Analysis of the ANTARES data for SN neutrino detection

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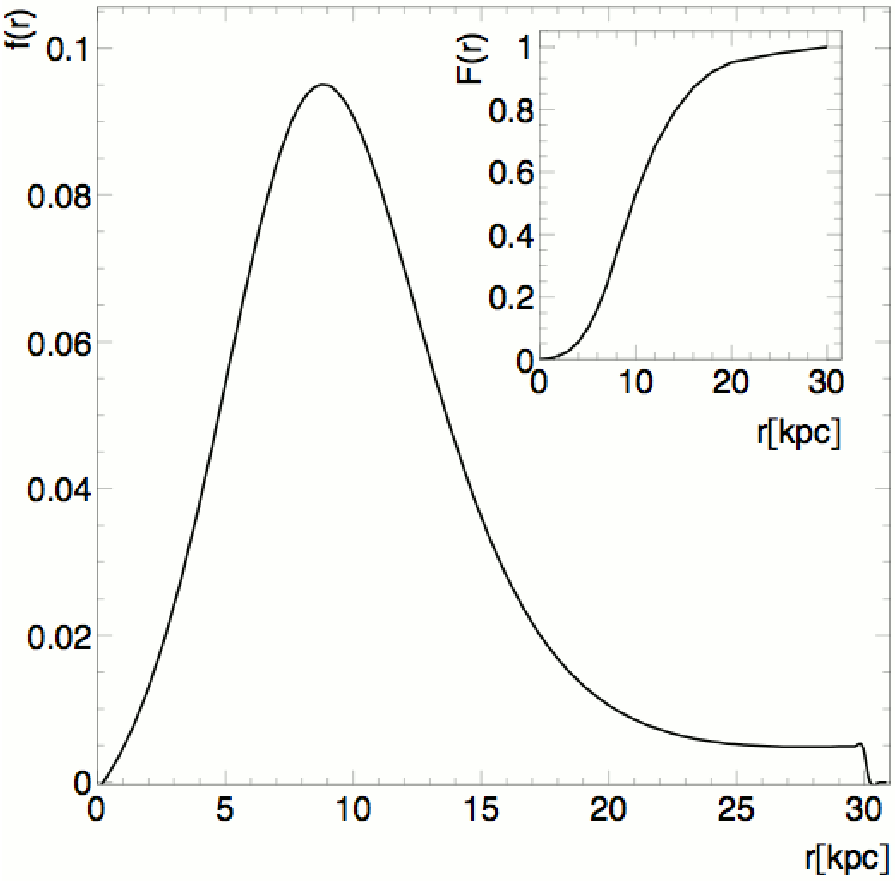
SN progenitor stars distribution



- A half of the possible sources of SN type II explosion are at 10kpc.
- Sensitivity decreases as the square of the distance to SN

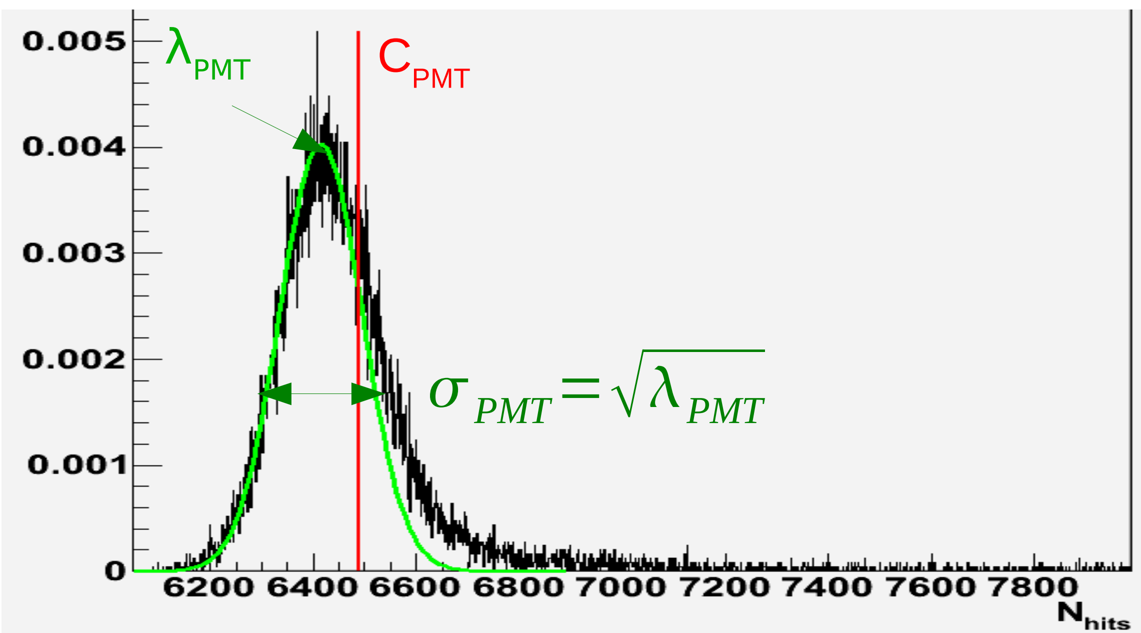
Methods overview

- Single rate
  1. exclude OMs affected by bio bursts
  2. Sum all hits of the selected OMs in the detector in 100ms
  3. Compare with total detector rate in case of no SN

     (background is slow varying bioluminescence + ^{40}K)
- Coincidence rate
  1. Obtain sum of true coincidences in the detector in 100ms
  2. Compare with total coincidence rate in the detector in case of no SN

Single rate: Bioluminescence cut

- Collection of distributions of hit counts in 100ms for each OM during ~45min
- Usually these distributions consist of 2 parts – Poissonian (due to ^{40}K and plankton bioluminescence) and long tail (due to bioluminescence bursts)



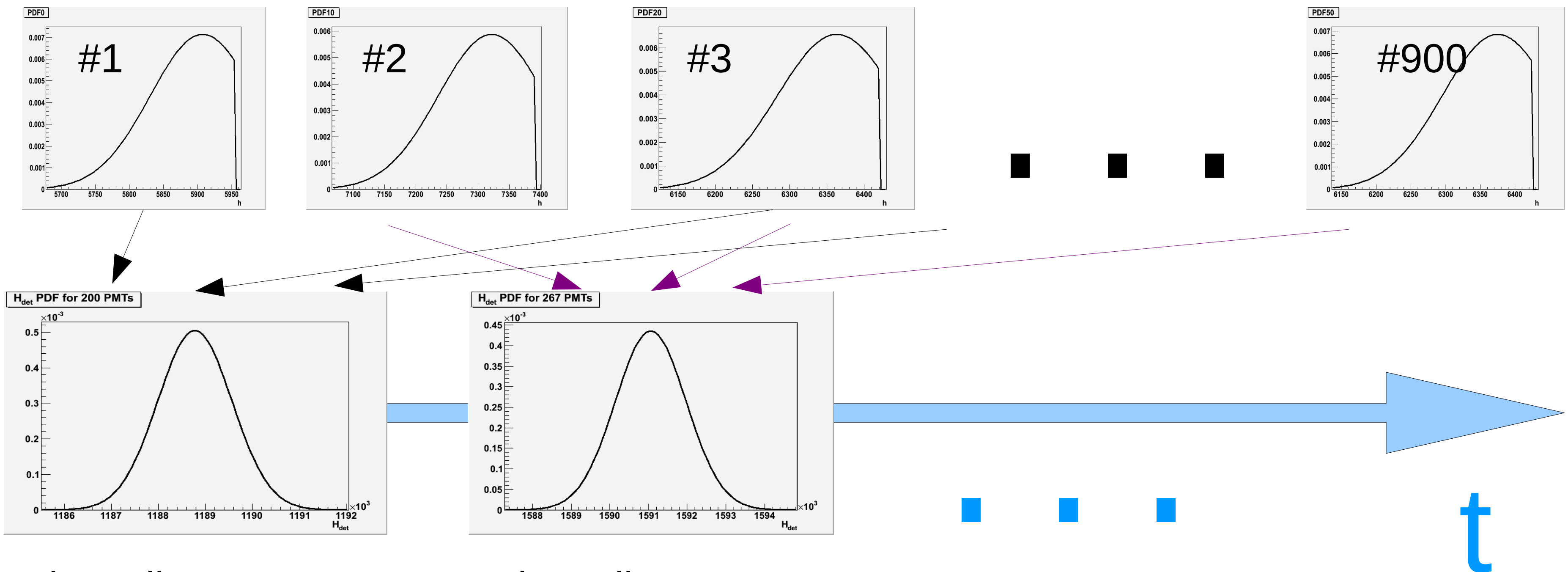
Fit with Poisson distribution.
Free parameters:

- λ_{PMT} (mean value)
- C_{PMT} (fit only until this hit count)

If number of hits in 100ms in the OM $N_{hits} < C_{PMT}$
it will be used in the total detector hits H calculation.

Single rate: PDF of hits in the detector

- with known C_{PMT} and λ_{PMT}, we know PDFs of hit counts in each PMT
- In each time slice the set of PMTs which passed bioluminescence cut is different
- So, the PDF of the detector is different for every time slice (100ms)

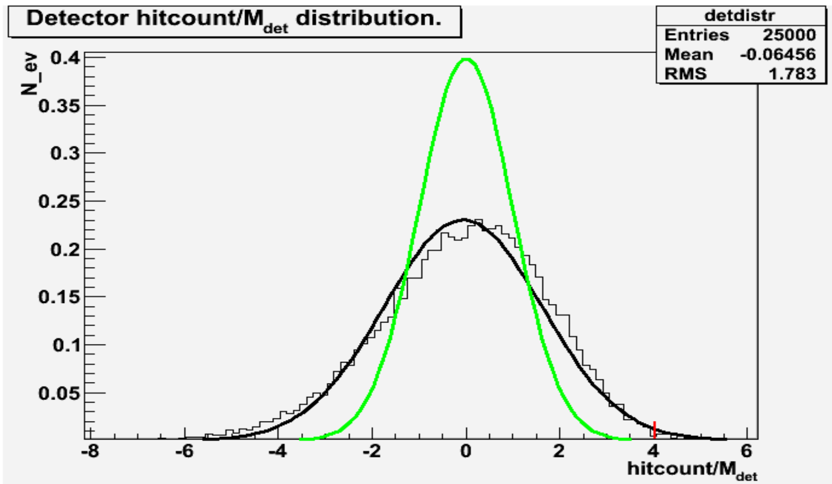


time slice 100ms #1

time slice 100ms #2

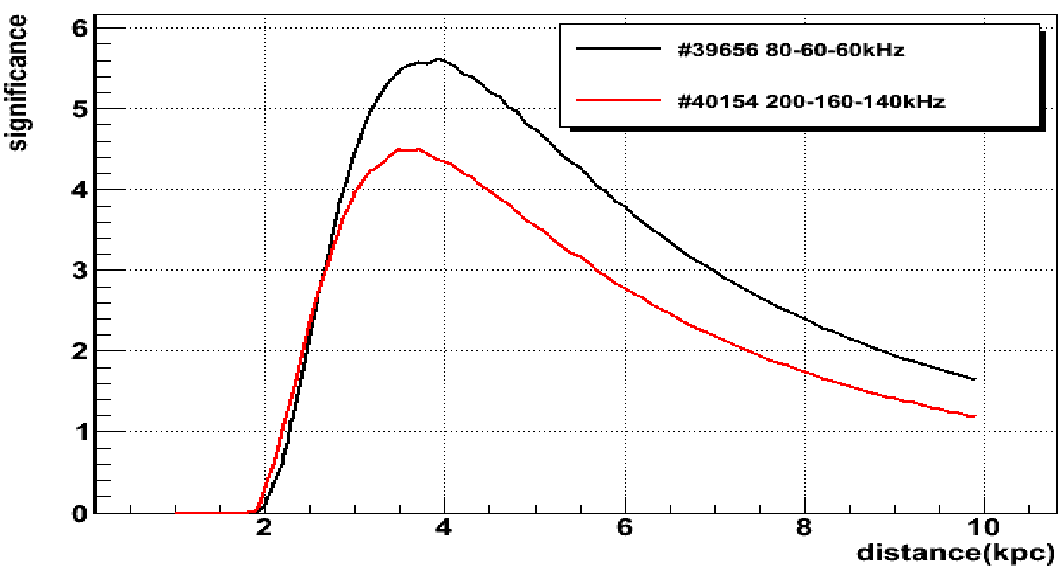
Detector PDF could be approximated as a Gaussian with $M = \sum_{N_{pmts}} m_{exp}$ and $S = \sqrt{\sum_{N_{pmts}} \sigma^2_{exp}}$

Single rate: results



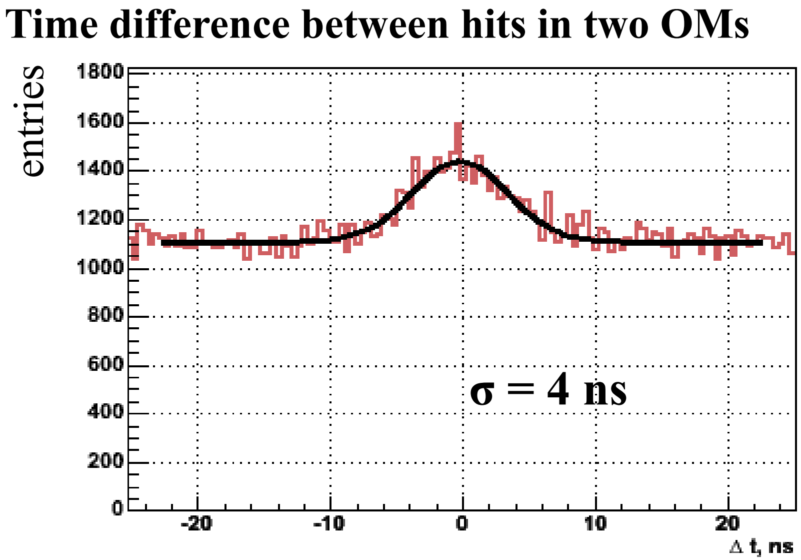
(H-M)/S distribution

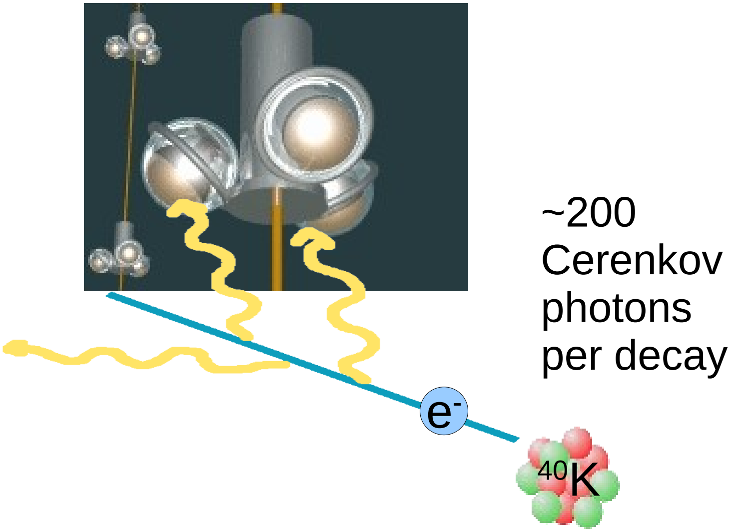
- 1.7 larger than expected due to the slow change of bioluminescence activity



- Significance as a function of distance
- simulations for 900 Oms in the conditions of run 39856(low bioluminesce) 40154(high bioluminescence)

Double coincidences: how to obtain number of true coincidences

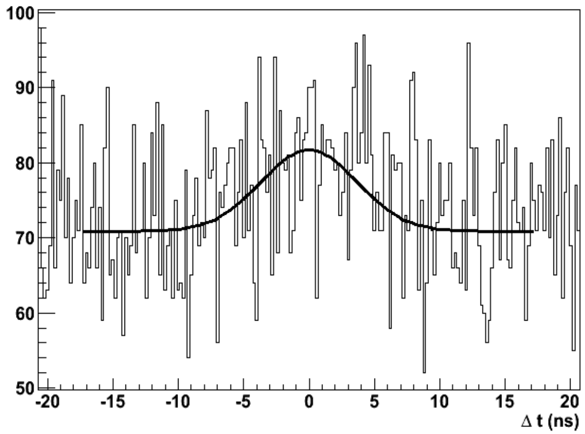




- For every couple of OM in a storey: collect time difference between hits in the 2 OMs during 2000s
- Random rate gives constant pedestal
- ^{40}K decay, which flashes both OMs, produces Gaussian peak with width ~4ns (compatible with distance between OMs and time resolution)
- Concentration of ^{40}K is very stable.
  Rate of true coincidences is 16±3Hz

Double coincidences: search method

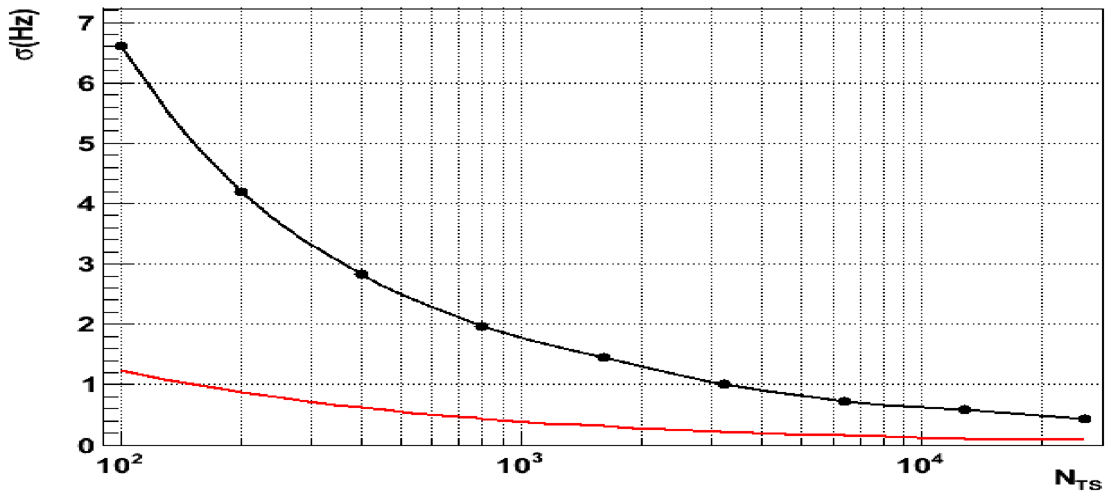
- Find rate of true coincidences for every couple of OMs, analyzing 2000s of data.
- apply quality cuts to exclude couples of bad OMs (problems with the high voltage or bad calibration).



- In one time slice (100ms) collect time difference distribution for all coincidences in the detector. Obtain total number of true coincidences in the detector in the time slice.
- Compare total coincidence rate in the detector in 100ms with sum of coincidence rates of every OM couple.

Double coincidences: error on coincidence measurements

Two components – a statistical fluctuation of ^{40}K coincidence rate + fluctuation of a random background(bioluminescence).

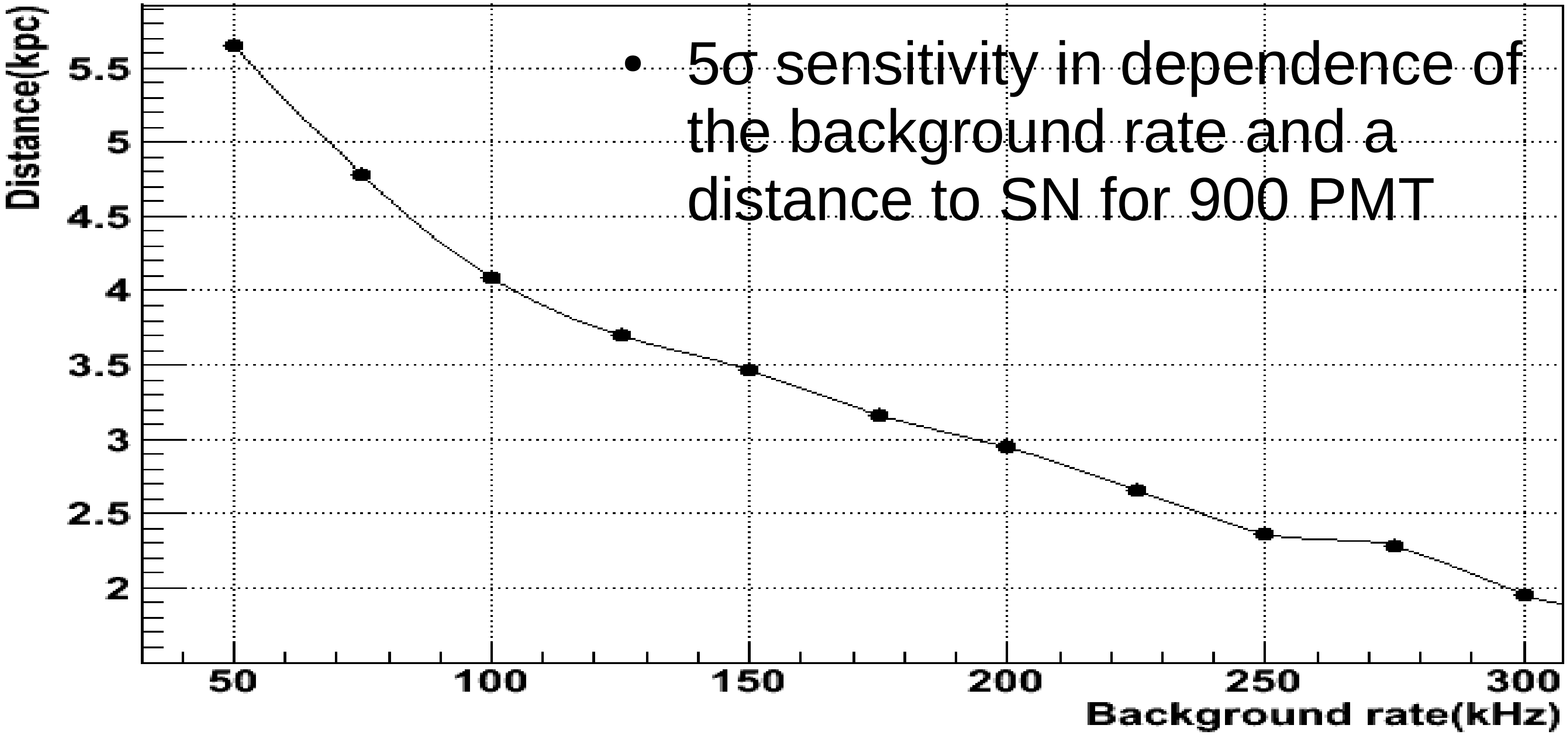


Black – error of the fit
Red – statistical fluctuation
Of 16Hz signal only

- The plot could be used for error estimation:
  - of a OM distribution fit (in dependence of time slices)
  - Of a time slice fit (in dependence of number of OMs)

Double coincidences: results

- For 450 couples (runs 24/10/2009-29/10/2009) uncertanty for rate was 2.6 sigma, which is in correspondence with the simulations

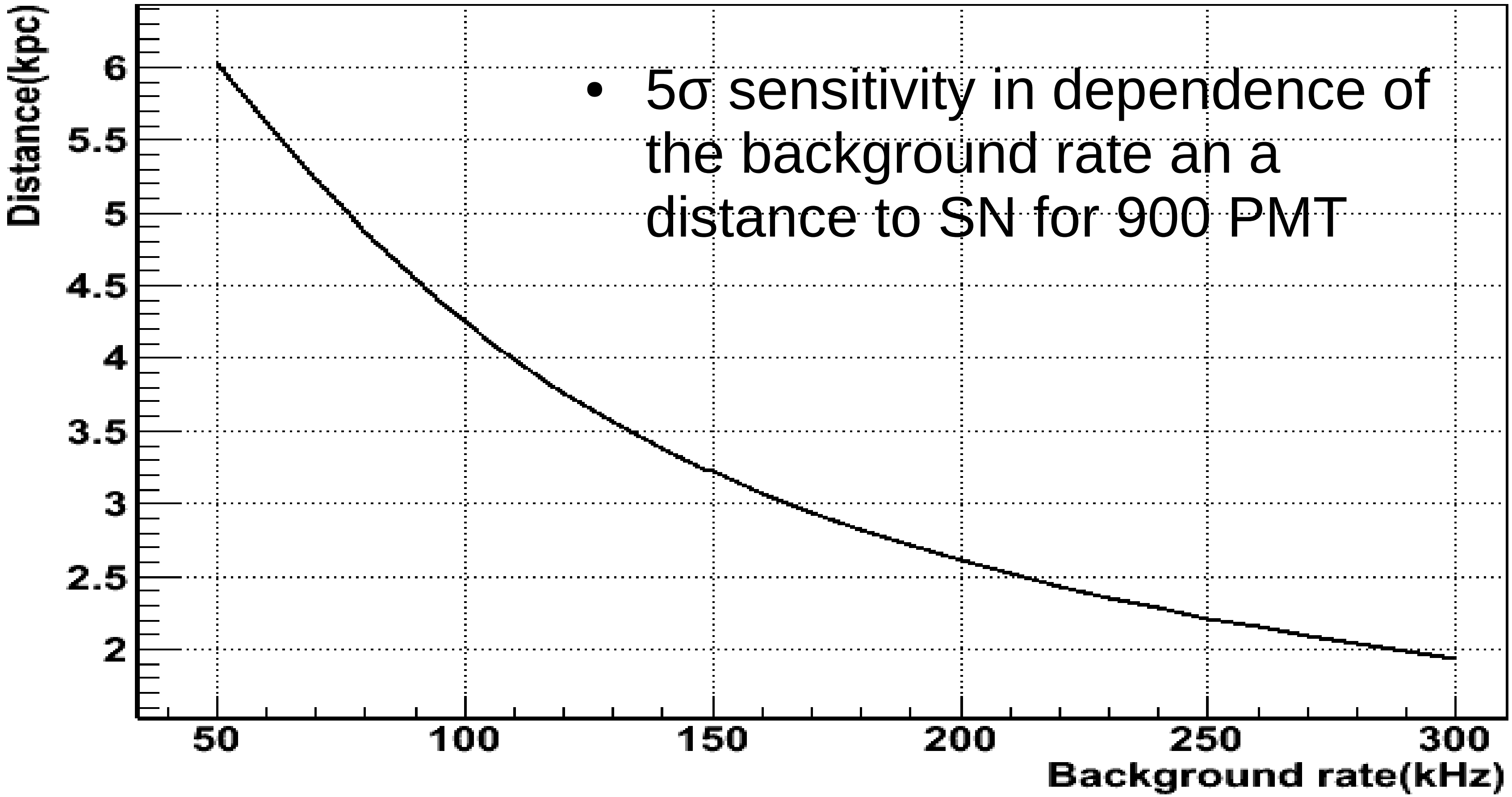


Method with triples

- Simulations show the best ratio of signal to noise.
- Very low statistics the 100ms time slice: the fit of the time difference distribution for triples is not possible.
- Only the total number of triple coincidences is considered in the time slice by time slice analysis.

Triple coincidences: Results

- For January 2009 uncertainty is in correspondence with statistical fluctation



- 5σ sensitivity in dependence of the background rate an a distance to SN for 900 PMT

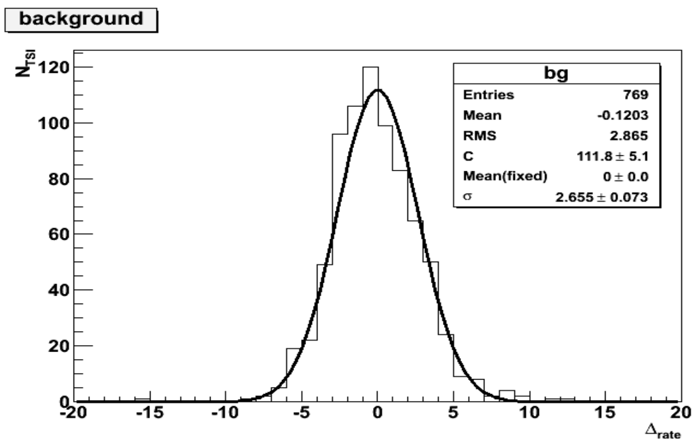
Implementation of the trigger

- The sensitivity of the 3 methods is comparable (methods with doubles and triples don't have a decreasing efficiency for very close SN).
- 5σ sensitivity gives 90% probability to detect event and ~1 fake event in 17 minutes – fine for writing coincidences, but not raw data. 5σ is achievable only for distances to SN ~4kpc, so if we want to be able to detect closer SN, fake event will be much higher (for 10kpc it's about 1 every 2 time slices).
- SNEWS could help to save a raw data for offline analysis. Delay is maximum 10 minutes (this time is due to the slowest experiment in the network and probably could be minimized as we don't need precise coordinates).
- Two proposals:
    - Use 2 sec buffer of raw data to store coincidences - sufficient to cover the 10' SNEWS latency time & can be used by the current analysis methods.
    - Possibly a big 10' buffer to store all data for future improvements.

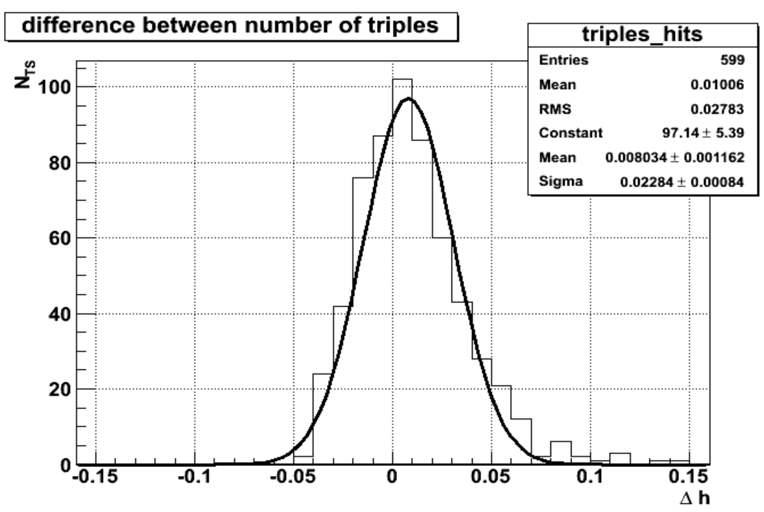
Summary

- ANTARES works with high level of noise from the environment.
- Different SN detection methods were introduced. Uncertainties are understood. Efficiency of methods is comparable for 900 OMs ANTARES.
- SNEWS seems to be useful for
  - Raw data writing for offline analysis (10min buffer is needed)
  - Coincidence data writing (500 times smaller buffer is enough)

Uncertainty verification



- Double: difference between number of true coincidence from the fit in time slice and sum of the hits from ever OM rates (~450 OMs). Sigma 2.6 is in correspondence with simulations.



- Triple: difference between number of true coincidence from the fit in time slice and sum of the hits from ever OM rates (~85 storeys).

- Sigma is in respondence with statistic fluctuation.

$$\sigma_{th} = \frac{\sqrt{h_{bg} N_{storey}}}{N_{storey}}$$

$$= \frac{\sqrt{(0.065 + 4 \times (10^{-8})^2 * (97000)^3) * 0.1045 * 85}}{85} \approx 0.023$$