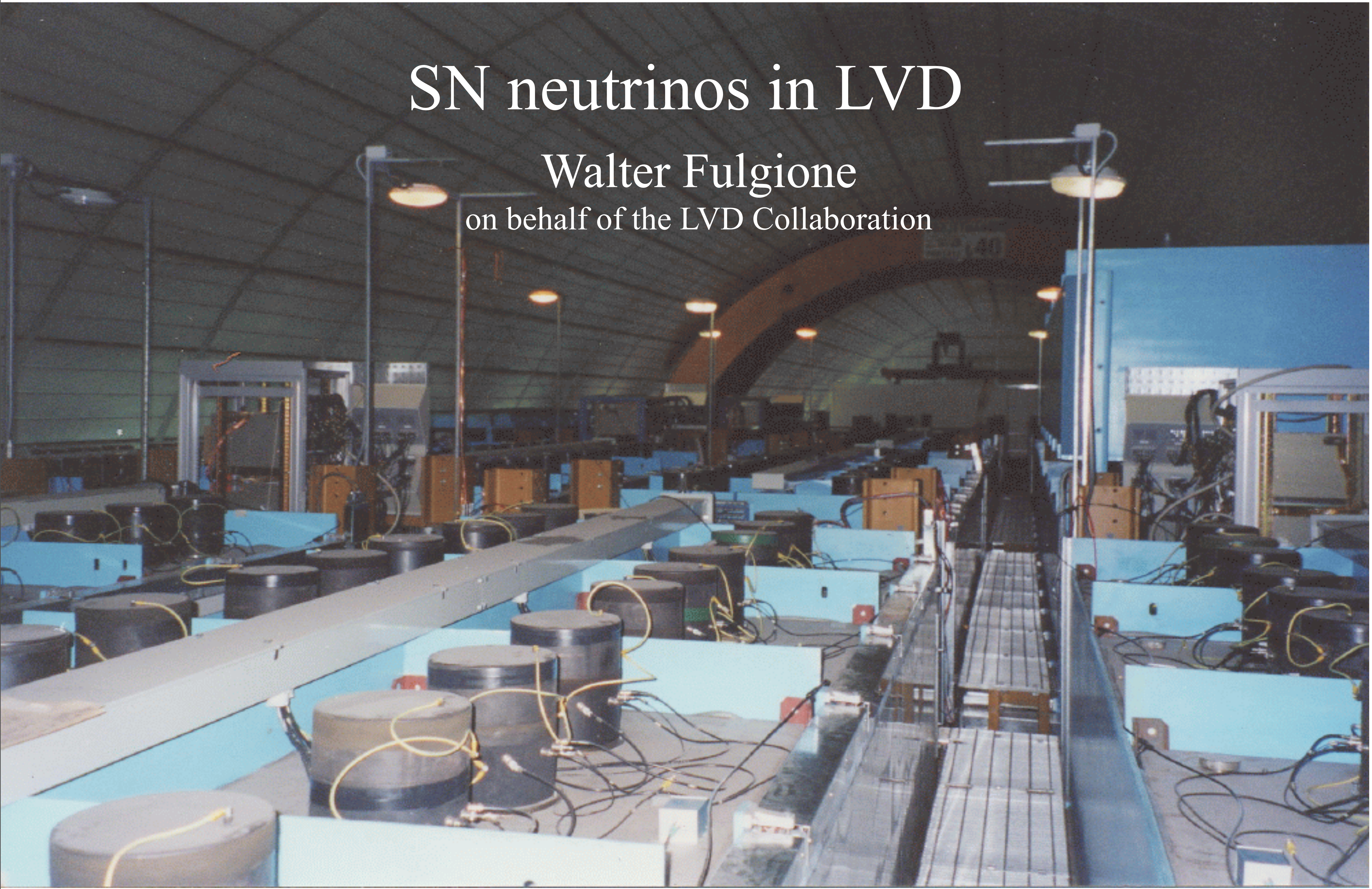
SN neutrinos in LVD

Walter Fulgione
on behalf of the LVD Collaboration



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Outline

- The history
  - a detector dedicated to SN neutrino observation
  - data taking since 1992
  - LVD in the SN Early Warning System
- Detector characteristics
  - 1 kt scintillator detector
  - performance
- Search for neutrino burst
  - strategy
  - sensitivity
  - results
  - monitoring the background
- Possible futures
  - Gd doping
  - muon veto

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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).
- Another experiment, MACRO, using the same couple of techniques, was approved and started to be operational on 1989 in the Gran Sasso Laboratory (no more in operation since 2000).

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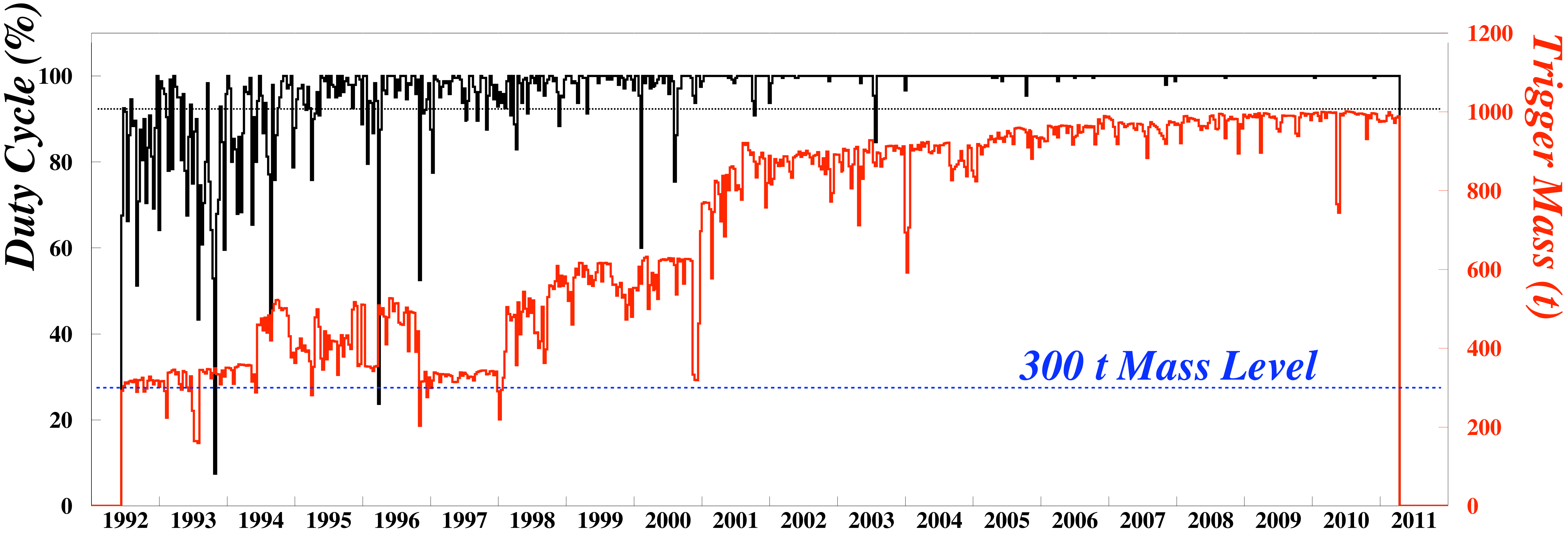
LVD - operating since 1992



- 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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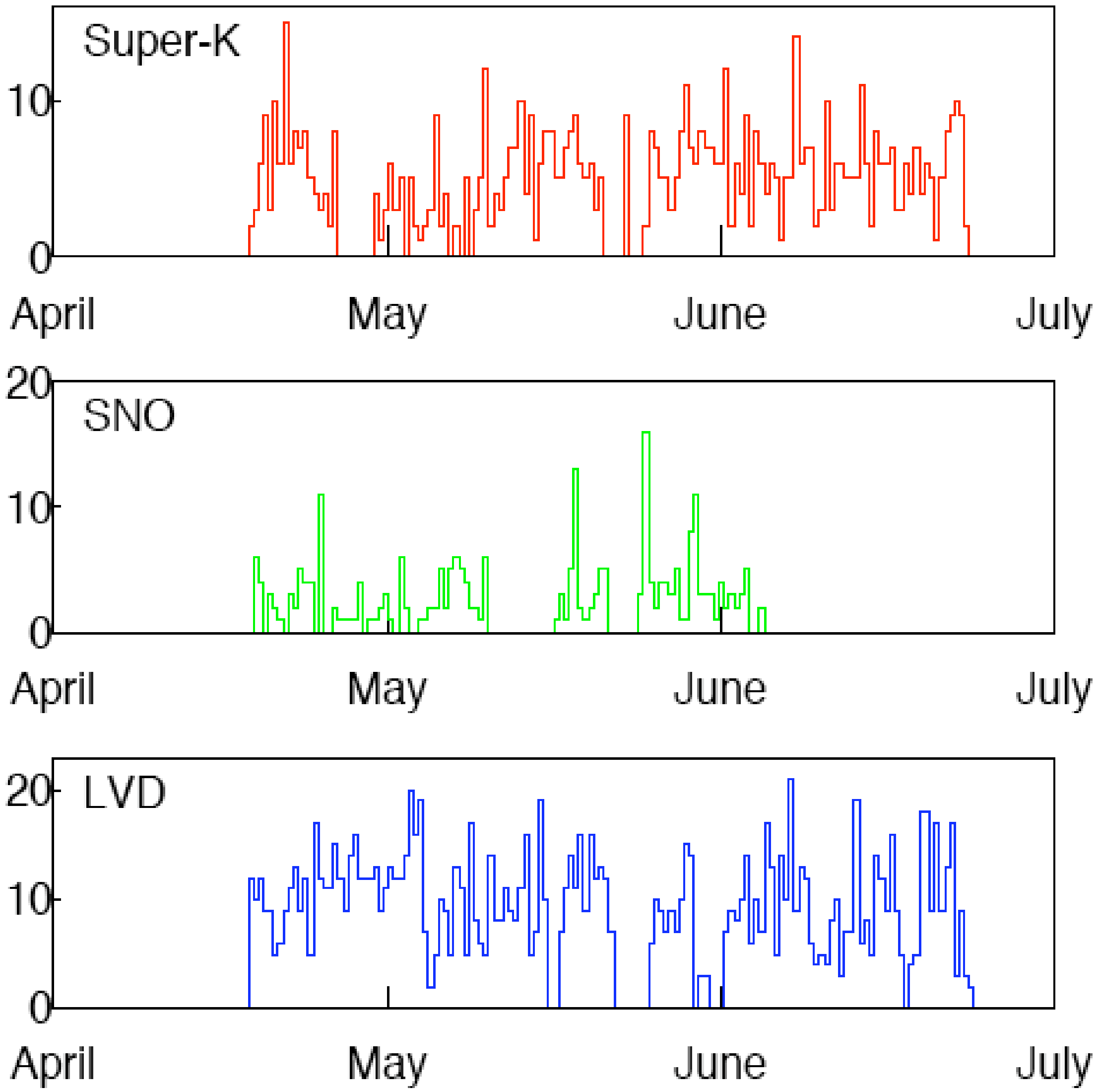
LVD and SNEWS

- 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

Alarm times



- 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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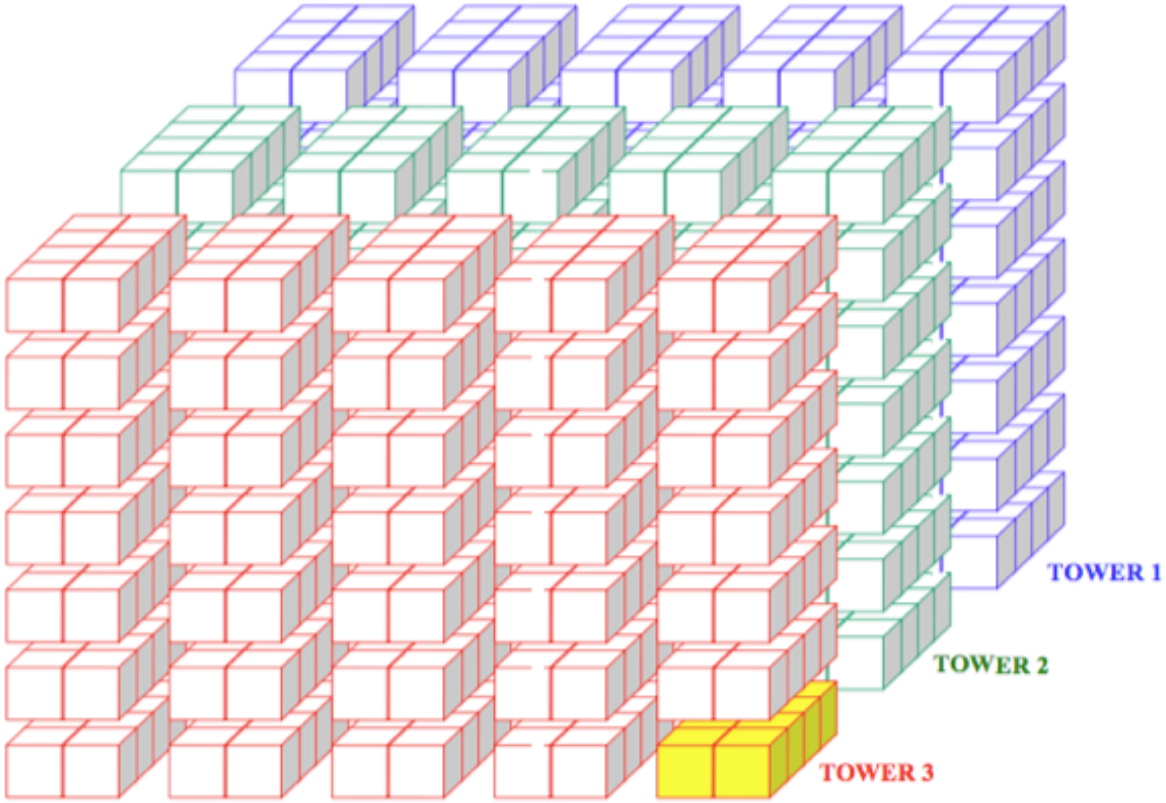
detector characteristics



- 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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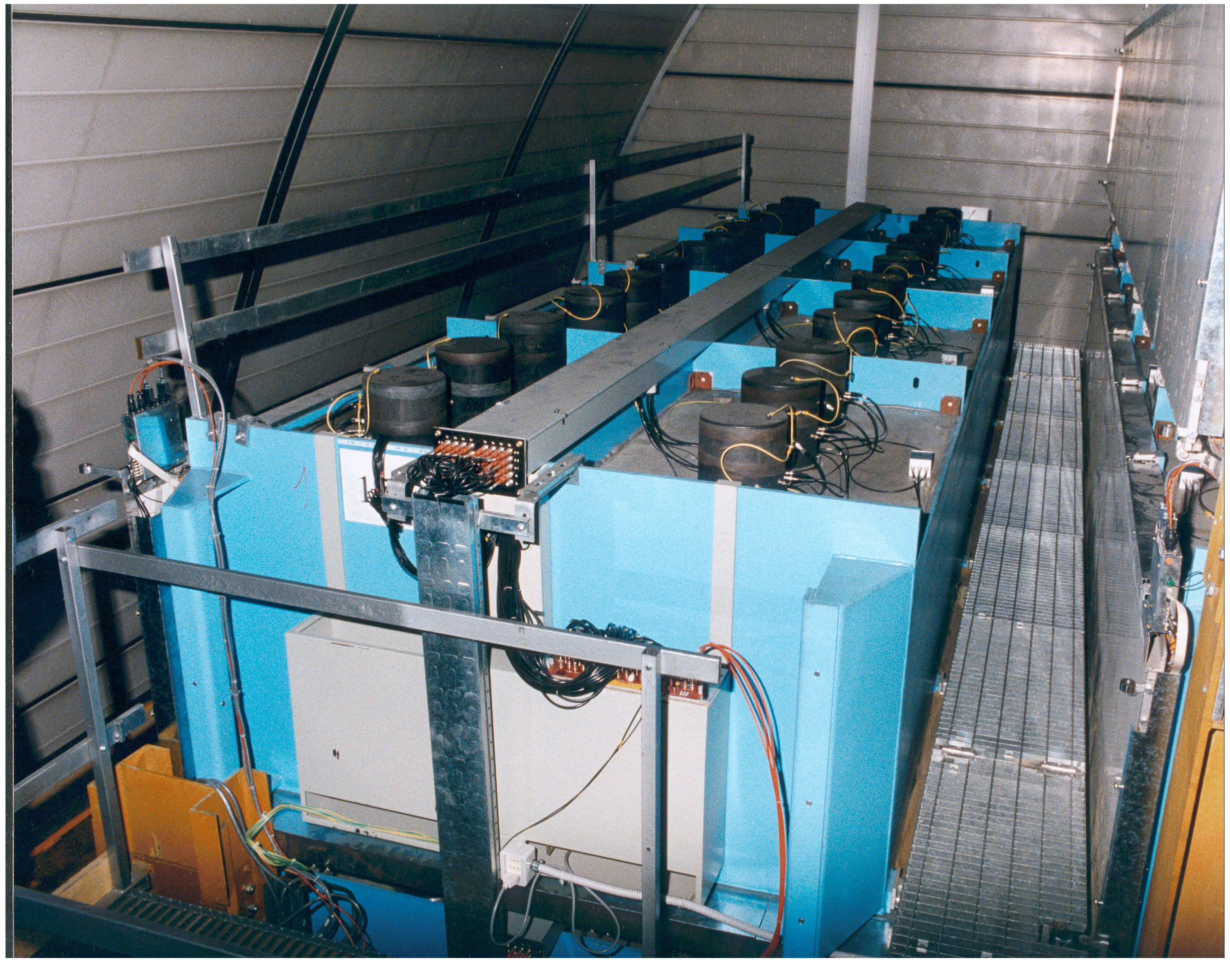
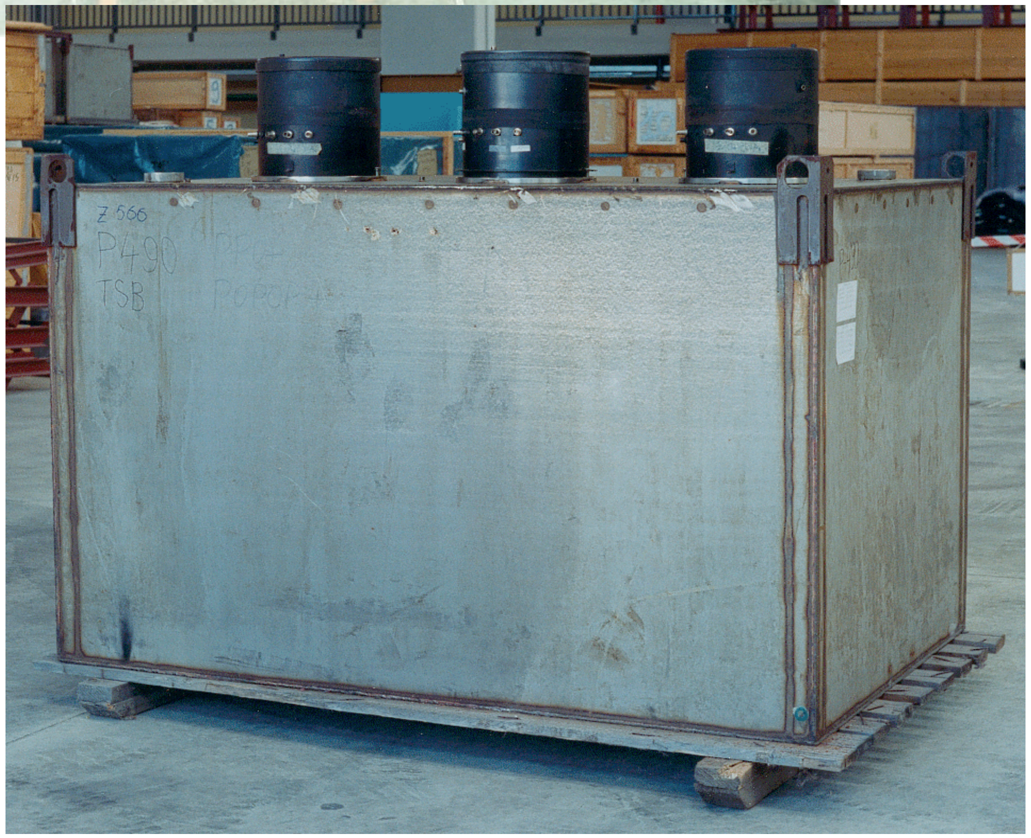
detector characteristics

- 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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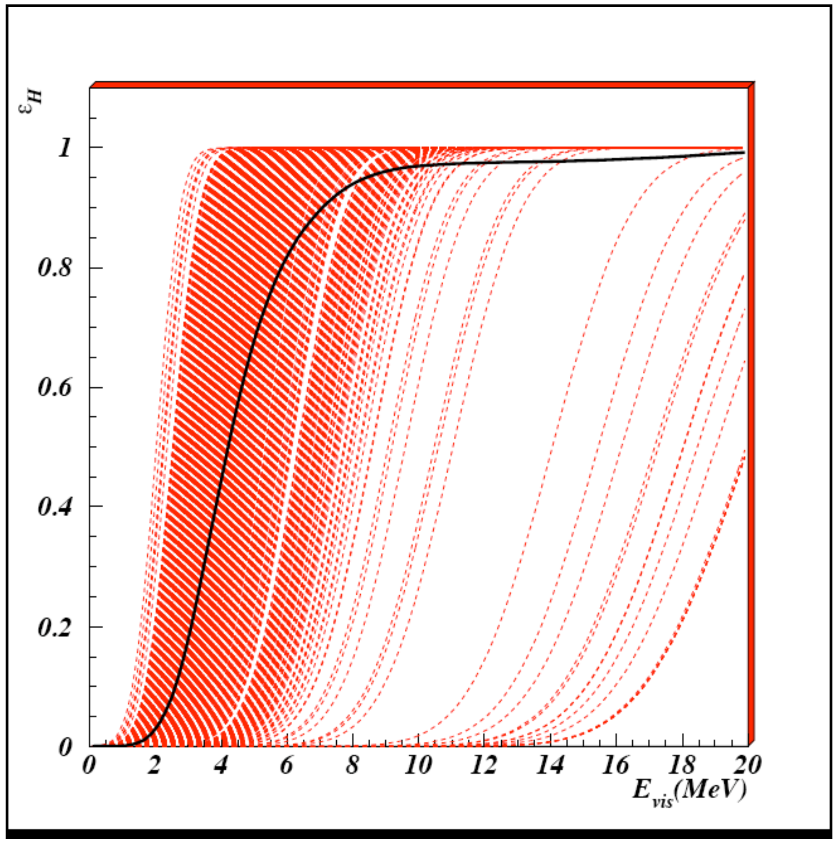
detector characteristics



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 (<Δt> = 185 μs) γ(2.2 MeV)

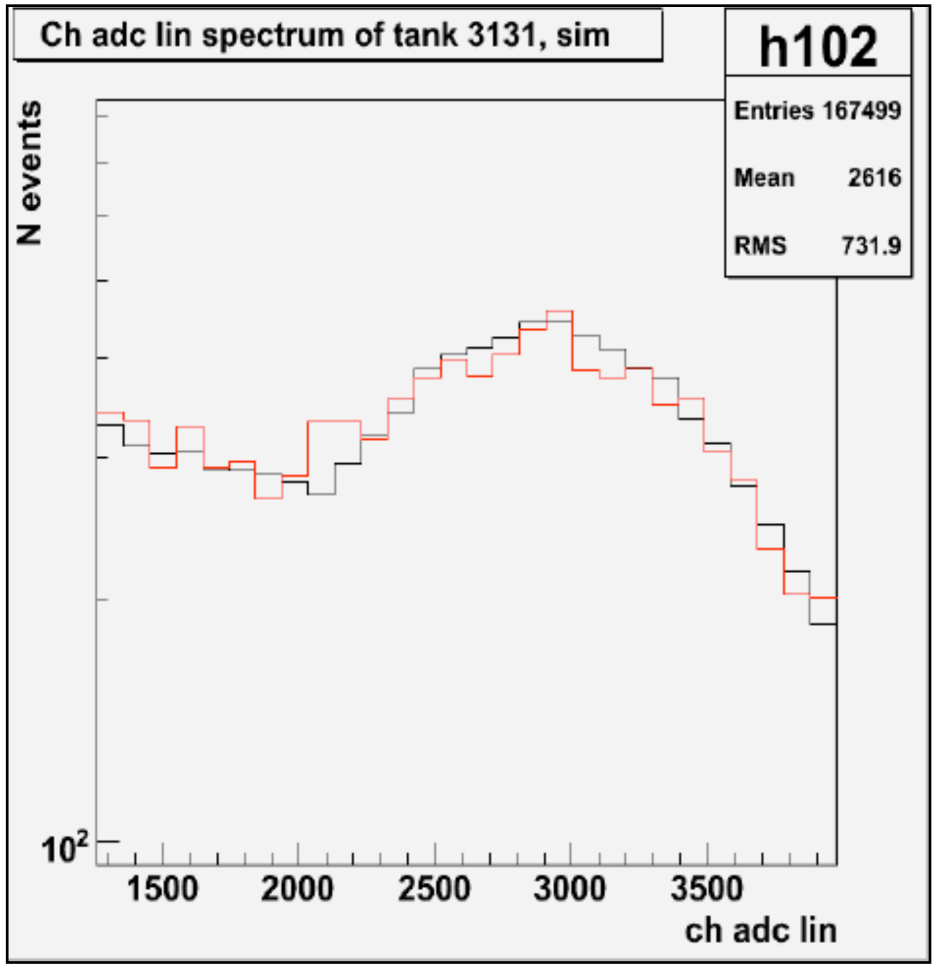
- ○ The trigger logic is based on the 3-fold coincidence of the 3 PMTs of each counter and optimized for the detection of both products of iβd.
- ○ Each PMT is discriminated at two different thresholds resulting in two possible levels of coincidence:

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

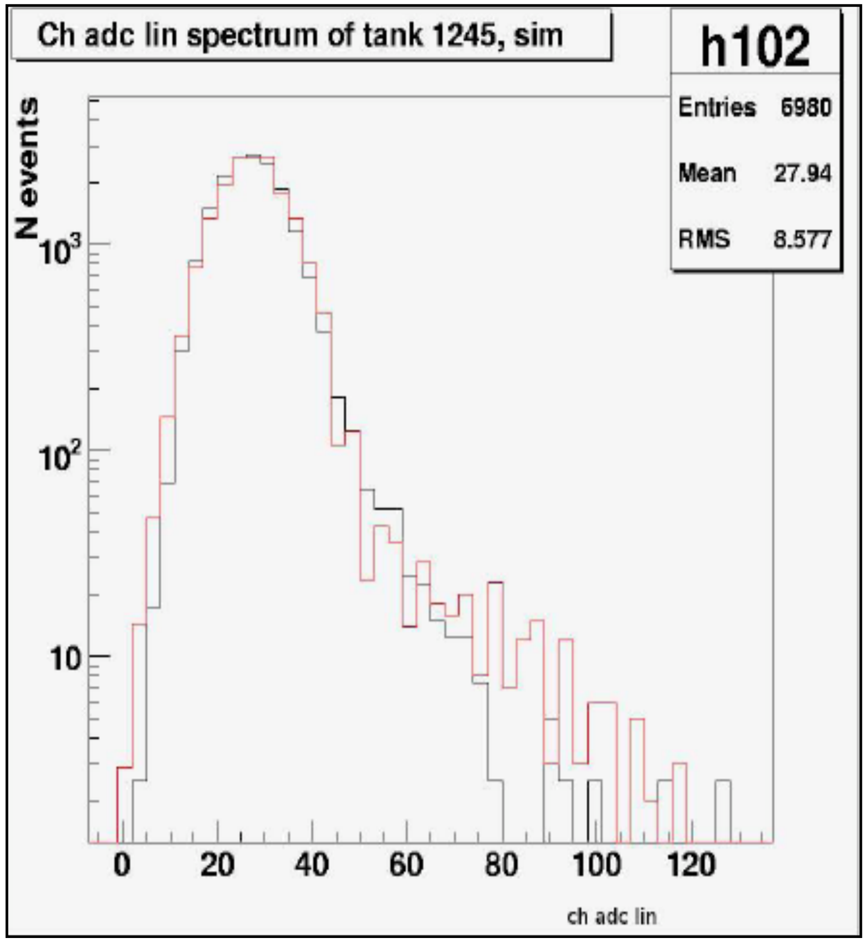
→ The OR of the H coincidence of all counters is trigger condition for the tower

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

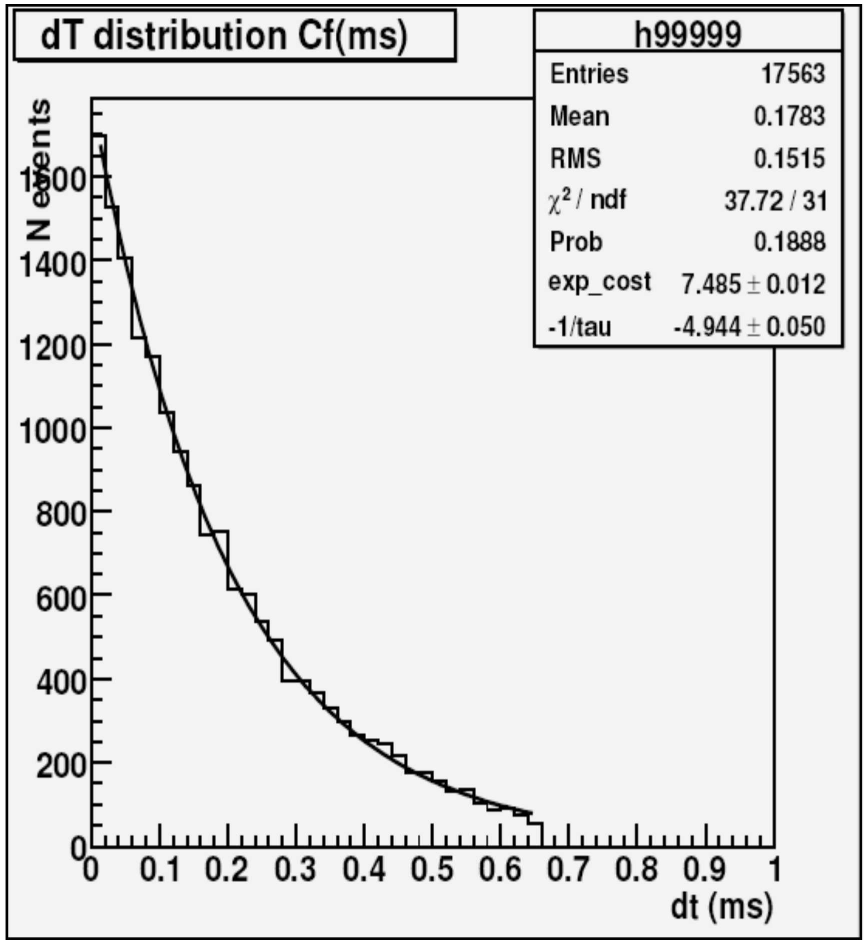
→ Single counter low threshold counting rate is continuously monitored for noise rejection purposes



detector characteristics

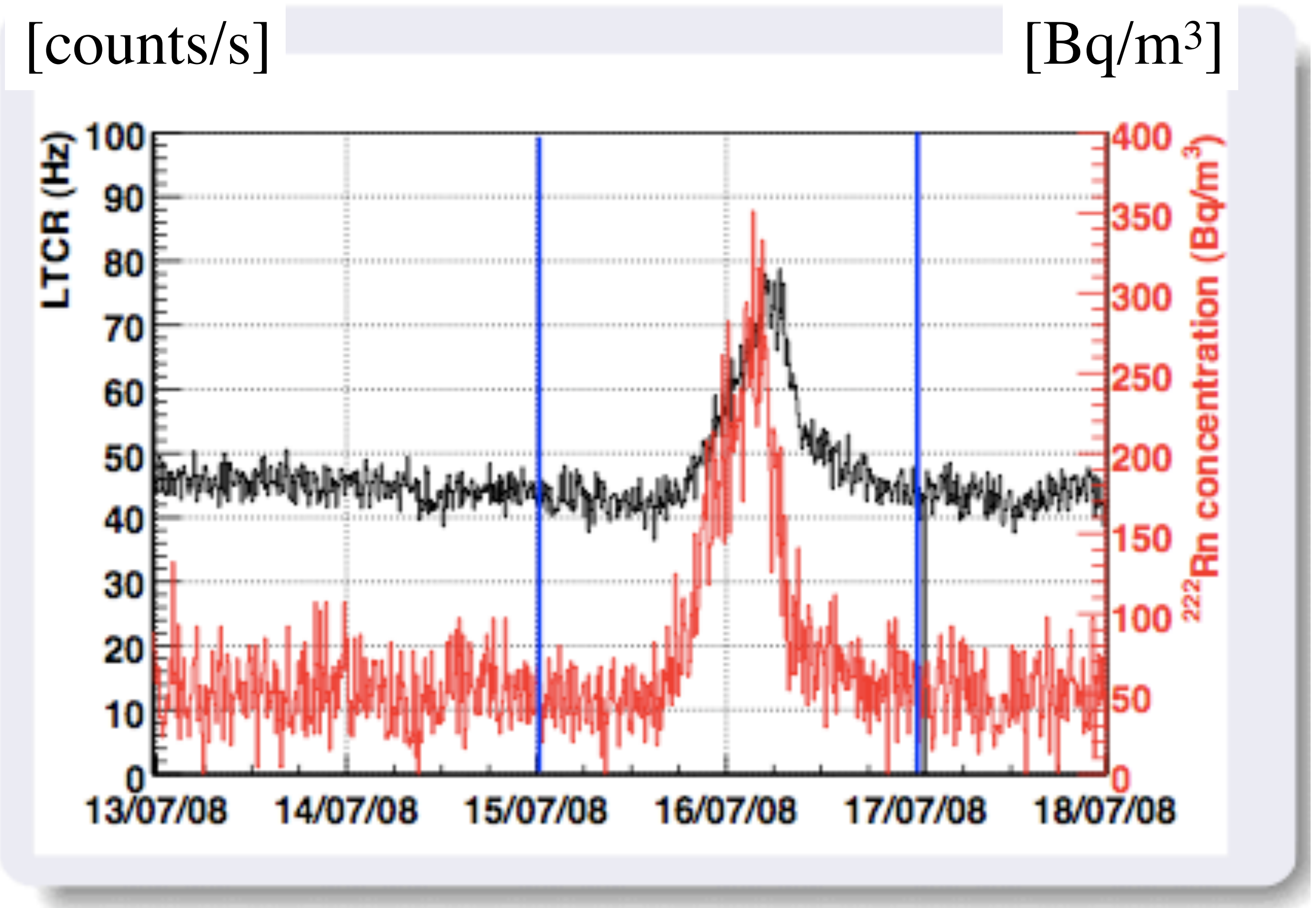


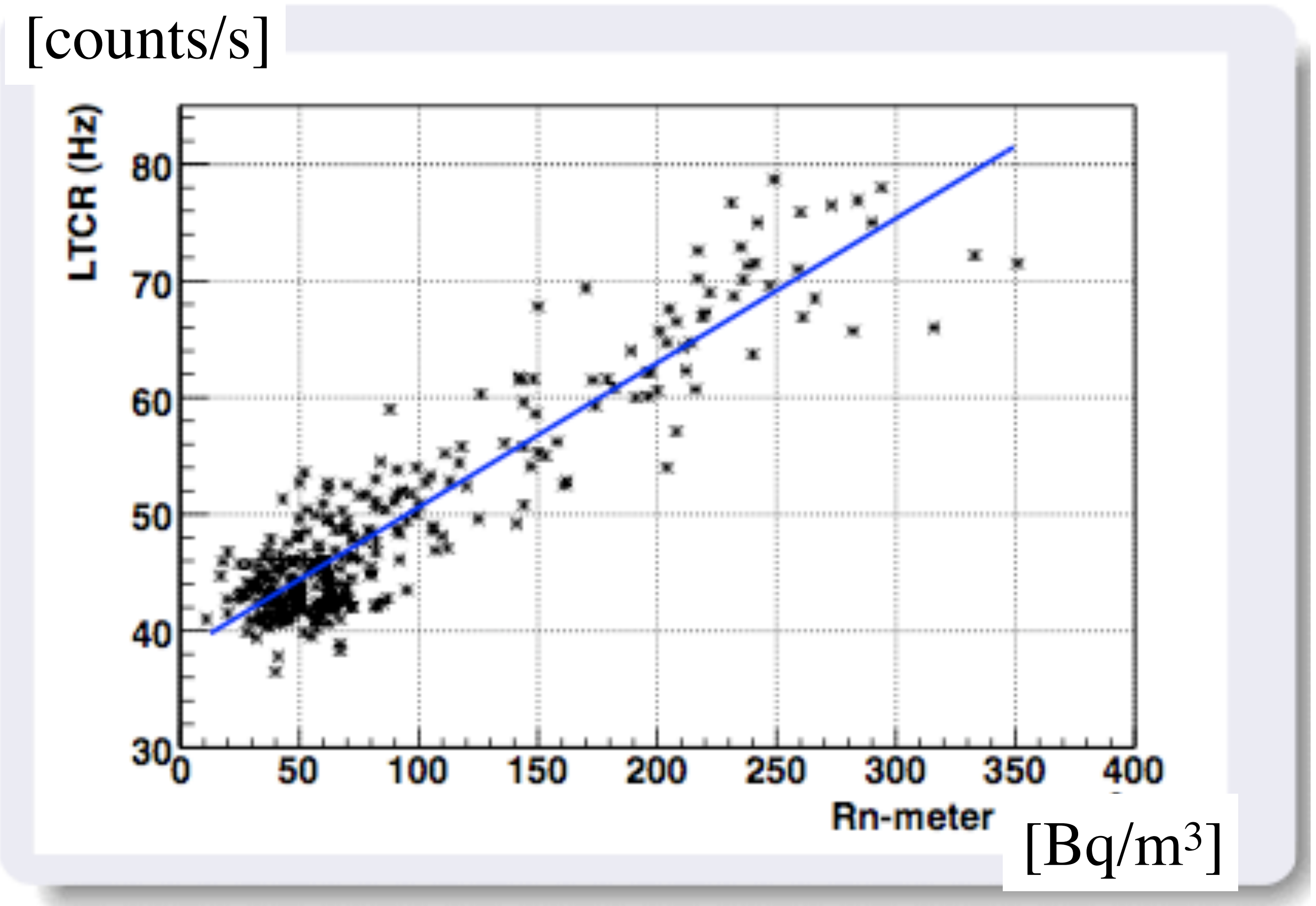
- neutron detection efficiency, ε_n, is measured by using a ^{252}Cf source placed in the center of the counter.
  For neutrons due to iβd, detected in the same counter where e^+ has been detected, the efficiency cannot be greater than:
  - → $\varepsilon_n \leq 60\%$
- LVD modularity impacts the detector energy resolution:
  - → η_{FWHM} ~ 35% at 15 MeV
- Absolute time accuracy better than
  - → <1 μs
- Relative time accuracy:
  - → 12.5 ns



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





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.

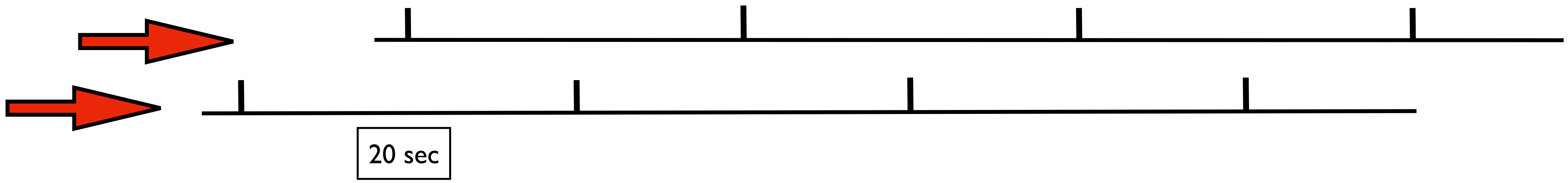
- **Only requirements are:**

  → 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**

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 ≥m

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

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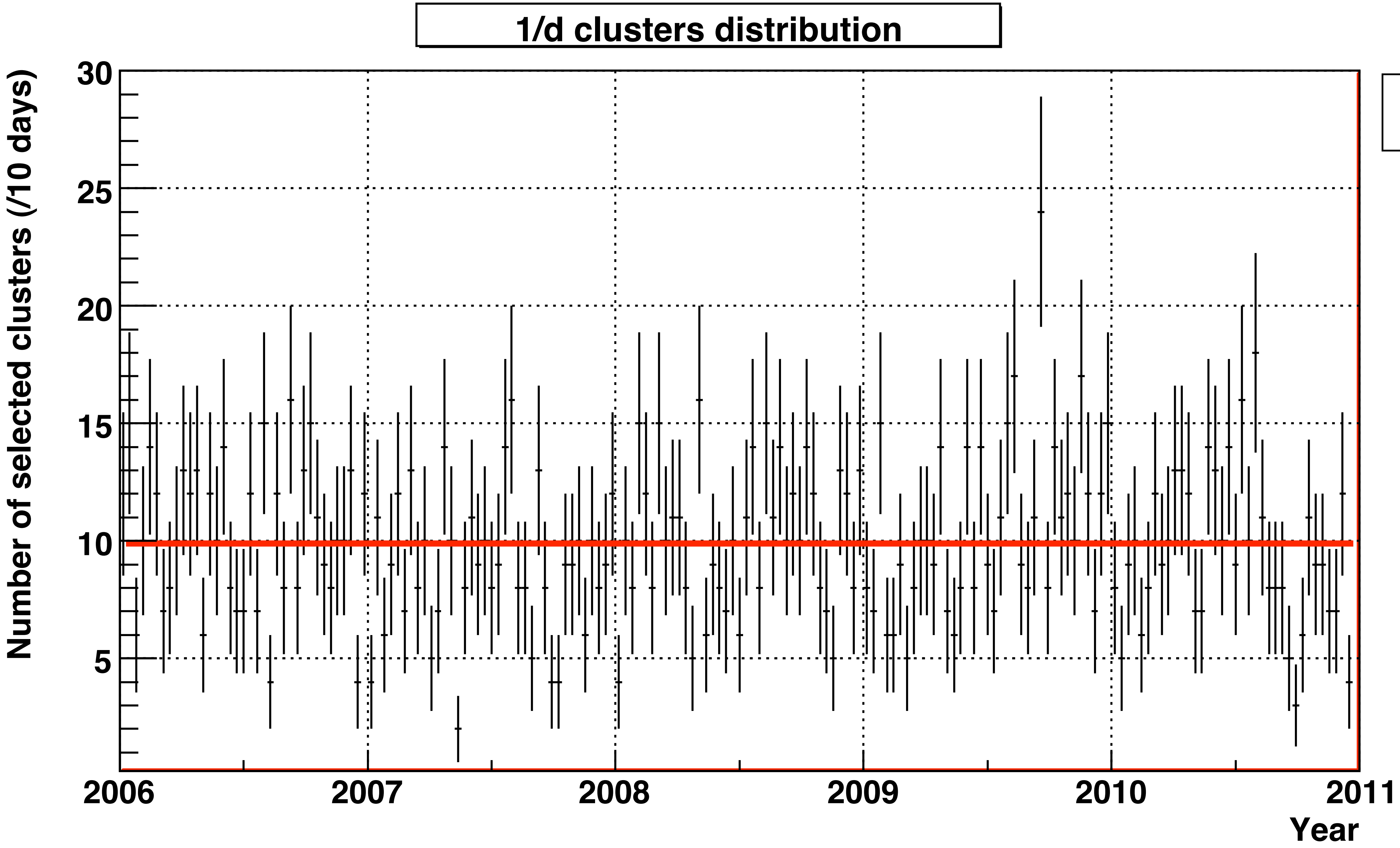
LVD: search for ν burst - results -

- 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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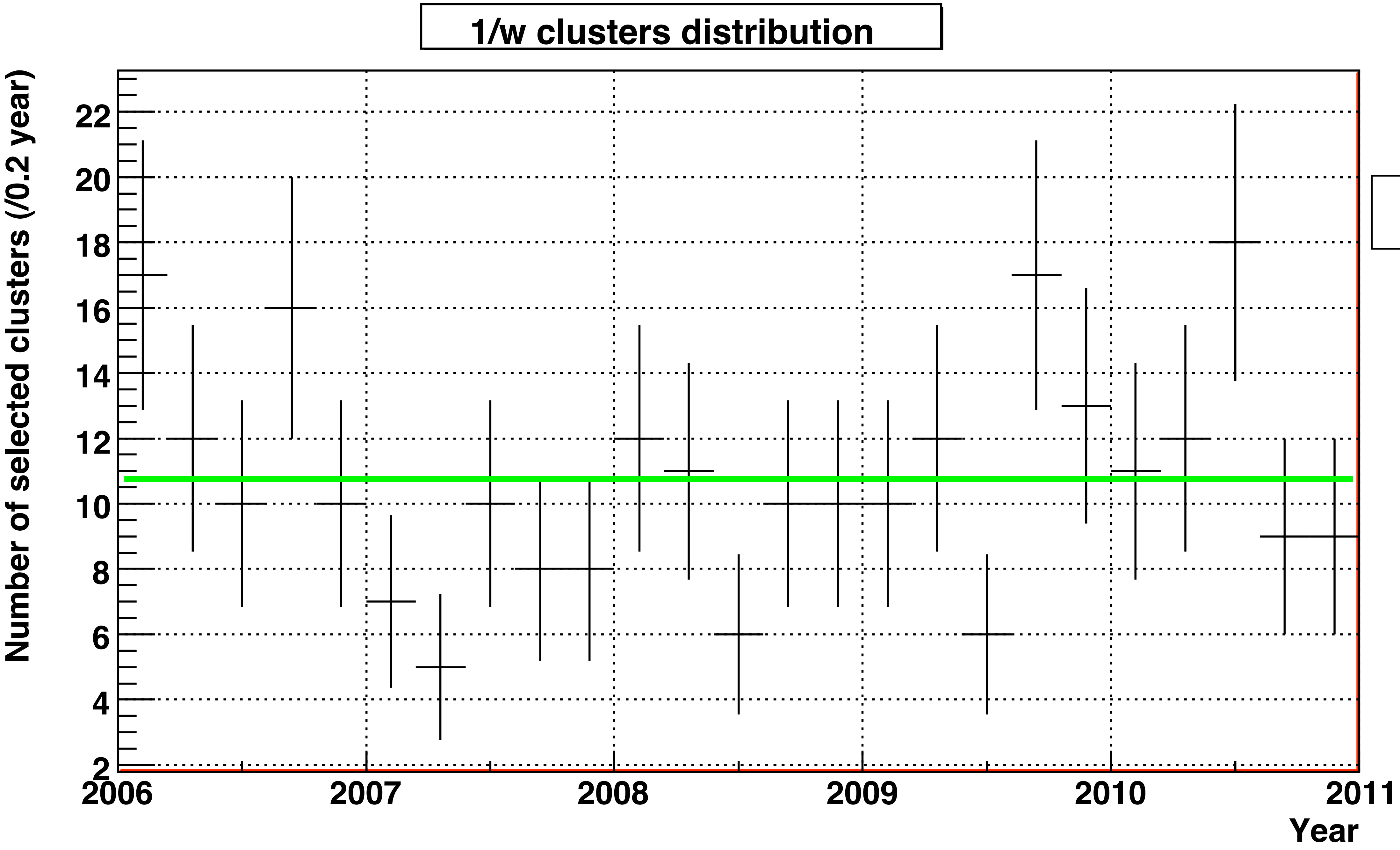
LVD: search for ν burst - results -



1/week

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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 -

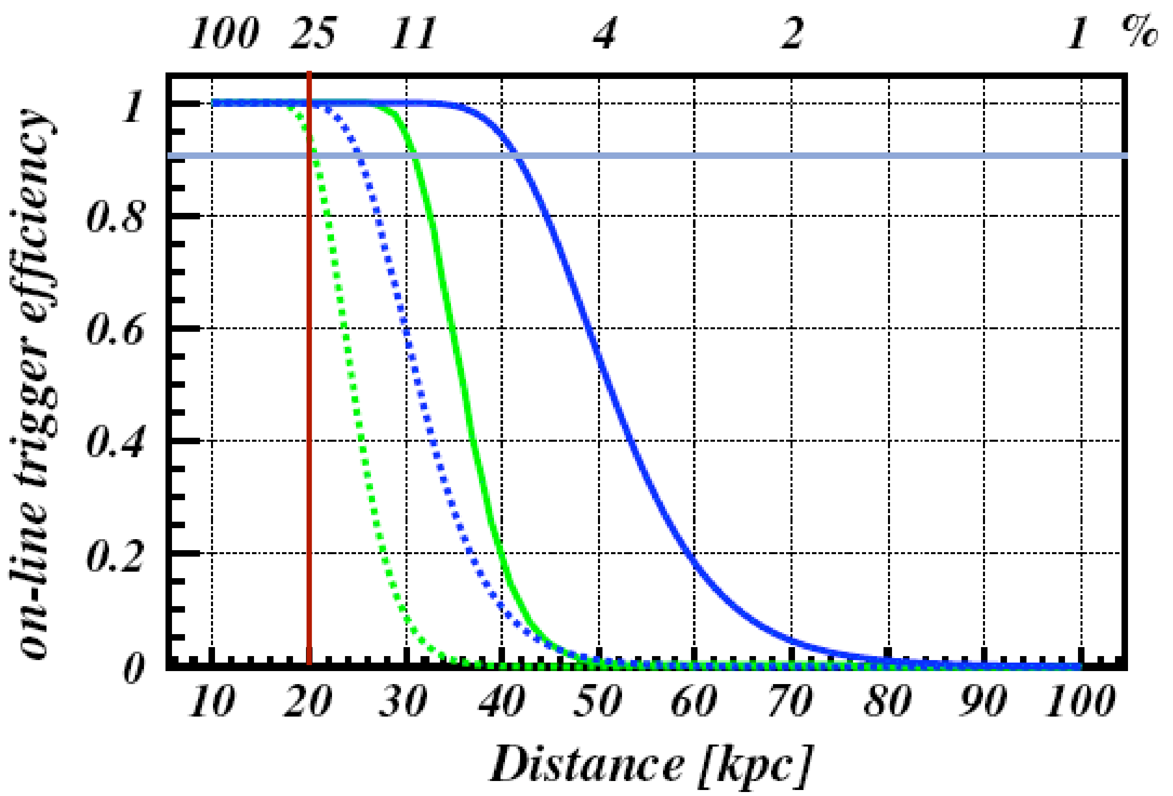
- With these assumptions on the neutrino emission and for a Fim < 1 fake event/100 years, we have full efficiency up to 20 kpc when the detector mass is greater than 300 ton

STAND ALONE

(F_{im} < 1 fake event/100 years)

E_{cut} = 7 MeV 🟩

E_{cut} = 10 MeV 🟦



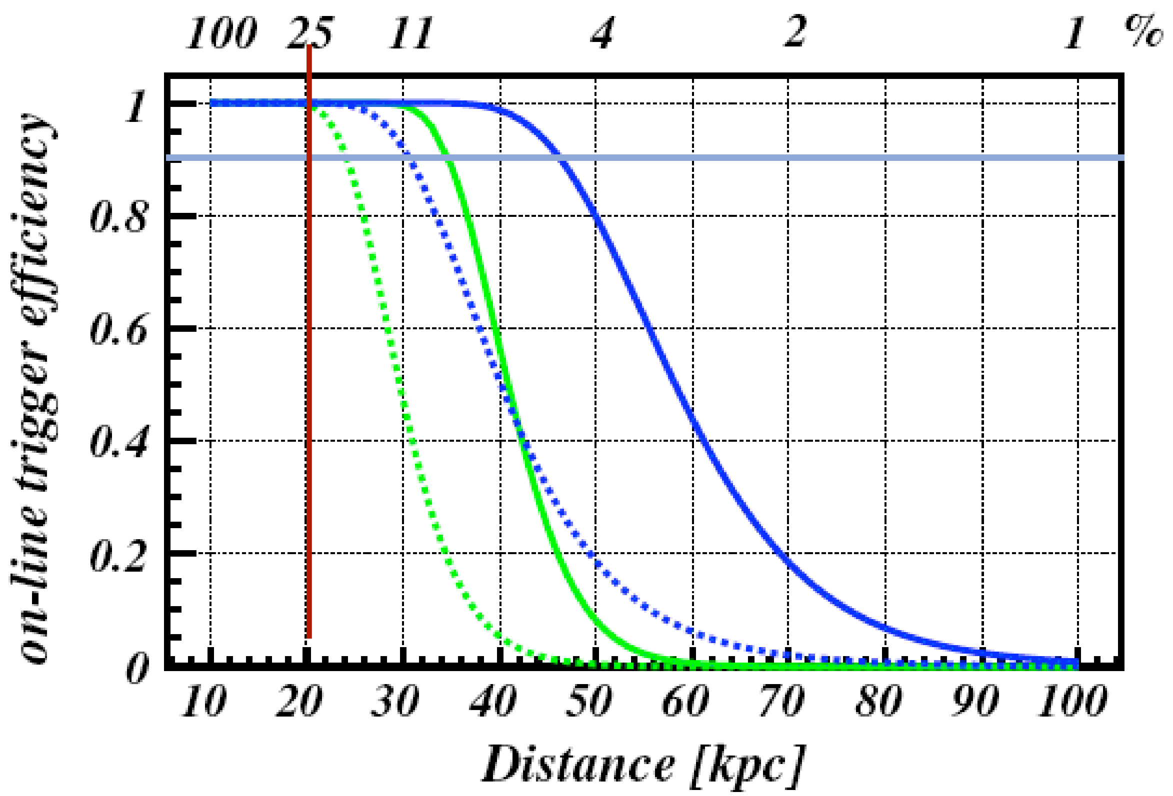
- Working in coincidence with other detectors we relax Fim to 1 fake event/month.

SNEWS

(F_{im} < 1 fake event/month) !!

E_{cut} = 7 MeV 🟩

E_{cut} = 10 MeV 🟦



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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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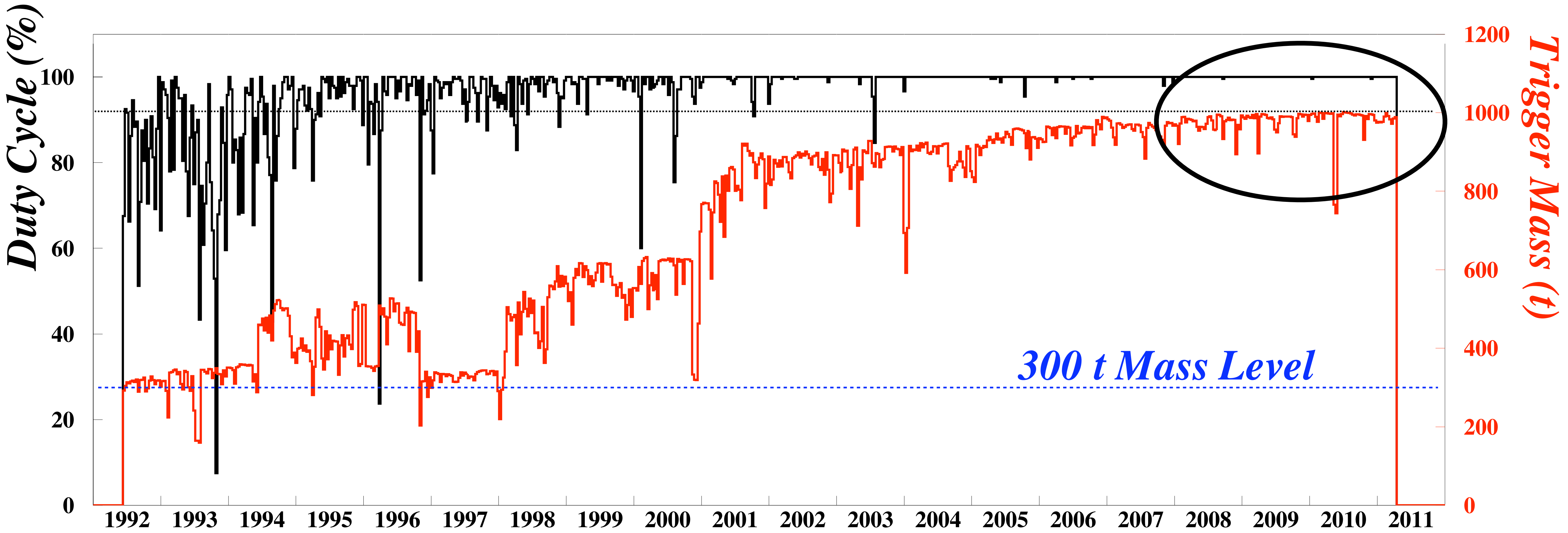
Conclusions

- 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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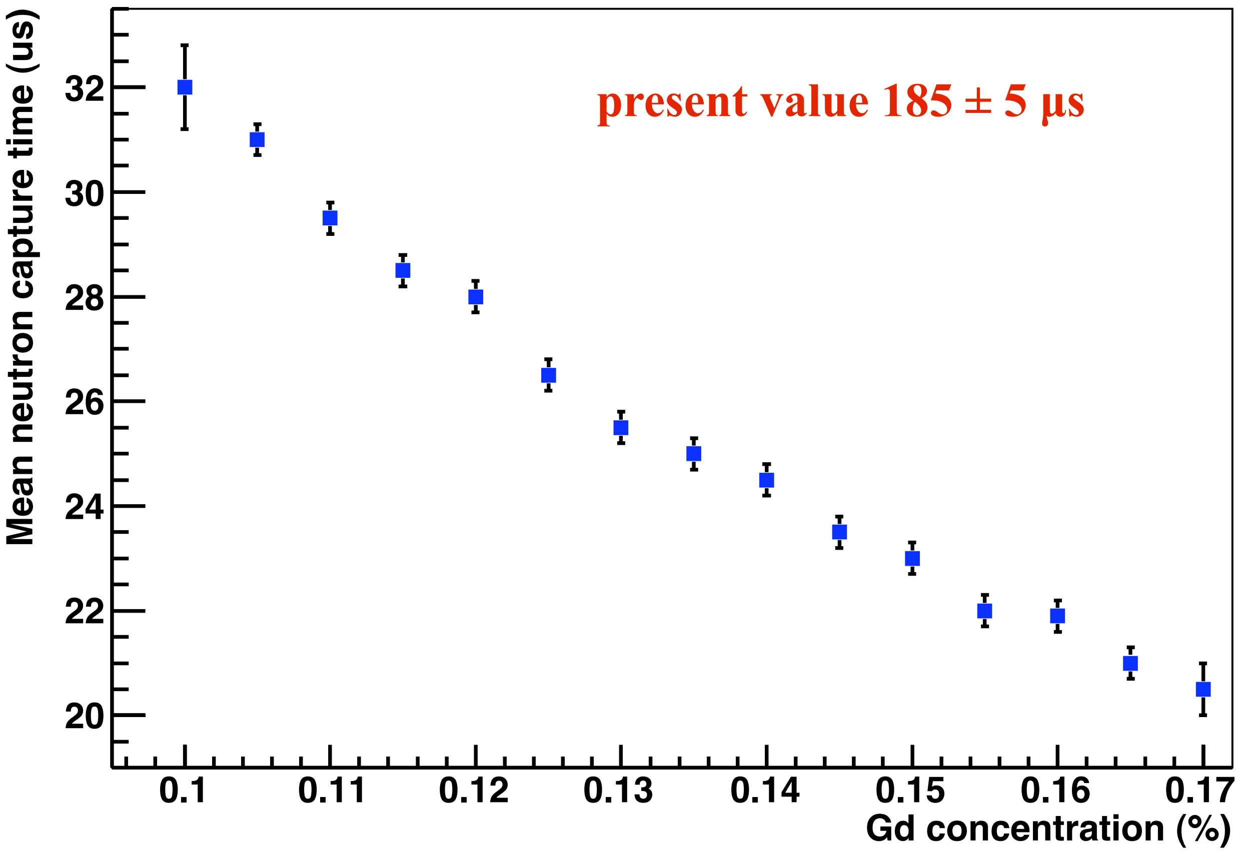
LVD: Gd doping

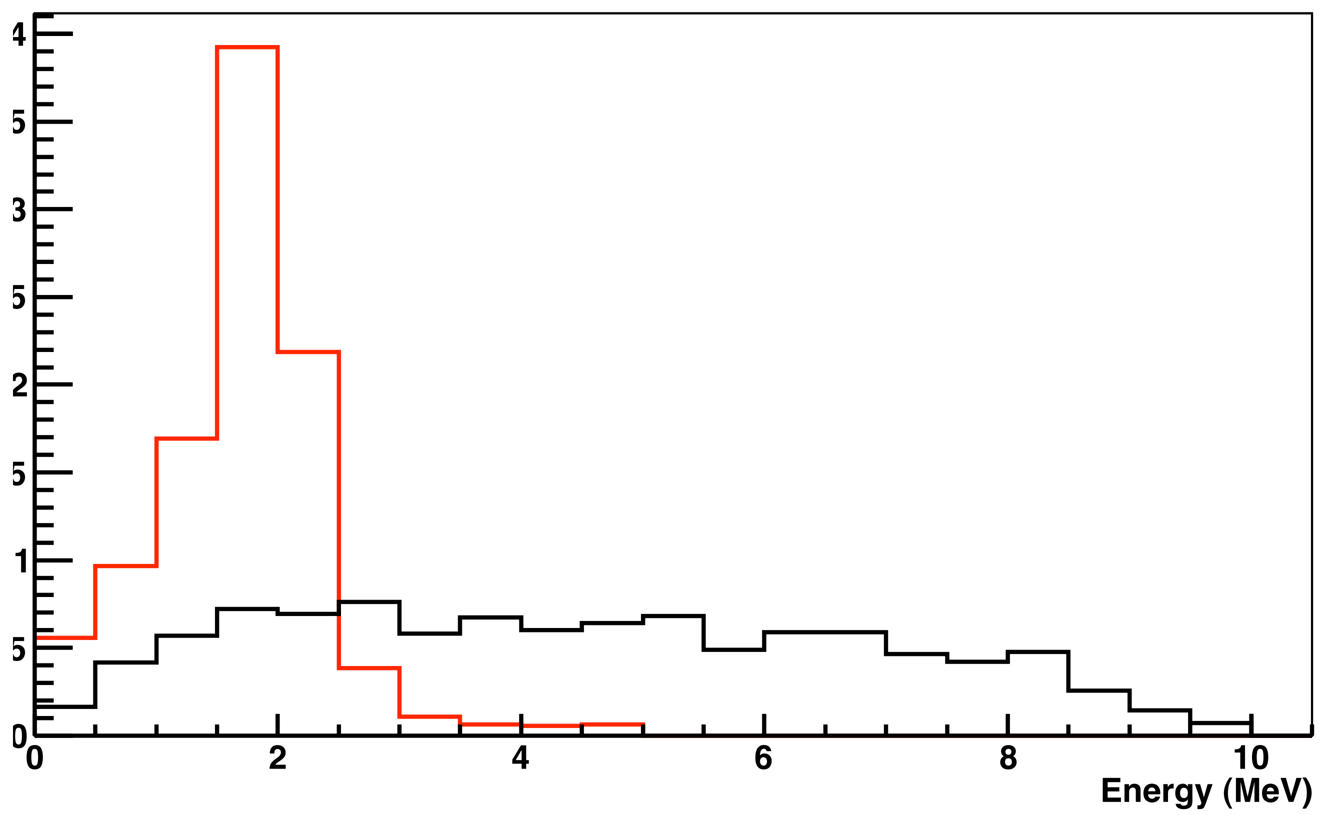
I.R.Barabanov,, L.B.Bezrukov, C.M.Cattadori, N.A.Danilov, A.di Vacri, Yu.S.Krilov, L.Ioannucci, E.A.Yanovich, M.Aglietta, A.Bonardi, G.Bruno, W.Fulgione, E.Kemp, A.S.Malguin, A.Porta and M.Selvi, 2010 JINST 5 P04001

- 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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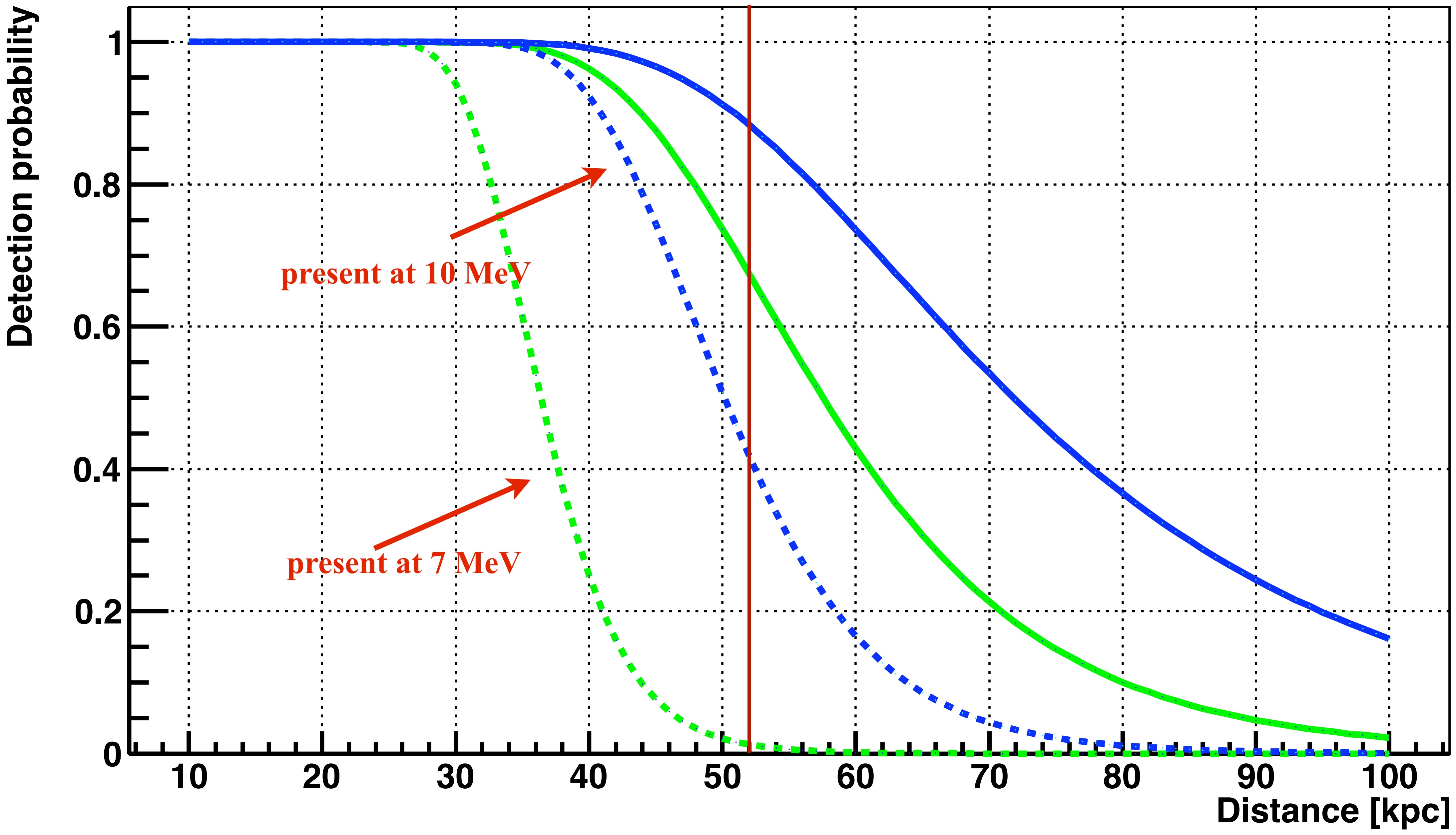
LVD: Gd doping

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.



present at 10 MeV

present at 7 MeV

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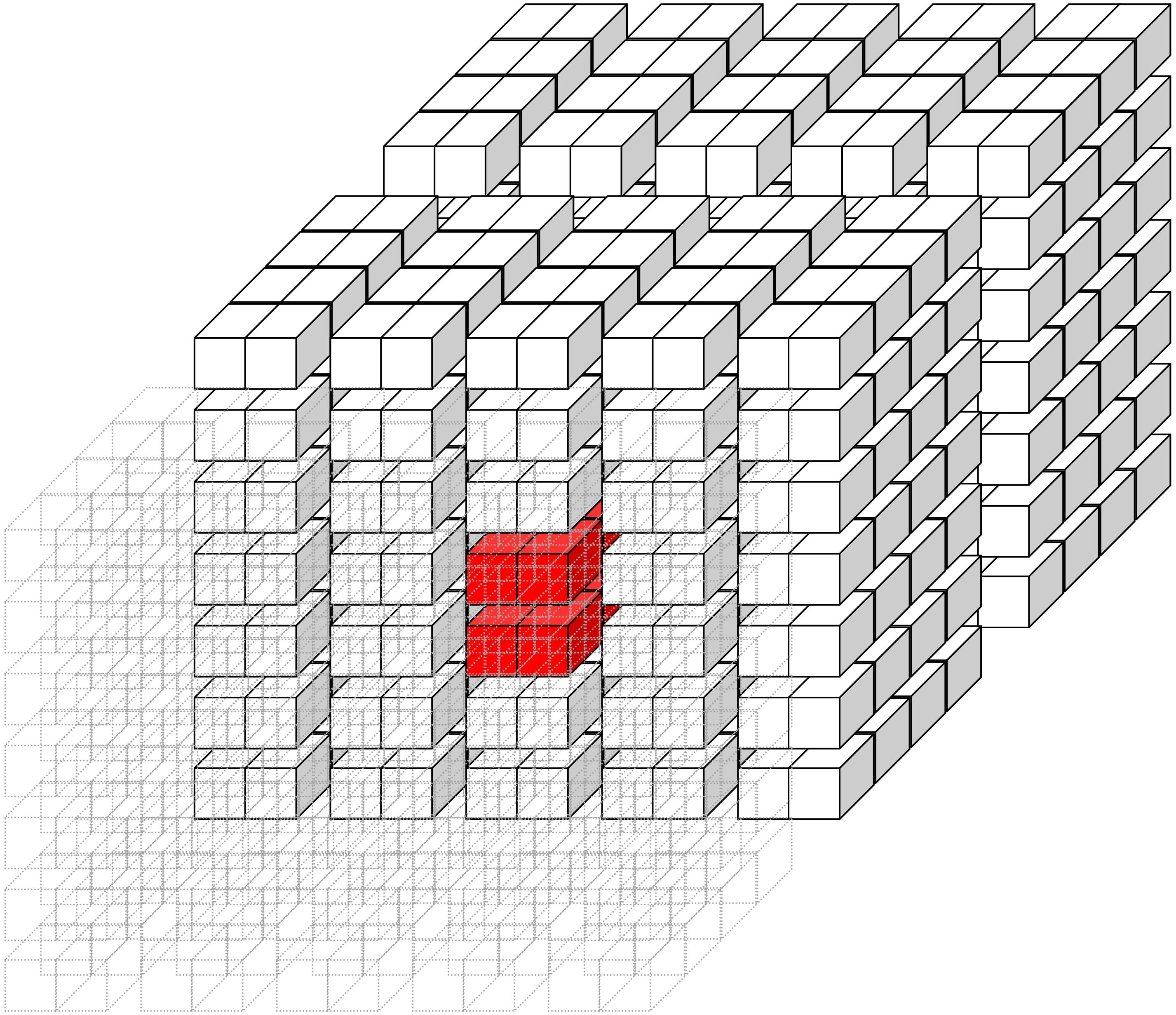
The LVD Core Facility

- An inner region inside the LVD structure could be effectively exploited by a compact experiment 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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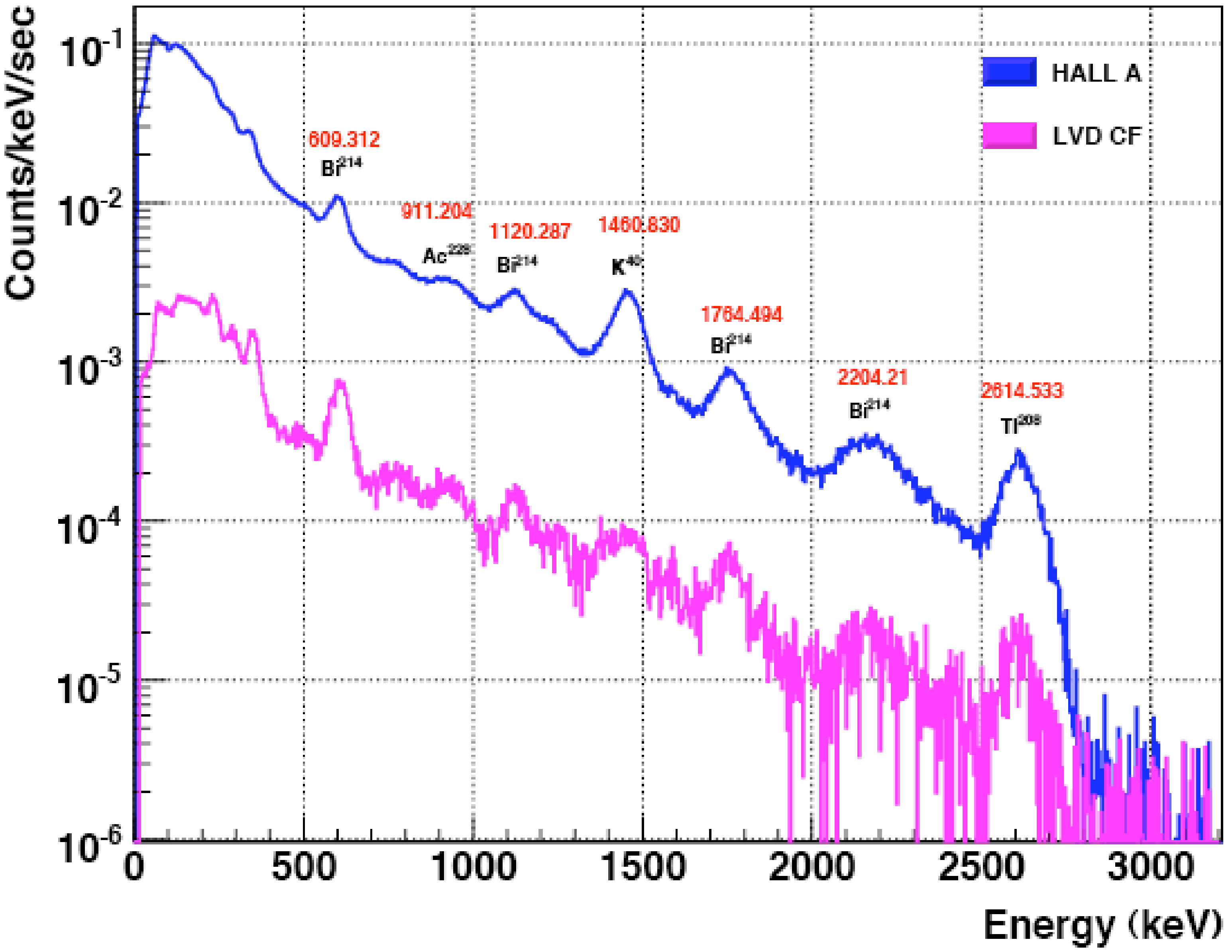
The LVD Core Facility

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, $5 \cdot 10^{-2}$**

LVD can act as a **muon veto** with respect to the LVD CF volume. 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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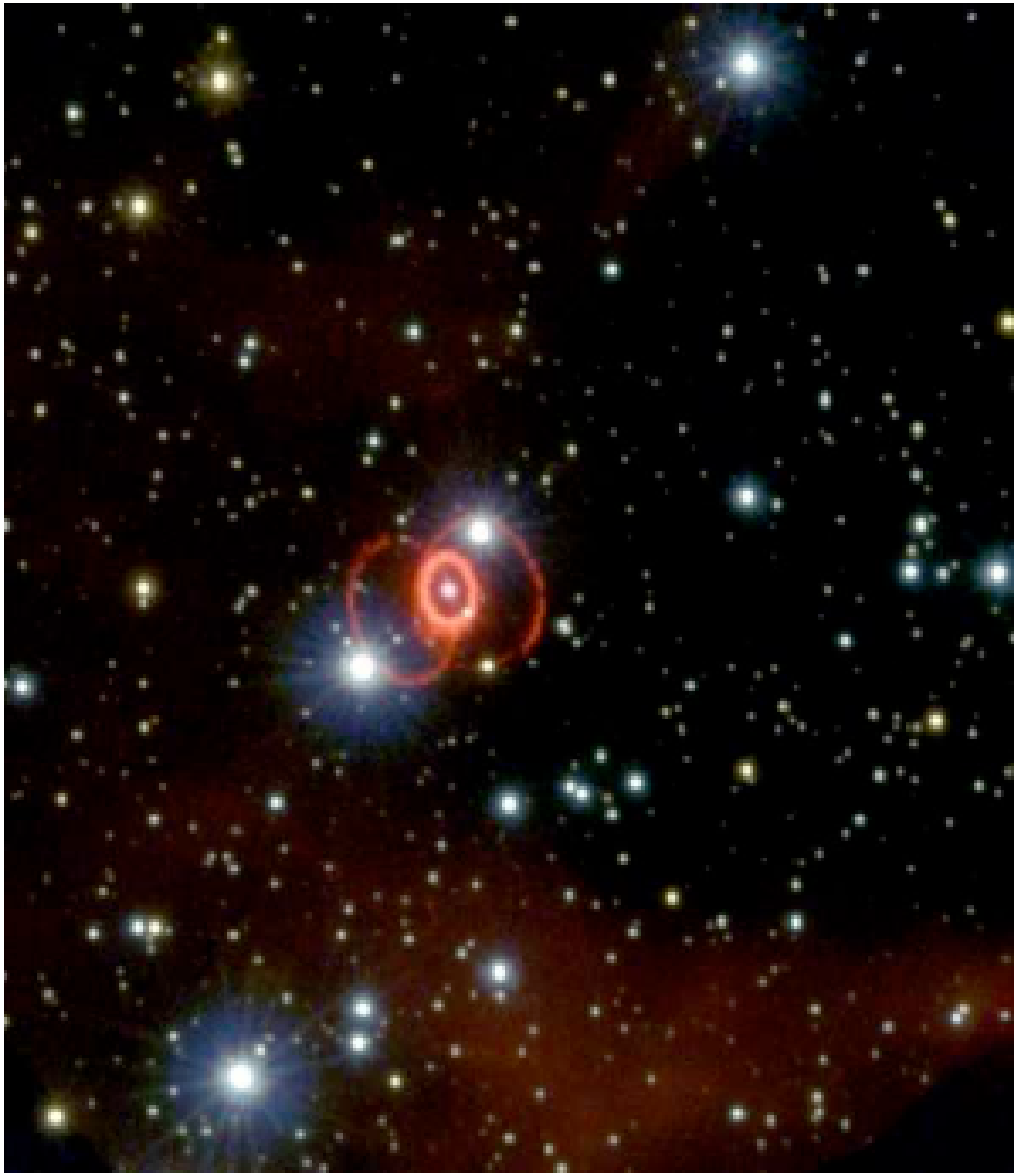

Hubble image

Thank you

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