COHERENT
at the Spallation Neutron Source

Yu.Efremenko – University of Tennessee

Coherent Elastic Neutrino Nuclear 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*

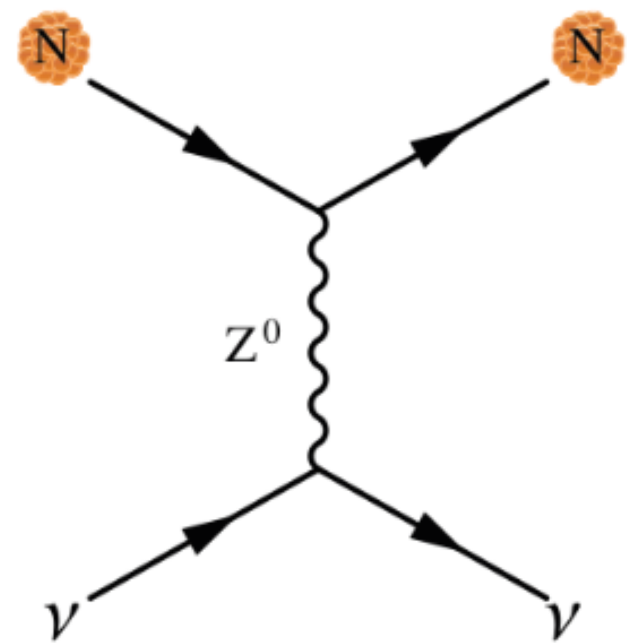
E_ν – *neutrino energy*

Z – *nucleus charge*

N – *number of neutrons in the nucleus*

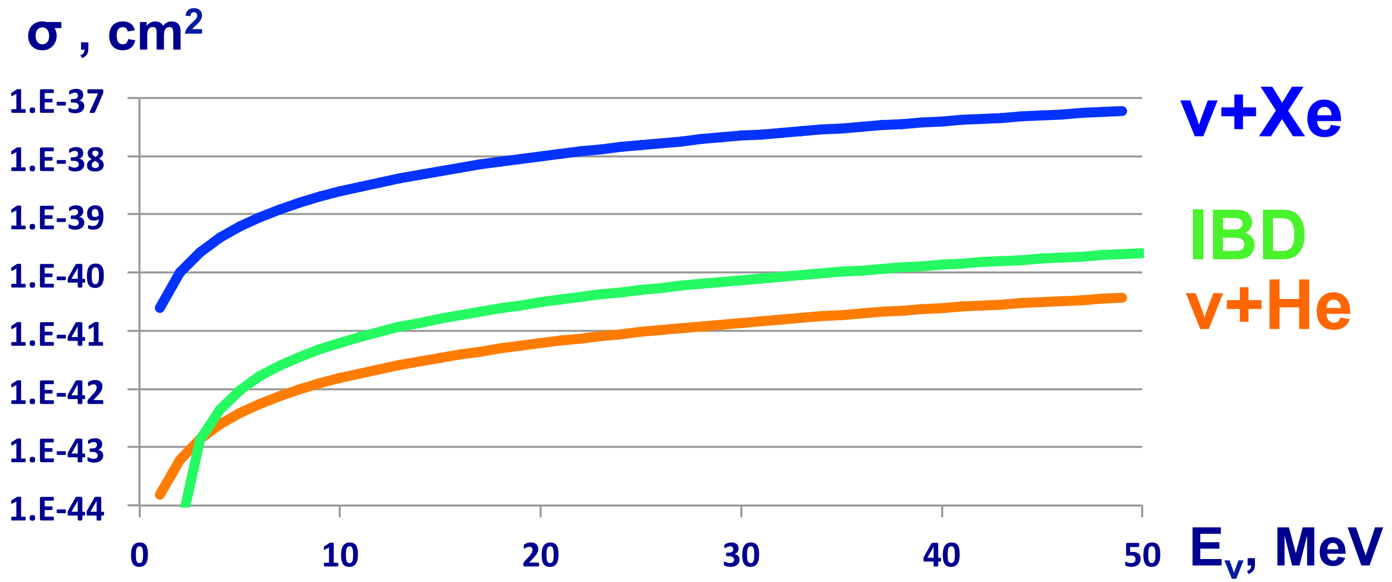
F *is nucleus form factor*

$E_\nu < 50 MeV$

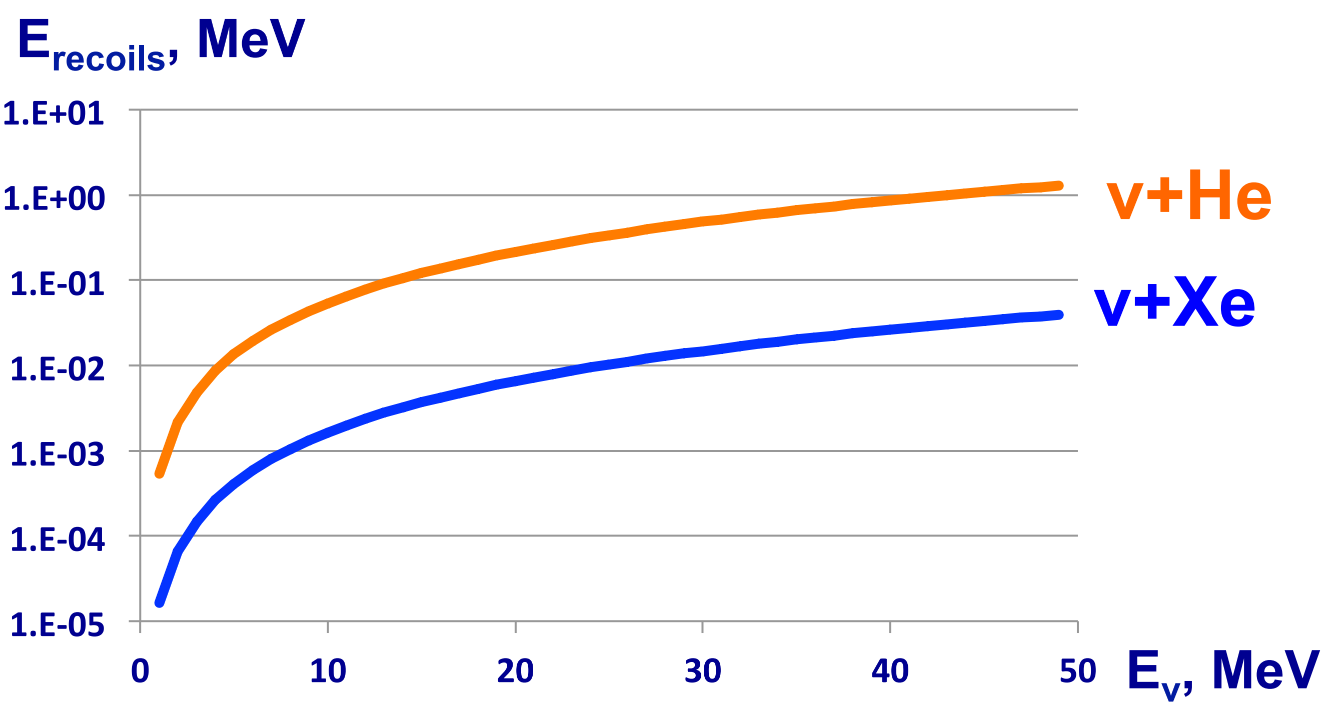


D.Z. Freedman PRD 9 (1974)
A. Drukier & L. Stodolsky, PRD 30, 2295 (1984)
Horowitz et al. astro-ph/0302071

Why we do not see it yet?

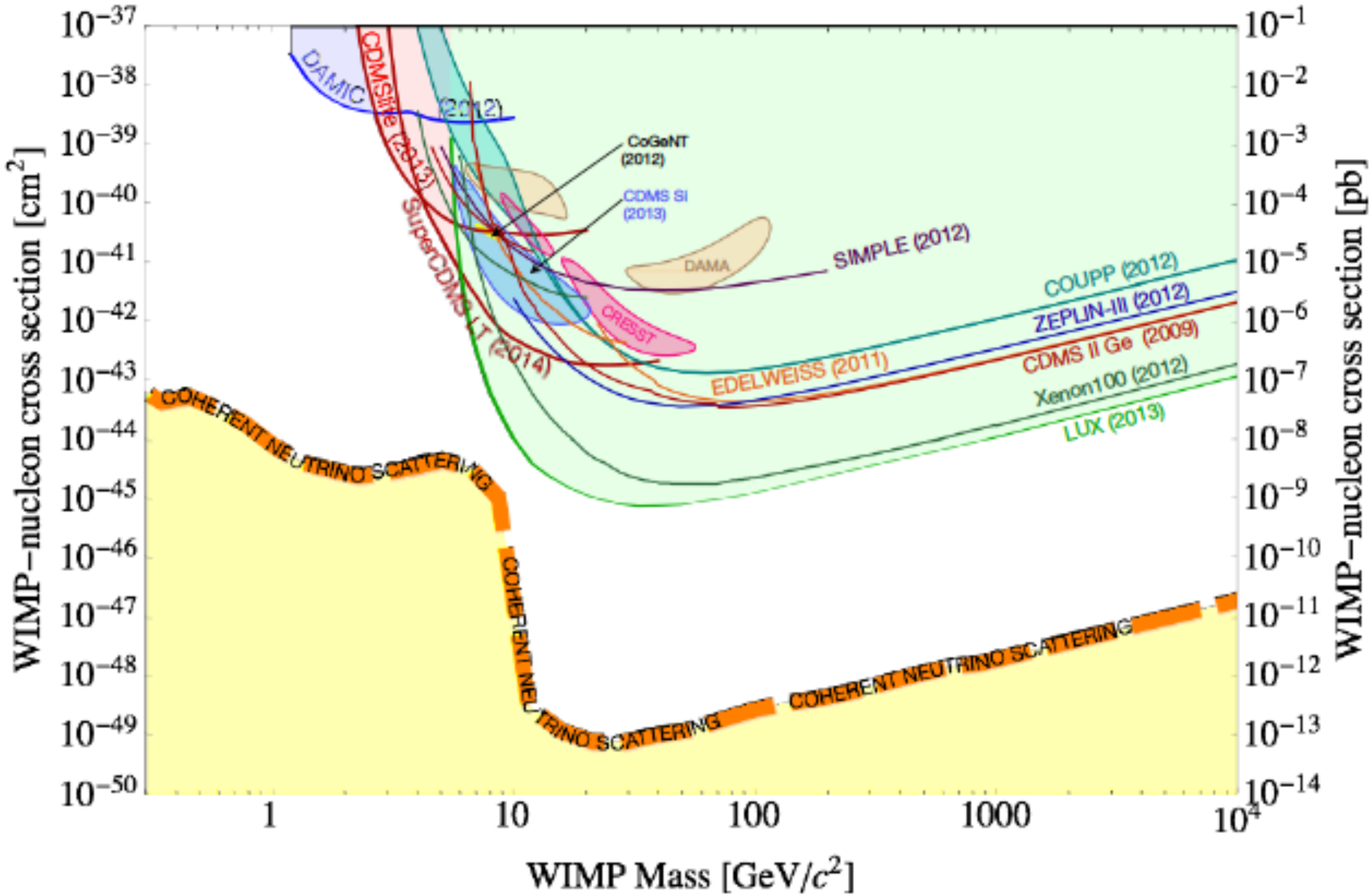


Cross Section is Large !!!



But the Signal is Hard to Detect

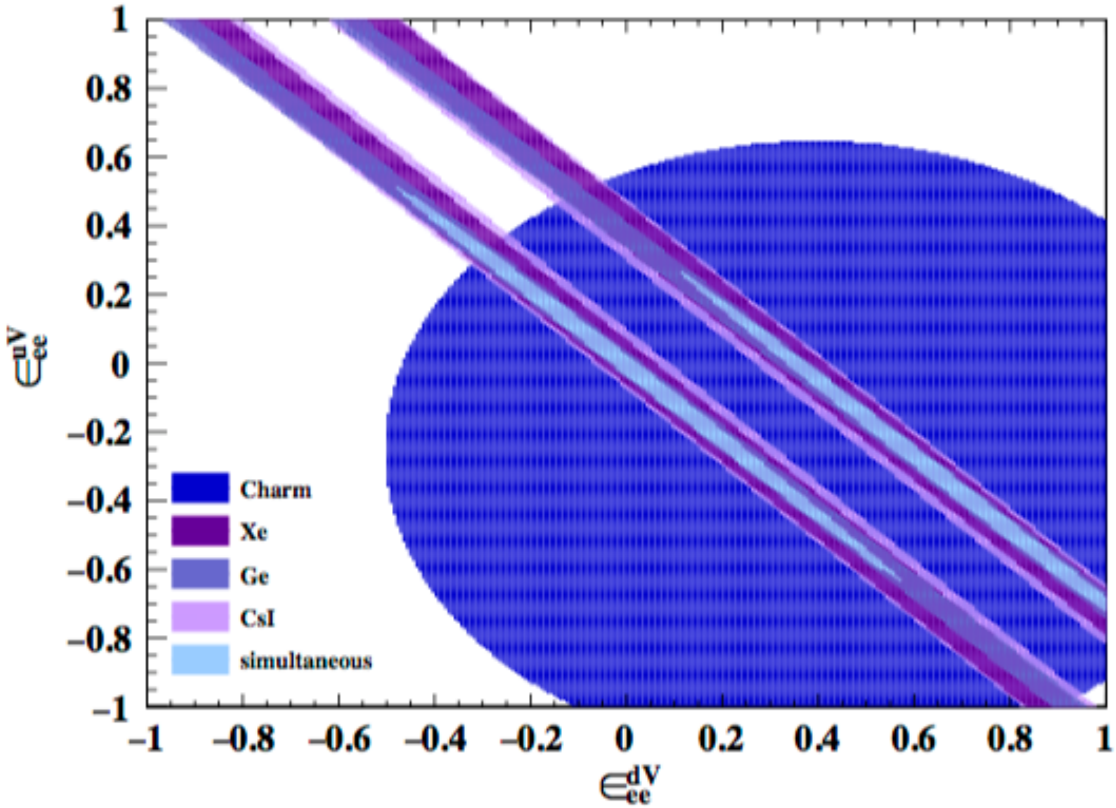
CEvNS from natural neutrinos creates ultimate background for direct DM search experiments



Understand nature of background (& detector response)

CEvNS is cleanly predicted in the SM, so any deviation could represent new physics

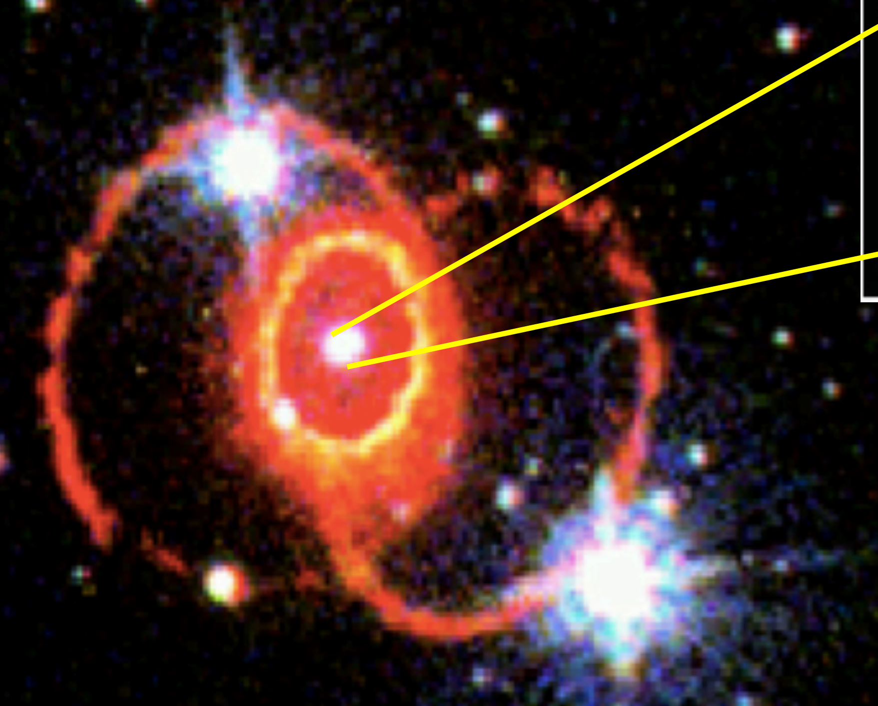
Example: sensitivity to **Non-Standard Interactions (NSI)** of neutrinos and quarks; could get ~factor of 10 beyond existing limits with current-generation CEvNS experiment

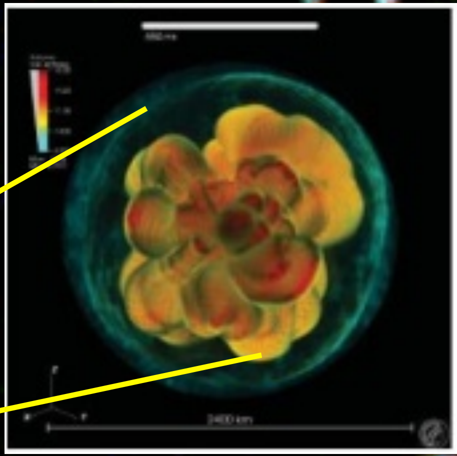


Scholberg 2005, Barranco et al. 2005

$$\frac{d\sigma}{dT}(E_\nu, T) = \frac{G_F^2 M}{\pi}\left(1 - \frac{MT}{2E_\nu^2}\right) \times \left\{\left[Z(g_V^p + 2\varepsilon_{ee}^{uV} + \varepsilon_{ee}^{dV}) + N(g_V^n + \varepsilon_{ee}^{uV} + 2\varepsilon_{ee}^{dV})\right]^2 + \sum_{\alpha=\mu,\tau}\left[Z(2\varepsilon_{\alpha e}^{uV} + \varepsilon_{\alpha e}^{dV}) + N(\varepsilon_{\alpha e}^{uV} + 2\varepsilon_{\alpha e}^{dV})\right]^2\right\}$$

CEvNS is important in supernova models and supernova neutrino detection



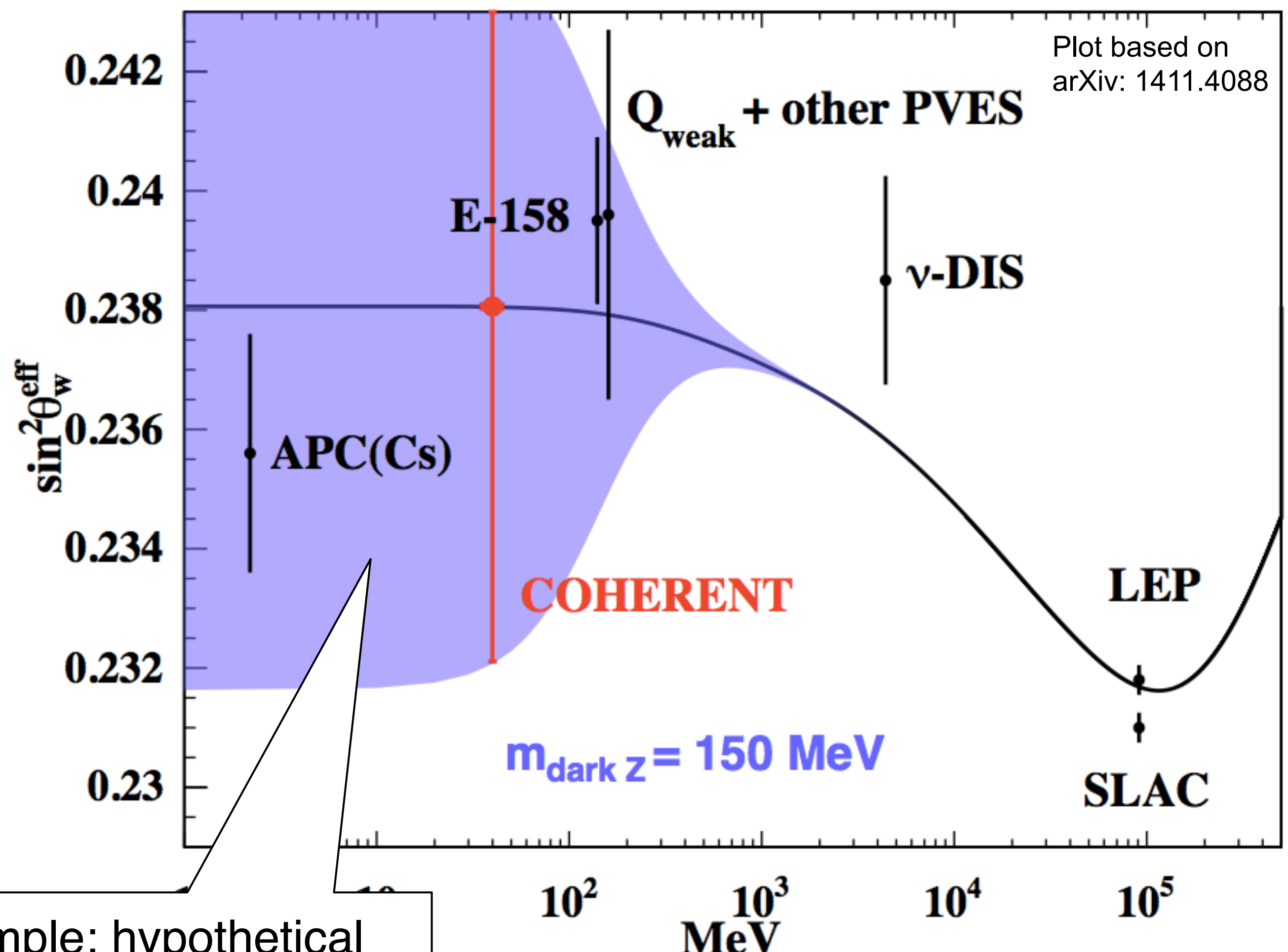


J.R. Wilson, PRL 32, 849 (1974)
C. Horowitz et al., PRD 68, 02005 (2003)

Clean SM prediction for the rate → measure $\sin^2\theta_W$eff ;

deviation probes new physics

$$\sigma \sim \frac{G_f^2 E^2}{4\pi}(N - (1 - 4\sin^2\theta_W)Z)^2$$



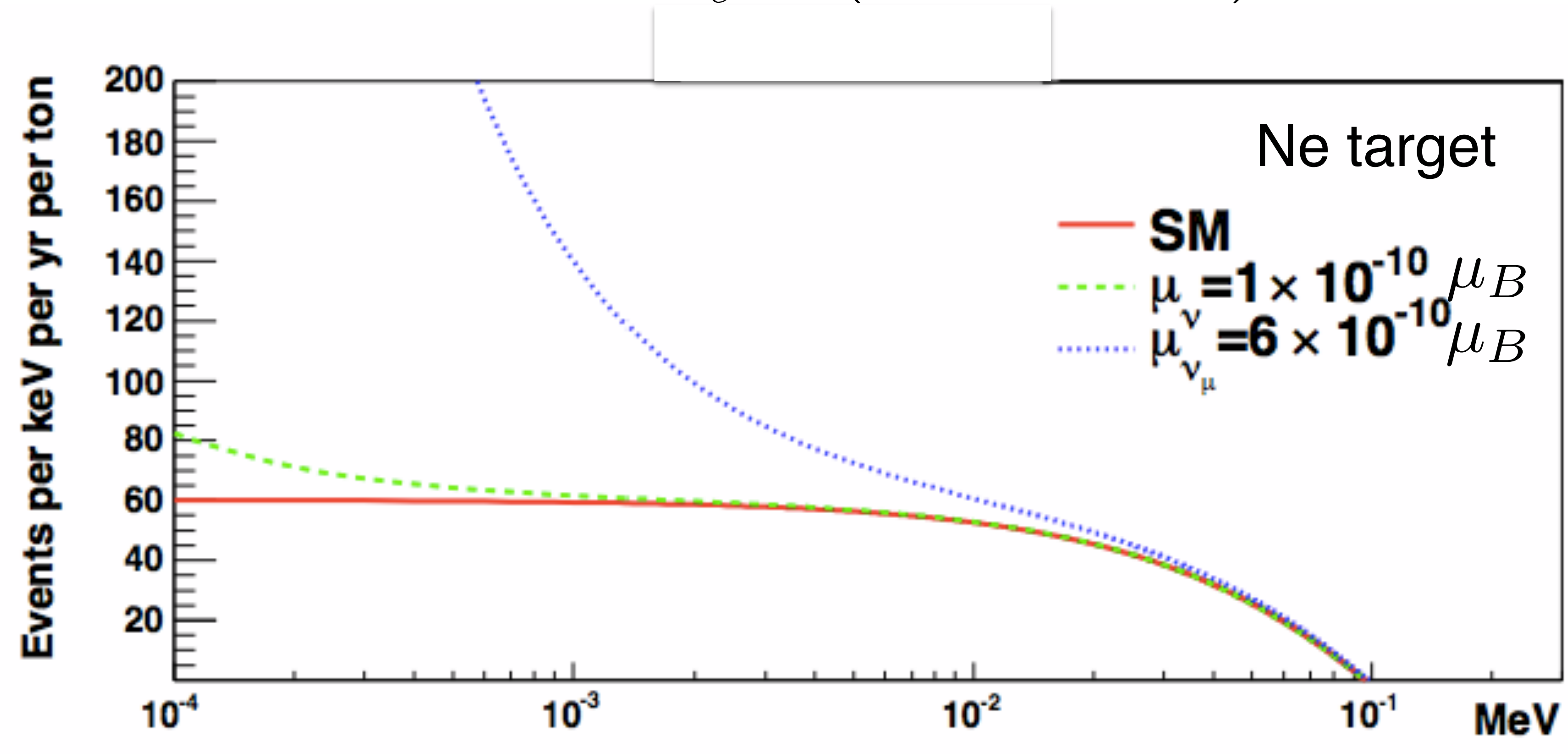
Example: hypothetical dark Z mediator (explanation for g-2 anomaly)

CEvNS sensitivity is @ low Q; need sub-percent precision to compete w/ electron scattering & APV, but **new channel**

Neutrino magnetic moment

Signature is **distortion at low recoil energy E**

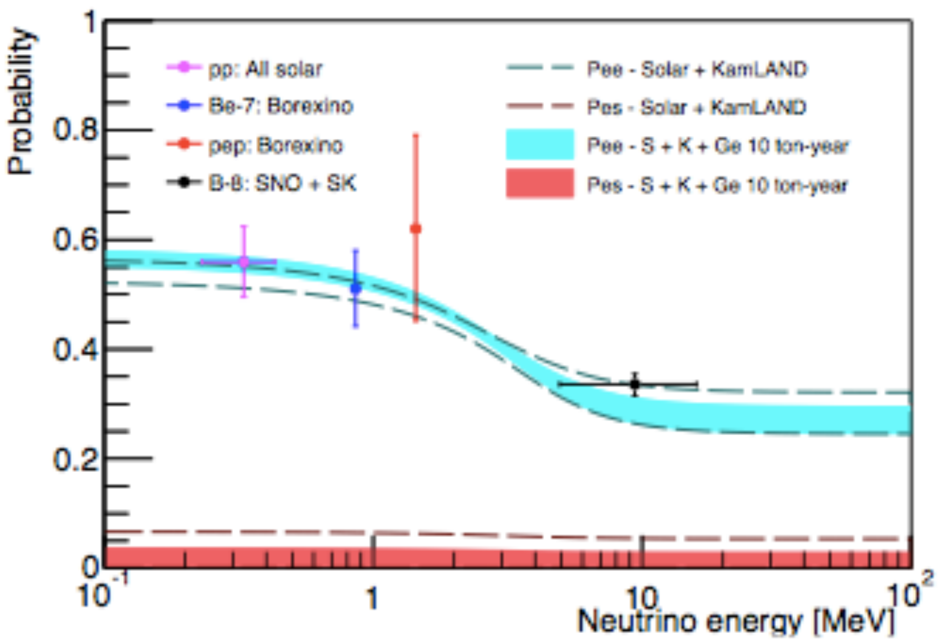
$$\frac{d\sigma}{dE} = \frac{\pi\alpha^2\mu_\nu^2 Z^2}{m_e^2}\left(\frac{1-E/k}{E} + \frac{E}{4k^2}\right)$$

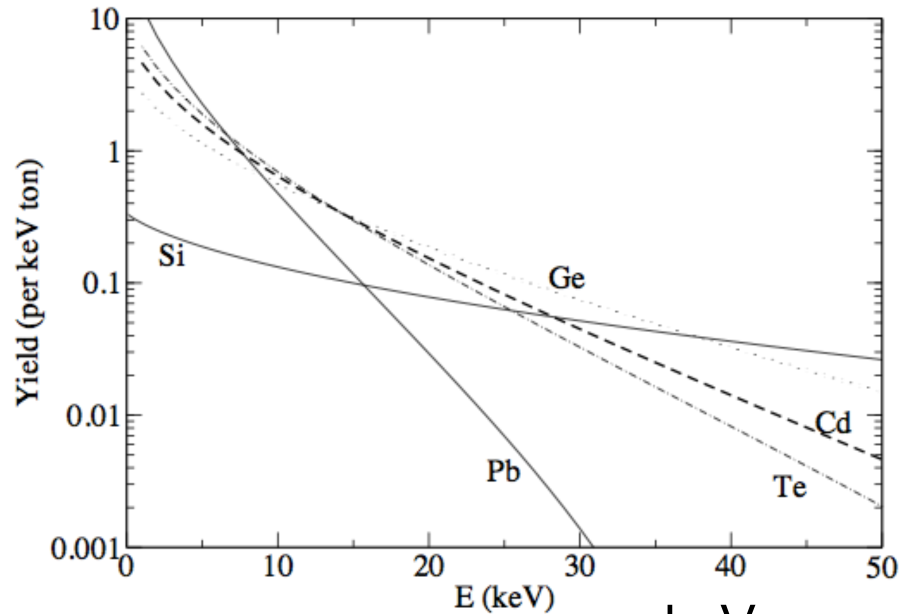


➔requires low energy threshold

See also new paper: Kosmas et al., arXiv:1505.03202

Also note: tone-scale underground detectors can do astrophysics





keVr

Billard et al., arXiv:1409.0050

Horowitz et al., PRD68 (2003) 023005

Solar neutrinos:
rule out sterile oscillations using CEvNS (NC)

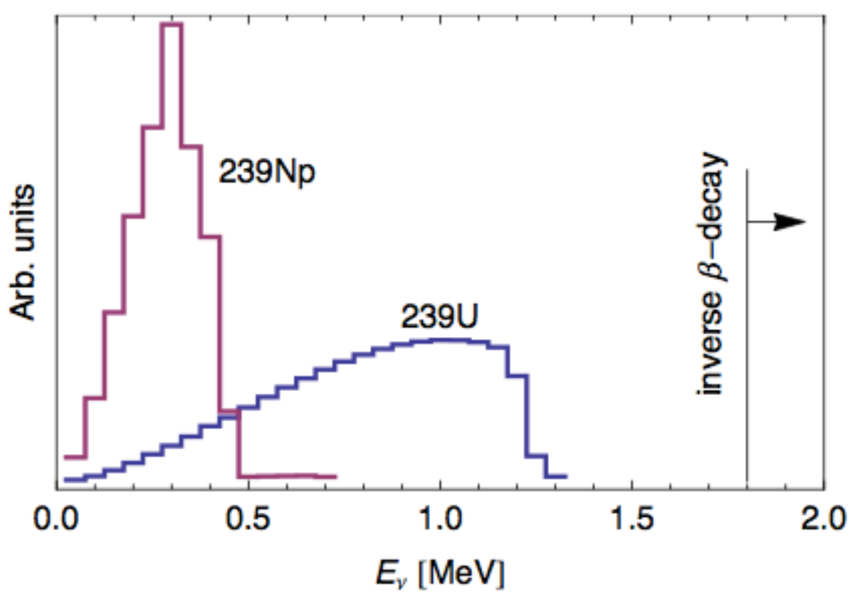
Supernova neutrinos:
~ handful of events per tonne @ 10 kpc: sensitive to ***all flavor components*** *of the flux*

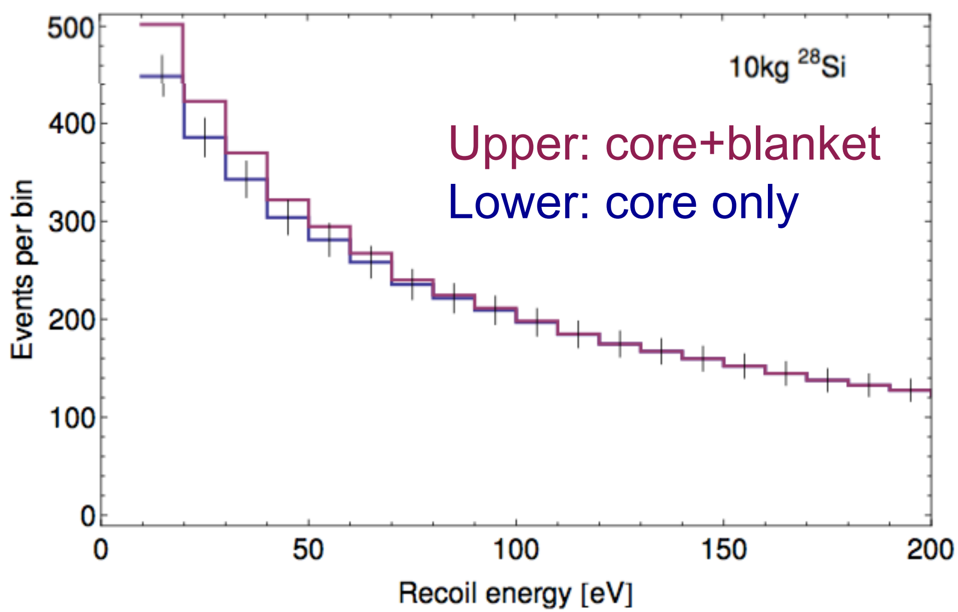
A practical application in nuclear safeguards:

P. Huber, talk at NA/NT workshop, Manchester, May 2015

Presence of **plutonium breeder blanket** in a reactor has ν spectral signature

$$^{238}\mathrm{U} + n \rightarrow {}^{239}\mathrm{U} \xrightarrow{\beta} {}^{239}\mathrm{Np} \xrightarrow{\beta} {}^{239}\mathrm{Pu}$$





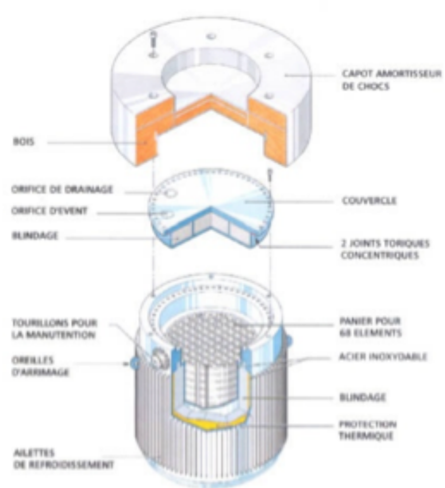
ν spectrum is below IBD threshold

➔ accessible with CEvNS, but require low recoil energy threshold

What Source We Can Use to Look for Neutrino Coherent Scattering

Radioactive sources

^{144}Ce, 75 kCi

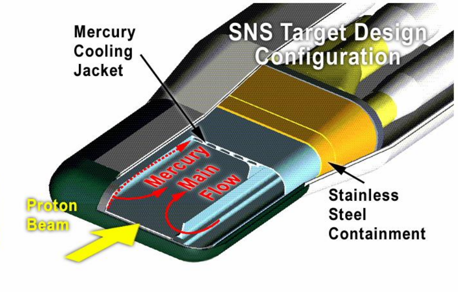


1 kW
Practical distance between source and detector is ~2 m
E_ν ~ 1.5 MeV

Nuclear Reactors

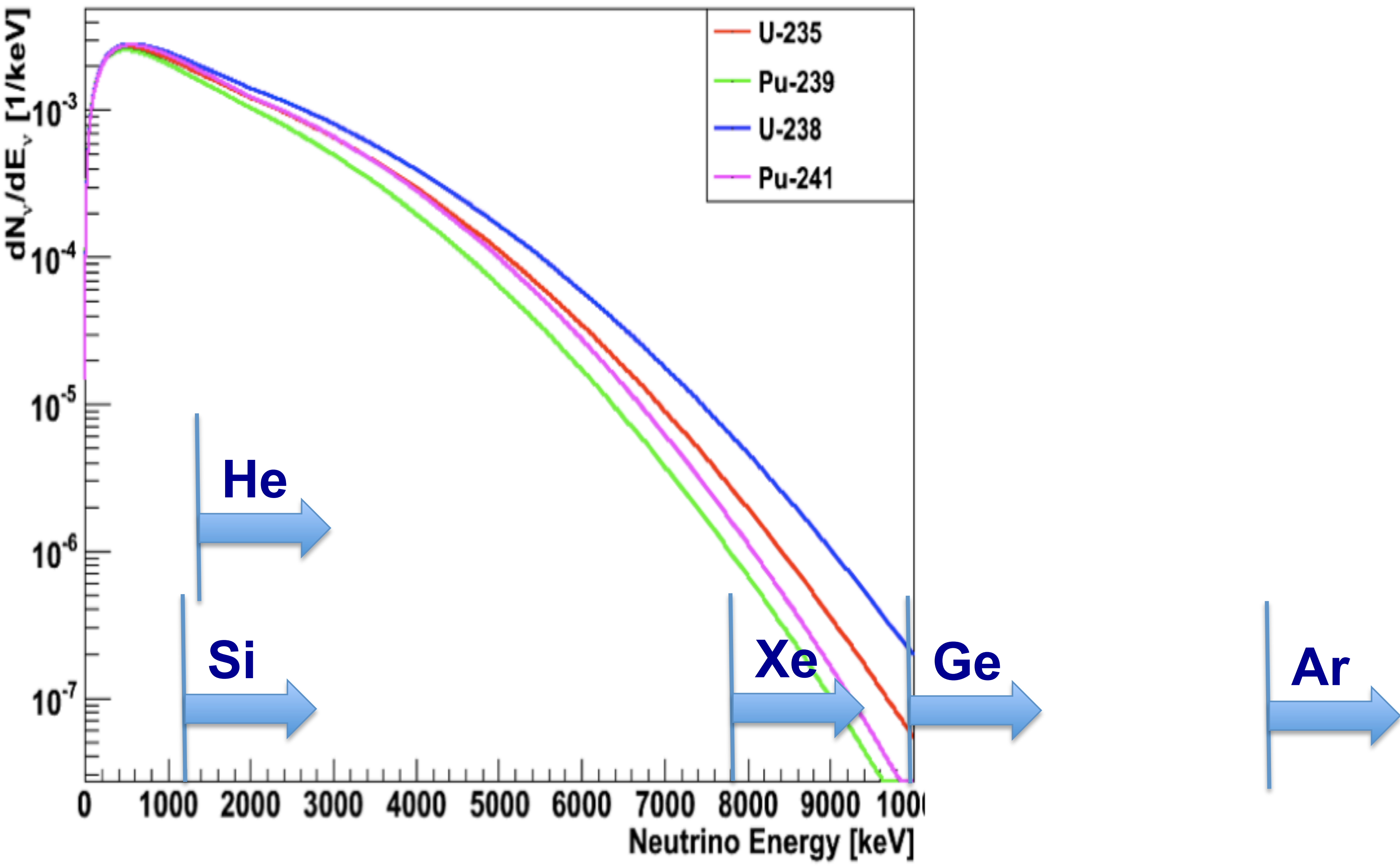
3 GW
Distance ~20 m
E_ν ~ 3 MeV

Stopped Pion Faciliti



1 MW
Distance ~15 m
E_ν ~ 30 MeV

Reactor Neutrinos



Proton beam energy – 0.9 - 1.3 GeV

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

Pulse duration - 380ns(FWHM)

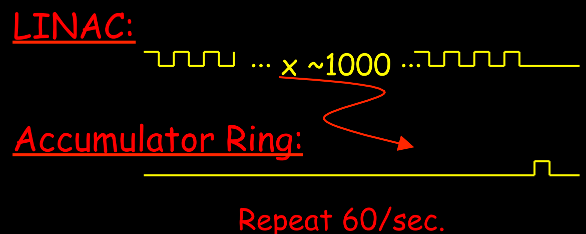
Repetition rate - 60Hz

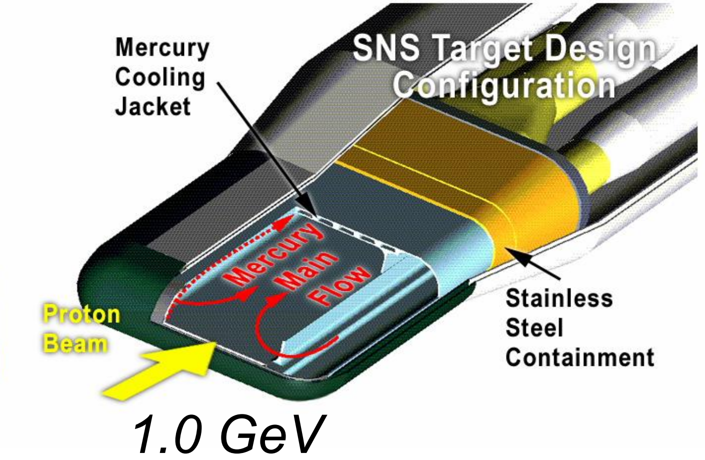
Total power – 0.9 – 1.4 MW

Liquid Mercury target

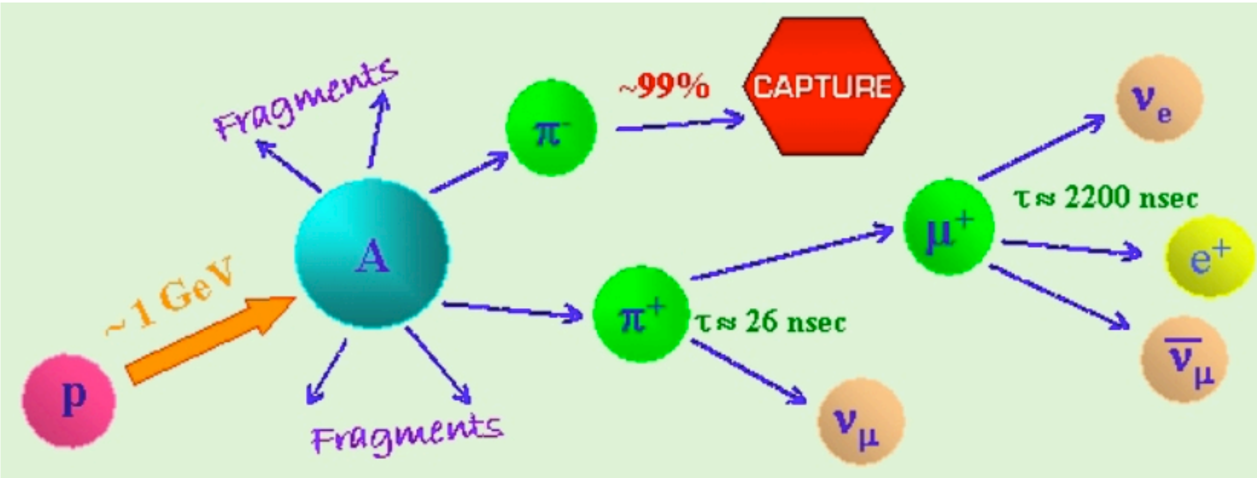
SNS-Spallation Neutrino Source

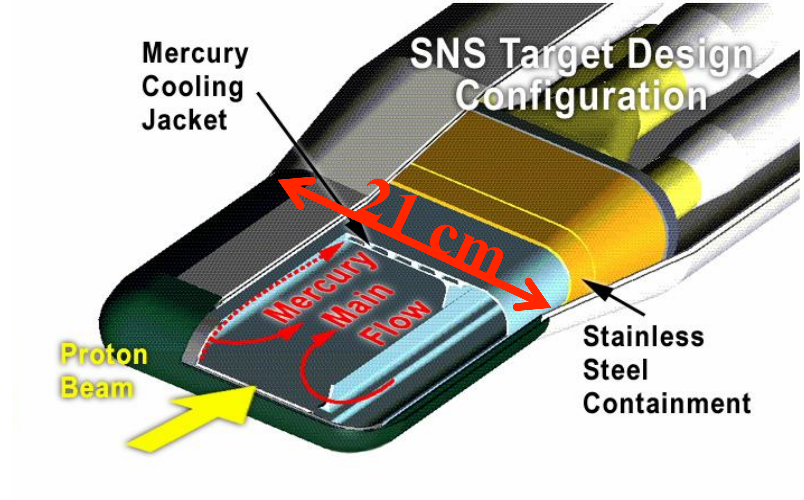
Spallation Neutron Source





Neutrino Production at SNS





Number of protons on target for 1.1 mA at 1.3 GeV is $0.687 \cdot 10^{16}$ sec^{-1}

Number of each flavor neutrino produced by one proton is 0.13

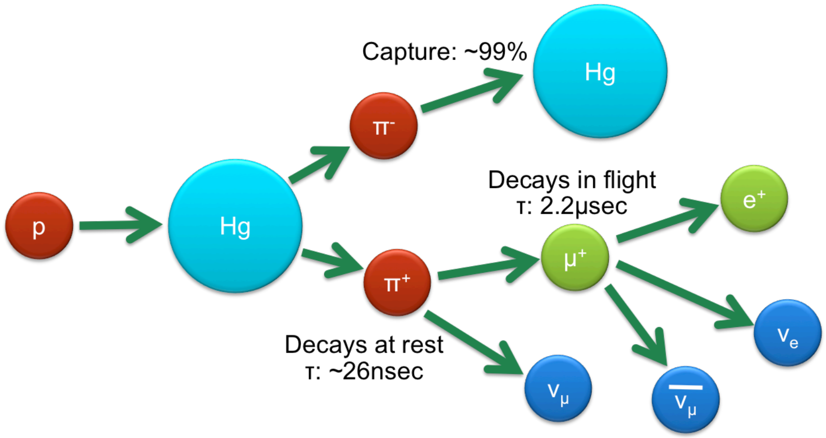
SNS is operational 2/3 part of the year

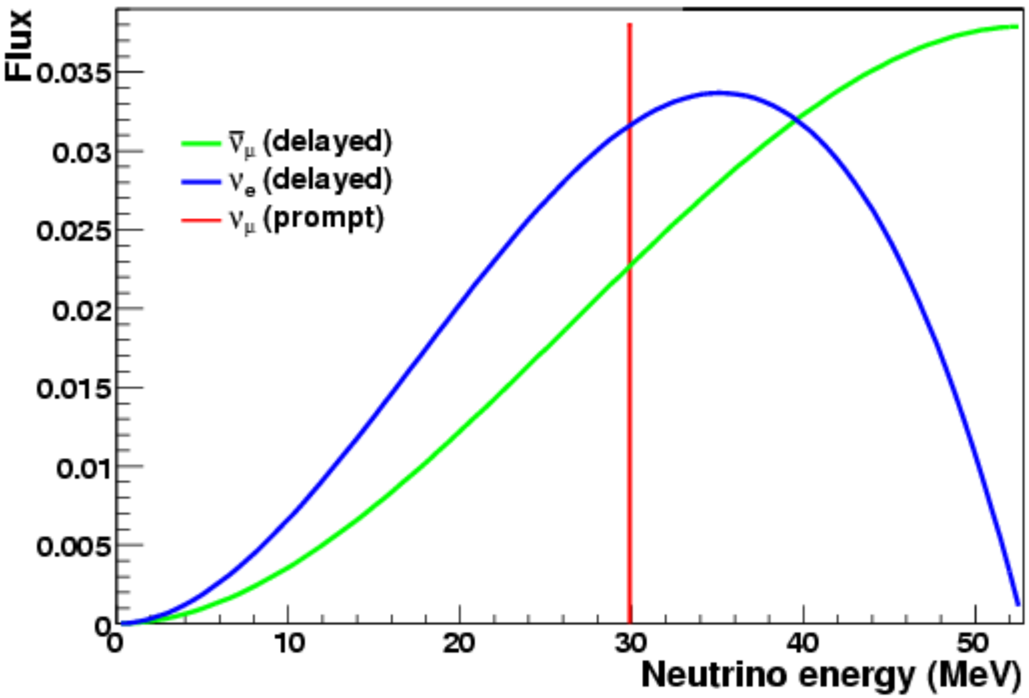
Number of each flavor of neutrinos produced at SNS is $1.9 \cdot 10^{22}$ year^{-1}

Caveat:

There is larger flux of antineutrinos from decay of radioactivity in the target
However, their energy is at a few MeV and almost continues in time.

Stopped-Pion (πDAR) Neutrinos





$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

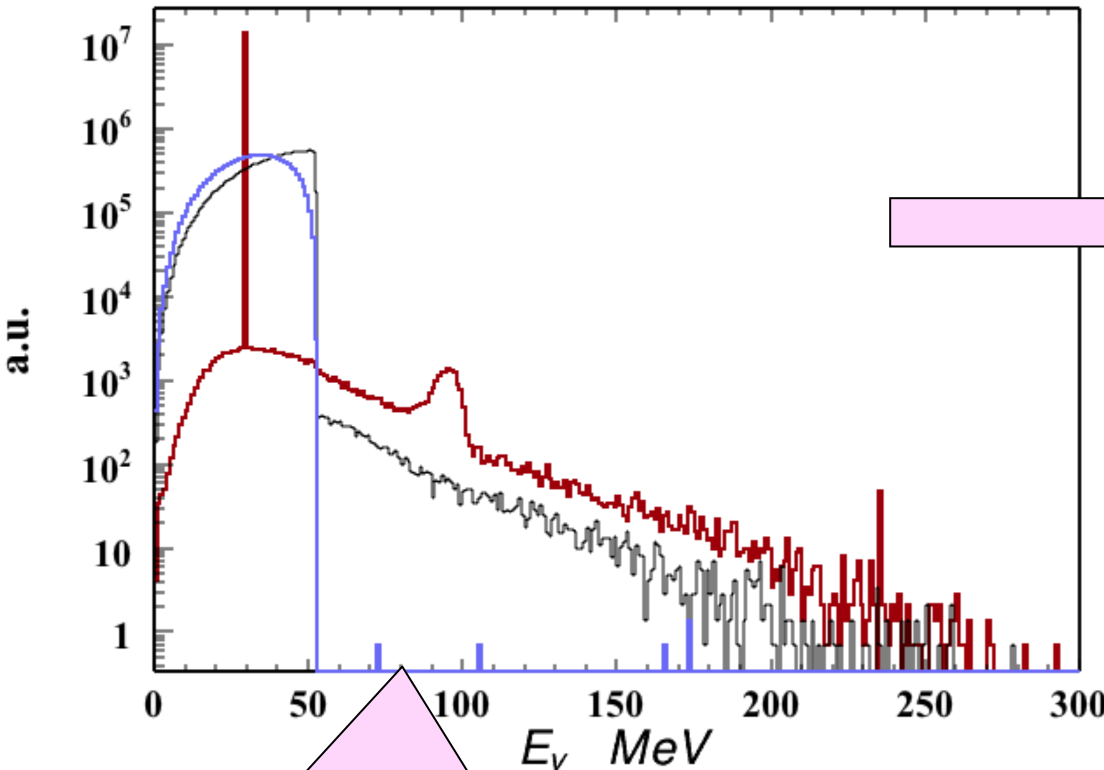
2-body decay: monochromatic 29.9 MeV ν_μ
PROMPT

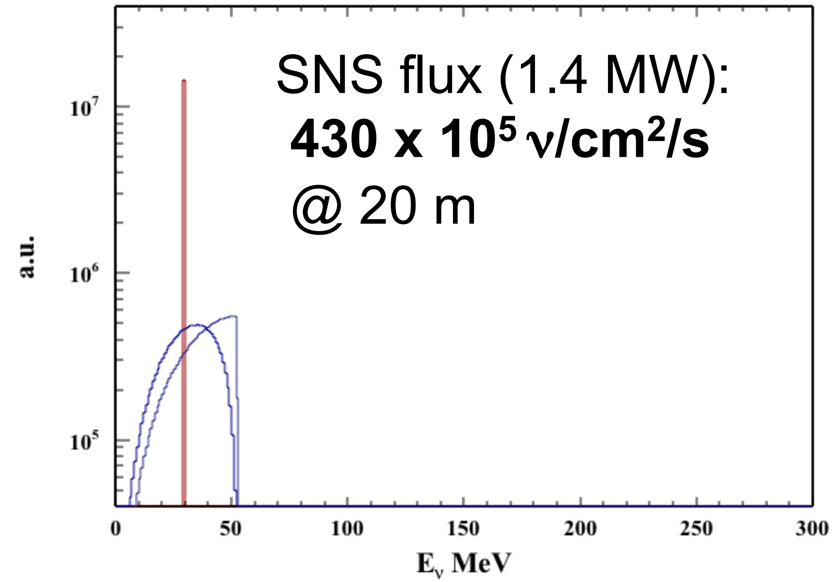
$$\downarrow$$

$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

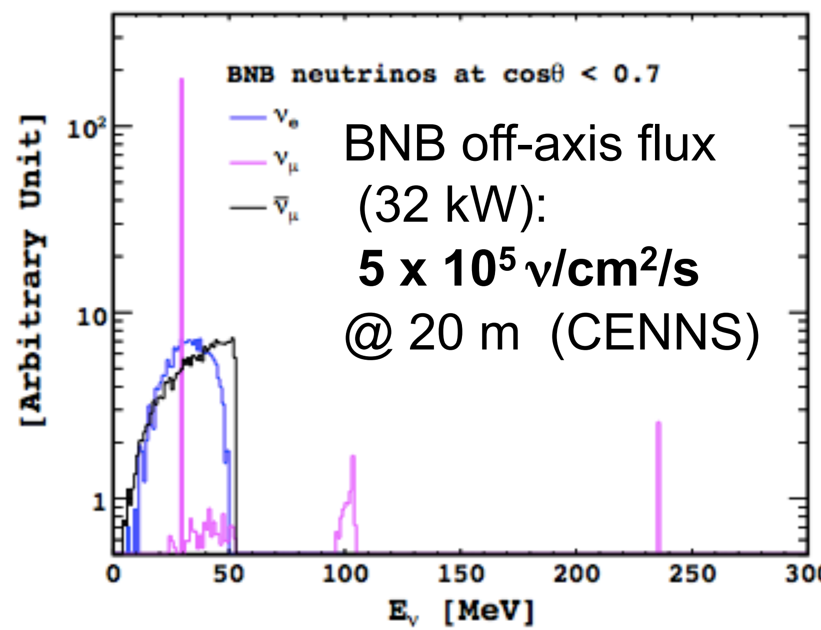
3-body decay: range of energies between 0 and $m_\mu/2$
DELAYED (2.2 μs)

The SNS has large, extremely clean DAR ν flux



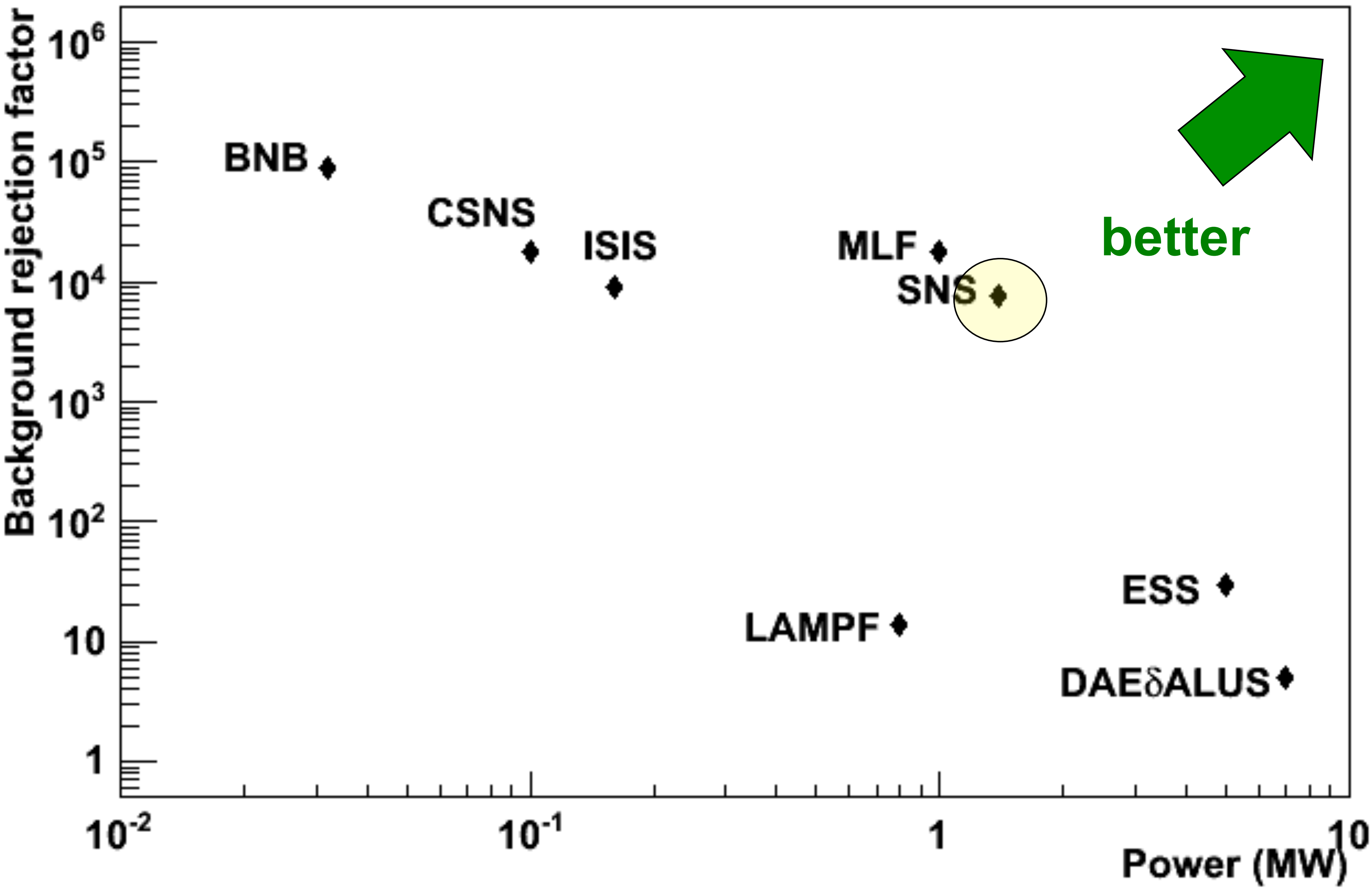


Note that contamination from
non π-decay at rest
(decay in flight, kaon decay, μ capture...)
is **down by several orders of magnitude**



Comparison of pion decay-at-rest ν sources

from duty cycle



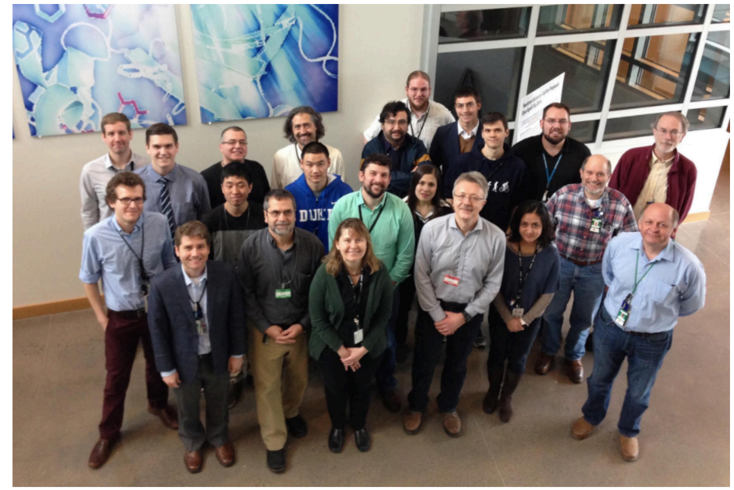
$\propto \nu$ flux

The COHERENT collaboration

arXiv:1509.08702

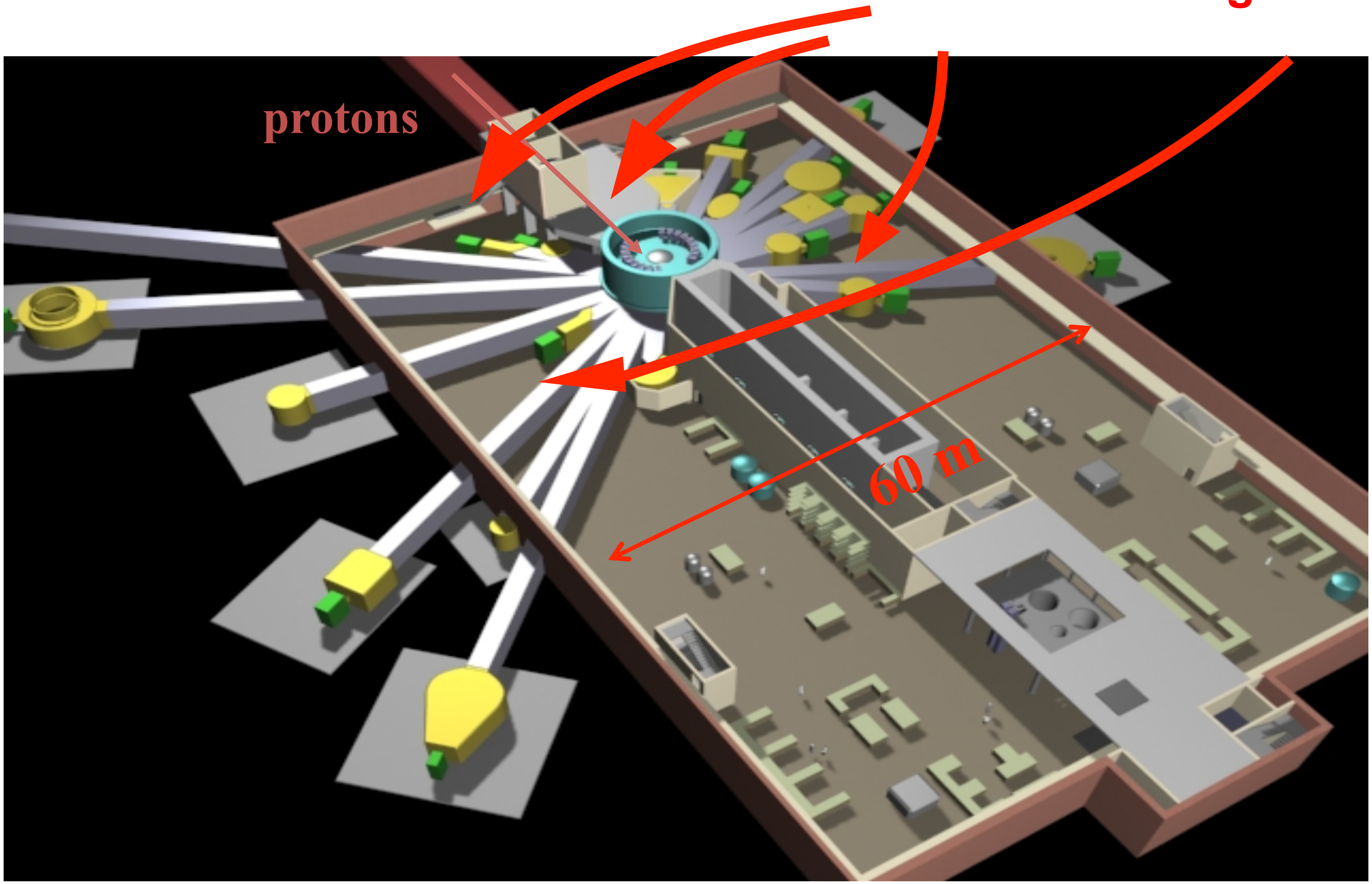
Institution	Board Member
University of California, Berkeley	Kai Vetter
University of Chicago	Juan Collar
Duke University	Kate Scholberg
University of Florida	Heather Ray
Indiana University	Rex Tayloe
Institute for Theoretical and Experimental Physics, Moscow	Dmitri Akimov
Lawrence Berkeley National Laboratory	Ren Cooper
Los Alamos National Laboratory	Steve Elliott
National Research Nuclear University MEPhI	Alex Bolozdynya
New Mexico State University	Robert Cooper
North Carolina Central University	Diane Markoff
North Carolina State University	Matt Green
Oak Ridge National Laboratory	Jason Newby
Sandia National Laboratories	David Reyna
University of Tennessee, Knoxville	Yuri Efremenko
Triangle Universities Nuclear Laboratory	Phil Barbeau
University of Washington	Jason Detwiler

- Collaboration: ~65 members, 16 institutions (USA+ Russia)
- Spokesperson: K. Scholberg
  ORNL PI: J. Newby
- Technical coordinator/PM: D. Reyna



Potential Locations for Neutrino Experiment at the SNS

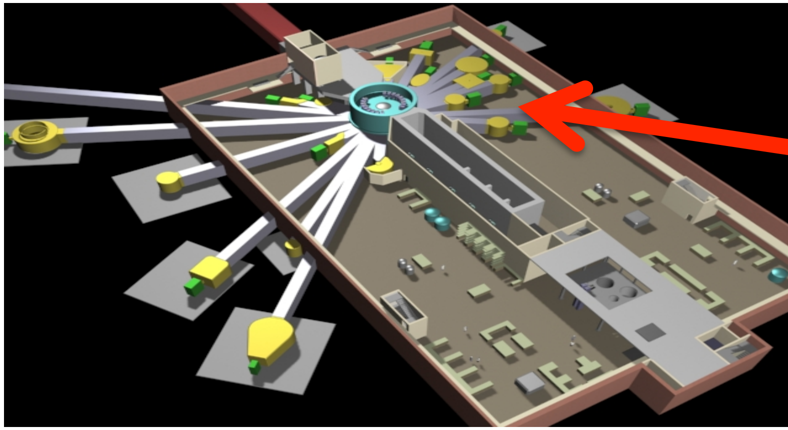
sites inside target building

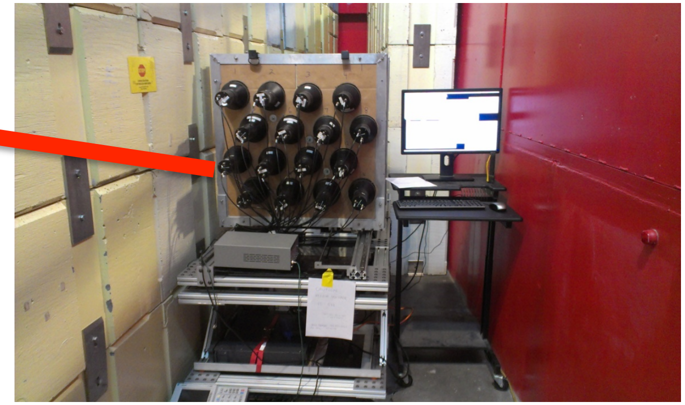


Multiple sites are available at a distance 15-20 m.

"Green field" is outside of the target building distance is more than 30 m

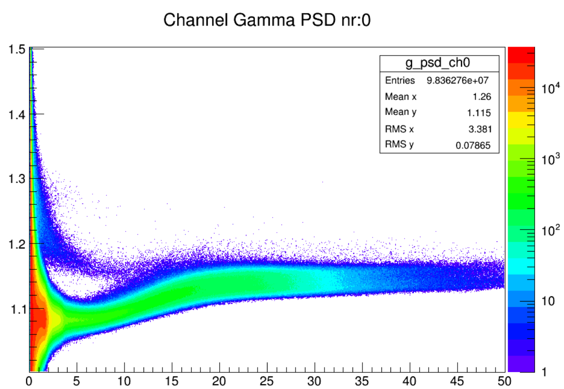
Background Measurements at SNS

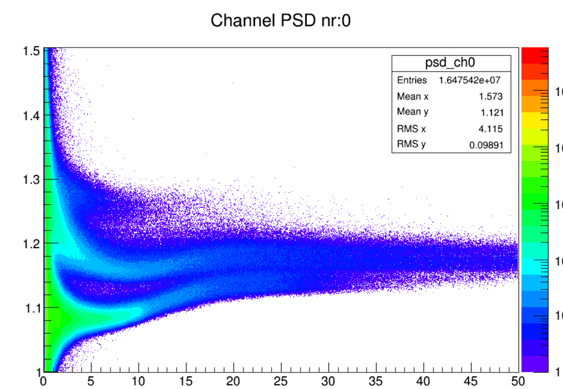


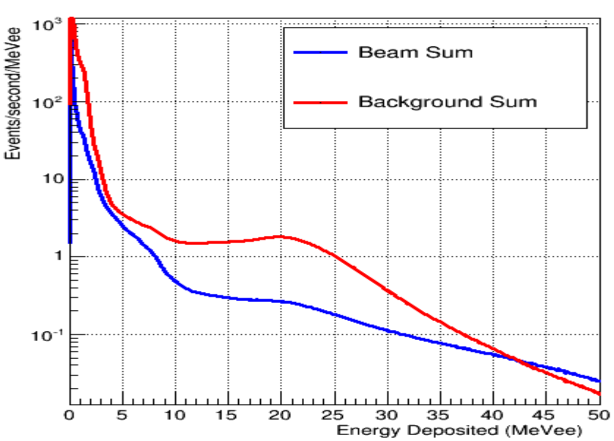


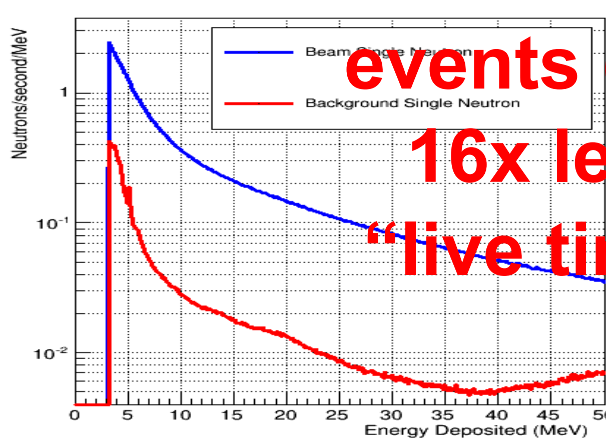
Started in Sept 2013

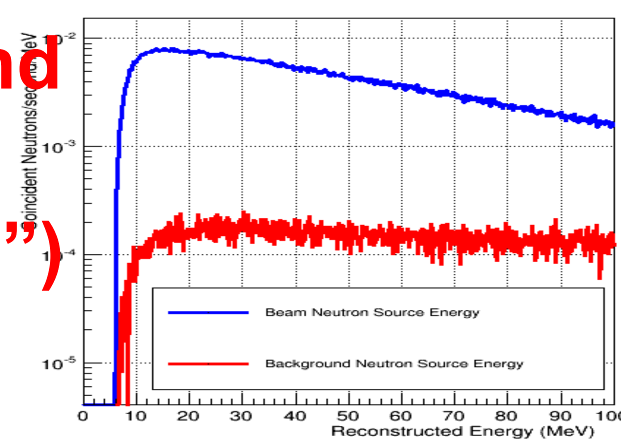
"Out-of-beam" events, primarily







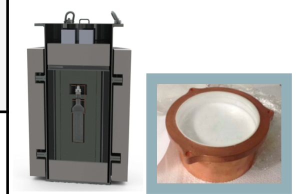


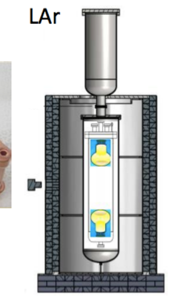


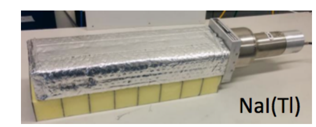
"In-Beam" events, considerably more neutron events (and 16x less "live time")

COHERENT detectors and Status

Nuclear Target	Technology	Mass (kg)	Distance from source (m)	Recoil threshold (keVr)	Data-taking start date; CEvNS detection goal
CsI[Na]	Scintillating Crystal	14	20	6.5	9/2015; 3σ in 2 yr
Ge	HPGe PPC	10	22	5	Fall 2016
LAr	Single-phase	35	29	4	Fall 2016
NaI	Scintillating crystal	85*	29	TBD	*high-threshold deployment done last week

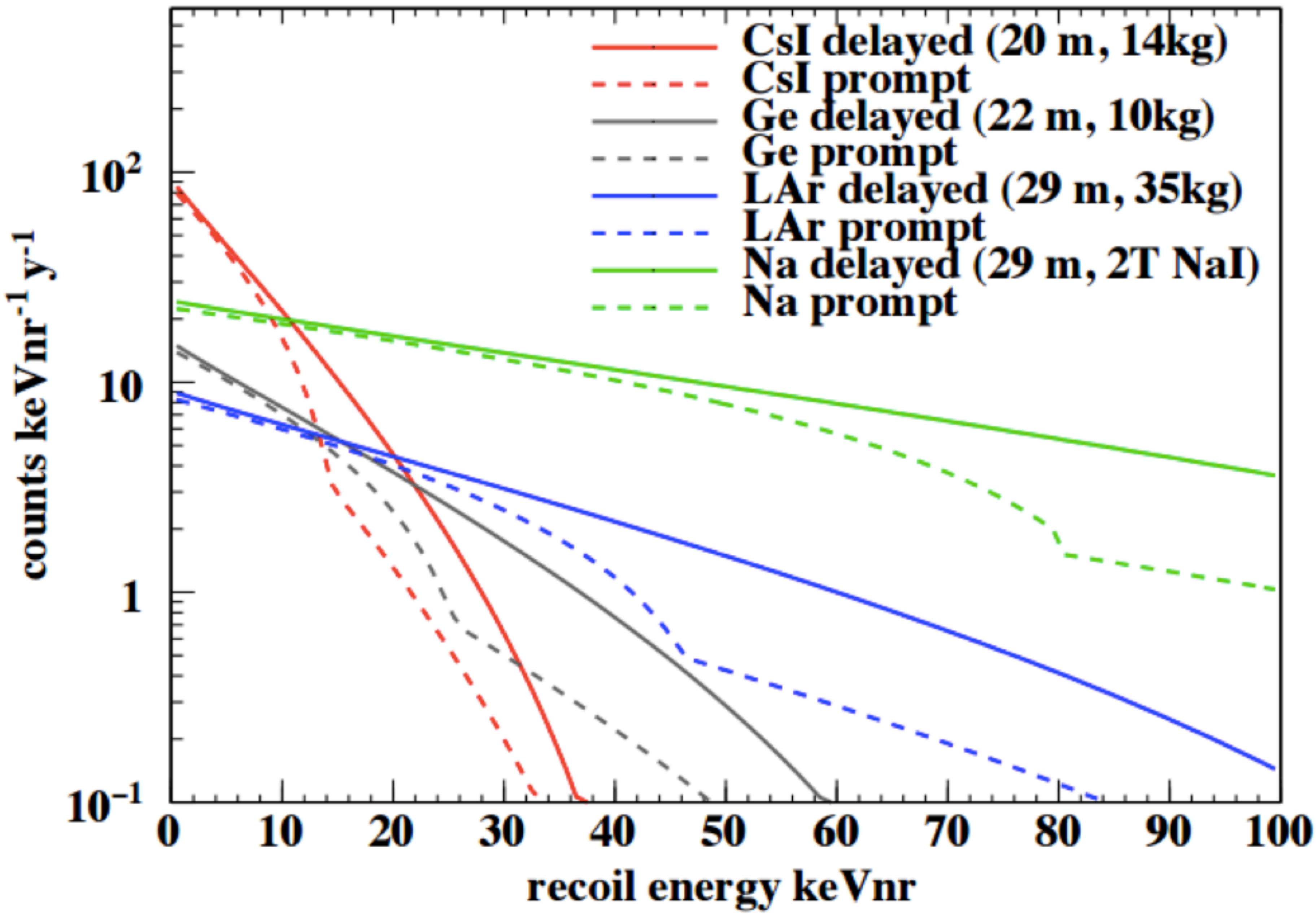






- Measurements indicate **SNS basement is neutron-quiet**
- CsI installed July 2015
- Three more detectors to be deployed summer/fall 2016

Expected signals



Other potential neutrino physics at the SNS

Neutrino oscillations – Test of the LSND claim

Search for Sterile Neutrinos

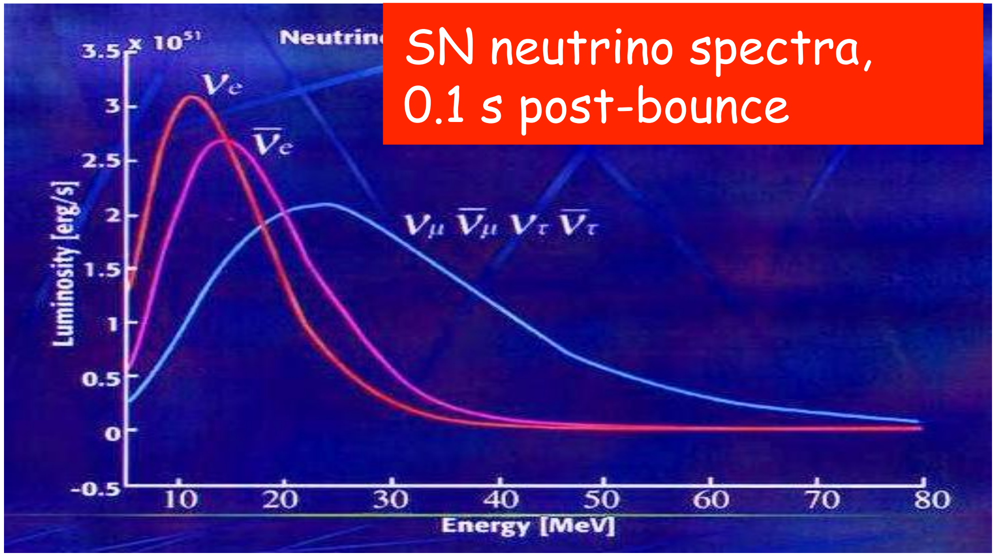
Neutrino Magnetic moment

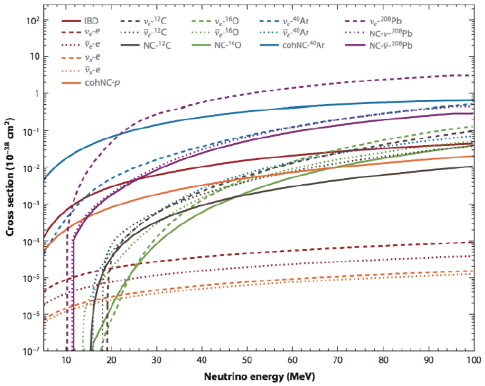
Measurement of Neutrino Spectra from Muon Decay

Cross section Measurements

Core-collapse supernovae

- Destruction of massive star initiated by the Fe core collapse
  - 10^{53} ergs of energy released
  - 99% carried by neutrinos
  - A few happen every century in our Galaxy, but the last one observed was over 300 years ago
- Dominant contributor to Galactic nucleosynthesis
- Neutrinos and the weak interaction play a crucial role in the mechanism, which is not not well understood





Neutrino Induced Neutrons (NIN)

Never been measured.
There are only theoretical calculations

This reaction on Lead is used by HALO experiment in the SNOlab,

In

Fitting the annual modulation in DAMA with neutrons from muons and neutrinos

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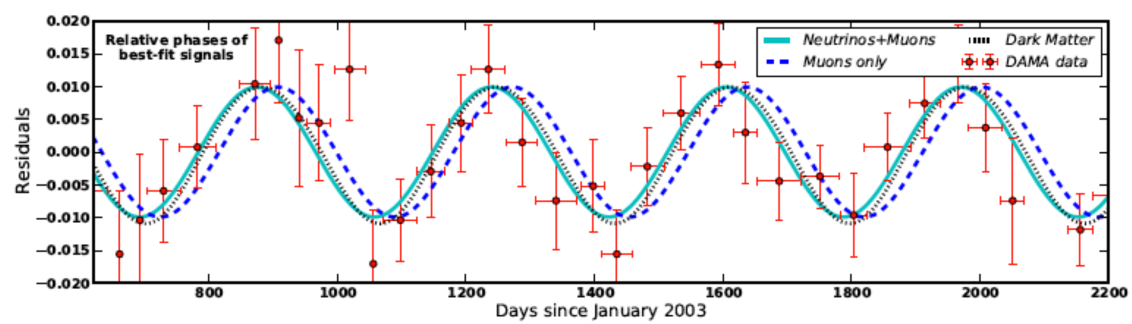
j.h.davis@durham.ac.uk

author explain DAMA seasonal modulations by solar neutrino induced interactions in the DAMA shielding



In this article authors believe that J.Davis is wrong by >6 orders of magnitude.

Comment on "Fitting the annual modulation in DAMA with neutrons from muons and neutrinos"

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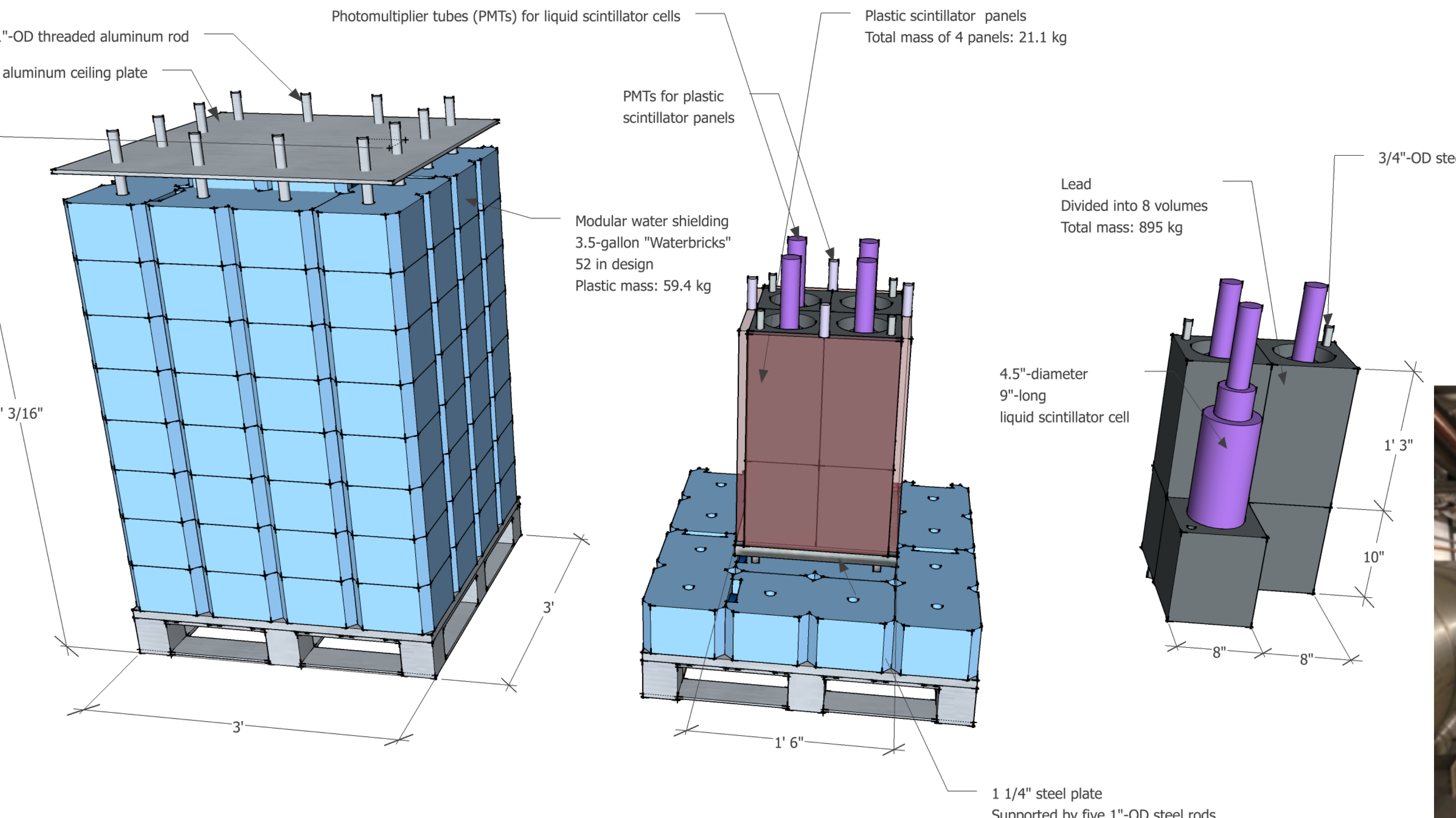
[*] *Corresponding author. E-mail: schol@phy.duke.edu*

NIN measurement in SNS basement

- Scintillator inside CsI detector lead shield (now)
- Liquid scintillator surrounded by lead (swappable for other NIN targets) inside water shield



Measurement of Neutrino Induced Neutrons

It is First Neutrino Experiment at the SNS

Liquid Scintillator detectors inside Lead, Poly, Cd, Water shield with muon veto

(Expected 3 events per day)

On the next day after we finished installation, SNS got water leak in the accelerator, then target failed.

It has been fixed

No we are running for one full year.

Have a statistics.
Data are being analyzed

Conclusion

It is time to measure COHERENT neutrino scattering !!!

Appropriate technology and sources are available

SNS is the best place for the first observation of CEvNS

Reach neutrino program at SNS is being developed