Search for Supernova Bursts with the AMANDA Neutrino Telescope

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The AMANDA collaboration

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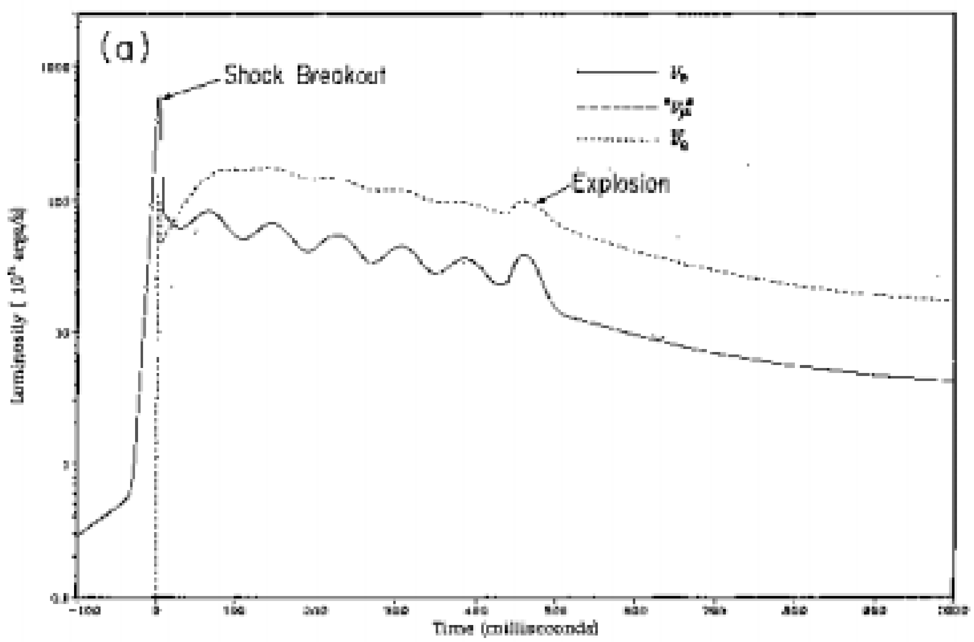
Dept. of Physics, University of Wuppertal, Germany
Mainz University, Mainz, Germany
South Pole Station, Antarctica

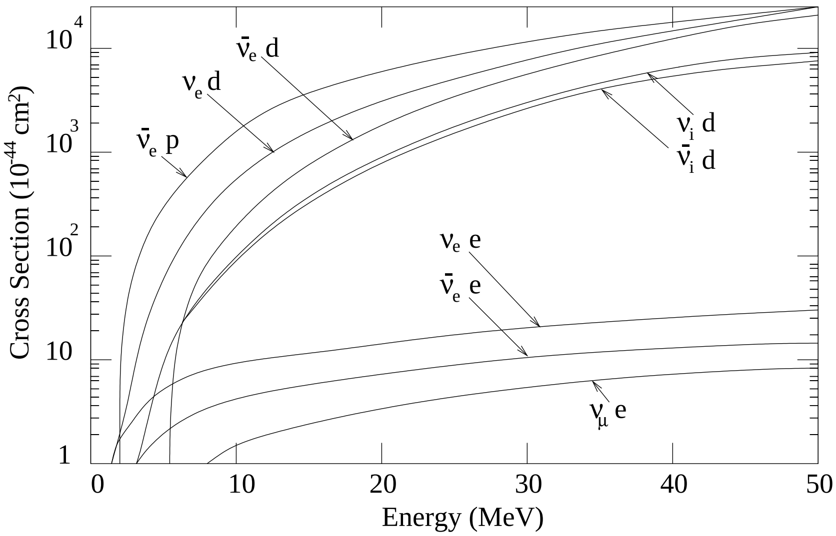
AMANDA operated as a counting rate detector

Neutrino burst from Supernova lasts $\sim$ 10 secs. Rise-time of signal $\sim$ ms.

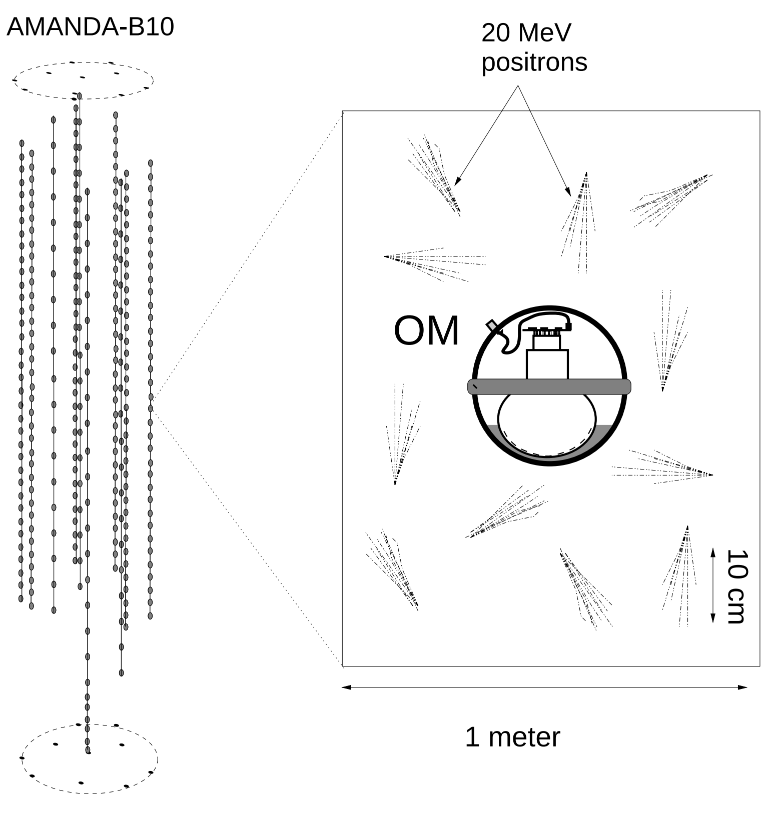


([Burrows Phys Rev D '92])

All flavors of ν contribute, but $\bar{\nu_e}$ dominant (largest cross-section). $\bar{\nu_e} + p \rightarrow n + e^+$.



$$kT_{\bar{\nu_e}}^{Fermi-Dirac} \sim 4 \text{ MeV} \Rightarrow \langle E_{e^+} \rangle \sim 20 \text{ MeV}.$$



Supernova neutrino burst detection

$\sim$ 12 cm positron tracks $\rightarrow$ $\sim$ 3000 Cherenkov photons$/e^+$

A supernova should yield a significantly increased counting rate for the **whole** array (but no reconstruction of individual events is possible).

Ice is a very quiet medium: no K^{40},no bioluminescence.

No energy threshold.

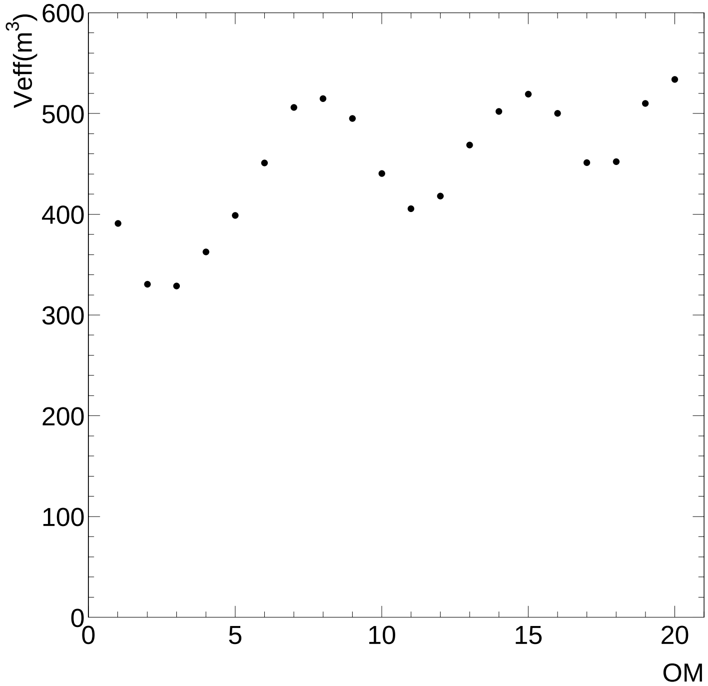
Signal: excess photon counts due to neutrinos

Effective volume $V_{eff} \propto L_{absorption}$. For AMANDA-B $V_{eff} \sim 400\mathrm{m}^3$ per OM.

The predicted number of photons is:
$N \sim 11 \cdot N_{OM} \cdot \left[\frac{\rho \cdot V_{eff}}{2.14kton}\right] \left[\frac{52\mathrm{kpc}}{d_{\mathrm{kpc}}}\right]^2$
(*cf.* Halzen *et al Phys. rev. D* **49**, 1994)

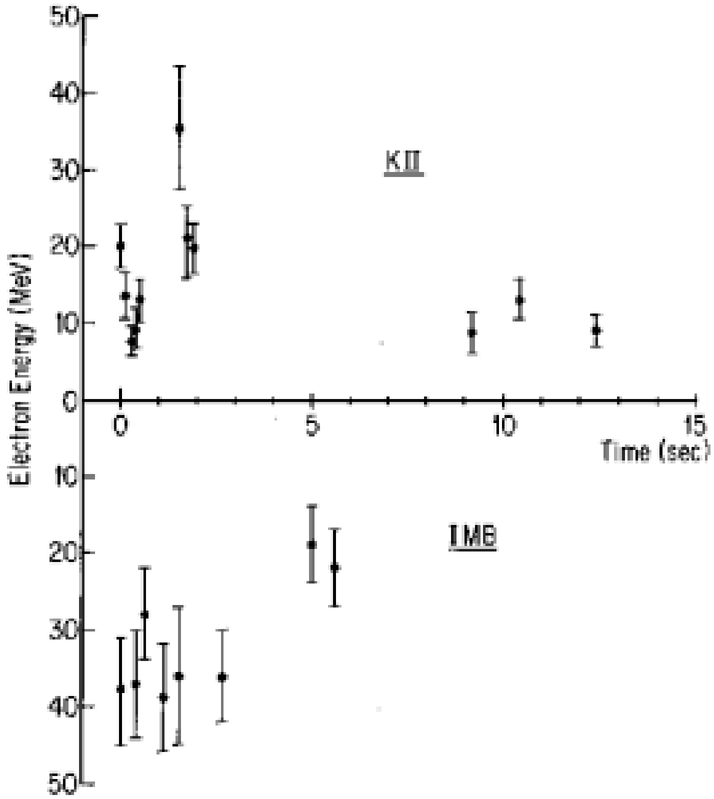
For a SN1987A-like supernova at 8 kpc (center of the Galaxy), we expect $\sim$ 100 counts/OM in 10 sec.

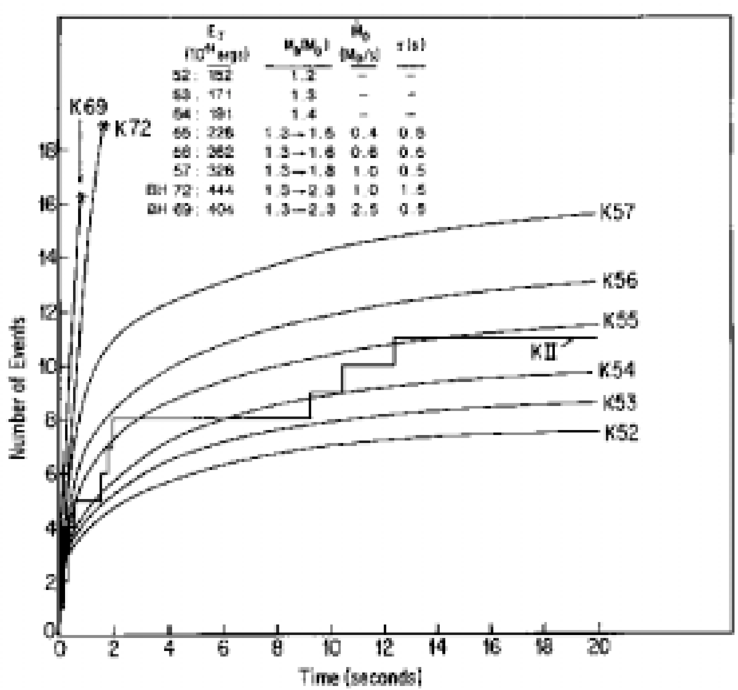
Effective Volume



SN1987A in the LMC (∼52 kpc)

([Burrows Ap.J. '88])





The background: OM dark noise

If the dark noise from the OMs is purely Poissonian, the fluctuation of the noise summed over the whole array is:

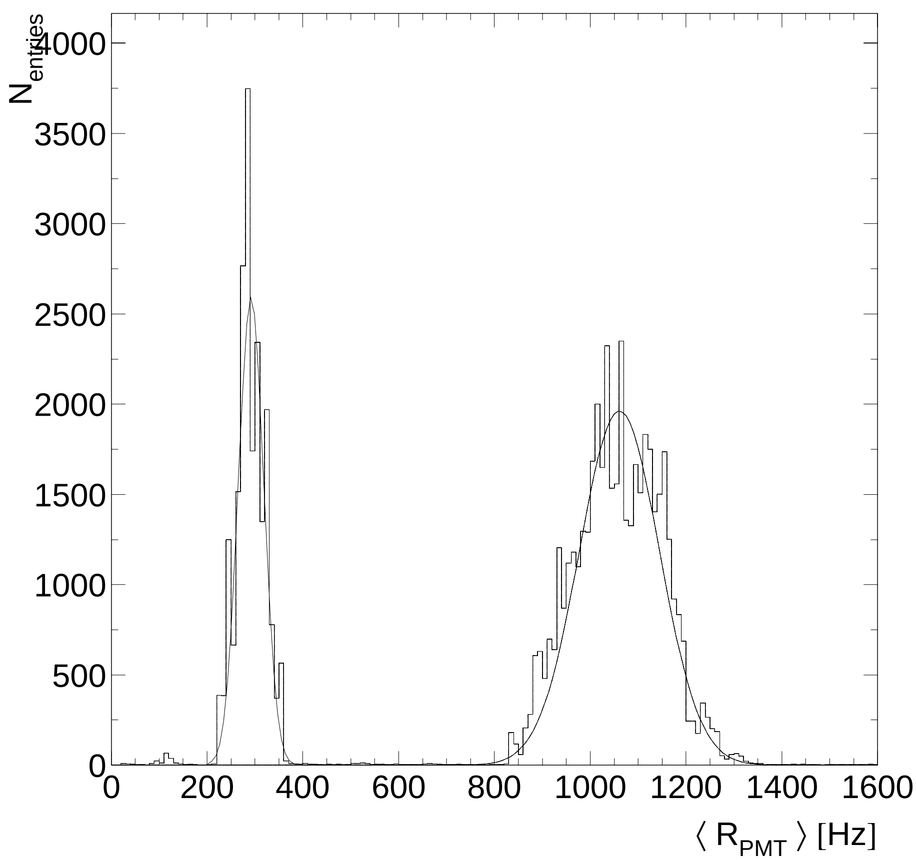
$$\sqrt{10\text{sec} \cdot R_{noise}[Hz] \cdot N_{OM}}$$

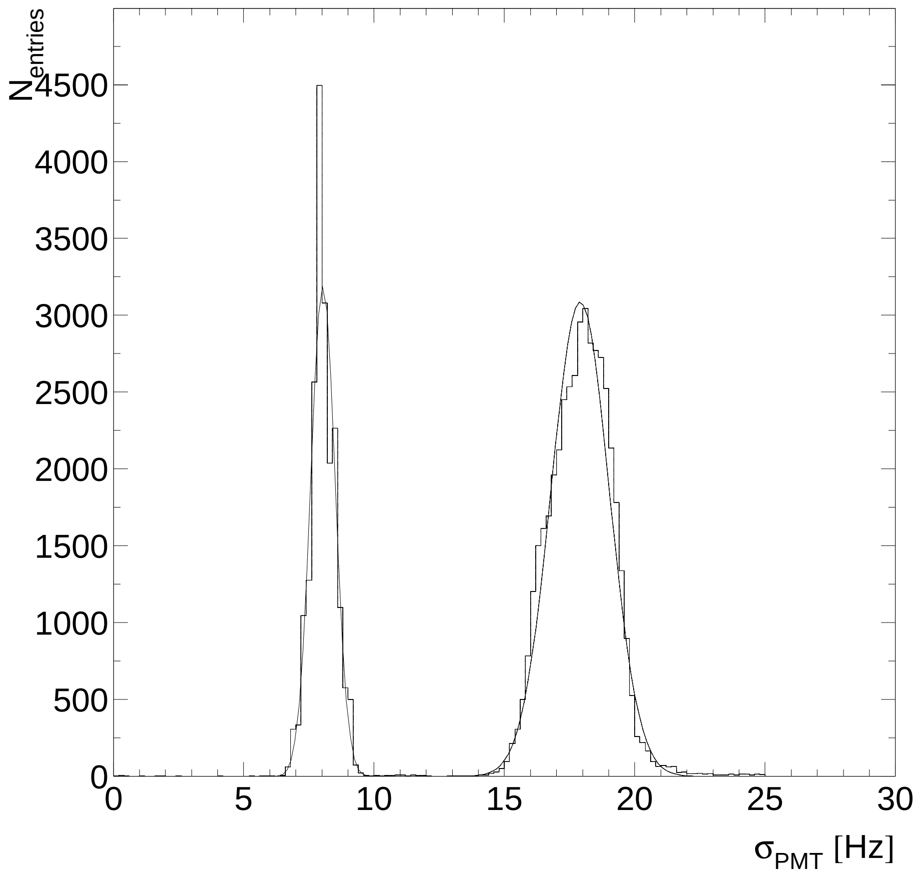
An effect of at least 6σ is needed in order to get $\mathcal{O}(1\text{fake}/100\text{y})$.

OM behaviour and data cleaning

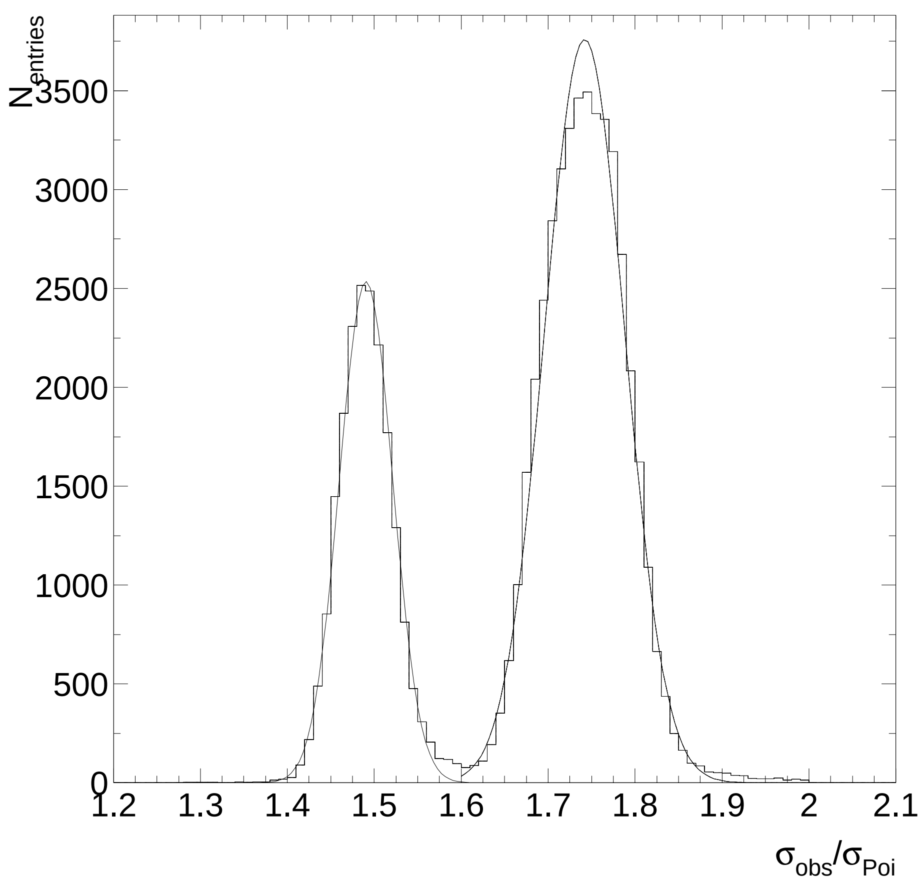
For AMANDA-B, $\sigma_N/\sigma_{Poisson}$ is $\sim 1.6 - 1.8$ in spite of afterpulse suppression. The dark noise is not Poissonian, but still very Gaussian.

(OMs on strings 1-to-4 have ~ 300 Hz and OMs on strings 5-to-10 have ~ 1160 Hz)





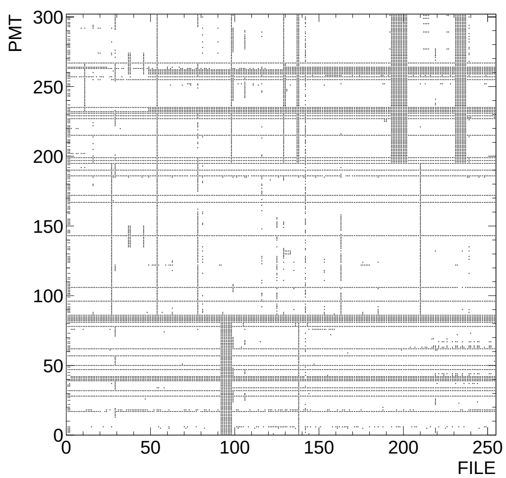
N_entries
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
σ_PMT [Hz]

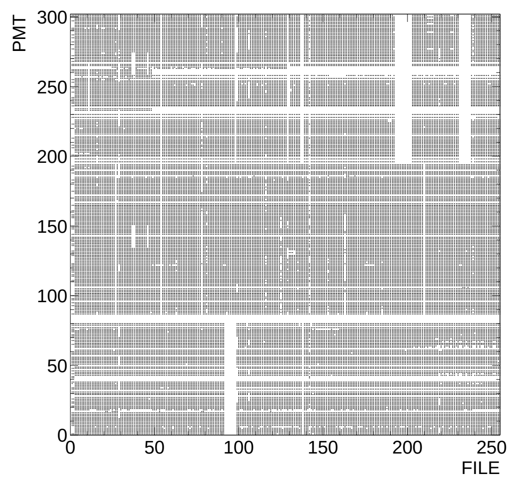


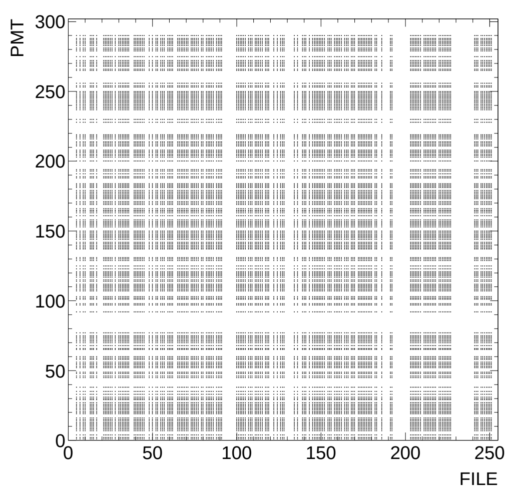
N_entries
3500
3000
2500
2000
1500
1000
500
0
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
σ_obs/σ_Poi

The different sub-detectors (AMANDA-B strings 1-4, AMANDA-B strings 5-10) have different systematics. This has to be taken into account in the analysis.

The analysis was made with a subset of runs and OMs. An algorithm optimizing the size of that subset based on the stability and quality of OMs and runs was used.

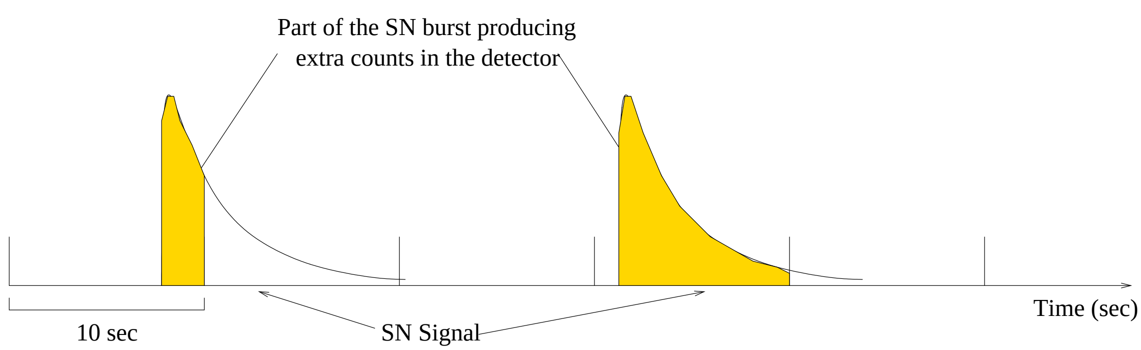






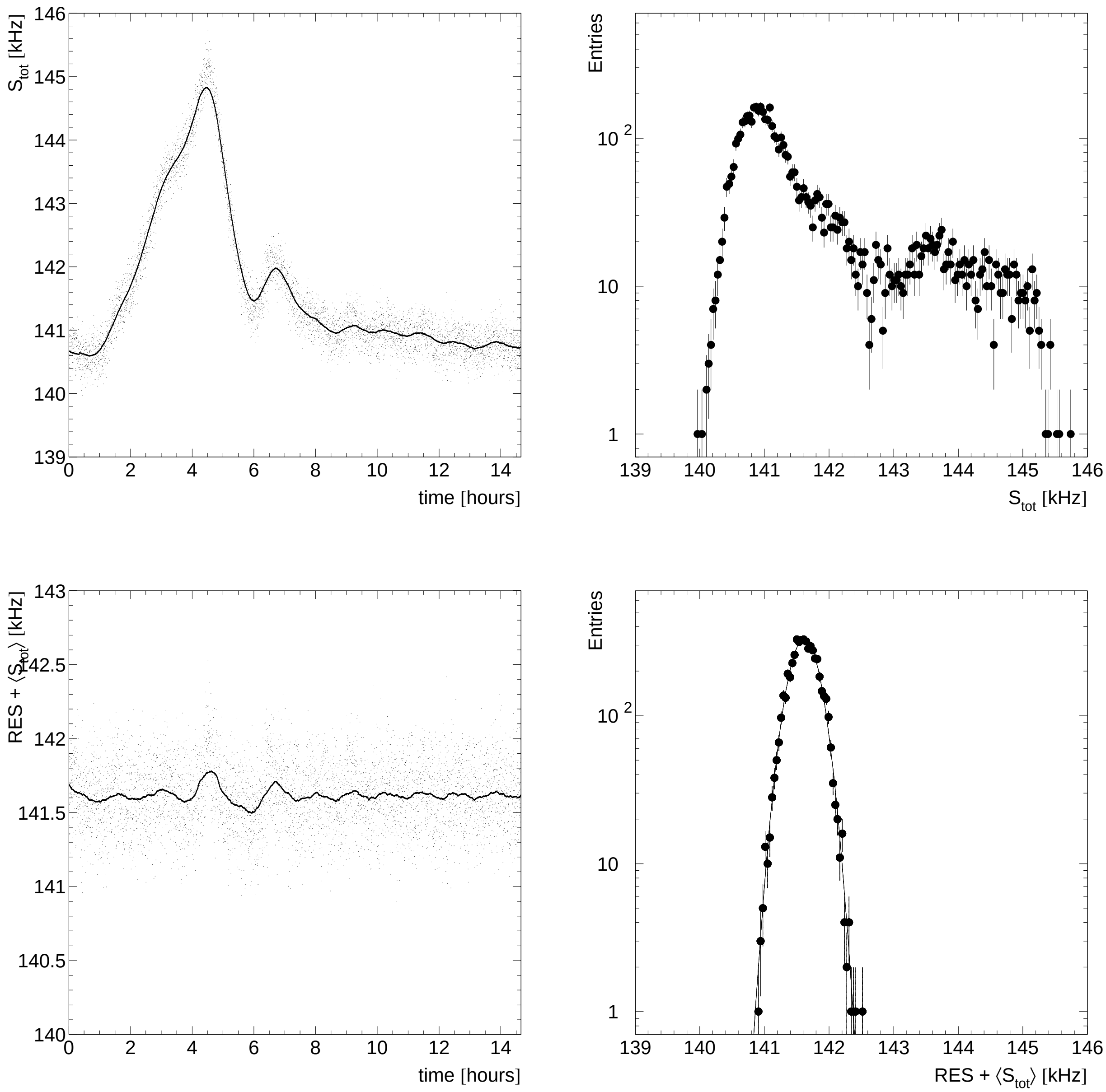
Analysis

The number of noise hits in each OM is counted during subsequent intervals of 10 sec.
This means that if a candidate supernova event is found, it will consist only of the fraction of the signal it produced in a fixed 10 sec time window.
Our signal efficiency is not 100%



In order to correct for trends in the OM noise, the *deviation* of the noise from a moving average calculated over 250 sec is used, rather than the noise itself. The same applies to the sum of the noise for all OMs: only its deviation from its moving average needs to be considered.

Moving average



As a first step in the analysis, the noise (or equivalently, the deviation from their moving average) of all OMs is summed, without weighting OMs differently.

There are three classes of events to distinguish:

- supernova signal on top of dark noise (our signal events)
- dark noise background
- all other types of noise (electronics, cross-talk, etc.)

Analysis method

In order to take into account the individual characteristics of OMs, the *likelihood* of each event can be calculated:

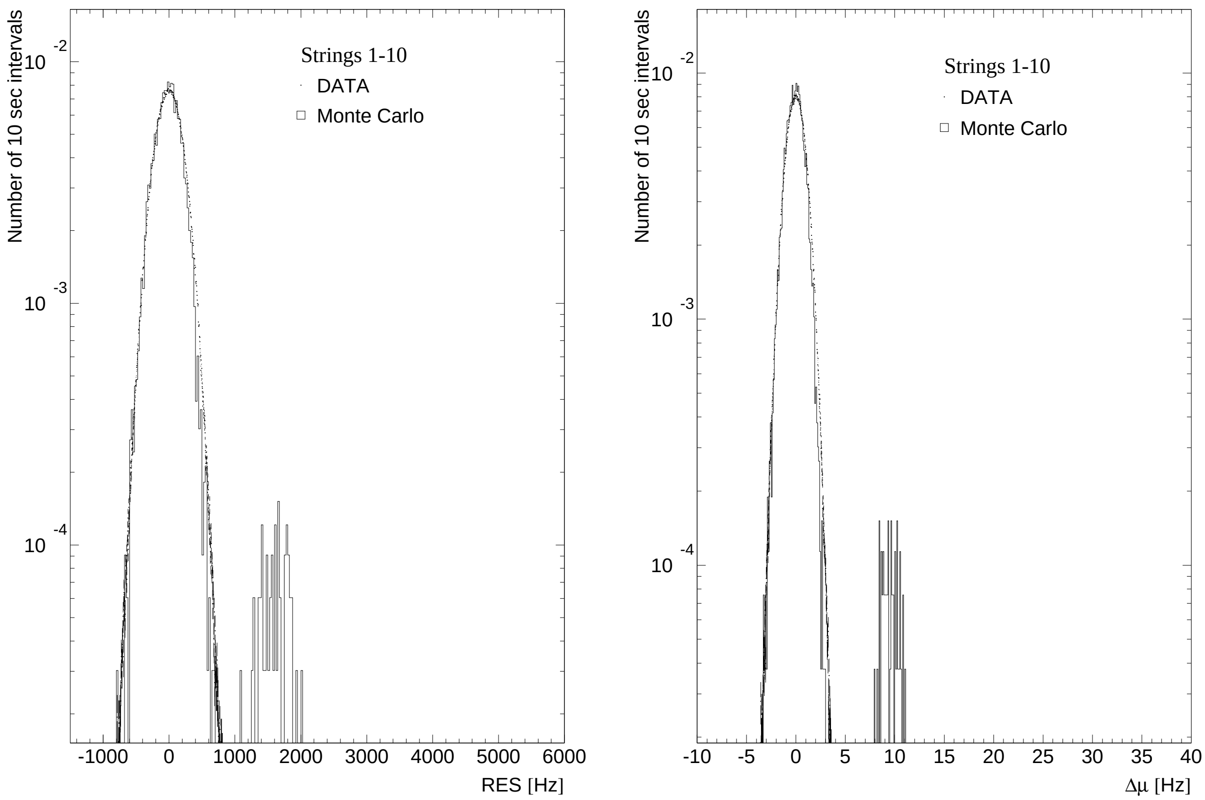
$$\chi^2 = \sum_{i=1}^{N_{OMs}} \left(\frac{x_i - \mu_i - \Delta\mu}{\sigma_i} \right)^2$$

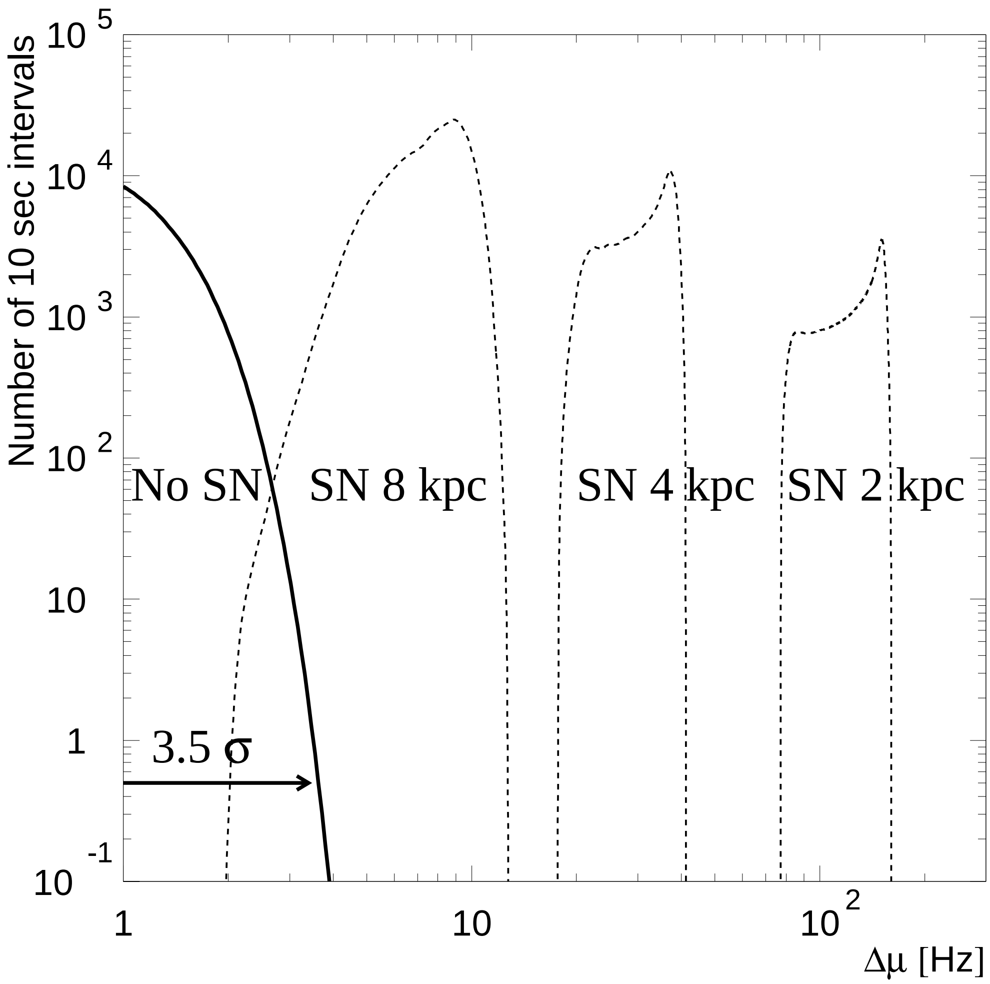
where x_i is the measured noise of an OM, μ_i its mean ($x_i - \mu_i$ is equivalent to the deviation from the moving average) and σ_i is the standard deviation for that OM.

$\Delta\mu$ is the expected excess in the number of counts, due to the signal (100 counts in 10 sec, or 10 Hz per OM)

One can use the χ^2 function and solve for $\Delta\mu$:

$$\Delta\mu = \frac{1}{\sum_{i=1}^{N_{OMs}} 1/\sigma_i{}^2} \sum_{i=1}^{N_{OMs}} \frac{1}{\sigma_i} \left(\frac{x_i - \mu_i}{\sigma_i} \right)$$





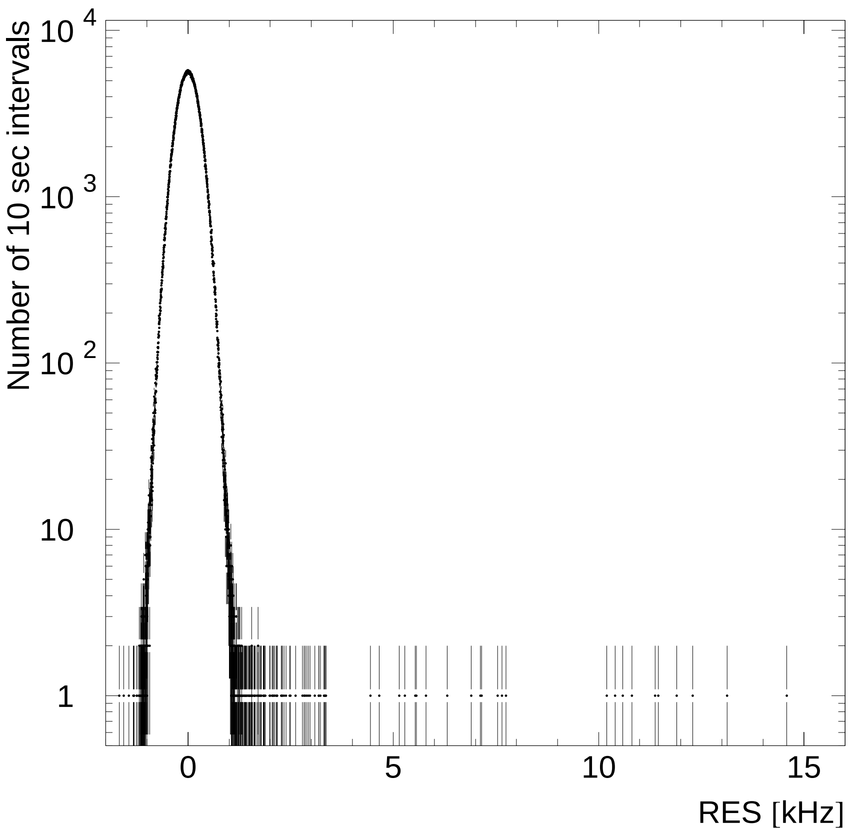
Expected signal distributions at various distances.

The different characteristics of the individual OMs are now taken into account.

The likelihood, or χ^2 of the fitted events can be used to reject outside noise. (e.g. not evenly distributed over all the OMs)

The strength of the signal $\Delta\mu$ is actually measured, $\Delta\mu \approx 640/d_{\mathrm{kpc}}^2$

Preliminary Results



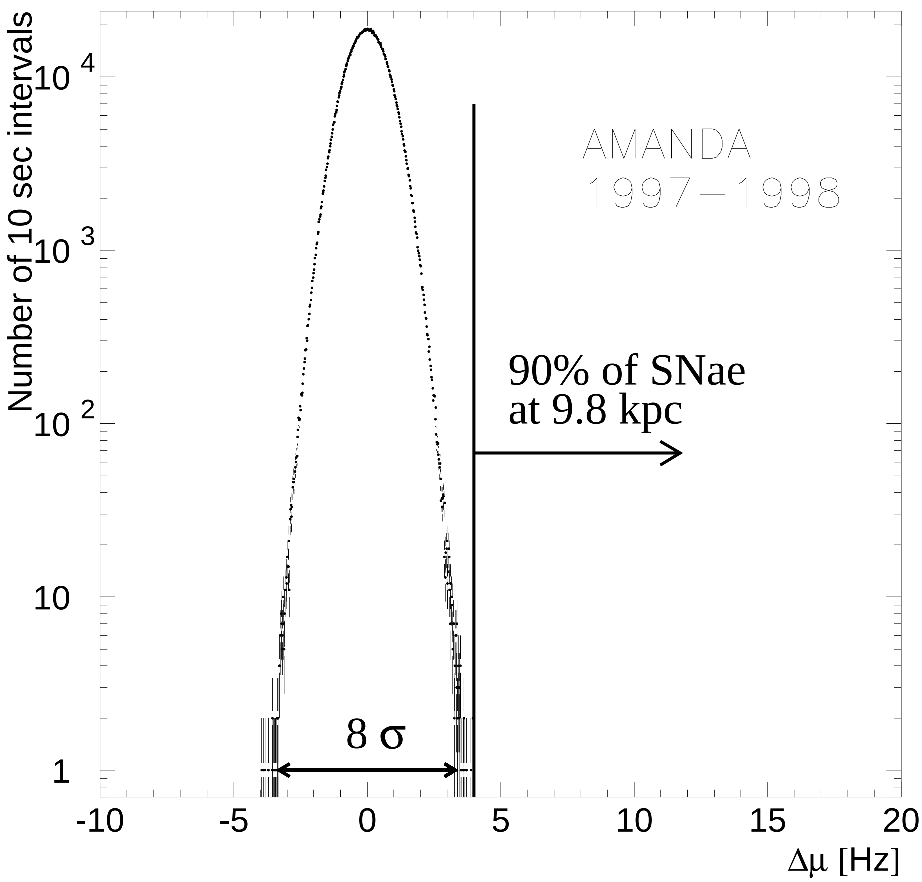
Before making any cuts: there are many events in the tail of $\mathrm{RES} = \sum_i^{N_{OMs}} R_i$, where R_i is the noise of OM(i), minus its average.

This means that we have external noise or other sources of disturbances..

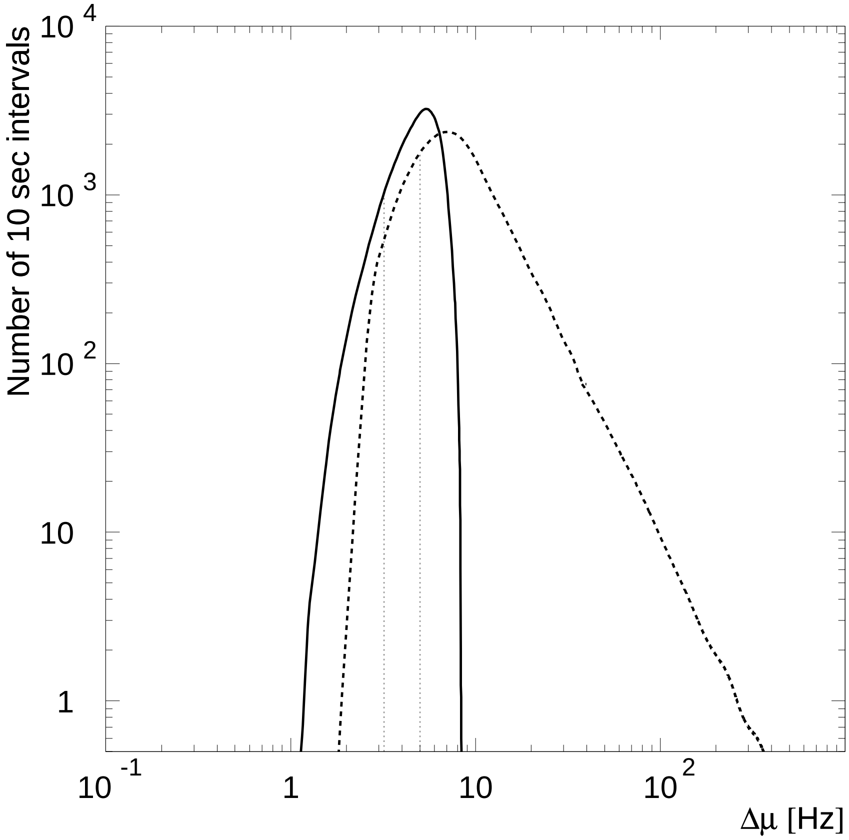
Final results

Fitting the signal $\Delta\mu$, we can cut on $\chi 2/n.d.f. < 1.3$ to get rid of outside noise.

Cutting at the level of a SN1987A-type event at 9.8 kpc, we expect one background event per year.



After cut on the χ^2, and for 215 days of live-time.
Preprint with more details: astro-ph/0105460



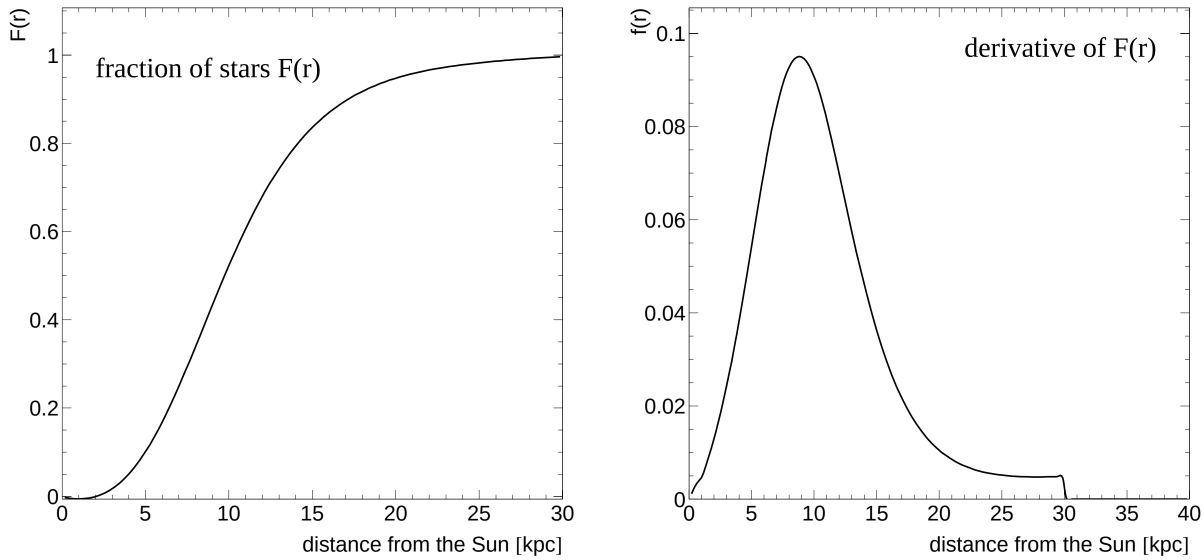
Signal prediction for a supernova at/within 10 kpc distance with a 90% efficiency level shown.

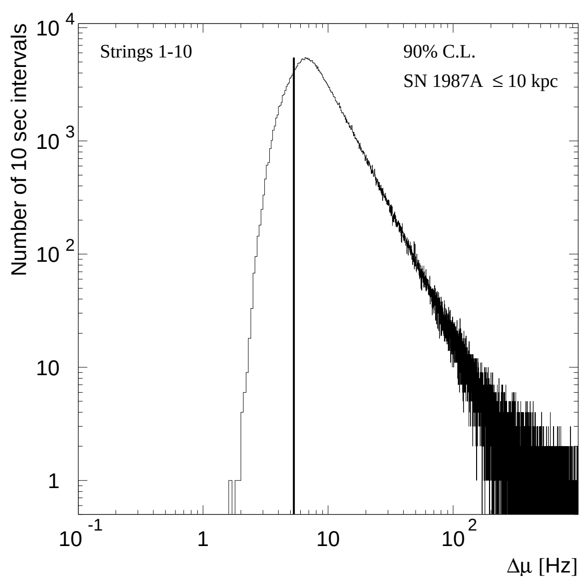
Signal to noise calculations

We calculated the expected signal for the Milky Way using the following assumptions:

- a conservative estimate of 1 SN/100 year
- using Bahcall's distribution for the SN progenitors ('Neutrino Astrophysics', 1989)

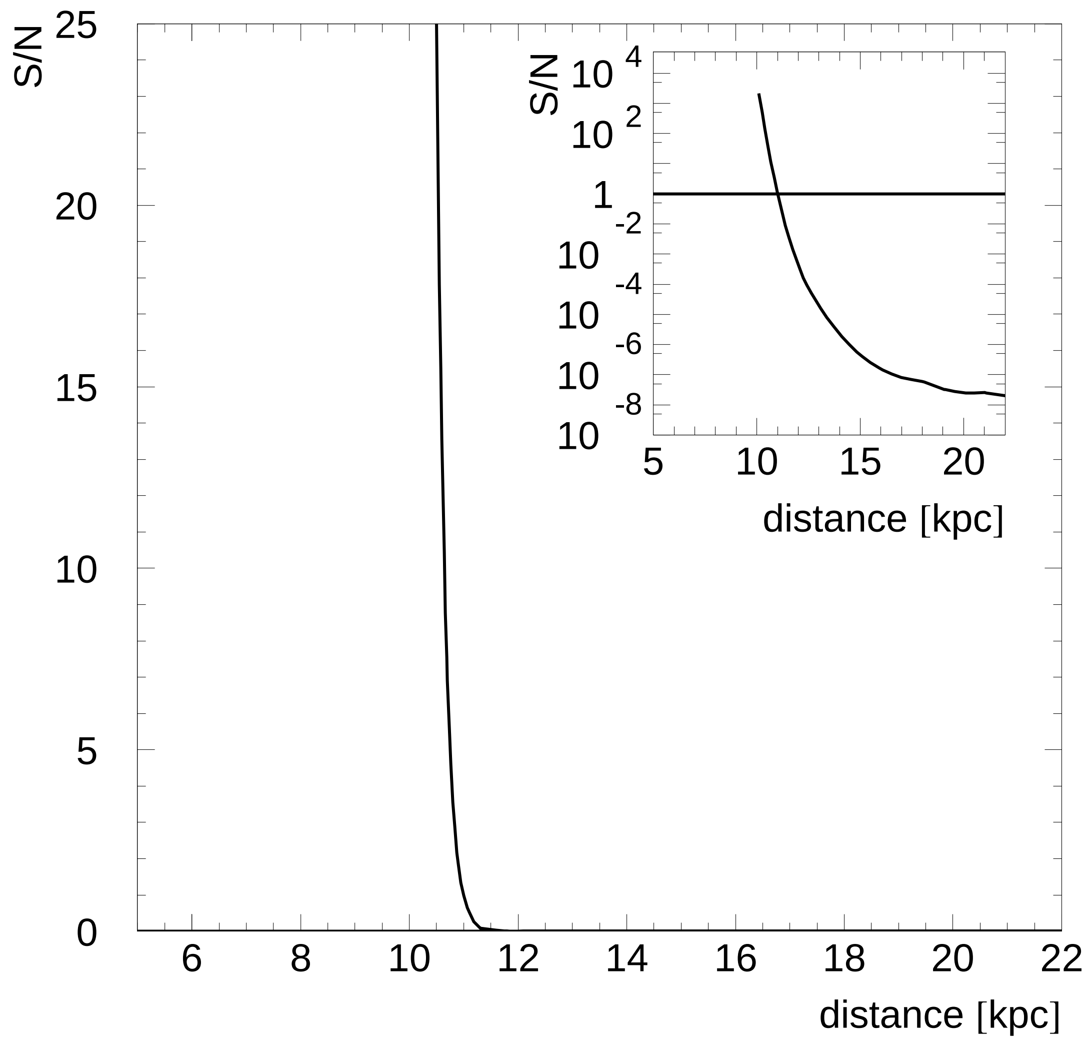
Probability function and p.d.f of supernova star progenitors.





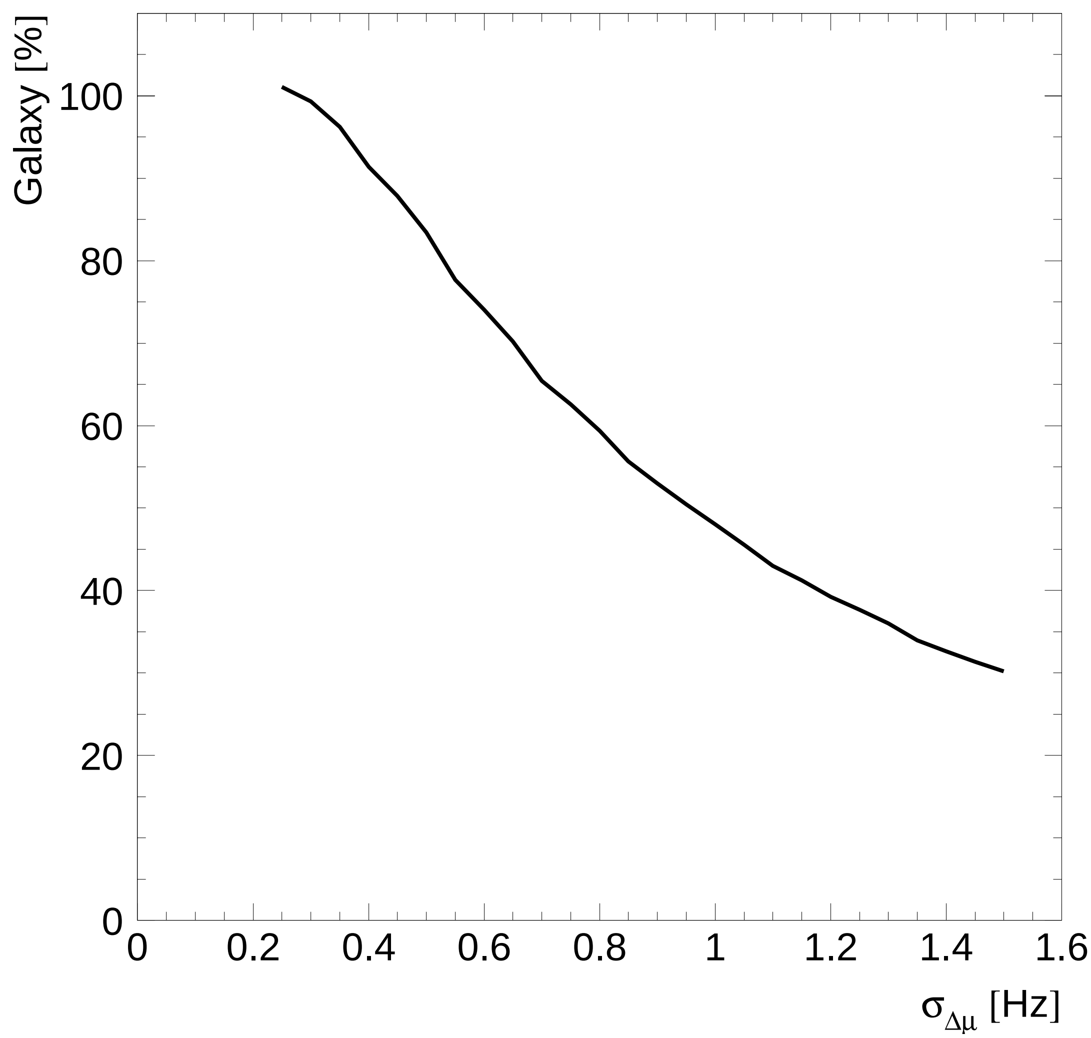
Signal-prediction from within 10 kpc.

The signal-to-noise is a very fast decreasing function of distance and depends chiefly on the number of OMs deployed (and their dark noise rate).



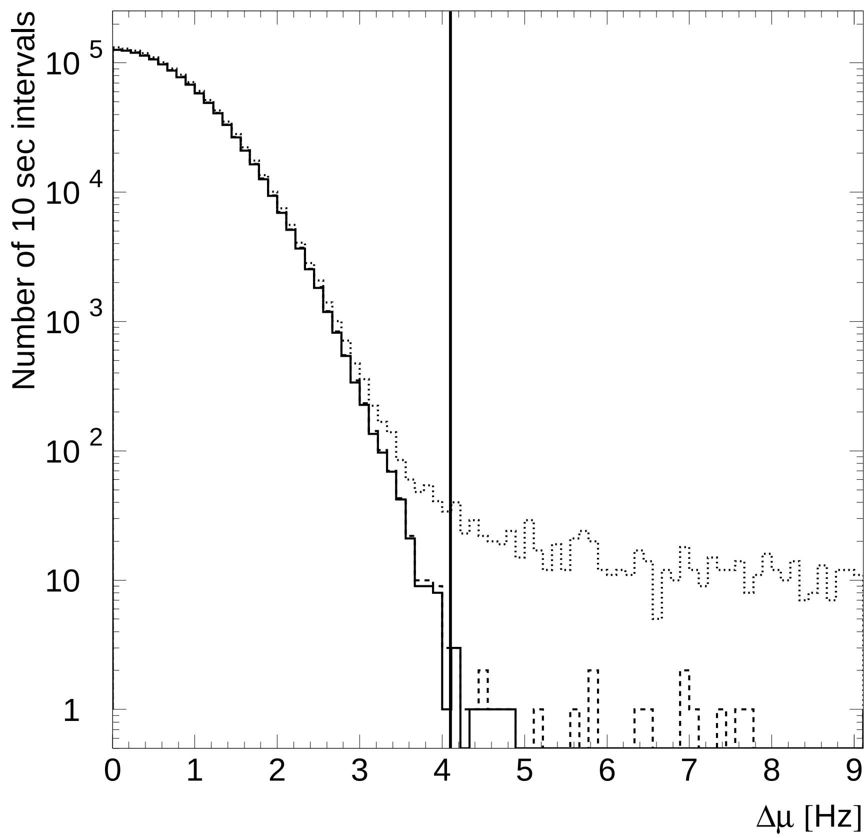
The 10-strings detector covers 70% of the Galagy with 90% efficiency (letting through one statistical background event per year).

Galactic coverage for different detector configurations



Trigger algorithm

Amanda Supernova Trigger Algorithm.



- Tested on all available runs and on MC.

- The dead time is about 5%

- Cuts can be tightened without reducing efficiency much.

- Not inplemented in the DAQ yet.

- The aim is to connect AMANDA to SNEWS (SuperNova Early Warning System) together with SuperK, MACRO, LVD, SNO,...

Possible improvements

Since the chief parameter for performance is:

$$\sigma_{\Delta_\mu}^{\mathrm{noise}} = \frac{\sigma_{\mathrm{OM}}}{\epsilon\sqrt{N_{\mathrm{OM}}}}$$

where ϵ is any improvement in the collection efficiency, several steps can be studied to improve the performance:

- wavelength shifter coating of OMs
- larger cathode area
- reducing noise spread
- optimizing time window location
- etc.

SNEWS (SuperNova Early Warning System)

- Increase the sensitivity of existing detectors by operating them in coincidence.
- If the rise time of SNae neutrino bursts is $\sim$msecs., triangulation of the source can be done with detectors at different locations on Earth.
- Alert optical telescopes of the location minutes or hours in advance.
- Satellite coverage of the South Pole is about 50% ; this will improve in the future and existing Iridium or other commercial satellite network is sufficient in principle for an alert to be sent out.

Conclusions

- We have analyzed 215 days of 1997 and 1998 supernova data using $\sim$230 OMs.
- An algorithm to select stable runs and OMs has been developed.
- The different characteristics of individual OMs are taken into account, by fitting the signal strength. The statistics are understood.
- The present detector has a range of 9.8 kpc (i.e. a bit beyond the center of our galaxy).
- Studies of the signal to noise as a function of size of the detector have been made. The S/N is $>>$ 1 for 70% of the Milky Way.
- A trigger algorithm based on the methods ouli-ned has been developed.