# Seasonal Variations of Atmospheric Neutrinos

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*This work reports about a study of the seasonal variations in the atmospheric neutrino flux with the AMANDA-II-detector. Variations in the upcoming neutrino flux from the northern hemisphere are due to density variations in the atmosphere. A similar effect was already measured with AMANDA on the downgoing atmospheric muon flux around the South Pole. For this work we used neutrino data from the final sample of the years 2000 to 2003. The goal is to investigate whether the AMANDA-II-detector shows enough sensitivity to measure an effect on atmospheric neutrinos.*

## 1 Introduction

### 1.1 Atmospheric neutrinos

Atmospheric neutrinos are produced from interactions between cosmic rays and particles of the Earth's atmosphere.

When cosmic gamma rays or protons reach the Earth and interact with the atmosphere, pions and kaons are produced. The decay of these particles produces muons and neutrinos. Neutrinos also arise from the decay of muons.

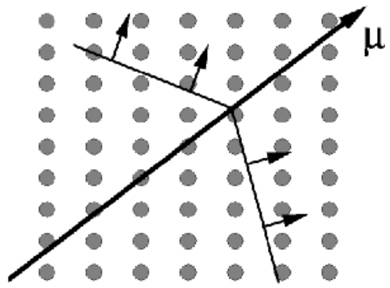


Fig. 1: *Cherenkov cone of a muon*

$$
\begin{aligned}
X + p/\gamma &\rightarrow \pi^\pm/K^\pm + ... \\
\pi^\pm/K^\pm &\rightarrow \mu^\pm + \nu \\
\mu^\pm &\rightarrow e^\pm + \nu + \bar{\nu}
\end{aligned}
$$

Because of their weak interactions neutrinos are able to penetrate the Earth and thus neutrinos coming from the northern hemisphere can be detected by the AMANDA-II-detector in the ice at the South Pole. That happens in case of interactions between neutrinos and nuclei in the rock or ice near the detector. With a high probability a muon arises from this keeping the direction of the parent neutrino. Due to the energy loss in matter the muon produces cherenkov photons (Fig. 1). Because of travelling faster than the speed of light in ice the light is emitted in the shape of a cherenkov cone.

This cherenkov light is detected by a matrix of photomultipliers. The direction of the muon tracks, and thus also the direction of the neutrinos, can be reconstructed by measuring the arrival time of the photons.

### 1.2 Density variations of the Earth's atmosphere

To measure seasonal changes in the neutrino flux we observe with AMANDA the northern hemisphere.

In the northern winter, between September and March, the air temperature on the northern hemisphere decreases. That leads to an increase of the air density. In contrast to that the temperature increases in the northern summer and the density of the atmosphere is lower.

With a higher atmospheric density the probability for decays of pions and kaons decreases, because of earlier interactions with other atmospheric particles. This means a lower production of high energy neutrinos. Whereas a lower density raises the fraction of decaying pions and kaons and thus the number of incoming neutrinos.

According to these facts, we expect during the northern winter a decreasing number of upcoming neutrinos and during the northern summer an increasing number .

### *1.3 Observation area*

Like already mentioned in the last section we look with AMANDA to the northern hemisphere. Thereby we can be quite sure that a possible modulation of the event rate due to seasonal variations comes from seasonal variations of the neutrino flux. If we incorporated parts of the southern hemisphere the data would be mixed up with fake events from atmospheric muons. The so called fake events from energetic downgoing muon bundels mean signals that reach the detector horizontally. They arise from the different degrees of transmittance of the ice layers. When a layer of a high transmittance is very thin and followed by a high absorbing layer the arriving photons loose their vertical propagation component due to absorption and go on propagating horizontally along that transmitting ice layer. This leads to a wrong reconstruction of a muon track after detecting these photons.

To be able to see seasonal variations as clearly as possible we have selected as observation area a declination range from 60 to 90 degrees. That corresponds to a latitude between 30 and 90 degrees. Fig. 2 shows the relation to the geographical latitudes.

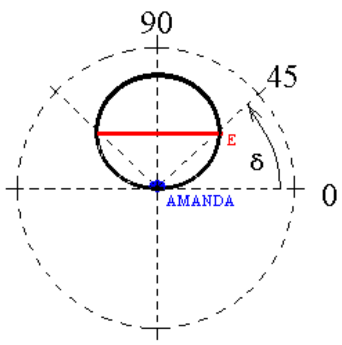


Fig. 2: *Meaning of the declination angle*

Around the North Pole the biggest differences between summer and winter are expected. On the other hand the area must not be chosen too small in order to have enough statistics to get still a representative result.

Independent from this observation events coming from a declination range between 15 and 30 degrees (southern hemisphere) were additionally investigated. An opposite effect is expected and compared with that one around the North Pole.

These two declination ranges provide also similar event rates.

### *1.4 Seasonal variations of atmospheric muons*

A similar investigation of atmospheric muons was already done in detail several times. These muons are produced from pion and kaon decay in the atmosphere as described in subsection 1.1 and detected by AMANDA above the South Pole as downgoing particles. Fig. 3 shows the variation of the muon rate in the detector.

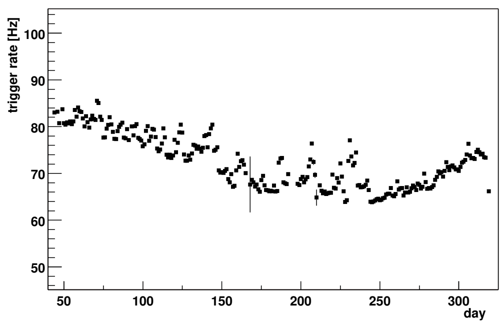


Fig. 3: *Seasonal variations of the muon rate*

The result of this investigation was the observation of a 15% effect. In Fig. 3 it can be seen that during the southern winter between around May and August the muon rate goes down due to the same reasons as explained in subsection 1.2. This is in principle the same behaviour that we expect for atmospheric neutrinos only with an opposite sign.

## 2 Data analysis

### *2.1 Data sample*

The data which was used in this study is the final neutrino sample of the years 2000 to 2003. This corresponds to a sample of atmospheric neutrinos with a fake contamination of less than 10 %.

The whole analysis was made with the data analysis framework ROOT. A second dataset used was a textfile which contained the lifetime of the AMANDA-detector for each day of the four years. The lifetime or uptime is the fraction of the day when the detector was actually ready to record data.

## 2.2 Lifetime correction

The first step was to correct the event rate for the lifetime of the detector. Therefor a histogram with the event rate for the four years ranging from day 50 to 300 in 25 bins was created. Then a weight for each bin was calculated to correct for different lifetimes in different periods.

$$weight = \frac{sum\ of\ days/bin}{sum\ of\ lifetimes/bin} > 1$$

In the following two figures the reciprocal weights are shown.

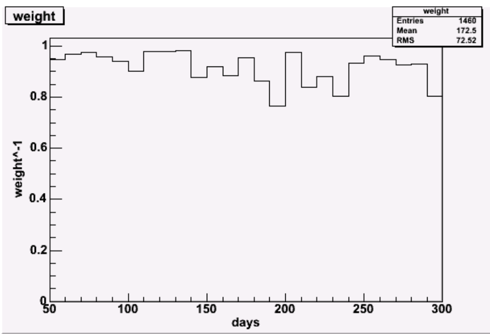


Fig. 4: *Mean values of* $weight^{-1}$ *for four years*

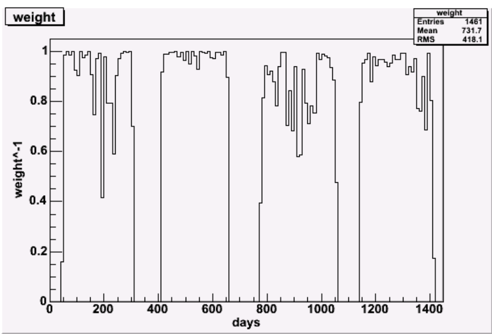


Fig. 5: *Values of* $weight^{-1}$ *for each year*

Such weights were applied to the final data sample. So we got the corrected event rates for both observation areas (Fig. 6 and 7).

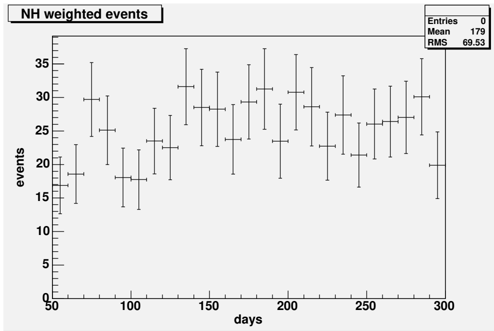


Fig. 6: *Weighted events in the declination range between 60 and 90 degrees*

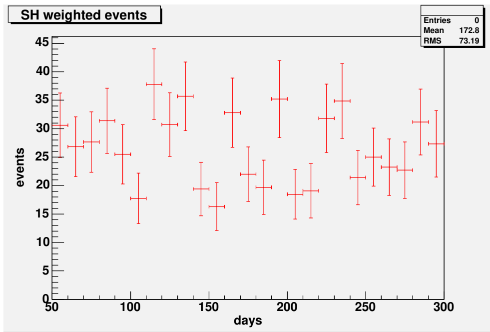


Fig. 7: *Weighted events in the declination range between 15 and 30 degrees*

## 2.3 Moving average

The next step was to calculate a moving average to smooth the distribution of the event rates. For this a new histogram was created whose bin entries are always the sum over five bins.

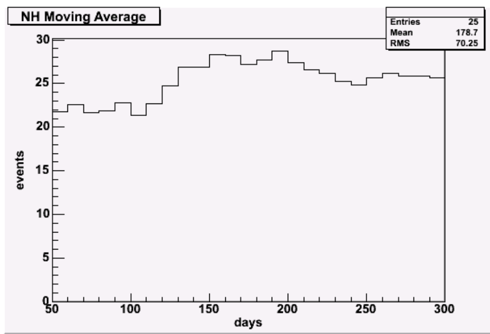


Fig. 8: *Moving average of weighted events between 60 and 90 degrees*

In Fig. 8 and 9 there is the event rate from the northern hemisphere between 60 and 90 degrees of declination. It is distinguishable that between day 50 and day 130 the event rate is clearly lower than in the rest of the year. There is a maximum between the $150^{th}$ and the $200^{th}$ day and at the

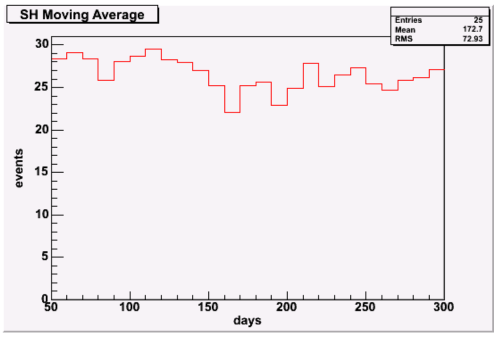


Fig. 9: *Moving average of weighted events between 15 and 30 degrees*

end of the year the number of events decreases again.

In the southern area shown in Fig. 9 we can recognize an opposite effect: an event maximum between day 50 and 130, a lower event rate in the middle of the year and from around day 250 a slight increase.

## *2.4 Fits and $\chi^2$*

The histograms containing the weighted events (Fig. 6 and 7) were fitted with a sine function. Because of the alternation of seasons the period was fixed to one year. The fit parameters were the amplitude $p_0$, the phase $p_1$ and the average event rate $p_2$.

$$n = p_0 * sin(\frac{2\pi}{365}d + p_1) + p_2$$

Here n is the number of events and d means the day of the year. The fitted parameters of the distributions for the two different observation areas are displayed in Tab.1:

| fit parameters | $60 < \delta < 90$ | $15 < \delta < 30$ |
|---|---|---|
| $p_0$ | $-5 \pm 2$ | $-4 \pm 2$ |
| $p_1$ | $-5.0 \pm 0.3$ | $-1.7 \pm 0.4$ |
| $p_2$ | $23 \pm 1$ | $27 \pm 1$ |
| $\chi^2$/ndf | 13.32/22 | 31.10/22 |

Tab. 1: *Fit parameters*

The fit functions are shown in Fig. 10 and 11. The $\chi^2$ shows that the given distributions are well approximated by these fit functions, especially for the declination range between 60 and 90 degrees.

In addition we made a fit with a constant function to test how likely it is to have a flat

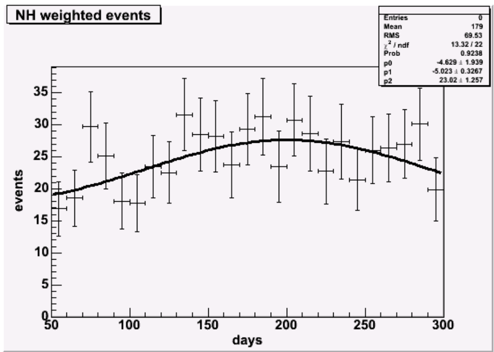


Fig. 10: *Event rate of the northern area fitted with a sine function*

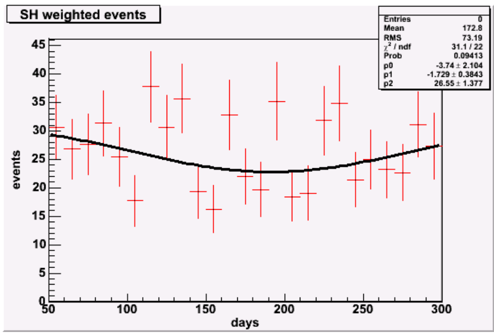


Fig. 11: *Event rate of the southern area fitted with a sine function*

distribution. In the following table the $\chi^2$ values and degrees of freedom for the two different fit functions are listed (Tab.2):

| \ | $60 < \delta < 90$ | $15 < \delta < 30$ |
|---|---|---|
| sin fit | 13.32/22 | 31.10/22 |
| const. fit | 20.04/24 | 34.46/24 |

Tab. 2: *Comparison of $\chi^2$ values and degrees of freedom for two different fit functions*

According to this it is more likely to have a sine-shaped distribution than a flat distribution.

In Fig. 12 the fitted event rates of both observation areas are diagrammed. We can see a phase shift between the two sine functions of around $\pi$. This is also exactly what we expect because the seasons on the northern and the southern hemisphere are shifted by half a year against each other.

## *2.5 Result and Conclusion*

After finishing a first data analysis on seasonal variations in the upcoming neutrino flux we have observed a 20% effect. That means that at an

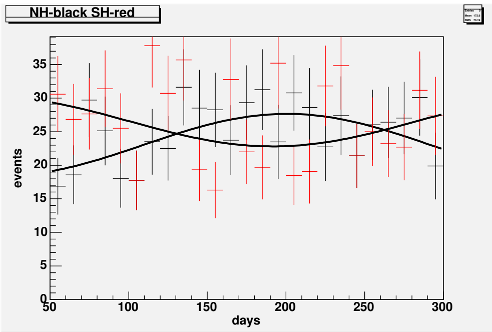


Fig. 12: *Comparison of the effect on the northern and southern hemisphere*

average event rate of 25 events per ten days the highest difference in the neutrino rate between summer and winter amounts to around 10 per ten days. Like we have expected, we can see a lower event rate in the northern winter and a maximum in the summer. An opposite but less significant effect was also observed in a declination range corresponding to southern mid-latitudes. The result gives a positive answer to the question whether AMANDA is able to measure changes in the neutrino flux due to seasonal variations.

## Acknowledgements

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## References

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