AMANDA

ANTARCTIC MUON AND NEUTRINO DETECTOR ARRAY

Status and Results

(http://www.amanda.uci.edu)

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VLVnT Workshop
Amsterdam, Oct. 2003

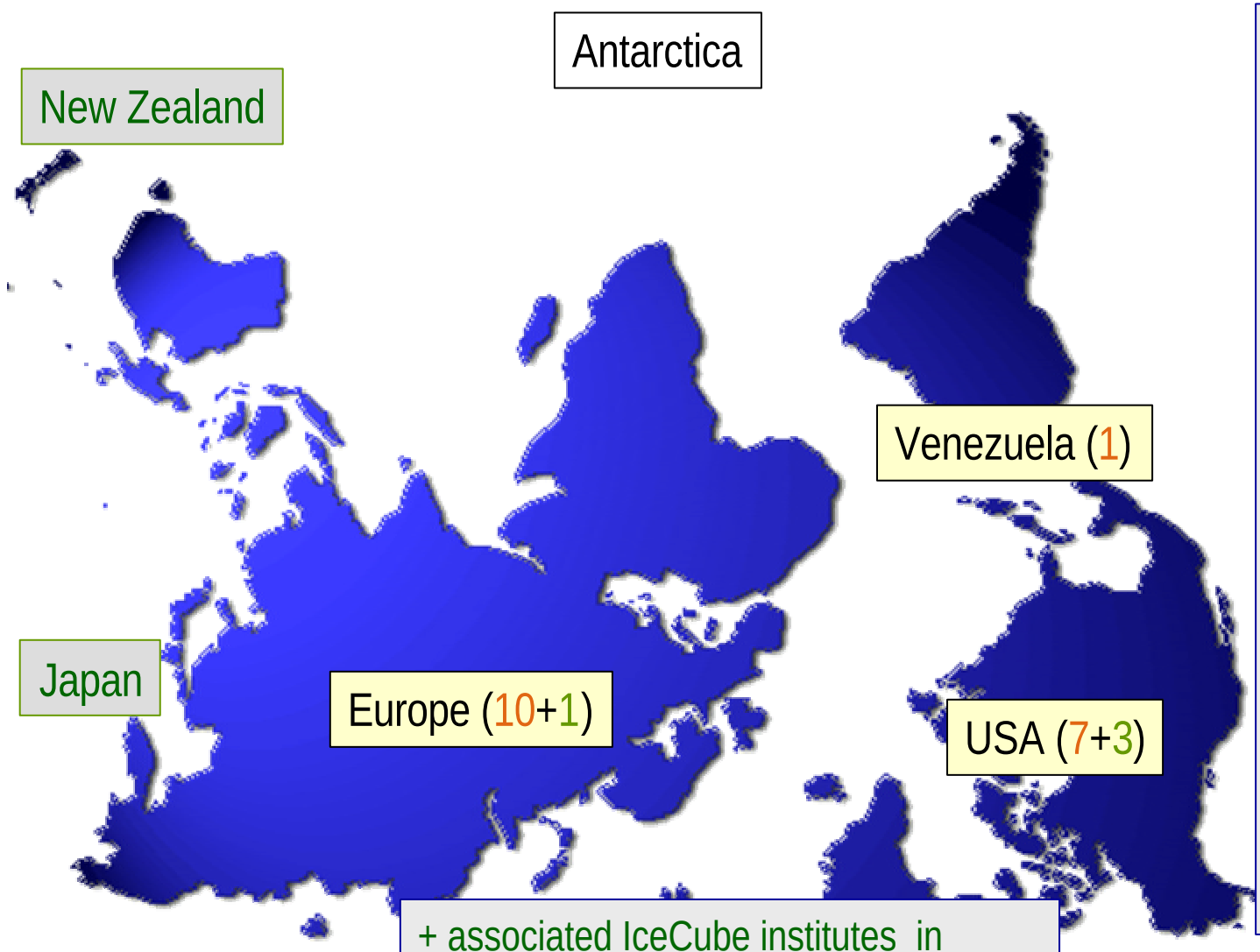
DESY

Content

1. AMANDA: set-up and detection parameters
2. Atmospheric ν's
3. Search for astrophysical ν's:
   → diffuse/point-like sources
4. Indirect WIMPs search
5. Other physics topics
6. Conclusions and Outlook

The AMANDA Collaboration

≈150 members



Bartol Research Institute
UC Berkeley
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Pennsylvania State
UW Madison
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VUB, Brussel
ULB-IHEE, Bruxelles
U. de Mons-Hainaut
Imperial College, London
DESY, Zeuthen
Mainz Universität
Wuppertal Universität
Stockholm Universitet
Uppsala Universitet
Kalmar Universitet
South Pole Station

+ associated IceCube institutes in USA, Europe, Japan, New Zealand

The Site

The new station operating at least until 2035

The Dome

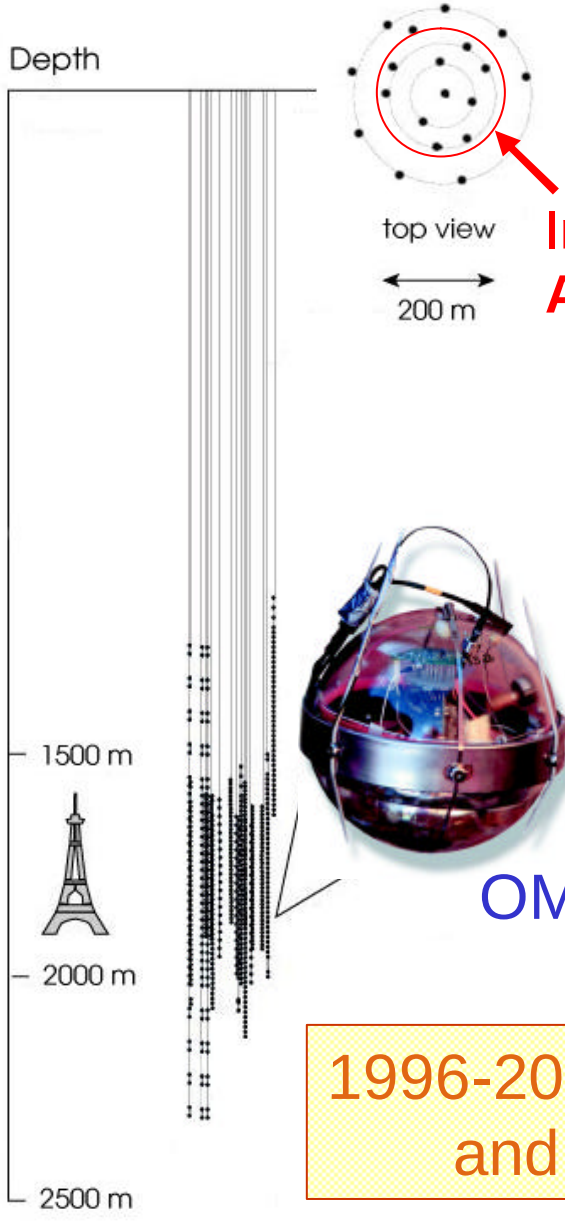
AMANDA

South Pole

2km deep

Amundsen-Scott Station

AMANDA-II and SPASE



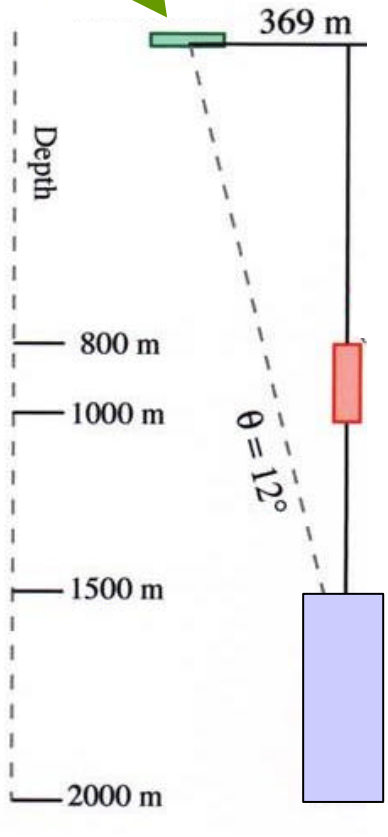
Inner 10 strings:
Amanda-B10

19 strings
677 PMTs

OM:optical module

1996-2000: deployment
and first data taking

South Pole Air Shower Experiment



AMANDA II

Detection parameters

ice optical parameters:

λ_{abs} ~ 110 m @ 400 nm

λ_{scatt} ~ 20 m @ 400 nm

noise rate:

~ KHz (or below)

trigger rate:

~ 80 Hz

muons:

directional error: 2.0 - 2.5°

log E resolution: 0.3 – 0.4

coverage: **2**p

energy range: ~ 50 GeV ± 100 PeV

n **effective area:** ~ 2-5 m^2 @ 100 TeV

cascades: ($e^{\pm}$, $\tau^{\pm}$, *neutral current*)

zenith error: 30 - 40°

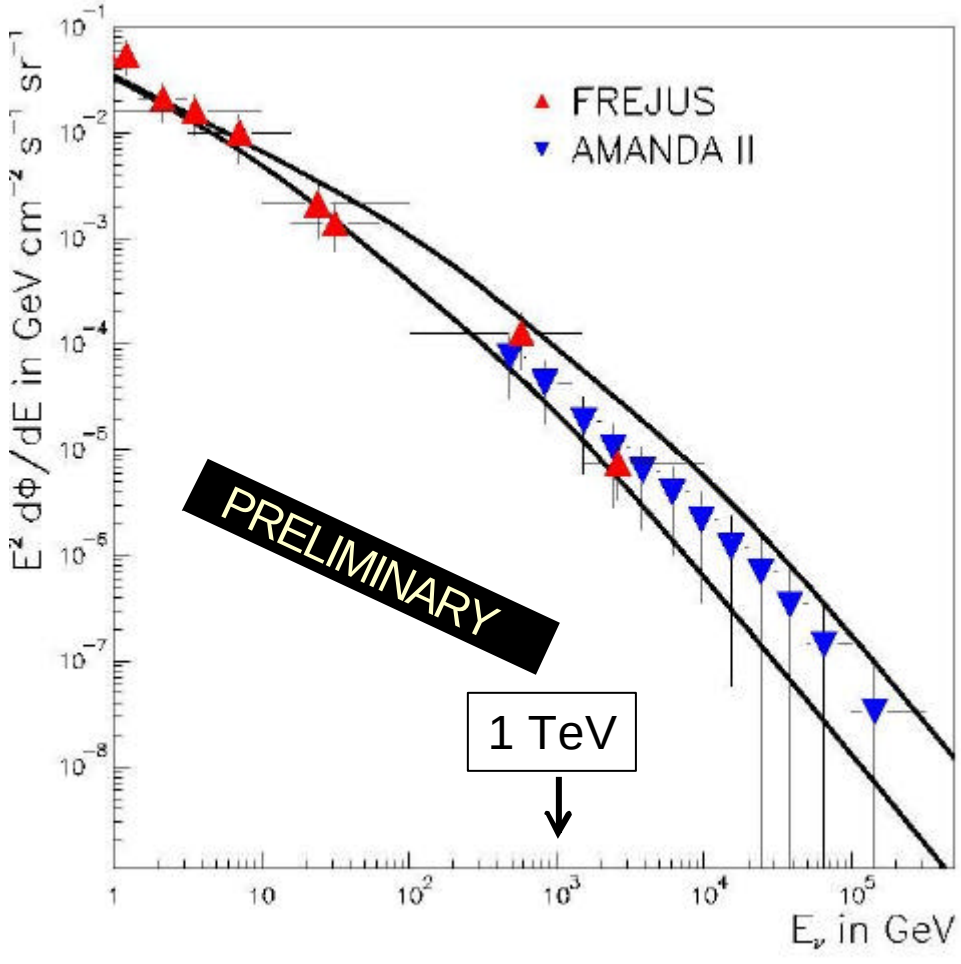
log E resolution: 0.1 – 0.2

coverage: **4**p

energy range: ~ 50 TeV ± 100 PeV

Atmospheric n's in AMANDA-II

Atmospheric muons and neutrinos: AMANDA's test beams



- Neural network energy reconstruction
- regularized unfolding
  → spectrum up to 100 TeV
- results compatible with Frejus data

Possible to use the energy spectrum to study excess due to cosmic n's

Search for astrophysical neutrinos

background:

→ fake-reconstructed atmospheric muons,

→ neutrinos from atmospheric air showers

signal:

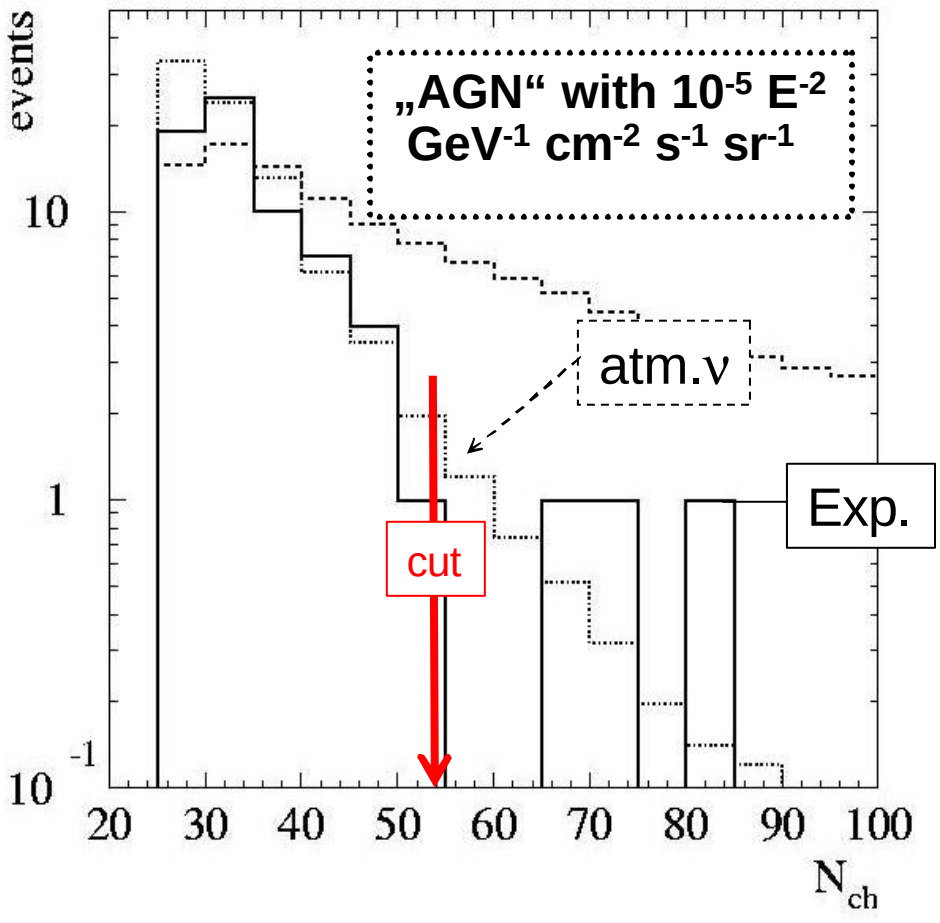
→ diffuse flux at high energy,

→ accumulation at point sources

- search for **high energy muon neutrinos**
  upward and
  downward (with extreme high energy)
- search for **cascades** with high energy

- search for **point sources**
- search for neutrinos in **coincidence with GRB**

Search for a TeV-PeV diffuse flux: upward going muons



1997 data sample ¶

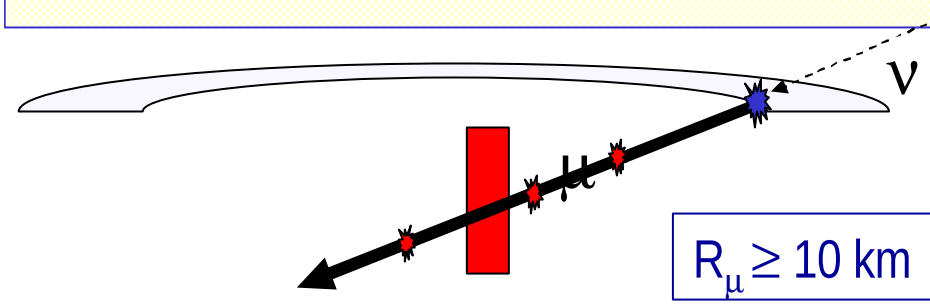
- Hit channels multiplicity as energy indicator
- Cuts optimized for best sensitivity

NO EXCESS OBSERVED

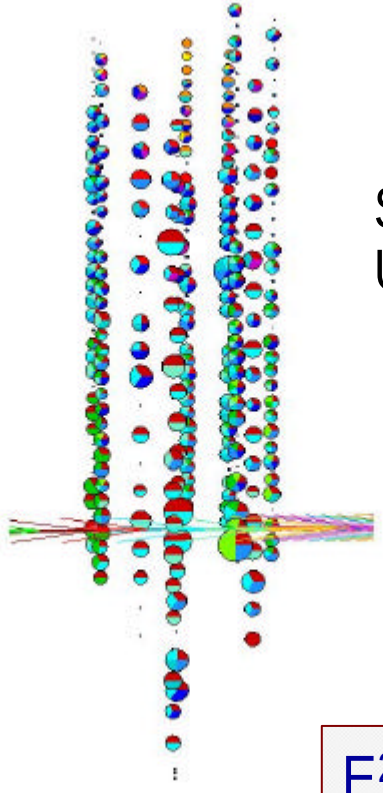
¶ PRL 90 (2003), 251101

$E^2 \Phi(E) < 8.4 \cdot 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}

Search for a PeV-EeV diffuse flux: downward muons and muons close to horizon

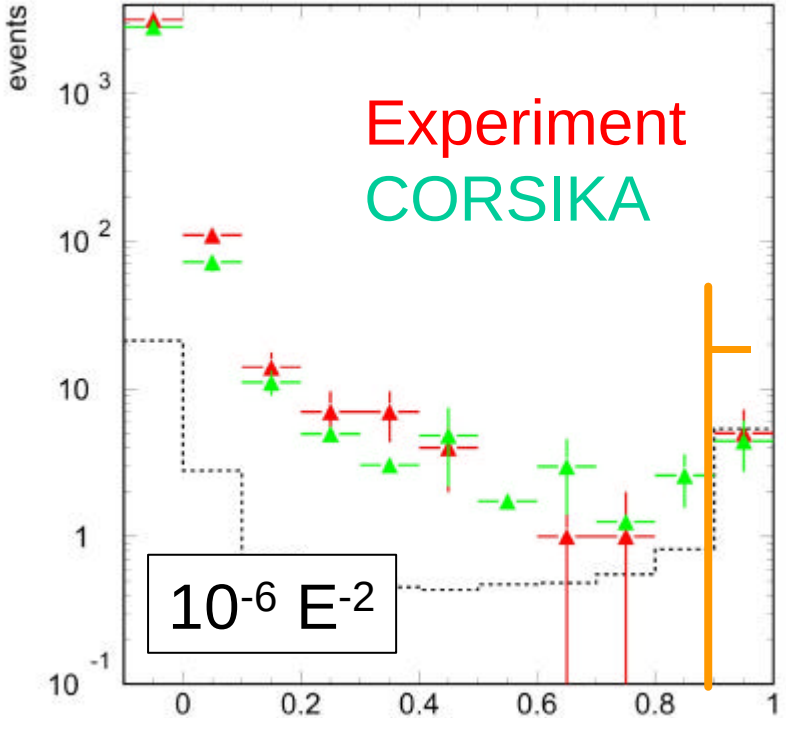


$R_\mu \geq 10$ km



Simulated
UHE event

NO EXCESS
OBSERVED



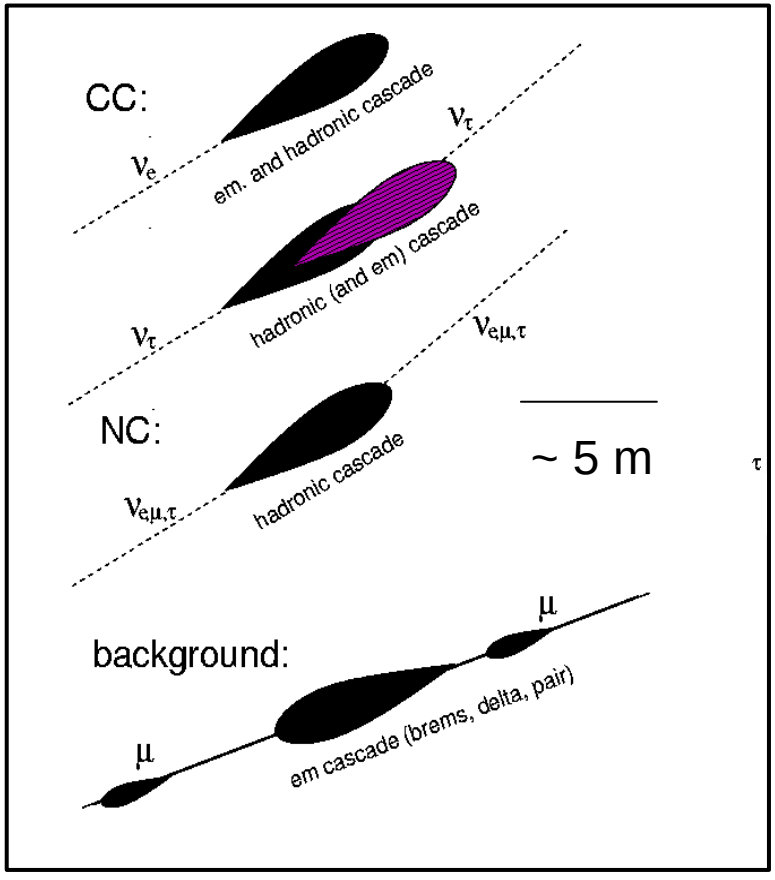
Neural Net Parameter „NN2“ for
neutrino vs.atm muon separation

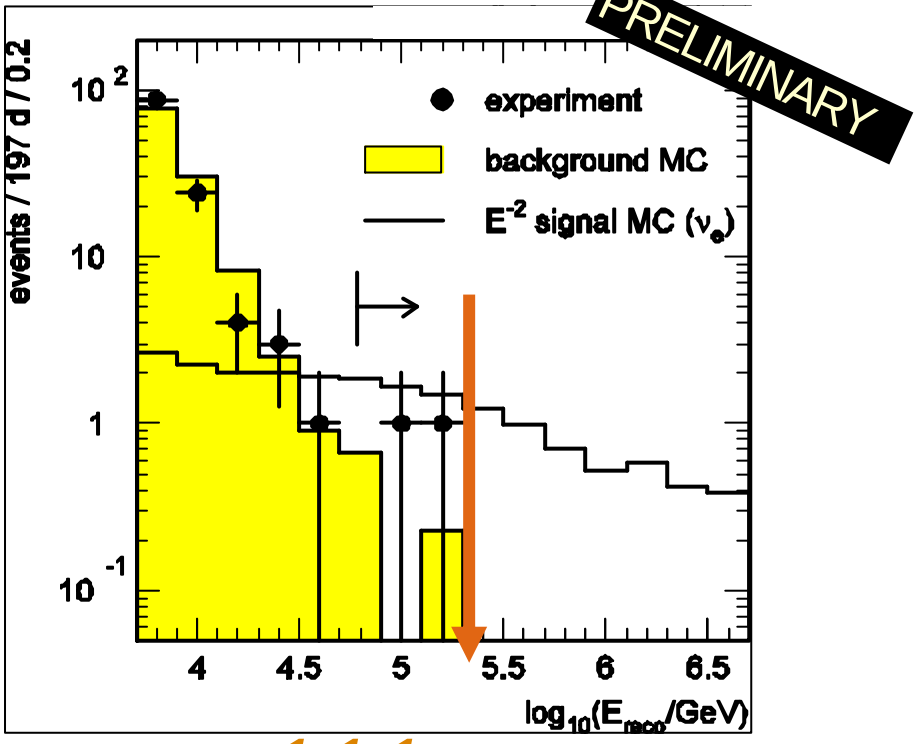
PRELIMINARY

$E^2 \Phi(E) < 7.2 \cdot 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}

Diffuse limit from cascades

Electromagnetic and hadronic cascades:





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

for $E^2\Phi(E) = 10^{-6}$ GeV cm^{-2}s^{-1}sr^{-1}

expect 9.3 ν_e , 3.8 ν_μ , 6.2 ν_τ events

→ 2 candidate events observed

→ 0.5 expected background

$E^2\Phi_{all\ \nu}(E) <$ **$9 \cdot 10^{-7}$** GeV cm^{-2}s^{-1}sr^{-1}

Synthesis: diffuse flux limits for all flavours

assuming $\nu_e:\nu_\mu:\nu_\tau = 1:1:1$ @ Earth

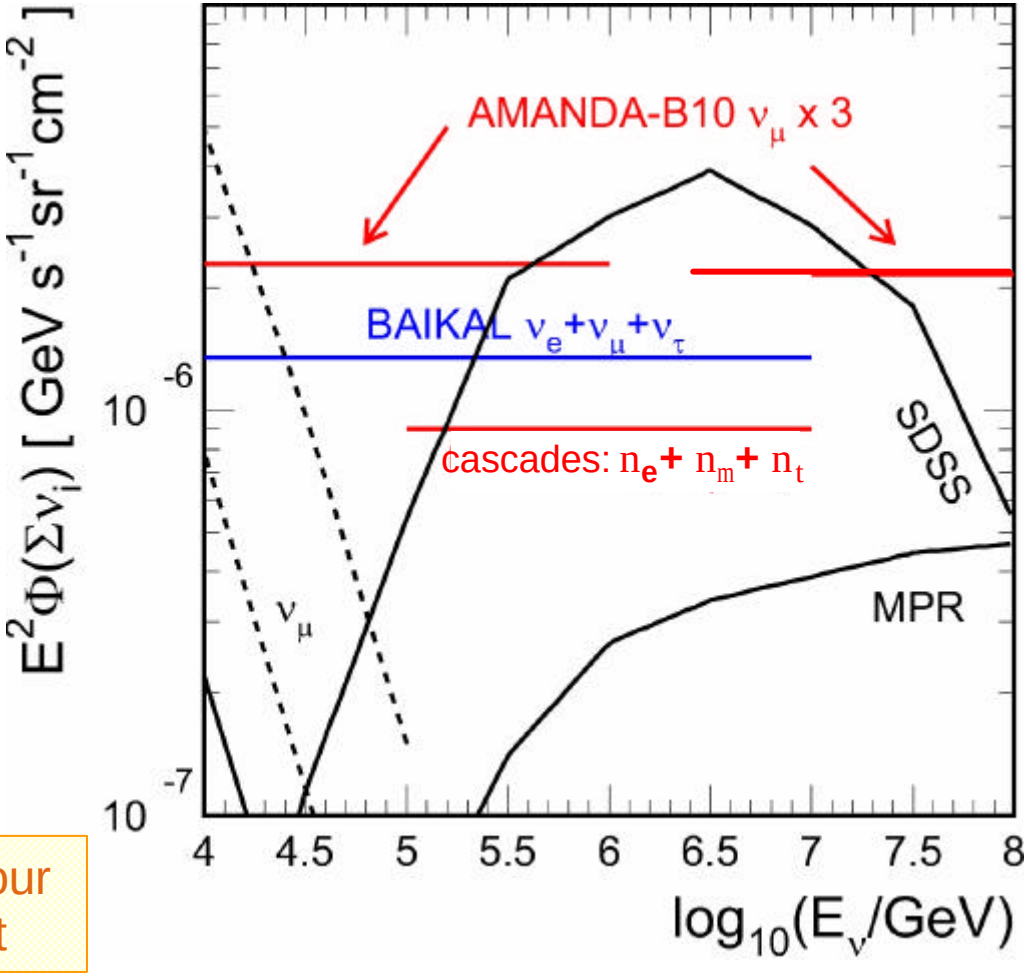
- multiplicative factor 3 applied for single ν_μ channel

- e-production on Glashow resonance (@ 6.3 PeV):

  $\bar{n}_e + e^- \rightarrow W^- \rightarrow \bar{n}_e + e^-$

  90% CL limit

  $2.3 \cdot 10^{-20}$ GeV^{-1} cm^{-2} s^{-1} sr^{-1}



2000 ν_μ analysis will yield all-flavour limit comparable to cascade limit

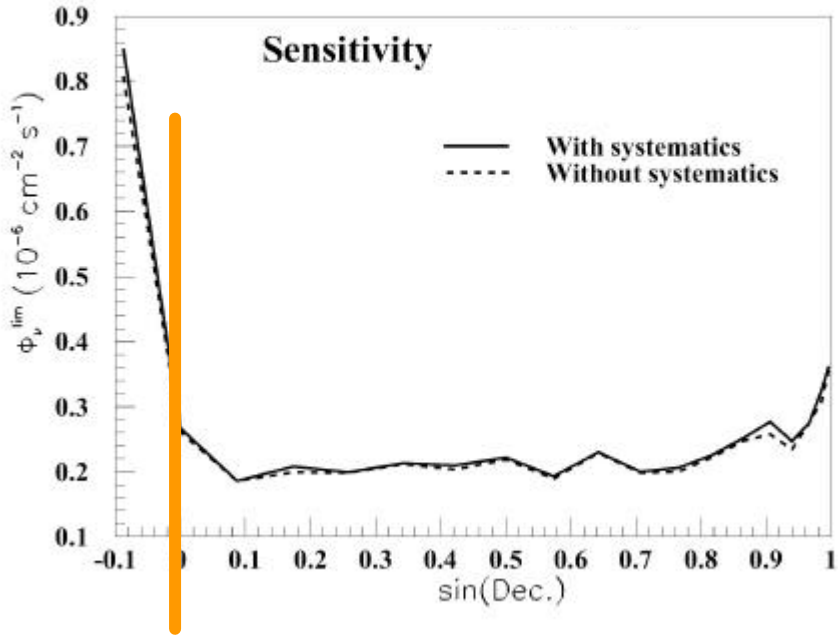
Point source search in AMANDA II

Search for excess events in sky bins for up-going tracks

- Cuts optimized in each declination band
- sensitivity ≈ flat up to horizon, in average 4 times better than B10 ¶

- 697 neutrino events observed from below the horizon
- 5% non-neutrino background for $\theta > 5°$

1. Grid Search
   (sky subdivided into 300 bins ~7°x7°)
2. Search around defined sources



declination averaged sensitivity:
$\Phi_\nu^{lim} \approx 0.23 \cdot 10^{-7}$ cm^{-2}s^{-1} @ 90%CL

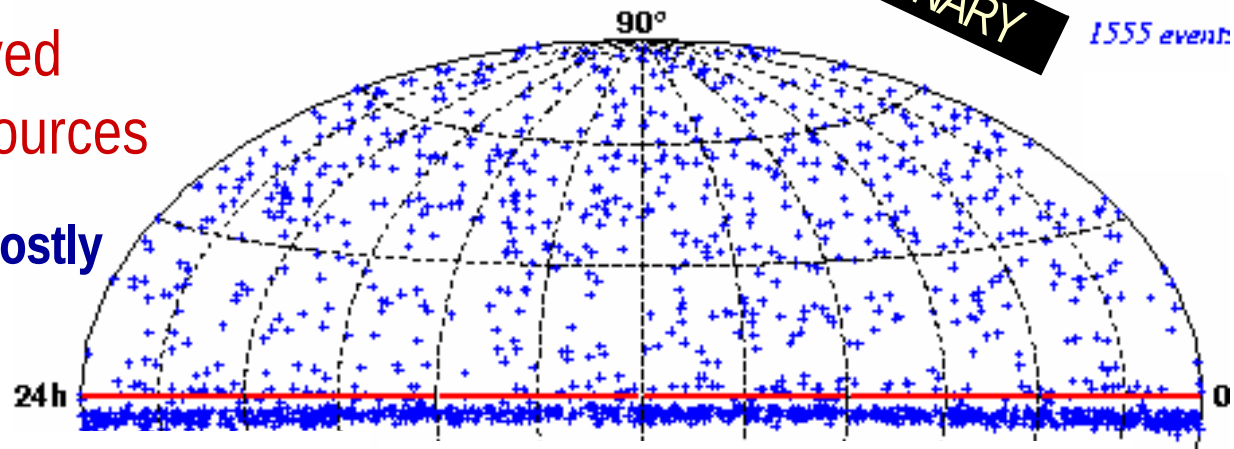
¶ Ap. J, 582 (2003)

Search for excess events in sky bins for up-going tracks

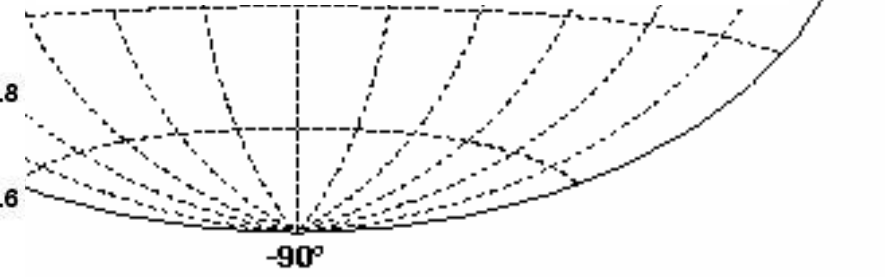
PRELIMINARY

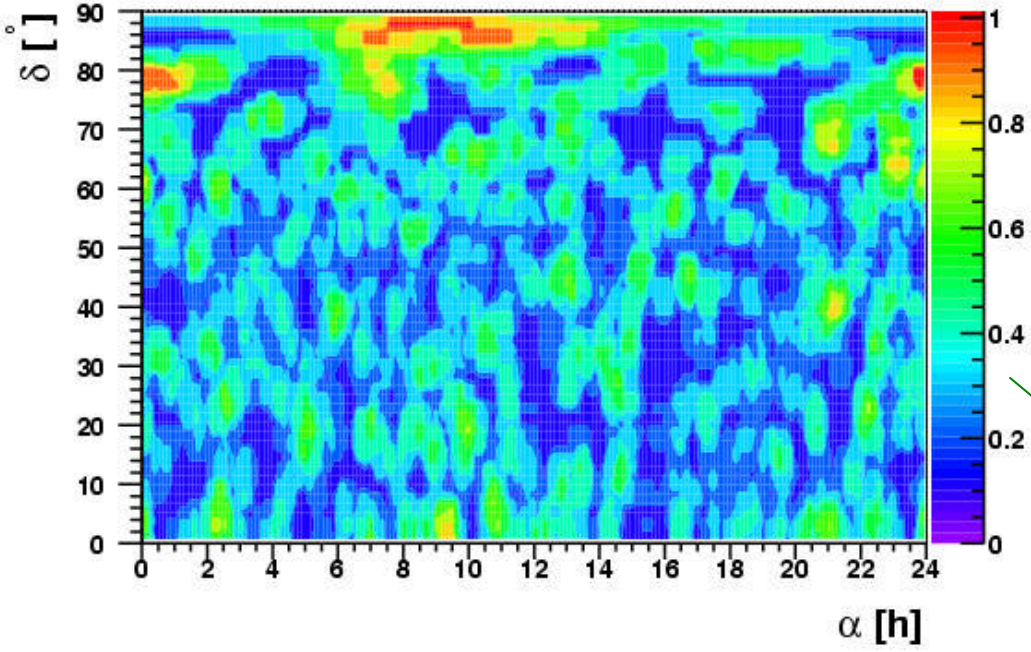
no clustering observed
no evidence for point sources

below horizon: mostly atmospheric n's



above horizon:mostly fake events





upper limits @ 90% CL
in units of $10^{-7}cm^{-2}s^{-1}$
integrated above E_ν=10 GeV

Point source flux limits

PRELIMINARY

Sources	declination	1997	2000
SS433	5.0^o	-	0.7
M87	12.4^o	17.0	1.0
Crab	22.0^o	4.2	2.4
Mkn 421	38.2^o	11.2	3.5
Mkn 501	39.8^o	9.5	1.8
Cyg. X-3	41.0^o	4.9	3.5
Cas. A	58.8^o	9.8	1.2

1.07 events predicted¶
90% CL upper limit of
1.24 events

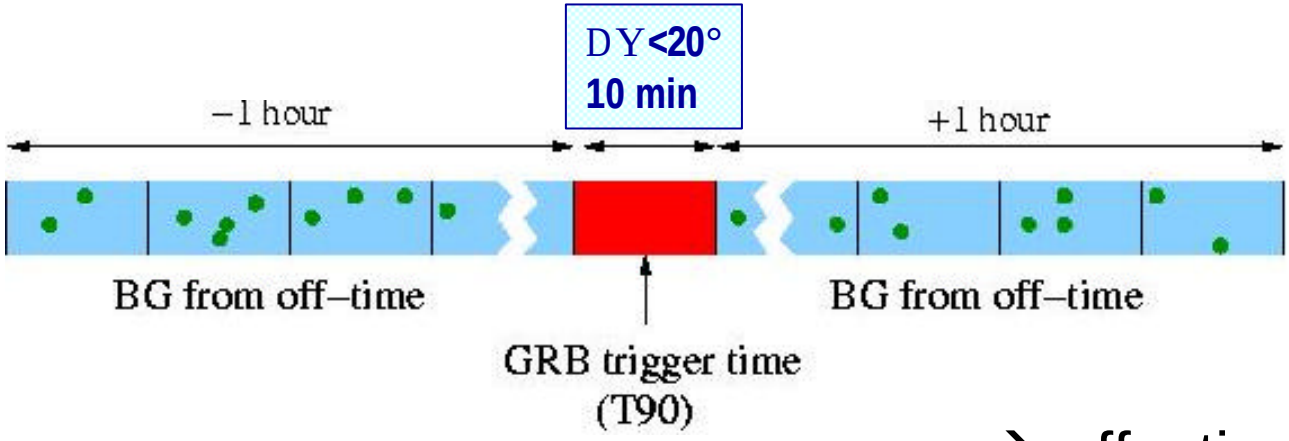
Sensitivity comparable
TeV γ-ray flux (HEGRA)

upper limits @ 90% CL in units of $10^{-8}cm^{-2}s^{-1}$
for an assumed E^{-2} spectral shape
integrated above E_ν=1 GeV

¶C.Distefano et al., Ap. J., 575 (2002)

AMANDA-II achieved the sensitivity to search for neutrinos from TeV γ-ray sources ($\nu/\gamma \sim 1$)

Search for ν_μ correlated with GRBs



Low background due to space and time coincidence

→ effective μ-area ≈ 50000 m²

Year	#GRB	bkg	observed
1997	78	0.10	0
1998	99	0.20	0
1999	96	0.20	0
2000	44	0.60	0
Total	**317**	1.30	0

NO EXCESS OBSERVED

→ assuming WB spectrum (E_B at 100 TeV and Γ = 300) flux limit:

~ 4 x 10^{-8} GeVs^{-1}cm^{-2}sr^{-1}

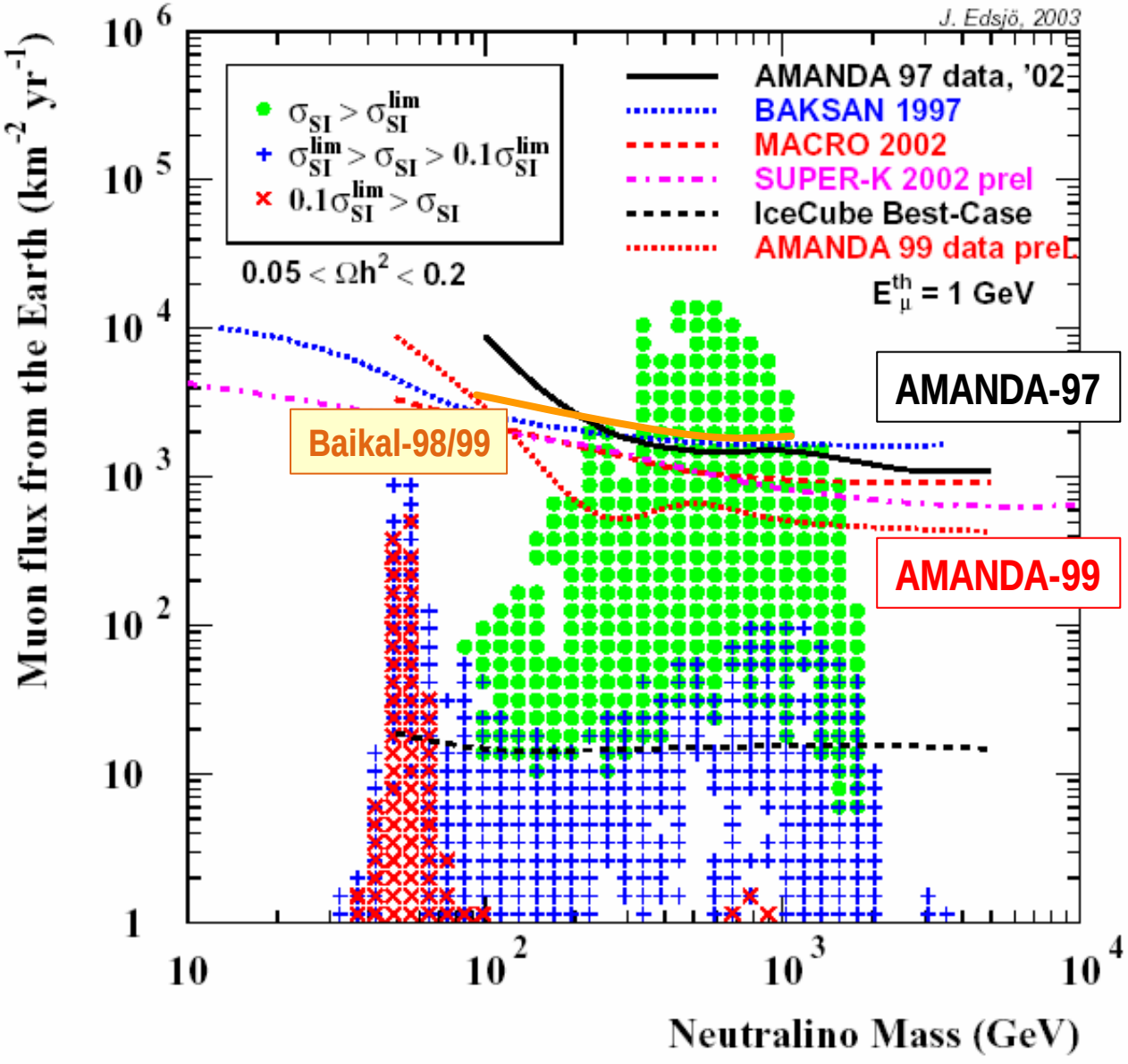
PRELIMINARY

Upper limits on the muon flux coming from neutralino annihilations in the center of the Earth

1999 data sample

Improvement of **upper limits** compared to 97-data analysis:
→ larger effective live time
→ development of cuts adapted to each WIMP mass individually

NO WIMP SIGNAL DETECTED

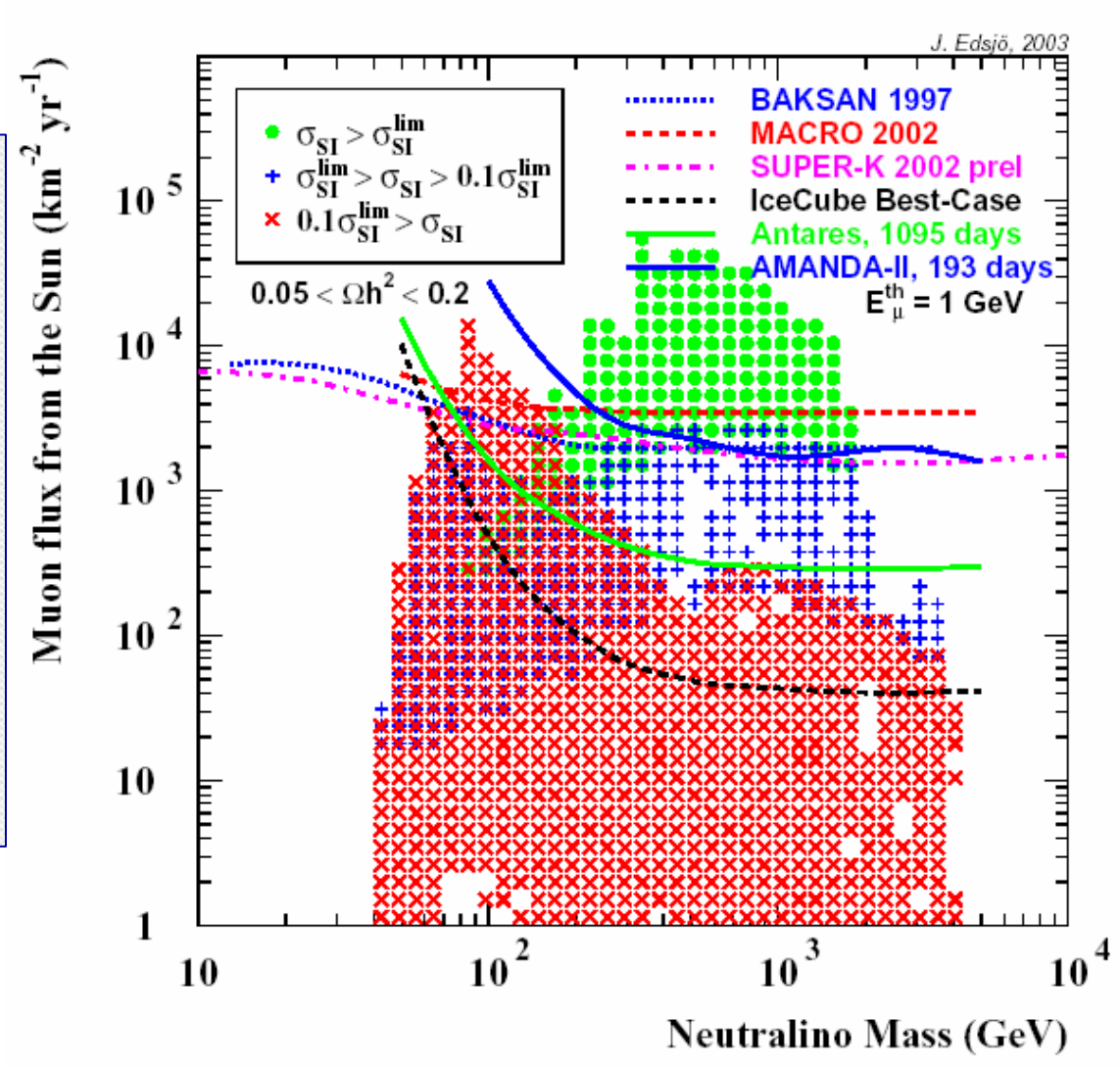


Sensitivitiy on the muon flux coming from neutralino annihilations in the center of the Sun

Analysis made feasible by the **improved reconstruction capability** for **horizontal tracks**, compared to B-10.

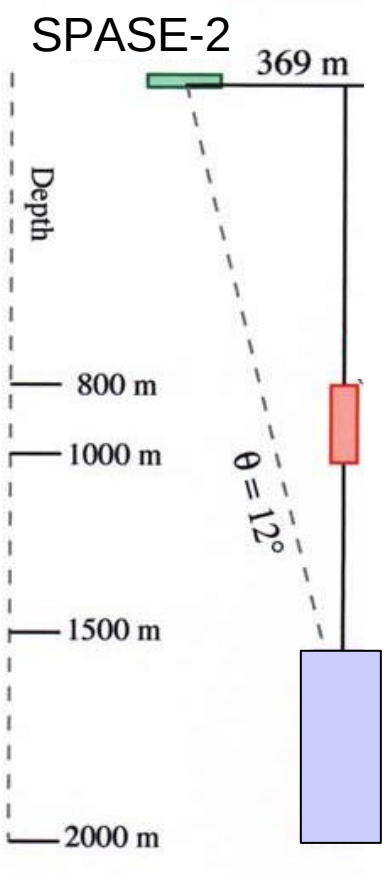
AMANDA-II results:
→**Exclusion sensitivity** from analyzing the off-source bins

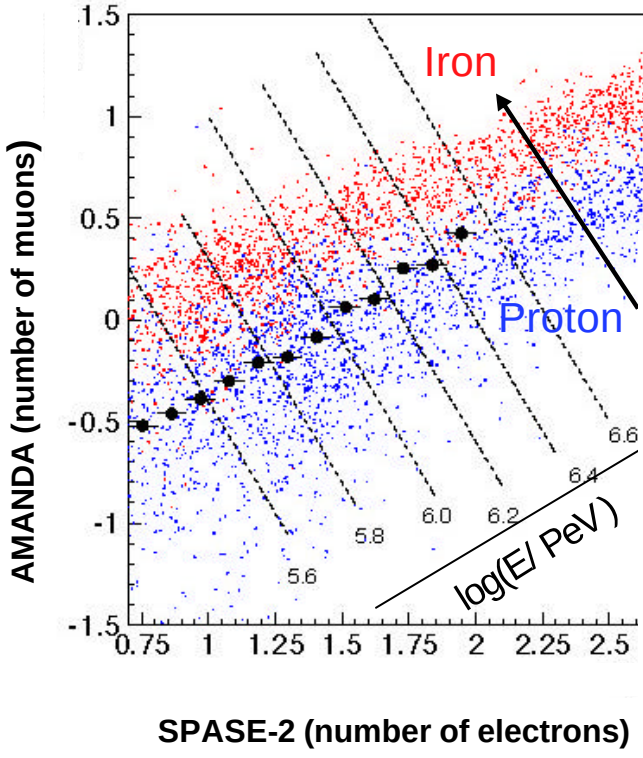
Sensitivity competitive with direct searches

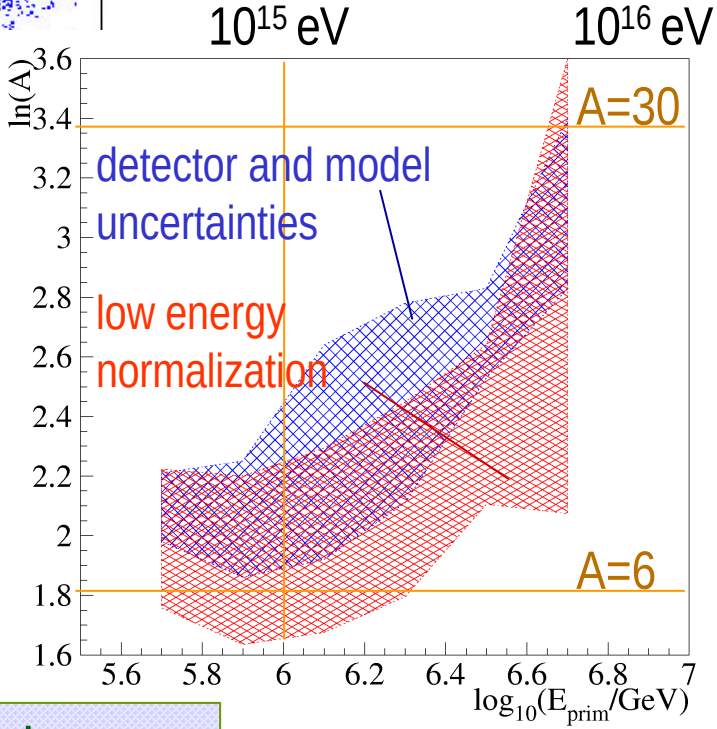


Cosmic ray composition studies

SPASE-2 (electron component) - AMANDA B10 (muon component)







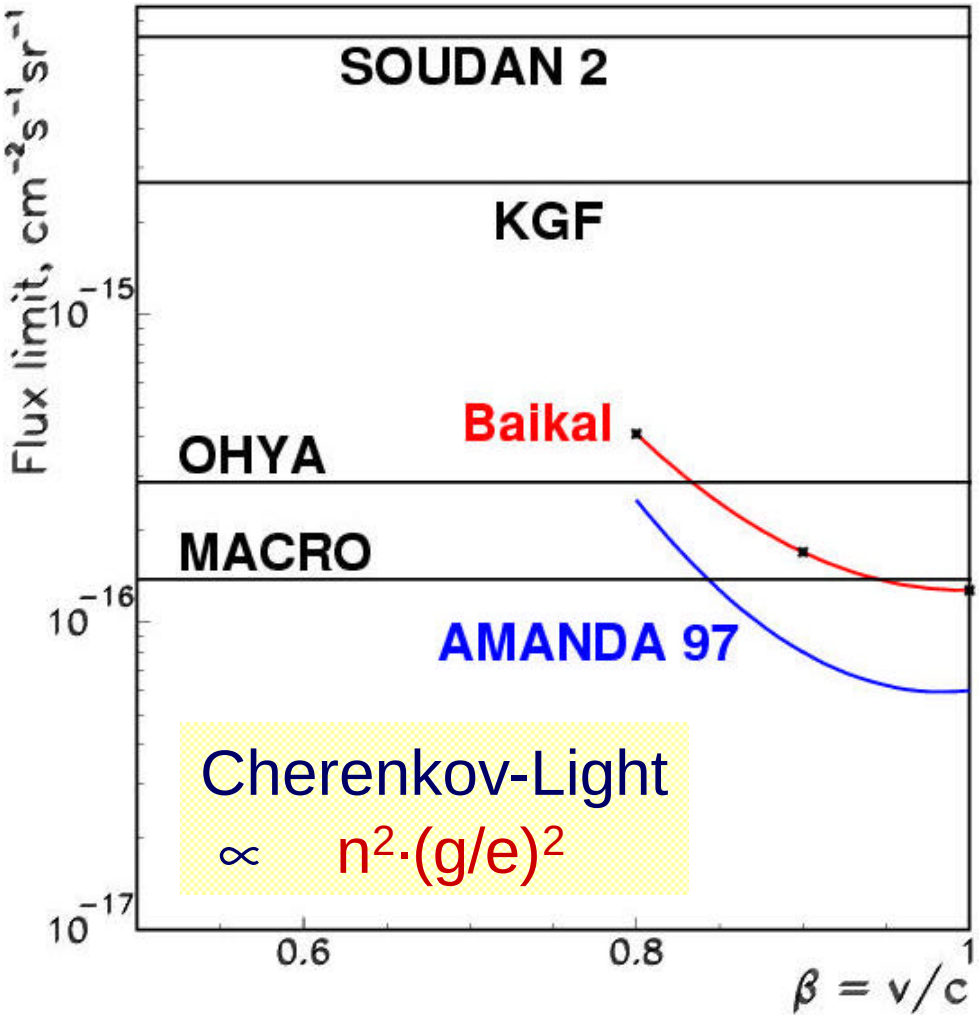
confirms trend seen by other experiments:
composition change around the knee

Relativistic Magnetic Monopoles

1997 data sample

→ Signal: much **higher light output** (~8300) compared to muons
→used simple track reconstruction
→background (atm. neutrinos): suppressed on the basis of channel multiplicity

NO EXCESS OBSERVED



Summary

- **The AMANDA detector is complete since 2000:**
  19 strings, 677 OMs
  - → analyzed data from 97-99 (B10) and 2000 (A-II)
  - → atmospheric ν: energy spectrum (1÷100 TeV)

- **Results on the search for extraterrestrial ν:**
  - → limits on diffuse flux at high E_ν
  - → limit on diffuse flux at extreme high E_ν
  - → limits on flux from point sources

  no effect seen up to now

  limits are at the level of optimistic expectations
- **Search for ν resulting from WIMP annihilations**:
  - → center of the Earth: limit
  - → center of the Sun: sensitivity

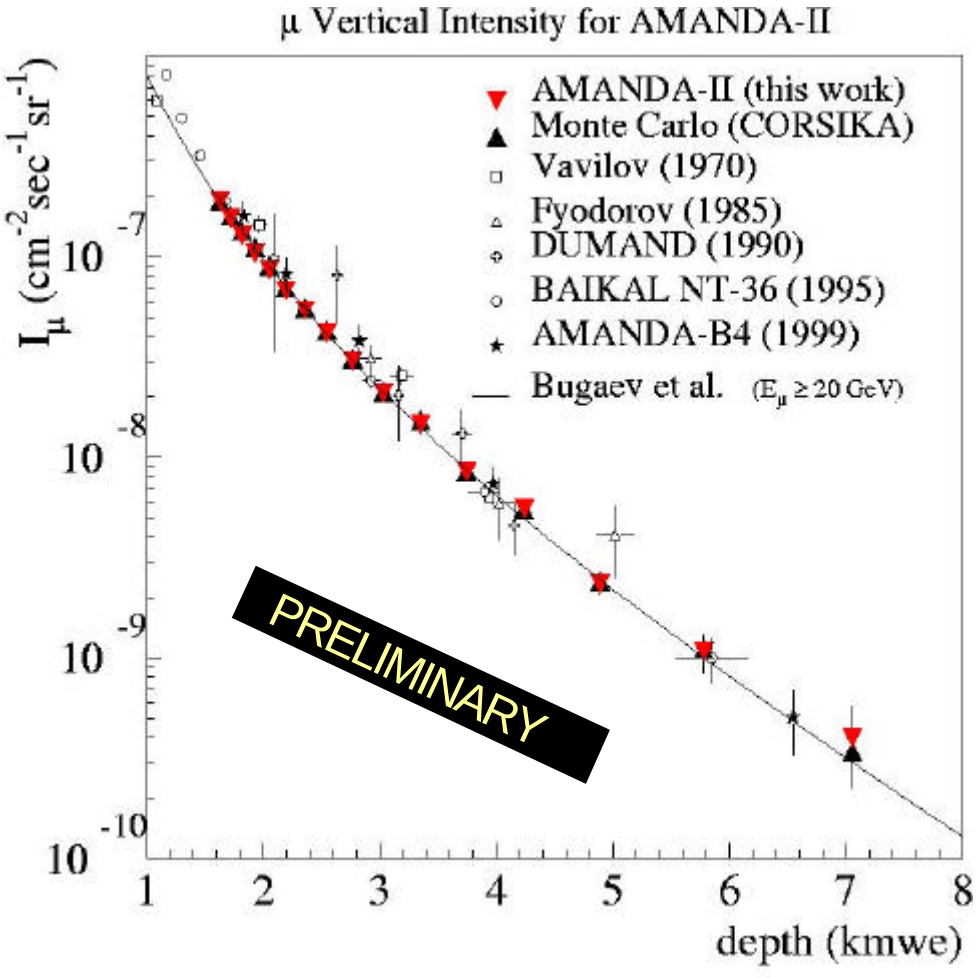
    (**competitive to results from direct searches**)

Outlook

- **Complete analysis of 2000 data:**
  → diffuse flux of HE neutrinos
  → WIMPs from Earth and Sun
- **combined analysis of 2000 … 2003:**
  factor 4 in statistics
- **improve search for magnetic monopoles:**
  extend search to non-relativistic monopoles

- **FADC readout (single photoelectron resolution):**
  → improved reconstruction and
  → analysis for high energy events
- first **IceCube strings** 2004/05
  → combined analysis with AMANDA

Atmospheric muons in AMANDA-II



data 30% higher than MC (QGSJET)

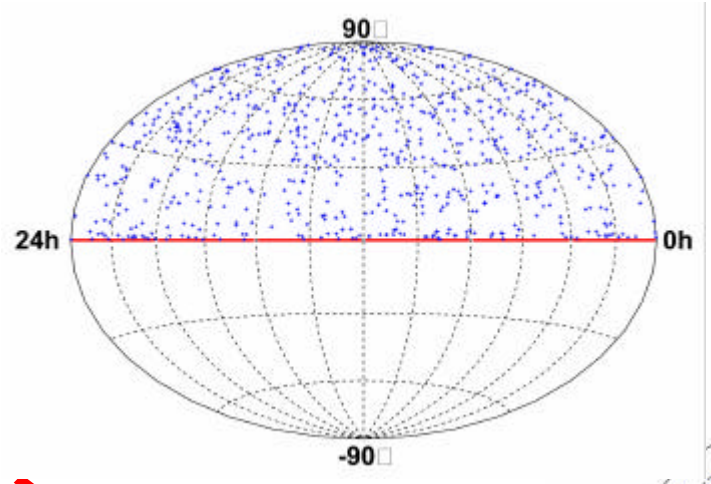
↙ normalize to most vertical bin

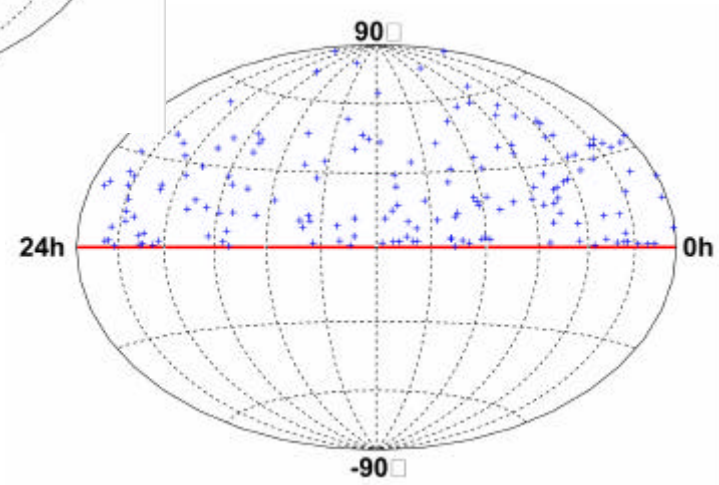
Systematic errors:

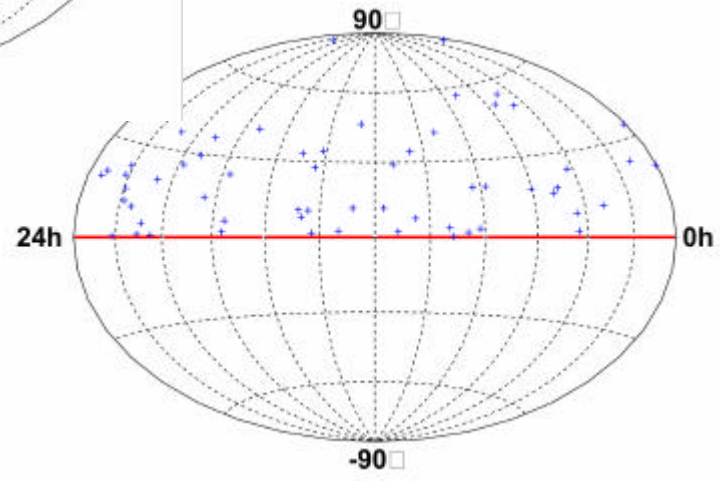
- 10% ice parameters:
  scattering (20m @ 400nm)
  absorption (110m @ 400nm)
- 20% optical module sensitivity
- 10% refreezing of ice in hole

threshold ~ 40 GeV
(zenith averaged)

Is there a signal at higher energies?







increasing energy deposition
(use N(PMT) as energy measure)

no indication of clustering
also at higher energies !

Limit on diffuse flux for muon neutrinos

6·10³ – 10⁶ GeV:
$E^2\,\Phi(E) < 8 \times 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}

2.5·10⁶ – 6.3·10⁹ GeV:
$E^2\,\Phi(E) < 7.2 \times 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}

Expected sensitivity 2000 data:
~ 3×10^{-7} GeV cm^{-2} s^{-1} sr^{-1}

Limits for generic E^{-2} spectra :