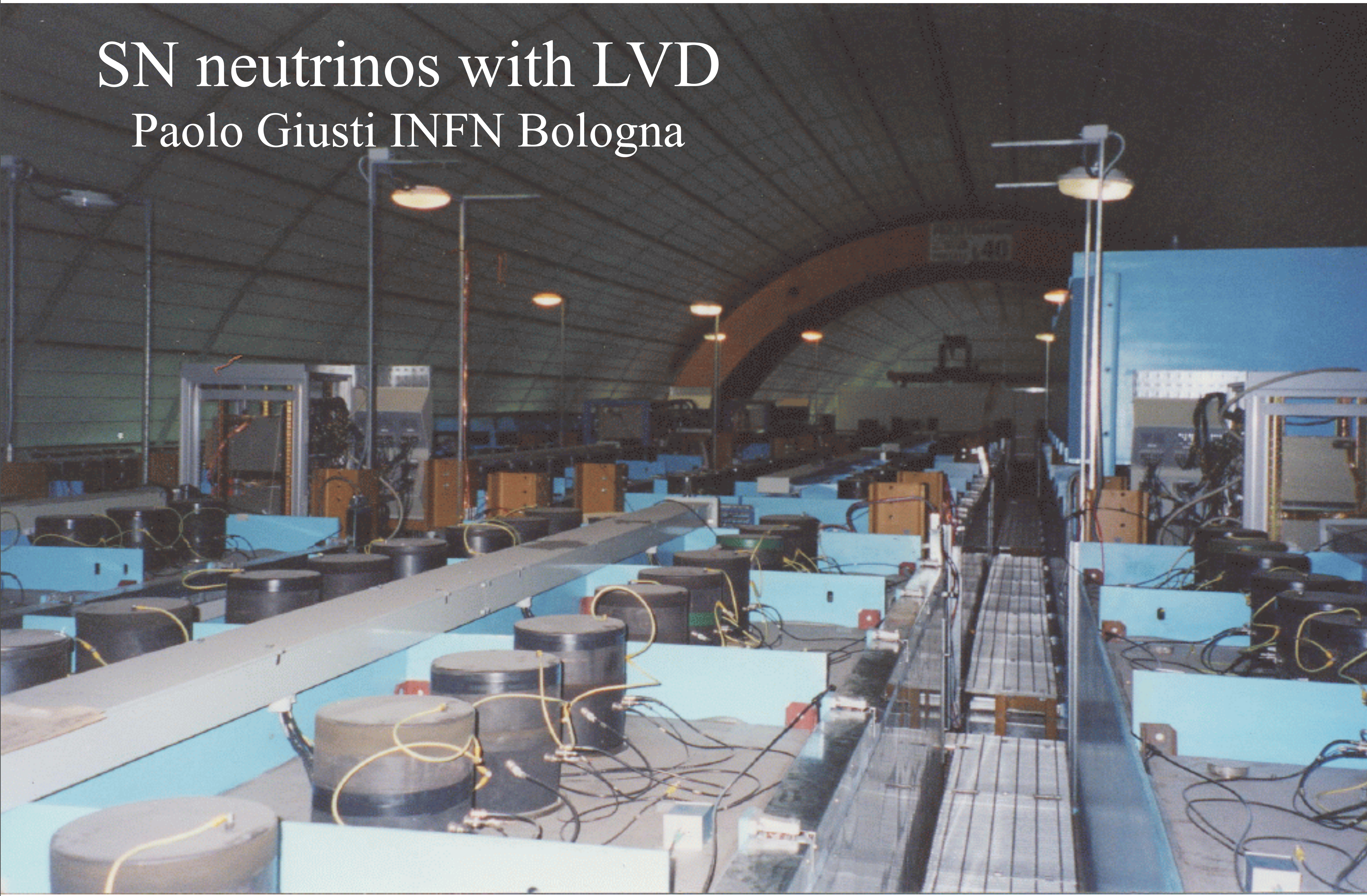
SN neutrinos with LVD

Paolo Giusti INFN Bologna



SN neutrinos astronomy

"Neutrinos astronomy is interesting for the same reason it is difficult. Because neutrinos only interact weakly with matter, they can reach us from otherwise inaccessible regions where photons, the traditional messengers of astronomy, are trapped. Hence, with neutrinos we can look inside stars and examine directly energetic physical processes that occur only in stellar interiors."

John N. Bahcall

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Outline

- The science case
    models
    SN1987A
    open problems, main difficulties and new strategies

- LVD history
    - a detector dedicated to SN neutrino observation
    - data taking since 1992
    - LVD in the SN Early Warning System

- Detector characteristics

- Search for neutrino burst
    - strategy
    - sensitivity
    - results

- Possible futures

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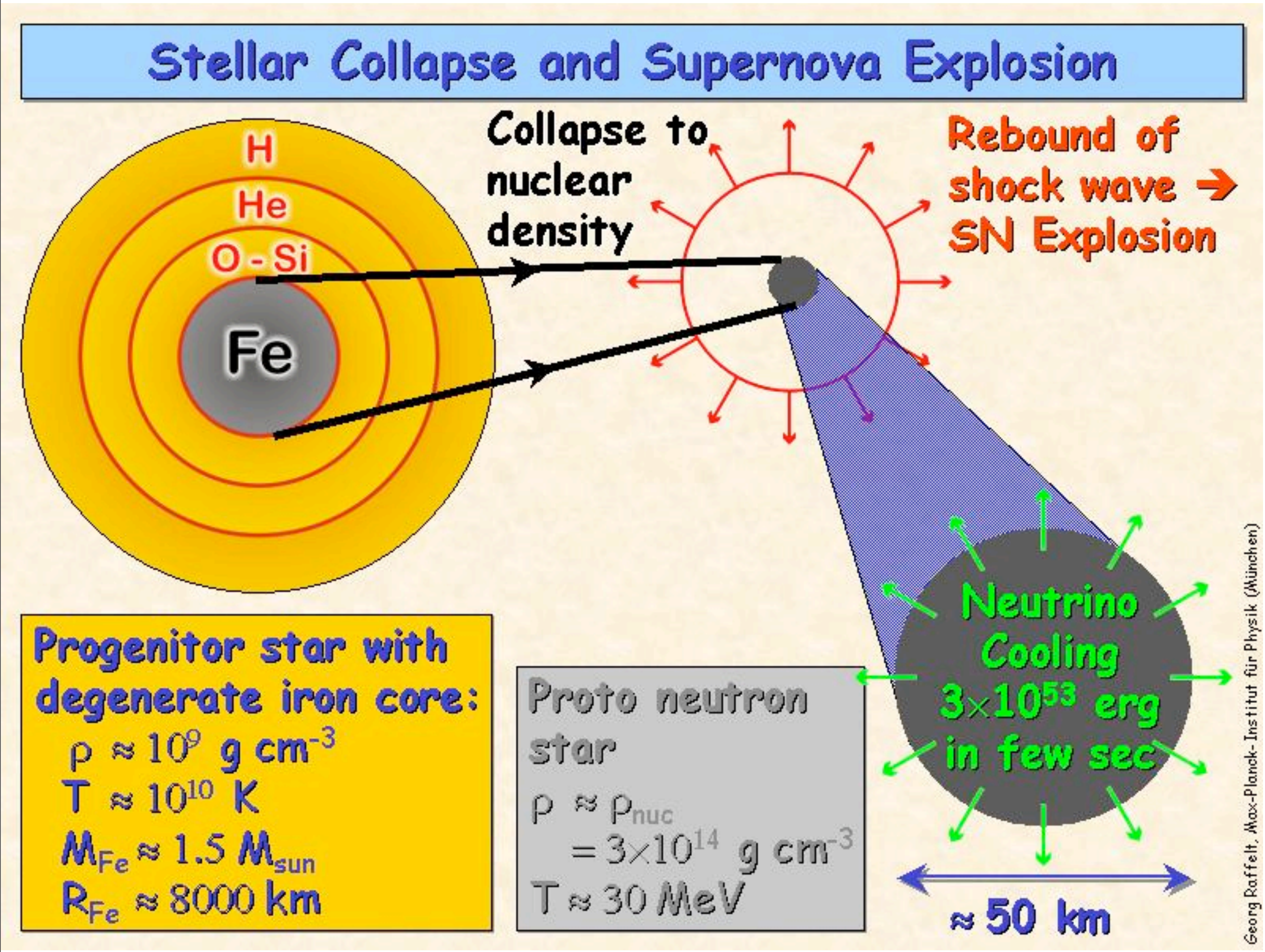
One of the unsolved problems of astrophysics is how core-collapse supernovae explode..



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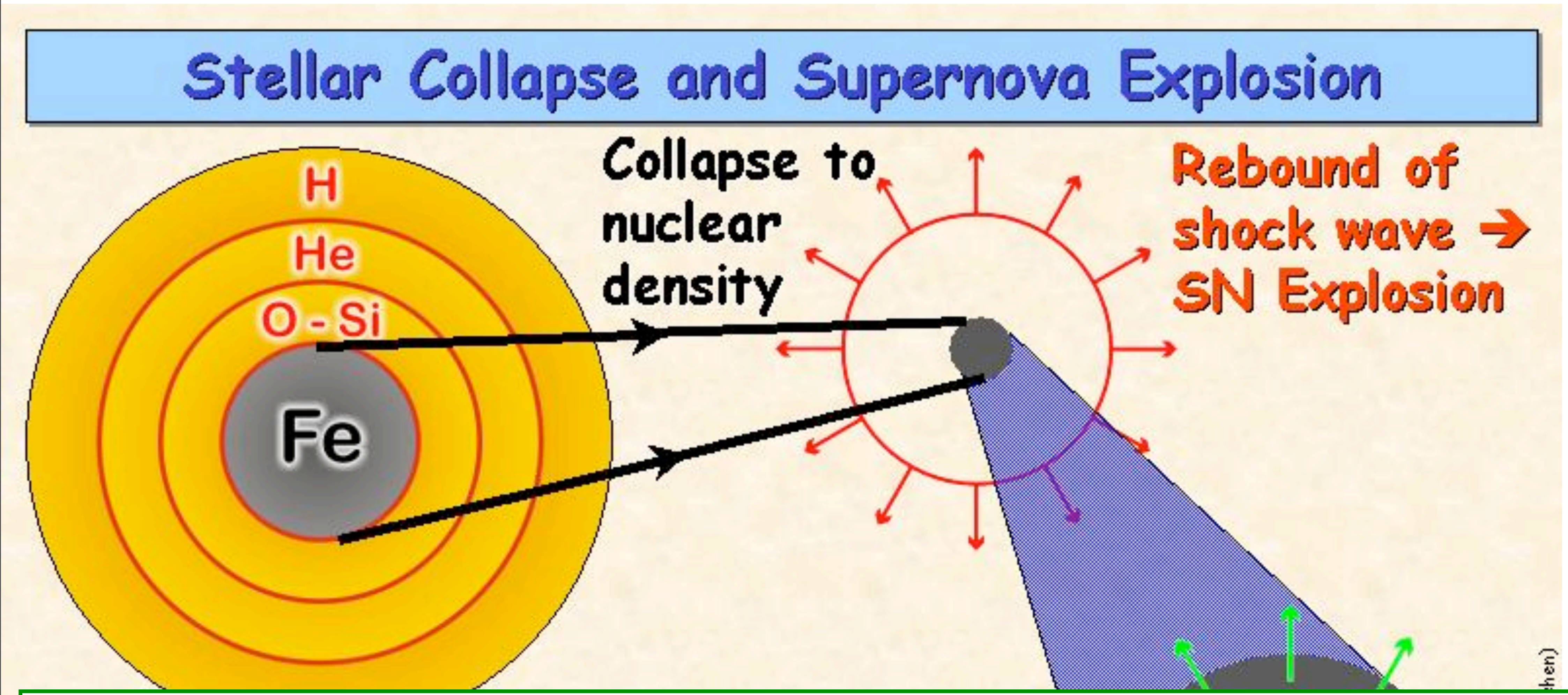

While successful in nature, in most numerical supernova models the shock stalls, so that the fate of the entire star is to produce a black hole, but no optical supernova.

(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 oxigen, magnesium, silicon, sulphur and calcium.)

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why neutrinos

Since the gravitational energy release transferred to neutrinos is 100 times greater than the required kinetic energy for the explosion, it is thought that neutrino emission and interactions are a key diagnostic or ingredient of success.

Moreover,

r-process nucleosynthesis, that is thought to occur when the supernova is only a few seconds old, strongly depends upon the properties of the proto-neutron star matter and finally to neutrino luminosities and temperatures.

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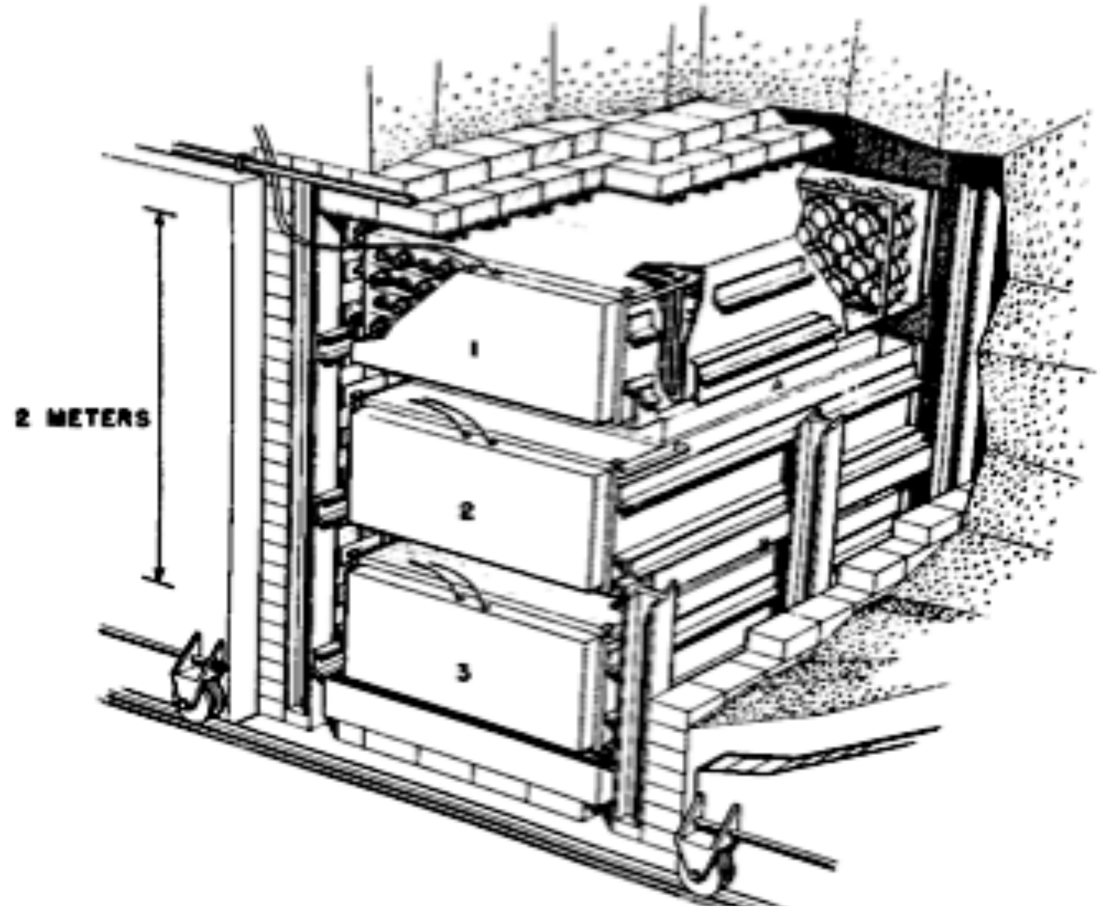
Core collapse neutrino detection

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} 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 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.

Observation of neutrinos from SN1987A

water Cherenkov:
Kamiokande II 2000 t.
IMB 5000 t.

liquid scintillator:
LSD 90 t.
BUST 200 t.

LSD, under the Mont Blanc
in collaboration between:
INR of Moscow, led by G.T.Zatsepin,
ICG (now IFSI-To) led by C.Castagnoli.

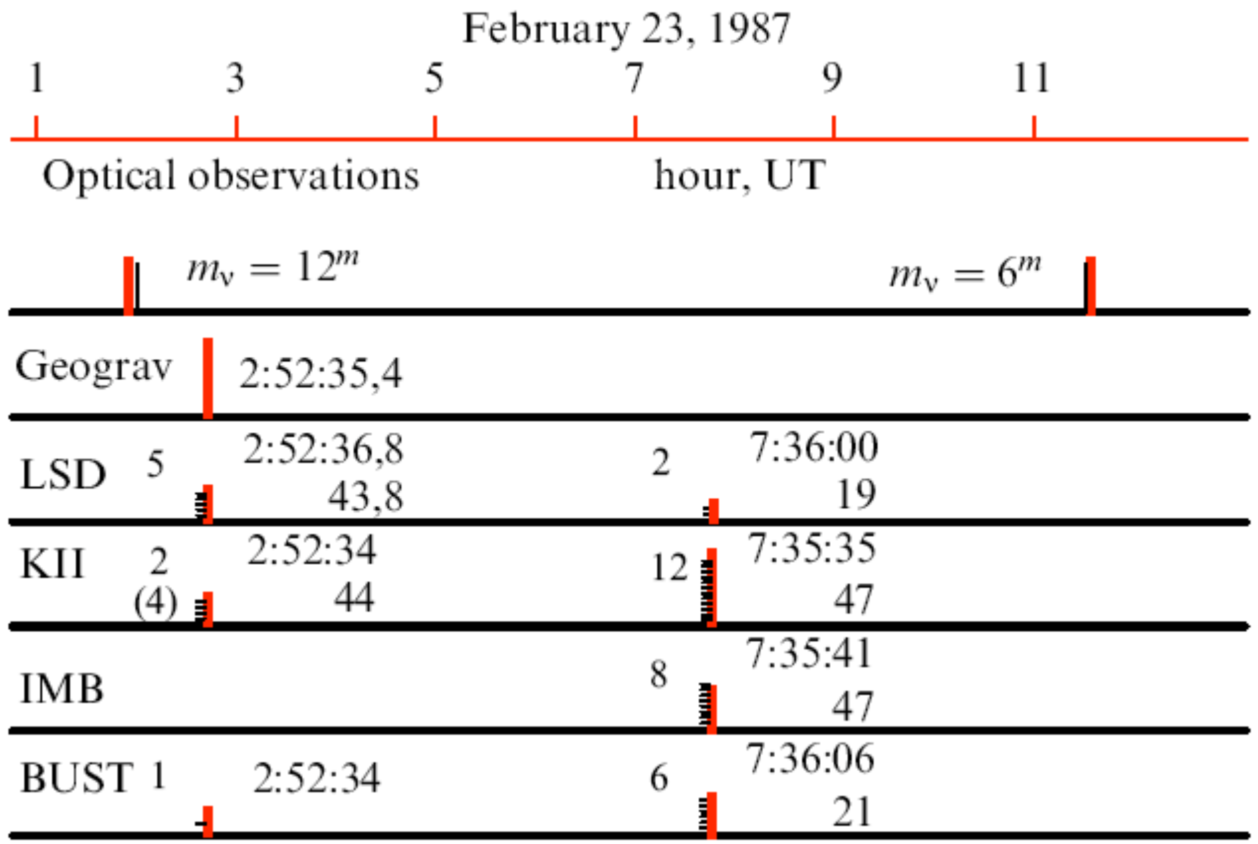


Figure 1. Temporal sequence of events observed at different neutrino detectors on February 23, 1987. The number of pulses in the series is conventionally shown for each detector. Times of arrival of the first and last pulse are also indicated.

O.G.Ryazhskaya, Physics - UPhysics - Uspekhi 49 (10) 1017 - 1027 (2006)

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

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Observation of neutrinos from SN1987A

represents the experimental evidence that the mechanism responsible for type II SN is the gravitational collapse of the core:

1. emitted energy in neutrinos in agreement with the n-star binding energy: $E_b = G_N M^2_{NS}/R_{NS} \sim (1 - 4) \times 10^{53}$ erg
2. spectrum in reasonable agreement with a thermal one;
3. time duration of the signal in agreement with the formation of a ν opaque region.

Nevertheless, the small statistics, only about 30 events (ν interactions candidates) in total, left a lot of open problems.

"It is clear that the ultimate energy source is gravity, but the relative roles of neutrinos, fluid instabilities, rotation and magnetic fields continue to be debated."

Stan Woosley and Thomas Janka 2006 (astro-ph 0601261)

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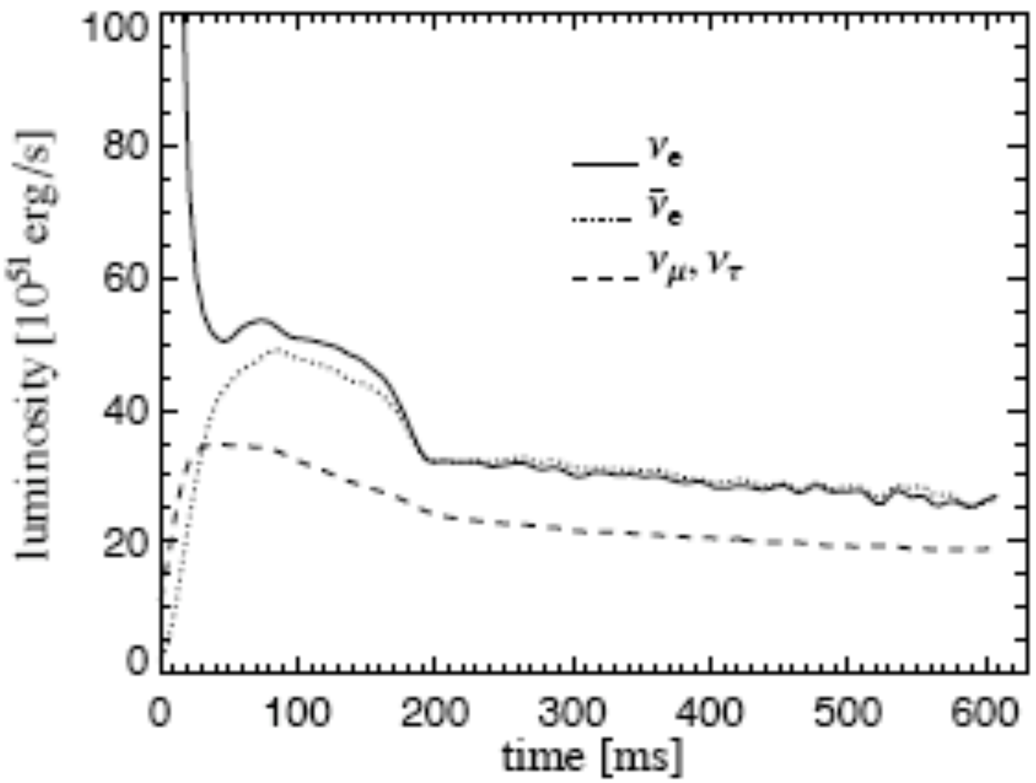
open problems

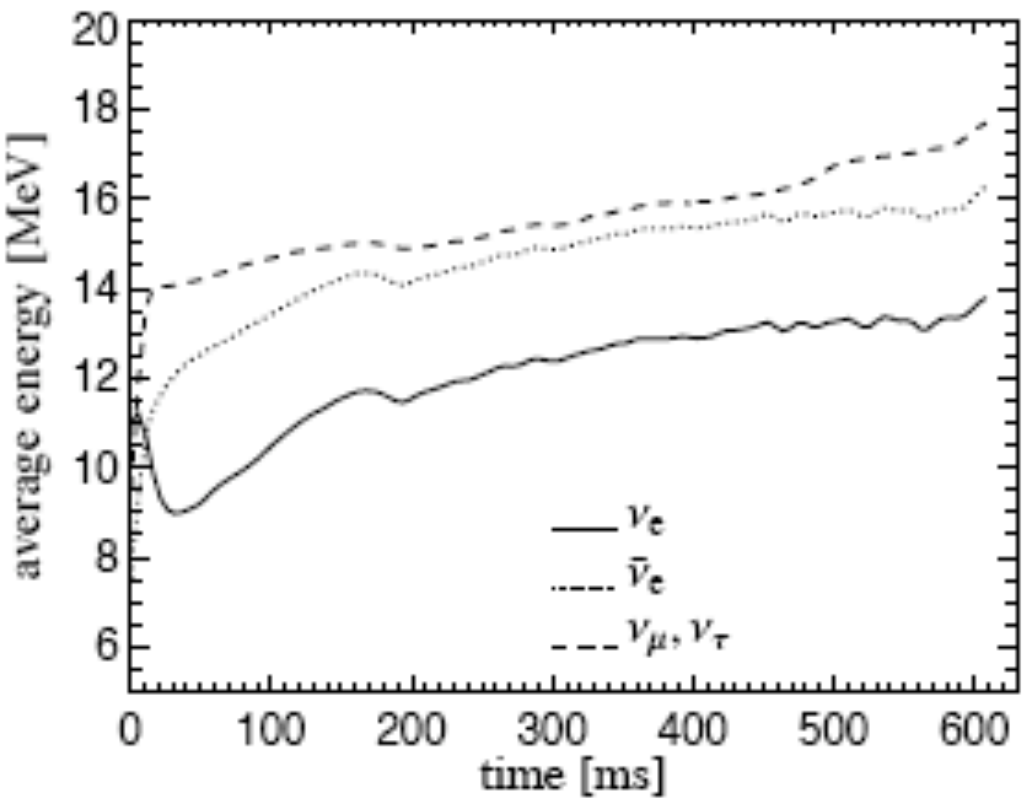
the mechanism responsible of the supernova explosion is unknown;

models seems not be able to reproduce the elemental abundances due to r-process nucleosynthesis.

some aspects of the signal detected in occasion of SN1897A are not understood.

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





→ The model could be right, but simulations not enough detailed.

→ The model could be wrong, other models have been proposed, but they are not yet studied and simulated in detail.

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

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Main difficulties

Extremely small interaction cross section of neutrinos with matter.

$$N_{ev} \propto M_H/D^2$$

for a scintillator or water Cerenkov detector, ~ 0.2-0.3 events/ton, for a "standard" core collapse at 10 kpc.
Detectors of hundreds and better thousands of tons equipped with hundreds and thousands of PMTs are required to observe the entire Galaxy;

The cosmic ray background,especially secondaries produced in muon interactions with rock, can mimic the signal.
Detectors are therefore set deep underground in galleries or mines.

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

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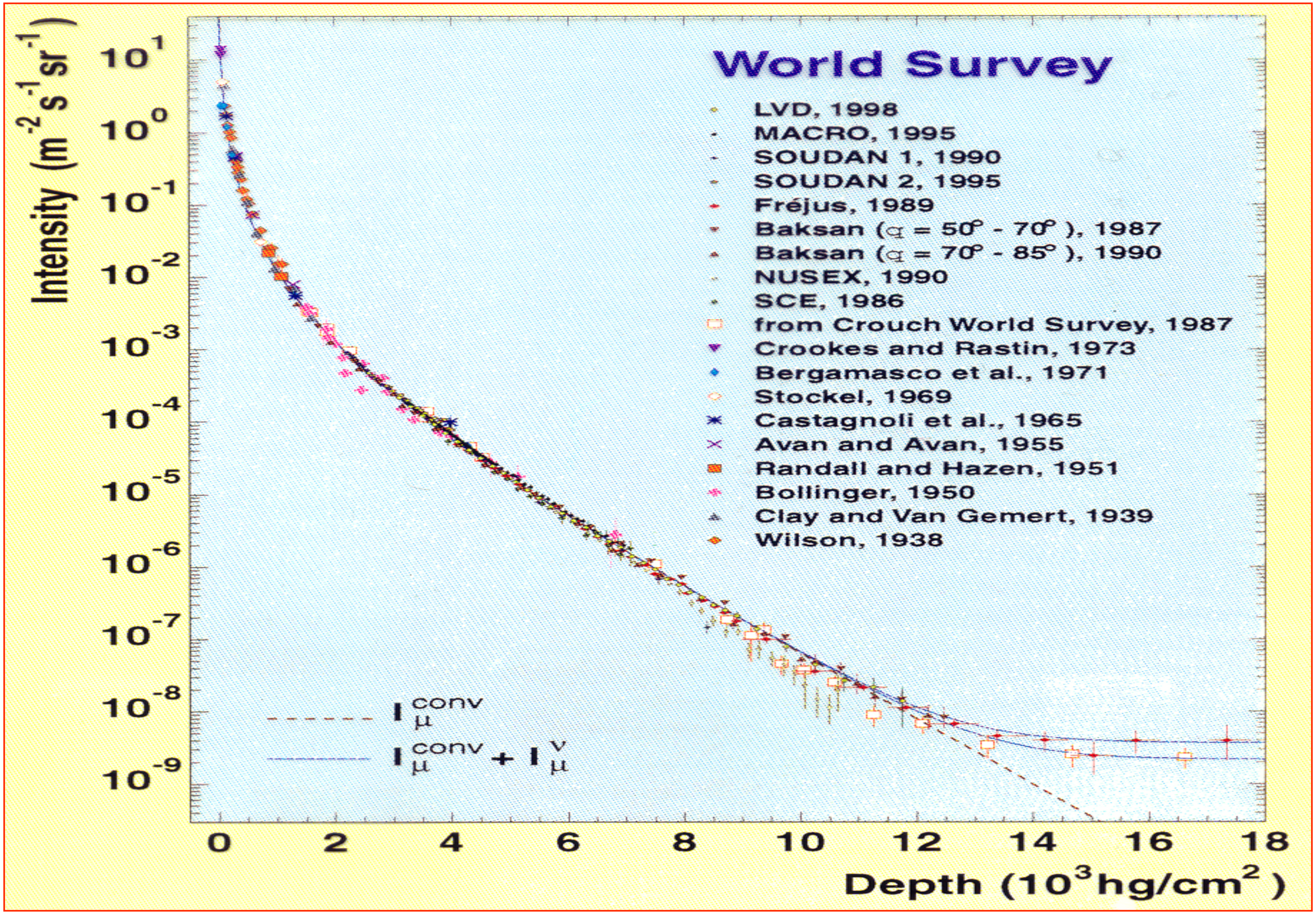
The cosmic ray background



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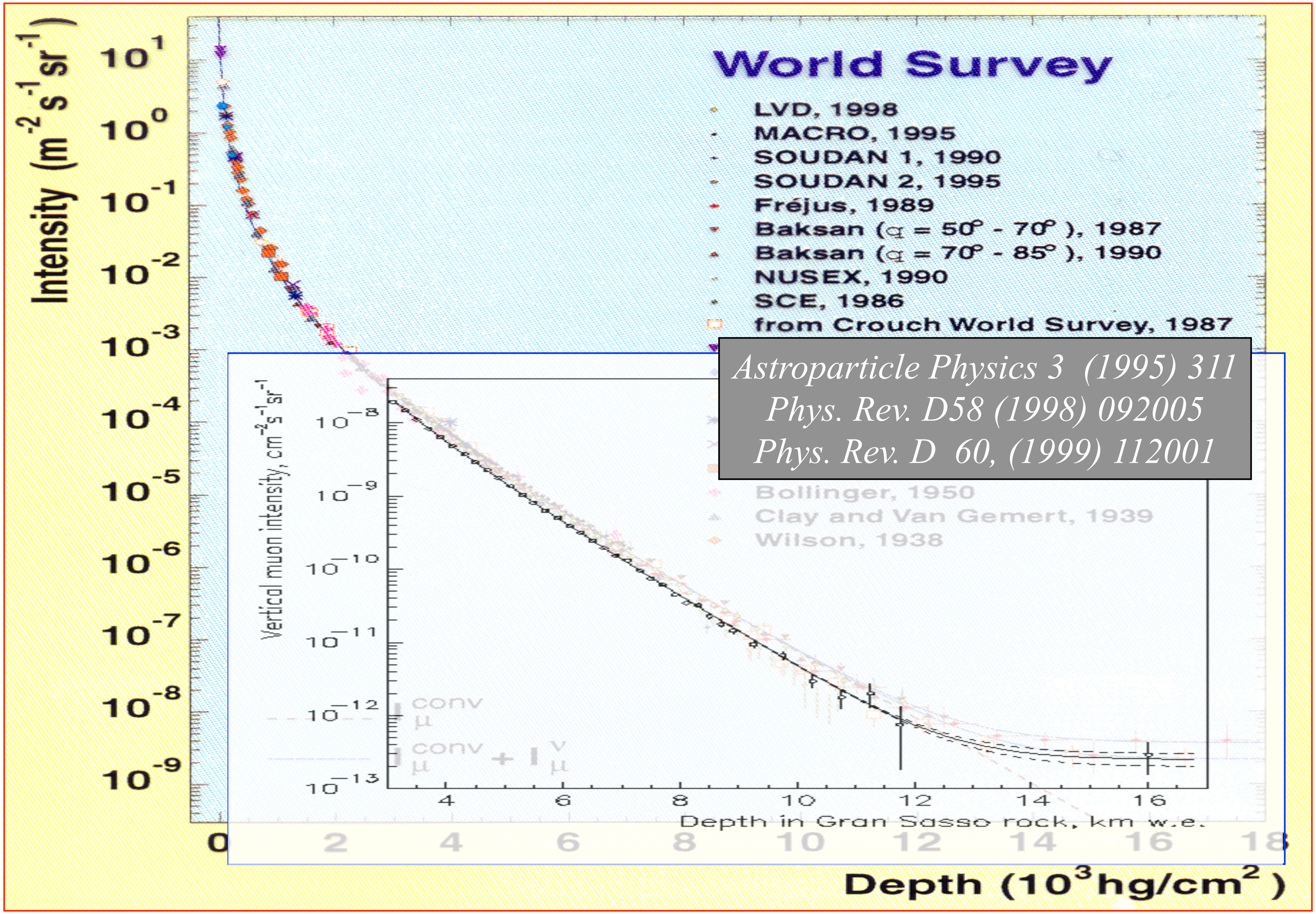

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new strategies

..after the detection of neutrinos from SN1987A:
two main directives:

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new strategies

..after the detection of neutrinos from SN1987A: two main directives:

the neutrino detection must be independent from any other signal from a galactic core collapse (the Galaxy is not transparent to e.m radiation).

The only neutrino burst detected (SN1987A) have been recognized because of its correlation with the electromagnetic signal.

We need experiments able to disentangle the ν burst in the absence of any other signal and promptly, to be used to triggering all others detectors (gravitational waves, electromagnetic and particle detectors), allowing the study of this rare event since its first instant.

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collect all possible information coming from the neutrino signal.

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	$\nu_e, \bar{\nu}_e$
Long string water Cherenkov	H_2O	n	y	n	$\bar{\nu}_e$
Liquid argon	Ar	y	y	y	ν_e
High Z/neutron	Pb, Fe	y	y	n	All
Radio-chemical	^{37}Cl, ^{127}I, ^{71}Ga	n	n	n	ν_e

The ideal experiment should have the capabilities to measure: $L\nu_e$, $L\bar{\nu}_e$, $L\nu_x$ and ν_e, $\bar{\nu}_e$, ν_x spectra; and to point the source by $\nu_e e^- \rightarrow \nu_e e^-$ scattering.

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It is impossible to find all these characteristics in a single detector.

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LVD - operating since 1992

- Next year LVD will celebrate twenty years of operation.
- In 1965 Domogatsky and Zatsepin showed that neutrinos from SN explosions could be detected by huge scintillator detectors.

  G. V. Domogatsky and G. T. Zatsepin, Proc. 9th ICRC London 39, 1030 (1965).
- LVD project was approved in 1985, scintillator counters and PMTs were exactly the same as in the Mont Blanc LSD detector, in operation from '84 to '99.
- Main improvements were the scintillator mass (20 time the mass in LSD) and the presence of the tracking system based on several layers of streamer tubes (no more in operation for safety reasons).

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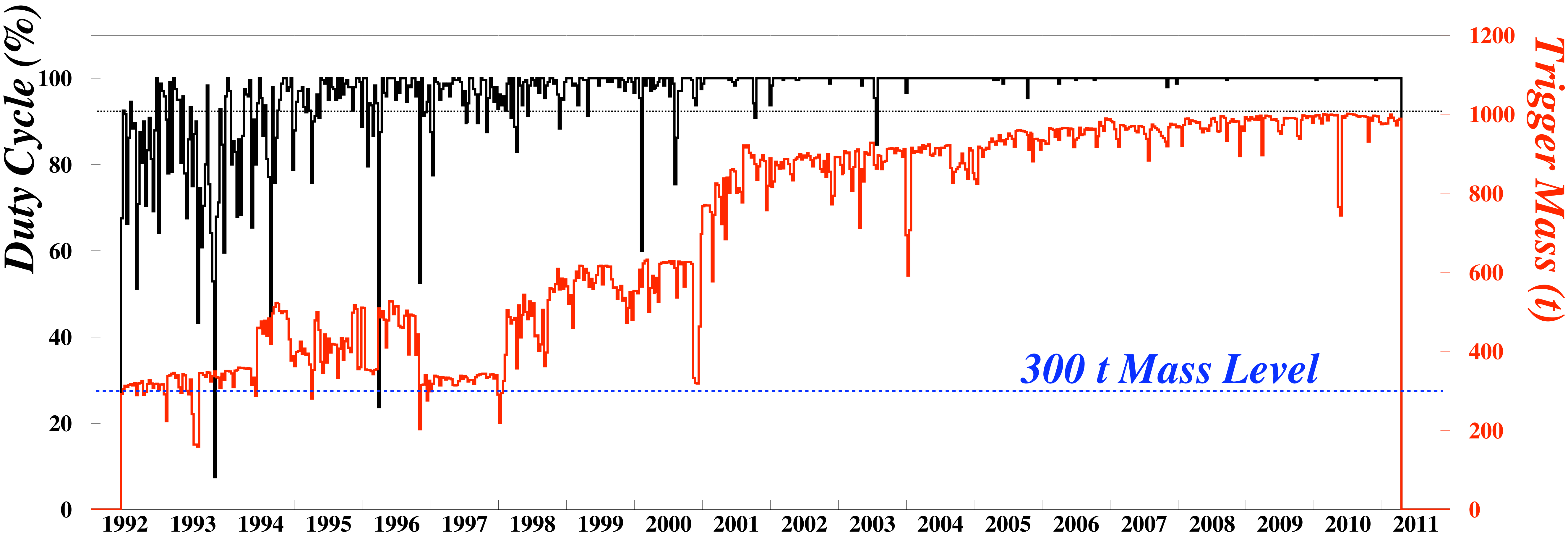
LVD - operating since 1992



- LVD began taking data on June 1992 with 1/5 of its projected mass.
- In the following years the project was modified and the total mass reduced to 1 kton
- At the end of 2001 LVD reached its present configuration.
- Since 2001 the detector sensitive mass and duty cycle improved continuously.

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The Supernova Early Warning System

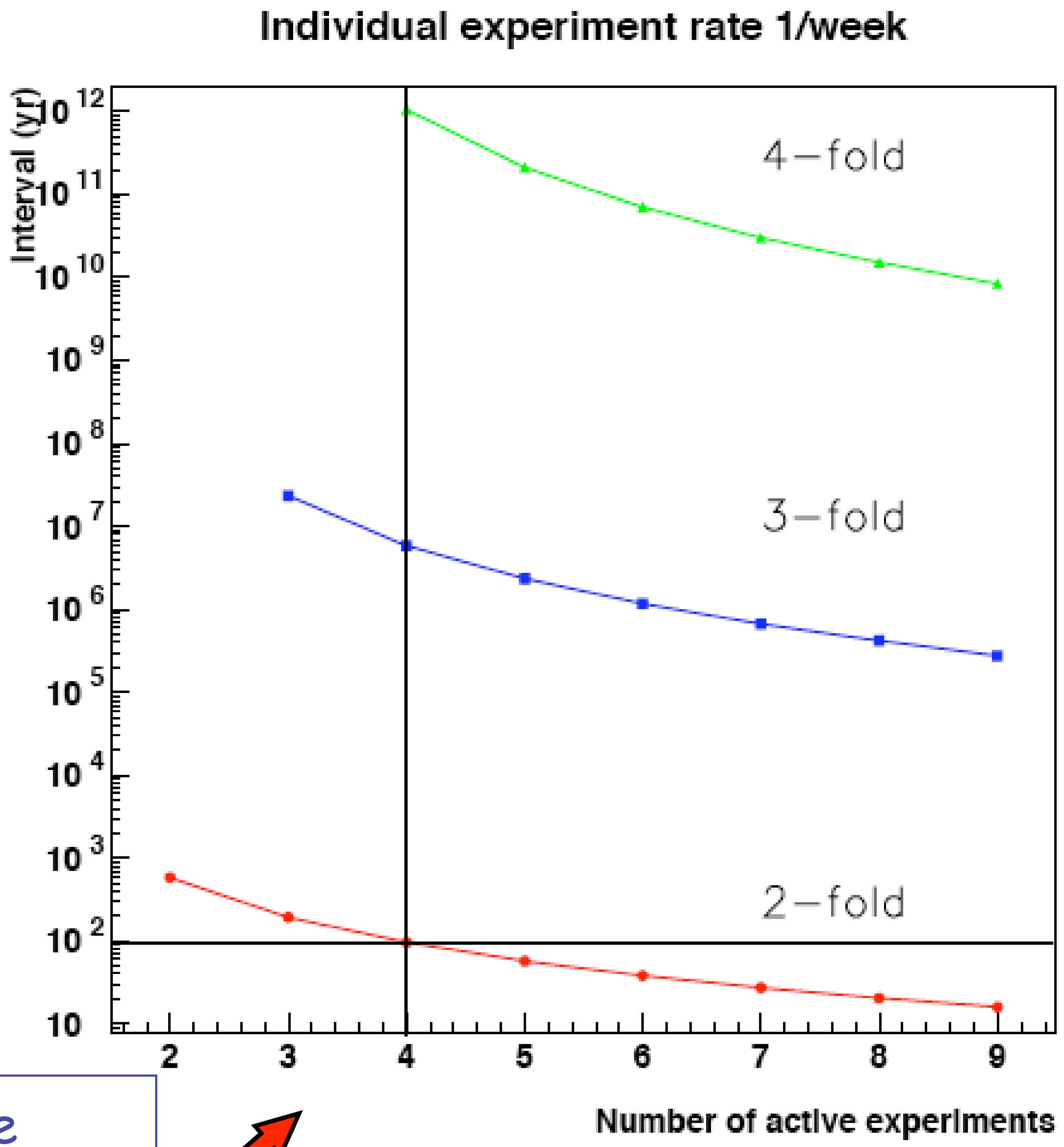
SNEWS: The Supernova Early Warning System
Pietro Antonioli,et al., New J. Phys. 6,114 (2004)

"..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:



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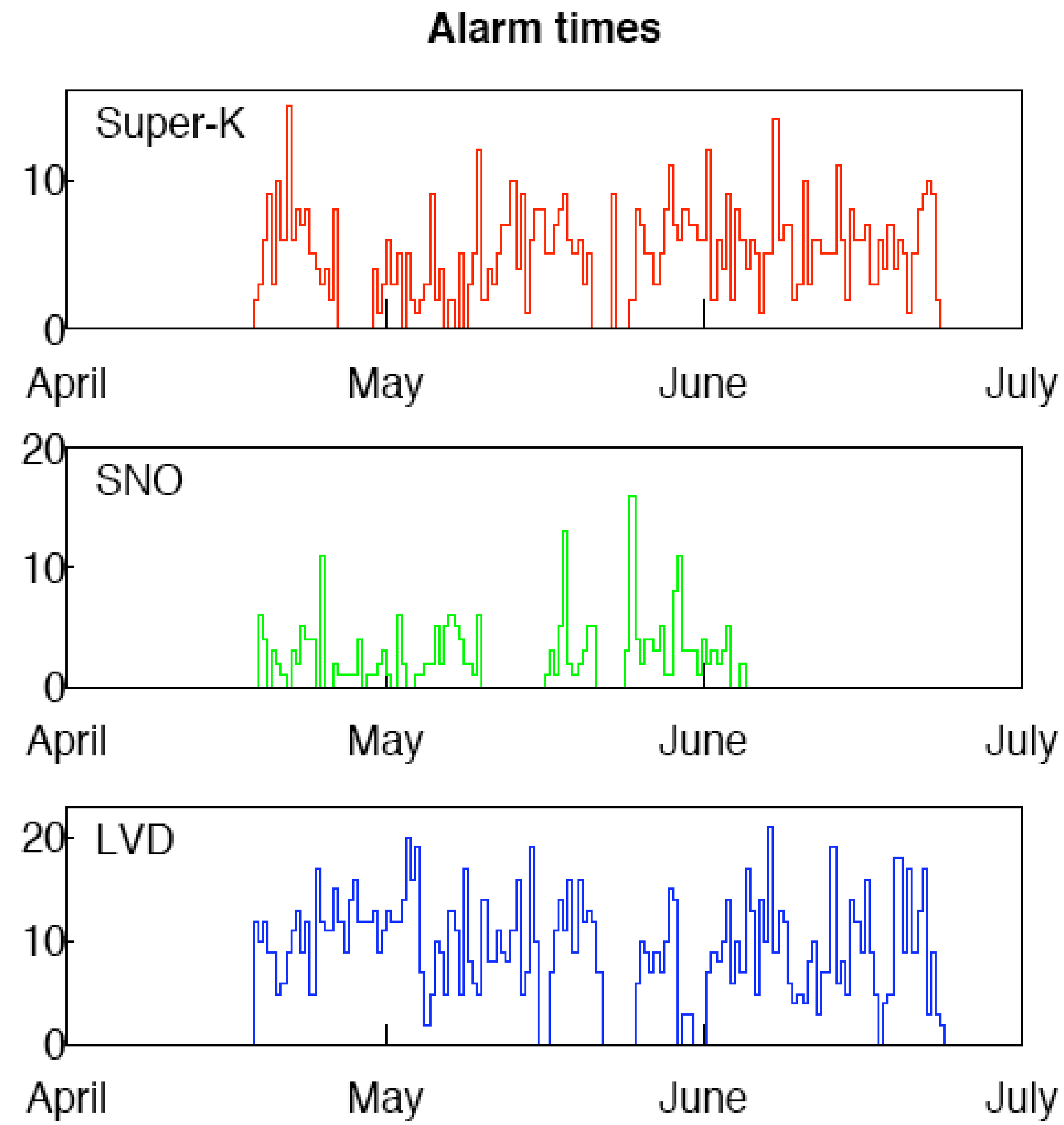
LVD and SNEWS

- LVD has been participating to the SN Early Warning System since its very beginning
- In 2001 LVD participated to the High Rate Test together with SUPERK and SNO



- Two purposes:
  - check the software robustness
  - increase our confidence on the expected coincidence rates.
- Made by:
  - lowering the thresholds of the experiments' SN monitors;
  - increasing the coincidence time window.

- SNEWS started to be fully operational on July 2005 after a long period of commissioning.
- At present with LVD, SUPERK, ICECUBE and BOREXINO

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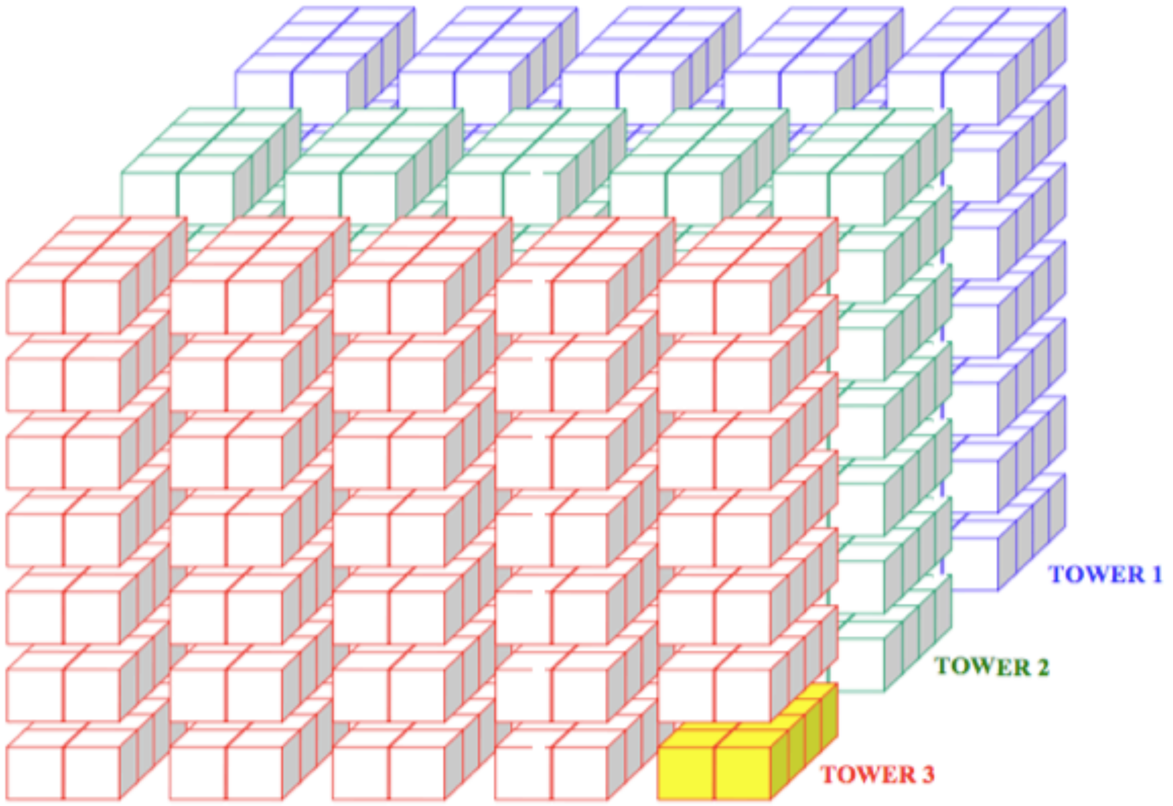
detector characteristics

- Main peculiarities:
  - high modularity
  - presence of Fe target

- The LVD array is divided in three "towers" fully independent concerning HV, trigger and data acquisition;
  the tower event fragments, if present, are sent to a central processor which provides event-building.

- each "tower" consists of 35 Fe "gondolas" hosting a cluster of 8 counters;



In total:
840 counters (72 in LSD), 1.5 m^3 each.
2520 PMTs
1000 ton of C_nH_{2n}
900 ton of Fe

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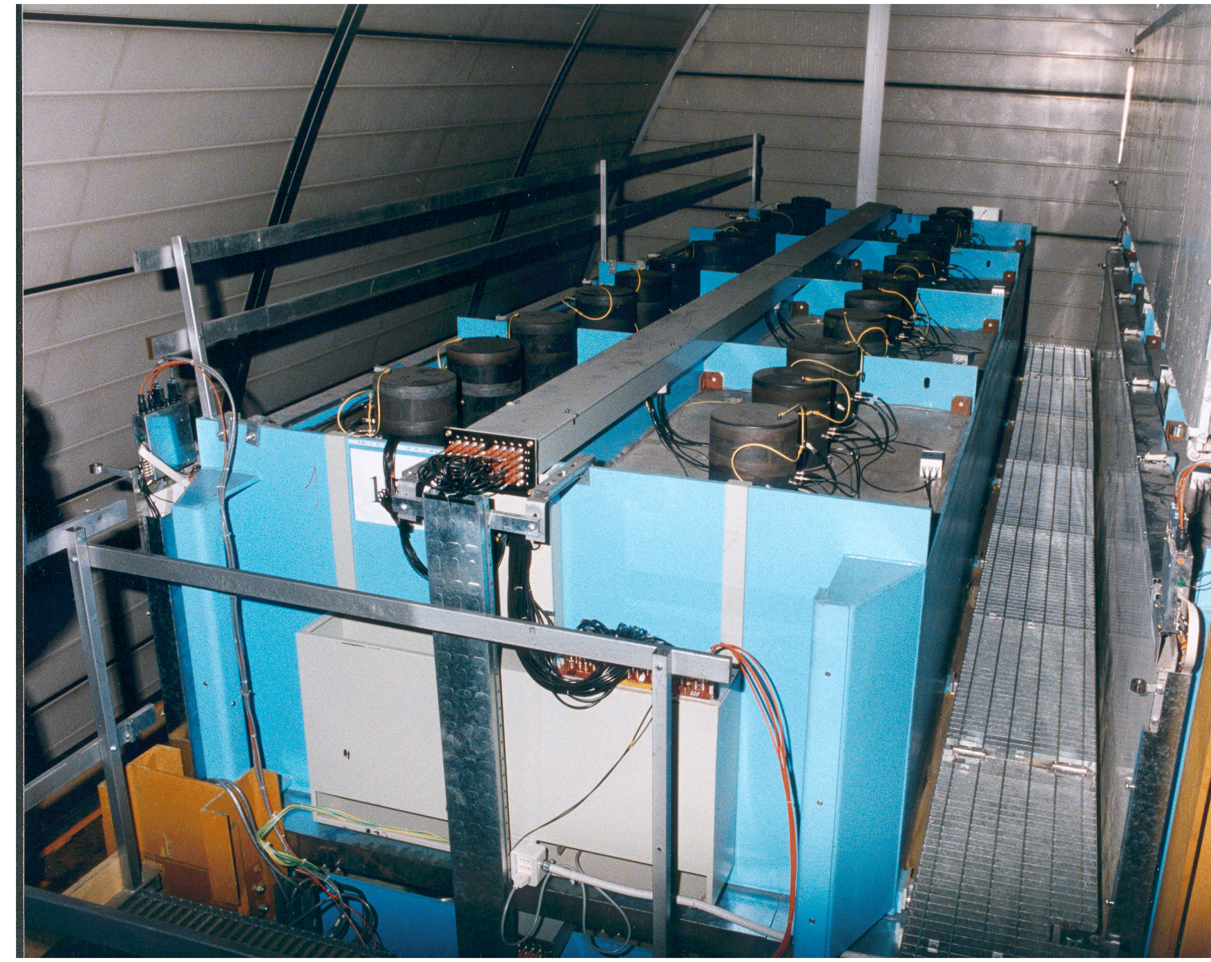
detector characteristics

- 3 towers
- 105 modules
- 840 counters
- 2520 PMTs

Each counter is viewed on the top by three PMTs FEU49b or FEU125.



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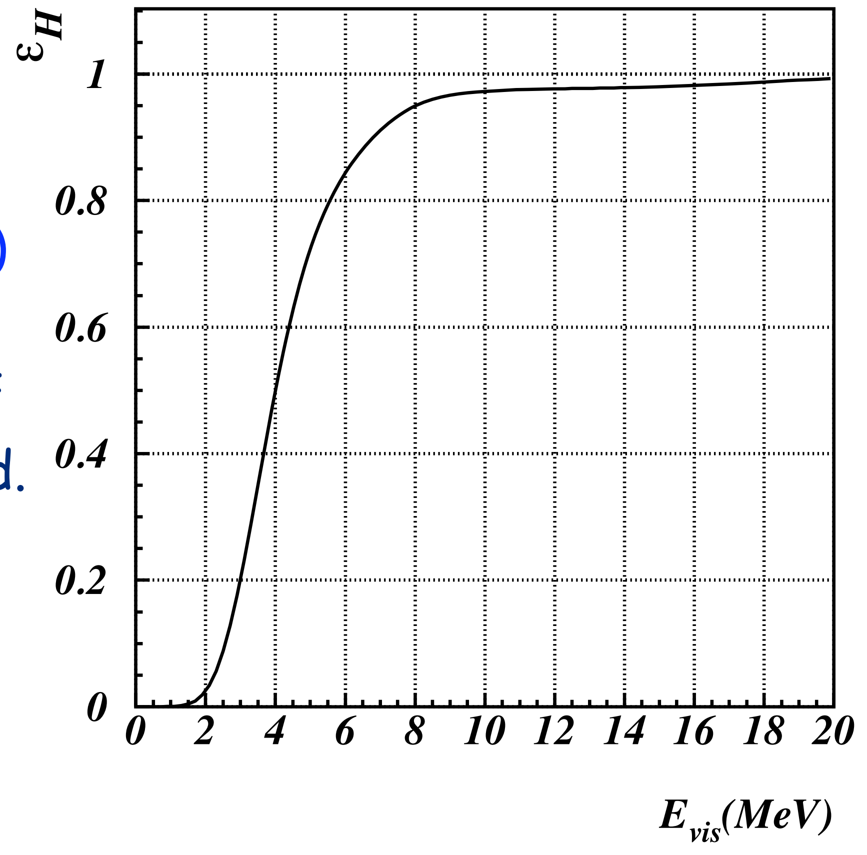
detector characteristics

Main reaction iβd: $\bar{\nu}_e\, p \rightarrow e^+\, n$

→ two detectable signals: prompt e^+ ($E_{vis} \sim E_{\bar{\nu}e} - 0.8$ MeV)
delayed ($\langle\Delta t\rangle = 185\ \mu s$) γ(2.2 MeV)



- The trigger logic is based on the 3-fold coincidence of the 3 PMTs of each counter and optimized for the detection of both products of iβd.

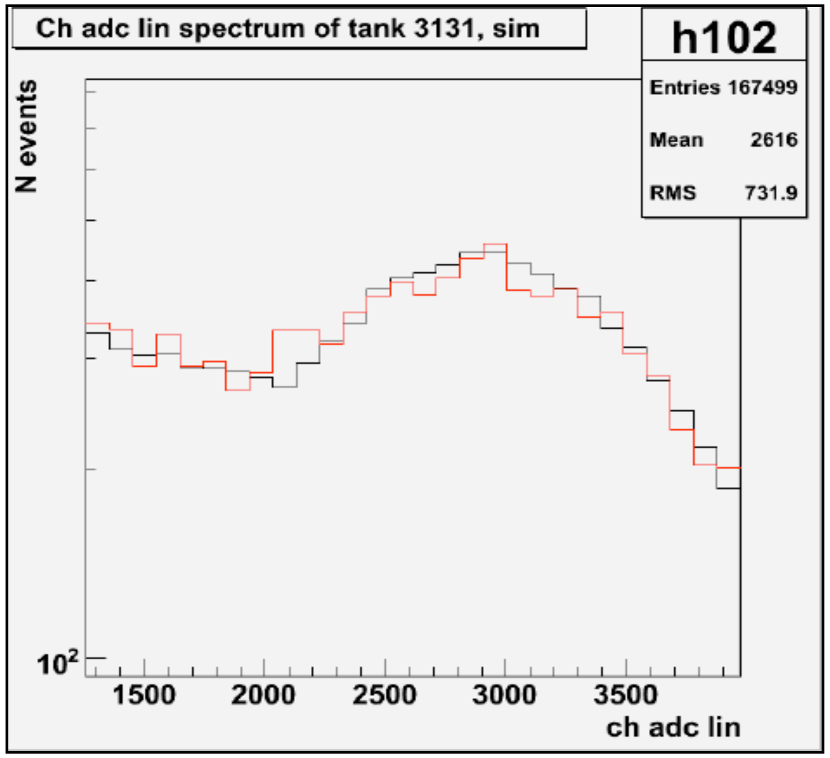
- Each PMT is discriminated at two different thresholds resulting in two possible levels of coincidence:

  High $E_H \sim 4$ MeV
  Low $E_L < 1$ MeV

→ The OR of the H coincidence of all counters is trigger condition for the tower

→ Each counter is calibrated by the energy spectrum of atmospheric muons, collected during 30 days
[$R\mu \approx 2\ h^{-1} \cdot counter^{-1}$].

→ Single counter low threshold counting rate is continuously monitored for noise rejection purposes



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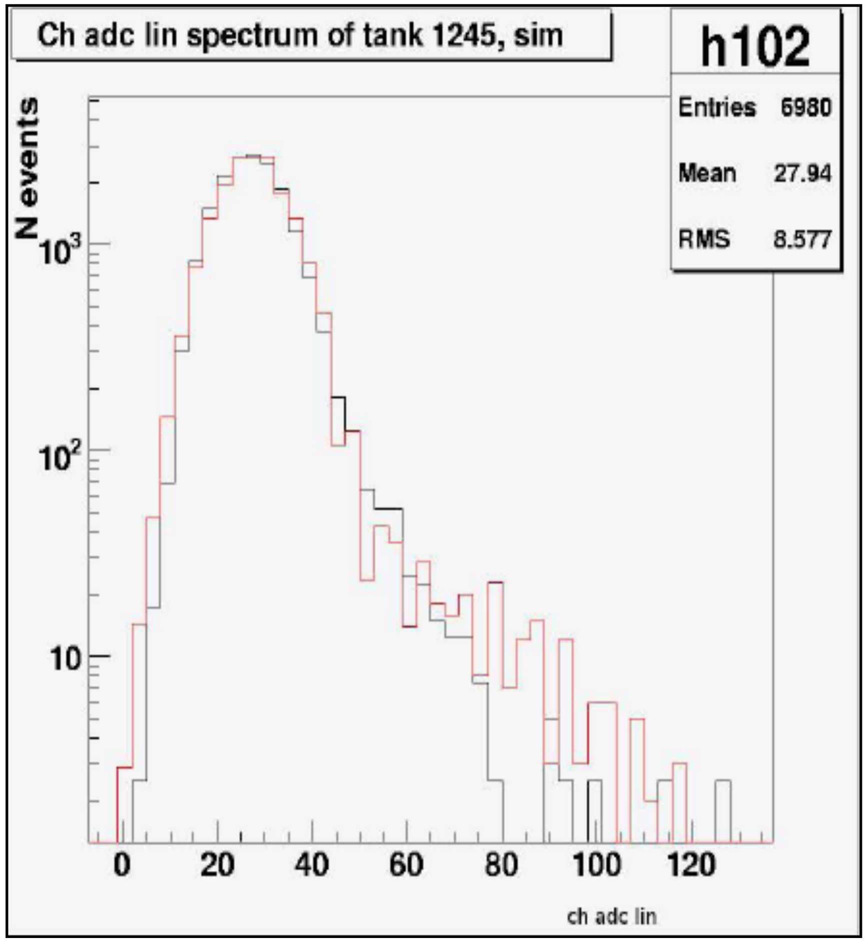
detector characteristics

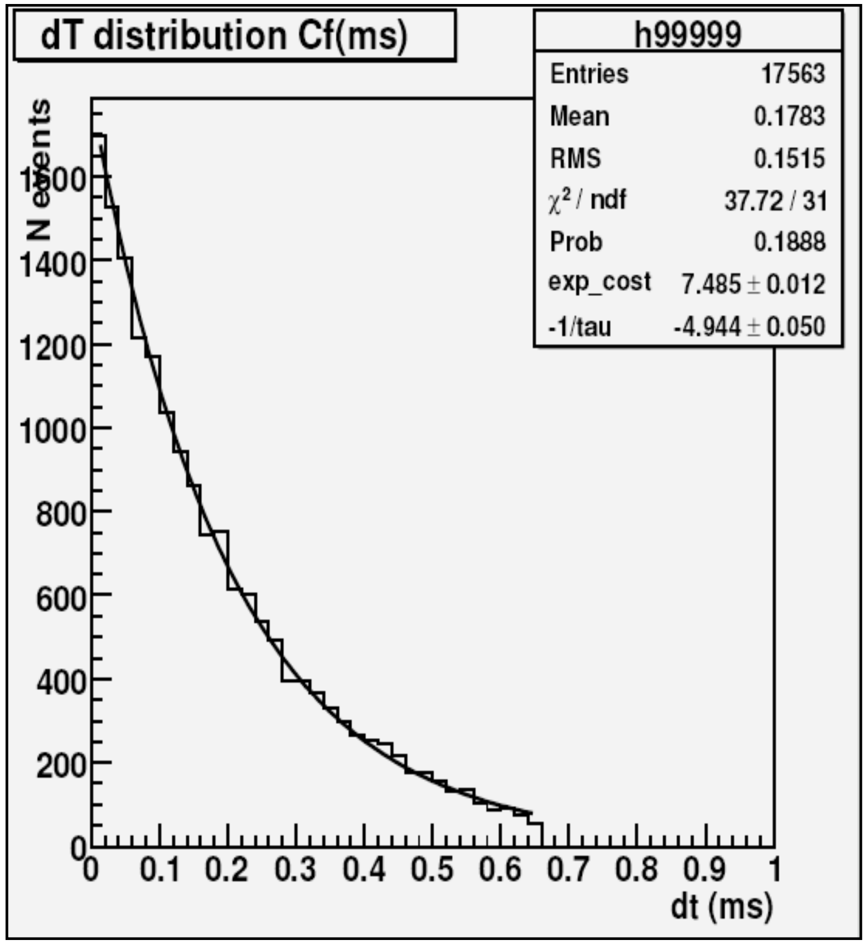
- neutron detection efficiency, ε_n, is measured by using a ^{252}Cf source placed in the center of the counter.
  For neutrons due to iβd, detected in the same counter where e^+ has been detected, the efficiency is about:
  - ➙ ε_n ~ 60%



- LVD energy resolution is:
  - ➙ η_{FWHM} ~ 35% at 15 MeV

- Absolute time accuracy better than
  - ➙ <1 μs

- Relative time accuracy:
  - ➙ 12.5 ns



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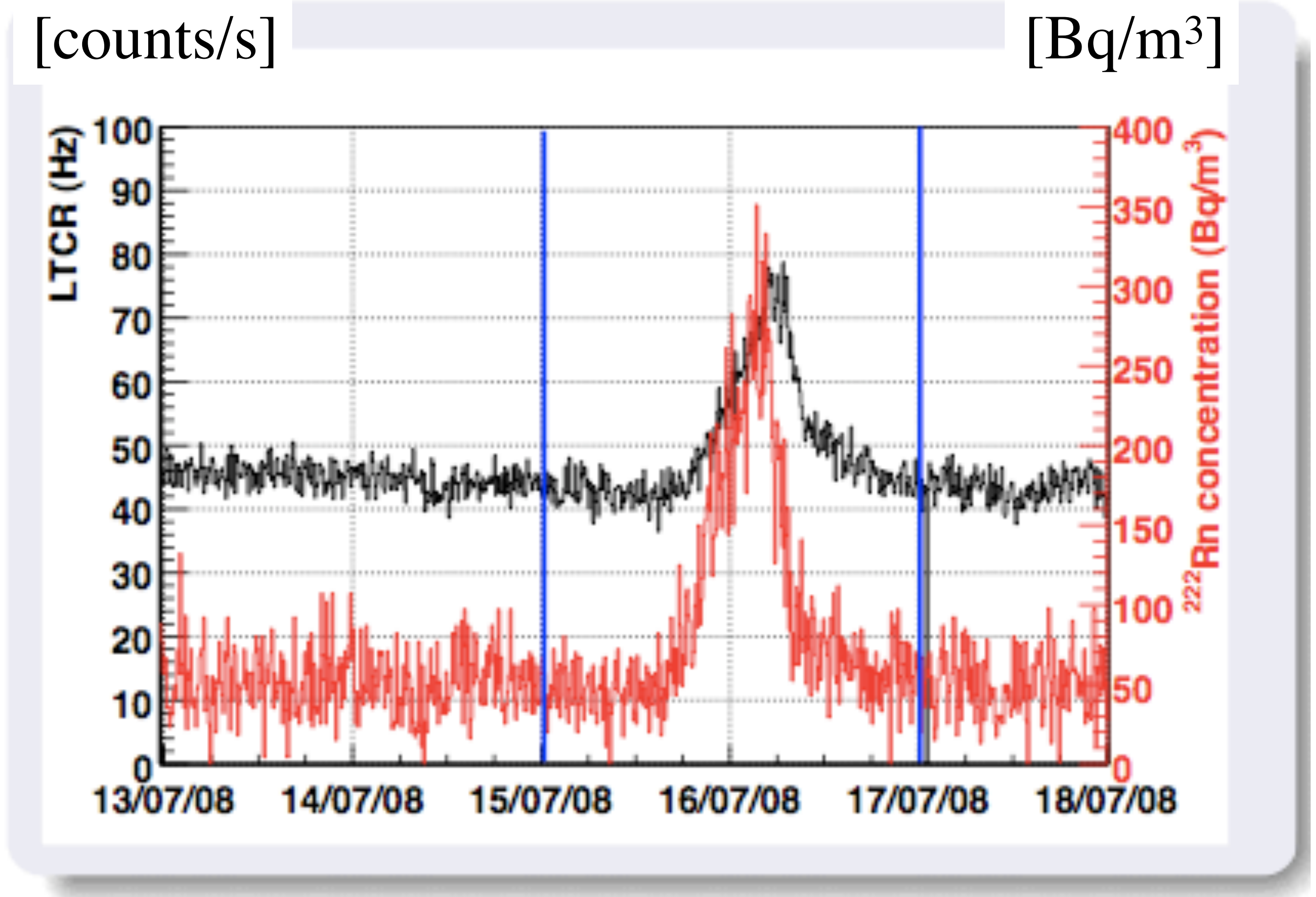
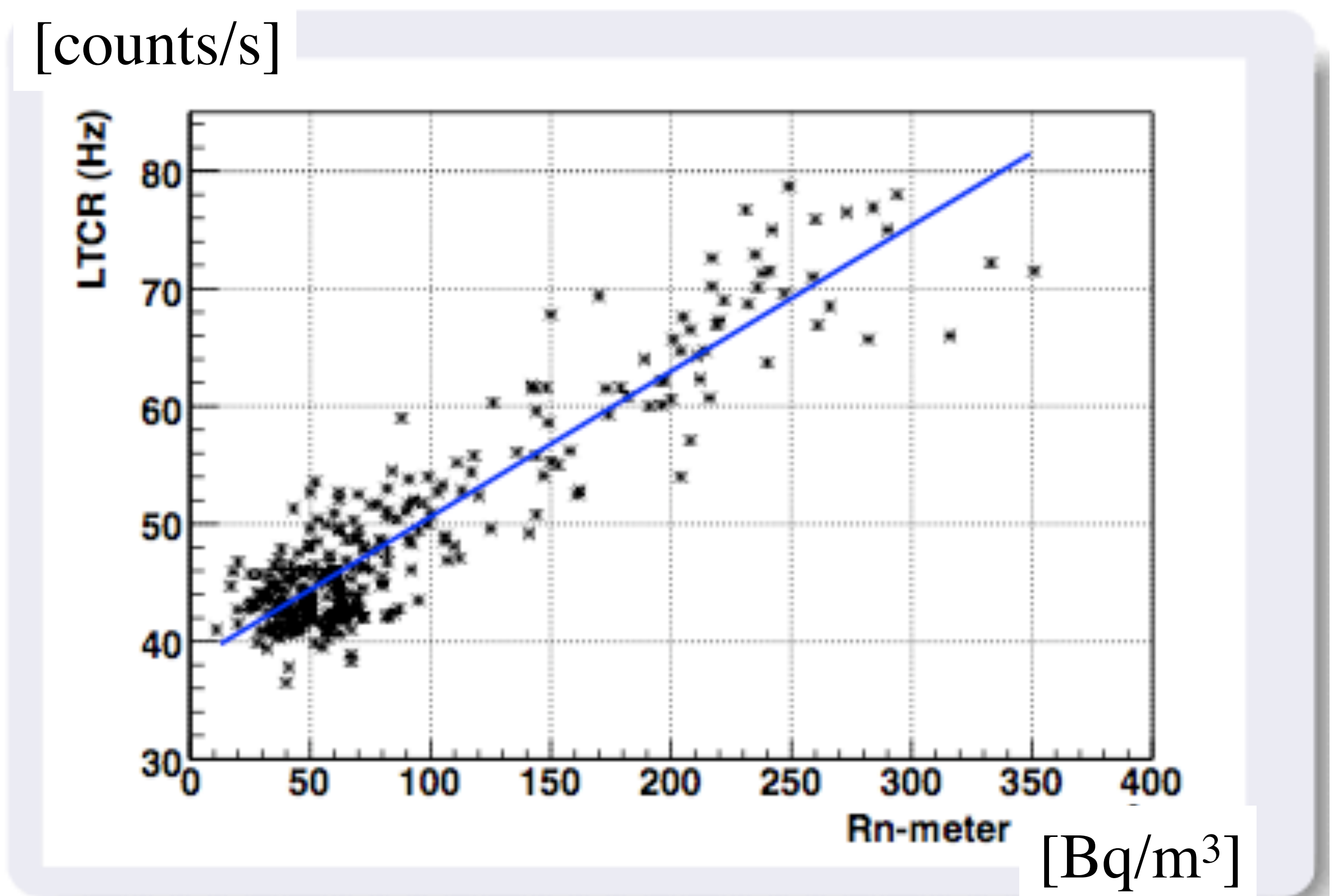
detector characteristics

- At low energies, uniformity of the response of the 840 counters is kept under control by using the correlation between time variation on Rn contamination in the cavern, measured by an α-radonmeter, and single counter low threshold rate.
- In this way we compare the counter's sensitivity to 609 KeV gammas from ^{214}Bi.
- On average, Rn variation of 1Bq/m^3, corresponds to a variation of 0.3 ± 0.1 counts/sec in each counter





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LVD: search for ν burst - strategy -

- LVD takes advantage of its characteristic geometry to design its strategy searching for ν burst.

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

- After muon rejection, based on sharp time coincidence among them, counters behaves as completely independent detectors.

- In this way the search for cluster of signals can be purely statistical, leaving the study of physical aspects of the detected cluster (energy, time distribution and flavor contain) to a following, confirming stage of analysis.

- **Only requirements are:**

  → the bulk of the signal must be contained inside a time window of 10 sec
  (relaxed to 100 sec in the off-line search)

  → signals of the cluster must be uniformly distributed inside the array
  (uniformity of the counter's response is guaranteed against threshold effects, by a sharp energy cut at 7 and 10 MeV)

- **If it works we will be able**
  - **to predict the rate of fake alarms (clusters)**
  - **to define the significance of each of them**

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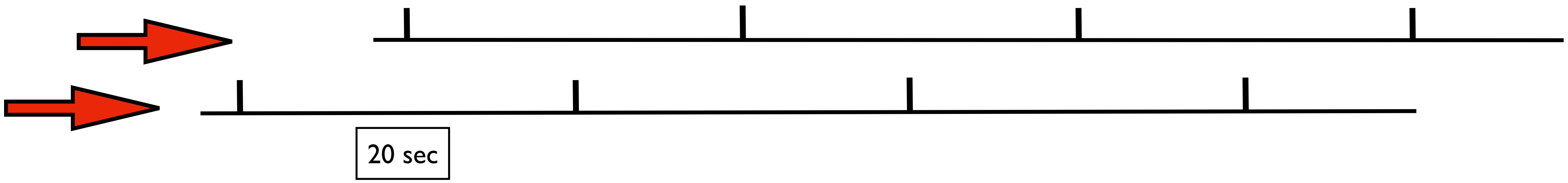
LVD: search for ν burst - strategy -



- Data stream is analyzed by counting the number of events (m) simultaneously at E_{cut}=7 and 10MeV in two time windows (20 s) that are out of phase from each other.

- Each cluster of multiplicity = m is associated to an expected imitation frequency, F_{im}, calculated as:

$$F_{im}(m, f_{bk}, 20) = 17280 \cdot P_{k \geq m}(f_{bk} \cdot 20) \text{ alarm} \cdot \text{day}^{-1}$$

F_{im} is the expected rate of bk clusters with multiplicity $\geq$m

F_{im} represents the cluster's significance defined "a priori"

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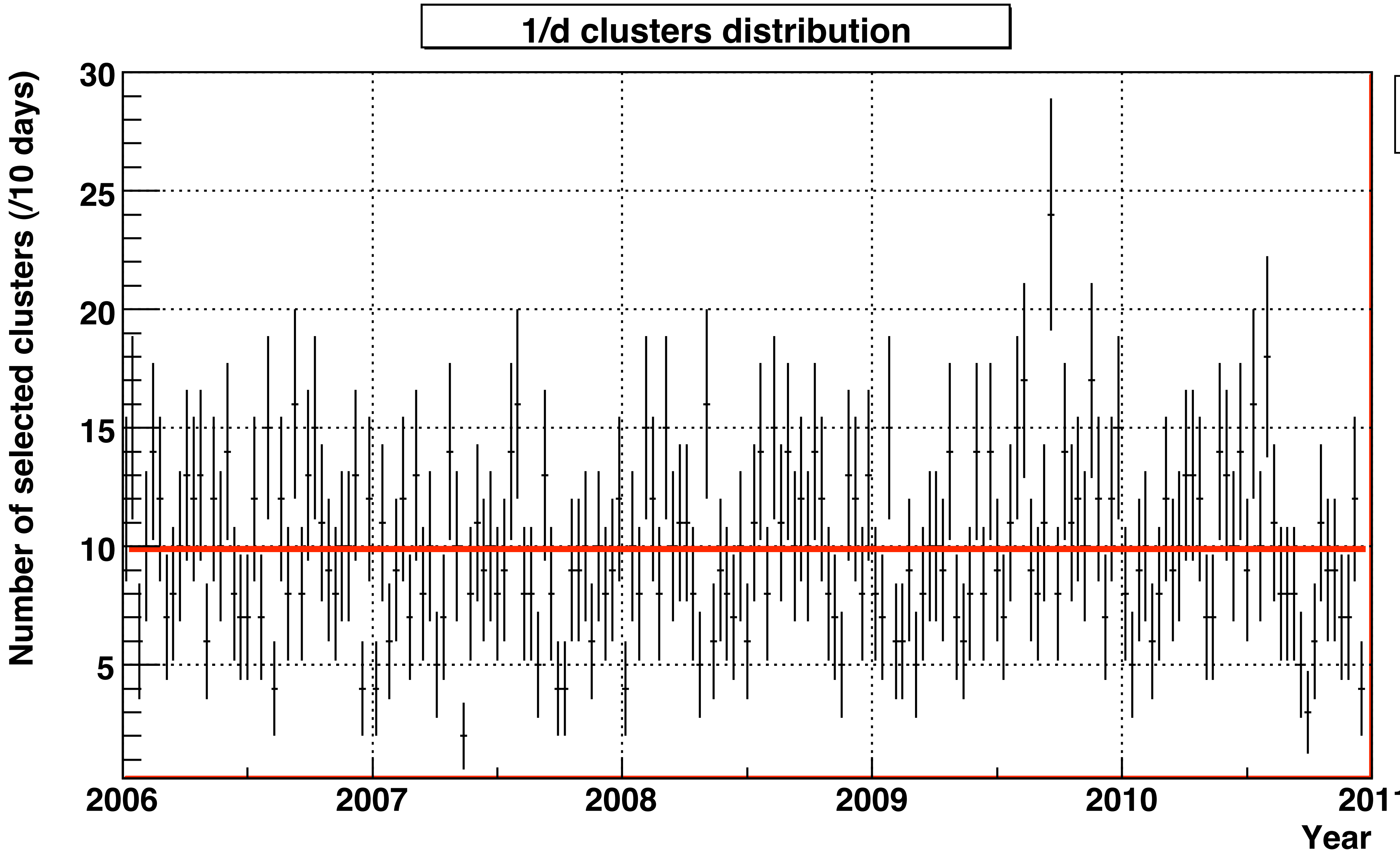
LVD: search for ν burst - results -

- to keep under control the detector we monitor the experimental rate of clusters with expected imitation frequencies: **1/hour; 1/day; 1/week**



1/day

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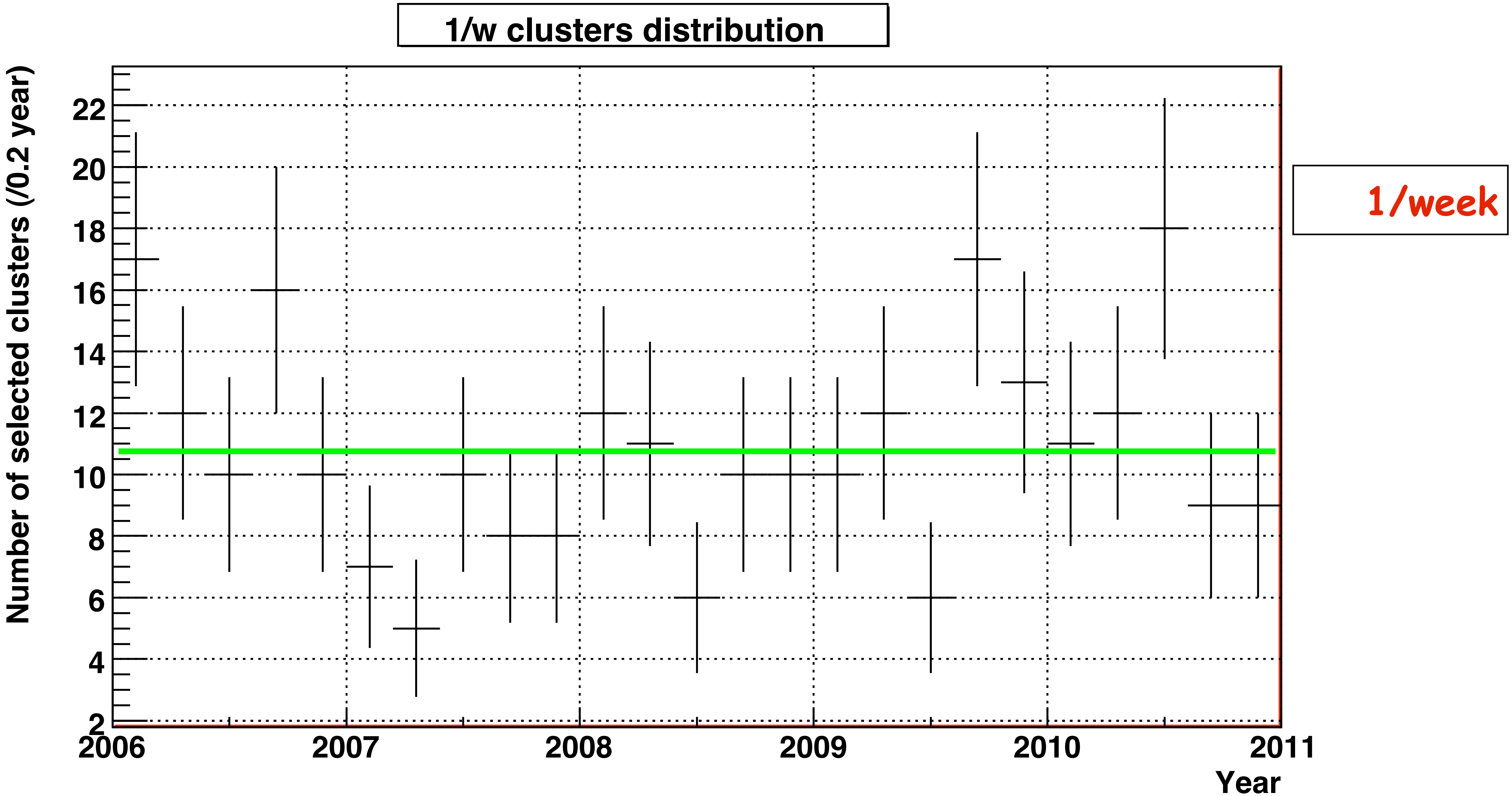
LVD: search for ν burst - results -



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LVD: search for ν burst - sensitivity -

- To define the detector sensitivity in terms of maximum distance, for the neutrino emission, we assume the parameterized model:

M.L. Costantini, A. Ianni, G. Pagliaroli, F. Vissani, Astroparticle Physics 31 (2009) 163

- with the parameters determined from SN1987A as standard candle:
  - $E_b = 2.4 \cdot 10^{53}$ erg;
  - average $\bar{\nu}_e$ energy = 14 MeV
  - $T_{\nu_x} / T_{\bar{\nu}_e} = 1.2$

Table 3. Total number of expected events for a supernova at 10 kpc and percentage of the events in the various interaction channels for all the detectors under study. Normal hierarchy non adiabatic.

	LVD	Borexino	KamLAND	SuperKamiokande	IceCube
Total number @ 10 kpc	335	138	573	7400	1423800
$\bar{\nu}_e + p \to n + e^+$	87.1%	58.7%	66.8%	86.8%	87.5%
$\nu_x + e^- \to \nu_x + e^-$	3.2%	3.2%	2.6%	2.8%	1.5%
$\nu_e + ^{12}C \to ^{12}N + e^-$	1.1%	1.1%	0.8%	-	-
$\bar{\nu}_e + ^{12}C \to ^{12}B + e^+$	1.0%	2.2%	1.7%	-	-
$\nu_x + ^{12}C \to \nu_x + ^{12}C + \gamma_{15.1MeV}$	2.1%	5.8%	4.4%	-	-
$\nu_e + ^{56}Fe \to ^{56}Co^* + e^-$	3.0%	-	-	-	-
$\bar{\nu}_e + ^{56}Fe \to ^{56}Mn + e^+$	0.6%	-	-	-	-
$\nu_x + ^{56}Fe \to \nu_x + ^{56}Fe^*$	1.9%	-	-	-	-
$\nu_x + p \to \nu_x + p$	-	29.0%	23.7%	-	-
$\nu_e + ^{16}O \to ^{16}F + e^-$	-	-	-	0.9%	1.0%
$\bar{\nu}_e + ^{16}O \to ^{16}N + e^+$	-	-	-	5.9%	6.5%
$\nu_x + ^{16}O \to \nu_x + O^*/N^* + \gamma$	-	-	-	3.6%	3.5%

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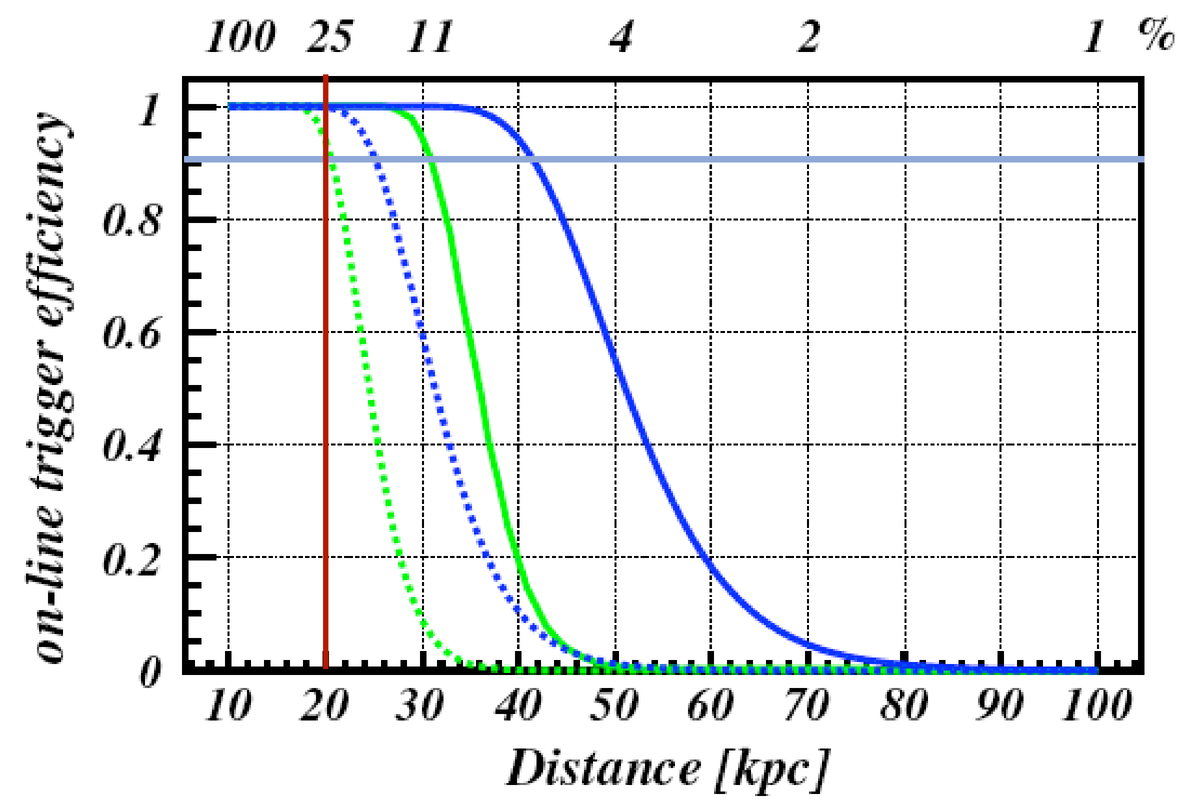
LVD: search for ν burst - sensitivity -

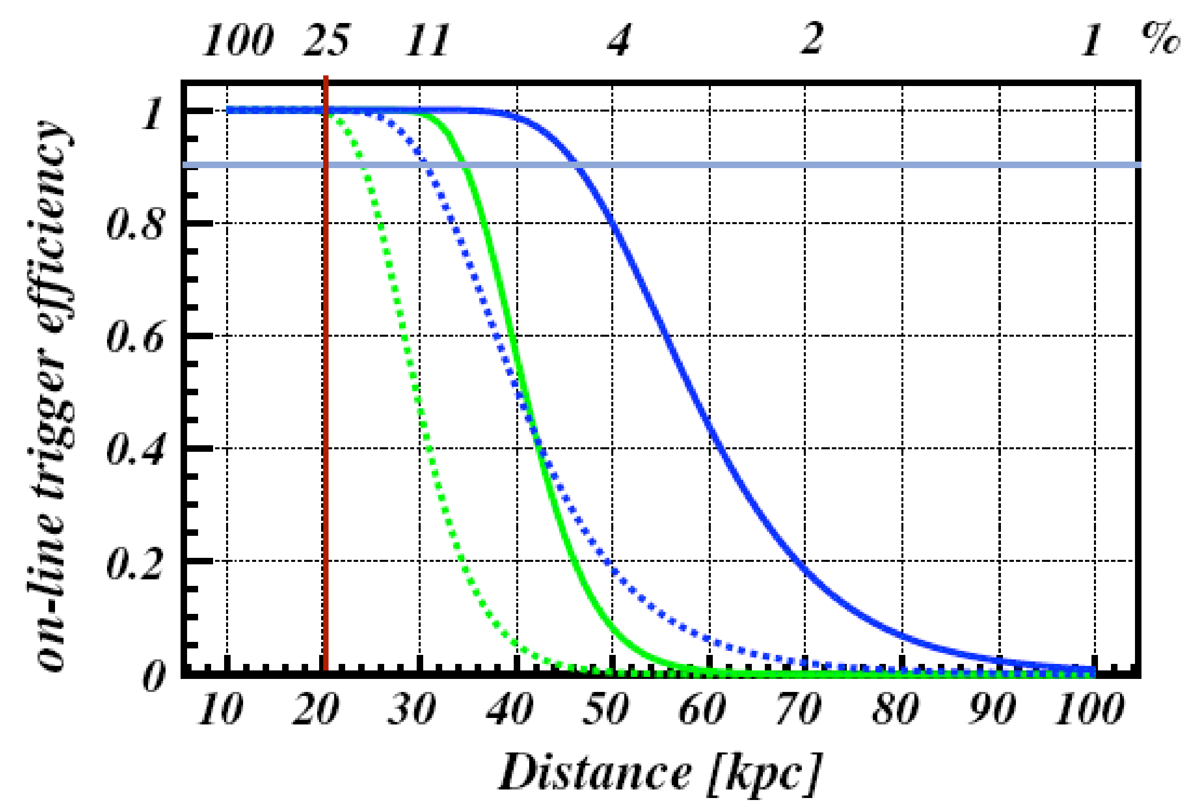
- With these assumptions on the neutrino emission and for a Fim < 1 fake event/100 years, we have full efficiency up to 20 kpc when the detector mass is greater than 300 ton

STAND ALONE
(F_{im} < 1 fake event/100 years)
E_{cut} = 7 MeV
E_{cut} = 10 MeV



- Working in coincidence with other detectors we relax Fim to 1 fake event/month.

SNEWS
(F_{im} < 1 fake event/month) !!
E_{cut} = 7 MeV
E_{cut} = 10 MeV



LVD: search for ν burst - results -

	SINCE	TO	LIVE TIME days	DUTY CYCLE	MASS ton	
RUN 1	Jun 6th '92	May 31st '93	285	60%	310	23rd ICRC 1993
RUN 2	Aug 4th '93	Mar 11th '95	397	74%	390	24th ICRC 1995
RUN 3	Mar 11th '95	Apr 30th '97	627	90%	400	25th ICRC 1997
RUN 4	Apr 30th '97	Mar 15th '99	685	94%	415	26th ICRC 1999
RUN 5	Mar 16th '99	Dec 11th '00	592	95%	580	27th ICRC 2001
RUN 6	Dec 12th '00	Mar 24th '03	821	98%	842	28th ICRC 2003
RUN 7	Mar 25th '03	Feb 4th '05	666	> 99 %	881	29th ICRC 2005
RUN 8	Feb 4th '05	May 31st '07	846	> 99 %	936	30th ICRC 2007
RUN 9	May 31st '07	Apr 30th '09	699	> 99 %	967	31st ICRC 2009
RUN 10	May 1st '09	Mar 27th '11	696	> 99 %	981	32nd ICRC 2011
Σ	Jun 6th '92	Mar 27th '11	6314			

- The resulting 90% c.l. upper limit to the rate of gravitational stellar collapses in the Galaxy (D ≤ 20 kpc) is: 0.13 events/year

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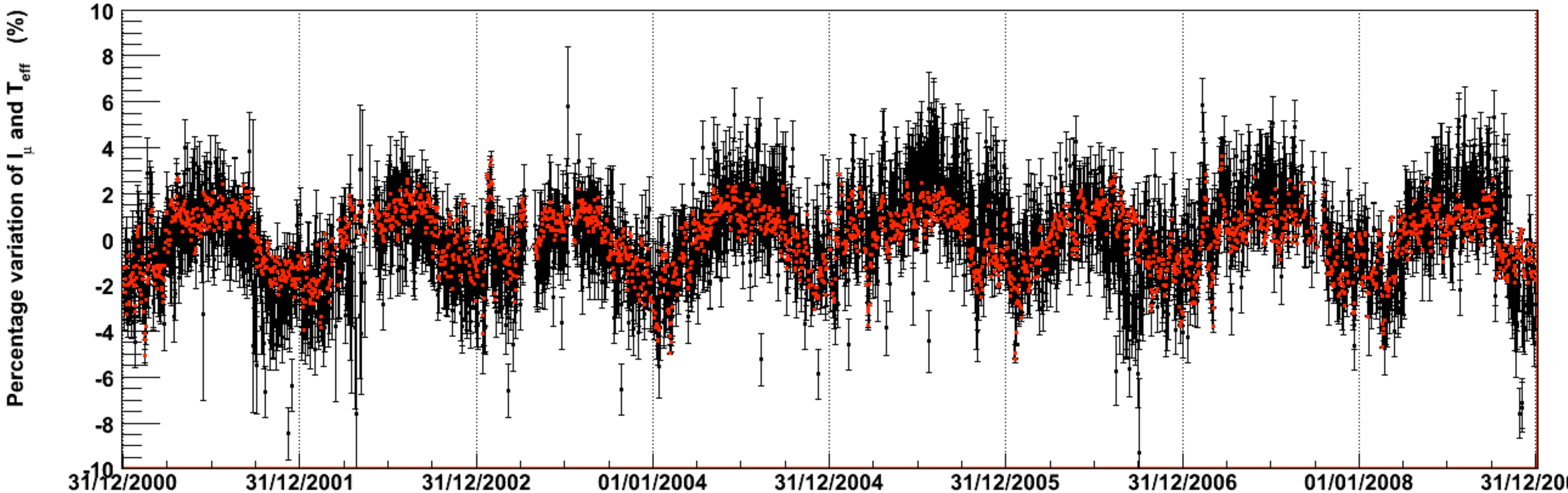
LVD: monitoring the background

Fractional variation of the muon intensity (black) and effective temperature (red)

M.Selvi for the LVD Collaboration, 31st ICRC 2009



The measurement of the atmospheric temperature is done by Aeronautica Militare at Pratica di Mare (near Rome), about 100 km away from Gran Sasso, via radio-soundings operated 2-4 times per day at 0, 6, 12, 18 h UTC.

The radio-soundings provide the temperature at several atmospheric layers: mainly from the ground level to about 27 km of altitude.

Correlation coefficient: **r=0.53**

Temperature coefficient α_T**=0.89±0.02**

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LVD: monitoring the background

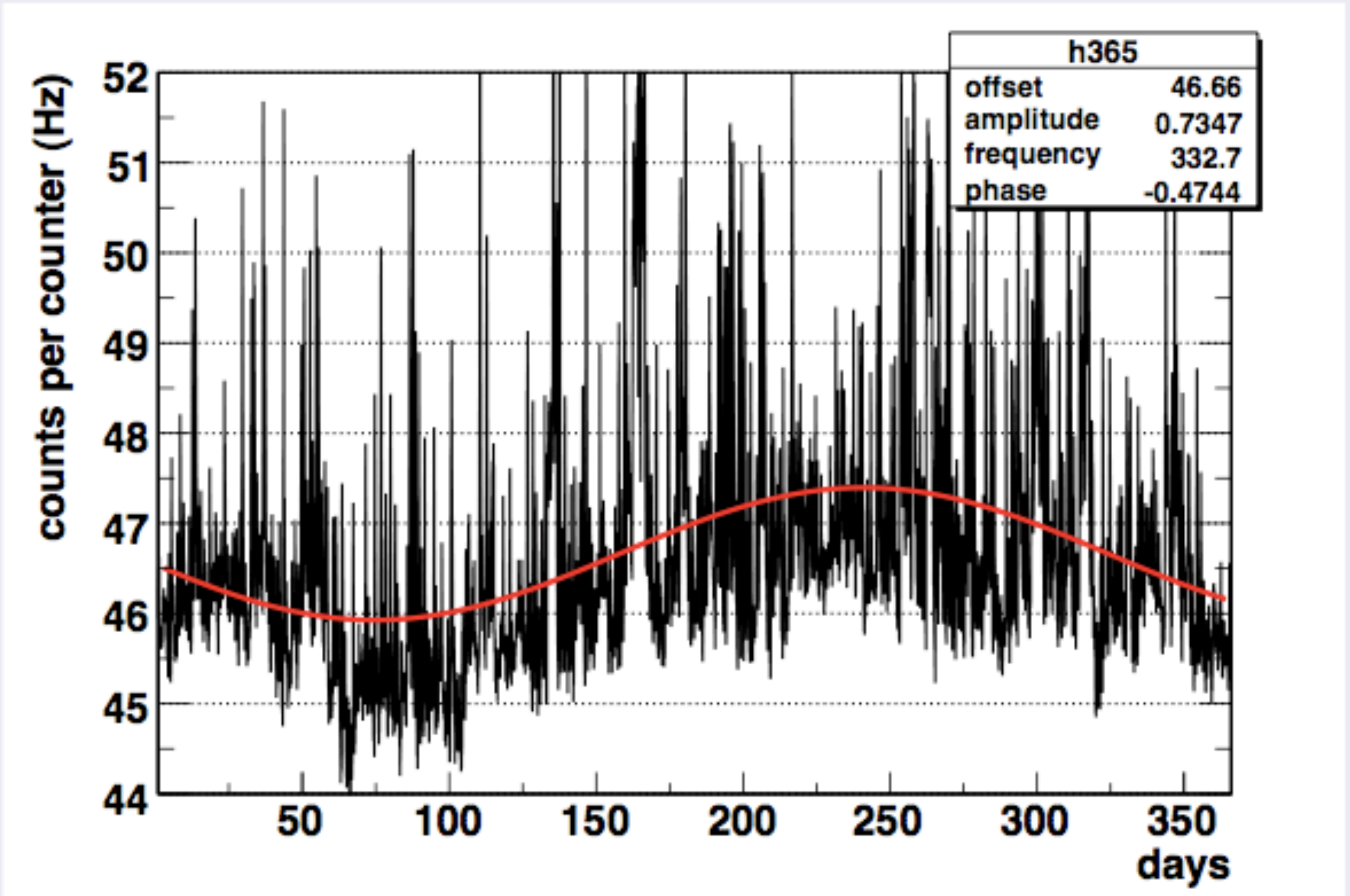
LVD Counting Rate measured at E > 0.5 MeV during 1997 – 2004.

The sensitivity in terms of Rn activity has been measured for each counter. The analysis of the time delay in the radon component confirms that we are counting gammas from ^{214}Bi.

Spectral analysis shows evidence (better than 7 σ c.l.) of annual modulation during 6 years, with:

- frequency = 333 ± 32 d
- Amplitude ≃ 1.5 ÷ 2.5 Hz
  5 ÷ 8 Bq/m^3
- Maximum at 28th August (± 32 d)

G.Bruno for the LVD Collaboration,
"Long term study of low energy counting rate with the Large Volume Detector", TAUP 2009



Counting rate of 6 years averaged and fitted by sinusoidal function:

$$k+A\sin(2\pi(t/f+\varphi))$$

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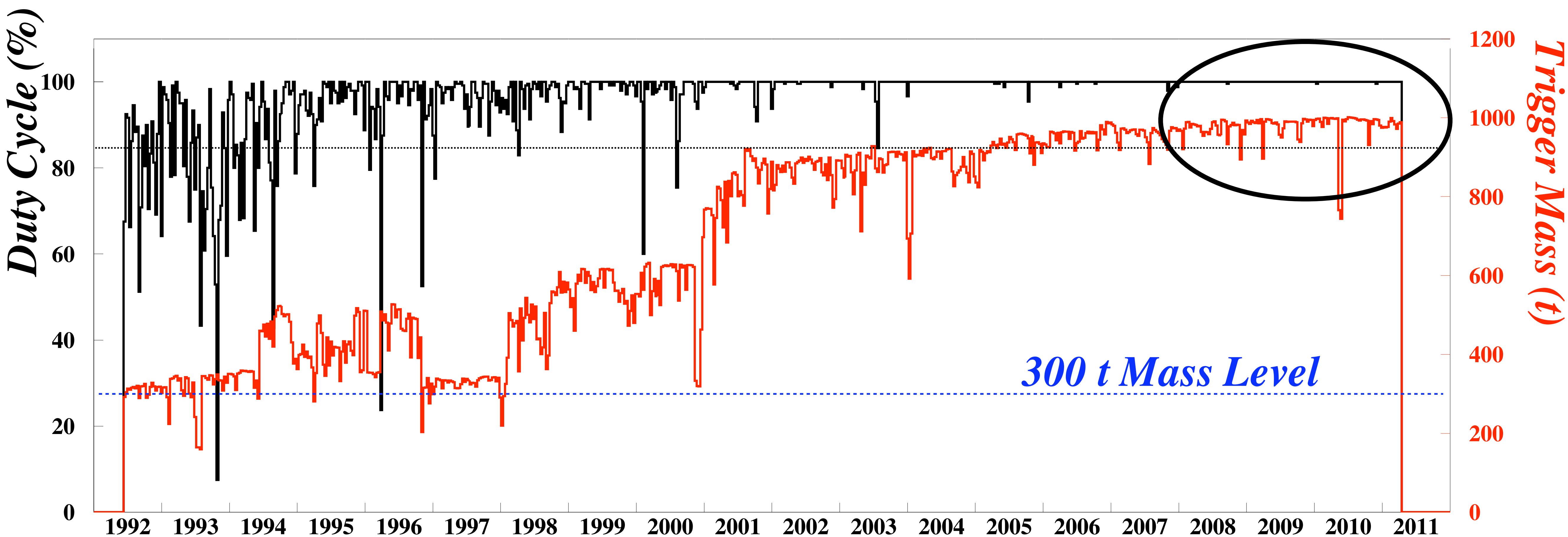
The future

- Next year LVD will celebrate twenty years of operation, some hint of fatigue become visible...
- In the last years we explored at least two possible future for the LVD ν observatory:
  - doping the liquid scintillator with Gd, to enhance the sensitivity of the detector increasing the S/n ratio in the inverse beta decay interactions;
  - realize an inner region inside the LVD structure to host a compact experiment for the search of rare events, such as double beta decay or dark matter. LVD would act as a passive shield and active veto continuing to play its role in the search for neutrino bursts.



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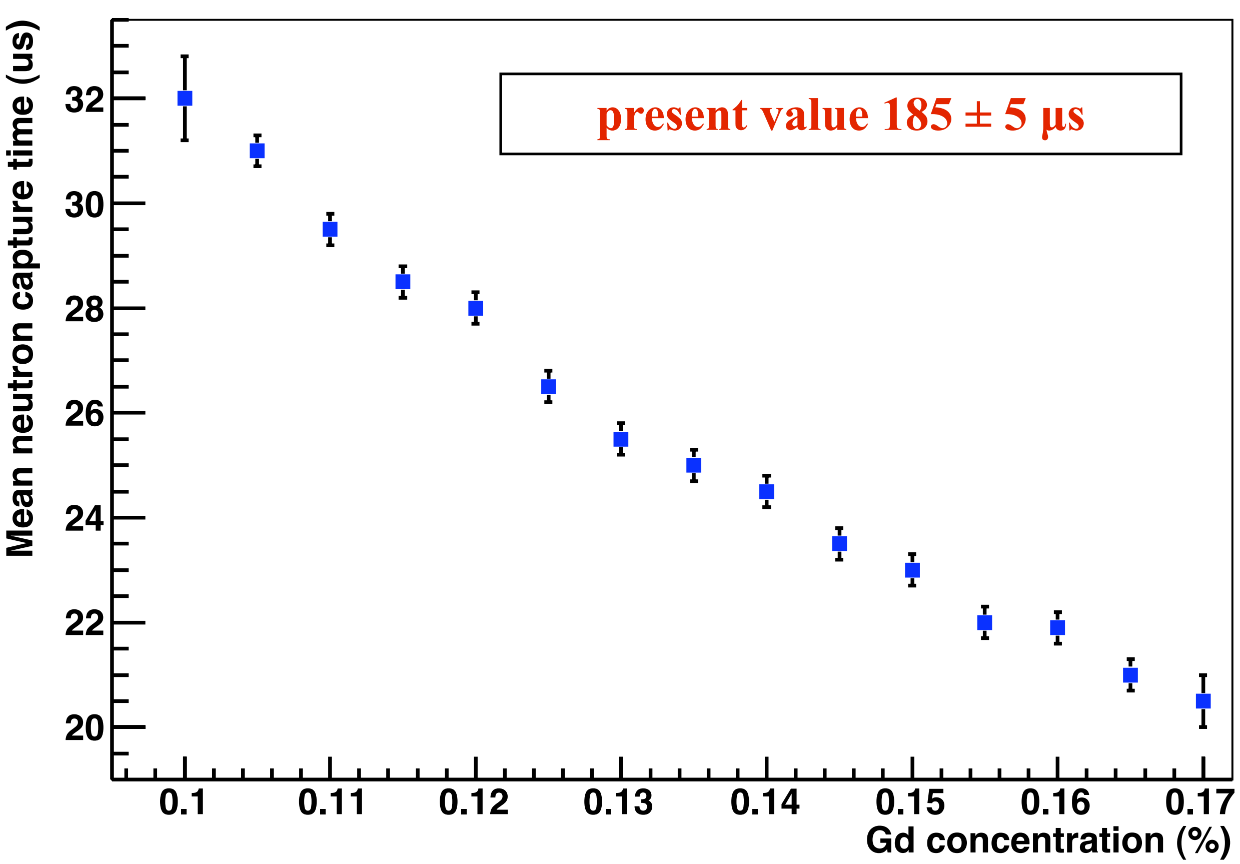
LVD: Gd doping

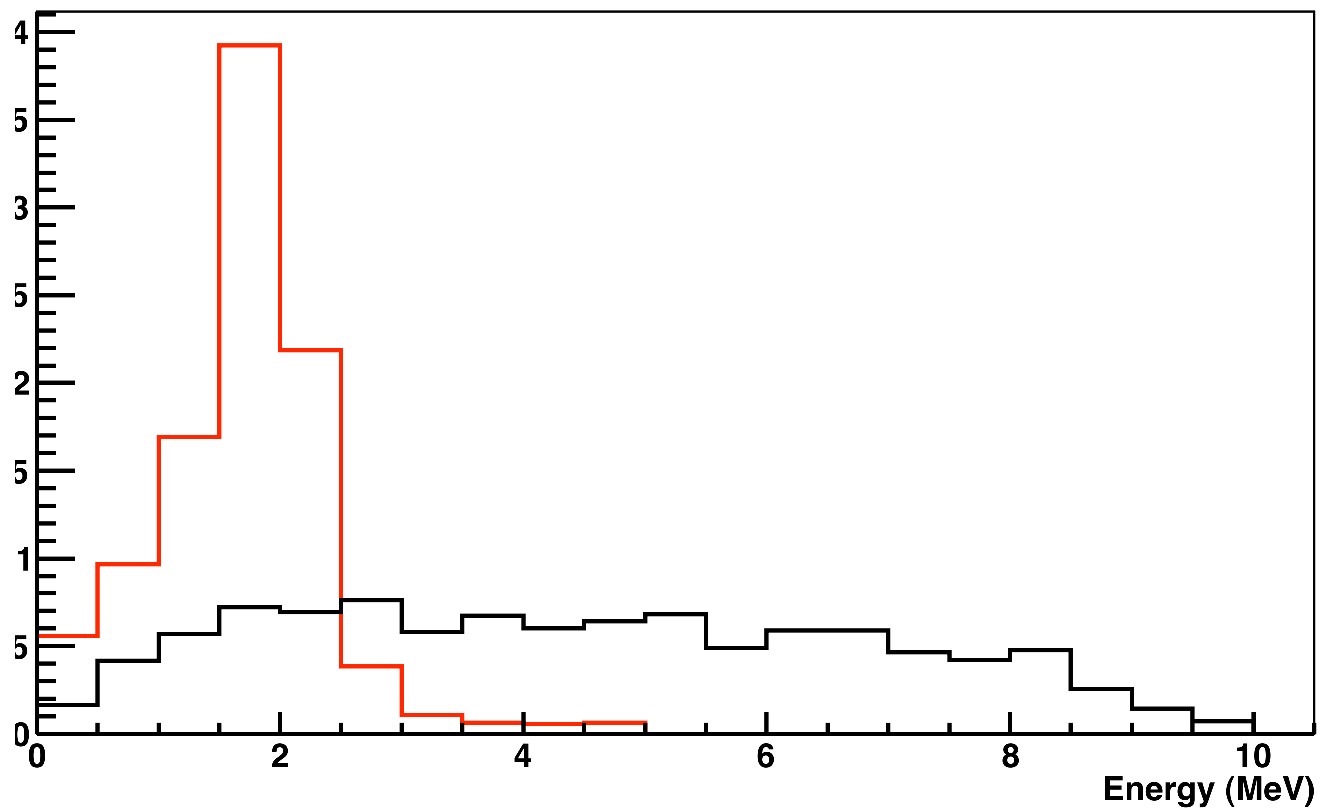
I.R.Barabanov,, L.B.Bezrukov, C.M.Cattadori, N.A.Danilov, A.di Vacri, Yu.S.Krilov, L.Ioannucci, E.A.Yanovich, M.Aglietta, A.Bonardi, G.Bruno, W.Fulgione, E.Kemp, A.S.Malguin, A.Porta and M.Selvi, 2010 JINST 5 P04001

- Long term test have been performed on two counters, one underground and the other at surface.
- Doping the scintillator improves the S/n ratio in the IBD detection due to a better signature of n-capture:
  - ~ 10 time shorter average neutron capture time and
  - harder spectrum of gamma capture.

Neutron Capture Time Delay



Neutron Capture Energy Spectrum



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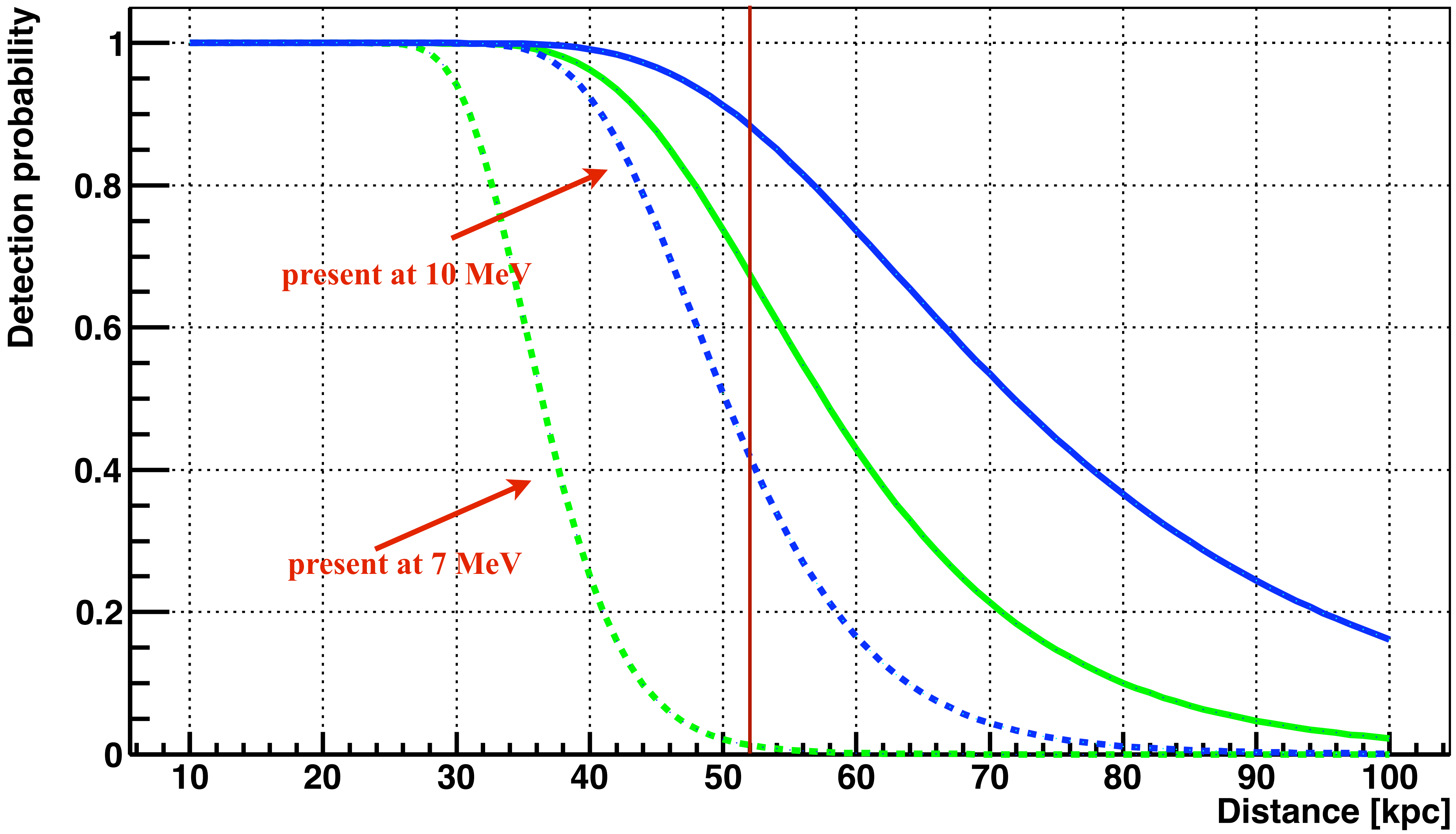
LVD: Gd doping

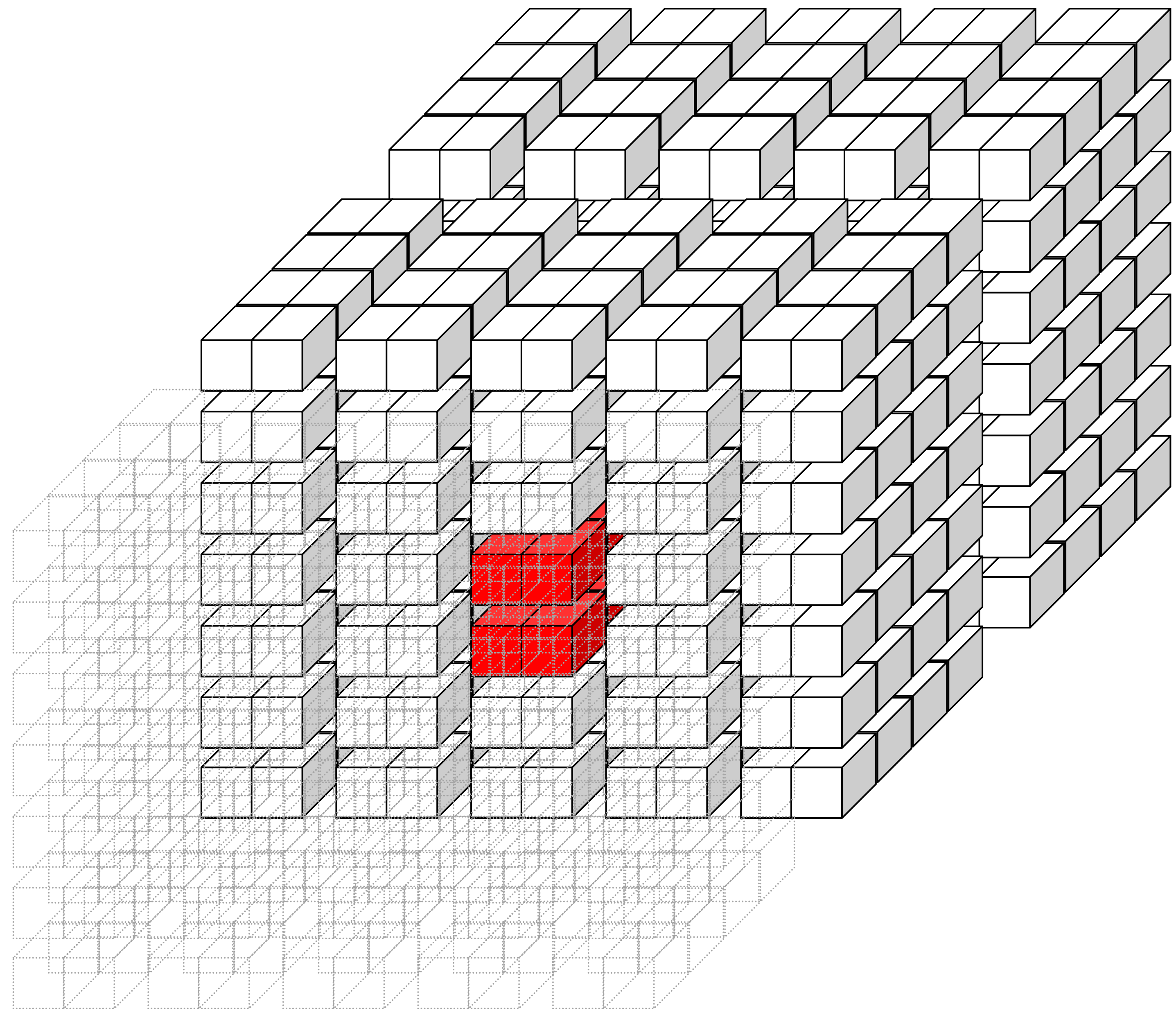
GianmarcoBruno, Walter Fulgione, Ana Amelia Bergamini Machado, Alexei Mal'gin, Andrea Molinario, Amanda Porta and Carlo Vigorito JCAP 06 (2011) 024

- How the LVD sensitivity should become,
  it should be equivalent to that obtained by doubling the number of counters.



The LVD Core Facility

- An inner region inside the LVD structure could be effectively exploited by a compact detector for the search of rare events, such as double beta decay or dark matter.
- This facility can be realized with a negligible impact on LVD operation and sensitive mass.



F.Arneodo and W.Fulgione,
“A low background facility inside the LVD detector at Gran Sasso,”
JCAP 0902 (2009) 028. [arXiv:0808.1465 [astro-ph]].

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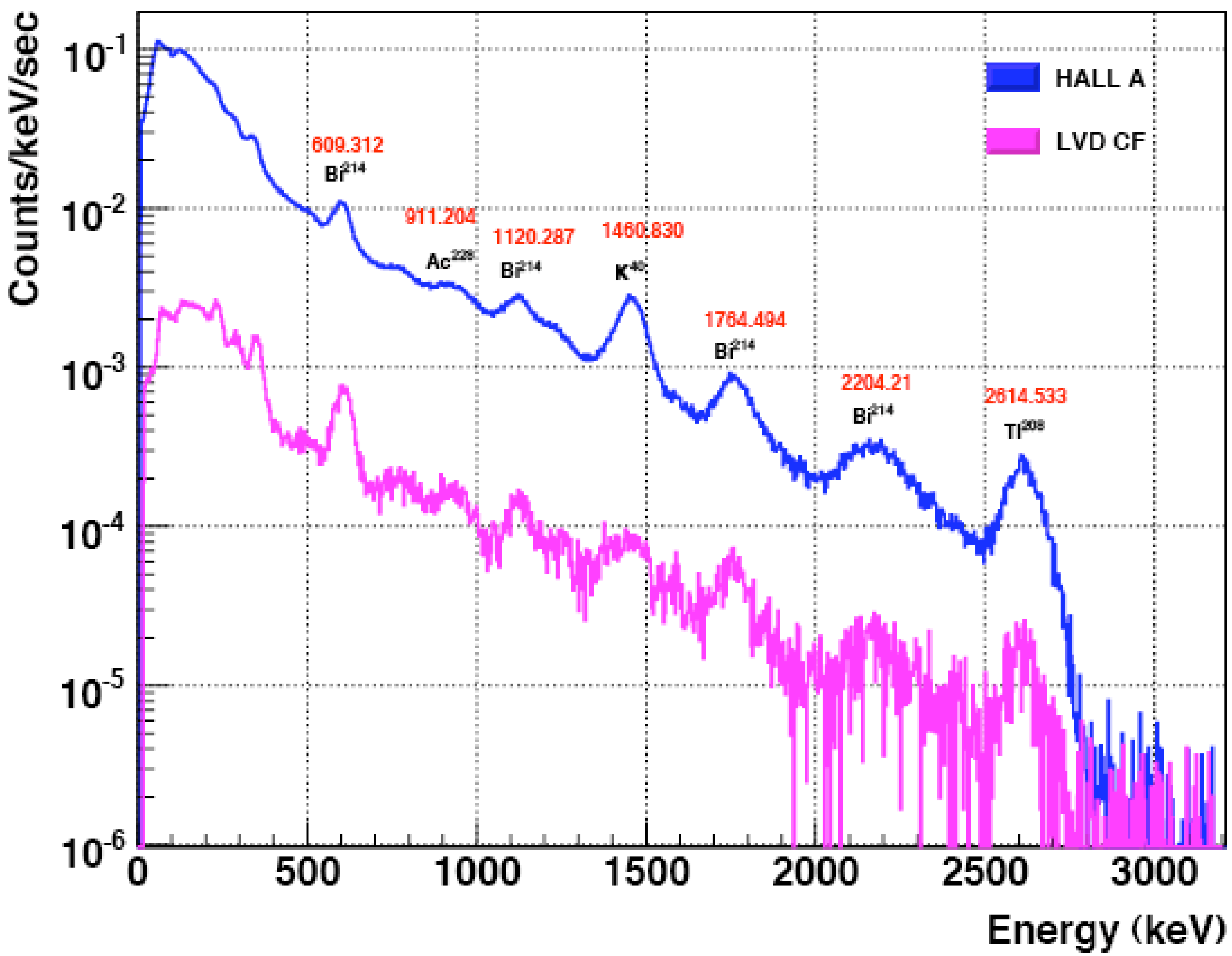
The LVD Core Facility

Gamma spectra, up to 3 MeV, have been measured inside and outside the LVD array. The surviving flux, in the LVD CF, results **attenuated of about a factor 20**.



An upper limit has been set, showing a scaling-down of the **thermal neutron flux of, at least, $5\cdot10^{-2}$**

LVD can act as a **muon veto**. Assuming the angular distribution measured by LVD we expect a veto **efficiency in excess of 99%**

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The LVD Core Facility

Muon-induced neutron flux in the LVD-CF in units of 10^{-9} cm^{-2} s^{-1}

	hall A	LVD passive	LVD μ veto	Sudbury
total	1,7800	0,6020	0,0221	0,0337
E_n > 1 MeV	0,2990	0,2970	0,0066	0,0048
E_n > 10 MeV	0,1130	0,1030	0,0023	0,0015
E_n > 100 MeV	0,0300	0,0304	0,0005	0,0004

Monte Carlo

M.Selvi "The LVD core facility" IDM 2008

- Comparing the neutron flux in absence of LVD and the one of untagged neutrons, the reduction factor due to LVD is about 50, for neutron energy > 1 MeV.

- These result makes the muon-induced neutron background in the LVD Core Facility equivalent to that of the deepest existing underground laboratory, i. e. Sudbury (6000 m w.e.).

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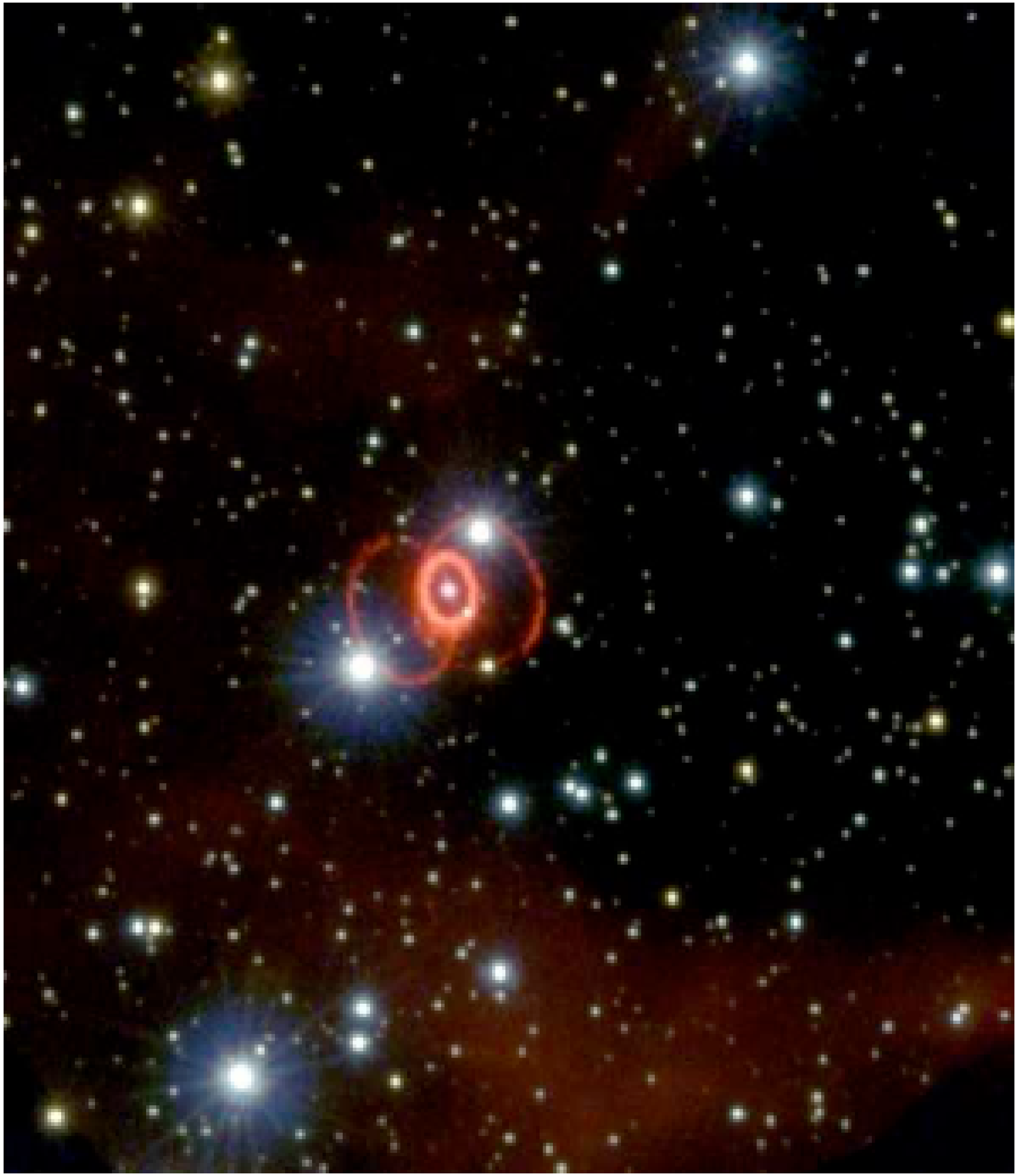

Thank you

Hubble image

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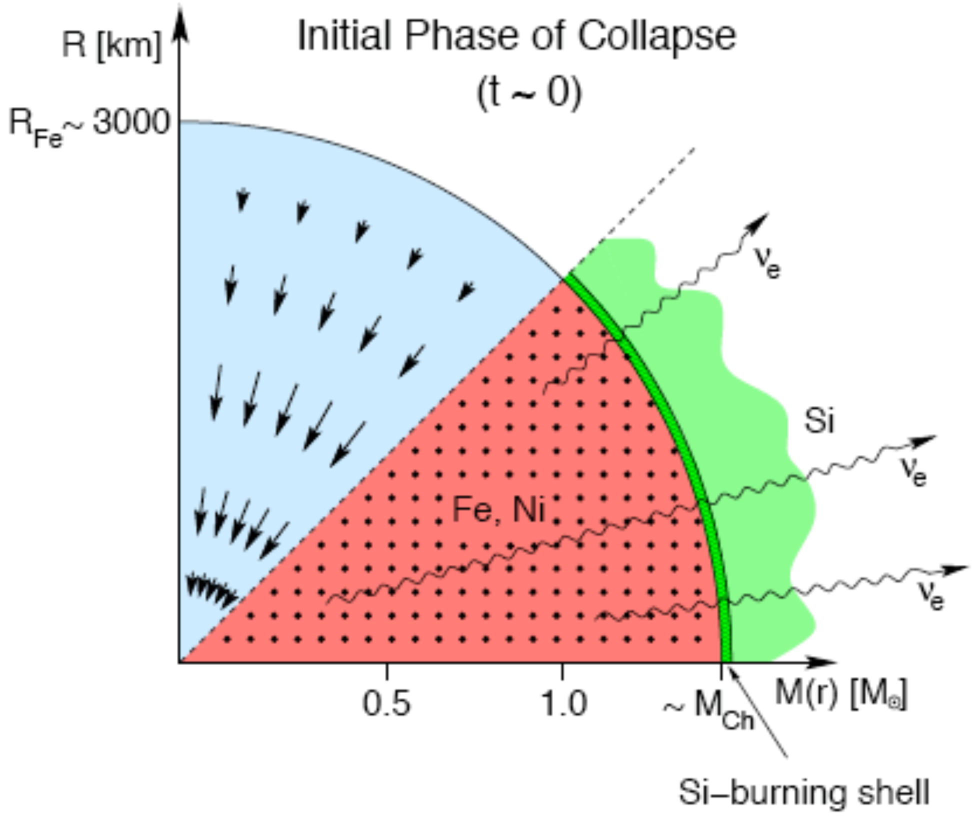
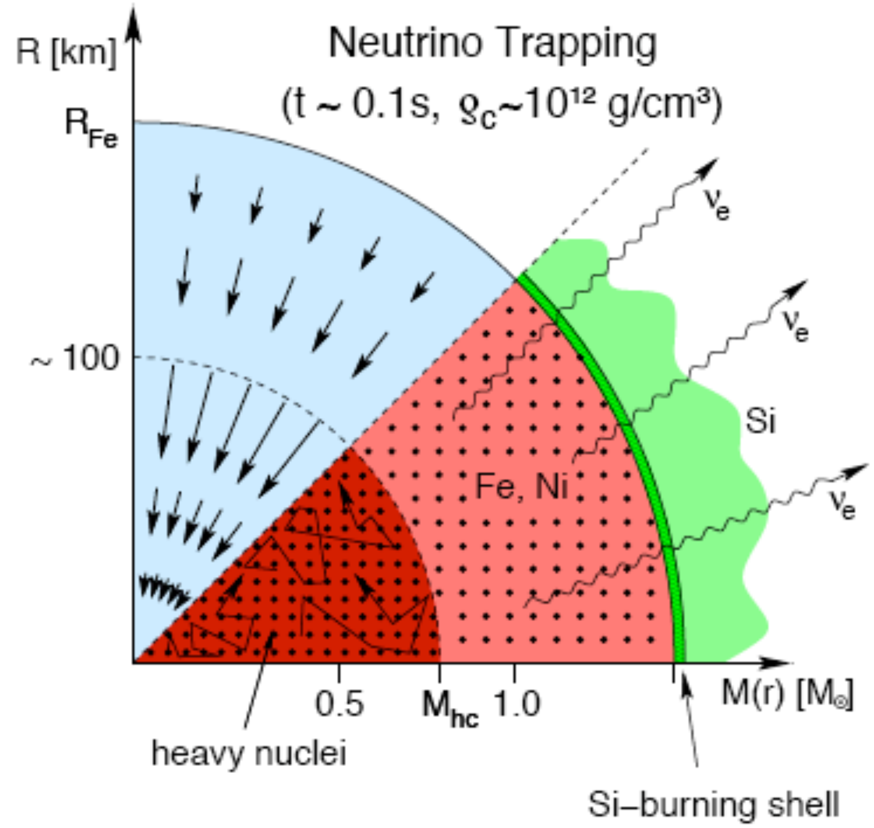
The current picture of stellar collapse and explosion





from Janka et al. astro/ph0612072

- At the end of hydrostatic burning, a massive star consists of concentric shells. Iron is the final stage of nuclear fusion in hydrostatic burning.

- When the iron core, grows by silicon shell burning to the Chandrasekhar mass limit (~1.44 Mo), electron degeneracy pressure cannot longer stabilize the core and it collapses.

- This starts the core-collapse supernova, the star explodes and parts of the star's heavy-element core and of its outer shells are ejected into the Interstellar Medium.

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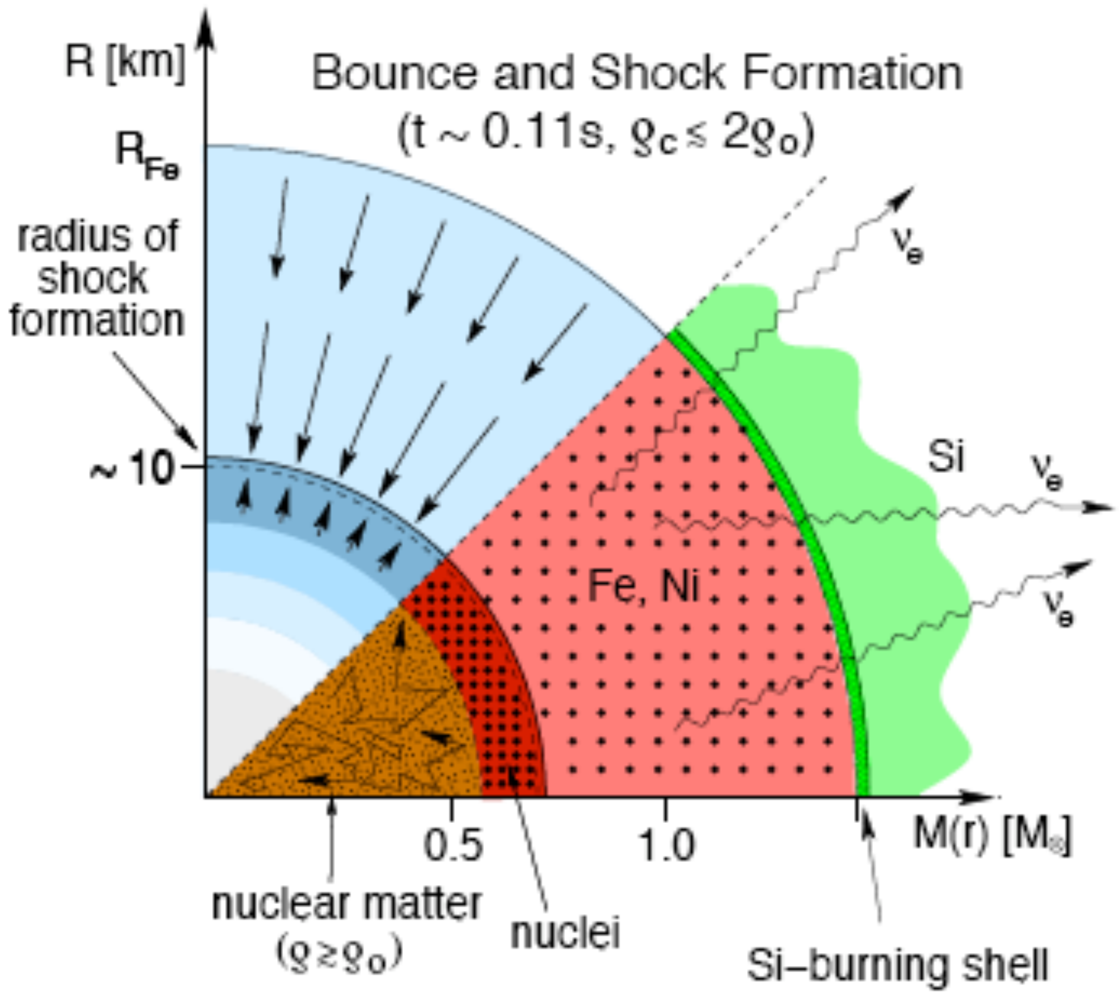
The current picture of stellar collapse and explosion

from Janka et al. astro/ph0612072



- At densities above 10^{10} g/cm^3, electrons are squeezed into iron-group nuclei:

$$(Z,A) + e^- \to (Z-1,A) + \nu_e$$

- Soon the core is falling nearly freely at about 1/4 of c.
  Starting from the size of the Earth, the core collapses to a hot, dense, neutron-rich sphere about 30 Km in radius, the proto-neutron star.

- The repulsive component of the short-range nuclear force halts the collapse when the density is nearly twice that of the atomic nucleus, or 4-5 10^{14} g/cm^3).

- The abrupt halt of the collapse of the core and its rebound generates a shock wave.

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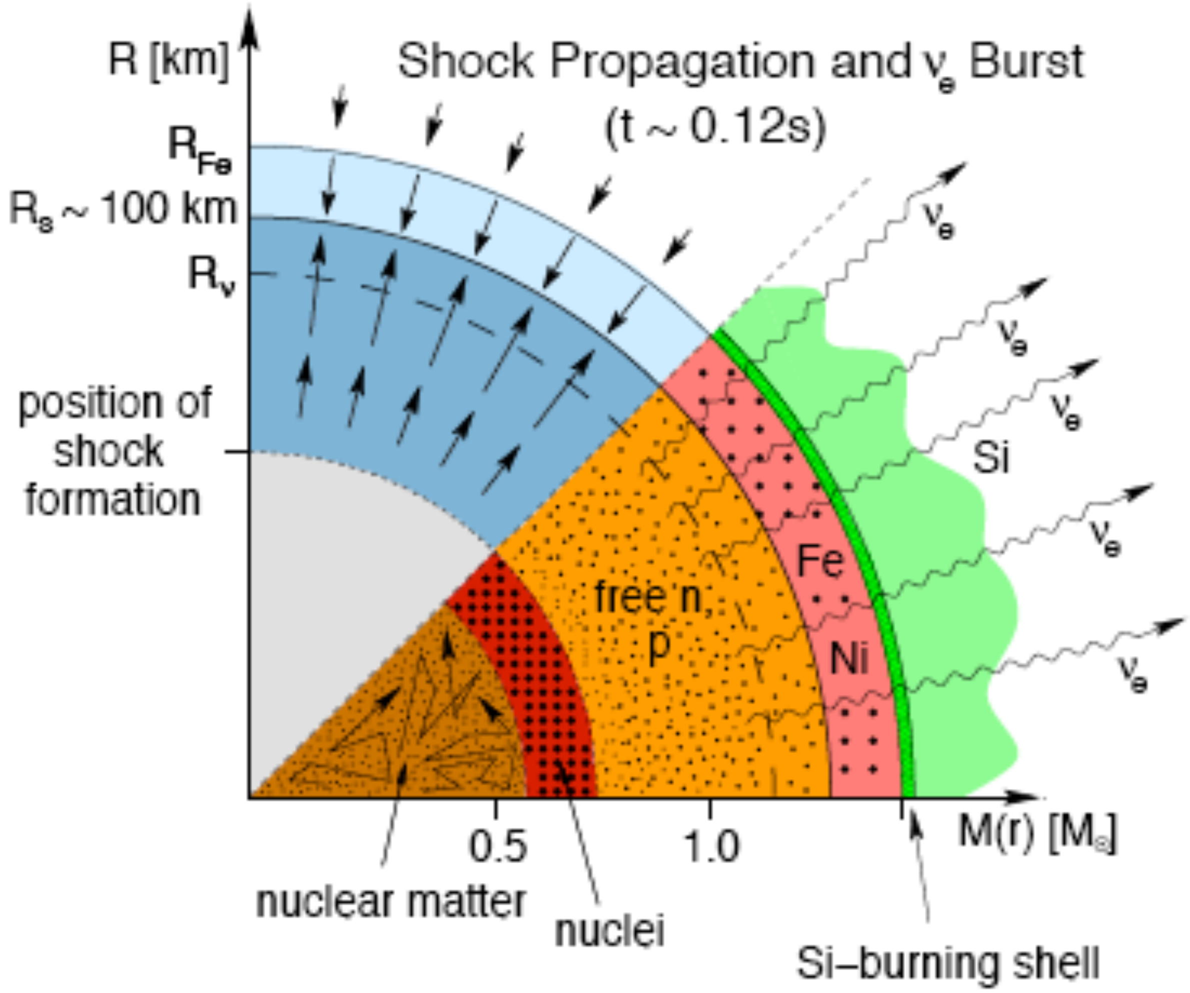
The current picture of stellar collapse and explosion

from Janka et al. astro/ph0612072



- After the core bounce, a compact remnant begins to form at the center of the collapsing star, rapidly growing by the accretion of infalling material until the explosion sets in.
  This nascent remnant will evolve to a neutron star or may eventually collapse to a black hole.

- The core bounce with the formation of a shock wave will finally trigger a supernova explosion, but..

- 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 ($e^- + p \rightarrow n + \nu_e$).
- 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 oxigen, magesium, silicon, sulphur and calcium.

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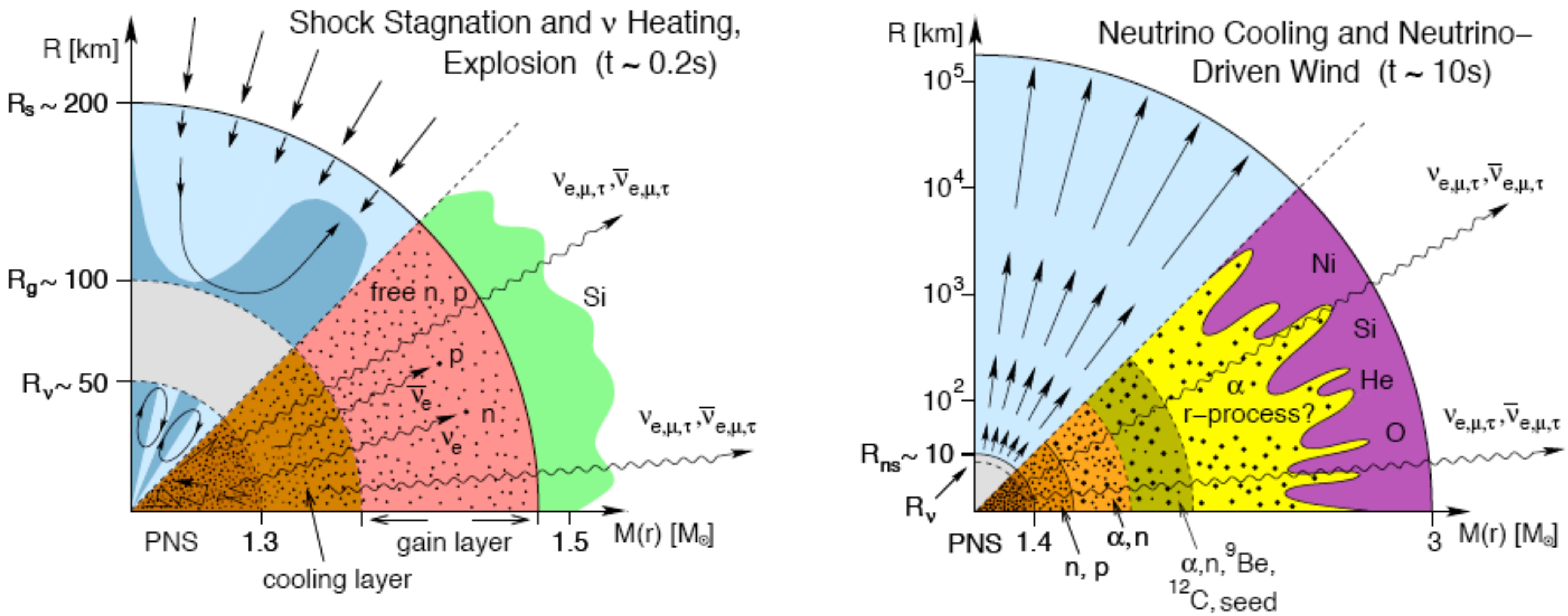
The current picture of stellar collapse and explosion



from Janka et al. astro/ph0612072

- The model predicts a second impulsive neutrino signal of the duration af ~ 500 ms related to the accretion phase just before the explosion.
- The further 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. $e^- + e^+ \rightarrow \nu_i + \nu_i$
- 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.

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SNEWS

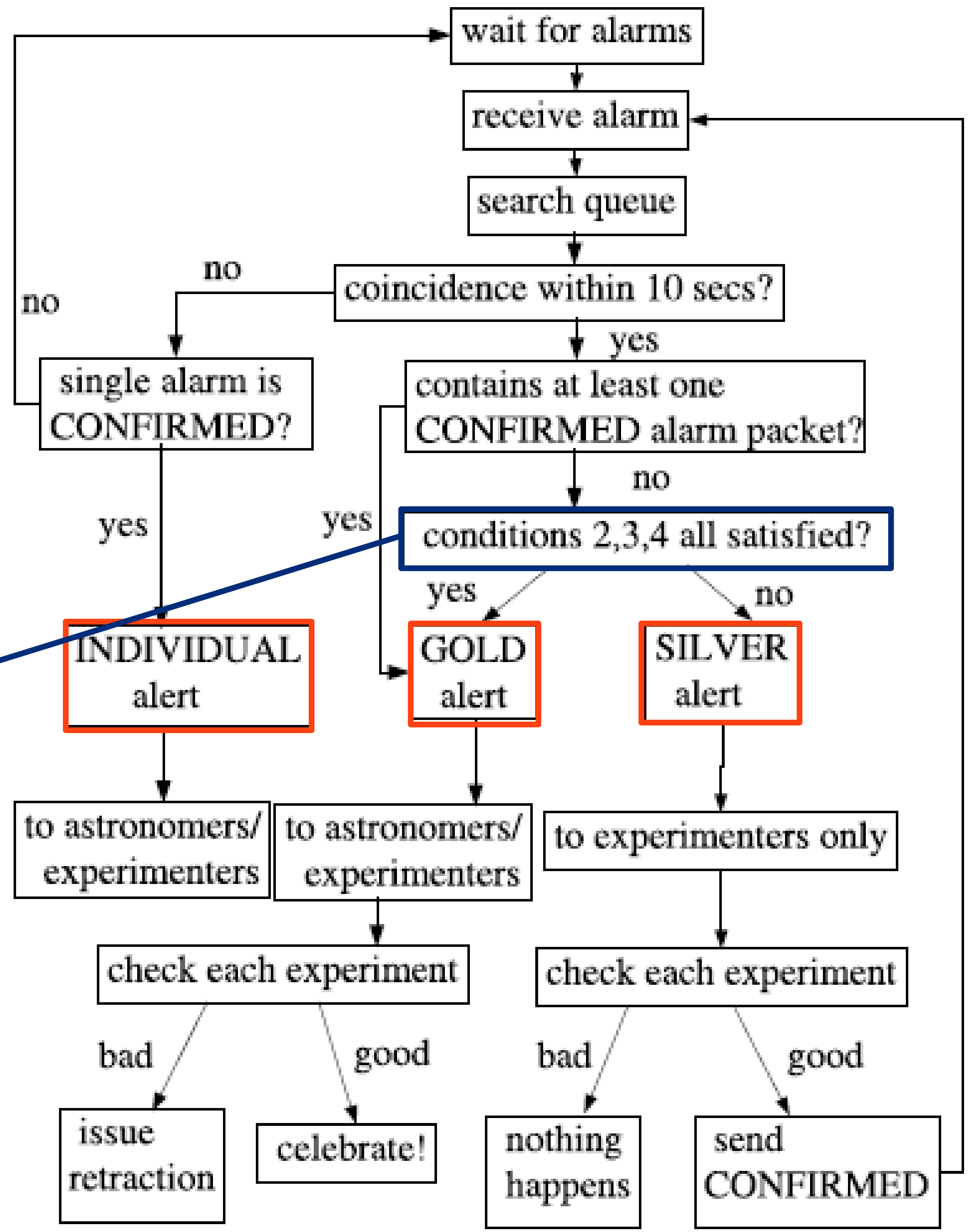
- ***GOLD*** alerts are intended for automated dissemination to the community [http://snews.bnl.gov]
- ***SILVER*** alerts will be disseminated among the experimenters requiring human checking.

1) coincidence in 10 sec.

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

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

7) 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**



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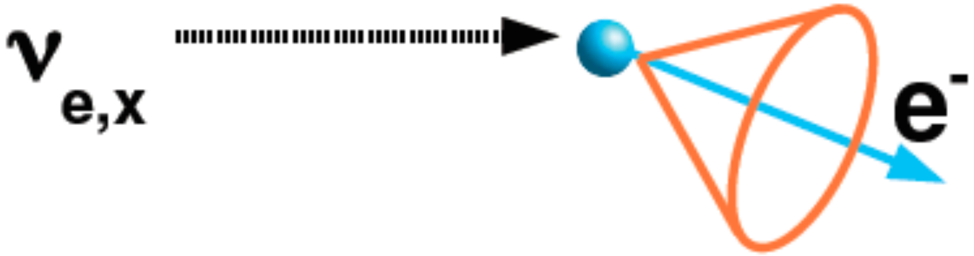
POINTING

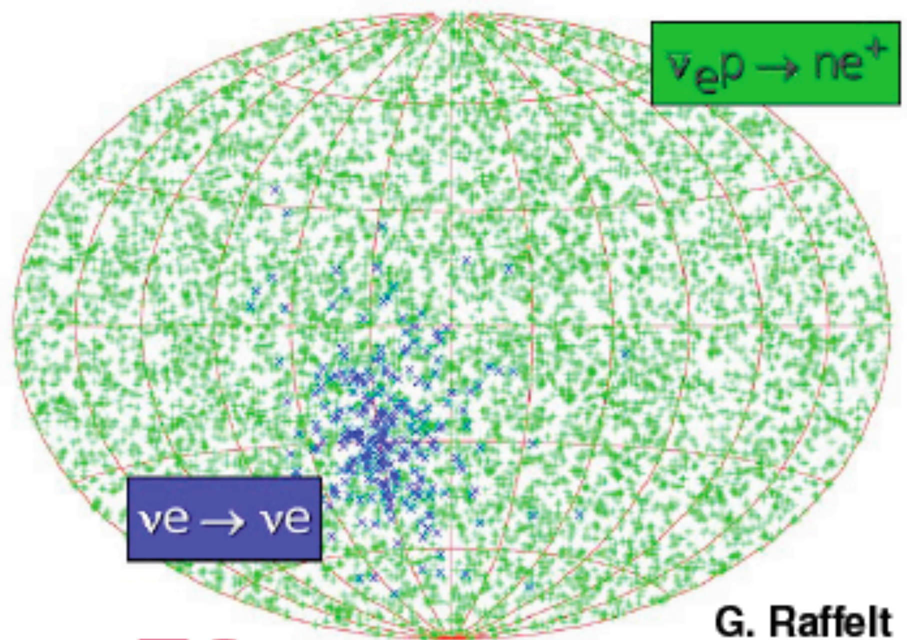
Individual experiments can use ASYMMETRIC REACTIONS

Elastic scattering off electrons is the best bet

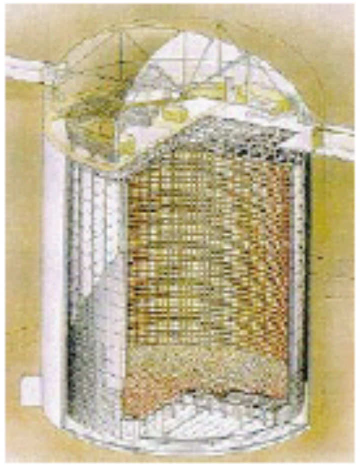
$$\nu_{e,x} + e^- \rightarrow \nu_{e,x} + e^-$$



In water Cherenkov and scintillator, few % of inverse βdk rate



POINTING from Cherenkov cone: (slightly degraded by isotropic bg)



Super-K: expect ~200 ES for 8.5 kpc SN (5-10 from breakout)

$\Rightarrow$ ~ 4° pointing

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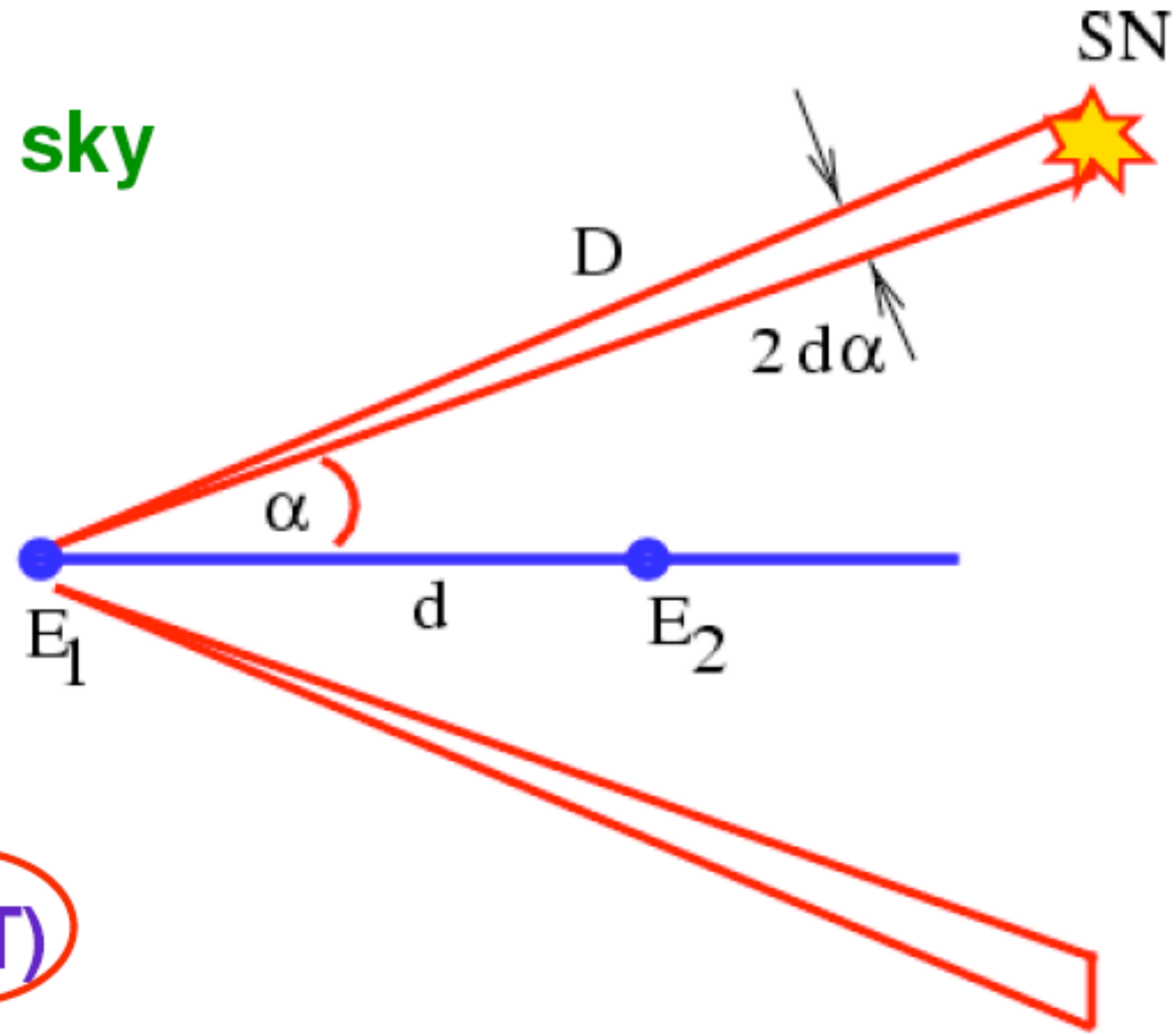
With 2 or more experiments, use absolute times of ν signals for TRIANGULATION?

2 exp'ts: circle on sky

3 exp'ts: 2 blobs

4 exp'ts: 1 spot



$\cos \alpha = c\Delta T/d$

$\delta(\cos \alpha) = c/d\ \delta(\Delta T)$

"registration error": pointing accuracy limited by pulse shape timing

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