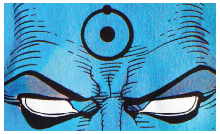
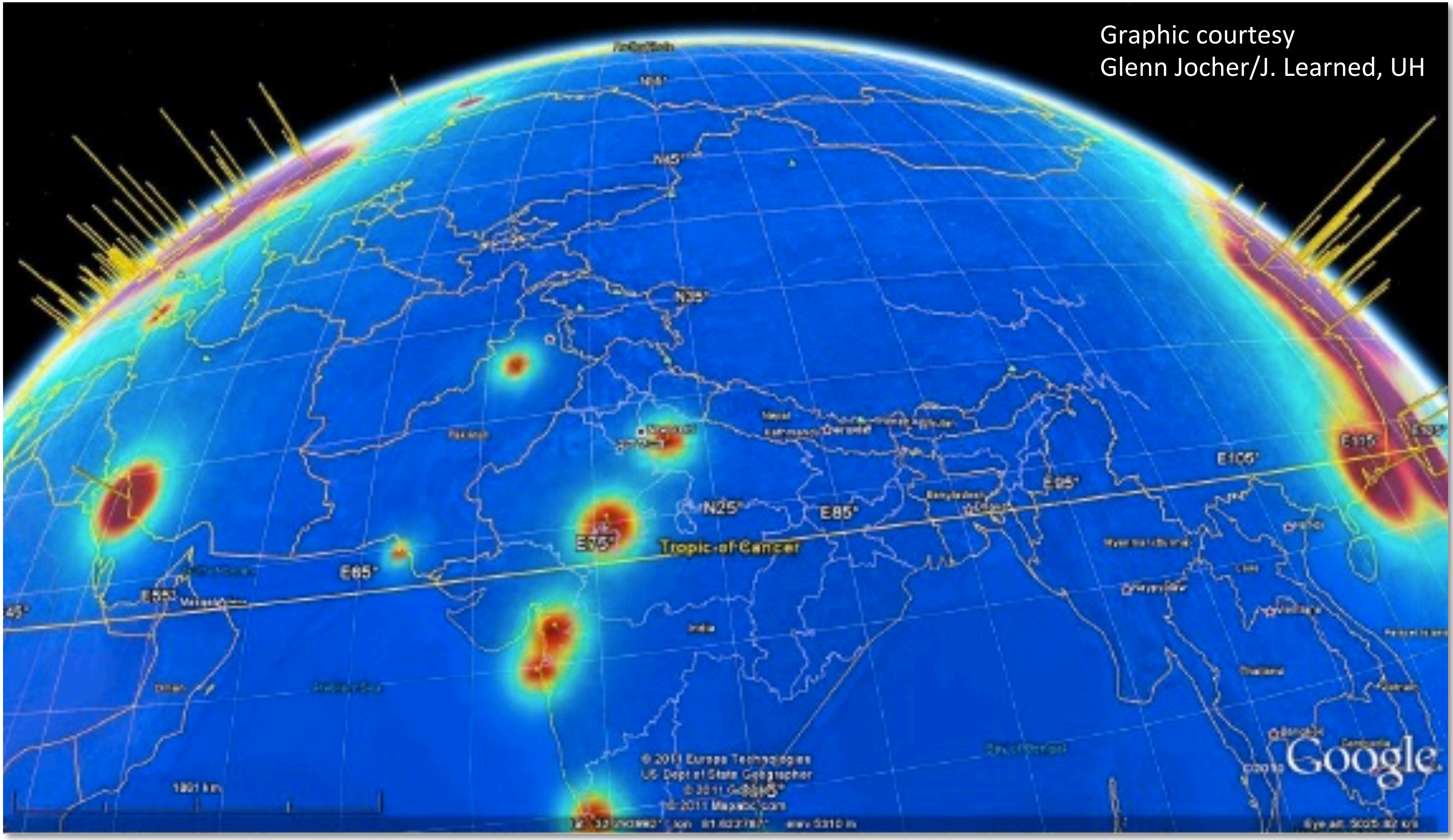
WATCHMAN

WATer CHerenkov Monitoring of Anti-Neutrinos

Marc Bergevin, UC Davis





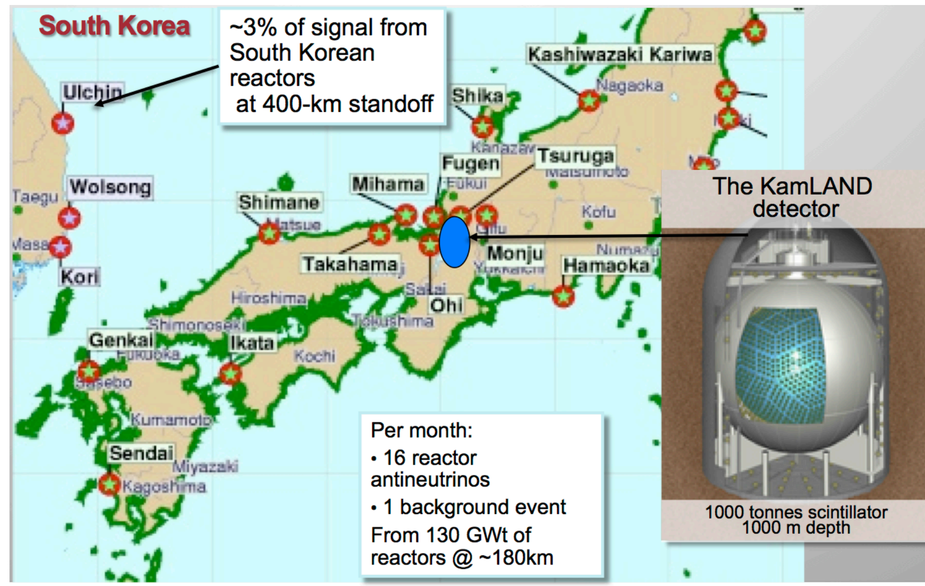
Graphic courtesy
Glenn Jocher/J. Learned, UH

Goal of WATCHMAN

Measure neutrino from low power reactors over large distances

- National Nuclear Security Agency strategic plan 2016 (DOE program): demonstrate remote reactor monitoring capabilities

- Megaton scale detectors are required for remote monitoring of 10 MWt reactors anti-neutrinos over 10^2 km distances (Water Cherenkov would be ideal)



Inverse beta event rates in a 1 Megaton detector	Reactor Thermal power (MWt)	Standoff distance (km)	Signal rate (per month)	background (non-reactor, per month)	Detection efficiency	Over-burden (mwe)	3 sigma significance
	10	400	1	0.5	50%	2000	1 year

Why water Cherenkov?

- Lower cost, safety and environmental consideration at Megaton scale

- Light propagation properties for a 1 Megaton option:

  - Attenuation length >100 m @ 400 nm *[This should be compared to the attenuation length of ~20 meter for LS]*

- Reactor anti-neutrino detection has not been demonstrated with water-based Cherenkov detector
  - Gadolinium has been proposed for Super-K and Hyper-K (also LBNE considered it prior to LAr decision)

WATCHMAN Collaboration

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P. Marleau, W. Hsu, , J. Goldsmith, S. Kiff, D. Reyna, C. Tewell	Sandia National Laboratories*
K. Van Bibber, R. Norman, K. Vetter, C. Roecker, J. Vujic, T. Shokair	UC Berkeley
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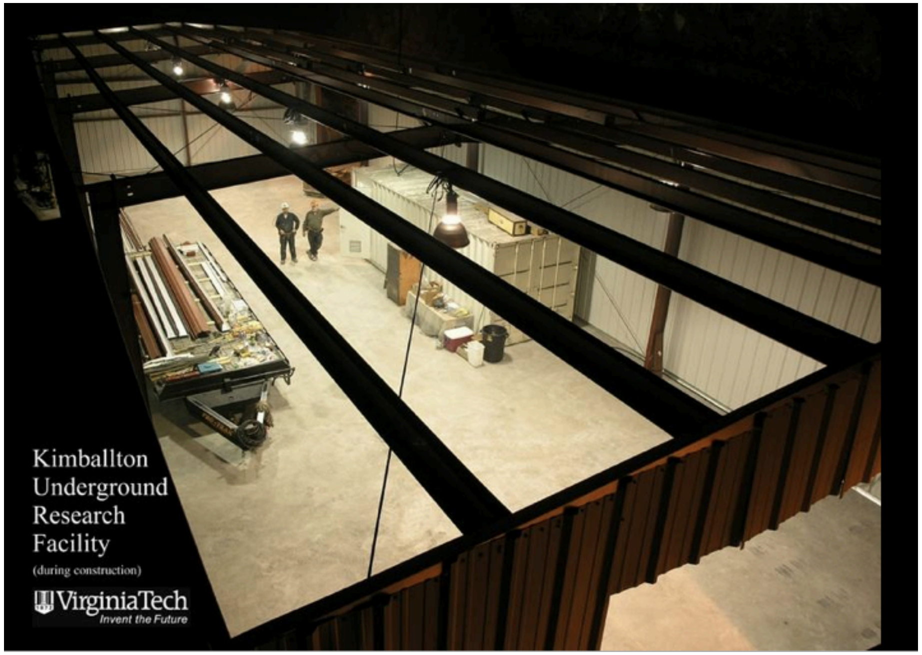
J. Learned, S. Dye , J. Maricic	University of Hawaii
M. Vagins	UC Irvine

*** Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000. SAND Number 2013-1563C**

Two-Phase Project Timeline

- Two intermediate phases to evaluate background and feasibility of technology
  - Phase I (funded, content of this talk):
    - Fast neutron assay at varying depth
    - Radionuclide production studies in water target
    - Deployment planned for June 2013 -2014 at KURF.
  - Phase II (proposed):
    - 1 kiloton water-based Cherenkov detector at 1 to 10 km standoff from a 0.1 to 10 GWt reactor.
    - Decision late 2014 to early 2015

Phase I : Measurement at KURF (Kimballton Underground Research Facility)

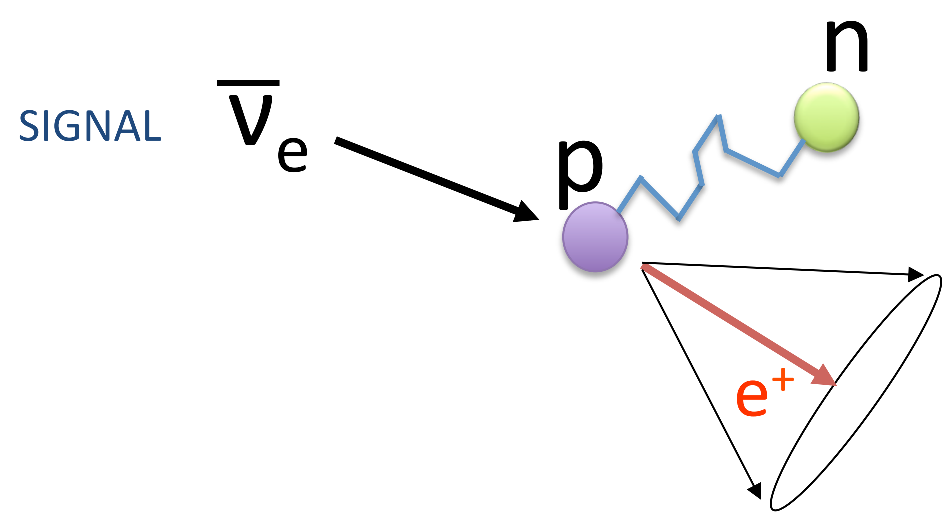


Background data will be acquired at a range of depths at KURF in 2013-2014.

KURF is an operating underground science facility operated by the Virginia Tech Neutrino Science Center.

Access to multiple depths 100 - 600 m.w.e.

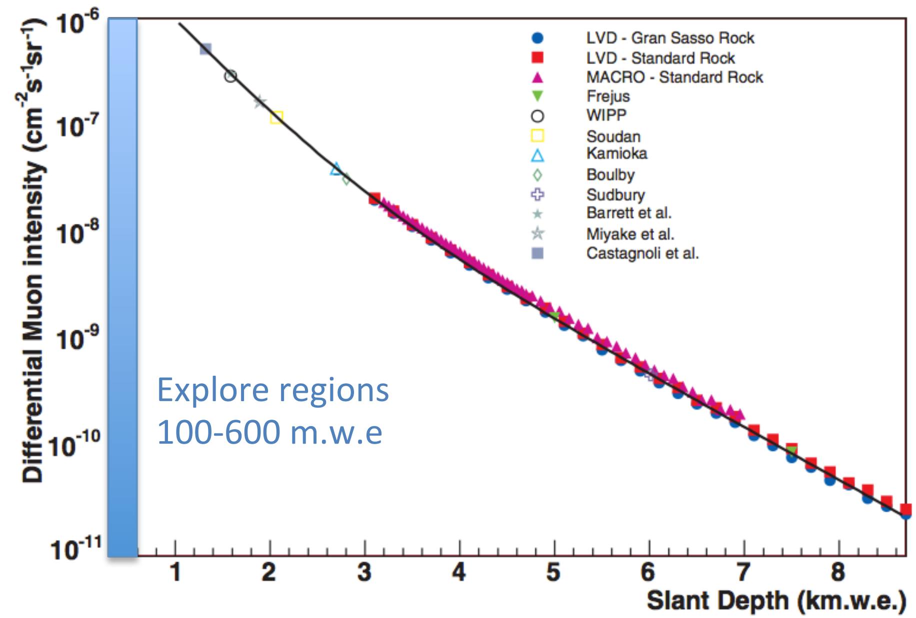
Note on signal and backgrounds



- The main backgrounds to anti-neutrino detection (positron-neutron pair), in the optic that one would like to go to shallow depths (for demonstrators):
  - Radionuclide production is not well measured in water and the production rate vary as a function of muon rate and energy
  - Fast neutrons signature will depend on the depth of detector

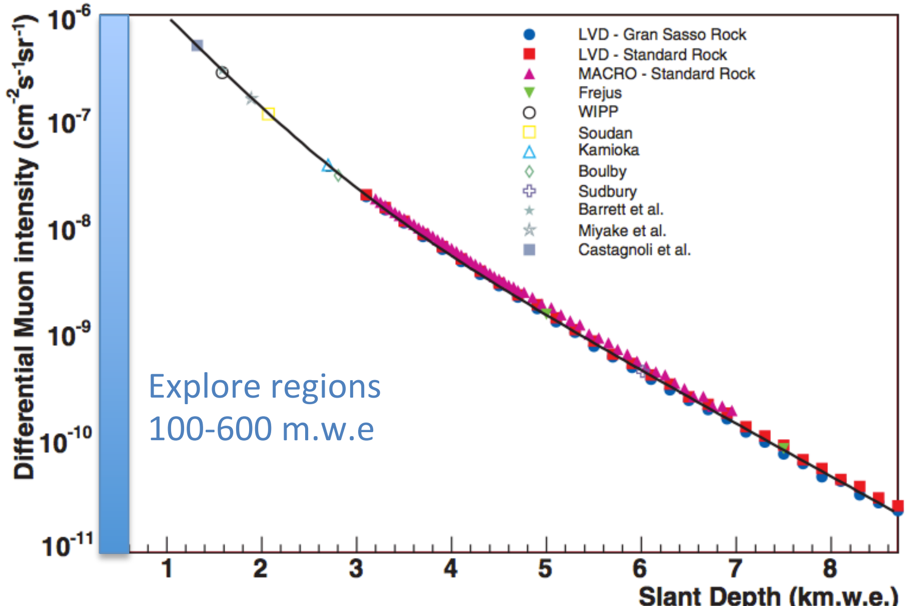
Muon related backgrounds at shallow depths

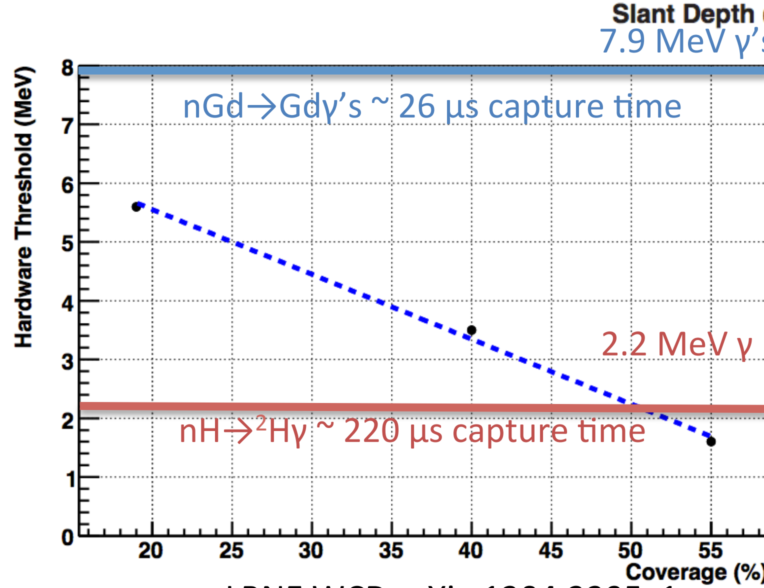
- Characterization of backgrounds to anti-neutrino detection (Pair of events):
  - ^{9}Li, other muon cosmogenics producing (β,n) experiment
  - Fast neutrons contamination coincident pair



Muon related backgrounds at shallow depths

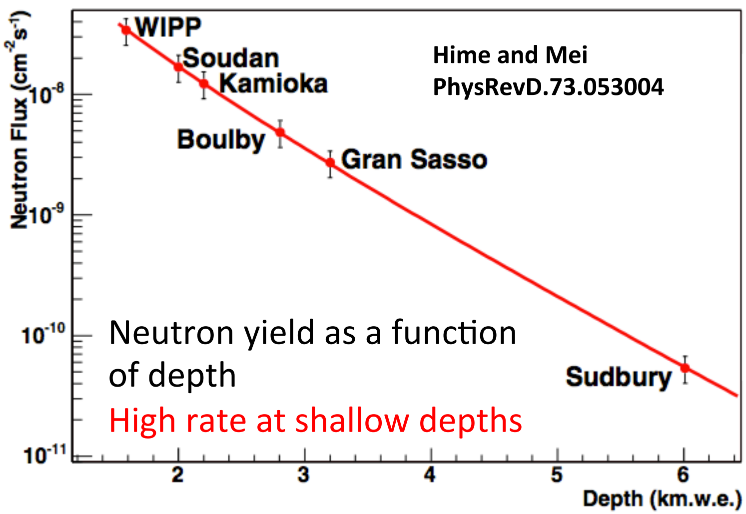
- Characterization of backgrounds to anti-neutrino detection (Pair of events):
  - ^{9}Li, other muon cosmogenics producing (β,n) experiment
  - Fast neutrons contamination coincident pair
- Do we understand radio-nuclide backgrounds in water detectors?
  - Super-K was not sensitive to neutron *[neutron capture on hydrogen (2.2 MeV) was below trigger threshold, these have since been measured with new electronics]*
  - SNO was sensitive to neutron capture for muon-related backgrounds, however large depth made these events very rare and easily removable with timing cut

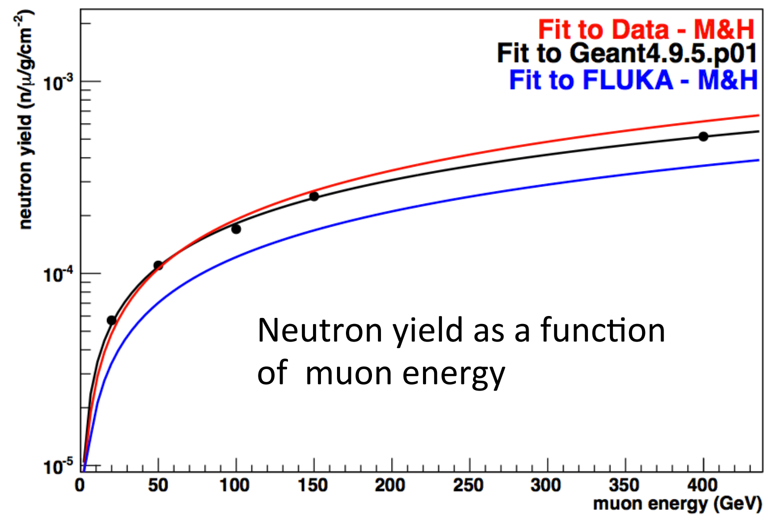




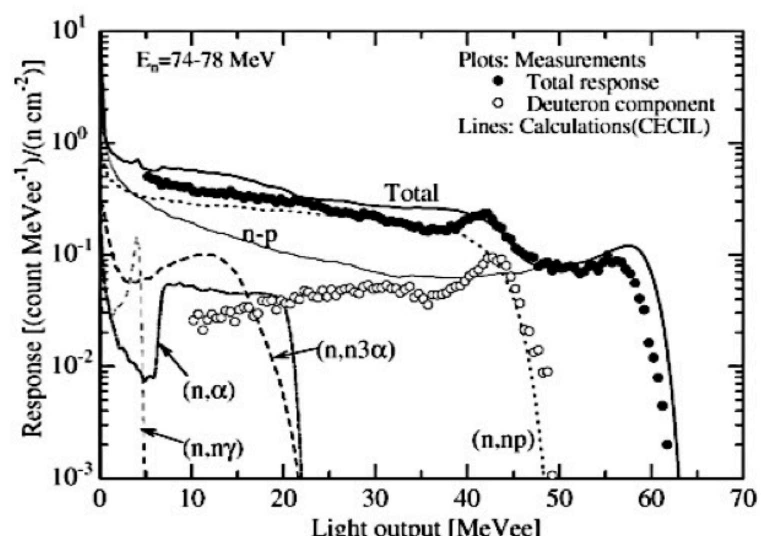
LBNE WCD arXiv:1204.2295v1

Why fast neutrons are a problem



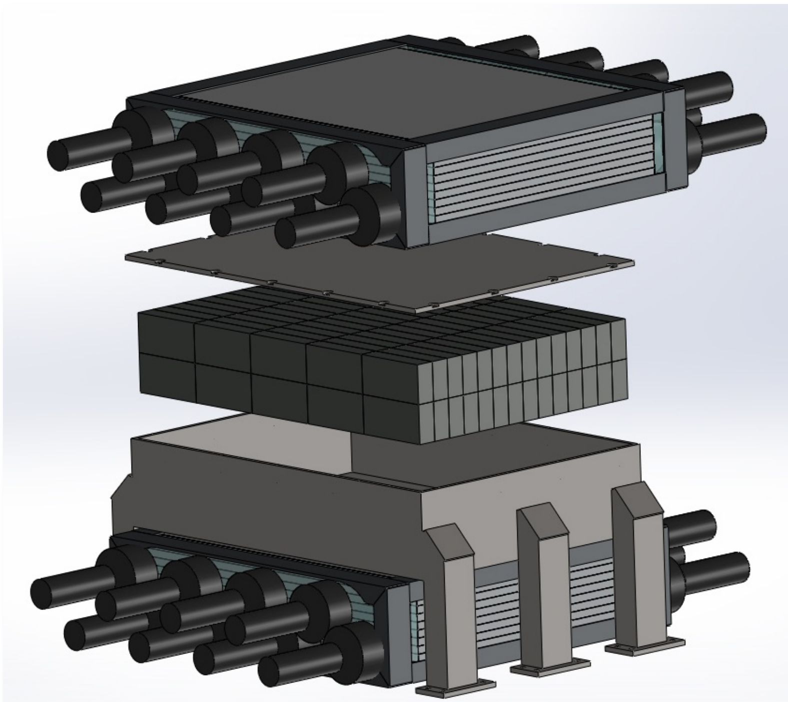


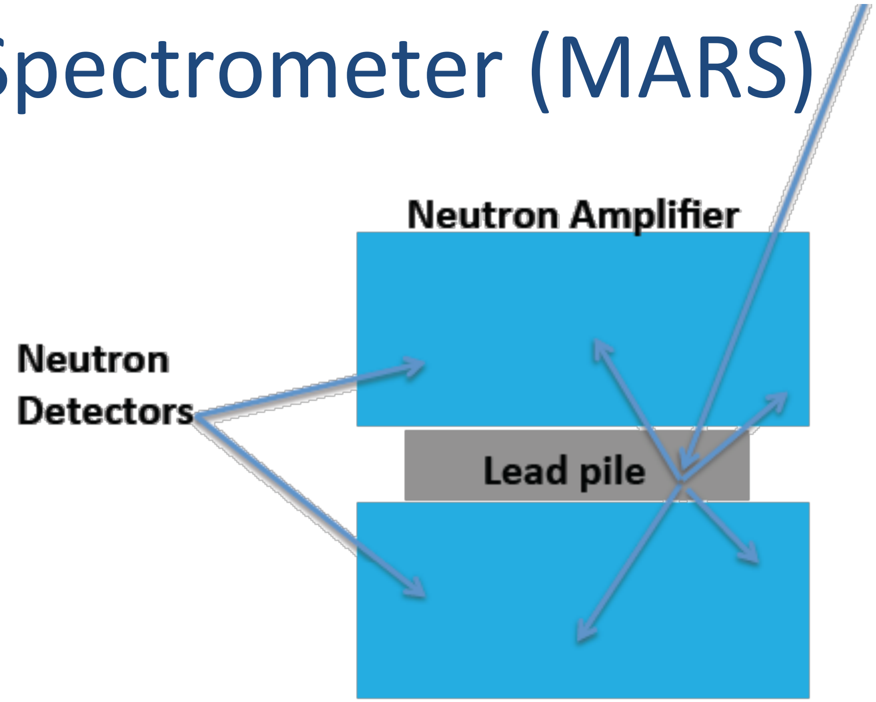
- A single fast neutron entering the detector can produce a multiplicity of particles
- A single fast neutron may also knock off a gamma creating a prompt-delay pair (bkgd)



N.Nakao et al, Nuclear Instruments and Methods in Physics Research A 463 (2001) p. 275.

Phase I: Fast Neutron detector Multiplier and Recoil Spectrometer (MARS)

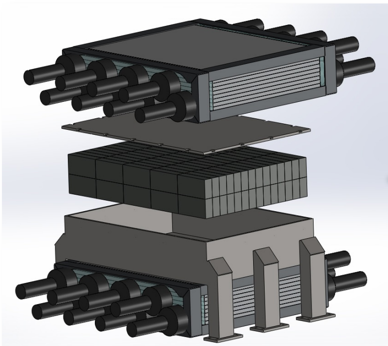


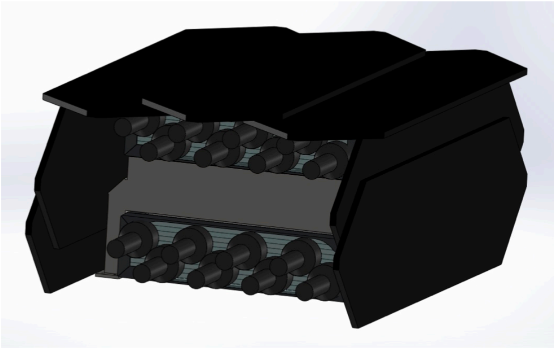


- Plastic scintillator/Gd doped paint detectors sandwich ~4 tons of lead.
- Direct interaction with scintillator for E < ~100 MeV.
- Neutron multiplication off of the lead for E > ~50 MeV.
- Expect 3000-5000 events per month at 100 m.w.e.

Set a flux at different depth and do relative measurements

Phase I: Fast Neutron detector (MARS) Deployment



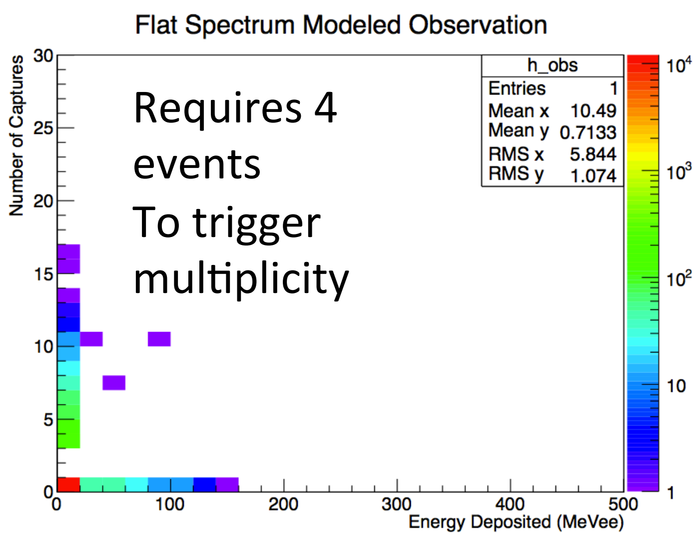


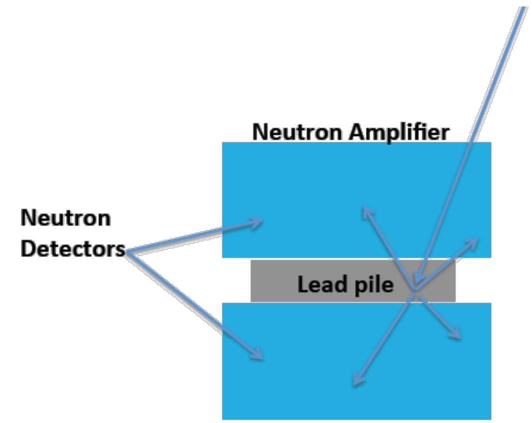
Timeline

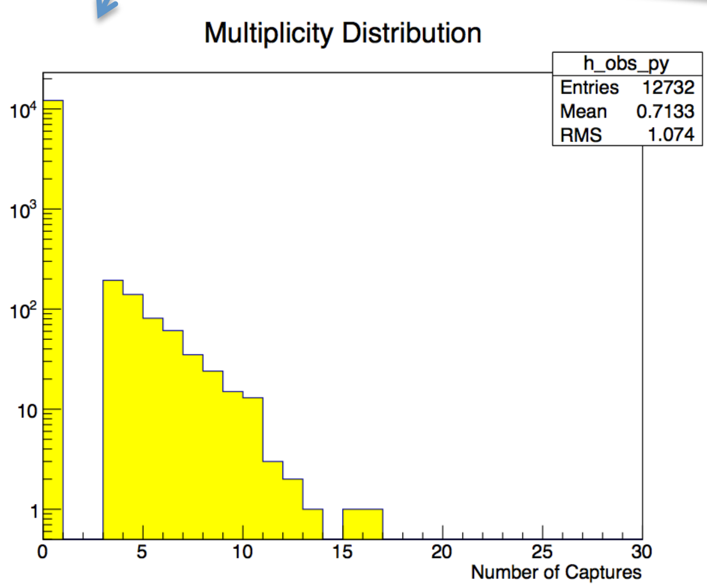
Starting in june:

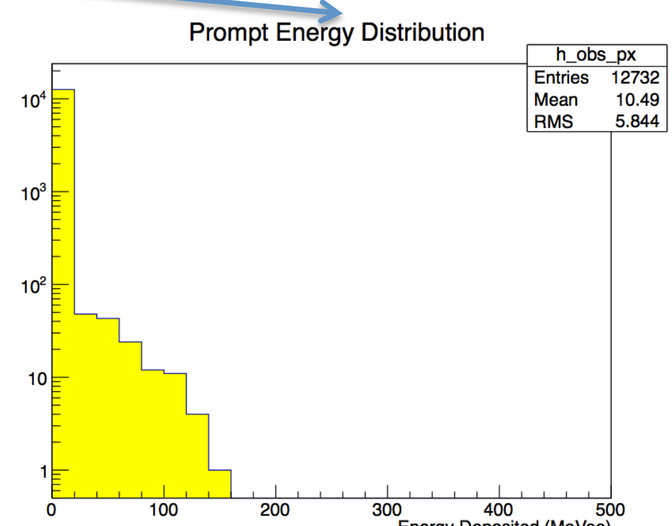
- 3 months at ~290 m.w.e.
- 3 months at ~375 m.w.e.
- 3-6 months at ~550 m.w.e.

Phase I: Fast Neutron detector (MARS) Simulation



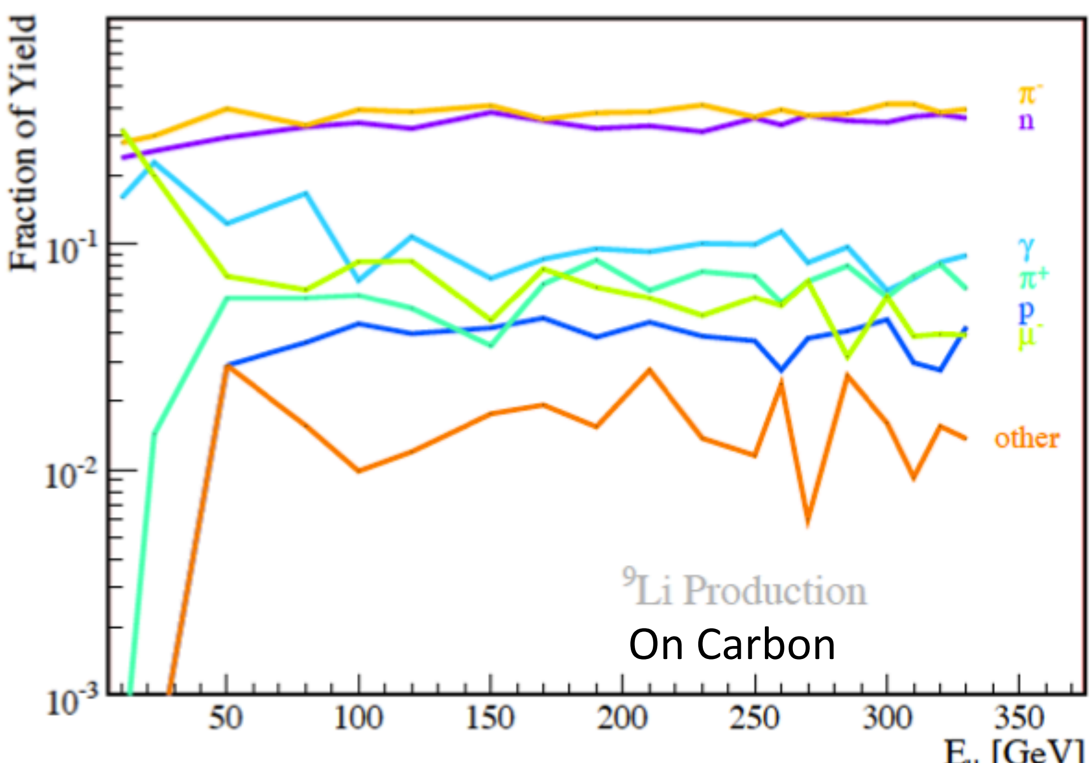






2nd experiment:
Radio-isotope background in water

Experiment to measure cosmogenics in water is underway. Various process can lead to specific radio-isotope production:



L. Winslow Ph.D. Thesis, University of California at Berkeley (2008)

2^{nd} experiment: Radio-isotope background in water

Experiment to measure cosmogenics in water is underway, especially β^{-}n production

Isotope	$\tau_{1/2}$ (s)	Mode	Q (B.R.)
Carbon			
^{9}C	0.127	β^{+}	16.5
^{15}C	2.45	β^{-}	9.77
^{16}C	0.747	β^{-}	8.01
		β^{-}n	(>98.8%)
^{17}C	0.193	β^{-}	13.2
		β^{-}n	(32.3%)
^{18}C	0.093	β^{-}	11.8
		β^{-}n	(28%)

Isotope	$\tau_{1/2}$ (s)	Mode	Q (B.R.)
Nitrogen			
^{12}N	0.011	β^{+}	17.3
^{16}N	7.13	β^{-}	10.4
^{17}N	4.17	β^{-}	8.6
		β^{-}n	(95.1%)
^{18}N	0.624	β^{-}	13.9
		β^{-}n	(14.3%)
Oxygen			
^{13}O	0.00858	β^{+}	17.7
^{14}O	70.6	β^{+}	5.14

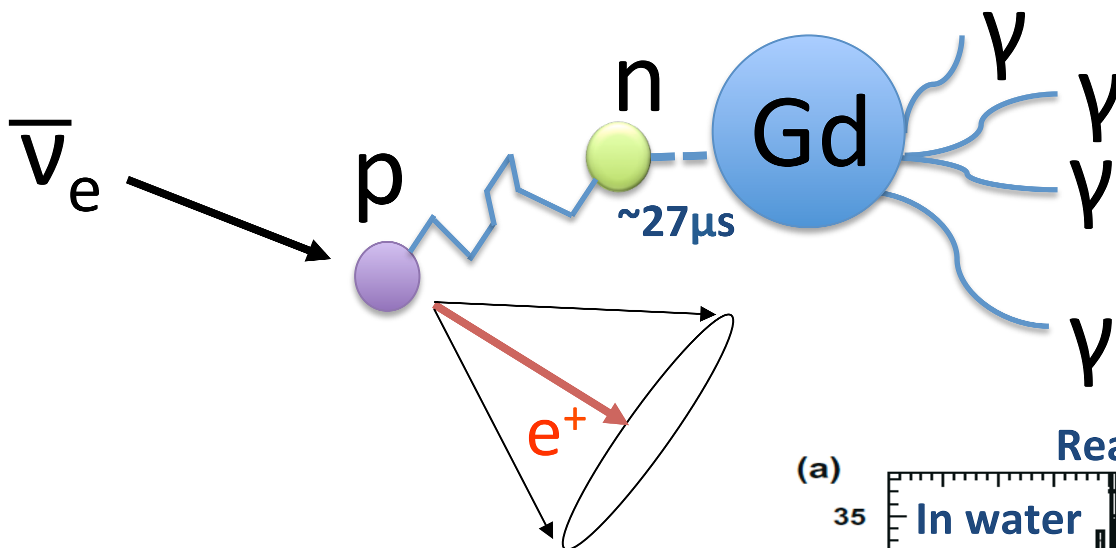
2nd experiment: Radio-isotope background in water

Experiment to measure cosmogenics in water is underway, especially β^-n production

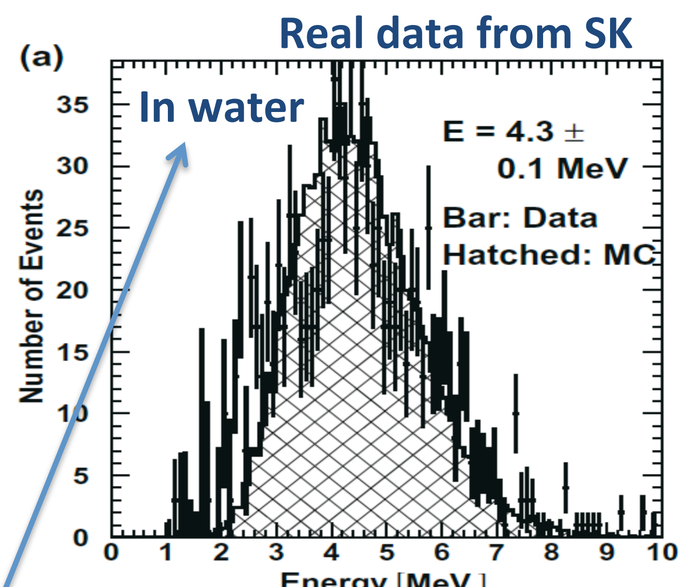
Isotope	$\tau_{1/2}$ (s)	Mode	Q (B.R.)
Helium			
^{8}He	0.119	β^-	10.6
		β^-n	(16%)
Lithium			
^{8}Li	0.838	β^-	16.0
^{9}Li	0.178	β^-	13.6
		β^-n	(49.5%)
^{11}Li	0.00875	β^-	20.6
		β^-n	(85%)
		β^-2n	(4.1%)
		β^-2n2α	(1.9%)
		β^-nα	(0.9%)

Isotope	$\tau_{1/2}$ (s)	Mode	Q (B.R.)
Beryllium			
^{11}Be	13.8	β^-	11.5
		$\beta^-\alpha$	(3.1%)
^{12}Be	0.0236	β^-	11.7
^{14}Be	0.0043	β^-	16.2
Boron			
^{8}B	0.77	β^+	18.0
^{12}B	0.0202	β^-	13.4
^{13}B	0.0174	β^-	13.4
		β^-n	(0.25%)
^{14}B	0.0138	β^+	20.6
^{15}B	0.0105	β^-	19.1

Quick reminder before proceeding: Gd-doping to detect neutrons



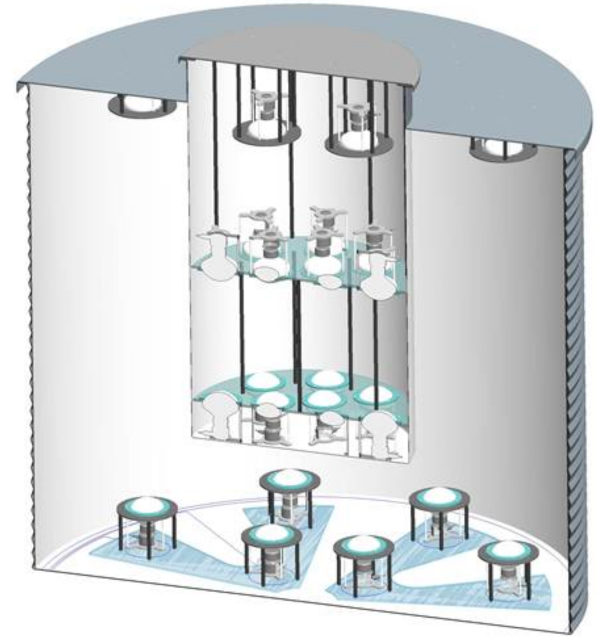
- Gadolinium enables neutron detection
- Release of total 8.0 MeV of γ's delayed by ~27μs
- Already proven in liquid scintillator
- R&D underway for Gadolinium sulfate and filtration for EGADS will be key for the water Cherenkov development (M. Vagins)



Letter of Intent:

The Hyper-Kamiokande Experiment — Detector Design and Physics Potential — arxiv.1109.3262v1

Radio-isotope production Detector



Properties

- 3.5x3.5 meter detector
- 1.5x1.5 meter active inner volume.
- 0.1% Gd doping.
- Depth chosen as to produce a muon rate of 1 Hz within the inner volume of the detector

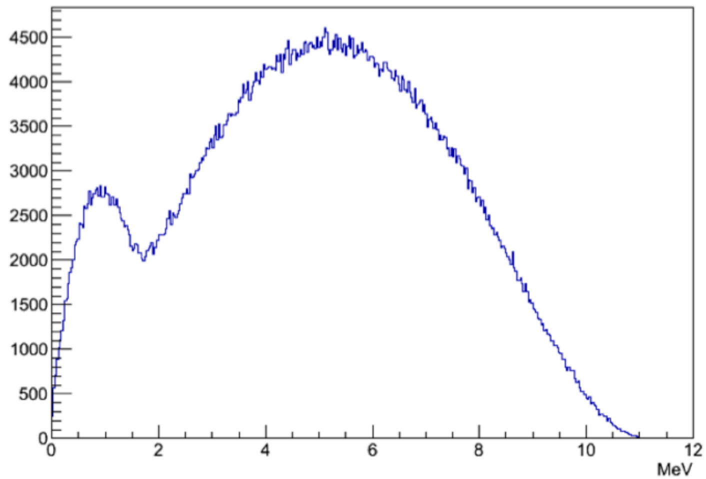
Timeline

Startining in june:

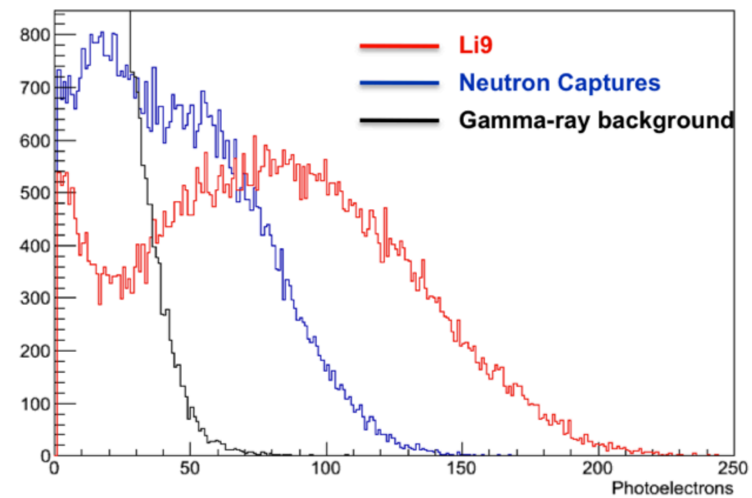
- One year at 300 m.w.e..

Radio-isotope production Simulation

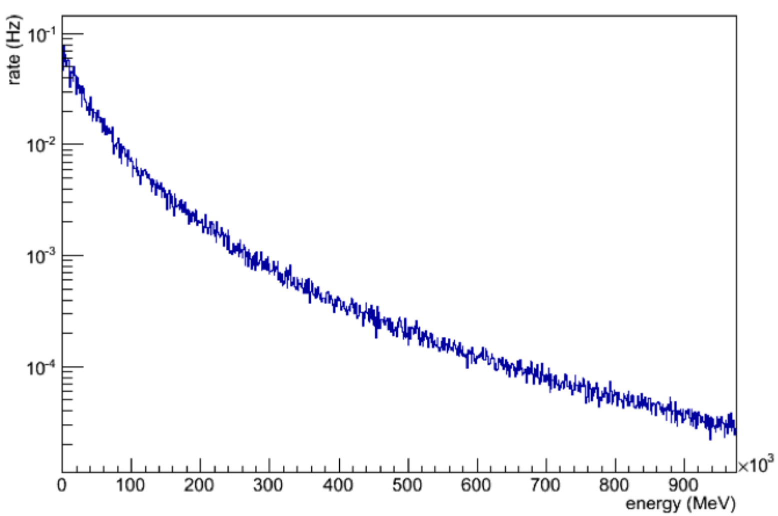
Theoretical 9Li Spectrum

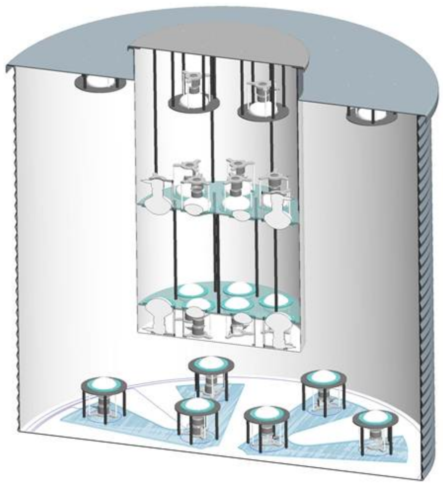


Above Ground 1-tonne Detector Response



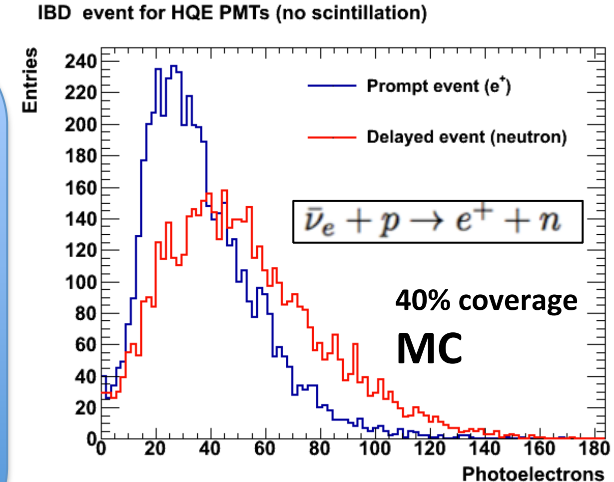
Muons @ 300 mwe





Quick word on Phase II
WATCHMAN – LAND OPTION

- 1 kiloton water-based Cherenkov detector
- 1 to 10 km standoff at 0.1 to 10 GWt reactor
- Light collection choice and detector improvement under review
- Science review this Fall, collaborator welcomed
- Decision late 2014 to early 2015



Lawrence Livermore National Laboratory

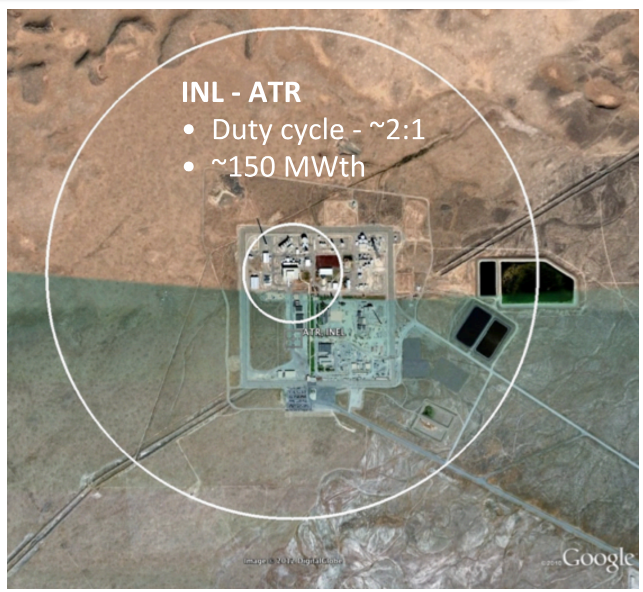
Sandia National Laboratories

UC Berkeley

UC Davis

University of Hawaii

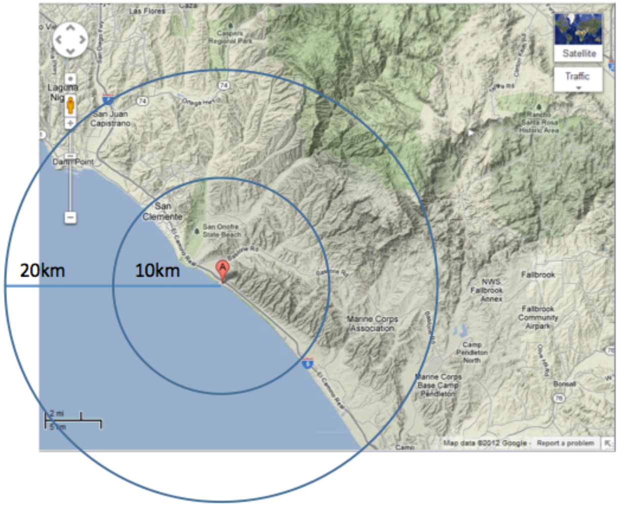
UC Irvine

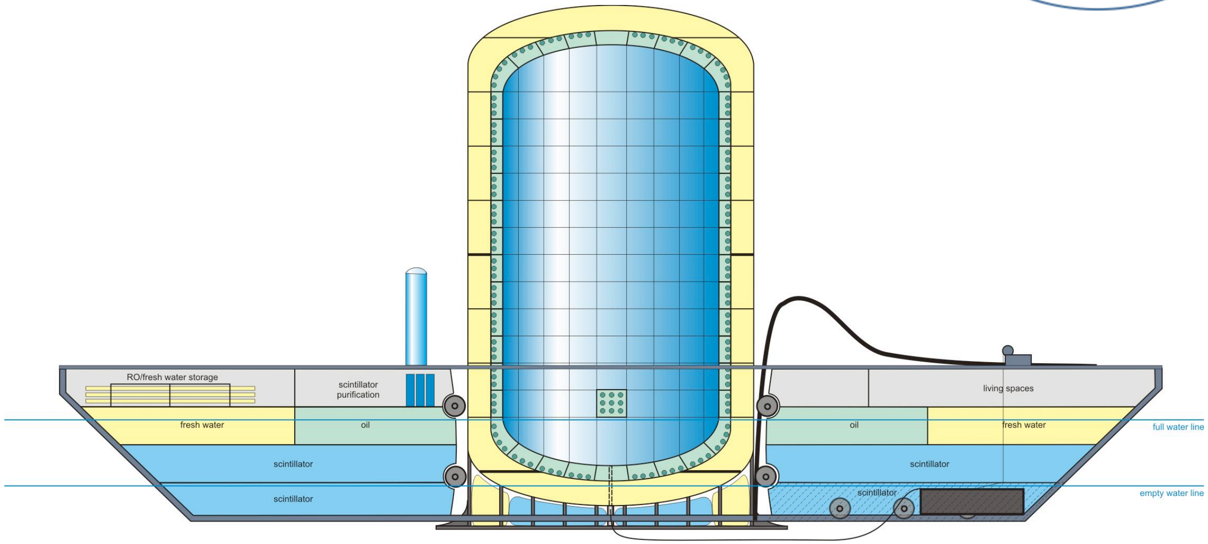


Quick word on Phase II
WATCHMAN – SEA OPTION

- Off the coast-line from an active reactor (SONGS is still un-operational, but would make a good candidate)
- Next to a submarine (50~80 MWth reactor)

SONGS Topography





Hanohano style detector

Summary

- Deployment campaign is underway: Data-taking will start in June for both detectors (MARS and radio-nuclide detector)

- Survey of site with muon paddle are currently underway, confirming early estimates of muon rates

- Experiments will provide results on fast neutron production at shallow depth and cosmogenic production in water at shallow depths

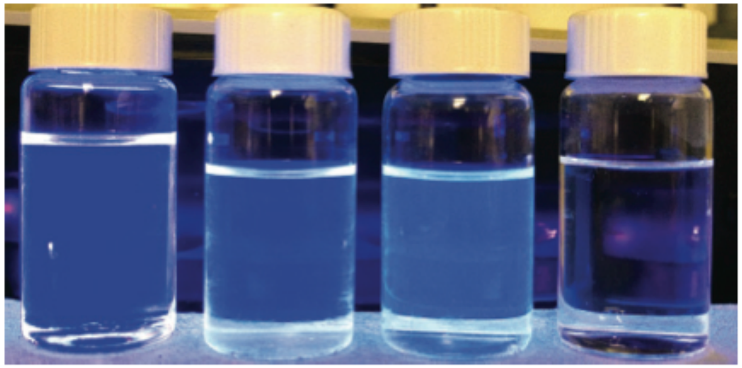
EXTRA: Phase II
How to improve water-based detectors

- Option I : Light collection improvements and what can be learned from a water R&D perspective (which is wrapping up):
  - High quantum efficiency PMTs
  - Winston cones
  - wavelength shifter plates
  - wavelength shifter films
  - Large Area Picosecond Photo-Detectors

- Option II : Light output improvements
  - Gd water loading R&D
  - Water-based scintillator

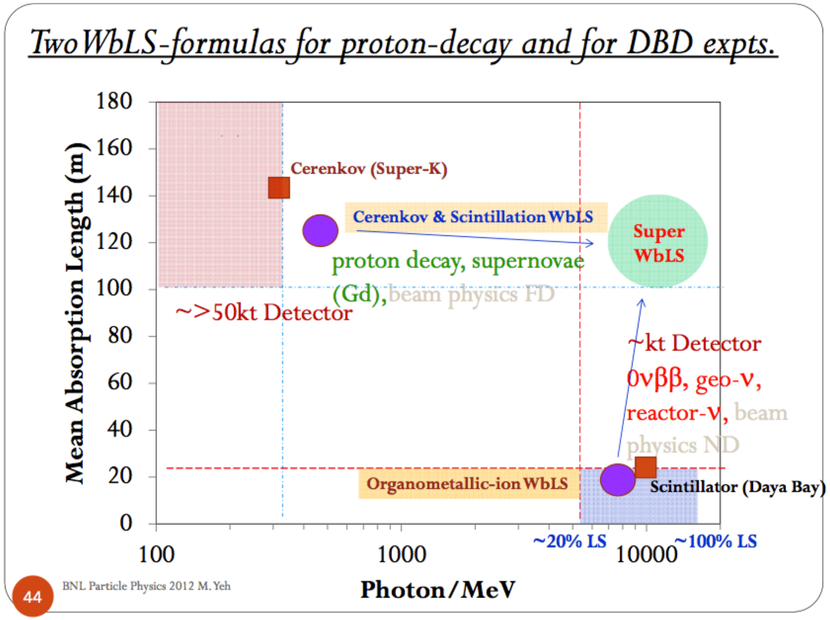
EXTRA: Investigating water-based liquid scintillation wbLS

- Ongoing research in mixing oil and water. Surfactant is necessary to emulsify (or aggregate) organic liquid scintillator into the water solvent.
- Surfactant: Linear Alkylbenzene Sulfonic acid (LAS) used
- A stable, first-generation, WbLS with sufficient scintillation light has been developed at BNL



LS WbLS(1) WbLS(2) Water
with UV illumination

- **Goals/challenges :**
  - measure below Cherenkov threshold
  - keep track information
  - Improve energy resolution



Benefits of and progress towards massive water-based liquid scintillator detectors, David E. Jaffe, HYPER-K, 22-23 August 2012