Status of AMANDA and IceCube

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Universität Mainz
PRC, Oct. 25, 2001

What happened since last PRC?

- International Cosmic Ray Conference
  lots of (preliminary) physics results
- reconstruction of 98-00 data
- 2001 running
- improvements at Pole for coming season

- All important review for IceCube (Oct.19, 01) [Hartill II]

German groups:

..given larger AMANDA II detector, take a fresh look at tools, methods and systematics ...

Present status of analysis (1997 data)

Published:

ν_μ :
Astrop. Phys 13,1 (2000)
Nature 410, 441 (2001)
Supernova:
Accept. by Astrop. Phys. (2001)
WIMPS, point source, Atmosph. Neutrinos:
Close to submission

International Cosmic Ray Conference 2001

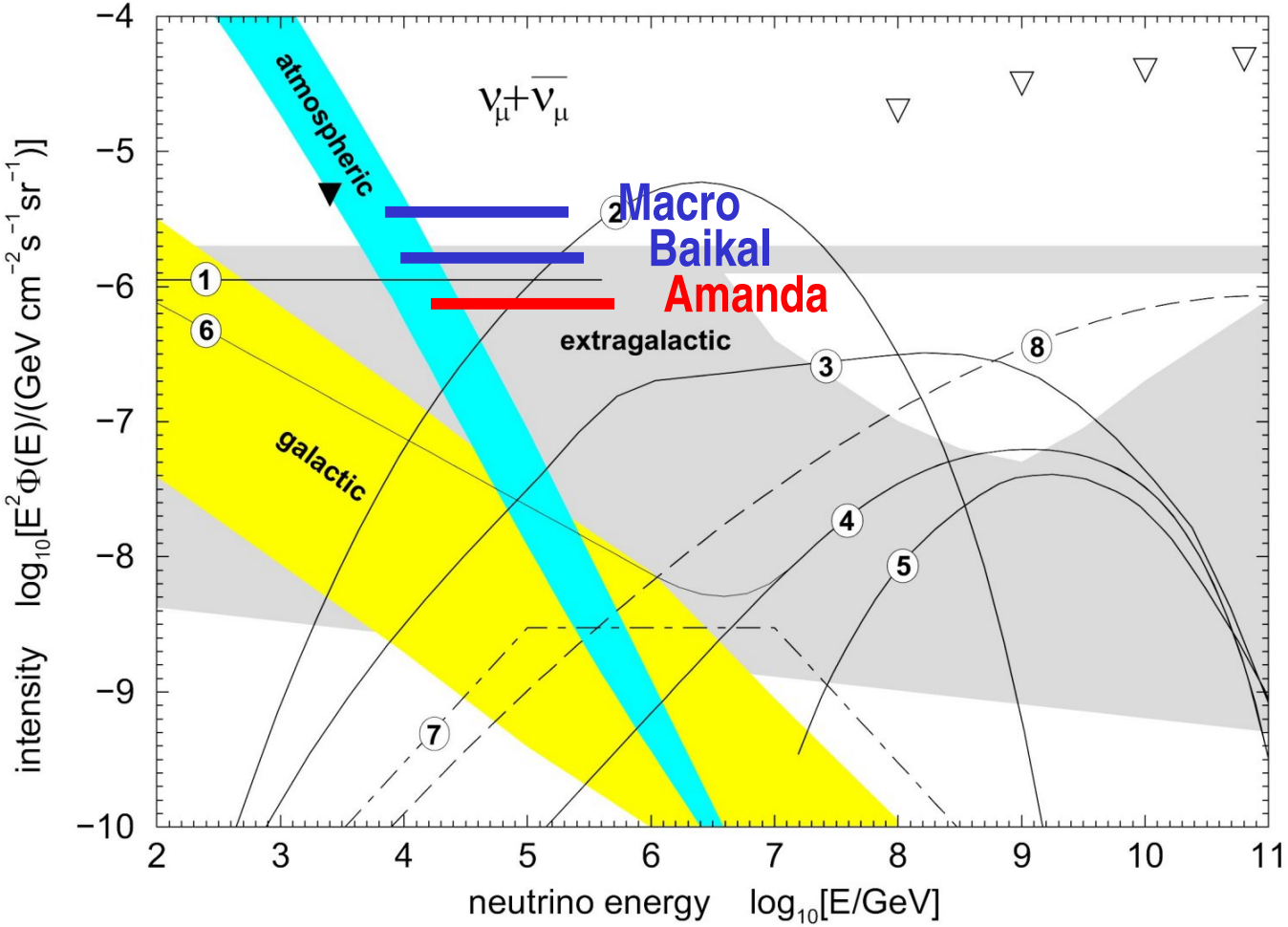
12 AMANDA papers submitted to ICRC:

Potential of AMANDA-II	(S. Barwick et al.)
Performance of the AMANDA-II detector	(R. Wischnewski et al.)
Observation of high-energy atmospheric neutrinos	(C. Wiebusch et al.)
Search for a diffuse flux of high-energy neutrinos	(G. Hill et al.)
A method to detect ultra-high-energy neutrinos	(S. Hundertmark et al.)
Search for high-energy neutrinos from Gamma-Ray bursts	(R. Hardtke et al.)
Cascades	(I. Tabaoda et al.)
Search for relativistic monopoles	(P. Niessen et al.)
Supernova neutrino burst search	(T. Neunhoeffer et al.)
Analysis of atmospheric muons	(P. Desiati et al.)
Time calibration with cosmic ray muons	(K. Hanson et al.)
Calibration and survey of AMANDA with Spase	(G. Spiczak et al.)

3 ICECUBE papers submitted to ICRC:

The ICECUBE detector	(B. Stockstad et al.)
Science potential of the ICECUBE detector	(C. Spiering et al.)
Performance studies for the ICECUBE detector	(M. Leuthold et al.)

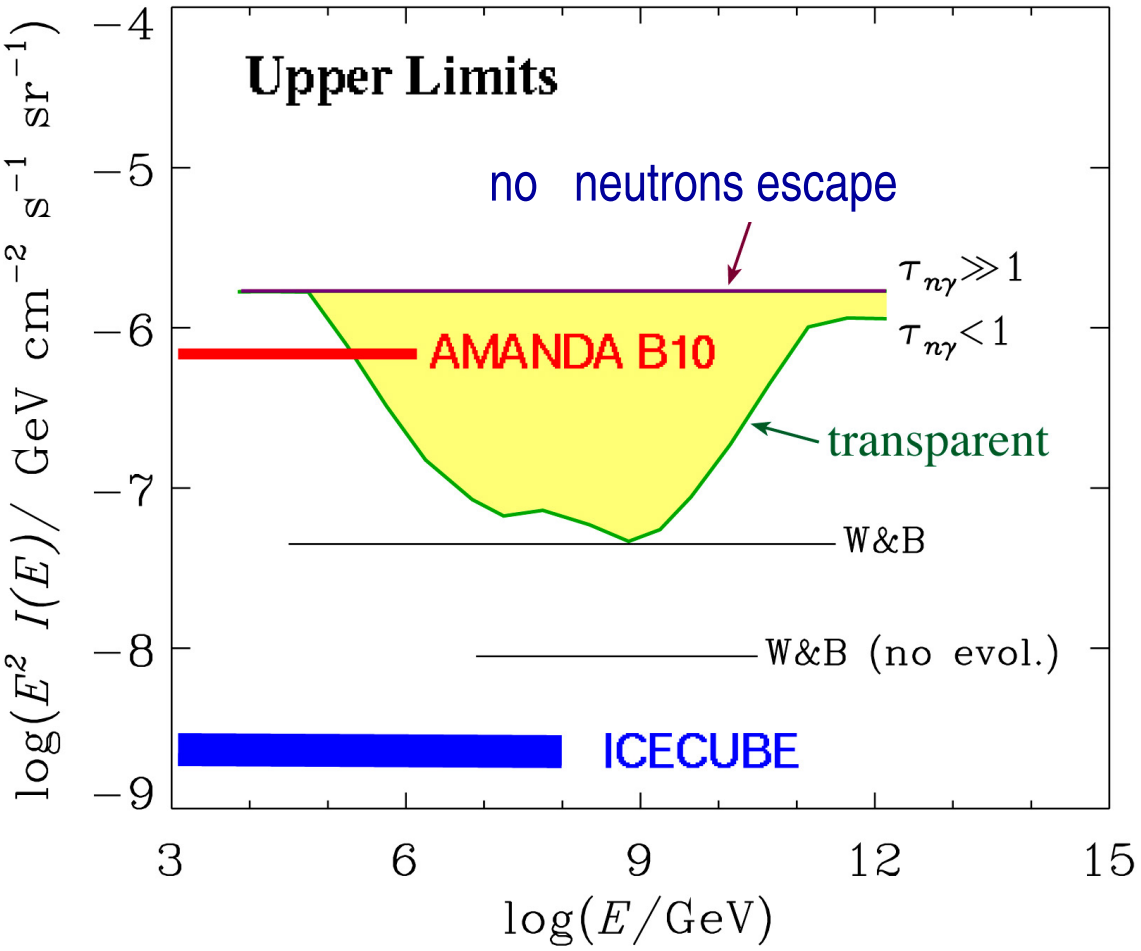
Diffuse fluxes (prediction/limits)



1 pp core AGN (Nell en)
2 pγ core AGN
(Stecker & Salomon)
3 pγ „maximum model“
(Mannheim et al.)
4 pγ blazar jets (Mannh)
5 pγ AGN
(Rachen & Biermann)
6 pp AGN (Mannheim)
7 GRB
(Waxman & Bahcall)
8 TD (Sigl)

Compilation by Mannheim & Learned, 2000

Bounds to diffuse fluxes



Mannheim, Protheroe, Rachen, 2000

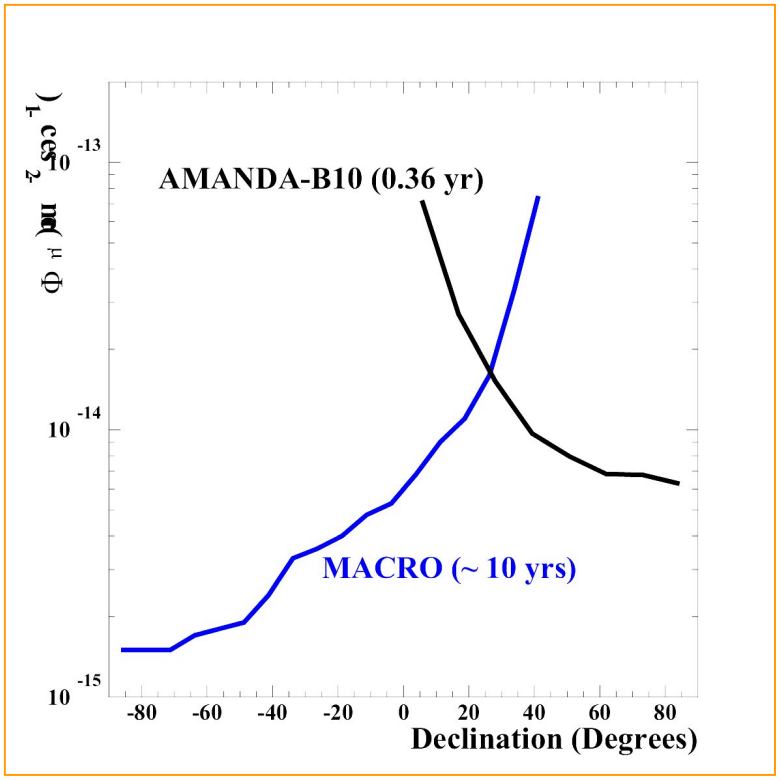
- No specific spectrum assumed
- Use available upper limit on extragalactic proton contribution

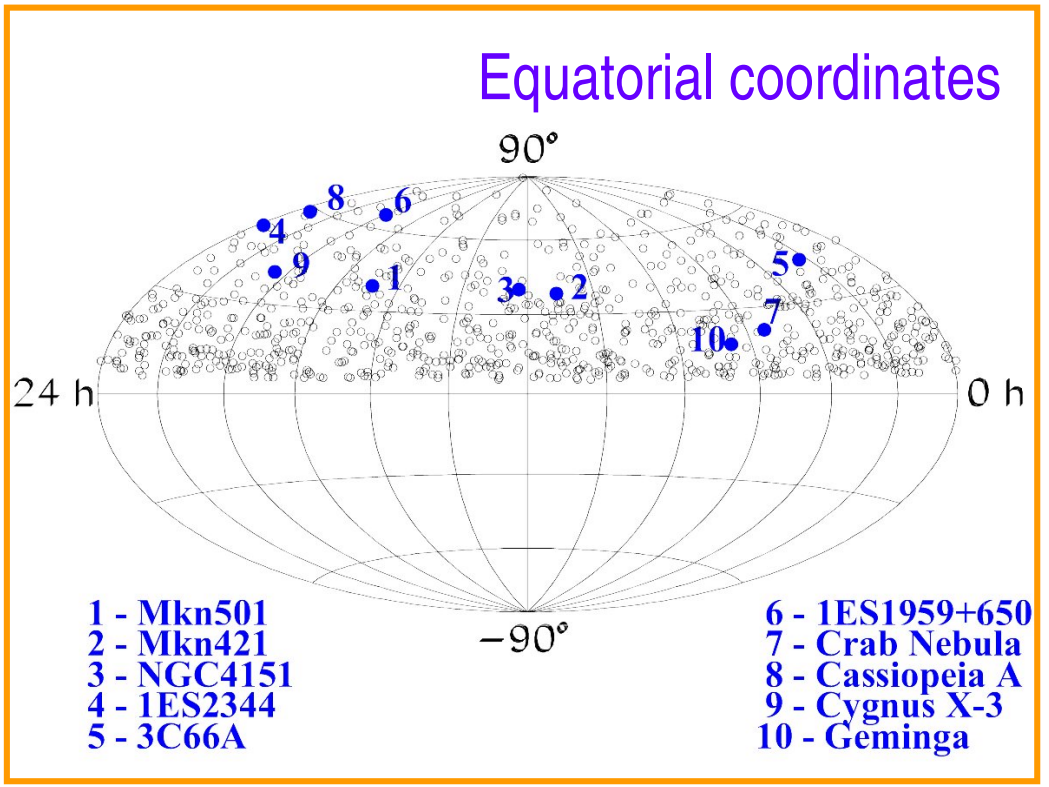
Searching for point sources

If spectral index of sources < 2.7:

☛ looser cuts -allowing for more background - give better limit !

- 1097 events
- No obvious clustering!





From 10-string to 19 string analysis

- Most methods developed „the hard way“ for 10 string detector data
  - basic detector understanding, ice features and their effects
  - hit cleaning / reconstruction / selection / MC
  - analysis and (party complex) statistical methods

- Larger 19-string detector should allow for
  - simplified and more efficient methods
  - fast and efficient analysis,
  - and improved understanding of open questions

..can't profit from many decades of experience (as e.g. accelerator particle physics ...)

Next steps...

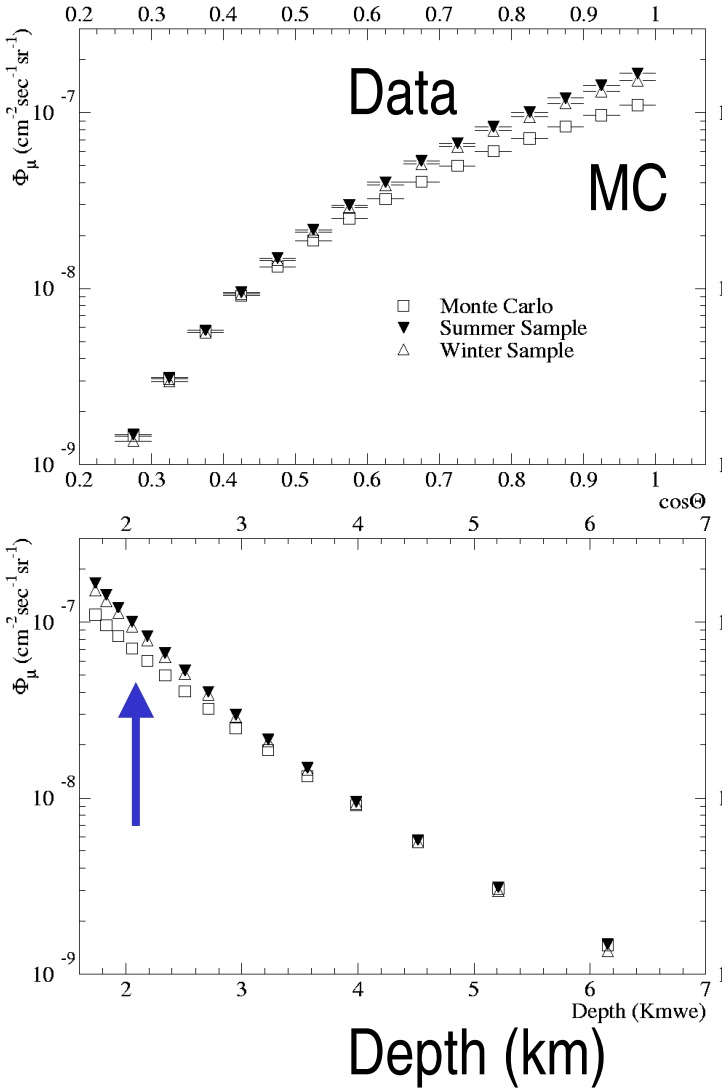
.... in analysis and detector understanding ...

- enforce and tighten blind analysis techniques
  - scramble data
  - cut checking with 20% of data
- attack systematic errors (up to 50%)
  - very detailed study of muon propagation
  - continue with in-situ efficiency determination
- attack and study specific backgrounds
  - e.g. coincident muons
- try to understand all basic, low level behaviour of detector

Bigger detector allows for many new checks

Understanding atmospheric muons ...

(Wuppertal, Zeuthen

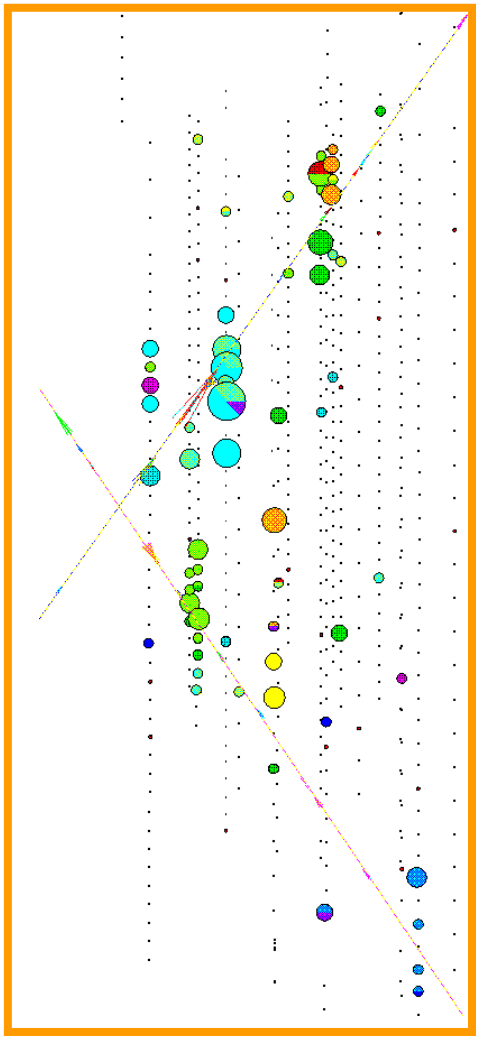


- Seasonal flux differences well understood
- developed fast and accurate MMC-MC
  Clear deficiencies of older propagation codes
  small errors in muon x-section add up after 500 interactions ..
- still MCs underestimate observed flux + shape different (also in Frejus ...)
- Not explained by systematic errors
  absolute OM sensitivity (≈ 10%)
  ice optical properties around hole (≈ 15%)
  Uncertainty in primary flux (≈ 7%)
- needs MC-independent verification!

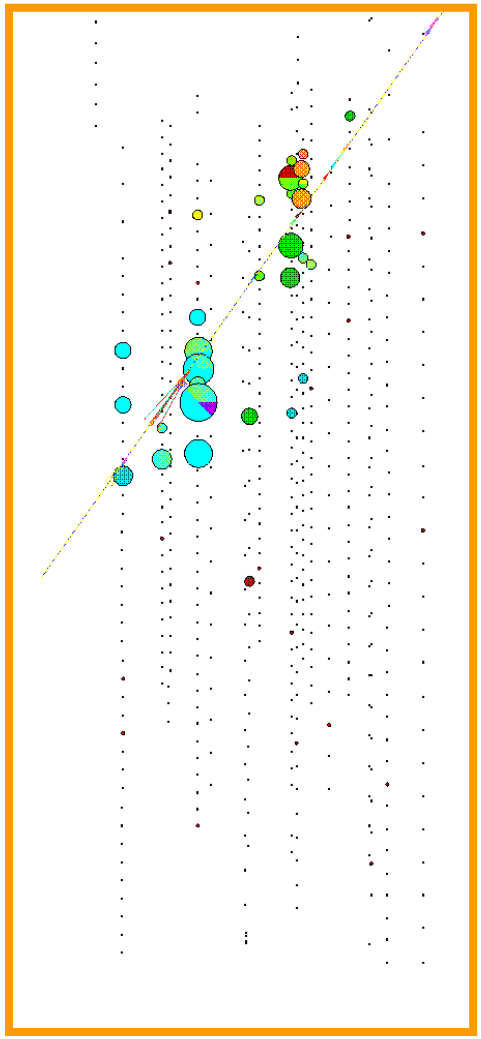
Effects can be studied with AM

Coincident muons

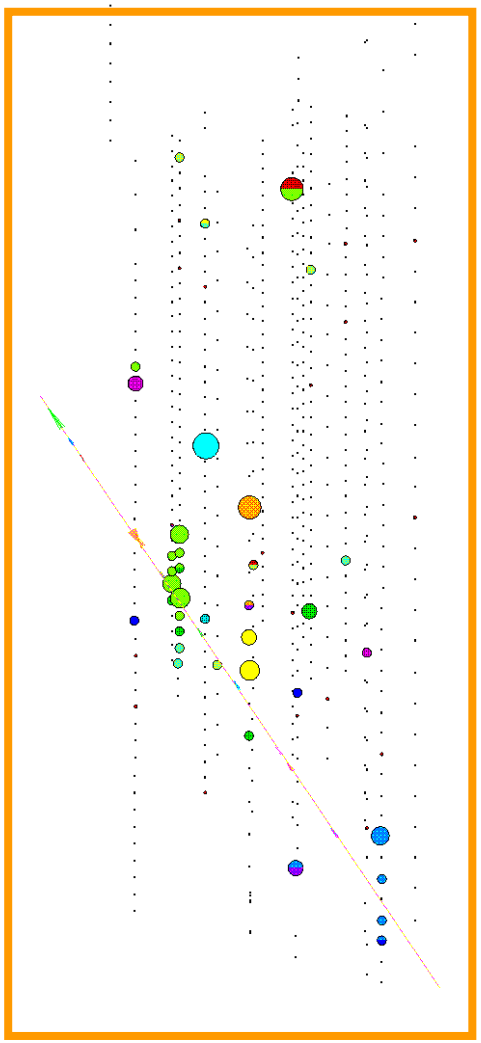
MC



Full event



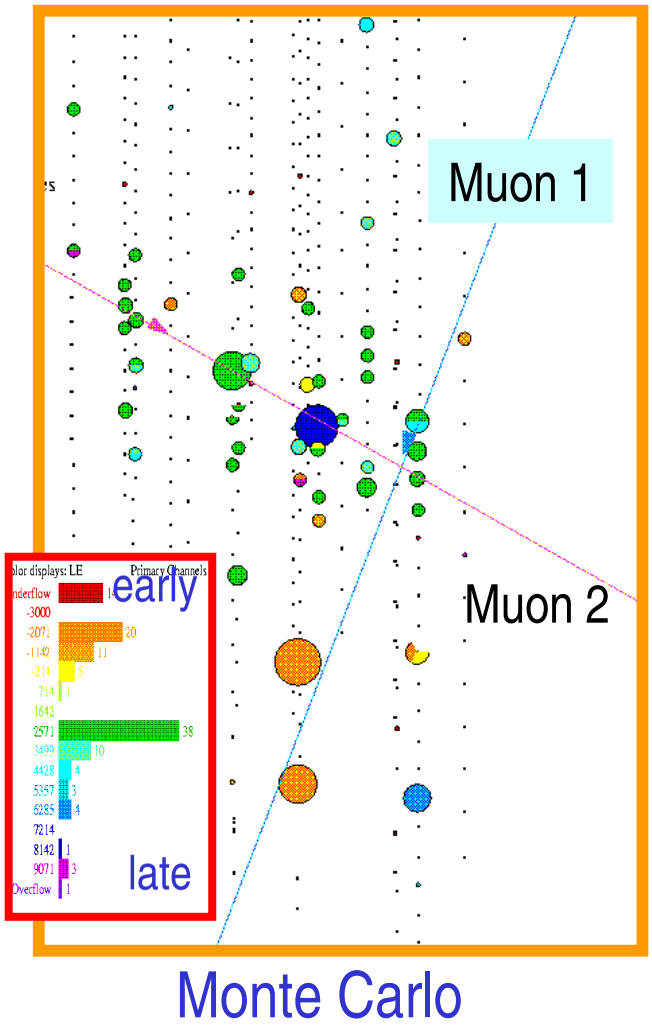
Muon 1



Muon 2

Coincident muons

...an example for a systematic backgrour



Monte Carlo

0.7 Hz (2.5%) at trigger level!
Dominant background in final sample

...up to now, partly discarded b
non-specific cuts and scanning

- New track finding for two tracks under development
- Calculate muon flux independent of MC!
  (compare single and double track rates ....)

New tools

.... considerable progress in analysis and monitoring ..

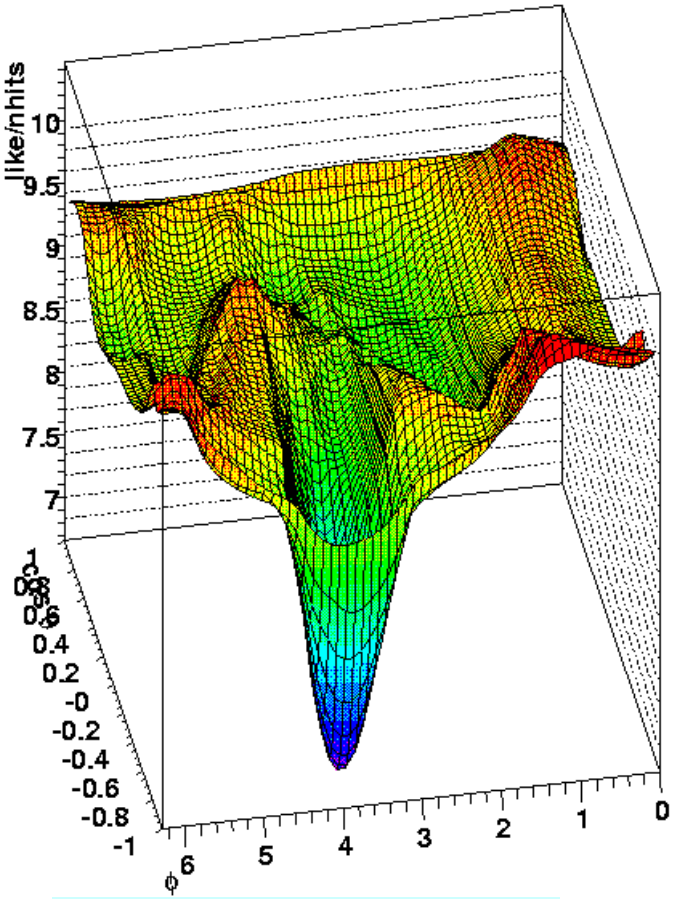
- better understanding of likelihood fitting
- alternative track-finding and event topology criteria
- much improved energy estimator
- use data to understand pointing resolution
- first-principle understanding of (small) cross talk features
- calibration with atmospheric muons

.... Note that selection efficiency much higher in compa

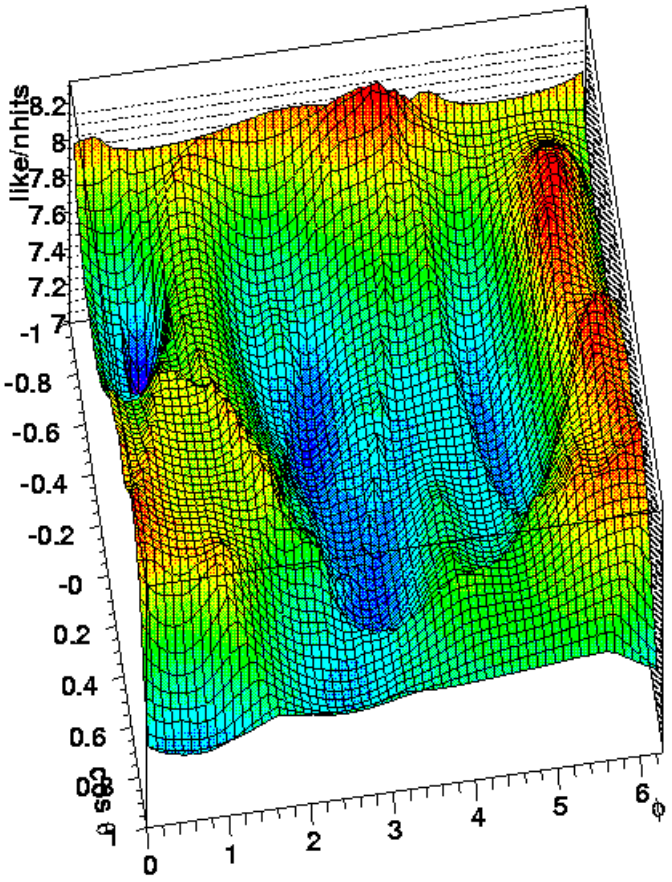
Atmospheric neutrino analysis:	4% $\rightarrow \approx$ 15%
Point search	15% $\rightarrow \approx$ 30%
Gamma Ray bursts:	30% $\rightarrow \approx$ 50% (75%?)

Likelihood contours

Detailed study of minimum structures



Well reconstructed track

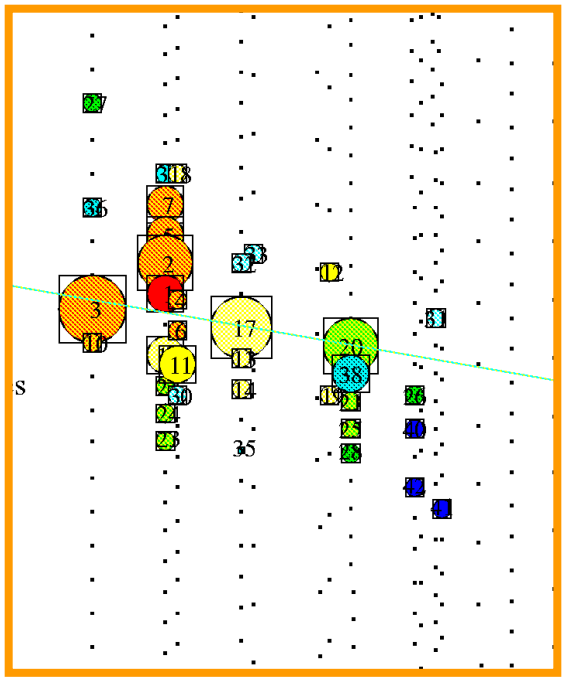


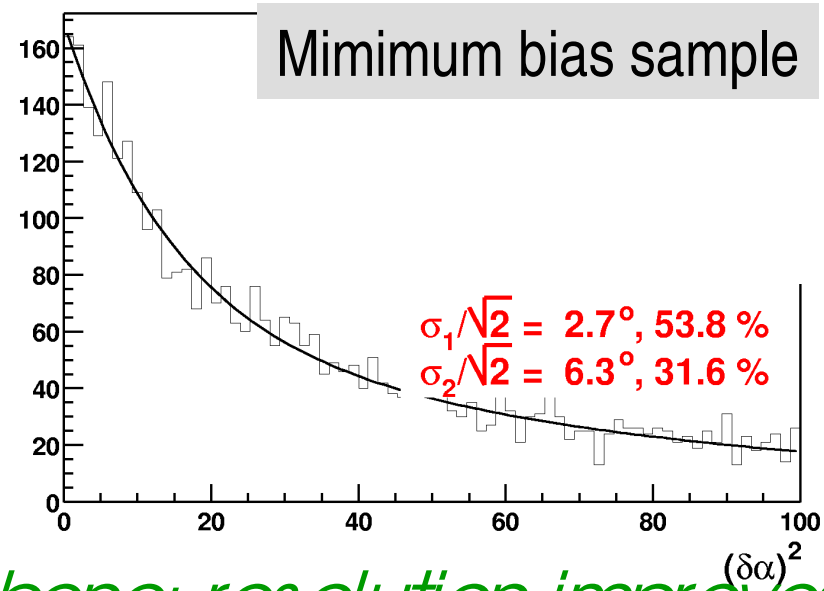
Badly reconstructed track

Resolution check in data

Example for a study only possible due to large

- Divide time-ordered hits in 2 samples (1,3,5..) and (2,4,6...)
- Treat as two independent tracks and look at relative resolution



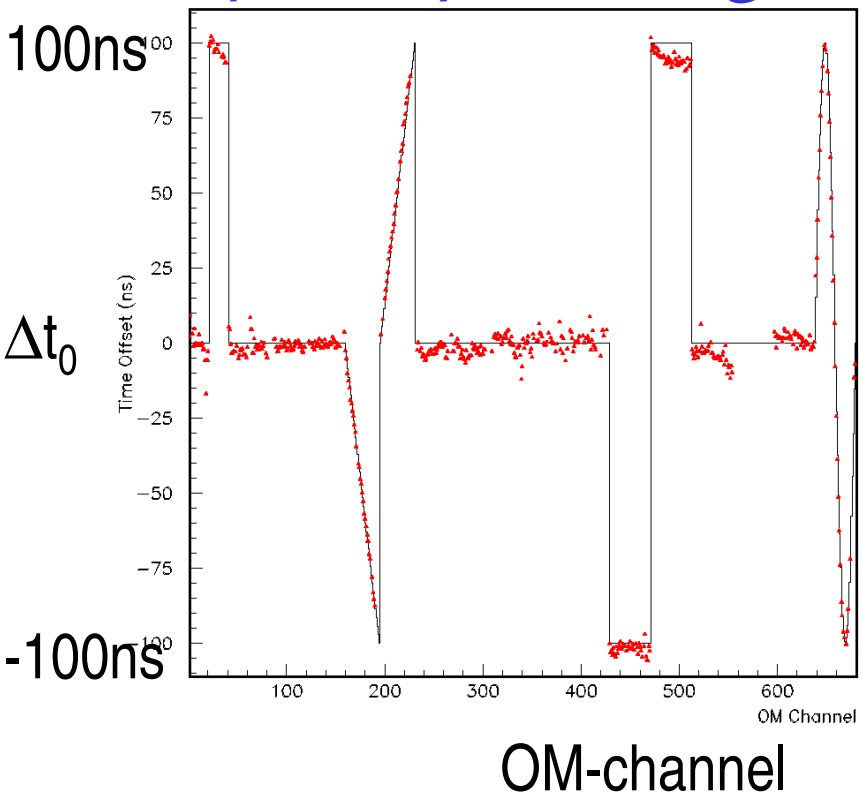


Nota bene: resolution improves with

Example for calibration procedure

- Measure transit time of laser light (time and work consuming)
- Iterative fit to abundant atmospheric muon tracks (10^9/year)

Purposely misaligned



- Algorithm finds correct offset t_0
- Accuracy ≈ 1.5 ns
- Systematics ≈ 8 ns

studies show that track fits insensitive to t_0 errors < 20 ns

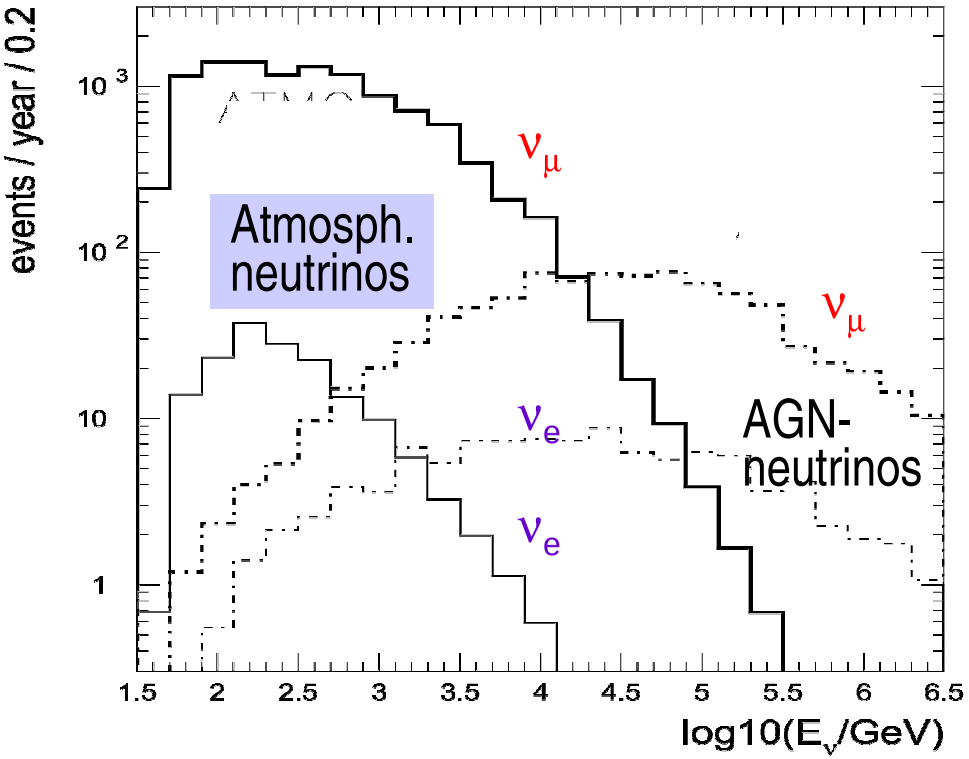
..can be done online .

Status processing

1998-1999:	LBL and Stockholm processing started will take about 2-3 months
2000:	Zeuthen L1 selection finished > 10% of level 2-4
2001:	online processing at Pole and at Mainz

AMANDA II expectation

Energy distribution



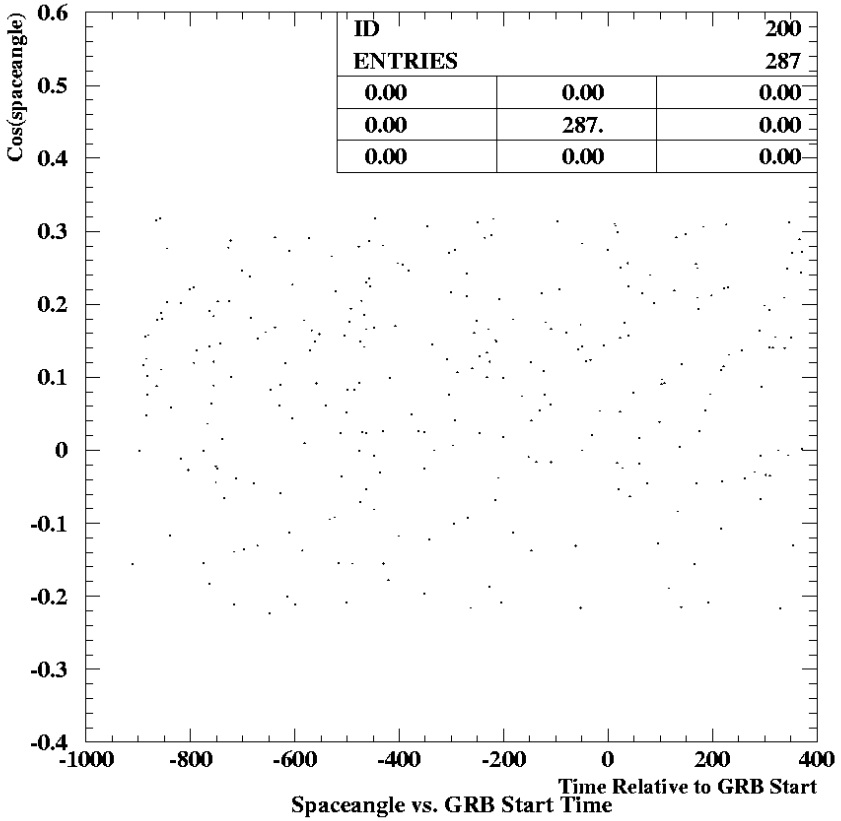
Triggered events/per year

	atm. CC	atm. NC	AGN CC
ν_μ	11000	130	853
ν_e	162	9	103

assumed E^{-2} AGN flux: $10^{-6}\ E^{-2}$ GeV sr^{-1} s^{-1} cm^{-2}

GRB in 2000

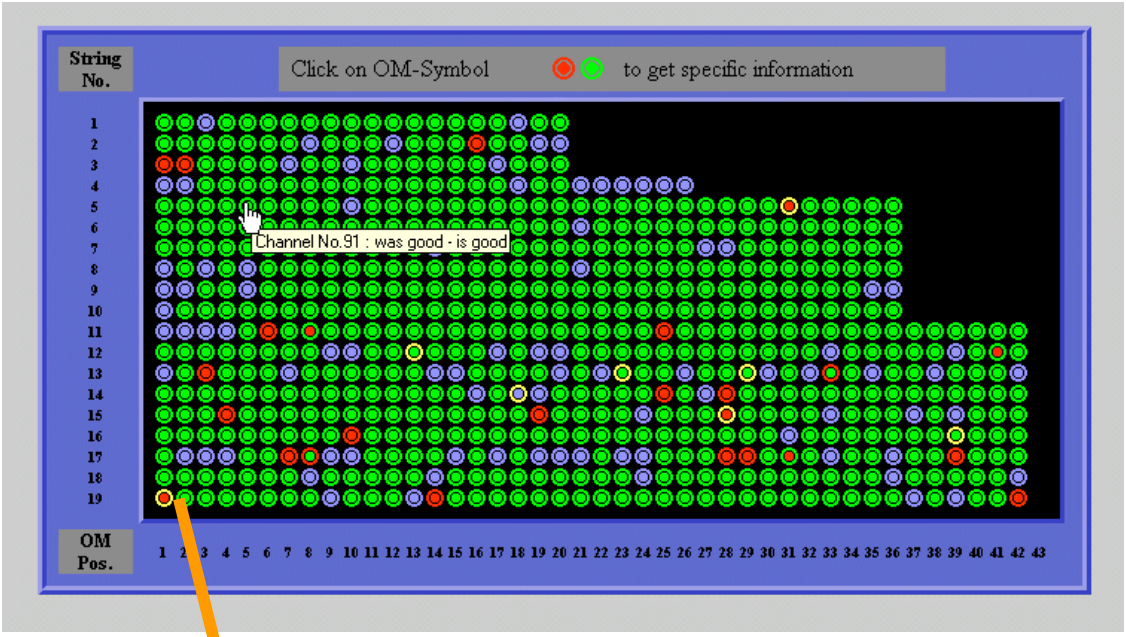
raw data in time slice around detected GRB are transmitted from Pole...
little background, as direction and time known ...



Example: GRB 8986

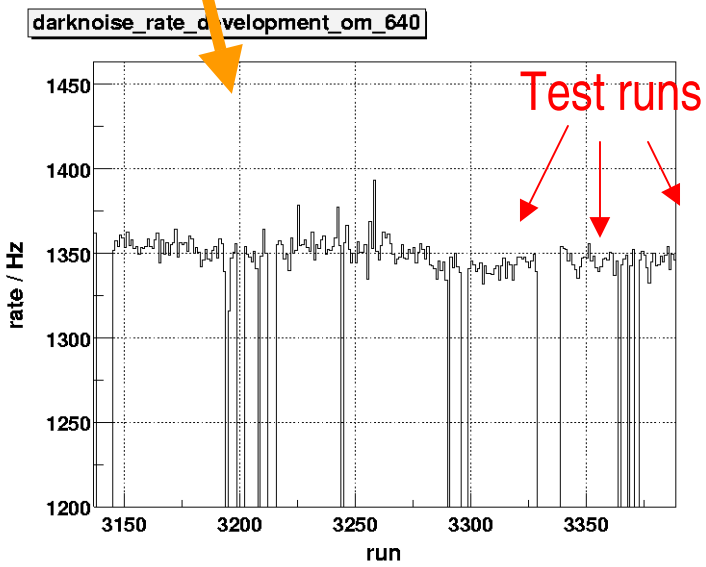
Neither clustering in time nor in angle observed ...

Run 2001



smooth running for 229 days
much improved monitoring

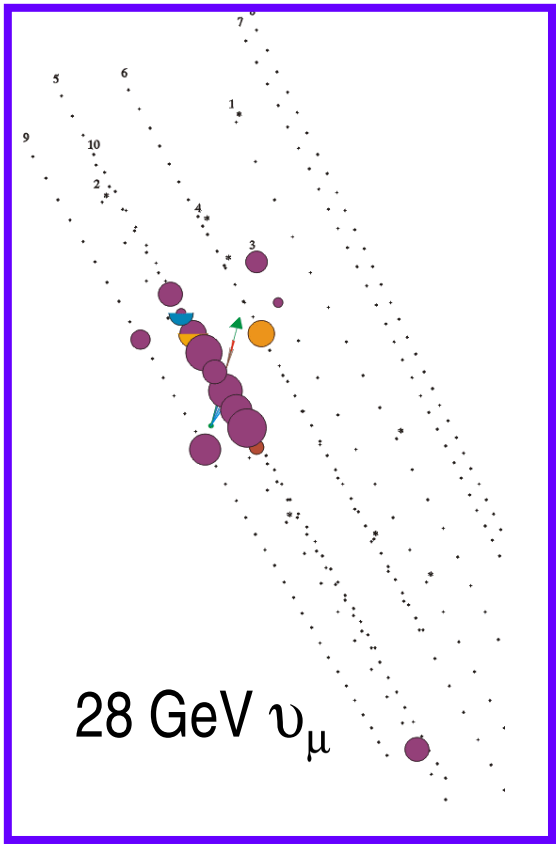
...regular data taking f

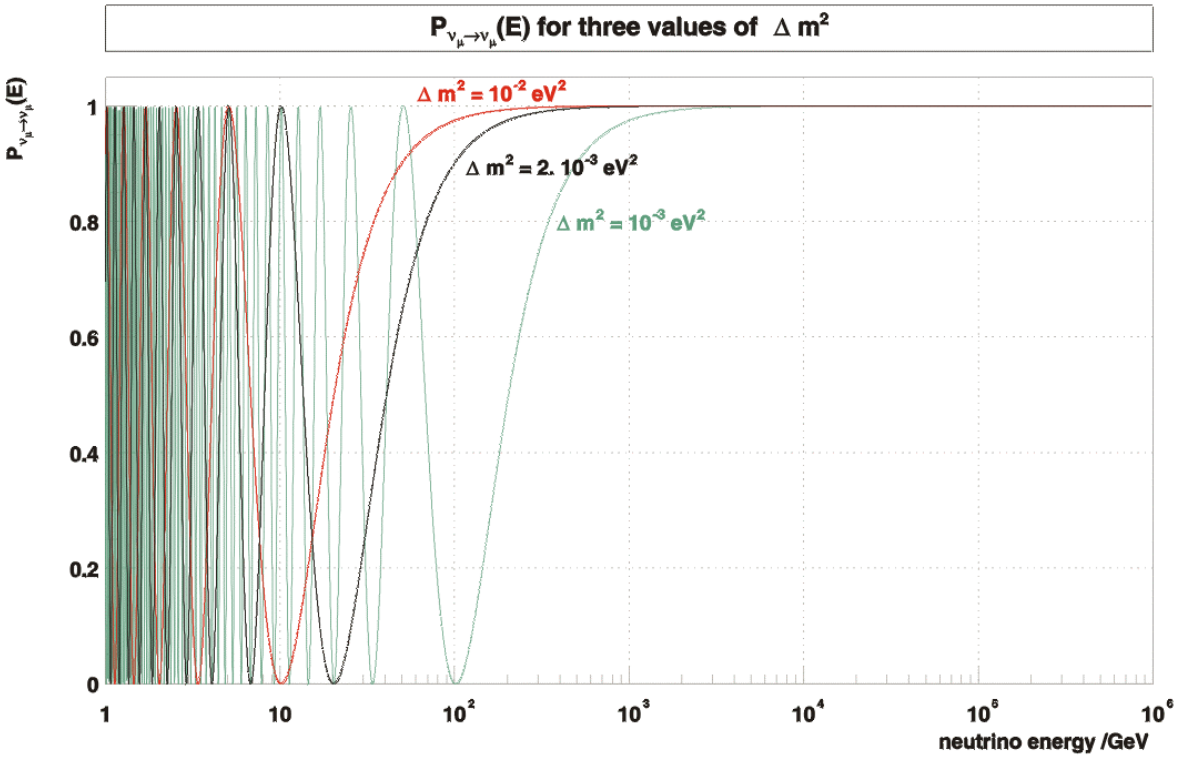


- Optical modules:
  - no new problems (12% dead, 3% noisy)
- Trigger:
  - more than 24 hits overall or
  - 6 out 9 hits in one string
- Much improved monitoring
- Real-time filtering and data processing

Extending to low energy neutrinos

...needs completely new tools to subtract backg





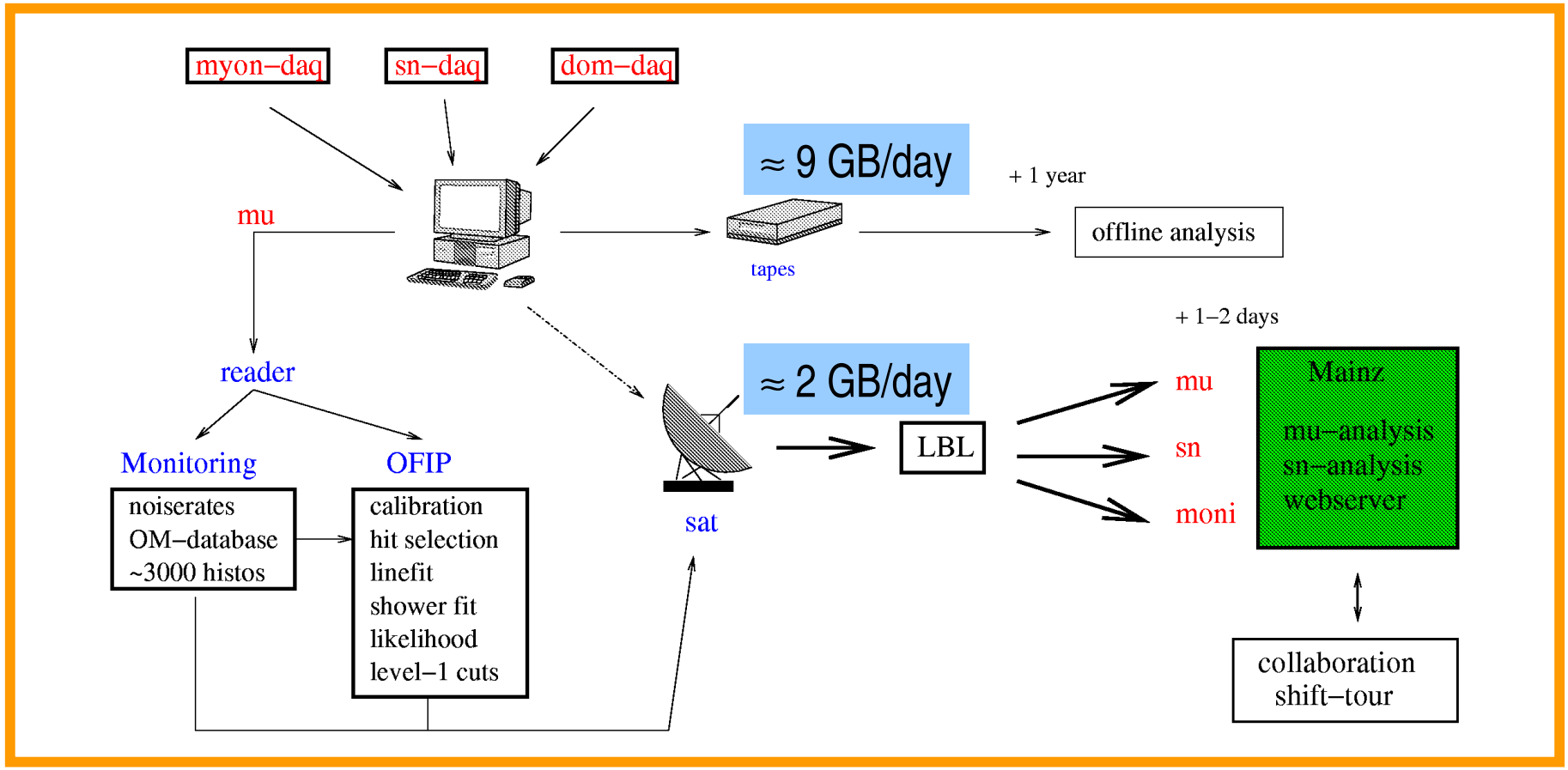
To study neutrino oscillations, sensitivity in 20 GeV energy region required ...

New string correlation trigger from 2001 on ...

Online 2001 analysis

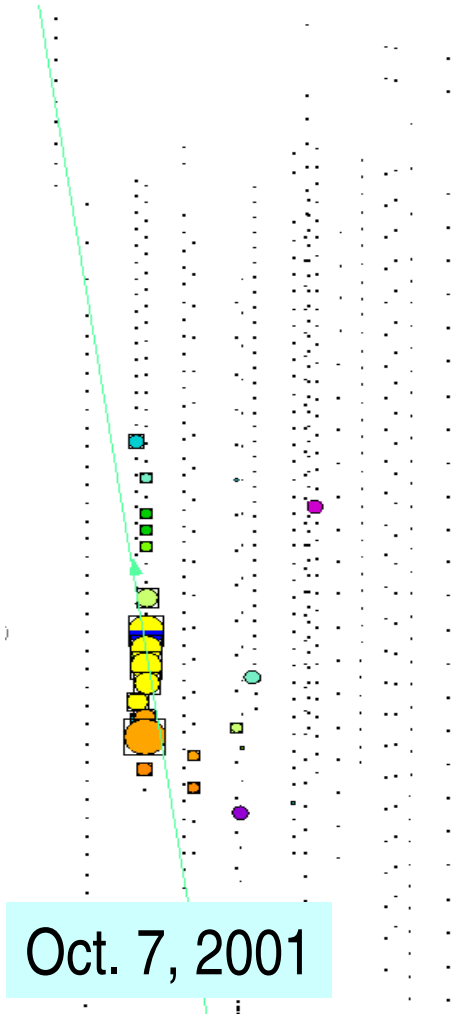
...operational since beginning of 2001 season

e.g. ν_μ-filter:
8.1% passing rate
5.1 ms/event

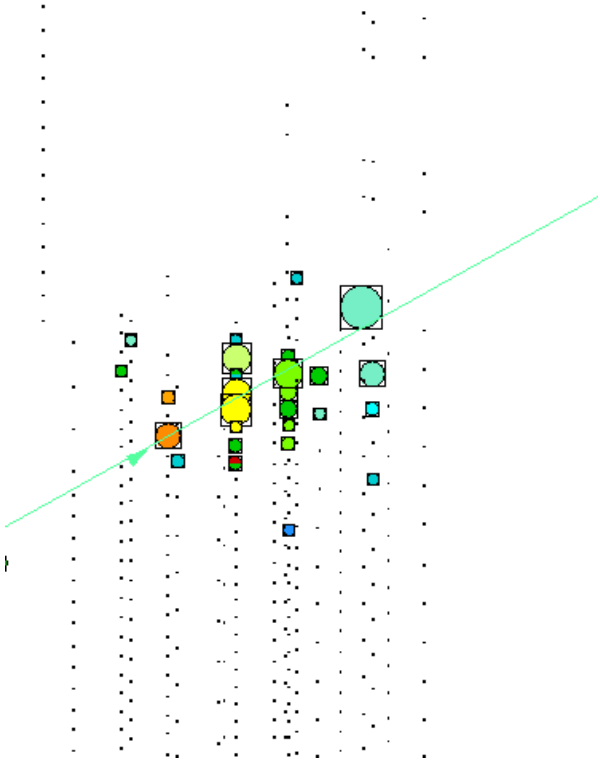


...online 2001 analysis

2 recent events:



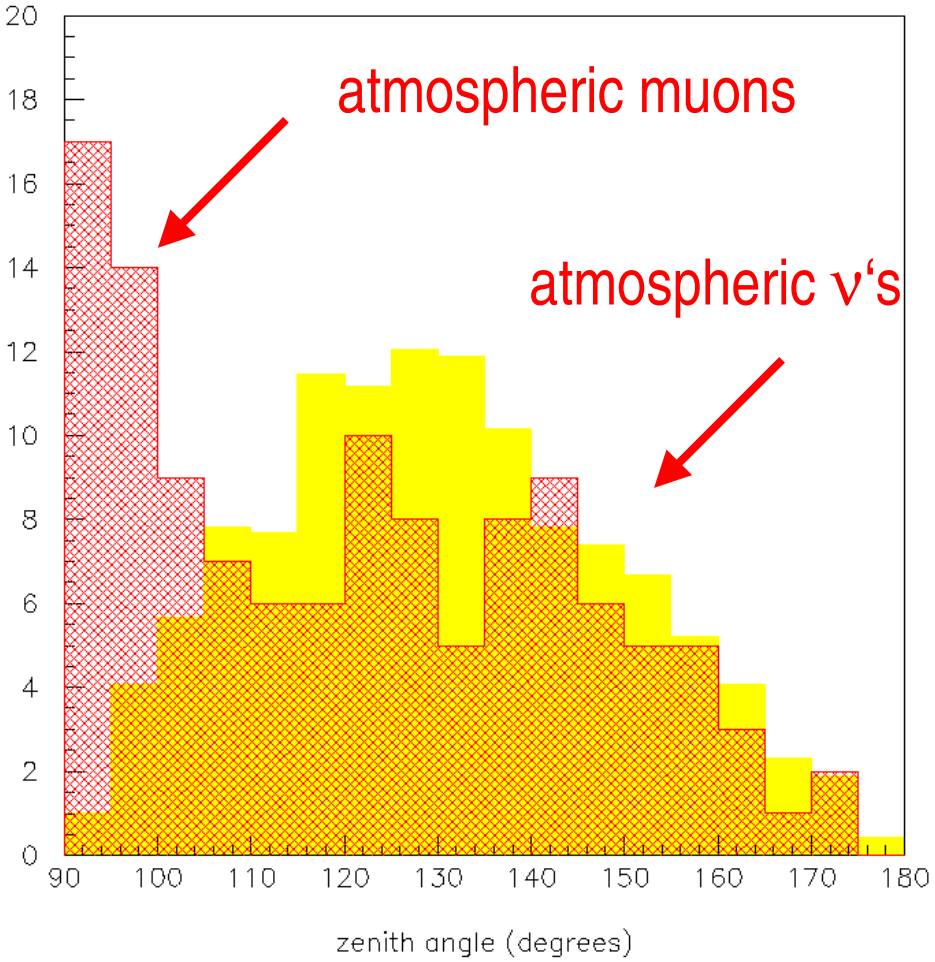
Oct. 7, 2001



Oct. 10, 2001

..online 2001 analysis

Zenith angle comparison with signal MC



- real-time filtering at Pole
- real-time processing (Mainz)

Left plot:

- 20 days (Sept/Oct 2001)
- 90 ν–candidates above 100°

4.5 ν–candidates / day

Hardware upgrades (01/02)

- Install full IceCube-like readout of 32 digital modules
- Install flash-ADC readout for 48 selected channels
- Reduce dead time (move to VME TDC's and improved readout)
- IceTop prototype tank
- Strongly suppress noise (install filters on all channels)

  Search for ultrahigh energy neutrinos (bremsstrahlung!)

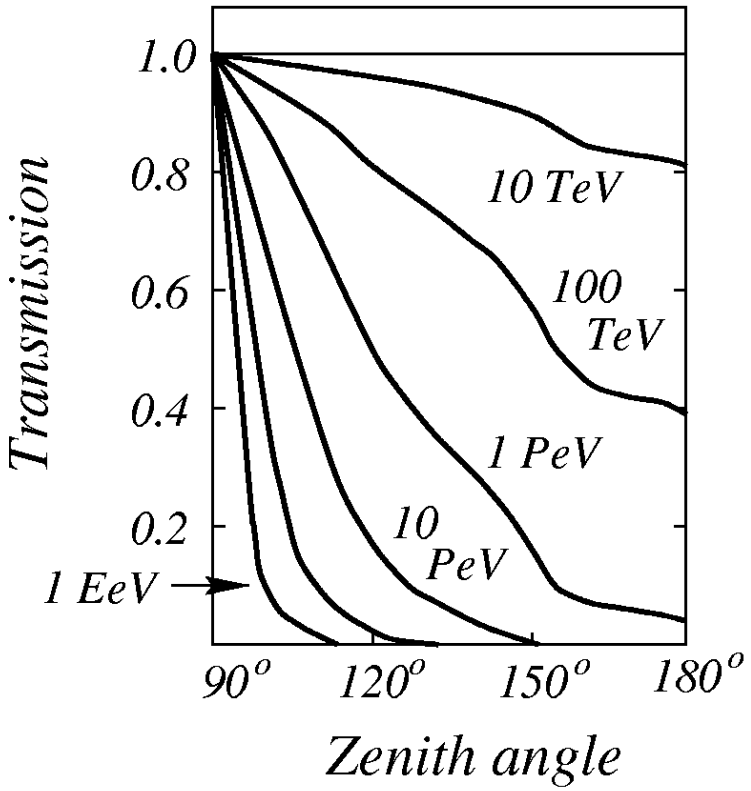
Future: AMANDA-ICECUBE integration

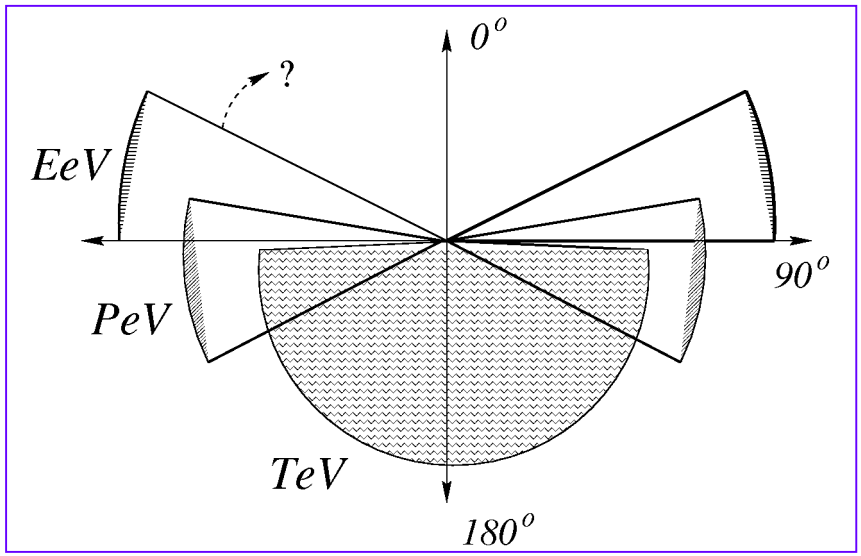
- keep AMANDA running for many years (lower energy threshold, etc.)
- combine trigger, run AMANDA as ICECUBE subdetector
  - 02/03 waveform for all (optical?) channels,
  - 02/04 integrate AMANDA with first IceCube strings

Extending to ultrahigh energy neutrinos

... Earth becomes opaque for neutrino energies above 10^{16} eV

Spectacular signatures (lots of light due to bremsstrahlung!)

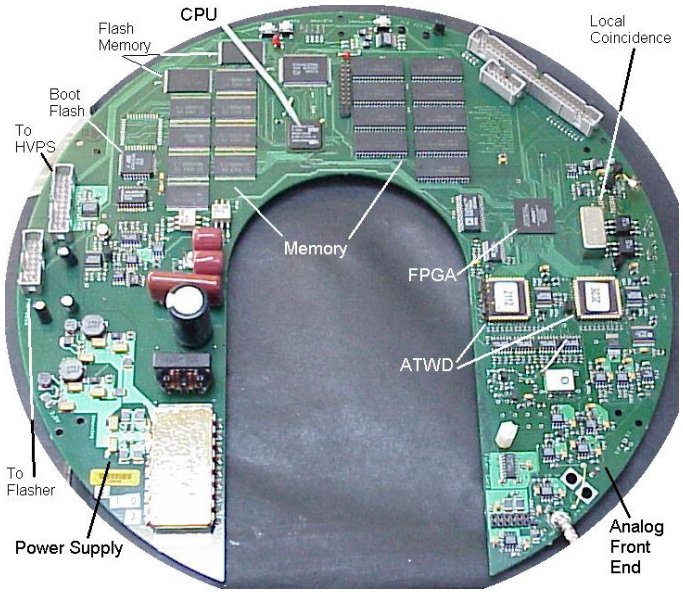


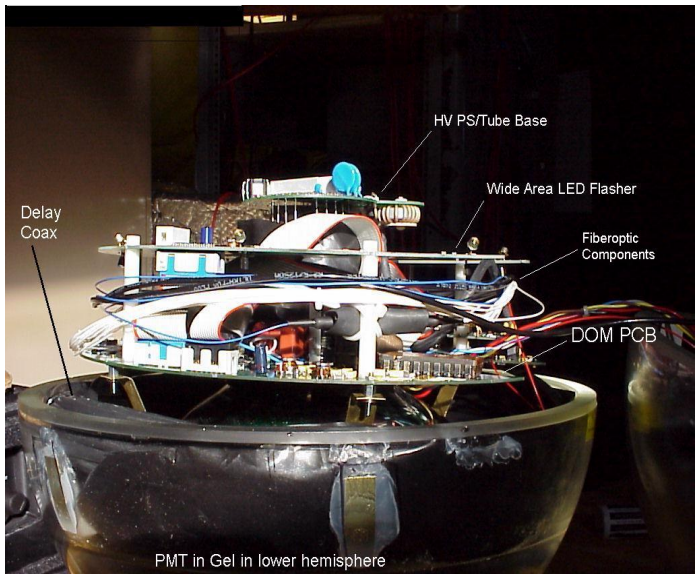


☛ Look at horizontal and down-going neutrinos
effective volume limited to < 4 km^3

new FADC readout for large dynamic range in 2002

Digital optical modules (string 18)





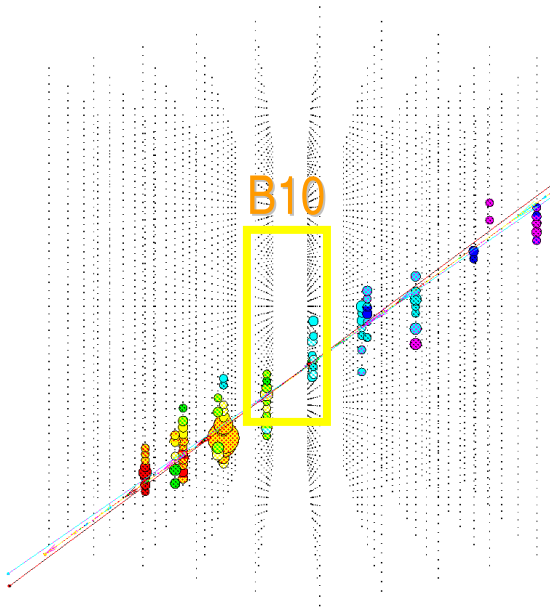
15% of waveforms are complex:

- Timing: 3.5 ns rms
- clear detection of down-going μ

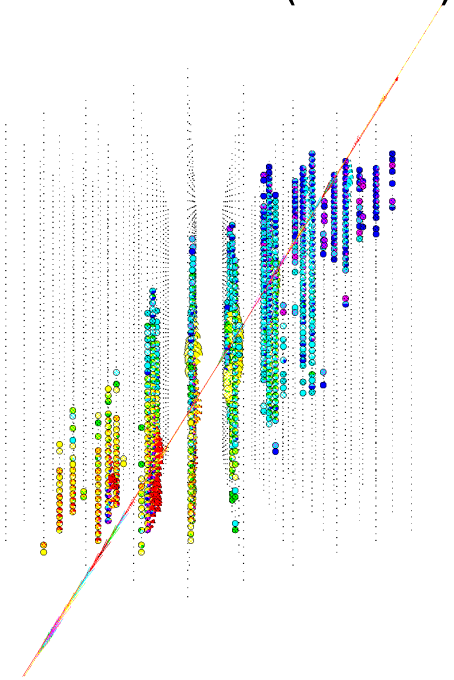
Full IceCube like readout

Neutrinos in Icecube …

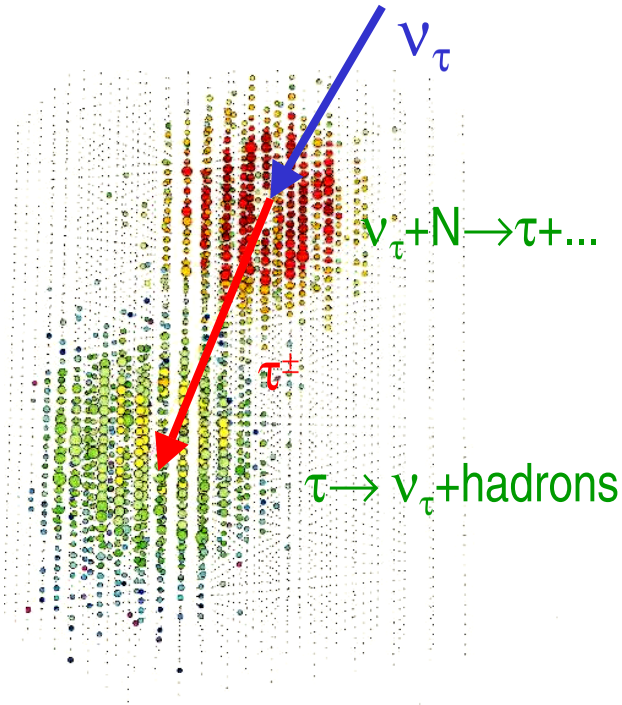
10^{13} eV (10 TeV)



$6x10^{15}$ eV (6 PeV)



Multi-PeV

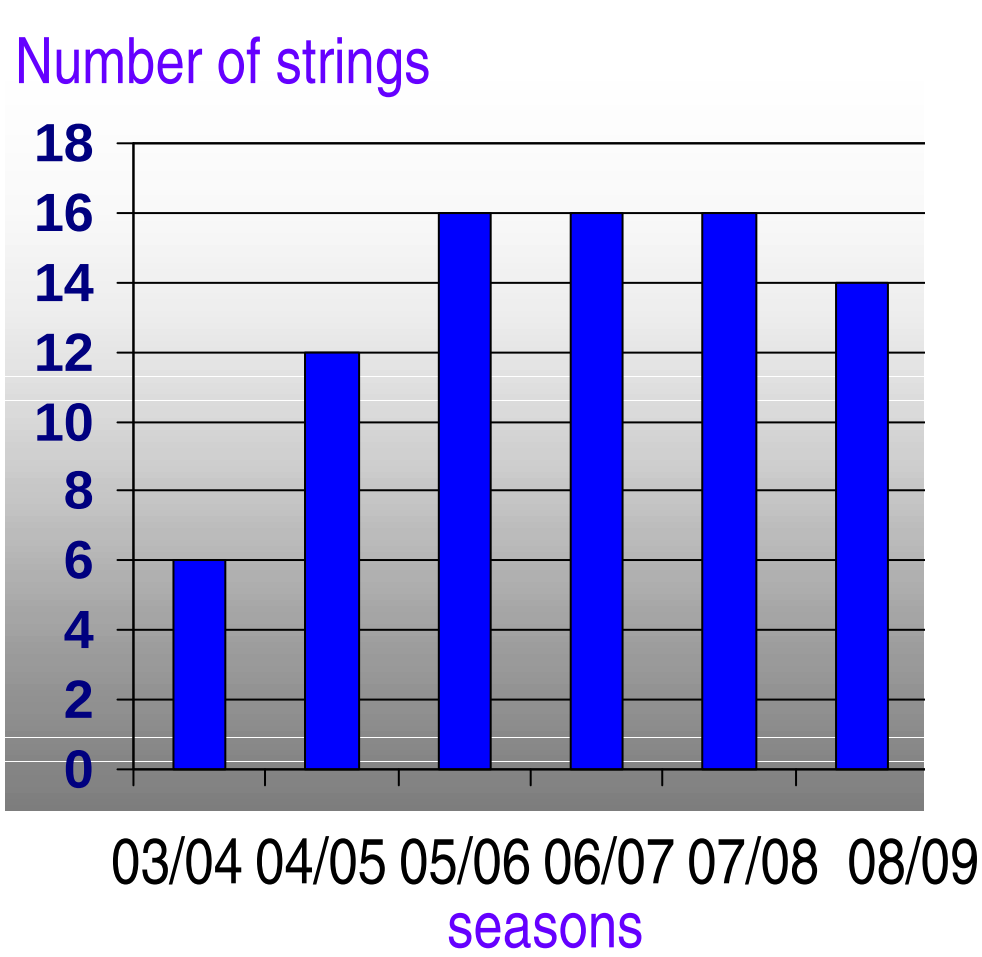


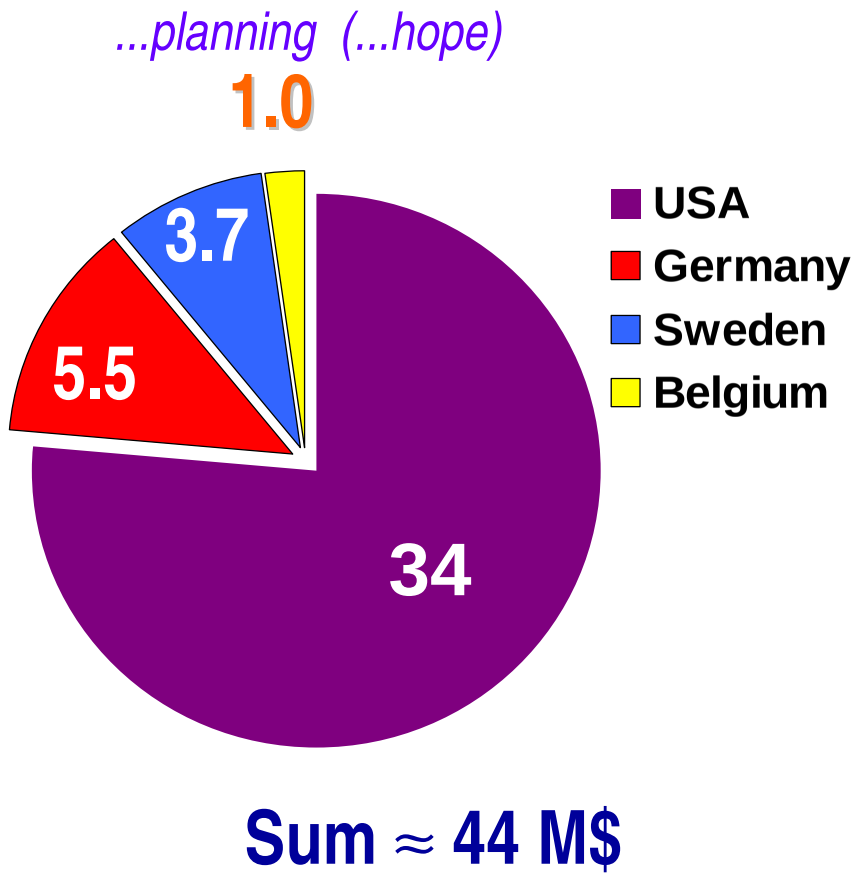
Signatures of ν_μ

Signature of ν_τ

Schedule and costs of ICECUBE

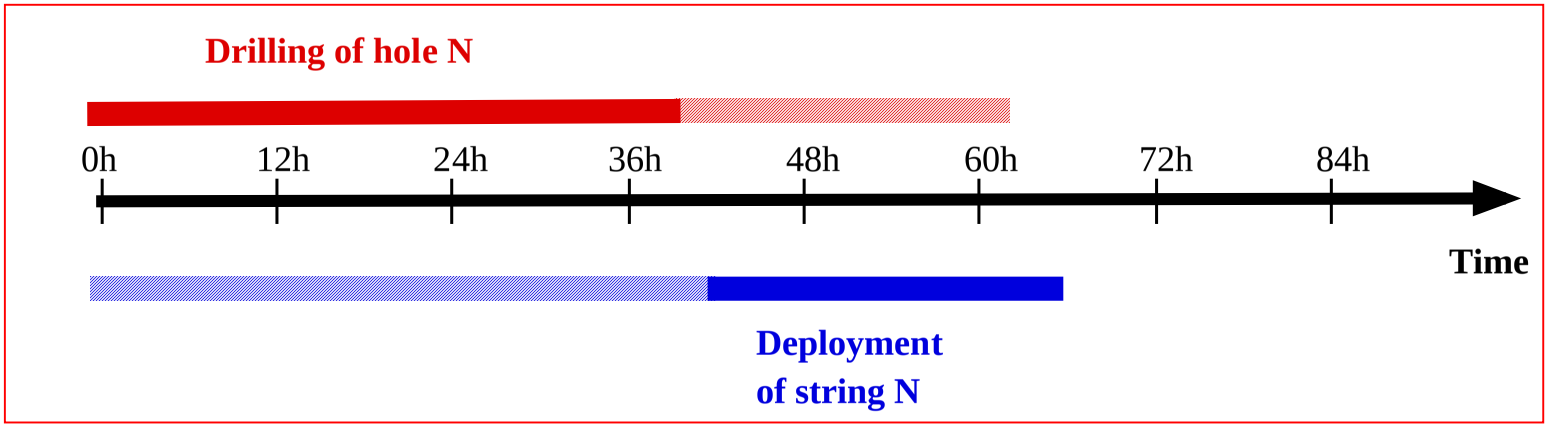
... slow start due to construction of new South Pole station ...





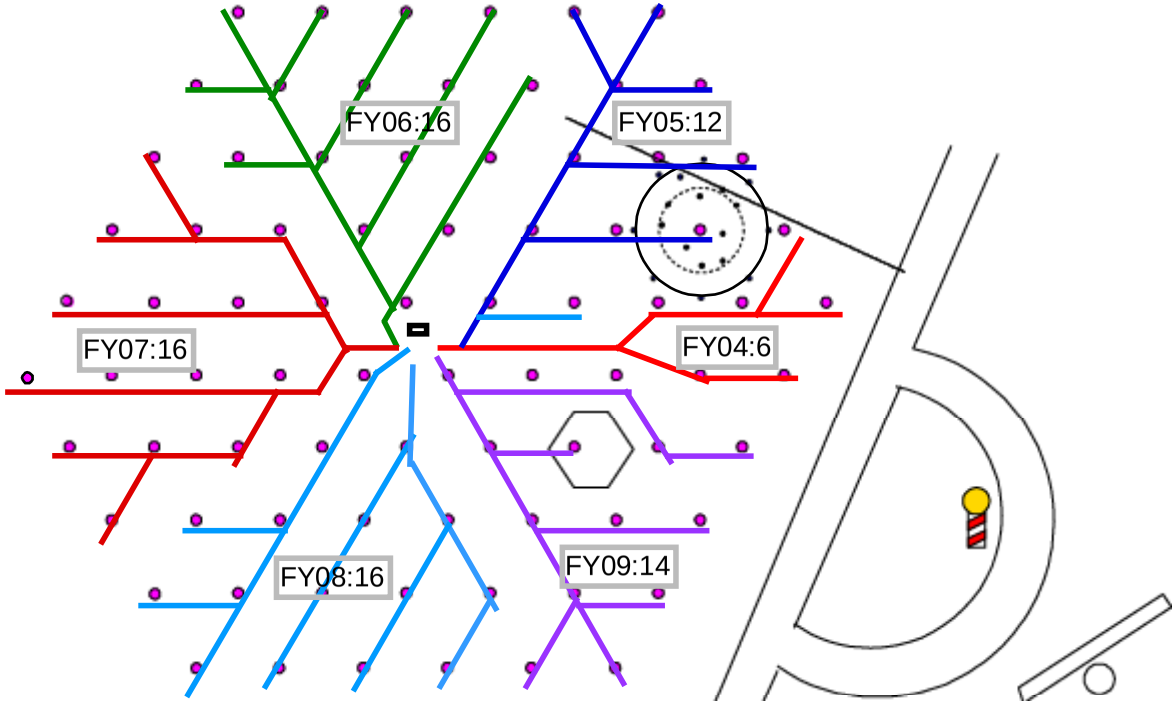
Sum ≈ 44 M$

Construction 11/2003-1/2009



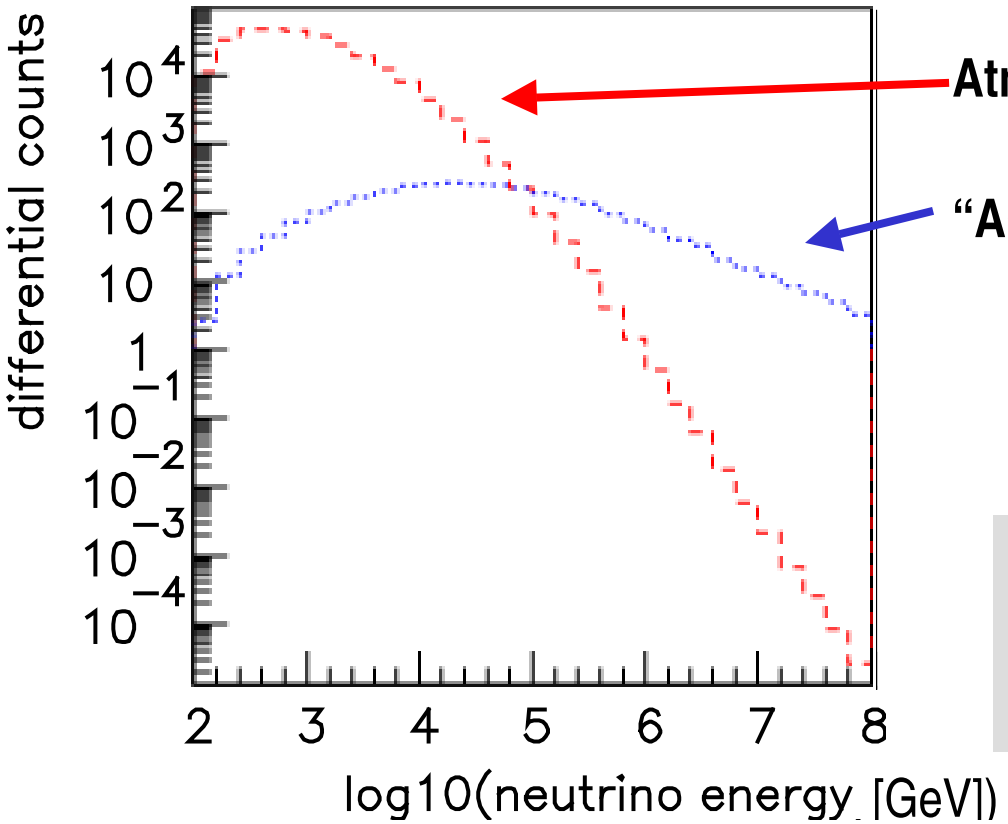
16 holes per season:

Nov.: preparation
Dec.: deployment
Jan.: deployment
Feb.: commissioning



IceCube sensitivity

- 200 GRB needed to detect/rule outWaxman/Bahcall flux
  1000 GRB give 11 reconstructed upgoing muons at 0.05 background
- „Diffuse neutrino“s:



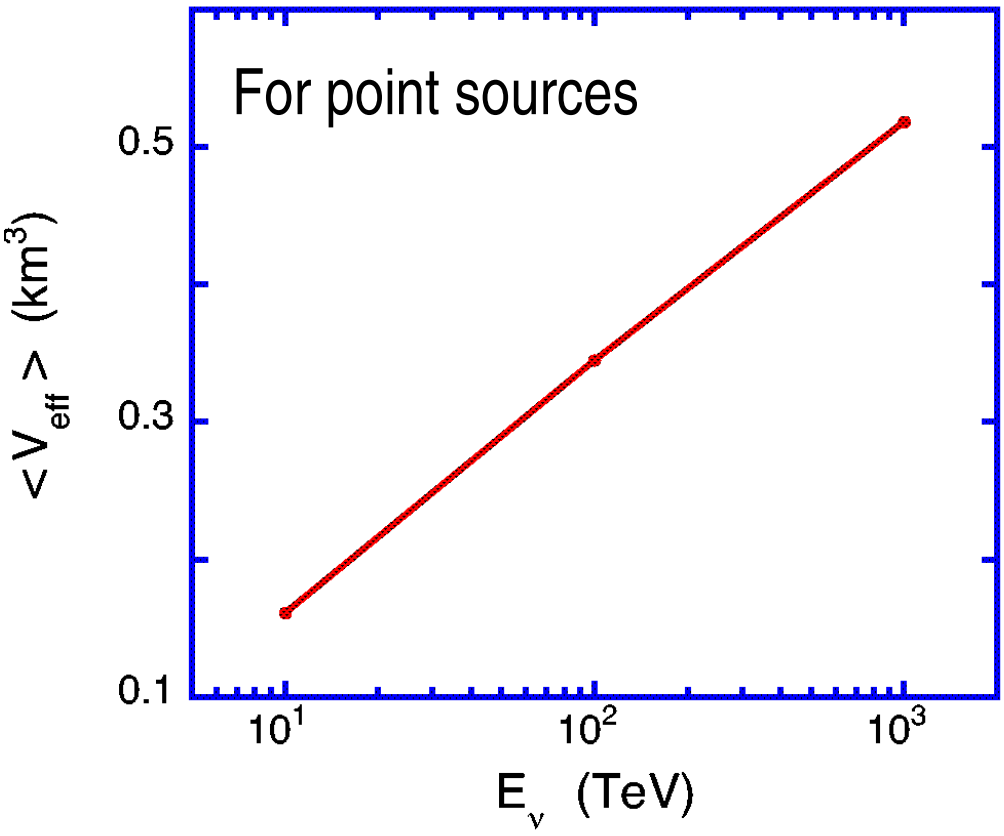
Atm. neutrinos (after qual. cuts):
→ **130.000** events / year

“**AGN**” (dN/dE = $10^{-7} \cdot E^{-2}$ cm^{-2} s^{-1} GeV^{-1}):
→ **2.300** events / year

Sensitivity after 3 years: on E^2 dN/dE:
$2.7 \cdot 10^{-9}$ cm^{-2} s^{-1} GeV (limit expectation)
$8.0 \cdot 10^{-9}$ cm^{-2} s^{-1} GeV (5σ detectable flux)

Improvements expected

Effective volume for AMANDA II



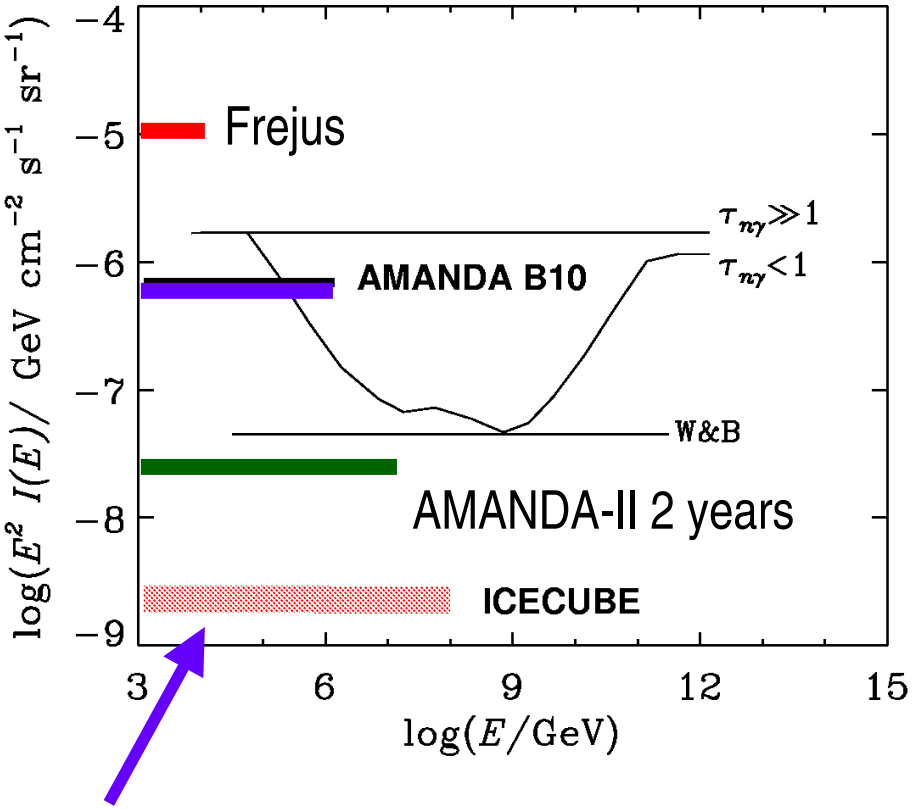
AMANDA II:
Pointing error ≈ 2.3°
Sensitivity ≈ 10-20 x „B10“

ICECUBE :
Pointing error ≈ 0.6-1°
Sensitivity ≈ 100-500 x „B10“

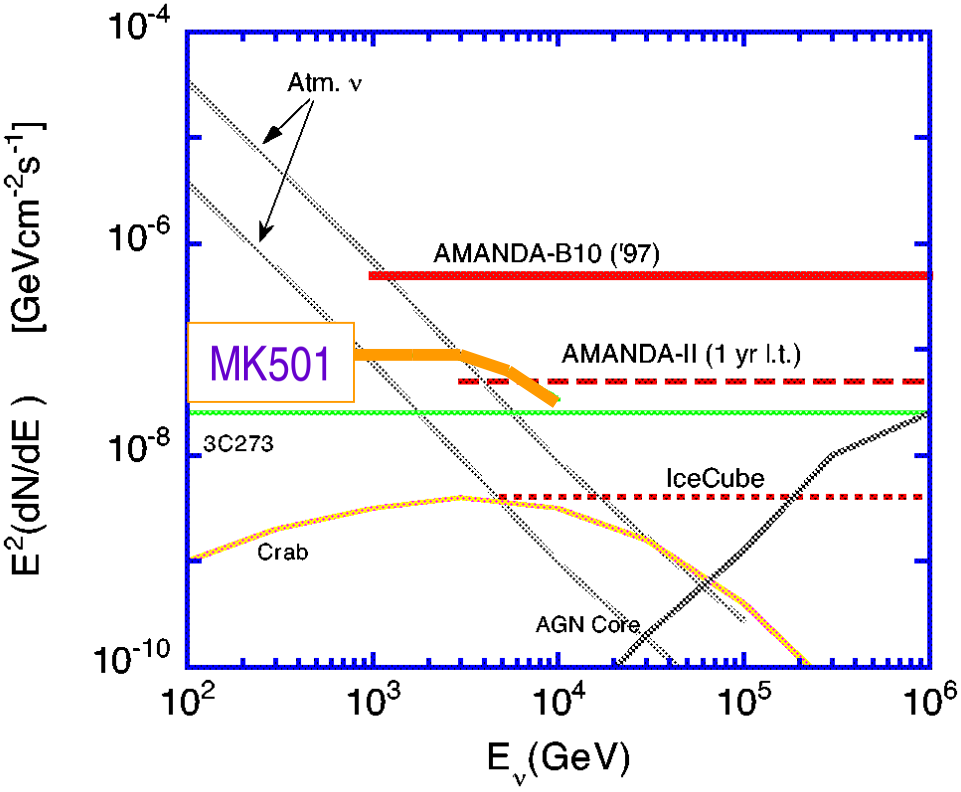
4 years

AMANDA and ICECUBE reach

Diffuse flux



Point sources



Energy region AMANDA was optimized for

ν/γ=1 assumed for MK501

IceCube Review (Oct.18-20,01)

Don Hartill chairing ...

- Panel strongly supports physics goals of IceCube
- Very significant progess in all areas
- Contributions of Europeans add significantly to confidence in sucess
- Hot water drill on critical path
- This and optical module electronics need highest priority
- Look for ways to improve satellite connections

Very positive outcome

..however, situation for NSF very undear due to Sept. 11 events ...

Summary

- 1997 results in process of being published
- 1998-1999 data reconstruction started
- 2000 data reconstruction well advanced, first results
- 2001 online reconstruction , first results
- New tools and methods for Amanda II data under development

- IceCube review („Hartill II“) very positive ...*but*