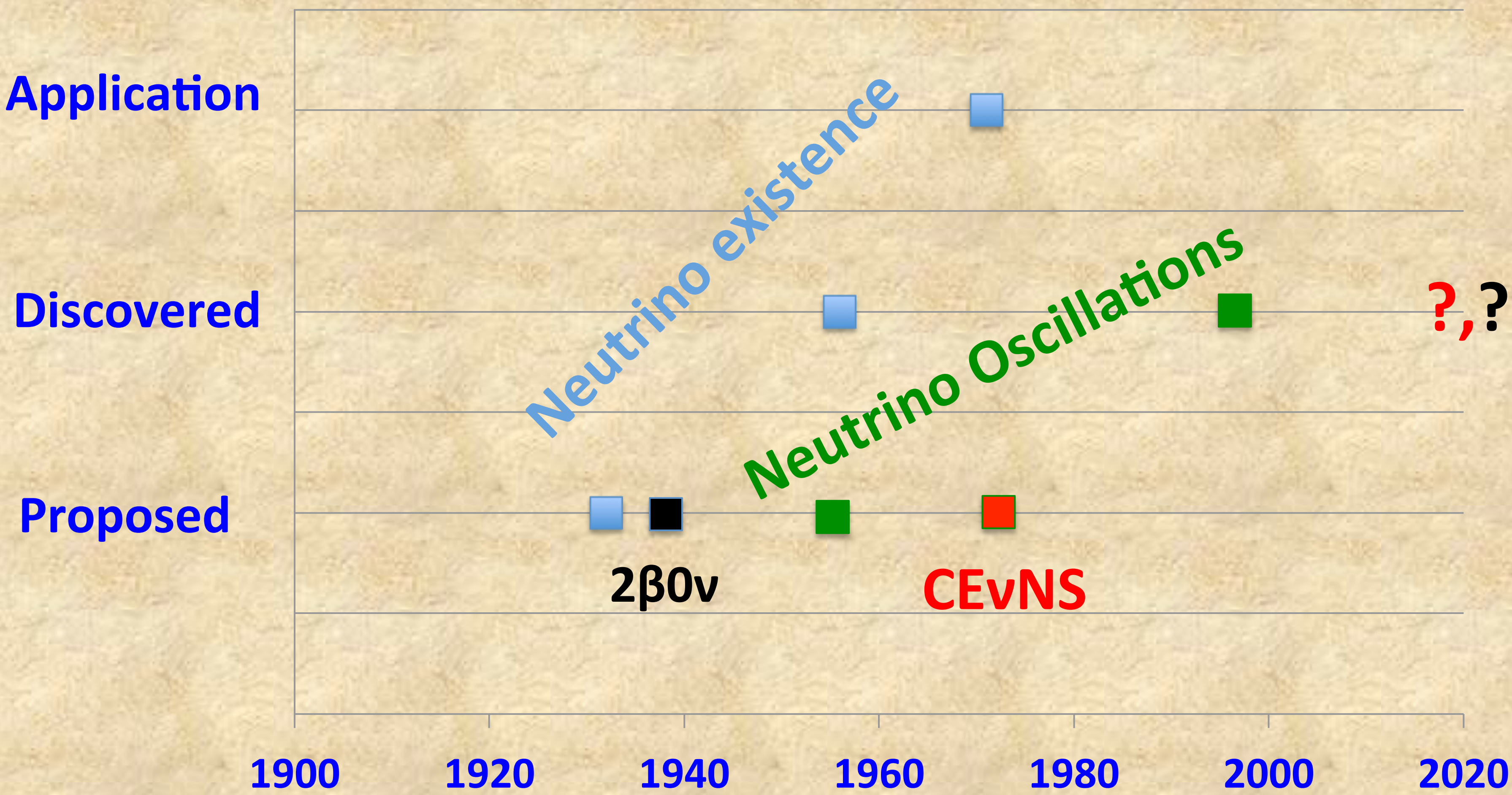
Coherent Elastic Neutrino Nuclear Scattering (CEvNS)

Will we see it soon?

Yuri Efremenko, UTK/ORNL
June 8th 2017, Nalchik
50 years of BNO

Time scales in Neutrino Physics



Coherent 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

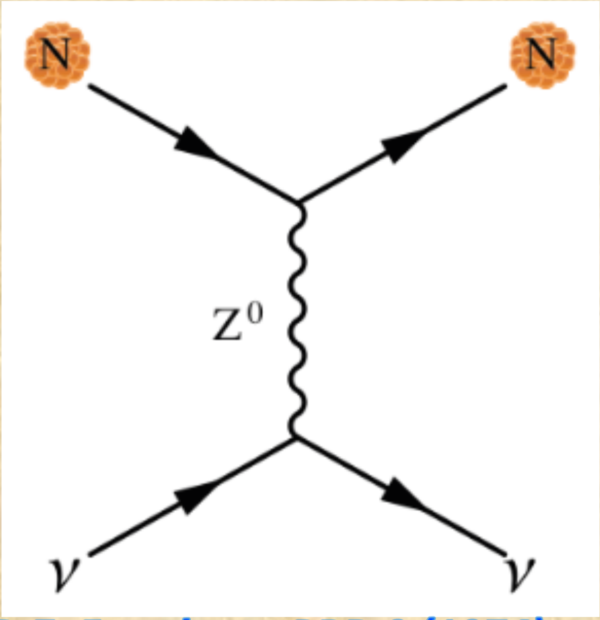
E_ν – neutrino energy

Z – nucleus charge

N – number of neutrons in the nucleus

F is nucleus form factor

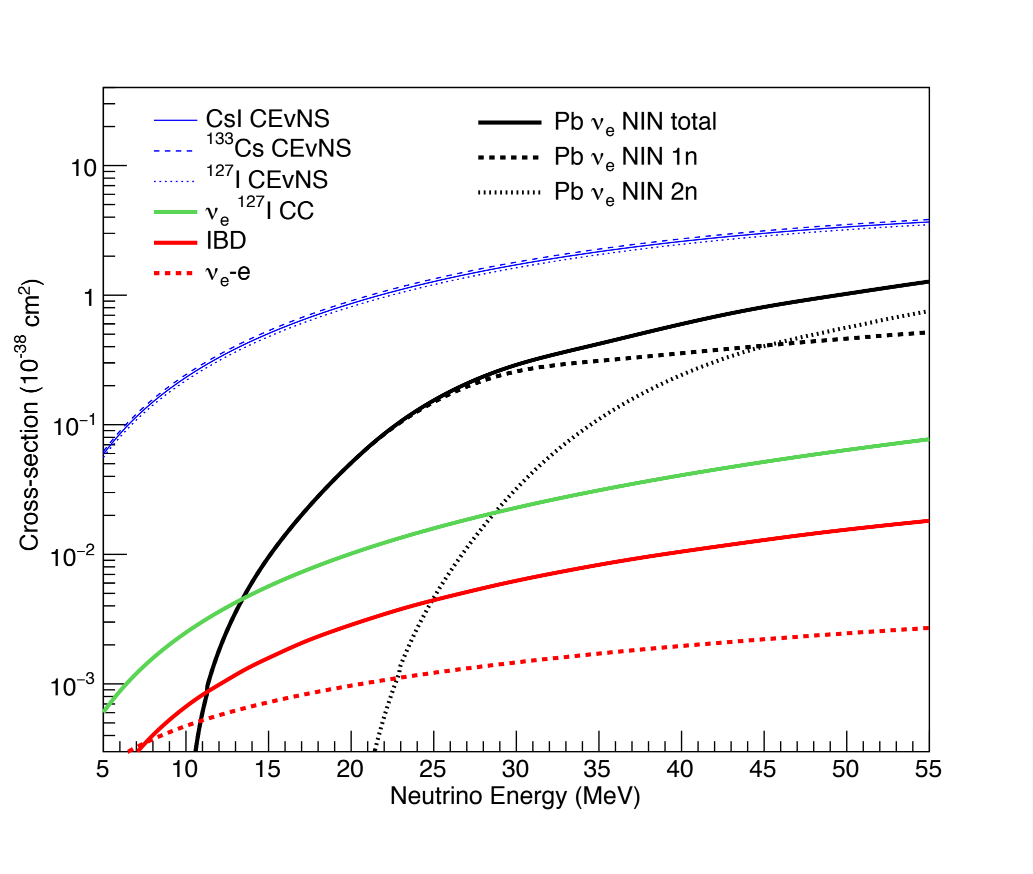
$E_\nu < 50 MeV$



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

Predicted 43 years ago!!!

CEvNS cross section



Cross section for CEvNS is predicted exactly, so any deviations will tell us about new physics outside of the SM

For experimentalists it is very attractive to see something new, which never been detected before

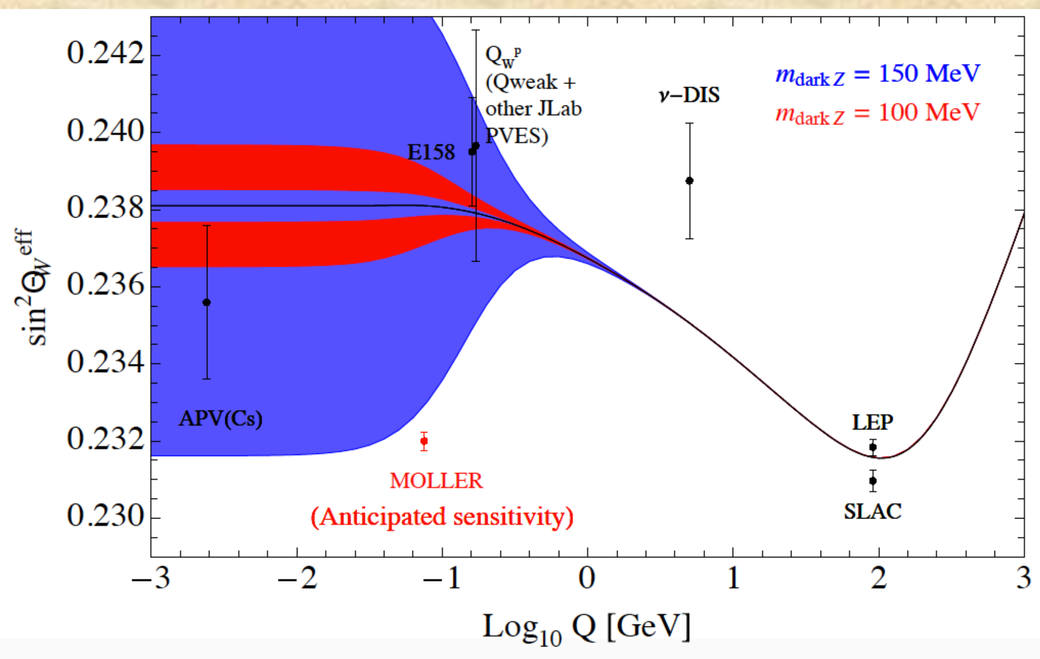
Weinberg (Electro week) angle

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

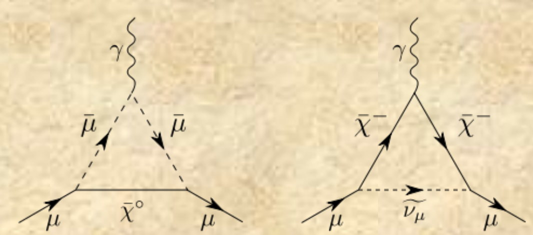
$$\sigma_{tot} = \frac{G_F^2 E_\nu^2}{4\pi}\left[Z\left(1-4\sin^2\theta_W\right)-N\right]^2 F^2(Q^2)$$

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

θ_w is free parameter in the Standard Model
There is no fundamental theory which explain its value
It is "running" constant, it depends on the momentum transfer.



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

Non-Standard Interactions of Neutrinos

new interaction specific to ν's

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

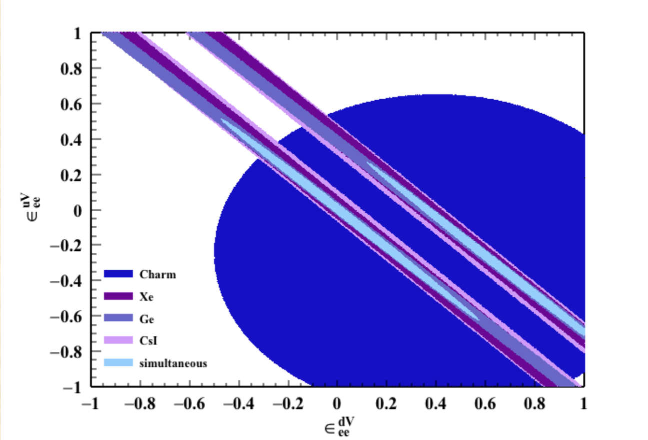
J. High Energy Phys. 03(2003) 011

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

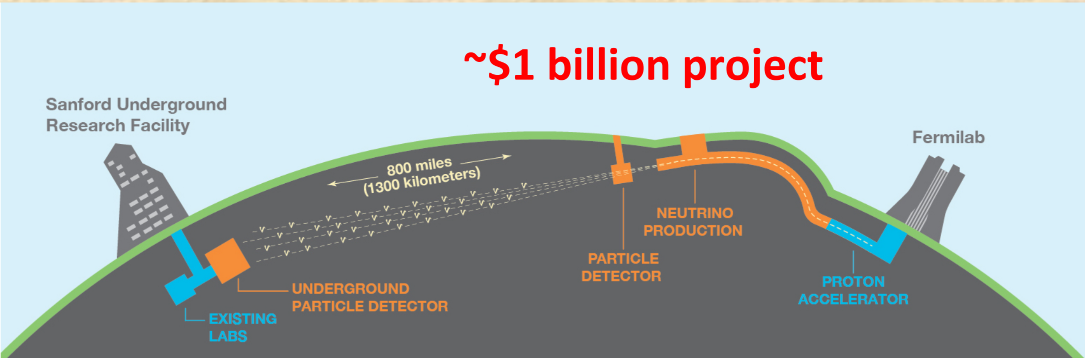
NSI parameter limit	Source
$-1 < \varepsilon_{ee}^{uL} < 0.3$	CHARM $\nu_e N$, $\bar{\nu}_e N$ scattering
$-0.4 < \varepsilon_{ee}^{uR} < 0.7$	
$-0.3 < \varepsilon_{ee}^{dL} < 0.3$	CHARM $\nu_e N$, $\bar{\nu}_e N$ scattering
$-0.6 < \varepsilon_{ee}^{dR} < 0.5$	
$\vert\varepsilon_{\mu\mu}^{uL}\vert 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



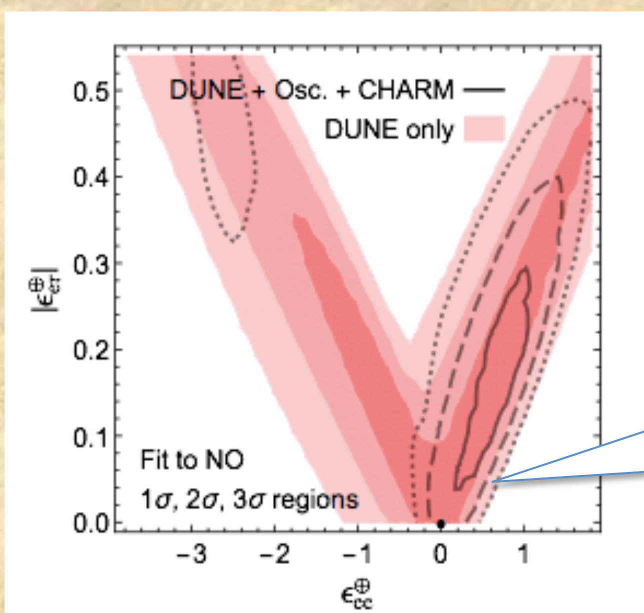
DUNE degeneracy I



– 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

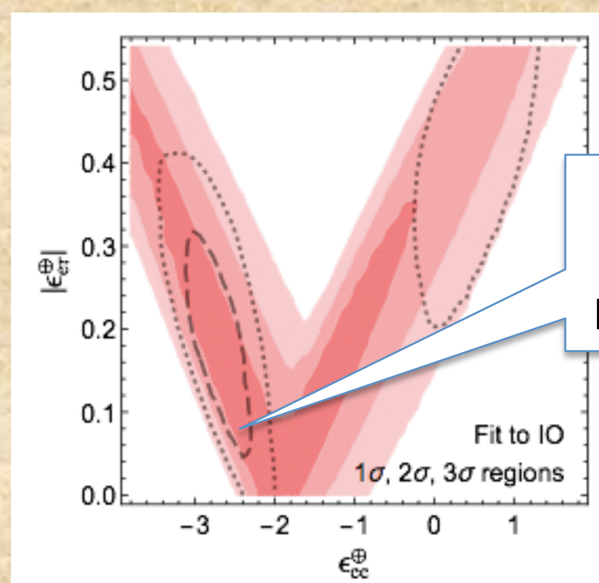
Generalized mass ordering degeneracy in neutrino oscillation experiments

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 is appears.

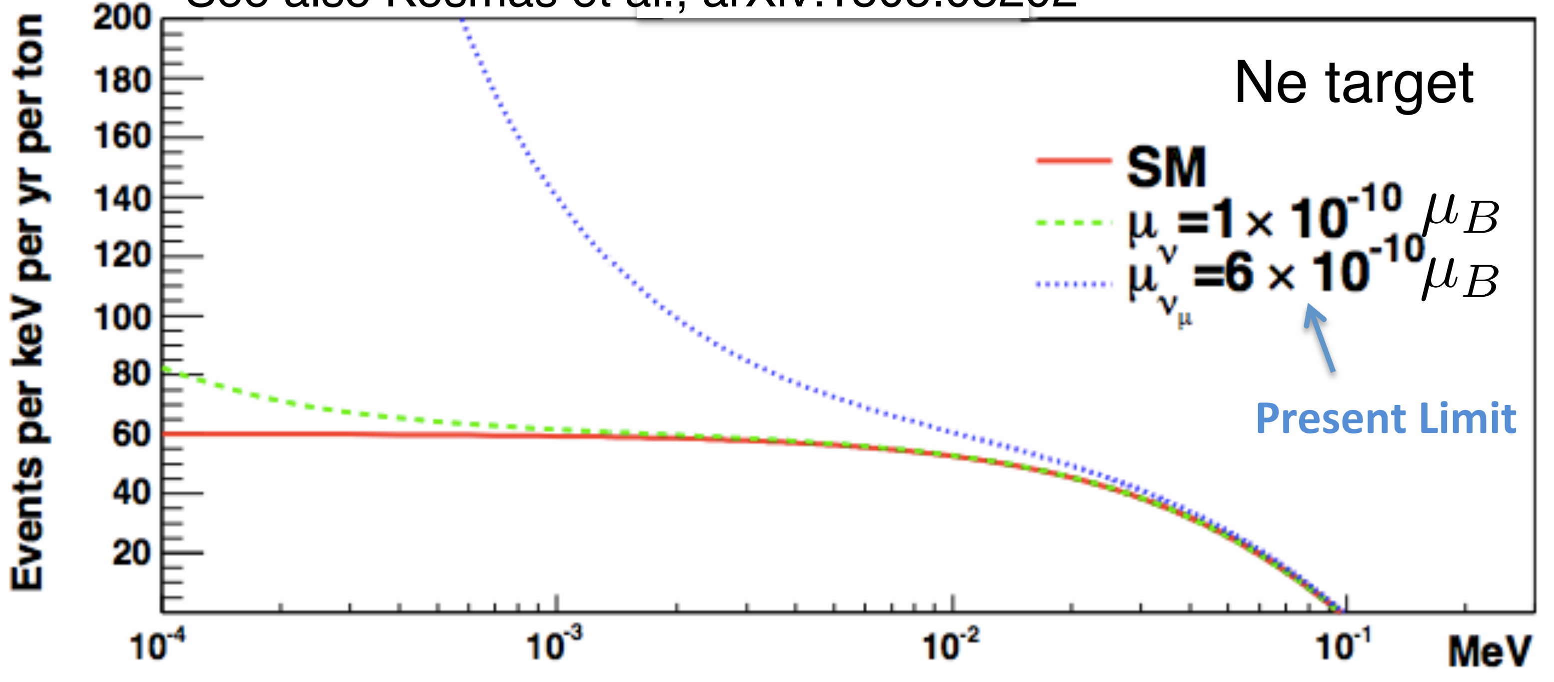
We can not tell the neutrino mass ordering without constrains on NSI

Neutrino magnetic moment via Coherent scattering

Signature is distortion at low recoil energy E

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

See also Kosmas et al., arXiv:1505.03202



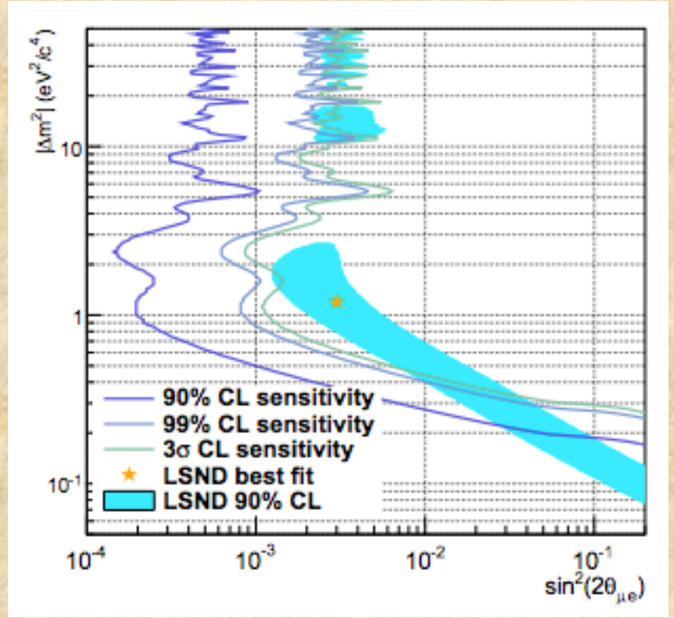
→requires very low energy threshold

Physics for Future Expansions

The development of a coherent neutrino scattering detection capability provides the <u>most natural</u> way to explore the sterile neutrino sector.

A. Drukier & L. Stodolsky, PRD 30 (84) 2295

A. J. Anderson et al., PRD 86 013004 (2012)



- The cross-section is sensitive to the magnitude of the Neutrino Magnetic Moment (Supersymmetry, Large Extra Dimensions, Right Handed Weak Currents).

  A. C. Dodd, et al., PLB 266 (91), 434

- COHERENT may be the first experiment to observe the Effective Neutrino Charge Radius.

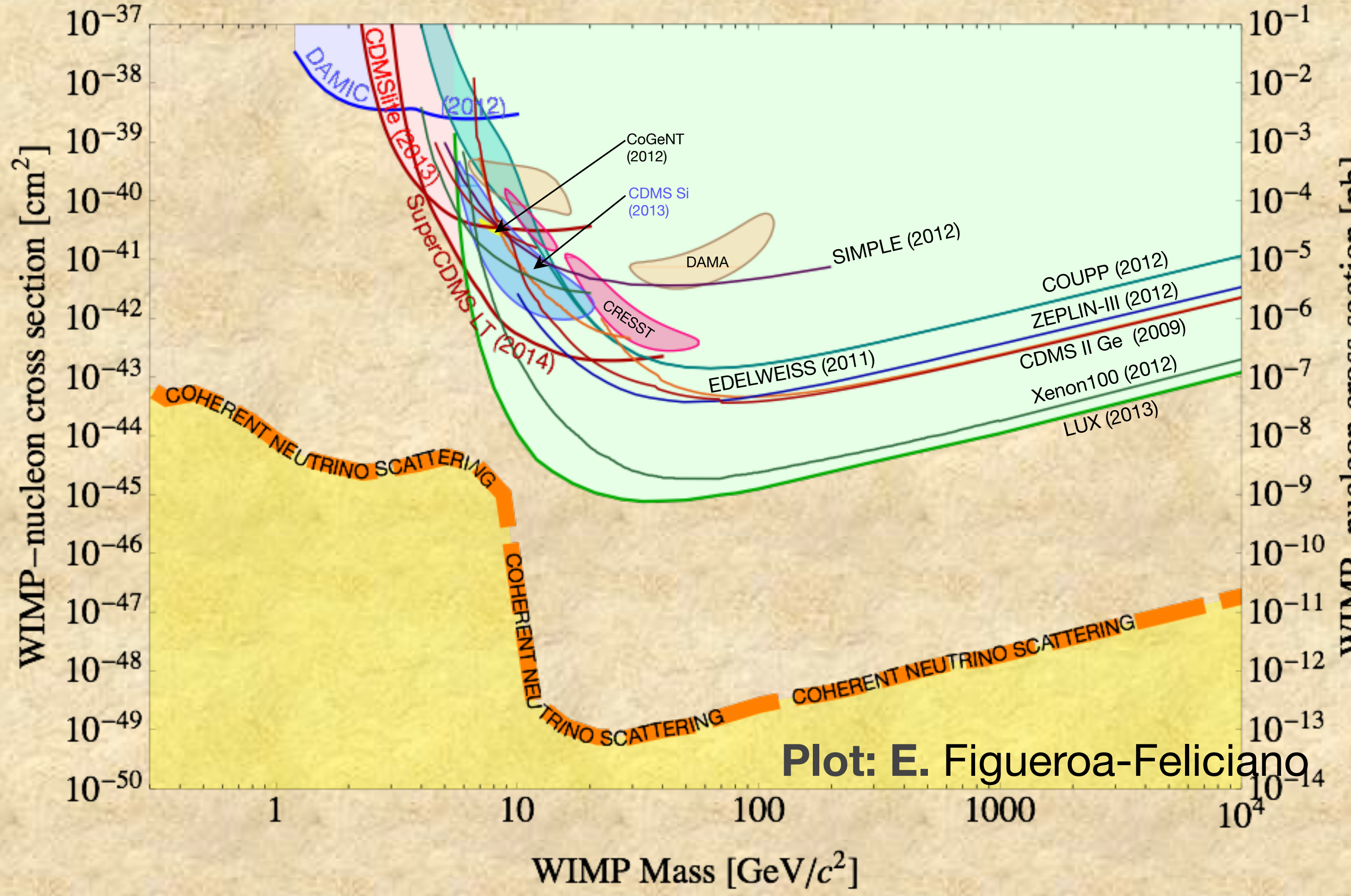
  J. Papavassiliou, J.Bernabeu, M. Passera, HEP-EPS 2005, Lisbon, arXiv:hep-ph/0512029

- The neutron distribution within the nucleus impacts the recoil energy dependent cross-section (Form Factor)

  K. Patton, et al., PRC 86, 024216

Why to Search for Coherent ν-Nucleus Scattering?

It will be irreducible background for Dark Matter experiments

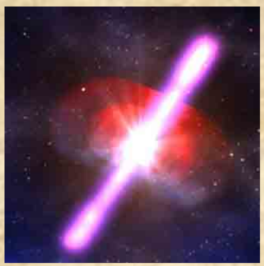


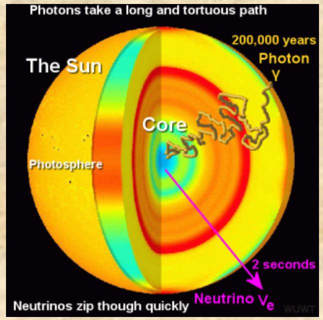
Possible Applications of Coherent Scattering

SN DETECTION (Stodolsky)

10 kpc, 10 ton → 100 events

sensitive to all favours

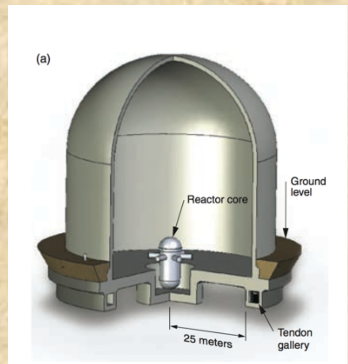




SOLAR NEUTRINOS

~1K events per ton per year.

REACTOR MONITORING



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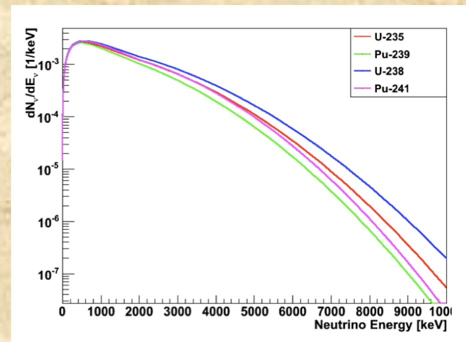

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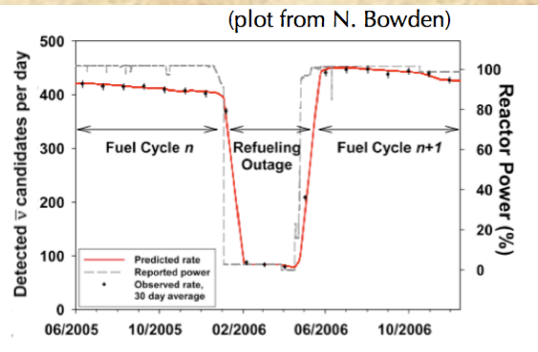
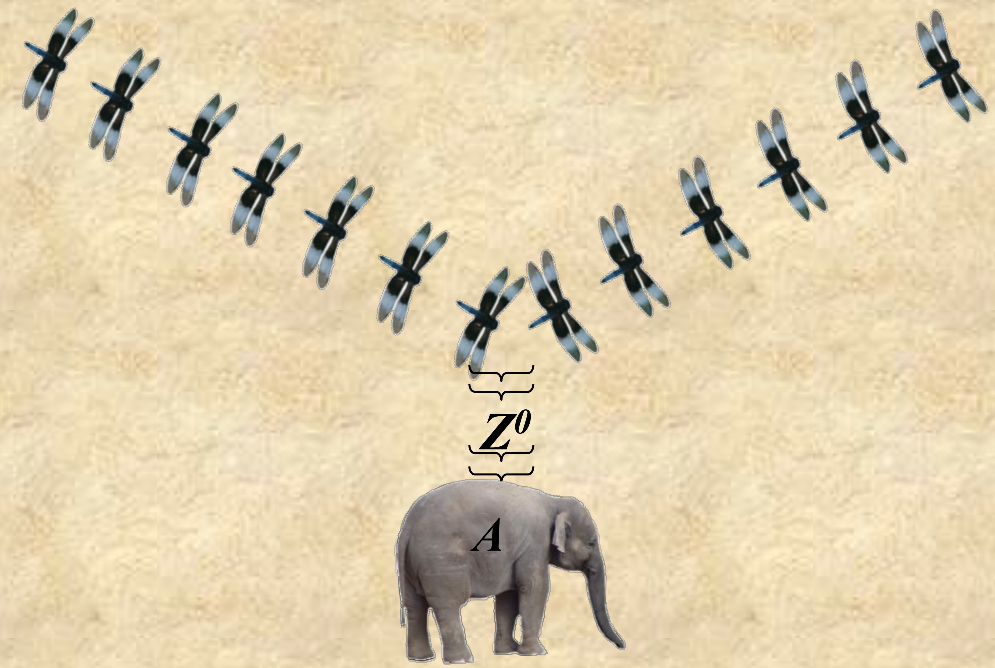


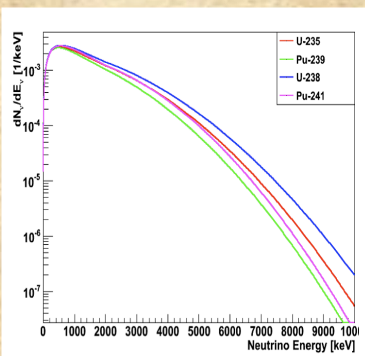
Why we have not detect CEvNS yet?



Nuclear recoils are in the range of keV!!!!

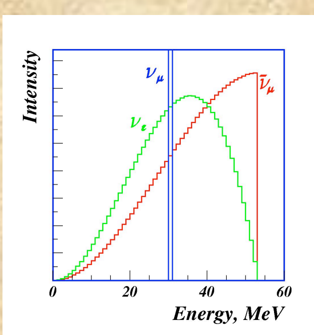
What Neutrino Sources We Can Use to Look for Neutrino Coherent Scattering

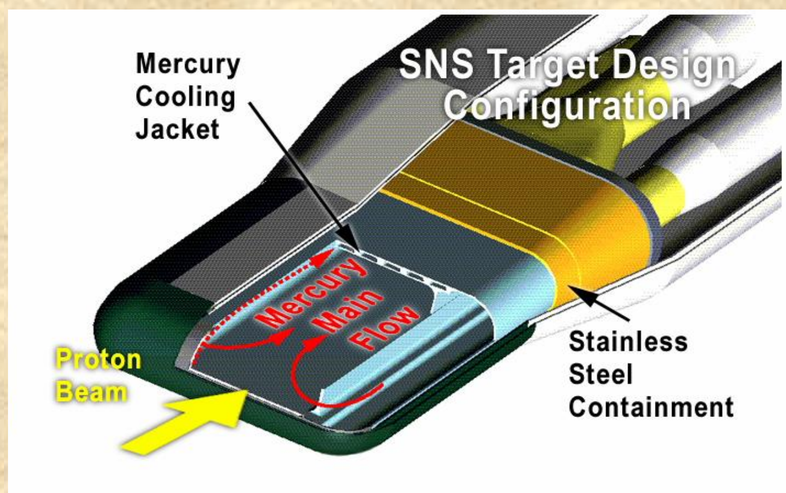
Nuclear Reactors



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

Stopped Pion Facilities





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

Race for the first CEvNS detection

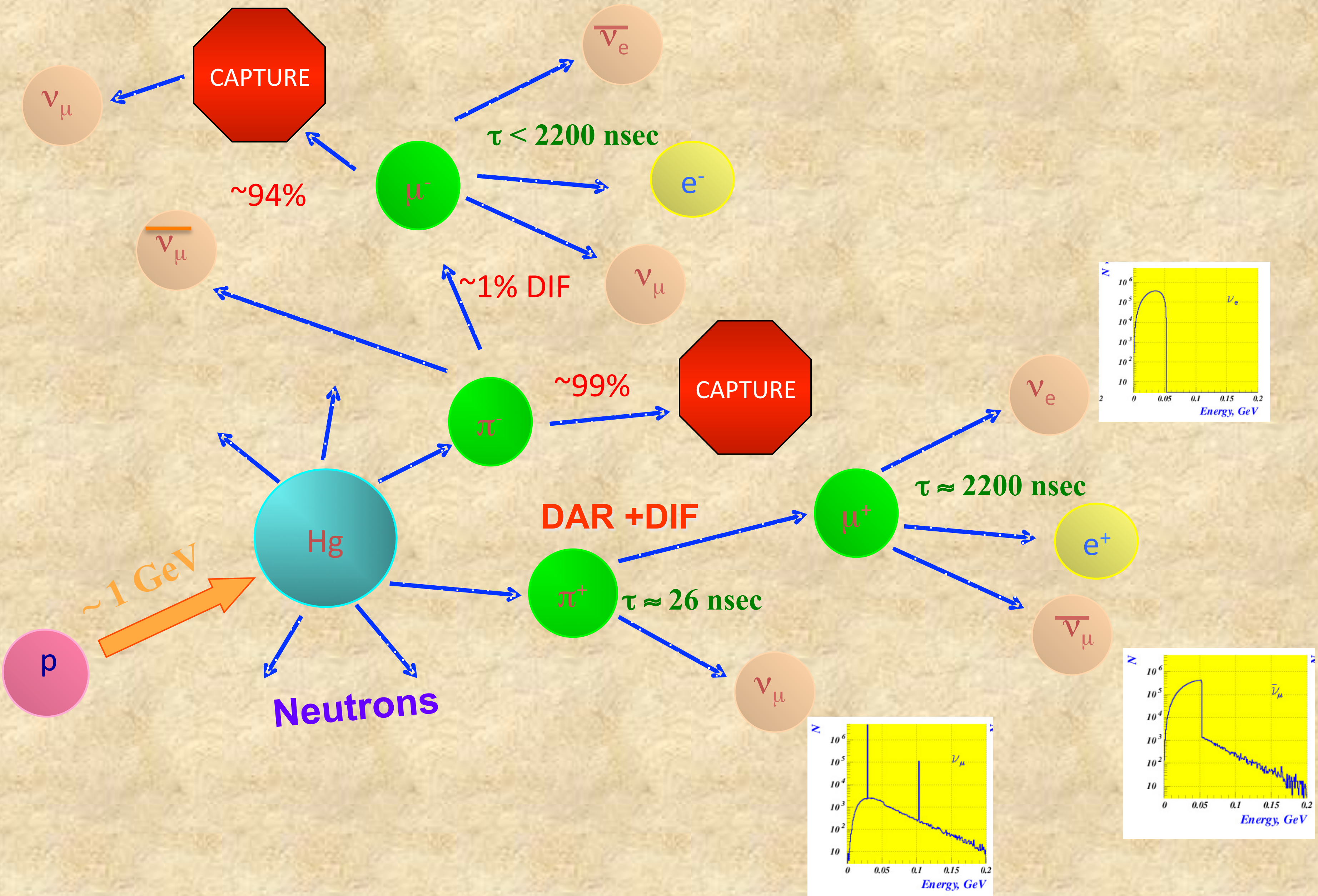
Experiment	Neutrino Source	Effective E_ν	Distance	Technology	Target	Mass
Ricochet at Chooz	Chooz 2x4.3GW	~4 MeV	355 m	Bolometer	Ge, Zn	5 + 5 kg
Ricochet at MIT	MITR 5 MW	~4 MeV	4 m	Bolometer	Ge, Zn	5 + 5 kg
MINER	Texas A&M 1 MW	~4 MeV	2 m	Ionization	Ge, Si	~ kg
CONNIE	Angra 3.8 GW	~4 MeV	30 m	CCD	Si	0.1 kg
RED-100	Kalinin 3.2 GW	~4 MeV	25 m	2 phase	Xe	100 kg
νGeN	Kalinin 3.2 GW	~4 MeV	10 m	Ionization	Ge	~5 kg
CONUS	Brokdorf 3.9 GW	~4 MeV	10 m	Ionization	Ge	~6 kg
COHERENT	SNS (DAR)	~40 MeV	20-30 m	Ionization	CsI, Ar, Ge	14, 30, 10 kg

In blue shown experiments which are taking data now

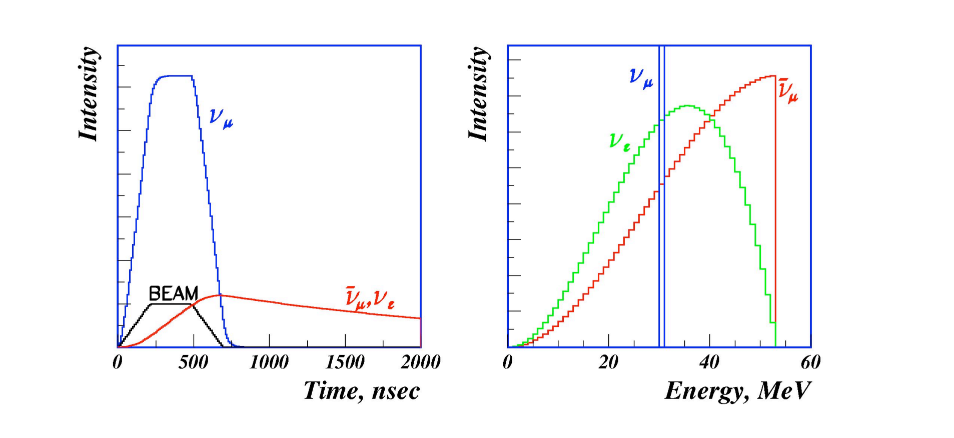
SNS-Spallation Neutrino Source

1 GeV proton beam on Hg target
1.0-1.4 MW of beam power
600 nsec pulses, 60 Hz
Operation: 9 month per year

Neutrino Production at SNS



Stop Pion Neutrinos at SNS



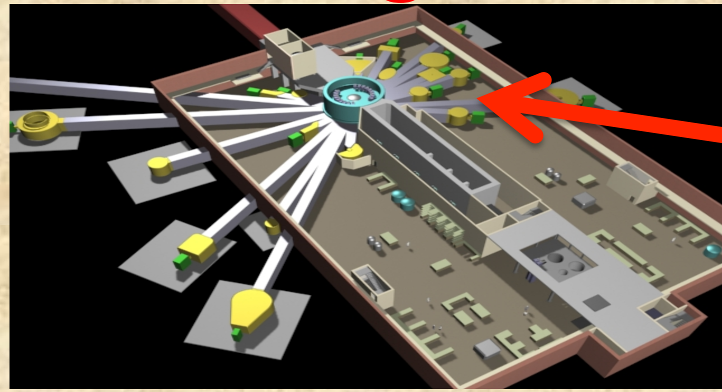
1 MW spallation source, 15 m from the target, 100 kg detector, prompt 30 MeV neutrinos, event rates for CEvNS

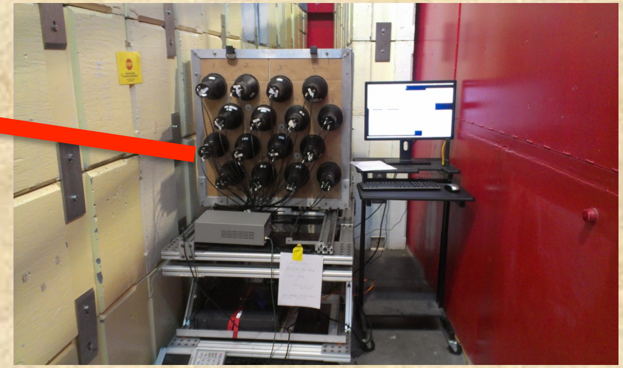
Target	Max Recoil (keV)	Cross section $10^{-42}cm^2$	Threshold, keV_{nr}	N events, year
He	483	13.8	10	134
C	161	125	10	370
Ne	96	609	10	980
Si	69	688	0.1	990
Ar	48	1700	10	1080
Ge	27	5830	3	2560
I	15	19400	10	732
Xe	15	22300	1	5970

Collaboration to make the first detection of the Neutrino Neutral Current Coherent scattering at the SNS

University of California, Berkeley
University of Chicago
Duke University
University of Florida
Indiana University
Institute for Theoretical and Experimental Physics, Moscow
Lawrence Berkeley National Laboratory
Los Alamos National Laboratory
National Research Nuclear University MEPhI
North Carolina Central University
Oak Ridge National Laboratory
Pacific Northwest National Laboratory
Sandia National Laboratory
University of Tennessee, Knoxville
Triangle Universities Nuclear Laboratory

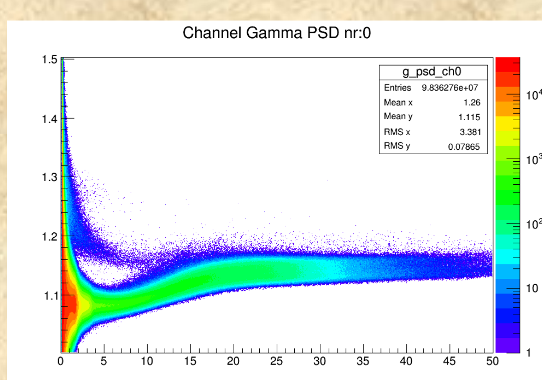
Background Measurements at the SNS



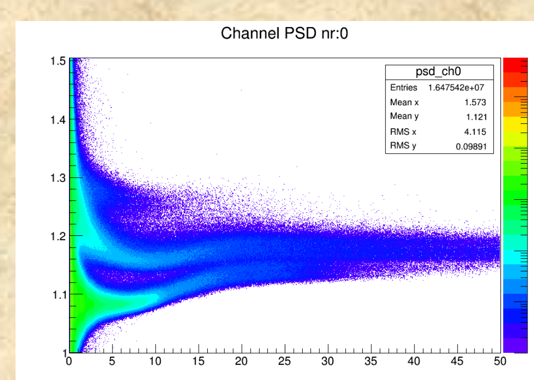


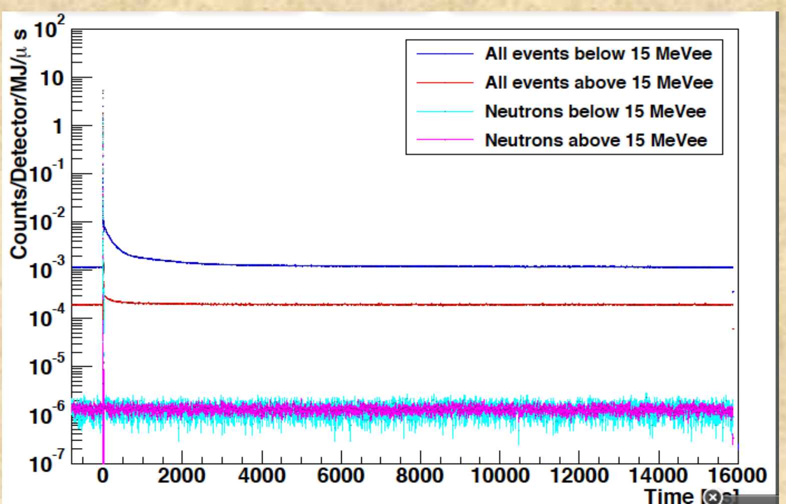
Started in 2013

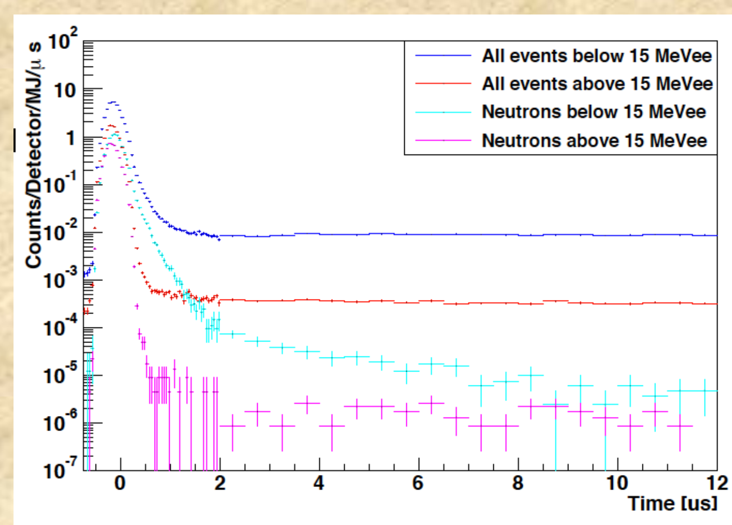
"Out-of-beam" events, primarily muons.



"In-Beam" events, considerably more neutron events (and 16x less "live time")

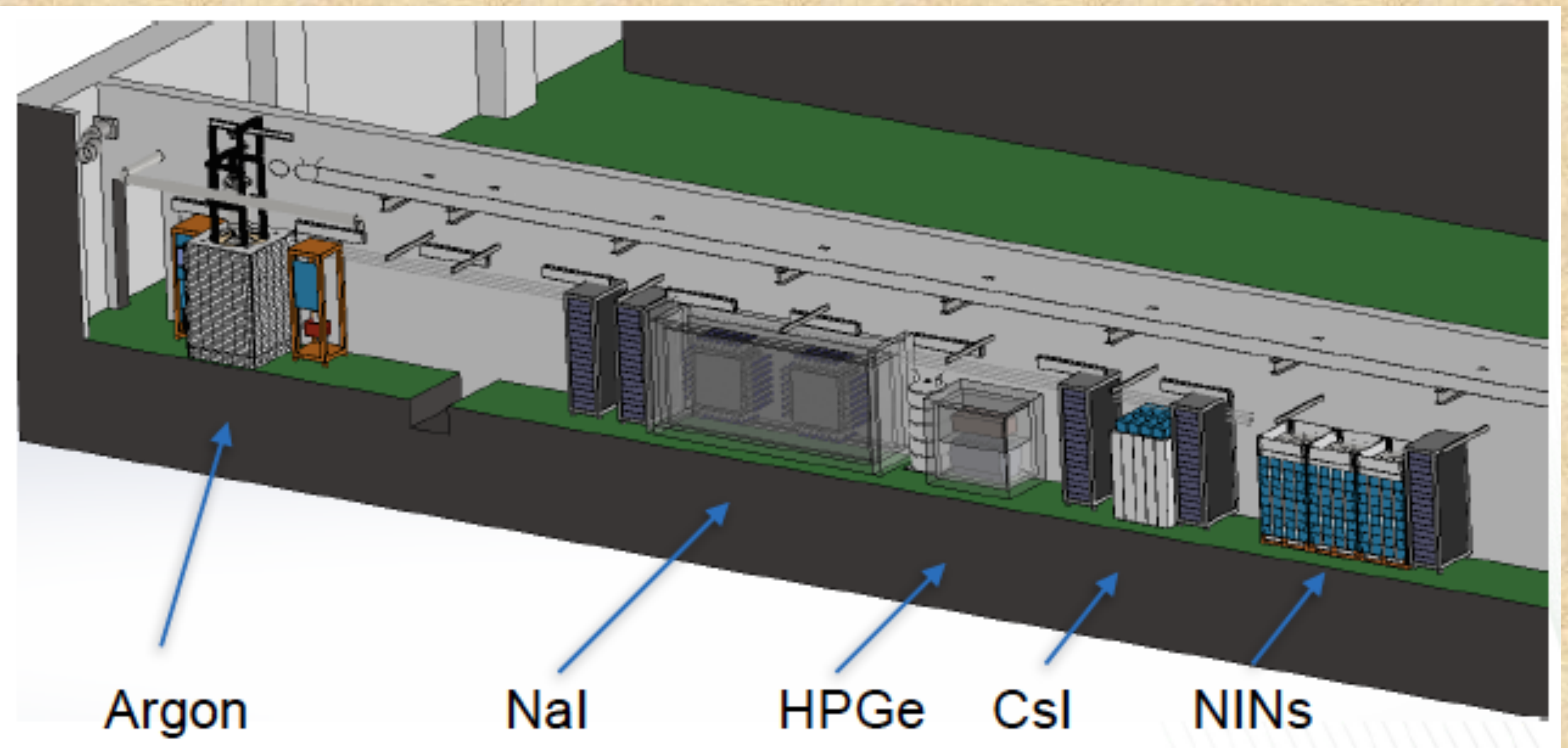






Neutrino Alley at the SNS

Underground location – 8 M.W.E.
20 meters to the target filled with Still and concrete.



Basement location is far away from Neutron beam Lines.
Extra protection from cosmic rays

Three Detector Technology for COHERENT Phase I

CsI

LAr

HPGe

Target	Target Mass	Max Recoil (keV)	Cross section $10^{-42}cm^2$	Threshold, keV_{nr}	N events, year
Ge	~10 kg	27	5830	3	280
CsI	14 kg	15	19400	10	170
Ar	30 kg	48	1700	10	250

Neutrons with energy > 50 keV can produce similar recoils → major background

Conclusion

CEvNS has been predicted 43 yeas ago, but so far never been detected

Their discovery will give us tool to study physics beyond the SM

SNS is the world most powerful pulsed neutrino source

Neutrino Energy range at the SNS is just right for search of CEvNS

There is comprehensive and exciting neutrino program at the SNS

Presently COHERENT collaboration is working with the first generation of detectors to see a “First Light”

There are many ideas for the “what to do after the first observation of CEvNS”

Will we see CEvNS soon?   I hope so!!!!