NOW 2022

Ostuni, BR, Italy

REGIONE PUGLIA

CEvNS and COHERENT

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COHERENT Collaboration

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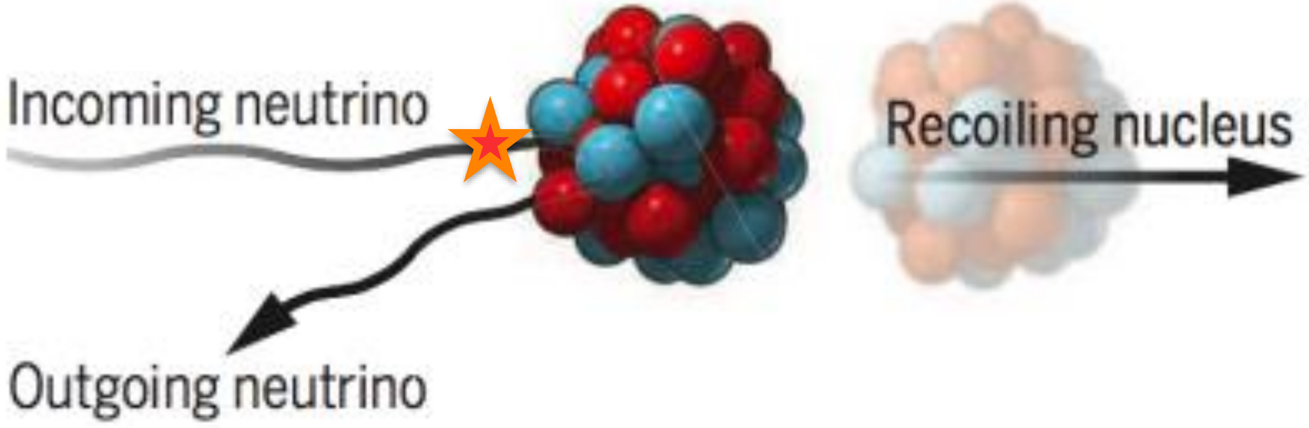
THE UNIVERSITY OF TENNESSEE KNOXVILLE

Outline

- Theoretical overview
  - CEvNS
- COHERENT Detectors
  - CsI
  - CENNS10 (LAr)
  - Liquid Argon (1 ton)
  - D_2O
  - NaI-185/NaIvETe
  - Ge-mini
  - Nubes
  - NuThor

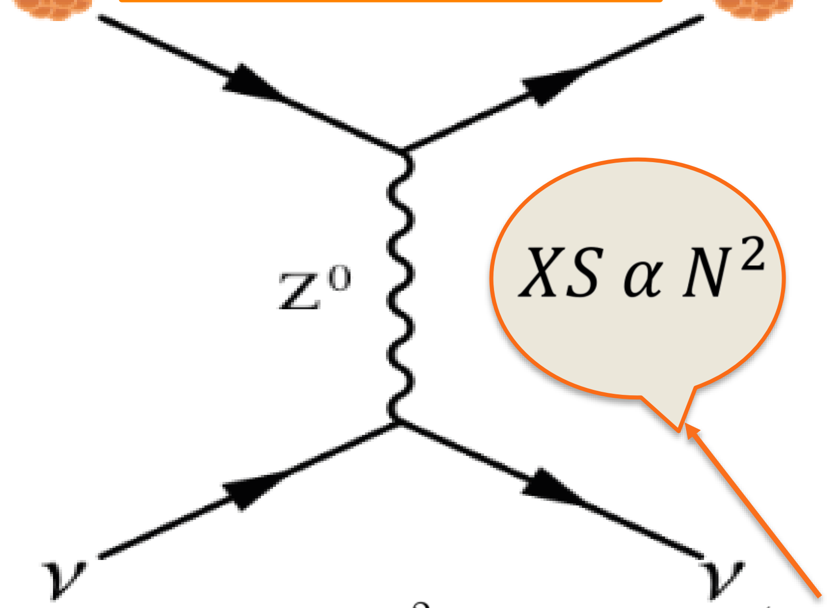


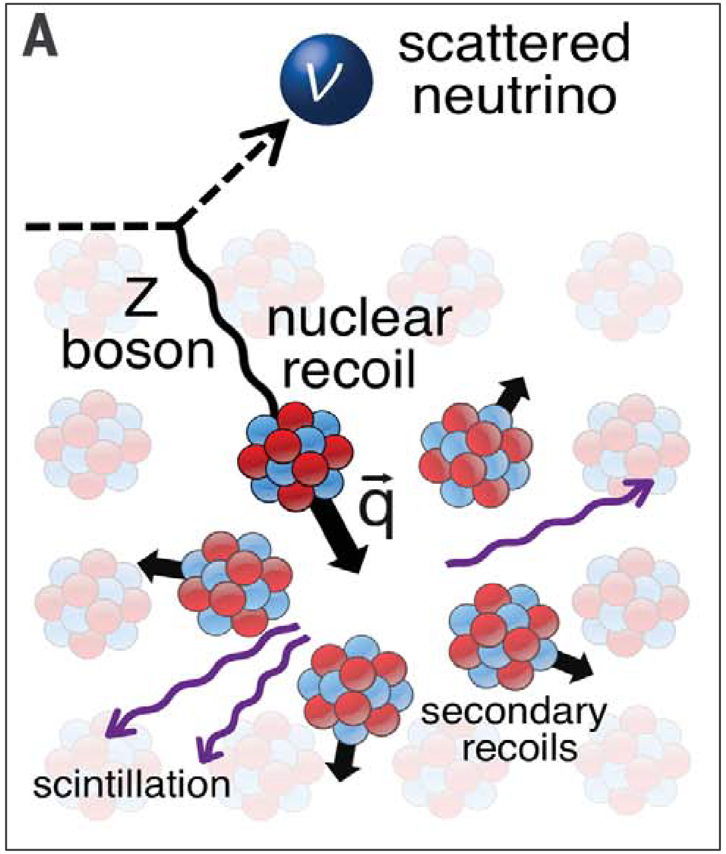
COHERENT

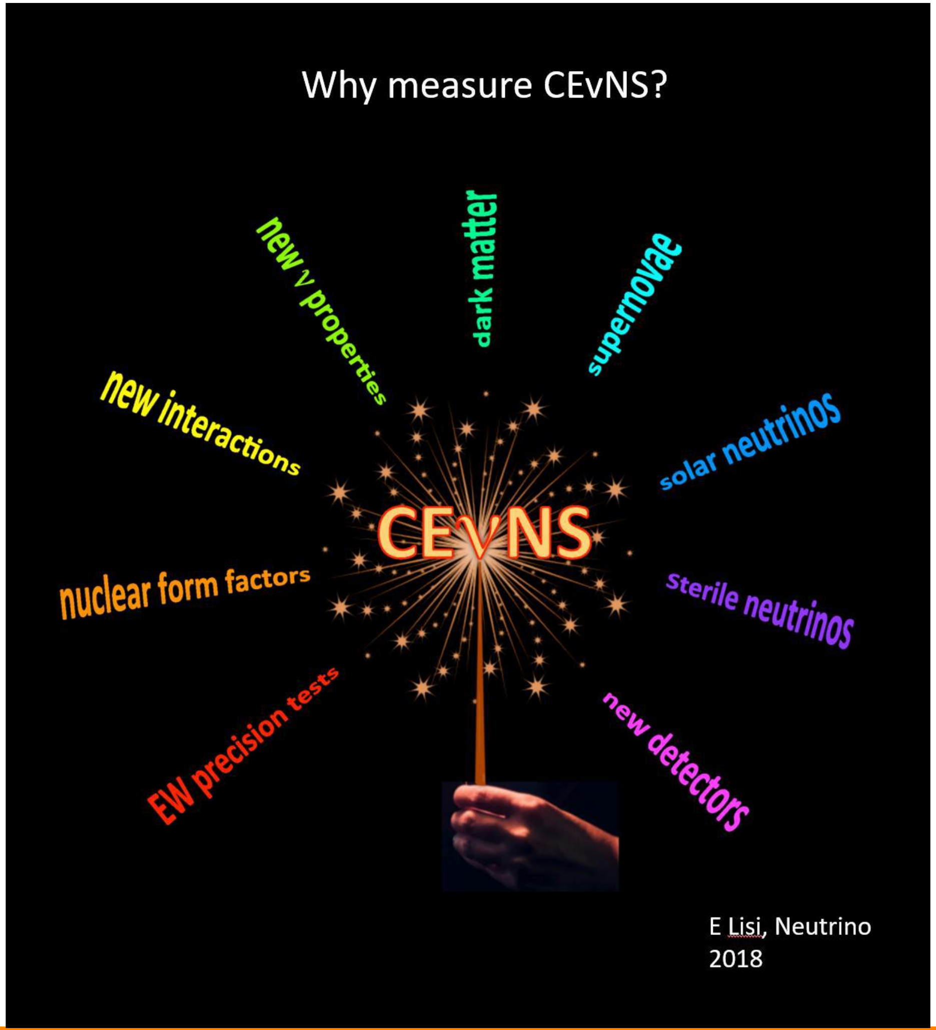
SNS
SPALLATION NEUTRON SOURCE

CEvNS (Coherent Elastic Neutrino-Nucleus Scattering)

> Our suggestion may be an act of hubris, because the inevitable constraints of interaction rate, resolution, and background pose grave experimental difficulties for elastic neutrino-nucleus scattering.

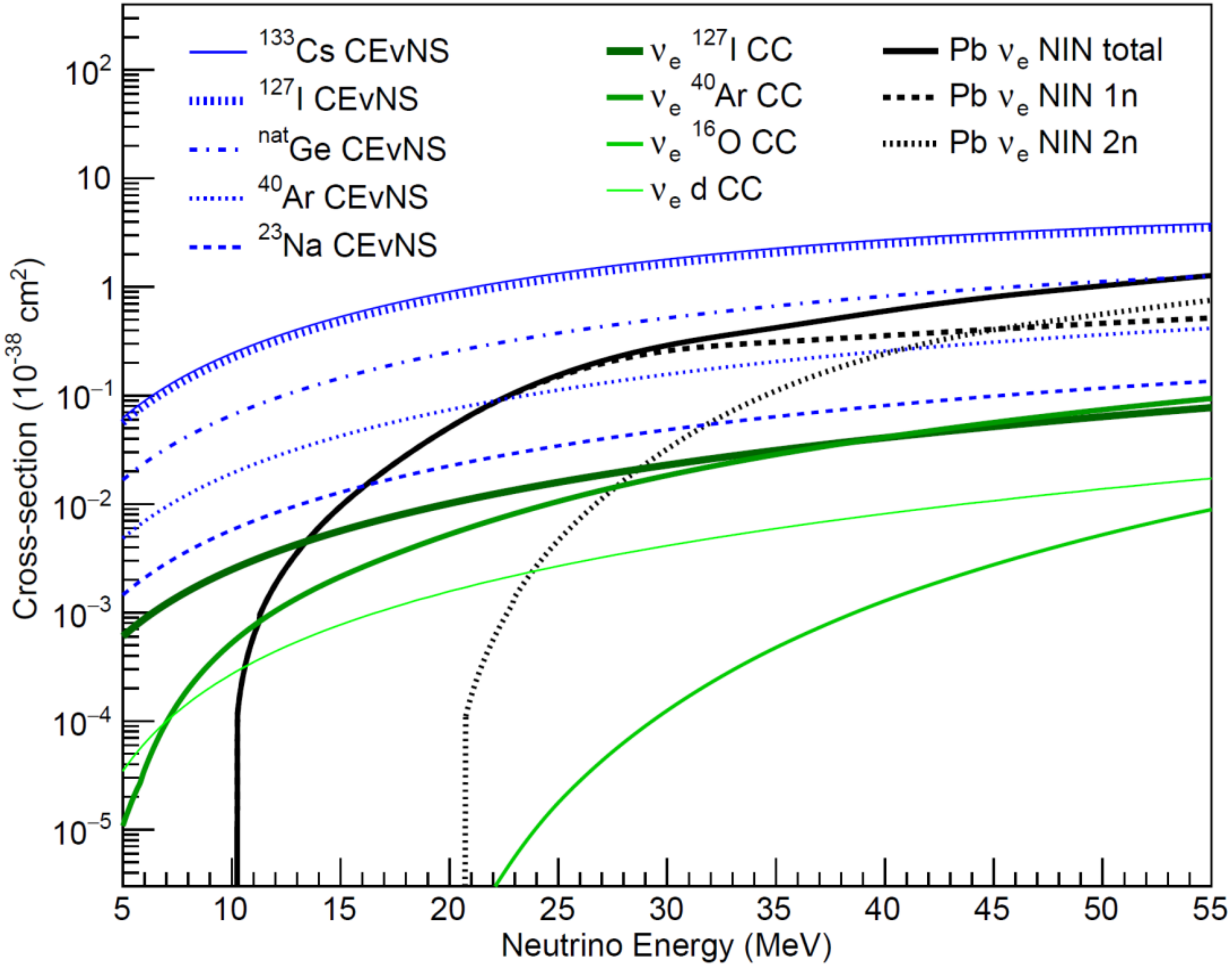


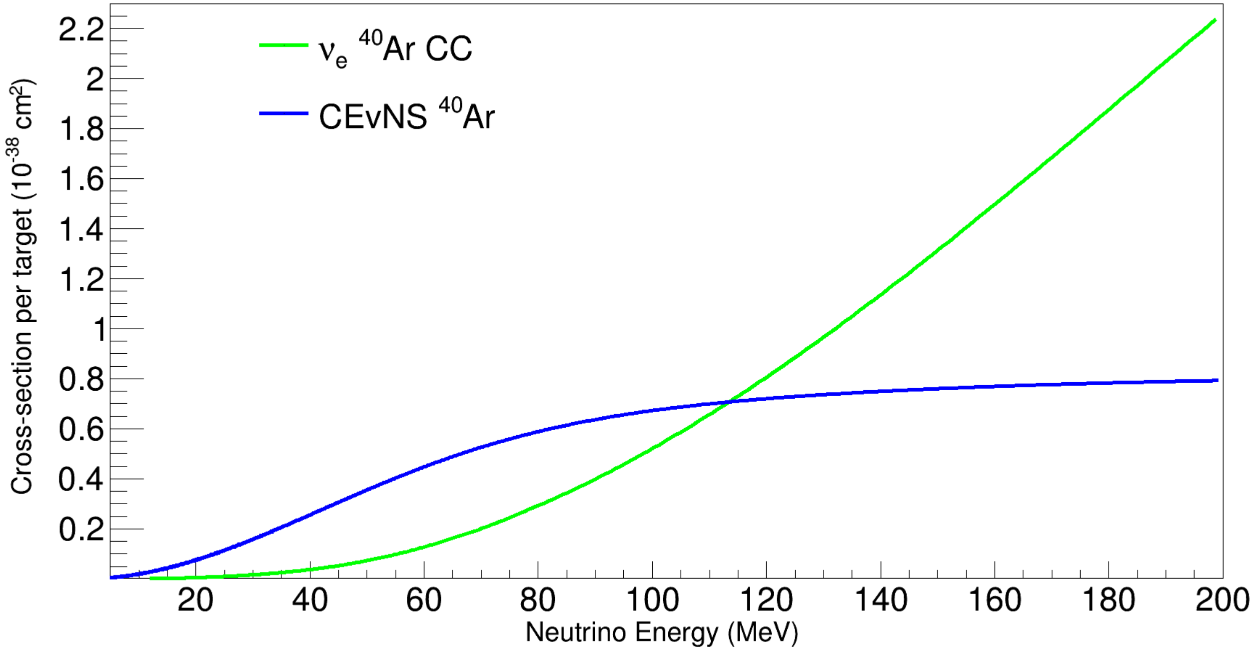


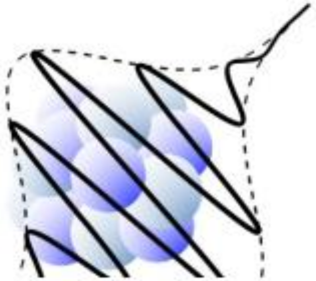


$$\frac{d\sigma}{d\Omega} = \frac{G^2}{4\pi^2} k^2 (1+\cos\theta) \frac{(N-(1-4\sin^2\theta_W)Z)^2}{4} F^2(Q^2)$$

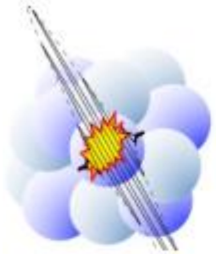
CEvNS cross section comparison





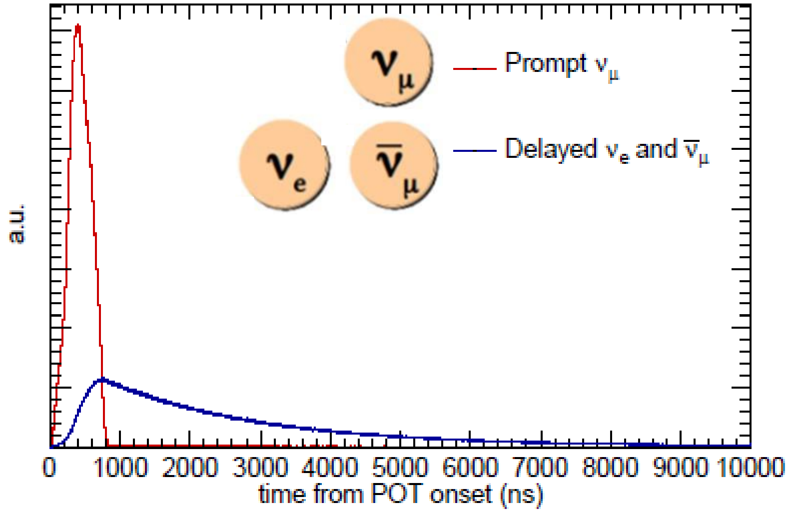


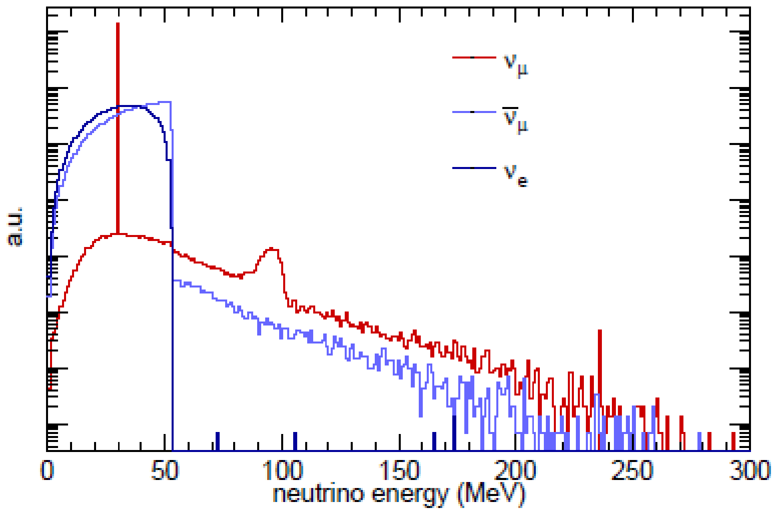
CEvNS is dominant at lower energies, due to larger de Broglie wavelength.

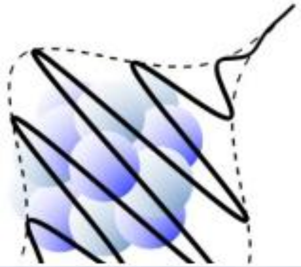


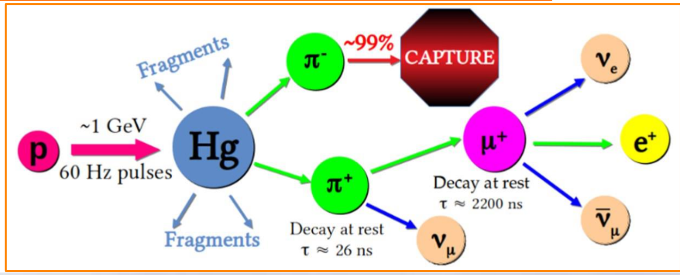
Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL)

Located in Tennessee - USA









Ideal environment to study CEvNS:

- 1.4MW Spallation Neutron Source used as neutrino source
- Pulsed neutrino source (most powerful in the world)
- $\sim 10^{20}$ Protons on Target per day, ~9% of protons producing 3 neutrinos each
- Ideal neutrino energies (<53MeV) for the study of CEvNS.

Neutrino Alley @ SNS/ORNL

Detectors in Neutrino Alley are 20~30 meters from the target, and the distance is completely filled with steel, gravel, and concrete; thus protecting from SNS neutrons.

Concrete overburden from above eliminates hadronic component of cosmic rays and attenuates muon flux by a factor of 3

After extensive BG studies we found a well protected location at the SNS basement

Nubes (neutrino cubes): Measured NINs (neutrino induced neutrons)

NaI 185

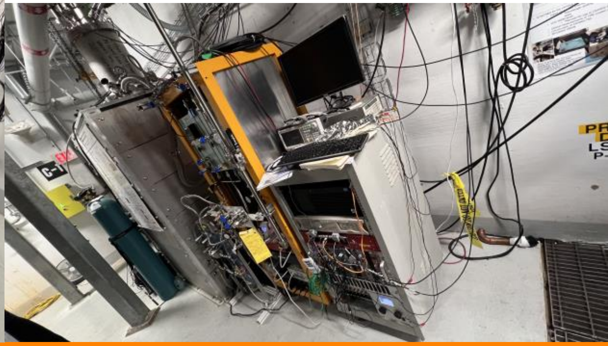
D2O

Ge-mini

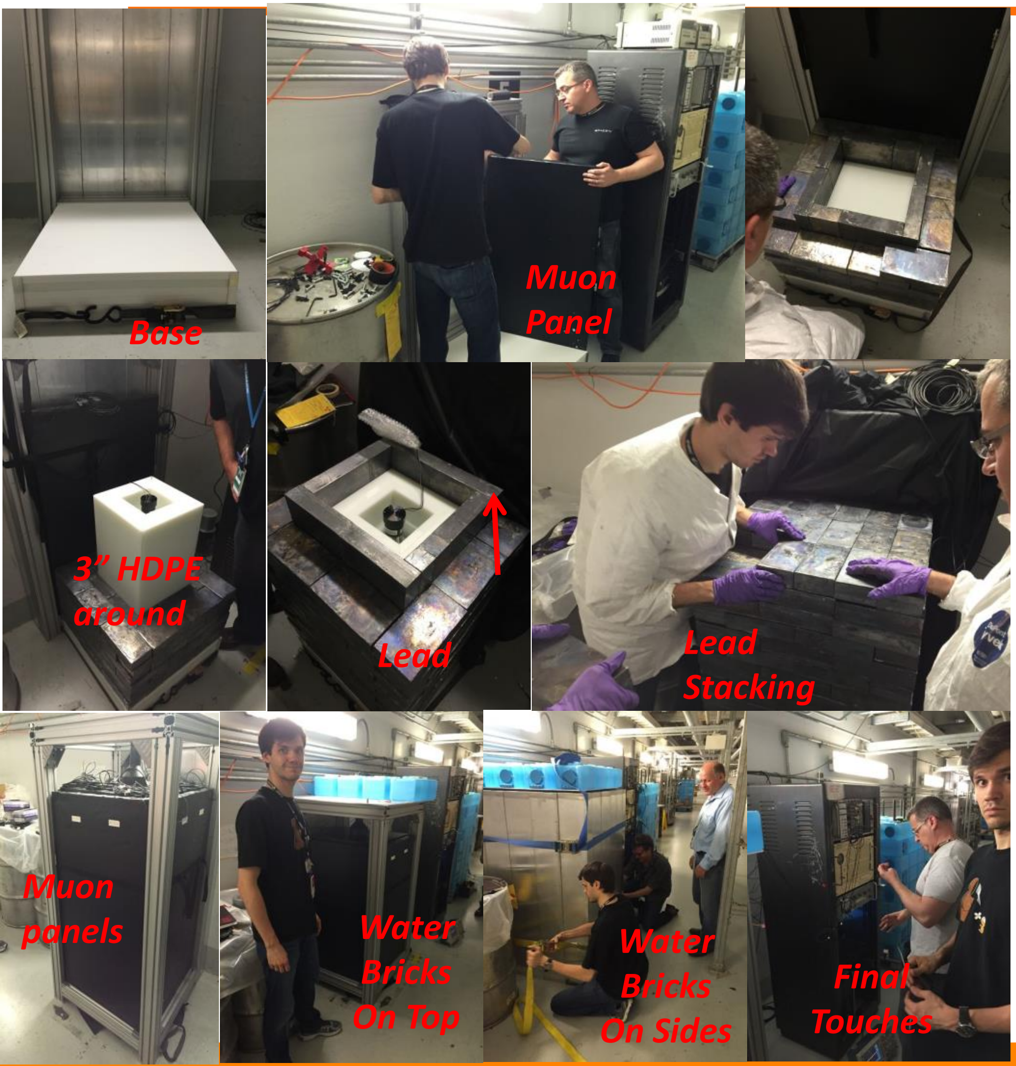
NuThor

NaIveTe

CENNS10

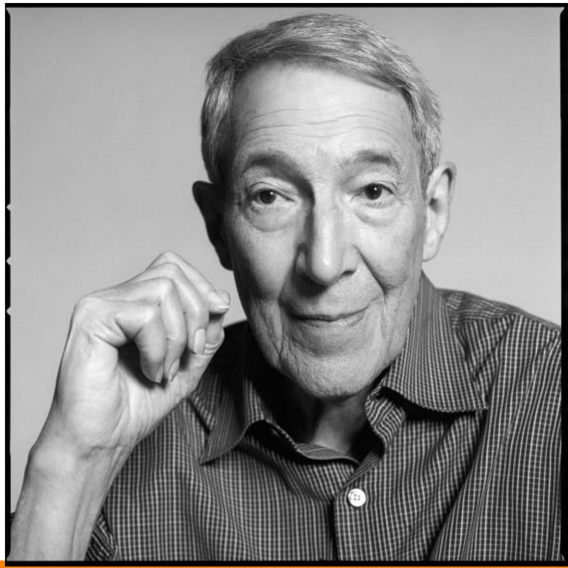


CsI detector – first observation of CEvNS



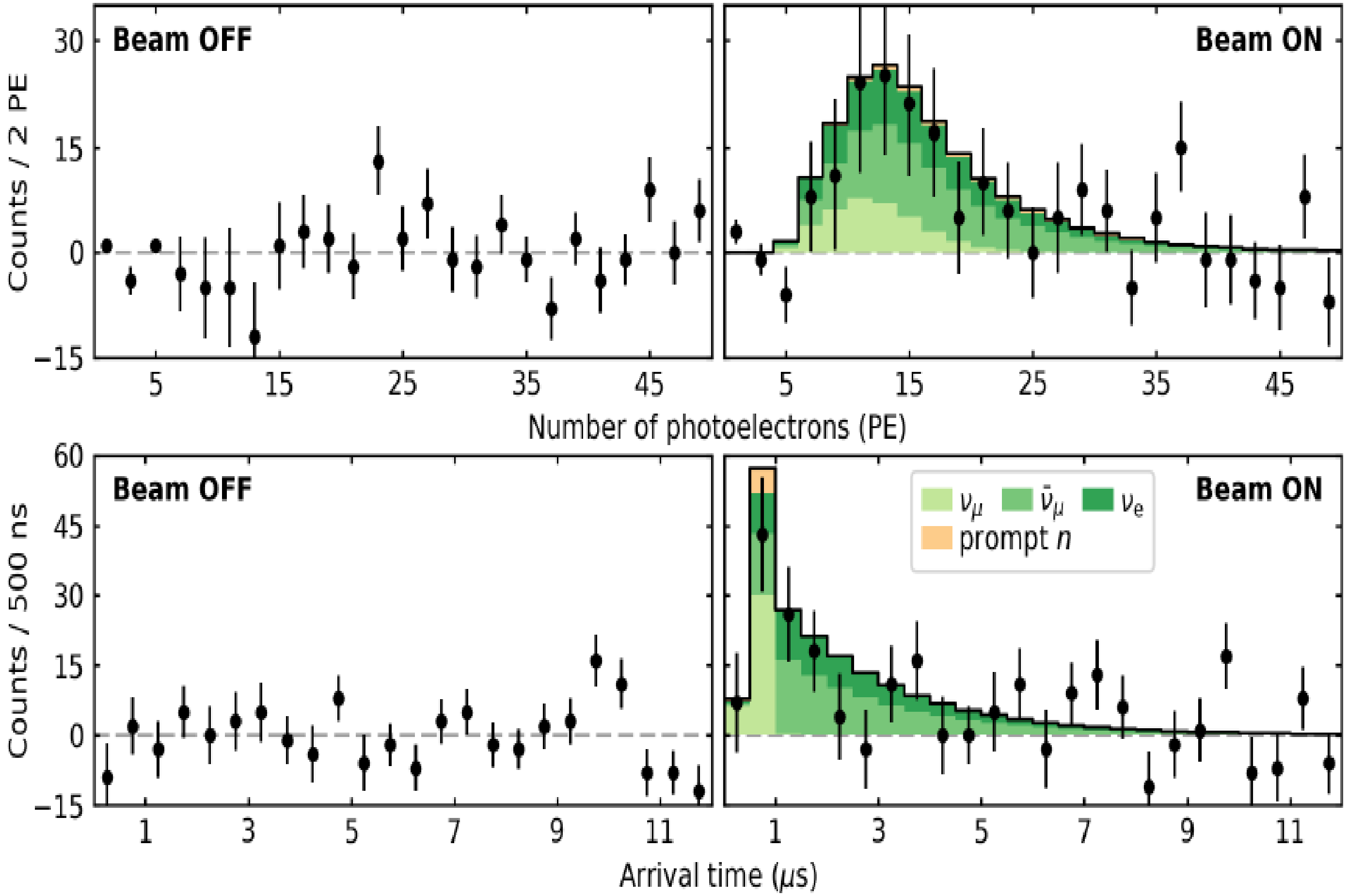
- Years of studies and simulations
- Experimental assembly at Neutrino Alley took less than 24h (detector preassembled at University of Chicago)
- 15 months collecting data before first results were published → observation of CEvNS
- 43 years after prediction by Daniel Freedman →
- Updated results published last month
- Paved the way for further detectors, measurement of CEvNS cross sections with different elements, and serves as a probe for different kinds of new physics, such as DM, oscillations, NSI, etc.

2017: COHERENT observed CEvNS using a 14.6kg CsI[Na] detector at SNS-ORNL – 40 years since theoretical prediction by D. Z. Freedman (PRD 9, 1974)

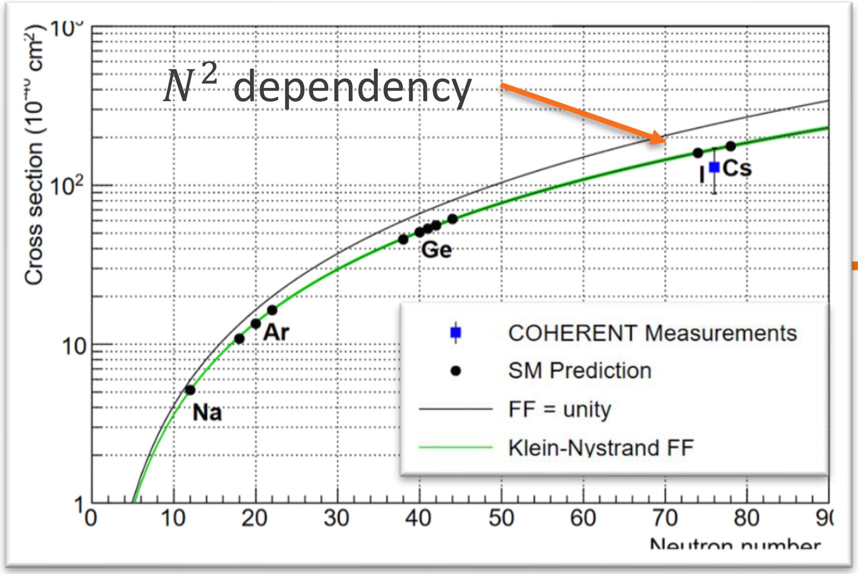


CsI detector – CEvNS results

Science 357 (2017) 6356, 1123-1126



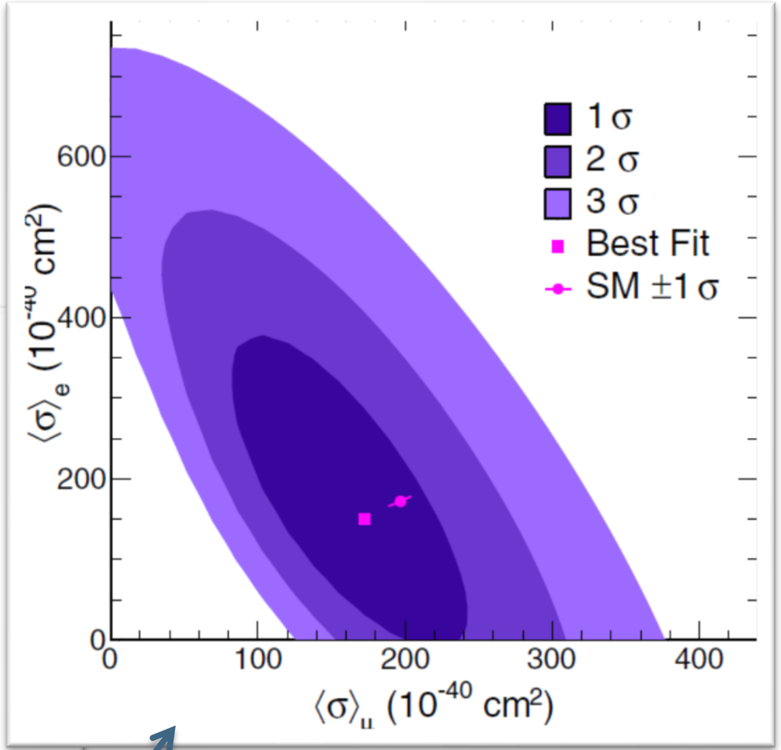
First working, handheld neutrino detector <15kg!!!



Updated results:
*PRL **129,** 081801 (2022)*

CsI detector – CEvNS new results

Largest systematic uncertainty is due to neutrino flux uncertainty



Matching SM within uncertainties

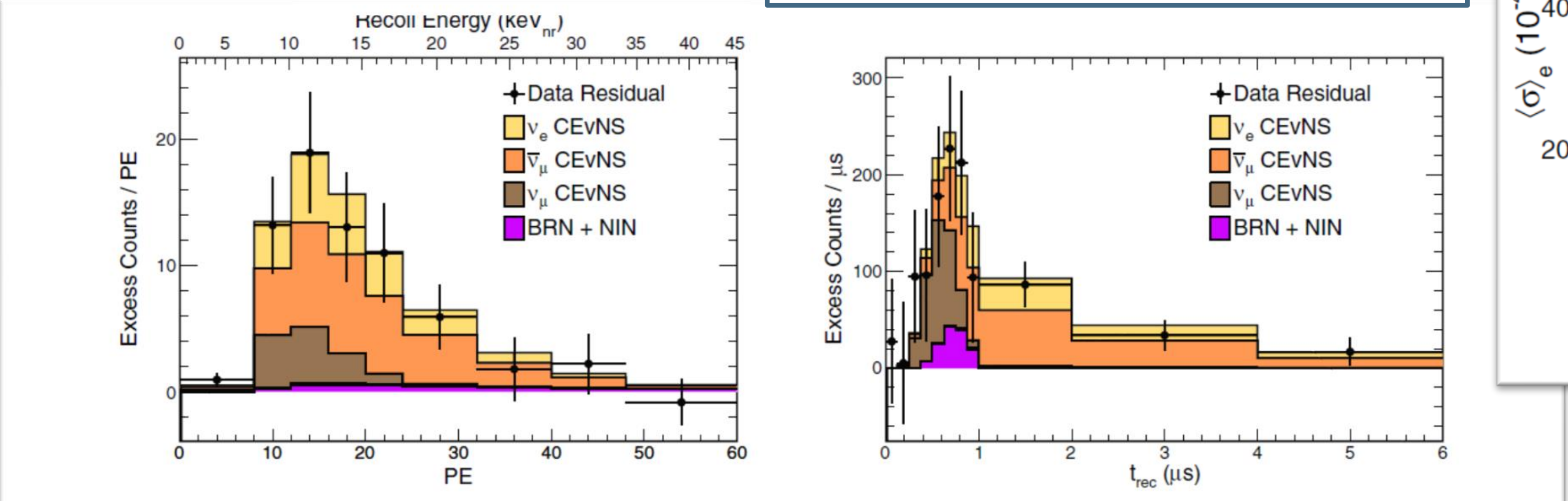
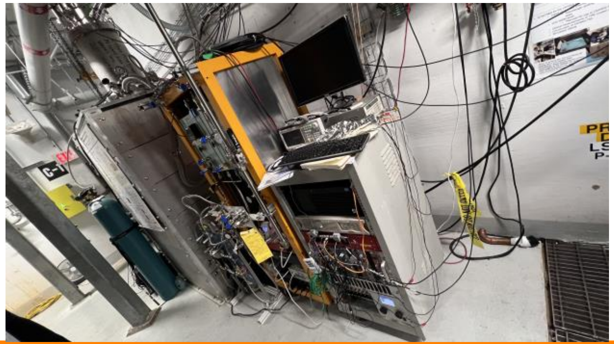
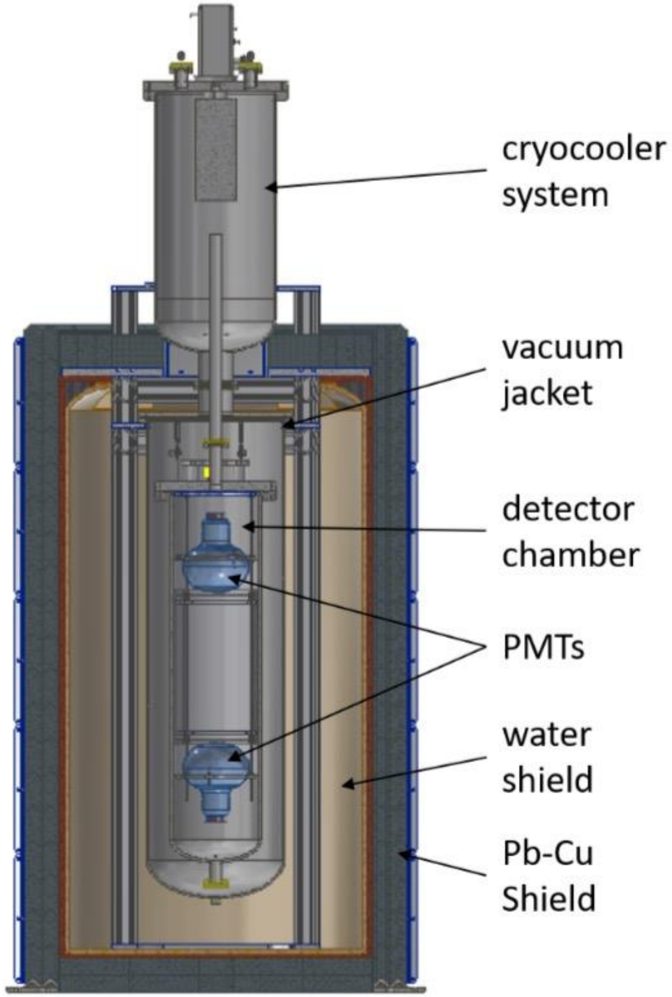


FIG. 1. The data residual over SSB compared to best-fit CEvNS, BRN, and NIN predictions projected onto the PE (left) and t_{rec} (right) axes. The CEvNS distribution has been decomposed into each flavor of neutrino flux at the SNS.

CENNS 10 – Observation of CEvNS in Ar

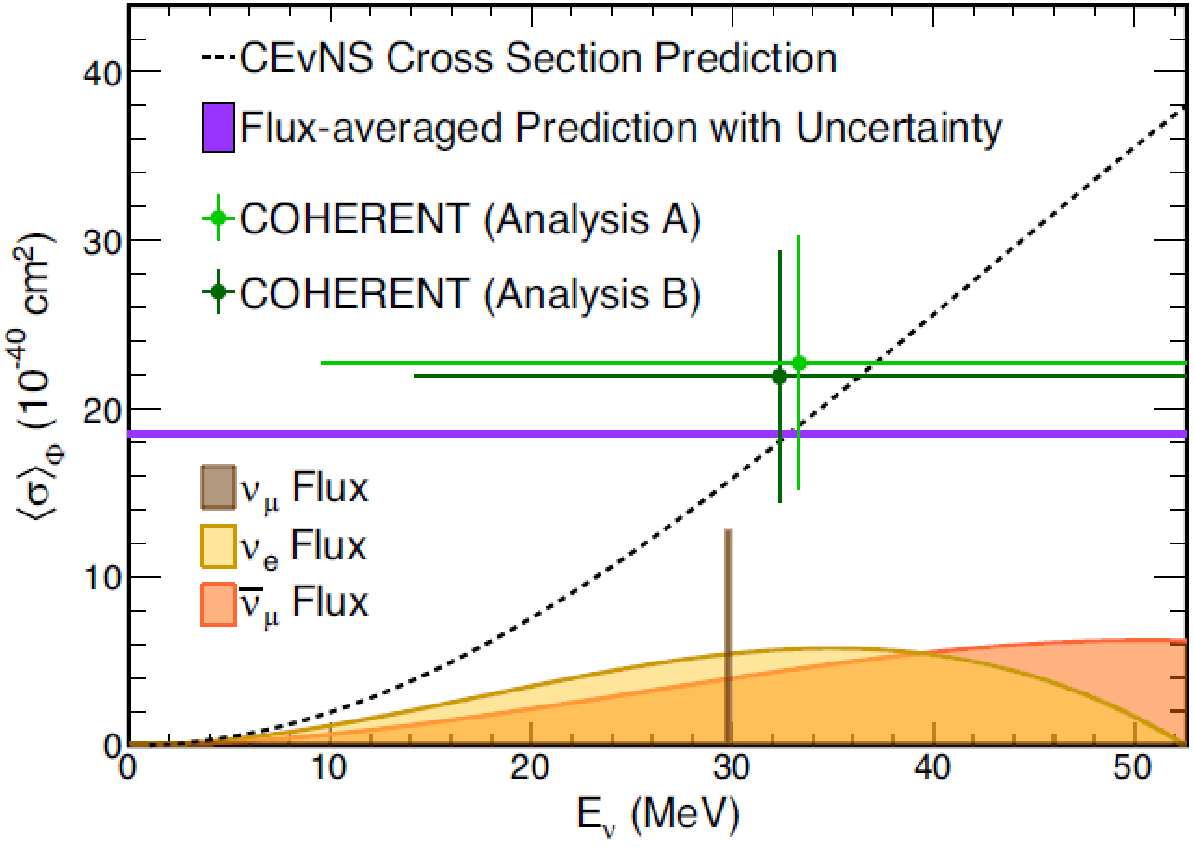
- Built at Fermilab (J. Yoo et al)
- Restored at Indiana University in 2016
- Engineering run: Jan – July 2017 at ORNL
- Rebuilt in ORNL with new PMTs
  - 2x 8" Hamamatsu PMTs, 18% QE at 400 nm
- Data taking started July 2017
- 24kg LAr

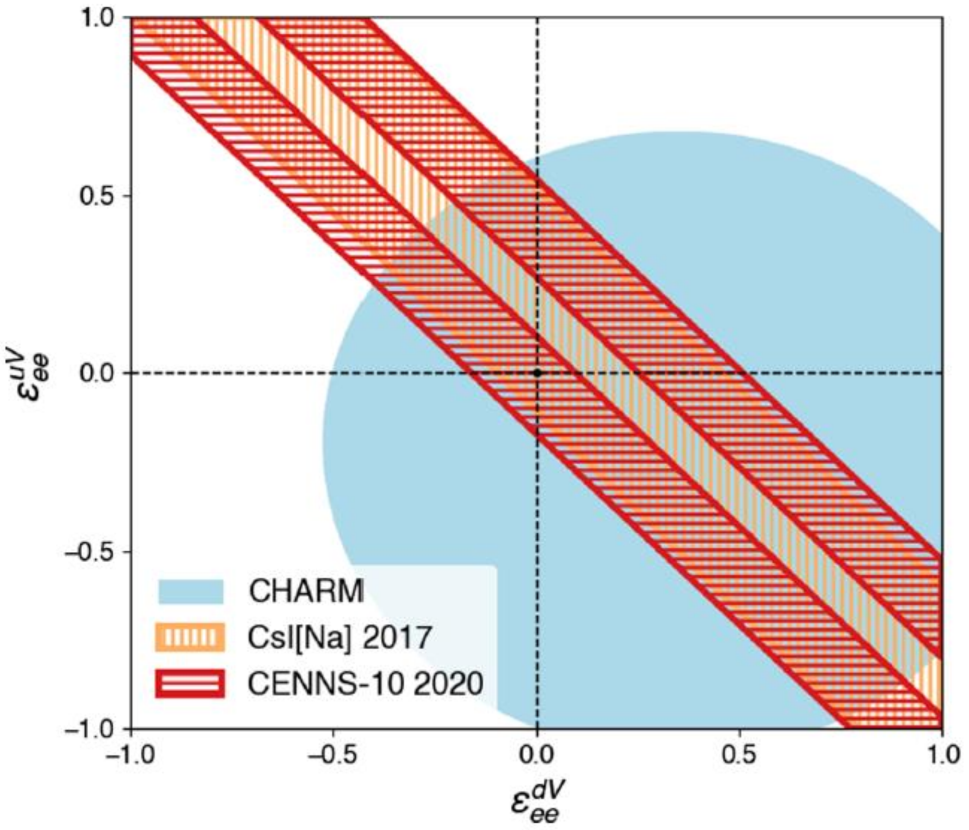




PRL **126**, 012002 (2021)

CENNS 10 results



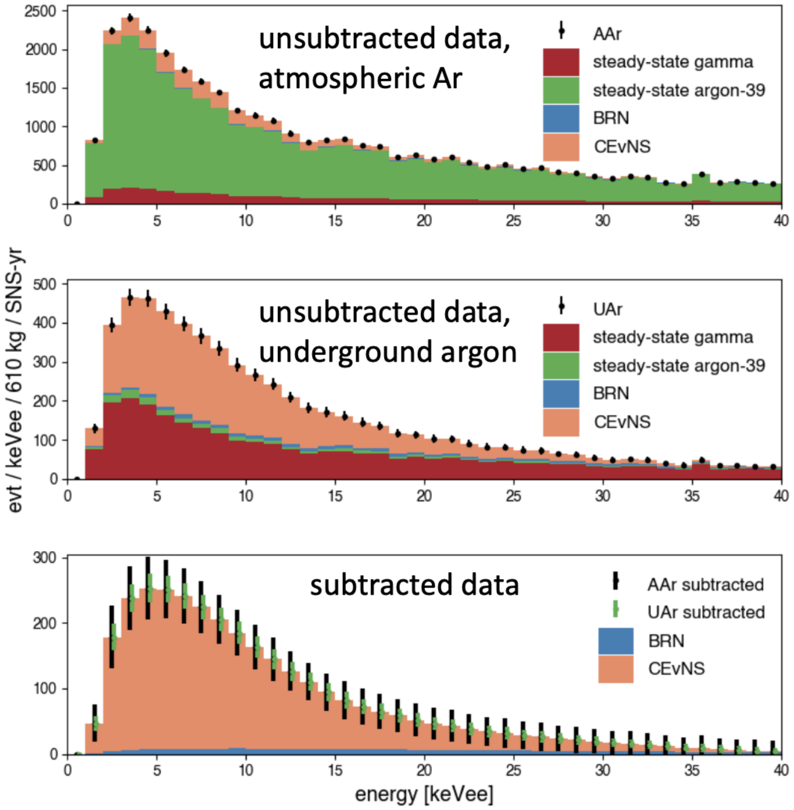


Studying possibility of new physics!

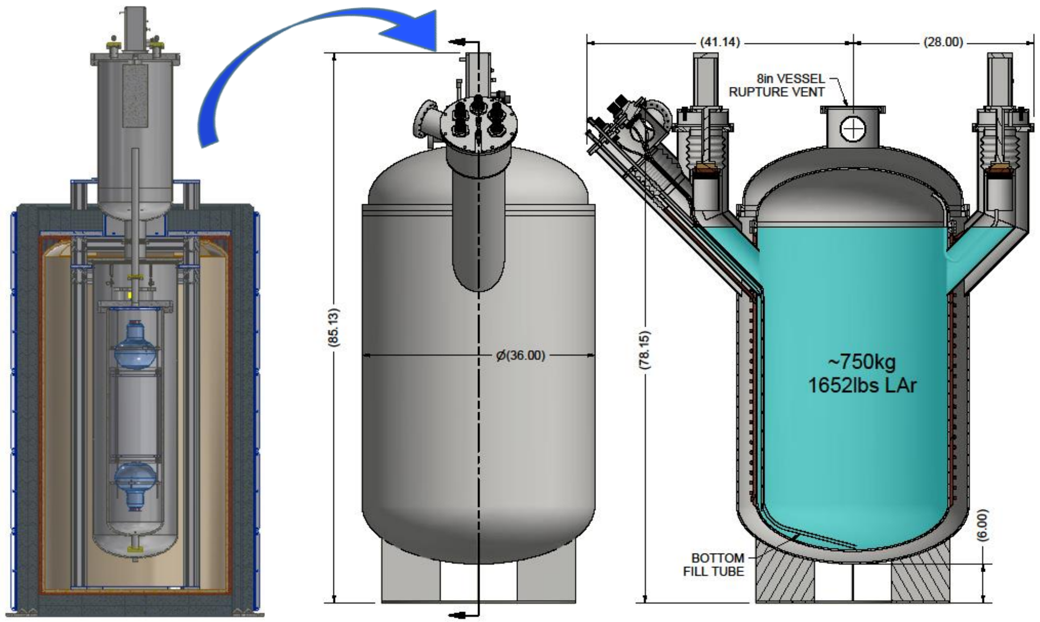
$$\mathcal{L}_{\nu H}^{NSI} = -\frac{G_F}{\sqrt{2}} \sum_{\substack{q=u,d \\ \alpha,\beta=e,\mu,\tau}} [\bar{\nu}_\alpha \gamma^\mu (1-\gamma^5)\nu_\beta] \times (\varepsilon_{\alpha\beta}^{qL}[\bar{q}\gamma_\mu(1-\gamma^5)q] + \varepsilon_{\alpha\beta}^{qR}[\bar{q}\gamma_\mu(1+\gamma^5)q])$$

Future Upgrade – 1 ton LAr detector

simulated CEvNS + background rates



Our collaborators have funds from National Research Foundation of Korea to build this detector!



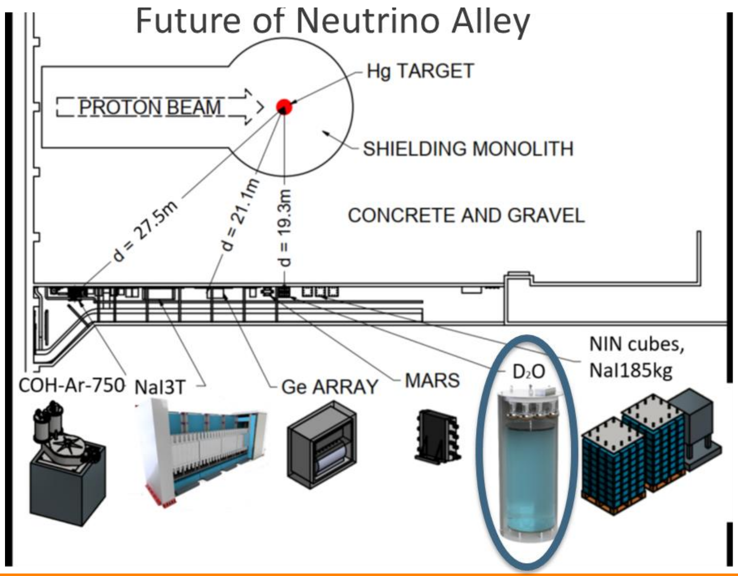
24kg to 1ton: same spot!

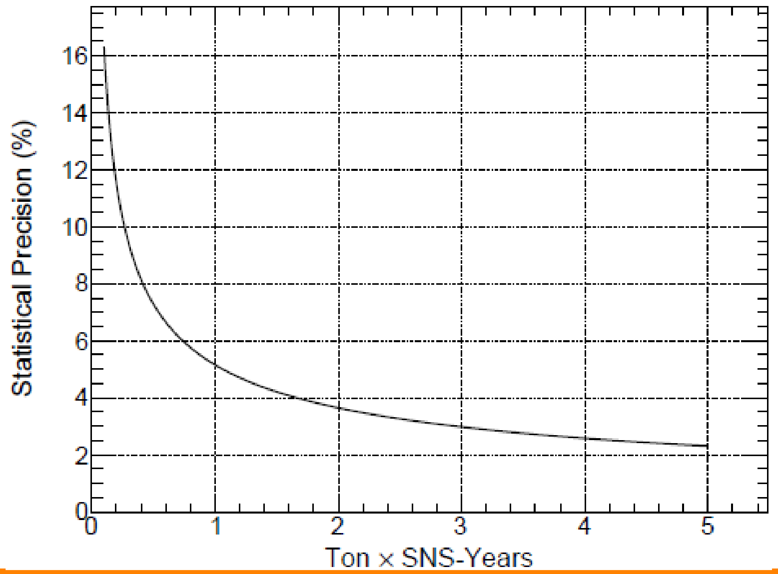
Expected 3000 CEvNS events per year, plus charged current events.

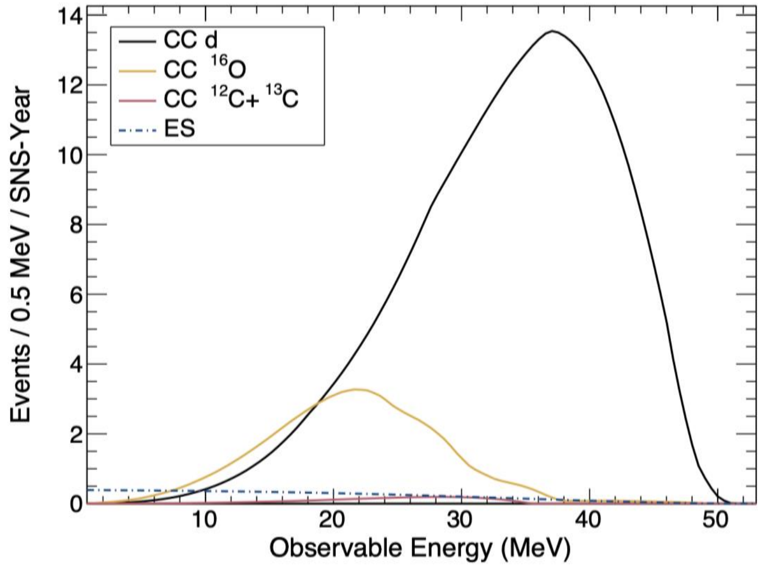
High statistics, low background.

Tackling current systematical uncertainties on neutrino flux

- Largest systematical uncertainty is in knowledge of neutrino production (~10%).
- D_2O based detector offers opportunity to calibrate neutrino flux from the SNS because of the well-known cross-section of neutrino-deuteron charged current interaction.
- Neutrino flux uncertainty: **As low as 2%** after a few years of data.





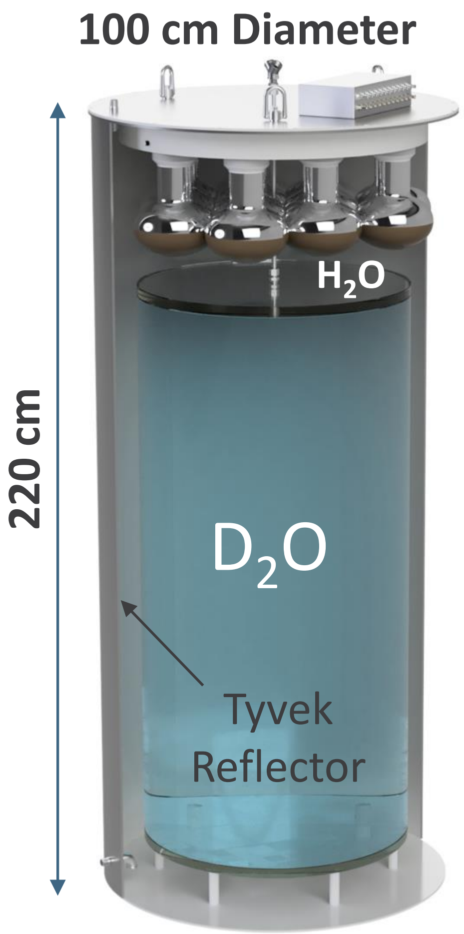


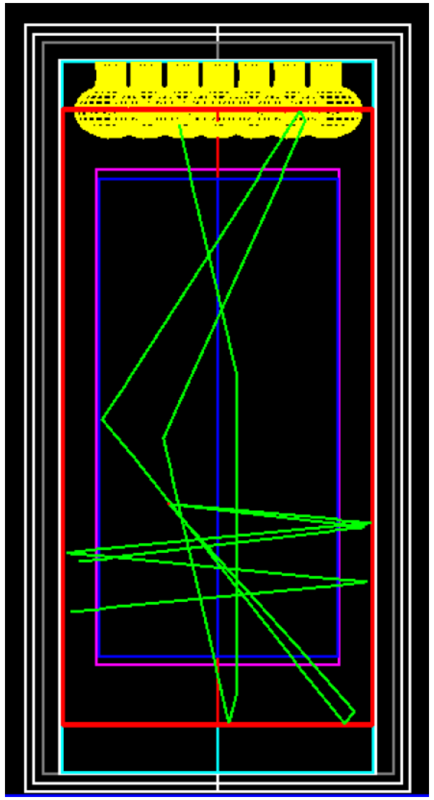
2021 *JINST* **16** P08048

D_2O detector

2021 *JINST* **16** P08048

- ~600kg of D_2O contained in acrylic vessel
- 12 8" high gain Hamamatsu PMTs
- Cherenkov light as a mode of detection
- H_2O "tail catcher" for electrons
- Outer stainless steel vessel
- Lead shielding
- Hermetic veto system outside lead shielding
- Detector located ~20m from the SNS target
- Will measure neutrino-deuterium interaction rate
  - therefore measure neutrino flux because of well known neutrino deuterium charge current interaction cross section.
- Additional goal: measure for the first time neutrino-oxygen CC cross section in the energy range relevant to the Supernovae neutrino detection
- Engineering run (with H_2O only) has already started. Heavy water run expected to start first half of 2023.

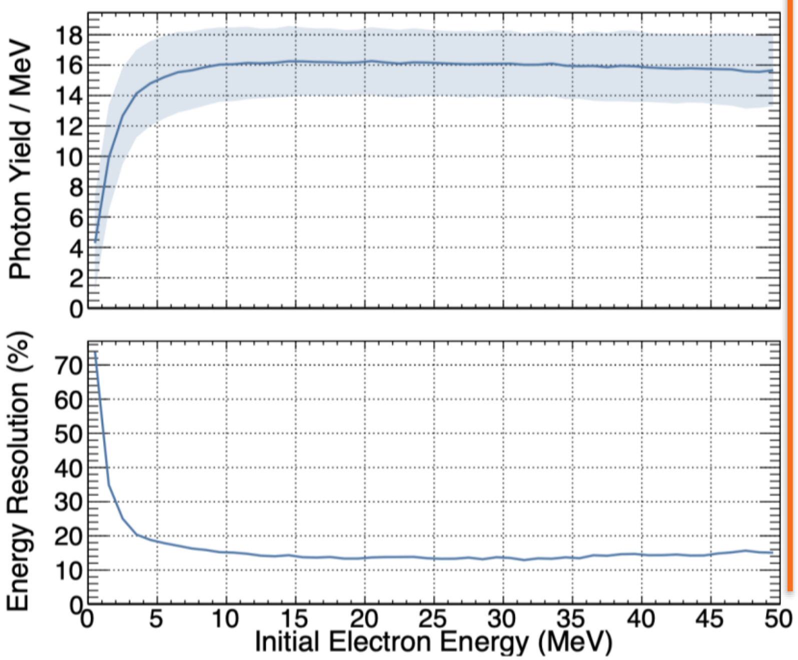


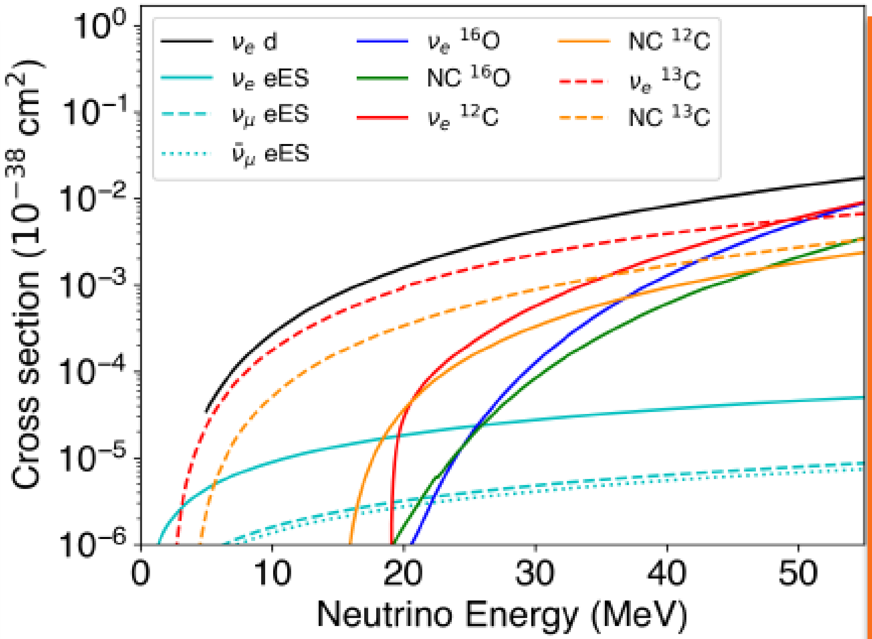


D_2O Detector performance simulations

Top: Light yield

Bottom: Resolution

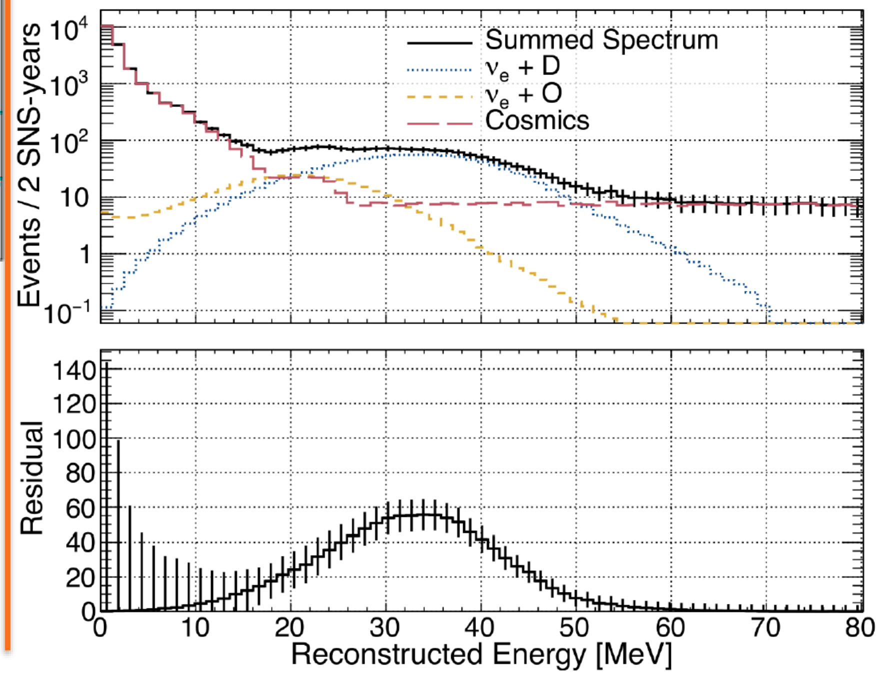




Neutrino-electron scattering background is insignificant because of low cross section

Top: Expected events vs cosmics

Bottom: Reconstructed energy

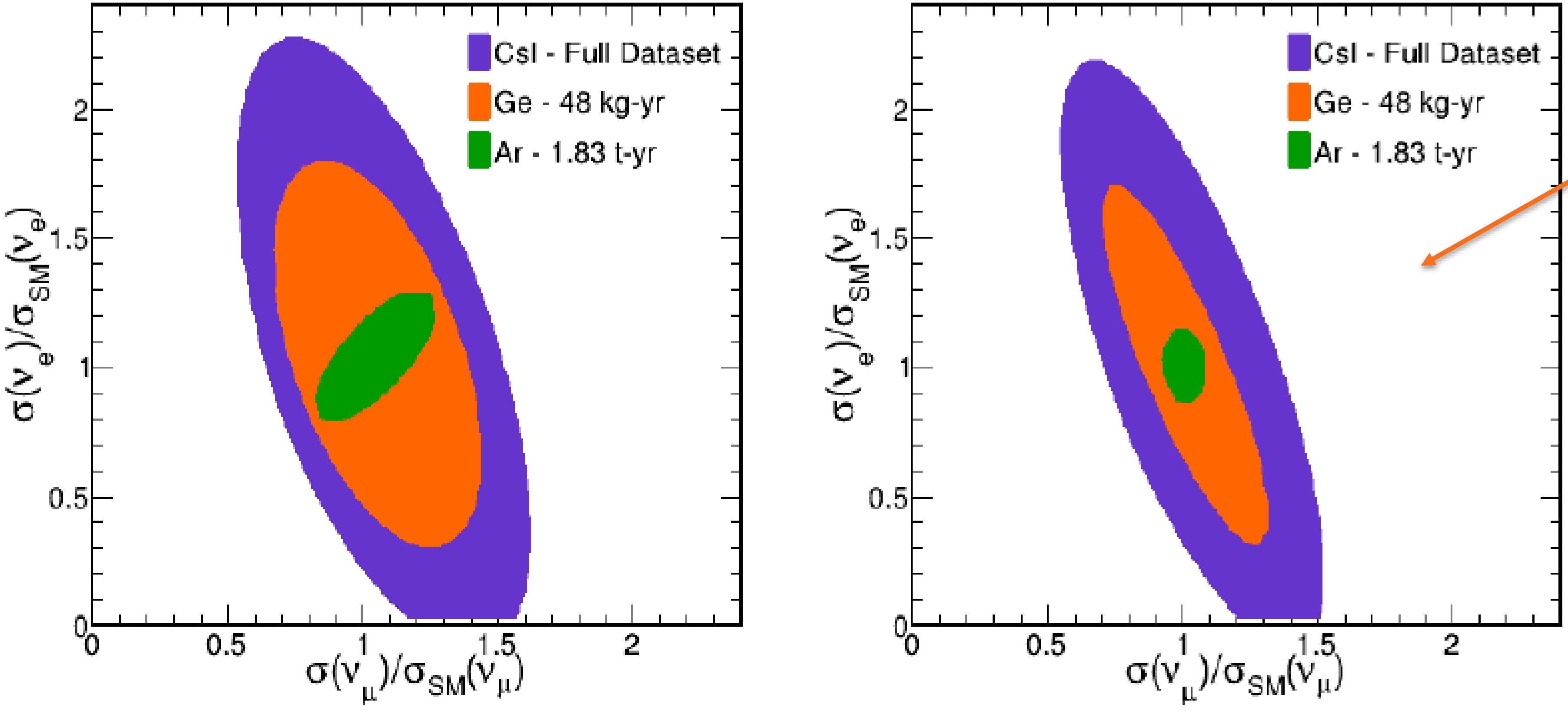


D_2O detector current status

- Engineering run has already started – regular water only, no shielding or veto panels.
- Acrylic vessel (for heavy water) should be installed in 2023.
  - We already have the required amount of D_2O
- Data acquisition started on light water.

How it currently looks

Possible search of new physics



After ν flux is normalized!

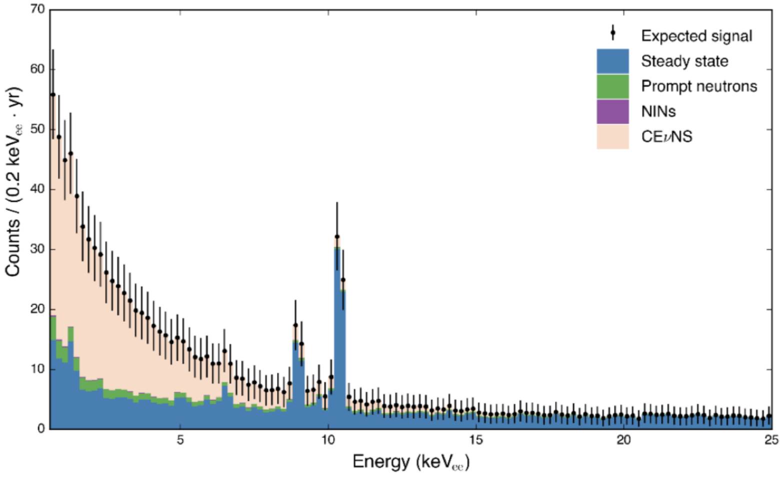
Expected precision difference after neutrino flux normalization.

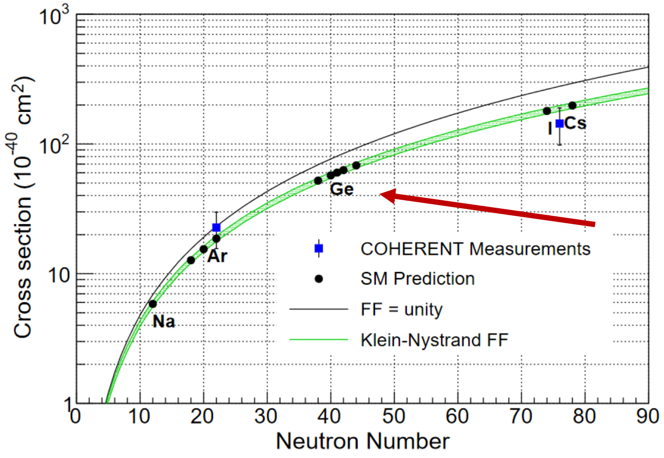
Data from D2O detector will impact data analysis from ***previous, current, and future detectors***.

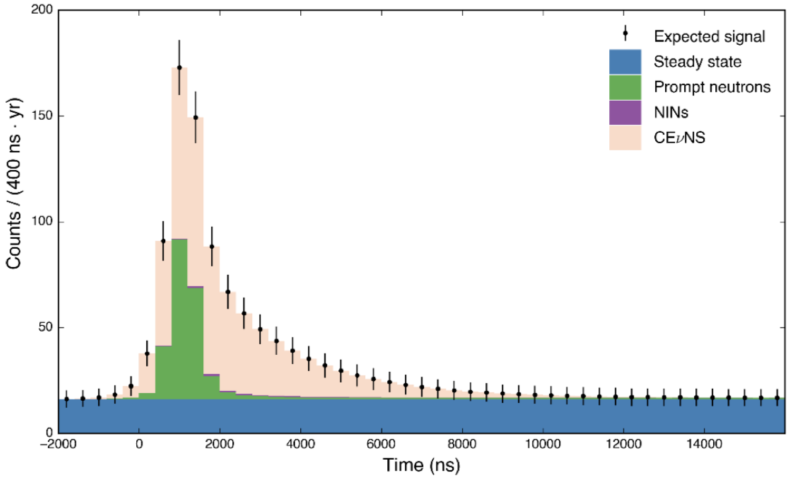
Plots include current CsI data as well as simulated predicted data to be collected from future Ge and Ar detectors. On the left, constraints are based on current uncertainty. On the right, how much more precise data will be after neutrino flux normalization from D_2O detector.

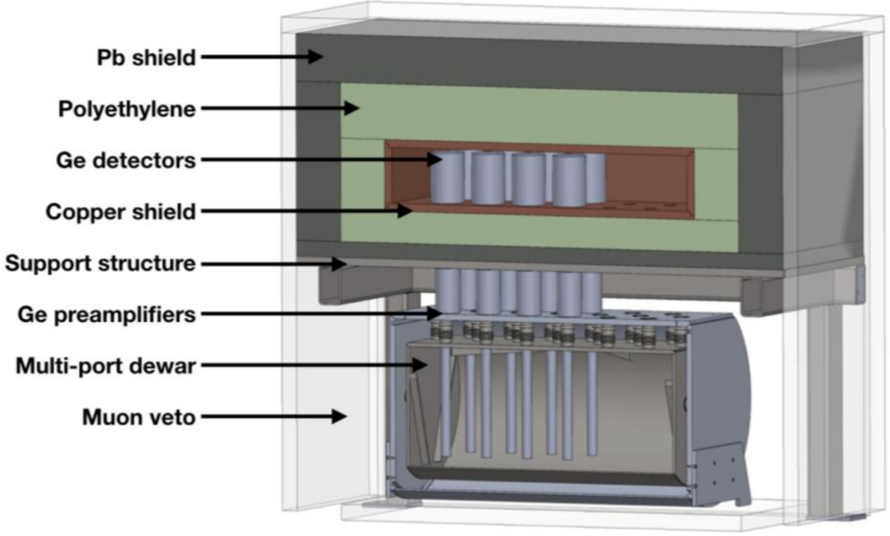
Germanium PPC array (Ge-mini)

- Estimation of 500 – 600 CEvNS events/year in a ~18 kg array.
- Detector will have great resolution
- Electronic noise from detector + preamp limited to < 150 eV FWHM
    - Results in an energy threshold of ~0.4 keVee, roughly 2-2.5 keVnr.
- Cryostat already available
- Quenching factor well understood
- All parts already at ORNL









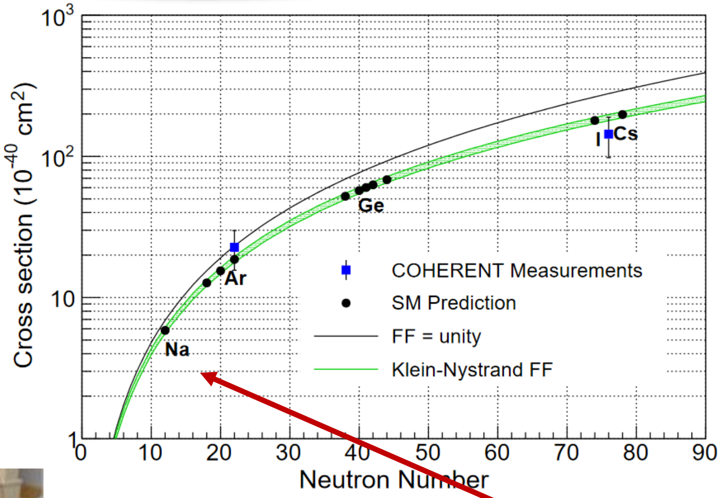
Large NaI Detectors Array (NaIvETe)

Transition from 185 kg to 2 ton array of NaI detectors:
Detectors are available
Measured Quenching Factors at TUNL
Potential to detect both CEvNS and CC on Iodine
Requires dual gain bases to look for CEvNs and CC

Final stages of NaI-185 data analysis

First of seven modules is deployed, and more modules soon!

Quenching factor measurement at TUNL

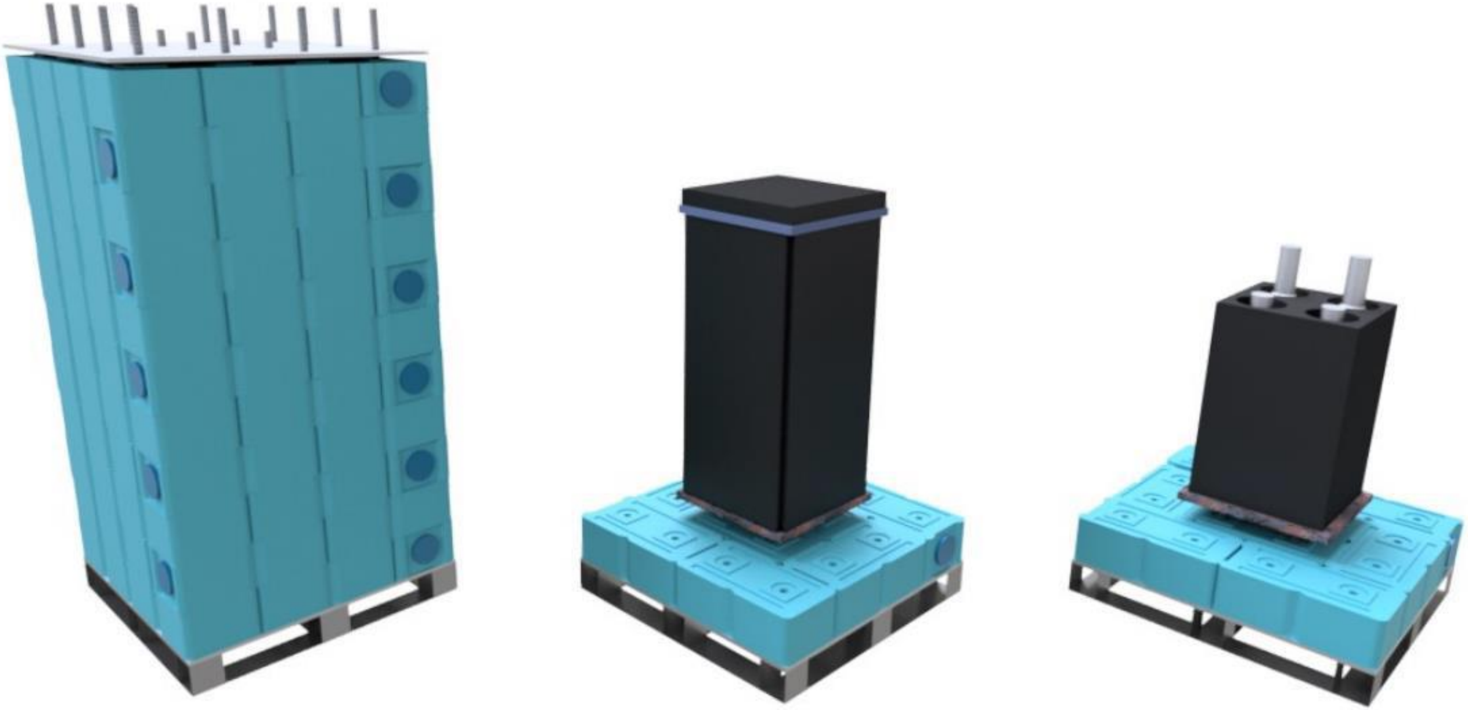


Another test of N^2 dependency

Nubes – Neutrino Cubes

Nubes was a liquid scintillator detector that observed NINs (neutrino induced neutrons), via inelastic scattering.

BRNs (beam-related neutrons) were shielded by water blocks, but SNS neutrinos interacted with Pb and generated neutrons: liquid scintillator cells were coupled with PMTs.



Publication coming soon!

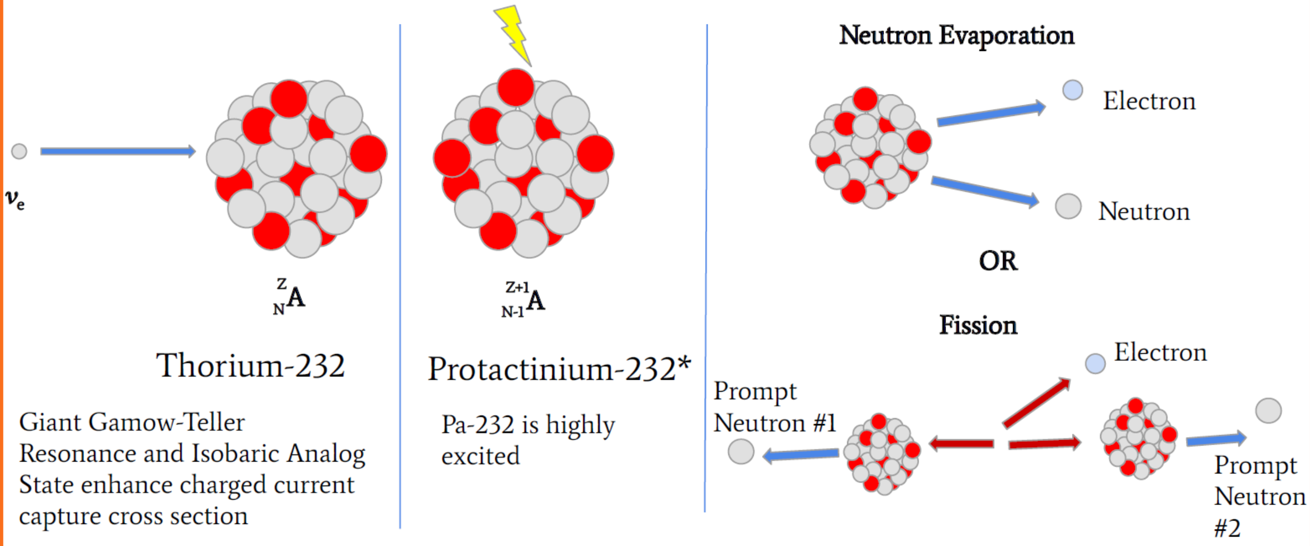
NuThor

Very exciting development!

Expect to hear more about this project in the future!

Neutrino Induced Fission (NIF) has never been observed. Tyler Johnson's (Duke U.) idea.

Neutrino-Induced on Fission on Thorium



COHERENT Collaboration

Funding agencies:

U.S. DEPARTMENT OF ENERGY | Office of Science

NSF

NNSA National Nuclear Security Administration

NRF National Research Foundation of Korea

Not all people could be depicted!

Carnegie Mellon University | Duke University | UF University of Florida | IU

Laurentian University Université Laurentienne | Los Alamos National Laboratory EST. 1943 | MEPhI

NC Central University | NC State University | Oak Ridge National Laboratory | Sandia National Laboratories

서울대학교 Seoul National University | SLAC National Accelerator Laboratory | University of South Dakota | The University of Tennessee Knoxville

Tufts University | TUNL Triangle Universities Nuclear Laboratory | Virginia Tech | University of Washington

- 20+ institutions
- 70+ people