SEARCH FOR SUPERNOVA NEUTRINO BURSTS WITH THE LARGE VOLUME DETECTOR

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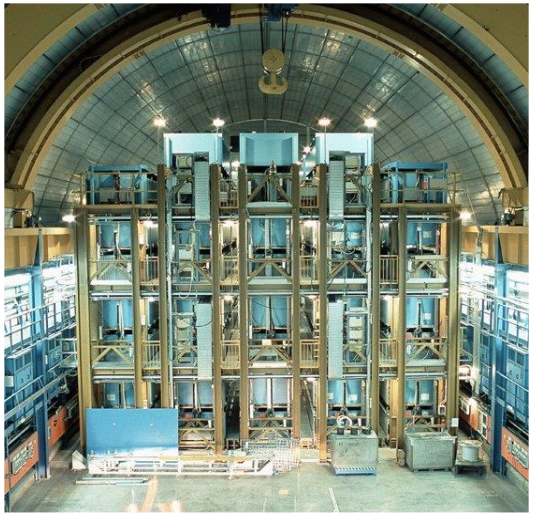
OUTLINE

- The LVD Experiment
- Detector Performances
- Search for Neutrino Bursts
- The Expected Signal & Detector Sensitivity
- Results
- Conclusions

THE LVD EXPERIMENT

- 1000 tons of liquid scintillator @ LNGS
- 840 counters
- Compact & Modular Geometry
- Member of the SNEWS network



- 1.2 ton per counter viewed by three 15” PMTs
- Trigger mode: three-fold coincidence of PMTs of a single counter (H0)
- H0 Energy Threshold : E_H~4 MeV (E_L~0.5 MeV for 1 ms after H0)

NEUTRINO INTERACTION CHANNELS

1-5 on Scintillator (1000 t)

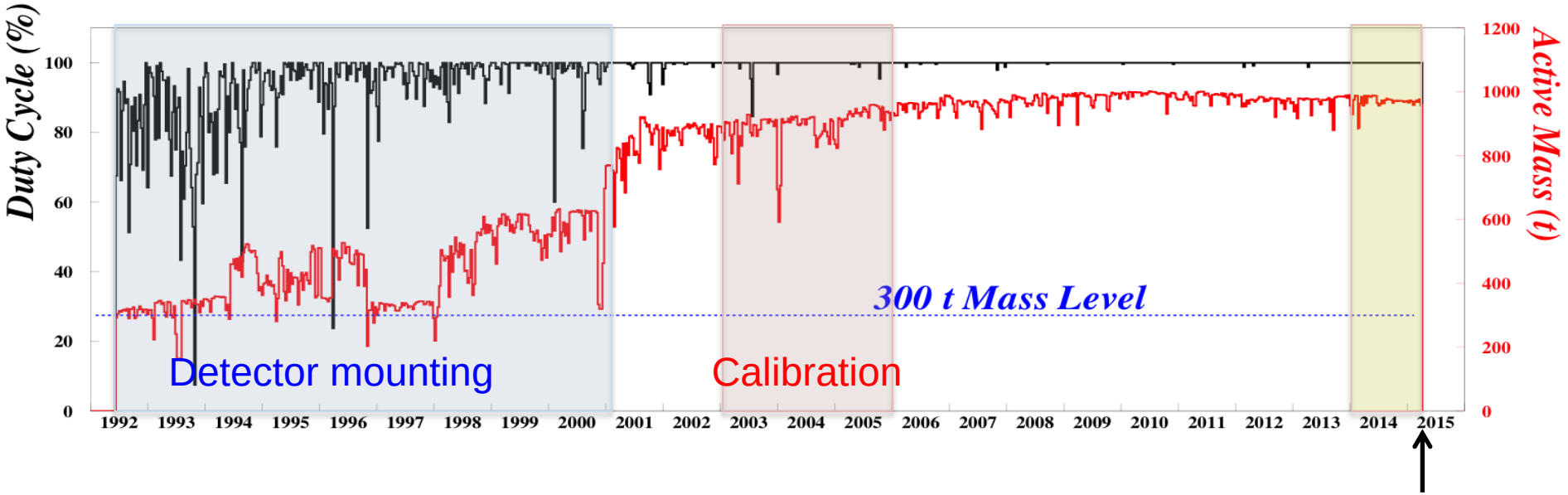
6-8 on Iron Structure (850 t)

	ν Interaction Channel	E_ν Threshold	%
1	$\bar{\nu}_e + p \rightarrow e^+ + n$	(1.8 MeV)	(88%)
2	$\nu_e + {}^{12}C \rightarrow {}^{12}N + e^-$	(17.3 MeV)	(1.5%)
3	$\bar{\nu}_e + {}^{12}C \rightarrow {}^{12}B + e^+$	(14.4 MeV)	(1.0%)
4	$\nu_i + {}^{12}C \rightarrow \nu_i + {}^{12}C^* + \gamma$	(15.1 MeV)	(2.0%)
5	$\nu_i + e^- \rightarrow \nu_i + e^-$	(-)	(3.0%)
6	$\nu_e + {}^{56}Fe \rightarrow {}^{56}Co^* + e^-$	(10. MeV)	(3.0%)
7	$\bar{\nu}_e + {}^{56}Fe \rightarrow {}^{56}Mn + e^+$	(12.5 MeV)	(0.5%)
8	$\nu_i + {}^{56}Fe \rightarrow \nu_i + {}^{56}Fe^* + \gamma$	(15. MeV)	(2.0%)

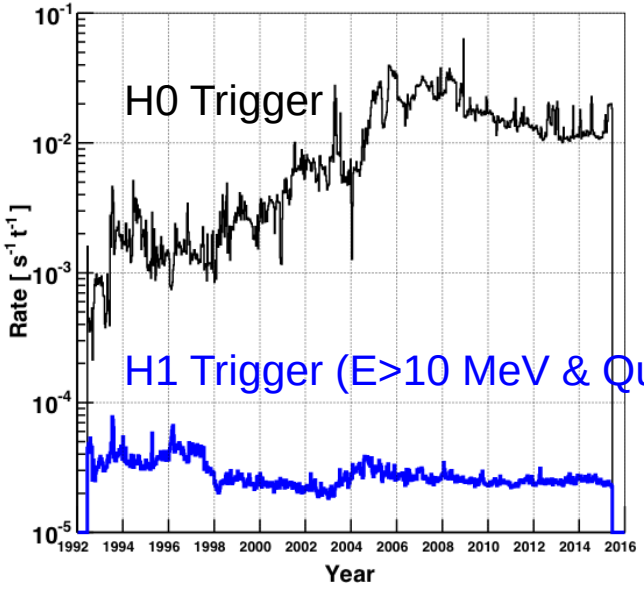
Trigger mode & Energy Thresholds optimized for IBD

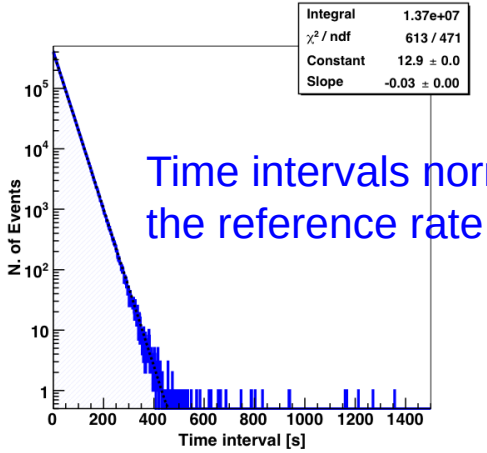
DETECTOR PERFORMANCES

- On line since 1992
- Total livetime 8060 days / 7843 days @ M>300 tons

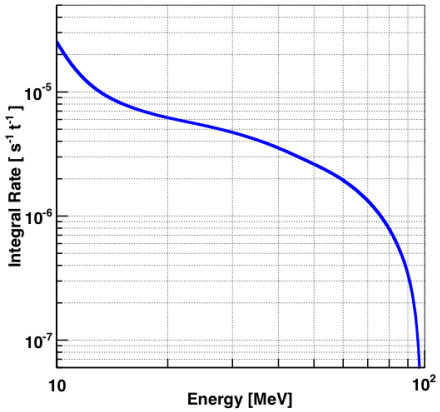


TRIGGER RATES & SPECTRUM





Time intervals normalized to the reference rate f=0.03 Hz



- H0 Trigger ~5 10^9
- H1 Trigger 13722887 -> Time Sequence

SEARCH FOR NEUTRINO BURSTS

- Two step process :

S1) Searching for clusters of events within a time window Δt

S2) Selecting the candidates

- Two methods

M1) On-line / Fixed Time Window $\Delta t=20$ s *APh, 28, 516 (2008)*

PROs: Fast & Reliable CONs: model dependent

M2) Off-line / Variable Time Window $\Delta t<100$ s *NIMPA, 368, 512 (1996) & ApJ, 802, 47 (2015)*

PROs: less model dependent CONs: more complex procedure

THE OFF-LINE METHOD

- S1) Defining the cluster: $m \geq 2$ events initiated by each H1 trigger in the time serie, with $\Delta t < 100$ s

  N_{cls}= 29331397 over 22 years

- S2) Selecting the bursts candidates by its imitation frequency, the statistical significance of the cluster

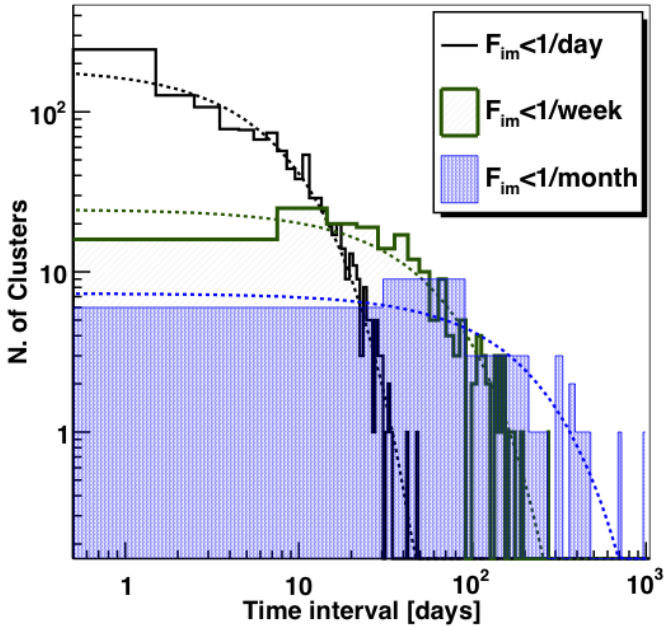
See details in NIMPA, 368, 512 (1996)

$$F_{im} = f_{bk}^2 \cdot \Delta t_{\max} \cdot \sum_{k \geq m-2}^{\infty} P\left(k, f_{bk} \cdot \Delta t\right)$$

$$F_{im} < 1/100\, yr^{-1}$$

MONITORING THE ALGORITHM

- Different value for F_{im} (< 1/day, 1/week, 1/month) allow to monitor the performances , full data set



F_{im}	<1/day	<1/week	<1/month
N_{cls}	1199	179	49

Distributions behave as expected

Algorithm stable & reliable

LVD EXPECTED SIGNAL

- Modelling the neutrino flux for core collapse SN (ccSN)

  Standard ccSN as in Pagliaroli et al. *Aph, 31, 163 (2009)*

  Failed ccSN as in Nakazato et al. *PhRvD, 78, 083014 (2008)*

- Oscillation effects

- Detector response function

→

Expected Signal @ 10 kpc & 1000 t

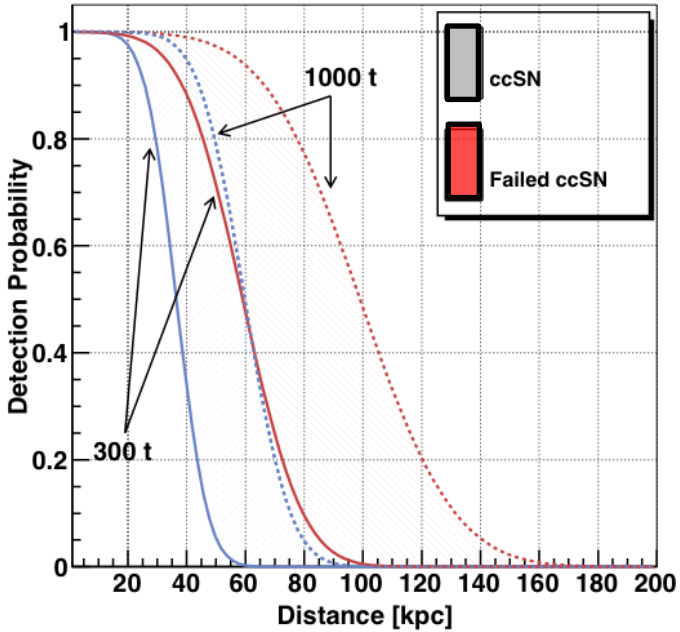
ccSN: 260 events in 10 s

Failed ccSN: 500 events in 360 ms

See details in ApJ, 802, 47 (2015)

LVD SENSITIVITY

Full efficiency in the Galaxy @ M>300 t



RESULTS

- 1992-2015 (May) summary

Livetime: 7843 days @ M> 300 t

H1 Trigger: 13722887

N_{cls} with m≥2 & Δt<100 s: 29331397

No burst canditates @ $F_{im} < 0.01$ yr^{-1}: 6 clusters with $F_{im} < 1$ yr^{-1}

ApJ, 802, 47 (2015)

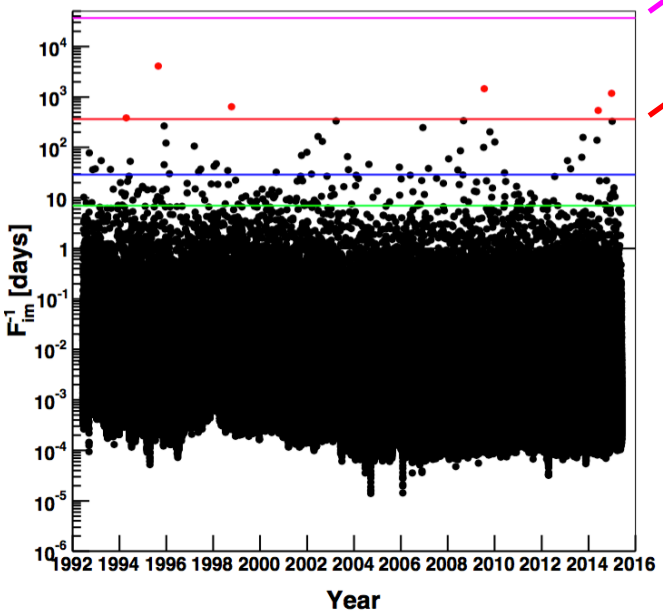
ICRC Update:2014-2015

n.	UTC	$M_{act}[t]$	$f_{bk}[s^{-1}]$	$D_{90\%}[kpc]$	m	$\Delta t[s]$	$F_{im}^{-1}[years]$	$\bar{E}_{signal}[MeV]$	N_L
1	1994 16 April 10:40:49.263	346	$1.08 \cdot 10^{-2}$	29.5	7	18.88	1.06	26.5	2
2	1995 27 August 16:18:10.478	431	$1.85 \cdot 10^{-2}$	35.0	7	5.49	11.16	36.2	1
3	1998 7 October 15:41:41.775	552	$1.40 \cdot 10^{-2}$	30.6	12	90.05	1.76	32.2	3
4	2009 18 July 7:39:20.517	976	$2.40 \cdot 10^{-2}$	40.4	12	42.71	4.02	14.6	1
5	2014 25 May 3:54:14.555	959	$2.78 \cdot 10^{-2}$	36.8	14	61.56	1.49	22.6	4
6	2014 18 December 20:21:28.787	937	$2.33 \cdot 10^{-2}$	45.9	8	9.98	3.22	18.8	3

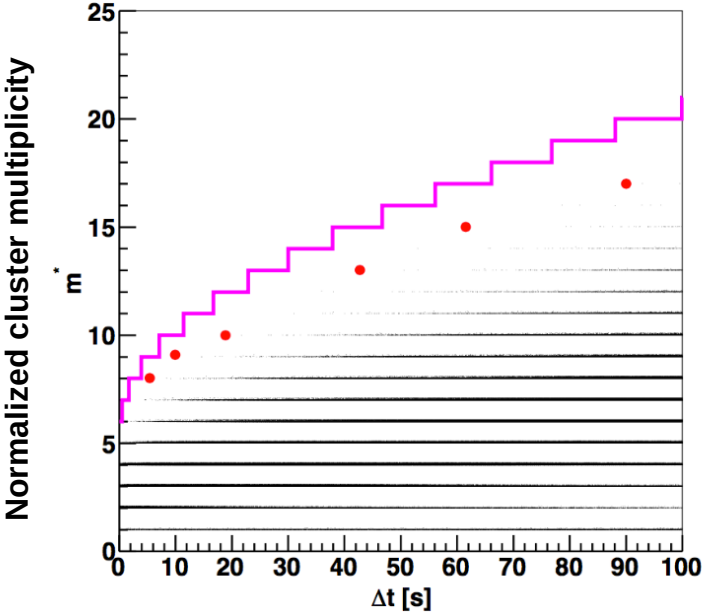
Table 1: Characteristics of clusters with significance $F_{im} < 1 \cdot \text{year}^{-1}$.

Individually checked / Compatible with background fluctuation.

- Fim vs Time



M* vs Δt



No evidence for a neutrino burst from a ccSN over 7843 days

Upper limit 0.11 yr^{-1} (90% c.l.)

CONCLUSIONS

- LVD on-line since 1992
- Full sensitivity to ccSN in the Galaxy in both on-line and off-line mode
- Active member of the SNEWS network
- 1992-2015 data (7843 days) have been analized searching for SN neutrino burst
- No evidence for a signal @ $F_{im} < 1/100\ yr^{-1}$
- Most stringent upper limit ever achieved: $0.11\ yr^{-1}$ @ 90% c.l.