The Abdus Salam International Centre for Theoretical Physics

2047-13

Workshop Towards Neutrino Technologies

13 - 17 July 2009

On-line recognition of SN neutrino bursts

Walter FULGIONE

Istituto Nazionale di Fisica Nucleare INFN
Laboratori Nazionali del Gran Sasso LNGS
S.S. 17 Bis - Km. 18.910
67010 Assergi, L'Aquila, ITALY

On-line recognition of SN neutrino bursts

Walter Fulgione

IFSI-To and INFN
Torino - Italy

Workshop Towards Neutrino Technologies

ICTP, July 13-17, 2009

Walter.Fulgione@gmail.com

Outline

- The neutrino signal
  - neutrino burst from core collapse SN
  - neutrino oscillations
  - open problems
- Core collapse neutrino detection
  - Main difficulties
  - rate
  - model predictions
  - SNEWS
- Different strategies
  - Water Cherenkov [Superk]
  - Long string Cherenkov [IceCUBE]
  - Scintillators [LVD and Borexino]

Walter.Fulgione@gmail.com

Outline

- The neutrino signal
  - neutrino burst from core collapse SN
  - neutrino oscillations
  - open problems
- Core collapse neutrino detection
  - Main difficulties
  - rate
  - model predictions
  - SNEWS
- Different strategies
  - Water Cherenkov [Superk]
  - Long string Cherenkov [IceCUBE]
  - Scintillators [LVD and Borexino]

Walter.Fulgione@gmail.com

Neutrino emission in Core Collapse SN

from Janka et al. astro/ph0612072

..the shock spends energy, mostly by the photo dissociation of heavy nuclei into nucleons and stalls, before reaching the outer shells. This change in the matter composition increases the electron capture rate producing a first neutrino burst: the **shock break-out neutrino burst:** $e^- + p \rightarrow n + \nu_e$

The model predicts a second impulsive neutrino signal of the duration of ~ 500 ms related to the **accretion** phase just before the explosion:

$e^- + p \rightarrow n + \nu_e$ $\quad e^+ + n \rightarrow p + \bar{\nu}_e$ [10-20%]

The **cooling** of the hot interior of the proto-neutron star proceeds by neutrino-pair production and diffusive loss of neutrinos of all three lepton flavors: $e^- + e^+ \rightarrow \nu_i + \bar{\nu}_i$ [80-90%]

Walter.Fulgione@gmail.com

Neutrino emission in Core Collapse SN

from Janka et al. astro/ph0612072

..the shock spends energy, mostly by the photo dissociation of heavy nuclei into nucleons and stalls, before reaching the outer shells. This change in the matter composition increases the electron capture rate producing a first neutrino burst: the **shock break-out neutrino burst:** $e^- + p \rightarrow n + \nu_e$

The model predicts a second impulsive neutrino signal of the duration of ~ 500 ms related to the **accretion** phase just before the explosion:

$e^- + p \rightarrow n + \nu_e \qquad e^+ + n \rightarrow p + \bar{\nu}_e$ [10-20%]

The **cooling** of the hot interior of the proto-neutron star proceeds by neutrino-pair production and diffusive loss of neutrinos of all three lepton flavors: $e^- + e^+ \rightarrow \nu_i + \bar{\nu}_i$ [80-90%]

The explosive nucleosynthesis process (r-process and νp-process) are thought to occur in this phase. They strongly depend upon the properties of the matter when the supernova was only a few seconds old, sampling directly the neutrino luminosity and temperatures.

Walter.Fulgione@gmail.com

observables

1) ...as the density reaches ρ_{trap}~10^{12} g\cm^3, neutrinos interact efficiently with matter and are essentially trapped in the core.

This determines duration and spectra of the ν emission

(thermal spectra with average neutrino energy 10-20 MeV during some 10 seconds)

2) The proto-neutron star will liberate its binding energy radiating neutrinos of all flavors:

$$E_b = G_N M^2_{NS}/R_{NS} \sim (1 - 4) \times 10^{53} \text{ erg}$$

3) Due to their different interaction with the stellar matter, neutrinos decouple at different stellar radii and then at different temperatures following the hierarchy:

$$T_{\nu_e} \leq T_{\bar{\nu}_e} \leq T_{\nu_x}$$

with ν_x representing all non electron neutrino flavors.

but...

Walter.Fulgione@gmail.com

..neutrinos oscillates

Matter effects inside the star: MSW

In their path from the high density region where they are generated to the lower density one where they escape the star, neutrinos cross two resonance layers.

H resonance ($\Delta m^2_{atm}, \theta_{13}$), $\rho_H \sim 10^3 - 10^4$ g/cm^3

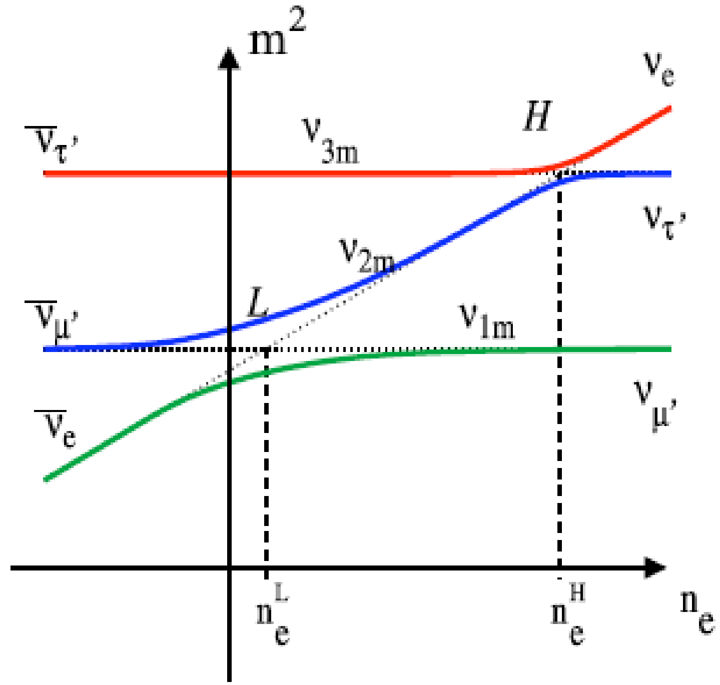
L resonance ($\Delta m^2_{sol}, \theta_{sol}$), $\rho_L \sim 10 - 100$ g/cm^3

..mixing their energy spectra.

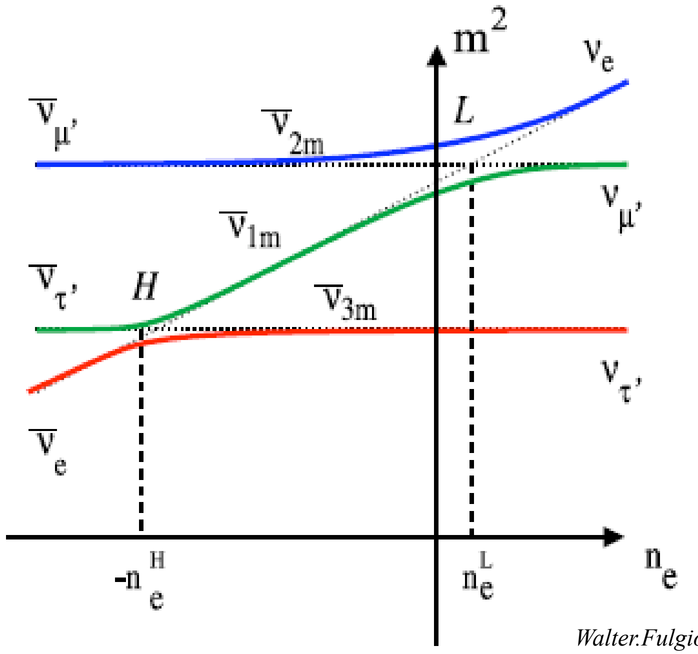
Resonances occur at relatively low densities, without any influence on the explosion dynamics.

The temperature hierarchy at the detector will be modified according to the values of θ_{13} and on the ν mass hierarchy.

Normal mass ordering



Inverted mass ordering



A. Dighe and A. Yu. Smirnov, Phys. Rev. D 62, 033007 (2000).

Walter.Fulgione@gmail.com

ν self-nteractions

see for example G.Sigl et al., Nuclear Physics B (Proc. Supp.) 188 (2009) 101 and references therein

In the last years has been realized that in the early cooling phase of core collapse SNe, the density of ν streaming is sufficiently high to cause non-linear phenomena that can have practical importance..

How these effects can influence the expected neutrino signal is not completely understood (see A.Dighe at TAUP2009).

They occur in a region of the star were supernova nucleosynthesis and explosion mechanism could be affected.

Walter.Fulgione@gmail.com

open problems

While successful in nature, in most numerical supernova models the shock stalls, so that the fate of the entire star is to produce a black hole, but no optical supernova.

Stars of 8-11 solar masses may be relatively easy to explode. These stars, however, do not eject enough mass to explain the origin of abundant heavy elements such as O, Mg, Si, S and Ca.)

open problems

While successful in nature, in most numerical supernova models the shock stalls, so that the fate of the entire star is to produce a black hole, but no optical supernova.

Stars of 8-11 solar masses may be relatively easy to explode. These stars, however, do not eject enough mass to explain the origin of abundant heavy elements such as O, Mg, Si, S and Ca.)

models cannot reproduce the elemental abundances due to r-process nucleosynthesis.

Walter.Fulgione@gmail.com

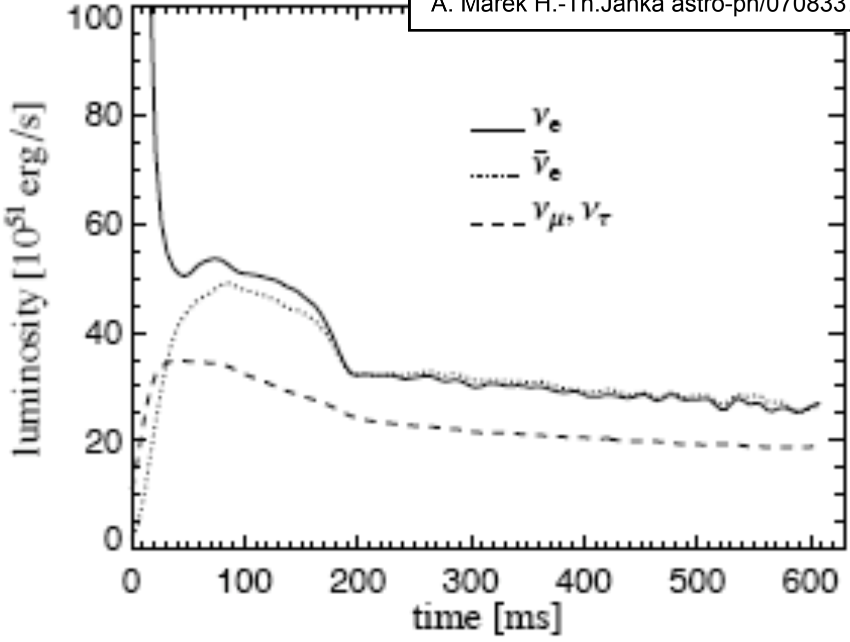
open problems

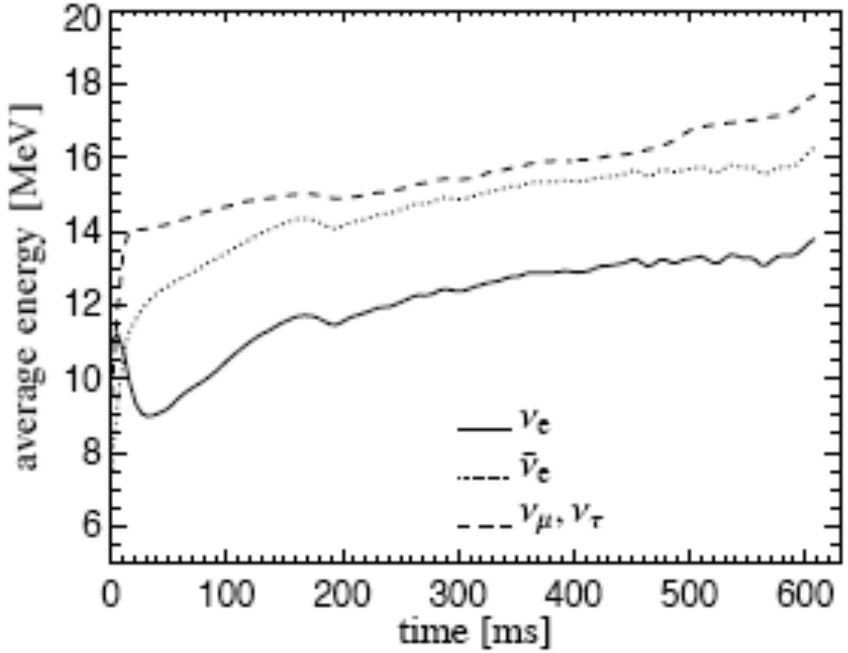
A. Marek H.-Th.Janka astro-ph/07083372

While successful in nature, in most numerical supernova models the shock stalls, so that the fate of the entire star is to produce a black hole, but no optical supernova.

Stars of 8-11 solar masses may be relatively easy to explode. These stars, however, do not eject enough mass to explain the origin of abundant heavy elements such as O, Mg, Si, S and Ca.)

models cannot reproduce the elemental abundances due to r-process nucleosynthesis.





Core collapse dynamics and explosion mechanism must be stamped in the features of the neutrino signal.

Outline

- The neutrino signal
  - neutrino burst from core collapse SN
  - neutrino oscillations
  - open problems
- Core collapse neutrino detection
  - Main difficulties
  - rate
  - model predictions
  - SNEWS
- Different strategies
  - Water Cherenkov [Superk]
  - Long string Cherenkov [IceCUBE]
  - Scintillators [LVD and Borexino]

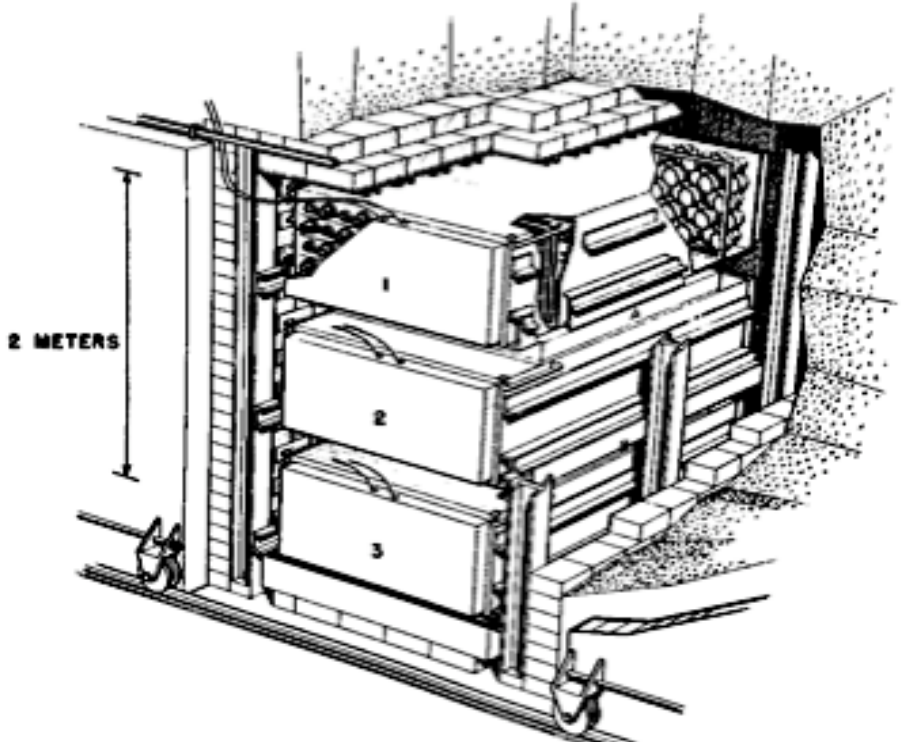
Walter.Fulgione@gmail.com

Core collapse neutrino detection

G.V. Domogatsky and G.T. Zatsepin,
in Proc. of the 9th ICRC, London, 1965

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

$$n + p \rightarrow d + \gamma_{[2.2\mathrm{MeV}]}$$



PHYSICAL REVIEW VOLUME 117, NUMBER 1 JANUARY 1, 1960

Detection of the Free Antineutrino*

F. Reines,† C. L. Cowan, Jr.,‡ F. B. Harrison, A. D. McGuire, and H. W. Kruse
Los Alamos Scientific Laboratory, University of California, Los Alamos, New Mexico

(Received July 27, 1959)

The antineutrino absorption reaction $p(\bar{\nu},\beta^+)n$ was observed in two 200-liter water targets each placed between large liquid scintillation detectors and located near a powerful production fission reactor in an antineutrino flux of 1.2×10^{13} $\mathrm{cm^{-2}\,sec^{-1}}$. The signal, a delayed-coincidence event consisting of the annihilation of the positron followed by the capture of the neutron in cadmium which was dissolved in the water target, was subjected to a variety of tests. These tests demonstrated that reactor-associated events occurred at the rate of 3.0 $\mathrm{hr^{-1}}$ for both targets taken together, consistent with expectations; the first pulse of the pair was due to a positron; the second to a neutron; the signal dependended on the presence of protons in the target; and the signal was not due to neutrons or gamma rays from the reactor.

Golden channel: inverse beta decay

Main difficulties

cross sections

For scintillators and water Cherenkov detectors and for a "1987A-like" core collapse at 10 kpc.

$$N_{ev} \approx 0.2 \div 0.3 \times [M/1 \text{ ton}] \times [D/10 \text{ kpc}]^{-2}$$

hundreds tons of target are required to observe the entire Galaxy.

rate of gravitational collapses in our Galaxy: 2±1 event/100 years.

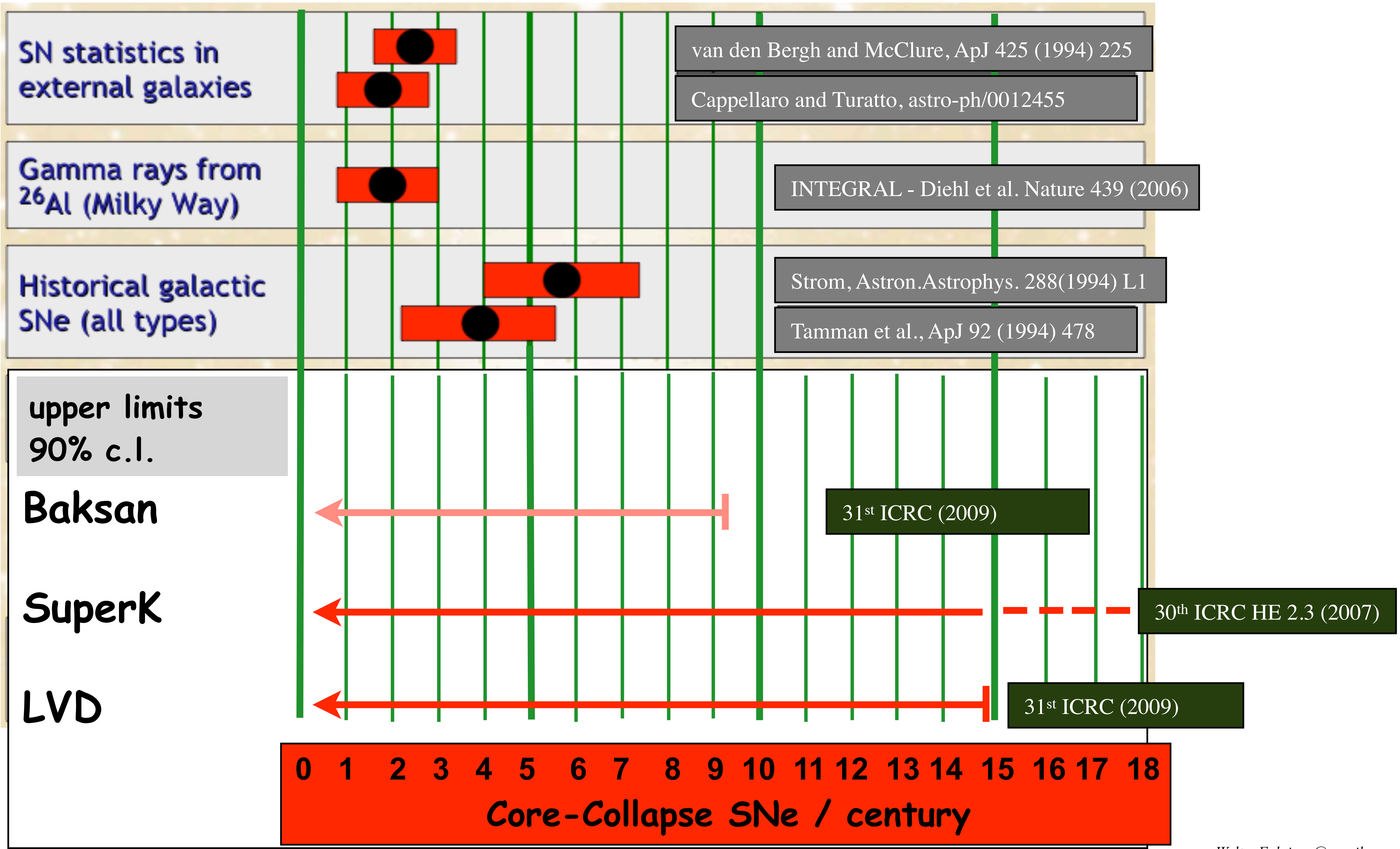
absence of a firm model.

you are not allowed to make a fine tuning in the search for ν bursts.

Walter.Fulgione@gmail.com

Rate of Core Collapse SNe in the Galaxy

thanks to G.Raffelt



Walter.Fulgione@gmail.com

model predictions

..even if based on the same general model, different numerical experiments give different results.

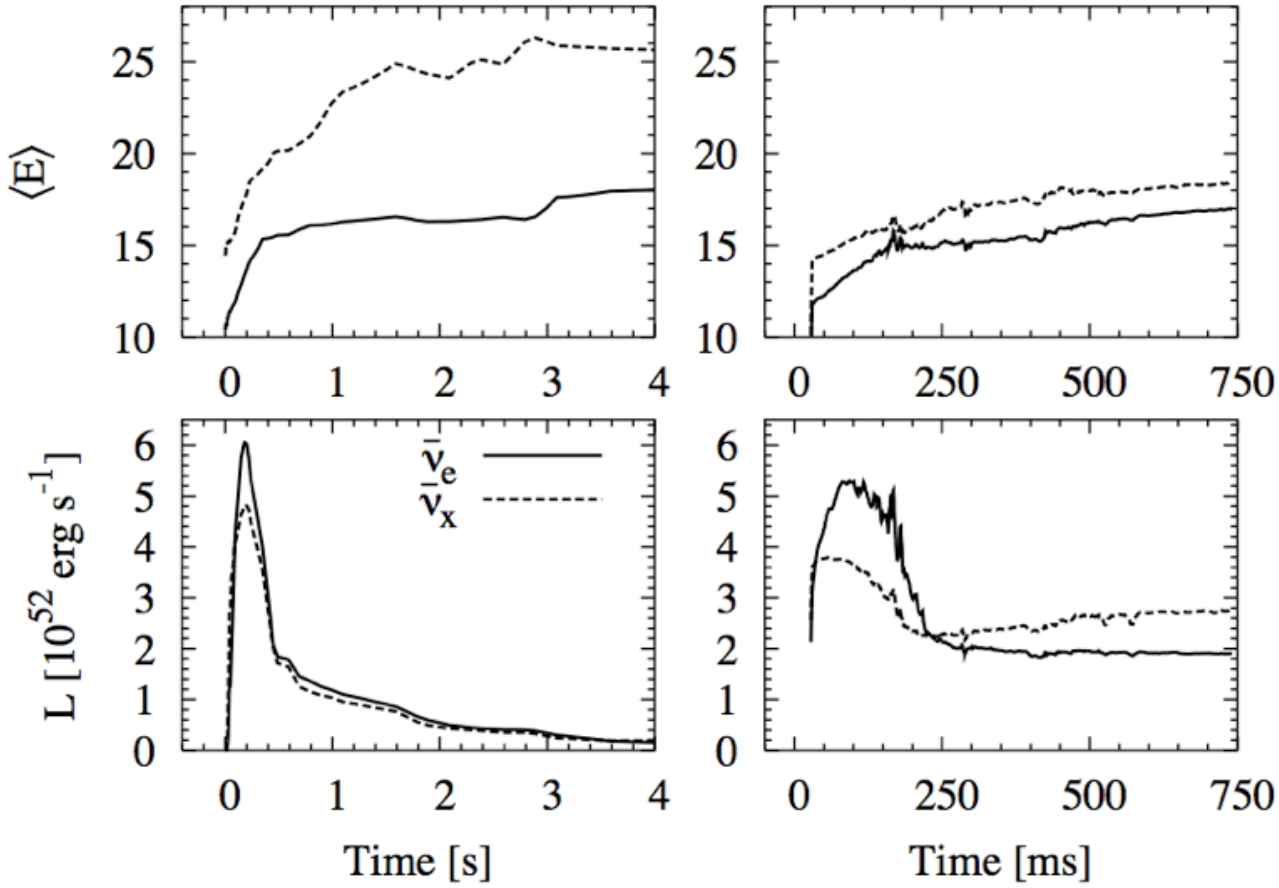


Figure 1. Supernova $\bar{\nu}_e$ and $\bar{\nu}_x$ light curves and average energies. *Left:* Livermore simulation [20]. *Right:* Garching simulation [18].

Differing model predictions in cooling phase:

Model	$\langle E_0(\nu_e)\rangle$	$\langle E_0(\bar{\nu}_e)\rangle$	$\langle E_0(\nu_x)\rangle$	$\frac{\Phi_0(\nu_e)}{\Phi_0(\nu_x)}$	$\frac{\Phi_0(\bar{\nu}_e)}{\Phi_0(\nu_x)}$
Garching (G)	12	15	18	0.8	0.8
Livermore (L)	12	15	24	2.0	1.6

A.Dighe TAUP 2009, Rome, Italy

G. G. Raffelt, M. T. Keil, R. Buras, H. T. Janka and M. Rampp, astro-ph/0303226

T. Totani, K. Sato, H. E. Dalhed and J. R. Wilson, Astrophys. J. 496, 216 (1998)

dependence on the model

(Reprinted from Nature, Vol. 251, No. 5475, pp. 485–486, October 11, 1974)

Possible antineutrino pulse of extraterrestrial origin

WE report an unusual event observed during our search for electron antineutrino $\bar{\nu}_e$ bursts of extraterrestrial origin[1]. Our experiment uses a deep underground $\bar{\nu}_e$ burst-detector station, adjacent to the Brookhaven Solar Neutrino Observatory[2] at a depth of 4,400 metres water equivalent (m.w.e.) in the Homestake Gold Mine in Lead, South Dakota. At this station we have placed a number of large water Cerenkov

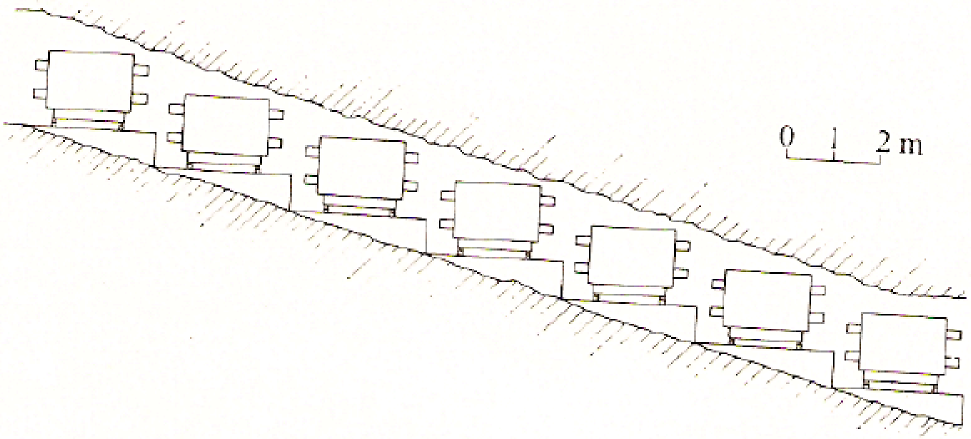


Fig. 1 Arrangement of water Cerenkov counters in a tunnel 1,480 m below surface in the Homestake Mine in Lead, South Dakota. The lowest right hand counter is No. 1 and the highest left hand one is No. 7.

over the six counters, the second group involved six pulses and the third group eight pulses. These three groups used up 23 of the 24 available readout channels leaving only one readout channel available for the last pulse. From our detector thresholds and pulse height data, we estimate the energy of the particles involved in these pulses to be 20 MeV $\leqslant E \leqslant$ 100 MeV. These pulse heights indicate that the charged particles responsible for these pulses had ranges considerably less than half of the diameter of our counters and so are unlikely to have traversed our counters.

Since our readout channels were completely filled by the four recorded bursts we do not know if there were any subsequent pulses. We only know that 0.8 s after the first pulse, when our transfer to tape was completed, there were no more counts, so that the pulse duration period was less than this time.

Figure 2 shows the time distribution of the observed bursts and Fig. 3 gives the pulse distribution within each burst. Details of the burst data are given in Table 1.

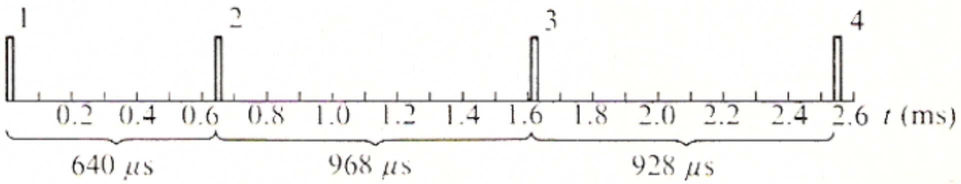


Fig. 2 Time distribution of narrow bursts of observed pulses.

Walter.Fulgione@gmail.com

The ideal experiment

..should have the capabilities to measure: →

- $L_{\nu_e}(t)$, $L_{\bar{\nu}_e}(t)$, $L_{\nu_x}(t)$;
- $\langle E_{\nu_e}(t)\rangle$, $\langle E_{\bar{\nu}_e}(t)\rangle$, $\langle E_{\nu_x}(t)\rangle$;
- and pointing to the source

Table 1. Supernova neutrino detector types and their primary capabilities.

Detector type	Material	Energy	Time	Point	Flavour
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	ν_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	Pb, Fe	y	y	n	All
Radio-chemical	^{37}Cl, ^{127}I, ^{71}Ga	n	n	n	ν_e

Walter.Fulgione@gmail.com

The ideal experiment

..should have the capabilities to measure: →

- $L_{\nu_e}(t)$, $L_{\bar{\nu}_e}(t)$, $L_{\nu_x}(t)$;
- $<E_{\nu_e}(t)>$, $<E_{\bar{\nu}_e}(t)>$, $<E_{\nu_x}(t)>$;
- and pointing to the source

Table 1. Supernova neutrino detector types and their primary capabilities.

Detector type	Material	Energy	Time	Point	Flavour
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	ν_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	Pb, Fe	y	y	n	All
Radio-chemical	^{37}Cl, ^{127}I, ^{71}Ga	n	n	n	ν_e

Moreover some measurement requires the comparison among the results obtained by detectors placed in different locations, to disentangle ν properties from astrophysical parameters. [MSW Earth matter effects].

Walter.Fulgione@gmail.com

..after SN1987A

The ν-burst must be recognized independently from any other signal

The only ν–burst detected (SN1987A) was recognized because of its correlation with the electromagnetic signal.

and promptly.

to be used to triggering all others detectors (gravitational waves, electromagnetic and particle detectors), allowing the study of the event since its first instant.

"We must take special care not to miss anything when one occurs."

Walter.Fulgione@gmail.com

The Supernova Early Warning System

SNEWS: The Supernova Early Warning System
Pietro Antonioli,et al., New J. Phys. 6,114 (2004)

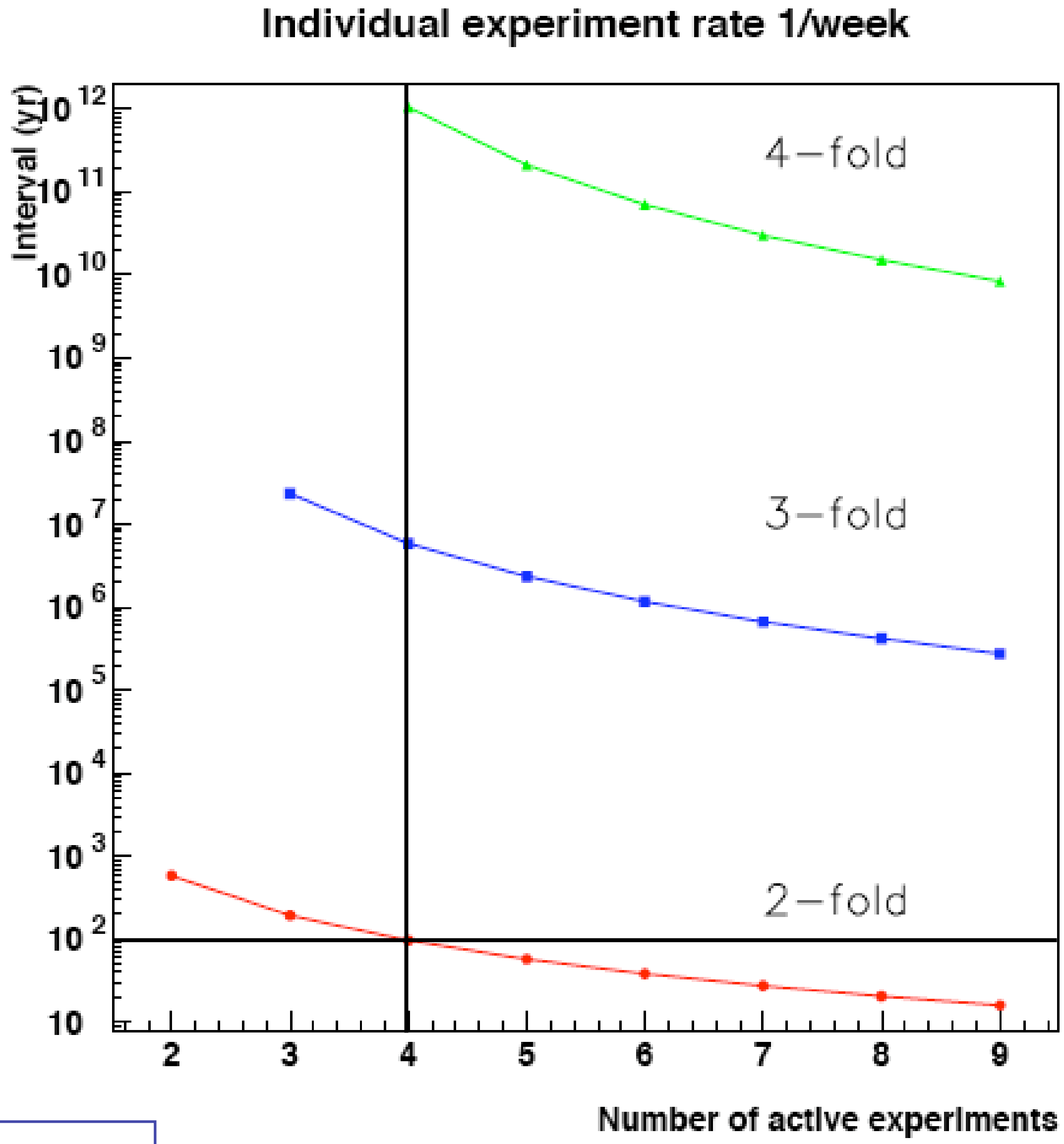
"..The fundamental motivation for the SNEWS **coincidence** is the reduction of false alert.

each detector develops its technique to disentangle burst candidates.

The arrival time of the candidate is sent to the central coincidence server at Brookhaven N.L. (backup server at Bologna)

The requirement for an experiment to participate in SNEWS is an average alarm rate of no more than 1 per week (now 1 per 10 days).

assuming the limit conditions of single experiment alarm rate = 1/ week, the expected average interval between **accidental coincidence** will be:



Walter.Fulgione@gmail.com

SNEWS

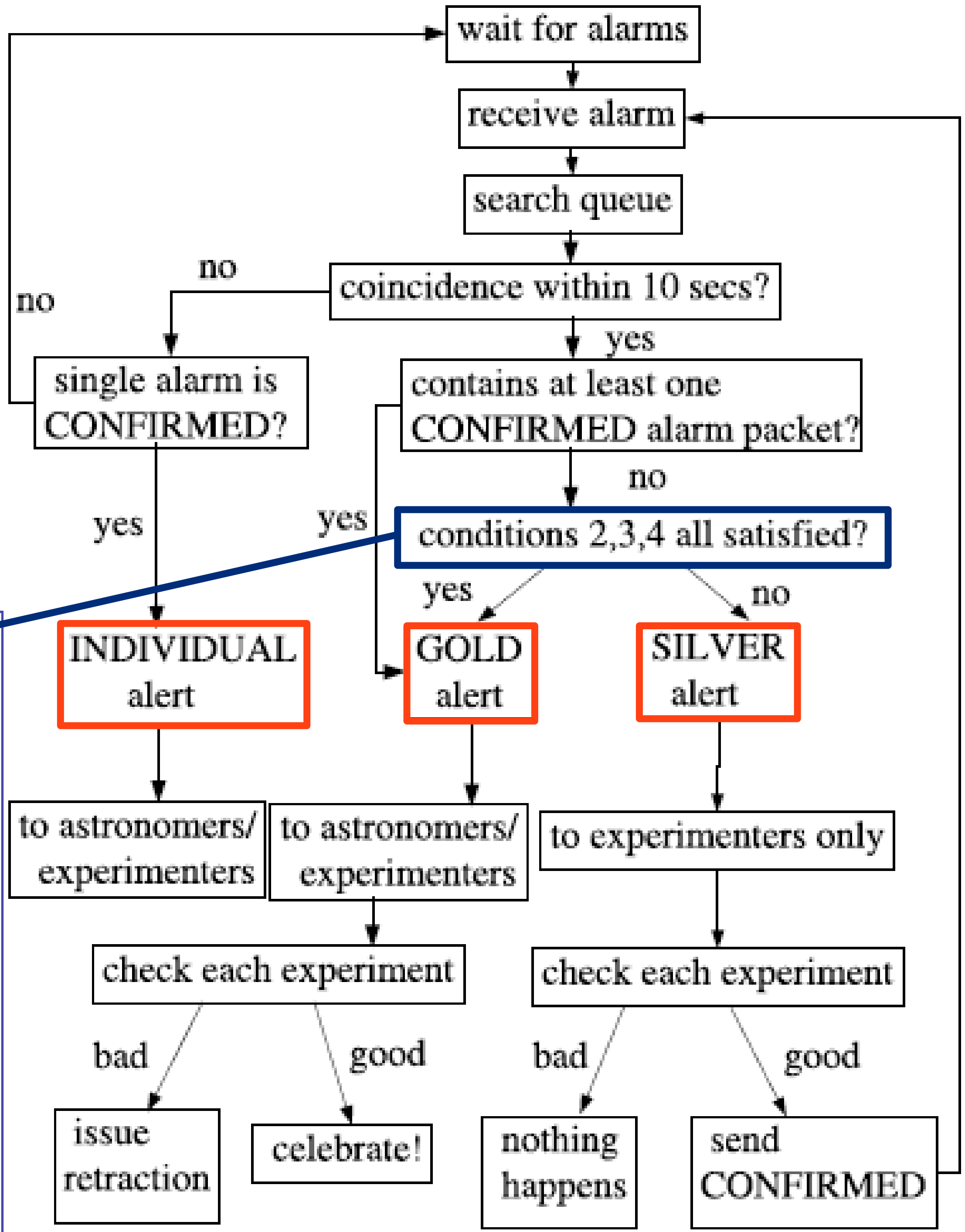
- **GOLD** alerts are intended for automated dissemination to the community [http://snews.bnl.gov]
- **SILVER** alerts will be disseminated among the experimenters requiring human checking.

1) coincidence in 10 sec.

2) **at least two of the experiments involved are in different Labs.**

3) two or more of the alarms flagged as GOOD.

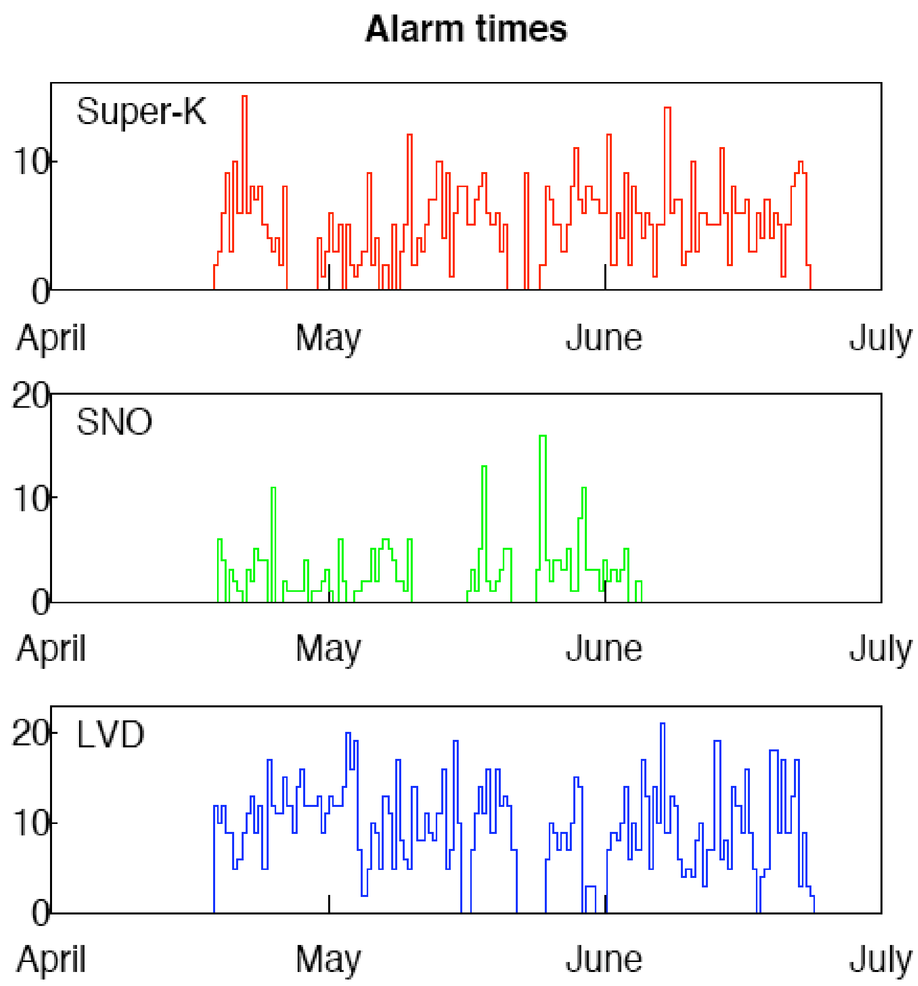
4) for at least two of the experiments involved the rate of alarms for past time intervals, **10min, 1hour, 10hours, 1day, 3days, 1week, 1month**, preceding the candidate, must be consistent with: λ_{max}=**1/week**



Walter.Fulgione@gmail.com

SNEWS - high rate test

- During April-June 2001 Superk, LVD and SNO prformed an “high rate test”.
- Two purposes:
  - check the software robustness
  - increase our confidence on the expected coincidence rates.
- lowering the thresholds of the experiments’ SN monitors;
- increasing the time window from 10 to 400 sec.



Experiment Combination	Common live time (days)	SK/SNO/LVD alarms	N_{coinc} expected (eqn)	N_{coinc} expected (shift)	N_{coinc} observed raw (unique)
SK/SNO	$24.1^{+1.1}_{-0.5}$	334/187/-	$24.1^{+1.0}_{-2.2}$	24.9 ± 7.0	30 (17)
SK/LVD	$44.6^{+1.1}_{-0.9}$	576/-/1025	$122.6^{+4.9}_{-5.8}$	133.8 ± 13.7	149 (112)
SNO/LVD	$27.7^{+0.7}_{-0.6}$	-/189/646	$40.8^{+1.6}_{-2.0}$	46.4 ± 9.2	52 (41)
SK/SNO/LVD	$19.6^{+1.1}_{-0.6}$	276/144/431	$2.9^{+0.3}_{-0.5}$	4.2 ± 2.9	4 (4)

SNEWS started to be full operational on July 2005 after a long period of commissioning.

Walter.Fulgione@gmail.com

Outline

- The neutrino signal
  - neutrino burst from core collapse SN
  - neutrino oscillations
  - open problems

- Core collapse neutrino detection
  - Main difficulties
  - rate
  - model predictions
  - SNEWS

- Different strategies
  - Water Cherenkov [Superk]
  - Long string Cherenkov [IceCUBE]
  - Scintillators [LVD and Borexino]

Walter.Fulgione@gmail.com

Super-Kamiokande

22.5 kton H_2O fiducial mass

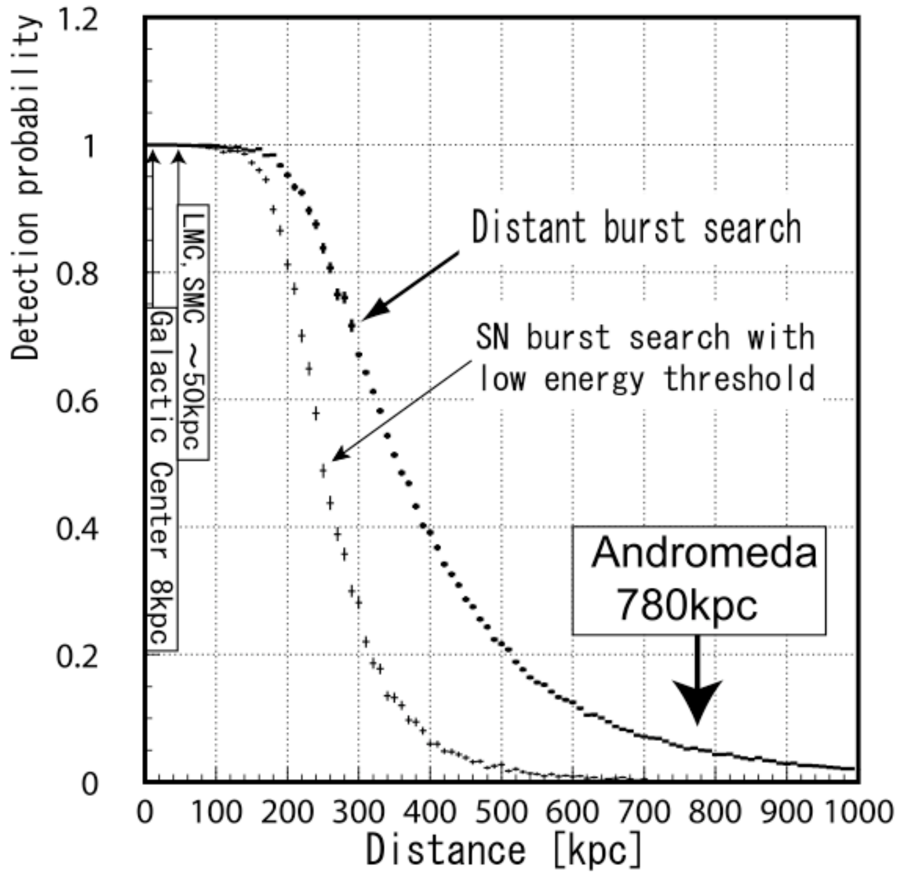
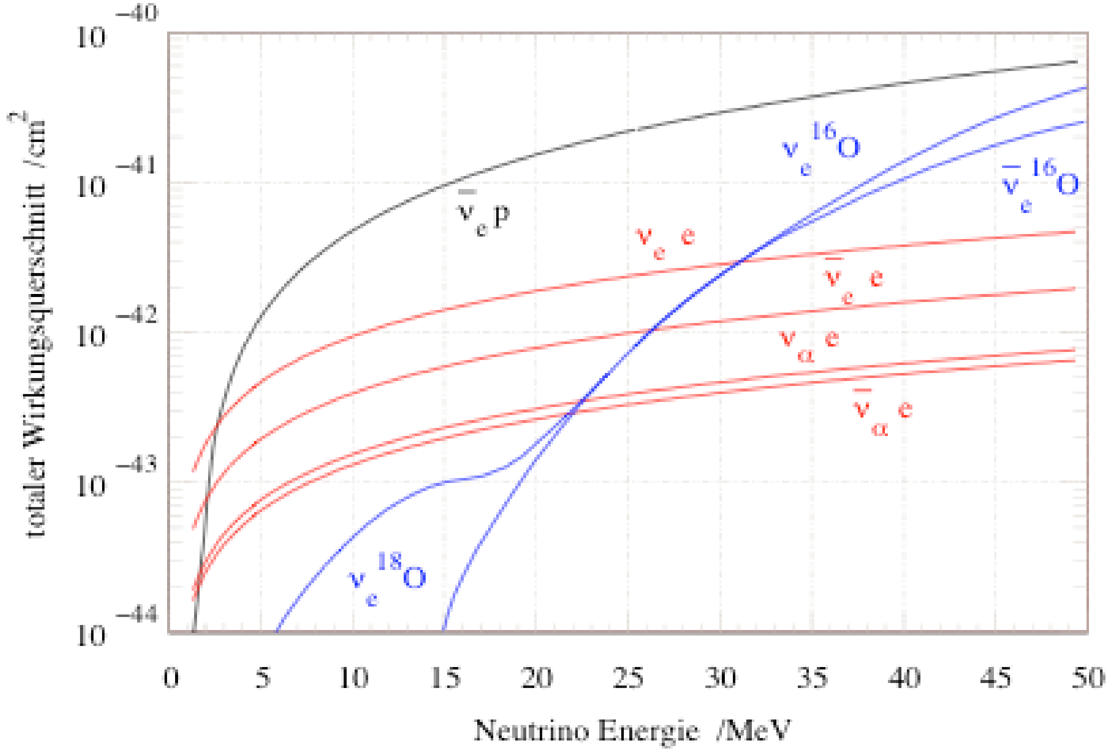


FIG. 6.—Probability of detecting supernovae assuming a specific supernova model at SK. Full (100%) detection probability is retained out to around 100 kpc.



$$\bar{\nu}_e + p \rightarrow n + e^+ \quad (88\%/89\%), \quad (1)$$

$$\nu_e + e^- \rightarrow \nu_e + e^- \quad (1.5\%/1.5\%), \quad (2)$$

$$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^- \quad (<1\%/<1\%), \quad (3)$$

$$\nu_x + e^- \rightarrow \nu_x + e^- \quad (1\%/1\%), \quad (4)$$

$$\nu_e + {}^{16}\mathrm{O} \rightarrow e^- + {}^{16}\mathrm{F} \quad (2.5\%/<1\%), \quad (5)$$

$$\bar{\nu}_e + {}^{16}\mathrm{O} \rightarrow e^+ + {}^{16}\mathrm{N} \quad (1.5\%/1\%), \quad (6)$$

$$\nu_x + {}^{16}\mathrm{O} \rightarrow \nu_x + \mathrm{O}^*/\mathrm{N}^* + \gamma \quad (5\%/6\%), \quad (7)$$

SEARCH FOR SUPERNOVA NEUTRINO BURSTS AT SUPER-KAMIOKANDE
M. Ikeda, et al. The Astrophysical Journal, 669:519Y524, 2007 November 1

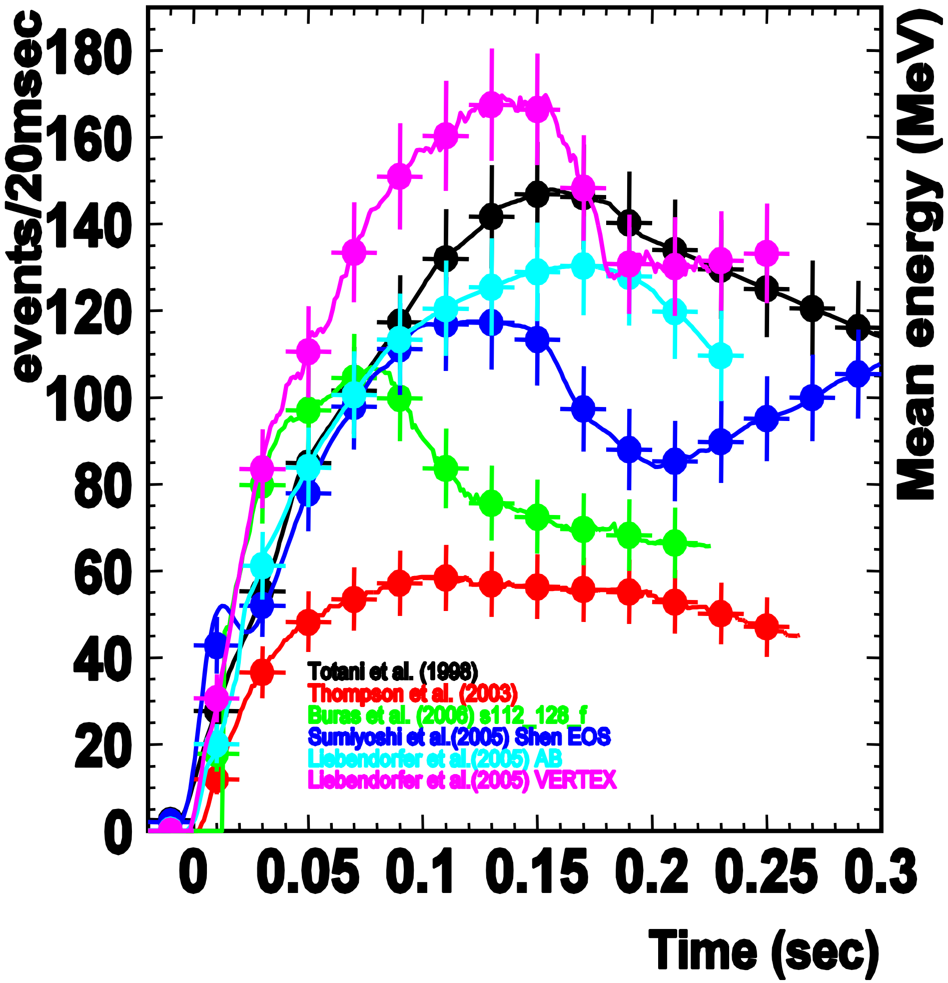
Walter.Fulgione@gmail.com

M.Nakahata, Neutrino 2008

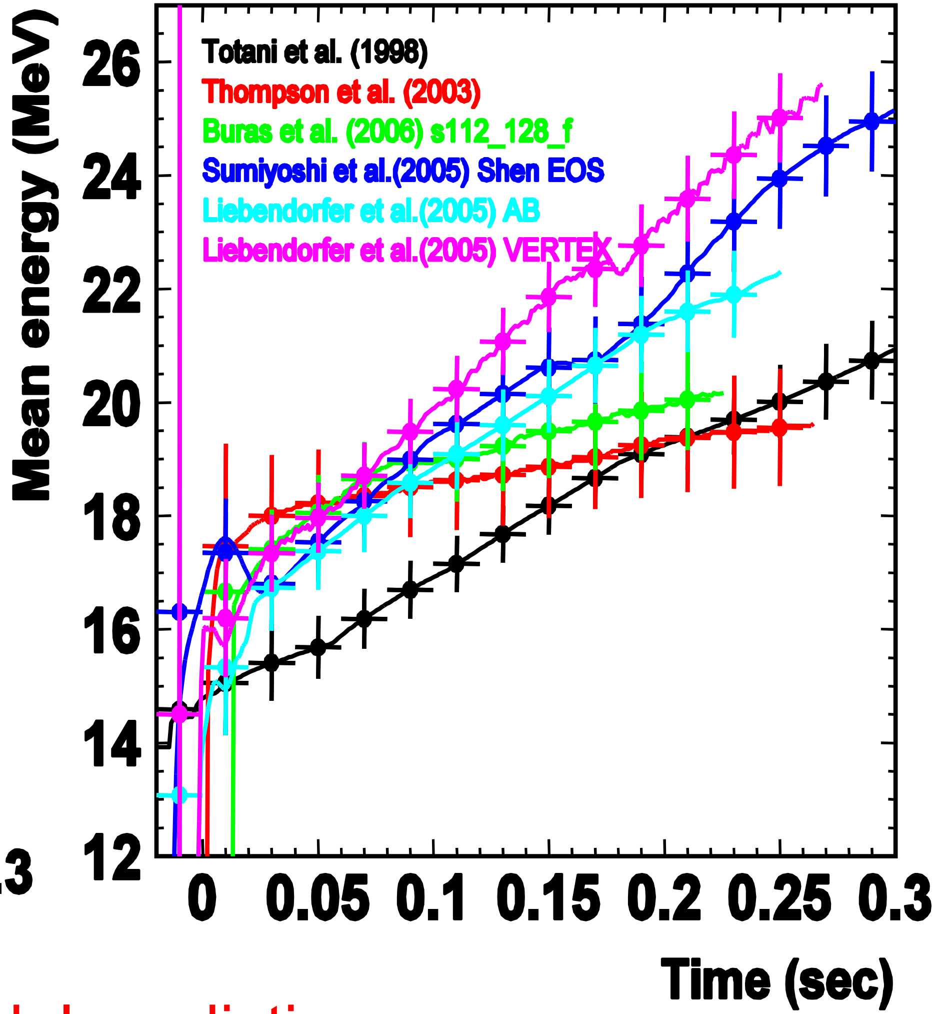
Super-K: Time variation measurement by $\overline{\nu}_e$+p

Assuming a supernova at 10kpc.
$\overline{\nu}_e p \rightarrow e^+ n$ events give direct energy information ($E_e = E_\nu - 1.3$MeV).

Time variation of event rate



Time variation of mean energy

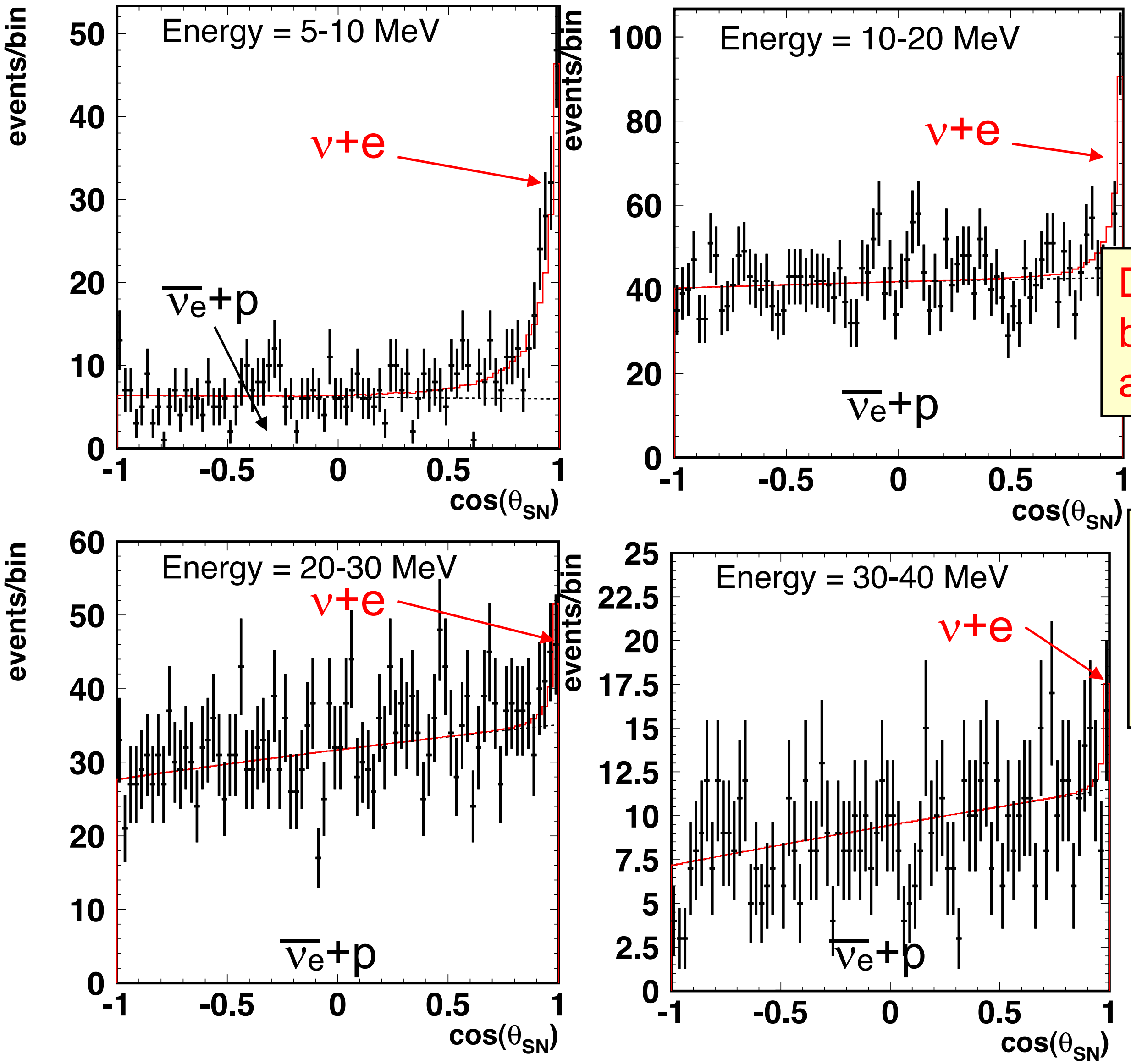


Enough statistics to discuss model predictions

M.Nakahata, Neutrino 2008

Pointing

Super-K: ν+e scattering events



SN at 10kpc

Direction of supernova can be determined with an accuracy of ~5 degree.

Spectrum of ν+e events can be statistically extracted using the direction to supernova.

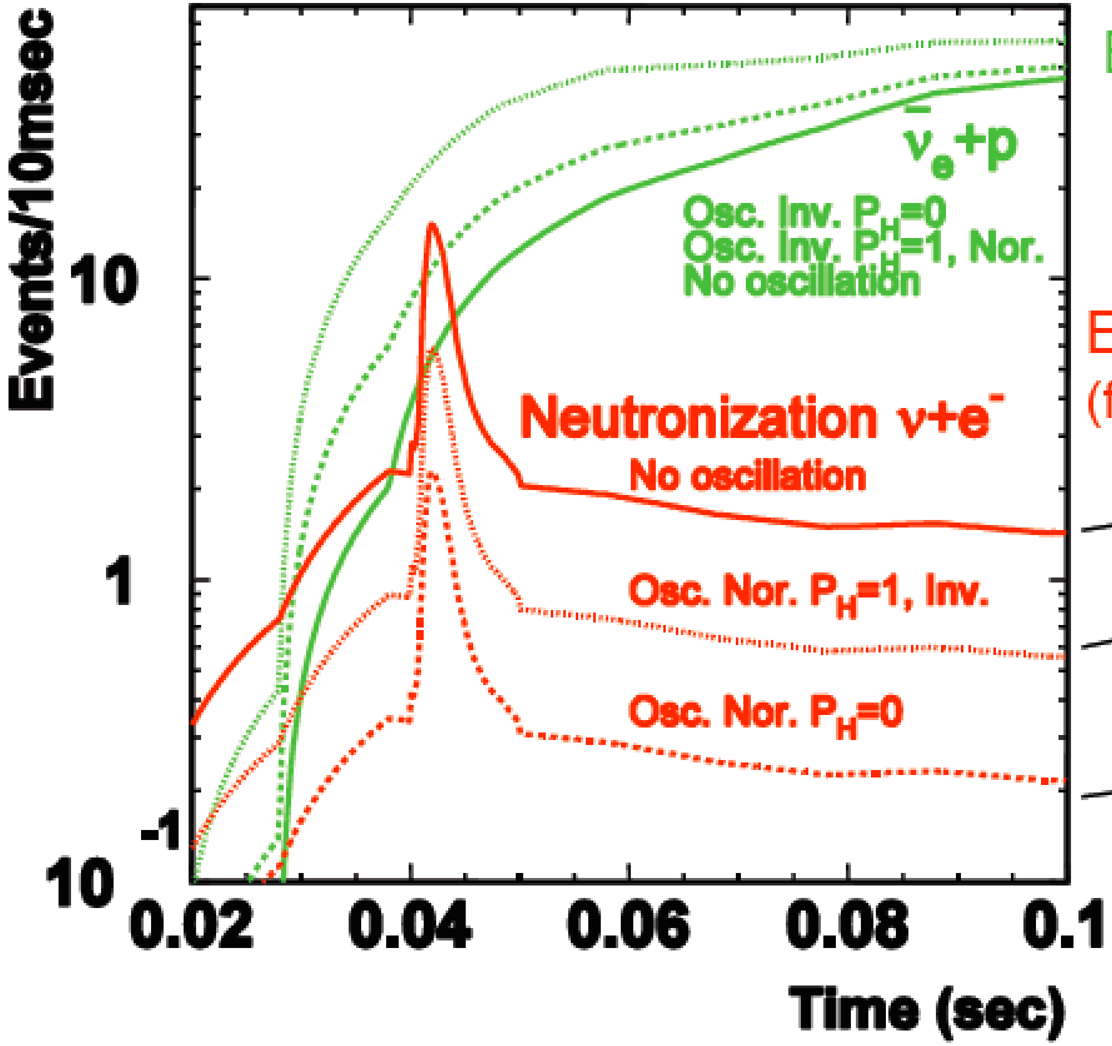
Neutrino flux and spectrum from Livermore simulation

Walter.Fulgione@gmail.com

Super-K: Neutronization burst ($e^- + p \rightarrow n + \nu_e$)

SN at 10kpc

Neutrino flux and spectrum from Livermore simulation



Event rate of $\bar{\nu}_e$+p events

Event rate of neutronization burst (forward peaked ν+e scattering events)

No oscillation

Normal P_H=1 or Inverted hierarchy

Normal hierarchy P_H=0

P_H: crossing probability at H resonance (P_H=0: adiabatic)

Number of events from neutronization burst is 0.9~6 events for SN@10kpc.

$\bar{\nu}_e$p events during this 10msec is about 8 - 30 events.

N.H. +adiamacitc case: neutronization=0.9ev., $\bar{\nu}_e$p = 14 ev.(1.4 for SN direction).

Super-Kamiokande on-line

- fiducial mass: **22.5 kton** H_2O
- Energy threshold ~ 7 MeV

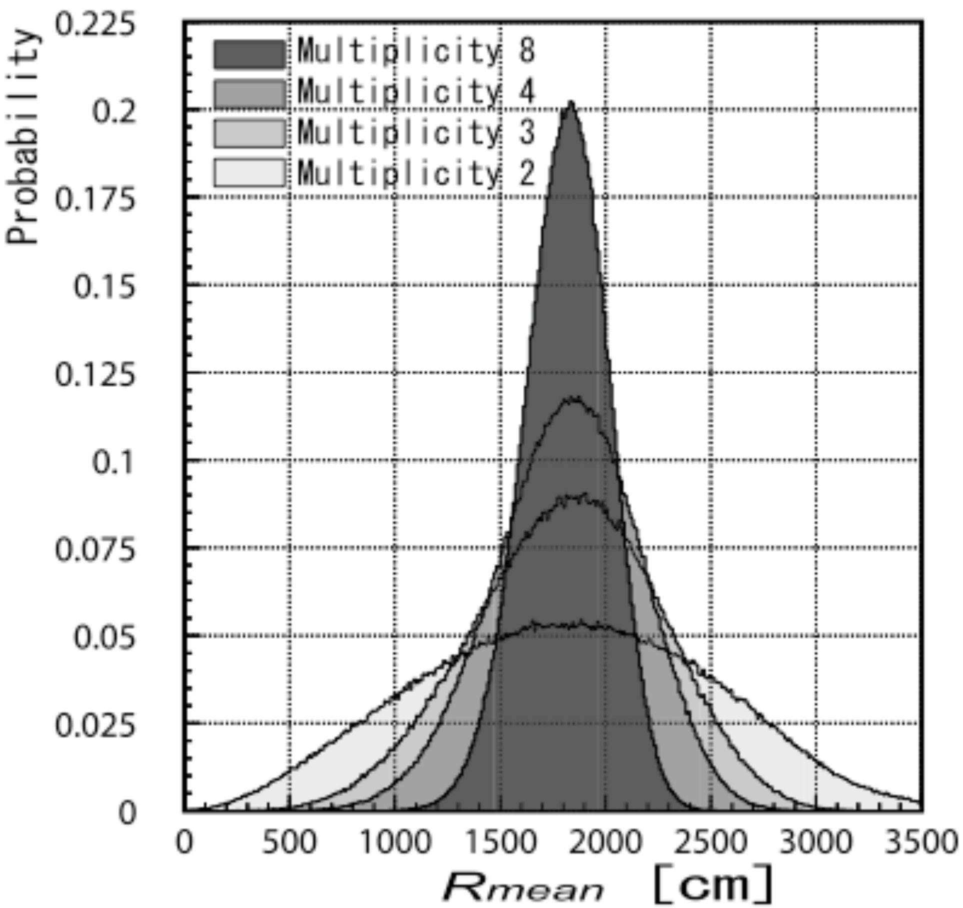


FIG. 2.—Expected R_{mean} distributions of supernova events obtained by Monte Carlo simulation for multiplicities of 2, 3, 4, and 8.

(R_{mean}). R_{mean} is defined by the averaged spatial distance between each event,

$$R_{mean} = \frac{\sum_{i=1}^{M-1} \sum_{j=i+1}^{M} |\boldsymbol{r}_i - \boldsymbol{r}_j|}{{}_M C_2}, \quad (8)$$

- **event multiplicity in 20 s window, N**
- **spatial analysis of vertex, R_{mean}**

HP = uniformity = neutrino burst

candidate if N > N_{th} and R_{mean} > R_{th}

"Because reconstruction of thousands of events in a real SN burst could require an hour or more to fully analyze, pre-alarms are generated after 100 events if a candidate is found."

on-line search (~ 1 min)

"A preliminary estimate of the SN direction from elastic scattering in few hours"

SNEWS: The Supernova Early Warning System
Pietro Antonioli,et al., New J. Phys. 6,114 (2004)

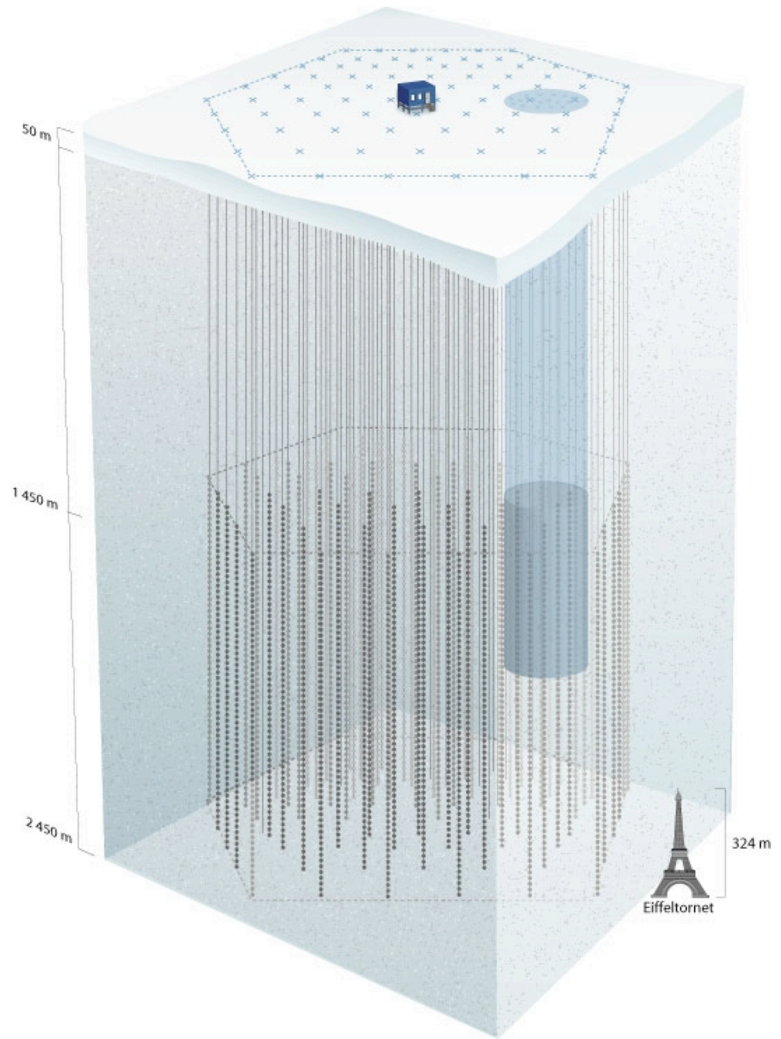
Walter.Fulgione@gmail.com

AMANDA / IceCUBE

Jacobsen, Halzen, Zas PRD **49** (1994) 1758 first proposed.

Follow-up calculation for IceCube presented in JCAP **6** (2003) - Dighe, Keil, Raffelt.

AMANDA Ph.D. thesis by T. Feser



- The detection comes from increase in background counts across the entire array.

- Principal detection channel is IBD.
  The observable signal is totally dominated by events where a e^{+} shower yields a single photoelectron hit in a single DOM.

AMANDA / IceCUBE

- Effective volume, V_{eff}, approximate a sphere around each module of 5 m radius.

- Currently, with ~ 3500 deep ice modules (59/86 strings) detector mass ~ 2 Mton.
  (Full IceCube ~ 5000 modules detector mass ~ 3 Mton)

$$V_{eff} \propto N_{\nu} \cdot A \cdot \Lambda_{abs} \propto E_{e+} \cdot A \cdot \Lambda_{abs} \propto E_{\nu}^{3} \cdot A \cdot \Lambda_{abs}$$

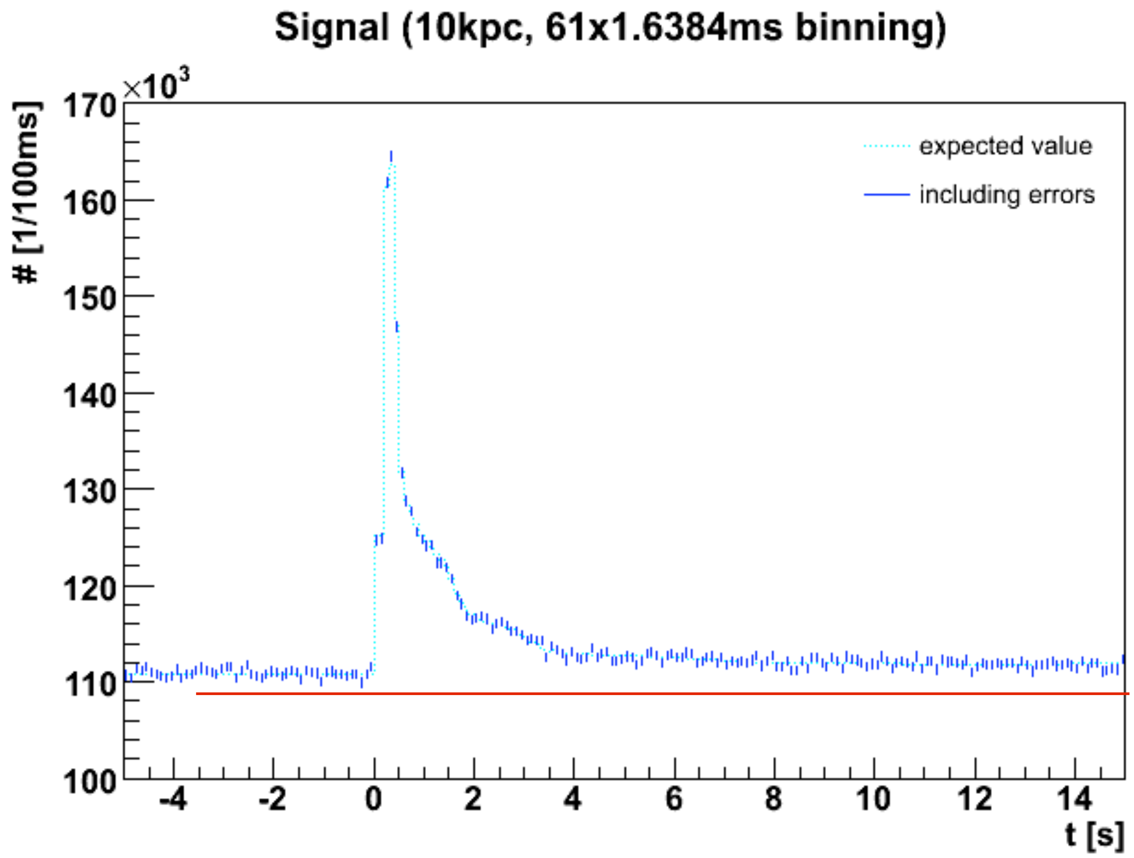
- Neutrino effective volume is proportional to:
  - E_{ν}^{3} : 2 powers from σ 1 power from e^{+}/e^{-} track length;
  - Λ the optical pathlength in the ice that depends on depth (each module may be treated independently);
  - A, the photocatode area of the OM.

- Thus, detection is sensitive to neutrino energy spectra - or, stated another way, effective volumes are all dependent on SN models / oscillations, & c.

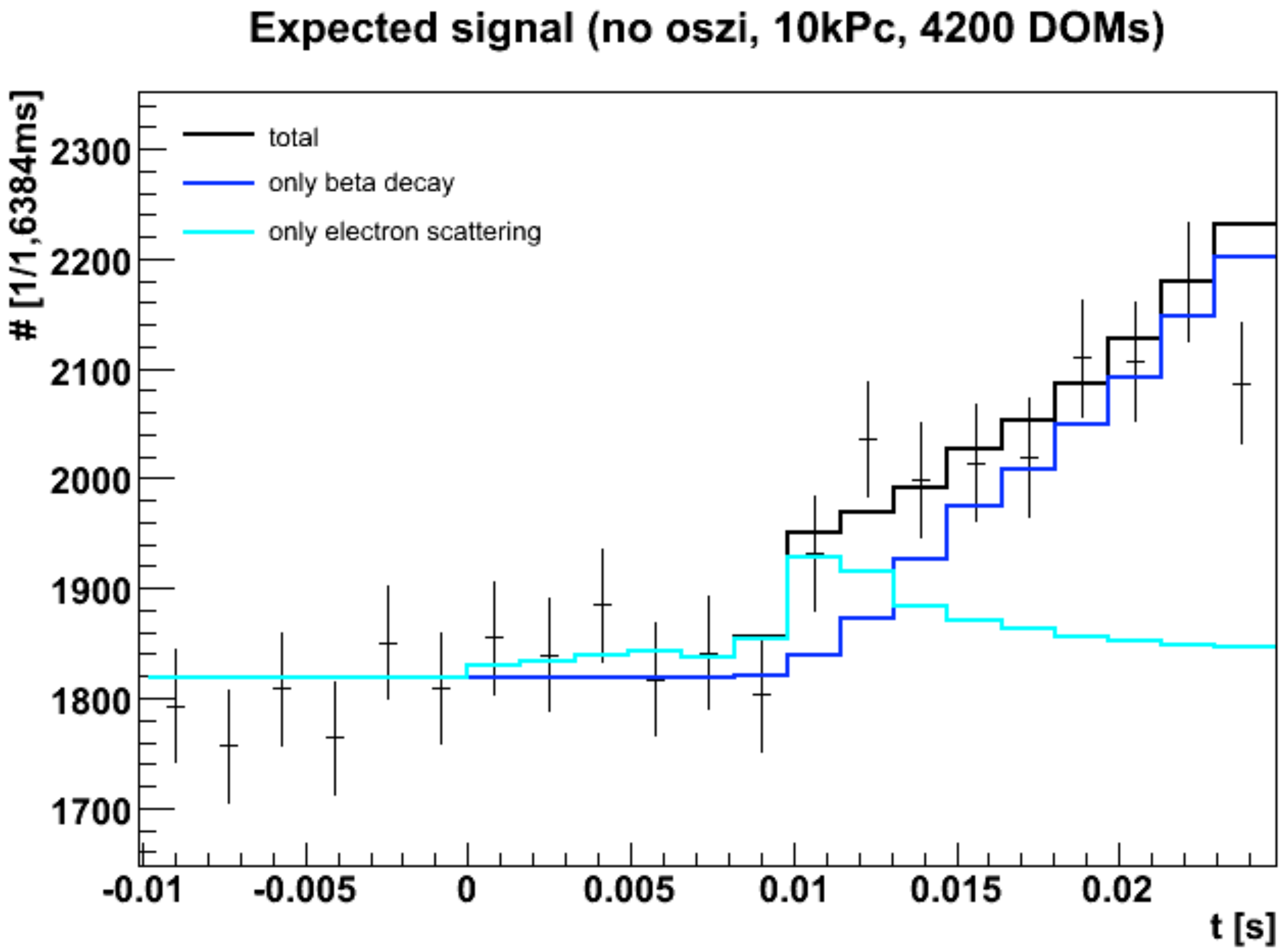
Advantages

- ➡ enormous volume provides high-statistics measurement. Time binning can be made fine.
- ➡ Signal from 1987A SN at galactic center would produce 475000 excess counts in ~10 sec window on a background of 12 $\times 10^6$ counts from noise - S/N ~ 150:1 in full IceCube;

~ 100 counts/DOM during 10 sec for a SN1987A-like at galactic center

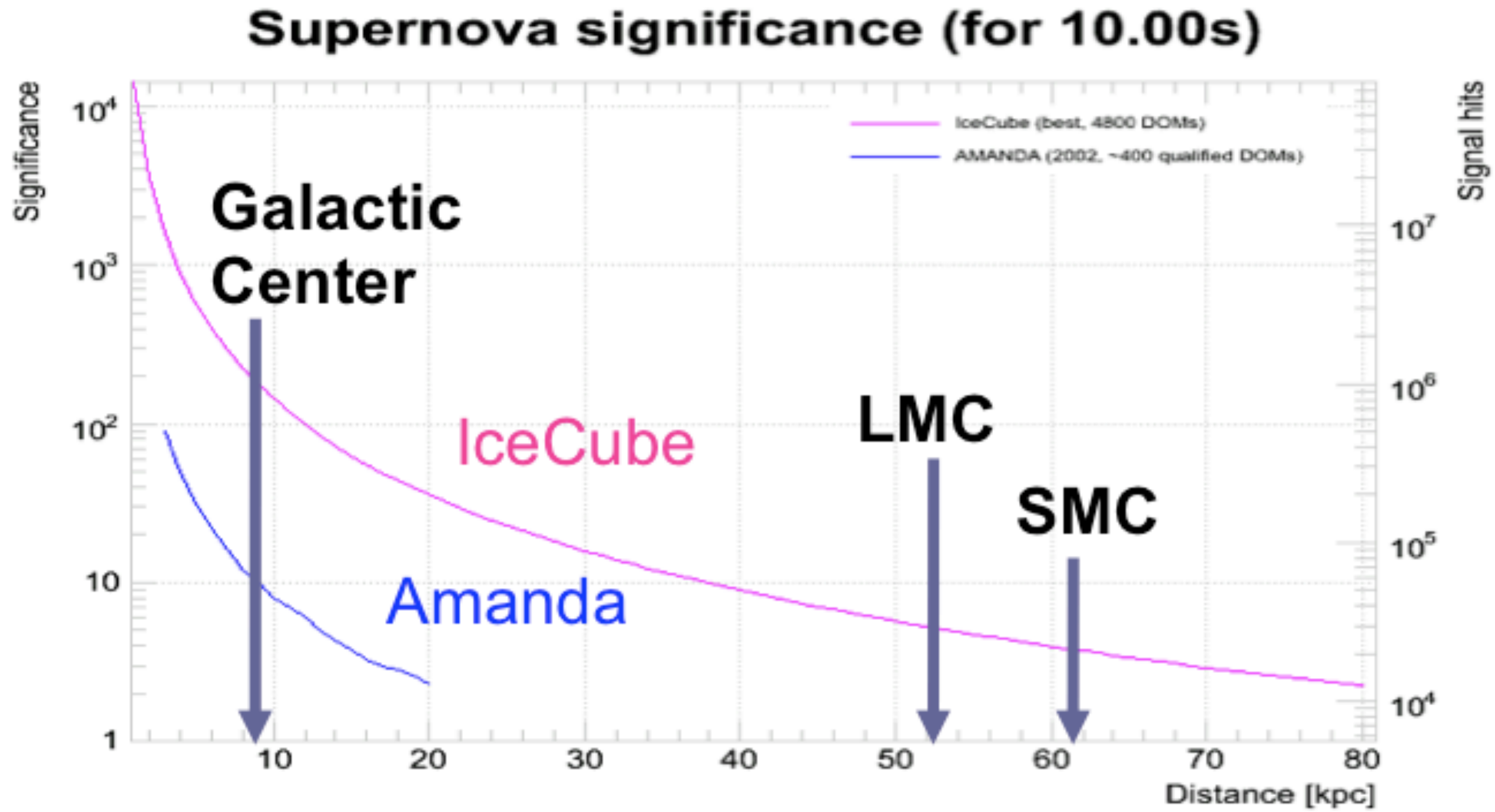


Detection of neutronization peak



Neutronization fluence is largely independent of SN model and progenitor mass - useful as a neutrino standard candle. IceCube detection is marginal.

AMANDA / IceCUBE



today 59/86 strings = 3540/5160 DOM

- IceCube longevity gives good chance of observing significant galactic core collapse event.

- **IceCube is operating and is sensitive to GC events NOW,**
  It participates in SNEWS since 2007

AMANDA / IceCUBE on-line

Search for supernova neutrino bursts with the AMANDA detector
A.Bouchta et al., Astrop. Phys. 16,4 (2002) 345

AMANDA SUPERNOVA TRIGGER ALGORITHM (ASTA)

noise rates:

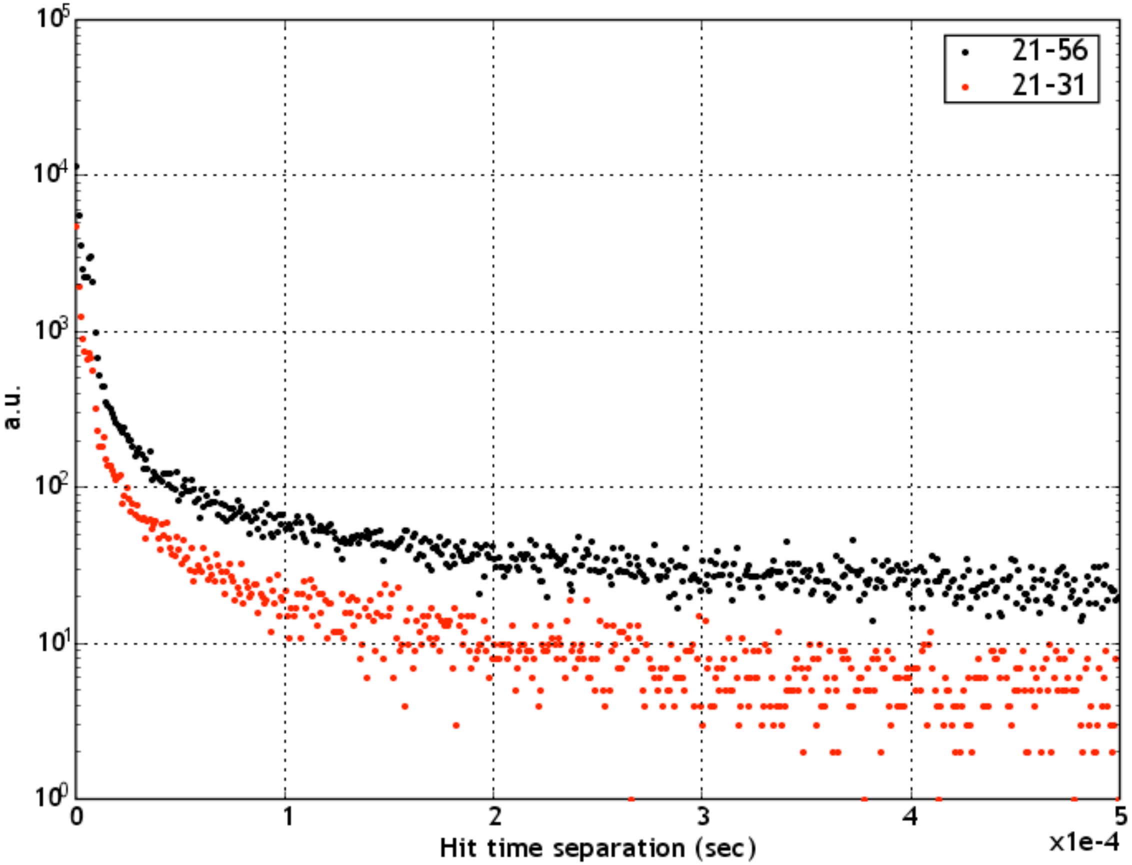
- noise rate without dead time: 700 Hz;
- noise rate with suppression of 50μs: 300Hz;

on-line search over asynchronous 10 s time windows

noise rejection:

- Moving Average Subtraction (over a time window of 1000 s) acting as a high-pass filter;
- uniformity throughout the detector by:

$$\chi^2 = \sum_{i=1}^{N_{\mathrm{OM}}} \left(\frac{n_i - \mu_i - \Delta\mu}{\sigma_i} \right)^2$$

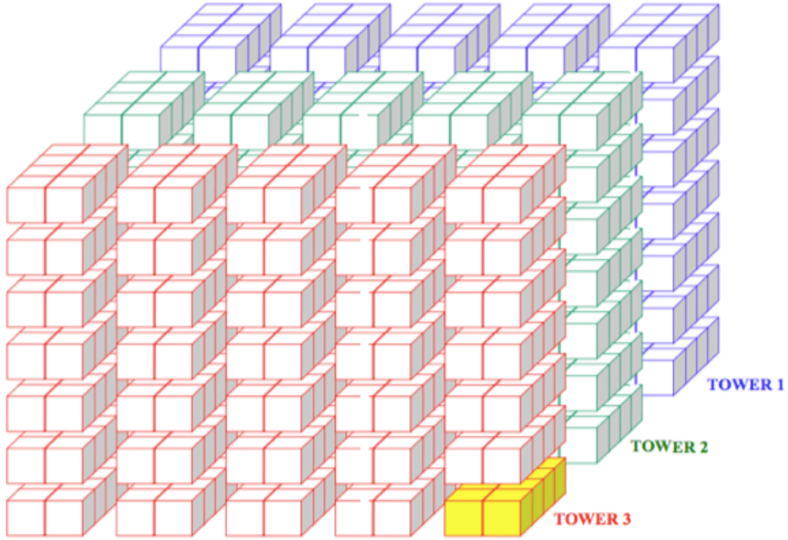


Walter.Fulgione@gmail.com

LVD at LNGS

Scintillator - modular

LVD is an array of 840 counters 1.5 m^3 each,
total target: 1000 ton of C_nH_{2n+2}
900 ton of Fe
divided in three independent, identical "towers".



$\bar{\nu}_e + p \rightarrow e^+ + n$
$(n,p) \rightarrow d + \gamma$

$\nu_e + {}^{12}C \rightarrow {}^{12}N + e^-$

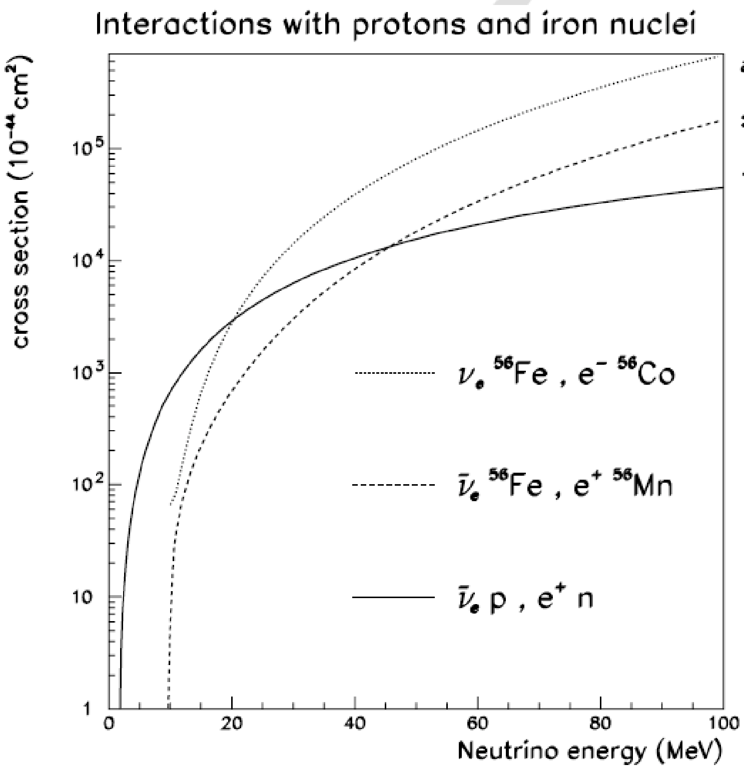
$\bar{\nu}_e + {}^{12}C \rightarrow {}^{12}B + e^+$

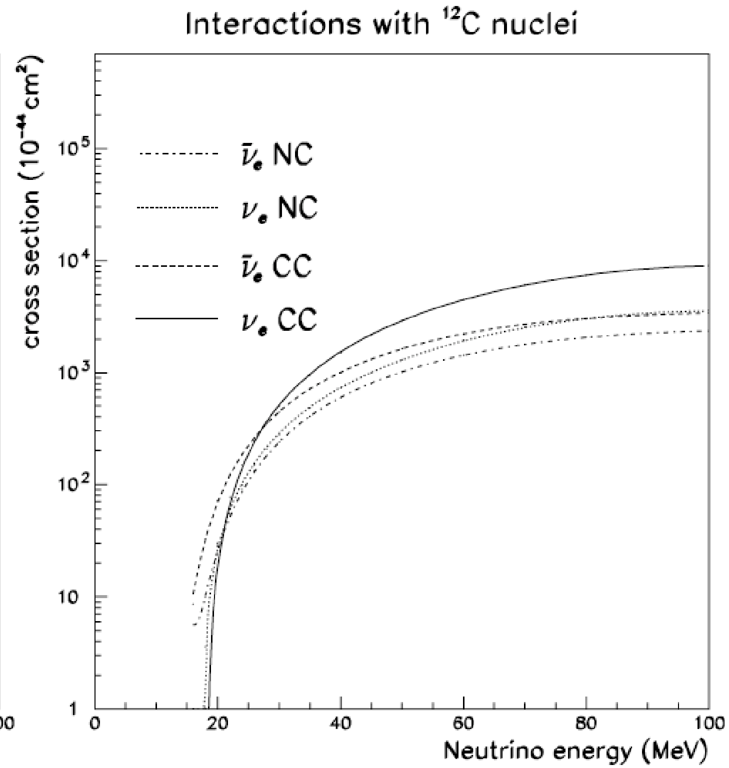
$\nu_i + {}^{12}C \rightarrow \nu_i + {}^{12}C + \gamma$

$\nu_e + {}^{56}Fe \rightarrow {}^{56}Co + e^-$

$\bar{\nu}_e + {}^{56}Fe \rightarrow {}^{56}Mn + e^+$

$\nu_i + Fe \rightarrow \nu_i + Fe + \gamma$



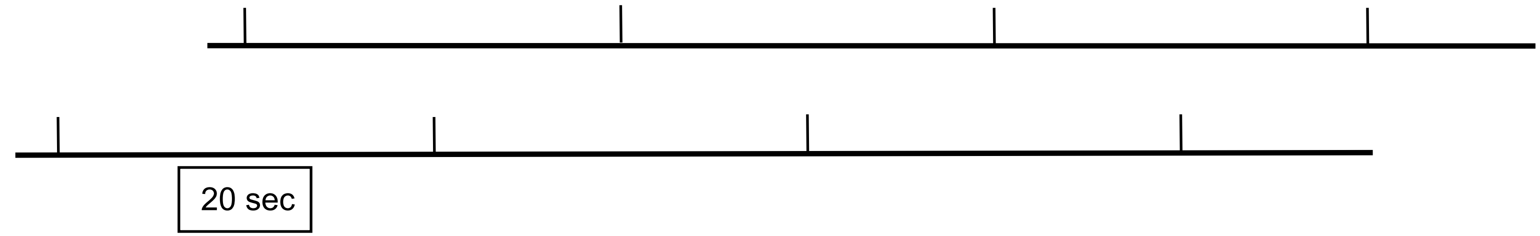


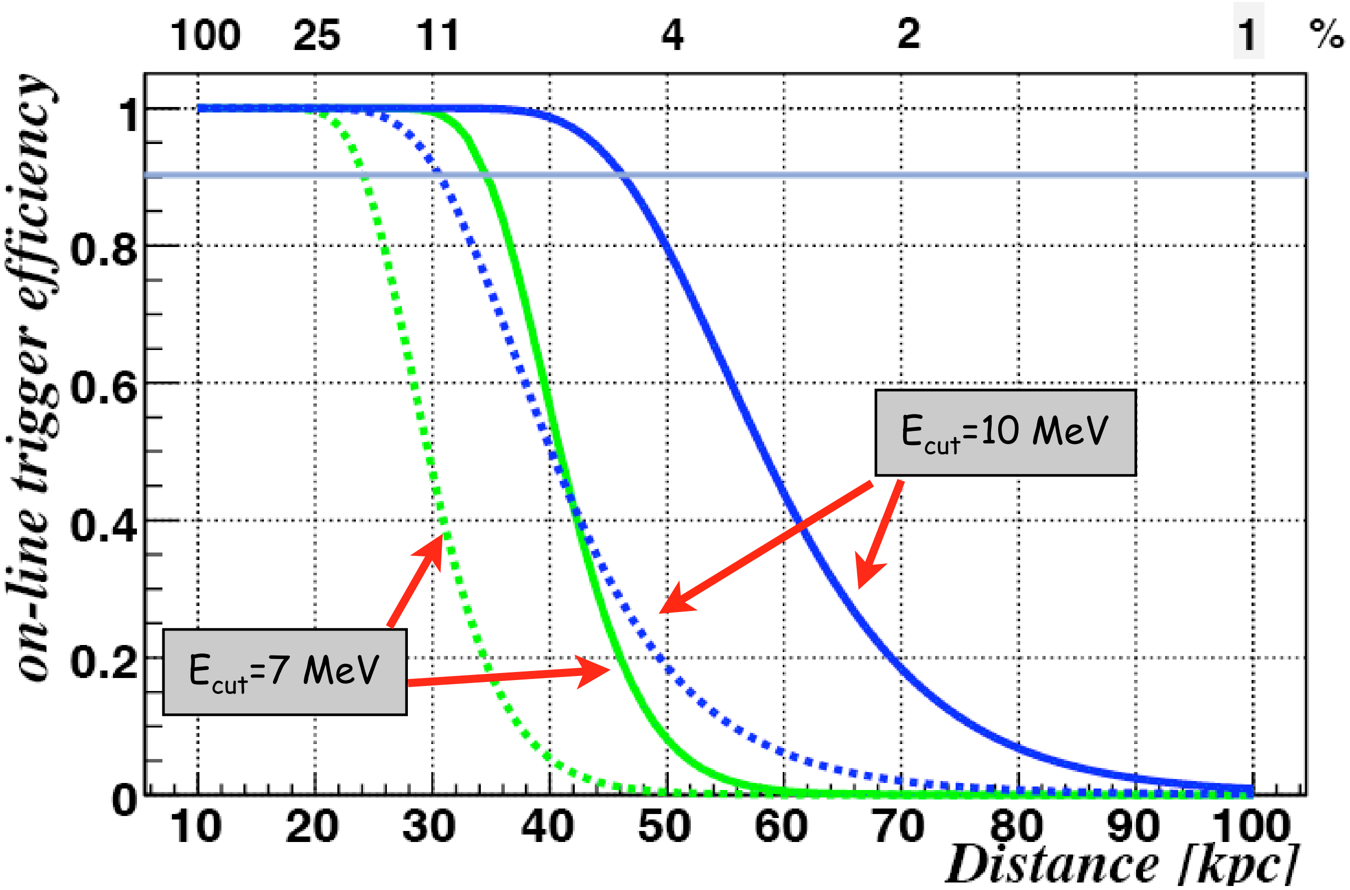
LVD: on-line SN monitor

LVD Collaboration, "On-line recognition of supernova neutrino bursts in the LVD detector", Astropart. Phys. 28, 516-522 (2008) [arXiv:0710.0259].

for prompt alert (SNEWS)

quality cuts applied simultaneously at E_{th}=7 and E_{th}= 10 MeV





The detector sensitivity has been evaluated assuming the signal from SN1987A as a standard candle:

- $E_b = 2.4\cdot10^{53}$ erg;
- average $\bar{\nu}_e$ energy = 14 MeV
- $T_{\nu_x} / T_{\bar{\nu}_e}$ = 1.1

M.L. Costantini, A. Ianni, G. Pagliaroli, F. Vissani, JCAP 05 (2007) 404 astro-ph/0608399(2006)

Walter.Fulgione@gmail.com

LVD: on-line SN monitor

LVD Collaboration, "On-line recognition of supernova neutrino bursts in the LVD detector", Astropart. Phys. 28, 516-522 (2008) [arXiv:0710.0259].

After the application of the cuts:

1. The LVD active mass M_{act} it is not constant in time
2. the time distribution of the signals is Poissonian

Studying the fluctuations of the 5 min counting rate (collected during 100 days) the residual non-Poisson contribution to the fluctuations: $\sigma_{res} = \sqrt{(\sigma^2 - 1.)} < 20\%$

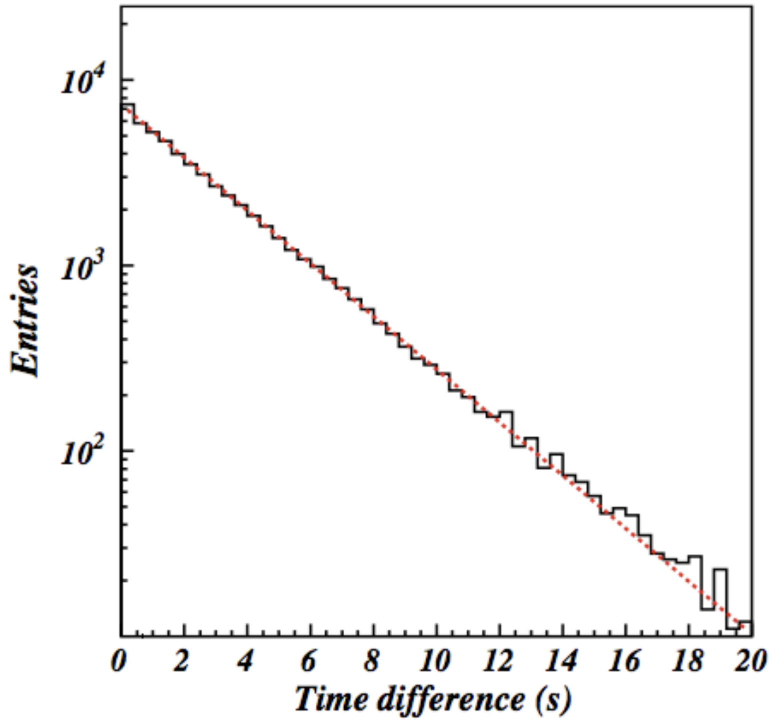


Fig. 5. Distribution of the difference of the arrival time between successive signals, compared with Poisson expectations.

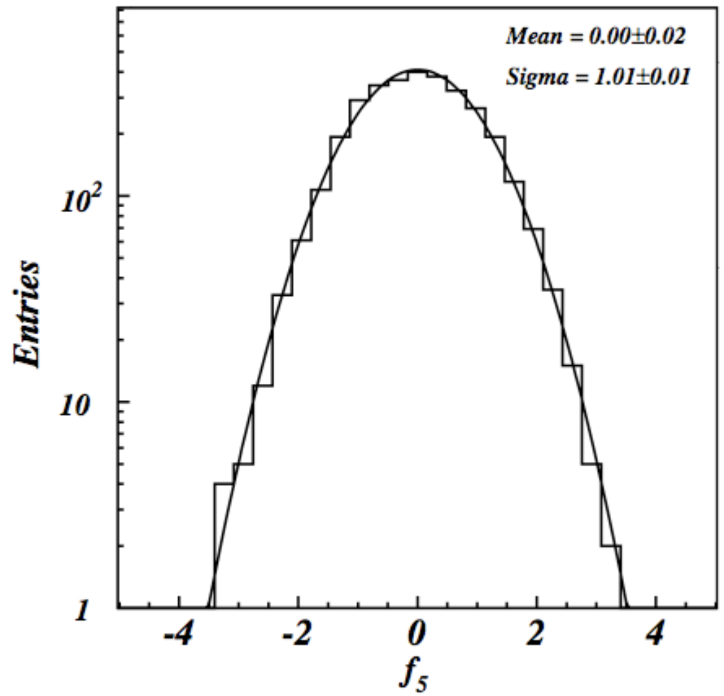


Fig. 6. Distribution of the fluctuations of the 5 min counting rate ($f_5 = (s_5 - \bar{s}_5)/\sigma_{exp}$). The superimposed curve is the free parameters Gaussian fit. The statistics represents 100 days of data taking.

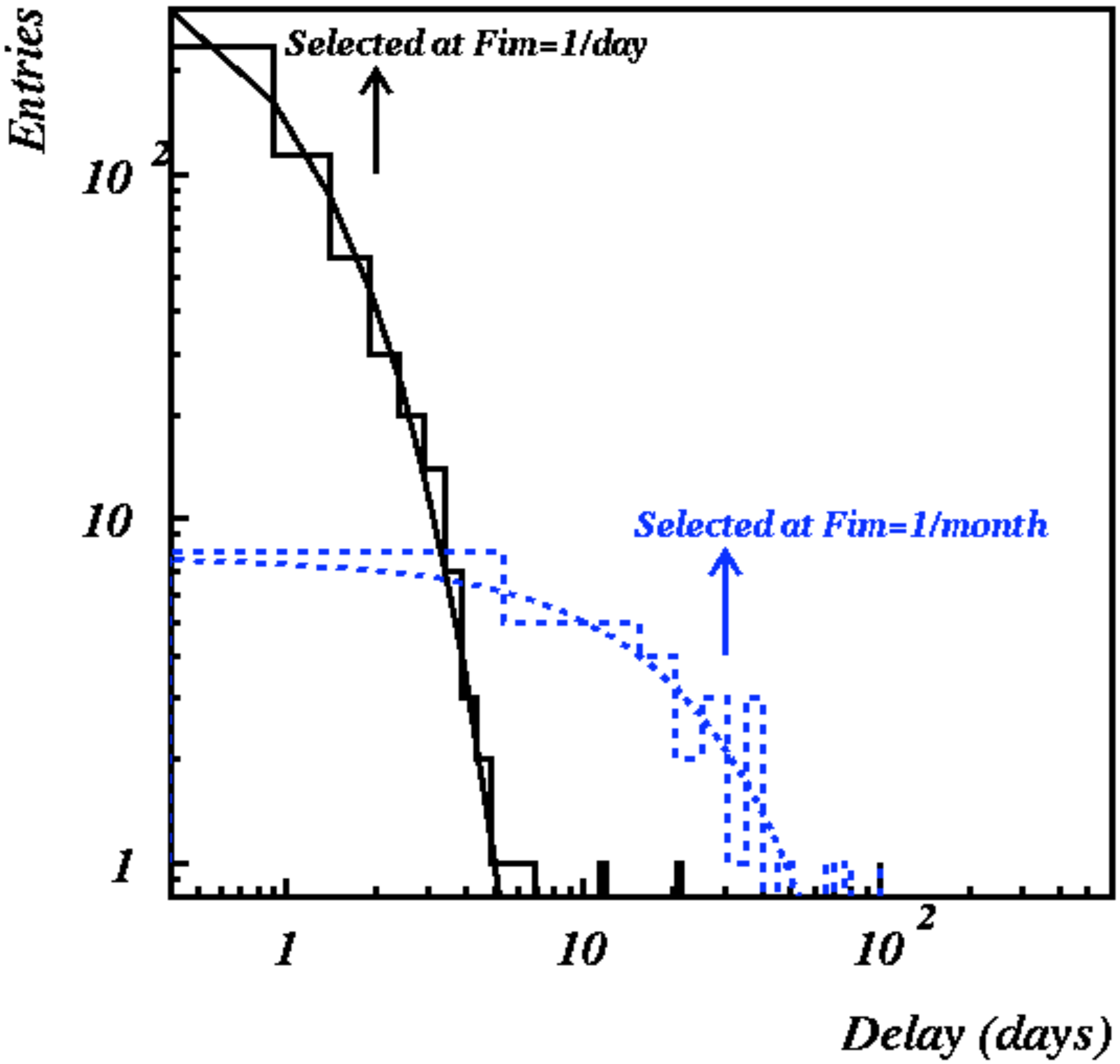
Walter.Fulgione@gmail.com

LVD: on-line alarm rate

Cluster selected on-line in 688 days at different threshold

Observed rate of alert (fits of the delay distributions)
1.24 day^{-1}
1.28 $month^{-1}$

$R_{set} - R_{exp} < 30\%$

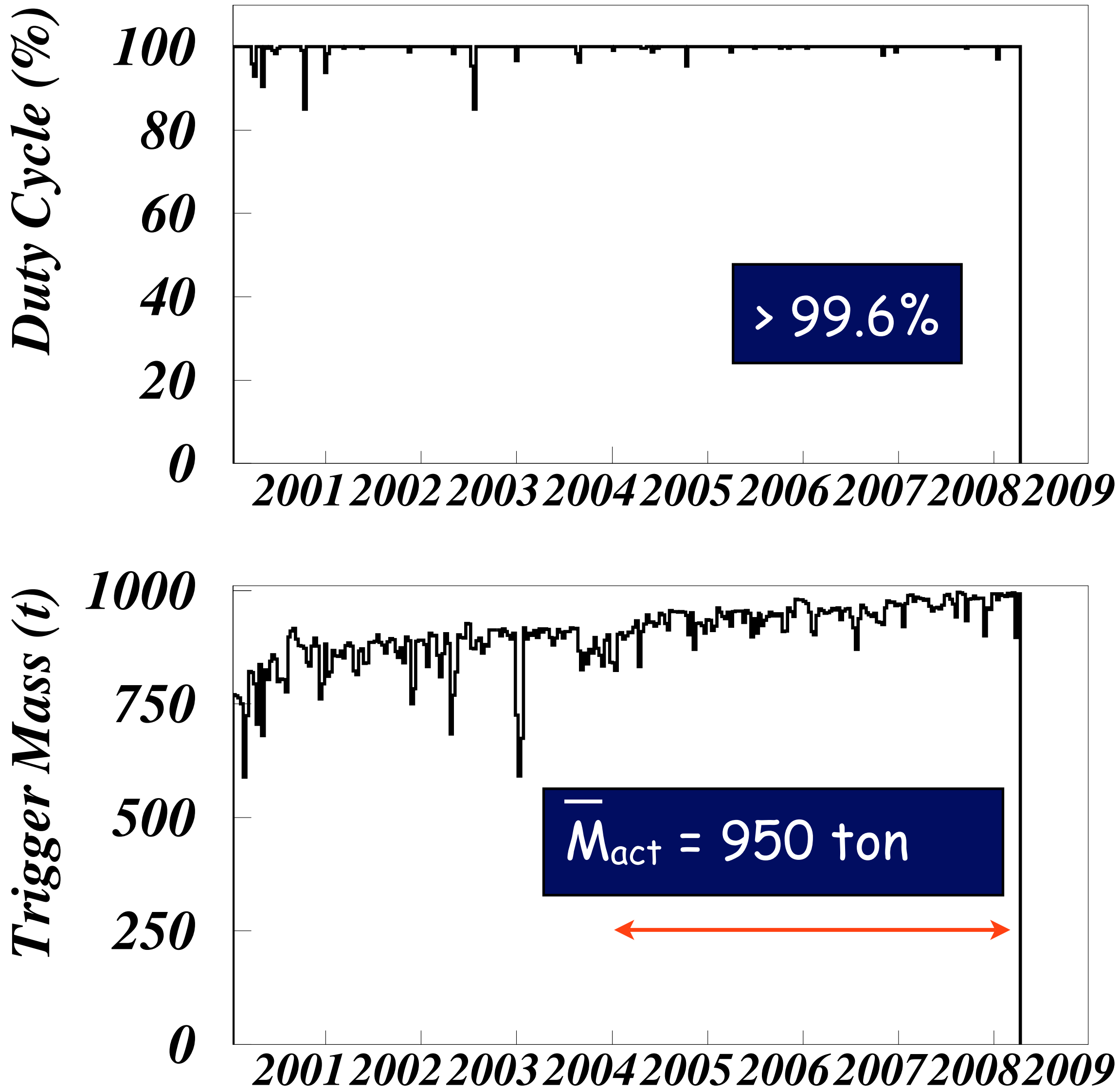


LVD Collaboration 30th ICRC HE 2.3 (2007)

Walter.Fulgione@gmail.com

Active Mass and Duty Cycle

The ν observatory reached its final configuration at the end of 2000.



..because of its modularity, LVD can be serviced during data taking.

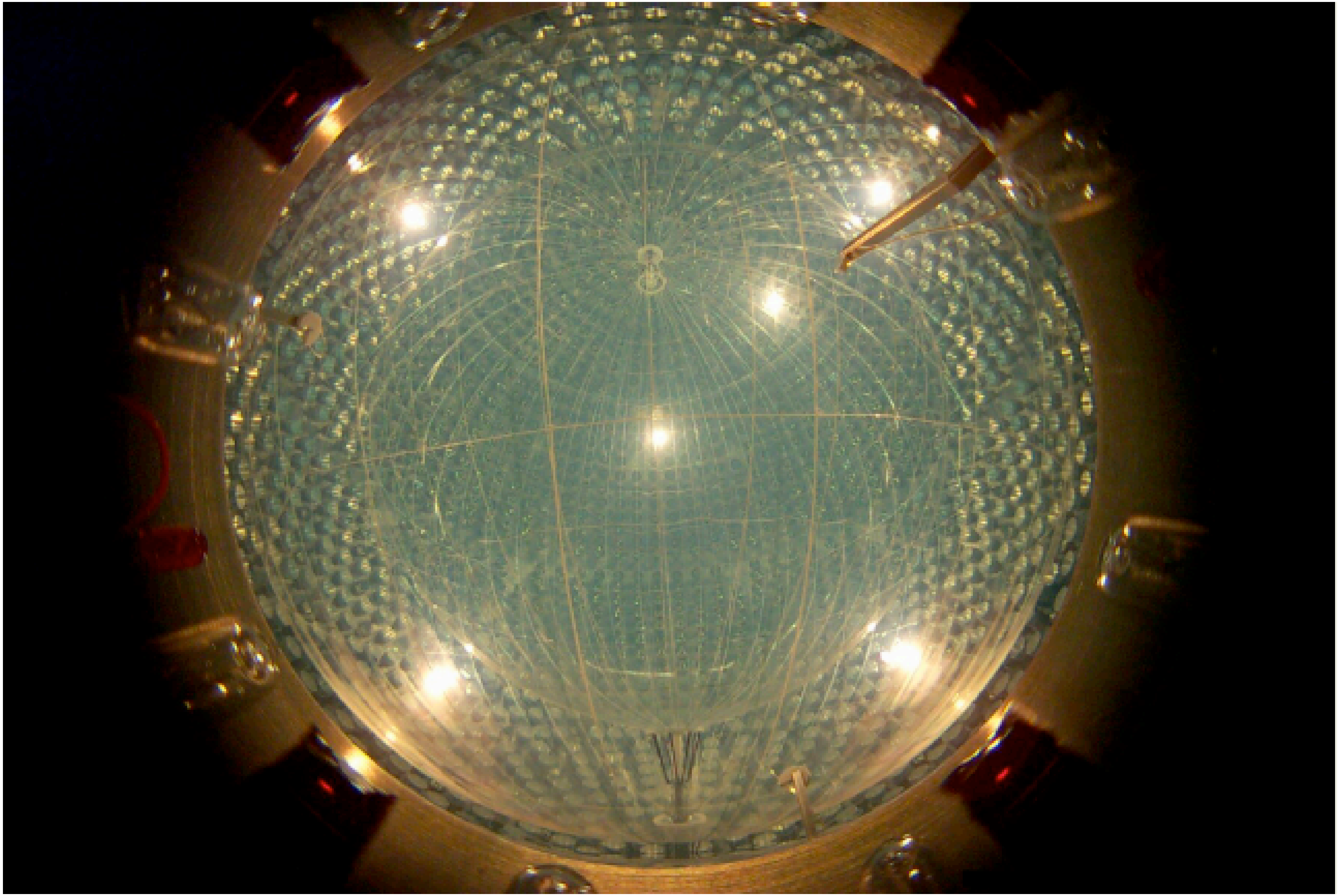
In case of failures, the telescope automatically remove the not properly working region and reconfigures itself at lower mass.

The effect is to adjust dynamically the LVD active mass, M_{act}

Walter.Fulgione@gmail.com

Borexino

Thanks to:
A.Chavarria, A.Ianni and A.Razeto



Walter.Fulgione@gmail.com

Borexino

Thanks to:
A.Chavarria, A.Ianni and A.Razeto

Scintillators - single volume

Interaction	Prompt E_{vis} (MeV)	Delayed E_{vis} (MeV)	Delay (ms)	Number of events $E_{vis} > 0.2$ MeV
$\nu + e^- \rightarrow \nu + e^-$	$0 - 30$	–	–	5
$\bar{\nu}_e + p \rightarrow e^+ + n$	$0.9 - 50$	1.9	0.26	78
$^{12}C\ (\nu_e, e^-)\ ^{12}N$	$0 - 40$	$0.9 - 17$	11	9
$^{12}C\ (\bar{\nu}_e, e^+)\ ^{12}B$	$0.9 - 50$	$0 - 13$	20	3
$^{12}C\ (\nu, \nu')\ ^{12}C^*$	–	13	–	15
$\nu + p \rightarrow \nu + p$	$0 - 2$	–	–	52

Table 1: This table shows the supernova induced neutrino interactions that are observable in Borexino [3]. The energy of the prompt signal from the primary interaction products is presented in the second column, while the the delayed signal from secondary decays and de-excitations (not shown in the table) are presented in the third column. The average time difference between prompt and delayed signal is shown in the fourth column. The expected number of interactions from a "typical" supernova for each interaction is shown in the last column.

Walter.Fulgione@gmail.com

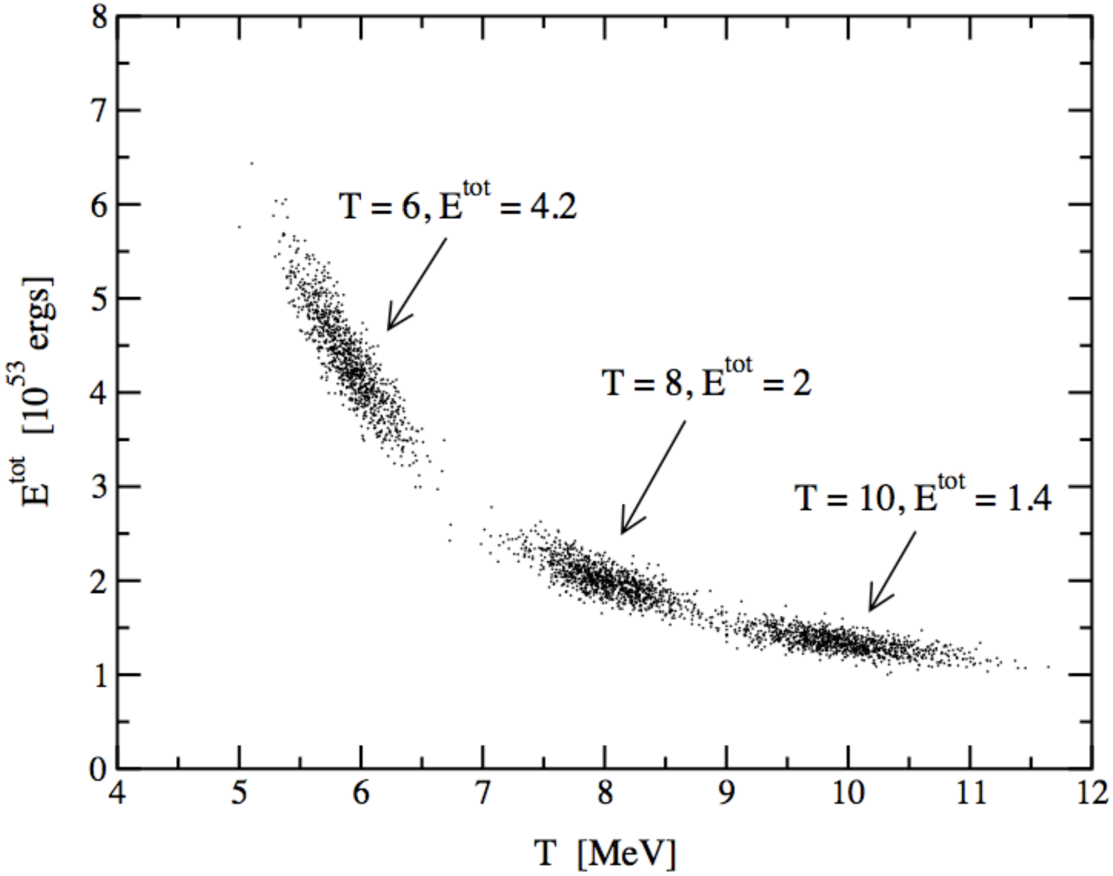
Borexino

The golden channel gives the temperature of $\bar{\nu}_e$ (**at the detector**).

The ν + p channel can give the temperature of ν_x (**at the neutrino sphere**).

Other N.C. detection channels cannot break the degeneracy:

$$N \sim E^{tot} \frac{\langle\sigma\rangle}{T}$$

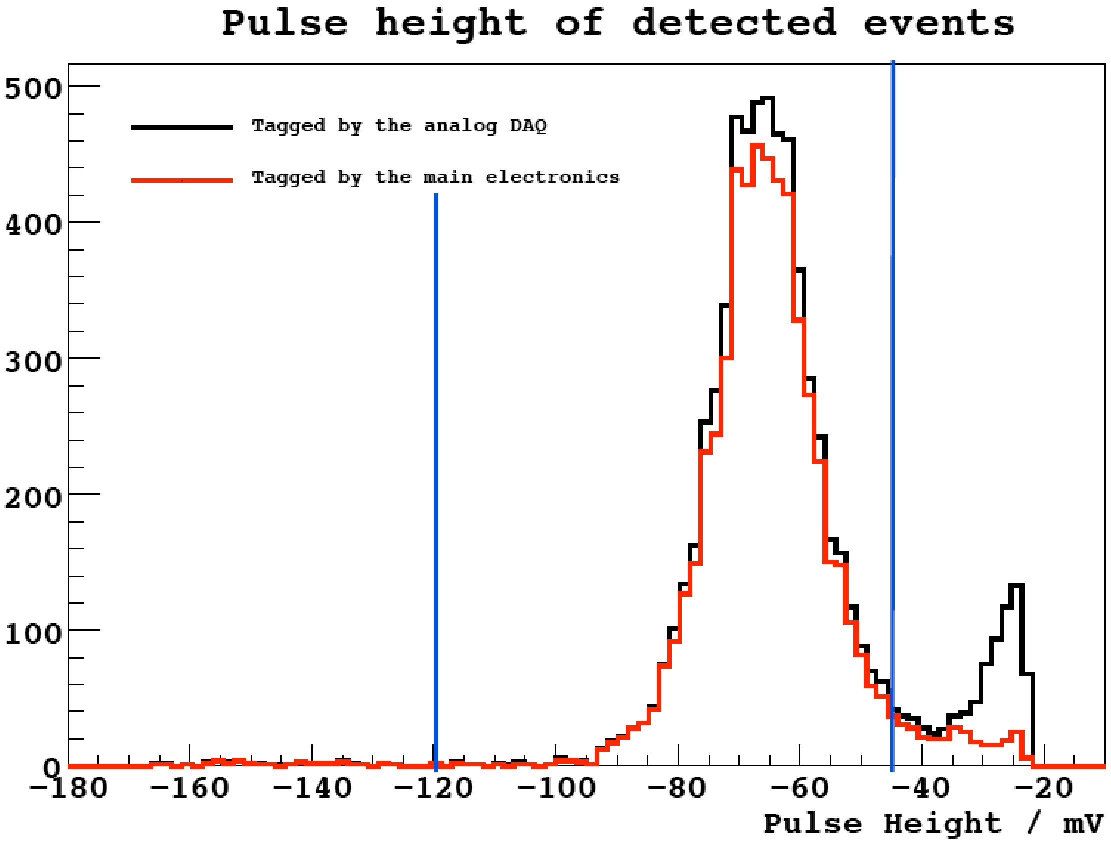


J. Beacom, W.Farr and P.Vogel, Phys. Rev. D **66**, 033001 (2002)

Borexino on-line

The system consists of the acquisition of individual pulses in the energy region of the neutron capture...
Noise cuts are made on the pulses based on the position and stability of the baseline.

Basically, a list of candidate pulses is considered a supernova signal if it has six or more pulses where the time between subsequent pulses is less than 10 s and the time difference between first and last pulse is > 2 ms (to avoid cosmogenic neutrons).



..with this settings, the system is able to trigger on only 6 neutron captures, which corresponds to ≈ 1/10 of the expected signal from a "typical" galactic supernova and therefore, even a supernova considerably weaker or further away can potentially be detected.

Walter.Fulgione@gmail.com

ν_e

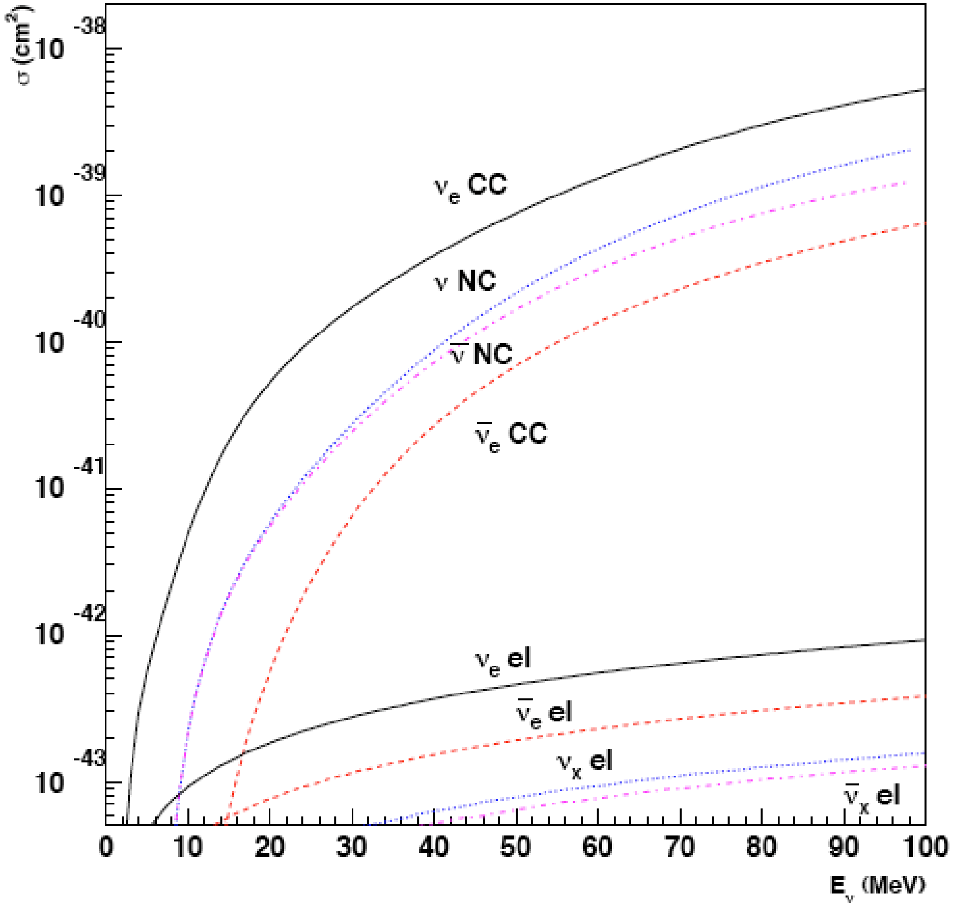
Liquid Ar

SNO studyed ν_e through:

$\nu_e + d \rightarrow e^- + p + p$

ICARUS T600 will do it through:

$\nu_e + {}^{40}Ar \rightarrow {}^{40}K + e^-$



at Gran Sasso:

n.c.:	$\nu_x + p \rightarrow \nu_x + p$	Borexino
c.c.:	$\nu_e + {}^{40}Ar \rightarrow {}^{40}K + e^-$	Icarus
c.c.:	$\bar{\nu}_e + p \rightarrow e^+ + n$	LVD

Walter.Fulgione@gmail.com

ν_e

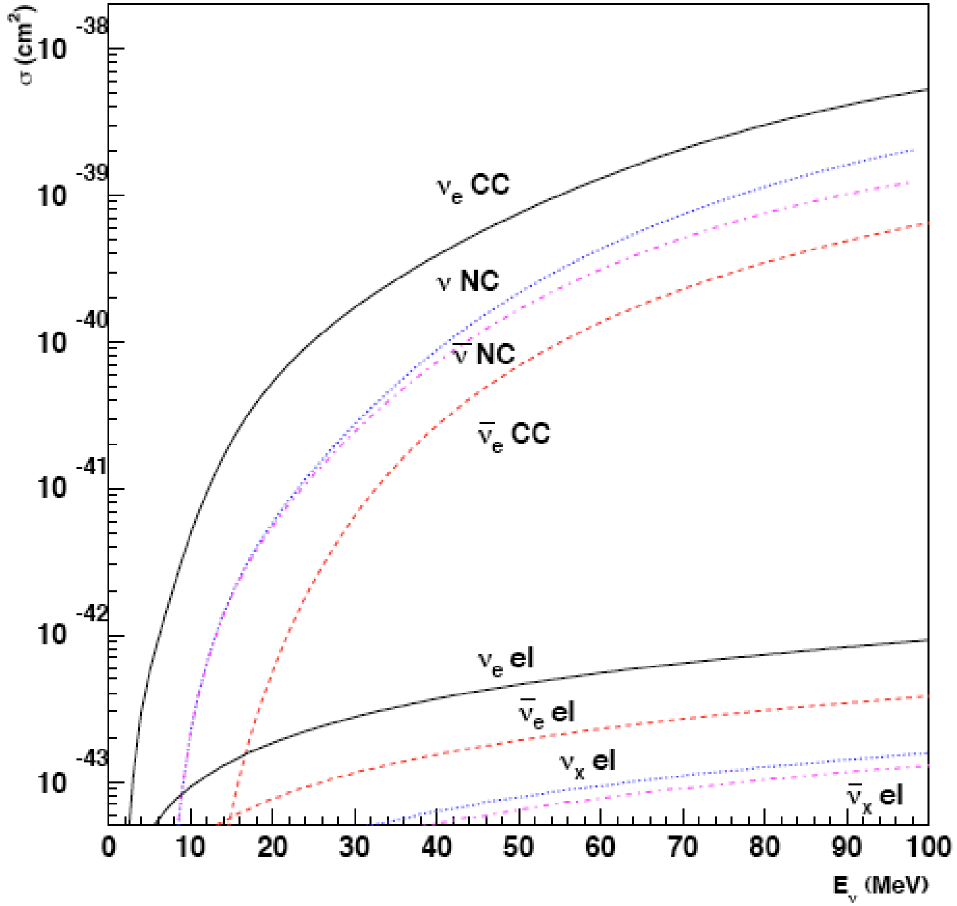
Liquid Ar

SNO studied ν_e through:

$\nu_e + d \rightarrow e^- + p + p$

ICARUS T600 will do it through:

$\nu_e + {}^{40}Ar \rightarrow {}^{40}K + e^-$

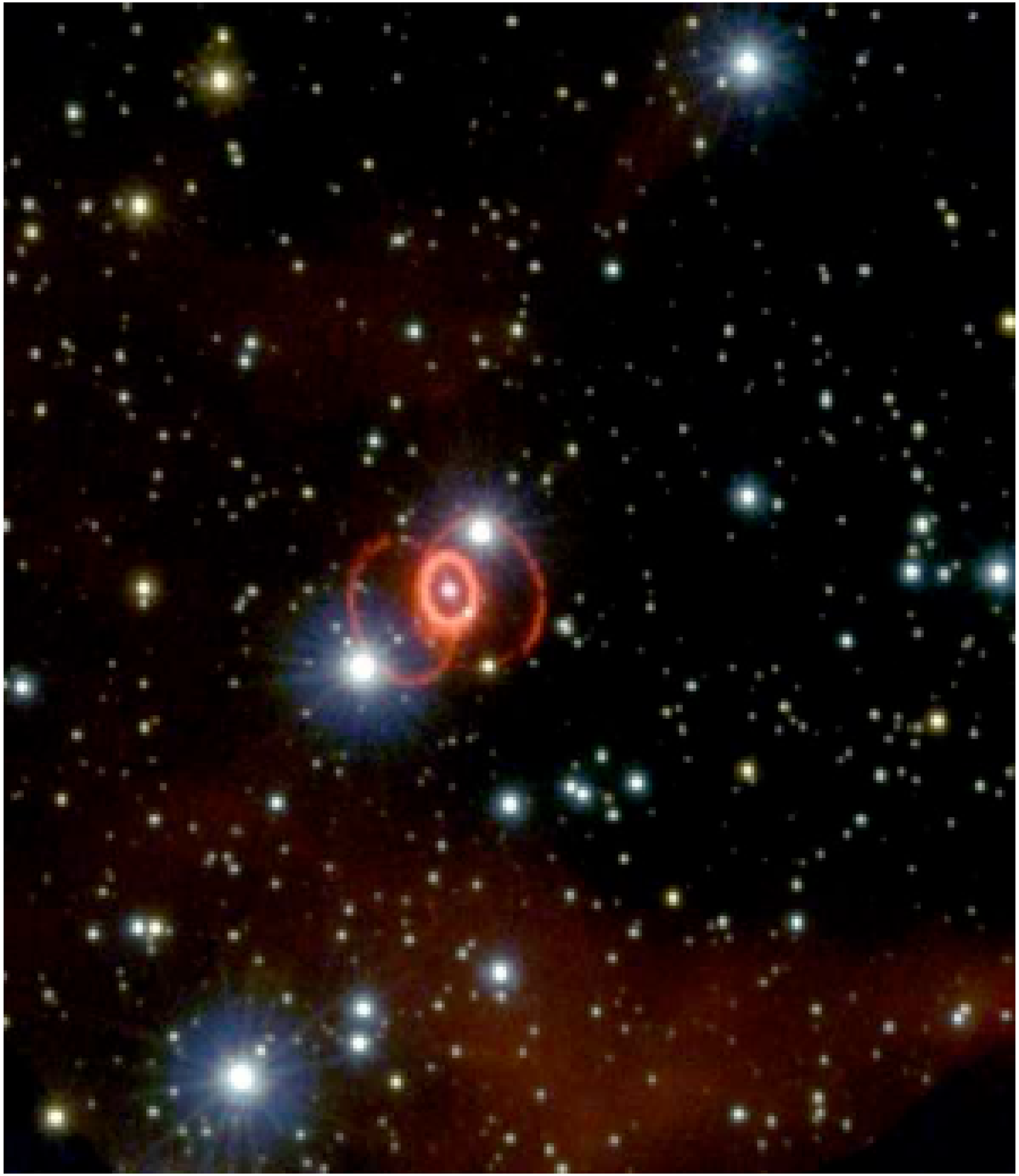


at Gran Sasso:

n.c.:	$\nu_x + p \rightarrow \nu_x + p$	Borexino
c.c.:	$\nu_e + {}^{40}Ar \rightarrow {}^{40}K + e^-$	Icarus
c.c.:	$\bar{\nu}_e + p \rightarrow e^+ + n$	LVD

The number of expected events in 600 tons of Ar is not so big, nevertheless nobody knows the distance of the next galactic SN.

Walter.Fulgione@gmail.com



Hubble image

Thank you

Walter.Fulgione@gmail.com

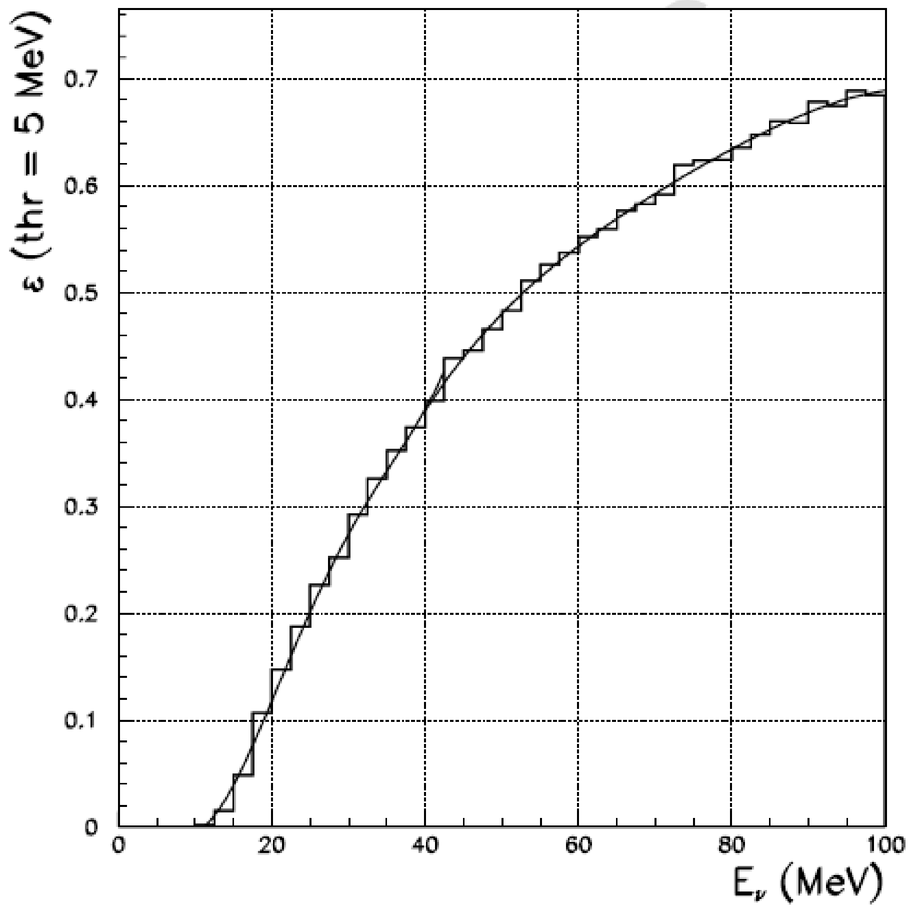


Fig. B.2. Detection efficiency of neutrino–iron interaction for an energy threshold of the scintillation counters of 5 MeV.

Walter.Fulgione@gmail.com

Observation of neutrinos from SN1987A

water Cherenkov:

Kamiokande II	2000 t.
IMB	5000 t.

liquid scintillator:

LSD	90 t.
BUST	200 t.

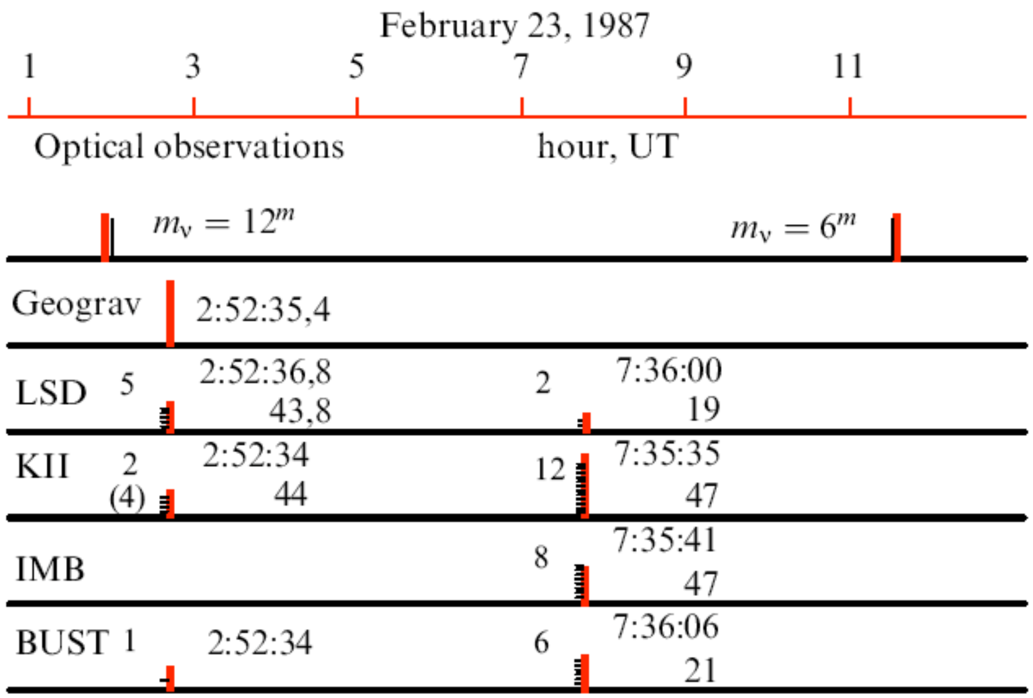


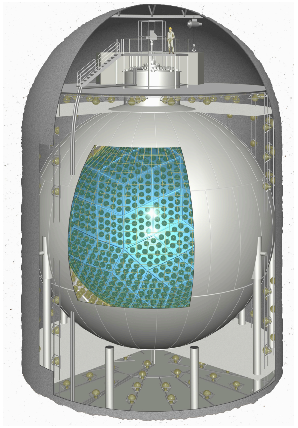
Figure 1. Temporal sequence of events observed at different neutrino detectors on February 23, 1987. The number of pulses in the series is conventionally shown for each detector. Times of arrival of the first and last pulse are also indicated.

This was the first observation of neutrinos coming from outside the solar system, a miles stone in the experimental neutrino astrophysics.

Walter.Fulgione@gmail.com

Scintillators - single volume

KamLAND



Reaction	# Events
$\overline{\nu}_e + \mathrm{p} \rightarrow \mathrm{e}^+ + \mathrm{n}$	~300
$\nu_x + \mathrm{p} \rightarrow \nu_x + \mathrm{p}$ (for 0.2MeV thr)	~270
$\nu_x + {}^{12}\mathrm{C} \rightarrow \nu_x + {}^{12}\mathrm{C}(15.11\mathrm{MeV})$	~60

Assuming 1KT and "Standard Supernova"

The old trigger system (pre ~2008) had a SN trigger, the normal threshold was E_{thr} ~ 0.9MeV.

After purifying the detector (i.e. removing radioactive isotopes) the trigger threshold is now **E_{thr} ~ 0.35 MeV** and the SN trigger is not longer used.

An algorithm, similar to the old SN trigger, runs online to notify shift personnel of a possible SN event.

Thanks to Patrick Decowski

SEARCH FOR ν BURSTS

Run	Start	End	Time (*days*)	Uptime (%)	Mass (*t*)
1	June 6th 1992	May 31st1993	285	60	310
2	Aug.4th 1993	Mar.11th1995	397	74	390
3	Mar.11th 1995	Apr.30th 1997	627	90	400
4	Apr.30th 1997	Mar.15th1999	685	94	415
5	Mar.16th 1999	Dec.11th 2000	592	95	580
6	Dec.12th 2000	Mar.24th 2003	821	98	842
7	Mar.25th 2003	Feb.4th2005	666	>99	881
8	Feb.4th 2005	May 31st 2007	846	>99	936
9	**May 31st 2007**	**Apr.30th 2009**	**699**	**>99**	**967**
Σ	June 6th 1992	Apr.30th 2009	5618	94	

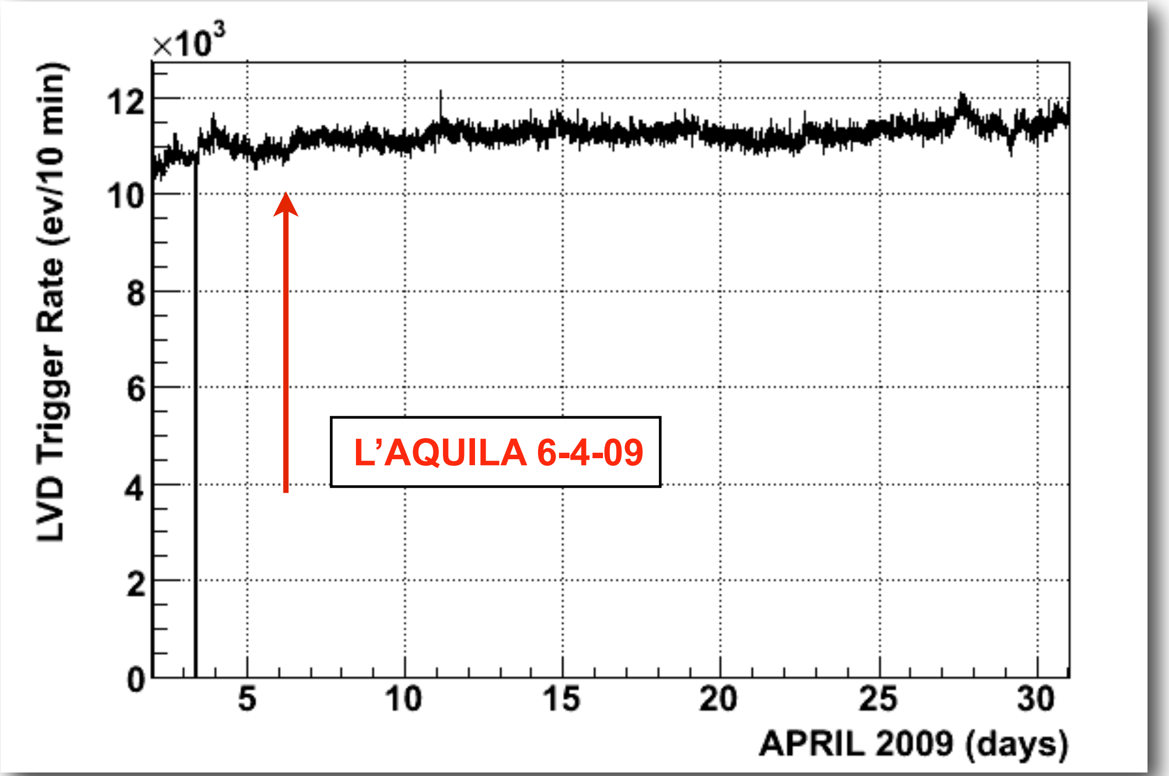
90% C.L. Upper Limit to gravitational stellar collapses in the Galaxy is
0.15 /year

Walter.Fulgione@gmail.com

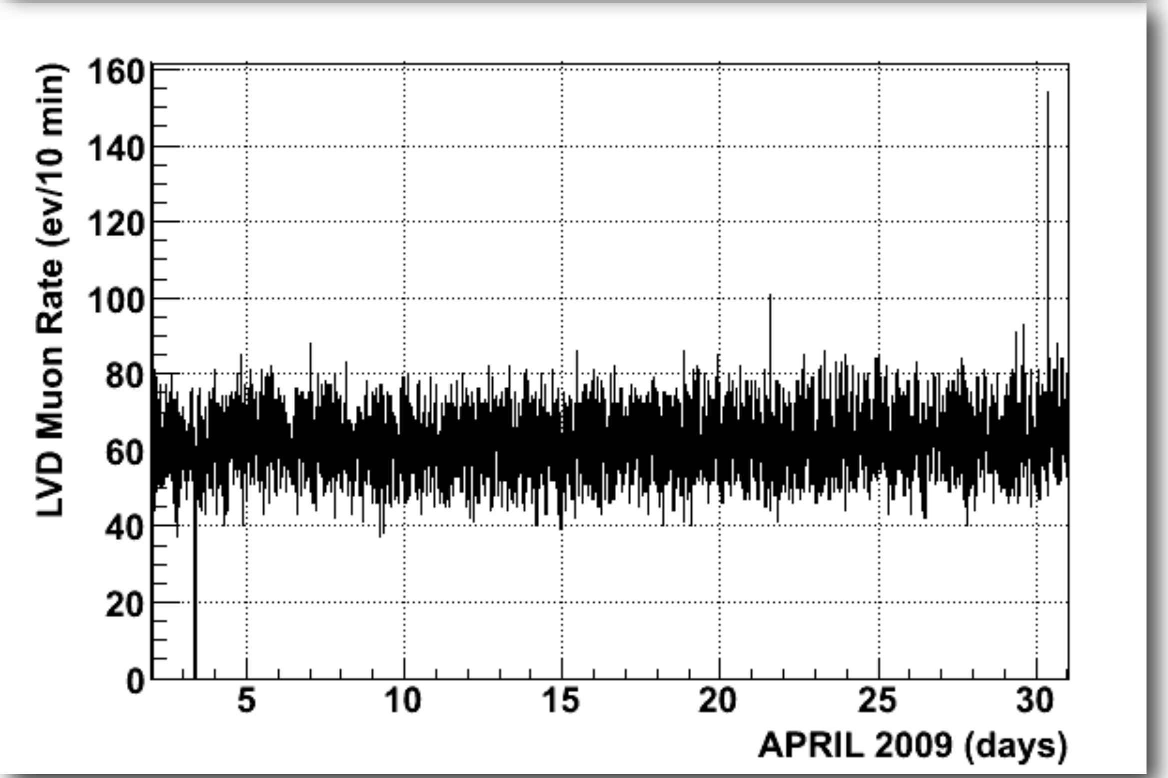
April 6th 2009

LVD

LVD monitoring task



Trigger rate



muon rate

Walter.Fulgione@gmail.com