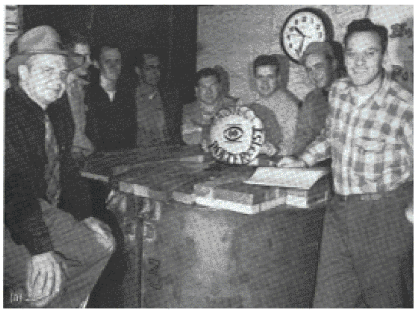
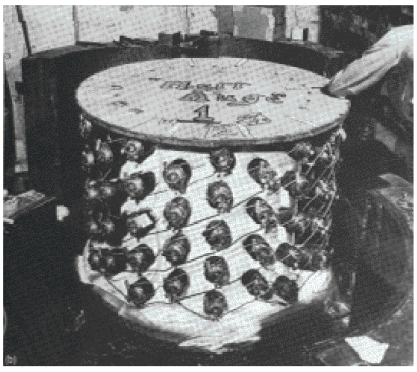
Francis Halzen
University of Wisconsin
http://icecube.wisc.edu

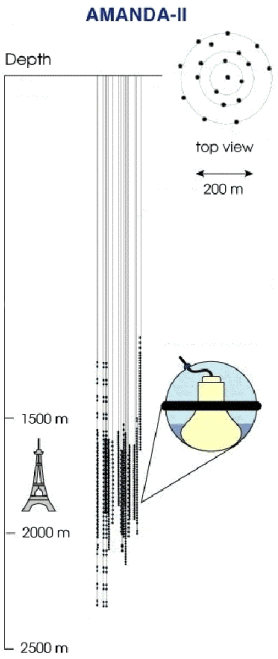
The real voyage is not to travel to new landscapes, but to see with new eyes. . .

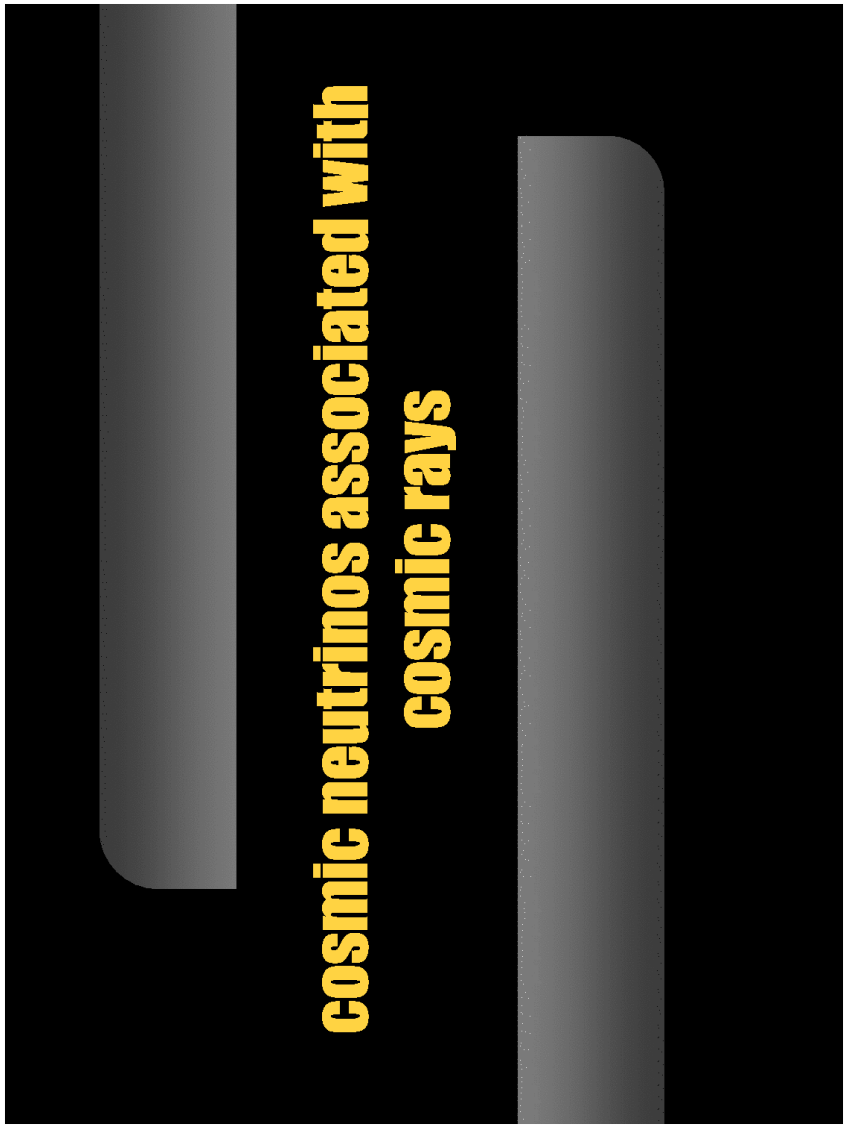
Marcel Proust

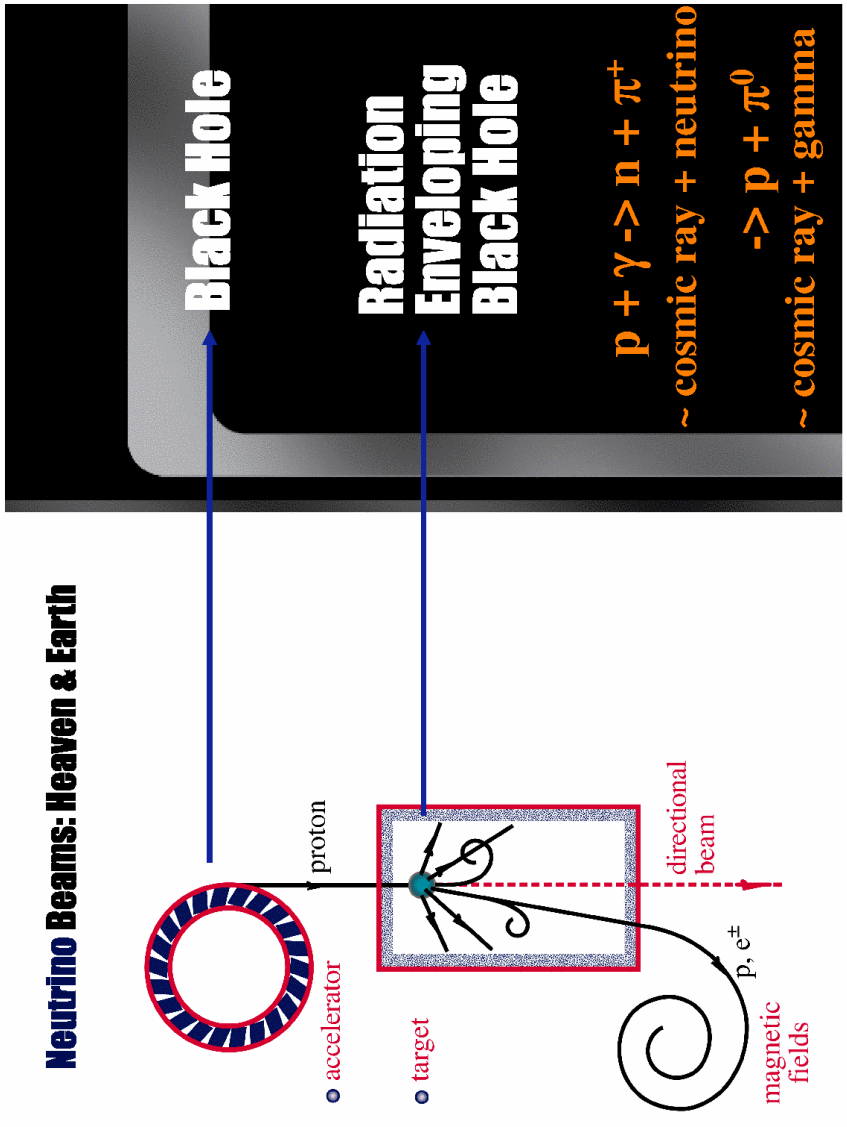
Kilometer-Scale Neutrino Detectors





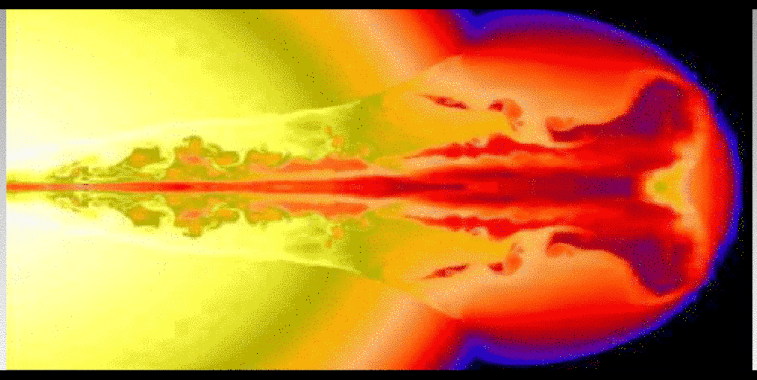



cosmic neutrinos associated with
cosmic rays


Black Hole
Radiation
Enveloping
Black Hole
p + γ -> n + π+
~ cosmic ray + neutrino
-> p + π0
~ cosmic ray + gamma
Neutrino Beams: Heaven & Earth
proton
accelerator
target
directional
beam
p, e±
magnetic
fields

Gamma Ray Bursts

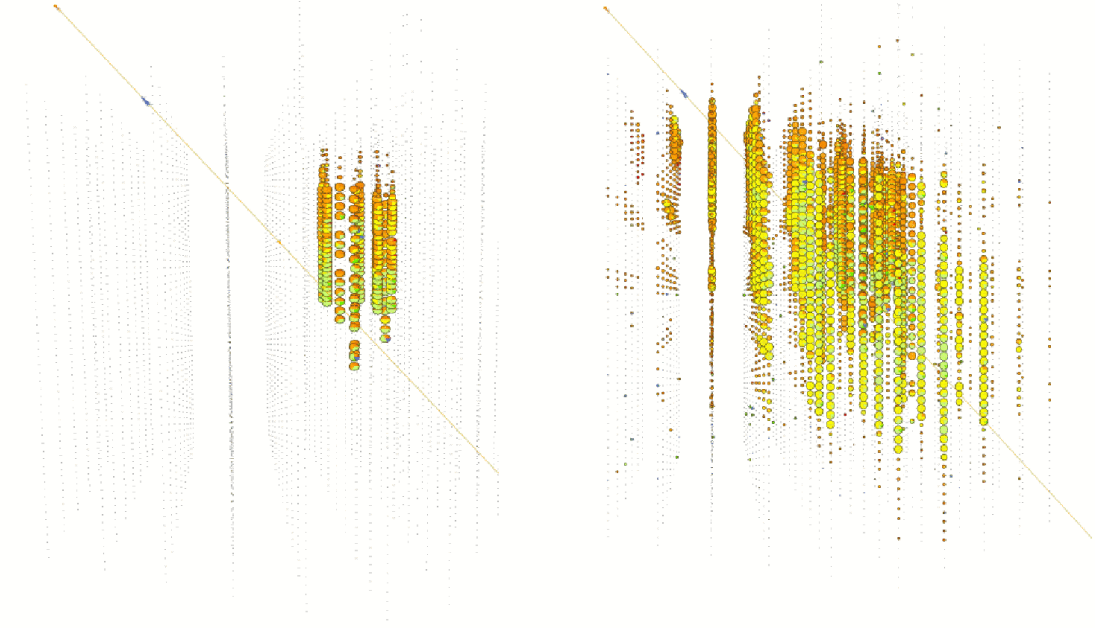
Fireball: Rapidly expanding collimated jet of photons, electrons and positrons becoming optically thin during expansion



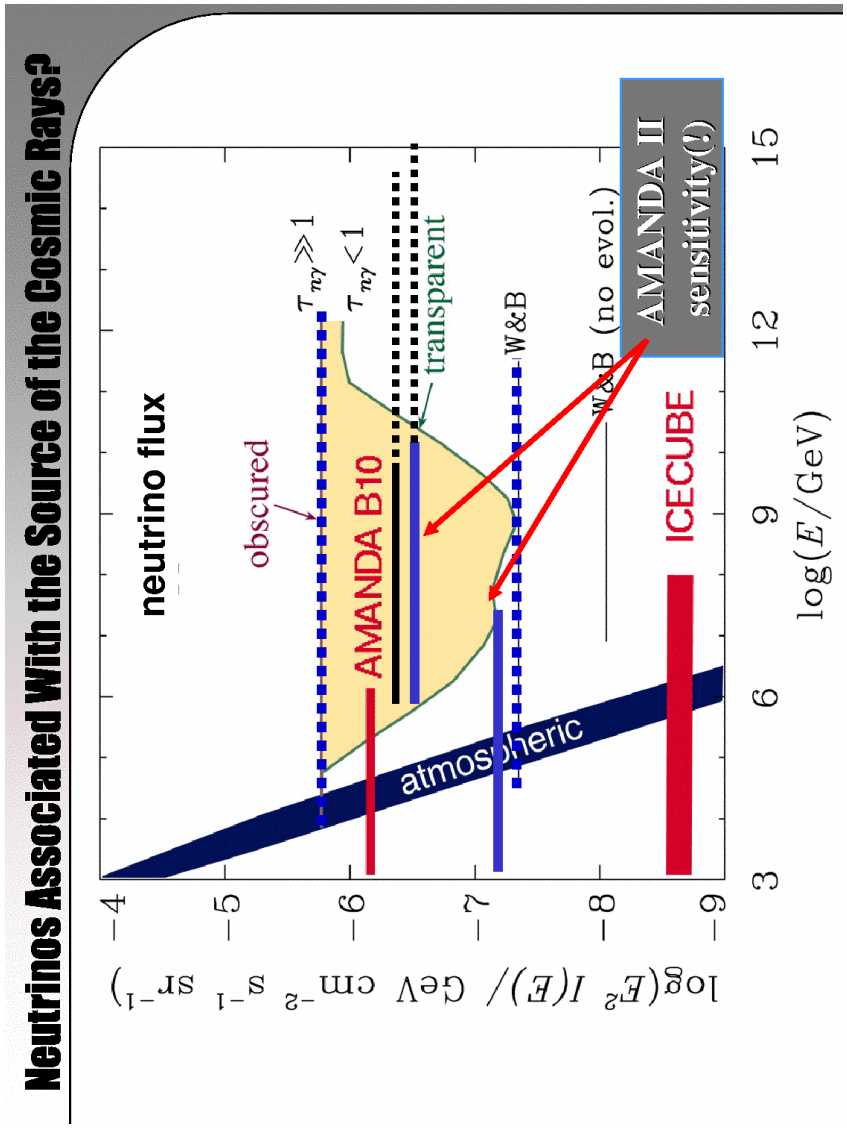
Shocks: external collisions with interstellar material (**e.g. remnant—guaranteed TeV neutrinos**!!!) or internal collisions when slower material is overtaken by faster in the fireball.

Protons and photons coexist in the fireball

2 x 10^{19} eV event in AMANDA and IceCube:

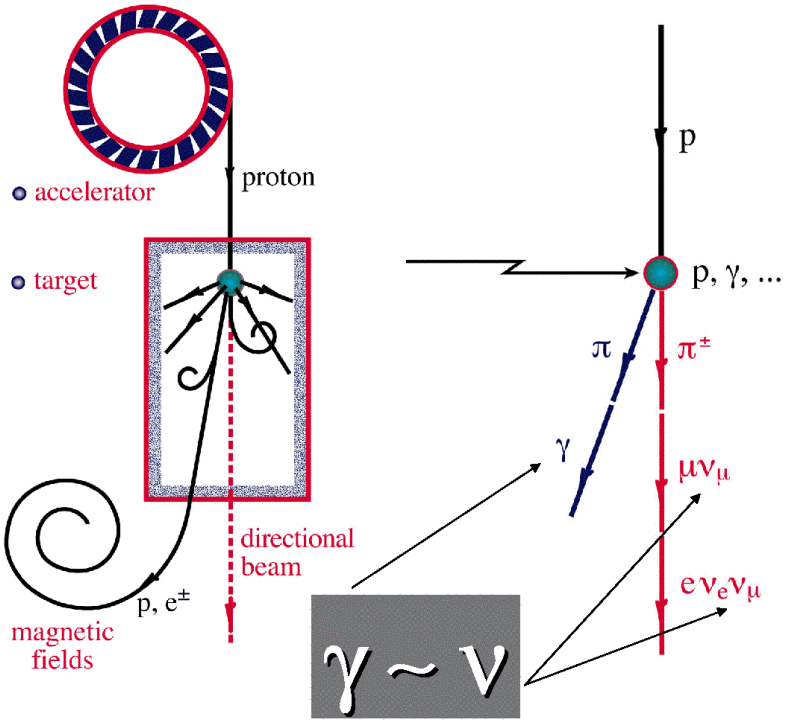


GZK neutrino: $p + \gamma_{CMB} \rightarrow \pi + n$


Neutrinos Associated With the Source of the Cosmic Rays?
neutrino flux
obscured
$\tau_{n\gamma} \gg 1$
$\tau_{n\gamma} < 1$
transparent
AMANDA B10
W&B
W&B (no evol.)
AMANDA II sensitivity(4)
ICECUBE
atmospheric
$\log(E^2 I(E)/$ GeV cm^{-2} s^{-1} sr^{-1})
$\log(E/\mathrm{GeV})$
−4
−5
−6
−7
−8
−9
3
6
9
12
15


cosmic neutrinos associated with gamma rays

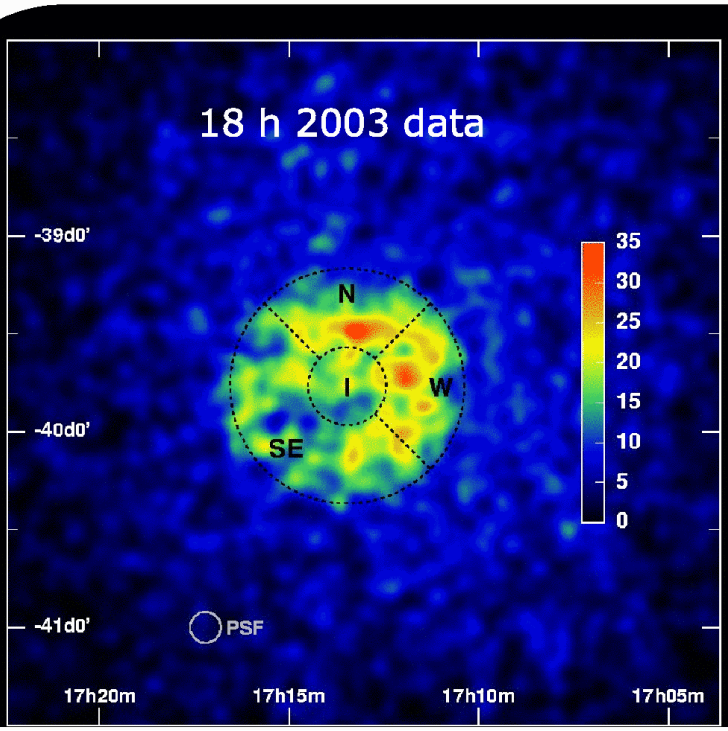
Neutrino Beams: Heaven & Earth



HESS: RX J1713 Spectrum

resolution ~10 arcmin

where are the electrons?



γ-rays from π^0 decay discovered ?

$$\int E_\nu N_\nu (E_\nu) = \varepsilon \int E_\gamma N_\gamma (E_\gamma)$$

$1 < \varepsilon < \infty$

transparent source

$\pi^0 = \pi^+ = \pi^-$

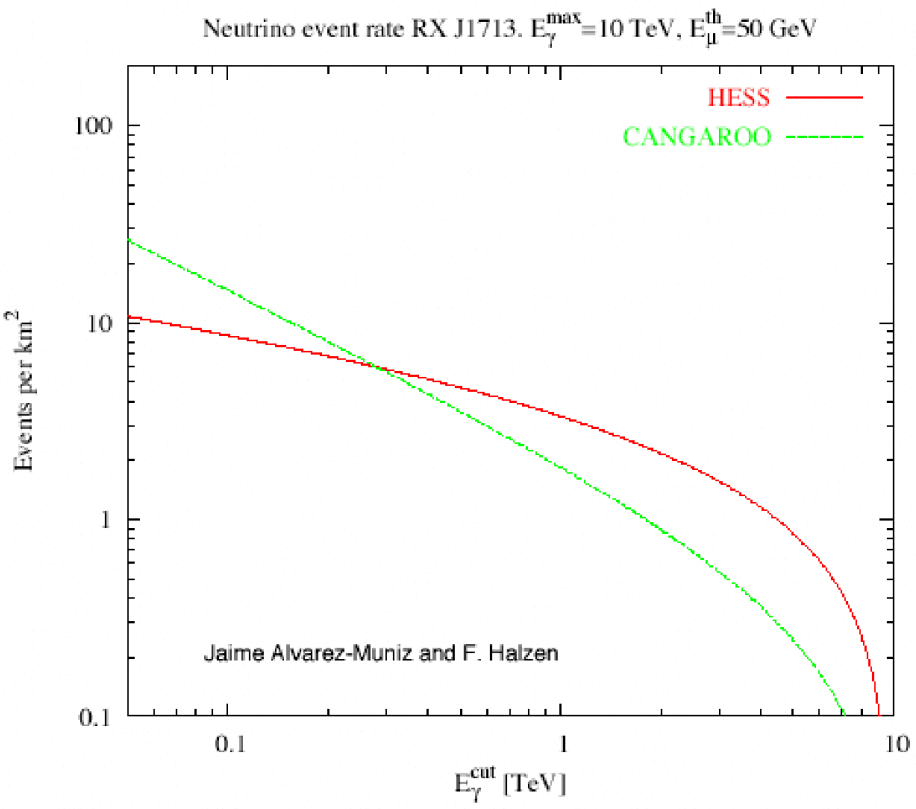
accelerator beam dump (hidden source)

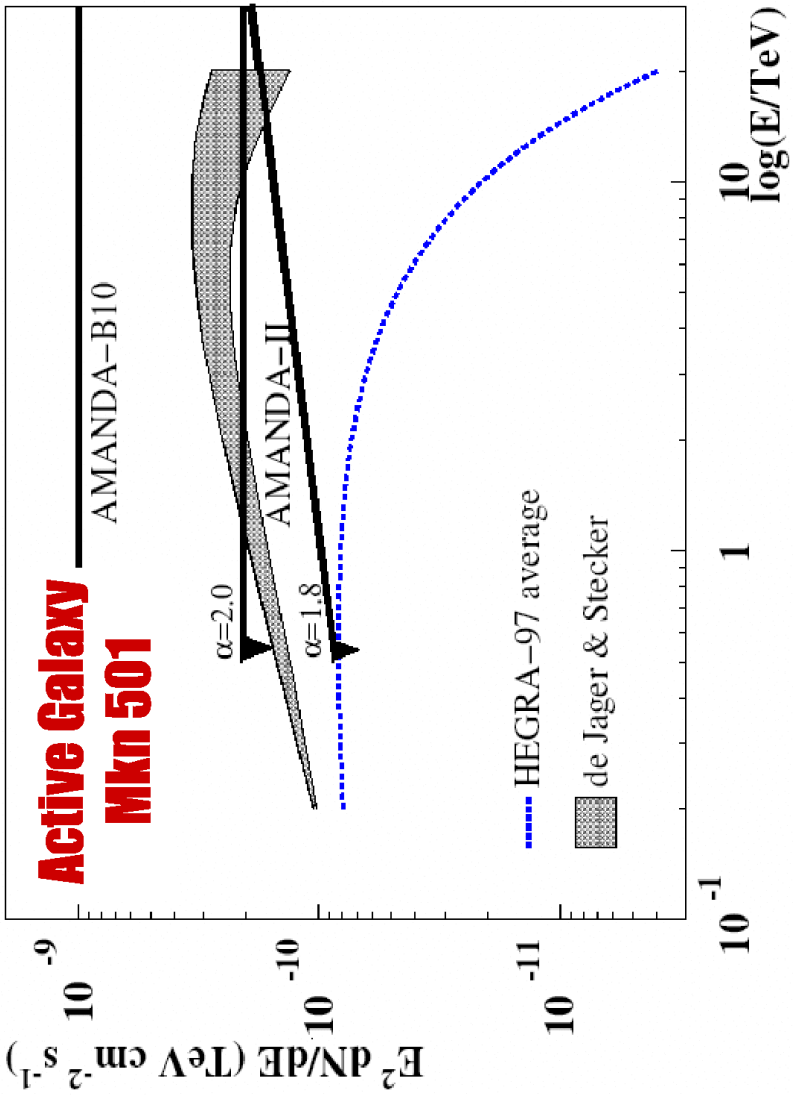
ν flux predicted

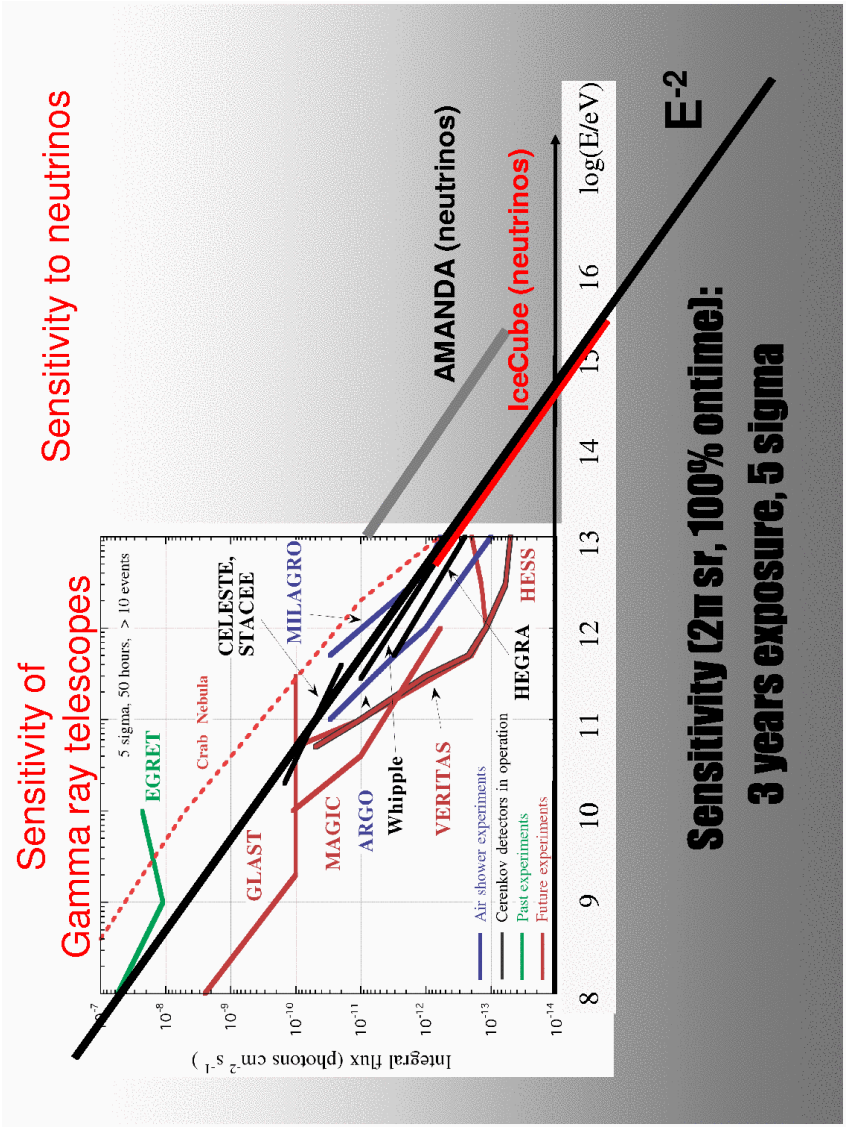
observed γ-ray flux

~ 20 per km2 per year

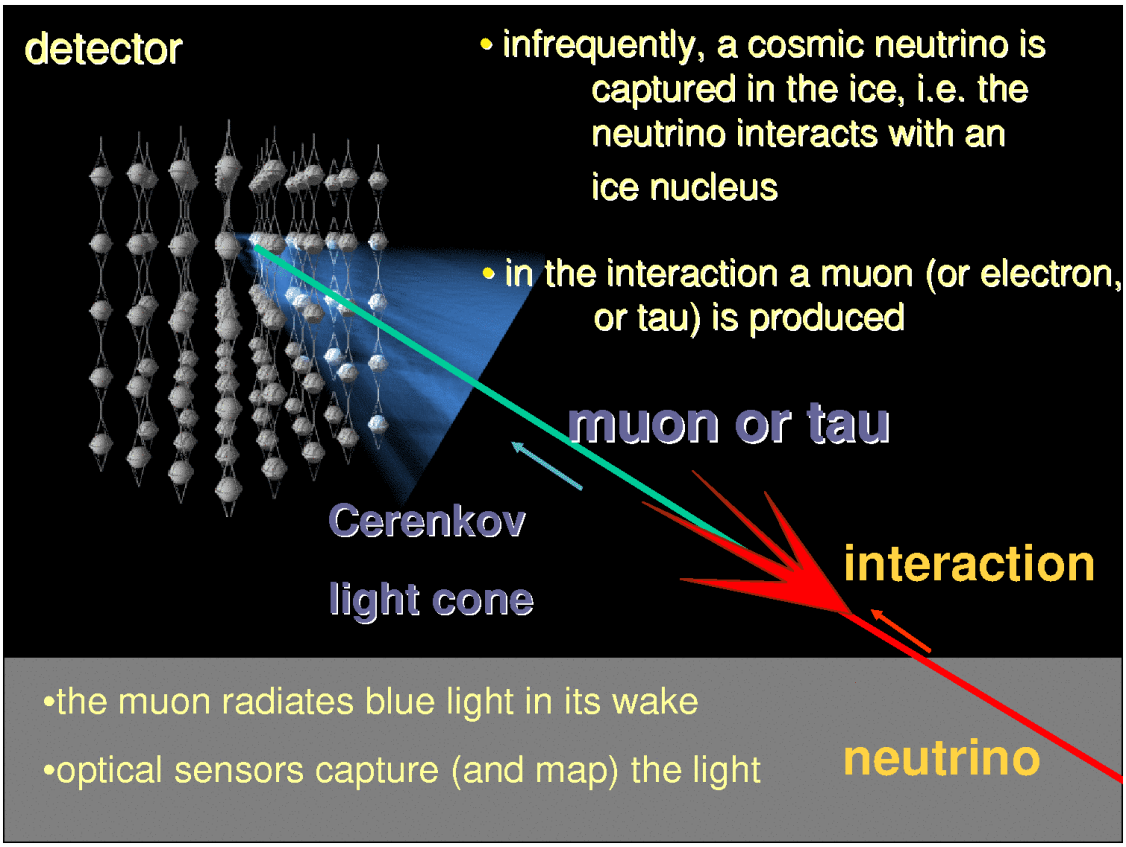
RX J1713-3946 (galactic center)

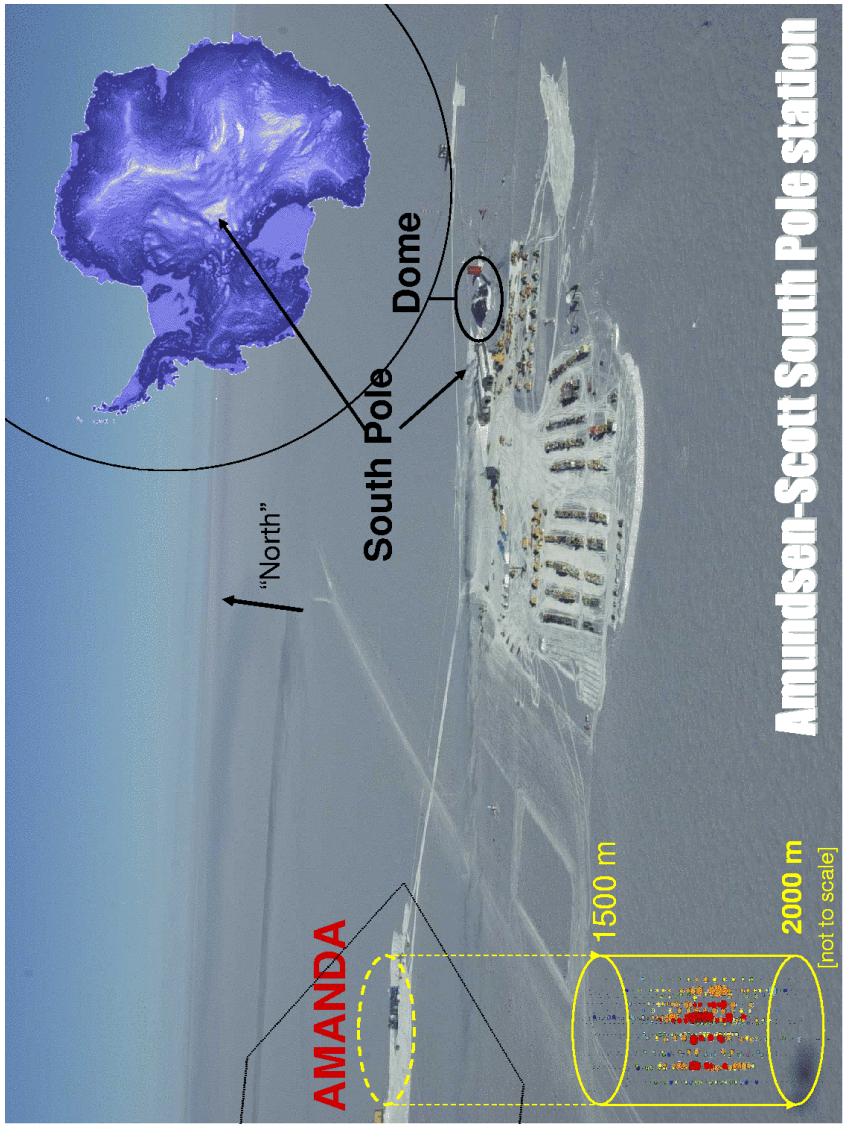


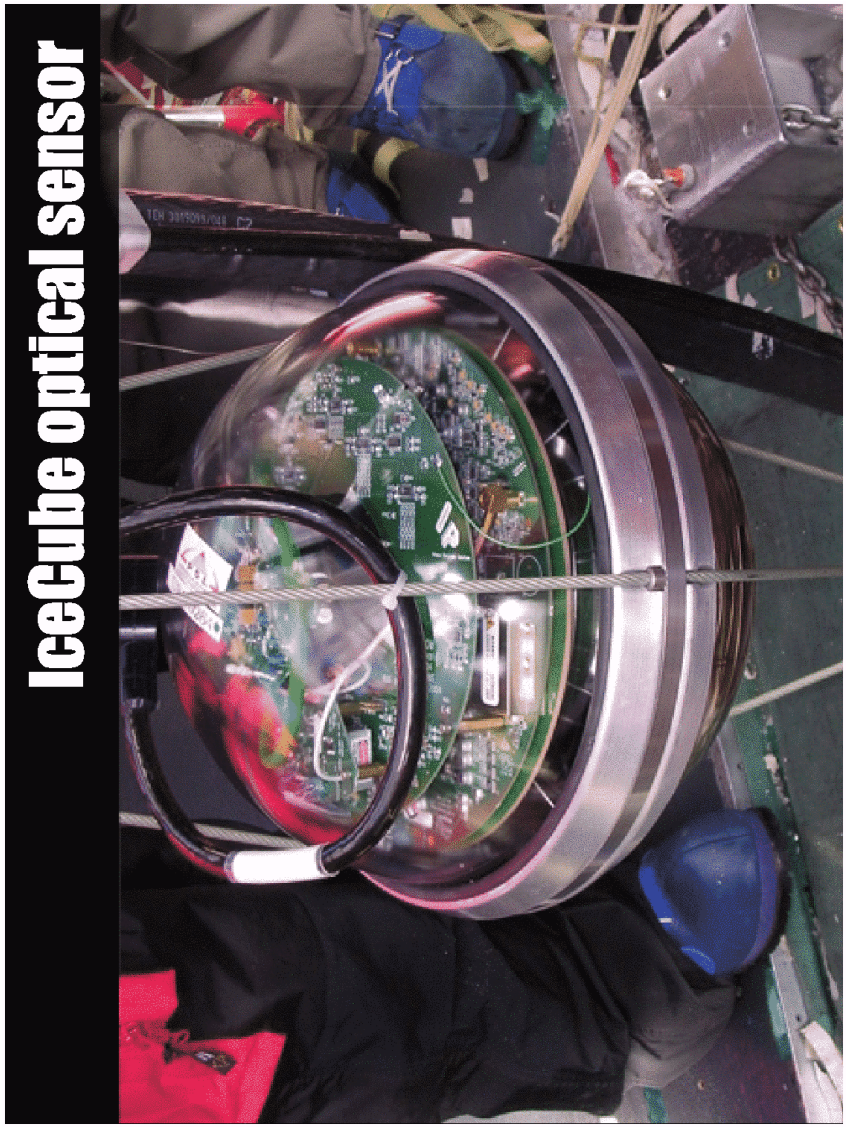

Active Galaxy
Mkn 501
AMANDA–B10
AMANDA–II
α=2.0
α=1.8
HEGRA–97 average
de Jager & Stecker
E² dN/dE (TeV cm⁻² s⁻¹)
log(E/TeV)


Sensitivity of
Gamma ray telescopes
Sensitivity to neutrinos
AMANDA (neutrinos)
IceCube (neutrinos)
E-2
Sensitivity (2π sr, 100% ontime):
3 years exposure, 5 sigma
5 sigma, 50 hours, > 10 events
EGRET
Crab Nebula
CELESTE, STACEE
MILAGRO
GLAST
MAGIC
ARGO
Whipple
VERITAS
HEGRA
HESS
Air shower experiments
Cerenkov detectors in operation
Past experiments
Future experiments
Integral flux (photons cm⁻² s⁻¹)
log(E/eV)

AMANDA : proof of concept



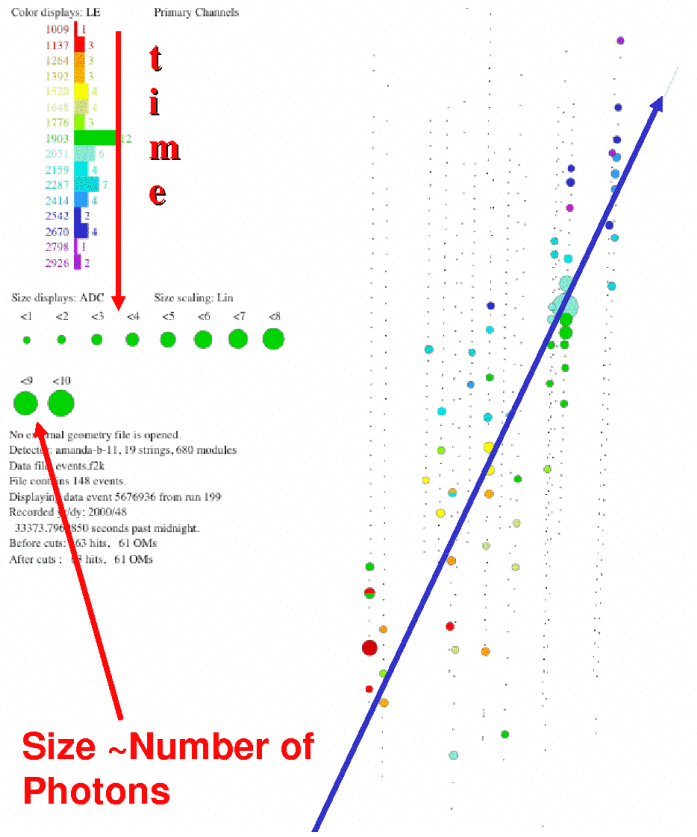

Amundsen-Scott South Pole station
Dome
South Pole
"North"
AMANDA
1500 m
2000 m
[not to scale]


IceCube optical sensor

AMANDA II

- up-going muon
- 61 modules hit

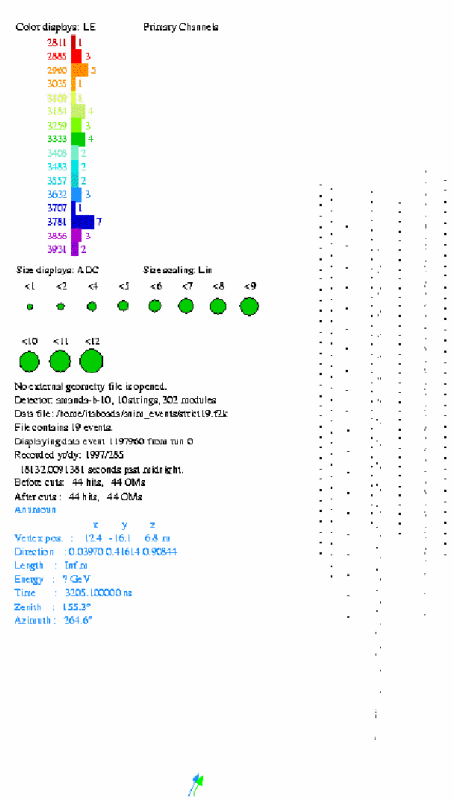
>7 neutrinos/day on-line

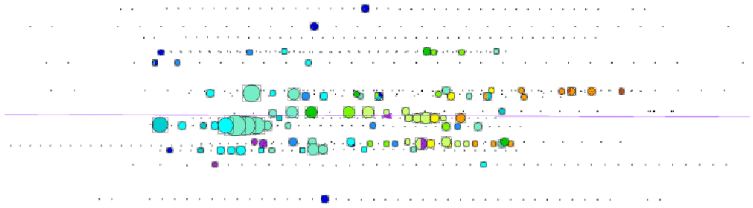


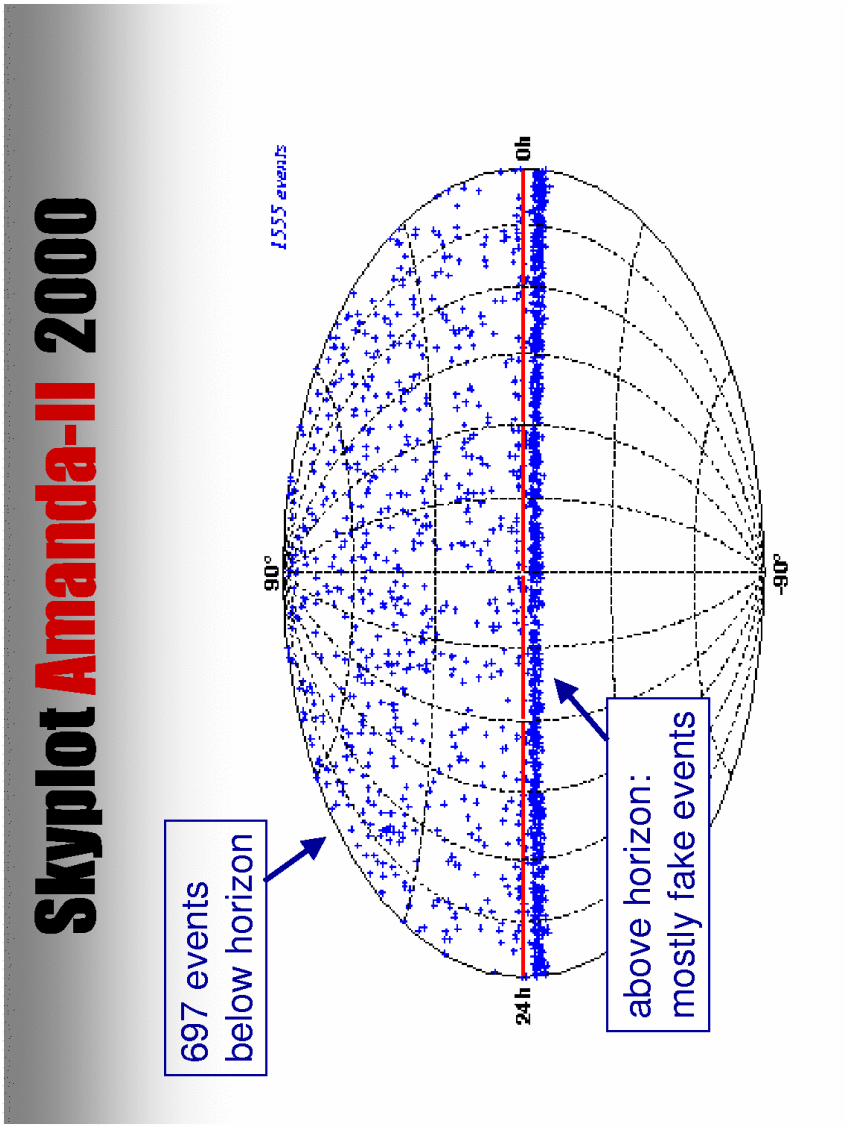
AMANDA Event Signature: Muon

CC muon neutrino interaction → track

$$\nu_\mu + N \rightarrow \mu + X$$



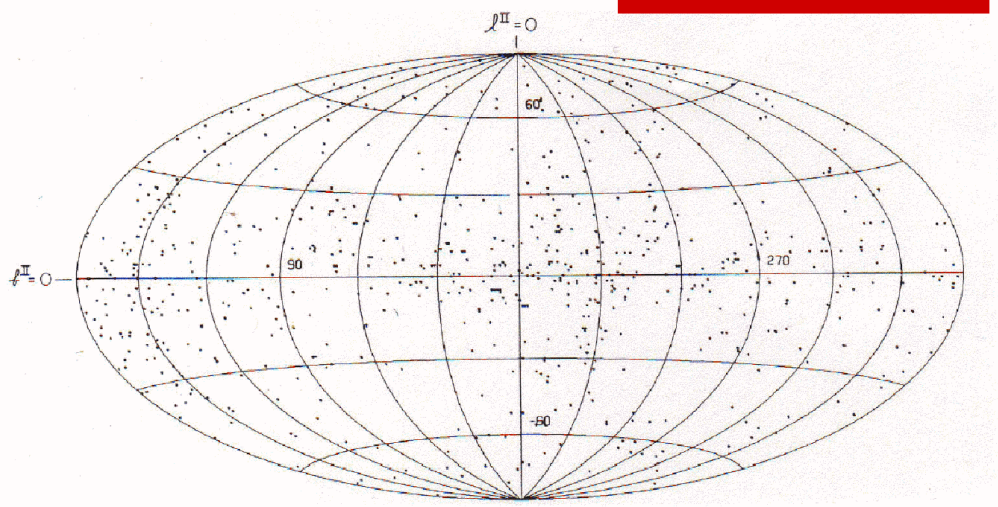



Skyplot Amanda-II 2000
1555 events
0h
90°
-90°
24 h
697 events
below horizon
above horizon:
mostly fake events

1968 OSO-3 (Kraushaar et al. 1972)

- effective area 4 cm²
- 600 photons

sources seen in next mission! SAS-2 100 cm²

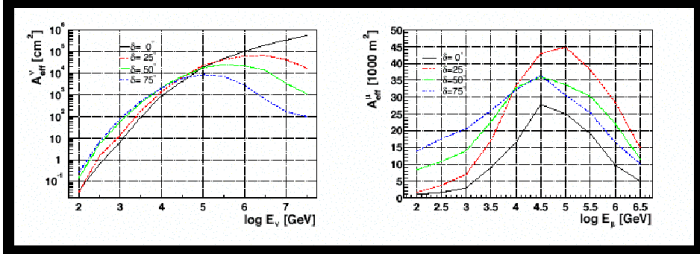


at TeV energy

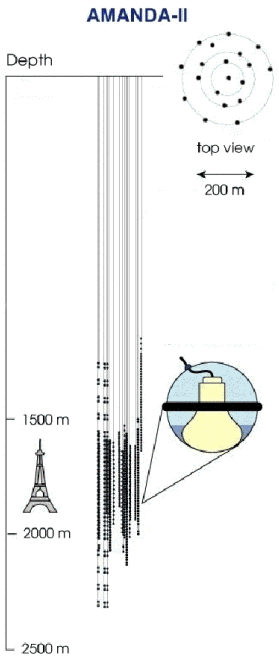
Neutrino area: 10~100 cm²

Muon area: ~ 10,000 m²

(geometric area 0.03—0.1 km²)



The AMANDA Detector



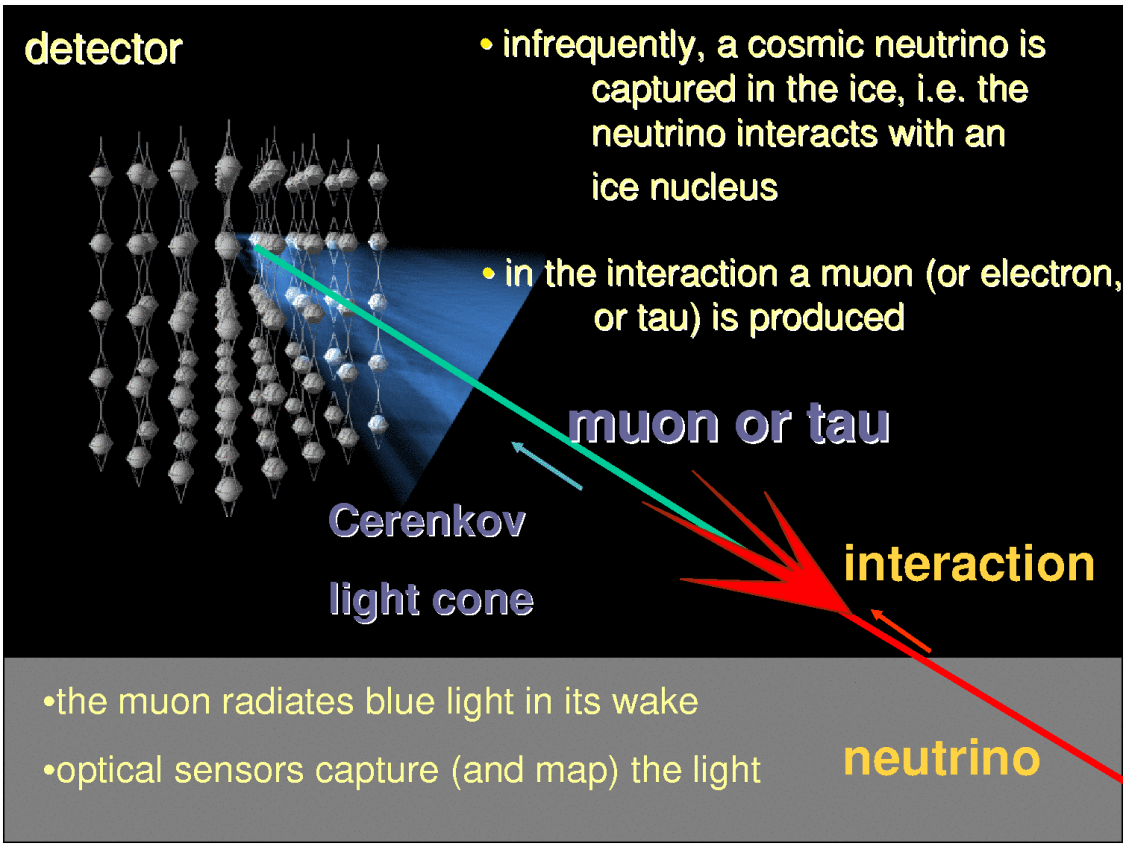
Detection of $\phi_\nu(E_\nu)$

$$dN/dE = A_\nu \phi_\nu$$

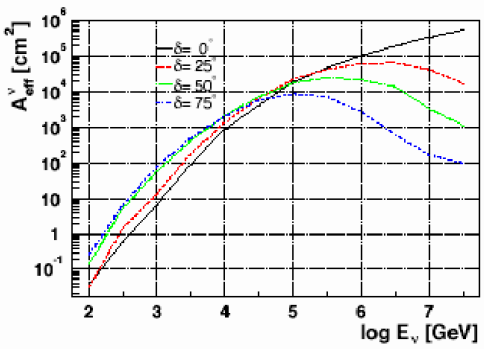
$$= \{P_{earth} P_\mu A_\mu\} \phi_\nu$$

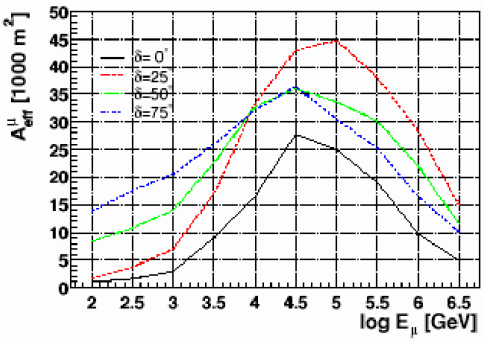
with $P_\mu = n R_\mu \sigma_\nu \sim 10^{-6} E_{Tev}$

$$A_\nu = P_{earth} P_\mu A_\mu$$



amanda effective area

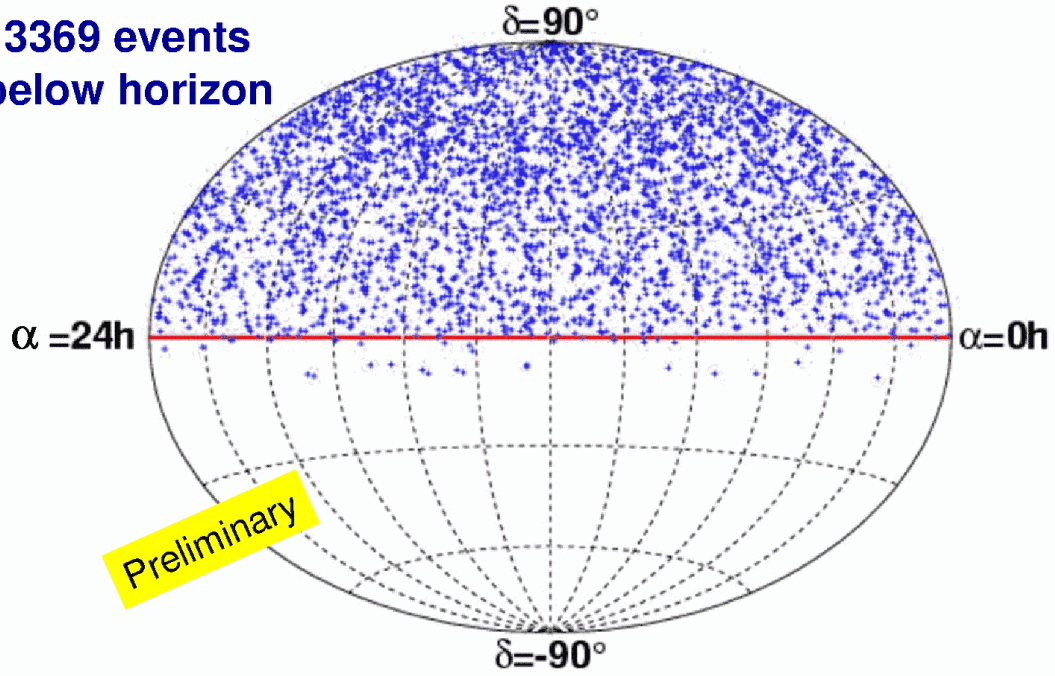


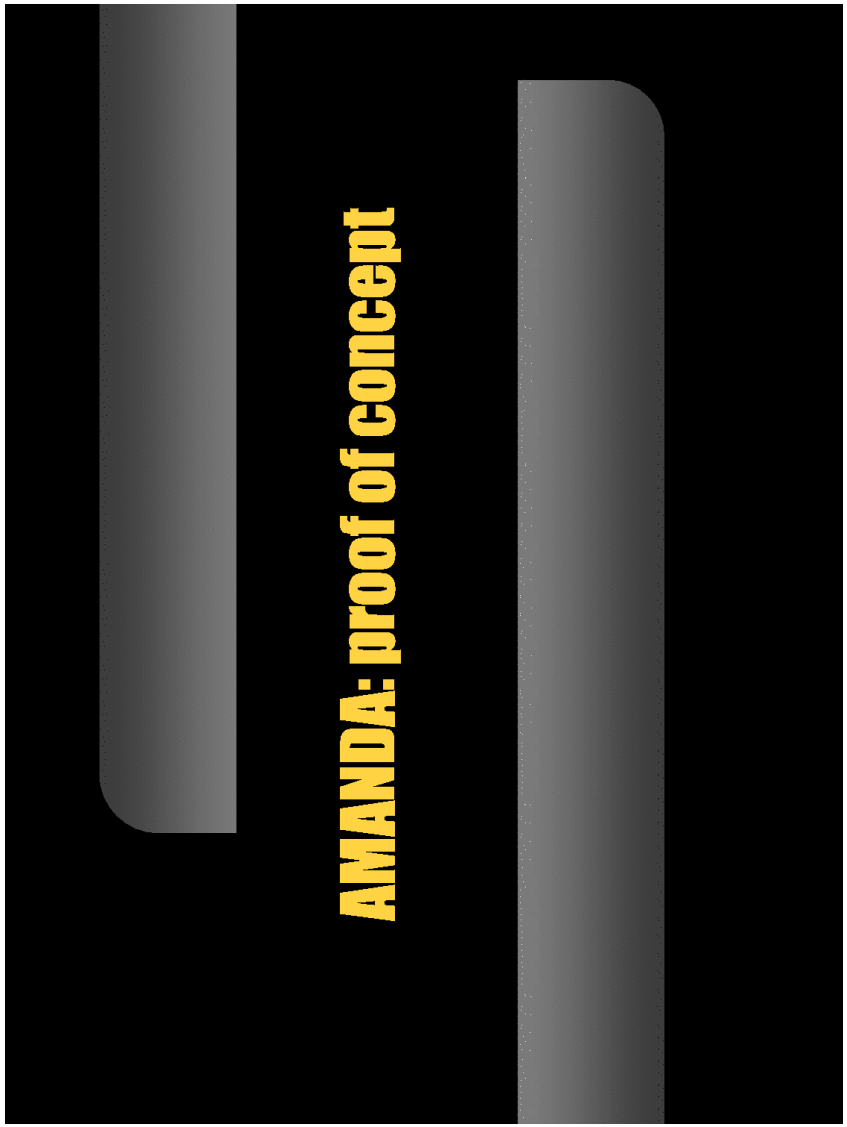


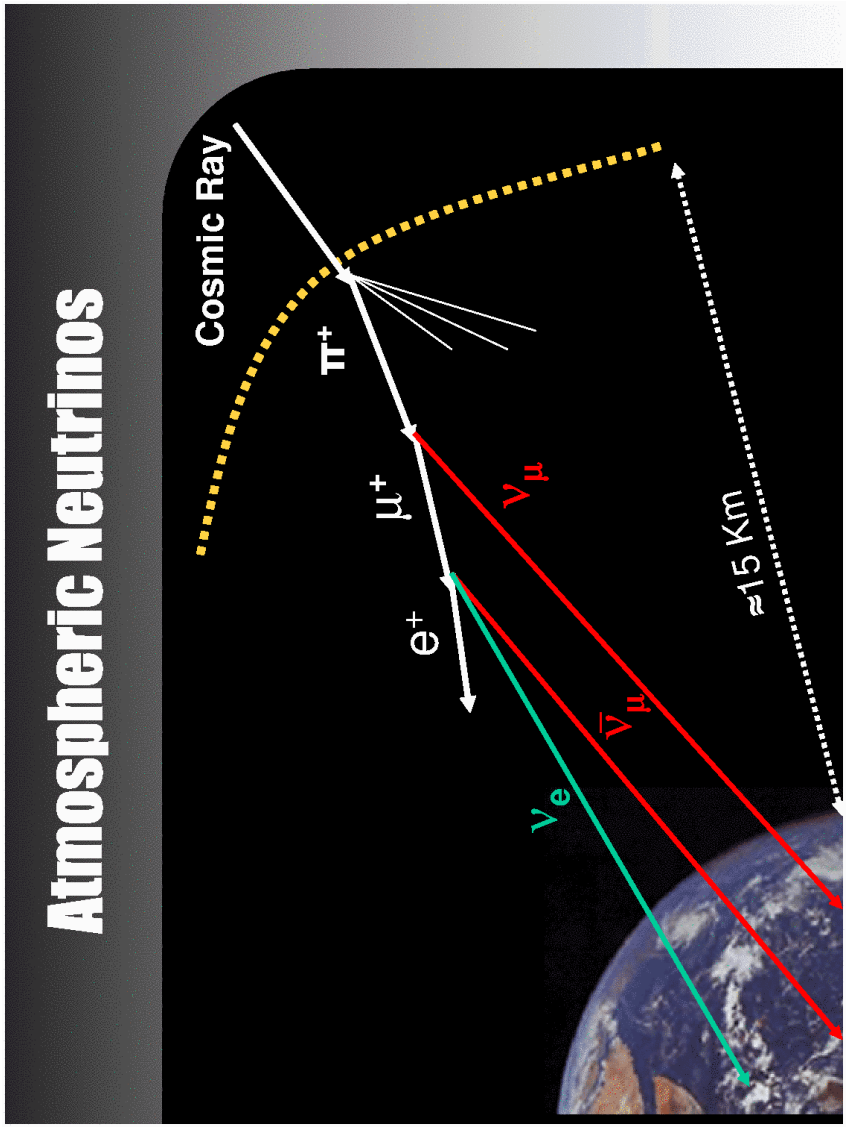
AMANDA skyplot 2000-2003

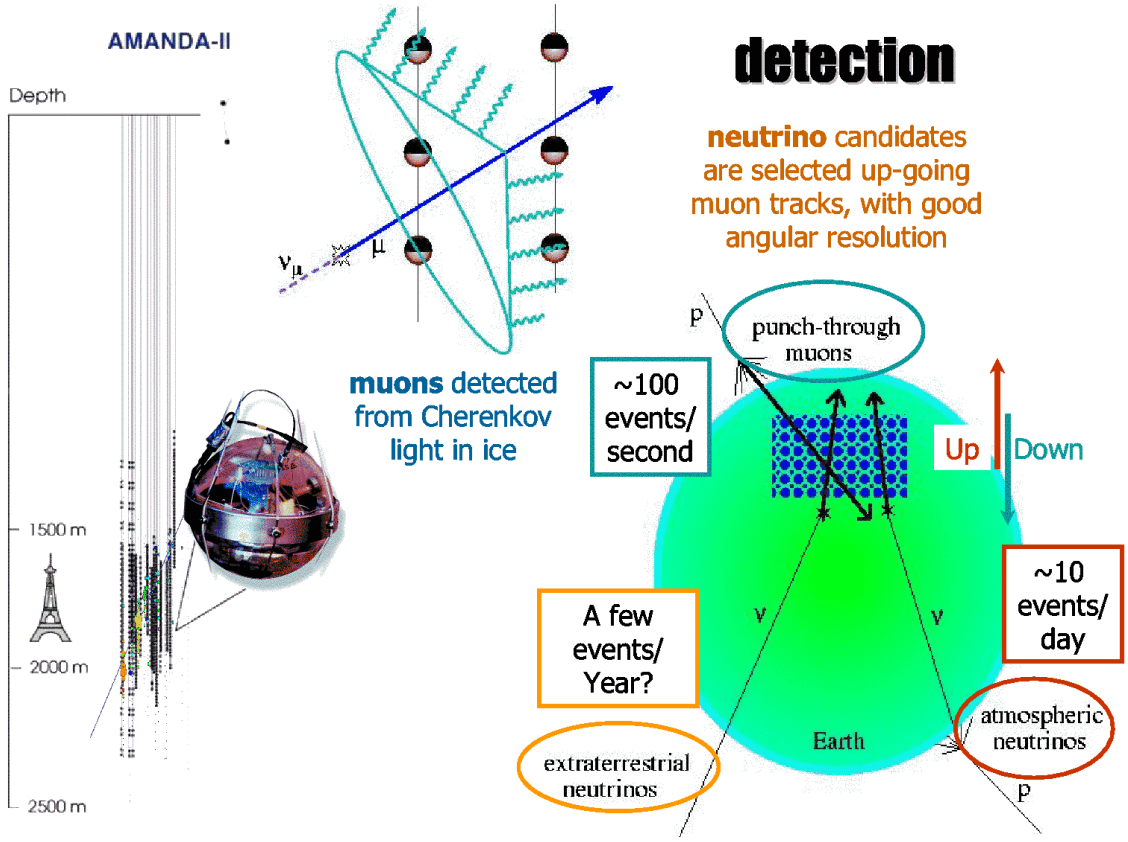
optimized for best sensitivity to E^{-3} – E^{-2} sources

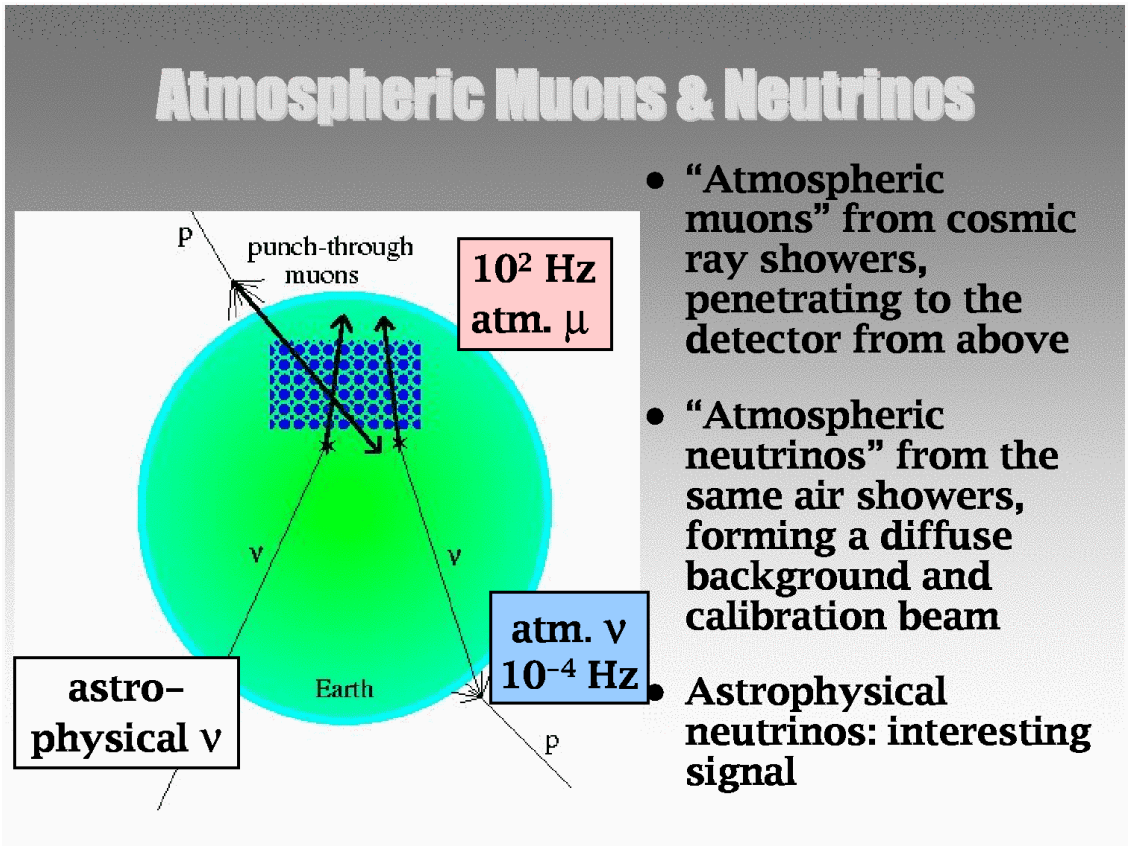
3369 events below horizon



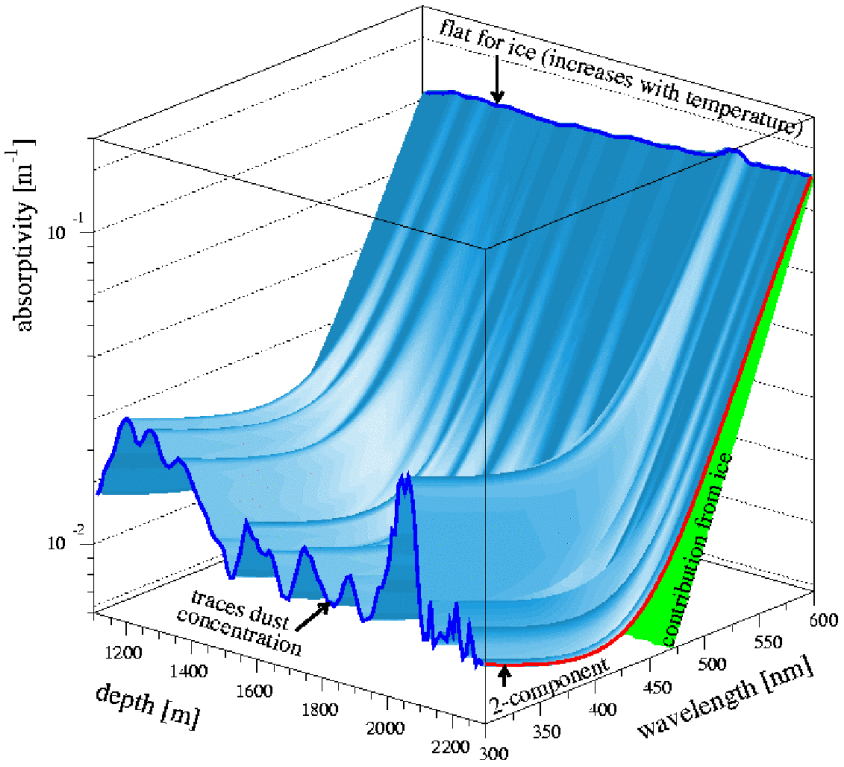

AMANDA: proof of concept


Atmospheric Neutrinos
Cosmic Ray
π+
μ+
e+
νμ
ν̄μ
νe
≈15 Km


AMANDA-II
Depth
1500 m
2000 m
2500 m
ν_μ
μ
detection
neutrino candidates are selected up-going muon tracks, with good angular resolution
muons detected from Cherenkov light in ice
p
punch-through muons
~100 events/ second
Up
Down
~10 events/ day
A few events/ Year?
ν
ν
Earth
atmospheric neutrinos
extraterrestrial neutrinos
p


Atmospheric Muons & Neutrinos
p
punch-through muons
10^2 Hz atm. μ
ν
ν
Earth
atm. ν 10^{-4} Hz
astro–physical ν
p
• "Atmospheric muons" from cosmic ray showers, penetrating to the detector from above
• "Atmospheric neutrinos" from the same air showers, forming a diffuse background and calibration beam
• Astrophysical neutrinos: interesting signal

Absorption in AMANDA ice



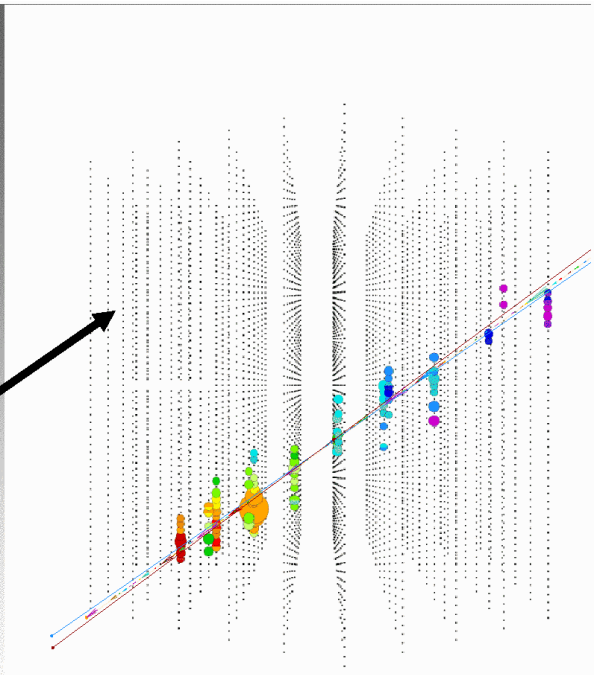
Experimental Challenges ...

- Optical properties of deep south pole ice:
  - **Most transparent natural solid**
  - **Scattering length 6 ~ 52 m**
  - **Absorption length 9 ~ 240 m**

μ-event in IceCube

300 atmospheric neutrinos per day

AMANDA II



1 km

IceCube:

Larger Telescope
Superior Detector

Atmospheric ν 's as Test Beam

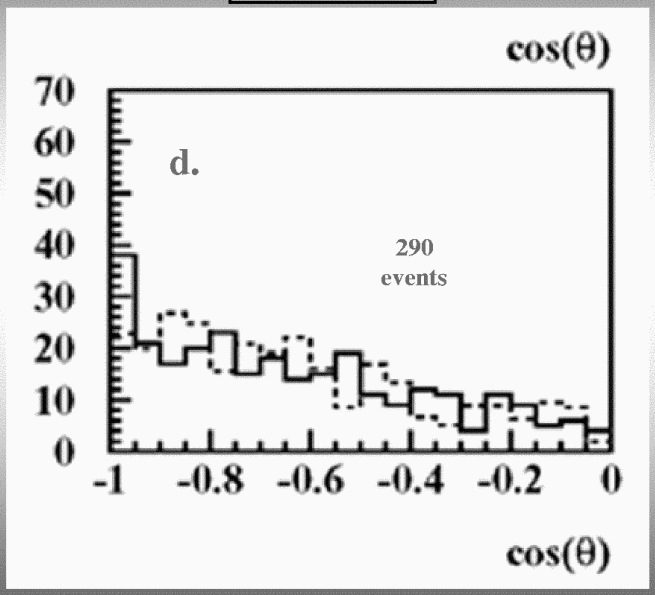
Selection Criteria:

- (N_{hit} < 50 only)
- Zenith > 110°

- High fit quality
- Uniform light deposition along track

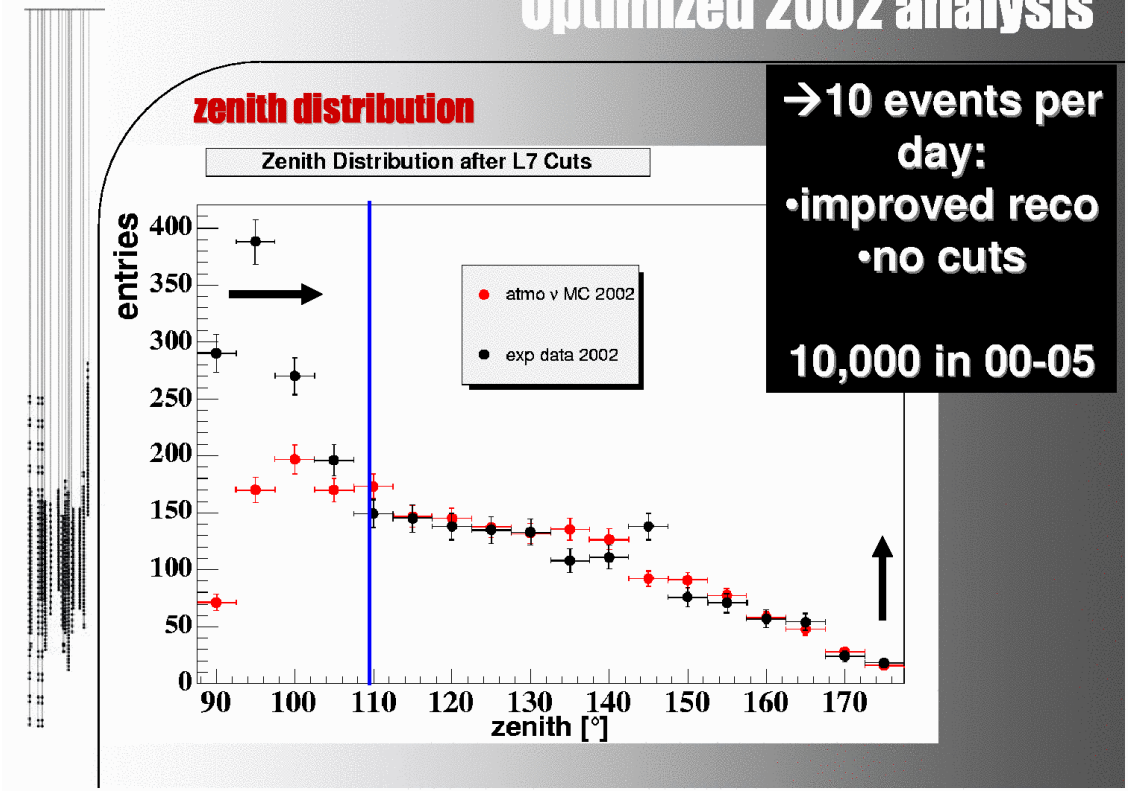
2 cuts only!

4 nus per day



tightening of cuts extracts atm. ν signal

Optimized 2002 analysis



→10 events per day:
•improved reco
•no cuts

10,000 in 00-05

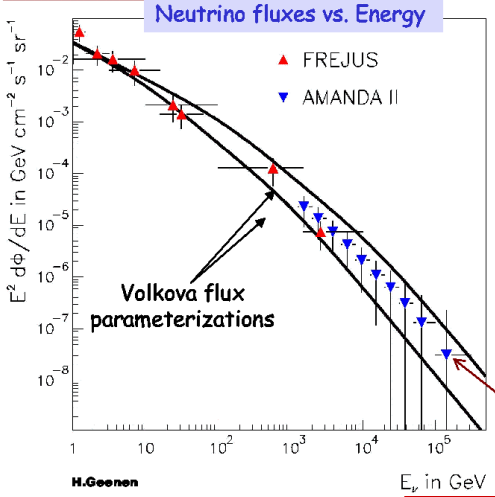
ATMOSPHERIC ν & DIFFUSE FLUX LIMITS [νμ]

Neural Network energy reconstruction
Regularized unfolding → energy spectrum

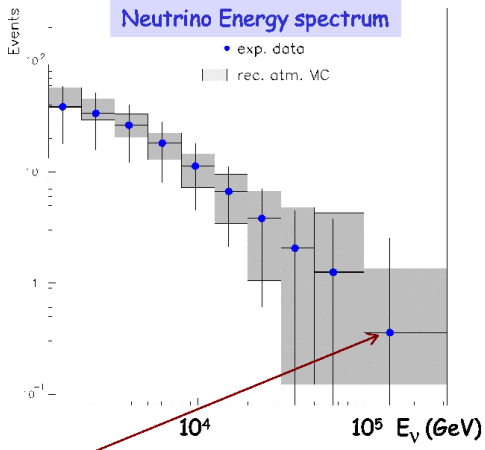
AMANDA test beams: atmospheric ν and μ

First spectrum > 1 TeV (up to 100TeV)

Neutrino fluxes vs. Energy



Neutrino Energy spectrum

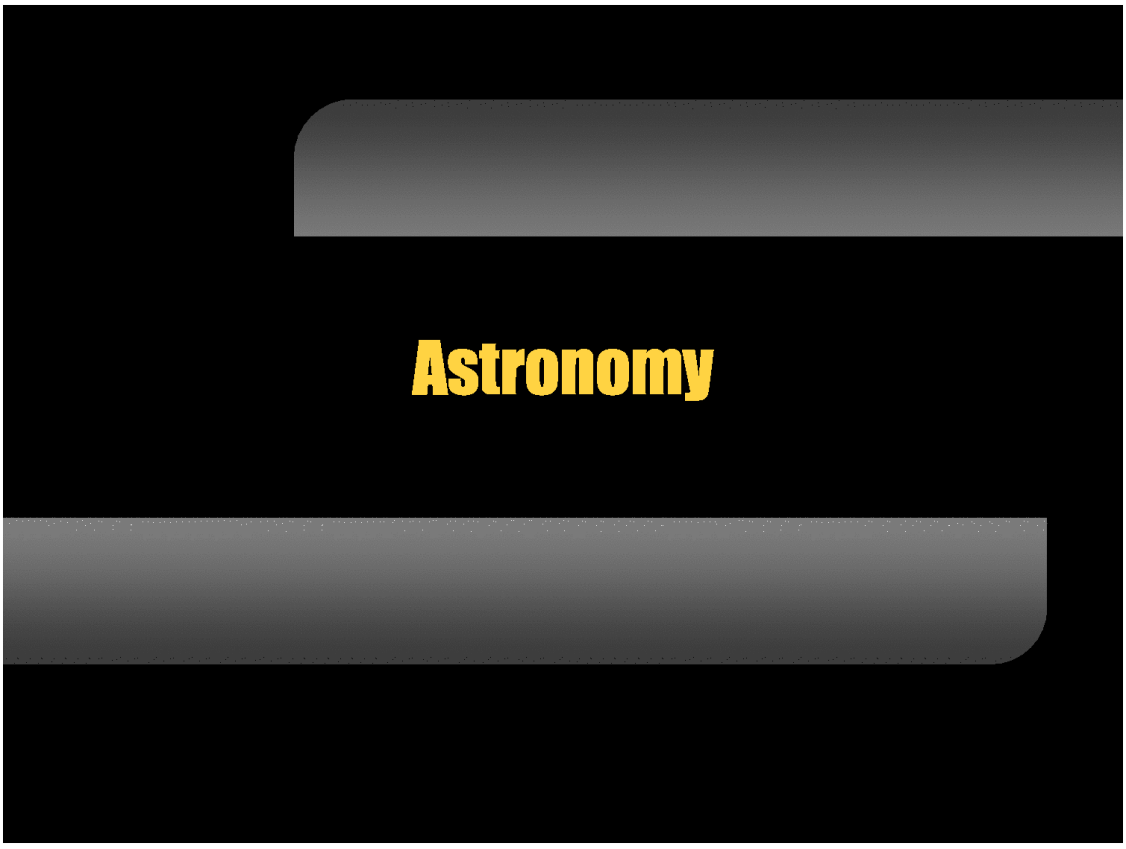


Last bin info to calculate the limit to Extraterrestrial E^2 neutrino flux

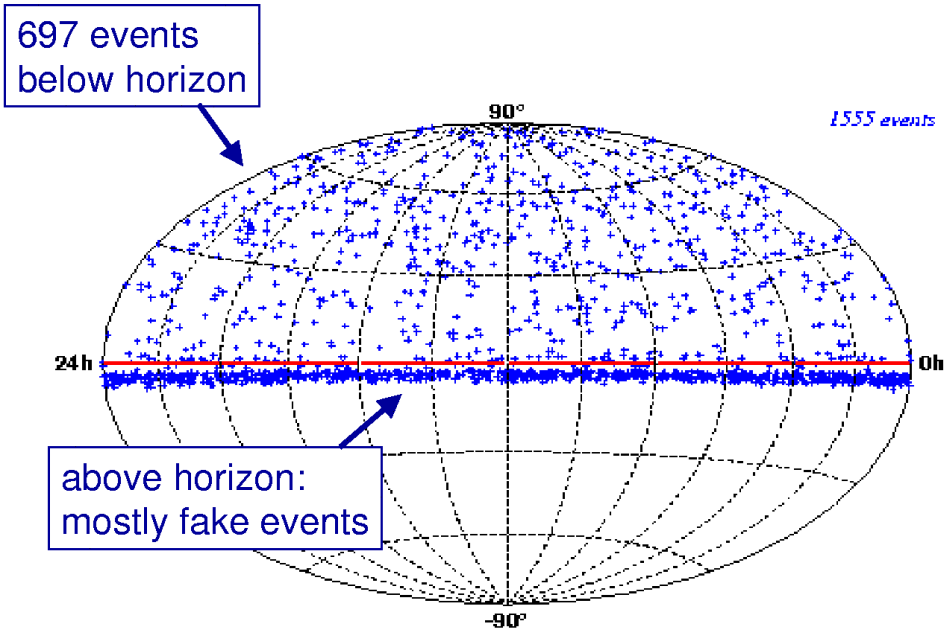
Previous analysis publication
Phys. Rev. Lett. 90 251101 (2003)

Includes 33% systematic uncertainty

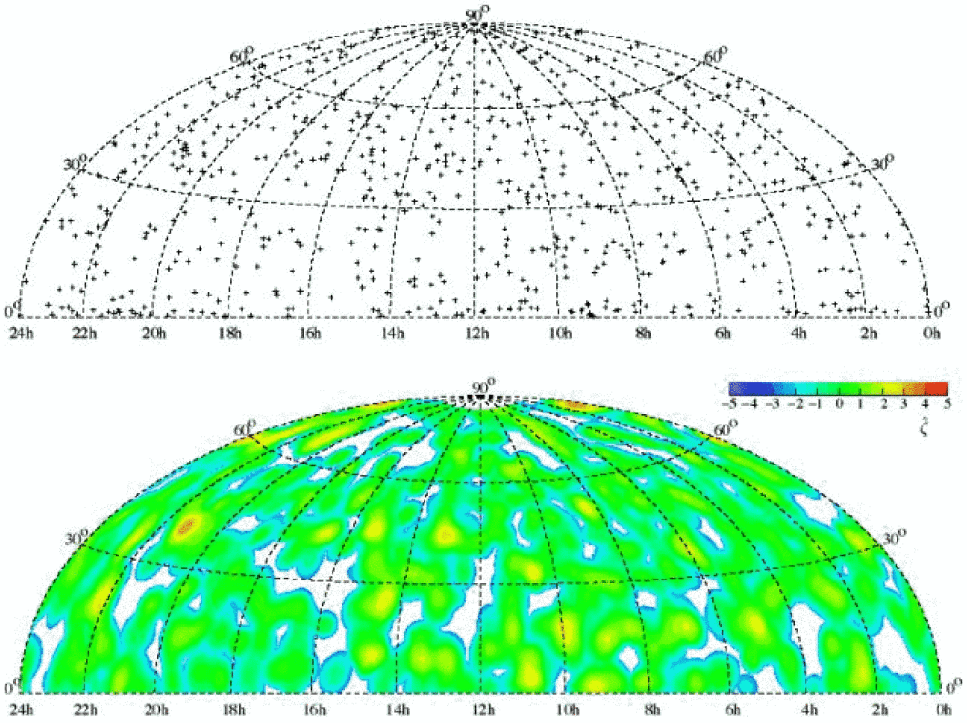
$$E^2\Phi_{\nu_\mu}(E) < 2.58\cdot10^{-7}\ \text{GeV cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}$$



Skyplot Amanda-II, 2000

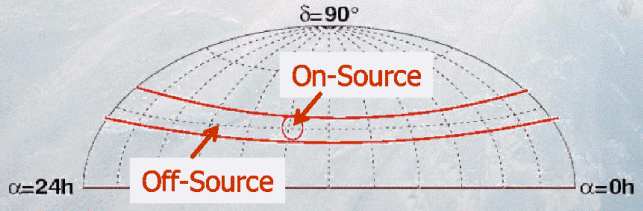


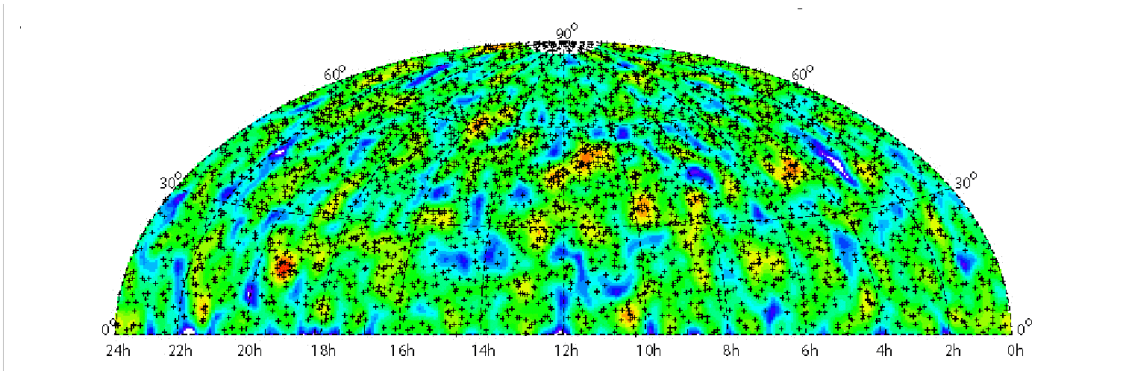
AMANDA 2000



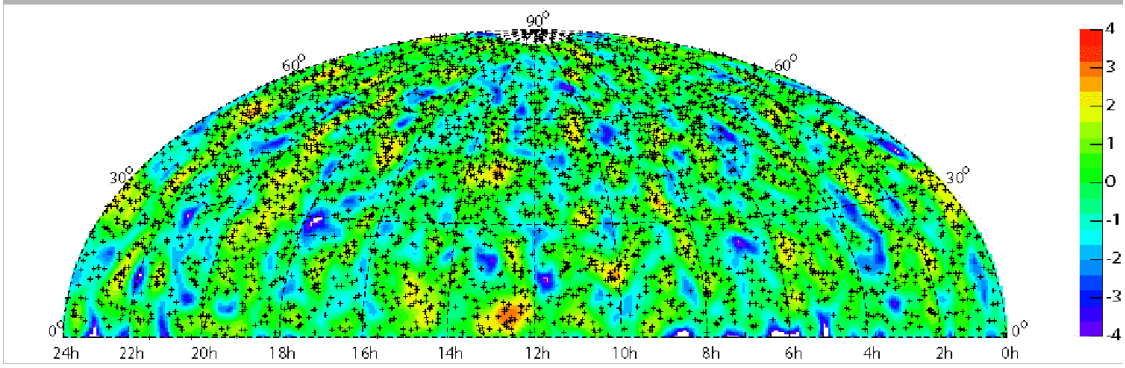
Search for a neutrino signal from point sources: 4 years time-averaged

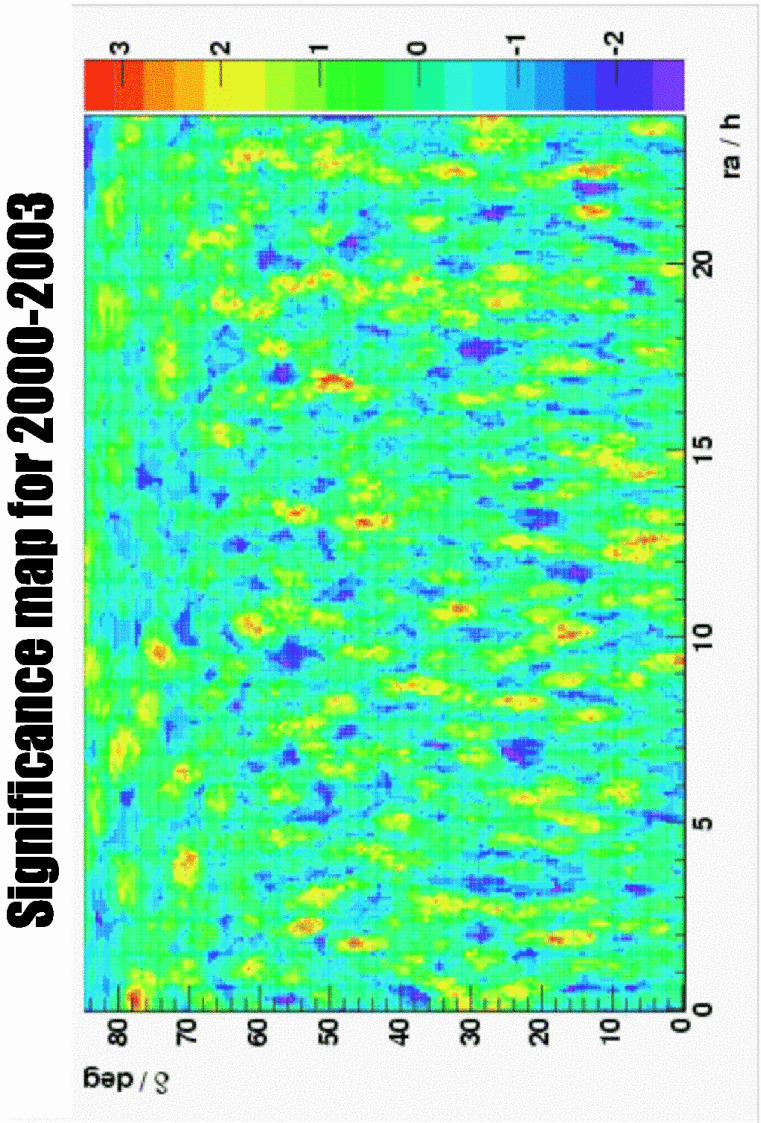
'Blind-Analysis':
- Event selection and analysis procedures are optimized on events with randomized right ascension and/or time
- Background estimated from the data (off-source)

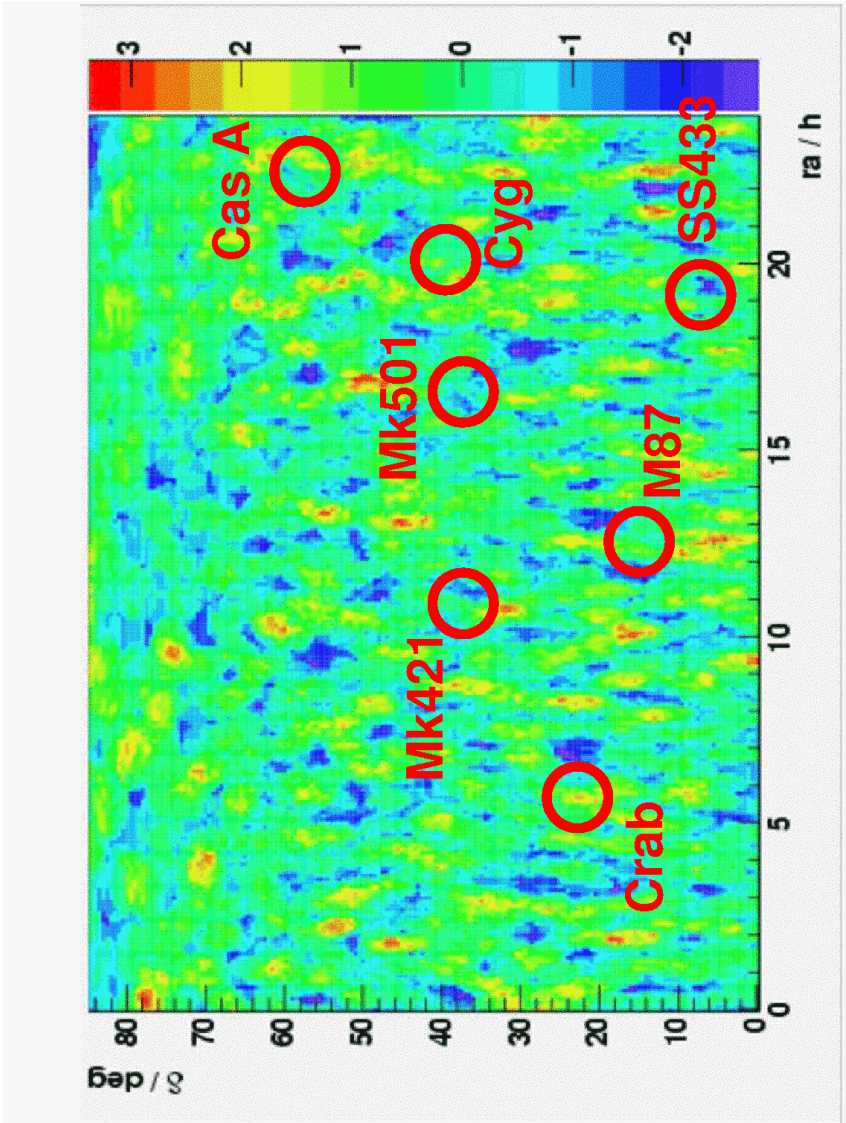


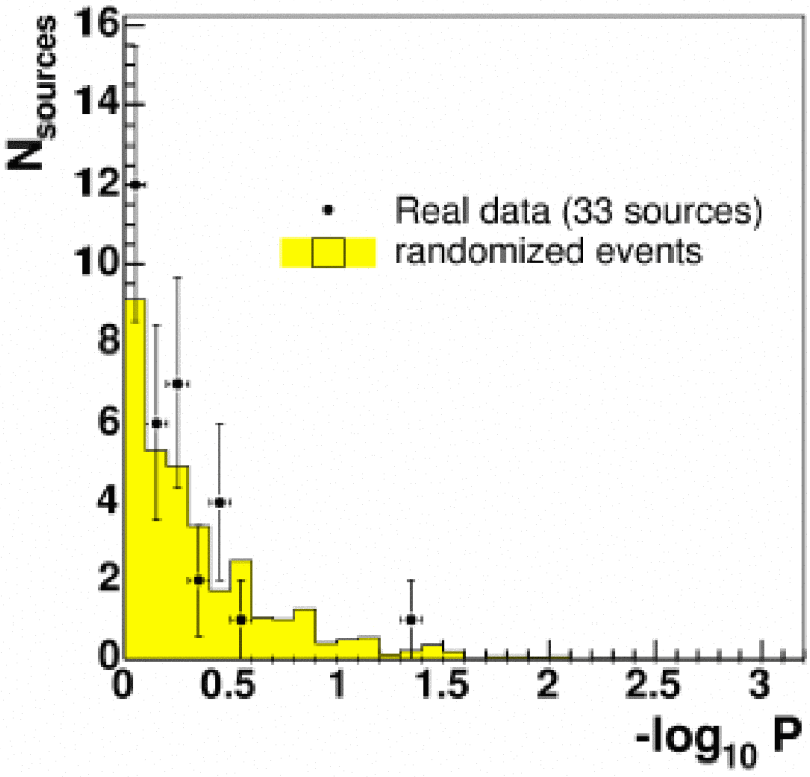


2000-03: scrambled (top) and unblinded (bottom)




Significance map for 2000-2003
dec / deg
ra / h
3
2
1
0
-1
-2
0
10
20
30
40
50
60
70
80
0
5
10
15
20

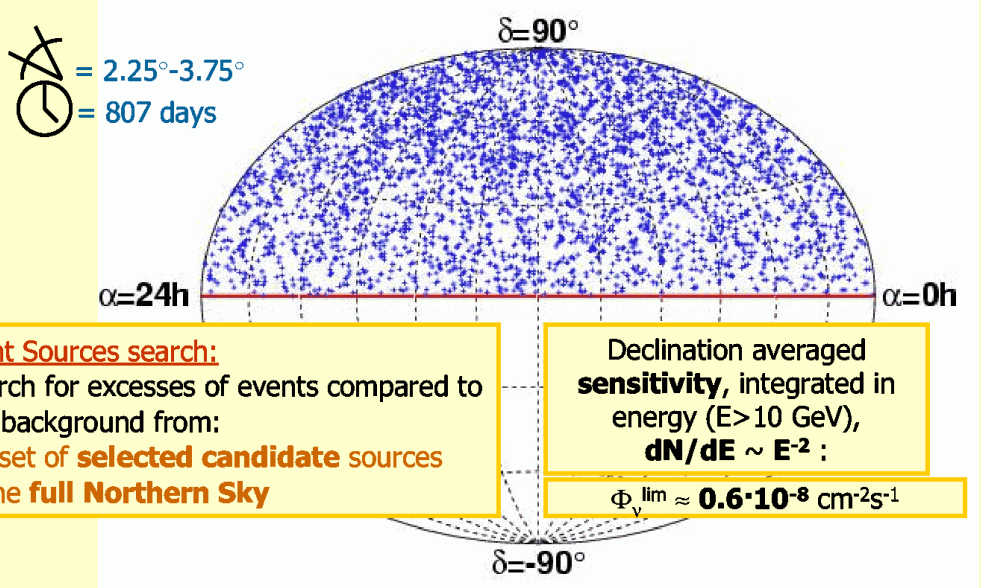

dec / deg
ra / h
Cas A
Cyg
Mk501
Mk421
M87
SS433
Crab
3
2
1
0
-1
-2
0
10
20
30
40
50
60
70
80
0
5
10
15
20



search for clusters of events in the Northern sky

The data sample:
3369 neutrino candidates
Event selection optimized for
both **dN/dE ~ E^{-2}** and **E^{-3}** spectra

3329 ↑ observed
3438 ↑ expected atm. MC



Point Sources search:
Search for excesses of events compared to the background from:
- A set of **selected candidate** sources
- The **full Northern Sky**

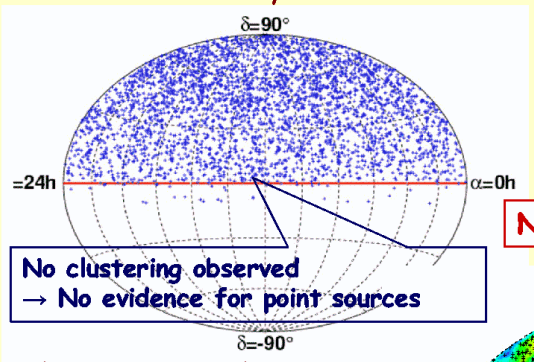
Declination averaged **sensitivity**, integrated in energy (E>10 GeV), **dN/dE ~ E^{-2}** :

$\Phi_\nu^{lim} \approx$ **0.6·10^{-8}** cm^{-2}s^{-1}

4 YEAR AMANDA-II (00-03) POINT SOURCE SEARCH

Search for event excess in Northern sky: → Cuts optimized in declination bands for $E^{-2..-3}$ signal spectra (grid of 300 bins)

above horizon: mostly fake events



No clustering observed
→ No evidence for point sources

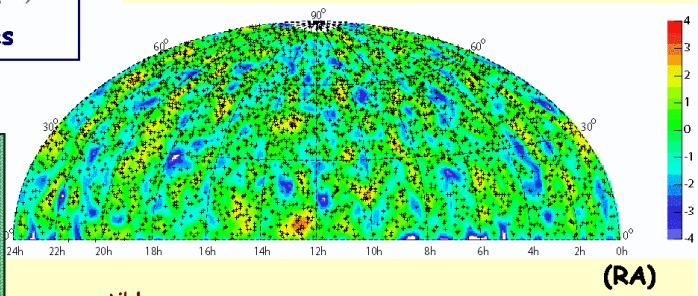
3369 observed below the horizon [+ declination]

3438 expected from atm-V simulation

PRELIMINARY

NO EXCESS beyond randomly expected

below horizon: mostly atmosphe



Livetime = 807 Days
2000: 197 days; 2001: 194 days;
2002: 213 days; 2003: 203 days.
2000+2001+2002+2003 = 3369 events

Phys. Rev. Lett. 92 071102 (2004)

compatible → Atmospheric Neutrinos!

search for clusters of events in the Northern sky

Selected objects and full scan of the northern sky:
No statistically significant effect observed

Sensitivity $\Phi_\nu/\Phi_\gamma \sim 2$ for 200 days of "high-state" and spectral results from HEGRA

Crab Nebula: MC probability to obtain an entry with at least this excess significance is **64%**

Source	Nr. of ν events (4 years)	Expected backgr. (4 years)	Flux Upper Limit $\Phi_{90\%}(E_\nu>10\ \mathrm{GeV})$ $[10^{-8}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$
Markarian 421	6	5.58	0.68
1ES1959+650	5	3.71	0.38
SS433	2	4.50	0.21
Cygnus X-3	6	5.04	0.77
Cygnus X-1	4	5.21	0.40
Crab Nebula	10	5.36	1.25

... out of **33** Sources

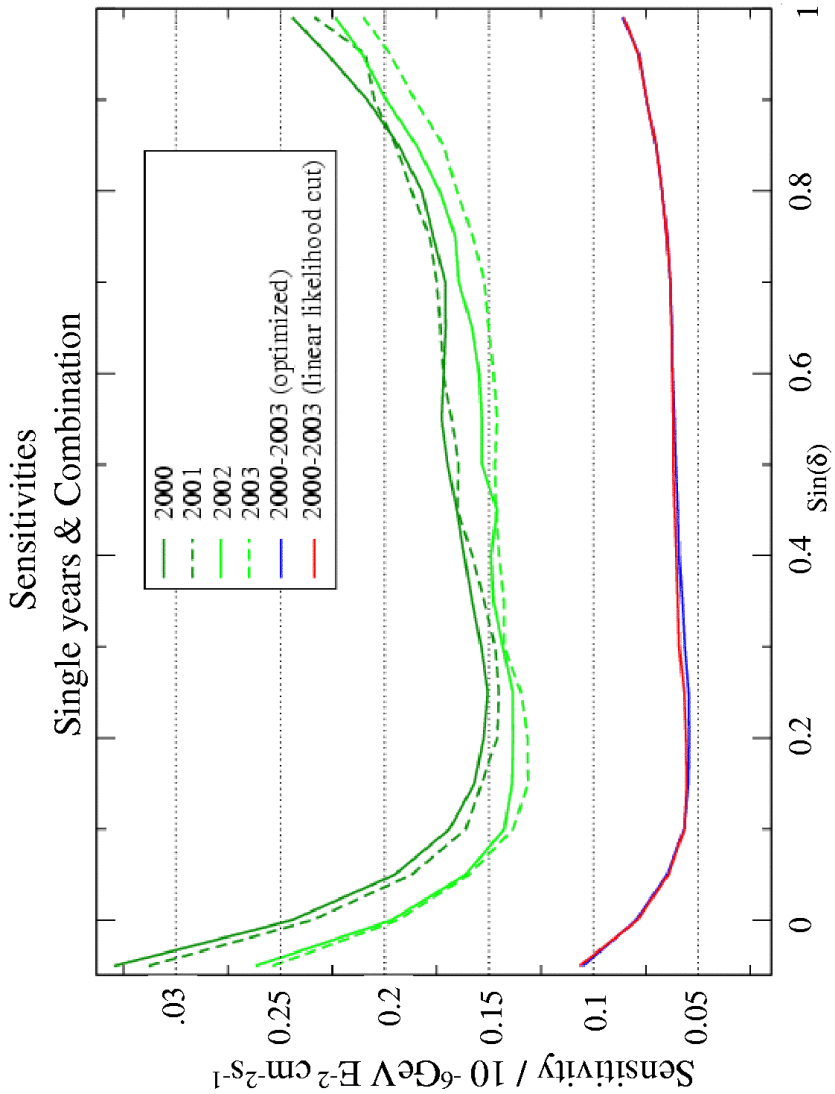
Systematic uncertainties under investigation

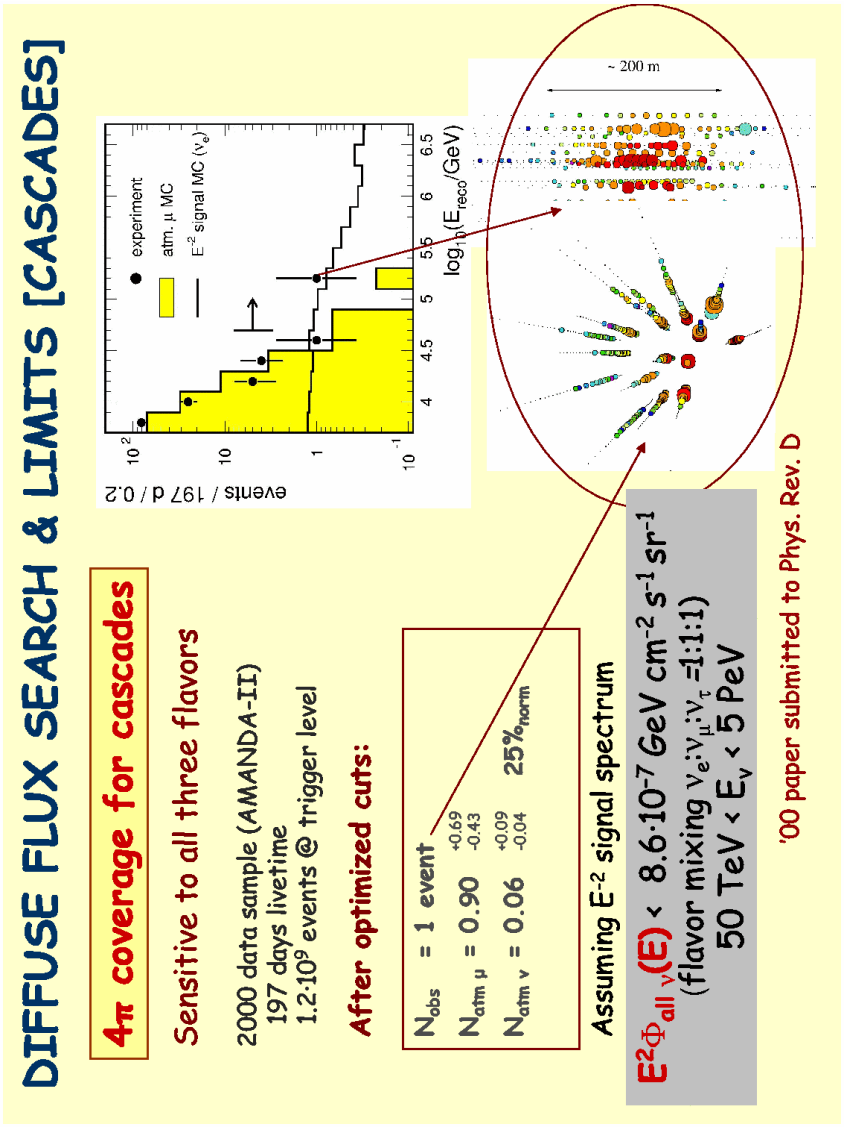
90% C.L. upper limits (in units of $10^{-8}cm^{-2}s^{-1}$) for selected sources for an E^{-2} spectral shape integrated above E_ν=10 GeV

		1997	2000		2000+2001	
Source	Declination	Φ_ν^{limit}	Φ_ν^{limit}	N_{obs}/N_{bgr}	Φ_ν^{limit}	N_{obs}/N_{bgr}
SS433	5.0°	-	0.7	**0 / 2.38**	2.3	**1 / 1.69**
M87	12.4°	17.0	1.0	**0 / 0.95**	3.8	**2 / 1.10**
Crab	22.0°	4.2	2.4	**2 / 1.76**	4.2	**3 / 1.10**
Mkn 421	38.2°	11.2	3.5	**3 / 1.50**	1.5	**0 / 0.65**
Mkn 501	39.8°	9.5	1.8	**1 / 1.57**	1.4	**0 / 0.69**
Cyg. X-3	41.0°	4.9	3.5	**3 / 1.69**	1.5	**0 / 0.67**
Cas. A	58.8°	9.8	1.2	**0 / 1.01**	4.7	**2 / 1.03**

PRELIMINARY

			1997	2000	2000-2003	
Candidate	Dec(°)	RA(h)	Φ_ν	Φ_ν	N_{obs}/N_{bg}	Φ_ν
Markarian 421	38.2	11.1	11.2	3.5	6 / 5.58	0.68
Markarian 501	39.8	16.9	9.5	1.8	5 / 4.96	0.61
1ES 1426+428	42.7	14.5		1.7	4 / 4.29	0.54
1ES 2344+514	51.7	23.8	12.5	2.0	3 / 4.86	0.38
1ES 1959+650	65.1	20.0	13.2	1.3	5 / 3.71	1.01
QSO 0528+134	13.4	5.5		2.0	4 / 4.98	0.39
QSO 0235+164	16.6	2.6		1.7	6 / 5.04	0.70
QSO 1611+343	34.4	16.2		0.8	5 / 5.24	0.56
QSO 1633+382	38.2	16.6		1.7	4 / 5.58	0.37
QSO 0219+428	42.9	2.4		1.6	4 / 4.31	0.54
QSO 0954+556	55.0	9.9		1.7	2 / 5.23	0.22
QSO 0716+714	71.3	7.4		4.4	1 / 3.25	0.30
SS433	5.0	19.2		0.7	2 / 4.50	0.21
GRS 1915+105	10.9	19.2		2.2	6 / 4.76	0.71
GRO J0422+32	32.9	4.4		2.9	5 / 5.12	0.59
Cygnus X-1	35.2	20.0		2.5	4 / 5.21	0.40
Cygnus X-3	41.0	20.5	4.9	3.5	6 / 5.04	0.77
XTE J1118+480	48.0	11.3		2.2	2 / 5.40	0.20
CI Cam	56.0	4.3		0.8	5 / 5.11	0.66
LS I +61 303	61.2	2.7		1.5	3 / 3.65	0.60
SGR 1900+14	9.3	19.1		1.0	3 / 4.27	0.35
Crab Nebula	22.0	5.6	4.2	2.4	10 / 5.36	1.25
Cassiopeia A	58.8	23.4	9.8	1.2	4 / 4.59	0.57
Geminga	17.9	6.6	6.8	3.3	3 / 5.17	0.29

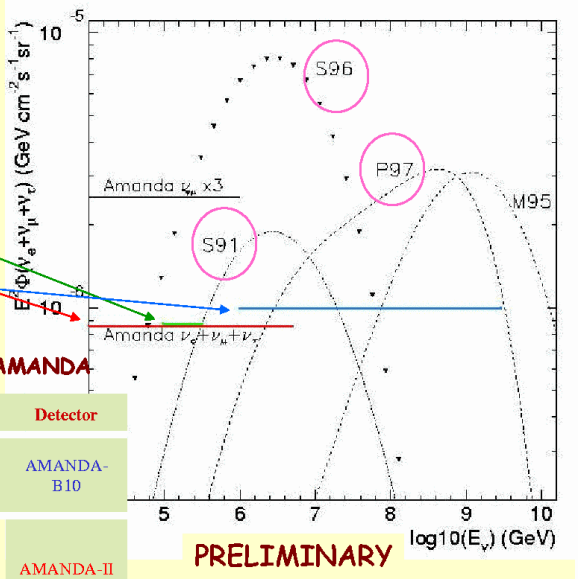

Sensitivities
Single years & Combination
2000
2001
2002
2003
2000-2003 (optimized)
2000-2003 (linear likelihood cut)
Sensitivity / 10 -6GeV E-2 cm-2s-1
Sin(δ)
0.05
0.1
0.15
0.2
0.25
.03
0
0.2
0.4
0.6
0.8
1


DIFFUSE FLUX SEARCH & LIMITS [CASCADES]
4π coverage for cascades
Sensitive to all three flavors
2000 data sample (AMANDA-II)
197 days livetime
1.2·10⁹ events @ trigger level
After optimized cuts:
N_obs = 1 event
N_atm μ = 0.90 +0.69 -0.43
N_atm ν = 0.06 +0.09 -0.04 25%norm
Assuming E⁻² signal spectrum
E²Φ_all ν(E) < 8.6·10⁻⁷ GeV cm⁻² s⁻¹ sr⁻¹
(flavor mixing ν_e:ν_μ:ν_τ =1:1:1)
50 TeV < E_ν < 5 PeV
'00 paper submitted to Phys. Rev. D
experiment
atm. μ MC
E⁻² signal MC (ν_e)
events / 197 d / 0.2
log10(E_reco/GeV)
~ 200 m

DIFFUSE NEUTRINO FLUXES $\Phi_{all\nu}$

AMANDA 90% CL upper limits to a diffuse E^{-2} all neutrino flux obtained from :

- High energy tail of atmospheric neutrino spectrum
- search for cascade events
- search for UHE events



Specific predicted model spectra excluded by AMANDA

Reference	Prediction	Analysis	Detector
Szabo,Protheroe (1992) Protheroe (1997) Stecker,Salamon (1996)	SPH92L P96pγpp SSQC	Diffuse (97) [published]	AMANDA-B10
Szabo,Protheroe (1992) Protheroe (1997) Stecker,Salamon (1996) Nellen et al.(1993)	SPH92L P96pγpp pγ:SS pp:N	Diffuse (00) [in progress]	AMANDA-II
Stecker(1991) Stecker,Salamon (1996) Szabo,Protheroe (1992) Szabo,Protheroe (1992) Protheroe (1996)	SDSS SS Quasar SP u SP l P pp+pγ	Cascades (00) [submitted]	AMANDA-II
Stecker,Salamon (1996) Protheroe (1996)	S96 P97	UHE (97) [submitted]	AMANDA-B10

Stecker,Salamon (1996) prediction excluded by all these AMANDA analyses

Search for a neutrino signal from point sources: transient phenomena

'Enhance the detection chance by using the time information':
- Search for transient signals, still compatible with the 4 years-averaged flux upper limits

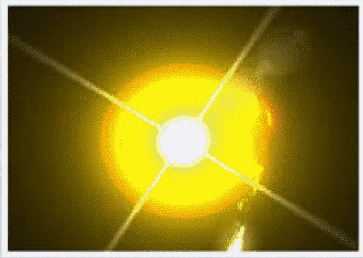


IMAGE CREDIT: NASA/Honeywell Max Q Digital Group, Dana Berry

look at known periods (active states)

Search for events in coincidence with known periods of enhanced electromagnetic emission:

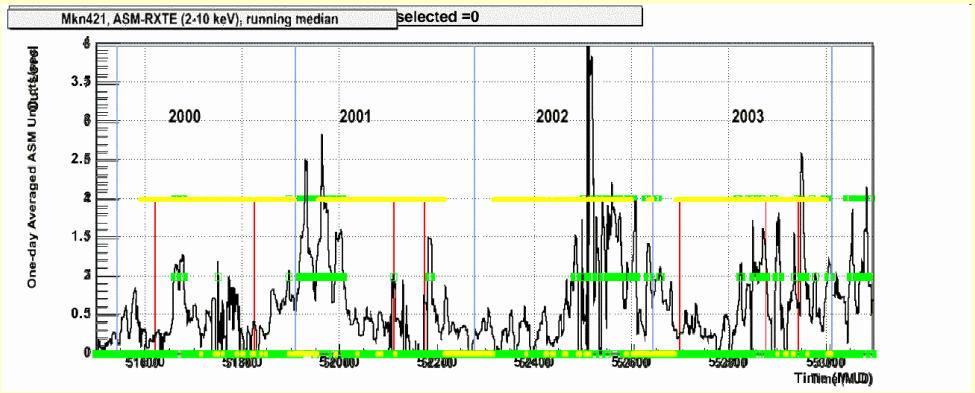
- Periods and sources selected on the basis of the *available multi-wavelength information*
- Wavelengths investigated are *possible indicators for a correlated neutrino emission* (X-ray for Blazars and radio for Microquasars)

Source	EM light curve source	Livetime in periods of high activity	Nr. of ν events in high state	Expected backgr. in high state
Markarian 421	ASM/RXTE	141 days	0	1.63
1ES1959+650	ASM/RXTE	283 days	2	1.59
Cygnus X-3	Ryle Telesc.	114 days	2	1.37

Multi-wavelength information and theoretical knowledge of the time-correlation with the possible neutrino emission are meager:
Search for neutrino flares without a-priori hypothesis on their time of occurrence

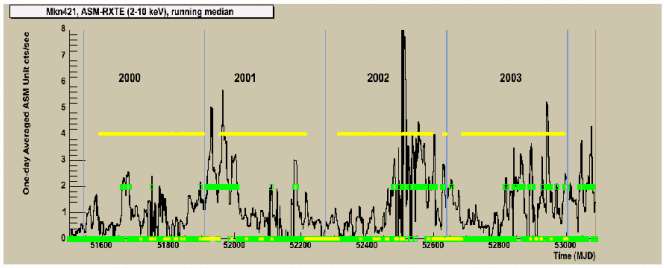
results of the multi-wavelength comparison

Source	EM light curve source	Livetime in periods of high activity	Nr. of ν events in high state	Expected background (high state)	Expected background (4 years)
Markarian 421	ASM/RXTE	141 d	0	1.63	9.44
1ES1959+650	ASM/RXTE	283 d	2	1.59	4.67
Cygnus X-3	Ryle Telesc.	114 d	2	1.37	9.86

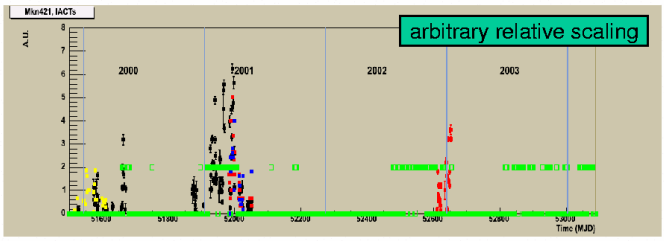


multi-wavelength comparison

- very limited TeV-γ measurements
- x-ray all-sky monitor provides continuous data



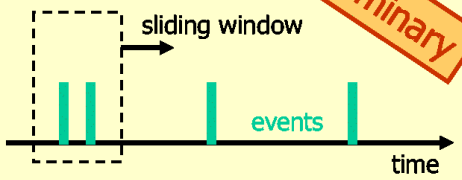
- high state: x-ray luminosity > L
- L defined by optimizing S/sqrt(N) ratio
  (S=integr. luminosity, N=duty cycle)



2. Search for neutrino flares

Preliminary

Search for excesses in time-sliding windows:
No statistical significant effect observed



= 2.25°-3.75°

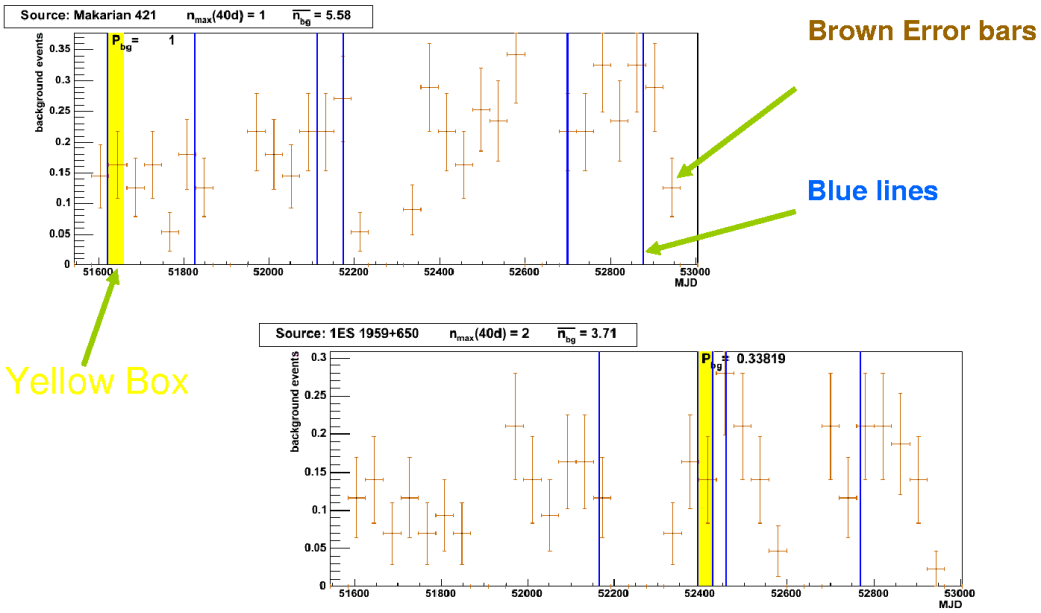
= 40/20 days for Extragalactic/Galactic Objects

Source	Nr. of ν events (4 years)	Expected backgr. (4 years)	Period duration	Nr. of doublets	Probability for highest multiplicity
Markarian 421	6	5.58	40 days	0	Close to 1
1ES1959+650	5	3.71	40 days	1	0.34
3EG J1227+4302	6	4.37	40 days	1	0.43
QSO 0235+164	6	5.04	40 days	1	0.52
Cygnus X-3	6	5.04	20 days	0	Close to 1
GRS 1915+105	6	4.76	20 days	1	0.32
GRO J0422+32	5	5.12	20 days	0	Close to 1

... out of **12** Sources

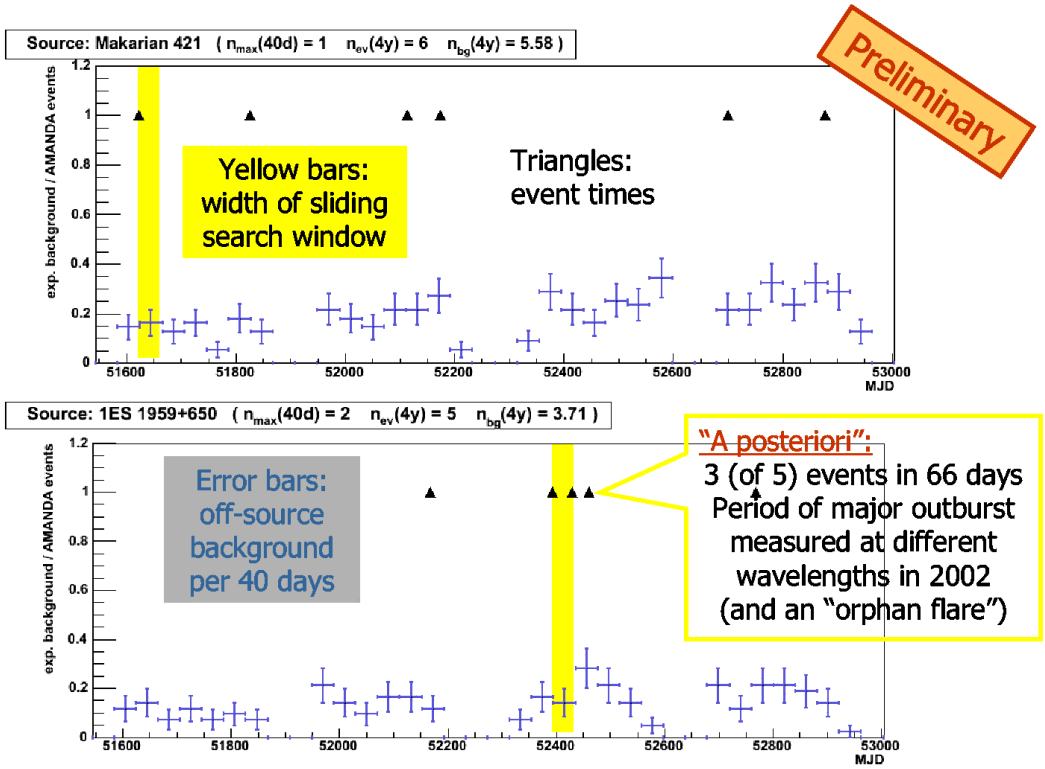
Source	Total Nr. Events	Total Backgr.	Period duration	Nr. of doublets	Probability for highest significance
Markarian 421	6	5.58	40 days	0	Close to 1
1ES1959+650	5	3.71	40 days	1	0.34
3EG J1227+4302	6	4.37	40 days	1	0.43
3EG J0450+1105	6	4.67	40 days	1	0.47
QSO 0235+164	6	5.04	40 days	1	0.52
QSO 0528+134	4	4.98	40 days	0	Close to 1
Cygnus X-3	6	5.04	20 days	0	Close to 1
Cygnus X-1	4	5.21	20 days	0	Close to 1
GRS 1915+105	6	4.76	20 days	1	0.32
GRO J0422+32	5	5.12	20 days	0	Close to 1
3EG J1828+1928	3	3.32	20 days	0	Close to 1
3EG J1928+1733	7	5.01	20 days	1	0.35

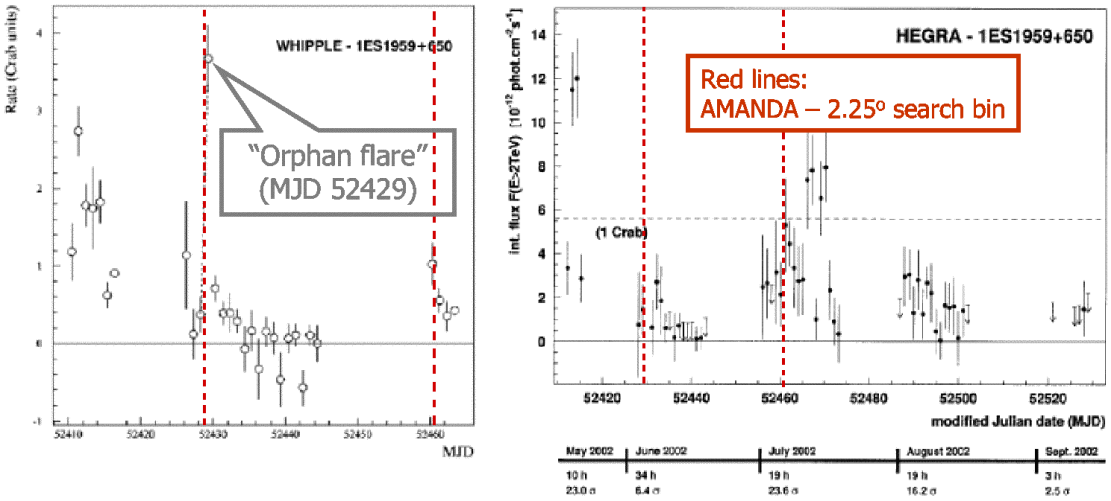
Search for neutrino flares



results of neutrino flare search

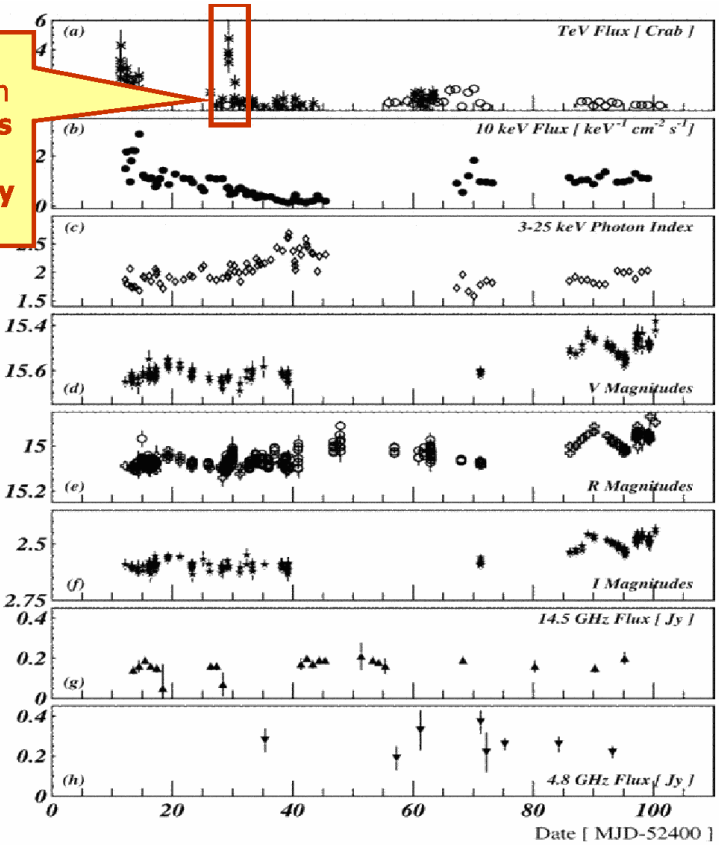
- **No significant event cluster found in sliding windows for the selected sources**
- Easy test for event clusters with relatively low trial factor
- Included in 2000-2003 point source paper draft





Probability of a random coincidence
with the "orphan flare" or the enhanced γ-ray activity **undefined:** a-posteriori hypothesis relative to the test

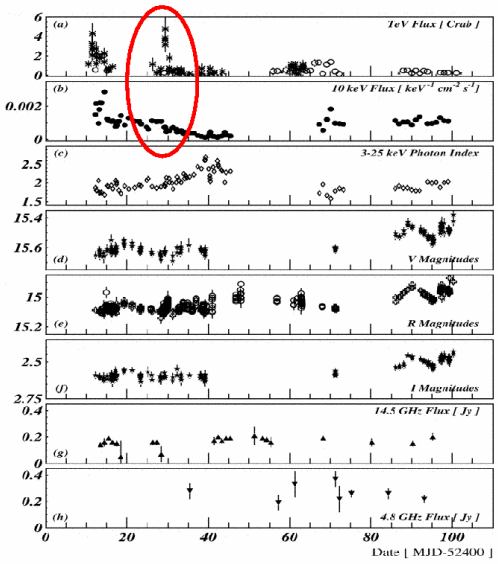
Unique observation of a high flux γ-**rays flare without** corresponding **X-ray** counterpart

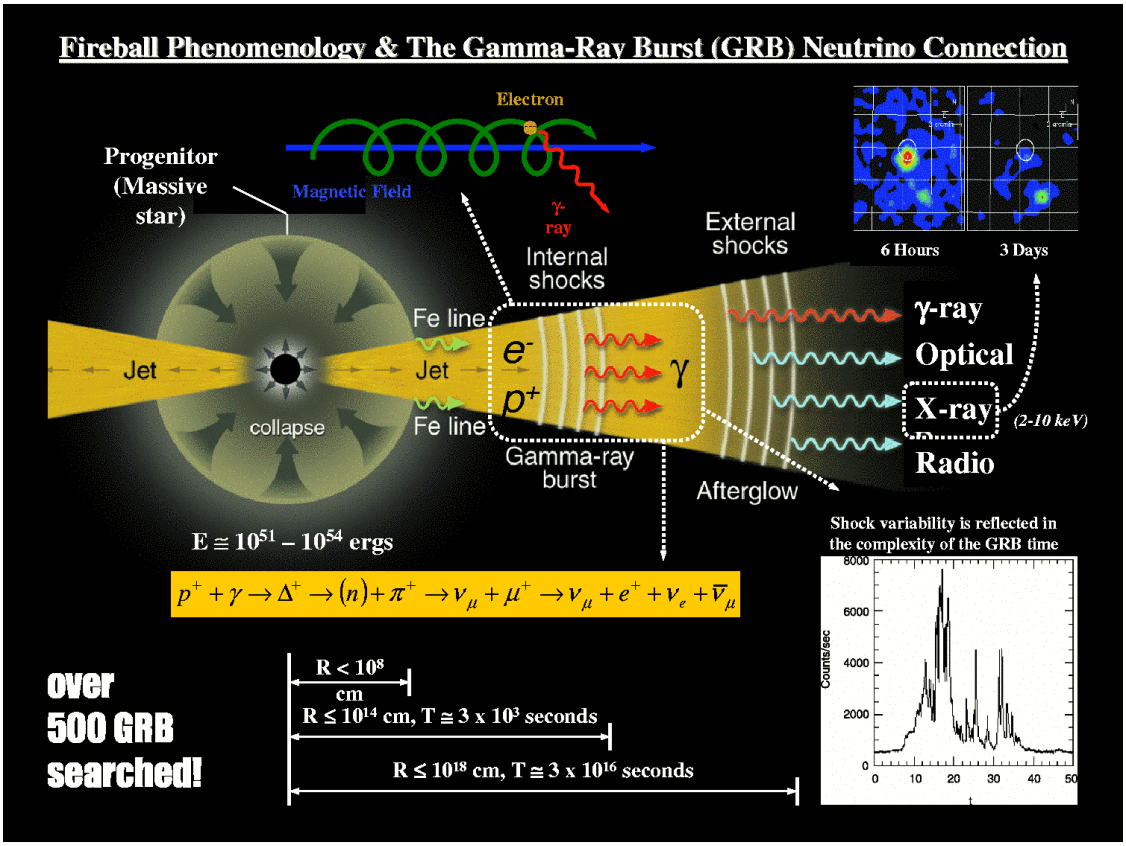


Results from the multi-wavelength campaign
(a) Whipple and HEGRA
(b-c) X-ray
(d-f) optical
(g-h) radio
ApJ 601, 151 (2004)

Orphan flares

- Only one orphan flare known (1ES 1959+650, MJD 52429)
- very short duration
- NOT included in high state period defined by x-ray luminosity
- independent test was taken into consideration
- rejected for low detection probability (short flare duration)





examples of other AMANDA results

…leaving the 3 σ club

	IceCube	AMANDA-II**	ANTARES
# OF PMTS	4800/10 INCH	600/8 INCH	900/10 INCH
point source sensitivity (ν_μ per year)	6×10^{-17} cm^{-2} s^{-1}	1.6×10^{-15} cm^{-2} s^{-1} weakly dependent on declination	$0.4–5 \times 10^{-15}$ cm^{-2} s^{-1} depending on declination
diffuse limit* (ν_μ per year)	$3–12 \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}	2×10^{-7} GeV cm^{-2} s^{-1} sr^{-1}	0.8×10^{-7} GeV cm^{-2} s^{-1} sr^{-1}

* depends on assumption for background from atmospheric neutrinos from charm
** includes systematic errors

SUPERNOVA SEARCH '97 + '98

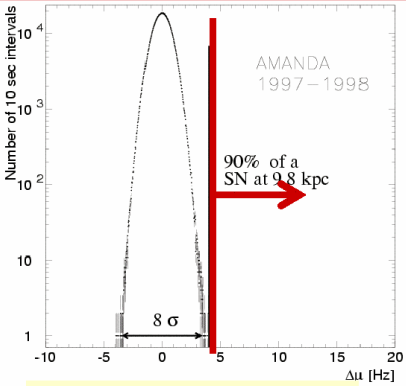
AMANDA-B10 with 302 OMs
Selection of very stable OMs

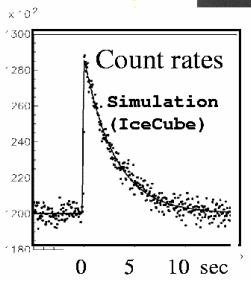
AMANDA-II with 677 OMs

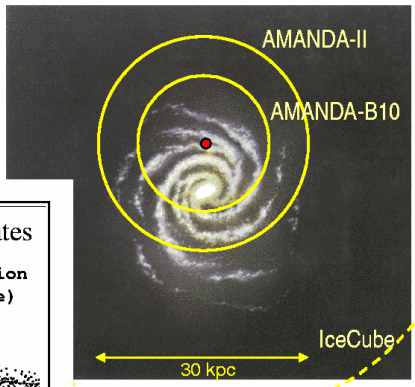
SN Signal proportional
To number of OMs !

CRUCIAL = LOW NOISE

215 Days live time; 90% = 9.8 kpc







Astropart.Phys. 16 (2002) 345

70% of Galaxy coverage

$\Phi_{sn} < 4.3$ Event yr^{-1}

- B-10: 70% of Galaxy
- A-II: 95% of Galaxy
- IceCube: up to LMC

Joined SNEWS (SuperNova Early Warning System)
[with Super-K, SNO, Kamland, LVD, Boone]

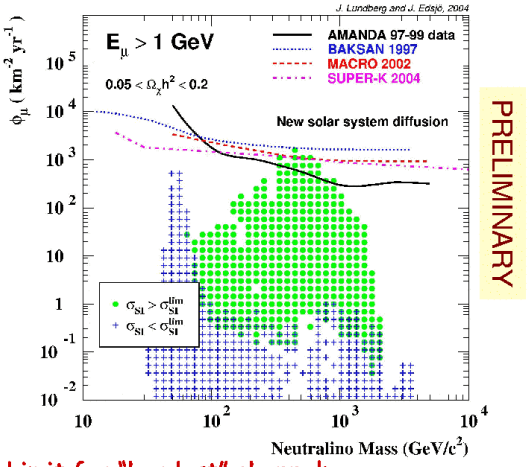
DARK MATTER SEARCH

Look for vertically upgoing tracks

WIMPs from Sun vs Earth:
+ larger mass → deeper gravitational well
+ increased capture: spin-dependent processes
Sun is maximally 23° below horizon
2001 data 0.39 years livetime

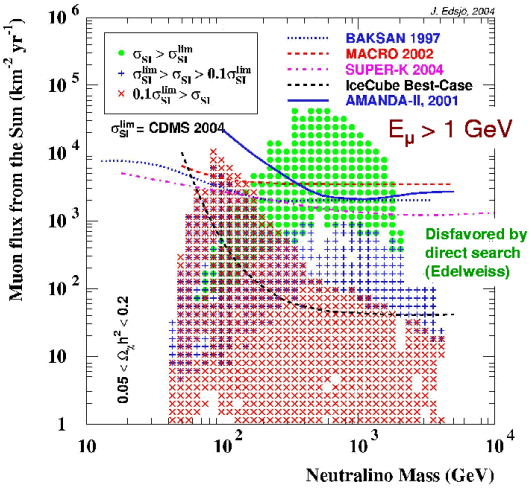
Combine 3 years: 1997-99
Total livetime (80%): 422 days

Muon flux limits



PRELIMINARY

Muon flux limits



Limit for "hardest" channel:

$xx \rightarrow \tau^+\tau^- \rightarrow \nu_\mu$ $\quad M_x = 50$ GeV

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

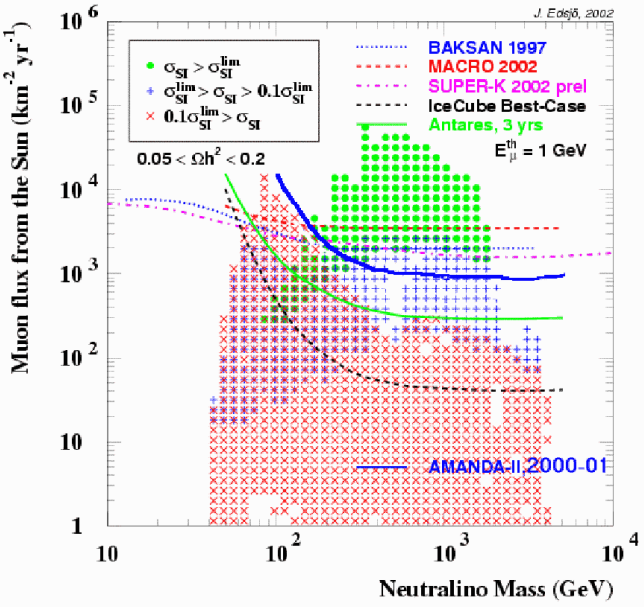
No WIMP signal detected!

Sensitivity to the Muon Flux from WIMP Annihilation in the Center of the Sun

AMANDA-II results:

- based on 280 days of live time
- Exclusion *sensitivity* from analyzing the off-source bins

→Will un-blind data soon

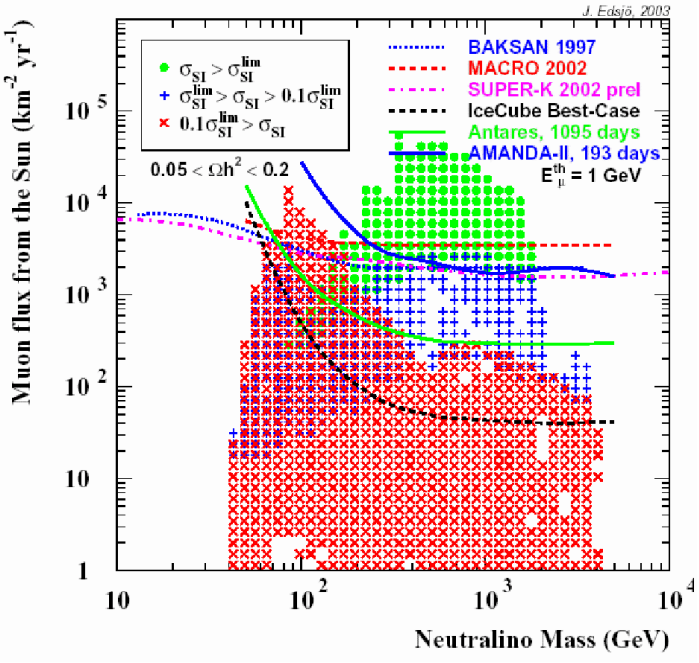


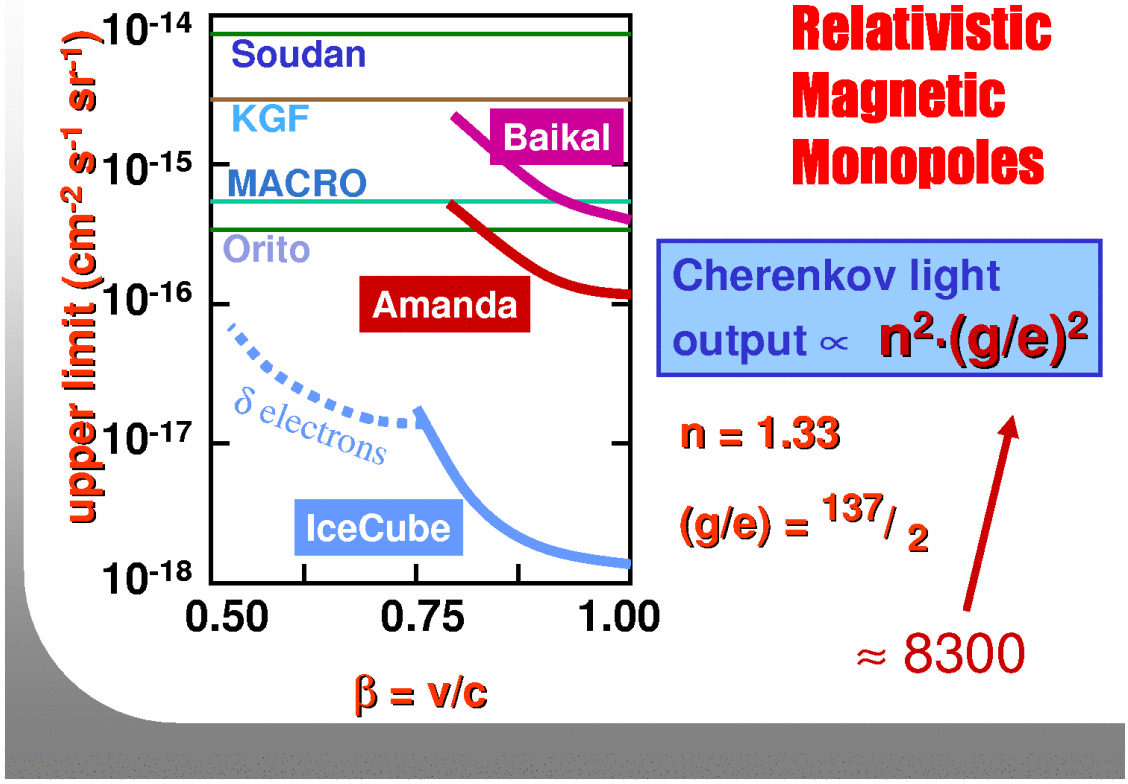
Upper Limits / Sensitivities on the Muon Flux from WIMP Annihilation in the Center of the Sun

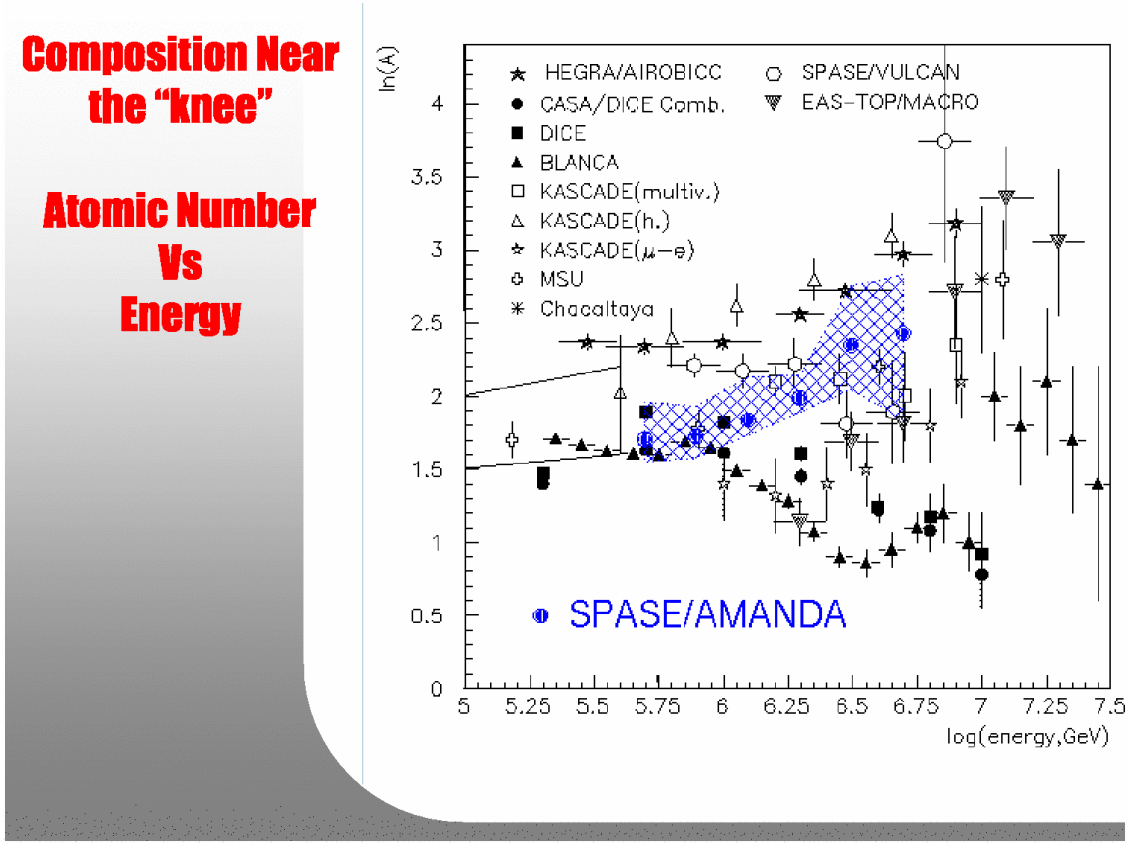
AMANDA-II results:

- based on 193 days of live time
- Exclusion *sensitivity* from analyzing the off-source bins

→Will un-blind data soon

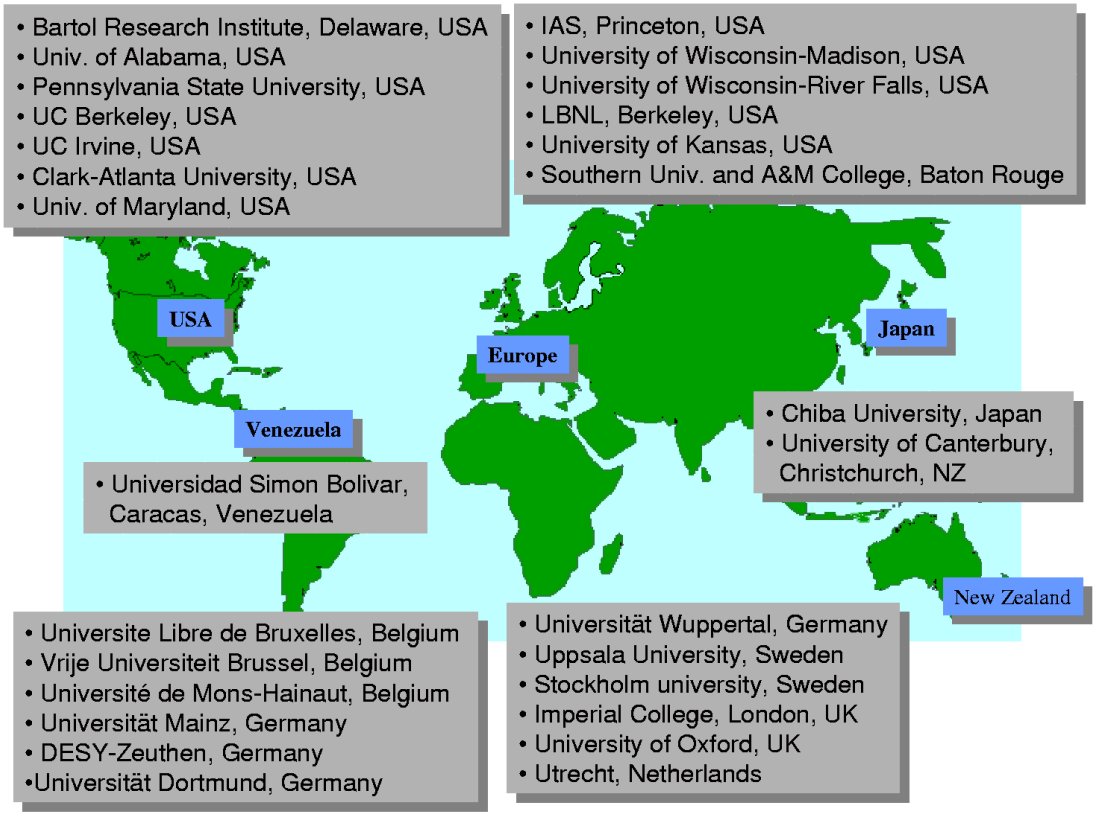


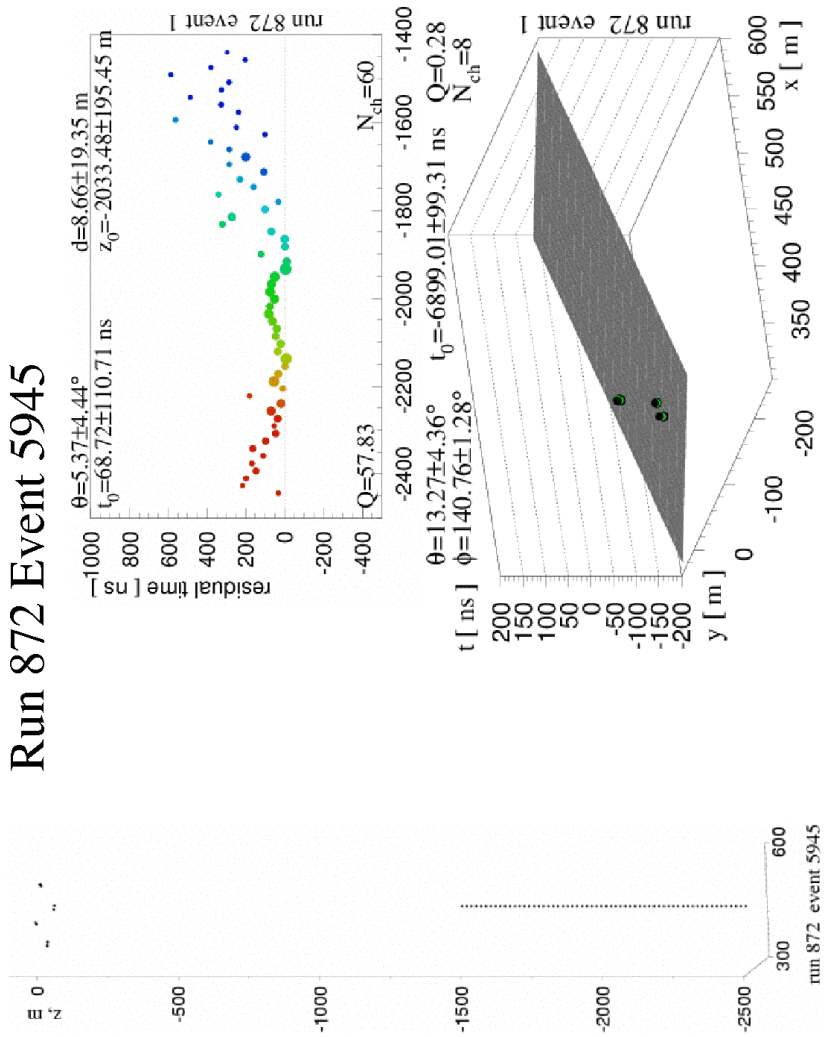

Relativistic
Magnetic
Monopoles
upper limit (cm-2 s-1 sr-1)
10-14
10-15
10-16
10-17
10-18
Soudan
KGF
MACRO
Orito
Baikal
Amanda
δ electrons
IceCube
0.50
0.75
1.00
β = v/c
Cherenkov light
output ∝ n2.(g/e)2
n = 1.33
(g/e) = 137/2
≈ 8300


Composition Near
the "knee"
Atomic Number
Vs
Energy
ln(A)
HEGRA/AIROBICC
CASA/DICE Comb.
DICE
BLANCA
KASCADE(multiv.)
KASCADE(h.)
KASCADE(μ-e)
MSU
Chacaltaya
SPASE/VULCAN
EAS-TOP/MACRO
SPASE/AMANDA
log(energy,GeV)

conclusions

- AMANDA collected > 5,000 ν's
- ~ 10 (7) more every day on-line
- neutrino sensitivity has reached $\nu = \gamma$
- > 100,000 per year from IceCube
- from 1 Crab to < 0.01 Crab sensitivity




Run 872 Event 5945
run 872 event 5945
run 872 event 1
θ=5.37±4.44°
t0=68.72±110.71 ns
d=8.66±19.35 m
z0=-2033.48±195.45 m
Q=57.83
Nch=60
residual time [ns]
θ=13.27±4.36°
ϕ=140.76±1.28°
t0=-6899.01±99.31 ns
Q=0.28
Nch=8
t [ns]
y [m]
x [m]