SUPERNOVA NEUTRINOS SEARCH WITH THE LARGE VOLUME DETECTOR

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On behalf of the LVD Collaboration

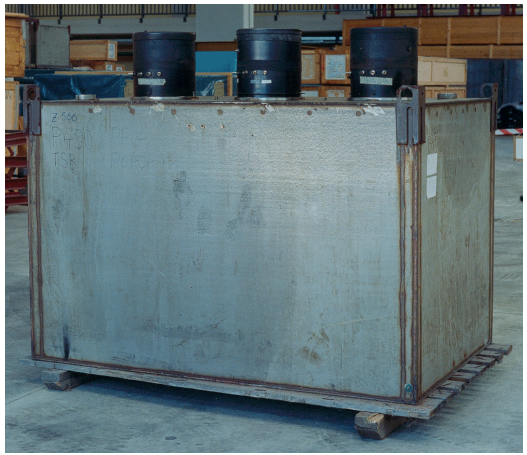
OUTLINE

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

THE LVD EXPERIMENT

Target:1000 tons of liquid scintillator @ LNGS

840 counters in a compact & Modular Geometry



Counter: 1.2 ton viewed by three 15” PMTs

L0 Trigger: three-fold coincidence

Threshold: E_H~4 MeV (E_L~0.5 MeV for 1 ms)

Energy Resolution: 15% @10 MeV

Relative/Absolute Time Accuracy: 12.5 / 100 ns

Calibration: via atmospheric muons (0.1 Hz)

TEV MUON MODULATION

INFN Istituto Nazionale di Fisica Nucleare

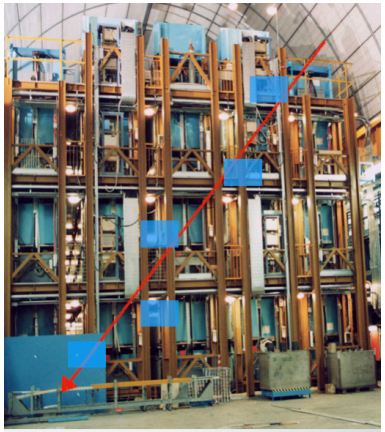
LVD

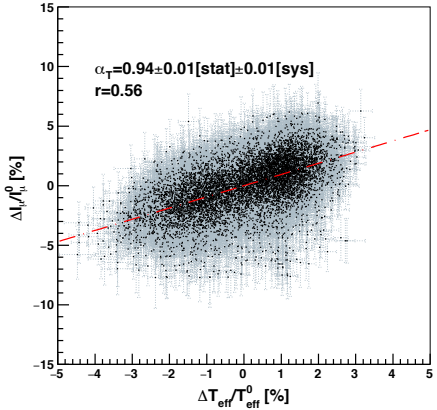
PHYSICAL REVIEW D
covering particles, fields, gravitation, and cosmology

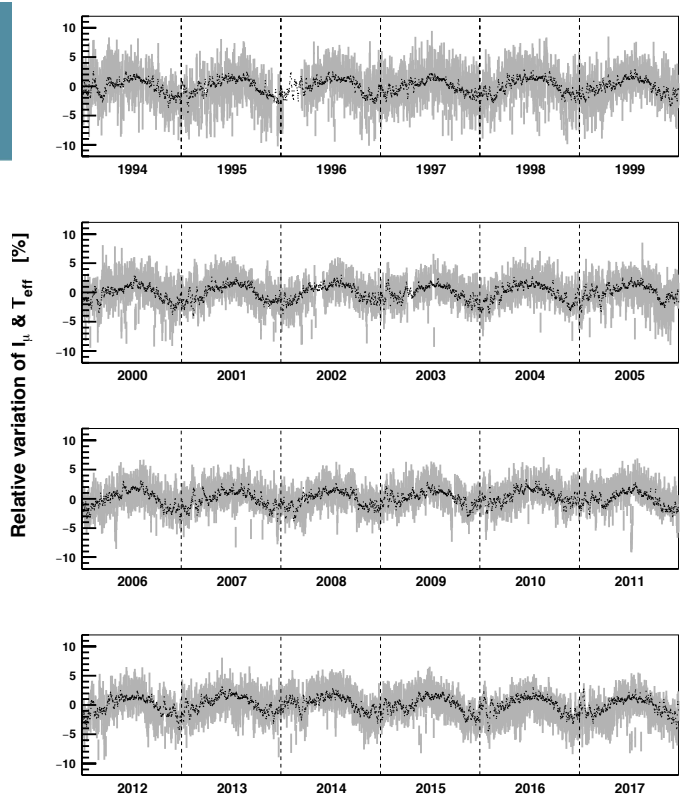
Highlights Recent Accepted Authors Referees Search Press About

Characterization of the varying flux of atmospheric muons measured with the Large Volume Detector for 24 years

N. Yu. Agafonova *et al.* (LVD Collaboration)
Phys. Rev. D **100**, 062002 – Published 19 September 2019



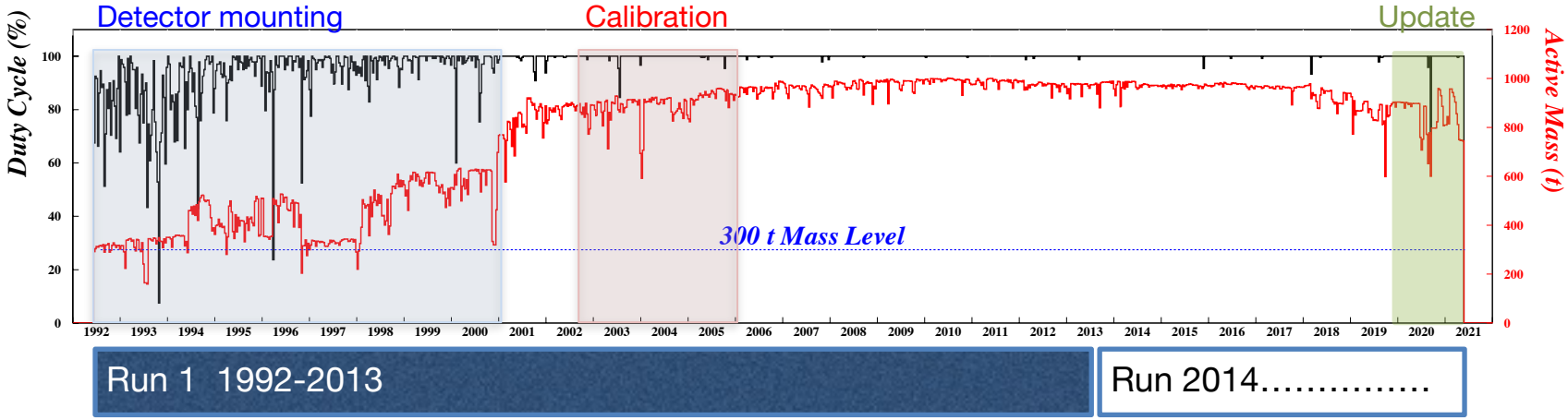




ONLINE ICRC 2021 37th International Cosmic Ray Conference 12–23 July 2021 THE ASTROPARTICLE PHYSICS CONFERENCE BERLIN | GERMANY

DETECTOR PERFORMANCES

- On line since 1992
- Total livetime days 10224 / 10007 days @ M>300 tons



May 5th, 2021

- Decommissioning by the end of 2021

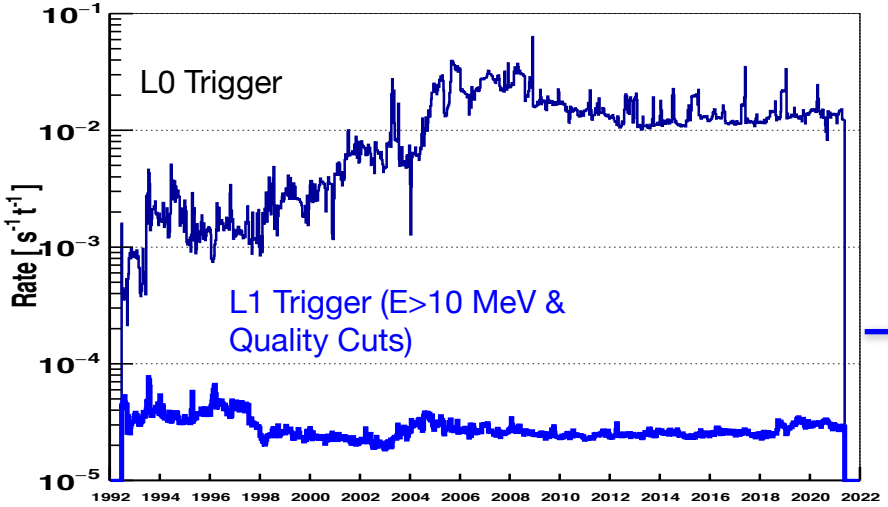
NEUTRINO CHANNELS

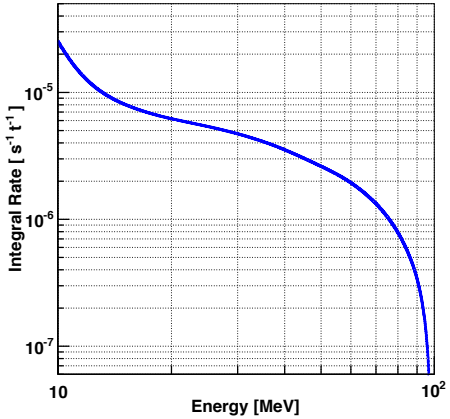
	ν Interaction Channel	E_ν Threshold	%
1	$\bar{\nu}_e + p \rightarrow e^+ + n$	(1.8 MeV)	(88%)
2	$\nu_e + {}^{12}C \rightarrow {}^{12}N + e^-$	(17.3 MeV)	(1.5%)
3	$\bar{\nu}_e + {}^{12}C \rightarrow {}^{12}B + e^+$	(14.4 MeV)	(1.0%)
4	$\nu_i + {}^{12}C \rightarrow \nu_i + {}^{12}C^* + \gamma$	(15.1 MeV)	(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%)

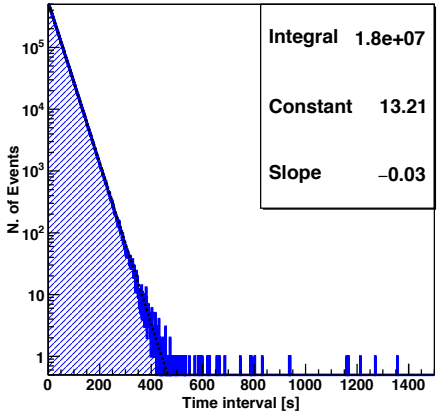
Fraction of events from a CCSN

Trigger mode & thresholds are optimised for the ***IBD*** channel and signals of interactions on ***Fe*** are also expected.

TRIGGER RATES & SPECTRUM







Time intervals normalised to the reference rate f=0.03 Hz (see paper for details)

- L0 Trigger ~ 7.13 10^9
- L1 Trigger 18. 10^6 -> Time Sequence

SEARCH FOR NU-BURSTS

- ***Two Steps Process:***

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

S2) Selecting the candidates

- ***Two Search Methods:***

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

PROs: Fast & Reliable CONs: model dependent

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

PROs: less model dependent CONs: more complex procedure

THE OFF-LINE METHOD

- S1) ***Cluster Selection***: each group of m≥2 events initiated by each L1 trigger in the time series, with Δt<100 s.

  N_{cls}= 3.86 millions of clusters monitored from 1992 to 2021

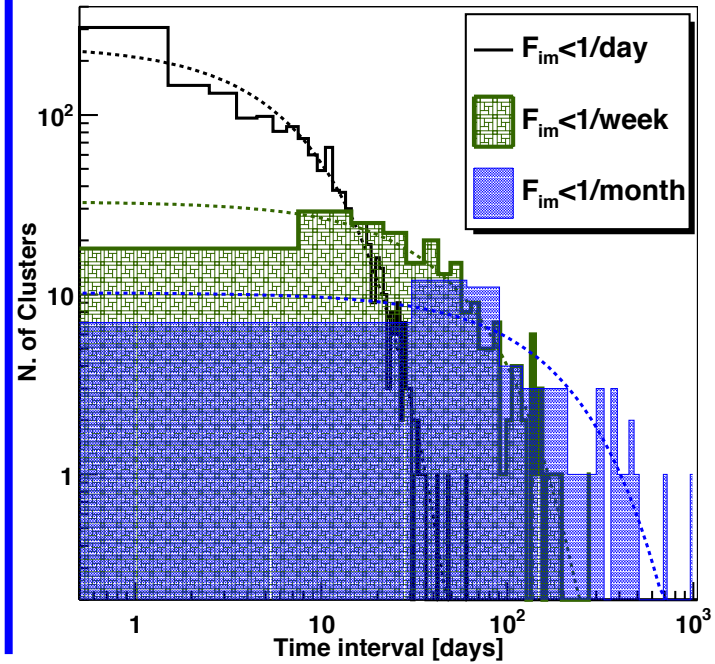
- S2) ***Candidate Selection***: looking at the statistical significance of each cluster, i.e. the F_{im} the imitation frequency

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

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

NIMPA, 368, 512 (1996

MONITORING THE ALGORITHM



F_{im}	<1/day	<1/week	<1/month
N_{cls}	1489	218	60

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)*

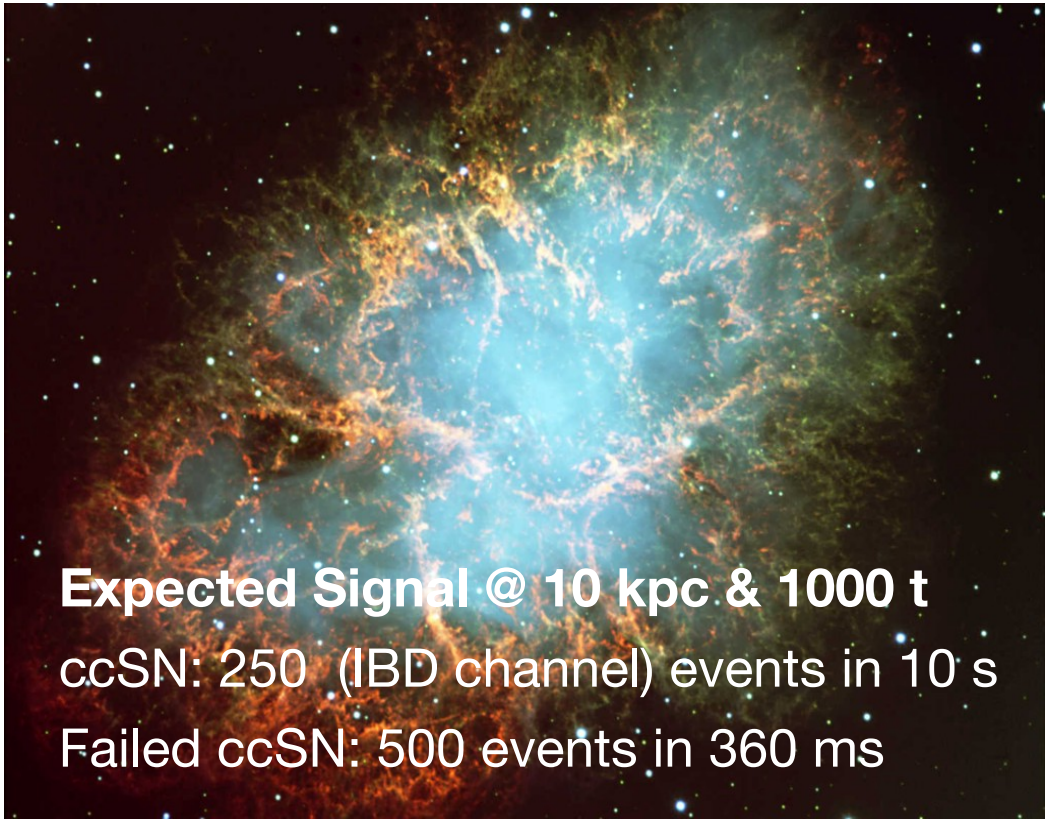
  Failed ccSN as in Nakazato et al. *PhRvD, 78, 083014 (2008)*

- Oscillation effects

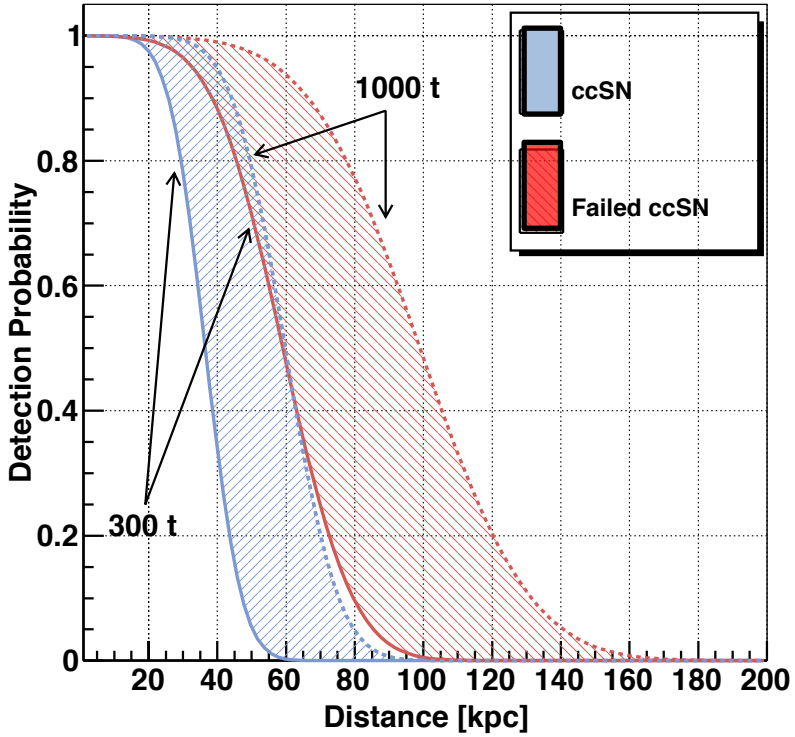
- Detector response function

CCSN Expected Signal @ 10 kpc

Neutrino interaction channels	Expected events
$\bar{\nu}_e + p \rightarrow e^+ + n$	250
$\nu_e + {}^{12}C \rightarrow {}^{12}N + e^-$	15
$\bar{\nu}_e + {}^{12}C \rightarrow {}^{12}B + e^+$	
$\nu_i + {}^{12}C \rightarrow \nu_i + {}^{12}C + \gamma$	
$\nu_i + e^- \rightarrow \nu_i + e^-$	10
$\nu_e + {}^{56}Fe \rightarrow {}^{56}Co + e^-$	25
$\bar{\nu}_e + {}^{56}Fe \rightarrow {}^{56}Mn + e^+$	
$\nu_i + {}^{56}Fe \rightarrow \nu_i + {}^{56}Fe + \gamma$	
Total	300



LVD SENSITIVITY



RESULTS 1992-2021

1992-2021 (May)

Livetime: 10007 days @ M> 300 t

L1 Trigger: 18.2 Millions

N_{cls} with m≥2 & Δt<100 s: 3.86 Millions

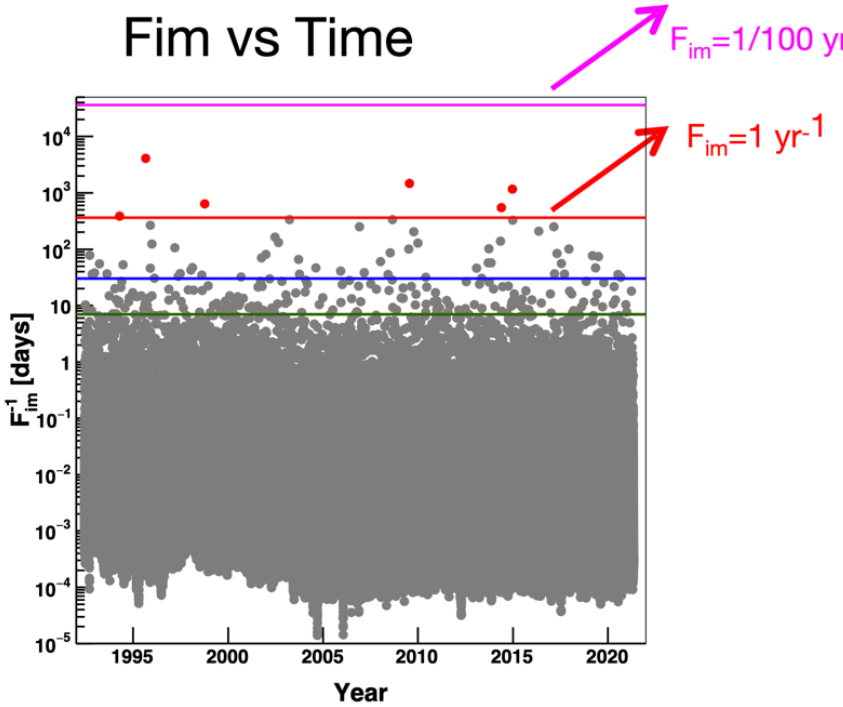
No burst canditates @ $F_{im} < 0.01$ yr^{-1}, 6 clusters with $F_{im} < 1$ yr^{-1}

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

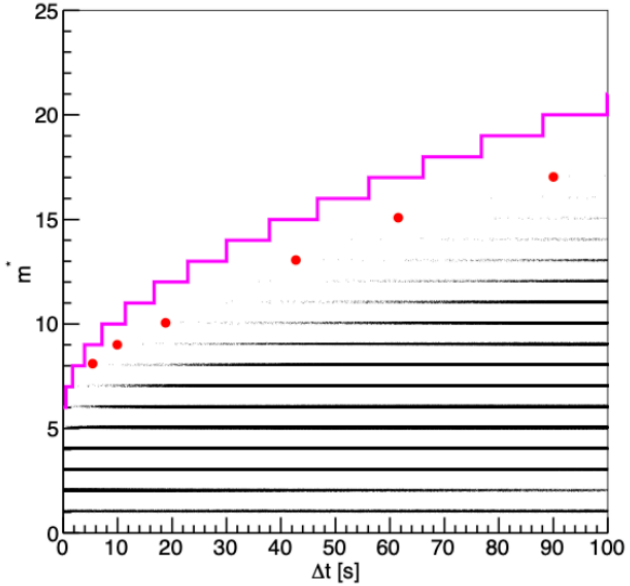
Individually checked / Compatible with background fluctuation

CLUSTER POPULATION

Fim vs Time



M* vs Δt



No evidence for a neutrino burst from a ccSN over 10007 days

Upper limit 0.08 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
- 1992-2021 data (10007 days) have been analised searching for SN neutrino burst with no evidence for a signal ($F_{im} < 1/100\ yr^{-1}$)
- Upper limit: 0.08 yr^{-1}@ 90% c.l.
- Detector decommissioning expected by the end 2021 after almost 30 years of operations at LNGS