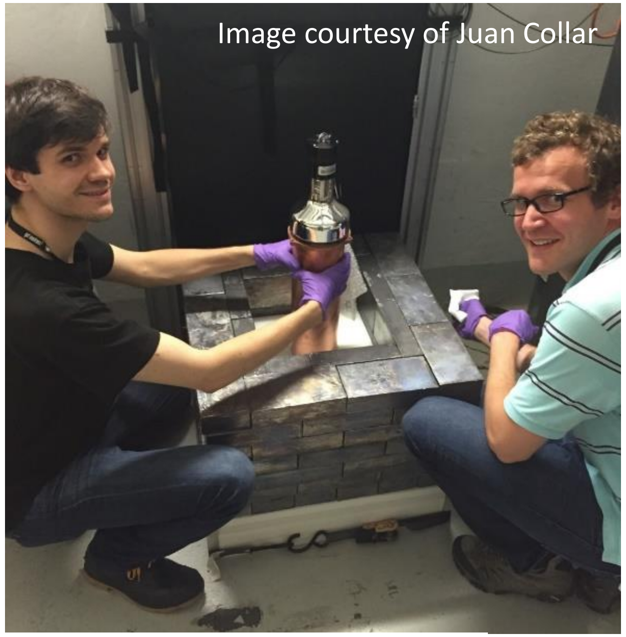
Status of CsI[Na] at COHERENT

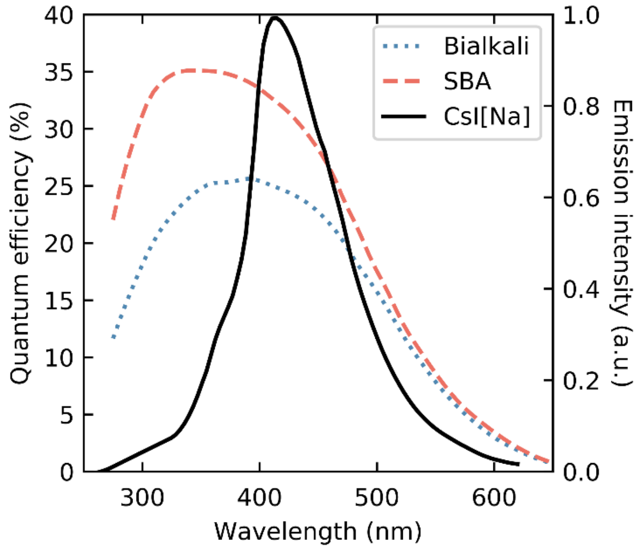
presented by Bjorn J. Scholz
On behalf of the COHERENT collaboration

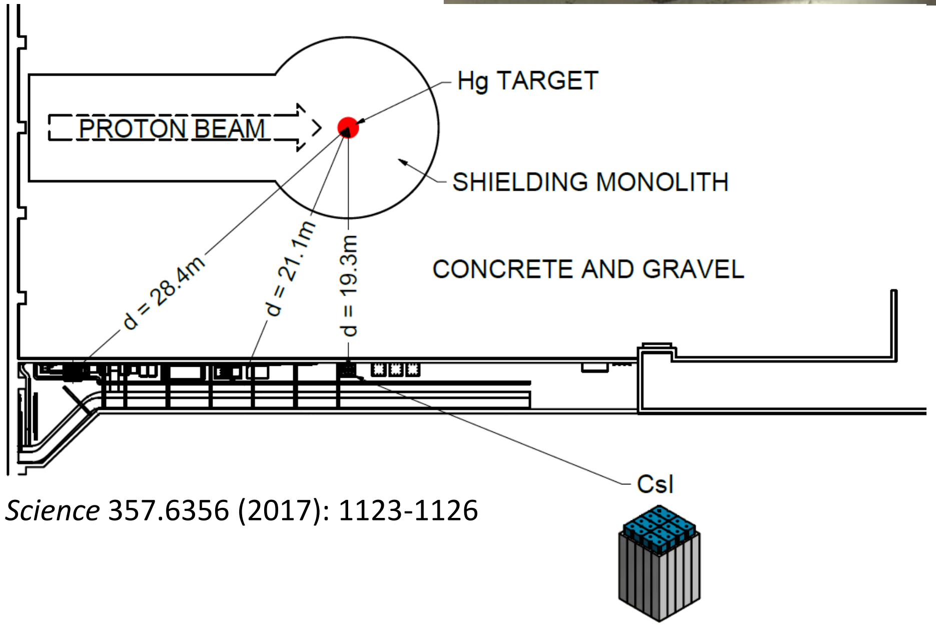
Fall Meeting of the APS Division of Nuclear Physics
October 27, 2017

The inorganic scintillator CsI[Na]

- 34 cm long and a mass of 14.57 kg positioned at 19.3 m from the SNS target
- Encapsulated in ultra-pure electroformed copper
- R877-100 super bialkali PMT from Hamamatsu
- Emission wavelength (420 nm) well matched to PMT quantum efficiency (~34%)
- Both Cs (N=78) and I (N=74) show very similar recoil spectra

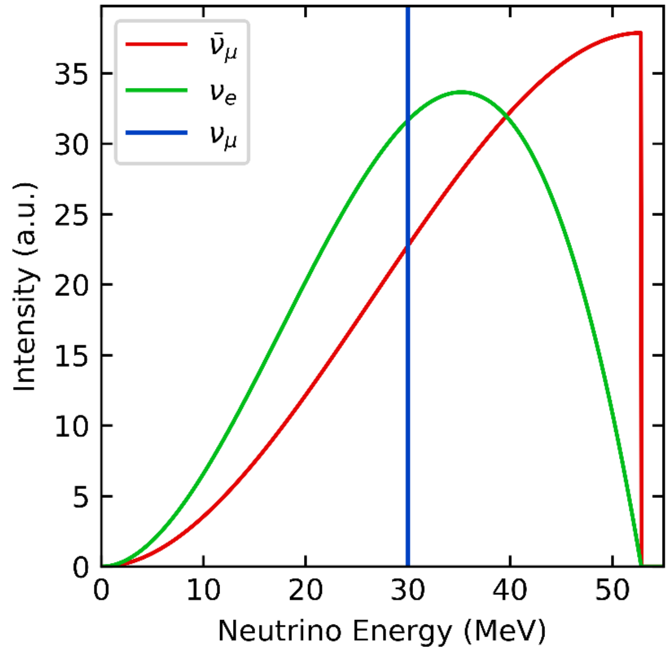




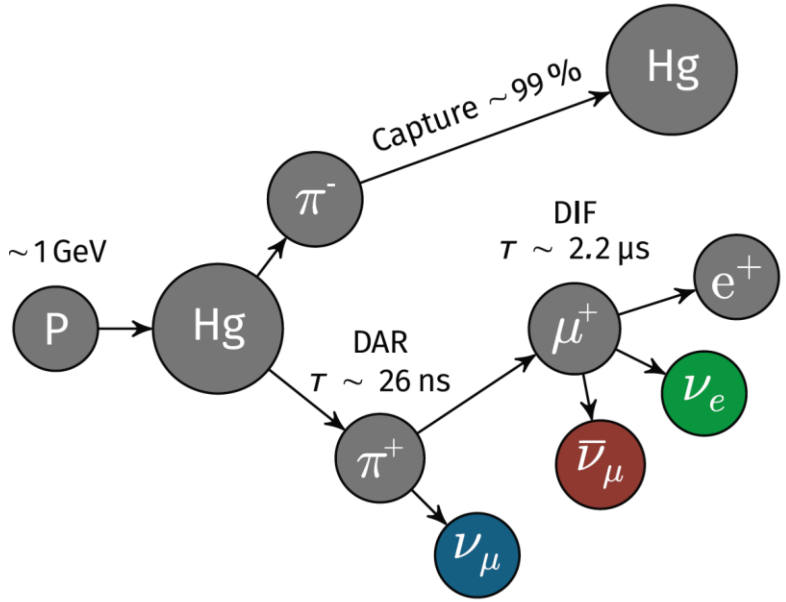


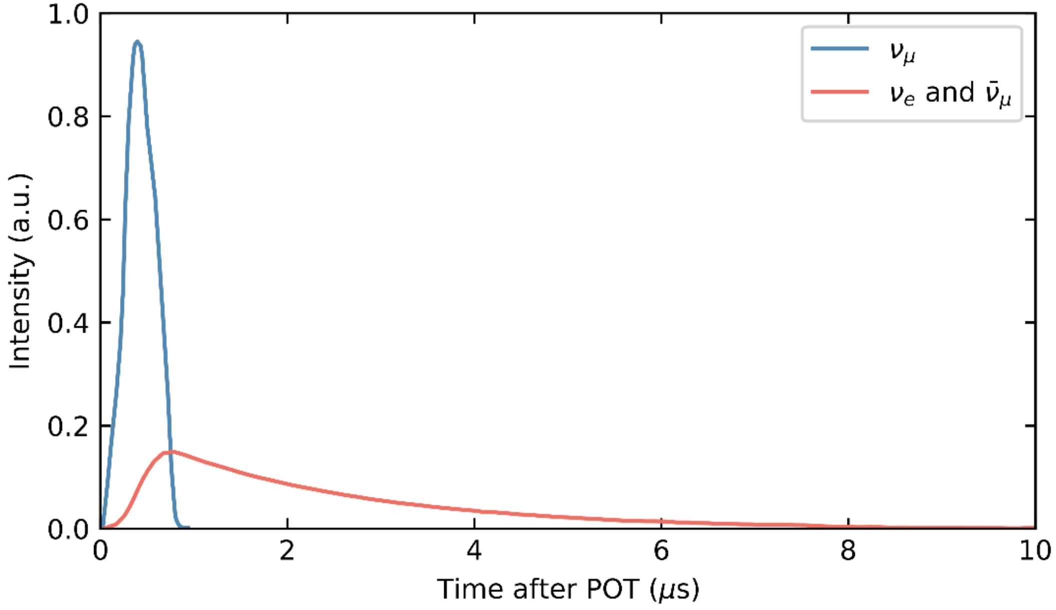
Science 357.6356 (2017): 1123-1126

The Spallation Neutron Source



- A pulsed proton beam impinges on a mercury target at a 60 Hz repetition rate
- The pulse has a total temporal width of ~800 ns
- Neutrino emission processes well understood
- Neutrino flux at 20 m: ~ 2 x 10^7 cm^{-2} s^{-1} per flavor
- Due to the pulsed nature of the beam a CEvNS signal can only occur directly following a POT trigger.

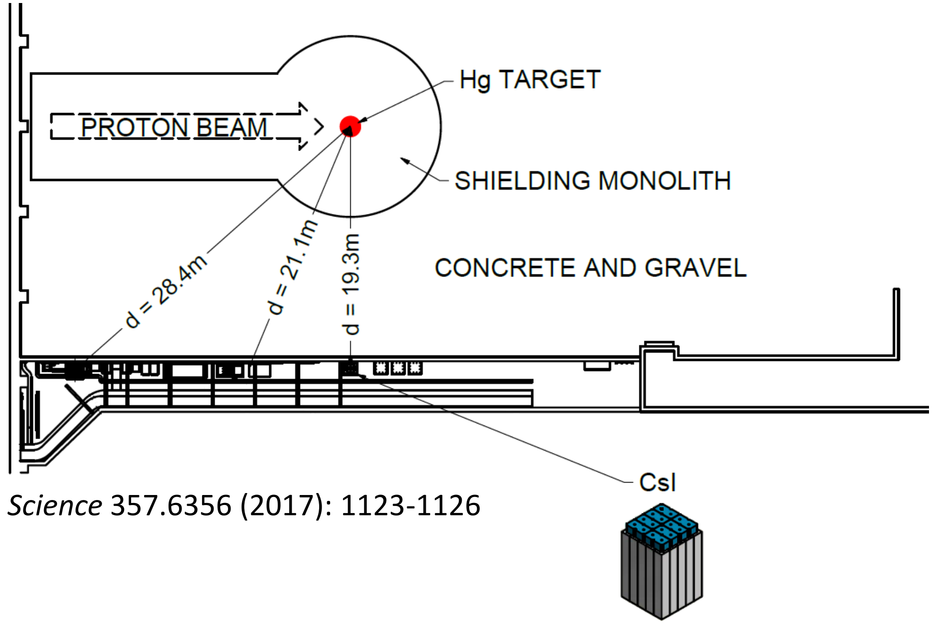




Background measurements – Prompt Neutrons

- Besides neutrinos, the SNS produces $\sim 10^{17}$ prompt neutrons per second, some of which might be able to reach the CsI[Na] CEvNS search detector introducing backgrounds
- The Scibath and Sandia Camera neutron detectors measured a prompt neutron flux in the vicinity of the CEvNS search location of $\sim 1.5 \times 10^{-7}$ neutrons/cm^2 s (1-100 MeV)
- In addition a dedicated neutron detector was deployed at the exact location later used by the CsI[Na] CEvNS search detector
- This neutron detector consisted of two 1.5 L cells filled with EJ-301
- Using the EJ-301 cells a neutron flux was measured

$$\phi_n = 1.09 \times 10^{-7} \frac{\text{neutrons}}{\text{cm}^2\,\text{s}}$$



Science 357.6356 (2017): 1123-1126

- The event rate from prompt neutron in the CsI[Na] detector was found to be $\Gamma_{\text{prompt}} = 0.92 \pm 0.23\ \frac{\text{events}}{\text{GWh}}$ which is much smaller than the expected CEvNS signal

Background measurements – NINs

- A second, potential background are neutrino induced neutrons (NIN) originating in the lead surrounding the CsI[Na] CEvNS search detector. NINs are primarily created via the charged-current interaction:

$$\nu_e \quad + \quad {}^{208}\mathrm{Pb} \quad \rightarrow \quad {}^{208}\mathrm{Bi}^* \quad + \quad e^-$$
$$\downarrow$$
$${}^{208-y}\mathrm{Bi} \quad + \quad x \times \gamma \quad + \quad y \times n$$

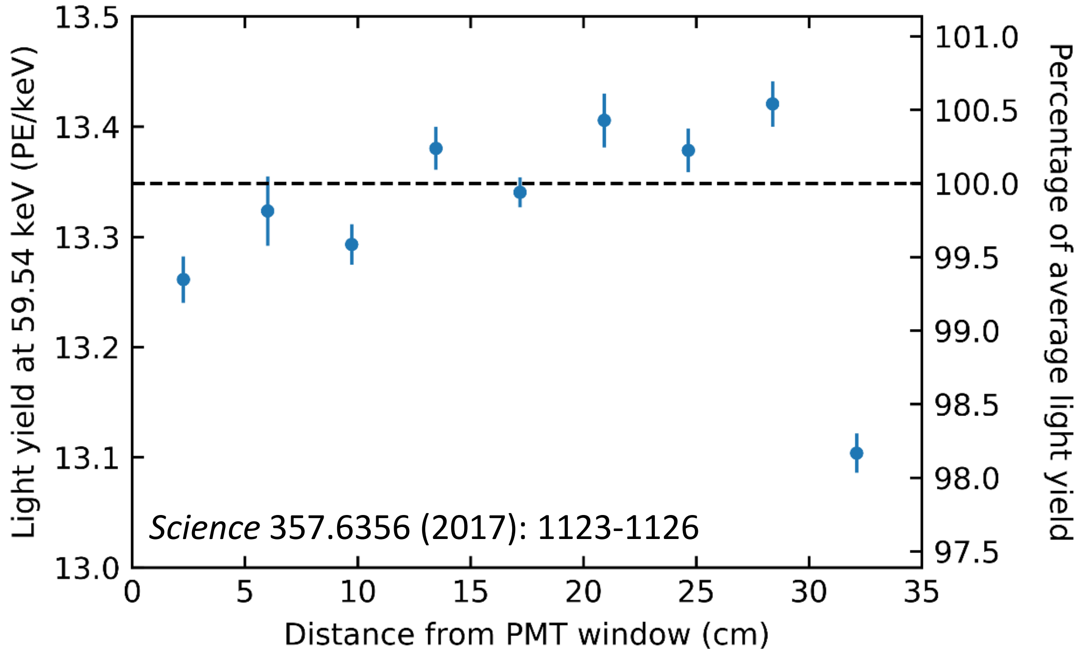
- NIN related events therefore show a characteristic 2.2 μs time profile following the delayed ν_e production at the SNS
- Using the EJ-301 data set the NIN production rate was measured and the background event rate from NINs expected in the CsI[Na] CEvNS search detector was found to be

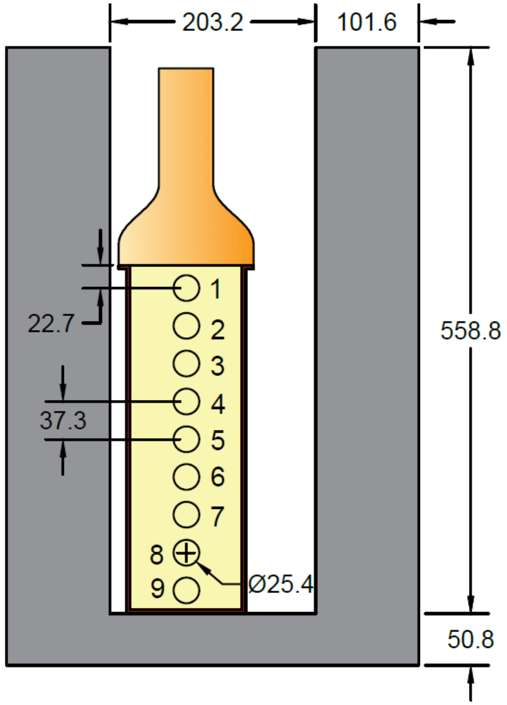
$$\Gamma_{\mathrm{NINs}} = 0.54 \pm 0.18 \frac{\mathrm{events}}{\mathrm{GWh}}$$

- Even smaller than prompt neutron background component

Light yield calibrations at UChicago

- A ^{241}Am source was placed on the outside of the copper can at 9 locations along the crystal to measure the light yield, i.e. the number of photoelectrons produced per unit energy
- Main γ emission from ^{241}Am has an energy of $E = 59.54$ keV
- This guarantees that all interactions within the crystal happen in the vicinity of the source → Allows to measure local light yield

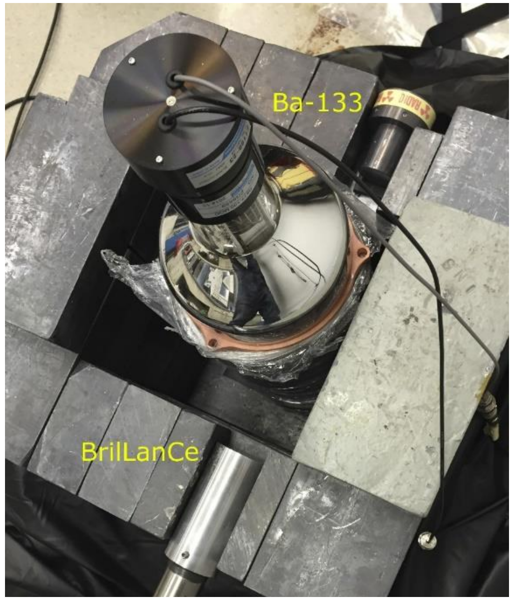




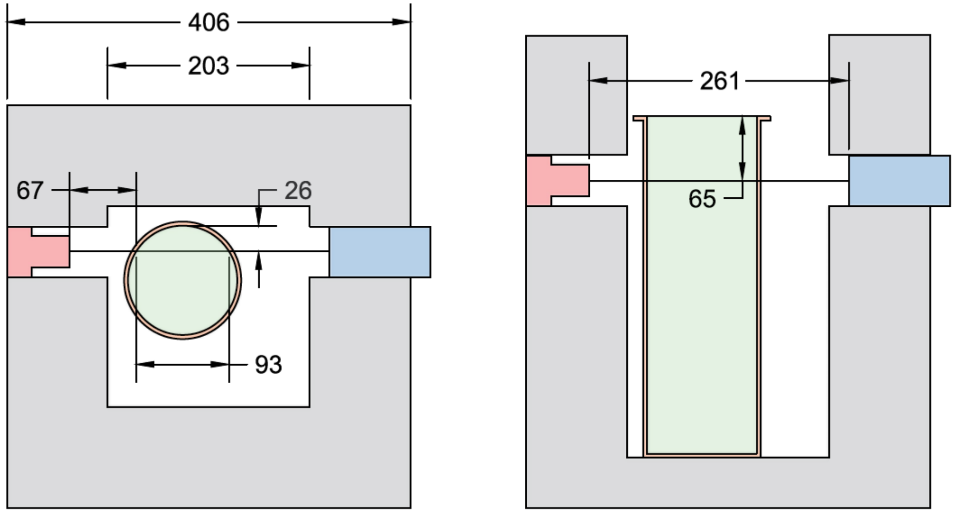
- Light yield is uniform within $\sim$0.5% for the closest 8 positions
- Largest deviation right at the back reflector (1.8%)

$$L_{\mathrm{csi}} = 13.348 \pm 0.019 \ \frac{\mathrm{photoelectrons}}{\mathrm{keV}}$$

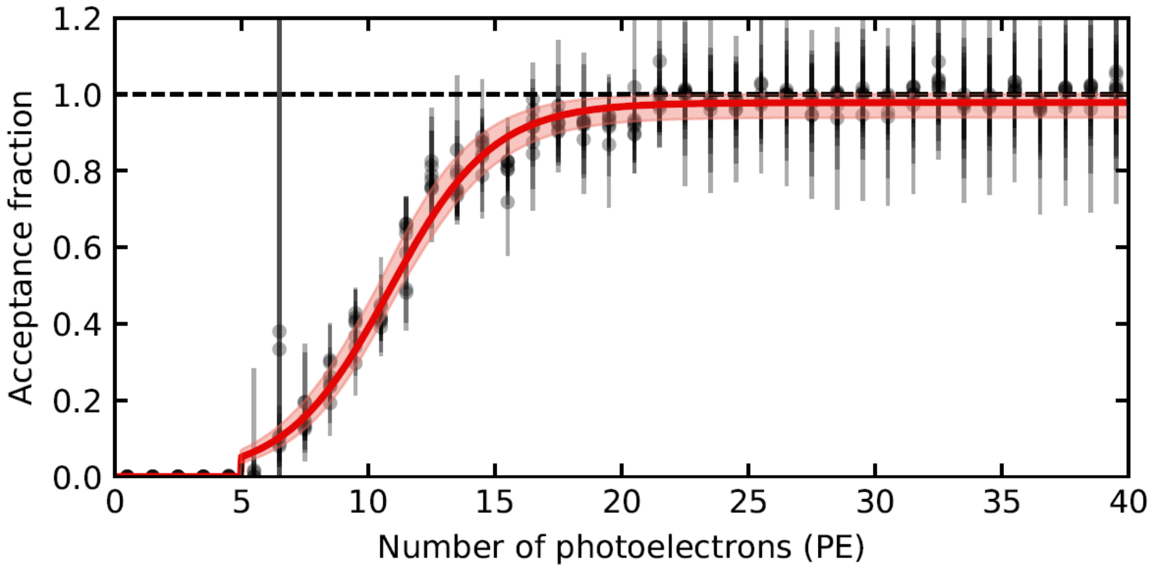
Low energy response calibrations at UChicago



- Purpose: Built a library of low energy events that we could later use to train our data analysis on
- Nuclear and electronic recoils show almost an identical scintillation decay profile in CsI[Na]
- A pencil beam of ^{133}Ba γs traverses the crystal and triggers the data acquisition on forward Compton-scattered events



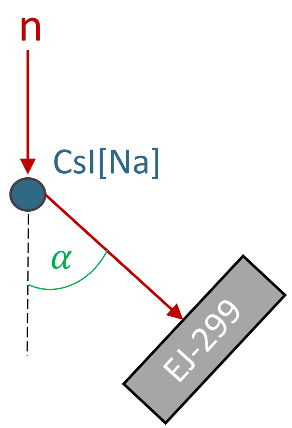
signal acceptance fraction for different energies

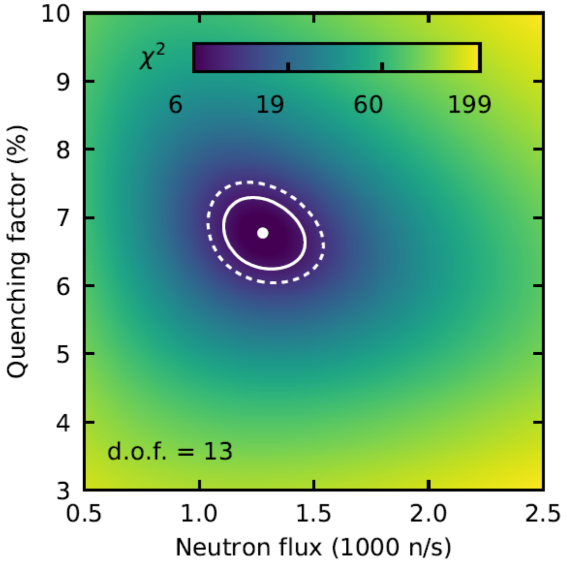


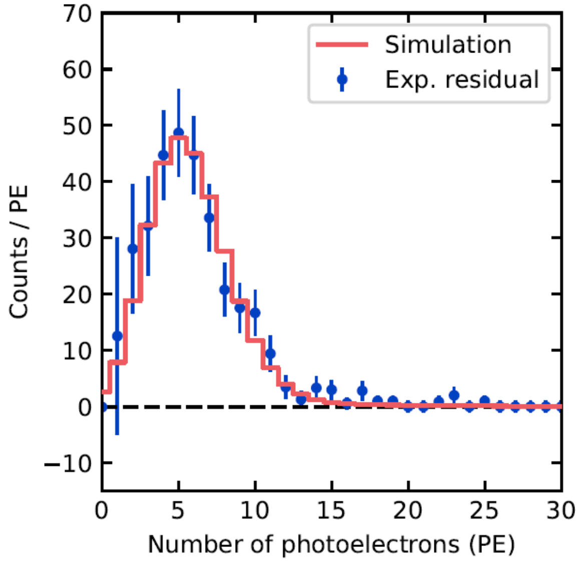
Quenching factor measurements at TUNL

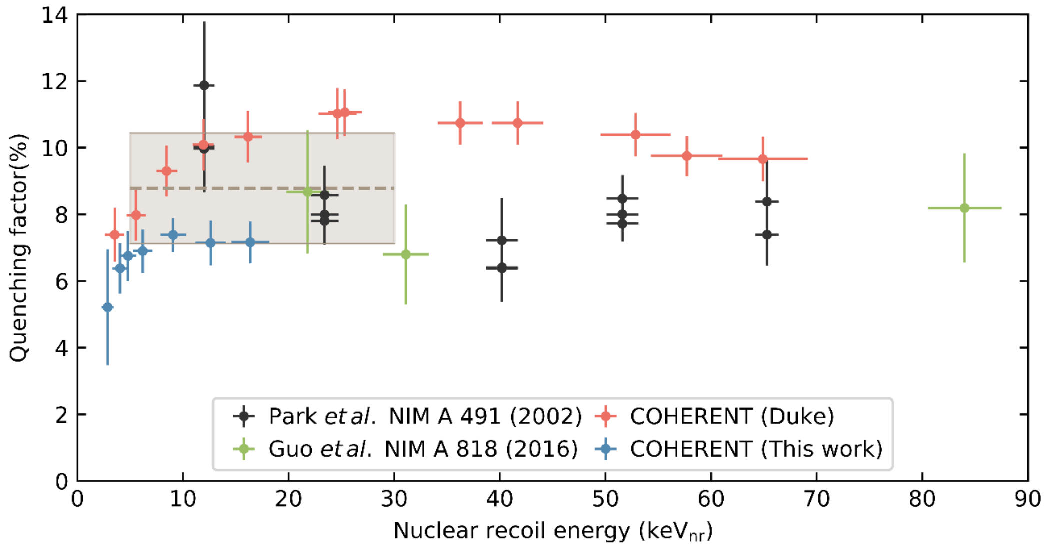
- A small CsI[Na] detector was positioned in a highly collimated neutron beam of known energy
- The angle between the incoming neutron beam and the backing detector selects a specific recoil energy
- By comparing the experimental recoil spectrum to simulations a corresponding quenching factor was calculated
- A pragmatic choice was made by adopting an energy independent Q_f within the CEvNS energy region

$$Q_f = 8.78 \pm 1.66\%$$



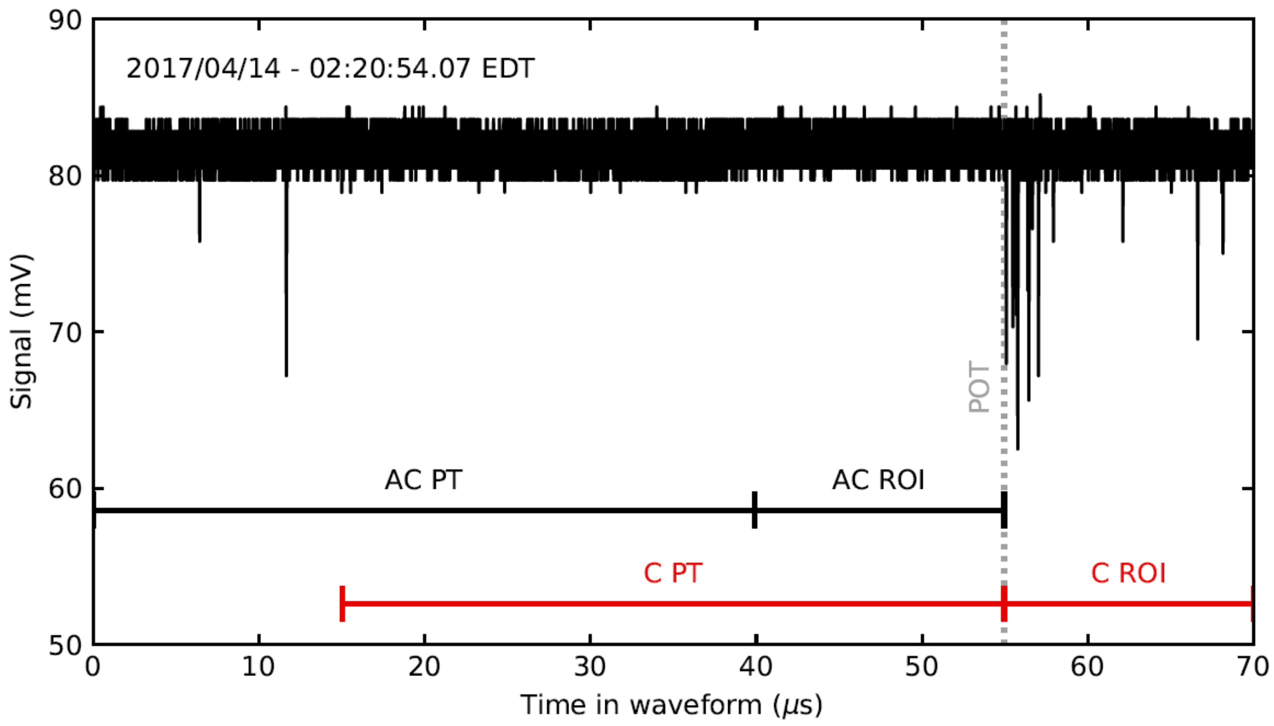






CsI[Na] at the SNS – CEvNS search

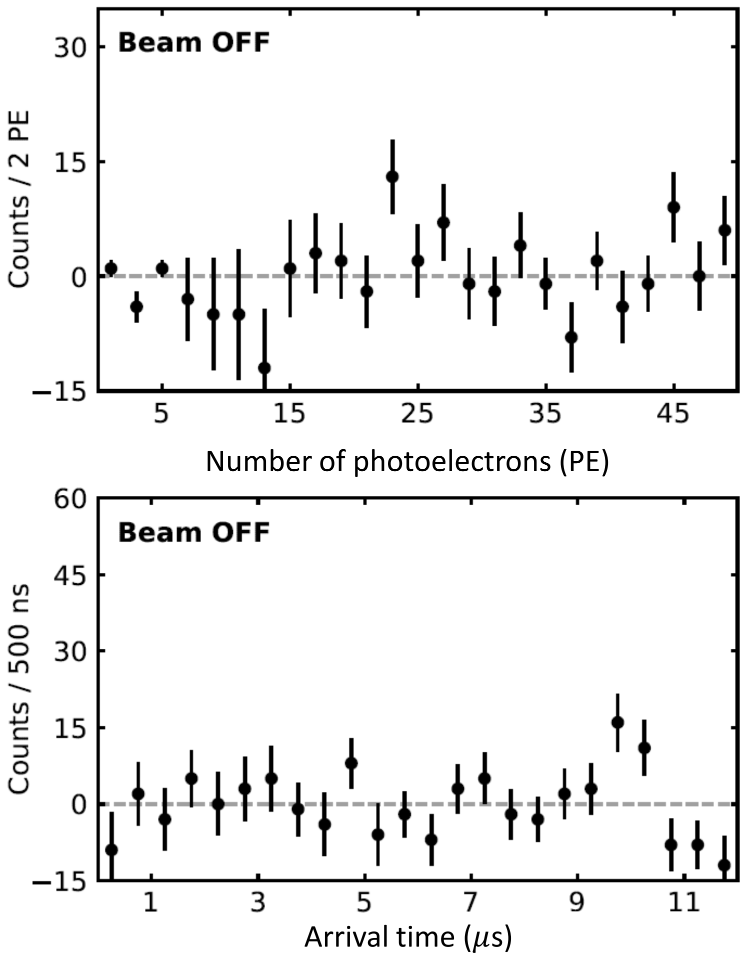
- CEvNS search data taken between June 25, 2015 and May 26, 2017
- Almost continuous acquisition at 60 Hz trigger rate
- Each waveform is divided into anti-coincidence (AC) and coincidence (C) regions
- The AC region probes the steady-state background only, whereas the C region contains both beam related events and contributions from steady-state backgrounds
- A residual between C-AC therefore only contains beam-related signals as the steady-state background has been subtracted.



- Data has further been categorized as ‘Beam OFF’ and ‘Beam ON’ – Neutrinos are only produced in the latter.

First observation of CEvNS

- As expected, the residual of the beam OFF data fluctuates around zero



First observation of CEvNS

- As expected, the residual of the beam OFF data fluctuates around zero
- Stacked histogram represents the Standard Model prediction of CEvNS + background from prompt neutrons

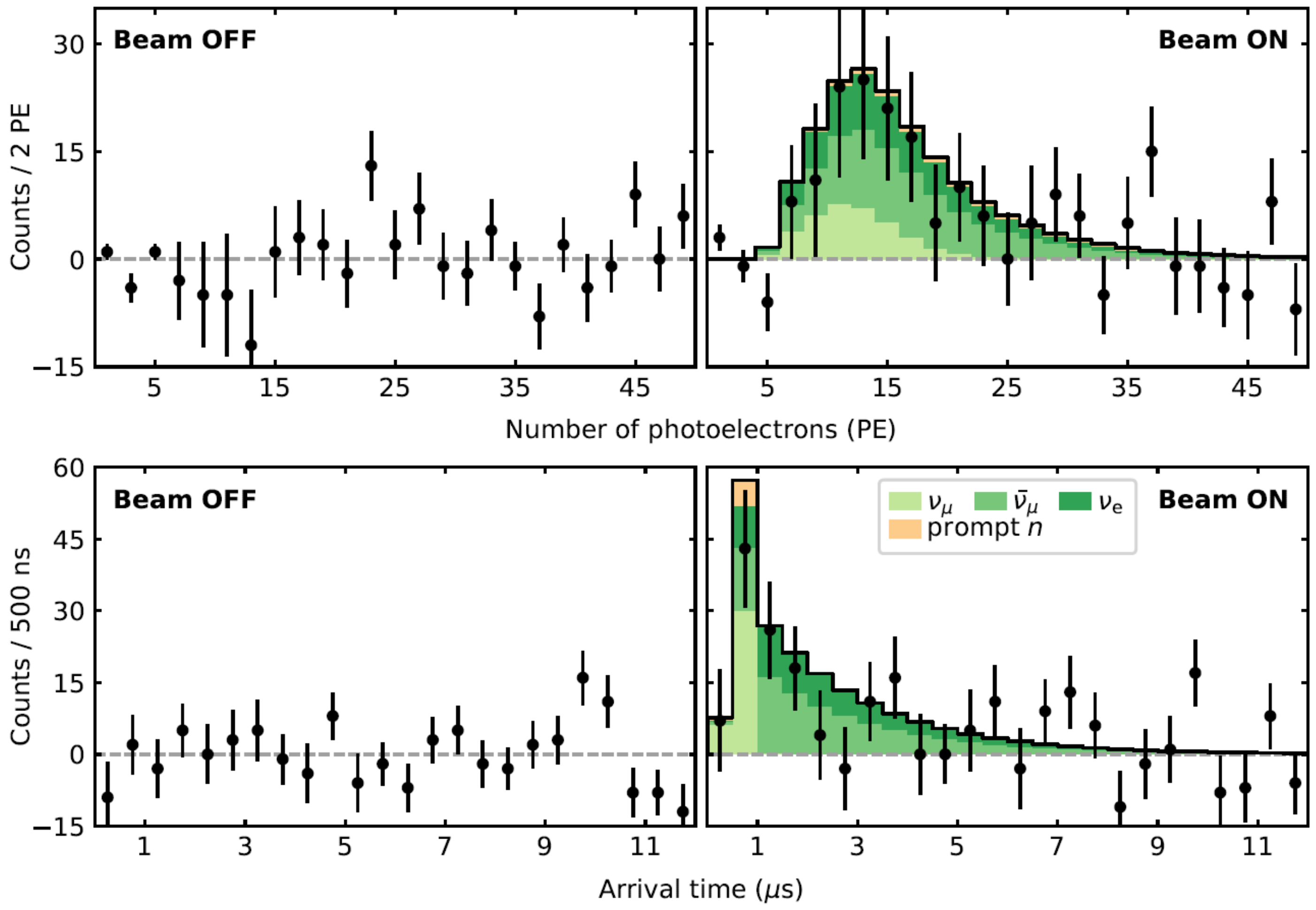
$$N_{SM} = 173 \pm 48$$

- Fitting the data to the CEvNS signal

$$N_{fit} = 134 \pm 22$$

- All neutrino flavors contribute to the CEvNS signal
- Presence of CEvNS is favored at the 6.7σ-level over its absence
- CsI[Na] continues to acquire data

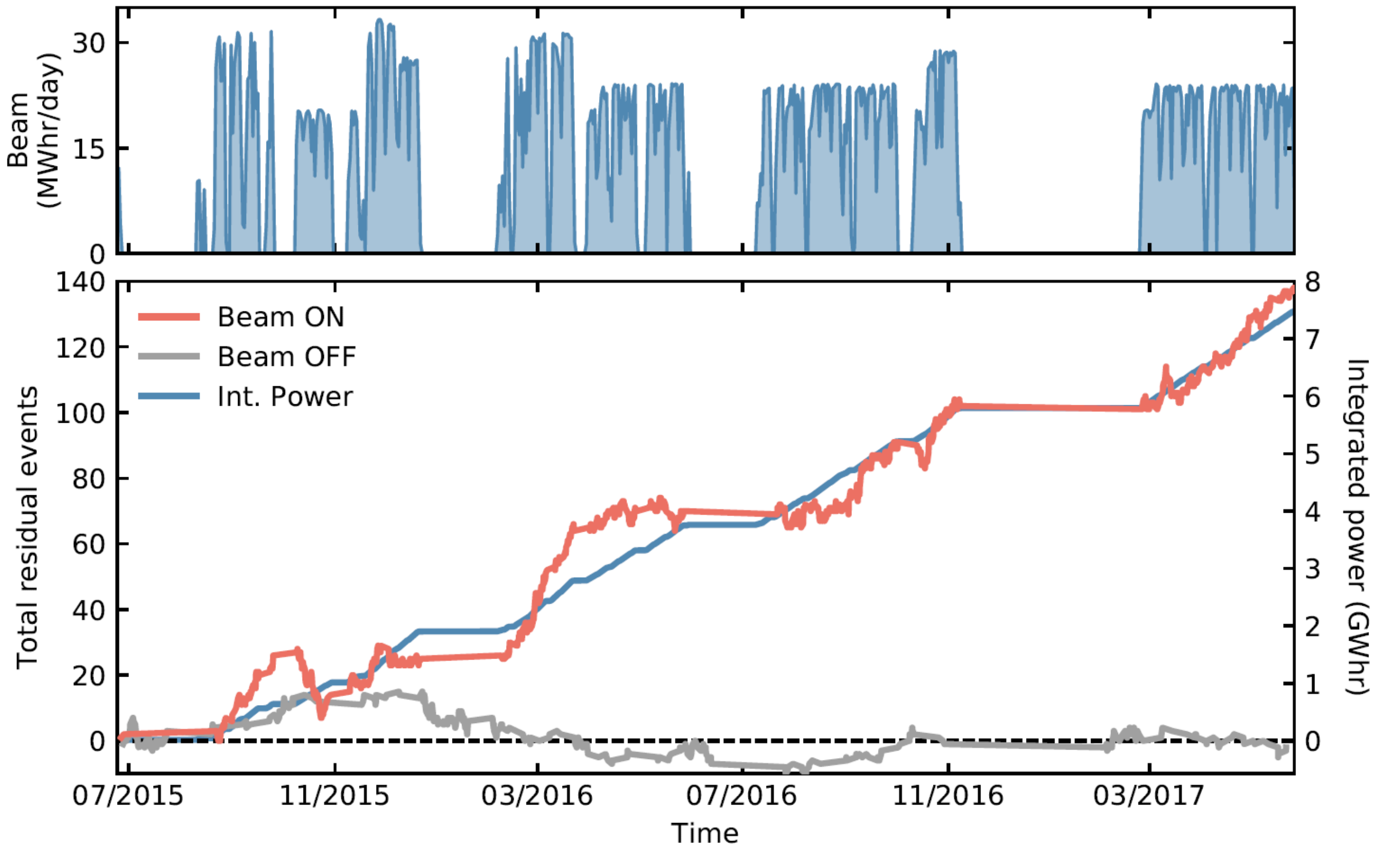
Science 357.6356 (2017): 1123-1126



Backup

Time evolution of the beam-related excess

- A clear correlation between the the excess in the beam ON residual and the integrated beam power is apparent
- The event rate is directly correlated to the total beam energy provided on the SNS target
- The beam OFF residual simply fluctuates around zero over time
- The beam OFF residual changes during days for which beam power on target was delivered, due to short term maintenance of the SNS.
- CsI[Na] continues to acquired data



CEvNS search at the SNS