DETECTION METHODS OF SUPERNOVA EXPLOSION WITH THE ANTARES TELESCOPE.

V. Kulikovskiy[1,2], M. Anghinolfi[2], H. Costantini[2], E. Shirokov[1]

1 Moscow State University,Skobeltsyn Institute of Nuclear Physics,Leninskie gory, 119991 Moscow, Russia

2 INFN - Sezione di Genova, Via Dodecaneso 33, 16146 Genova, Italy

vladimir.kulikovskiy@ge.infn.it

Section 1. Supernova.

Supernova explosion is occurring for stars which are heavier than Chandrasekhar's limit (1.38 solar mass). It's a fast conversion to a neutron star when the thermonuclear processes can't withstand to the gravitation force. During the explosion about 99% of the gravitational binding energy radiates in neutrinos. About 1% are electron neutrinos from the initial "neutranization" phase while the residual 99% are produced during the cooling phase through weak interactions in the hot and dense matter. The latters are roughly equally distributed among all flavours. The time scale of this process lasts over tens of seconds and about one half of the neutrinos escapes the star during the first 1-2s.

The famous supernova explosion in 1987 occurred in the Large Magellanic cloud (SN1987A) and it was seen by the Cherenkov detectors Kamiokande II and IMB and by the scintillation detectors Baksan and LSD. It's predicted that SN explosions in our galaxy should occur once in about 30 years[1].

Our ANTARES neutrino telescope is a large water Cherenkov detector and can provide the opportunity to detect the Cherenkov light produced by positrons from SN antineutrinos.

To investigate this possibility we describe the various procedures which use the data recorded during the normal run operation and the response of our Optical Modules to SN neutrinos evaluated with a Geant4 simulation.

A method to minimize the effect of the bioluminescence burst is discussed in the section 2 while the statistical analysis based on singles rates and double coincidences in one storey is presented in sections 3 and 4.

Section 2. The bioluminescence filter.

In addition to the Cherenkov light produced by muons, neutrino telescopes also detect Cherenkov light from the decay of radioactive elements and light from luminescent organisms. Fig. 1 represents the variation in time of the rate of the single photon events that are the hit counts detected in one OM. One of the main contributions comes from the radioactive decay of 40K. The frequency of this noise is evaluated by MC calculations to be around 40kHz and does not change since the 40K concentration depends on the salinity which is almost constant on time and sea depth. However in fig.1 the mean rate is about 60kHz, the additional contribution being due to a constant bioluminescent activity.

Above this slow variable noise one can see high sharp peaks due to the emission of light bursts from small animals in transit close to the OM. Later in this note we will term these peaks as "bioluminescent burst" to distinguish them with respect to the continuous or slowly variable bioluminescence noise even if the origin of both is biological.

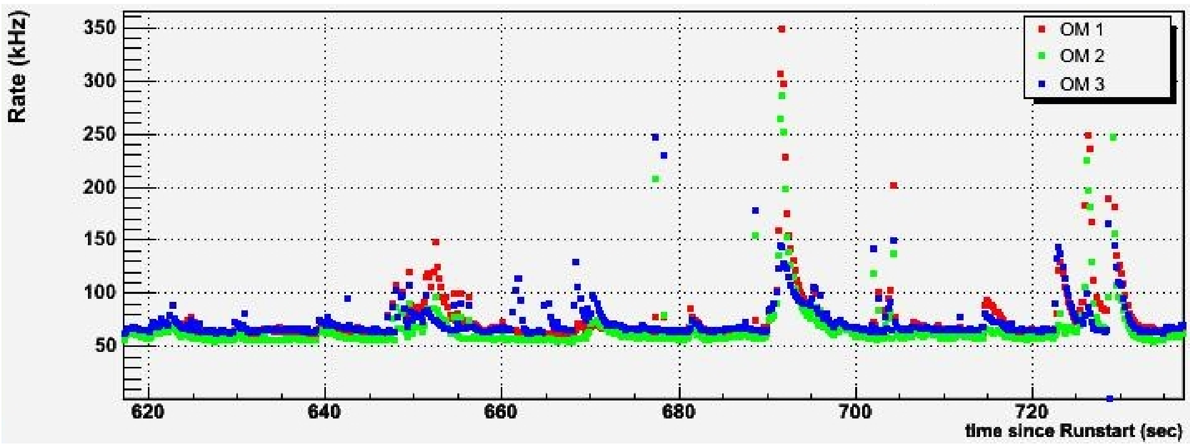

Fig. 1 Example of singles rate (0.3 pe threshold) events in three OMs of the detector

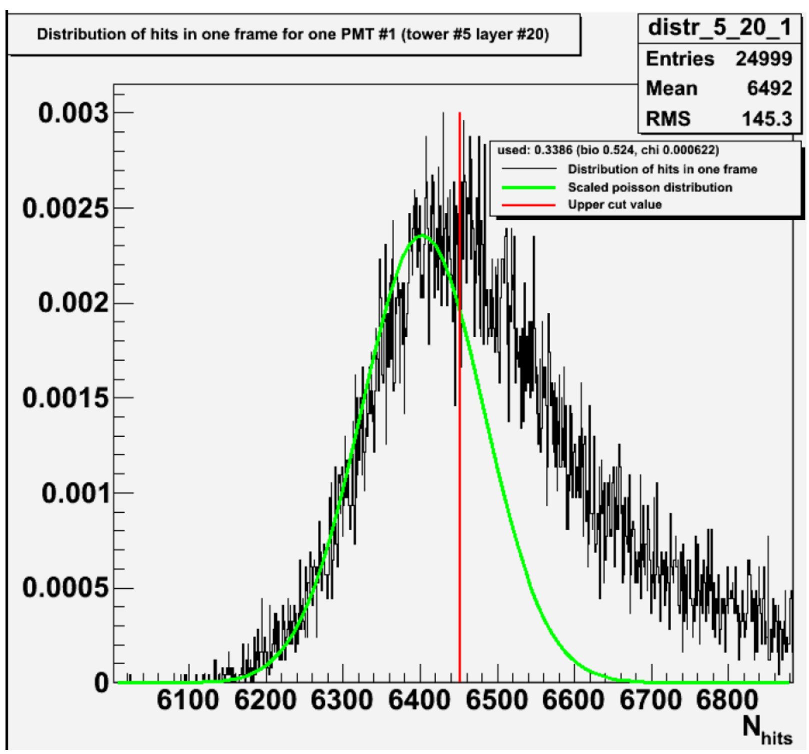

Fig. 2 Example of hit counts distribution in one OM. This distribution was evaluated for 2500 time slices each of 105ms duration time

Considering that the hits in one OM are independent one from each other and that their frequency doesn't change in time with the exclusion of the bioluminescence bursts periods, then the hits for every OM must follow the Poisson distribution.

As an example in fig.2 the distribution hiexp of the hit counts above the 0.3 photoelectron (pe) threshold in each time frame of 105 ms for one OM is shown. One can distinguish two particular areas: the region on the left side which is well fitted with the Poisson distribution and a tail on the right where the hit counts distribution is higher than the fit. The hits on the left part of the distribution are mostly from 40K decay and from the continuous bioluminescence noise while the bioluminescence bursts clearly determine the right part of the distribution.

The left region is fitted with a Poisson's function up to a right margin imax which is a free parameter. There are three parameters in the fit: λ, the mean value of the Poisson distribution, the right margin of the fit and the scaling factor (height of the distribution).

The output of the fit can be used as a filter to exclude time frames where OMs are affected by bioluminescent bursts: for a given OM only time frames with rates lower than imax were considered for this bioluminescence bursts filter. When applying the filter, the number of working OMs is strongly decreased depending on the environmental conditions.

Section 3. Super Novae registration with singles.

According to a note of Y.Becherini, G. Ramadori and M.Spurio[2], one should expect ~12 hits on the single OM from a SN1987A like supernova in a 105 ms time interval. The main idea is to measure the increase of the total hits in the detector in one time slice.

This method, in the specific case of ANTARES, can not be directly applied due to the bioluminescence bursts which have been therefore excluded using the filter as described above.

The procedure we have used is the following:

The data collected in a 45 min time interval, sufficiently large to have good statistics, were used to determine the fit hiexp of the hit counts distribution for each ith OM in the detector. These hiexp are different because detection efficiencies of OMs are different and also because the bioluminescent activity can vary in the various parts of the detector. This hiexp can be seen as the probability density function (PDF) of the hits in each OM.

The results from the fit were also used to define quality cuts that fit converges, λ>2000, and the area of the Poisson component is larger than 30%.

For a given time slice, we sum the contributions of all OMs that aren't affected by bioluminescence (counting rate below the cut imax) to determine the total hit counts in the detector for that time slice.

Probability density function of the hit counts in the detector can be estimated as Gaussian with $M = \sum m_i$, where mi is mean of PDF for ith working OM (mathematical expectation of hit counts in particular OM after bioluminescence filter) and with a sigma $S = \sqrt{\sum \sigma_i}$, where σ_i is a variance for ith PDF. Using this PDF of hit counts in the detector is possible to define cut value according to predefined probability to have a fake signal. After actual total number of hits in time slice compared with this cut value.

Section 4. Supernova registration with coincidences between Optical Modules.

The ANTARES storey includes OMs which are arranged close to each other (distance is less than 1m), and light from 40K decay can be simultaneously seen by a couple of OMs. This fact is rather well known and it's used in the detector calibrations. One example of the time distribution of this coincidence in one storey is shown in fig.3. We can distinguish a plateau due to the random coincidences in the time window of 20 ns and a Gaussian shaped distribution due to 40K decay.

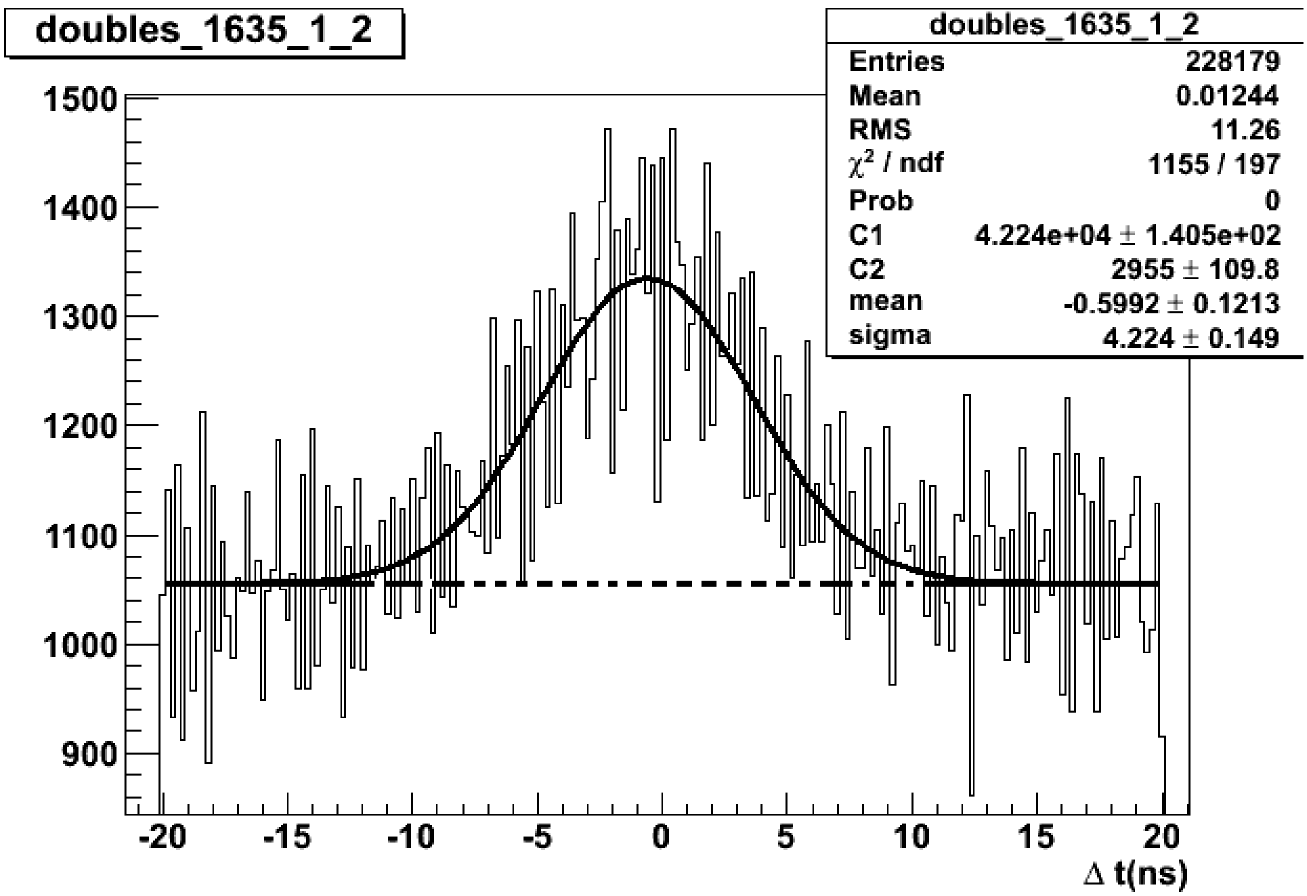

Fig. 3 Example of the time difference between hits on OM 1 and 2, storey 1635. Dashed line represents random coincidence level. The area of the Gaussian accounts for the number of hits from ^{40}K coincidences.

The mean coincidence rate for each couple of OMs from the fit is about 16Hz for the 40K events which we indicate as "true" coincidence. It's rather constant in time because it is almost independent by the biological activity but it is different for different couples due to non uniformity in the efficiency of the OMs which depends on high voltage, quality of the OM (and photomultiplier) surfaces and so on. Geant4 simulations show that the light produced by the positrons induced by SN neutrinos simultaneously hits two and even three OMs in the same storey. These additional events should increase the coincidence rate during the SN explosion. The Geant4 simulation of this effect gives a rate of about 2.8Hz in the first 100ms time window i.e. an increase of 0.28 events for each pair of OMs in the considered 105 ms time slice.

The measurement of this small increase in the detector can extend the discovery potential of ANTARES to the SN explosion.

Section 5. Conclusion.

The ANTARES detector operates in the environment with high background rates from bioluminescence and 40K decay. In this note we've described two different possibilities for detecting supernova. Efficiency of this methods is under investigation. Also approaches for SN detection described here could be implemented in other Cherenkov's telescopes (Baikal, NEMO) and in case of bigger detectors in future (KM3net) capabilities will be much more encouraging.

1. Tammann G A et al 1994 Astrophys. J. Suppl. 92 487
2. Y.Becherini, G. Ramadori and M.Spurio "Detection of νe from Supernovae with ANTARES", ANTARES-PHYS-2002-002.