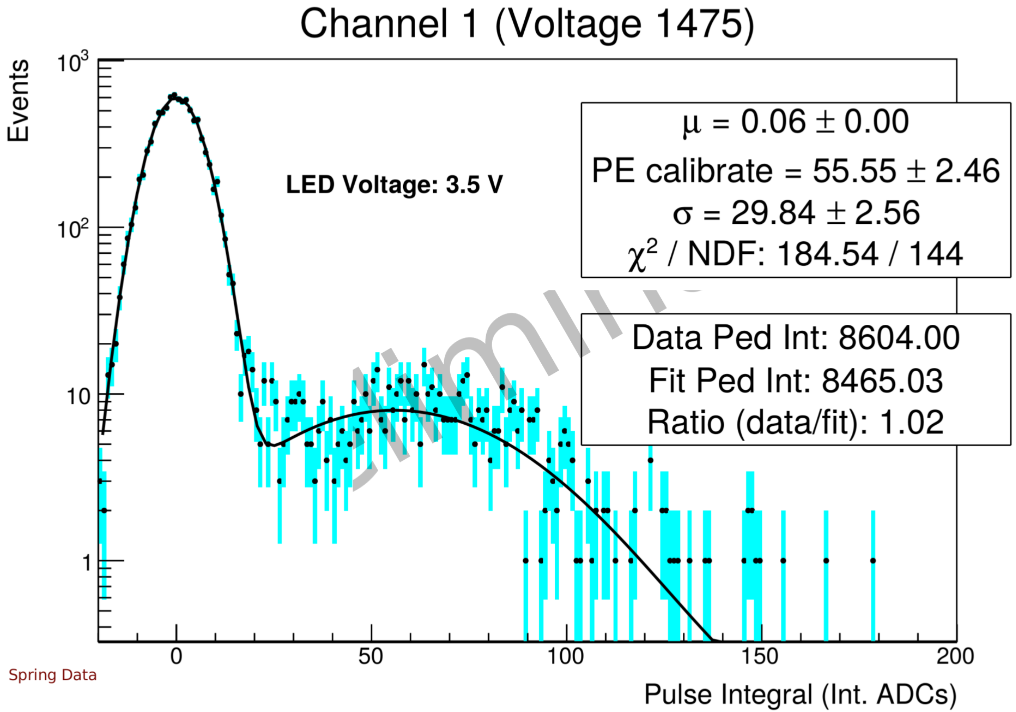
SNS SPALLATION NEUTRON SOURCE

Oak Ridge National Laboratory · Duke University · TUNL · Sandia National Laboratories · The University of Tennessee Knoxville · Los Alamos National Laboratory EST. 1943 · NC State University · University of Washington · The University of Chicago · NM State · MEPhI · University of Florida The Foundation for The Gator Nation · KAIST · North Carolina Central University Founded 1910 · Carnegie Mellon University · Tufts University · Laurentian University Université Laurentienne · University of South Dakota

CNEC Consortium for Nonproliferation Enabling Capabilities · KICP · NNSA National Nuclear Security Administration · NSF · U.S. Department of Energy

Backup Slides

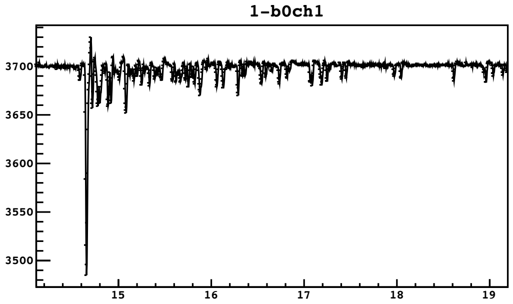
Engineering Run SPE



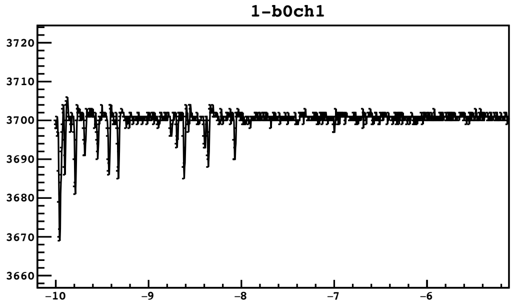
Spring Data

Event Quality Cuts

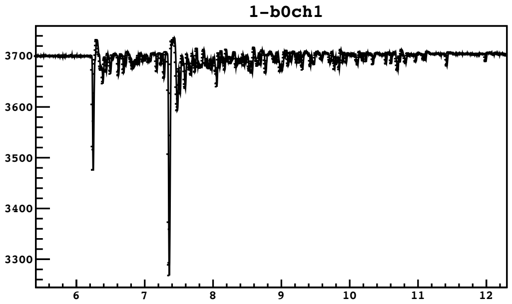
Bad Local Baseline



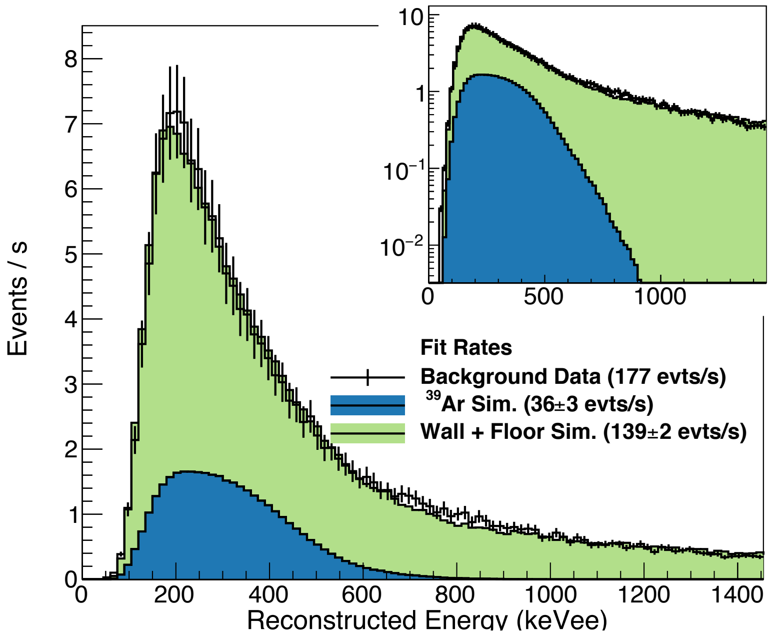
Bad Fit Result (usually too close to beginning for valid baseline)

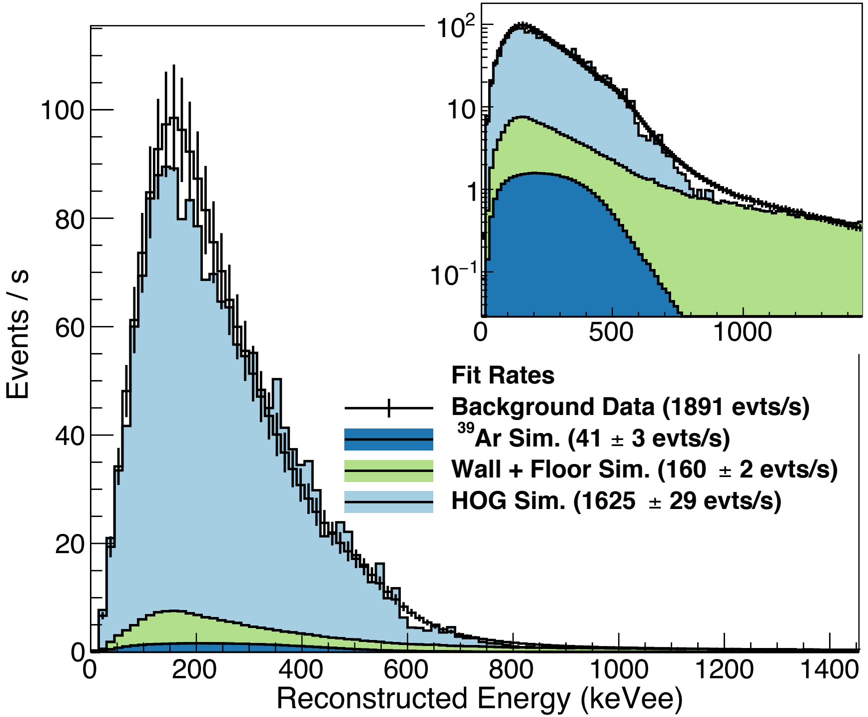


Bad Peak (typically pileup)

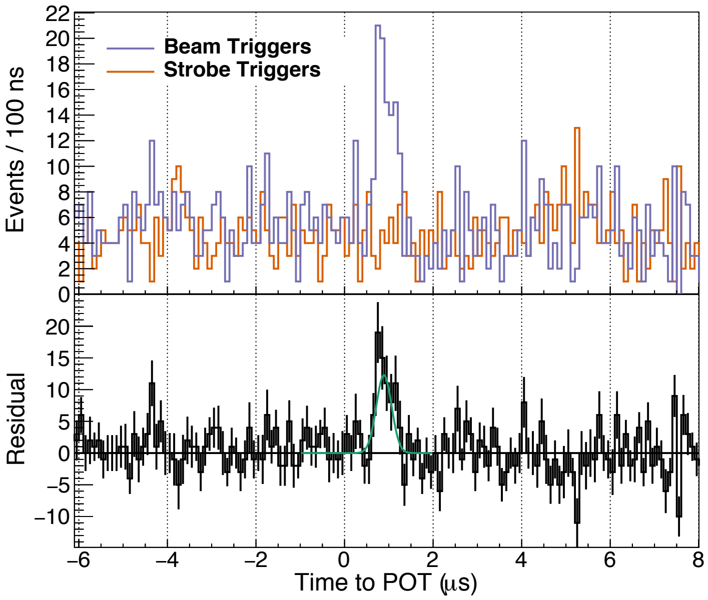


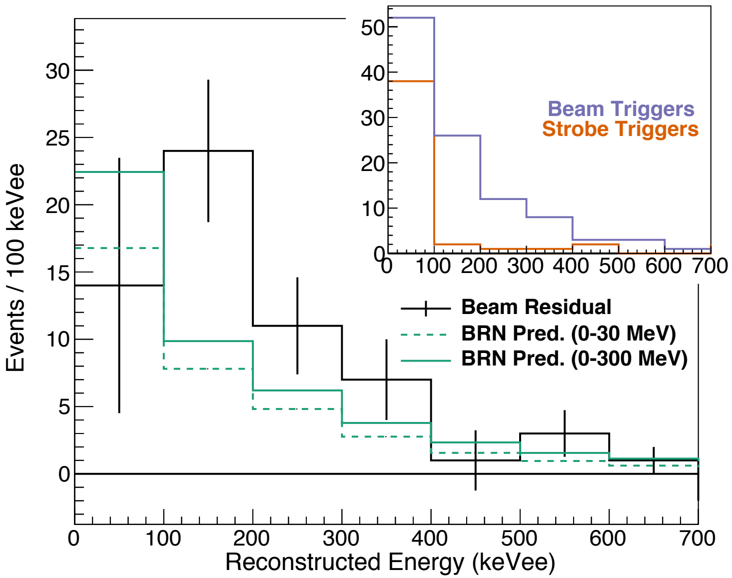
Engineering Run Beam-Unrelated Background





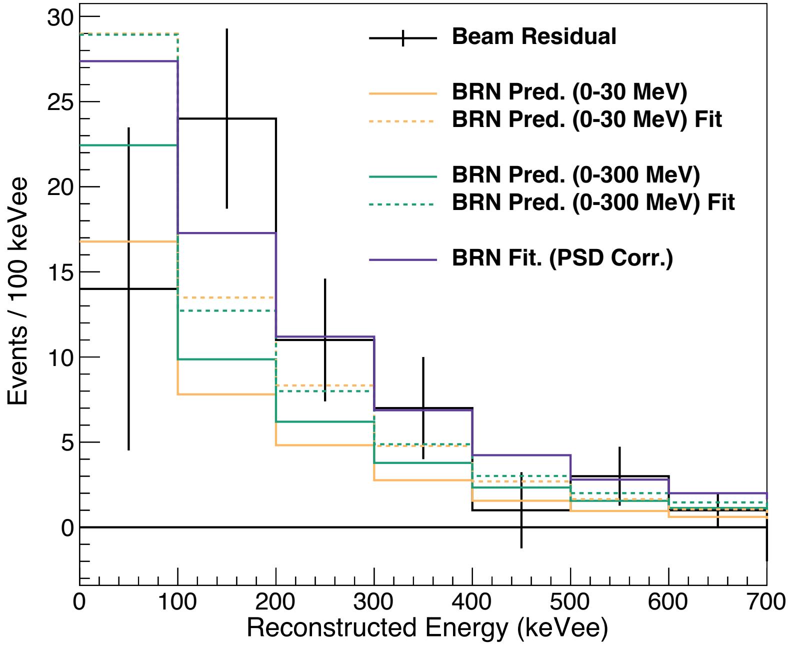
Engineering Run No-Shielding Data



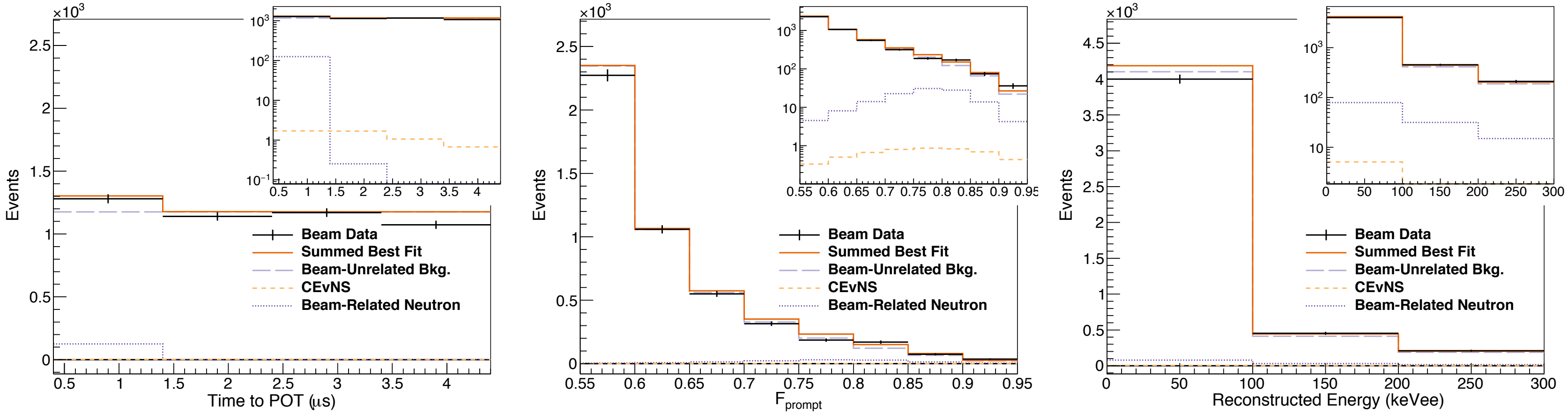


Beam-Related Neutron Normalization

- Beam-related neutron predictions from IU-built SciBath detector
    - Measured neutron flux in CENNS-10 location in Neutrino Alley
    - Energy shape agreement with measured no-shielding data in Engineering Run
    - Best fit shows 30% increase in normalization from SciBath predicted flux



Engineering Run Likelihood Results



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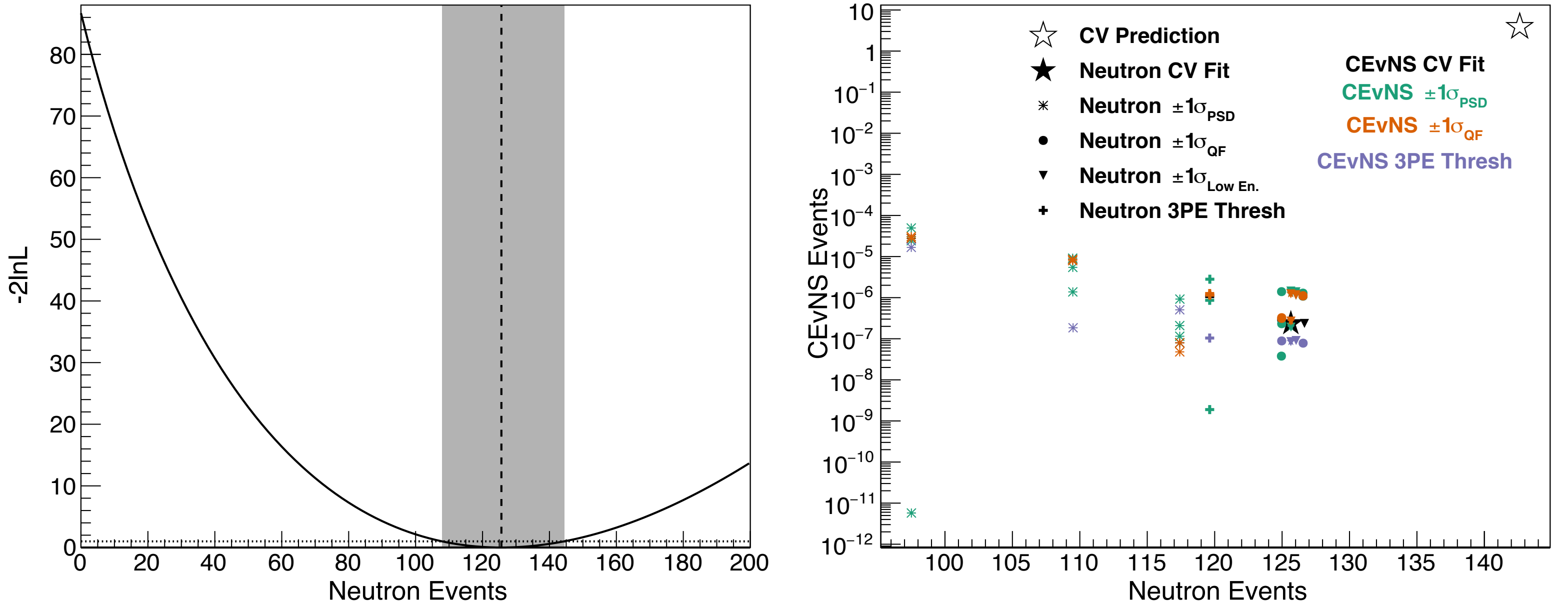
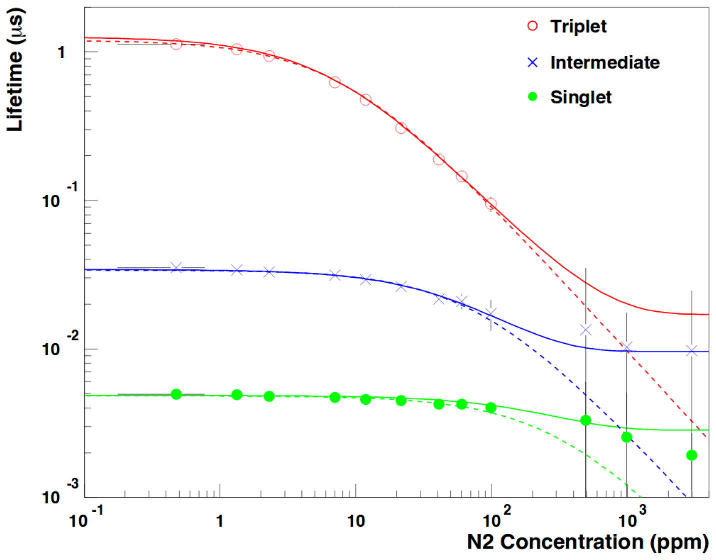
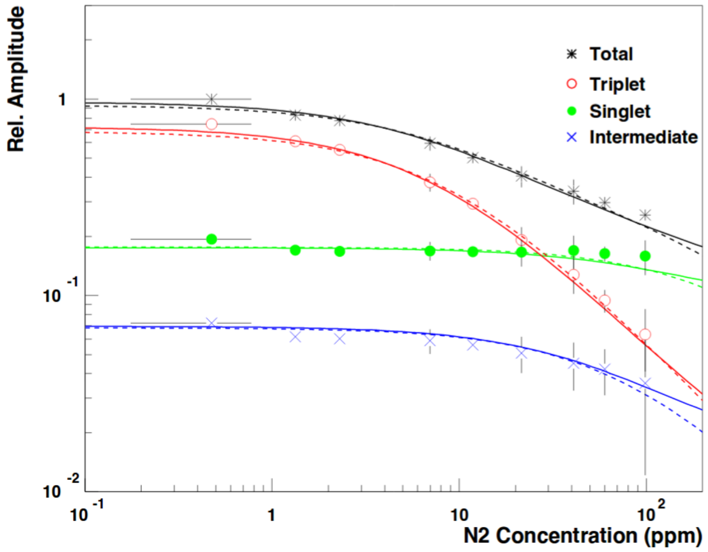


Nitrogen Contamination





arXiv:0804.1217[nucl-ex]