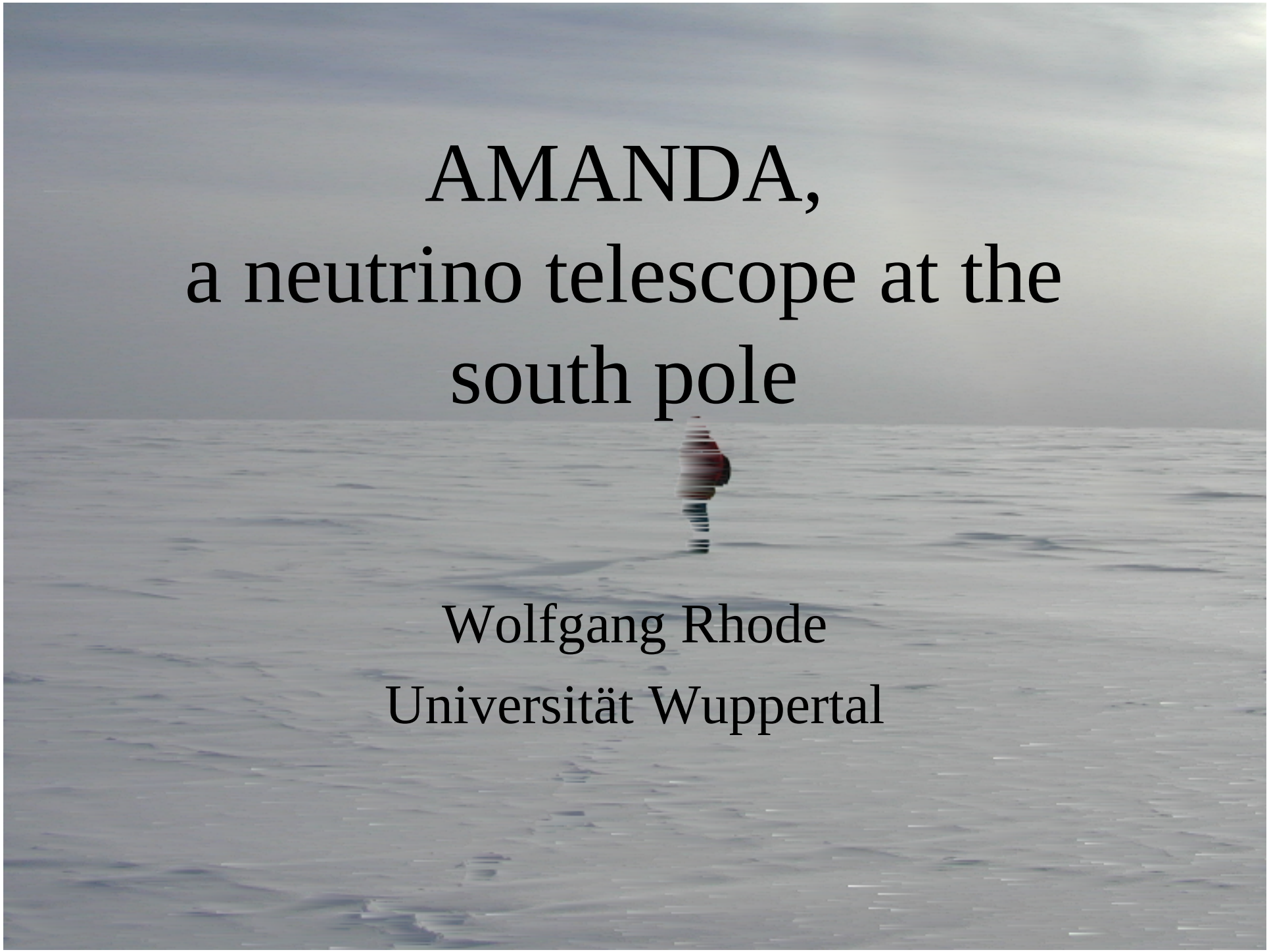


AMANDA, a neutrino telescope at the south pole

Wolfgang Rhode

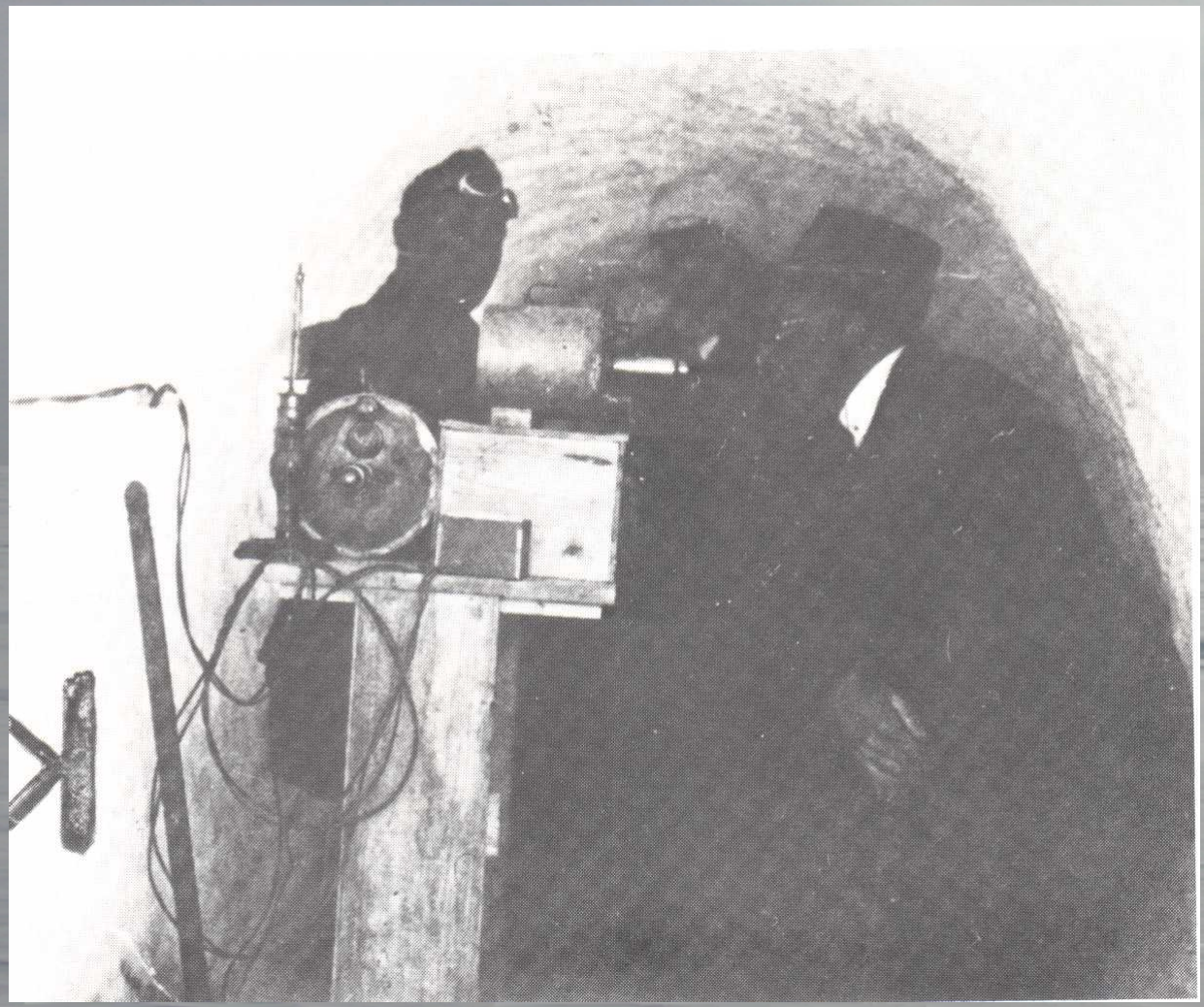
Universität Wuppertal

AMANDA Collaboration

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[10] Lawrence Berkeley Laboratory, Berkeley, CA, USA
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[12] South Pole Station, Antarctica
[13] ULB - IIHE - CP230, Boulevard du Triomphe, B-1050 Bruxelles, Belgium
[14] University of Kansas, Lawrence, KS, USA
[15] University of Uppsala, Uppsala, Sweden



V.F. Hess 1960; „Strahlungsapparat“ 1927-1931

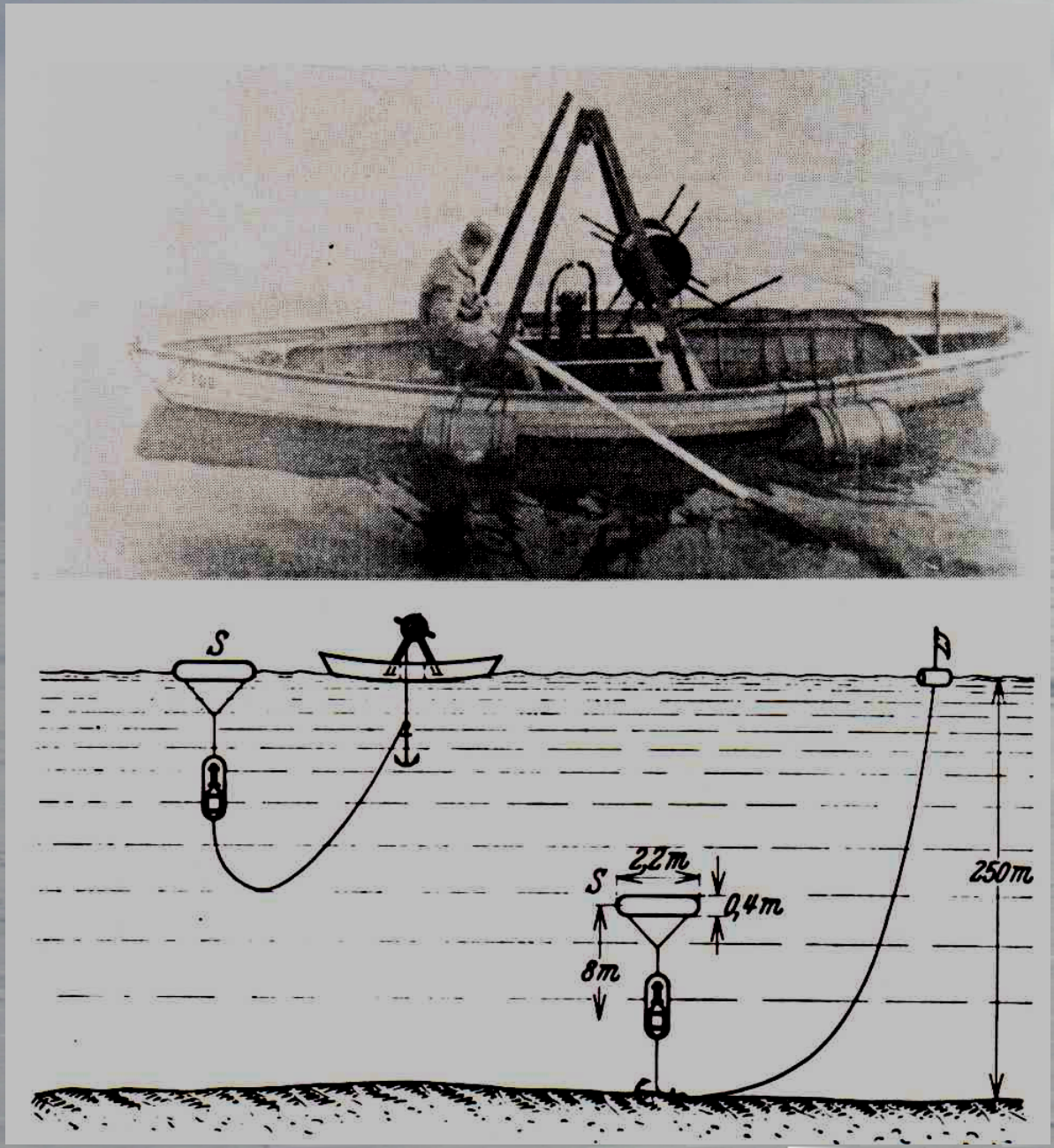


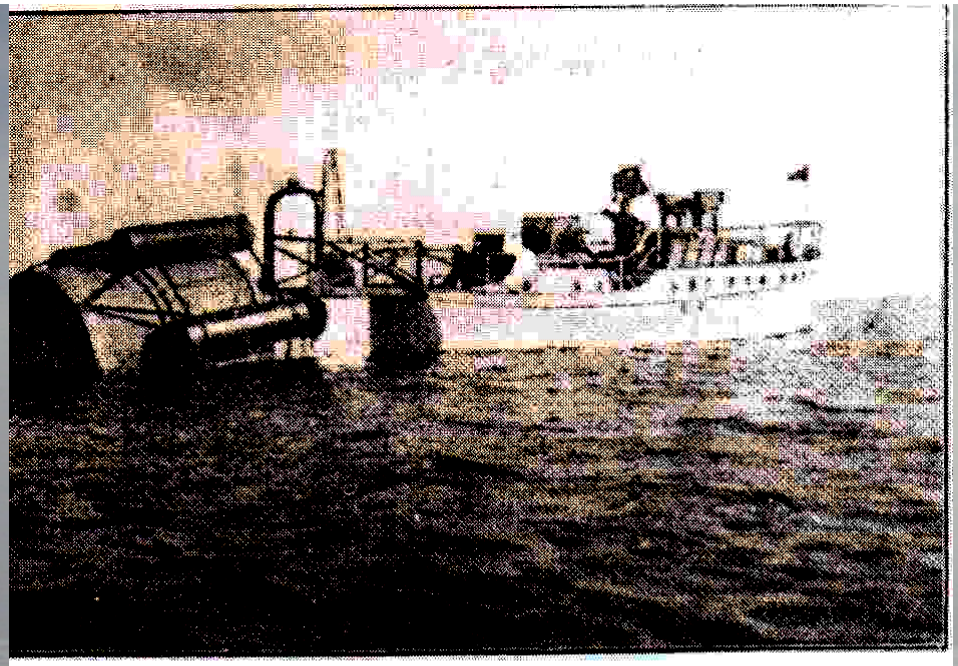
W. Kohlhörster measuring in a ice-hole in the Eiger glacier, 1923

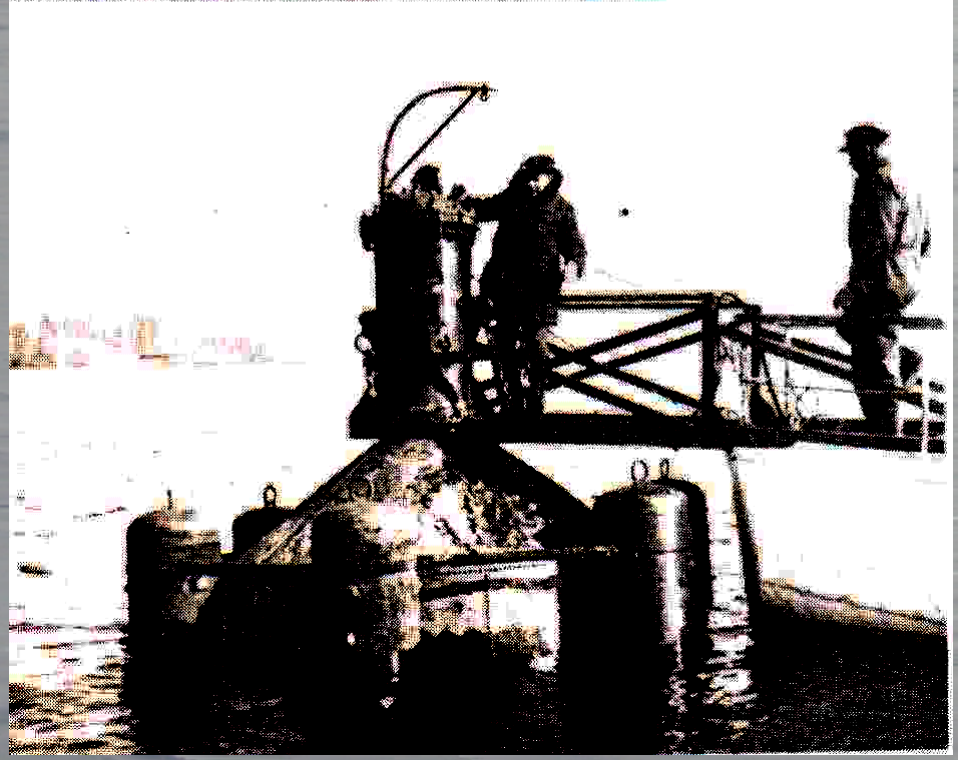
E. Regener,

Bodensee,

1928







E. Regener,

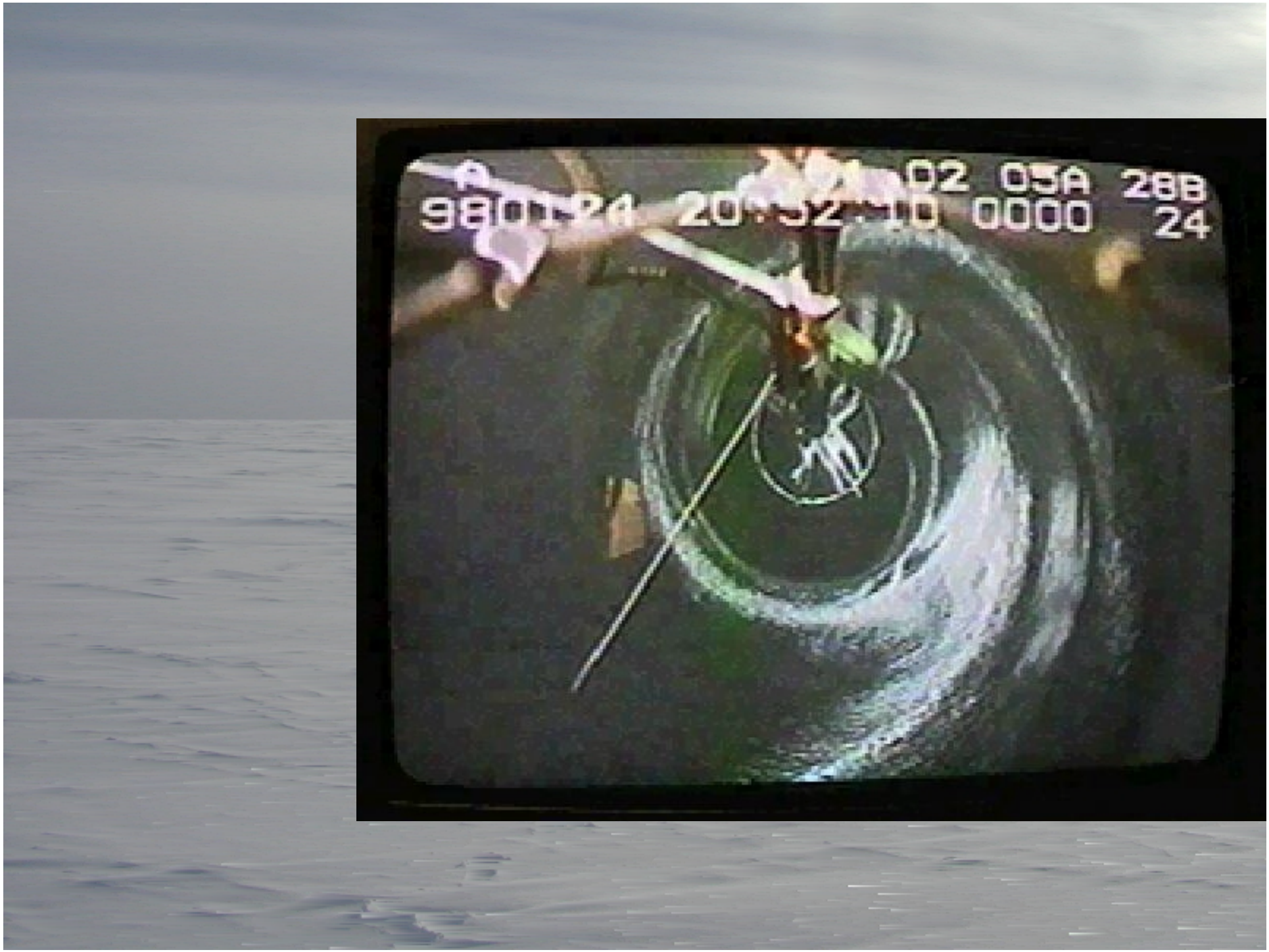
Bodensee,

1932

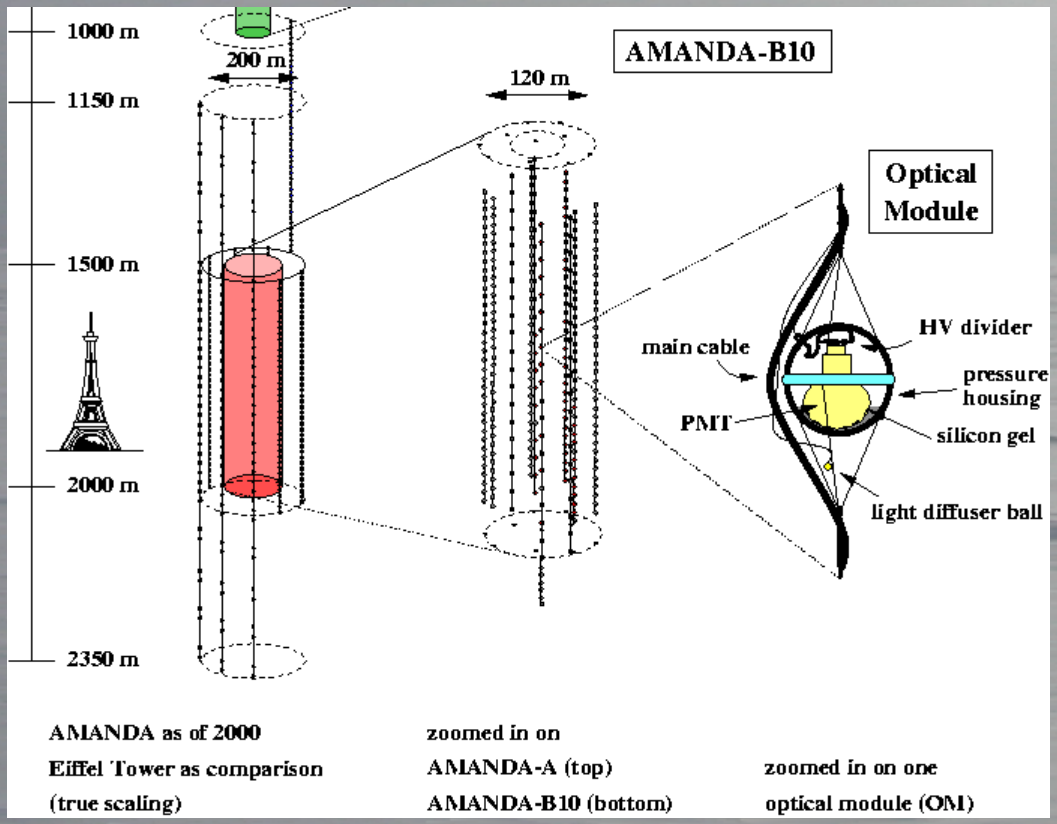

HAPPY NEW YEAR 2000

9356-05




02 03A 28B
0000 24

Neutrino Telescope in Ice



1997:

AMANDA-B10

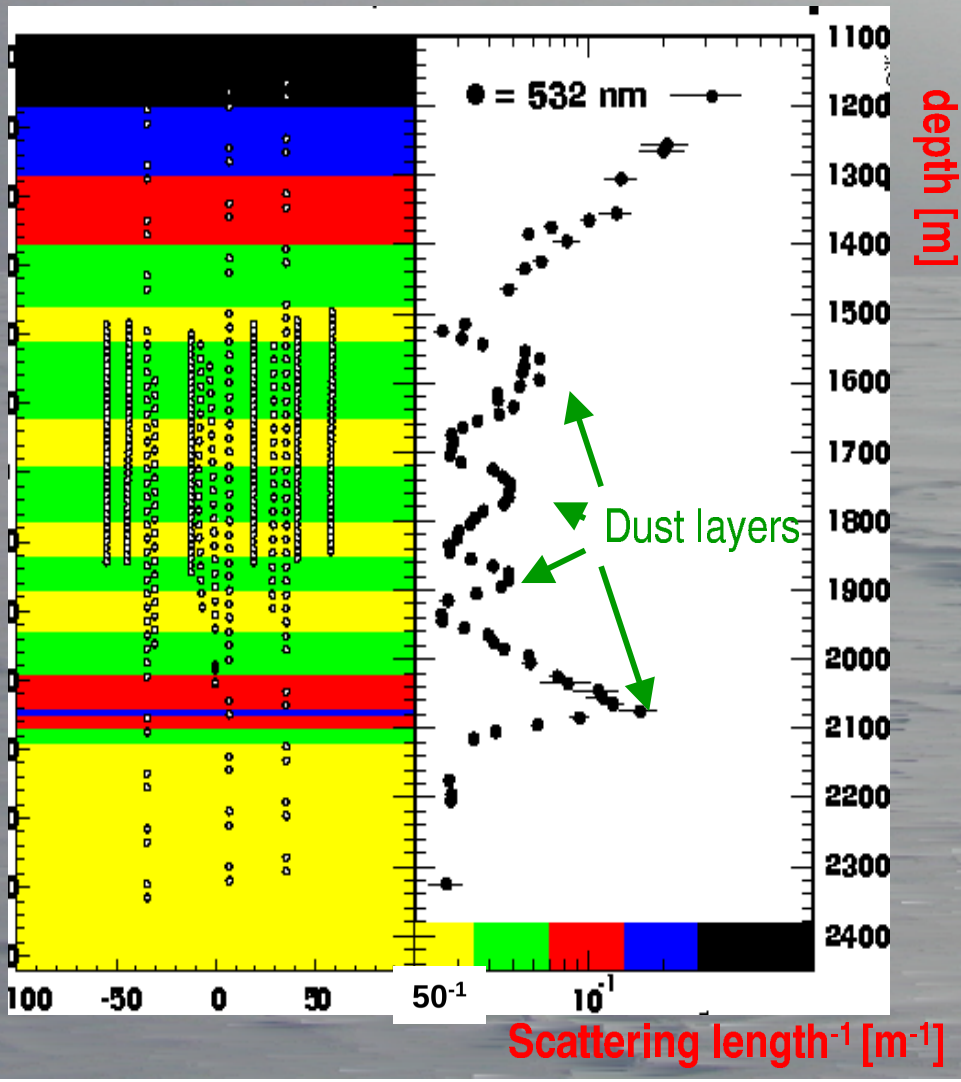
302 OMs at 10 Strings

2000:

AMANDA-B19

680 OMs at 19 Strings

Ice-properties



λ= 400 nm:
Scattering length ≈ 25 m
Absorption length ≈ 100 m

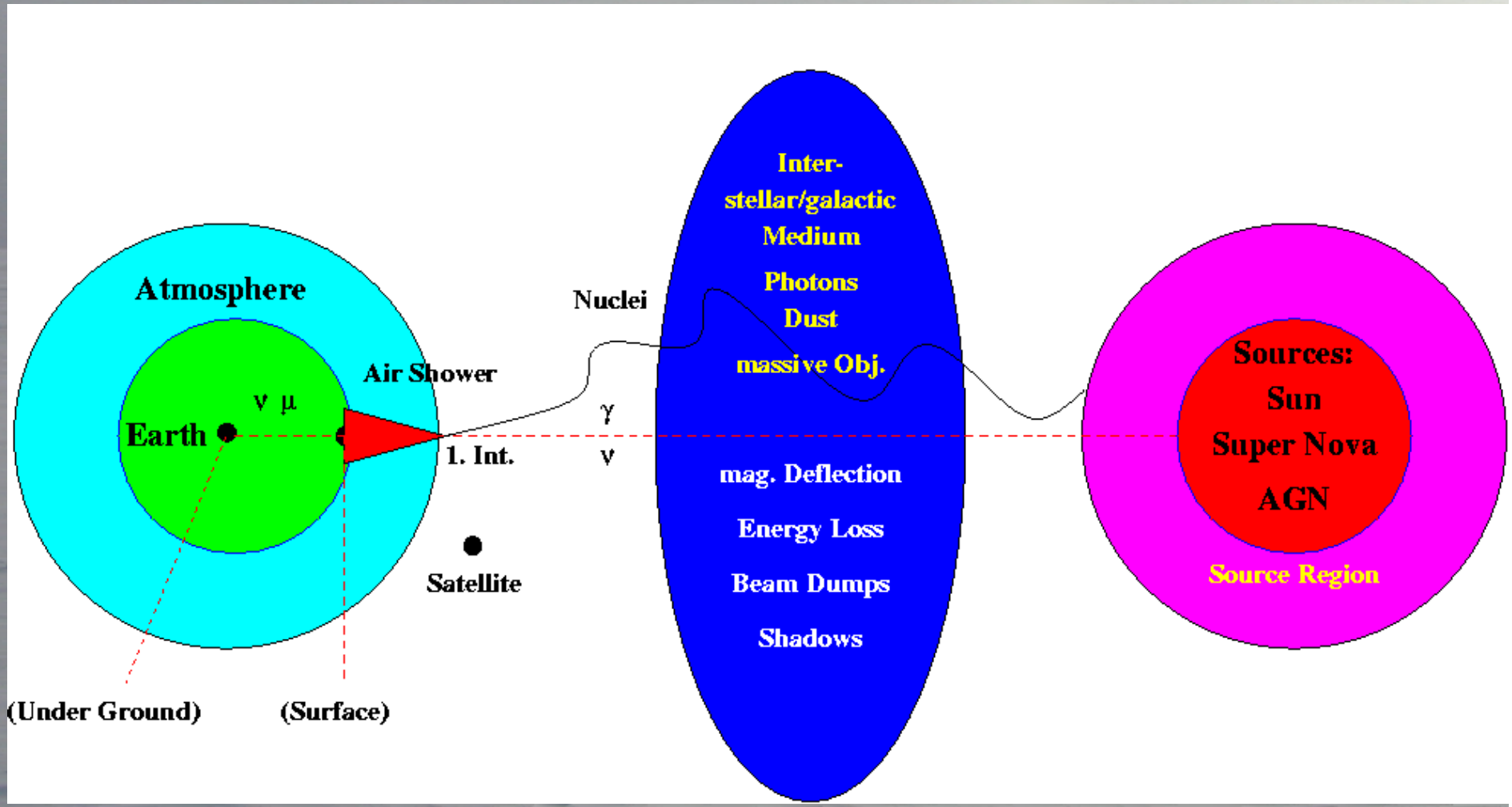
Advantages of ice:

"good" energy resolution
low noise (300 -1500 Hz)
few sensors required
detector stable

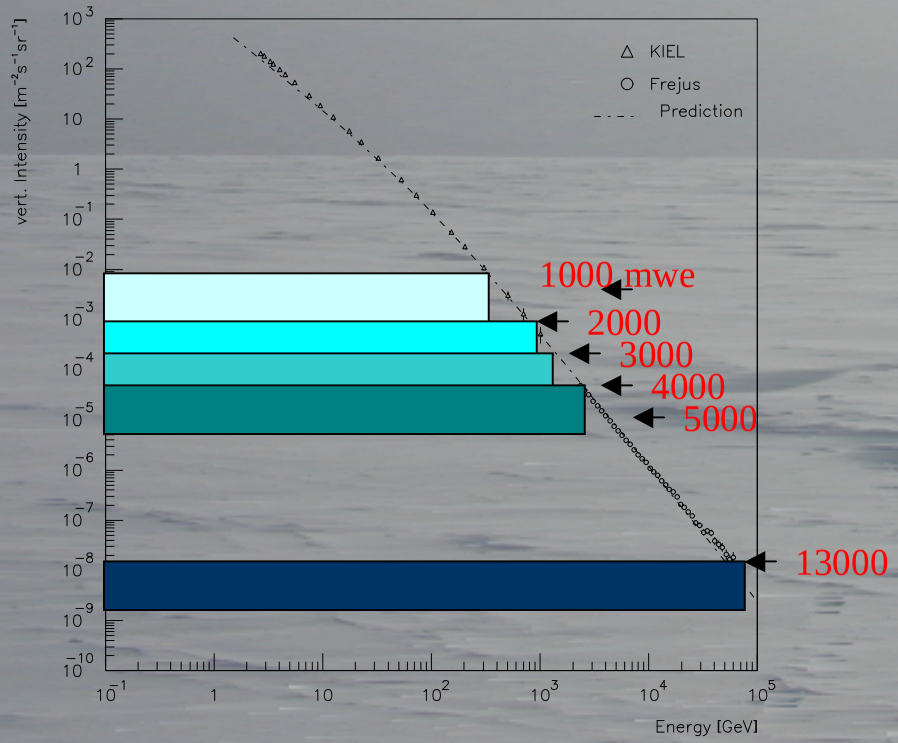
Disadvantages of ice:

diffuse, delayed light
directional measurement
no repair of detector possible!

dramatis personae

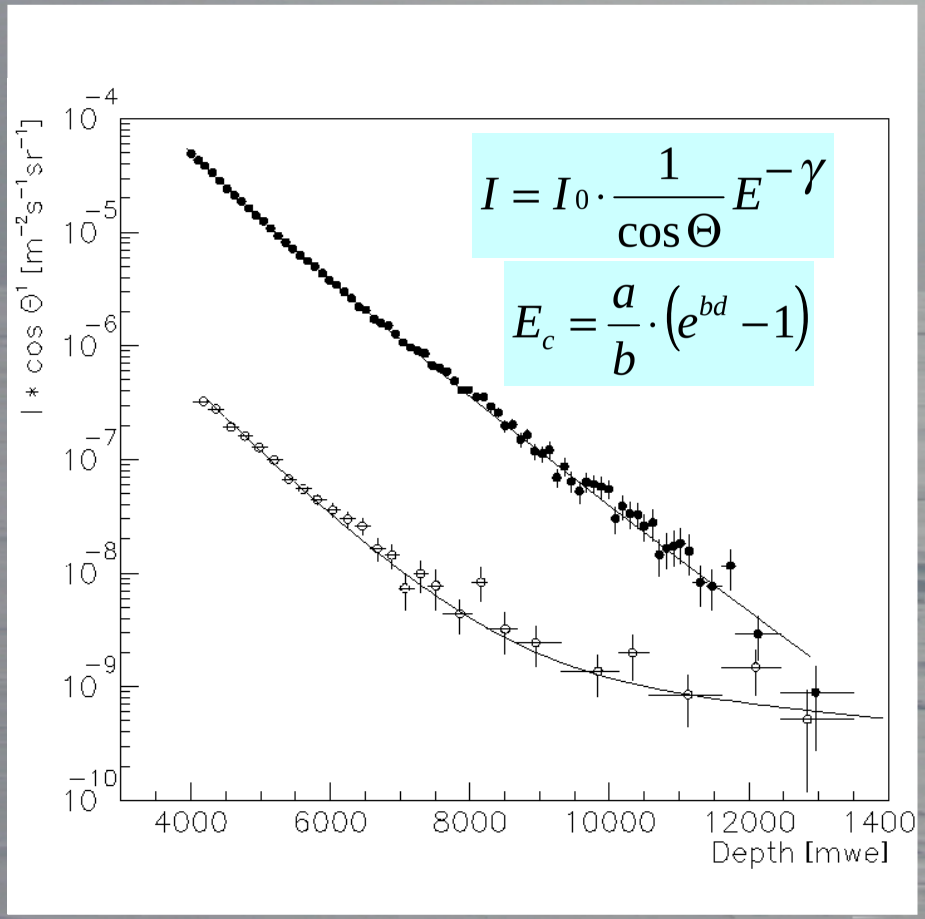


Background: Atmospheric Muons



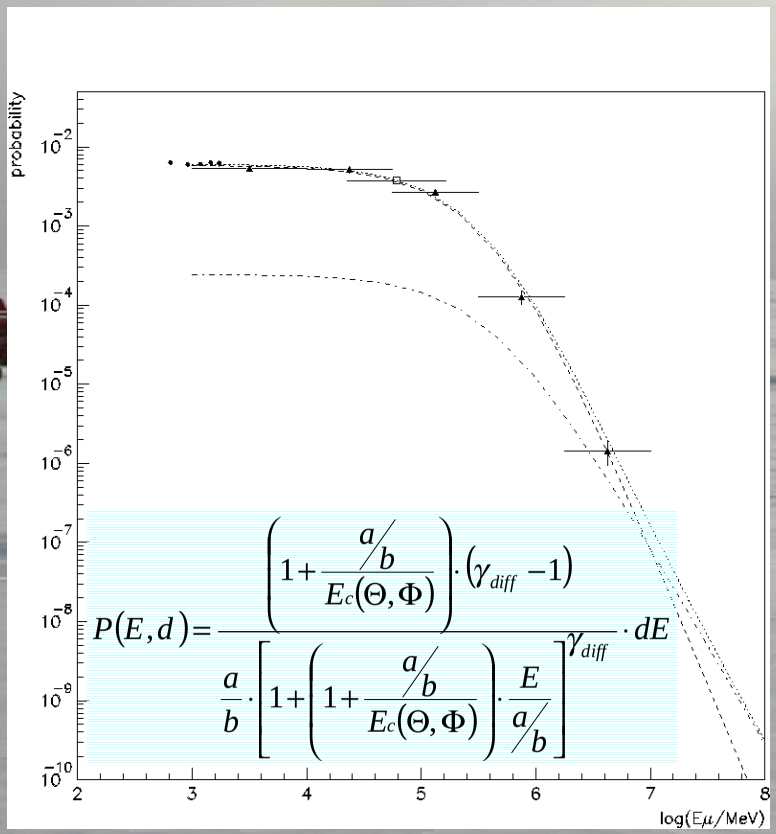
- 3-6 o.m. above atm ν
- 5-8 o.m. above new signal.
- Suppression by
  - angular resolution
  - energy resolution

Test Beam: Atmospheric Muons



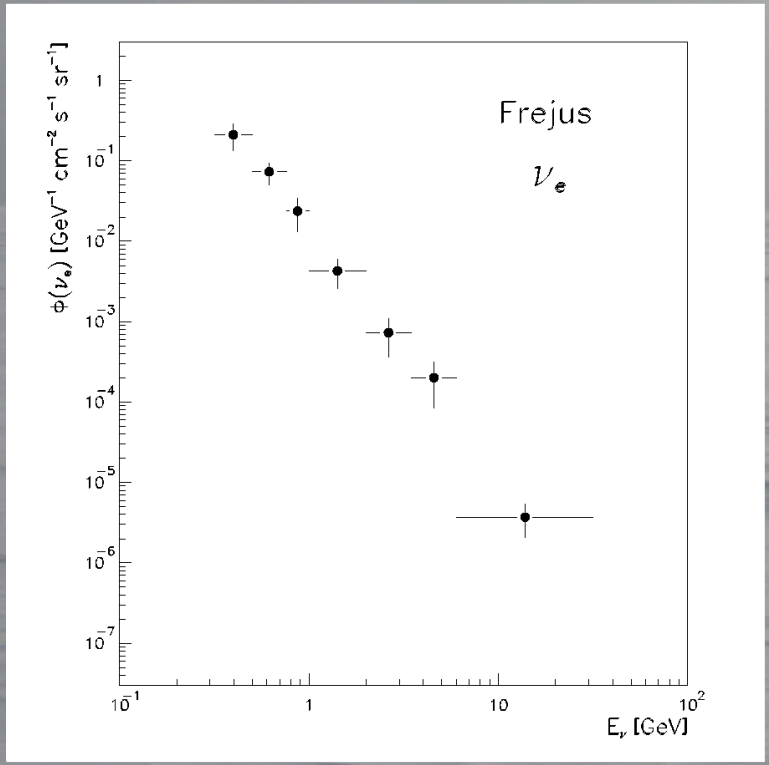
$$I = I_0 \cdot \frac{1}{\cos\Theta} E^{-\gamma}$$

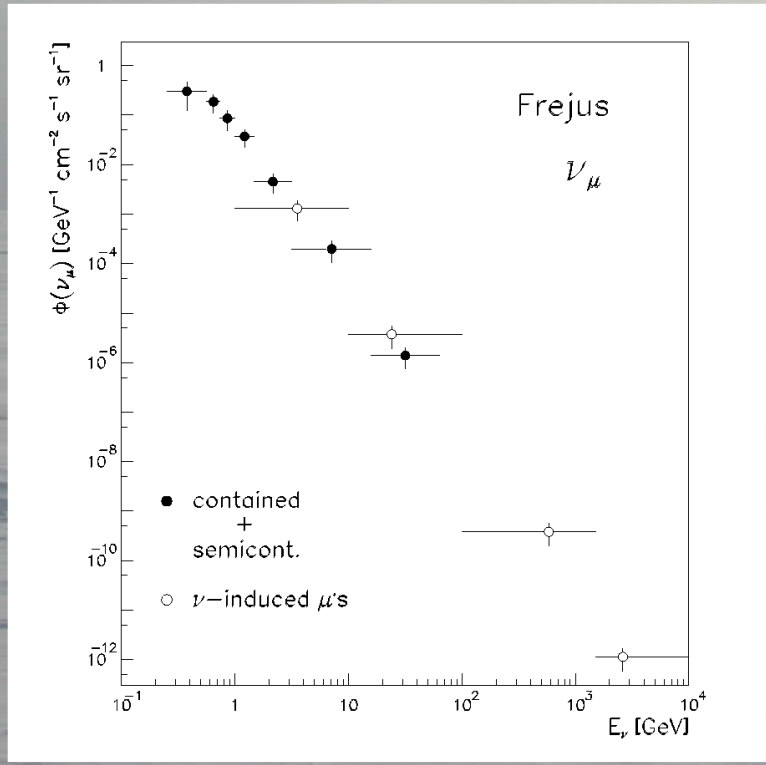
$$E_c = \frac{a}{b} \cdot \left(e^{bd} - 1\right)$$



$$P(E,d) = \frac{\left(1 + \frac{a/b}{E_c(\Theta,\Phi)}\right) \cdot \left(\gamma_{diff} - 1\right)}{\frac{a}{b} \cdot \left[1 + \left(1 + \frac{a/b}{E_c(\Theta,\Phi)}\right) \cdot \frac{E}{a/b}\right]^{\gamma_{diff}}} \cdot dE$$

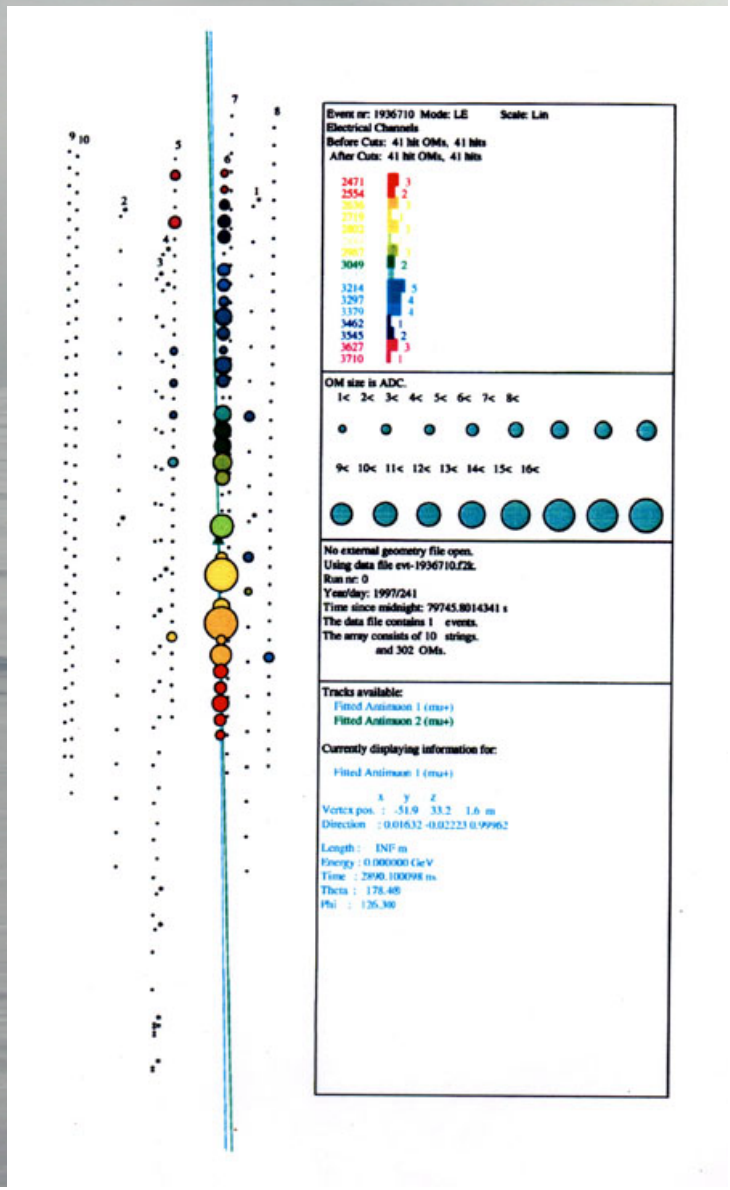
Atmospheric Neutrinos





AMANDA ν-candidate

- Early photons are red, late photons are blue. More photons are larger circles
- Bottom of array is toward center of earth
- Event is clearly traveling in the upward direction



Selection criteria

Select northern hemisphere tracks

Require minimal number and distance of "unscattered" photons

Require "smooth light emission" (no catastrophic brems, misrec.) etc.

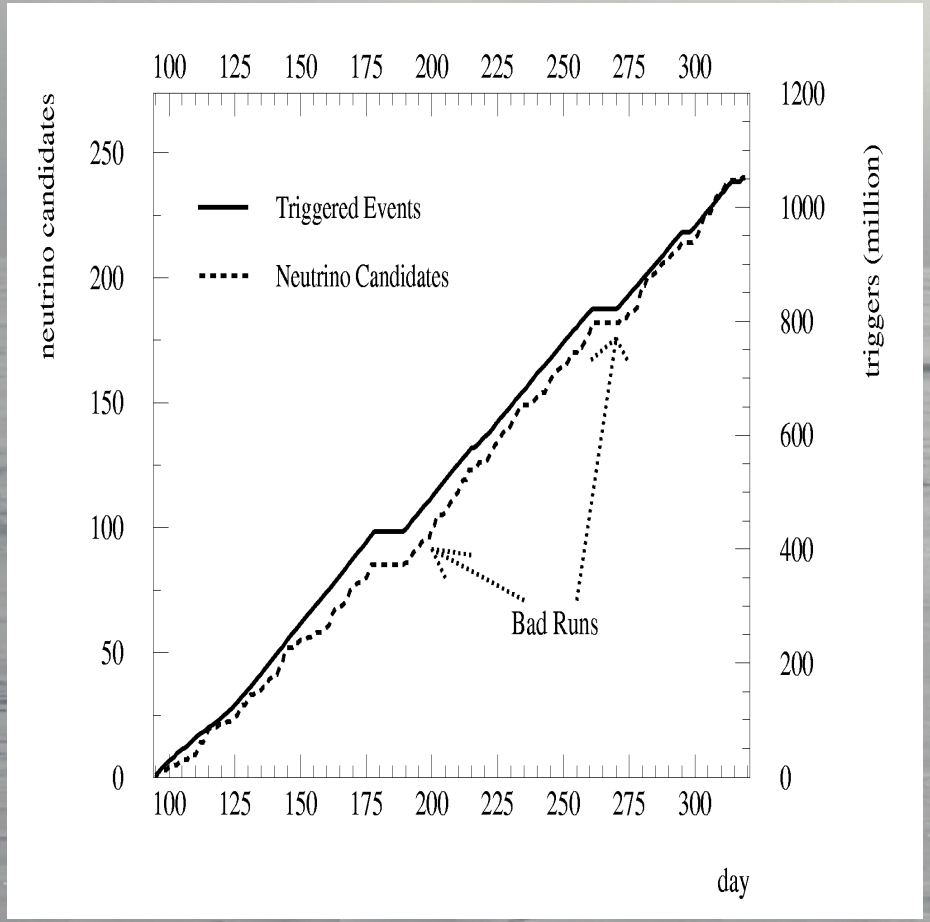
Optimize cuts values using "CUTEVAL" algorithm or use Bayesian prior

	Signal MC	Backgr. MC	experiment
Events triggered	5759	9.03×10^{8}	1.18×10^{9}
Level 1	34 %	4 %	5 %
Level 2	15 %	4×10^{-2} %	4×10^{-2} %
Level 3	7 %	7×10^{-4} %	1×10^{-3} %
Level 4	4 %	5×10^{-7} %	2×10^{-5} %
without oscillation	236.9±5.5	7.5 ±4.8	-
with Oscillation	219.3±5.5	7.5 ±4.8	223

uncertainties in MC modeling of hole ice and flux ...

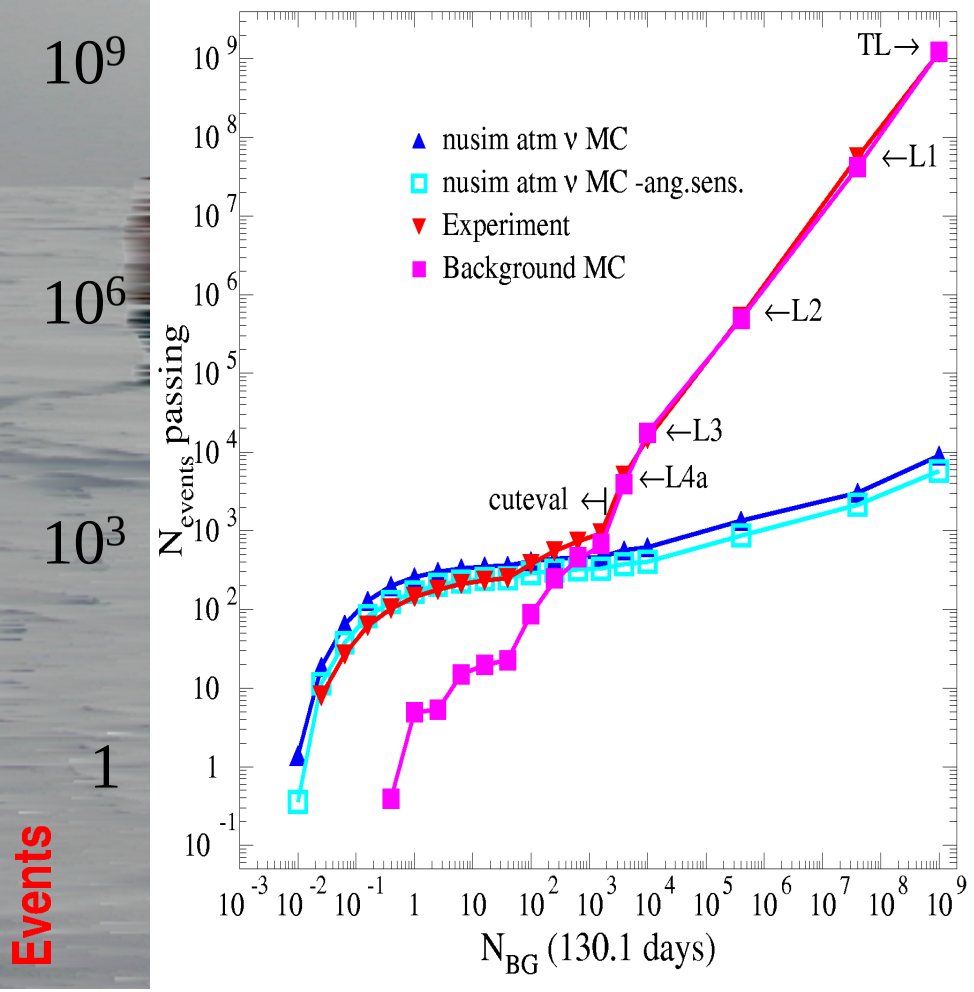
Atmospheric Neutrinos

- Continuously data taking
- Number of candidates follows the number of trigger
- Seasonal flux variation



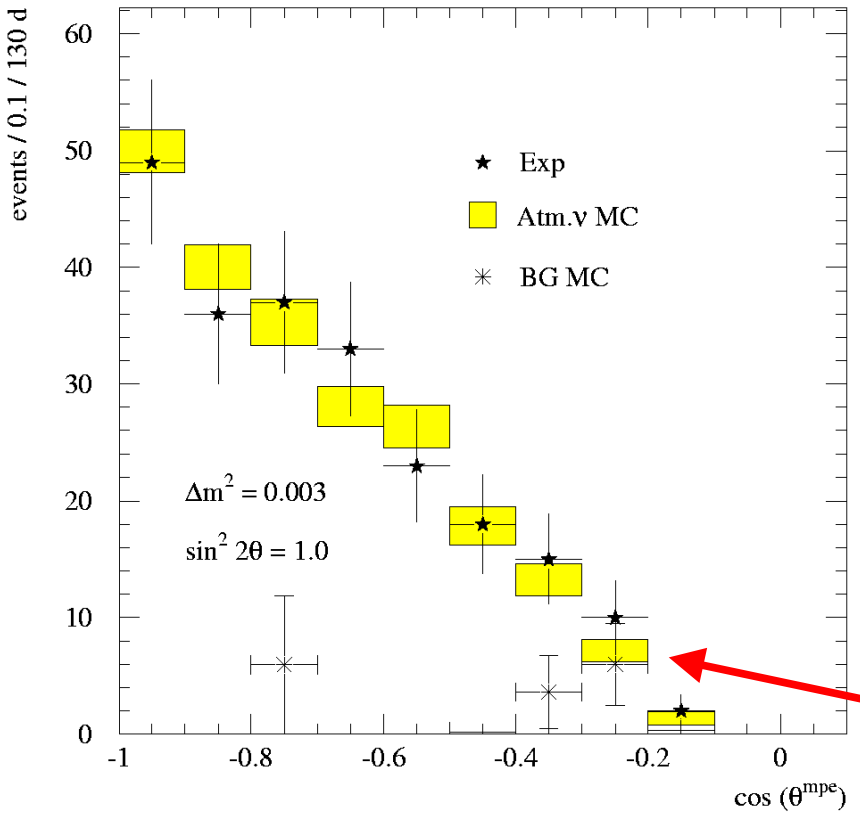
Background suppression

- Data/MC agreement at better than 50% as function of cuts
  - parametrized by N_{BG} ...
- First agreement with background then with signal
- Large sample of background MC



Zenith distribution of atmospheric neutrinos

Various background estimators agree ...



Uncertainties:

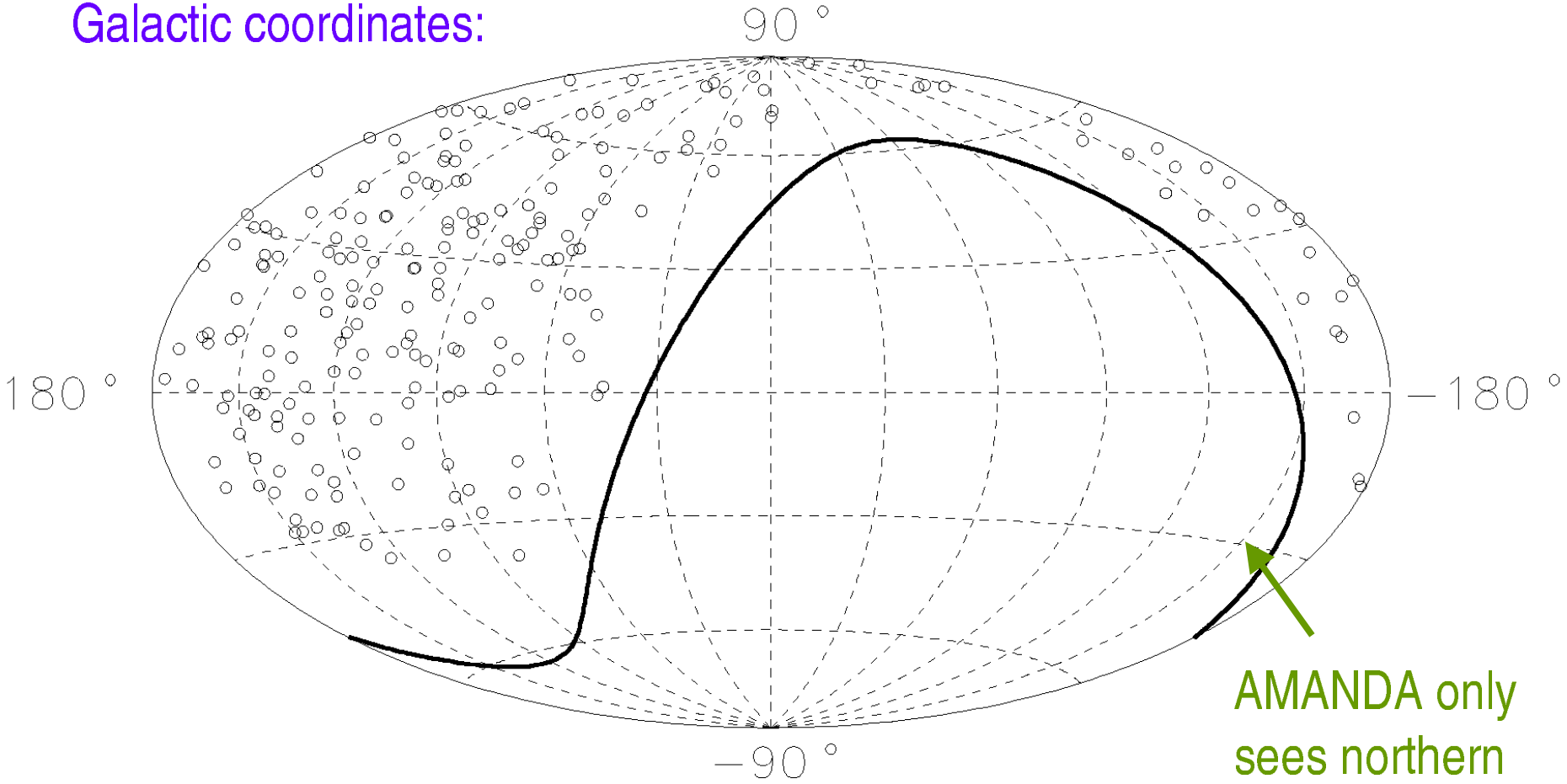
neutrino flux	30%
muon range	20%
PMT efficiency	10% (+effect of local bubbles)
ice parameters	15 %

MC with local bubble effect in re-frozen ice – otherwise 35 % higher prediction!

Neutrino oscillations (E>65 GeV) reduce flux ≈10%, small w.r.t. to uncertainties

Celestial distribution of events

Galactic coordinates:



AMANDA only sees northern hemisphere!

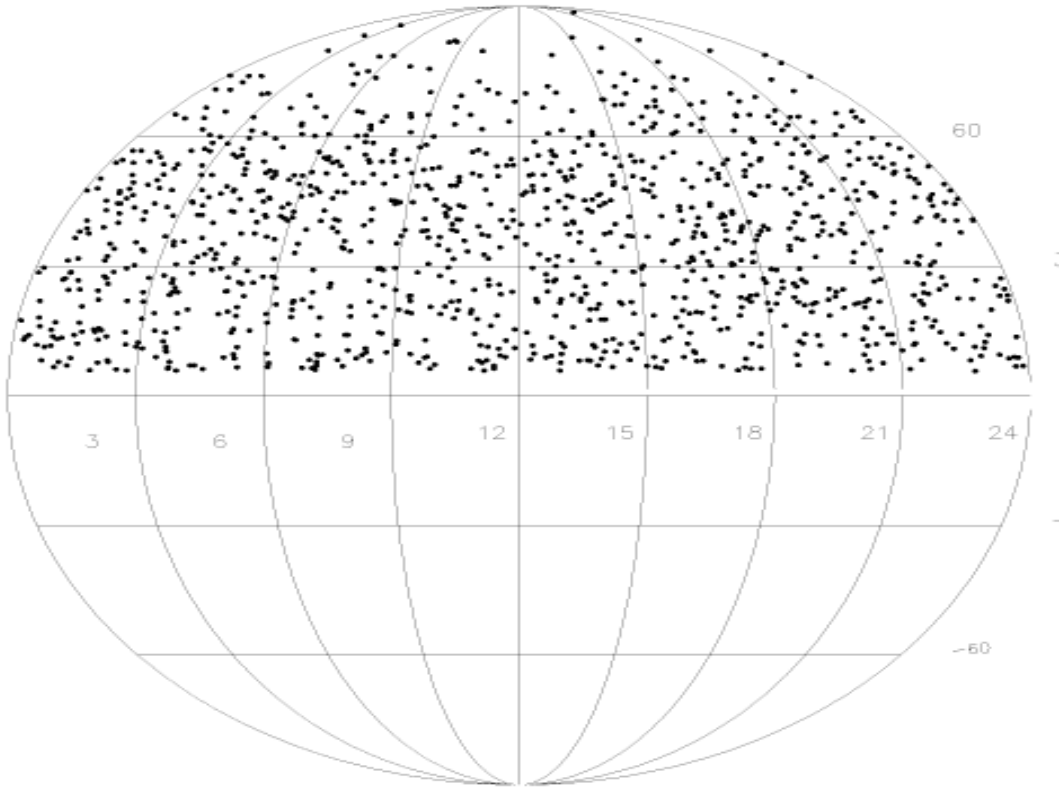
mean angular pointing resolution is 3-4 degrees

Point Source Search

looser cuts with more background improve the limit !

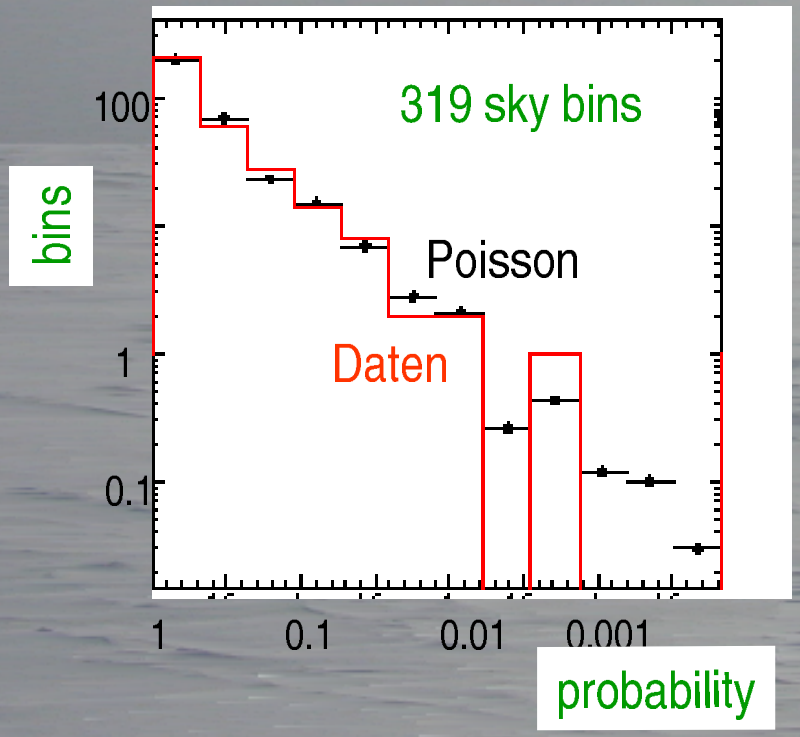
- 1097 events
- No obvious clustering!
- Sample dominated by cosmic muons and atmospheric ν's

Equatorial coordinates

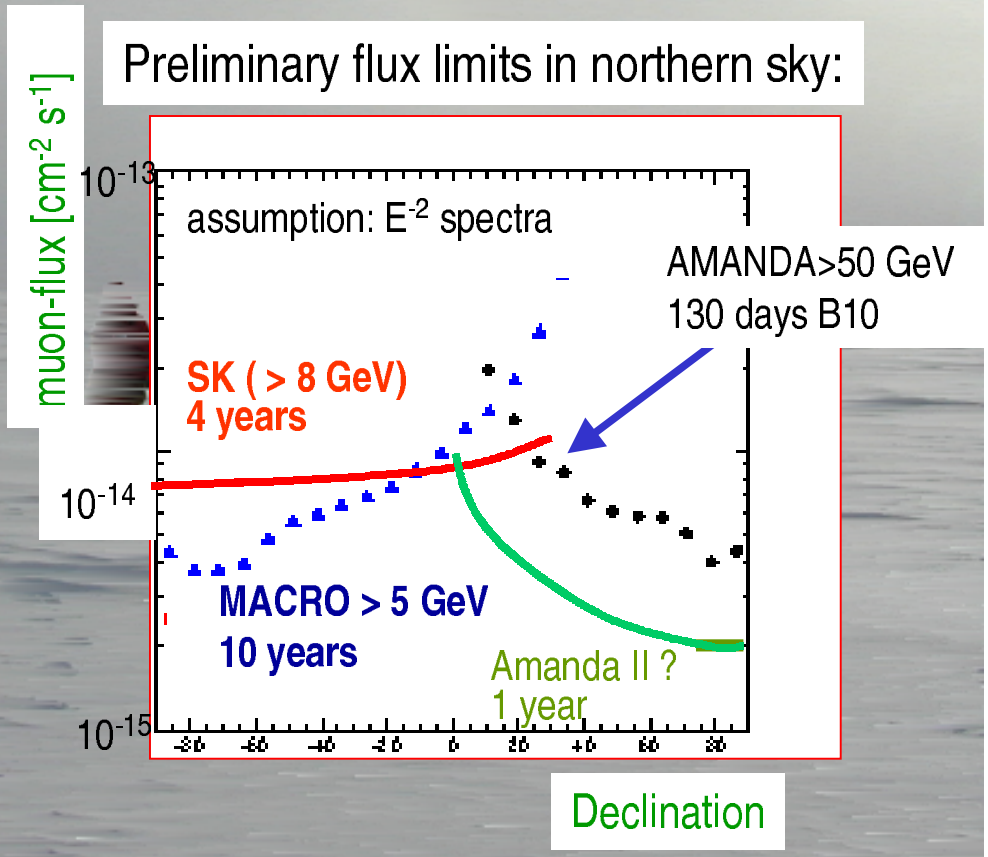


Is there a significant excess anywhere ?

130 days of data taking 1997:



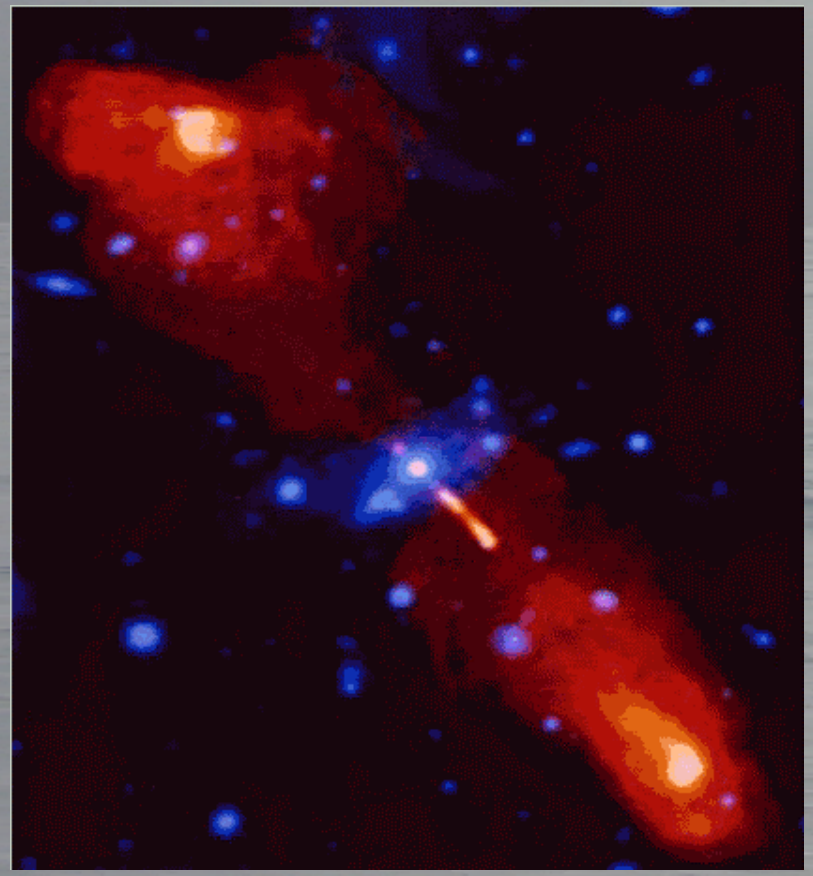
Preliminary flux limits in northern sky:



... limits for the northern sky ...

Flux (>10 GeV) < 10^{-7} cm^{-2} s^{-1} @90%

AGN



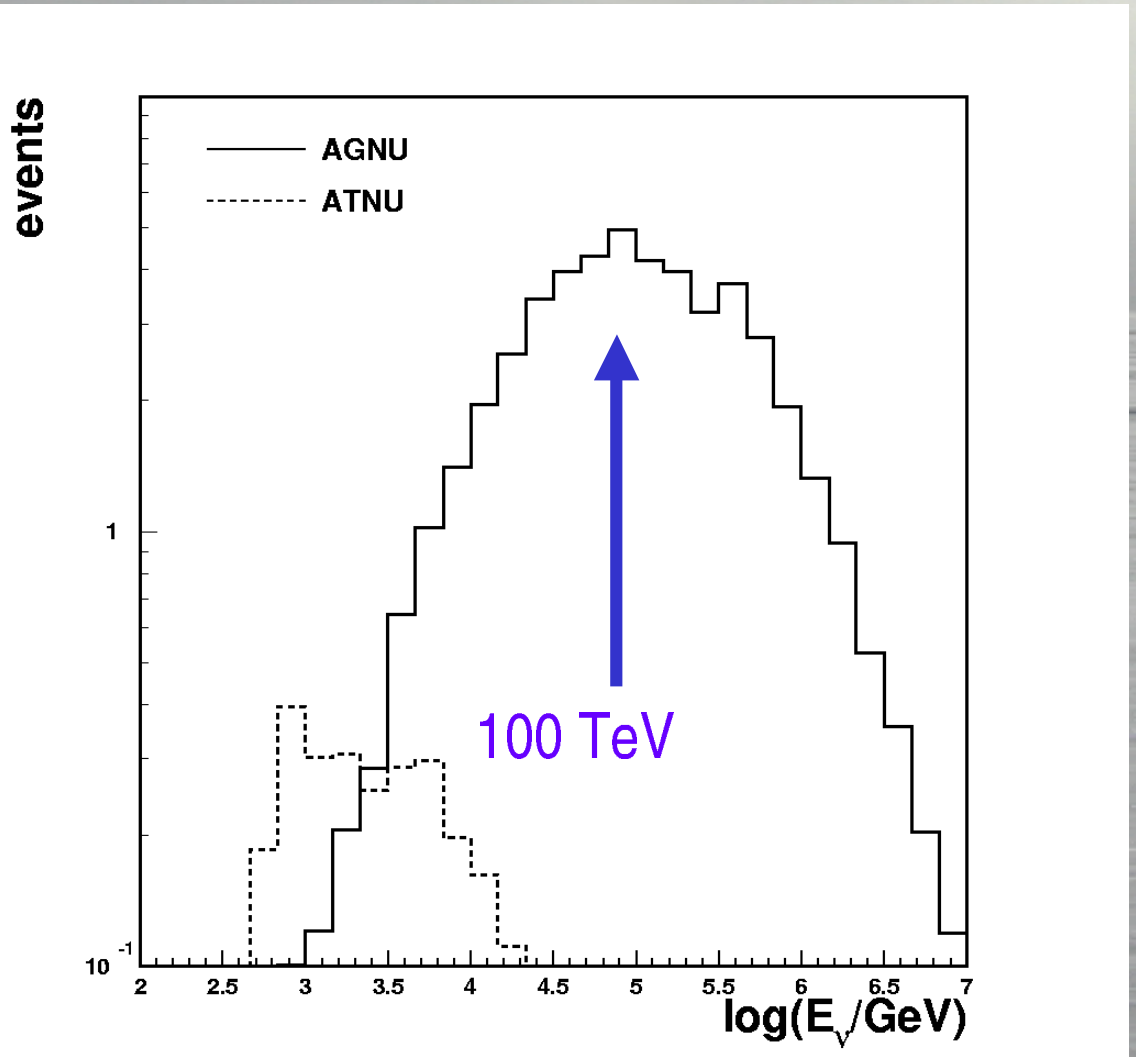
- Components:
- Supermass. Black Hole
- Accretion Disc
- Jets
- Blazar - flat Spectrum
- here: 3C219
- red: radio picture
- blue: optical picture

Neutrino energy acceptance

...after cut on multiplicity

Accepted energy range:

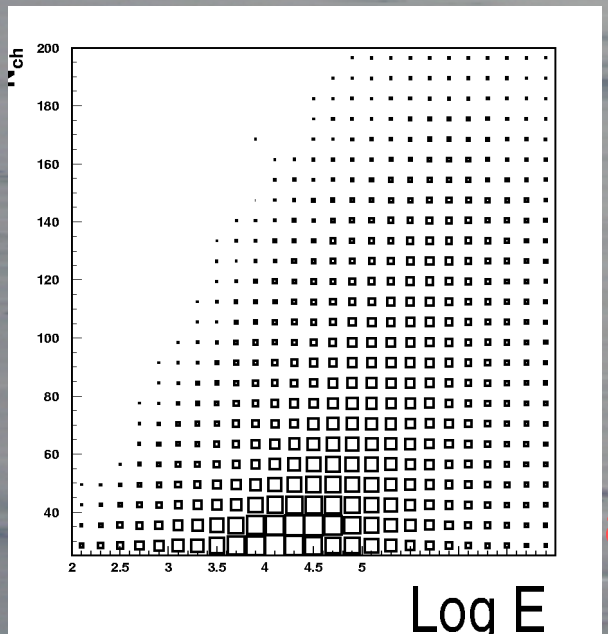
- threshold: 500 GeV
- sensitivity: 10^4-10^6 GeV

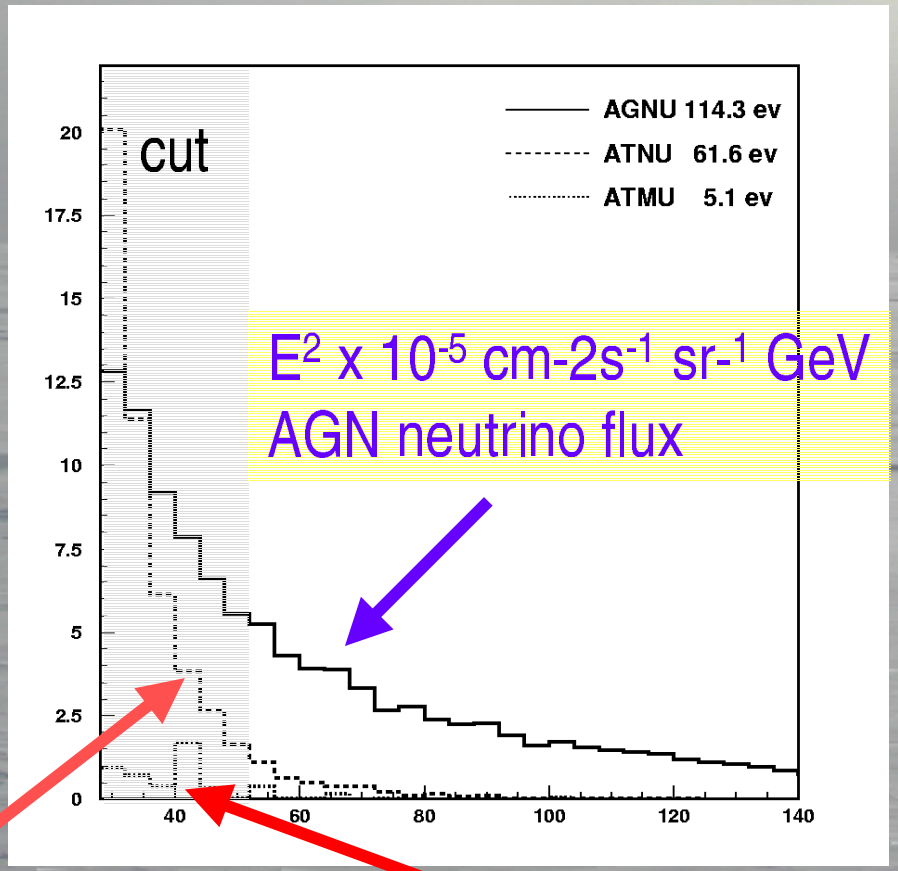


Limit on the diffuse flux

PMT-multiplicity weakly correlated with ν-energy

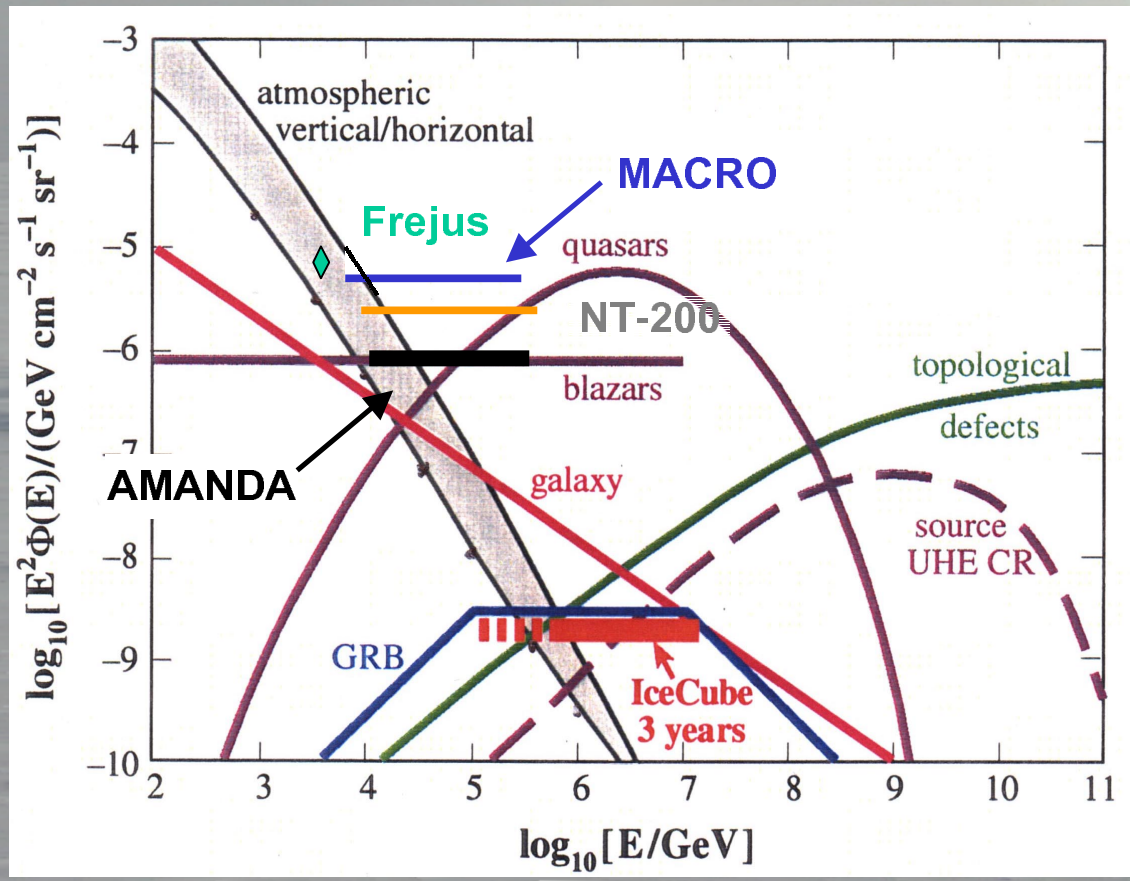
Several improved energy estimators under test …



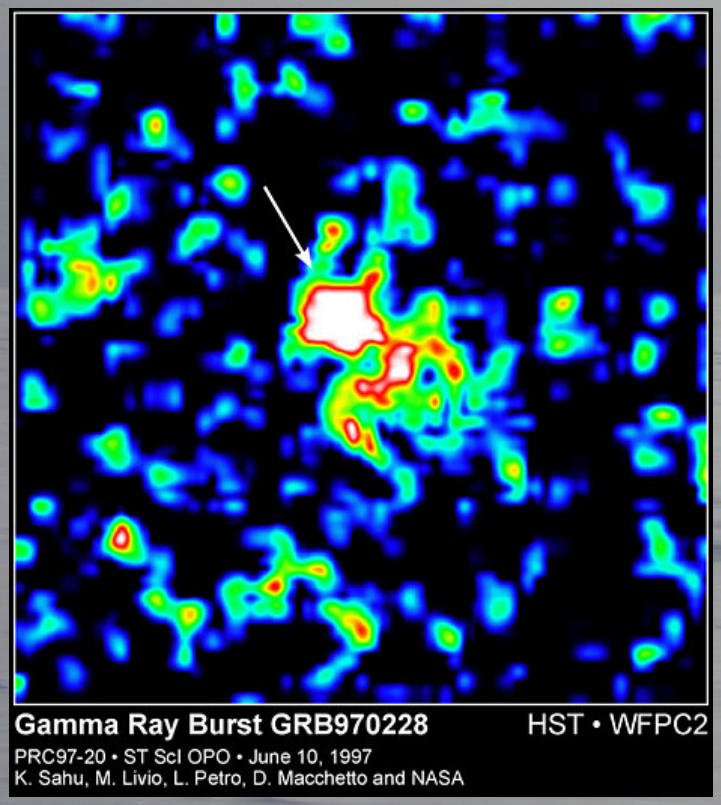


Diffuse Flux

- Generally 10^3 larger than point fluxes
- Atm. ν backgrounds 10^3 worse
- $E^2\Phi_\nu < 1.0 \times 10^{-6}$ GeV $cm^{-2}s^{-1}sr^{-1}$



Gamma Ray Bursts

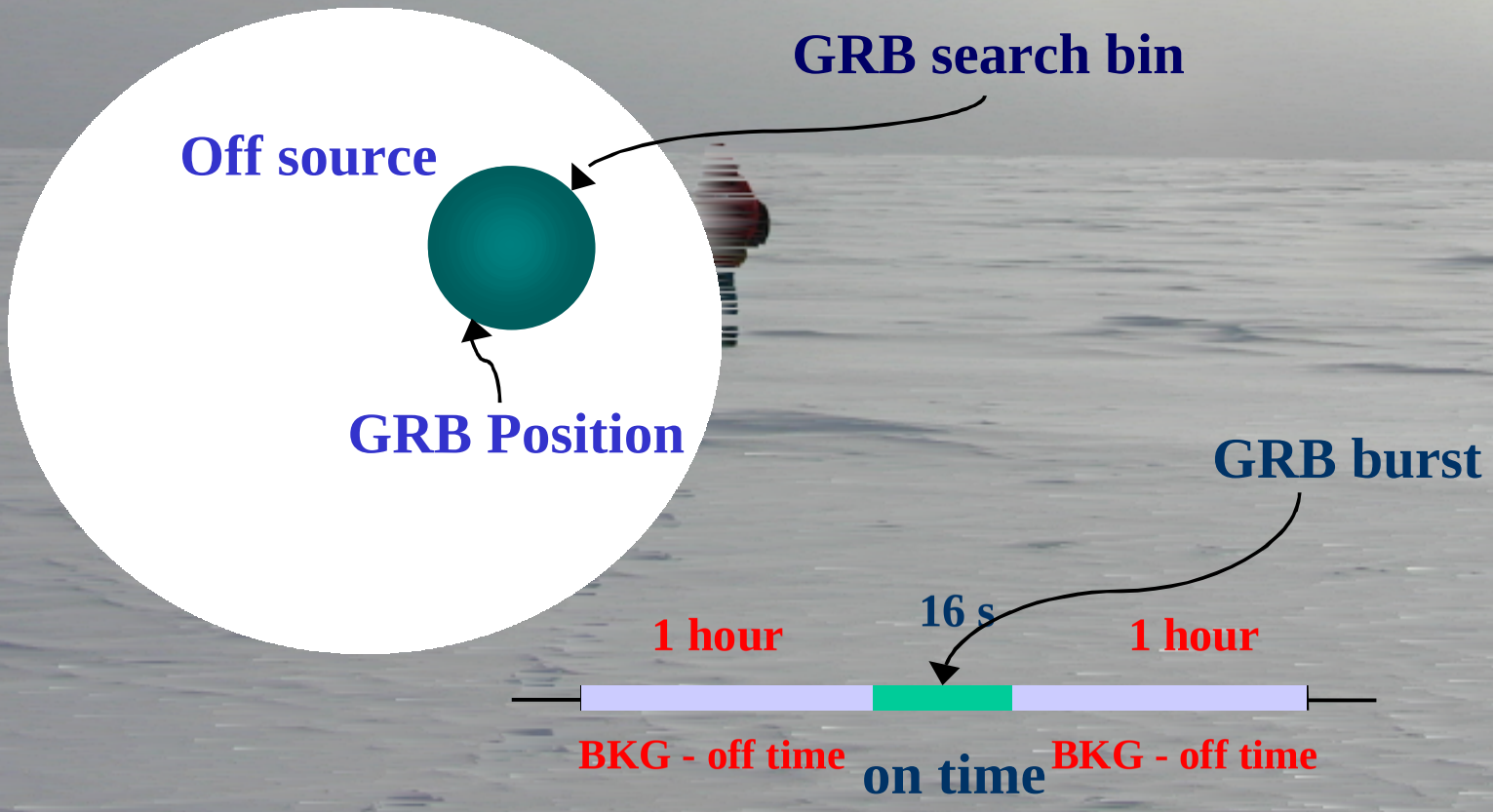


Visible image in April 97

- Highly rel. Outflow:
  - coalescence neutron star bin.
  - collapse of a supermass. star
- Cosmological dist.

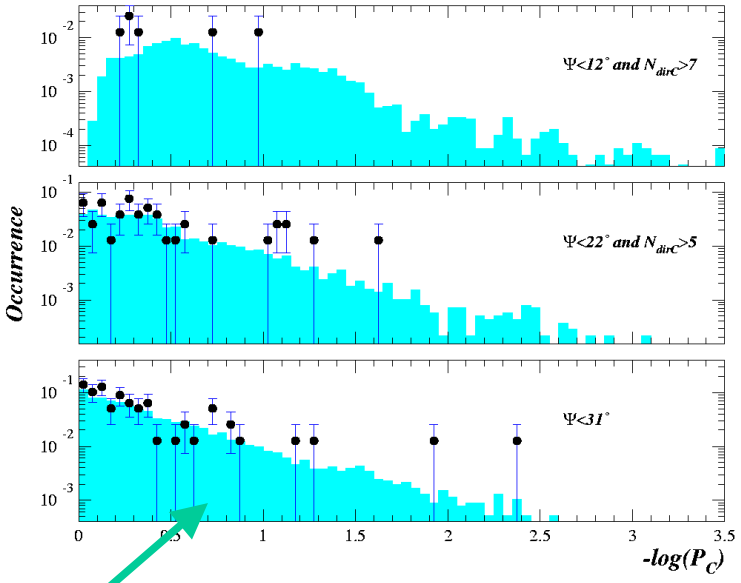
  $L \approx 10^{51} \, erg/s$ in thermal 5 MeV ν
- Timescale: msec - min,
  - $E\,\gamma_{typ}$:300 keV
- Shock accel. (int. or ext.)
  - e: sync. + IC
  - p: pγ, pp → ν

High energy neutrinos from GRB ‘s ?

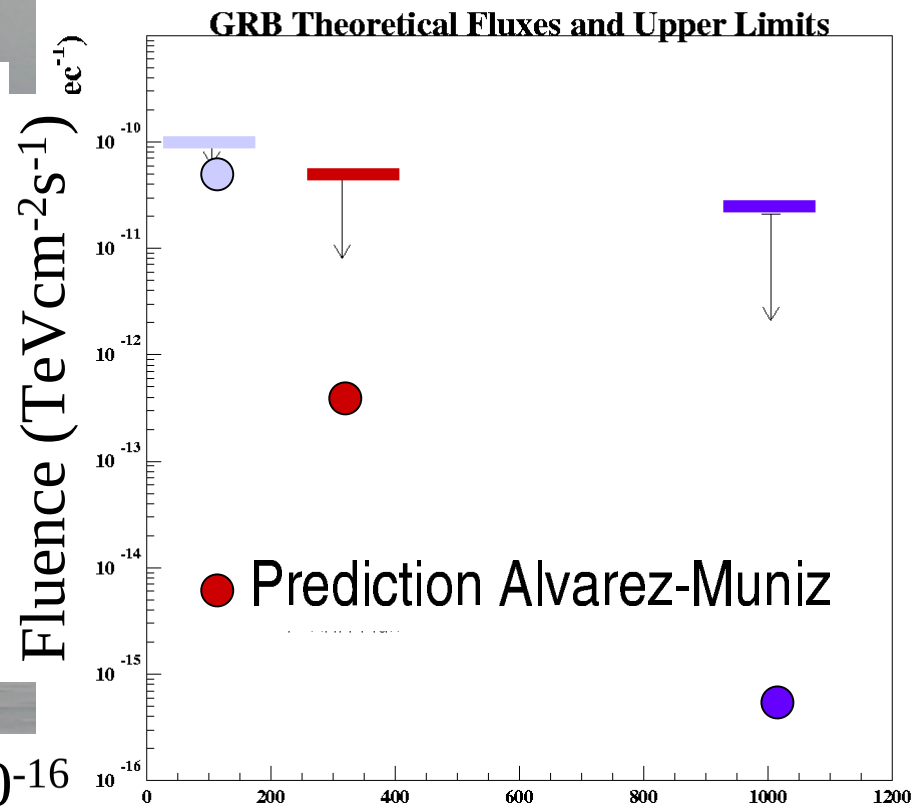


No evidence for GRB neutrino emission …

Chance probability for different Cuts (78 bursts):



Fake searches



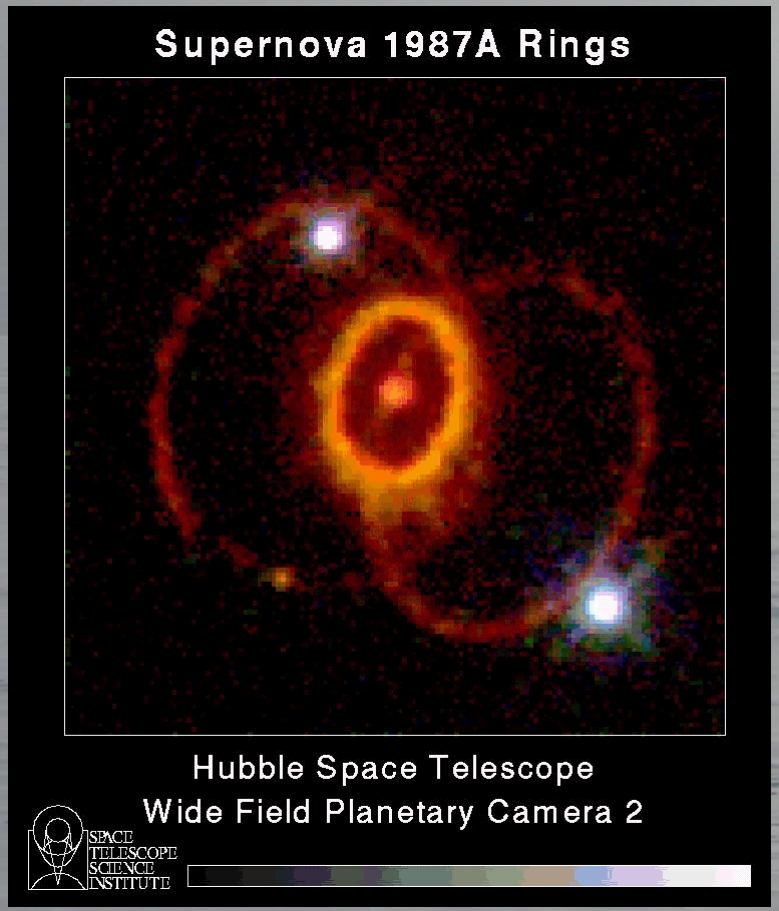
10^{-10}

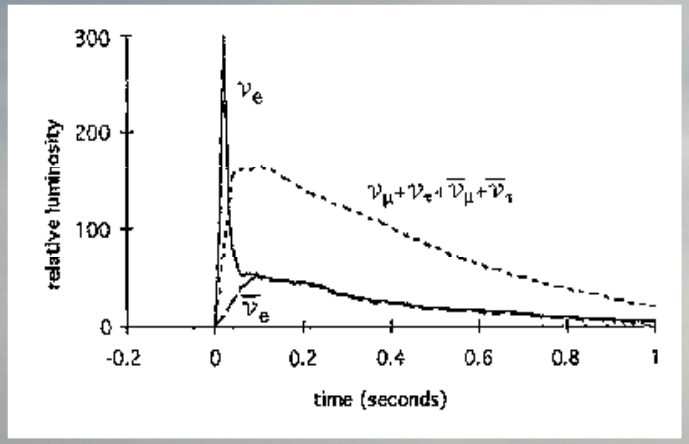
10^{-16}

0

1000

Supernovae





- Photo-desintegration:

$$^{56}Fe \rightarrow 13^{4}He + 4n$$

- Electron capture:

$$e^- + p \rightarrow n + \nu_e$$

$$e^- + {}^{Z}A \rightarrow {}^{Z-1}A + \nu_e$$

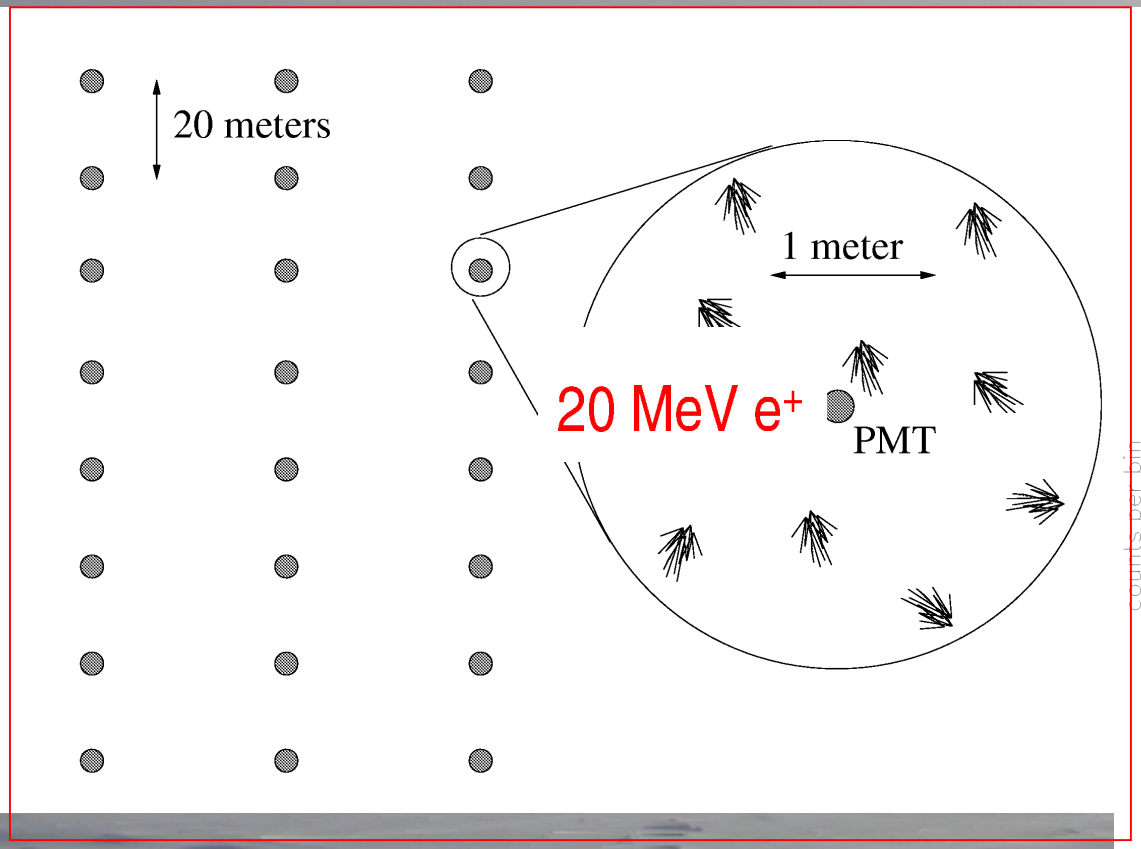
- Thermal cooling:

$$\gamma \rightarrow e^+e^- \rightarrow \nu_e\bar{\nu}_e, \nu_\mu\bar{\nu}_\mu, \nu_\tau\bar{\nu}_\tau$$

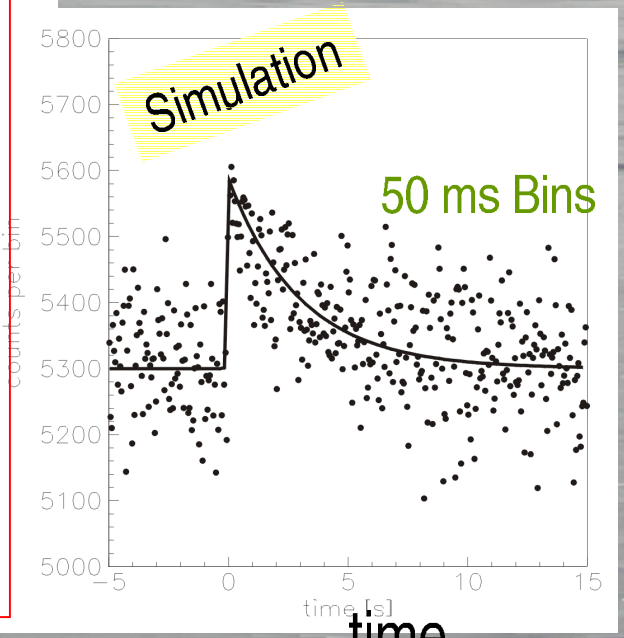
$$E_\nu < 50 MeV, \sum E_\nu \approx 3 \cdot 10^{53} erg$$

Burst detection

Low noise (300-1000 Hz) makes AMANDA a low energy neutrino detector



detect simultaneous rate increase in all PMTs:



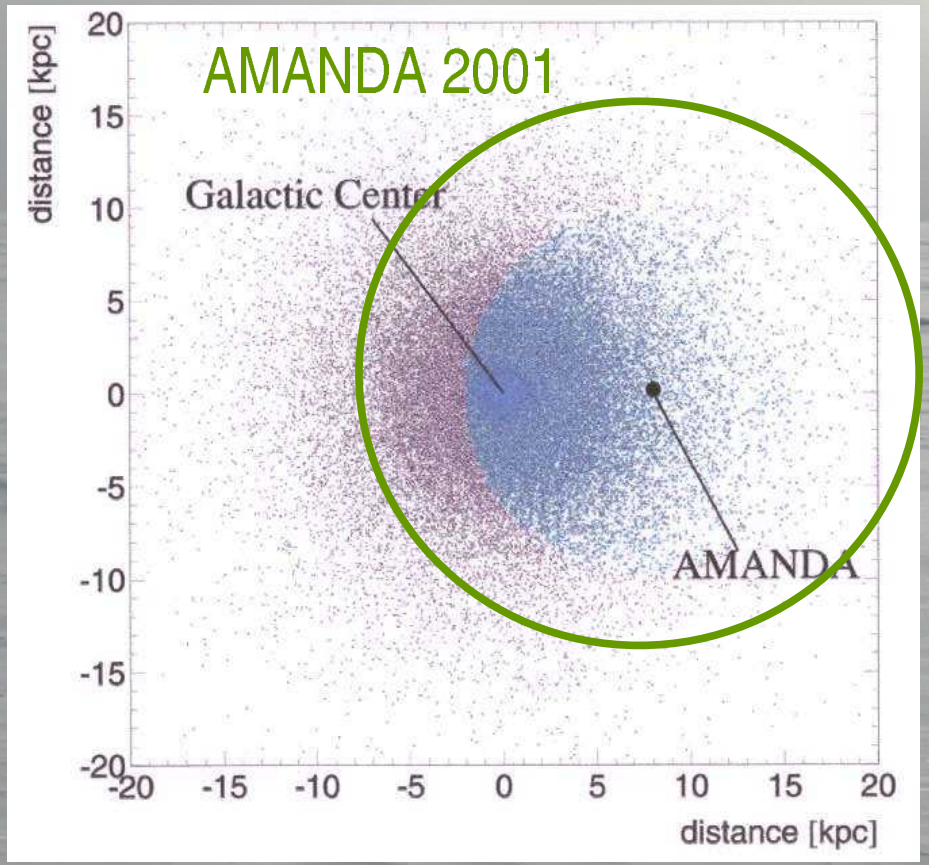
time

Supernova detection

Sensitivity:

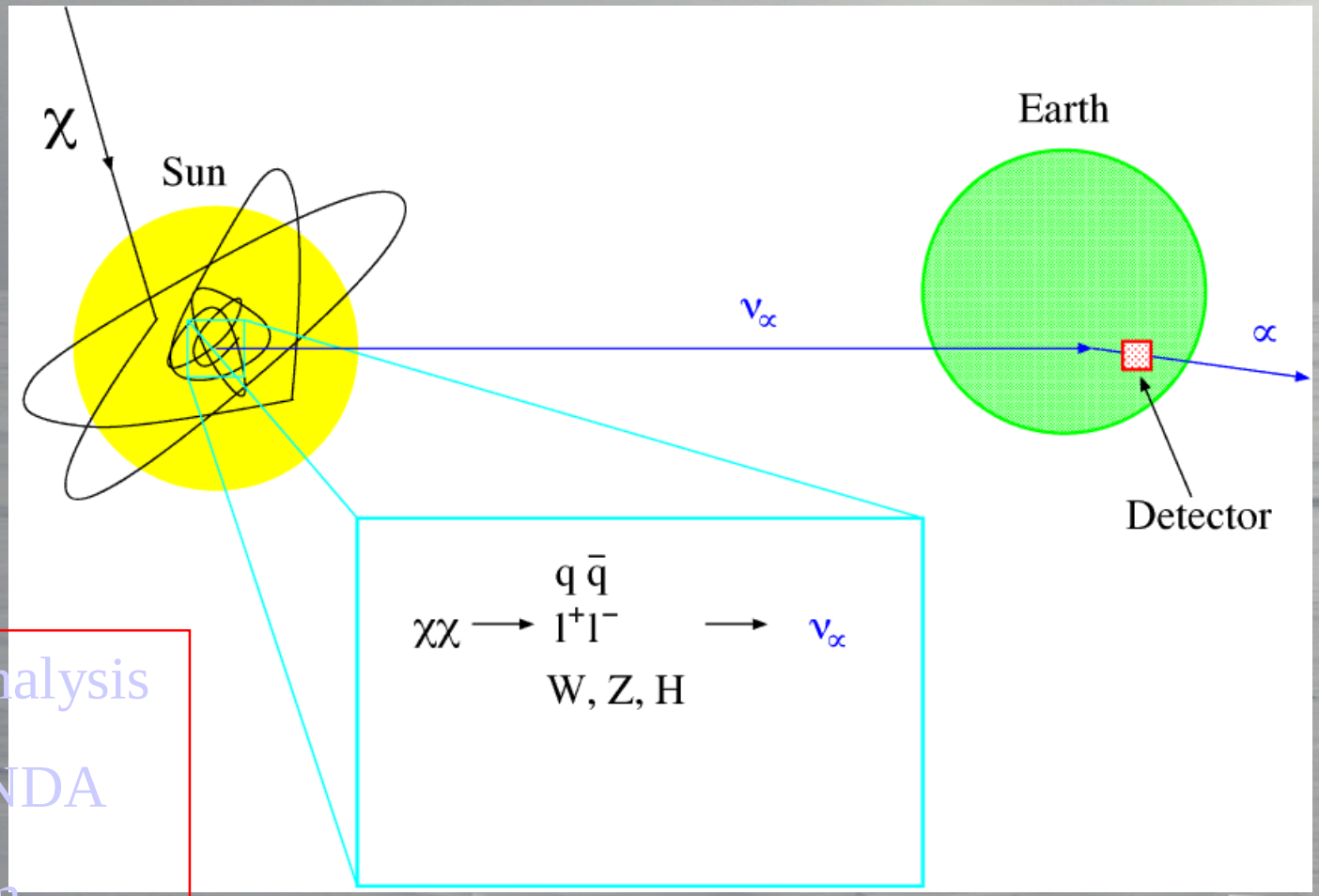
Amanda B10: 70% of galaxy
with 90% efficiency
@ 1fake/year

AMANDA II (2001):
new readout, more PMT's
optimized artificial deadtime to
suppress non-Poissonian noise...
90% (97%) of galaxy
with 90% efficiency
@ 1fake/year



n.b.: galactic supernovae every 15-100 years

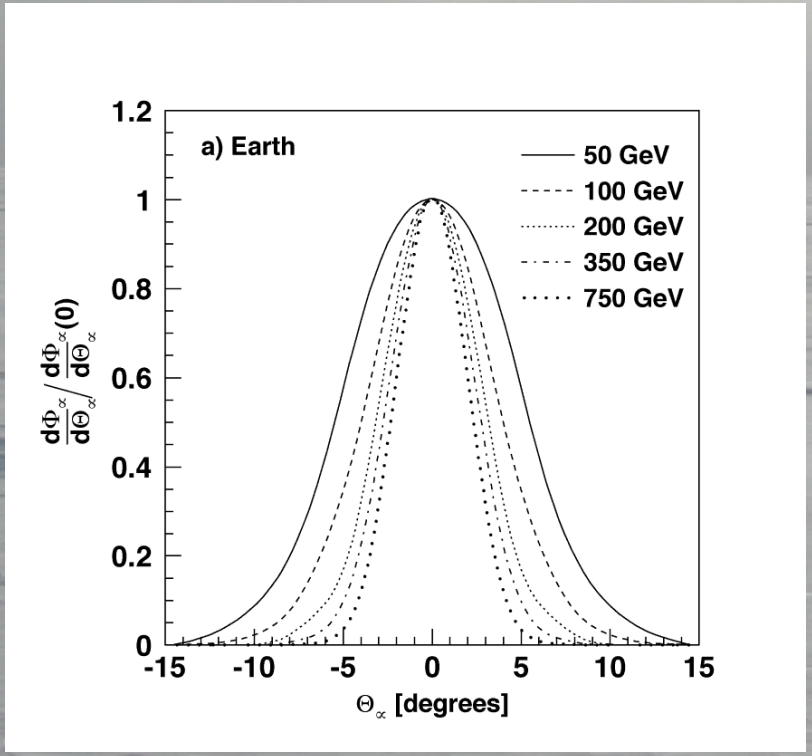
WIMPs from Sun/Earth



WIMP Analysis by AMANDA Stockholm...

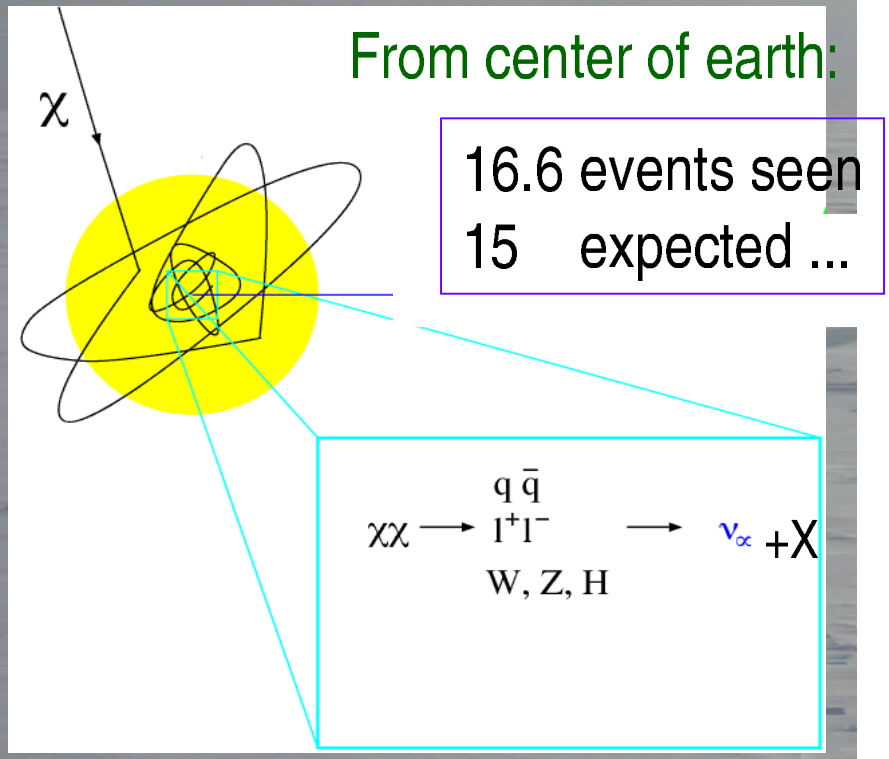
Angular Spread of WIMP signal

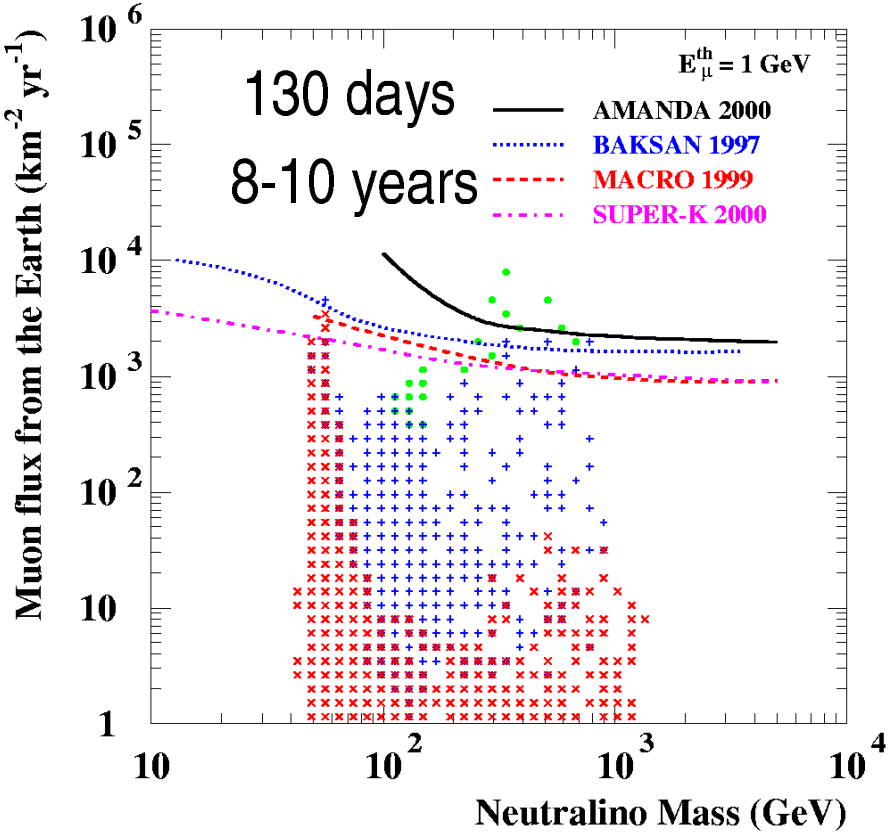
- Angular spread decreases as WIMP mass increases, reducing atm. ν background



Neutralino search in AMANDA

..heavy, slowly moving χ's trapped in gravitational field of earth …



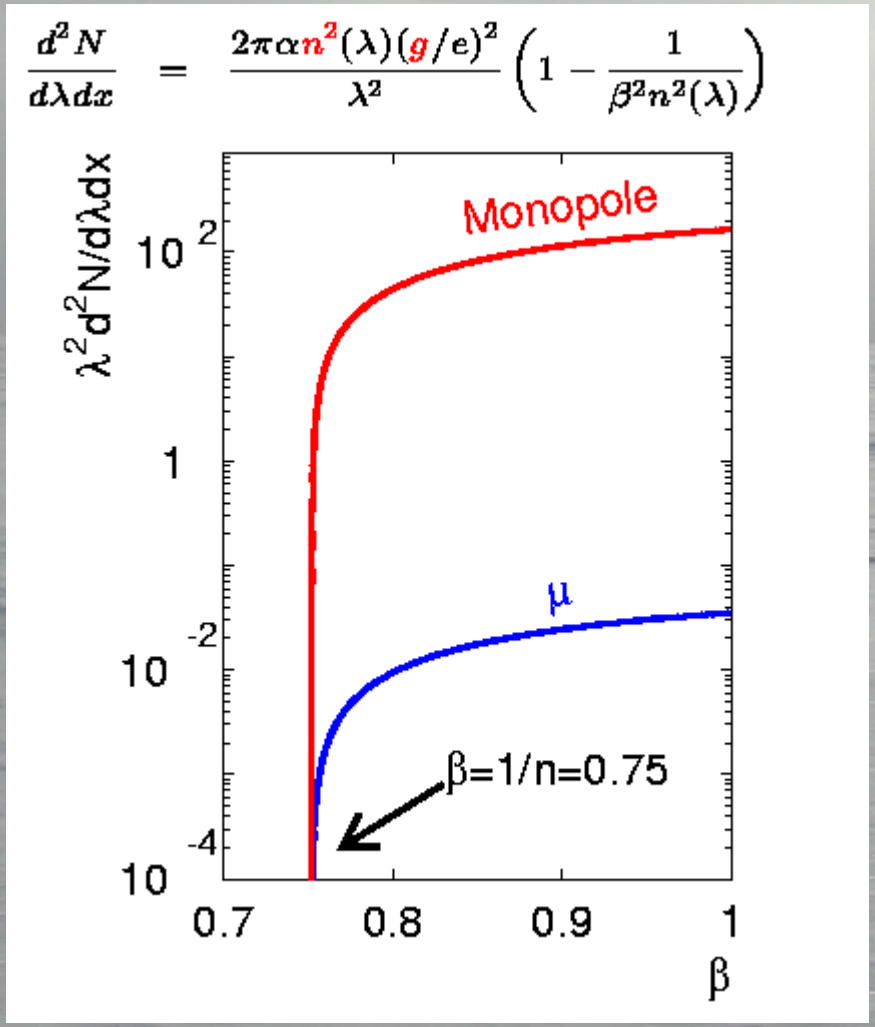


Assumption on dark matter: due to neutralinos, energy density 0.3 GeV/cm^3

Monopole and Muon Light Yield

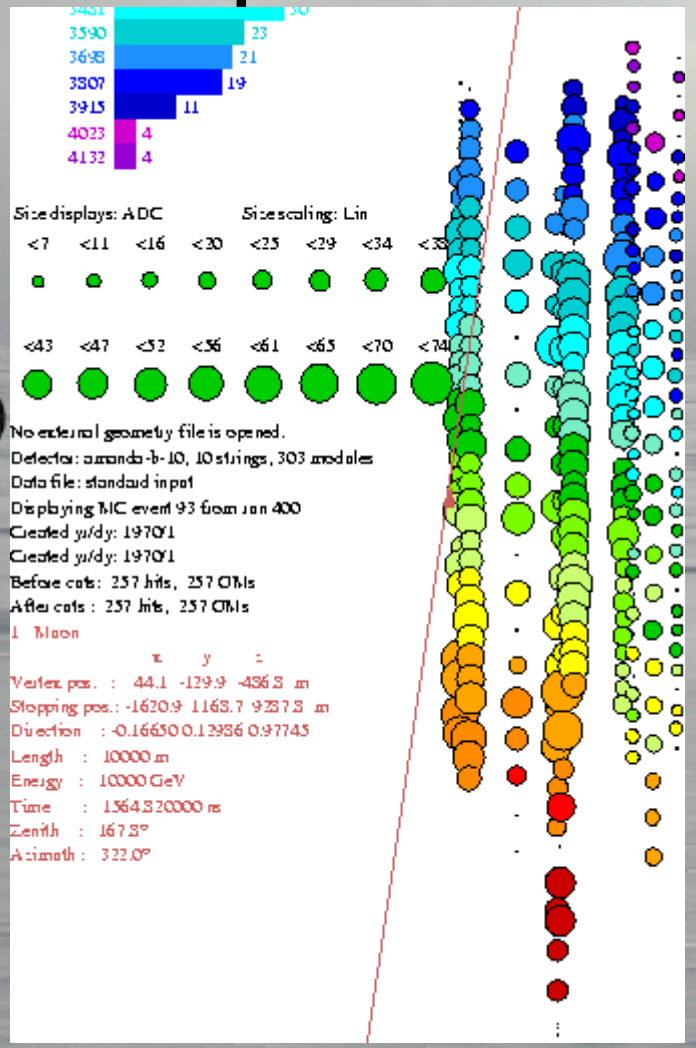
- Due to $n^2(g/e) \sim 8300$ the light production is enhanced compared to muons.

Monopole Analysis by AMANDA Zeuthen...



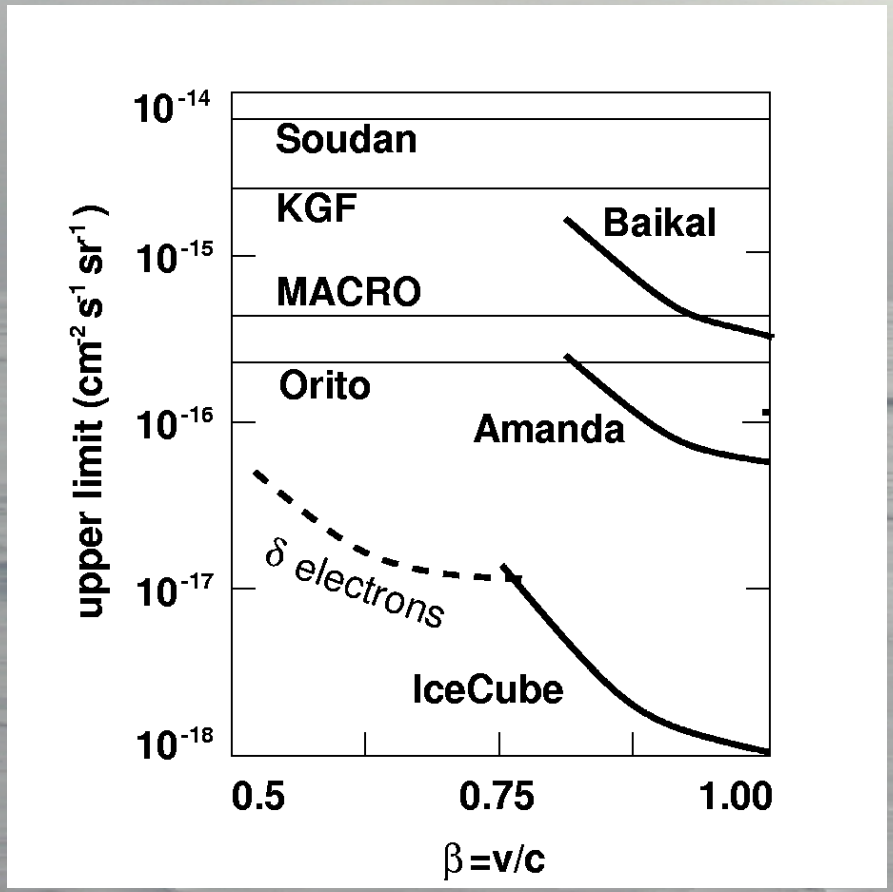
Monte Carlo: Monopole

- Early photons are red, late photons are blue. More photons are larger circles
- Bottom of array is toward center of earth
- Upgoing Monopole



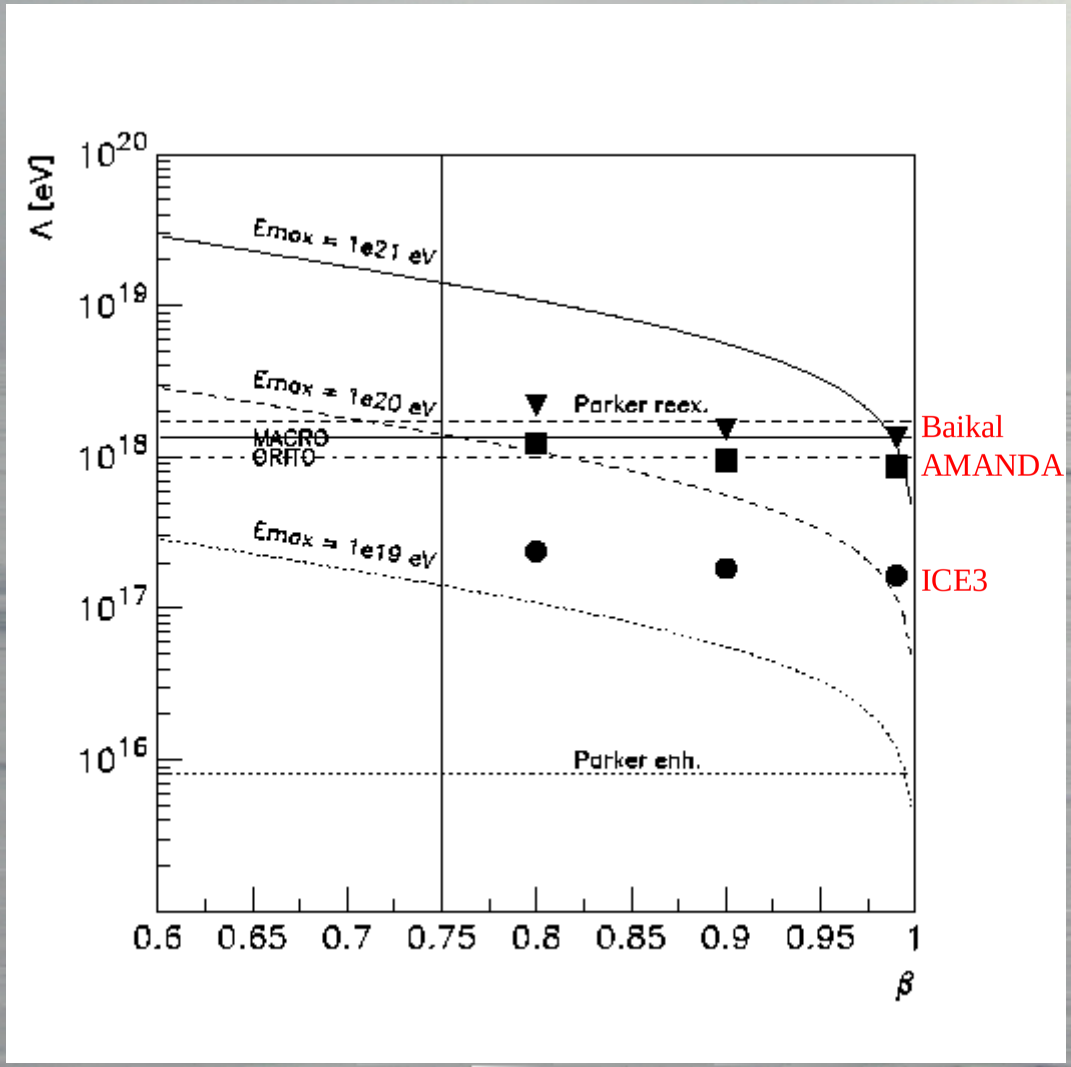
AMANDA Monopole Limits

- Sensitive to relativistic Monopoles
- at $\beta \sim 0.8$ comparable to other experiments
- slight improvement towards $\beta=1.0$



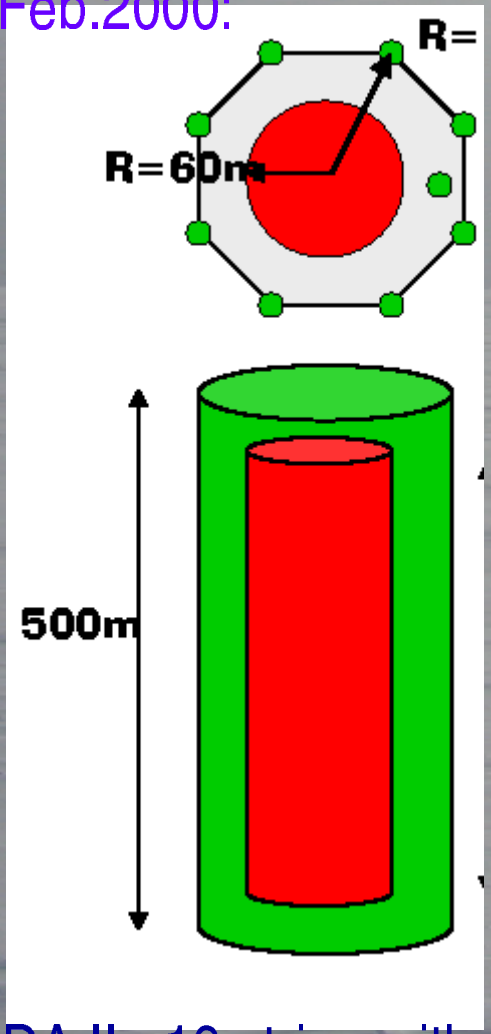
GUT-scale-sensitivity

- $\Phi \sim \Lambda^3$
- $m = \Lambda/\alpha$
- $\beta = \beta\,(E=gBL,m)$
- Maximal GUT scale $\sim 10^{20}$ eV
- sensitive to Weiler-Monopoles of $m < 10^{11}$ GeV



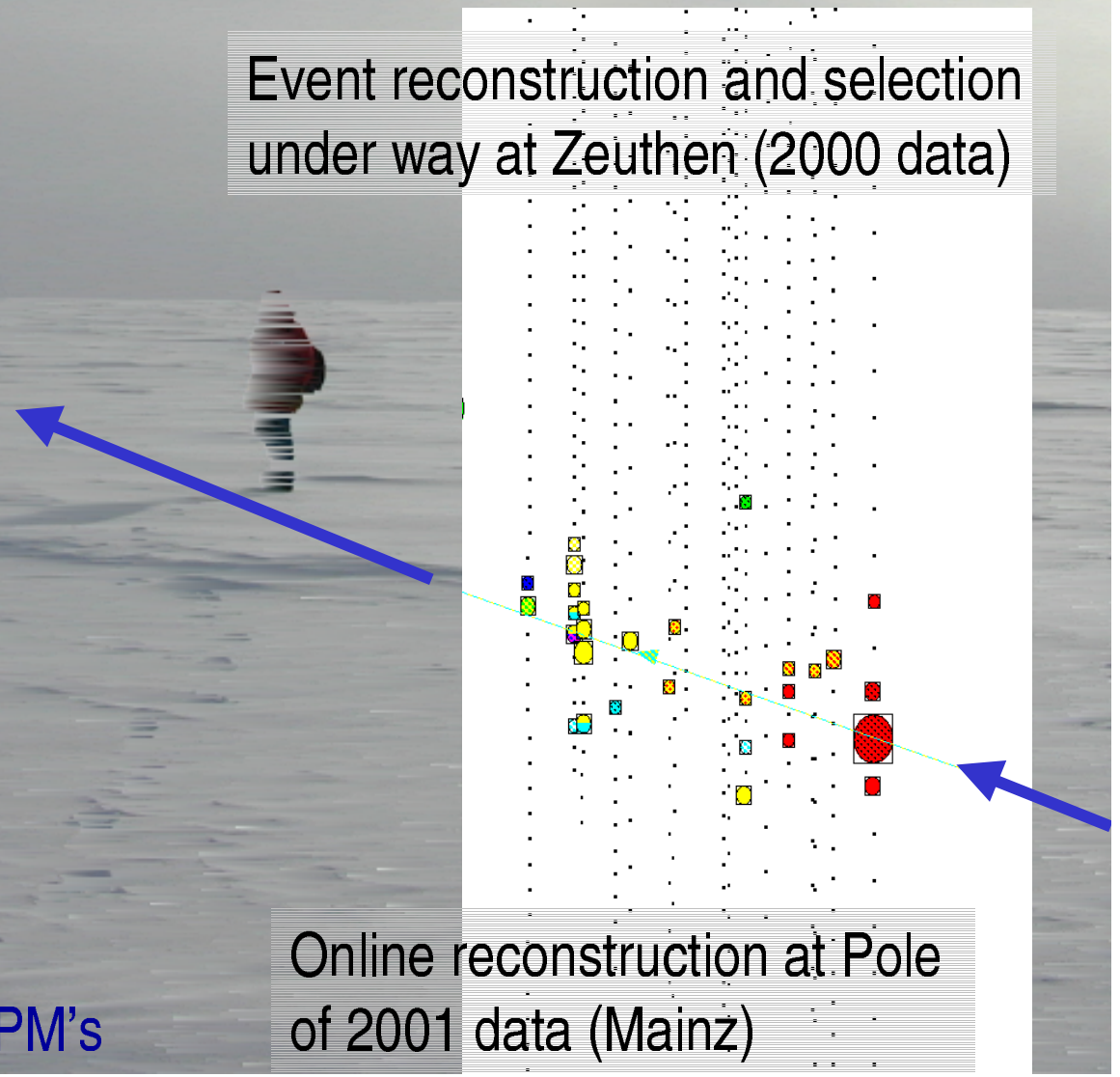
AMANDA II

Since Feb.2000:



AMANDA II: 19 string with 677 PM's

Event reconstruction and selection under way at Zeuthen (2000 data)



Online reconstruction at Pole of 2001 data (Mainz)

AMANDA II, first look at data

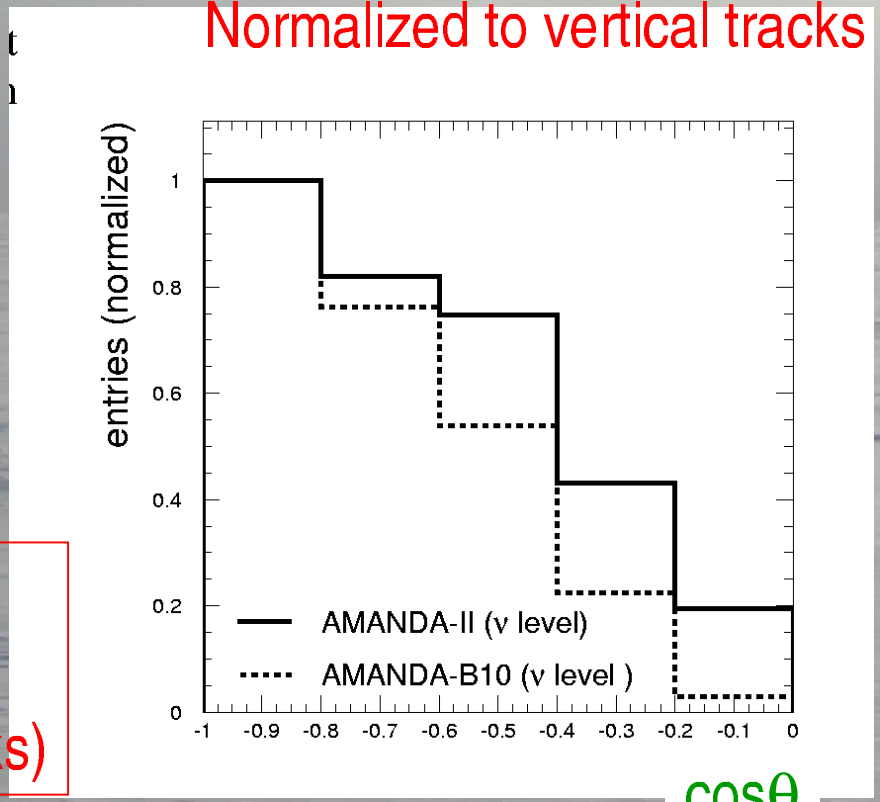
Atmospheric neutrino events triggered per year:

ν_μ: 11000 (CC), 130 (NC)
ν_e: 160 (CC), 9 (NC)

4 ν_μ per day
cut efficiency improved x 2-5 !
(in particular for horizontal tracks)

... improved in 2001....

Normalized to vertical tracks





2002 improvements:

- Big effort to re-organize DAQ software
  - improve dead time
  - read out of several parallel system
- Big effort to reduce electronics noise
  - increase efficiency by lower discriminator thresholds
- Installation of wave form digitizing system
  - about 40 channels, sufficient for physics
  - study extremely high energy events
  - learn how to integrate AMANDA and ICECUBE