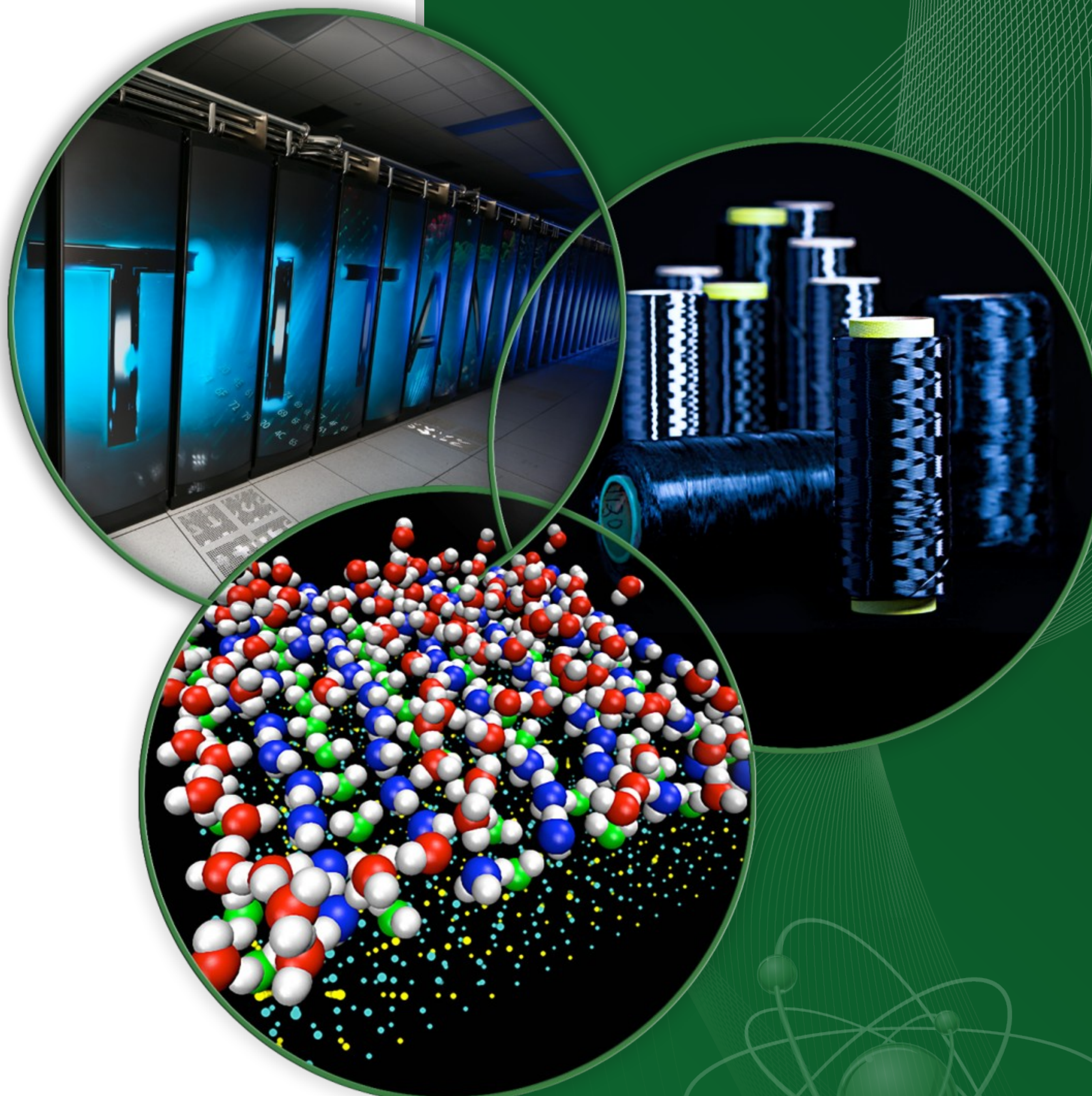
The COHERENT Experiment:
Overview and Update of Results



- Jason Newby for the COHERENT Collaboration

- 2016 Fall Meeting of the APS Division of Nuclear Physics, Vancouver, B.C.

ORNL is managed by UT-Battelle
for the US Department of Energy

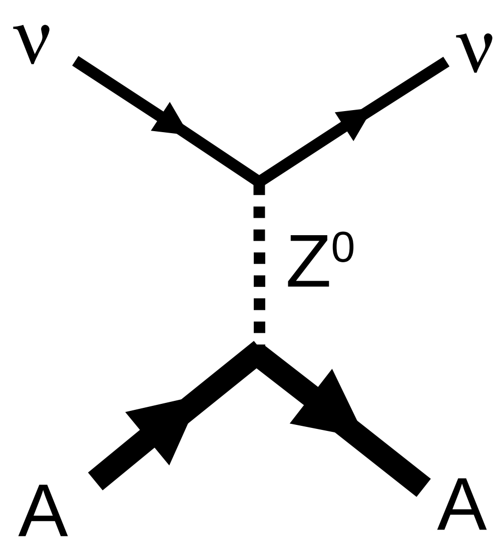
COHERENT

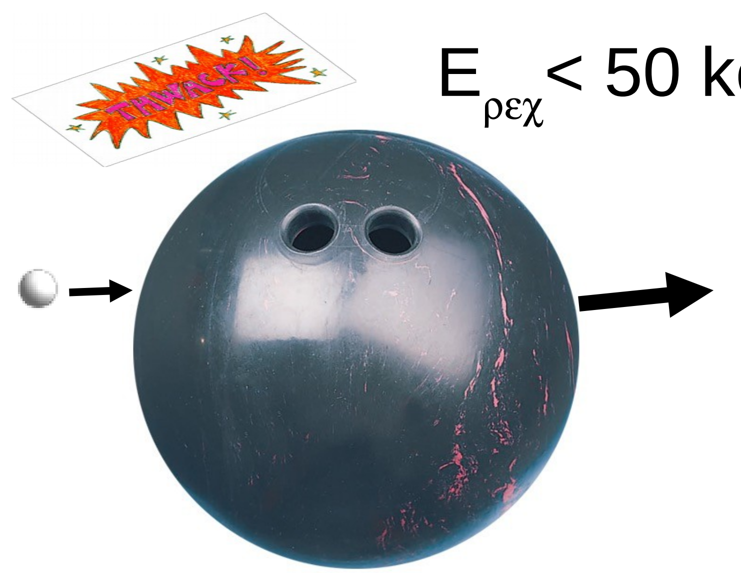
SNS SPALLATION NEUTRON SOURCE

OAK RIDGE National Laboratory

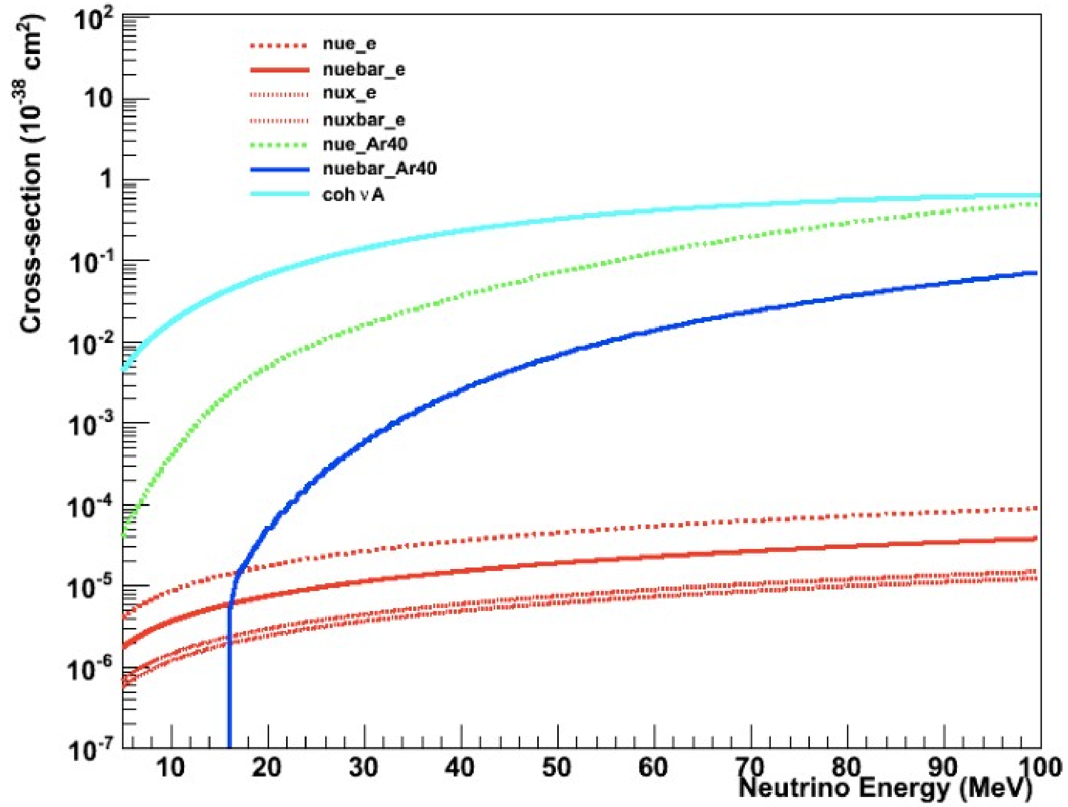
Coherent elastic neutrino-nucleus scattering (CEvNS)

A neutrino smacks a nucleus via exchange of a Z, and the nucleus recoils as a whole; **coherent** up to $E_\nu \sim$ 50 MeV





$E_{\rho\varepsilon\chi} <$ 50 keV

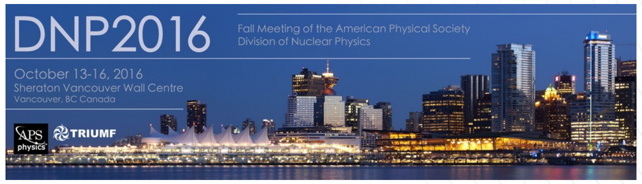


CEvNS cross-section is "large" for neutrinos!

CEvNS cross section is well calculable in the Standard Model

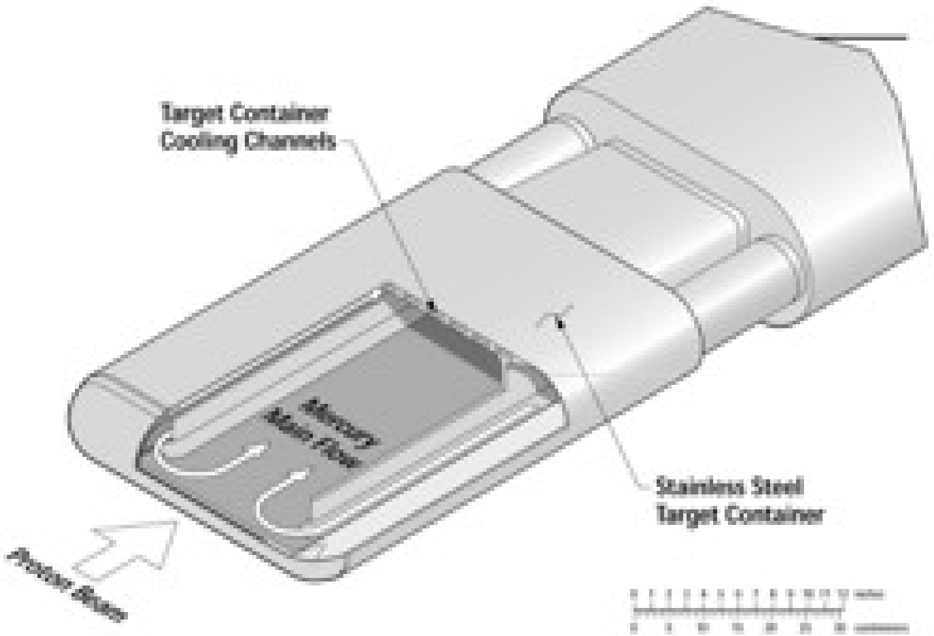
$$\frac{d\sigma}{d\Omega} = \frac{G^2}{4\pi^2} k^2 (1+\cos\theta) \frac{(N-(1-4\sin^2\theta_W)Z)^2}{4} F^2(Q^2) \quad \boxed{\propto N^2}$$

- Largest neutrino cross section but never observed!
  - ➡No neutrino source with compatible characteristics.
  - Detectors are just now becoming sensitive to these small recoils.



Spallation Neutron Source

Oak Ridge National Laboratory, TN

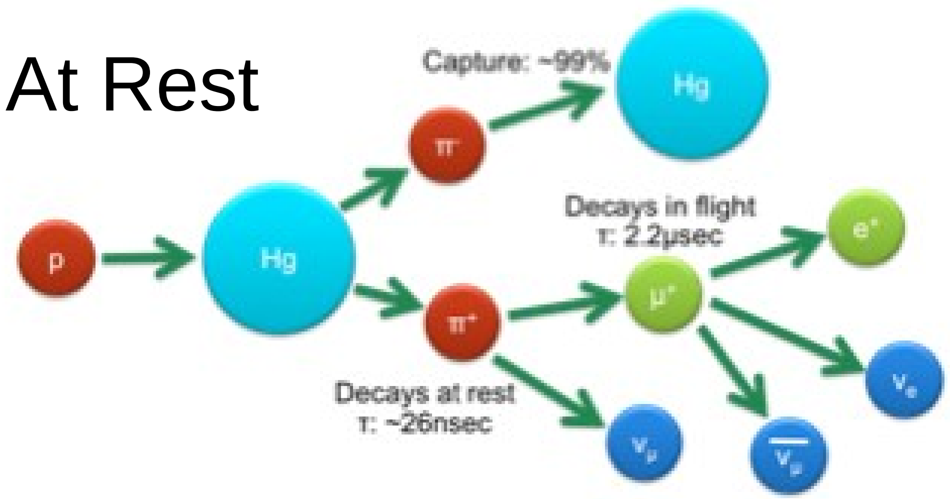


Proton beam energy: 0.9-1.3 GeV
Total power: 0.9-1.4 MW
Pulse duration: 380 ns FWHM
Repetition rate: 60 Hz
Liquid mercury target
5000 hours/year

Neutrinos at the SNS

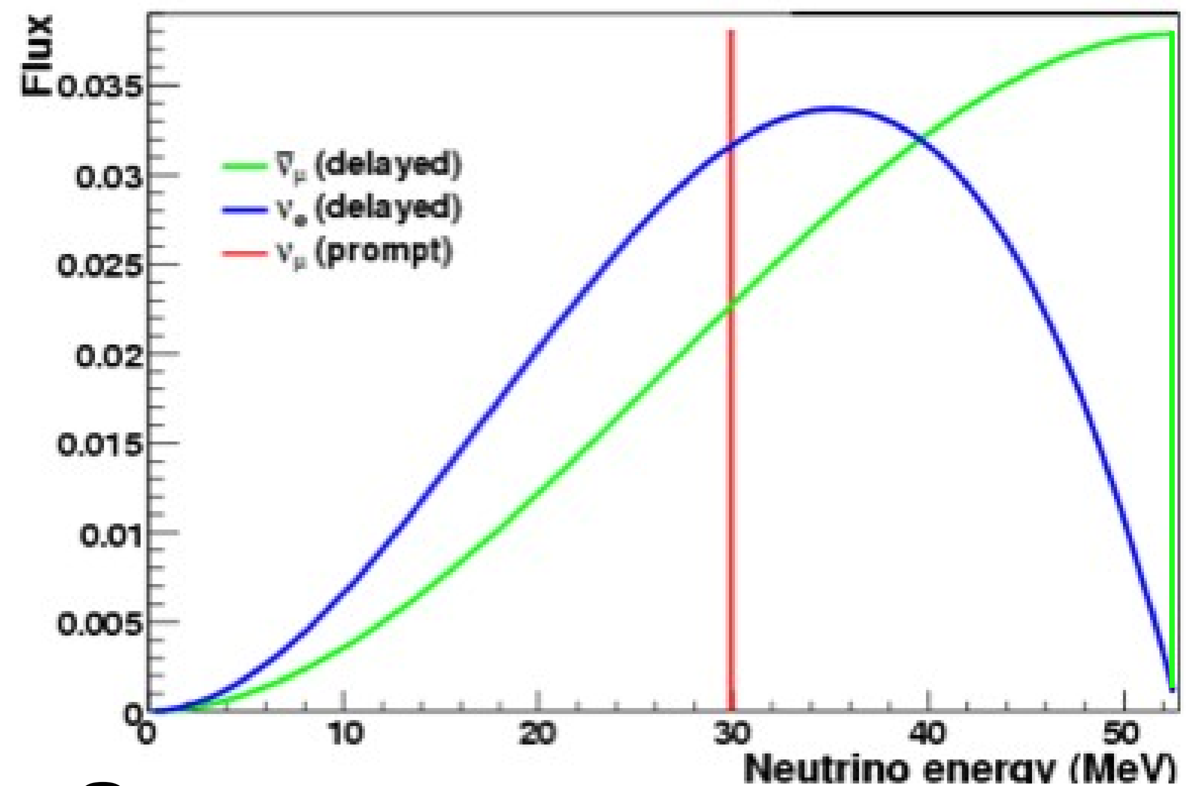
Neutrinos via

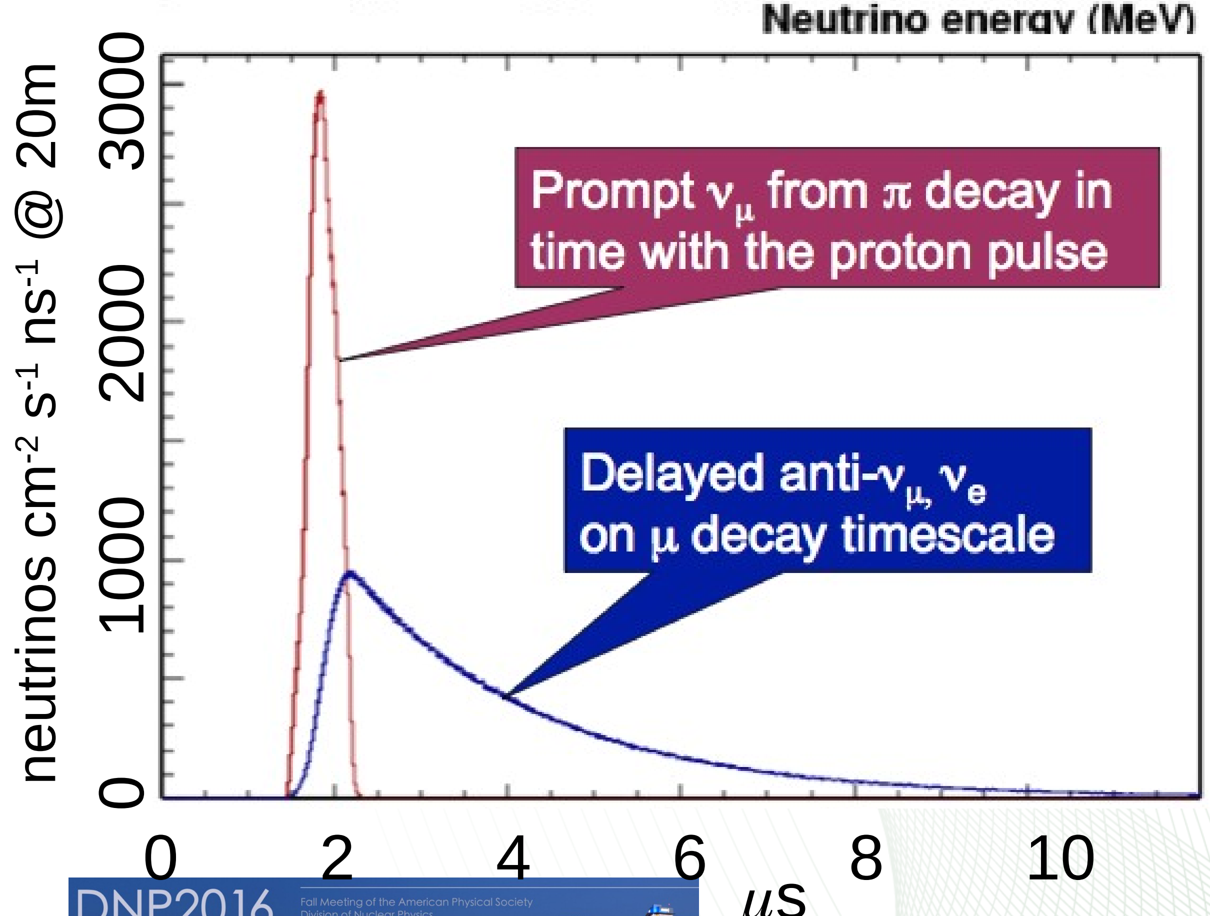
πDecay At Rest



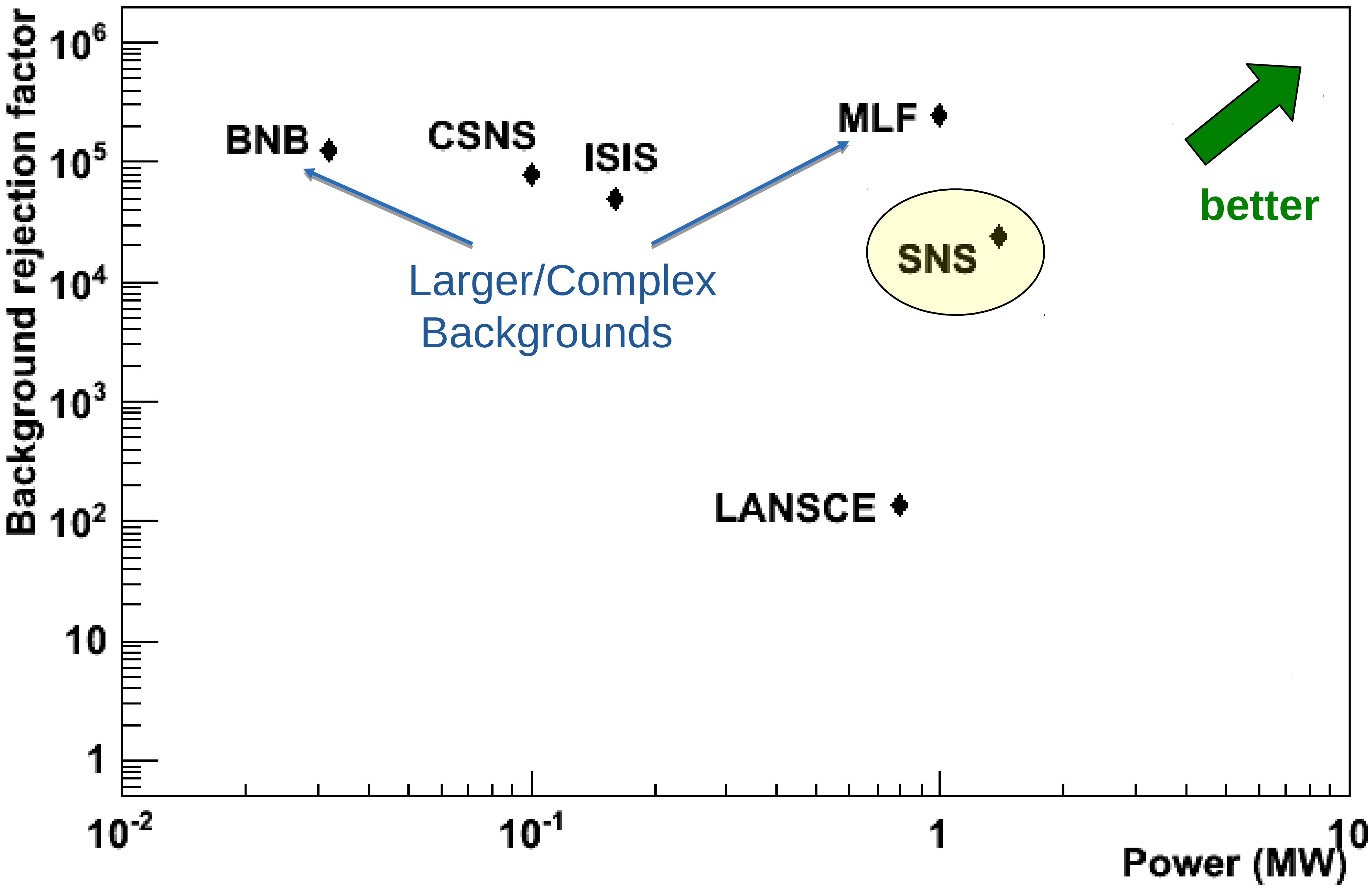
- High Intensity (10^7/s/cm^2 @ 20m)
- Ideal Neutrino Energy → Coherence
- Ideal Beam Energy
- Complete Stopping: Pointlike source
- Multiple Neutrino Flavors: ν_e, (anti)ν_μ
- Prompt & delayed neutrinos provide additional handle for systematic errors
- Ideal Time Structure (Short Pulses)

Background rejection factor ~few x 10^4



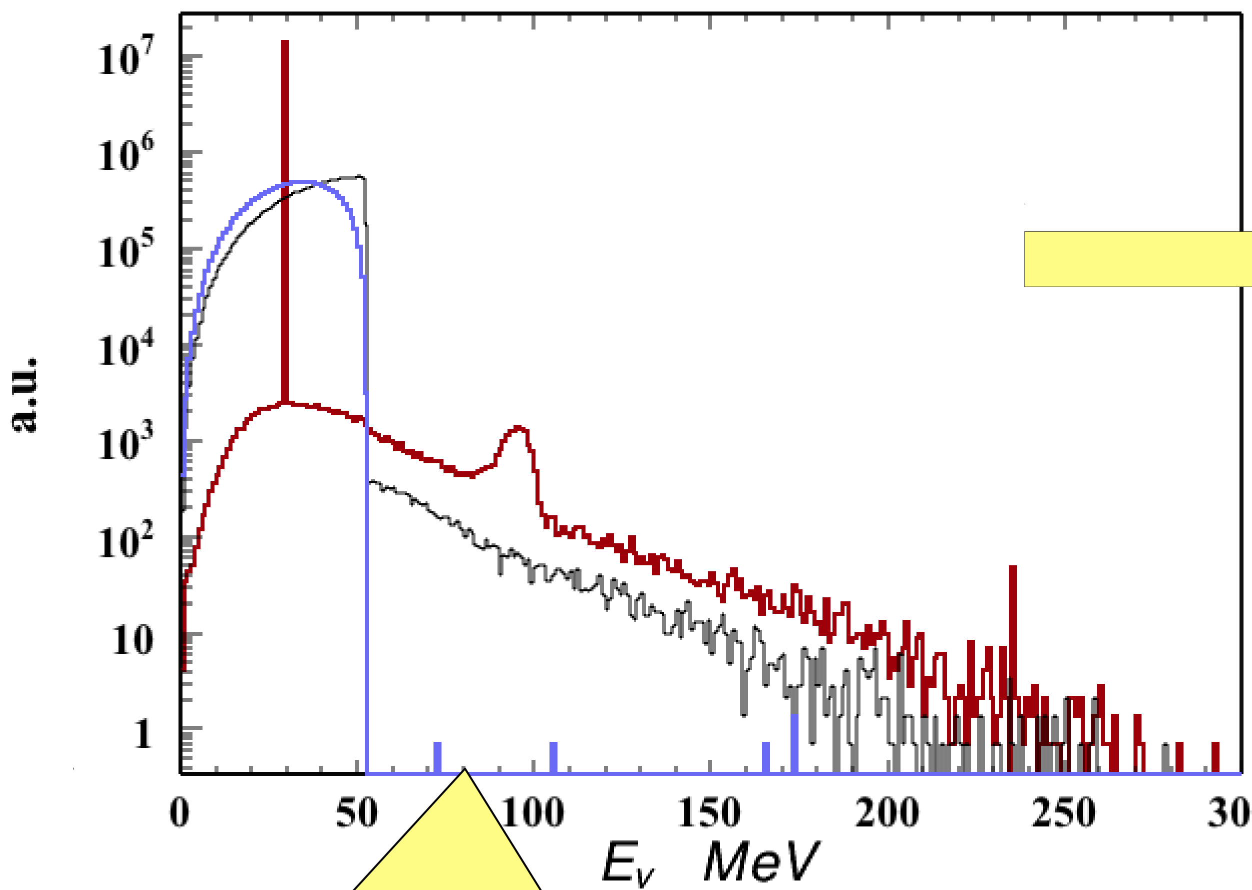


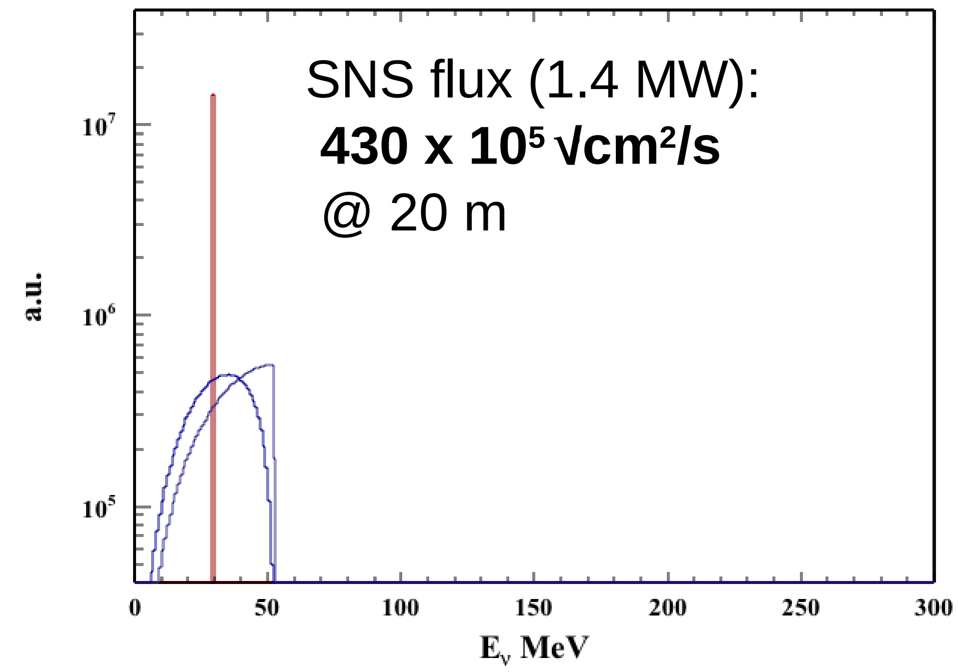
Other Neutrino sources?

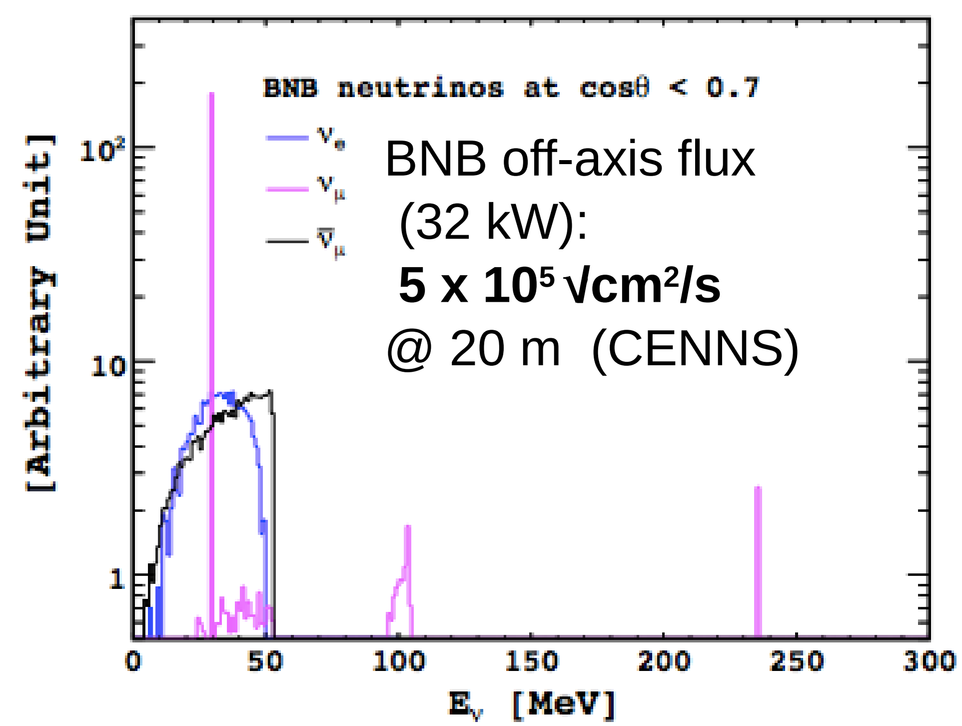


The SNS is the cleanest, most intense neutrino source in the world for CEvNS!

The SNS DAR neutrino flux is large, extremely clean







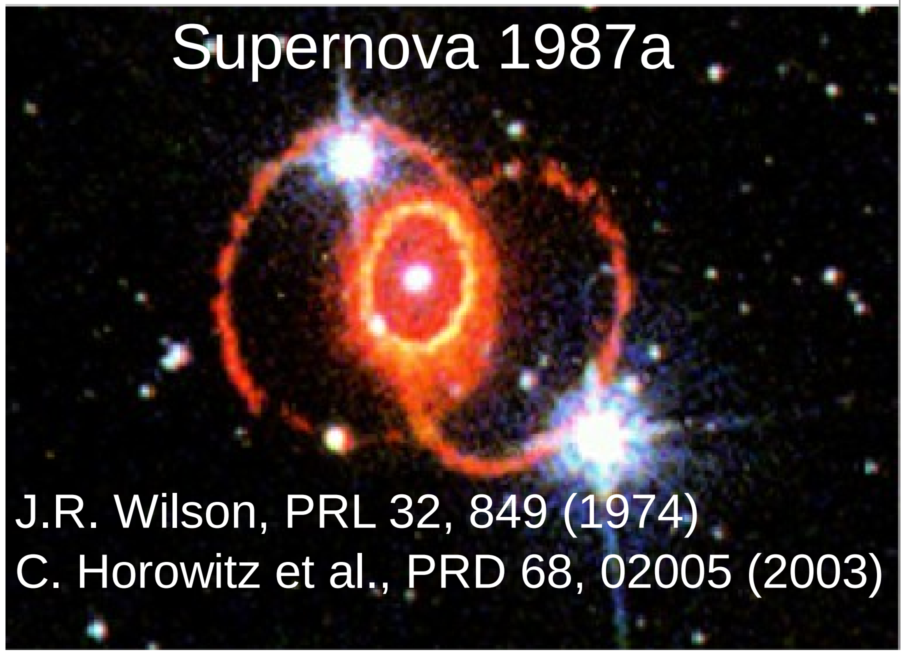
Note that contamination from
non π decay at rest
(decay in flight, kaon decay, μ capture...)
is **down by several orders of magnitude**

Why Measure Coherent ν-Nucleus Scattering?

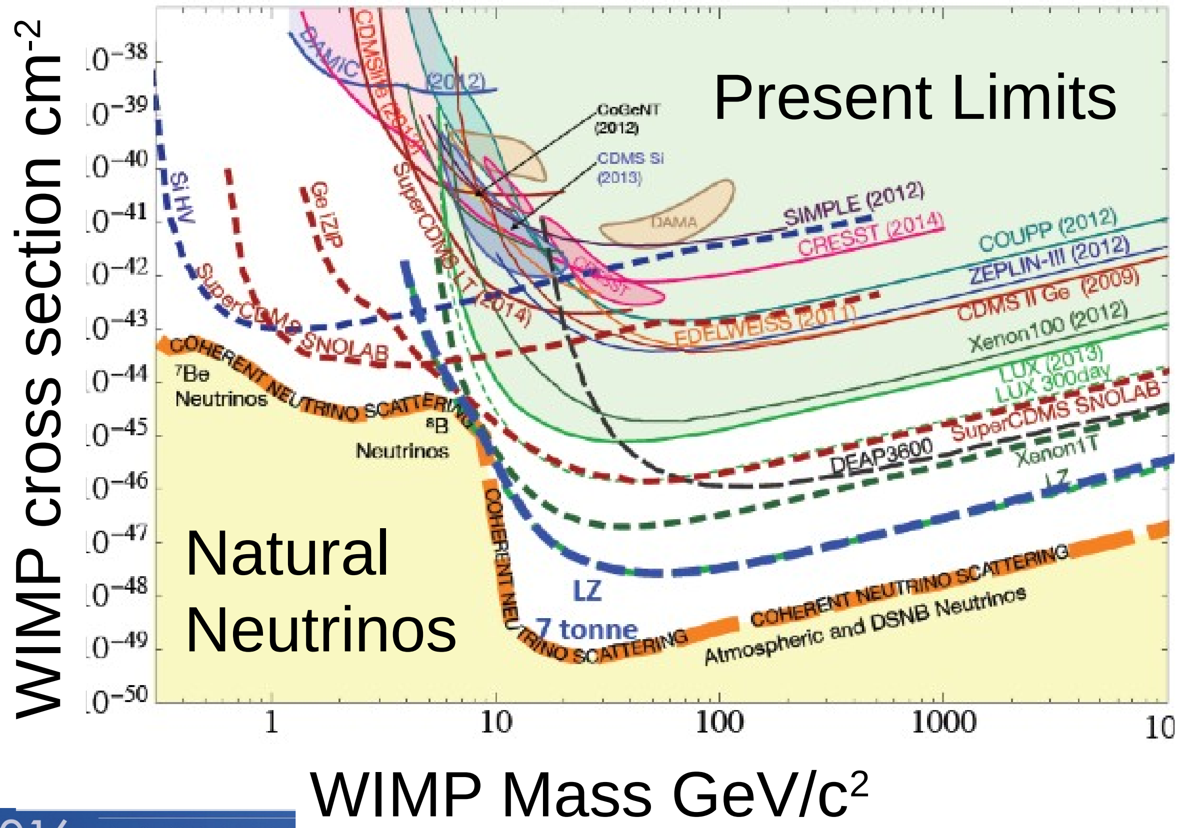
- Predicted 41 years ago, but yet to be observed!
- Non-Standard ν Interactions impact N^2-dependence
- Largest σ in Supernovae dynamics
- Mechanism for SN detection
- Background for Dark Matter (WIMP) searches

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

J. Barranco et al., JHEP0512:021, 2005



- In 2013 Oak Ridge National Laboratory hosted a CEvNS Workshop at the SNS
- In July 2013 feasibility measurements began.
- COHERENT Collaboration formed in 2014 to pursue a phased CEvNS program at the SNS.
- Collaboration Activities at SNS:
  - Siting and background measurements
  - Neutrino-Induced-Neutron measurements on Pb
  - 14kg CsI[Na] CEvNS detector installed
  - Commissioning a 185kg NaI detector



The COHERENT collaboration

- Collaboration: ~65 members, 16 institutions (USA+ Russia)

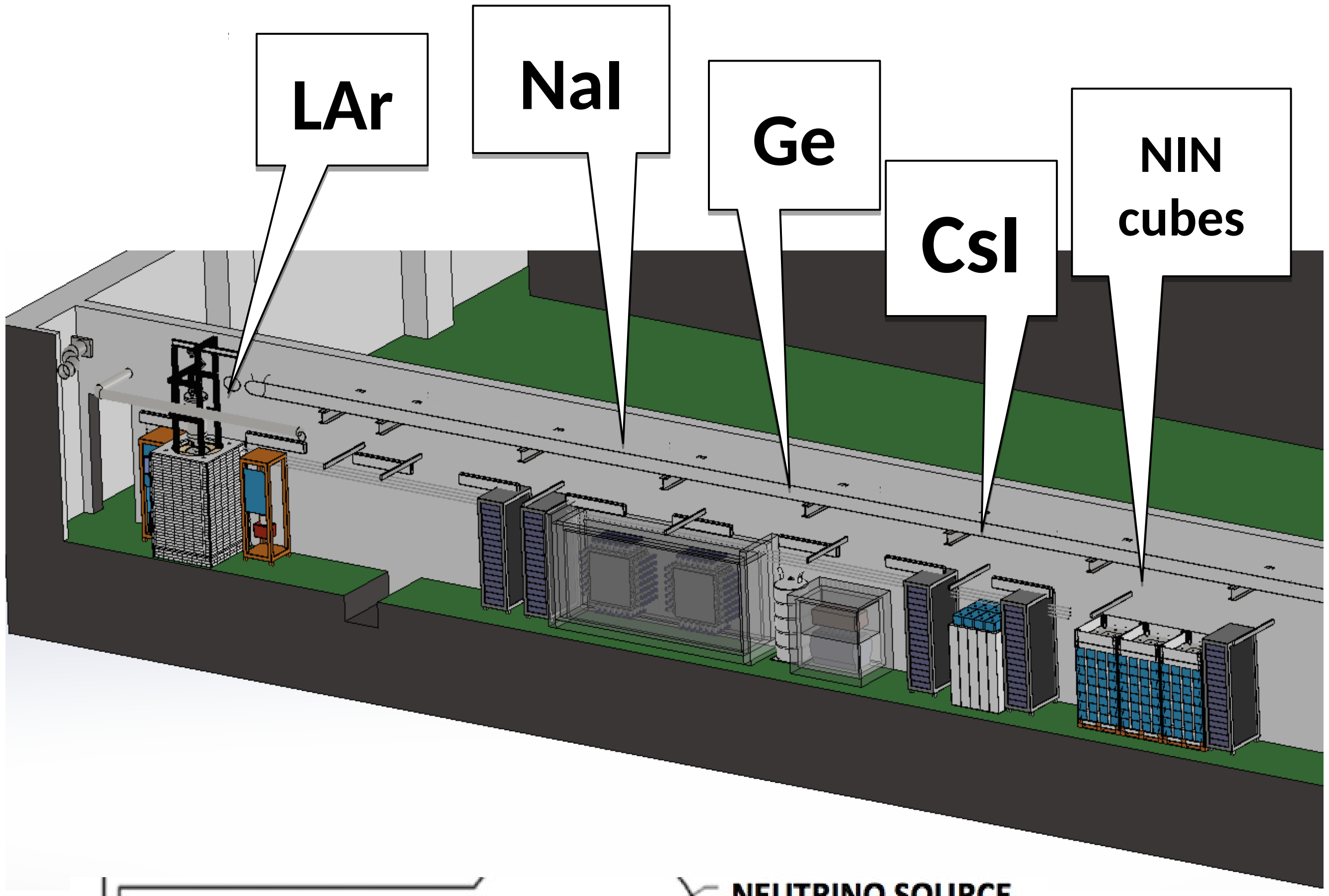
arXiv:1509.08702

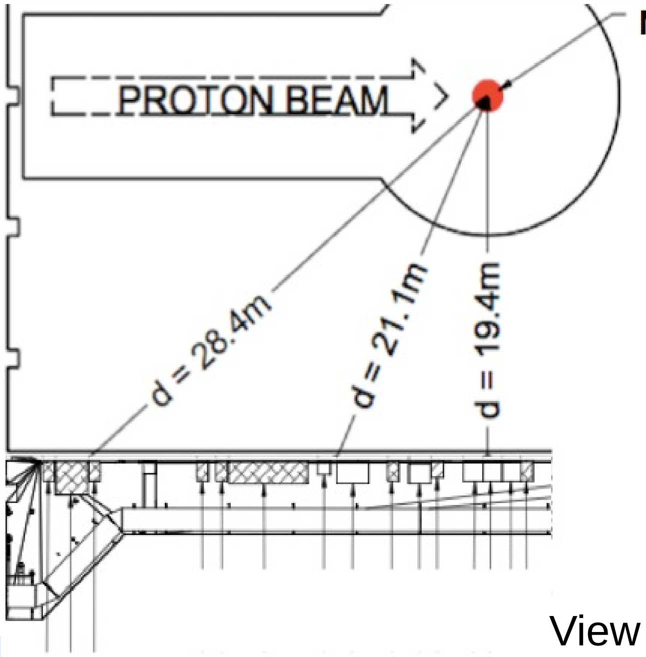
Institution	Board Member
University of California, Berkeley	Kai Vetter
University of Chicago	Juan Collar
Duke University	Kate Scholberg
University of Florida	Heather Ray
Indiana University	Rex Tayloe
Institute for Theoretical and Experimental Physics, Moscow	Dmitri Akimov
Lawrence Berkeley National Laboratory	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

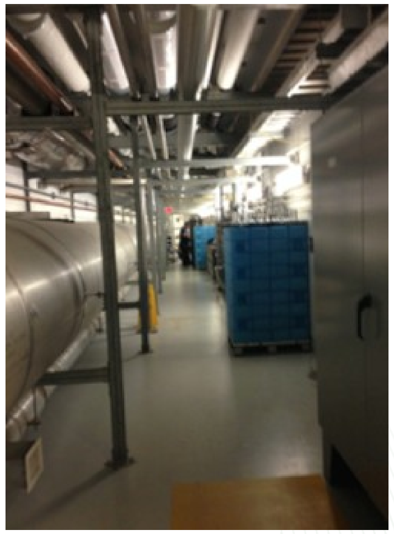
Siting for deployment in SNS basement: “Neutrino Alley”

- Utility corridor converted to a neutrino laboratory - largely decoupled from SNS operations
- 22.5 m^2 floor space for equipment footprint
- 1.5 m concrete floor supports massive shielding structures
- Truck bay access to basement level
- 40kW dedicated electrical power installed Oct 2016
- 8 m.w.e. overburden to suppress cosmic backgrounds
- Engineered backfill to suppress fast neutrons from target
- Measured neutron backgrounds low

Talk by Matthew Heath on backgrounds next





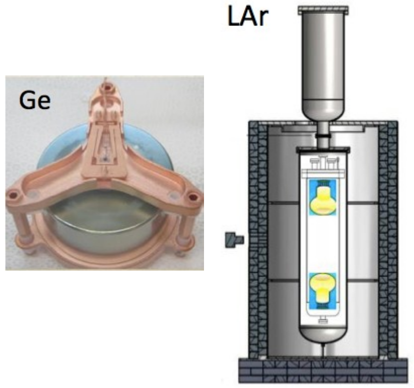


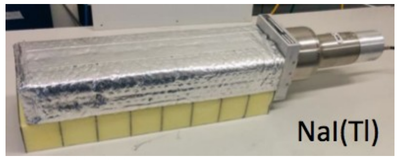
View looking down “Neutrino Alley”

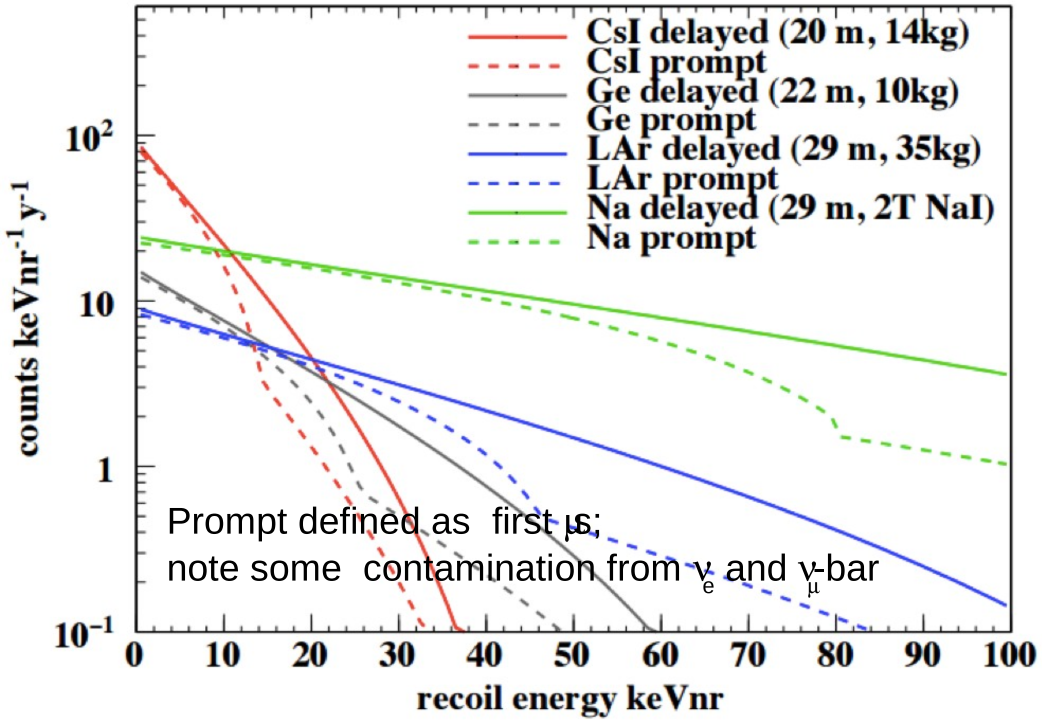
COHERENT Deployment Plan

- Unambiguous first observation from the N^2-dependence of the CEvNS cross-section in multiple targets.

Nuclear Target	Technology	Mass (kg)	Target Distance (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	20	Installing now
NaI[Tl]	Scintillating crystal	185*/2000	28	13	*high-threshold deployment summer 2016

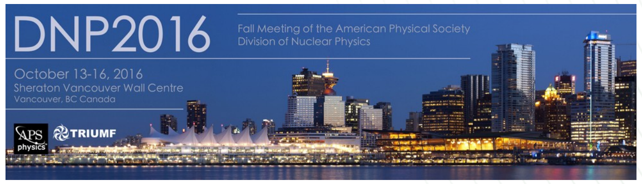




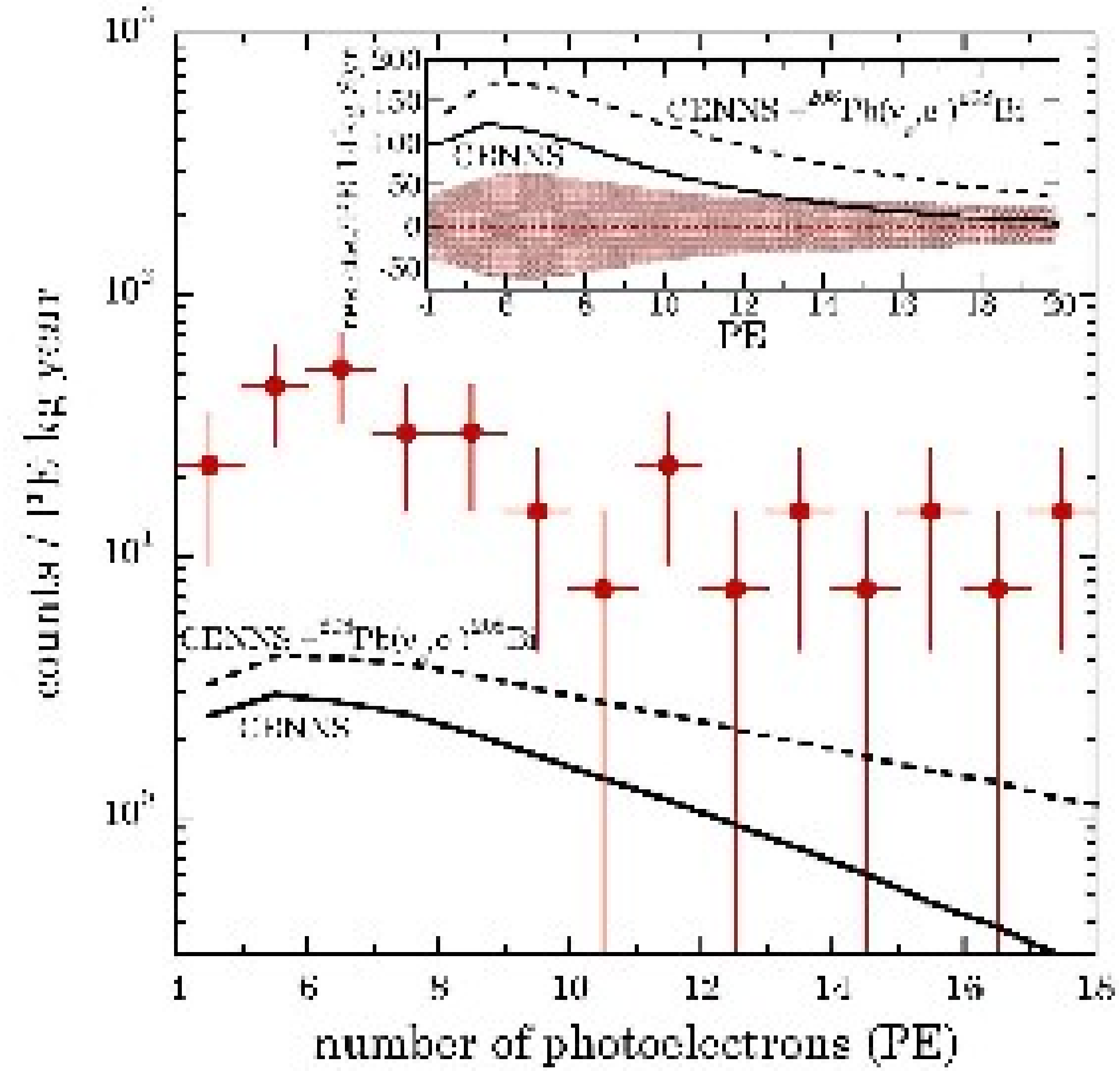


- 100's CEvNS detections expected per year
- Experimental Challenges: Backgrounds, Quenching Factors, Thresholds

Detector details presented by Rex Tayloe in earlier session



CsI[Na] Analysis Summary



CsI[Na] instrument designed by U. of Chicago
J.I.Collar et al. NIM A773 (2014) 56

- Over 1 calendar year of data recorded and analysis is underway
- Steady state backgrounds at the SNS installation are 10-20% of measurements at U. of Chicago.
- Recent quenching factor measurements indicate non-trivial increase in signal
- Expected neutrino-induced-neutron backgrounds reduced to 4% with HDPE inne

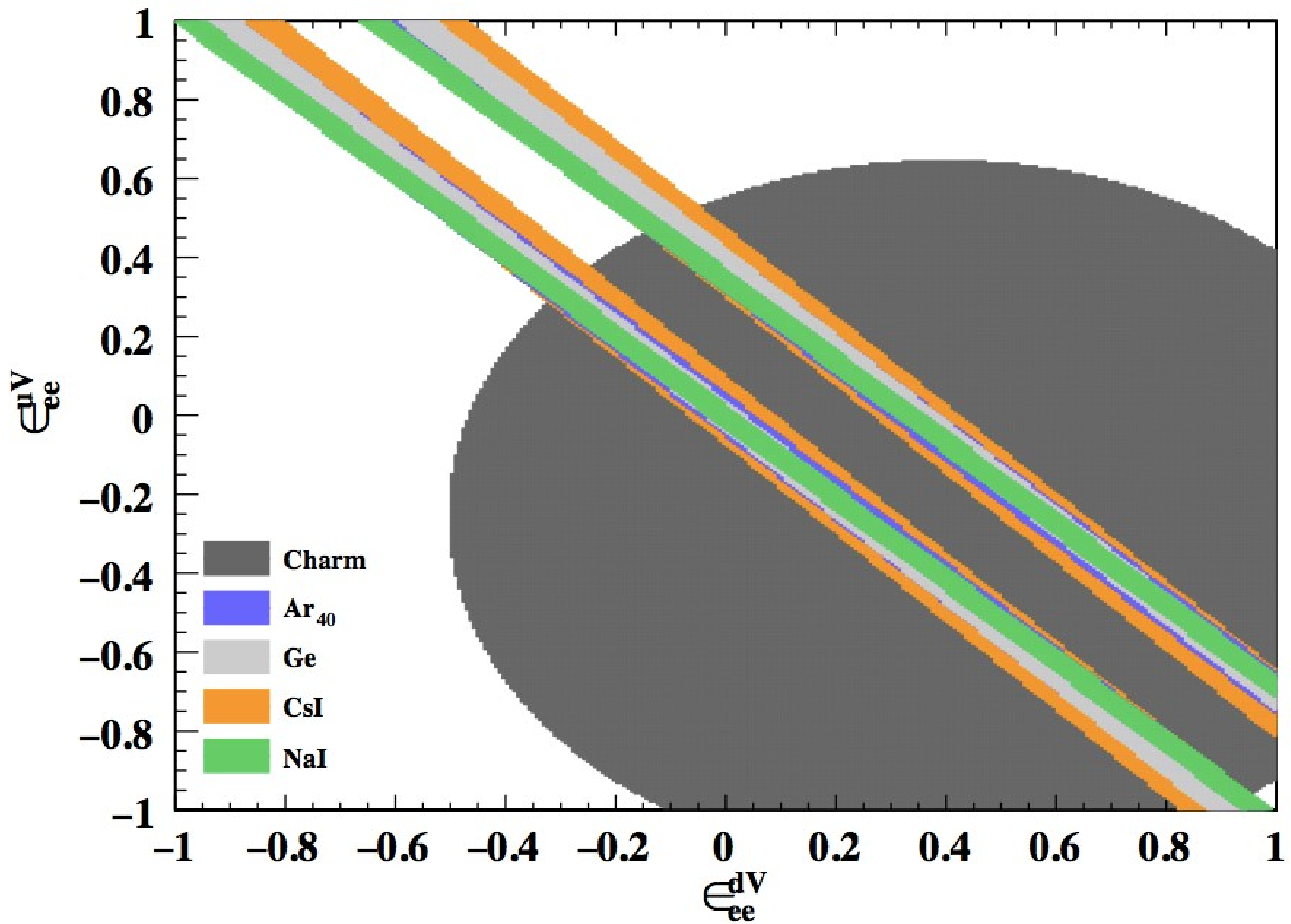
CEvNS Physics beyond first observation with precision measurements

- Non-standard interactions
- Oscillations to sterile neutrinos
- Neutrino magnetic moments
- Nuclear Form Factors

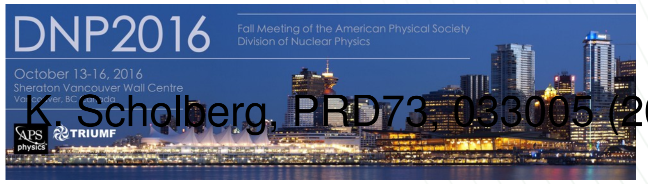
Non-Standard Interactions of Neutrinos

new interaction **specific to νs**

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



Can improve ~order of magnitude beyond CHARM limits with a first-generation experiment (for best sensitivity, want ***multiple targets***)

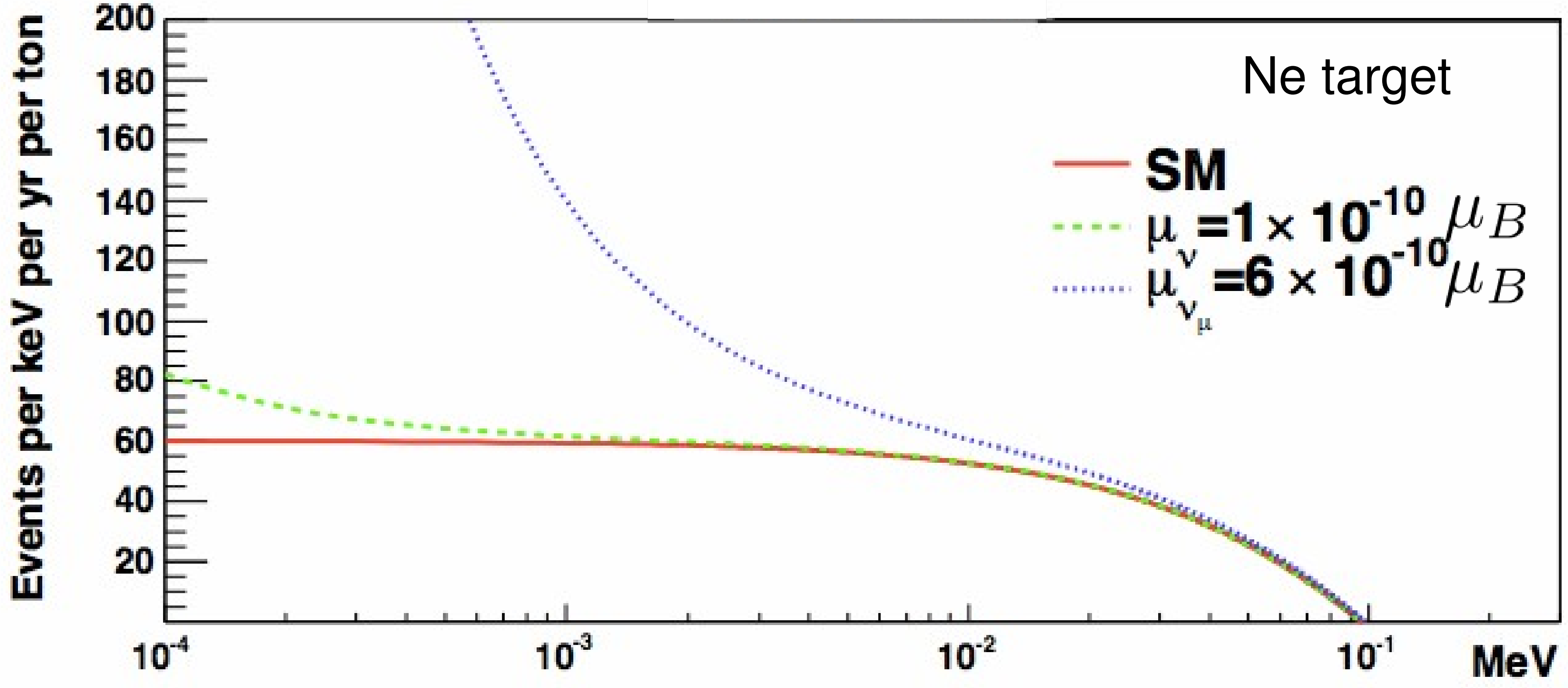


K. Scholberg, PRD73, 033005 (2006)

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, well-understood quenching factors

See also Kosmas et al., arXiv:1505.03202

Nuclear physics with CEvNS

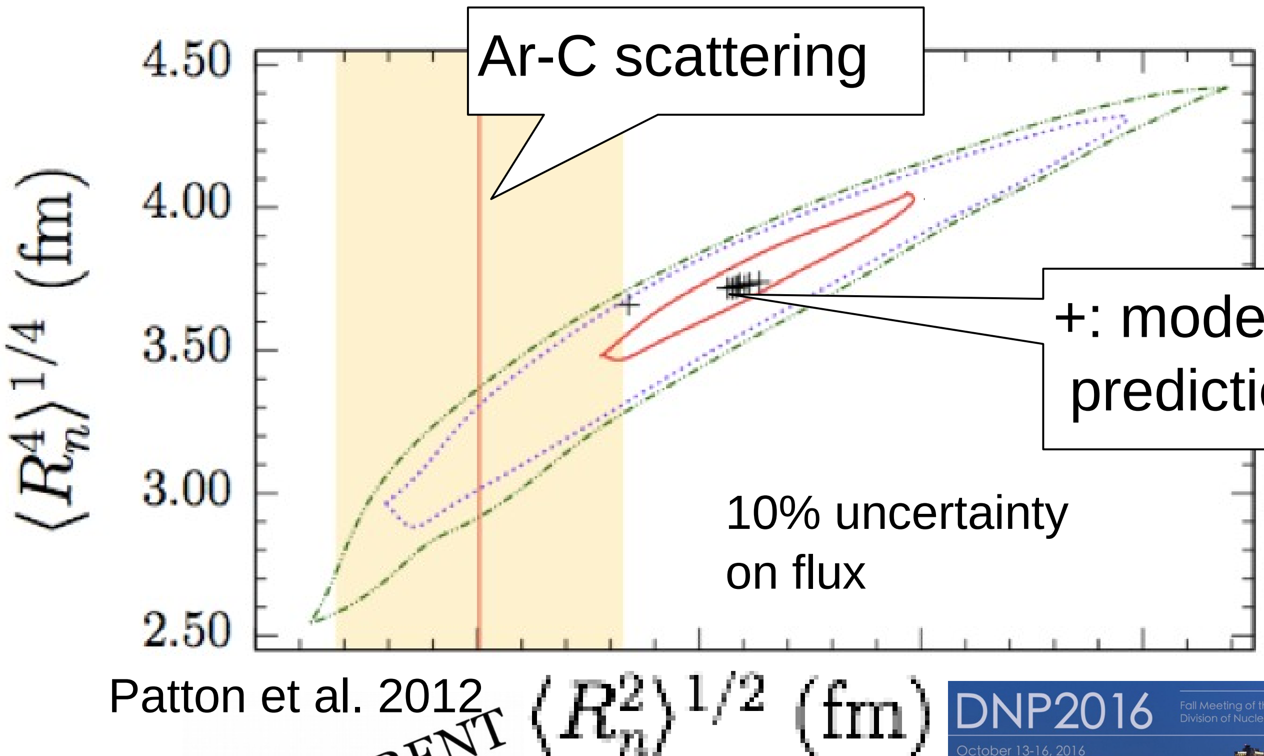
If systematics can be reduced to ~ few % level,
we can start to explore nuclear form factors

P. S. Amanik and G. C. McLaughlin, J. Phys. G 36:015105
K. Patton et al., PRC86 (2012) 024612

$$\frac{d\sigma}{dT}(E,T) = \frac{G_F^2}{2\pi} M \left[2 - \frac{2T}{E} + \left(\frac{T}{E}\right)^2 - \frac{MT}{E^2}\right] \frac{Q_W^2}{4} F^2(Q^2)$$

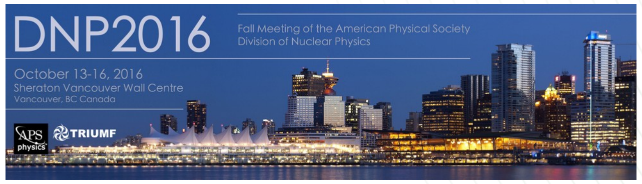
Form factor: encodes information about nuclear (primarily neutron) distributions

Fit recoil ***spectral shape*** to determine the $F(Q^2)$ moments
(requires very good energy resolution,good systematics control)



Patton et al. 2012

Example: tonne-scale experiment



Summary

- The Spallation Neutron Source is an ideal πDAR source of neutrinos for CEvNS measurements
- ORNL has created a neutrino laboratory within the target facility for smaller proof-of-concept measurements
- The COHERENT experiment is underway to make an unambiguous first observation of CEvNS with multiple targets.
- COHERENT is anticipating a rich neutrino physics program with precision measurements with ton scale detectors

Acknowledgements

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