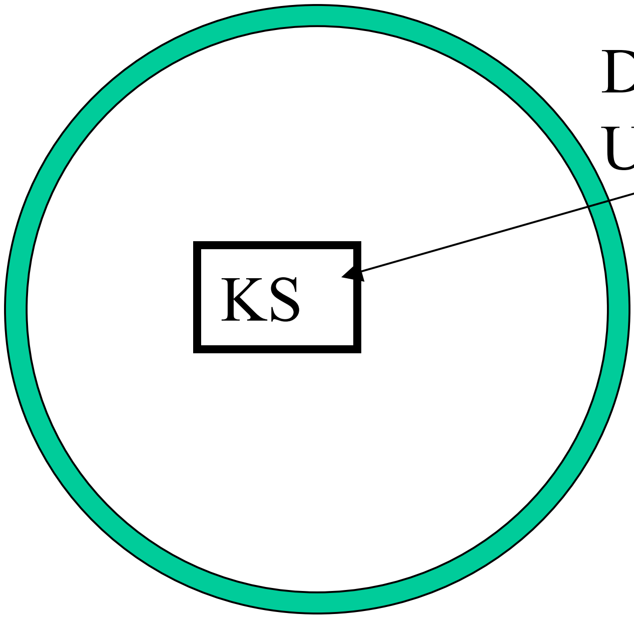
Neutrino astronomy: Status And New Techniques

Dave Besson,
U. Of Kansas



Thanks to: Peter Gorham, Francis Halzen, John Learned, Josh Meyers, David Saltzberg, Dave Seckel

- Optical Cherenkov Detection
- Radio Cherenkov Detection
- Acoustic, air showers, etc…
- Will focus on Effective Volume Comparison

some of the various active neutrino projects:

- *under-water:* ANTARES, Baikal, NEMO, and NESTOR, AUTEC (and more)
- *under-ice:* AMANDA, ICECUBE, RICE
- *atmosphere:* ASHRA, AUGER, EUSO, OWL
- *salt:* SALSA
- *ground to air:* GLUE, Forte', NuTel, ANITA

Planned, coming-on-line, taking data/setting limits

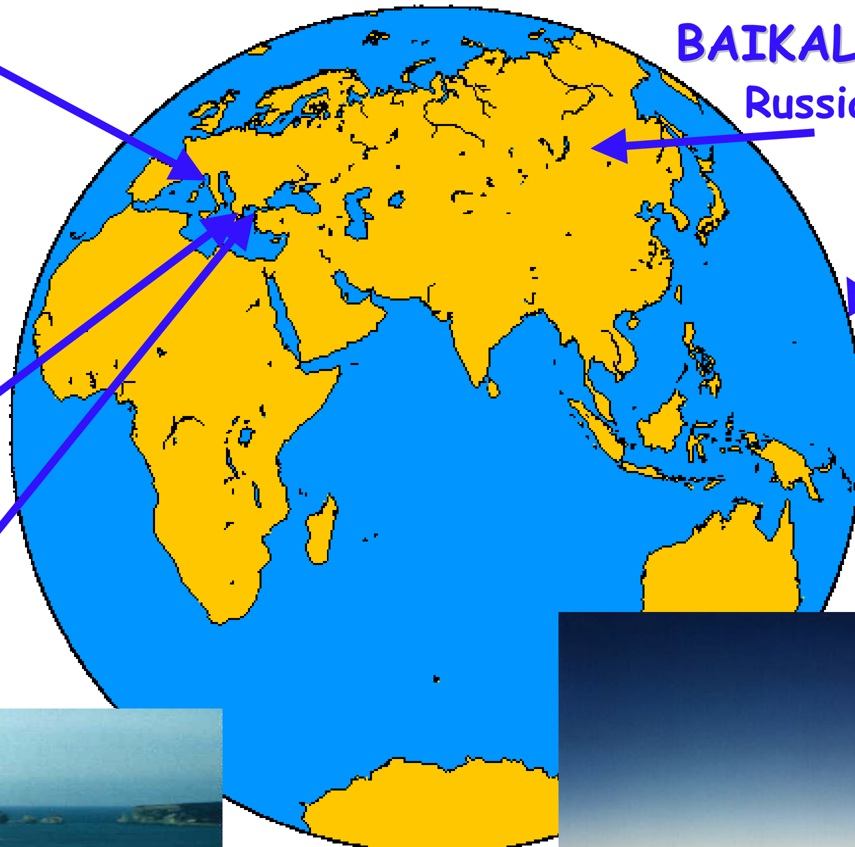
- **Techniques: Optical & Radio Cherenkov radiation, N_2 Fluorescence, Thermoacoustic**

Optical Cherenkov
Neutrino Telescope Projects

ANTARES
La-Seyne-sur-Mer, France

NEMO
Catania, Italy

NESTOR
Pylos, Greece

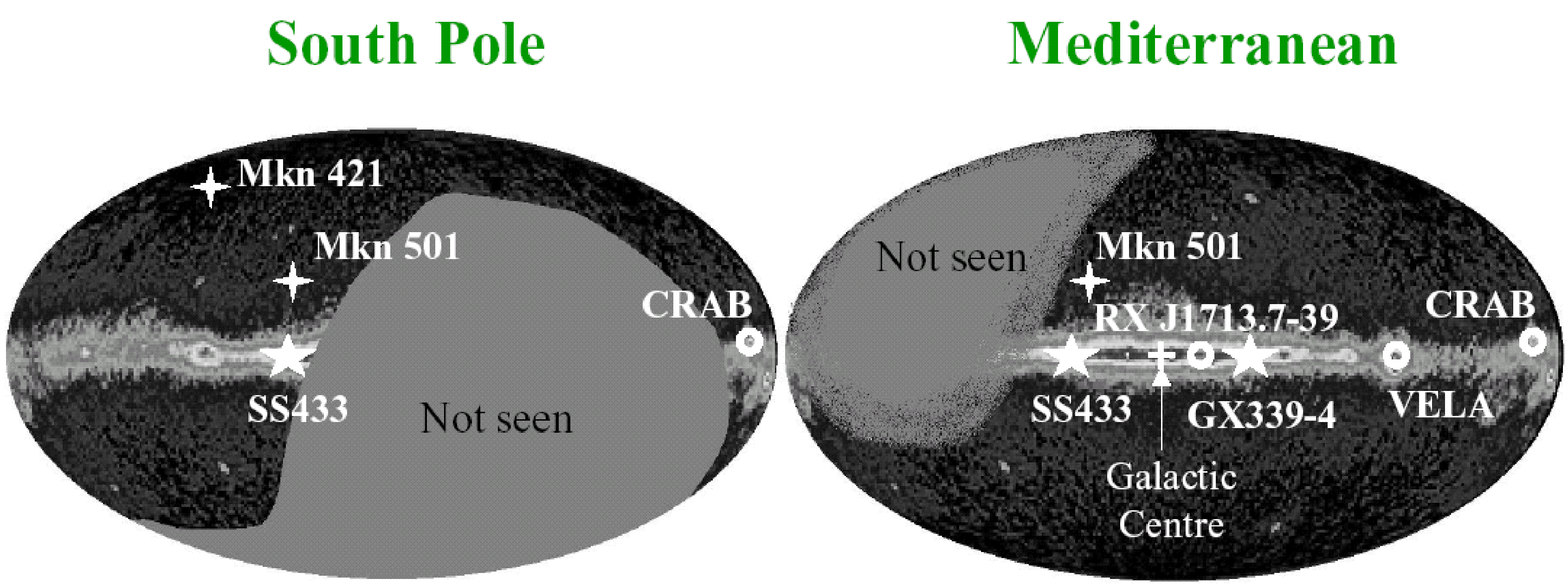


BAIKAL
Russia

DUMAND
Hawaii
(cancelled 1995)

AMANDA/ICECUBE,
South Pole, Antarctica

Complementarity of Sky Coverage by Neutrino Telescopes



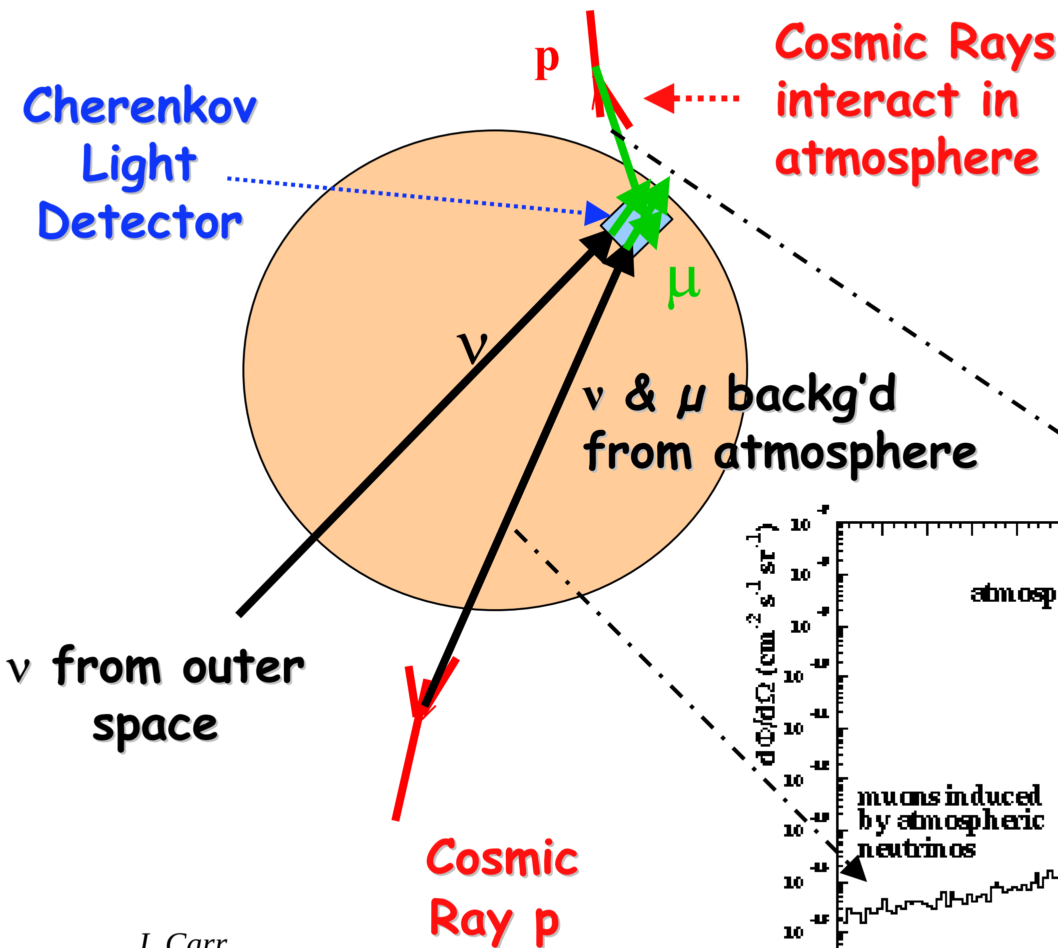
Gamma ray flux >100 MeV observed by EGRET

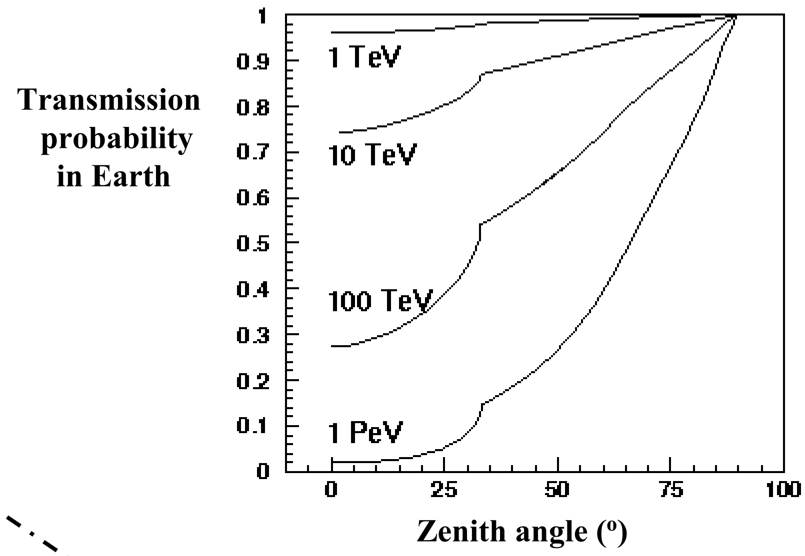
Region of sky seen in galactic co-ordinates assuming efficiency=100% for 2π downwards

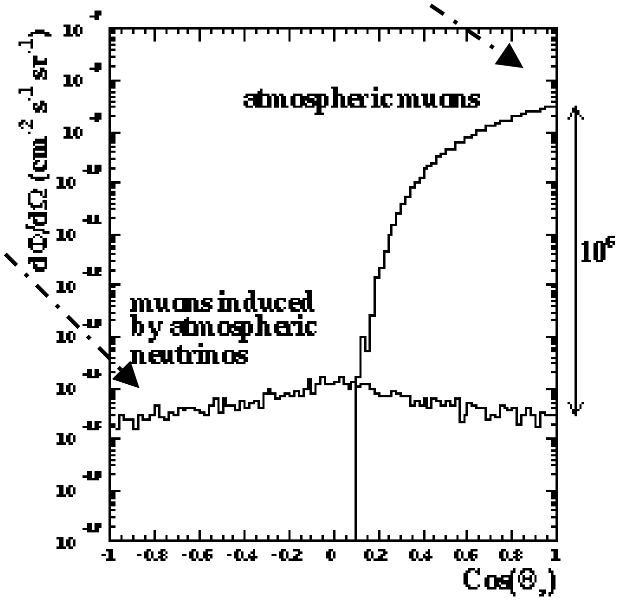
J. Carr, Nu2002

Under Sea, Lake or Ice

Neutrino Telescopes







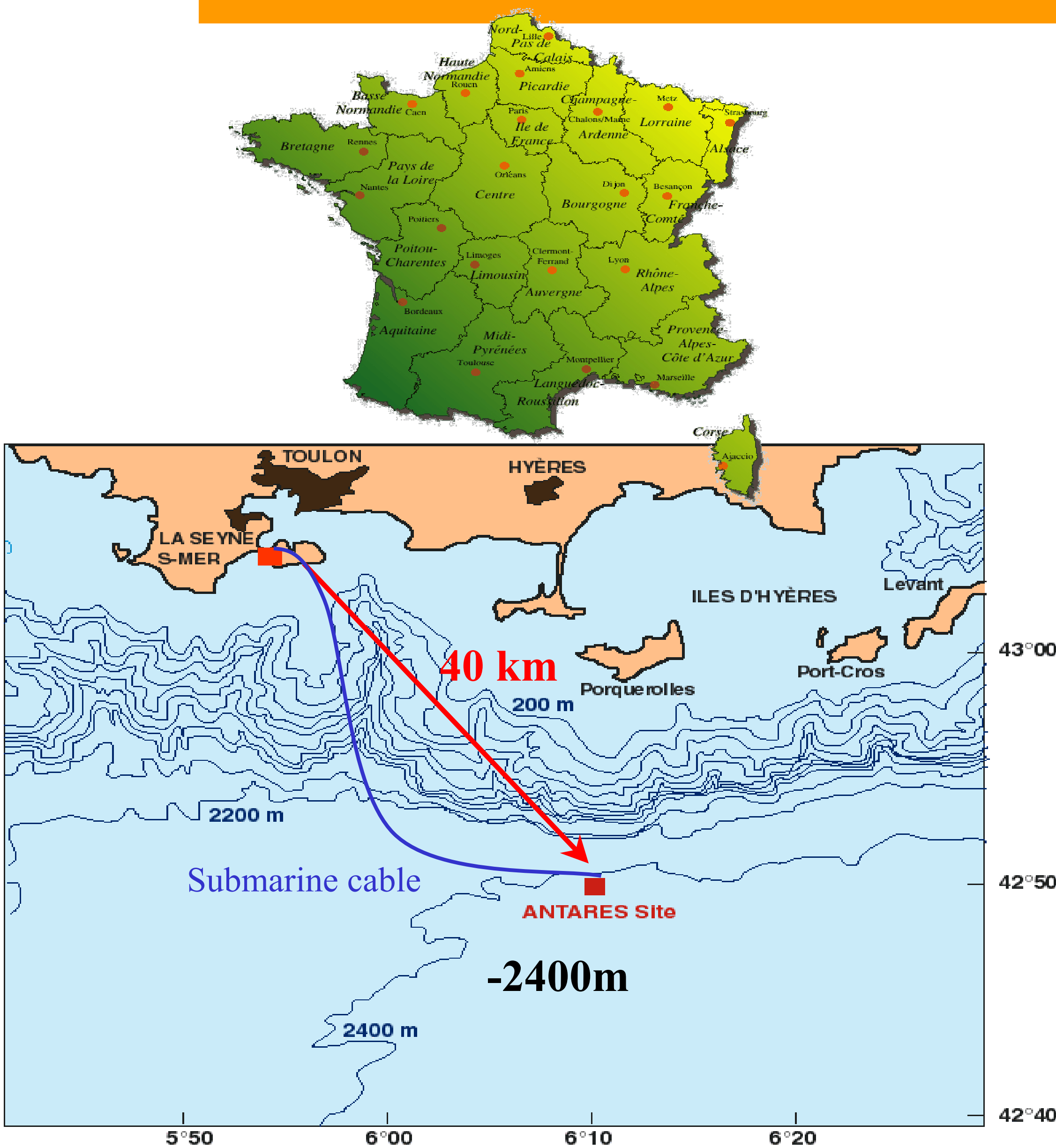
J. Carr

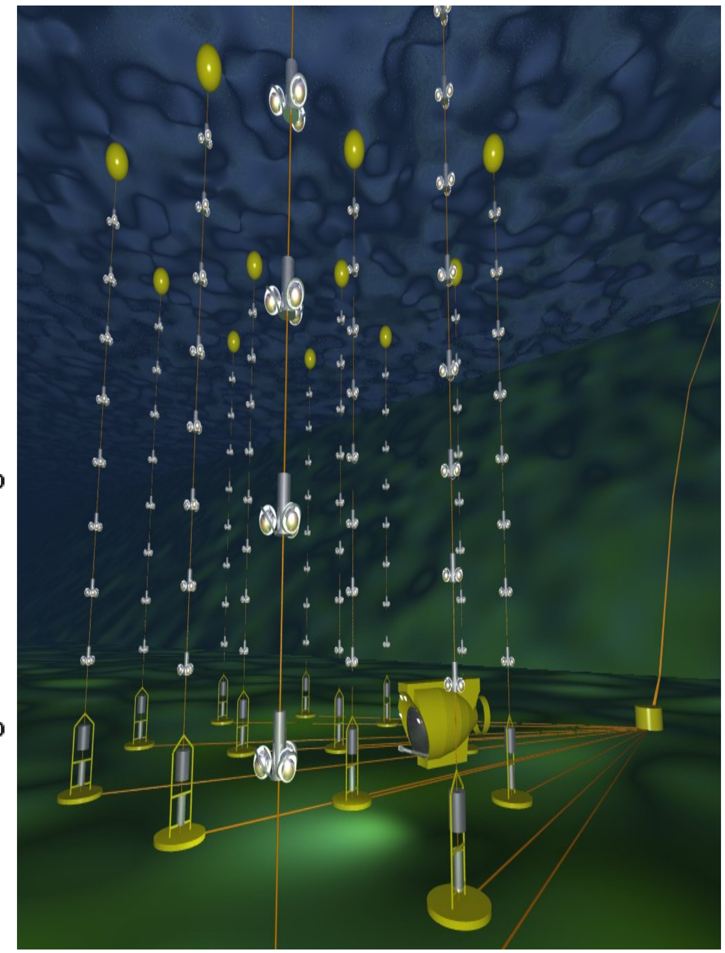
< 1PeV: look for upcoming events

>100 TeV: look for downgoing events

ANTARES SITE

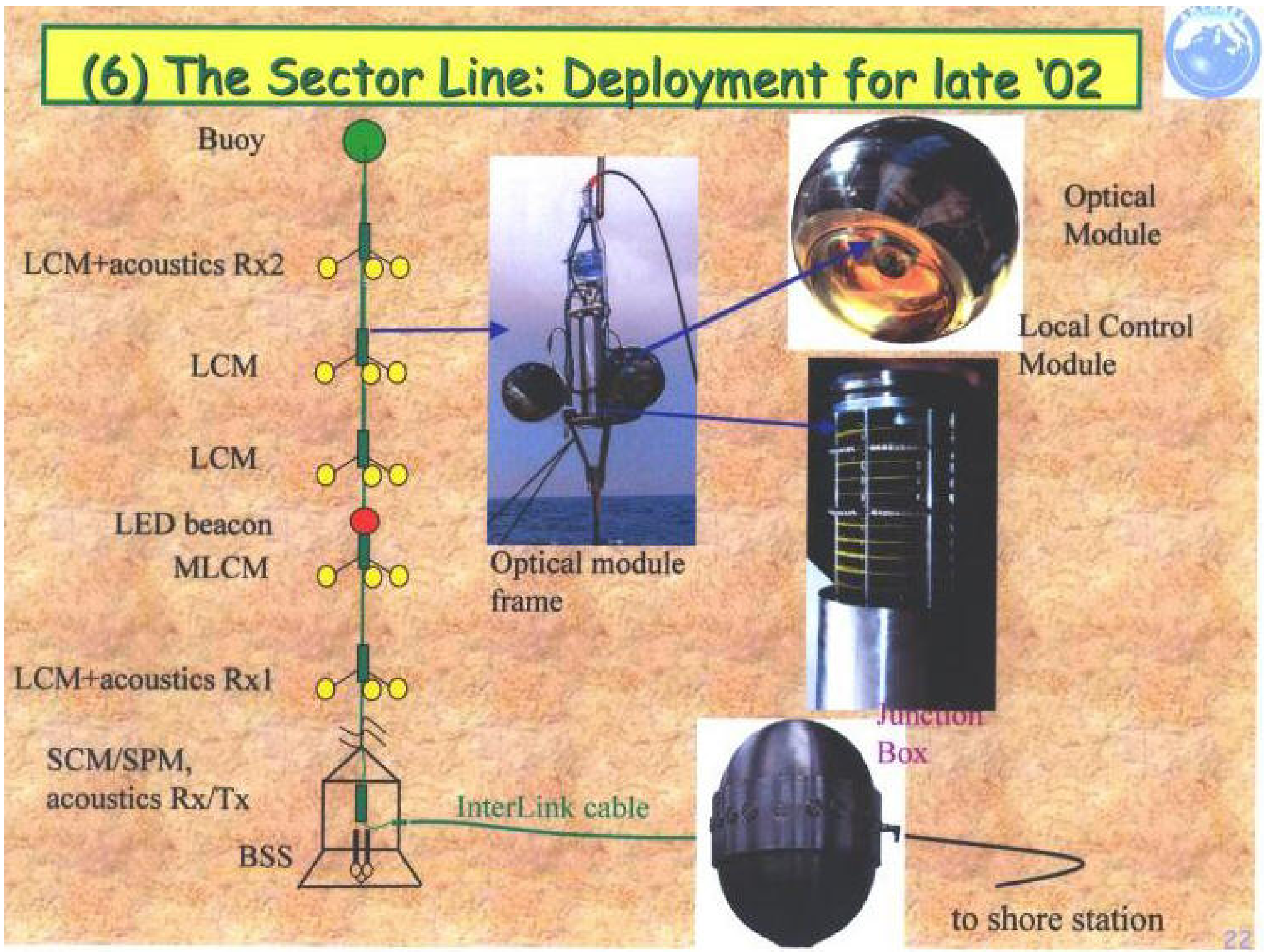
40Km SE Toulon
Depth 2400m
Shore Base
La Seyne-sur-Mer





J. Carr

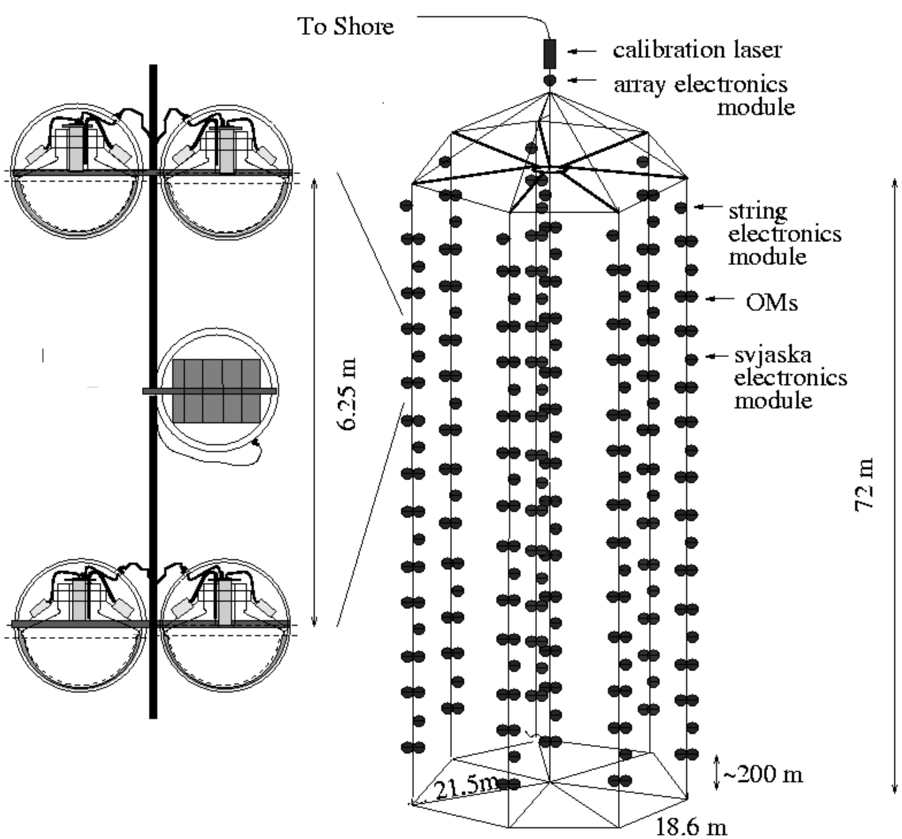
ANTARES Prototype Connected March '03
1/12 strings deployed

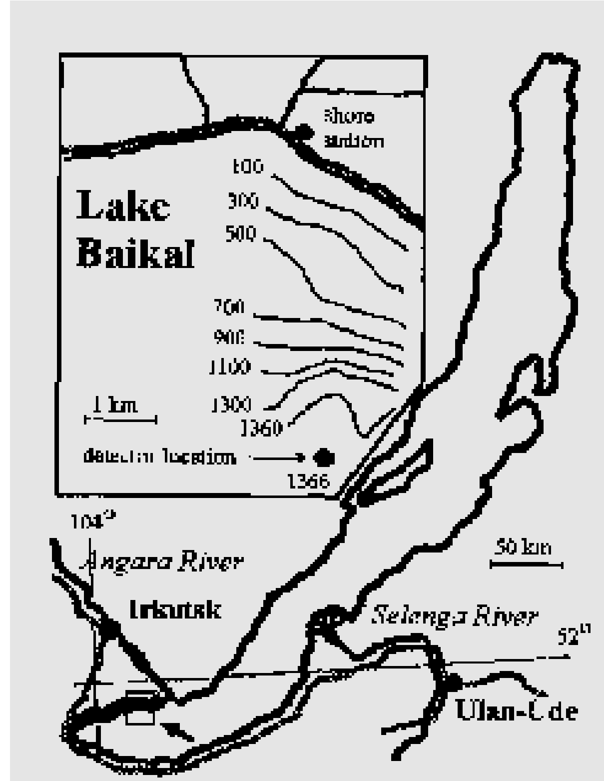


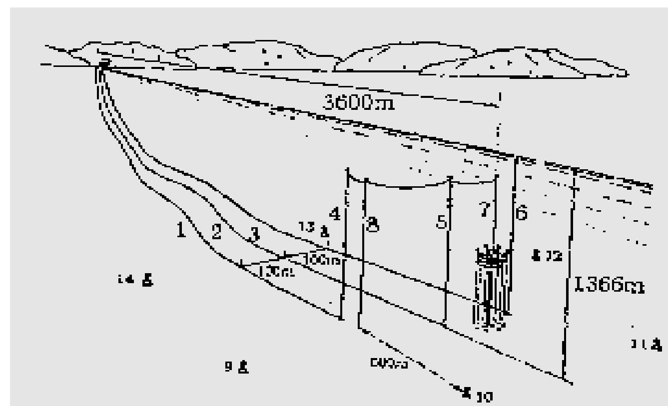
BAIKAL Project

Lake Baikal, Siberia:
surface frozen in winter

1993 36 Optical Modules
1998 192 Optical Modules

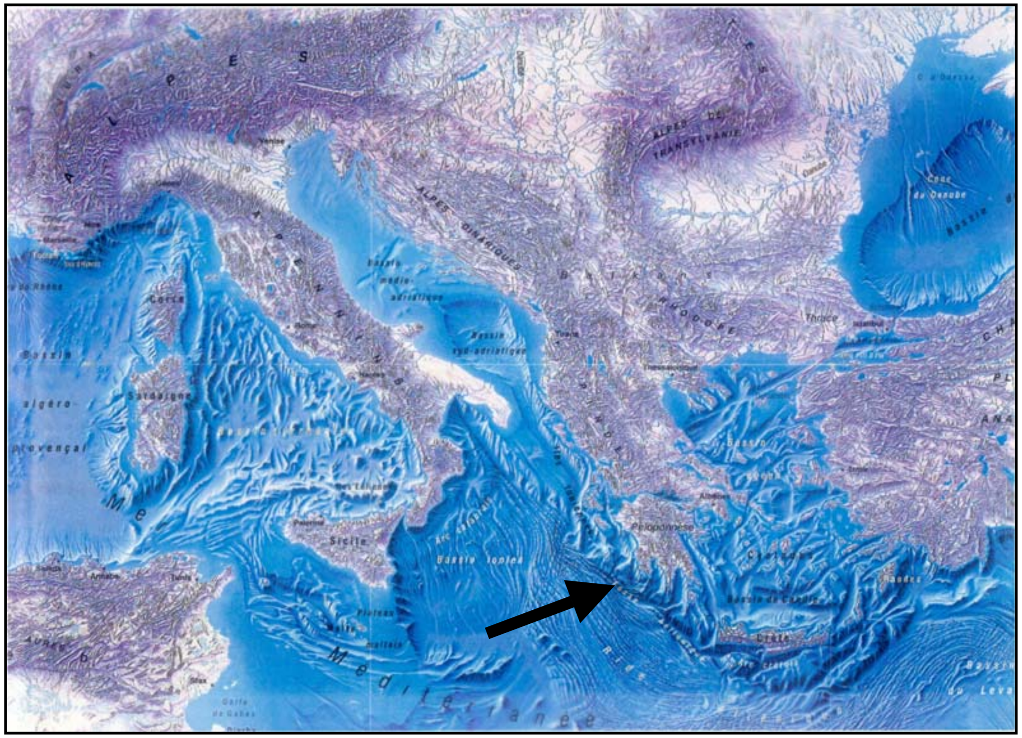


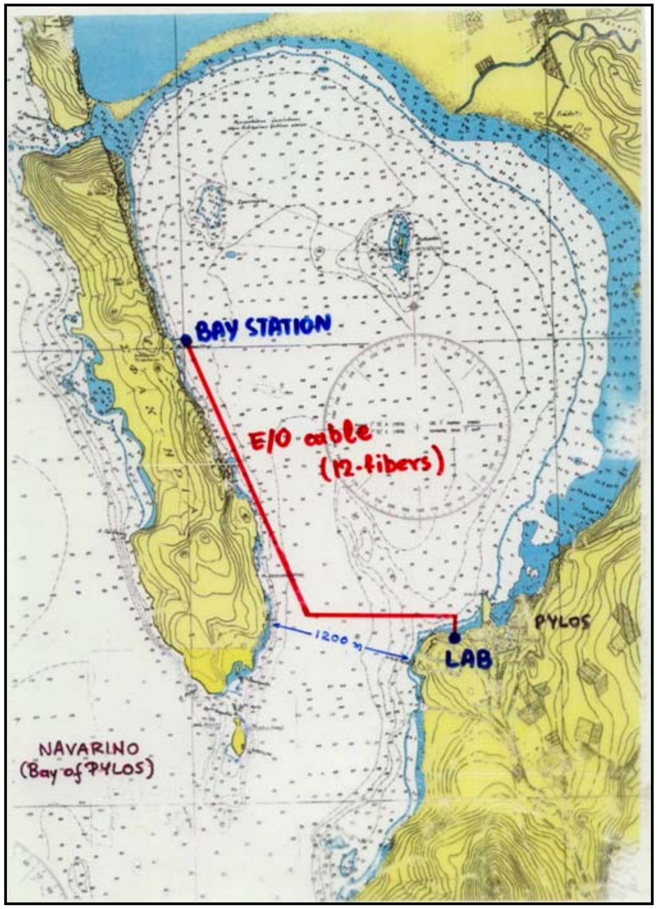




NESTOR

Pylos, Greece

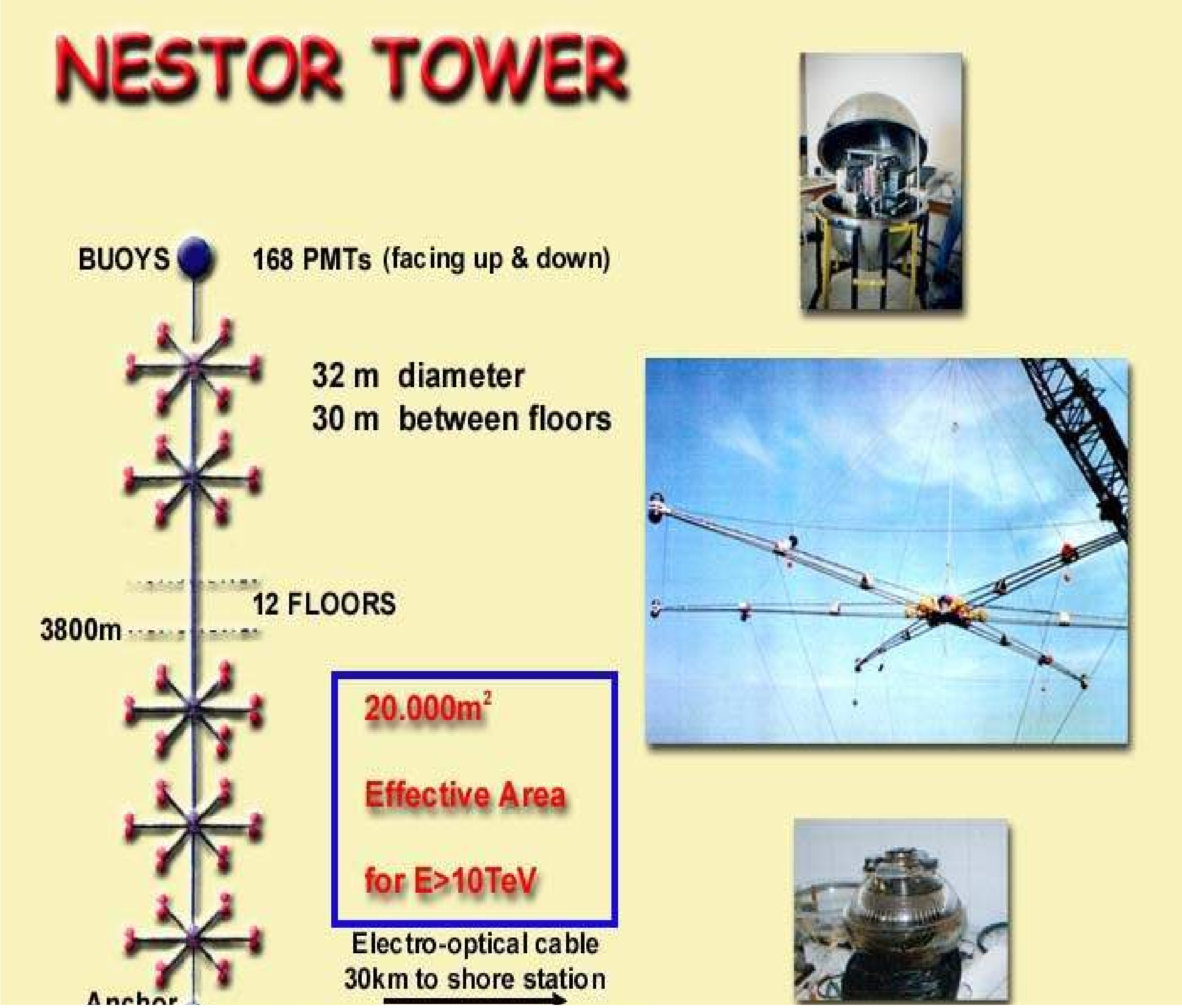




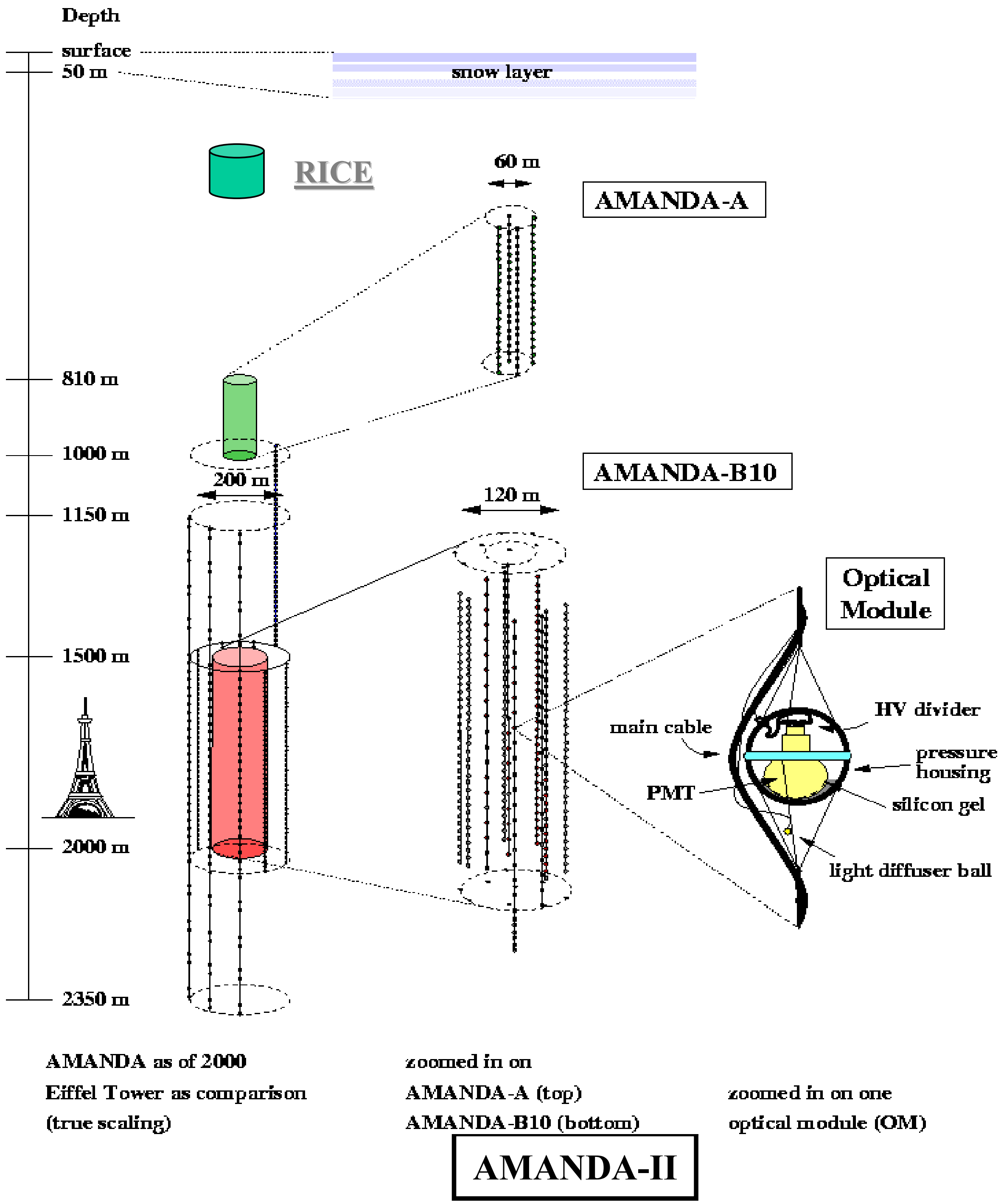
Pylos

NESTOR Project
Pylos, Greece 3800m depth

~1991 Started
1992 Counted Muons
'92-'01 Many ocean tests, build lab and insfrastructure
2000 Lay Cable to site
2001 Repair cable,
2003 Deploy 1-floor
2004 Full tower
200? Deployment of 7 NESTOR towers



AMANDA



Amanda-II:
677 PMTs
at 19 strings

(1996-2000)

AMANDA RESULTS

Atmospheric Muons and Neutrinos

... are natural calibration tools

Much improved understanding over last 2 years:
- better detector (Amanda-B10 → Amanda-II)
- better description of ice !

Compare:
- rate
- angular distribution
- energy spectrum

Search for a Diffuse Extraterrestrial Flux

Diffuse Flux

Two cases:

a) upward muons (+ downward muons, for E>1 PeV)

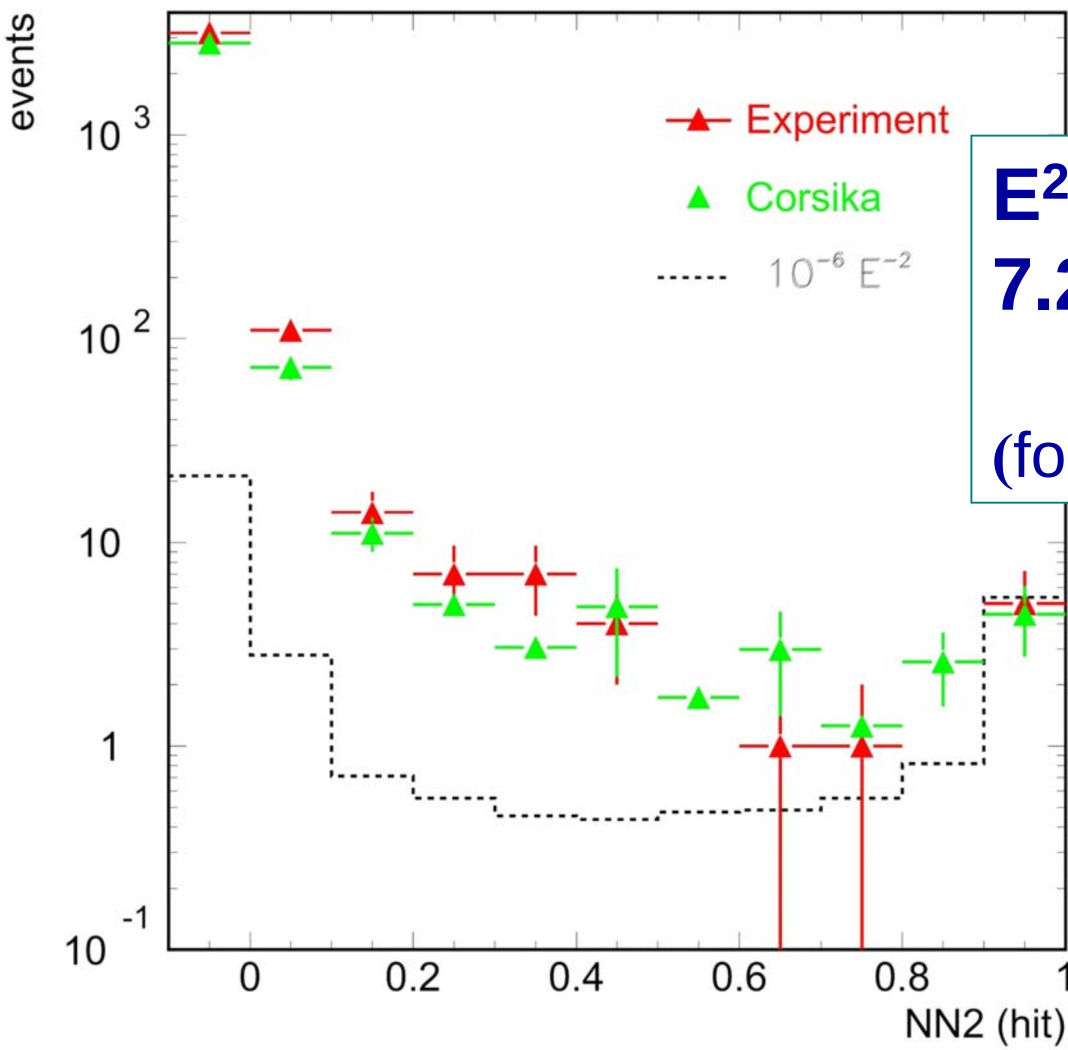
-Search for excess over atm. Nu MC

b) Cascades (E-estimate possible here...)

-Require E>Emin, count evts.

No signals found→Limits set

AMANDA B10,1997 data, upcoming mu



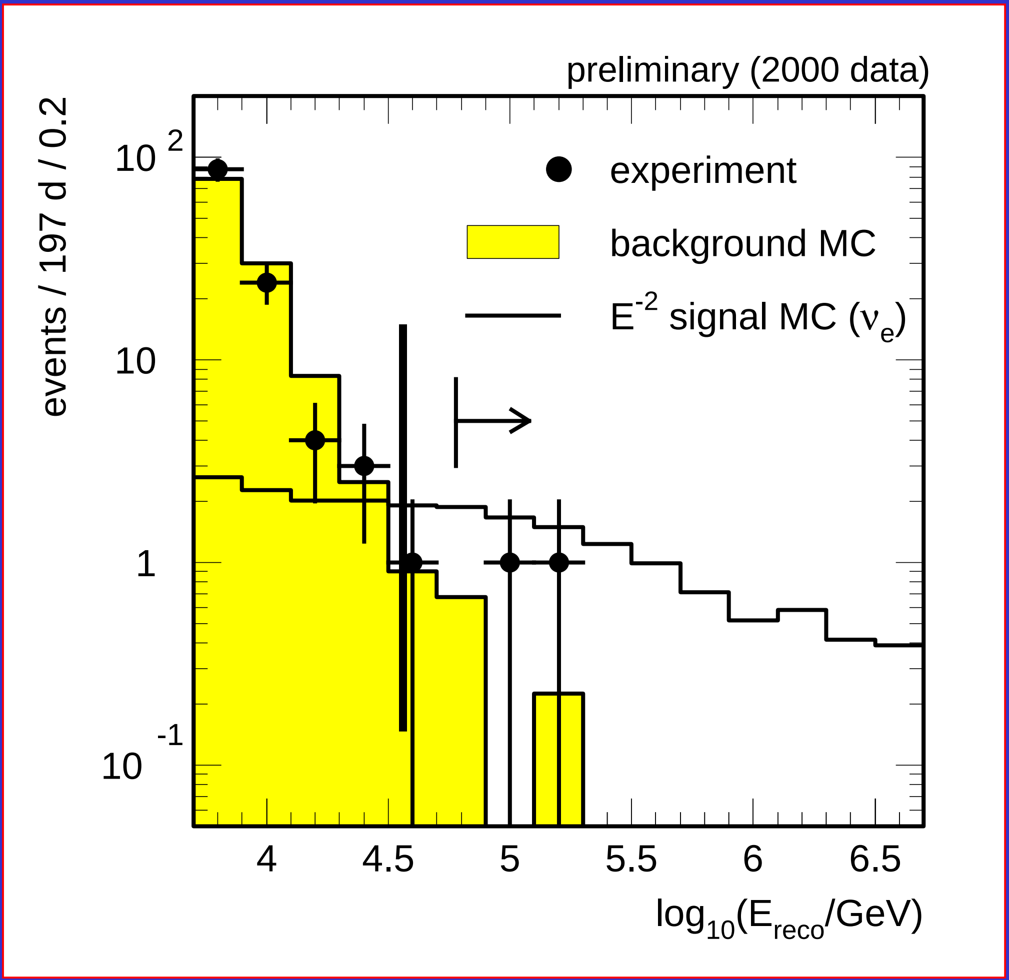
$E^2\,\Phi <$

$7.2 \cdot 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}

(for $2.5 \cdot 10^{15}$ eV – $5.6 \cdot 10^{17}$ eV)

UHE selection:
Neural Net Parameter
NN2 for neutrino vs.
atm muon separation

Cascade energy spectrum (2000 data)

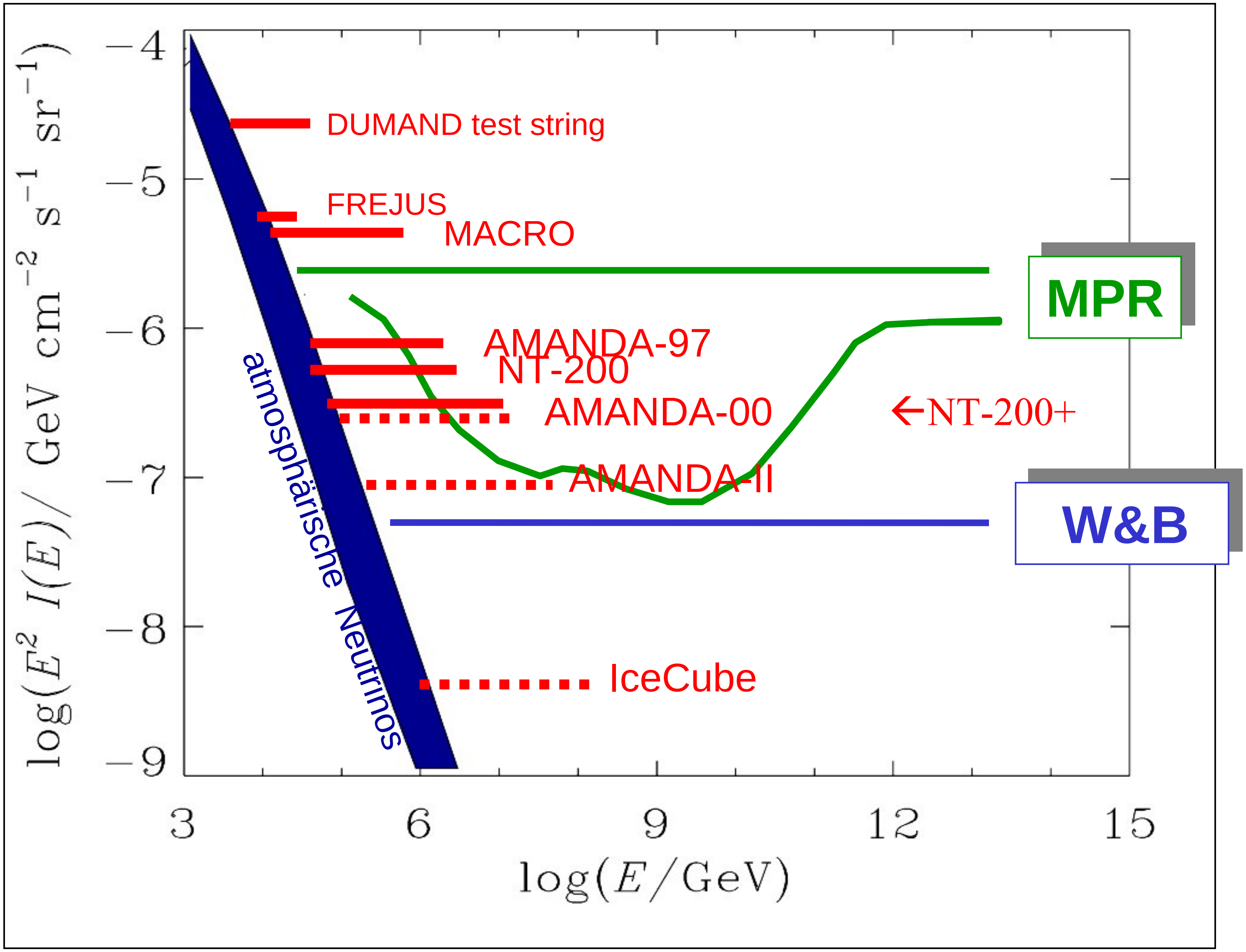


Energy cut chosen by MC Optimization (see next slide)

2 events passed all cuts

Background	Expectation
Atmospheric muons	**$0.45^{+0.5}_{-0.3}$**
Conventional atmospheric ν	**$0.05^{+0.05}_{-0.02}$**
Prompt charm ν	**0.015-0.7**
Sum (w/o charm)	**$0.50^{+0.5}_{-0.3}$**

Diffuse fluxes: theoretical bounds and experimental limits

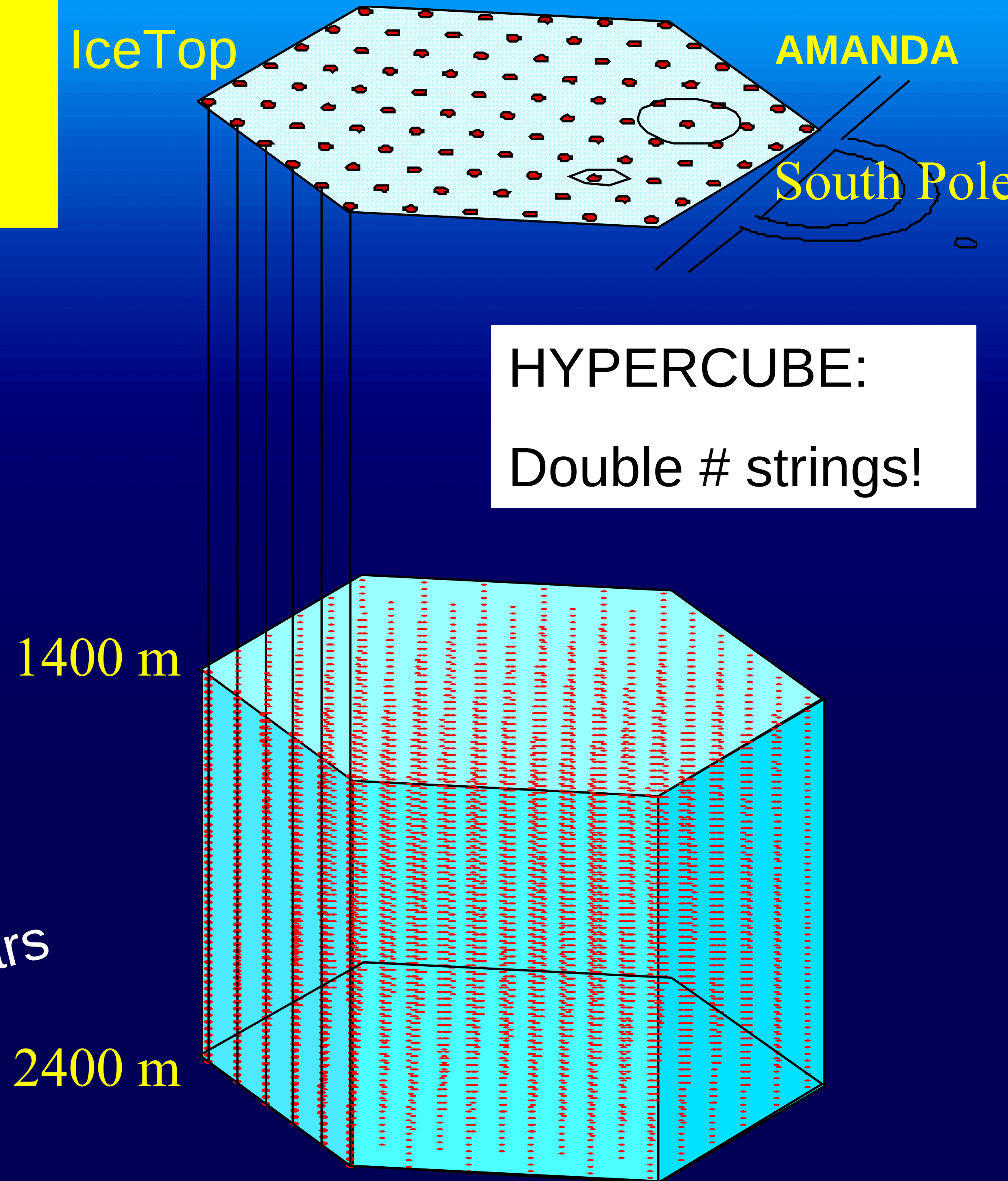


IceCube

- 80 Strings
- 4800 PMTs
- Instrumented volume: 1 km^3
- Installation: 2004 -2010

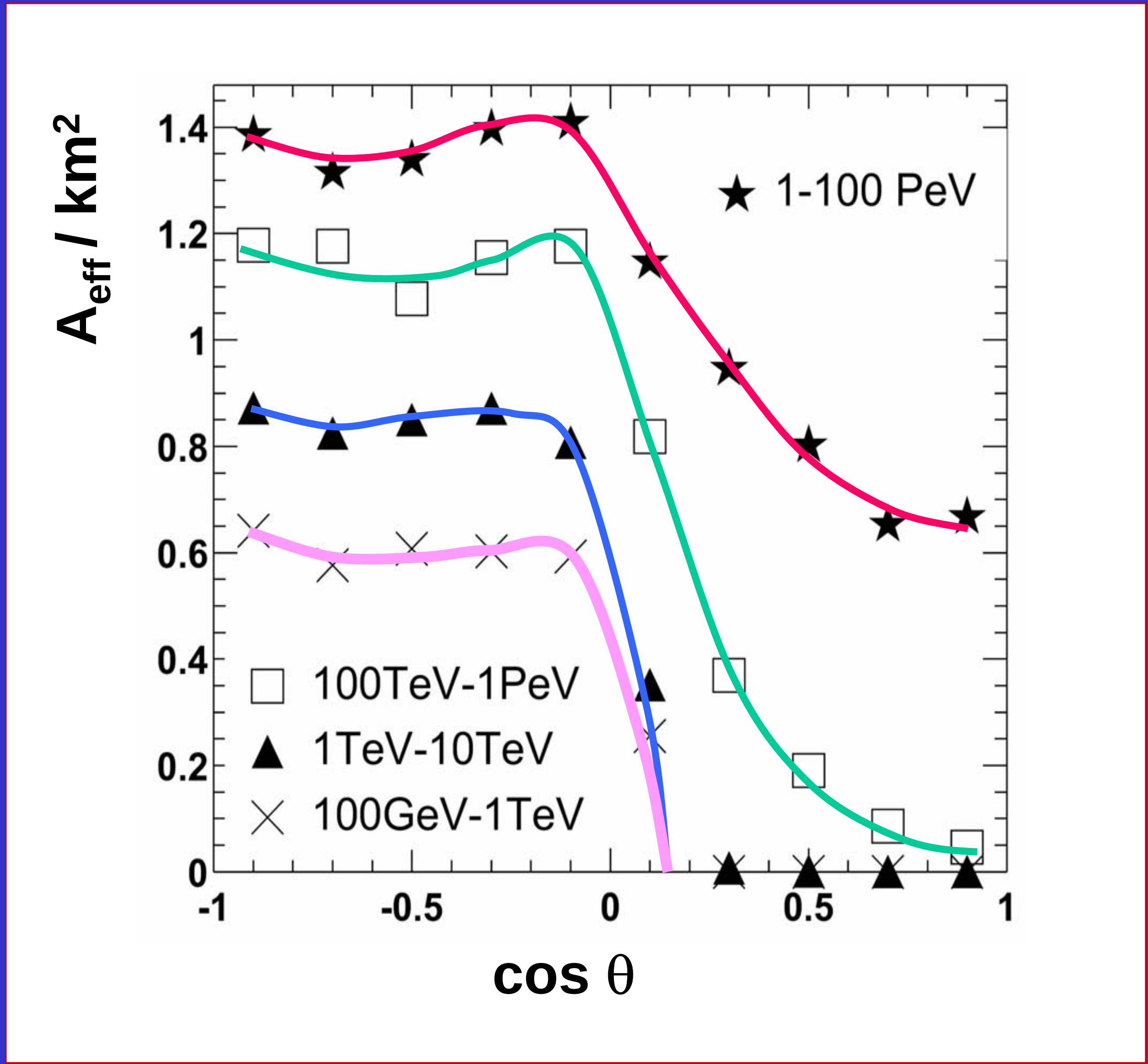
HYPERCUBE:

Double # strings!



~ 80.000 atm.ν per years

IceCube Effective Area



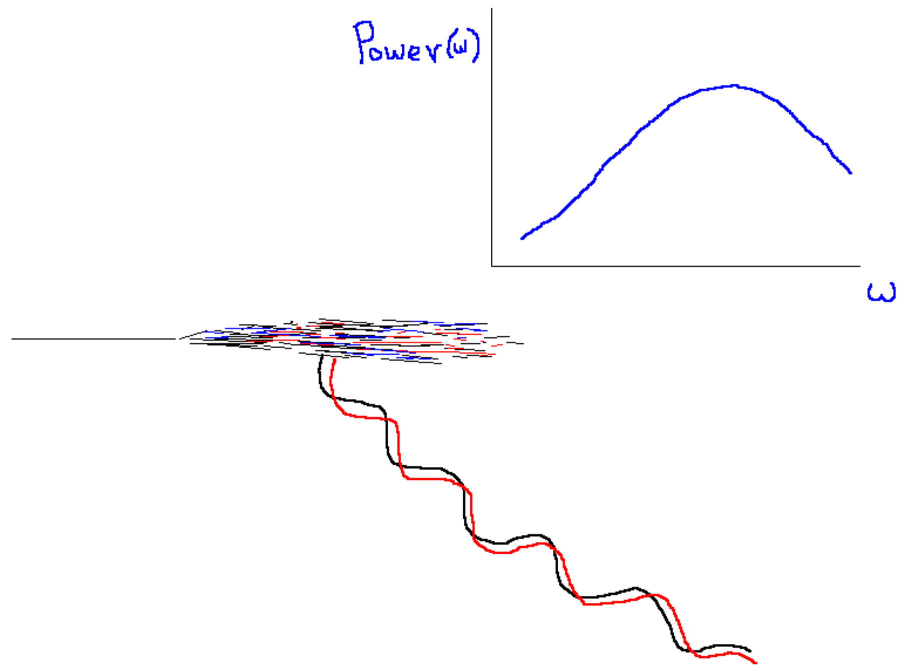
There is a spectre haunting optical.....

..it is the spirit of Radio.

Radio Emission From EM-Showers: IV

Power spectrum turns over at scale $1/R_{moliere}$ (transverse shower size); $R_{moliere}$~10 cm

Coherence→1 GHz

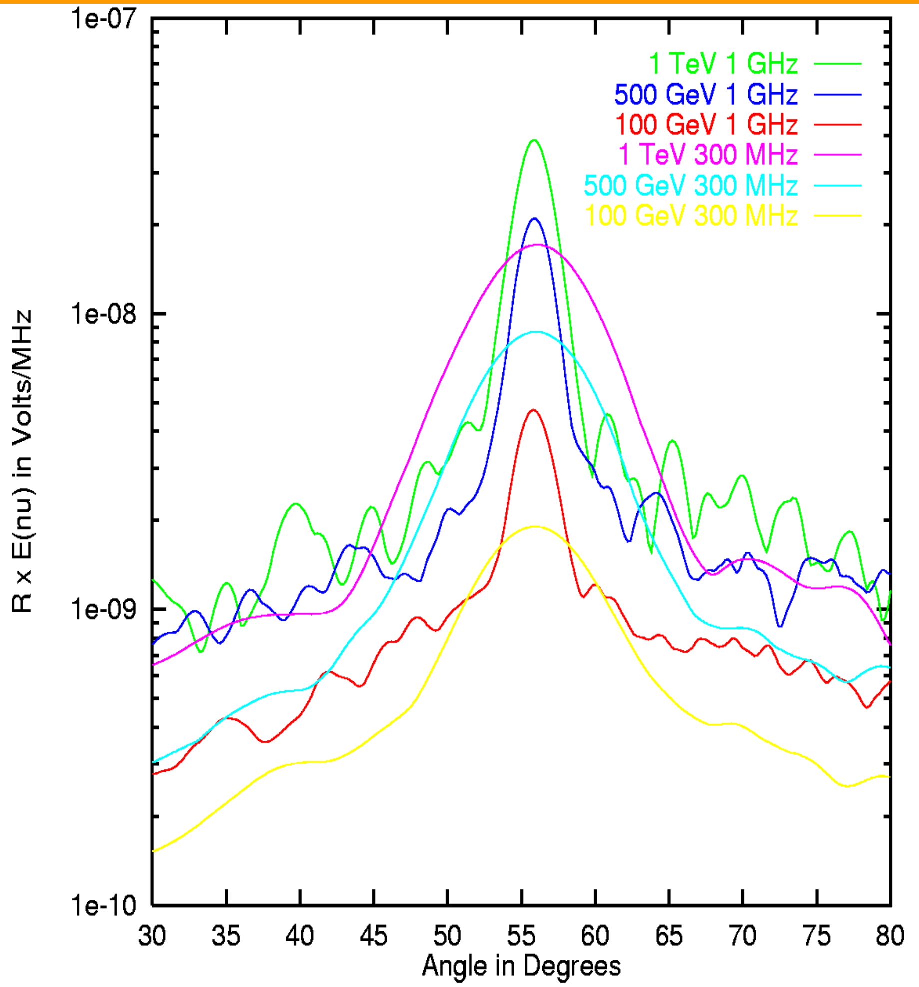


Signal characteristics ~ single-slit diffraction

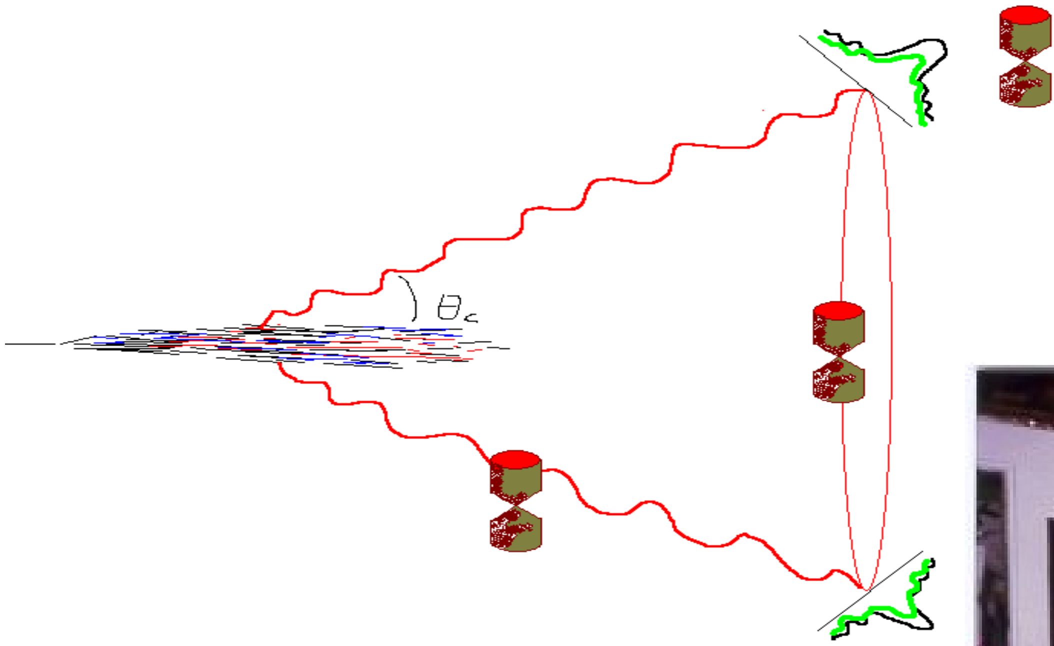
EM Pulse Generation G4 simulations

- Pulse increases with frequency, (and, of course, energy).
- Narrows with frequency.
- Again, single-slit diffraction analogy.

Simulations verified in both E-field strength + polarization by SLAC testbeam experiments (2001-03)



RICE dipole radio antennas – f_0~500 MHz; λ~60 cm.



Antennas are calibrated & stress-tested pre-deployment

Optical/Radio Comparison

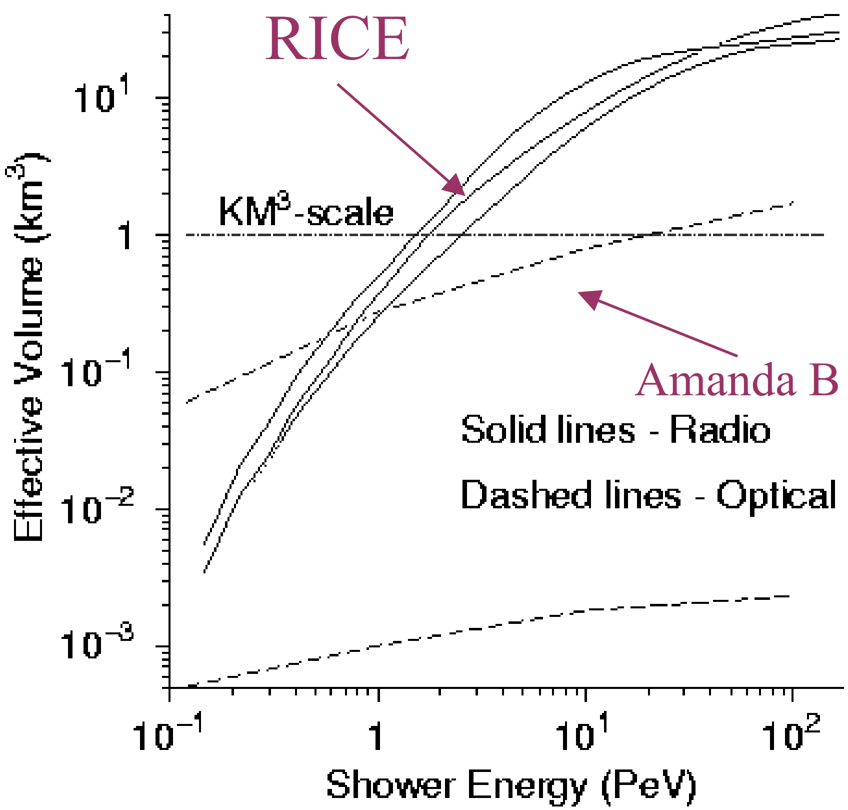
Optical : ♦ Thru-going muons

♦ best in range up to 1 PeV

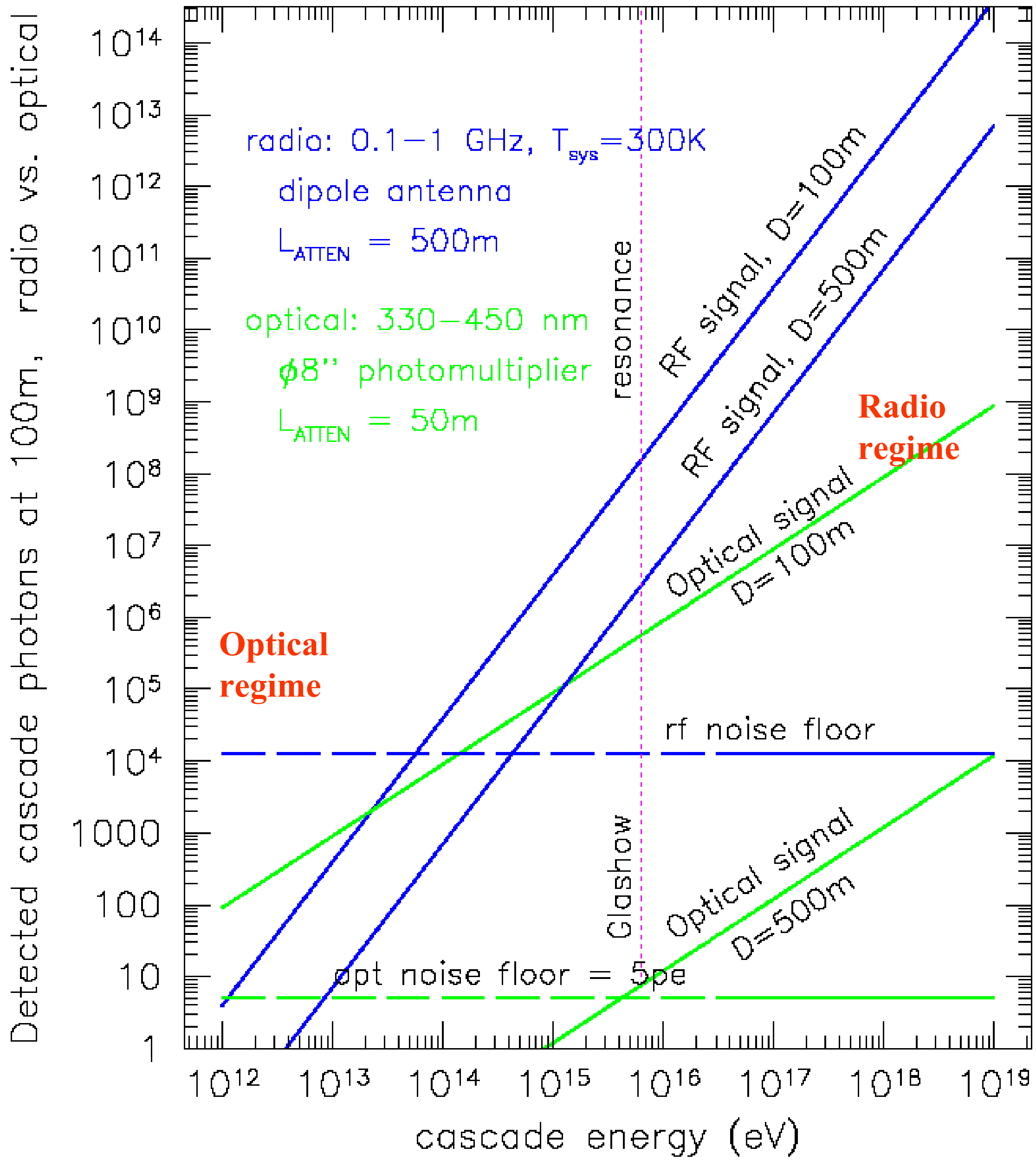
Radio: ♦ Cascade detection

♦ Ice transparency allows detection at R~km

♦ Energies~ >PeV

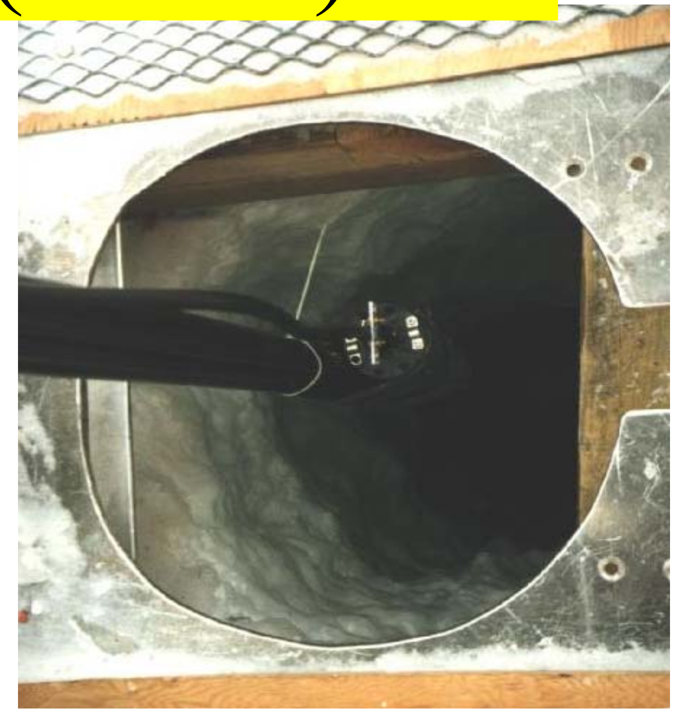


2nd simulation comparison: Radio vs. optical



RICE (PeV-EeV) (in situ)

- 20-channel array, co-deployed with AMANDA, Rx at –200 m
- RICE Calibration (Astropart. Phys.02)
- RICE Results (Astropart. Phys03 + ICRC03)



ANITA/GLUE/FORTE (in-air)

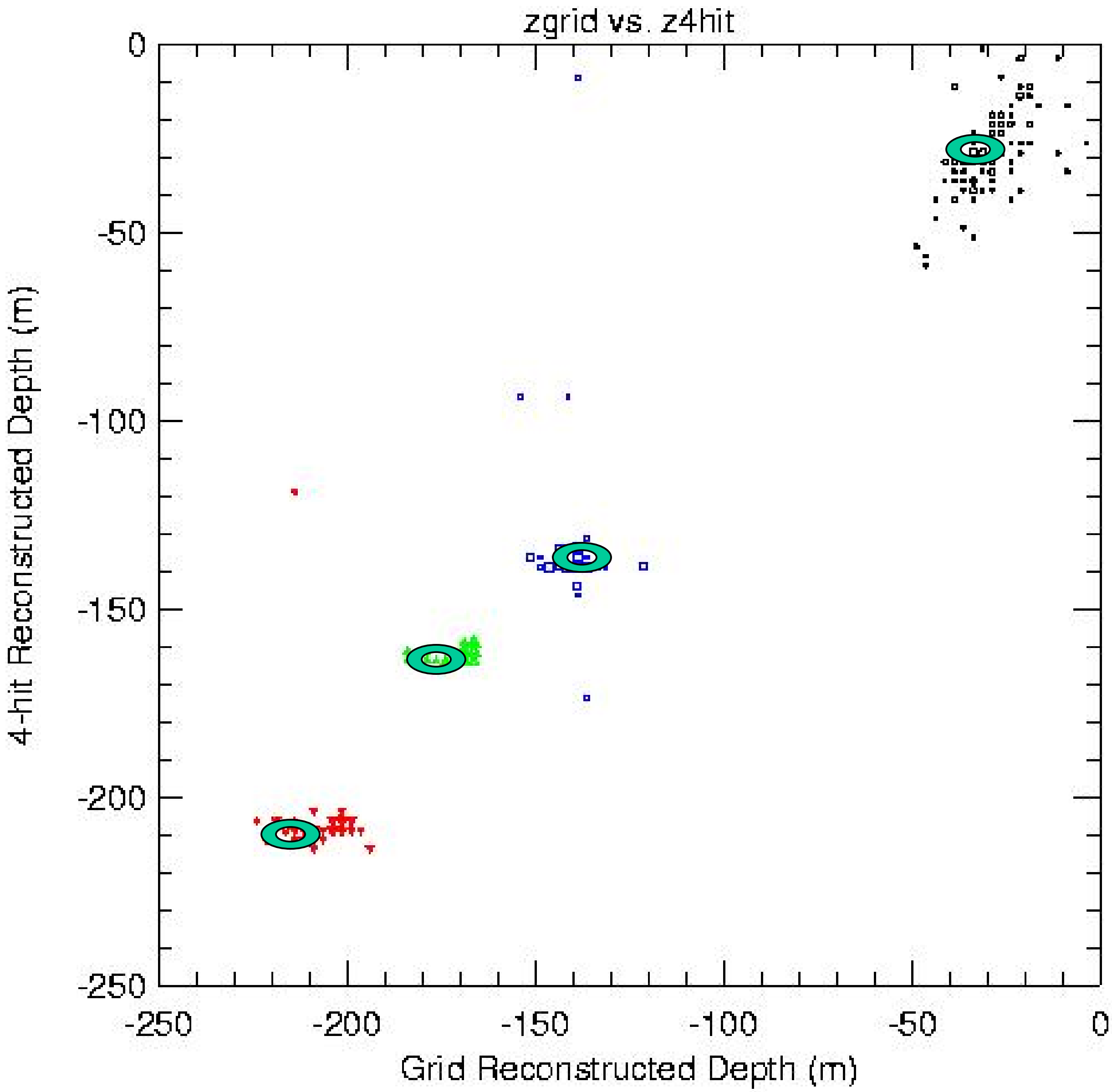
•GLUE/FORTE use pre-existing data/facilities;

•ANITA test flight in 2003-04 / 15-day flight 2006/7

Radio Technique: **RICE**
CALIBRATION BENCHMARKS

- Demonstrate vertex reconstruction
  - Use pulse-edge from buried radio transmitters
- Demonstrate understanding of time domain (and frequency domain) waveform shape
  - Use signal shape from transmitters
- Overall absolute gain calibration
  - Calibrate to transmitter amplitude

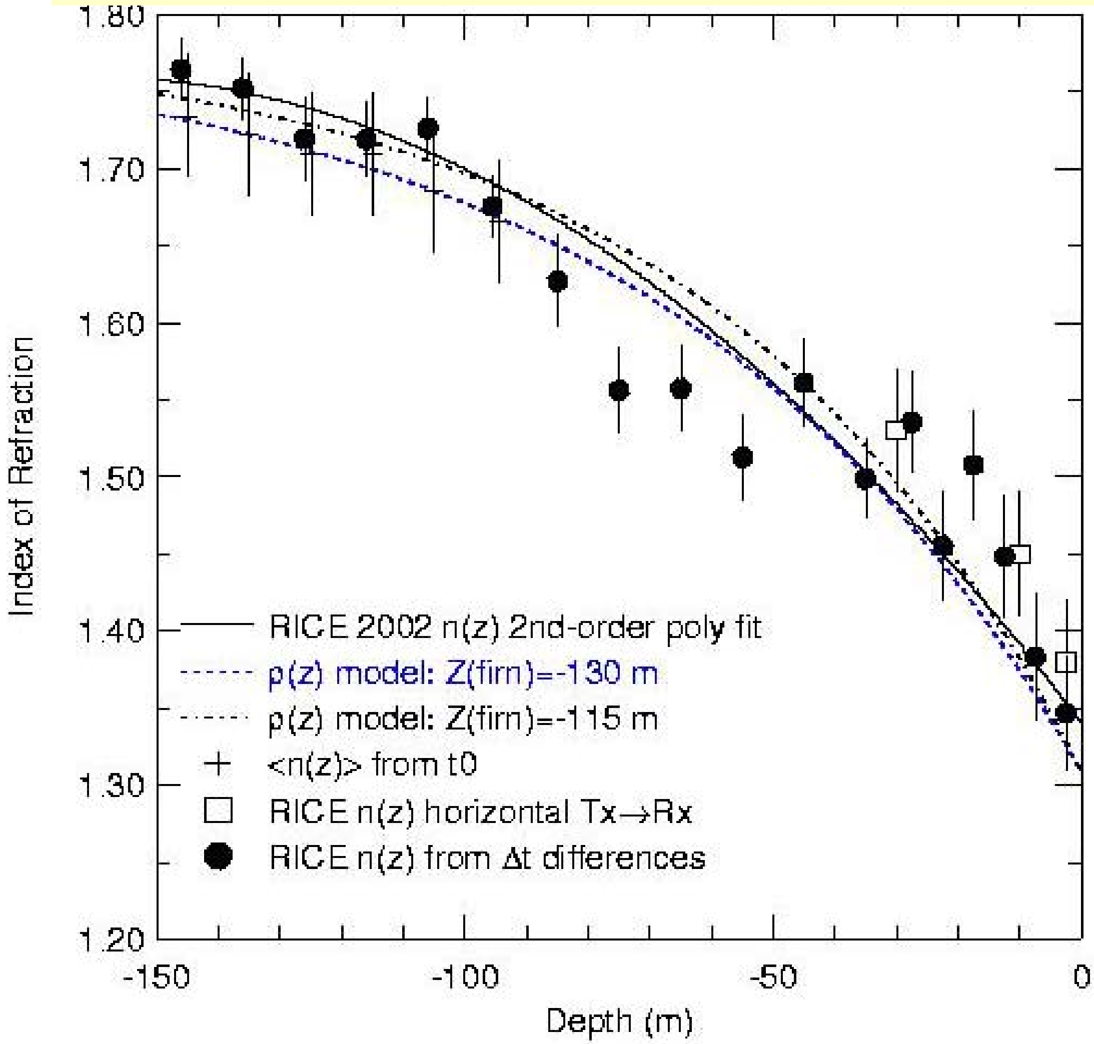
Transmitter Location Reconstruction



Surveyed z(transmitter)

- $\delta t \sim 10$ ns
- $\delta r = 10$ m nearby
- $\delta r = 0.1$ R , < 1 km
- $\delta\theta \sim 10$ deg
- $\delta E/E \sim 0.5$

Glaciology - Index of refraction measurement as f(depth) (2003) Drop transmitter into a hole; broadcast to RICE, measure c(z)

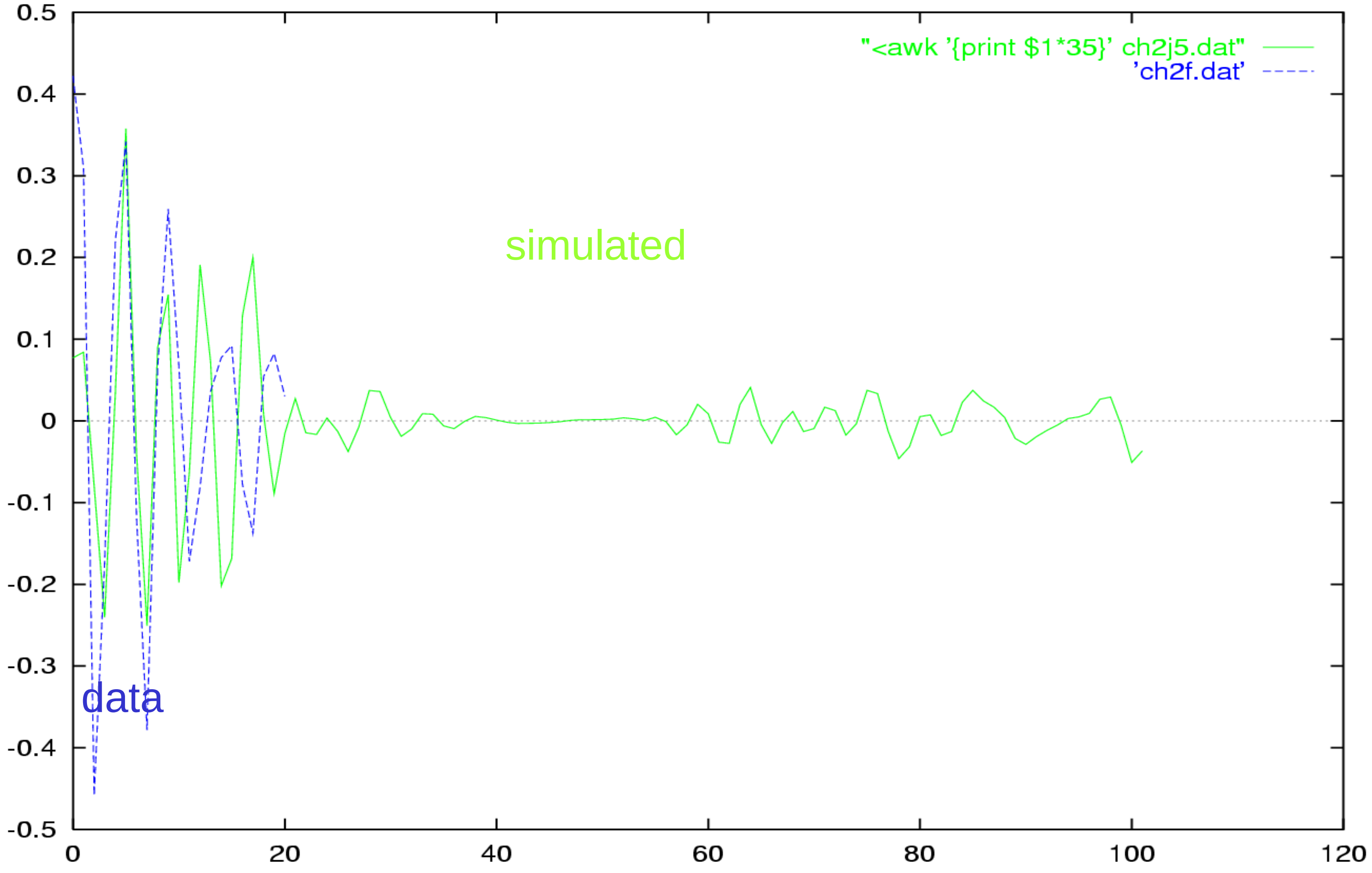


Data points: RICE data

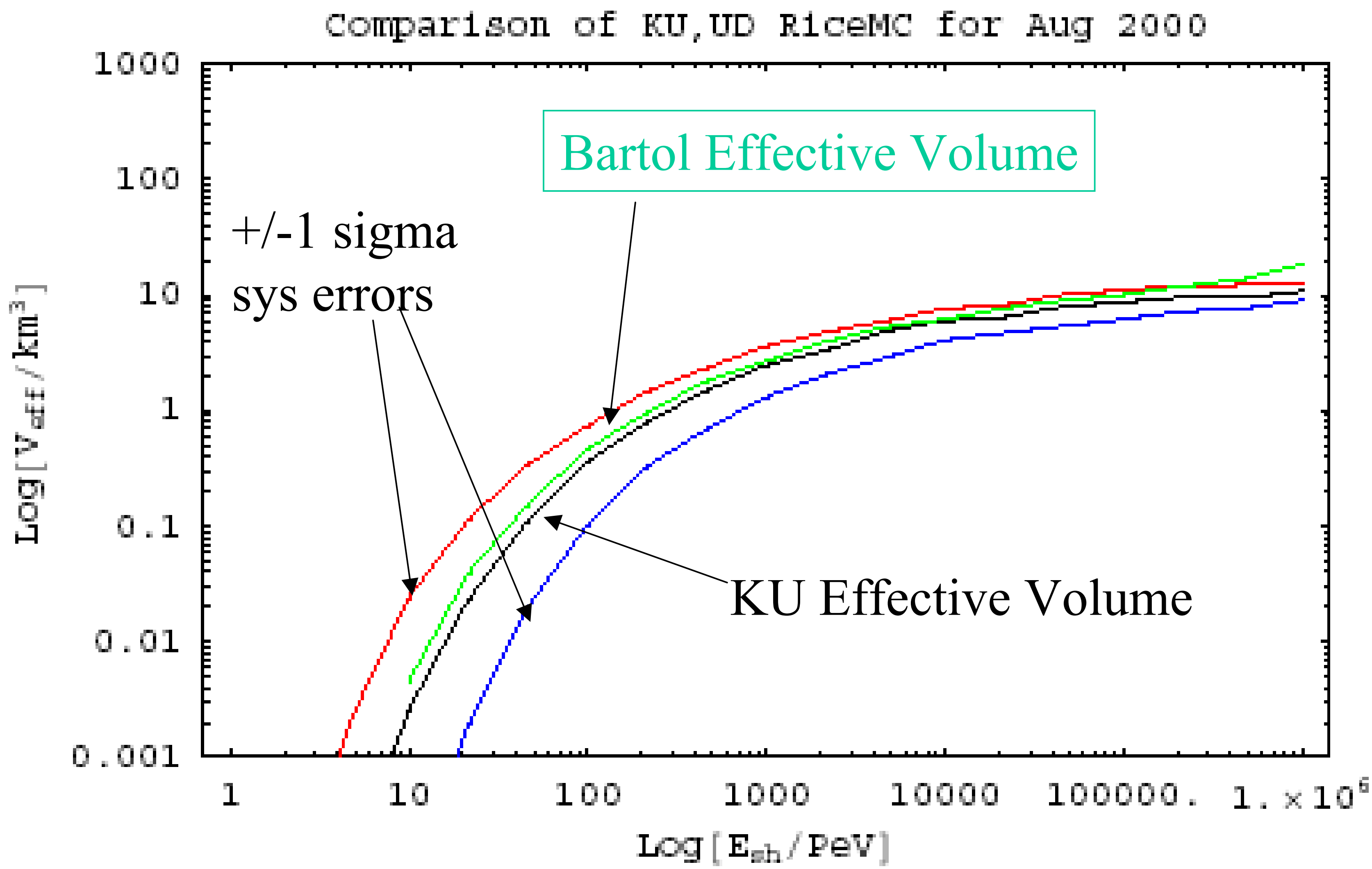
Curve: Lab measurements of n(density)

RICE Tx → Rx waveform sim. vs. data

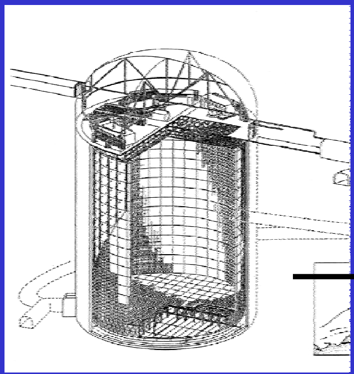
Still need to add filter phase delay in passband

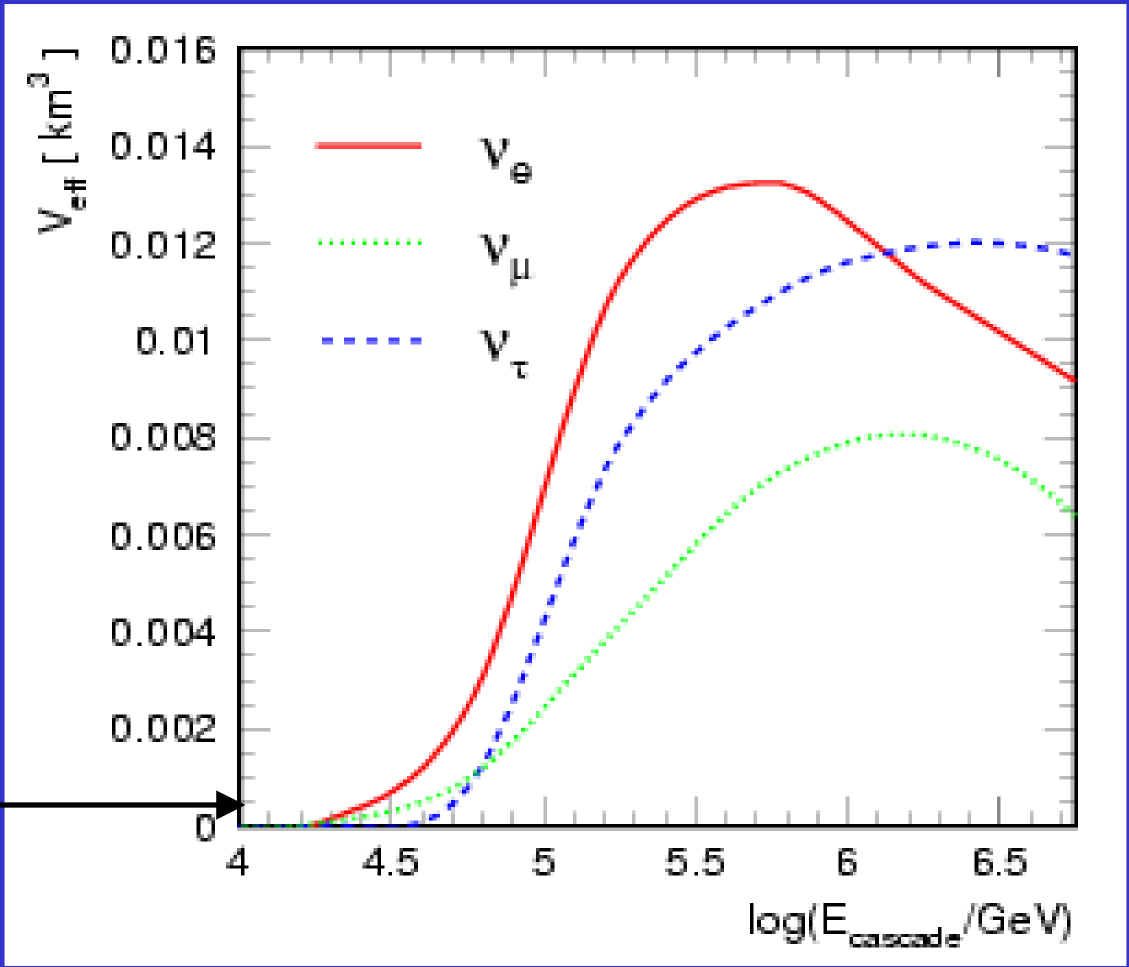


Calculation of RICE Effective Volume (2 different MC's}

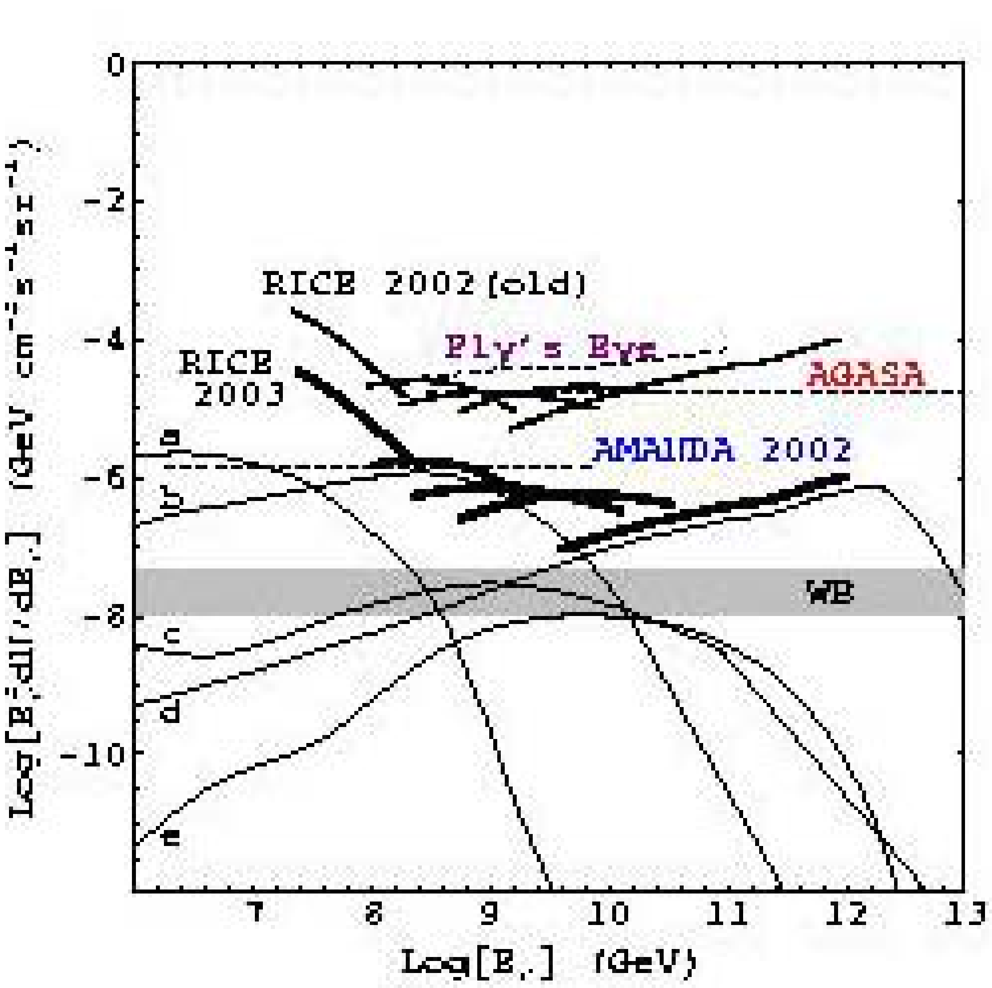


AMANDA Effective Volume: ν_e, ν_μ and ν_τ





RICE ICRC03 diffuse flux limit



Thin lines= Models

Thick lines= Exptl. UL's

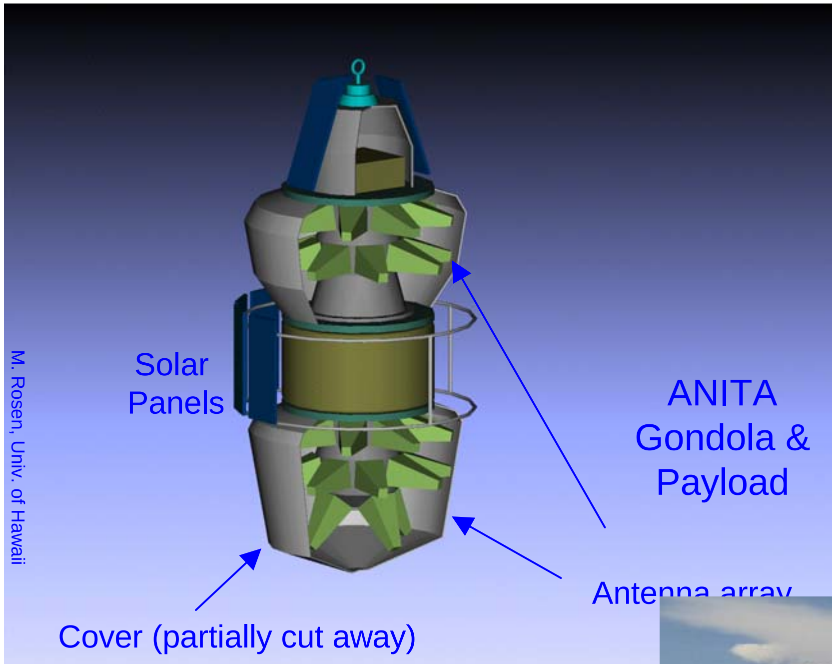
TBD: GRB, monopole, BH-analyses. Diffuse flux through 2003

Future: 2004-10: Plan co-deploy with ICE3

1.5x per-channel sensitivity;

50x gain in channels

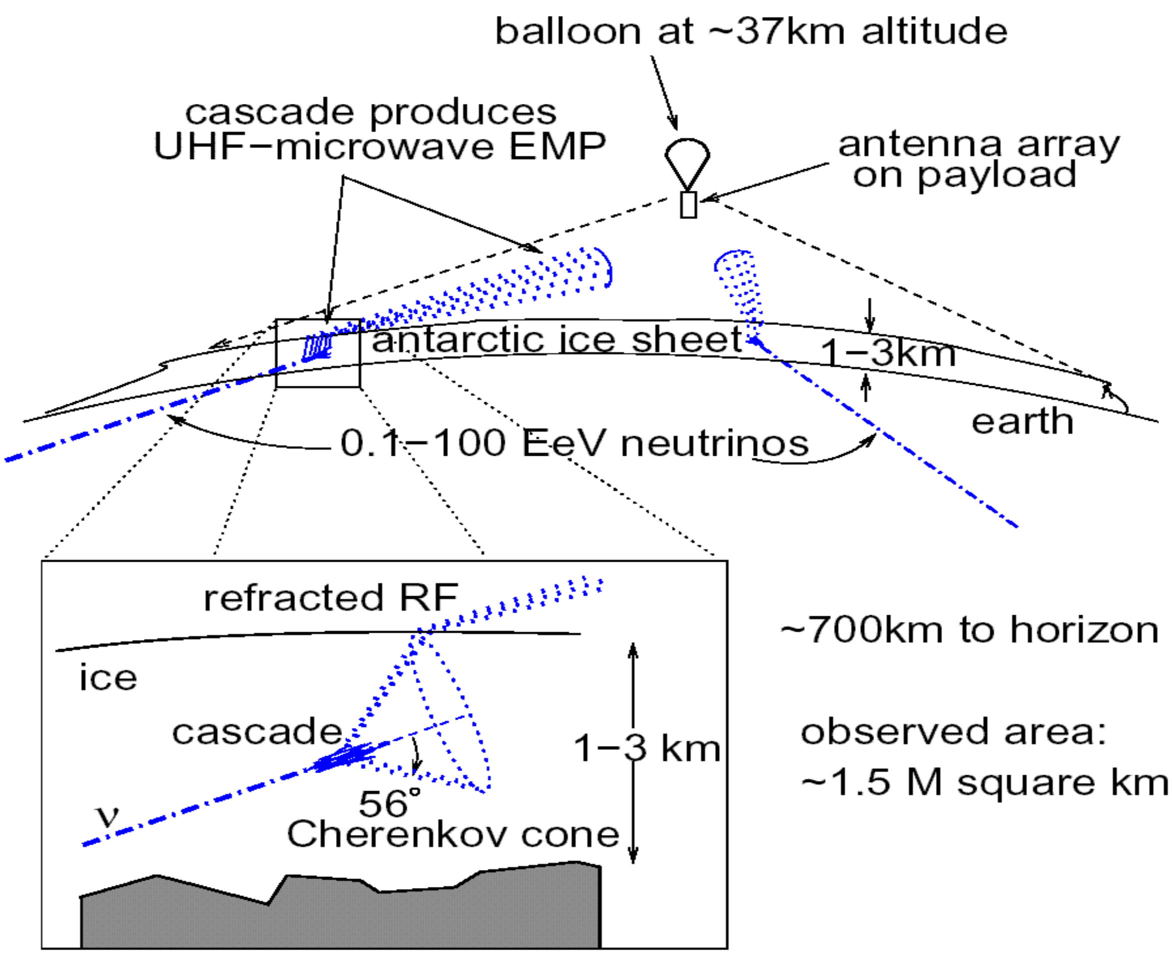
Antarctic Impulsive Transient Antenna (ANITA)



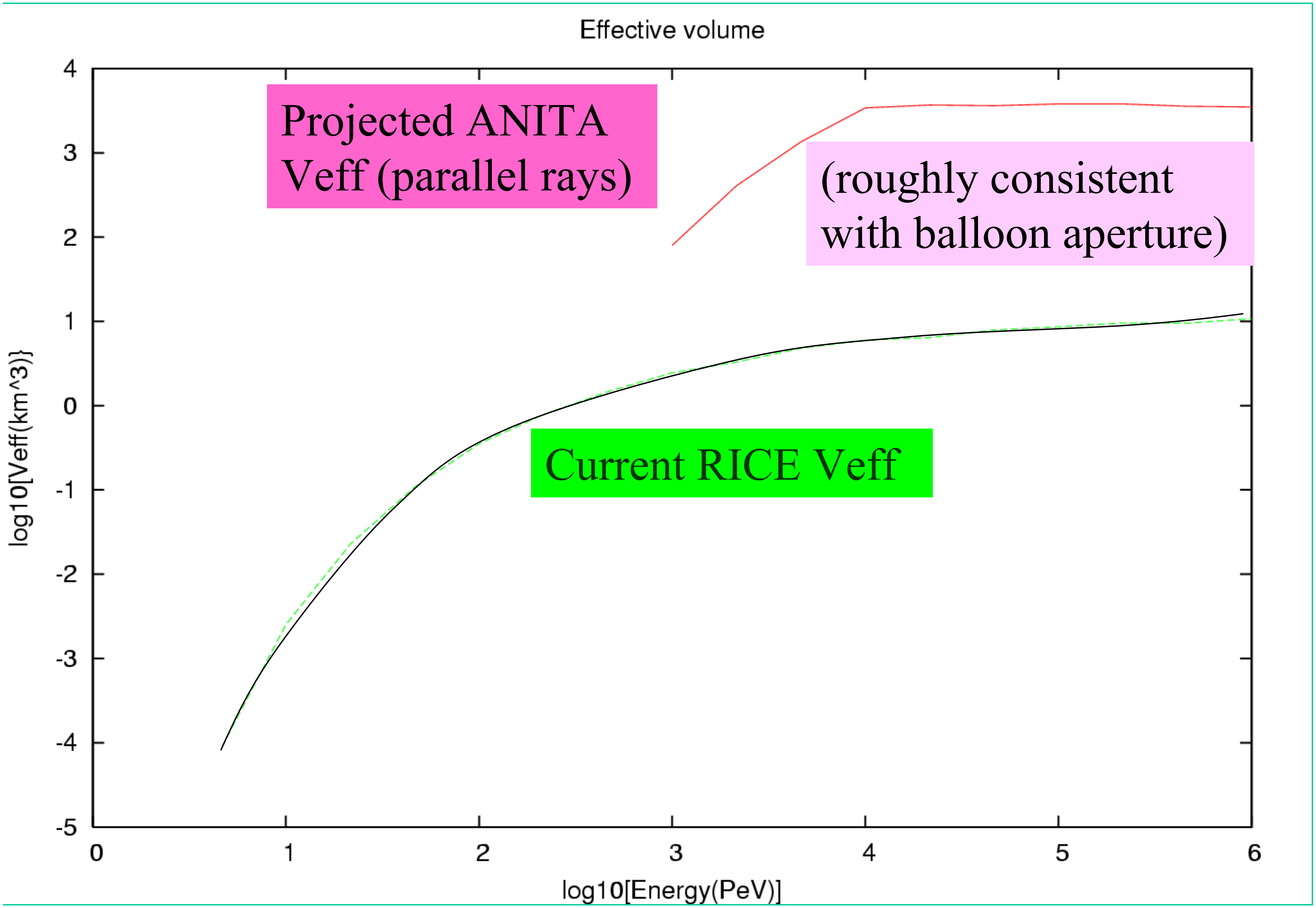
- ANITA Goal: Pathfinding mission for GZK

U. Of Hawaii, UC Irvine, UCLA, Bartol Research Institute, U. of Wisconsin, Penn State U., U. of Minnesota, Cal Tech, KU, JPL

ANITA concept

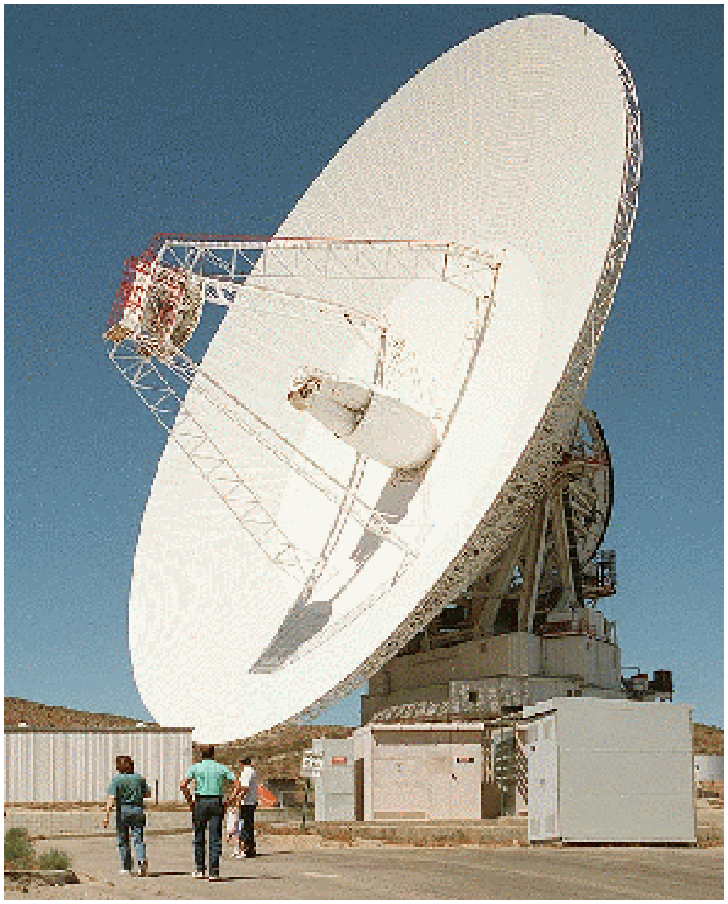


Estimate Effective Volume: $3x10^6$ km^3 x (.01) aperture=> 10^4 km3



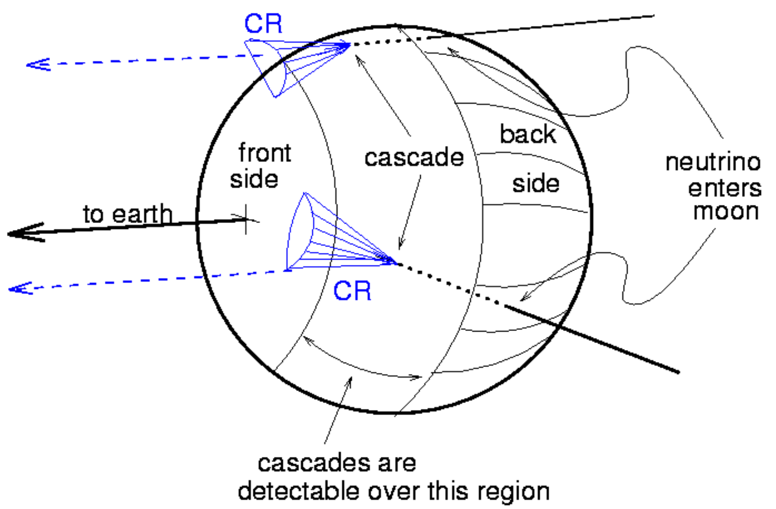
Effective volume
Projected ANITA Veff (parallel rays)
(roughly consistent with balloon aperture)
Current RICE Veff
log10[Veff(km^3)]
log10[Energy(PeV)]
4
3
2
1
0
-1
-2
-3
-4
-5
0
1
2
3
4
5
6

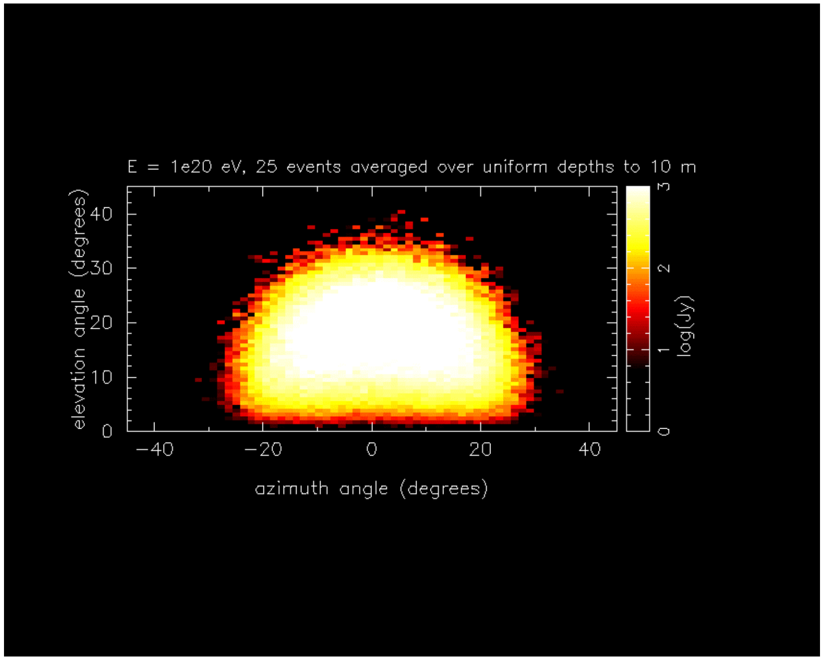
Goldstone Lunar Ultra-high energy neutrino Experiment (GLUE)
[Similar activity in Russia]



- Utilize NASA Deep Space telecom 70m antenna DSS14 for lunar RF pulse search--fill gaps in SC sched.
- First observations late 1998:
  - approach based on Hankins et al. 1996 results from Parkes 64 m telescope (10hrs live)
  - idea due to I. Zheleznykh, Neutrino `88
  - utilize active RFI veto
- Preliminary data taken 1999 through present, with continuing improvements in configuration and sensitivity.
- First results and limits available.

Lunar Regolith Interactions & RF Cherenkov radiation

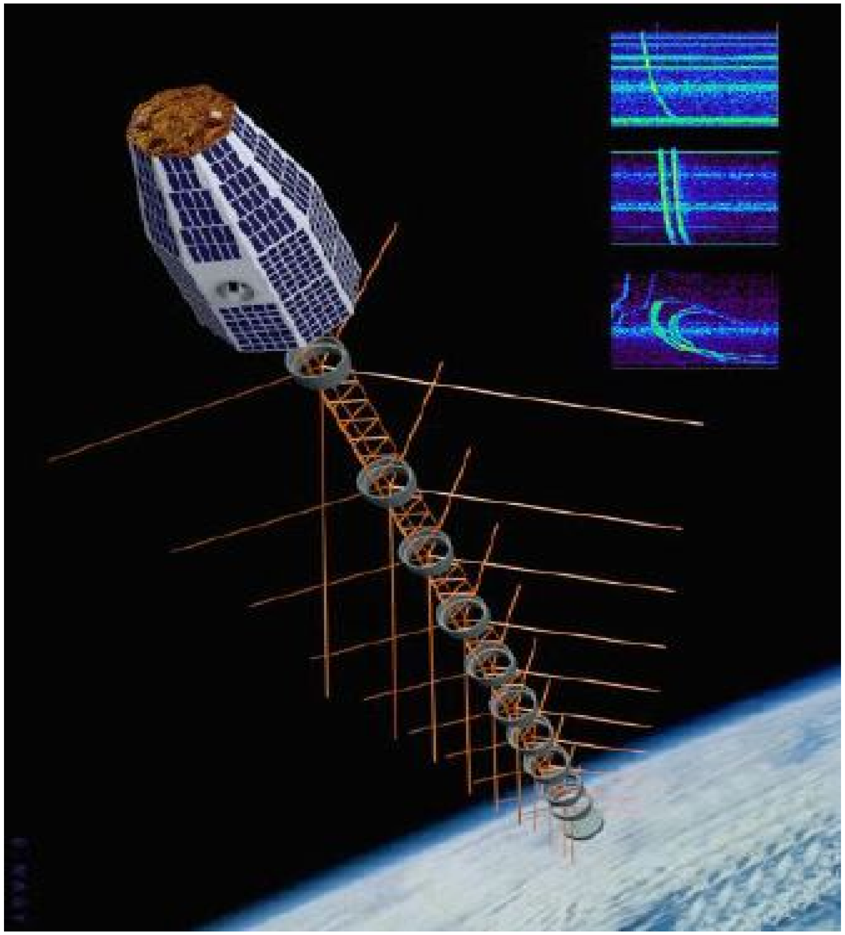




- At ~100 EeV energies, neutrino MFP in lunar material is ~60km.
- R_{moon} ~ 1760 km, so most detectable interactions are grazing rays, but detection not limited to just limb.
- Refraction of Cherenkov cone at regolith surface "fills in" the pattern, so acceptance solid angle is ~50 times larger than apparent solid angle of moon.

FORTE:

An Existing Space-based EHE Neutrino & Cosmic Ray Radio Detector?

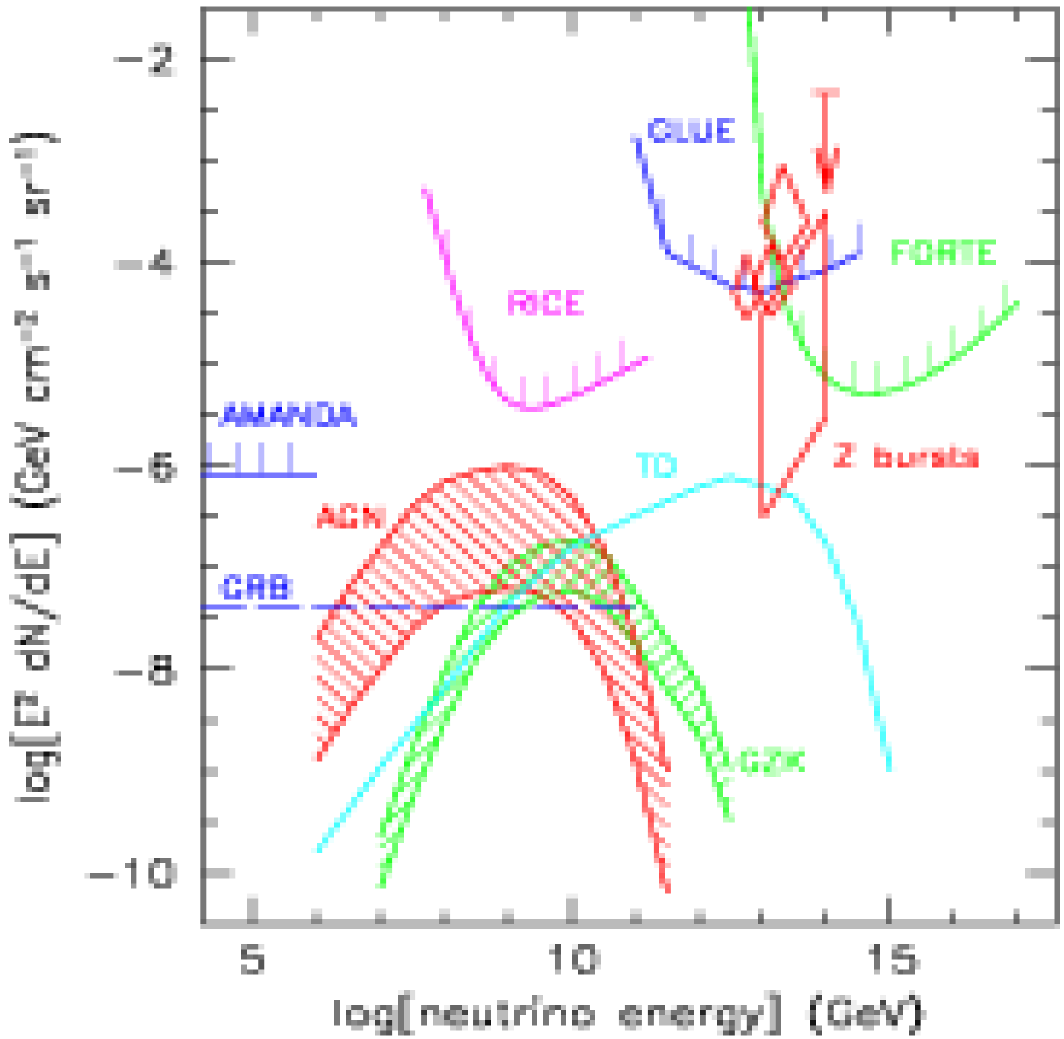


Fast On-orbit Radio Transient Expt.

- Pegasus launch in 1997
  - 800 km orbit, 3 year planned life
  - Testbed for non-proliferation & verification sensing
  - Dept. of Energy funded, LANL & Sandia construction & operation
  - Scientific program in lightning & related atmospheric discharges
- 30-300MHz range, dual 20 MHz bands, 16 1MHz trigger channels
  - ~2M triggers recorded to date
- FORTE can trigger on radio emission from Giant air showers E~100 EeV
- Preliminary estimates: could be ~50-100 100 EeV cosmic ray events in sample

FORTE/GLUE/RICE02

Forte has collected RF data in scan of Greenland ice; convert non-observation of signals into UL on neutrino flux.



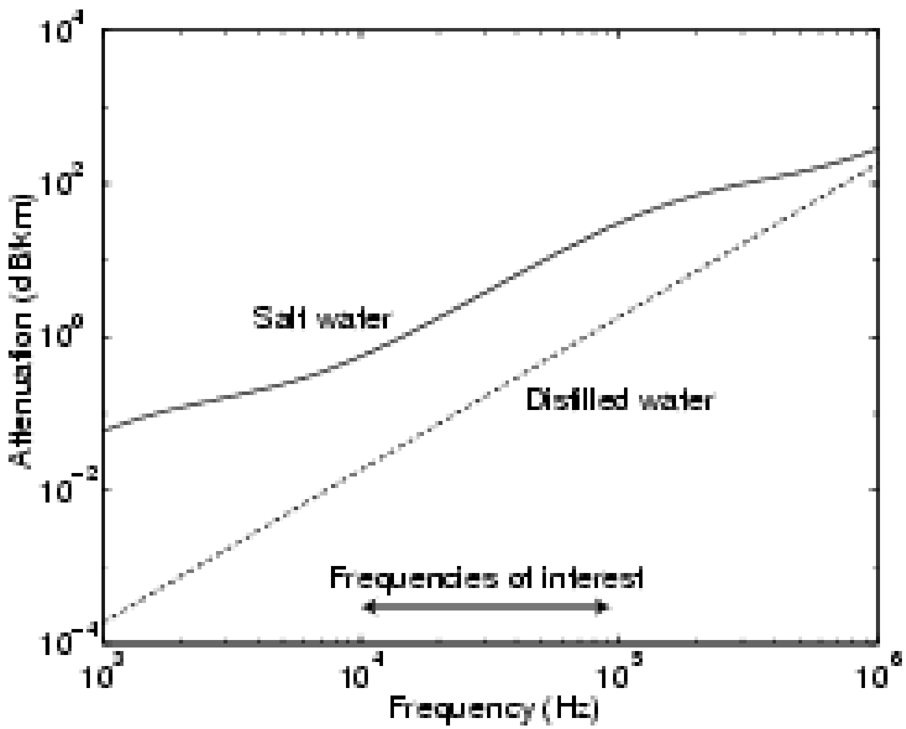
Nu astronomy active in Antarctica!

Other Possibilities

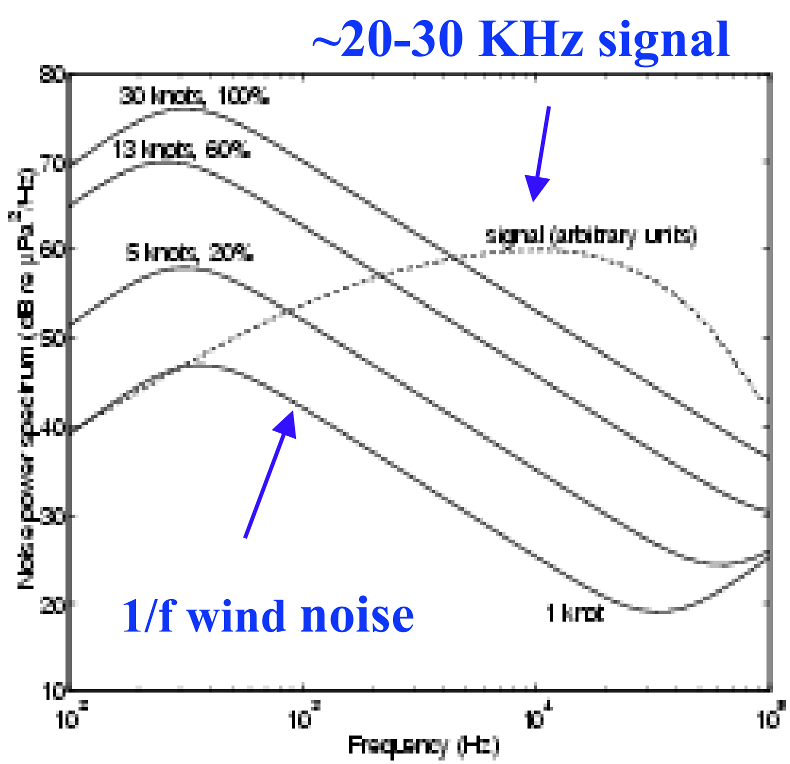
- Acoustic detection of compressional wave produced by shower in water→BURY hydrophones
- Under investigation by Gratta et al., Caribbean site

Neutrino Noises are Weak, but
10^{21} eV ν's can be Heard from Afar

Attenuation Length:
Many Km in Ocean

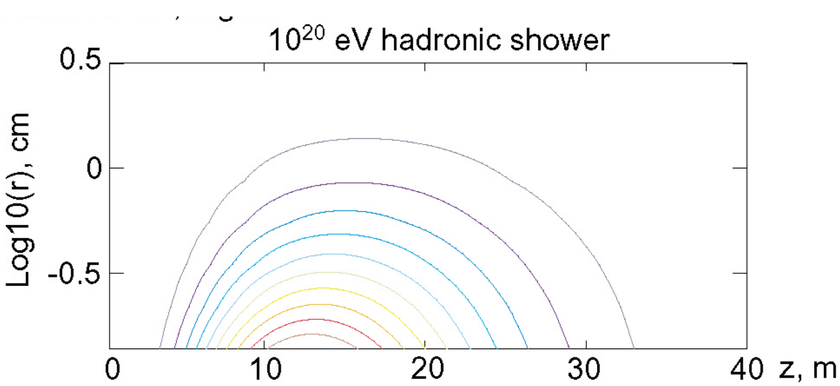


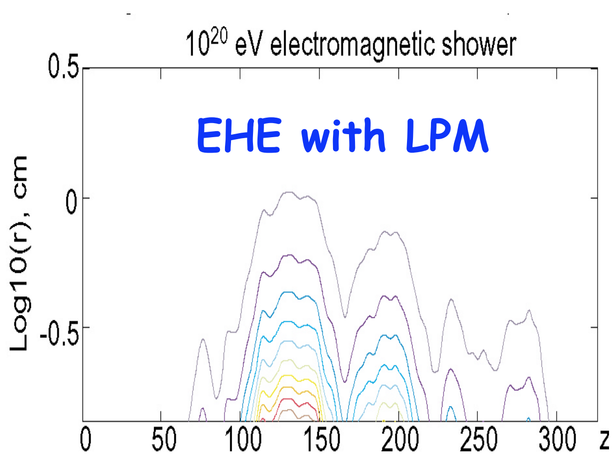
Noise:
Near Deep Ocean Thermal Minimum



G. Gratta astro-ph/0104033

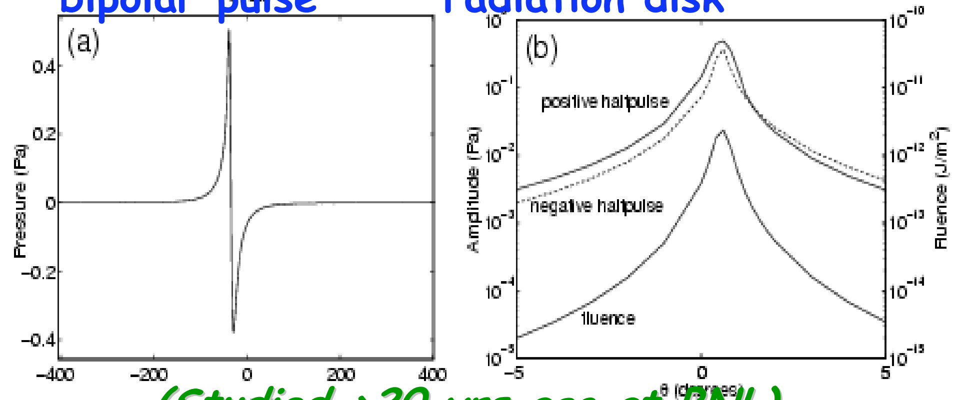
Shower Heating → Expansion → Bipolar Pressure Pulse





bipolar pulse

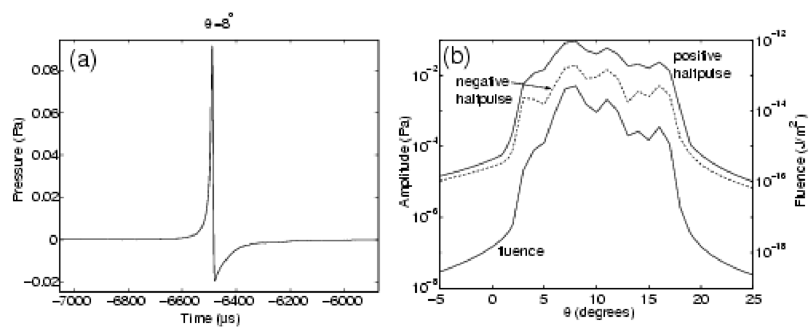
radiation disk



(Studied >20 yrs ago at BNL)

off-axis is asymmetric

LPM →fat disk

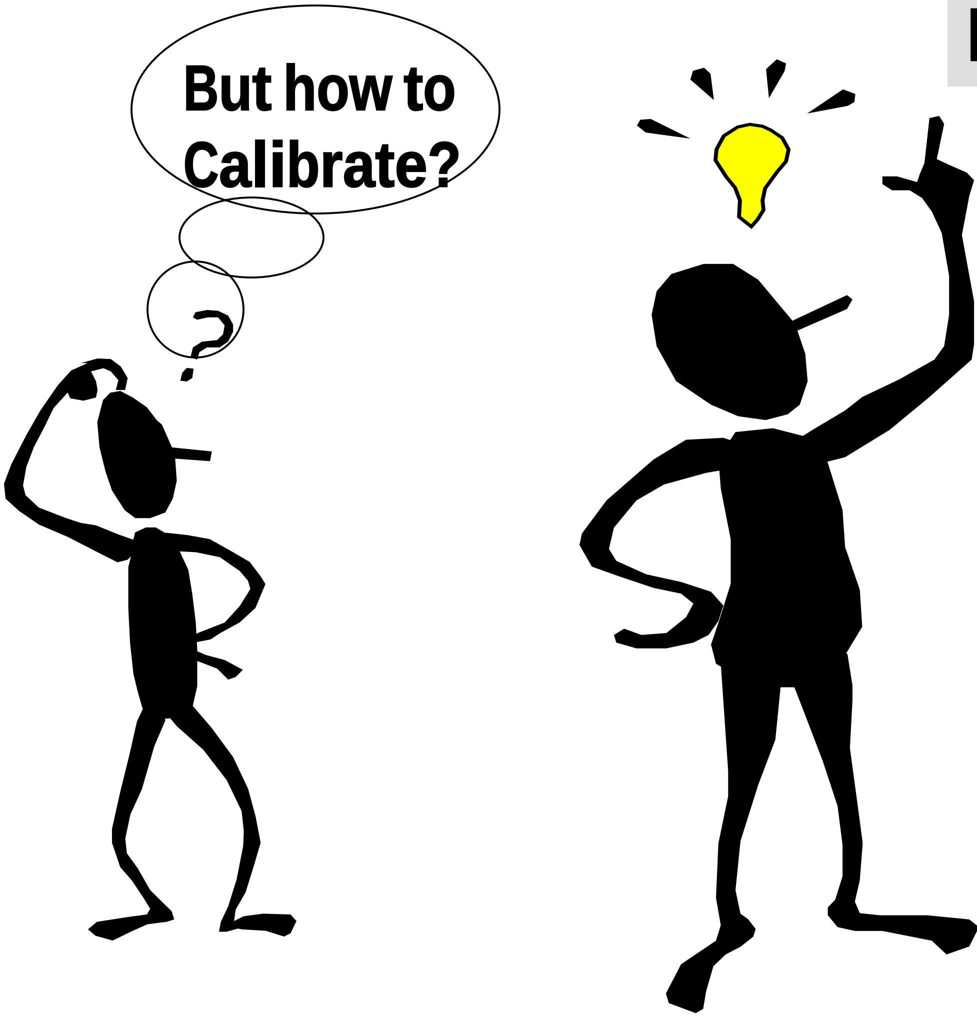


Gratta, et al

Acoustic Pulse Attenuation of order 1 dB/km

Lower a light bulb into water until it implodes and measure acoustic signal in hydrophones!

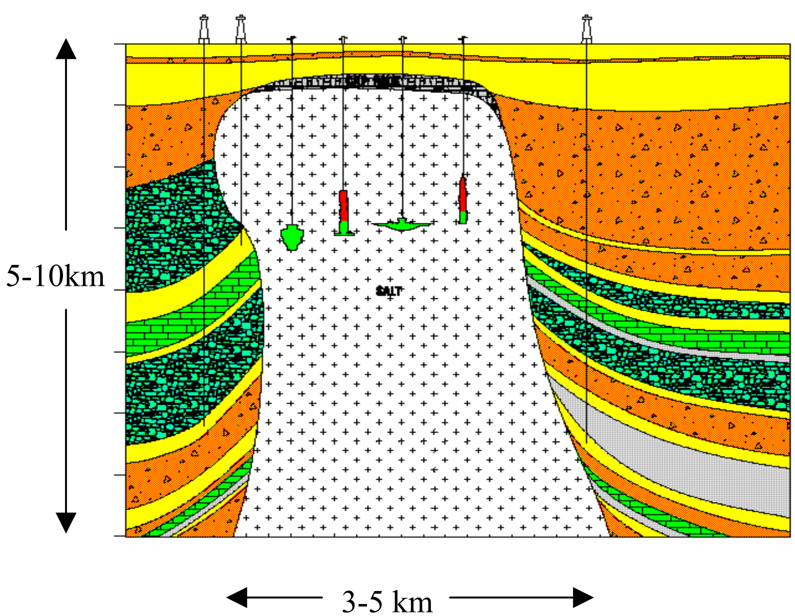
Release~1 PeV energy

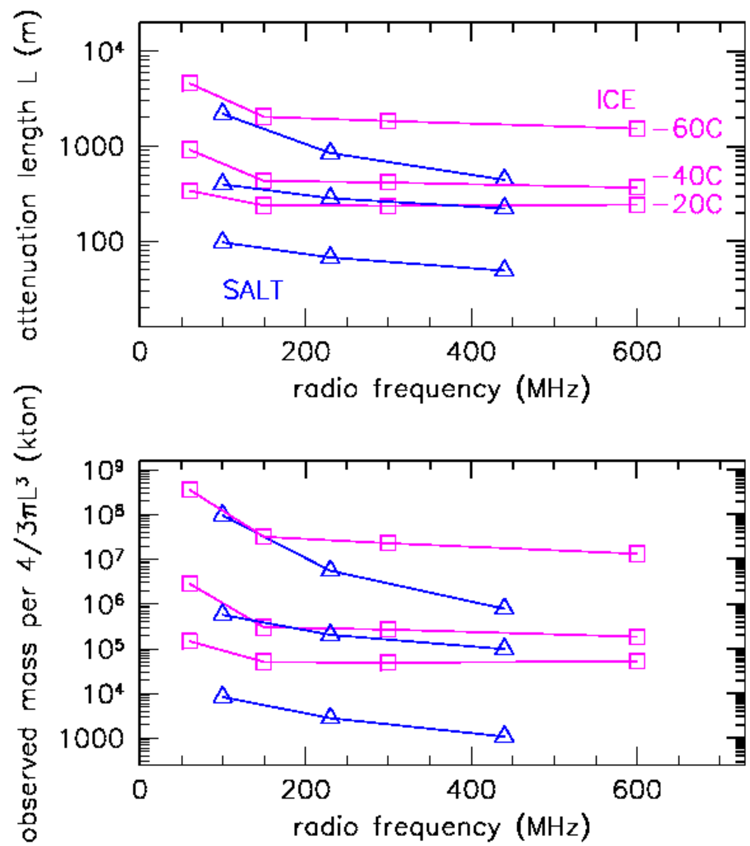


Radio Detection in Natural Salt Domes

SALSA

- Natural salt can be extremely low RF loss: ~ as clear as very cold ice, but nearly 2.5 times as dense.
- Typical salt dome halite is comparable to ice at -40C for RF clarity.

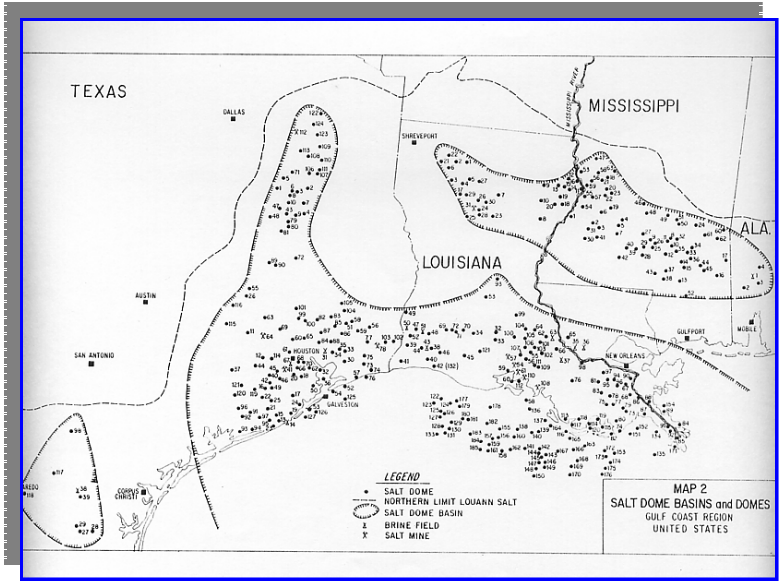




SALT curves are for (top): purest natural salt; (middle): typical good salt dome; (bottom) best salt bed halite. New measurements 2001, SLAC 2002.

P. Gorham

Hockley Mine Prototype



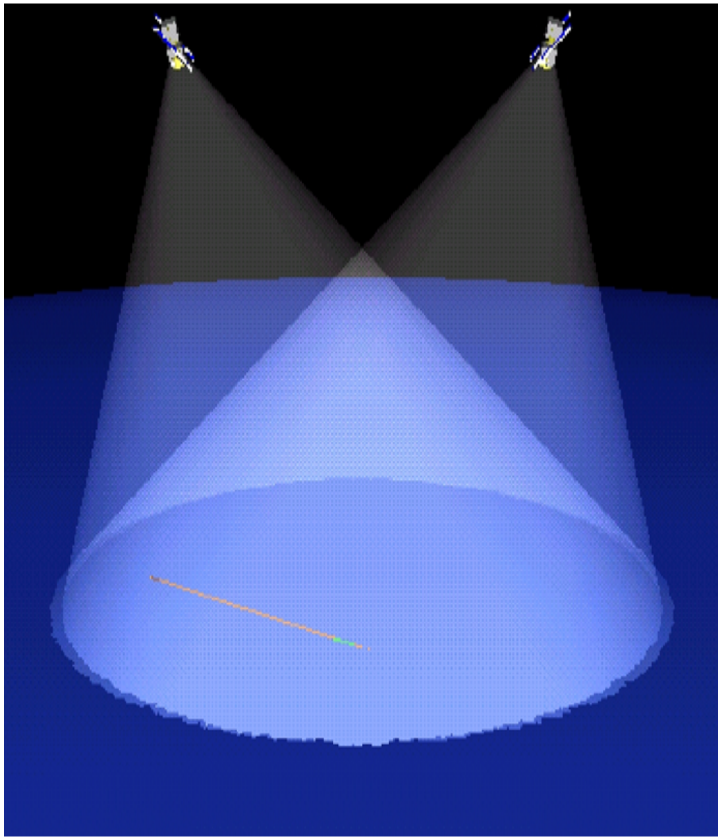
Many available salt domes
In Southwest USA

- Cluster of 4-6 antennas, with trigger & DAQ
  - Insert into shallow boreholes within mine, ~40 m separation
  - Measure background noise levels, HE muons?
  - Effective volume ~1 cubic km water equivalent at 1 EeV
- Deploy in mine for 6-12 months, target date late 2003-2004
  - Existing seismic system (UT Austin) could provide fiber link to surface
- Testbed for a GZK neutrino detector!
- *Emphasis on simplicity, scalability, low cost*

All Experiments Built to Explore GZK Anomaly are also ν Telescopes

- Limits from Fly's Eye, AGASA, Hi-Res …
- Better limits will come from ground (Auger) and space (EUSO/OWL/….)
- Area large, solid angle is small; but may measure

  GZK Neutrinos

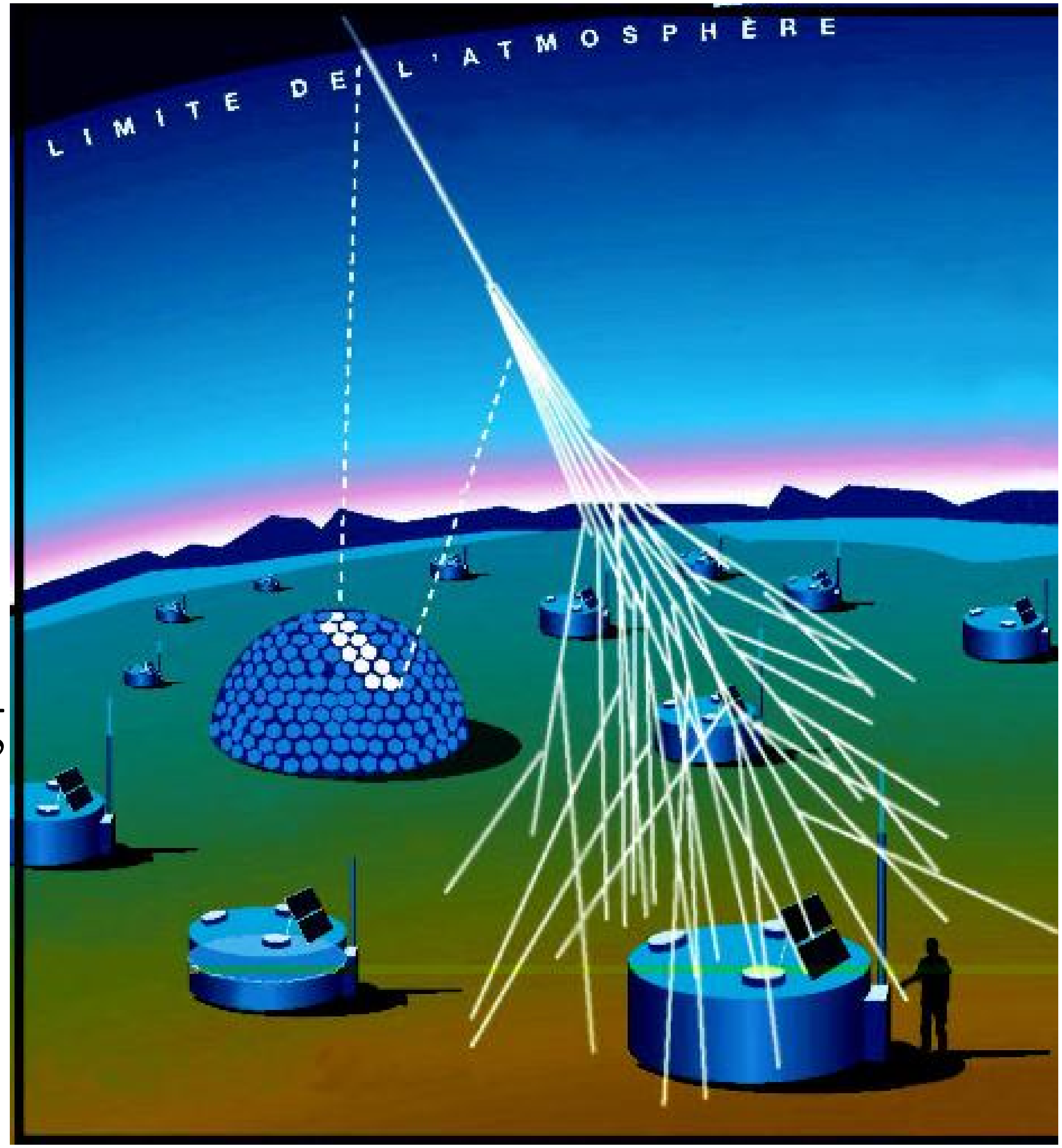


- Plus see neutrinos exiting ground?

J. Krizmanic

Auger and UHE neutrinos

- Sensitive to horizontal air showers: ~10^4 gm/cm^2
  V_{eff}~40 km^3 at 10^{19} eV.
- Best sensitivity to tau neutrinos interacting nearby (regeneration) –
- Expect competitive



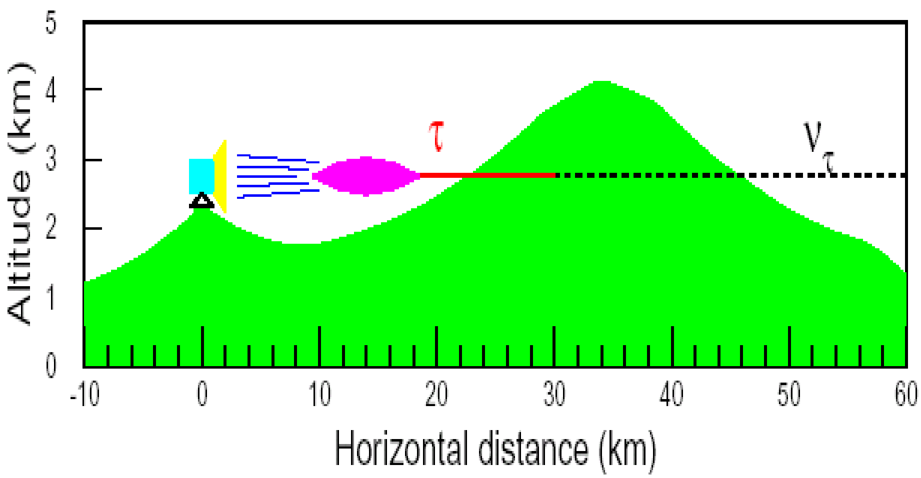
NuTel: Tau Watch in Hawaii
Neutrinos Converted in Mountain

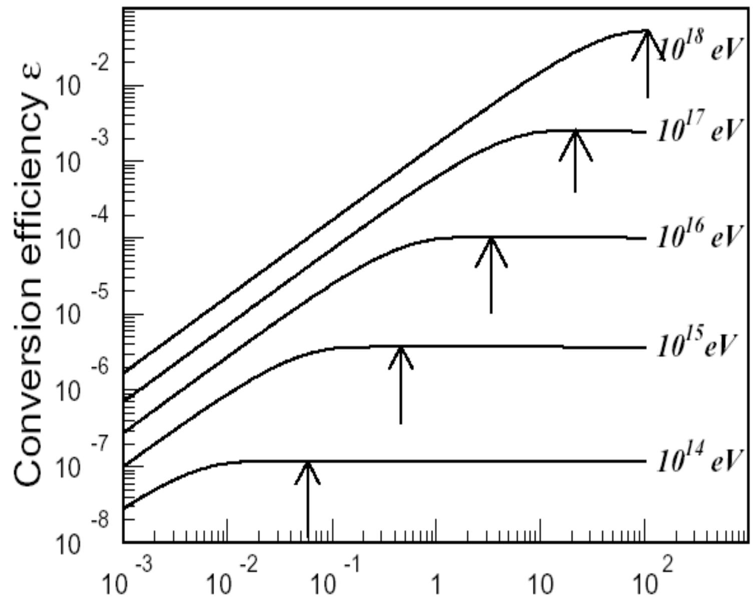
- Astronomer's dream site
  - Excellent weather
  - Little artificial light
- 3km Mt. Hualalai provides good view of Mauna Loa.
- Mauna Loa provide long base line, ~ 90 km wide and 4 km high.

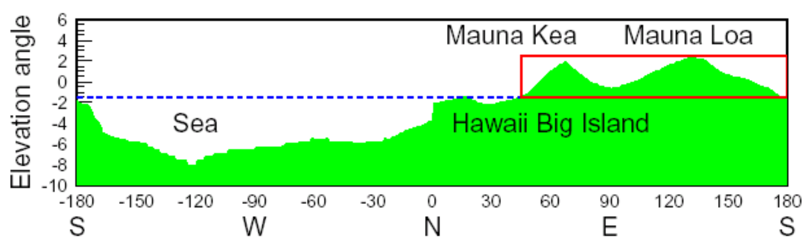
NuTel

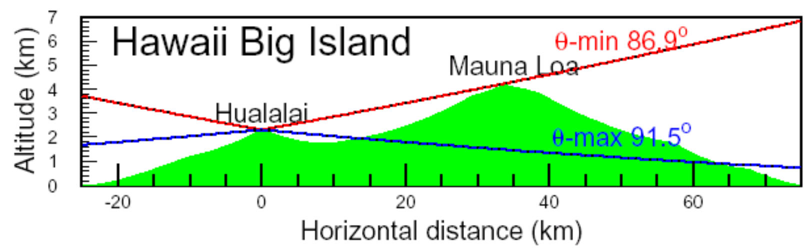
Using Mountains to Convert ν_τ

3/02 Workshop in Taiwan, 8/02 HI, 1/03 Italy see http://hep1.phys.ntu.edu.tw/vhetnw



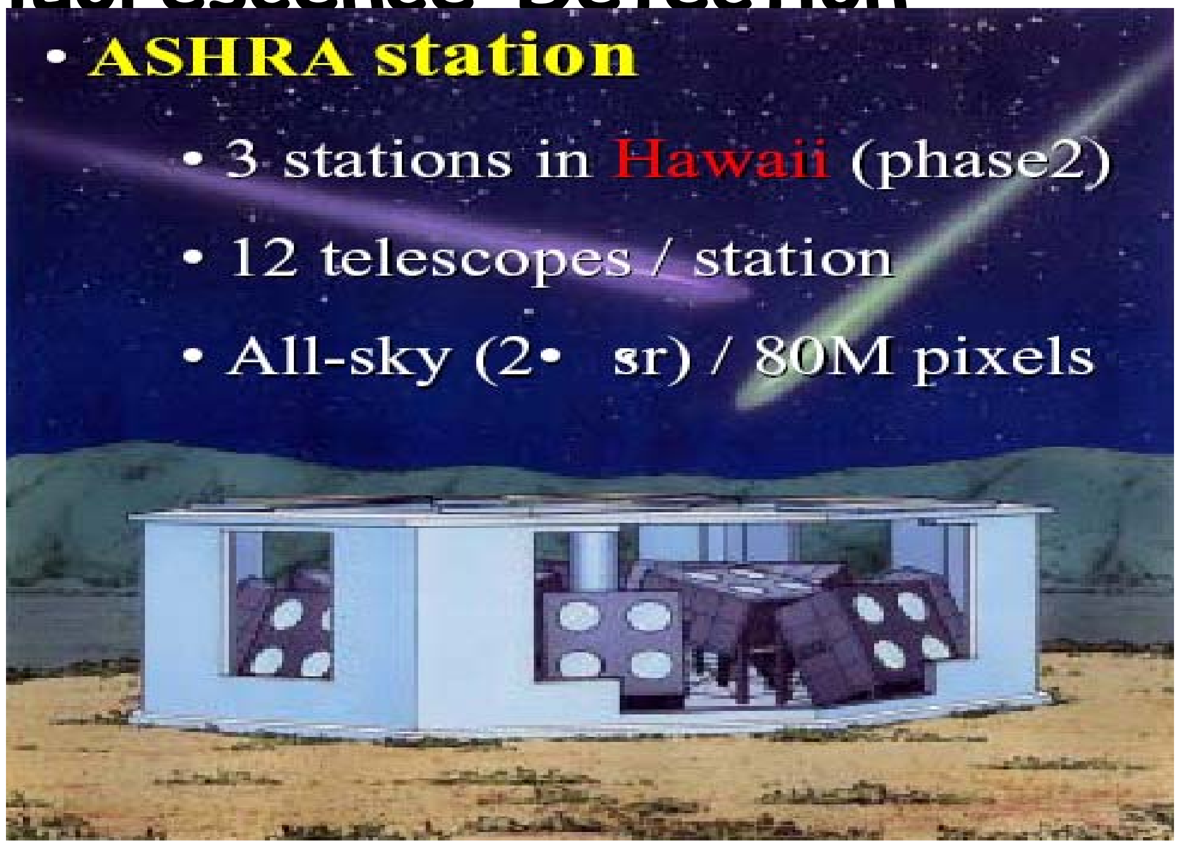






ASHRA

New Project Combining Air Cherenkov and Fluorescence Detection



$0.04/pixel

Test Telescope on Haleakala in '03

M. Sasaki U. Tokyo ICRR

Some Projected Yields

NB: RICE numbers based on 16-channel array only

		N_{events}			
		Top. Def.	GZK		WB
Telescope	Duration	(PS)	(min)	(max)	
Anita	45 live days	78	8.5	31	12
Amanda B10	130 live days	-	-	-	0.12
Auger	3 live years	1.2	1.8	5.3	1.8
EAS-TOP	326 live days	-	-	-	-
Euso	2.7 live years	18	0.9	3.6	1.9
Glue	80 hours	0.20	-	0.020	-
Ice Cube	3 live years	2.0	0.9	2.4	501
Macro	5.8 live years	-	-	-	0.036
Rice	2.5 live years	8.7	2.3	7.4	3.1
Salsa-1000	2 live years	60	69	232	67

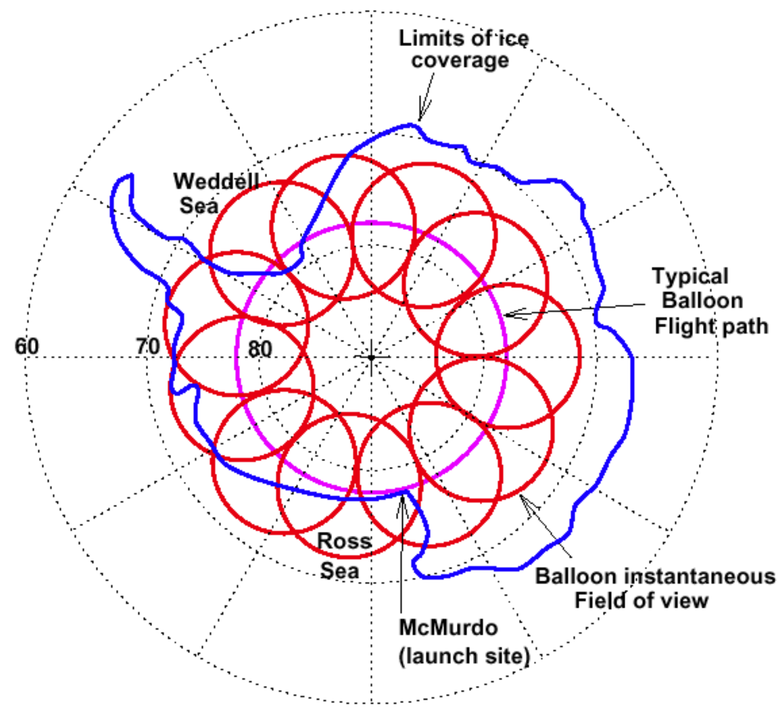
Summary

- <1 PeV exclusive domain of optical Cherenkov (ANTARES/AMANDA/NESTOR/ICE3)
  - AMANDA has reconstructed ~10^3 atmospheric ν_μ
  - However, must statistically separate AGN ν_μ from atmospheric ν_μ for E<1 PeV
- Radio>Optical V_{eff} for E>1 PeV (ice, salt)
  - "coherence" + long-attenuation length
  - Per-$ Radio advantage grows ~linearly with E
  - Atmospheric neutrino background→0
    - Air shower backgrounds currently under study
    - RICE preliminary study=>comparable to signal neutrino flux
    - Radio detection of air showers (LOFAR) under study
- >1 EeV: Auger/Forte get neutrinos "for free"
  - Acoustic may be competitive (no LPM)

Experiment operations

- The ANITA floats above Antarctica at altitude of ~37 km - observes an instantaneous ice volume of ~1 M km^3
  – aperture ~3000 km^3 sr (water equivalent)

- flights last ~10 days duty cycle~ 100%
- depending on the source models used, ANITA may observe 10-100 nu per flight



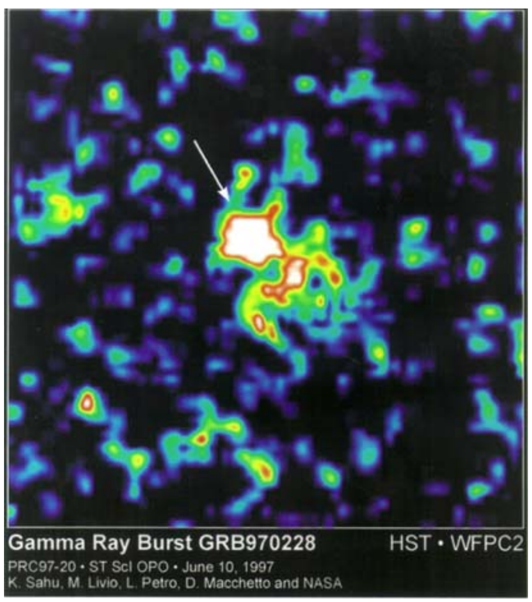
Expected performance

Parameter	*Description*	*Estimated value*
θ reconstruction	event nadir angle	~ 2º at θ ~ 85º
ϕ reconstruction	azimuth using amplitude ratio	< 12º
track reconstruction	based on polarization plane	~10º error box
fractional range resolution	near the horizon	< 50 %
energy uncertainty	measured field is lower limit	$\Delta E/E \sim 1$
effective aperture at 3×10^{18} eV	volumetric aperture	1260 km^3 sr
expected trigger rate	Thermal noise triggers	< 0.01 Hz
event (data) size	288 total channels/event	~ 30 Kbyte
maximum archive size	10 times expected trig rate	8 Gbyte

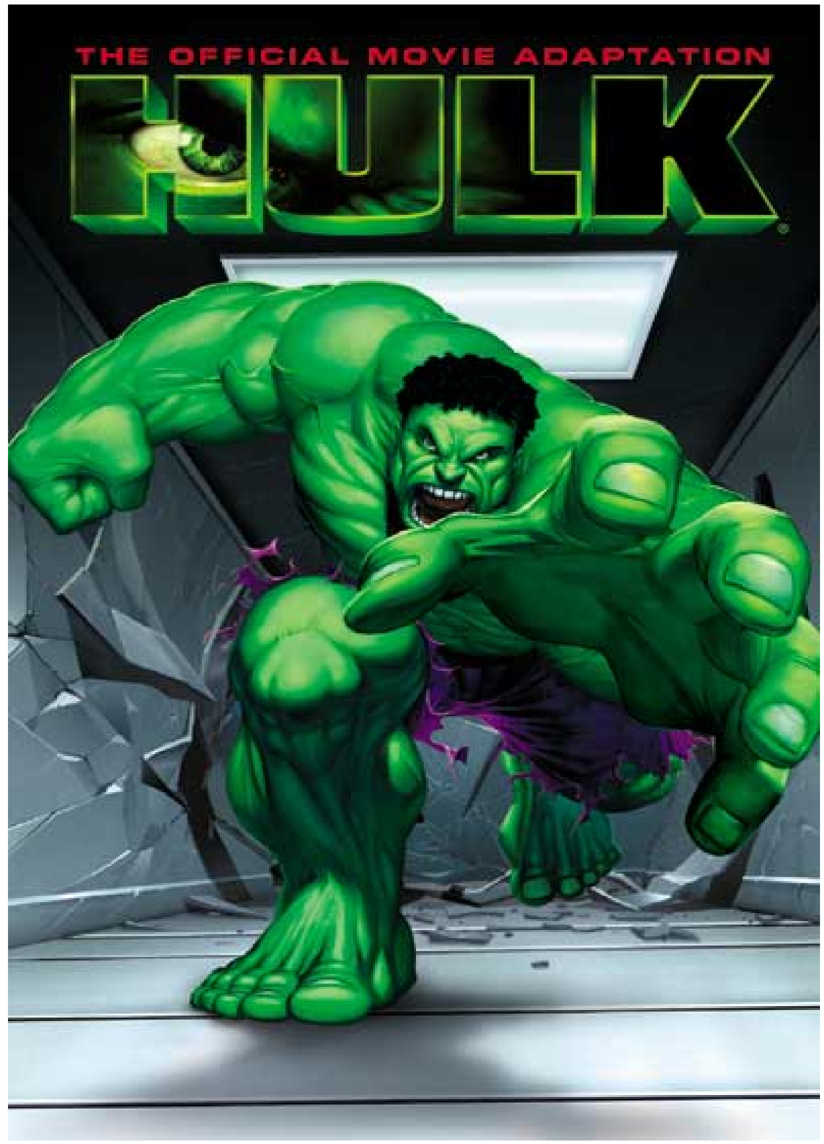
Correlations w/ Gamma Ray Bursts (BATSE)?

Caution: Gamma Ray studies can be dangerous

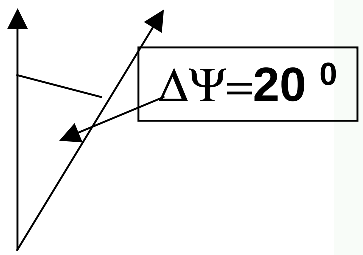
1969

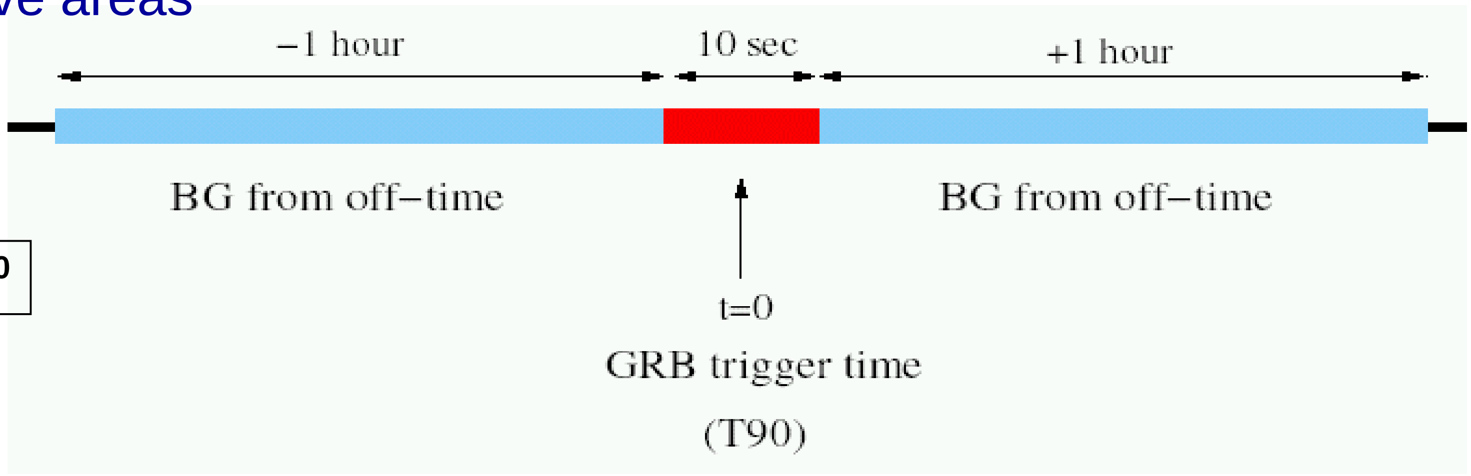


1997



- Low background (due narrow time and space coincidence)
- Large effective areas





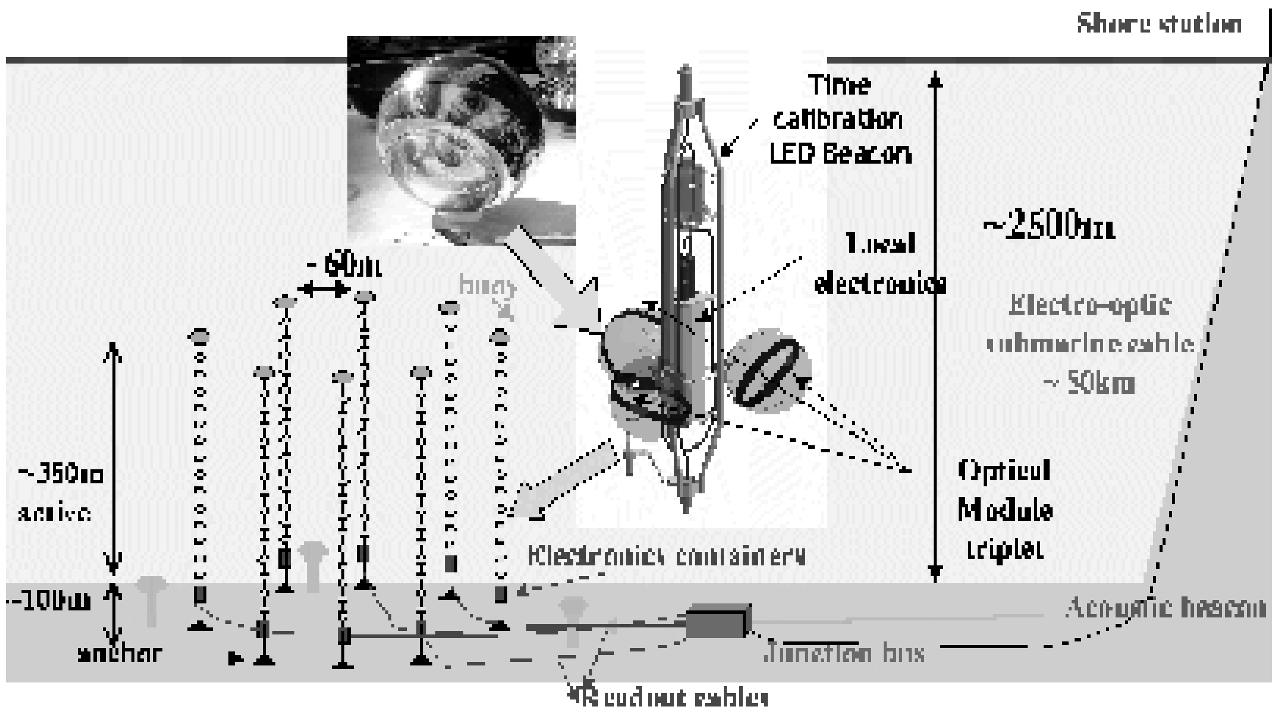
Year	# of GRB	Bkgd	seen events
1997	78	0.06	0
1998	99	0.20	0
1999	96	0.20	0
2000	44	0.40	0
Total	218	0.86	0

Water Optical Cerenkov Detection

- Lake Baikal: ~100 atmospheric nu, plan expansion
- ANTARES: 1/12 strings deployed in Mediterranean
  - Full deployment 2006 – km^2 V_{eff}
  - Angular resolution ~0.5 degree! Water: attenuation limited

NESTOR-

12-PMT "STAR" taking muon data



ANITA questions & issues

Energy & Angular resolution?

- Pulse interferometry & beam gradiometry ➔ ~5-10^0
- Depth of cascade from spectral rolloff & known ice properties
- Track angle from plane of polarization

- Surface refraction effects?
- RF interference? RICE: Antarctica quiet
- Uniformity of temperature, attenuation length profiles?

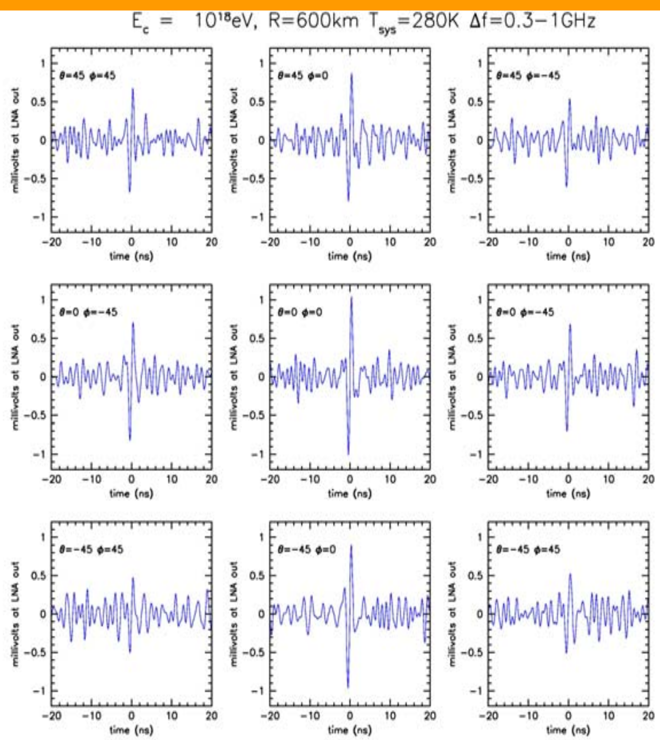
Antarctic ice topography

~few m feature relief

~5 mile long “highway”

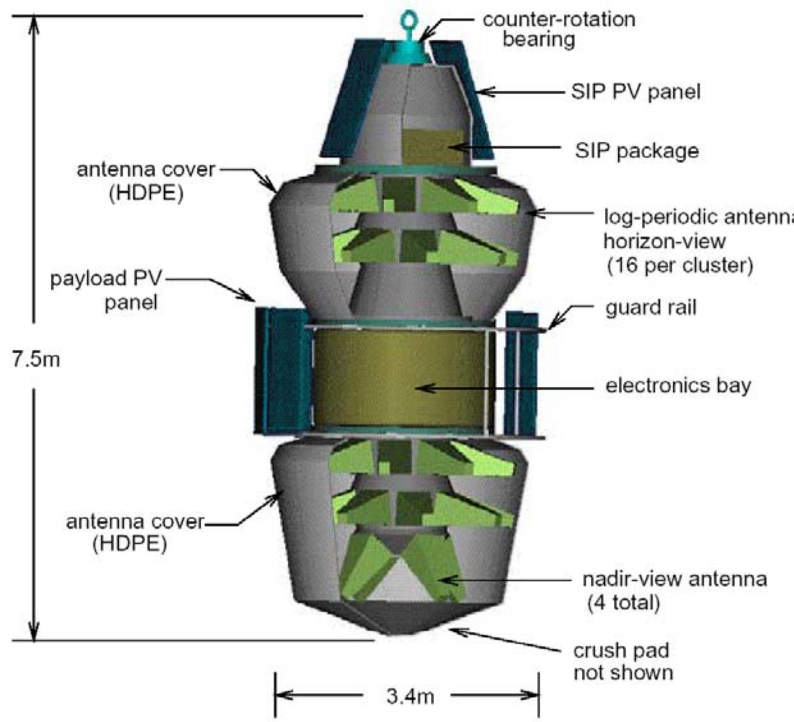
- RadarSat completed comprehensive SAR map of Antarctica in late 1990s—feature resolutions of ~10-50m, available public domain
- Calibrate surface roughness—SAR $\lambda = 5.6$ cm

ANITA Payload



Simulated pulse—multiple antennas

antenna cluster detail

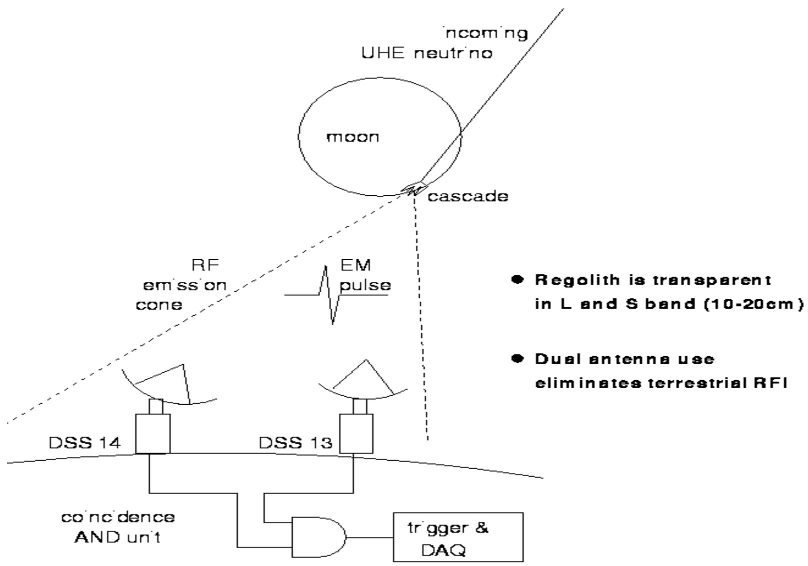


- ANITA antennas view ~2pi sr / 60 deg overlapping beams
- Beam intensity gradiometry, interferometry, polarimetry used to determine pulse direction & thus original neutrino track orientation

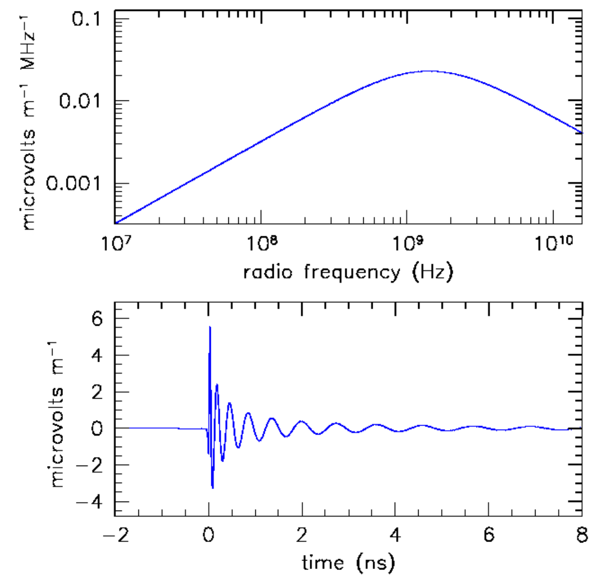
Goldstone DSN

Radio Detection Approach

P. Gorham



RF pulse spectrum & shape

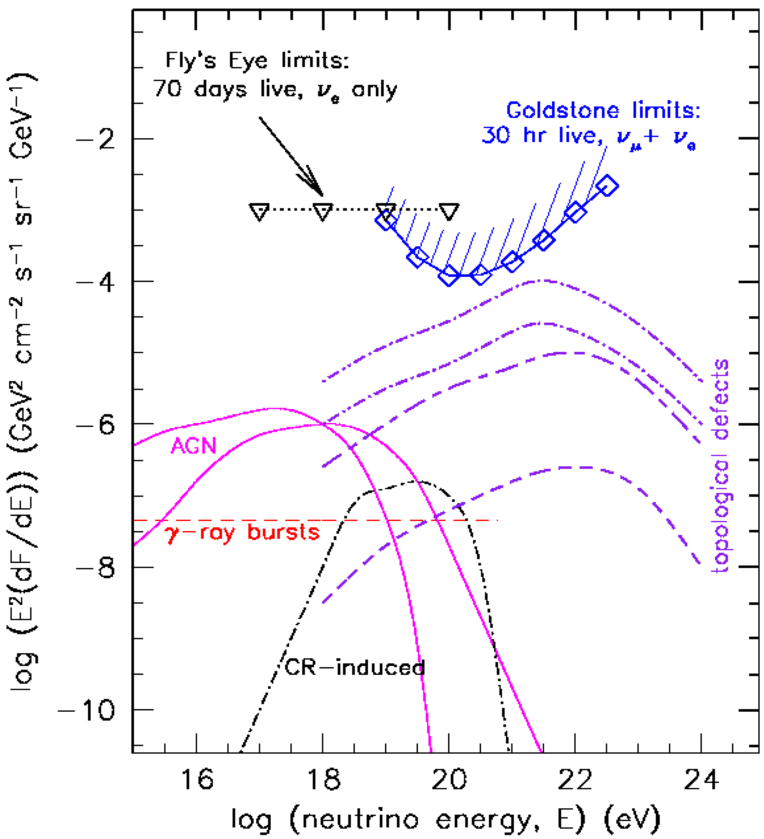


- Effective target volume: antenna beam (~0.3 deg) times ~10 m layer

  => ~100,000 cubic km !
- Limited primarily by livetime - small portion of antenna time devoted to any single project.

Goldstone

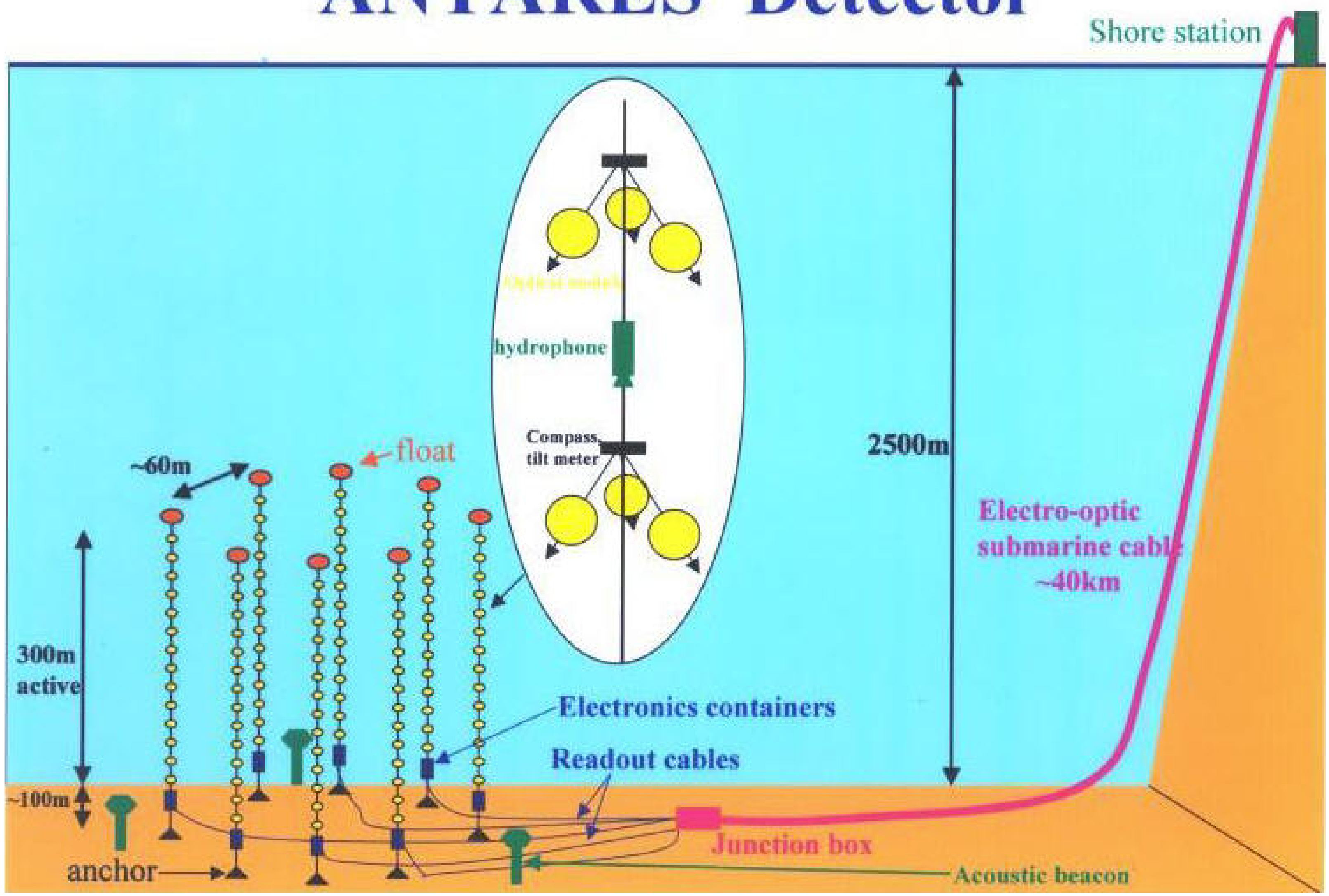
diffuse EHE neutrino flux limits



- **~30 hrs livetime**
  - No events above net 5 sigma
- **New Monte Carlo estimates:**
  - cross-sections 'down' by 30-40%
  - Full refraction raytrace, including surface roughness, regolith absorption
  - Y-distribution, LPM included
- **Limb observations:**
  - lower threshold, but much less effective volume (factor of ~1/10)
  - 'Weaker' limit but with more confidence
- **Fly's Eye limit: needs update:**
  - Corrected (PG) by using published CR aperture, new neutrino cross sections.

P. Gorham

ANTARES Detector



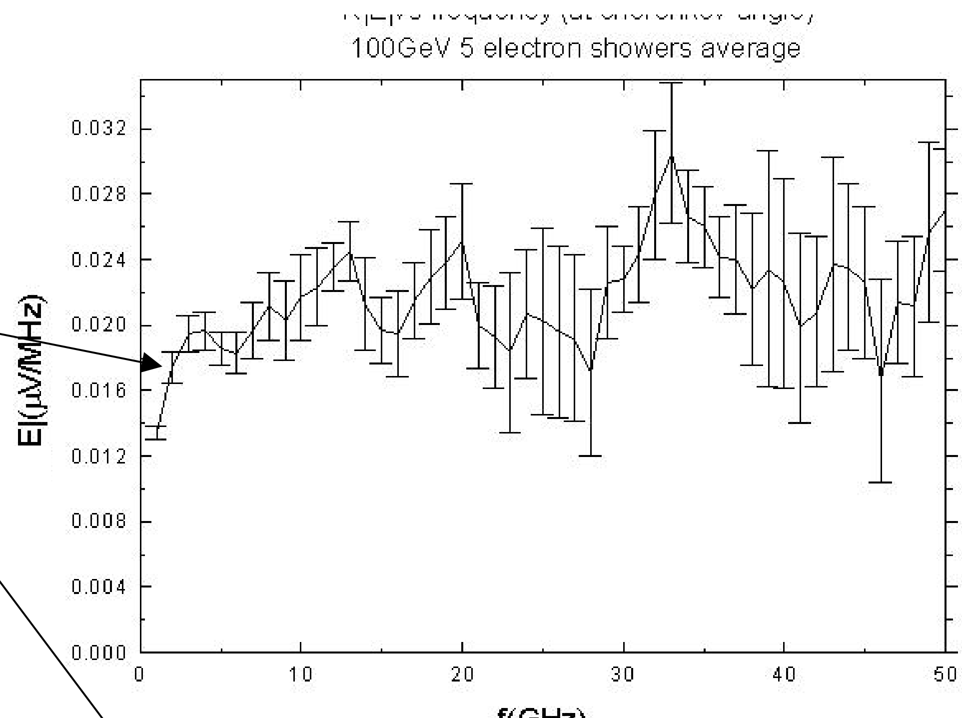
Shower Simulations

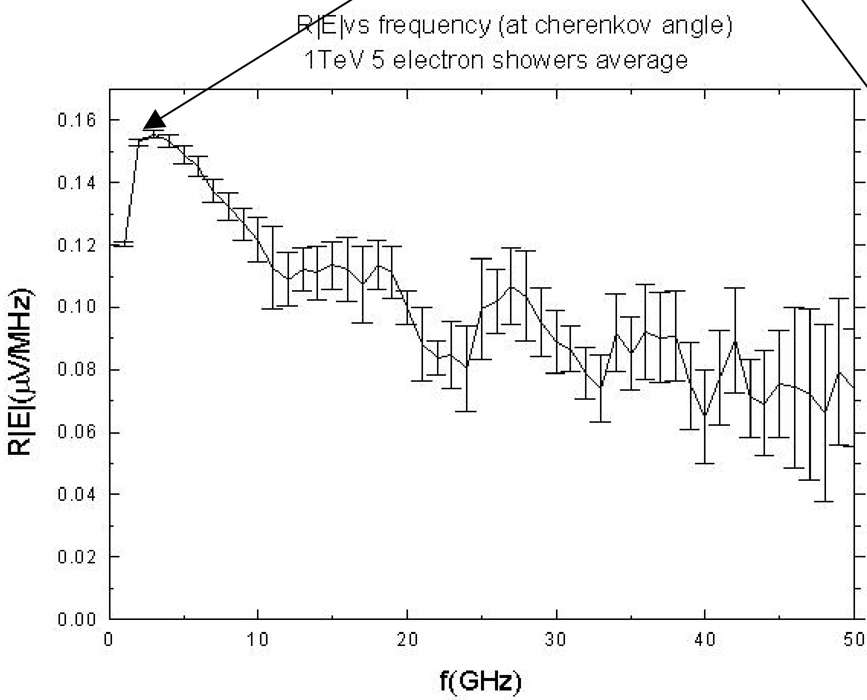
- Shower simulation
  - Now GEANT 4 (100 GeV – 1 TeV)

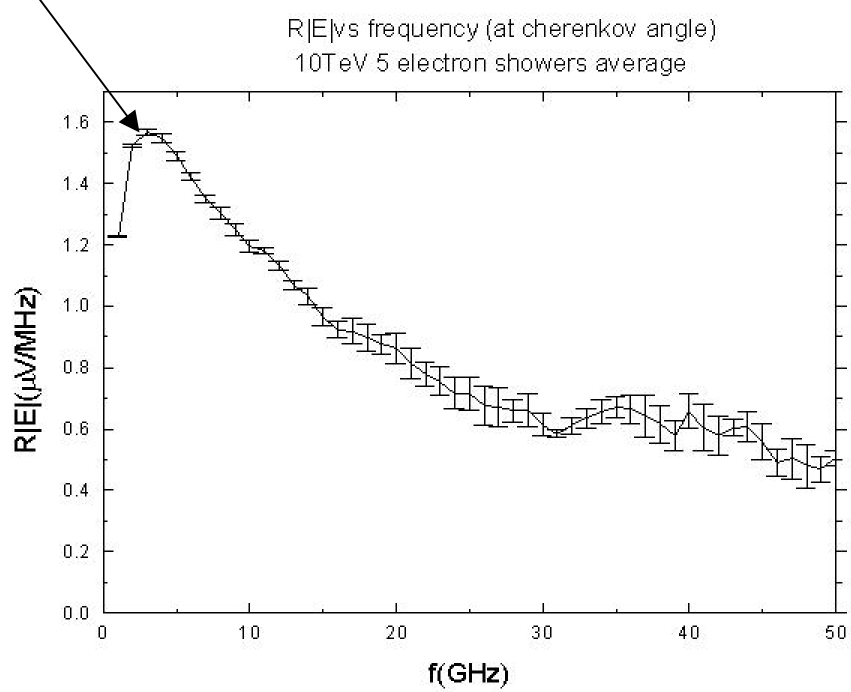
    10% smaller than ZHS (but …tracklength? Power spectrum?)
  - Extrapolate to higher energies
  - LPM from Alvarez & Zas
  - Hadronic cascades convert completely to EM with no LPM
  - EM & hadronic cascades treated separately, in progress

Simulations verified in both E-field strength + polarization by SLAC testbeam experiments (2001-03)

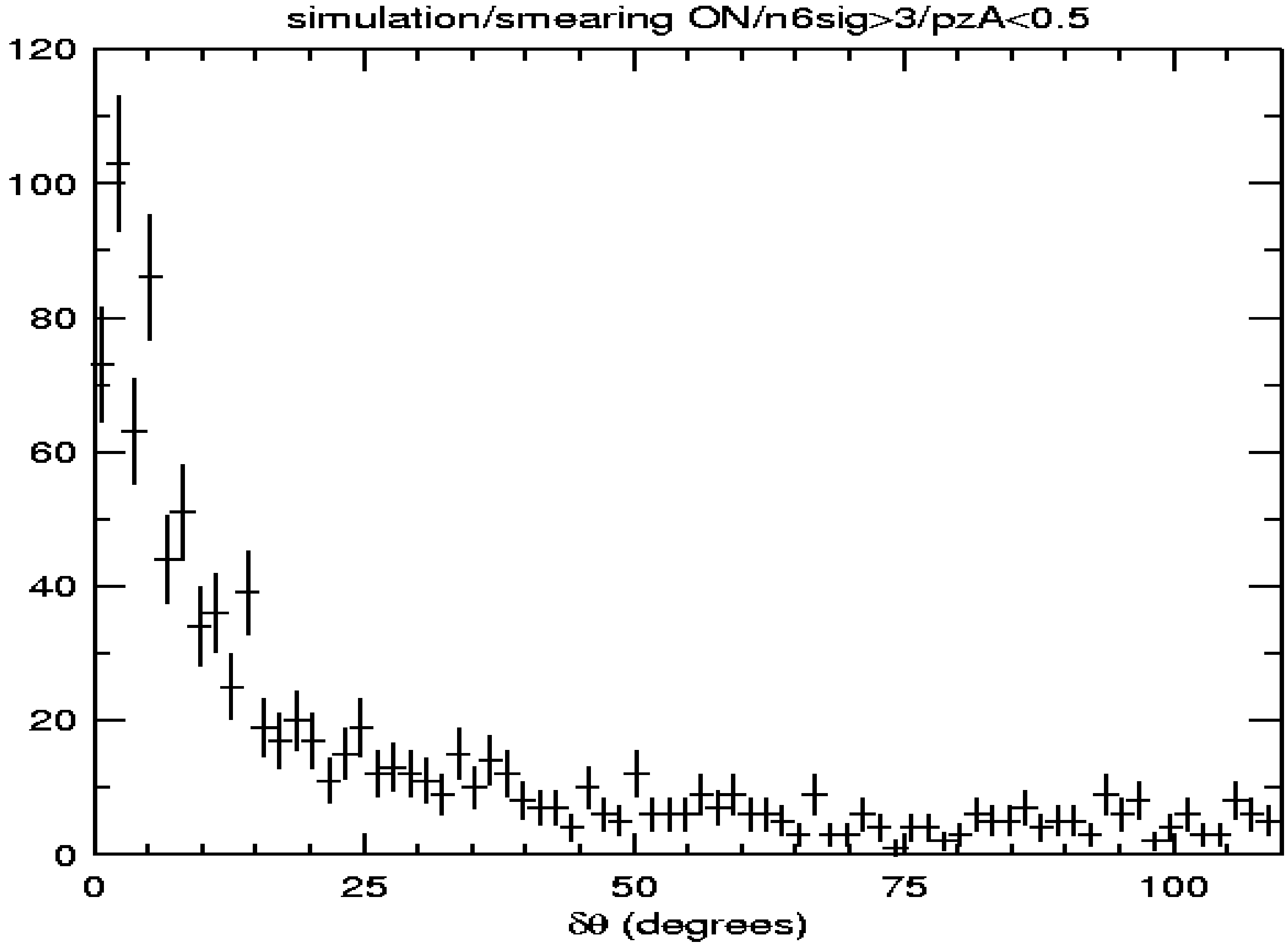
E-field(f) scales with neutrino E up to 1 GHz







Angular Resolution simulation



Energy resolution~50% for r<1 km