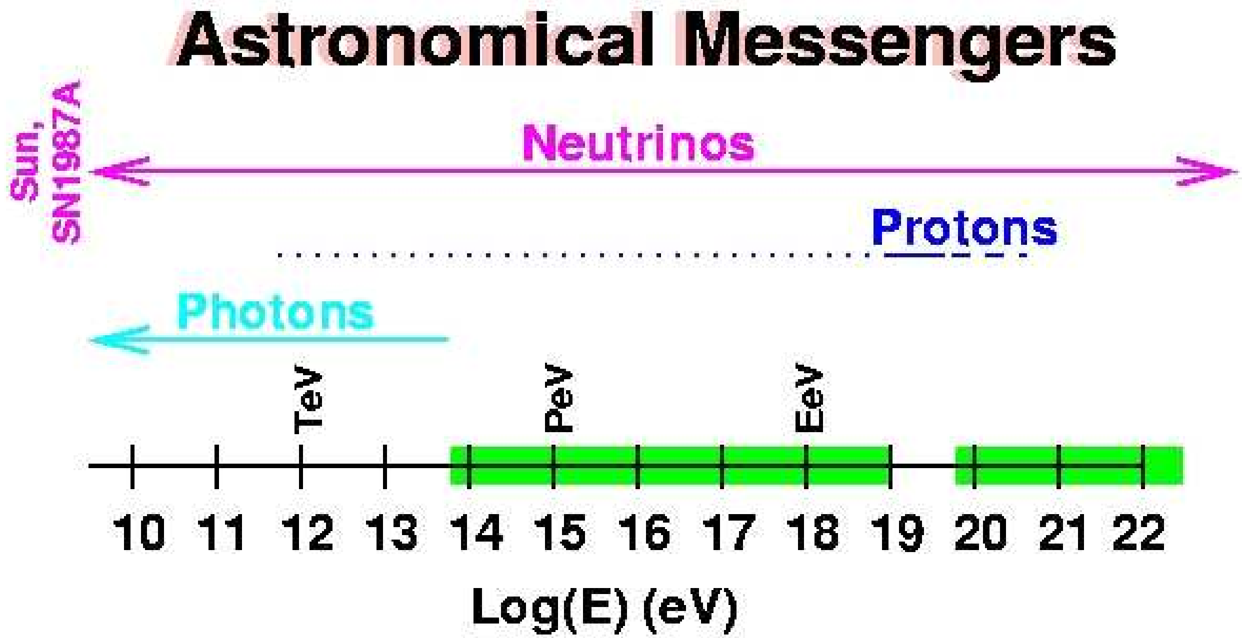
Icefishing for Neutrinos with AMANDA

- **Astrophysics and particle physics allure of ultrahigh energy (UHE) neutrinos**
- **The AMANDA neutrino telescope at the South Pole**
- **Recent AMANDA results**
- **IceCube: Bigger *and* Better**

Astrophysics, Particle Physics and Other Cool Science

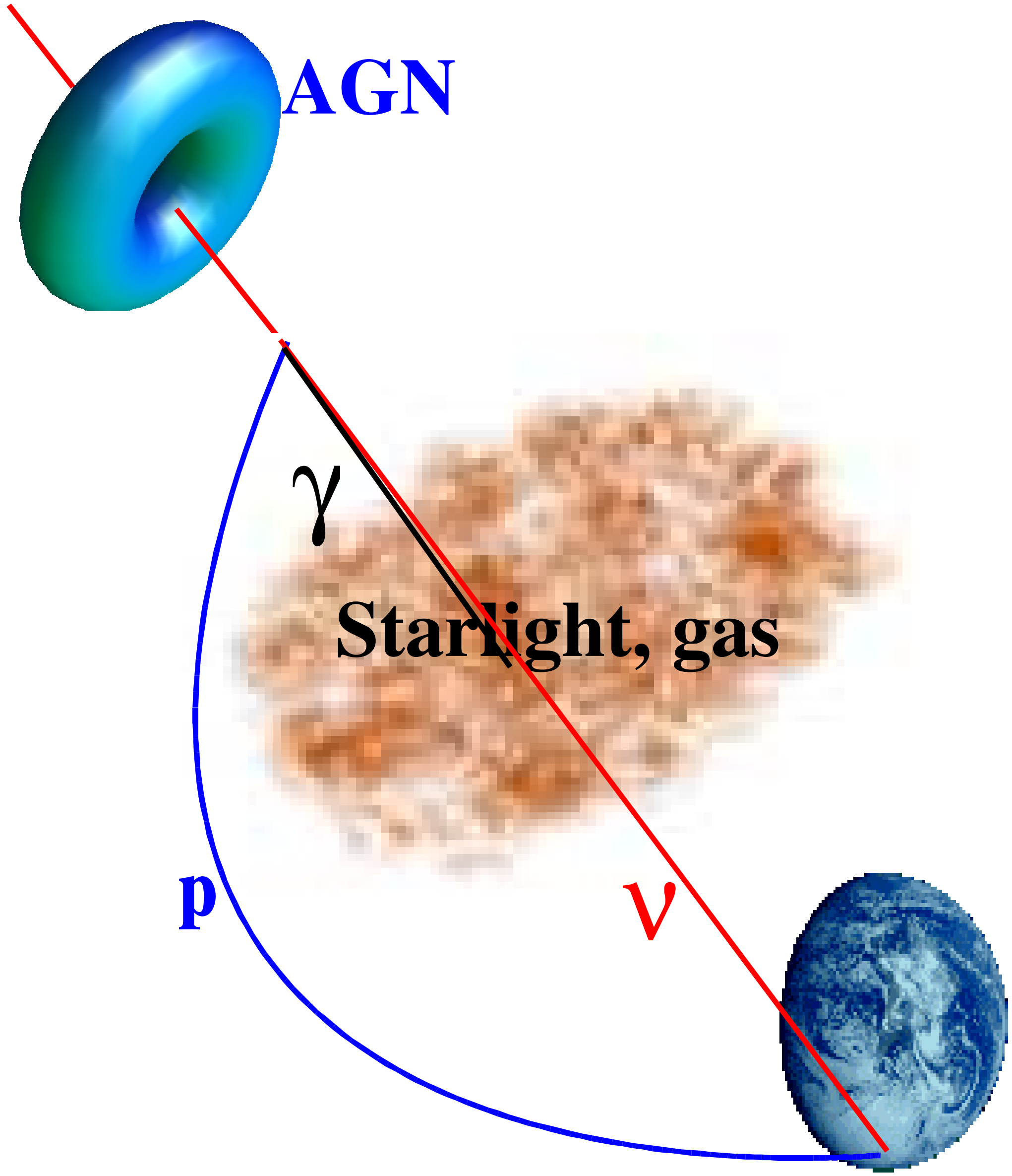
- Main foci for neutrino telescopes:
  - astrophysics: using UHE neutrinos to explore GRBs, AGN, UHECR...and the unknown
  - particle physics: WIMPs, neutrino oscillations, monopoles, topological defects
- Other cutting-edge science:
  - radio Cherenkov array
  - paleoclimatology, glaciology
  - psychrophilic life, subglacial lakes
  - seismology & geophysics (earth tomography)

The Gap



Instrument	Discovery
Galileo's spyglass	Lunar craters, Jovian moons
US surveillance satellites	Gamma Ray Bursters
Radio Telescopes	CMBR,...
CCD cameras	Gravitational lensing,...
UHE neutrino telescopes	???

Generic Cosmic Proton Accelerator and Beamdump



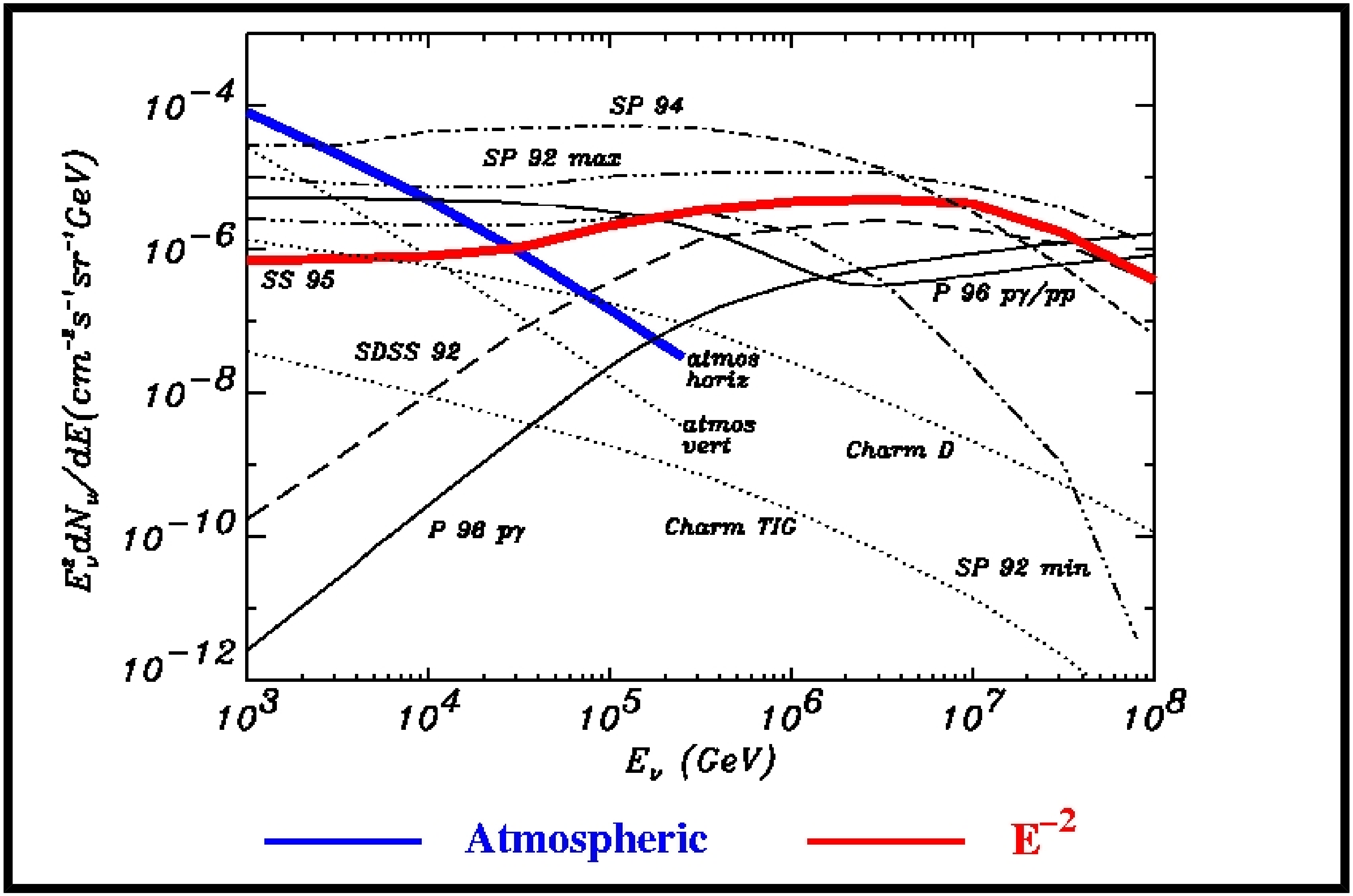
Some Questions UHE Neutrinos May Help Answer

- Gamma ray bursters (GRBs) observed to produce 10^{53} ergs in 1s burst (as luminous as entire universe!). Mechanism?
- Active Galactic Nuclei (AGN) are brightest objects with L = 10^{45} ergs. Mechanism?
- Ultrahigh energy cosmic rays (UHECR) with energies of 10^{20} eV. Production mechanism?
  - GZK cutoff: λ = 50-100 Mpc due to
  - $p+\gamma_{3K} \rightarrow \Delta^{+} \rightarrow pions(\rightarrow \nu, \gamma)$
  - No evidence for nearby sources-can GZK be violated?

Possible Answers from UHE Neutrinos

- GRBs: contemporaneous neutrinos would validate *relativistic fireball* model:
  - merging black holes, merging neutron stars
  - creation of rotating black hole
  - (bonuses: check weak equivalence principle, ν_τ appearance, $\nu - \gamma$ simultaneity)
- AGN: 10^9 M_{solar} black hole at a galaxy's center
  - proton and/or electron acceleration?
- If case for GZK cutoff grows stronger, *Z burst* models may get more interesting

Some UHE ν Flux Predictions

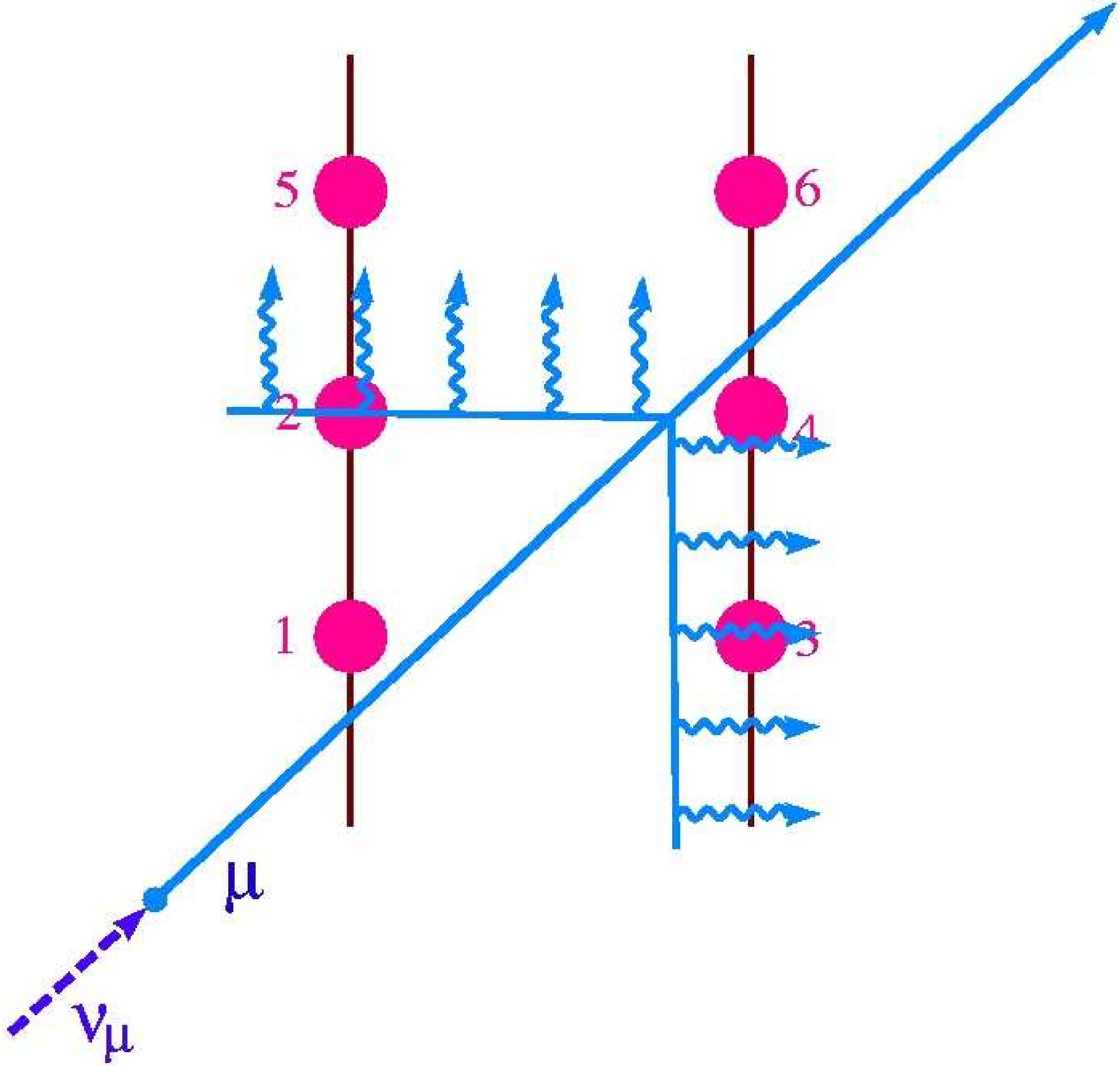


- GRBs: 1-10/y/0.1km^3 with E > 10^{14}eV; one 3-ν burst/decade
- AGN: 1-100/y/0.1km^3 with E > 10^{14}eV

UHE ν Detection

- Rarity and fairly low interaction probability of UHE ν's is balanced by their ultrahigh energy:
  - their interactions produce unmistakable signatures
- But to see them, must instrument very large & deep volumes
  - the bigger the net, the better
  - improve probability of event containment
  - greater depth decreases cosmic ray muon fake rate
- To enhance S/N strive for best possible σ_{ϕ}, σ_E
- Basic detection principle: detect Cherenkov photons
  - Cherenkov radiation is produced when a charged particle moves faster than c/n in a medium: roughly speaking, EM equivalent to sonic boom

Detecting Cherenkov Radiation



Detect Cherenkov photons with array of PMTs. Reconstruct tracks (or cascades) with maximum likelihood technique using photon arrival times.

UHE ν Detection

- large volume must be reasonably transparent to Cherenkov radiation. Too large to build from scratch, so use what Mother Nature provides:
  - water
  - ice
  - salt domes (*radio* Cherenkov)
- transparency requirement:
  - for tracking, want large scattering length
  - for calorimetry, want large absorption length

Past & Present Experiments

Experiment	Locale	Status
DUMAND	Hawaiian coast	Pioneer, defunded
BAIKAL	Lake Baikal, Siberia	Has results on WIMPS, monopoles
AMANDA	South Pole	[doing great! See this talk.]
NESTOR	Greek coast	Prototype studies
ANTARES	French coast	Prototype running

The AMANDA Collaboration

About 100 scientists from 15 universities and laboratories in the US, Europe and Antarctica

Bartol Research Institute
UC-Berkeley
UC-Irvine
U-Kansas
LBNL
U-Penn
UW-Madison

Brussels Free U., Belgium
DESY-Zeuthen, Germany
Kalmar University, Sweden
U-Mainz, Germany
Stockholm University Sweden
U-Uppsala, Sweden
U-Wuppertal, Germany

South Pole Station, Antarctica

The AMANDA Detector

- Building AMANDA
  - Getting to the South Pole
  - Drilling holes in the ice
  - Deploying strings of detectors
- Some sample events
- Results

Getting to the South Pole

Boarding in New Zealand.
Note ECW gear
...in mid-summer.

Everyone flies Connoisseur Class!

Arrival at Pole

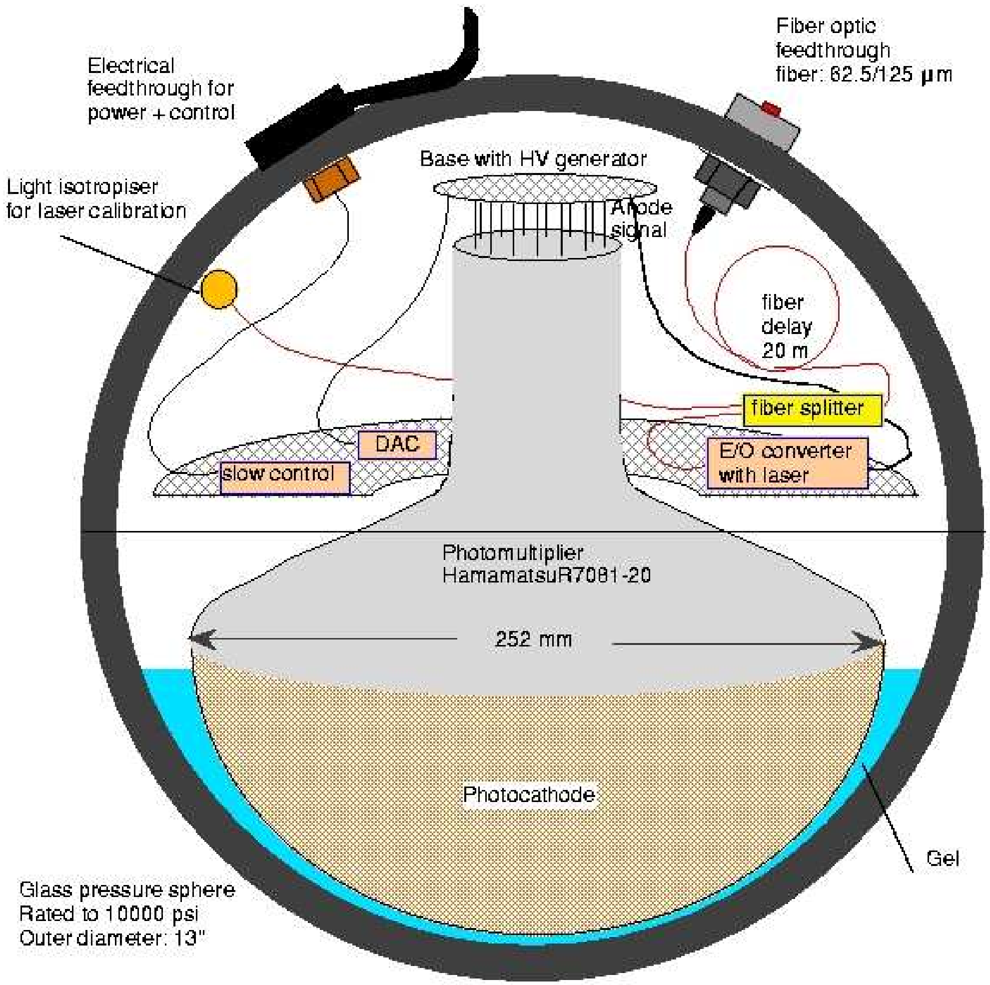
Deployment: Drilling

A completed hole.

Inserting the hot water drill

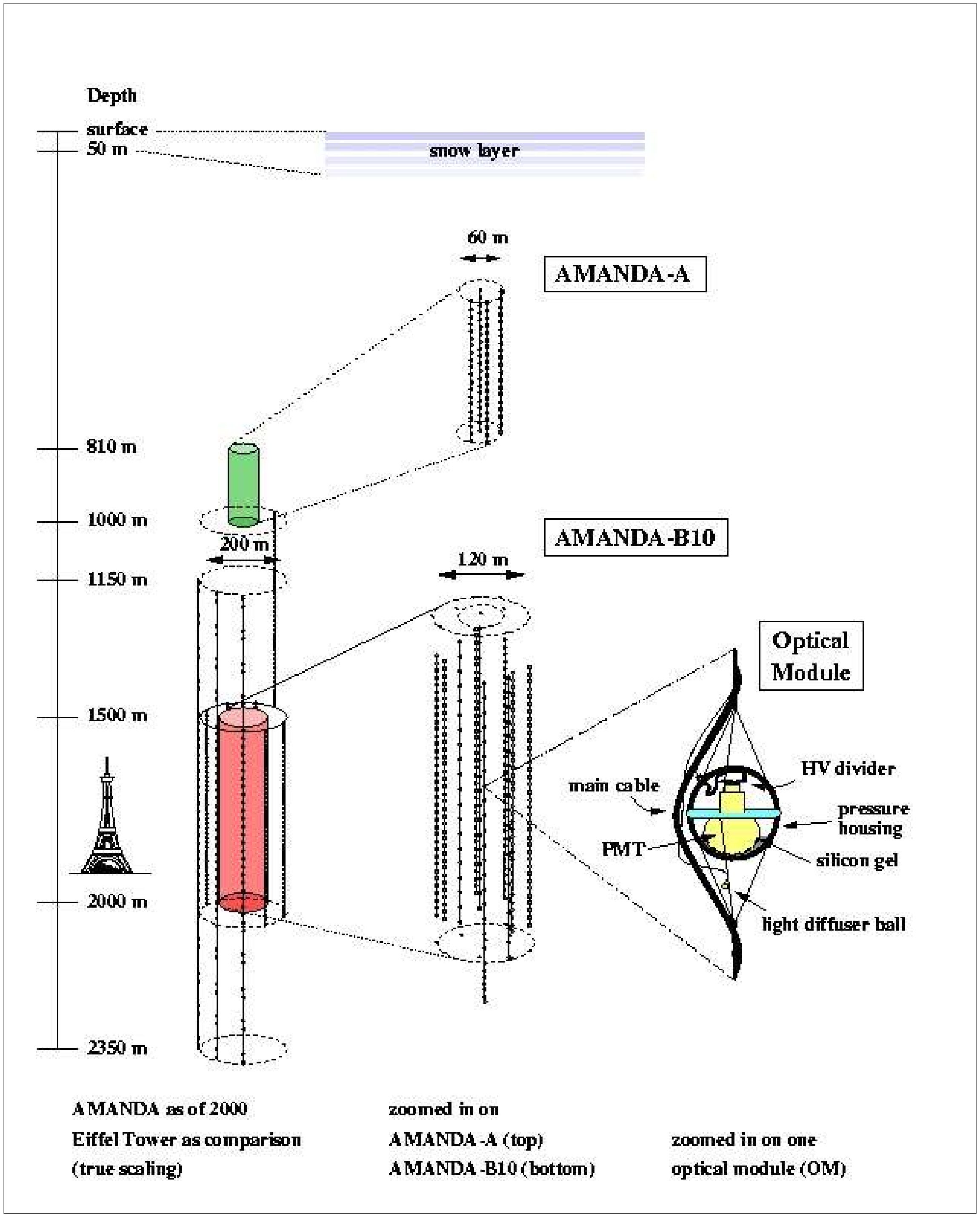
Deployment: String Insertion

The Optical Module

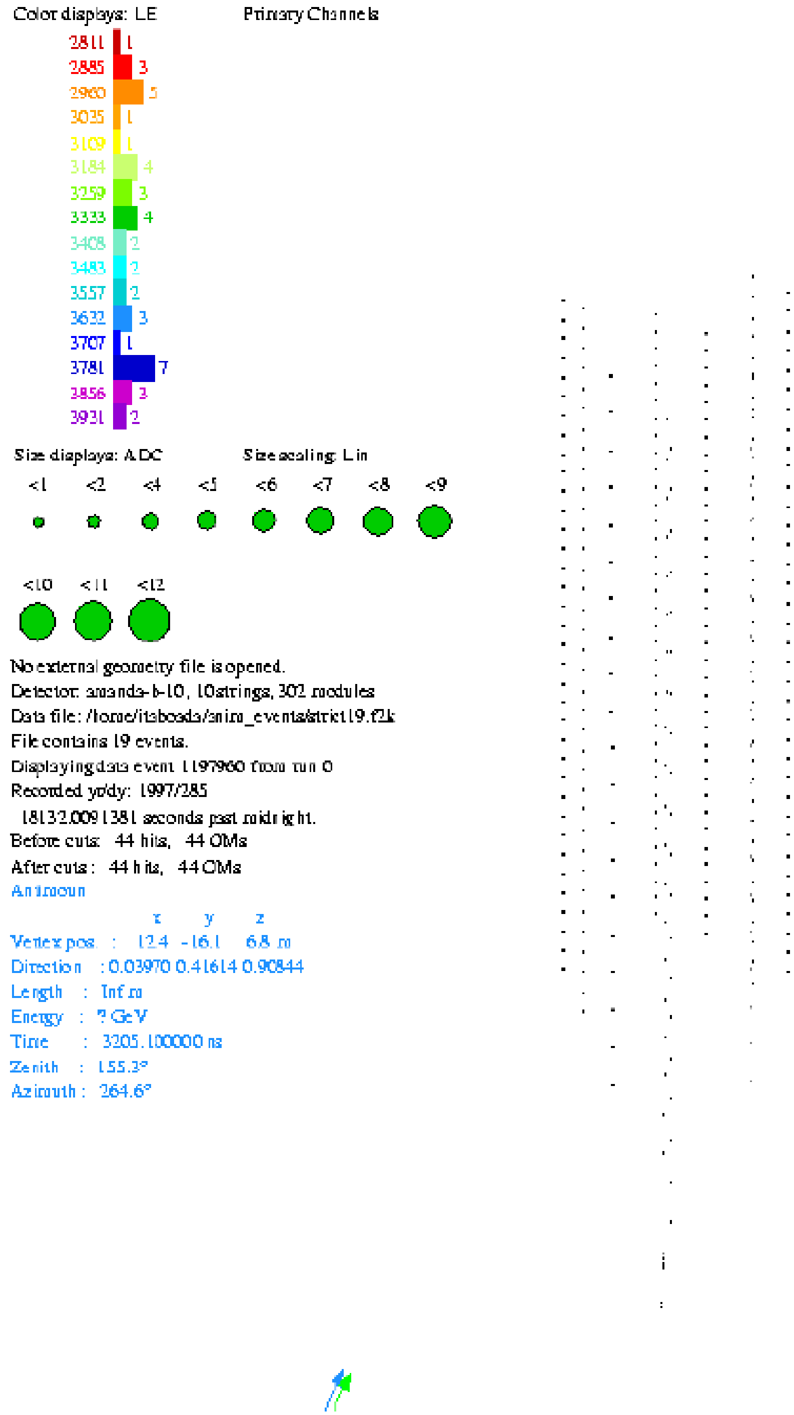


The Millenium Module

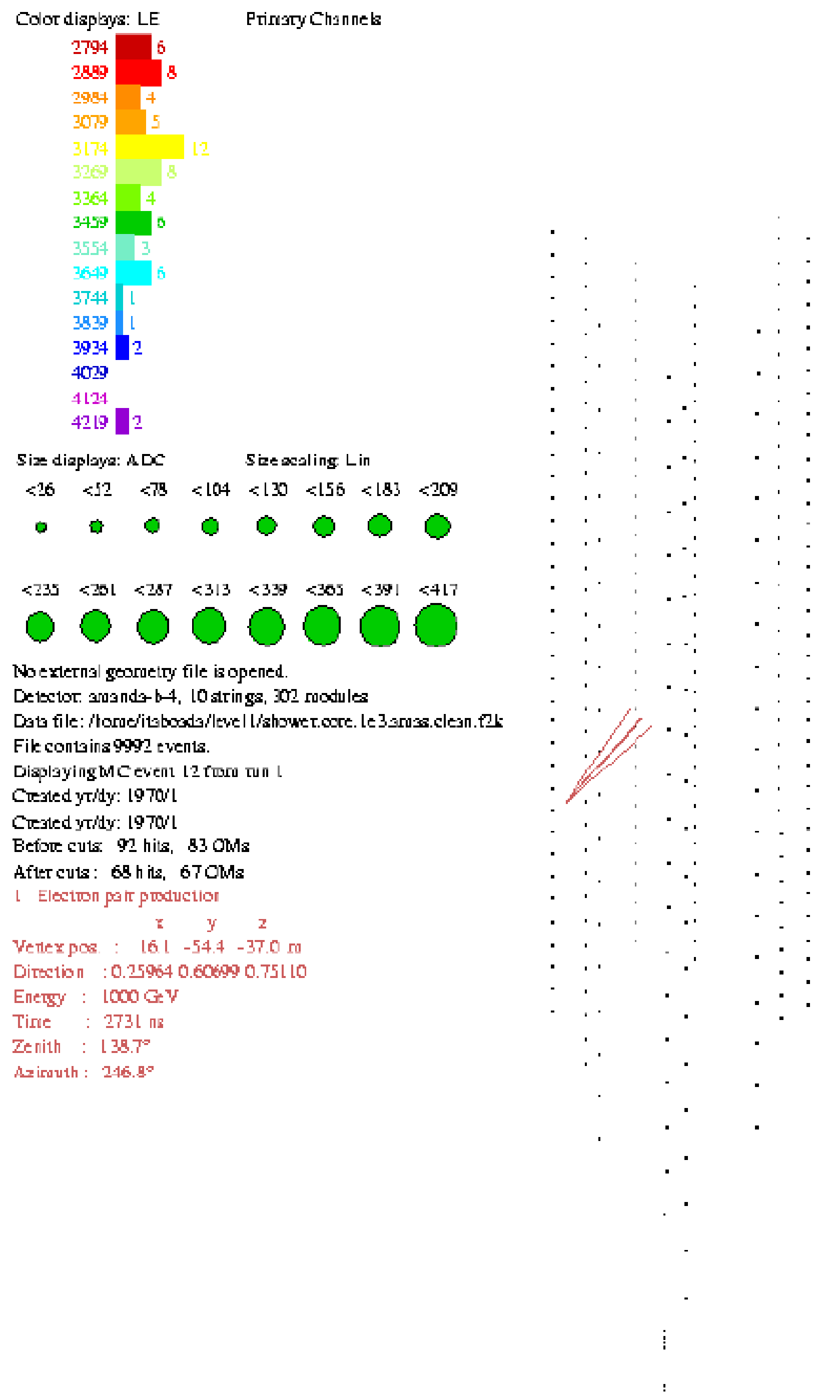
The Completed AMANDA: AMANDA-II



Candidate Muon Neutrino



Simulated 1 TeV Electron Neutrino



Physics Results

- Atmospheric neutrino "test beam" (138 live days, 1997)
- UHE neutrino diffuse flux search
- UHE neutrino point source searches
  - AGN with E^{-2} assumption
  - GRB with spacial *and* temporal coincidence requirements
- WIMPs from earth's core

Decreasing intrinsic difficulty

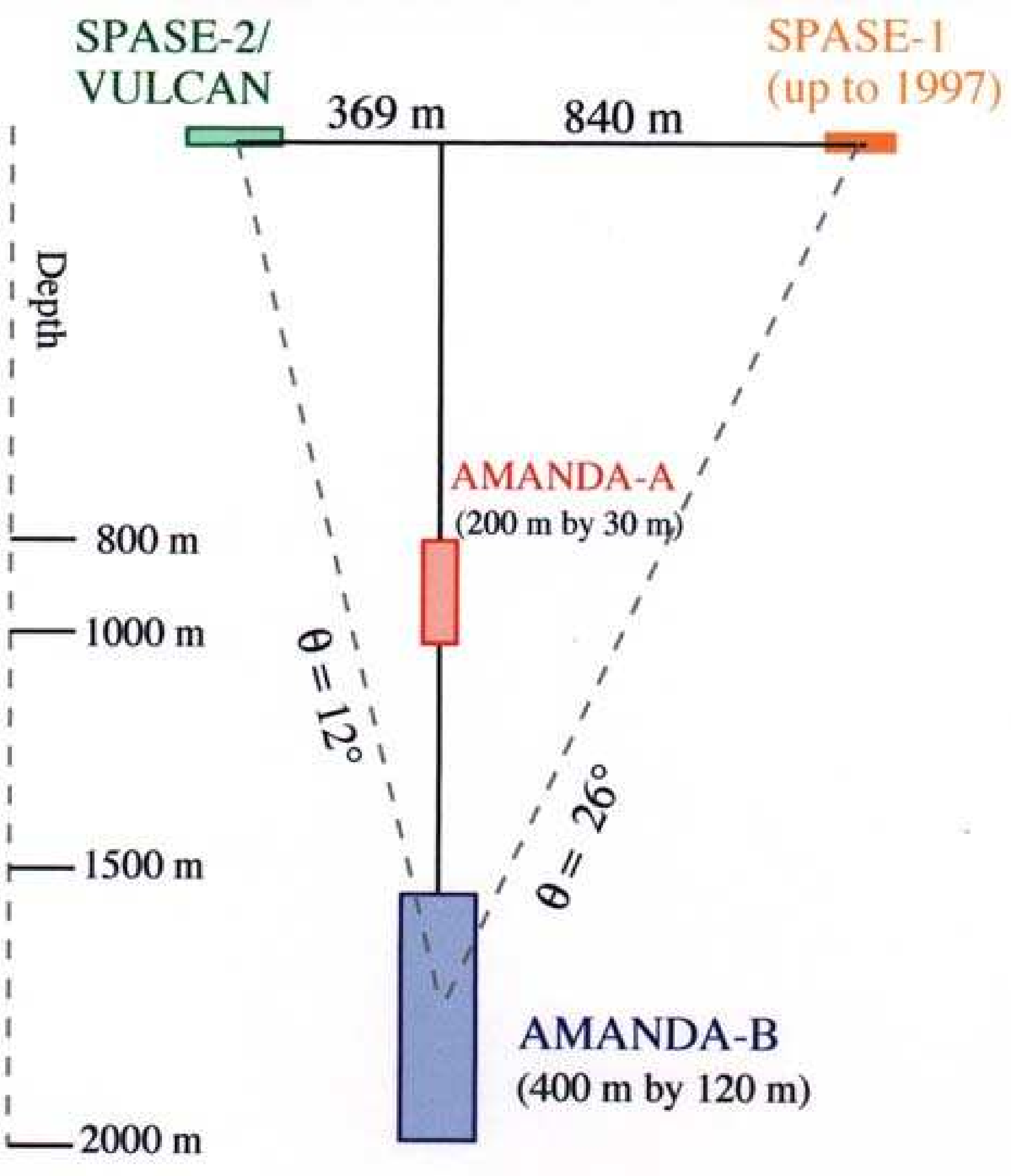
Physics Handles

After removing instrumental noise and requiring good event reconstruction, can then look for one or more of:

- **upward vs. downward**
- energy of event
- **source location in universe**
- **time of event**

	T	r	E	u/d
GRBs	✔	✔	(✔)	✔
AGN, WIMPs		✔	(✔)	✔
Diffuse ν			✔	✔
Atm. ν			✔	✔

SPASE-AMANDA



SPASE (South Pole Air Shower Array) permits calibration of:

- **absolute pointing,**
- **pointing resolution and**
- **signal efficiency.**

Atmospheric ν Analysis

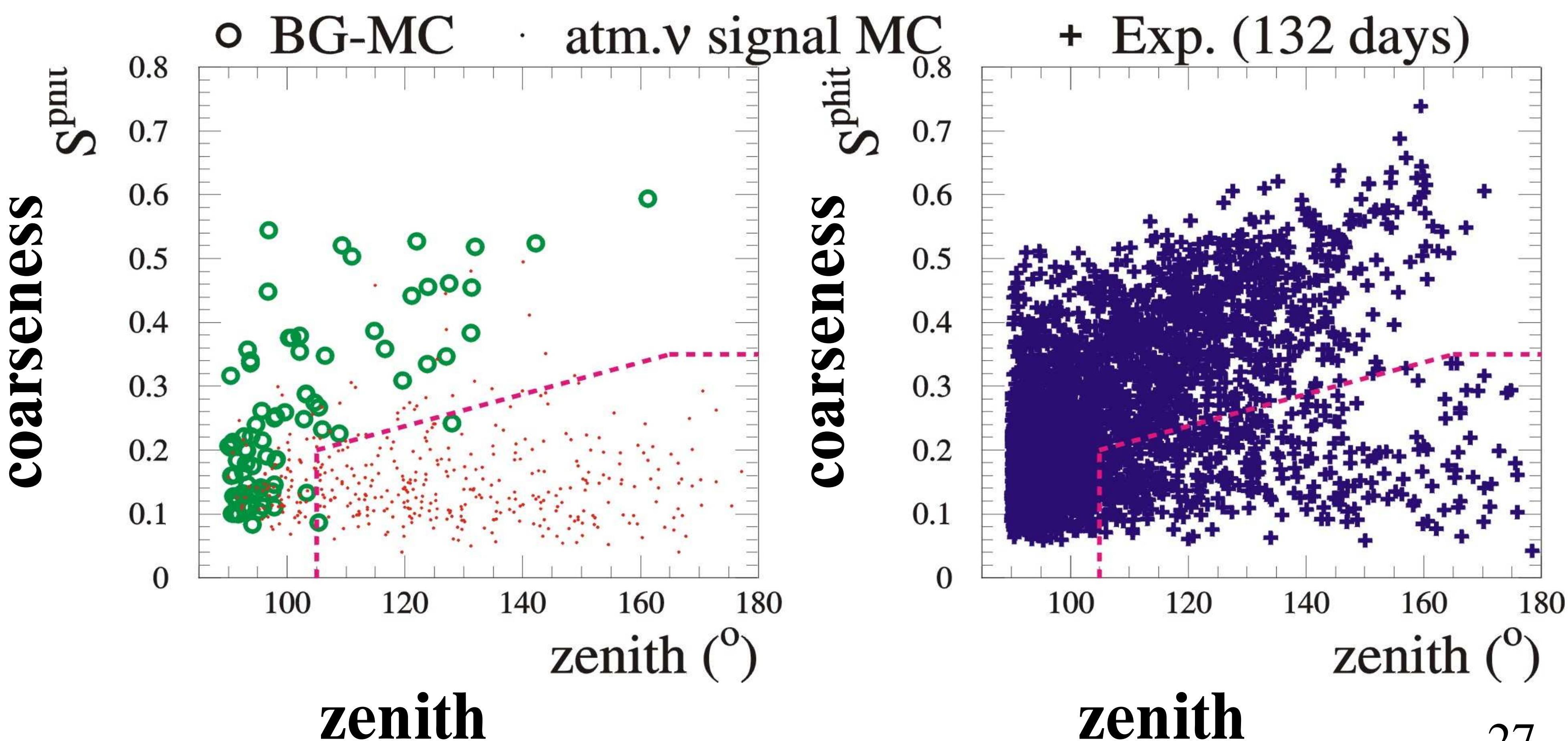
- Confirmation of expected flux of upward-going muon-neutrino-induced muons is a critical milestone for a UHE neutrino telescope
  - Can the detector be calibrated well enough to reconstruct muons?
  - Do we have sufficient pointing accuracy to do astronomy?
  - Can the huge downward-going cosmic ray muon background be overcome?

AMANDA	Down-going cosmic rays	Up-going atm. νs	Detected up-going νs
Events/day	6×10^6	12	1.5

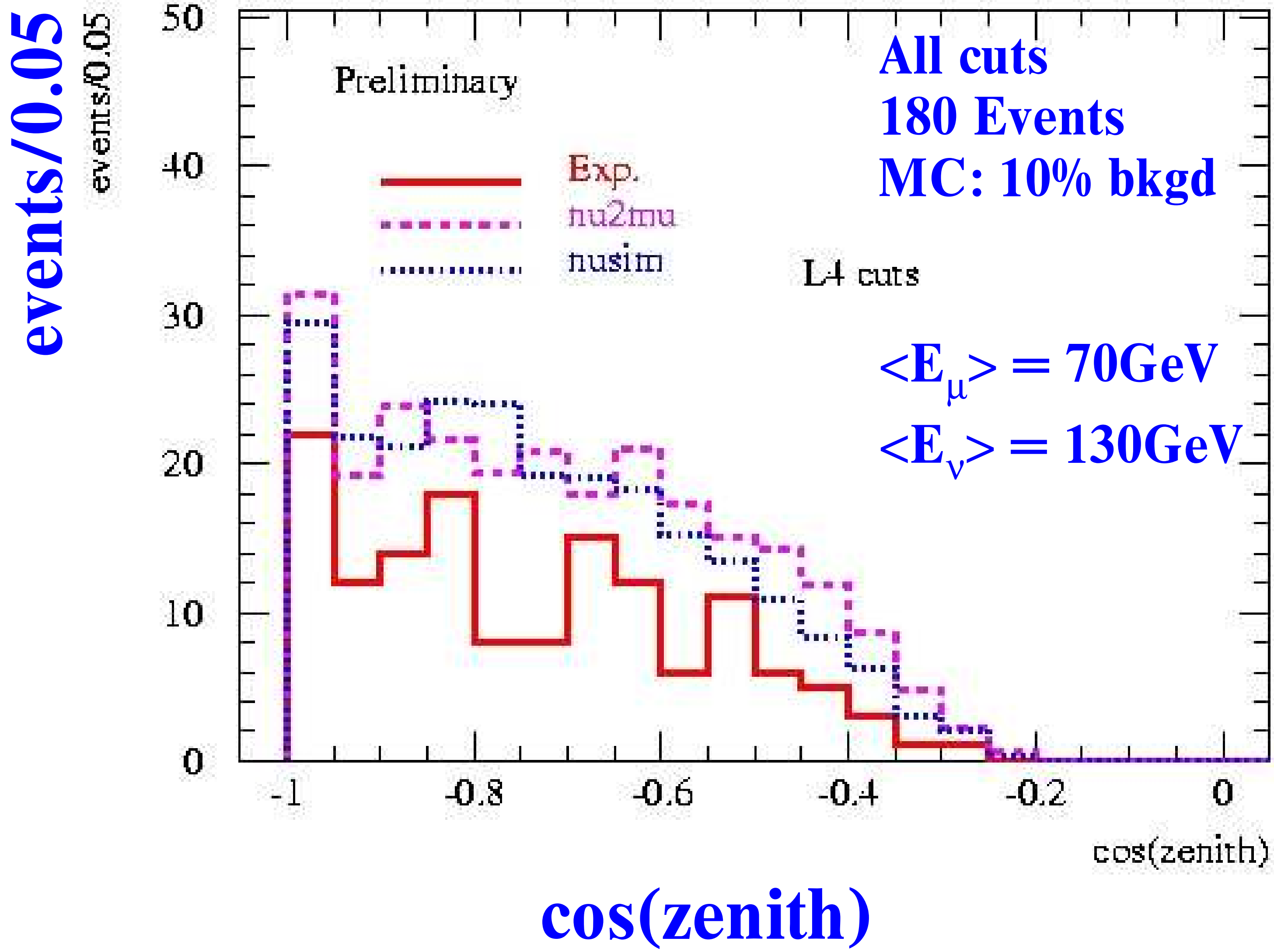
Atmospheric ν Reconstruction

- **Principle selection criteria (after removing noise hits):**
  - minimum number of unscattered photon hits (typically 5 or more)
  - zenith angle (upward going)
  - low “coarseness”
  - track velocity
  - fit likelihood
  - event center of gravity
  - event shape

Signal-Background Separation for Atmospheric Neutrinos



Atmospheric Neutrino Angular Distribution

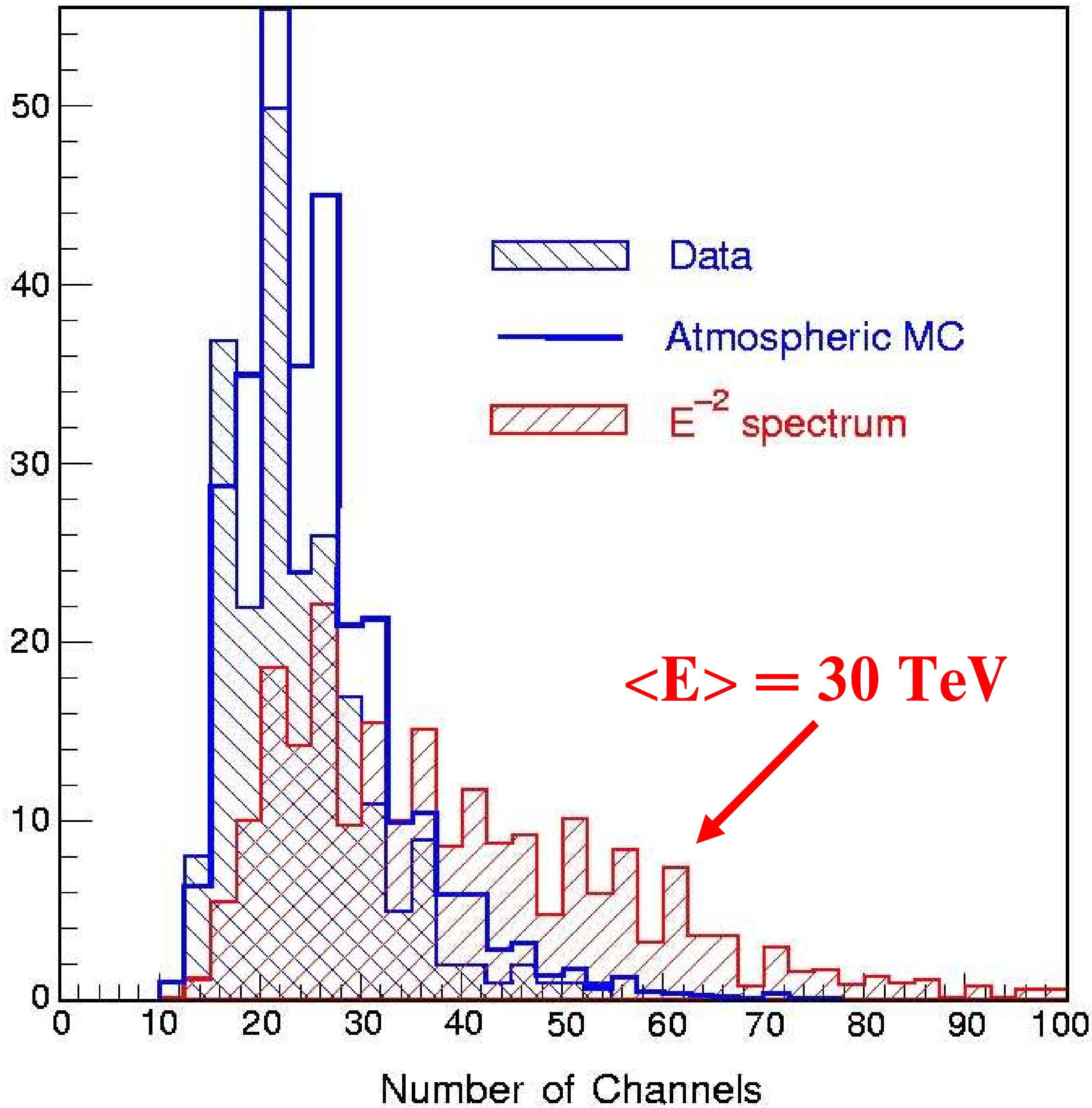


See about 1 evt/day; Good shape agreement

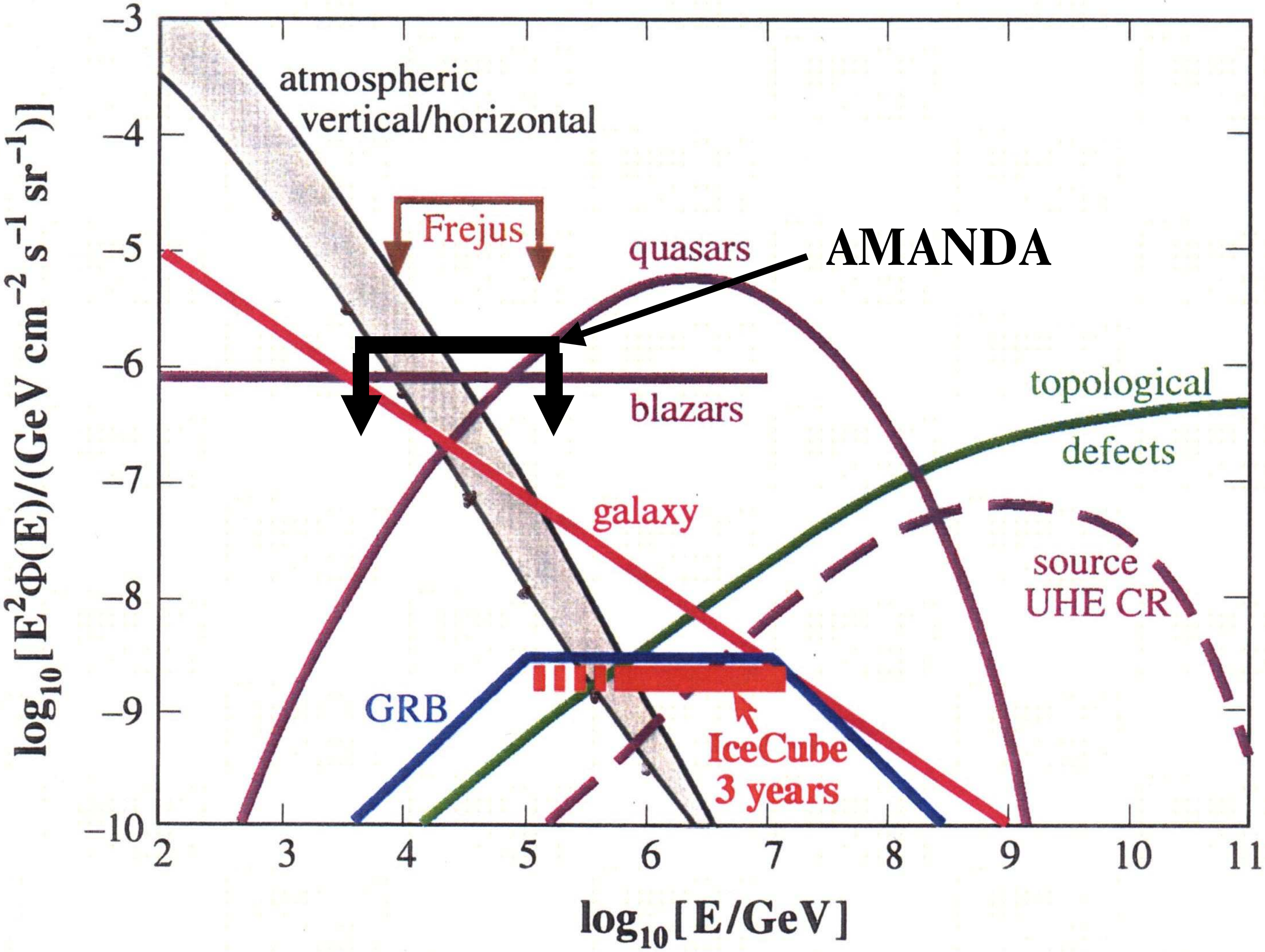
Normalization off by 50%:
- **atm. flux unc.,**
- **ice properties,**
- **obscuration of light by cables, ...**

Diffuse UHE ν Flux

- Use event multiplicity as (so-so) energy estimator
- High multiplicity distribution consistent w/atm. neutrino flux



Diffuse UHE ν Flux Limit

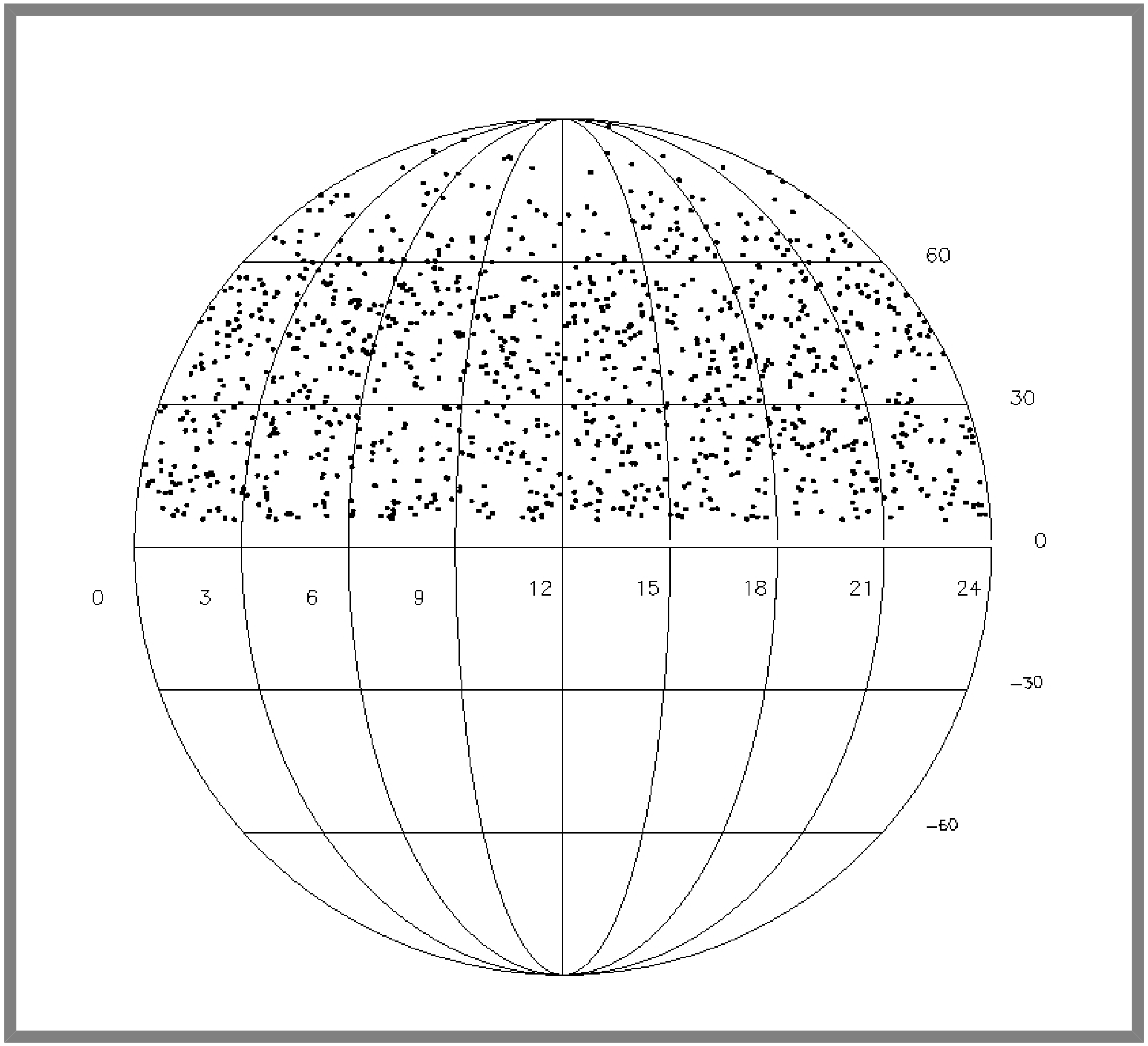


Note that this flux is expected to be 10^3 larger than that for point sources. Also, atm. ν backgrounds are somewhat worse.

$E^2\Phi_\nu < 1.6 \times 10^{-6}$ GeV $cm^{-2}s^{-1}sr^{-1}$

UHE ν Point Source Search

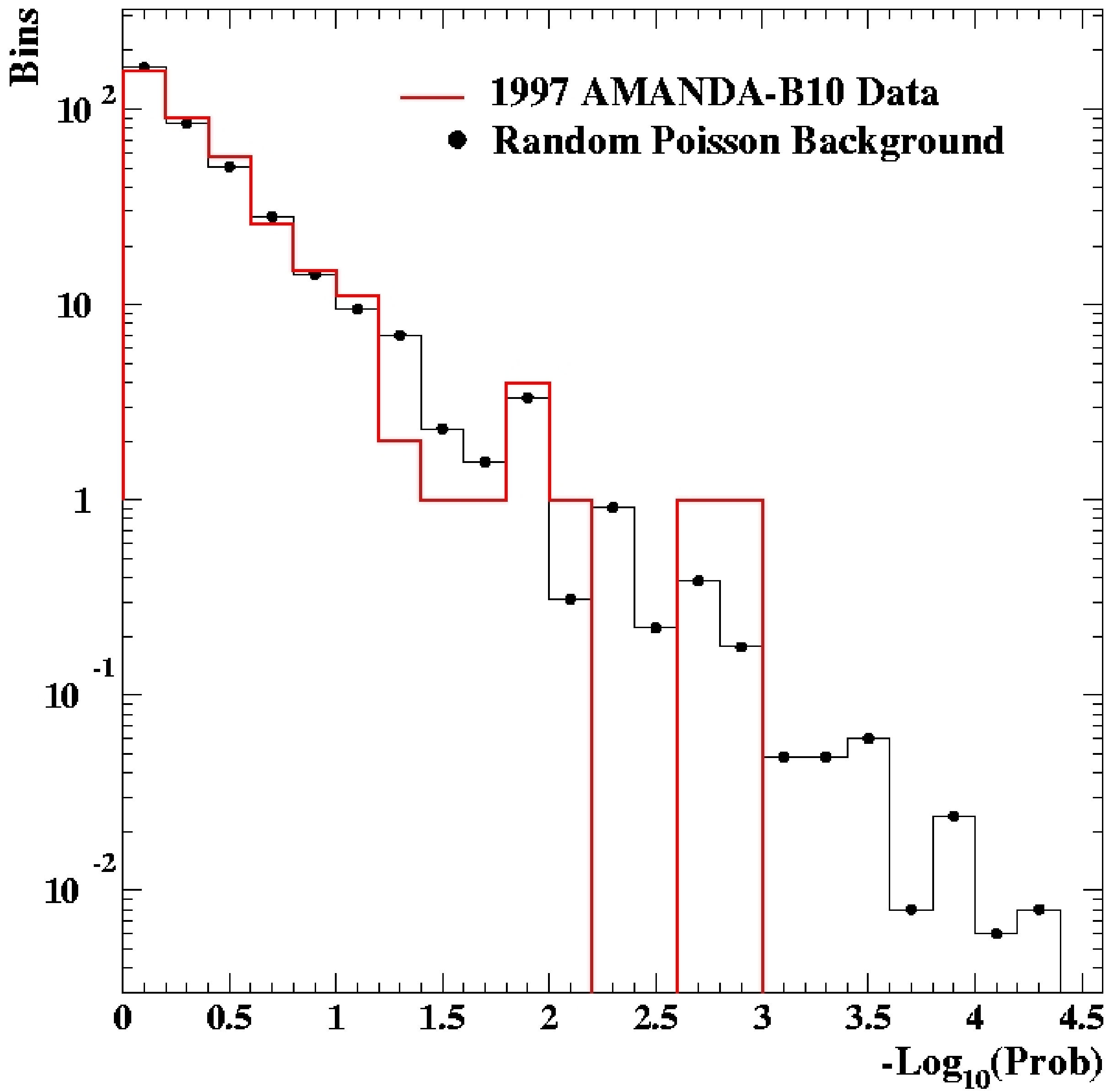
- Focus on continuous emission from putative sources with hard (E^{-2}) spectra
- Backgrounds come from
  - misreconstructed atm. muons
  - atmospheric neutrinos
- From 1997 data see 1097 events with no obvious clustering



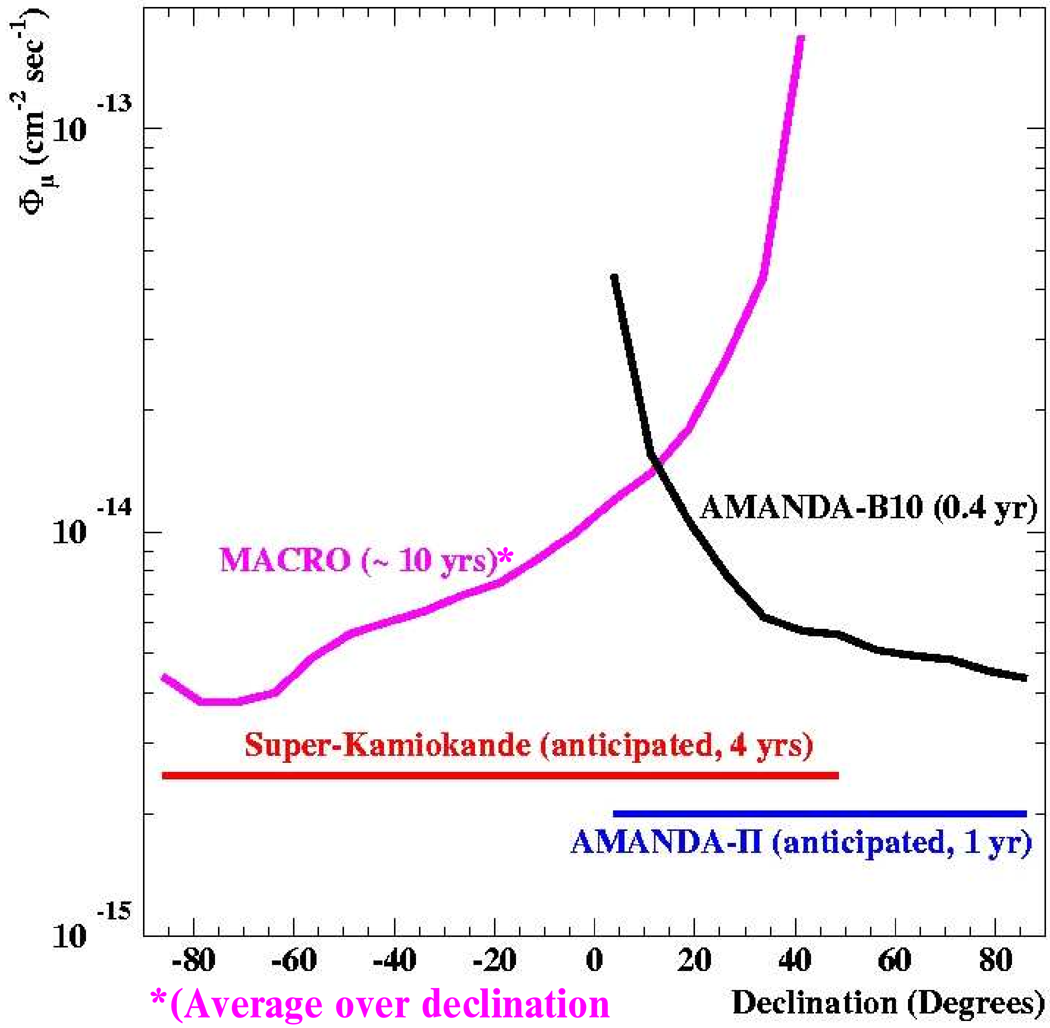
Equatorial coordinates

UHE ν Point Source Significance

- bin sky according to angular resolution
- estimate background from declination band
- no statistically significant excess



UHE ν Point Source Flux Limit (preliminary)



*(Average over declination bands given in astro-ph/0002492)

Comparison with Models

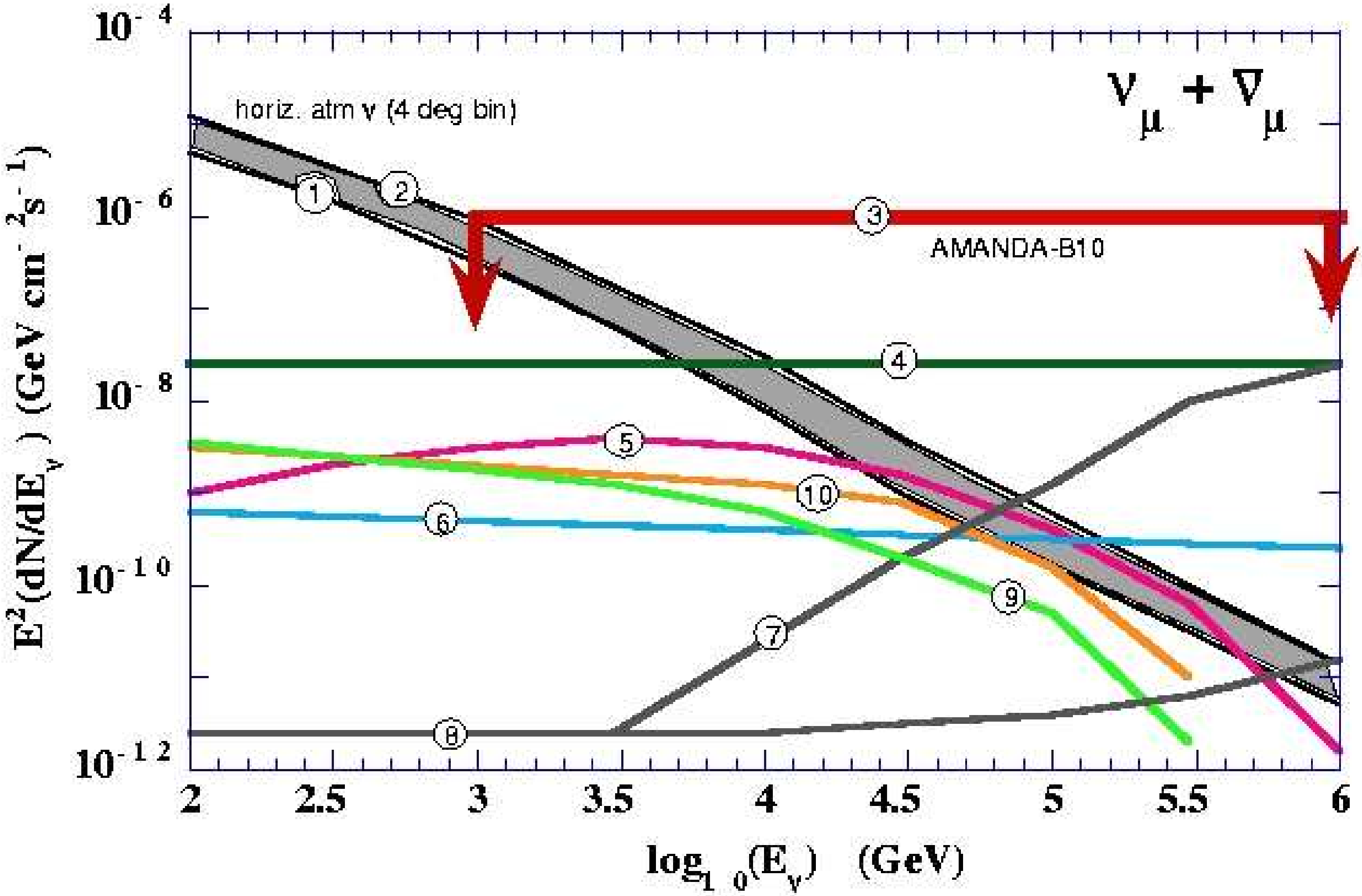
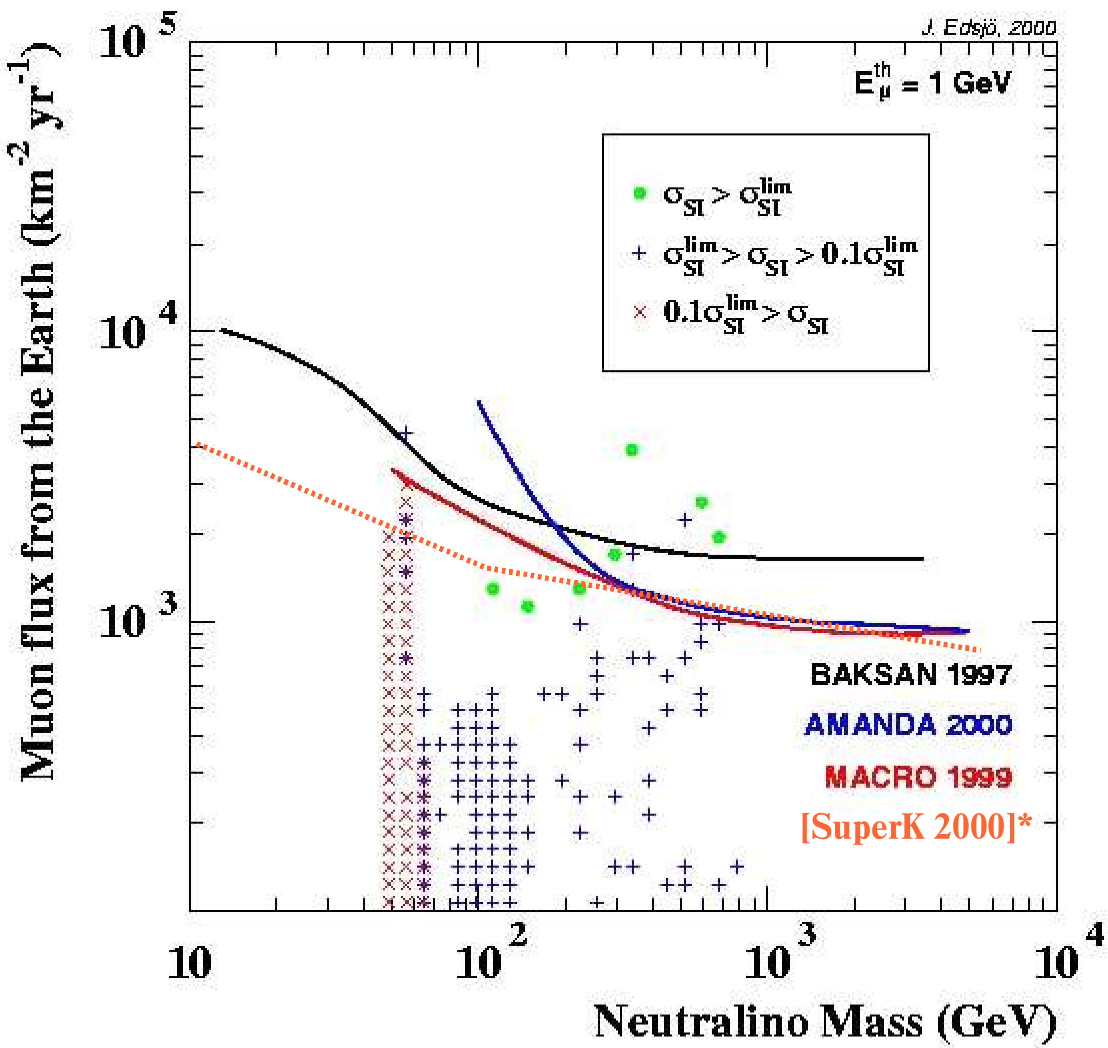


Figure adapted from Mannheim & Learned

WIMPs from Earth

Optimize for vertical neutrinos.

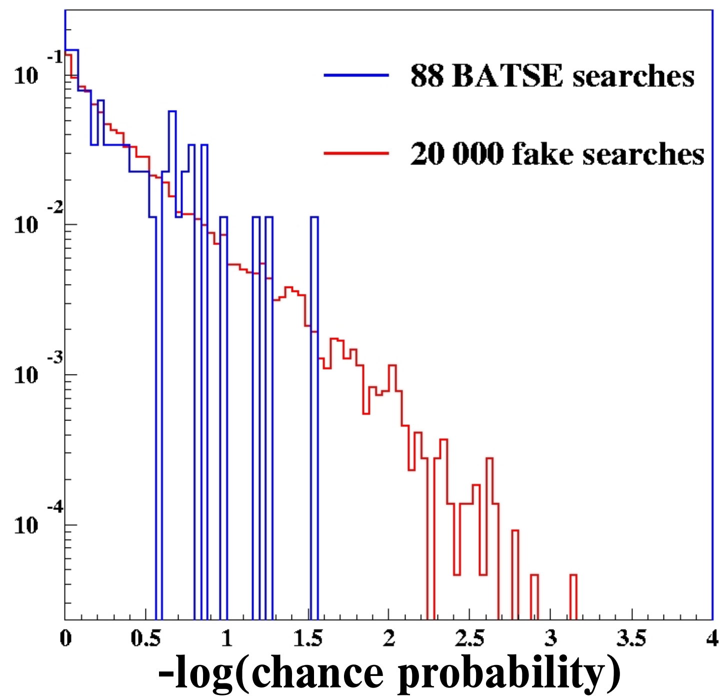
AMANDA limits are competitive.

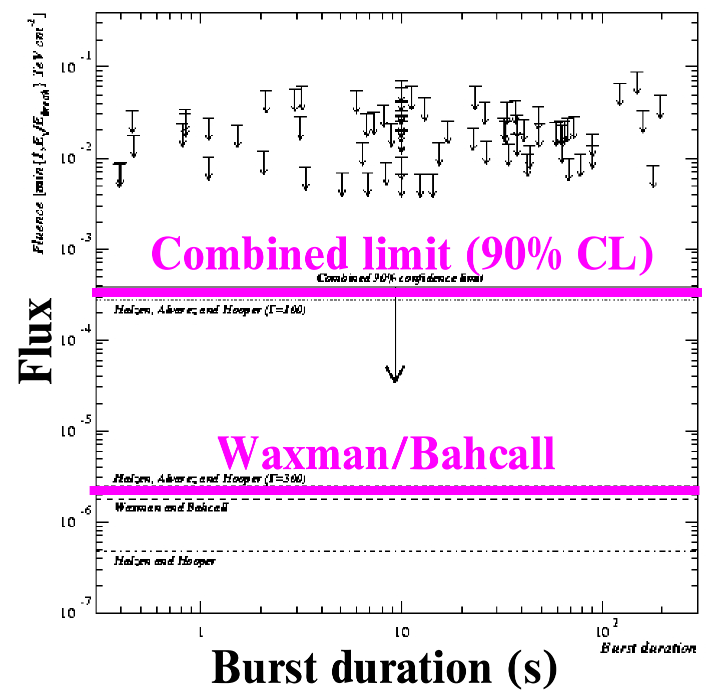


*Unofficial, added for completeness

Search for UHE νs from Gamma Ray Bursters

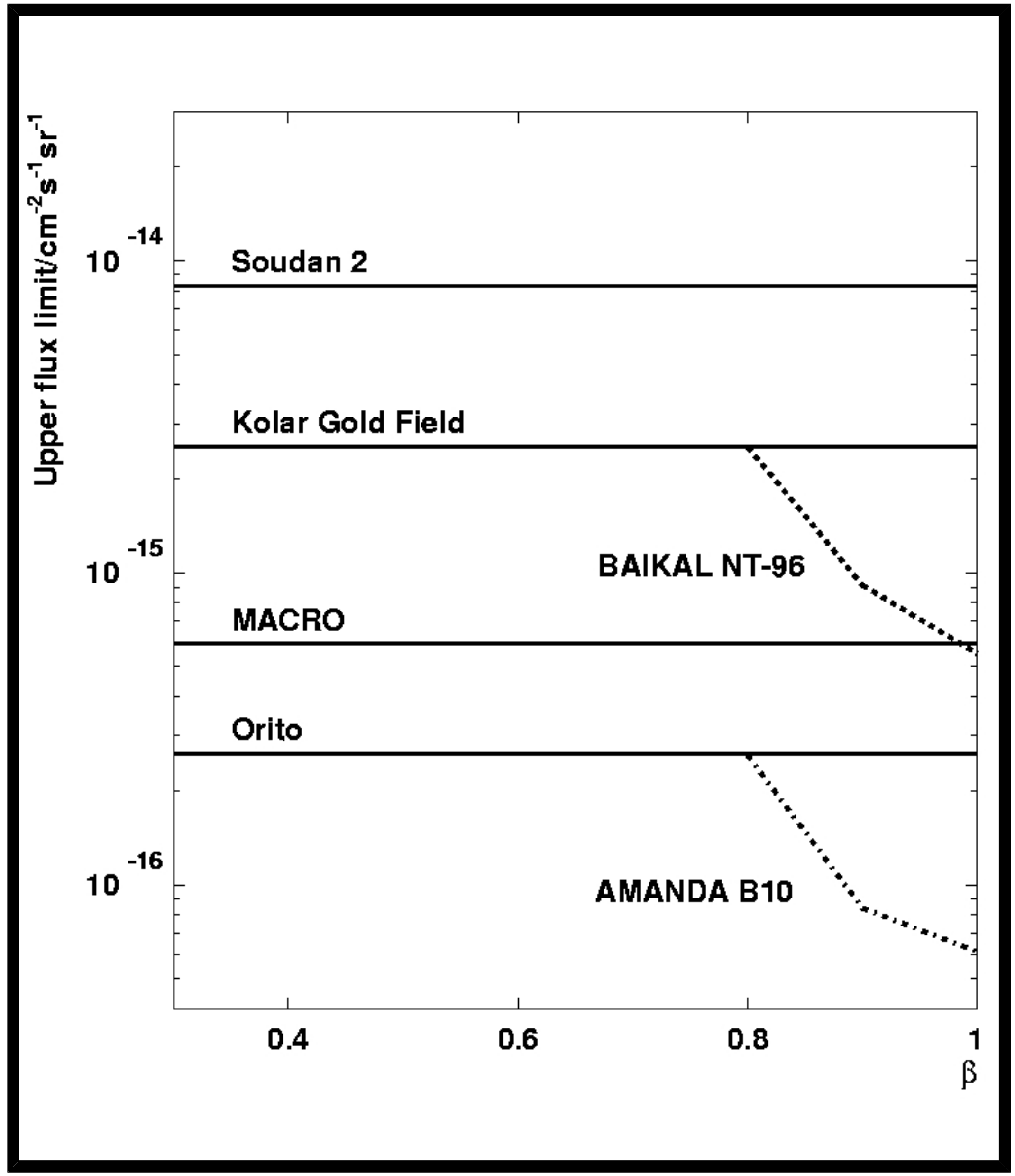
- GRBs last about 1s, occur roughly daily. Possible neutrino production of intrinsic interest. Also, can provide ultralong baseline for ν osc., test of weak equivalence principle.
- Use BATSE burst times and positions to define signal and background regions
- Search for upward going muons in these windows (permitting looser selection criteria)





Relativistic Monopole Search

Search for signal due to high ionization signal of monopole



Summary

- **AMANDA is a functioning neutrino telescope**
  - **reconstruction of roughly 200 atmospheric neutrinos from 1997 data demonstrates viability of technique**
  - **along with background studies and SPASE-AMANDA coincidences, we believe we understand detector sensitivity to within a factor of two**
  - **Limits on UHE neutrinos from AGNs, GRBs, WIMPs, generic point sources, diffuse sources. On several fronts we are beginning to challenge the existing models.**
  - **Also have limits on monopoles and low energy neutrino bursts (e.g., from supernovae)**
- **Data from 1998 and 1999 (larger detector *and* more data) are ready to be analyzed**
- **Now have 1 year of data from AMANDA-II: Discovery?**
- **All our fingers are crossed for IceCube approval!**

PHOTONS BEWARE!!!