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

2019 APS April Meeting

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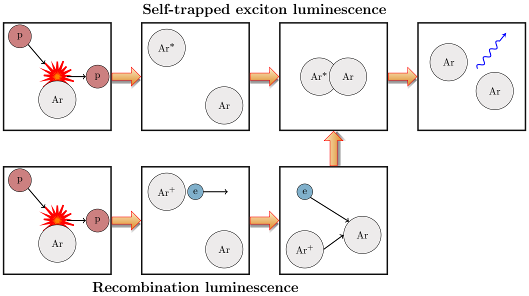
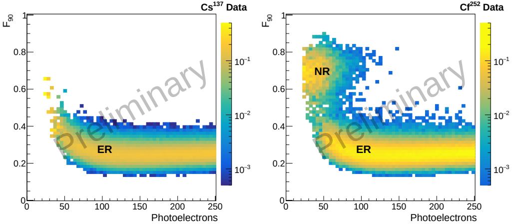
Why LAr

- Complementary to heavier Cs and I
  - Map out low N σ_{CEvNS}
  - Lower σ but more energetic recoils
- Large scintillation yield
  - $40\,\gamma$/keVee
- Quenching factor well measured
- Pulse Shape Discrimination (PSD)!
  - Argon scintillates with 2 time constants
    1. Singlet light: ~6 ns
    2. Triplet light: ~1.6 μs
  - Electronic Recoils mostly triplet light
  - Nuclear Recoils mostly singlet light

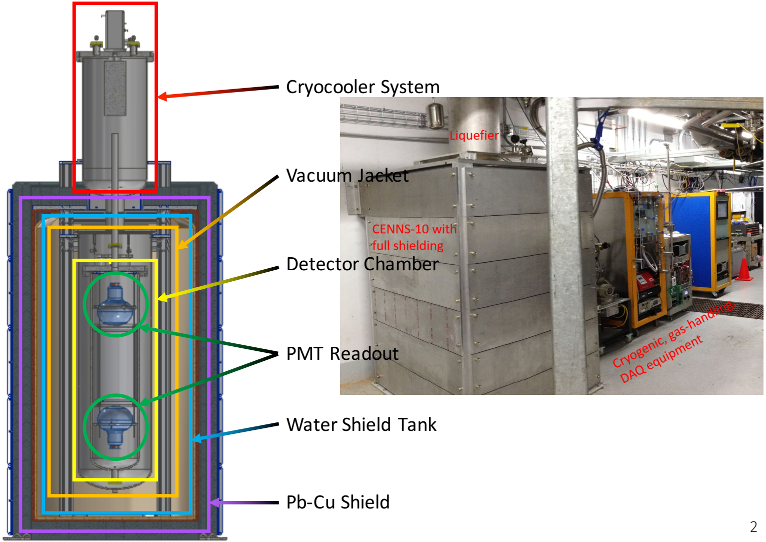




[0]Scint. diagram based on B. Jones *Introduction to Scintillation Light in Liquid Argon*

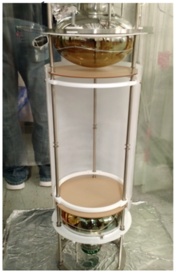
Specs

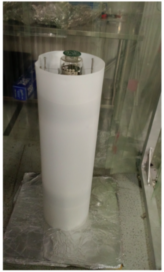
- Single-phase liquid argon detector
  - Constructed at FNAL
- 2x Hamamatsu R5912-20 PMTs
- Caen 1720 digitizer
  - 12 bit, 250 MS/s
- PT90 cold head
- Saes MonoTorr gas purifier
- Running at SNS 2016-present
  - “Engineering Run”: This talk
  - “Production Run”: Light collection upgrade, add’l shielding
    - Analysis in progress, stay tuned

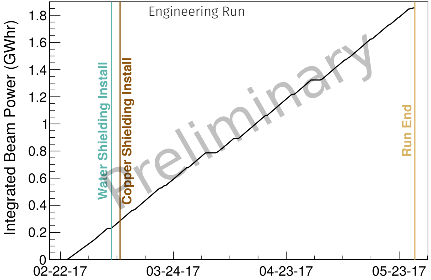


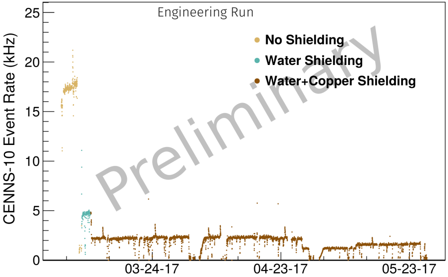
Run Summary

- 29 kg fiducial volume
- Tetraphenyl butadiene (TPB) coated acrylic cylinder backed by teflon
- TPB coated acrylic disks in front of PMTs
- Water, Cu shielding
- 1.5 GWh (3.5×10^{22} pot) full shielded config.
- Light collection upgrade Summer 2017
  $\rightarrow$ Production Run







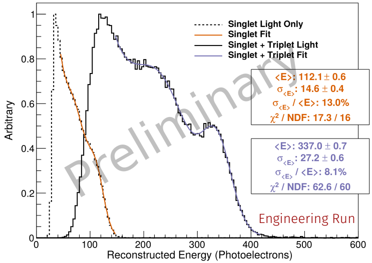


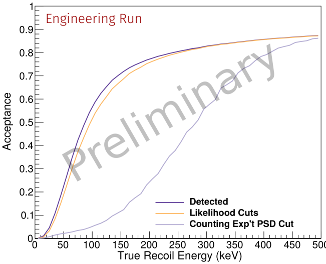
Detector Characterization

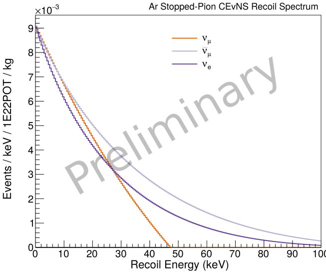
- Weekly calibration runs
  - LED for SPE calibration
  - ^{137}Cs for light yield calibration
- Monthly ^{252}Cf source for nuclear/electronic recoil discrimination
- Light yield 0.55 PEs/keVee
  - Much improved for Production Running!

Cuts

- General waveform quality cuts: no saturation, valid baseline...
  - $> 99\,\%$ waveforms pass
- Event specific cuts: pileup, pre-trace...
  - $> 98\,\%$ events pass
- Beam-related events: PSD

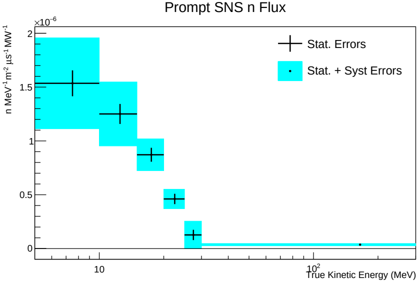


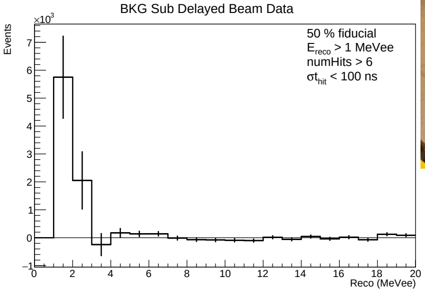


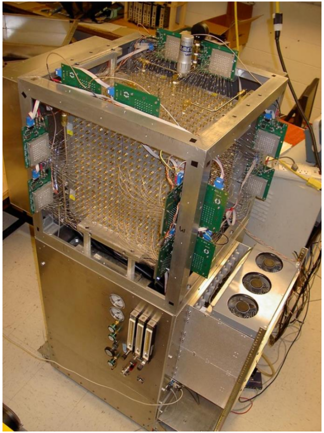


Beam-Related Backgrounds: Fast Neutrons

- BRNs cause nuclear recoils in time with the beam
  - Mimic CEvNS signal!
- SciBath neutron measurement in LAr location Fall 2015
- Prompt fast neutron flux ((5-30) MeV): $(2.1 \pm 0.4) \times 10^{-5}$ n/m^2/μs/MW
  - Limit $>$ 30 MeV flux
- Delayed fast neutron flux consistent with 0
  - Evidence for thermal neutron captures



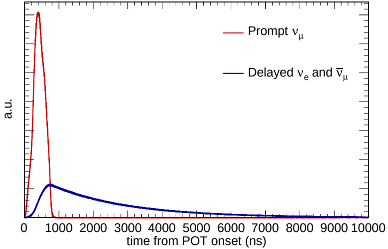


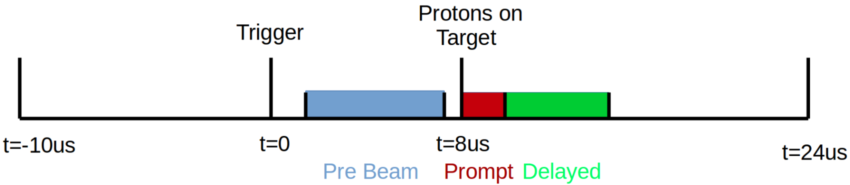


IU SciBath Detector

CEvNS Analysis Outline

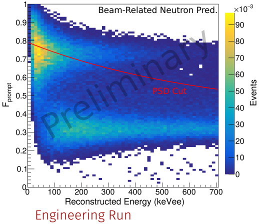
- Characterize expected backgrounds
  - Steady-state bkg from beam-off triggers
  - Beam-related neutrons from SciBath measurement, CENNS-10 no shielding run
- Finalize energy/psd/time cuts
- Verify bkg subtraction with 'pre-beam' data
- 'Box Opening:'
  1. Counting exp't: prompt and delayed
  2. Full likelihood analysis

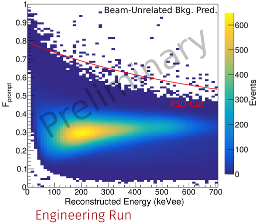


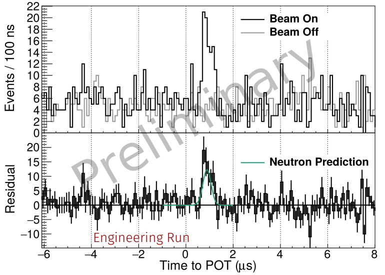


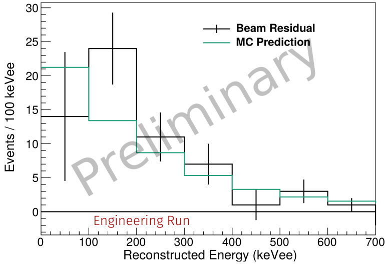
No-Shielding Neutron Run

- Minimal shielding run to further characterize ‘Neutrino Alley’ neutron flux
- 2 weeks of data
- Excess of (61 ± 12) events with PSD cut
- Delayed flux consistent with zero
  - (-18 ± 23) events







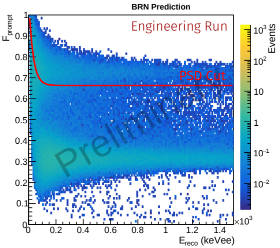


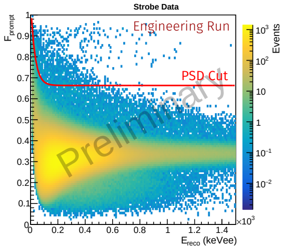
Full Shielding Analysis

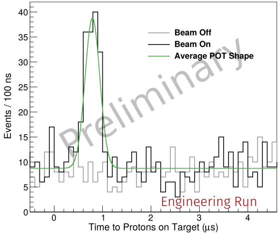
- Addition of 20.3 cm H_2O and 1.27 cm Cu
- 2 analysis methods:
  1. Counting exp't: cut in PSD/energy/time and count events
     - Prompt excess consistent with neutron prediction
     - χ^2/N_{bins} : 13.7/18

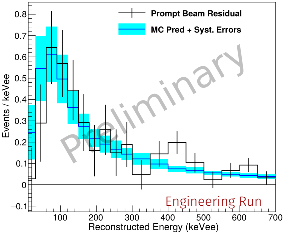
	Steady-State Backgrounds	Beam-Related Neutrons	CEvNS
Neutron Count. Exp't	88	123	0.2
CEvNS Count. Exp't	10.3	< 1	0.5
Likelihood	5200	143	3.9

Engineering Run Event Rate Predictions







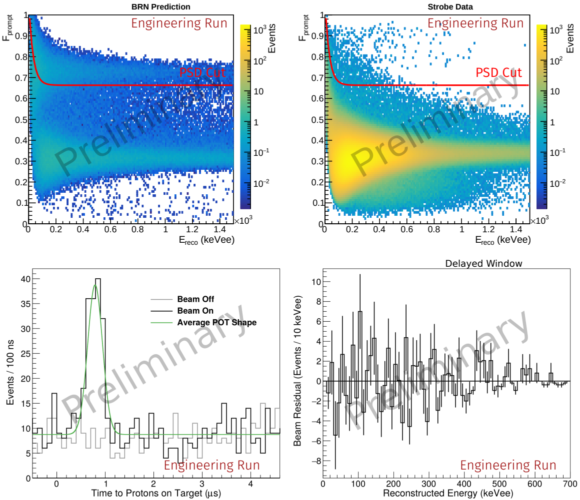


Full Shielding Analysis

- Addition of 20.3 cm H_2O and 1.27 cm Cu
- 2 analysis methods:
  1. Counting exp't: cut in PSD/energy/time and count events
     - No indication of neutrons/CEvNS in delayed window
     - Cross section limit: $\sigma^{Ar}_{CEvNS} < 150 \times 10^{-40}$ cm^2 ~8.6 x SM prediction

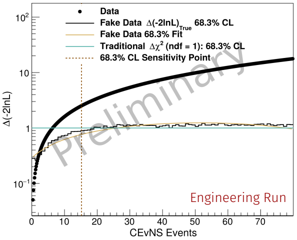
	Steady-State Backgrounds	Beam-Related Neutrons	CEvNS
Neutron Count. Exp't	88	123	0.2
CEvNS Count. Exp't	10.3	<1	0.5
Likelihood	5200	143	3.9

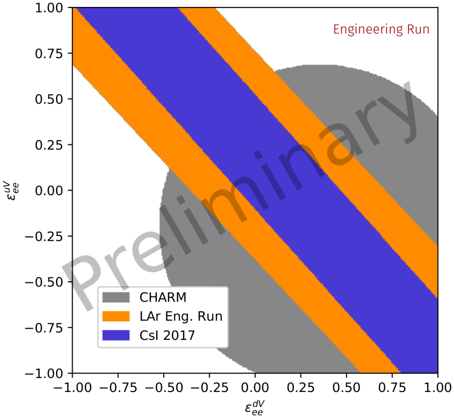
Engineering Run Event Rate Predictions



Full Shielding Analysis

- 2 analysis methods:
  1. Counting exp't
  2. Full likelihood analysis
     - Full 3D likelihood fit in energy/time/PSD with wider cuts
     - No CEvNS excess: $\sigma^{\mathrm{Ar}}_{CEvNS} < 24 \times 10^{-40}\ \mathrm{cm}^2 (68.3\,\%\ CL)$ following Feldman-Cousins
     - Non-standard interactions constraints[1]





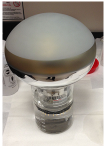
[1] To appear in M. R. Heath, IU Thesis

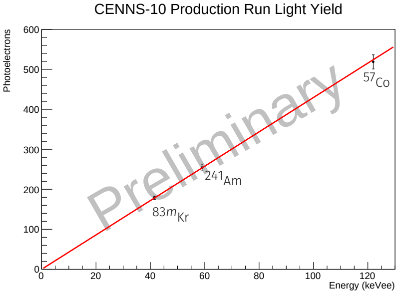
CENNS-10 Production Run

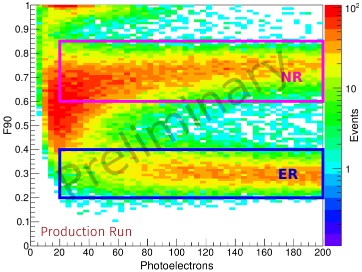
- Light collection upgrade Summer 2017
  - TPB-coated teflon, PMTs
  - 4.3 PEs/keVee (~20 keVnr thresh.)!
- Add'l shielding installed
- Low-energy ^{83m}Kr results promising!
- Results soon!
  - 6.1 GWh (1.5×10^{23} pot)

	Steady-State Background	Beam-Related Neutrons	CEvNS
Prompt	264	298	53
Delayed	924	< 1	67

Production Run Event Predictions

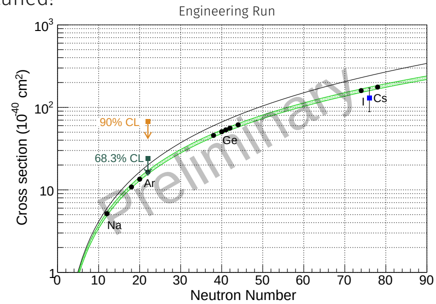


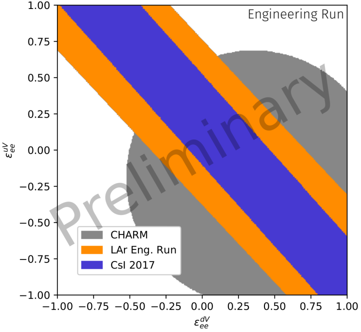




Summary

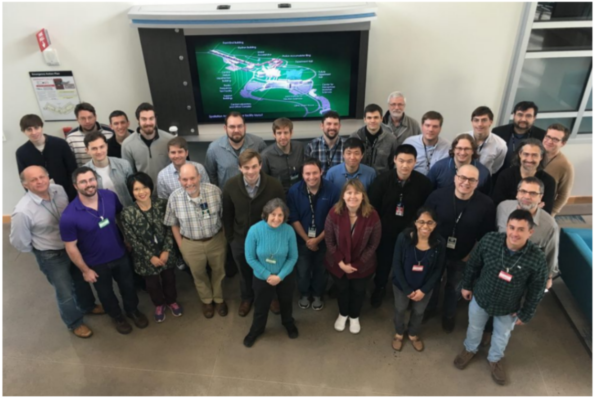
- Results from LAr detector Engineering Run![2]
  - Confirm all beam-related neutrons prompt and can be predicted
  - CEvNS limit from likelihood analysis
    - Confirm CsI NSI results even with high threshold, high bkg rate, and short run time
- CENNS-10 taking data
  - Production Run results soon!
    - Lower threshold, lower bkg rates, longer exposure time!
  - Stay tuned!





[2] To appear in M. R. Heath, IU Thesis

COHERENT SNS



THE UNIVERSITY OF CHICAGO
Carnegie Mellon University
Duke UNIVERSITY
UF UNIVERSITY of FLORIDA
KAIST
Los Alamos NATIONAL LABORATORY EST. 1943
NC STATE UNIVERSITY
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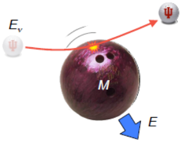
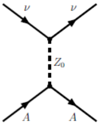
NORTH CAROLINA CENTRAL UNIVERSITY FOUNDED 1910
Laurentian University Université Laurentienne
NM STATE UNIVERSITY
Sandia National Laboratories
THE UNIVERSITY of TENNESSEE UT KNOXVILLE
TUNL
W UNIVERSITY of WASHINGTON
OAK RIDGE National Laboratory
CNEC Consortium for Nonproliferation Enabling Capabilities
KICP
NNSA National Nuclear Security Administration
NSF
U.S. DEPARTMENT OF ENERGY

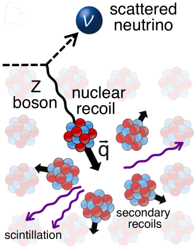
Backups

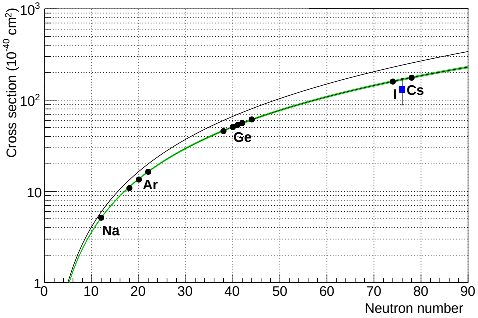
Coherent Elastic Neutrino Nucleus Scattering

- Neutrino collides with large nucleus which recoils coherently
  - $E_\nu \lesssim \frac{hc}{R_N} \approx 50\,\text{MeV}$
- Small recoil energy
  - $E_r^{max} \lesssim \frac{2E_\nu^2}{M_N} \simeq 50\,\text{keV}$
  - Difficult to detect
- Deploy a suite of detectors to measure N^2 cross section dependence
  - **CsI**[1], Ar, NaI, Ge



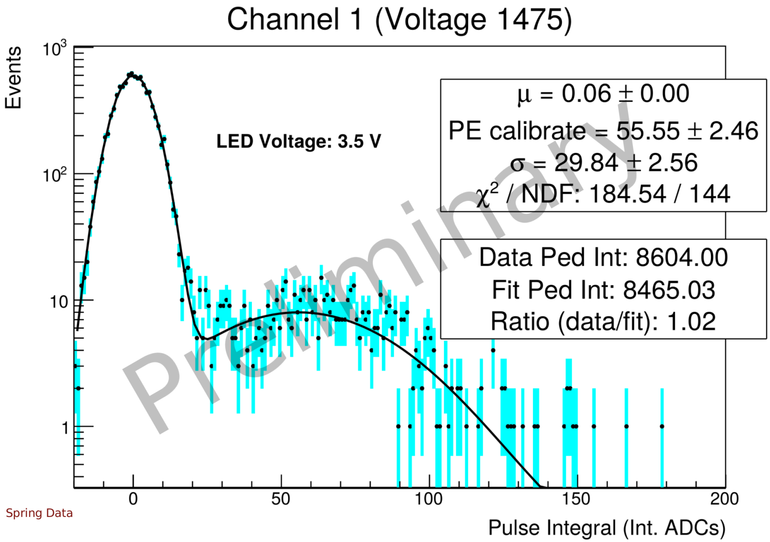






[1]DOI:10.1126/science.aao0990

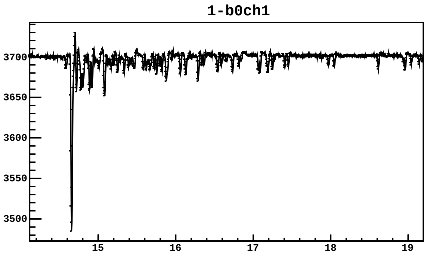
SPE Spectrum



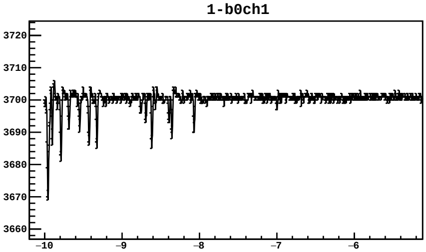
Spring Data

Event Quality Cuts

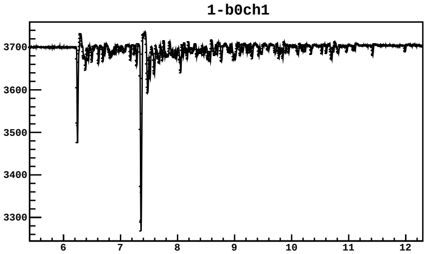
Bad Local Baseline



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



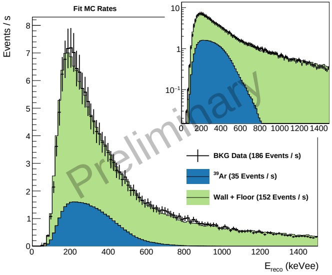
Bad Peak (typically pileup)



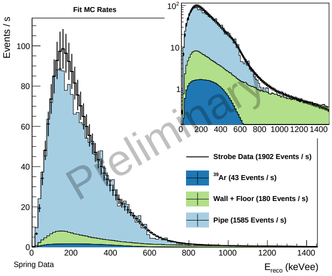
Steady State Backgrounds

- ^{39}Ar, 511 γs, wall + floor gammas dominate
- Bkg calibration runs give ^{39}Ar, wall + floor rates
- 511 γs from beam on strobe triggers
  - From beam exhaust pipe
- ~1.9 kHz steady state bkg rate

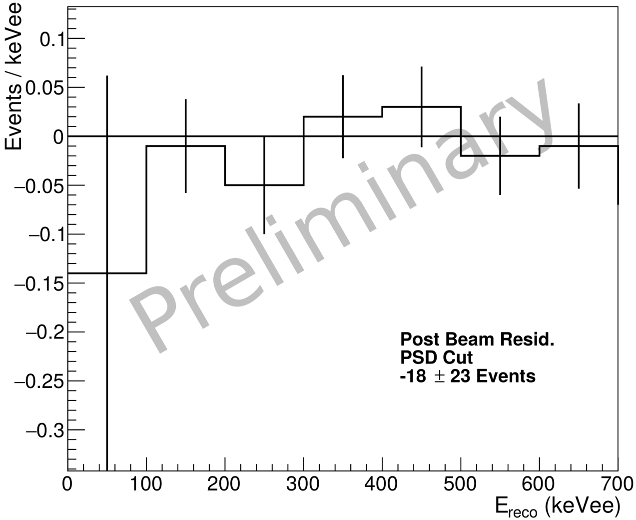
Beam Off



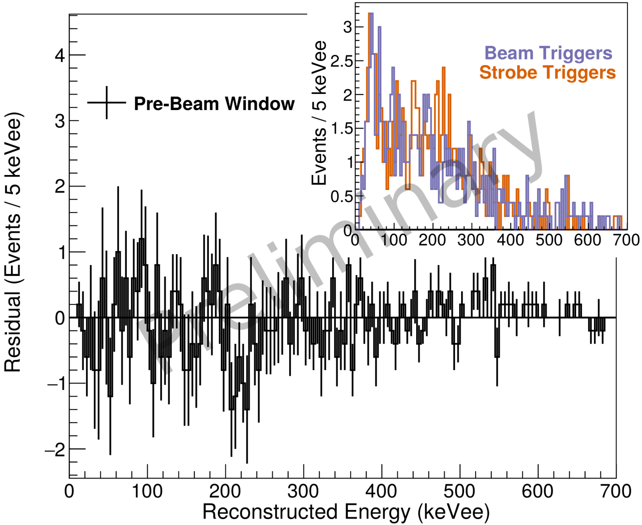
Beam On



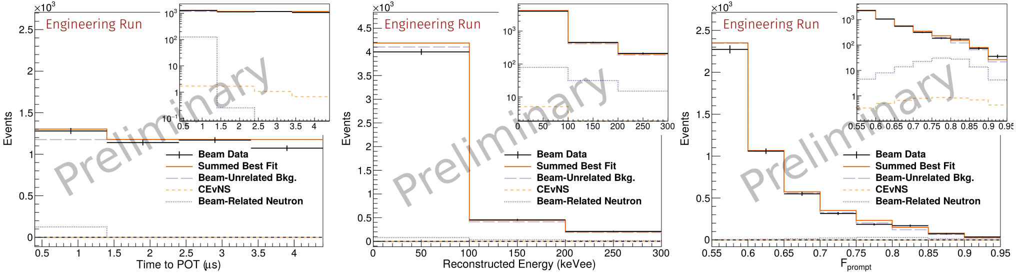
No-Shielding Delayed Residual



Full-Shielding Pre-Beam Residual

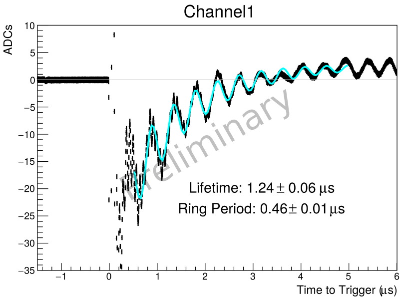


Likelihood Fit Results

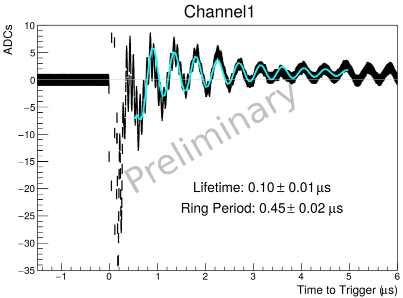


Triplet Lifetime

Pre-Doping



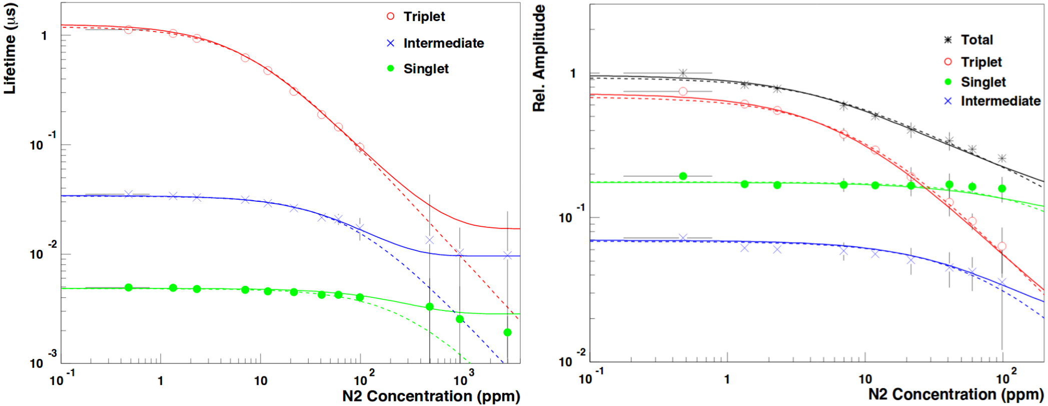
Post-Doping



- As data quality check introduce N_2 after spring run
  - ~25 ppm
- Triplet lifetime changed from ~1.2 µs to 0.2 µs
  - Roughly 1 ppm and 20 ppm respectively[2]

[2] arXiv:0804.1217 [nucl-ex]

N2 Contamination



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