AMANDA

Results from the AMANDA neutrino telescope

Carlos P. de los Heros

Department of High Energy Physics

Uppsala University

Physics
Detector concept
Data analysis & results
Conclusions
ICE3: an outlook

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The AMANDA collaboration

Antarctic Muon And Neutrino Detector Array

University of California, Irvine. US

University of California, Berkeley. US

Lawrence Berkeley National Laboratory. US

University of Wisconsin, Madison. US

University of Pennsylvania. US

University of Kansas. US

Bartol Research Institute. US

University of Stockholm. Sweden

University of Uppsala. Sweden

Kalmar Technical University. Sweden

ULB/VUB-IIHE. Belgium

DESY-Zeuthen. Germany

University of Wuppertal. German

University of Mainz. Germany

South Pole Amundsen-Scott station. Antarctica

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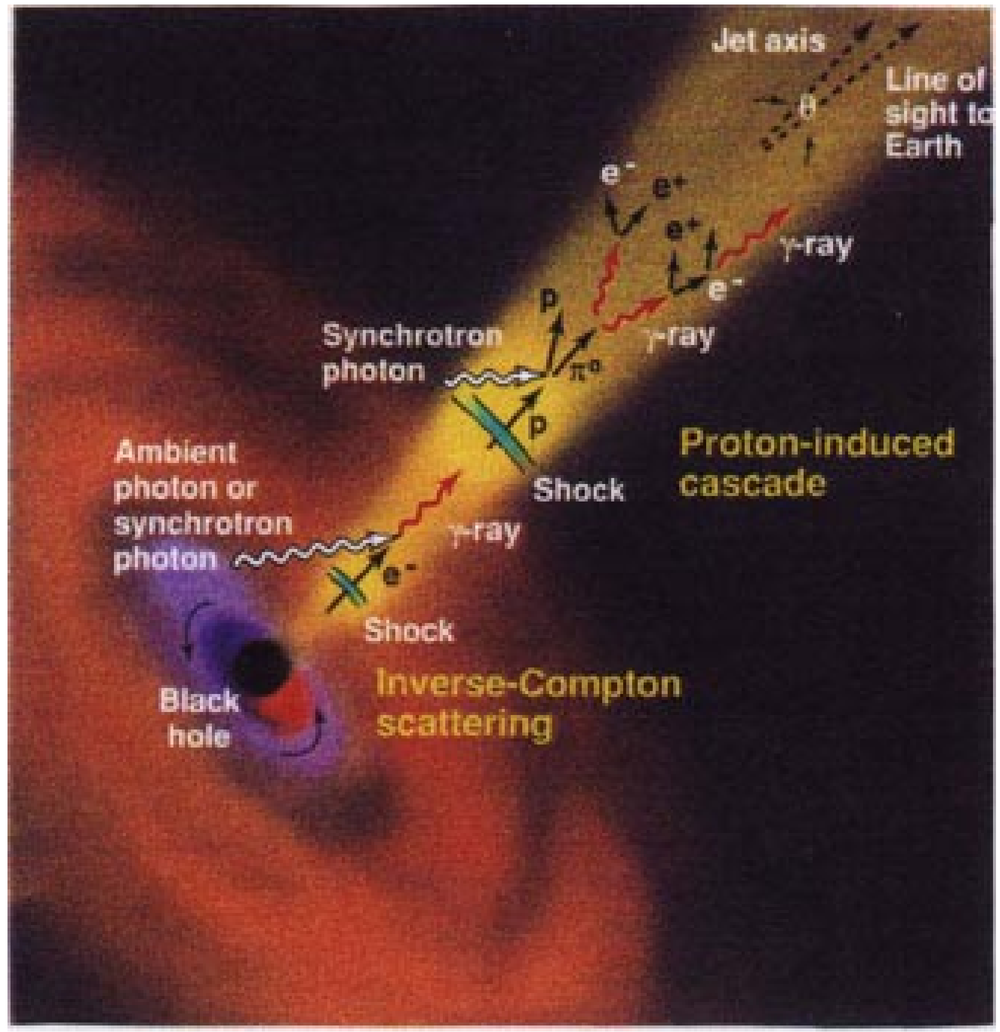
Cosmic Neutrino Factories-I

- AGNs :
- Most models assume a central black-hole and accretion disk.
- Particle acceleration occurs either near the black hole or in the jet
- Neutrinos would verify hadronic acceleration scenario



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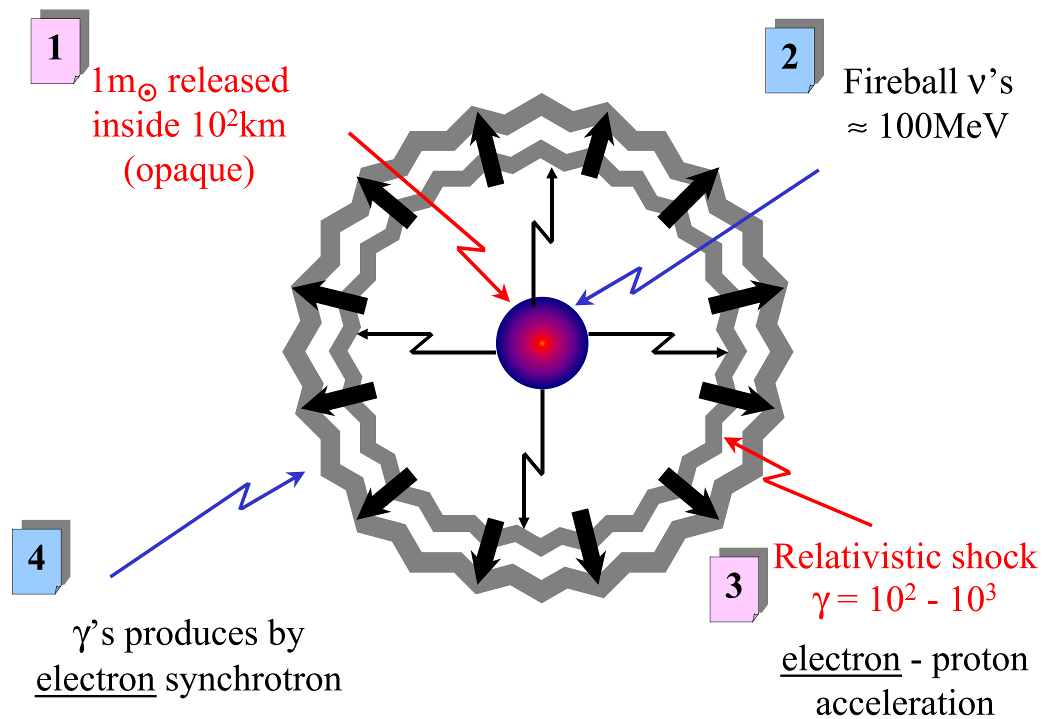
Cosmic Neutrino Factories-II

- GRBs :
- Search for ν emission in coincidence with Gamma ray detectors
- Verify fireball model
- Search for ν_τ appearance at $\Delta m^2 > 10^{-17} eV^2 (Ice^3)$



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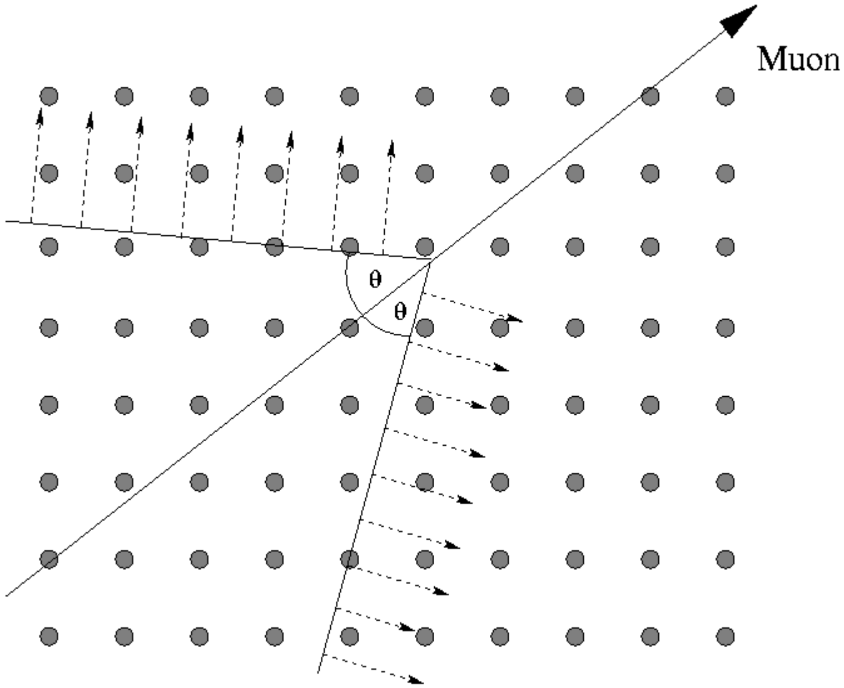
Detection Method for ν_μ

- Cherenkov photons are detected by array of PMTs

- Tracks are reconstructed by maximum likelihood method of photon arrival times.

- Essential:
  - Ice optical properties @1500-2000m
  - Geometry: relative OM position known within 0.5 m, absolute depth to within 1m

$\nu_\mu + N \longrightarrow \mu + X$



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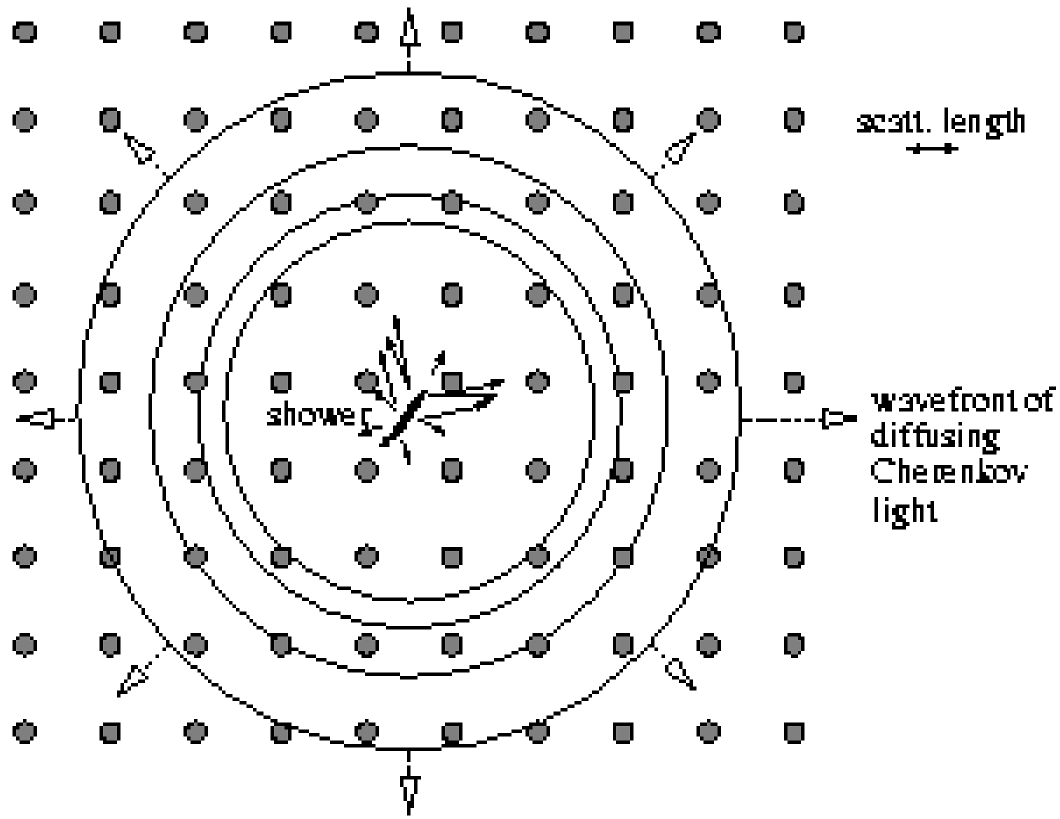
Detection method for UHE ν_e

- EM showers need special reconstruction techniques

$$\nu_e + N \longrightarrow e \longrightarrow X$$



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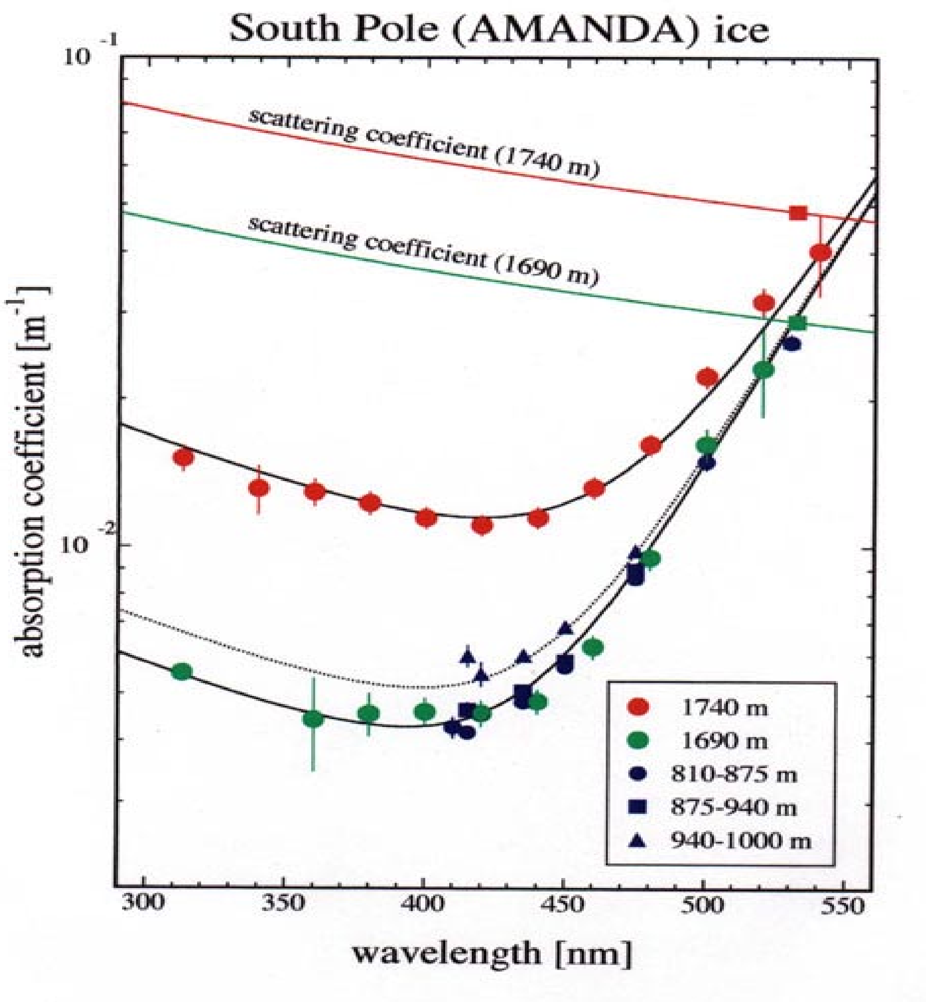
Optical Absorption Length

- ~200m for blue light
- Varies with depth, correlated with ice ages



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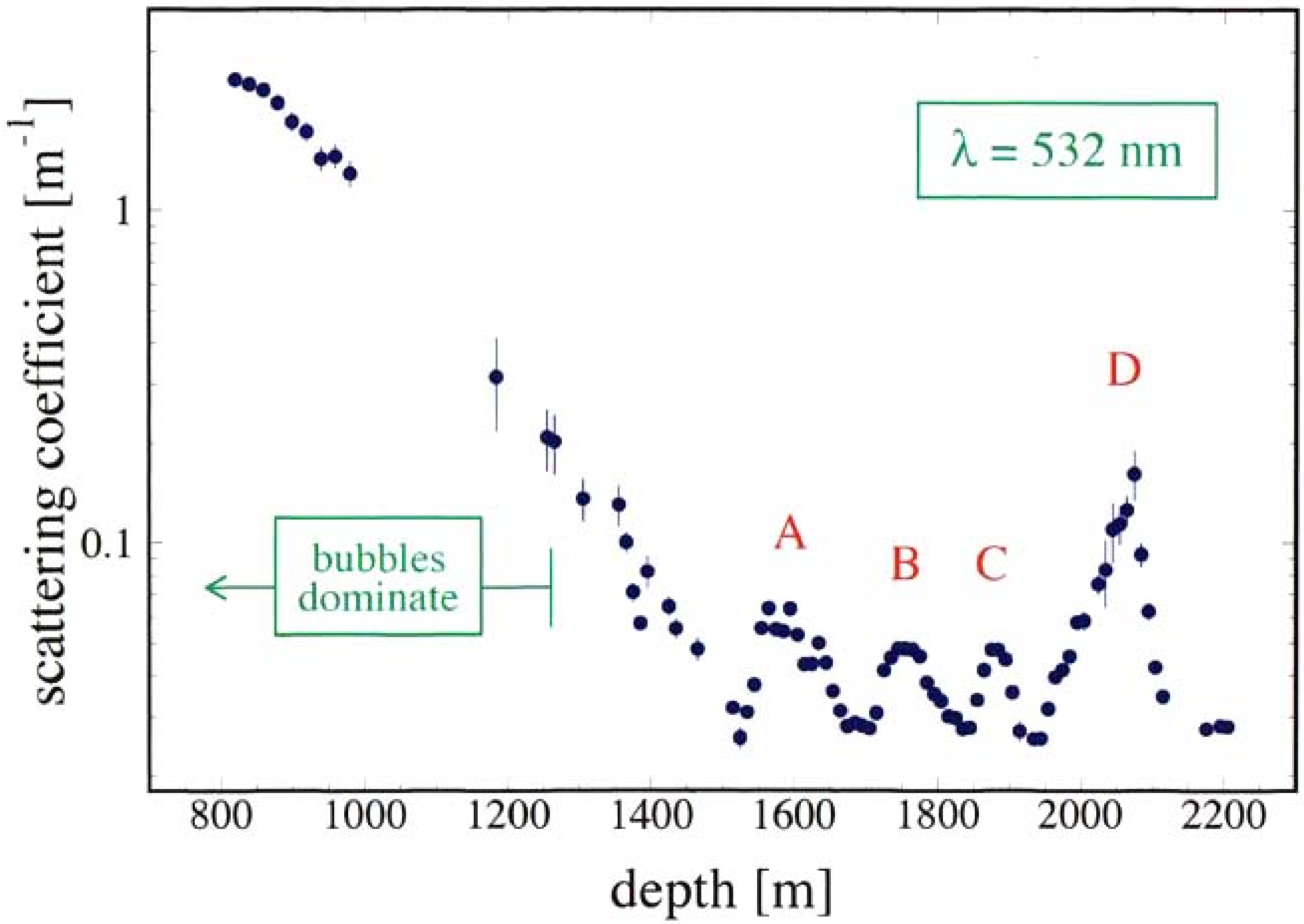
Scattering coefficient

- Variation with depth only recently included in detector simulation



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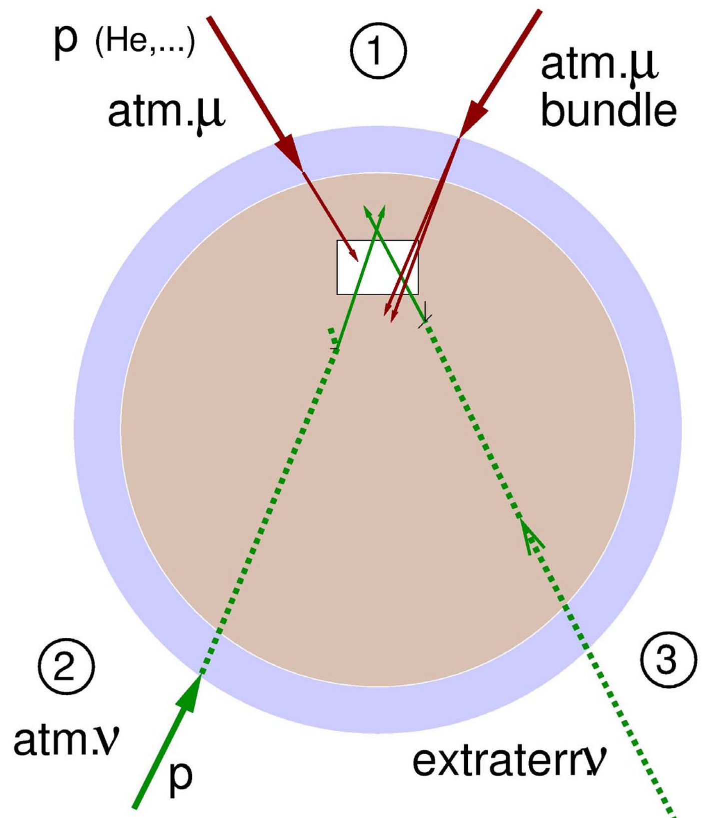
Neutrino separation

- neutrinos separation
  upward going tracks
- cosmic neutrinos
  energy (spectral index)



Calibration devices

SURFACE CONTROL BUILDING

- YAG laser (410-600 nm) @ 10 kHz
- Dye laser @ 20 kHz

DEPLOYED IN THE STRINGS

- 5 N_2 lasers (337 nm)
- Pulsed LEDs (390-450 nm)
- DC lamps (350, 380 nm)

SURFACE

- SPASE air shower array
- GASP air Cerenkov telescope

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A (BRIEF) HISTORY

- 1996: 4 strings, 86 OMs (AMANDA-B4)
- 1997: 10 strings, 302 OMs (AMANDA-B10)
- 1998: 13 strings, 425 OMs (AMANDA-B13)
- 1999: 19 strings, 677 OMs (**AMANDA-II**)

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Technical Achievements '00

- Completed AMANDA-II (19 strings, 680 OMs)
- Streamlined deployment of strings
- Improved DAQ (trigger, front-end electronics, readout)
- Deployed Ice3 technologies
  - Laser Diode transmitters using optical fiber
  - In situ HV, digital control
  - Full digitizing within OM
- Upgraded satellite link (6 GB/day)
- Detector and background simulations vastly improved

AMANDA Status

- AMANDA-II deployment finished Feb. 2000
- 1997 data analyses settled - final publications in preparation/submitted
- 1998 - 2000 data in first iteration
- IceCube - approved* in Germany, Sweden and Belgium. Approval in US expected

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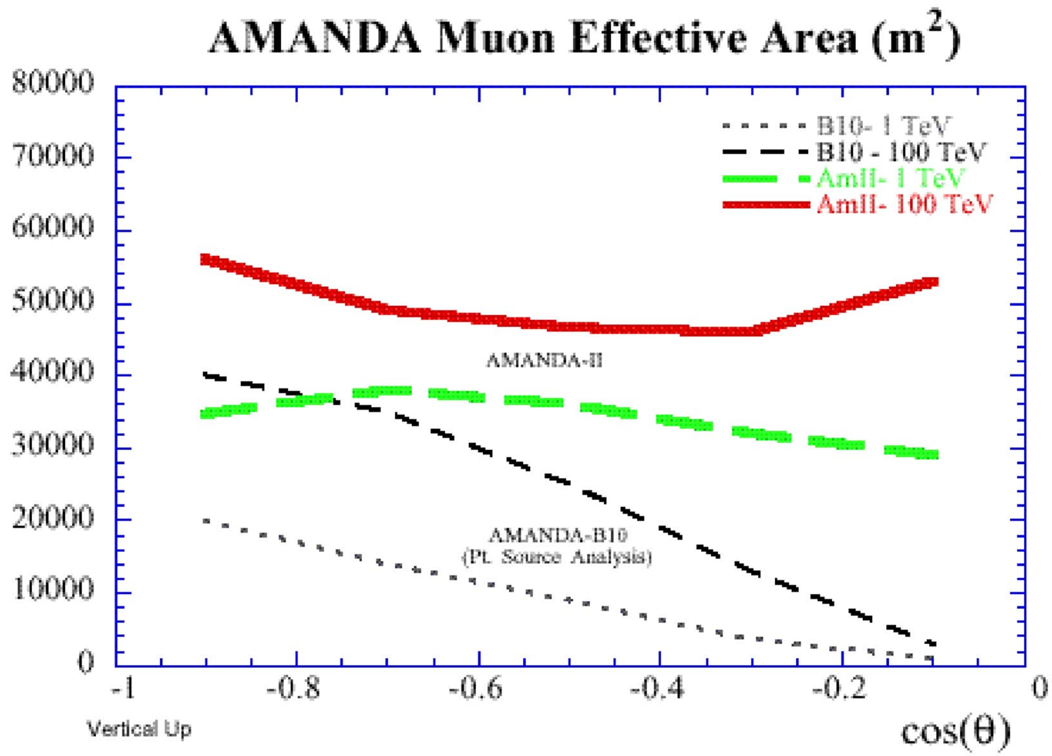
AMANDA Effective Area

- AMANDA-II 30,000-50,000 m^2

- AMANDA-II has nearly uniform response over all zenith angles



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Angular Resolution

Essential ingredient for physics

AMANDA can be calibrated with data from SPASE and GASP surface detectors

Reconstructed $\langle\Theta\rangle = 26.3^{o}$, $\sigma=3^{o}$

GASP at $\langle\Theta\rangle = 27.1^{o}$

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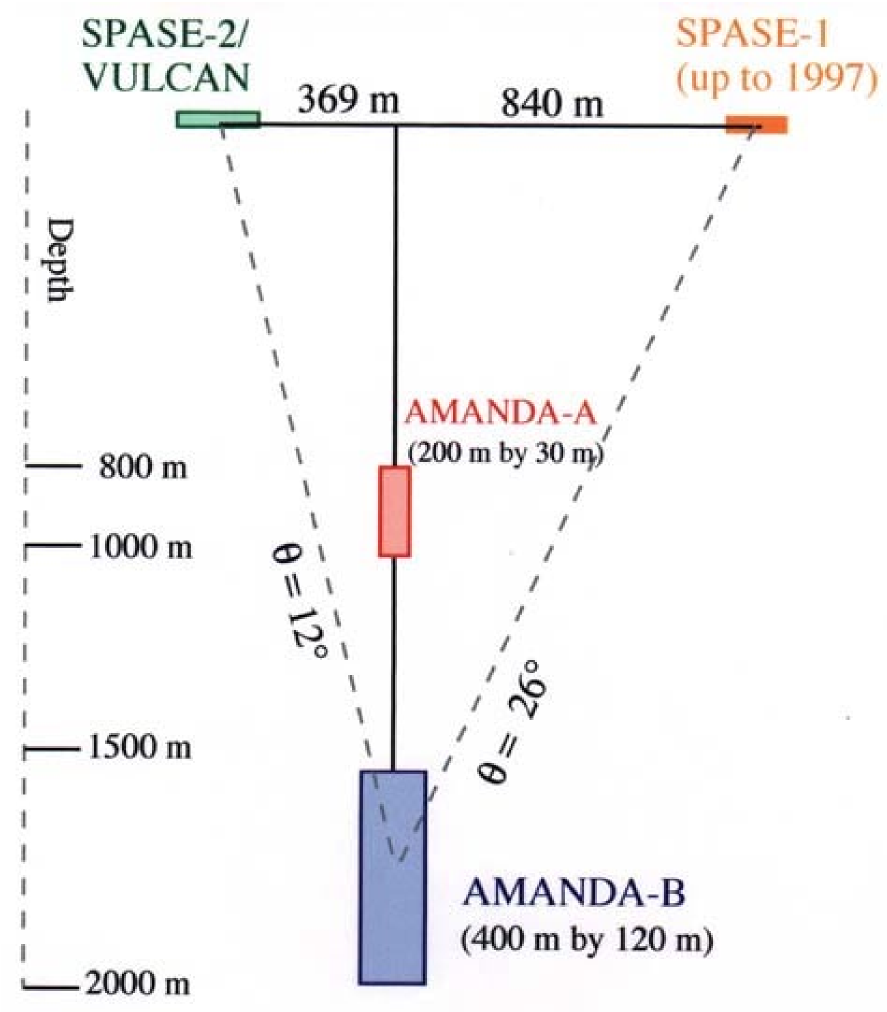
SPASE-AMANDA

SPASE: South Pole Air Shower Experiment

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



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Physics Results

130 days of detector lifetime analyzed

(10^9 events from 1997 data sample)

- atmospheric neutrino separation
- cosmic neutrino searches
  - diffuse fluxes
  - point sources
  - GRB
  - UHE neutrino search
  - Supernovae search (see A. Bouchta talk in this session)
- exotic searches
  - WIMPs
  - Monopoles

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Data Reduction 1997

E.g. one of the atmospheric neutrino analyses, 1997.

	Observed number of events	Predicted number of neutrinos
Triggered	*$1.2*10^9$*	*4500*
Reconstructed as upgoing track	*$5.1*10^4$*	*570*
Passing final cuts	*193*	*235*

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General analysis strategies

- Unstable run and noise hit selection
- Fast track fit and zenith angle cut
- Likelihood reconstruction
- Bayesian reconstruction with prior reflecting backgrnd. zenith distribution and relative intensity
- Further cuts based on:
  - Likelihood of fit
  - Sphericity of hit distributions
  - Track length
  - Number of hits from unscattered photons
  - ‘smoothness’ of hit distribution along track
  - Radial distribution of photons from track
  - Number of strings with > predefined number of hits
  - Number of hit OMs

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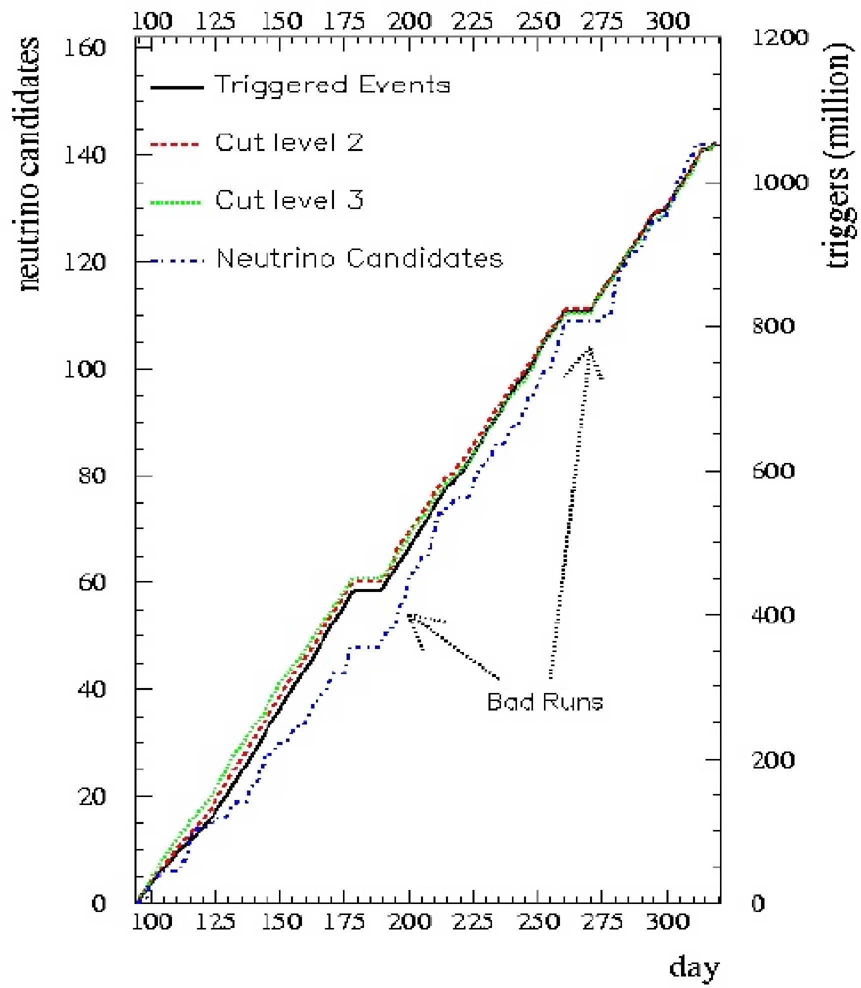
Atmospheric Neutrinos

- Strong selection criteria
- Two distinct analysis methods
- Expected number of events depends on cut efficiency



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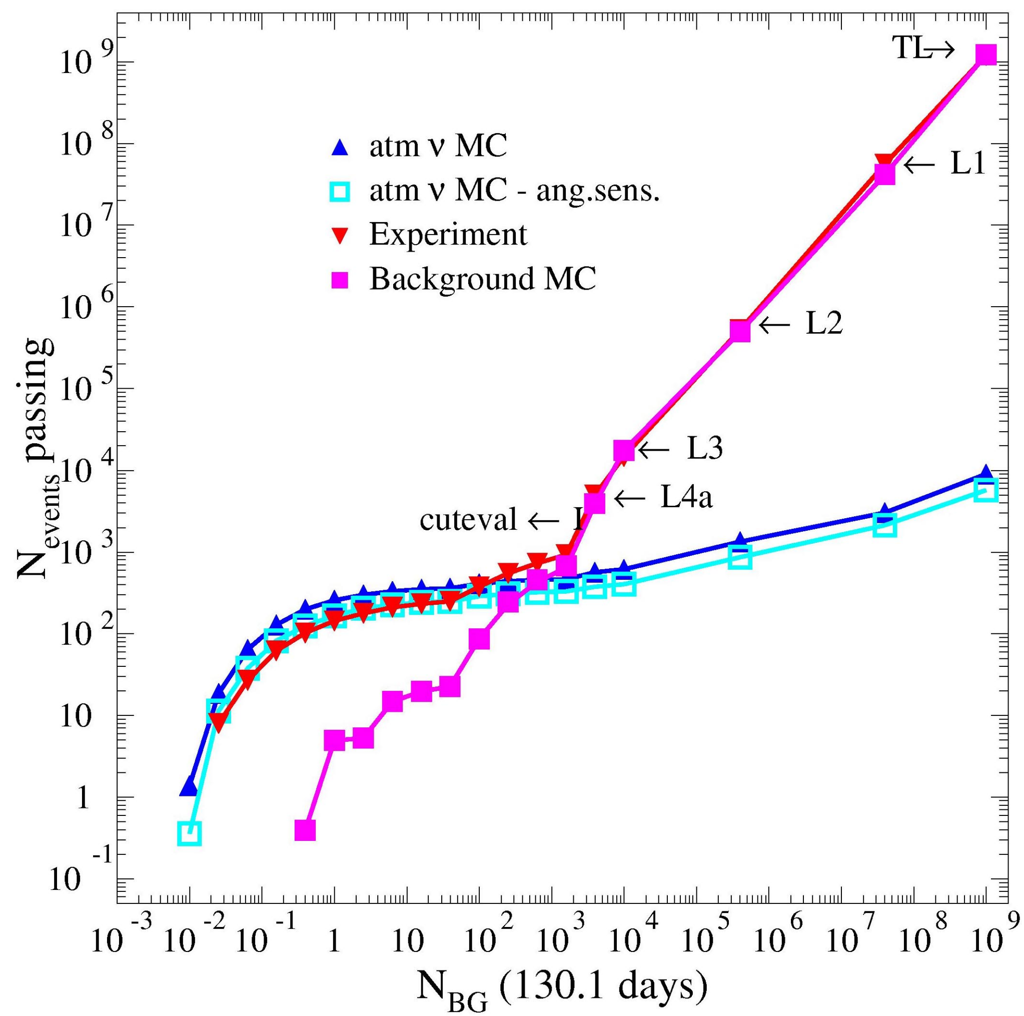
Atm. ν: background rejection

- Agreement within systematics at all stages of analysis
- Rejection criteria are progressively improved, leaving fewer down-going events
- Initially data agrees with BG simulation, but then agrees with atm. ν signal



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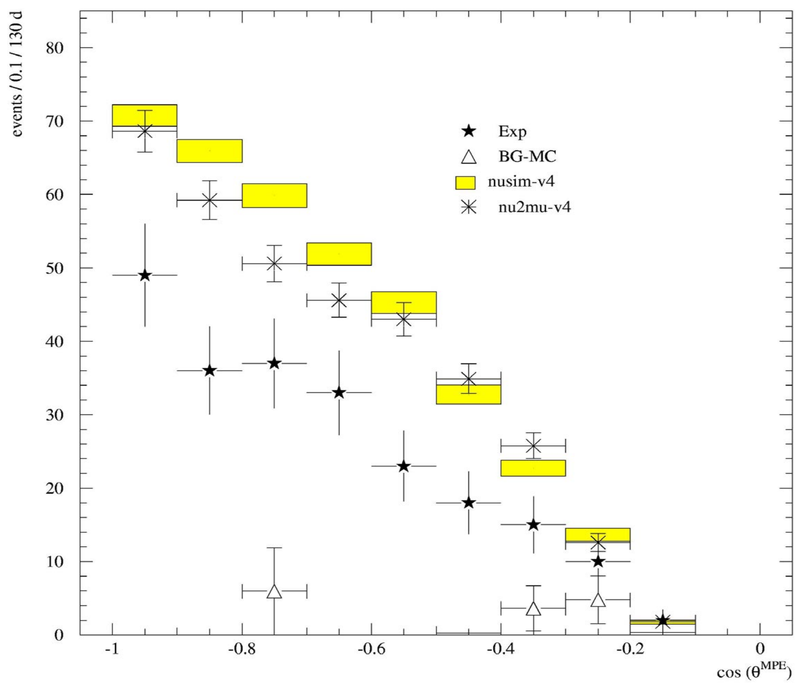
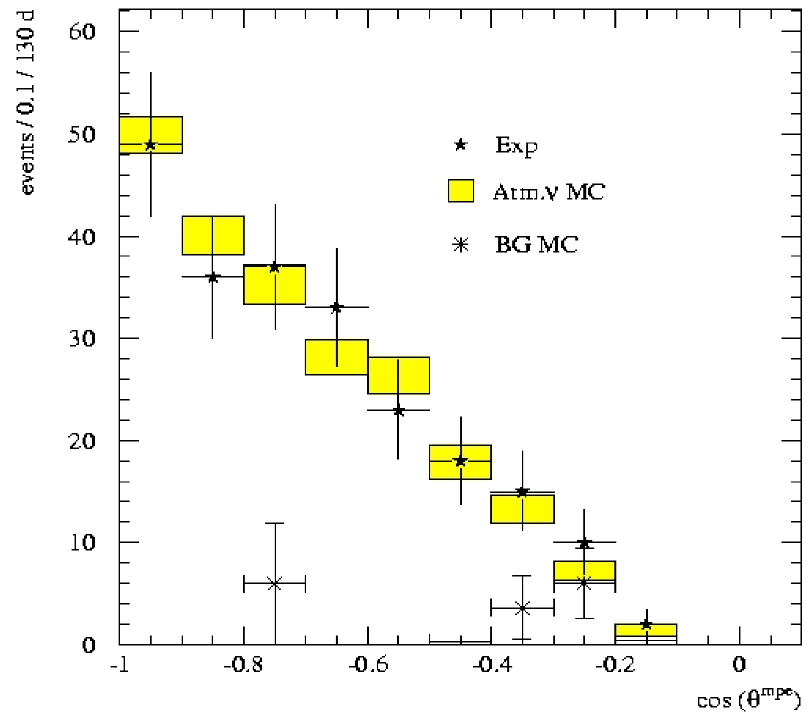
Angular Distribution

Two distinct analyses, not fully independent

AMANDA-B10, 223 (204) candidates, background < 10%

Analysis A: Preliminary





35% deficit: compatible with present sytematics

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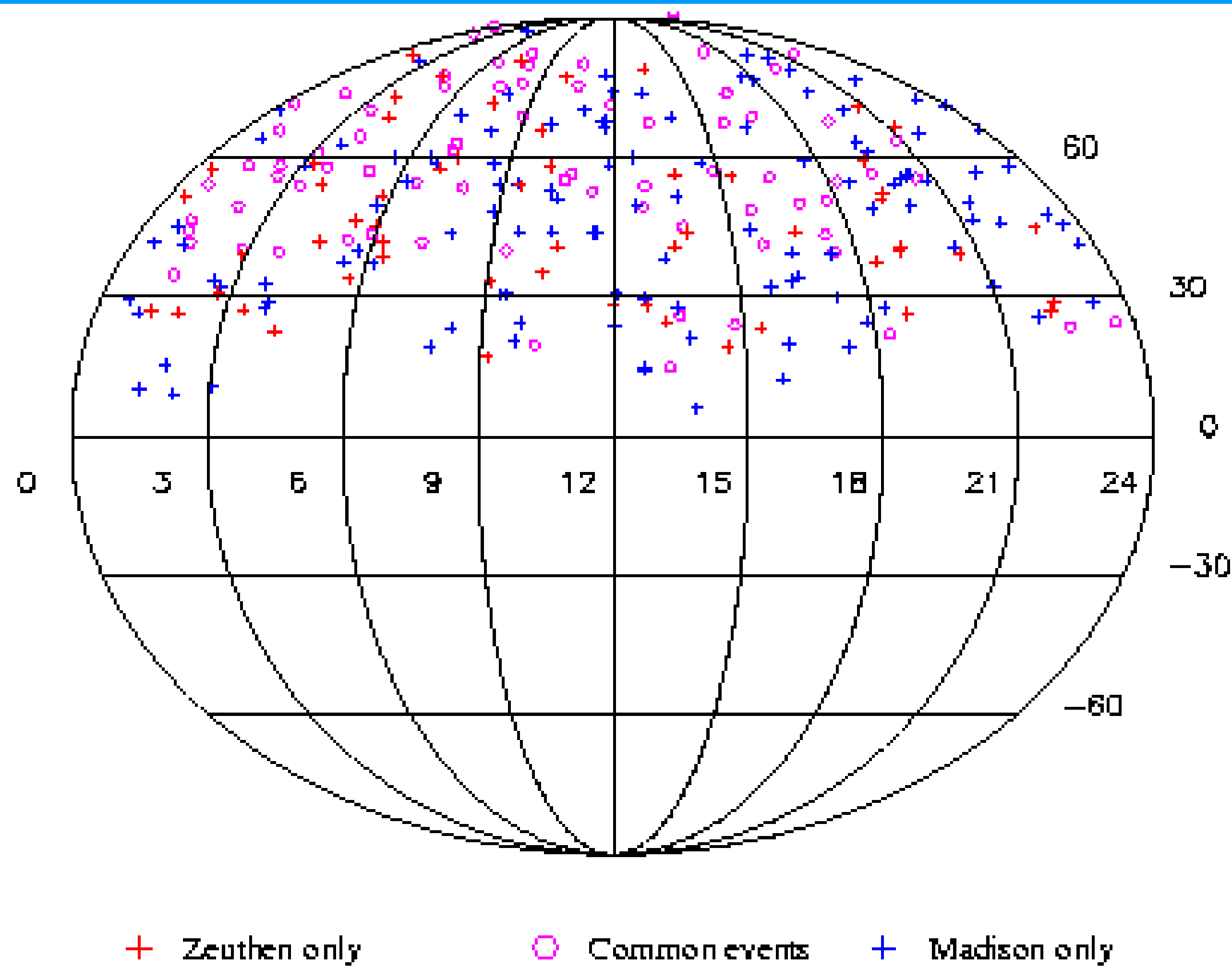
Atmospheric ν Sky Plot



compatible with random distribution

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Search for HE ν Point Sources

- Concentrate on continuous emission from sources with hard spectra (~E^{-2})
- Optimize search on Signal to Noise Ratio
  - A_{eff} depends on rejection requirements
  - Cut selection procedure defined *a priori*
- Background for this search
  - Poorly reconstructed atmospheric muons
  - Atmospheric neutrinos

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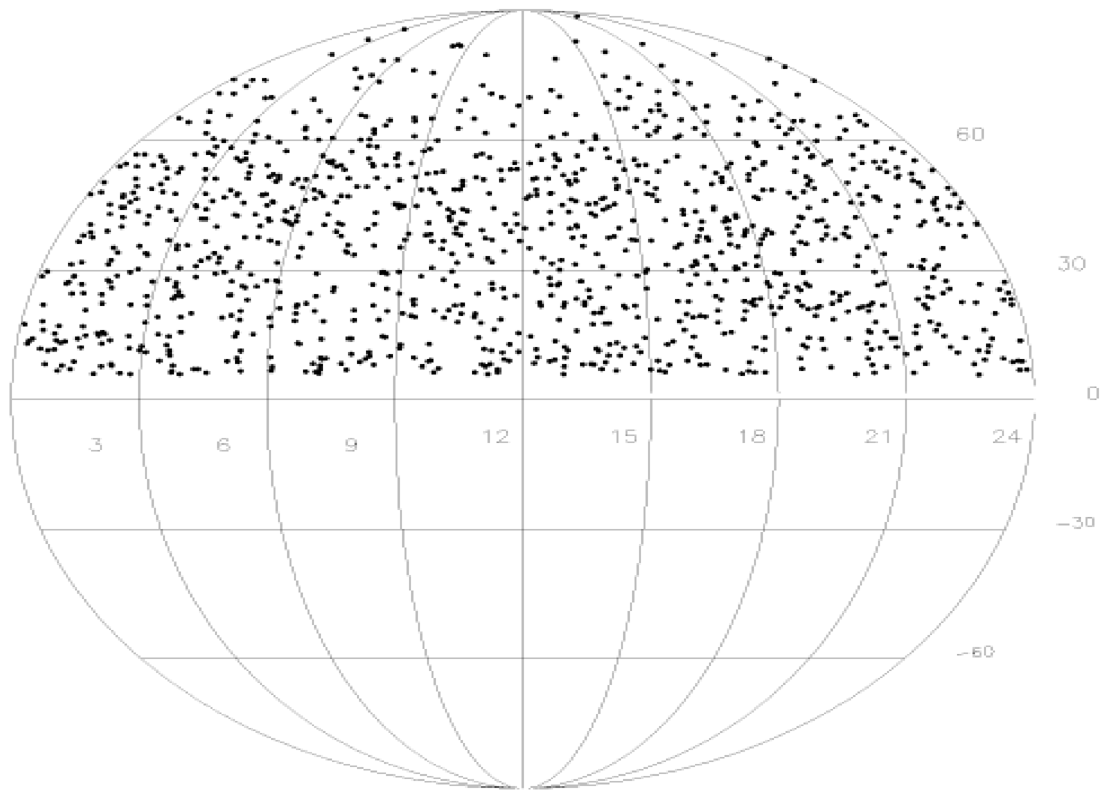
Point Source Search

- 1097 events
- No obvious clustering
- Event sample consists of atm. ν and atm. muons.

Equatorial Coordinates



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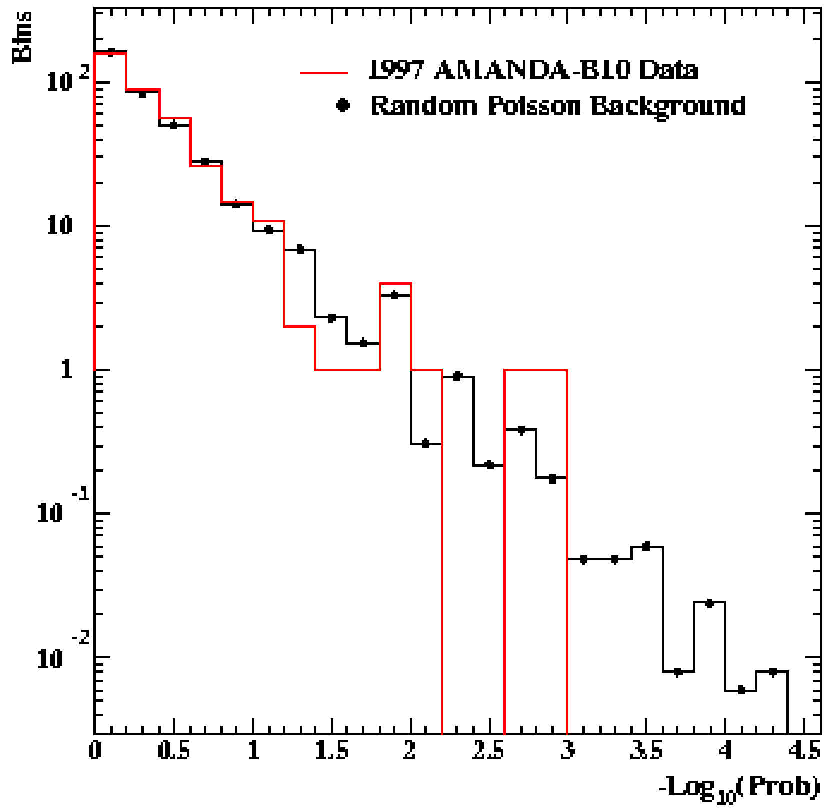
Significance distribution

- Bin sky according to angular resolution
- Use declination band to estimate background
- No statistically significant excess



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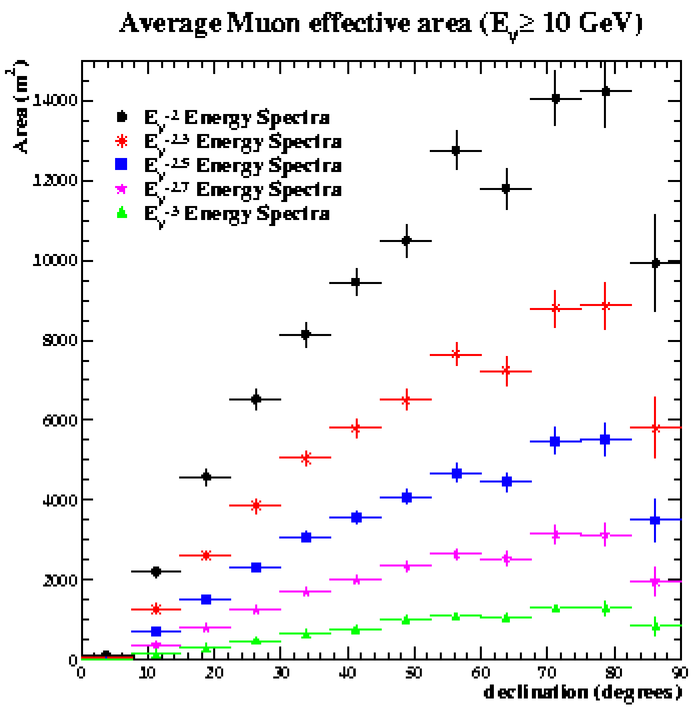
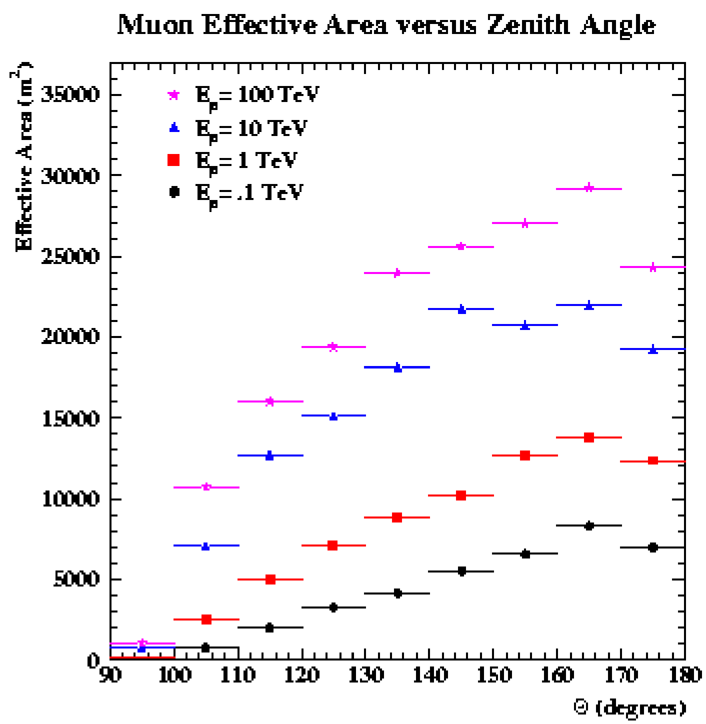
Effective Area for Muons

Point Source Analysis





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Expected Point Source Fluxes

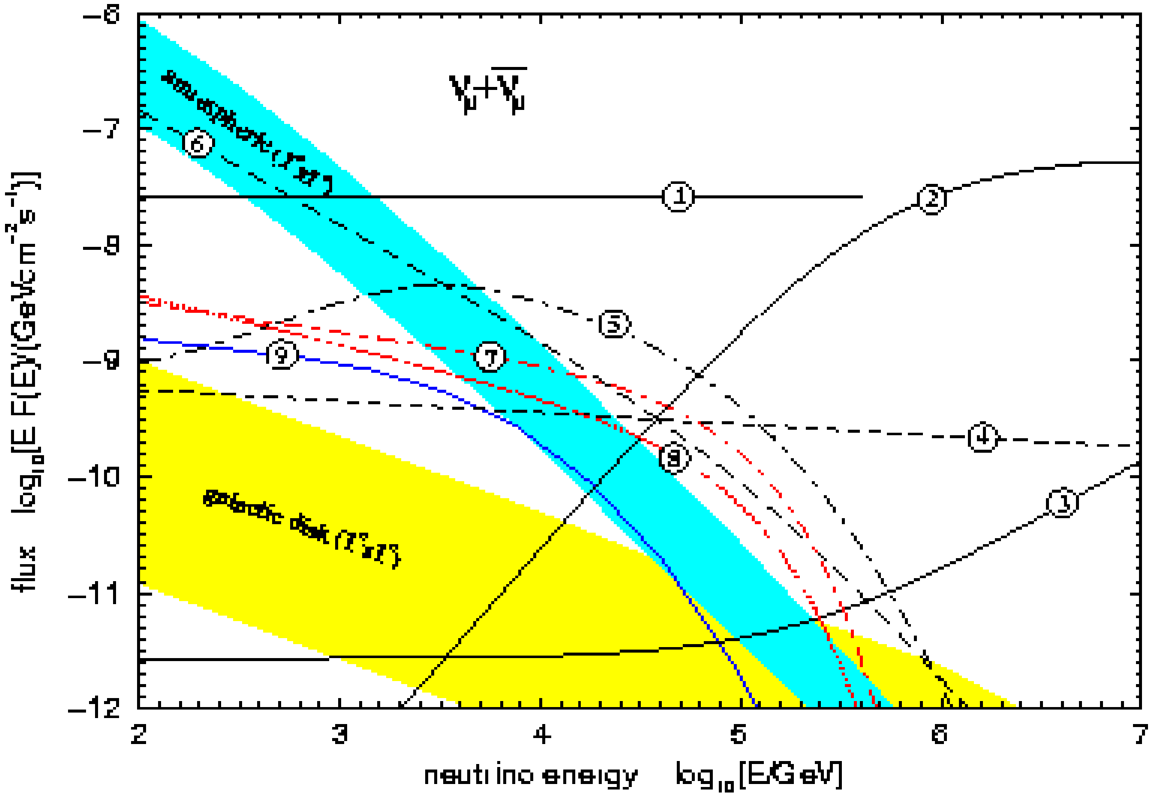

Figure adopted from Mannheim & Learned

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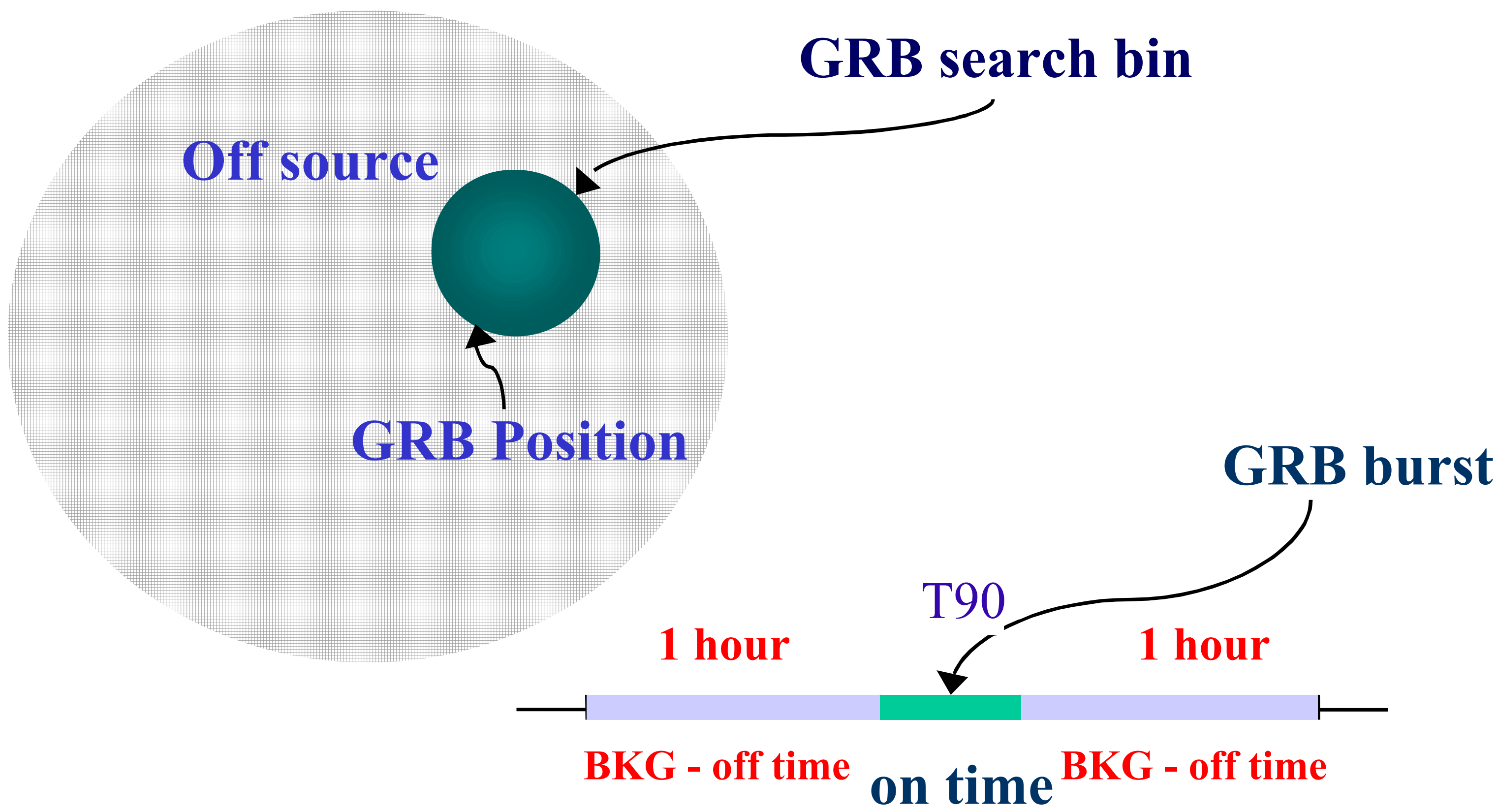
Search for HE ν from GRB



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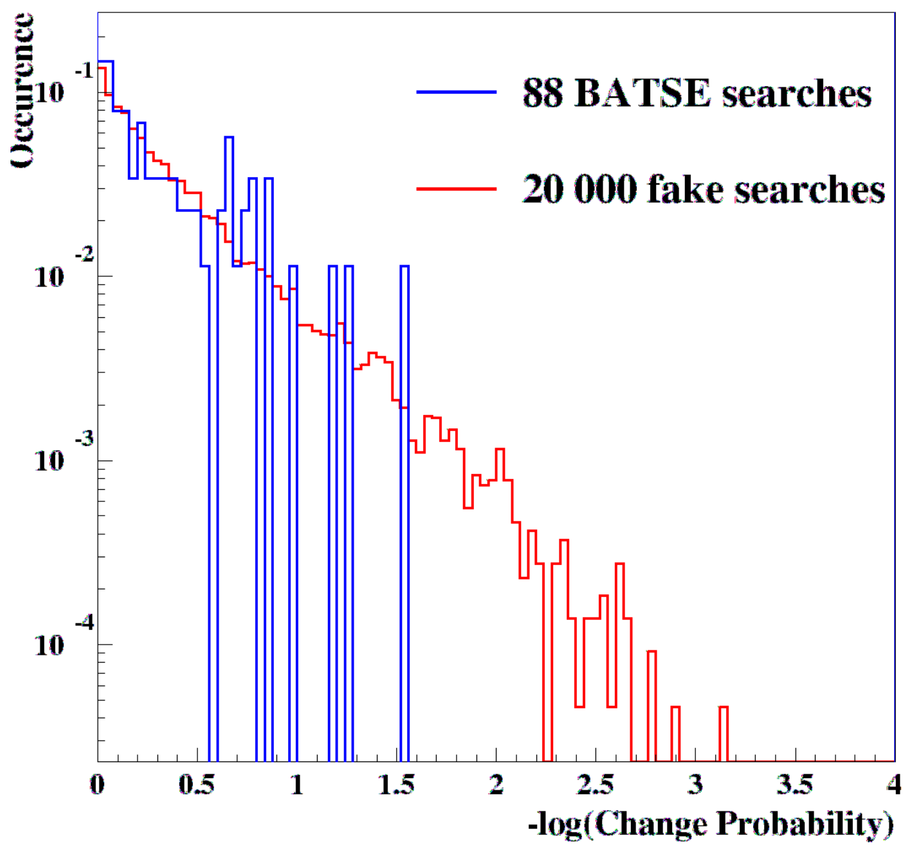
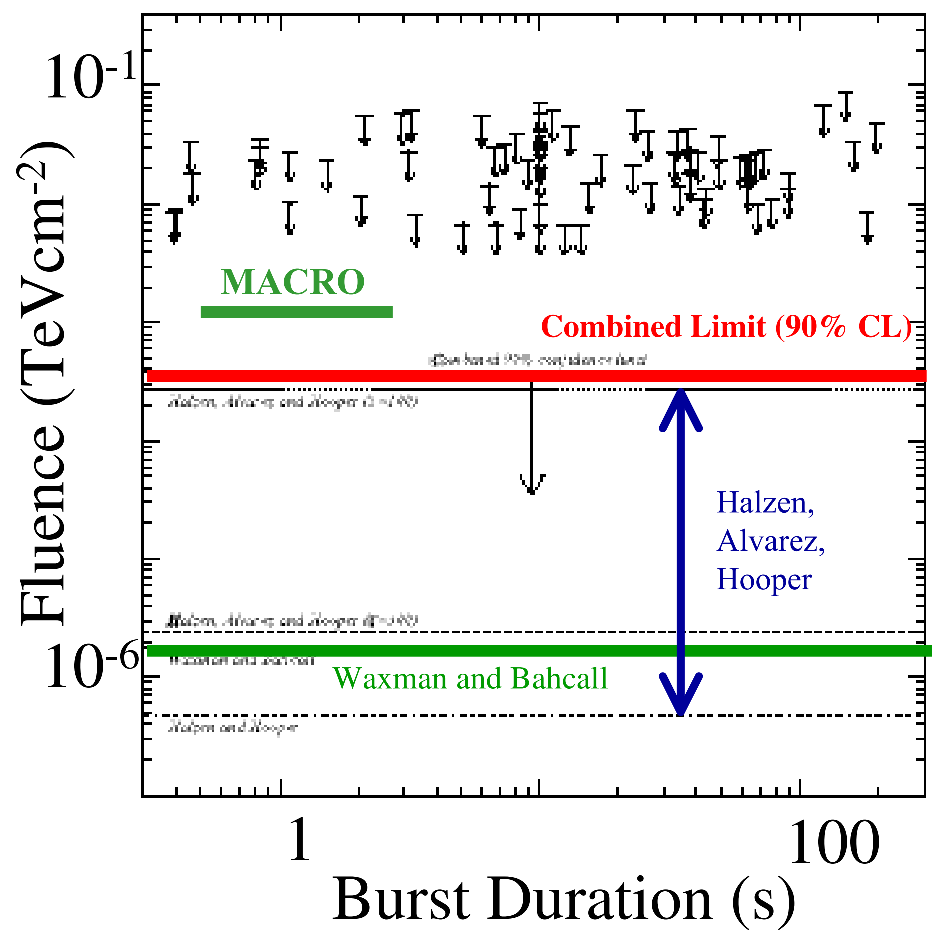
HE ν emission from GRB’s

- Not so far





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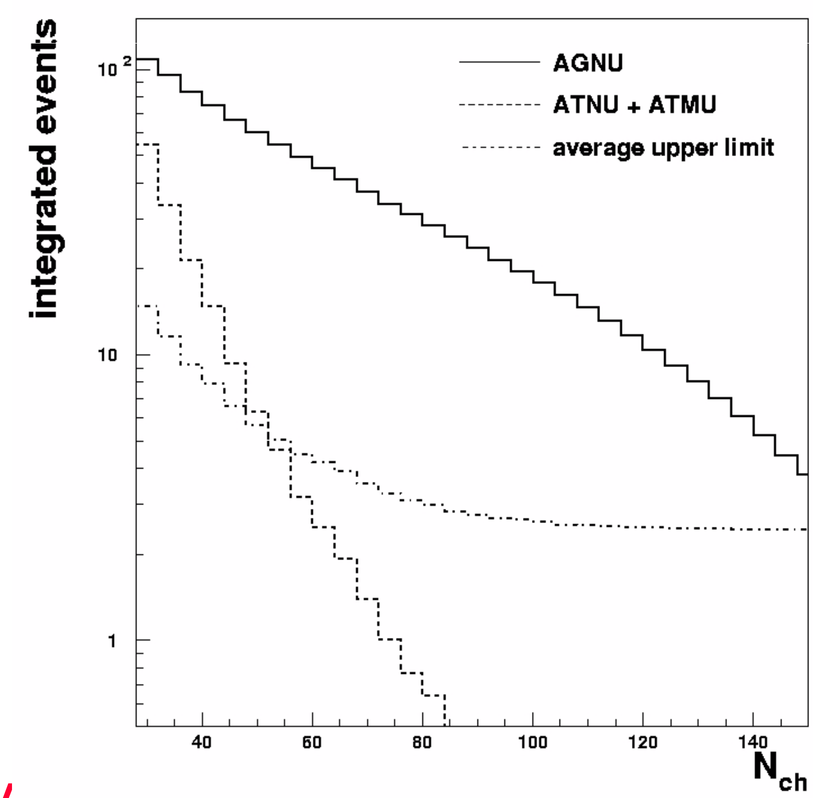
Diffuse flux of HE neutrinos

- Use N_{ch} as energy estimator
- Distribution compatible with atmosph. neutrinos

- Sensitivity to diffuse neutrino flux:



$dN/dE_\nu \sim 10^{-6} E_\nu^{-2}\ cm^2\ s^{-1} sr^{-1} GeV$

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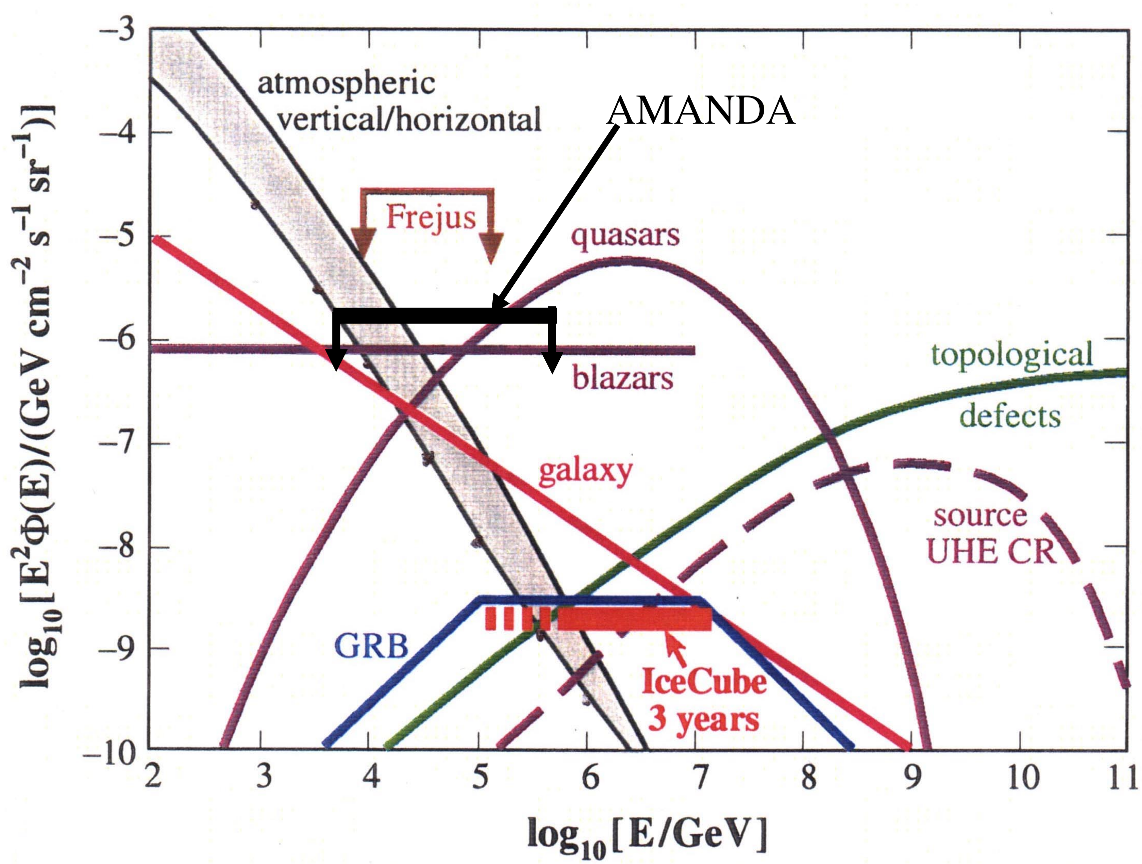
Diffuse Flux

- Generally 10^3 larger than point fluxes
- Atm. ν backgrounds 10^3 worse
- $E^2\Phi_\nu < 1 \times 10^{-6}$ GeV $cm^{-2} s^{-1} sr^{-1}$



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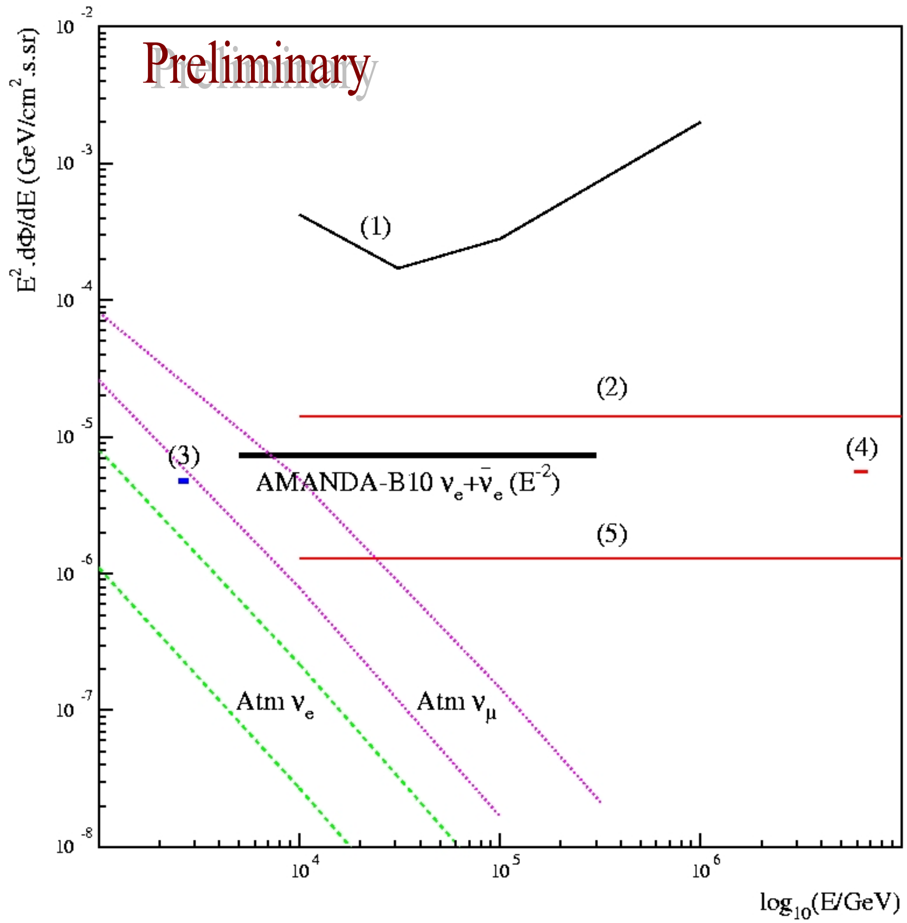
UHE ν_e cascade search

- Position reconstruction
  - Based on time-delay likelihood
  - <**r**> 🖫 0.6 x $\mathbf{r}_{true}$ (m)
  - rms $_{x,y}$ = 6.4 m, rms $_z$ = 5.3 m for inside interactions (<60 m)
- Energy and direction reconstruction
  - Based on P(hit) and P(no-hit)
  - rms $_{zenith}$ = 26°
  - rms $_E$ = 40-45% in 1-10 TeV range
- Data: 0 events left after cuts
- MC: 0.6 events expected



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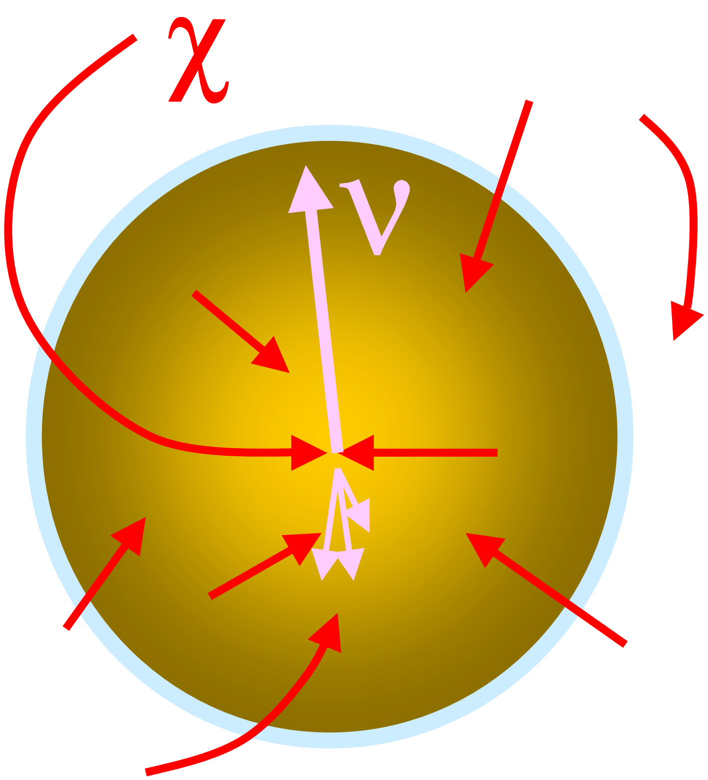
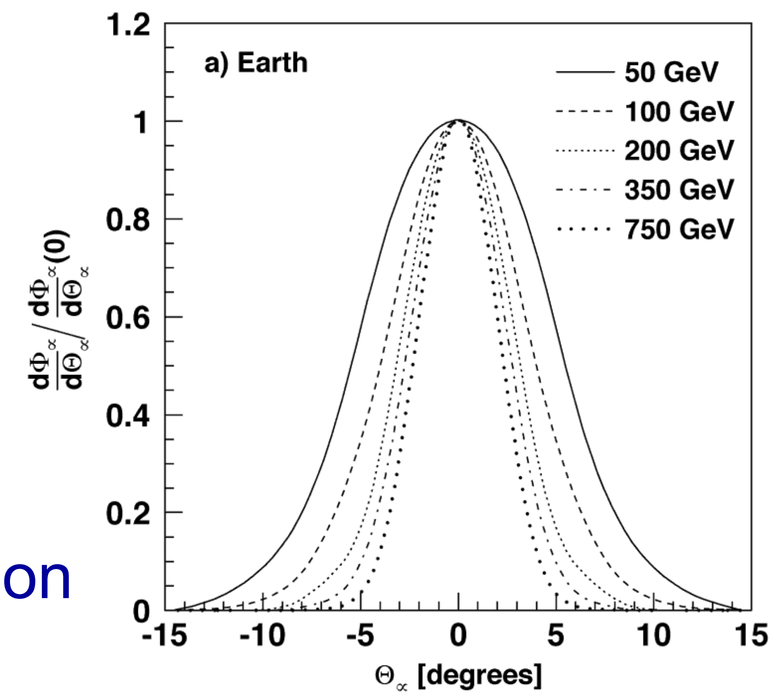
Search for Neutrinos from WIMP Annihilation



Assumption:
(At least some) dark matter in Galaxy due to neutralinos, density ≈ 0.3 GeV/cm^3

angular distribution



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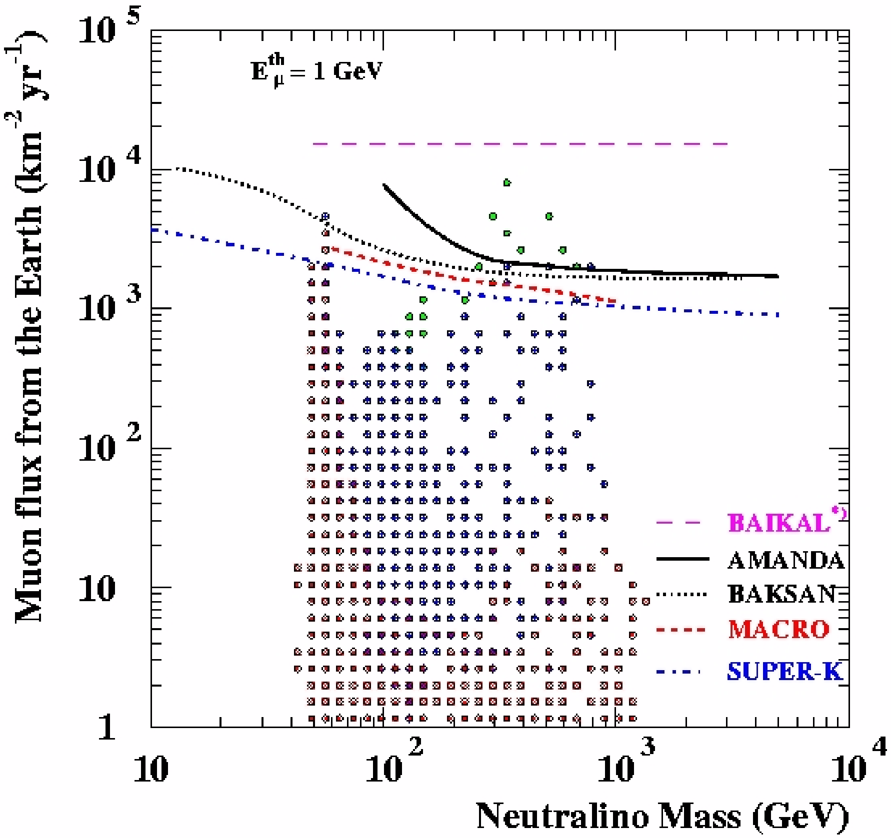
WIMP Limits

Zenith	#events	MC
>165°	14	16.0

- Limit with only 130 days livetime close to detectors with much longer lifetimes
- Systematic uncertainties included in limit evaluation



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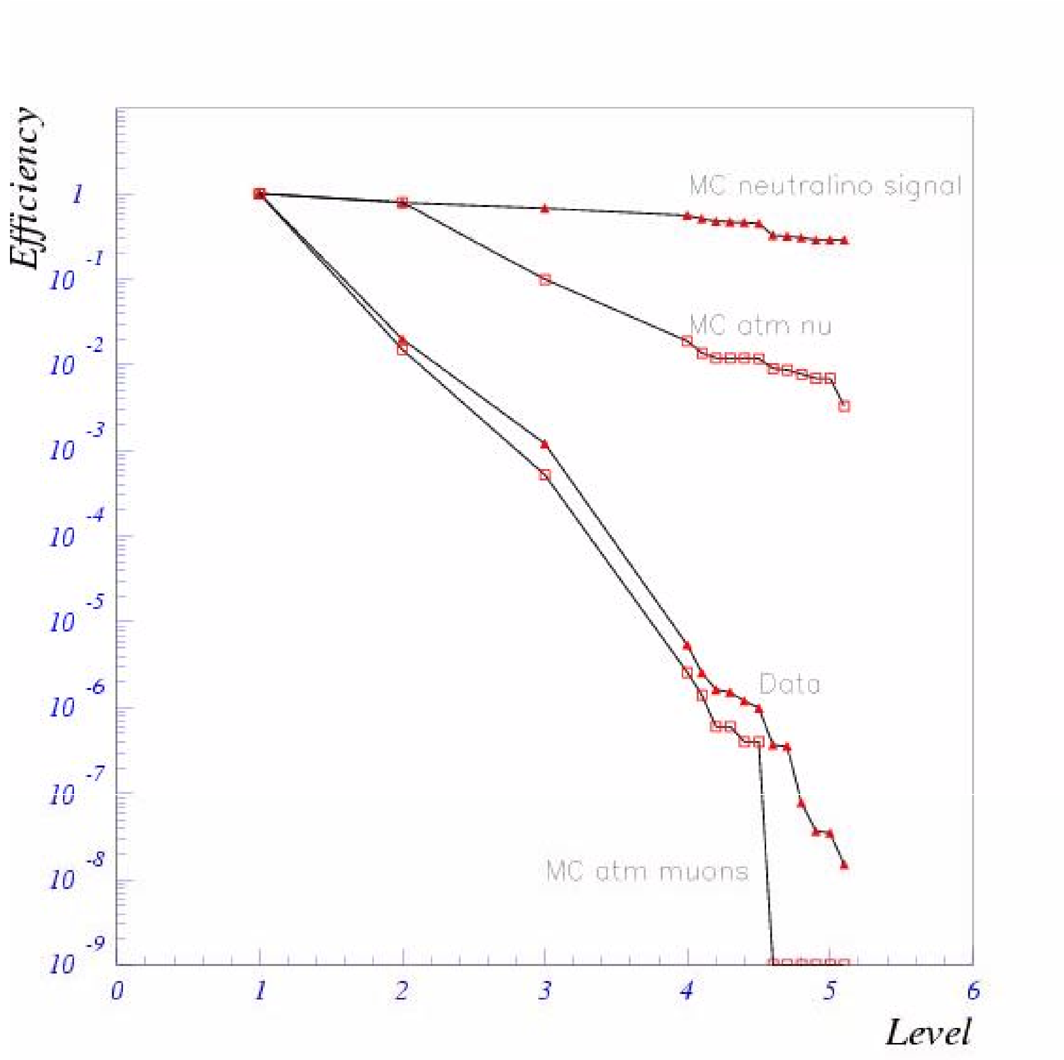
Cuts for WIMP search

- Optimized cuts for almost vertical upward moving muons.
- The simulated WIMP signal is reduced to 30% after reducing background by 10^8.



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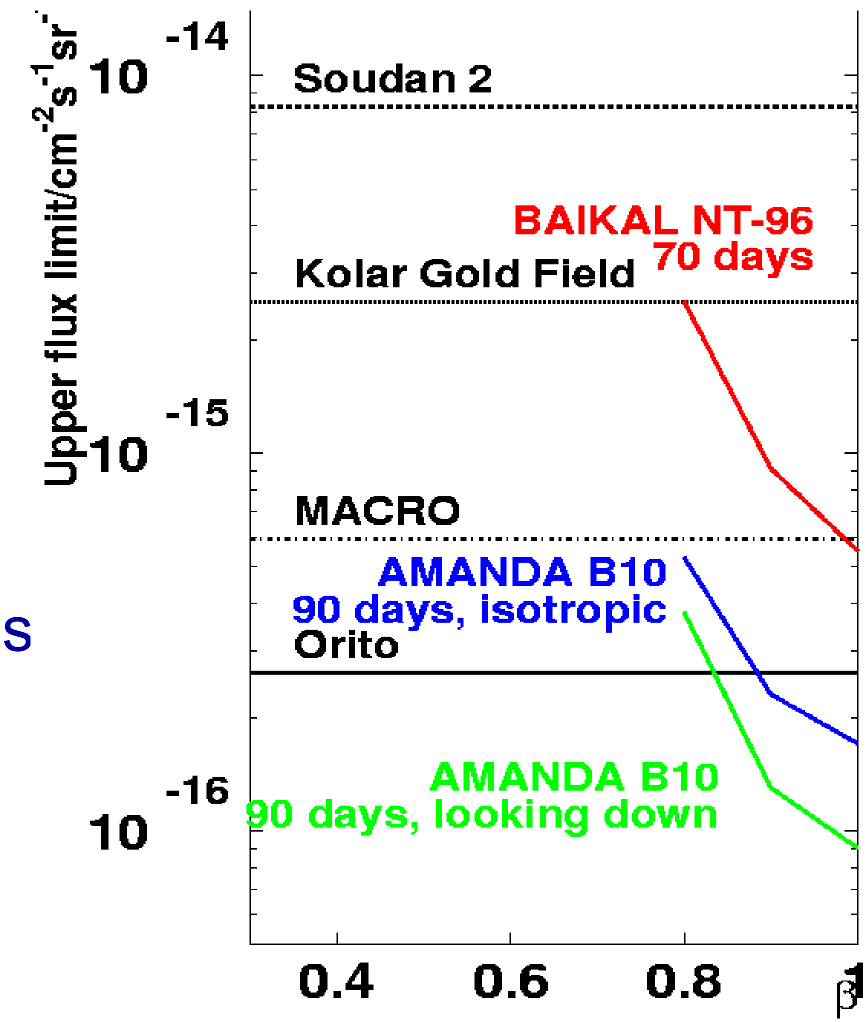
Magnetic Monopole search

- Monopole light output x8300
- Search for high multiplicity events
- Background: muon bundles or very energetic single muons



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AMANDA Results I

- Atmospheric neutrinos (135 live days)
  - ~170 events from 1997, depends on analysis
  - Calibration of sensitivity within factor 2
- Supermassive Black Holes (AGN)
  - E^{-2} point source: ϕ_{ν} (>10 GeV) <10^{-7} ($cm^{-2}s^{-1}$)
  - E^{-2} diffuse flux: $E^2\phi_{\nu}$< $1x10^{-6}$ GeV $cm^{-2}s^{-1}sr^{-1}$
- GRB in coincidence with BATSE
  - Cumulative $Fluence_{\nu}$< $4x10^{-4}$ $TeVcm^{-2}$

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AMANDA Results II

- Supernova sensitivity
  - 60% of galaxy at 90% C.L. (SN1987a type)
- WIMPs from the earth center
  - Flux: $\phi_{WIMP} < 2x10^{3}$ $km^{-2}yr^{-1}$; M>200GeV
- Magnetic Monopoles
  - isotropic Flux: $\phi_{M.M.} < 2x10^{-16}$ $cm^{-2}s^{-1}sr^{-1}$; β=1
  - upgoing Flux: $\phi_{M.M.} < 1x10^{-16}$ $cm^{-2}s^{-1}sr^{-1}$; β=1

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Conclusions

- First neutrino results (AMANDA-B4)
  - Astroparticle Physics **13** (2000) 1
- Atmospheric neutrinos (AMANDA-B10)
  - Nature, 410, 441-443, 2001.
  - detailed paper in preparation
- Supernova
  - accepted for publication by Astropart. Phys.
- Drafts in preparation for submission in autumn 2001

  (AMANDA-B10, 1997 data)
  - WIMPs, Point source, Diffuse sources, GRBs
- Current effort on evaluating systematic uncertainties

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ICE3: OVERVIEW

- Proposal passed physics reviews
- Project conditionally approved in Sweden, Belgium and Germany. Expected in the USA.
- ~5000 Oms in 80 strings instrumenting 1Km^3
- DOM technology (tested in one string of AMANDA-II)
  - captures all complexity of PMT waveform
  - digtization and timestamp @ the OM
  - standard copper cable: reduces cost of fiber optics
  - simplified deployment

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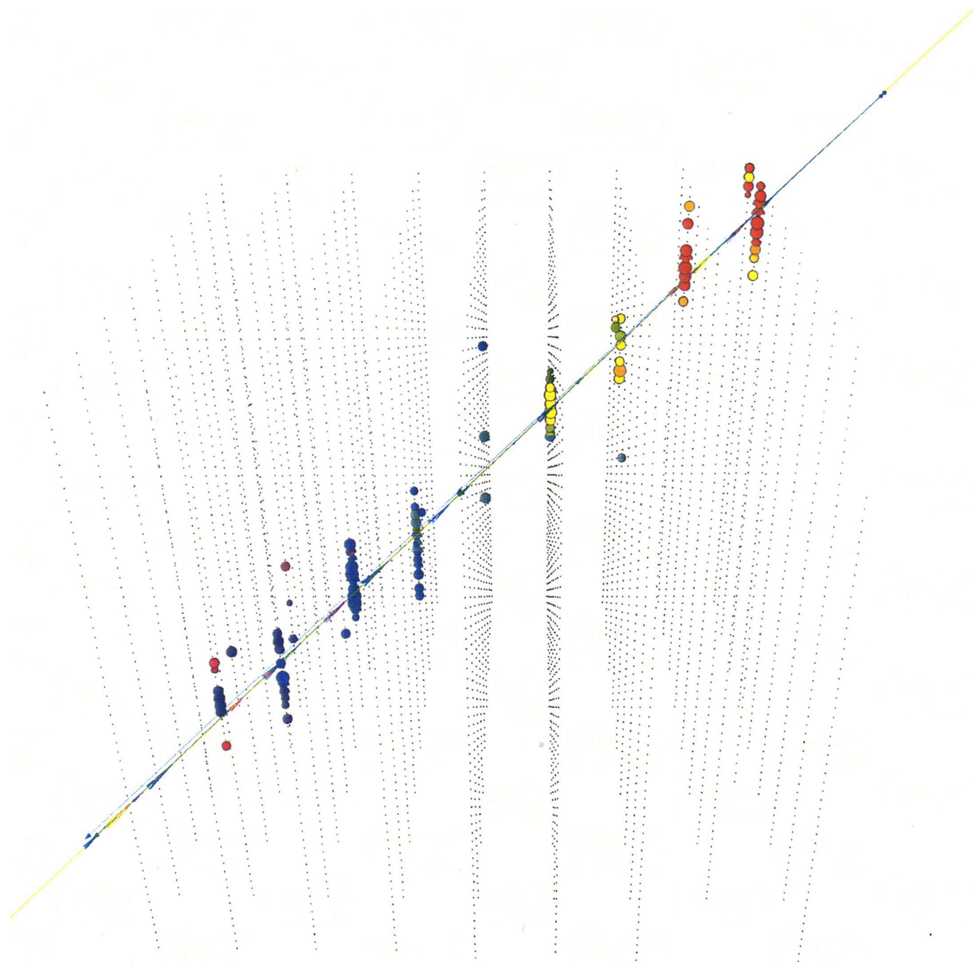
Ice^3 Muon Event (simulated)

- OMs that detect Cherenkov photons are colored circles
- Earliest photons are red, latest photons are blue.



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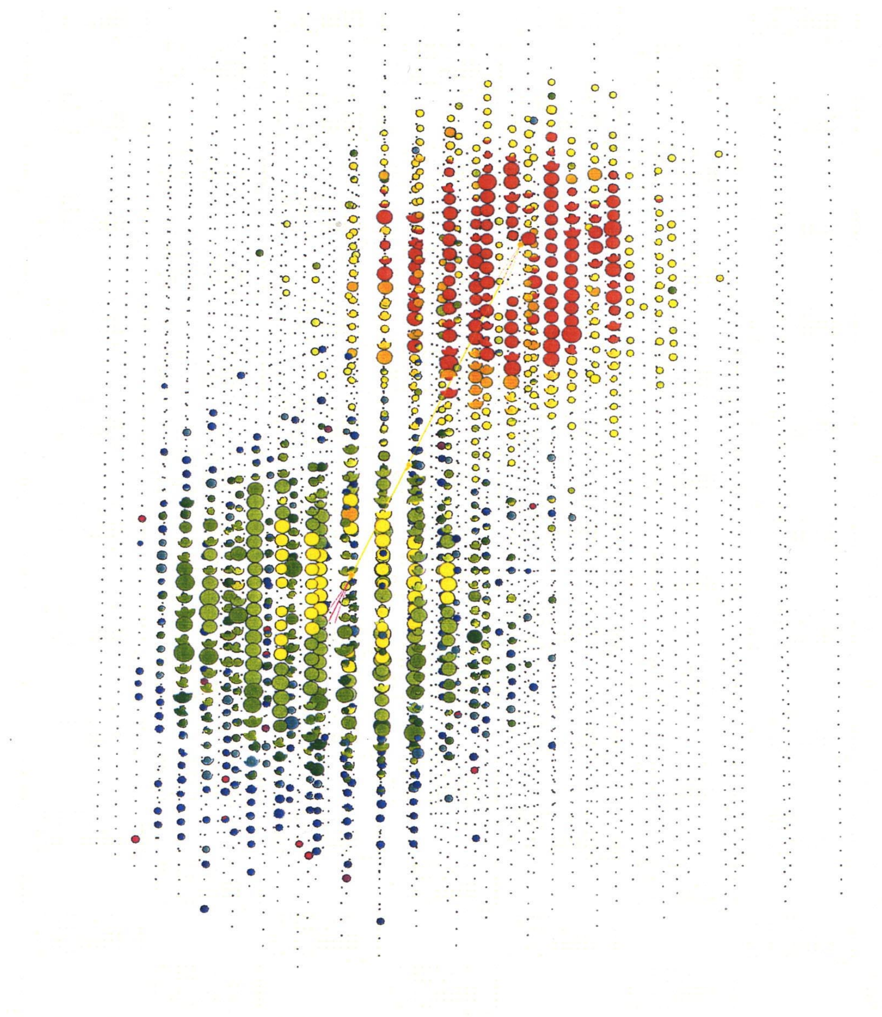
Ice^3 Tau Event (double-bang)

- Color circles indicate OMs that detect Cherenkov photons.
- Earliest photons are red, latest photons are blue.



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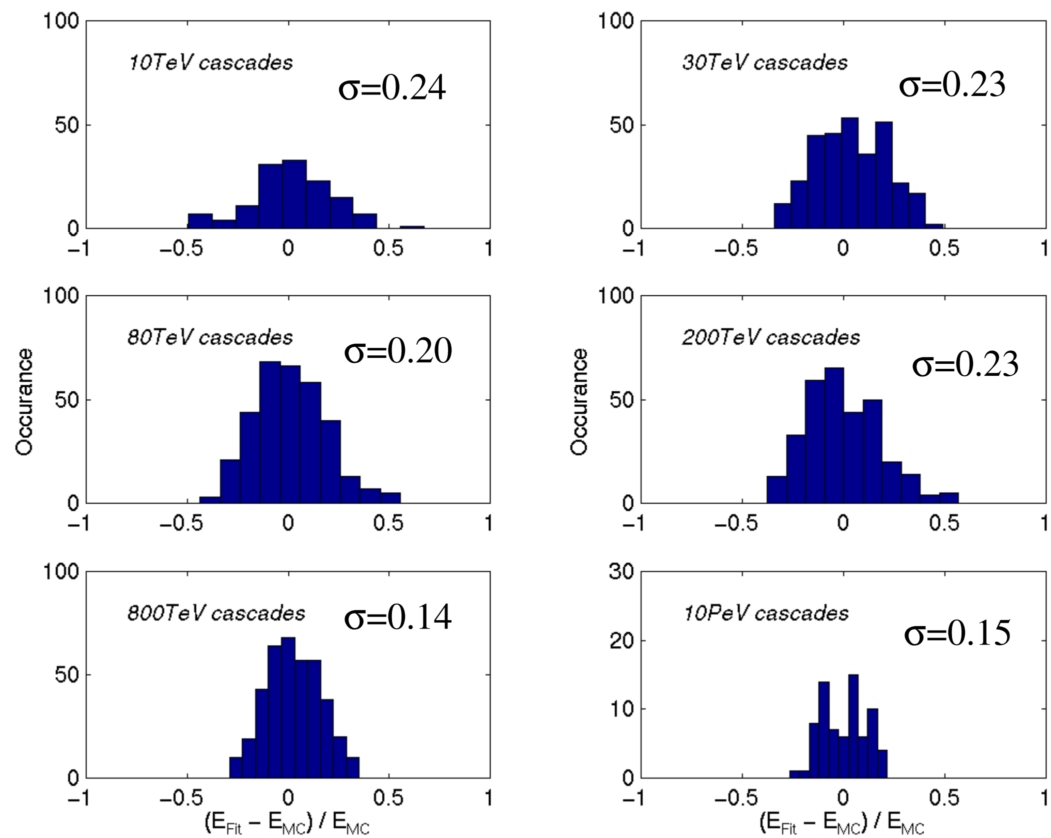
Cascade events in Ice^3

Energy Resolution (sumTOT)

- Simulations idealistic
  - Linear response
  - No saturation
  - dE/E~25%



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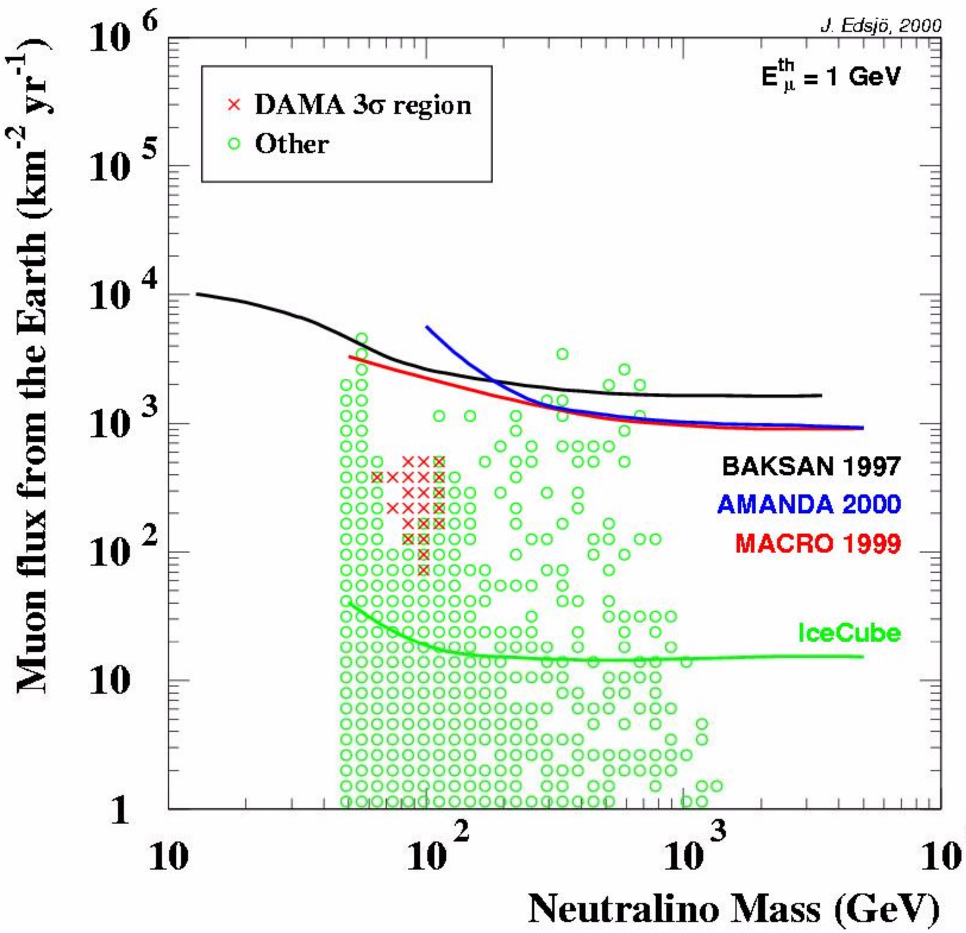
WIMPs from the Earth with Ice^3

Optimized search for vertical neutrinos

- Ice^3 will completely cover the DAMA area



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WIMPs from the SUN with Ice^3

- Ice^3 will significantly improve the sensitivity