# Study of CEvNS by the COHERENT collaboration


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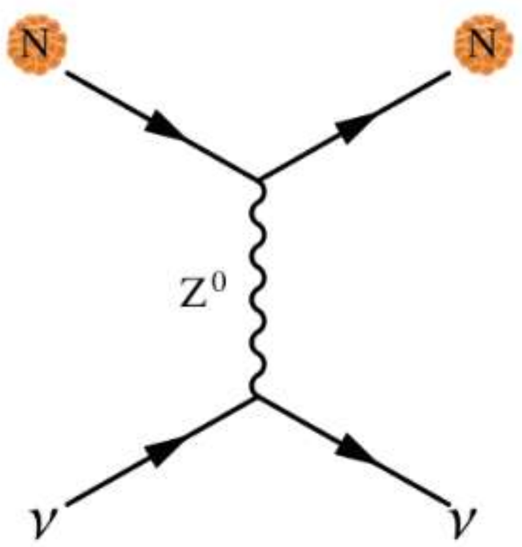
April 24$^{th}$, Vienna. IAEA

**23 Institutions (USA, Russia, Canada, Korea)**

# Coherent Elastic neutrino-Nucleus Scattering (CEvNS)

A neutrino scatters on a nucleus via exchange of a Z, and the nucleus recoils as a whole;

**coherent** up to $E_\nu \sim 50$ MeV




**D.Z. Freedman PRD 9 (1974)**

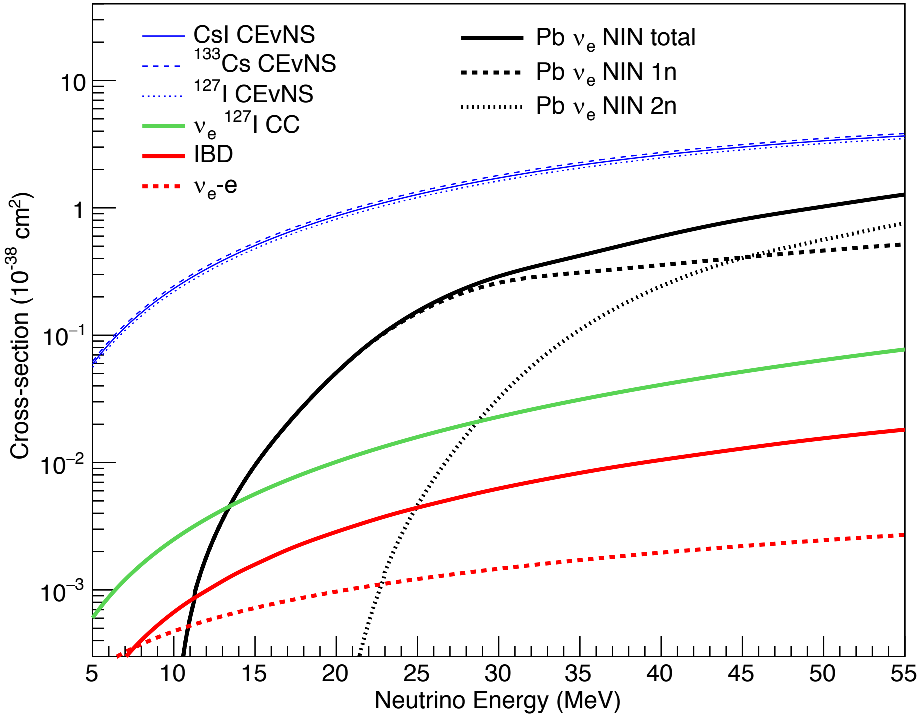
**Submitted Oct 15, 1973**

> 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.

**V.B.Kopeliovich & L.L.Frankfurt**

**JETP Lett. 19 (1974)**

**Submitted Jan 7, 1974**




**CEvNS cross-section is large!**

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

**Out of many neutrino interactions CEvNS and scattering on electron do not have thresholds**

**If one like to study neutrino reactor spectra below 1.8 MeV → try to use CEvNS**



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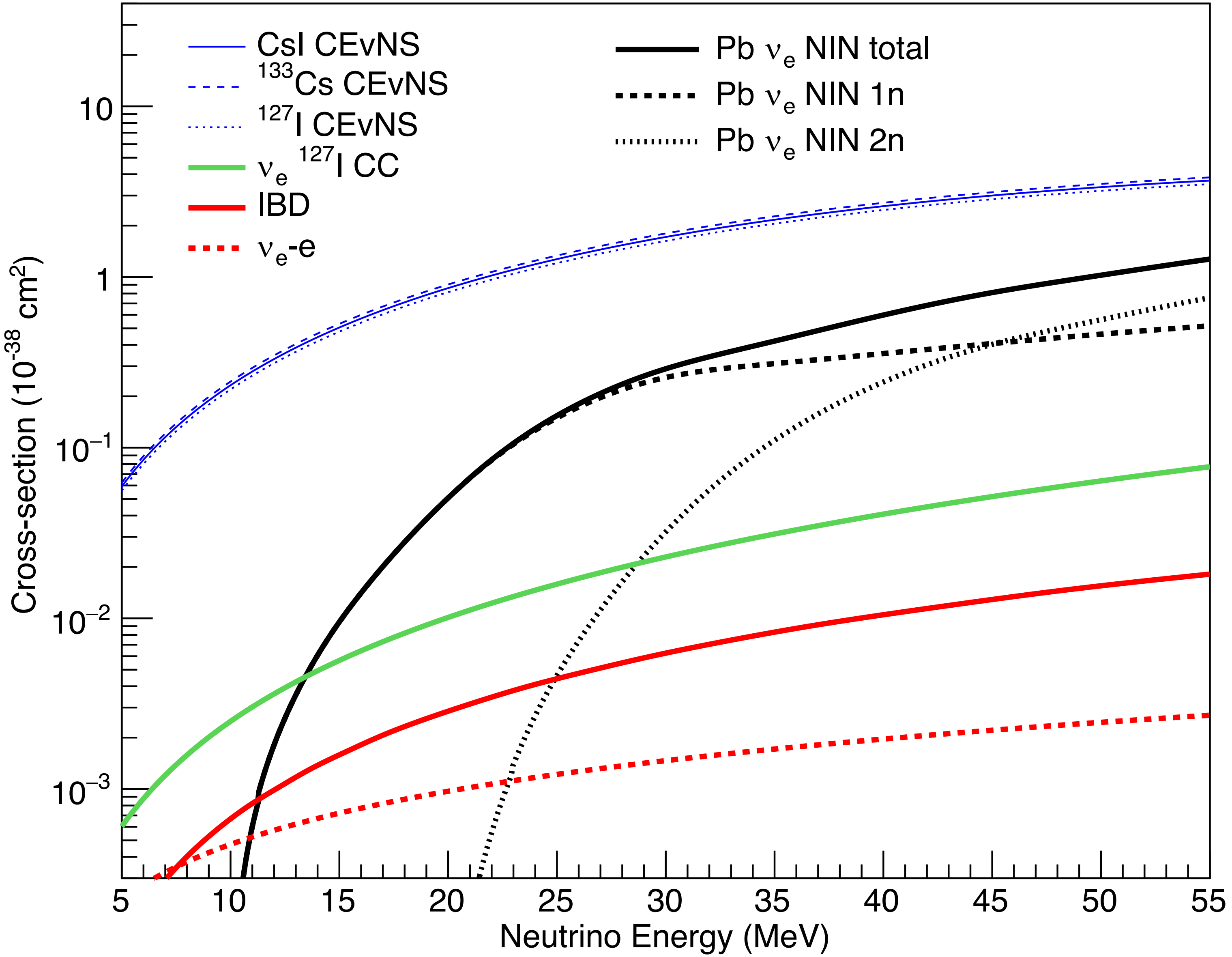
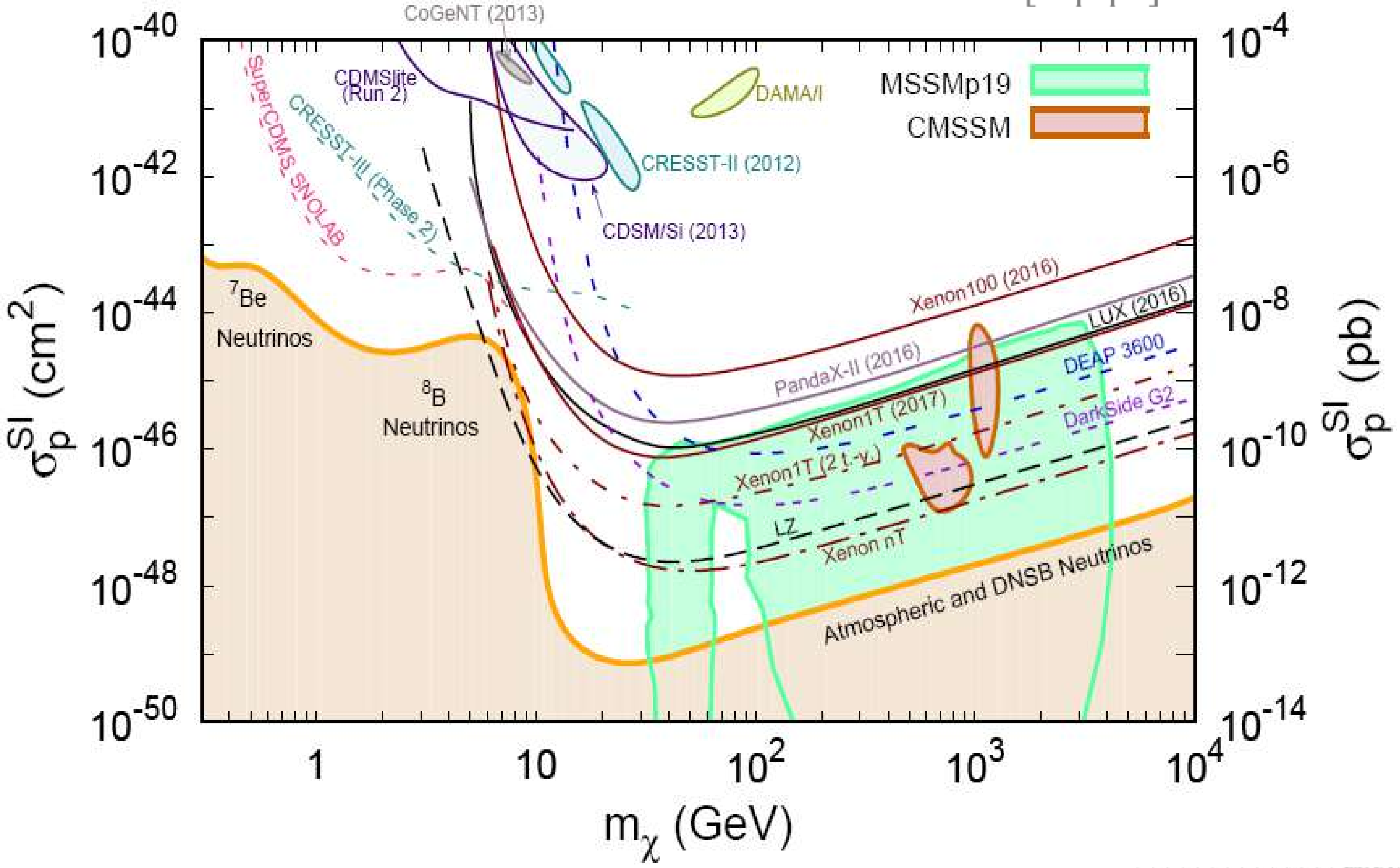


CsI CEvNS
$^{133}$Cs CEvNS
$^{127}$I CEvNS
$\nu_e$ $^{127}$I CC
IBD
$\nu_e$-e
Pb $\nu_e$ NIN total
Pb $\nu_e$ NIN 1n
Pb $\nu_e$ NIN 2n
Cross-section ($10^{-38}$ cm$^2$)
10
1
$10^{-1}$
$10^{-2}$
$10^{-3}$
5
10
15
20
25
30
35
40
45
50
55
Neutrino Energy (MeV)

# CEvNS is irreducible background floor for DM experiments

arXiv:1707.06277v1 [hep-ph] 19 Jul 2017



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# Why CEvNS is interesting?
# Non-Standard Interactions of Neutrinos

new interactions specific to ν's

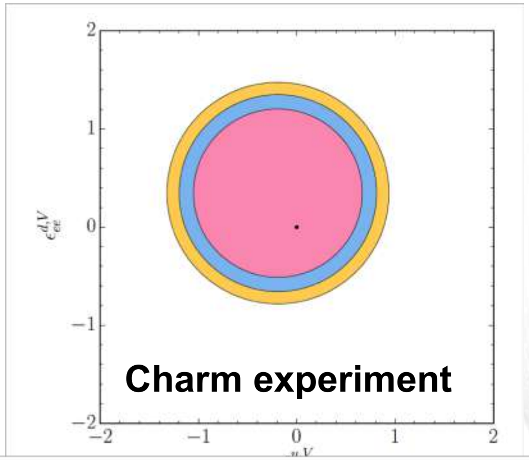
$$\mathcal{L}_{\nu H}^{NSI} = -\frac{G_F}{\sqrt{2}} \sum_{\substack{q=u,d \\ \alpha,\beta=e,\mu,\tau}} [\bar{\nu}_\alpha \gamma^\mu (1-\gamma^5)\nu_\beta] \times (\varepsilon_{\alpha\beta}^{qL}[\bar{q}\gamma_\mu(1-\gamma^5)q] + \varepsilon_{\alpha\beta}^{qR}[\bar{q}\gamma_\mu(1+\gamma^5)q])$$

J. H J. High Energy Phys. 03(2003) 011

TABLE I. Constraints on NSI parameters, from Ref. [35].

| NSI parameter limit | Source |
|---|---|
| $-1 < \varepsilon_{ee}^{uL} < 0.3$ | CHARM $\nu_e N$, $\bar{\nu}_e N$ scattering |
| $-0.4 < \varepsilon_{ee}^{uR} < 0.7$ | |
| $-0.3 < \varepsilon_{ee}^{dL} < 0.3$ | CHARM $\nu_e N$, $\bar{\nu}_e N$ scattering |
| $-0.6 < \varepsilon_{ee}^{dR} < 0.5$ | |
| $\lvert\varepsilon_{\mu\mu}^{uL}\rvert < 0.003$ | NuTeV $\nu N$, $\bar{\nu} N$ scattering |
| $-0.008 < \varepsilon_{\mu\mu}^{uR} < 0.003$ | |
| $\lvert\varepsilon_{\mu\mu}^{dL}\rvert < 0.003$ | NuTeV $\nu N$, $\bar{\nu} N$ scattering |
| $-0.008 < \varepsilon_{\mu\mu}^{dR} < 0.015$ | |
| $\lvert\varepsilon_{e\mu}^{uP}\rvert < 7.7 \times 10^{-4}$ | $\mu \to e$ conversion on nuclei |
| $\lvert\varepsilon_{e\mu}^{dP}\rvert < 7.7 \times 10^{-4}$ | $\mu \to e$ conversion on nuclei |
| $\lvert\varepsilon_{e\tau}^{uP}\rvert < 0.5$ | CHARM $\nu_e N$, $\bar{\nu}_e N$ scattering |
| $\lvert\varepsilon_{e\tau}^{dP}\rvert < 0.5$ | CHARM $\nu_e N$, $\bar{\nu}_e N$ scattering |
| $\lvert\varepsilon_{\mu\tau}^{uP}\rvert < 0.05$ | NuTeV $\nu N$, $\bar{\nu} N$ scattering |
| $\lvert\varepsilon_{\mu\tau}^{dP}\rvert < 0.05$ | NuTeV $\nu N$, $\bar{\nu} N$ scattering |

**Non-Standard ν Interactions (Supersummetry, neutrino mass models) can impact the cross-section differently for different nuclei**

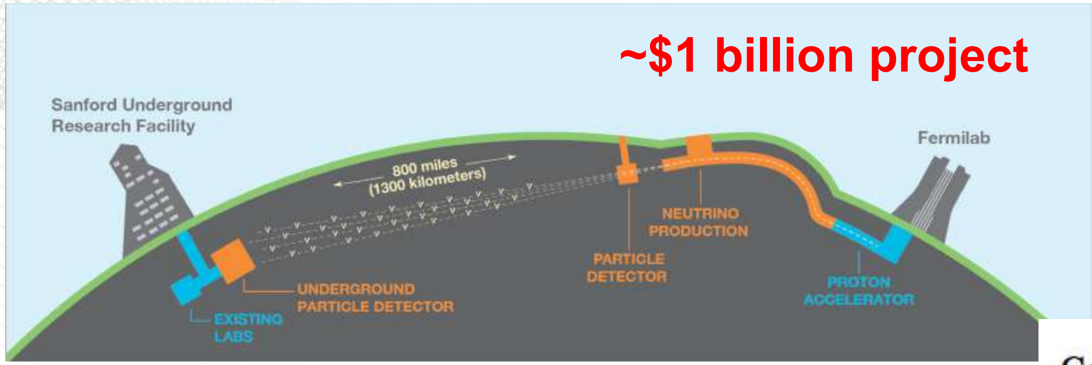



Curtailing the Dark Side in Non-Standard Neutrino Interactions

Pilar Coloma[a] Peter B. Denton,[a,b,1] M. C. Gonzalez-Garcia,[c,d,e] Michele Maltoni,[f] Thomas Schwetz[g]

arXiv:1701.04828v2 [hep-ph] 20 Apr 2017

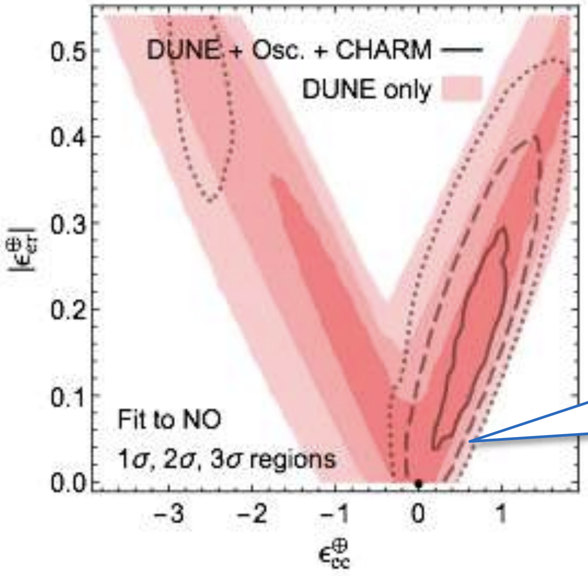
# Why CEvNS is interesting?
# Oscillation degeneracy for DUNE



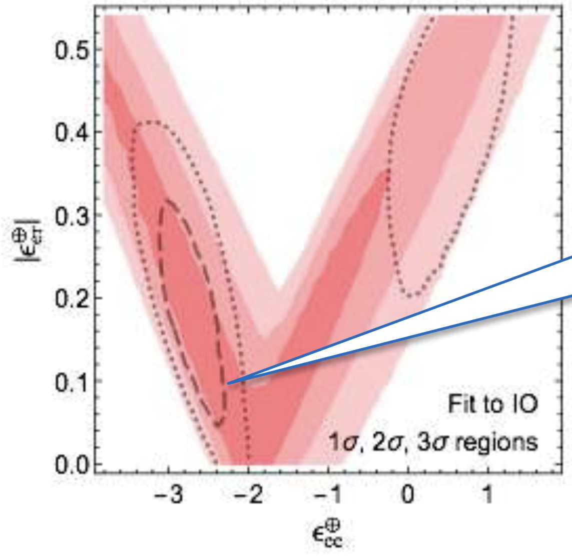

**– measuring the charge-parity (CP) violating phase CP,**
**– determining the neutrino mass ordering (the sign of $\Delta m^2_{12}$)**
**– precision tests of the three-flavor neutrino oscillation paradigm**

Generalized mass ordering degeneracy in neutrino oscillation experiments

Pilar Coloma[1] and Thomas Schwetz[2] arXiv:1604.05772v1




NO w/no NSI...




...looks just like IO w/NSI

**If you allow for NSI to exist, Degeneracy appears.**

**We can not tell the neutrino mass ordering without constrains on NSI**

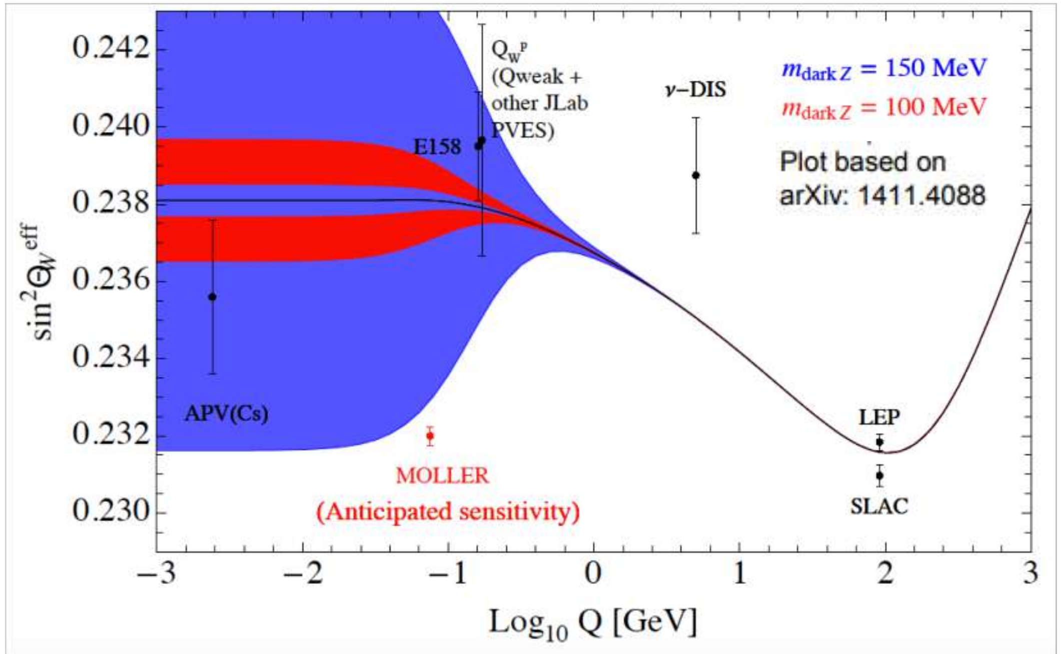
# Why CEvNS is interesting?
# It is sensitive to the Electro Week angle at low Q

$$\begin{pmatrix} \gamma \\ Z^0 \end{pmatrix} = \begin{pmatrix} \cos\theta_W & \sin\theta_W \\ -\sin\theta_W & \cos\theta_W \end{pmatrix} \begin{pmatrix} B^0 \\ W^0 \end{pmatrix}$$

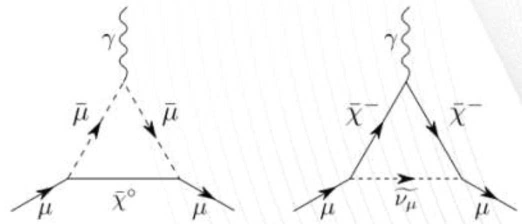
$$\sigma_{tot} = \frac{G_F^2 E_\nu^2}{4\pi}\left[Z\left(1-4\sin^2\theta_W\right)-N\right]^2 F^2(Q^2)$$

**Measurements with targets having different Z/N ratio are required.**

**$\text{Sun}^2\theta_w$ is a free parameter in the Standard Model**
**There is no fundamental theory which explain its value**
**It is "running" constant, its value depends on the momentum transfer.**




**Proposed correction to g-2 for muon magnetic moment due to a light mediator**

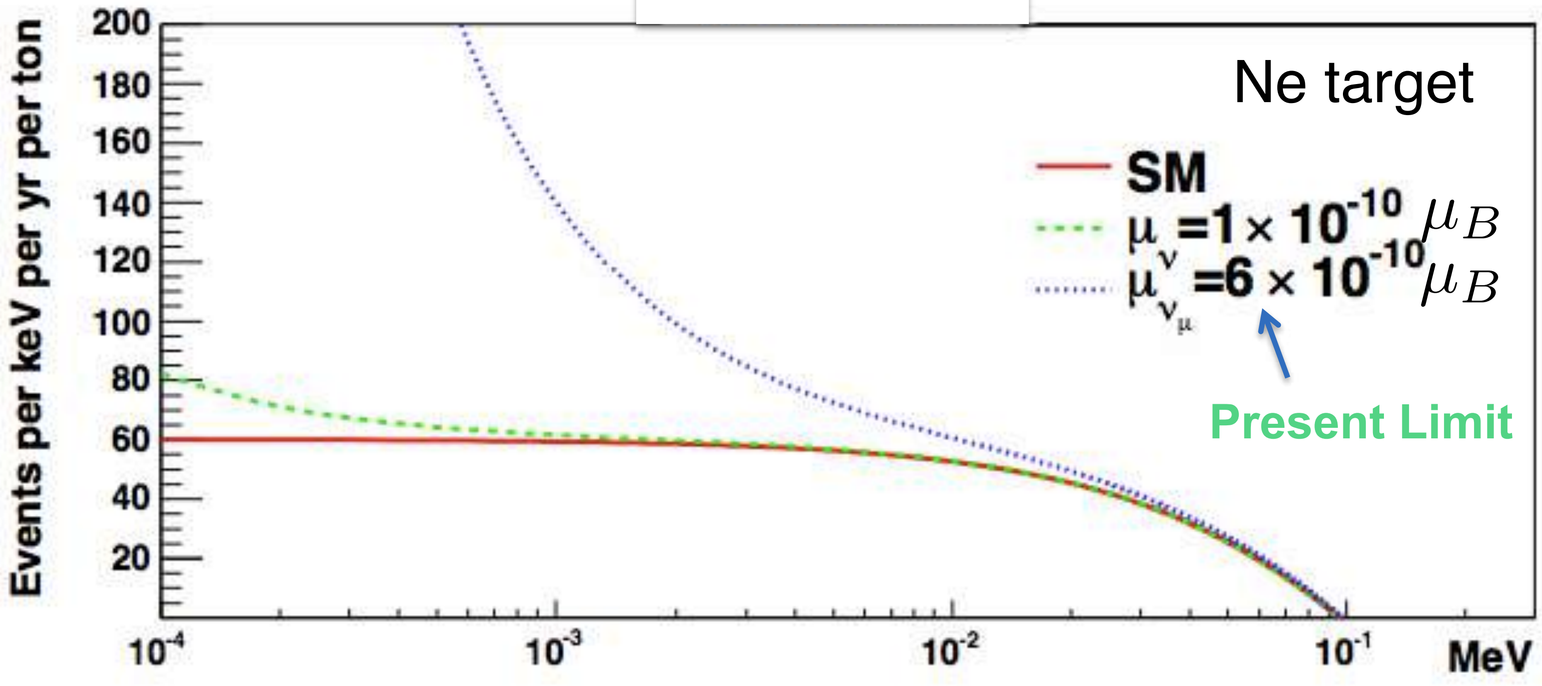



**If this is correct it can manifest itself in $\theta_w$ value at low $Q^2$**

# Why CEvNS are interesting?
## Search for neutrino magnetic moment

Signature is distortion at low recoil energy E

$$\frac{d\sigma}{dE} = \frac{\pi\alpha^2\mu_\nu^2 Z^2}{m_e^2}\left(\frac{1 - E/k}{E} + \frac{E}{4k^2}\right)$$




→requires detector with very low energy threshold

See also Kosmas et al., arXiv:1505.03202

# For first CEvNS detection COHERENT collaboration used SNS

- It is world  most powerful pulsed neutrino source. Presently it delivers 7 · $10^{20}$ POT daily

  *~10% of protons produce 3 neutrinos*

- Neutrino energies at SNS are ideal to study CEvNS.

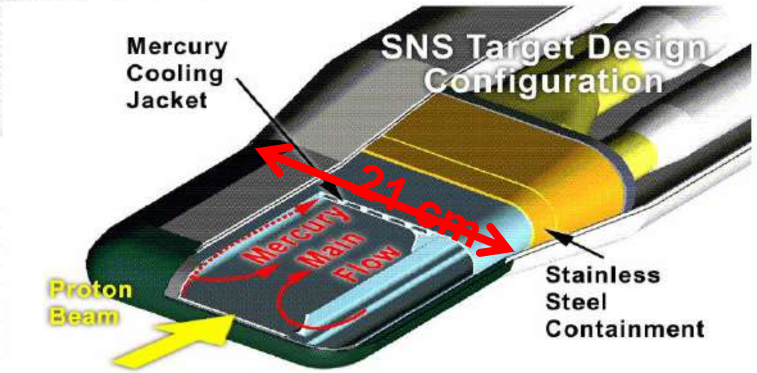
  *For 99% of neutrinos $E_\nu$ < 53 MeV*

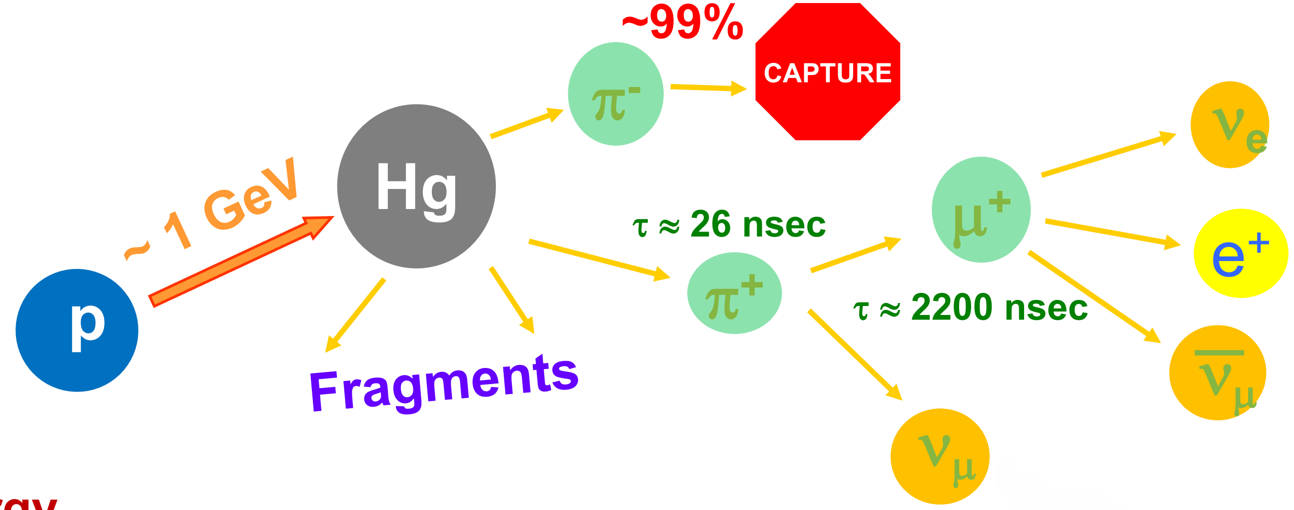
- Decay At Rest from pions and muons (DAR) gives very well defined neutrino spectra

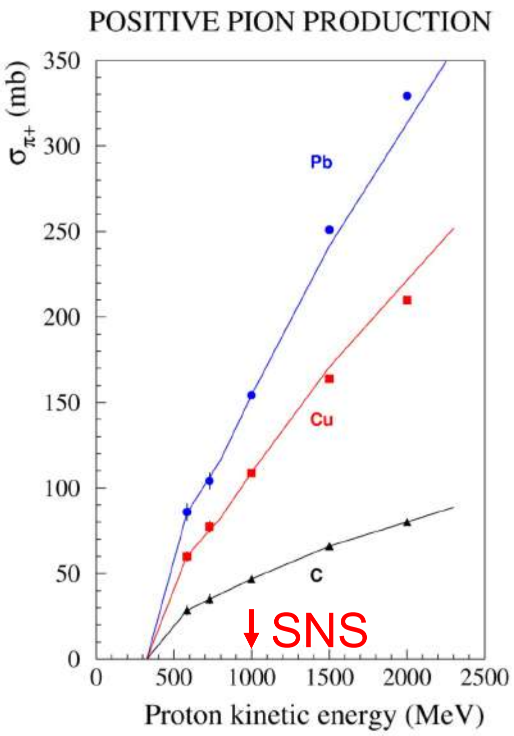
- Fine duty factor let suppression of steady background by a factor of 2000.

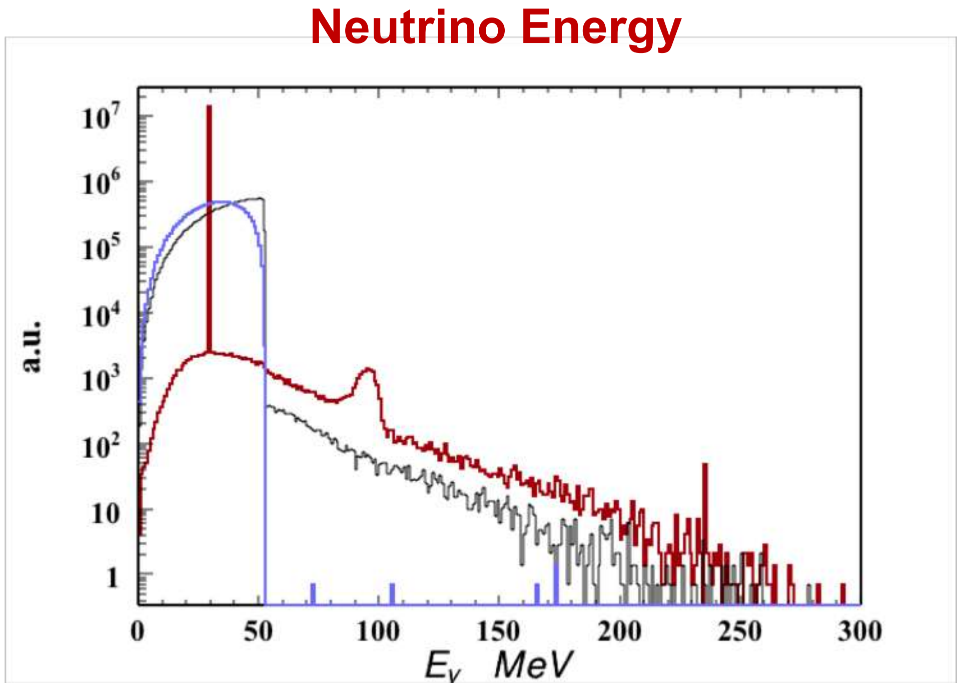
  *It is like being at the 1000 m.w.e underground*

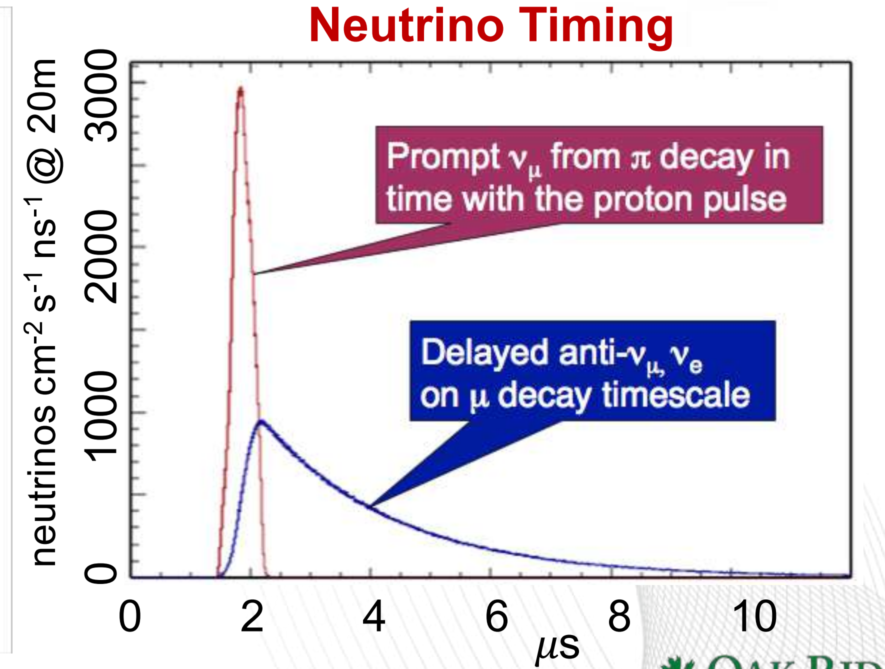
# Neutrino Production at the SNS



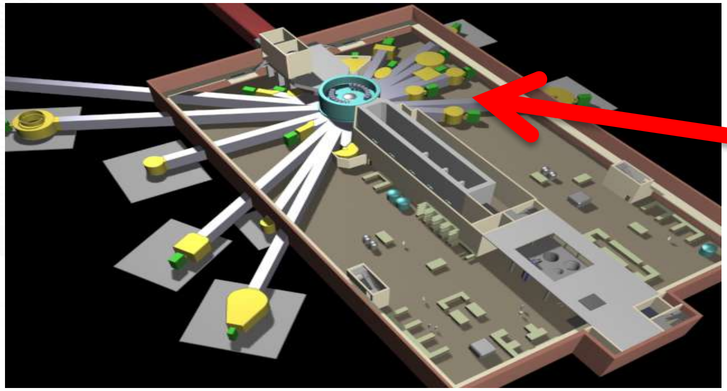



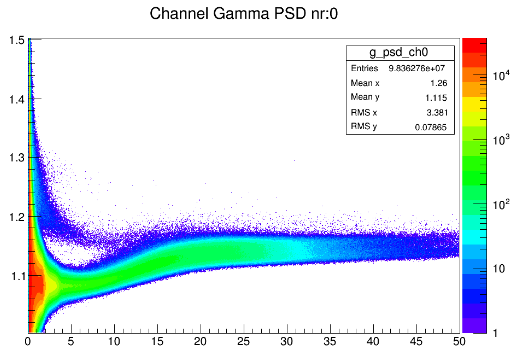




**Present Uncertainties in the neutrino flux is ~10%**

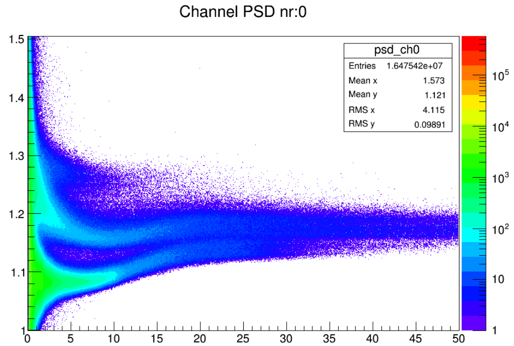
# Search for a good Spot at the SNS

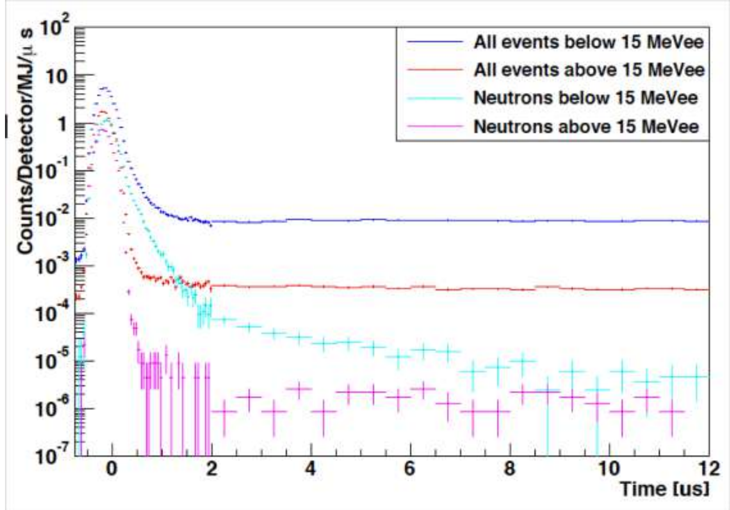


"Out-of-beam" events, primarily muons and gammas




"In-Beam" events, considerably more neutron events




Neutrons flux in the target building is 100000 times more than we can tolerate

Time structure is similar to the ones from neutrinos



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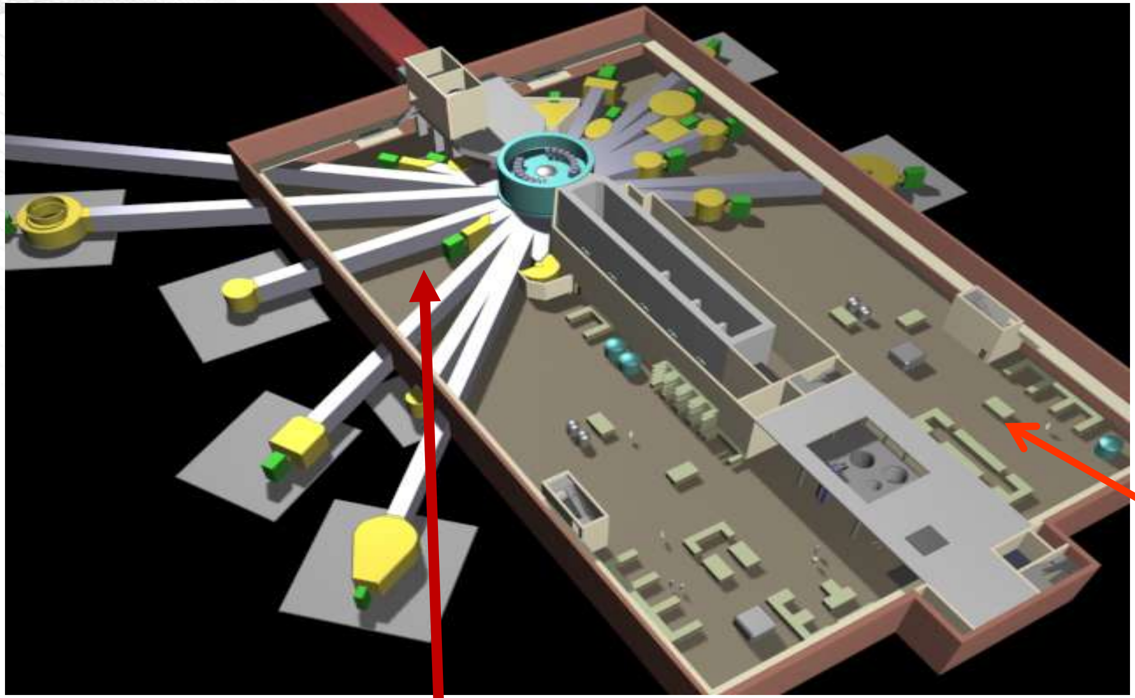
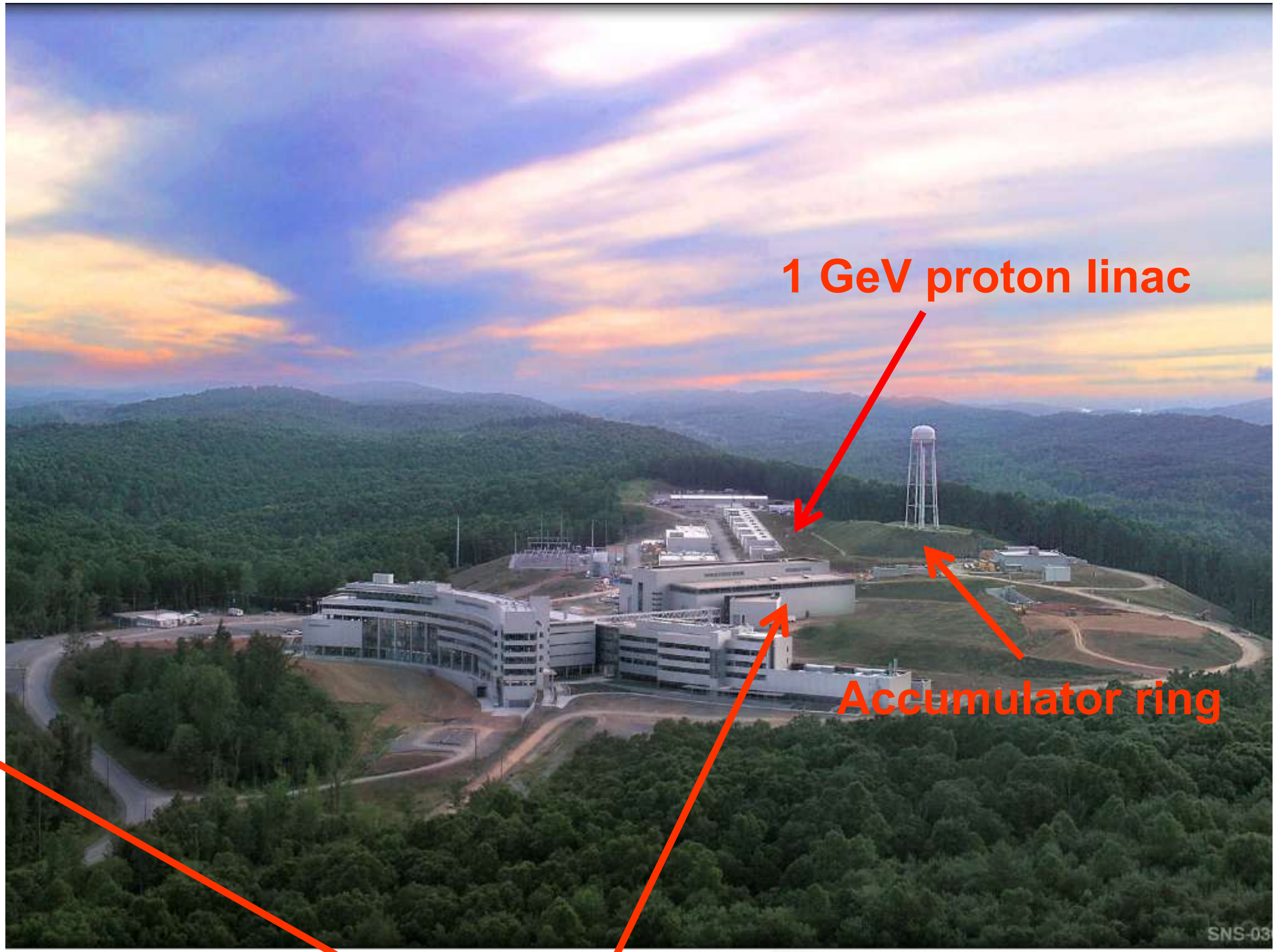
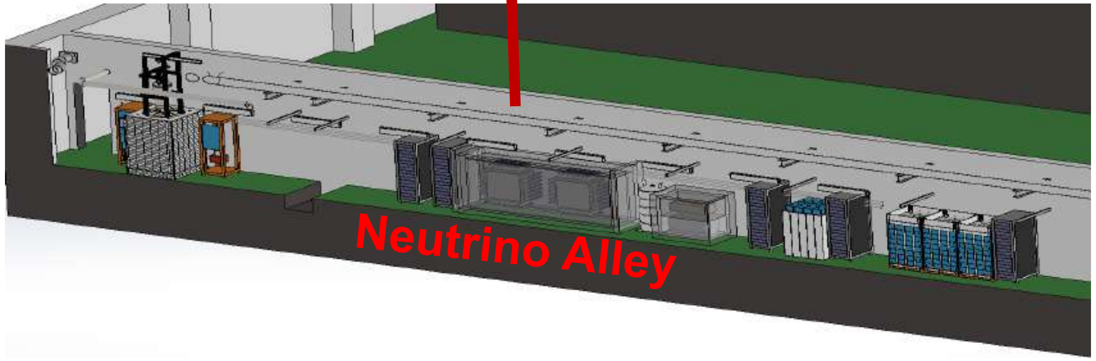
# Neutrino Alley Location

After extensive BG program study we find a well protected location





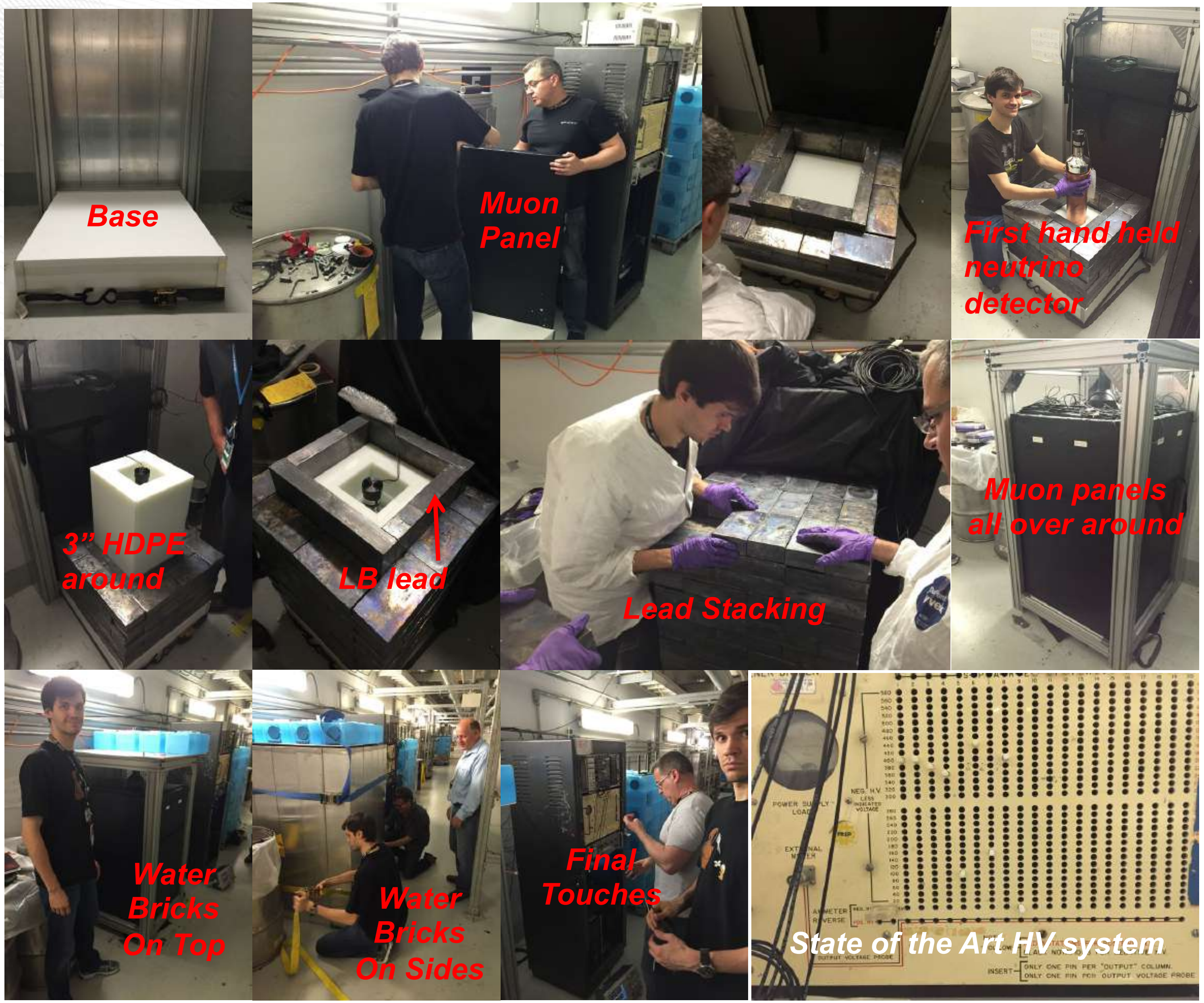

**Target Building**

After extensive background studies, good place for experiment has been located at the SNS basement → Neutrino Alley.

It is 20-30 meters from the target. Space between target and alley is filled with steel, gravel and concrete

There are 10 MWE from above

# First Deployment: 14 kg CsI Detector




Single CsI crystal.

It has been custom grown from preselected low background material

Layers of dedicated shielding:

Poly to protect from NINs

Low background lead

Regular good quality lead

Veto system

Water shielding

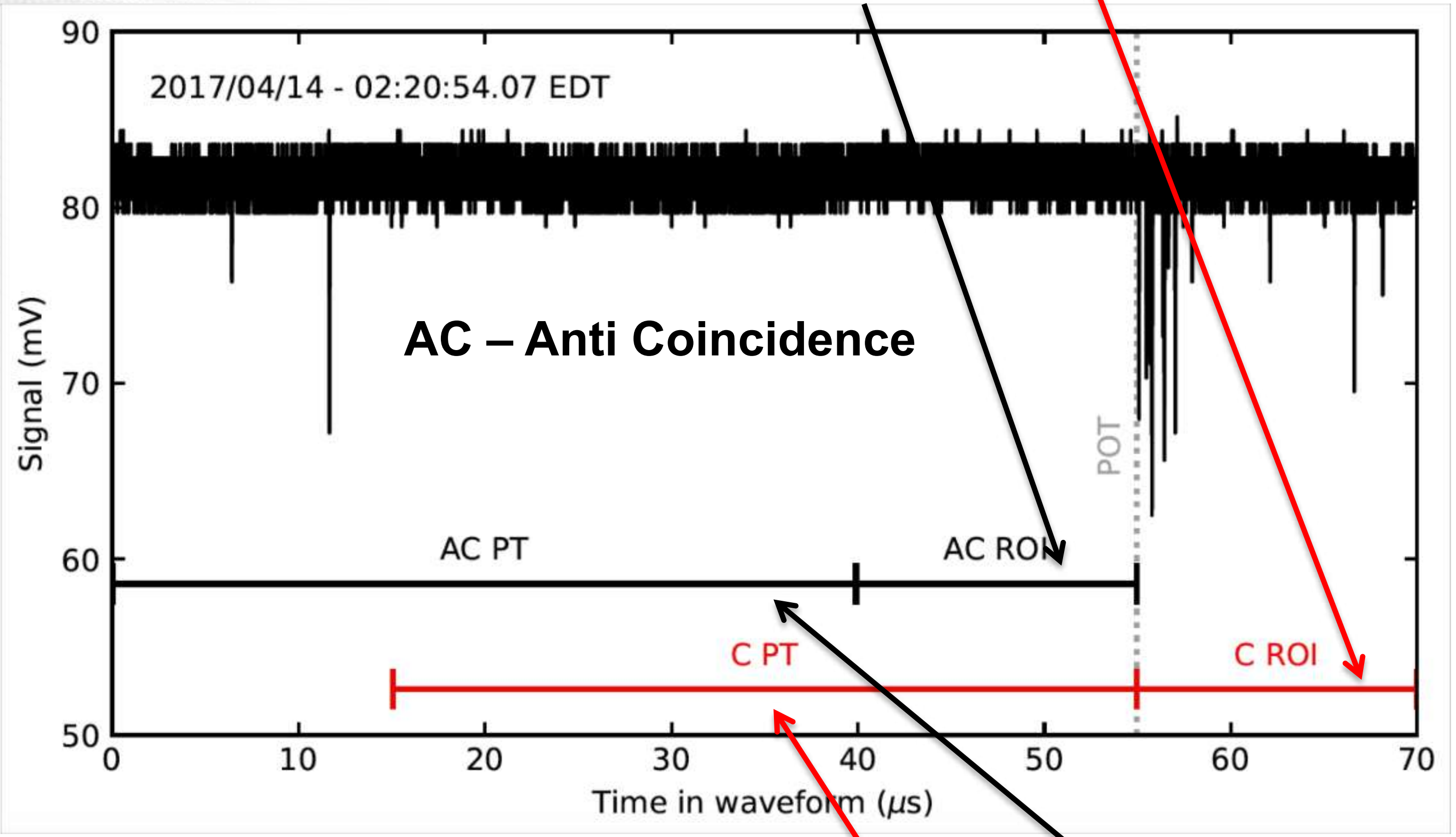
One day installation !!!!

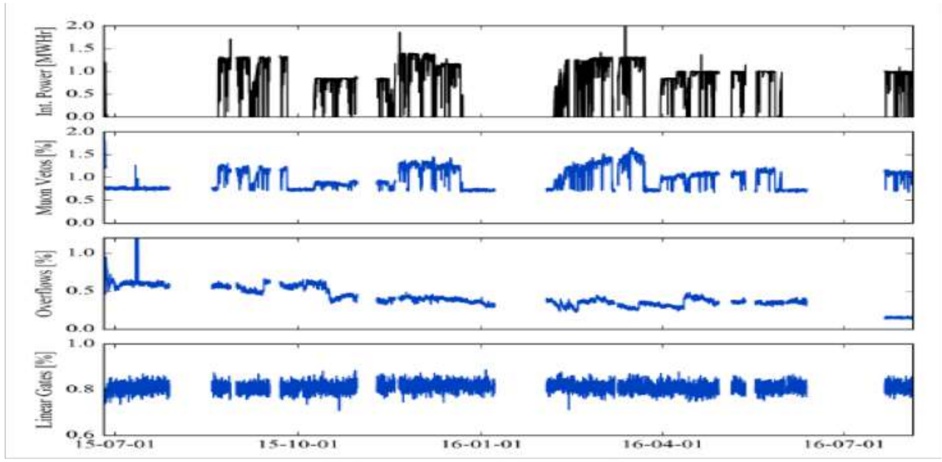
# CsI Events Selection Cuts

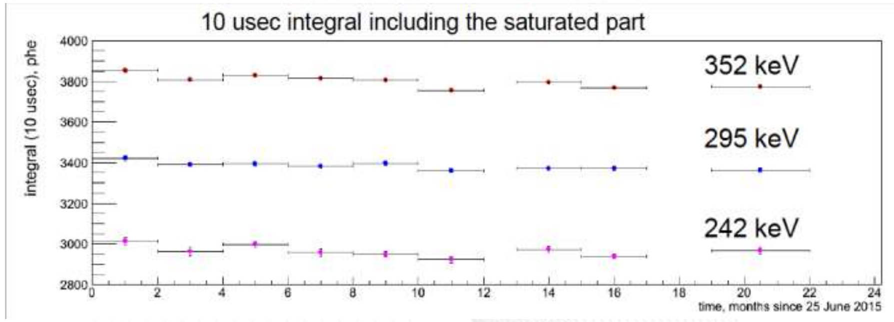
Cherenkov cut is to eliminate high amplitude short signals

**Analysis procedure:**

**Apply same "Cherenkov" cut for AC and signal and ROI windows**



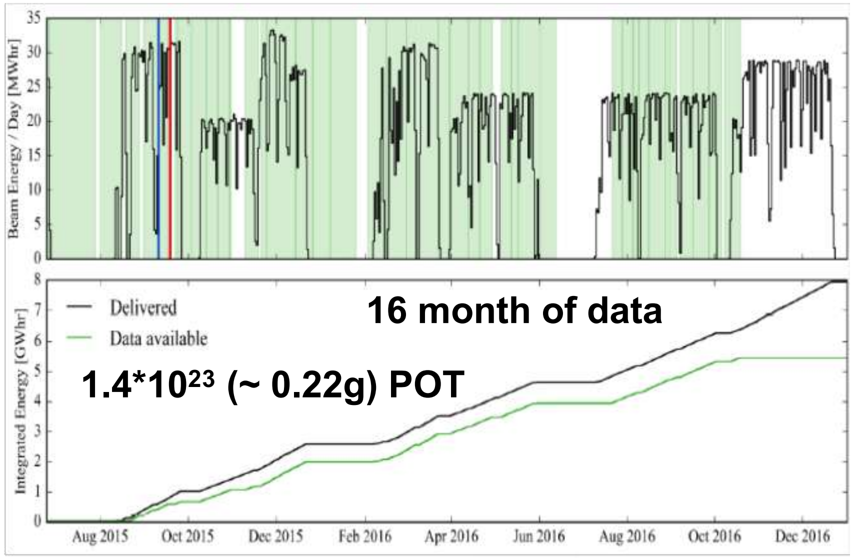

**Apply cut on prior activity using signal and AC pre trace windows**

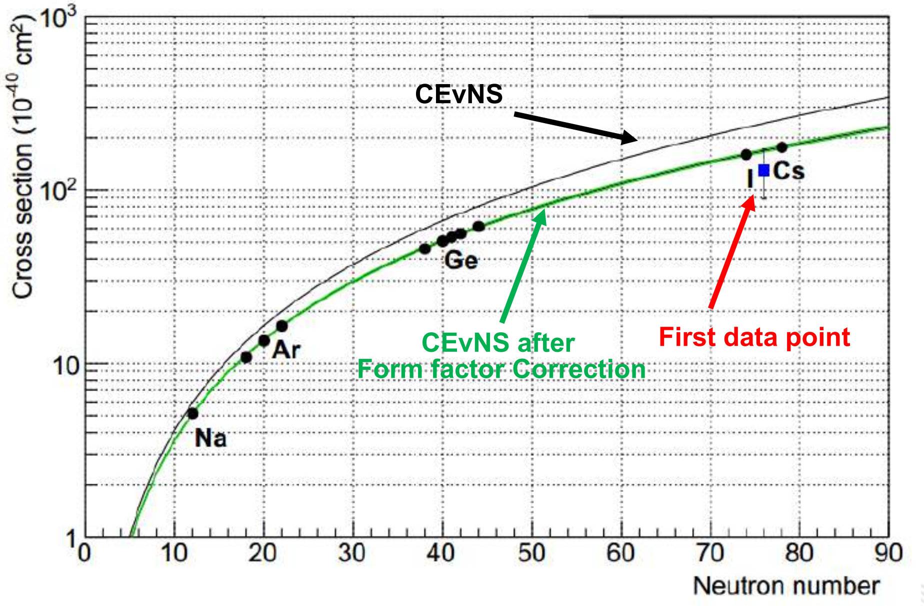
**Subtract BG ROI events from Signal ROI events.**

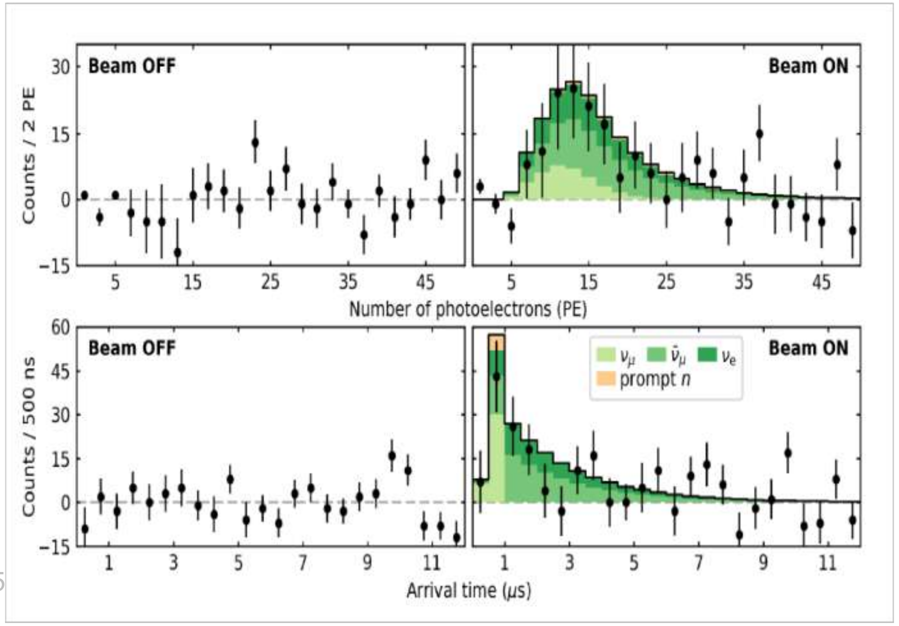
**Signal and BG are measured at the same time!!!**

# First Detection of CEvNS with CsI detector


First working hand held neutrino detector -14kg!!!




We continue to take data with CsI detector

Now we have x2.5 times more statistics. New update soon

# What Did We Learn So far?

**CEvNS does exists**
**However, nobody doubt that !!!**

"It's a real thrill that something that I predicted 43 years ago has been realized experimentally,"

Daniel Freedman

**SNS is beautiful low energy pulsed neutrino source with "Neutrino Alley"**

**We know how to detect CEvNS**

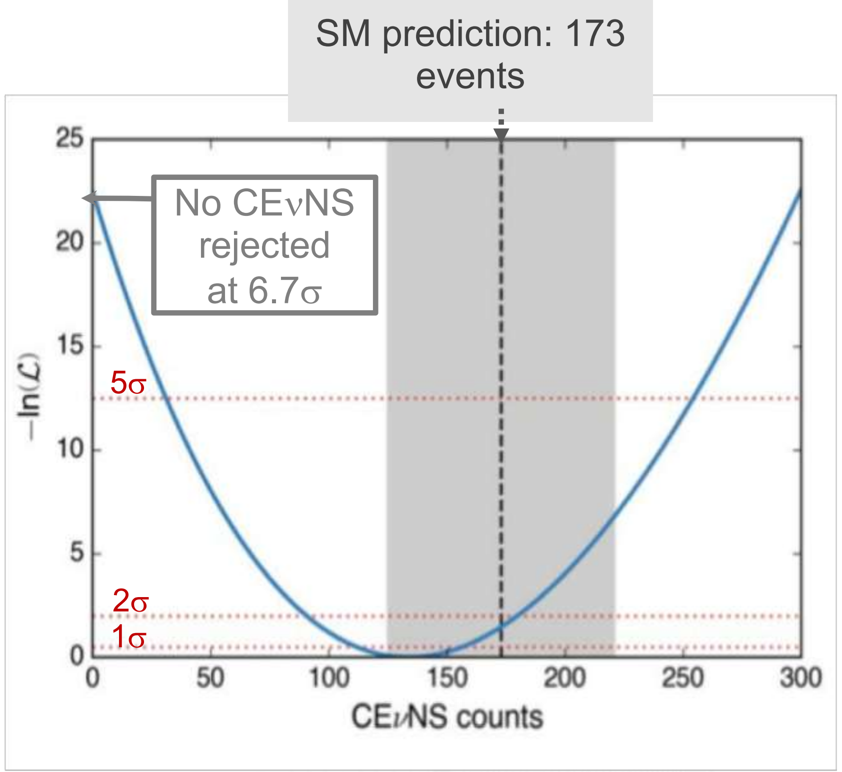
**So far we have a binary answers "*YES*"**

***Next step is precision measurements of CEvNS cross sections to search for anomalies***

# Some Details About the First CEvNS Detection

| | |
|---|---|
| Beam ON coincidence window | 547 counts |
| Anticoincidence window | 405 counts |
| Beam-on bg: prompt beam neutrons | 7.0 ± 1.7 |
| Beam-on bg: NINs (neglected) | 4.0 ± 1.3 |
| Signal counts, 2D likelihood fit | 134 ± 22 (16%) |
| Predicted SM signal counts | 173 ± 48 (28%) |

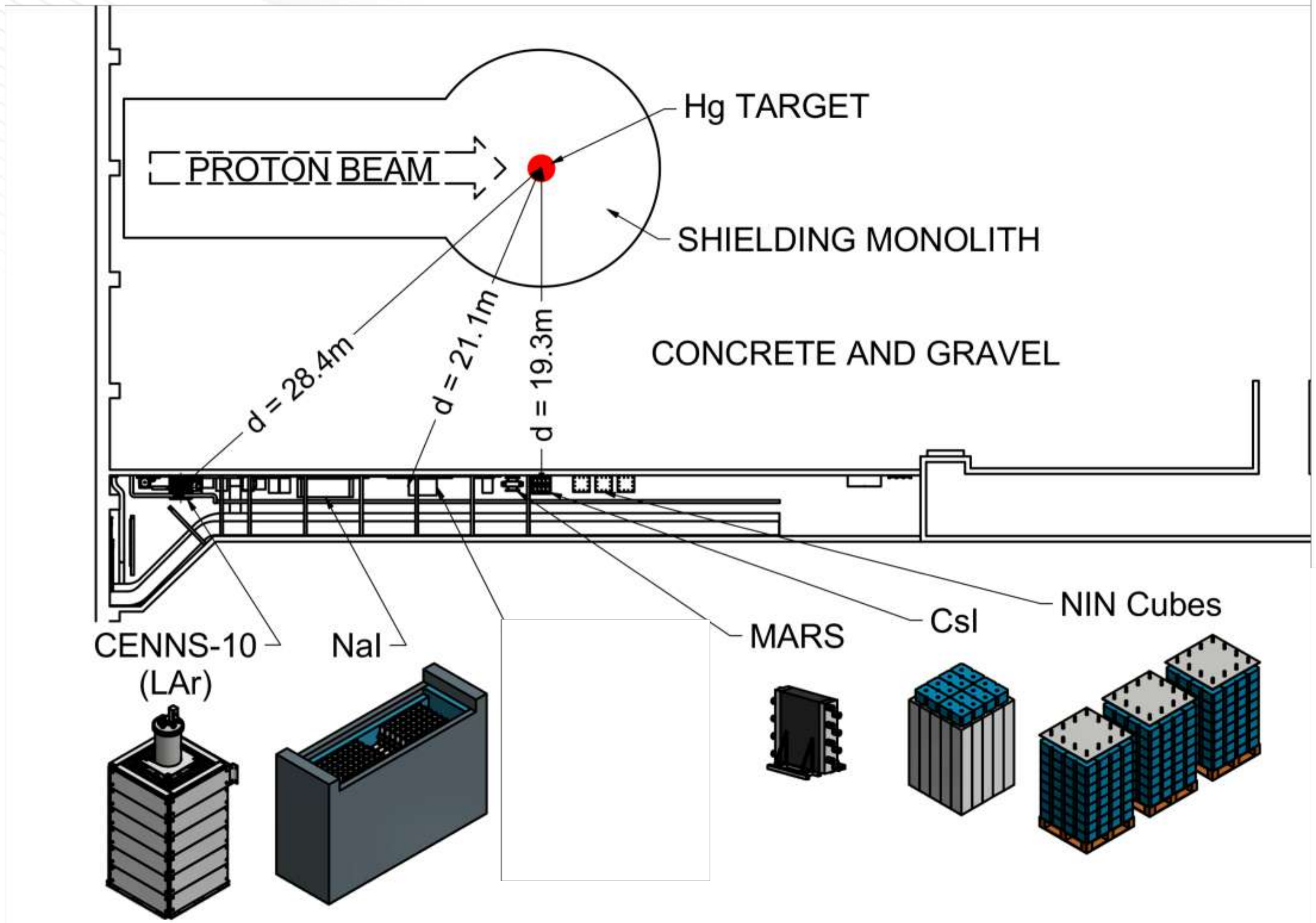
| Uncertainties on signal and background predictions | |
|---|---|
| Event selection (signal acceptance) | 5% |
| Form Factor | 5% |
| Neutrino Flux | 10% |
| CsI Quenching Factor (QF) | 25% |
| Total uncertainty on signal prediction | 28% |

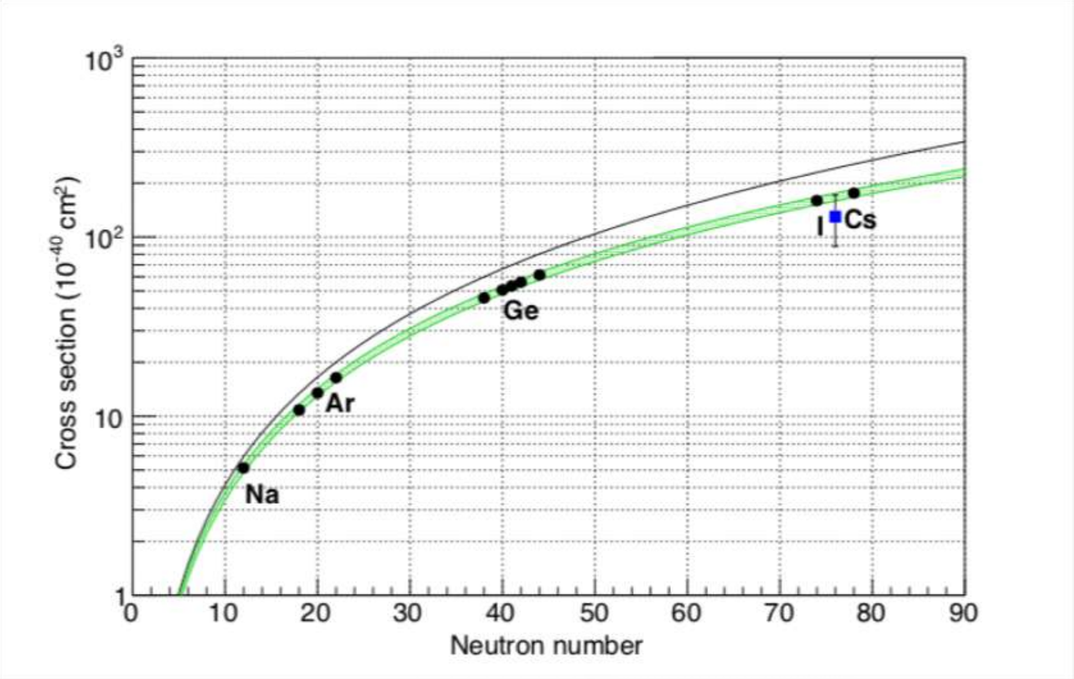



**All uncertainties except neutrino flux are detector specific and could be much less for other technologies**

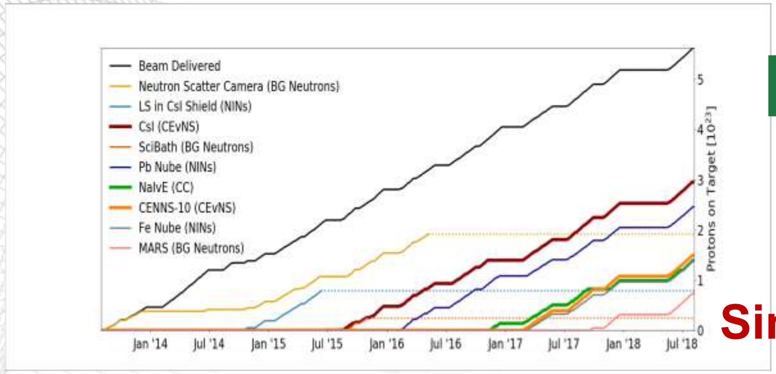
**To unlock high precision CEvNS program we need to calibrate SNS neutrino flux, measure QF well and accumulate large statistics on multiple targets**

# The Present COHERENT Program at the SNS

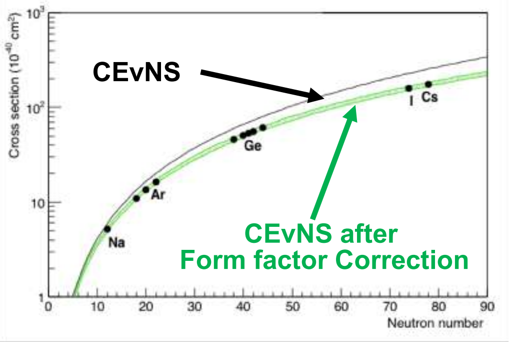



$N^2$ dependence of the CE$\nu$NS cross section.




# Next Step is Detection CEvNS With LAr Detector




**Single Phase Liquid Argon Detector CENNS-10**

**Aim is to detect CEvNS for a very different target**

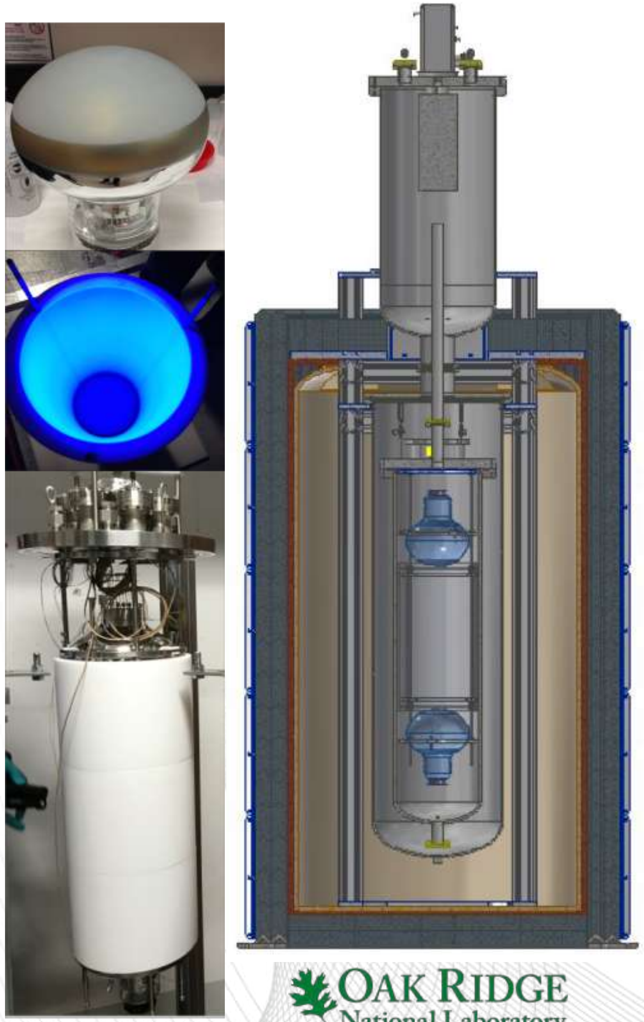
**CENNS-10 SNS timeline:**

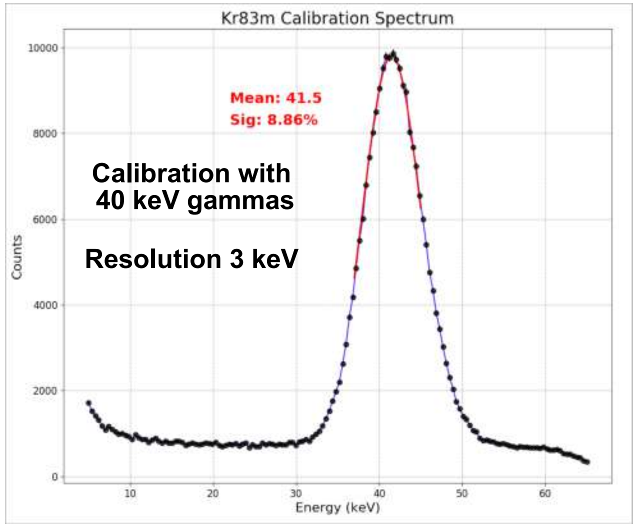
**10-12/2016: commission and deployed detector at SNS**

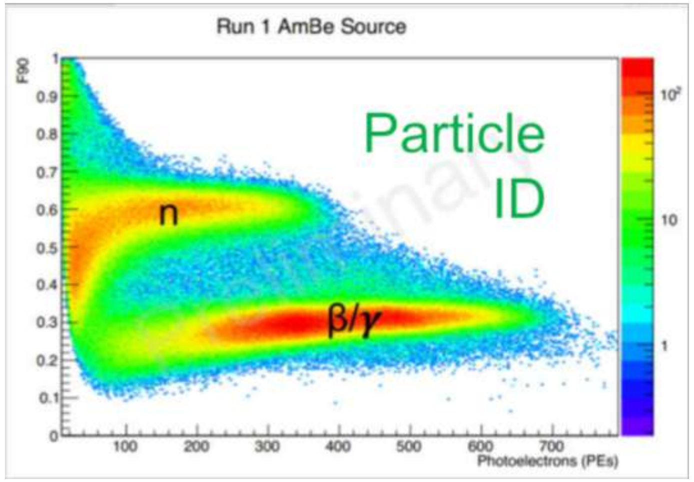
**We see about 4500 ph.e. per MeV**

**It should be enough to see CEvNS. $E_{thresh}$~20keVnr**

**Presently accumulated statistics is ~6 GWhr (~1.4*$10^{23}$ POT)**





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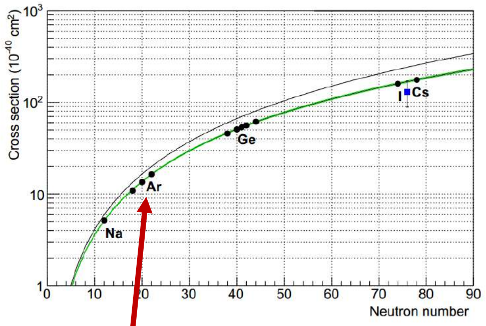
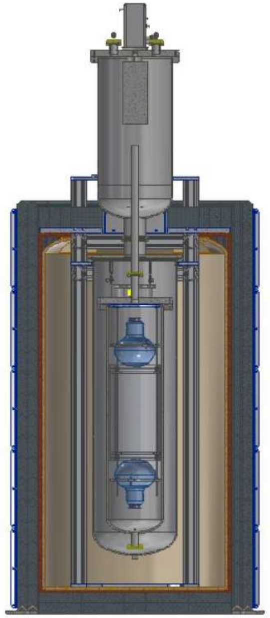
# Future Activities - 1 ton LAr detector




**Need high statistics low background measurements of CEvNS**

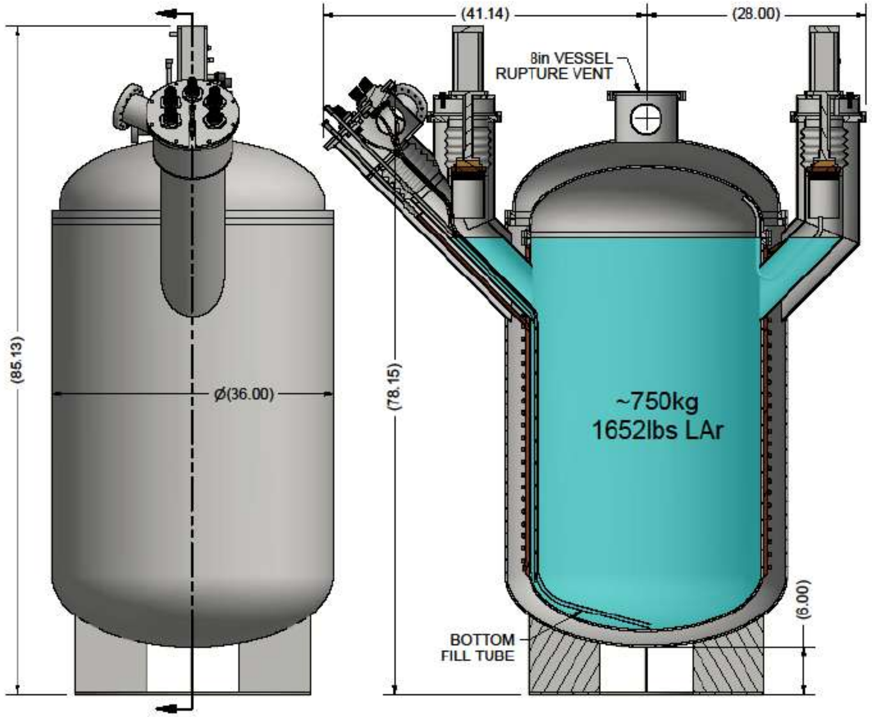


**Transition from 22 kg to 1 ton LAr detector.**

**Can fit at the same place where presently 22 kg detector is sitting**

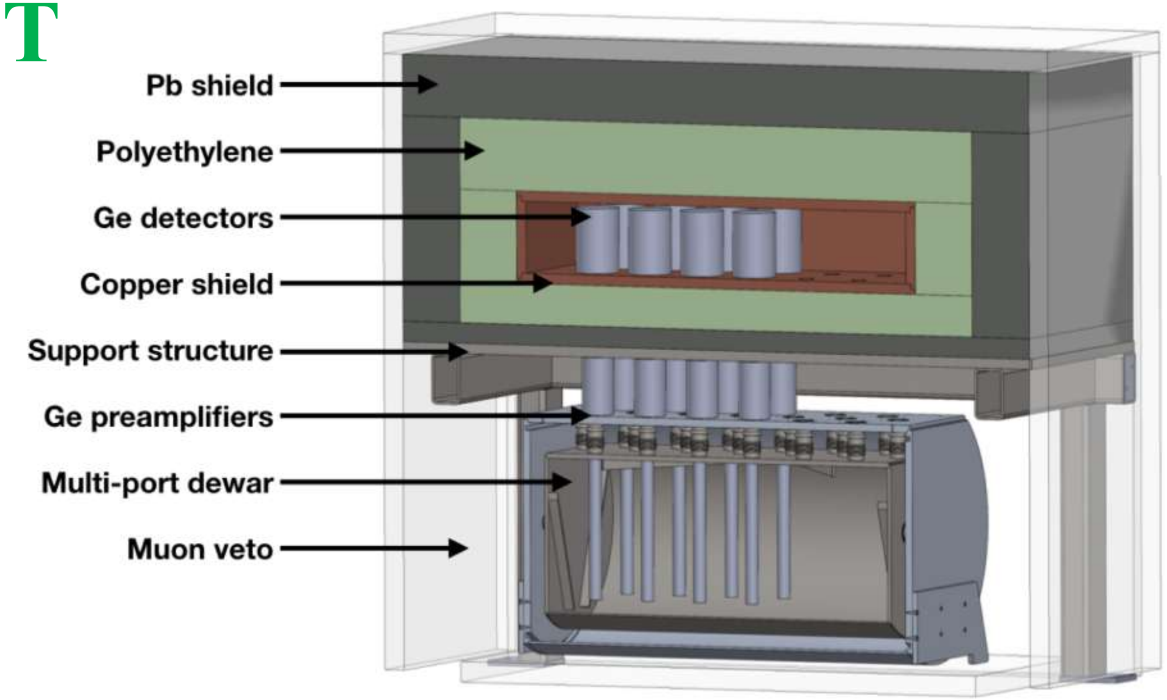
**Will see 3 000 of CEvNS events per year**

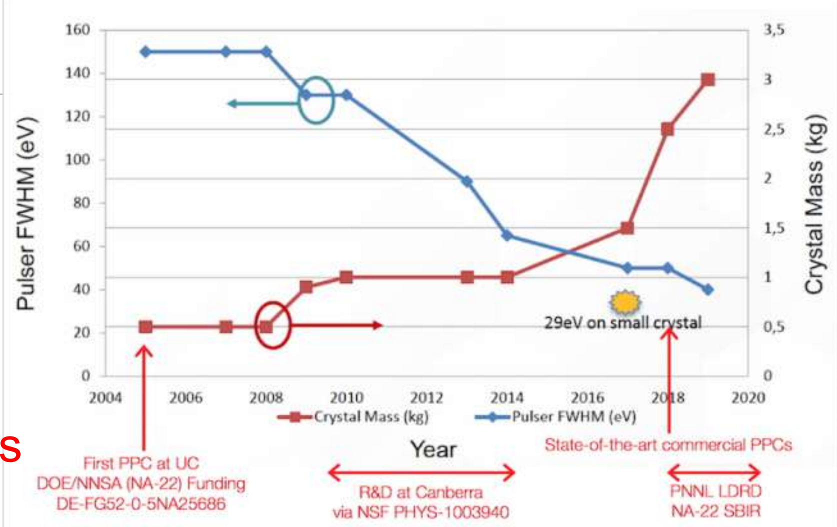
**+ CC (interest for DUNE SN program)**



# Ge PPC Detectors for COHERENT

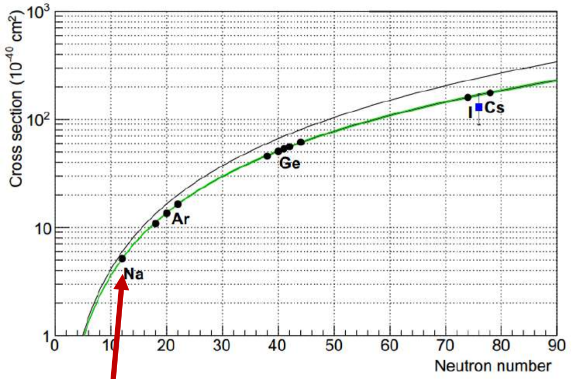
- Estimate 500 - 600 CEvNS events/year in a 16 kg array.
- Electronic noise from detector + preamp limited to < 150 eV FWHM.
    - Results in an energy threshold of ~0.4 keVee, roughly 2-2.5 keVnr.
- Cryostat already available.
- MRI proposal this year.




Excellent potential candidate technology for Reactor Neutrinos

# 2t NaI detectors array

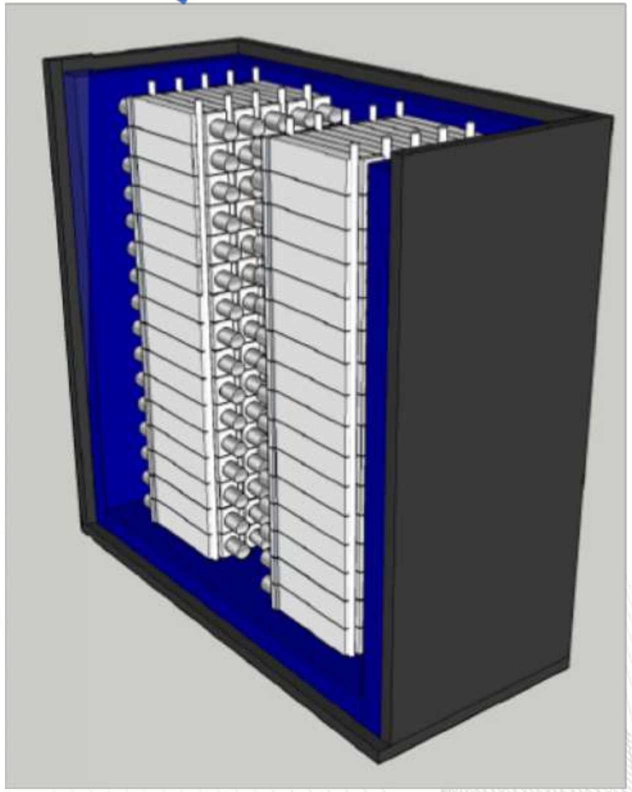



Transition from now deployed 185 kg to 2 ton array of NaI detectors

Detectors are available

Need dual gain bases (prototypes has been build)

Program to measure Quenching Factors is ongoing at TUNL



Potential to detect both CEvNS on Na and CC reactions on I

# Future Activities – SNS Neutrino Flux Normalization

Presently we assume that neutrino flux at SNS is known within 10%

Cross sections of neutrino interaction with Deuterium are known with 2-3% accuracy

*S.Nakamura et. al. Nucl.Phys. A721(2003) 549*

Prompt NC $\nu_\mu$ +d → $1.8 \times 10^{-41}$ cm$^2$
Delayed NC $\nu_{e\mu\text{-bar}}$+ d → $6.0 \times 10^{-41}$ cm$^2$
Delayed CC $\nu_e$ + d → $5.5 \times 10^{-41}$ cm$^2$

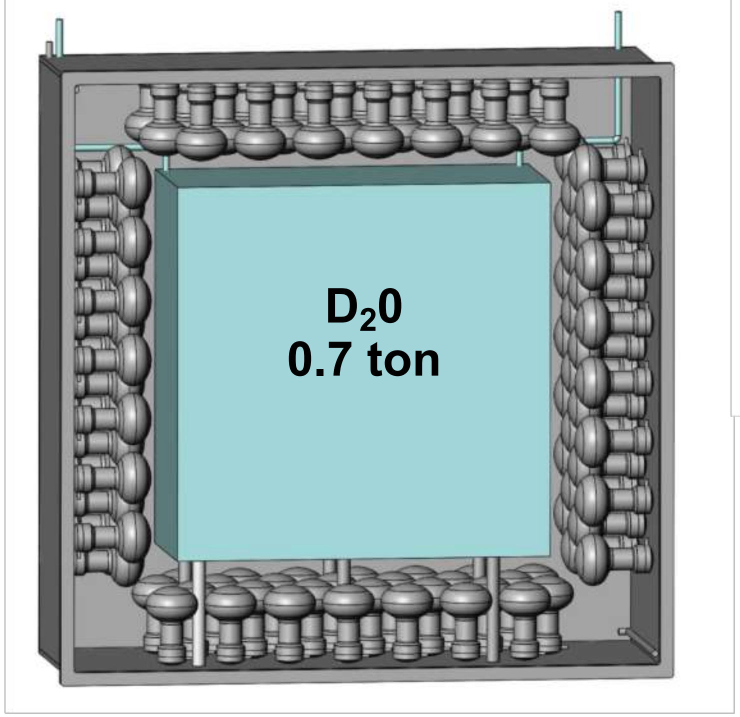
For 1 t fiducial mass detector ~ thousand interactions per year

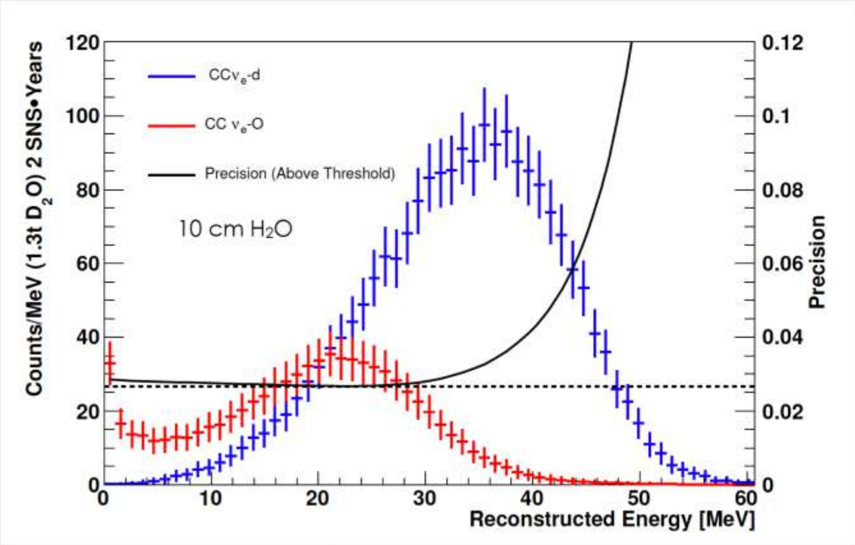
Detector calibration with Michel Electrons from cosmic muons (same energy range)

Well defined $D_2O$ mass constrained by acrylic tank

10 cm of light water tail catcher

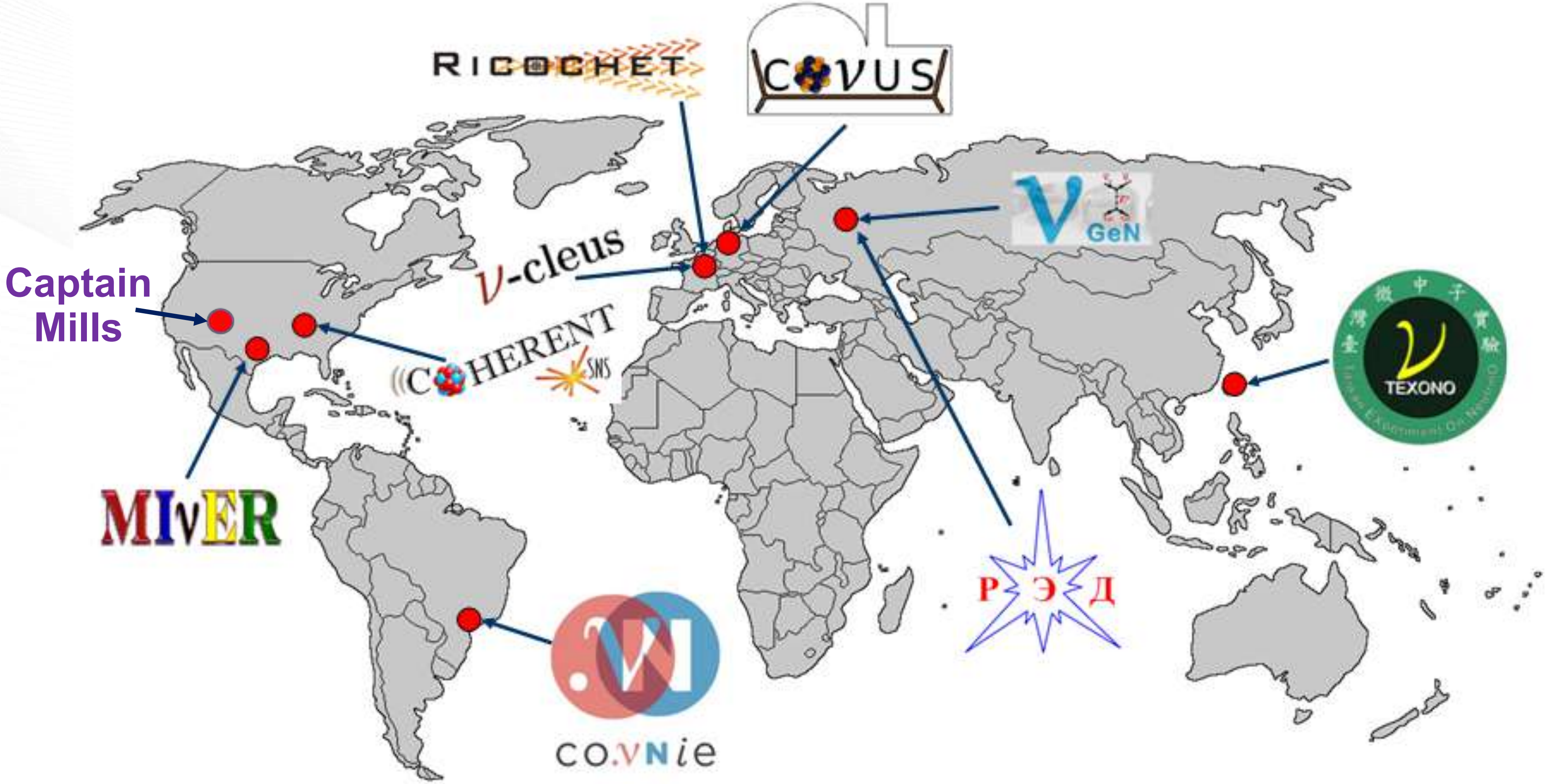
Outer dimensions 1.8 * 1.8 * 1.0 m$^3$




SNS calibration + CC measurements on Oxygen for SK SN neutrino program

# World Wide Efforts to Detect CEvNS




**Except COHERENT and CM collaborations, all others attempting to use nuclear reactors as a neutrino source**

**Nuclear reactors give large flux, but low energy neutrinos with a constant flux**

**Various detector technologies are being investigated. We heard first indication of positive signal from the Conus experiment last year**

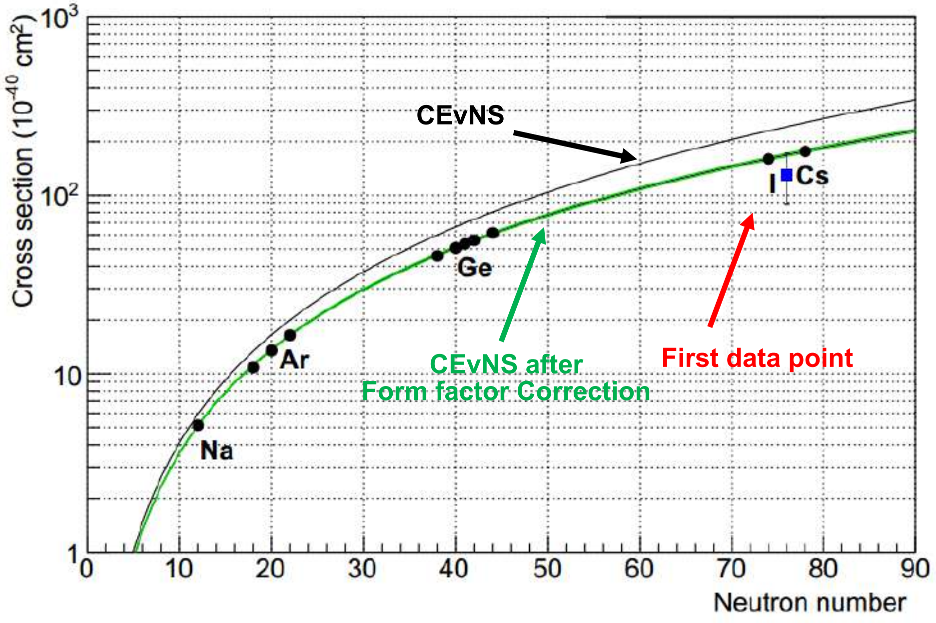
# Summary

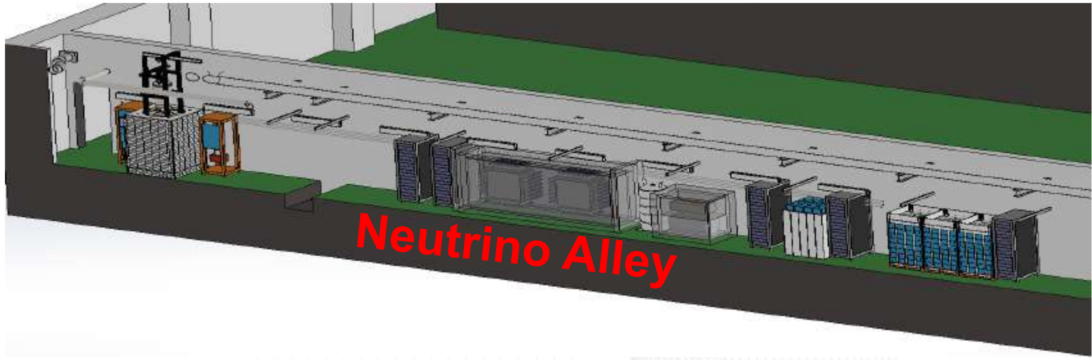
- Detection of CEvNS opened new portal to look for physics beyond the SM

- CEvNS experiments at nuclear reactors will open opportunity to test predictions for neutrino spectra below 1.8 MeV with extremely compact detectors.

- COHERENT collaboration is deploying several new detectors for precision tests of CM predictions for CEvNS for various nuclei

- Neutrino Alley at the SNS is ideal place to study various detector technologies for CEvNS

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