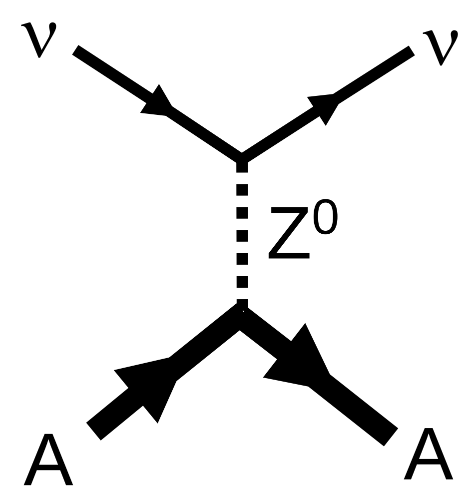
K. Scholberg, Duke University
On behalf of the COHERENT collaboration
August 2, 2017
DPF 2017, Fermilab

Coherent elastic neutrino-nucleus scattering (CEvNS)

$$\nu + A \rightarrow \nu + A$$

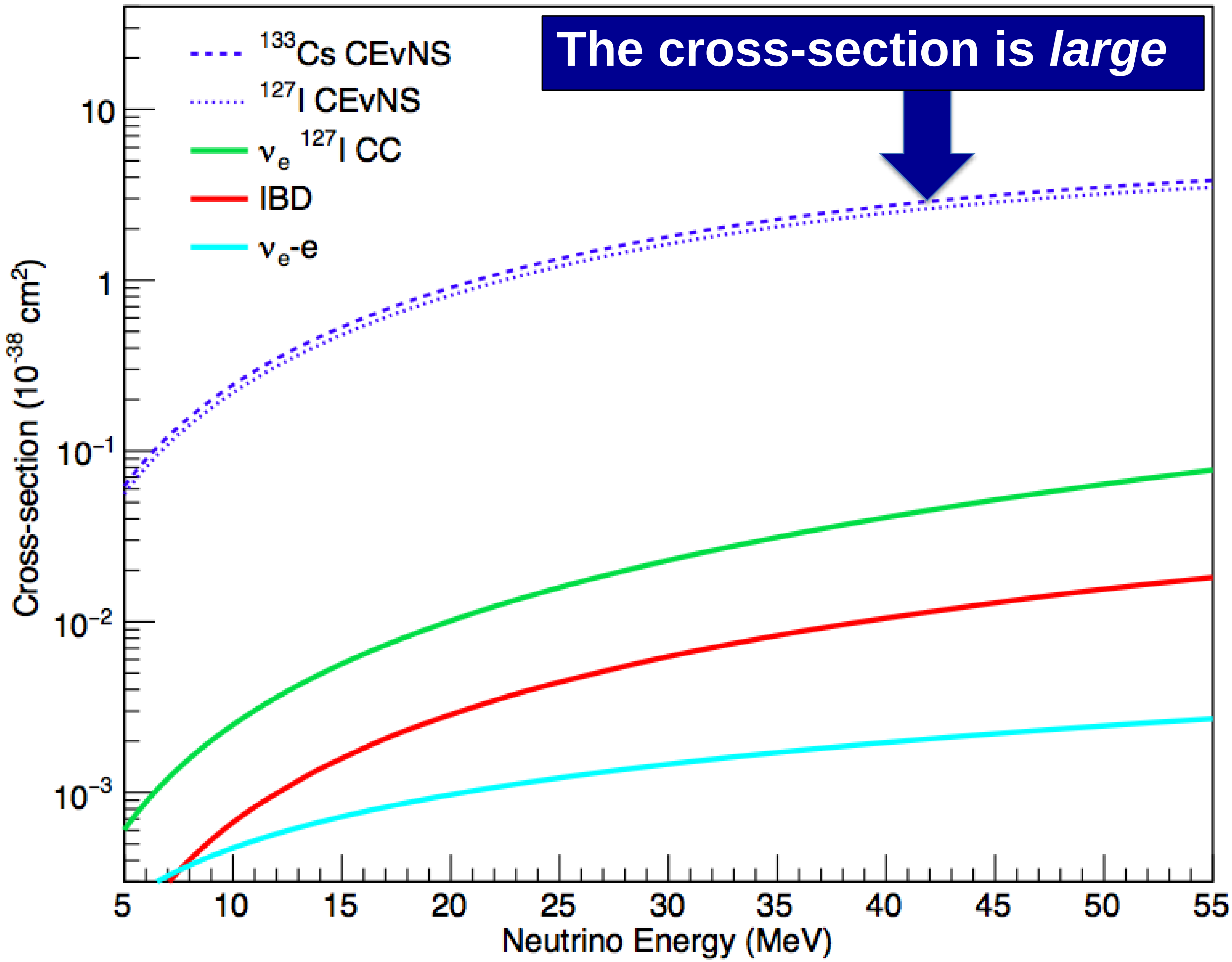
A neutrino smacks a nucleus via exchange of a Z, and the nucleus recoils as a whole; **coherent** up to E_ν~ 50 MeV



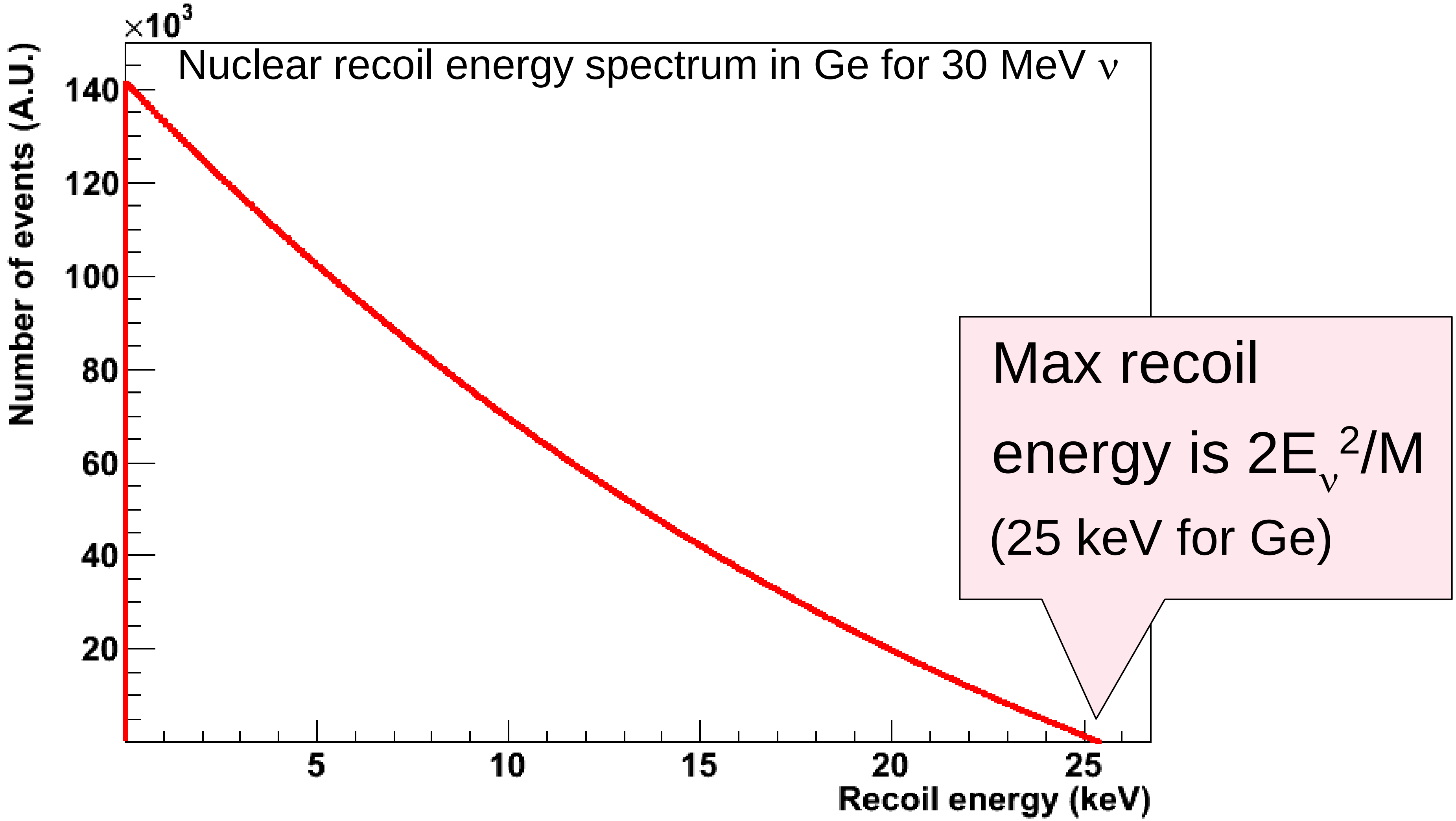
- Important in **SN processes & detection**
- Well-calculable cross-section in SM:
  SM test, probe of neutrino NSI
- Dark matter direct detection background
- Possible applications (reactor monitoring)

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

$$\propto N^2$$

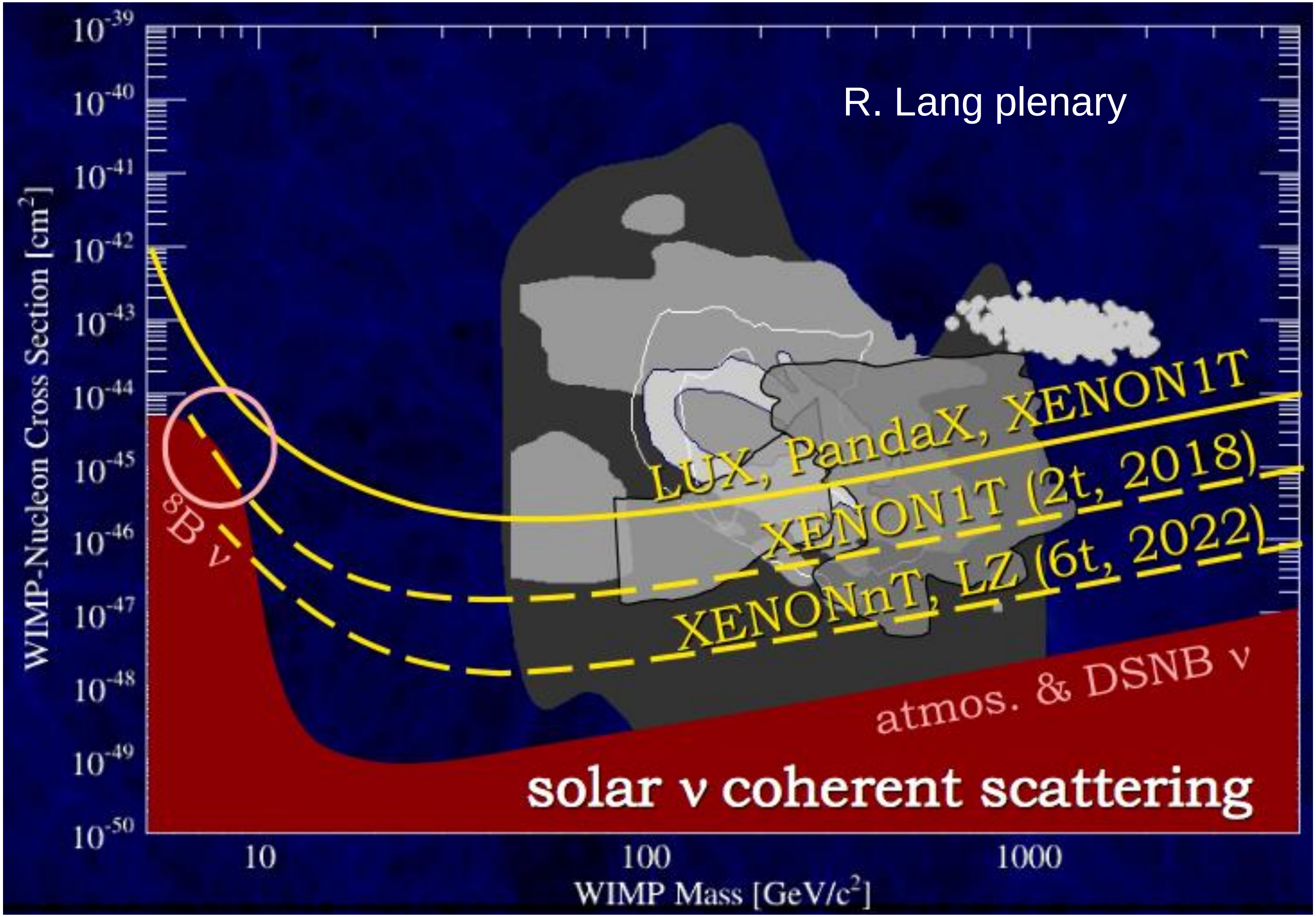

The cross-section is *large*
^{133}Cs CEvNS
^{127}I CEvNS
ν_e ^{127}I CC
IBD
ν_e-e
Cross-section (10^{-38} cm^2)
Neutrino Energy (MeV)
10
1
10^{-1}
10^{-2}
10^{-3}
5
10
15
20
25
30
35
40
45
50
55

Large cross section, but never observed due to **tiny nuclear recoil energies:**



➔ but **WIMP dark matter detectors** developed over the last ~decade are sensitive to ~ keV to 10's of keV recoils

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

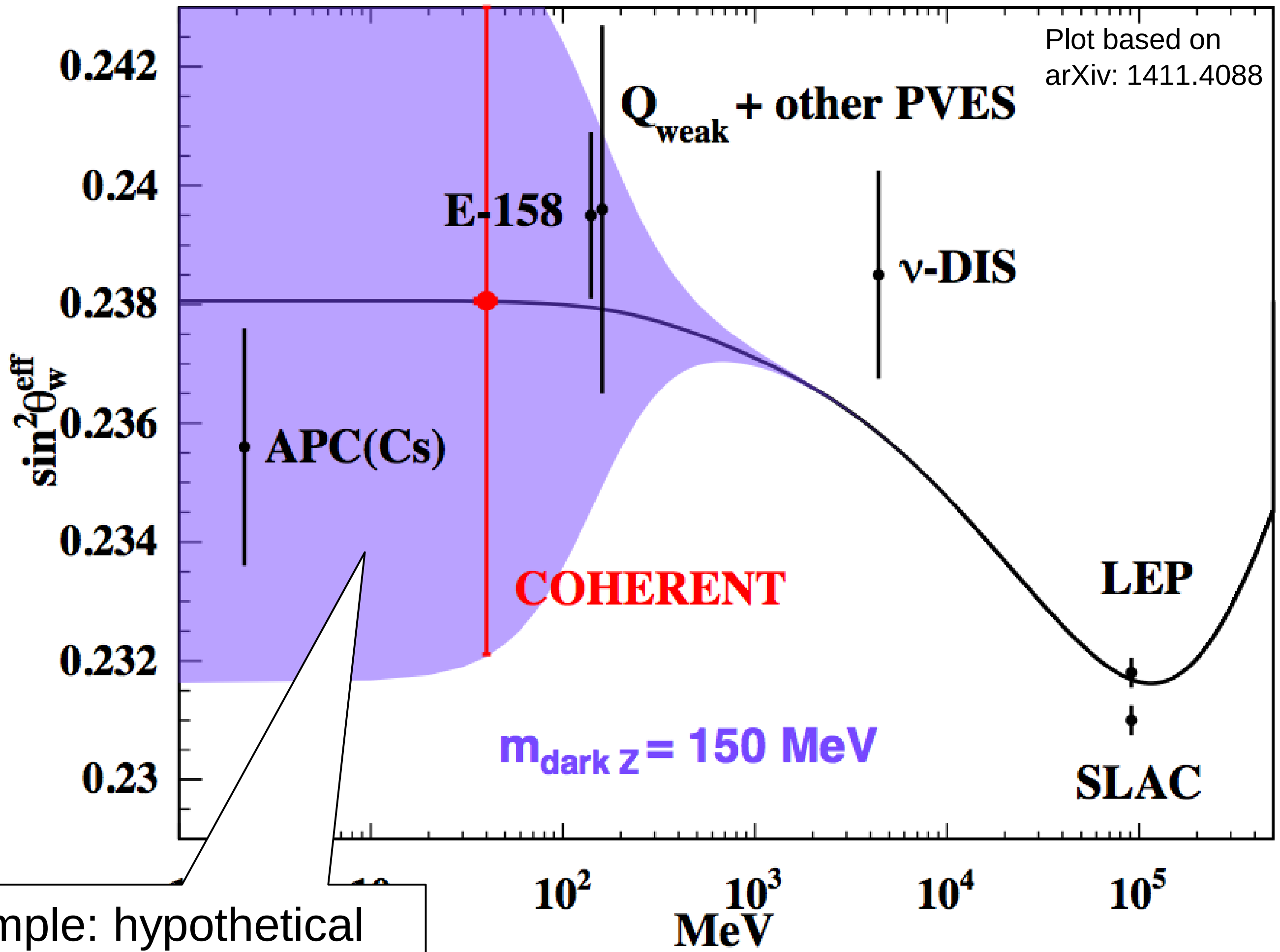


Understand nature of background (& detection response)

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

deviation probes new physics

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



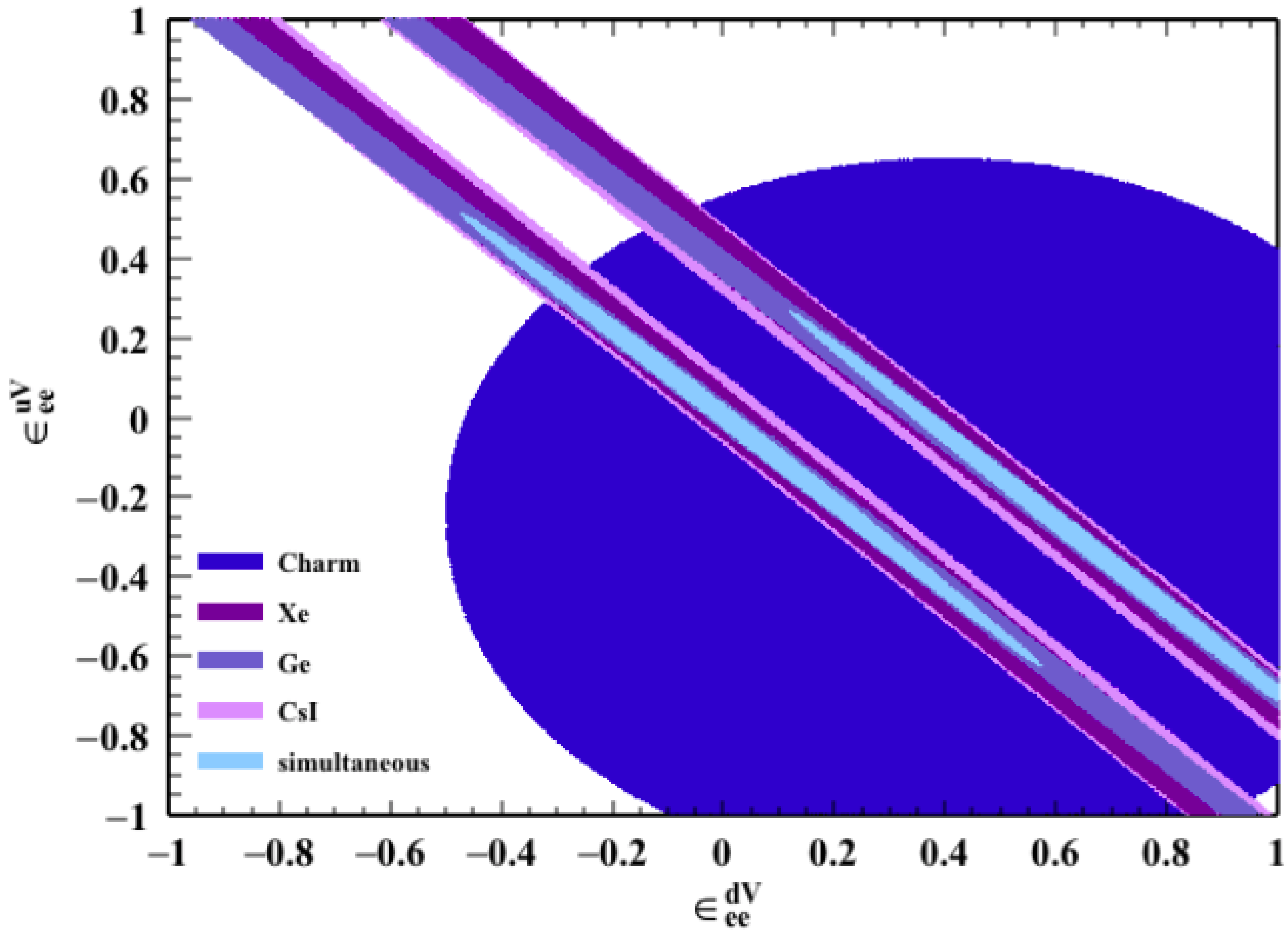
Example: hypothetical dark Z mediator (explanation for g-2 anomaly)

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

Non-Standard Interactions of Neutrinos:

new interaction **specific to ν's**

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



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

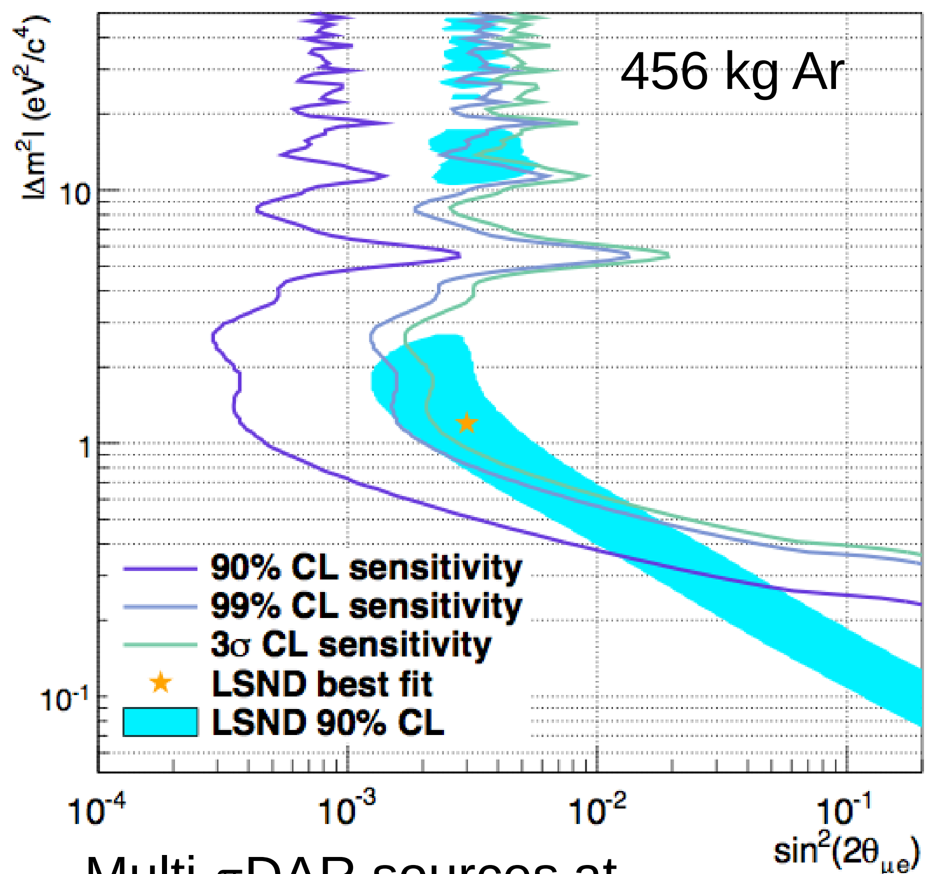
K. Scholberg, PRD73, 033005 (2006)

Oscillations to sterile neutrinos w/CEvNS

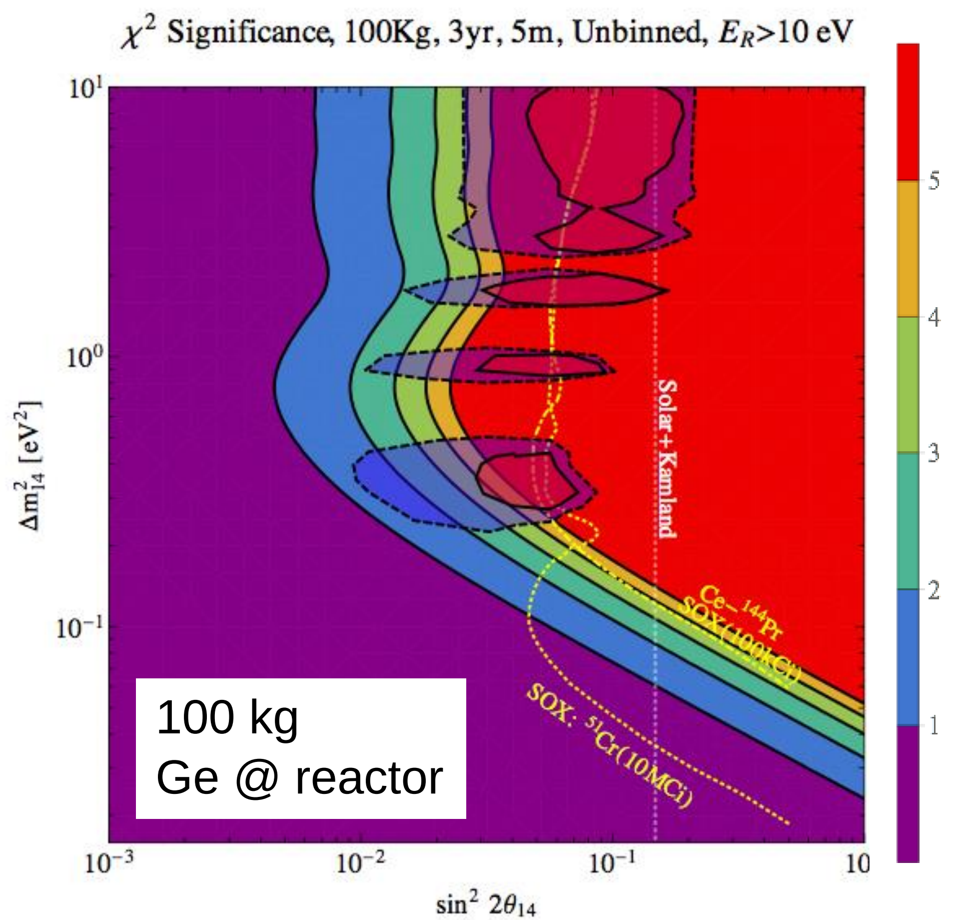
(NC is flavor-blind): a potential new tool;

look for deficit and spectral distortion vs L,E

Examples:



Multi-πDAR sources at different baselines (20 & 40 m)



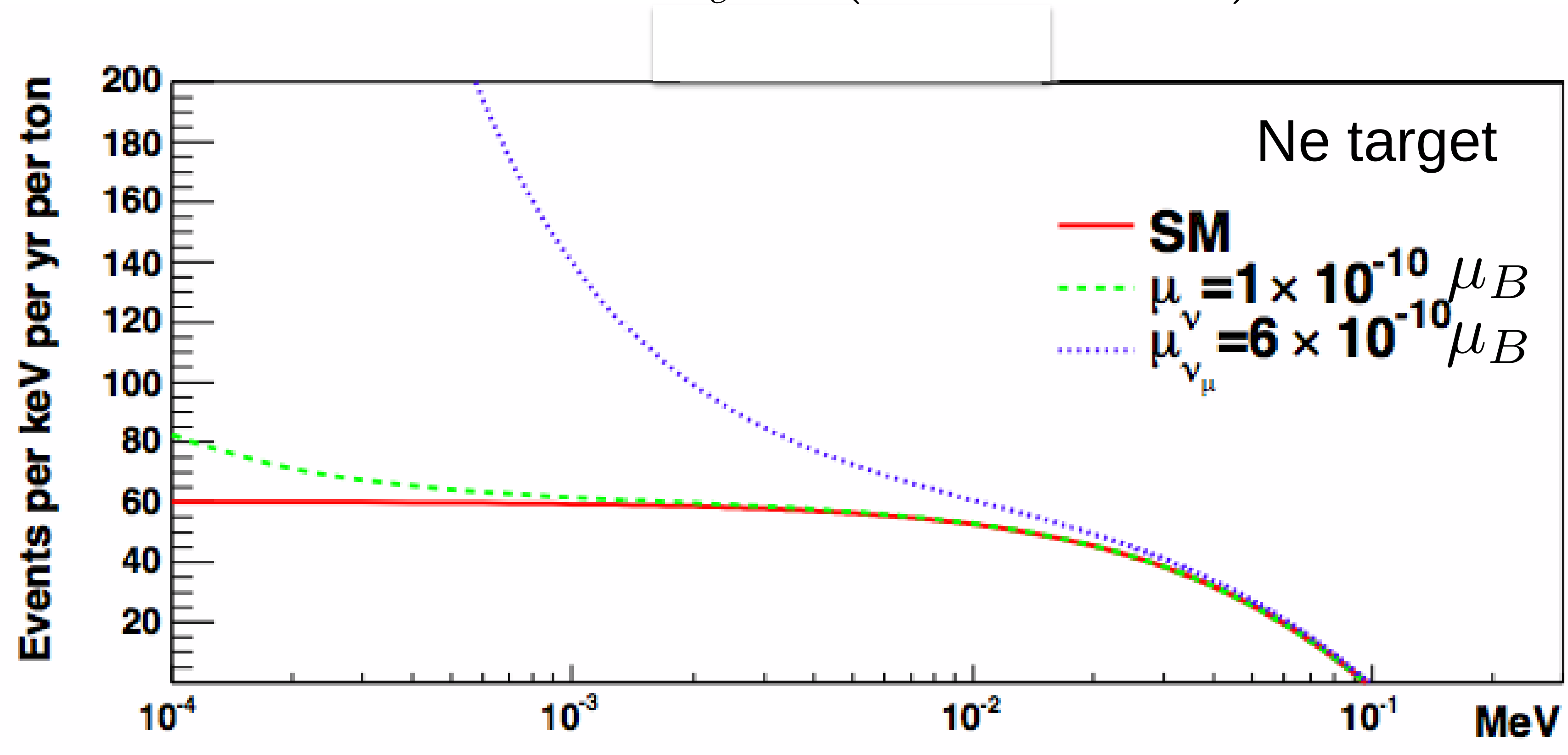
B. Dutta et al, arXiv:1511.02834

Anderson et al., PRD86 (2012) 013004, arXiv:1201.3805

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 Kosmas et al., arXiv:1505.03202

Nuclear physics with coherent elastic scattering

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

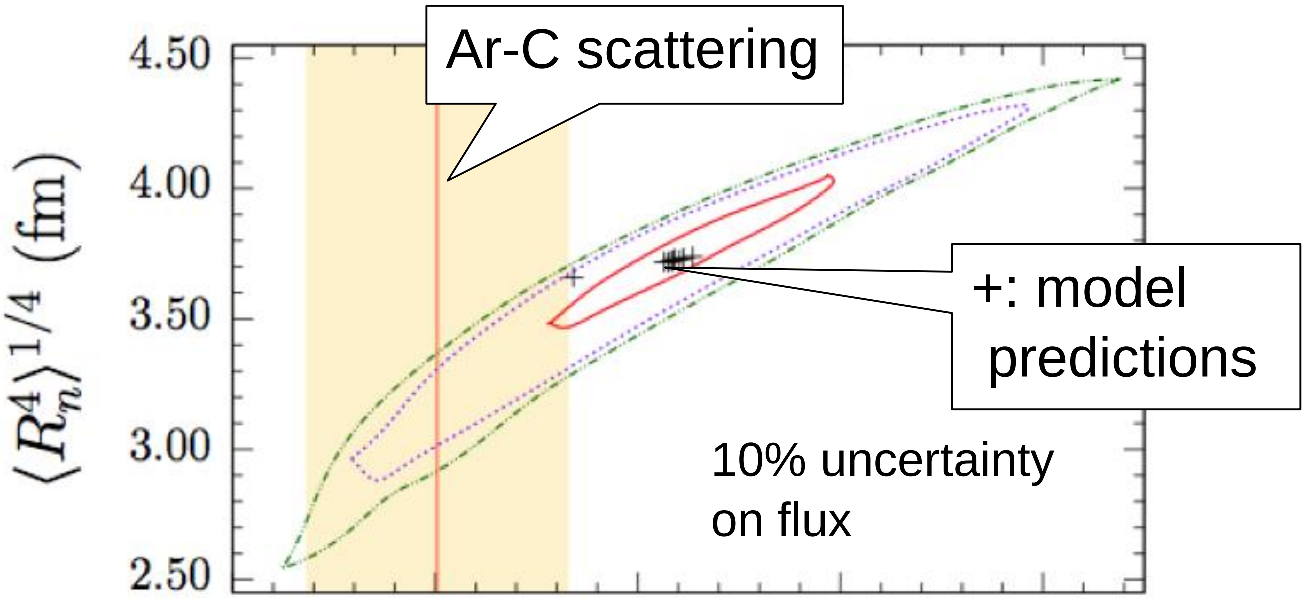
K. Patton et al., PRC86 (2012) 024612

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

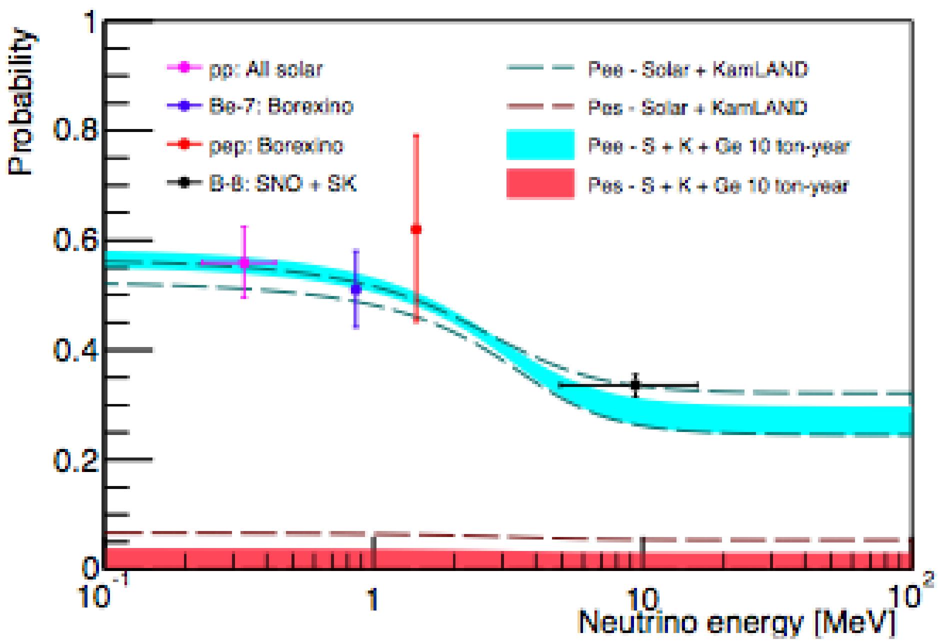
Form factor: encodes information about nuclear (primarily neutron) distributions

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

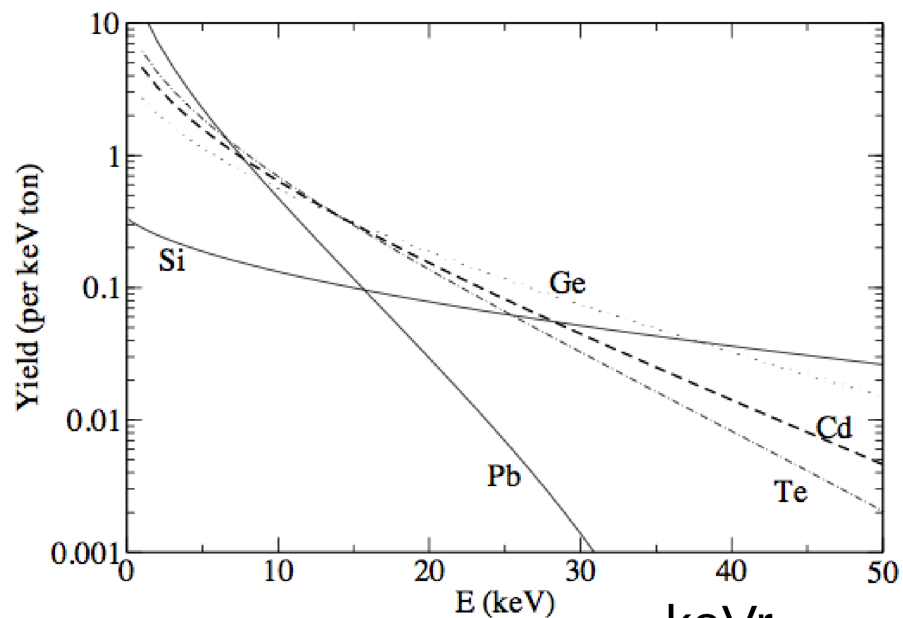
Example:
tonne-scale experiment at πDAR source



Tonne-scale underground DM detectors can measure **solar and supernova neutrinos**



Billard et al., arXiv:1409.0050



keVr

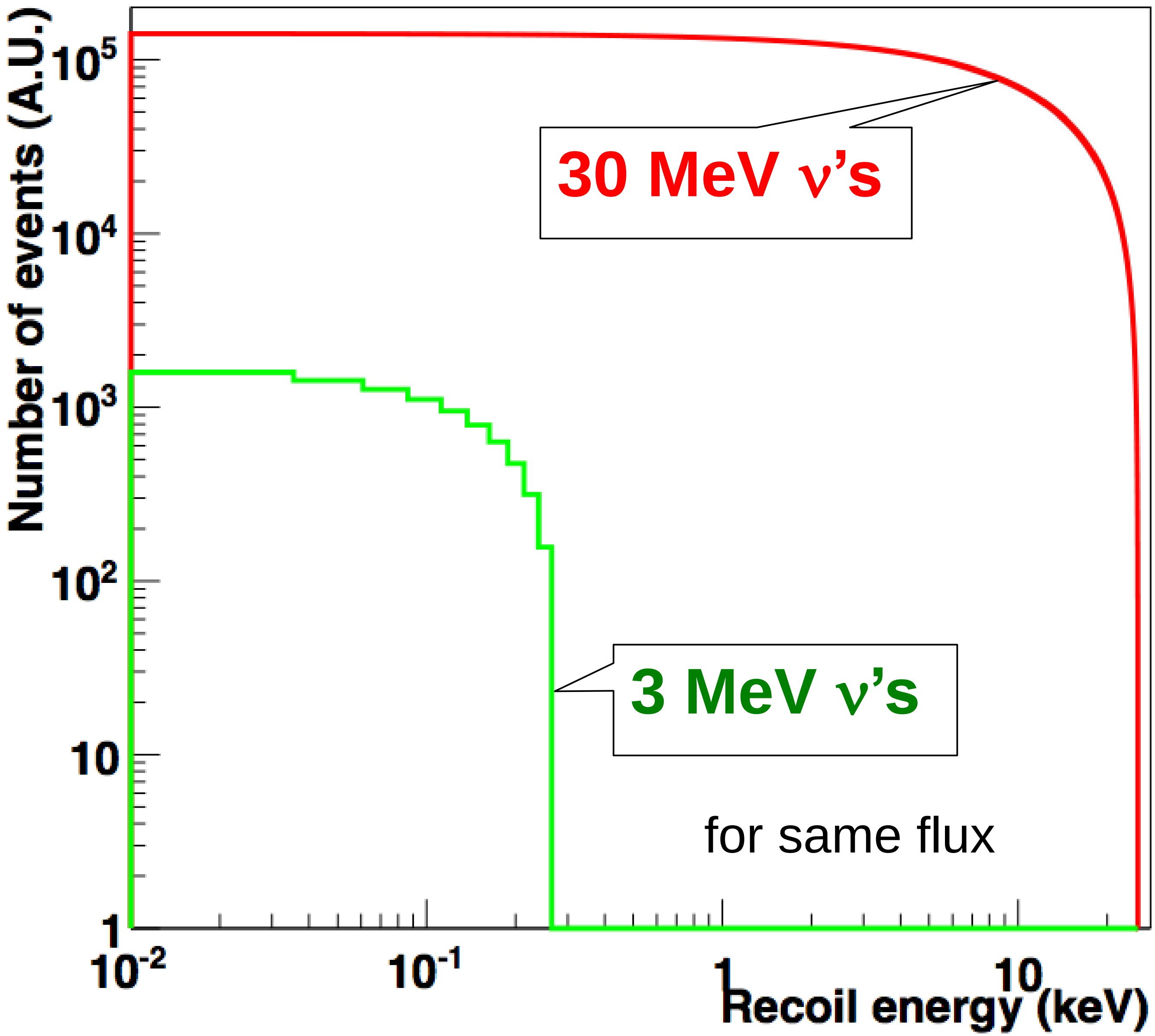
Horowitz et al., PRD68 (2003) 023005

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*

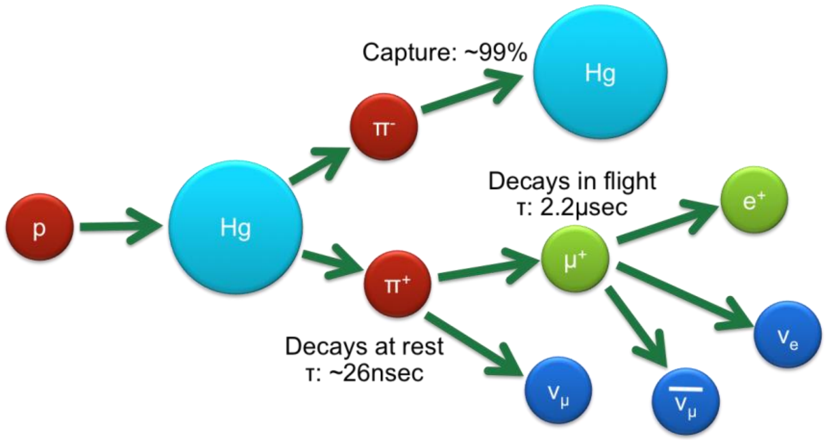
Why use the 10's of MeV neutrinos from π decay at rest?

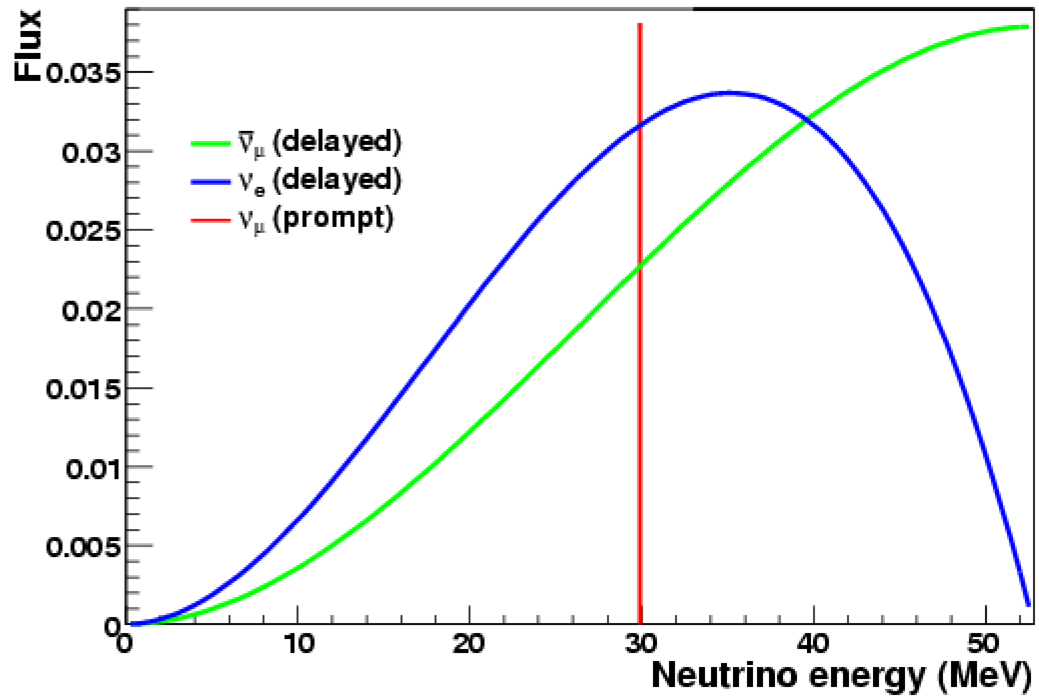
➔higher-energy neutrinos are advantageous, because both **cross-section and maximum recoil energy increase with ν energy**



Reactor experiments (RICOCHET, CONNIE, CONus etc.) can take advantage of very large flux (~factor of 10^4) but require very low energy thresholds, where background can be daunting; radioactive source experiments require even lower thresholds

Stopped-Pion (πDAR) Neutrinos





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

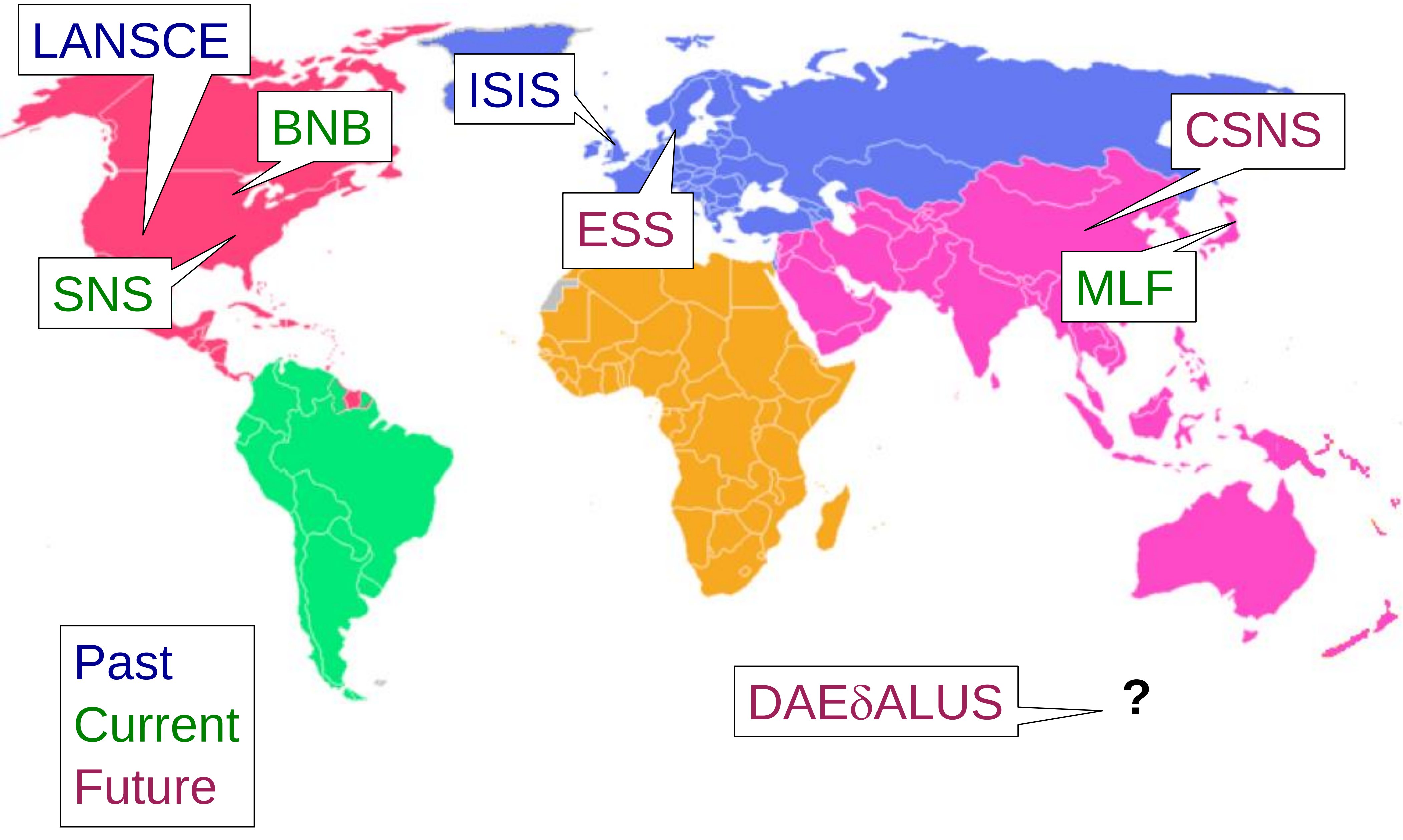
2-body decay: monochromatic 29.9 MeV ν_μ
PROMPT

$$\downarrow$$

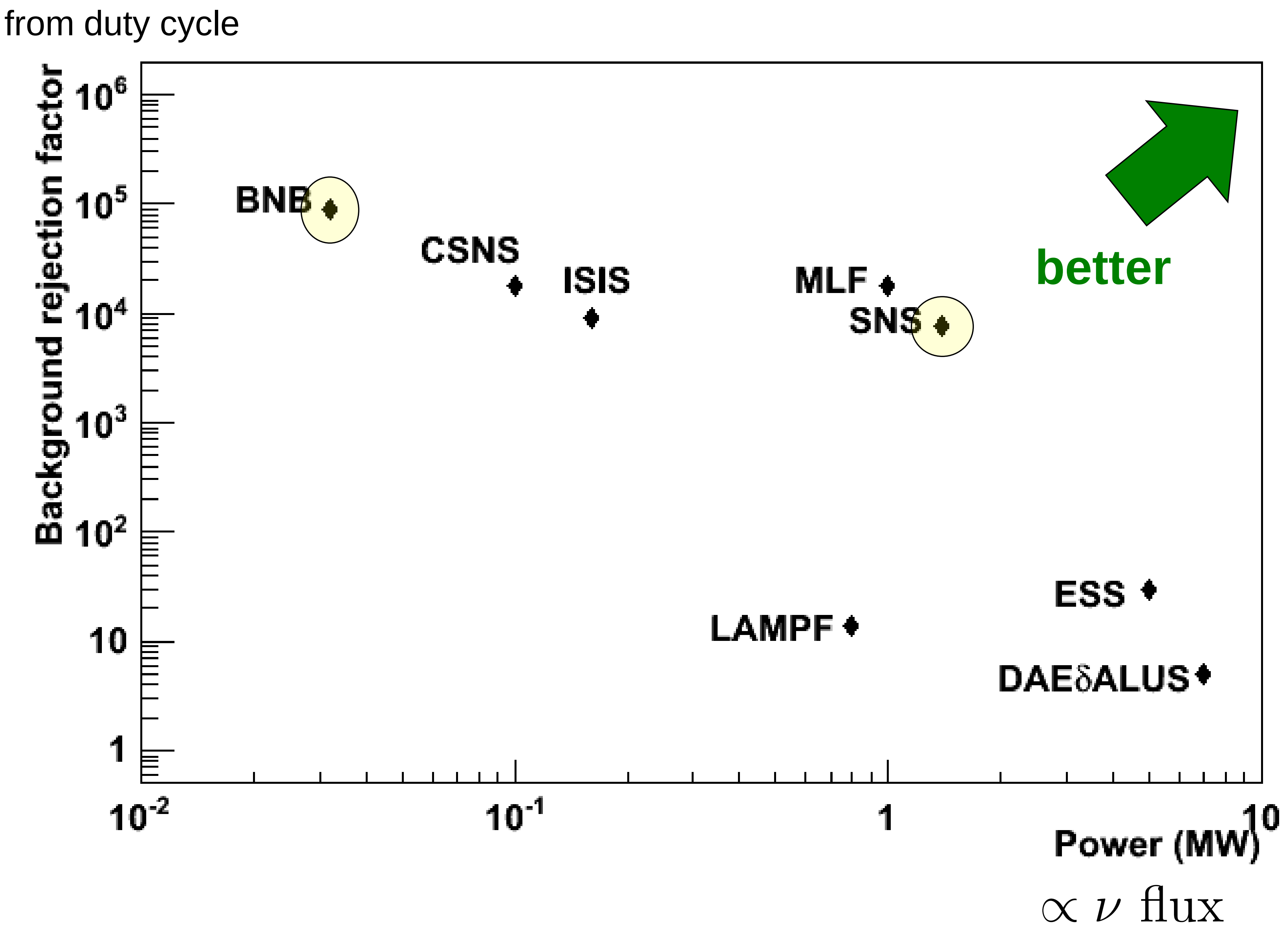
$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

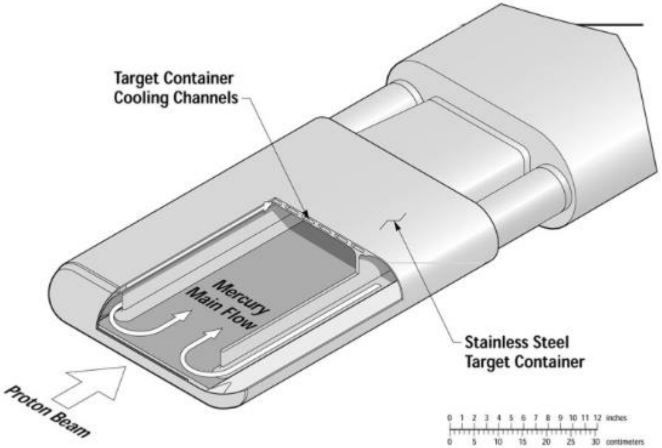
3-body decay: range of energies
between 0 and $m_\mu/2$
DELAYED (2.2 μs)

Stopped-Pion Sources Worldwide



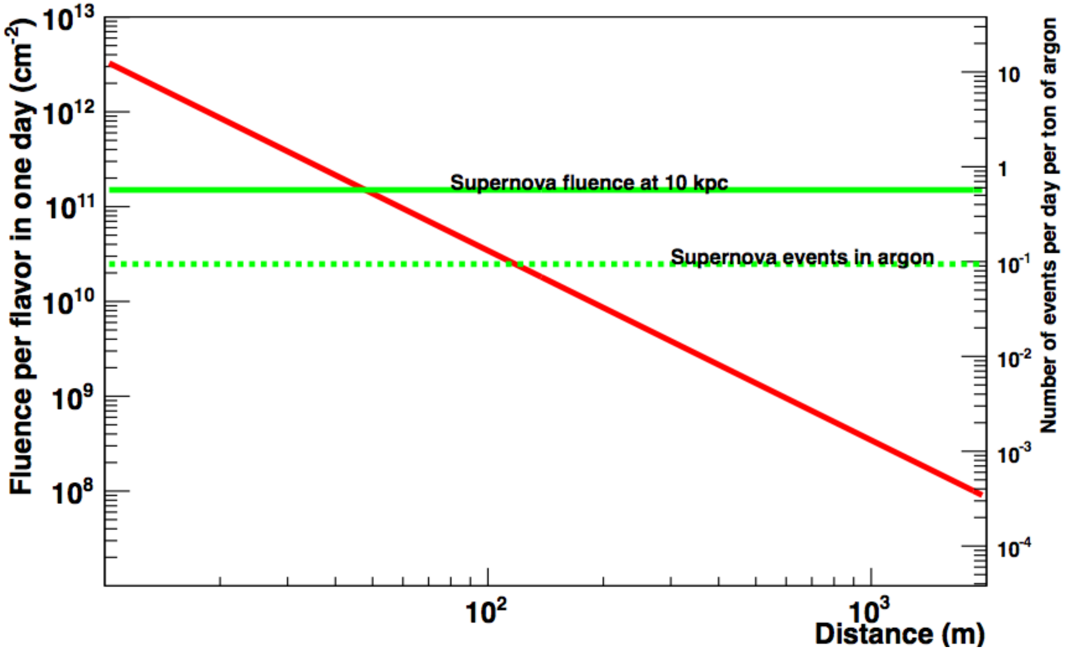
Comparison of pion decay-at-rest ν sources



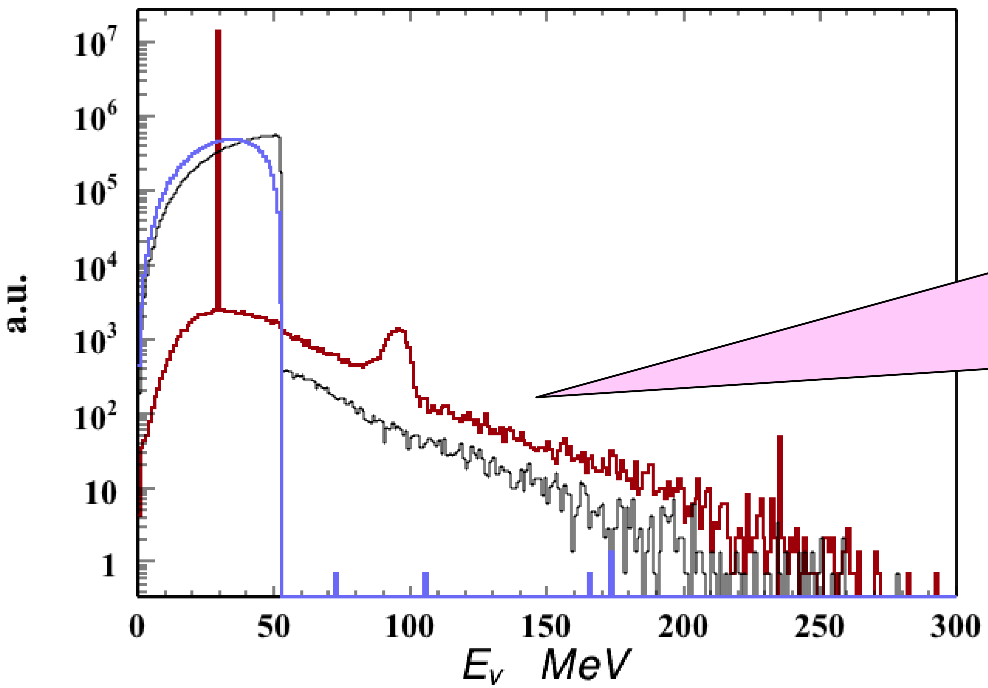


Proton beam energy: 0.9-1.3 GeV
Total power: 0.9-1.4 MW
Pulse duration: 380 ns FWHM
Repetition rate: 60 Hz
Liquid mercury target

The SNS has **large, extremely clean** DAR ν flux



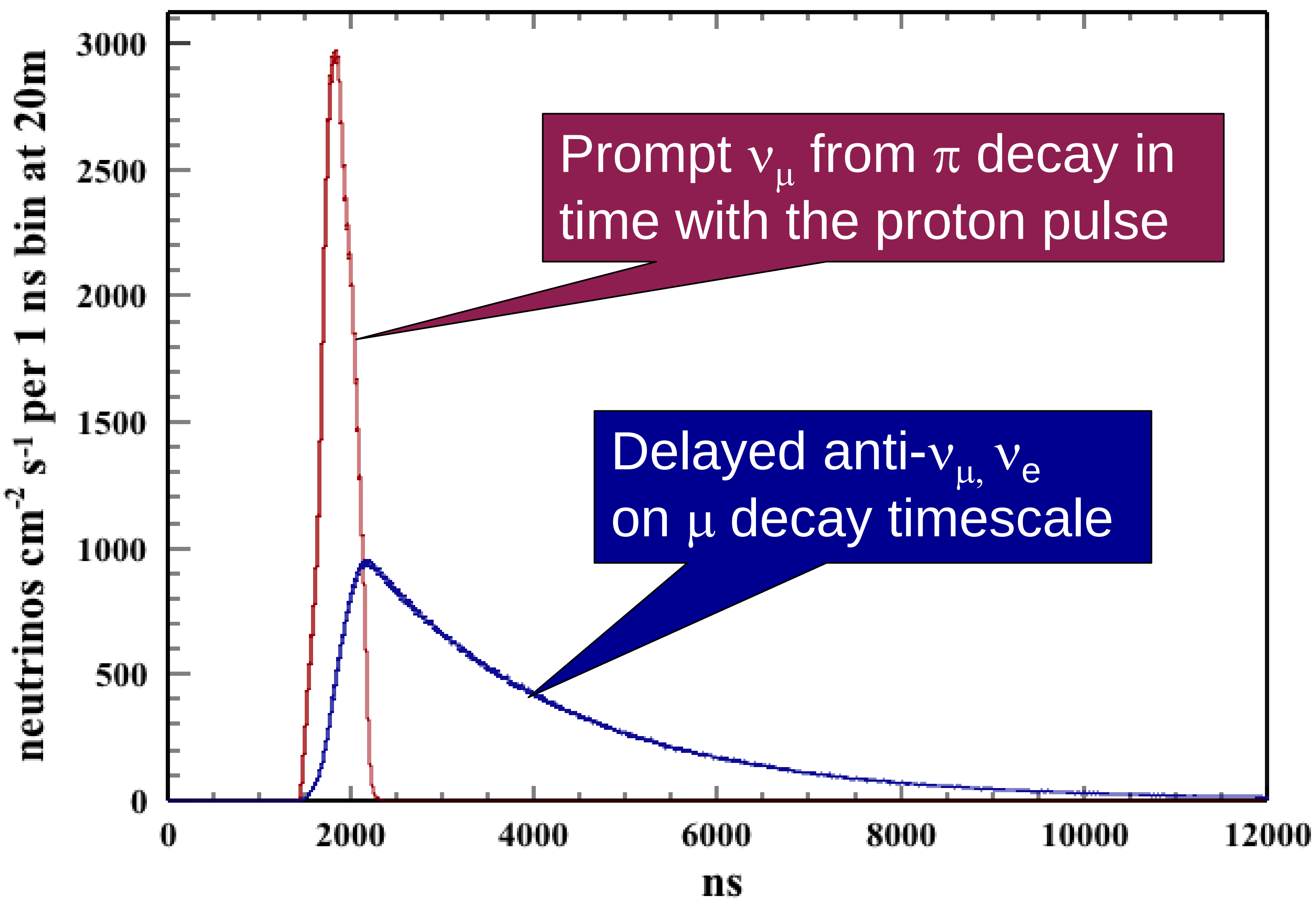
SNS flux (1.4 MW):
430 x 10^5 ν/cm^2/s
@ 20 m



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

Time structure of the SNS source

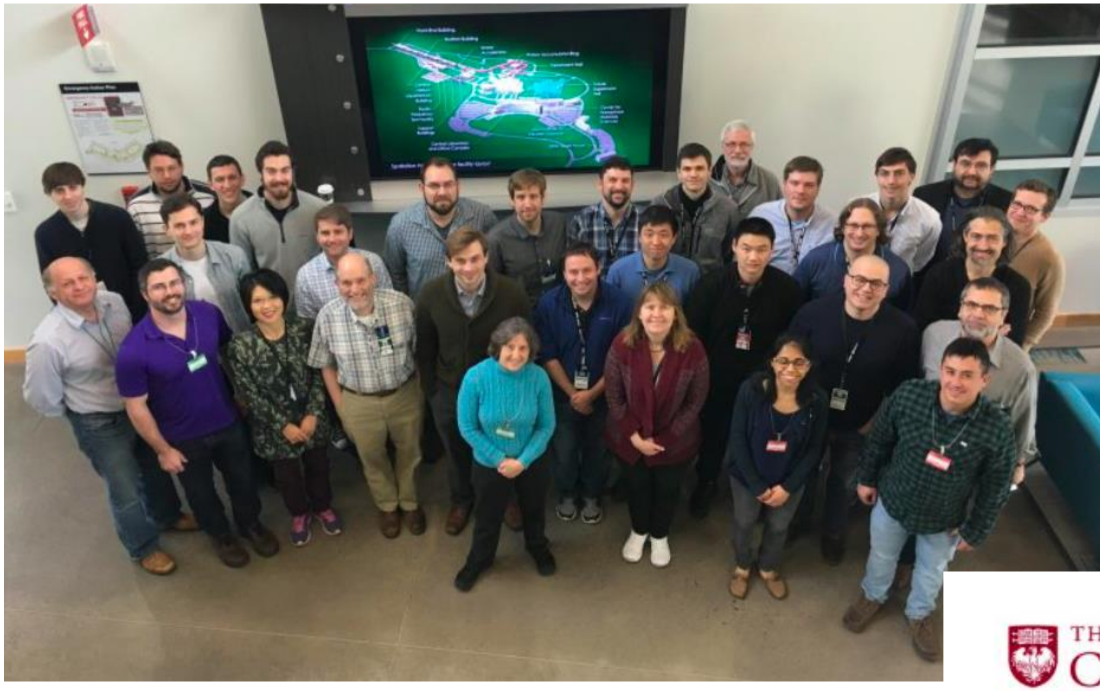
60 Hz *pulsed* source



Background rejection factor ~few x 10^{-4}

The COHERENT collaboration

http://sites.duke.edu/coherent



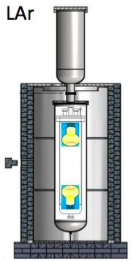
~80 members,
18 institutions
4 countries

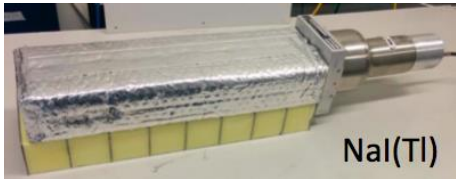
arXiv:1509.08702

COHERENT Detectors

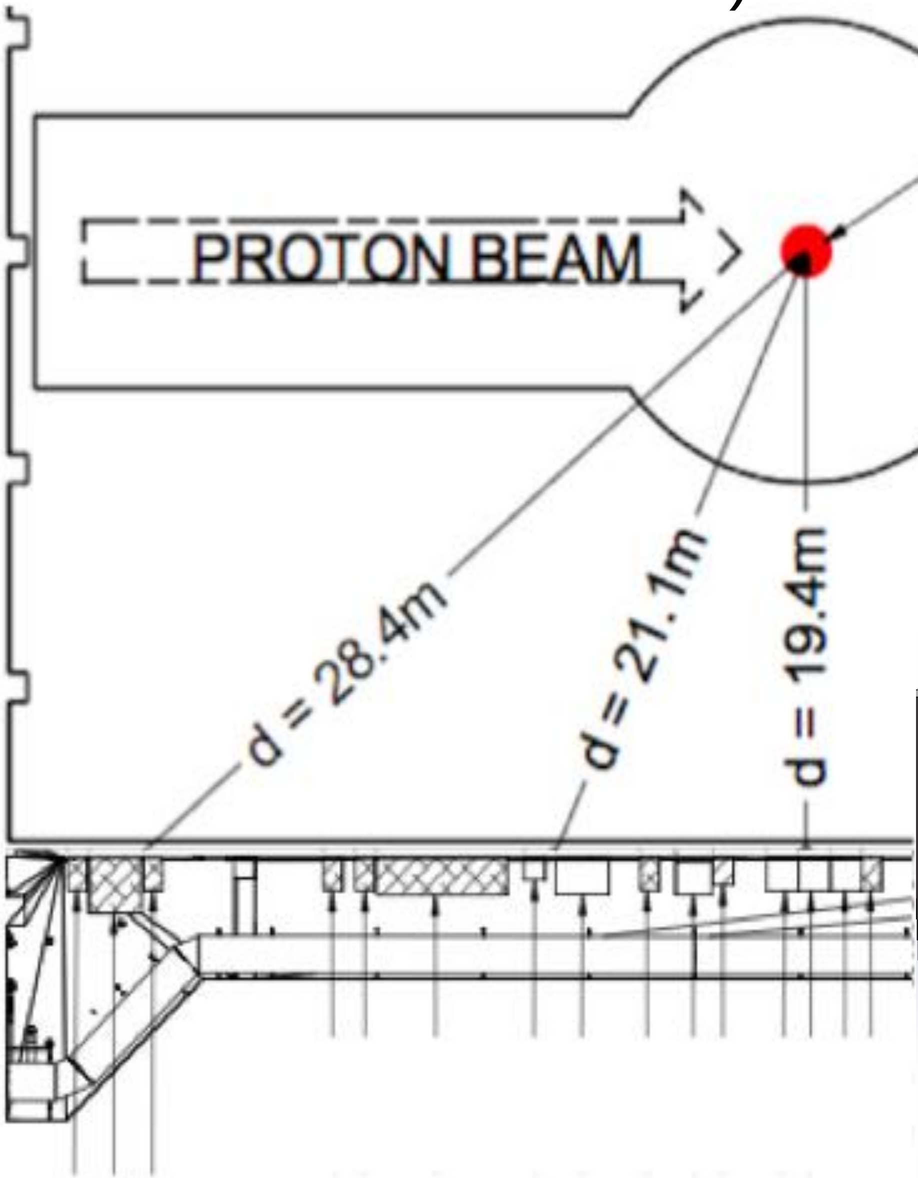
Nuclear Target	Technology	Mass (kg)	Distance from source (m)	Recoil threshold (keVr)
CsI[Na]	Scintillating Crystal	14.6	20	6.5
Ge	HPGe PPC	10	22	5
LAr	Single-phase	22	29	20
NaI[Tl]	Scintillating crystal	185*/2000	28	13

Multiple detectors for N^2 dependence of the cross section

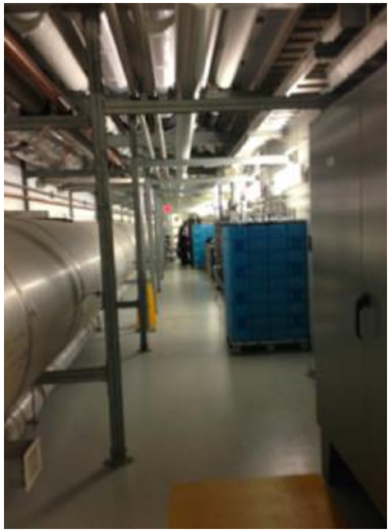


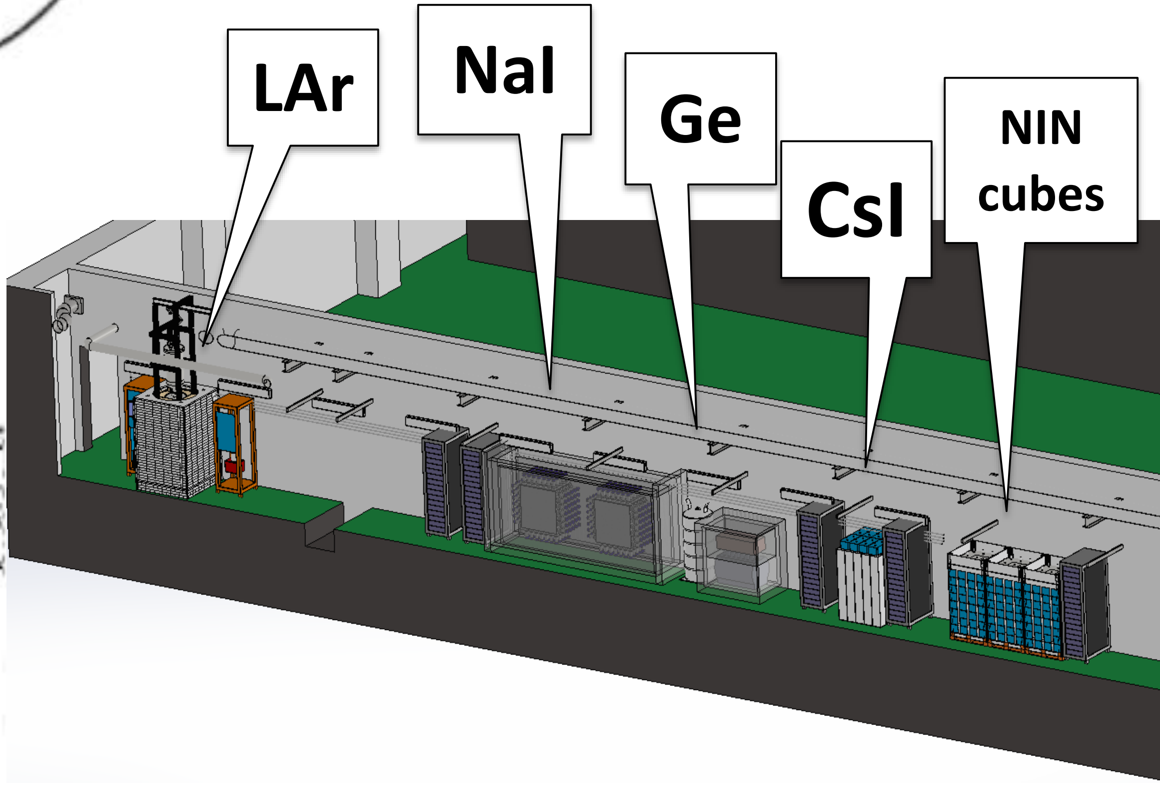


Siting for deployment in SNS basement
(measured neutron backgrounds low,
~ 8 mwe overburden)

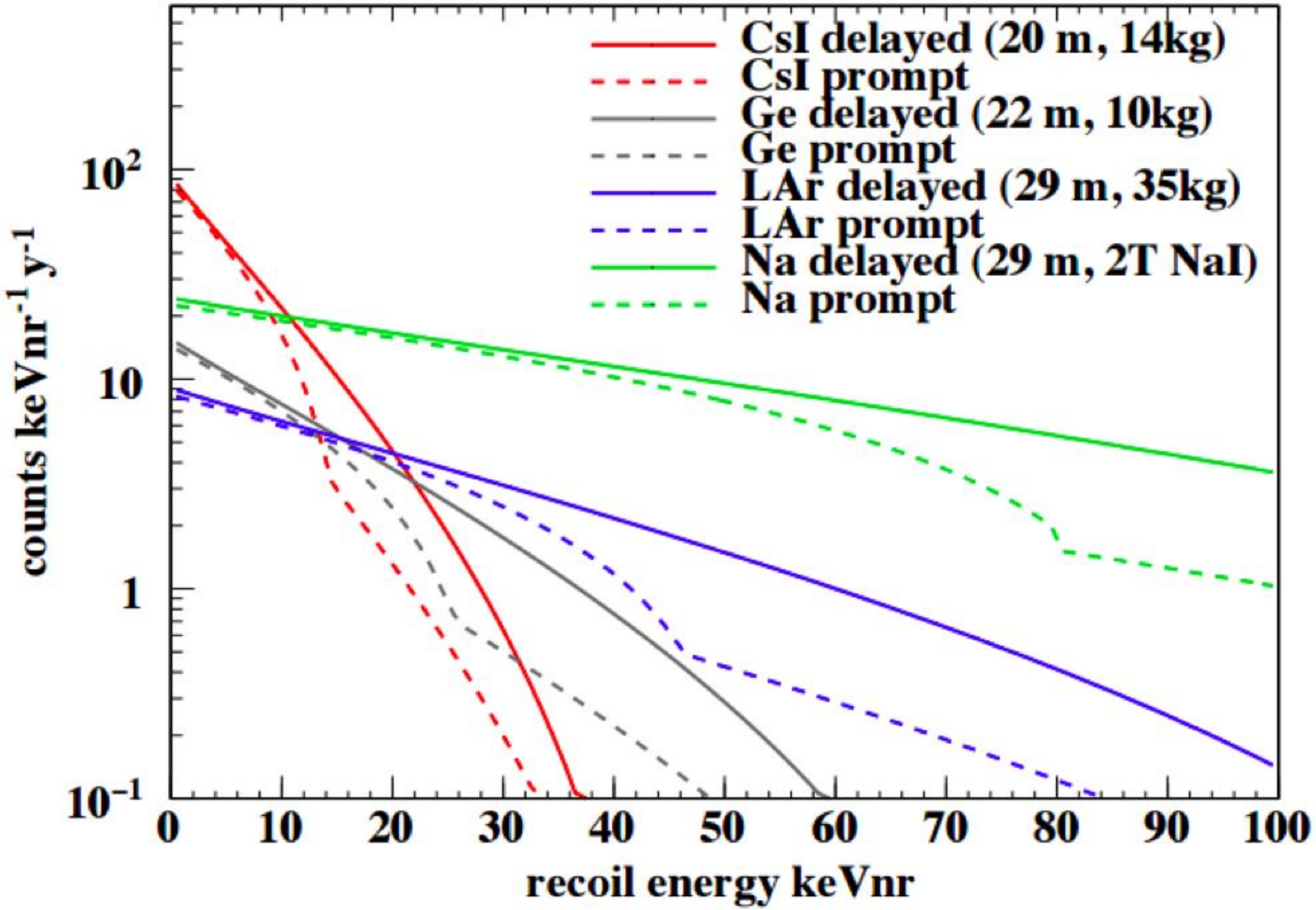


View looking
down "Neutrino Alley"





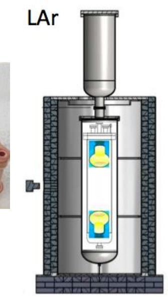
Expected recoil signals

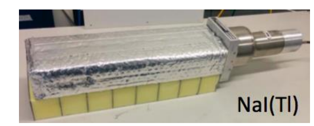


Prompt defined as first μs; note some contamination from ν_e and ν_μ-bar

COHERENT Detector Status

Nuclear Target	Technology	Mass (kg)	Distance from source (m)	Recoil threshold (keVr)	Data-taking start date
CsI[Na]	Scintillating Crystal	14.6	20	6.5	9/2015
Ge	HPGe PPC	10	22	5	2017
LAr	Single-phase	22	29	20	12/2016
NaI[Tl]	Scintillating crystal	185*/2000	28	13	*high-threshold deployment summer 2016





- CsI installed in July 2015
- 185 kg of NaI installed in July 2016
- LAr single-phase detector installed in December 2016,
  upgraded w/TPB coating of PMT & Teflon; commissioning underway
- Ge detectors to be installed late 2017

CsI results soon: embargoed until Aug 3, 2 pm EST

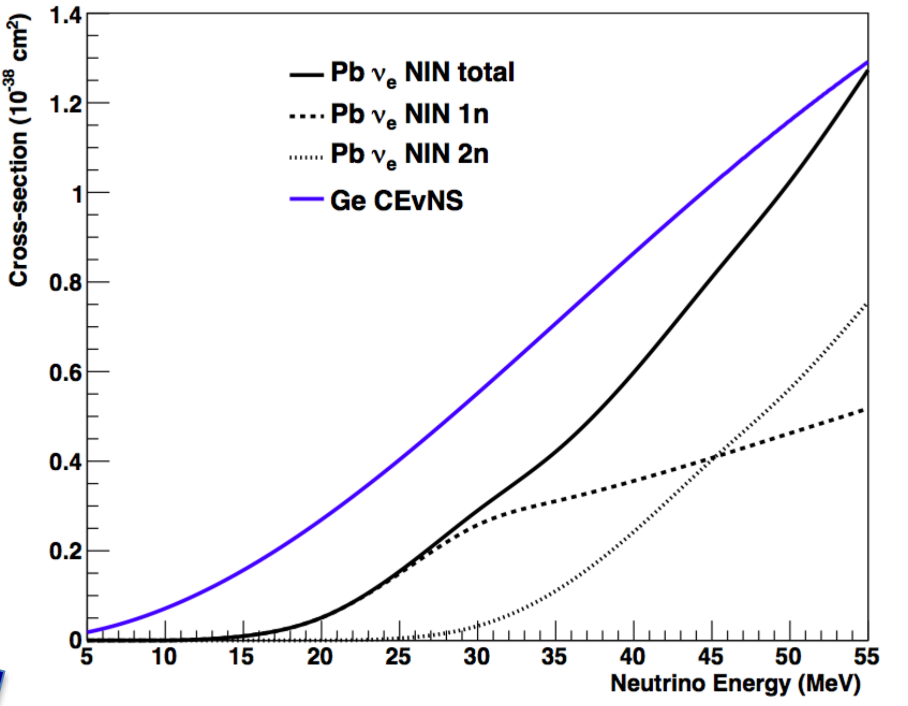
Currently measuring *neutrino-induced neutrons* in lead, (iron, copper), ...

$\nu_e + {}^{208}Pb \rightarrow {}^{208}Bi^* + e^-$ CC

↘ 1n, 2n emission

$\nu_x + {}^{208}Pb \rightarrow {}^{208}Pb^* + \nu_x$ NC

↘ 1n, 2n, γ emission

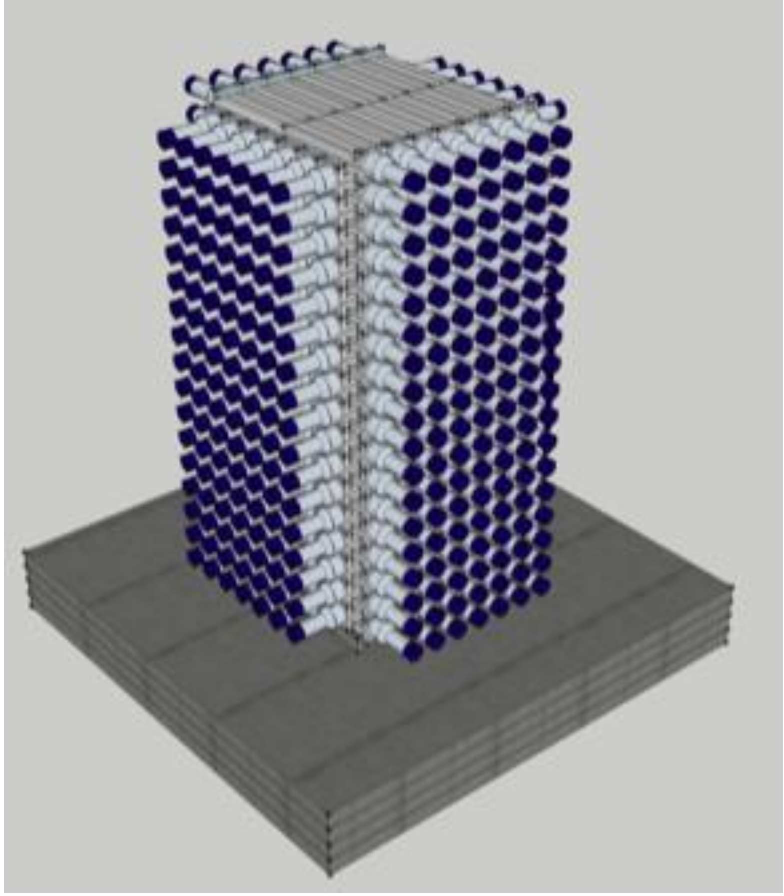


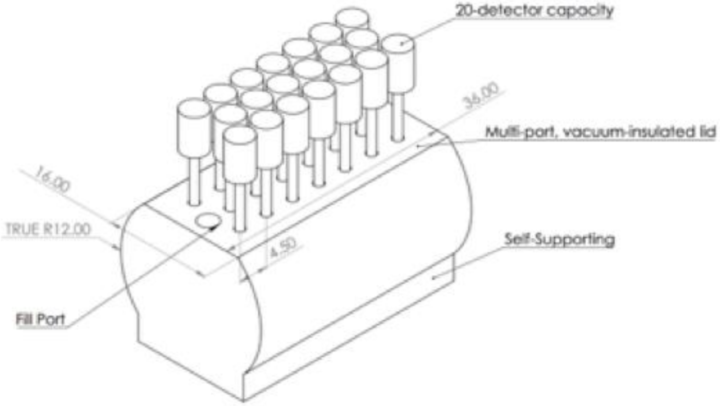
- potentially a non-negligible background, especially in lead shield
- valuable in itself, e.g. HALO SN detector

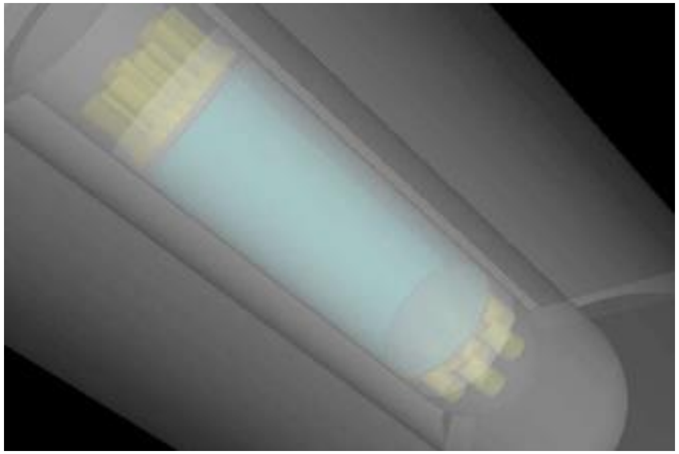
Talk by Brandon Becker next!

Potential upgrades

- additional Ge detectors
- larger LAr (up to few 100 kg)
- up to 7 ton NaI
- additional targets/detectors



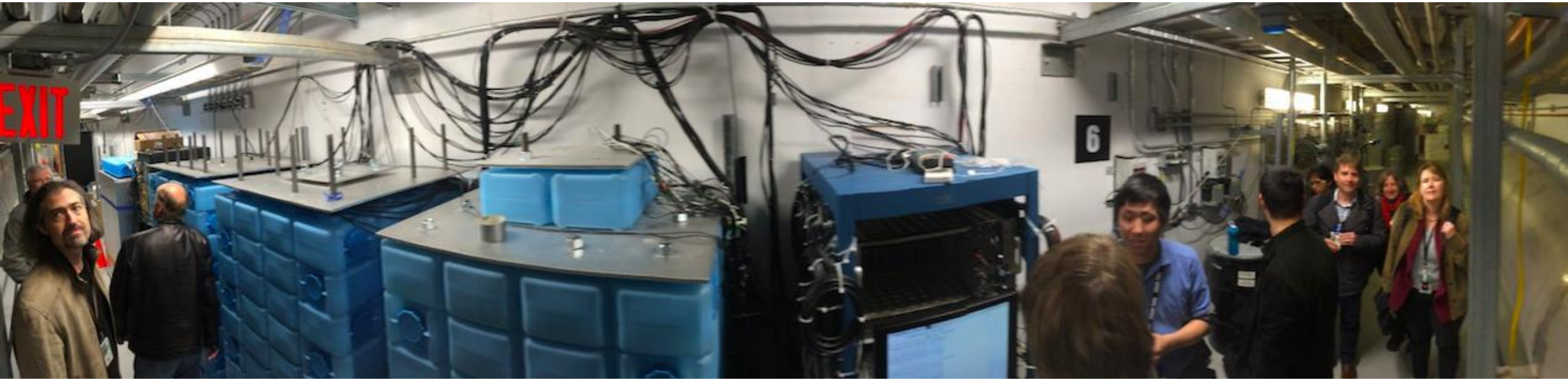




Summary

- **CEvNS** never before measured
- Multiple physics motivations
  - DM bg, SM test, astrophysics, nuclear physics, ...
- Now within reach with WIMP detector technology and neutrinos from pion decay at rest

COHERENT@ SNS going after this
with multiple targets, extremely clean neutrino flux

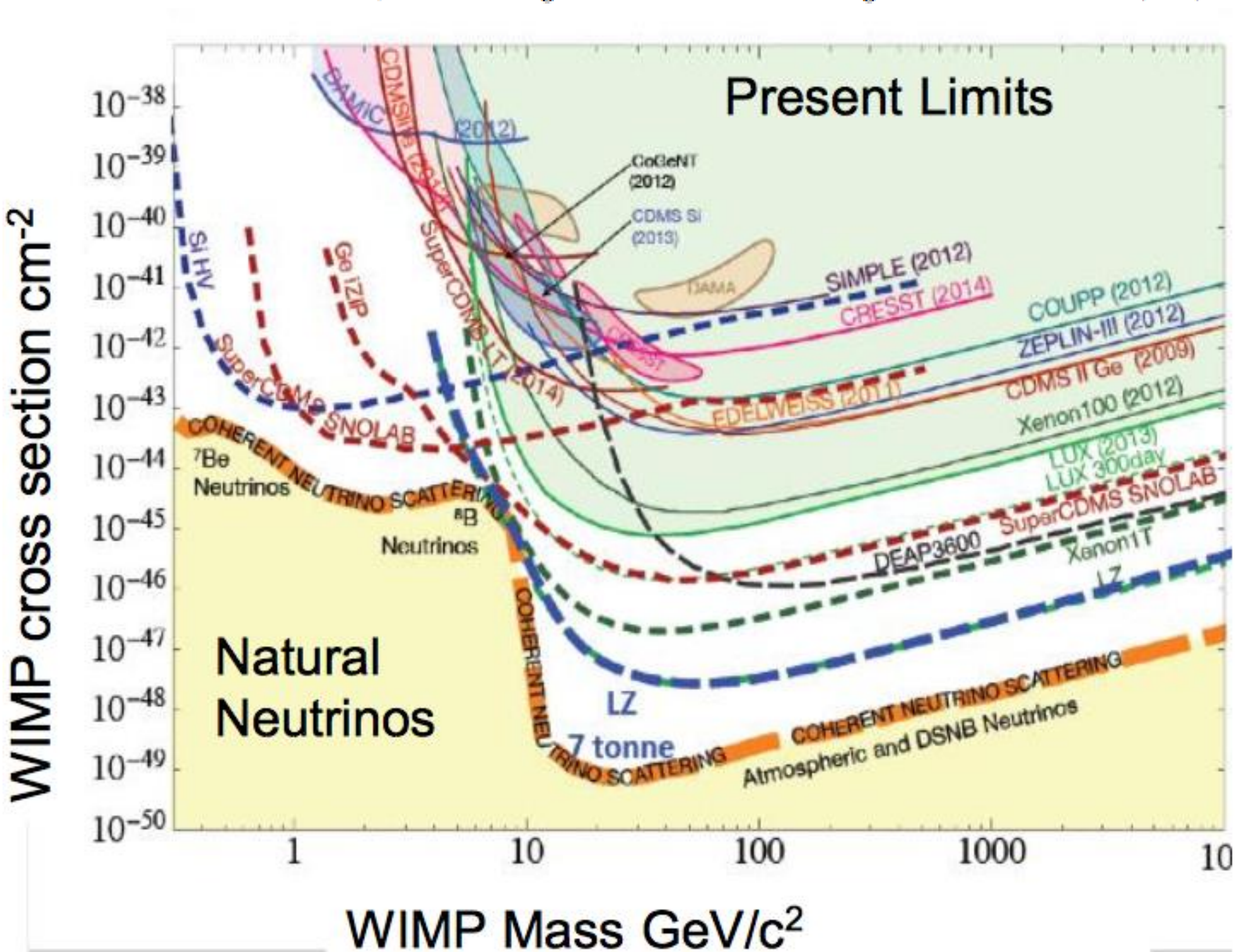


Talk by Phil Barbeau Fri morning plenary

Extras/backups

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

J. Billard, E. Figueroa-Feliciano, and L. Strigari, arXiv:1307.5458v2 (2013).



Understand nature of background (& detector response)

Neutron Backgrounds

Several background measurement campaigns have shown that Neutrino Alley is neutron-quiet