

Search for High Energetic Neutrinos from Supernova Explosions with AMANDA

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This analysis searches for high energetic (TeV) neutrinos emitted from young supernova shells on a typical time scale of two weeks [1] using the data taken with the AMANDA-II neutrino telescope between 2000-2006 [2]. In this sample no steady point sources have been discovered so far. A new likelihood based method which searches for directional and temporal coincidences between neutrino events and known extragalactic supernovae is used.

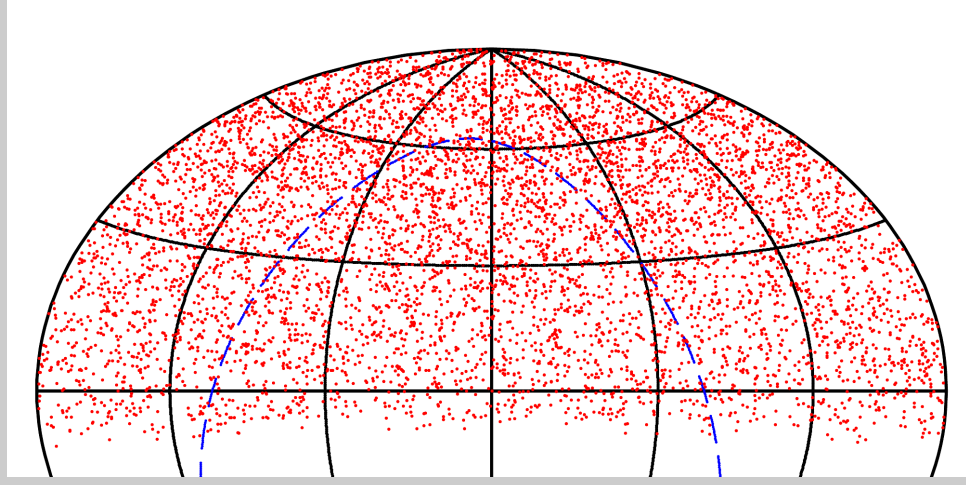


Fig. 1: Equatorial sky-map of the experimental AMANDA data.

Physics case

- Cosmic rays up to the knee are believed to be produced in supernova remnants on a typical time scale of a thousand years after the explosion while the origin of cosmic rays beyond the ankle is presumably extragalactic.
- The other cosmic rays might be accelerated with the rotational energy released by a pulsar e.g. via magnetic dipole radiation. The interaction of these particles with the expanding supernova envelope can produce secondary particles that decay into neutrinos and other particles [3].
- Characteristic time scale for the neutrino emission is determined by the times at which the:
 - pion decay time is less than the time between two nuclear collisions (t_c),
 - cosmic rays escape from the envelope without nuclear interaction (t_e).

Supernova neutrino luminosity (energy release per time) as a function of time (light curve) was elaborated into a model [4]:

$$L(t) = \left(1 - \exp\left(-\left(\frac{t_c}{t}\right)^2\right)\right) \cdot \frac{1}{1 + \left(\frac{t_e}{t}\right)^3} \cdot \lambda L_0 \left(1 + \frac{t}{\tau}\right)^{-2}$$

Shape and length of the light curve depend on the supernova envelope mass, expansion velocity and uniformity, characteristic pulsar breaking time τ , maximum pion energy.

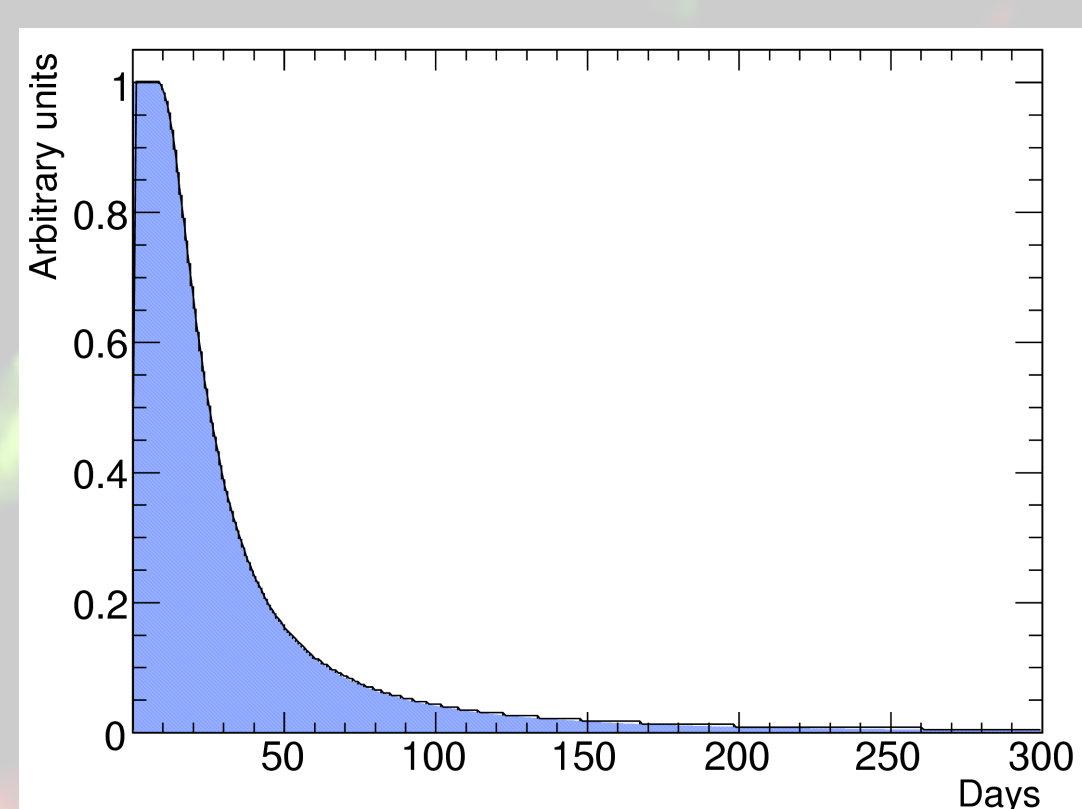


Fig. 2: Supernova neutrino light curve for typical model parameters.

Expected energy spectrum

E^{-2} with energy cut-off at 10^{14} eV

Likelihood approach

- A small neutrino signal is expected, hence the supernovae are stacked in order to enhance the sensitivity. Therefore a likelihood method capable of stacking is developed.
- Observables a of neutrino events are:
 - reconstructed neutrino direction,
 - arrival time.

Principal idea

- Compare all neutrino events to every relevant core-collapse supernova.
- Evaluate likelihood ratio (LHR) between signal and background $LHR_{\text{event}} = \frac{L(\text{Sig}|\vec{a})}{L(\text{BG}|\vec{a})}$ hypothesis.
- Sum over all events for a cumulative result.

Adaptation for supernova analysis

- Sum signal likelihood for all supernovae, because events can come from every supernova.
- Rewrite likelihood with Bayes' theorem.

Advantage

Irrelevant neutrino supernova combinations automatically receive a small weight and no optimisation on the number of stacked supernovae is needed.

Fig. 3: PDF derived from angular difference between neutrino and reconstructed muon direction for expected energy spectrum.

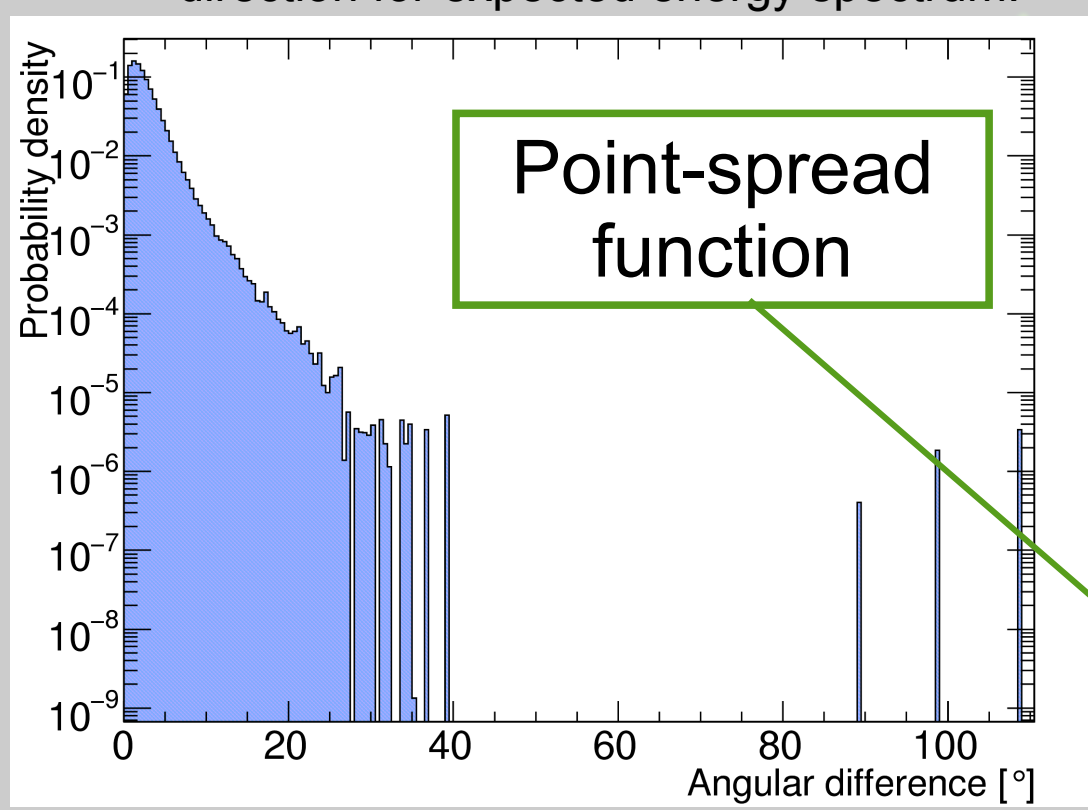


Fig. 4: PDF of the zenith angle dependence of the AMANDA angular acceptance for expected energy spectrum.

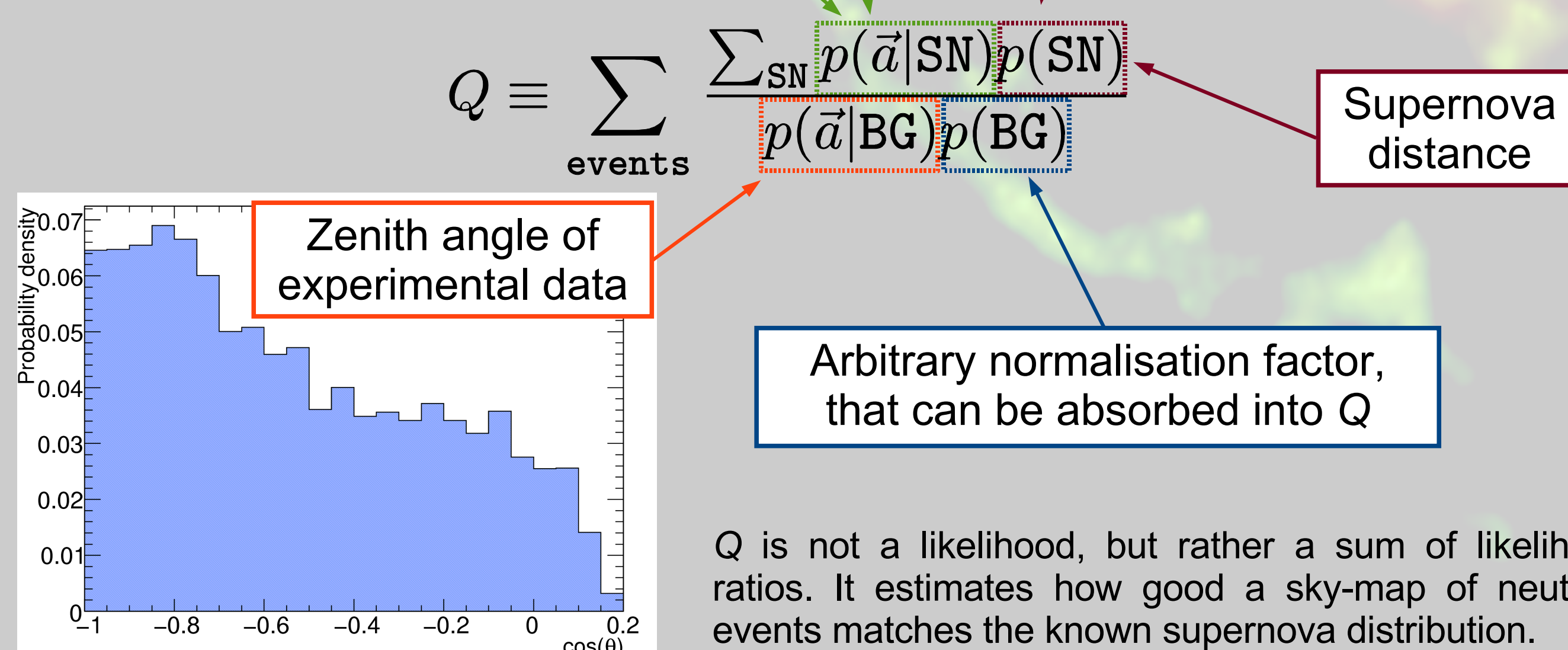
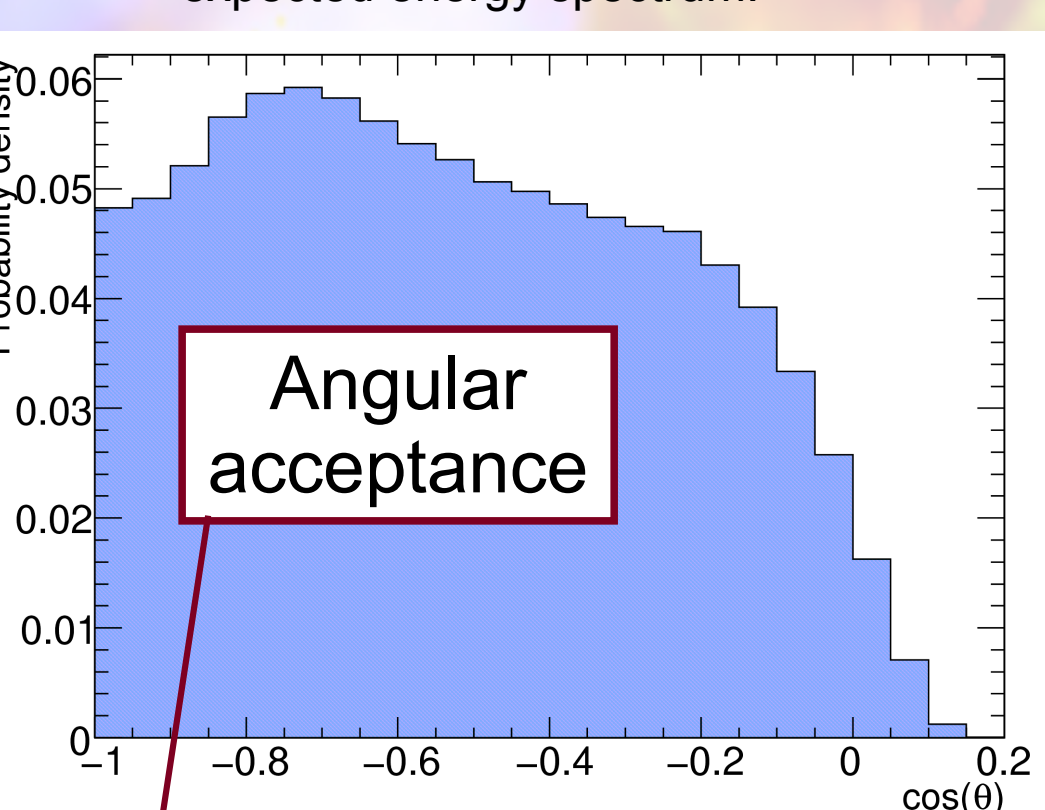


Fig. 5: PDF derived from zenith angle distribution of the experimental data.

References

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- [4] H. Sato, *Pulsars Covered by the Dense Envelopes as High-Energy Neutrino Sources*, Progr. Theor. Phys., 58 (1977), 2, 549
- [5] List of supernovae from the CBAT, <http://cfwww.harvard.edu/iau/lists/Supernovae.html>
- [6] Asiago Supernova Catalogue, <http://cdsarc.u-strasbg.fr/vizbin/Cat?B/sn>
- [7] Sternberg Astronomical Institute (SAI) Supernova Catalogue, <http://www.sai.msu.ru/sn/sncat/>
- [8] G. J. Feldman, R. D. Cousins, *Unified Approach to the Classical Statistical Analysis of Small Signals*, Phys. Rev. D, 57 (1998), 7, 3873

Supernova catalogue

- New catalogue of relevant supernovae was created from three existing catalogues [5][6][7].

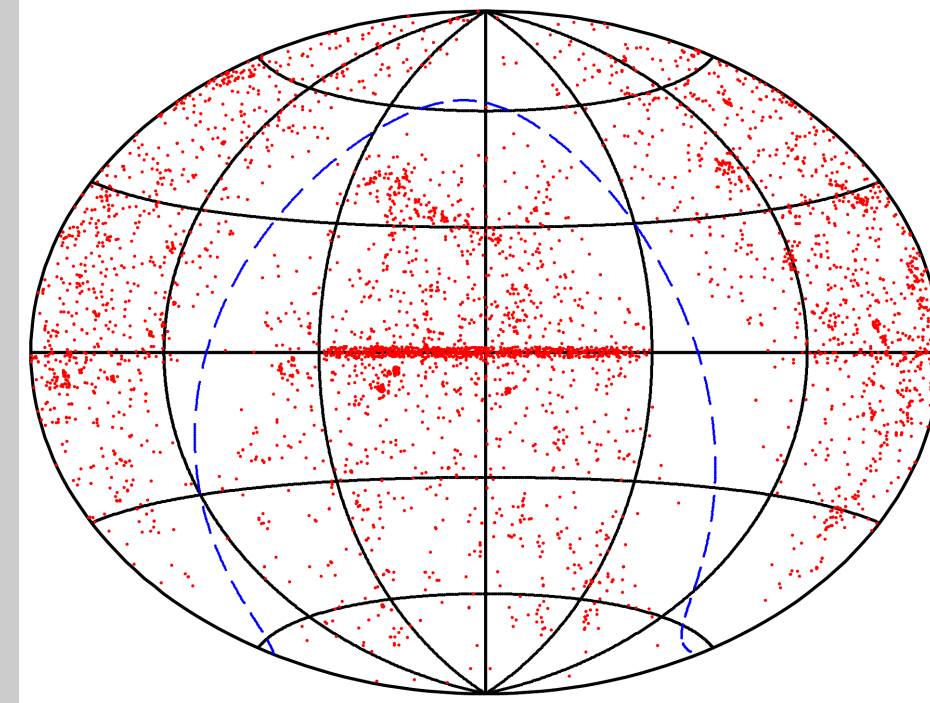


Fig. 6: Distribution of the observed supernovae in equatorial coordinates.

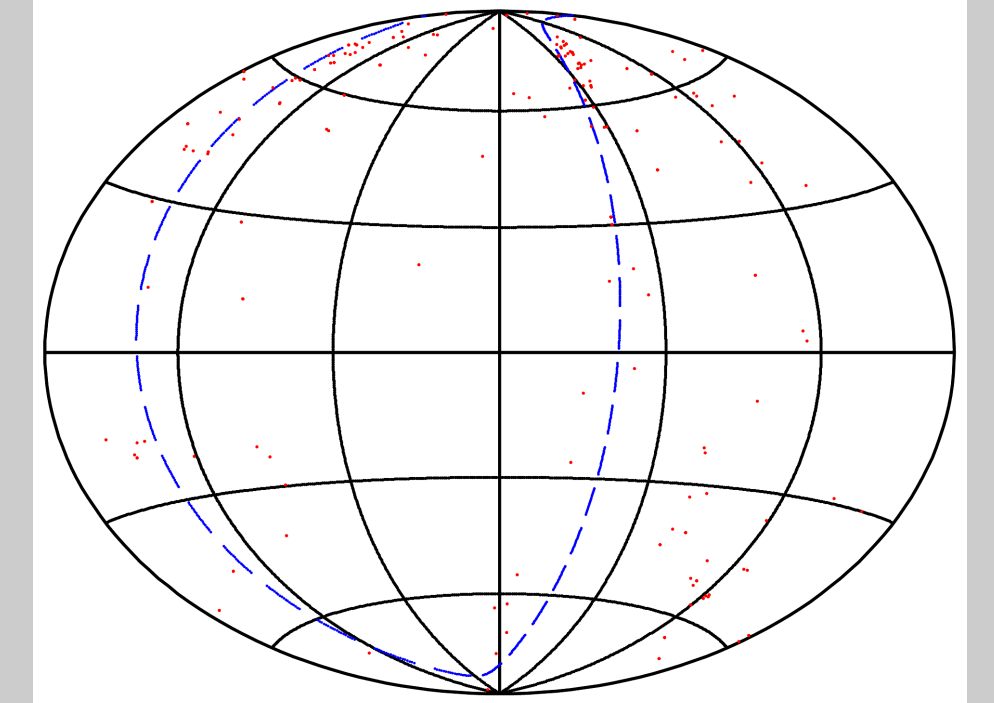


Fig. 7: Distribution of supernovae with a host galaxy closer than 20 Mpc in galactic coordinates

- Consistency checks between different catalogues resolve inconsistencies in the listed information.
- The redshift distance estimate is replaced by the distance to the host galaxy from NASA/IPAC Master list of galaxy distances (NED1D) for an accurate flux estimate.
- The model input is not constrained by observation. Hence, all supernovae are treated equally and three sets of input parameters are chosen. One set consists of typical parameters, while the other two result in very short and long light curves.
- The explosion date is unknown, sometimes the date of the optical maximum, but in most cases only the date of discovery is known. Using well observed supernovae (e.g. 1999ex and 2008D) and the time between optical maximum and discovery the explosion date can be estimated.

Likelihood light curves

- Generic light curves are constructed for the likelihood according to the model taking into account the uncertainty of the explosion date.
- Each light curve (typical, short, long) imitates the corresponding model light curve, but the plateau is lengthened by the uncertainties of the explosion date.

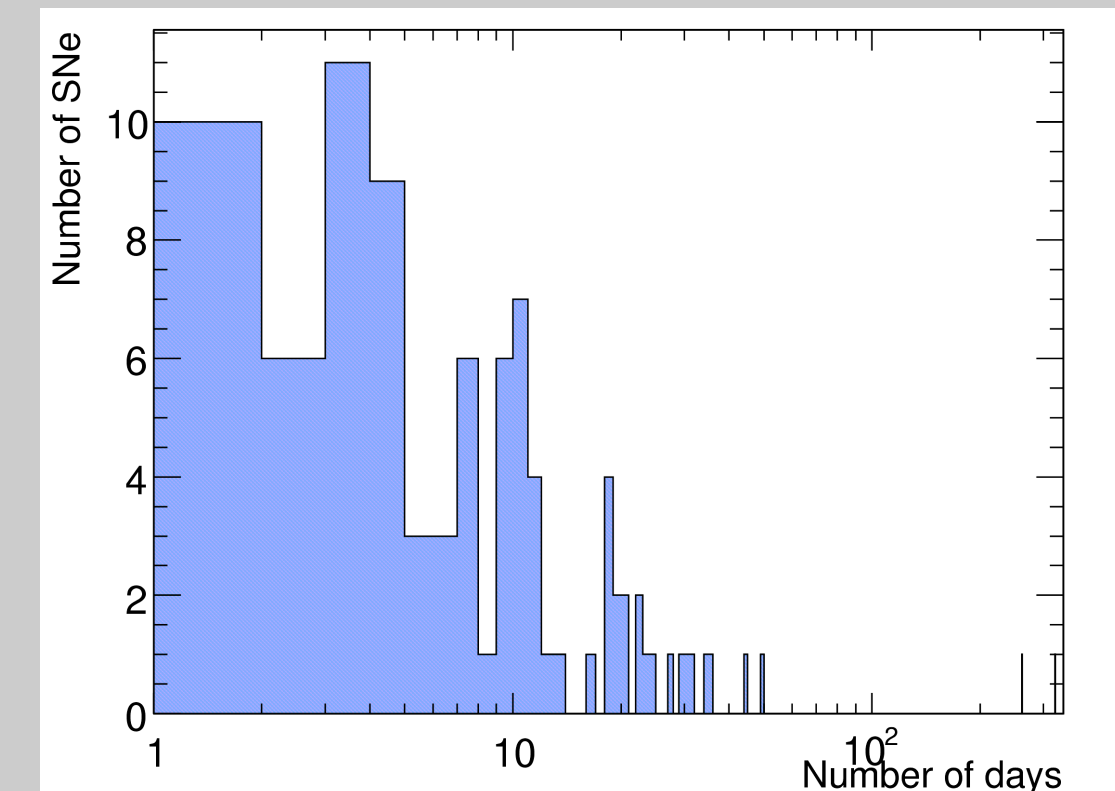


Fig. 8: Days between optical maximum and date of discovery.

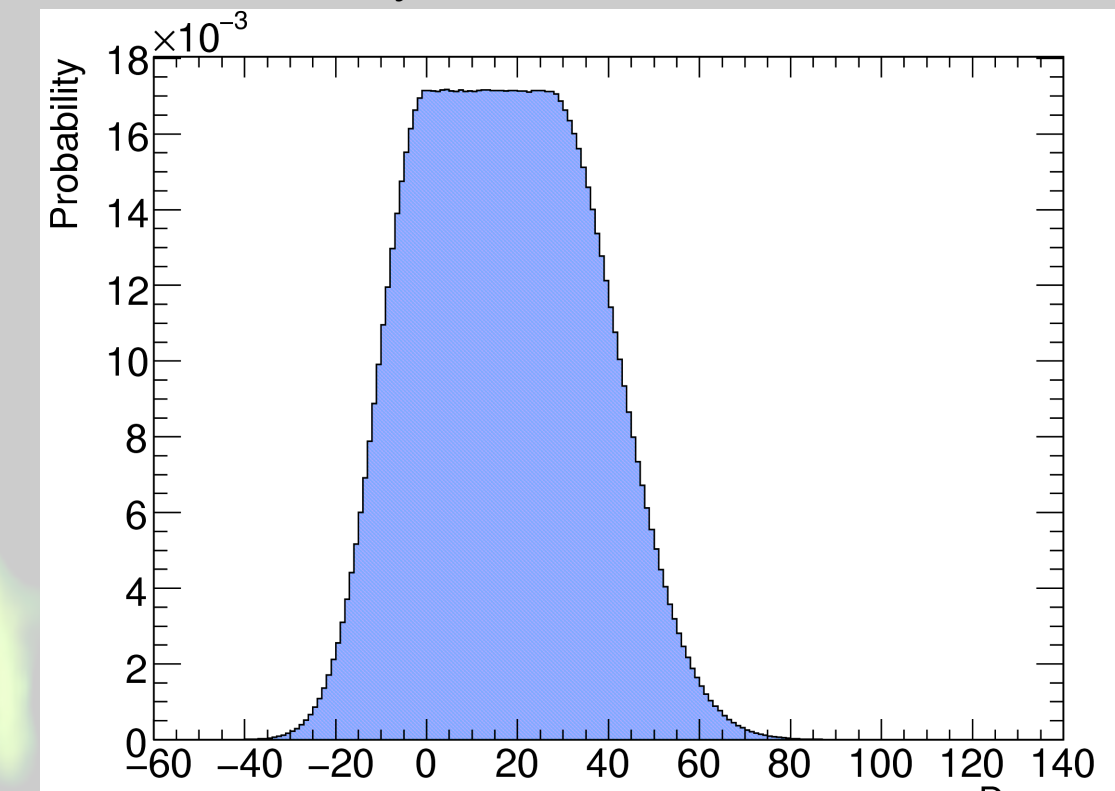


Fig. 9: Generic light curve tailored for the typical model parameters. The plateau is lengthened by the uncertainty in the explosion date.

Simulation

This analysis used data blindness. Therefore simulations prior to the analysis are needed in order to estimate the sensitivity.

Background simulation

- Right ascension and declination are randomised according to the distributions of the experimental data.
- A time is diced according to the AMANDA live-time.

Signal simulation

- The number of neutrinos from each supernova is diced according to a Poisson with a distance weighted mean.
- The time is simulated according to the assumed pulsar model (typical, short, long) with a random explosion date.
- The AMANDA reconstruction error, temporal and angular acceptance (including systematic uncertainties) are simulated.

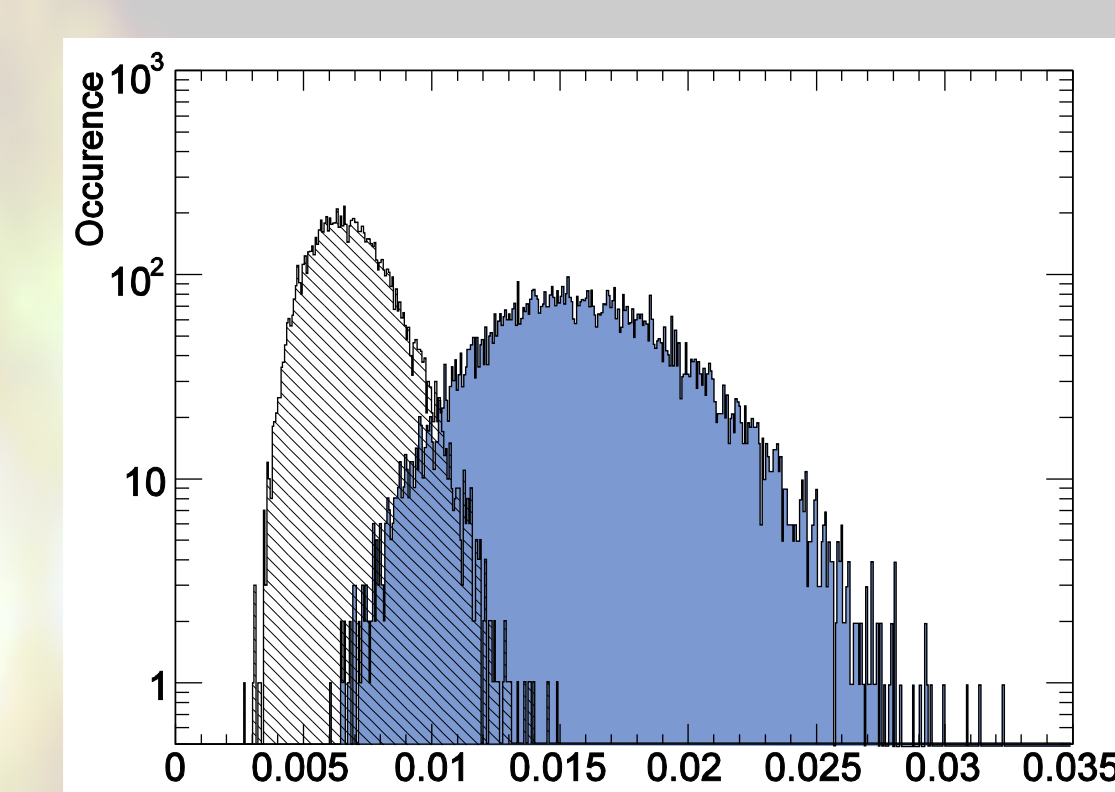


Fig. 10: Q distribution for signal (blue) and background only (black)

Results

- Experimental data was analysed with the typical likelihood light curve.
- **No deviation from the background only hypothesis found.**
- Feldman-Cousins approach to the analysis of small signals [8] is used to derive limits from 90% confidence belts.
- 3 limits for the different pulsar models can be derived
- Nearest and best visible supernova for AMANDA: SN2004dj

Limits on the number of observed signal neutrinos

Pulsar Model	Typical	Short	Long
All SNe	< 5.4	< 4.1	< 67.3
SN2004dj	< 1.0	< 0.9	< 5.9

Flux limit (assuming typical model, during plateau length of 12 days)

$$\frac{d\phi}{dE} \cdot E^2 < 5.2 \times 10^{-6} \frac{\text{GeV}}{\text{cm}^2\text{s}}$$

Limit for all supernovae

$$\frac{d\phi}{dE} \cdot E^2 < 8.4 \times 10^{-7} \frac{\text{GeV}}{\text{cm}^2\text{s}}$$

Limit for SN2004dj

Limits are valid from 1.1 TeV to 84 TeV

Assuming no cut-off in neutrino energy spectrum

$$\frac{d\phi}{dE} \cdot E^2 < 3.9 \times 10^{-6} \frac{\text{GeV}}{\text{cm}^2\text{s}}$$

Limit for all supernovae

$$\frac{d\phi}{dE} \cdot E^2 < 7.5 \times 10^{-7} \frac{\text{GeV}}{\text{cm}^2\text{s}}$$

Limit for SN2004dj

Limits are valid from 1.7 TeV to 2 PeV

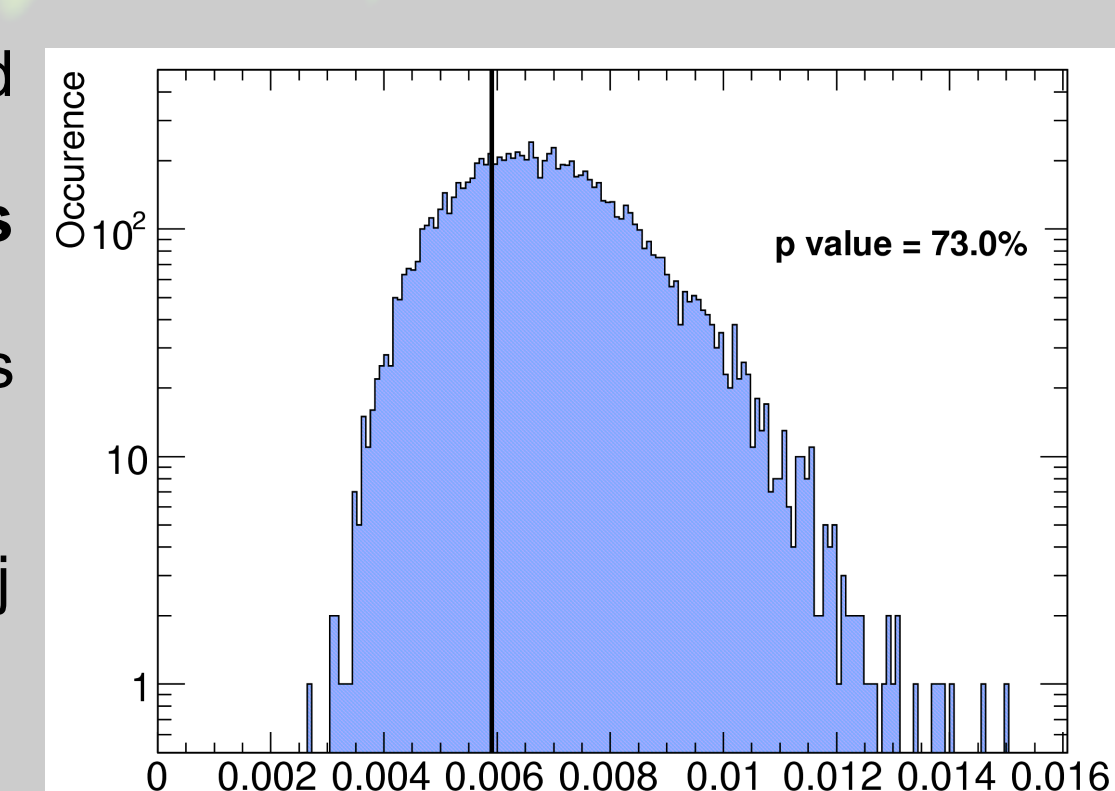
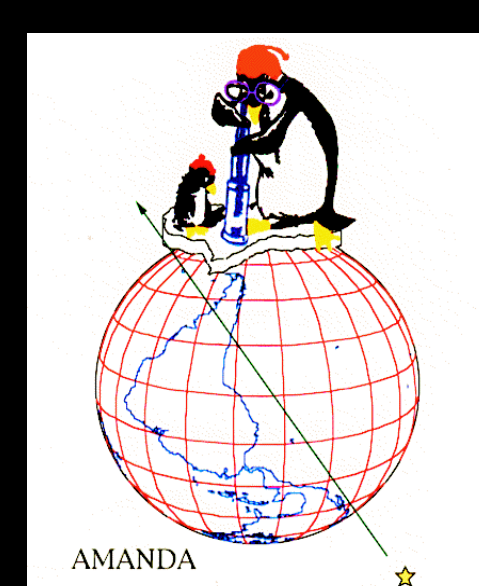


Fig. 11: Q result from experimental data (black line) in background simulation



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