Borexino Supernova Alarm System 2.0

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on behalf of the Borexino collaboration

SNEWS 2.0 Workshop
16.06.2019
**Laben DAQ**
Energy range: 200 keV – 20 MeV
+ PSD
+ position reco
*Made for solar ν*

**FADC DAQ**
Energy range: 1 – 50 MeV
+ PSD
+ position reco
*Made for SN-ν*

**Energy:**
5% @ 1 MeV

**Position:**
10 cm @ 1 MeV

**Water tank:**
γ and n shield
μ water
Cherenkov detector
2100 m³
208 PMTs in water

**Scintillator:**
278 t PC+PPO (1.5 g/l)

**Nylon vessels:**
(125 μm thick)
Inner: 4.25 m
Outer: 5.50 m
(radon barrier)

**Stainless Steel Sphere**
6.85 m, 1340 m³
- 2212 8” (ETL 9351) PMTs
- ~1000 m³ buffer of PC+DMP
(light quenching)

*Based on the original picture by A. Brigatti & P. Lombardi*
Borexino SNEWS history
Original design (2009)

- Princeton supernova monitor
- Independent systems
- Online Echidna supernova monitor

It manages all the alarms

SNEWS Server

No information about significance of a burst in Borexino

Borexino has been a member of the SNEWS group since 2009
Borexino SNEWS history
Original design and status

Princeton SN monitor

Based on hardware independent from the Laben and FADC DAQs

- Searching for bursts of neutrons
- Input: analog sum of all ID PMTs
- Active while the PMTs are on
  - Multiplicity ≥ 6
- Δt (subsequent pulses) < 10 s
- Real burst duration ≥ 2 ms
  - Noise cut
  - Working up to now

Online Echidna SN monitor

Online Echidna is a lightweight version of the reconstruction framework

- Searching for bursts of events
  - In 30 s window
  - Multiplicity ≥ 15
- Energy threshold ≥ 500 keV
- Reject muons and neutrons
- Partly tested (offline mode)
  - Not commissioned
Borexino SNEWS history
Current status (2019)

Only one SN monitor (Princeton) is alive

No information about significance of a burst in Borexino
Borexino SNEWS 2.0 (2019)

- Outer Pre-SN trigger
- FADC SN monitor
- New Online Echidna SN monitor
- FADC data checking
- Laben data checking
- SNEWS and other alarms checking
- To GCN/TAN NASA

Princeton SN monitor + Borexino Server Brain

SNEWS 2.0 Server
What is expected? One of the possibilities

GCN/TAN NASA

SNEWS 2.0
network & framework

Standard SNEWS

Low threshold SNEWS

GWNU Online

GWNU Offline

Presupernova neutrino triggers

…

Common Database
The False Alarm Rate (FAR or the Imitation Frequency) is a number of accidental background fluctuation above the SN detection threshold per year.

The joint FAR is a number of accidental coincidence of detector signals in the network where $t_{\text{coin}}$ is a coincidence window between GW and neutrino signals in which the correlation is looked for.

Conservative approach: $t_{\text{coin}} = 10$ s, whereas in some paper it's in order of tens ms [1]. The factor "2" is due to unknown time order of signals.

$$FAR_{\text{joint}} = \prod_{i=1}^{N} FAR_i \times \left(2t_{\text{coin}}\right)^{N-1},$$

where $t_{\text{coin}}$ is a coincidence window between GW and neutrino signals in which the correlation is looked for.

Let's choose the joint FAR of 1 cluster/1000 yr and the GW subnetwork FAR of 1 cl/1 month.

\[
FAR_{\text{joint}} = \frac{1 \text{ CL}}{1000 \text{ YR}} = \]

\[
= FAR_{\text{GW}} \times FAR_{\text{LVD}} \times FAR_{\text{IceCube}} \times FAR_{\text{BX}} \times (2t_{\text{coin}})^3
\]

Assuming the same FAR per each neutrino detector:

\[
FAR_{\nu} \sim 2 \times 10^{-3} \text{ Hz} \sim \frac{1 \text{ CL}}{10 \text{ MIN}}
\]

If there is only one detector it's necessary to stay at very low value of \(FAR_i\) in order to be statistically significant.

The value equals 1 cl/100 yr in the LVD paper [2].

Parameters of $\nu$ bursts selection

In case of counting detectors like Borexino, LVD, KamLAND, JUNO

Type of the event bursts:  
- a) burst consisting of single events
- b) burst of the IBD events

Type of the burst window:  
- a) fixed (static) time window
- b) fixed time windows with shifts  
  (duration - 20 s, start shift - 10 s)
- c) dynamic (every event is a starting point)

Multiplicity:  
- a) based on the signal/background ratio
- b) based on the significance (FAR)

Well-developed approaches:


According to the LVD article [3] the technique implies for JUNO-like detectors:

- the search for a burst of events within a fixed-duration time window \( \Delta t = 20 \text{ s} \)
- each burst is characterized by duration \( \Delta t \) and multiplicity \( m_i \)
- each data period \( T \) is divided into \( N = 2 \frac{T}{\Delta t} - 1 \) intervals, each one starting in the middle of the previous one
- as a result the unbiased time window is 10 s
- calculation of average background \( f_{bk} \) for each period of measurements under constant conditions (trigger levels, purity,...)

Note: Every \( \nu \) - candidate is considered as a background event

- each burst is associated with FAR which is based on the Poisson distribution:

\[
FAR(m, f_{bk}, 20 \text{ s}) = 8640 \cdot \sum_{k \geq m} \frac{1}{k!} \left( 20 \cdot \frac{f_{bk}}{s^{-1}} \right)^k \frac{ek}{day}
\]

BX SNEWS: ν event bursts selection

Lower multiplicity \( m \) \( \rightarrow \) higher False Alarm Rate

\[
FAR = 8640 \sum_{k=m}^{\infty} \frac{(f_{bk}\Delta t)^k e^{-f_{bk}\Delta t}}{k!}
\]

1 fake burst per day
1 fake burst per \(~2.7\) years
Mean bkg: \(~0.025\ s^{-1}\)
1 fake burst per \(~2.7\) kyears
1 fake burst per \(~2.7\) Myears

For Borexino
Simulation

Goals:
• Verification techniques and tools
• The efficiency of the coincidence search depending on the distance to the supernova and the number of detectors in the network

How? By inserting the generated signals into real data

SN models (penalty: model-dependent efficiency):
1) Pagliaroli’s approach: reproduce SN1987A signal, taking the main parameters from the analysis
2) Lawrence Livermore model (characteristics similar to SN1987A)
3) One of the most conservative assumptions producing the lowest flux
4) “Optimistic assumption”: lots of neutrinos with rising energy
Possible data format

Two types of data lists for each detector

The first type: for the coincidence search itself

<table>
<thead>
<tr>
<th>GPS time of the burst start, seconds, precision 1 s</th>
<th>FAR, events/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>562392268</td>
<td>2199.78</td>
</tr>
<tr>
<td>562392288</td>
<td>652.72</td>
</tr>
<tr>
<td>562392308</td>
<td>5377.14</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
### Possible data format

Two types of data lists for each detector

The second type: for further investigation *in case of LVD, Borexino, KamLAND, JUNO*

<table>
<thead>
<tr>
<th>multiplicity</th>
<th>FAR, events/day</th>
<th>GPS start time, seconds</th>
<th>GPS start time, nanoseconds</th>
<th>duration, seconds</th>
<th>Real duration, seconds</th>
<th>Parameter $\xi$, events/second</th>
<th>mean energy, MeV</th>
<th>after muon event</th>
<th>energy, MeV</th>
<th>time, us</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>652.71</td>
<td>562389708</td>
<td>226221964</td>
<td>20.000</td>
<td>18.436148</td>
<td>0.16</td>
<td>1.49</td>
<td>0</td>
<td>0.94</td>
<td>504194.836</td>
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<td>1.59</td>
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<td>18940342.891</td>
</tr>
</tbody>
</table>

See also the GWNU poster
Conclusions and proposals

- Borexino SN Alarm System 2.0 is in progress
- The new design is quite flexible and independent from the design of the SNEWS server
- Looking for manpower for simulations

Next milestones:
- SNEWS 2.0: general framework and network uniting various experiments
- SNEWS 2.0 and/or GWNU MoU
- The low threshold analysis and sky localization
Thank you for your attention!
Backup slides
Current situation

SNEWS

under revision

GWNU WG Activities

GWNU analyses

Offline
Based on “archival data”

ongoing

Online
Low latency

MoU in progress!

NEW study!

proposed in 2010/2013, MoU since 2015
Current NU experiments in SNEWS:
- LVD
- IceCube
- KamLAND
- Borexino
- Super-K
- Daya Bay
- HALO

GW experiments:
- LIGO
- VIRGO

GWNU

Other experiments in GWNU:
- NOνA
- JUNO

Perspective experiments in GWNU:
- KM3NET
- XENON1T
- MicroBooNE
Detection efficiency study (simplified)
By Claudio Casentini and Giulia Pagliaroli

Simulation of background for Borexino, KamLAND and LVD; statistics – 1 month
Simulation and injection 50 signals per distance using the Pagliaroli model [4]
Energy thresholds: Borexino, KamLAND – 1 MeV, LVD – 10 MeV
Detection channel: IBD
After clusterization three cases were considered: 1, 2 and 3 detectors in the neutrino network with the Joint False Alarm Rate $R_{Joint}$ at 1 ev/day:
   a) Network of one detector: $R = 1$ ev/day
   b) Network of two detectors: $R = 66$ ev/day
   c) Network of three detectors: $R = 265$ ev/day
Burst selection according to the required FAR
Simplified mode: no coincidence search was made
For each distance the average efficiency of any detector in the network:

$$< \eta > = \frac{1}{10000} \sum_{i=1}^{10000} \frac{\text{the number of recovered signals (i)}}{\text{the number of injected signals (i)}}$$

Borexino efficiency
By Claudio Casentini and Giulia Pagliaroli

- Single detector
- Network of two detectors
- Network of three detectors

Events recovered vs. Distance [kpc]

- Large Magellanic Cloud
- Small Magellanic Cloud
- Galactic edges
LVD efficiency
By Claudio Casentini and Giulia Pagliaroli

- Single detector
- Network of two detectors
- Network of three detectors

Graph showing the number of events recovered vs. distance (D[kpc]).

- Galactic edges
- Large Magellanic Cloud
- Small Magellanic Cloud
KamLAND efficiency
By Claudio Casentini and Giulia Pagliaroli

![Graph showing the number of events recovered with different detector configurations and distances to different cloud edges. The graph includes data for Single, Two detectors, and Three detectors. The x-axis represents distance in kiloparsecs (kpc), and the y-axis represents the number of events recovered. The graph shows data points for the Large Magellanic Cloud, Galactic edges, and Small Magellanic Cloud.]