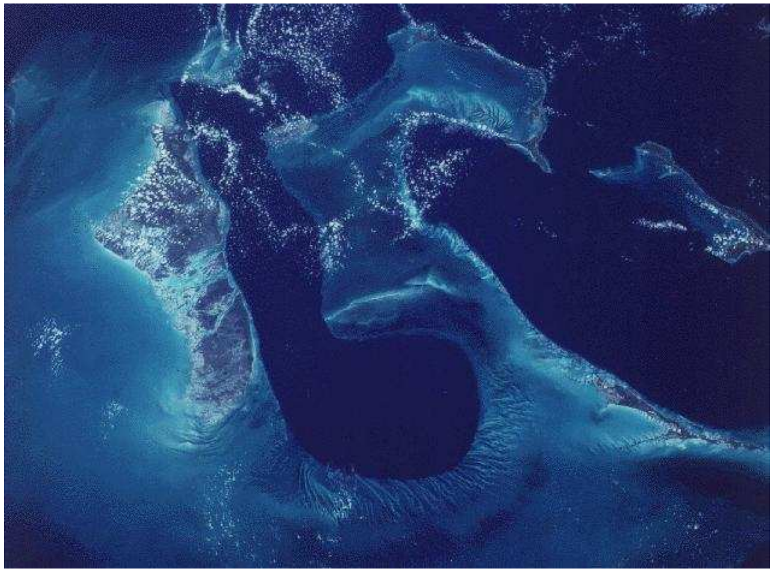
A Study of Acoustic Ultrahigh-energy Neutrino Detection (SAUND)

http://hep.stanford.edu/neutrino/SAUND/



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Como, Italy

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Thanks to my SAUND collaborators:

Current:

- G. Gratta (Stanford)
- M. Buckingham (Scripps)
- J. Vandenbroucke (Stanford, now at Berkeley)

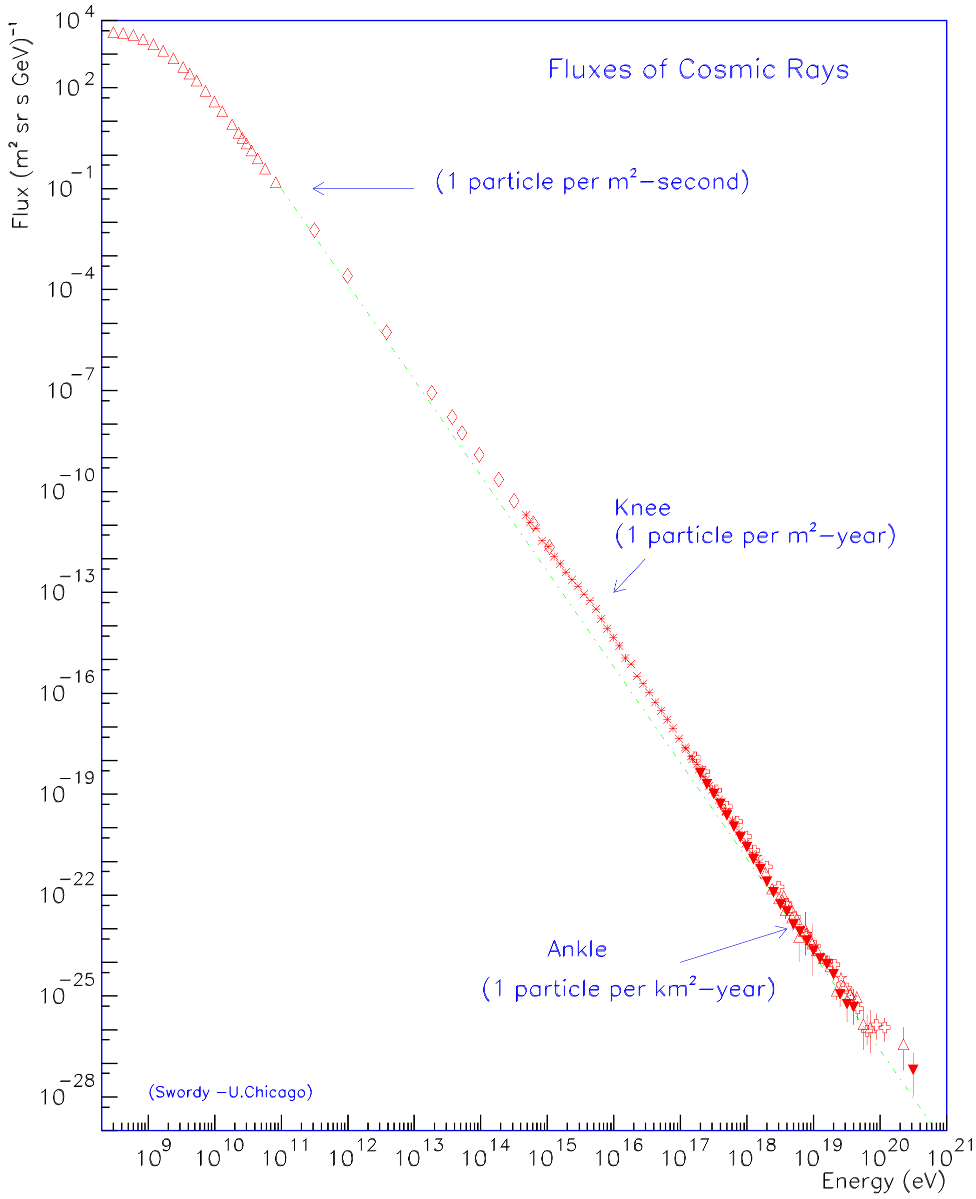
Past:

- N. Lehtinen (Stanford, now at Hawaii)
- S. Adam (Stanford, now at Cornell)
- Y. Zhao (Stanford)
- T. Berger (Scripps)

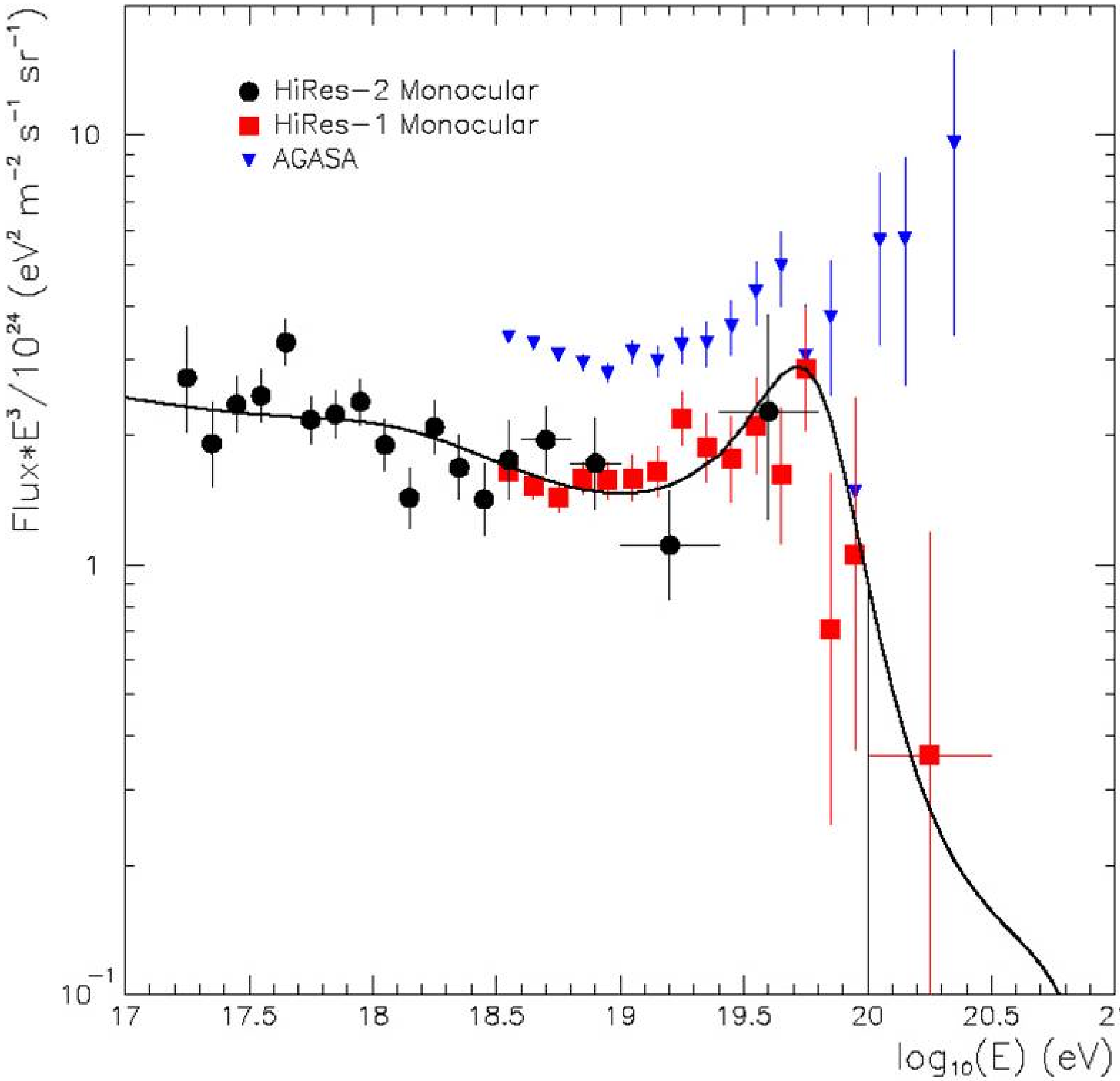
And to AUTEC and the U. S. Navy:

D. Belasco
J. Cecil
D. Deveau
D. Kapolka
T. Kelly-Bissonnette

Cosmic ray spectrum



The Greisen-Zatsepin-Kuzmin (GZK) cutoff



1 event / km^2 / century $\rightarrow$ detector innovation key!

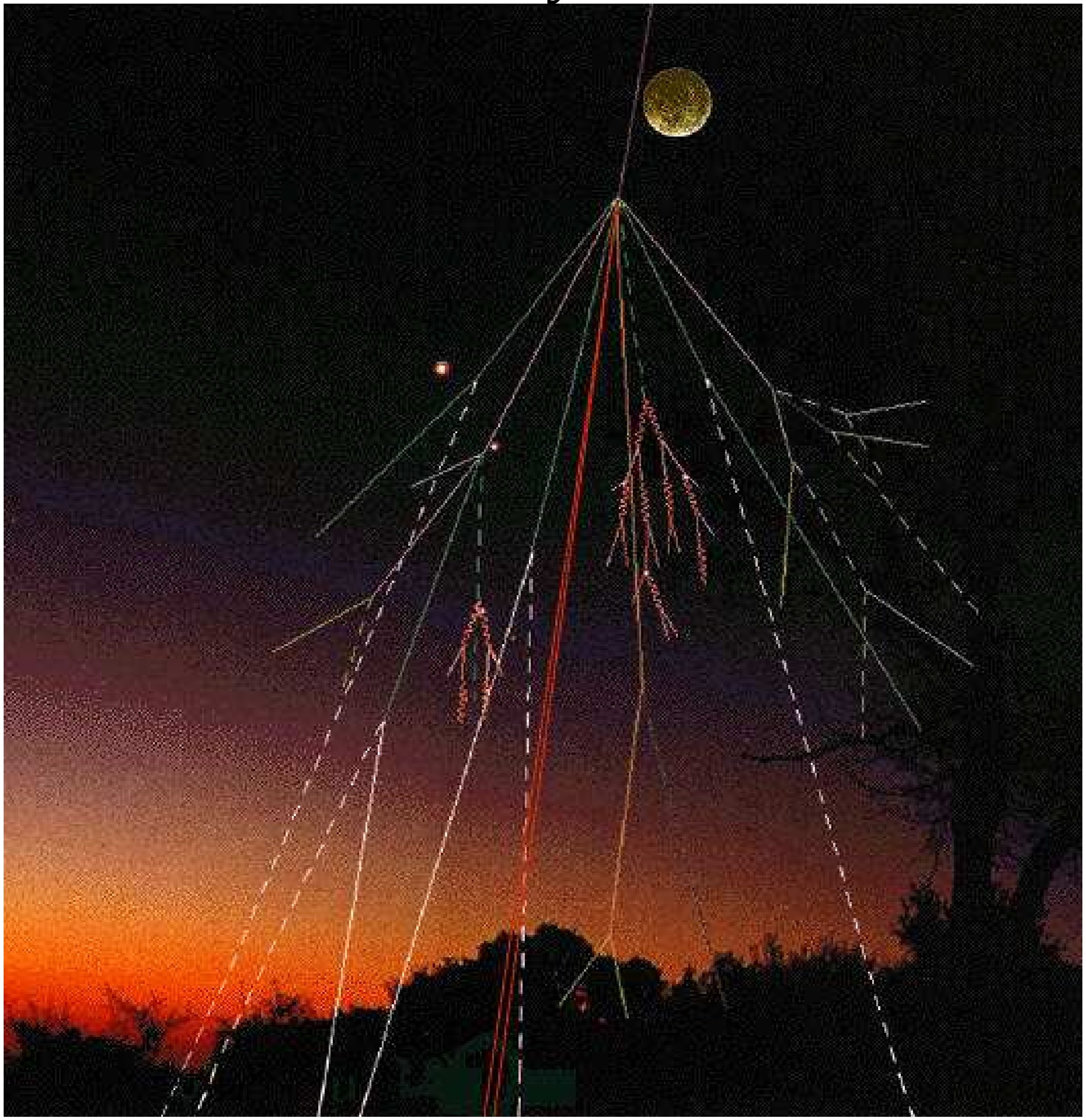
So what?

A crossroads of exciting physics

- active galactic nuclei
- gamma ray bursts
- grand unified theories
- topological defects (magnetic monopoles, cosmic strings, domain walls
- supersymmetry
- dark matter
- Lorentz invariance violation
- extra dimensions
- gravity at a TeV
- relic neutrinos

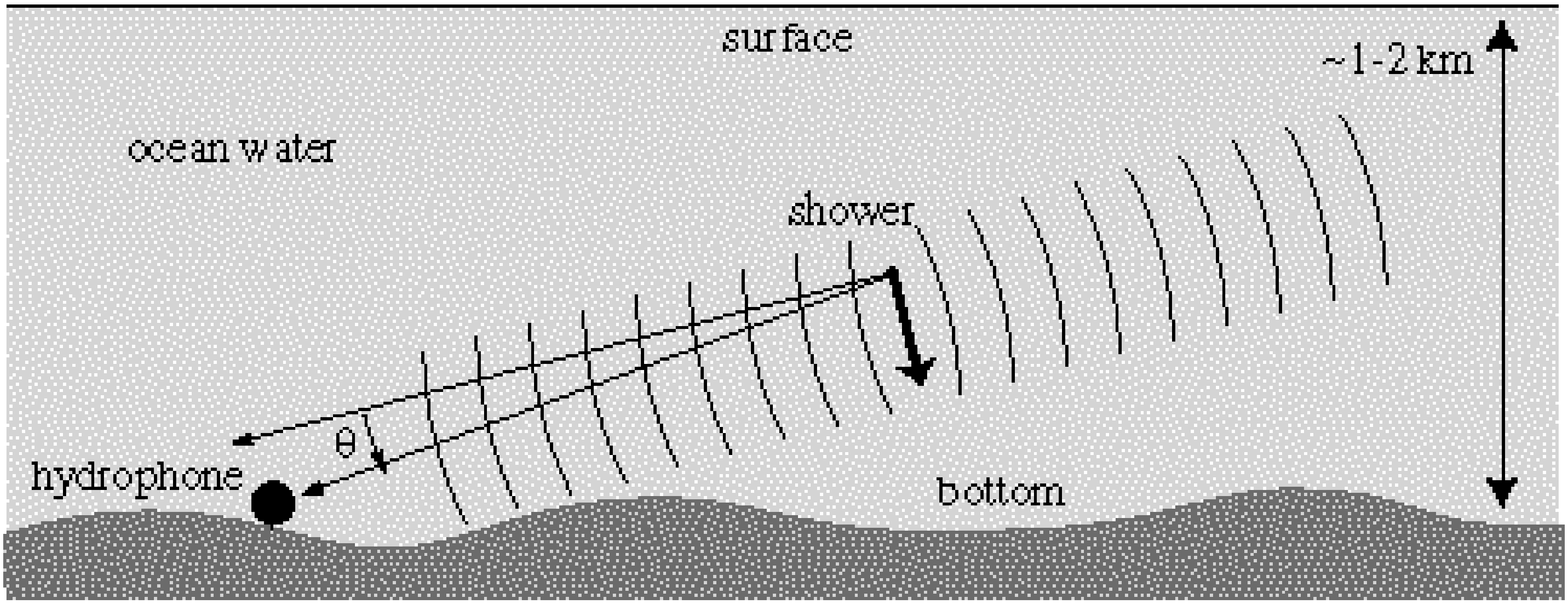
All key to understanding the universe!

Cosmic ray showers

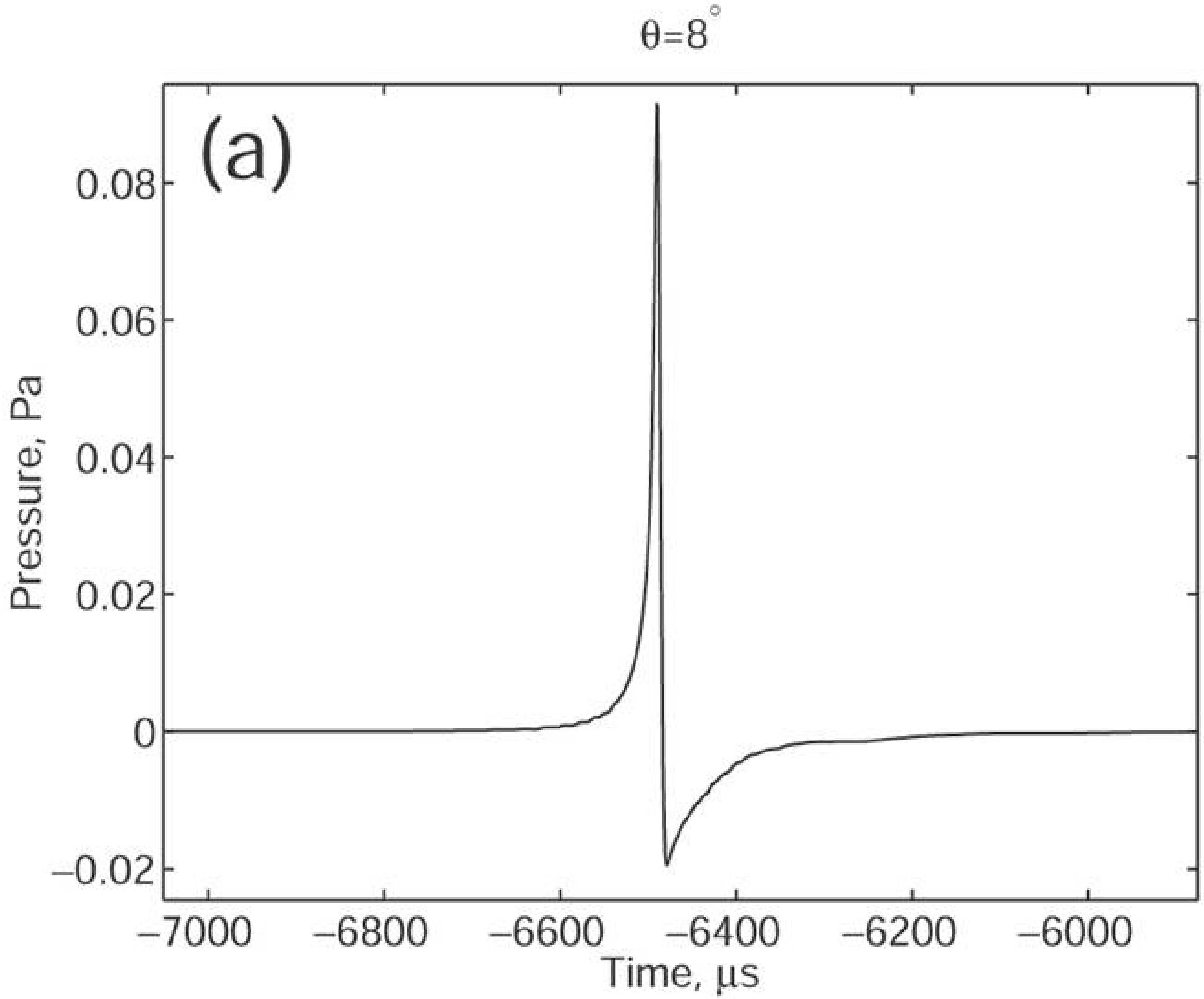


http://zebu.uoregon.edu/~js/glossary/cosmic_rays.html

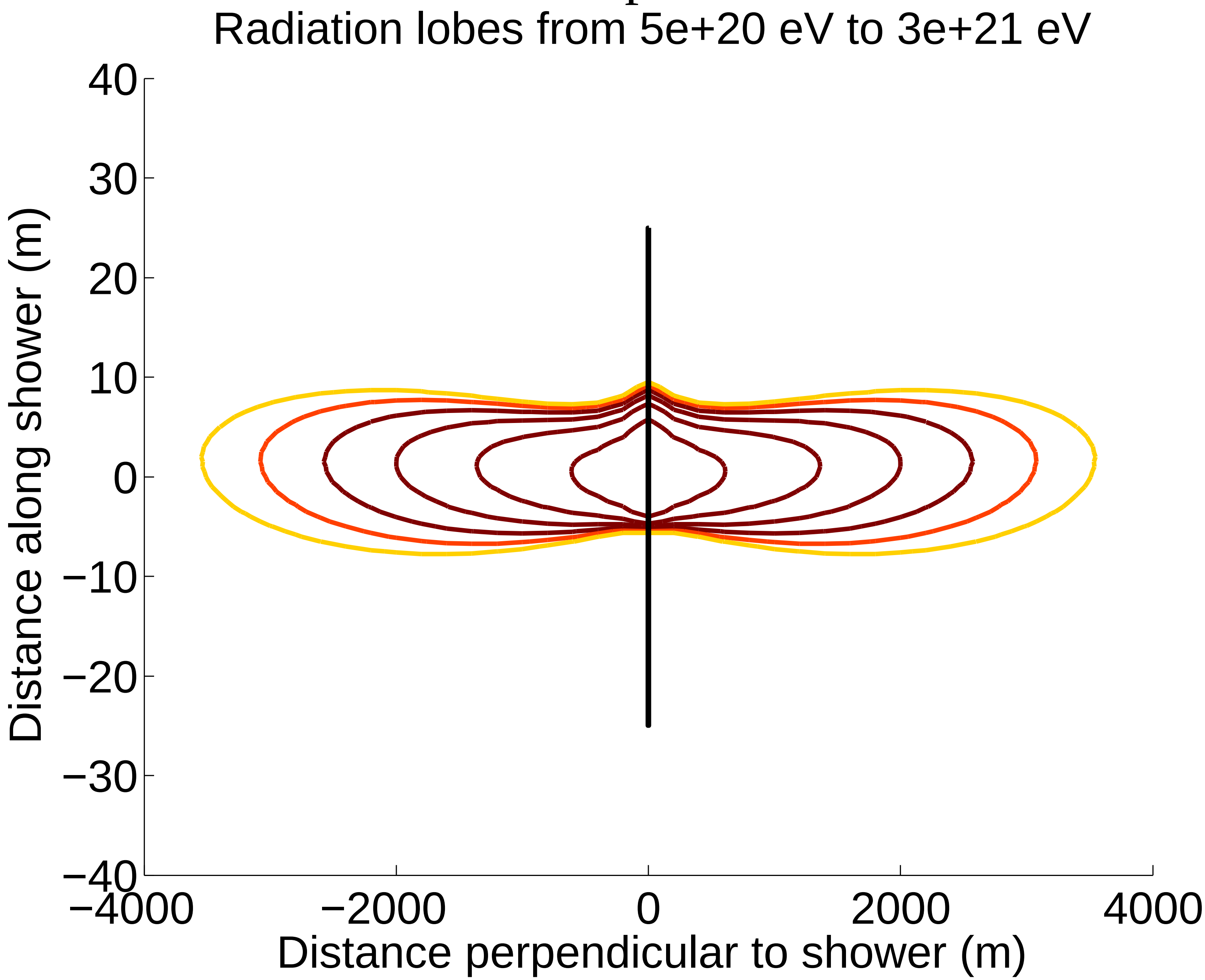
The ocean as a particle detector



Simulated neutrino signal



Extreme pancakes



Sound from charged particles in liquids: some background

- first discussion of the idea
  G. A. Askaryan Sov. J. Atom. Energy 3 (1957) 921

- extensive theoretical analysis
  J. G. Learned Phys. Rev. D 19 (1979) 3293

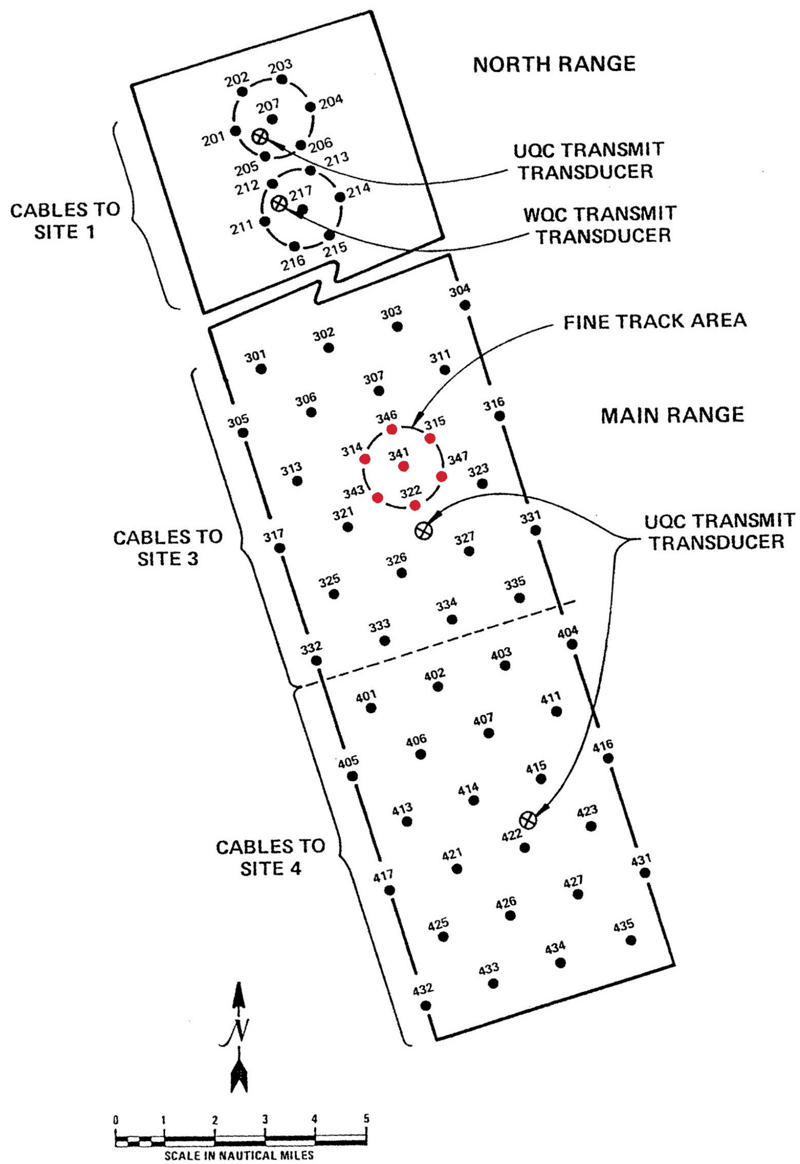
- experimental confirmation
  L. Sulak et al. NIM 161 (1979) 203

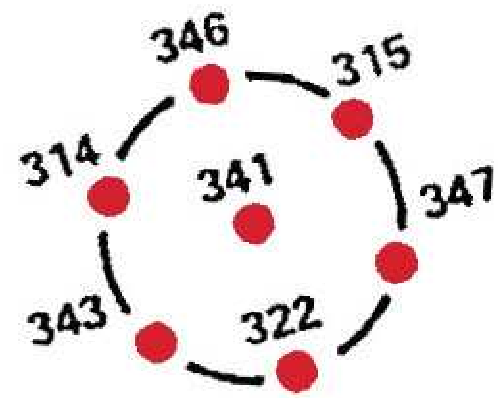
- sensitivity studies for neutrino detection
  N. Lehtinen et al. Astroparticle Physics 17 (2002) 279—292

- growing interest in acoustic arrays
  Stanford workshop on acoustic cosmic ray and neutrino detection, September 2003 http://hep.stanford.edu/neutrino/SAUND/workshop

The Atlantic Undersea Test and Evaluation Center (AUTEC)

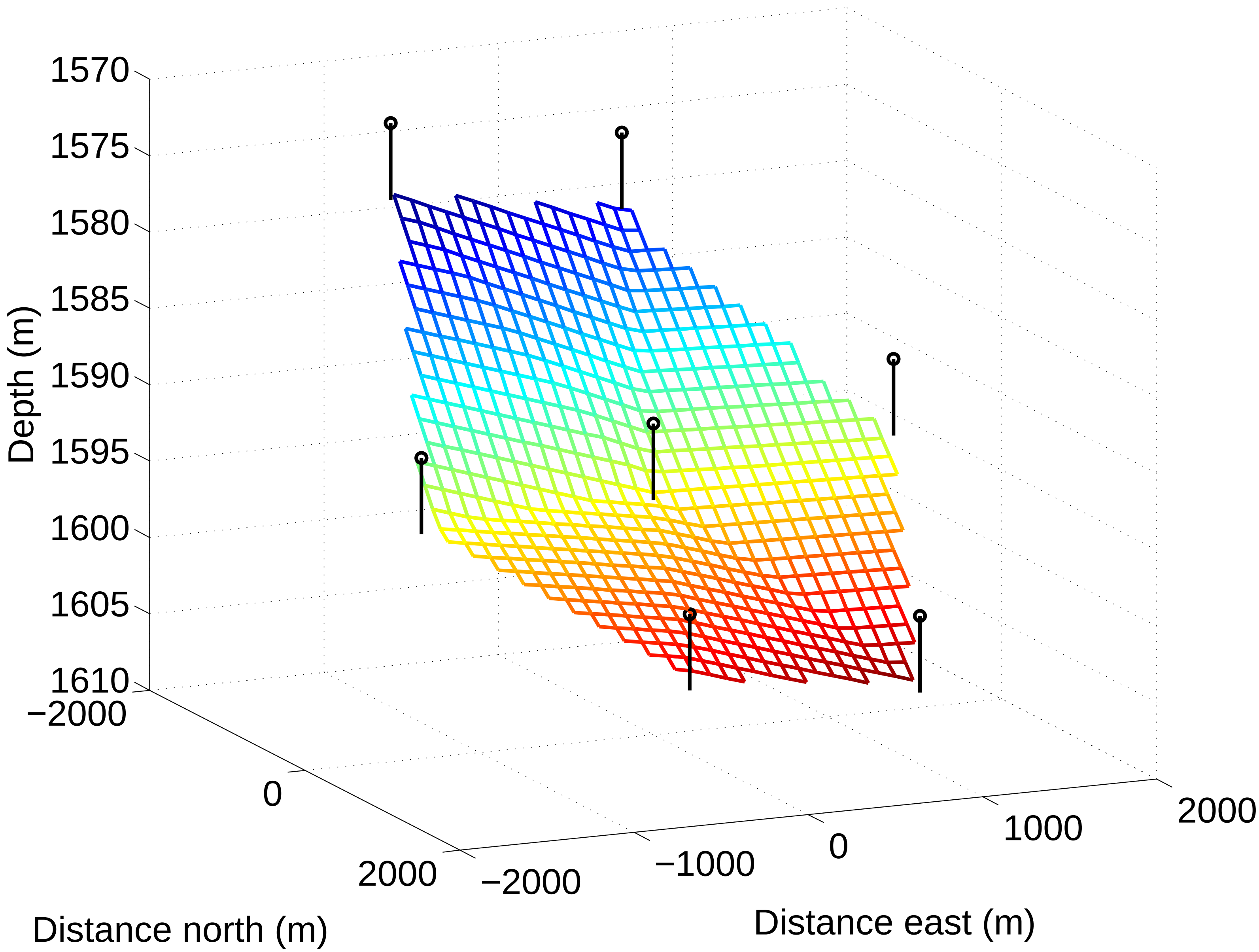
AUTEC hydrophones





SAUND
7 km^2

The SAUND array



Site 3

DAQ

DAQ

Software

- 179 kHz sampling
- digital matched filter
- variable threshold
- 60 events/minute target
- 1-2 GB / 24 hrs

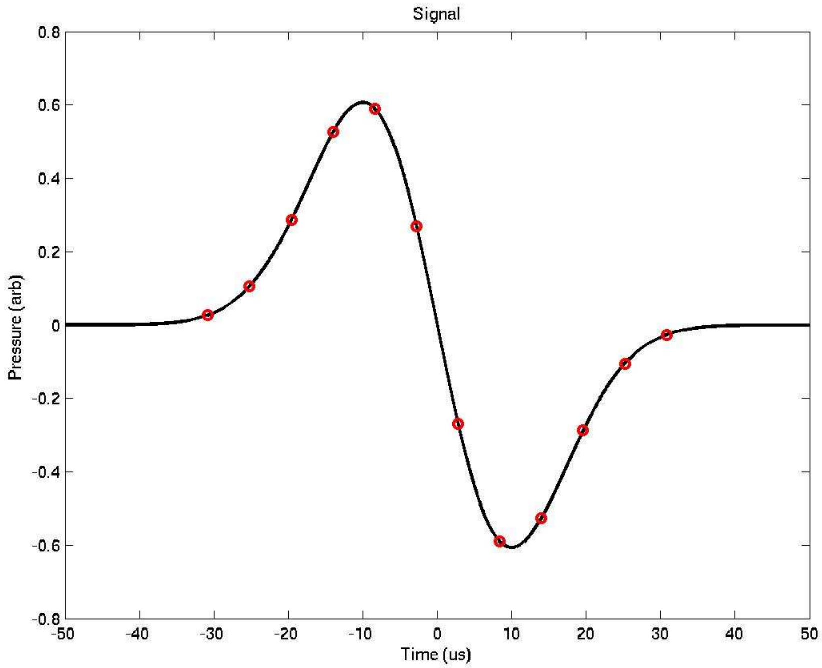
$$signal: S(t) \propto -\frac{t}{\tau} e^{-t^2/2\tau^2}$$

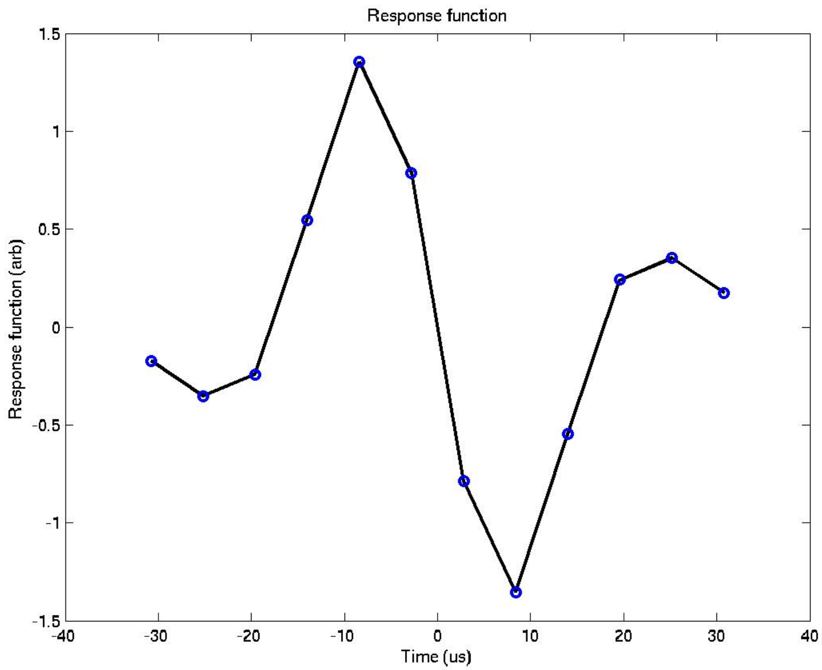
$$noise: N(t) \propto f^{-2}$$

$$\rightarrow response\ \ function: H(t) \propto -\left((\frac{t}{\tau})^3 - 3\frac{t}{\tau} \right) e^{-t^2/2\tau^2}$$

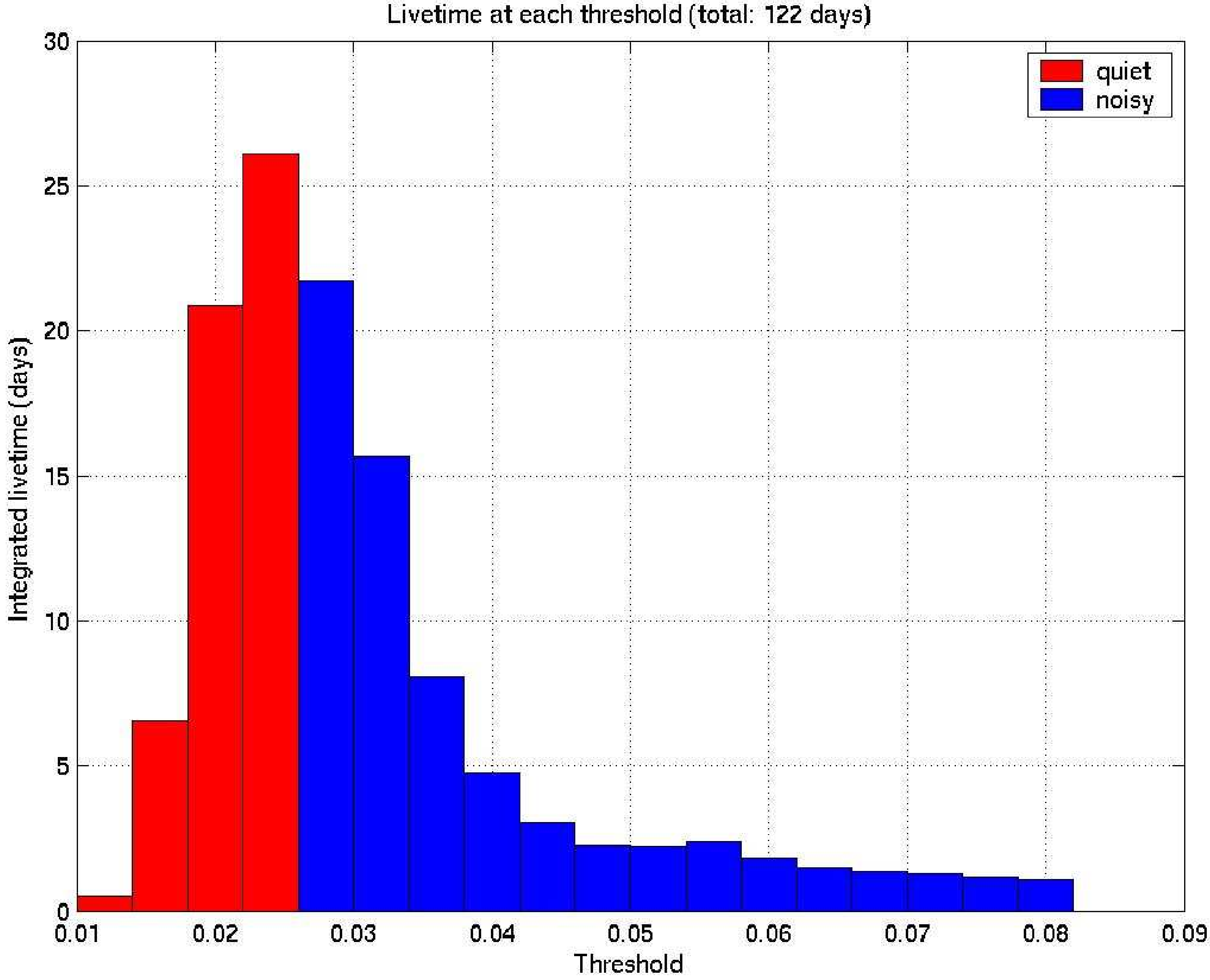
Hardware

- 1.7 GHz Pentium 4
- ADC card
- 60 GB external hard drive

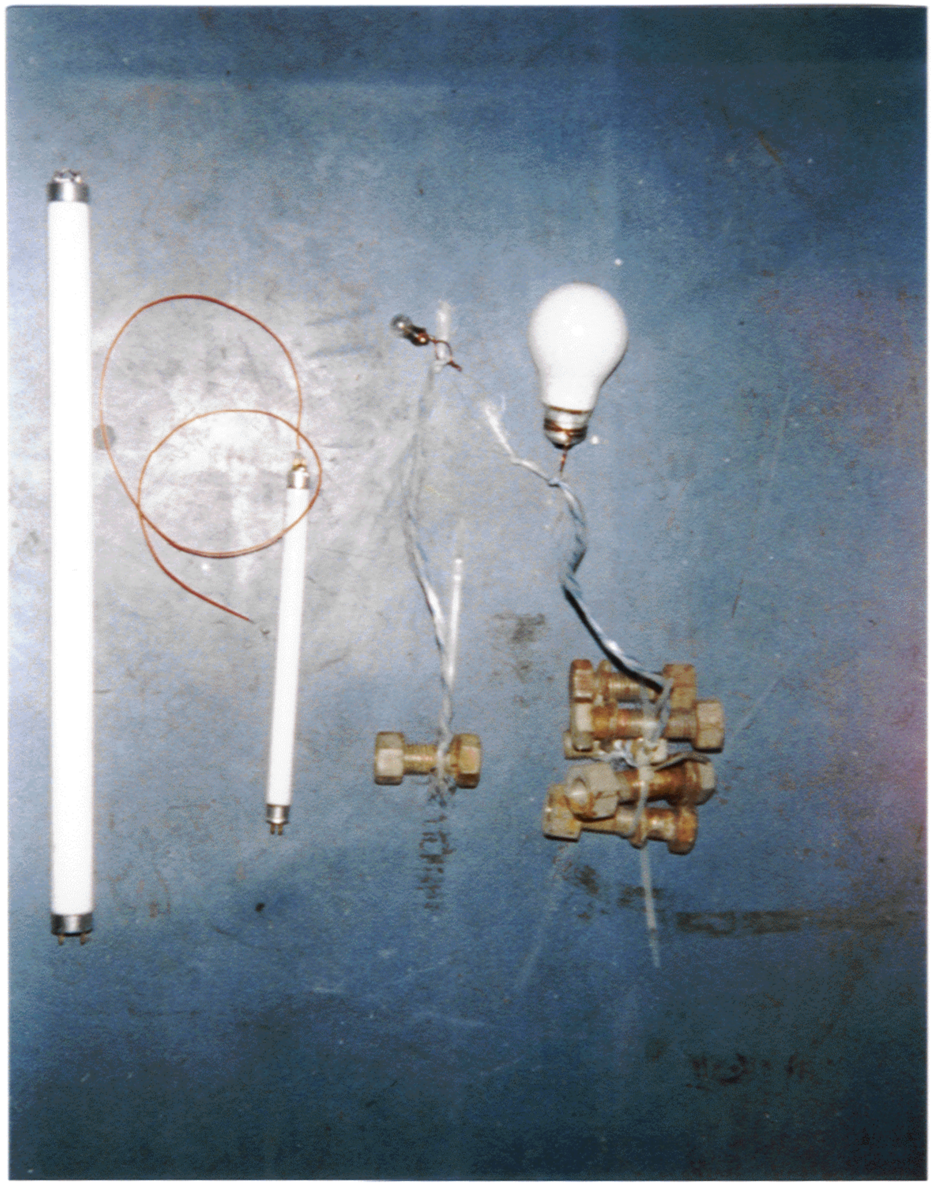




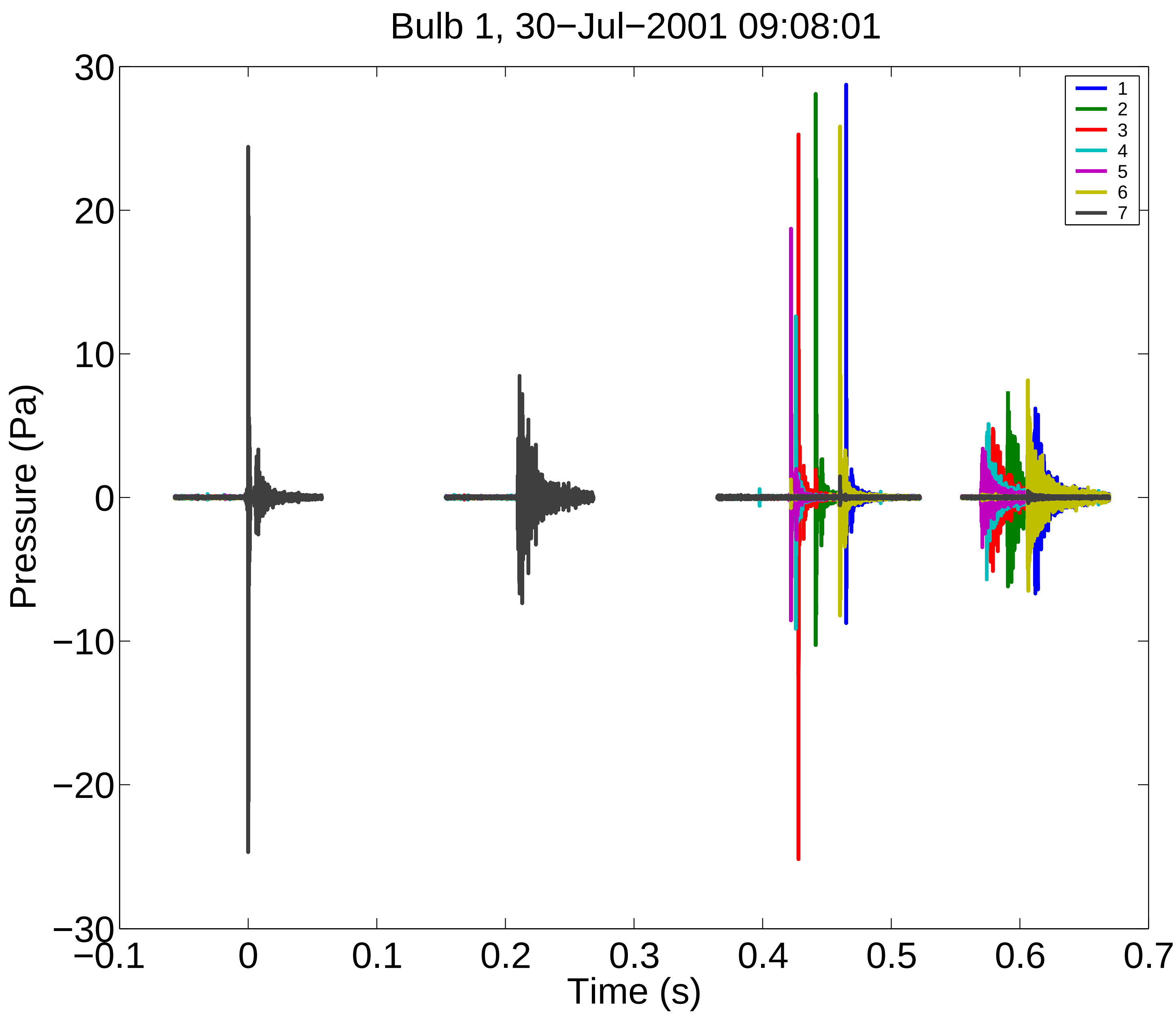
Adaptive threshold



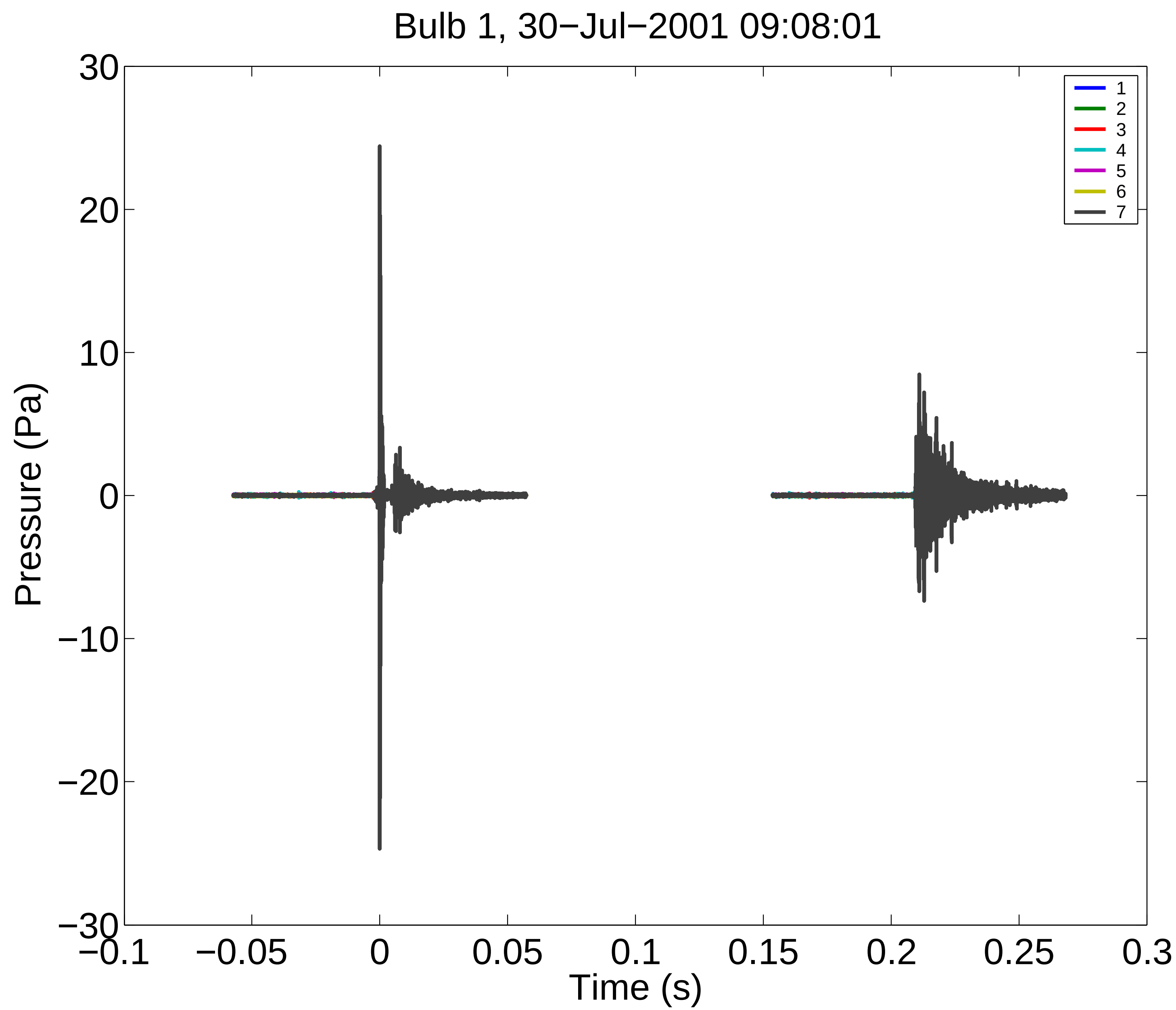
Calibration sources



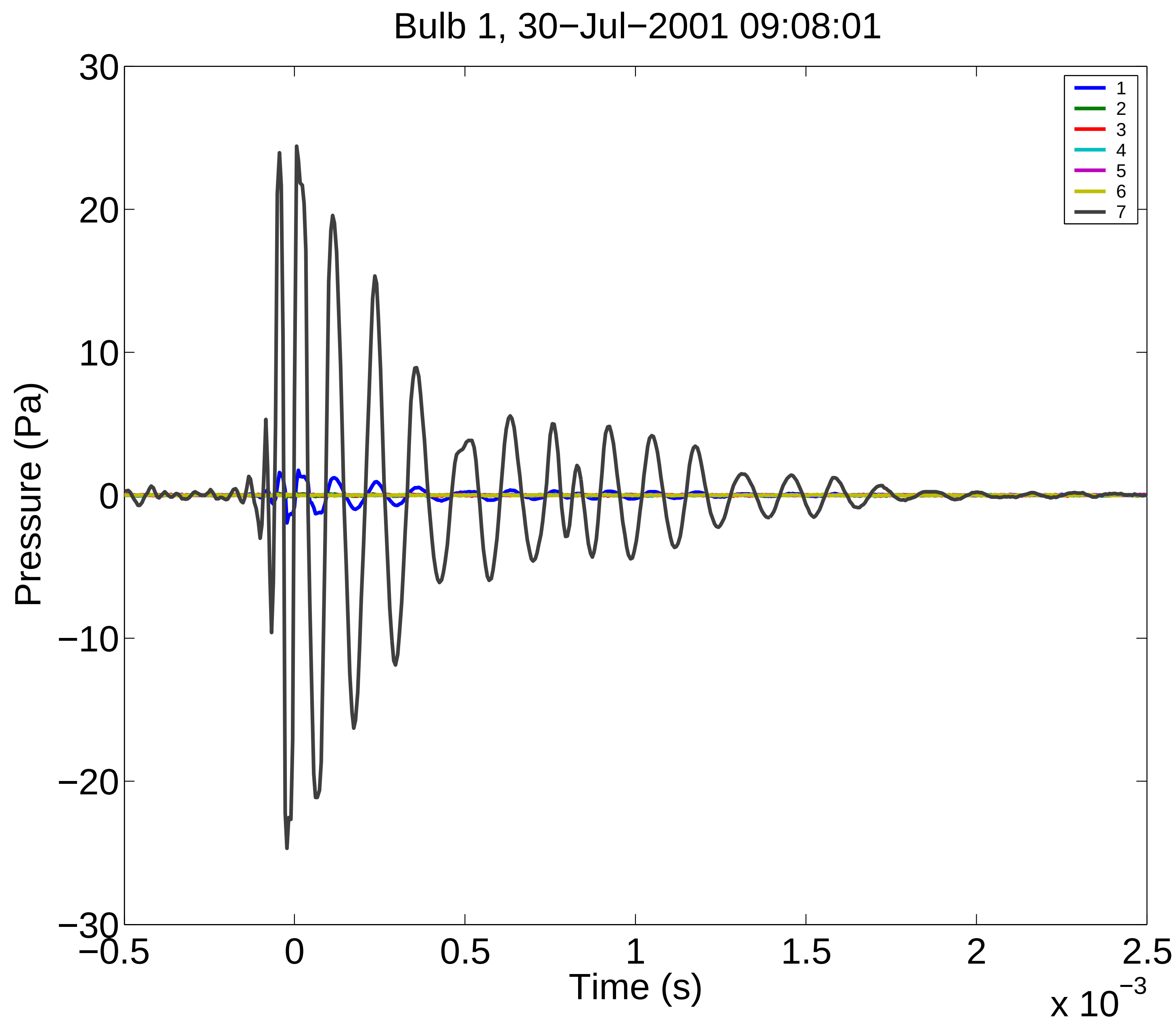
One bulb at all 7 hydrophones



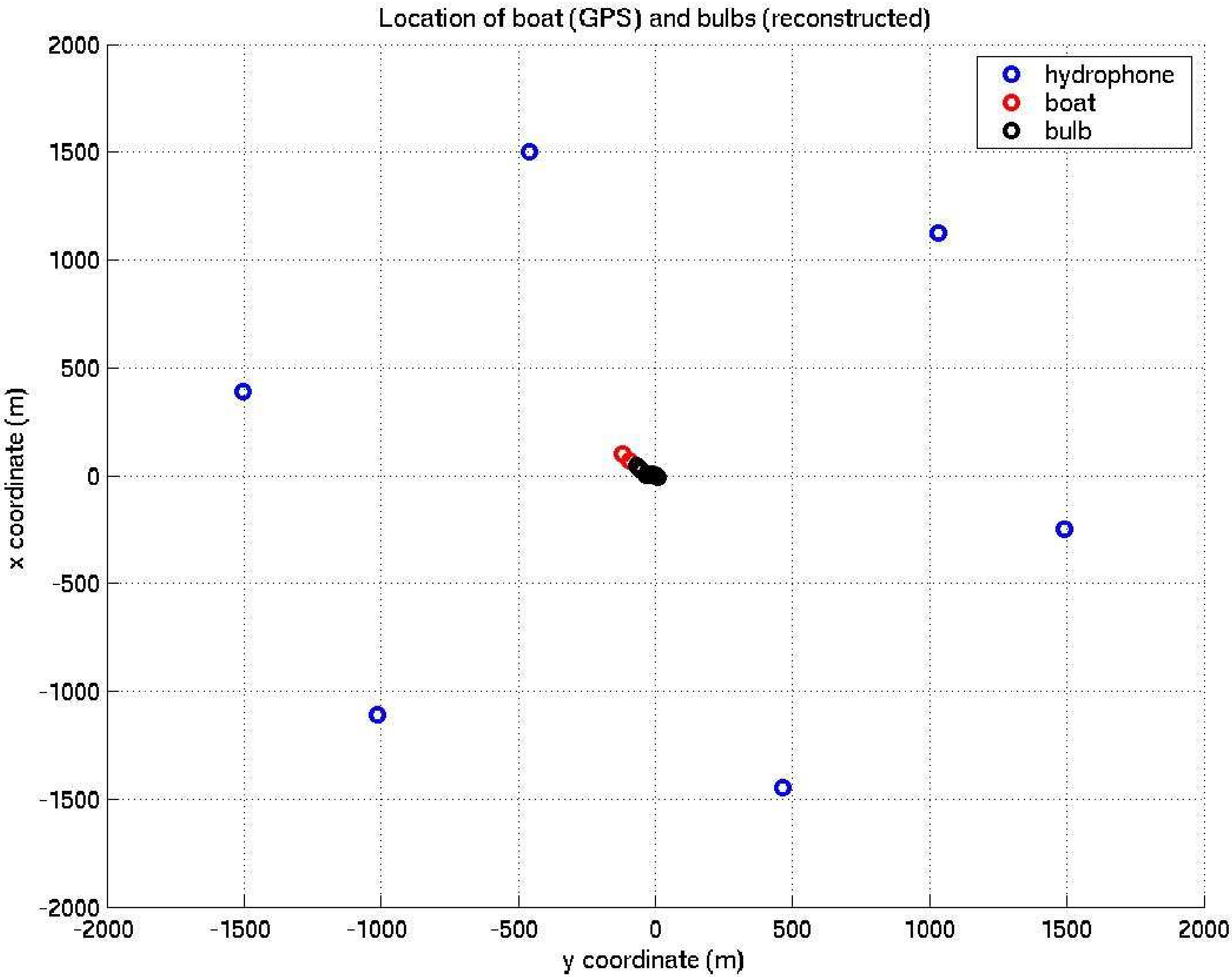
Two reflections!



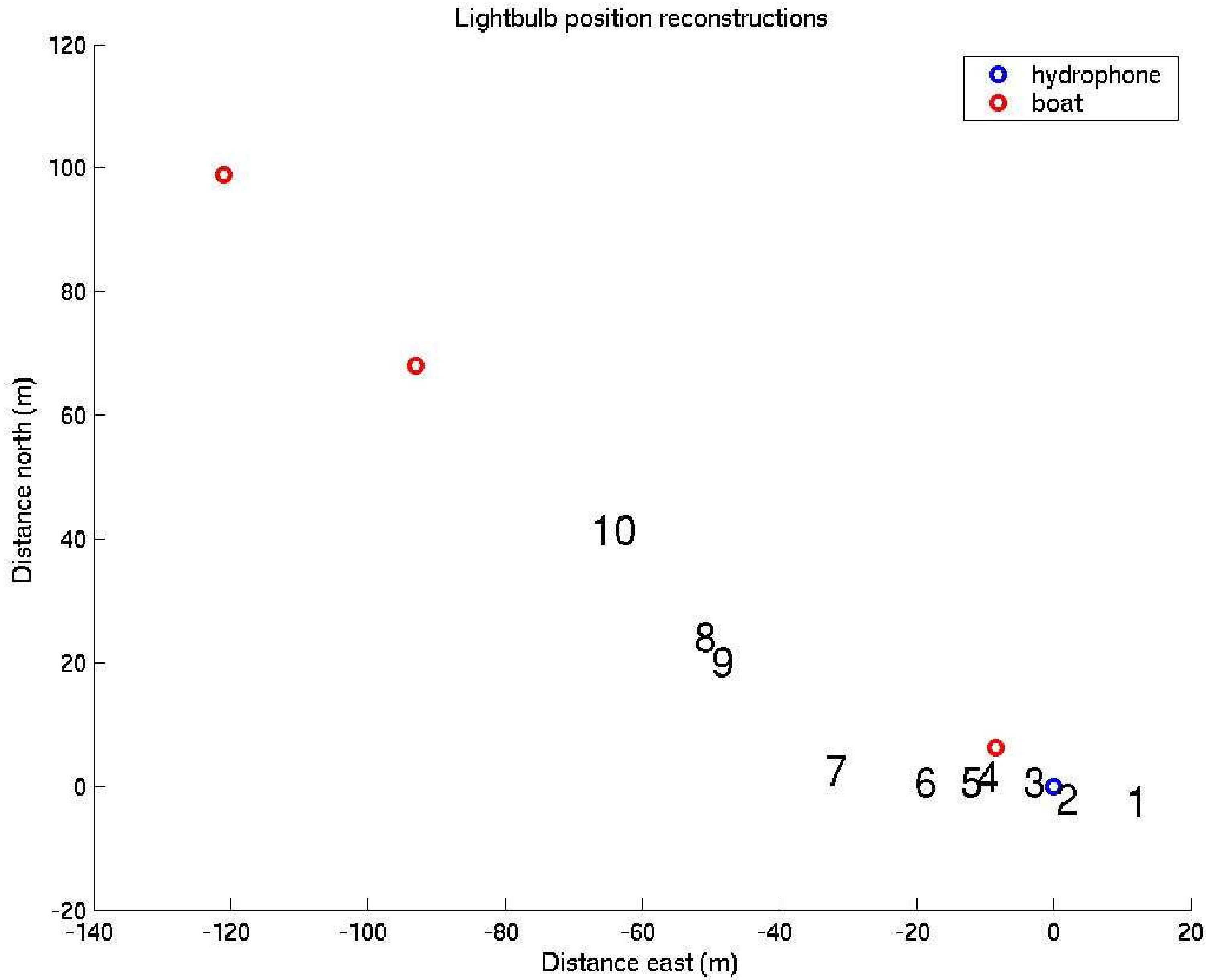
Direct signal



Lightbulb positions reconstructed



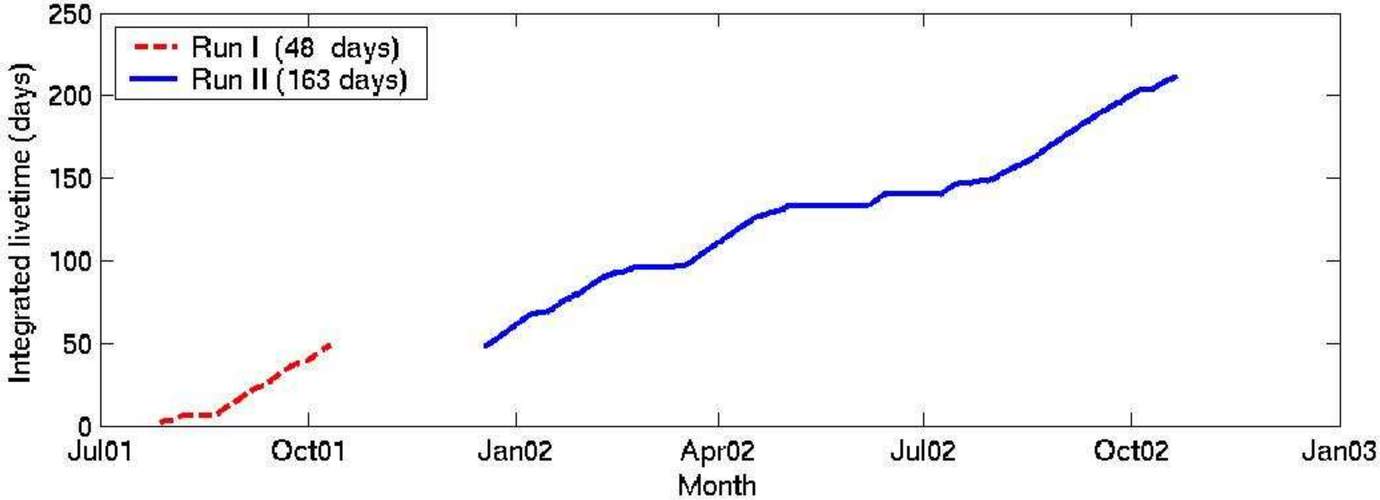
Lightbulb positions reconstructed

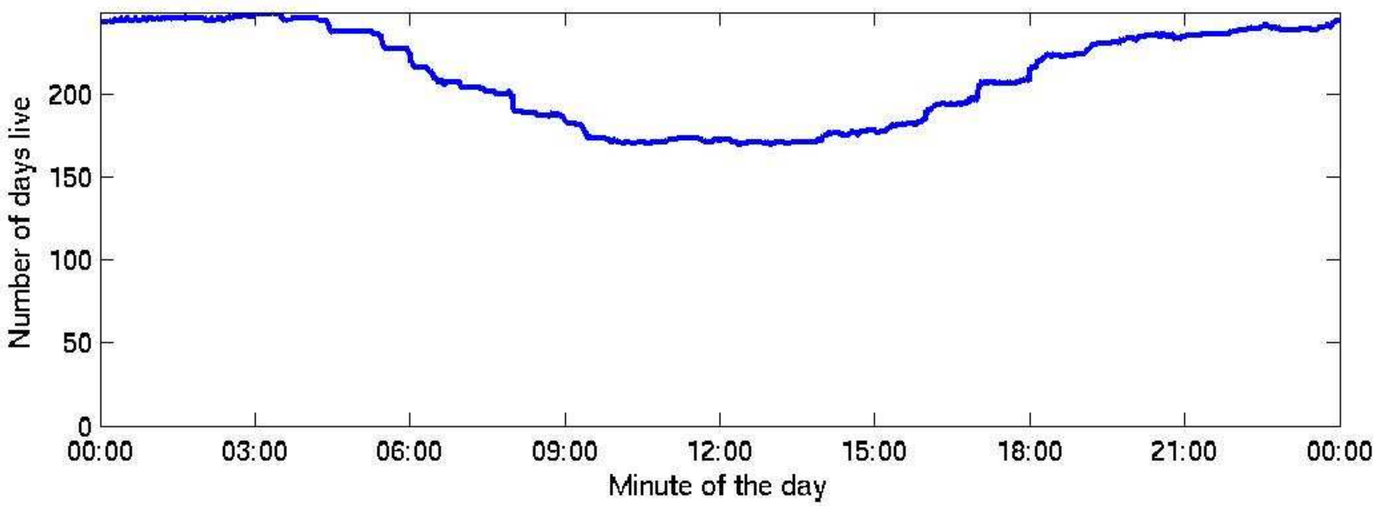


Lightbulb energies reconstructed

Bulb	Depth (m)	$P = \rho g h$ (kPa)	$E_0 = PV$ (J)
1	160	1563	234
2	107	1047	157
3	139	1360	204
4	166	1626	244
5	126	1237	186
6	101	990	148
7	86	838	126
8	135	1324	199
9	188	1842	276
10	290	2846	427

Data: a large livetime has been integrated





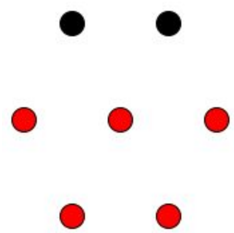
211 days livetime	25 million events	350 GB	70% duty cycle

Five-phone coincidence

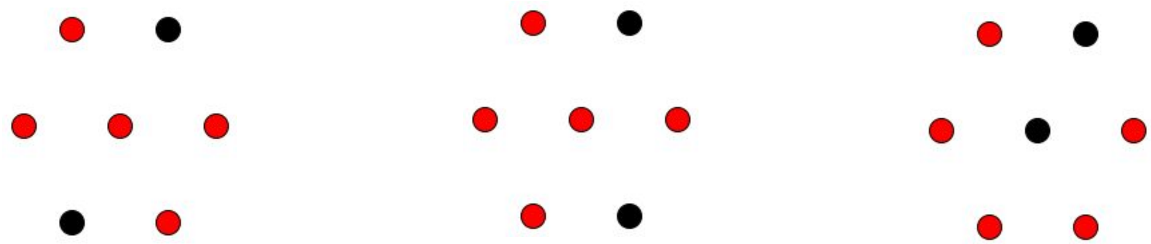
Require

1) Events obey causality: $t_{ij} \leq d_{ij} / v_{sound}$
2) Geometry consistent with pancake (2D circle) shape:

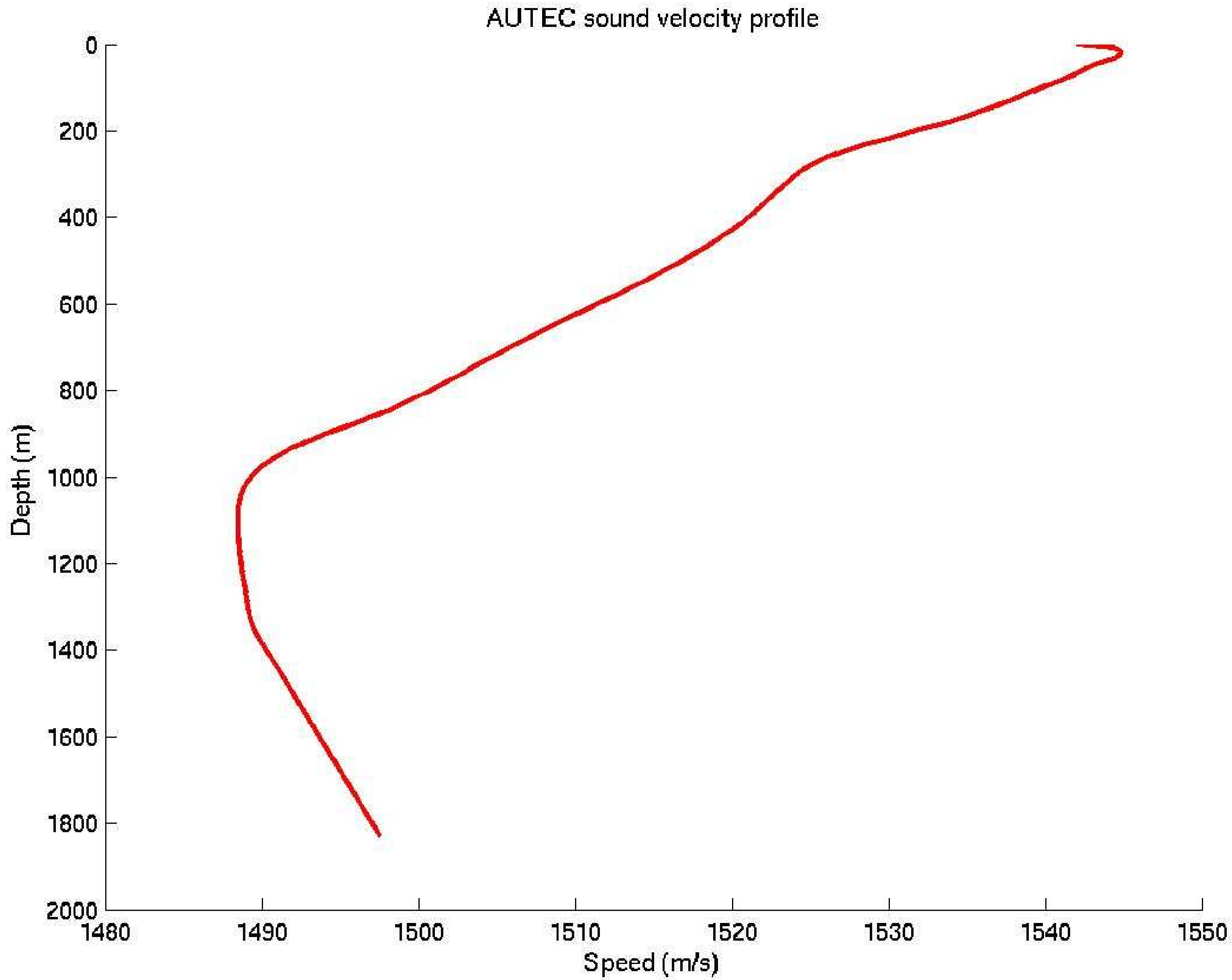
accepted:



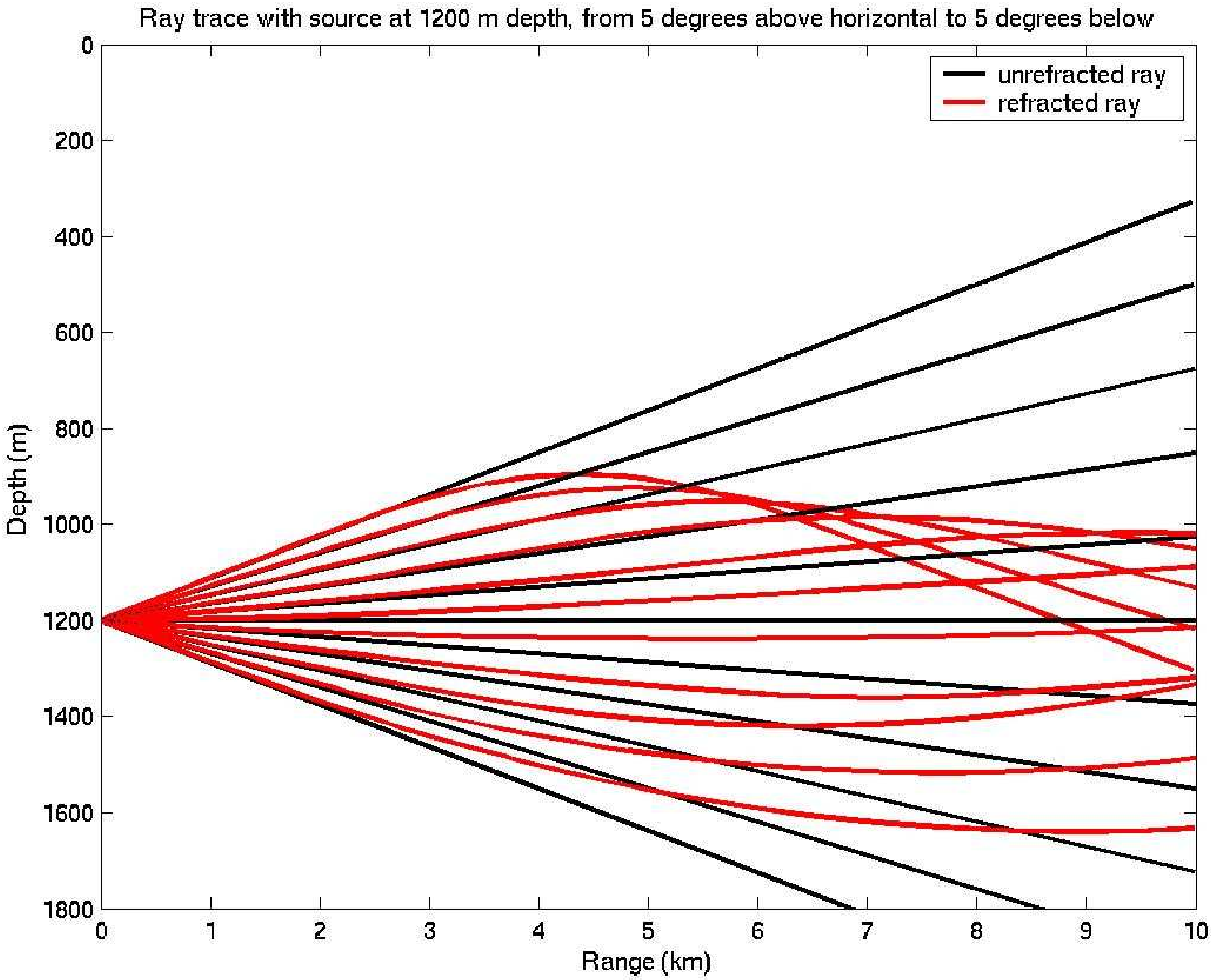
rejected:



AUTEC sound velocity profile (SVP)

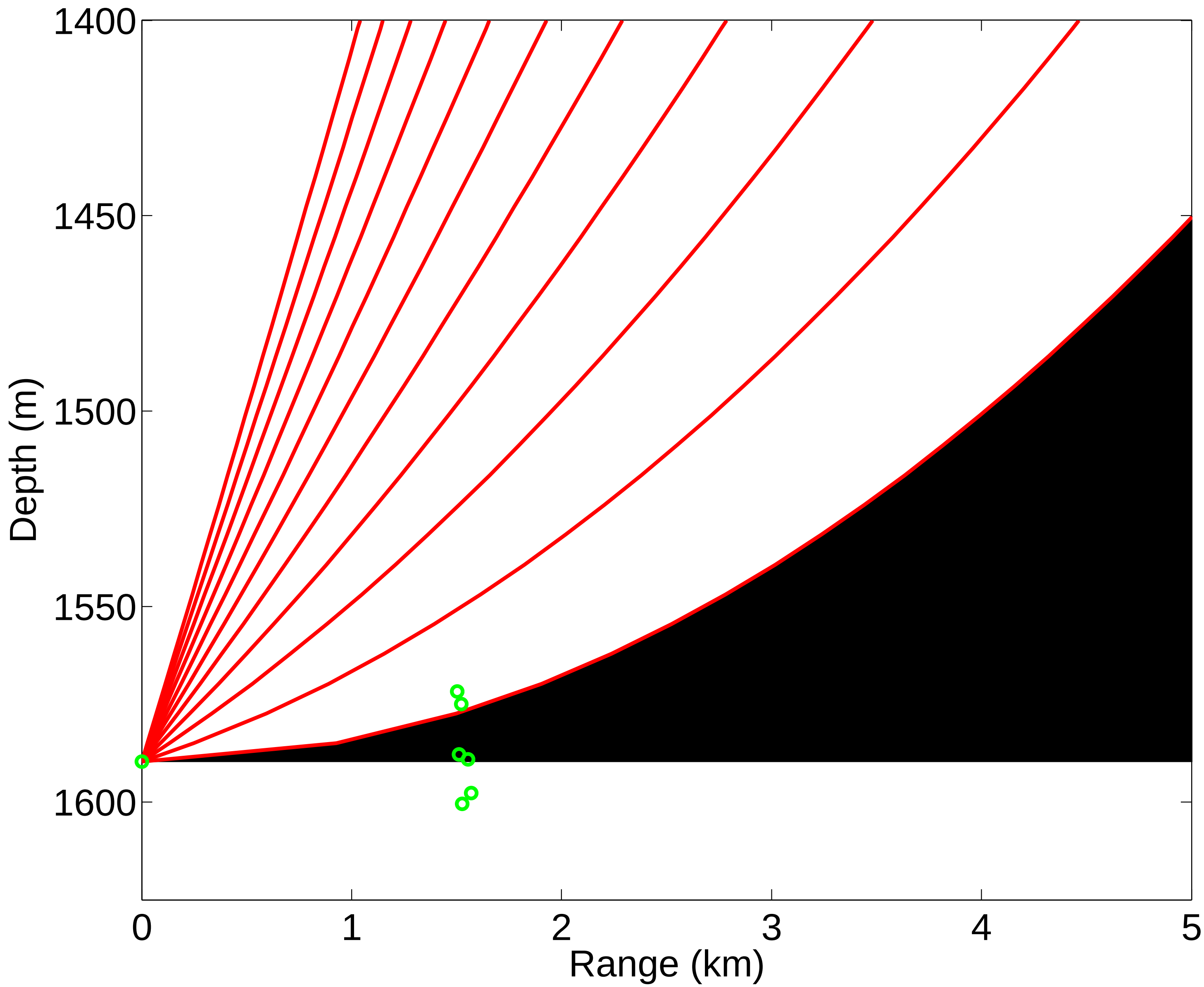


Refraction

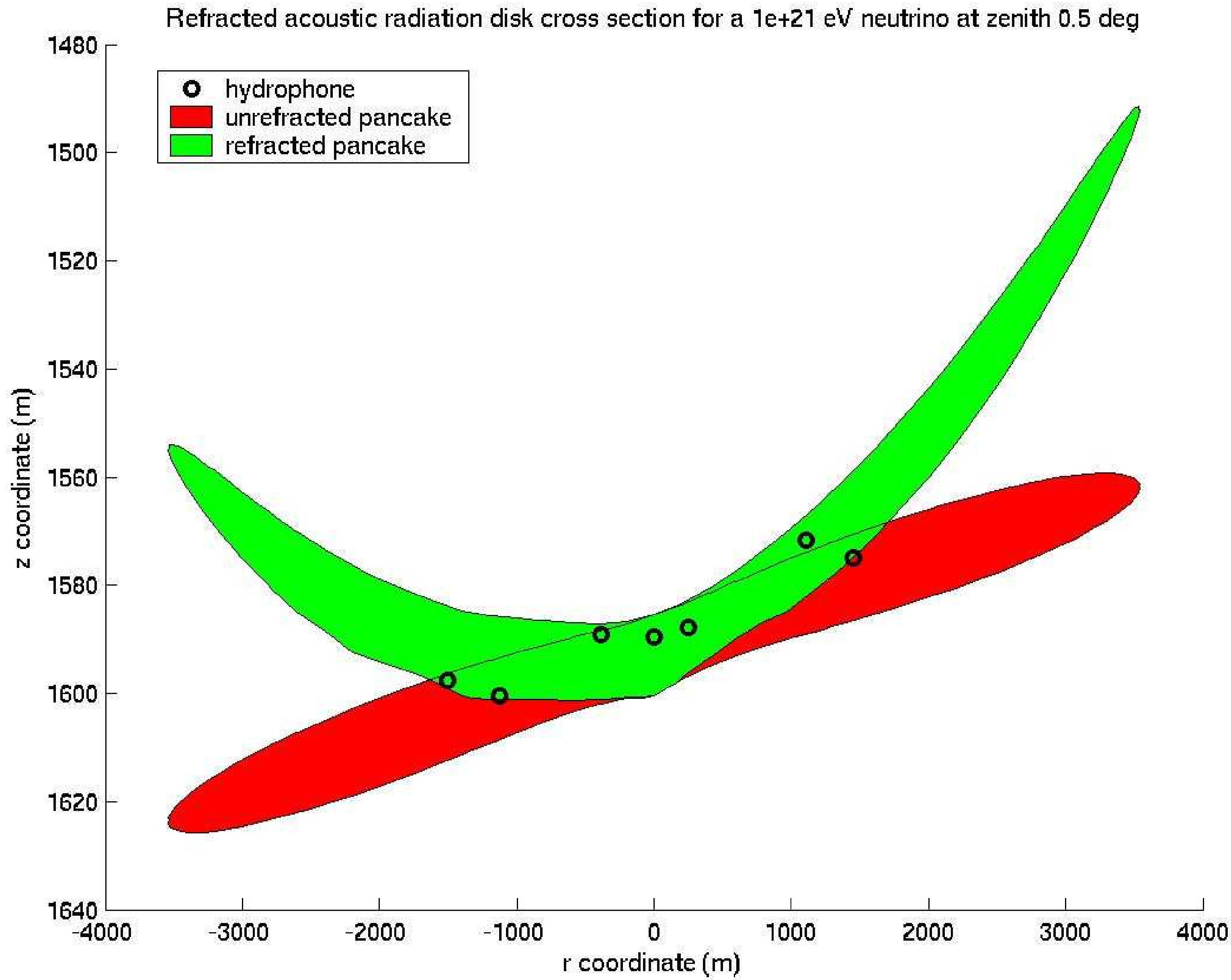


Ray trace with source at 1200 m depth, from 5 degrees above horizontal to 5 degrees below
unrefracted ray
refracted ray
Depth (m)
0
200
400
600
800
1000
1200
1400
1600
1800
0
1
2
3
4
5
6
7
8
9
10
Range (km)

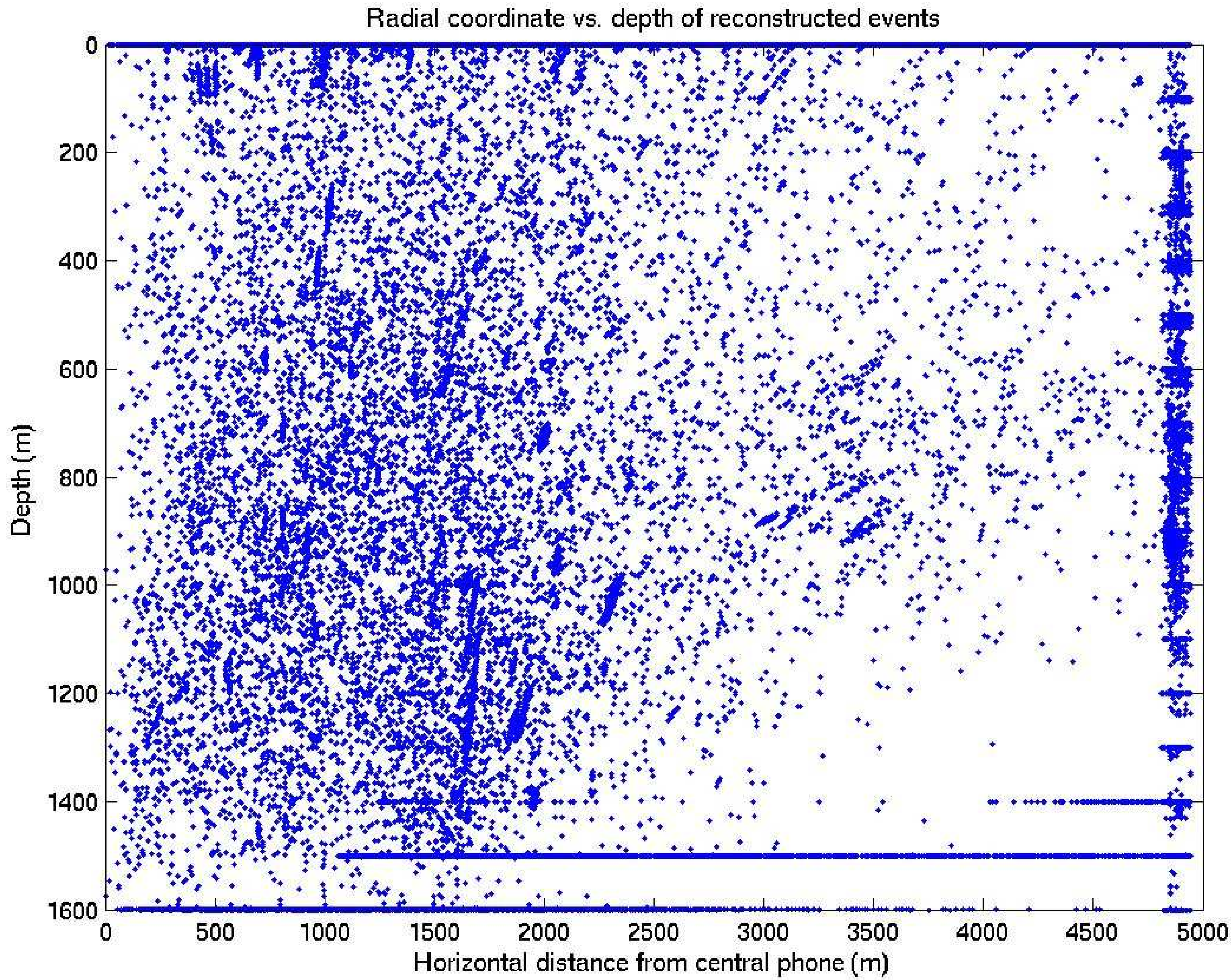
Refraction shadow



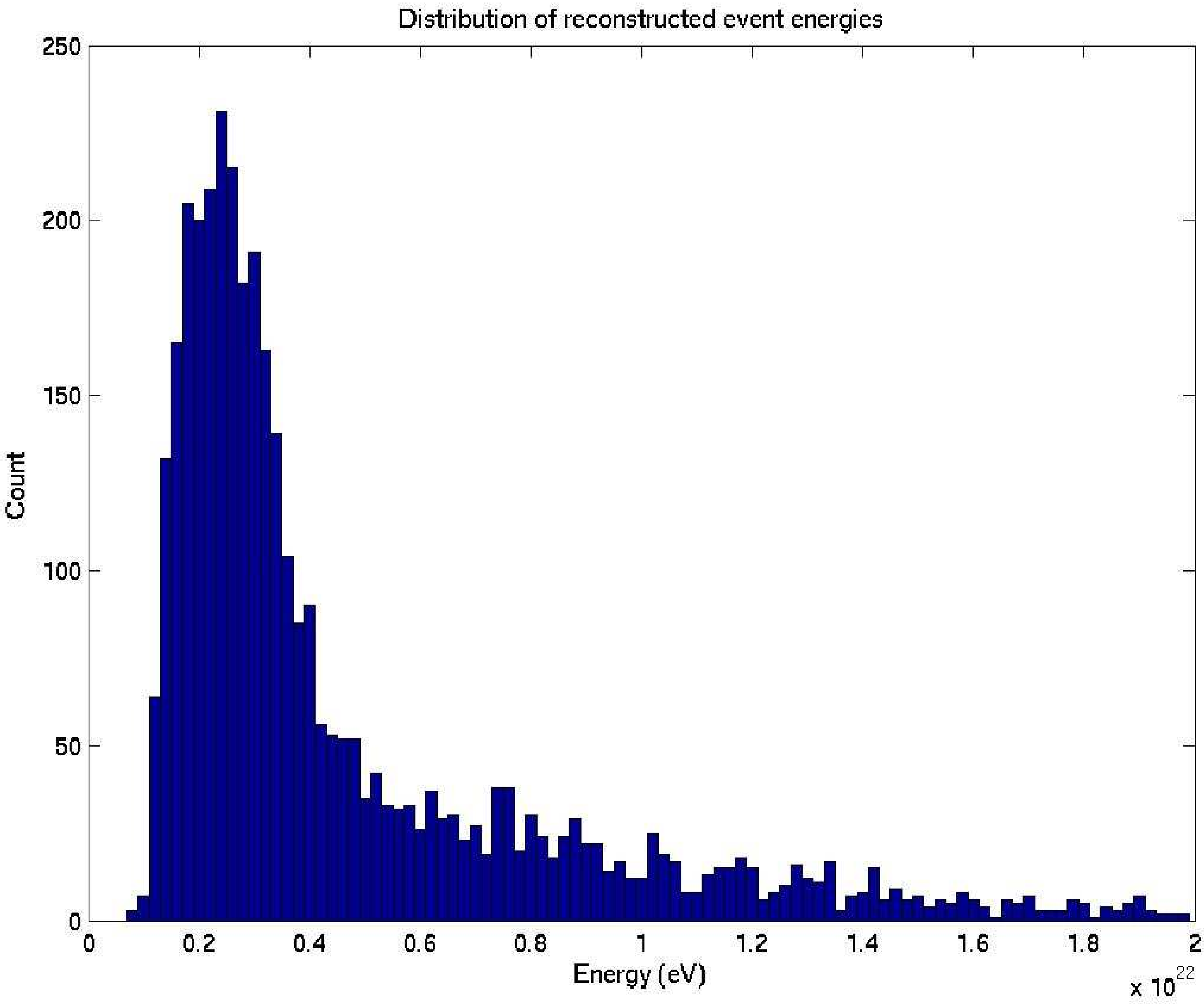
Refracted pancake



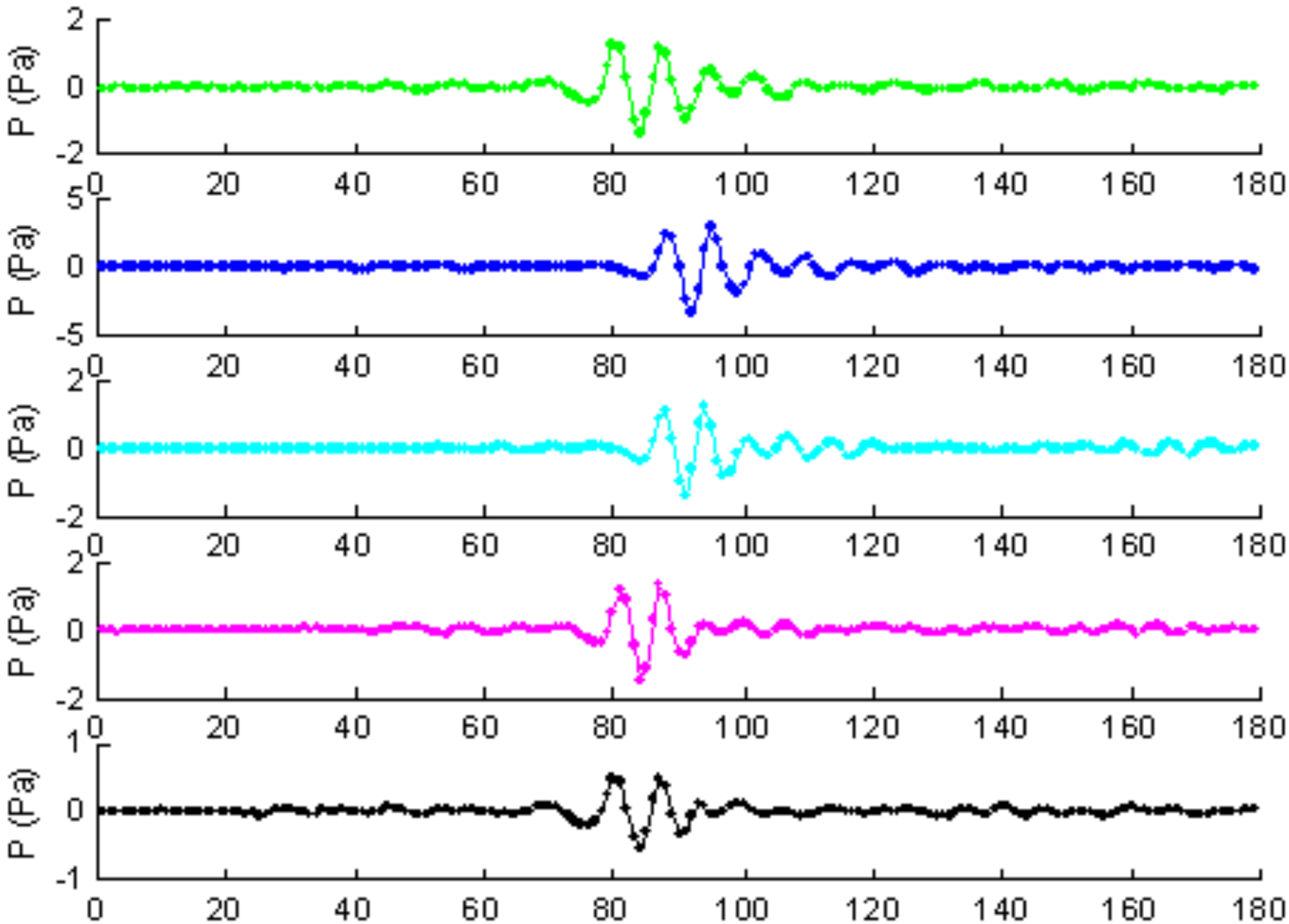
Position reconstruction achieved (10 m resolution)



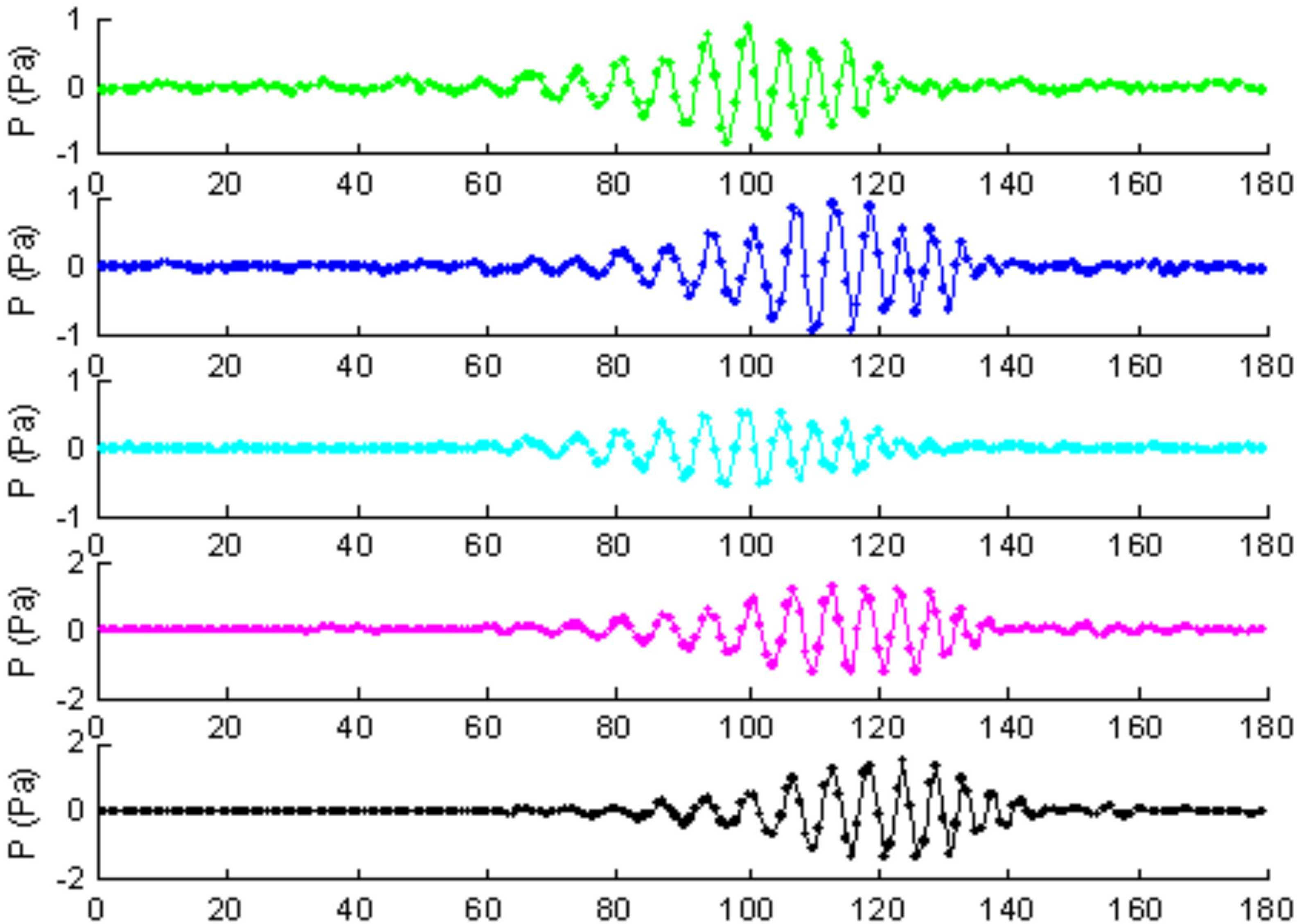
Localization → energy reconstruction



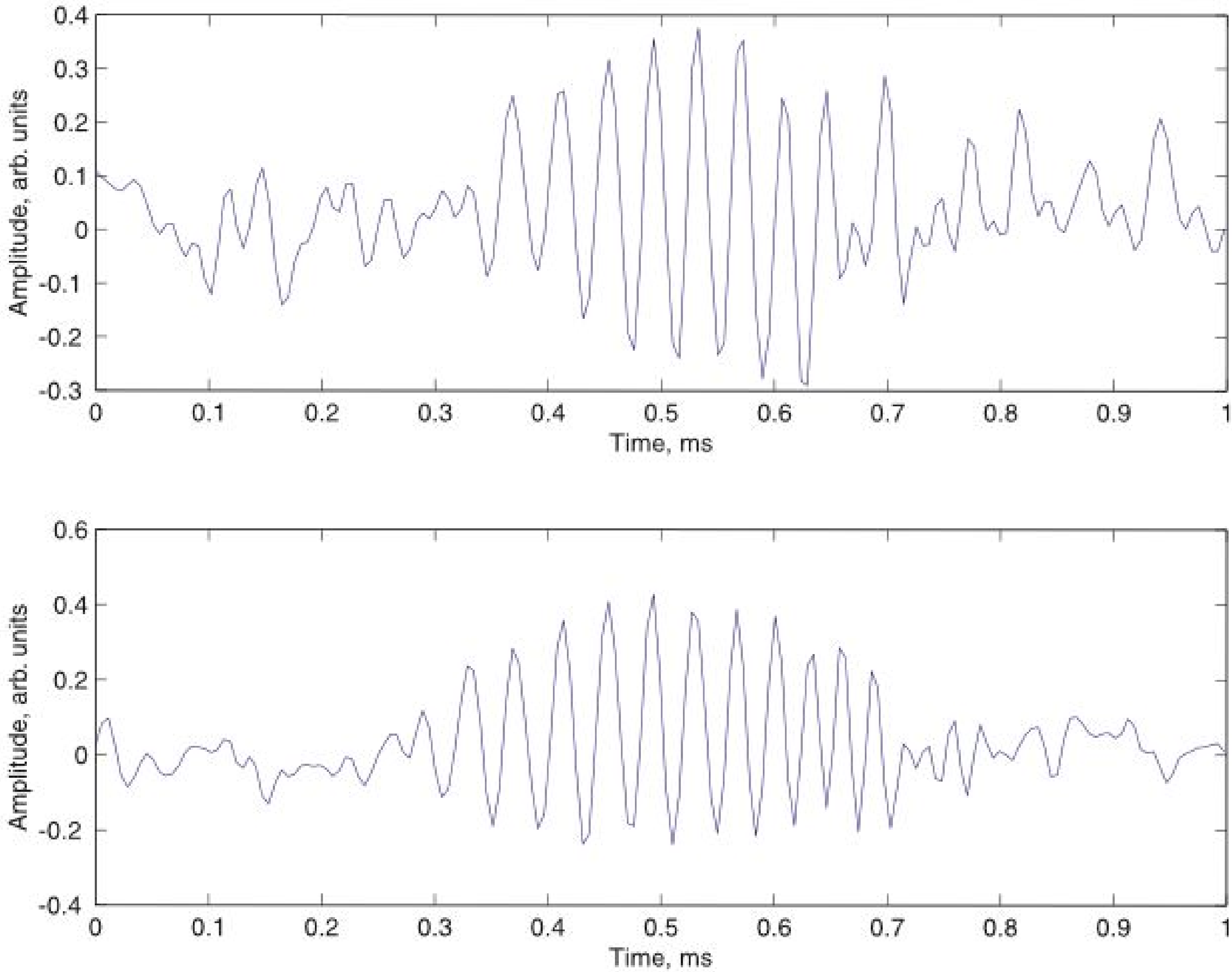
Background event type 1



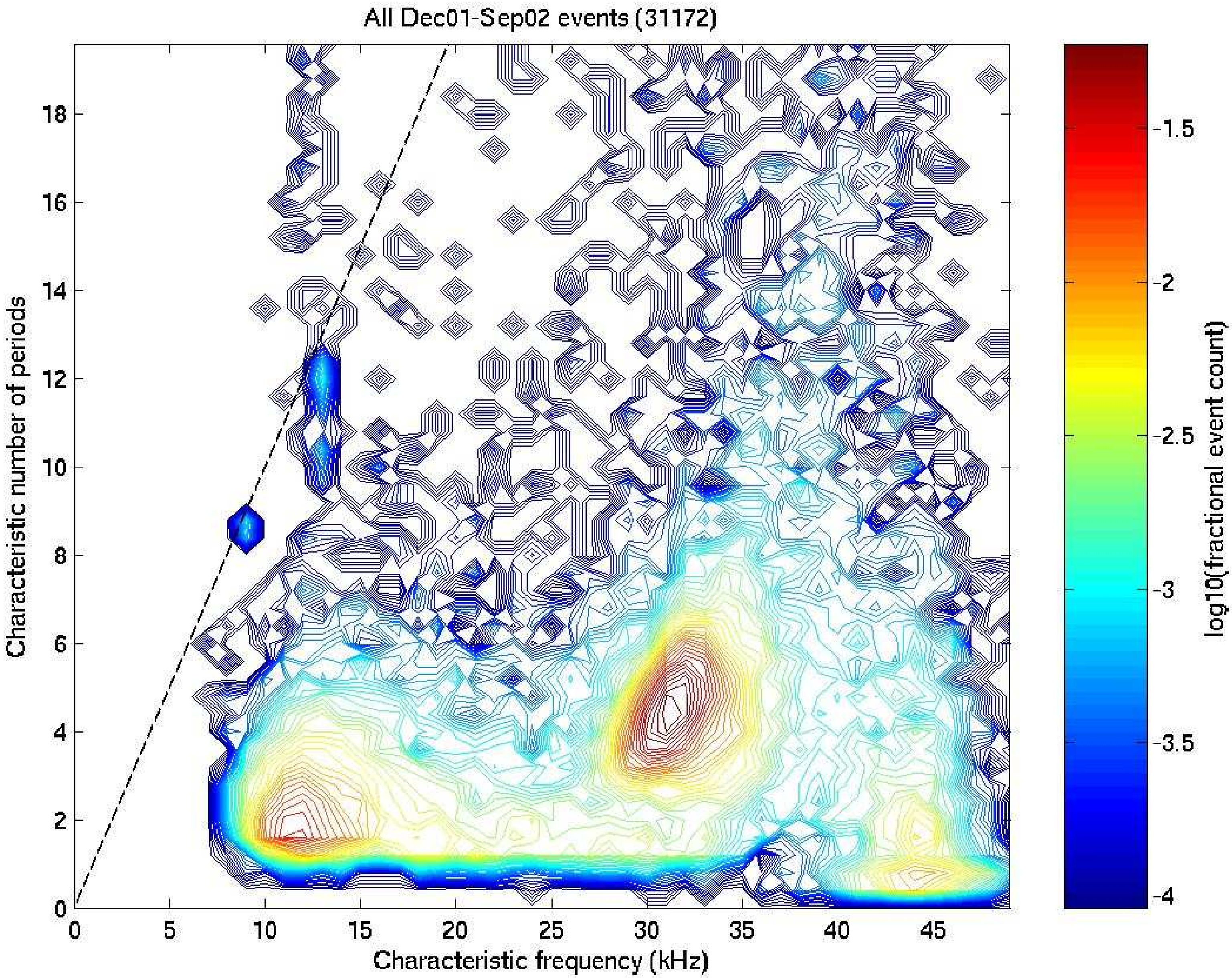
Background event type 2



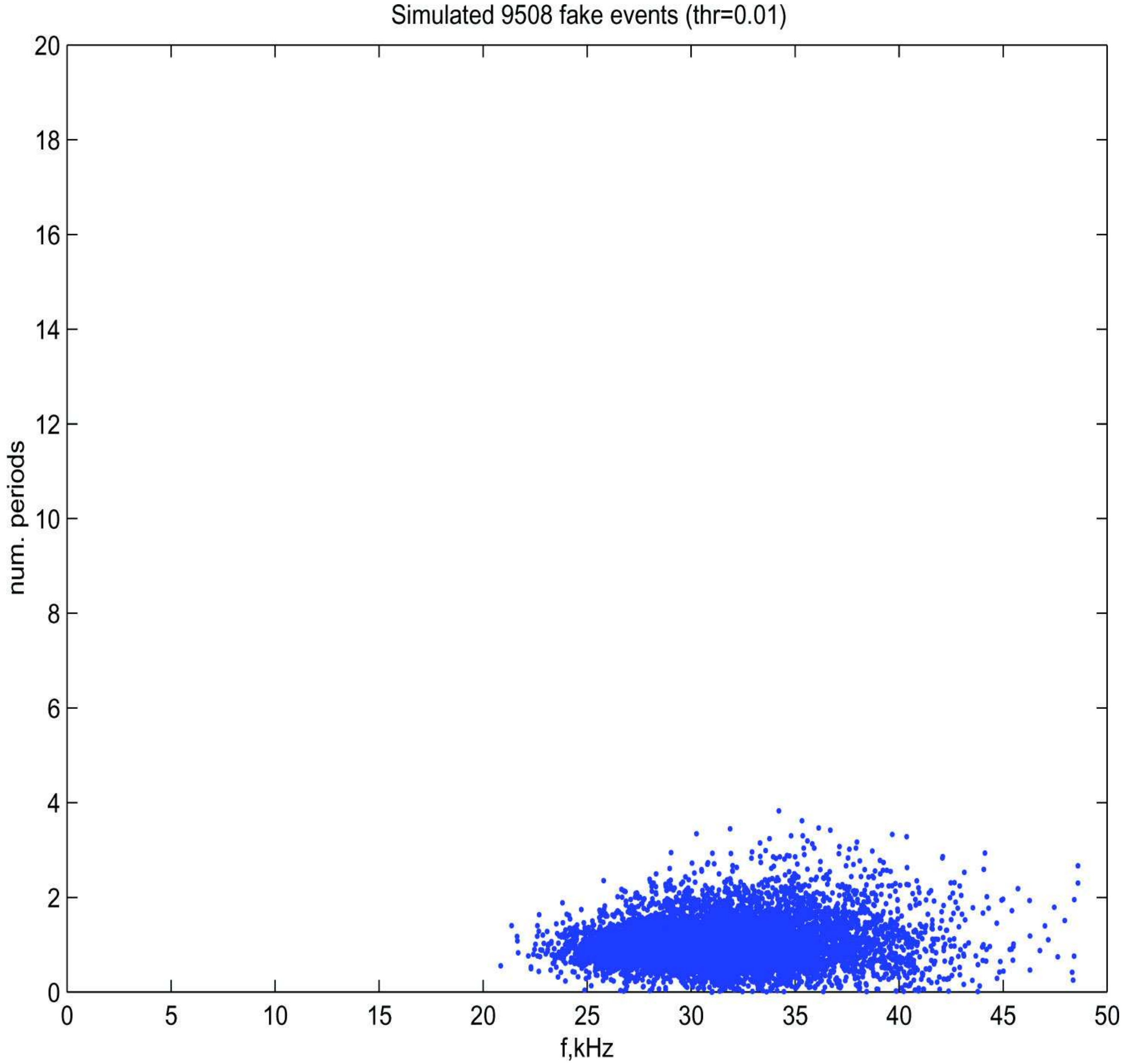
Examples of dolphin signals recorded by AUTEC personnel



Background categorization



Monte Carlo neutrinos

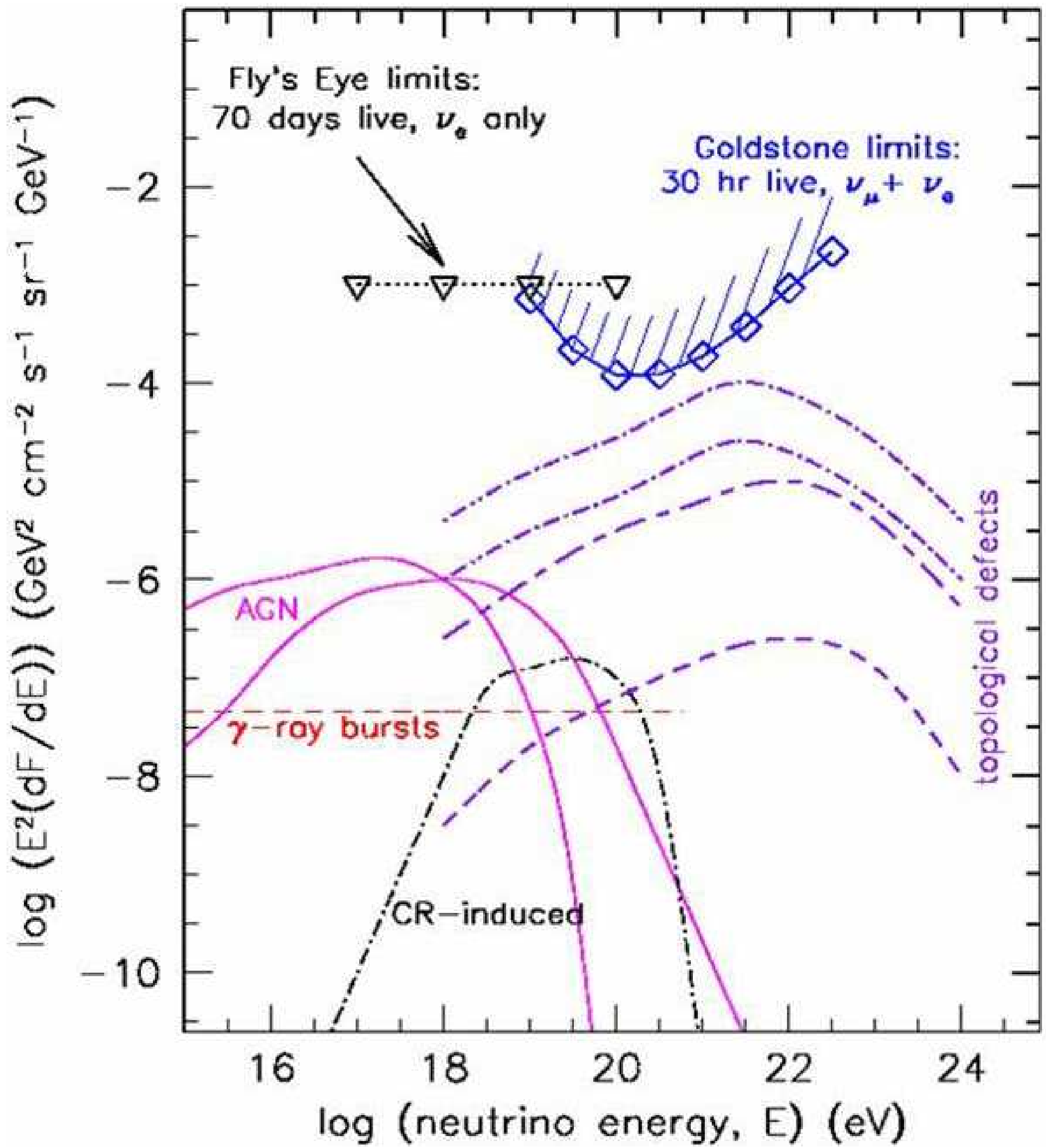


Background rejection

Cut	Events passing cut (Run II, 163 days integrated livetime)	
1) Filter trigger	40 million	single-phone events
2) Electronic noise	25 million	singles
3) 5-phone coincidence	5 million	combinations
4) Waveform analysis	3 thousand	combinations
a) Periods < 4		
b) 20 kHz < freq < 40 kHz		
c) Diamond metric < 0.7		
5) Threshold <= 0.024		
6) 5-phone localization	300	combinations
7) Threshold crossings < 2	0	combinations

(online, offline)

Diffuse neutrino flux



...SAUND measurements coming soon

Conclusions

Lessons and Accomplishments

- Large data set collected (211 days integrated)
- Backgrounds determined
- Refraction significant (esp. beyond 1 km)
    - position + direction reconstruction nontrivial; sea-floor phones bad
- $c_{sound} = c_{light}$ / 200,000 !! (coincidence not as powerful)
- first-generation threshold: 10^{21} eV (10^{19} eV possible?)

Upcoming

- Rigorous efficiency checks
- Flux limits

Onward and downward (SAUND-II)

- On to more phones (52), effective area (250 km^2), online rejection (7 CPUÕs)
- Down to the Gaussian floor

A first effort has been made toward acoustic neutrino detection.
The method will be fleshed out by SAUND-II and others
in the next few years.

http://hep.stanford.edu/neutrino/SAUND