Update on Neutrino/ Gravity Wave Correlations With a Focus on SNEWS LIGO-I

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Or “What About SNEWS and Neutrino/ GW Correlations in the Wake of the Super-K Accident and the startup of KAMLAND?”

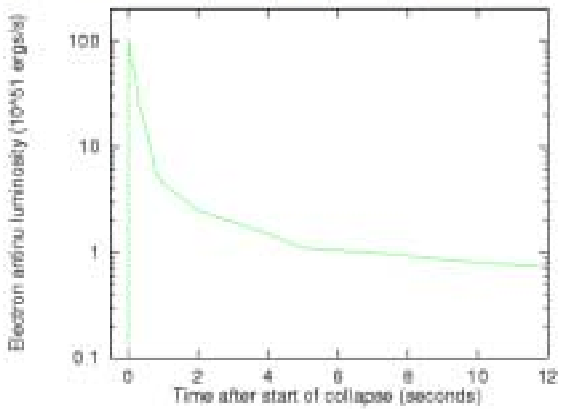
- Basic Ideas and Physics about Supernova Detection
- SNEWS and SNEWS News
- Some Related Measurements
- Some Future Possibilities for Neutrino/ GW Correlations

Slides from a poster on SNEWS by A. Habig, K. Scholberg, and M. Vagins (of Super-K) presented at the Neutrino-98 conference.

Neutrinos from Gravitational Collapse

Basic theory confirmed by Kamiokande II and IMB for SN1987A.

EXPECTED NEUTRINO SIGNAL[1]



- All flavors of neutrinos
- Typical energies ~ 10-30 MeV:
  $< E_{\nu_e} > \sim 12$ MeV
  $< E_{\bar{\nu}_e} > \sim 15$ MeV
  $< E_{\nu_\mu} > \sim 18$ MeV
- Time scale: tens of seconds
- PROMPT after core collapse

[1] A. Burrows *et al*, *Phys. Rev.* **D45**, 3362 (1992).

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Supernova Neutrino Detectors I

- SCINTILLATOR DETECTORS: Volume of liquid scintillator C_nH_{2n}, primarily sensitive to charged current $\bar{\nu}_e$ absorption,

$$\bar{\nu}_e + p \to e^+ + n. \tag{1}$$

NO POINTING: e^+ emitted nearly isotropically and scintillator light detected isotropically.

Examples: MACRO, LVD, KamLAND, Baksan, Mont Blanc, LSND, Borexino, Chooz, Palo Verde

- WATER ČERENKOV DETECTORS:

Volume of clear water viewed by PMTs. Also primarily sensitive to reaction 1. In addition, a few % of expected events are:

$$\nu_x + e^- \to \nu_x + e^-, \tag{2}$$

POINTING: $\Delta\Theta \sim 30°$, get direction from Čerenkov cone.

Examples: Super-Kamiokande, Kamiokande, SNO, IMB

Supernova Neutrino Detectors II

- HEAVY WATER DETECTORS:

D_2O viewed by PMTs + neutron counters

Charged current:

$$\nu_e + d \to p + p + e^- \tag{3}$$

$$\bar{\nu}_e + d \to n + n + e^+ \tag{4}$$

Neutral current:

$$\nu_x + d \to n + p + \nu_x \tag{5}$$

$$\bar{\nu}_x + d \to n + p + \bar{\nu}_x \tag{6}$$

Neutral current sensitivity => information on neutrino mass, oscillation from supernova neutrino burst.

Example: SNO

- LONG STRING WATER ČERENKOV DETECTORS:

$\sim$ km long strings of PMTs in very clear ice or water, with nominally $\sim$ GeV neutrino energy thresholds. Supernova neutrino bursts are detected as a coincident increase in PMT singles rates for many tubes.

Examples: Amanda, Lake Baikal, Nestor, Antares

Supernova Neutrino Detectors III

- HIGH Z/NEUTRON DETECTORS: large quantity of high Z material + neutron counters. Neutral current reaction

$$\nu_x + (A, Z) \rightarrow (A-1, Z) + n + \nu_x \qquad (7)$$

Example: OMNIS (SNBO), NaCl + BF_3 counters

- LIQUID ARGON:

Charged current

$$\nu_e + {}^{40}Ar \rightarrow {}^{40}K^* + e^- \qquad (8)$$

Example: ICARUS TPC @ Gran Sasso

- RADIOCHEMICAL: solar neutrino experiments NO TIMING, but may register counts for supernova neutrinos; prompt extractions could be performed in the case of a detected neutrino burst.

Examples: Homestake, Gallex, SAGE

Most Common Source of Background to SN detection is cosmic ray-muon induced breakup of target nuclei to radioactive fragments and neutrons (spallation). The geometry of the muon and the time signature of radioactive decay can be used to effectively veto spallation products.

SNEWS means SuperNova Early Warning System
SNEWS is
A Network of Neutrino and Possibly GW Experiments that are sensitive to a prompt SN signal that precedes the EM signature

Types of Neutrino Supernova Detectors

1. Scintillator 2. H_2O and D_2O 3. Radiochemical 4. High Z (Liquid and Solid)

TABLE 1. Supernova neutrino detector types.

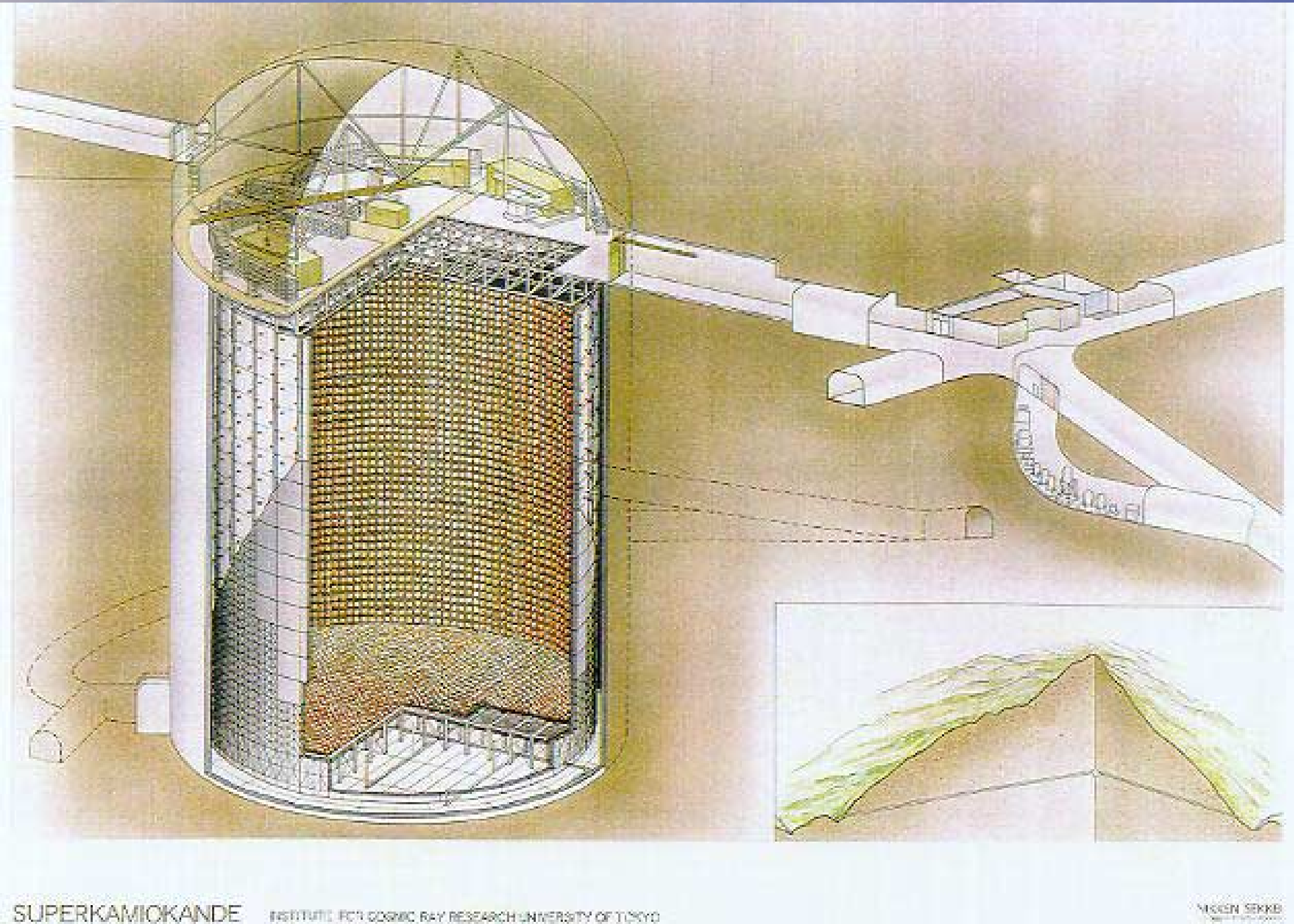
Detector type	Material	Energy	Time	Point	Flavor
scintillator	C,H	y	y	n	$\bar{\nu}_e$
water Cherenkov	H_2O	y	y	y	$\bar{\nu}_e$
heavy water	D_2O	NC: n	y	n	all
		CC: y	y	y	$\nu_e, \bar{\nu}_e$
long string water Cherenkov	H_2O	n	y	n	$\bar{\nu}_e$
liquid argon	Ar	y	y	y	ν_e
high Z/neutron	NaCl, Pb, Fe	n	y	n	all
radio-chemical	^{37}Cl, ^{127}I, ^{71}Ga	n	n	n	ν_e

Existing and Planed Supernova Neutrino Detectors (not necessarily complete or up-to-date)

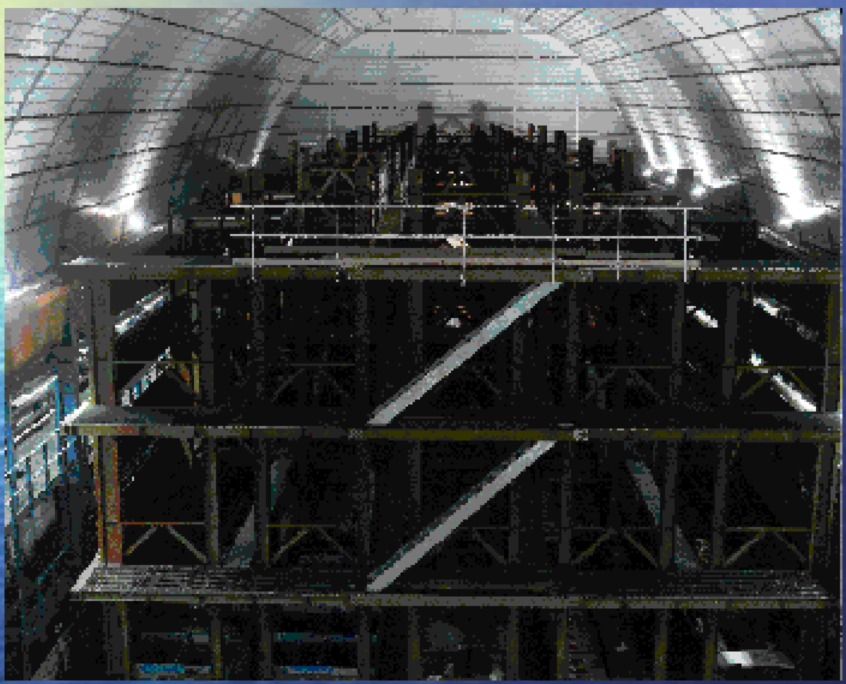
TABLE 2. Specific supernova neutrino detectors.

Detector	Type	Mass (kton)	Location	# of events @8.5 kpc	Status
Super-K	H_2O Ch.	32	Japan	5000	online
MACRO	scint.	0.6	Italy	150	online
SNO	H_2O, D_2O	1.4 1	Canada	300 450	running
LVD	scint.	0.7	Italy	170	online
AMANDA	long string	Meff ~0.1/pmt	Antarctica		running
Baksan	scint.	0.33	Russia	50	running
Borexino	scint.	0.3	Italy	100	2001
KamLAND	scint.	1	Japan	300	2001
OMNIS (Pb/Fe)	high Z	5	USA	2000	2000+
LAND (Pb)	high Z		Canada		2000+
Icanoe	liquid argon	9	Italy		2000+

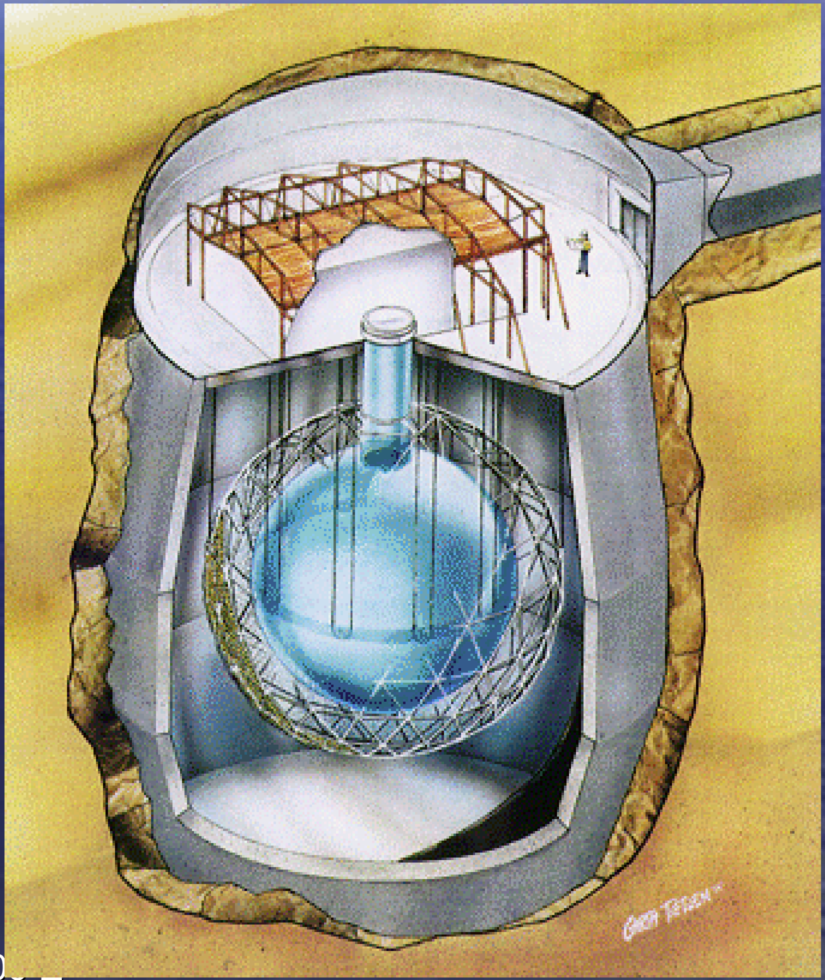
Super Kamiokande (Kamioka Nucleon Decay Experiment)



LVD (Large Volume Detector) in Gran Sasso.

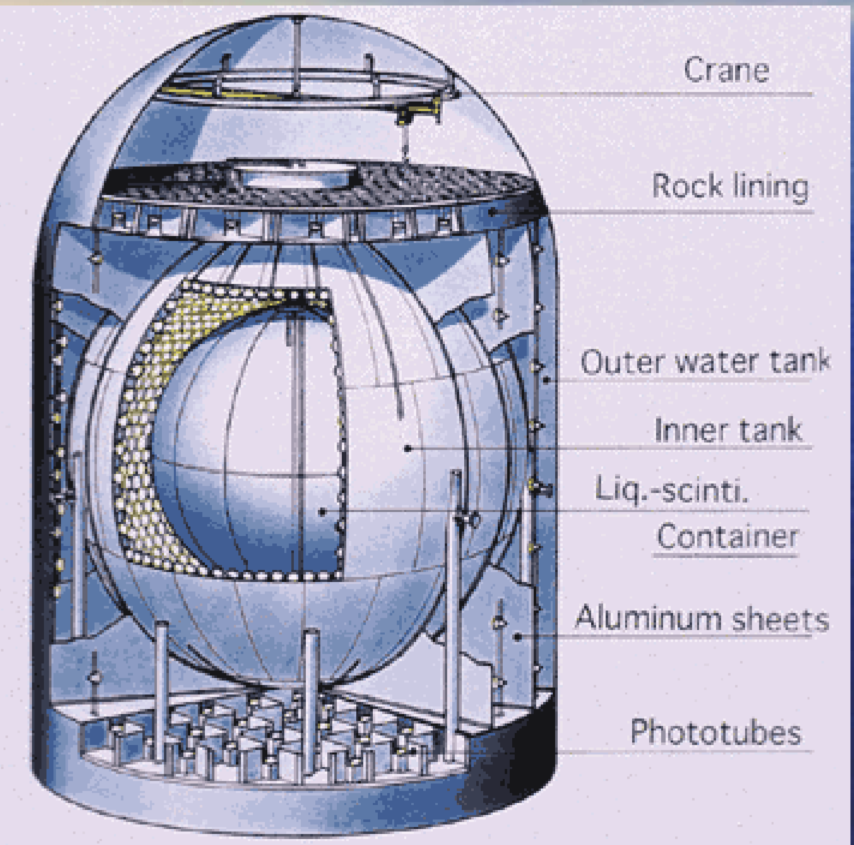


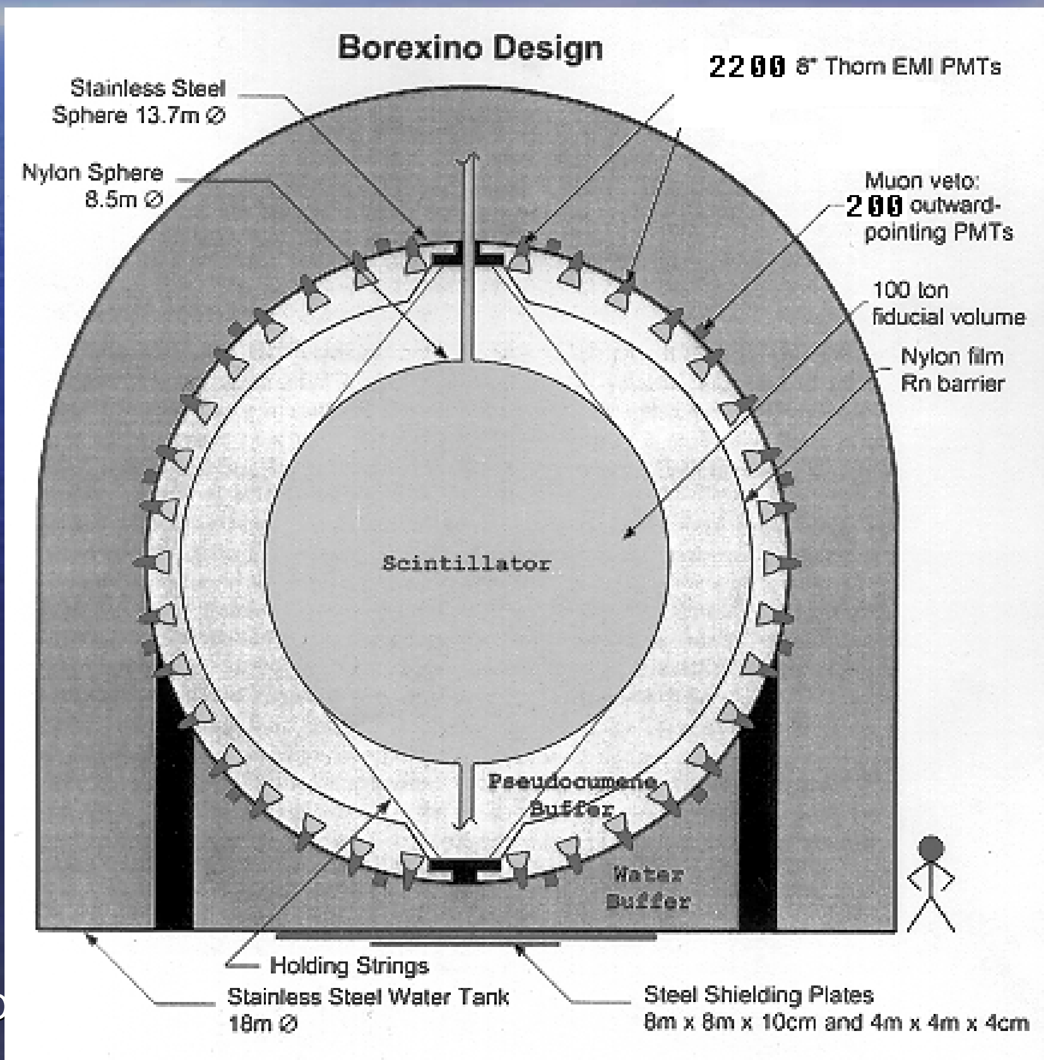
SNO (Sudbury Neutrino Observatory).

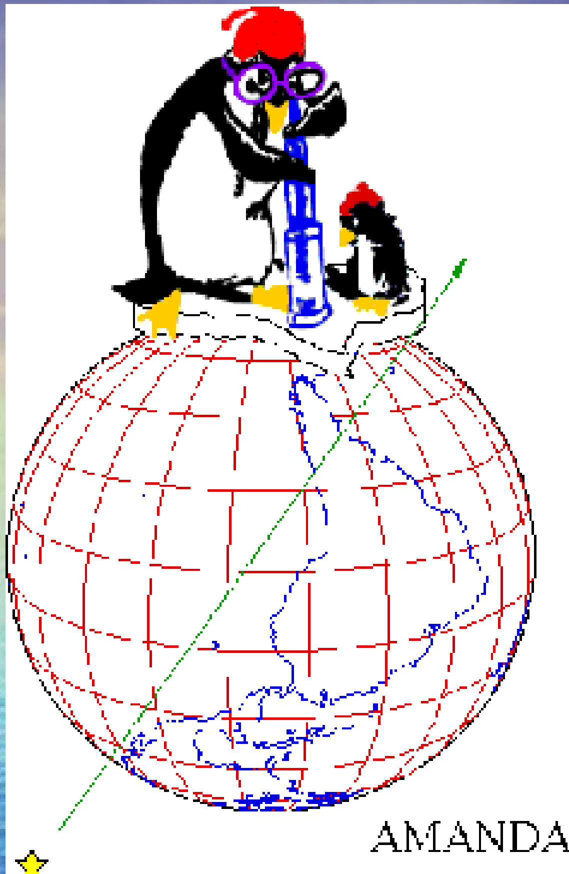


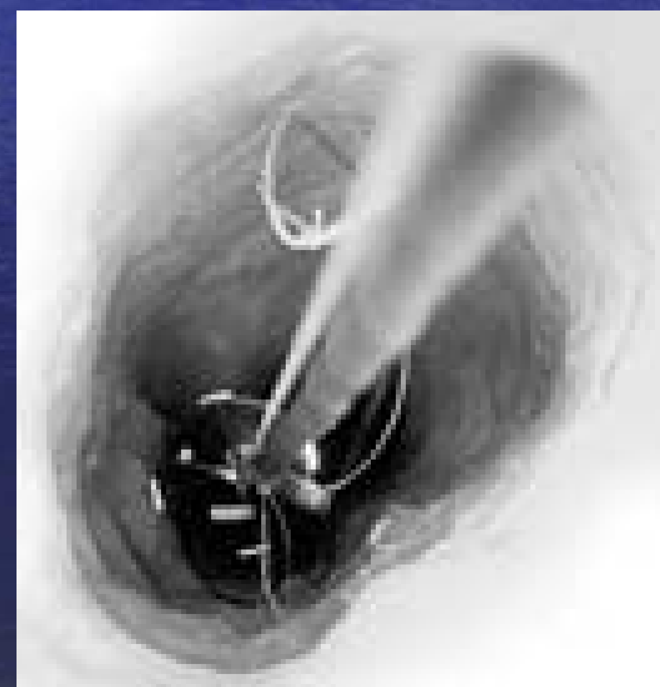
KAMLAND

Borexino









Antarctic Muon and Neutrino Detector Array (AMANDA) in the South Pole Ice to be expanded to 1 km^3 ICECUBE. High Energy muon or tau Neutrinos Interacting in Rock Below to produce the appropriate lepton.

FLOW DIAGRAM of SNEWS

- LIGO is now receiving e-mail datagrams with experiment and time stamp. Theseare being incorporated into the data-base.
- When SNEWS datagram is received by LIGO it is forwarded to the LSC Membership

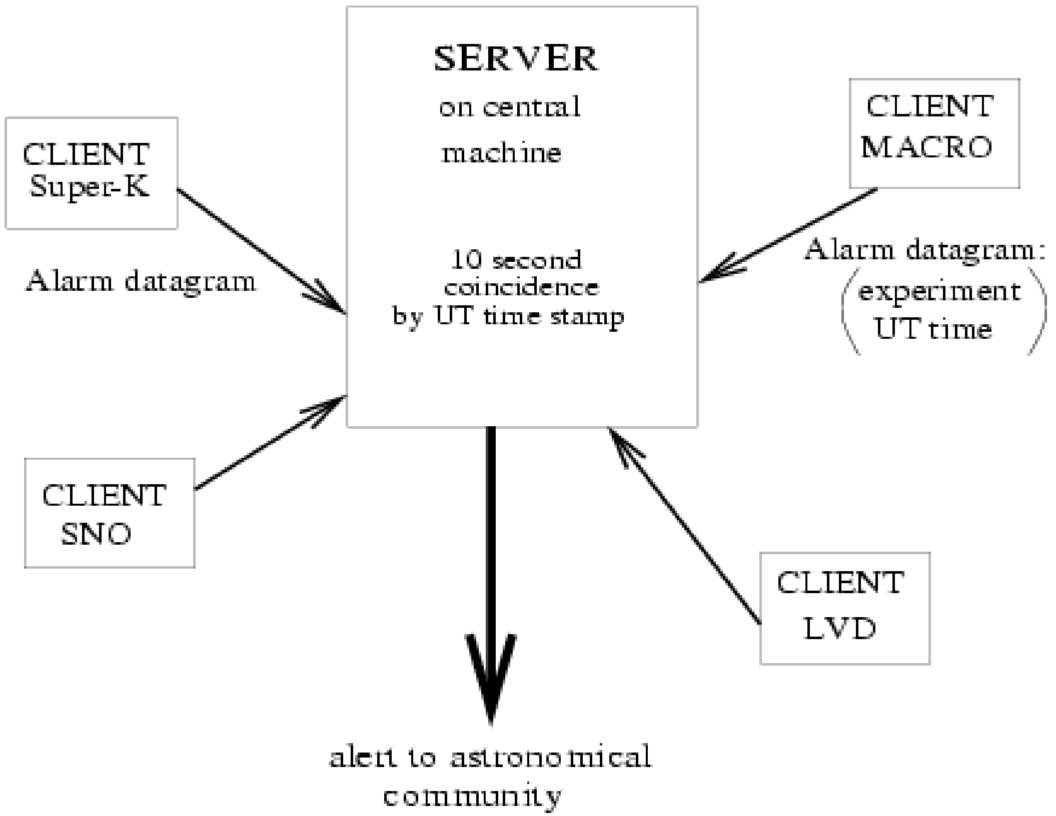


FIGURE 1. SNEWS setup.

This diagram is a bit out of data. MACRO is no longer operating, Super-K is presently being repaired, and SNO is not yet sending direct alarms.

Coincidences are great false alarm filters.

Even With A High false alarm rate (1 per week), Coincidences between as few as two experiments limit false alarms to very low rates (1 per decade or century). From A. Habig and K. Scholberg (formerly of BU now at U Minn Duluth and MIT).

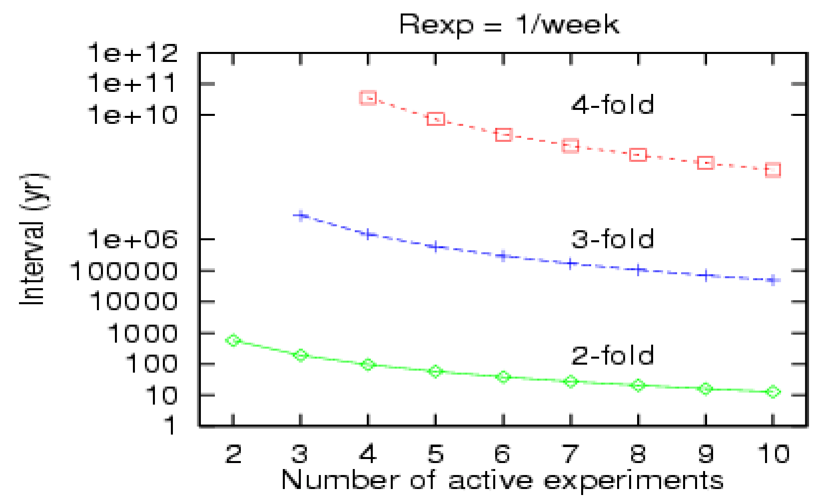


FIGURE 2. Average time between accidental coincidence alarms between experiments, as a function of number of experiments online, for a 10 second coincidence time window, for 2-fold, 3-fold and 4-fold coincidences. The assumed individual experiment alarm rate is $R = 1/\text{week}$.

Active SNEWS Members

Currently Sending Real –Time Alarms

- LVD (99.5% livetime)

SNEWS Members Sending Delayed Alarms

- SNO (Hand-Written with 20 minute delay)

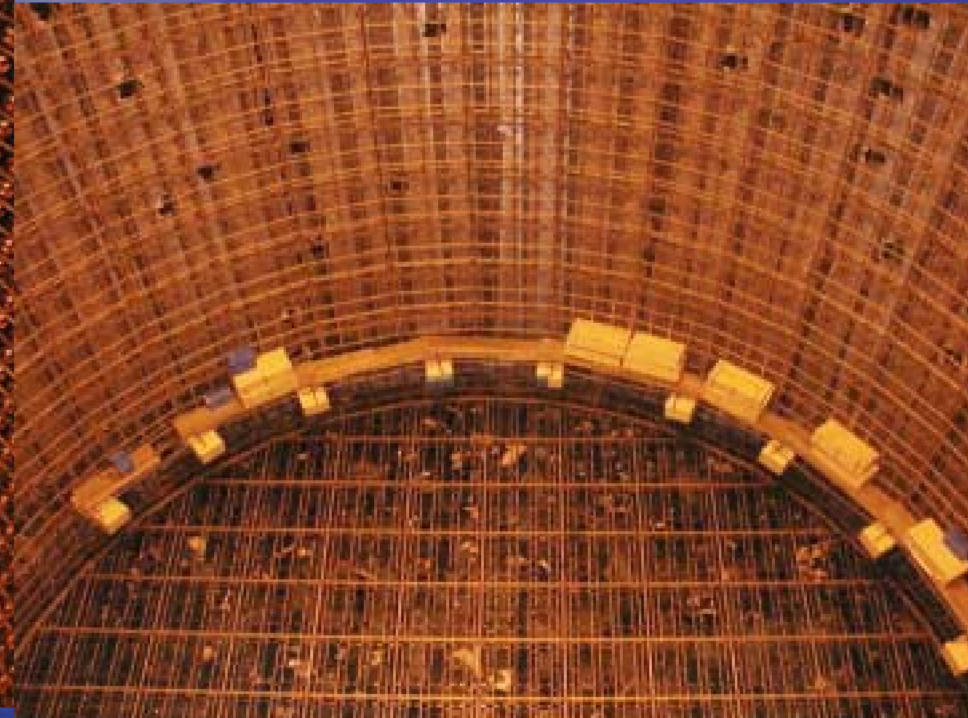
Under Repair

- Super-Kamiokande/ Scheduled for restart about 1/03

Damage to Super-K in chain reaction accident of November 11, 2001

7,000 of 11, 000

Inner Detector and 1000 of 1800 Outer Detector PMTs were destroyed. About 1000 new ID and OD tubes and surviving 4500 OD PMTs being redeployed to ½ coverage of S-K-I



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Super-K

1. **Before Accident During Upgrade.**
2. **After Accident During Cleanup.**
3. **During Cleanup Before Redeployment of PMTs (photos from M. Malek and E. Kearns of Super-K)**

Other experiments that may send SN alarms to SNEWS

•KamLAND
Is now taking preliminary data with 90% livetime.
An SN trigger has been formulated that lowers the threshold to .5 MeV for 3 minutes after a cluster of events is found. May join SNEWS shortly (by end of 02).

• AMANDA
Now has an SN trigger and plans to soon have 24 hour internet connectivity using the “Iridium” Satellite network.

• Borexino
Plans to start data taking near the beginning of 03.

• Mini-BooNE
Is testing hardware and could possibly have an SN trigger.

• OMNIS
Plans for a 2.5 Kton lead-scintillator detector.

SNEWS SOFTWARE AND HARDWARE

• Version 3.0 of SNEWS code has been written with provisions for 2 way communication, improved false alarm vetoes, and better security.

Supernova Neutrino Interactions and Event Rates

- Inverse Beta Decay (IVB) is isotropic
- Neutrino Electron Elastics Scattering (directional)
- Neutral Current Excitation of ^{16}O yielding 5-10 MeV Gamma Ray lines (isotropic)

Total Events from SN at 10 Kpc

LVD ~ 200-300

- Syper-K-II (rebuilt) 7750 (7200 IVB, 310 ^{16}O, 240 Elastic Scattering)
- SNO ~ 1000
- KamLAND ~ 500
- Borexino ~ 200

Directional and Spectral Information

- Only Available From Elastic Scattering Events (about 3% of total events from 5-30 MeV).
- Super-K is the only SN detector with significant numbers of Elastic Scattering (ES) Events.
- Super-K-II (rebuilt) would see about 240 ES Interactions from an SN at 10 Kpc; S-K-I would have gotten ~300 ES events.
- S-K-I would have had ~ 3-4 degree resolution for an SN at 10 Kpc (see Beacom and Vogel). For S-K-II new calculations should be done (~ 5 degree resolution).
- Spectral Information Determined by Energy Range and Number of Events.
- Super-K-II with a 7 MeV threshold (S-K-I threshold was 5 MeV) and 7750 events will give the best spectral information.

Information from Super-K Relevant to GW Detectors

- Upper Limits on Supernova rates at 90% CL(from full S-K-I data set) are .26 SNs per year in our galaxy and .49 extra-galactic SNs per year out to 80 Kpc.

- Searches for relic SN neutrinos. No evidence yet but limits are within a factor of 5 of theoretical predictions for relic signal detection. Paper in preparation.

- Searches for point sources of high-energy upward-going muons from neutrino interactions in the rock below; no point sources in S-K-I with 2000 events. Good Flux limits on neutrinos from interesting sources have been set.

- Searches for temporal and directional correlation between S-K solar, atmospheric, and high energy upward going muon creating neutrinos with BATSE GRBs. No evidence for correlation. Preprint submitted to Ap. J.

- A galactic SN may well yield interesting astrophysical measurements from S-K and other detectors (unavailable in current neutrino oscillation experiments) as well as a possible first GW detection.

Neutrino Correlations Beyond SNEWS

- Should Be Worked Out By Spokespersons and Approved By Collaborations.

- Directional Data is in-principle available from Super-K elastic scattering. But this unique information must be hand checked by experts and approved by collaboration leaders. So probably this cannot be disseminated before the optical burst arrives from an SN (thus not by SNEWS)

Enhancements to SNEWS

- With 3 or 4 detectors triangulation of time of burst may yield burst direction

Pointing to the Supernova

How well can neutrino experiments point back to the supernova?

Individual water Čerenkov experiments can use:

NEUTRINO-ELECTRON ELASTIC SCATTERING,

$$\nu_x + e^- \rightarrow \nu_x + e^-, \text{ NC and CC} \qquad (9)$$

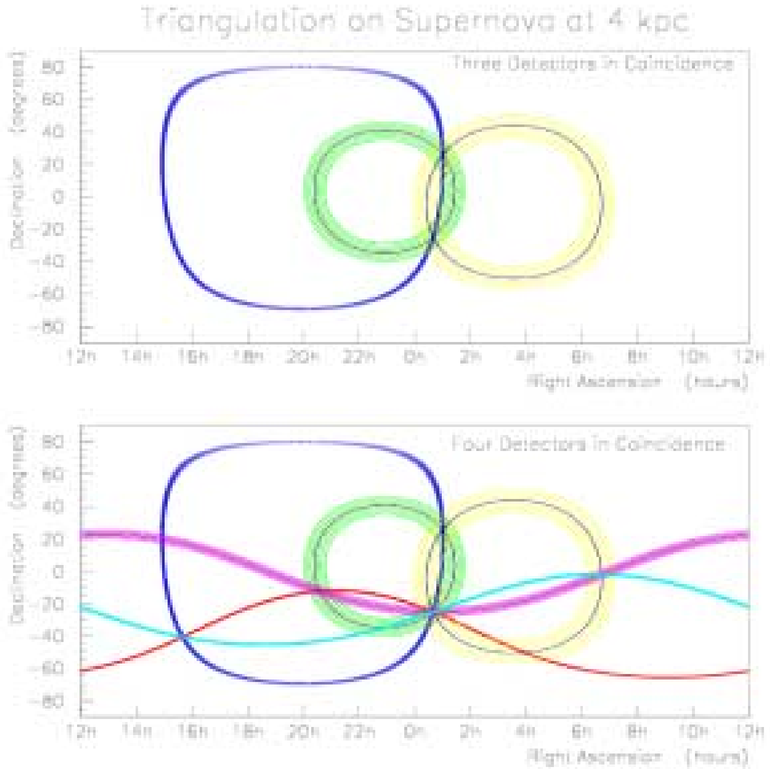
$$\Delta\Theta \sim 30^\circ$$

$$\delta\theta \sim \frac{30^\circ}{\sqrt{(n)}}$$

For a collapse at 8.5 kpc (Galactic center),

Super-K: $\delta\theta \sim 3^\circ$

SNO: $\delta\theta \sim 8^\circ$



Target box from 4 detectors: 4° by 2.5°

Summary and Conclusions

- At the moment the only fully active member of SNEWS is LVD with SNO submitting messages “by hand” .
- A rebuilt Super-K plans to return to SNEWS and KAMLAND plans to join SNEWS by the end of 02. Borexino may follow in early 03.
- By best estimates Super-K will see 7200 total events and 240 direction sensitive elastic scattering interactions from an SN at 10 Kpc with a threshold of 7 MeV (reduced from 8000 total and 240 elastic scatterings and a threshold of 5 MeV in S-K-I)
- Additional GW / Neutrino Correlations should be worked out through inter-collaboration agreements.
- SNEWS might provide directional information from time triangulation of bursts at different detectors.
- Unique Directional Information from rebuilt Super-K could localize an SN to about 5 degrees (MC results pending). Eventually, after public release, this information might be useful in testing a possible SN-GW signal.