CEνNS observation by COHERENT

Presented by Kangkang Zhao

2020.06.15

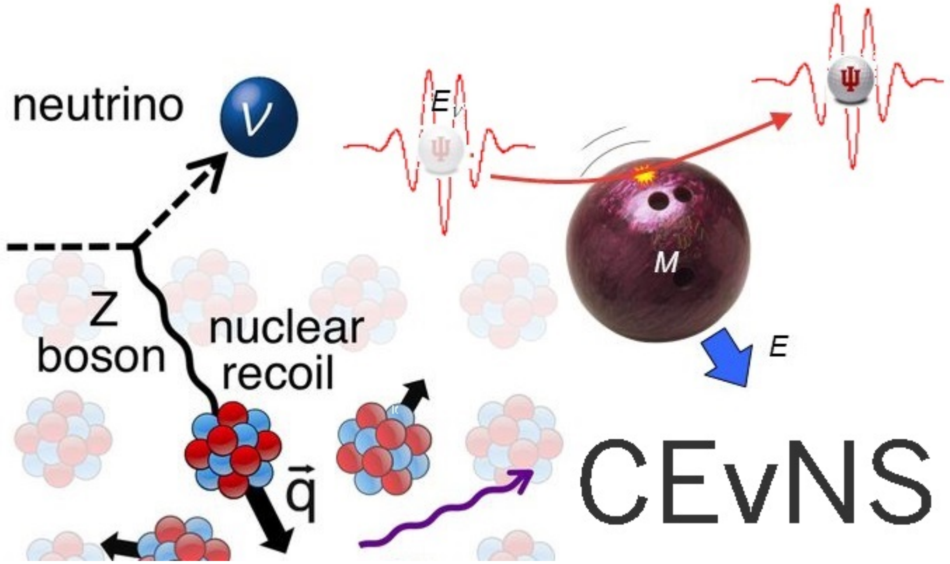
Outline

- Introduction of CEνNS process
- Experimental setup & Detector studies
- Data analysis
- Summary

- Introduction of CEνNS process
- Experimental setup & Detector studies
- Data analysis
- Summary

CEvNS : Coherent Elastic ν-Nucleus Scattering

- Firstly theoretical described in 1974
- Weak neutral current process
- Only the nuclear recoil detectable
- Large cross section (>10^2 IBD)
- Cross section VS recoil energy



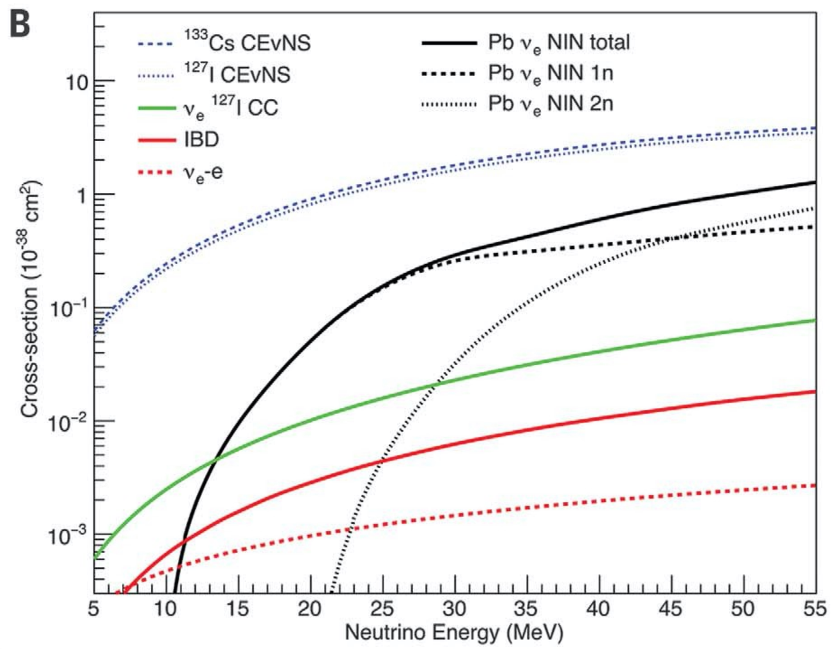
$$\frac{\mathrm{d}\sigma}{\mathrm{d}q^2} = \frac{G^2}{2\pi} a_0^2 A^2 e^{-2bq^2} \left(1 - q^2 \frac{2ME + M^2}{4M^2E^2}\right) \qquad E_{\mathrm{Recoil}} = \frac{q^2}{2M} \propto \frac{1}{A}$$

- Firstly observed by COHERENT in 2017

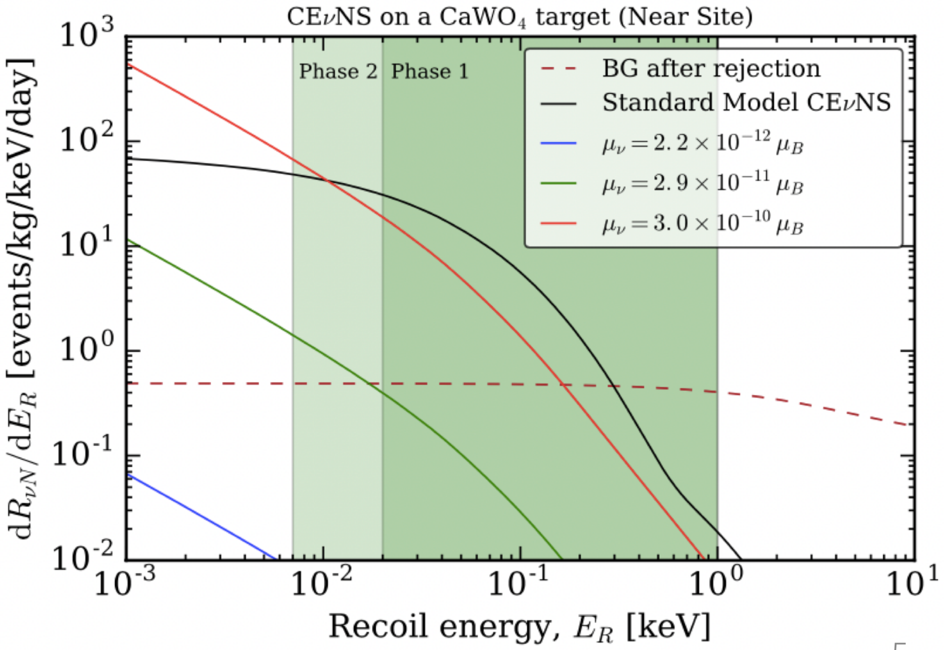
Interests in CEνNS

- Large cross section
  - Detector mass reduction (kg-scale)
  - Technological applications: nonintrusive reactor monitor
- Nuclear structure & beyond SM
- Neutrino properties:
  - sterile neutrinos
  - neutrino magnetic moment

$$\frac{d\sigma^{\text{mag.}}_{\nu-N}}{dE_R} = \frac{\pi\alpha^2\mu_\nu^2 Z^2}{m_e^2}\left(\frac{1}{E_R} - \frac{1}{E_\nu} + \frac{E_R}{4E_\nu^2}\right) F^2(E_R)$$



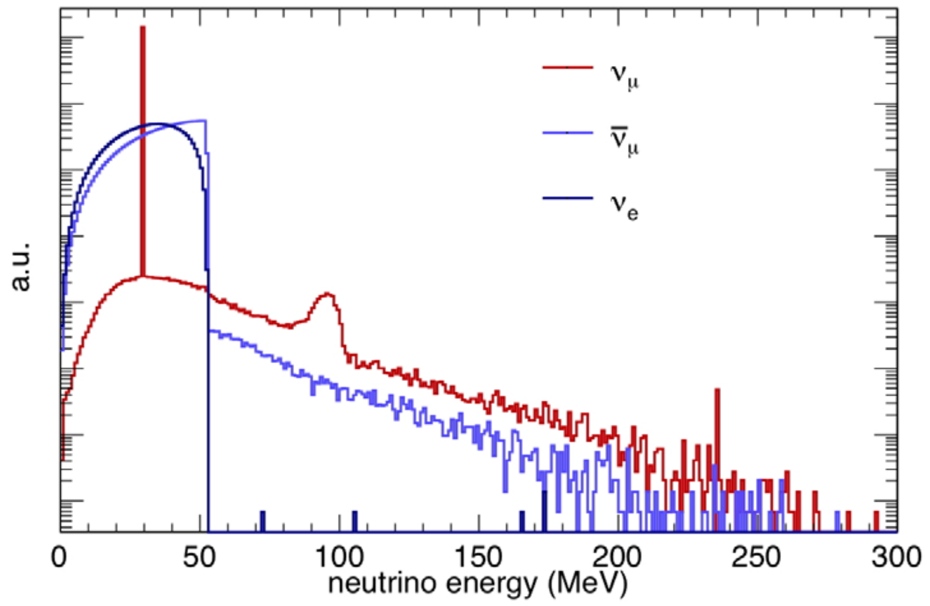
doi:10.1126/science.aao0990

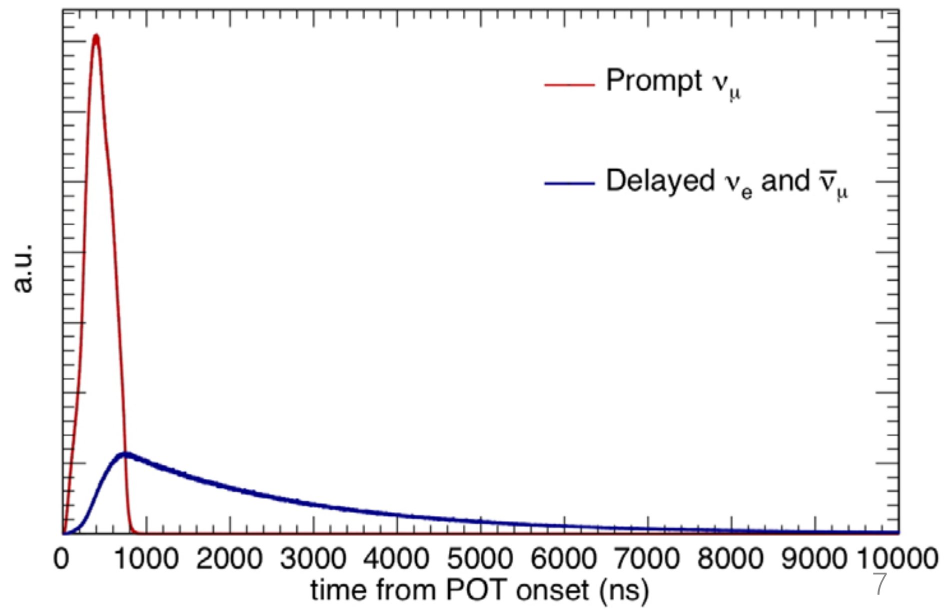


- Introduction of CEνNS process
- Experimental setup & Detector studies
- Data analysis
- Summary

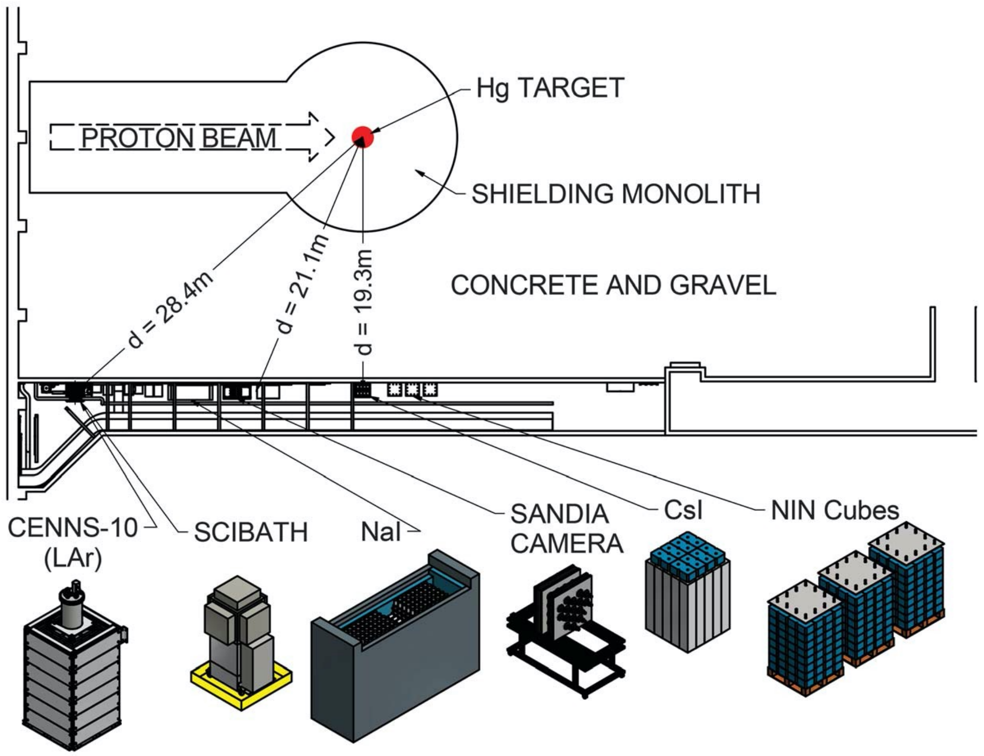
Neutrinos source & setup

- Spallation Neutron Source (SNS) @Oak Ridge National Laboratory
- Prompt ν_μ, delayed ν_e, $\bar{\nu}_\mu$
- Facility-wide 60-Hz trigger signal
- Protons-on-target (POT) as trigger
- 60 Hz of ~1 μs–wide POT spills: subtract steady-state backgrounds





Installation location



Neutron- induced nuclear recoils

- basement corridor

  >12 m moderating neutrons

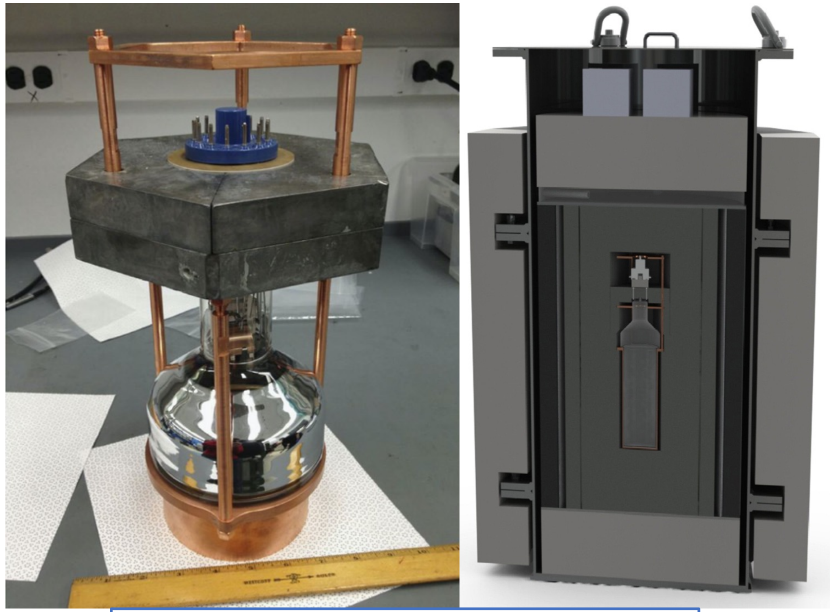
- 8 m.w.e. overburden reducing cosmic rays
- installed nearest to the SNS target

Detector & Shielding design

detector

- 14.6-kg sodium-doped CsI
- Scintillating response
- Hamamatsu R877-100 PMT

- Similar high mass:
  - similar response of the detector
- Large light yield:
  - ~ 9.9 PE/keVee yield in the 2 kg prototype
- low radioactivity:
  - ^{238}U, ^{235}U and ^{232}Th < 1 ppb
  - 177±16 mBq/kg of ^{40}K



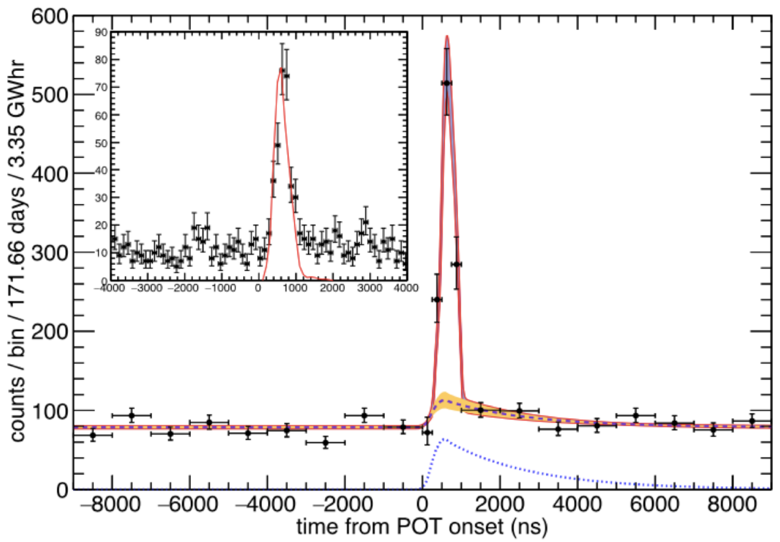
doi:10.1016/j.nima.2014.11.037

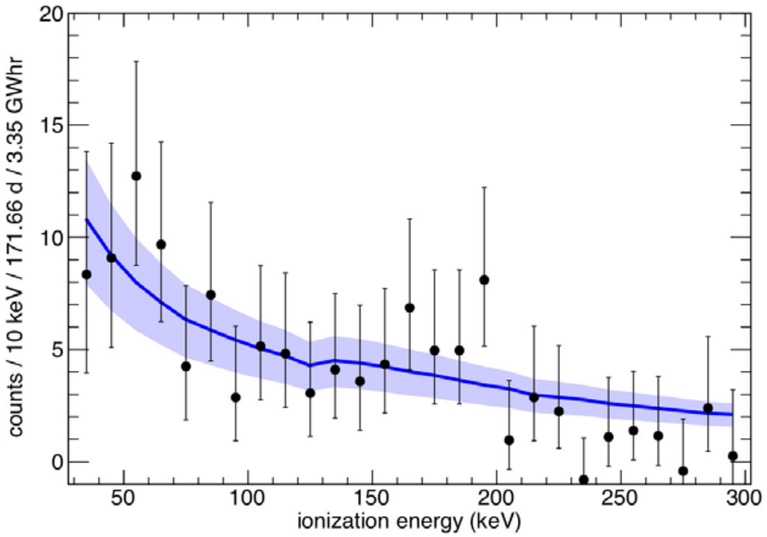
Shielding design

- 7.5 cm of high-density polyethylene (HDPE)
- Multi-layer lead for γ shielding
- 5 cm plastic scintillator muon veto
- 15 cm HDPE (bottom)+ >9 cm water tanks (top, sides) neutron moderator

Beam-Related Background

- prompt SNS neutron & neutrino-induced-neutron (NIN)
- Standard PSD techniques: neutron-like events
- unbinned fit to arrive time(NIN), fit energy spectrum (flux)



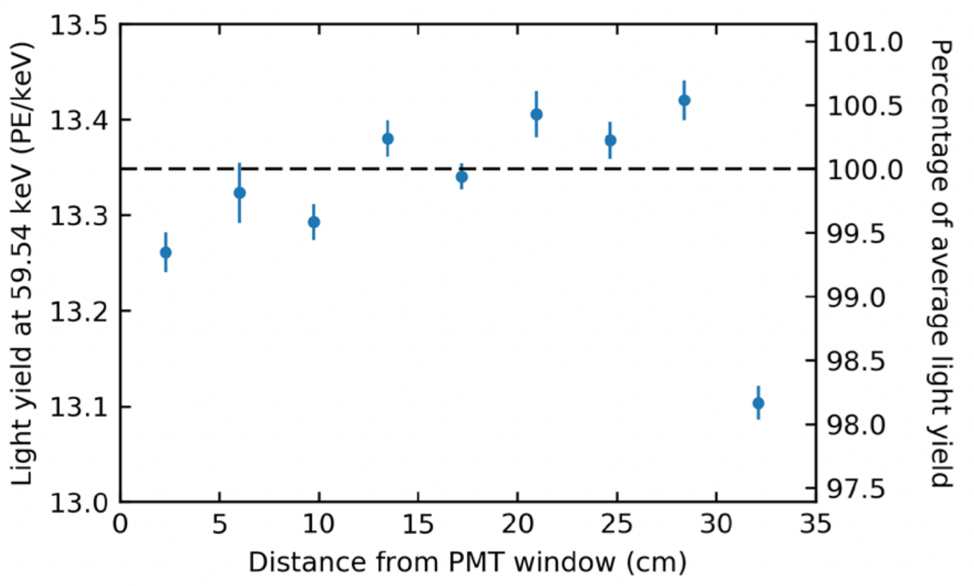


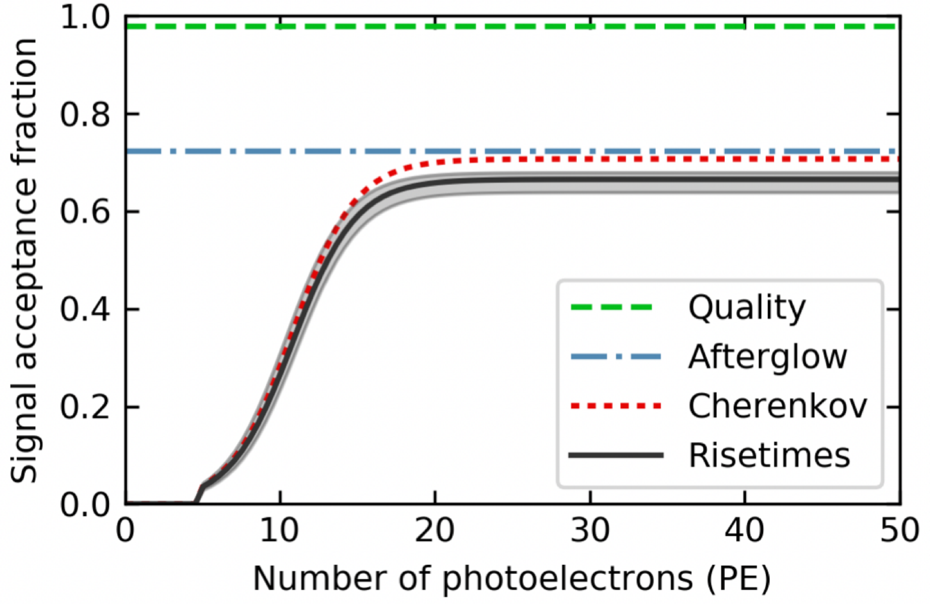
- prompt neutron: 0.92 ± 0.23 events / GWhr
- NIN : 0.54 ± 0.18 events / GWhr

doi:10.1126/science.aao0990

Detector calibrations

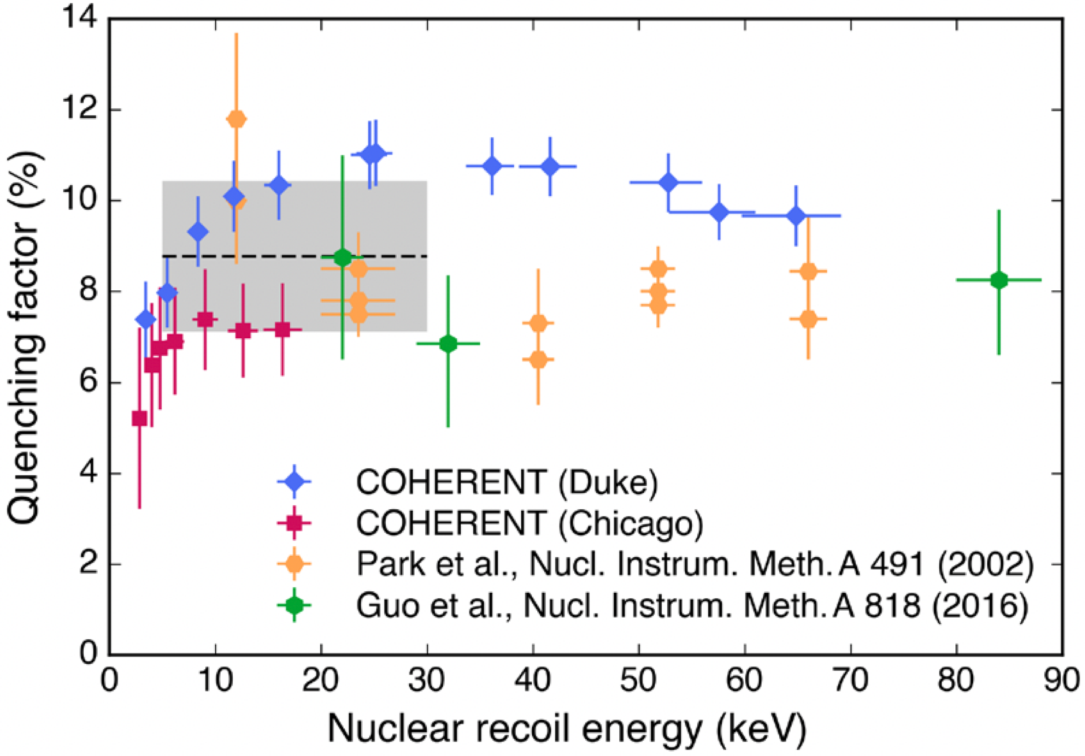
- light yield uniformity
  - ^{241}Am 59.54 keV gamma emission
  - Nine equally-spaced locations
  - PMT average light yield
    13.35 (0.5%) PE / keV
- low-energy signal characteristics
  - ^{133}Ba train data cuts for CEvNS signal acceptance
  - Cherenkov light emission in PMT window
  - dark-current photoelectrons





Quenching factor (QF)

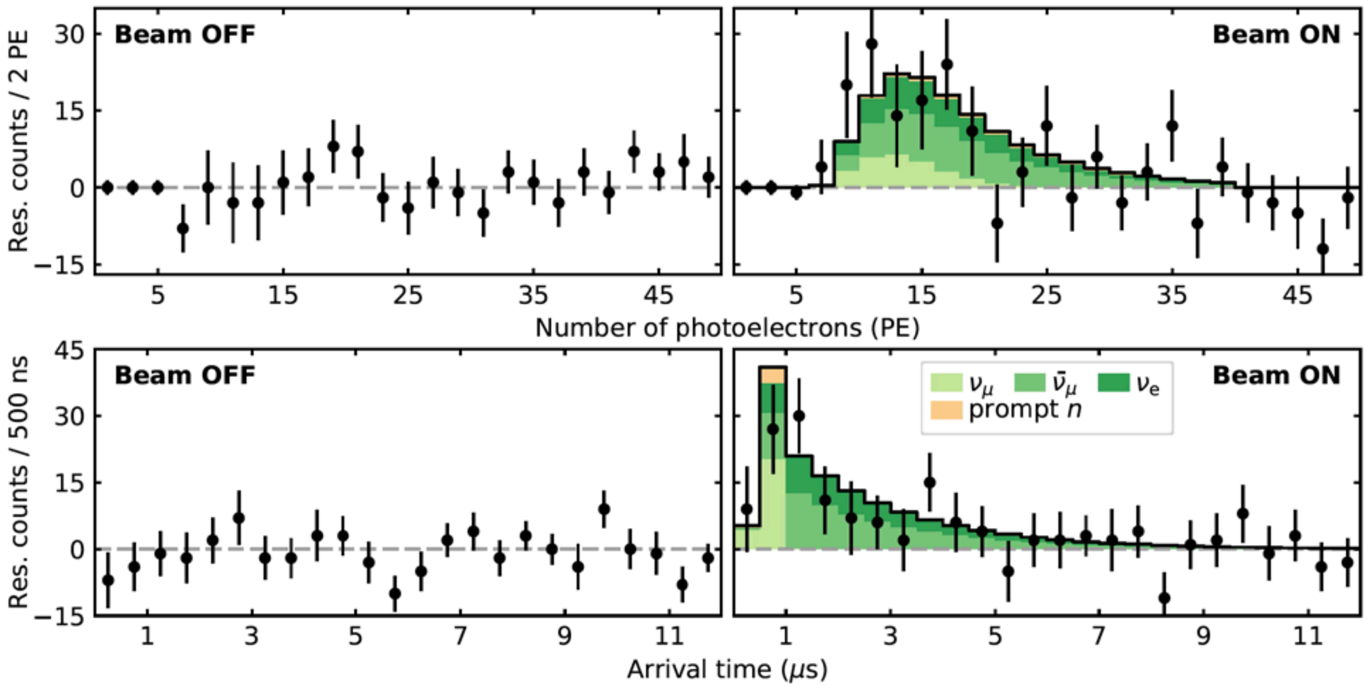
- QF: light yield from nuclear recoil / from electron recoil
- Down to 3 keV region



- Introduction of CEνNS process
- Experimental setup & Detector studies
- Data analysis
- Summary

Data analysis

Residual differences between signals in the 12 μs window after and before POT



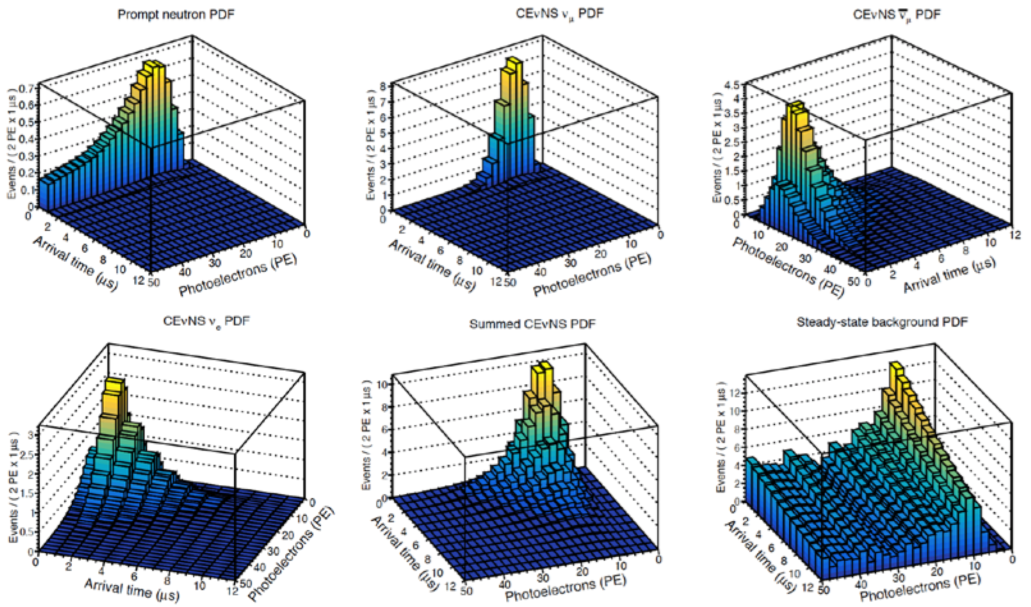
- Afterglow cut: SPEs ≤ 4 pretrace
- quality cuts :
  - muon veto coincidences
  - dead time from PMT saturation
  - digitizer range overflow
- Maximize the ratio of event acceptance in an energy ROI to the number of background events passing the same cuts

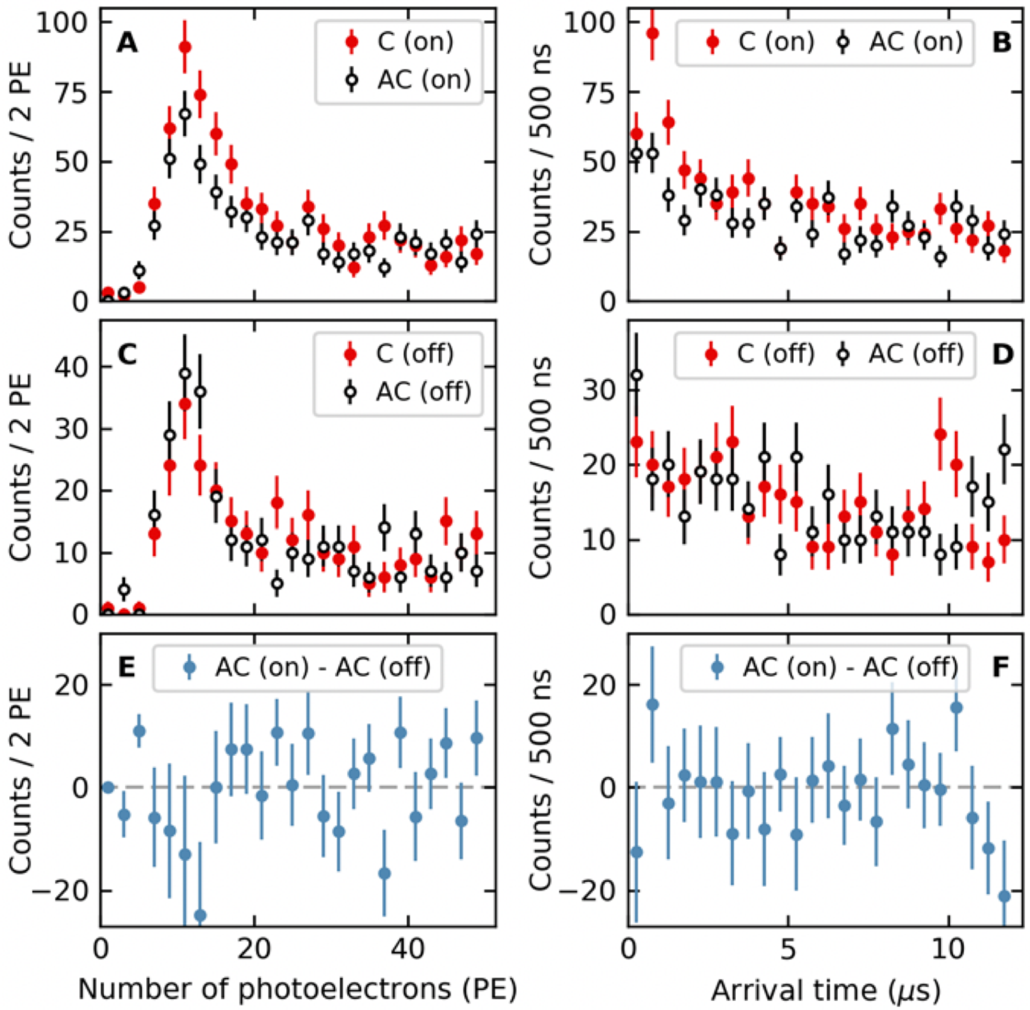
Arrival times cut: 0-5 μs
Energy cut: PE ≤ 20

CEνNS signal events

- PDFs 2-D (energy, time) MLE fit :
  - the CEνNS signal
  - the prompt neutron background
  - the steady-state environmental backgrounds

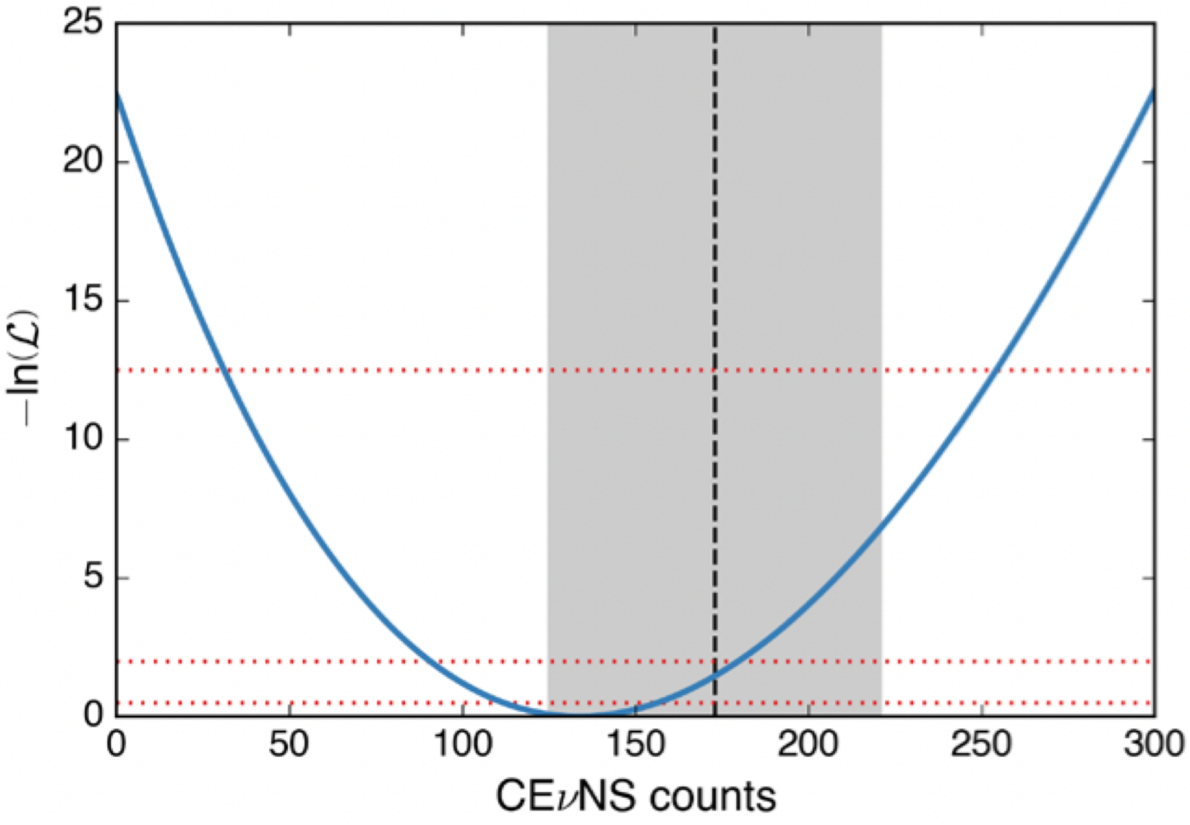
NIN backgrounds omitted





Outcome

- 134 ± 22 CEvNS events
- shaded region: 68% C.L. of the SM prediction (173 events)
- absence of CEvNS events rejected at a level of 6.7-sigma

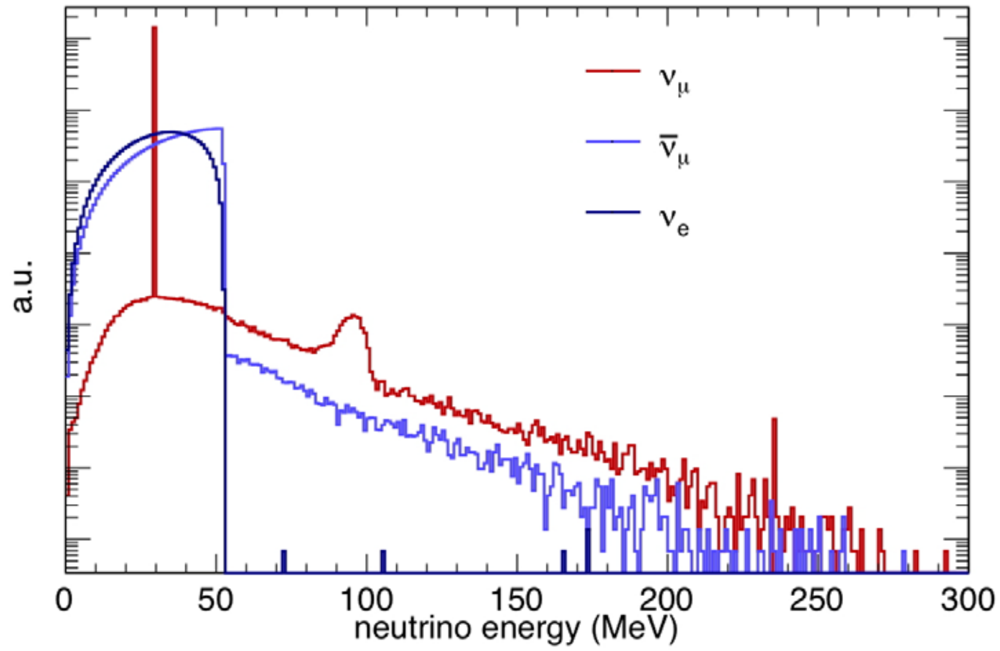


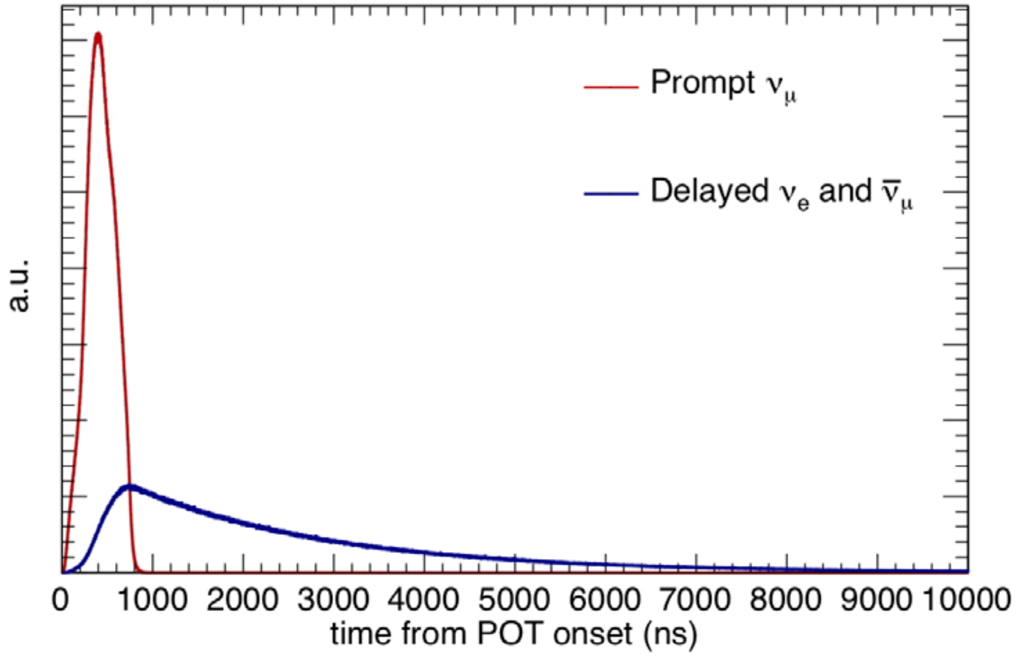
Summary

- Firstly observed CEvNS at 6.7-sigma
  - Well experimental design
  - Well detector studies
  - Well background studies
  - Well statistical analysis

Backup

- SNS neutrinos: prompt muon neutrinos, delayed electron neutrinos, delayed muon antineutrinos
- NIN: delayed ν_e through the $^{208}Pb(\nu_e,e^- xn)$ reaction





Backup

- 12 μs following POT triggers as coincident (C)
- 12 μs before POT trigger as anti-coincident (AC)