AMANDA – Search for UHE Neutrinos

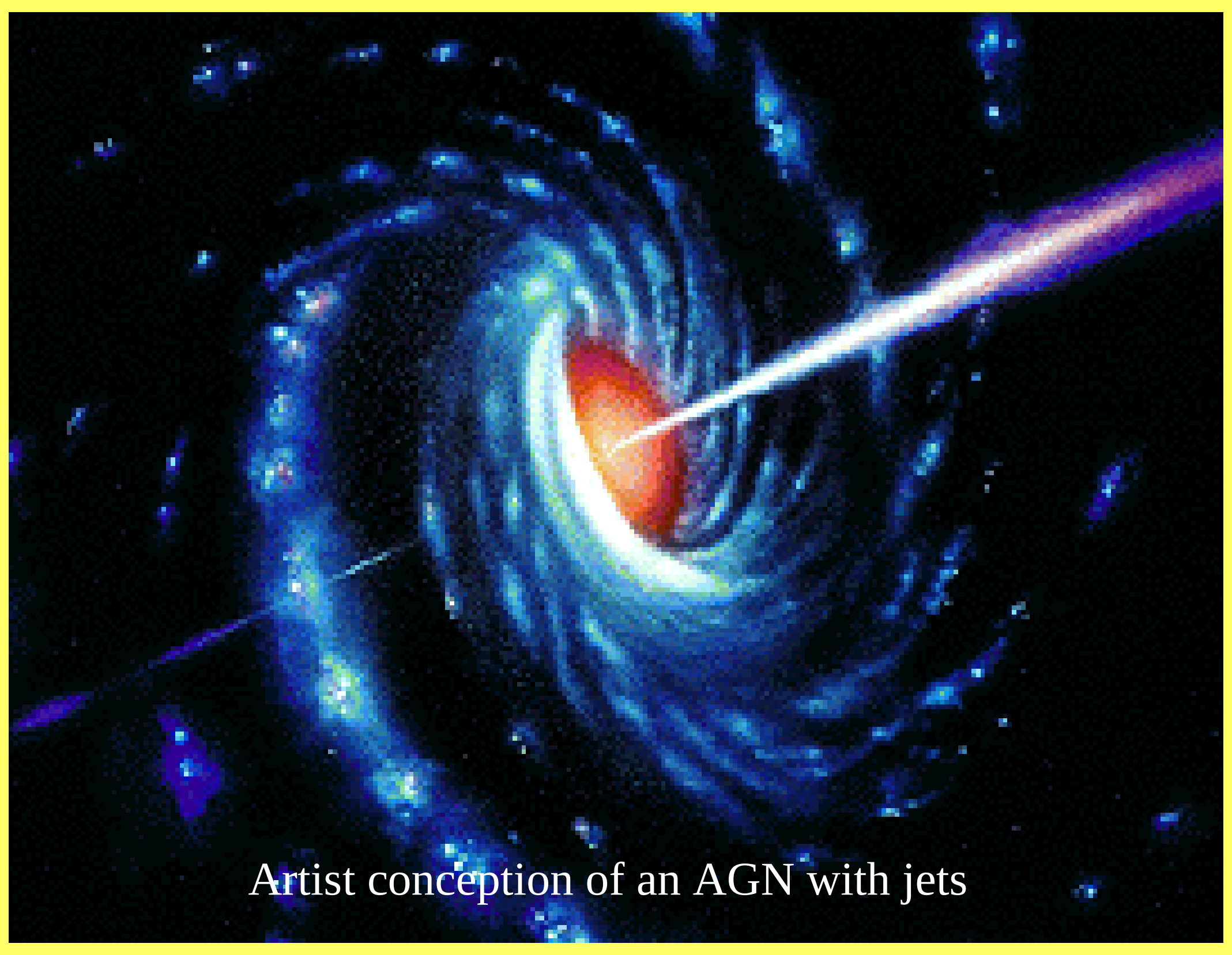
Stephan Hundertmark, Stockholm University, for the AMANDA Collaboration

Introduction

Cosmic Rays have been measured beyond 10^{20} eV, implying the existence of UHE ($> 10^{15}$ eV) neutrinos. Candidate sites or particles for the production of UHE neutrinos are:

- Active galactic nuclei (AGN)
- Gamma-ray burster (GRB)
- Topological defects (TD)

AMANDA is an open muon detector and allows to make use of the tens of kilometers range of UHE muons, thus monitoring huge volumes for charged current neutrino interactions. Most theoretical models require a km² detector to detect UHE neutrinos ①. Here it is shown that already the first stage AMANDA detector reaches areas of this order.



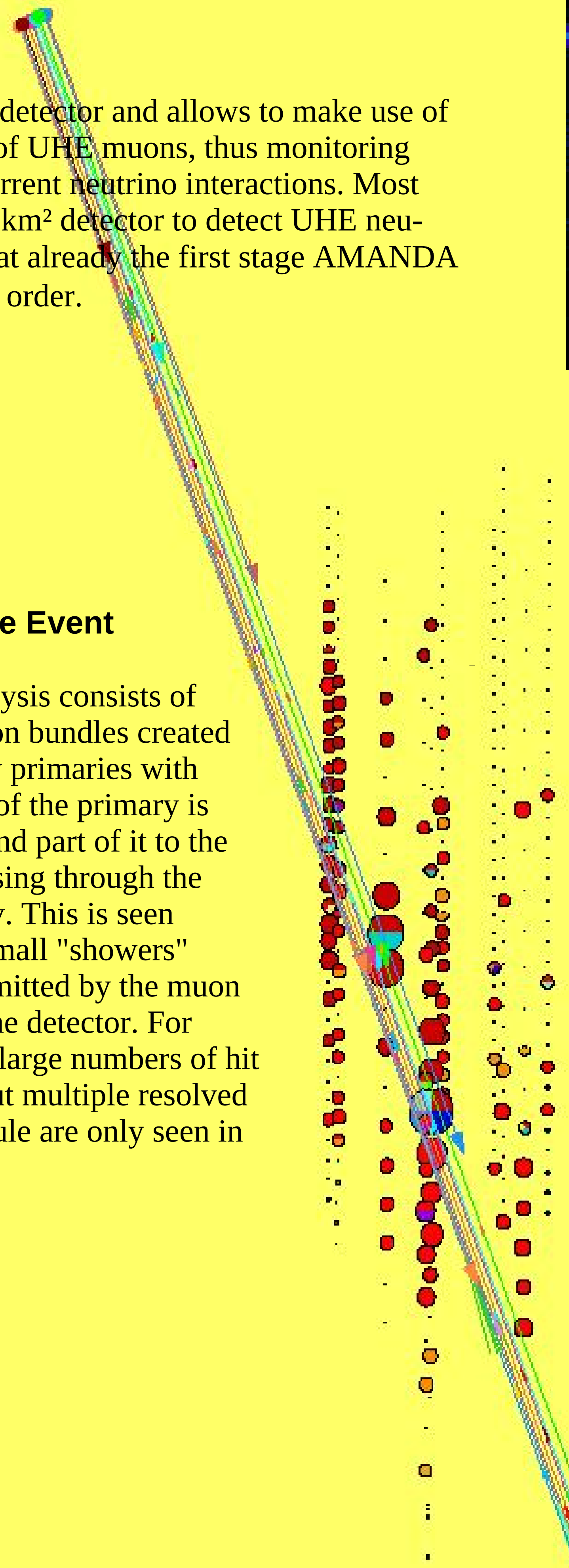
Artist conception of an AGN with jets

Where to look for the UHE Neutrinos ?

AMANDA is designed to detect neutrinos in the GeV to TeV region, looking downward to discriminate against the downgoing atmospheric muon flux. For UHE neutrinos the rising charged current cross section renders the earth opaque above 10 PeV, leaving the upper hemisphere to search for signal. The limited overburden of ~1.5 km of ice above the detector limits the interaction volume for vertical downward going UHE neutrinos. Therefore the expected signal concentrates at the horizon. Extracting the UHE neutrinos in the upper hemisphere requires the rejection of the large flux of downgoing atmospheric muons with a detector not being designed for these energies. A challenge that can be met, as shown here.

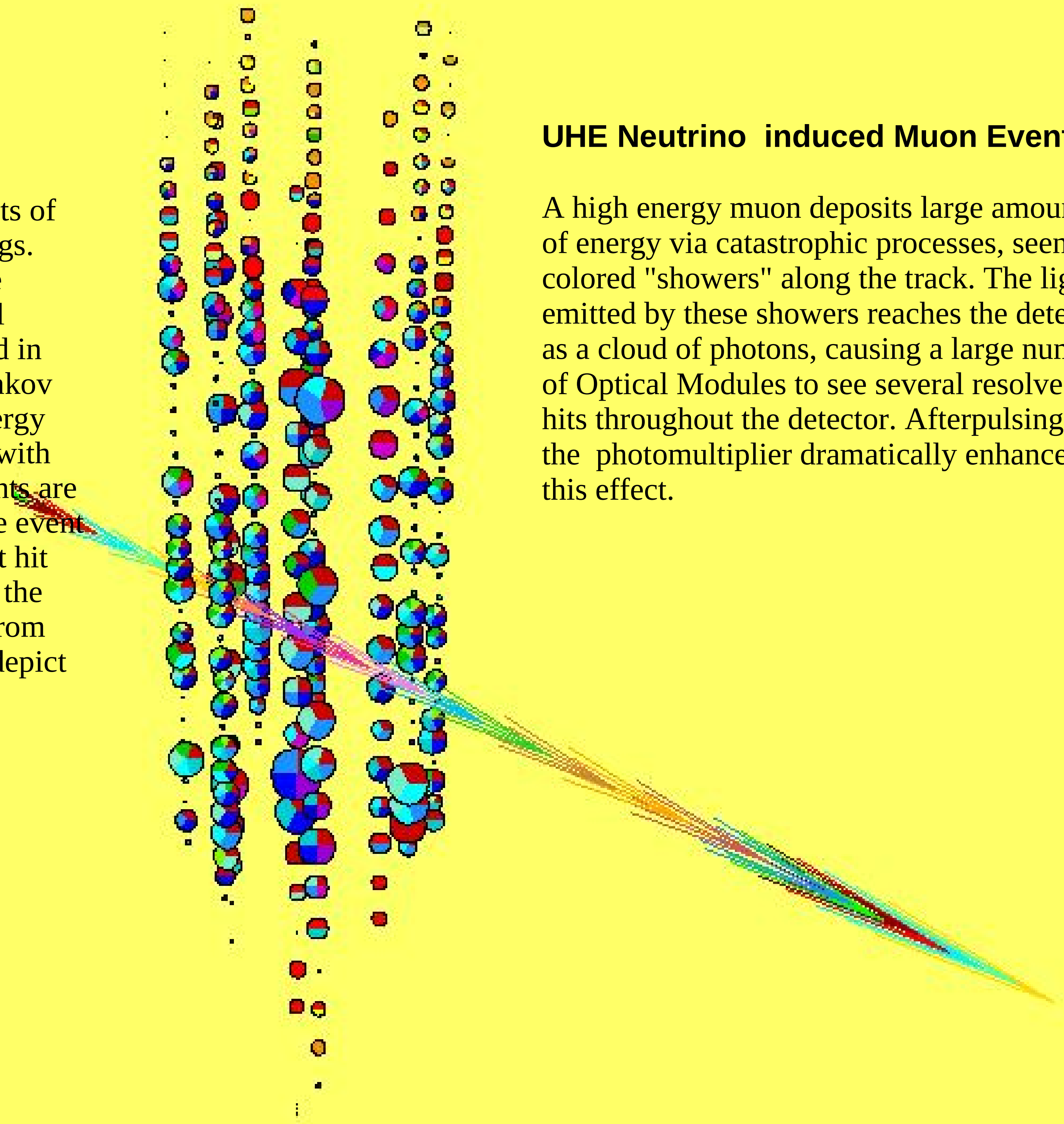
Downgoing Muon Bundle Event

The background for this analysis consists of downgoing atmospheric muon bundles created by interactions of cosmic ray primaries with the atmosphere. The energy of the primary is transfered to the airshower and part of it to the resulting muons. Muons passing through the ice lose energy stochastically. This is seen in the figure to the right as small "showers" along the tracks. The light emitted by the muon and the showers is seen by the detector. For sufficient energetic showers large numbers of hit Optical Modules are seen, but multiple resolved hits within one Optical Module are only seen in close encounters.



The AMANDA Detector

The B10 array used in this analysis consists of 302 Optical Modules arranged on 10 strings. It is buried at a depth of 1.5 to 2 km in the 2.8 km thick ice shield at the geographical South Pole. Photomultiplier tupbes housed in glass pressure spheres register the Cherenkov light emitted by muons and secondary energy losses. They are connected to the surface with electrical cables. The electronic components are located in a structure on the surface. In the event displays shown, the filled circles represent hit Optical Modules. The size corresponds to the amplitude and the color to the time from early (red) to late (blue). Multiple colors depict multiple separated hits.



UHE Neutrino induced Muon Event

A high energy muon deposits large amounts of energy via catastrophic processes, seen as colored "showers" along the track. The light emitted by these showers reaches the detector as a cloud of photons, causing a large number of Optical Modules to see several resolved hits throughout the detector. Afterpulsing of the photomultiplier dramatically enhances this effect.

Method and Analysis

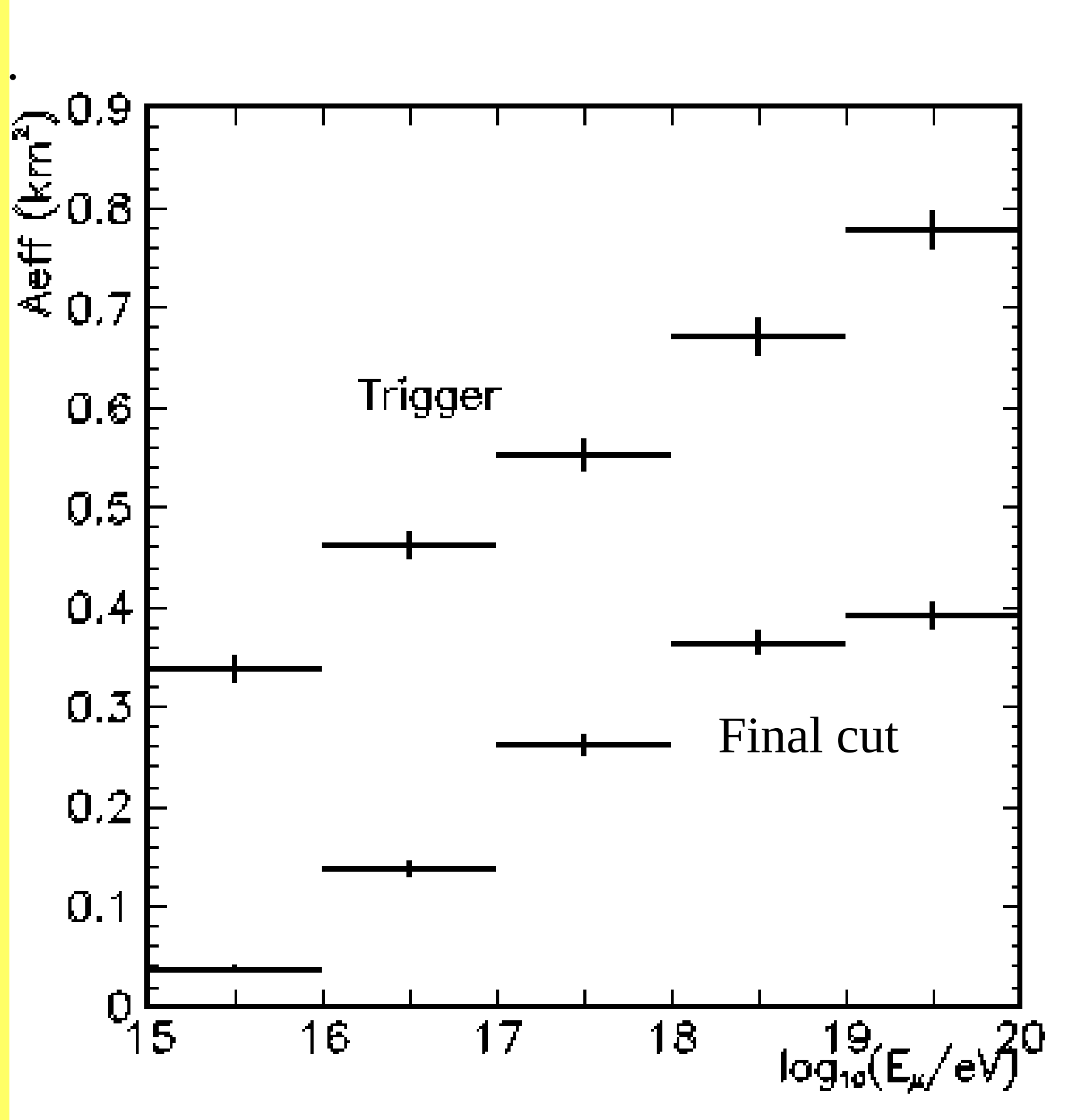
The main idea that drives this analysis is that UHE muon events passing through or close by the detector leave a different signature then downgoing muon bundles caused by a primary of the same or higher energy. This can be seen in the event displays above. Using simple global event variables downgoing muon bundle events can be separated from UHE neutrino induced events. The variables used separately and combined in two neural nets are:

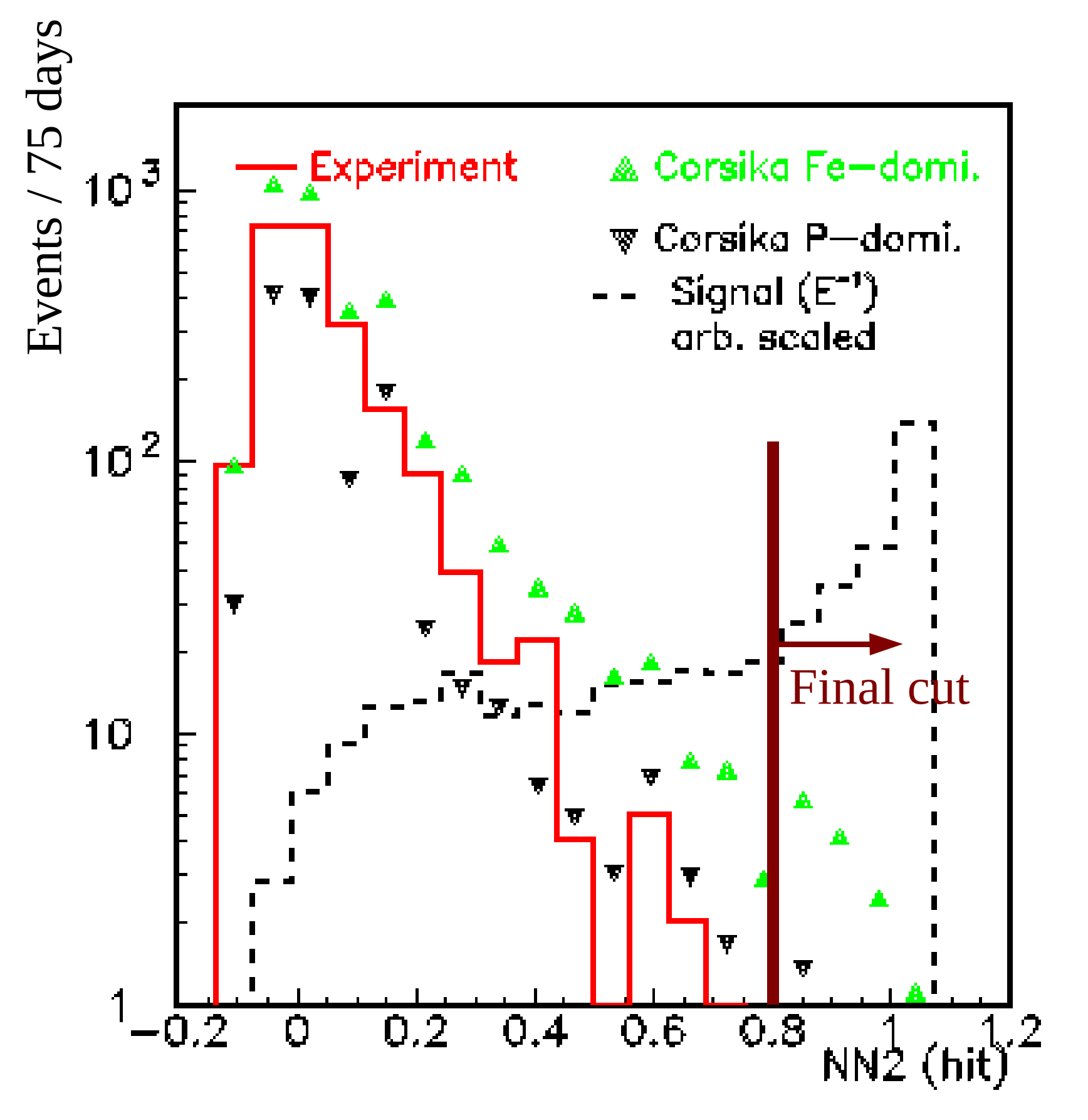
- Number of hit channels
- Number of all hits (each channel can register multiple hits)
- Fraction of hit channels with only one hit
- Mean amplitude
- Reconstructed zenith angle
- Reconstruction quality

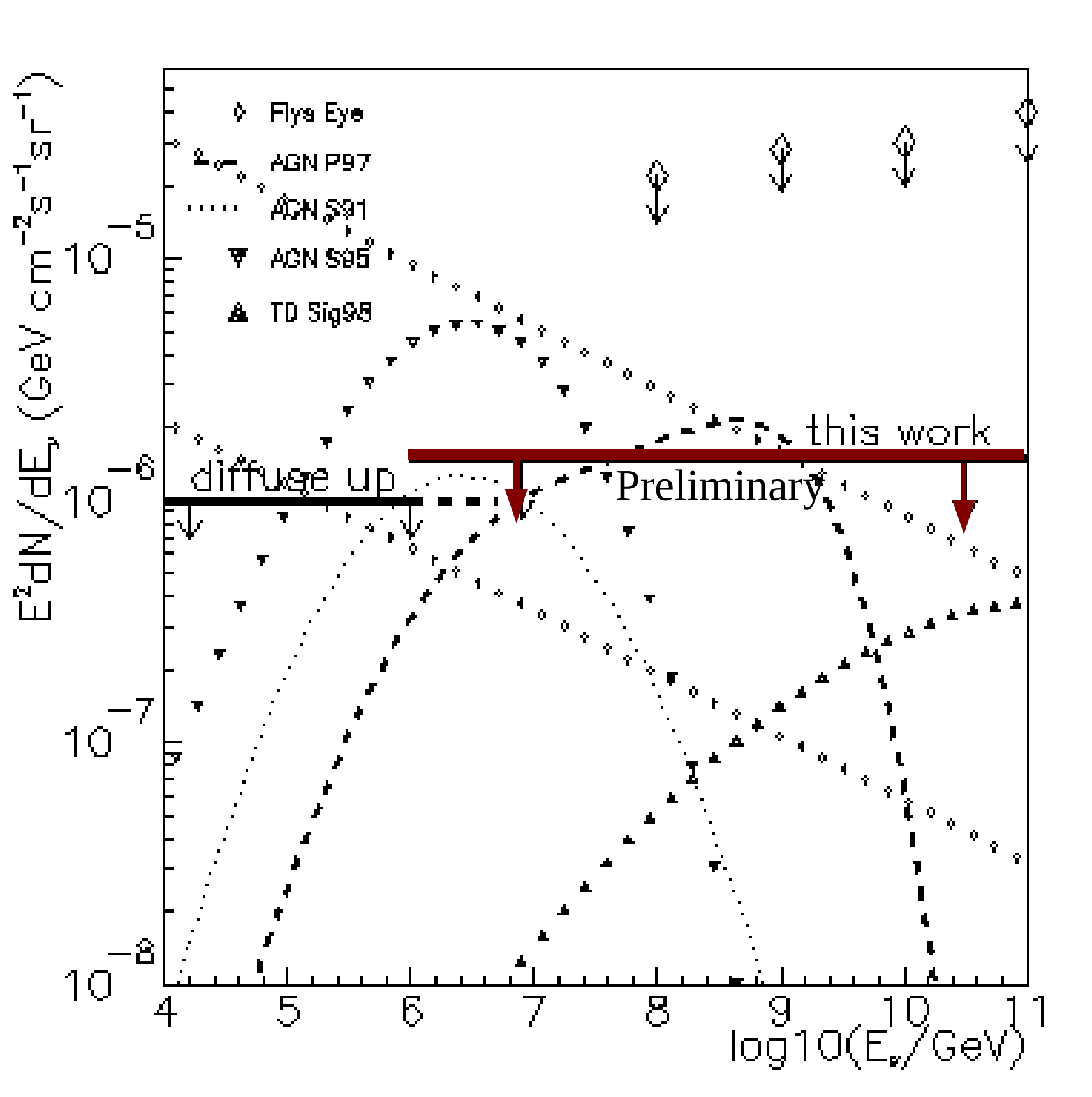
Three levels are defined that reject the $6{\cdot}10^{8}$ experimental events within 75 days of livetime. On the initial trigger level, the effective area for UHE induced neutrinos ranges from 0.3 km² at 10^{15} eV to 0.8 km² at 10^{20} eV. This huge area results in roughly 100 triggered events per year for different AGN models. The fluxes of atmospheric neutrinos and neutrinos from charmed mesons are too low at these energies to constitute a background. After applying the final cut an area of 0.4 km² is reached at 10^{20} eV. From the non-observation of experimental events a preliminary limit (90% CL) can be calculated for an E^{-2} emission, not including systematic errors to:

$$E^{2}\,\phi_{\upsilon}\,(E_{\upsilon}=10^{15\text{-}20}\,\mathrm{eV}) = 1.5{\cdot}10^{-6}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}\ \mathrm{sr}^{-1}\ \mathrm{GeV}$$

The second neural net output and the position of the final cut is shown in the middle below. At this level the cosmic ray primaries have energies above 10^{15} eV. Proton and iron primaries are mixed according to different composition models. In green triangles an iron dominated and in black triangles a proton dominated mixture is shown. Both describe the shape of the experimental distribution. The "real" primary composition will be somewhere in between. The signal events populate higher values for the neural net output, allowing a high passing fraction for this final cut.







Conclusion

Performing a search for UHE neutrinos, the AMANDA-B10 array reaches effective areas of 0.4 km² at the highest energies. There is good agreement between background simulation and the experimental data. Using 75 days livetime a preliminary limit without taking into account systematic uncertainties is set. It is shown that the AMANDA detector can set limits that will exclude models for UHE neutrino generation in the near future. AMANDA is currently the largest operating detector for UHE muons. In total data from more than 5 years of operation partly with the larger AMANDA-II detector is available and will be analysed. A writeup, including references, can be found at ②.

References

① F. Halzen, astro-ph/0103195
② S. Hundertmark,
http://www.ps.uci.edu/~hundert/amanda/nuws01/nuws_uhe.pdf

Stephan Hundertmark, Stockholm Universitet, email: Stephan.Hundertmark@physto.se