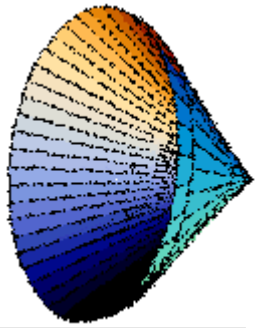
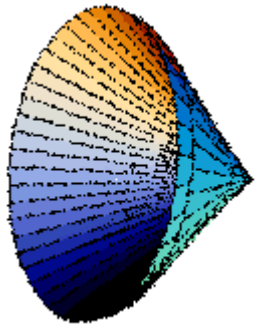


Neutrino Astrophyics at the South Pole.

S. Seunarine for the RICE Collaboration

RICE Objectives



- Primary goal: Detect UHE neutrinos ν's, En > 10^{15} eV.
- ν's probe large distances and point back to sources.
- AGN's, GRB's, Monopole decays, TD, BH, …
- Tomography of Earth.
- New physics: gravity, …

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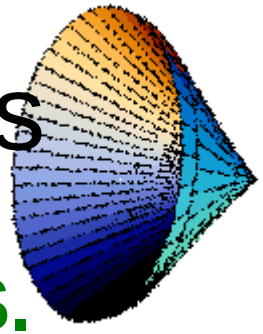
The Collaboration Members



I. Kravchenko[1], D. Seckel[2], J. Adams, S. Chruchwell[3], P. Harris[3] , S. Seunarine[3] ,P.Walrich[3], A. Bean[4], D. Besson[4], K. Byleen-Higley[4], S.Chambers[4], J. Drees[4], S. Graham[4], J. Laing[4], D. McKay[4], J. Meyers[4], L. Perry[4], J. Ralston[4], J. Snow[4], S. Razzaque[5],

1. M.I.T. Lab. for Nuclear Science, Cambridge, MA.
2. Bartol Research Institute, U. of Delaware, Newark DE.
3. U. of Canterbury, Christchurch, New Zealand.
4. University of Kansas, Lawrence, KS.
5. Pennsylvania State University, PA.

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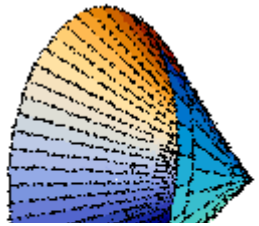
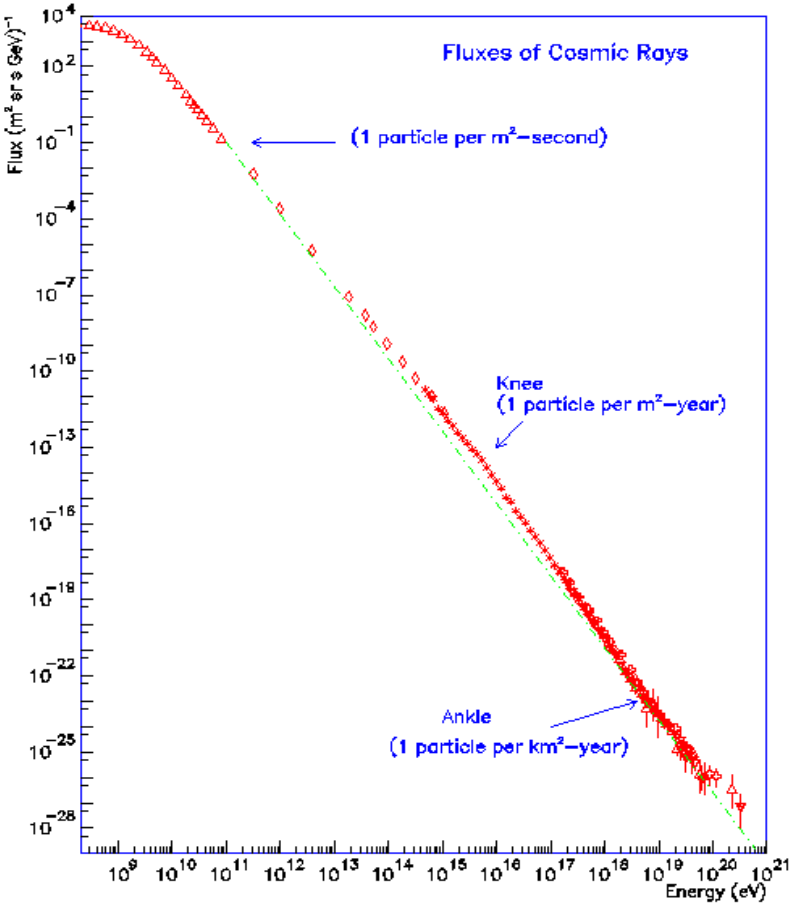
Review of Cosmic Rays

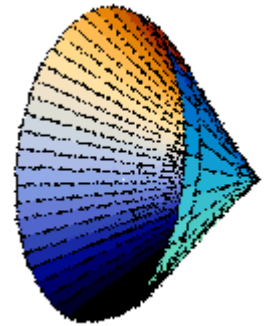


- Look at all particles incident on earth.
- Mostly protons.
- The slope is fairly constant to $3x10^{15}$eV where we have a “knee”
- Possible different accelaration mechanism.
- There is an “ankle” and a possible cut-off of the spectrum beyond $5x10^{19}$eV



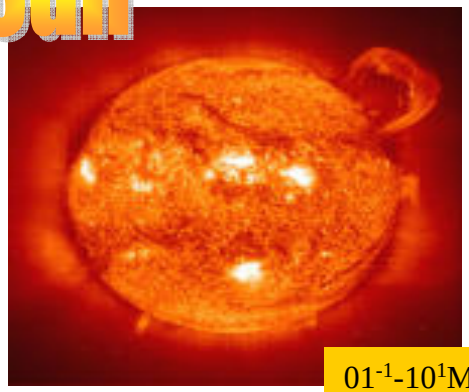
Suruj Seunarine, for the RICE Collaboration

Energy Scales

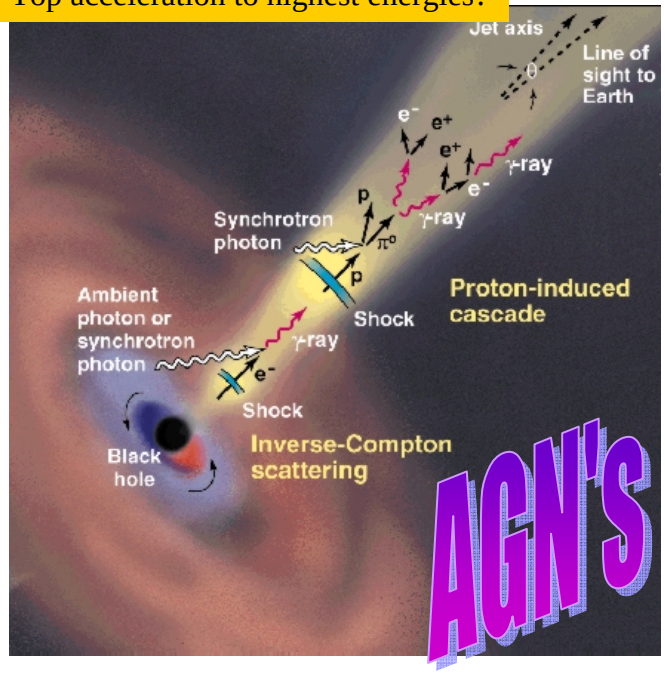


Bottom-Top acceleration to highest energies?

Sun



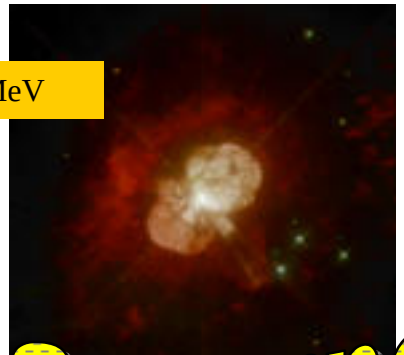
01^{-1}-10^{1}MeV



Big Bang!!

01^{-4}eV, ~300/cm^3

MeV



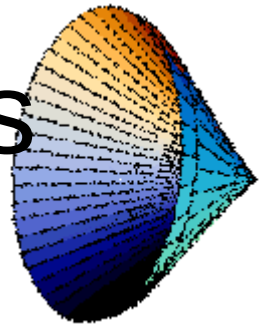
Supernova

Exotica

Top -Down

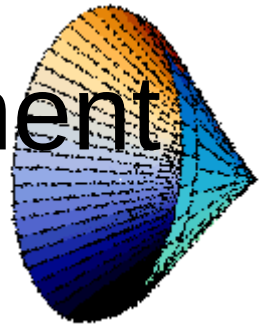
Suruj Seunarine, for the RICE Collaboration

Need Large Target Mass



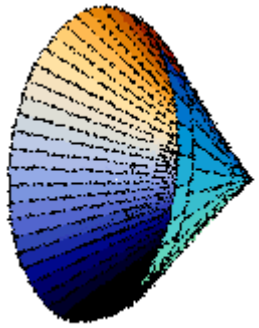
- Catch-22 for neutrinos:
- The interaction probability at low energies is low but the flux is high.
- At high energies the interaction probability increases but the flux falls off dramatically.
- To study high energy neutrinos we need a large target mass.
- Antarctic ice is the best natural target, both for radio and optical detection.

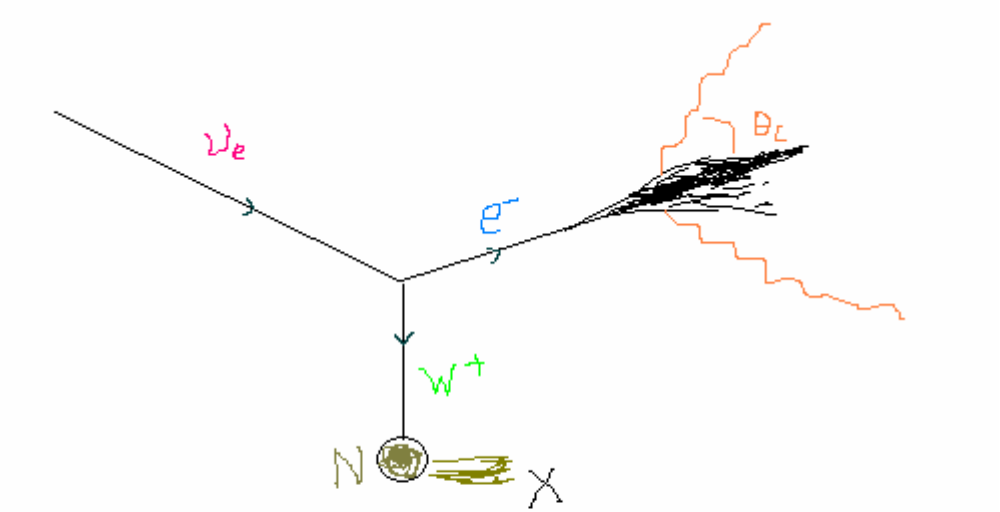
Concept of the RICE Experiment



- The RICE experiment is designed to detect compact electromagnetic cascades in Antarctic ice initiated by electrons coming from, $\nu_e + N \rightarrow e^- + X$.
- These cascades produce coherent Cerenkov radiation at radio wavelengths.

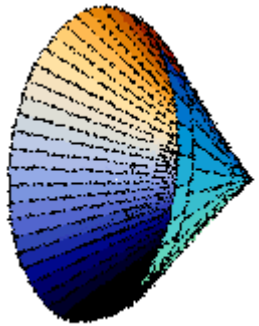
Basic Event



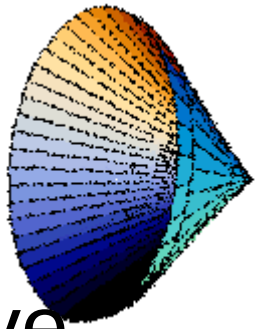


- θ_c ice ~ 56^0
- Eν ~ 80% Ee

Cascade Development

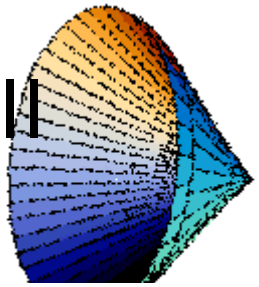


- The electron generates a cascade of particles.
- Bremsstrahlung and pair production dominate at high energies while dE/dx losses dominate a low energies.
- A net negative **charge excess** develops as atomic electrons are knocked forward with the shower and positrons annihilate.

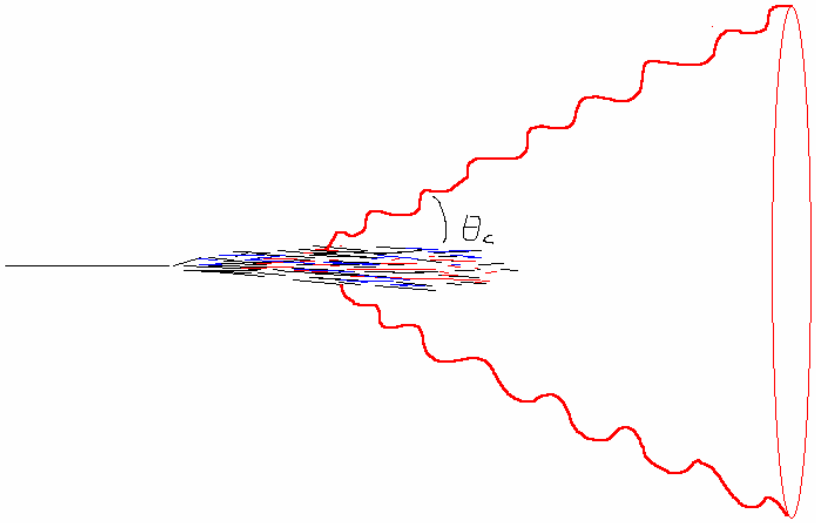


- Even at modest energies, the negative cahage excess moves faster than the velocity of light in the ice, $c_n=c/n$: n=refractive index of ice.
- Charge excess emits **Cerenkov** radiation.
- Radiation is coherent at radio wavelengths

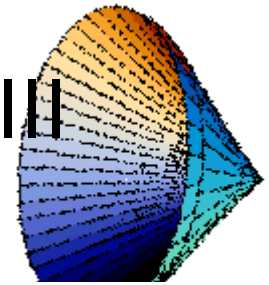
Radio Emission From EM-Showers: II



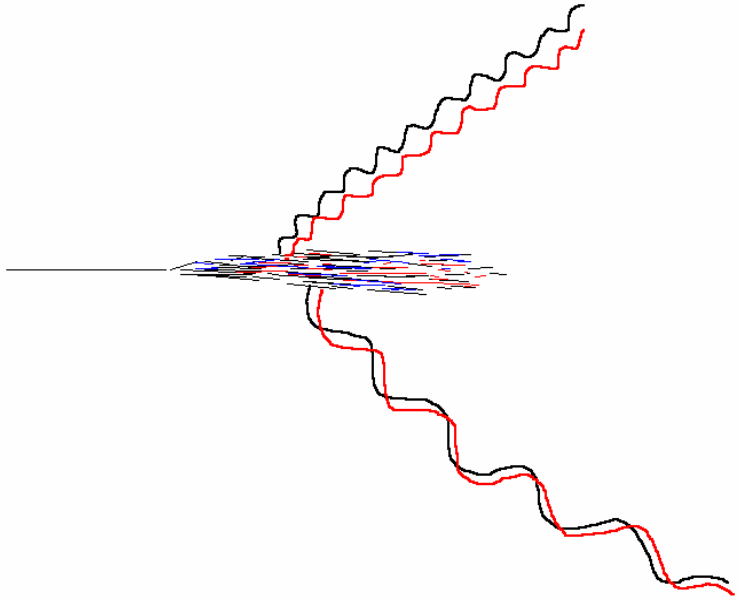
- The net negative charge travels faster than c in ice and therefore Cerenkov radiates

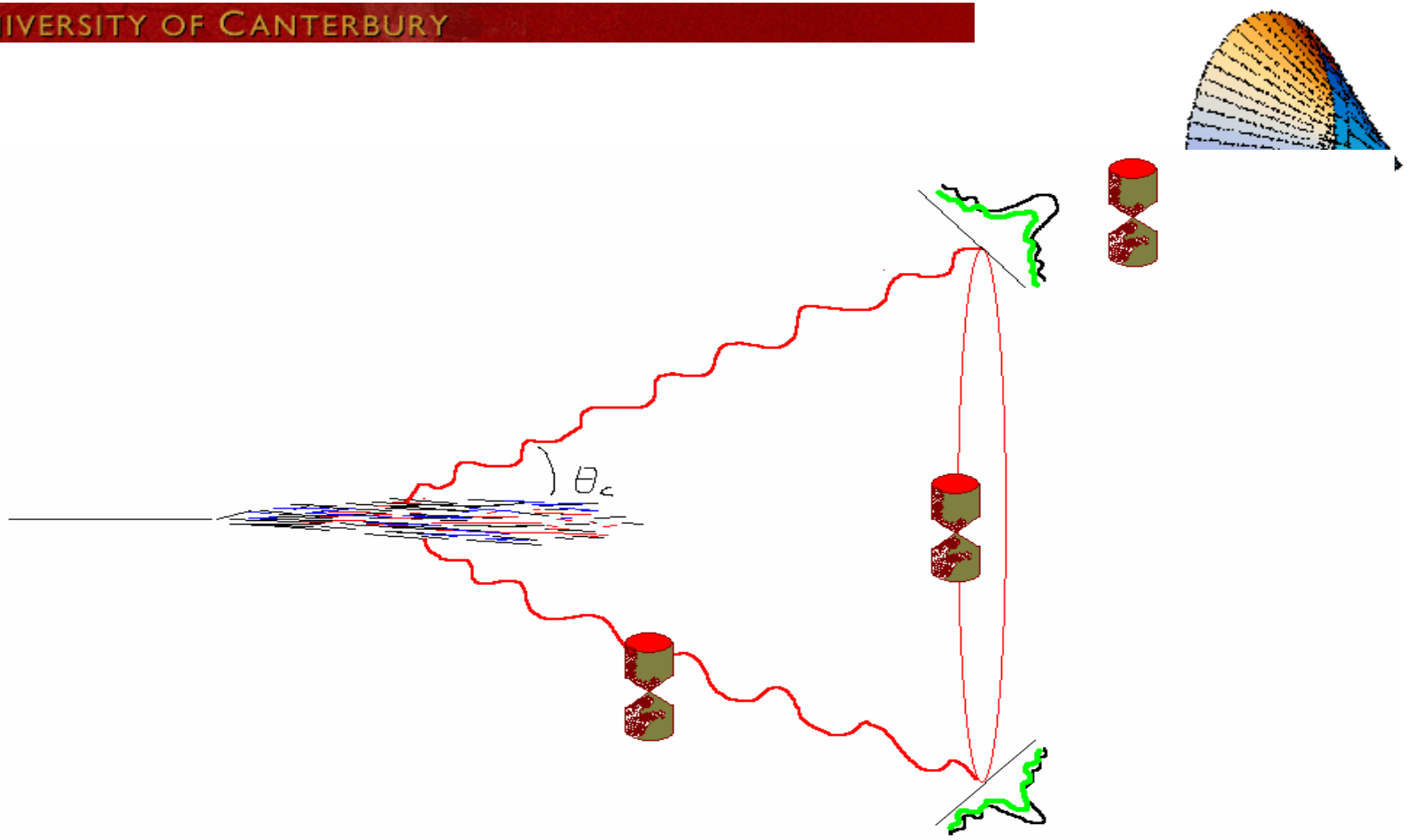


Radio Emission From EM-Showers: III



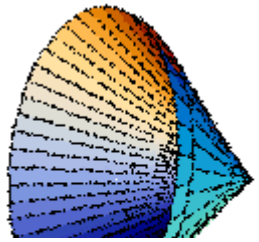
- Each charged particle emits broadband radiation. Shorter wavelength radiation interferes destructively

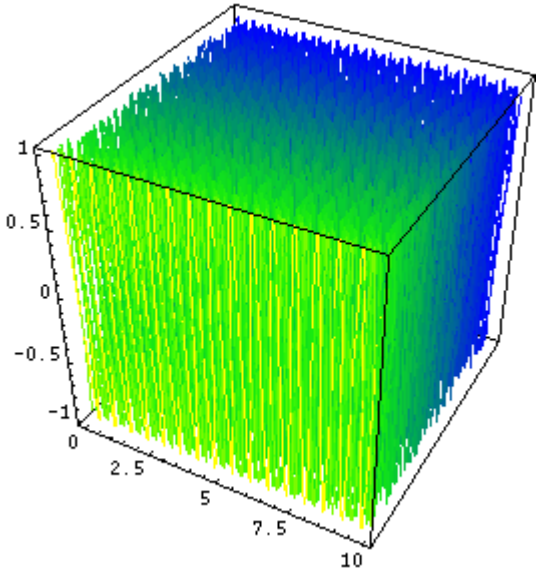




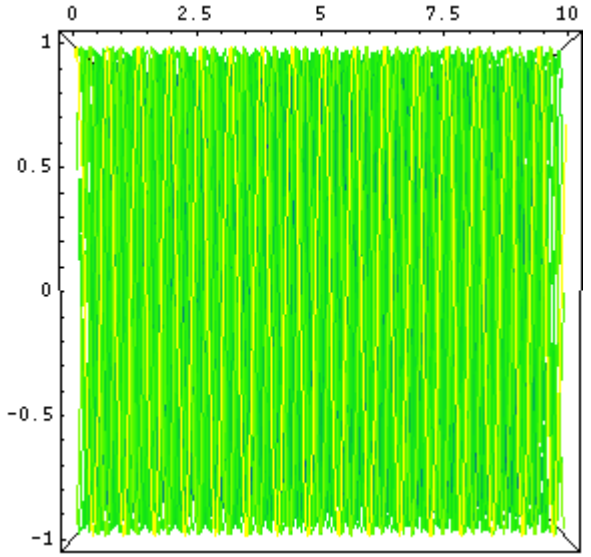
Suruj Seunarine, for the RICE Collaboration

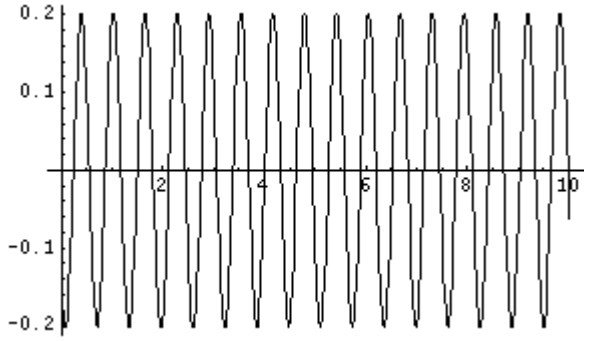
Concept of Coherence



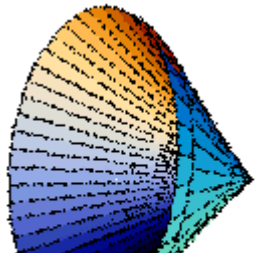


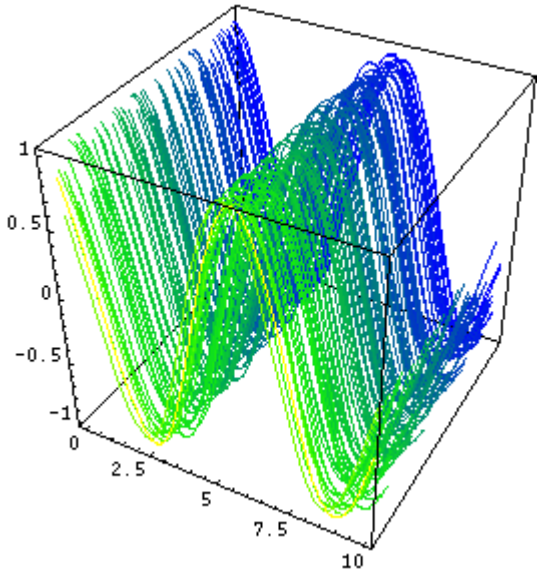
At short wavelengths the relative phases are random giving rise to a small signal.



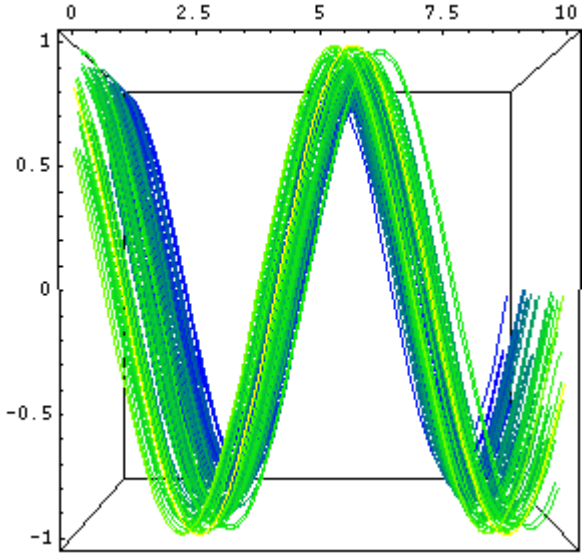


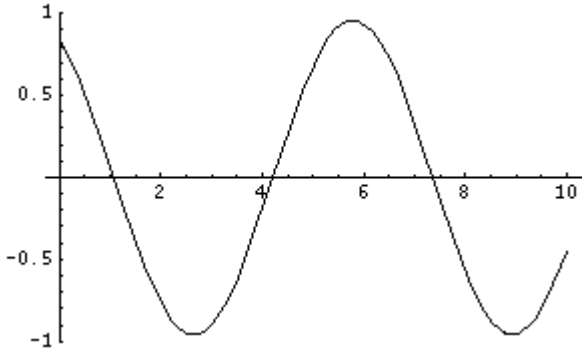
Coherence, continued

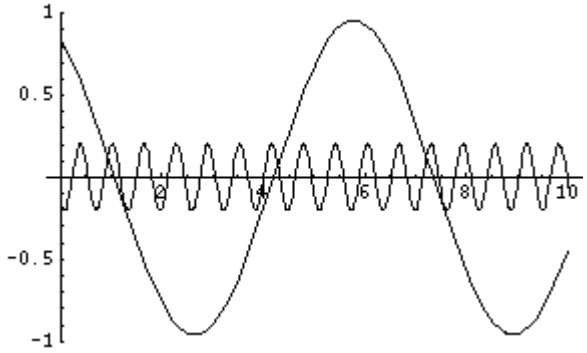




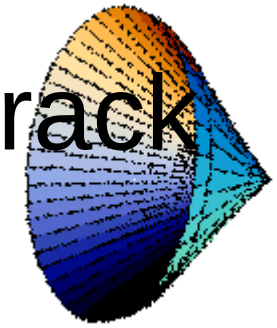
For wavelengths long compared to the dimension of the emission region the waves add coherently giving rise to a larger signal.







Radiation from short particle track

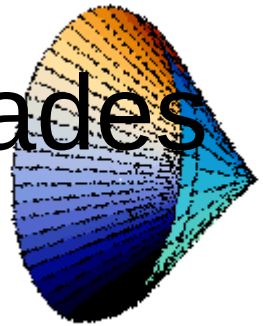


- Expected electric field from MC simulation(Razzaque et al, Zas et al) using GEANT3,4 and ZHS.

$$R|\vec{E}_{\omega}(\vec{x})| = \frac{1}{\sqrt{2\pi}}\left(\frac{\mu_r q}{c^2}\right) e^{ikR} e^{i\omega[t_1 - (n/c)\hat{n}.\vec{r}_1]} \vec{v}_{\perp} \frac{e^{i\omega\delta(1-\hat{n}.\vec{\beta}n)} - 1}{(1-\hat{n}.\vec{\beta}n)}$$

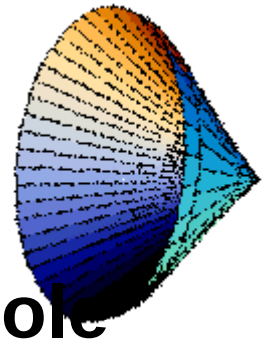
$$R\,|\vec{E}_{\omega}(\vec{x})| = \frac{i\omega}{\sqrt{2\pi}}\left(\frac{\mu_r q}{c^2}\right) e^{ikR} e^{i\omega[t_1 - (n/c)\hat{n}.\vec{r}_1]} \vec{v}_{\perp}\delta t$$

Typical Length scales in Cascades



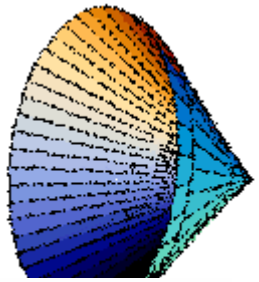
- Radiation length ~38cm.
- r_{Molier} ~13cm.
- Peak in transverse excess charge density ~0.1cm for 100GeV cascade, for example.
- All point to coherence at frequencies of order 10^2MHz and extending to 10^3MHz.

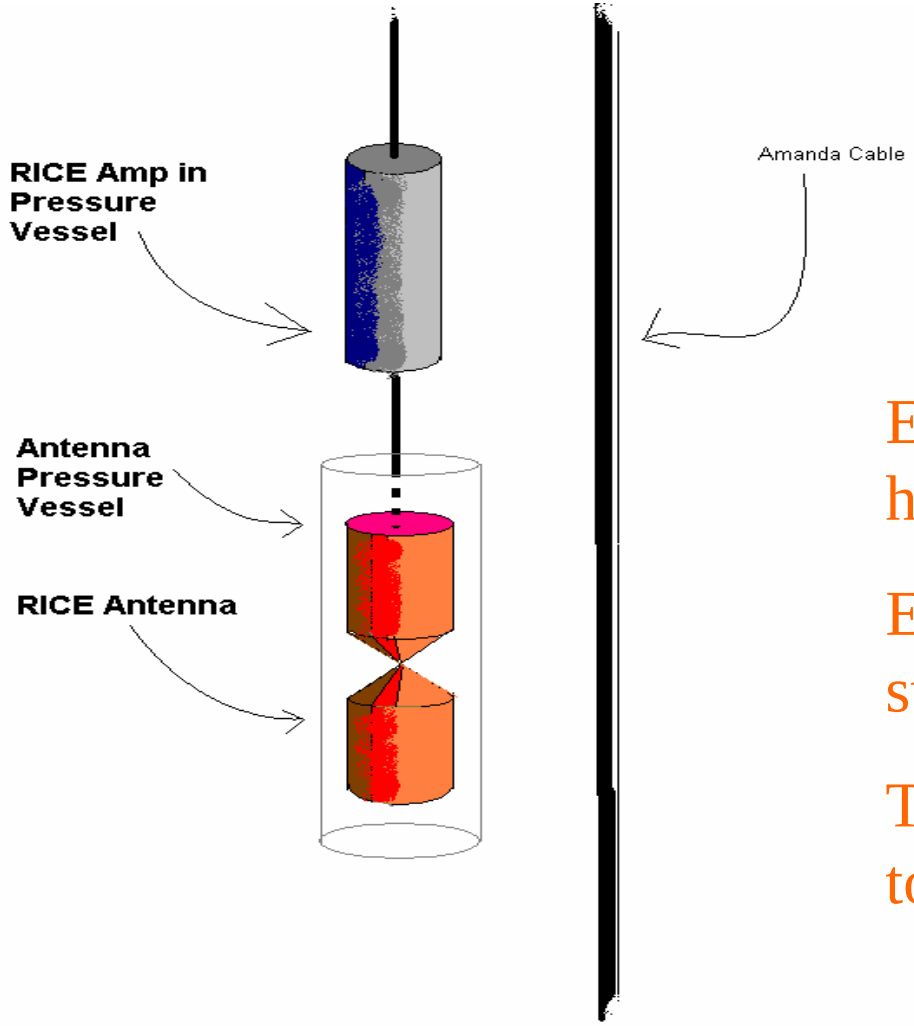
The RICE Array



- **Data taken with 16 channel array of dipole receivers (also have 4 more Rx, 5Tx, 3 horns).**
- **The array is scattered within a 200 m x 200m x 200m cube at, 100-300 m depths.**
- **The signal from each antenna is boosted buy a 36-dB amplifier in the ice and carried to the surface through coaxial cable.**
- **Filtered at surface to suppress noise <200MHz.**

RICE Antenna and Amplifier



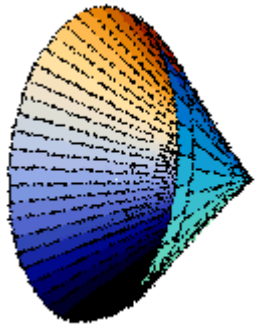


Each Antenna is housed in hard plastic pressure vessel.

Each in ice Amplifier is in a steel pressure vessel.

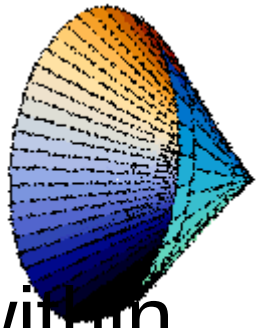
The whole thing is duct-taped to AMANDA cables.

The DAQ



- The signal is then re-amplified and split.
- One of two identical copies sent to
  - CAMAC crate to form event trigger
  - Channel of HP54542 oscilloscope
- 8 μs waveforms are captured from scopes when event is saved.

Triggers



- At least four under ice antennas hit within 1.2 μs (time for signal to propagate across array) and pass software surface veto.
- There are also trigger lines from SPASE and AMANDA.
- Unbiased "events" are saved for testing of vetos and event reconstruction software.
- Veto on surface horn hit or surface software veto. Turn off when 303 on.

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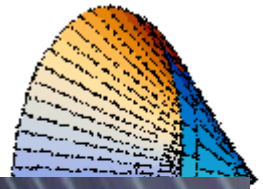

Flying to Mc Murdo

Suruj Seunarine, for the RICE Collaboration

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Mc Murdo Station

Suruj Seunarine, for the RICE Collaboration

The "Pole!!"

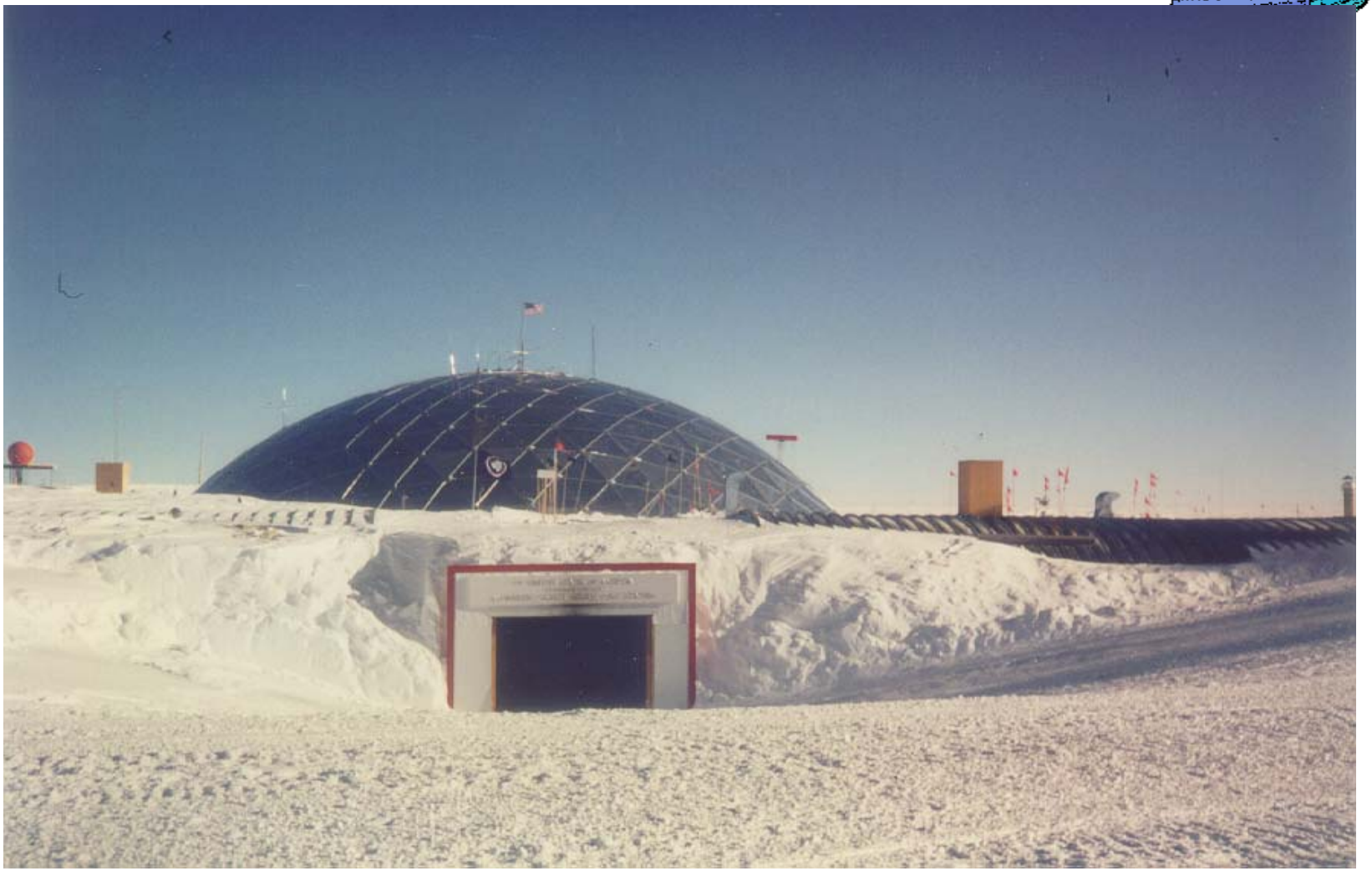
Suruj Seunarine, for the RICE Collaboration

Looking North

Suruj Seunarine, for the RICE Collaboration

Old Dorms

Dome--being replaced



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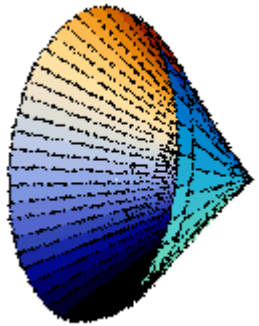
Counting house



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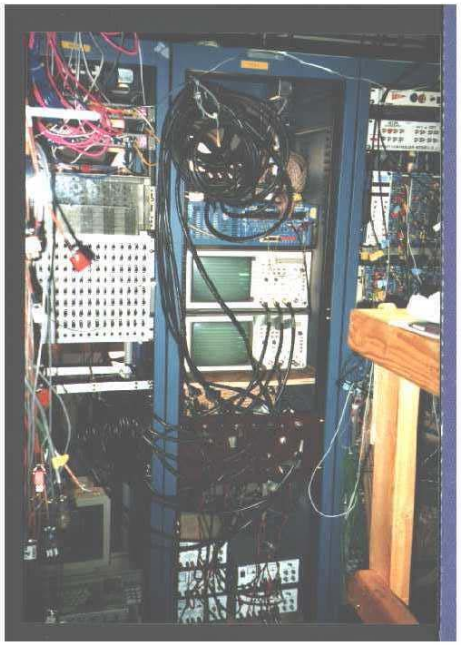
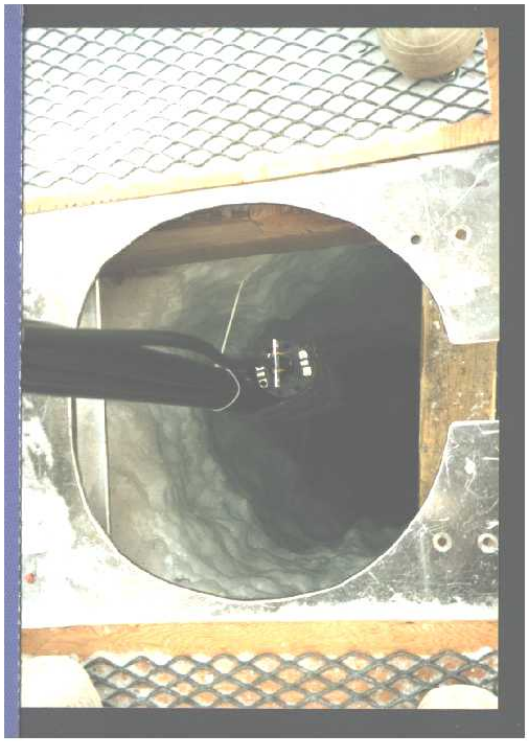
DAQ, Receiver Deployment





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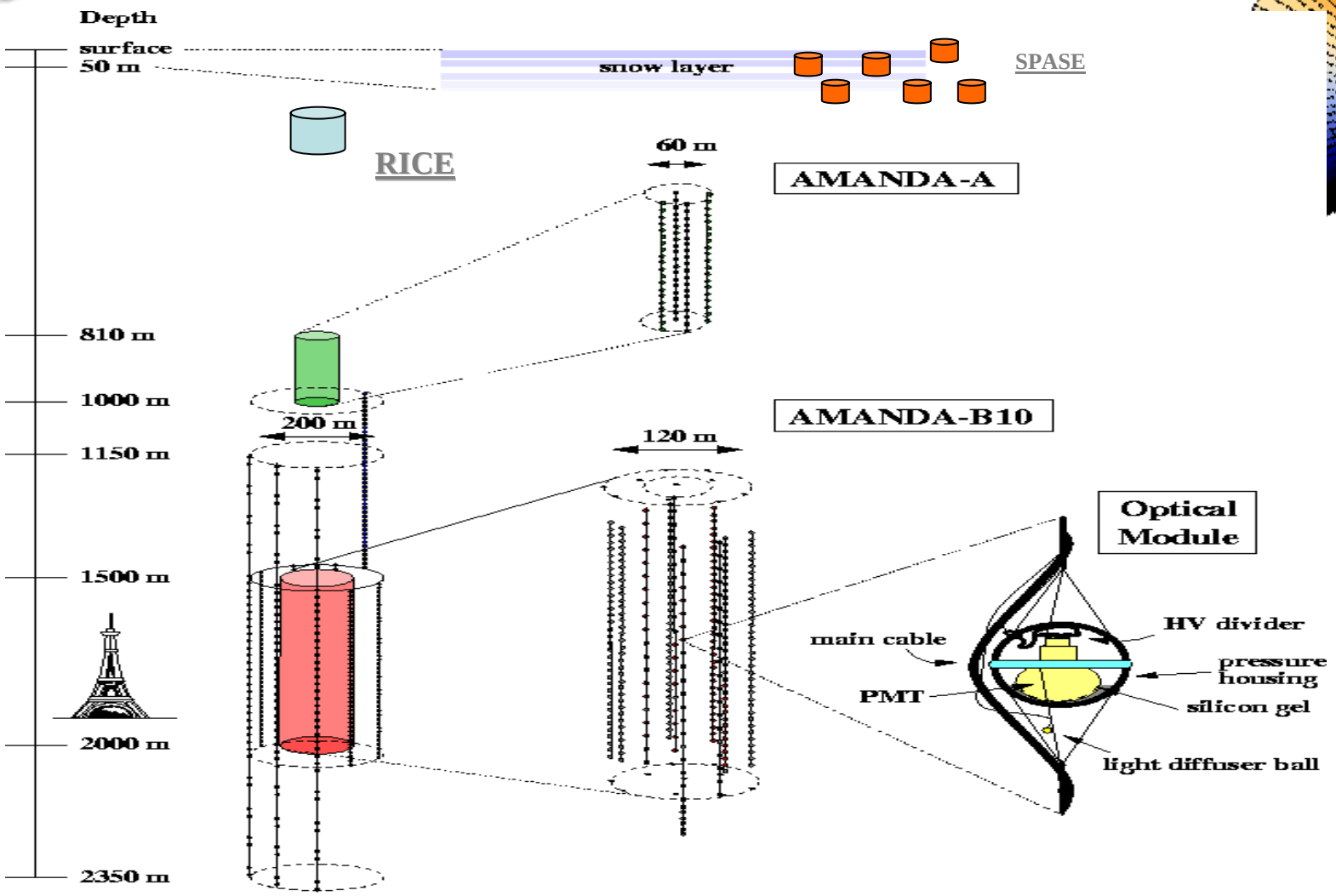


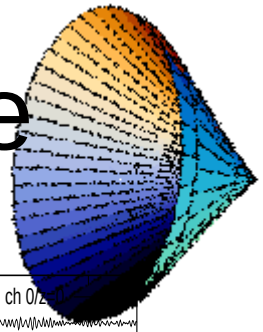
AMANDA as of 2000
Eiffel Tower as comparison
(true scaling)

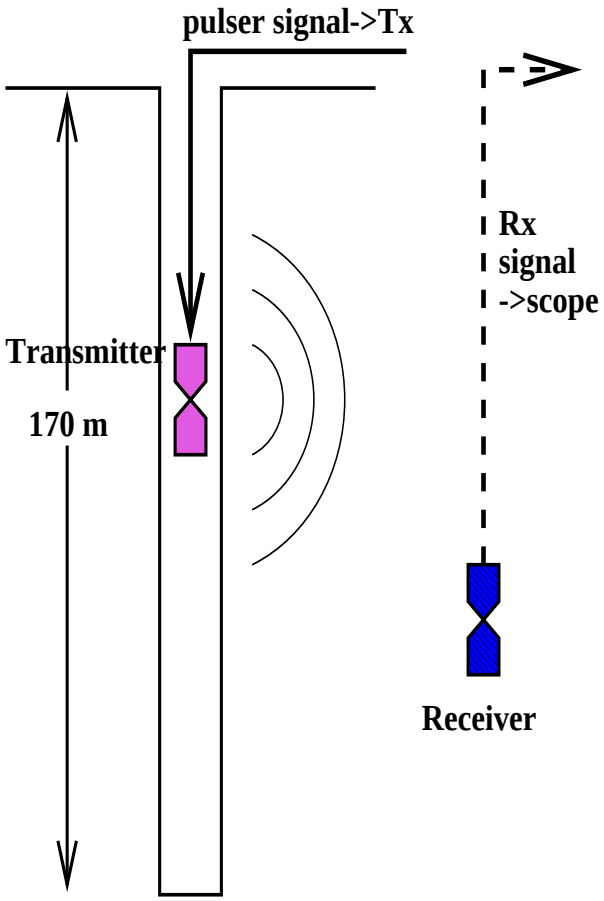
zoomed in on
AMANDA-A (top)
AMANDA-B10 (bottom)

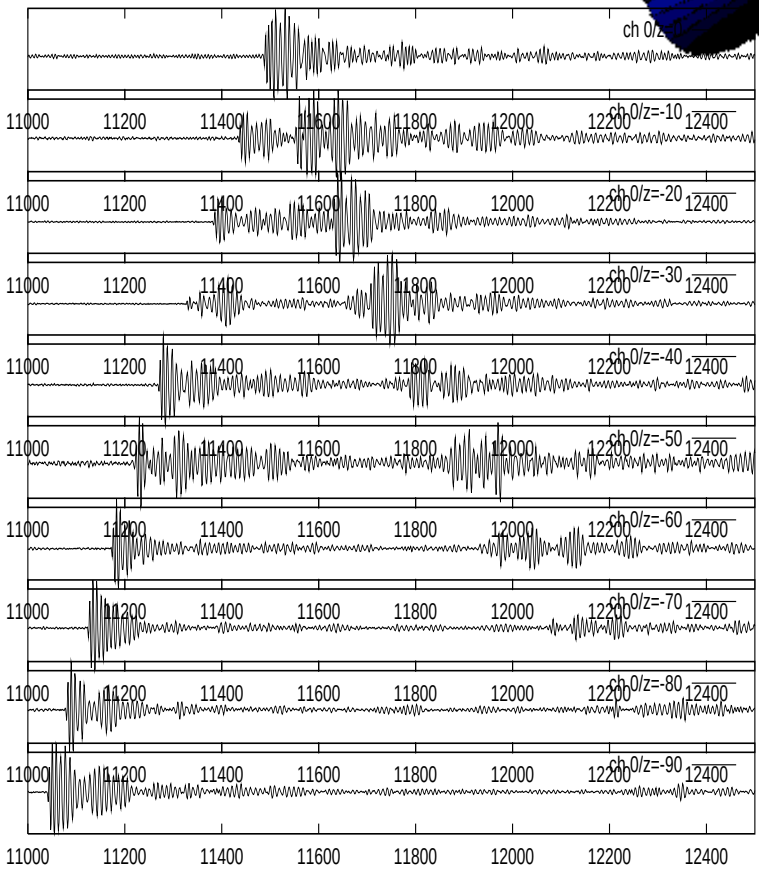
zoomed in on one
optical module (OM)

Suruj Seunarine, for the RICE Collaboration

RICE measured *n(z)* for ice







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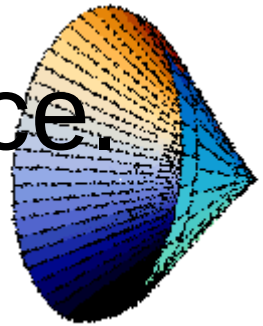
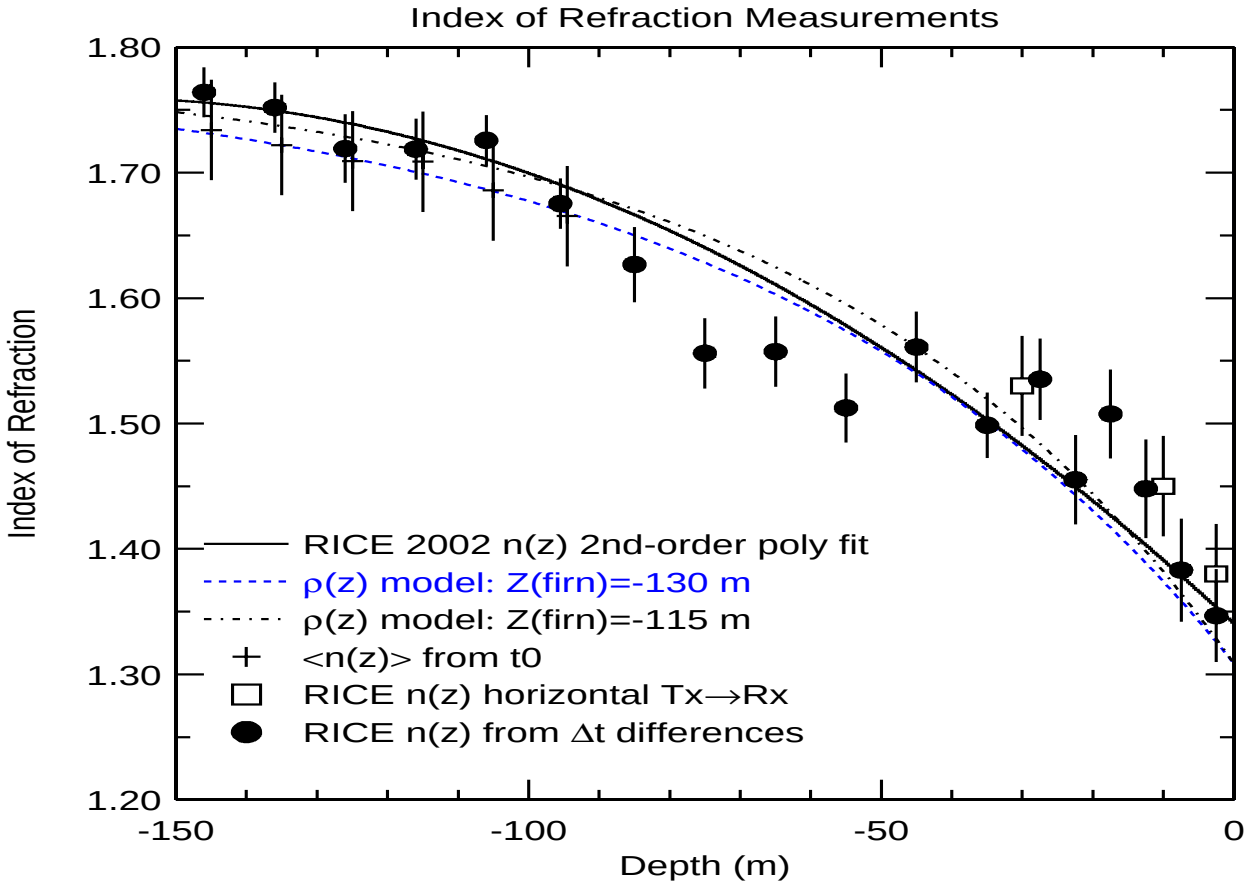
RICE measurement of *n(z)* ice.





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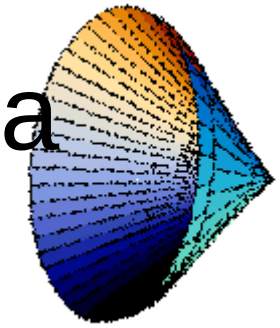
Analysis of 1999-2001 Data



To select ν's we require

- Events to have channels to have 5.5σ excursions in their waveform.
- Pass quality of vertex cuts.
- Reconstruct below 150m.
- Hit geometry consistent with Cerenkov cone.

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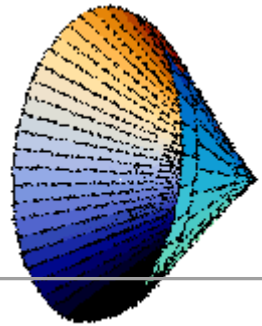
Filtering of Events



Cut imposed	Surviving Data Events 1999 / 2000 / 2001	MC events left
Total Triggers	297512 / 111586842 / 3174390	400
Passing surface veto	12674 / 406867 / 97357	400
Passing 4 x 5.5s cuts	323 / 9001 / 9089	400
(Z<-150m)*(vertex quality)	5 / 177 / 68	396
Conical geometry	0 / 3 / 2	378
Passing scanning	0 / 0 / 0	376

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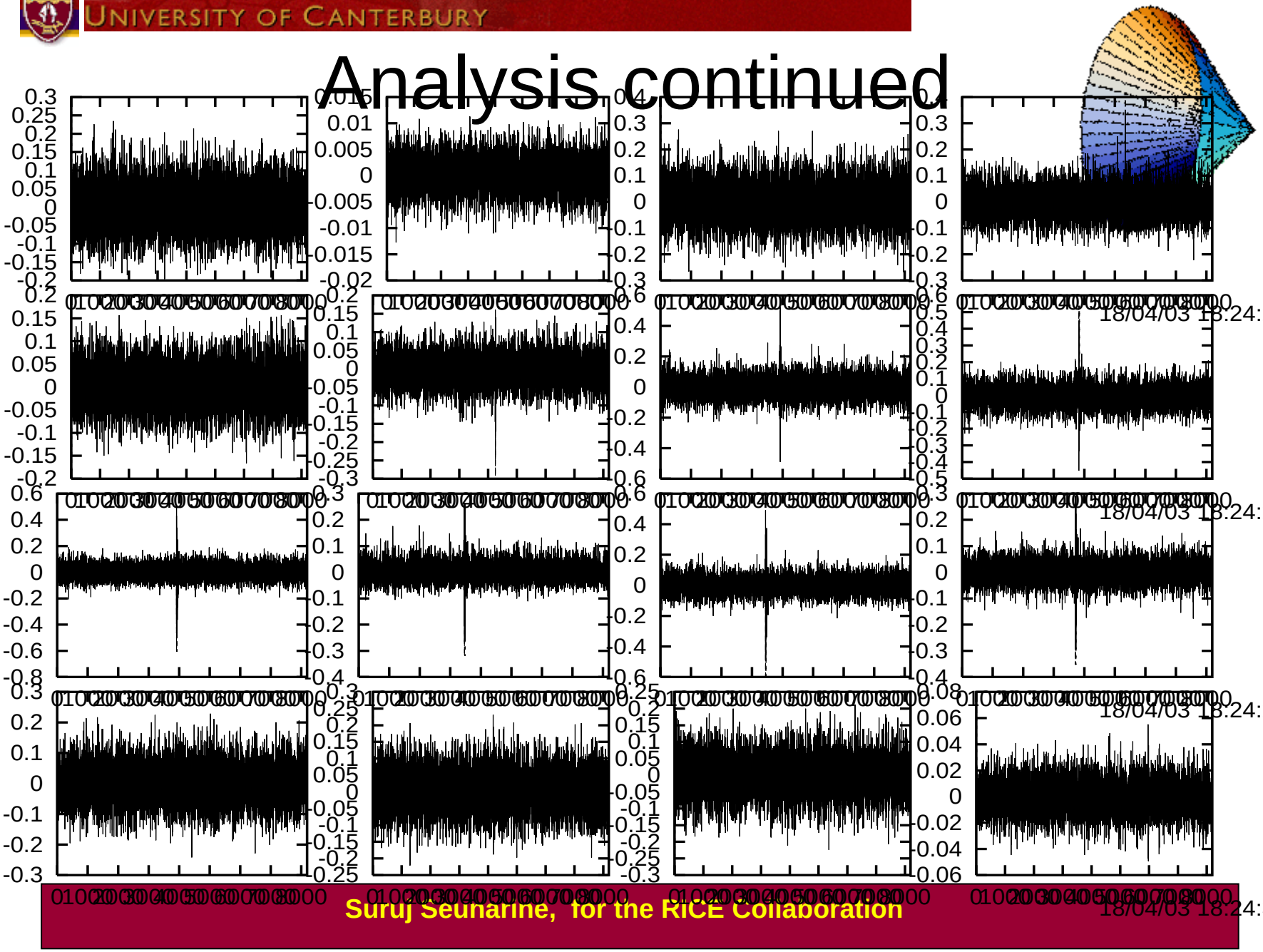
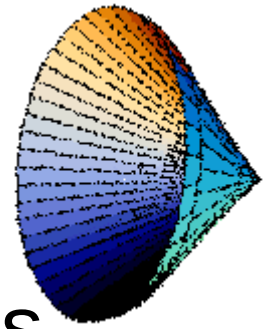
Analysis continued

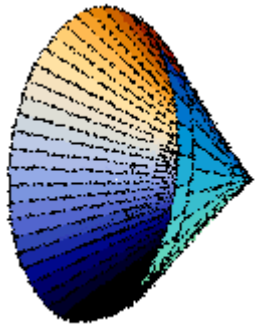


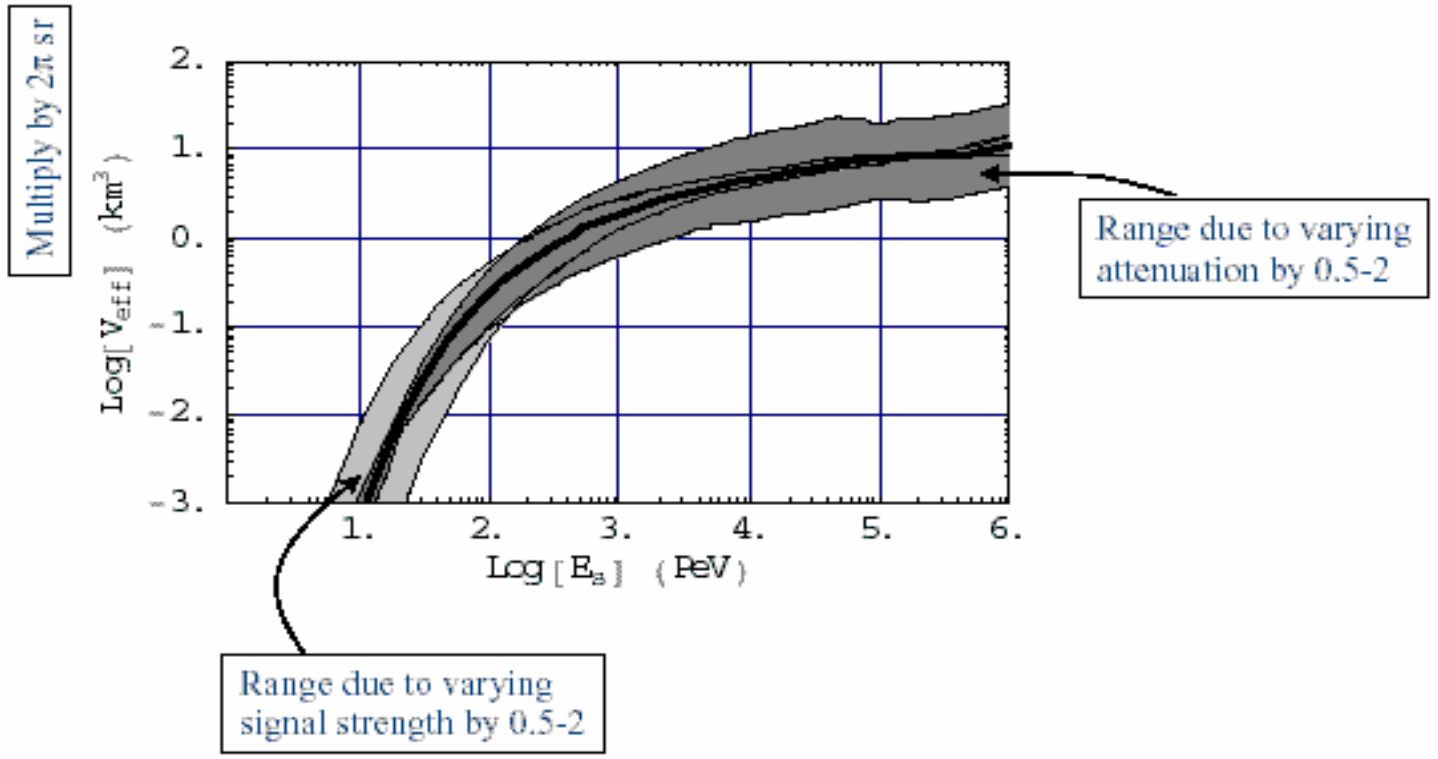
Analysis Continued



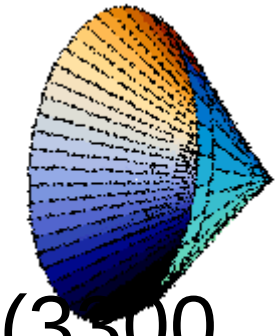
- Each of the remaining five candidates were hand scanned.
- All five had hits inconsistent with the time domain antenna response expected for a neutrino signal.
- After removal of spurious hits all five events reconstructed to the surface.

Effective Volume



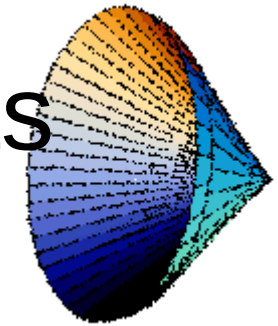


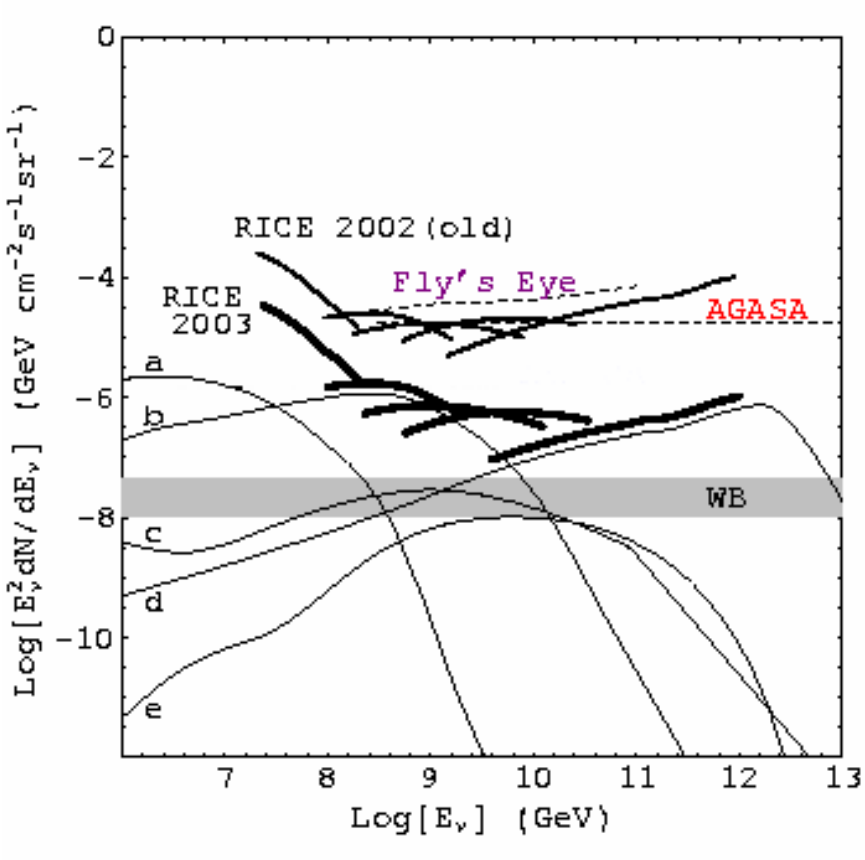
Analysis continued ….



- Knowing the live time of the data set(3300 hours) and based on the observation of zero candidates we calculate the upper limits to the incident neutrino flux as a function of energy and based on several models of neutrino sources.

95% Confidence level limits





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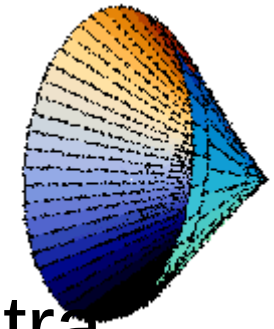
Summary-of RICE



- We have improved on the limits to ultra high energy neutrino fluxes.
- 2002-2003 data set will be the cleanest data set so far and further constrain on flux models will be made.

- Acknowledgements:We gratefully acknowledge the generous support of the AMANDA Collaboration, the National Science Foundation Office of Polar Programs, the KU General Research Fund and the KU Research Development Fund, the New Zealand Marsden Foundation, and the Research Corporation.

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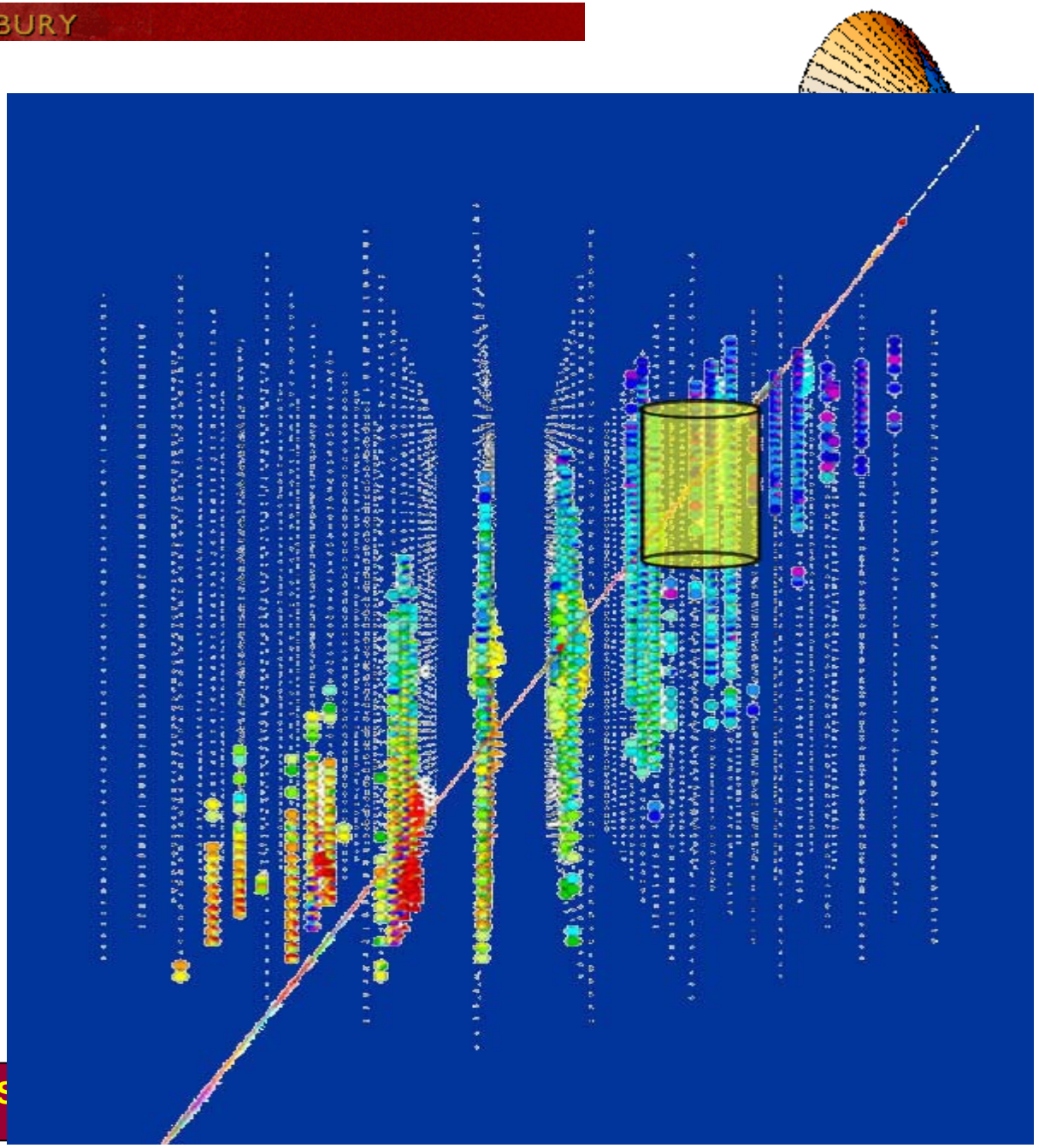
ICECUBE

- A 1km^3 array of photo multiplier tubes.
- Large scale neutrino astronomy.
- 80 Strings
- 4800 PMT
- Instrumented volume: 1 km3 (1 Gt)
- IceCube is designed to detect neutrinos of all flavors at energies from 10^7 eV (SN) to 10^{20} eV



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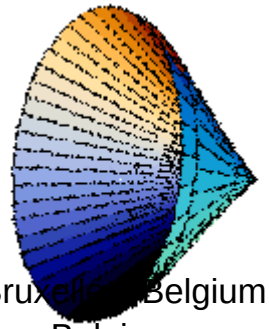
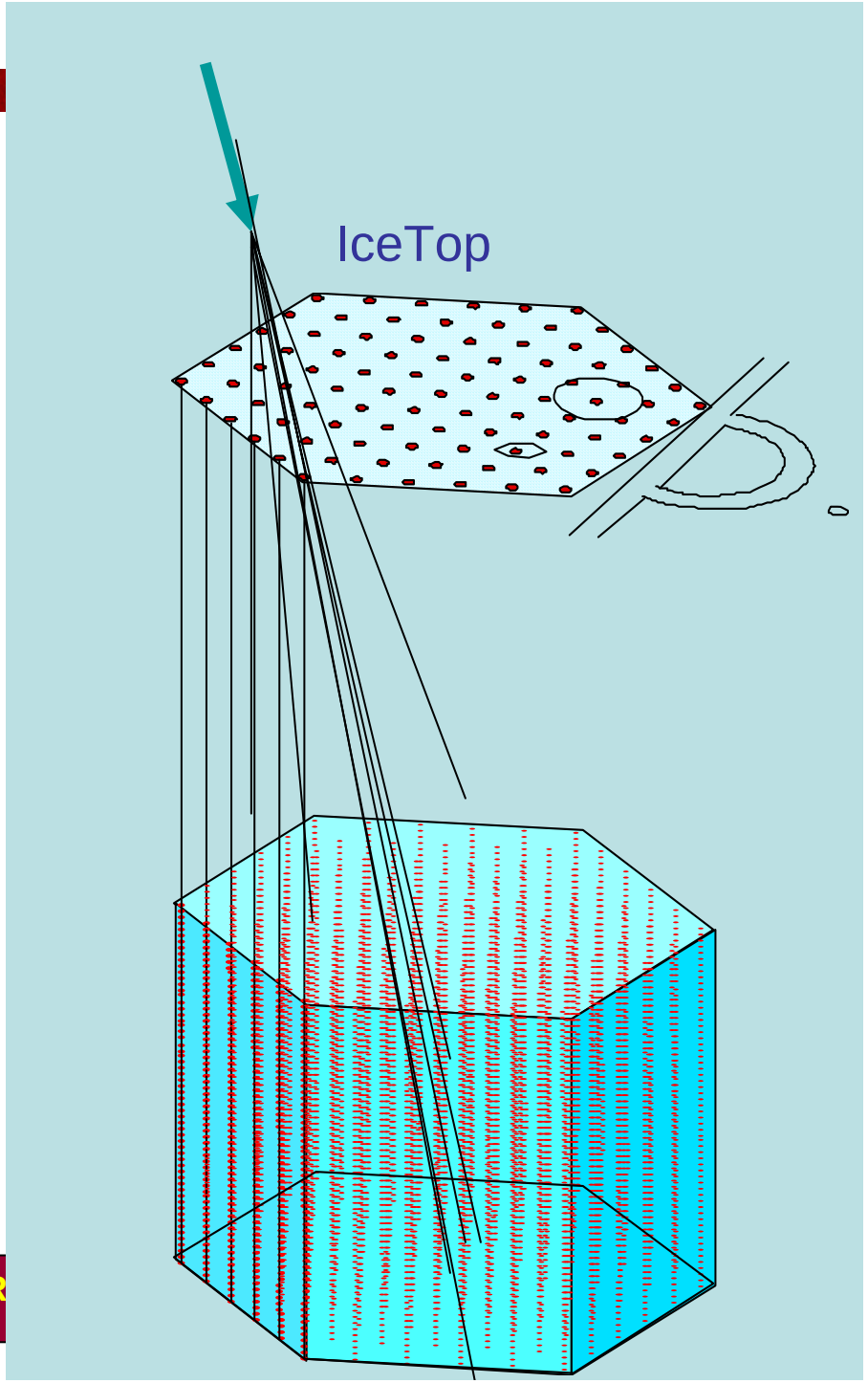


The IceCube Collaboration

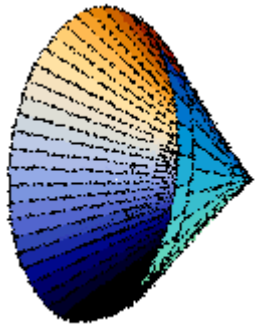
- Chiba University, Chiba, Japan
- Clark Atlanta University, Atlanta, GA
- DESY-Zeuthen, Zeuthen, Germany
- Imperial College, UK
- Institute for Advanced Study, Princeton, NJ
- Lawrence Berkeley National Laboratory, Berkeley, CA
- Pennsylvania State University, Philadelphia, PA
- South Pole Station, Antarctica
- Southern University and A & M College, Baton Rouge, LA
- Stockholm Universitet, Stockholm, Sweden
- Universität, Mainz, Germany
- Universität Wuppertal, Wuppertal, Germany
- Université Libre de Bruxeelles, Bruxelles, Belgium
- Université de Mons-Hainaut, Mons, Belgium
- University of Alabama, Tuscaloosa, AL
- University of California-Barkeley, Berkeley, CA
- University of Delaware, Newark, DE
- University of Kansas, Lawrence, KS
- University of Maryland, College Park, MD
- University of Wisconsin-Madison, Madison, WI
- University of Wisconsi-RiverFalls, River Falls, WI
- Universidad Simon Bolivar, Caracas, Venezuela
- Uppsala Universitet, Uppsala, Sweden
- Vriie Universiteit Brussel, Brussels, Belgium
- University of Canterbury, New Zealand

ICECUBE & ICETOP

Icetop is a surface air shower detector. Will be used as veto, to calibrate and to study cosmic rays to 10^{18}eV.



Modules



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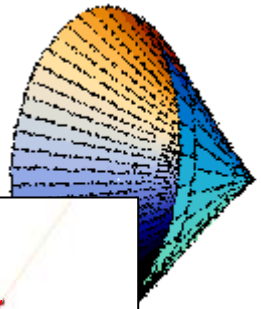
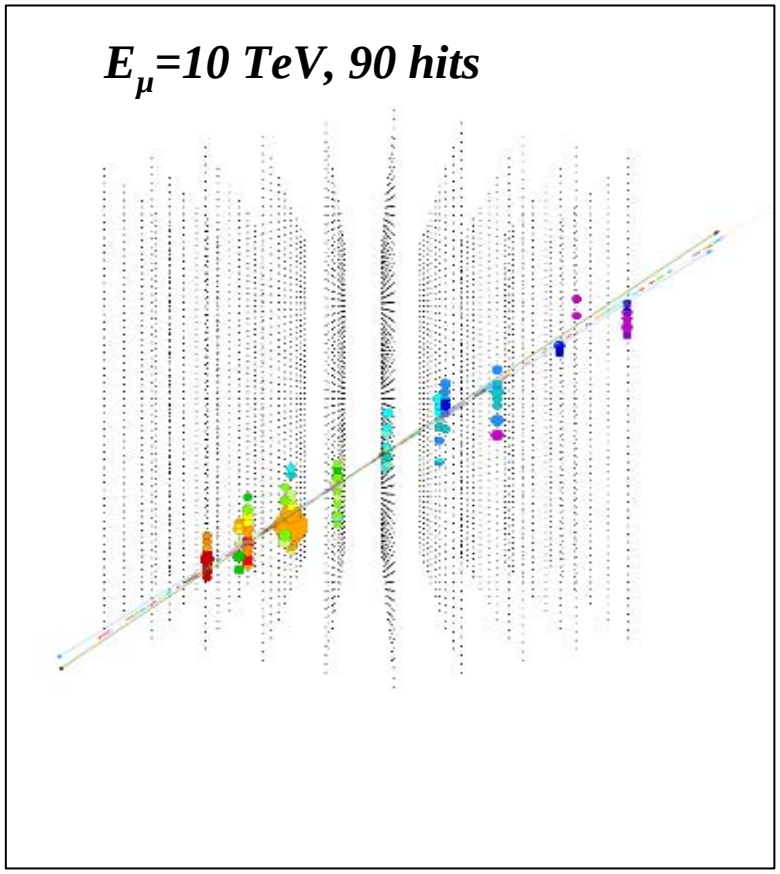
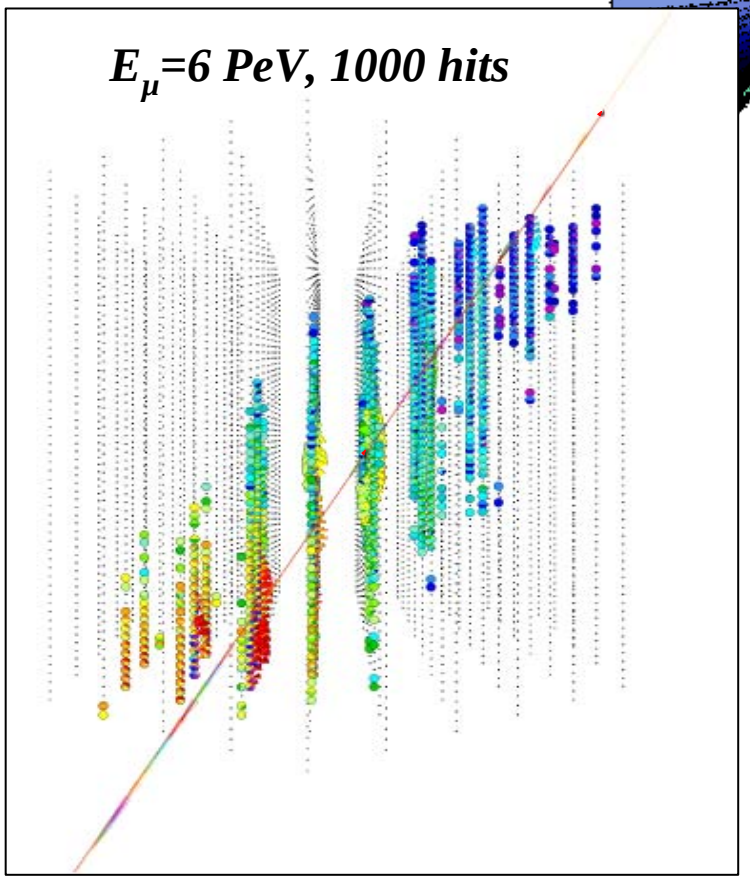
Simulated events

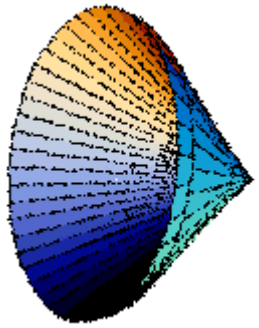


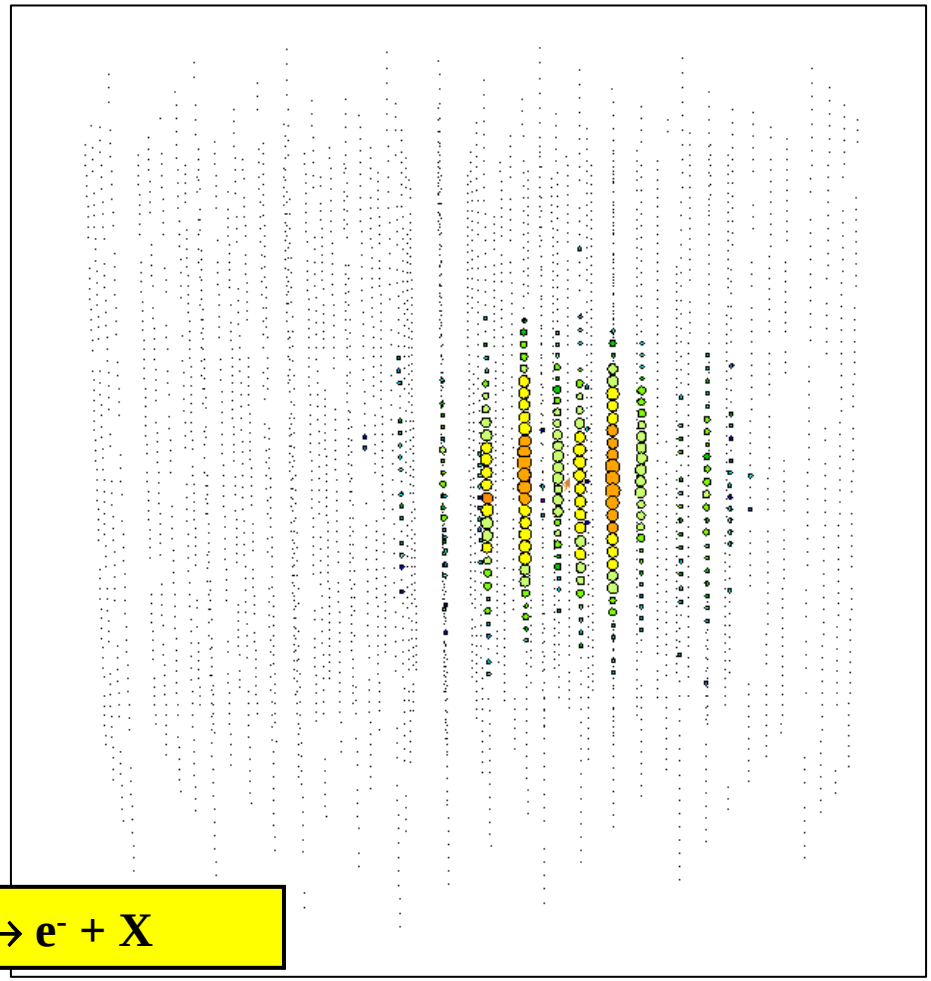




$$\nu_\mu + N \rightarrow \mu^- + X$$

Cascades have spherical geometry





$$\nu_e + N \rightarrow e^- + X$$

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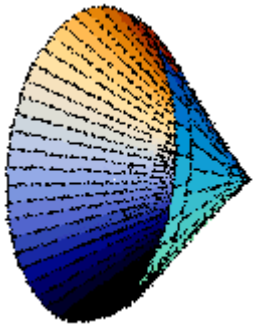
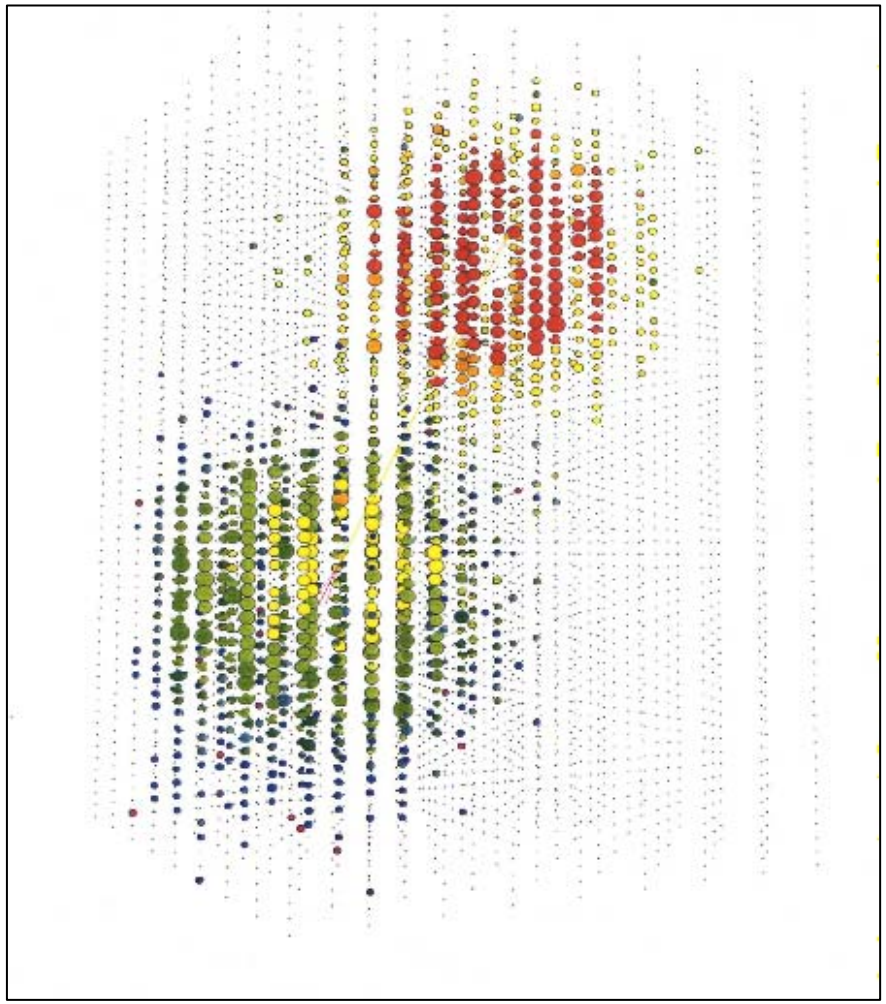
τ double bang





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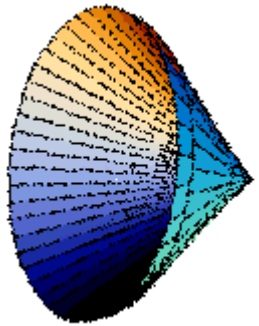
U. Canterbury's Contributions



- Monte Carlo Simulations.
- Calculating *light yield* from cascades using *GEANT4*.
- Studying hadronic component of cascades to see how often *long range μ's* are produced,
- Updating *photonics* data.

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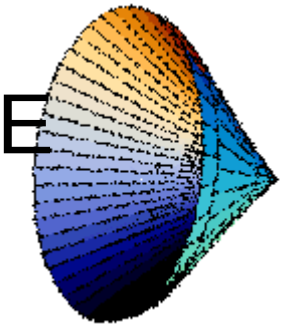
Status:Canterbury/RICE/ICECUBE



- ICECUBE Funded to >US$250x$10^6$.
- Drilling equipment sent to pole 03-04.
- Four or more holes drilled 04-05.
- Canterbury did well to get in after hard funding work done. We have human resources to contribute to simulations and analysis but anticipate we'll need modest treasure to sustain our collaboration.
- Precedent: new telescopes far exceed design goals(telescope, radio, GRB's….) and same is expected for ICECUBE.
- Support from ICECUBE for RICE co-deployment uncertain but RICE continues to operate and take data. Has history of successful co-deployment however other new detection strategy has made a strong bid…
- Look forward ν picture of the sky (night and day).