http://amanda.uci.edu

AMANDA

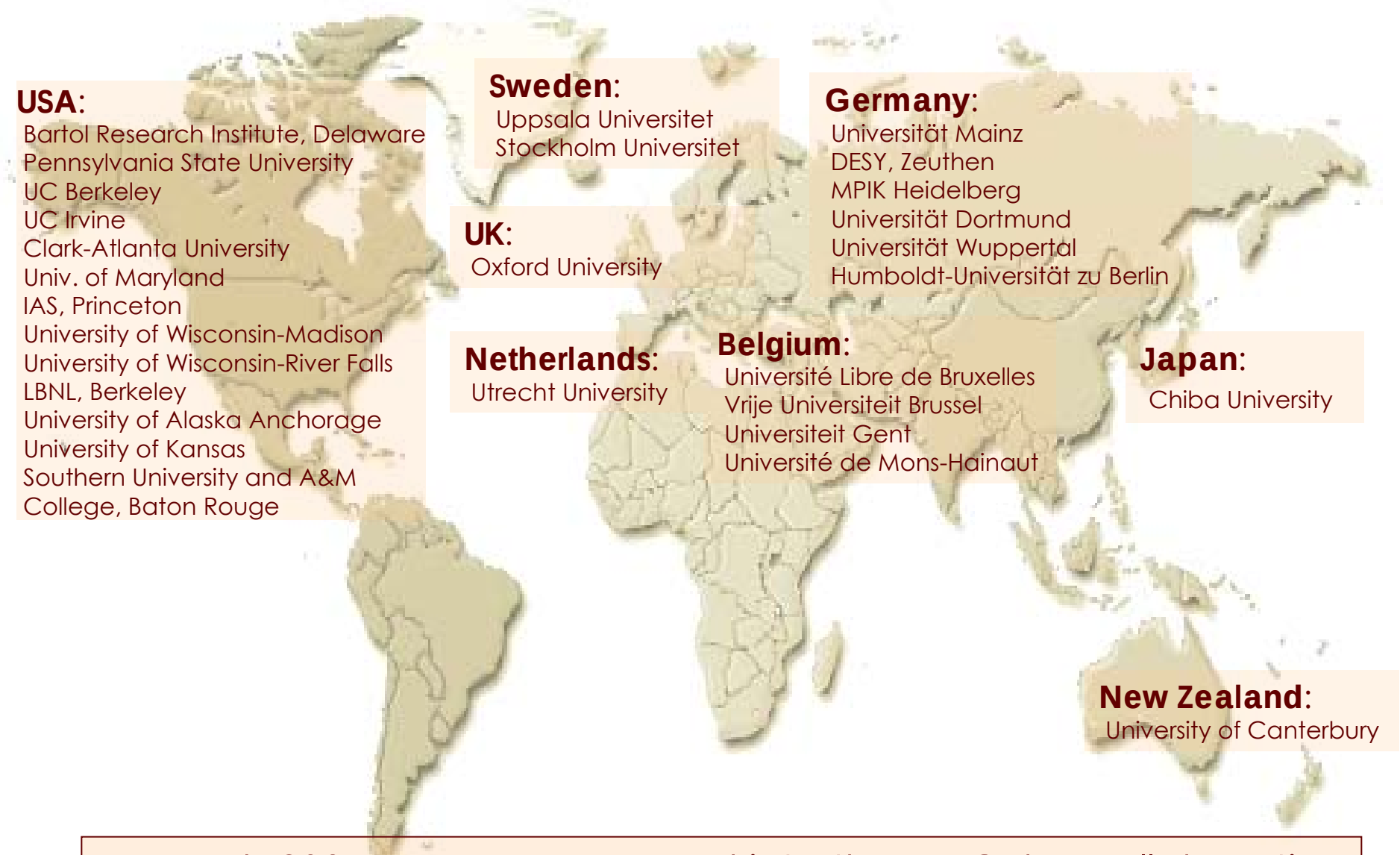
ANTARCTIC MUON AND NEUTRINO DETECTOR ARRAY

# First Results from AMANDA using the TWR System

Andrea Silvestri
University of California, Irvine

International School of Cosmic Ray Astrophysics
June 20-27, 2006 | Erice, Sicily

# The IceCube Collaboration



**USA**:
Bartol Research Institute, Delaware
Pennsylvania State University
UC Berkeley
UC Irvine
Clark-Atlanta University
Univ. of Maryland
IAS, Princeton
University of Wisconsin-Madison
University of Wisconsin-River Falls
LBNL, Berkeley
University of Alaska Anchorage
University of Kansas
Southern University and A&M College, Baton Rouge

**Sweden**:
Uppsala Universitet
Stockholm Universitet

**UK**:
Oxford University

**Netherlands**:
Utrecht University

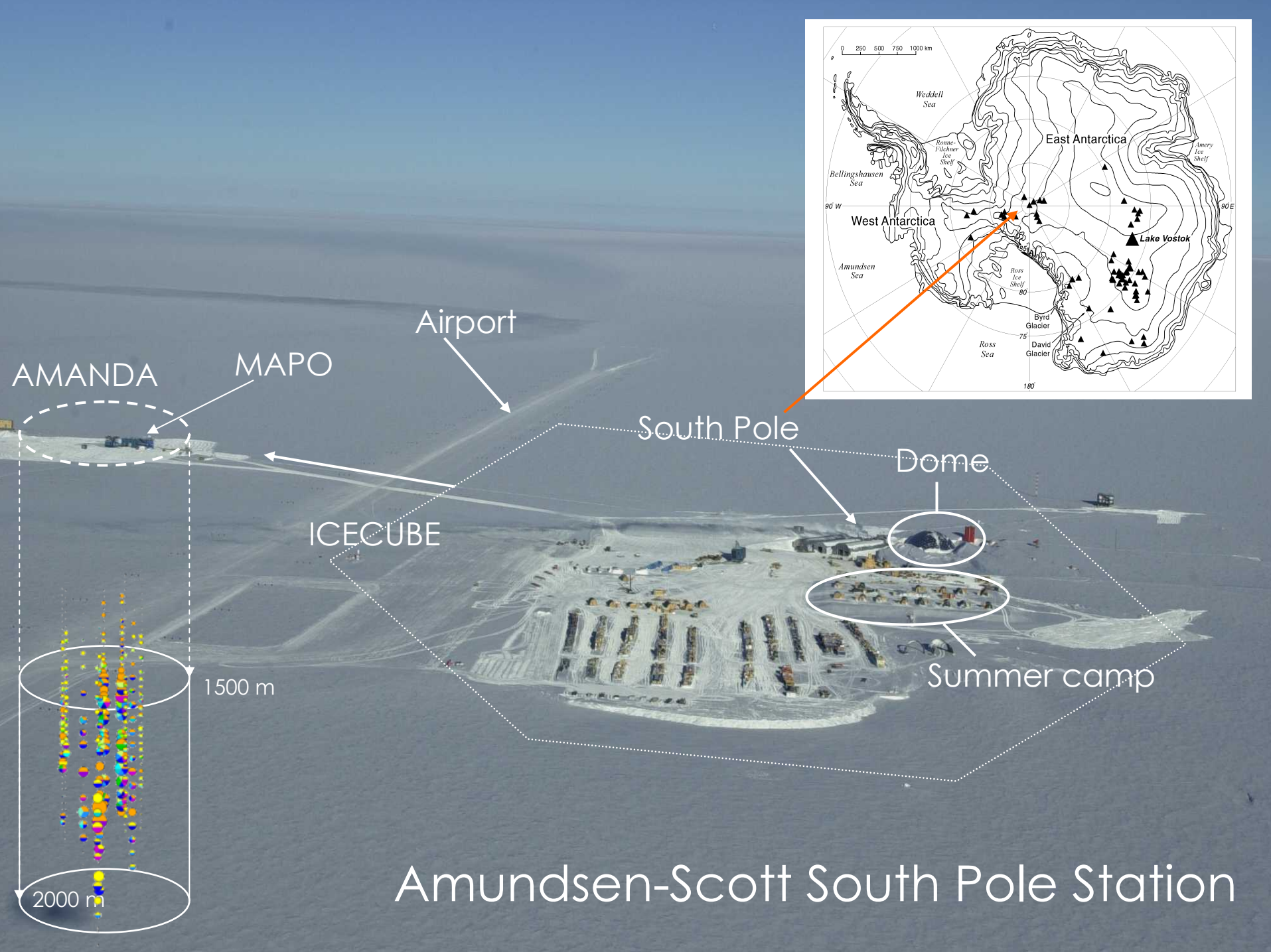
**Belgium**:
Université Libre de Bruxelles
Vrije Universiteit Brussel
Universiteit Gent
Université de Mons-Hainaut

**Germany**:
Universität Mainz
DESY, Zeuthen
MPIK Heidelberg
Universität Dortmund
Universität Wuppertal
Humboldt-Universität zu Berlin

**Japan**:
Chiba University

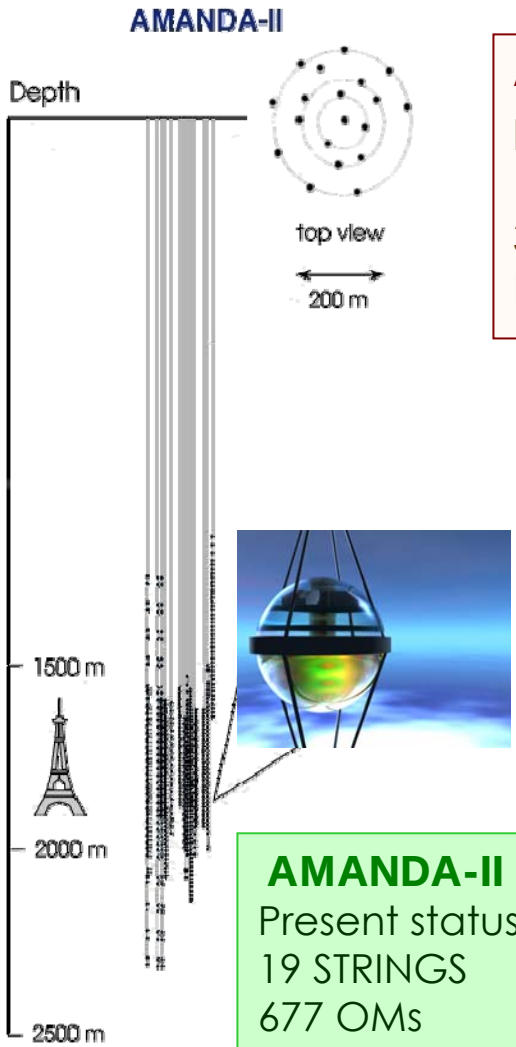
**New Zealand**:
University of Canterbury

In March 2005, AMANDA merged into the IceCube collaboration



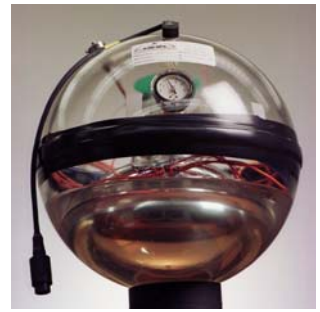

# Amundsen-Scott South Pole Station

# The AMANDA Detector




## AMANDA B-10

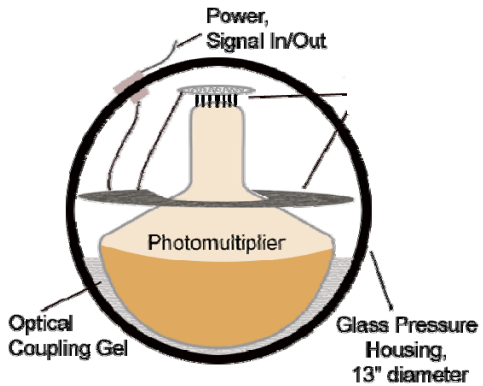
Inner core of AMANDA-II
10 STRINGS
302 OMs
Data years: 1997-1999



## OPTICAL MODULE

8-inch Hamamatsu R591202
$10^9$ gain, 14 dynode stages
PMT noise (300-1000)Hz

Time resolution ~ **5ns**

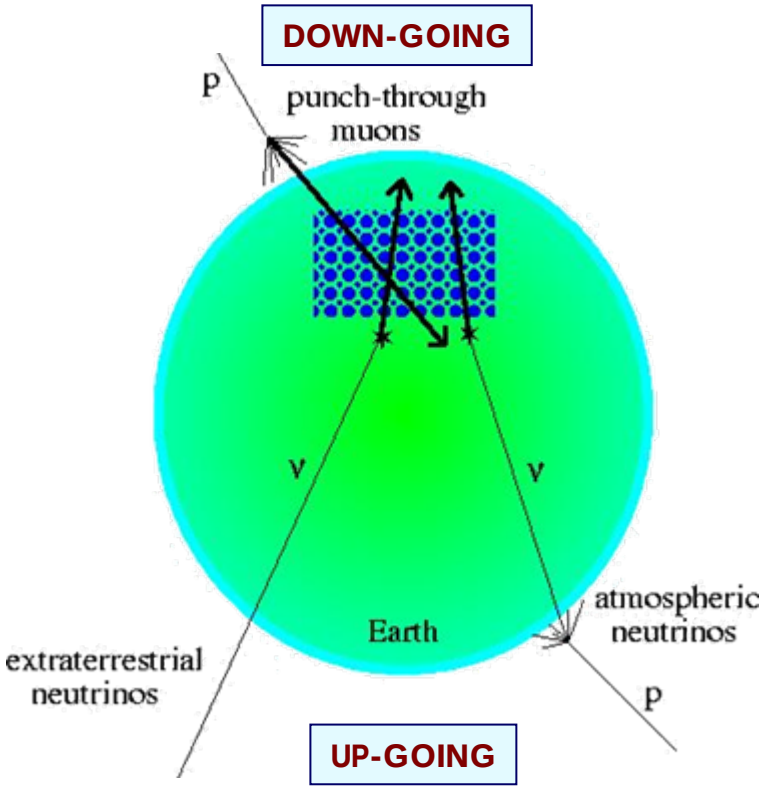


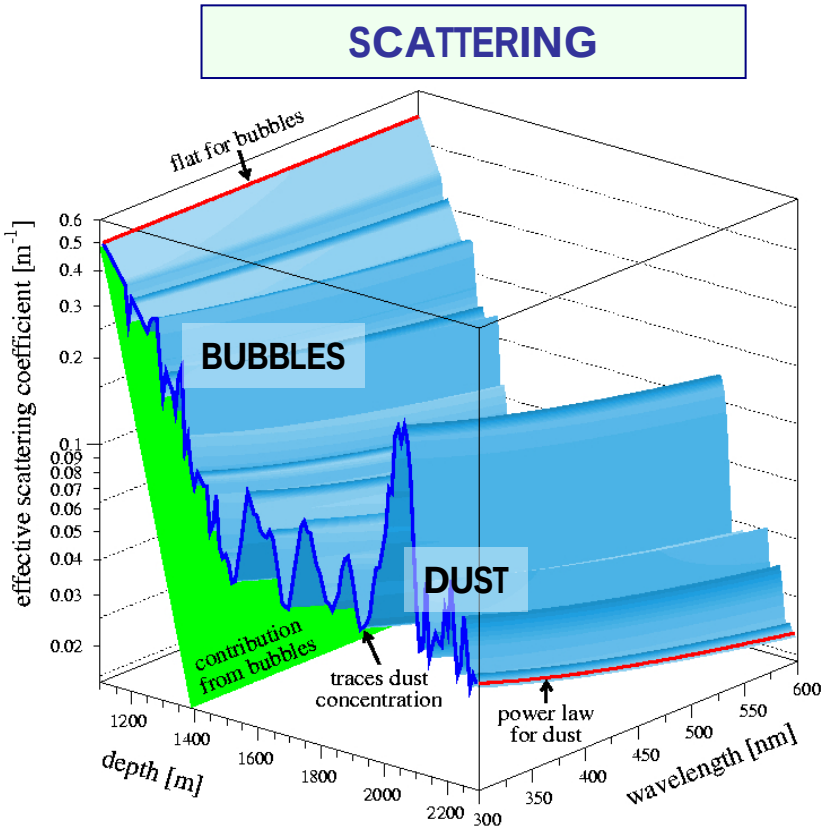

## AMANDA-II

Present status of the detector
19 STRINGS
677 OMs
Data years: 2000-2006
Trigger rate ~ 80Hz

A. Silvestri et al., the AMANDA Neutrino Telescope
Proc. of ISCRA 2004, Erice, Italy, 2-13 July 2004.

# Principle of Neutrino Detection

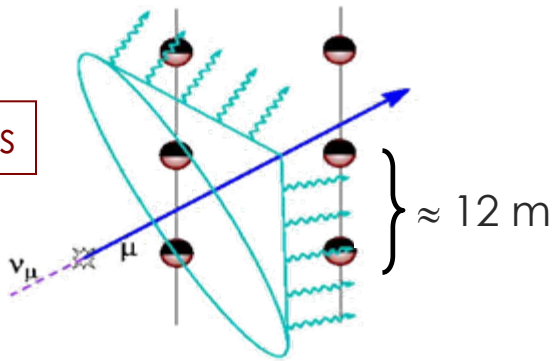



O(km) long muon tracks

TeV Muons

$\nu_\mu$ Event




**Experiment:**
- -100Hz of trigger rate
- - $2*10^9$ events/yr
- - lots of data

**Monte Carlo:**
- - Complicated ice models (bulk & layers)
- - very CPU intensive processes

# High-Energy Neutrino Production

Candidate astrophysical accelerators for high energy cosmic rays:

- **Active Galactic Nuclei**
- **Gamma-Ray Bursts**
- **Supernova Remnants**
- **…**

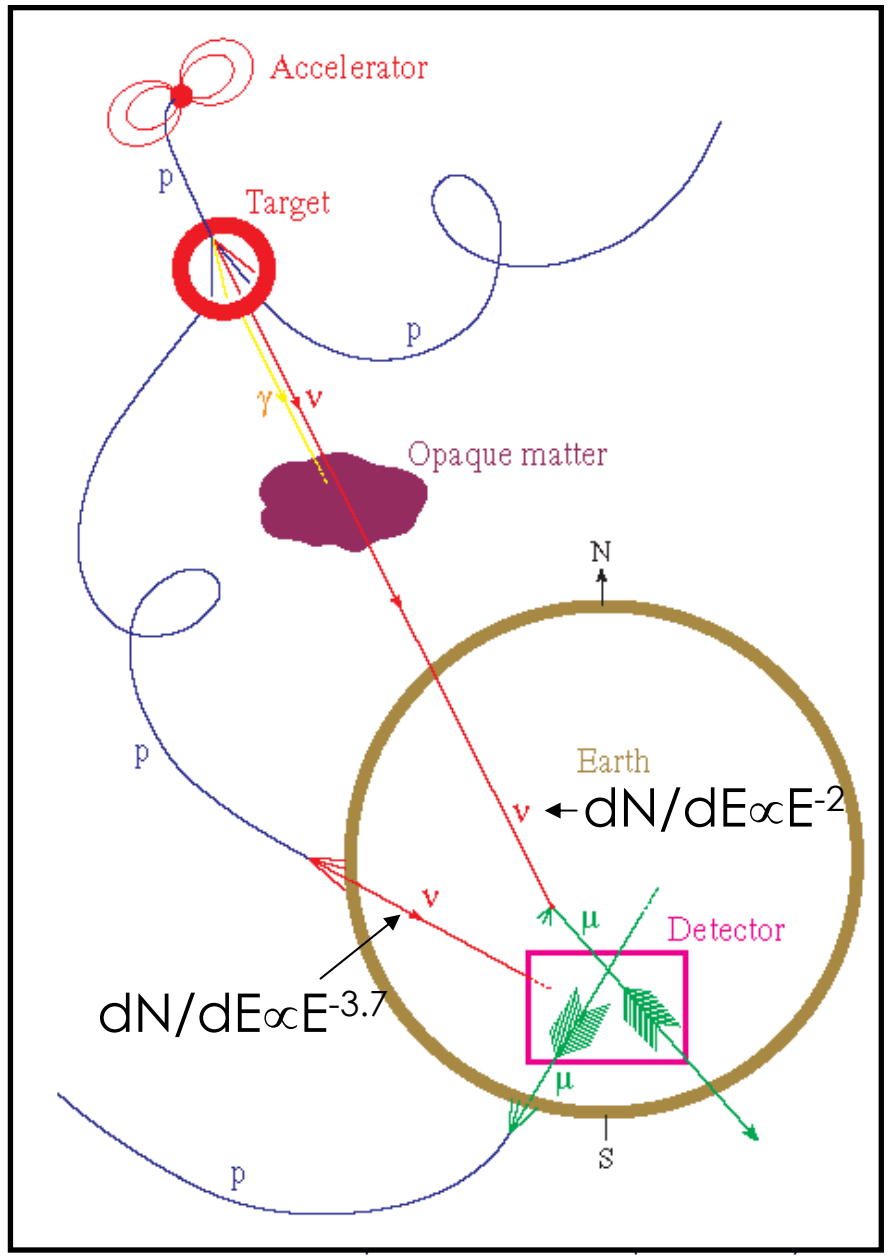
Neutrino production at source:

**p+γ** or **p+p collisions**

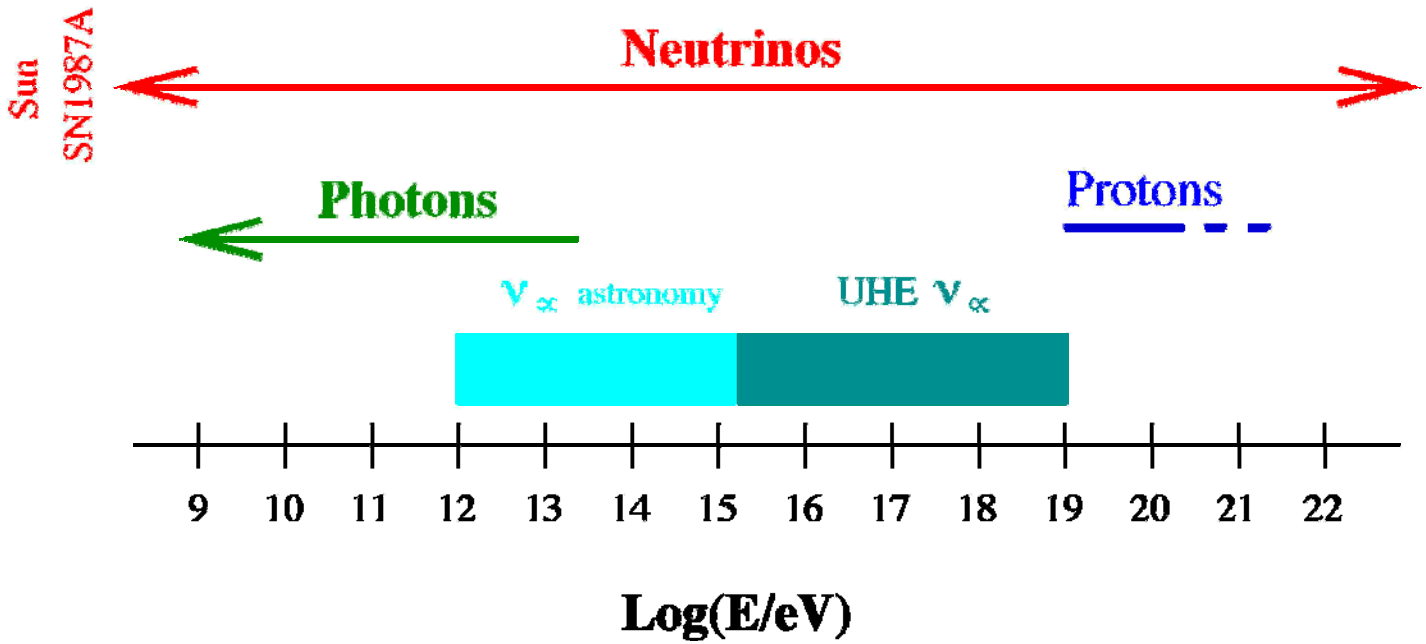
→ **pion decay** → **neutrinos**

Neutrino astronomy requires large detectors:

- **Low extra-terrestrial neutrino fluxes**
- **Small cross-sections**

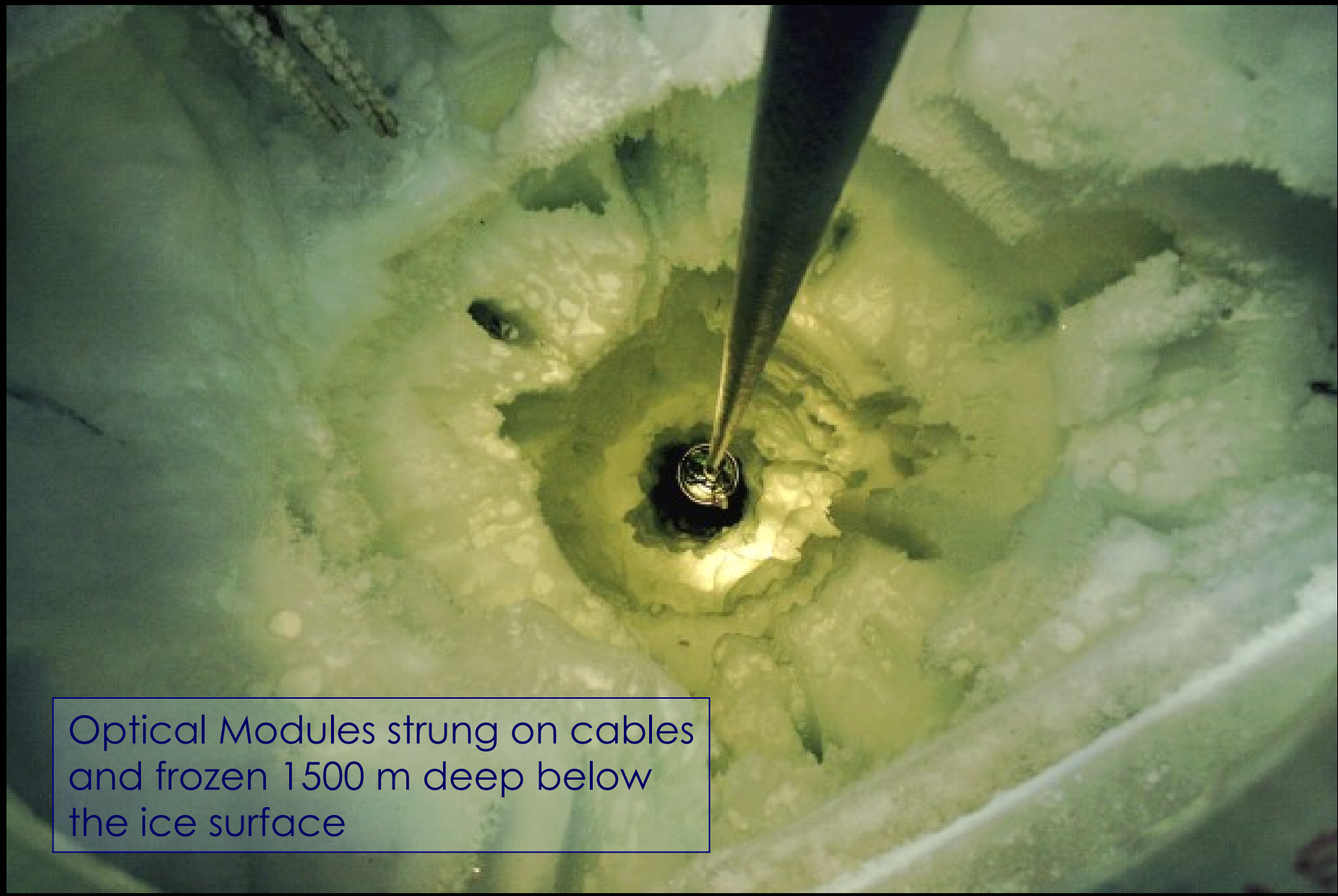


# Neutrino Astronomy




- **NEUTRINOS**: not absorbed, not deflected.
- **PROTONS**: deflection in magnetic fields, GZK
- **PHOTONS**: not deflected, but: reprocessed in sources, absorbed in IR (100 TeV), and CBR

# OMs Deployment into the Polar Ice

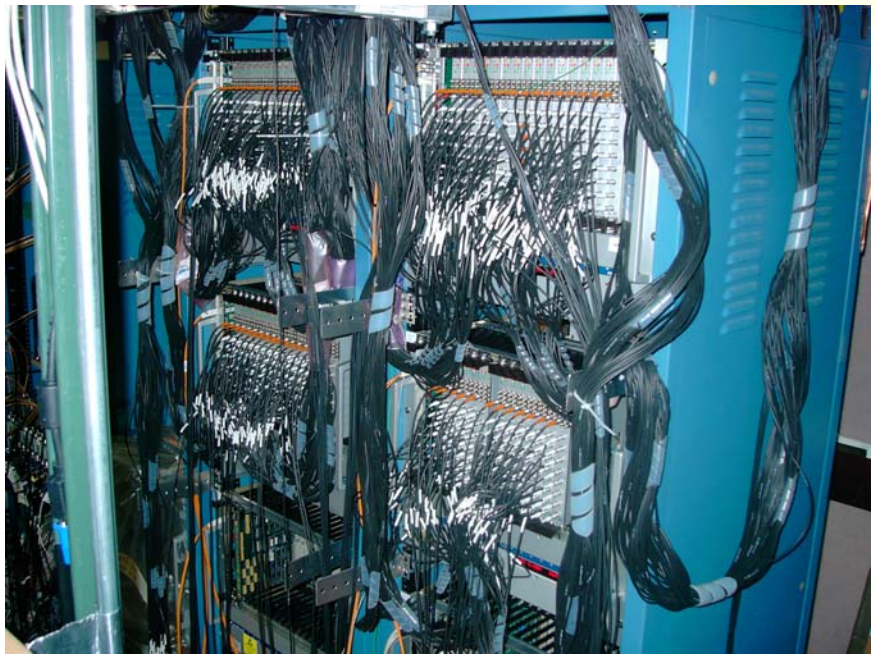


Optical Modules strung on cables and frozen 1500 m deep below the ice surface

# The TWR System

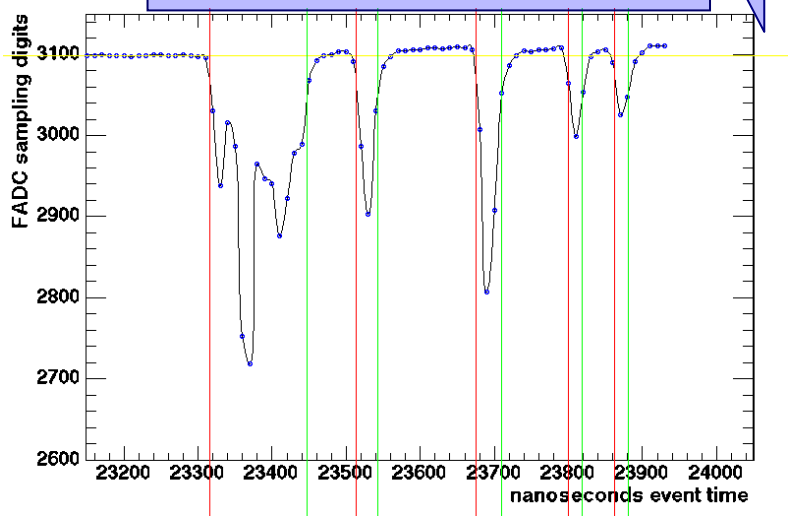
**Major Hardware Upgrade!**

**TWR**=(**T**ransient **W**aveform **R**ecorder) system installed between 2001/02 and 2003/04 campaigns



**NEW TWR DAQ**:
- Data Volume: **20TB/Year in (2003)**
- more then **3 billlion** of events
- Trigger Rate ~ **150Hz** (majority 18)
- ~ **5 billions** of events
- Data Volume: ~**33TB in 2004**

**A lot more data!!**




**Physics benefits**:
- Much larger dynamic range ~ x100
- Improved Energy reconstruction
- Improved Angular resolution
- Increased 1pe detection efficiency

crucial for **UHE/EHE physics**

**OLD MUON DAQ**:
- TDC to measure the arrival pulse times
- pADC to measure pulse amplitudes

**Def.: TWR-DAQ**

**Def.: MUON-DAQ**

# How do we process 20 TB of Data?

- **SDCD:**

SAN DIEGO SUPERCOMPUTER CENTER

  - Research unit of the UC San Diego

TeraGrid and SDSC are primarily funded by NSF

http://www.teragrid.org

TERAGRID

- **SRB:**

STORAGE RESOURCE BROKER

  - A network data storage system

SRB is virtually an unlimited storage system

http://www.npaci.edu/DICE/SRB


- World's largest computer!
- World's fastest computer!
- **20 TeraFlops!**
- **1 PetaByte!**
- **40 Gigabits** per second!

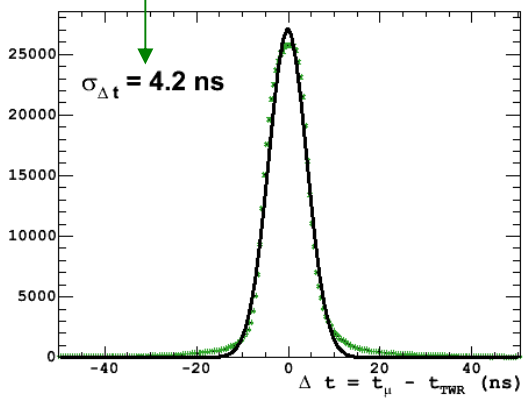
**Entire DATA set 2003:**

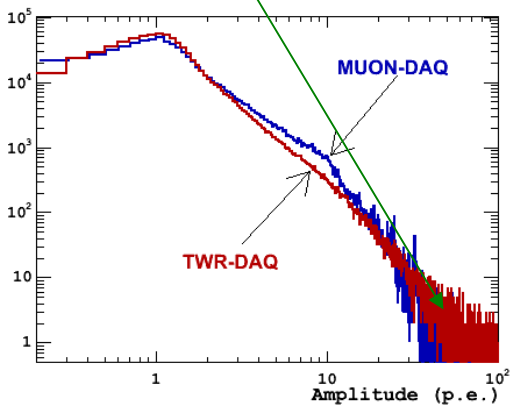
- AMANDA can use one of the most powerful computing resources on the planet
- We sent over **NETWORK 20TB** data
- Data can be stored on hard-drive 'forever'
- Data processing in a weekly time scale

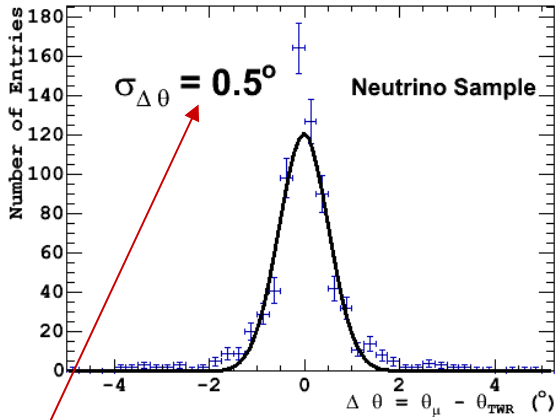
We can store our data:
**20TB** (2003) and **33TB** (2004) for
**UNLIMITED SPACE & TIME!!!**

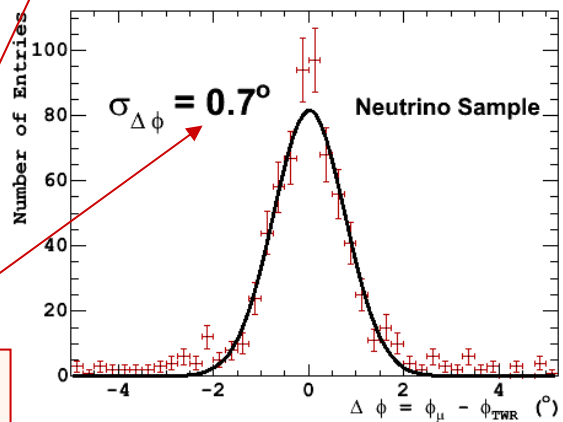
# Analysis & Reconstruction Results

- Timing resolution ~ **4ns** (limited by systematic errors)
- Better Photon-Electron amplitude reconstruction from Integrated Charge



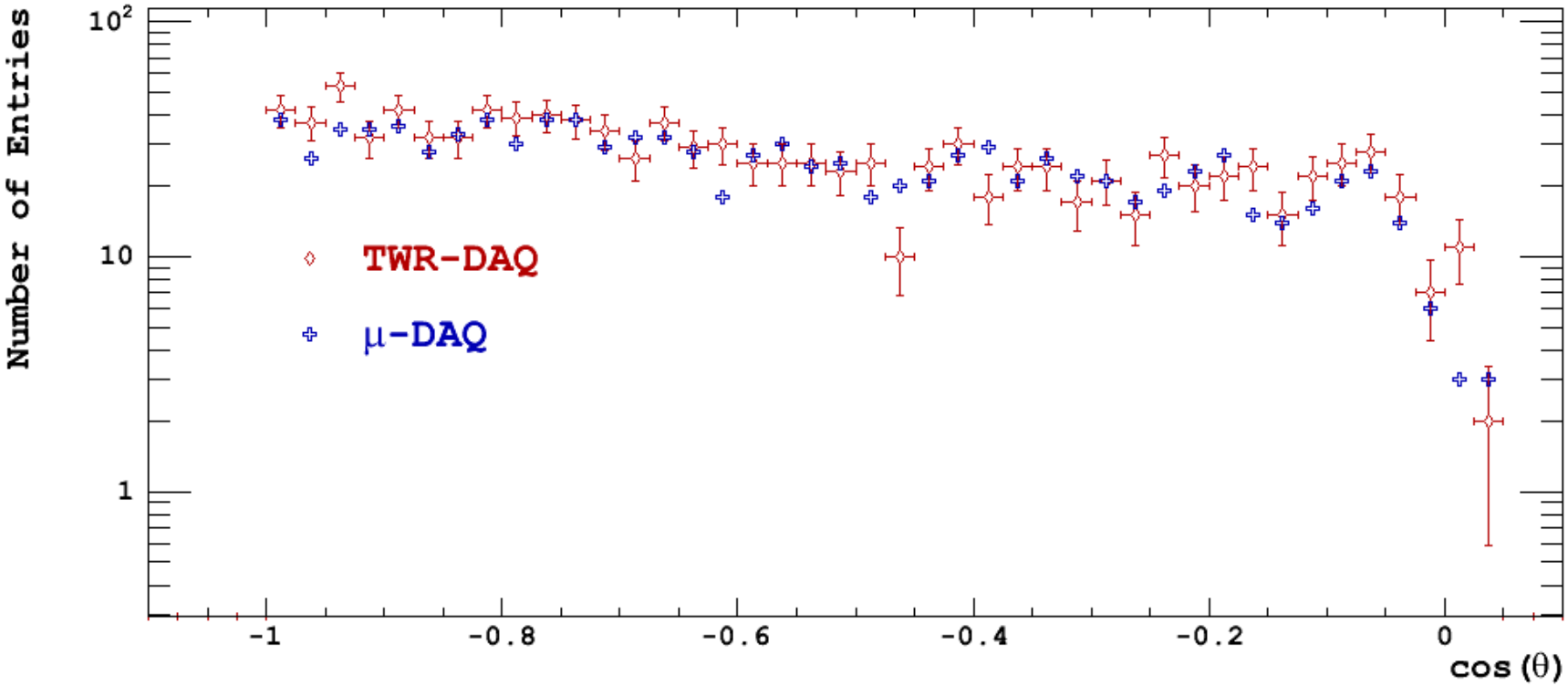




- Good agreement between the reconstructed direction of the same event taken with **MUON-DAQ** and **TWR-DAQ** systems (zenith **0.5°** and azimuth **0.7° )**
- Much below the detector pointing resolution (1.5-2 degrees)

# Atmospheric Neutrinos

**This analysis is performed by restricting the TWR-DAQ to the MUON-DAQ information**

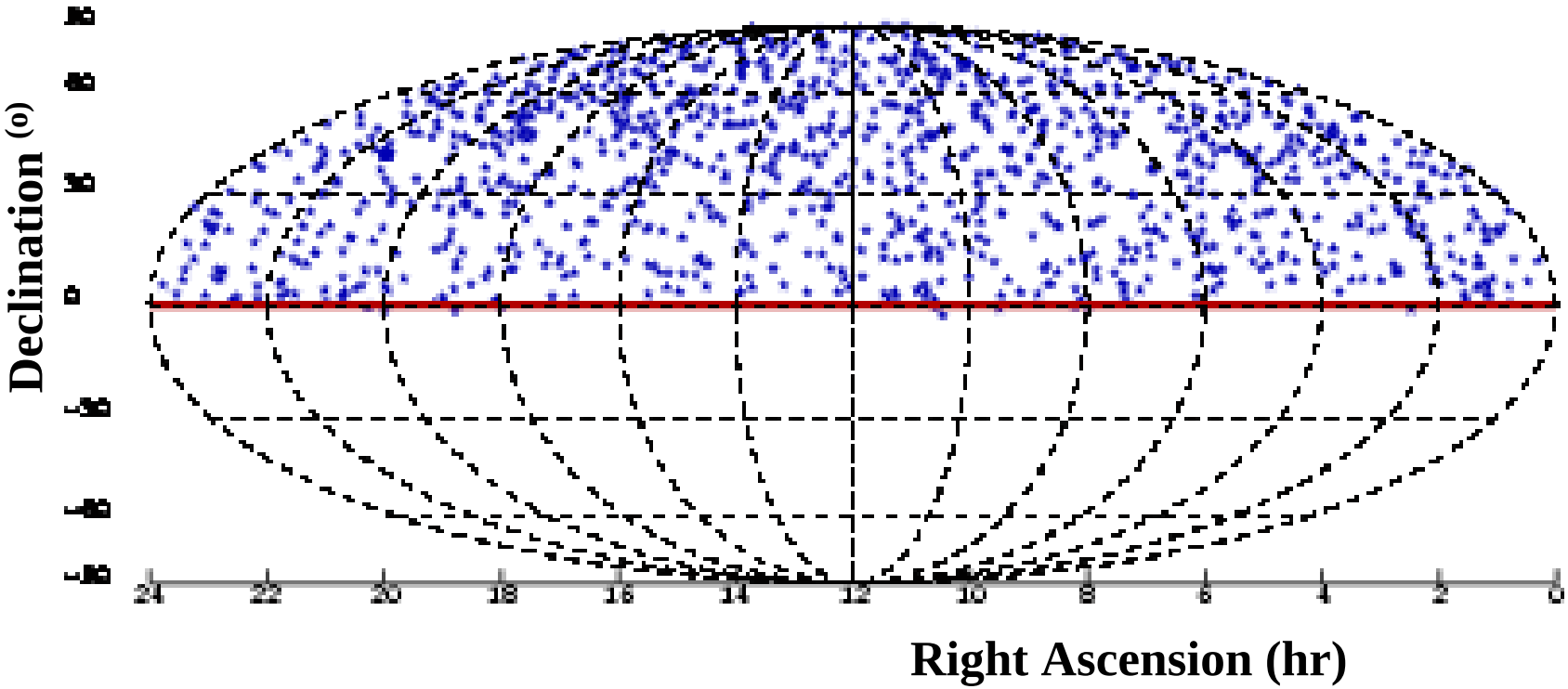



A. Silvestri et al. (2005) Proc. ICRC 2005, Pune, India

Good agreement of ν's **Cos(θ)** distribution for the two DAQ systems

TWR Data from 2003 (**213 days**)
**1112** ν from northern hemisphere

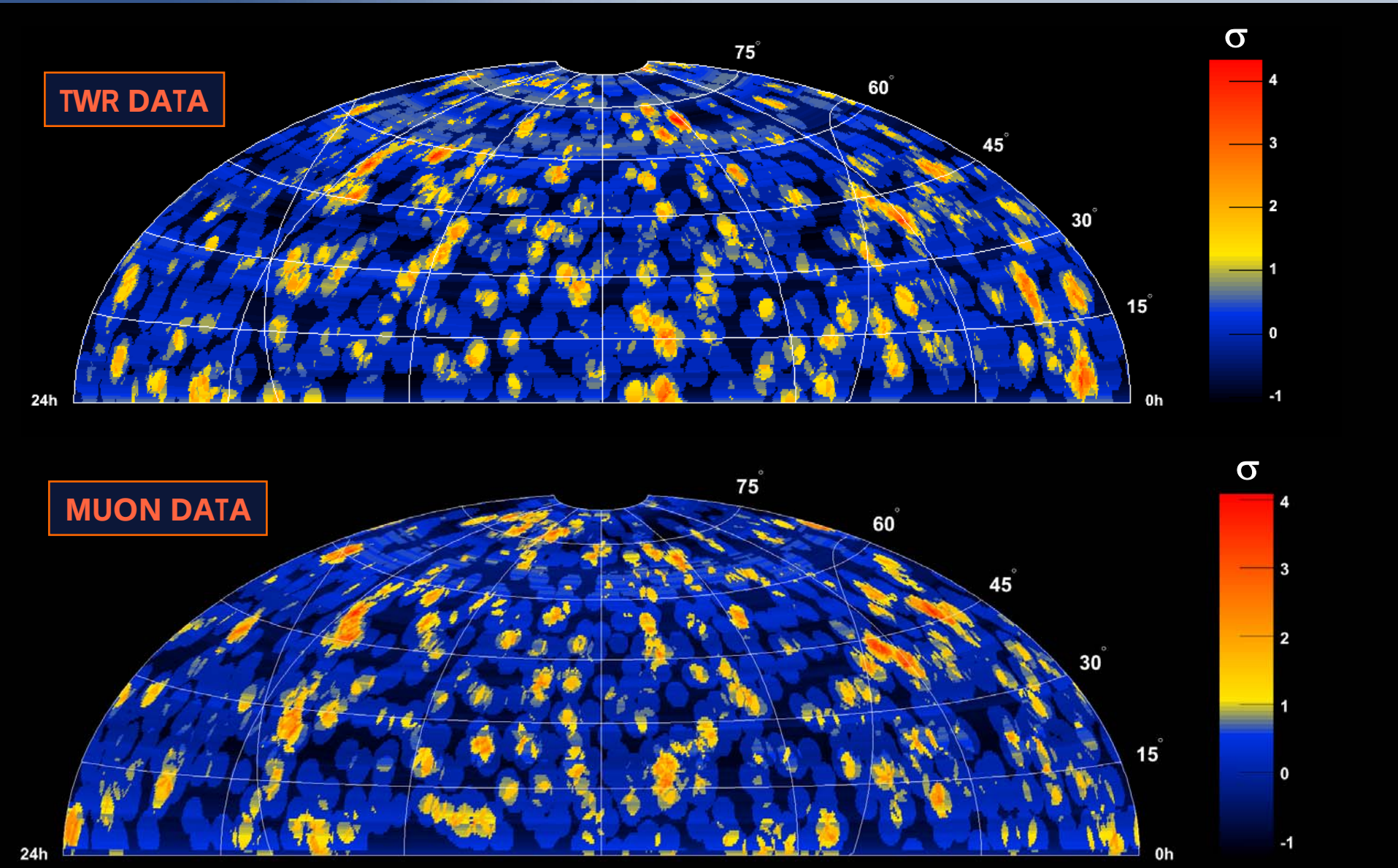
# Search for Clusters of Events in the Northern Sky



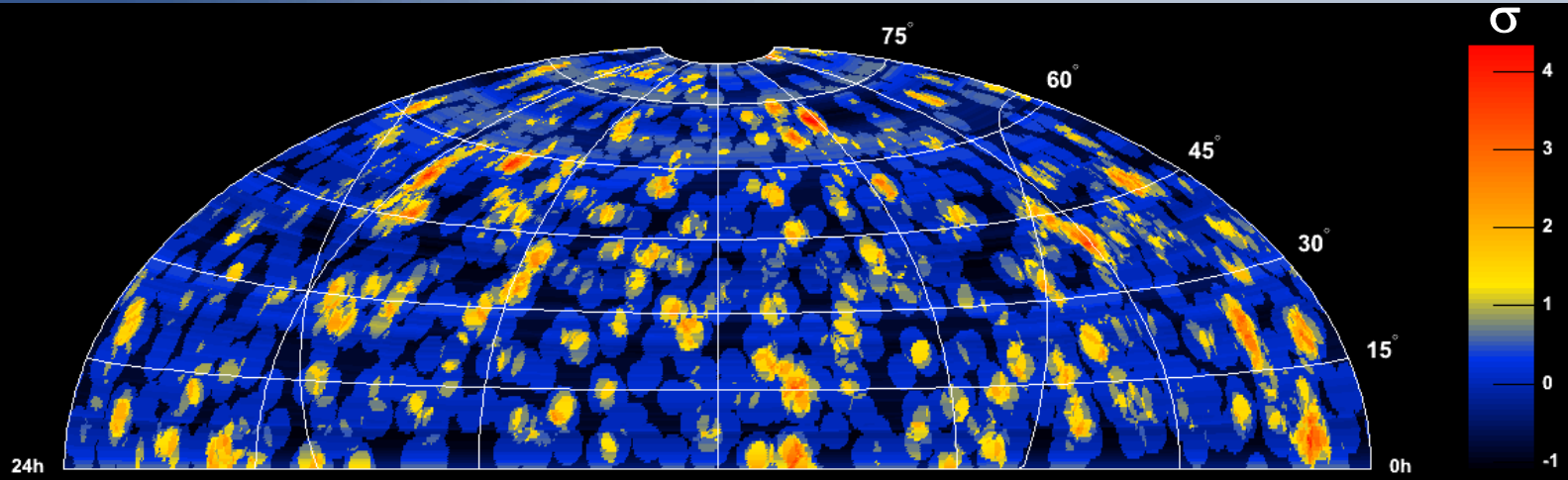

Final sample:

- **1112 neutrinos**
- cluster search radius between **2.25° - 3.75°** declination -dependent
  (due to AMANDA-II resolution improving with declination)

# Significance Map - data 2003



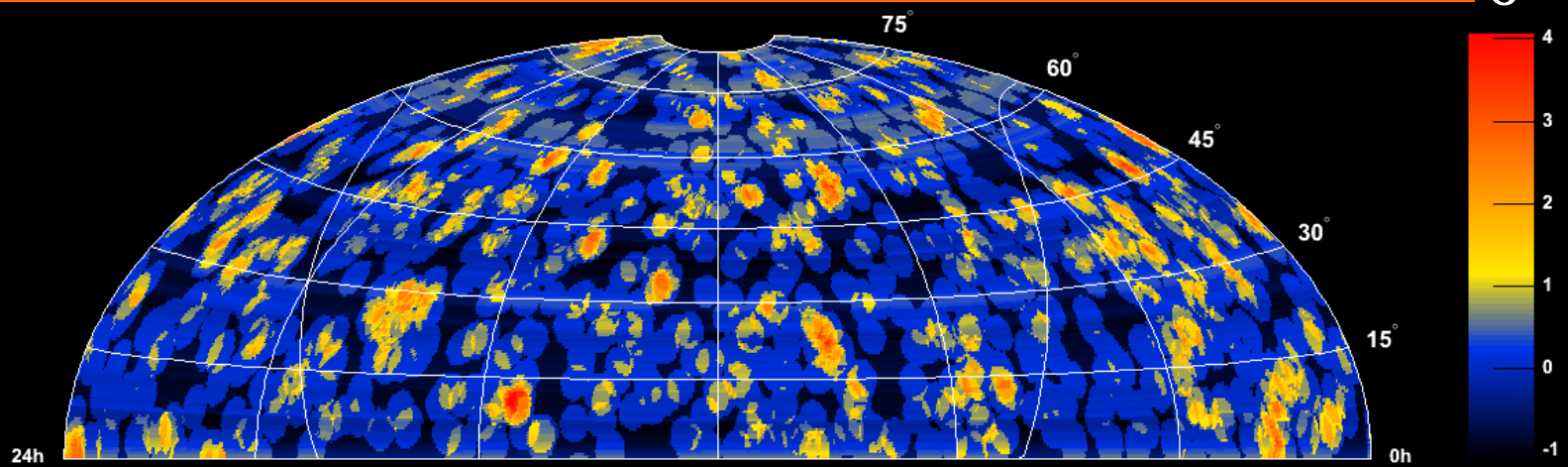
# Significance Map - TWR data 2003




Reconstructed Sky coordinates

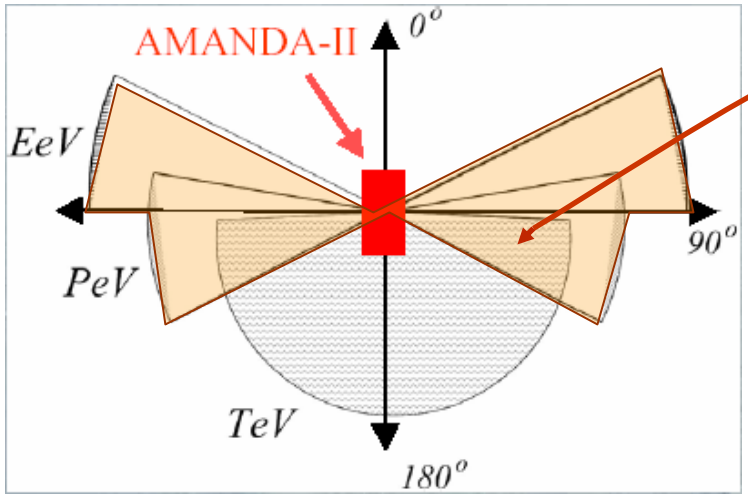
**NO EXCESS**

beyond randomly expected: **compatible with atmospheric neutrinos**

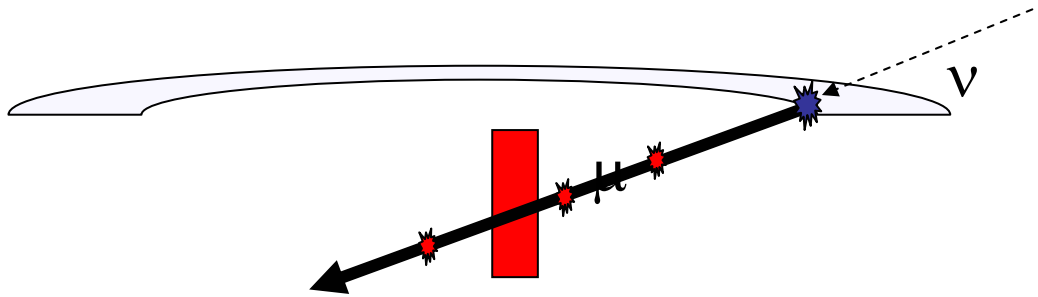



Scrambled in Right Ascension

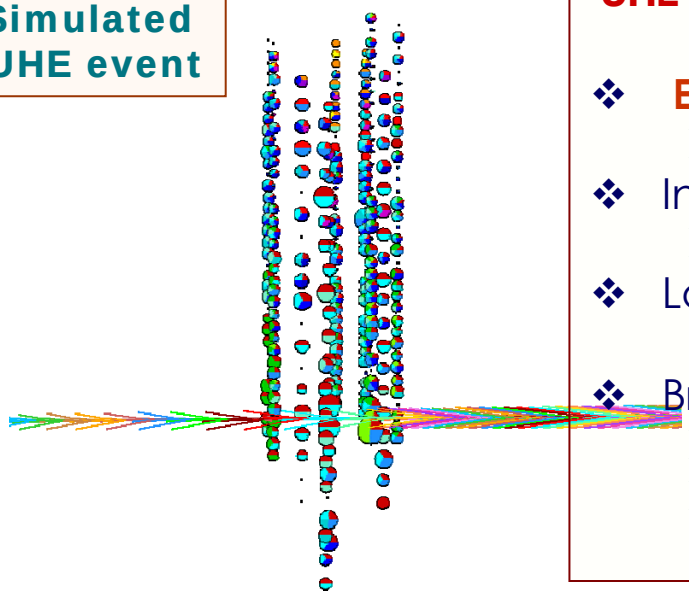
# Ultra – High – Energy (UHE) ν's Search




angular range for $\nu_\mu$ detection




**Simulated UHE event**



**UHE Neutrinos Search strategies:**

- **$E_\nu > 10^{16}$ eV**: Earth opaque
  - Search in the upper hemisphere and close to horizon
- Increased ν - X section
  - However uncertainties at these energies
- Long μ tracks
  - way outside the detector (**> 10 km**)
- Bright events
  - Atmospheric μ-bundles major background
  - Energy-related variables best handle of analysis

# Ultra – High – Energy (UHE) ν's Search

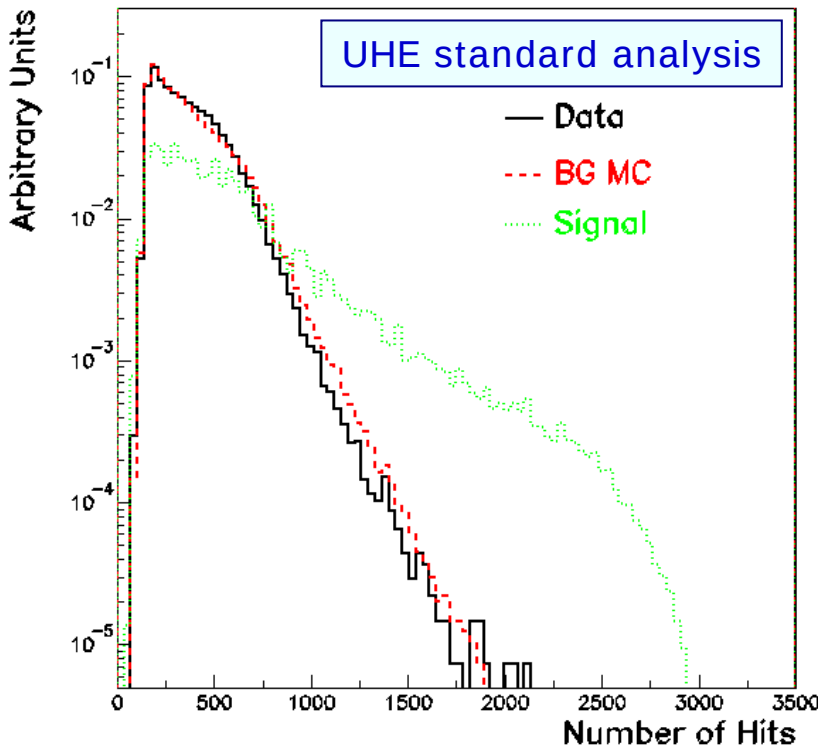
Very Preliminary

**Ultra – High – Energy Neutrinos: Events which deposit an enormous amount of light (energy) in the detector**

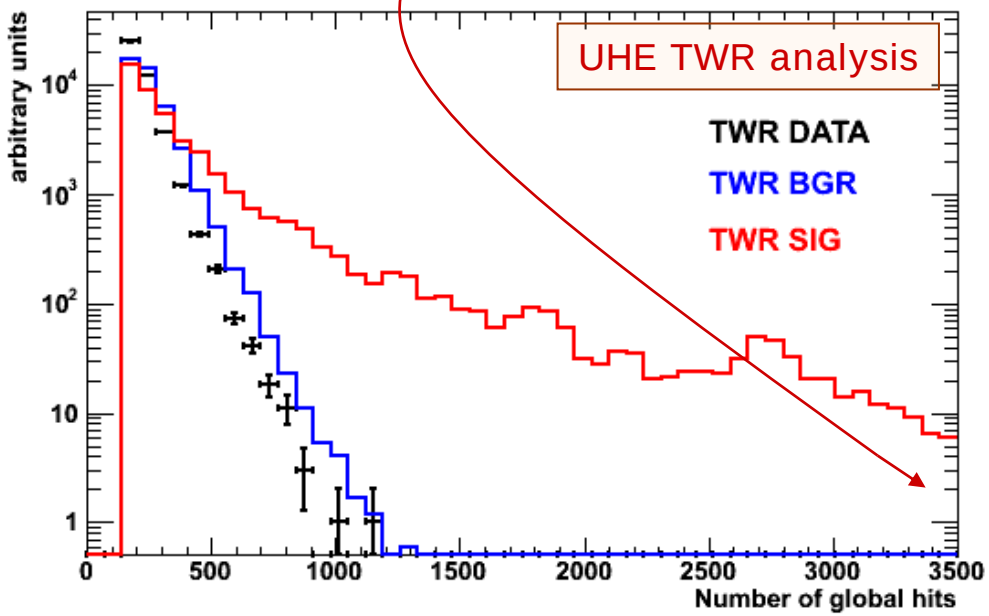
Choose of variables which can help best separate $E^{-2}$ SIG from BGR

**Blind Analysis performed with 20% of the full data set**

**Def.:**
**The Global Number of Hits**




- The number of global Nhits for TWR-data extends over **5000 Nhits** almost a factor 2 compared to the UHE standard analysis

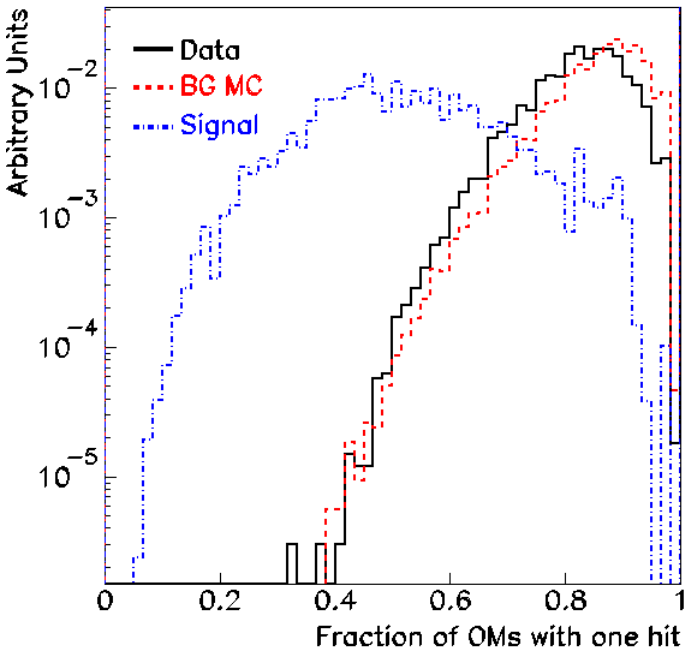


# Fraction of OMs with 1 Hit

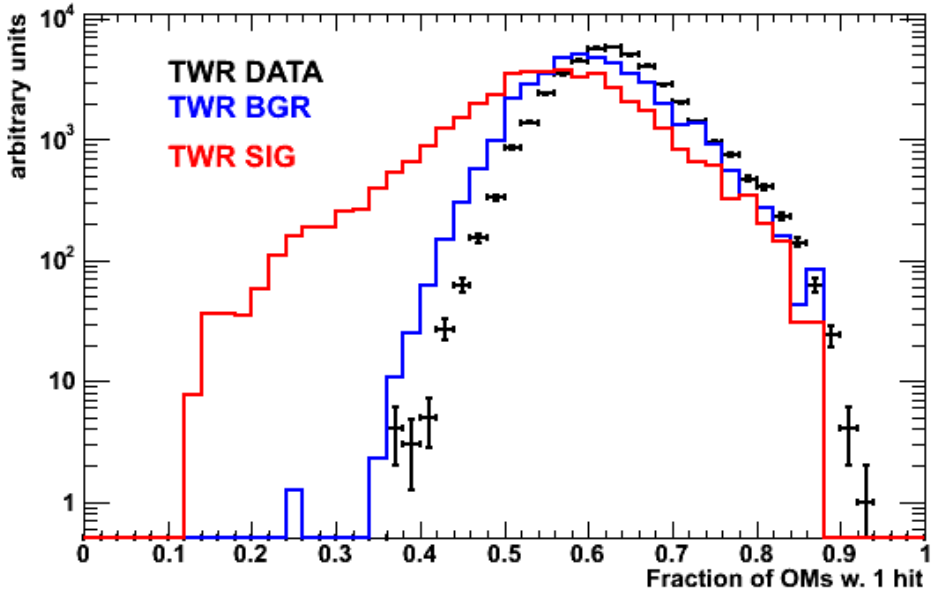
Good agreement for data and BGR MC. Variable used in the UHE standard analysis to reject large amount of BGR events

**Def.:**
**The Fraction of Optical-Modules with one Hit**

UHE standard analysis




UHE TWR analysis




- However a cut at any value on this variable kills a substantial fraction of the signal:

**more efficient variables needed!**

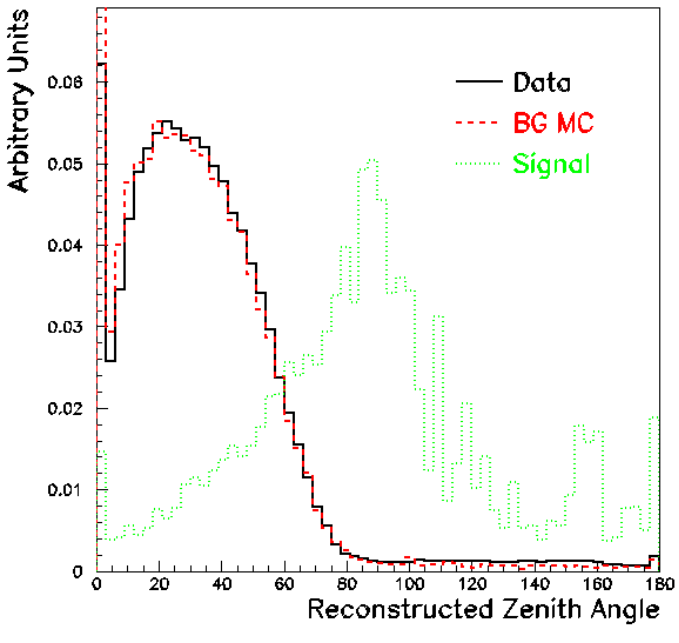
# Angular Information

Reconstructed **SIG MC** zenith with **TWR** at similar analysis level shows a resolution ~ **2.8 degrees,** a **factor 4 better** than the UHE standard analysis

**Def.:**
**The reconstructed Zenith**

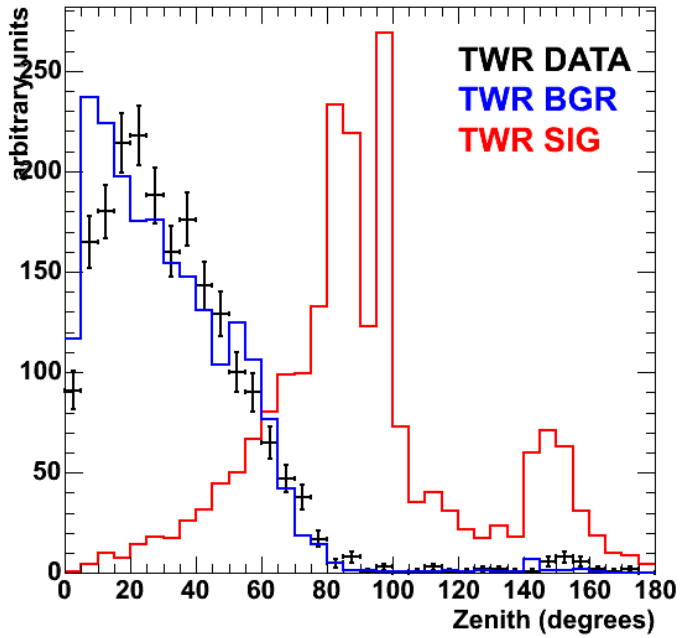
**Main Differences:**
- **Different set of cuts applied at this analysis level**
- **Different reconstruction algorithm used**

UHE standard analysis




$\sigma_{\Delta\theta}$~ 11° and $\Delta\theta$ ~ –10°

UHE TWR analysis




$\sigma_{\Delta\theta}$~ 2.8° and $\Delta\theta$ ~ 0°

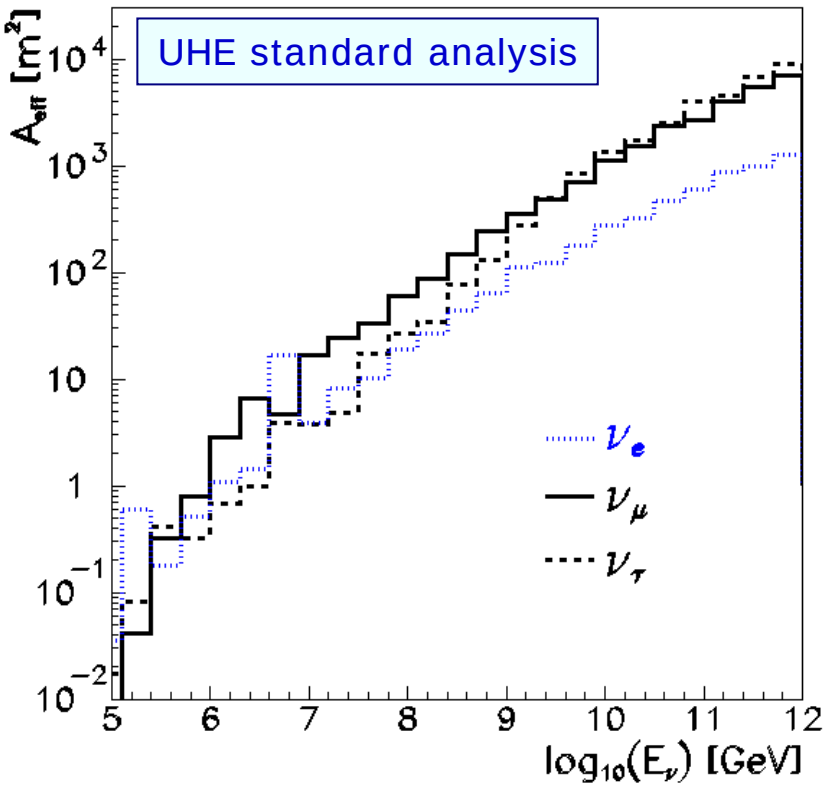
# Final Sample of SIG Neutrinos

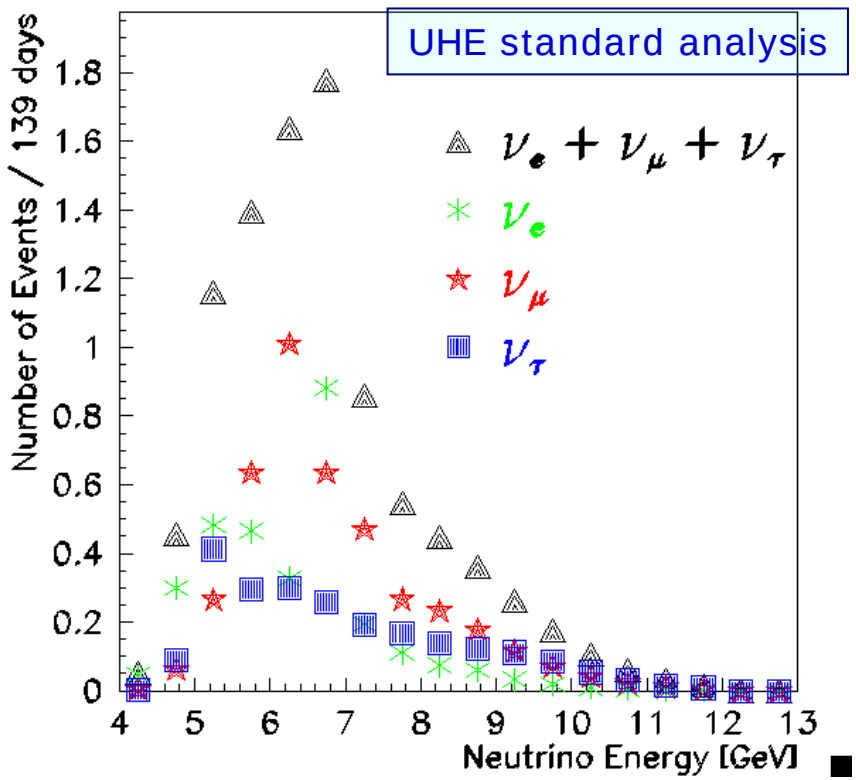
Detector effective area for all Neutrino Flavors increases with energy

**Def.:**
**The Detector effective area**

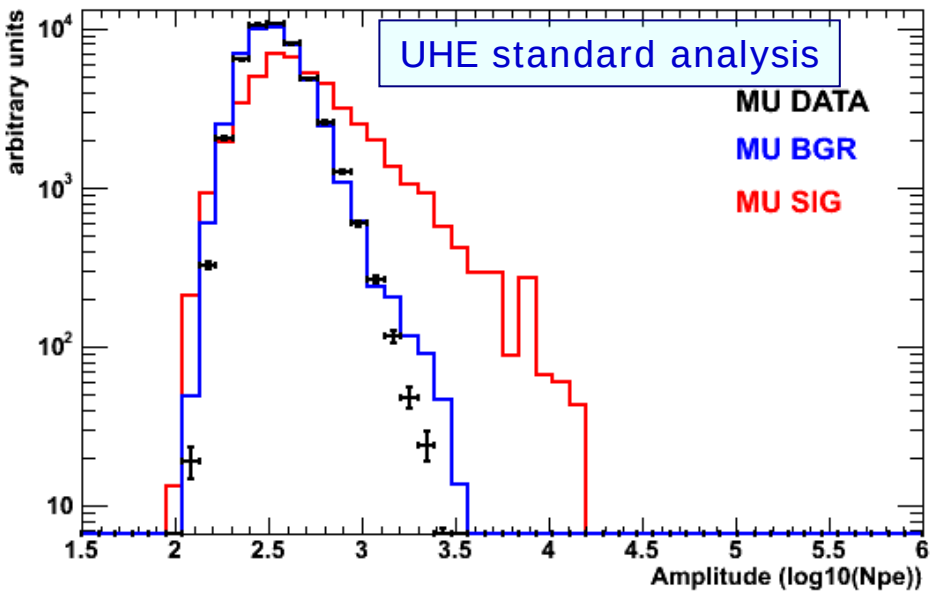
Larger contribution from Muon-Neutrinos in the Energy distribution for a **SIG** of $\mathbf{E^{-2}}$ spectrum

**Def.:**
**The Energy distribution of all ν's**



# TWR New variables

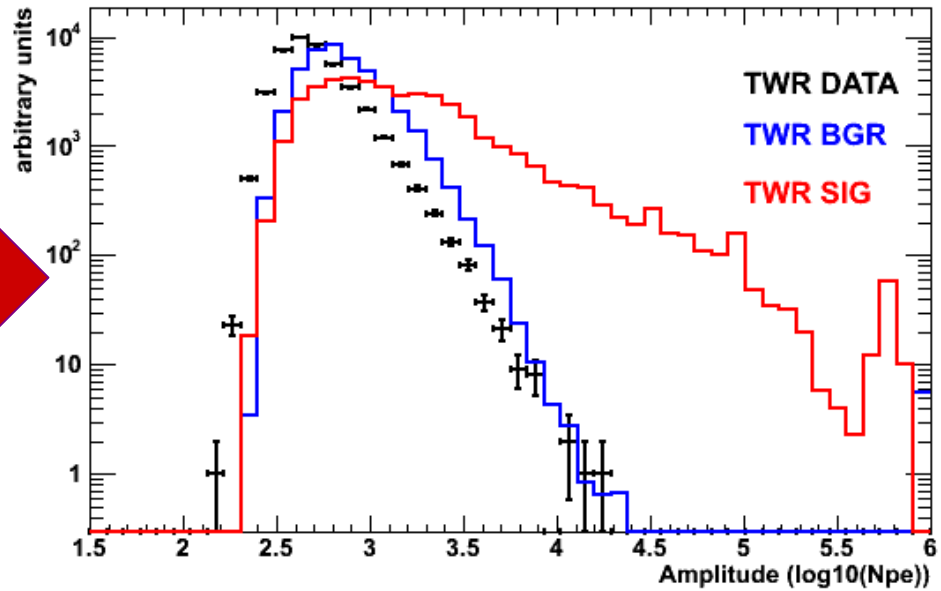



**Def.:**
**The Global Number of photo-electrons**

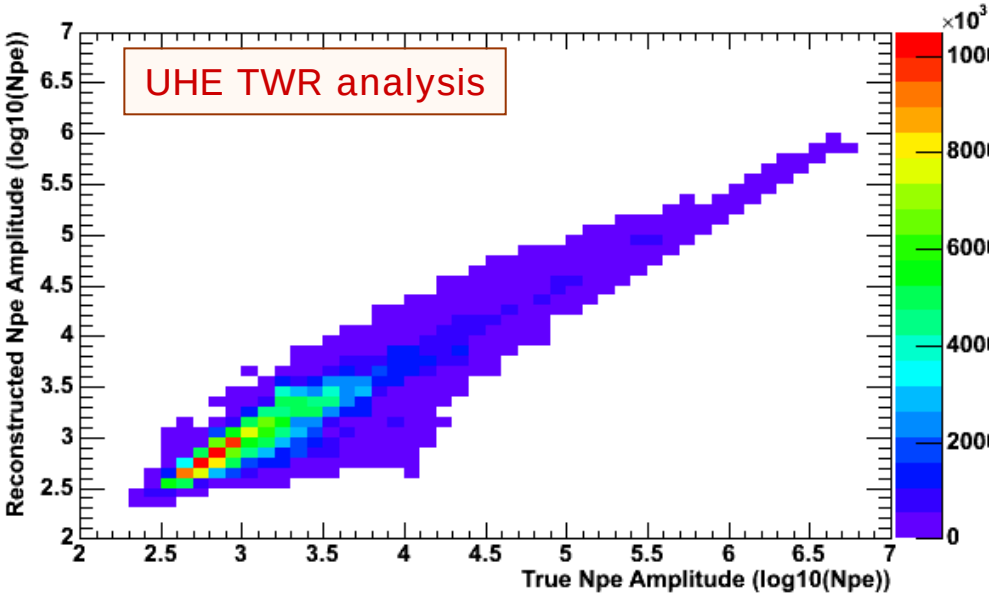
Limited capability of the standard **Muon-DAQ**, where the number of Npe saturates ~ 10 pe/OM

Total Number of photon electrons (Npe) can extend up to **6 order of magnitudes** for **TWR-DAQ** data including After-Pulse information

UHE TWR analysis



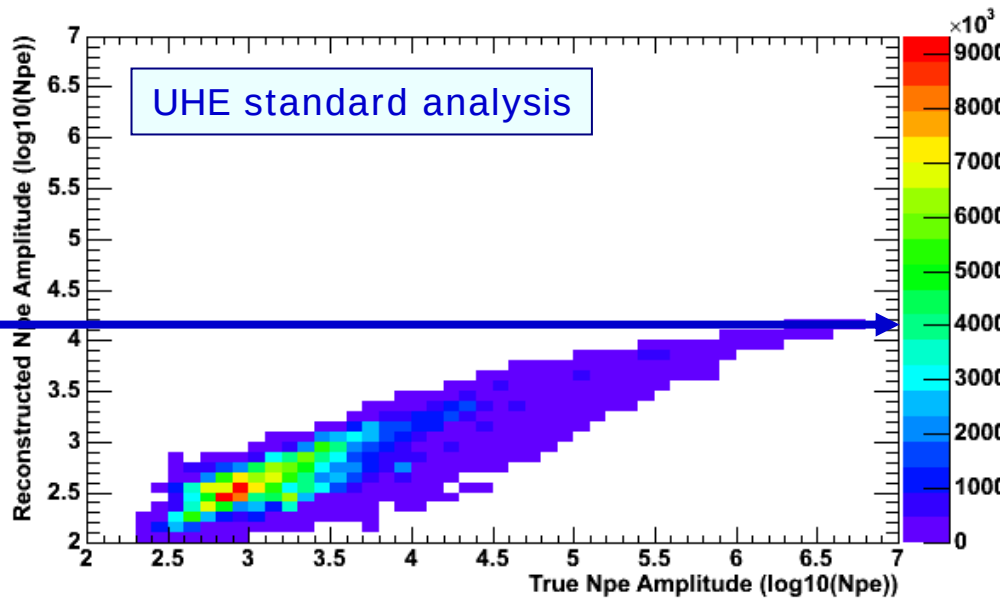
# Reconstructed Npe



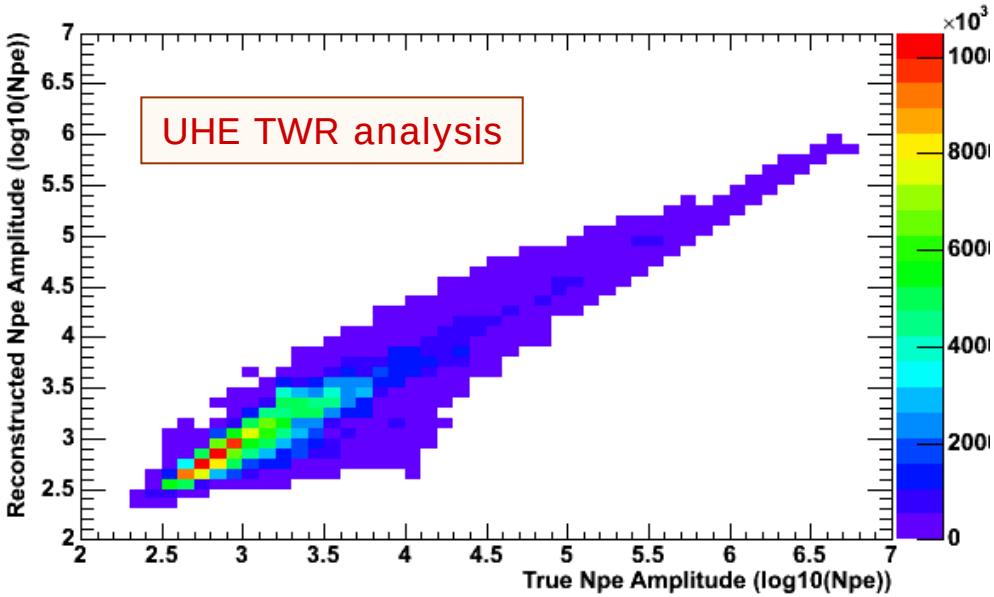

**Def.:**
**Reconstructed Npe vs. True Npe**

From TWR data is possible to reconstruct well the information of true Npe over the full range up to **log10(Npe) ~ 6, a factor 100 better** than the standard analysis

The analysis with standard Data is limited at **log10(Npe) ~ 4**, which shows a clear saturation of the DAQ system



# Energy Information

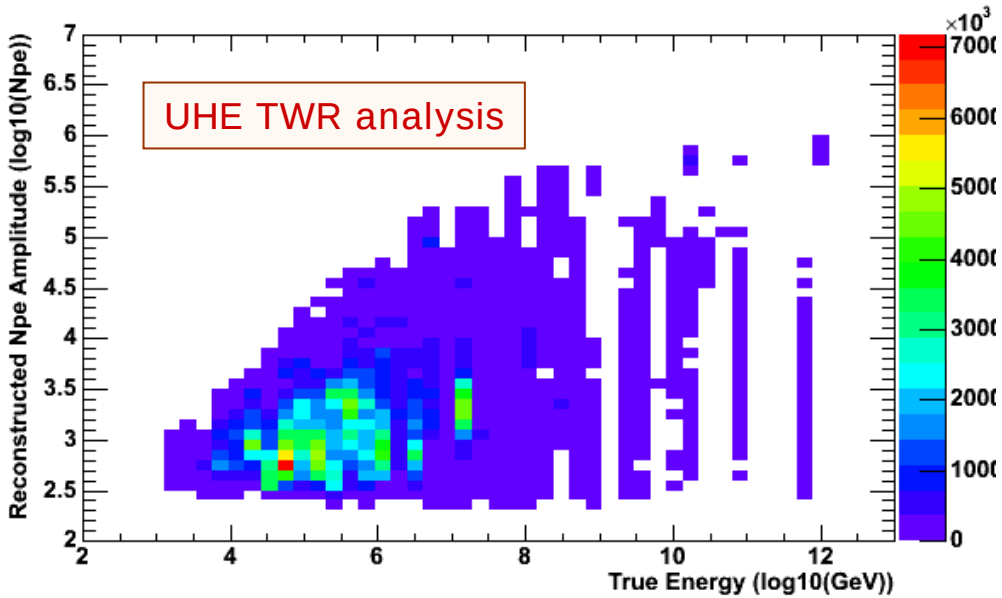



**Def.:**
**Reconstructed Npe vs. True Npe**

**Very good** agreement over the full range for the reconstructed and true Npe information

**Def.:**
**Reconstructed Npe vs. True Energy**

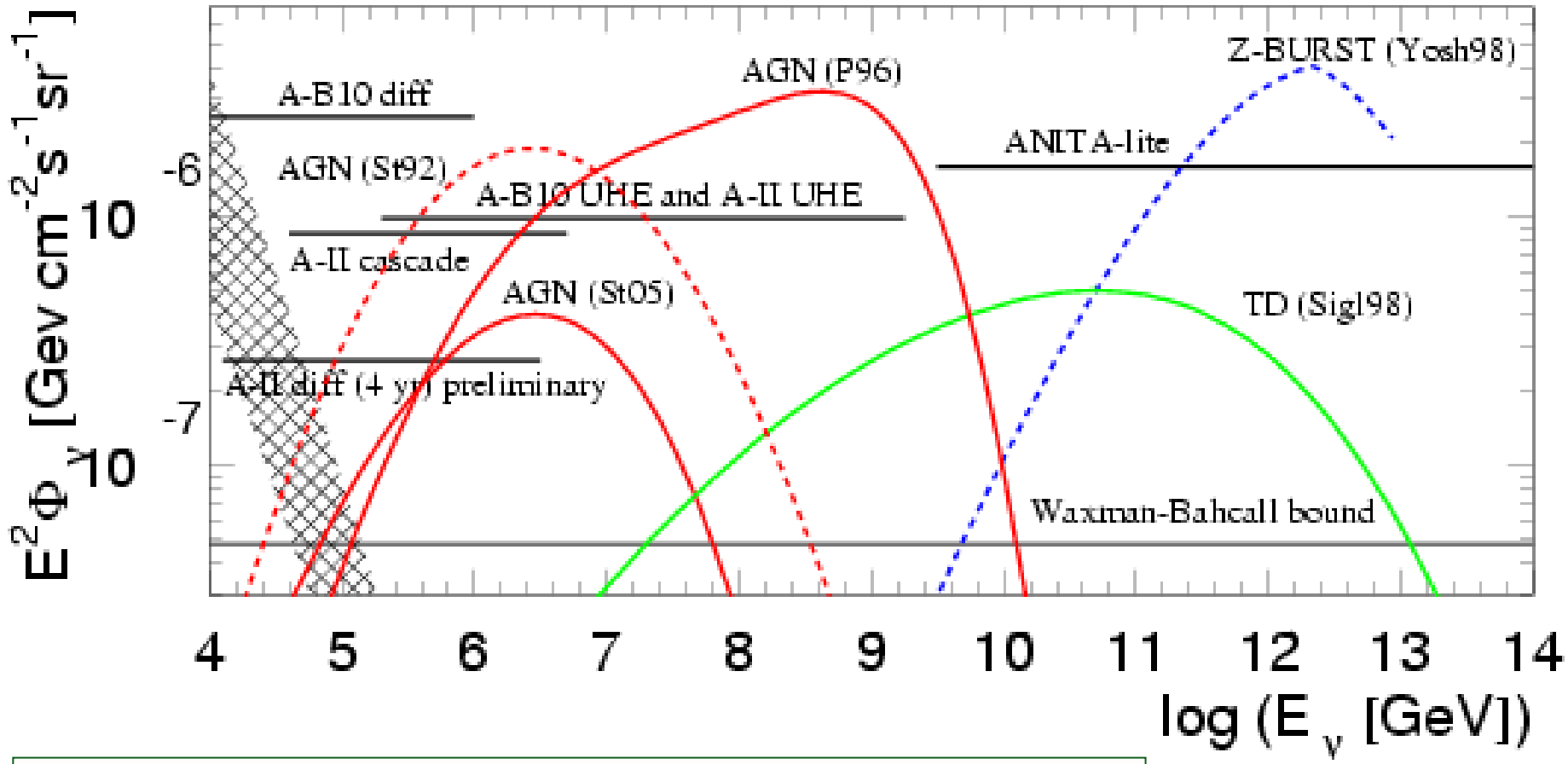
**However** more complicated variables including Npe info from **After-Pulses** is needed to reconstruct more precisely the energy



# AMANDA Experimental Limits

**Not TWR results included yet! The goal → improve current limits using TWR**

**The most stringent experimental limits on the planet**




**The AMANDA limits assume 1:1:1 ratio of the ν–flavors**

# Summary

## AMANDA & IceCube: world's largest Neutrino Telescope

- ☑ New TWR DAQ system installed and operating
- ☑ New challenges:
  - ☑ Large data volume production > 50TB in two years
  - ☑ Very CPU intensive processes
- ☑ New methods developed to face these challenges
- ☑ First large scale analysis of AMANDA data performed on TG
- ☑ First results published:
  - ☑ http://amanda.uci.edu/~silvestri/TWRicrc29.pdf
- ☑ For an update on this work:
  - ☑ http://www.ps.uci.edu/~silvestri
- ☑ New AMANDA limits on diffuse and UHE neutrino fluxes
- ☑ Very promising results by performing a UHE search using TWR
- ☑ Ongoing UHE analysis based on TWR data to improve current limits