RECENT RESULTS FROM AMANDA

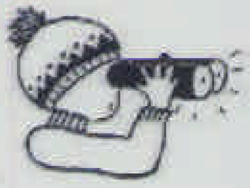
(The Antarctic Muon and Neutrino Detector Array)

D.F. Cowen

University of Pennsylvania, USA

(for the AMANDA Collaboration)

- **AMANDA goals:**
  - **Demonstrate that South Pole ice is a viable detection medium ✔**
  - **Demonstrate viability of neutrino telescope in South Pole ice ✔**
  - **Search for physics producing UHE (E>100TeV) neutrino signals**



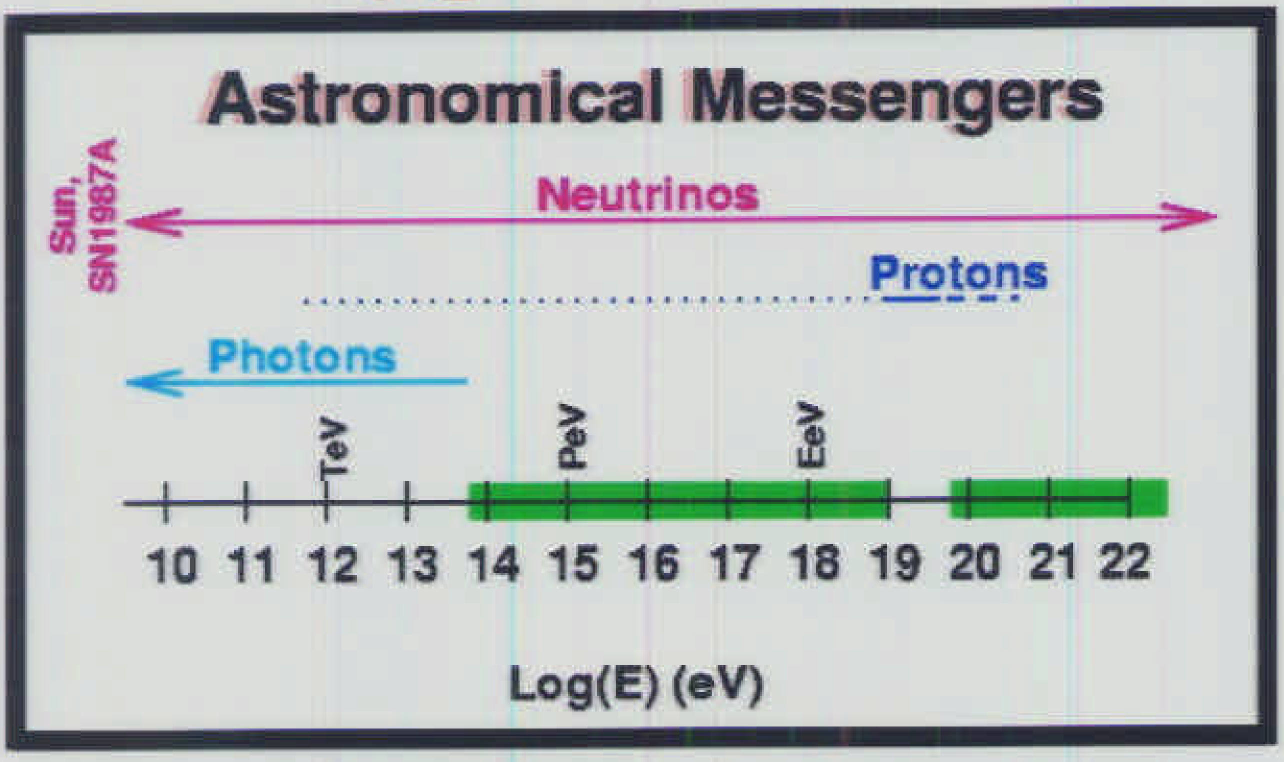
  - **Pave way for IceCube**

The AMANDA Collaboration

Bartol Research Institute, USA
DESY-Zeuthen, Germany
Kalmar University, Sweden
LBNL, USA
Mainz University, Germany
South Pole Station, Antarctica
Stockholm University, Sweden
University of California-Berkeley, USA
University of California-Irvine, USA
ULB-IIHE, Belgium
University of Pennsylvania, USA
University of Wisconsin-Madison, USA
University of Wuppertal, Germany
University of Uppsala, Sweden

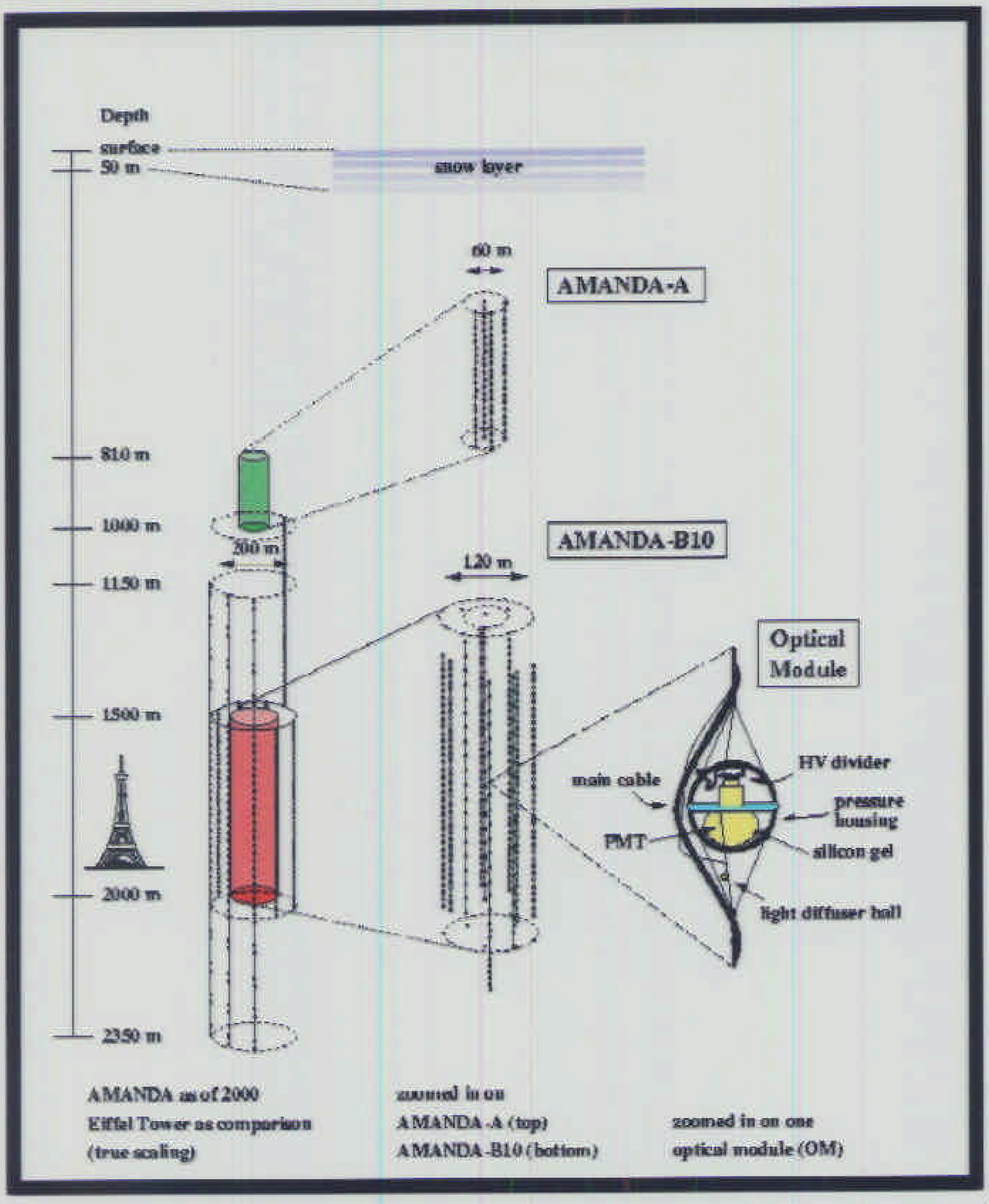
Physics Motivation

- Overwhelmingly motivated by discovery potential



- Unique probe of AGN and GRBs
- Dark matter and TD search tool
- ν oscillations
- special relativity, weak eq. princ.

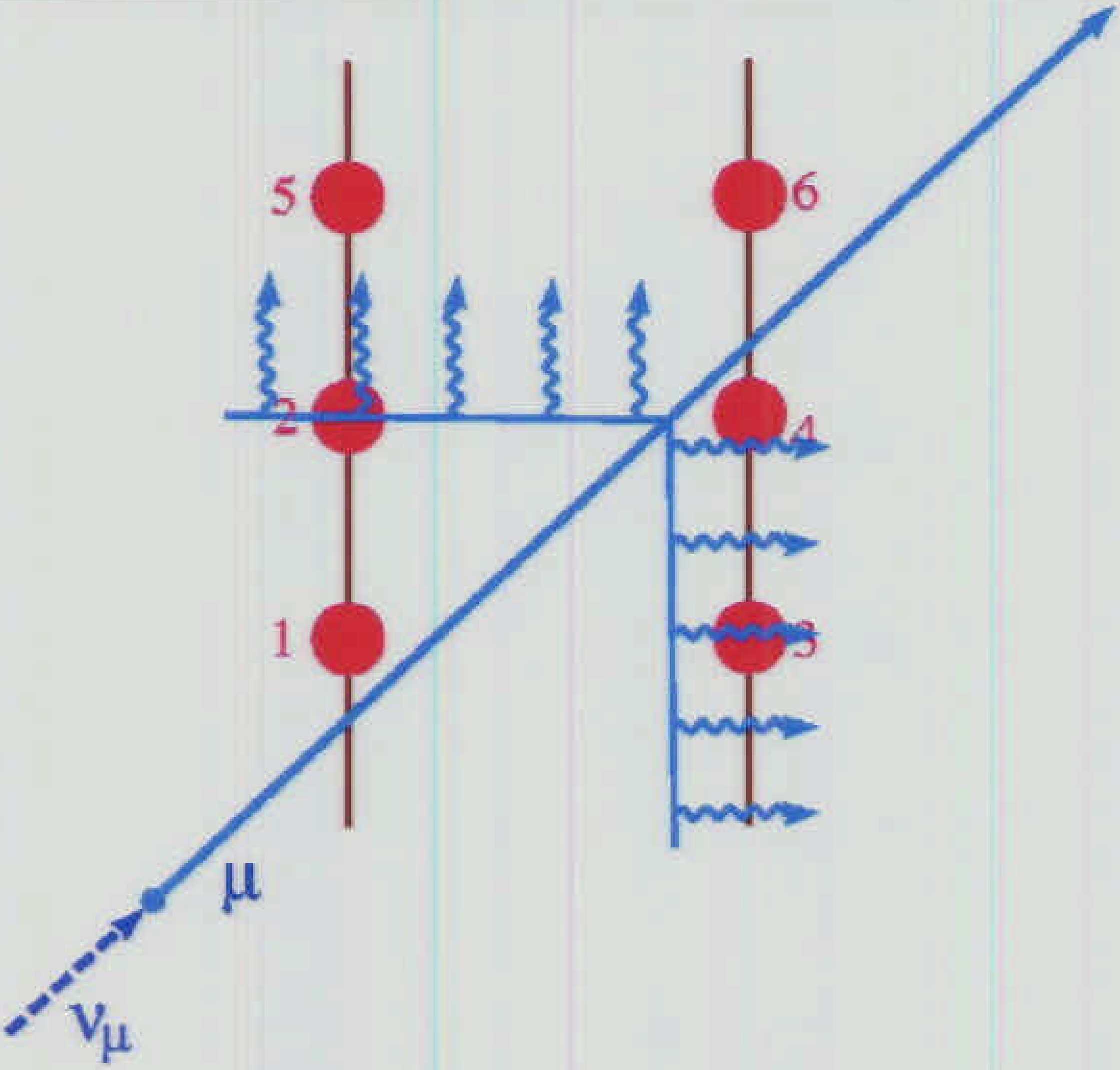
The AMANDA Detector



Deployment: Drilling

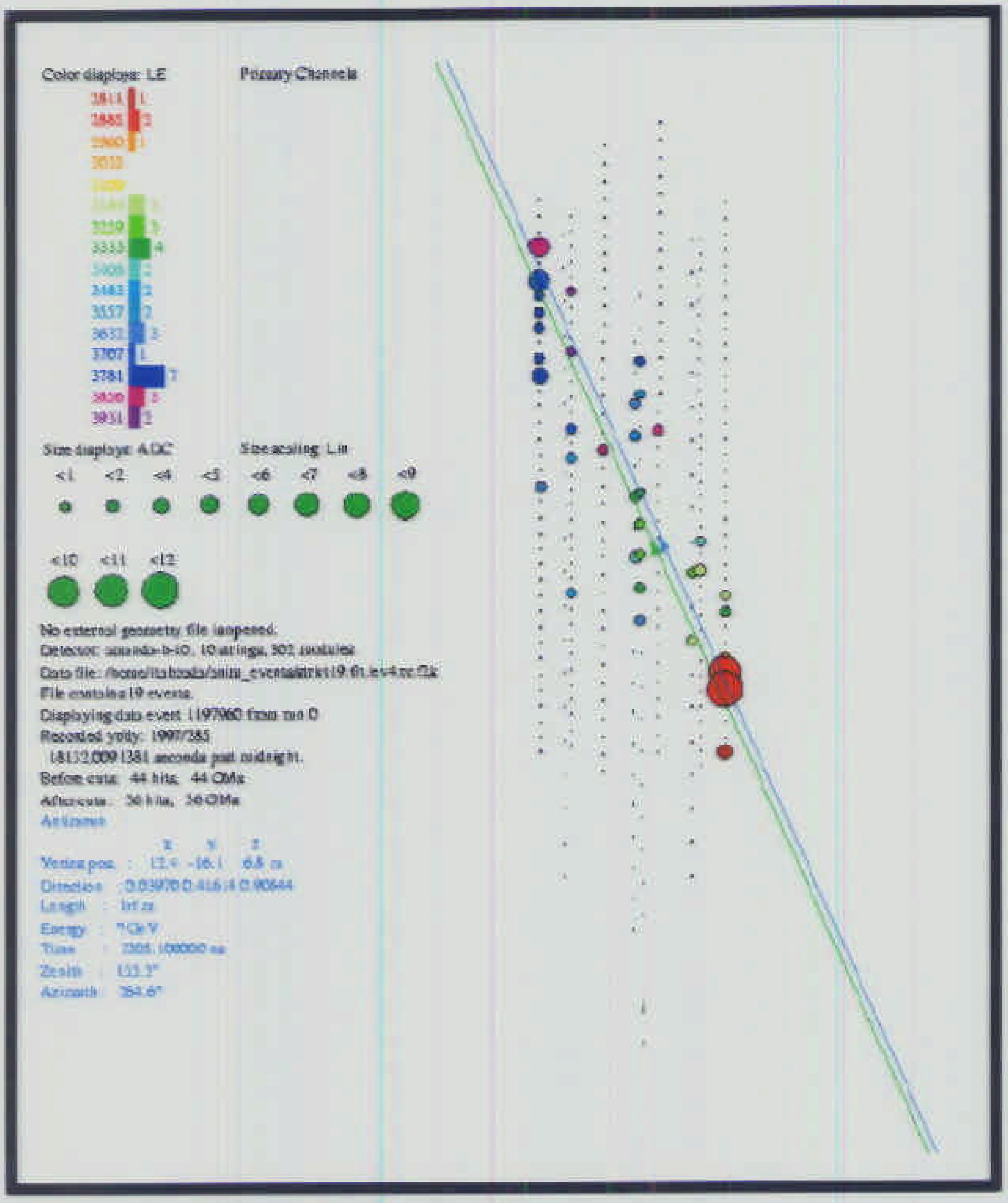
Deployment: String Insertion

Basic Detection Technique



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

Candidate Upward-Going μ



D. Cowen/AMANDA

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 spatial *and* temporal coincidence requirements
- WIMPs from earth's core

Decreasing intrinsic difficulty

- Low E, too: supernova search, relativistic monopoles

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			✔	✔

Atmospheric ν Analysis

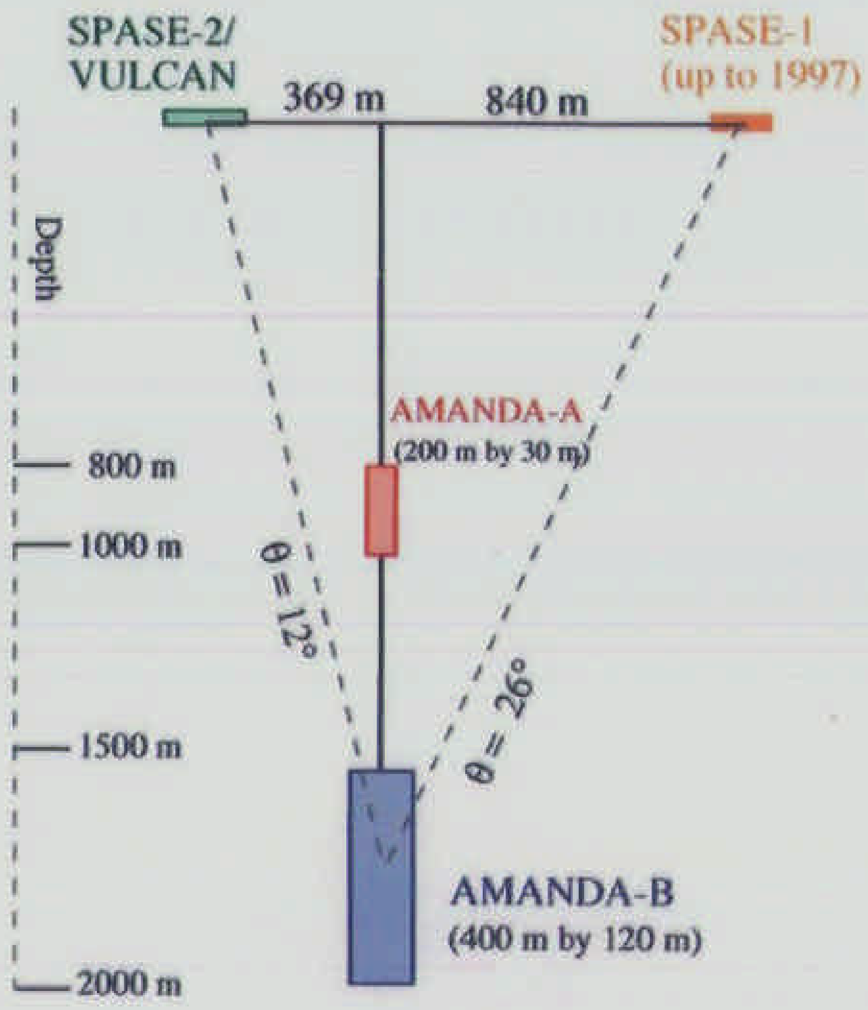
- Confirmation of expected flux of upward-going muon-neutrino-induced muons is a critical milestone for a UHE neutrino telescope
  - Can the detector be calibrated well enough to reconstruct muons?
  - Do we have sufficient pointing accuracy to do astronomy?
  - Can the huge downward-going cosmic ray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

AMANDA	Down-going cosmic rays	Up-going atm. νs	Detected up-going νs
Events/day	$6x10^6$	12	1.5

SPASE-AMANDA

SPASE: South Pole Air Shower Experiment

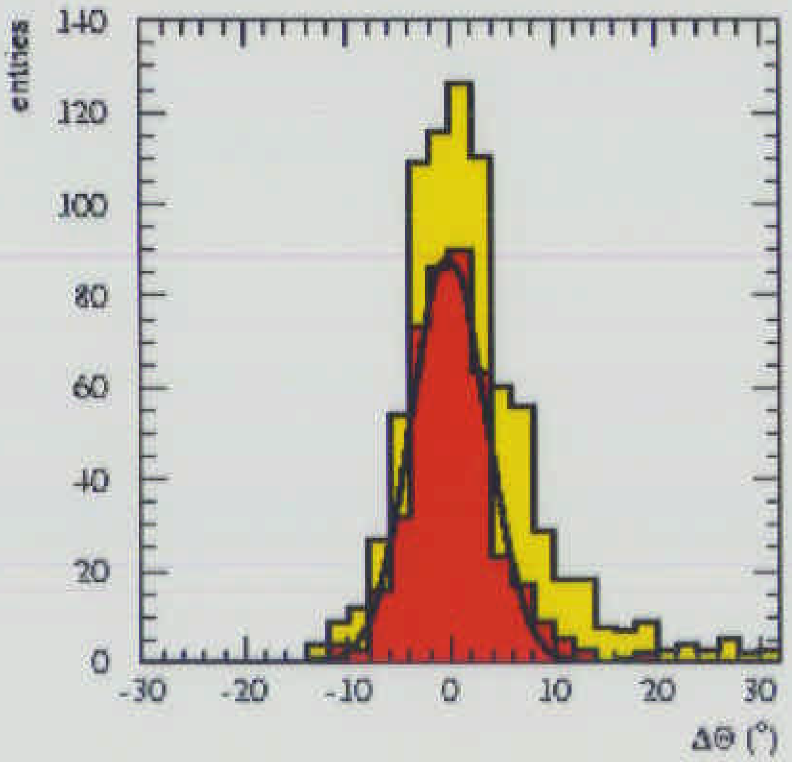
- Calibration of absolute pointing
- Calibration of pointing resolution
- Calibration of signal efficiency



D. Cowen

Space Angle Resolution/Offset

- SPASE events calibrate MC simulation of signal
- Absolute pointing $\Delta\Psi \sim 3$ degrees
- Offset $\Delta\theta \sim 1$ degree
- Multi-muon SPASE events similar to signal



Relative Efficiency = 0.86

Fraction of events remaining as a function of rejection criteria, normalized to number of triggers.

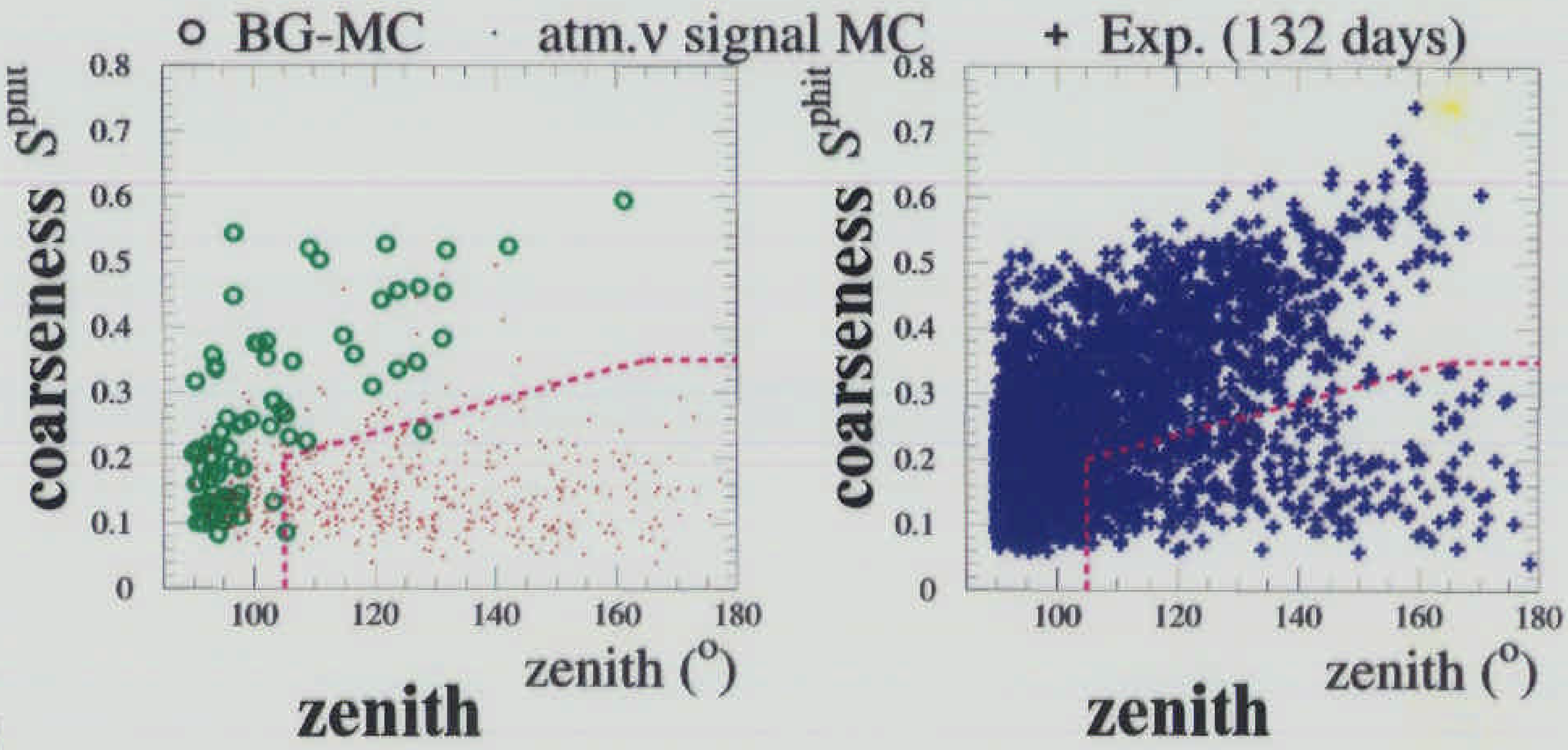
Data = SPASE-AMANDA coincidence events.
SPASE-MC = Monte Carlo simulation
Full analysis = point source analysis with inverted angle

Level	SPASE-MC	Data	Data/MC
Trigger	1.00	1.00	1.00
Filter-1	0.57	0.57	1.00
Filter-2	0.39	0.35	0.90
Full analysis	0.22	0.19	0.86

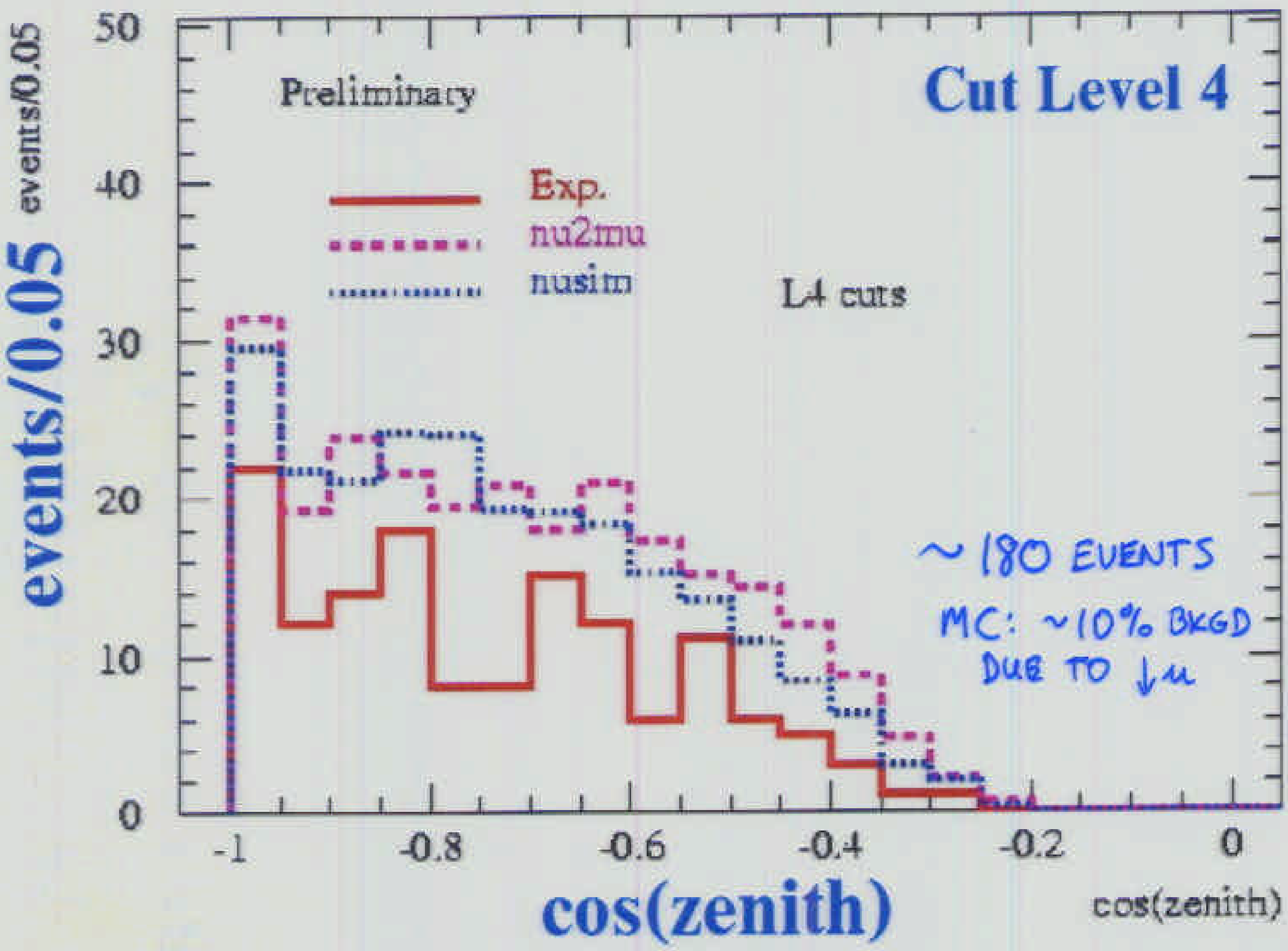
Atmospheric ν Reconstruction

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

Signal-Background Separation for Atmospheric Neutrinos



Atmospheric Neutrino Angular Distribution

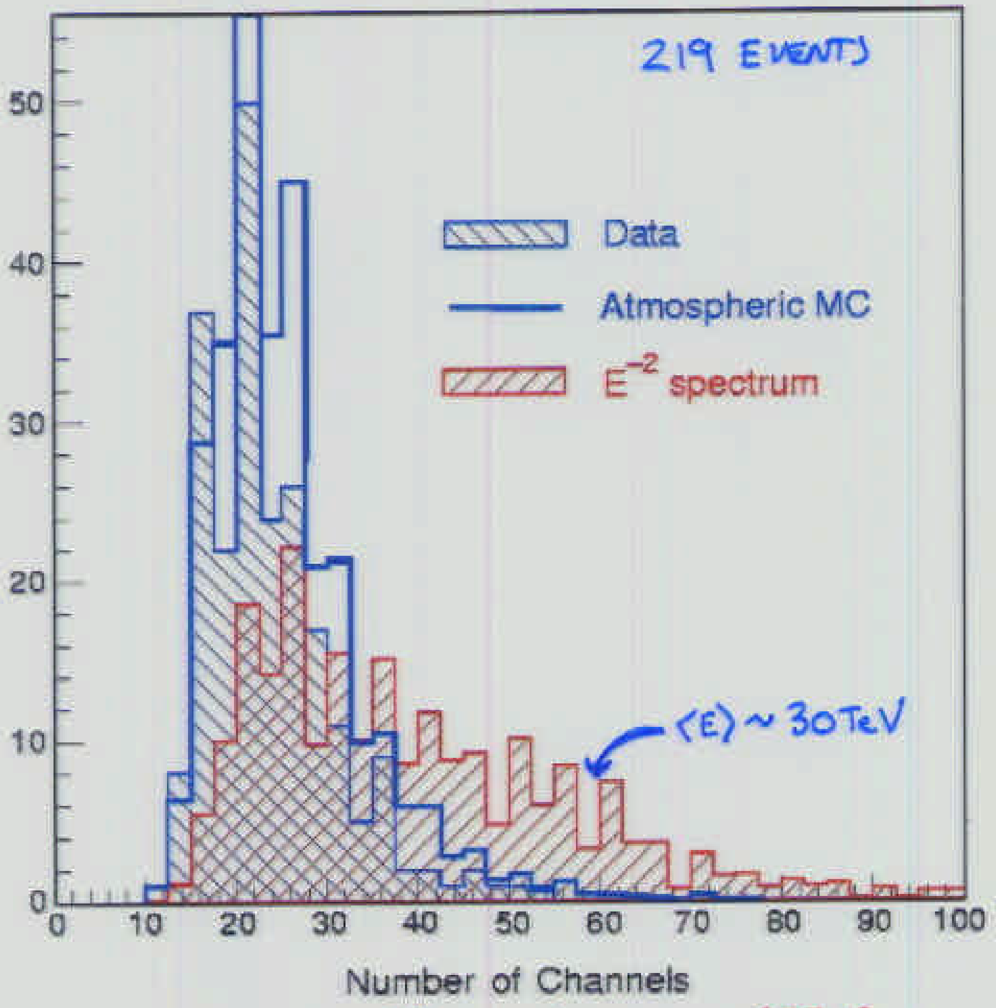


See about 1 evt/day; Good shape agreement
Normalization off by 50%:

atm. flux unc., ice properties, obscuration of light by cables, ...

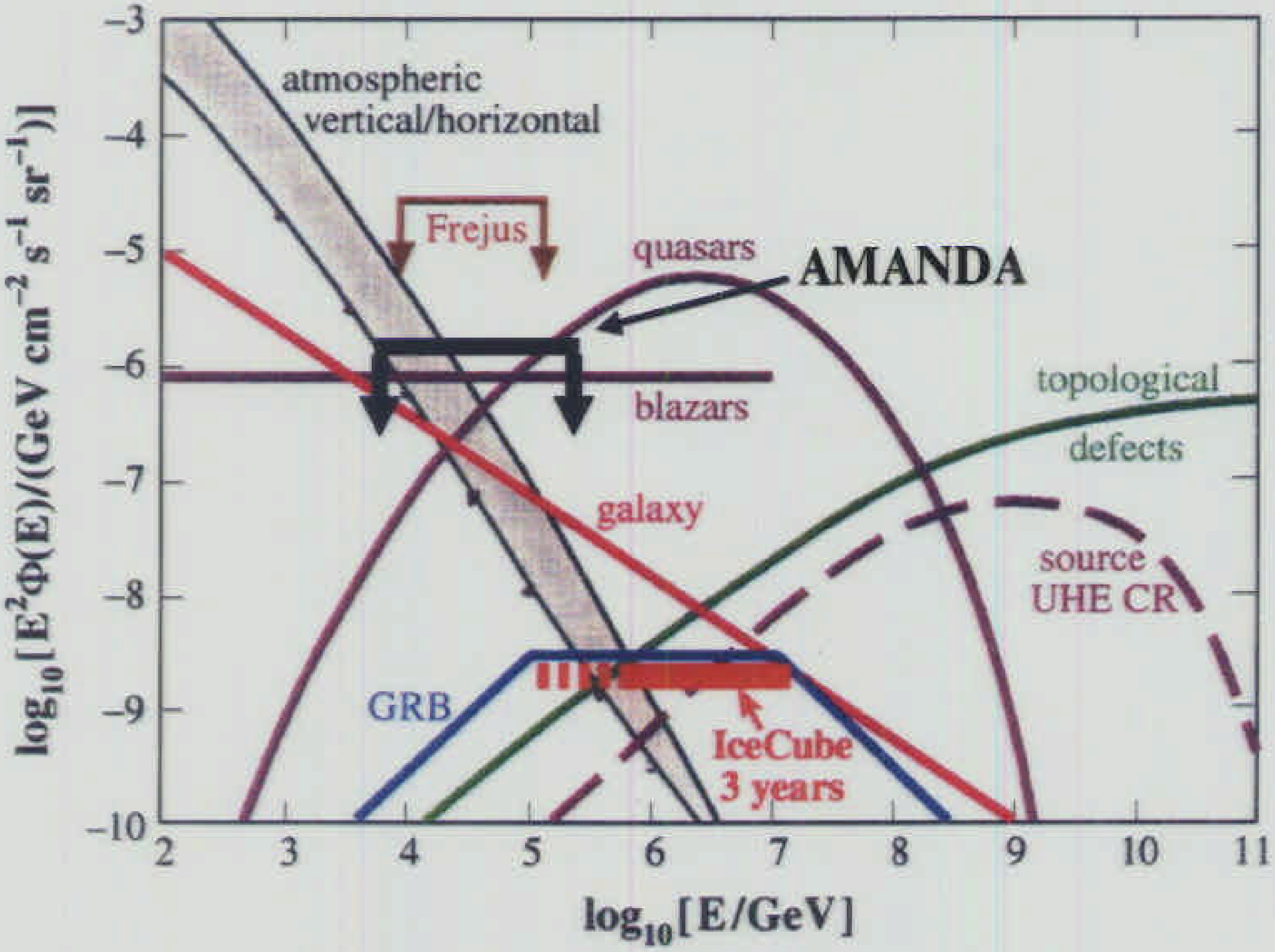
Diffuse UHE ν Flux

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



- New energy estimators will improve limits

Diffuse UHE ν Flux Limit

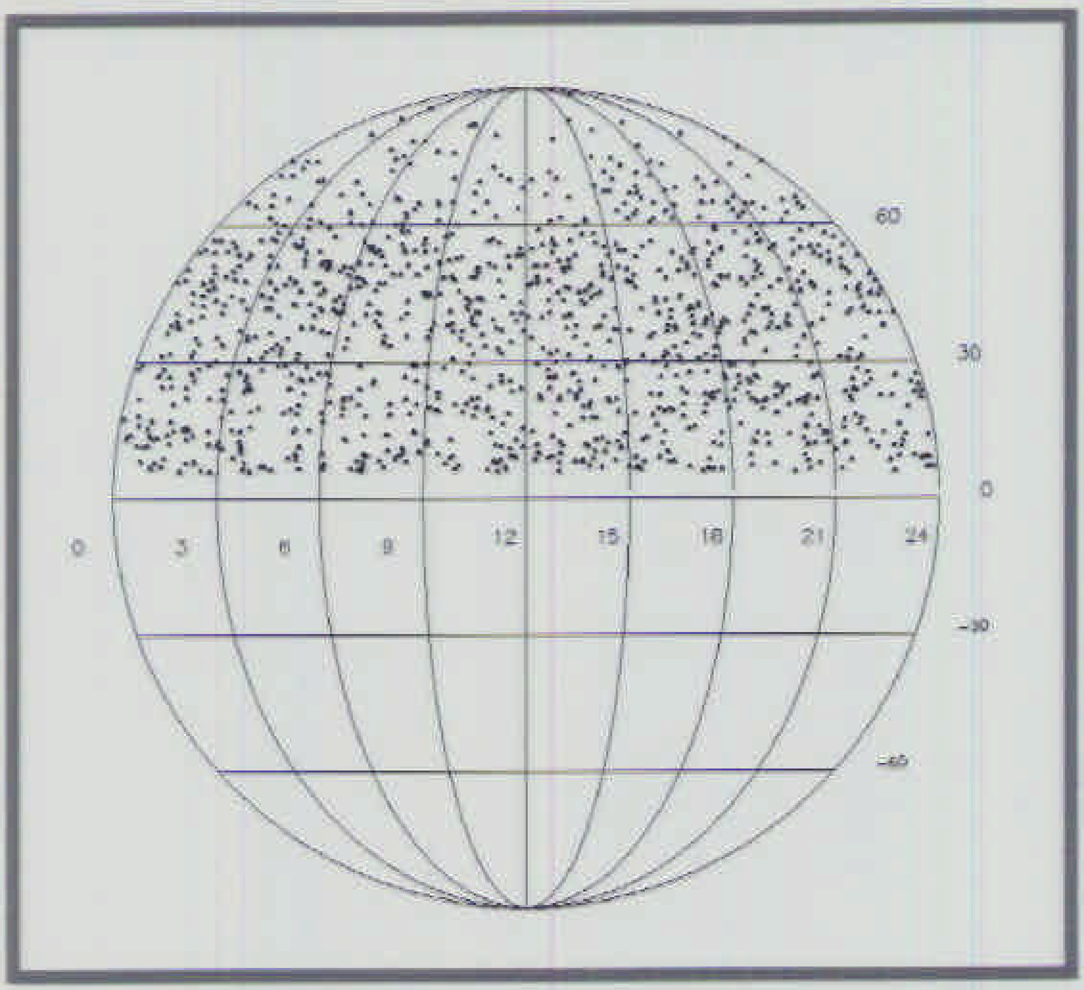


$E^2\Phi_\nu < 1.6 \times 10^{-6}$ GeV $cm^{-2}s^{-1}sr^{-1}$

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

UHE ν Point Source Search

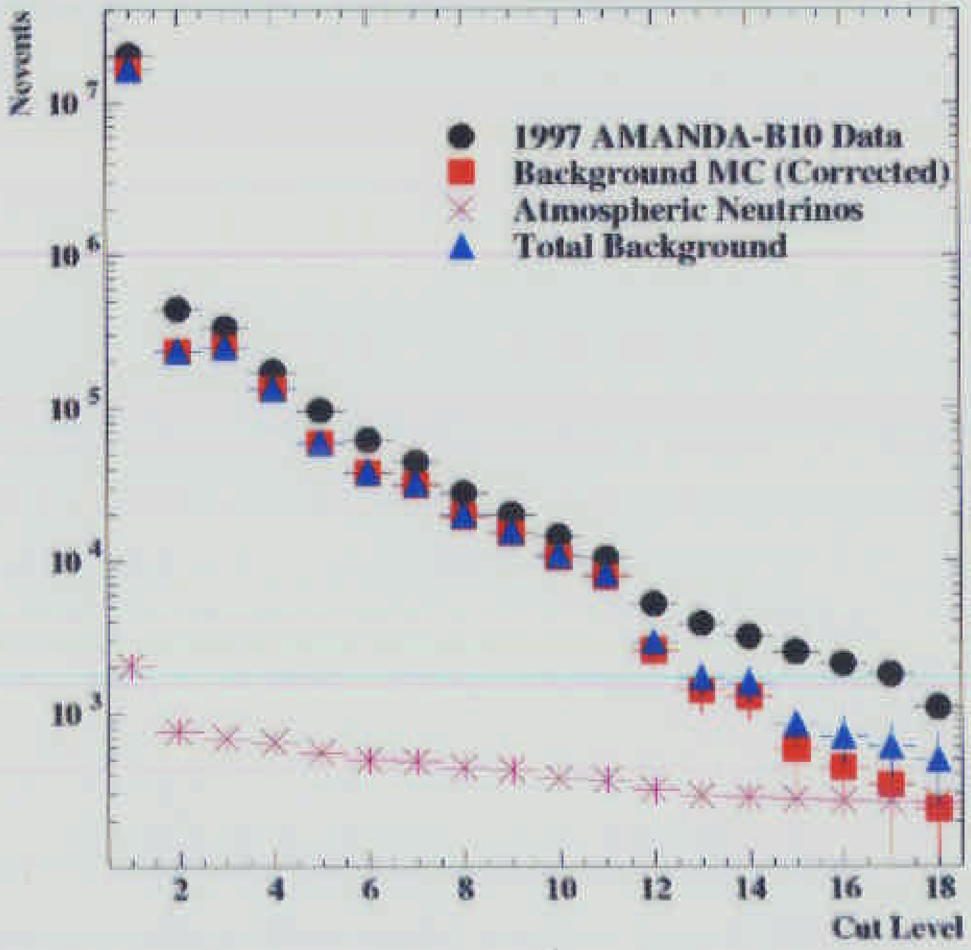
- Focus on continuous emission from putative sources with hard (E^{-2}) spectra
- Backgrounds come from
  - misreconstructed atm. muons
  - atmospheric neutrinos
- From 1997 data see 1097 events with no obvious clustering



Equatorial coordinates

Background rejection

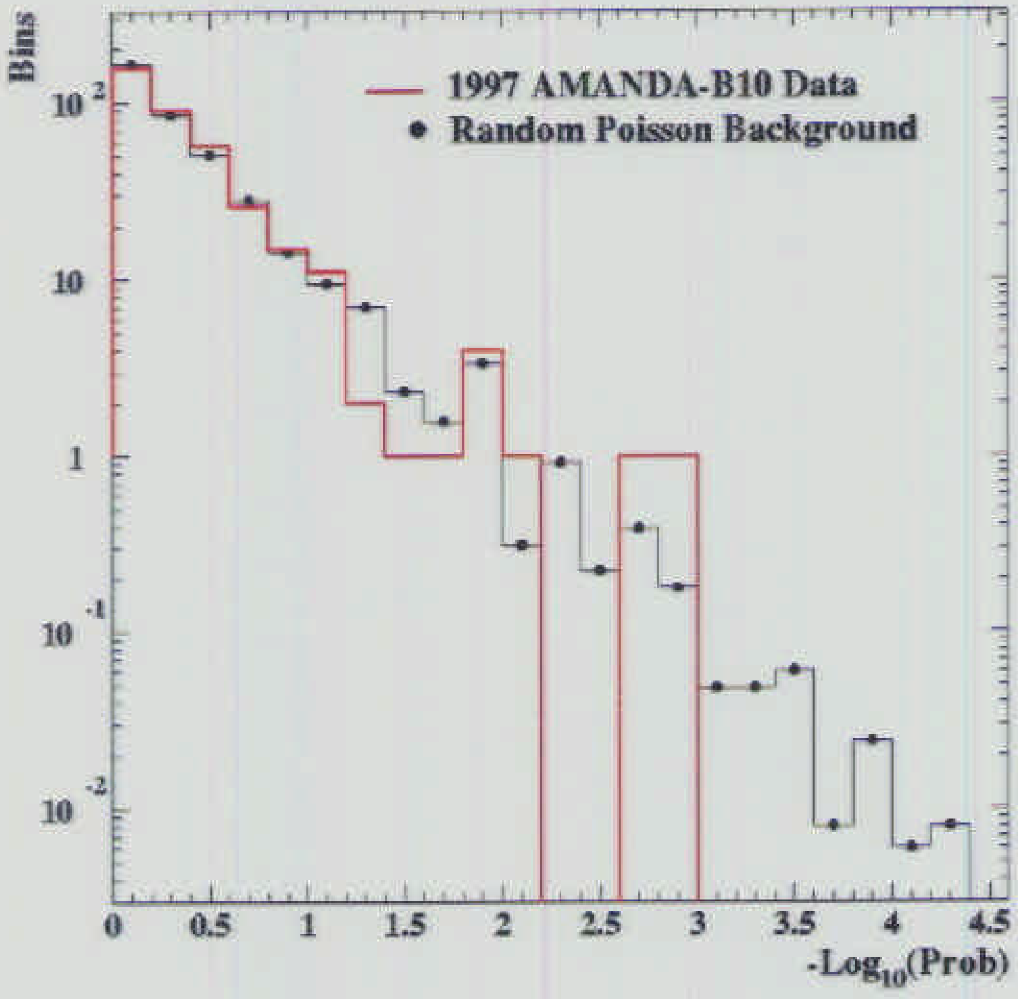
- Poorly reconstructed atmospheric muons
- Atmospheric ν_μ (Atm ν_e are negligible)
- Relative to trigger level, agreement at factor of 2.
- Simulations describe detector performance



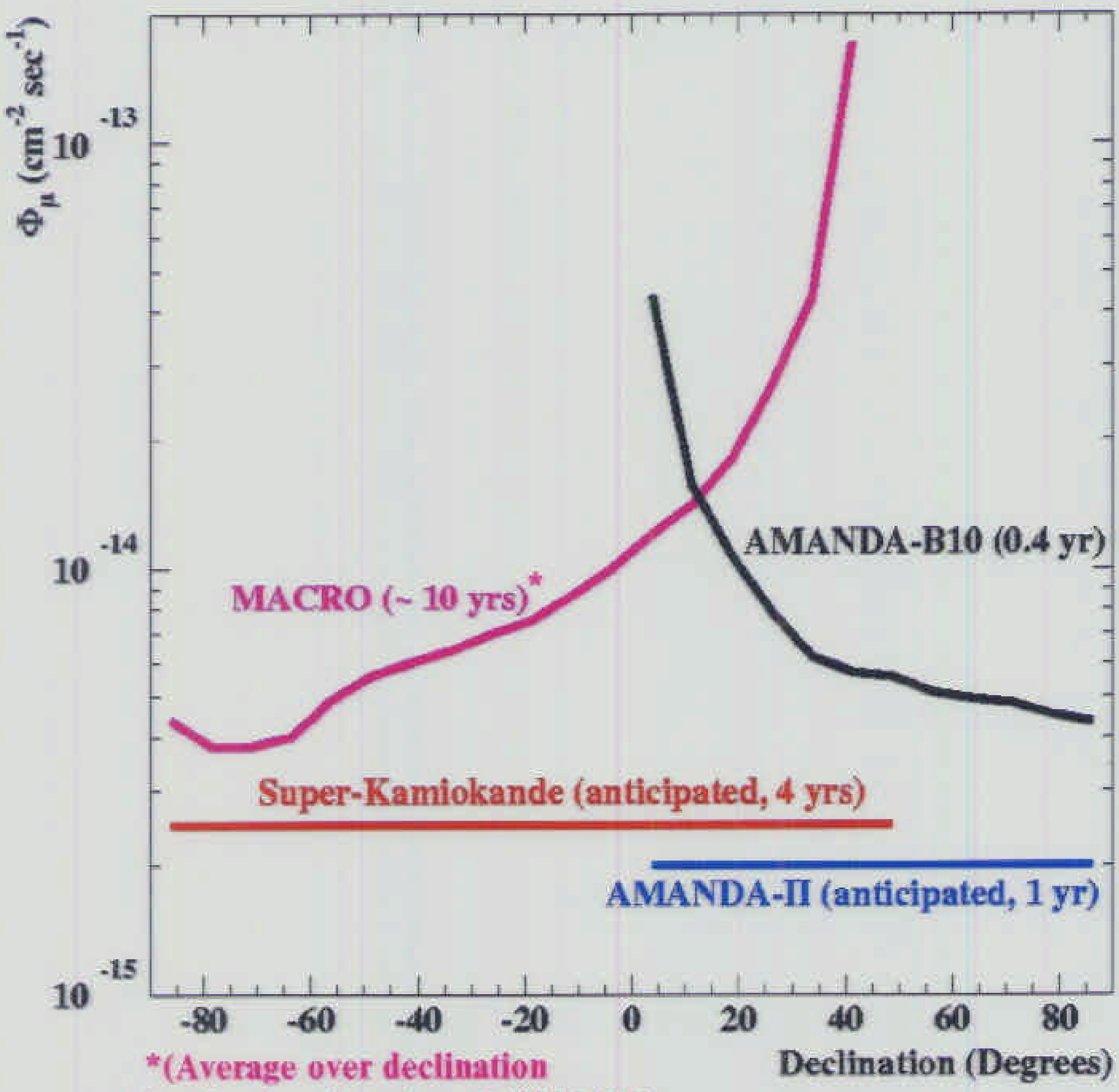
D. Cowen

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)

D. Cowen/AMANDA

Comparison with Models

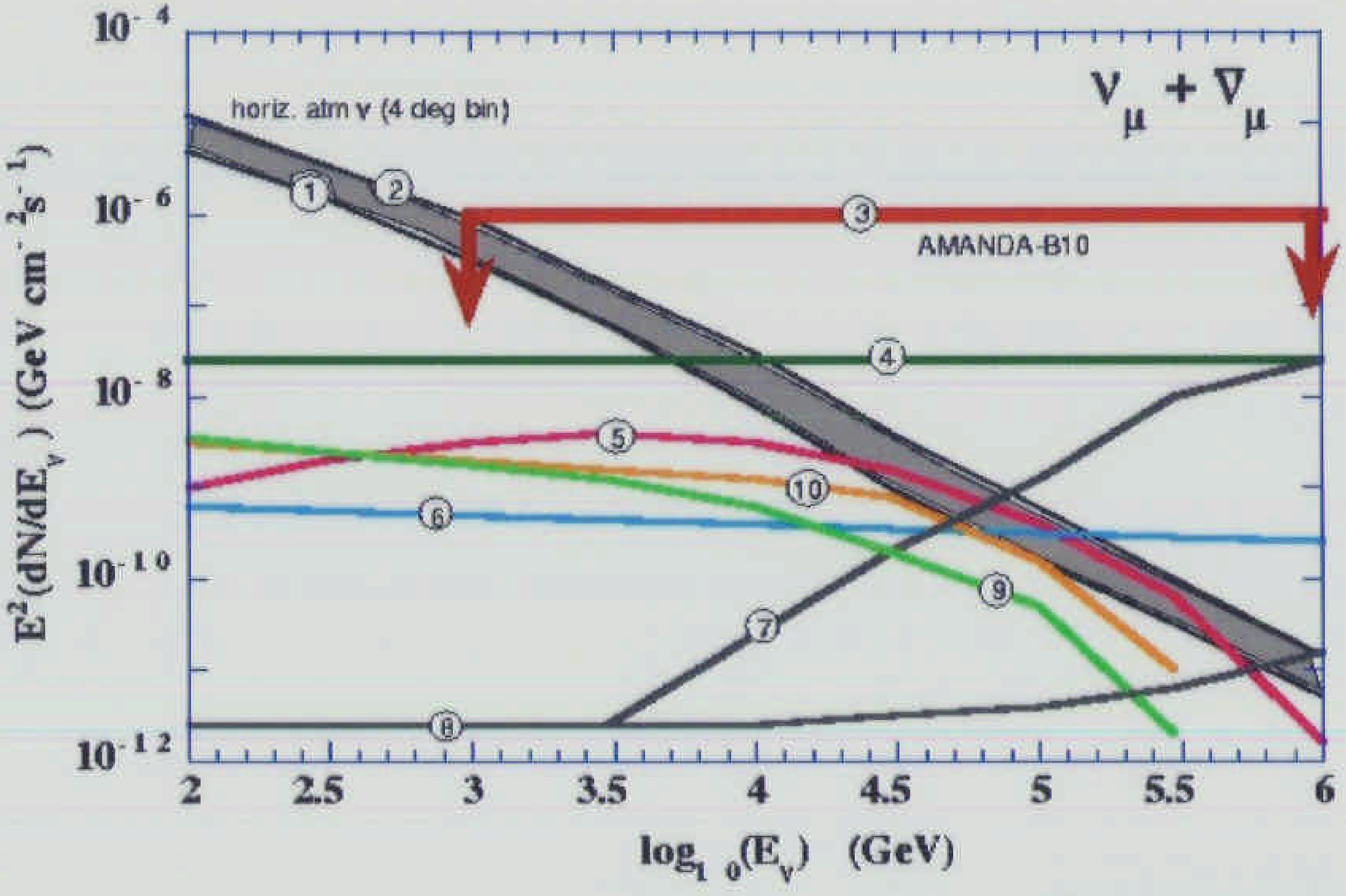
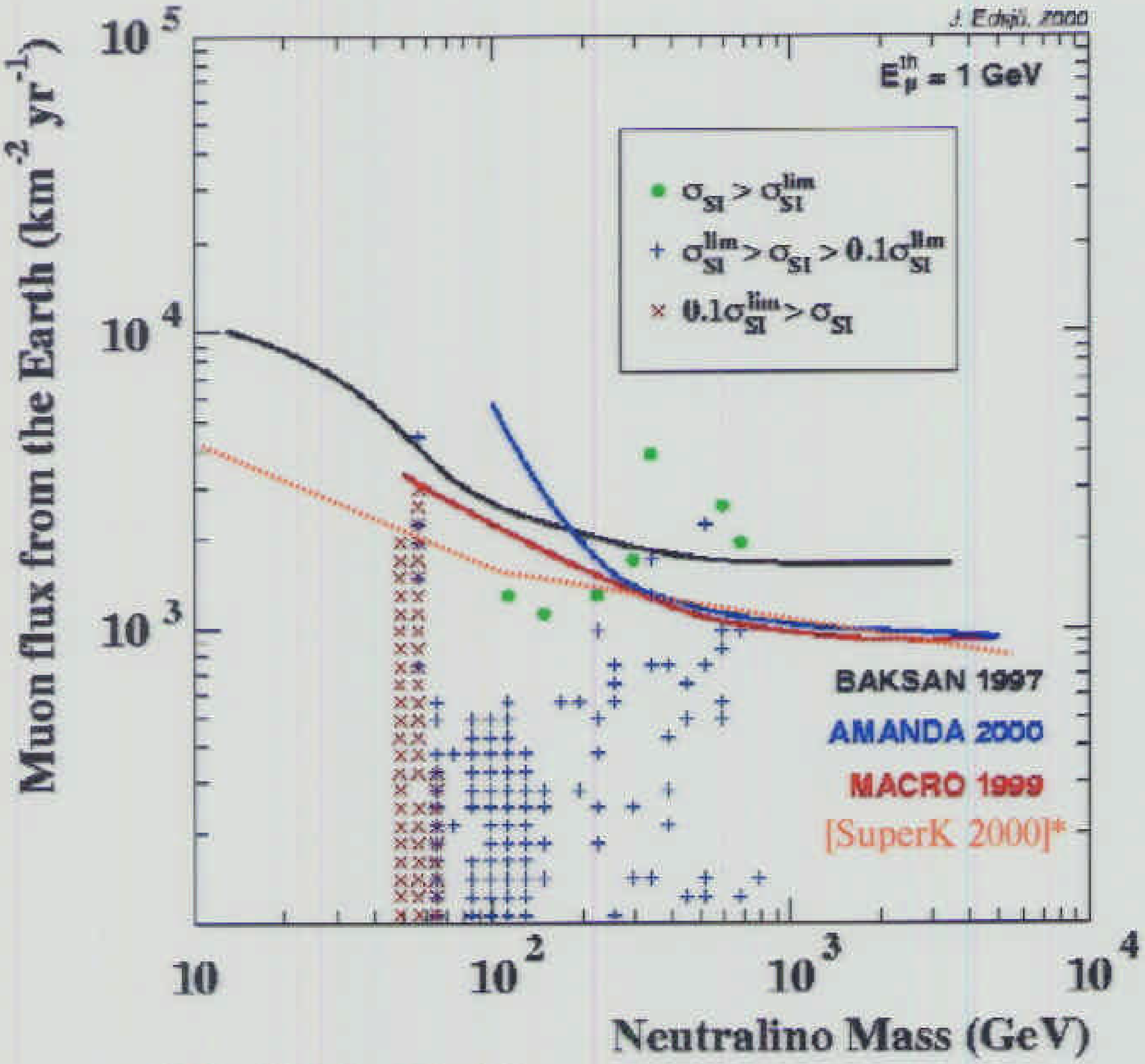


Figure adopted from Mannheim & Learned

WIMPs from Earth

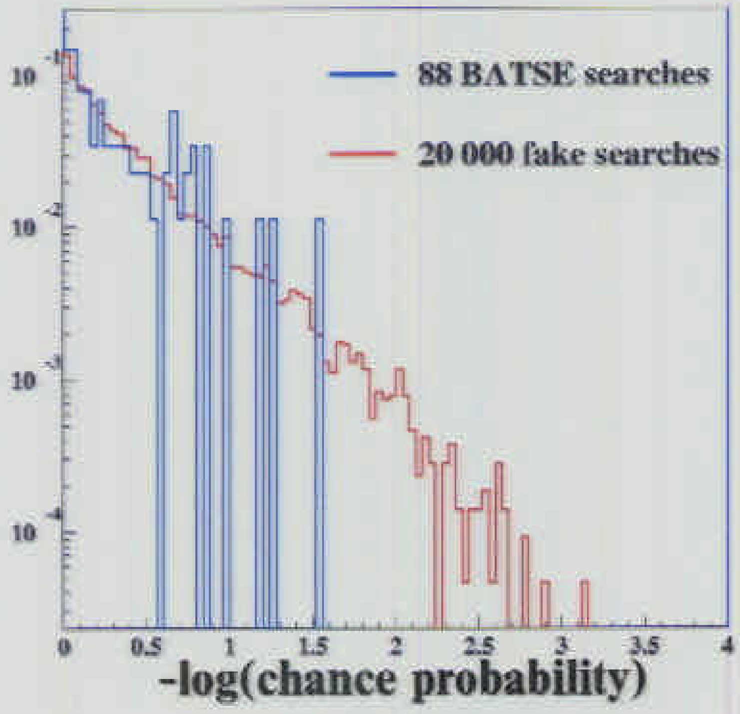
Optimize for vertical neutrinos.
AMANDA limits are competitive.

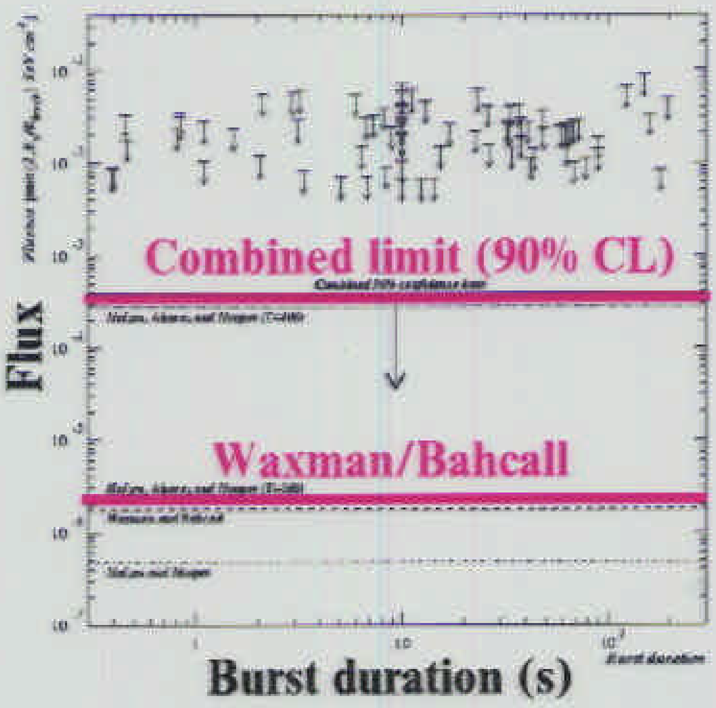


*Unofficial, added for completeness

Search for UHE νs from Gamma Ray Bursters

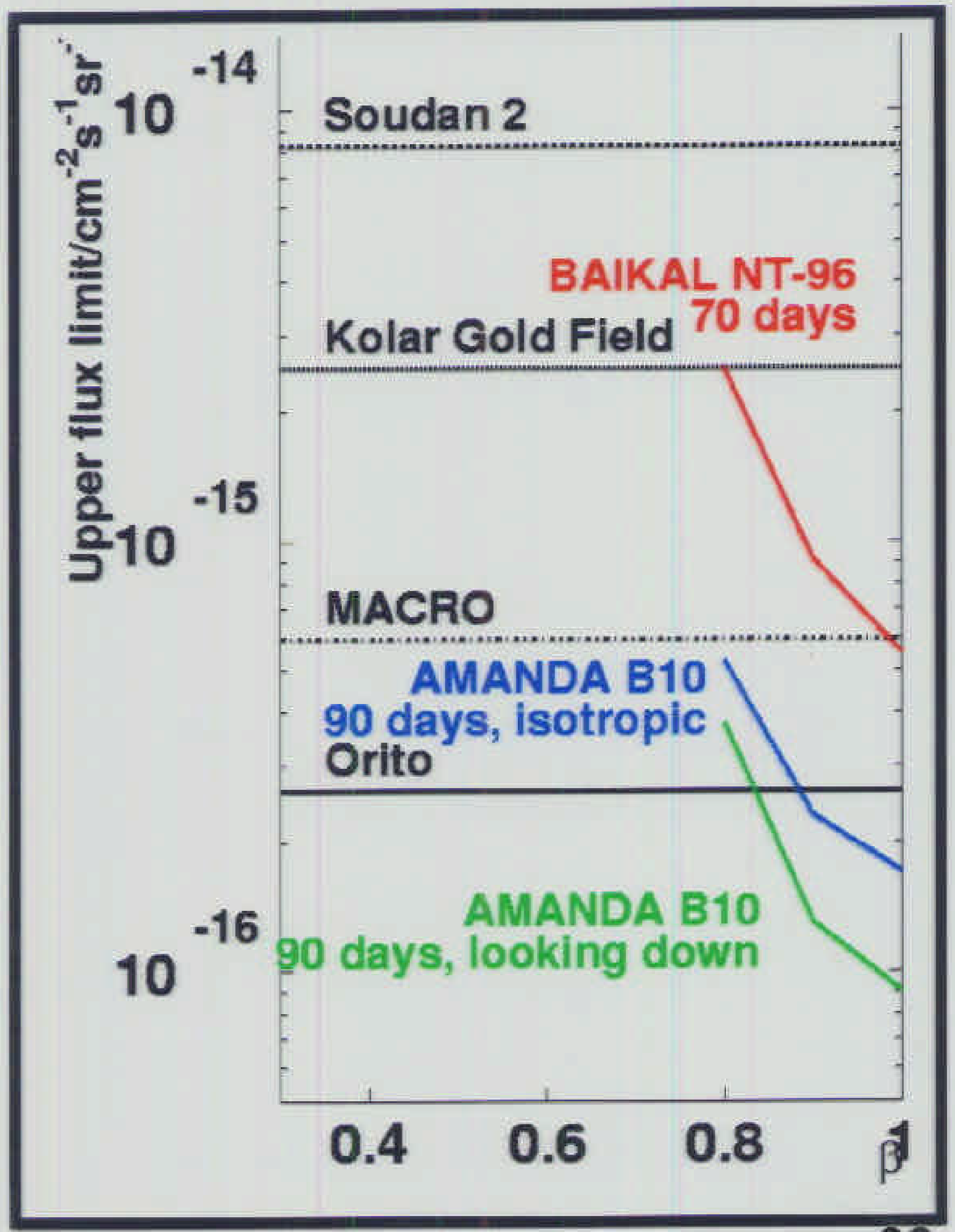
- GRBs last about 1s, occur roughly daily. Possible neutrino production of intrinsic interest. Also, can provide ultralong baseline for ν osc., test of weak equivalence principle.
- Use BATSE burst times and positions to define signal and background regions
- Search for upward going muons in these windows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





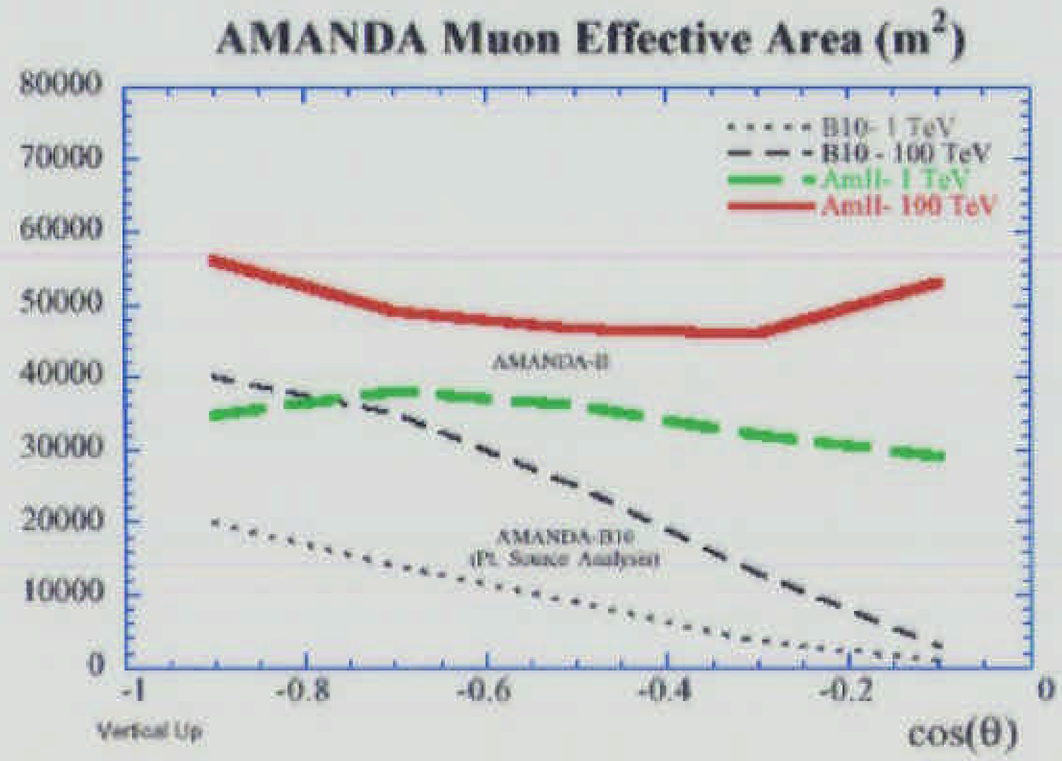
Relativistic Monopole Search

Search for signal due to high ionization signal of monopole



AMANDA Effective Area

- AMANDA-II 30,000-50,000 m^2
- AMANDA-II has nearly uniform response over all zenith angles



D. Cowen

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~~ 20%, backgrounds to factor 2.
  - 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
- The much larger AMANDA-II started data taking this year
- All our fingers are crossed for IceCube approval!