First Result From the COHERENT

Yuri Efremenko
on behalf of COHERENT collaboration

UTK/ORNL

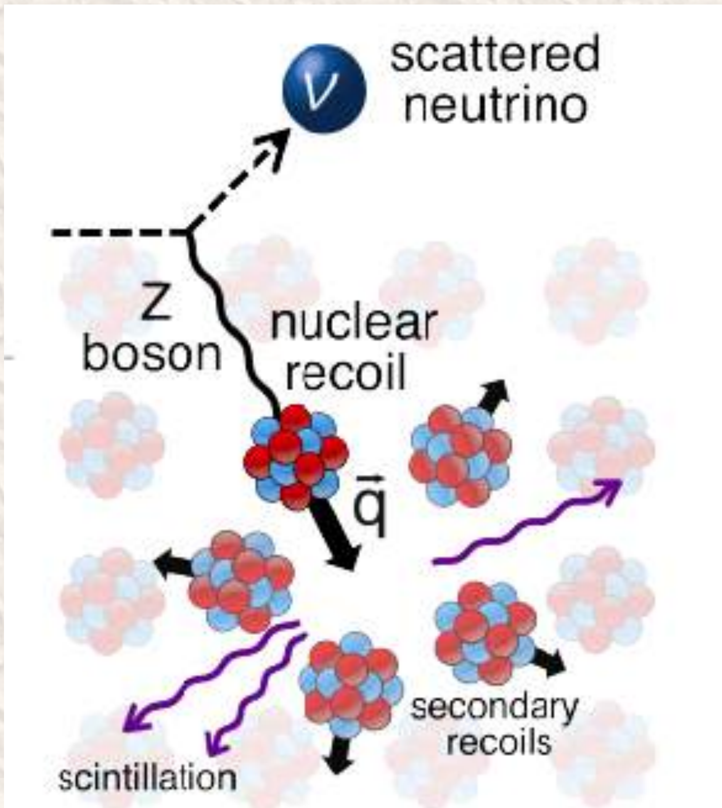
NuPhys2017
London, Dec 20 2017

All started a long time ago

PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790



- Neutral weak current process
- Low momentum transfer, $\lambda_z = 1/q > R_N$
- Identical initial and final states

<u>Enhanced cross-section for heavy nuclei!</u>

Coherence preserved for E_ν up to ~50 MeV

Current Eleatic Neutrino Nucleus Scattering (CEvNS)

$$\frac{d\sigma}{dT_A} = \frac{G_F^2}{4\pi} m_A \left[Z\left(1 - 4\sin^2\theta_W\right) - N \right]^2 \left[1 - m_A \frac{T_A}{2E_\nu^2} \right] F^2(Q^2)$$

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

m_A – *nucleus mass*

T_A – *kinetic energy of recoil nucleus*

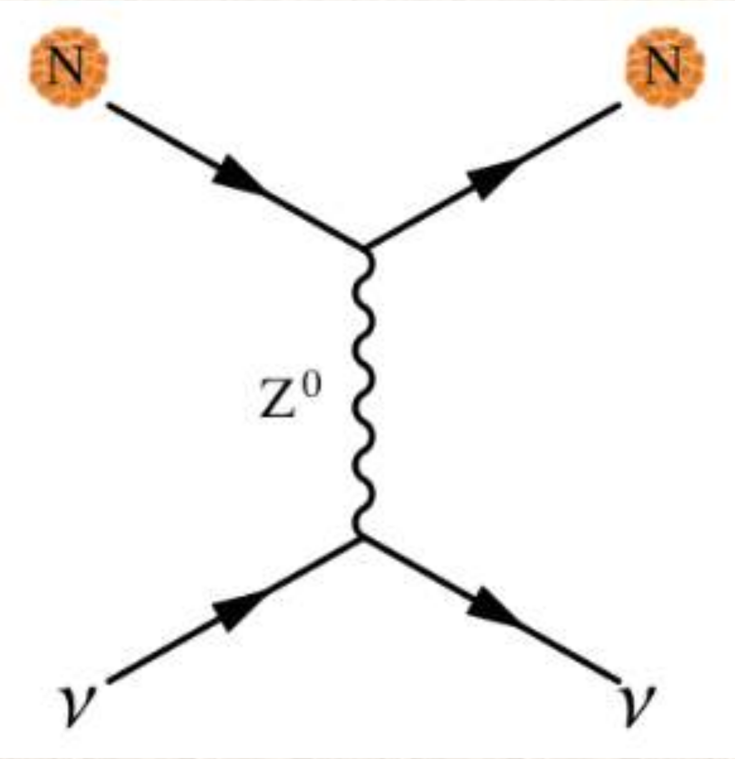
E_ν – *neutrino energy*

Z – *nucleus charge*

N – *number of neutrons in the nucleus*

F *is nucleus form factor*

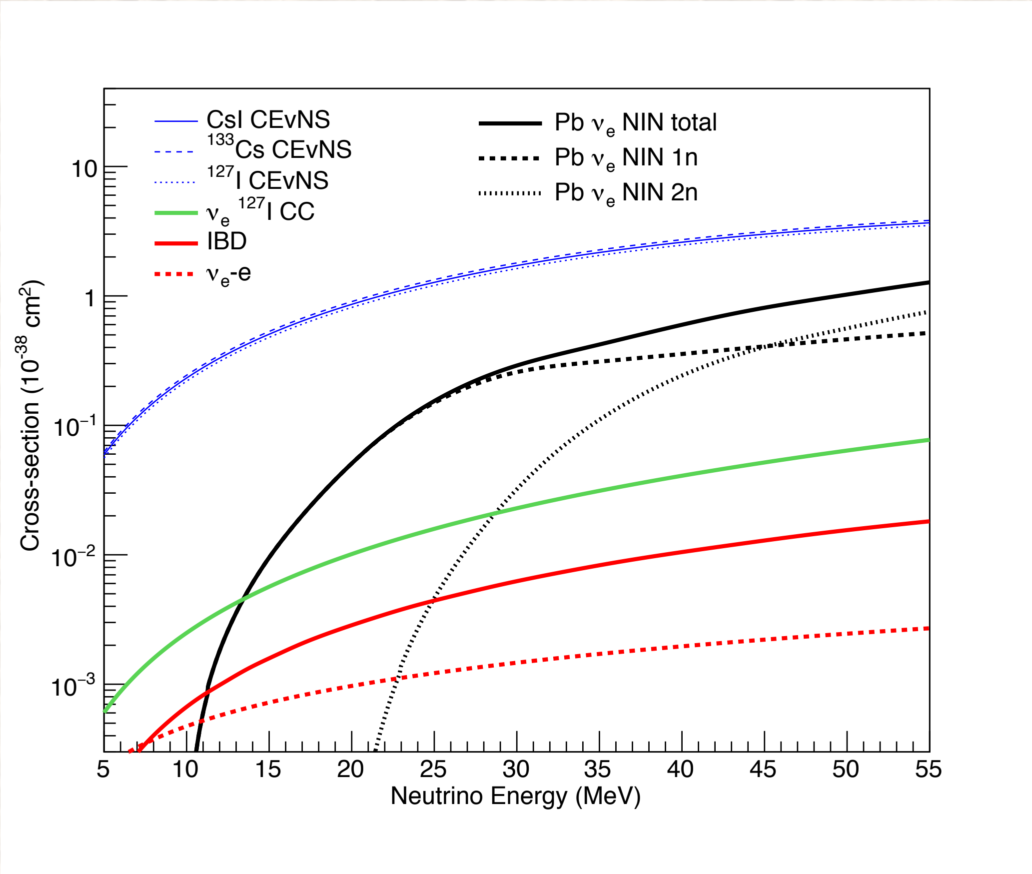
$E_\nu < 50 MeV$

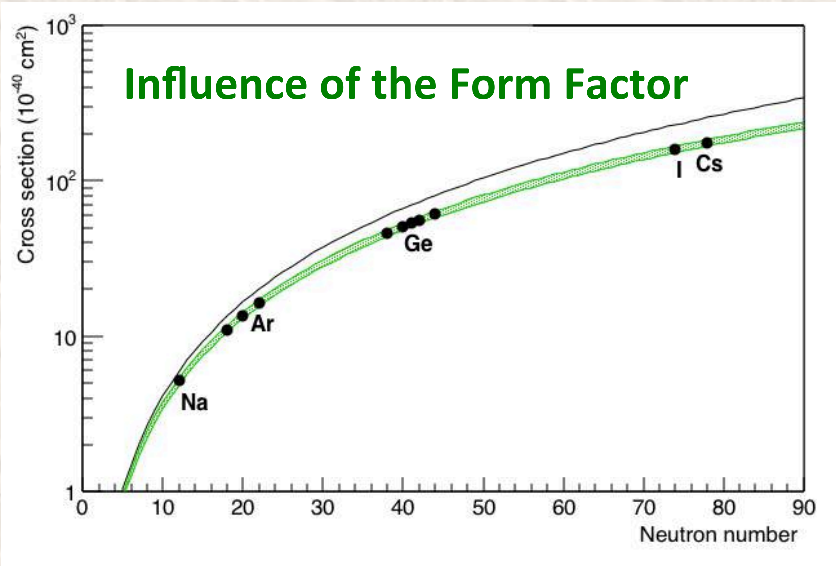


D.Z. Freedman PRD 9 (1974)
A. Drukier & L. Stodolsky, PRD 30, 2295 (1984)
Horowitz et al. astro-ph/0302071

CEvNS Cross Section is Large

It is the largest cross section at low energy





Cross section proportional to n^2 of the target

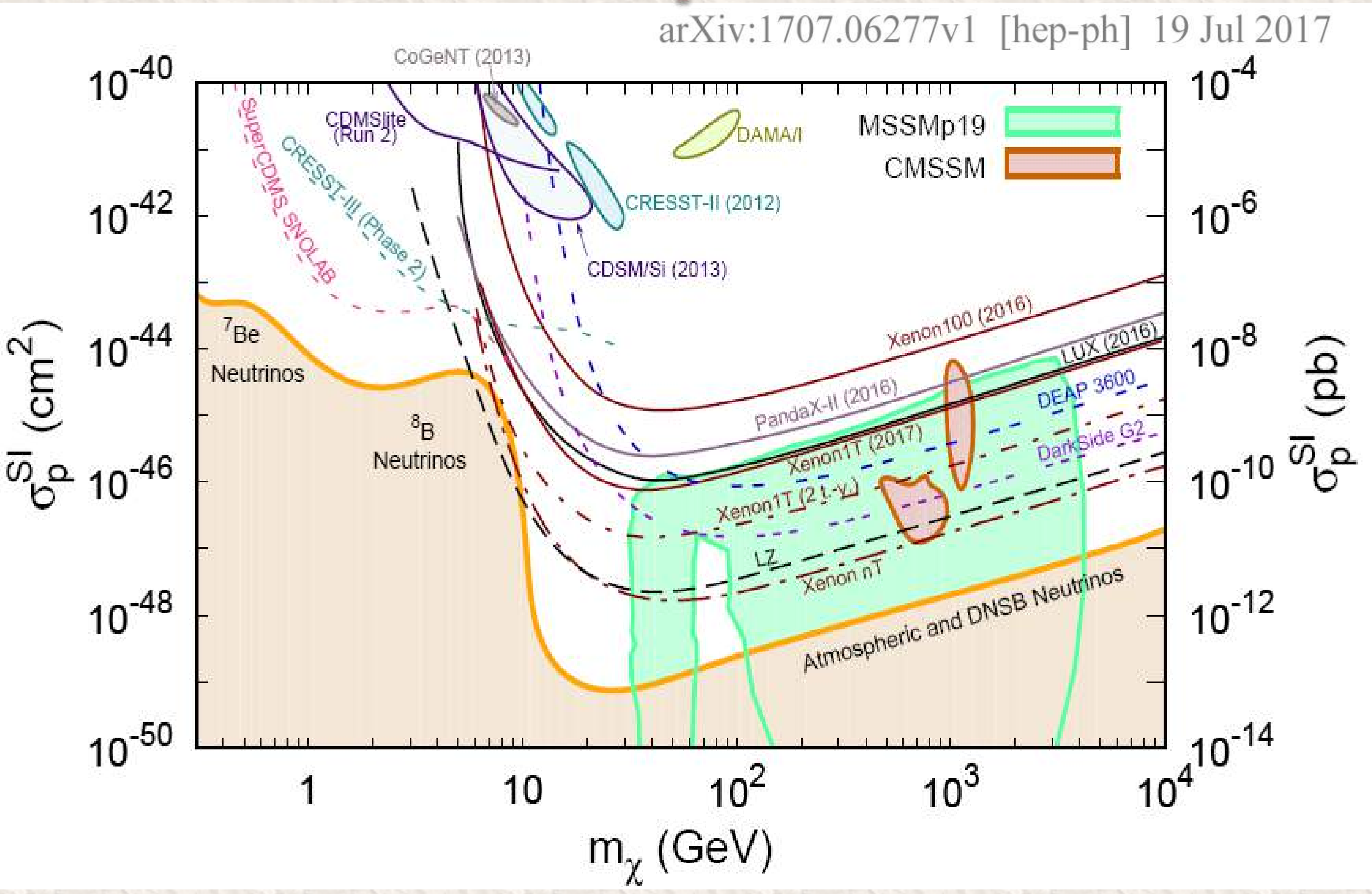
Some correction due to neutron radius is necessary

CEvNS is Hard to Detect

Target	Atomic weight, u	Max E_{nr} (5 MeV ν)	Max E_{nr} (30 MeV ν)
C	12.0	4.5 keV	161.0 keV
Na	23.0	2.3 keV	84.0 keV
Ar	39.9	1.3 keV	48.4 keV
Ge	72.6	0.74 keV	26.6 keV
Cs	132.9	0.40 keV	14.5 keV

Nuclear recoils have very low energy (max. $E_{nr} = 2E^2/M$)

CEvNS is irreducible background floor for DM experiments



Why CEvNS is interesting?

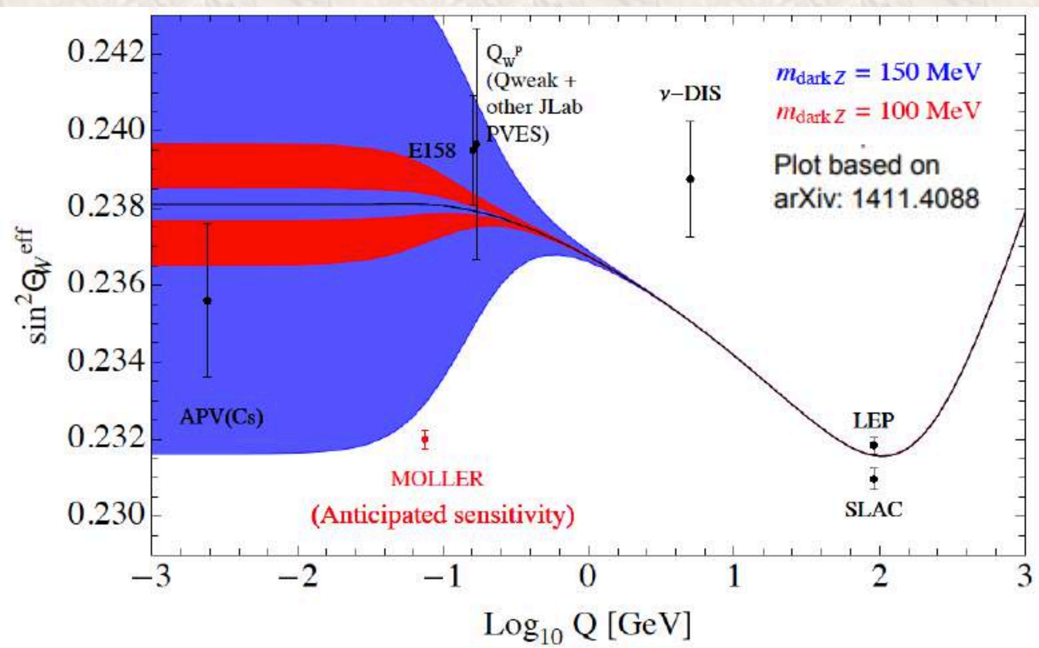
It is sensitive to the Electro week angle

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

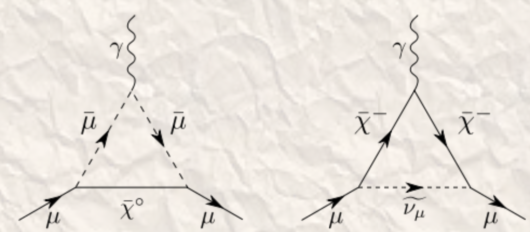
$$\sigma_{tot} = \frac{G_F^2 E_\nu^2}{4\pi}\left[Z\left(1-4\sin^2\theta_W\right)-N\right]^2 F^2(Q^2)$$

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

$Sun^2\theta_w$ 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 θ_w value at low Q^2

Why CEvNS are interesting?
Non-Standard Interactions of Neutrinos

new interaction 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. High Energy Phys. 03(2003) 011

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

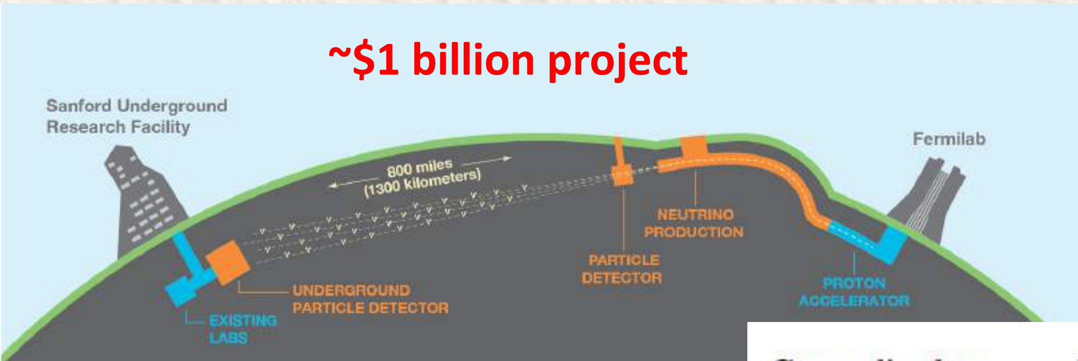
NSI parameter limit	Source
$-1 < \varepsilon_{ee}^{uL} < 0.3$	CHARM $\nu_e N$, $\bar{\nu}_e N$ scattering
$-0.4 < \varepsilon_{ee}^{uR} < 0.7$	
$-0.3 < \varepsilon_{ee}^{dL} < 0.3$	CHARM $\nu_e N$, $\bar{\nu}_e N$ scattering
$-0.6 < \varepsilon_{ee}^{dR} < 0.5$	
$\|\varepsilon_{\mu\mu}^{uL}\| < 0.003$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

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

K. Scholberg, Phys.Rev.D73:033005, 2006

Why CEvNS are interesting? Oscillation degeneracy

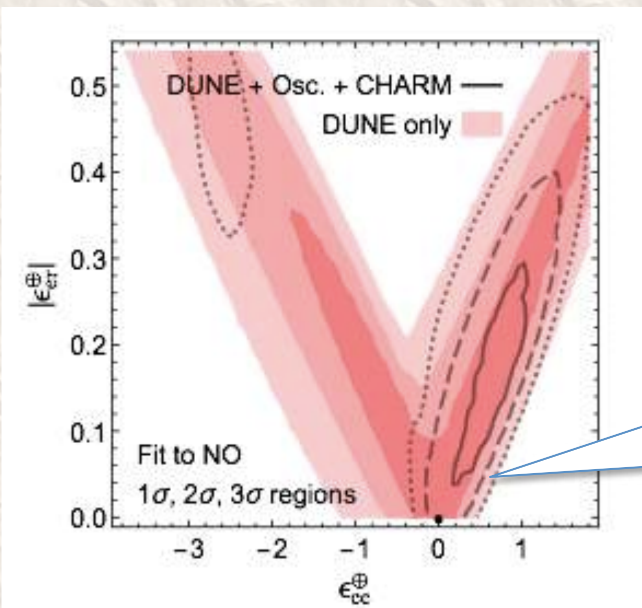
~$1 billion project



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

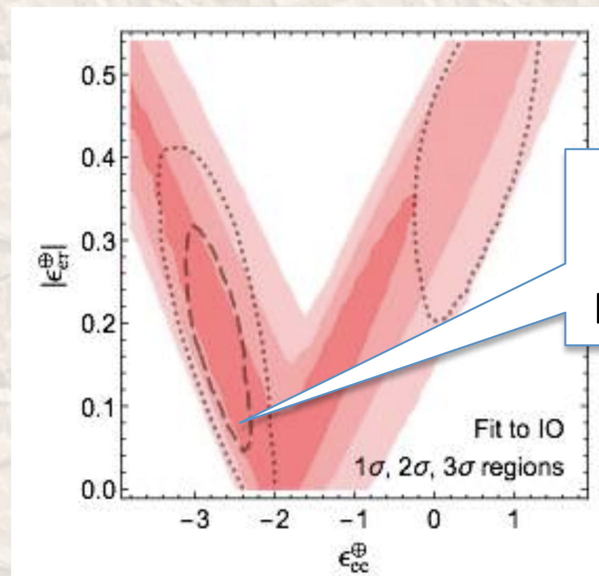
Generalized mass ordering degeneracy in neutrino oscillation experiments

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



NO w/no NSI...

...looks just like IO w/NSI



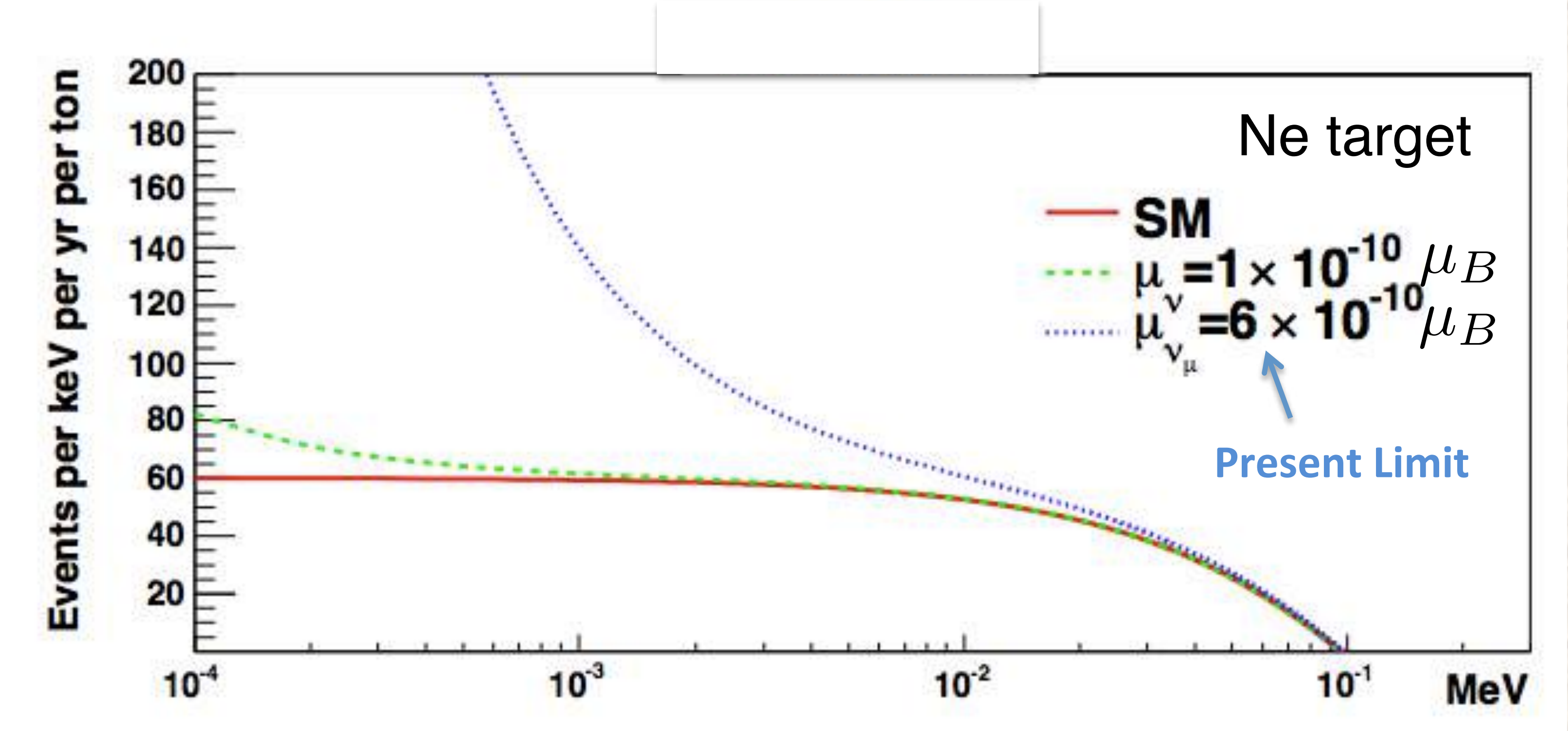
If you allow for NSI to exist, Degeneracy appears.

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

Why CEvNS 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

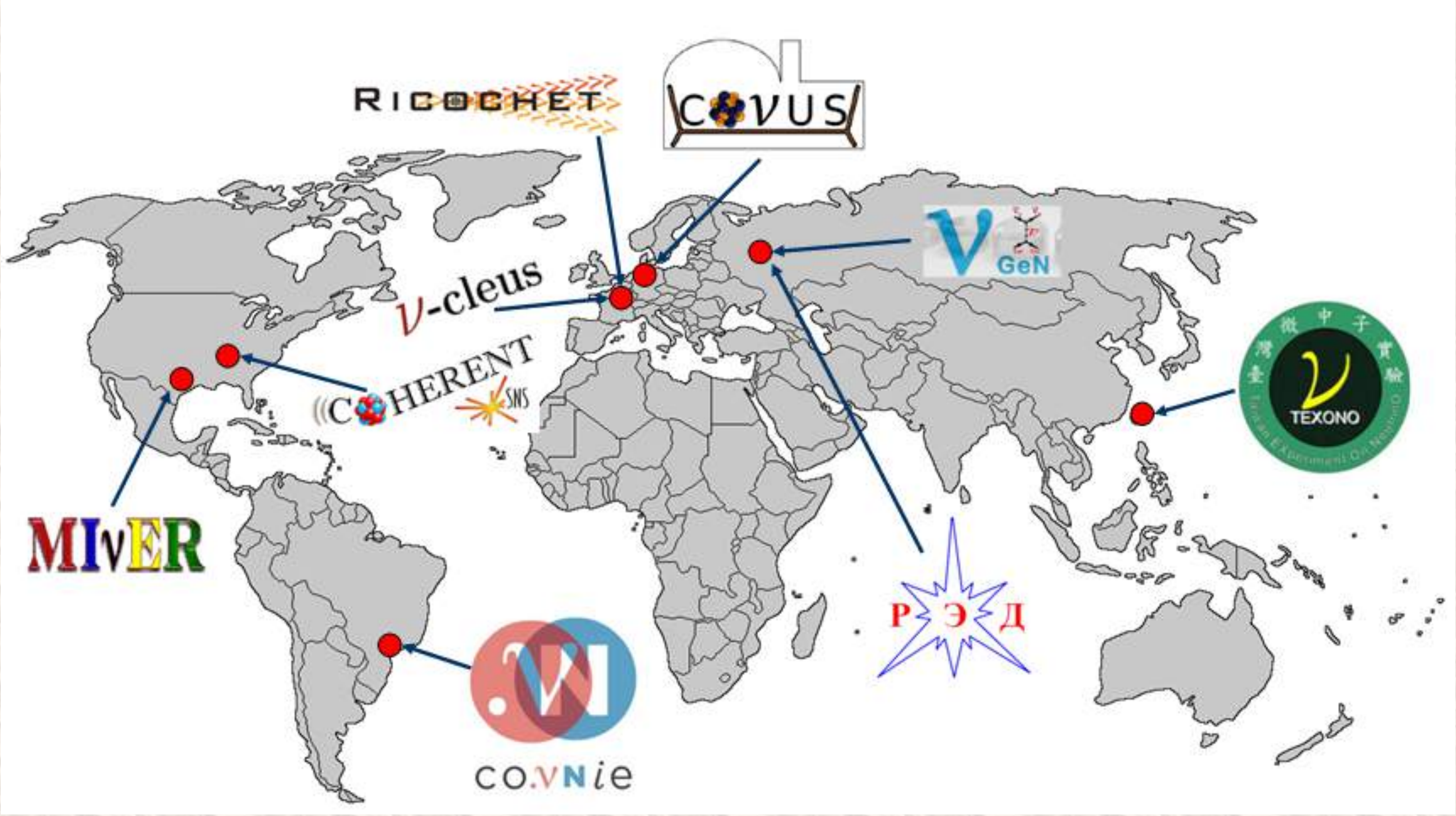
See also Kosmas et al., arXiv:1505.03202

Why to Search for CEvNS

Large effect on Supernovae dynamics.
We should measure it to validate the models

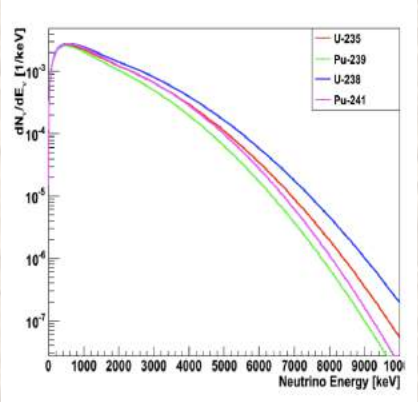
J.R. Wilson, PRL 32 (74) 849

World Wide Efforts



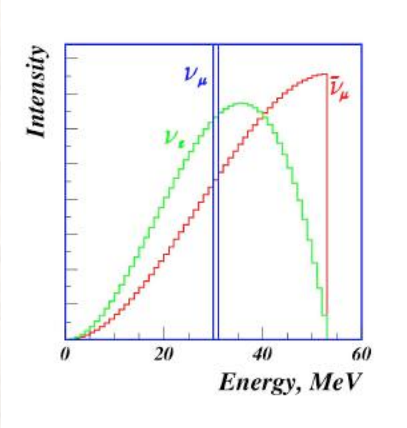
Two different neutrino Sources for CEνNS Detection

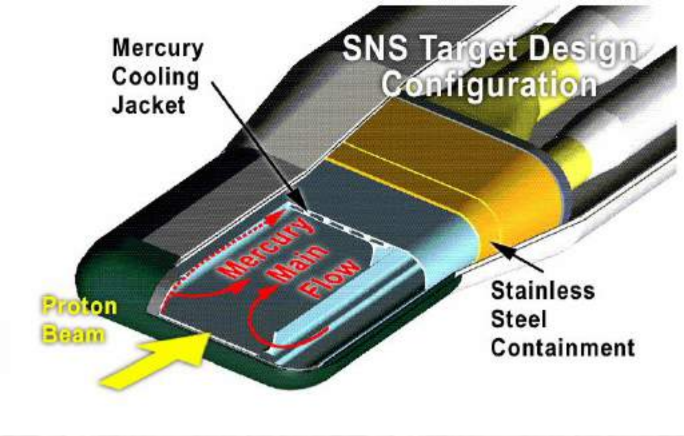
Nuclear Reactors



3 GW – 1 MW
Distance ~10 -20 m
E_ν ~ 4 MeV
Continues operation
$6*10^{20}$ ν/sec
One type of neutrino

Stopped Pion Facilities





1.3 MW
Distance ~20 m
E_ν ~ 40 MeV
Pulsed beam
$2*10^{15}$ ν/sec
Three types of neutrinos

SNS Layout

Proton beam energy – 1.0 GeV

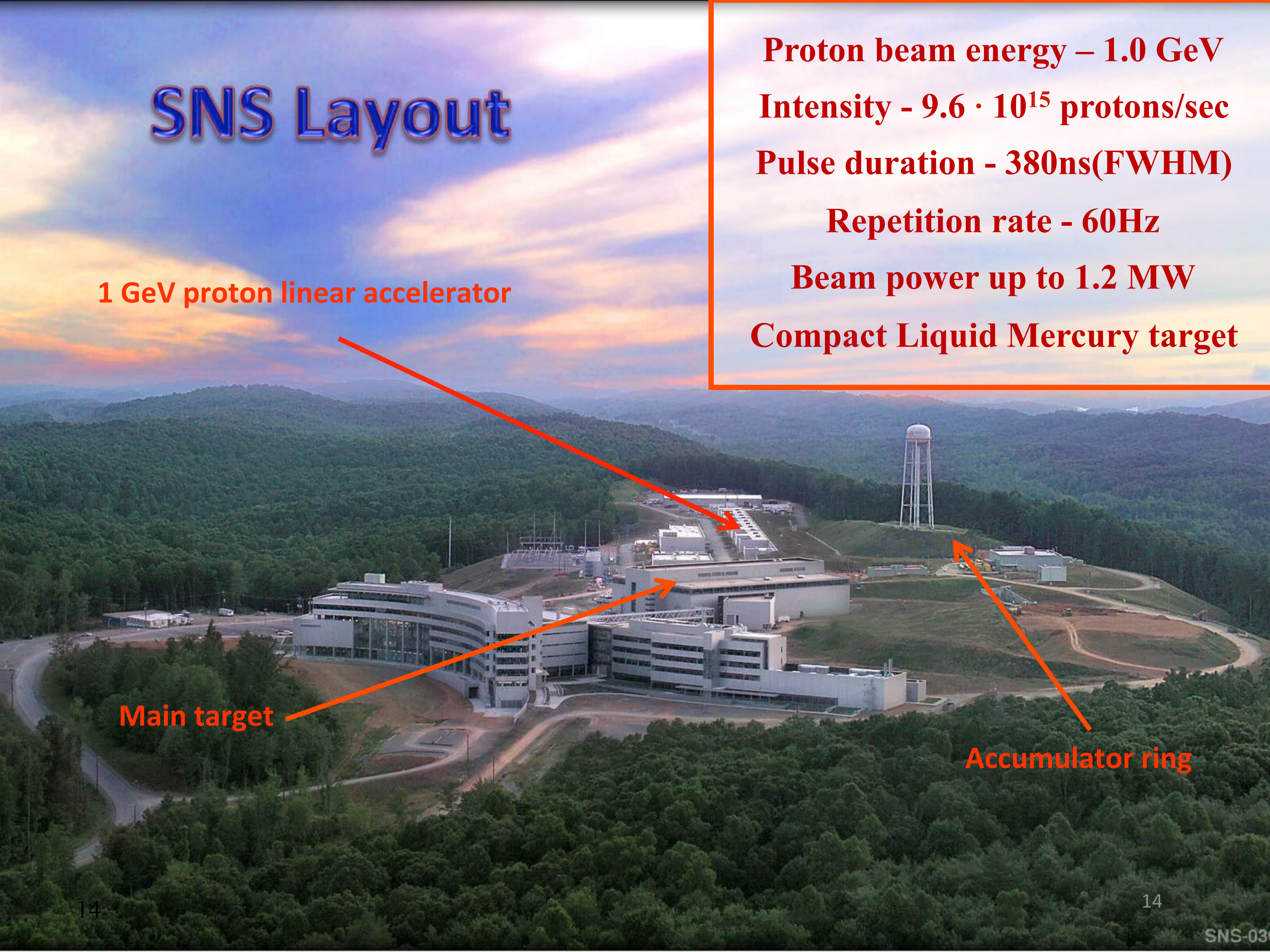
Intensity - $9.6 \cdot 10^{15}$ protons/sec

Pulse duration - 380ns(FWHM)

Repetition rate - 60Hz

Beam power up to 1.2 MW

Compact Liquid Mercury target



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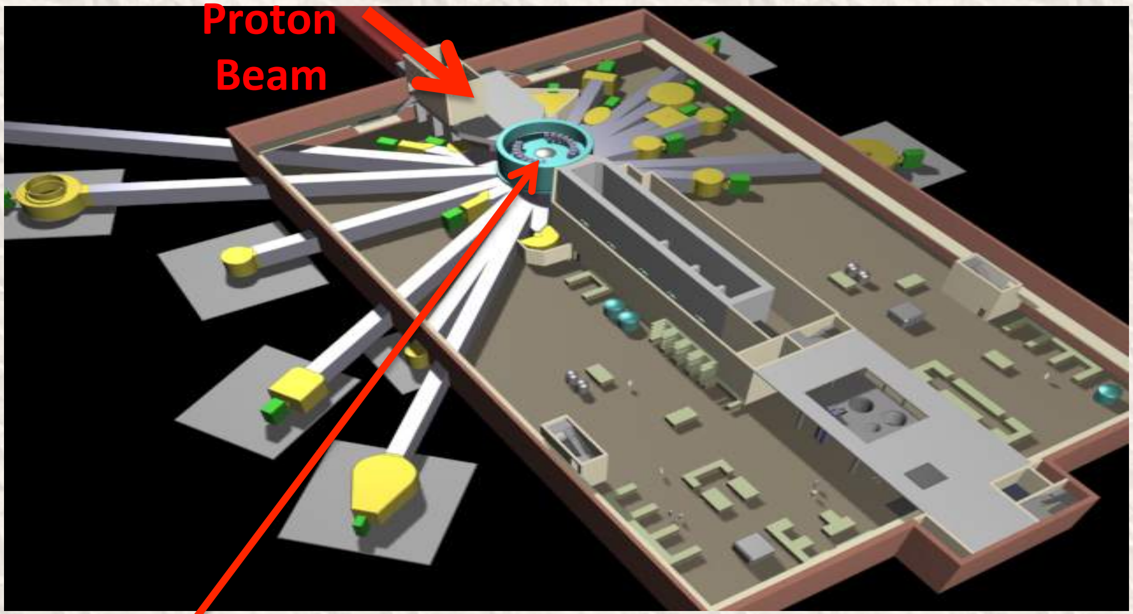
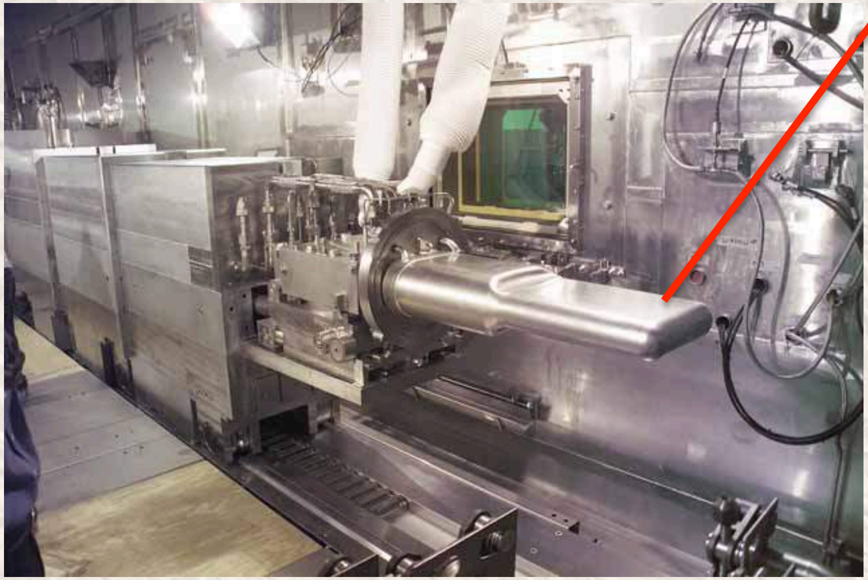
SNS main target





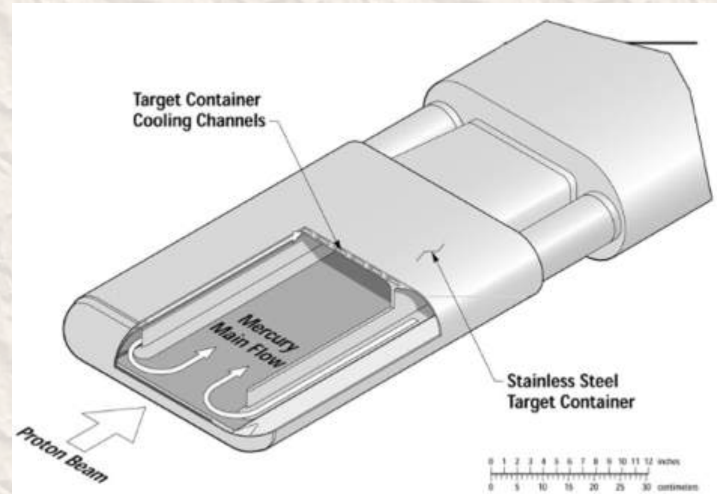
Mercury Inventory – 20 t
Flow rate 340 kg/sec
V_{max} 3.5 m/sec
T_{in} 60^0C
T_{out} 90^0C

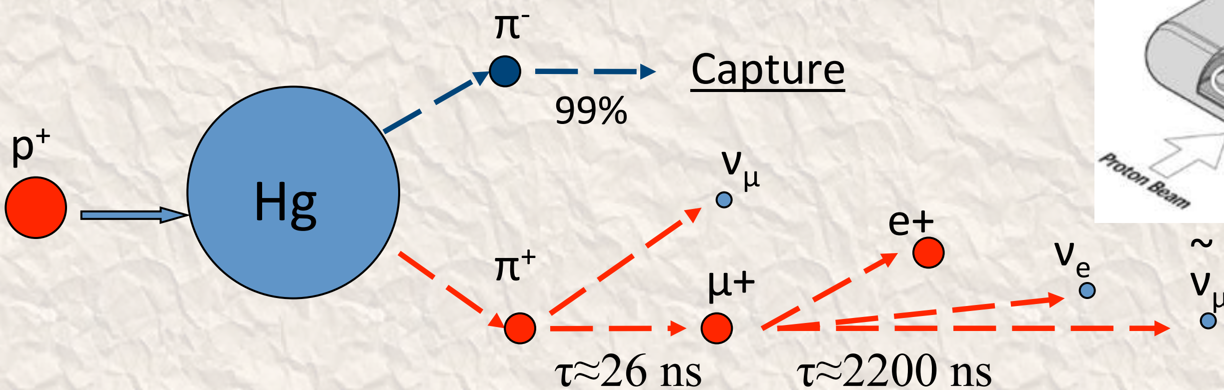
Mercury lasts the entire 40 year lifetime of SNS no change is required
Stainless steel vessel should be replaced periodically 2-3 times per year

Neutrino Production at the SNS

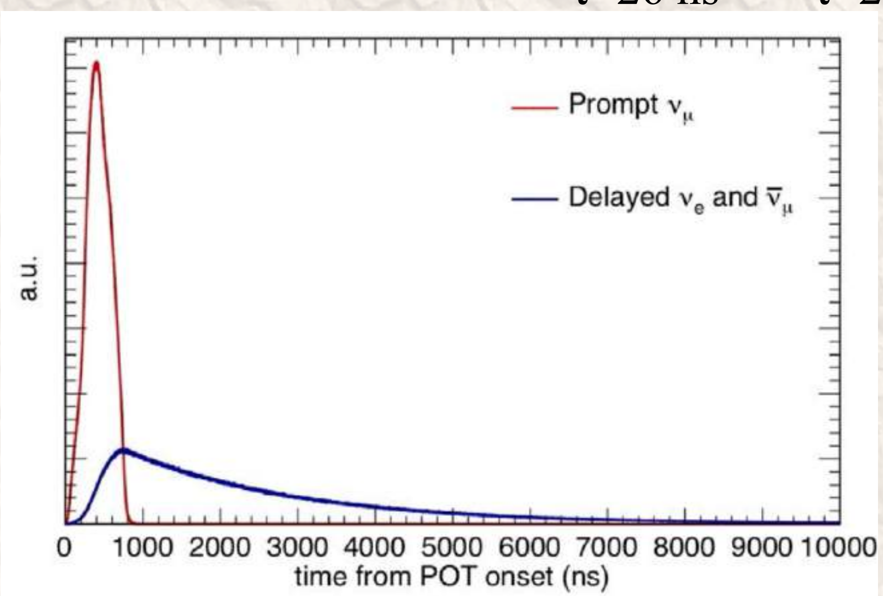
Dumping bunches of ~1 GeV protons on the Hg target with 60 Hz frequency

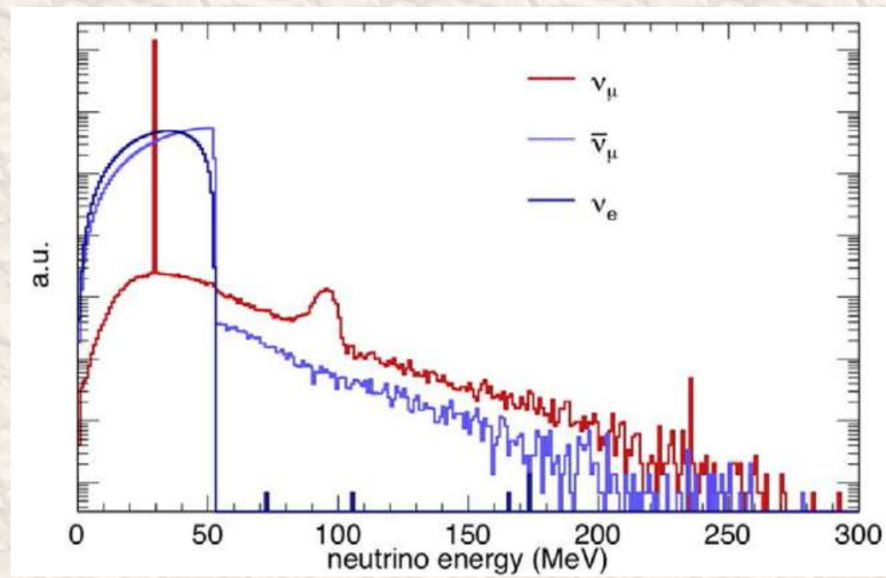
Full width of a bunch time profile ~800 ns





Total neutrino flux $4.3 \cdot 10^7$ $cm^{-2} * s^{-1}$ at 20m



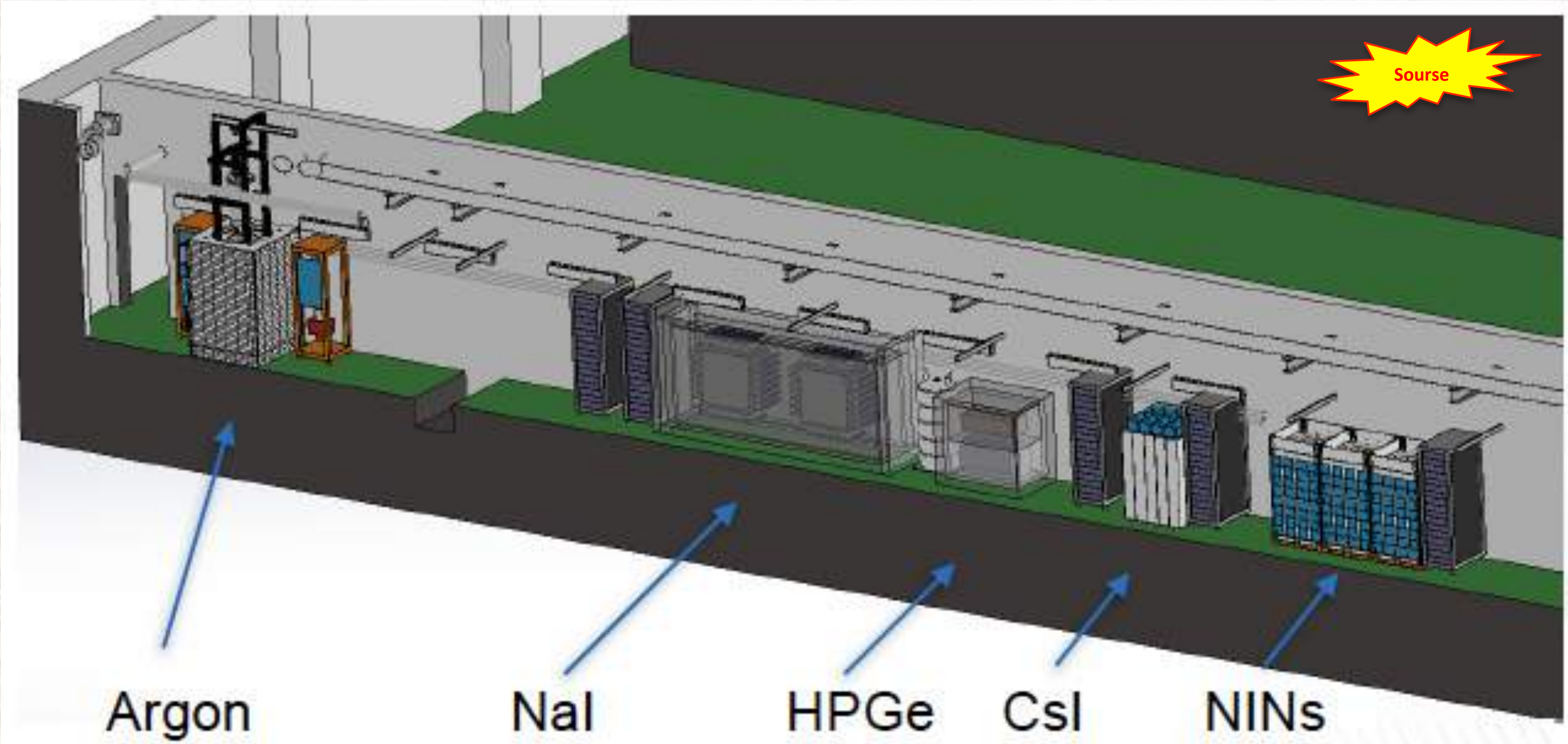


Collaboration COHERENT

COHERENT SNS

THE UNIVERSITY OF CHICAGO
Duke UNIVERSITY
UF UNIVERSITY of FLORIDA
KAIST
Laurentian University
Université Laurentienne
Los Alamos NATIONAL LABORATORY EST. 1943
BERKELEY LAB
MEPhI
NORTH CAROLINA CENTRAL UNIVERSITY FOUNDED 1910
NC STATE UNIVERSITY
NM STATE UNIVERSITY
OAK RIDGE National Laboratory
Sandia National Laboratories
THE UNIVERSITY of TENNESSEE UT KNOXVILLE
TUNL
W UNIVERSITY of WASHINGTON

Neutrino Alley at the SNS



Basement location is isolated from neutron beam lines

There are no voids between SNS target and Neutrino Alley → 20 meters of solid shielding

There is extra protection from cosmic rays by neutron beam lines shielding

There is no protection from Neutrinos

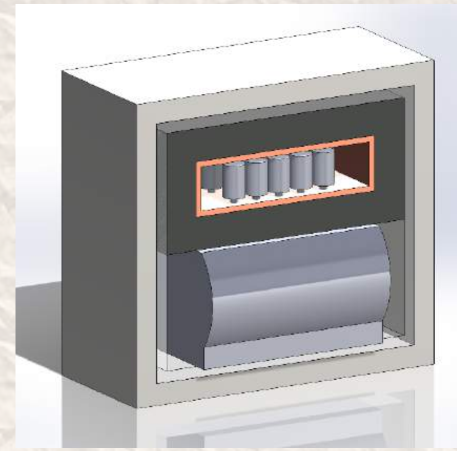
Three Detector Technology for the CEvNS
Phase I

CsI

First Result is based on this detector

LAr

HPGe
(not yet)



Target	Target Mass	Max Recoil (keV)	Cross section $10^{-42}\mathrm{cm}^2$	Threshold, keV_{nr}	N events, year
Ge	~10 kg	83	5830	3	280
CsI	14 kg	45	19400	10	170
Ar	30 kg	150	1700	10	250

Neutrino Induced Neutrons (NIN)

$$\nu_e + {}^{208}Pb \Rightarrow {}^{208}Bi^* + e^- \qquad (CC)$$
$$\Downarrow$$
$${}^{208-y}Bi + x\gamma + yn$$

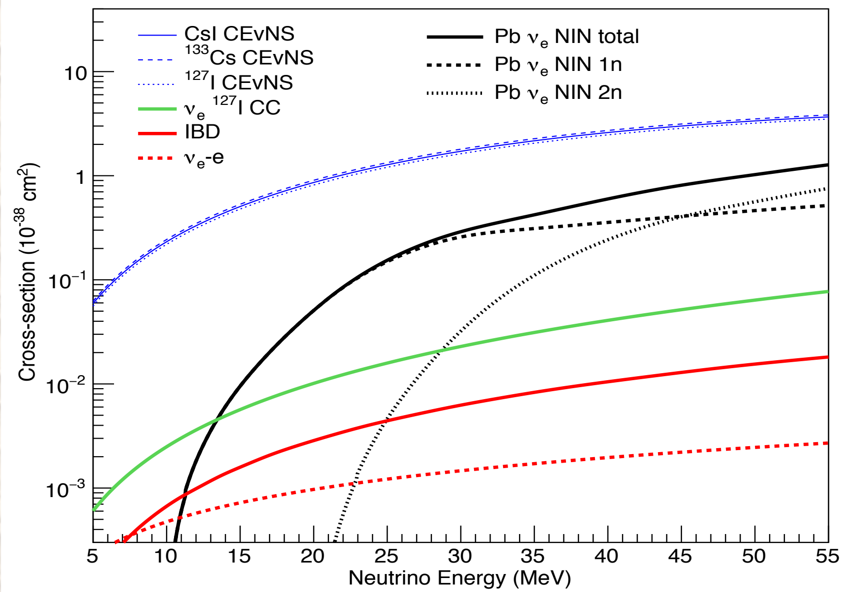
$$\nu_x + {}^{208}Pb \Rightarrow {}^{208}Pb^* + \nu_x' \qquad (NC)$$
$$\Downarrow$$
$${}^{208-y}Pb + x\gamma + yn.$$

NIN could be a background for COHERENT

It has the same timing as neutrinos !!!

This reaction never been measured
There are only theoretical calculations for cross section

HALO at SNOlab



NIN on lead is used by HALO experiment in the SNOlab, to watch for supernovae.

This process can be important in many stellar environments

E. Kolbe, E. Langanke, "Role of ν-induced reactions on lead and iron…", Phys. Rev. C63 (2001)

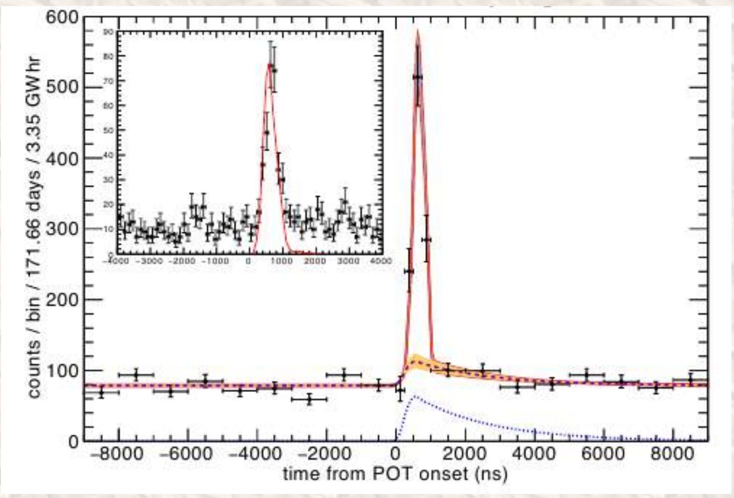
NINs For CsI detector

The "neutrino alley" @ SNS

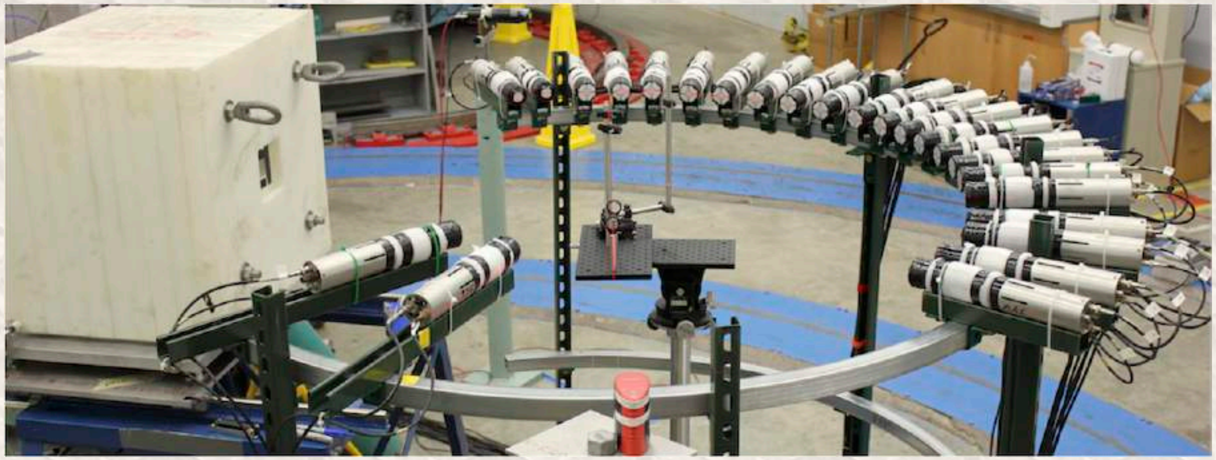
Prior to CsI installation LSc detector has been deployed at the same location with the same shielding but without inner poly layer

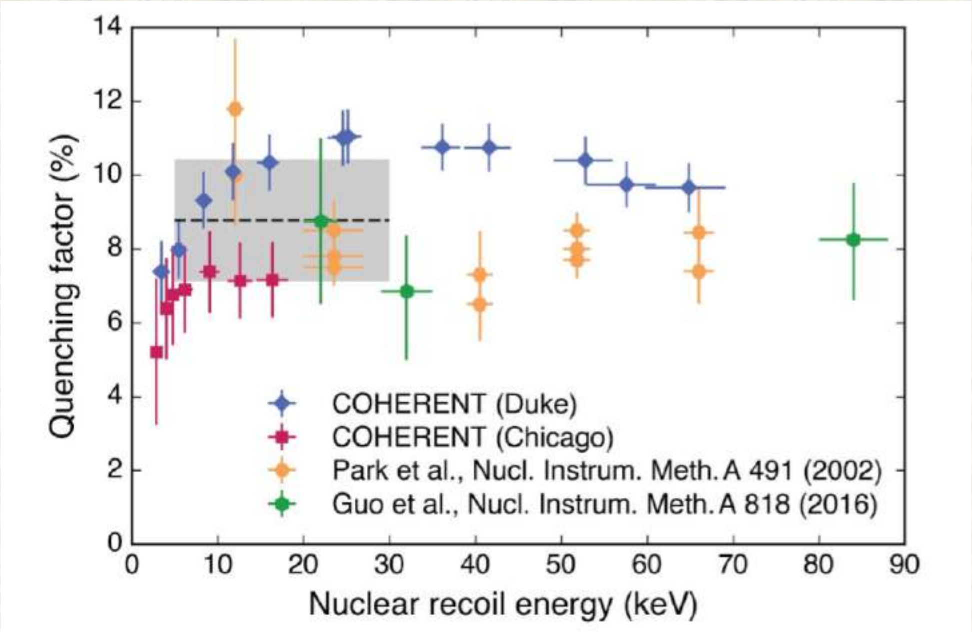
Took data from November 2014 till June 2015

No NINs has been seen, and non has been expected for this setup, good news!!!!



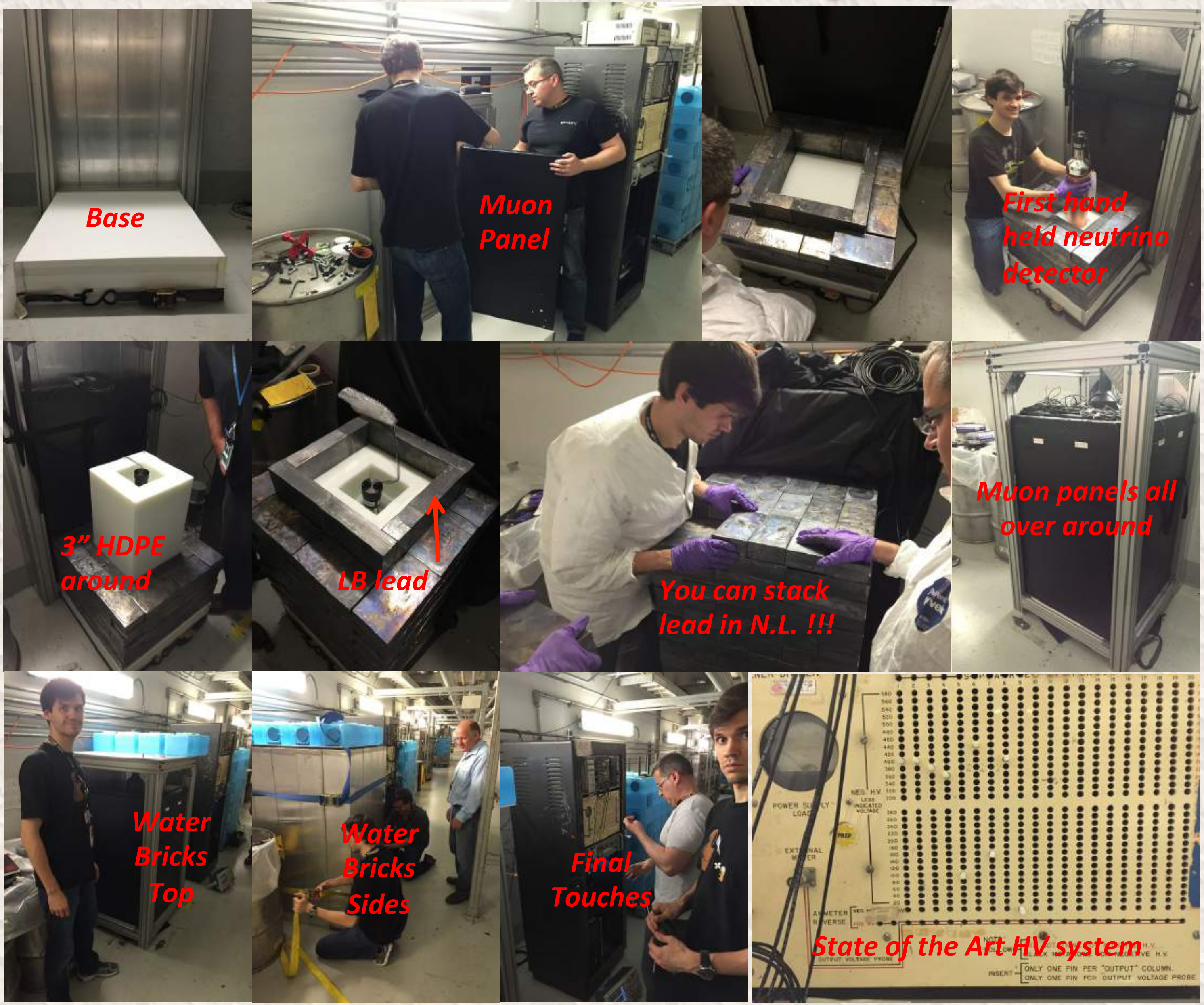
Quenching Measurement at TUNL neutron beam by COHERENT collaborators for CsI crystal





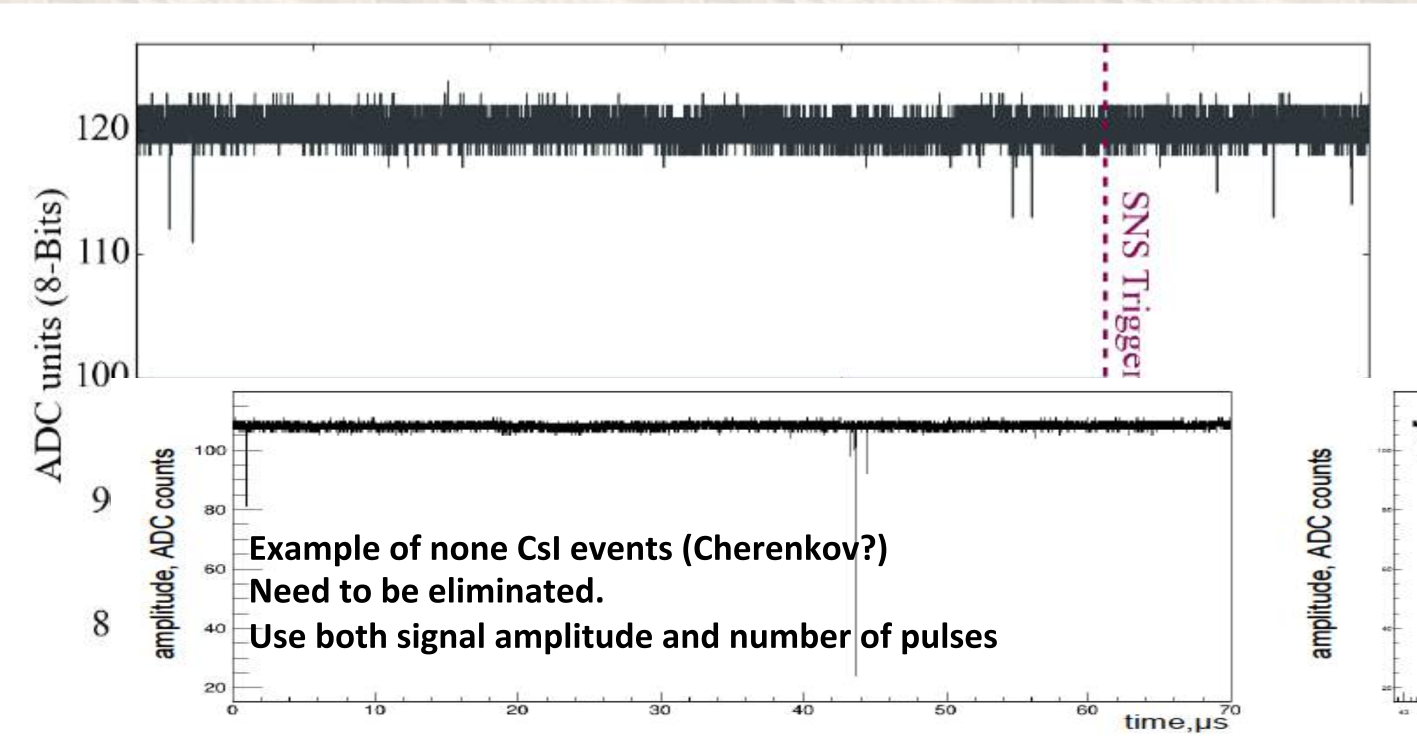
For the first publication we assumed flat quenching of 8.8% +/- 2.2%

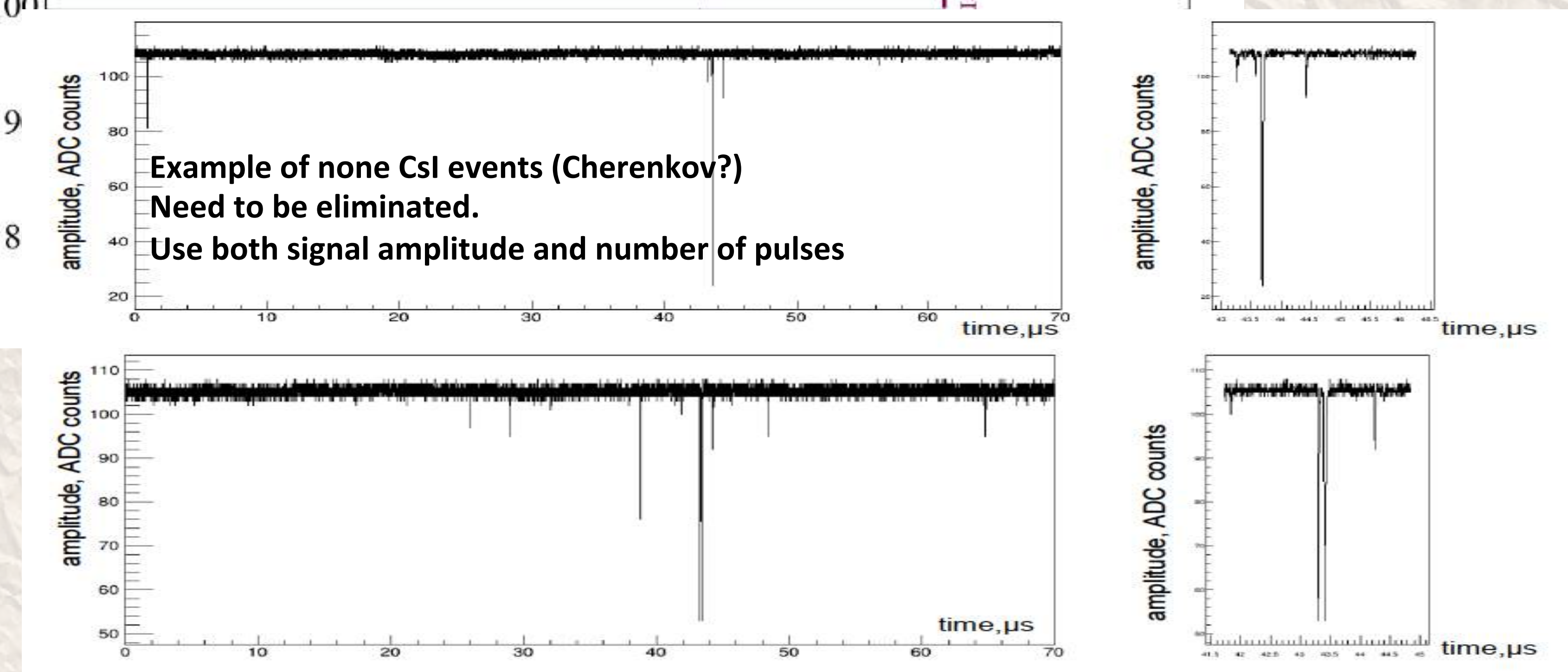
CsI detector Installation (August 2015)



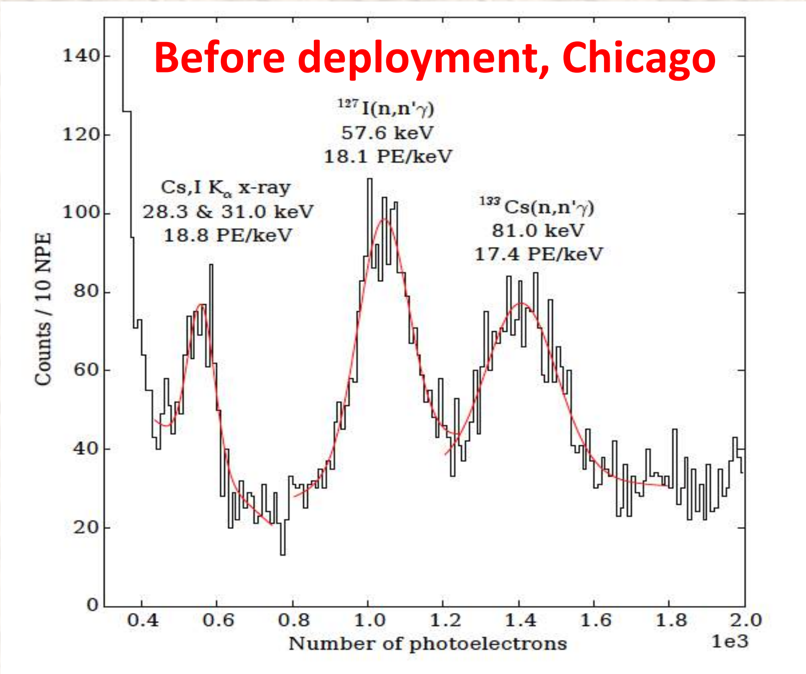
DAQ recorded waveforms in 70 usec window using SNS timer (60 Hz)

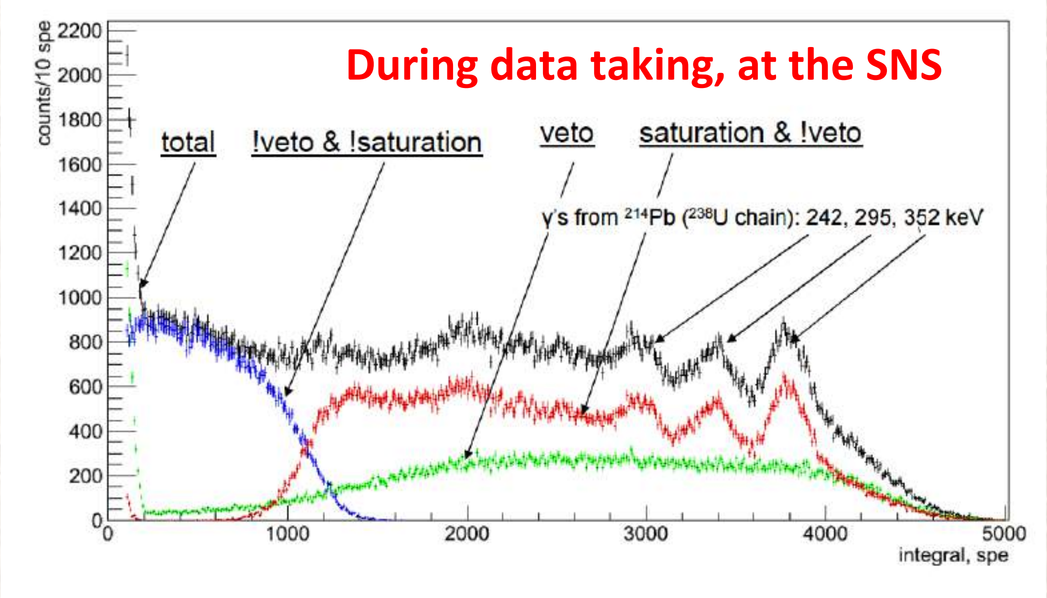
Around 2 billions of waveforms were recorded!

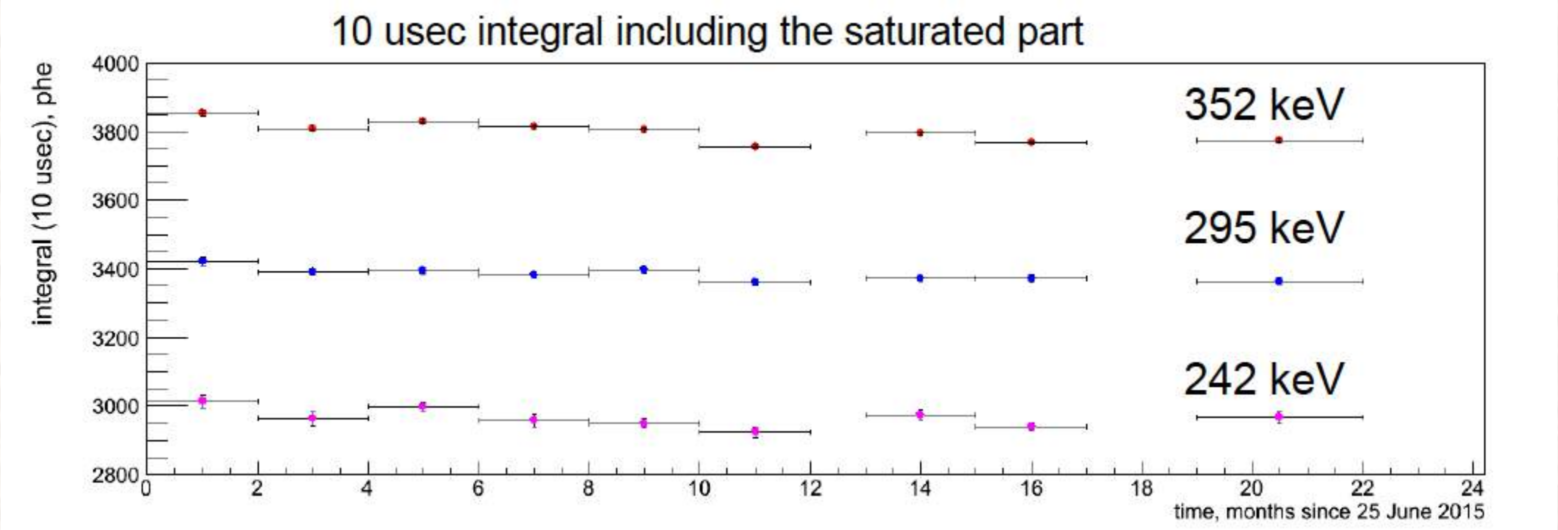




Detector Energy Calibration in Situ





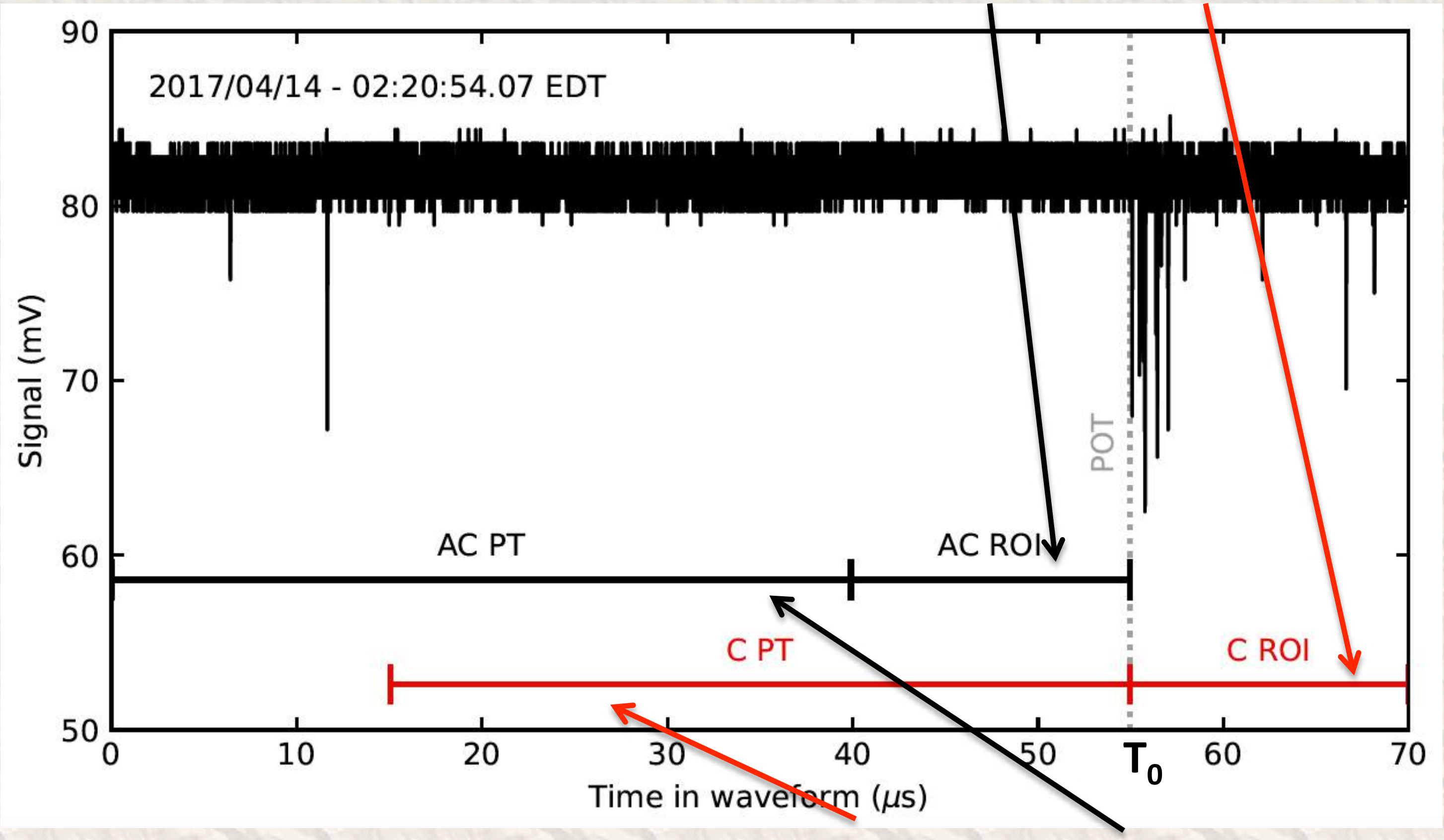


No energy drift

Selection Cuts

Analysis procedure:

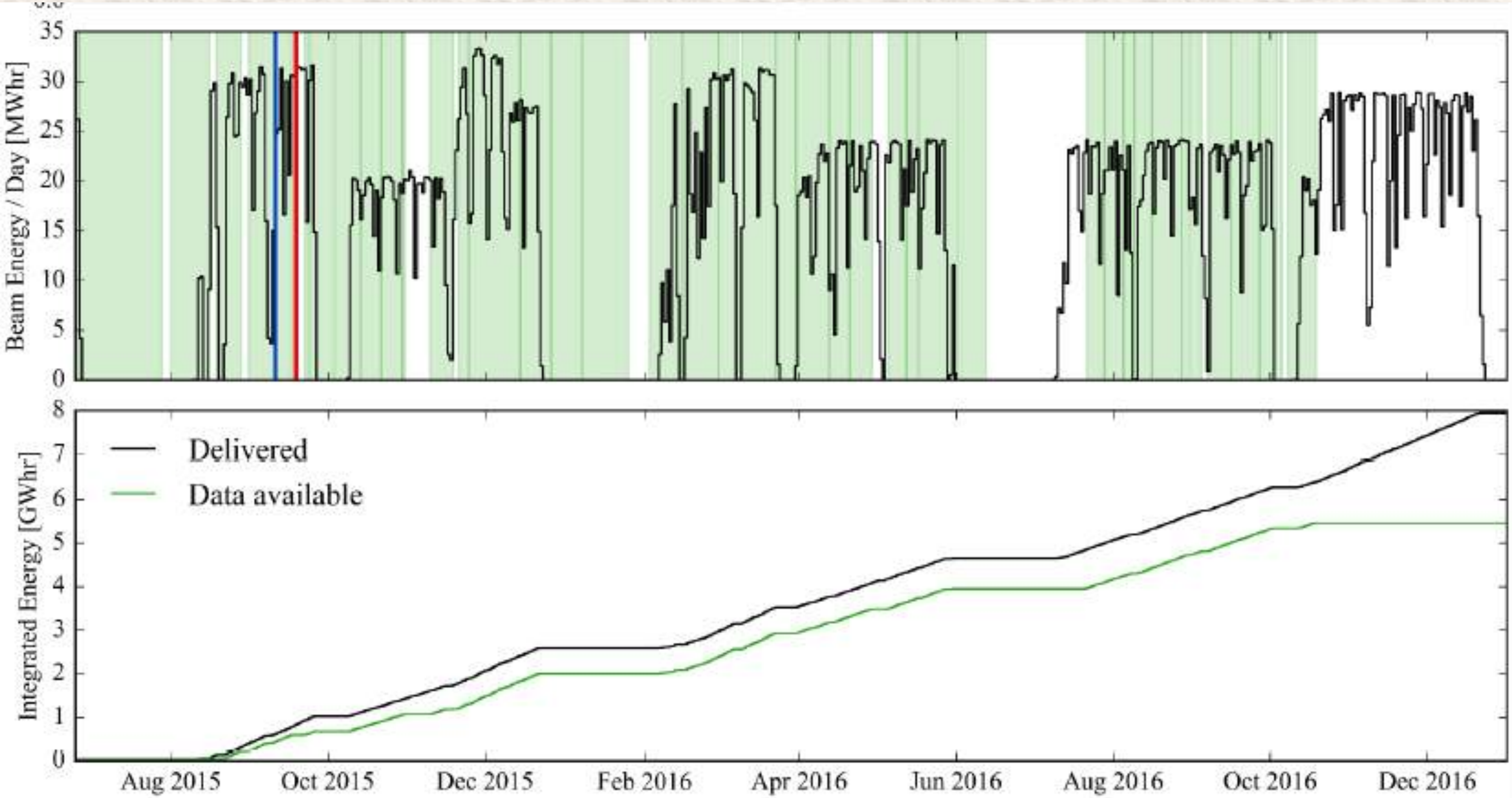
Apply same "Cherenkov" cut using BG and signal and ROI windows



Apply cut on prior activity using signal and BG pre trace windows

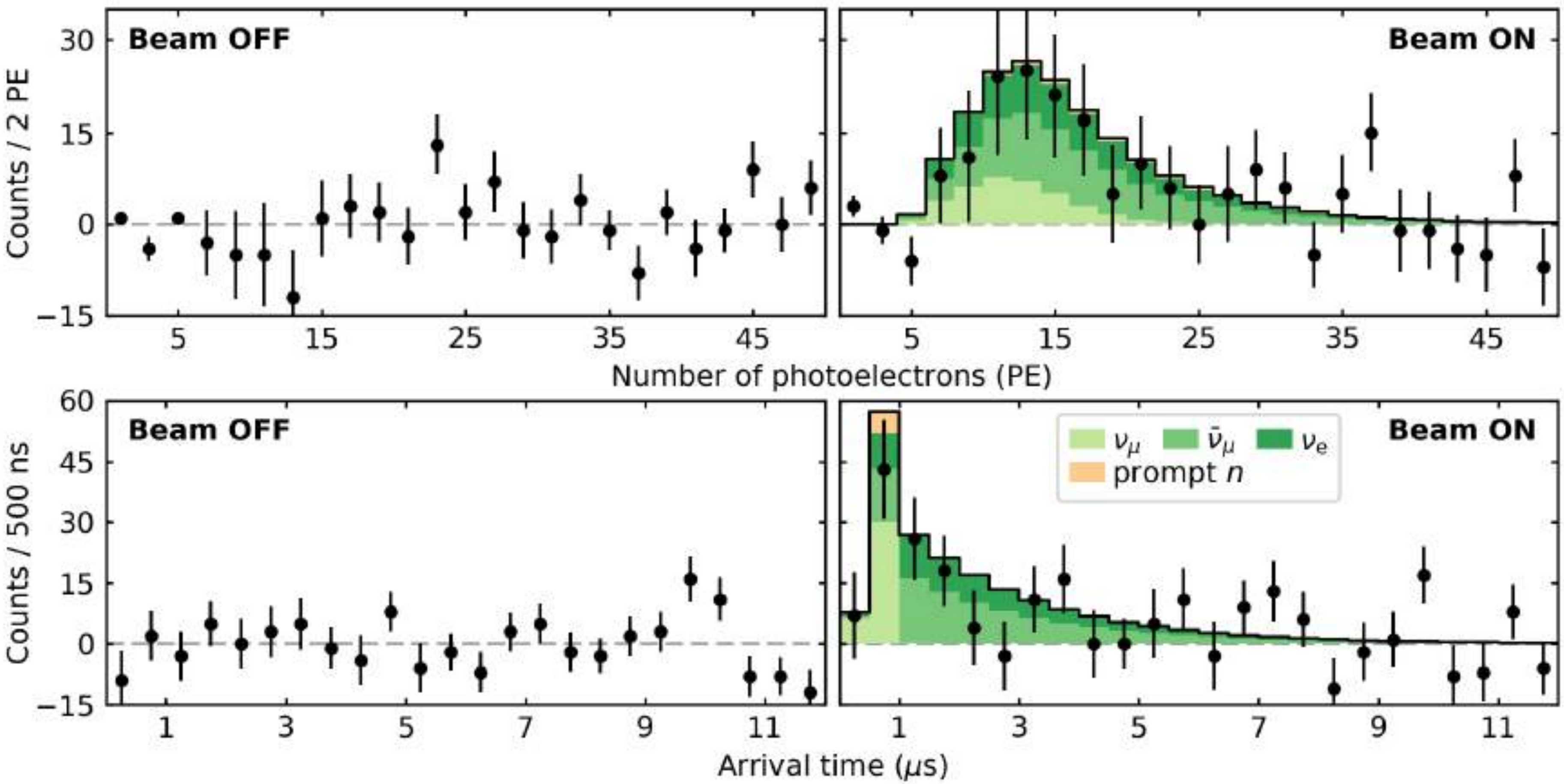
Subtract BG ROI events from Signal ROI events

Statistics for the First Data Set of CsI



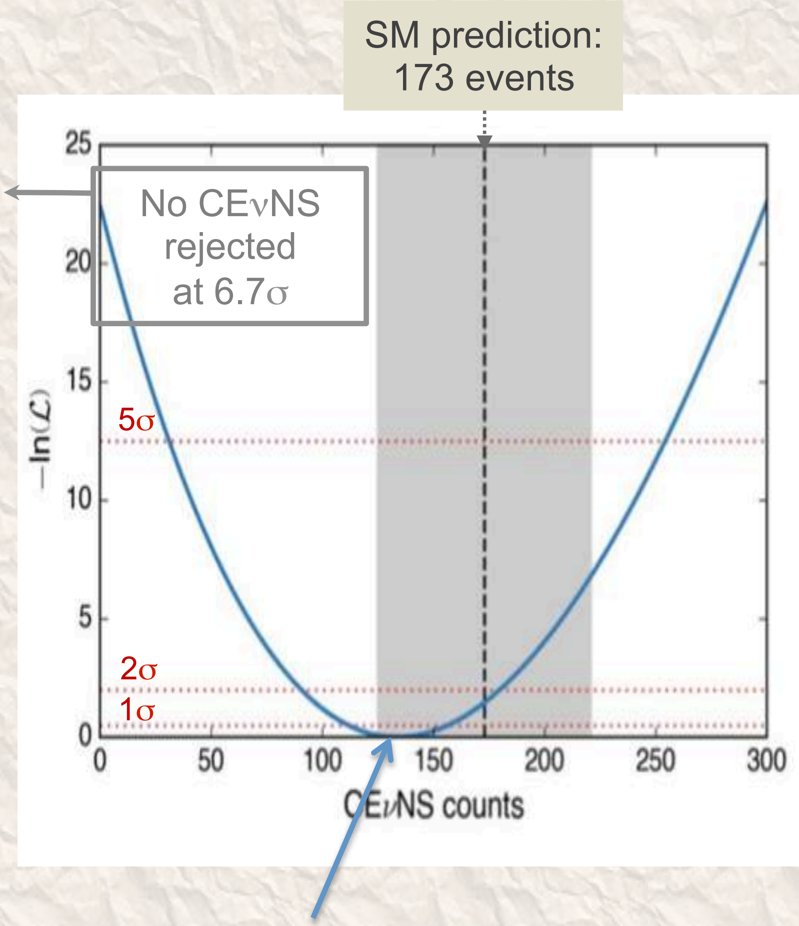
~6 GWh were recorded, this corresponds to $1.4*10^{23}$ POT or 0.22 grams of protons accelerated to the $\beta = 0.86$

CEvNS Detected



~6.7 sigma effect over background

Fitting data to expectation



Best fit is 134±22 observed events.
Consistent with SM within 1 sigma

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, single-bin counting	136 ± 31
Signal counts, 2D likelihood fit	134 ± 22
Predicted SM signal counts	173 ± 48

Uncertainties on signal and background predictions	
Event selection (signal acceptance)	5%
Neutrino Flux	10%
Quenching factor	25%
Form factor	5%
Total uncertainty on signal	28%

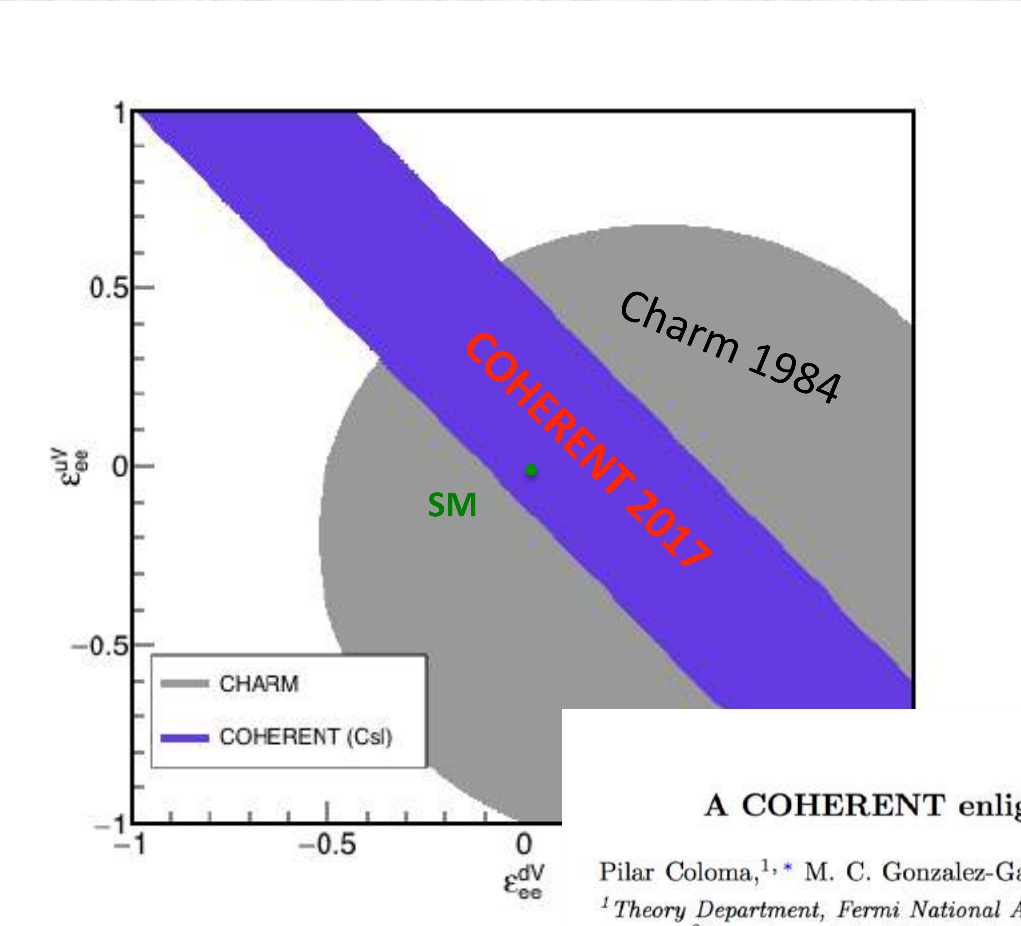
CEvNS detection published on August 3^d, 2017

Science Vol. 357,15 Sep. 2017, p. 1123

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

Daniel Free dman

First Application of CEvNS
Constrain on non standard neutrino interactions



Important for DUNE

9 Aug 2017

FERMILAB-PUB-17-308-T, YITP-SB-17-28, IFT-UAM/CSIC-17-073

A COHERENT enlightenment of the neutrino Dark Side

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[3]Institució Catalana de Recerca i Estudis Avançats (ICREA), Pg. Lluis Companys 23, 08010 Barcelona, Spain.
[4]C.N. Yang Institute for Theoretical Physics, Stony Brook University , Stony Brook, NY 11794-3840, USA
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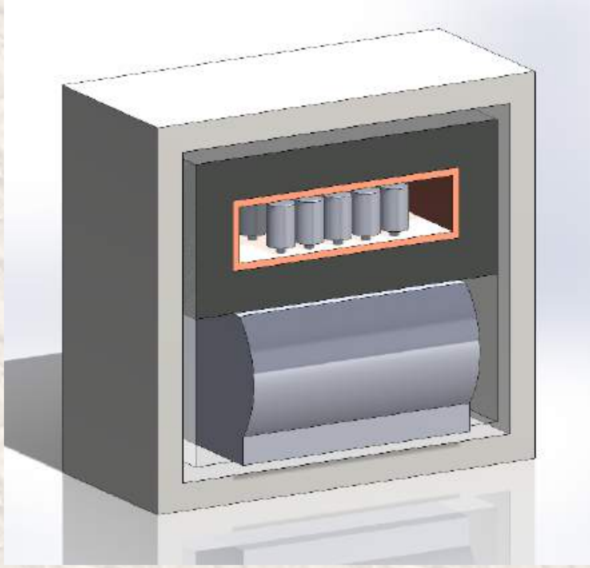
[6]Institut für Kernphysik, Karlsruher Institut für Technologie (KIT), D-76021 Karlsruhe, Germany

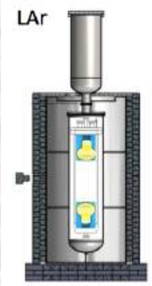
Other Detectors at Phase I

CsI	LAr	HPGe
		
14 kg	**30 kg**	**10 kg**
First result and continue to take data	Taking data from August 2017	Planning to deploy next summer

COHERENT Science Program

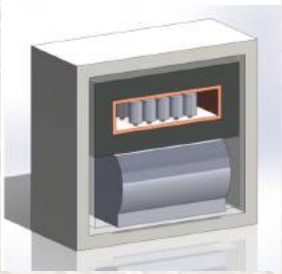
First Light

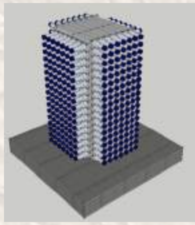
- Detect CEvNS
- Measure CEvNS for heavy and light nuclei
- Detect NINs

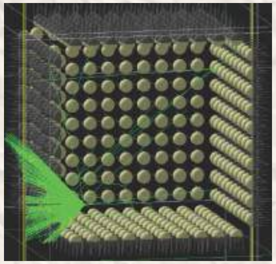


Second Step (under discussions)

- High precision CEvNS measurements on several nuclei, constrain NSI
- Measure CC for Supernovae detectors: O, Ar, Pb
- Measure nuclear neutron radiuses







Long Term (dreams)

- Separate contribution between Axial and Vector currents
- High precision measurements of Electro-Weak angle
- Strict constrains on NSI

Conclusion

SNS is the world most powerful pulsed neutrino source

Neutrino energy range at the SNS is just right to study CEvNS and nuclear reactions of interest for Astrophysics

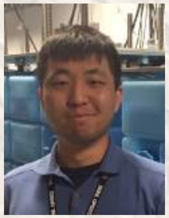
There is comprehensive and exciting neutrino program at the SNS

Presently COHERENT collaboration is engage in deployment of the first generation of detectors to see the “First Light”

We just detected the “First Light”

There are many ideas what to do next with neutrinos at the SNS

COHERENT students and postdocs working with detectors at SNS


Ben Suh
IU


Justin
Raybern
Duke


Sam
Hedges
Duke


Long Li
DUKE


Alexander
Kumpan,
MEPhI


Brandon
Becker
UT


Jacob
Zettlemoyer IU


Connor
Awe
Duke


Katrina
Miller
Duke


Hector
Moreno
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Alexey
Konovalov
MEPhI


Matt Heath
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Alex
Khromov
MEPhI


Gleb Sinev
Duke


Alexander
Kavner
Chicago


Dan Salvat
UW
(Postdoc)


Jacob
Daughhetee
UT (Postdoc)


Mayra
Cervantes
Duke
(Postdoc)


Ivan
Tolstukhin
IU
(Postdoc)


Josh
Albert
IU
(Postdoc)

Two PhD dissertations completed.


Bjorn Scholz
U of Chicago


Grayson Rich
Duke