



University of Washington
VISUAL TECHNIQUES LABORATORY
PHYSICS NOTE

subject

Copies of Transparencies

PHY - 147

DIR-18-91

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date 6/30/91 rev.
data

To: DUMAND files
From: B. Egaas
Subj: Copies of transparencies
Date: 30 June 1991

The following are copies of the viewgraphs from my Masters Examination presentation on 12 June 1991. Most have been previously circulated through the DUMAND group, but there are a few new ones on the following topics:

- * Neutrino physics - Only the basics of how neutrinos are produced and where we might expect to find them.
- * Sonar Equation - A fundamental ocean acoustics analysis applied to our system.
- * New Test Results - Correlation data for the June 7 chirping test conducted by R. Lord and B. Egaas in Union Bay.

The talk was divided into two areas. The first half was a general discussion of the DUMAND project, with an emphasis on the "physics" of the experiment. The second half concentrated on the specifics of the acoustic measuring system that we have been working on in Seattle. I described the progress from initial computer simulations to in-water testing of hardware and algorithms. At this point, we have demonstrated that our system will provide the resolution required by the DUMAND experiment.

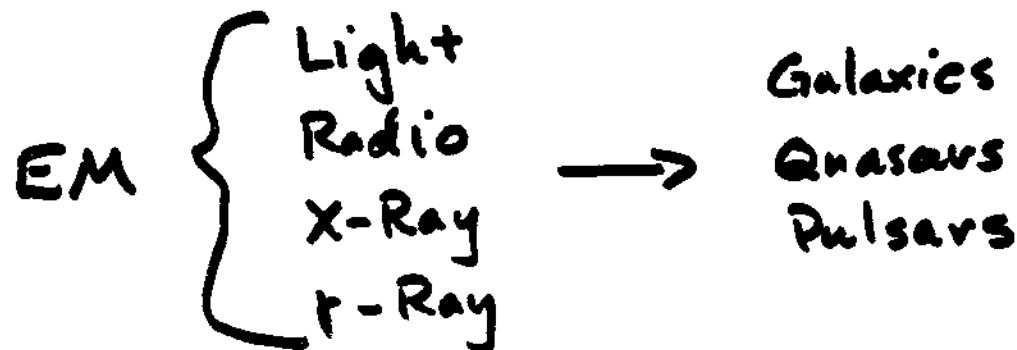
"An Acoustic Survey System
for DUMAND II"

Brian Egaas

12 June 1991

Deep
Undersea
Muon
And
Neutrino
Detector

- A telescope to identify + measure high energy neutrino sources in deep space. Neutrinos provide a signal from regions where EM radiation cannot escape.



Neutrinos → ?

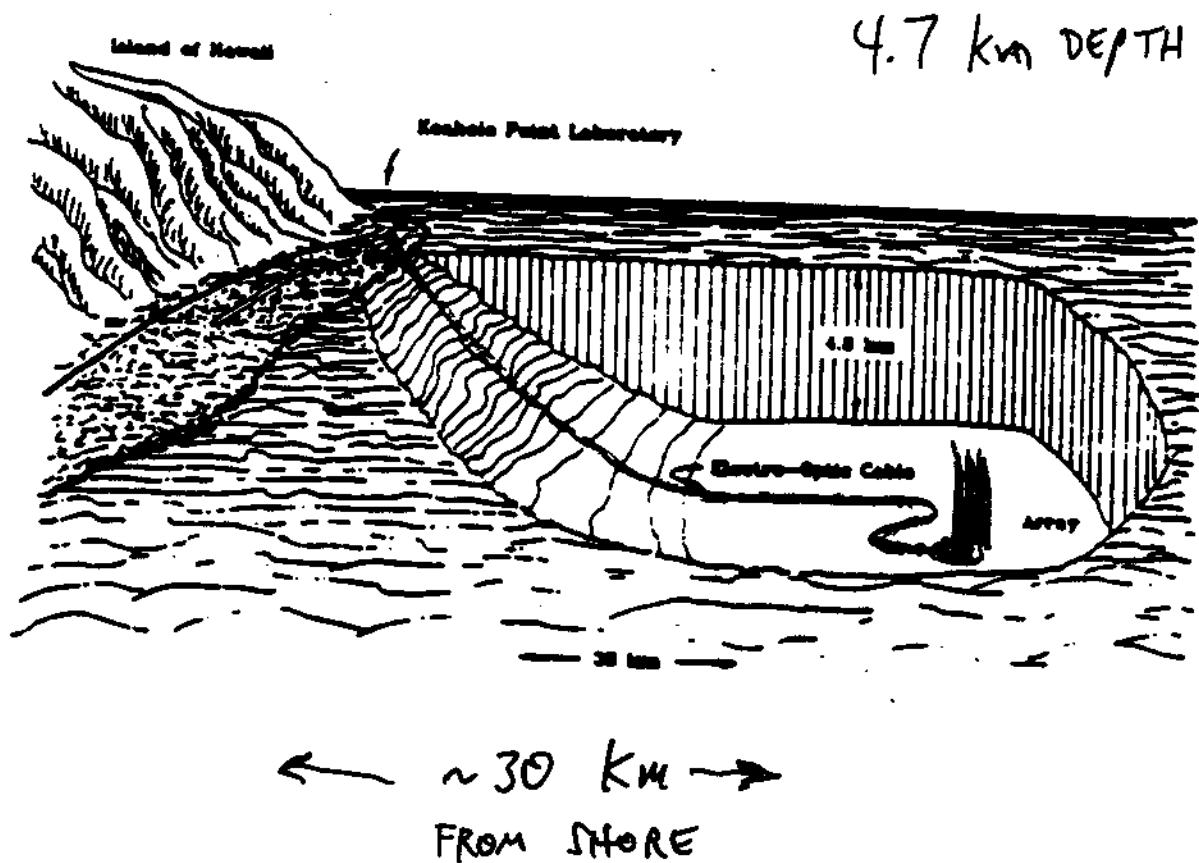


Figure 1.2: Disposition of the DUMAND detector at 4.7 km depth in subs basin ~ 35 km off Keahole Point, island of Hawaii. Armored cables carrying and fiber-optics communication connect DUMAND to the shore station.

DUMAND

DEEP UNDERSEA MUON & NEUTRINO Detector

AACHEN - BERN - CALTECH - HAWAII - KIEL - KINKI -
SCRIPPS - TOKYO - TOHOKU - VANDERBILT -
WASHINGTON - WISCONSIN

- WATER CERENKOV DETECTOR ARRAY
- DETECT $\gtrsim 50$ GeV μ 's FROM V INT.
4700 m UNDERWATER WITH 1° PRECISION

ESTIMATE: $3 \mu/\text{MIN}$ DOWNWARD

$3500 \mu/\text{YR}$ UPWARD

$50 \mu/\text{YR}$ CONTAINED EVENTS

POINT-SOURCE SENSITIVITY: $\sim 5 \times 10^{-10} / \text{cm}^2/\text{sec}$
 $> 1 \text{ TeV}$

DUMAND-I (1987) : PROTOTYPE STRING

DUMAND-II : 9-STRING ARRAY

3-STRING INITIAL DEPLOYMENT
(1992)

MEASURE: μ DIRECTION (TO 1°)

dE/dx (μ 's > 1 TeV, CONTAINED
CASCADES)

MULTIPLE MUONS

PHYSICS GOALS

1. POINT SOURCES OF ASTROPHYSICAL ν 's

BINARY SYSTEMS, PULSARS, GALACTIC CENTER, ACTIVE GAL.
NUCLEI...

2. ν 's FROM INTERACTIONS IN ATMOSPHERE

(ABOUT $1/2.8^\circ$ CONE/YR $\rightarrow 1^\circ$ RESOLUTION
ADEQUATE)

FLUX

SPECTRAL COEFFICIENT (FROM dE/dx)

3. MUON FLUX (> 3 TeV)

ANGULAR DIST.

dE/dx DIST.

MULTIPLE MUON SPECTRA

PRIMARY SPECTRUM & COMPOSITION

POINT SOURCES ?

4. PARTICLE PHYSICS:

ν CROSS SECTION (EARTH-IN, EARTH OUT)

ν OSCILLATIONS (FERMILAB BEAM?)

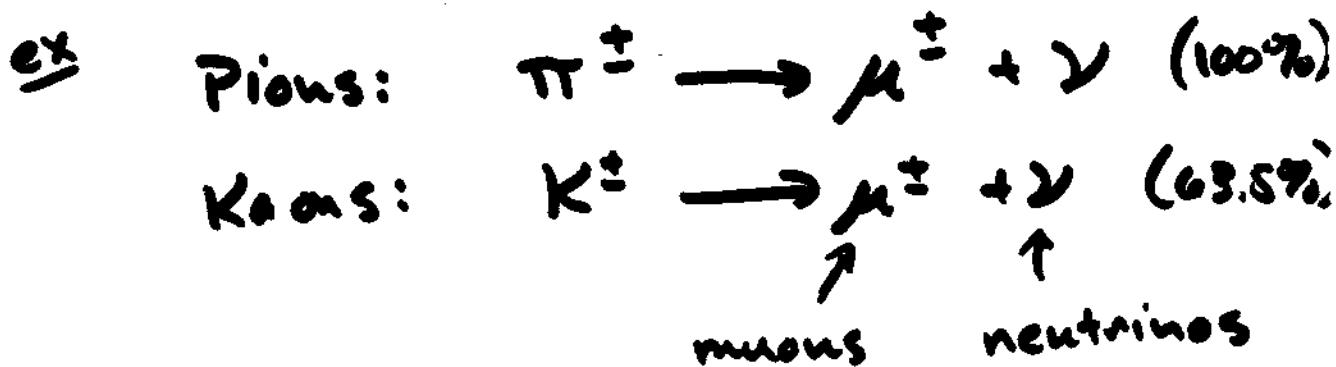
5. SLOW-MOVING PARTICLES, WIMPS, MONOPOLES...

$10 \text{ eVts/Yr} \rightarrow 2 \times 10^{-16} \text{ PART./cm}^2/\text{sec}/\text{sr}$

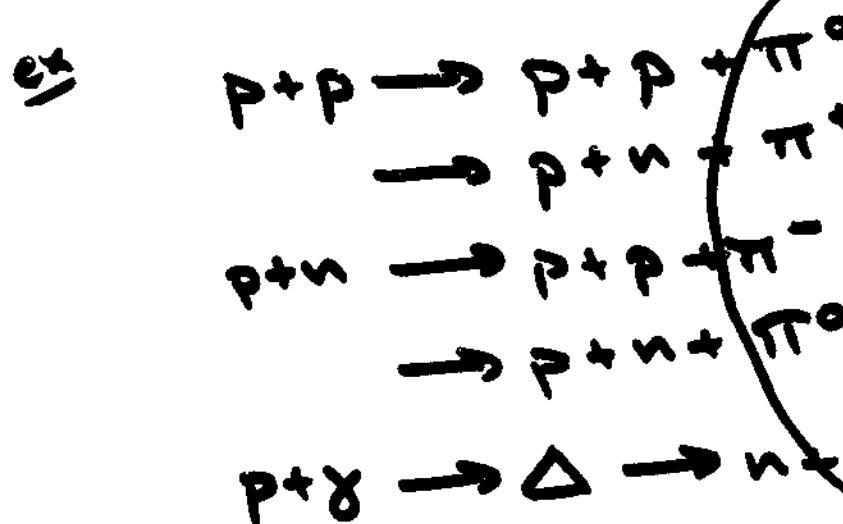
- 1.09:1.097 TARGET MASS TO ANT-PROTON TARGET

Neutrino Physics

Neutrinos are nearly massless neutral leptons that are generated as decay products of unstable hadrons.

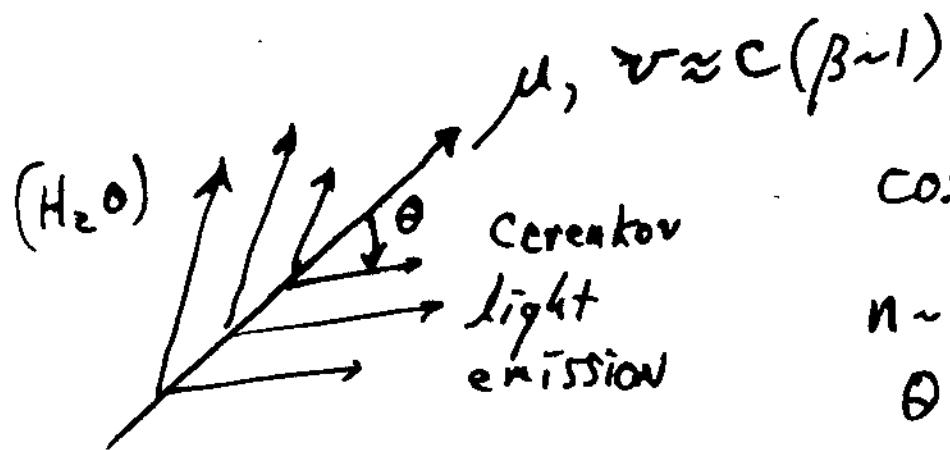


Highly energetic pions may be created when relativistic protons collide with targets



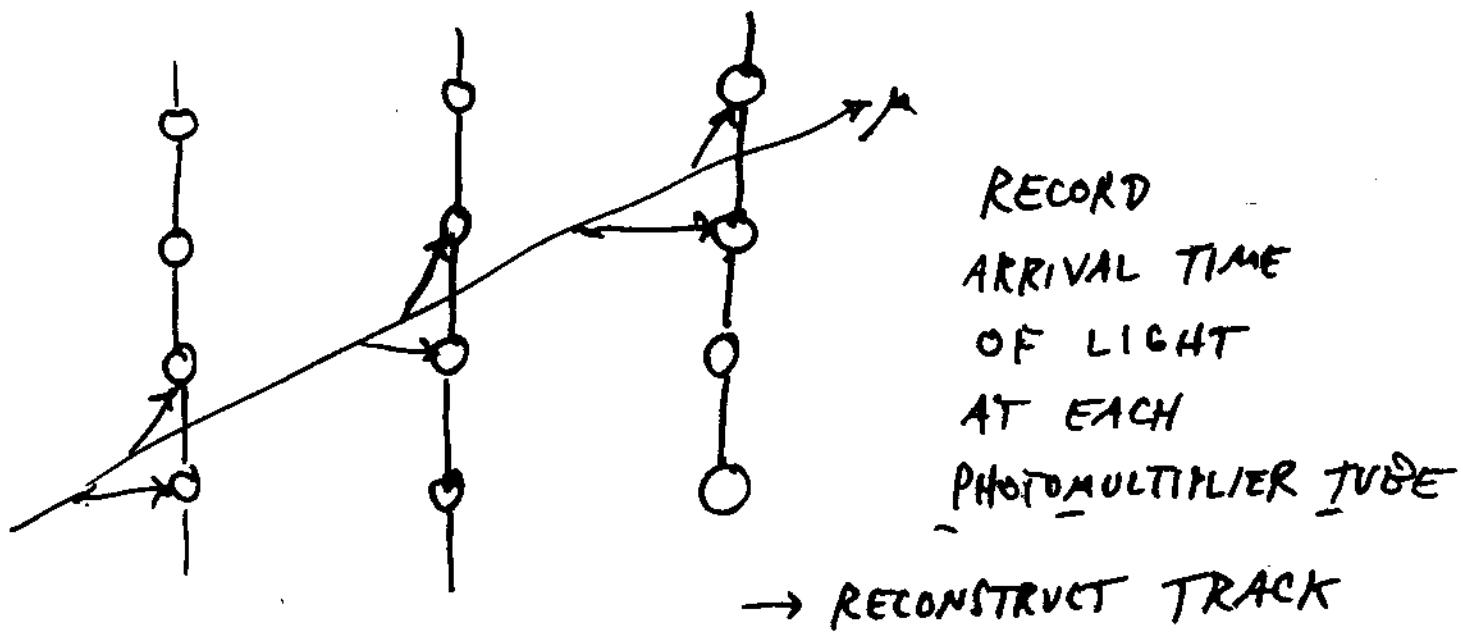
$$(\pi^0 \rightarrow \gamma + \gamma)$$

WATER CERENKOV DETECTOR



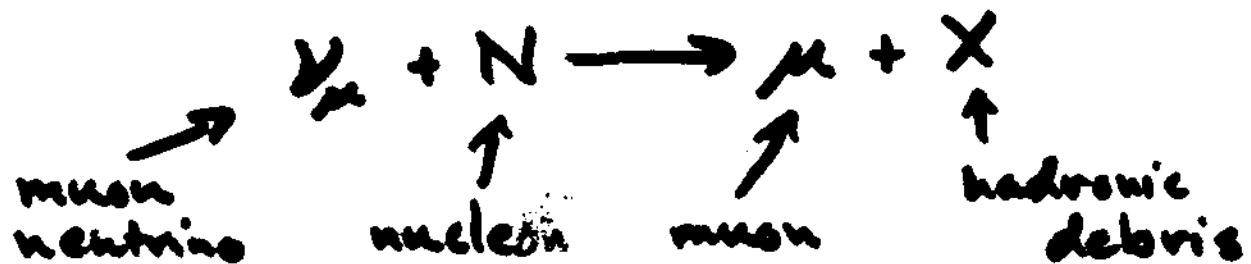
$$\cos \theta = \frac{1}{\beta n}$$

$$n \approx 4/3 \text{ so } \theta \approx 41^\circ$$



NOTE: μ TRAVELS AT c

LIGHT TRAVELS AT $\frac{3}{4}c$



DUMAND Optical Module

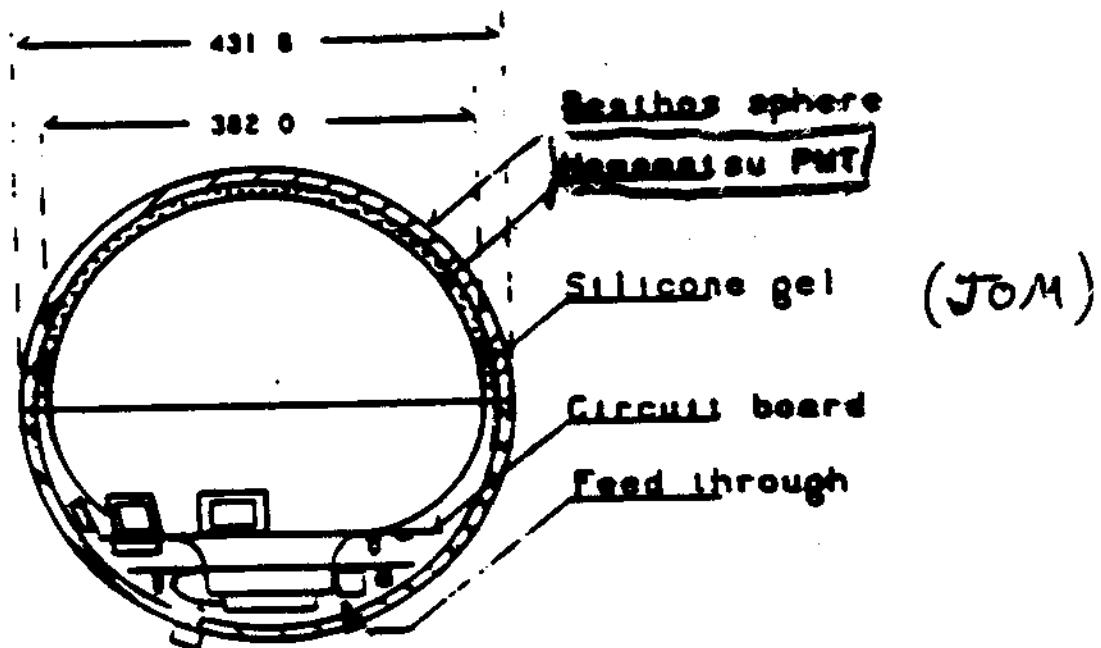


Figure 3.6: Cross sectional view of the Optical Module

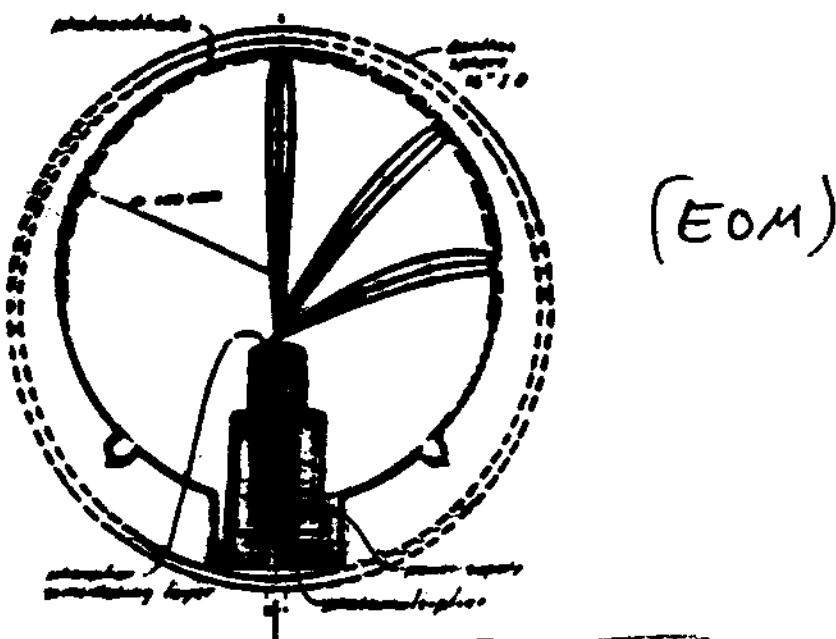


Figure 3.9: Internal structure of a Philips PMT

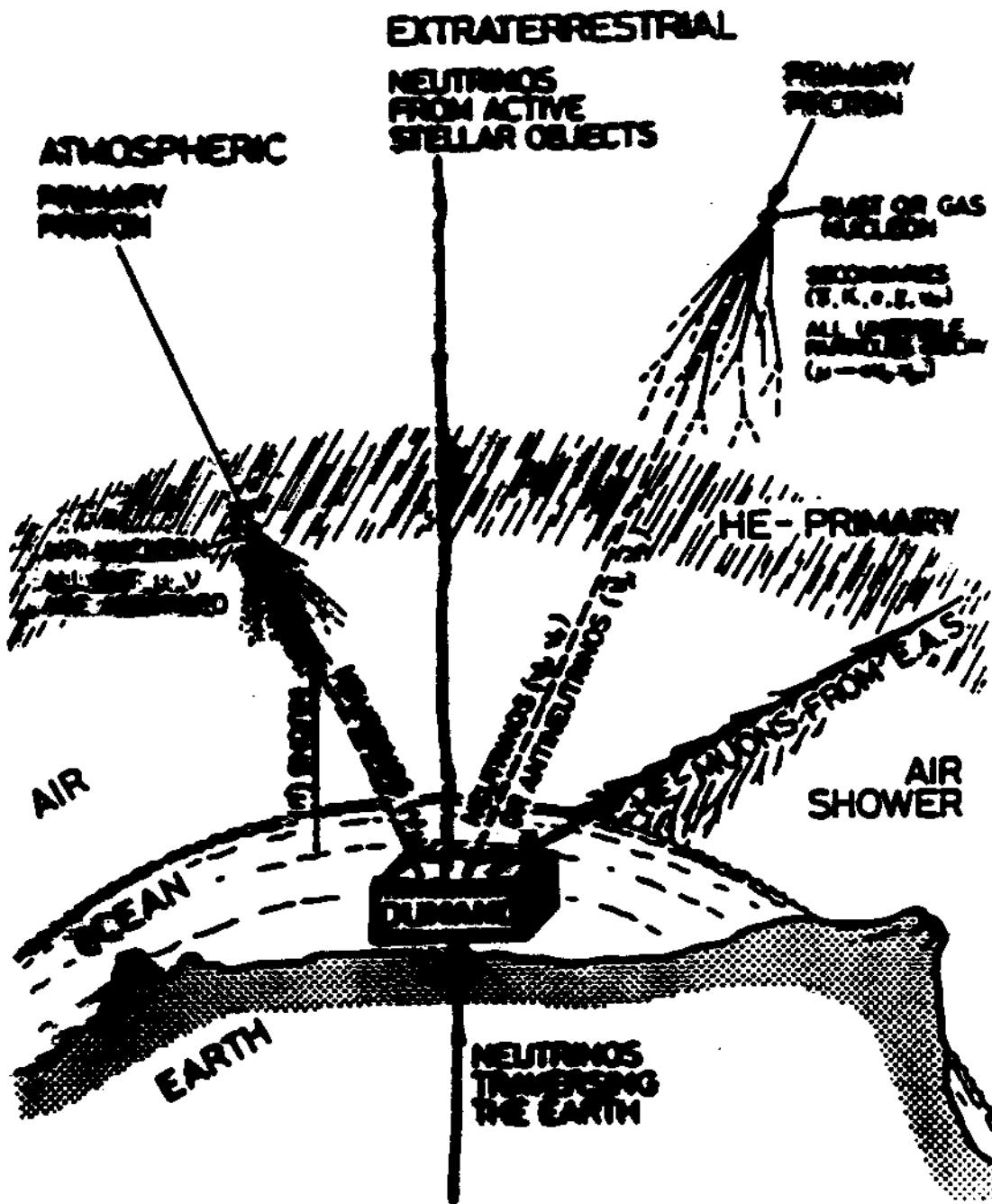


Figure 1.1: The concept of the DUMAND experiment. Cosmic ray protons (or other nuclei) of very high energy strike matter, either in the earth's atmosphere or down-going in the ocean. The resulting hadronic cascades decay into secondary particles which penetrate to the DUMAND array and are detected. Down going muons produced in the atmosphere with energy greater than ~ 3 TeV can also be detected and analyzed.

Possible Neutrino Sources

Anything that provides relativistic
protons + targets

Astrophysical

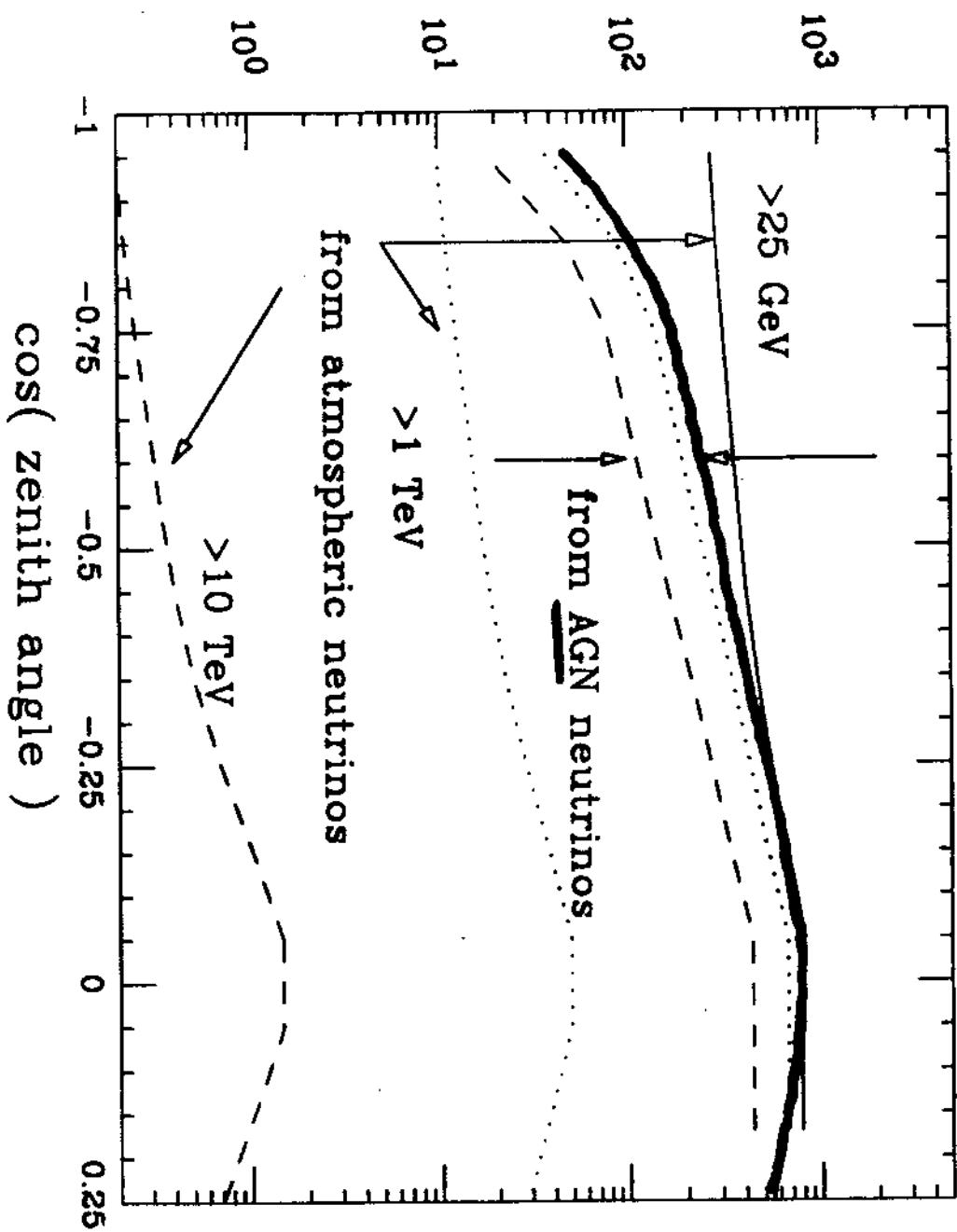
- {
 - Neutron Stars
 - Supernovas
 - Binary Star Systems
 - Cygnus X3 (supported by γ-ray studies)
 - Active Galactic Nuclei
 - Supermassive black holes (supported by recent X-ray studies)
 - Quasars, Crab Nebula, ...

Terrestrial

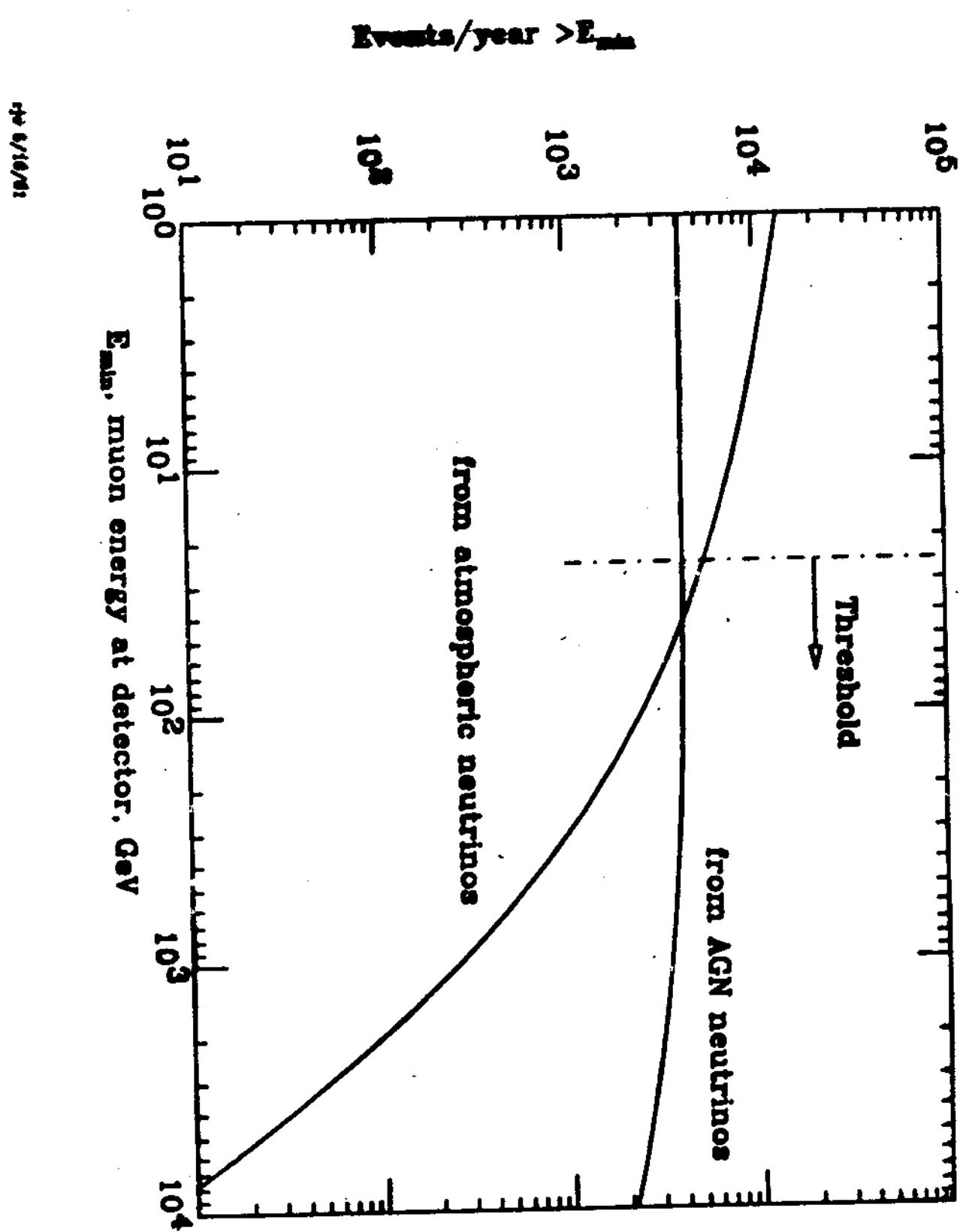
- {
 - Accelerators
 - Fermilab
 - Neutrino Oscillation
 - Solar Neutrino Problem

DUMAND-II: Muon angular distributions

muons/year/ $0.1 \times 2\pi$ sr

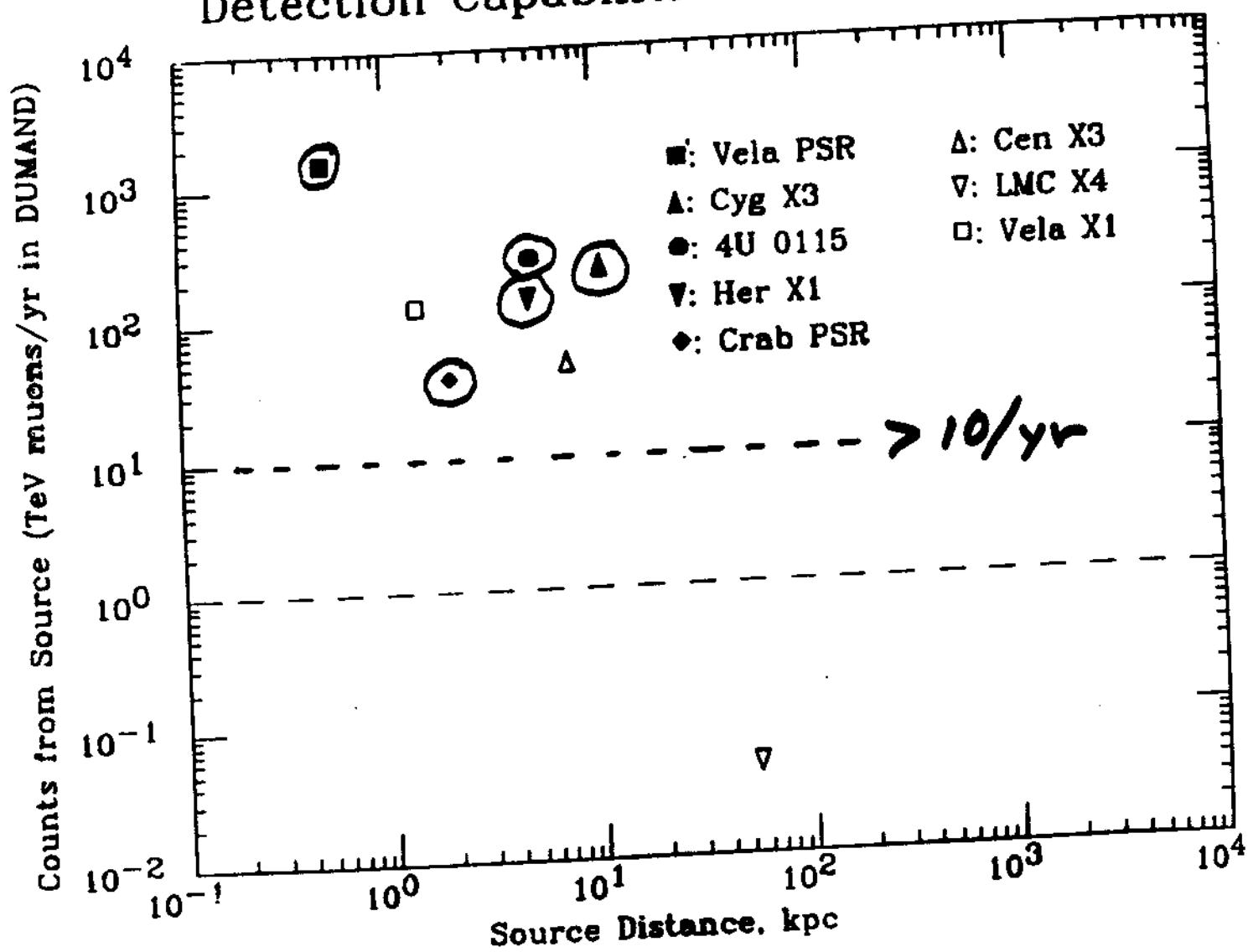


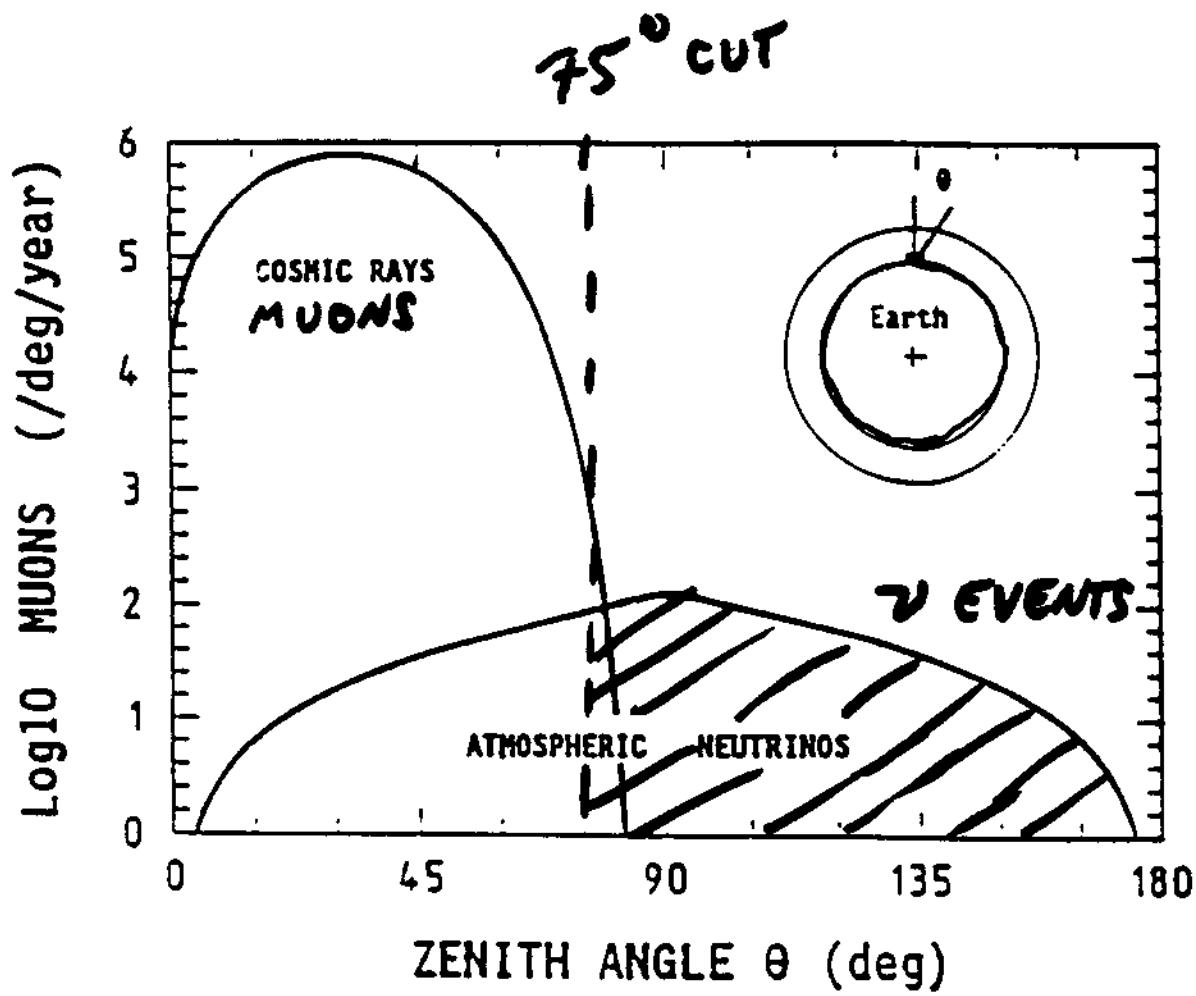
DUMAND-II: Integral spectrum of upcoming muons



10/16/01

Detection Capabilities of DUMAND-II





3500 EVTS/YR

$$= \frac{1}{2.8 \text{ deg}^2}$$

Other Neutrino Experiments

- Homestake Gold Mine, South Dakota
100,000 gallons Cerenkov

- Kamiokande
21,000 gallon Cerenkov

- Soviet American Gallium Expt.

- Gran Sasso, Italy
Gallium

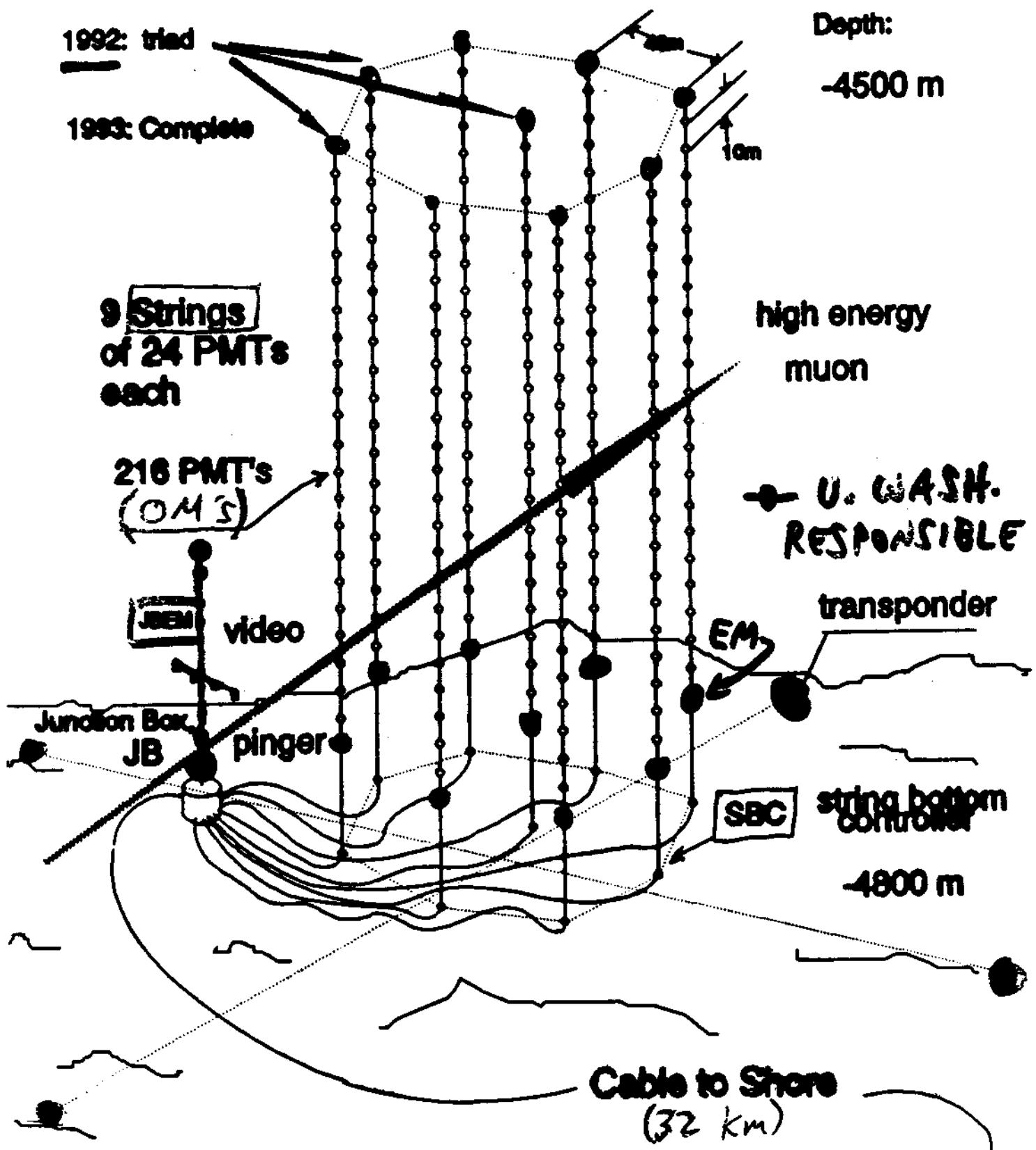
- Sudbury Nickel Mine, Ontario (1995)
Cerenkov w/ heavy water

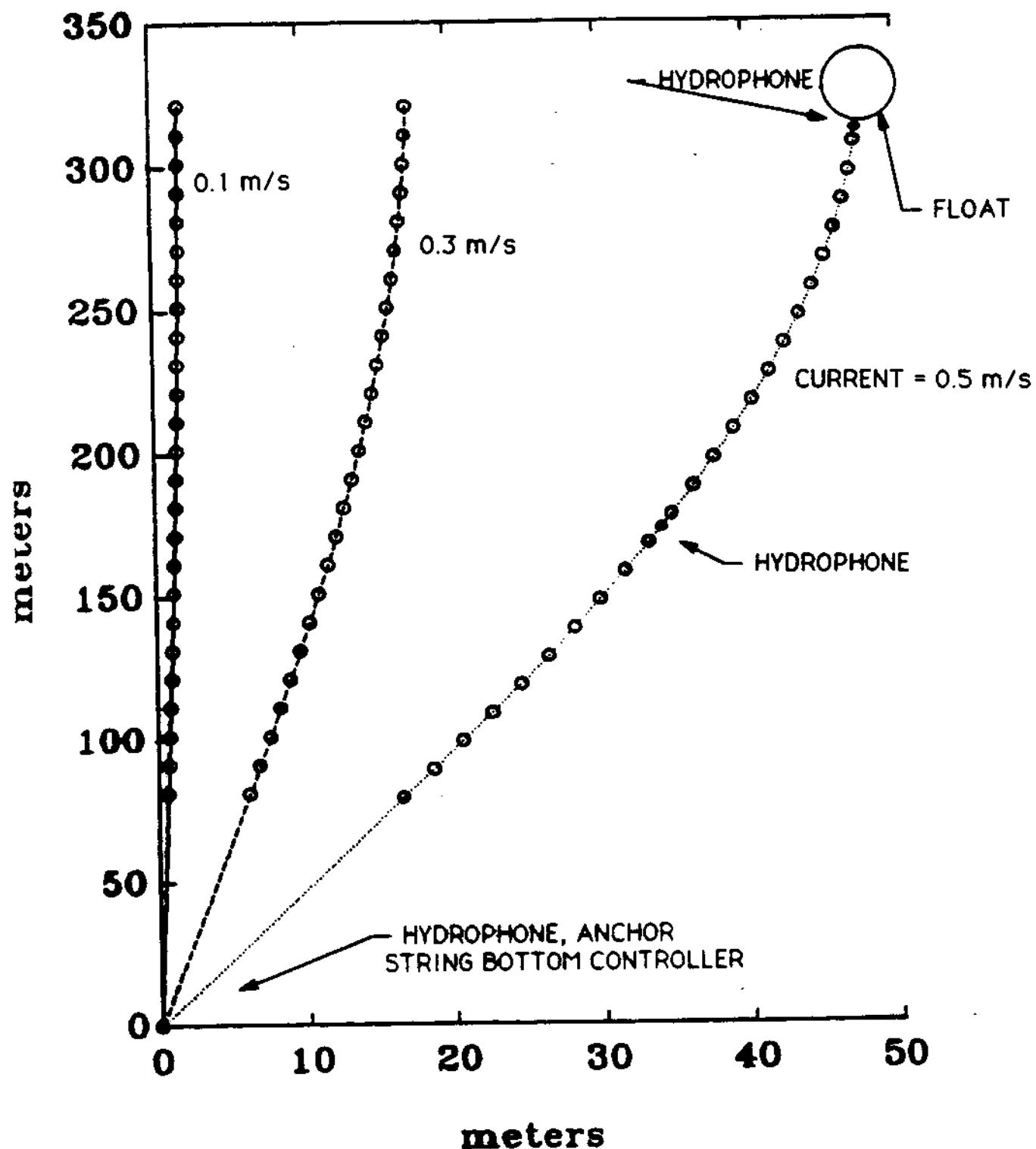
- IMB, Salt Mine, Cleveland

DUMAND will be the largest

Dumand II. Octagonal Neutrino Telescope

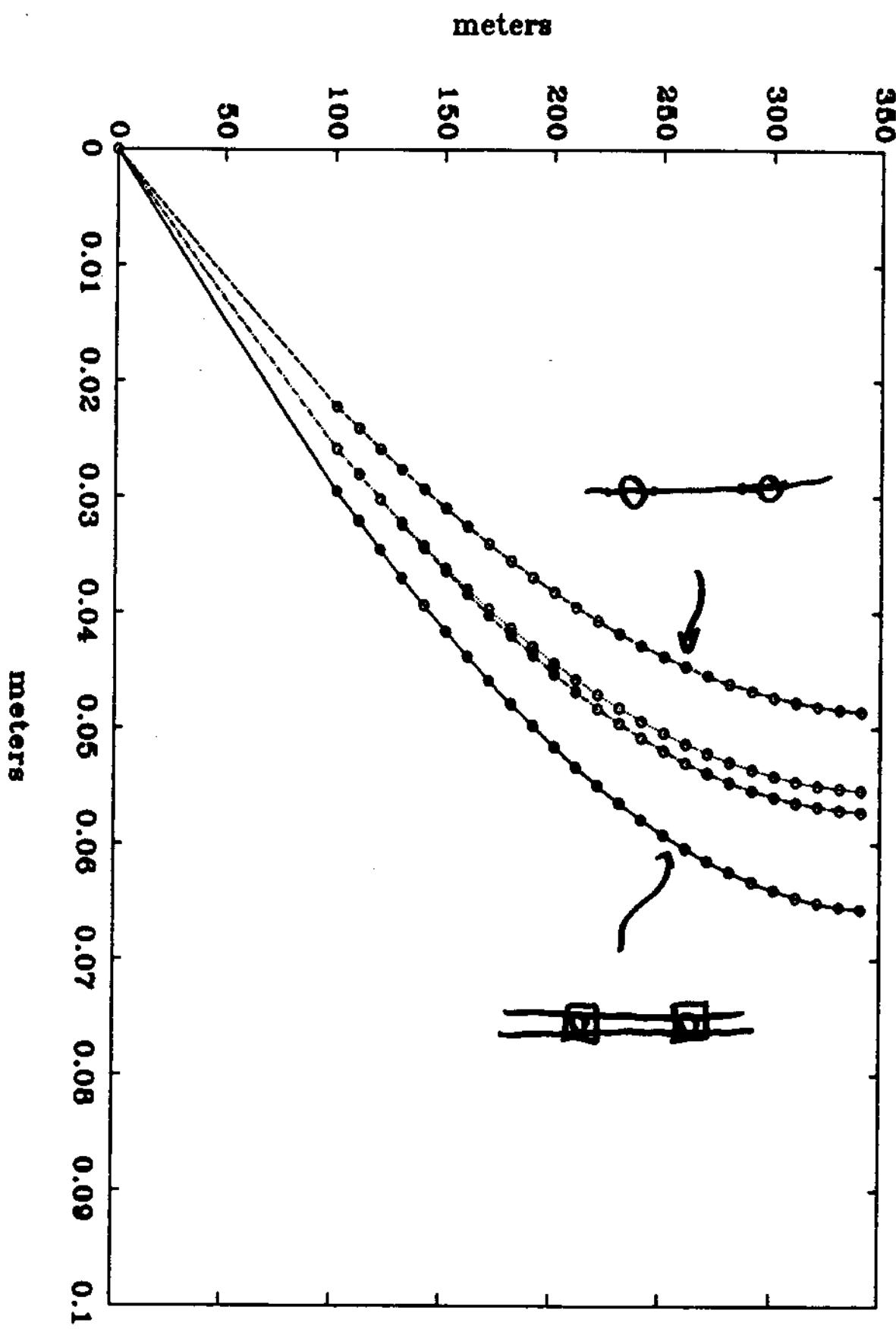
Array dimensions: 200 m high, 180m diameter





STRING PROFILE

String Profile $V=0.01$ m/s



Problem:

In order to calculate the incoming muon direction to within 1° , we need to know the position of each optical module (OM) to within $\sim 10\text{cm}$.

Also, we need to know the rotational orientation of the array to geodetic coordinates $\sim 1^\circ$.

How can you measure this?

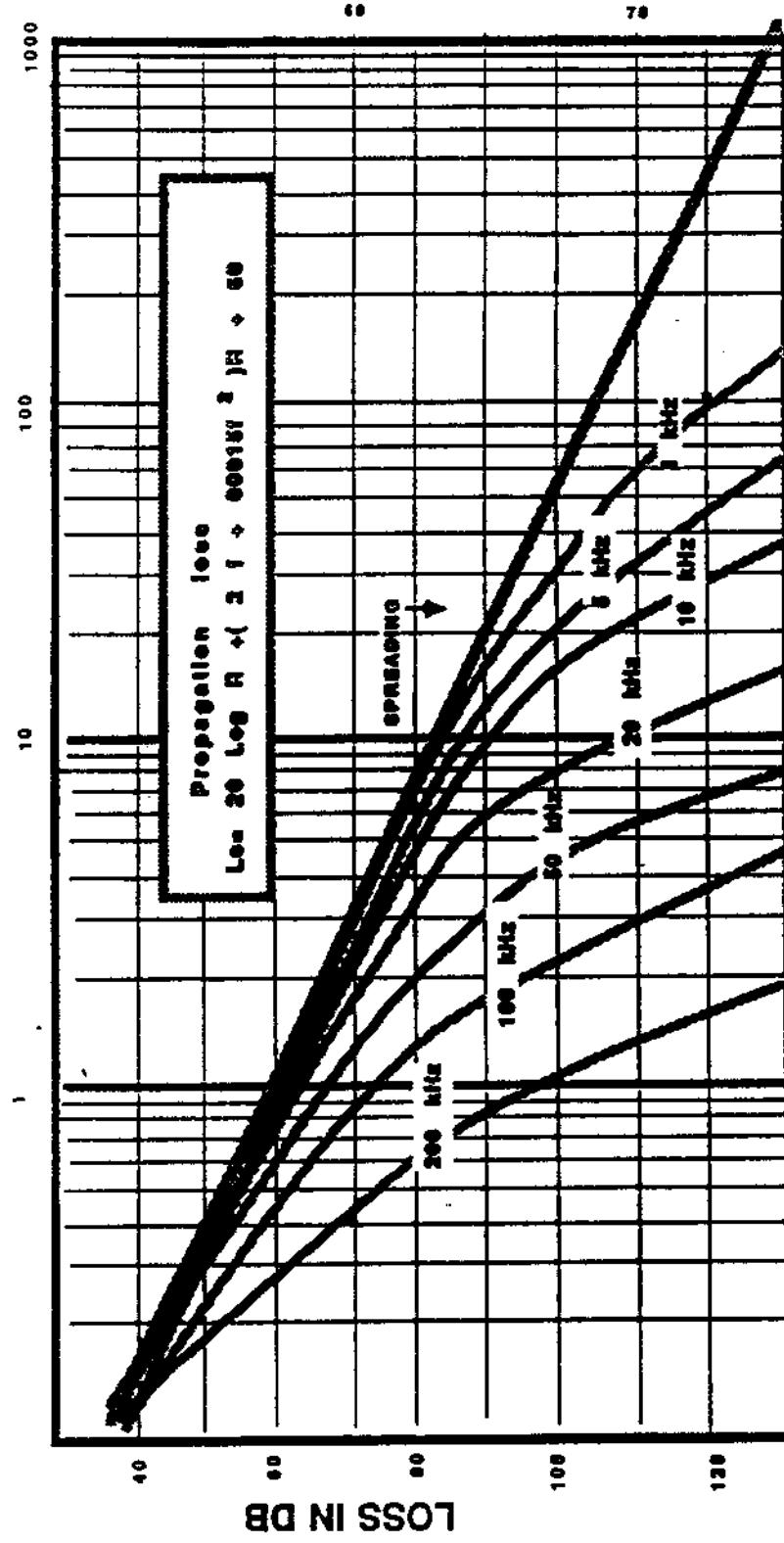
~~Lights~~

~~Radars~~

~~Topo. Survey~~

ACOUSTICS

RANGE IN KILOMETERS



ACOUSTIC LOSS

SONAR EQUATION

$$\text{SNR} = \text{SL} - \text{TL} - \frac{\text{NL}}{R}$$

↑ ↑ ↑ R
 Signal to Source Transmission Noise
 Noise Ratio Level Loss Level

$$\text{SL} = 10 \log \frac{I}{I_0} \approx 190 \text{ dB } (000\omega)$$

$$\text{NL} = \text{Noise Spectra} + 10 \log (\text{Bandwidth})$$

$$\approx 50 \text{ dB} + 43 \text{ dB} = 93 \text{ dB}$$

$$\text{TL} = 20 \log(\text{Range}) + \alpha \cdot \underset{\substack{\uparrow \\ \text{absorption}}}{\text{Range}}$$

$$\approx \begin{cases} 29 + 7 = 81 \text{ dB @ 5000m} \\ 54 \text{ dB @ 500m} \end{cases}$$

$$@ 500 \text{ m} \quad \text{SNR} = 43 \text{ dB}$$

$$@ 5000 \text{ m} \quad \text{SNR} = 16 \text{ dB}$$

Want $\text{SNR} \geq 12 \text{ dB}$ for reliable detection

$(10 \log(BW \cdot T))$ improvement due to signal processing

- Leading Edge detection not adequate for our system
- Enormous data rate to shore (\sim Mbytes/sec) allows for more sophisticated analysis of digitized signals
- Can match received signal with the transmitted signal

\rightarrow "Matched Filter"

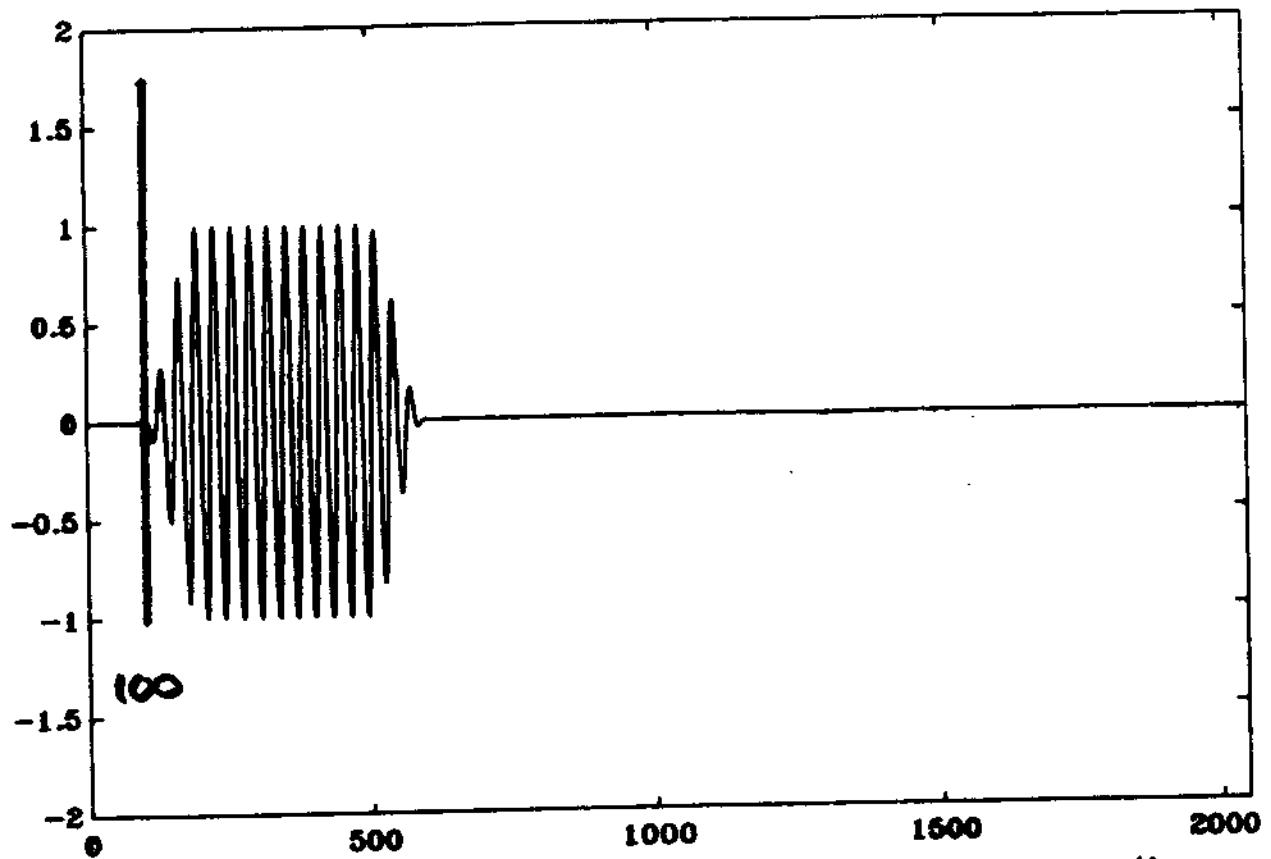
- Correlation Function

$$c(\tau) = \int s(t) r(t-\tau) dt$$

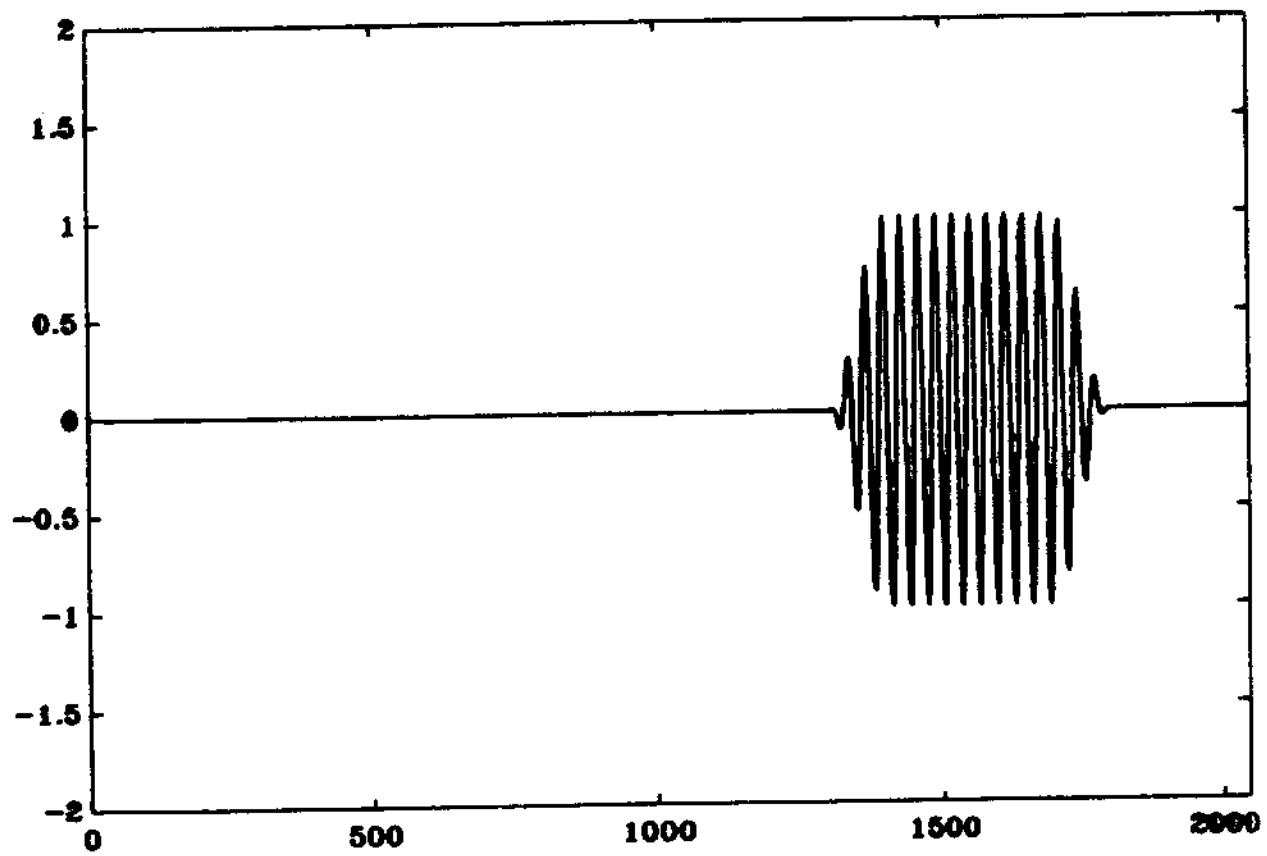
r = received signal

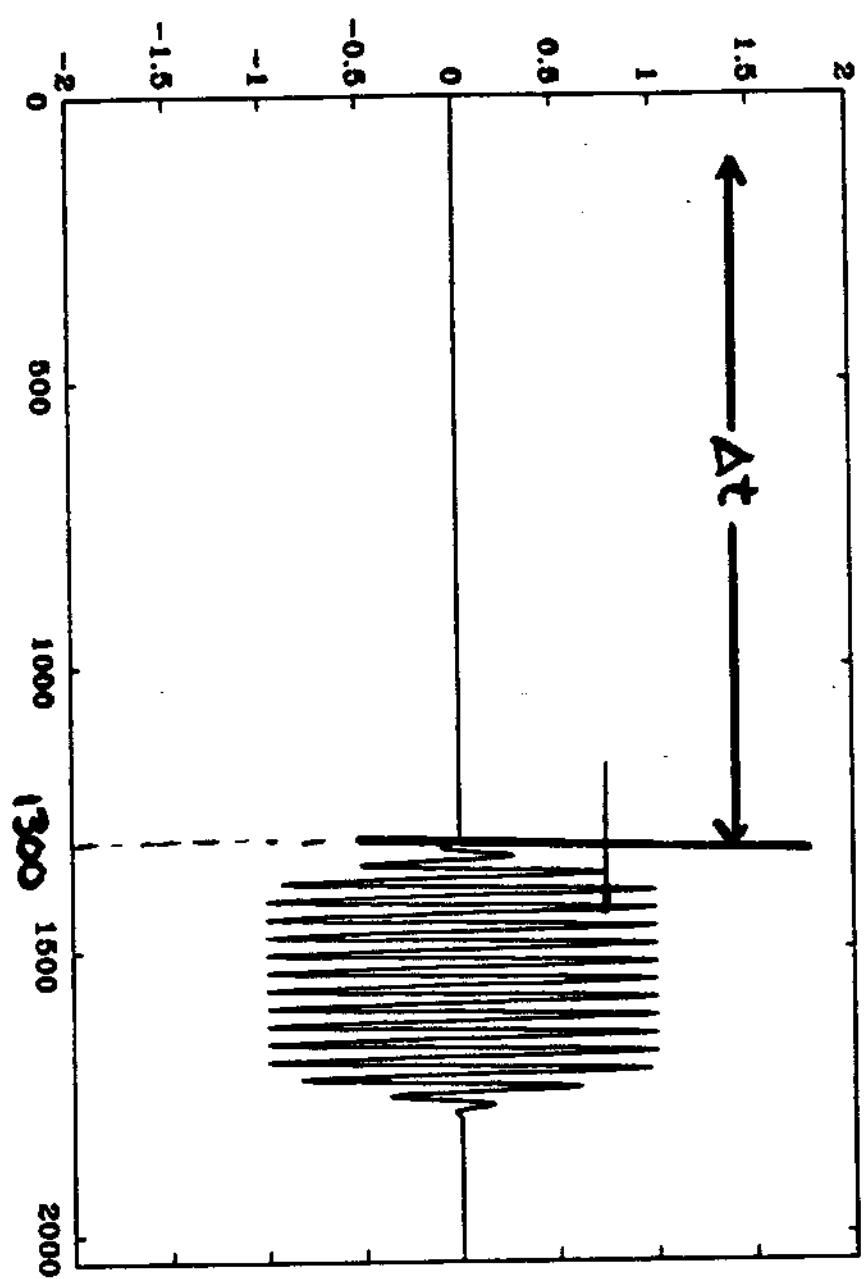
s = transmitted signal

τ = time delay

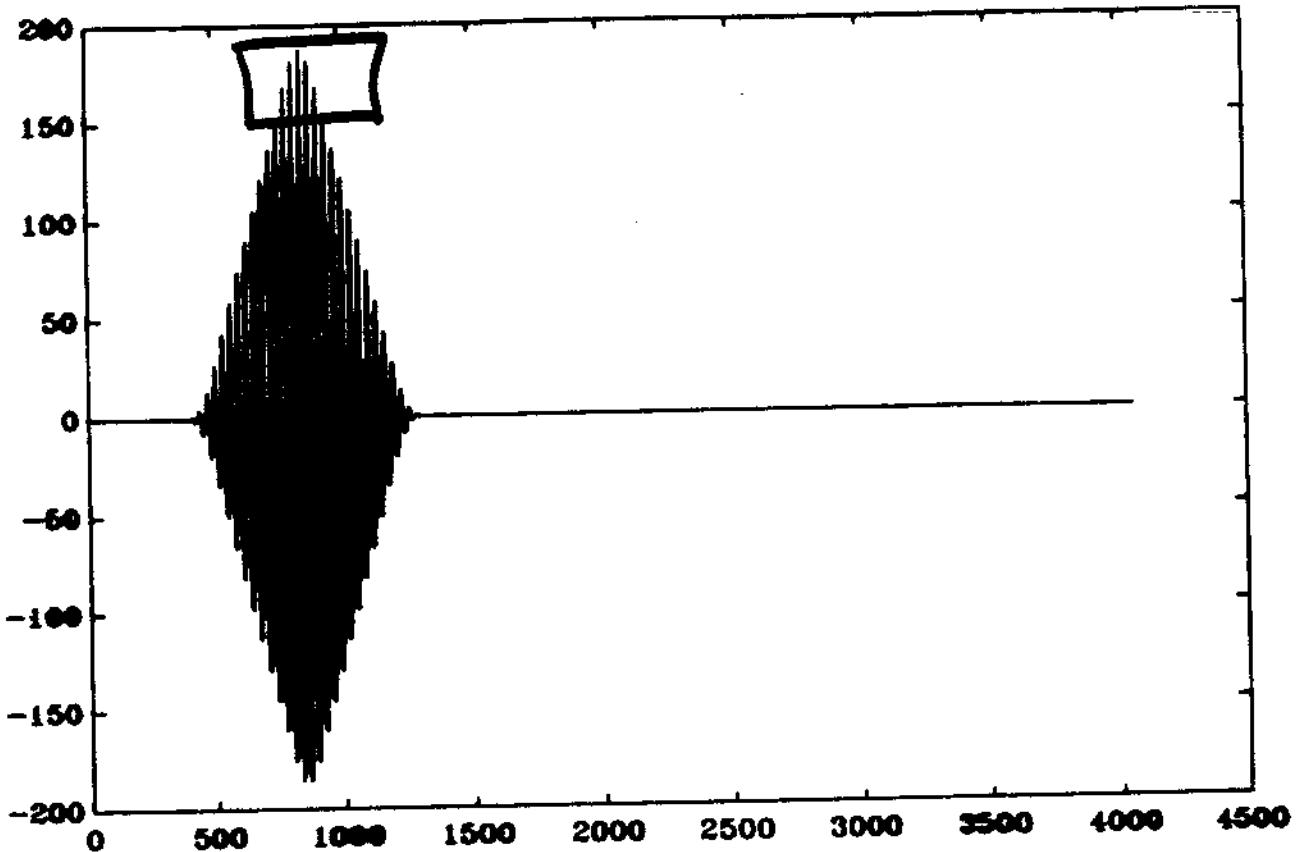


Artificial Transmitted "PING"

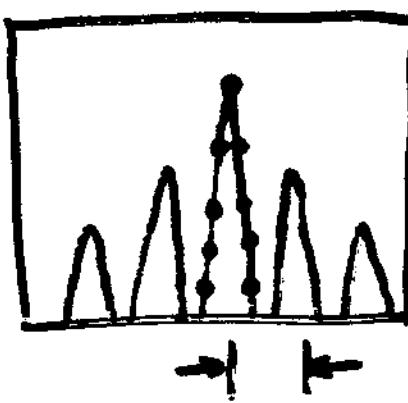




CORRELATION of Received + Transmitted Pings

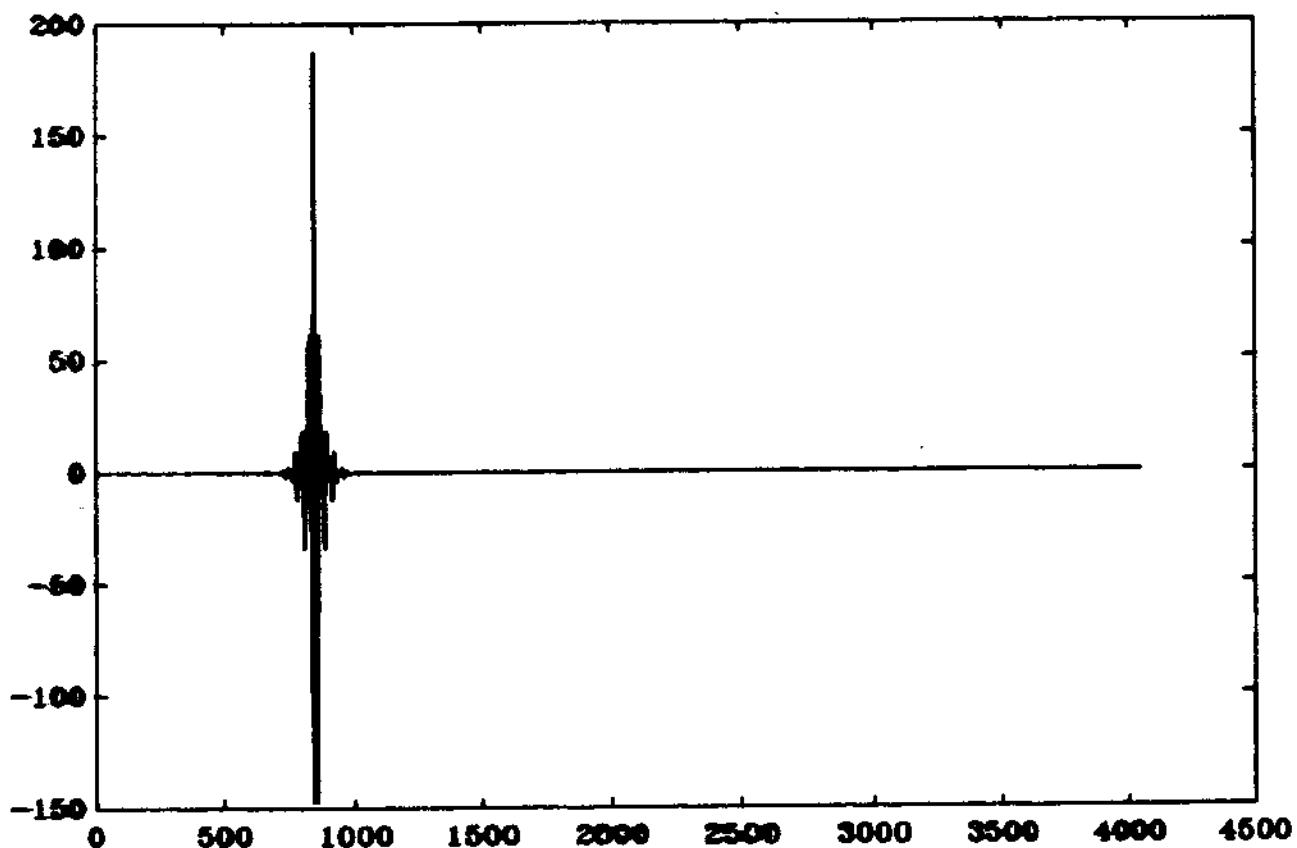


$$\frac{1}{10 \text{ kHz}} \times 1500 \text{ m/s} = 15 \text{ cm}$$



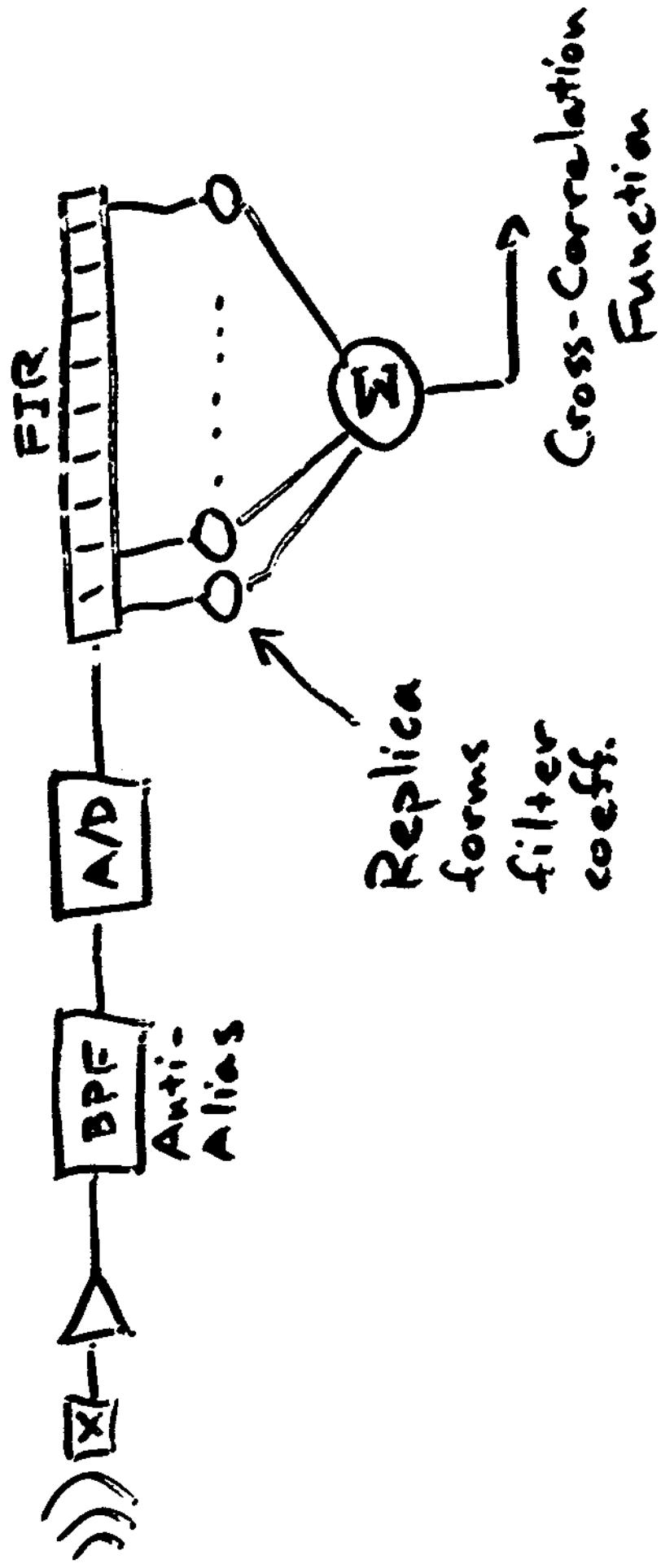
$$\frac{1}{200 \text{ kHz}} \times 1500 \text{ m/s} = 7.5 \text{ mm}$$

Improvement: FM waveforms give better time resolution, and also offer robustness against noise + multipath.



Correlation of Noiseless
FM Pulse

Time Domain Matched Filter Correlator



Frequency Domain Matched Filter

— Correlator

$$r_r(t)$$

$$R(k)$$

$$c(\tau)$$

Arrival
Time

$$S^*(f)$$

FM
Pulse

Pre-
Amp

Alias
Filter

Pre-
Amp

Alias
Filter

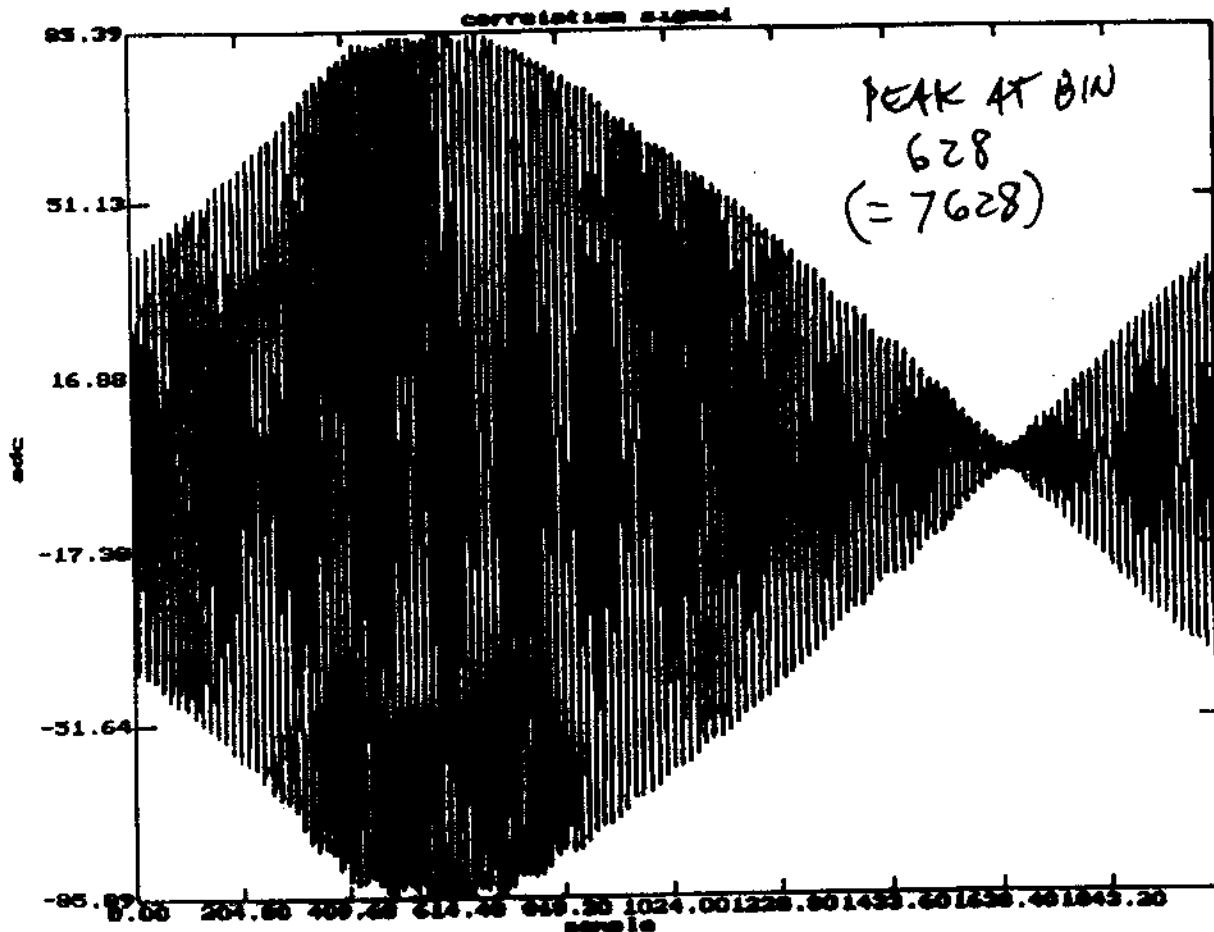


Correlation Function

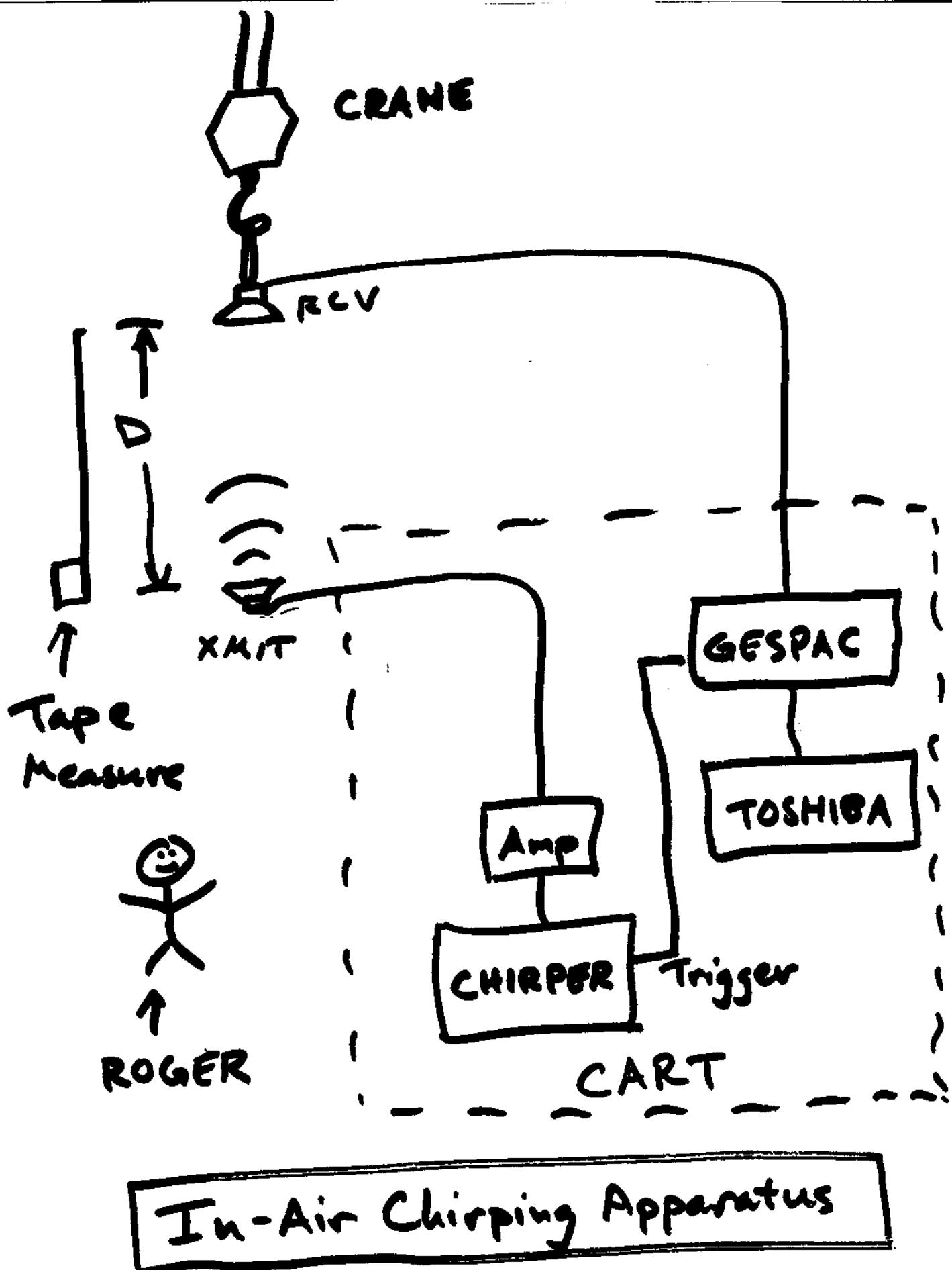
$$c(\tau) = \int r(t) s(t-\tau) = \mathcal{F}^{-1} \{ R(k) S^*(k) \}$$

$$\sum_n r(n)s(n-\tau)$$

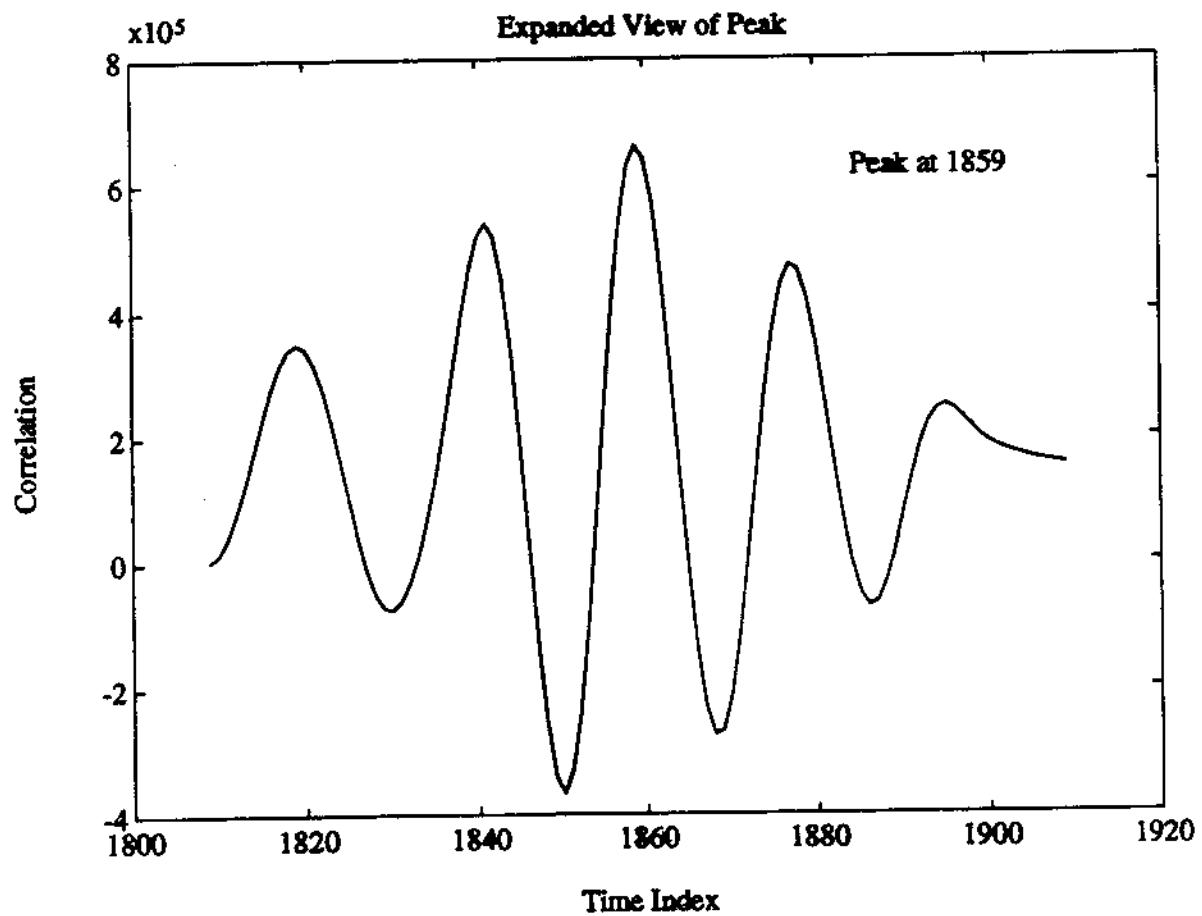
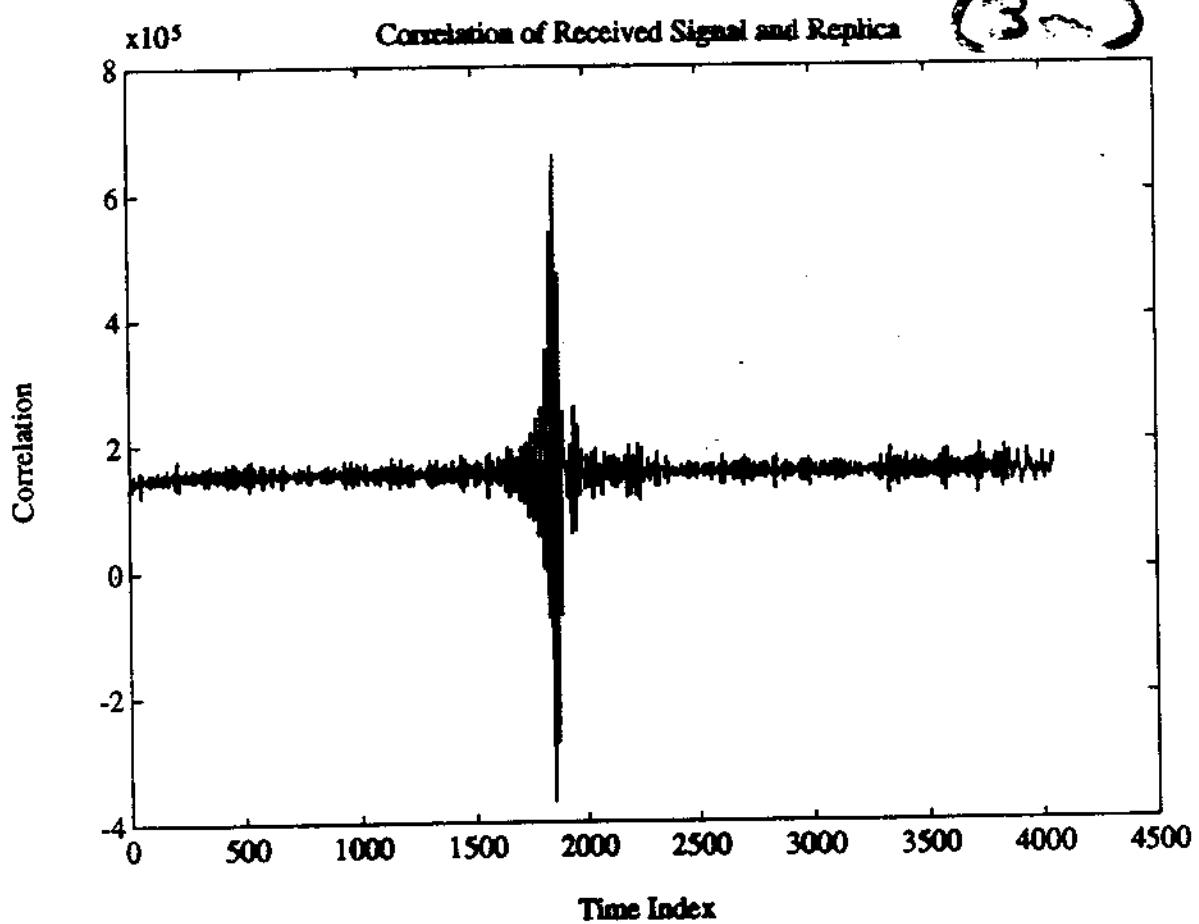
$1 \rightarrow 3$



Correlation Function from
Frost Pond Test. Waveform
is single frequency.

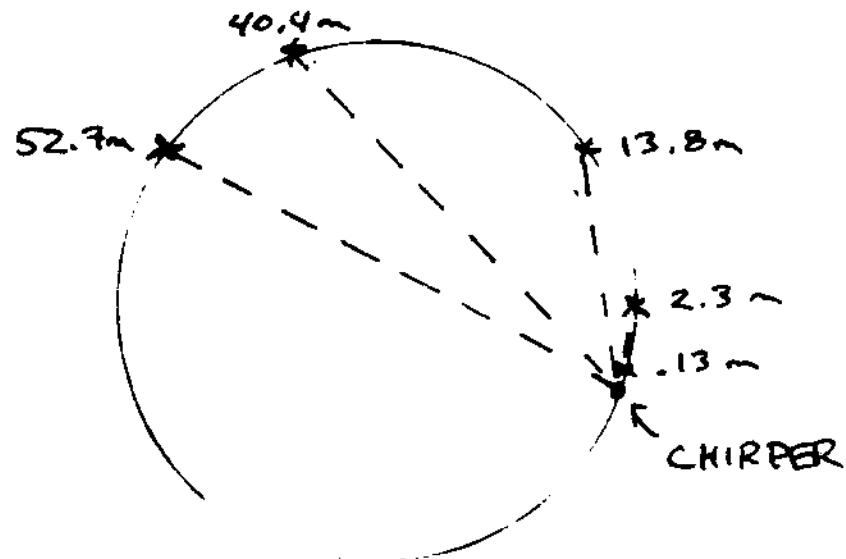
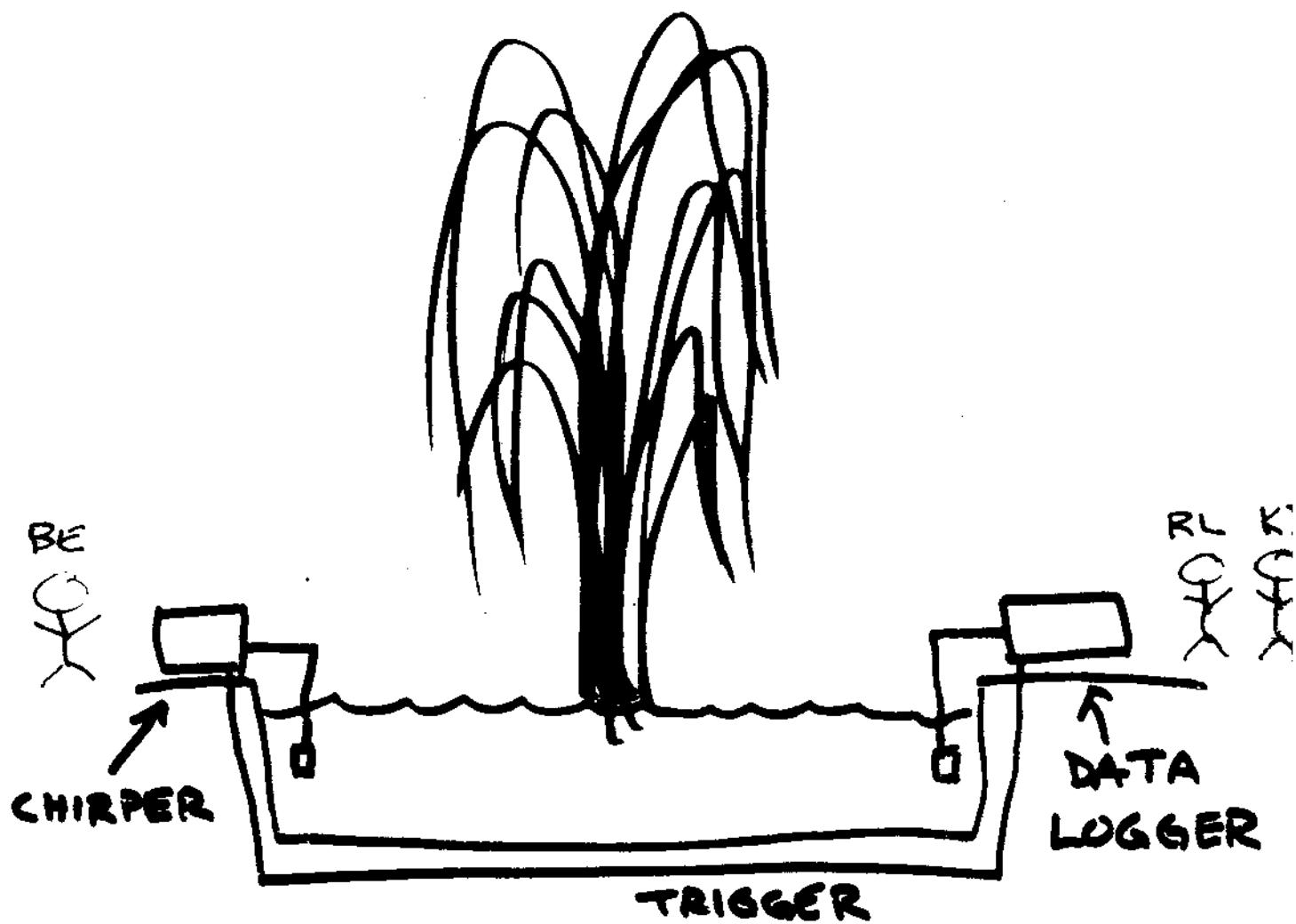


In Air Chirp Test

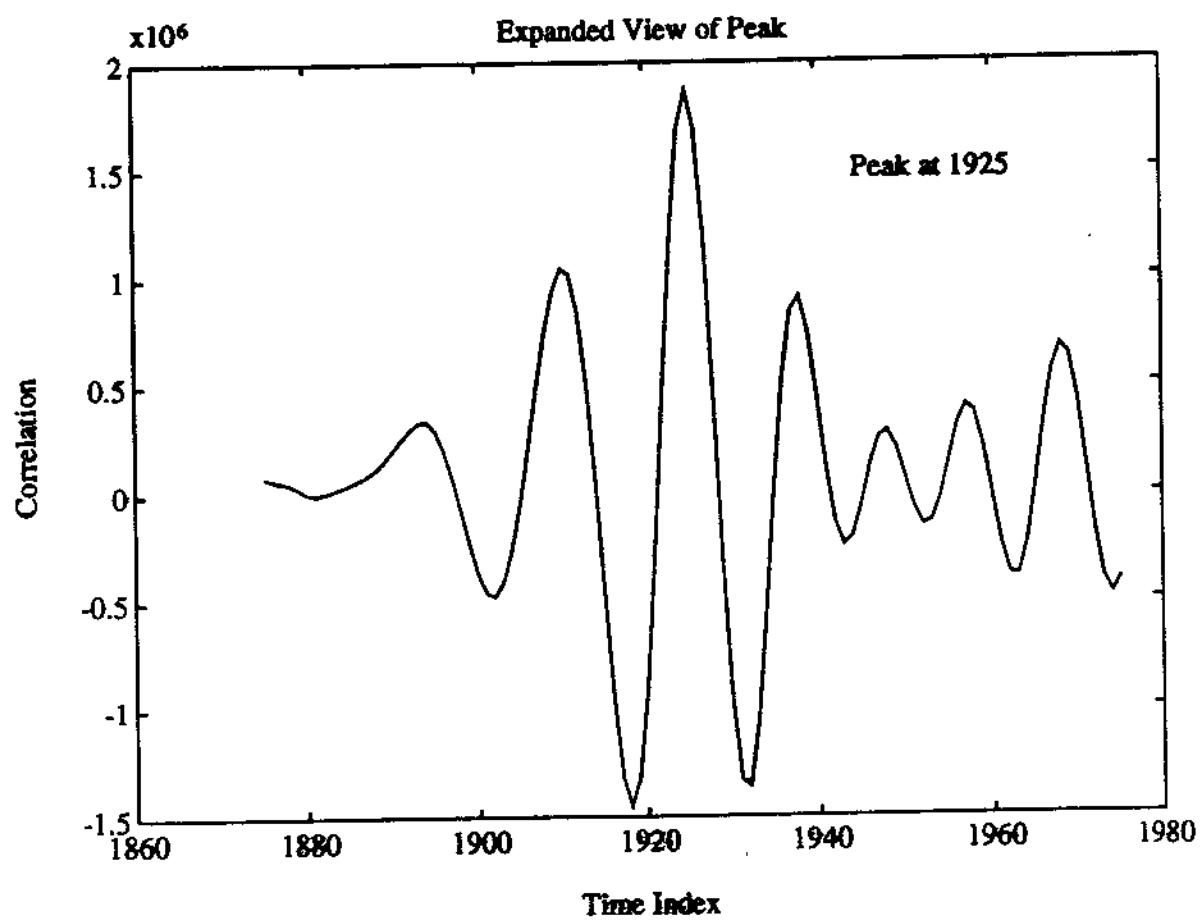
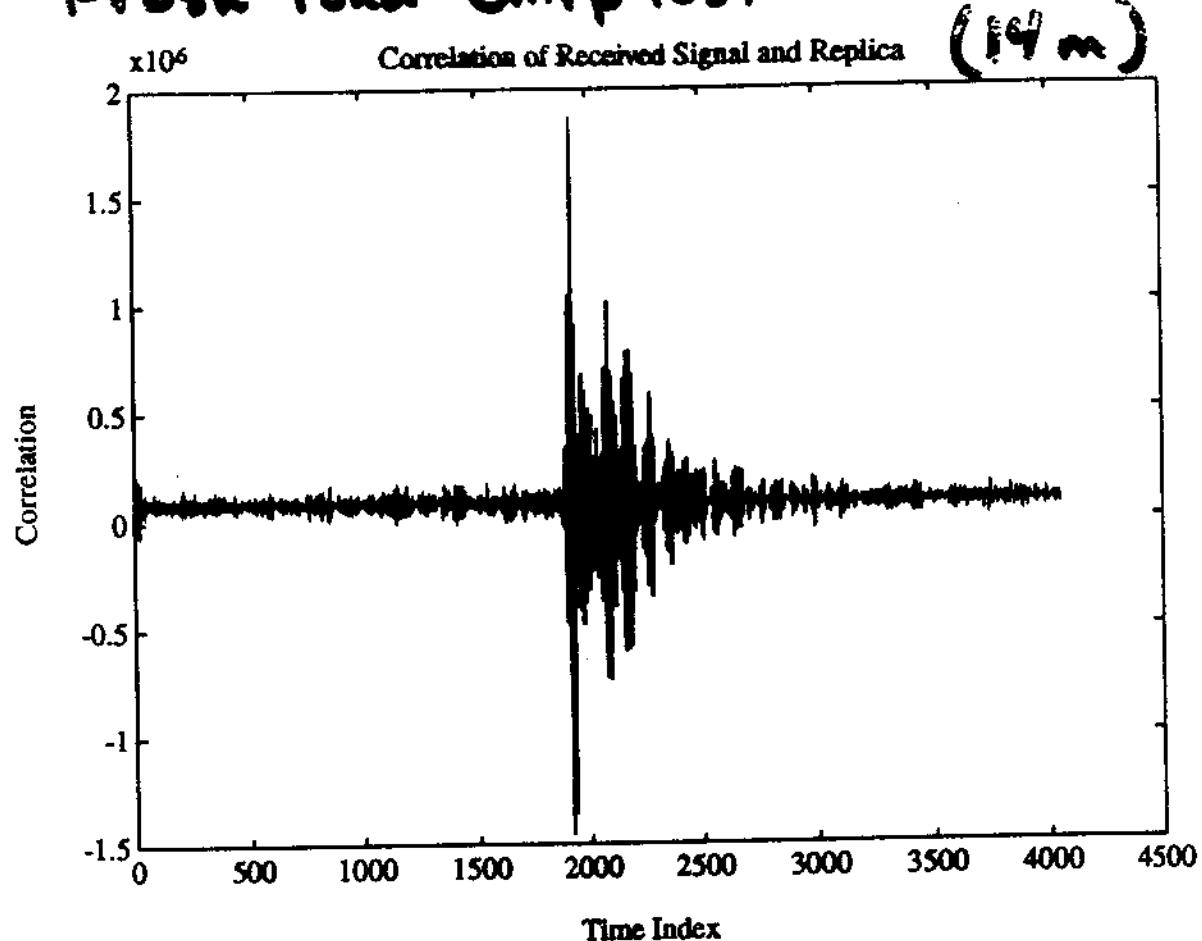


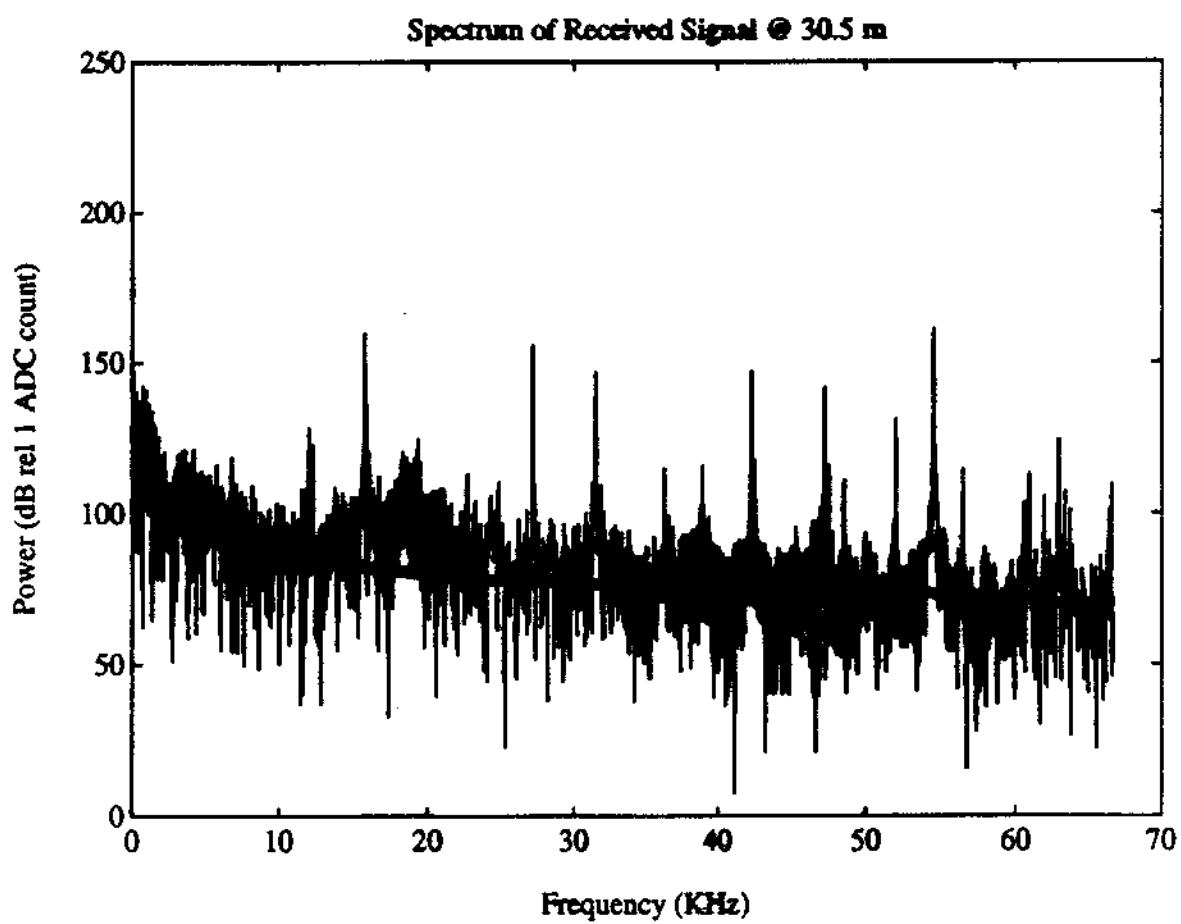
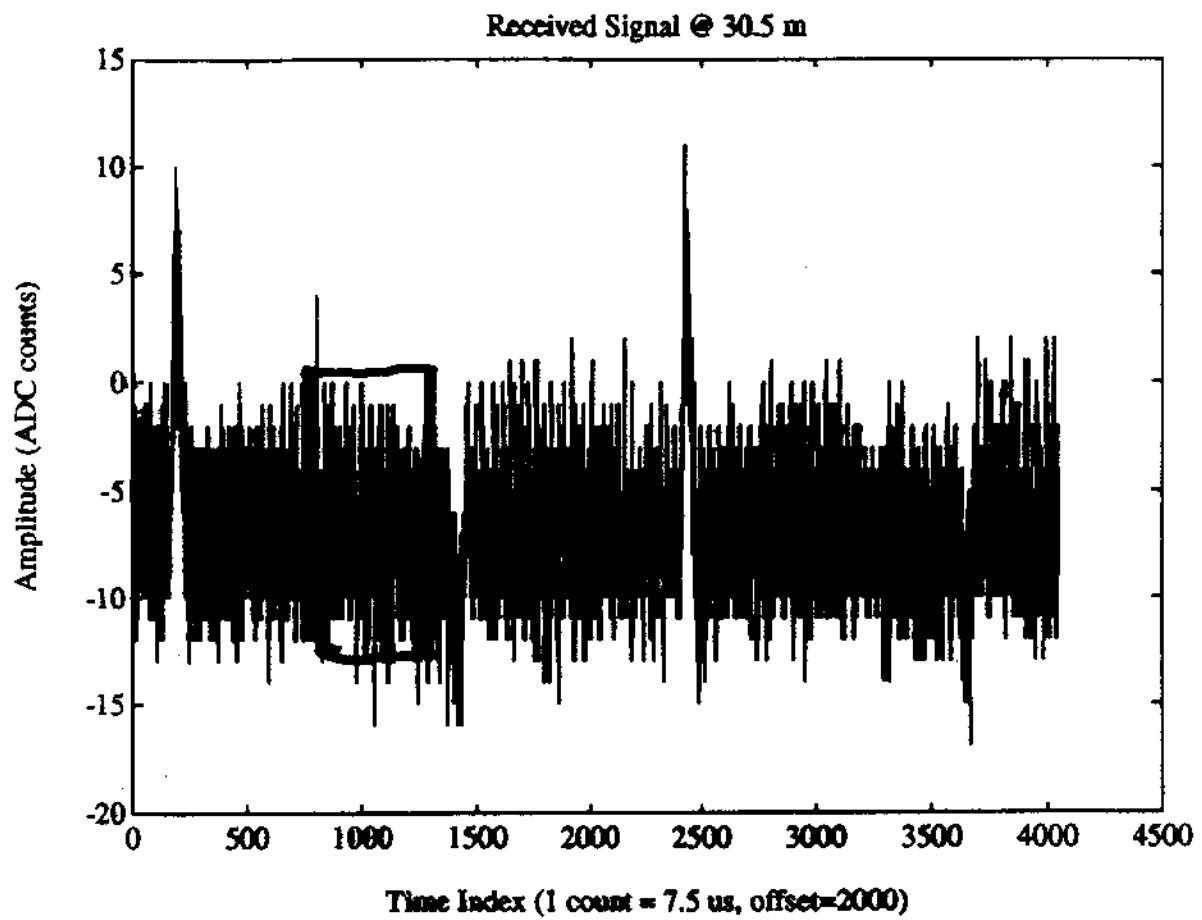
FROSH POND

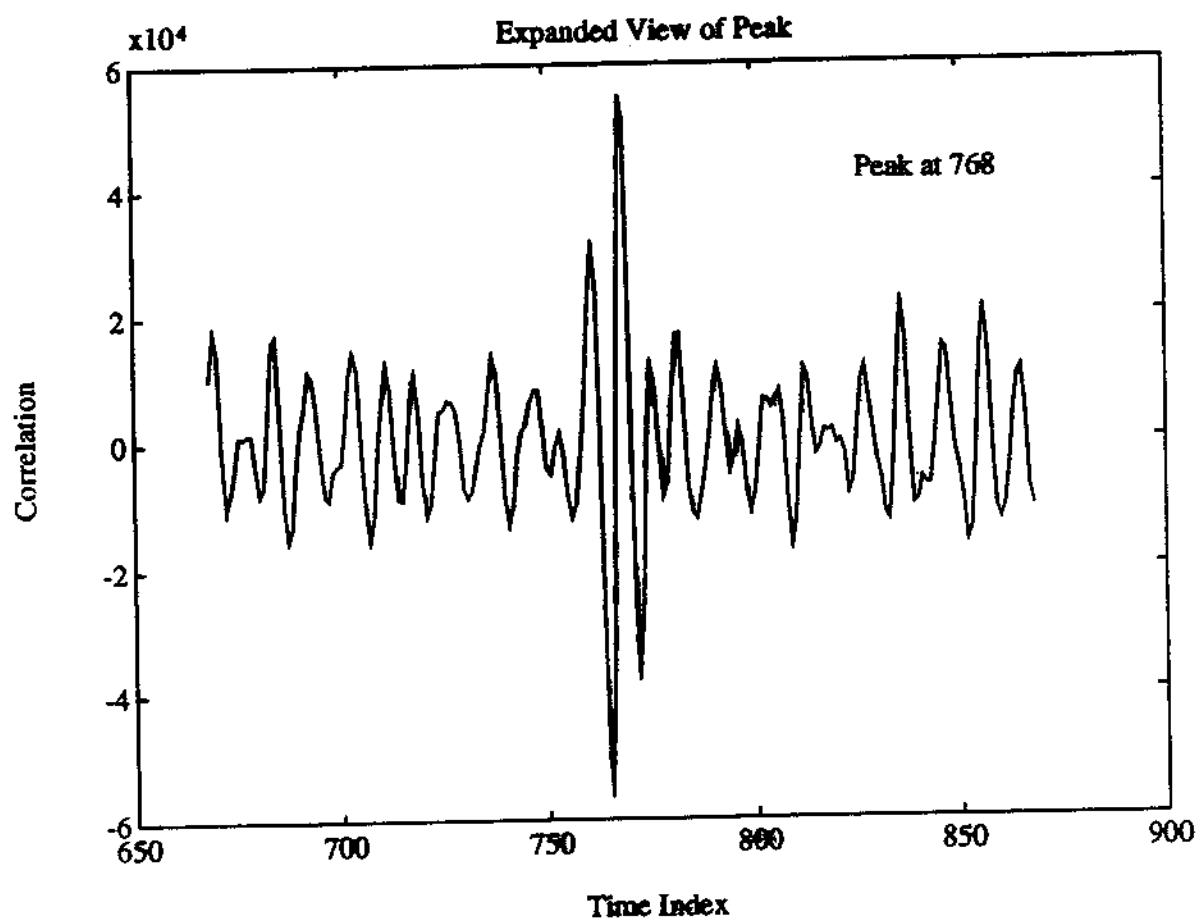
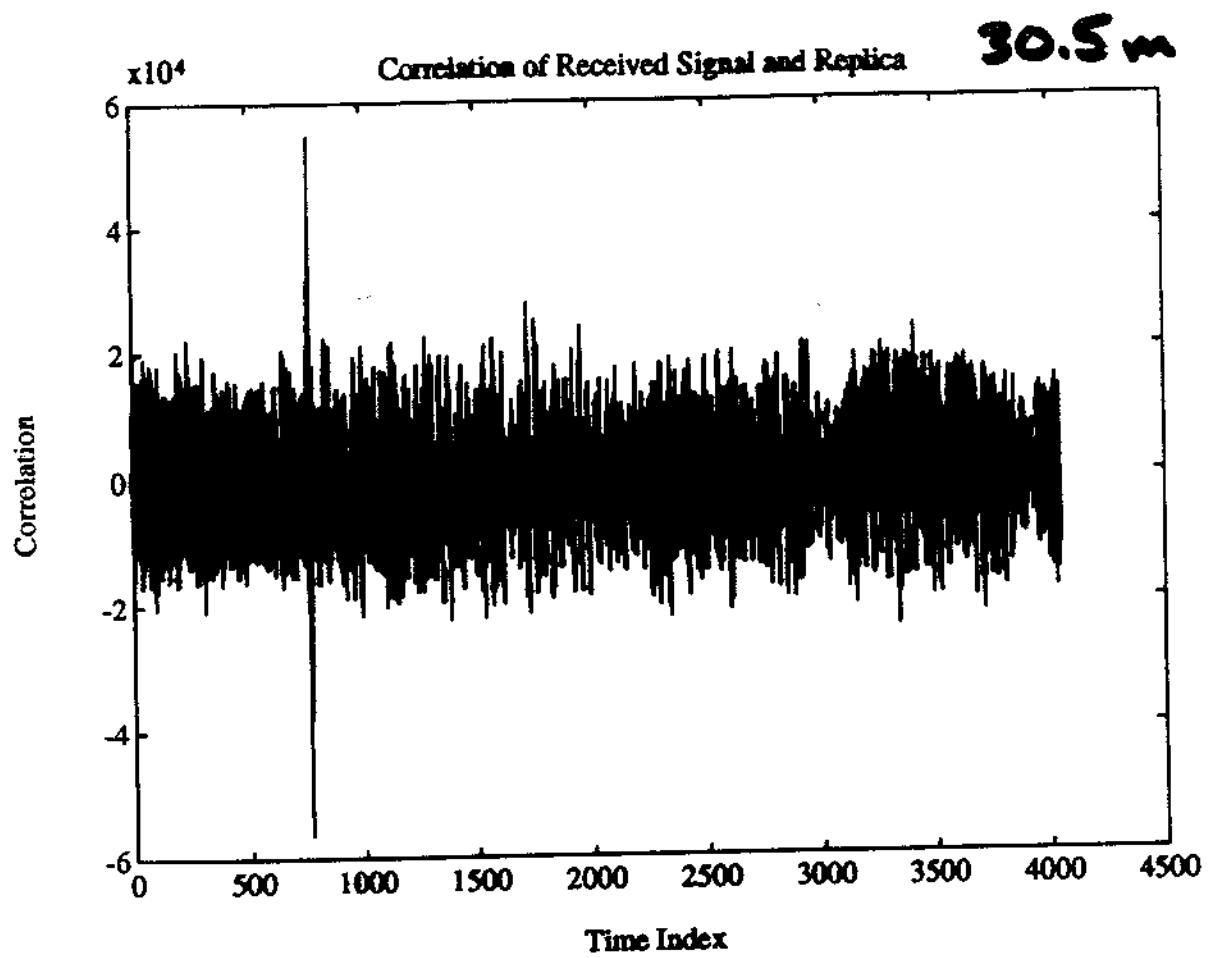
CHIRPING RESULTS



Frost Pond Chirp Test







10 June/91

Fit to Yacht club chirper data by BE

302.5	3.28	0.002269	Regression Output:
715.5	7.85	0.005366	Constant -0.05235 -0.05235
744	8.15	0.00558	Std Err of Y Est 0.008303 0.008303
2768	30.48	0.020759	R Squared 1 1
			No. of ObNo. of Observation 4 4
			Degrees of Freedom 2 2
			X CoefficX Coefficient(s) 1470.849
			Std Err oStd Err of Coef. 0.576488
Recalc	residue		
3.284456	-0.00446		
7.840167	0.009833		
8.154544	-0.00454		
30.48083	-0.00083		

- no jitter due to digital chirper/logger

- residues ~1cm

- poor source level \rightarrow mixed results

- $c = 1471 \text{ m/s}$ (Book 1481 m/s)

Summary of Tests

Feb 11 Proposed Chirping

Feb 20 Fresh Pond Test
Single Frequency

~1m

May 9 Analog Chirper
In Air Test

May 13 Analog Chirper
Fresh Pond Test

~2m

June 7 Digital Chirper
Union Bay Test

~1cm