Search for neutrino radiation from the collapse of stellar cores using LVD detector

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on behalf of the LVD Collaboration

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Introduction

Gravitational Stellar Collapses are astrophysical events of great interest. Because of the complexity of the problem, the modelling of the physical processes is still in evolution, but it is in general accepted that the role of neutrinos is critical to allow the supernova to form out of a collapse.

The detection of the neutrino signal from the SN 1987A marked the beginning of a new era in neutrino astrophysics and, in spite of some unresolved controversies, opened the way to the Neutrino Astronomy.

LVD Collaboration

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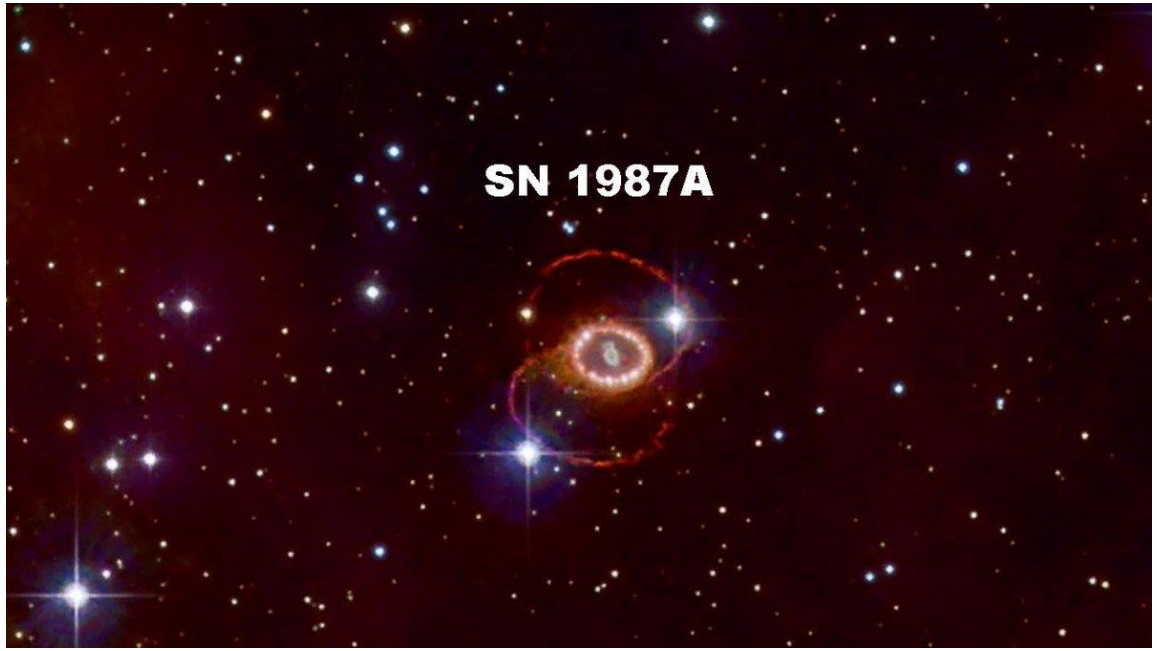
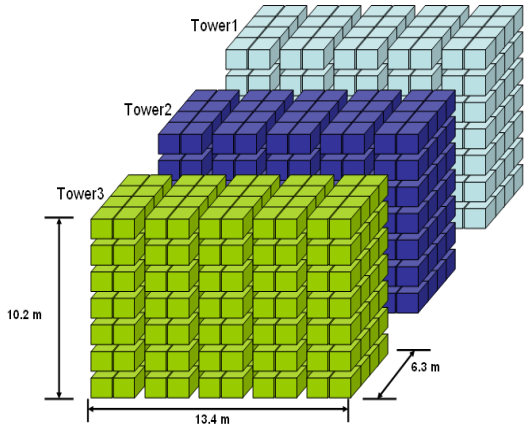


LVD – Large Volume Detector at LNGS, Italy, Gran Sasso

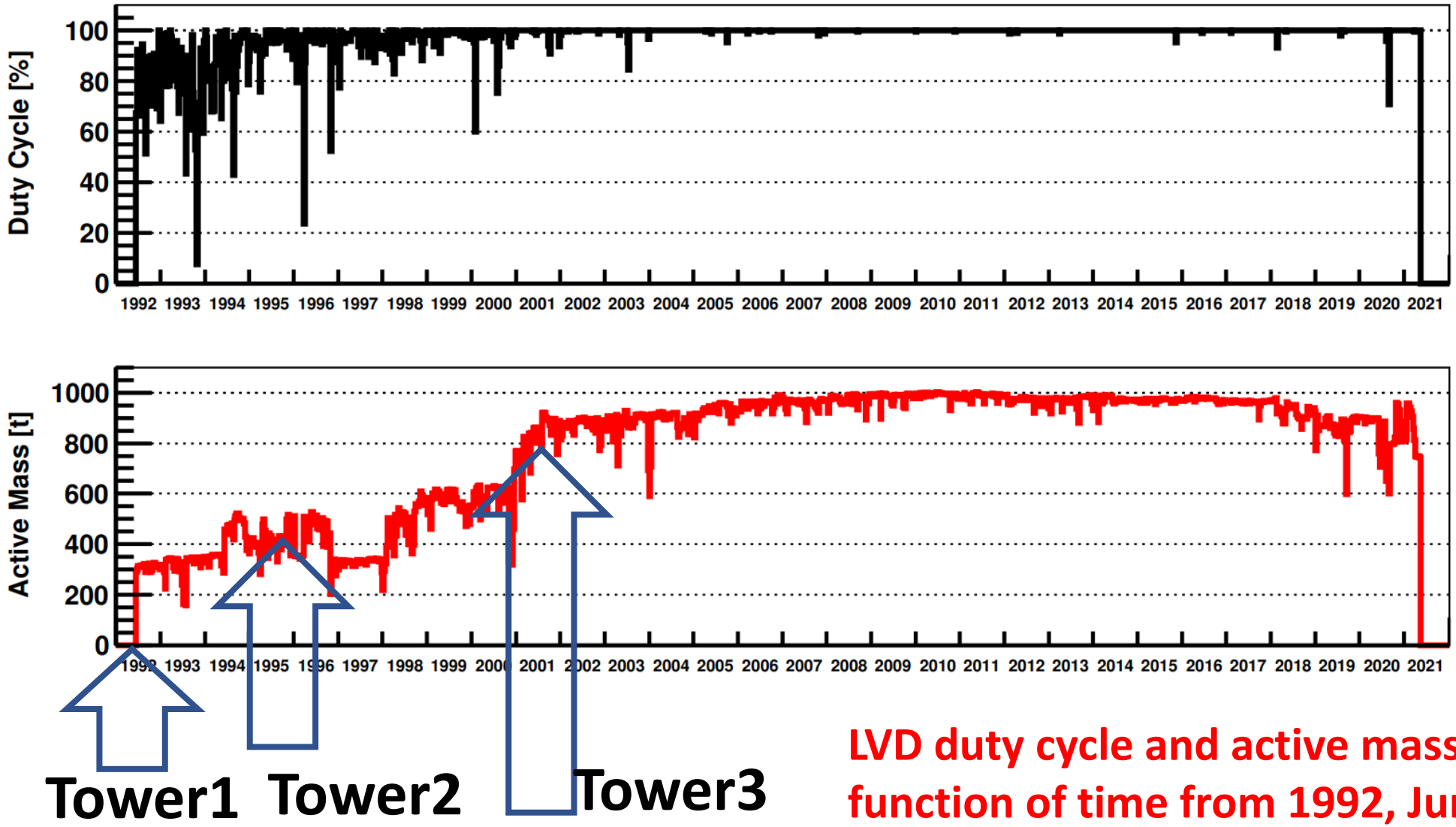


LVD@LNGS

The main goal of LVD is searching for neutrino radiation from stellar core collapse.

The coordinates of the LNGS: 13.5333 E, 42.4275 N.

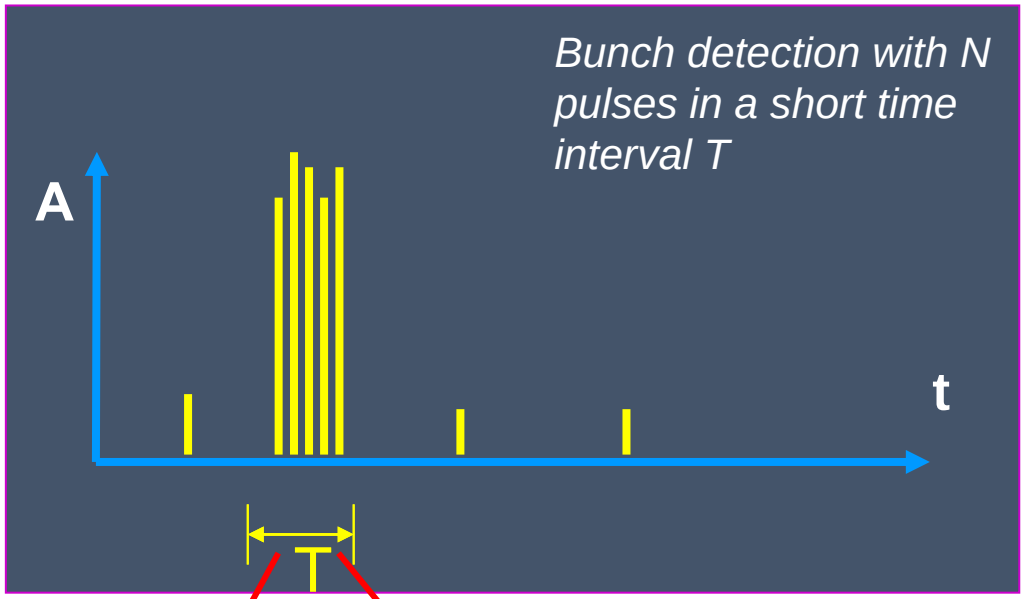
Length ×Width ×Height	22.7×13.2×10 m
Iron mass	1020 t
Scintillator mass (C_nH_{2n}, n~10)	1008 t
Amount of scintillation counters	840
Average depth Minimal depth	3650 m w.e. 3000 m w.e.
Mean muon energy	280 GeV
E_μ on see level (min.)	1.3 TeV
Muon rate (on 1 tower)	~ 120 h^{-1}
Average counting rate (7MeV)	$2x10^{-4}$ s^{-1} $count^{-1}$
Threshold E_{HET} (E_{LET},)	4 MeV (0.5 MeV)



LVD duty cycle and active mass as a function of time from 1992, June 9th 1992 to 2021, May 5th .

The detector maintenance can be done during data acquisition by stopping only the part that needs to be maintained, even a single counter. This peculiarity allows a dynamic active mass and a high duty cycle.

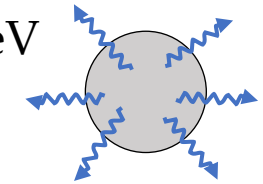
Neutrino detection. General principle. Standard model

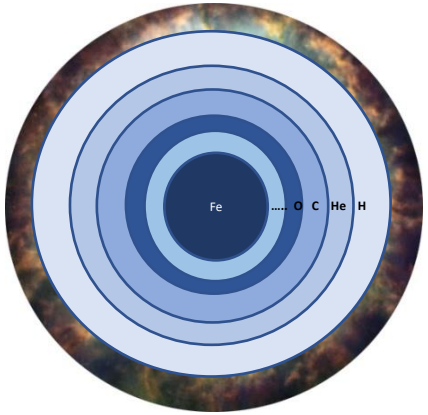


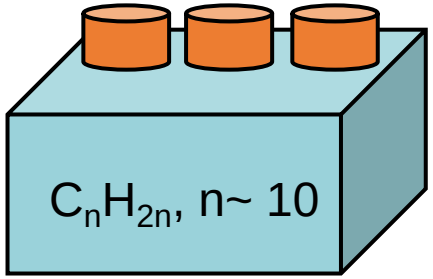
$\bar{\nu}_e + p \rightarrow e^+ + n$ $\quad E_{th} = 1.8$ MeV

$n + p \rightarrow d + \gamma.$ $\quad E_\gamma = 2.2$ MeV

$n + Fe \rightarrow Fe + \Sigma\gamma.$ $\quad \langle E_\gamma \rangle \approx 7$ MeV



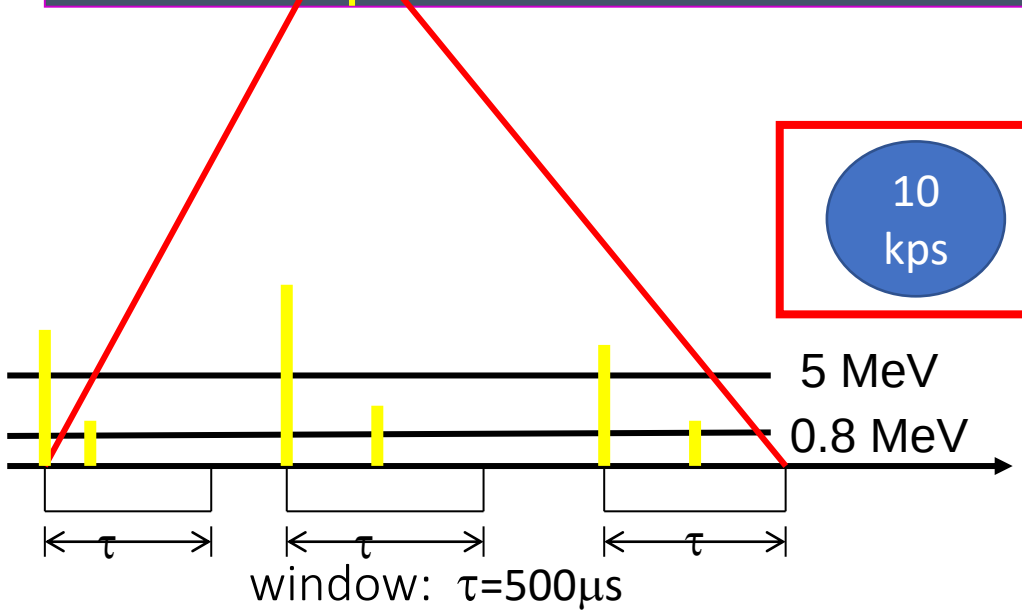


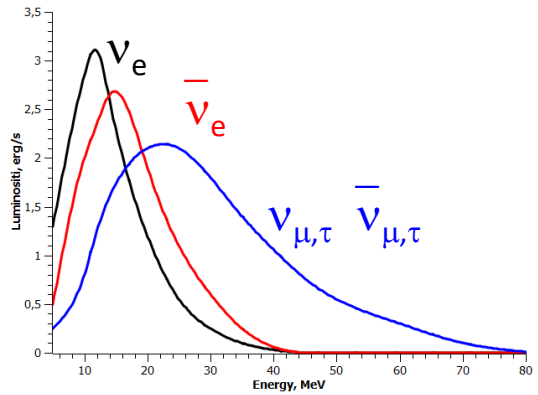


1 kt C_nH_{2n}
1 kt Fe
840 counters

10 kps → 300 ev. in LVD

The SN outburst is triggered by the gravitational collapse of the "iron" core of a mass M_{Fe}=1.2±2 M_c into a neutron star. About (10 ± 15)% $M_{Fe}c^2$ is radiated in the form of ν and $\bar{\nu}$ of all the flavors (e, μ, τ): $E_{\nu\,\bar{\nu}} = (3 - 5) \times 10^{53}$ erg. The total energy is assumed to be equally distributed among the six neutrino species: $E_i \sim 0.5 \times 10^{53}$ erg.



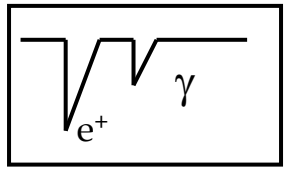


$\langle E_{\nu_e} \rangle = 9.5$ MeV,
$\langle E_{\bar{\nu}_e} \rangle = 12$ MeV,
$\langle E_{\nu_x} \rangle = 15.6$MeV

Neutrino spectra, 100ms after bounce

LVD is a detector of all types of neutrinos

Main reaction: $\tilde{\nu}_e + p \rightarrow e^+ + n$

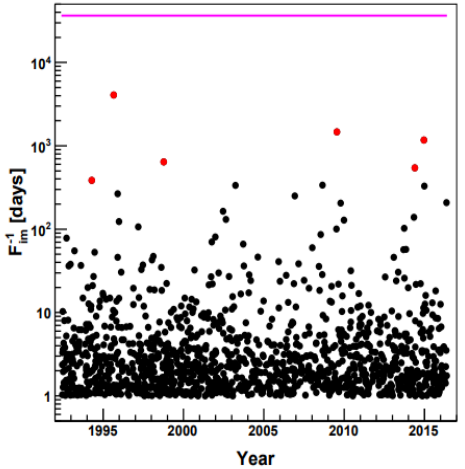


$n + p \rightarrow d + \gamma \quad (E_\gamma = 2.2\ \text{MeV})$

$n + {}^{56}Fe \rightarrow {}^{57}Fe + \Sigma\gamma \quad (\Sigma E_\gamma = 10.16\ \text{MeV})$

$\tau \cong 150\mu s$

The search for neutrino bursts is based on the identification of event clusters with a low probability of event imitation. These events are background fluctuations..



Registered clusters with F_{im} <1 day $^{-1}$. Clusters with high significance are marked in red.

Reaction with Iron and Carbon:

$\nu_e + {}^{56}\text{Fe} \rightarrow {}^{56}\text{Co}^* + e^-, \qquad {}^{56}\text{Co}^* \rightarrow {}^{56}\text{Co} + \Sigma\gamma,\ E_\gamma \approx 7\ \text{MeV}$

$\nu_i + {}^{12}\text{C} \rightarrow {}^{12}\text{C}^* + \nu_i,\ (i = e, \mu, \tau); \quad {}^{12}\text{C}^* \rightarrow {}^{12}\text{C} + \gamma,\ E_\gamma = 15.1\ \text{MeV}$

*N.Y. Agafonova et al. (LVD Collaboration) "**Implication for the core-collapse supernova rate from 21 years of data of the Large Volume Detector**" The Astrophysical Journal, 802:47 (9pp), 2015 March 20*

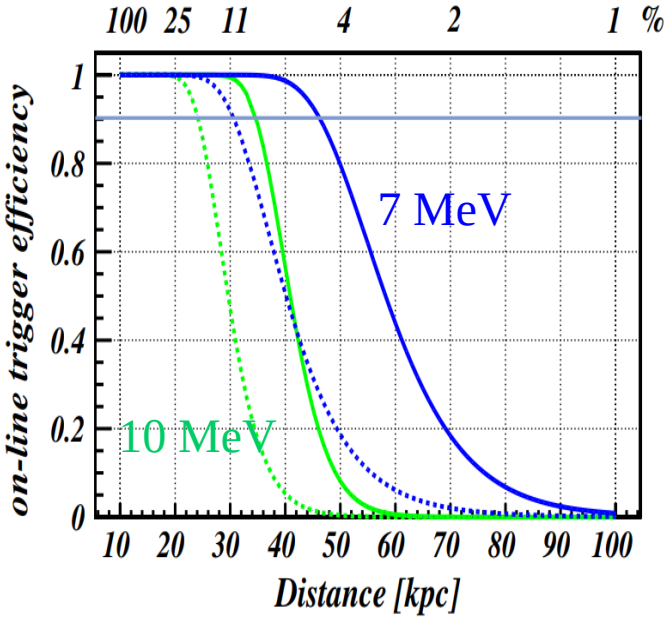
On-line and Off-line mode for cluster selection

1 "Good" counters with average counting rate is E ≥ 7MeV: **R=2×10^{-4} s^{-1} counter^{-1}**

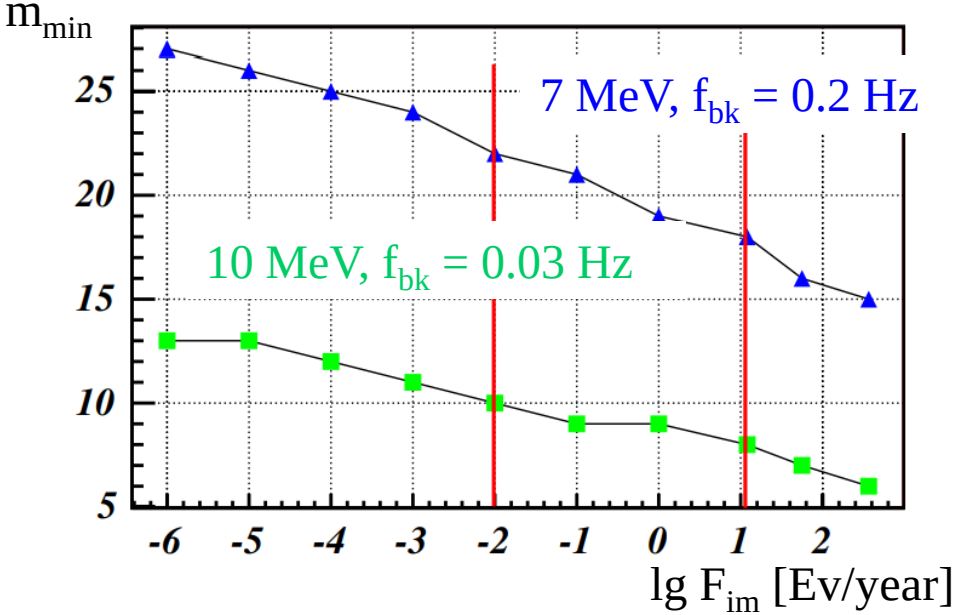
2 **Imitation frequency:** $$F_{im_i} = f_{bk}^2 \Delta t_{max} \sum_{k \geq m_i - 2} P(k, f_{bk_i} \Delta t_i)$$

$P(k, f_{bk_i}\Delta t_i)$ is the Poisson probability to have k events in the time window Δt_i
Δt_{max} - maximum cluster duration chosen for the analysis,
f_{bk}, f_{bk_i} is the background and instantaneous background frequency

LVD Collaboration. The Astrophysical Journal, 802:47 (9pp), 2015
LVD Collaboration. Astroparticle Physics 28 (2008) 516-522



On-line trigger efficiency versus distance (lower scale) and percentage of SN1987A signal at 10 kpc (upper scale) and Mact = 330 tons (dotted) and 1000 tons (continuous).

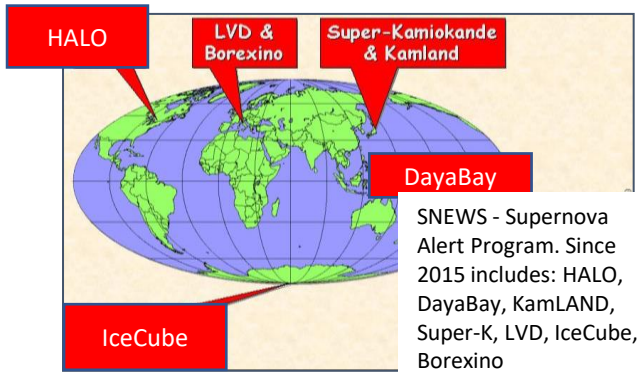


3 Minimum cluster multiplicity (m_{min}) vs. the imitation frequency (F_{im}). The lines represent the F_{im} thresholds of 1 candidate per 100 year (off-line) and of 1 per month (on-line).

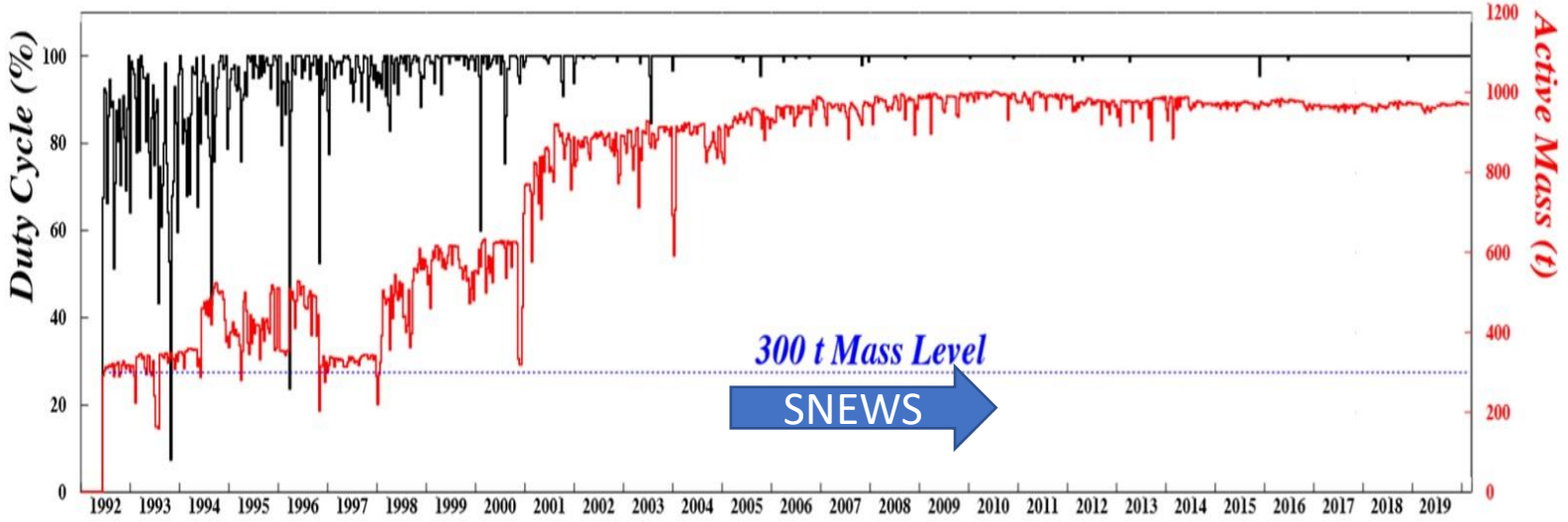
On-line: sliding window Δt_{max}=20 second

Off-line: sliding window Δt_{max}=100 second

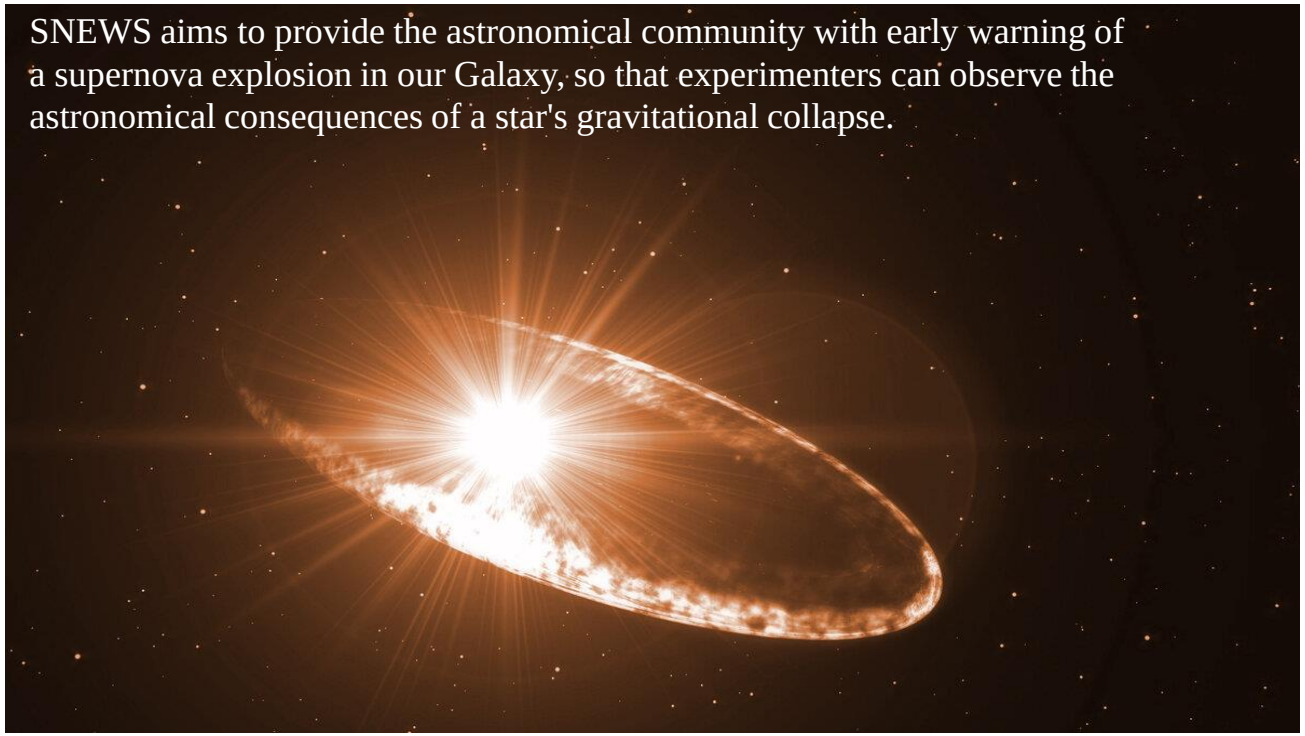
On-line:



SNEWS - Supernova Alert Program. Since 2015 includes: HALO, DayaBay, KamLAND, Super-K, LVD, IceCube, Borexino



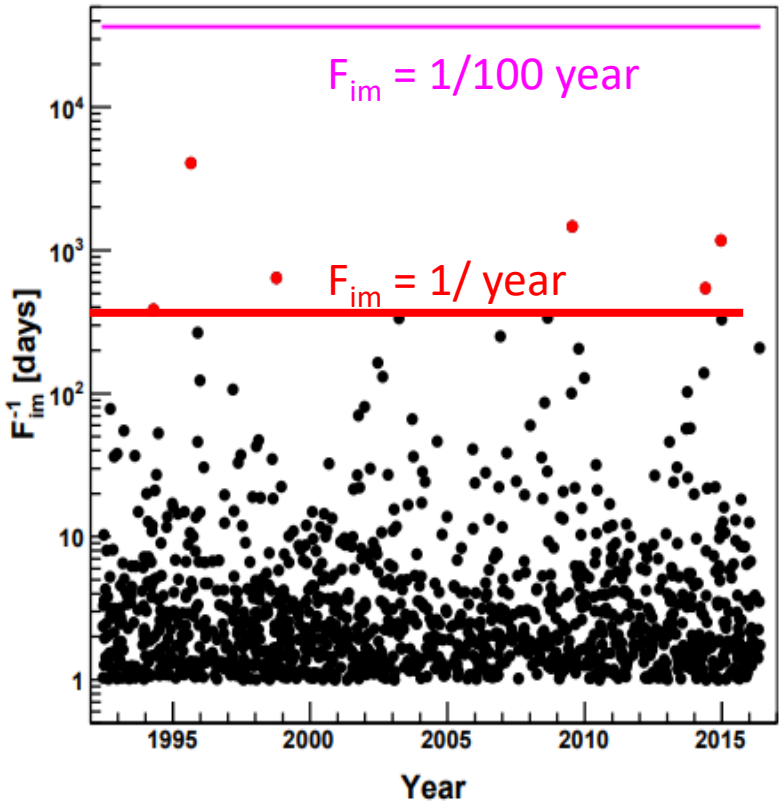
SNEWS aims to provide the astronomical community with early warning of a supernova explosion in our Galaxy, so that experimenters can observe the astronomical consequences of a star's gravitational collapse.



SNEWS: SuperNova Early Warning System

The detectors send reports of a possible supernova to a computer at Brookhaven National Laboratory to identify a supernova. If the SNEWS computer has signals from two detectors within 10 seconds, the computer will send a supernova alert to observatories around the world to study the supernova. The SNEWS mailing list is open-subscription, and the general public is allowed to sign up. https://snews.bnl.gov/alert.html

Results for Off-line mode:



Detected clusters with F_{im} <1 day^{-1}. Clusters with high significance are marked in red.

All clusters with F_{im} < 1/yr have been checked in terms of energy spectra and low energy signals that may be the signature of the IBD interactions. They are fully compatible with chance coincidence among background signals.

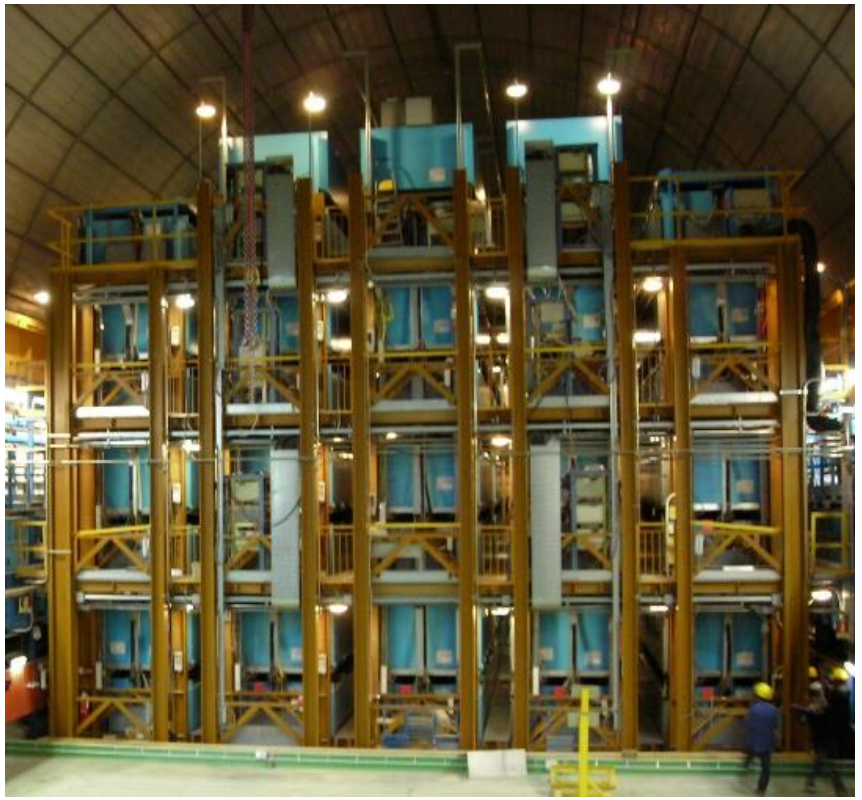
Cluster date and time	Cluster multiplicity	Duration Δt_i, s	Energy E, MeV	Frequency 1/F, y^{-1}
16.04.1994 10:40:49.263	7	18.88	26.5	1.06
27.08.1995 16:18:10.478	7	5.49	36.2	11.16
07.10.1998 15:41:41.775	12	90.05	32.2	1.76
18.07.2009 07:39:20.510	12	42.71	14.6	4.02
25.05.2014 03:54:14.555	14	61.56	22.6	1.49
18.12.2014 20:21:28.787	8	9.98	18.8	3.22

Characteristics of clusters with significance $F_{im} < 1$ year^{-1}.

Conclusion:

The detection of neutrino radiation has been carried out with the help of an LVD (LNGS, Italy) since 1992. A technique has been developed for observing neutrino bursts in our galaxy in on-line and off-line modes.

According to the data of the LVD neutrino telescope for 29 years of operation (1992 - 2021), an experimental limitation on the frequency of neutrino bursts from gravitational collapses of stars in the Galaxy was obtained: less than 1 event in 12.6 years (f = 0.08 y^{-1}) at a 90% confidence level.



Thank you!