Catching Rays in the Bahamas
Acoustic Detection of Ultra-High Energy Neutrinos

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

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Thanks to my SAUND collaborators:

Current:

M. Buckingham (Scripps)

G. Gratta (Stanford)

J. Vandenbroucke (Stanford, now at Berkeley)

Past:

S. Adam (Stanford, now at Cornell)

T. Berger (Scripps)

N. Lehtinen (Stanford, now at Hawaii)

Y. Zhao (Stanford)

And to AUTEC and the U. S. Navy:

D. Belasco
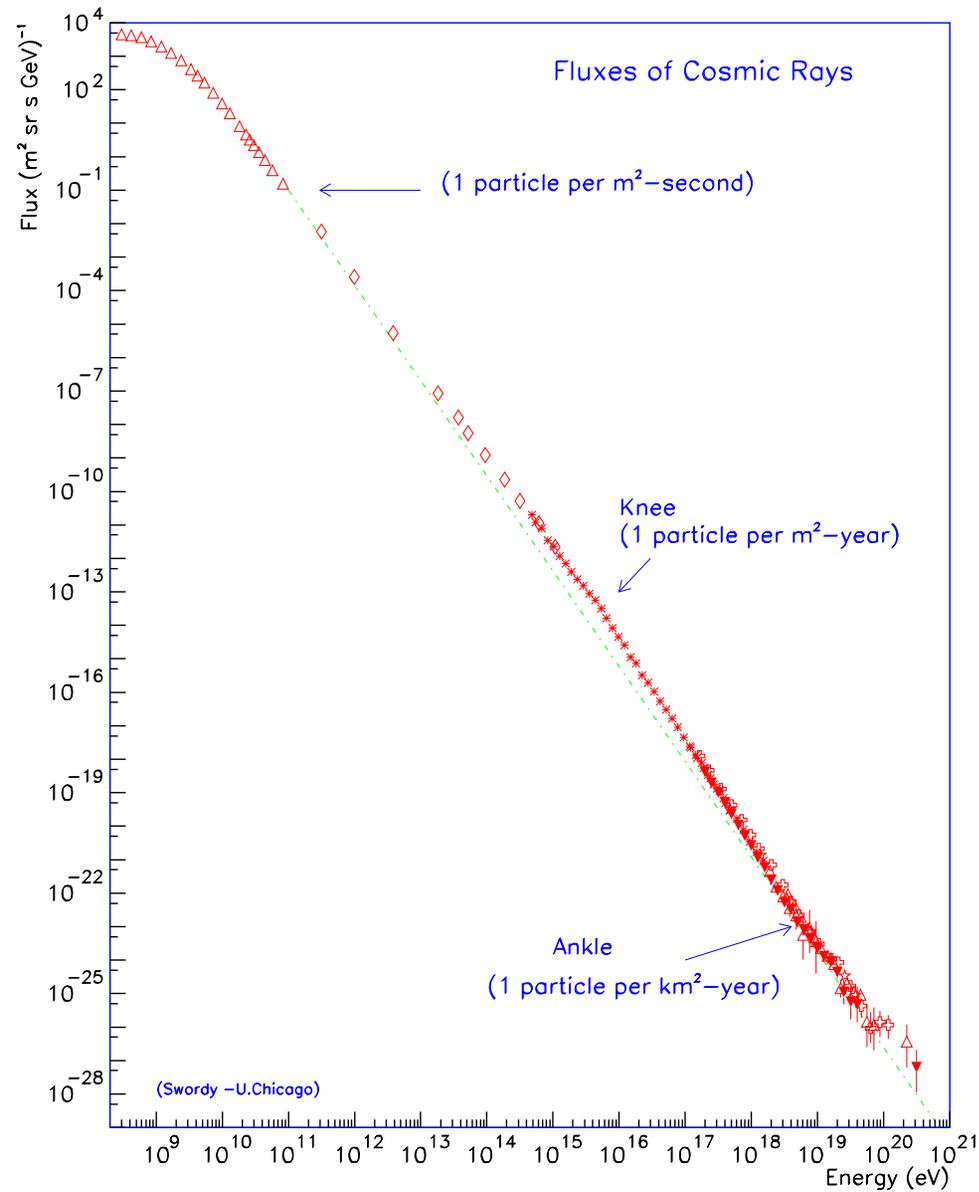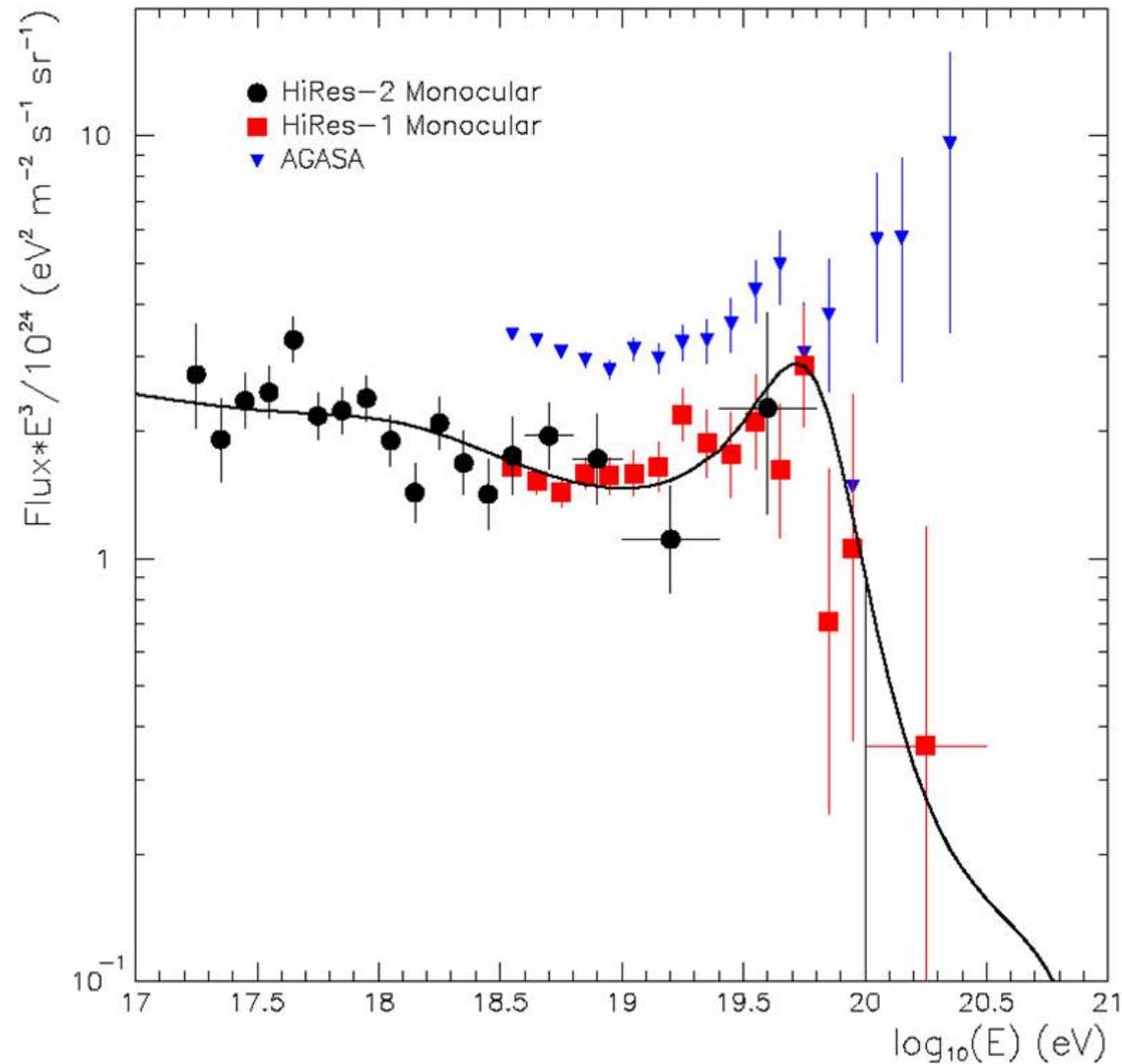
J. Cecil

D. Deveau
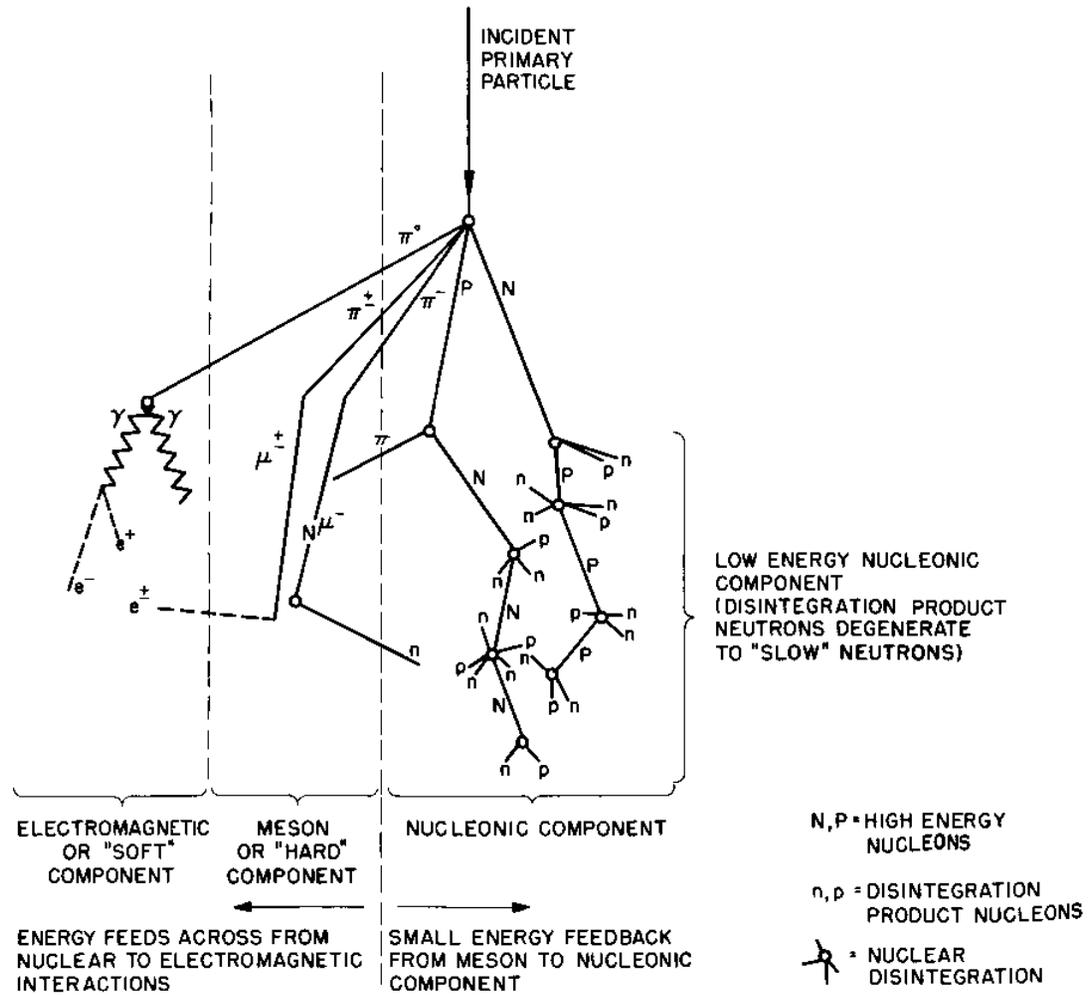
D. Kapolka

T. Kelly-Bissonnette

Cosmic ray spectrum

October 3, 2003　　　　　　Justin Vandenbroucke　　　　　　Rome

The Greisen-Zatsepin-Kuzmin (GZK) cutoff

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

Cosmic ray showers

Schematic Diagram of Cosmic Ray Shower

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

All key to understanding the universe!

Charged particles in fluids → sound!

- **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 towards a neutrino telescope**
  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*

Expected neutrino signal

$$\theta = 8°$$

(a)
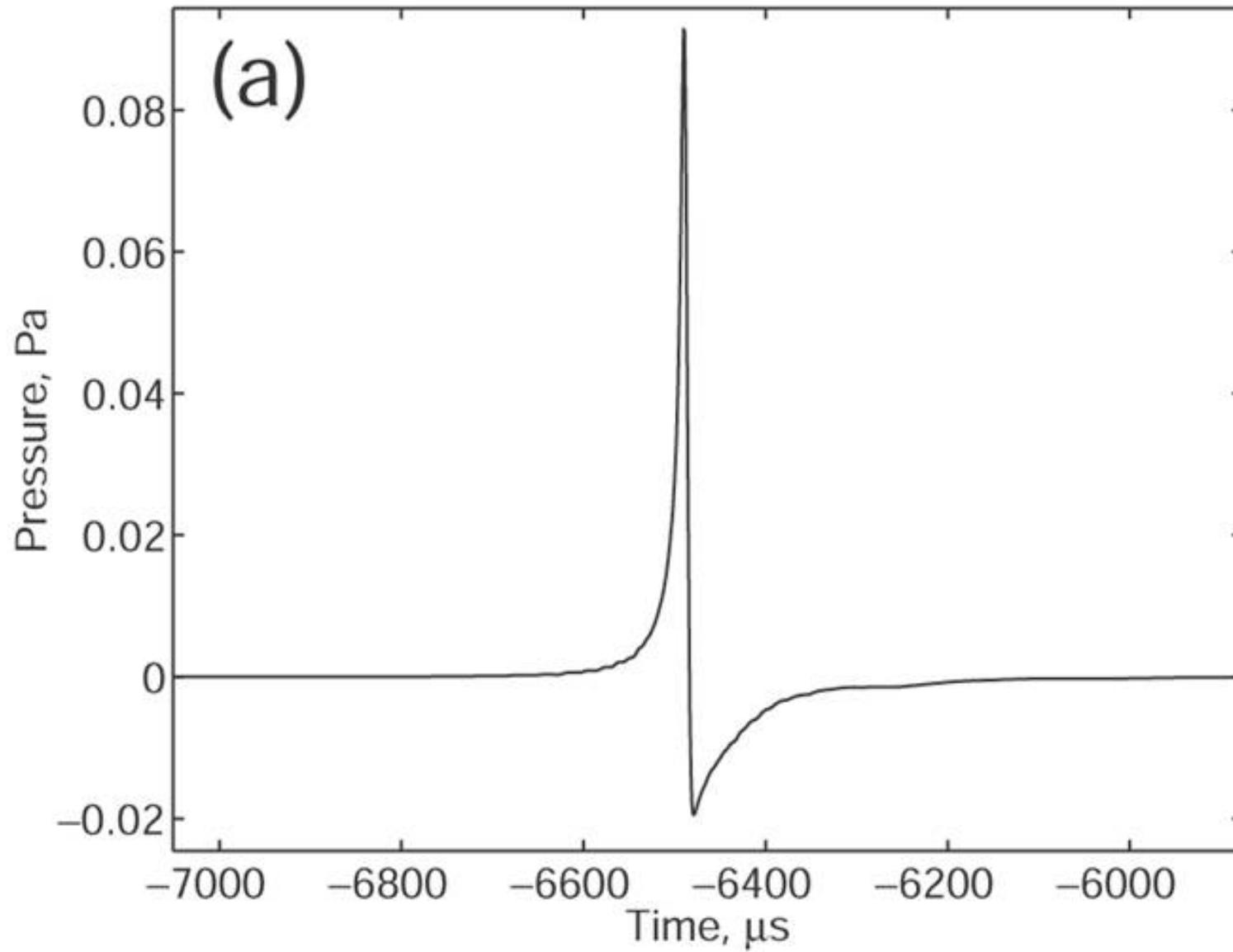
Ocean as particle detector
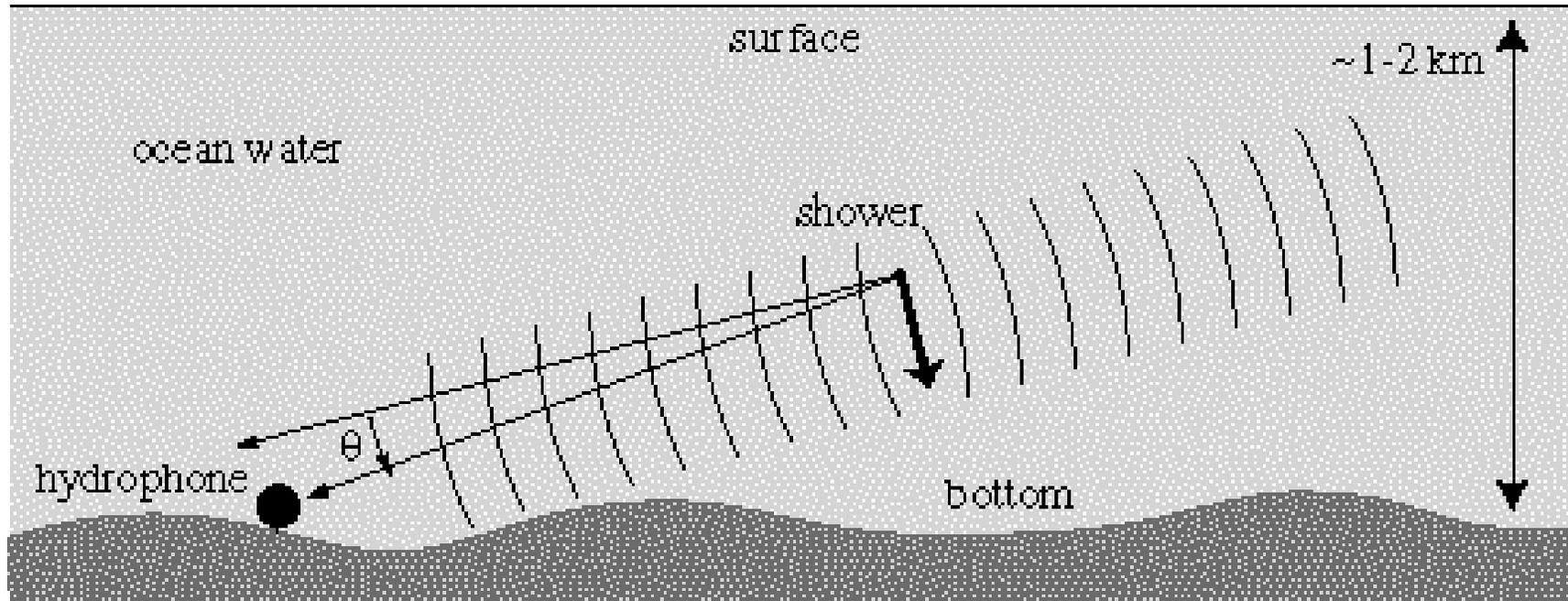
N. Lehtinen

Extreme pancakes

Detection volume contours, from 5e+20 eV to 3e+21 eV, contour interval 5e+20 eV
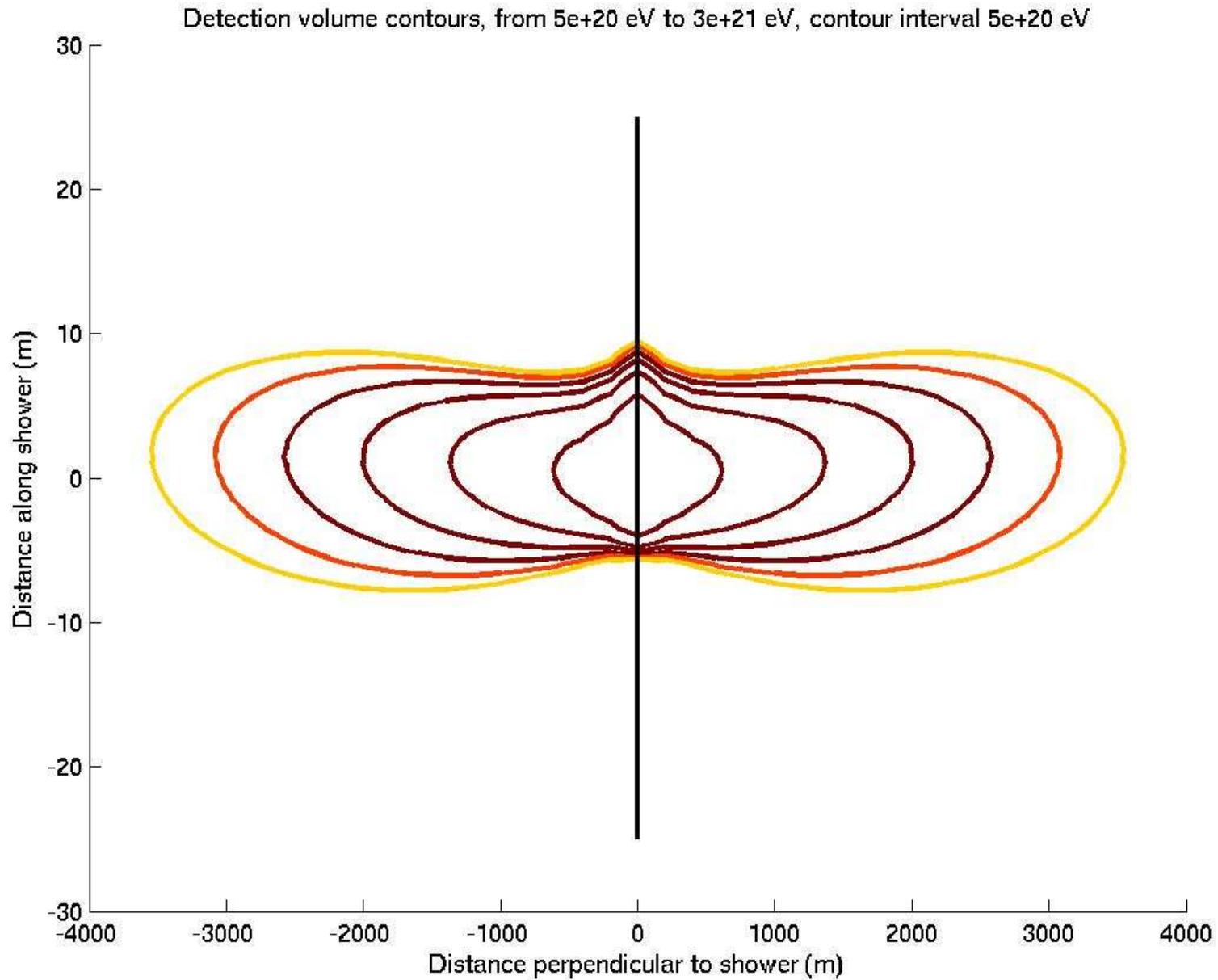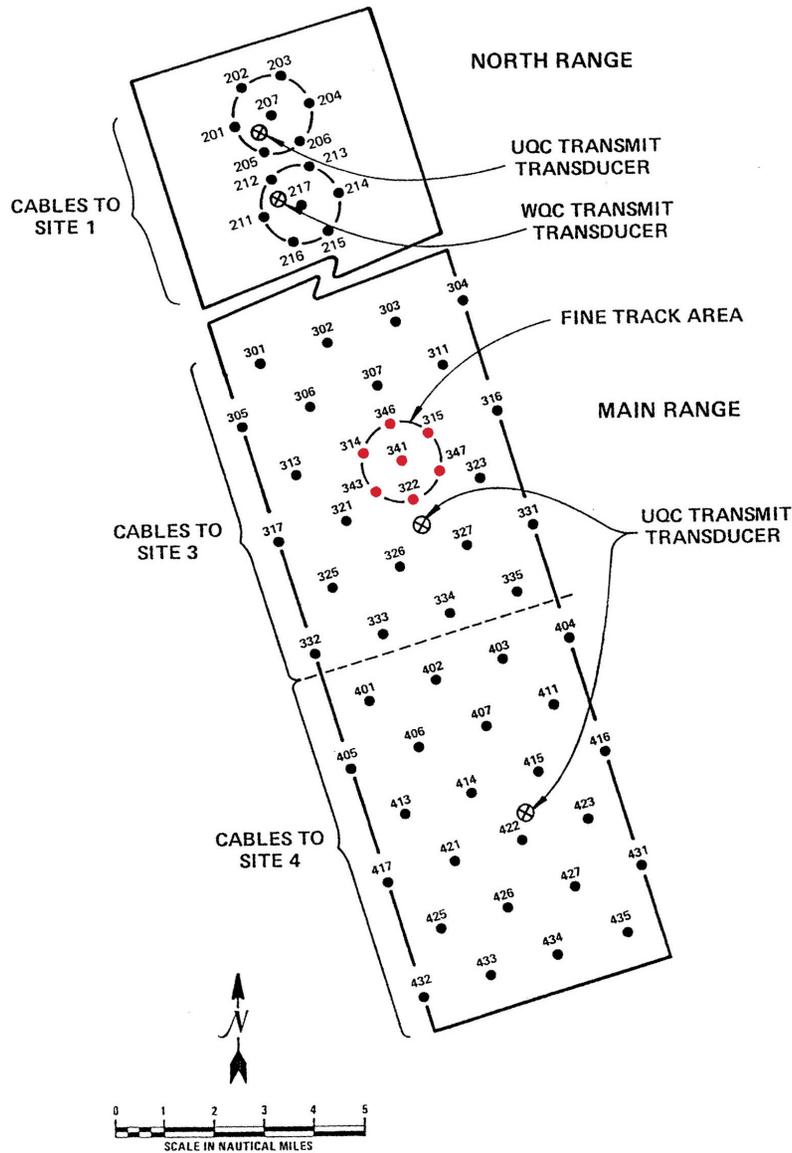
The Tongue Of The Ocean (TOTO)

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The Atlantic Undersea Test and Evalutation Center (AUTEC)
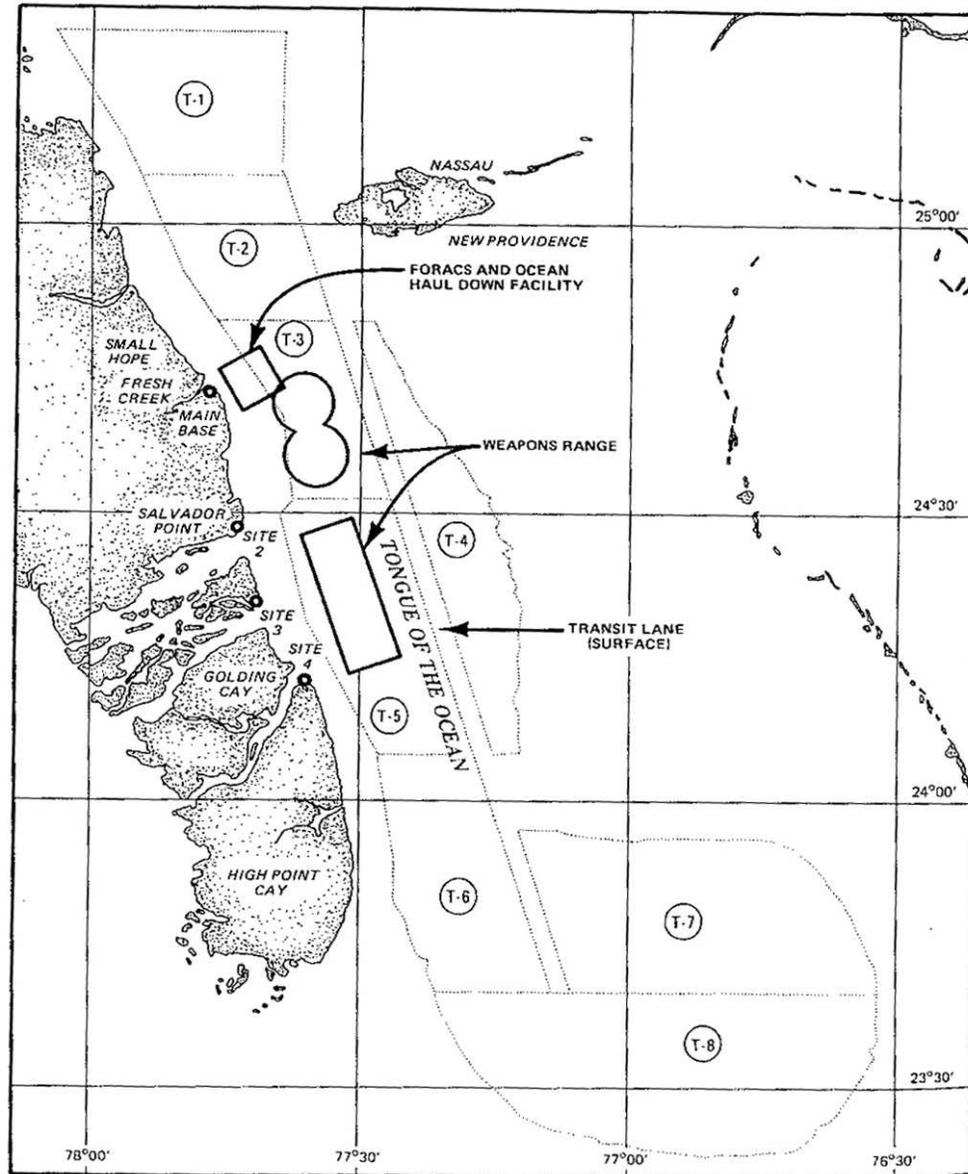
AUTEC hydrophones
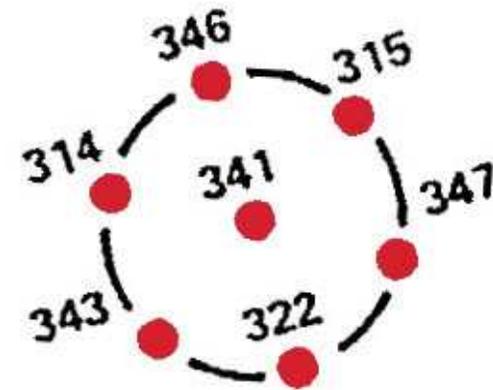
SAUND
(7 km^2)

The SAUND array

The 7-phone detector and sea floor
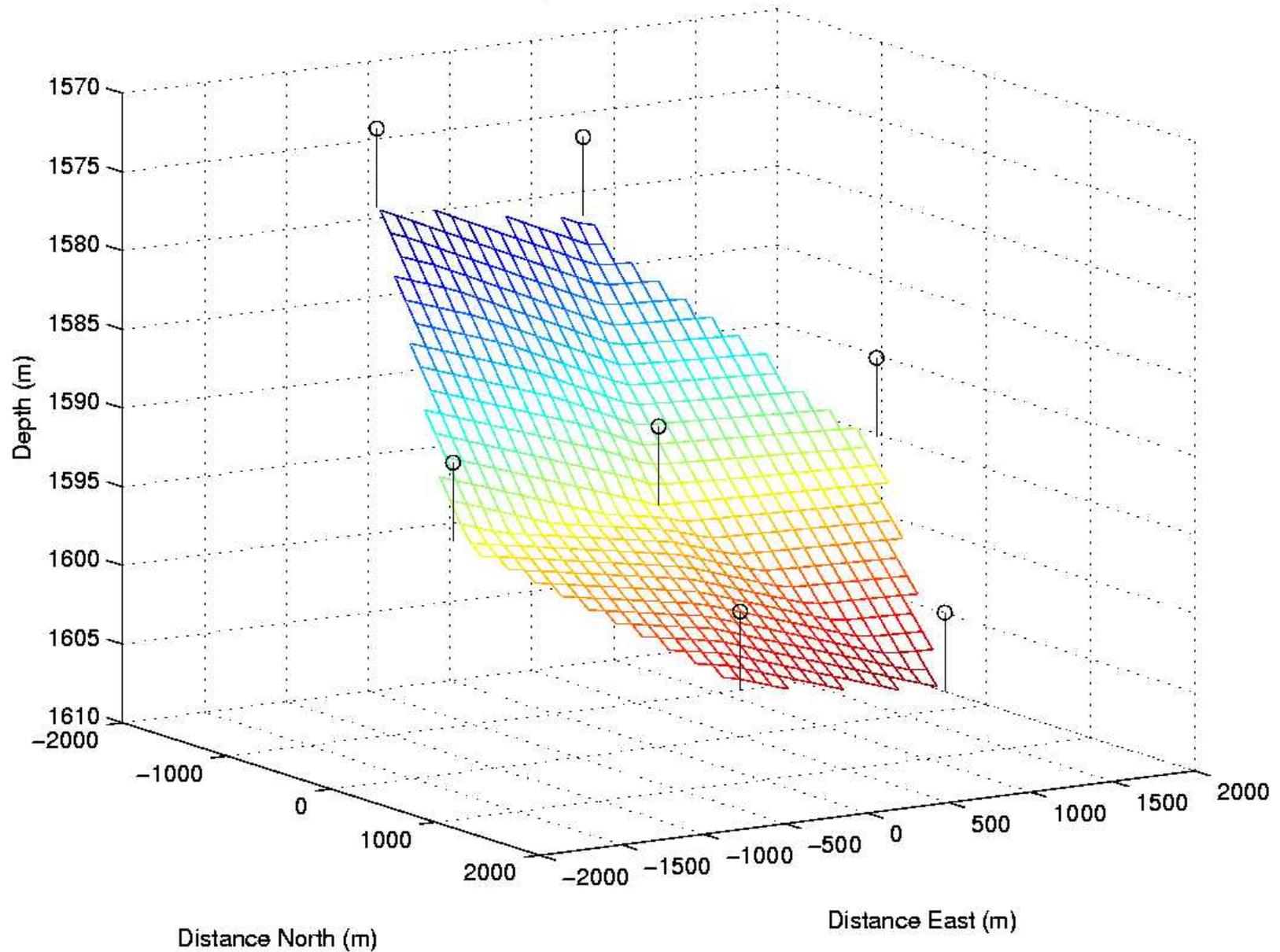
Hydrophones on sea floor

~4.5 m

BAIL LIES DOWN WITH
HYDROPHONE IN PLACE

Site 3

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Site 3

DAQ

DAQ

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

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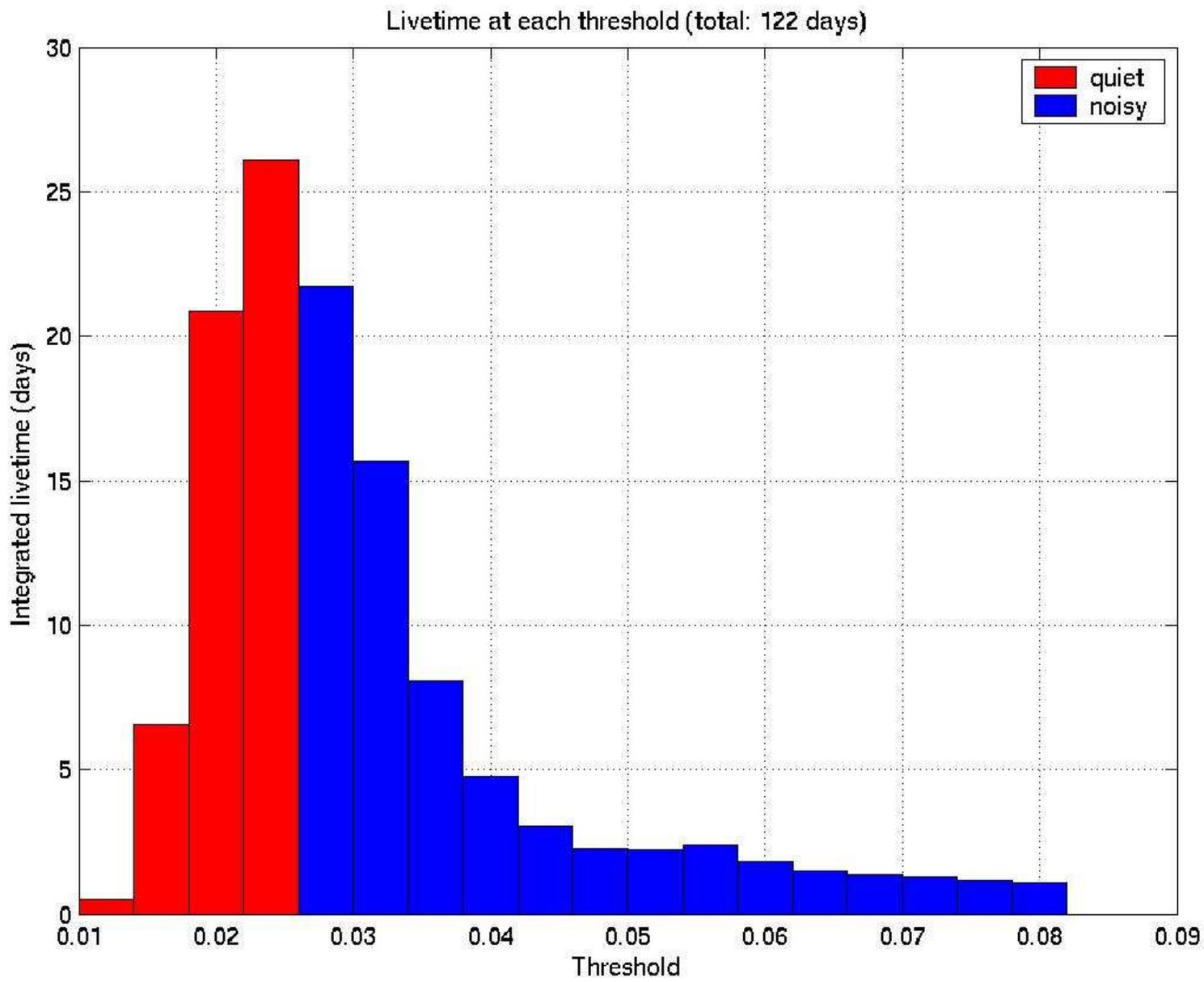- variable threshold
- 179 kHz sampling
- 60 events/minute target
- 1-2 GB / 24 hrs

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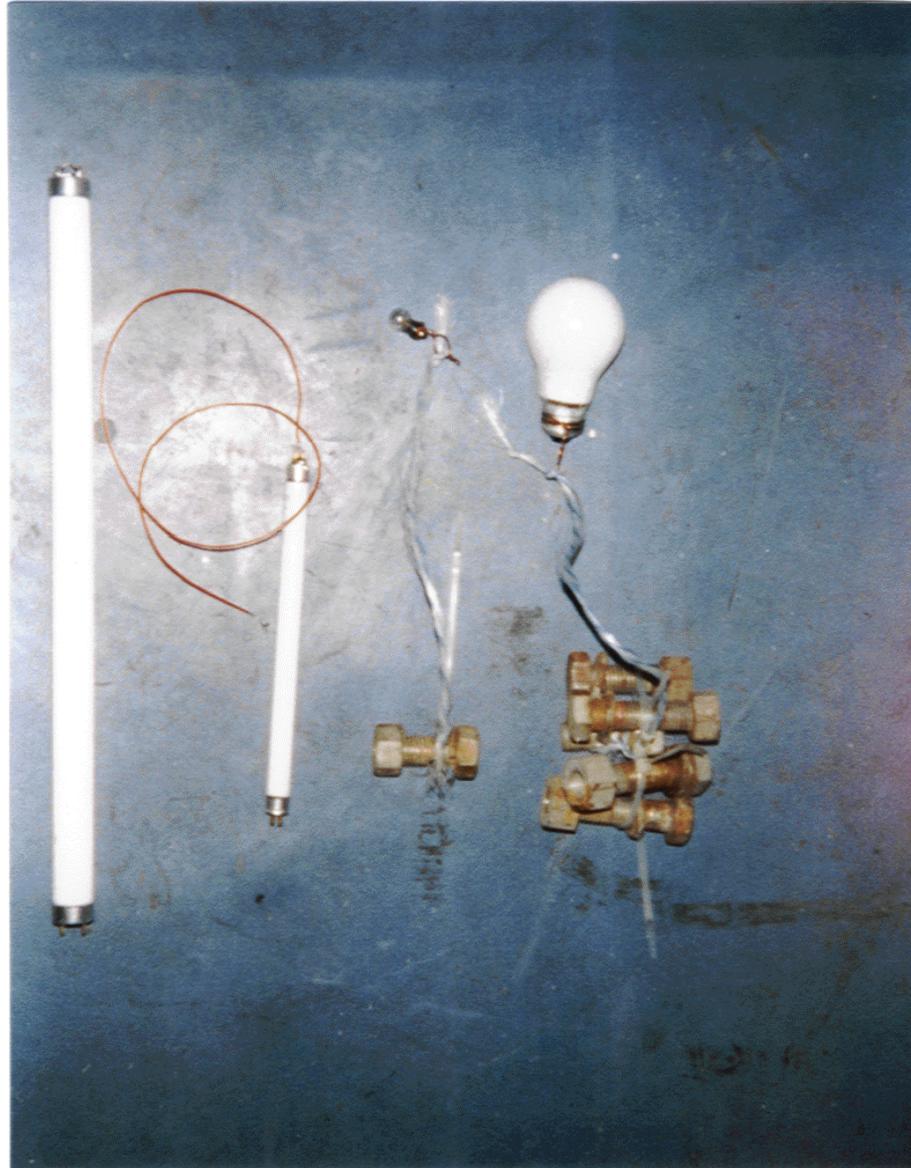
$$noise: N(t) \propto f^{-2}$$

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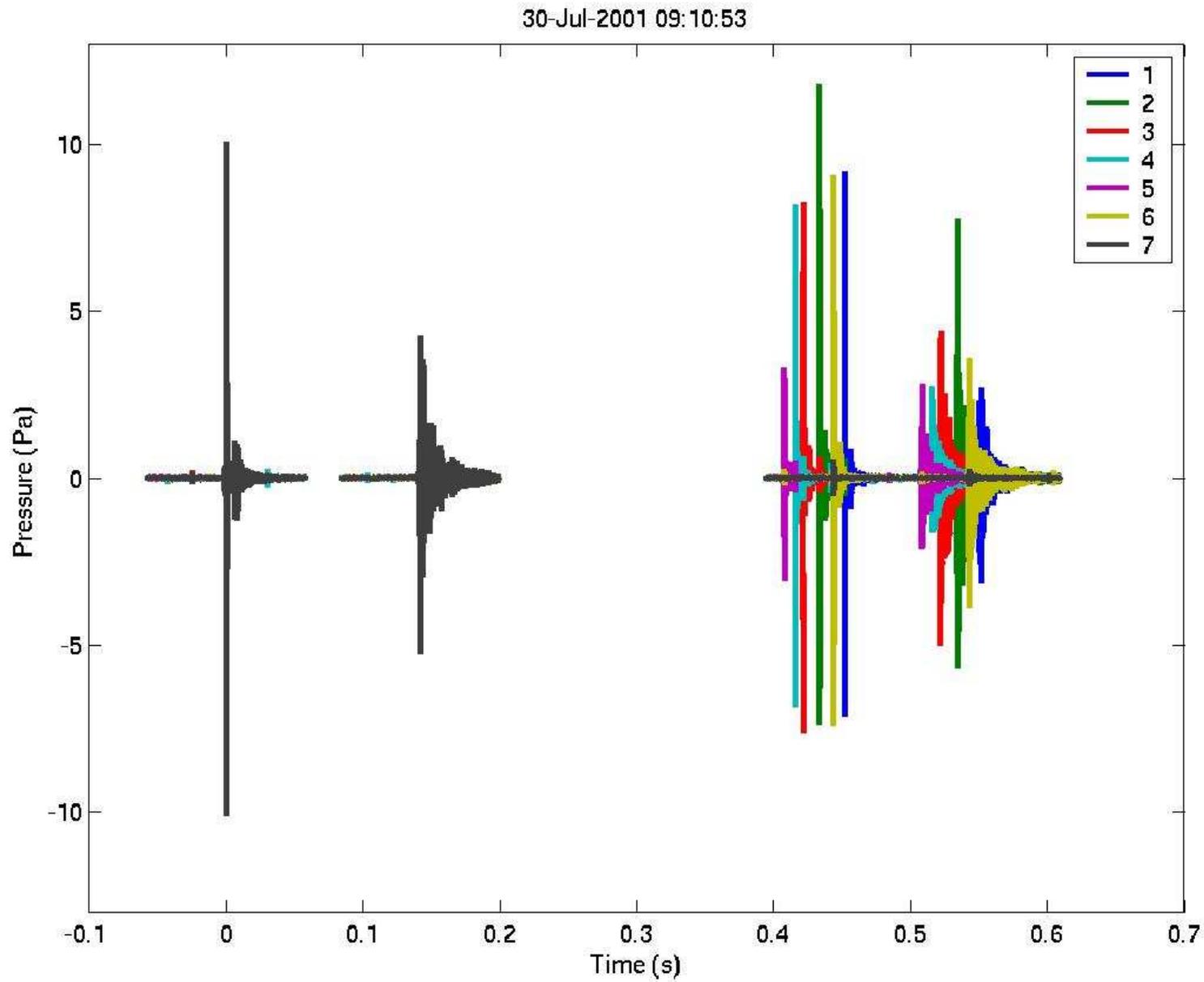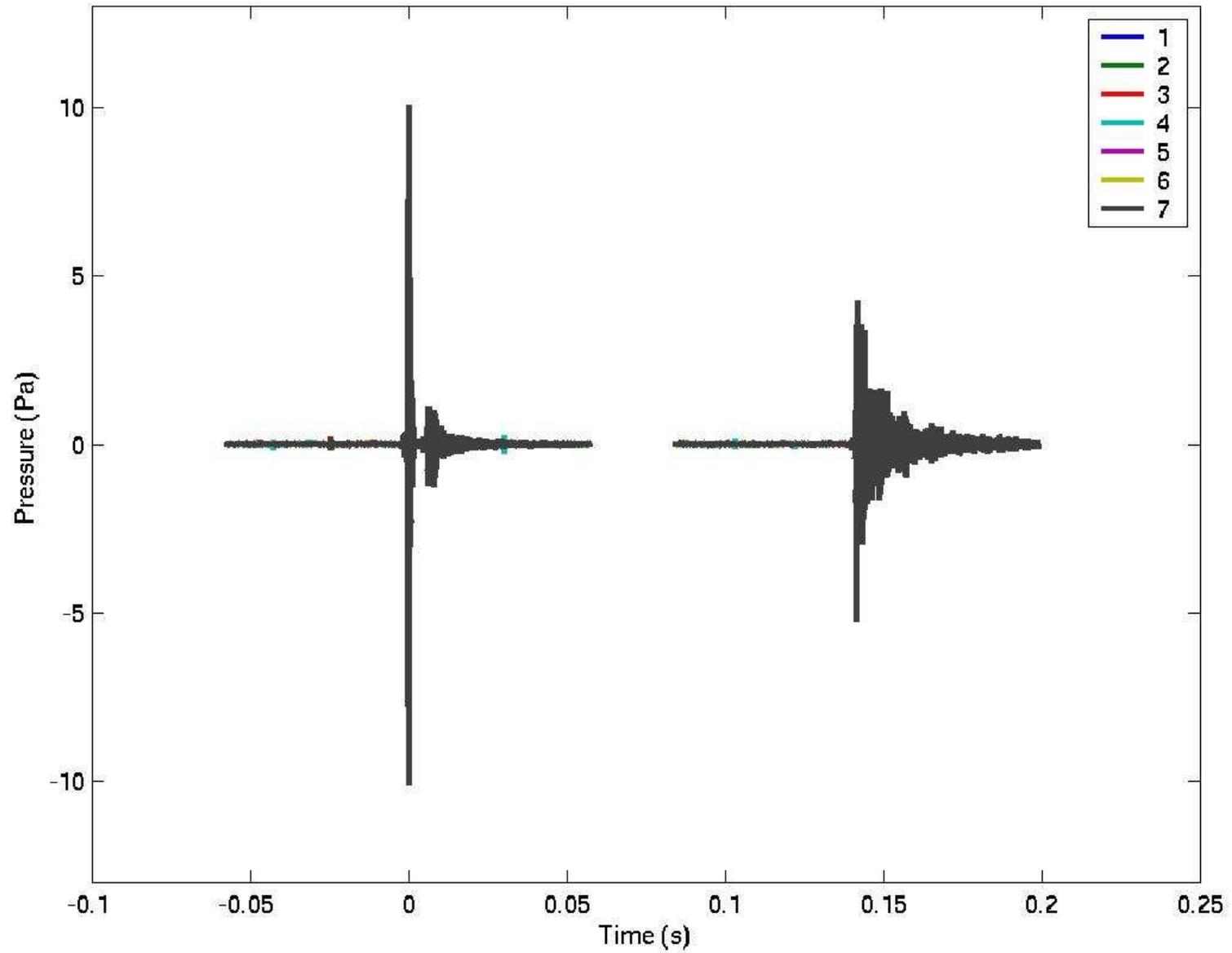

Signal

Response function

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Adaptive threshold

Livetime at each threshold (total: 122 days)
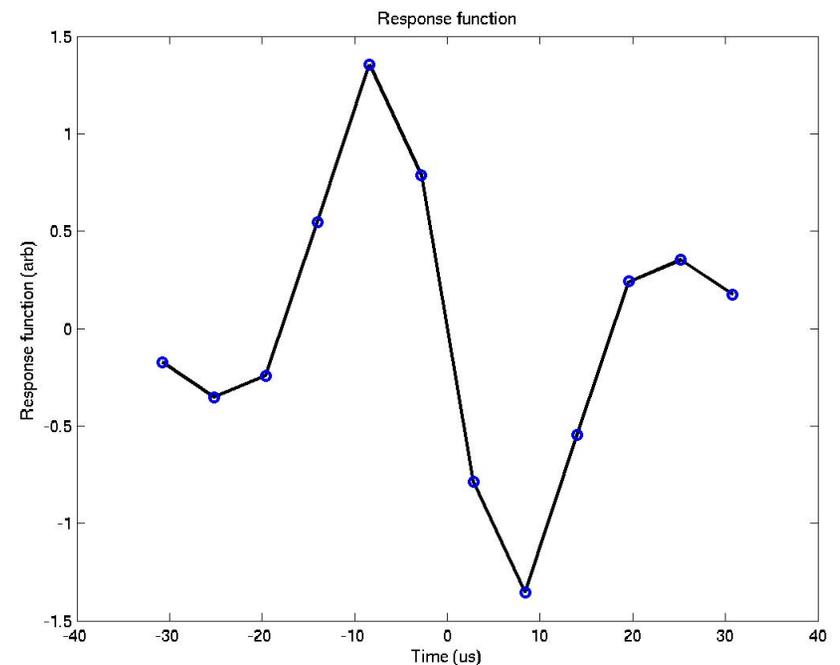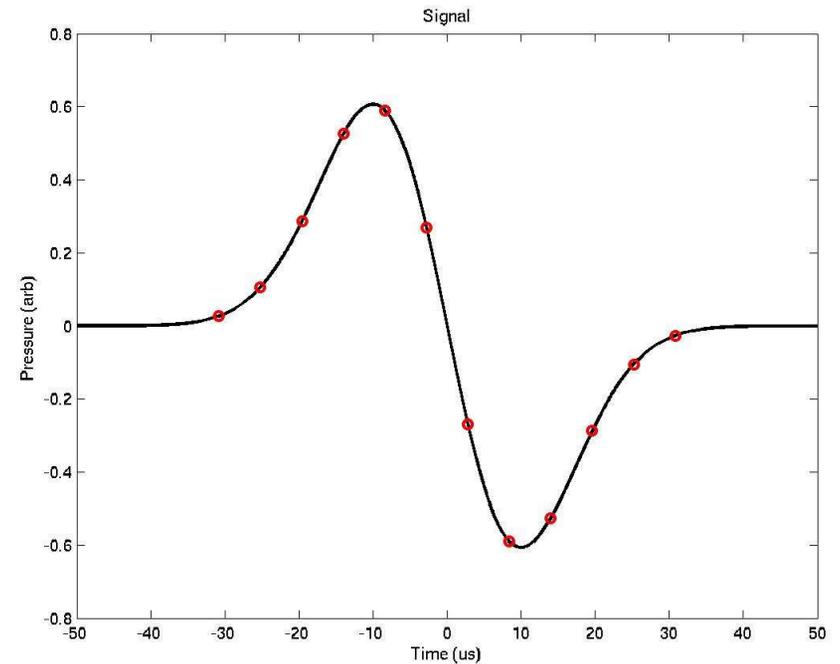
Calibration sources

21 events per lightbulb

30-Jul-2001 09:10:53

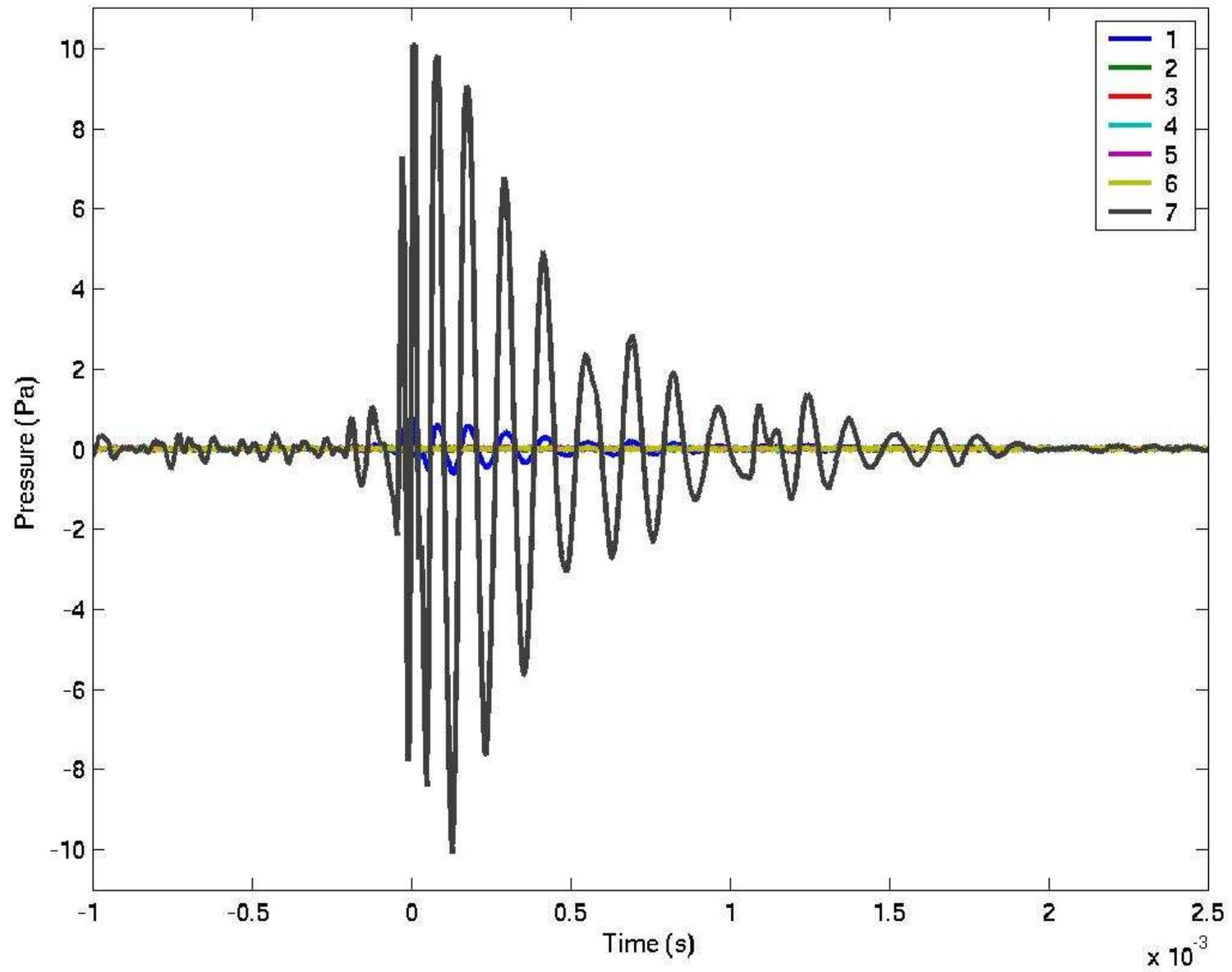# Sea surface reflection

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Sea floor reflection

30-Jul-2001 09:10:53
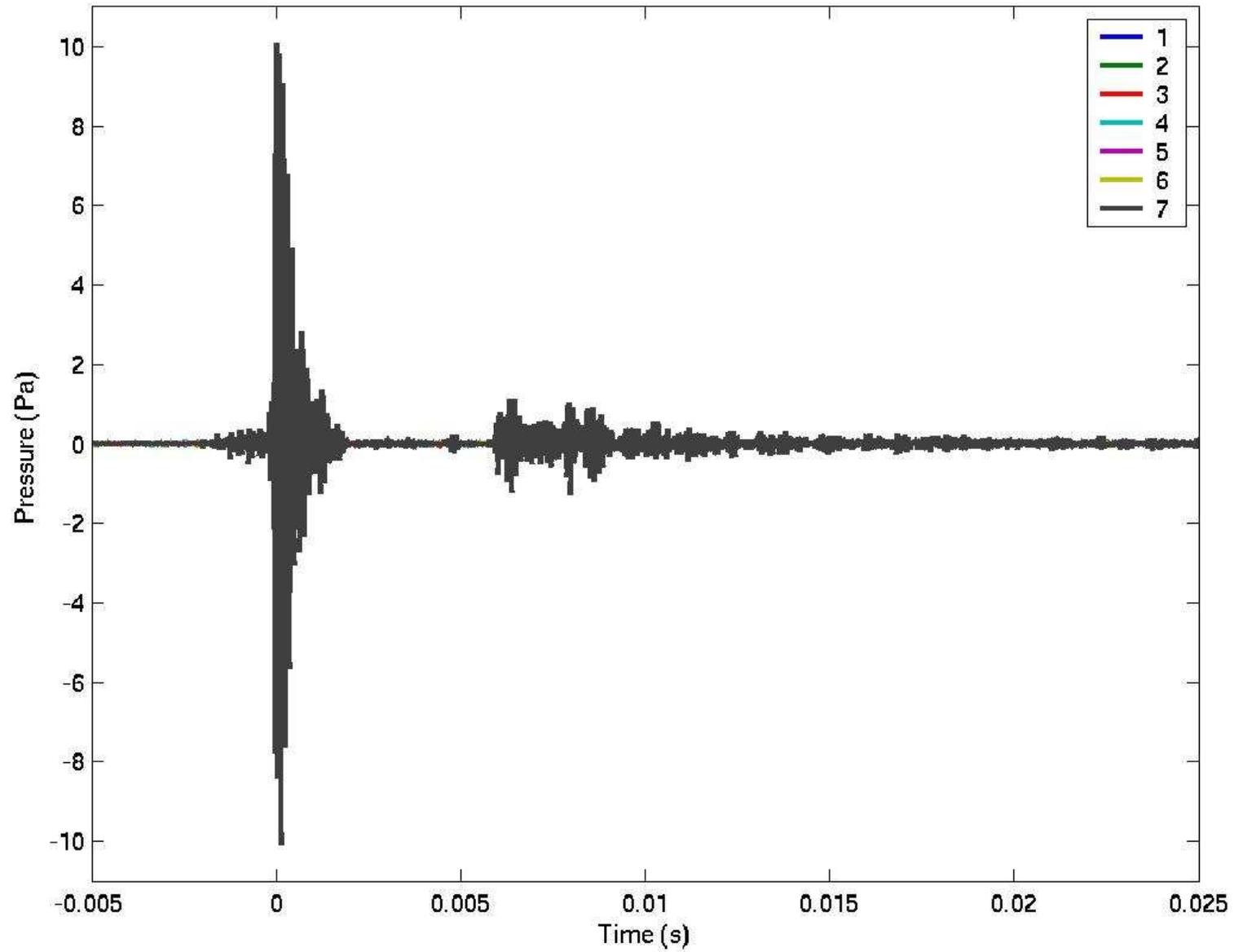
Direct signal

30-Jul-2001 09:10:53

Lightbulb positions reconstructed

Location of boat (GPS) and bulbs (reconstructed)
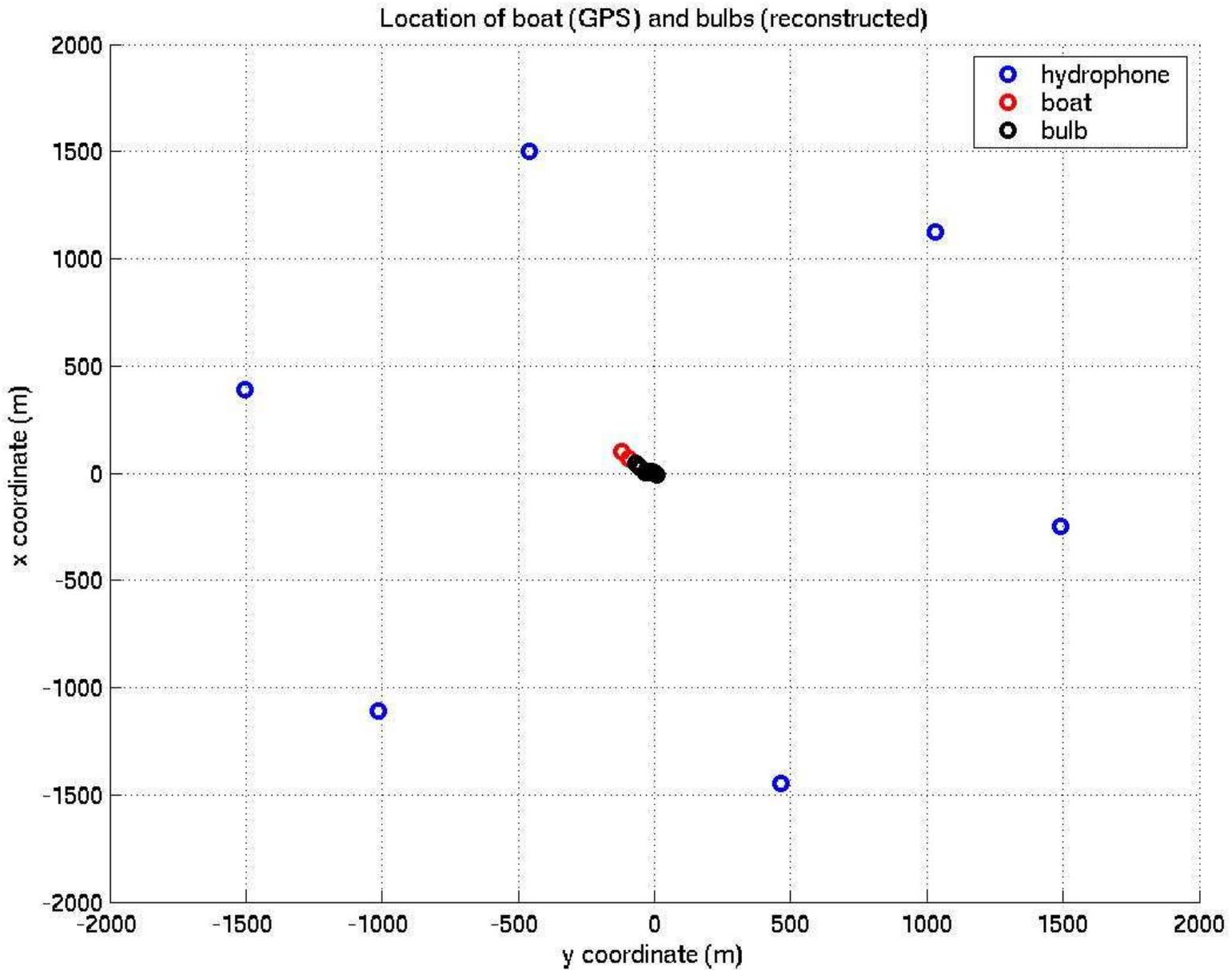
Lightbulb positions reconstructed
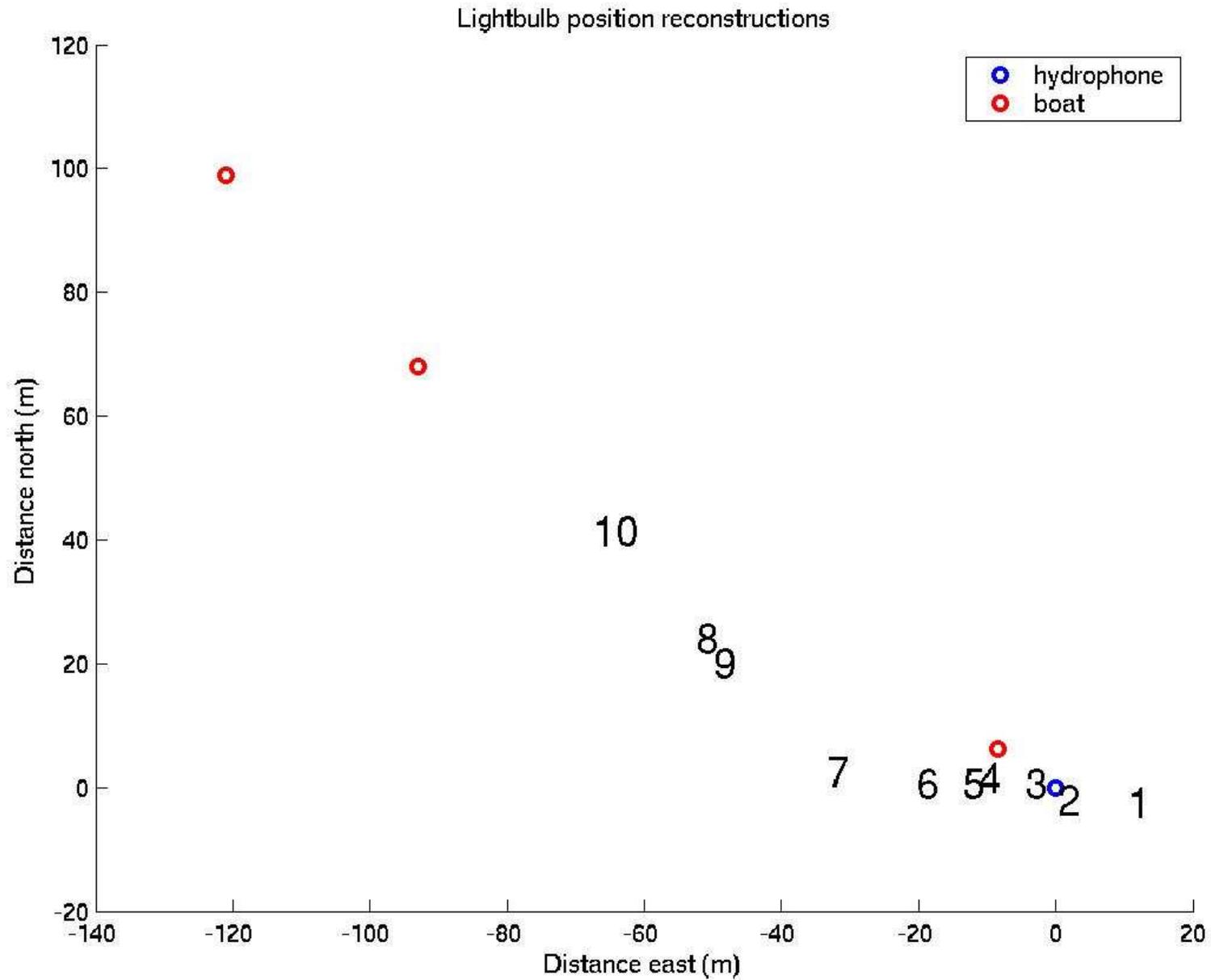
Lightbulb depths reconstructed

Reconstructed lightbulb implosion depths
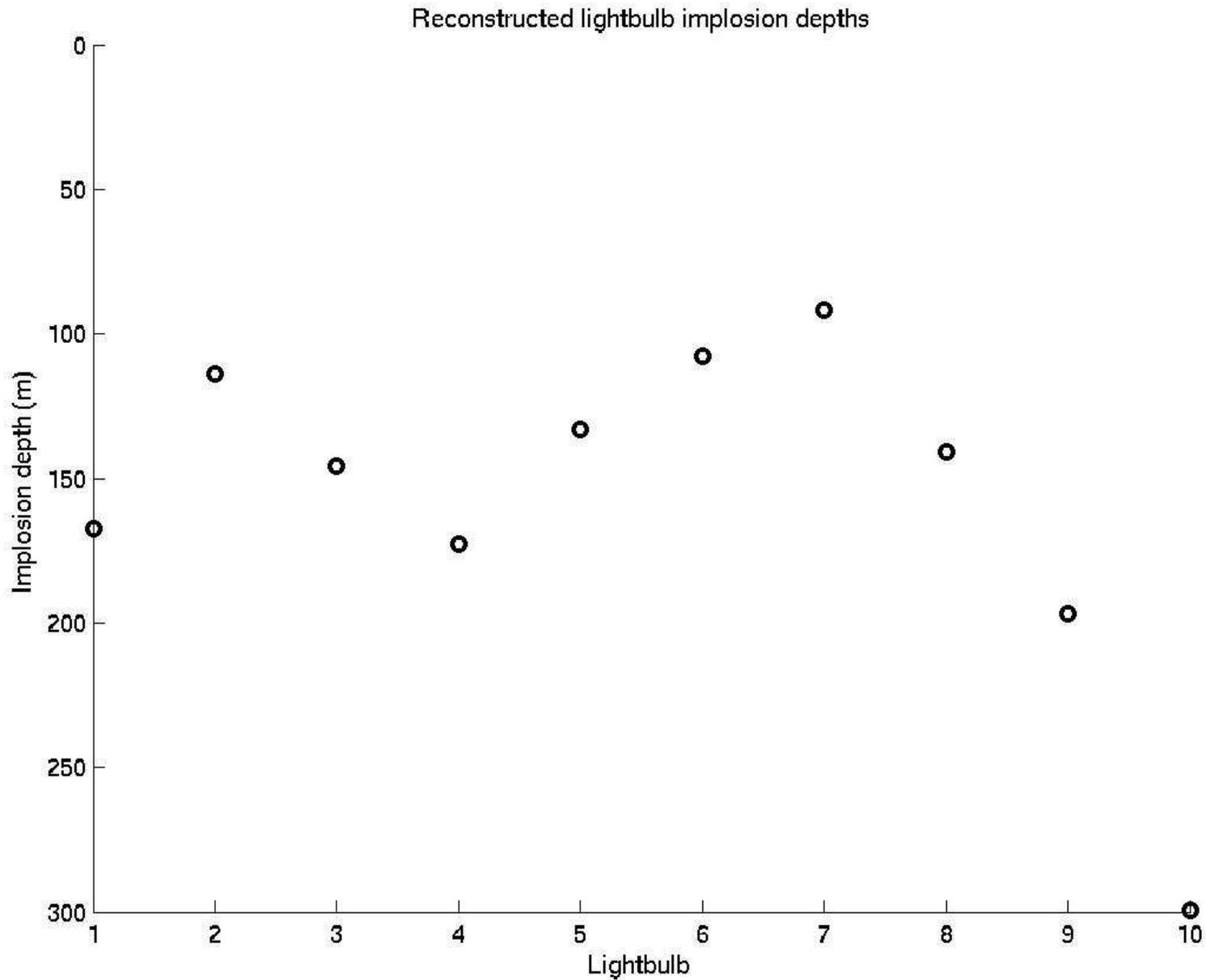
Lightbulb energies reconstructed

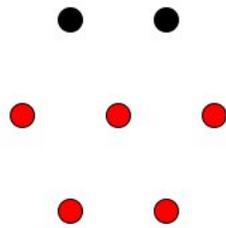| Bulb	Depth (m)	P (kPa)	E_0 (J)
1	160	1563	234
2	107	1047	157
3	139	1360	204
4	166	1626	244
5	126	1237	186
6	101	990	148
7	86	838	126
8	135	1324	199
9	188	1842	276
10	290	2846	427

Integrated livetime

- 70% duty cycle
- 211 days live
- 25 million events
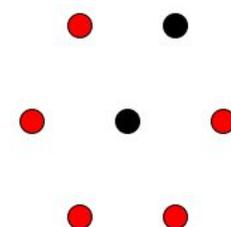- 350 GB
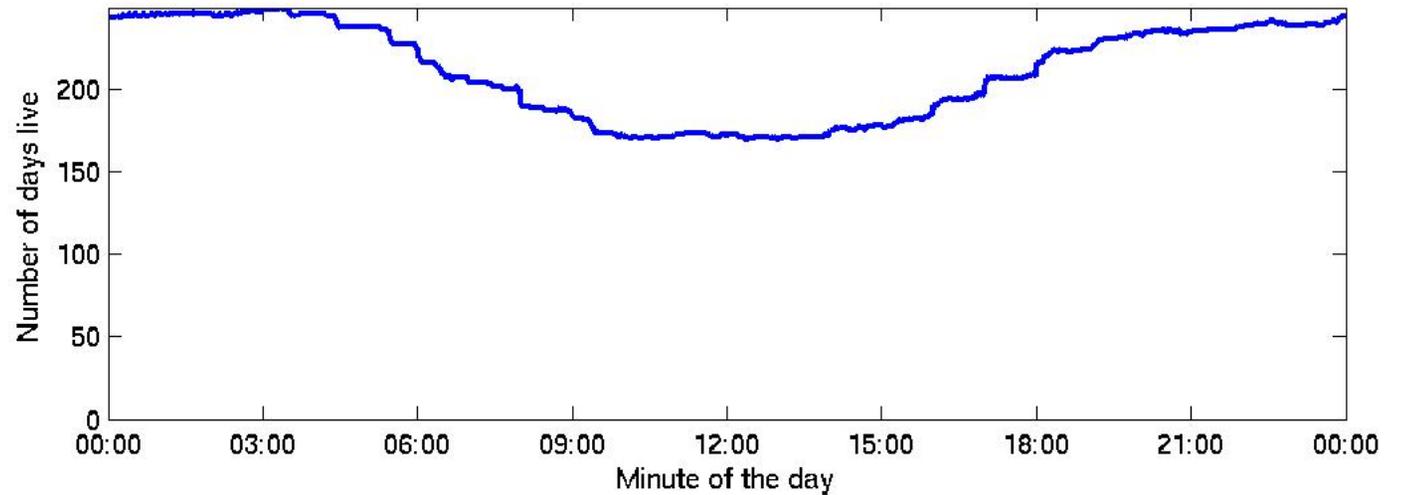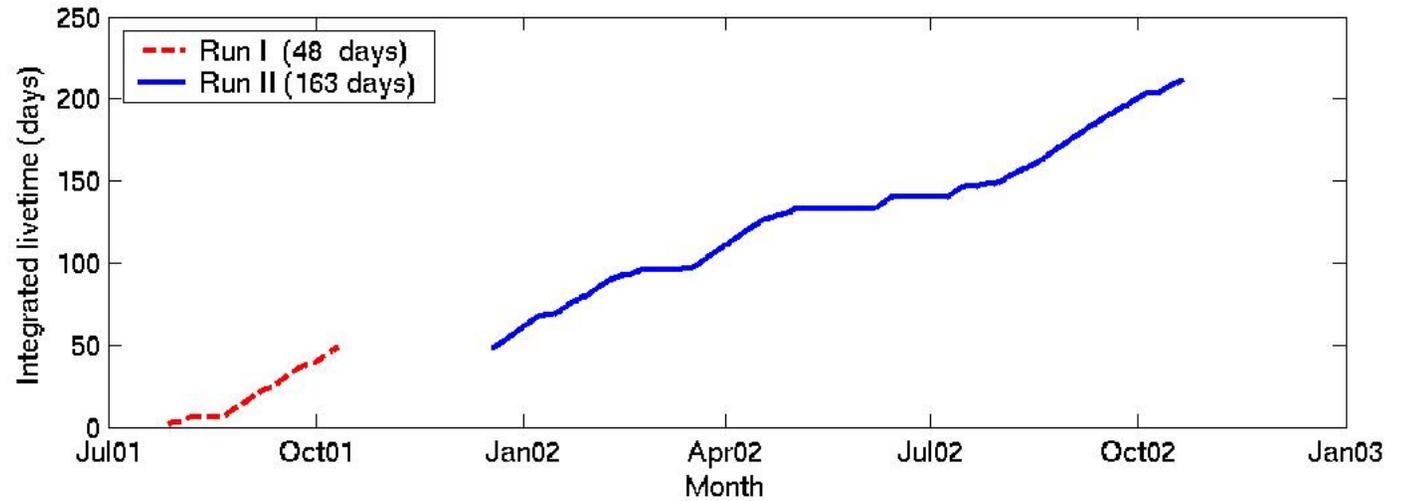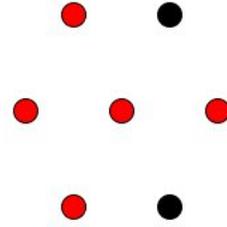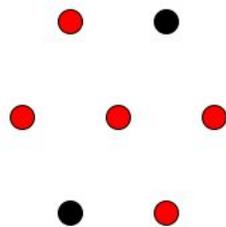
Five-phone coincidence

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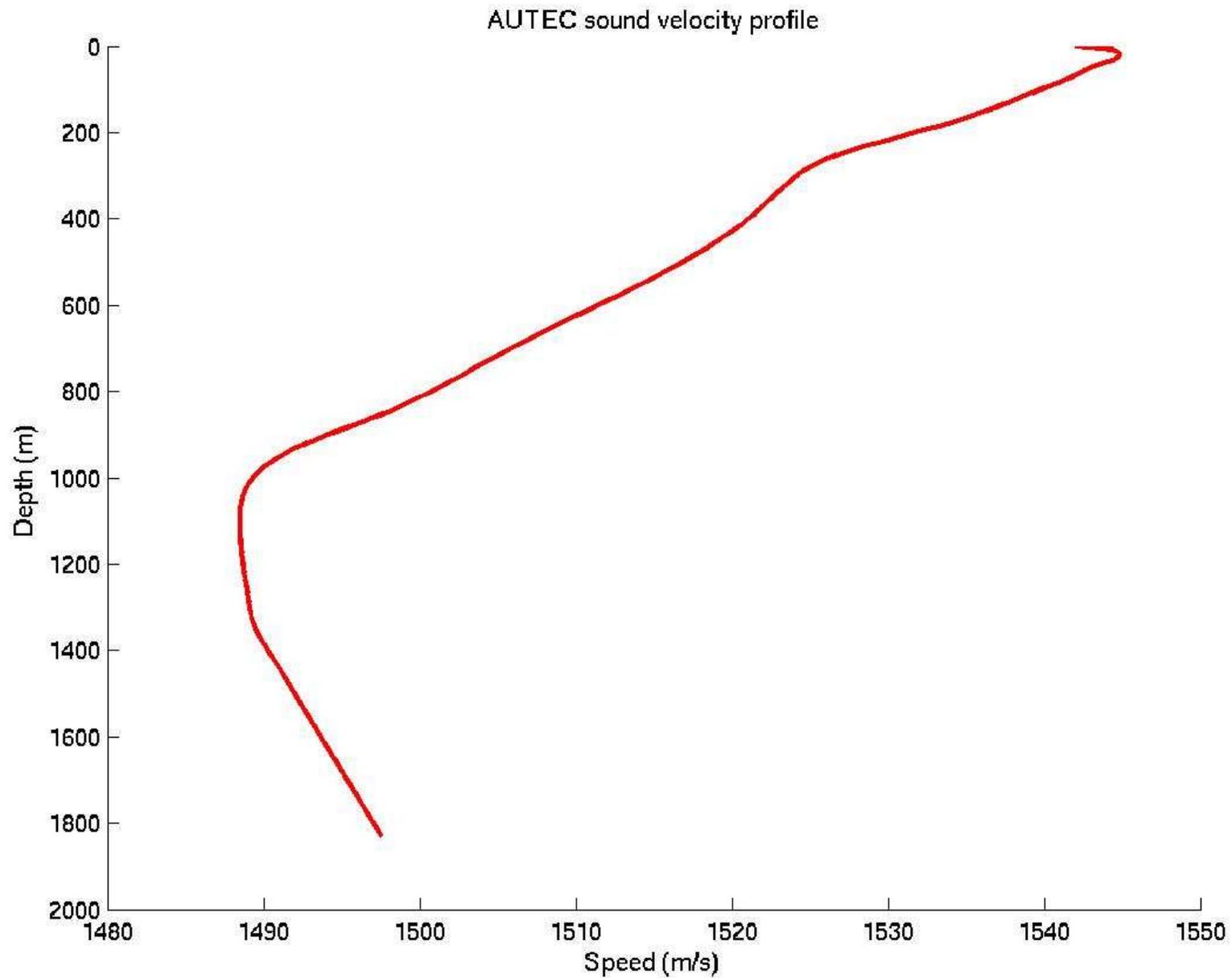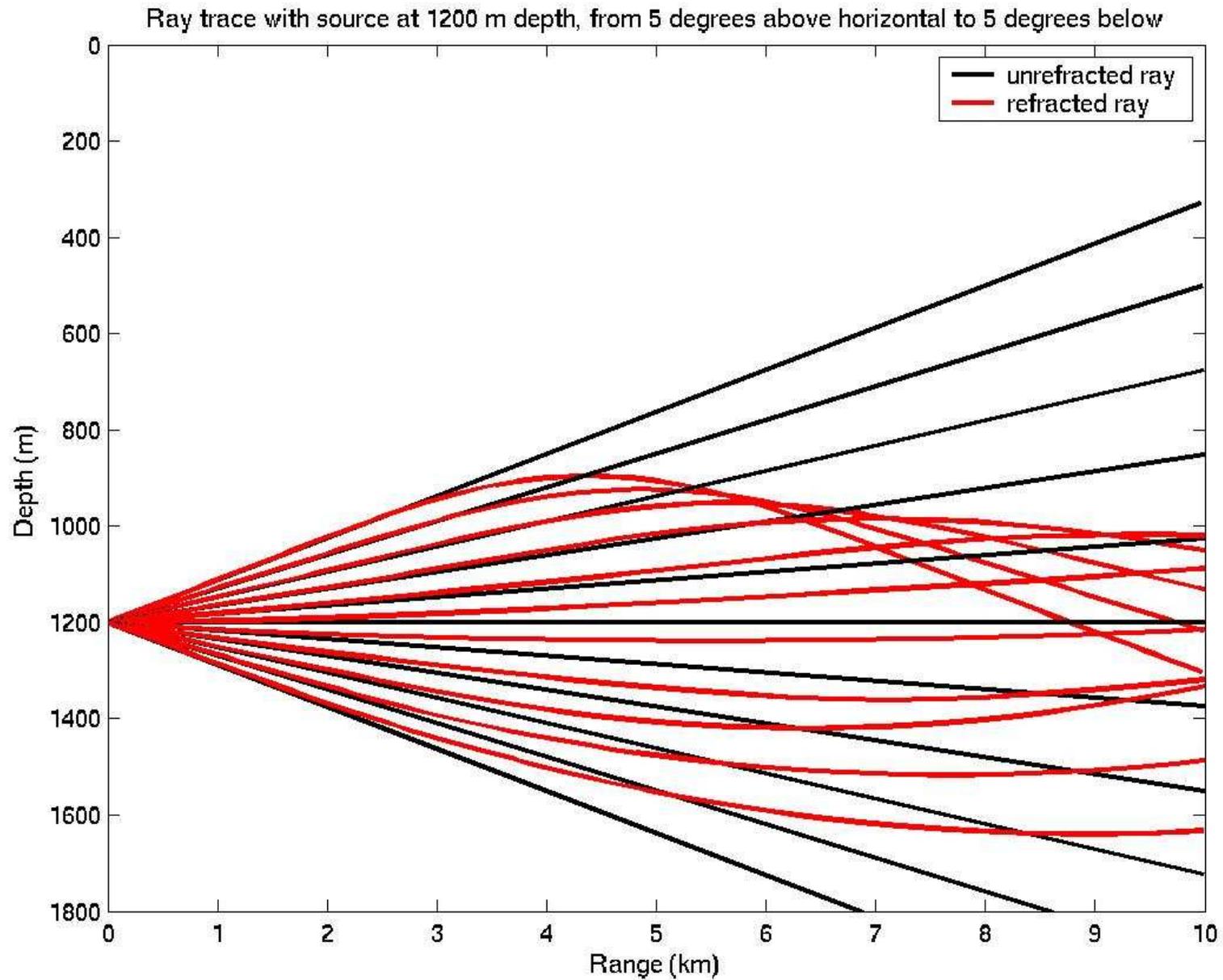2) Geometry consistent with pancake (2D circle) shape:

accepted:

rejected:

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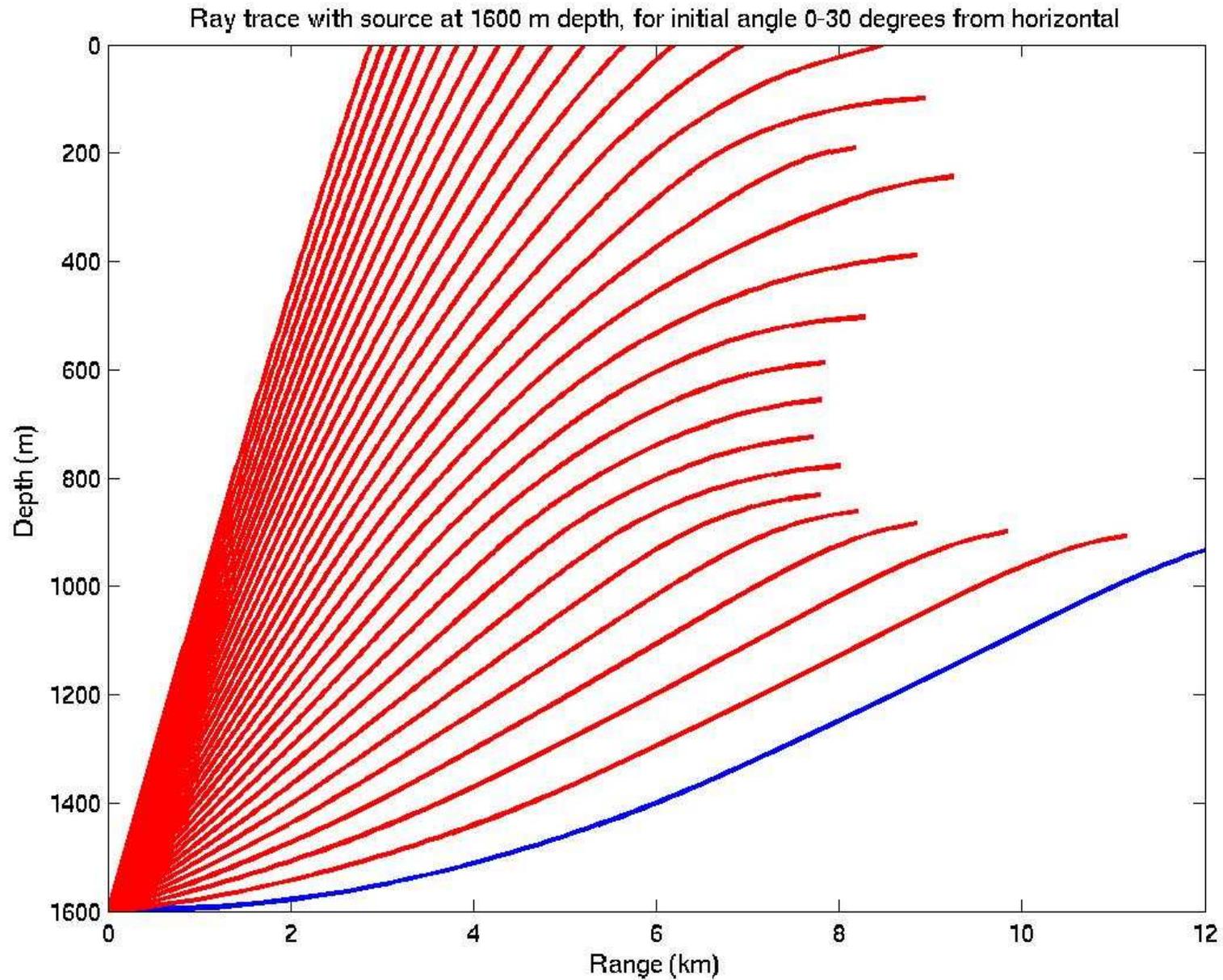
AUTEC sound velocity profile (SVP)

Refraction

Ray trace with source at 1200 m depth, from 5 degrees above horizontal to 5 degrees below

Legend:
- unrefracted ray
- refracted ray

Refraction shadow

Ray trace with source at 1600 m depth, for initial angle 0-30 degrees from horizontal

Refracted pancake

Refracted acoustic radiation disk cross section for a 1e+21 eV neutrino at zenith 0.5 deg
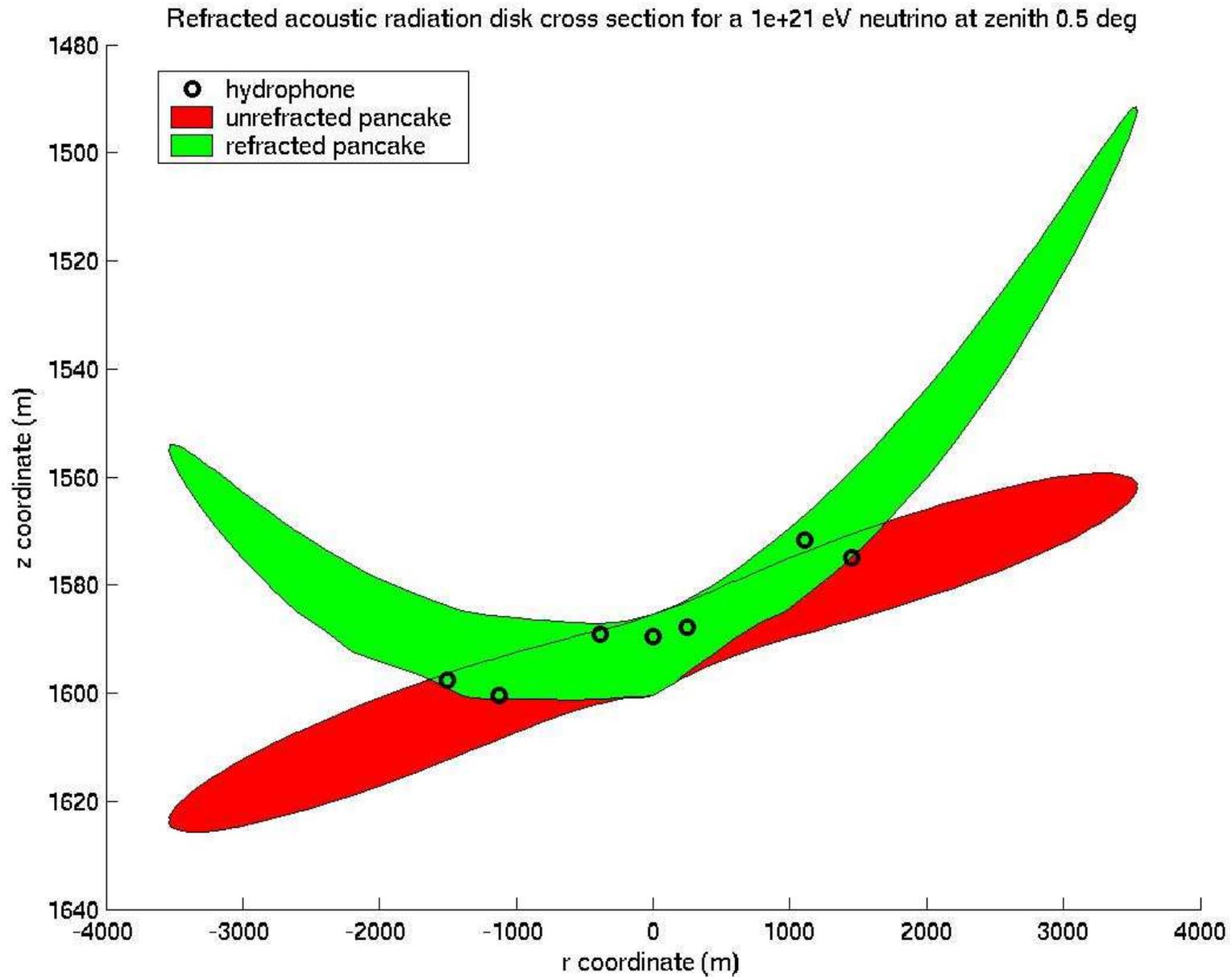
Time difference of arrival (TDOA) localization achieved

Radial coordinate vs. depth of reconstructed events
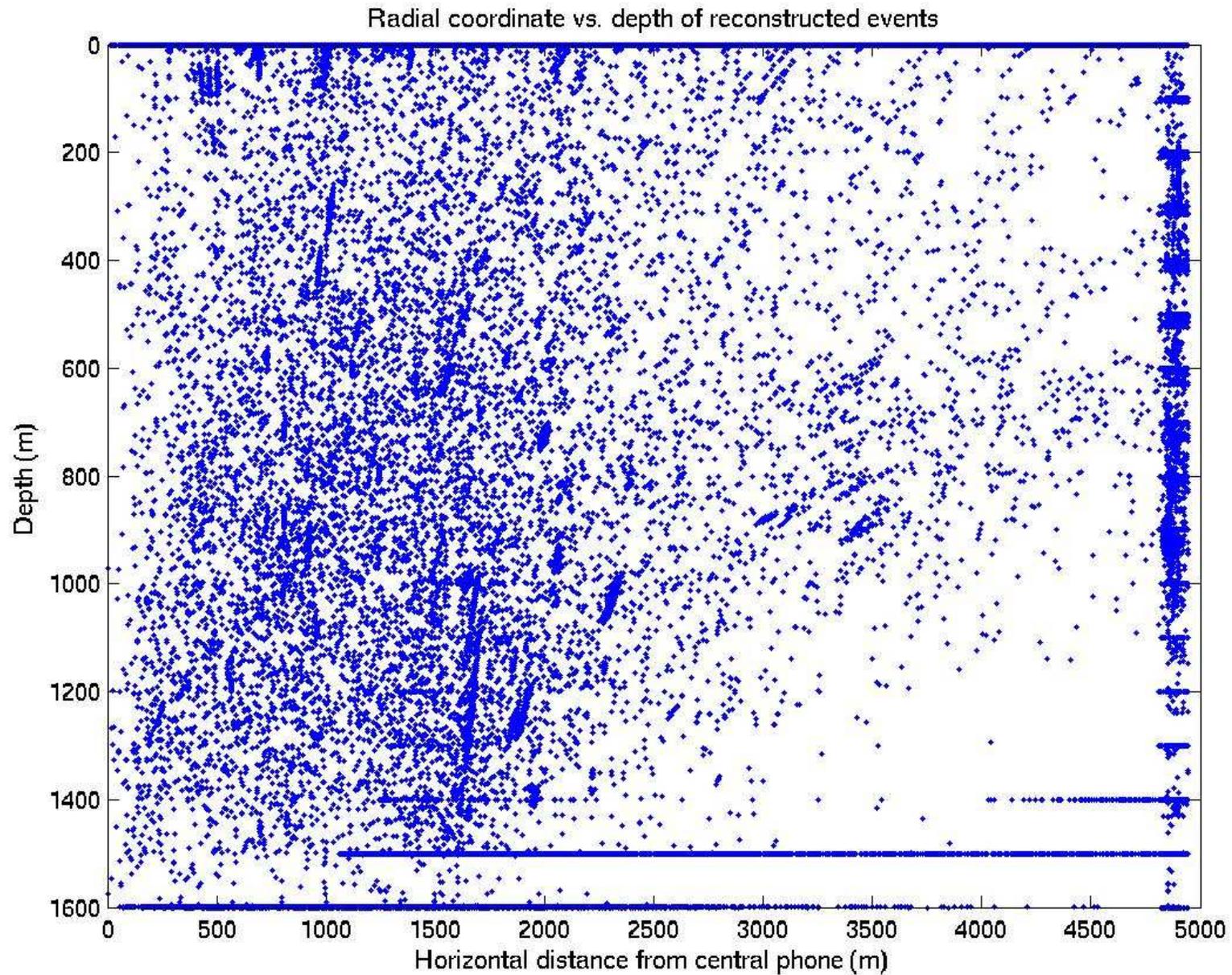
Localization → energy reconstruction

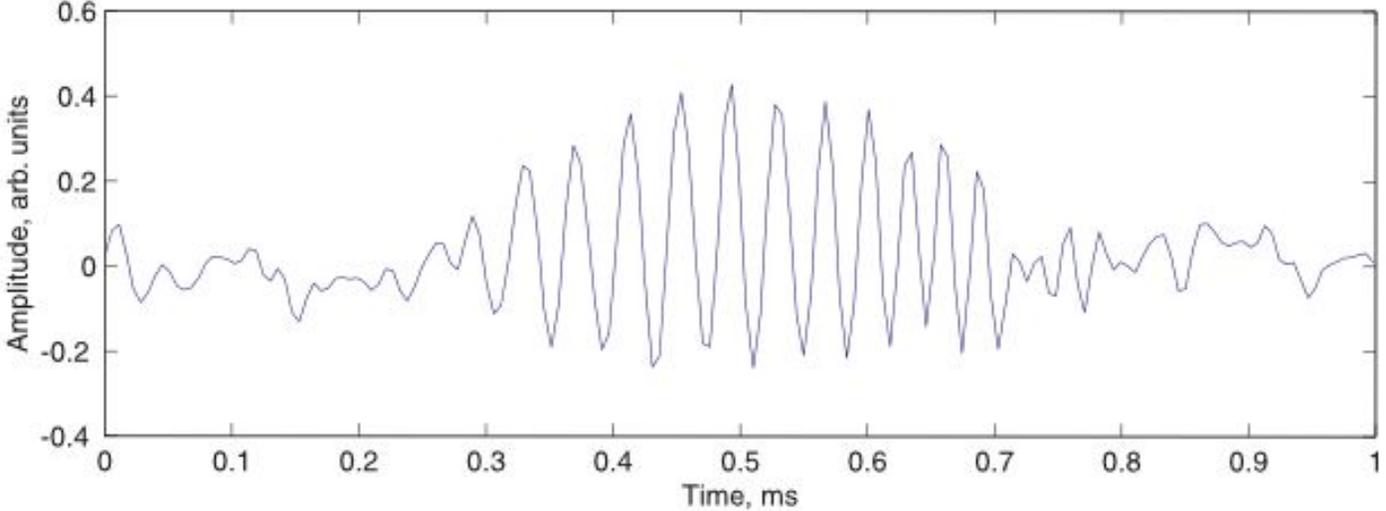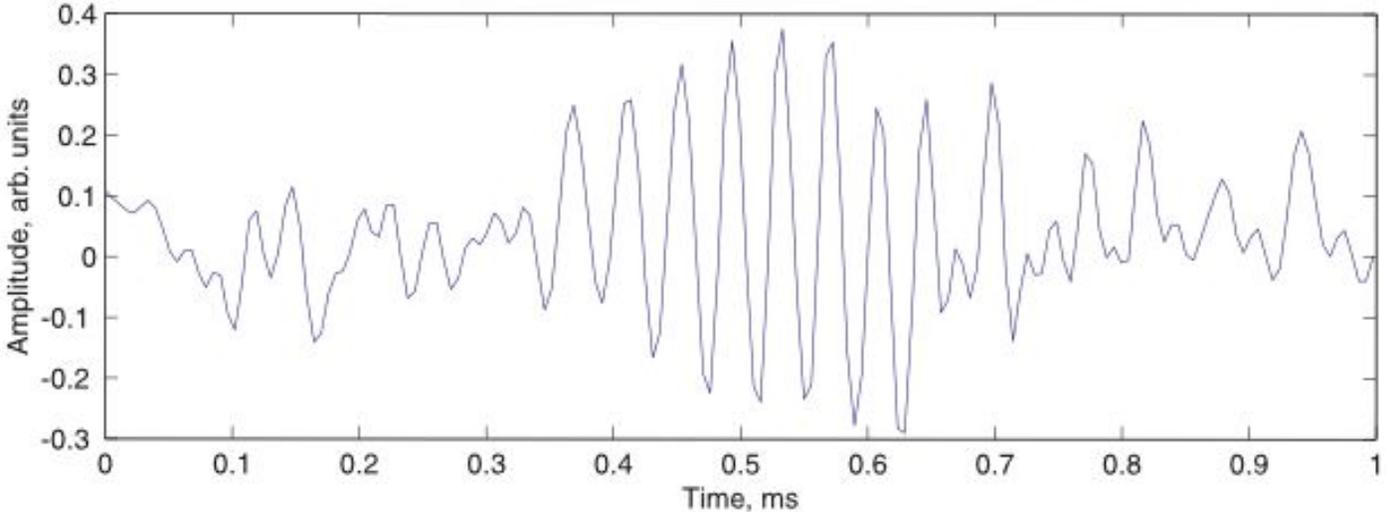Distribution of reconstructed event energies
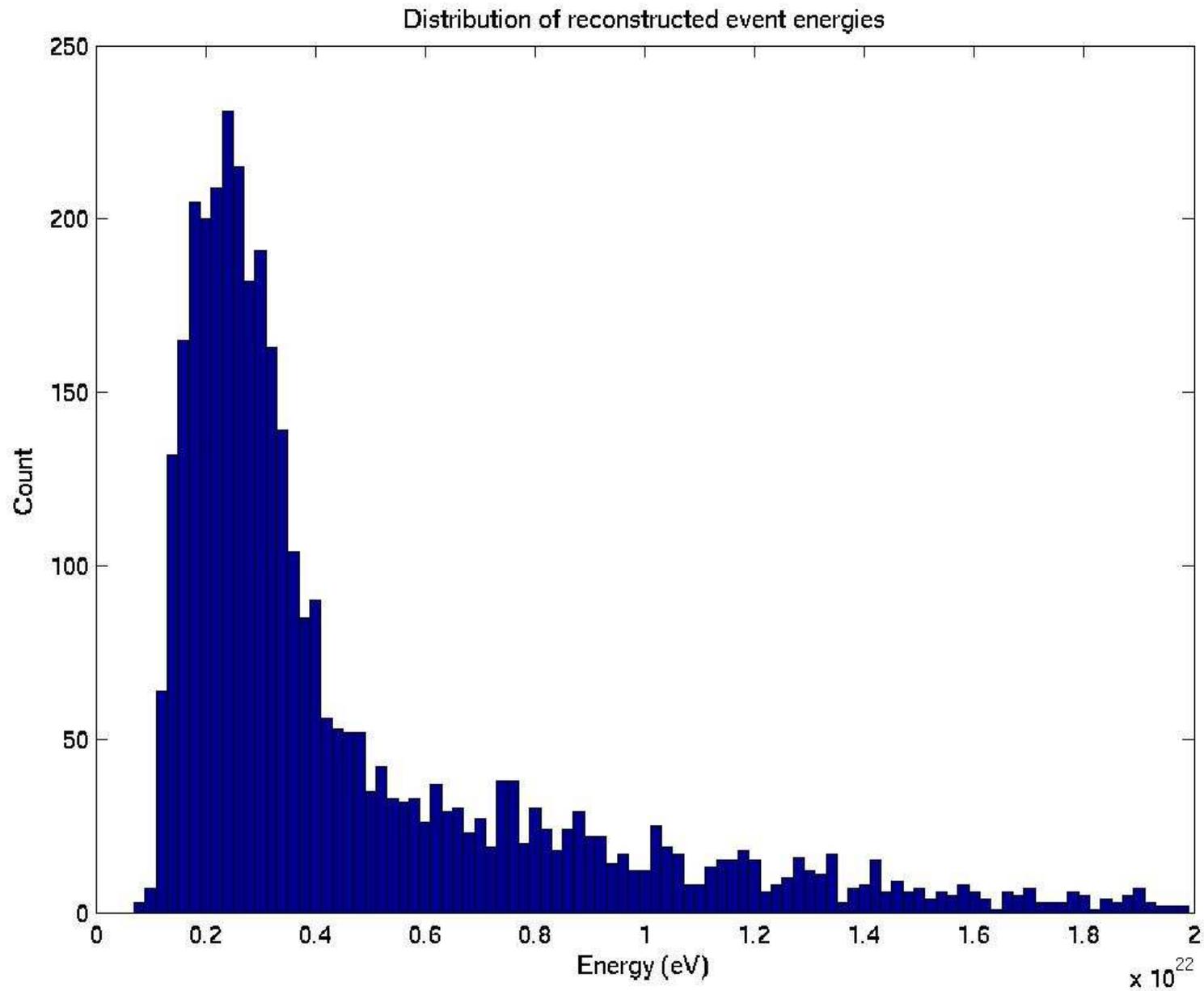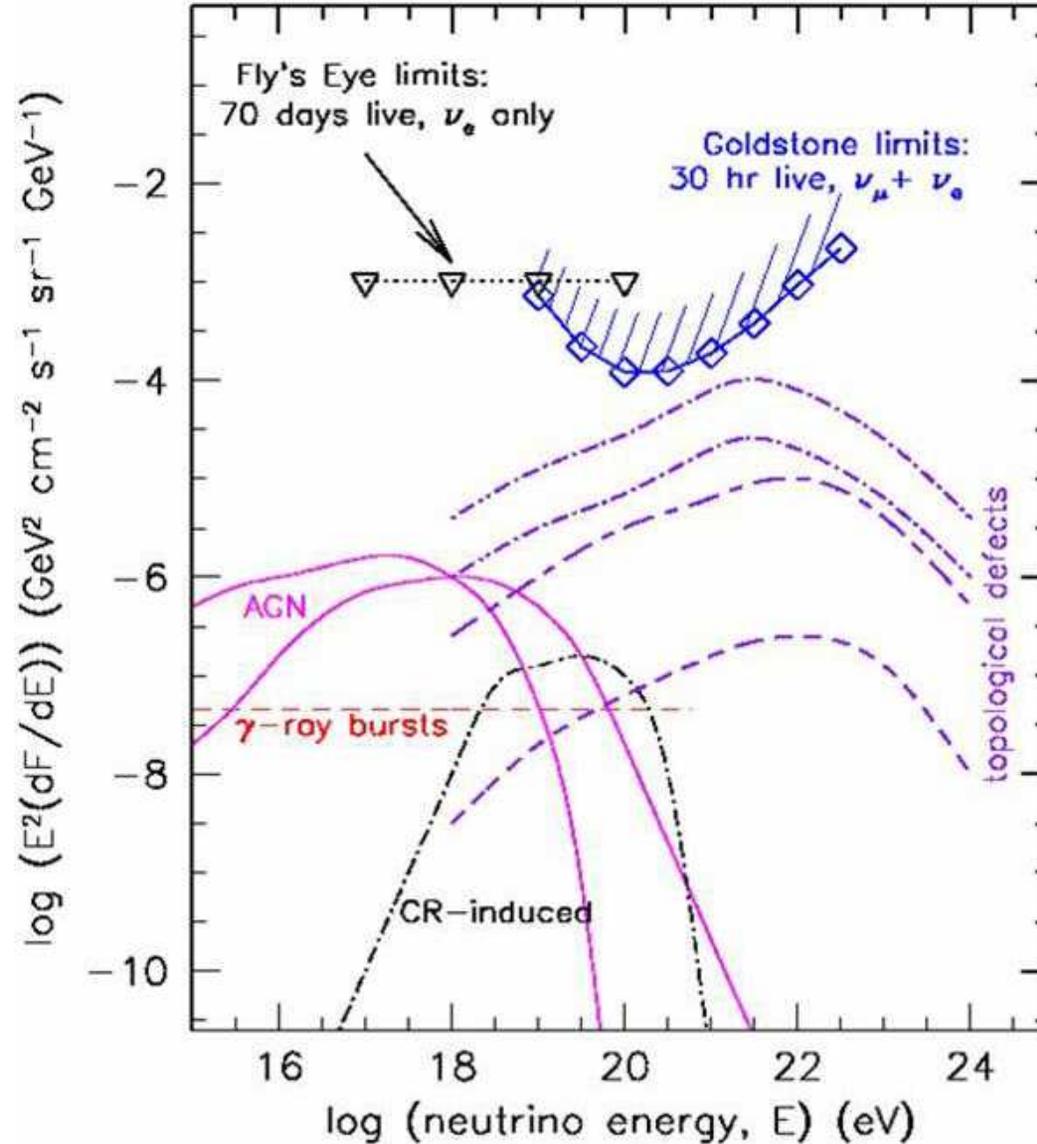
Example of a five-phone event
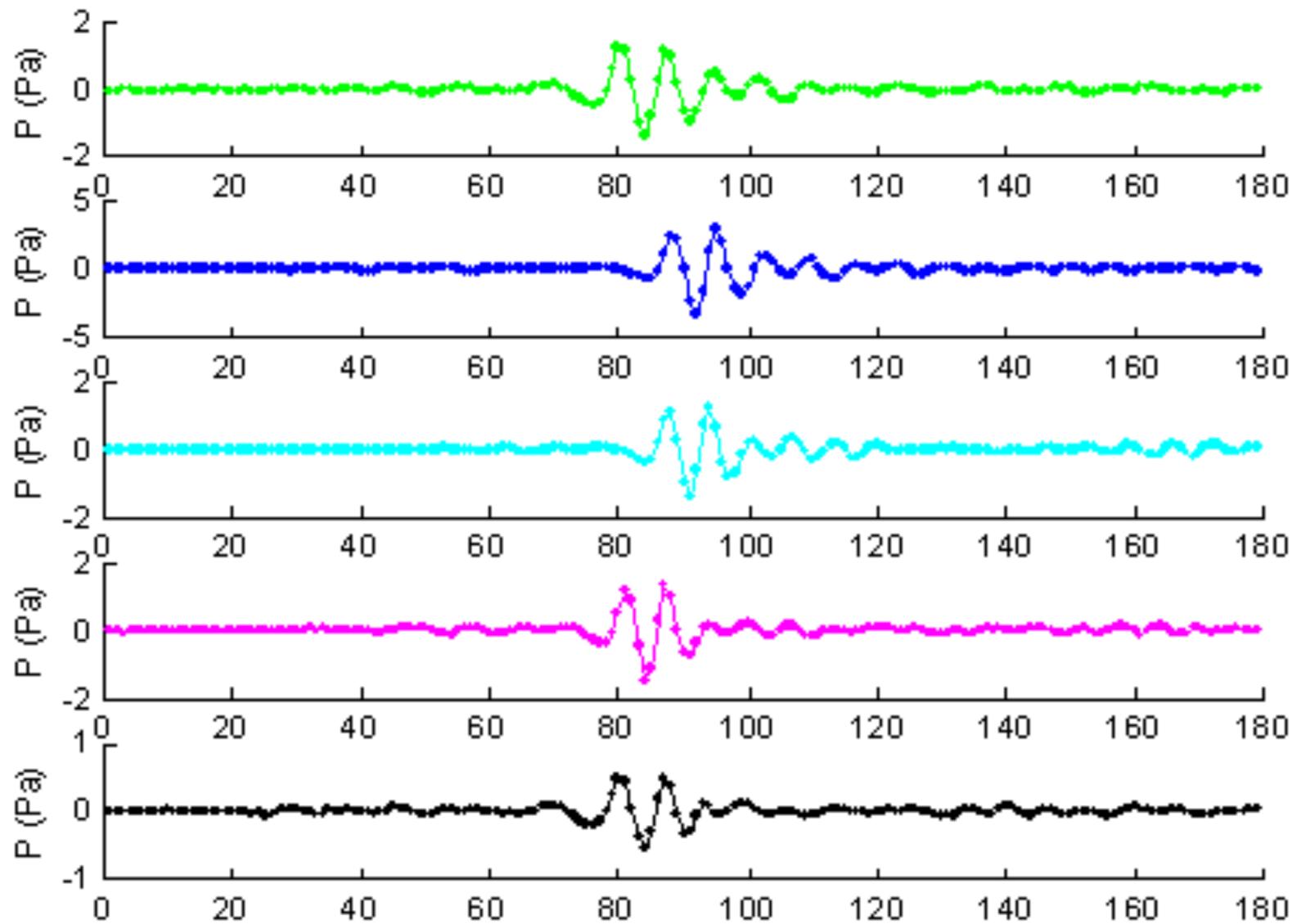
Example of a five-phone event
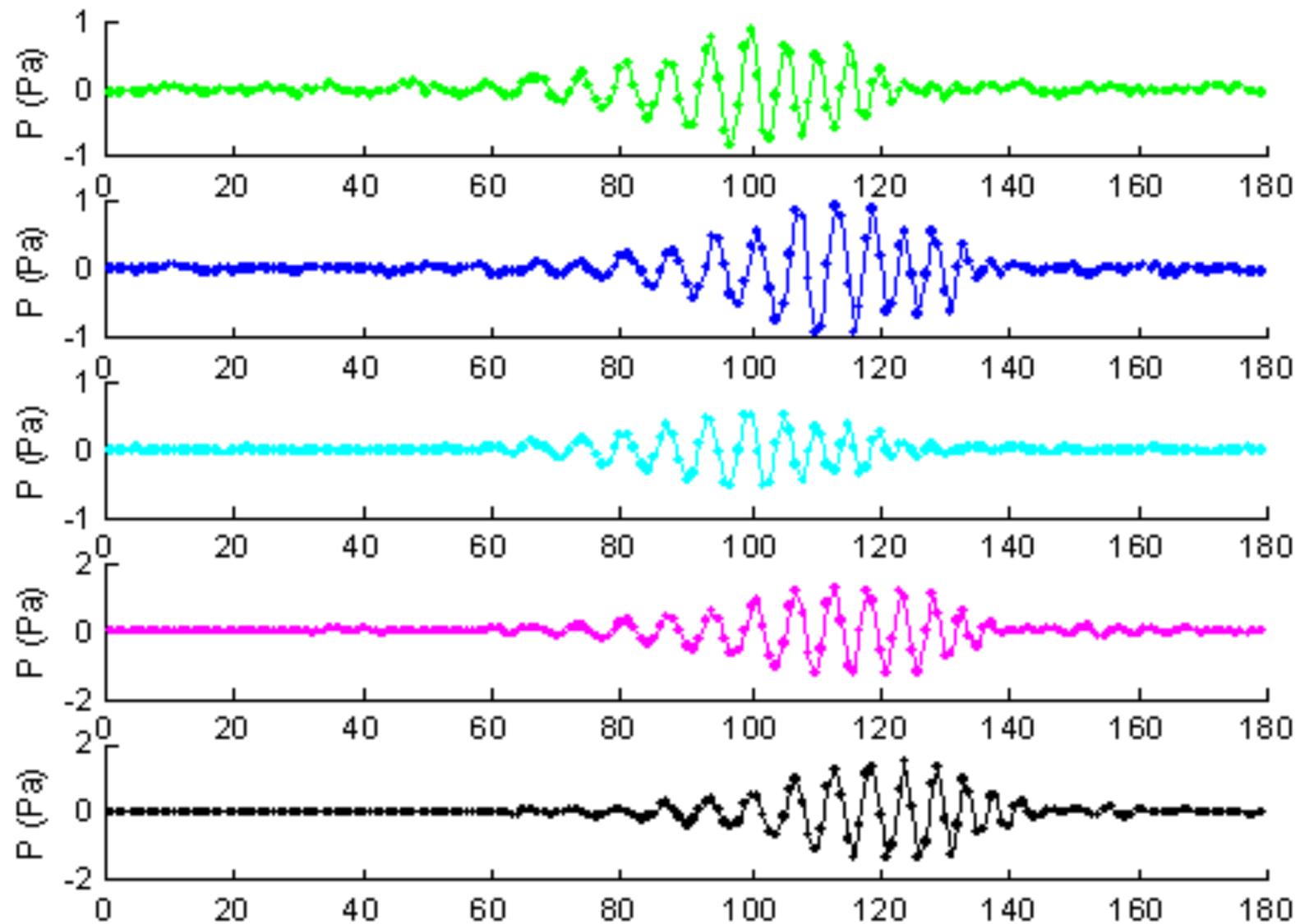
Examples of dolphin signals recorded by AUTEC personnel

Neutrino flux limits

...SAUND limits coming soon

Conclusions

What we have learned

Refraction significant > 1 km

$c_{sound} = c_{light} / 200{,}000$!!

(Distinguishable) backgrounds exist

~10^{21} eV threshold (1.5 km array spacing)

What is next

Efficiency checks

Flux limits

Onward and downward (SAUND-II)

On to more phones, collecting area (250 km^2), computing

Down to the Gaussian floor

Thanks to my SAUND collaborators:

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M. Buckingham (Scripps)

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J. Vandenbroucke (Stanford, now at Berkeley)

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More information:

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