Detector Depth Issues

International Workshop on a Far Detector in Korea

for the J-PARC Neutrino Beam

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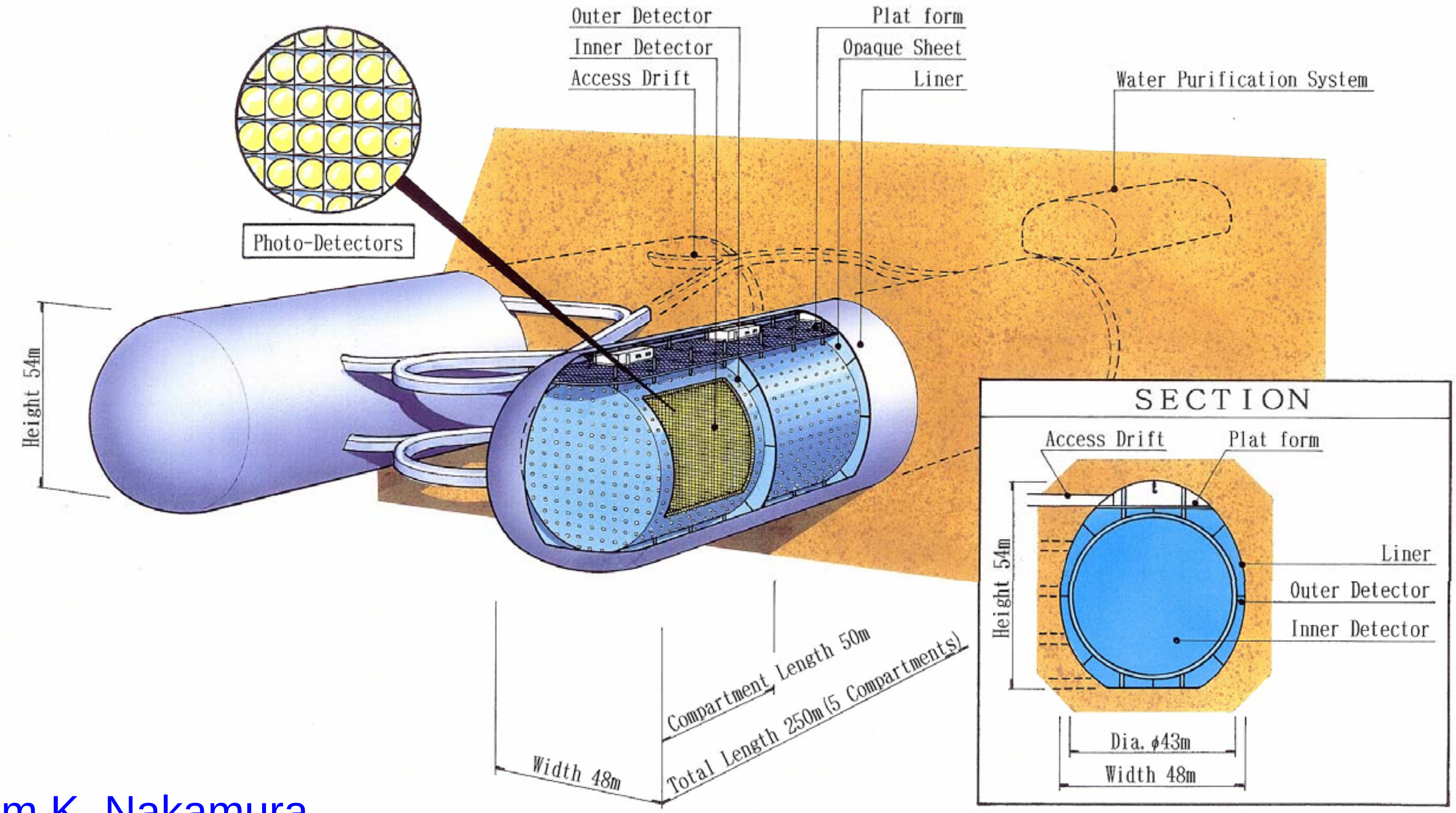
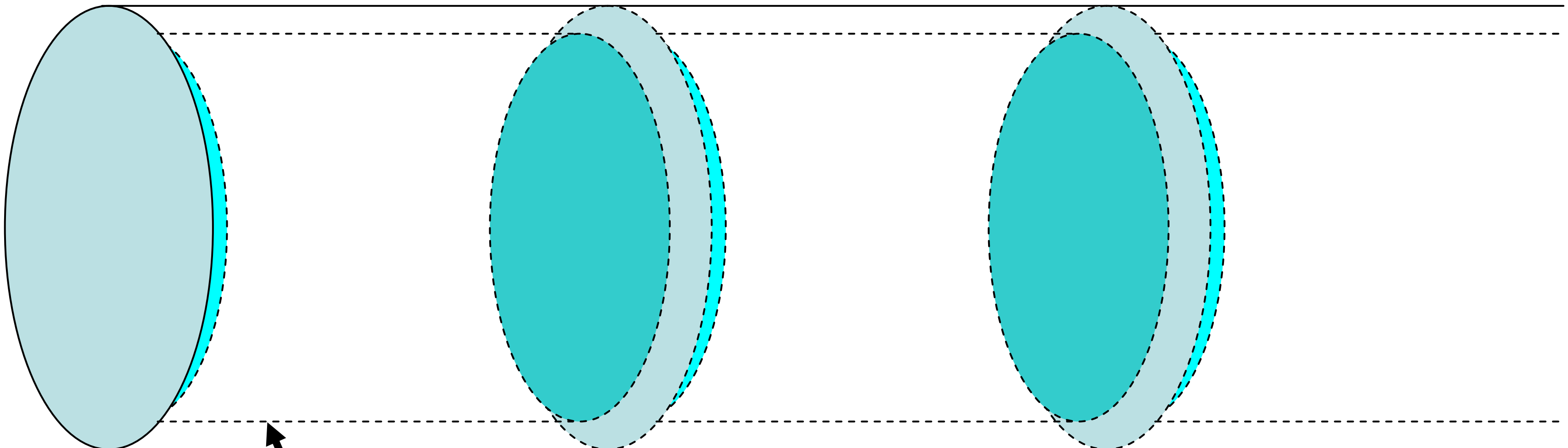
Assume Module With Hyper-Kamiokande Geometry

~1 Mton total in two x 250m detectors



From K. Nakamura

Sub-module Geometry



Assume optical separation & independence of sections

One section inner = 43mφ×49m

5 section fudical mass = .27 Mton

From K. Nakamura

Other Physics with Megaton Detector

- High Energy Events
  - Proton decay $e^+\pi^0$, νK^+, …
  - Atmospheric neutrinos
  - Neutrino oscillation measurements
- Low-energy Events
  - Solar neutrinos
  - Supernova neutrinos
  - Relic supernova neutrinos
  - Reactor neutrinos?

Proton Decay

As minimal first step lets say we don't want to be looking for PDK or any fully contained event while a muon is crossing the volume…

- Detector sub-module area ~ 43m x 49m
- Solid angle ~2π
- Crossing time ~ $0.4\mu s$ x 2 (reflection)

Take 70m/21.6 cm/ns

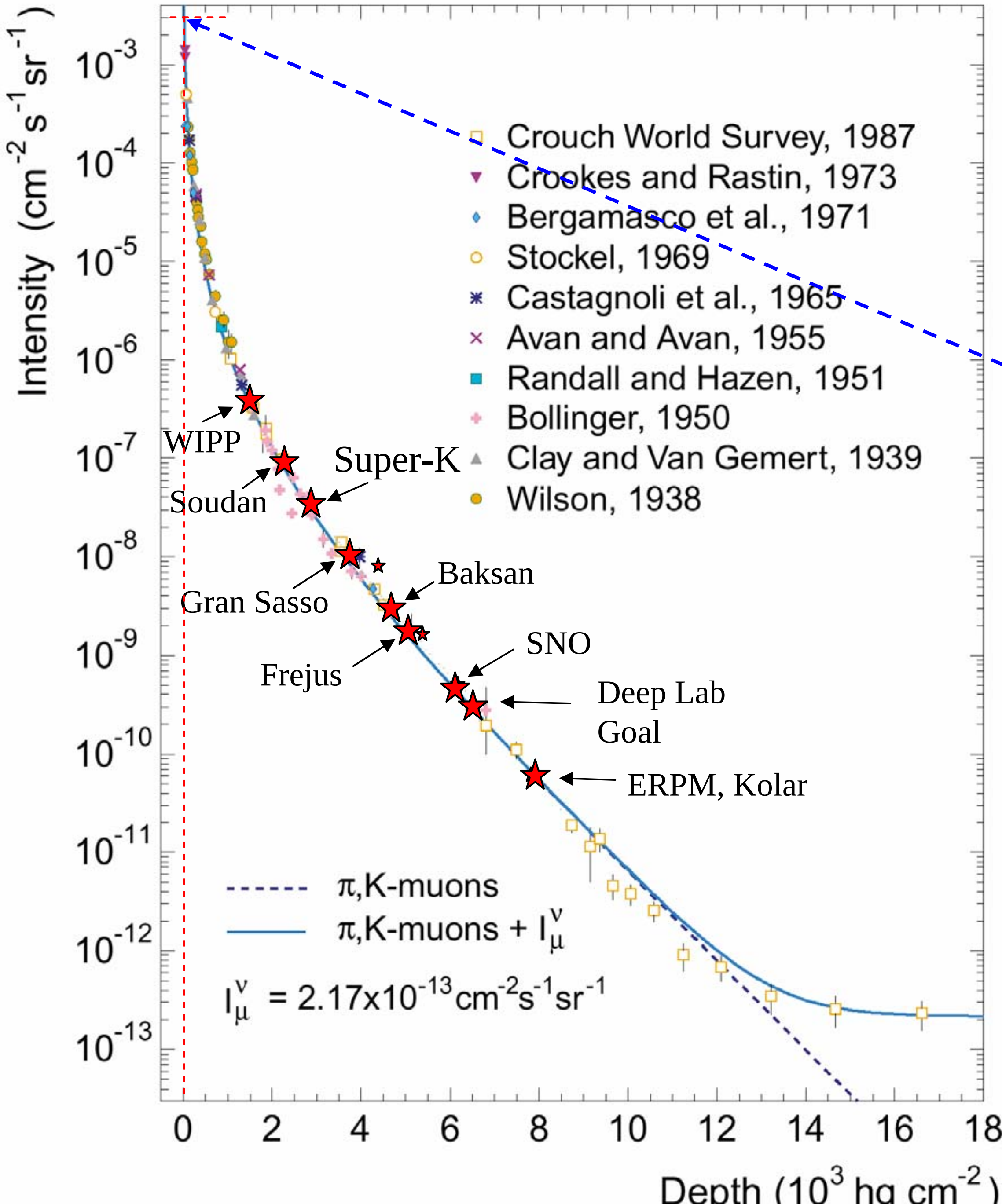
~ 125 cm^2 sr sec

Veto all muon crossings ➡ Dead time = ϕ_μ x 125 cm^2 sr sec

Let's say we want dead time to be < 20% (~SK present value)

➡ $\phi_\mu < 1.6 \times 10^{-3}\ cm^{-2}\ sr^{-1}\ s^{-1}$

Depth-Intensity Data



$\phi_\mu < 1.6 \times 10^{-3}$ cm^{-2} sr^{-1} s^{-1}

Shallow depth OK for this constraint…

Additional Constraints –($^{16}O \rightarrow ^{15}N^* + \nu K^+$)
Say look for 6 MeV gamma (νK^+)

Spallation: assume 1- 5 spallations per muon

$\phi_S < 5\ \phi_\mu \times (43 \times 48 m^2) \times 2\pi \sim 1.0 \times 10^6\ s^{-1}$

This has to be within ~30ns of a candidate.

If ϕ_C is candidate rate then:

$\phi_S \times 20ns \times \phi_C \sim 0.03\ \phi_C$

i.e. less than 3% of candidates will have accidental coincidence with a spallation event – further, not every spallation event will make 6 MeV worth of Cherenkov photons…so no problem.

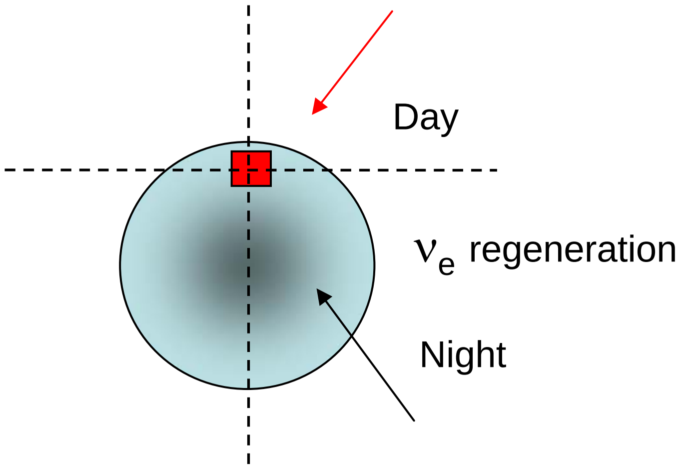
Other Backgrounds

- Muons which miss detector
  - High energy neutrons
- Go by example…IMB operated without visible entering background at 1600 mwe
- Probably could go some what shallower
- Muon rate from 1600 mwe to 800 mwe increases by factor of ~10…probably ~limit, but needs more careful work.

Solar Neutrinos

Goal for next detector:

- More statistics to observe D/N asymmetry.



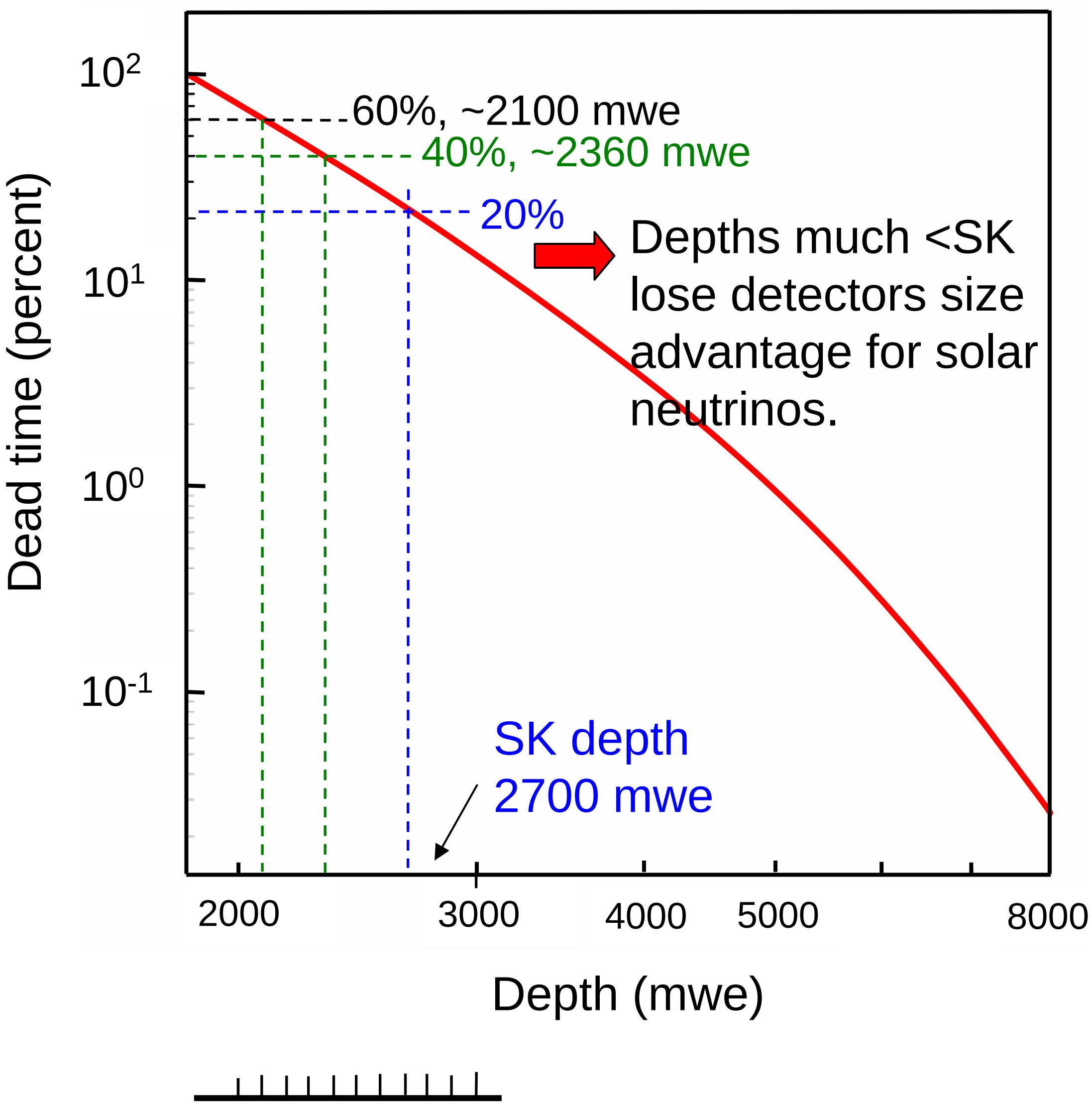
- More statistics/low threshold to see transition to vacuum region.

Survival probability for neutrinos <1 MeV ~58% (averaged vacuum oscillations)
For neutrinos >10 MeV ~30% (complete MSW resonance).
Transition occurs ~ 3 MeV ➡ distortion of the recoil spectrum

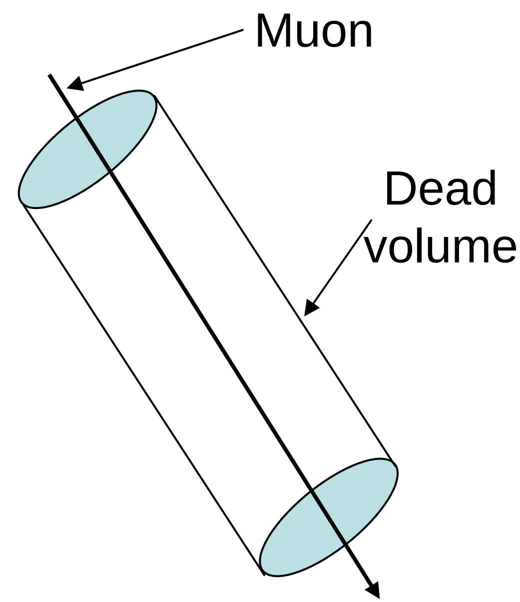
Solar Neutrinos

- Given current value of Δm^2_{12} from KamLand we expect about 1.5% D/N asymmetry.
- Let's say we want a minimum 3σ observation i.e. our total error must be < 0.5%
- With SK we achieved 1.6% stat error in 5 years real time. (systematic error is over-estimated at ~1.1% currently).
- Say we want 0.5% statistical error ➡ ~x10 exposure.
- Module of Megaton detector can achieve this IF dead time is comparable to present SK value ~ 20%.
- Similar argument for spectrum statistics…

Spallation-Induced Dead Time vs. Depth in Super-K et.al.



To first order, spallation % dead time is independent of detector size – volume effect



Effects from stopping muons imply somewhat larger dead time for larger detectors – ignore here

Supernovae

Are low energy spallation events a background for SN observation?:

Take SN at 10 kpc ➡ 112,000 SN events over 10 seconds in 360 Mtons.

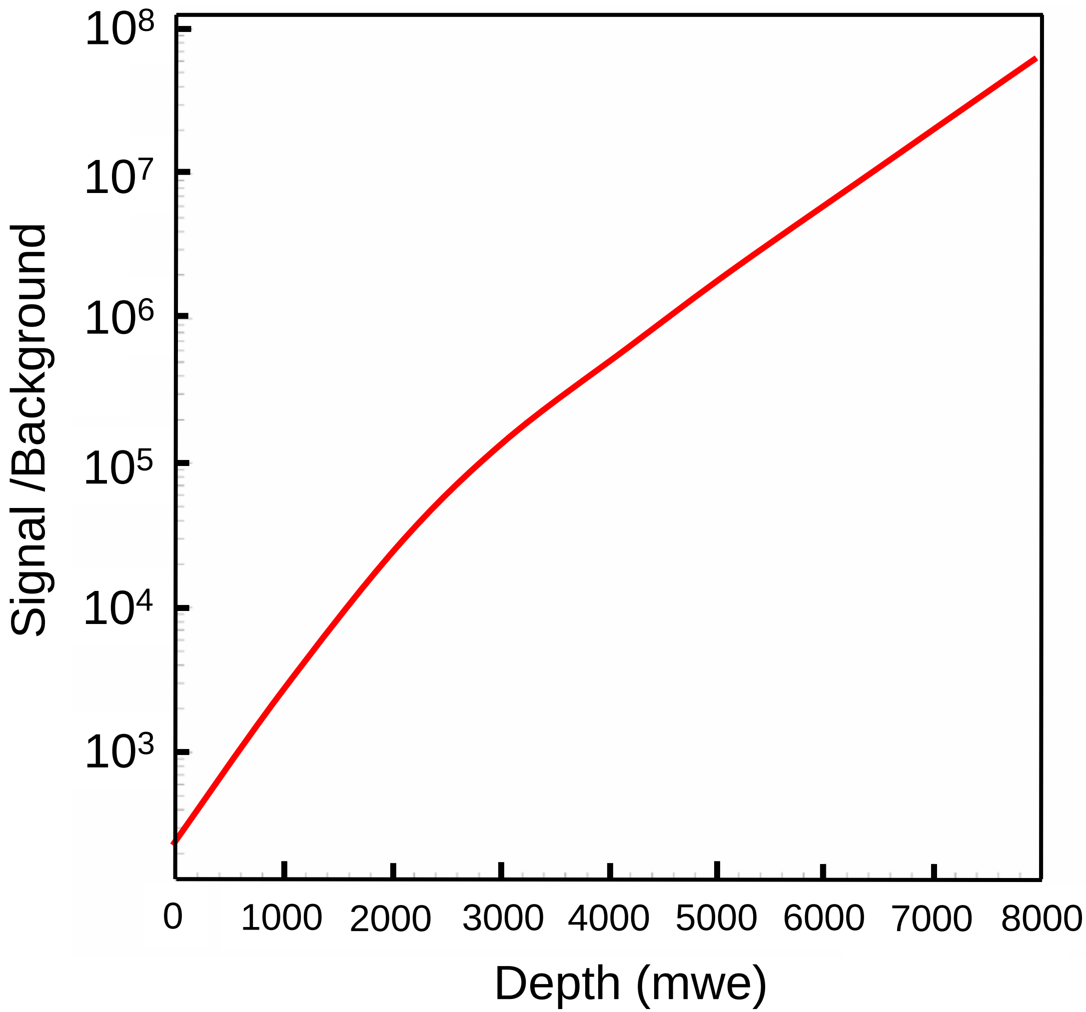
At SK depth, ~0.4 Mton detector has ~1 spallation event every 6 seconds.

So, Signal (SN) = 11,200 s^{-1}

Background (Spallation) = 1.7×10^{-1} s^{-1}

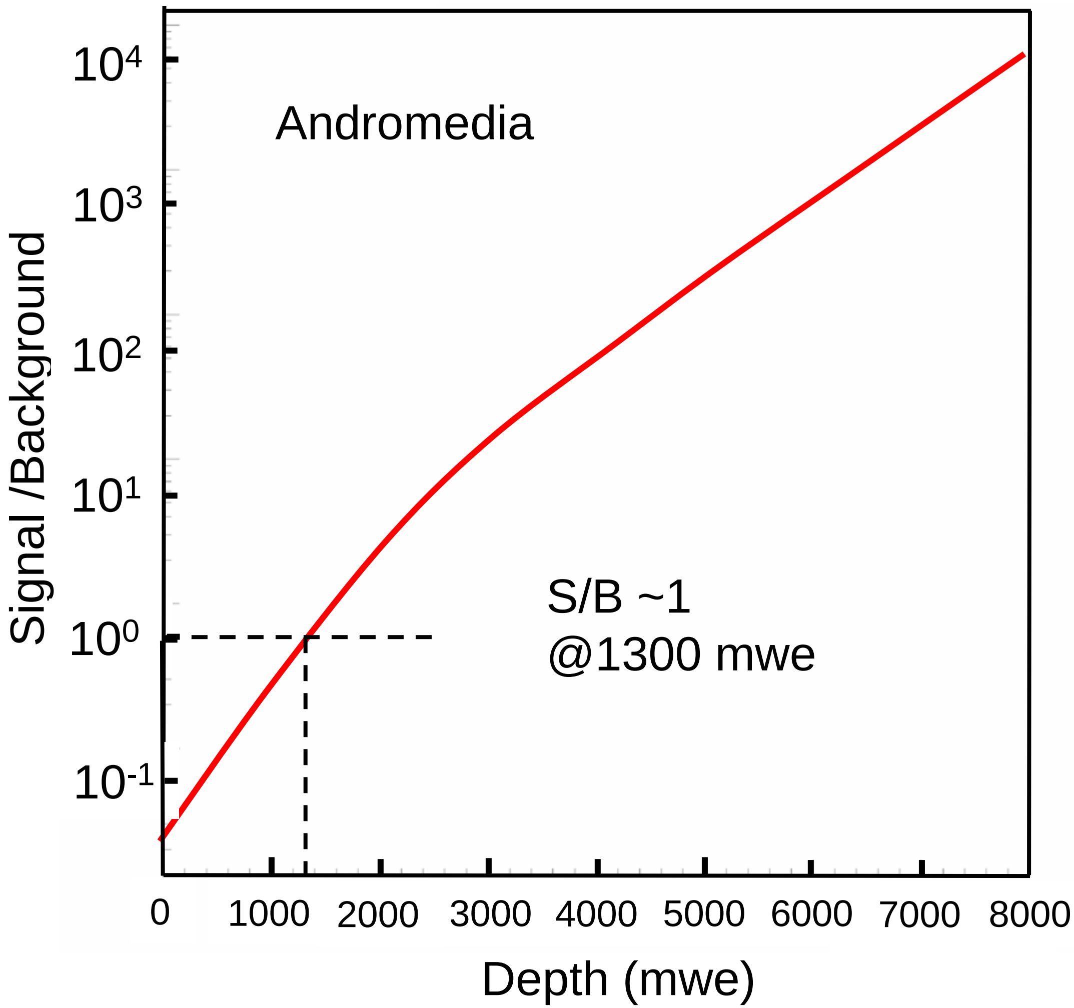
➡ No problem at SK depth

SN Signal/Background vs. Depth (assuming SN at 10 kpc)



Still usable for SN detection at very shallow depths

More Distant Events…

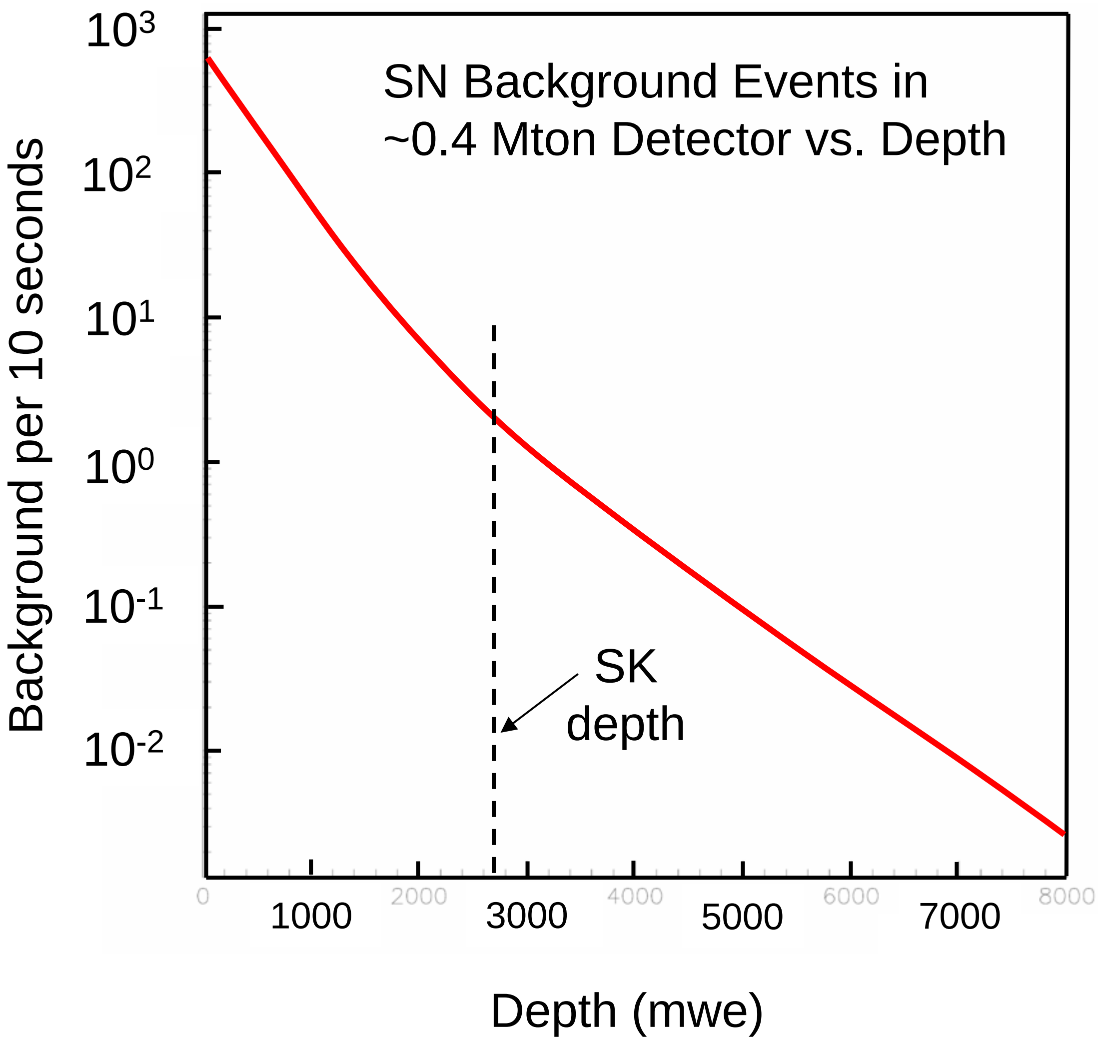


Andromedia ~ 2.5×10^6 ly
10 kpc ~ 3.3×10^4 ly

➡ factor of ~75 in distance
➡ factor of ~6×10^3 in rate

i.e ~20 events in 10 sec.

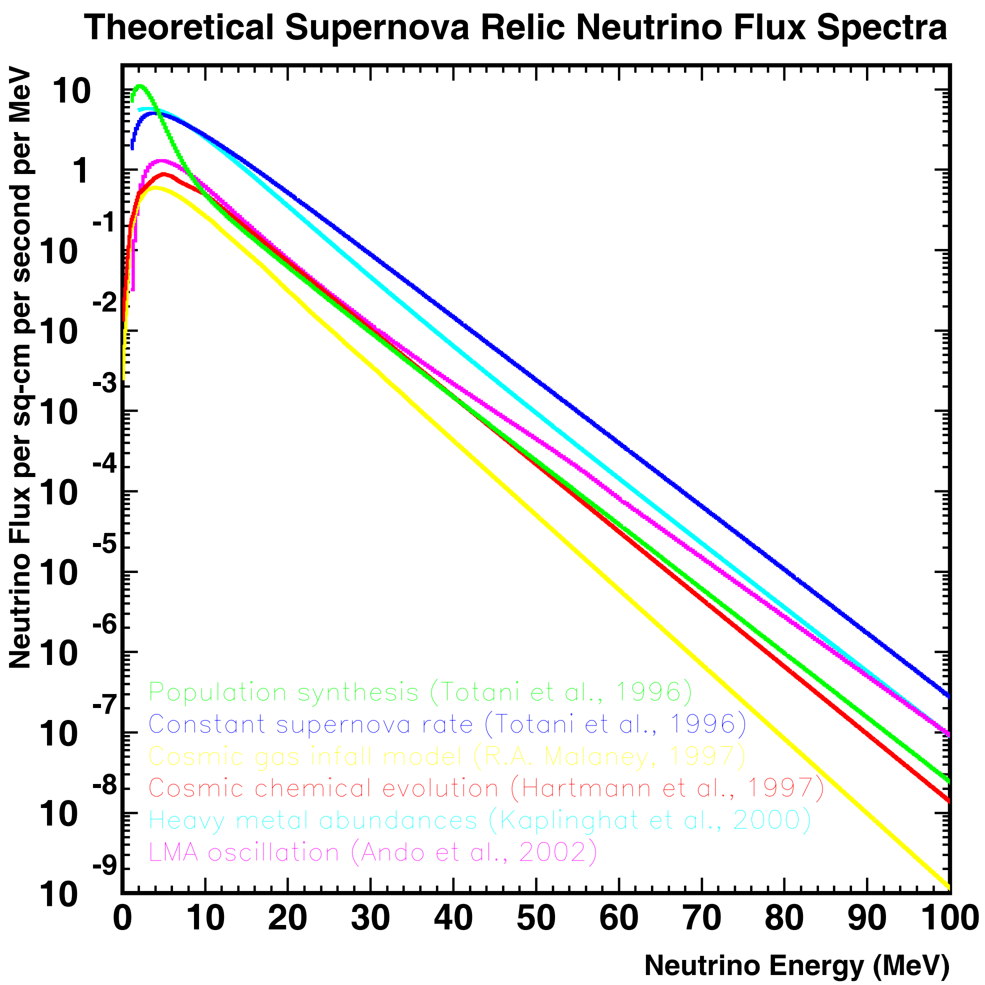
Delayed Neutrinos From SN



Detector Depth (mwe)	Background Rate (Hz)	Time (sec) After SN When S/B =1
200	40	22
500	22	24
1000	6.0	28
2000	0.7	35
3000	0.13	40
6000	0.003	51

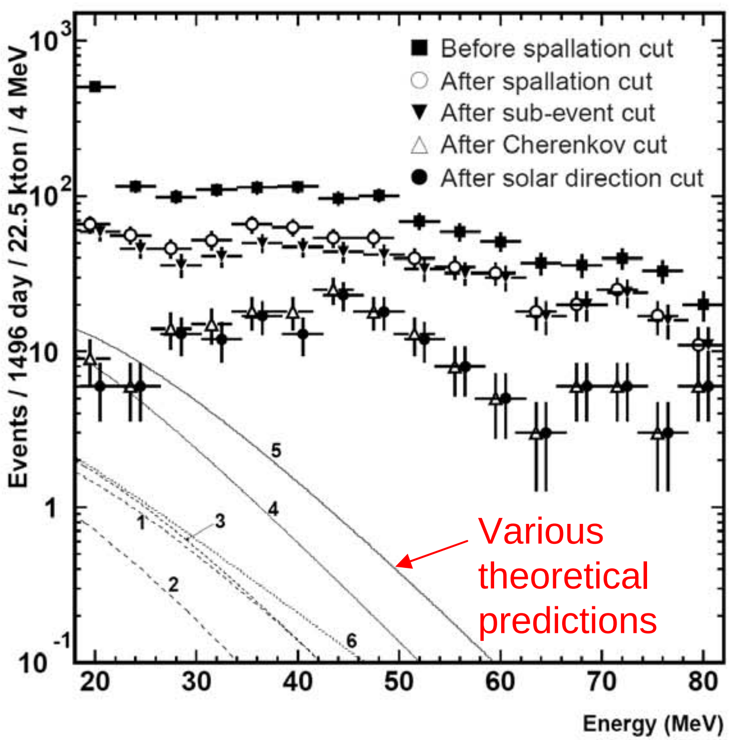
Assume $I = I_0\, e^{-(t/3)}$ i.e. 3 second time constant with $I_0 = 70{,}000$

SN Relic Neutrinos



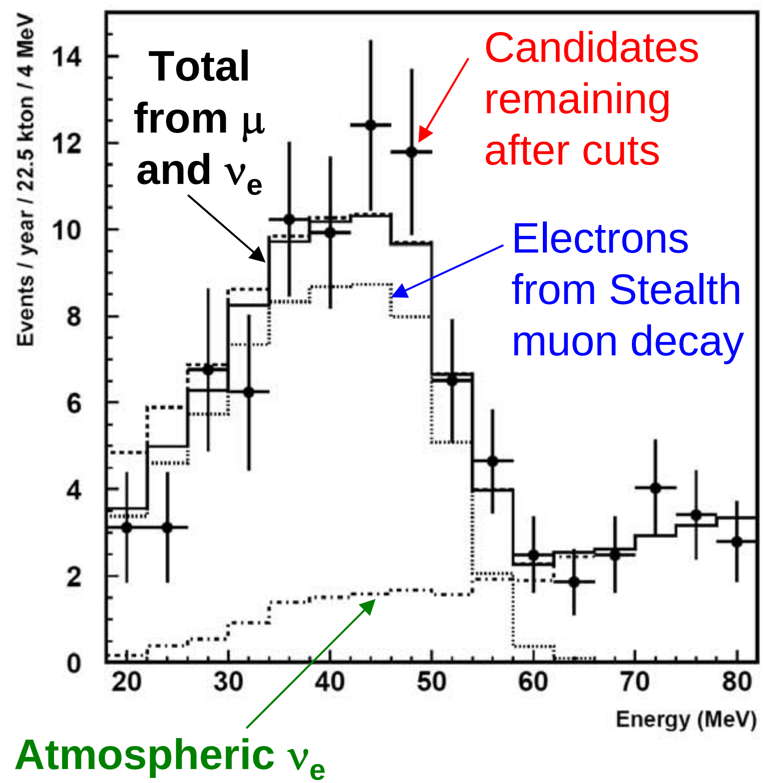
SK Relic SN Data at 2700 mwe

Initial backgrounds to relic SN signal are solar neutrinos, atmospheric neutrinos, spallation products, and atmospheric muons.



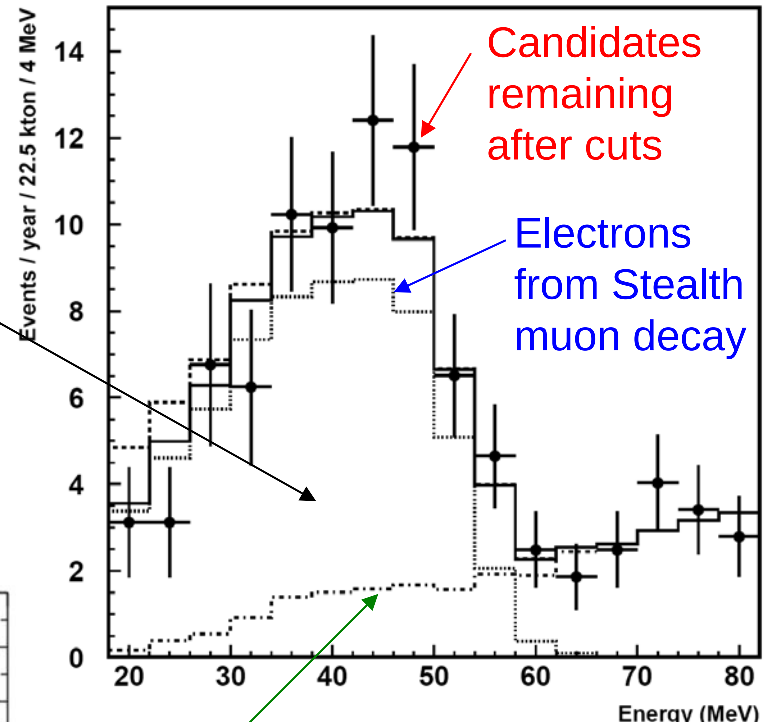
After cuts, major backgrounds are from atmospheric neutrinos and atmospheric muons.

The stealth muon induced background increases with shallower depth…

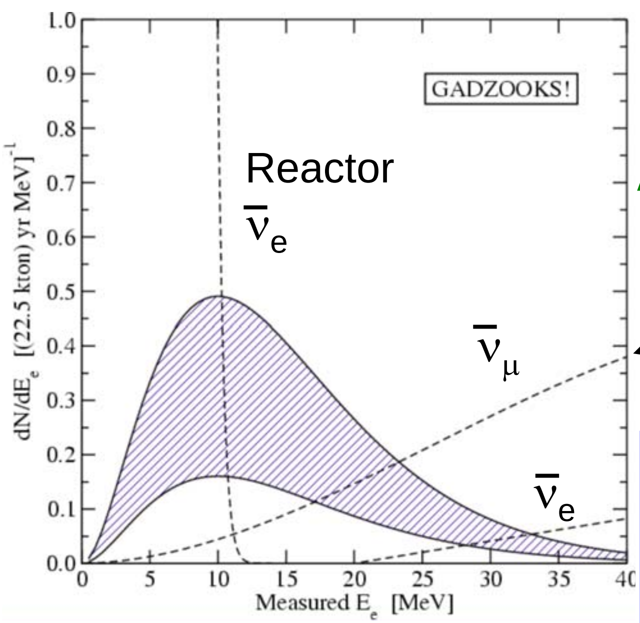


Extra Handles With Gd

Require delayed neutron to reduce stealth muon decay events ~a factor of 5
Beacom & Vagins *Phys.Rev.Lett.* **93**:171101 (2004).



Atmospheric ν_e



Here only consider background with coincident events simulating e+, n
$\bar{\nu}_\mu + p \rightarrow \mu^+ + n$; $\bar{\nu}_\mu + {}^{16}O \rightarrow \mu^+ + n + {}^{15}N$

Also may be able to lower search window threshold to below 18 MeV by reducing spallation beta singles.

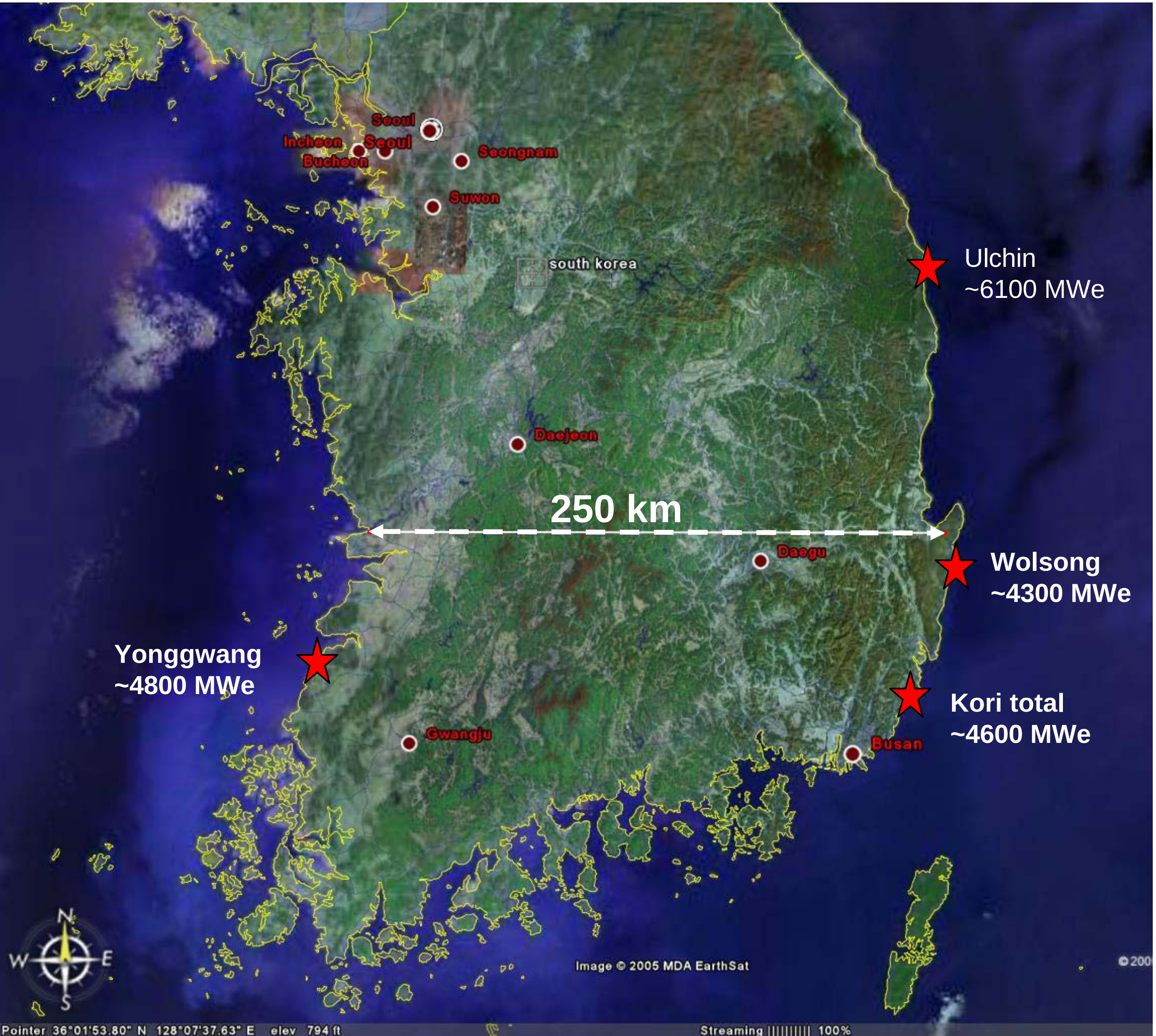
How Deep?

- Spallation daughter which then beta decays and ejects a neutron. Worst case Lithium-9, ~50% into electron and a neutron.
- ^{9}Li generated ~ one/kton/day at 2700 m.w.e. or about 10^{4}/yr of ^{9}Li in SK. Cylindrical cut reduces this by a factor of 10^{4} (20% deadtime at 2700 m.w.e.).
- But, fraction of ^{9}Li betas above 10 MeV is less than 10%. So, in SK, relic signal to ^{9}Li contamination is 5/0.1 events per year.
- Rate of relic events and the rate of ^{9}Li production scale linearly with detector volume, so, in 10x detector , 50 relics and 1 Li-9 event each year at 2700 m.w.e..
- Spallation-induced deadtime and ^{9}Li production rise with decreasing depth, but the relic rate is constant.

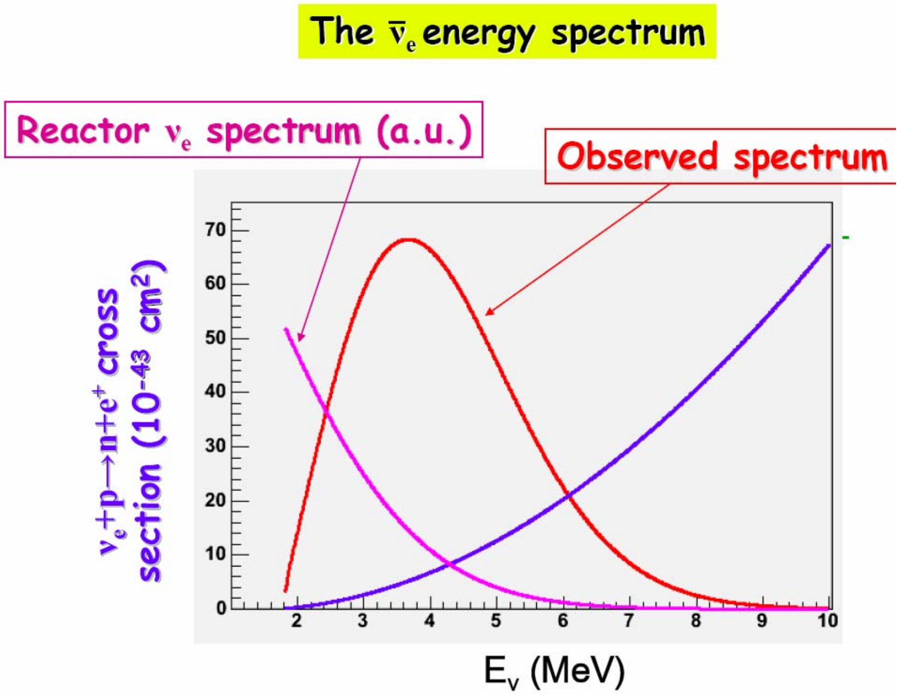
How Deep?

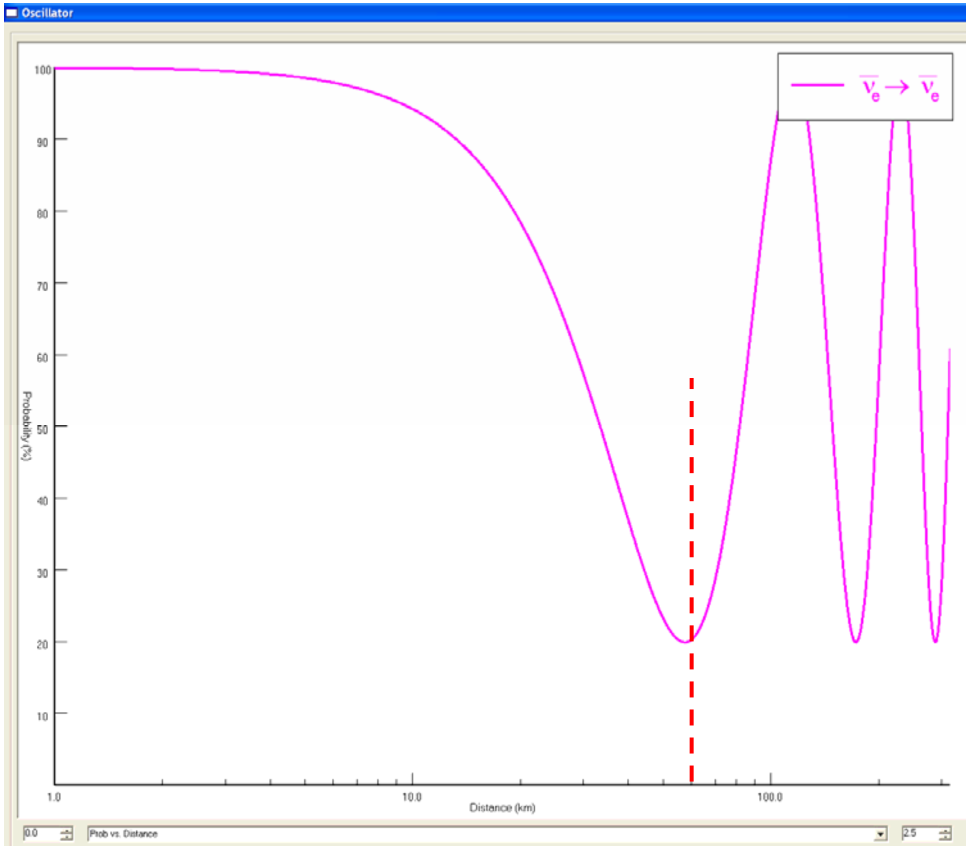
Depth (mwe)	SN Relic Signal yr^{-1}	^{9}Li Background yr^{-1}	Signal/background
4000	60	0.2	300
3000	53	.08	66
2700	50	1.0	50
2400	37	1.5	25
2000	16	1.25	13
1900	6	0.56	11

Reactor Neutrinos?



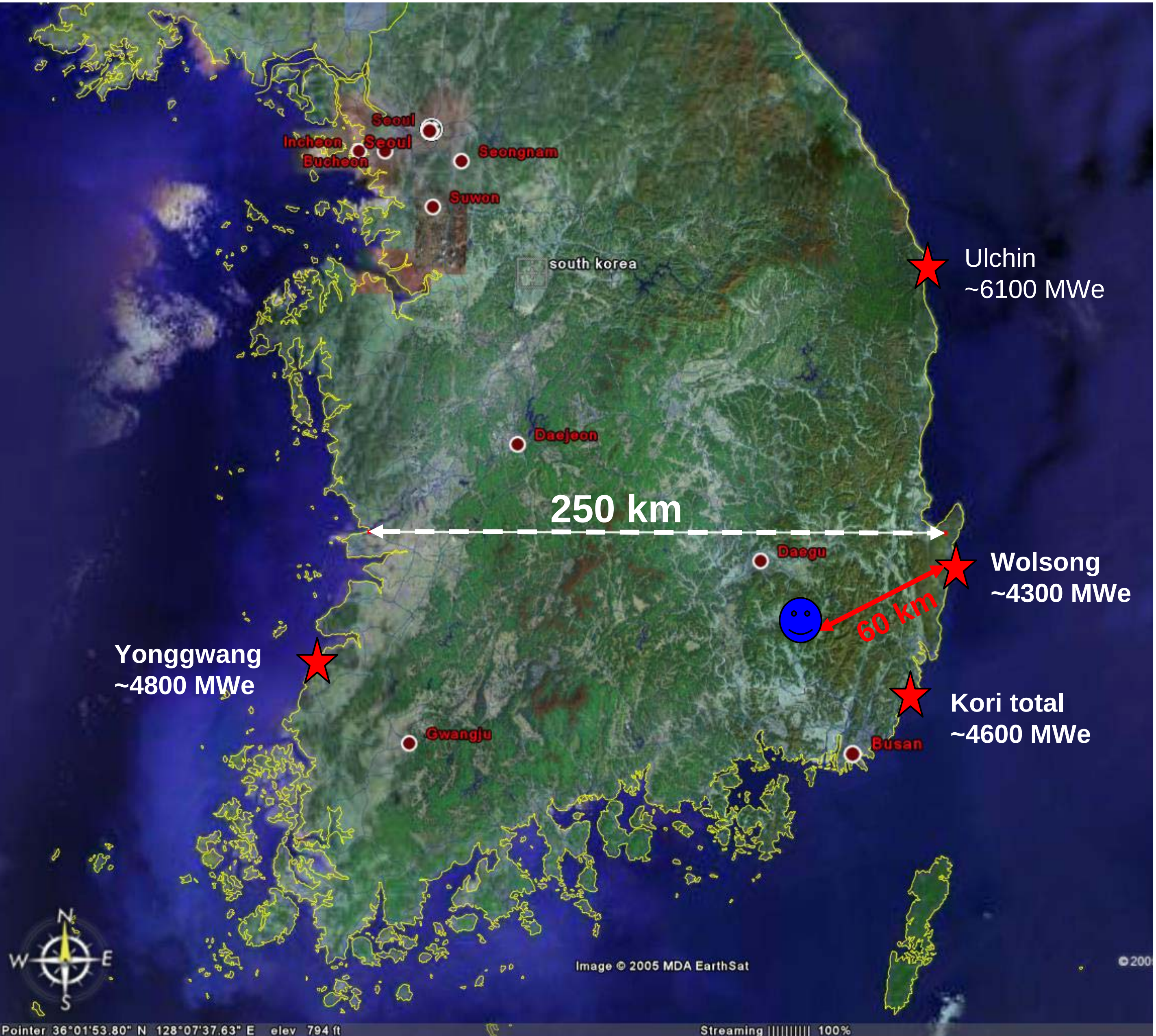
Reactor Neutrinos





4MeV ν minimum ~60 km

Reactor Signal



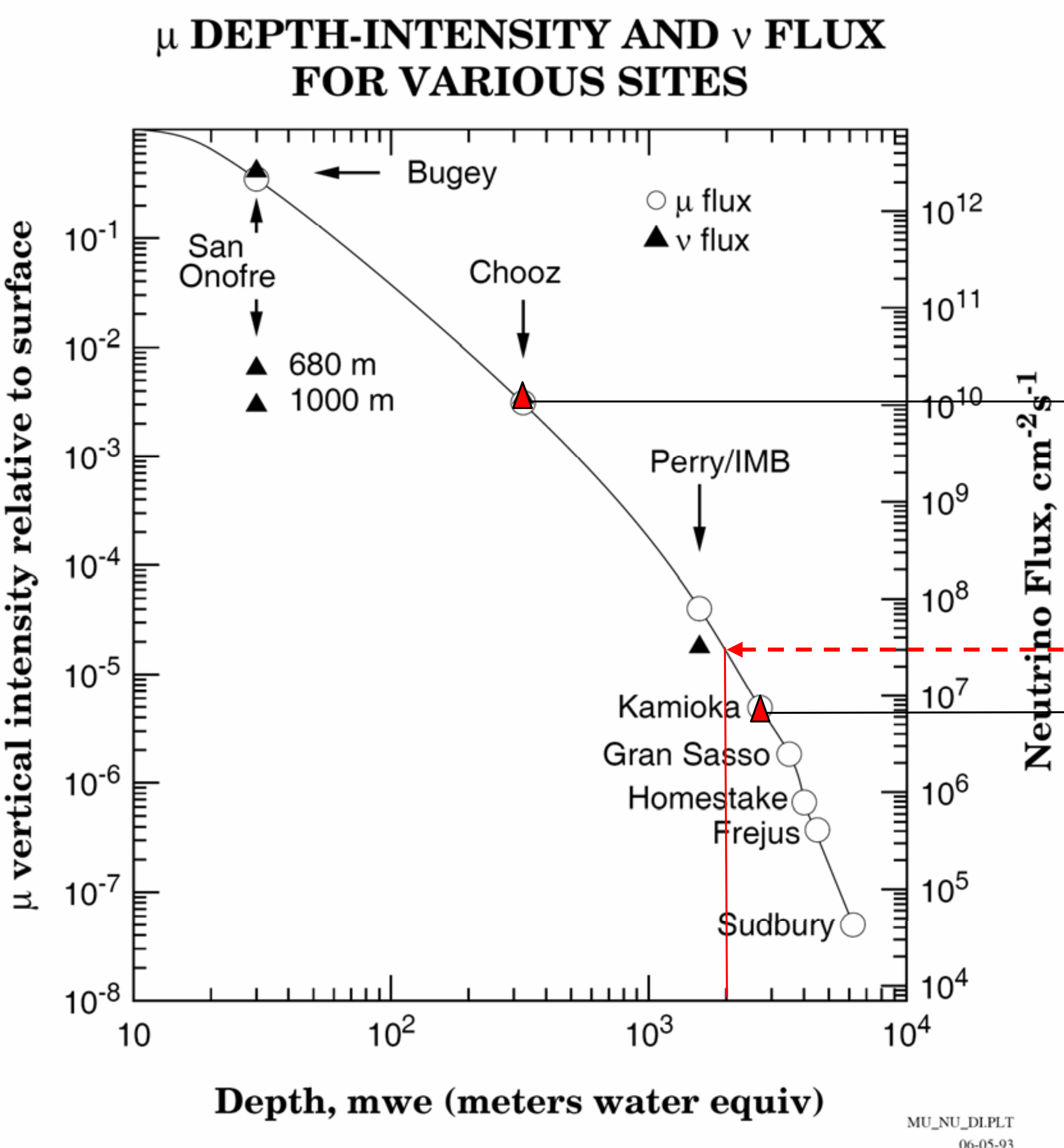
KamLAND/Korea Comparison

Very approximate scaling

KamLand		Korea
766 ton-yr	X 325 →	250,000 ton-yr
180,000 MWe	1/20 →	9,000 MWe
180 km nominal	x9 →	60 km nominal
365 expected events	x145 →	53,400 expected/yr

Precise determination of the solar neutrino oscillation parameters Δm^2_{21} and $\sin^2\theta_{12}$

Depth



1 km, 8.4 GW
~ 4% background

60 km, 9 GW ➡ 2000mwe

180 km, 180 GW
~3% background

Summing Up

- High energy signals; PDK, atmospheric neutrinos, depth ~ <1600 mwe required.
- Supernova in our galaxy S/B still ~10^3 at 500 mwe. Andromedia S/B ~1 at 1300 mwe.
- Relic neutrinos without Gd needs SK depth – with Gd could possibly go as shallow as ~2000 mwe.
- Reactor neutrinos need ~2000 mwe.
- Solar neutrinos deadtime ~40% at 2360mwe, much less not useful.