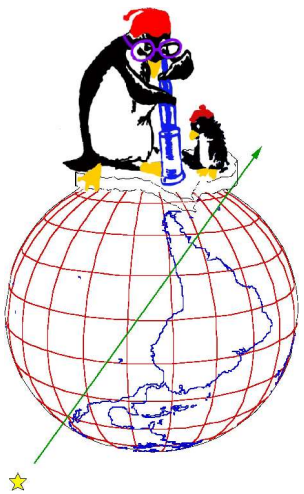
AMANDA / IceCube
Real Time Supernova Search
STATUS



AMANDA/IceCube Coollaboration Meeting
Berkeley/2005
Thomas Feser,
Institut für Physik,
Universität Mainz,
March, 18th, 2005

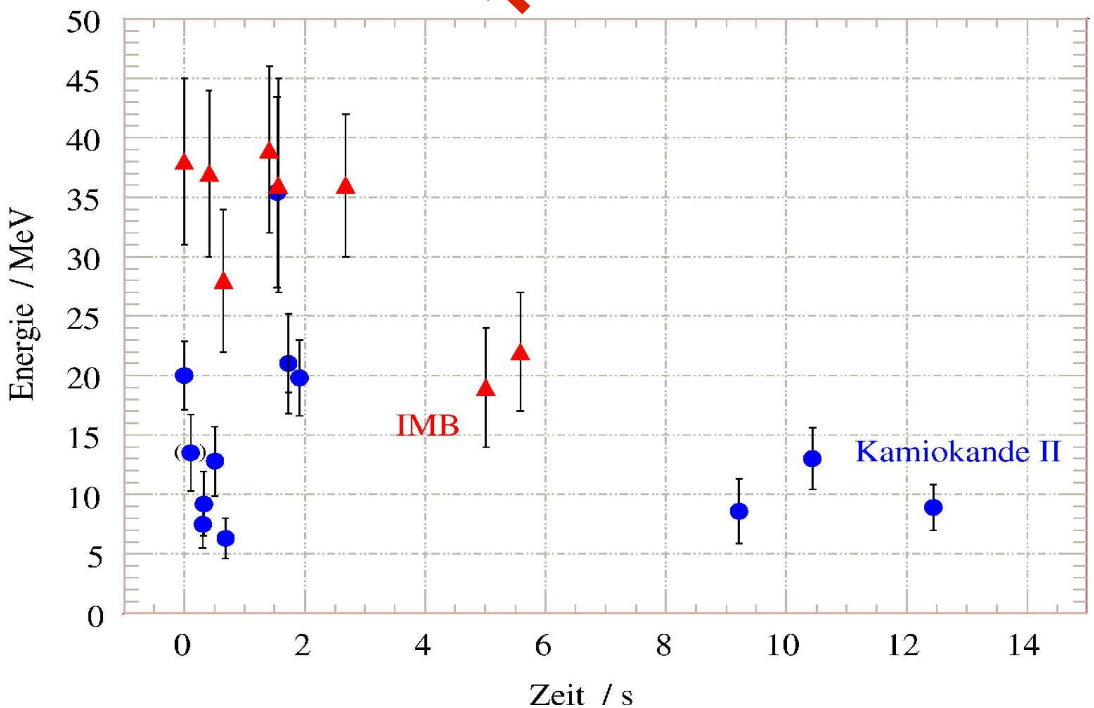
Topics

1) assumptions about the neutrino emissions of a supernova
2) how to detect MeV neutrinos in AMANDA
   - ”effective volume” of our optical modules and the sensitivity
3) data analysis in real time
   i. behaviour of our optical modules – qualification cuts
   ii. background, signal and simulation of both
   iii. results for the data taken from 2000-2003
4) summary, perspectives and remaining things to do

Supernovae as Neutrino Sources

relevant types are Ib, Ic, II
(engine: gravitational collapse)

(Ia: thermonuclear SNe - no neutrinos)



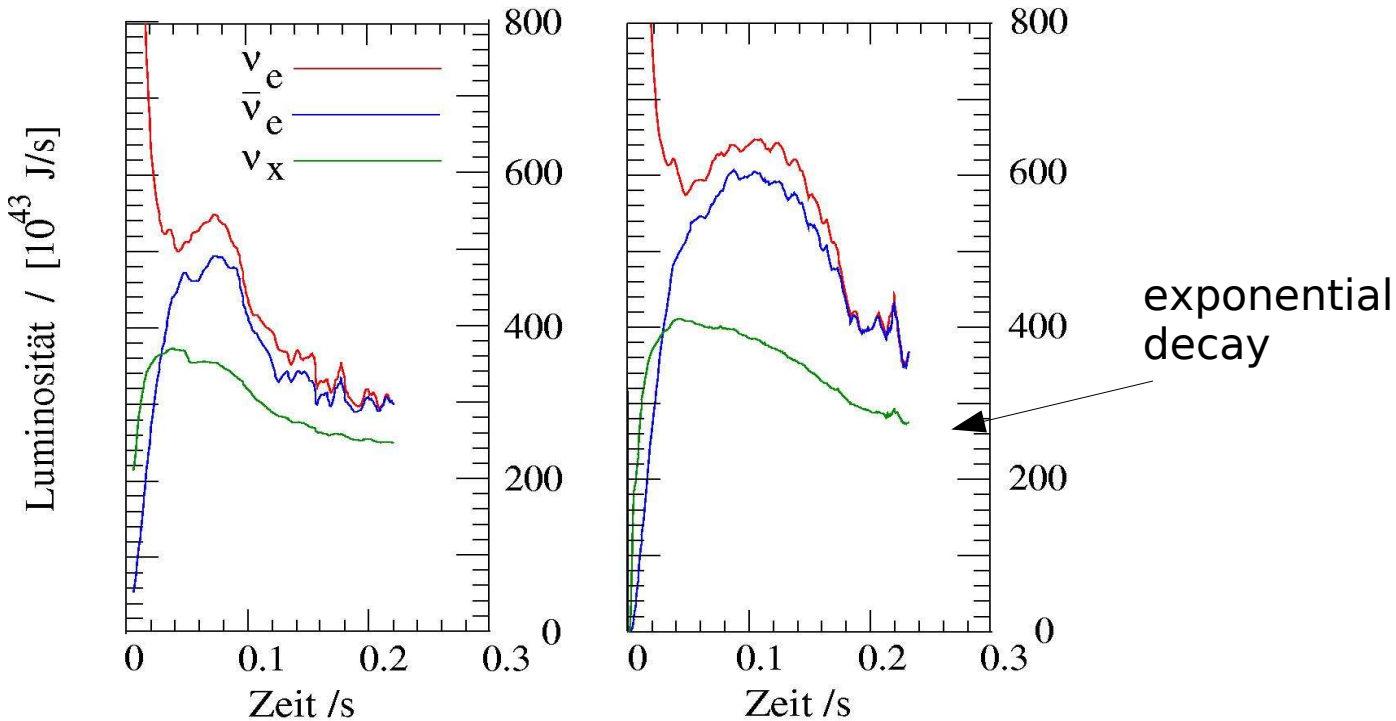
SN1987A
(february, 23rd, 1987)

(single neutrino events
measured by Kamiokande and IMB)

this is assumed to be
the typical supernova.

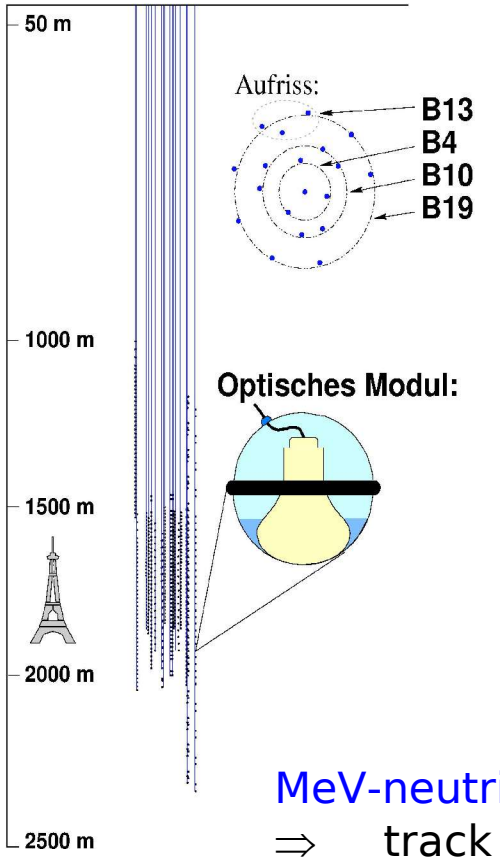
Supernovae as Neutrino Sources

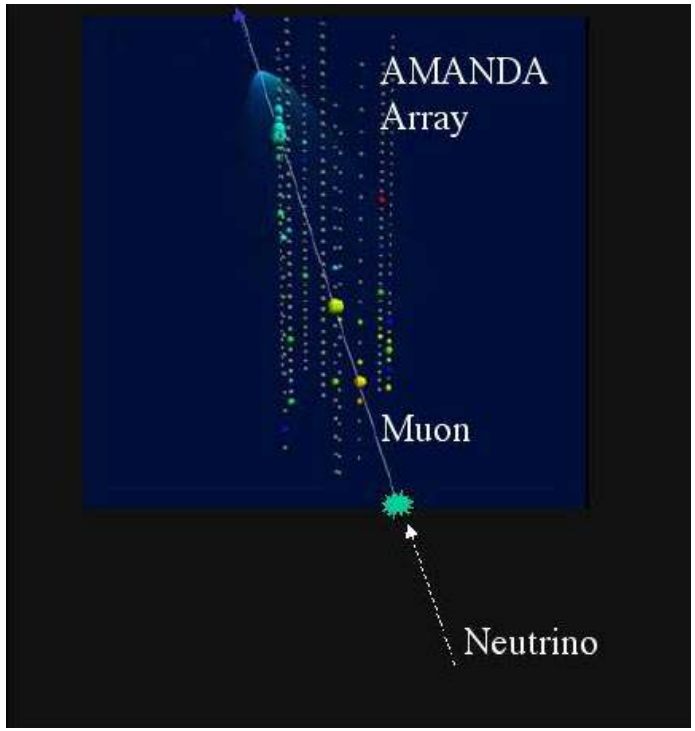
- alternatively: neutrino emissions from a simulation



simulations by Janka et al.
[PRL90,241101]

The AMANDA neutrino telescope





MeV-neutrinos: ~10 cm- tracks

⇒ track resolution is impossible

but: make use of the very low dark noise rates in the ice:

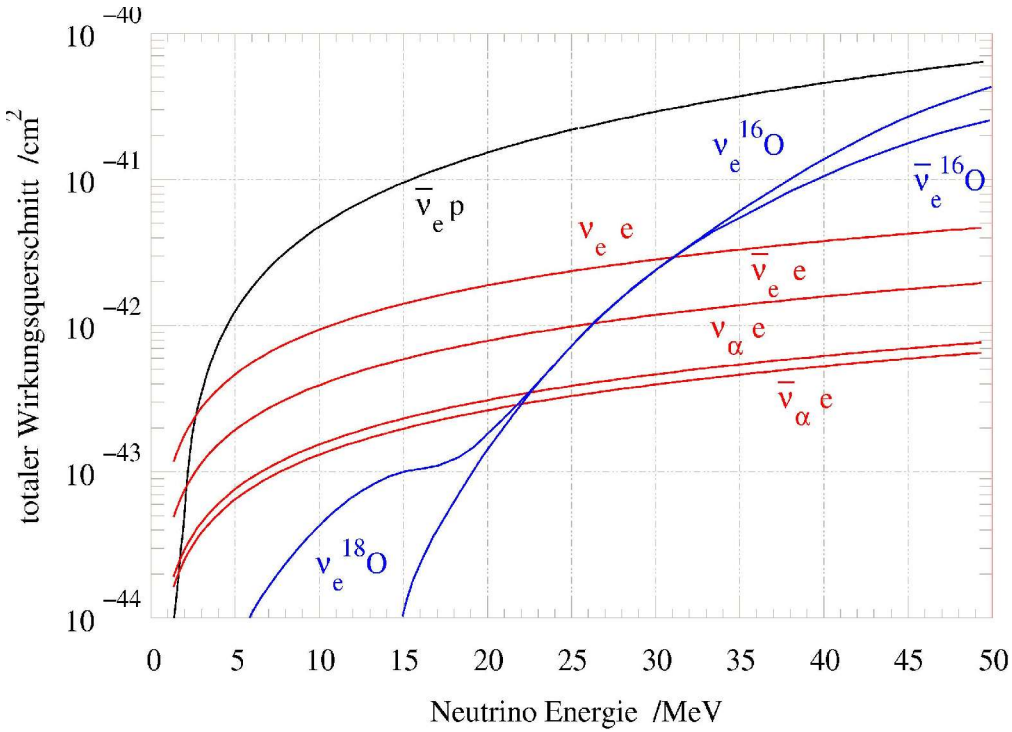
⇒ detection by a collective OM rate fluctuation

Detecting Supernova Neutrinos with AMANDA

low energy neutrino interactions with an H_2O molecule

inverse beta decays are dominant!
most important flavor: $\bar{\nu}_e$

remaining types/flavors lead to < 10 % additional light yield



we will have many of such interactions in the detector

⇒ tracks are homogenuously and isotropically distributed

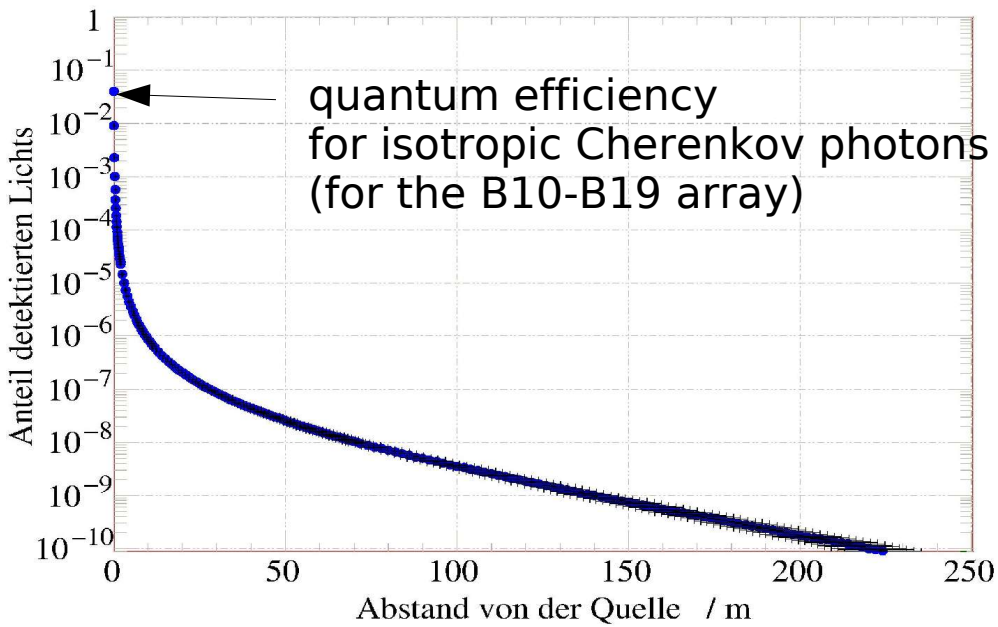
⇒ assume a homogenuous illumination of the ice

Detecting Supernova Neutrinos with AMANDA

if the light yield in the detector is characterised by N_γ / V

- how much light is seen by an individual module?

photon detection probability p(R):



(results of a MC-simulation using homogenuous ice)

define the effective volume V_{eff}:

$$V_{eff}(\gamma) = \int d^3x\, p(R) \approx 0.11\ m^3$$

number of detected photons:

$$N_{det} = (N_\gamma / V) \bullet V_{eff}(\gamma)$$

scale to other particles (e^+):

$$V_{eff}(e^+) = (N_\gamma / N_e) \bullet V_{eff}(\gamma)$$
$$\approx 316\ m^3\ (B4)\ ,$$
$$\approx 423\ m^3\ (other)$$

$$N_{det} = (N_e / V) \bullet V_{eff}(e^+)$$

Detecting Supernova Neutrinos with AMANDA

K2 neutrino interactions: (d/dt) N = 11 events in 10 seconds ≈ 1.1 Hz

distance K2-SN1987A: $R_{SN1987a}$ = 52 kPc (≈ Large Magellanic Cloud)

K2 target mass: m_{Kam2} = 2140 to

arbitrary reference distance: R_{GZ} = 7.5 kPc (≈ Milky Way center)

masse of an AMANDA-OM effective volume : $V_{eff}(e^+) \cdot \rho_{Eis}$ ≈ 400 to

(energy threshold correction)

≈1/5 ≈7

⇒ interactions in an AMANDA-II effective volume:
(for an SN in the galactic center)

$$\frac{d}{dt}(N_{Ama2}) = \frac{d}{dt}(N_{K2})\left(\frac{1}{f}\right)\frac{[\rho_{Eis} V_{eff}(e^+)]}{m_{Kam2}}\left(\frac{R_{SN1987A}}{R_{GZ}}\right)^2 \approx 12 \text{ Hz}$$

Data Analysis in Real Time

Extracting a mean collective rate deviation $\Delta\mu(t)$
of N_{OM} optical modules with mean rates $r_i(t)$
in a time intervall defined by [t , t + Δt[

$$r = \langle r \rangle_{\Delta t} = \frac{n}{\Delta t}$$

$$f(r) = \mathcal{L}(\mu) = \frac{1}{\sqrt{2\pi}\,\sigma} \exp - \frac{(r-\mu)^2}{2\sigma^2}$$

$$\mathcal{L}(\Delta\mu) = \prod_{i=1}^{N_{\mathrm{OM}}} \frac{1}{\sqrt{2\pi}\,\sigma_i} \exp - \frac{(r_i - (\mu_i + \Delta\mu))^2}{2\sigma_i^2}$$

$$-2\ln\mathcal{L}(\Delta\mu) + const = \boxed{\chi^2(\Delta\mu) = \sum_{i=1}^{N_{\mathrm{OM}}} \left(\frac{r_i - (\mu_i + \Delta\mu)}{\sigma_i} \right)^2}$$

rate of an OM

expectation value of the rate

variance of the rate

collective deviation from the “normal” expectation value

χ^2 : locating the minimum yields the most likely value $\Delta\mu(t)$
absolute value measures the uniformity of the rate increase over all OMs!

Data Analysis in Real Time

use the collective rate deviation $\Delta\mu > \eta$ as Supernova trigger

$$\Delta\mu = \left(\sum_{i=1}^{N_{\mathrm{OM}}} \frac{1}{\sigma_i^2}\right)^{-1} \cdot \sum_{i=1}^{N_{\mathrm{OM}}} \frac{(r_i - \mu_i)}{\sigma_i^2}$$

$$\sigma_{\Delta\mu} = \left(\sqrt{\sum_{i=1}^{N_{\mathrm{OM}}} \frac{1}{\sigma_i^2}}\right)^{-1}$$

simple sums,
can be calculated
in an highly efficient way

$\Rightarrow$ suitable for
real time approach
(SuperNova
Early Warning System,
SNEWS)

remember:

- every collective rate deviation $\Delta\mu$
  is a mean value for the time intervall defined by $[t,\ t + \Delta t[$
- single om rate expectation values and variances are calculated from times
  $t' \neq t,\ t' \in [(t - 5\mathrm{min}),\ (t + 5\mathrm{min})]$

Data Analysis in Real Time

detection of Supernovae

- supernovae are detected by a threshold condition $\Delta\mu > \eta$
- the threshold η therefore defines both
  detection range
  and rate of false alarms
  - SNEWS allows a strict 1 alarm/week at maximum

- problem: the distribution of $\Delta\mu$ depends on the general detector state!
  $\Rightarrow$ use $(\Delta\mu/\sigma_{\Delta\mu})$ instead (gaussian, width=1)

- using the SN trigger condition $(\Delta\mu/\sigma_{\Delta\mu}) > \xi$
  results in a time dependant detection range
  but a highly stable rate of background triggers (right at the SNEWS limit)

Data Analysis in Real Time

about data quality

- the method assumes Gaussian OM noise

- compatibility with gaussian behaviour is normally checked through fits and corresponding χ^2-probabilities

- But: fitting gaussians to spectra is too time consuming!
- However, a correlation between χ^2-probabilities and simple variables could be exploited. The variables that are used at the moment are
  - the mean values (μ)
  - the broadening ("fano") factors (f) $f = \frac{\sigma\sqrt{\Delta t}}{\sqrt{\mu}}$
  - the (absolute) skewness (|s|)

- Furthermore, global Detector conditions are required for a valid analysis
- $p(\chi^2) > 10^{-3}$
- $N_{OM} > 80$ (of 620 modules in total)

$\Rightarrow$ ~1.8 years of lifetime for the data taken from 2000-2003

Data Analysis in Real Time

coosing the optimal "time base" Δt

- to deal with Gaussian noise a minimum of $\Delta t = \Delta t_0 = 500ms$ is required

- SN1987A: all neutrinos arrived within in $\Delta t = 10s$

- for an exponentially decaying signal $\propto \exp(-t/\tau)$, $\tau \approx 3s$ [P.Rev. D60, 033007]
  $\Rightarrow$ $\Delta t = 3.8s \approx 4s$ yields the highest sesitivity

- Due to our efficient implementation
  $\Rightarrow$ multiple *simultaneous* analyses with various time bases Δt are feasible

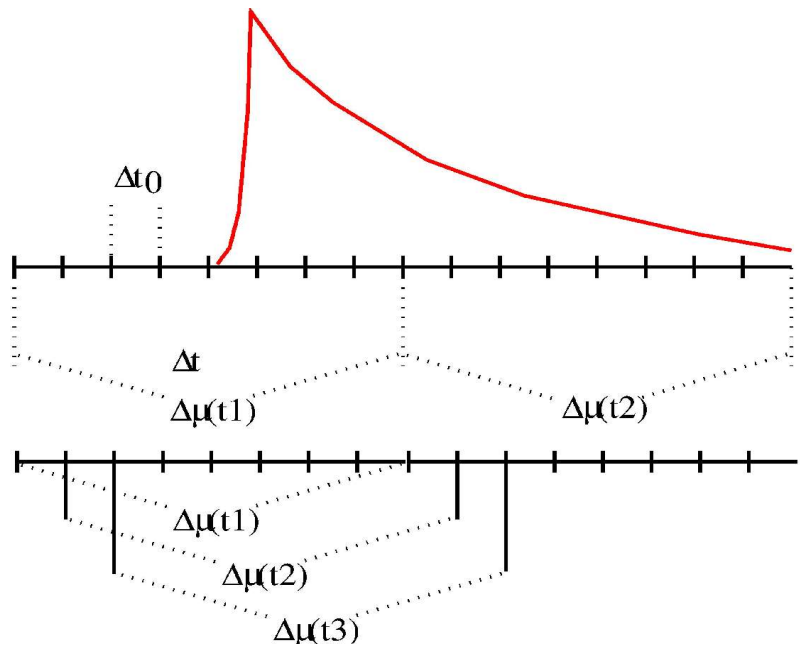
$\Rightarrow$ choose $\Delta t = 500ms$, $\Delta t = 4s$ und $\Delta t = 10s$ for the South Pole

short signals *exponential decay* ($\tau \approx 3s$) *SN1987A*

Data Analysis in Real Time

further optimizing our sensitivity

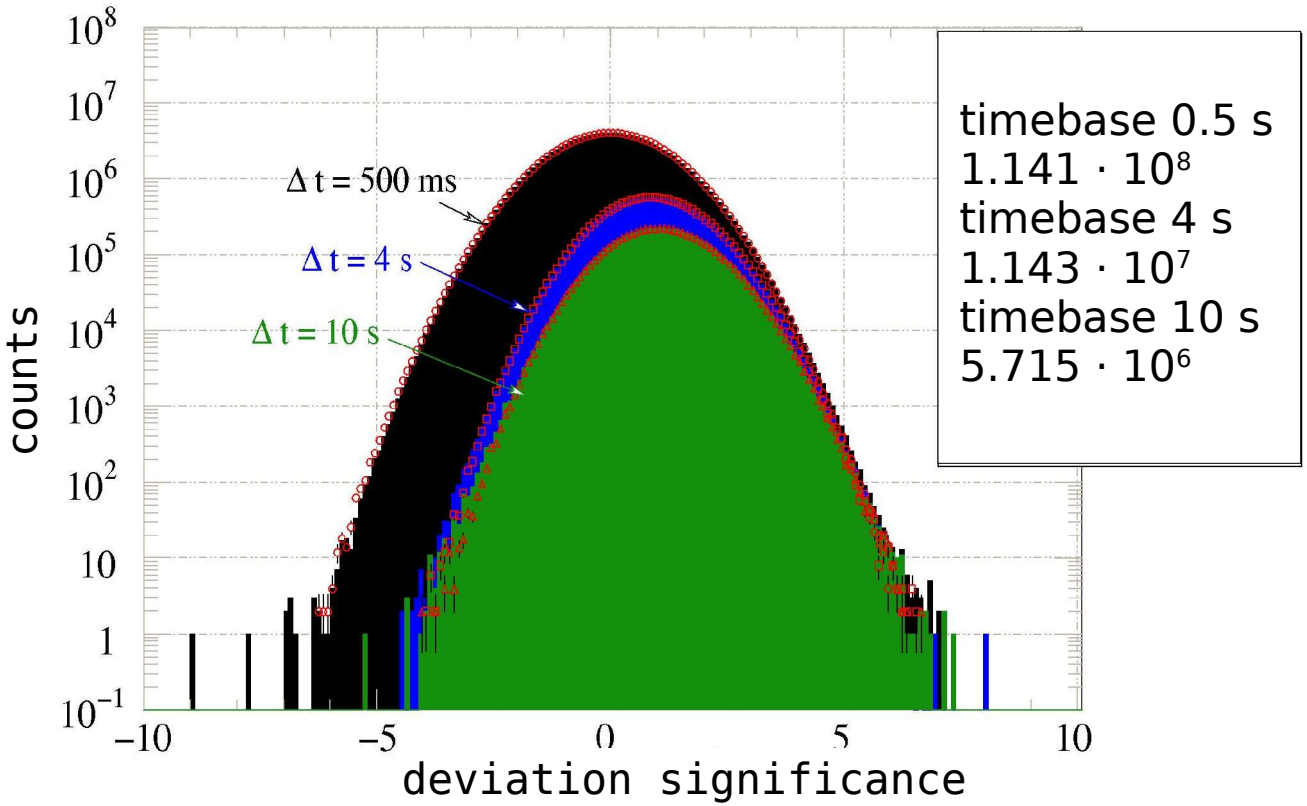
- For time bases $\Delta t > \Delta t_0 = 500ms$ the current time window Δt is also moved by only $\Delta t_0 = 500ms$ between the analysis steps



⇒ strong statistical correlations between adjacent values of $\Delta\mu(t)$
⇒ so select only the maximum among correlated values

Datenanalyse in Echtzeit
Simulation von Signal und Untergrund

- the expected statitical background is simulated accordingly
  (normal distribution, moving averages, selection of the maximum values)



hereby the SNEWS trigger threshold can be set: $\hat{\mu} = \quad (\Delta\mu/\sigma_{\Delta\mu}) > \xi_{Pol} = 5.5$

Separation of Signal and Statistical Background

simulation of the signal

add a random numer ρ to the number of measured OM pulses between t and [t+Δt[

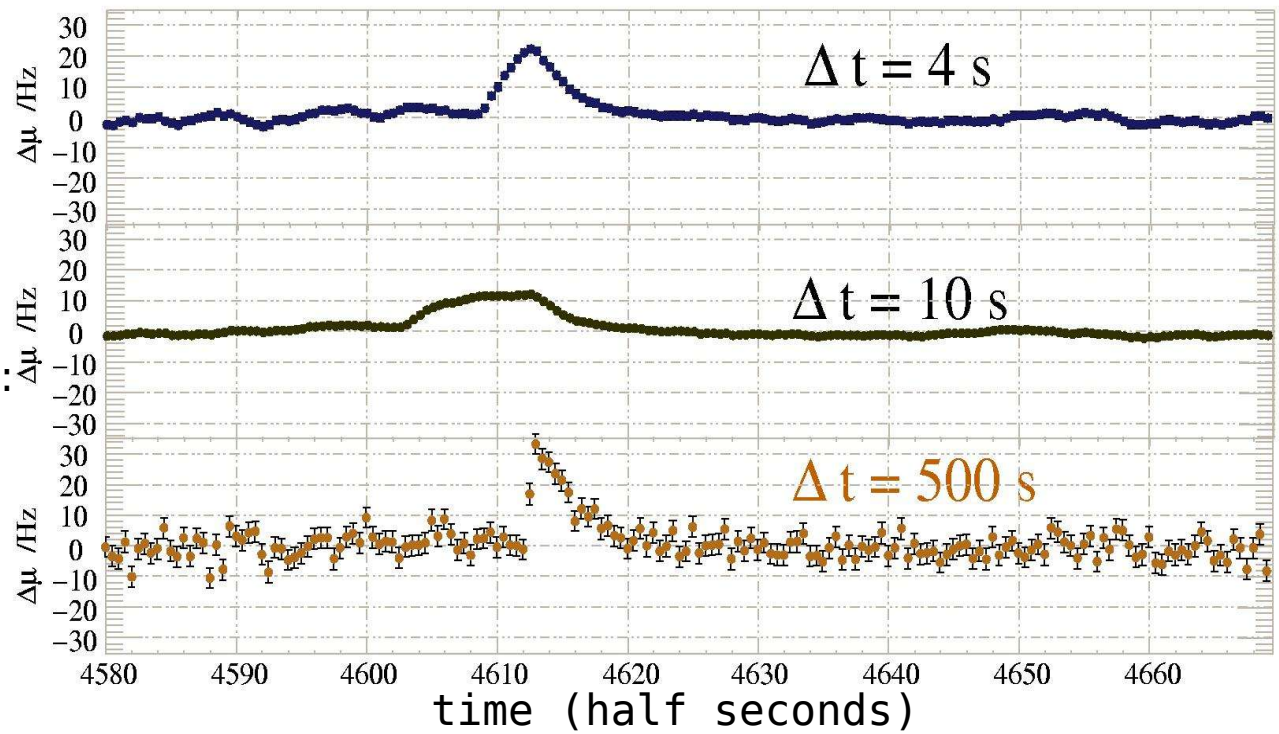
- ρ ist poissonian
- with a falling mean value proportional to exp(-t/τ), τ= 3s
- and the total signal expectation normalized to the SN1987A data

⇒ extract the signal

$\Delta\mu(t; \Delta t)$

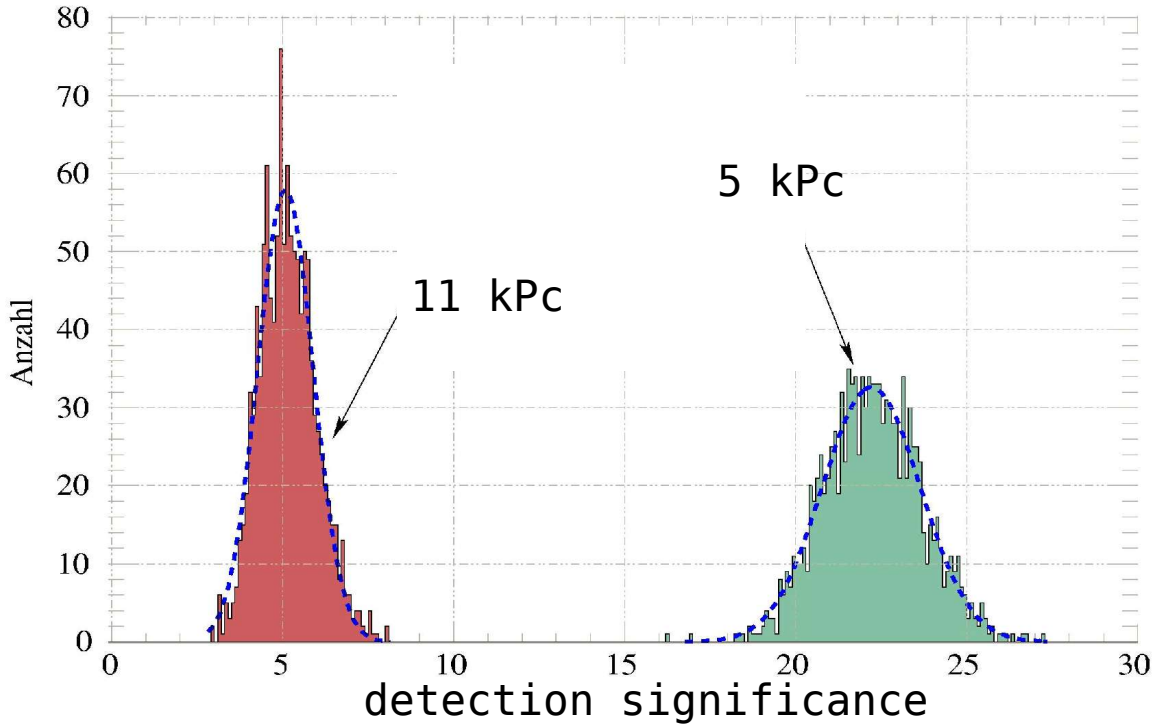
as described

result (for 7.5 kPc):



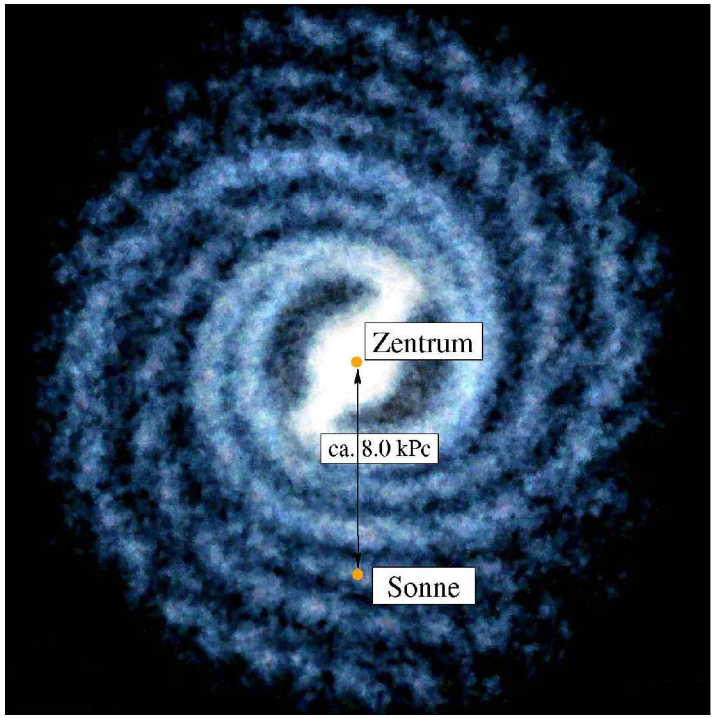
Separation of Signal and Statistical Background

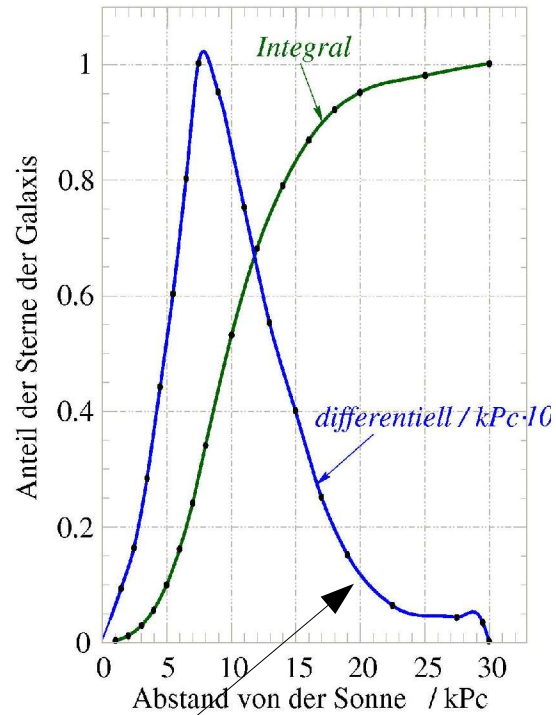
distribution of the maximum detection significance
for many SNe at two fixed distances (in the analysis based on Δt = 500ms)



Detector Performance w.r.t. the Milky Way

- galactic model of Bahcall und Soneira:



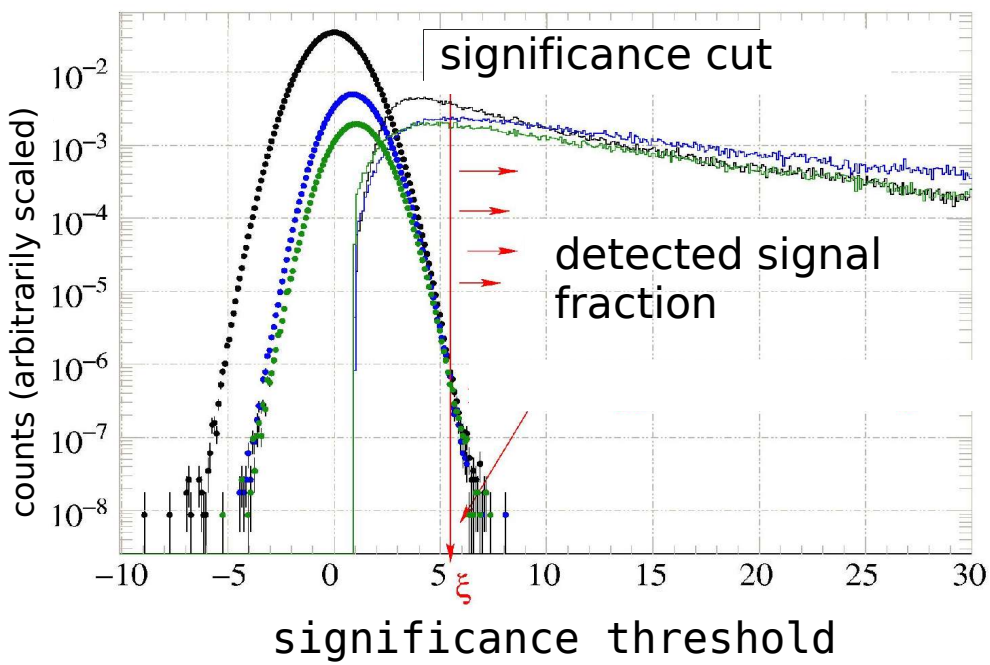


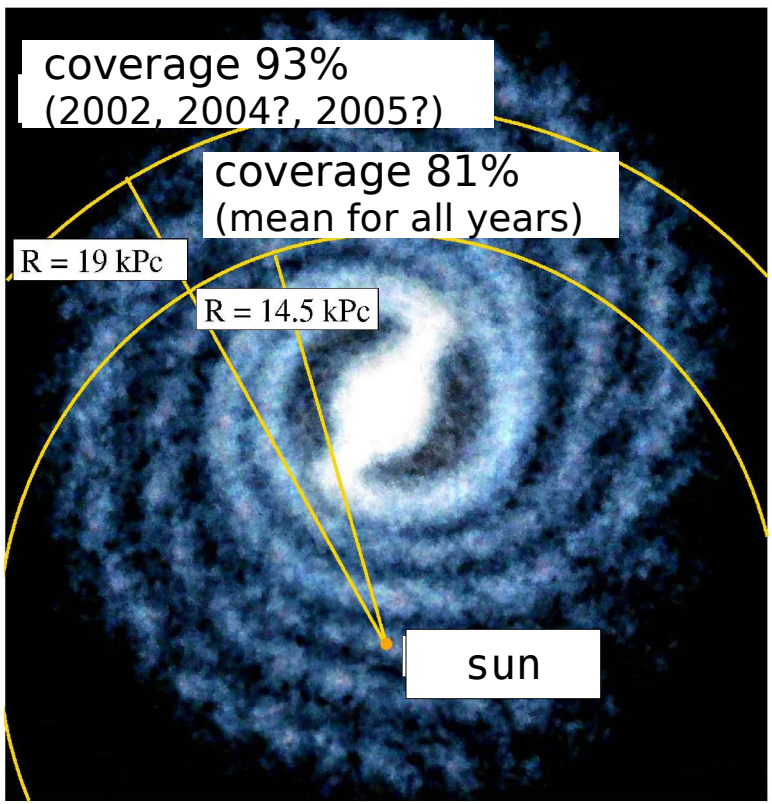
- differential curve ⇒ generate a set of simulated SN explosions with exactly THIS distribution

Results of the Analysed Data

the threshold $\xi_S < (\Delta\mu/\sigma_{\Delta\mu})$ determines

- the fraction of stars that are detected above ξ_S
- and the number of background events that are taken for SNe





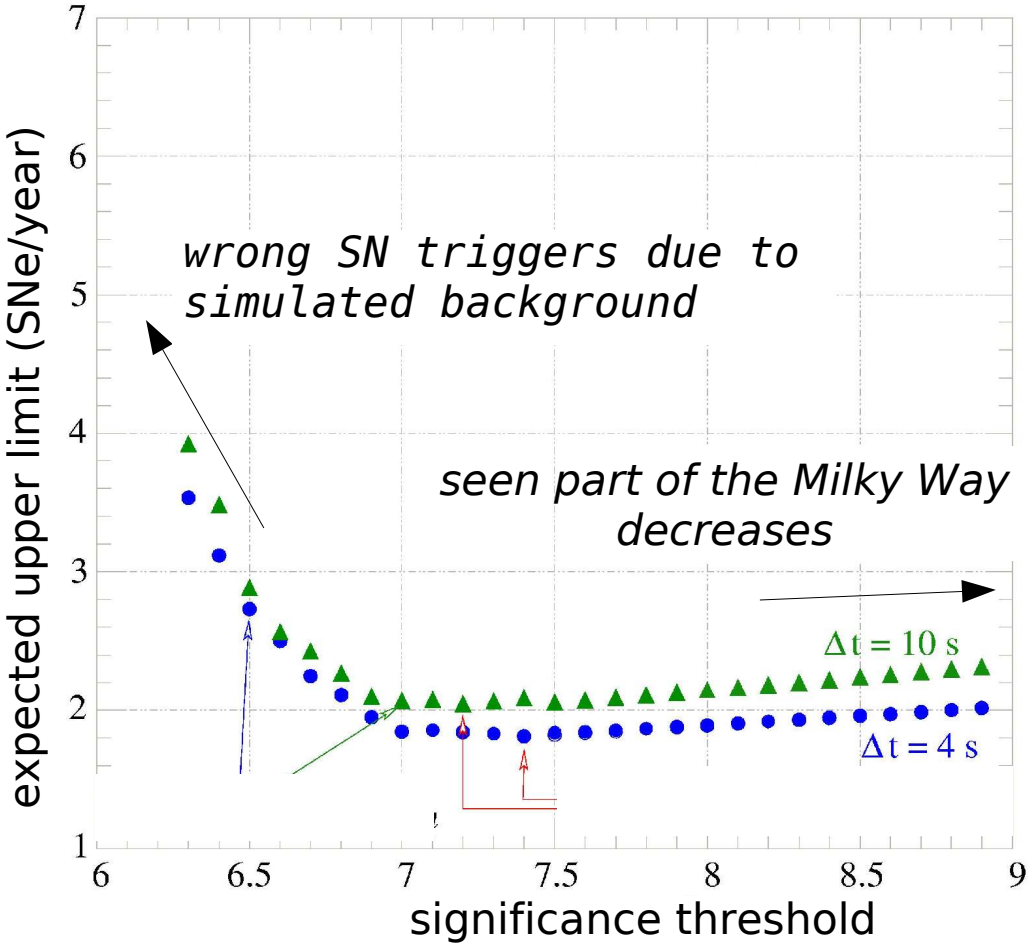
Results of the Analysed Data

setting a limit on the number of Supernovae within the Milky Way

optimizing the sensitivity:

- assumption: NO Signal!
- determine the expected for a given threshold ONLY from a simulations (“blind analysis”)

⇒ then look into the data



Results of the Analysed Data

The resulting upper limits
for the number of Supernova explosions within the Milky Way
are for the analysis based on $\Delta t = 4s$

$$r_{\text{Milky Way}} < 3.2 \text{ /year}$$
$$\langle r_{\text{Milky Way}} \rangle < 1.8 \text{ /year}$$

and for $\Delta t = 10s$ von

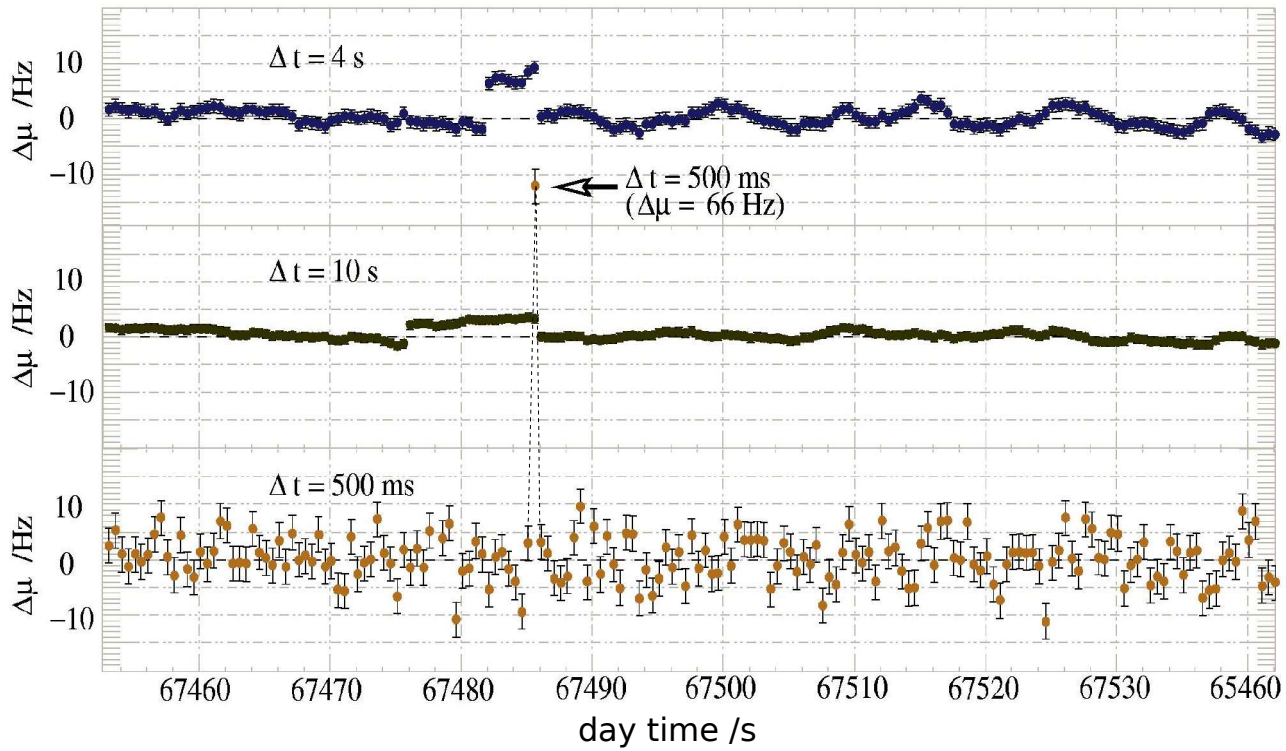
$$r_{\text{Milky Way}} < 3.5 \text{ /year}$$
$$\langle r_{\text{Milky Way}} \rangle < 2.1 \text{ /year}$$

(for a confidence level of 90%).

In both analyses the data yields
ONE Supernova Candidate Event
above the optimal sensitivity threshold ξ!

Results of the Analysed Data

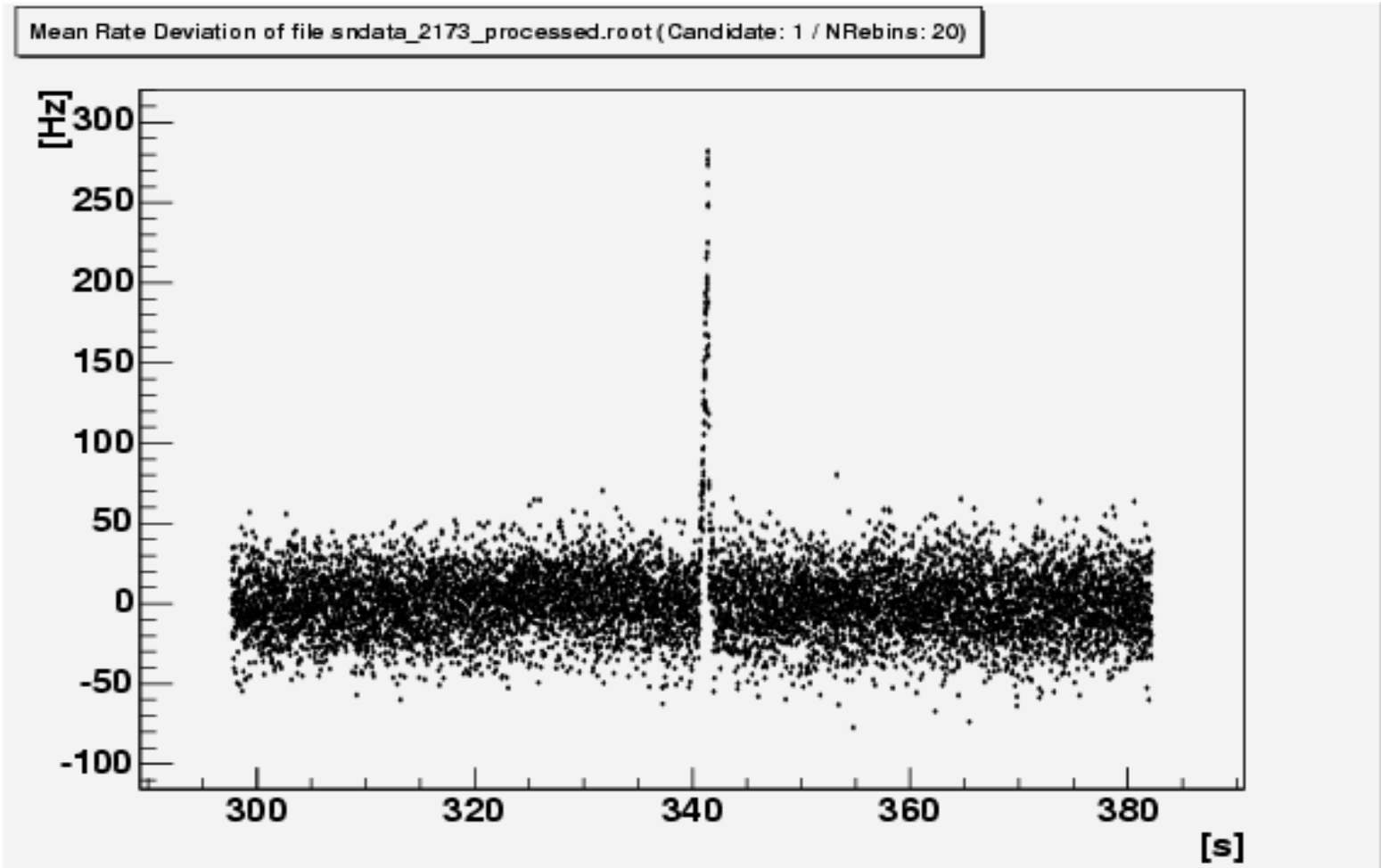
one Supernova Candidate Event (?)



(march, 3rd, 2000)

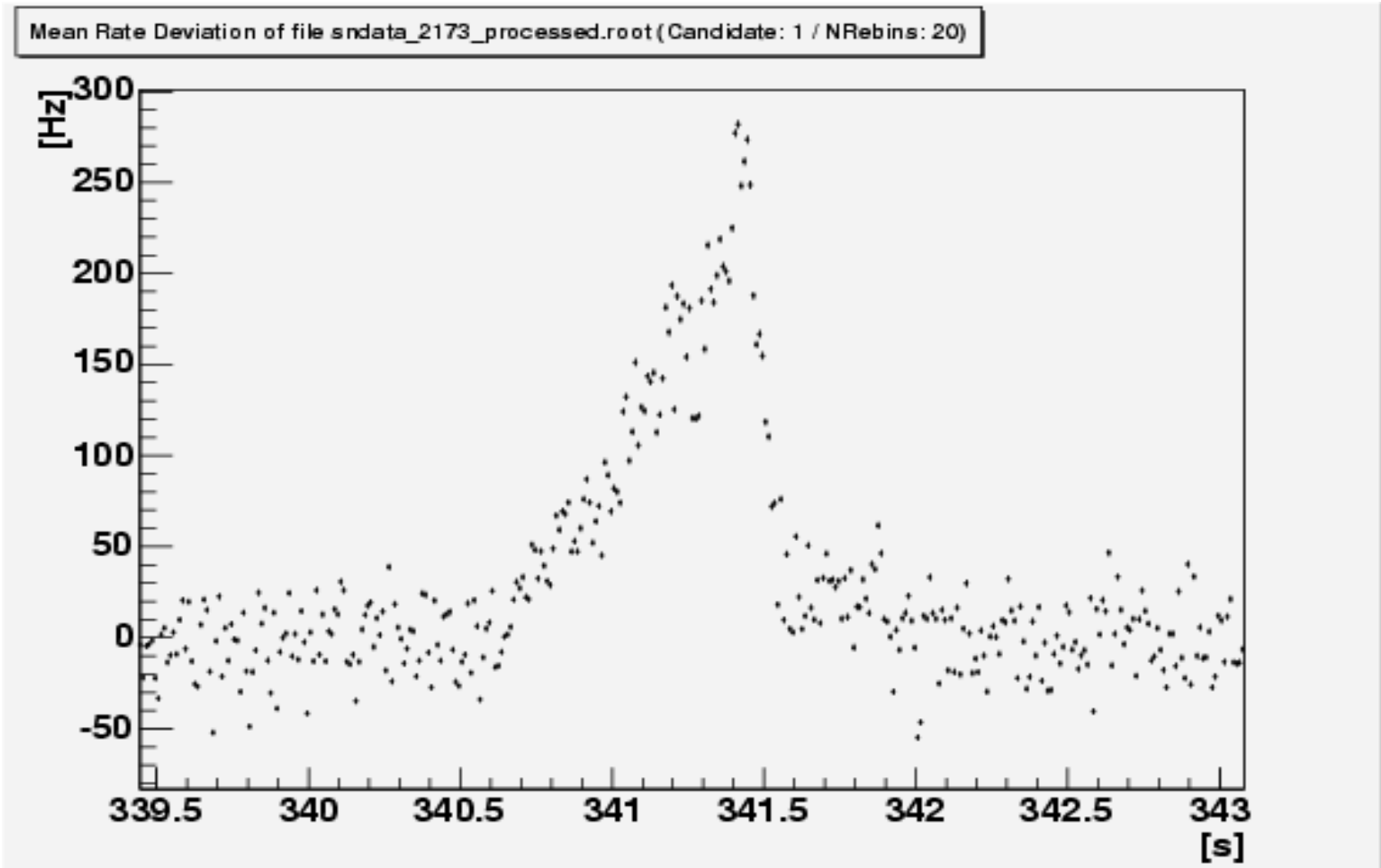
Ongoing work

Newer Supernova Candidate Events are resolved down to 10ms



Ongoing work

Newer Supernova Candidate Events are resolved down to 10ms



Ongoing work

What causes these events?

- The events do not appear in an easy pattern and are not obviously correlated with bad weather.

- There is a non neglebible difference between Simulation and Data for $\Delta t = 0.5s$ (on low timescales), which flattens out for higher timescales

- This could be due to
  - an unprecise simulation of our background
  - unstable HV, electronic noise
    - or possibly even “new physics” (*a slow particle*?)

    ....and is being investigated.

some new names:
Alexander Piegsa, Rebecca Gozzini, Thomas Kowarik

Summary and Outlook

- data from 2000-2003 has been analysed:

$\Rightarrow$ at $\geq$ 90% confidence level: $r^{SN}_{\text{Milchstraße}} < 3.2$ /year

(if SN1987A was a typical Supernova and Supernova progenitors are distributed within the galaxy as described by Bahcall and Soneira)

- the real time analysis is stable since june, 3rd, 2004.

- information transfer by Iridium has been activated a week ago.
- AMANDA is going to contribute to SNEWS soon (now: test phase).

(the Iridium beast is always good for another surprise)

- at the allowed rate of fake triggers (1/week)

$\Leftrightarrow$ 81% of the galaxy is seen with a data quality as from 2000-2003

$\Leftrightarrow$ 93% of the galaxy is seen with as in 2002 and (prel. also in) 2005

- we're investigating our not yet fully understood sample of SN candidates