AMANDA

ANTARCTIC MUON AND NEUTRINO DETECTOR ARRAY

Recent Results

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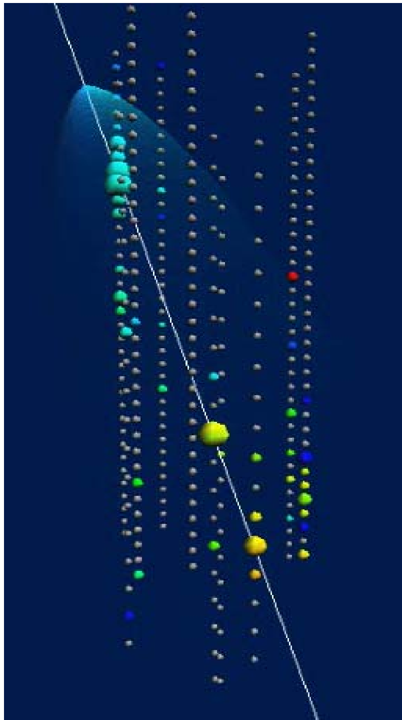
July 31, 2003

http://amanda.uci.edu

bmb+f - Förderschwerpunkt
Astroteilchenphysik
Großgeräte der physikalischen Grundlagenforschung



Contributed papers to ICRC

Cosmic rays

- Response of AMANDA to cosmic ray muons
- Cosmic ray flux measurement
- Cosmic ray composition at the knee with SPASE and AMANDA

Neutrinos

- Atmospheric neutrino and muon spectra
- Search for diffuse fluxes of extraterrestrial muon neutrinos
- AMANDA-B10 limit on UHE-Neutrinos
- Search for high energy neutrinos of all flavours
- Search for extraterrestrial point sources of neutrinos
- Search for muons from WIMP annihilation in center of earth
- Search for high energy neutrinos from GRBs
- Online search for neutrino bursts from Supernovae

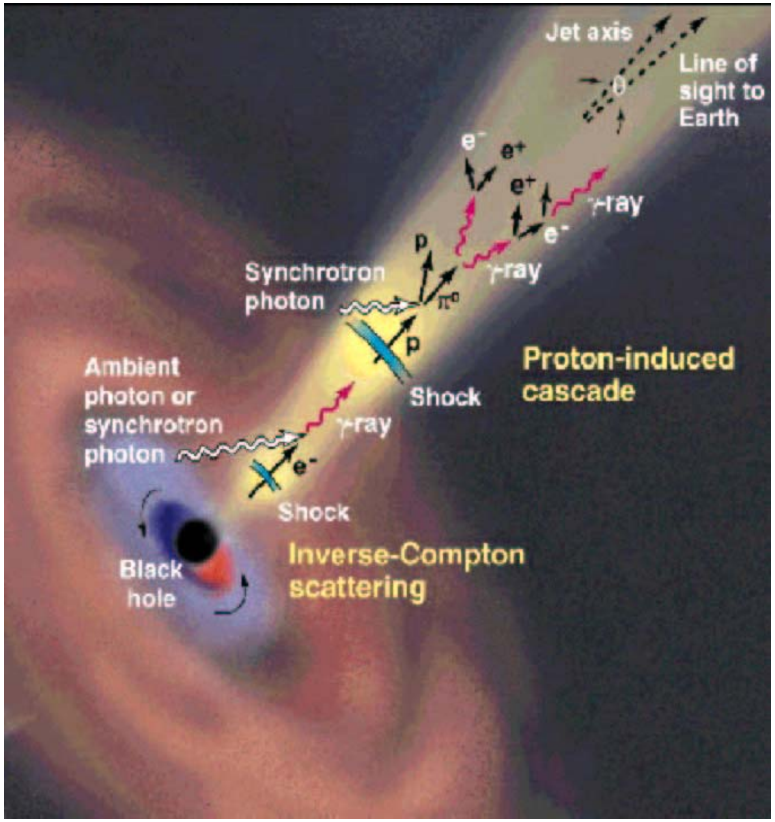
Upgrade and IceCube

- New capabilities of the AMANDA detector
- The IceCube high energy neutrino telescope
- IceTop: the surface component of IceCube
- Simulation of ice Cherenkov detectors for IceTop

black: parallel talk

+ 3 individual contributions

Physics motivation



- origin and acceleration of cosmic rays
- understand cosmic cataclysms
- find new kind of objects?

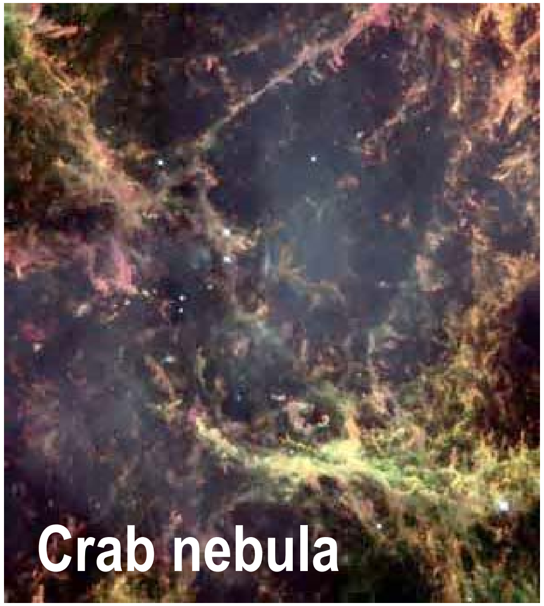
- neutrino properties (ν_τ , cross sections ..)

- dark matter (neutralino annihilation)

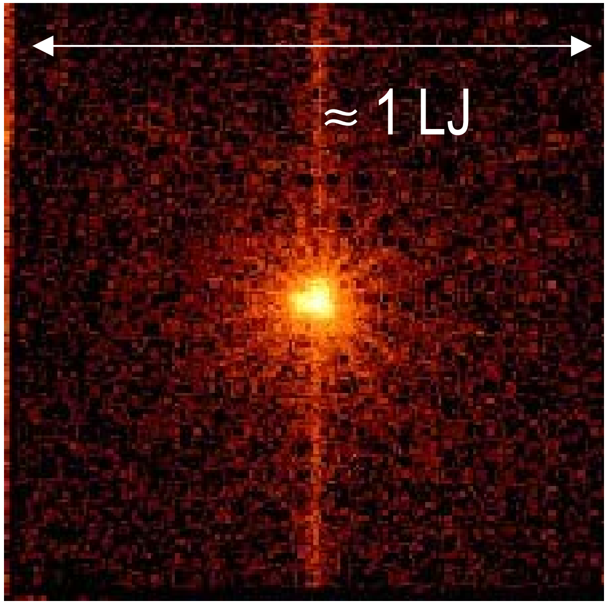
  - *tests of relativitiy ....*
  - *search for big bang relics ...*
  - *effects of extra dimension etc. ...*

Neutrino source candidates

Supernova remnant

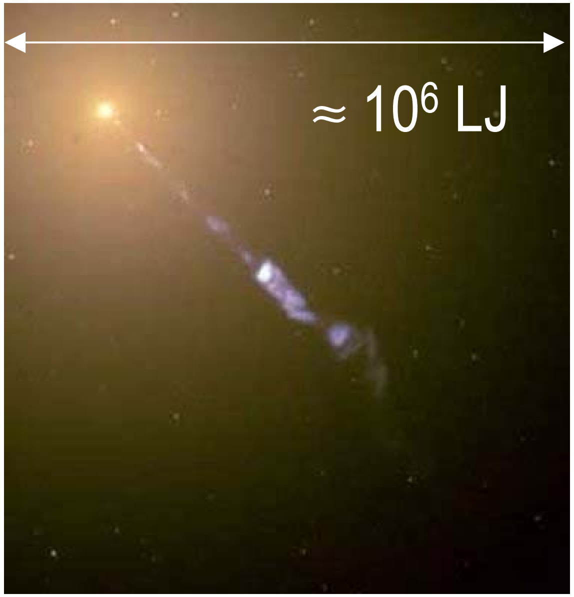


Microquasar
(SS433 etc.)



Black hole with
≈ mass of sun

Active Galaxy
(optically dense, e.g. FRII)



Black hole with
10^8 x mass of sun

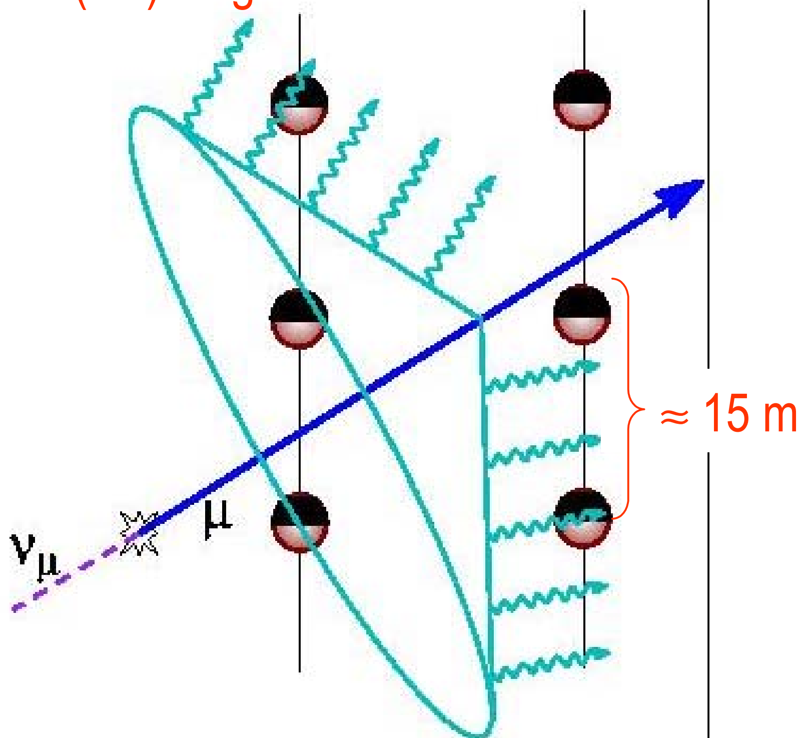
galactic

extra-galactic

Detection of ν_e, ν_μ, ν_τ

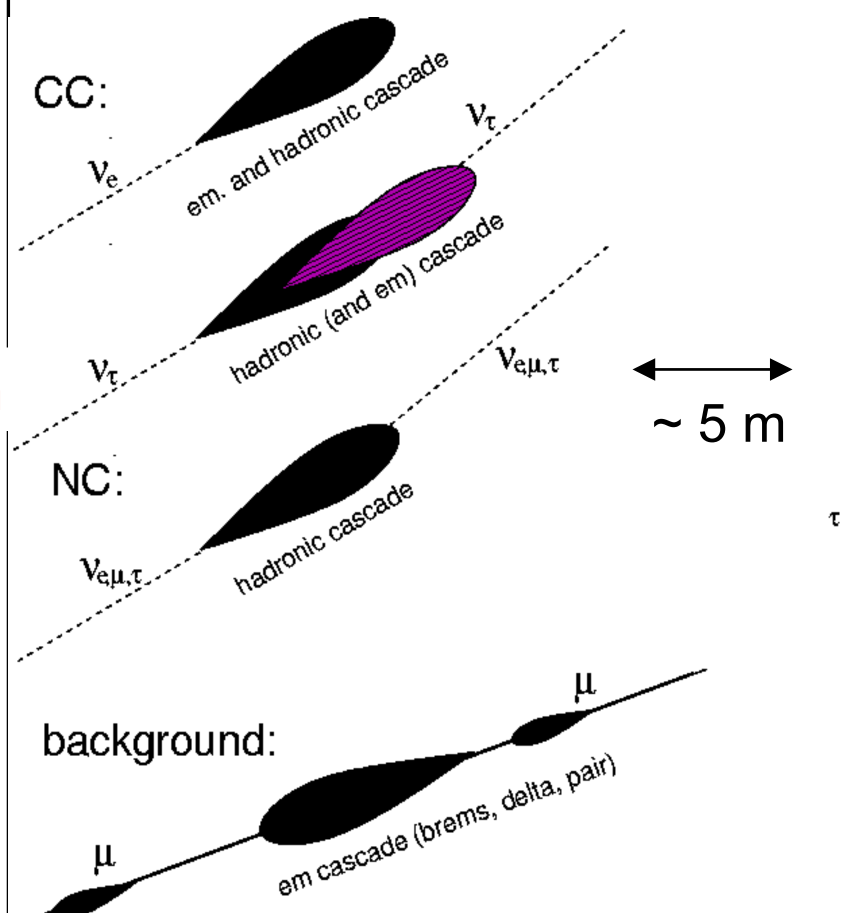
$\nu_e:\nu_\mu:\nu_\tau = 1:2:0$ at source —*oscillation*→ $\nu_e:\nu_\mu:\nu_\tau = 1:1:1$ at Earth !

O(km) long muon tracks

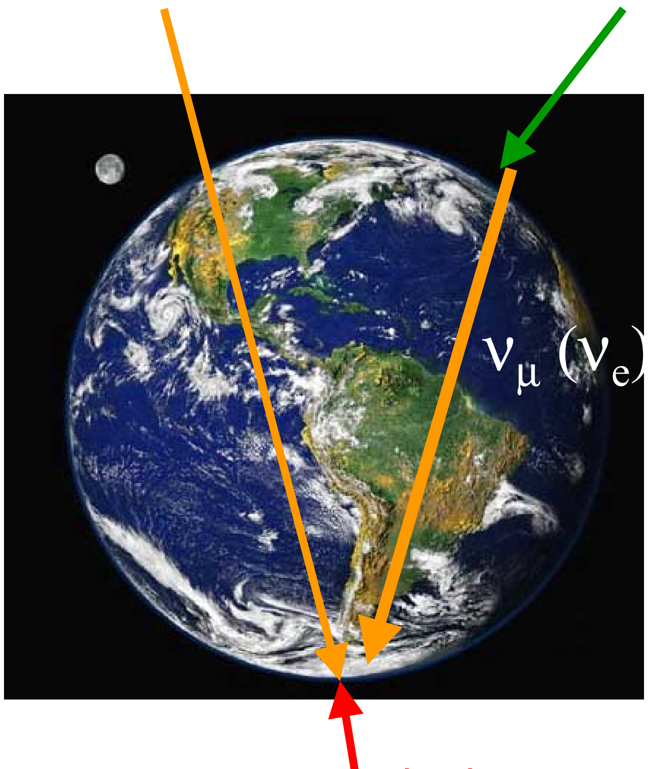


direction determination by Cherenkov light timing

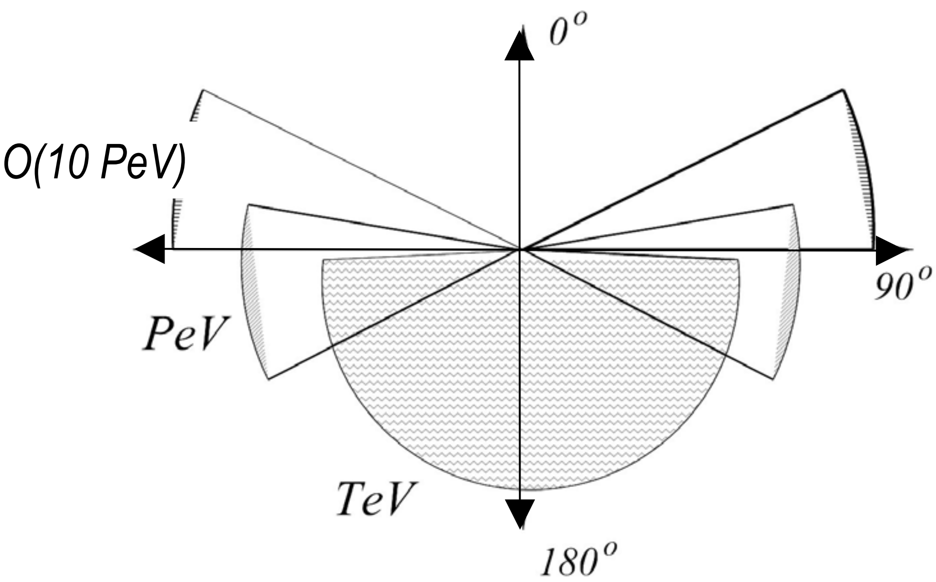
Electromagnetic and hadronic cascades



Detection of muon neutrinos



Above O(PeV): significant ν absorption:



Earth acts as shield

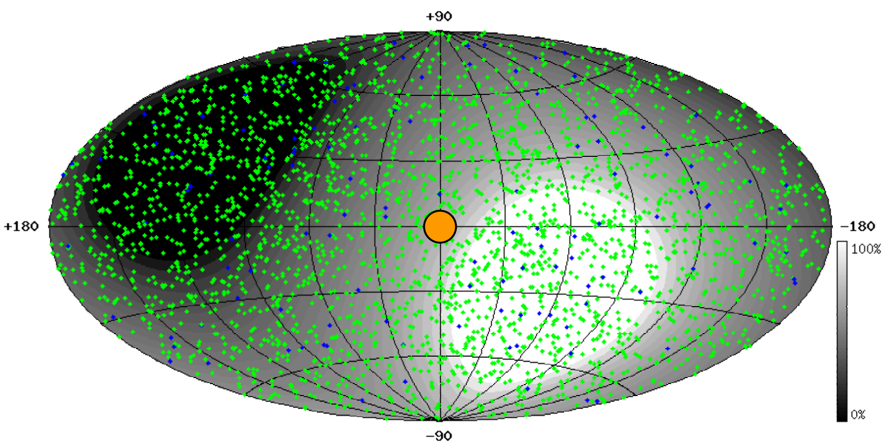
O(PeV): use horizontal events
O(10 PeV): use events from above

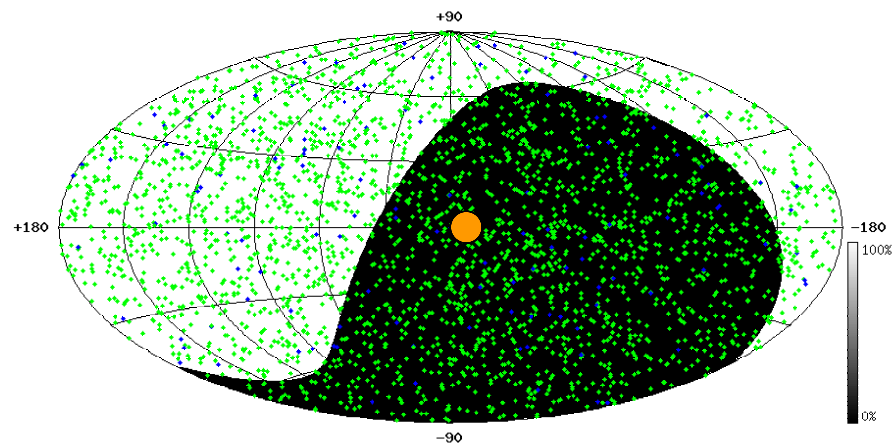
Complementarity (point sources):

E ≈< 100 TeV

Mediterranean (ocean)
Antares, Nestor, 1 km^3 ...

South Pole (ice)
AMANDA, ICECUBE



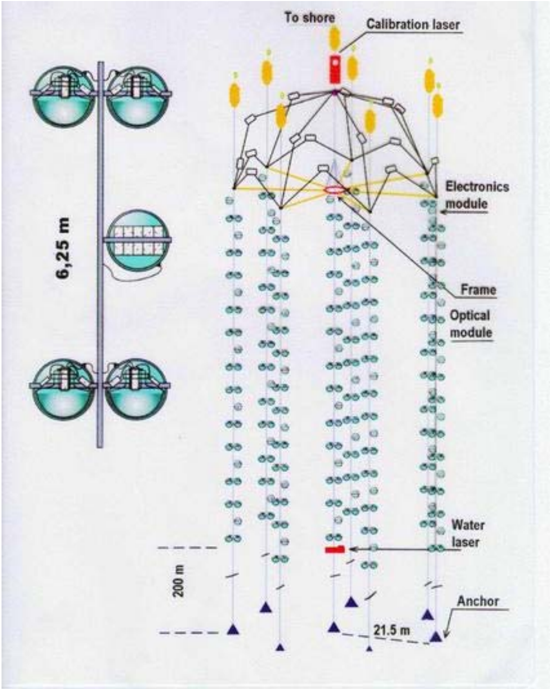


galactic center in middle

dots: distribution of gamma ray bursts (GRBs)

Northern hemisphere detectors

Baikal NT200

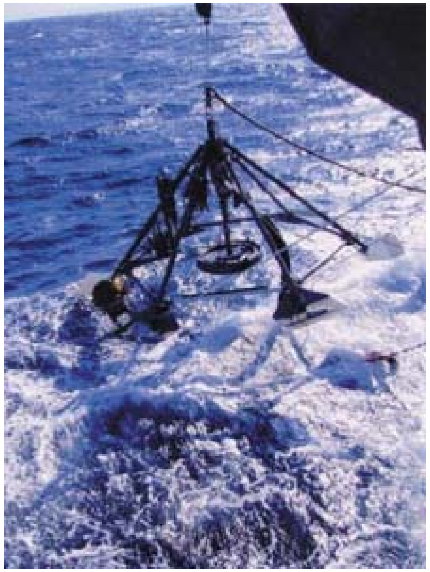


1100 m deep
data taking since 1998
new: 3 distant strings

Antares

March 17, 2003
2 strings connected
2400 m deep
completion: start 2006

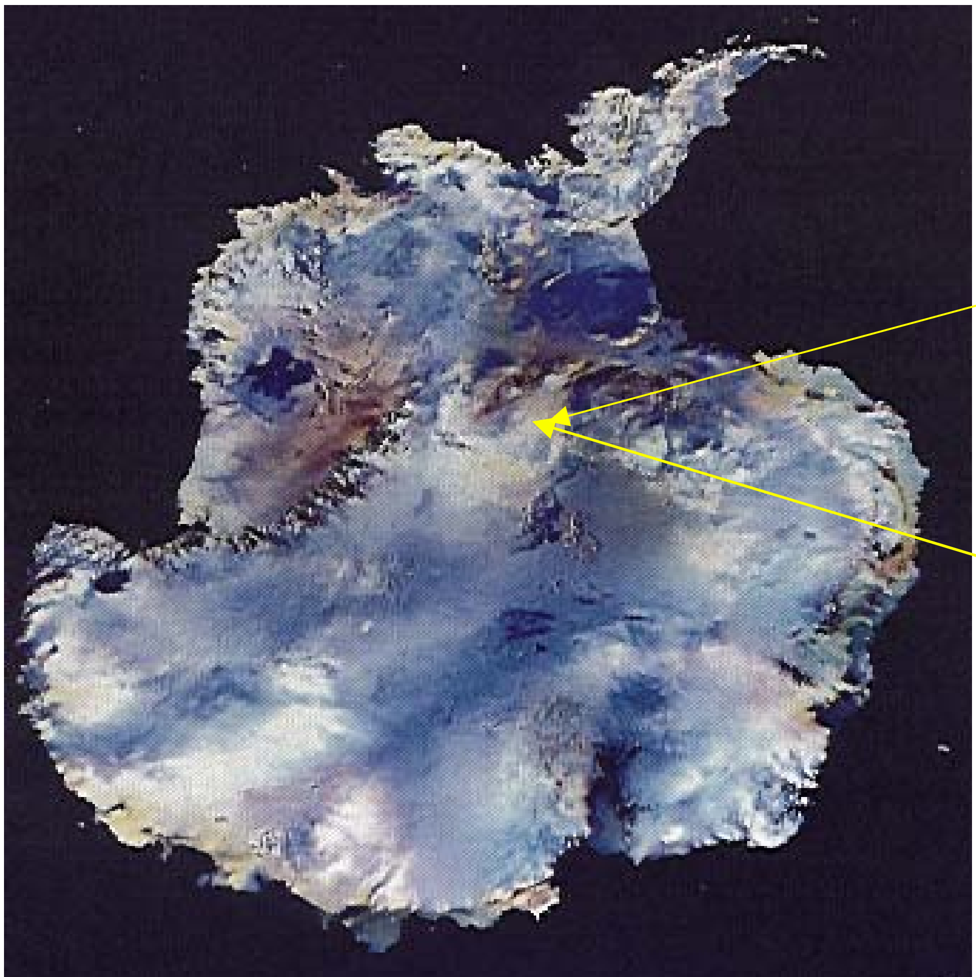
Nestor

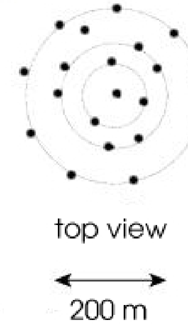


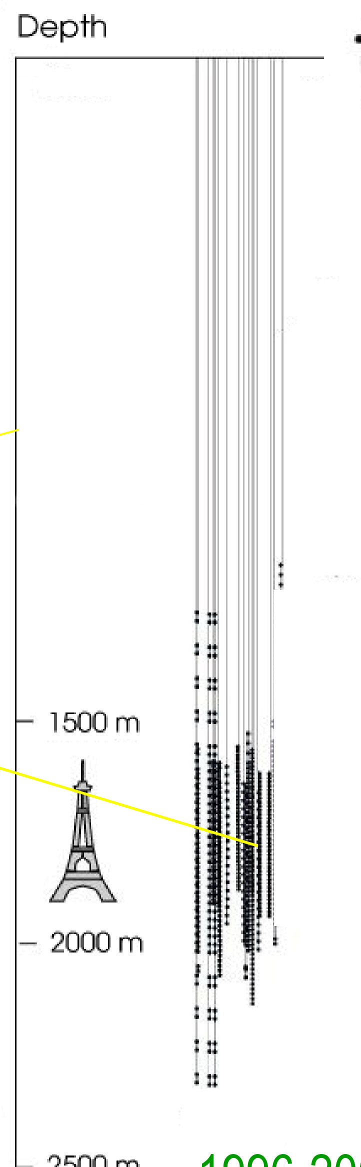
March 29, 2003
1 of 12 floors deployed
4000 m deep
completion: 2006

AMANDA II Detector

Amundsen-Scott Station South Pole





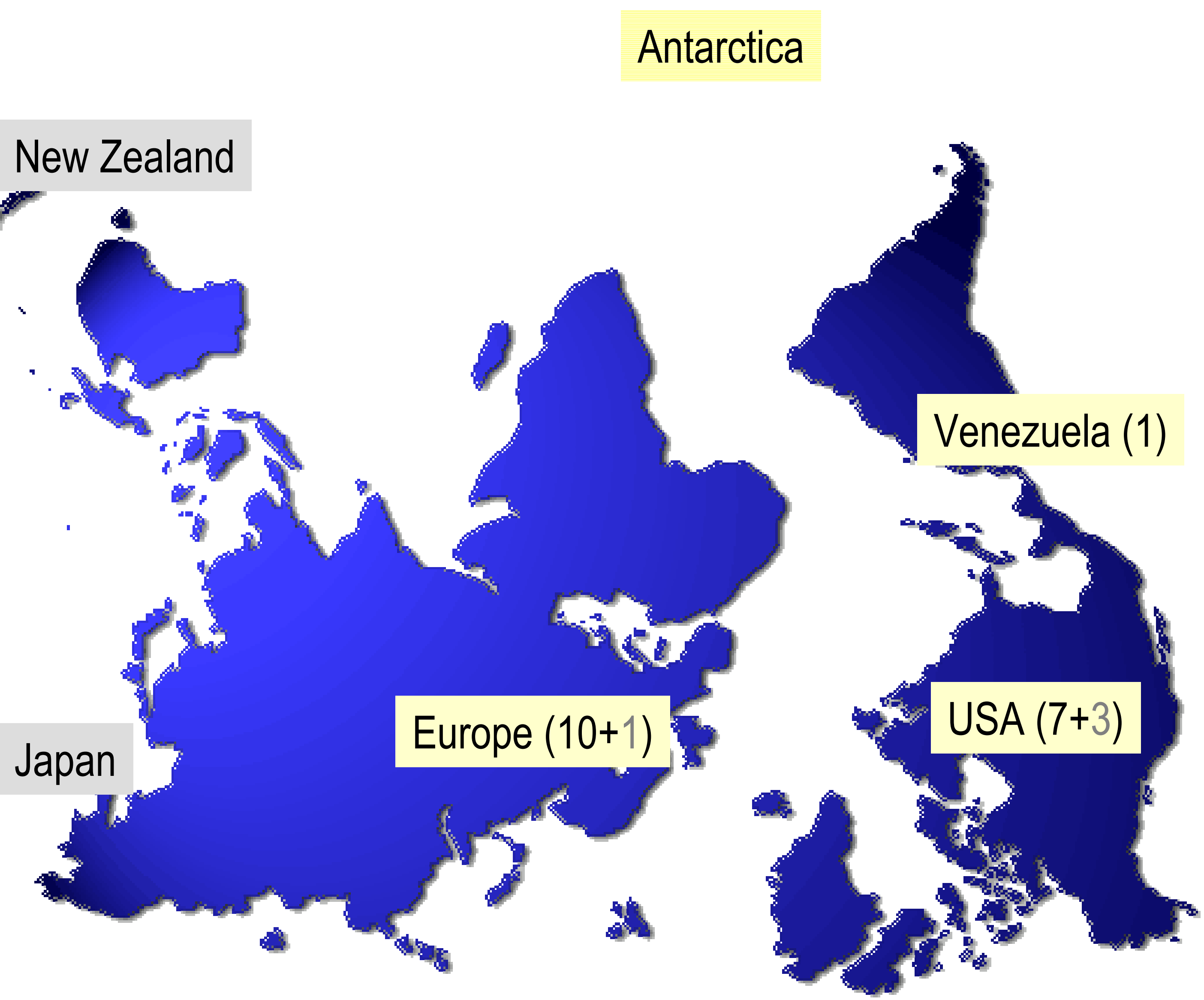


Optical module (677)

1996-2000

The AMANDA Collaboration

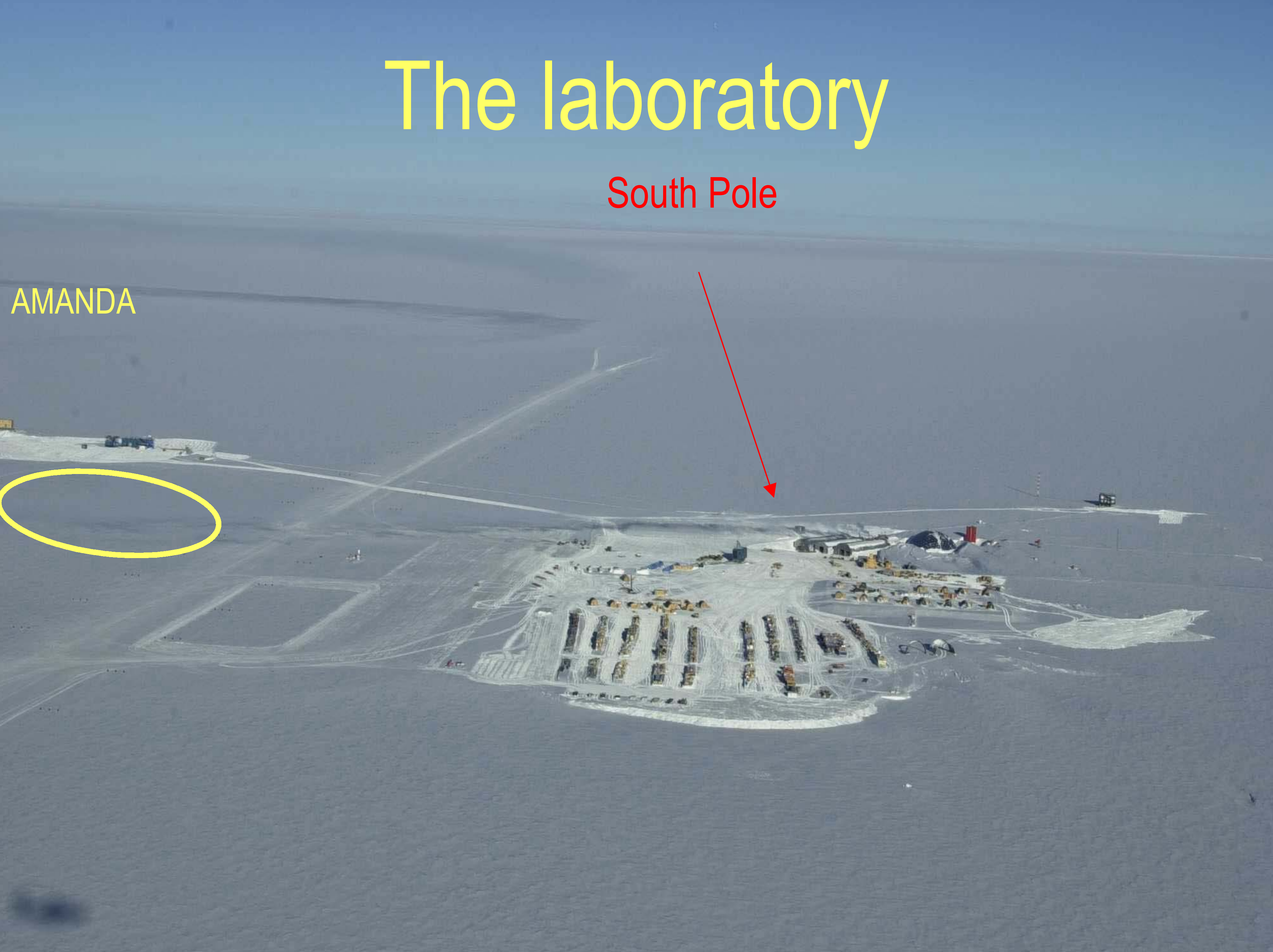
≈ 150 members



Bartol Research Institute
UC Berkeley
UC Iivine
Pennsylvania State
UW Madison
UW River Falls
LBL Berkeley
U. Simón Bolivar, Caracas
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 Antarctica

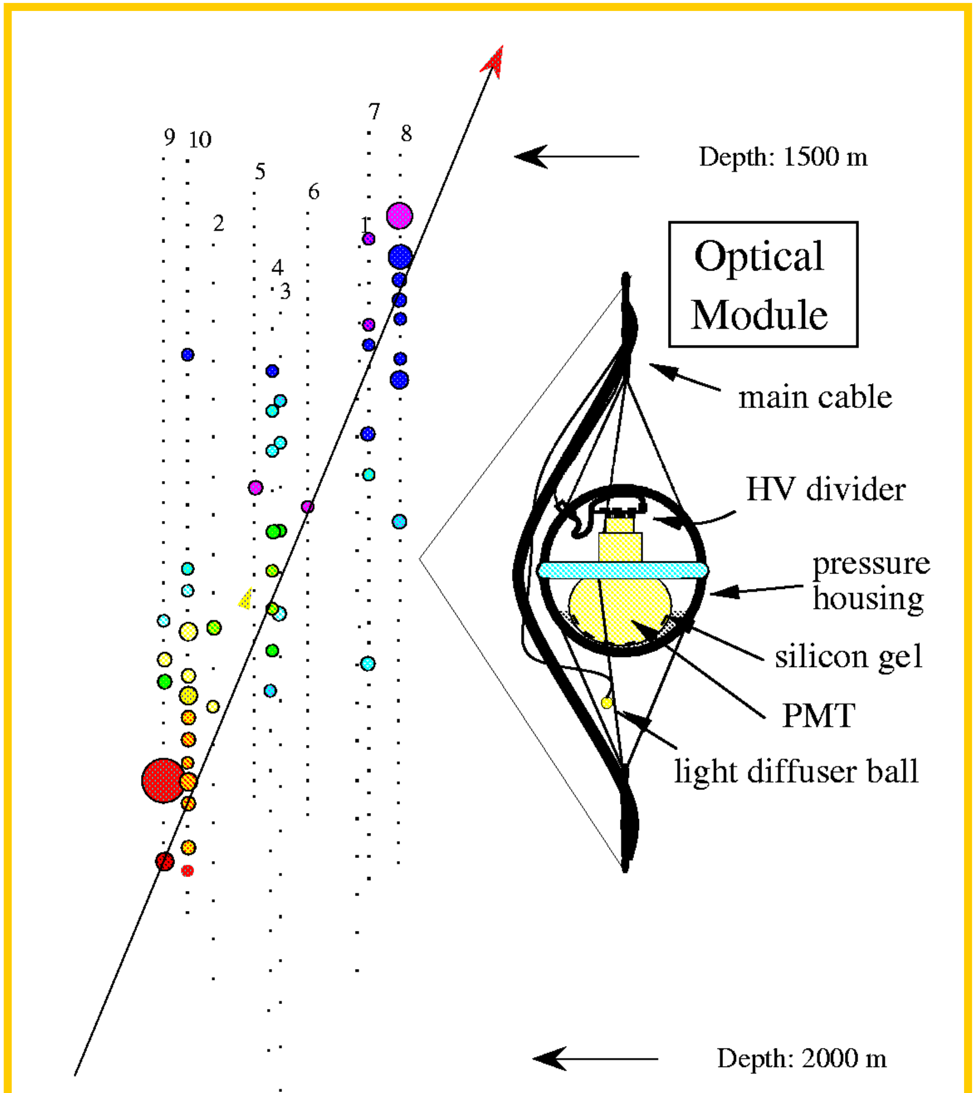
+ associated institutes
e.g. Chiba University

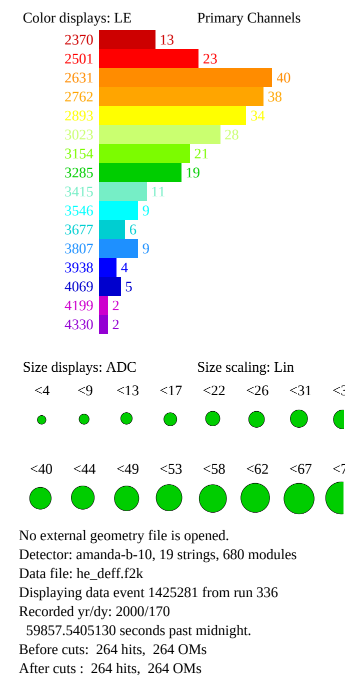
The laboratory




The new station
operating at least
until 2035
The Dome

Two events ...





200 TeV ν_e candidate

Detector capabilities

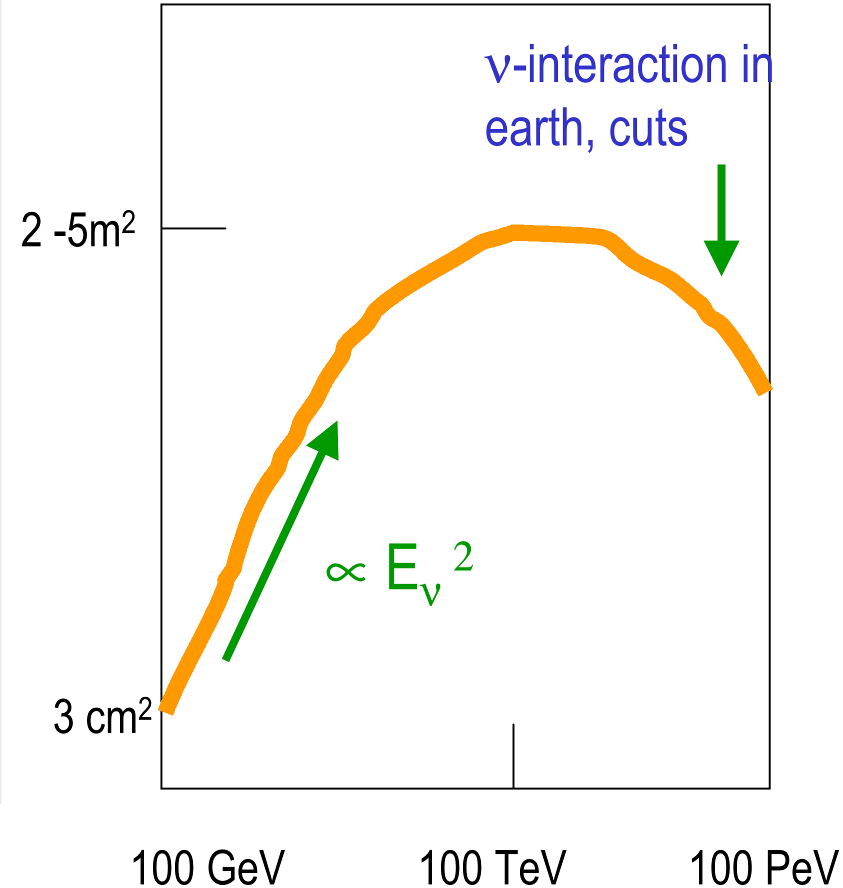
☛ **muons:**
directional error: 2.0 - 2.5°
energy resolution:¶ 0.3 – 0.4
coverage: **2π**

☛ **primary cosmic rays:** (+ SPASE)
energy resolution:¶ 0.07 – 0.10

☛ **„cascades":** ($e^{\pm}$, $\tau^{\pm}$, neutral current)
zenith error: 30 - 40°
energy resolution:¶ 0.1 – 0.2
coverage: **4π**

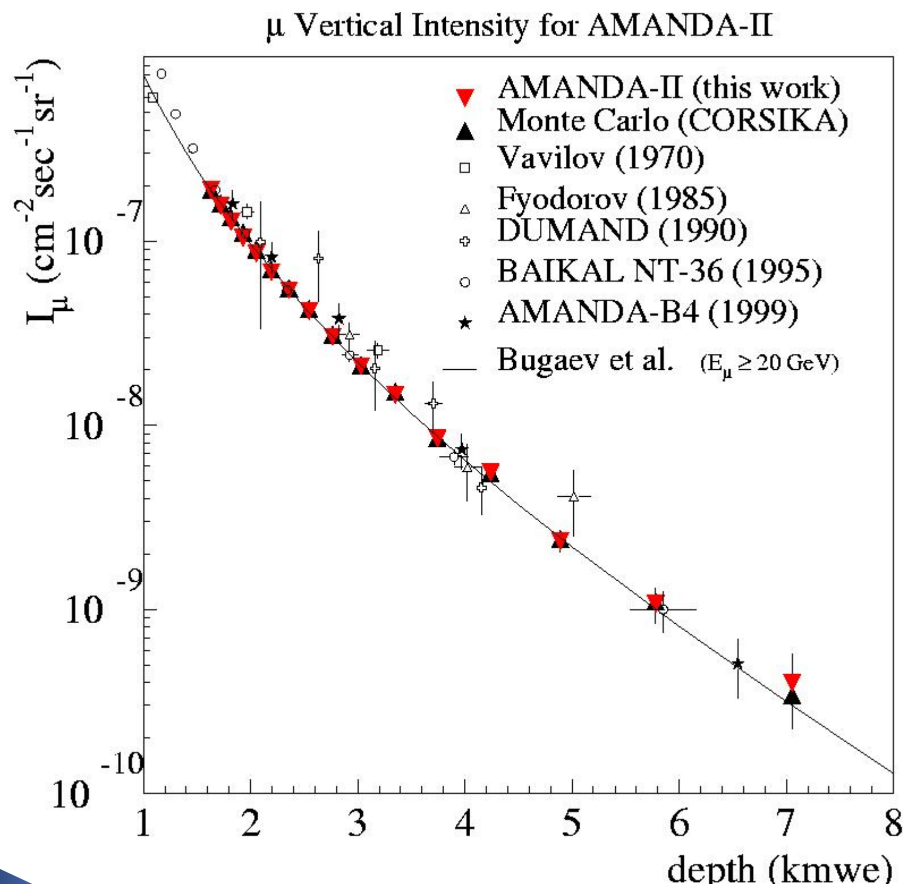
¶$\sigma[\log_{10}(E/TeV)]$

ν_μ effective area (schematic):



Atmospheric muons in AMANDA-II

Atmospheric muons and neutrinos: AMANDA's test beams



PRELIMINARY

much improved simulation

...but data 30% higher than MC ...

↪ normalize to most vertical bin

Systematic errors:

☛ 10% scattering (20m @ 400nm)
absorption (110m @ 400nm)

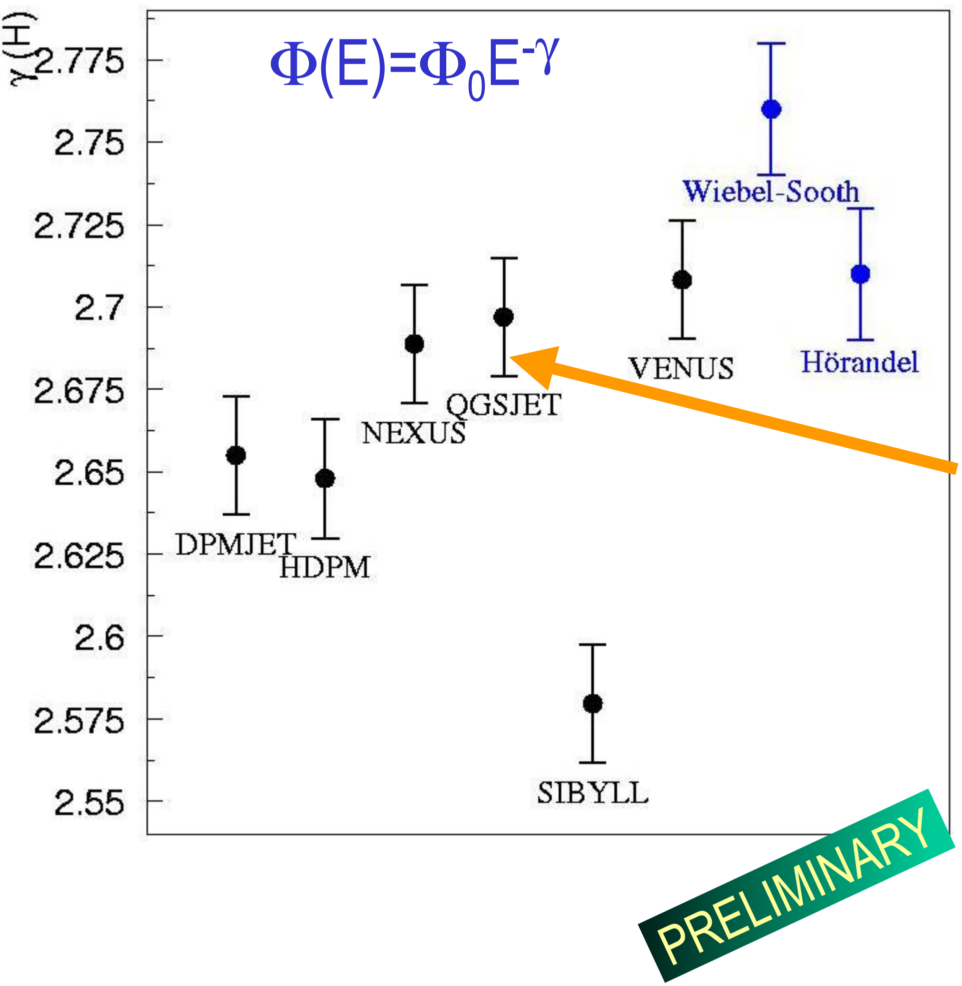
☛ 20% optical module sensitivity

☛ 10% refreezing of ice in hole

threshold energy ~ 40 GeV (zenith averaged)

Cosmic Ray flux measurement

In some cases ice and OM-sensitivity effect can be circumvented ...



empirical separation of ice and OM sensitivity effects

for QGSJET generator:

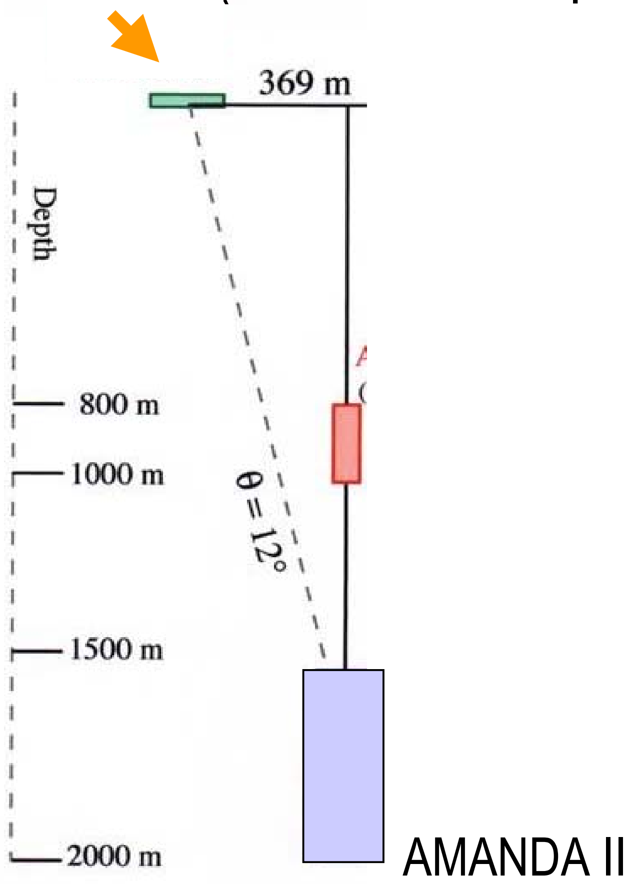
- γ(H) = 2.70 ± 0.02
- Φ_0 (H) = 0.106(7) $m^{-2}s^{-1}sr^{-1}TeV^{-1}$

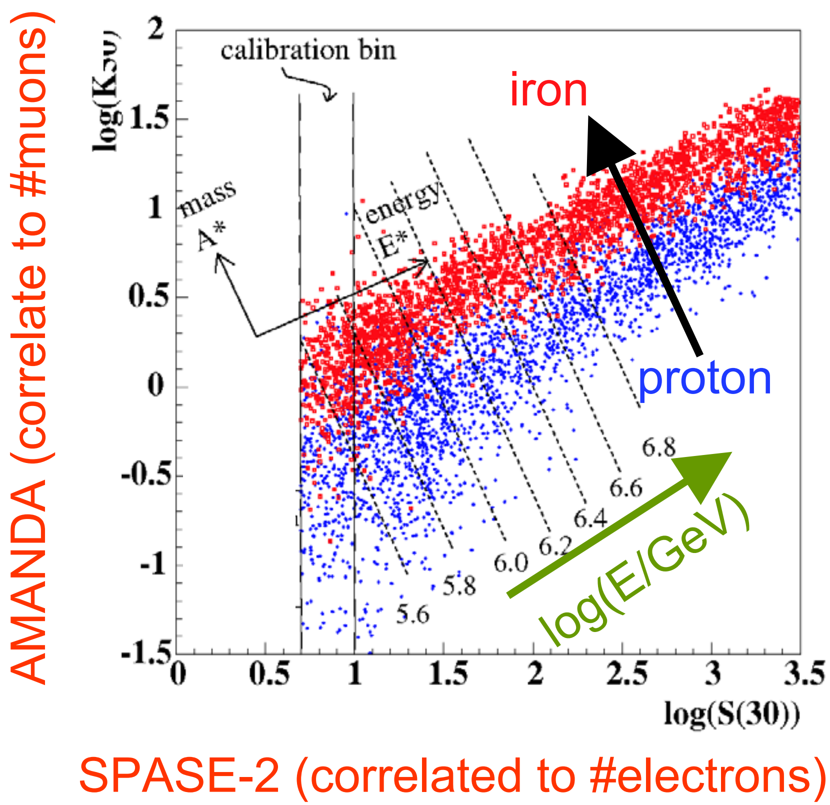
Spectral index γ compatible with direct measurements, error competivie

cosmic ray composition studies

SPASE-2 (electronic component) - AMANDA B10 (muonic component)

- unique combination!





robust evidence for composition change around knee ...

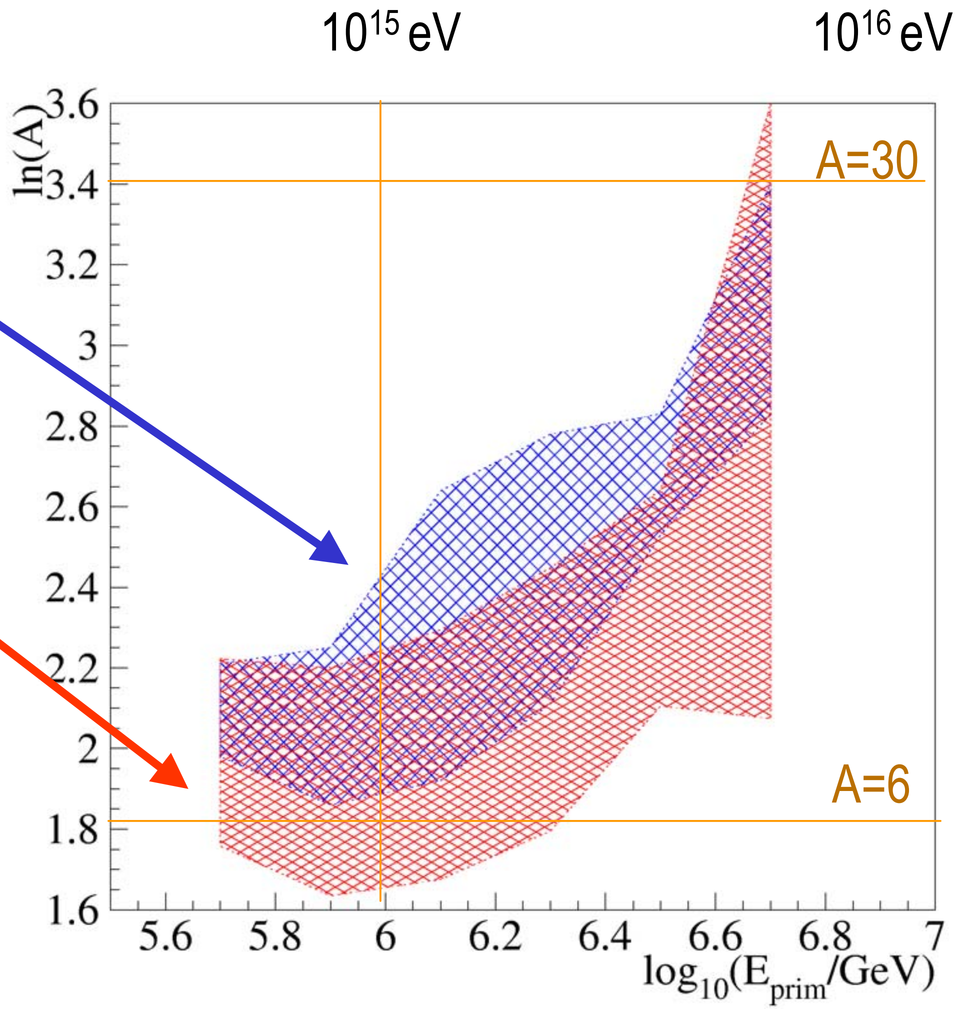
Composition change around „knee“

blue band: detector and model uncertainties

red band: uncertainty due to low energy normalization

confirms trend seen by other experiments ...

publication in preparation (1998 data)

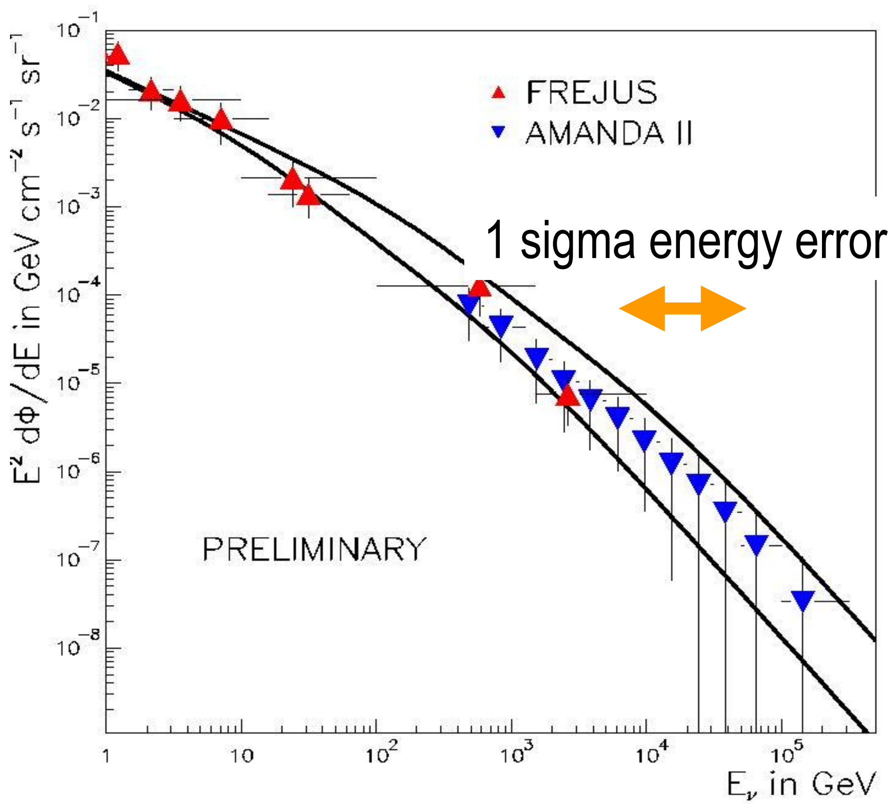


Atmospheric ν's in AMANDA-II

PRELIMINARY

- neural network energy reconstruction
- regularized unfolding

measured atmospheric neutrino spectrum



- spectrum up to 100 TeV
- compatible with Frejus data

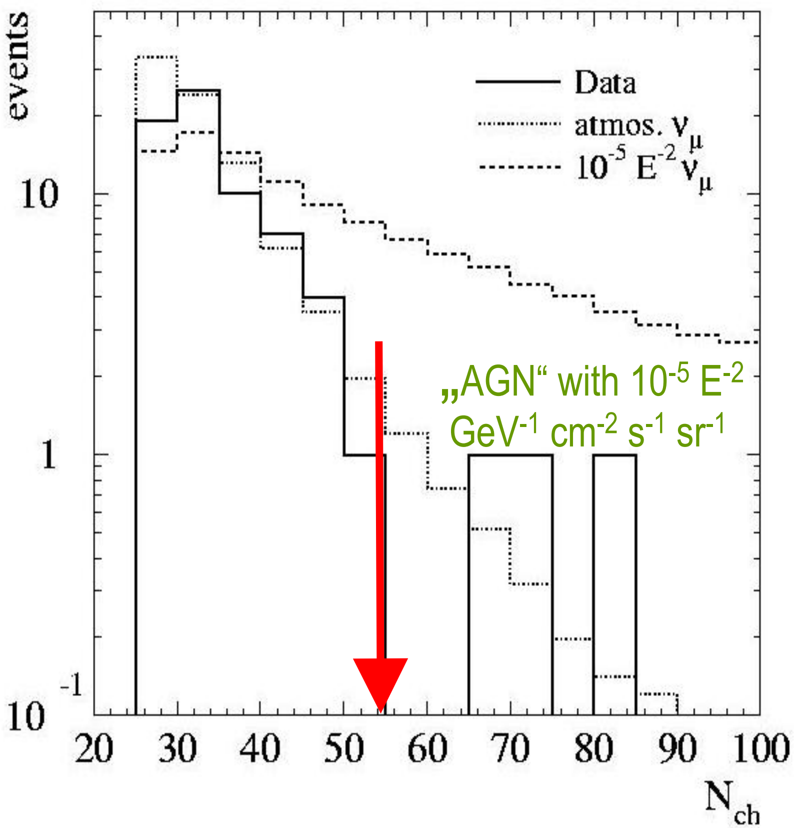
presently no sensitivity to LSND/Nunokawa prediction of dip structures between 0.4-3 TeV

In future, spectrum will be used to study excess due to cosmic ν's

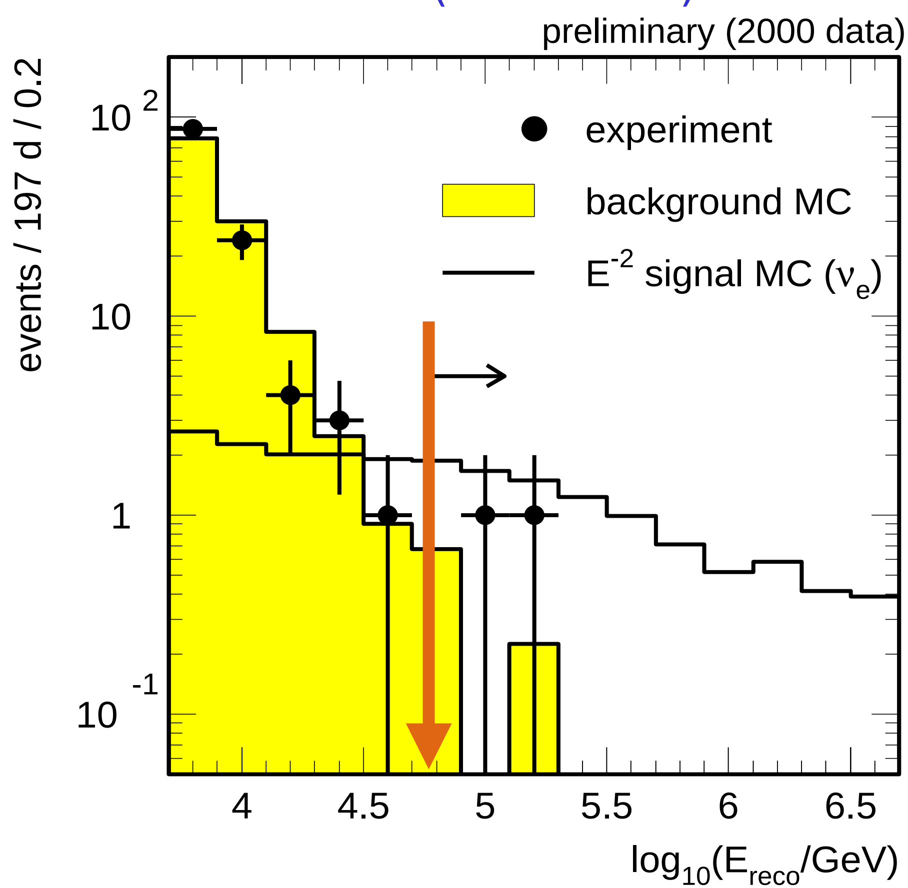
Excess of cosmic neutrinos? Not yet ...

.. for now use number of optical modules hit as energy variable ...

muon neutrinos (1997 B10-data) accepted by PRL



cascades (2000 data)



cuts determined by MC – blind analyses !

Diffuse flux muon neutrinos

Note that limits depend on assumed energy spectrum ...

$3 \cdot 10^3 - 10^6$ GeV:

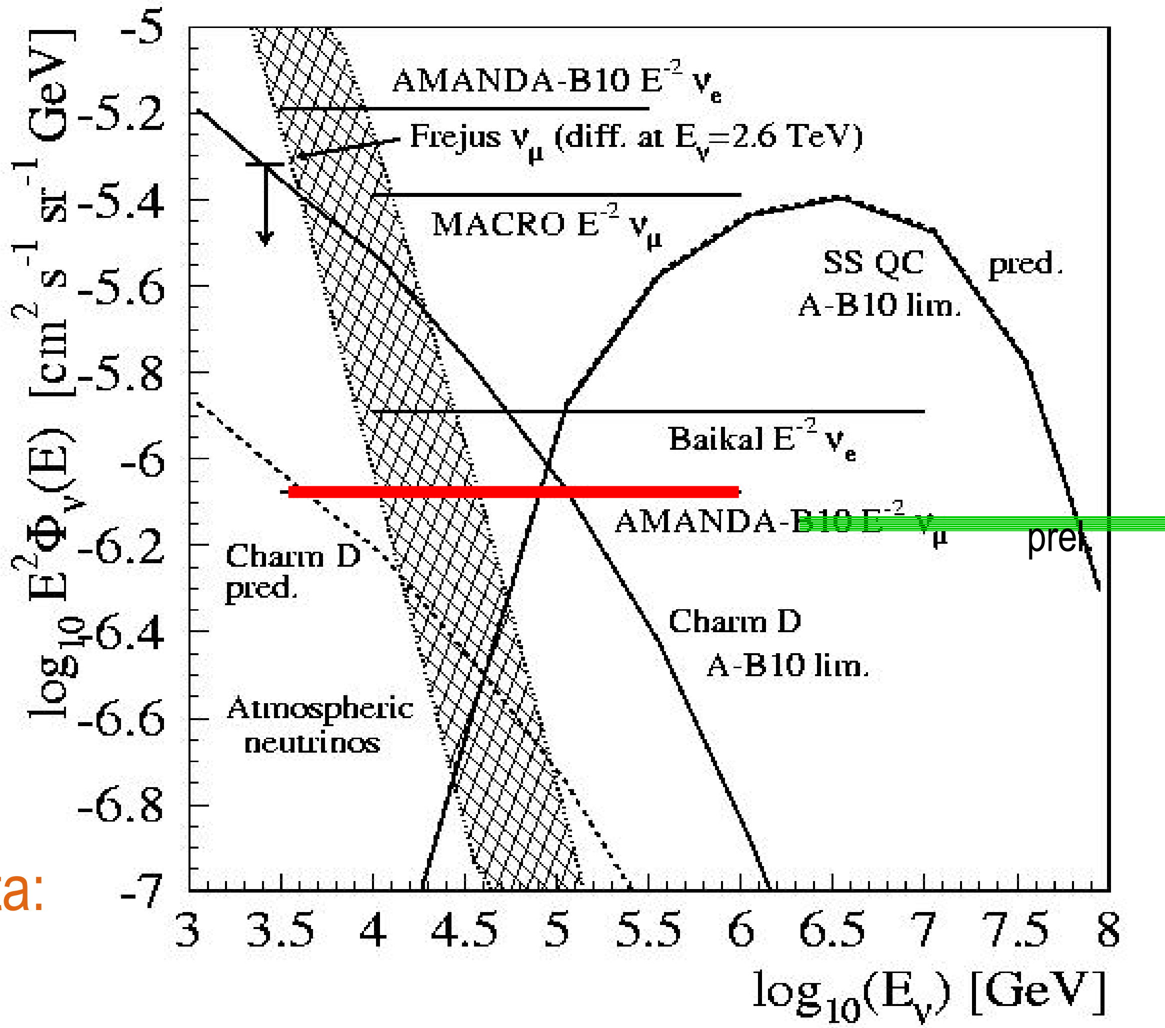
$E^2\,\Phi(E) < 8 \cdot 10^{-7}$

$GeV^{-1}\,cm^{-2}\,s^{-1}\,sr^{-1}$

$2.5 \cdot 10^6 - 5.6 \cdot 10^8$ GeV:

$E^2\,\Phi(E) < 7.2 \cdot 10^{-7}$

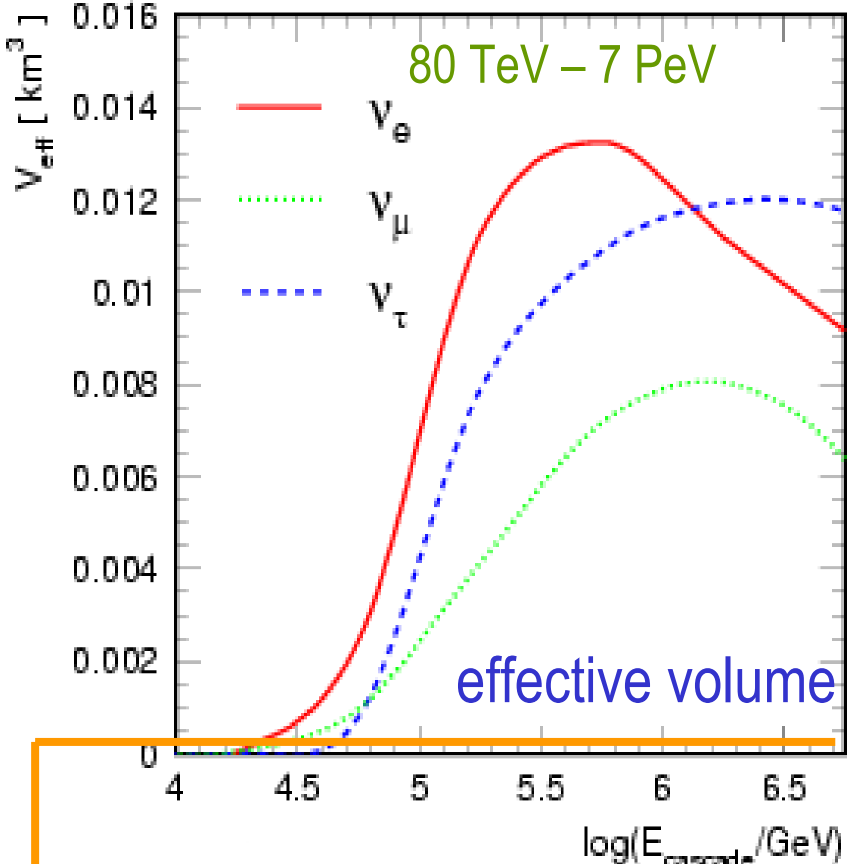
$GeV^{-1}\,cm^{-2}\,s^{-1}\,sr^{-1}$

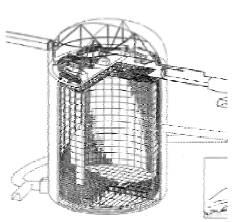


Expected sensitivity 2000 data:

$\sim 3 \cdot 10^{-7}$ $GeV^{-1}\,cm^{-2}\,s^{-1}\,sr^{-1}$

Diffuse limit cascades





PRELIMINARY

- after acceptance expect:

  $\nu_e : \nu_\mu : \nu_\tau \approx 1 : 0.67 : 0.85$ events

- 2 candidate events total observed

90% CL upper limit:

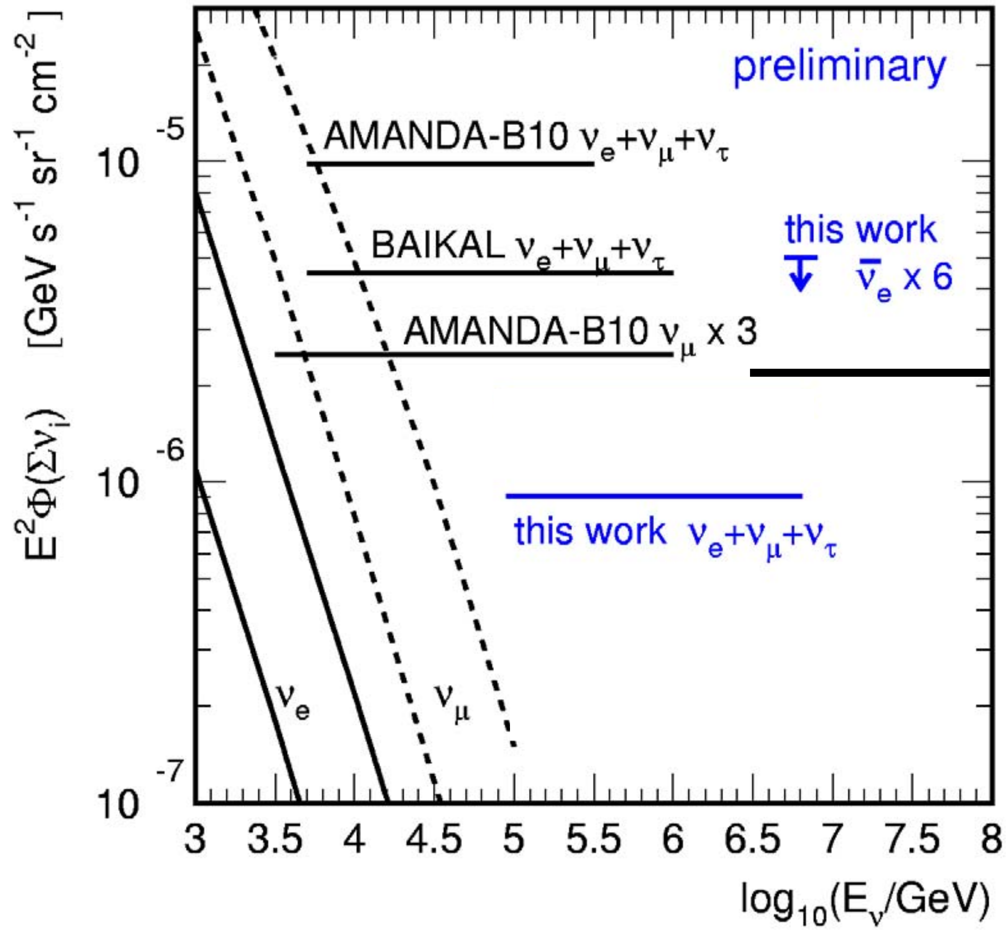
$E^2\Phi_{all\ \nu}(E) < 9\cdot10^{-7}$ GeV cm^{-2}s^{-1}sr^{-1}

Flux results summary (all flavors)

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

- special analysis for resonant
  $$\bar{\nu}_e + e^- \rightarrow W^- \rightarrow \bar{\nu}_e + e^-$$
  production (6.3 PeV)
- multiplicative factor 3 applied for single ν_e ,ν_μ channels …

...can combine analyses !



2000 ν_μ analysis will yield comparable result

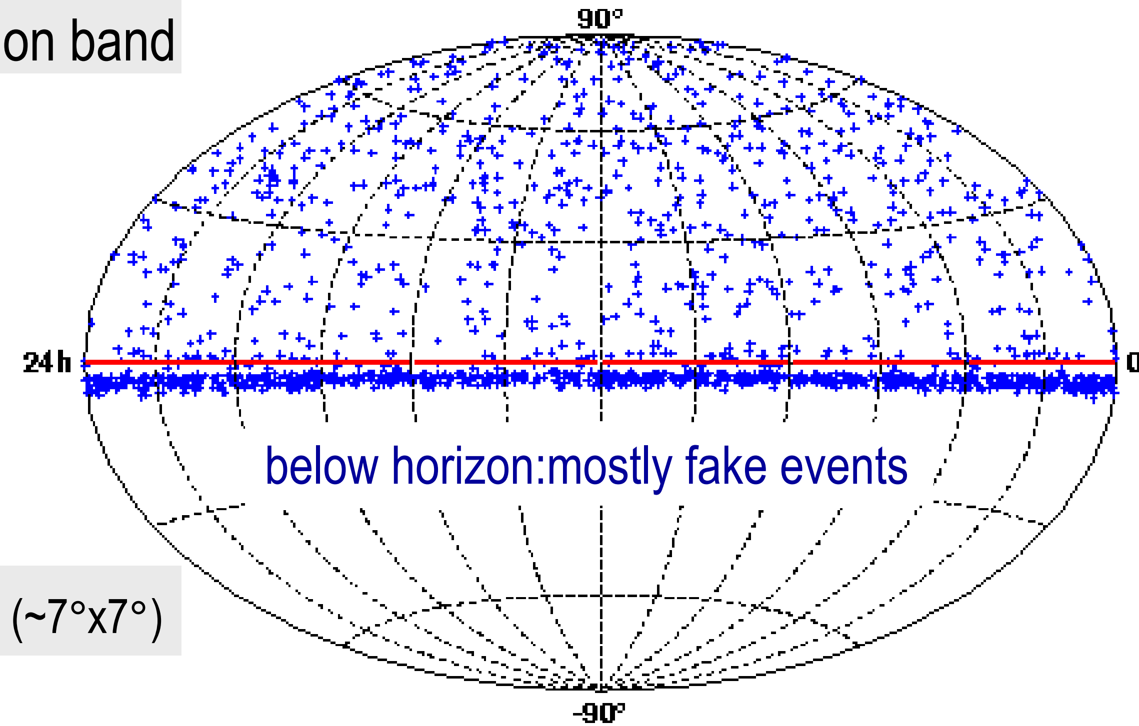
Point source search in AMANDA II

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

PRELIMINARY

- 697 events observed above horizon
- 3% non-neutrino background for $\theta > 5°$
- cuts optimized in each declination band

above horizon: mostly atmospheric ν's



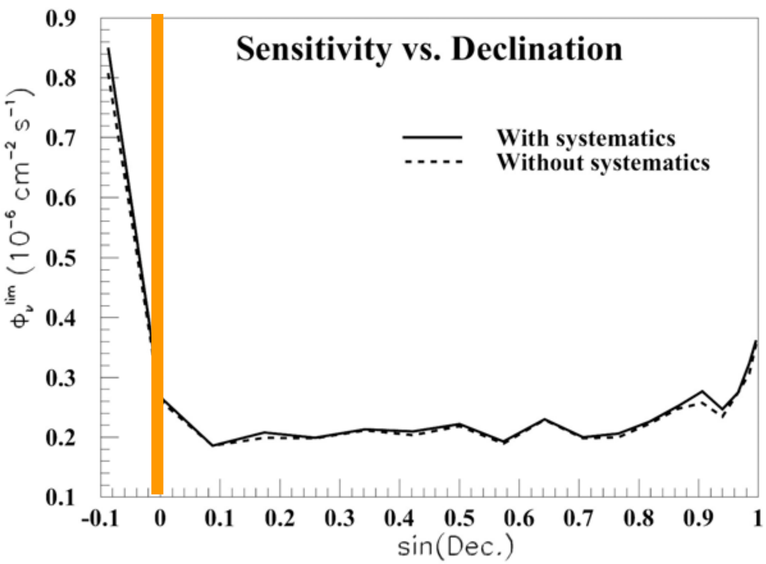
- sky subdivided into 300 bins (~7°x7°)

no clustering observed - no evidence for extraterrestrial neutrinos ...

Selected point source flux limits

sensitivity ≈ flat above horizon - 4 times better than B10 ¶!

PRELIMINARY

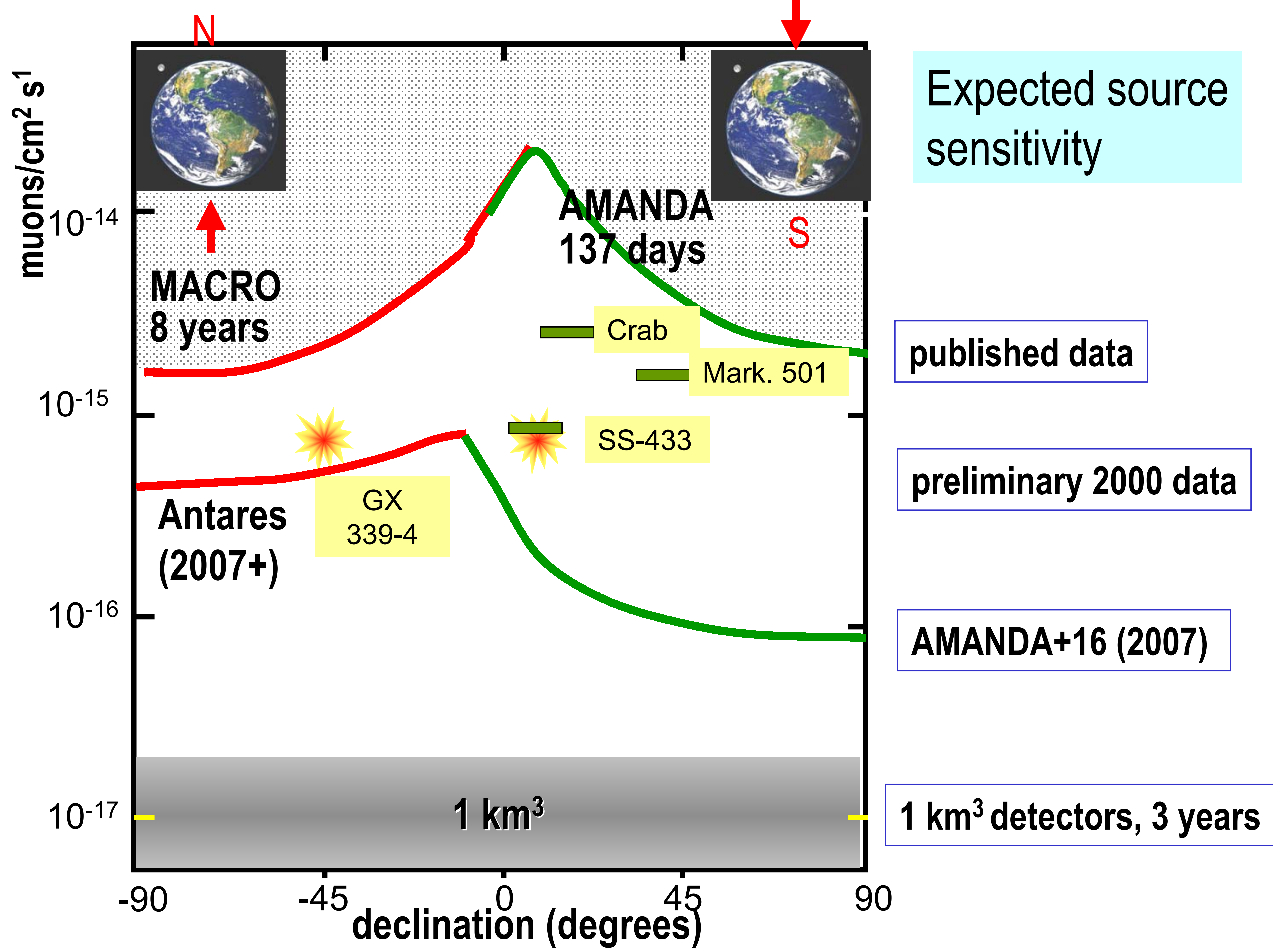


declination averaged sensitivity:
$\Phi_\nu^{lim} \approx 2.3 \cdot 10^{-8}$ cm^{-2}s^{-1} @90%

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

upper limits @ 90% CL in units of 10^{-8}cm^{-2}s^{-1}

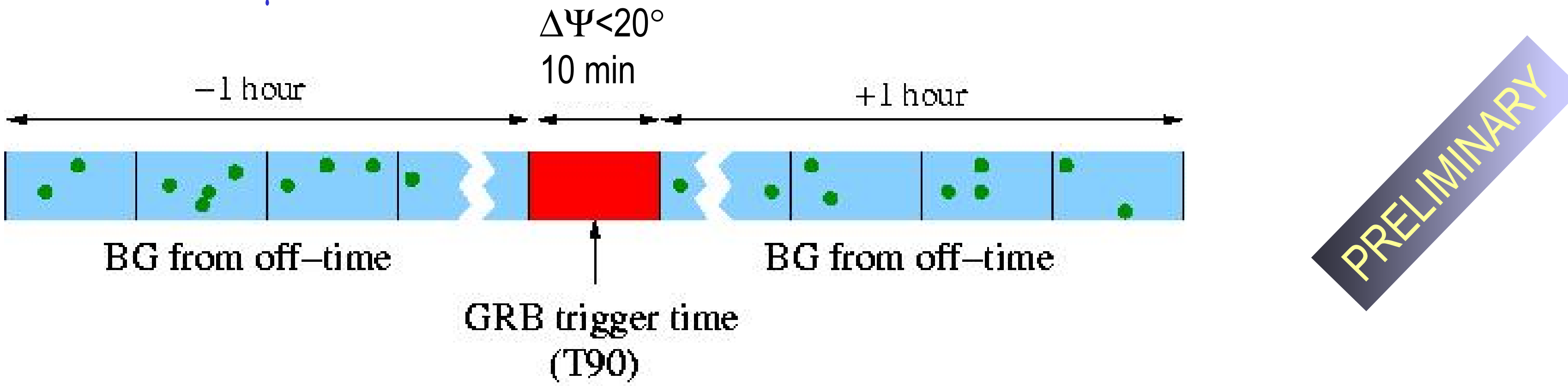
¶ published Ap. J, 582 (2003)



Expected source sensitivity
muons/cm² s¹
declination (degrees)
-90
-45
0
45
90
10-14
10-15
10-16
10-17
N
S
MACRO
8 years
AMANDA
137 days
Crab
Mark. 501
SS-433
GX
339-4
Antares
(2007+)
1 km³
published data
preliminary 2000 data
AMANDA+16 (2007)
1 km³ detectors, 3 years

GRB ν search in AMANDA

Search for ν_μ candiates correlated with GRBs - background established from data



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

- 317 BATSE triggers (1997—2000)
- effective μ-area ≈ 50000 m^2

  low background due to space- time coincidence

- **No excess observed!**

  assuming WB spectrum 4 x 10^{-8}GeV/s/cm^2/sr

analysis continues with non-triggered BATSE and IPN3 data …

Outlook

... did not mention new improved search for WIMPs (HE 3.3-6)
... supernova detection (1-P-258) *etc.*

..no extraterrestrial neutrinos found yet ...but:

☛ combined analysis 1997-2003: 8 x more days !

☛ improved selection and analysis methods ...

☛ new transition waveform based readout installed 02/03
improved performance in particular at high energies (1-P-264)

☛ first IceCube strings 2004/05 – combined analysis with AMANDA

Importance of all flavor detection

Extended source with $\nu_e:\nu_\mu:\nu_\tau$ =1:2:0 production (e.g. $\pi^\pm$ decay) :

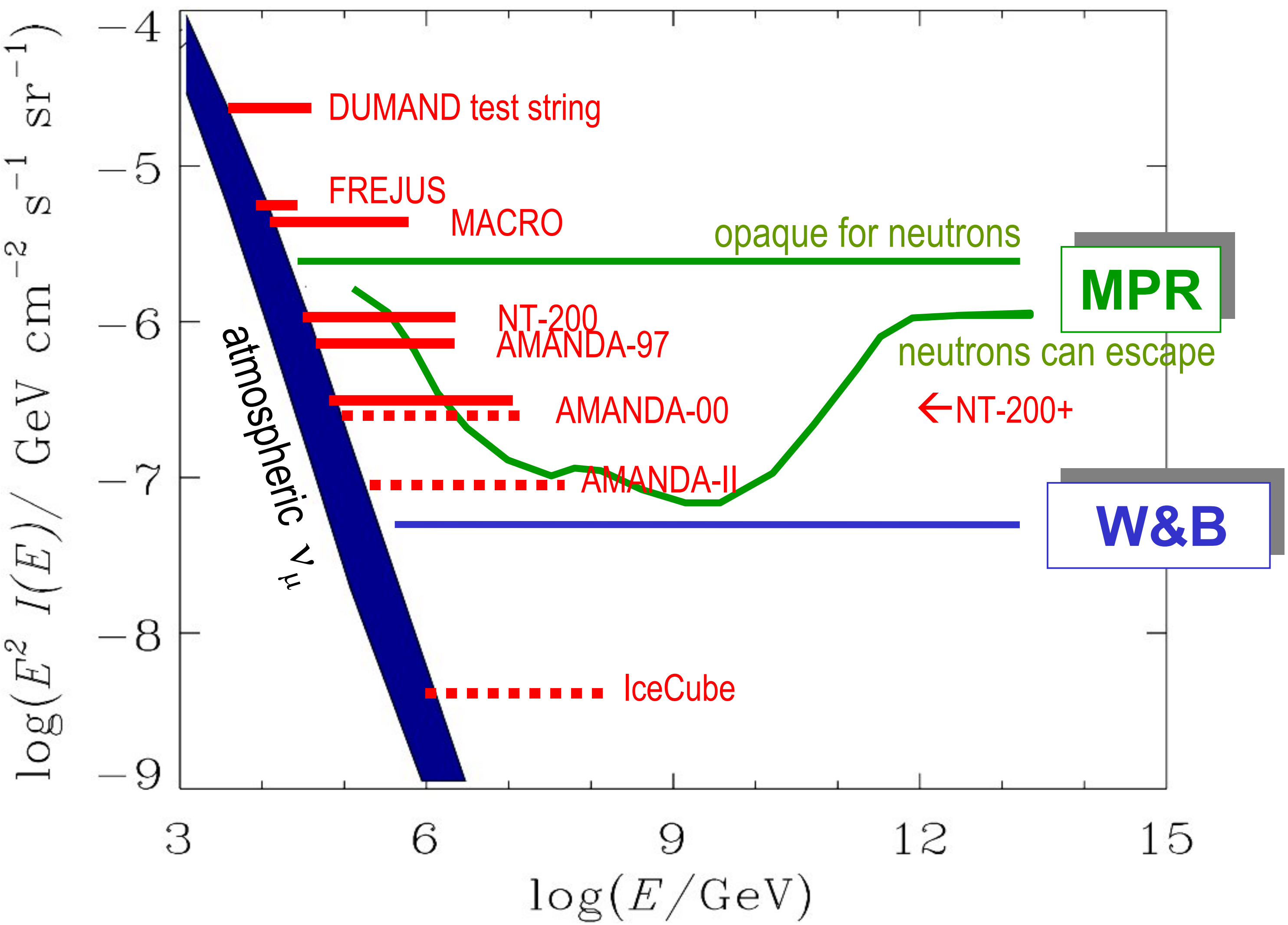
E.g.: Maki-Nakagawa-Sakato mixing matrix with $\theta_{12}=30°$, $\theta_{23}=45°$, $\theta_{13}=0°$*:*

$$U^{NMS} = \sqrt{\frac{1}{8}} \times \begin{pmatrix} \sqrt{6} & \sqrt{2} & 0 \\ -1 & \sqrt{3} & 2 \\ 1 & -\sqrt{3} & 2 \end{pmatrix}$$

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

- ☛ O(10) x less background for ν_e – but you don't profit from long μ-range
- ☛ Regeneration of ν_τ - no absorption in earth even at very high energies !

Theoretical bounds and future



Mannheim, Protheroe and Rachen (2000) – Waxman, Bahcall (1999)

↳ derived from known limits on extragalactic protons + γ-ray flux