# The Radio Ice Cerenkov Experiment : RICE

*Jenni Adams and Suruj Seunarine*

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# Rice Collaboration(average)

- *Bartol Research Institute at U. Delaware*:
  Dave Seckel
- *Florida State University*:
  Geroge Frichter
- *University Of Kansas*:
  Chris Allen, Alice Bean, Roman Buniy, Dave Besson, DJ Box, Eben Coppel, Tim Donohue, Ryan Dyer, Doug McKay, John Ralston, Lori Perry, Soeb Razzaque, Dave Schmitz, Jeff Allen
- *MIT*:
  Ilya Kravchenko
- *University of Wisconsin at River Falls*
  Glenn Spiczak
- *University of Canterbury*:
  Jenni Adams, Suruj Seunarine

# RICE Physics

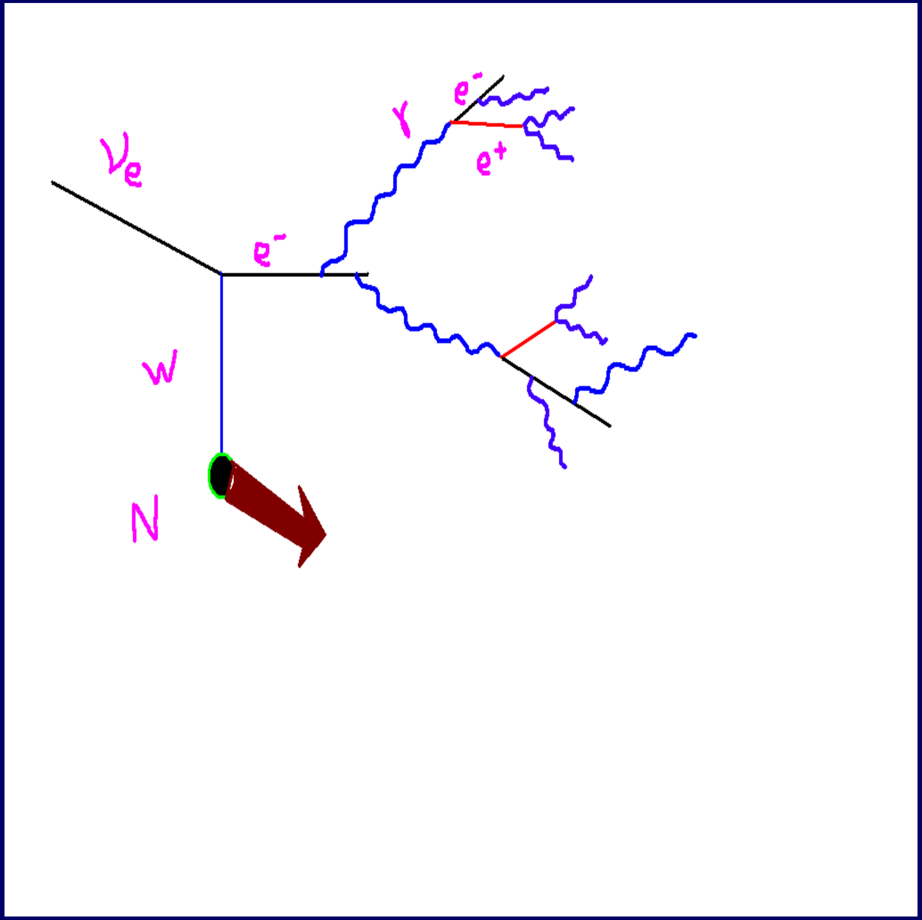
- Probe of Ultra High Energy Neutrinos(>$10^{14}$eV).
- Photons, protons other heavy cosmic rays scatter off CMB photons (GZK effect).
- Neutrinos point back to sources.
- Study of sources (Active Galactic Nuclei-AGN,  monopole decay, other topological defects, non-Standard Model Physics, (black holes?))
- Test of Standard Model at Ultra High Energies
- Neutrino Tomography of the earth
- Scientific overlap with other experiments(SPASE, AMANDA)

# Location of RICE Experiment

# Idea of Radio Detection

(Rice and PeVs)

- $\nu_e$+N -> e$^-$ + X
- High Energy e- initiates electromagnetic cascade in ice(bremsstrahlung and pair production at high energies, Compton, Bhabha, Moller, photoelectric effect…)
- Charge imbalance develops
- Net negative charge moving faster than c in ice=Cerenkov radiation

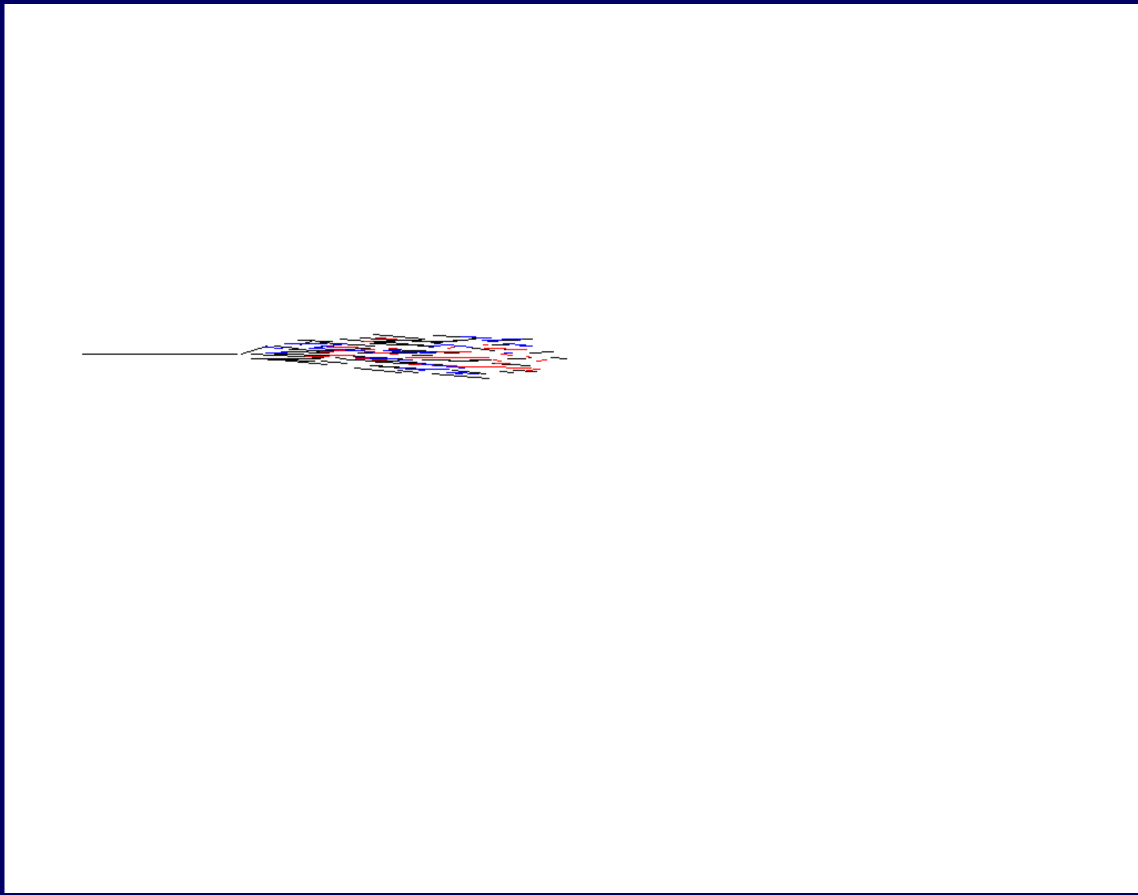


# Tuning in and Turning On

Where should we look for the Cerenkov radiation?

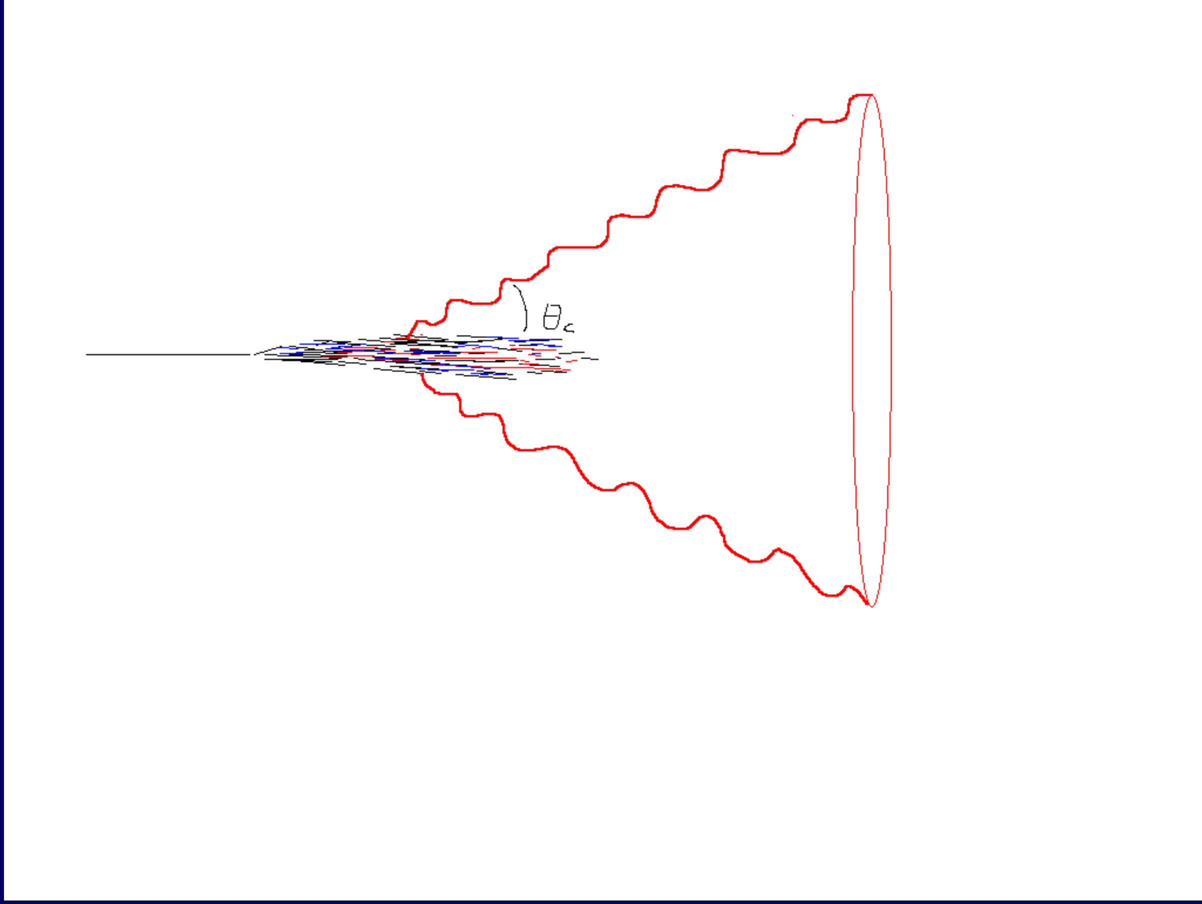
# Radio Emission From EM-Showers: I

- For PeV showers there are over 10 000 particles at shower maximum.
- $N_{max} \sim E_0$



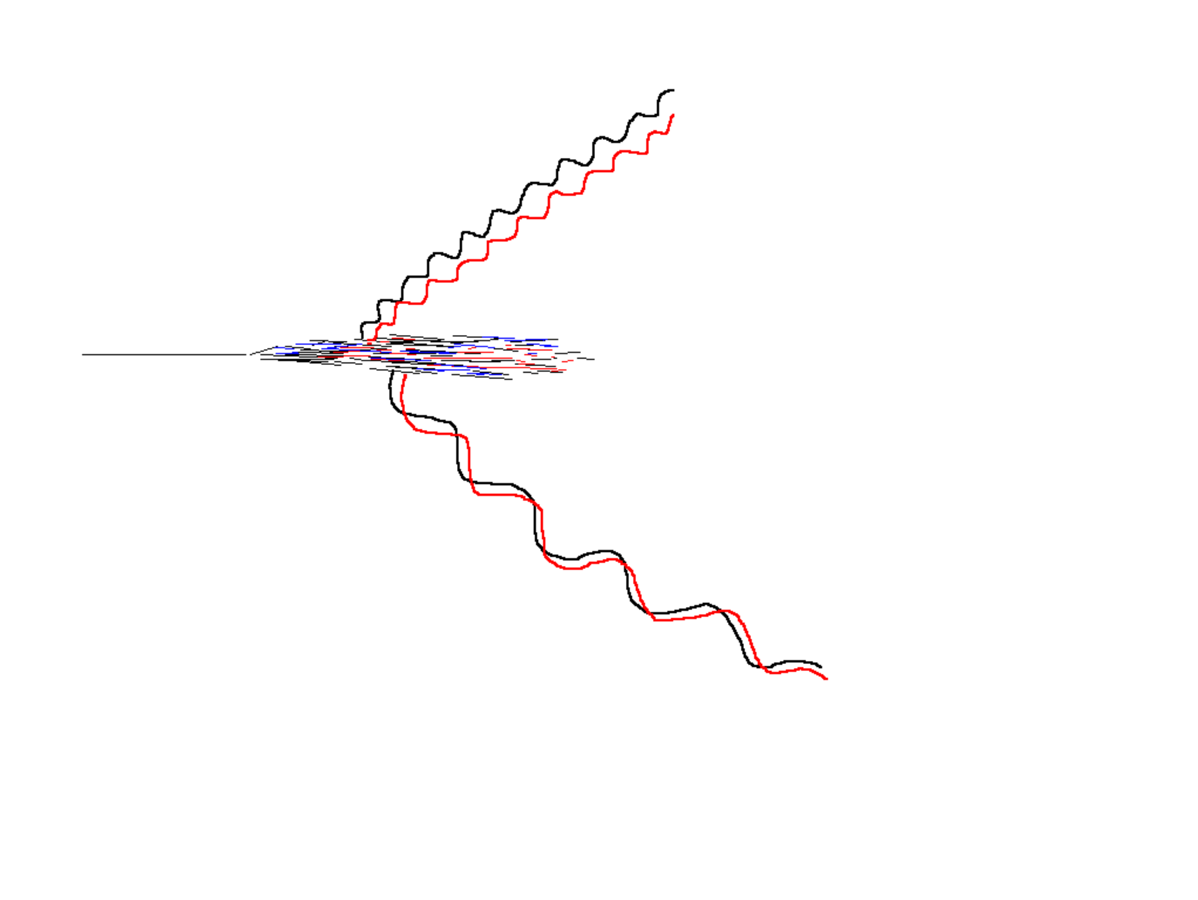
# Radio Emission From EM-Showers: II

- The net negative charge travels faster than c in ice and therefore Cerenkov radiates



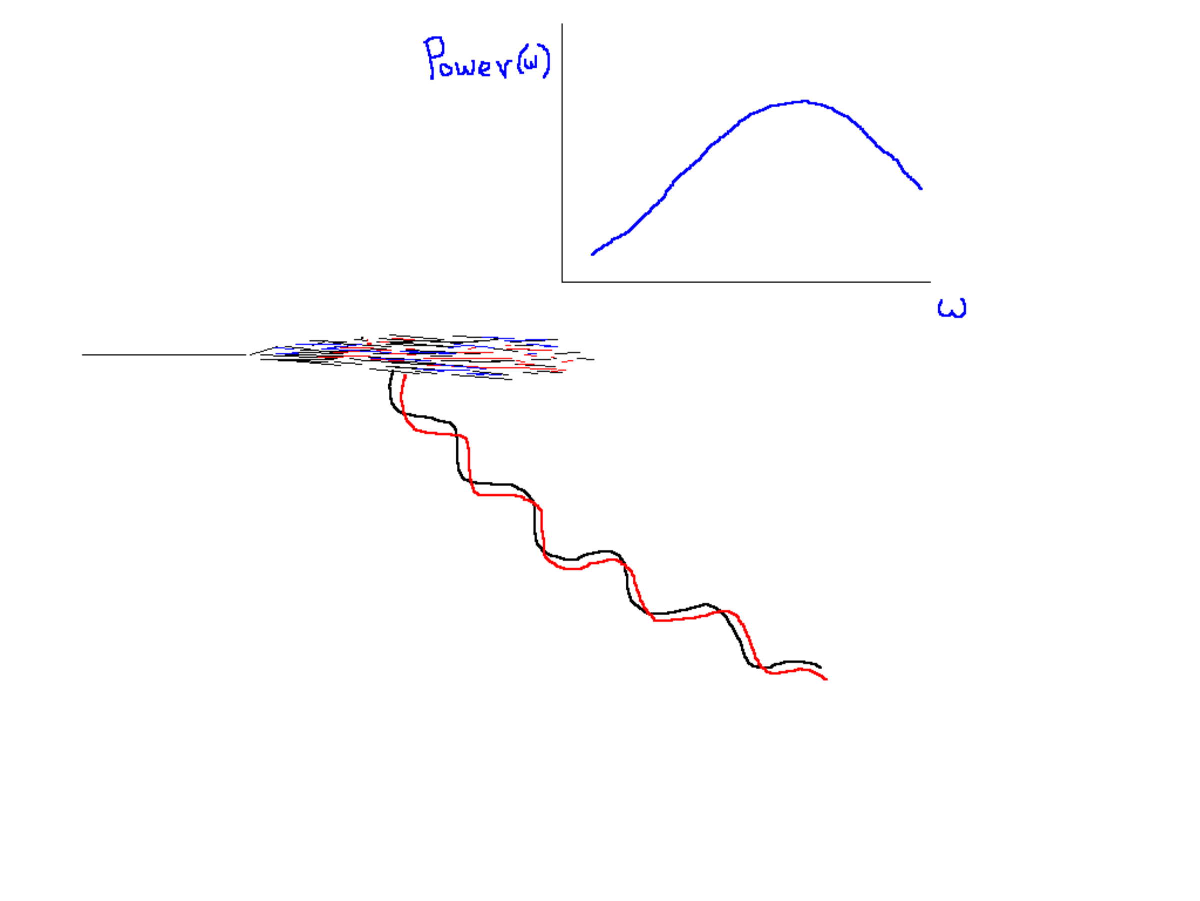
# Radio Emission From EM-Showers: III

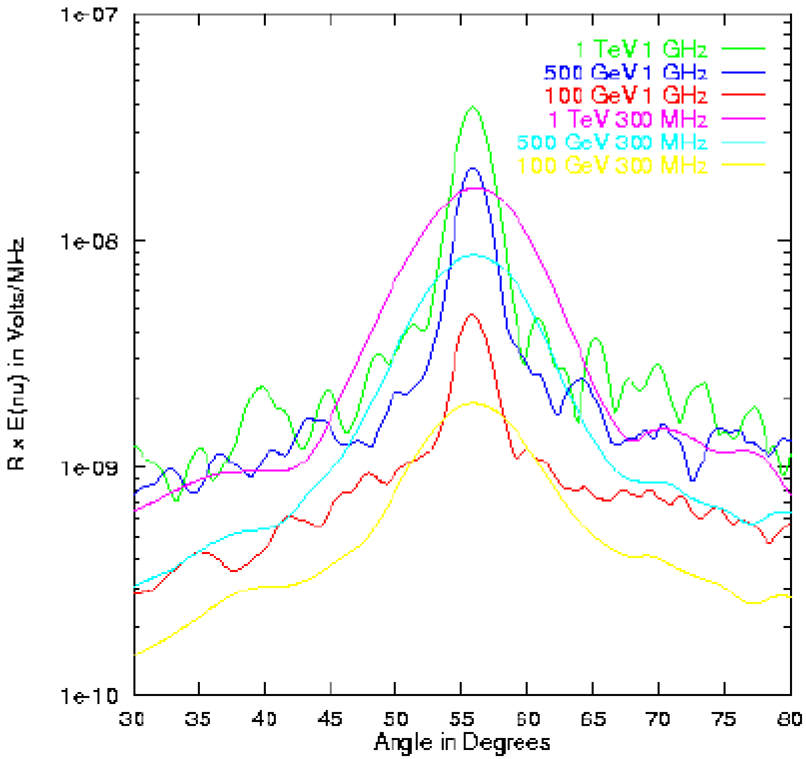
- Each charged particle emits broadband radiation. Shorter wavelength radiation interferes destructively



# Radio Emission From EM-Showers: IV

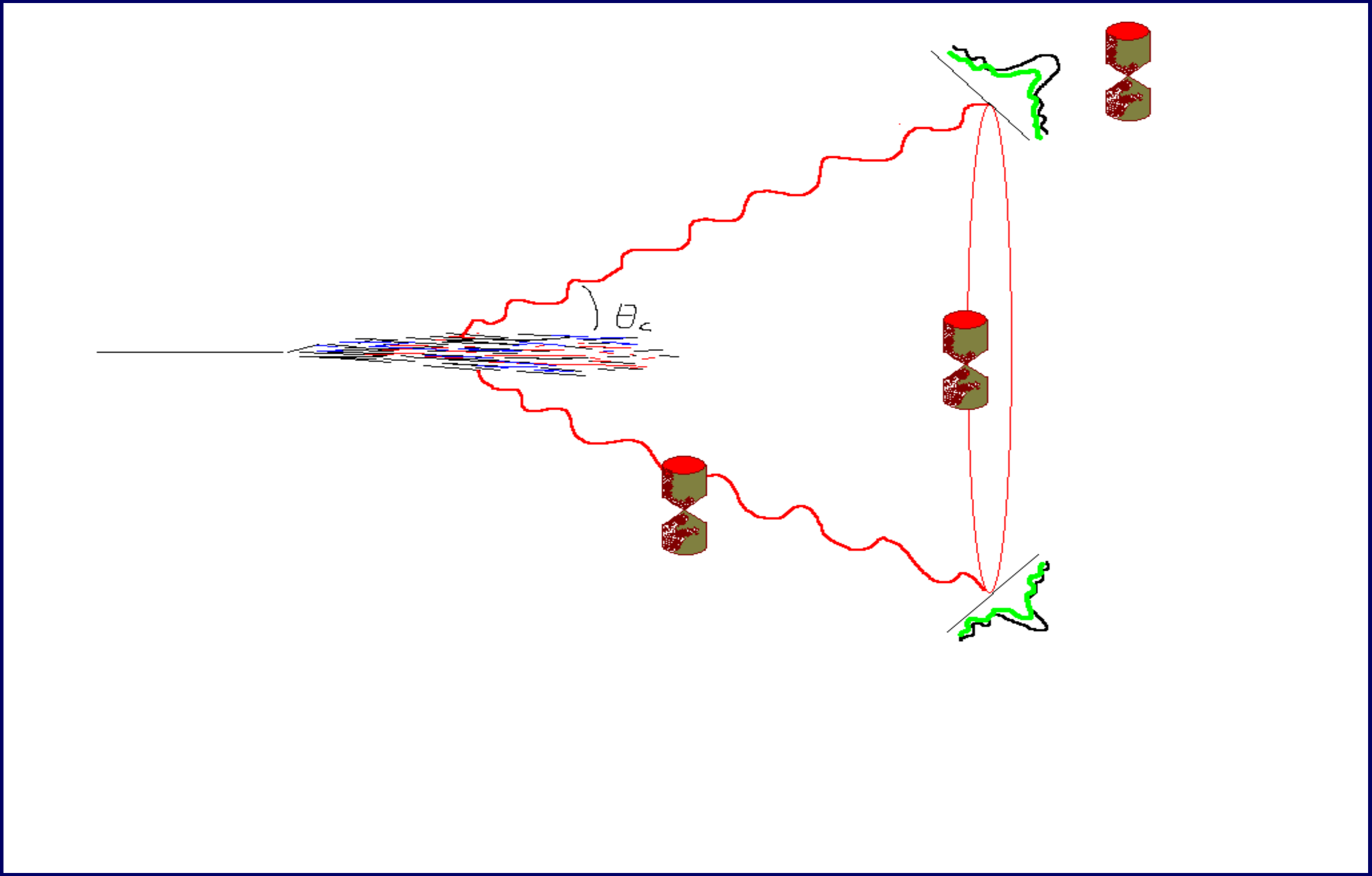
- The power spectrum turns over at both ends because of the physical dimensions of the shower





1 TeV 1 GHz
500 GeV 1 GHz
100 GeV 1 GHz
1 TeV 300 MHz
500 GeV 300 MHz
100 GeV 300 MHz
1e-07
1e-08
1e-09
1e-10
R x E(nu) in Volts/MHz
30
35
40
45
50
55
60
65
70
75
80
Angle in Degrees

# What the previous plot means



# Coherent Emission: Recent Observervation

- Recent experiment by Gohram and Salzburg using photon bunches dumped into a pile of sand at SLAC confirmed for the first time the Askaryan effect.
- They measured the radio signal and the negative excess charges.

# Brief History of RICE

- The RICE experiment got off the ground (and into the ice) in 1995 when the AMANDA collaboration generously agreed to co-deploy shallow radio receivers in the first holed drilled for AMANDA-B
- Surface transmitter was used to verify the antennas could detect with better than 10ns timing precision
- In 96-97 first two dedicated antennas were deployed along with an under ice transmitter.
- ANANDA PMTs could be “heard” 2km below giving preliminary indication of radio transparency of ice
- The next year there was further co-deployment with AMANDA.
- In 98-99 first RICE holes(5” mechanically drilled)

# RICE Facts:I

- Currently there are 18 dipoles + amplifiers in ice, 3 surface horns, 1 ‘line’ antenna (WWII surplus)
- 16 dipoles feed directly into scopes so we can capture waveforms as well as timing information
- Each receiver(aka channel) has a 36dB amp in ice and a 52dB amp on the surface

# RICE Facts:II

- Signals are fed to surface through coaxial cable(we're looking into fiber optics)
- Current RICE antennas are tuned to 200-300MHz (recent calibration studies show we have a ~200MHz band width)
- Attenuation length: $\lambda_{radio}$~ 1km so a single antenna can probe a large effective volume

# More Good Stuff:

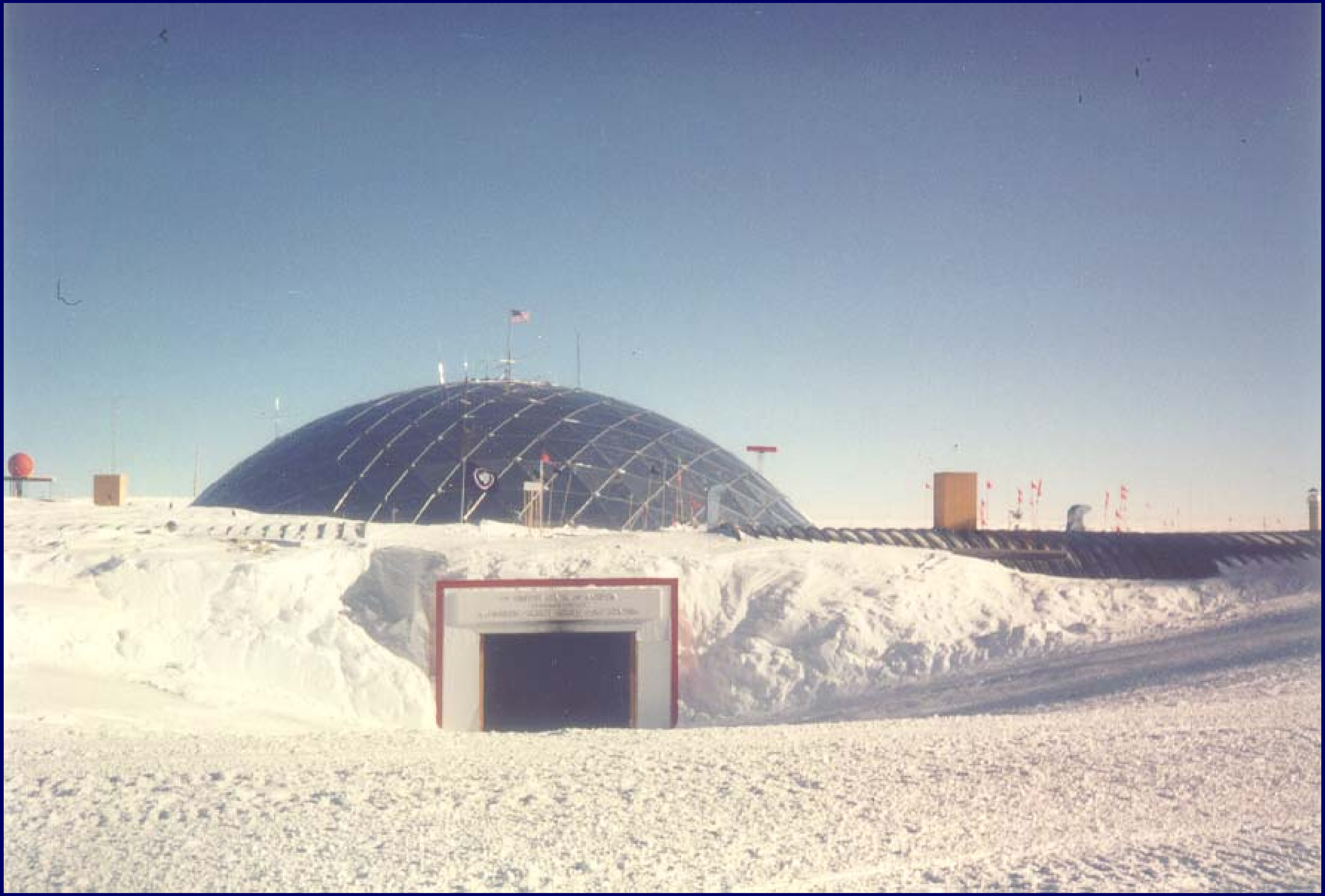
- RICE Data Acquisition System(DAQ) is housed in the MAPO lab which also is the home of AMANDA and SPASE electronics.
- PC running Lab View for trigger settings
  (we can run this software over the satellite up-link)

# Flight to Mc Murdo Station

# Ice runway on Ross Ice Shelf

# There really is a Pole.

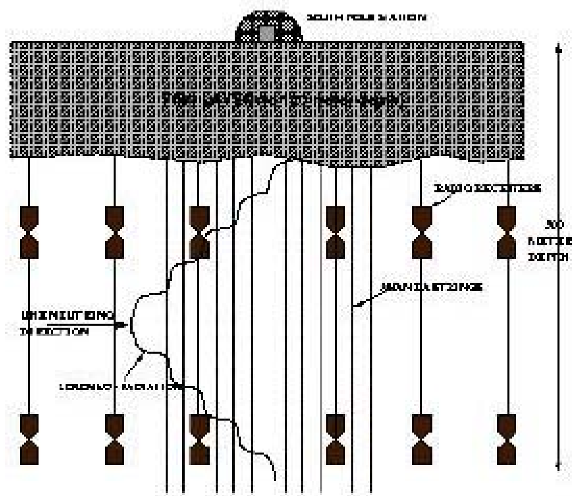
# Dome



# Summer Camp

# MAPO Lab (photo by AMANDA personnel)

# Basic RICE concept/schematic:



# Simulated Rice Event.
# The detector geometry is drawn to scale

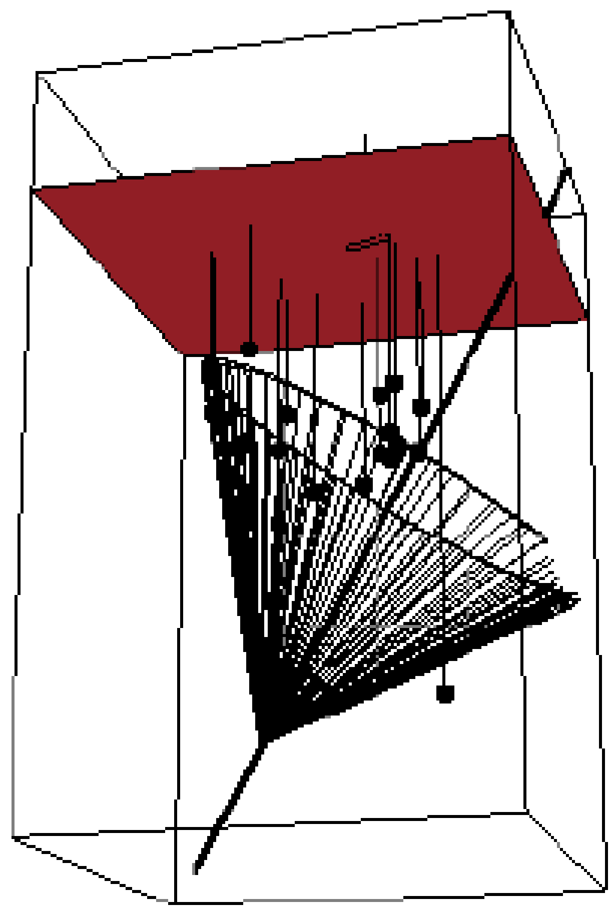
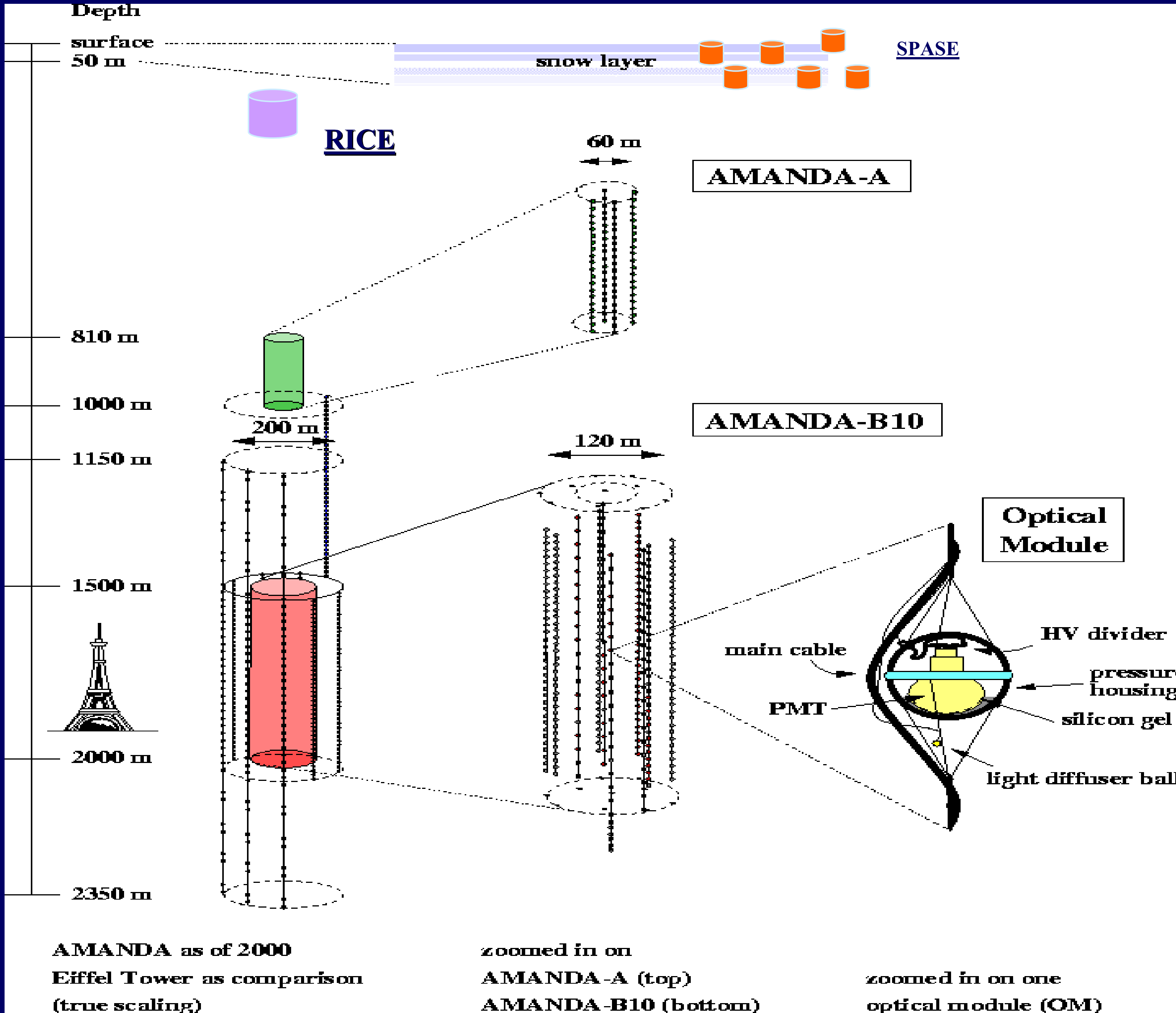


FIG. 1. Simulated RICE event. The actual detector geometry is shown, to scale.

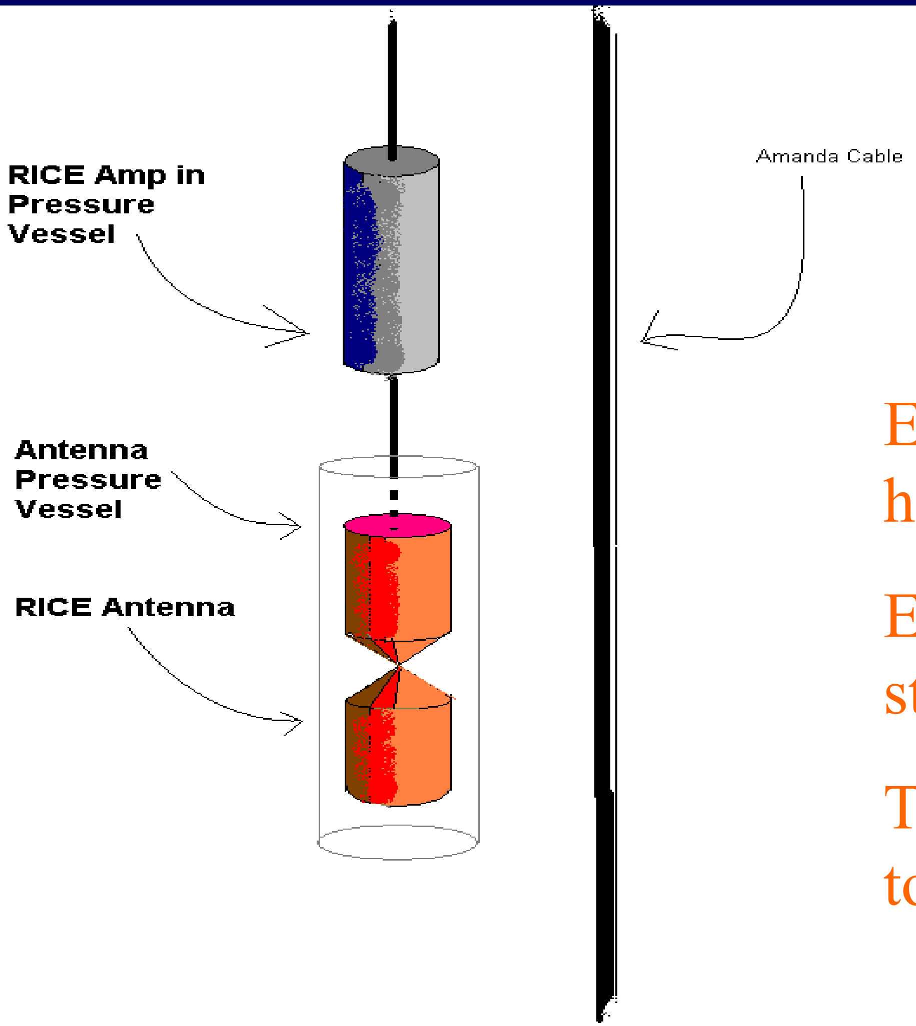
# AMDANDA and SPASE

- Antarctic Muon and Neutrino Detector Array(AMANDA):Detects optical Cerenkov radiation from $\mu$'s which pass through their array
- South Pole Air Shower Array(SPASE):Surface deployed air shower detector.

# RICE-AMANDA-SPASE



# RICE Antenna and Amplifier



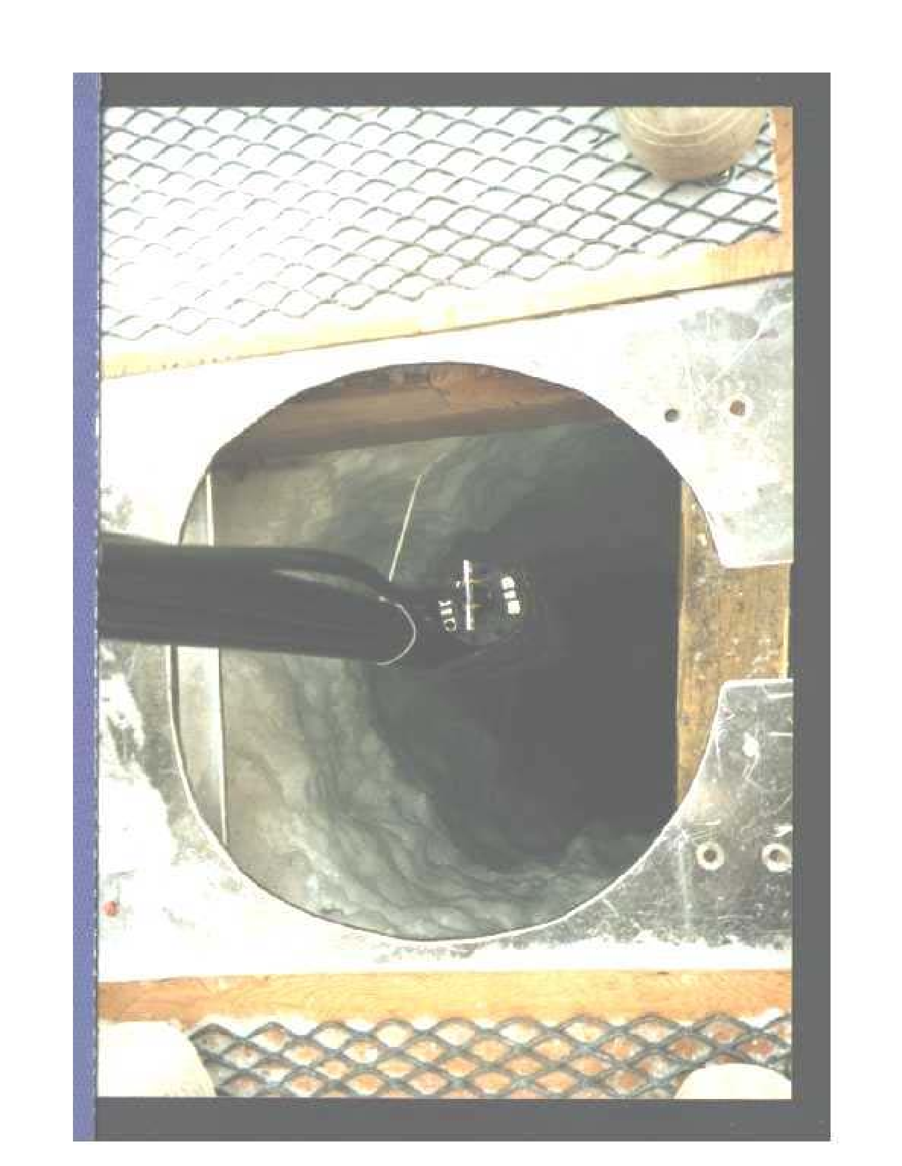

Each Antenna is housed in hard plastic pressure vessel.

Each in ice Amplifier is in a steel pressure vessel.

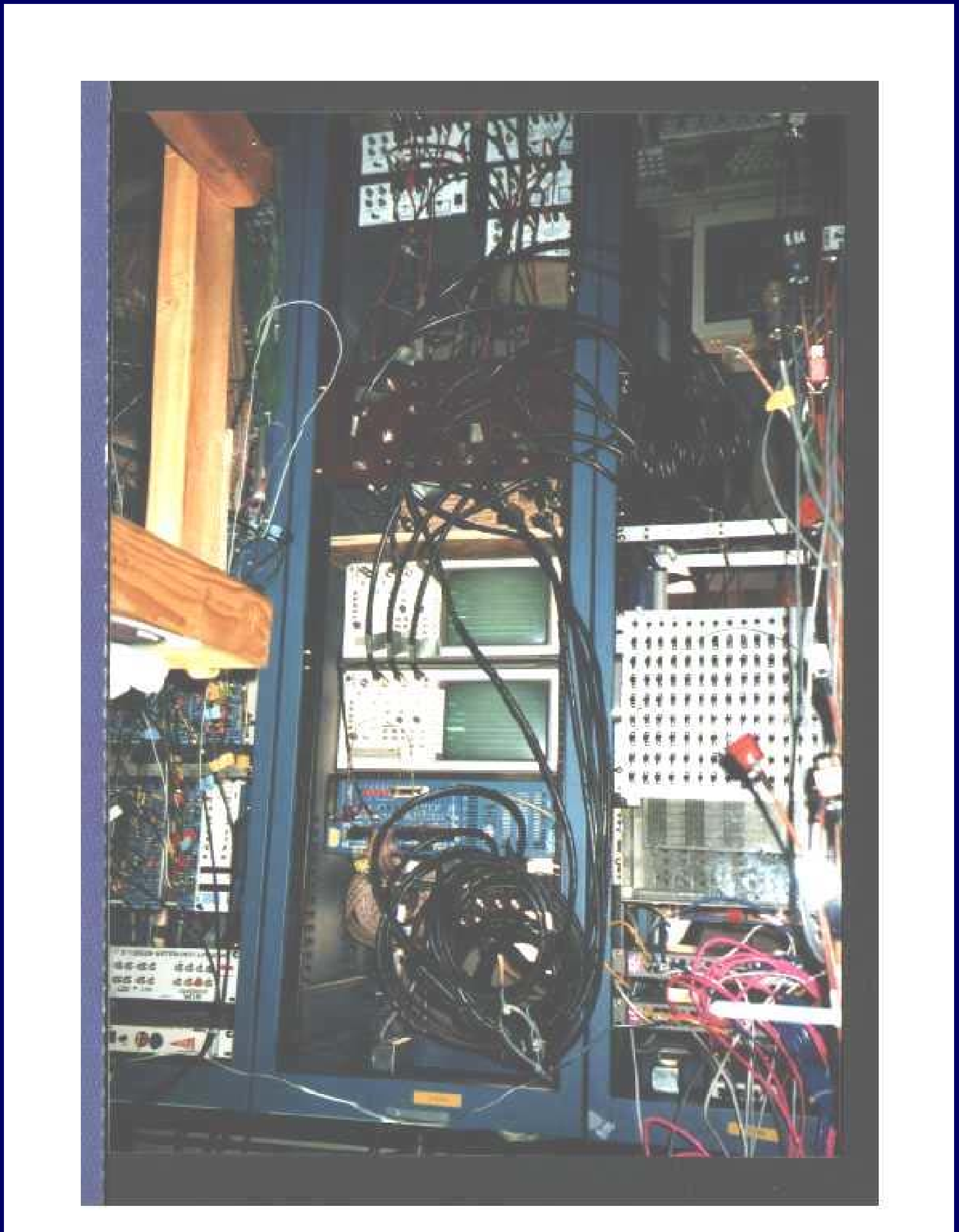
The whole thing is duct-taped to AMANDA cables.

# Antenna fastened to AMANDA cable

# Top of amplifier pressure vessel as it descends into hole



# RICE DAQ in Mapo Lab



# Locations of RICE modules relative to AMANDA hole #4

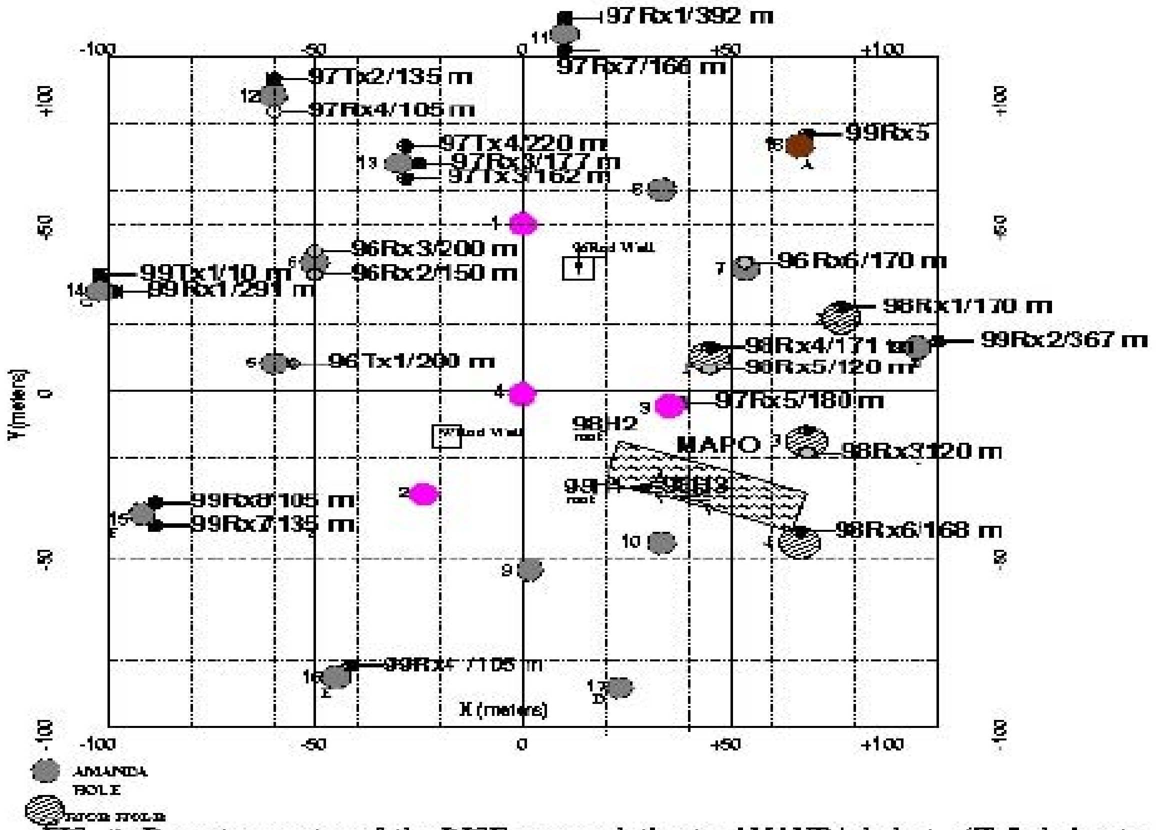


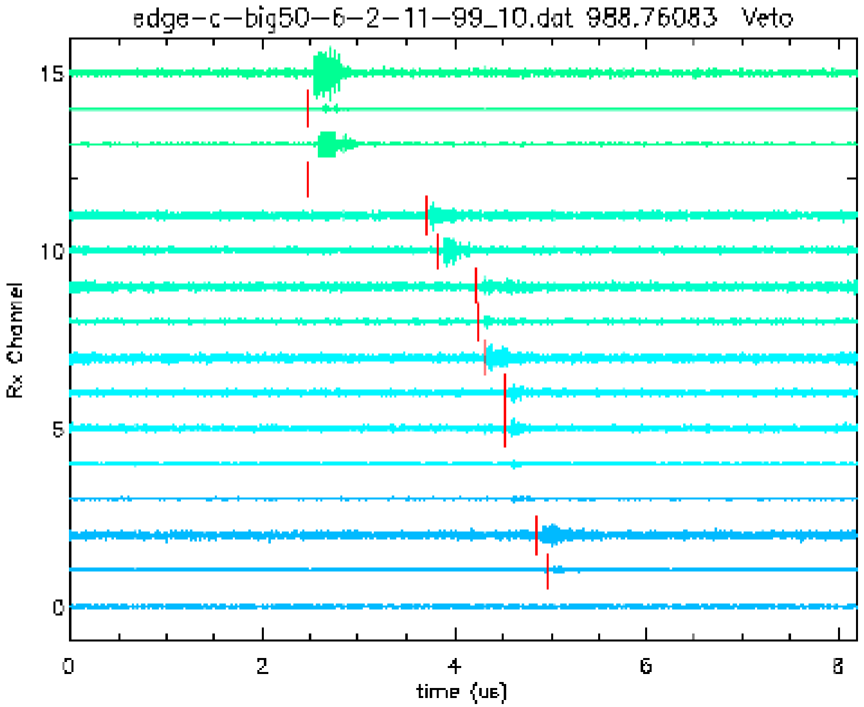

FIG. 3. Present geometry of the RICE array, relative to AMANDA hole 4. "Tx" designate transmitters; "Rx" designate receivers. Depths of receivers, as well as relative cable diameter (indicated by the thickness of horizontal lines before the antenna identifier), is also indicated.

# Triggers

- 4 RICE hits within 1.2 μs
  - 4 hits for reconstruction
  - 1.2 because of size of array
- AMANDA +1 RICE hit
- SPASE + 1 RICE hit
- Veto Surface noise
- Veto if 303MHz is on

# Typical Event (Surface-generated bkgnd.)

Scope traces ordered 0→15: furthest→closest to MAPO



# FFT of Channel 7: 98Rx2

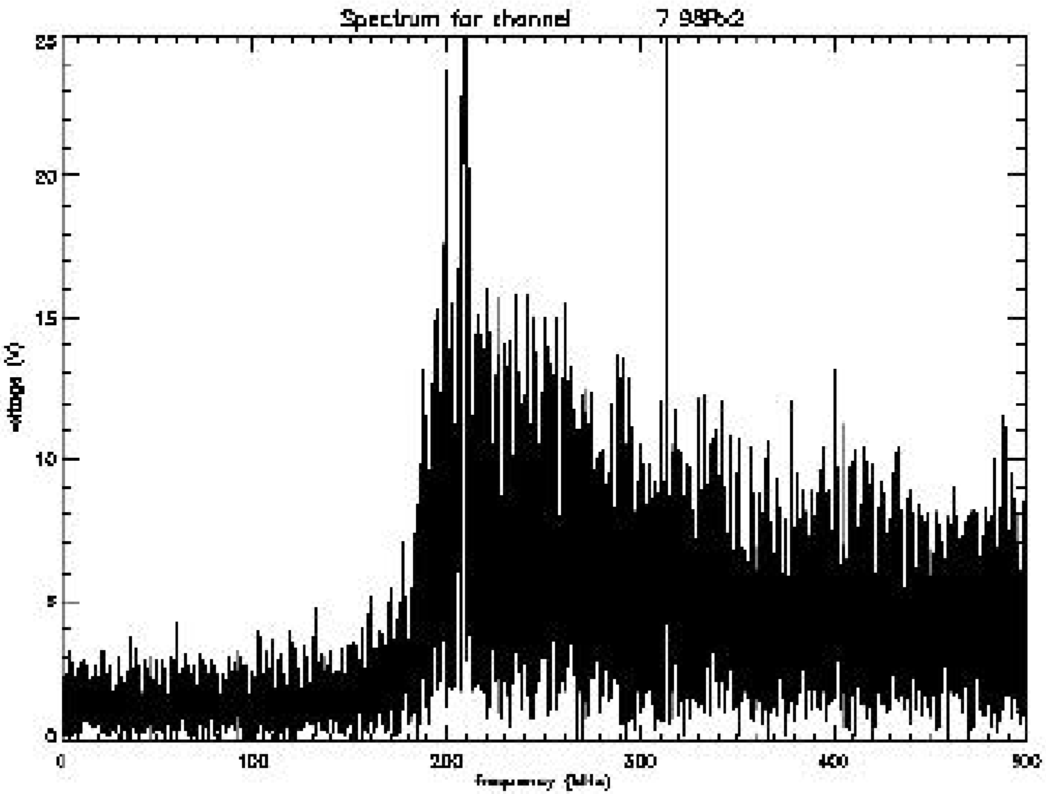
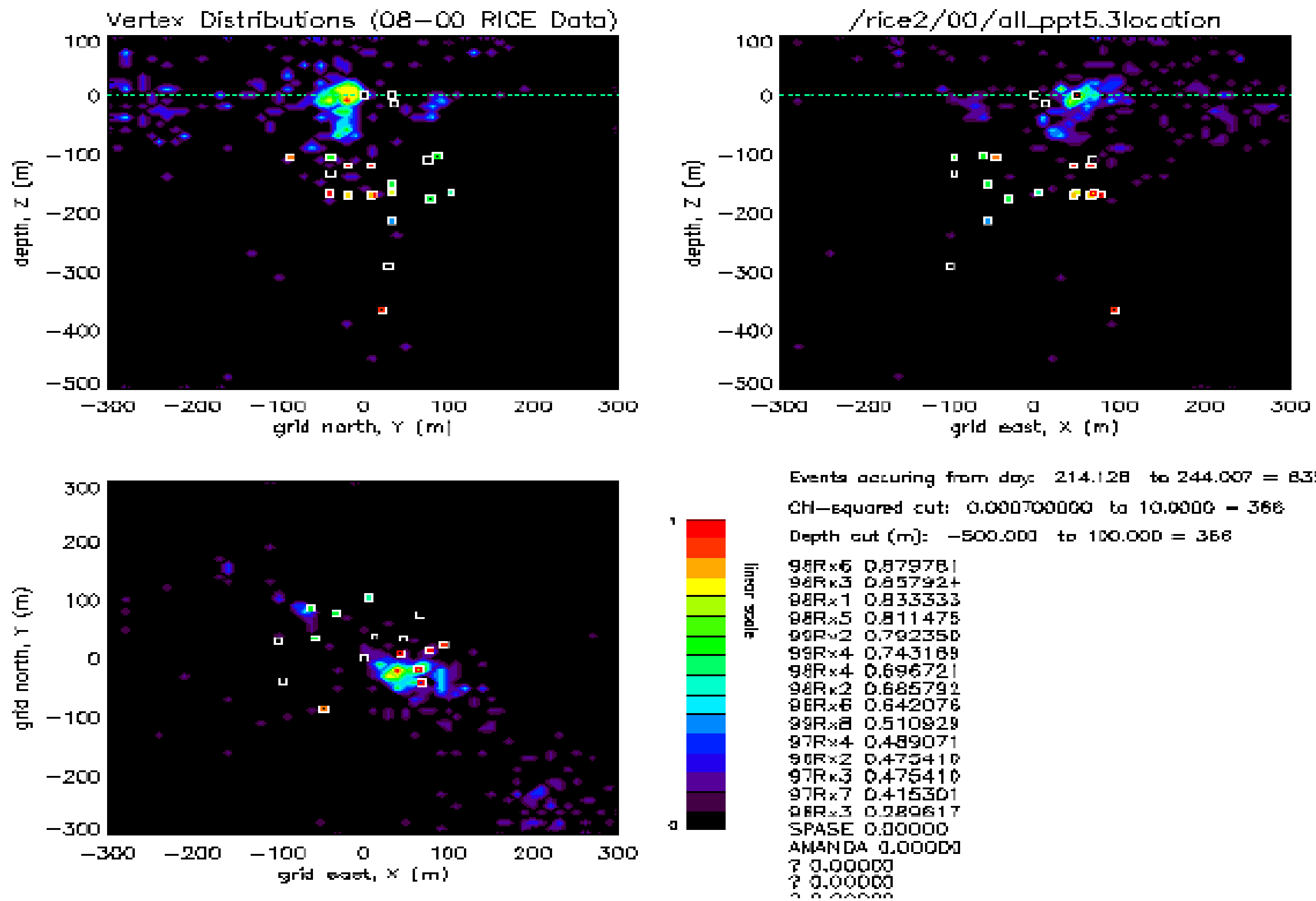



FIG. 6. Fourier transform of raw data waveform corresponding to channel 7 of the previous Figure. The South Pole station satellite uplink at 303 MHz is evident in the Figure. A high pass filter suppresses signals below ~180 MHz. Other features of this distribution are discussed in the text. No corrections for cable loss, signal amplification, etc. have been made. (The vertical scale is arbitrary.)

# Data Analysis: I

- So far we are using only timing information obtained from waveforms to reconstruct event vertex
- Fold in relative timing, $\Delta t$, of hits and refractive index of ice
- First look at using TDC times to reconstruct looks good


Vertex Distributions (08-00 RICE Data)
/rice2/00/all_ppt5.3location
depth, Z (m)
grid north, Y (m)
grid east, X (m)
linar scale
1
0
Events occuring from day: 214.128 to 244.007 = 835
CHI-squared cut: 0.000700000 to 10.0000 = 366
Depth cut (m): -500.000 to 100.000 = 366
98Rx6 0.879781
98Rx3 0.857924
98Rx1 0.833333
98Rx5 0.811475
99Rx2 0.792350
99Rx4 0.743169
98Rx4 0.696721
98Rx2 0.685792
96Rx6 0.642076
99Rx8 0.510929
97Rx4 0.489071
98Rx2 0.475410
97Rx3 0.475410
97Rx7 0.415301
98Rx3 0.289617
SPASE 0.00000
AMANDA 0.00000
? 0.00000
? 0.00000

# Data Analysis:II

- We also have amplitude information from waveforms.
- Using these require knowledge of
  - Electric fields due to showers(Monte Carlo studies)
  - Antenna properties(gains, effective height..).
  - Attenuation length of radio in ice.

# Calibration Studies

- Using under ice transmitters to broadcast to the array we a timing resolution of 1.5-2ns
- Monte Carlo studies show, for example, that the angular resolution of the current array is 10 degrees at 10PeV(for events scattered within 1km of array)

# More on Calibration

- Depth resolution study

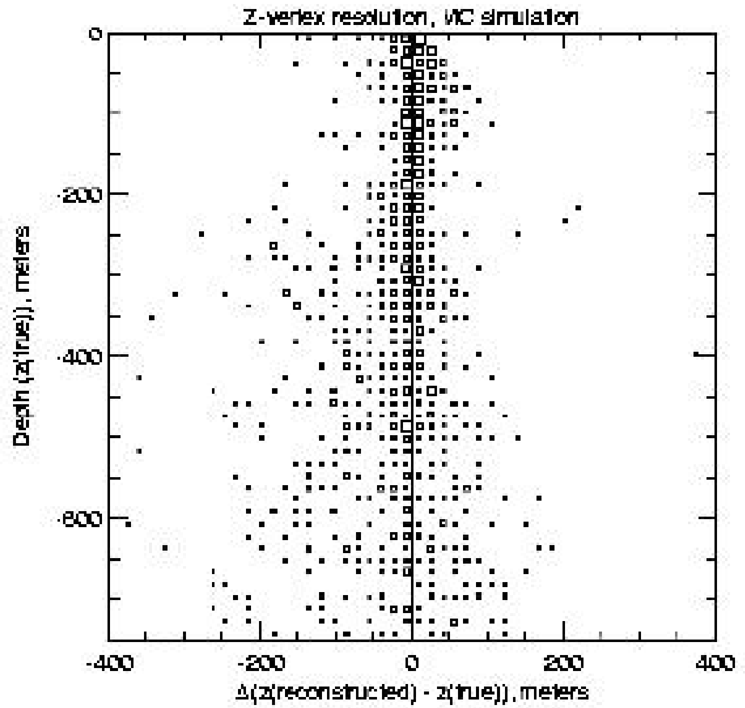



FIG. 17. Deviation between reconstructed and true interaction depth (z1hit), vs. true inter-
ion depth, from Monte Carlo simulations. The reconstructed vertex here was obtained using

# Ice properties study

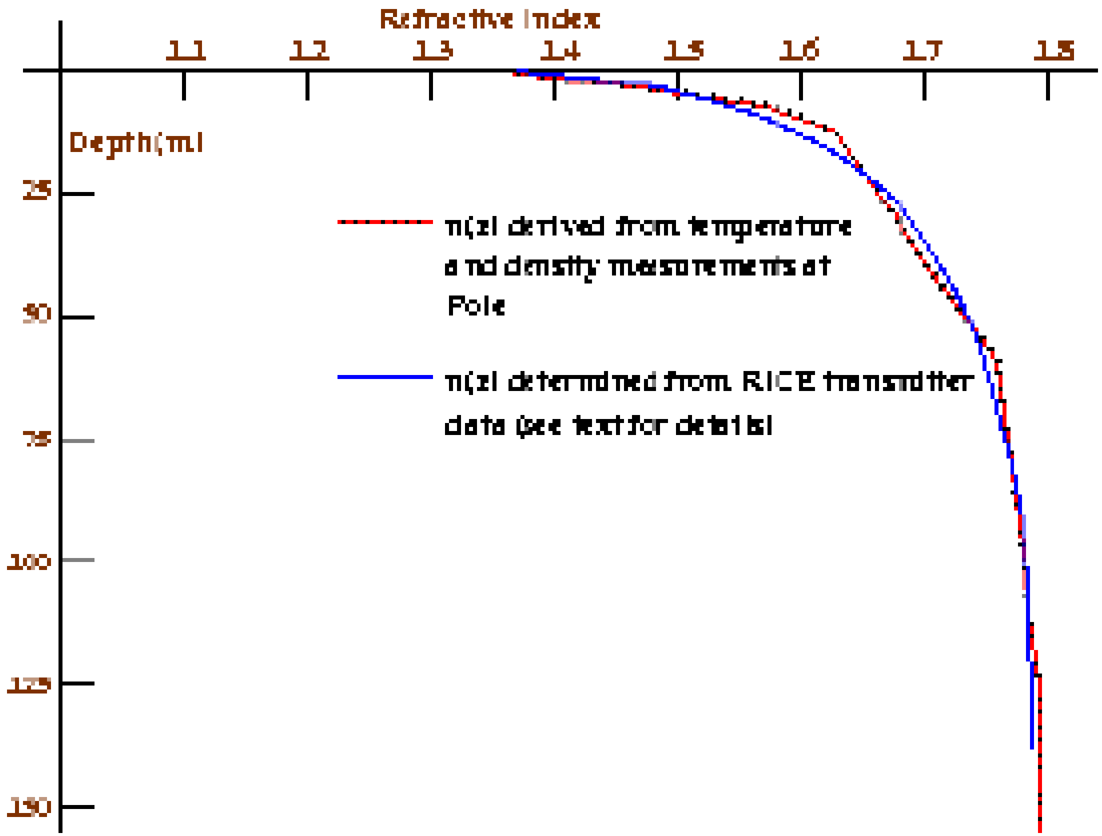


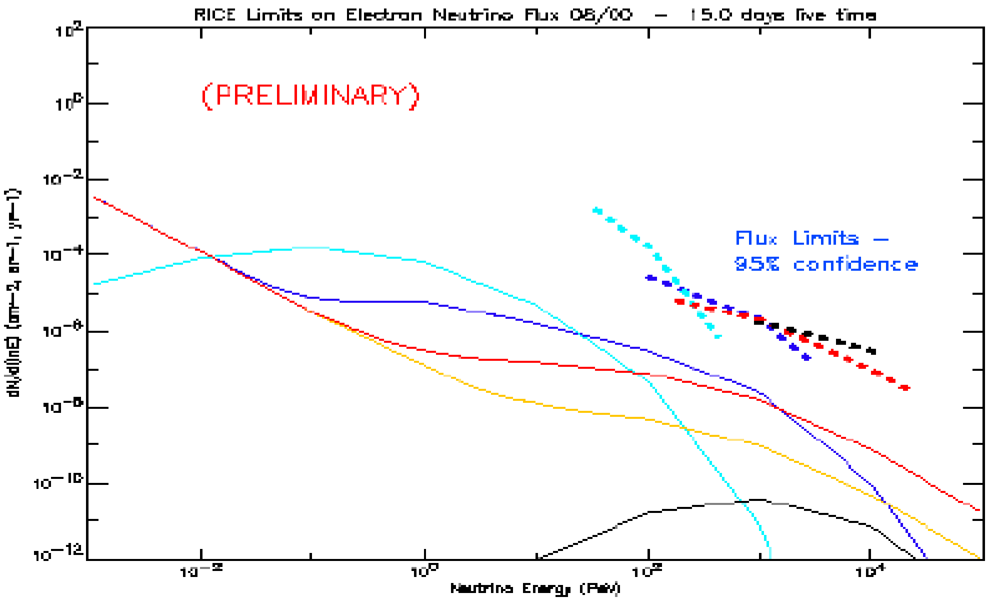

FIG. 11. Index of refraction as a function of depth.

# Flux Upper Limit

- Different models of sources of UHE $\nu$ are based on AGNs, GZK n’s and Atmospheric $\nu$’s.
- We know what if the effective volume of ice probed by the RICE array.
- Take a data set, look for clear $\nu$ signal.
- August 2000 data has two events that pass all cuts and filters and visual inspection by ‘trained physicists’.

# Lets Be Conservative

- Suppose detailed study using amplitude information etc. throws out these two events….
- Question: How large can the flux for each source model be so that we see no events 90% of the time?




Light Blue – Stecker, Dark Blue – Protheroe, Red – Mannheim B, Gold – Mannheim A, Black – Yoshida & Teshima GZK

# Work in Progress I

- Continue data analysis using more data(George @FSU and locally)
- Reconstruct directions(so far we have only reconstructed vertices)
- Use amplitude information:
  - Monte Carlo Shower(at KU and locally)
  - Antenna response(Antenna Testing Range @KU)
  - Ice transparency(data taken at Pole 00-01)

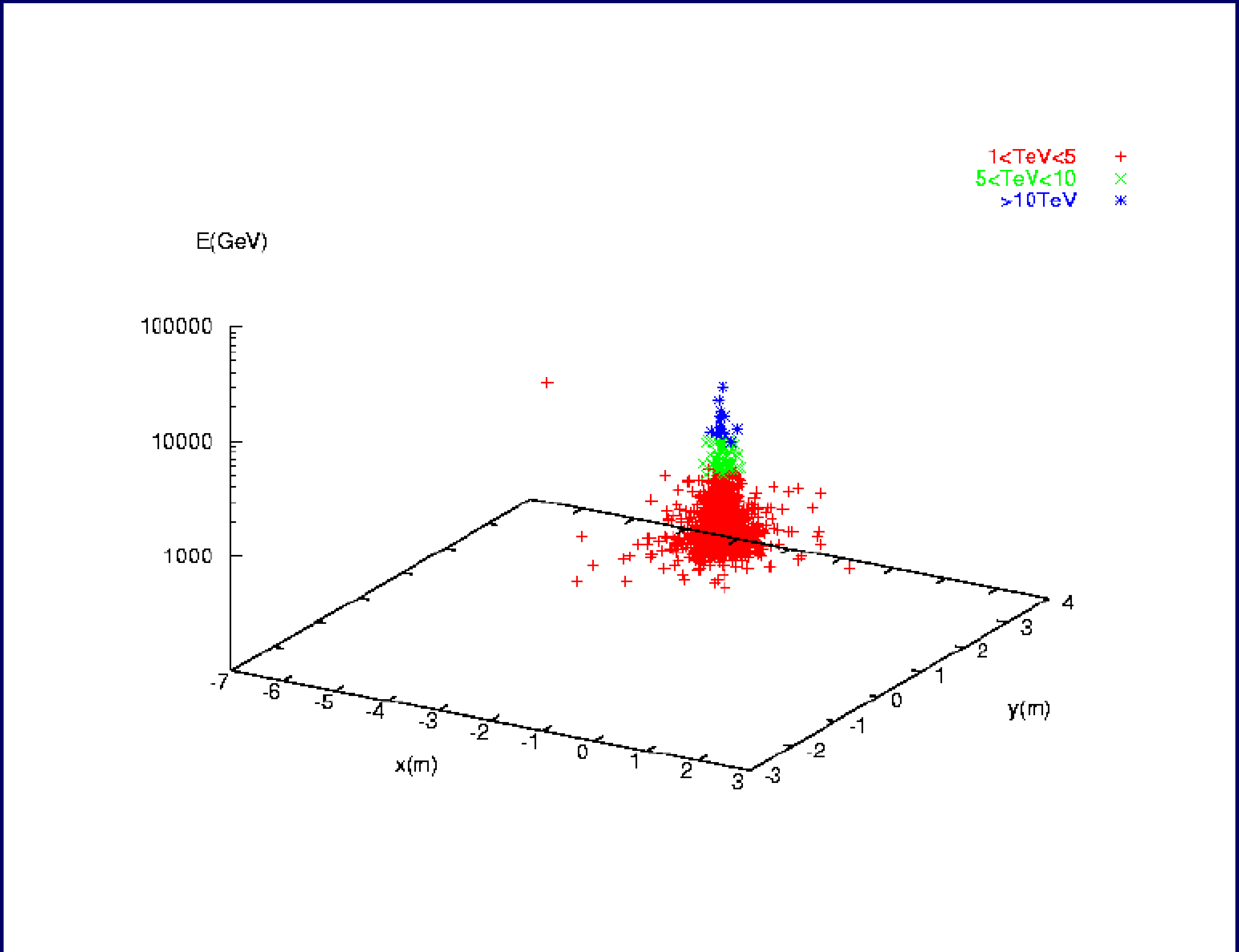
# Work in Progress II

- Study RICE/AMANDA/SPASE overlap physics (here at Canterbury)
  - Radio signals from electromagnetic component of air showers that stop in the ice

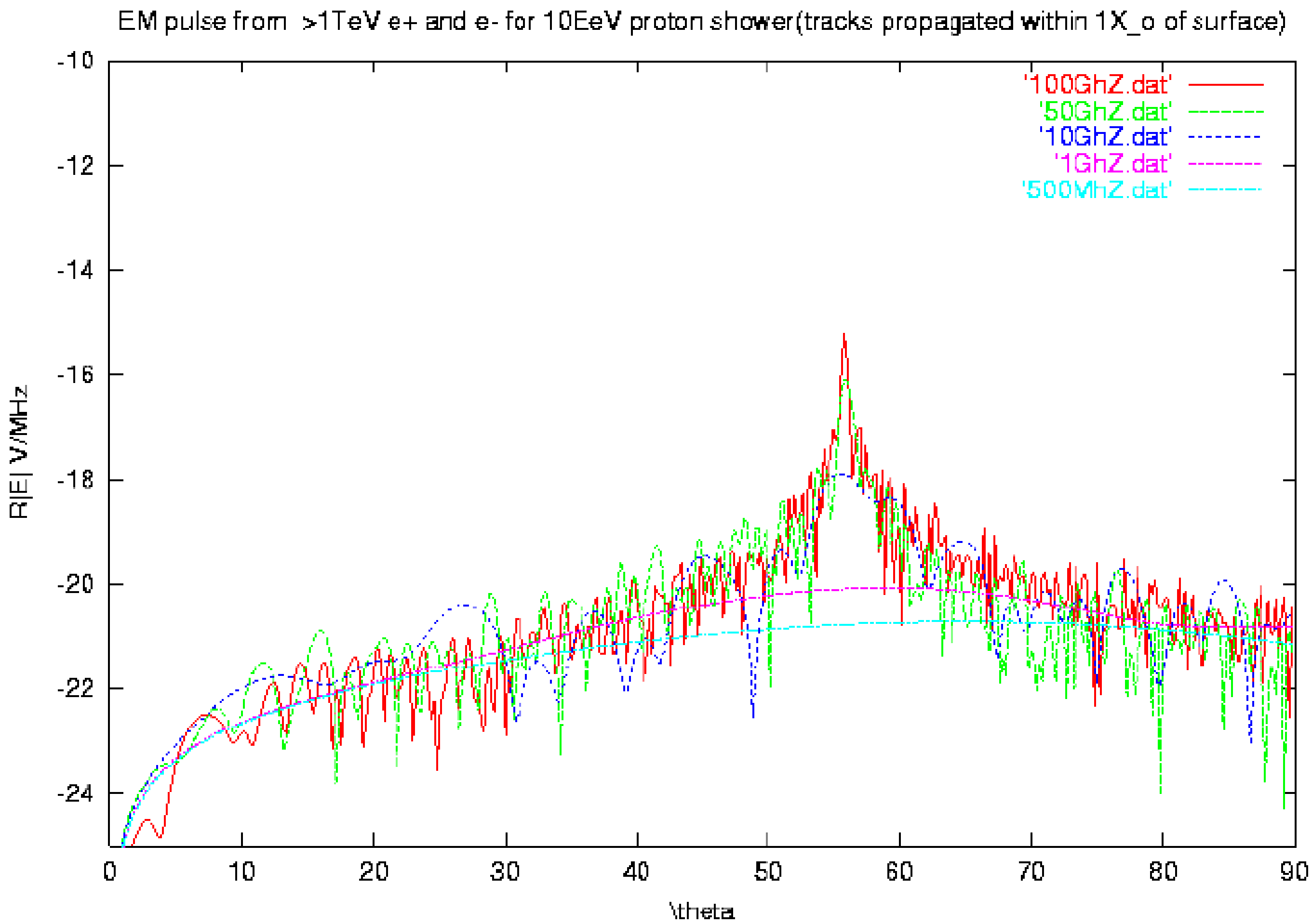
# Open Questions

- Can there be a sizeable radio signal from the electromagnetic component of air showers that stop in the ice?
- Is the EM component of the core compact enough to get a coherent signal?
- Radio signals from showers started just below the surface?
- Coherent radio signals from $\mu$ bundles?

# Locations of >1TeV particles from 1EeV proton shower above South Pole



# EM pulse from >1TeV particles propagated to ~1$X_o$ below surface



# Work in Progress III

- The Event Generator Monte Carlo is being updated. A more detailed model of the earth is included and  the code is written to run faster

# Work in Progress IV

- Filters (Galaxy, 303MHz)
- Study hadronic component of showers(small radio signal but maybe enough so that we can detect)
- This year we do reconstruction at the pole and send back only ‘good’ events

# Community Activities

- Radio methods in HEP cosmic rays was acknowledged  in Summer 2000 with the first ever conference dedicated to radio detection of cosmic rays RADHEP

# Conclusion

- Basic Calibration studies have been done, sufficient we feel to make credible flux upper limit. However a lot of data still have to be analyzed.........