LVD

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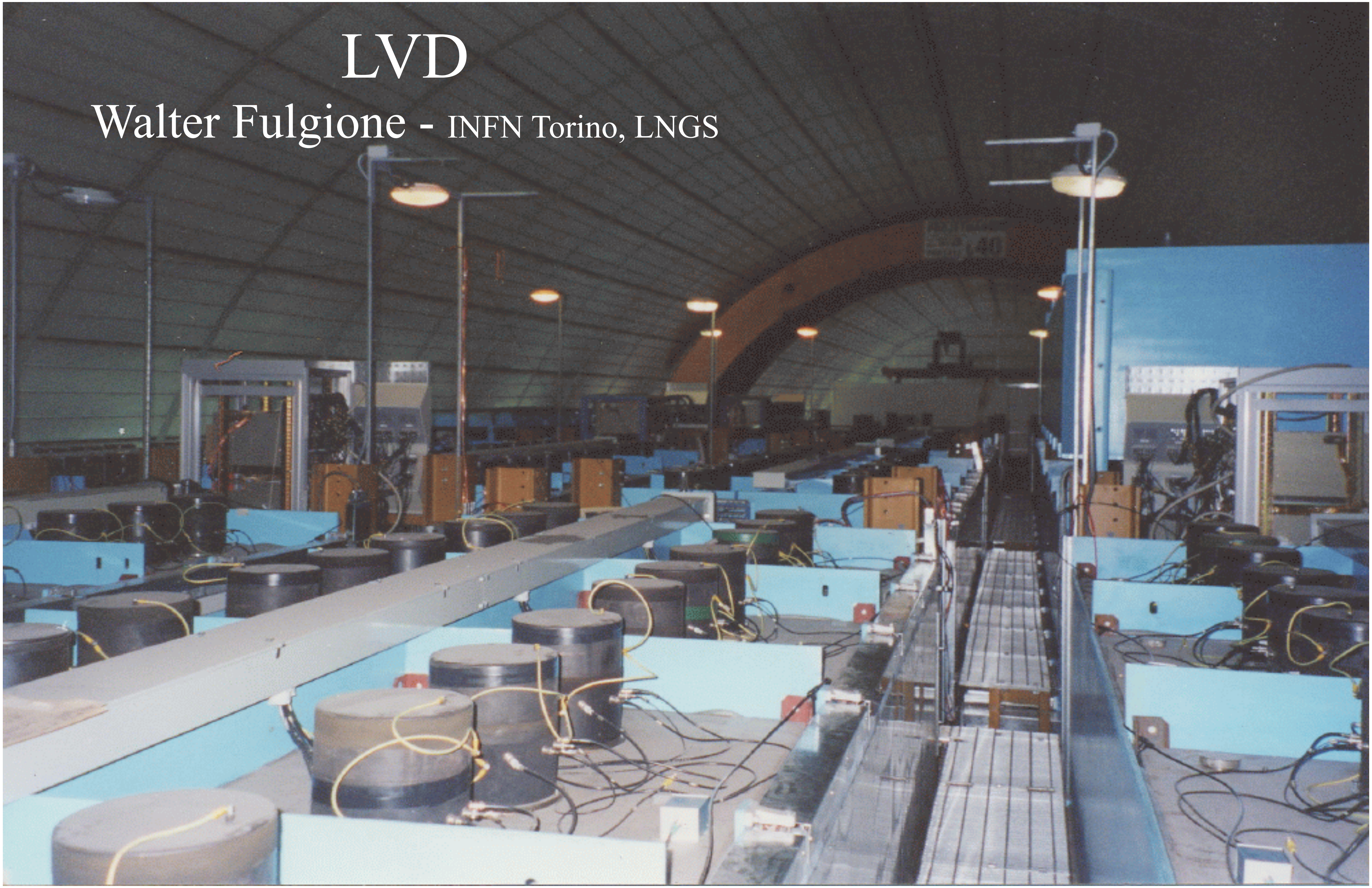

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SEARCH FOR SUPERNOVA NEUTRINO BURSTS AT LVD

- Introduction
  - the LVD project
  - data taking since 1992
  - LVD in the SN Early Warning System
- Detector characteristics
  - self shielding
  - detector uniformity
  - time variation of the bk rate
- Search for neutrino burst
  - sensitivity
  - competitors
  - data set
  - strategy
  - validation
  - results
  - consistency checks
- Conclusions

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LVD - operating since 1992

- Last June LVD celebrated 21 years of operation.
  - Data set taken from June 9th 1992 to August 31st 2013 corresponding to 7212 live days

- LVD project was approved in 1985, two years before the observation of neutrinos and photons from SN1987A !!

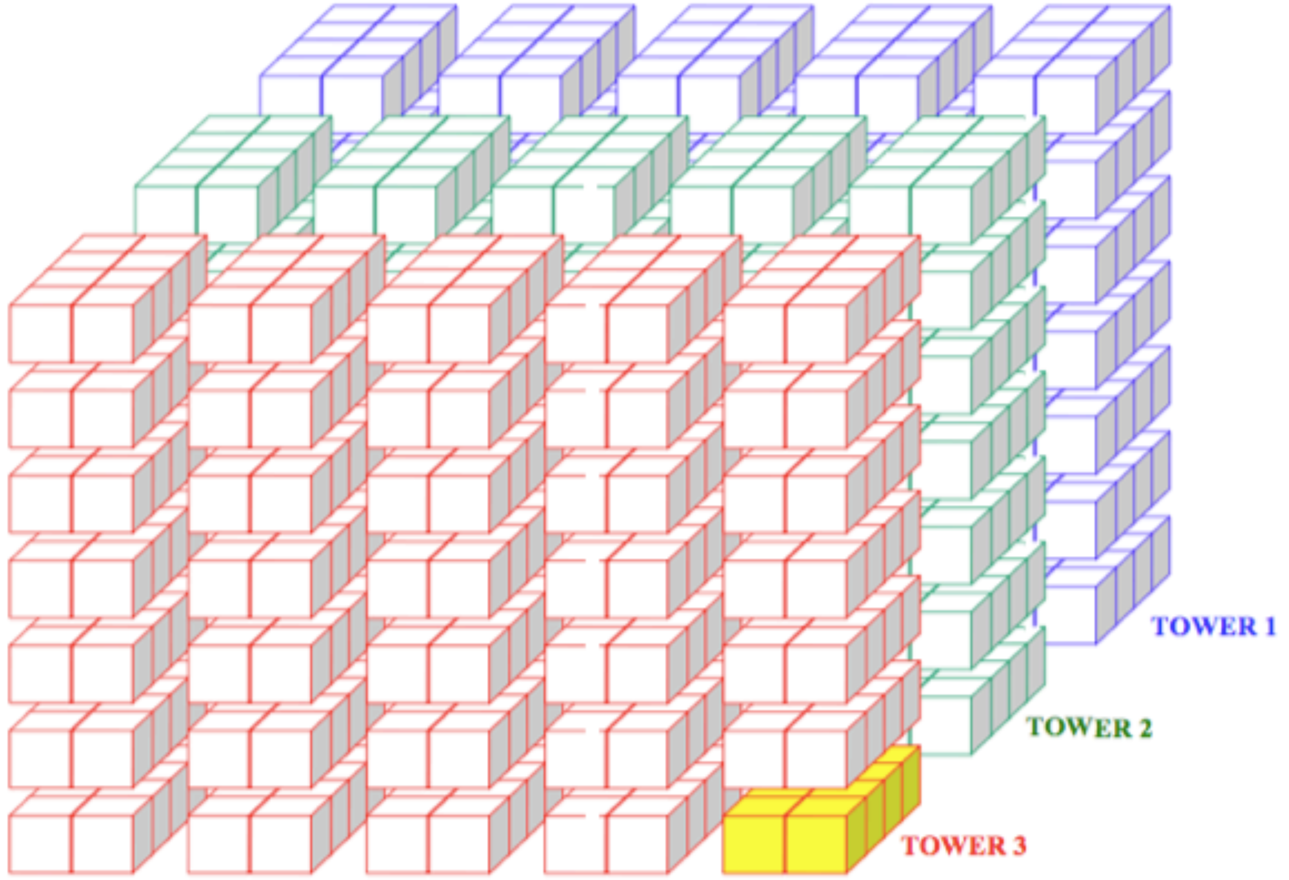
- LVD began taking data on June 1992 with 1/3 of its present mass. At the end of 2001 the detector reached the present configuration.

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

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

The Large Volume Detector

- modular liquid scintillator detector made by 840 stainless steel 1.5m^3 counters arranged in 3 identical towers
- each counter is viewed by 3 PMTs (3-fold coincidence).
- each TOWER is fully independent and can run all alone.

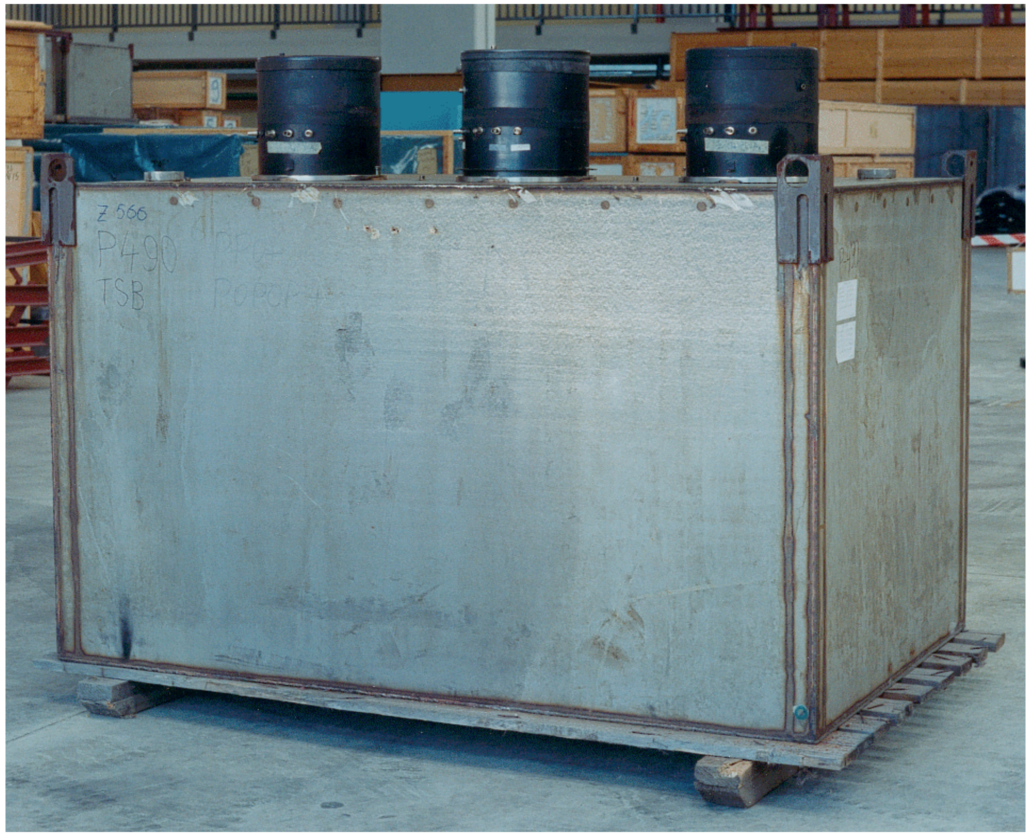


Main features:

Liquid Scintillator: C_nH_{2n+2} <n>=9.6 + 1g/l PPO + 0.03g/l POPOP, ρ=0.8 g/cm^3 **total 1 kt**

840 stainless steel, 1.5 m^3, counters **total 0.85 kt**

(FEU49b or FEU125) 15 cm diameter **2520 PMTs**



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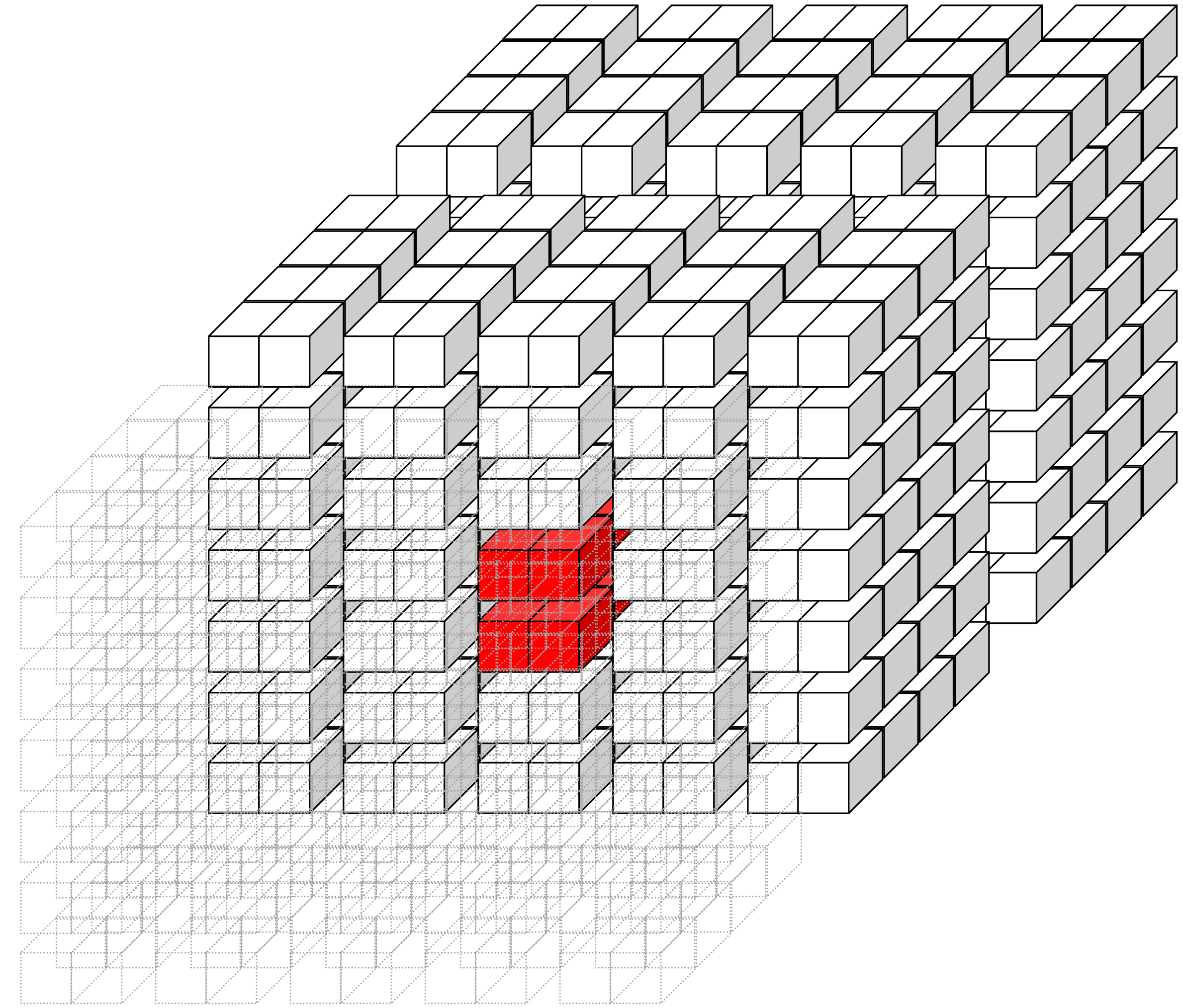
main characteristics

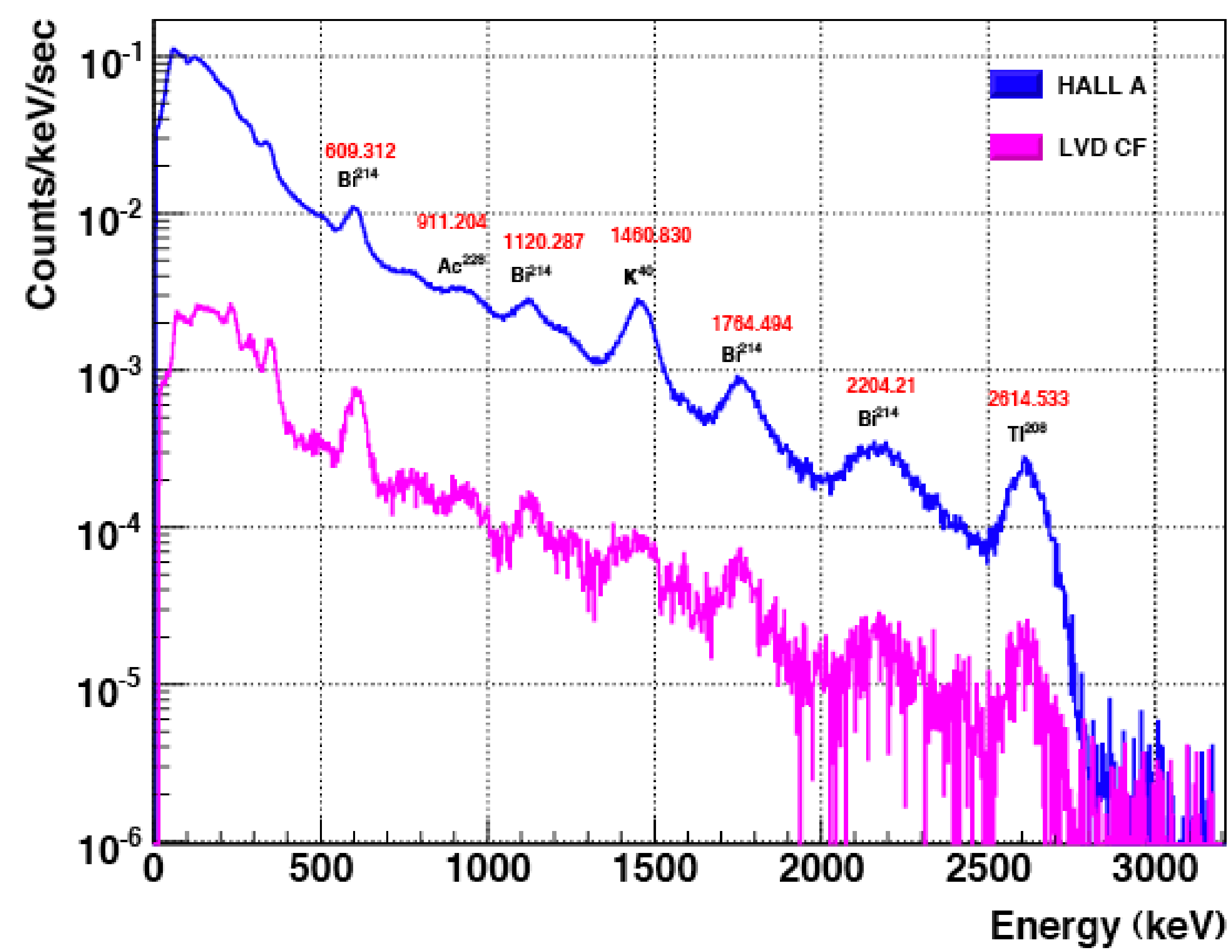
- LVD is modular and
- unshielded

- **consequences:**
  - very high duty cycle
  - Fe target
  - leakage affects E resolution and detection efficiencies

  - bk rate gradient among detector shells
    self shielding
    - γ spectra, have been measured inside and outside the LVD array. The flux, in the LVD Core, is **attenuated by a factor 20**.
    - The **bk rate** gradient is used to check the consistency of neutrino burst candidates.

  - Rn contamination of the cavern can be utilized
    - to monitor single counter sensitivity to 609 KeV gammas from ^{214}Bi.



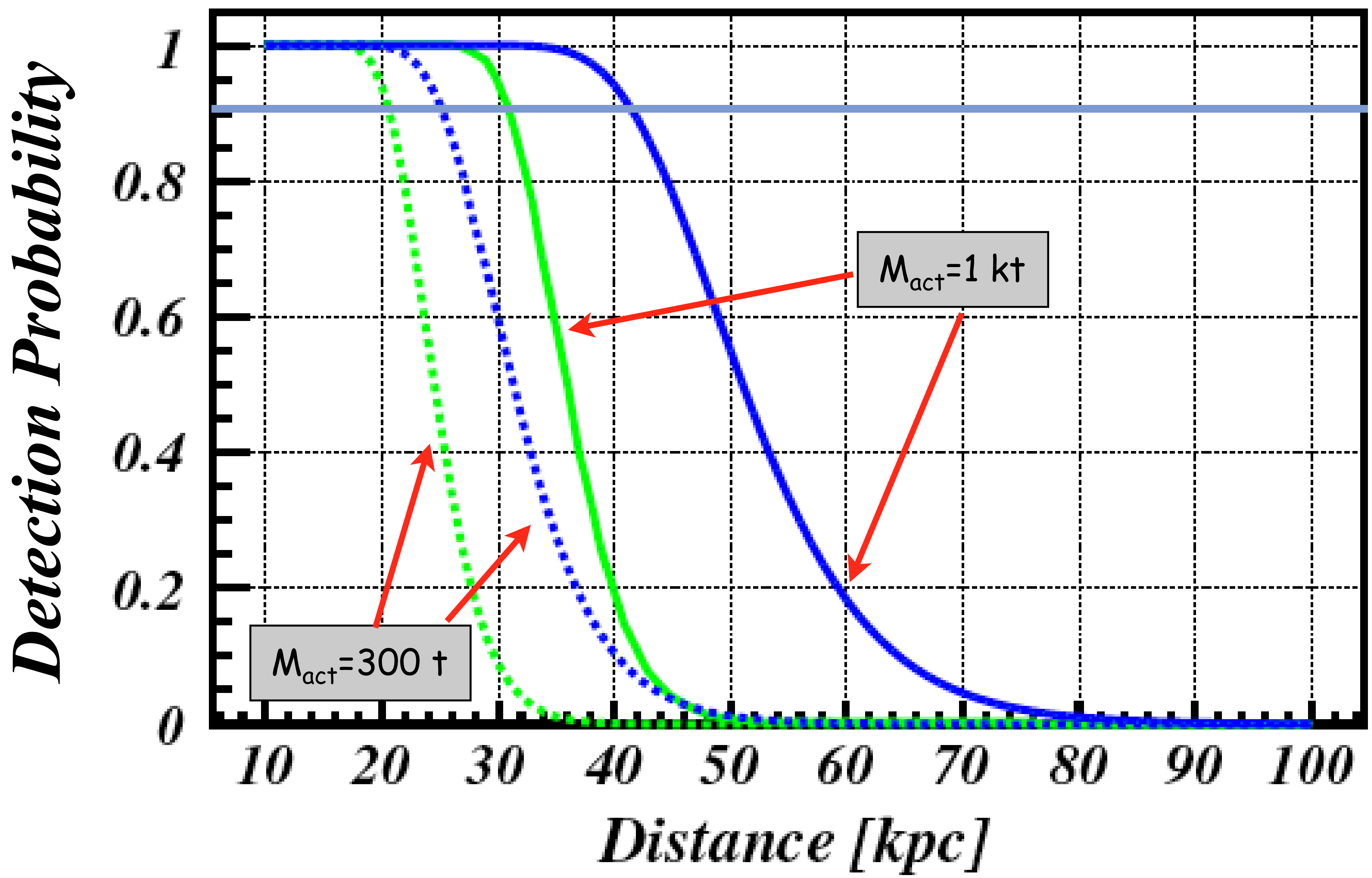


detector sensitivity

- Assuming a model for the neutrino emission and propagation, it is possible to express the sensitivity in terms of maximum distance of the source.
- We refer to the work (Pagliaroli et al. 2009) which considers the microscopic processes of the collapse to build a parameterization of the neutrino emission.
- The free parameters are determined from SN1987A.

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

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



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

→ full sensitivity up to 25 kpc for active mass > 300 t

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Competitors

$E_{tot}=2.6 \cdot 10^{53}$ erg.

$\bar{\nu}_e$ radius of neutrino-sphere Rc = 17.4 km
initial temp. of cooling phase Tc = 4.47 MeV

ν_e initial temp. of cooling phase = 0.8·Tc

ν_x initial temp. of cooling phase = 1.3·Tc

normal hierarchy - adiabatic

	LVD	Borexino	KamLAND
Mass (ton)	1000	300	1000
Technique	Liq. scint.	Liq. scint.	Liq. scint.
Composition of the target	$C_{10}H_{20}$	C_9H_{12}	CH_2
Energy threshold (MeV)	4	0.25	0.35
Protons (10^{31})	8.31	1.81	8.51
Carbon nuclei (10^{31})	4.27	1.36	4.23
Electrons (10^{31})	33.93	9.94	33.80
Iron nuclei (10^{31})	0.97	-	-

	SuperKamiokande	IceCube
Mass (ton)	32000	151000 (E_{e+}/MeV)
Technique	Cherenkov in water	Cherenkov in ice
Composition of the target	H_2O	H_2O
Energy threshold (MeV)	5	-
Protons (10^{31})	214.2	1010 (E_{e+}/MeV)
Electrons (10^{31})	1071	5050 (E_{e+}/MeV)
Oxygen nuclei (10^{31})	107.1	505 (E_{e+}/MeV)

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Competitors

	Interaction	LVD	Borexino	KamLAND	SuperK	IceCube
$\bar{\nu}_e$	$\bar{\nu}_e + p$	274	65	304	7150	613000
ν_e	$\nu_i + e^-$	10	4	14	260	18000
	$\nu_e +^{12} C$ (CC)	5	2	5	-	-
	$\bar{\nu}_e +^{12} C$ (CC)	3	1	4	-	-
ν_x	$\nu_i +^{12} C$ (NC)	7	4	13	-	-
	$\nu_e +^{56} Fe$ (CC)	13	-	-	-	-
	$\bar{\nu}_e +^{56} Fe$ (CC)	2	-	-	-	-
	$\nu_i + {}^{56}Fe$ (NC)	7	-	-	-	-
	$\nu_i + p$ (NC)	-	17	46	-	-
	$\nu_e +^{16} O$ (CC)	-	-	-	120	19000
	$\bar{\nu}_e +^{16} O$ (CC)	-	-	-	80	9000
	$\nu_i +^{16} O$ (NC)	-	-	-	60	1000
	Total	321	93	386	7670	$660 \cdot 10^3$

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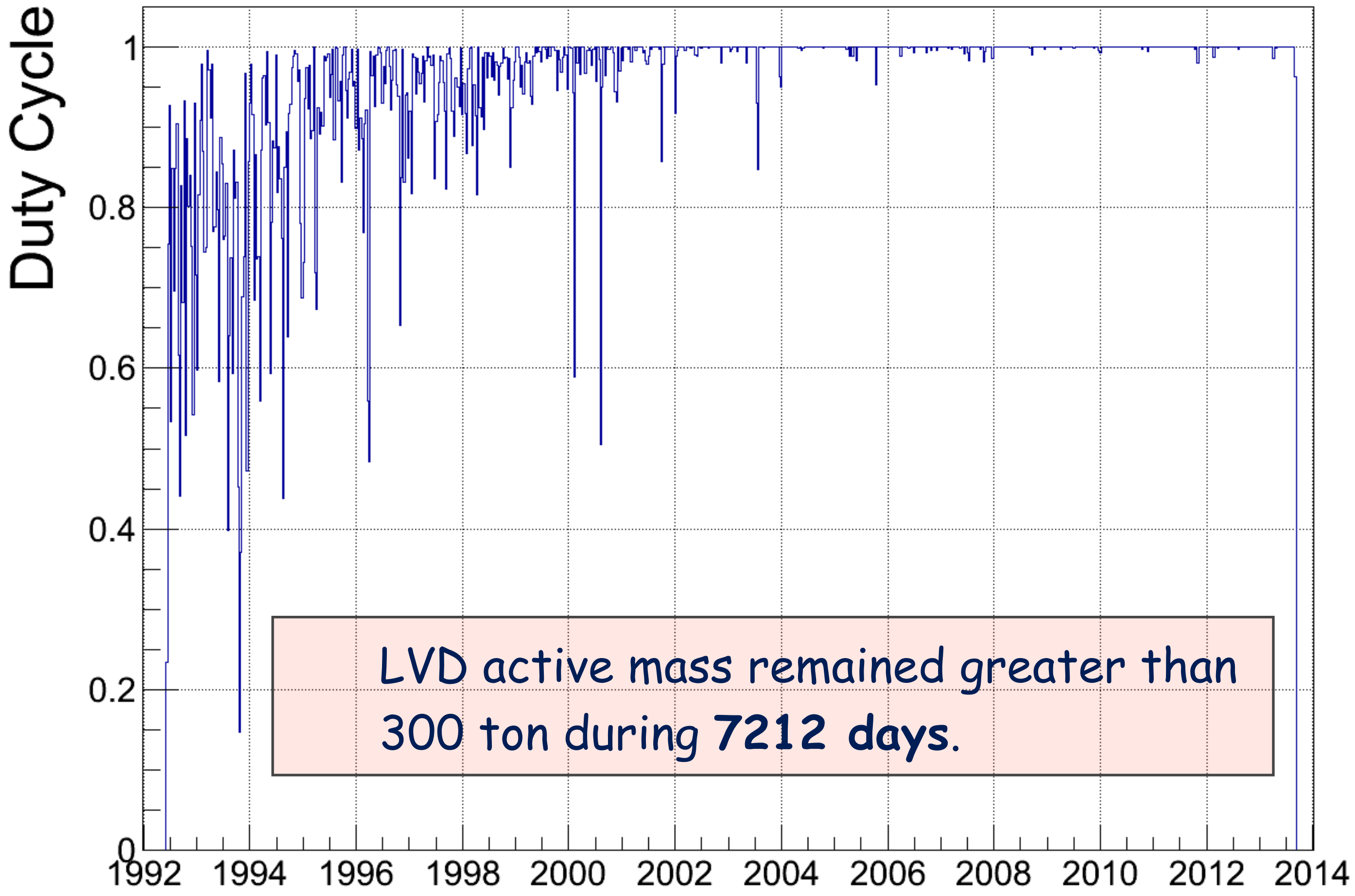
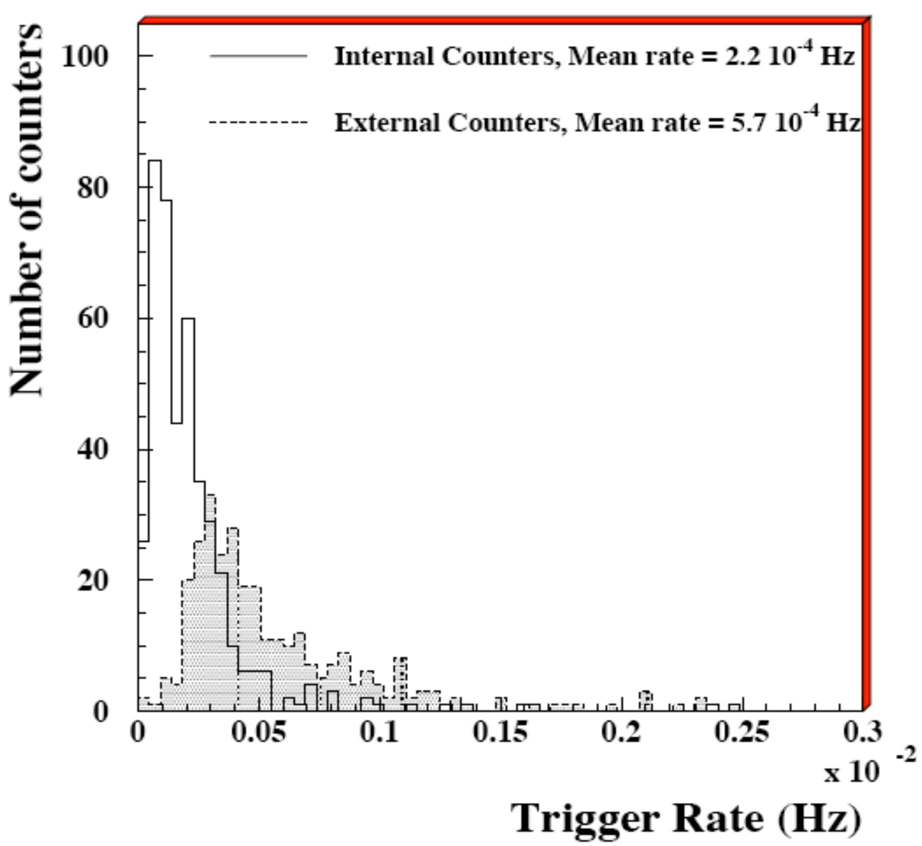
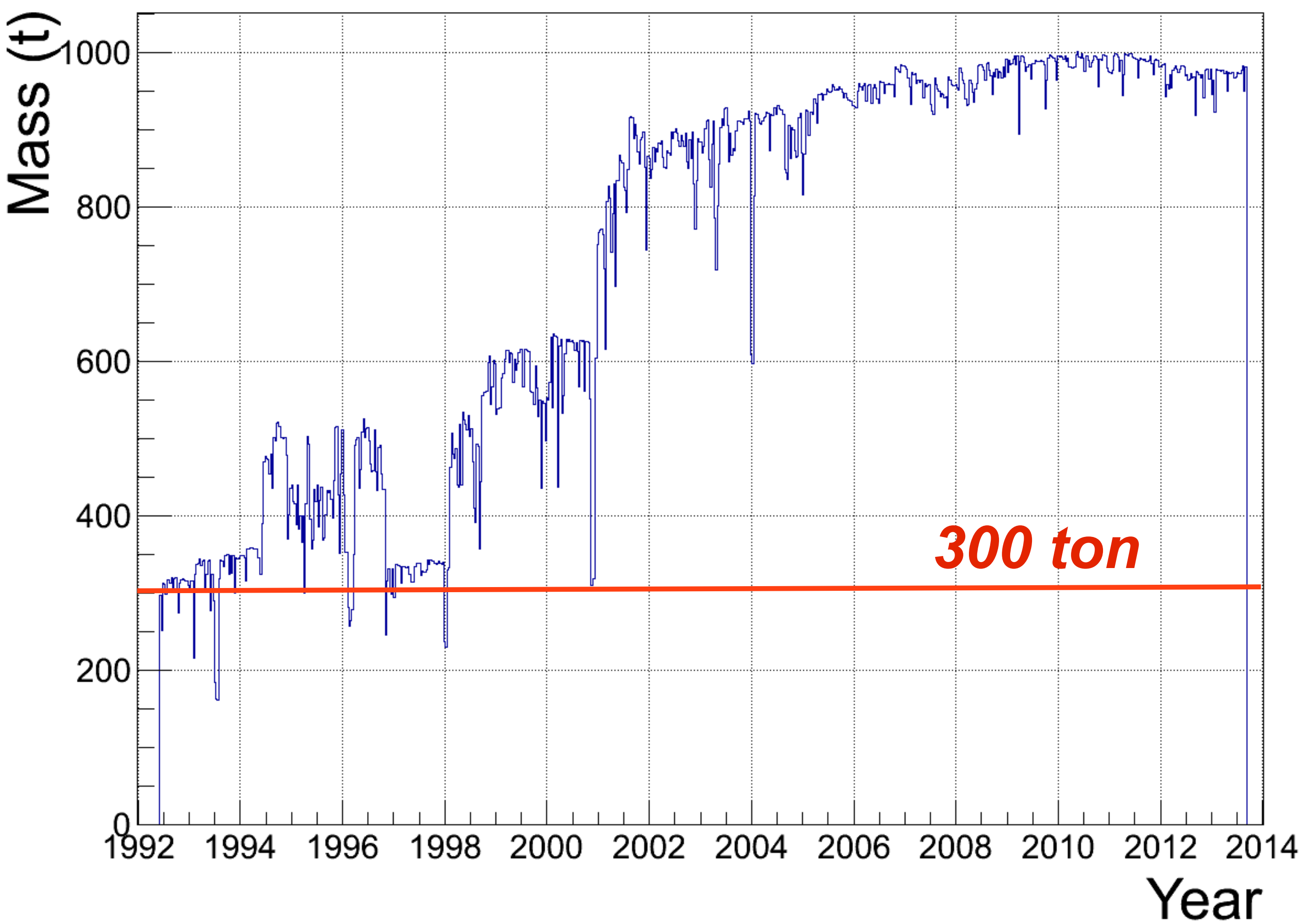
data set

The detector active mass, M_{act}, is updated every 8 hours:

- **The response to atmospheric muons is used to identify and discard bad working counters.**
- **Counters with a background rate: $R(E \geq 7MeV) \geq 3 \cdot 10^{-3}/s$ are rejected as noisy.**







quality cuts and data set uniformity

The whole LVD data set has been arranged in 2 periods according to slightly different values of the trigger threshold. In the first period, P1, the hardware trigger energy threshold was set to $E_H \simeq 5$ MeV, for the core counters, and $E_H \simeq 7$ MeV for external ones. In the second period, P2, from January 1st, 2004, the trigger energy threshold of the whole array was set to $E_H \simeq 4$ MeV.

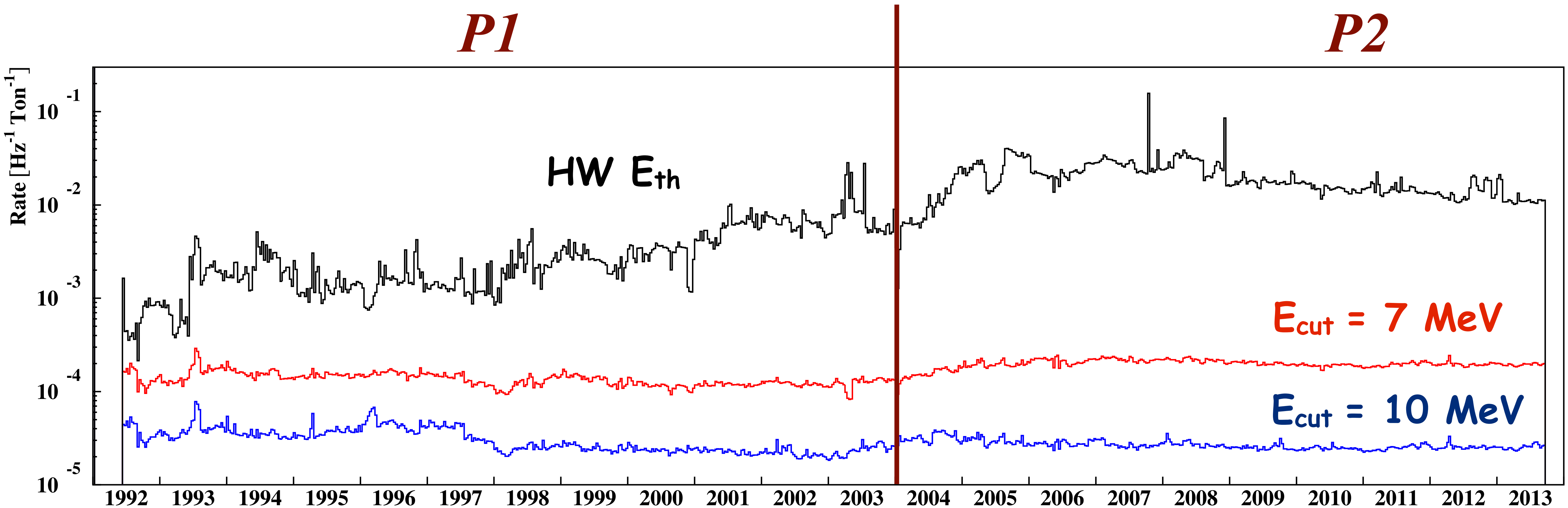


TABLE 1

DATA SET FEATURES FOR PERIODS *P1* AND *P2*.

	$R_7(E \geq 7\ MeV)$ $[s^{-1} \cdot t^{-1} \cdot 10^{-4}]$	$R_{10}(E \geq 10\ MeV)$ $[s^{-1} \cdot t^{-1} \cdot 10^{-4}]$	$R_L(E \geq 0.5\ MeV)$ $[s^{-1} \cdot t^{-1} \cdot 10^{3}]$	$\bar{M}_{act}$ [t]	Exposure $[kt \cdot year]$	live time $[days]$	live time(≥300t) $[days]$
P1	1.3	0.28	0.24	534	5.72	3908	3696
P2	2.0	0.27	0.25	917	8.84	3522	3516

search for ν burst - strategy -

- LVD takes advantage of its characteristic geometry to design its strategy searching for ν burst.
- The search is purely statistical, the study of physical aspects of the detected cluster (energy, time distribution, flavor content and event topology) is left to a susequent stage of analysis for validation.
- **Only requirements are:**
  - ➙ the bulk of signal must be contained inside a time window of 10 - 20 sec -
  - ➙ signals inside 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 10 MeV)
- **To validate the method we must be able:**
  - ➙ to predict the rate of fake alarms (background clusters)

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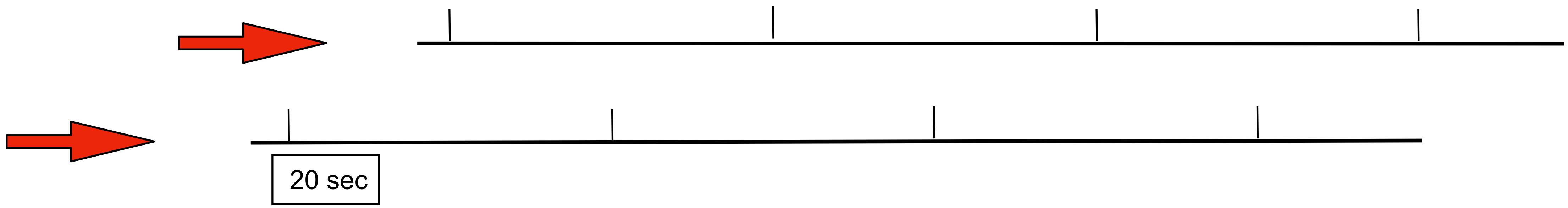
search for ν burst - strategy -

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



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

- The expected frequency of clusters of duration 20s and multiplicity ≥ m, due to bk. is:

$$F_{im}(m, f_{\rm bk}) = C \cdot \sum_{\rm k \geq m}^{\infty} P(k; 20 \cdot f_{\rm bk})\ ev \cdot day^{-1}$$

where f_{bk} is the background counting rate, $P(k; f_{bk}\Delta t)$ is the Poisson probability to have clusters of multiplicity k if $f_{bk}\Delta t$ is the average background multiplicity, and C=86400•2/Δt is the number of trials per day.

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

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validation

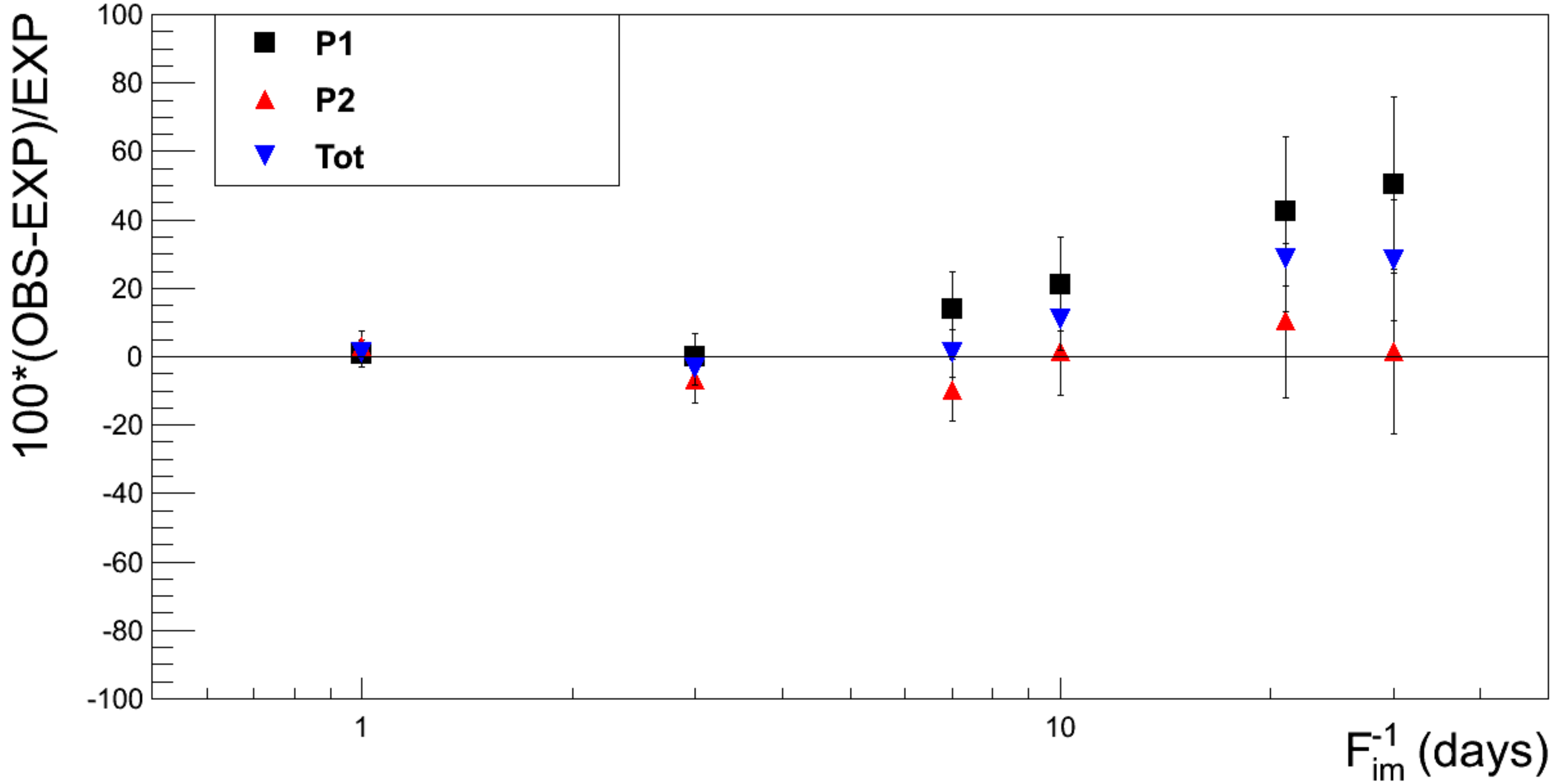

TABLE 2

COMPARISON BETWEEN EXPECTED AND DETECTED CLUSTERS IN THE TWO PERIODS *P1* AND *P2* FOR $F_{im} \leq 1 \cdot \text{day}^{-1}$, $1 \cdot \text{week}^{-1}$, $1 \cdot \text{month}^{-1}$.

	Live time [days]	$F_{im} \leq 1 \cdot \text{day}^{-1}$	$F_{im} \leq 1 \cdot \text{week}^{-1}$	$F_{im} \leq 1 \cdot \text{month}^{-1}$
P1 expected	3696	1166	191	40
P1 detected		1170	213	62
P2 expected	3516	1058	225	34
P2 detected		1091	205	35
P1+P2 expected	7212	2224	416	74
P1+P2 detected		2261	418	97

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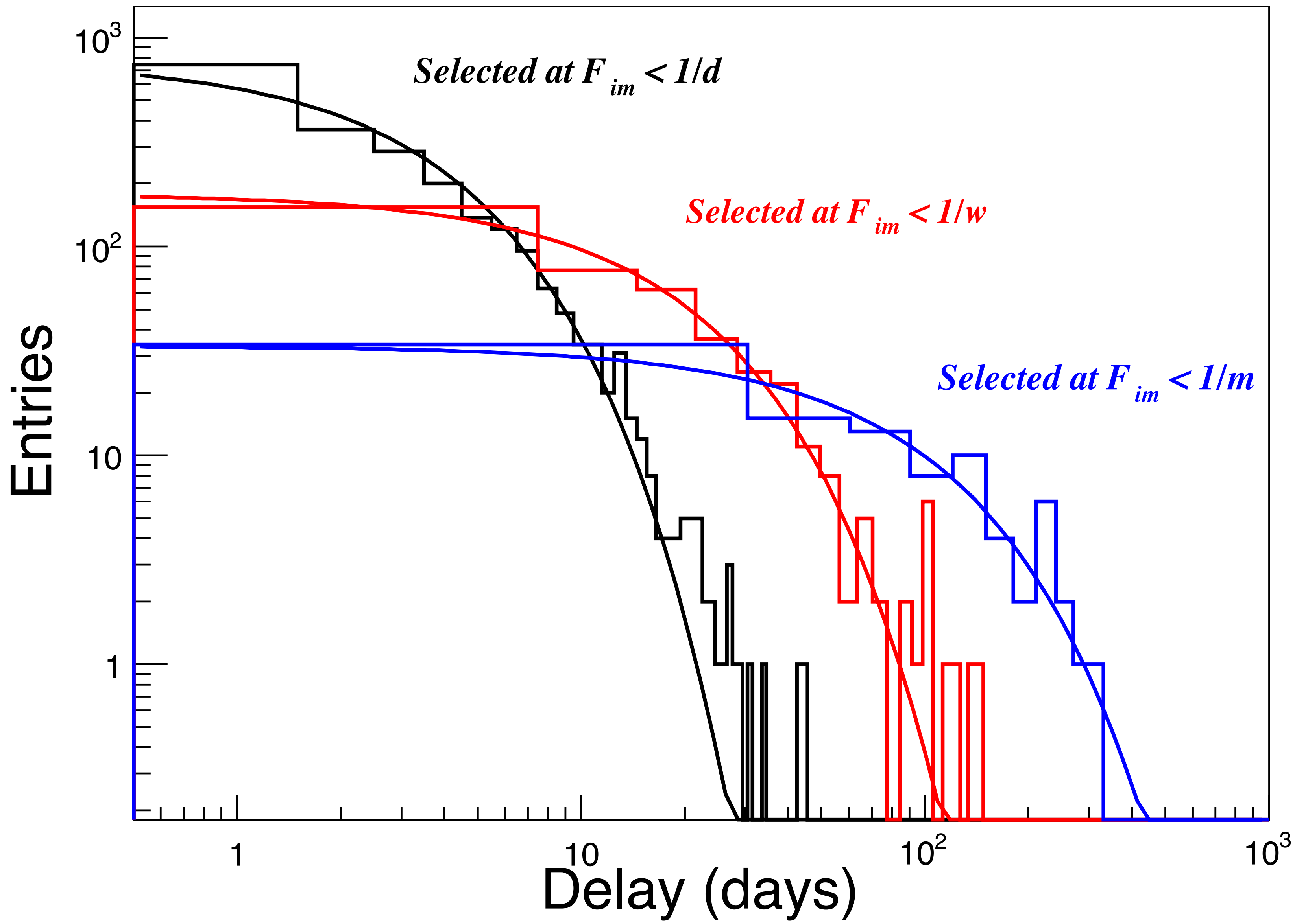
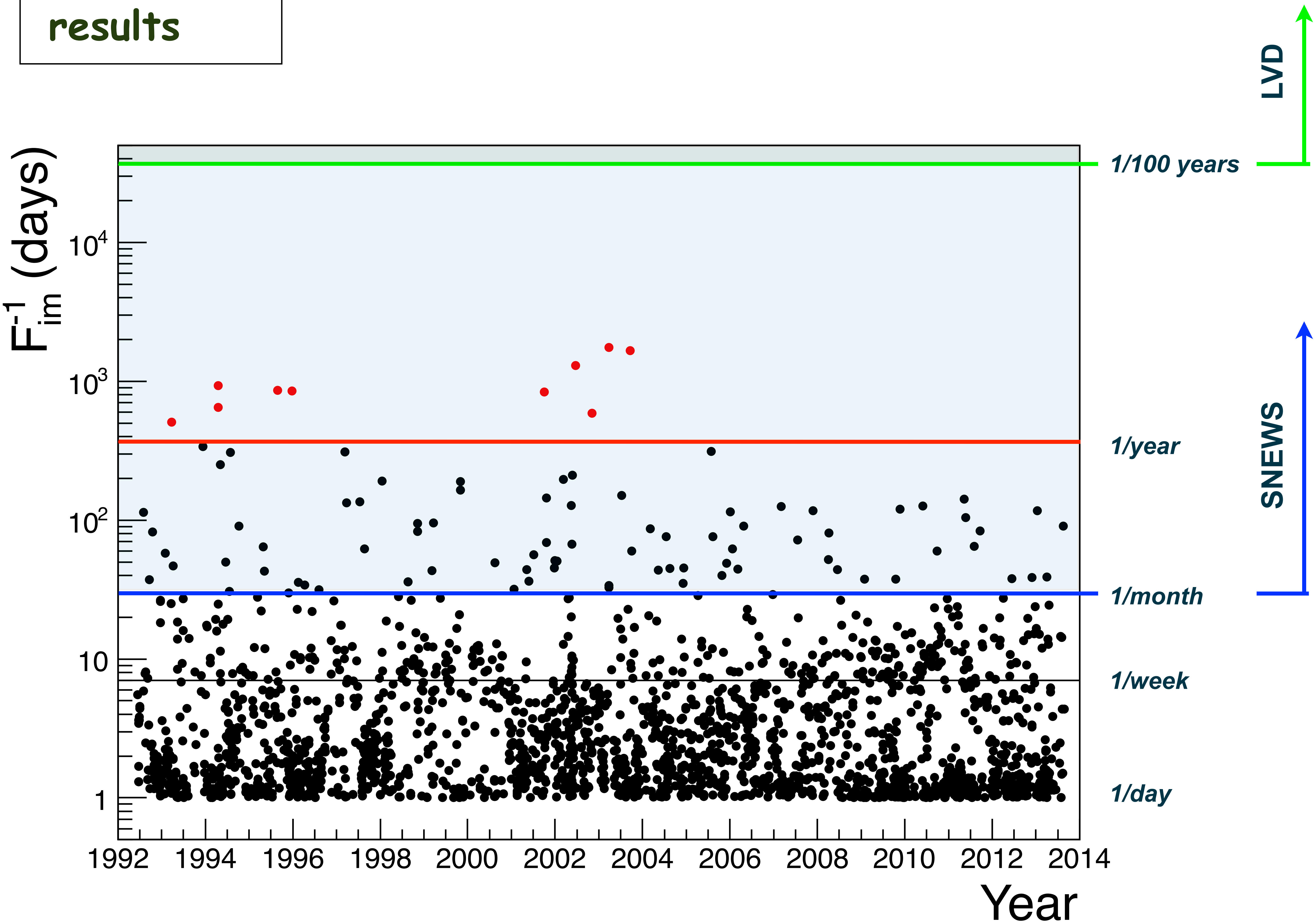
validation

Distribution of the time intervals between observed clusters (histograms) fitted by Poisson laws (lines) for:
F_{im} = 1/day, 1/week and 1/month,
during 7212 days and E_{cut}=10MeV.



results



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10 most significant clusters

TABLE 3

CHARACTERISTICS OF CLUSTERS WITH SIGNIFICANCE $F_{im} \leq 1 \cdot \text{year}^{-1}$

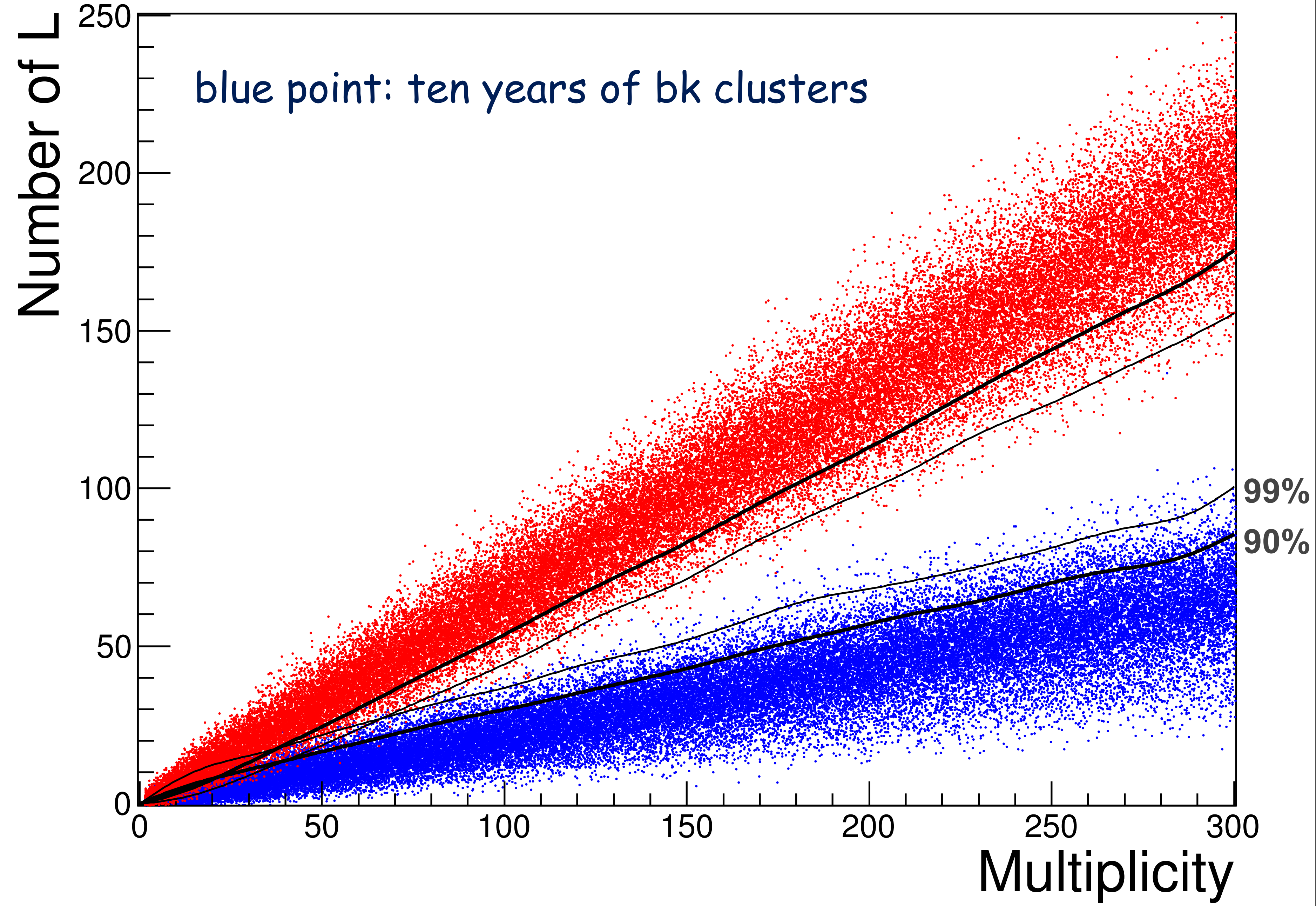
n.	date	$M_{act}[t]$	$f_{bk}[s^{-1}]$	m	$F_{im}[year^{-1}]$	$\bar{E}_{vis}[MeV]$	N_L	S
1	23/03/93	344	$1.21 \cdot 10^{-2}$	6	0.719	26.0	3	0.79
2	15/04/94	346	$1.16 \cdot 10^{-2}$	6	0.566	11.1	1	0.00
3	16/04/94	346	$1.09 \cdot 10^{-2}$	6	0.391	28.6	1	0.80
4	27/08/95	431	$1.85 \cdot 10^{-2}$	7	0.424	36.2	1	0.71
5	24/12/95	498	$1.85 \cdot 10^{-2}$	7	0.431	11.8	1	0.91
6	02/10/01	745	$1.85 \cdot 10^{-2}$	7	0.435	40.4	3	0.99
7	19/06/02	886	$1.74 \cdot 10^{-2}$	7	0.282	16.6	2	0.61
8	03/11/02	886	$1.95 \cdot 10^{-2}$	7	0.617	18.8	3	0.61
9	26/03/03	305	$4.80 \cdot 10^{-3}$	5	0.208	37.5	2	0.00
10	18/09/03	890	$2.54 \cdot 10^{-2}$	8	0.219	13.4	1	0.00

Consistency checks

In the "standard" core collapse SN models, and in all numerical experiments, neutrinos of all flavors are emitted with energy equipartition, at least in the cooling phase.

This implies that almost 90% of the events expected in experiments based on H targets should be due to IBD.

LVD has the capability to identify the signature of this interaction through the detection of the delayed 2.2 MeV gamma resulting from the neutron capture (np,d*) which, in our counters, occurs with a mean delay of 185±5μs with respect to the e^+ signal. $\varepsilon_n \lesssim 50\%$



Two observables can be exploited: the number of delayed low energy pulses and their time distribution with respect to the corresponding trigger.

$S/N = N_L|_s \; / \; N_L|_{bk} = (\langle R_L \rangle \cdot \delta t + 0.88 \cdot \varepsilon_n) / \langle R_L \rangle \cdot \delta t \;\sim 3$

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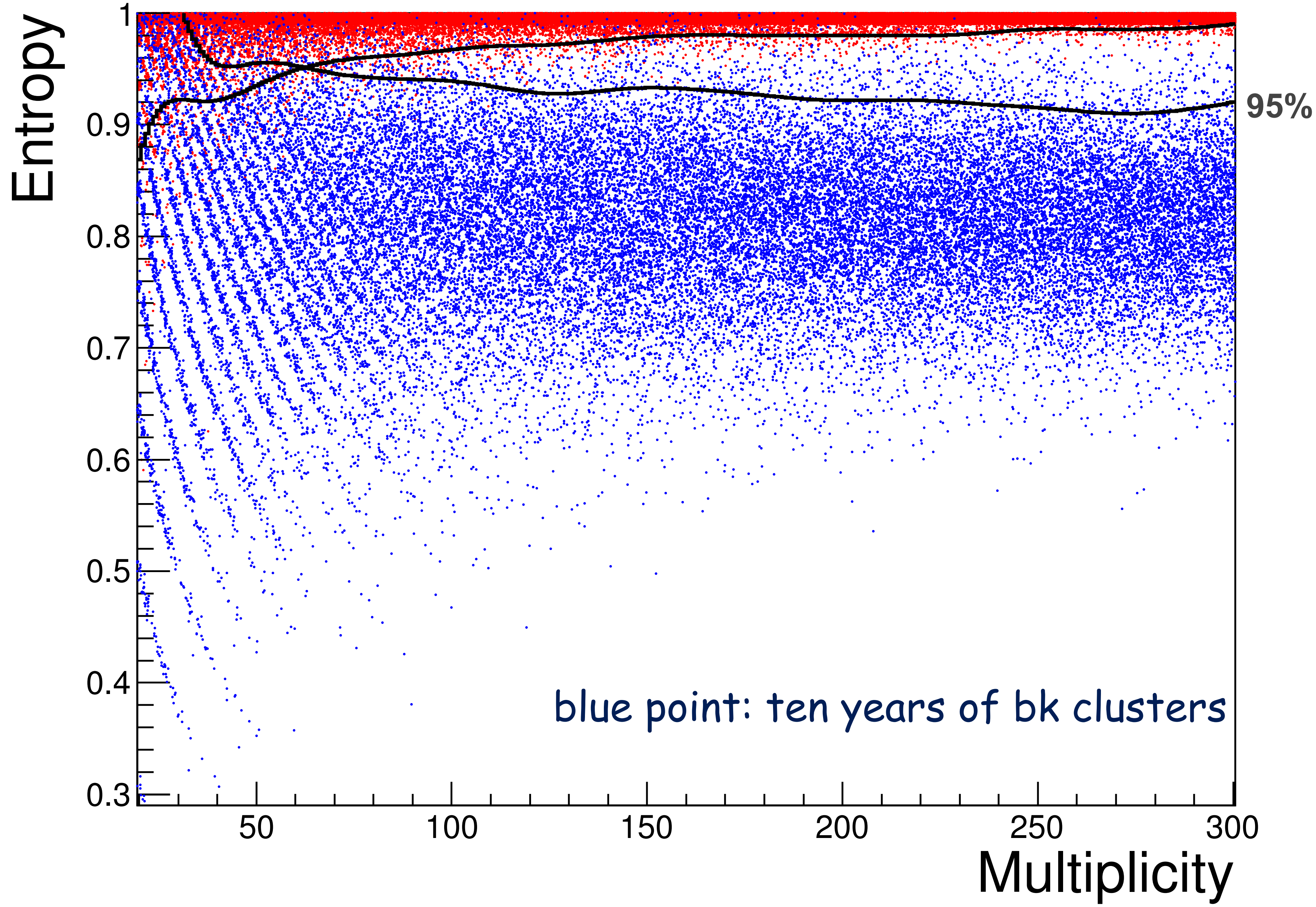
Consistency checks

On average, at the energy threshold of 10 MeV, the core subset of counters (which are ~ 50% of the total) contributes only for about 30% of the total bk counting rate.

This offers a chance to discriminate clusters due to background on the basis of their distribution within the array.

To quantify the uniformity of the cluster under analysis we defined the entropy parameter S as:



$$S = \frac{-1}{log(2)}(R_{\mathrm{int}} \cdot log(R_{\mathrm{int}}) + R_{\mathrm{ext}} \cdot log(R_{\mathrm{ext}}))$$

Fulgione W., Mengotti-Silva N., \& Panaro L., 1996, Nucl. Instr. Meth., A, 368, 512

where:

R_{int} and R_{ext} are the experimental relative fraction of internal and external counters inside the cluster. With: $R_{int} + R_{ext} = 1$

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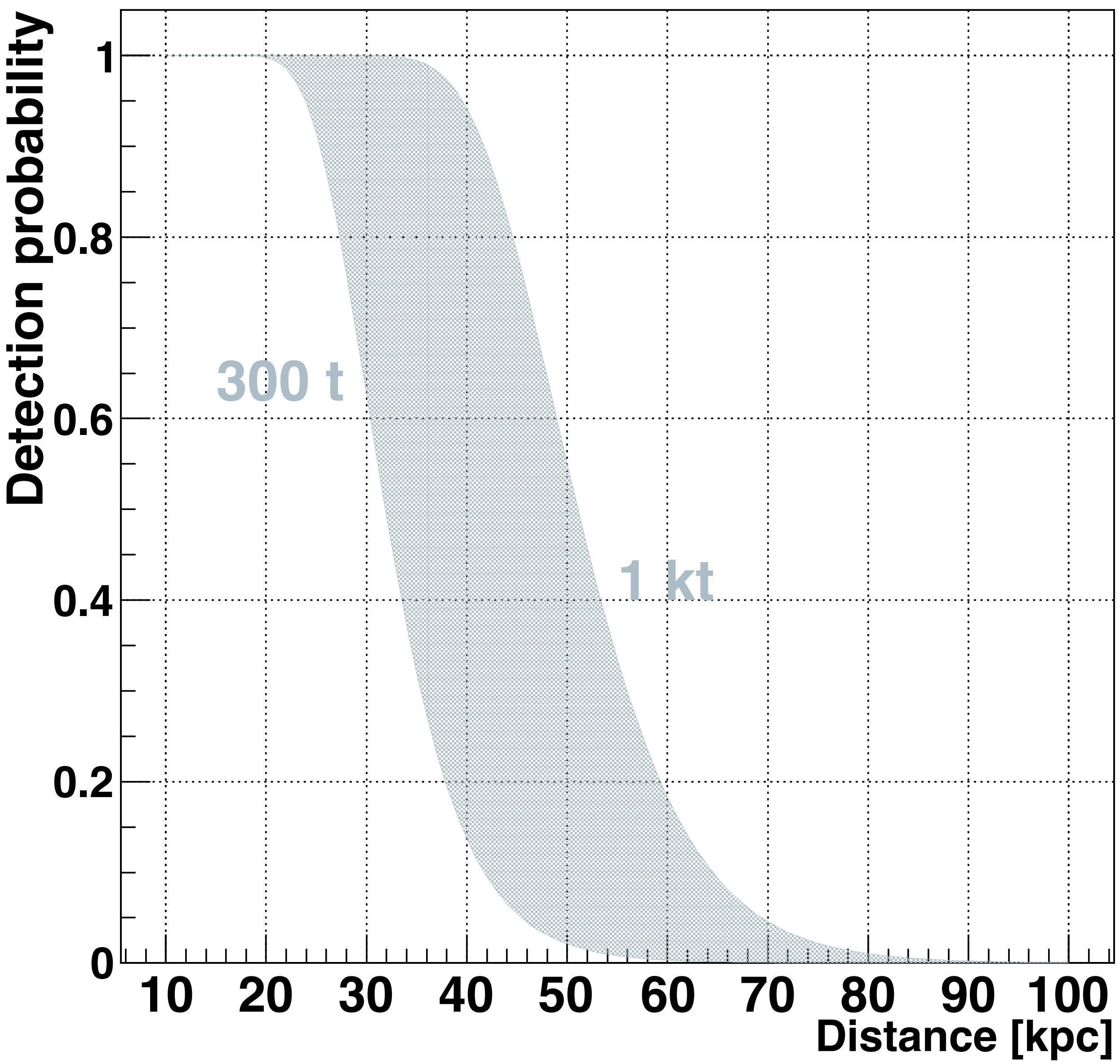
- conclusions -

Results of the analysis of data taken during 7212 days, from 1992 to 2013.

The detector is considered active only if **M_{act}>300 tons**, being, in this way, **fully sensitive to core collapse SN occurring at a distance D≤25 kpc from the Earth.**

No neutrino burst candidate has been detected during the whole period, the corresponding **upper limit on the rate of gravitational stellar collapse, at 90% C.L. is: 0.116 year^{-1}**.

This is the most stringent limit to date achieved by direct observation of the entire Galaxy.



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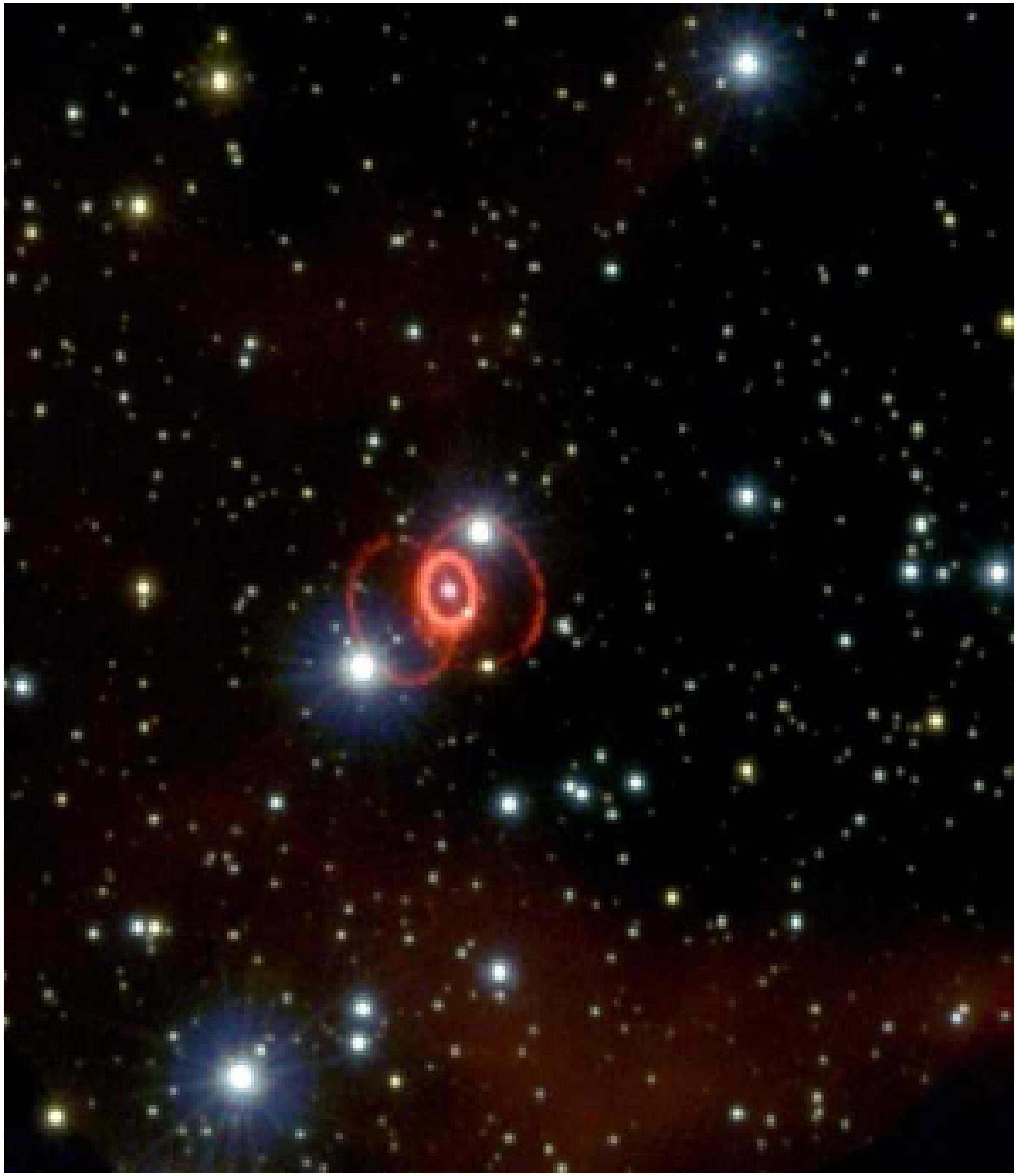

Hubble image

Thank you

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