Neutrino Astronomy at the South Pole
Status of AMANDA Experiment

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AMANDA Collaboration

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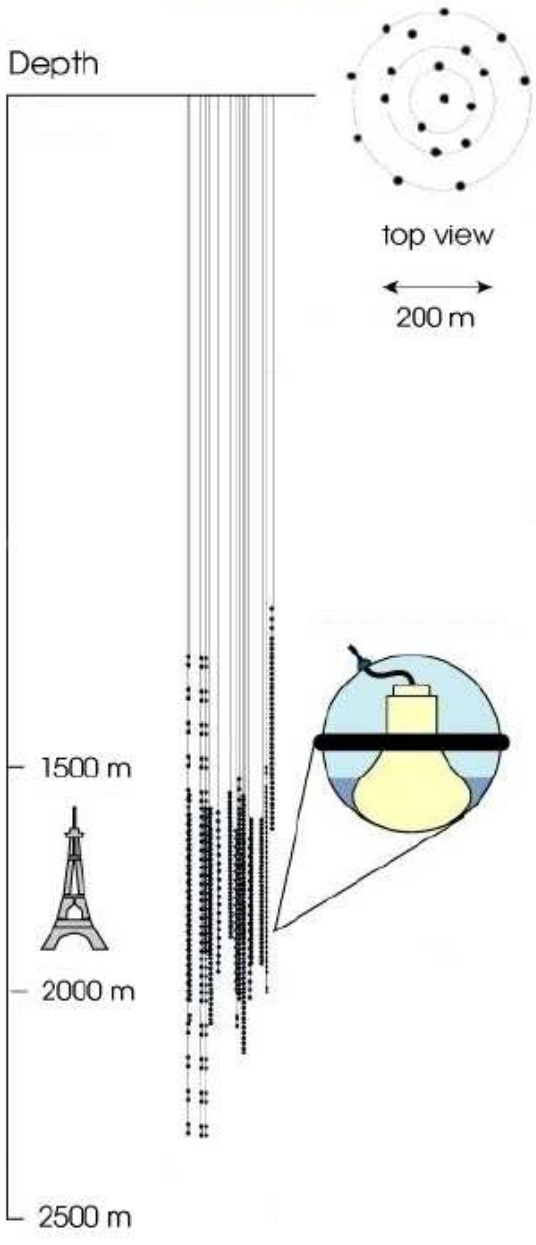
Dept. of Physics Stockholm University, Stockholm
Div. of High Energy Physics, University of Uppsala, Uppsala

Dept. of Technology, University of Kalmar, Kalmar

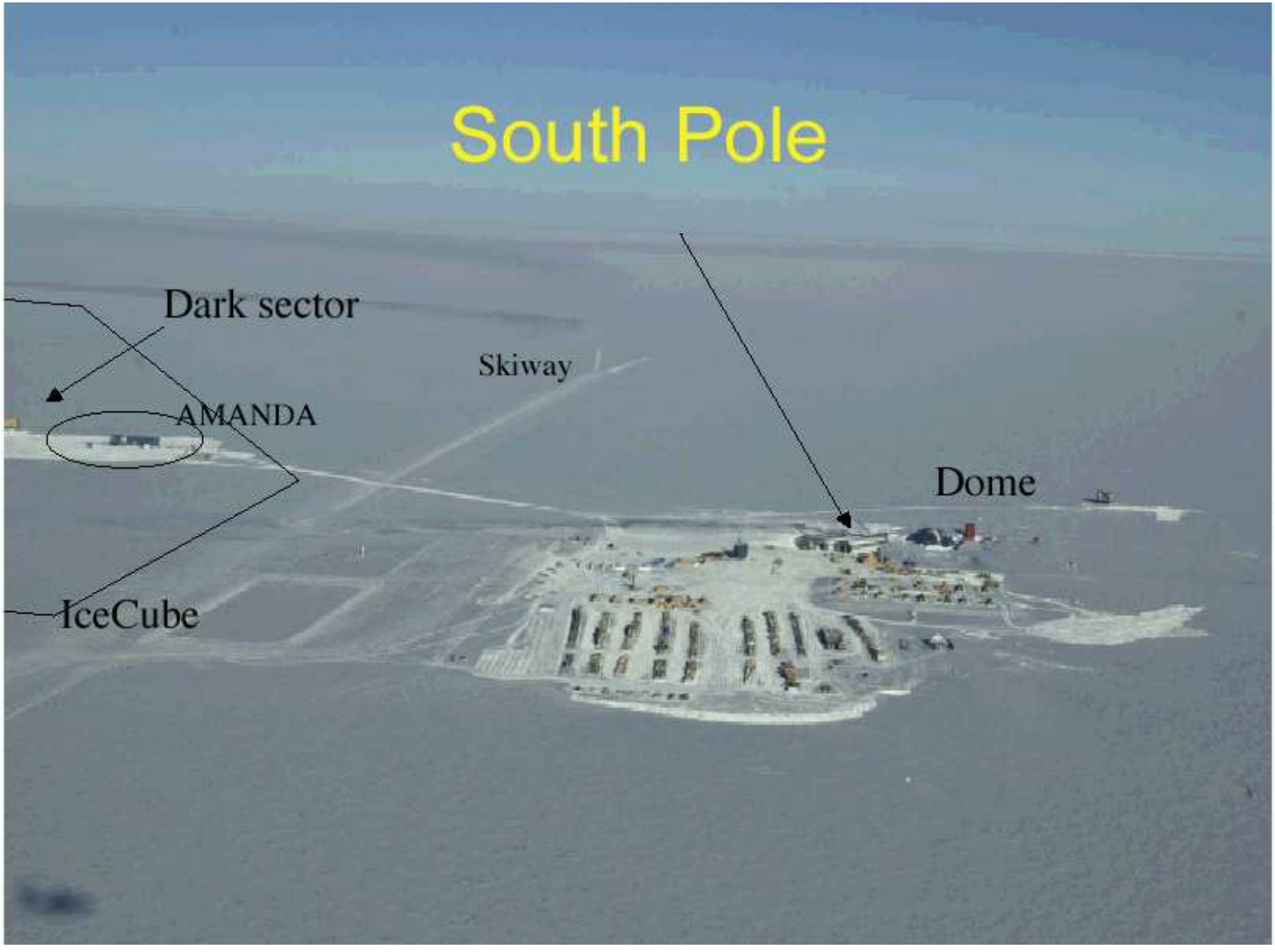
AMANDA-II Experiment



- 19 strings
- 677 Optical Modules (OM)
- 200 meters diameter
- 500 meters tall

- completed in 1999
- 1997-99 AMANDA-B10
  - 10 strings, 300 OM

AMANDA-II Location



AMANDA-II Deployment

- drill 2,000 m holes with $90°C$ water
- hole diameters is $\sim 50\ cm$ but varies with depth to correct for ice temperature profile
- drilling time is $84 - 160\ h$
- deploy strings with optical sensors
- deployment time is $\sim 20\ h$

Why Neutrinos ?

Astronomical Messengers

Sun, SN1987A

Neutrinos

Protons

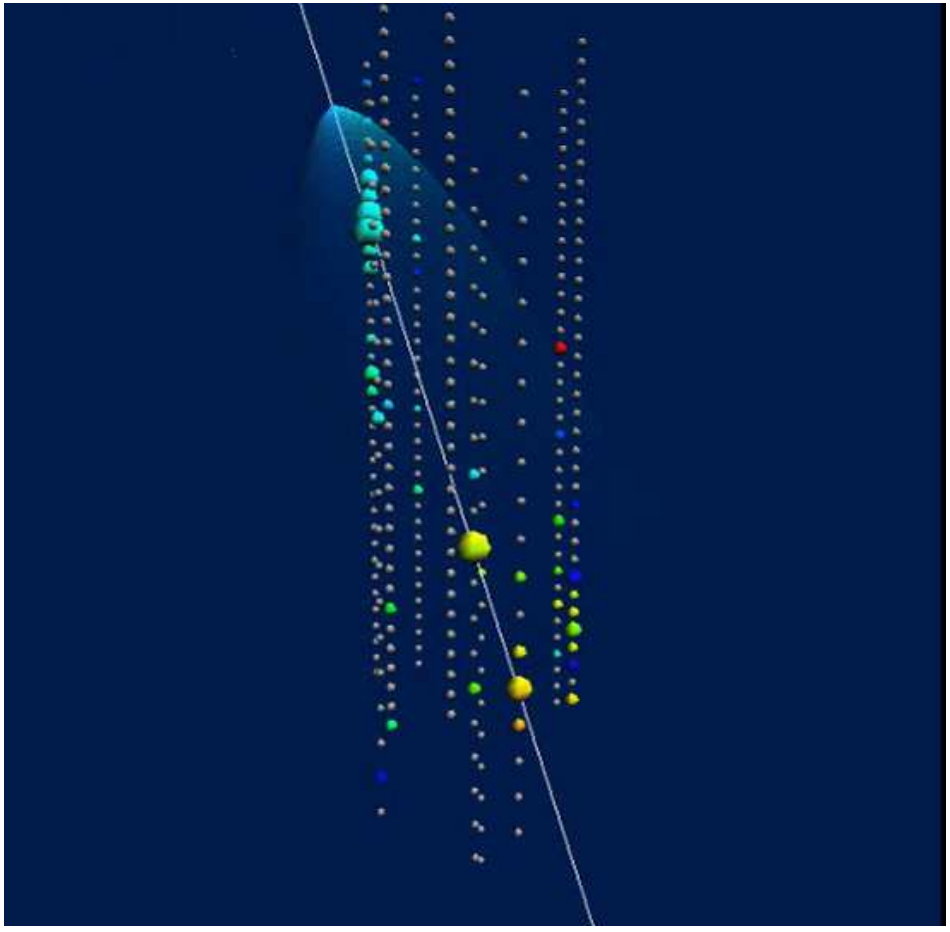
Photons

TeV PeV EeV

10 11 12 13 14 15 16 17 18 19 20 21 22

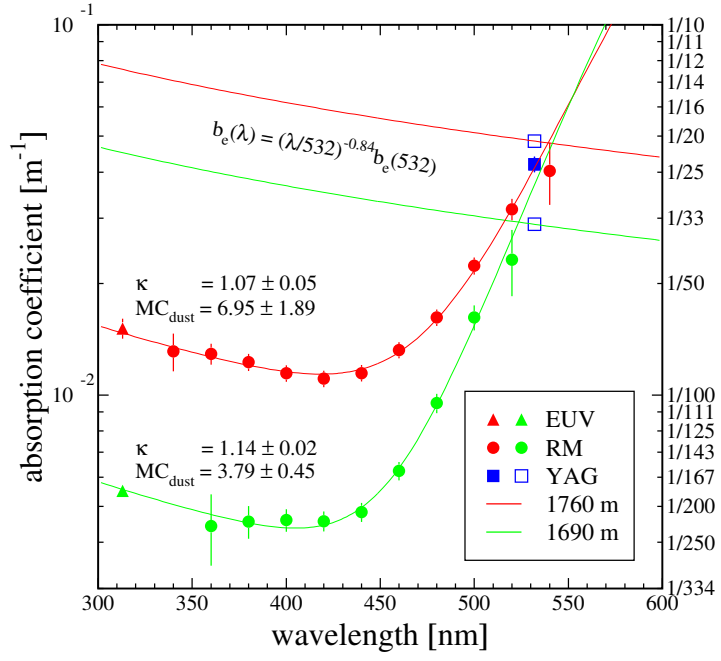
Log(E) (eV)

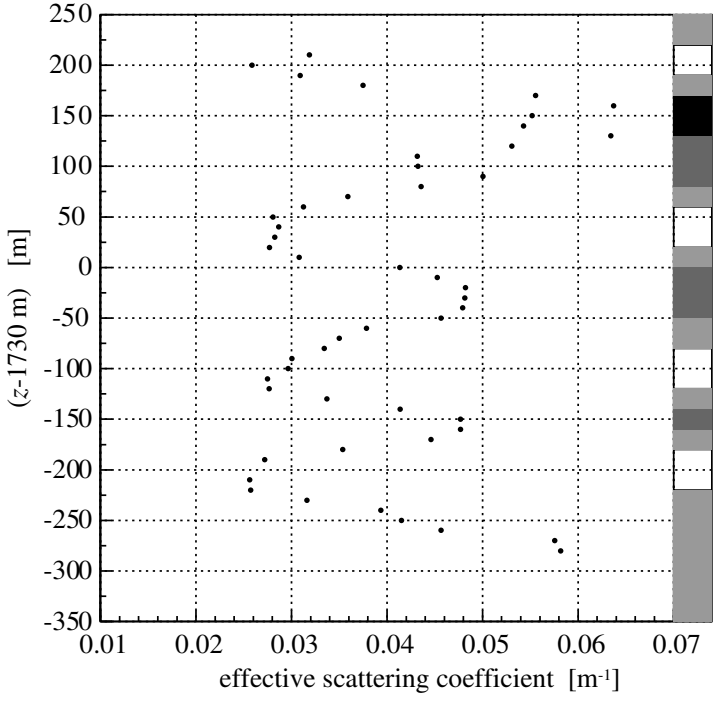
Detection Principle



- Cherenkov photons are detected by PMTs
- tracks are reconstructed by maximum likelihood method of photon arrival times
- cascades have a spherical topology
- need specific reconstruction technique
- $\Rightarrow$ ice properties
- $\Rightarrow$ array geometry

Ice and Geometry

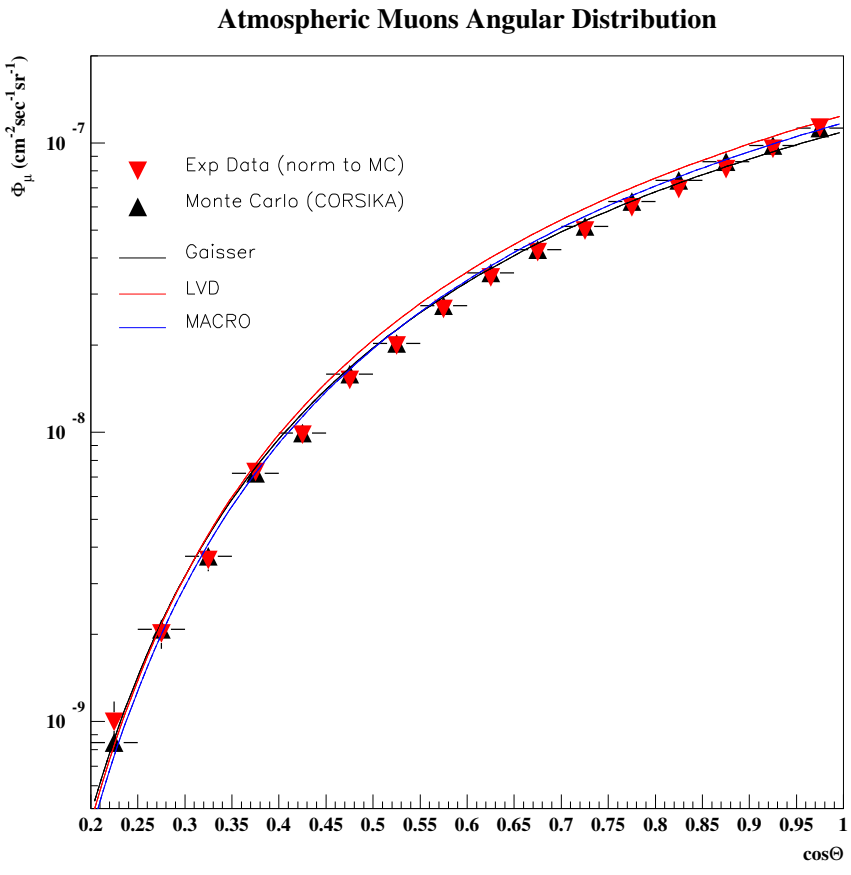




- ice optical properties non homogeneous
- scattering/absorption varies with depth and λ
- average properties at $\sim 400nm$
- $110m$ absorption
- $20m$ effective scattering

- in-situ calibration lasers used also for geometry/time calibration
- geometry precision is $\sim 0.5m$
- photon arrival time precision $\sim 5ns$

Cosmic Ray Muons

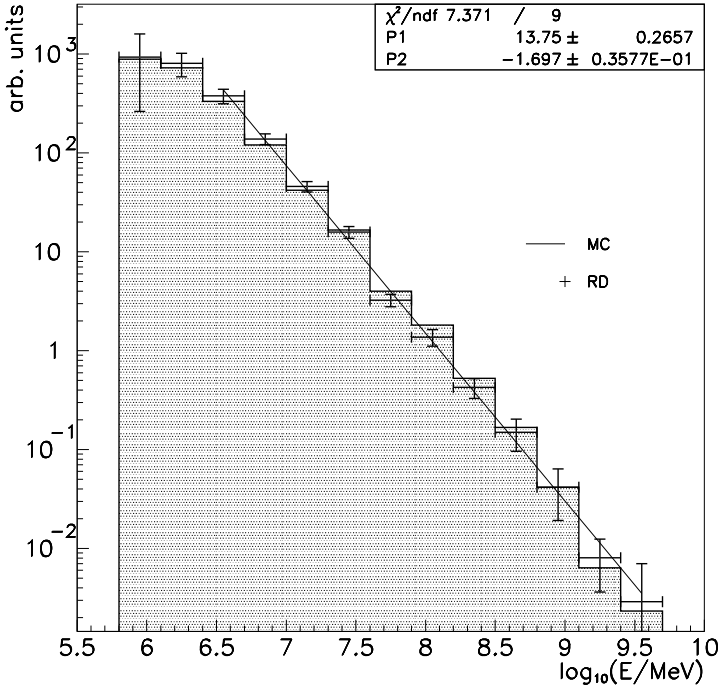


- $E_{th} \sim 40\ GeV$ in average
- good quality tracks
- resolution $\Delta\theta = 2.4°$
- $\sim 20\%$ ice models uncertainty

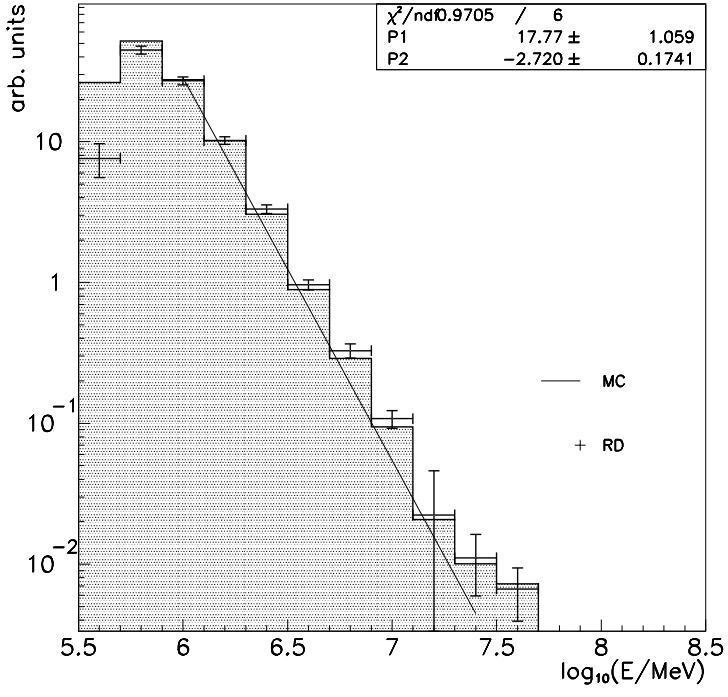
- Data/MC normalized to vertical bin
- MC uses CORSIKA with Wiebel-Sooth primary CR

- curves from Klimushin et al. Phys.Rev.D, 64, 014016
- predictions with experimentally measured parameters

Muon/Primary Energy Spectrum

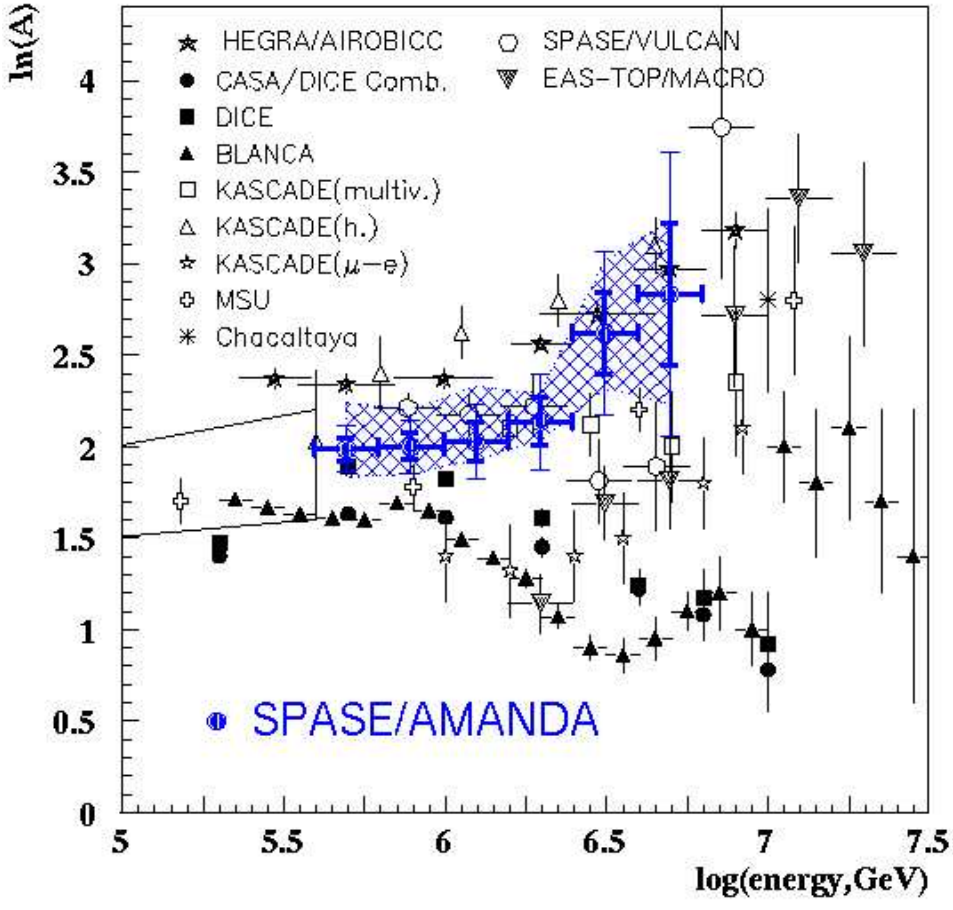


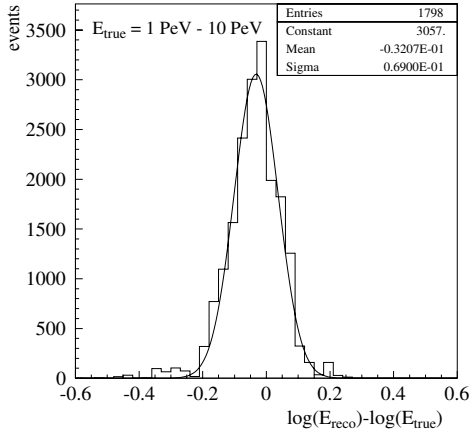
- CORSIKA with Wiebel-Sooth CR spectrum
- $\gamma_{all} = 1.68 \pm 0.03$ from MC
- primary cosmic ray spectrum
- $\gamma_{int} = 1.70 \pm 0.04$



- use of regularized unfolding
- sea-level single muon spectrum
- $\gamma_{int} = 2.72 \pm 0.17$

CR Composition





- SPASE-AMANDA coincidence
- SPASE S30 ($\rho_e(30m)$)
- AMANDA K50 ($< ADC > (50m)$)
- strong correlations with A and E_{CR}
- SPASE/AMANDA result normalized at first point
- $\sim 7\%$ resolution in E_{CR} in 1-10 PeV

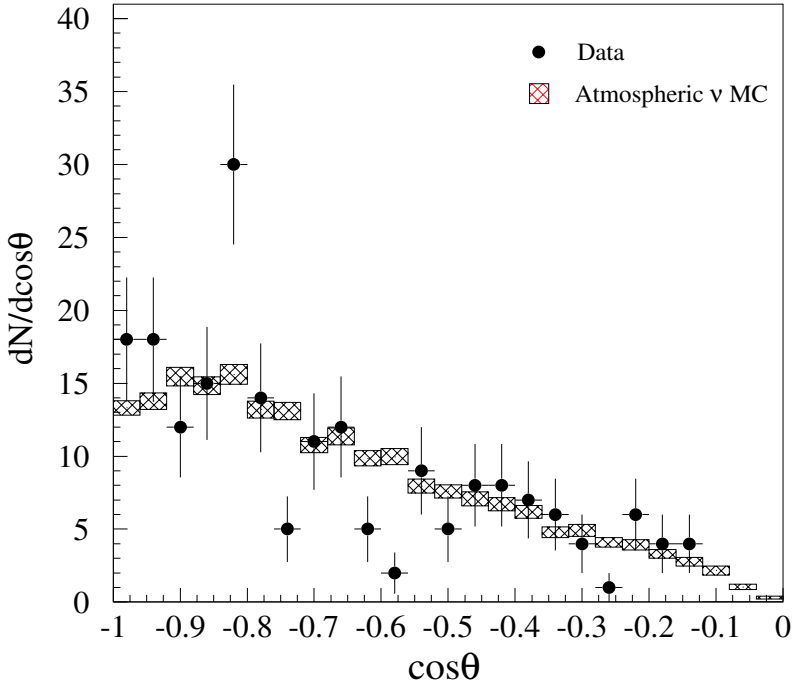
Neutrino Analyses

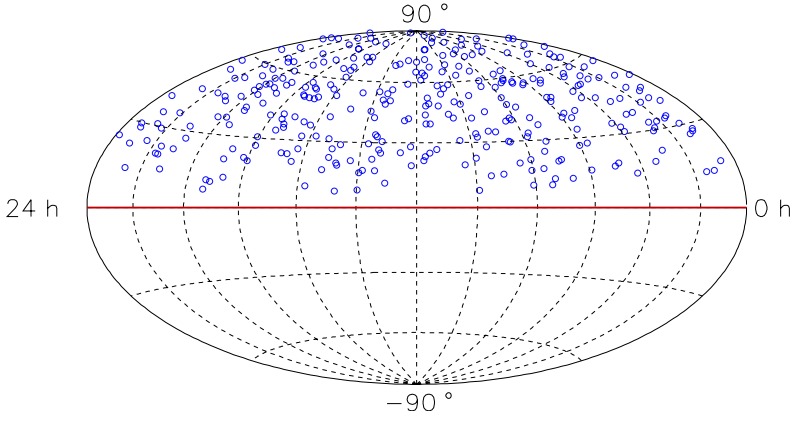
	up/down	energy	source direction	arrival time	count rate	topology
Atm ν_μ	★					
Diff & EHE ν	★	★				
Point Sources: AGN,WIMPS	★	★	★			
GRB	★	★	★	★		
Cascades	★	★		★		★
Supernovæ					★	

L1 [OM cleaning, first guess fit, loose angular cut]

L2 [max likelihood fit, bayes fit, tighter anguar cut, direct hits]

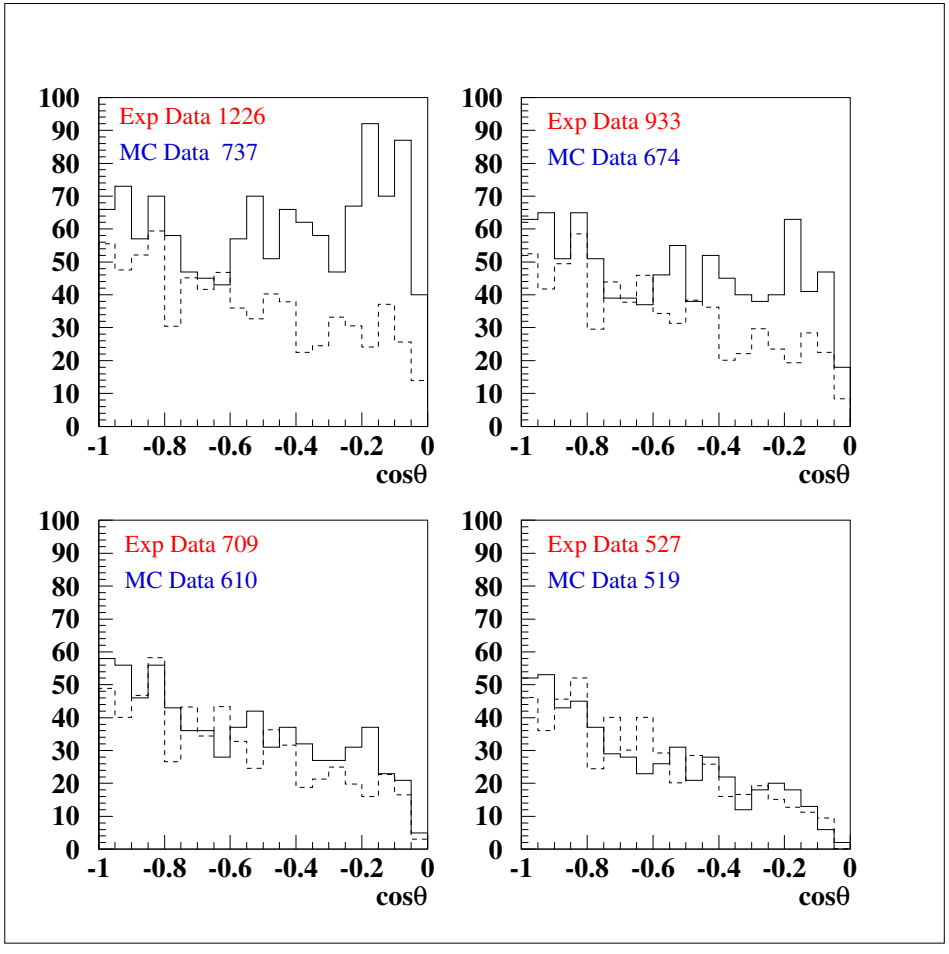
Atmospheric ν in AMANDA-B10





- in 130.1 days lifetime
- MC normalized to data at high cut level
  - $N_{exp} = 204$ events
  - $N_{mc} = 279 \pm 3$ events
- Background contamination
  - $\sim 5 - 10\ \%$
- pointing resolution $3.2°$
- $66GeV < E_\nu < 3.4TeV$
- Physical Review D, 66, 012005 (2002)
- Nature, Vol 410, 22 Mar 2001, 441-443

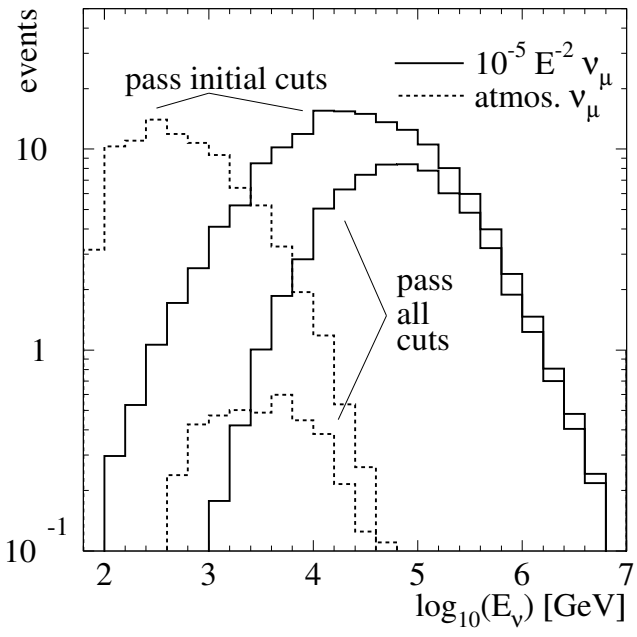
Atmospheric ν in AMANDA-II

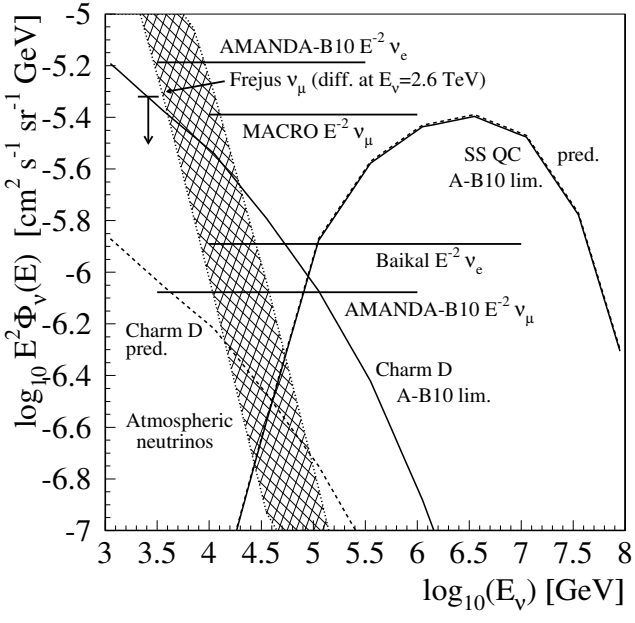


- pure ν sample
- easier to obtain than B10
- only 3 cuts $\Rightarrow 4\ \nu\ /\ d$

- 197 days in 2000
- good understanding of atmospheric ν_μ
  - $N_{hit} < 50$
  - $\Theta_{fit} > 110°$
  - high fit quality
  - uniform light deposition along the track
  - effect of cut tightening

Diffuse ν_μ in AMANDA-B10

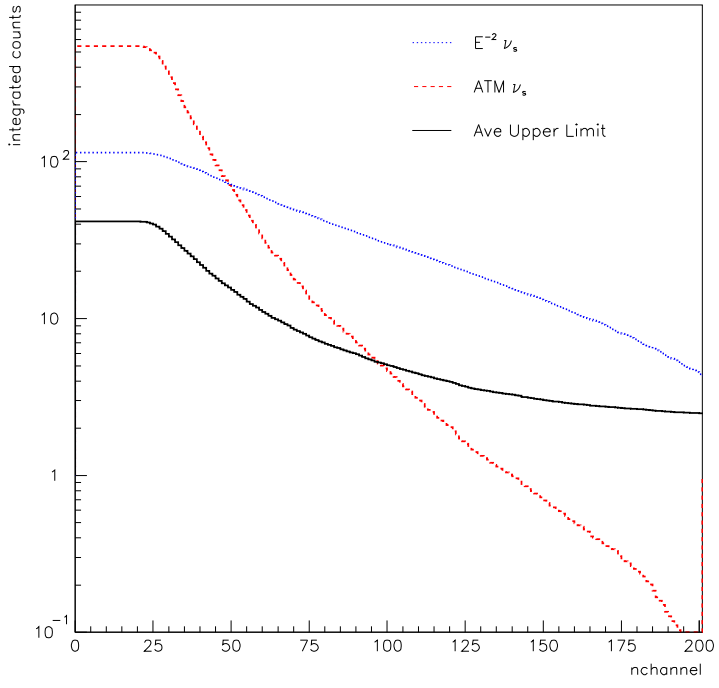




- search for HE ν_μ from unresolved sources
- assumes harder spectrum
- $\Phi_{\nu_\mu} = 1 \times 10^{-5} \cdot E^{-2}\ cm^{-2} s^{-1} sr^{-1}$
- background (atm ν_μ) suppressed by energy cuts (nch)
- 90% of events in $6TeV < E_\nu < 1PeV$

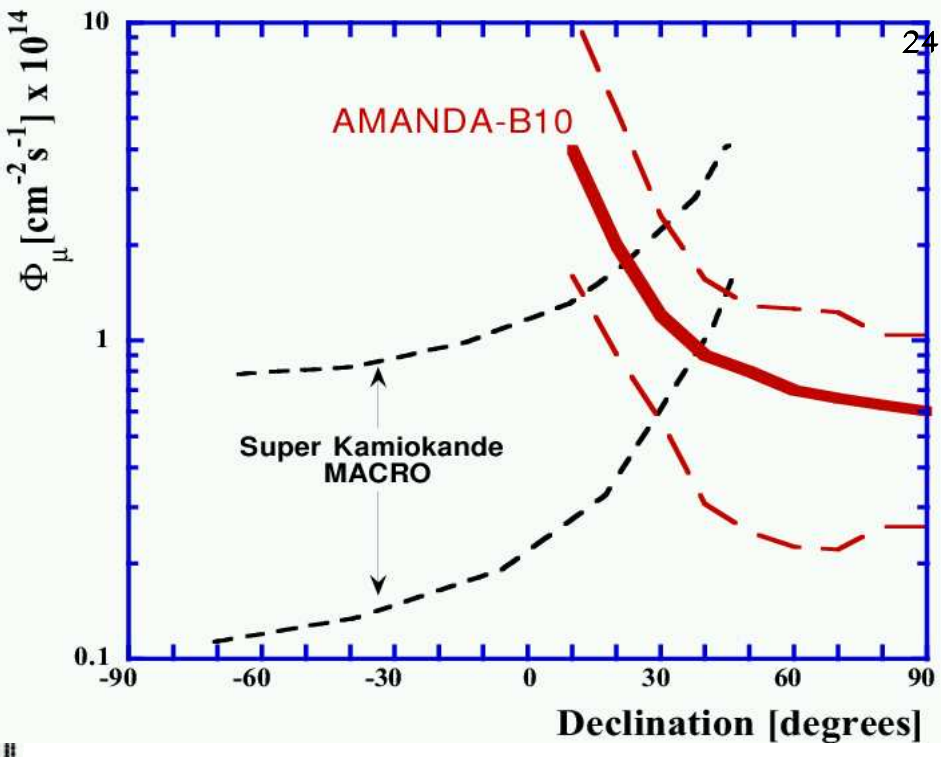
- limit(no sys uncertainty)
  - $\Phi_{90\%} < 7.7 \times 10^{-7} \times E^{-2} cm^{-2} s^{-1} sr^{-1} GeV$
- limit(with 25% sys uncertainty)
  - $\Phi_{90\%} < 8.4 \times 10^{-7} \times E^{-2} cm^{-2} s^{-1} sr^{-1} GeV$
- submitted to Physical Review Letters

Diffuse ν_μ in AMANDA-II

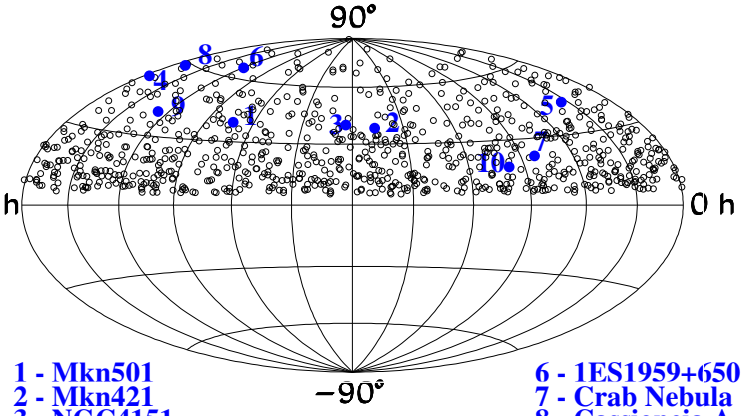


- $\Phi_{\nu_\mu} = 1 \times 10^{-6} \cdot E^{-2}\ cm^{-2} s^{-1} sr^{-1}$
- 90% of events in $10TeV < E_\nu < 10PeV$
- 90% CL Feldman-Cousins average upper limit
- optimal energy cut at nch=93
- sensitivity for 1y $1.7 \times 10^{-7} \cdot E^{-2}\ cm^{-2} s^{-1} sr^{-1}$
- $\times$ 4.5 better than AMANDA-B10
- still on-going analysis

Point Sources in AMANDA-B10



- Ap J, 583, 1040 (2003)

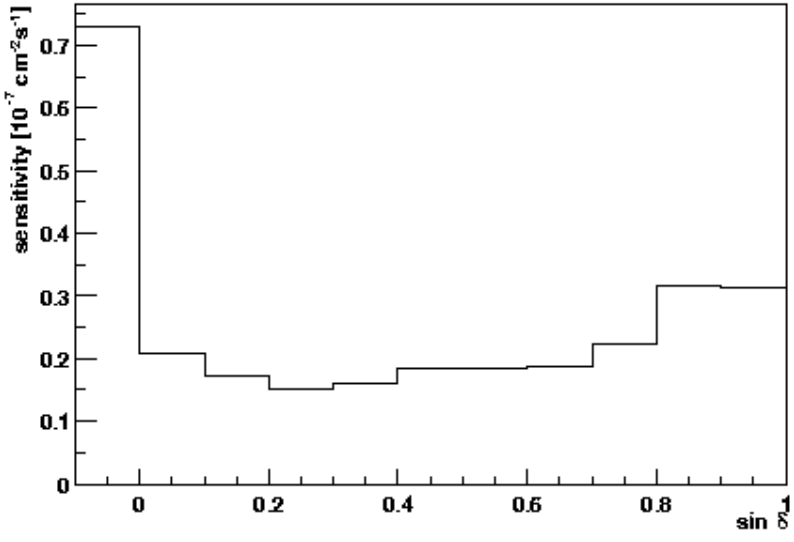


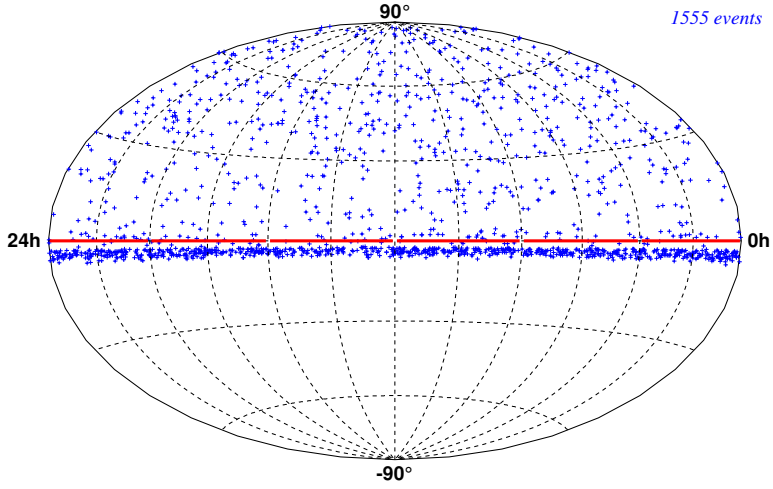
1 - Mkn501
2 - Mkn421
3 - NGC4151
4 - 1ES2344
5 - 3C66A
6 - 1ES1959+650
7 - Crab Nebula
8 - Cassiopeia A
9 - Cygnus X-3
10 - Geminga

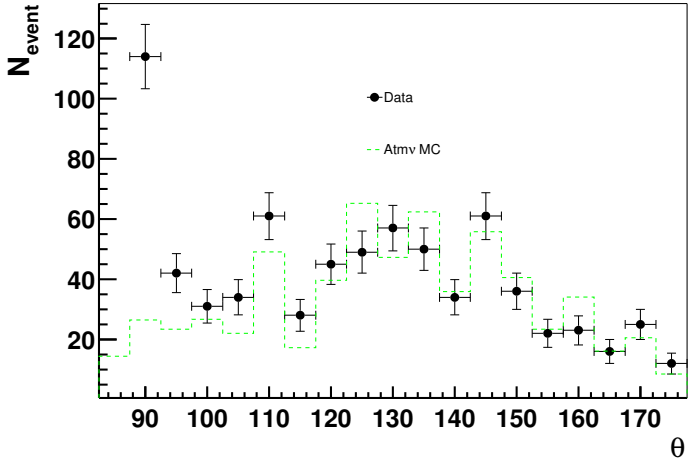
- median pointing resolution $\Psi = 3.9°$
- northen hemisphere sky divided in 154 bins ($\sim 11° \times 11°$)
- looser cuts than atmospheric $\nu \Rightarrow$ higher sensitivity
- $N_{exp} = 815$ events

Point Sources in AMANDA-II

- cut optimization at each declination band ($\Psi \sim 2.3°$)
- good sensitivity close to horizon
- 10% BG contamination in $\delta > 0°$
- $N_{exp} = 697$ events in $\delta > 0°$

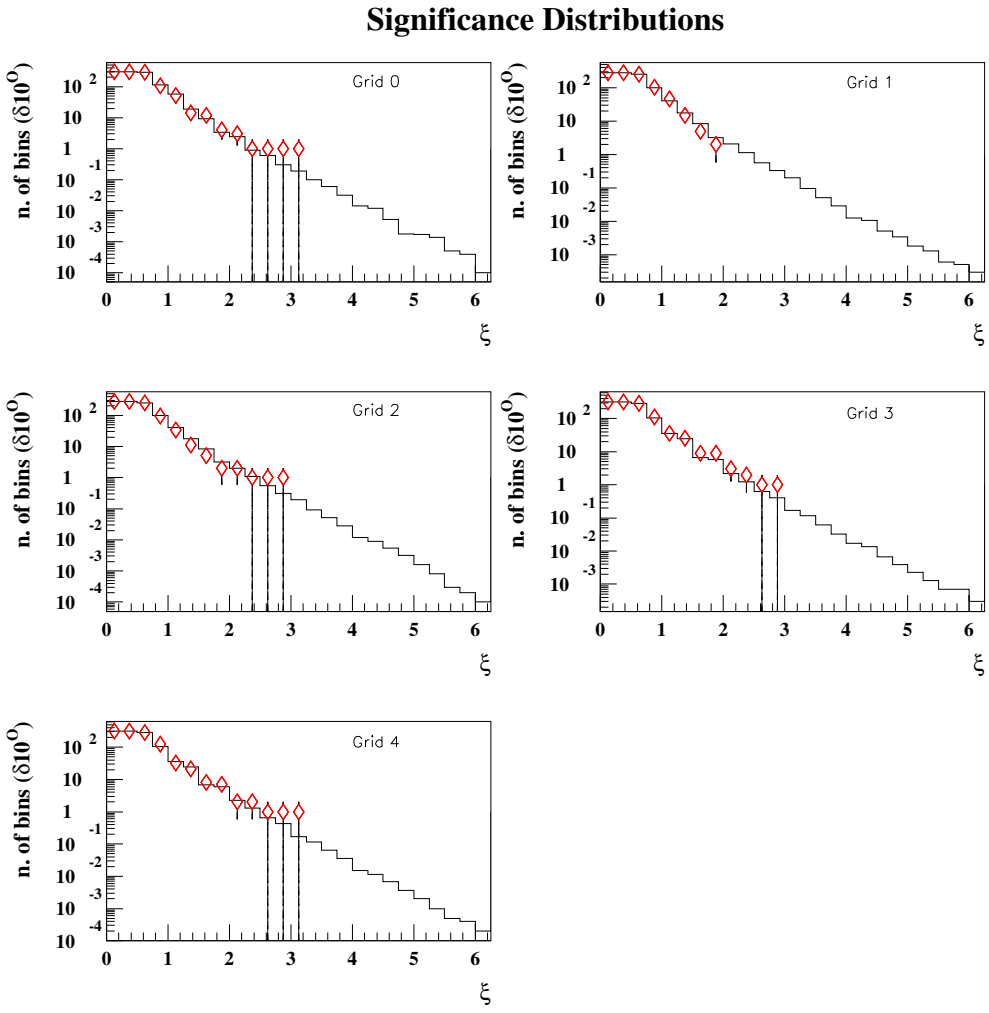






- northen emisphere divided in 300 bins ($\sim 7° \times 7°$)
- no significant excess observed

Point Sources in AMANDA-II



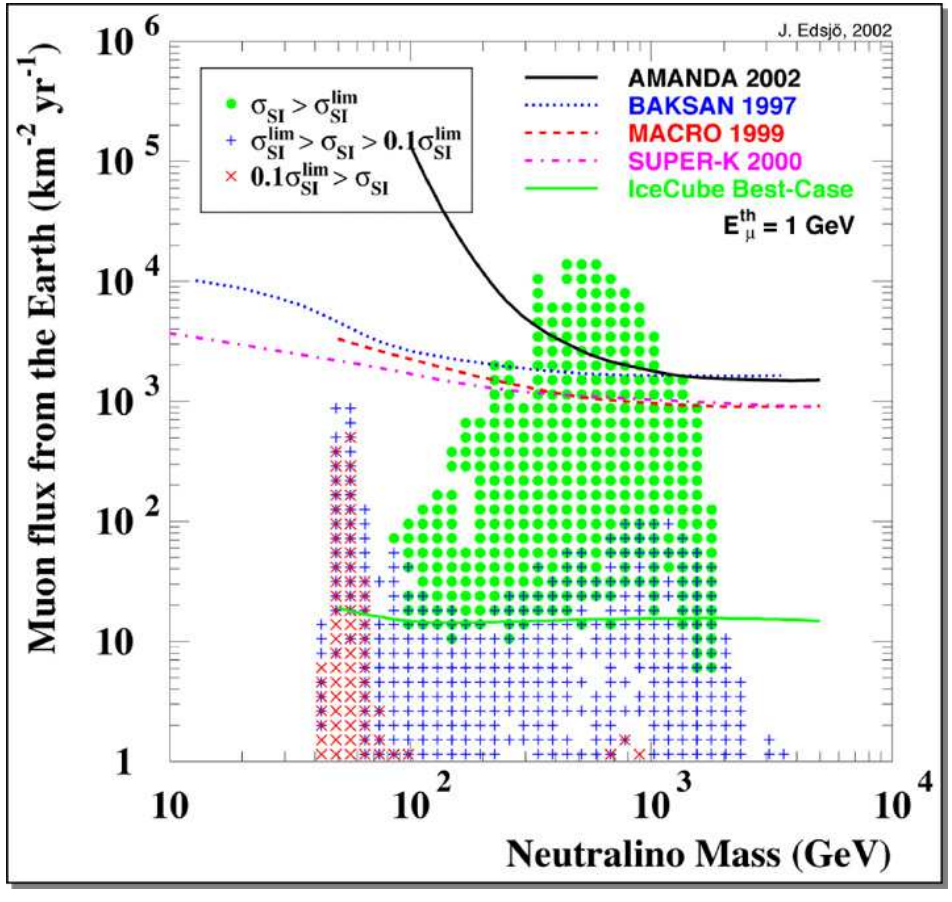
Significance distribution in all-sky grid search

Point Sources in AMANDA-II

Source	δ	1997	2000
Crab	$22°$	4.2	2.1
Mkn 421	$38.2°$	11.2	3.1
Mkn 501	$39.8°$	9.5	1.6
Cygnus X-3	$41.5°$	4.9	3.1
Cass. A	$58.8°$	9.8	1.0

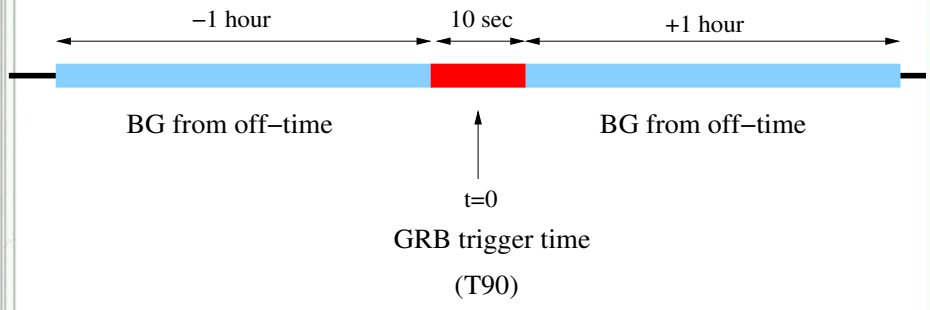
Table 1: Sensitivities in $10^{-7}\ cm^{-2}sec^{-1}$

WIMPS from the center of Earth

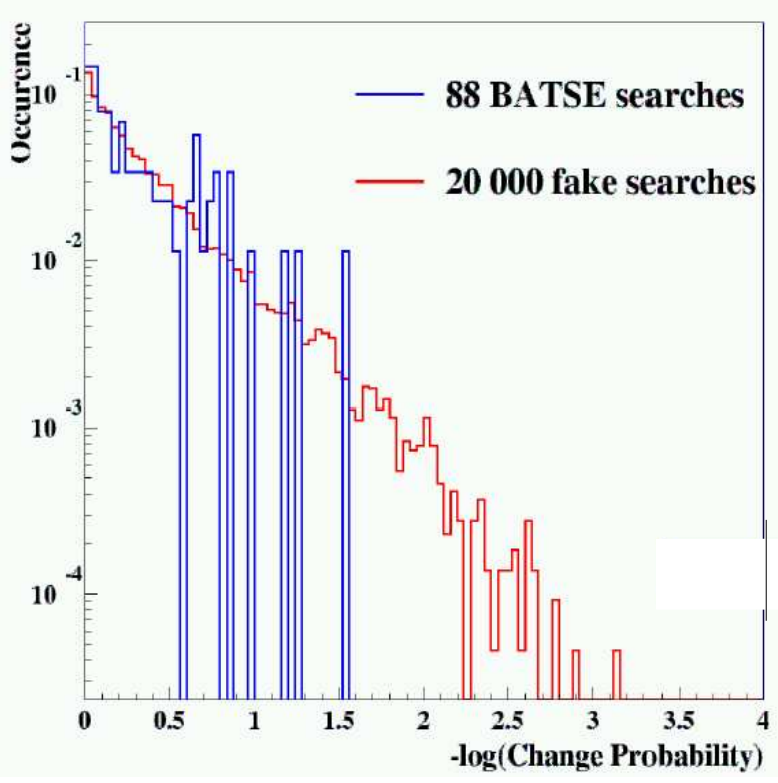


- $\sim$ vertical up-going muons
- high reco quality tracks
- 8-dim cut to separate signal/bg
- simulation of
  $m_\chi = 100 - 5000 GeV$
  - 6 annihilation channels
- $\epsilon_s \sim 30\%$
- $\epsilon_{bg} \sim 0.3\%$
- no excess observed
- Physical Review D, 66, 032006 (2002)

ν_μ from GRB

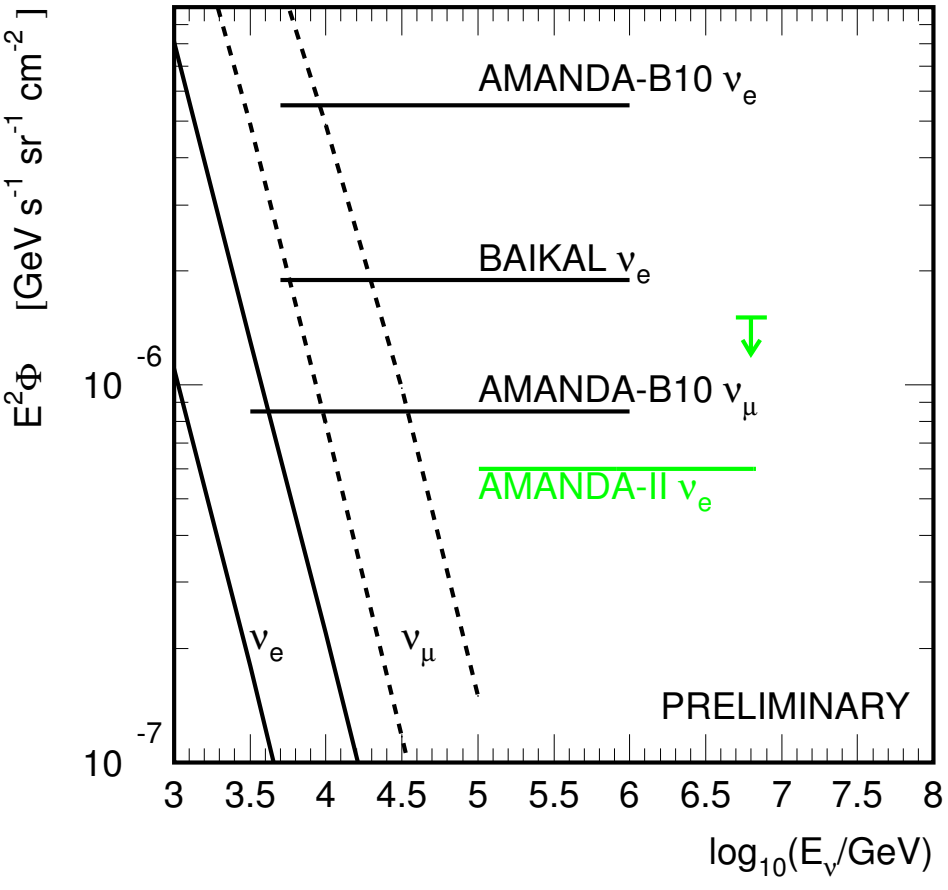


- AMANDA-B10
  - 273 BATSE triggers in 97-99
  - binsearch $\Psi \sim 7 - 21°$
  - high quality track fit
- AMANDA-II
  - 44 BATSE triggers in 2000
  - binsearch $\Psi < 20°$
  - high quality track fit
  - smooth hits distribution along track



- no excess found in any analyzed year

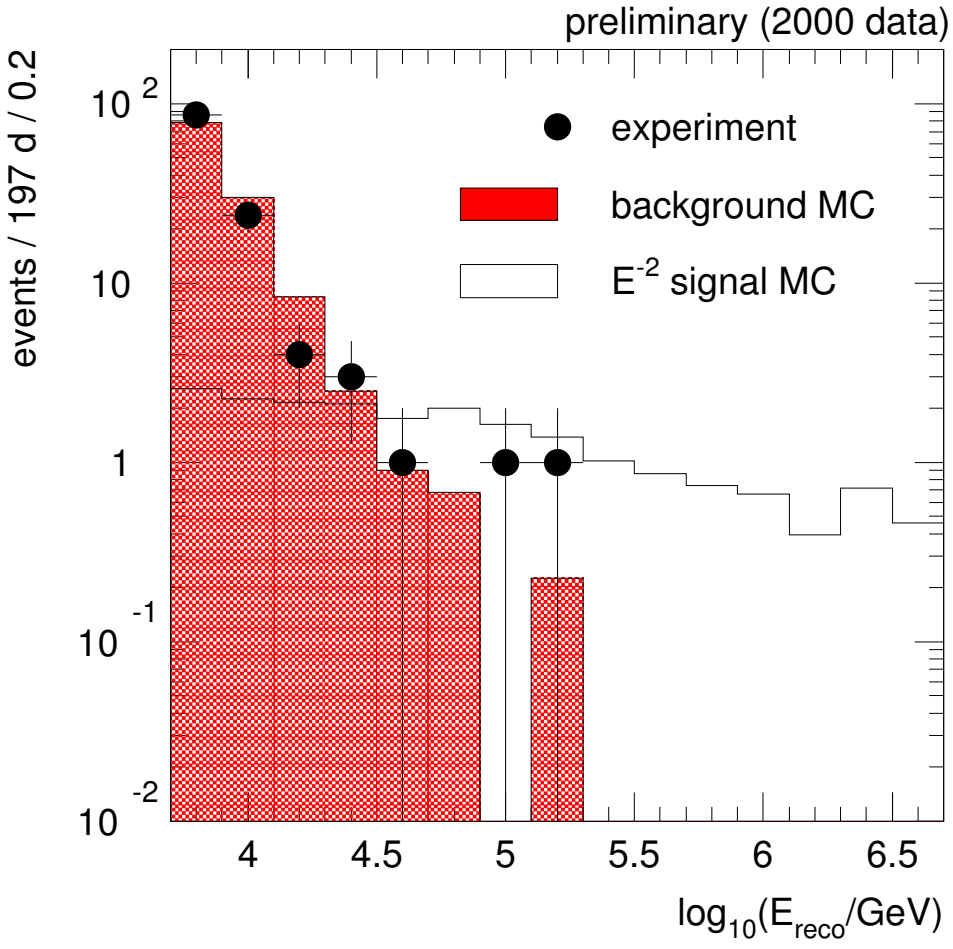
Cascades in AMANDA-B10



- $\frac{d\Phi}{dE}(\nu_e) < 6.5 \times 10^{-6} \times E^{-2}\ GeV cm^{-2} s^{-1} sr^{-1}$
- $5TeV < E_\nu < 300TeV$

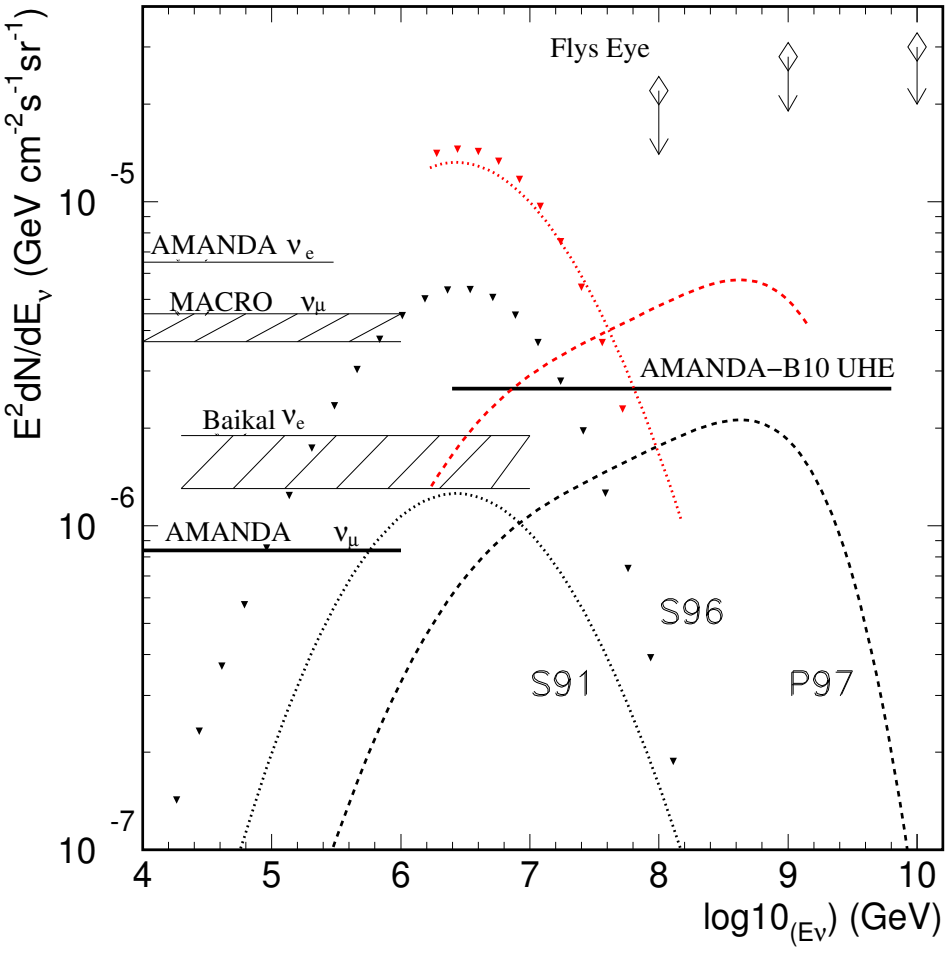
- cascades from em/hadronic showers
  - ν_e, ν_τ CC+NC
  - ν_μ NC
- vertex position
  - $\Delta r \sim 4 - 5\ m$
- energy resolution
  - $\Delta Log(E_{casc}) \sim 0.1 - 0.2$
  - better resolution than mu tracks
- performance tested with in-situ light sources
- Physical Review D, 67, 012003 (2003)

Cascades in AMANDA-II



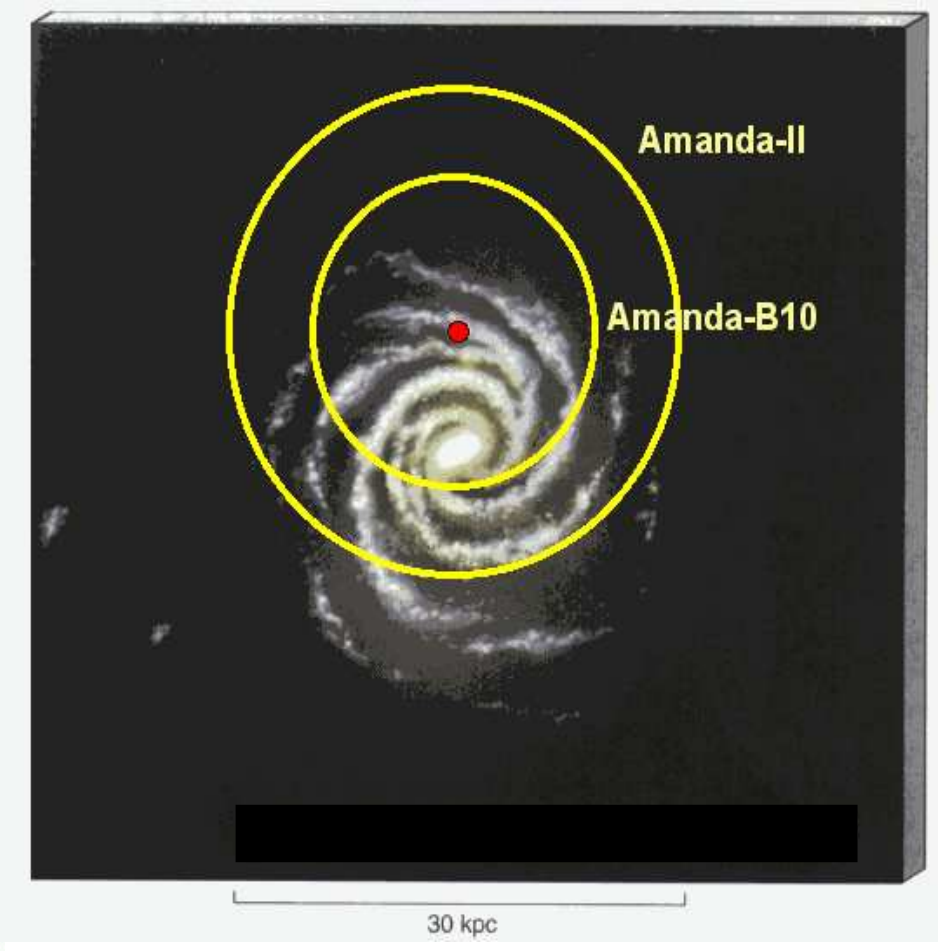
- specific filter applied
- spherical topology
- energy cut
- 4π search
- $\Phi_{\nu_e} = 1 \times 10^{-6} \cdot E^{-2}\ cm^{-2} s^{-1} sr^{-1}$
- $\frac{d\Phi}{dE}(\nu_e) < 0.6 \times 10^{-6} \times E^{-2}\ GeV cm^{-2} s^{-1} sr^{-1}$
- $3TeV < E_\nu < 10PeV$

UHE ν_μ in AMANDA-B10



- ν_μ with $E > 10^{15} eV$ from diffuse sources
- concentrated in the horizon
- selection of very bright events
- systematics study accounts for
  - ice properties modeling
  - absolute detector sensitivity
  - neutrino cross sections
- analysis under way in AMANDA-II also

ν from Supernovæ



- counting rate excess (in 10s bin) from $\nu_e + p \rightarrow n + e$
- noise from OM only (300/1100 Hz)
- subsample of OM over 97/98 is selected
- get stable counting rate with a moving average

- AMANDA-B10
  - 70% coverage of Galaxy
  - $\Phi_{up} = 4.3$ ev/y (90% CL)
- AMANDA-II
  - 90% coverage of Galaxy

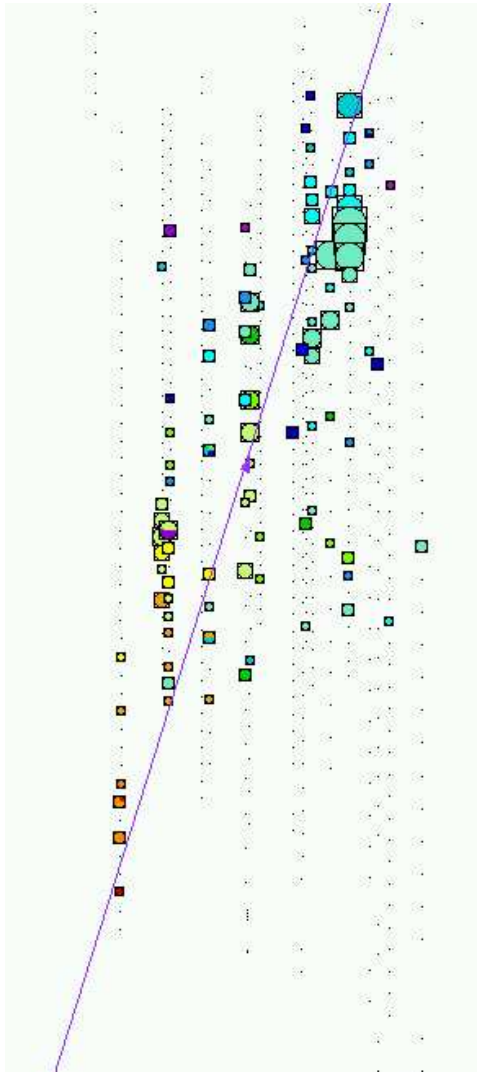
- Astrop Phys, 16 (2002)‘, 345-359

Summary

- AMANDA-B10 data published
- AMANDA-II data under analysis
- from 2002 online-filter
- AMANDA-II higher sensitivity
- THE FUTURE: IceCube
  - in 2004 start to build
  - 4800 OM (60 / string)
  - string spacing 125 m
  - digital transmission
  - 1 km^3 instrumented volume
  - IceTop surface array

Simulated UHE Event

Experimental ν_μ event



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