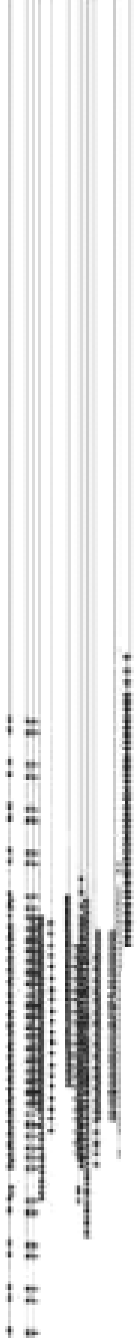


New results from AMANDA

Kurt Woschnagg

University of California – Berkeley

for the AMANDA collaboration

http://amanda.uci.edu

Neutrino 2004, Paris, June 14-19

The AMANDA Collaboration

United States

Bartol Research Institute
UC Berkeley
UC Irvine
Pennsylvania State
UW Madison
UW River Falls
LBNL Berkeley

South America

U. Simón Bolivar, Caracas

Europe

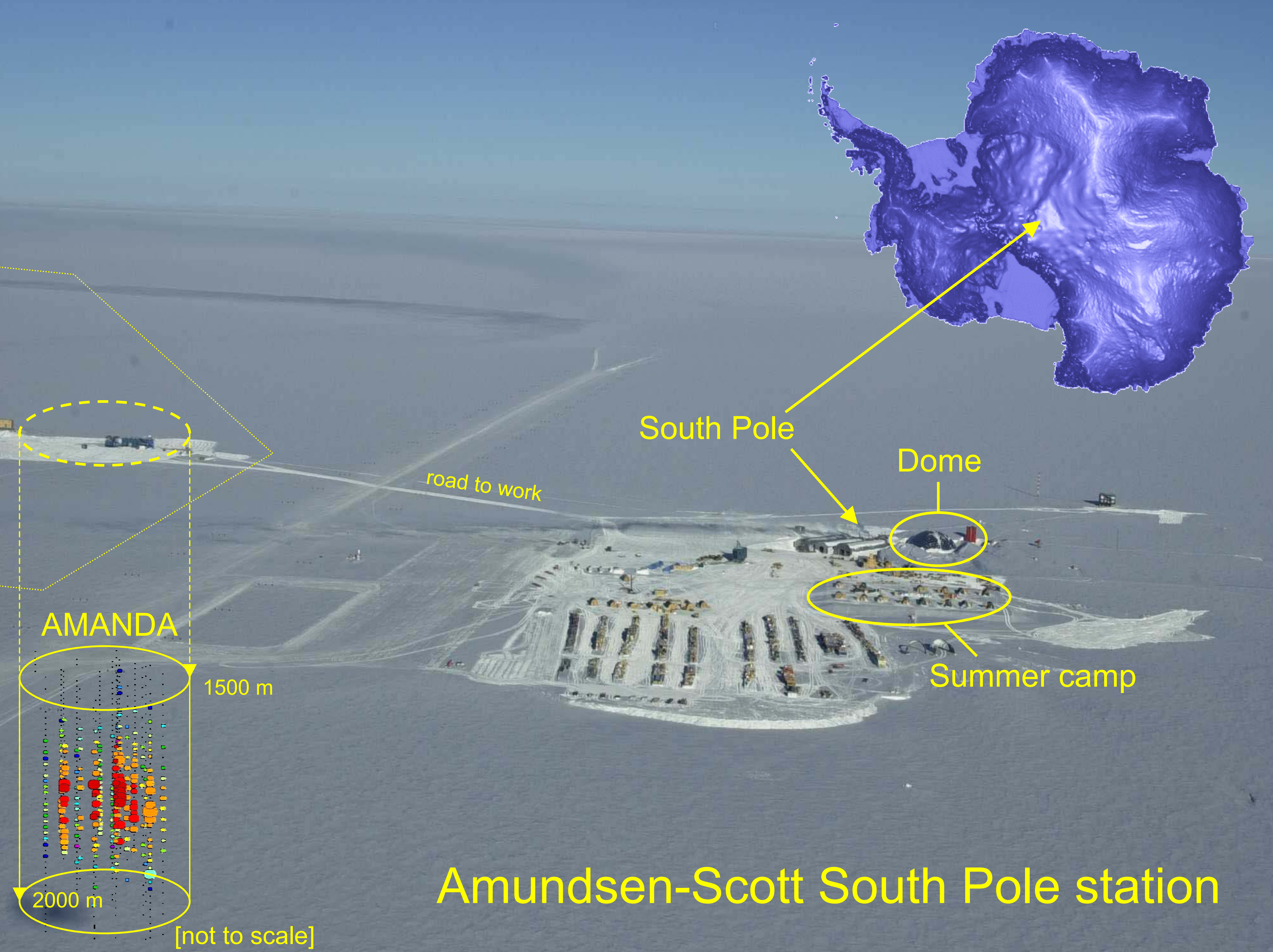
VUB-IIHE, Brussel
ULB-IIHE, Bruxelles
Université de Mons-Hainaut
Imperial College, London
DESY, Zeuthen

Mainz Universität
Wuppertal Universität
Stockholms Universitet
Uppsala Universitet
Kalmar Universitet

Antarctica

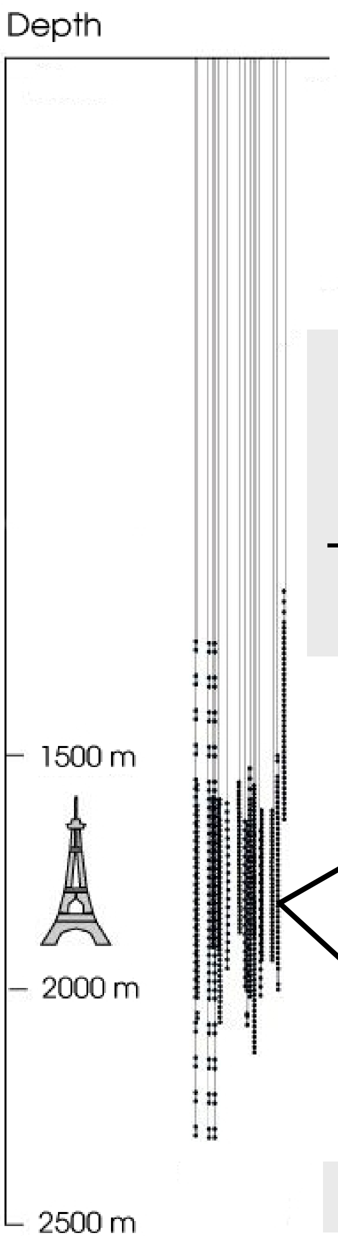
South Pole Station

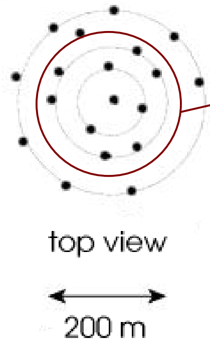
~150 members



South Pole
Dome
road to work
Summer camp
AMANDA
1500 m
2000 m
[not to scale]
Amundsen-Scott South Pole station

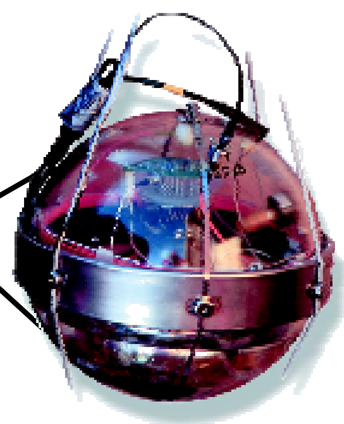
The Antarctic Muon and Neutrino Detector Array



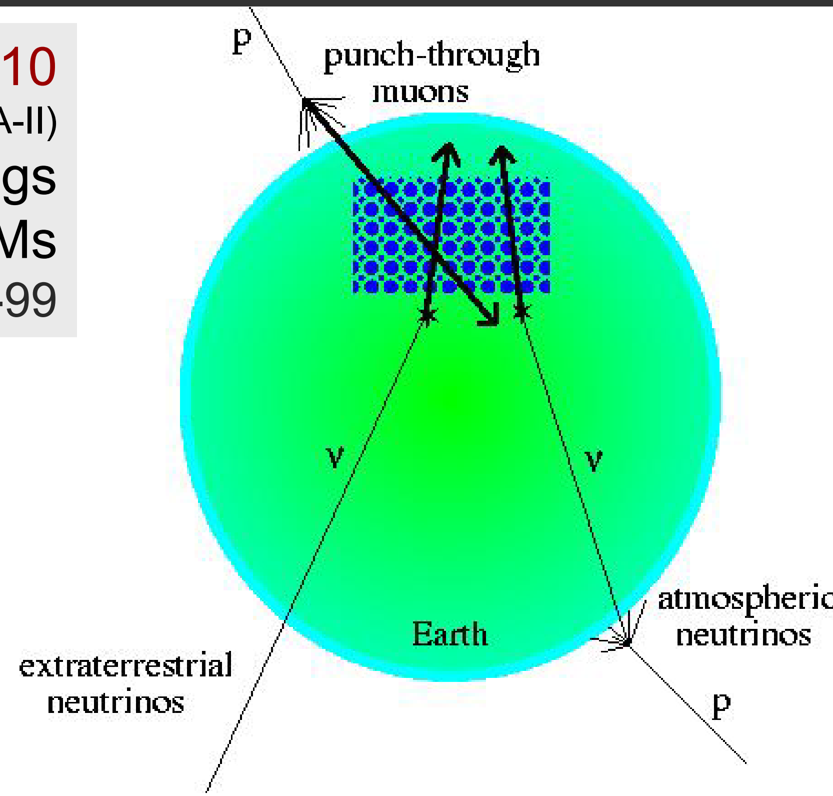


AMANDA-B10
(inner core of AMANDA-II)
10 strings
302 OMs
Data years: 1997-99

AMANDA-II
19 strings
677 OMs
Trigger rate: 80 Hz
Data years: 2000-

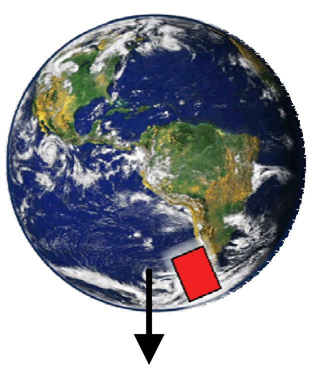


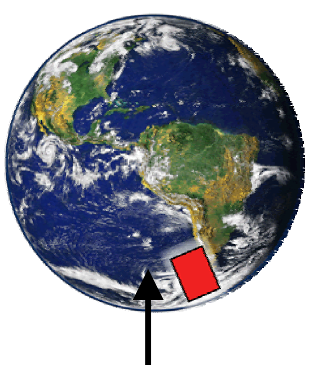
Optical Module
PMT noise: ~1 kHz



"Up-going"
(from Northern sky)

"Down-going"
(from Southern sky)

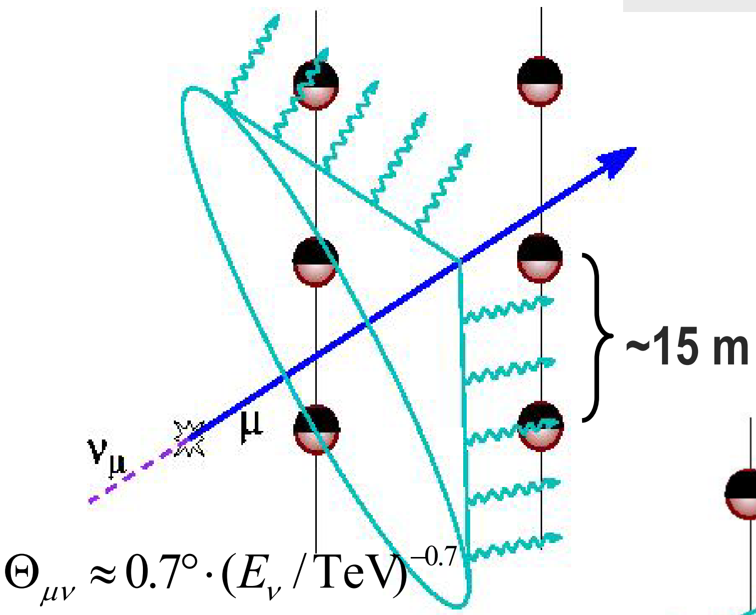




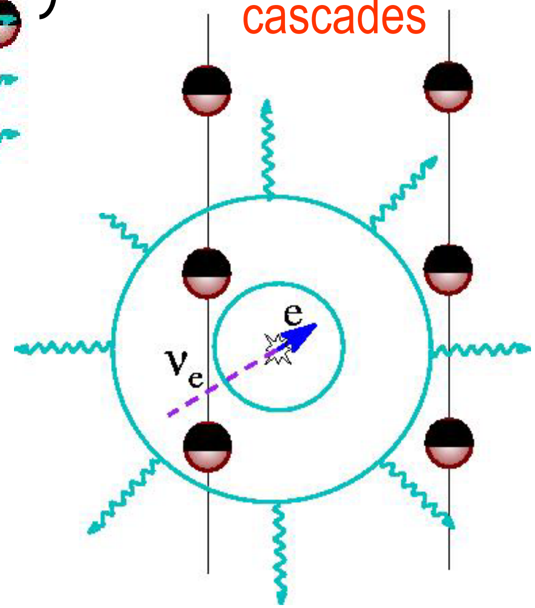
Neutrino detection in polar ice

O(km) long muon tracks

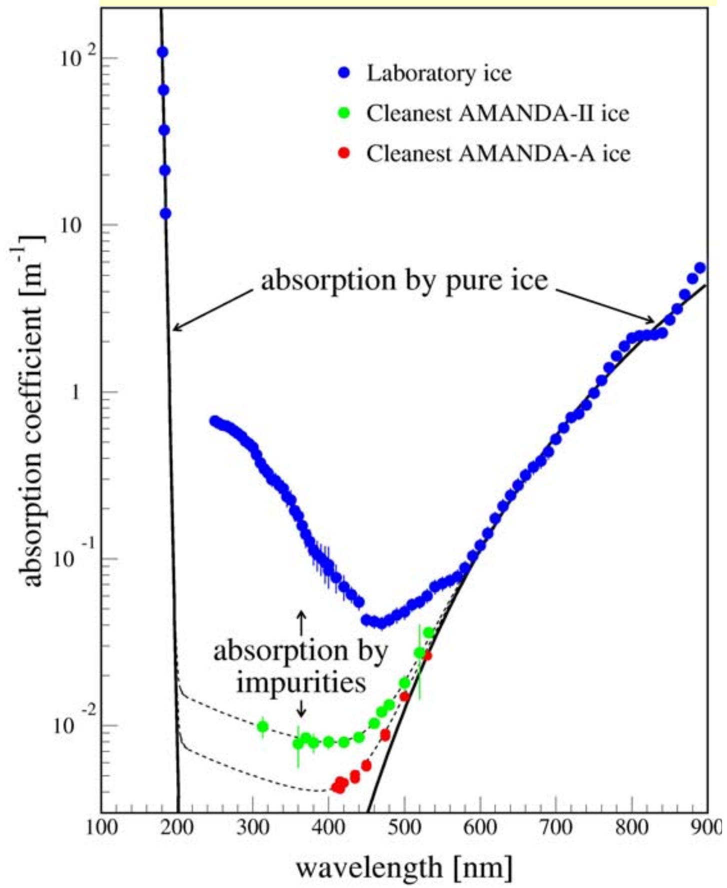
event reconstruction by Cherenkov light timing



cascades

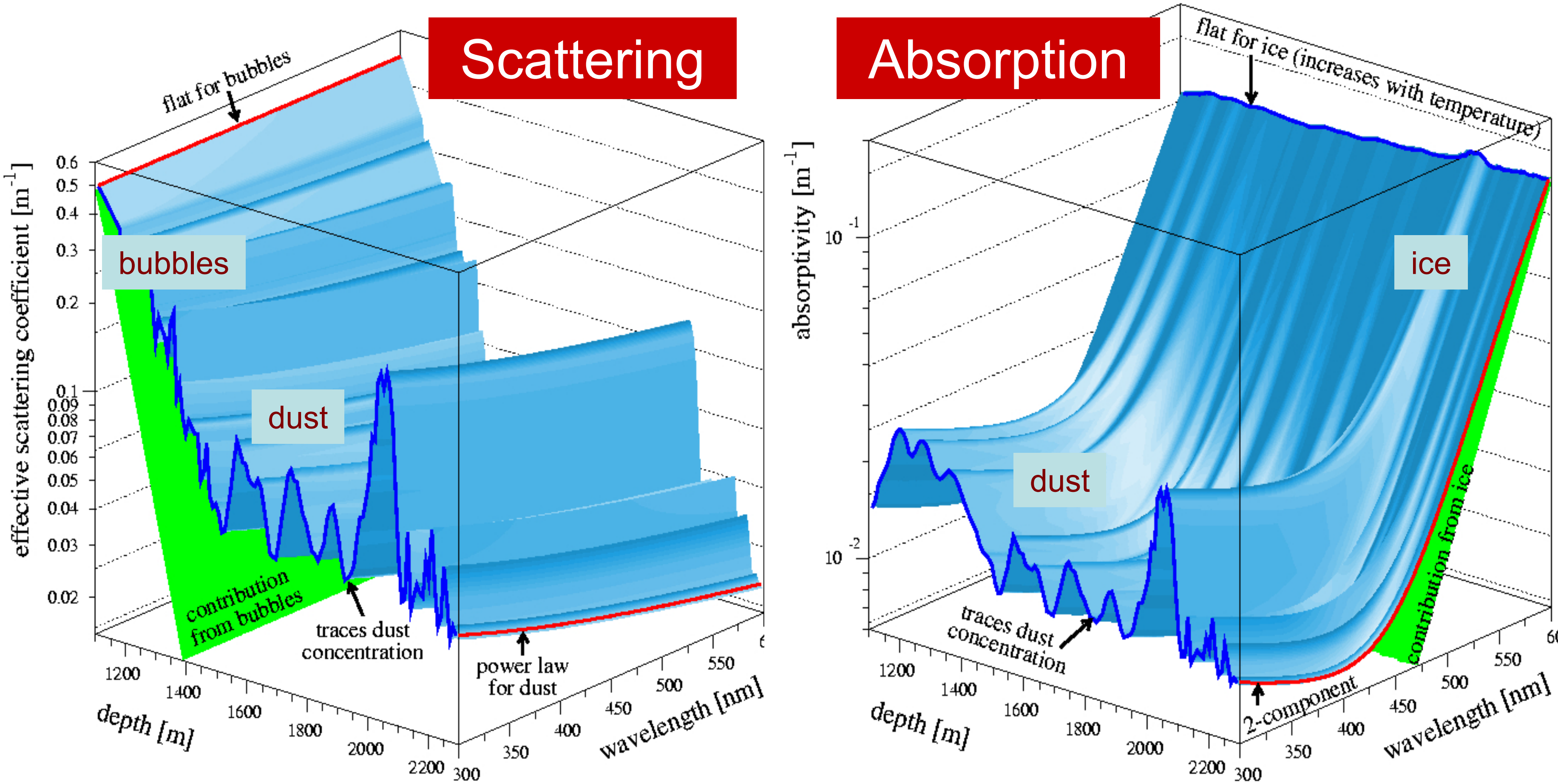


South Pole ice:
(most?) transparent
natural condensed material



Longer absorption length → larger effective volume

Detector medium: ice to meet you



Measurements:

- in-situ light sources
- atmospheric muons

Average optical ice parameters:

λ_{abs} ~ 110 m @ 400 nm
λ_{sca} ~ 20 m @ 400 nm

AMANDA Physics Topics

Astrophysics / Cosmology / Particle Physics

Primary CR spectrum

- → atmospheric muons / neutrinos (also calibration of AMANDA)
- → CR composition (with surface detector SPASE-2)

CR origin (acceleration sites: AGN, GRBs)

- → extra-terrestrial flux (diffuse / focused / punctual / transient) @ >TeV energies

Dark matter / exotic particles: neutralinos, magnetic monopoles, extra dim.

- → WIMP signature: excess from center of Sun/Earth
- → topological defects: extra-terrestrial UHE diffuse flux

SN monitor of the Milky Way

- → burst of low-energy neutrinos (global noise rate increase)

Reconstruction handles

	Up/Down	Energy	Source direction	Arrival time	Count rates
Atmospheric ν	×				
Diffuse ν, Cascades, UHE events	×	×			
Point sources: AGN, WIMPs	×	×	×		
GRB	×	×	×	×	
Supernovae					×

Collaboration Analysis Policy

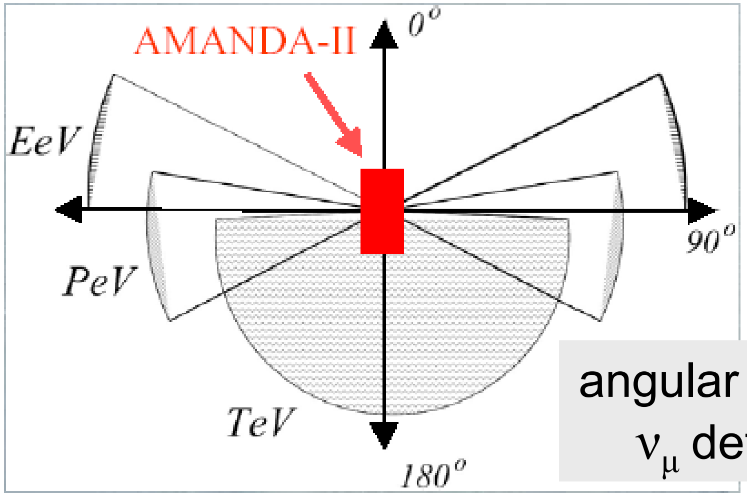
'blindness'

= cuts are optimized on fraction of data or on a time-scrambled data set

(except for SN searches which are based on detector noise rate monitoring)

AMANDA energy coverage

Energy range	Analysis	Production site(s)
~MeV	SN	Supernovae
GeV - TeV	Atmospheric ν Dark matter	Atmosphere Earth, Sun
TeV - PeV	Diffuse Cascades Point sources	AGN, GRB, …
PeV - EeV	UHE	AGN, TD, …
> EeV	EHE	?



angular range for ν_μ detection

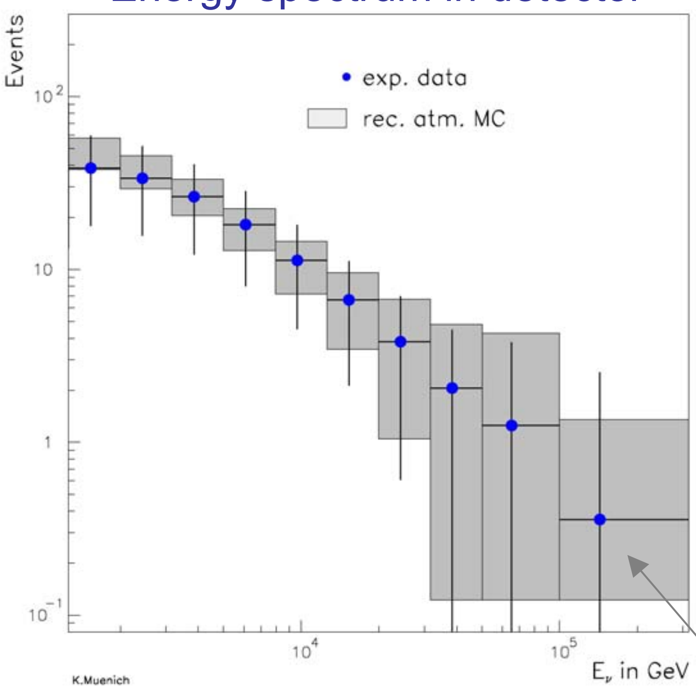
Atmospheric neutrinos

AMANDA test beam(s): atmospheric ν (and μ)

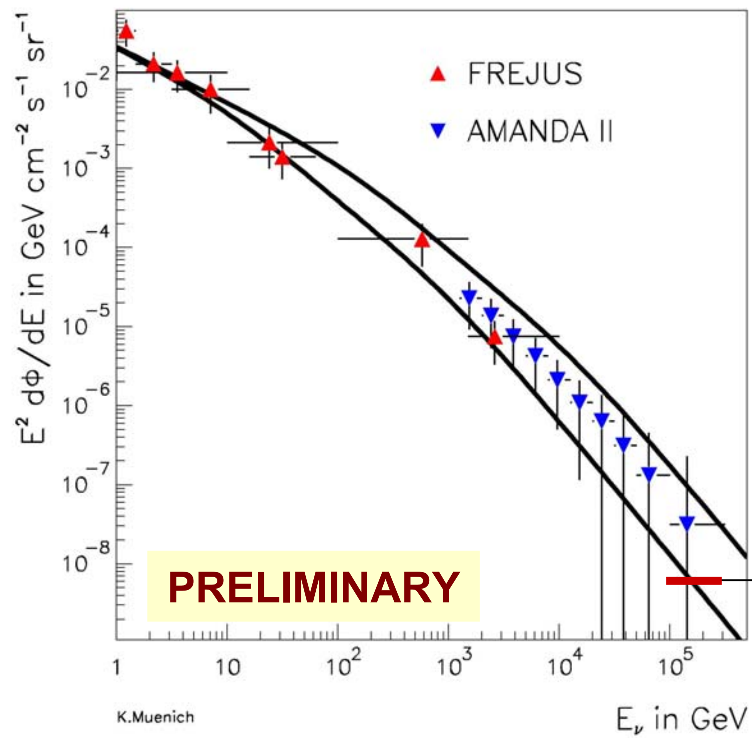
- ►Neural Network energy reconstruction
- ►Regularized unfolding
  → energy spectrum

First spectrum > 1 TeV (up to 300 TeV)
- matches lower-energy Frejus data

Energy spectrum in detector



determine statistics in last bin with MC
→ confidence belts (FC)



How much E^{-2} cosmic ν signal allowed within uncertainty?

Limit on diffuse E^{-2} ν_μ flux (100-300 TeV):

$$E^2\Phi_{\nu_\mu}(E) < 2.6\cdot10^{-7}\ \mathrm{GeV\ cm^{-2}\ s^{-1}\ sr^{-1}}$$

Includes 33% systematic uncertainty

Search for a diffuse ET neutrino flux (cascades)

4π coverage for cascades

2000 data sample (AMANDA-II)
197 days livetime
$1.2 \cdot 10^9$ events @ trigger level

Simulated background
- atmospheric μ (920 d)
- atmospheric ν

Event selection based on
- topology
- energy

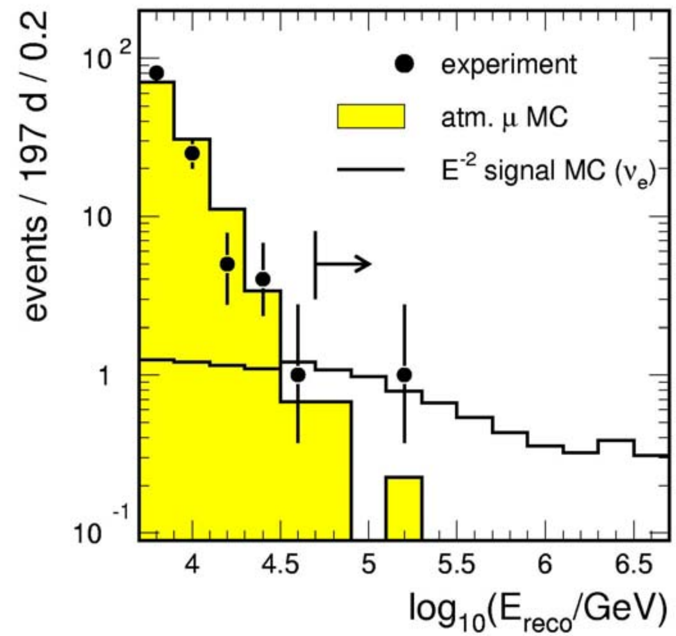
Model rejection factor optimized for E^{-2} signal

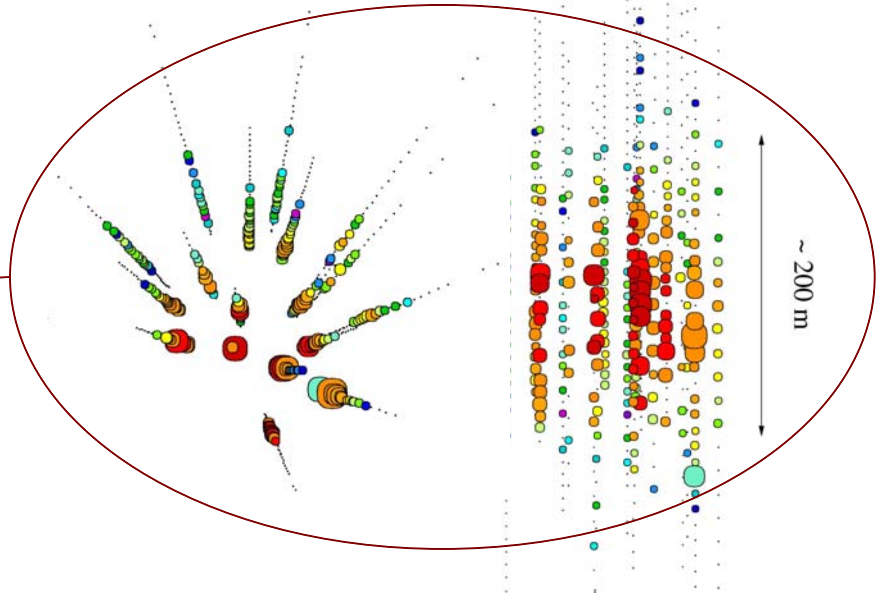
After optimized cuts:

N_{obs} = 1 event

$N_{atm\ \mu} = 0.90^{+0.69}_{-0.43}$

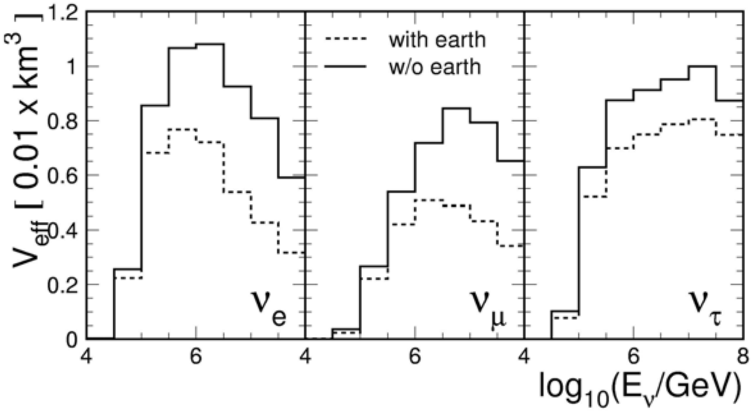
$N_{atm\ \nu} = 0.06^{+0.09}_{-0.04} \pm 25\%_{norm}$





Limit on a diffuse ET neutrino flux (cascades)

Sensitive to all three flavors



Assuming E^{-2} signal spectrum

$E^2\Phi_{\mathrm{all}\ \nu}(E) < 8.6\cdot10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}

(flavor mixing $\nu_e{:}\nu_\mu{:}\nu_\tau$ =1:1:1)

50 TeV < E_ν < 5 PeV

Glashow resonance:

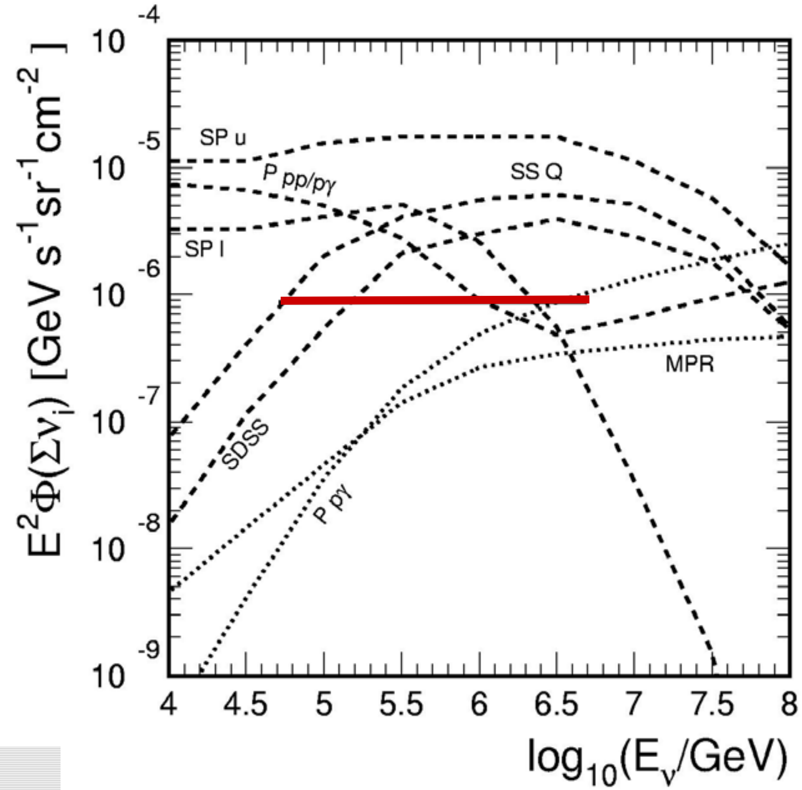
$E^2\Phi_{\bar{\nu}_e}(E = 6.3\ \mathrm{PeV}) < 2\cdot10^{-6}$ GeV cm^{-2} s^{-1} sr^{-1}

paper submitted to Astropart. Phys.

2000 AMANDA-II limits ×10 better than same searches with AMANDA-B10

1997: **Phys. Rev. D67 (2003)**

1999: **included in submitted AMANDA-II paper**



Some AGN core production models excluded at 90% C.L. (dashed in figure)

Ultra High Energy neutrinos **PeV - EeV**

$E_\nu > 10^{16}$ eV

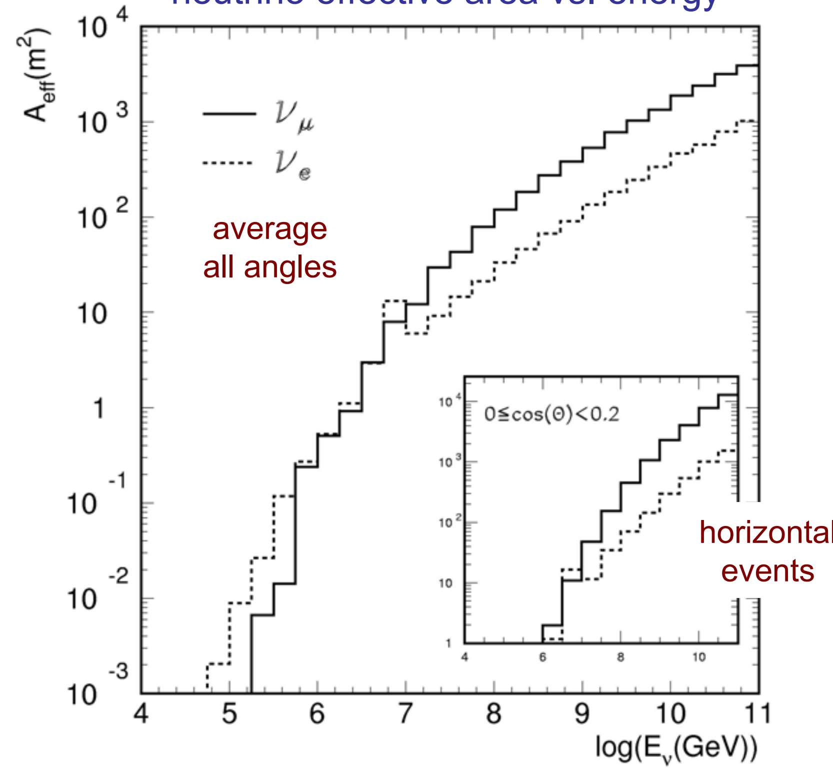
Earth opaque
→ look up and close to horizon

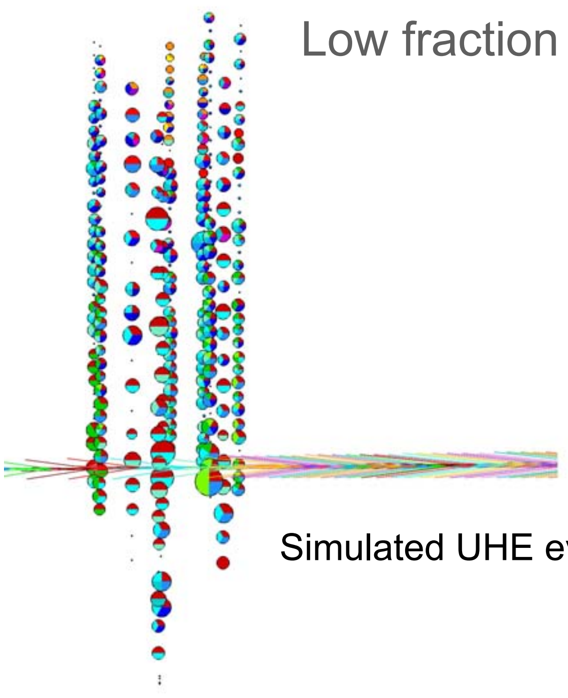
Bright events (high $N_{channel}$)
→ low atmospheric μ background

Long μ tracks (>10 km)

Low fraction of 1-p.e. hits

neutrino effective area vs. energy





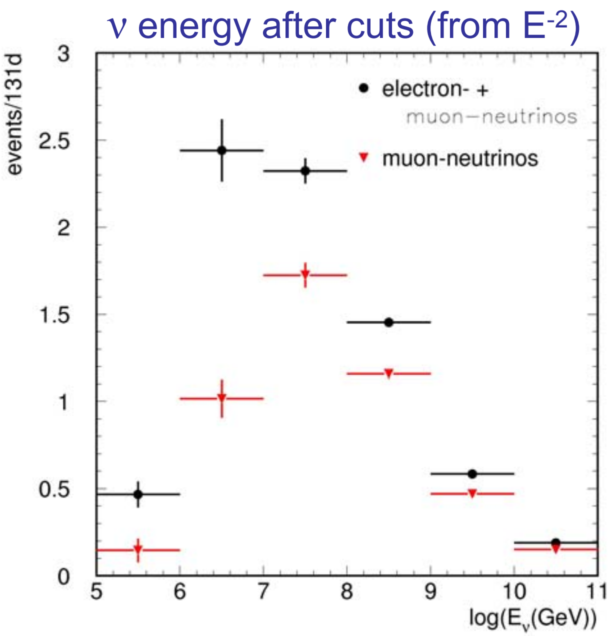
Simulated UHE event

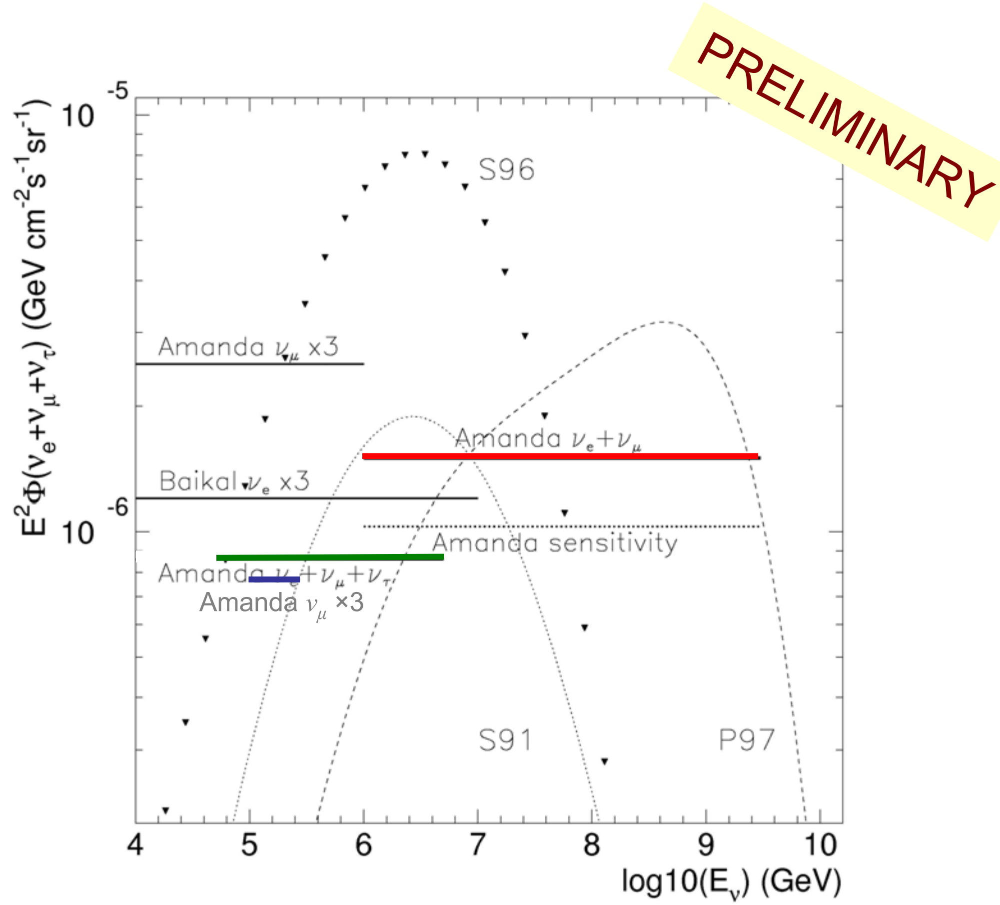
Train Neural Network with
UHE-sensitive parameters
to separate
E^{-2} signal from atmospheric ν (CORSIKA)

Limit for UHE neutrinos

PeV - EeV

1997 data (AMANDA-B10)
131 days livetime





N_{obs} = 5 events

N_{bgr} = 4.6 ± 36% events

assuming an E^{-2} flux (1 PeV < E_ν < 3 EeV) :

NO EXCESS OBSERVED

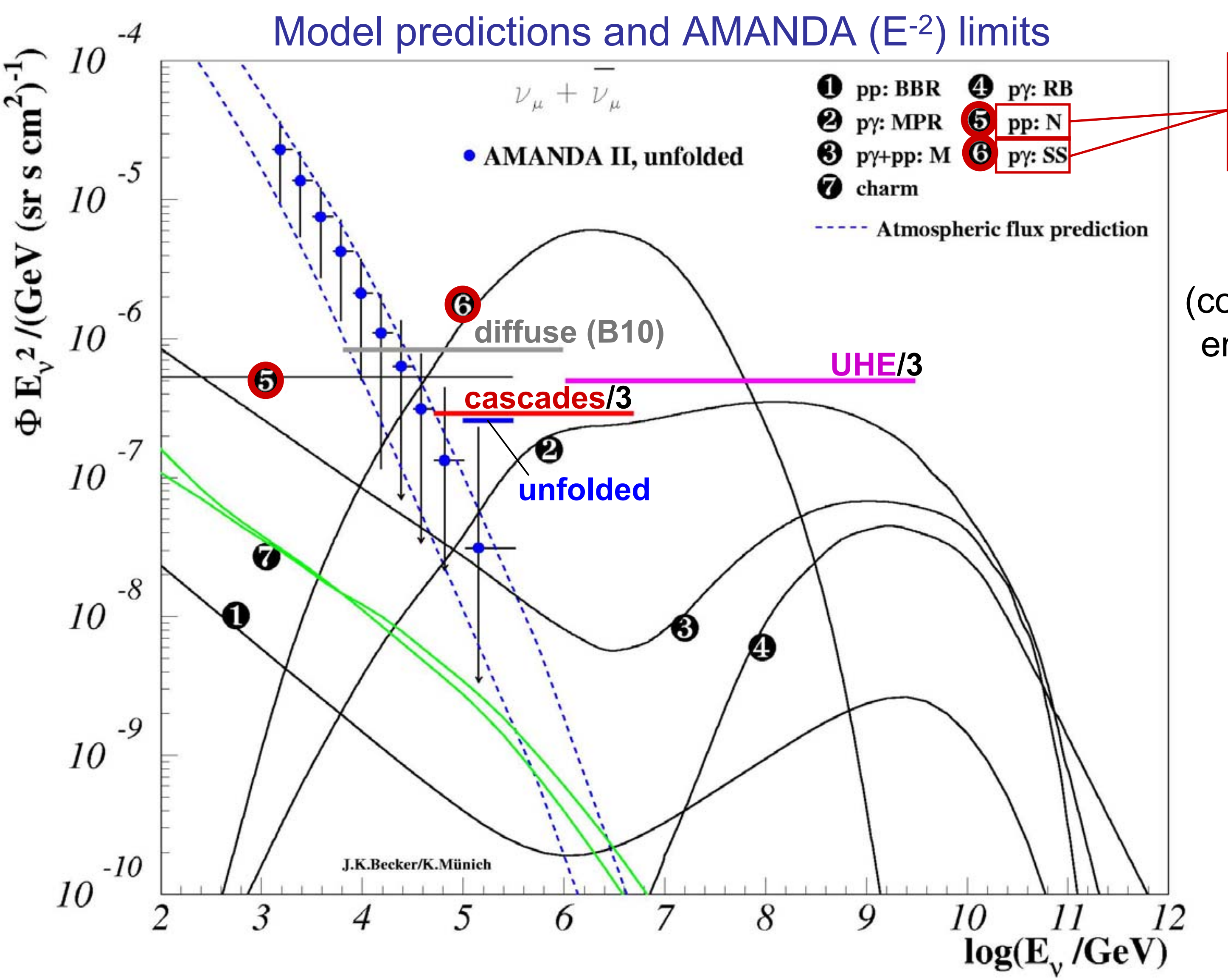
$$E^2\,\Phi_{\mathrm{all}\,\nu}(E) < 1.5\cdot10^{-6}\ \mathrm{GeV\,cm^{-2}\,s^{-1}\,sr^{-1}}$$

$(\nu_e:\nu_\mu:\nu_\tau = 1:1:1)$

Paper in preparation

AMANDA-II (2000): similar A_{eff}, gain in exposure time

Diffuse muon neutrino fluxes



Integral limits (cover 90% of final energy spectrum):

diffuse (B10)

cascades

UHE

Quasi-differential limit:

unfolded

Search for HE neutrino point sources

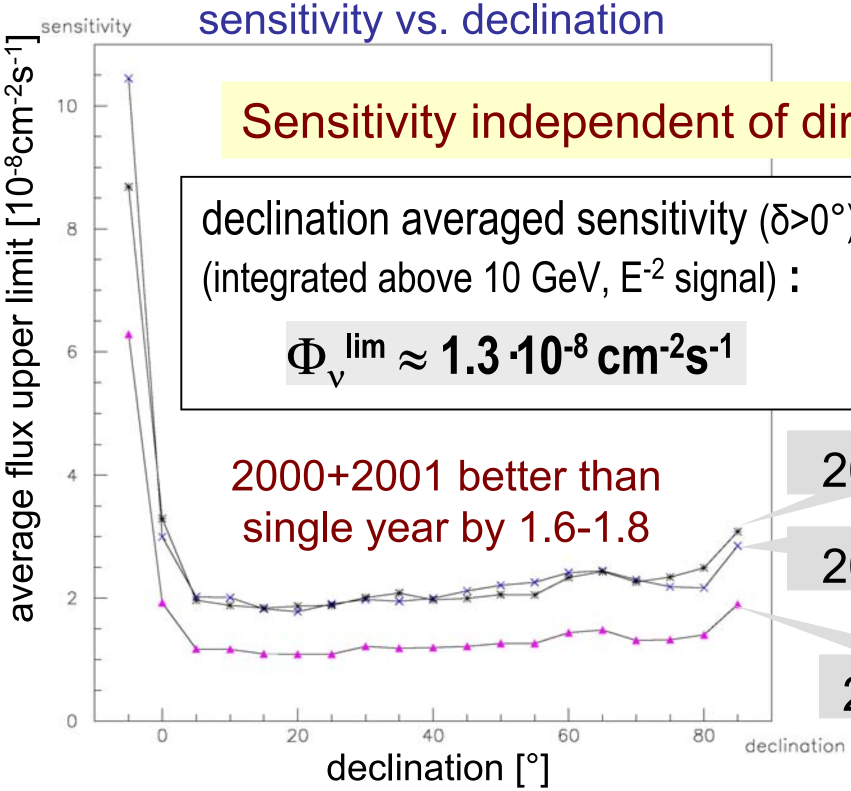
Need good pointing resolution → ν_μ

Combined 2000+2001 analysis

Step 1: Select up-going events:
Maximize ↑ν & minimize ↓μ

Optimize cuts in each declination band
- assume E^{-2} signal spectrum
- estimate BG from data in declination band

sensitivity vs. declination



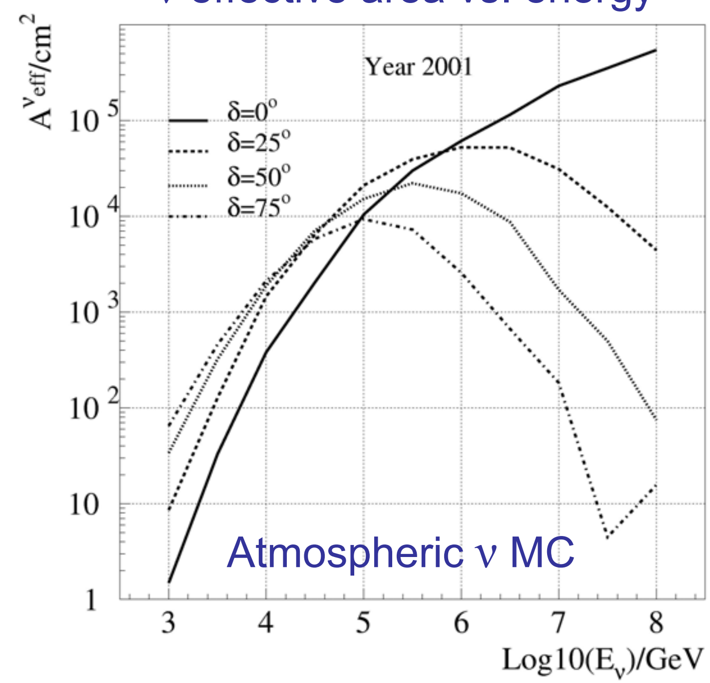
Sensitivity independent of direction

declination averaged sensitivity (δ>0°)
(integrated above 10 GeV, E^{-2} signal) :

$$\Phi_\nu^{lim} \approx 1.3 \cdot 10^{-8}\ cm^{-2}s^{-1}$$

2000+2001 better than single year by 1.6-1.8

ν effective area vs. energy

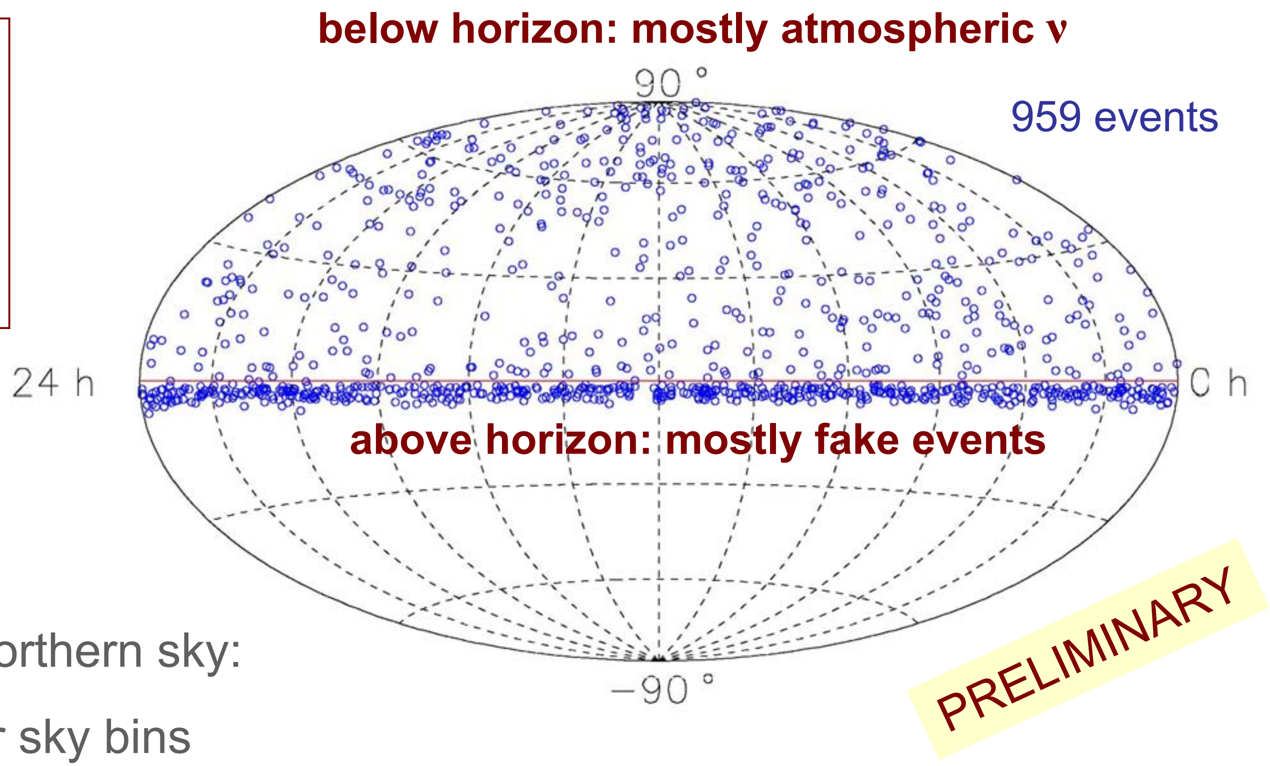


Angular resolution
(median space angle)

1.5° (near vertical) -
2.7° (near horizontal)

Search for HE neutrino point sources

Livetime
2000: 197 days
2001: 194 days
2000+2001: 959 events
465 below horizon



Step 2:

Search for clustering in Northern sky:

Grid search in rectangular sky bins
- bin size depends on declination
- shift grid 4 times to cover boundaries

No evidence for point sources
with an E^{-2} energy spectrum
based on first 2 years of AMANDA-II data

Consistent with atmospheric ν

Search for HE neutrino point sources

Very **PRELIMINARY**

Unbinned statistical analysis:
use track resolution (→pdf) for each event

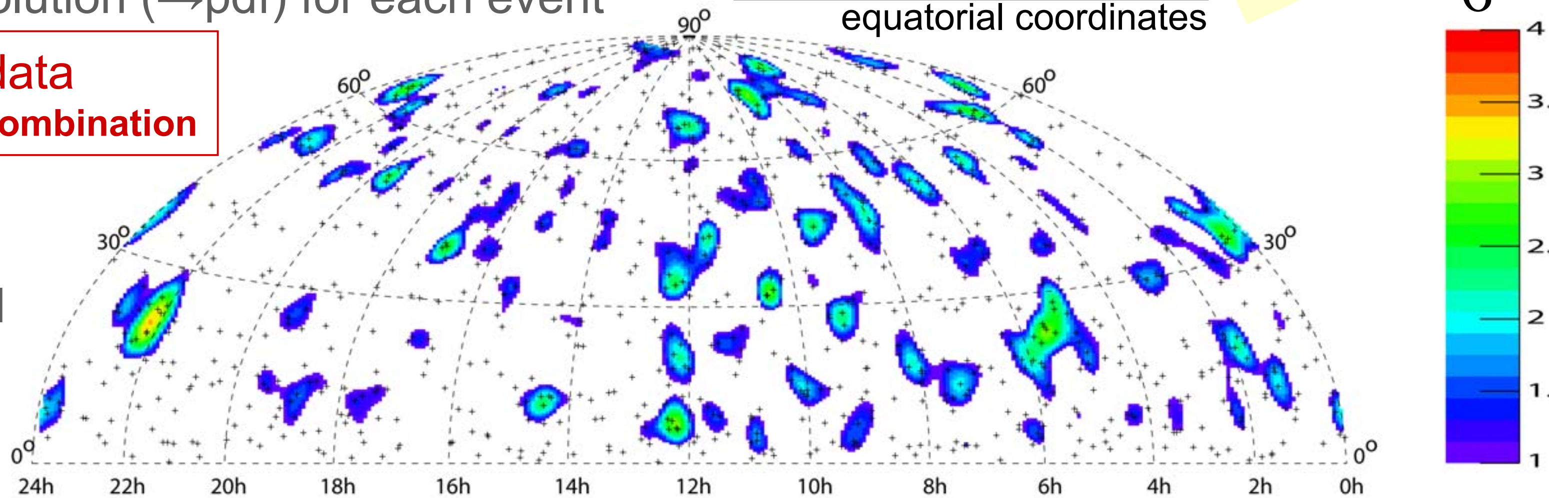
significance map
equatorial coordinates

2000-2002 data
non-optimized combination

922 events

Highest: 3.41

Above 3σ: 1

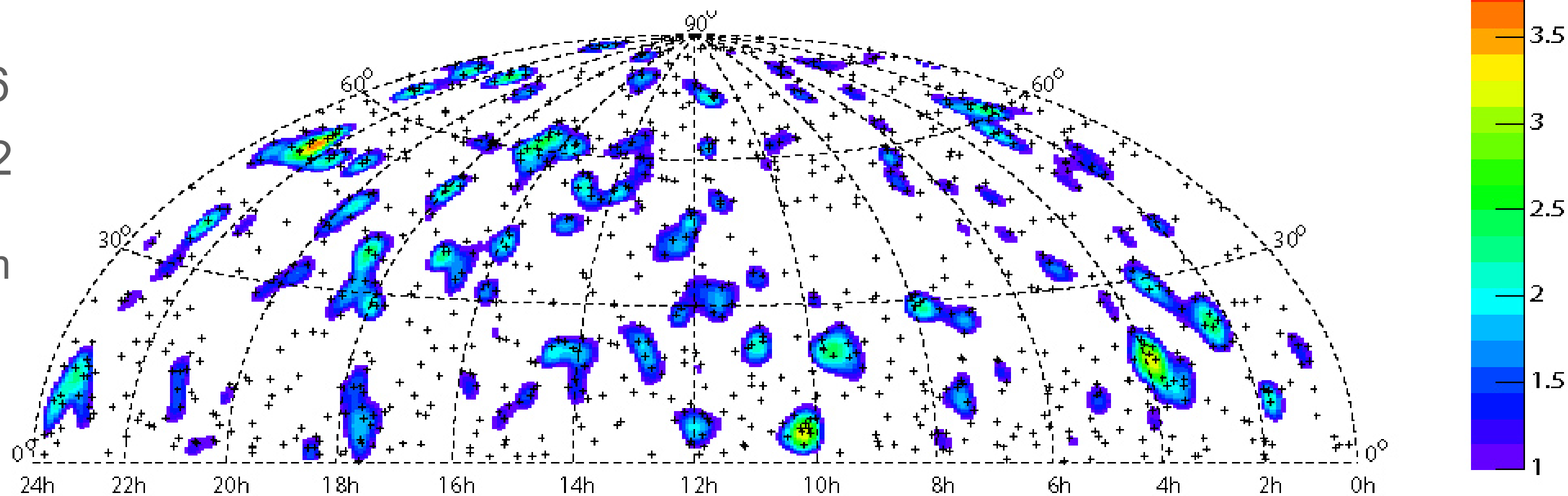


Scrambled in azimuthal direction!

Highest: 3.6

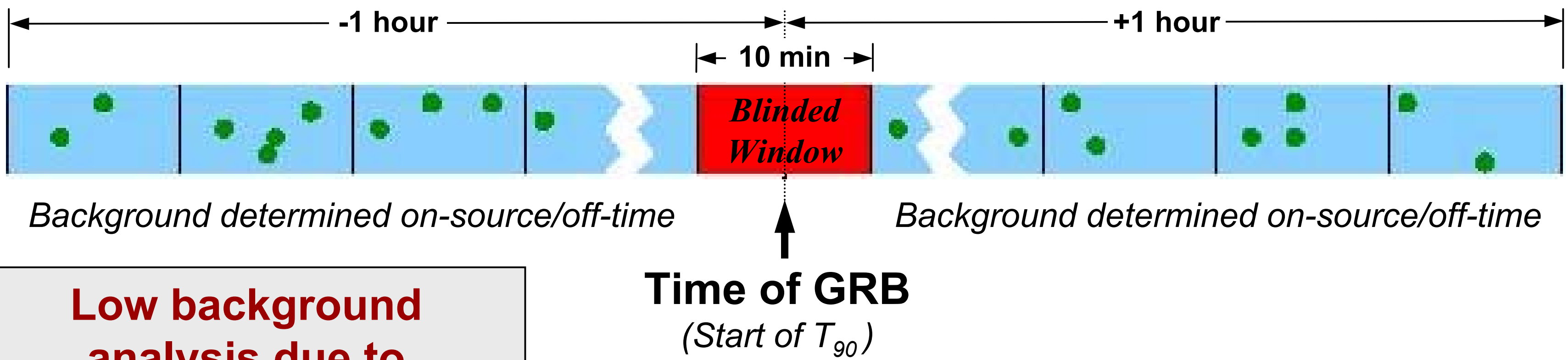
Above 3σ: 2

Expect 2.33 (from random distribution)



⇒ No excess in significance beyond randomly expected

Search for ν_μ correlated with GRBs



Low background analysis due to space and time coincidence!

GRB catalogs:
BATSE, IPN3 & GUSBAD

Analysis is blind:
finalized off-source (± 5 min)
with MC simulated signal

BG stability required within ± 1 hour

Muon effective area *(averaged over zenith angle)* ≈ 50,000 m² @ PeV

PRELIMINARY

Year	Detector	N_{Bursts}	$N_{BG, Pred}$	N_{Obs}	Event U.L.
1997	B-10	78 (BT)	0.06	0	2.41
1998	B-10	94 (BT)	0.20	0	2.24
1999	B-10	96 (BT)	0.20	0	2.24
2000	A-II (2 analyses)	44 (BT)	0.83/0.40	0/0	1.72/2.05
97-00	B-10/A-II	312 (BT)	1.29	0	1.45
2000	A-II	24 (BNT)	0.24	0	2.19
2000	A-II	46 (New)	0.60	0	1.88
2000	A-II	114 (All)	1.24	0	1.47

(BT = BATSE Triggered BNT = BATSE Non-Triggered New = IPN & GUSBAD)

97-00 Flux Limit at Earth*: $E^2\Phi_\nu \leq 4 \cdot 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}

*For 312 bursts w/ WB Broken Power-Law Spectrum (E_{break} = 100 TeV, Γ_{Bulk} = 300)

~15× WB flux

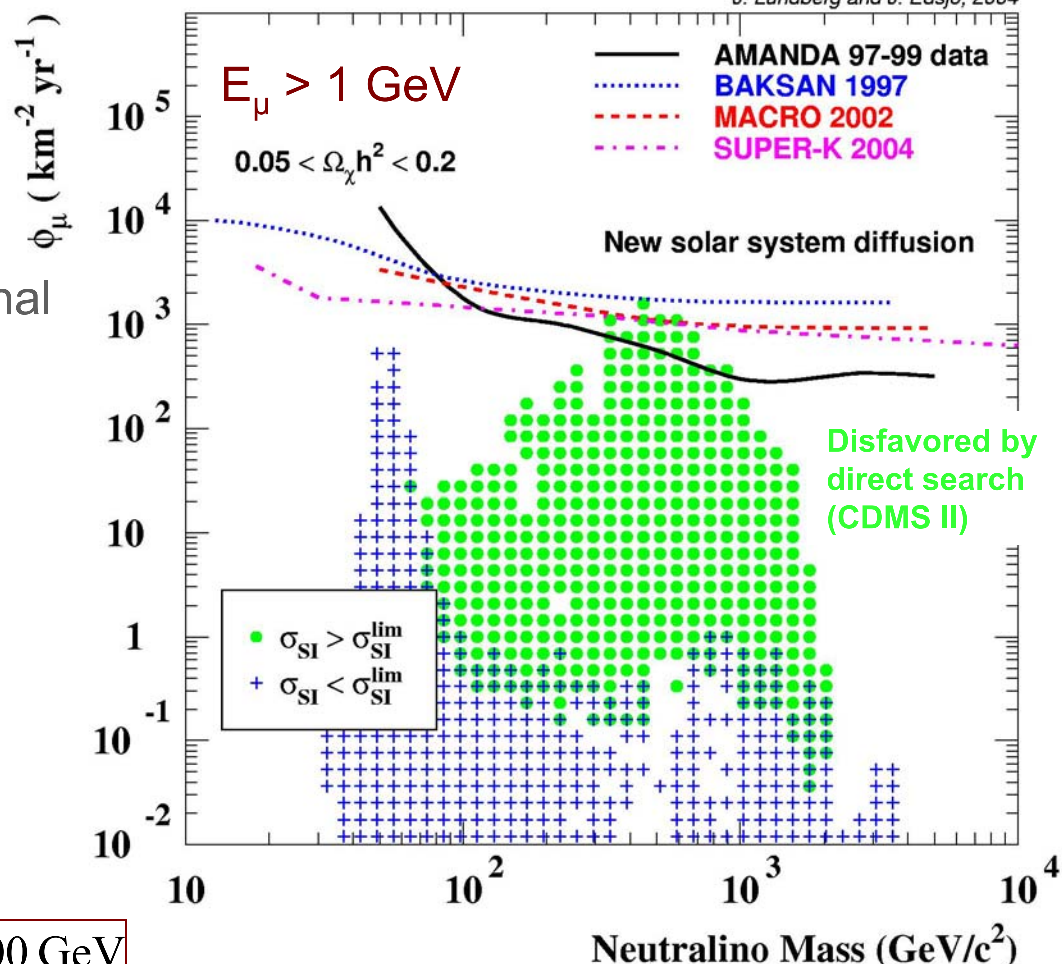
WIMP annihilations in the center of Earth

Sensitivity to muon flux from neutralino annihilations in the center of the Earth:

$$xx \rightarrow q\bar{q}, l^+l^-, W, Z, H \rightarrow \nu_\mu$$

PRELIMINARY

Muon flux limits



Look for vertically upgoing tracks

NN optimized (on 20% data) to
- remove misreconstructed atm. μ
- suppress atmospheric ν
- maximize sensitivity to WIMP signal

Combine 3 years: 1997-99

Total livetime (80%): 422 days

No WIMP signal found

Limit for "hardest" channel:

$$xx \rightarrow \tau^+\tau^- \rightarrow \nu_\mu \quad \boxed{M_x = 50 \text{ GeV}}$$

$$xx \rightarrow W^+W^- \rightarrow \nu_\mu \quad \boxed{M_x = 100\text{-}5000 \text{ GeV}}$$

WIMP annihilations in the Sun

WIMPs from Sun vs Earth:

+ larger mass → deeper gravitational well
+ increased capture rate due to addition of spin-dependent processes

− further away

Sun is maximally 23° below horizon

Search with AMANDA-II possible thanks to improved reconstruction capabilities for horizontal tracks

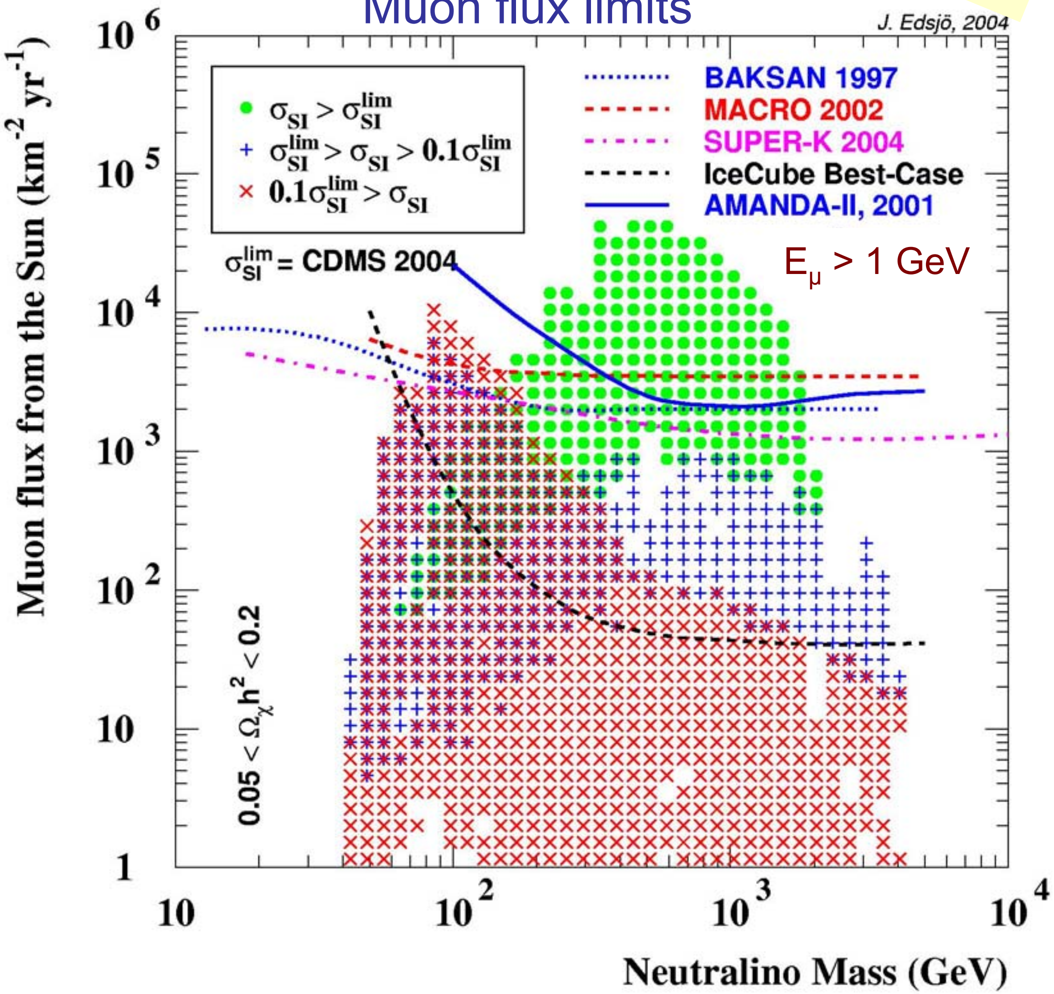
Exclusion sensitivity from analyzing off-source bins

2001 data
0.39 years livetime

No WIMP signal found

PRELIMINAR

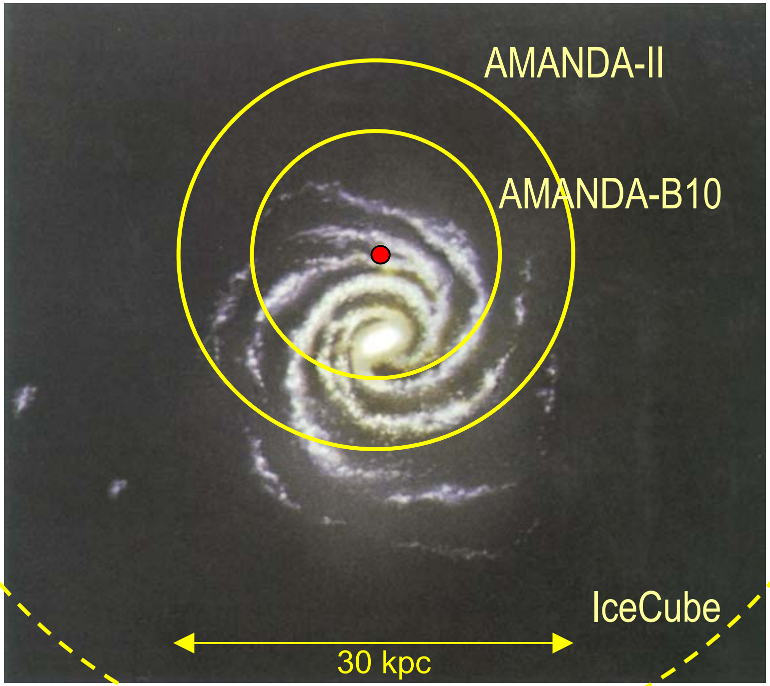
Muon flux limits



AMANDA as supernova monitor ~MeV

Bursts of low-energy (MeV) $\bar{\nu}_e$ from SN
- ► simultaneous increase of all PMT count rates (~10s)

Since 2003:
AMANDA supernova system
includes all AMANDA-II channels



Recent online analysis software upgrades
- ➢ can detect 90% of SN within 9.4 kpc
- ➢ less than 15 fakes/year

⇒ will contribute to
Super**N**ova **E**arly **W**arning **S**ystem
(with Super-K, SNO, LVD, …)
later this year

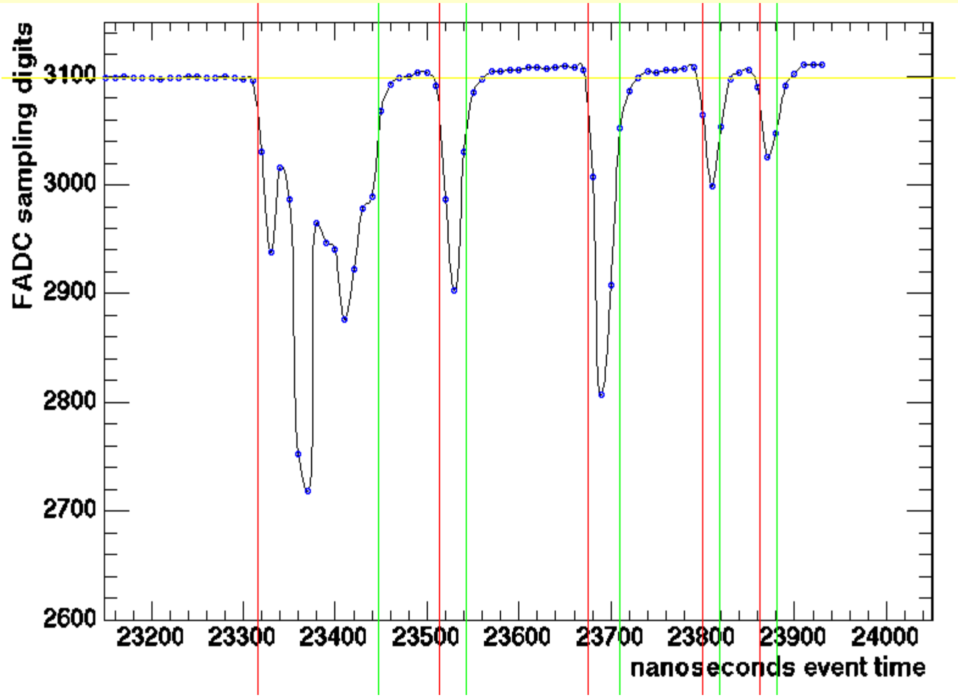
coverage

B10: 70% of Galaxy
A-II: 95% of Galaxy
IceCube: up to LMC

Analysis of 200X data in progress

Hardware upgrade: waveform readout

Transient Waveform Recorder system installed between 2001/02 and 2003/04 campaigns



Improvements

Increased OM dynamic range ~×100

Increased 1-p.e. detection efficiency

Virtually dead-time free

Manageable trigger rate: ~150 Hz
(majority 18)

Possibility of using software trigger

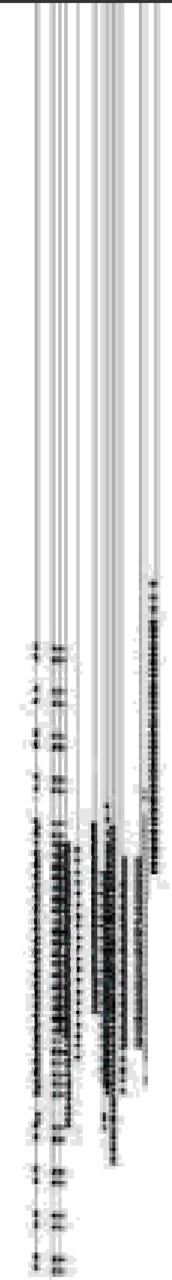
Physics benefits:
Improved energy resolution

UHE/EHE physics

Conclusion and Outlook

No extraterrestrial ν signal observed…yet

- Limits (TeV-EeV) on diffuse ET neutrino flux
- First results from AMANDA-II published:
  - point source search in 2000 data
- Combined analysis (2000-03) in progress
- Papers on 1997-2000+ data in progress
- Ice description mature
- Digitized waveform readout since 2003
- Will soon contribute to SNEWS



Next Generation: IceCube…(first strings in Jan 2005)