Results from a Study of Acoustic Ultrahigh-energy Neutrino Detection (SAUND)

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

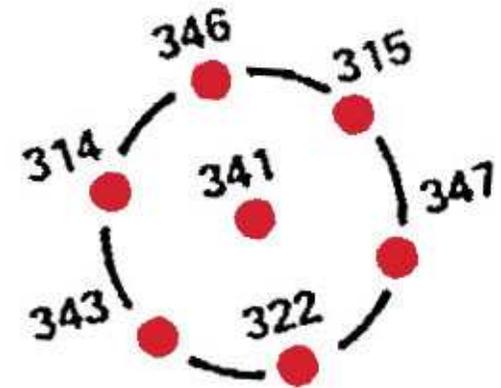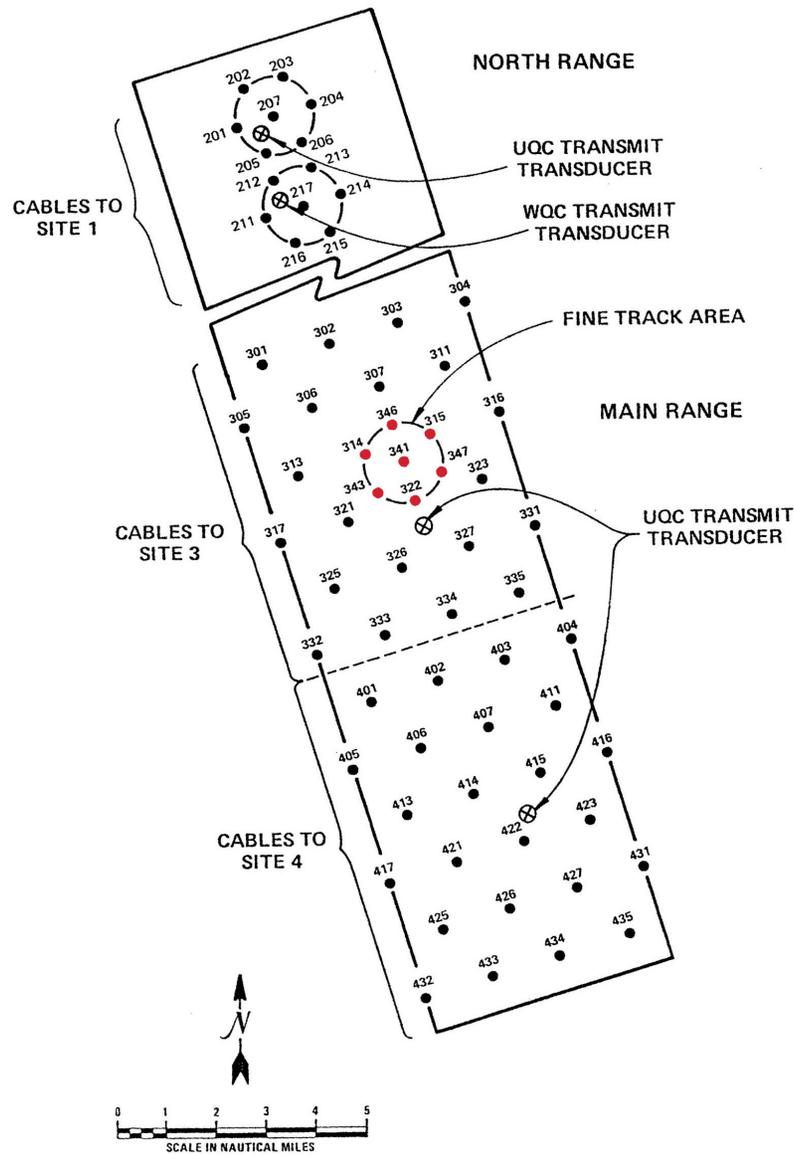## Justin Vandenbroucke

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September 13, 2003
Stanford University
Workshop on Acoustic Cosmic Ray and Neutrino Detection

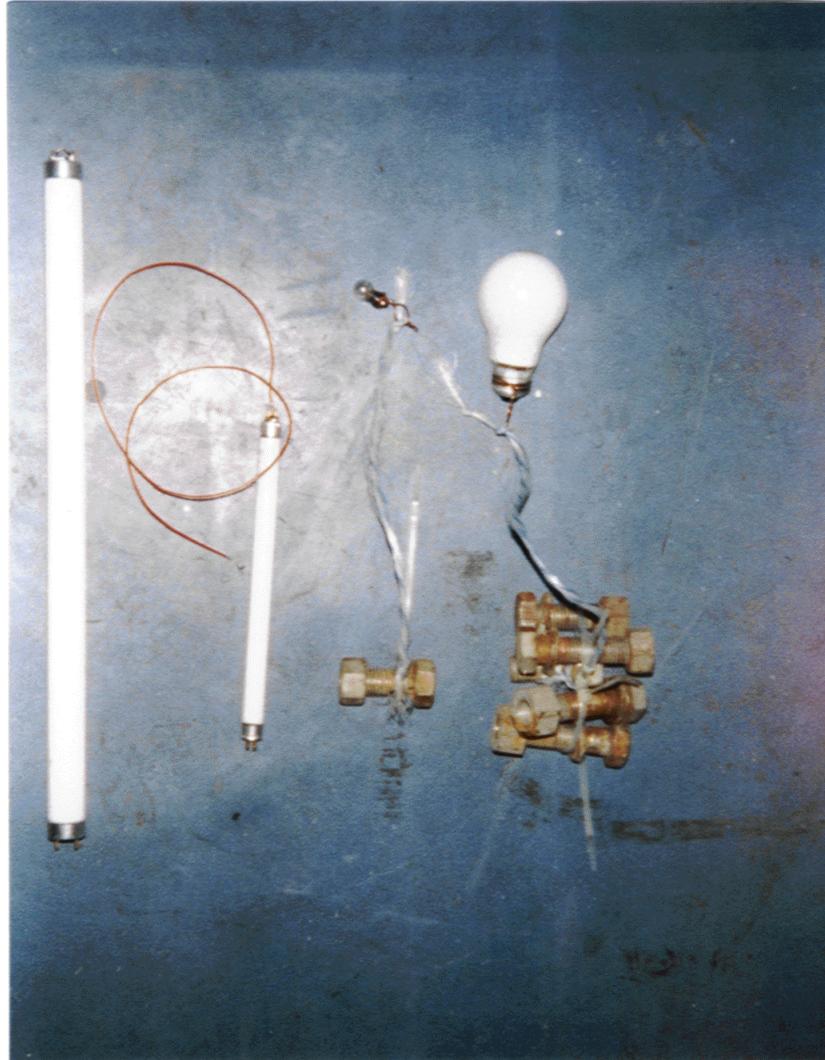# Andros Island, The Bahamas

AUTEC hydrophone array

NORTH RANGE

UQC TRANSMIT TRANSDUCER

WQC TRANSMIT TRANSDUCER

CABLES TO SITE 1

FINE TRACK AREA

MAIN RANGE

UQC TRANSMIT TRANSDUCER

CABLES TO SITE 3
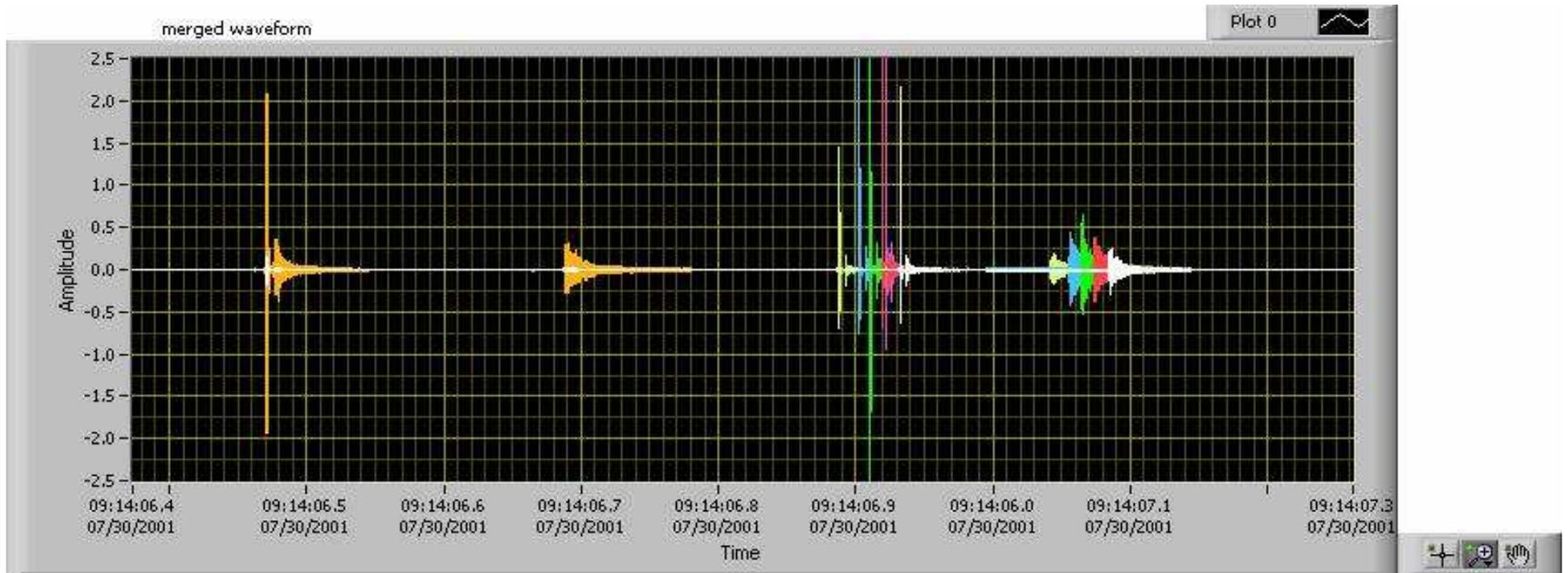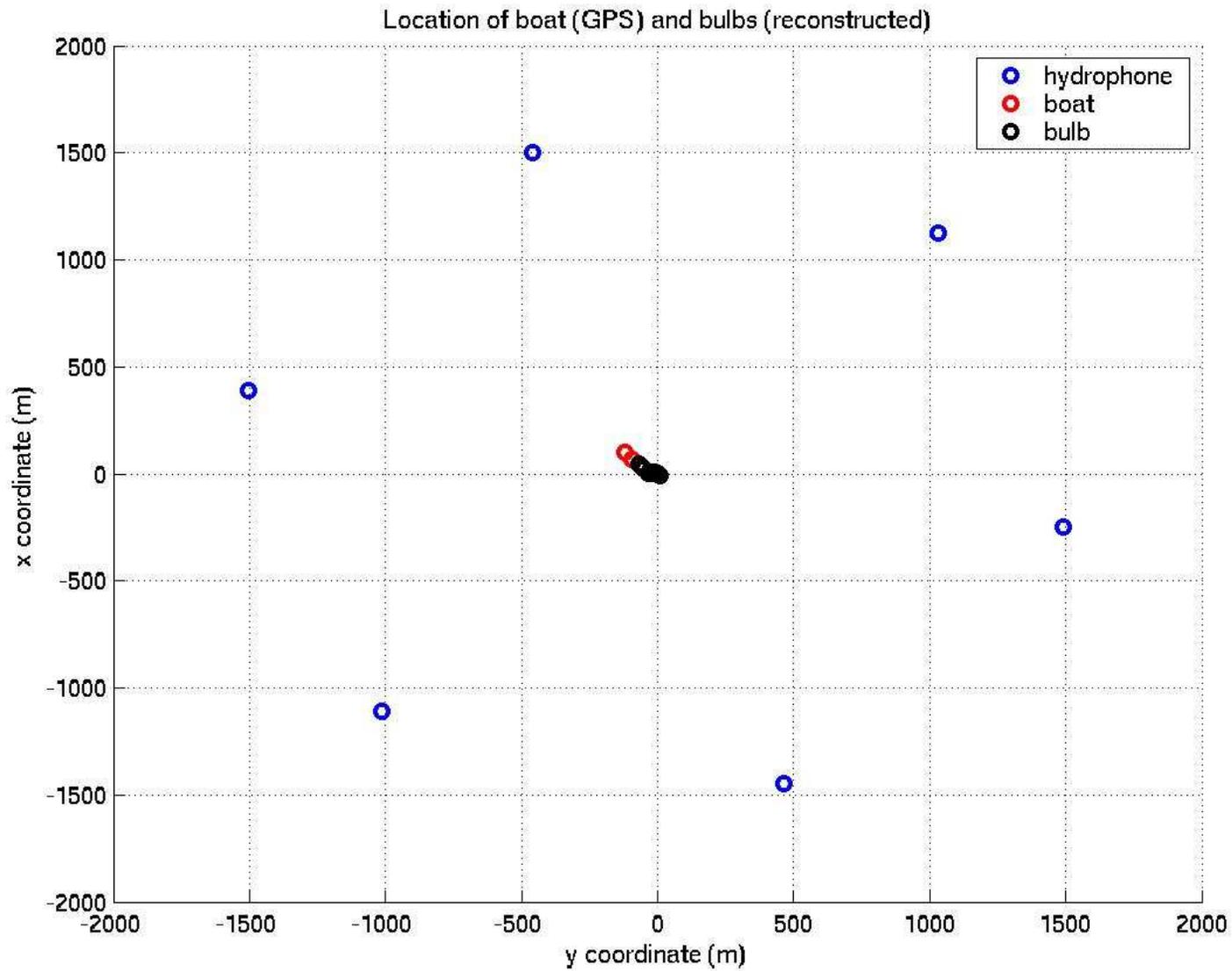
CABLES TO SITE 4

SCALE IN NAUTICAL MILES

SAUND

Site 3

Site 3

DAQ system

Calibration sources

21 Events per lightbulb

merged waveform

Plot 0

Light bulb positions and energies reconstructed

Location of boat (GPS) and bulbs (reconstructed)

Light bulb positions and energies reconstructed

Location of boat (GPS) and bulbs (reconstructed)
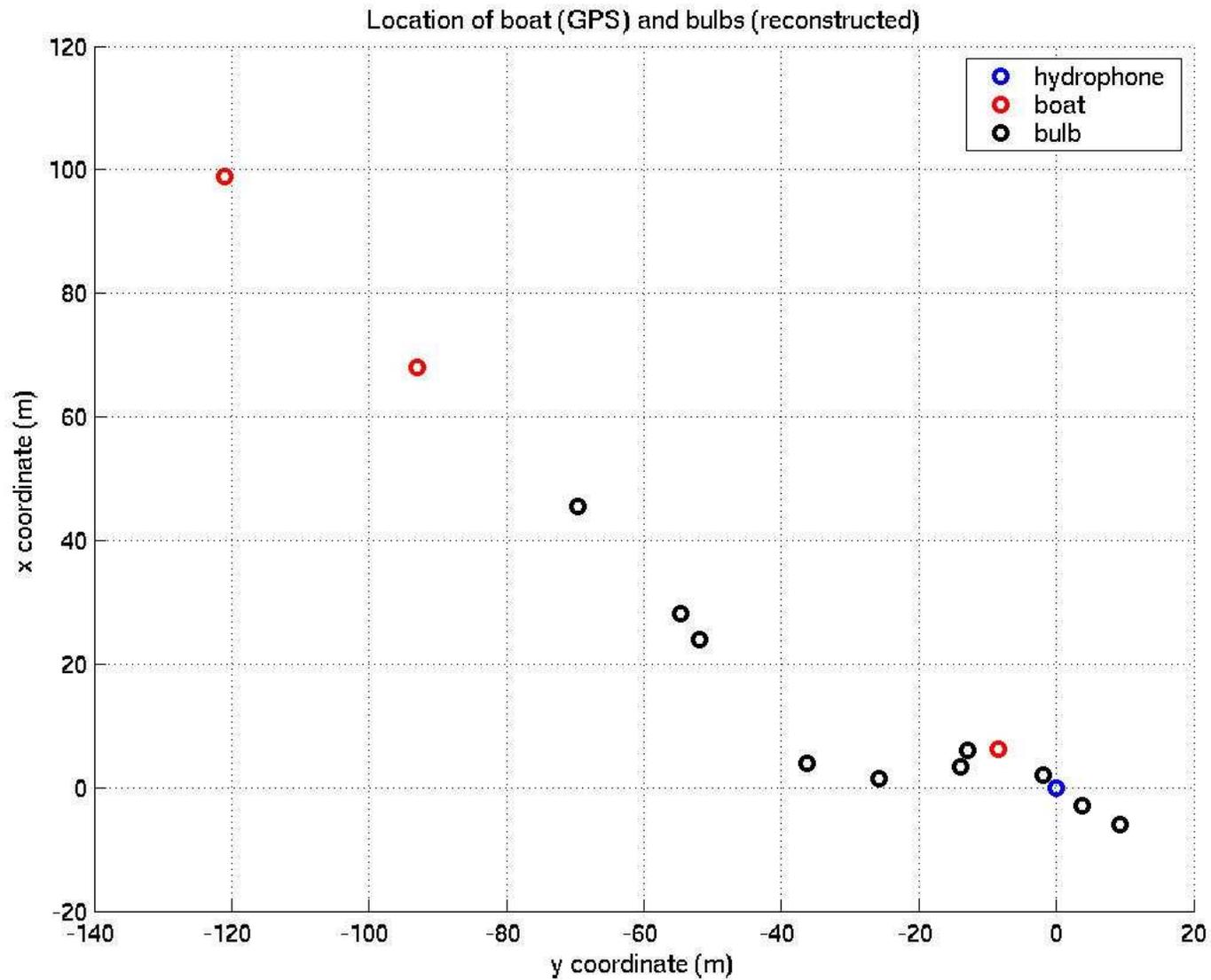
Detection contours under typical noise conditions

Detection volume contours, from 5e+20 eV to 3e+21 eV, contour interval 5e+20 eV
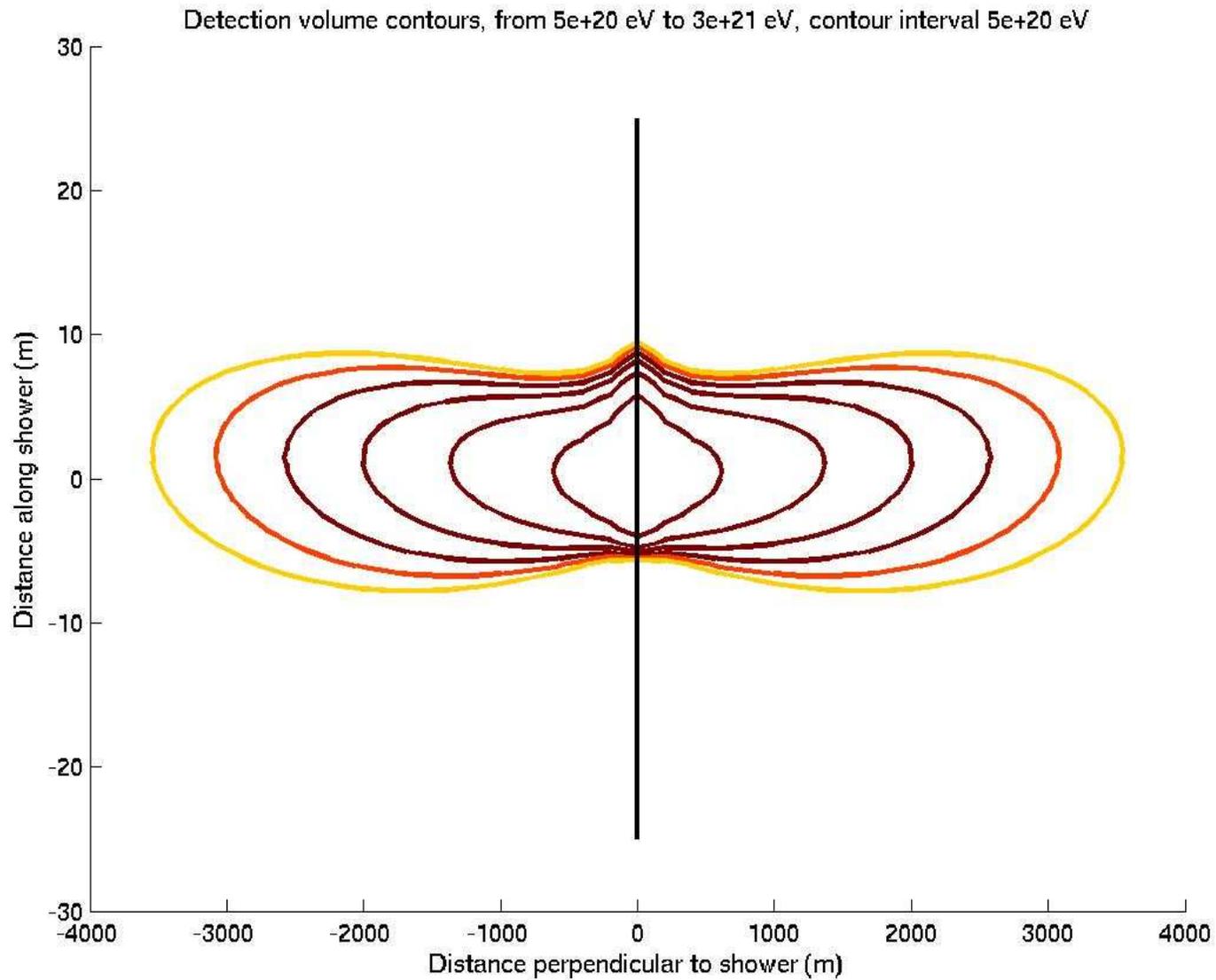
Detection contours under typical noise conditions
(zoomed in)
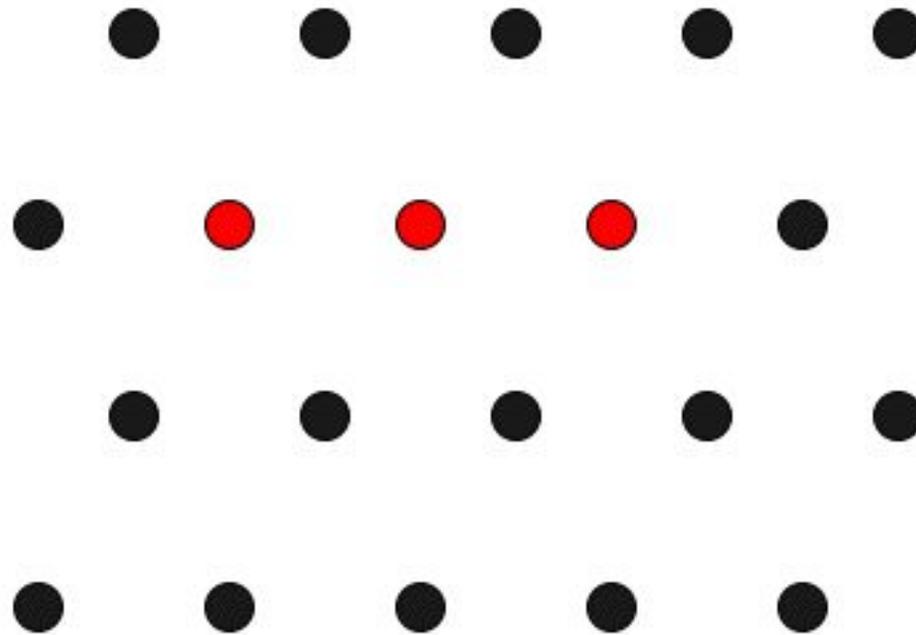
Detection volume contours, from 5e+20 eV to 3e+21 eV, contour interval 5e+20 eV

Pancakes can be good

AUTEC SVP
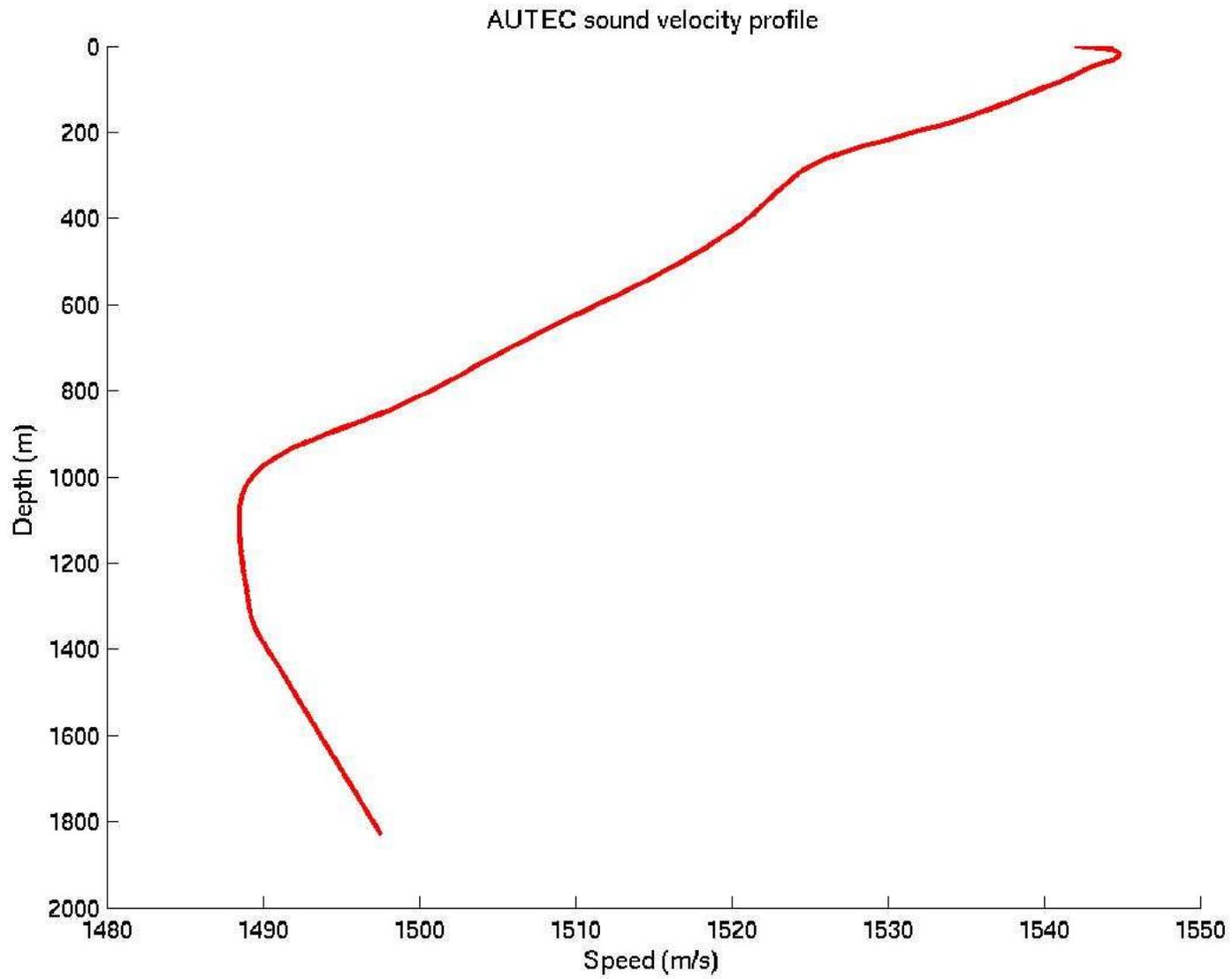
AUTEC sound velocity profile

Refraction is significant beyond 1 km

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

Legend:
— unrefracted ray
— refracted ray

Depth (m) / Range (km)

Refraction is significant beyond 1 km

Ray trace with source at 1600 m depth, for initial angle 0-30 degrees from horizontal
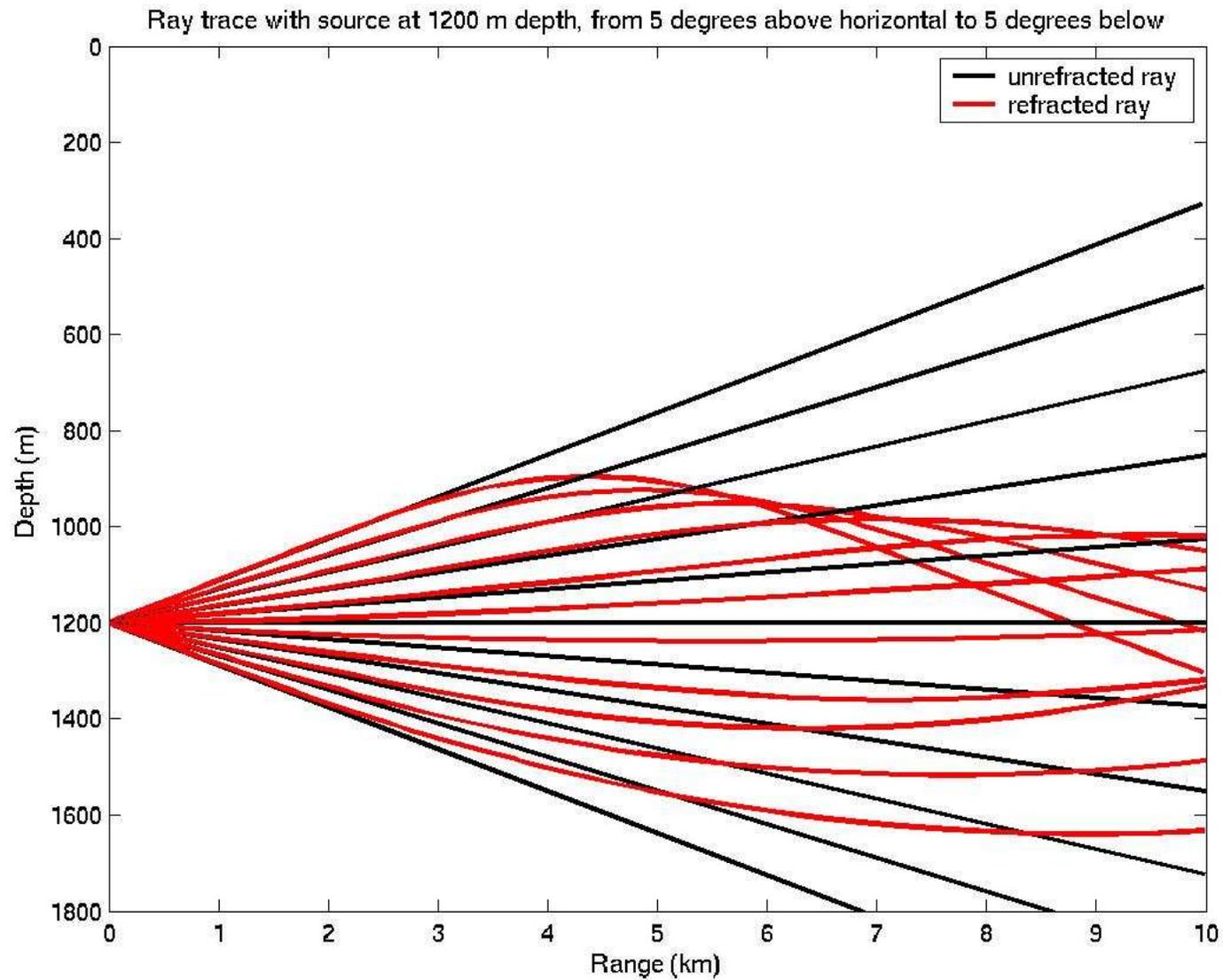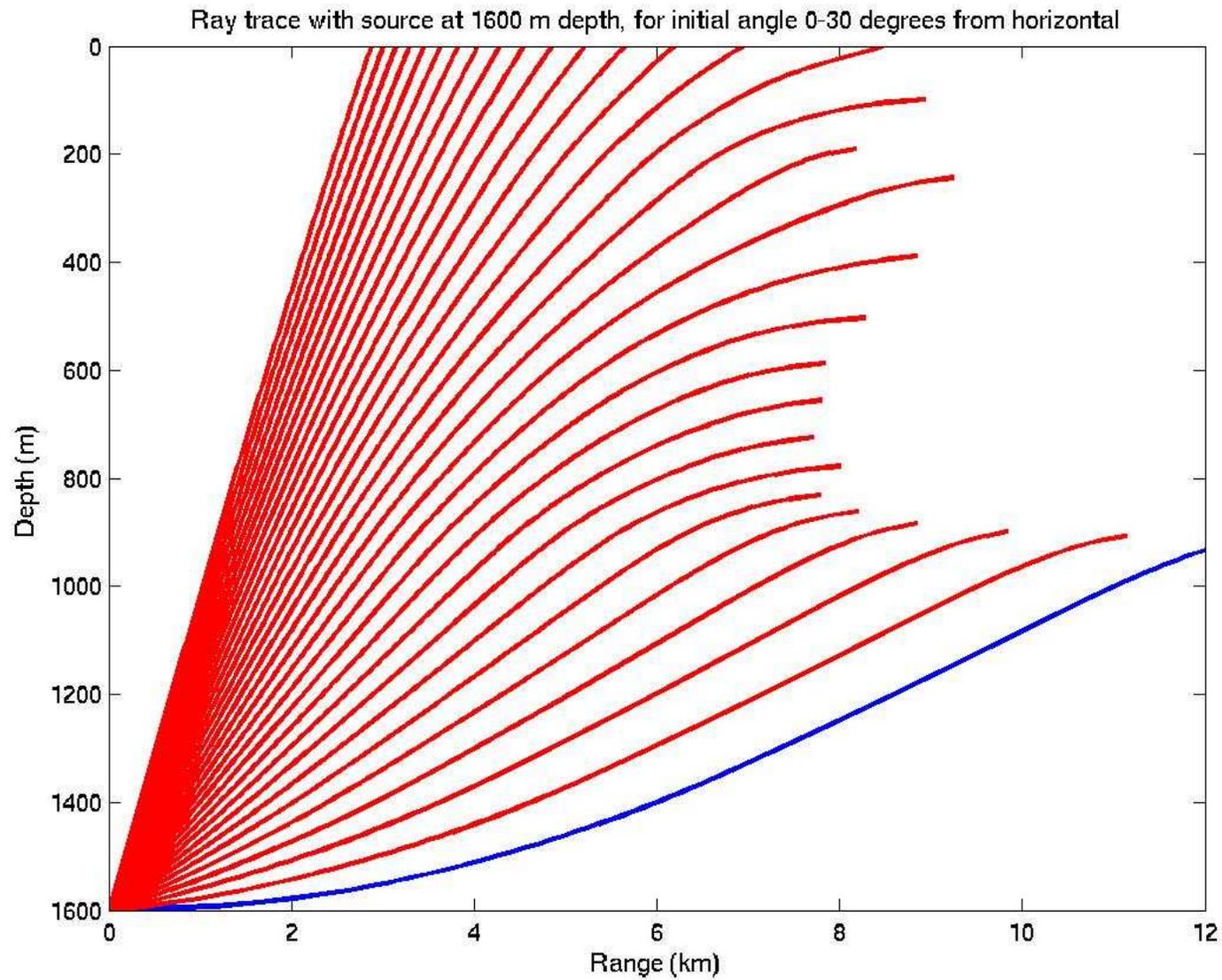
Refracted pancake (undetected)
300 m deflection!

Refracted acoustic radiation disk cross section for a 1e+21 eV neutrino at zenith 0 deg

Legend:
- o hydrophone
- unrefracted pancake
- refracted pancake
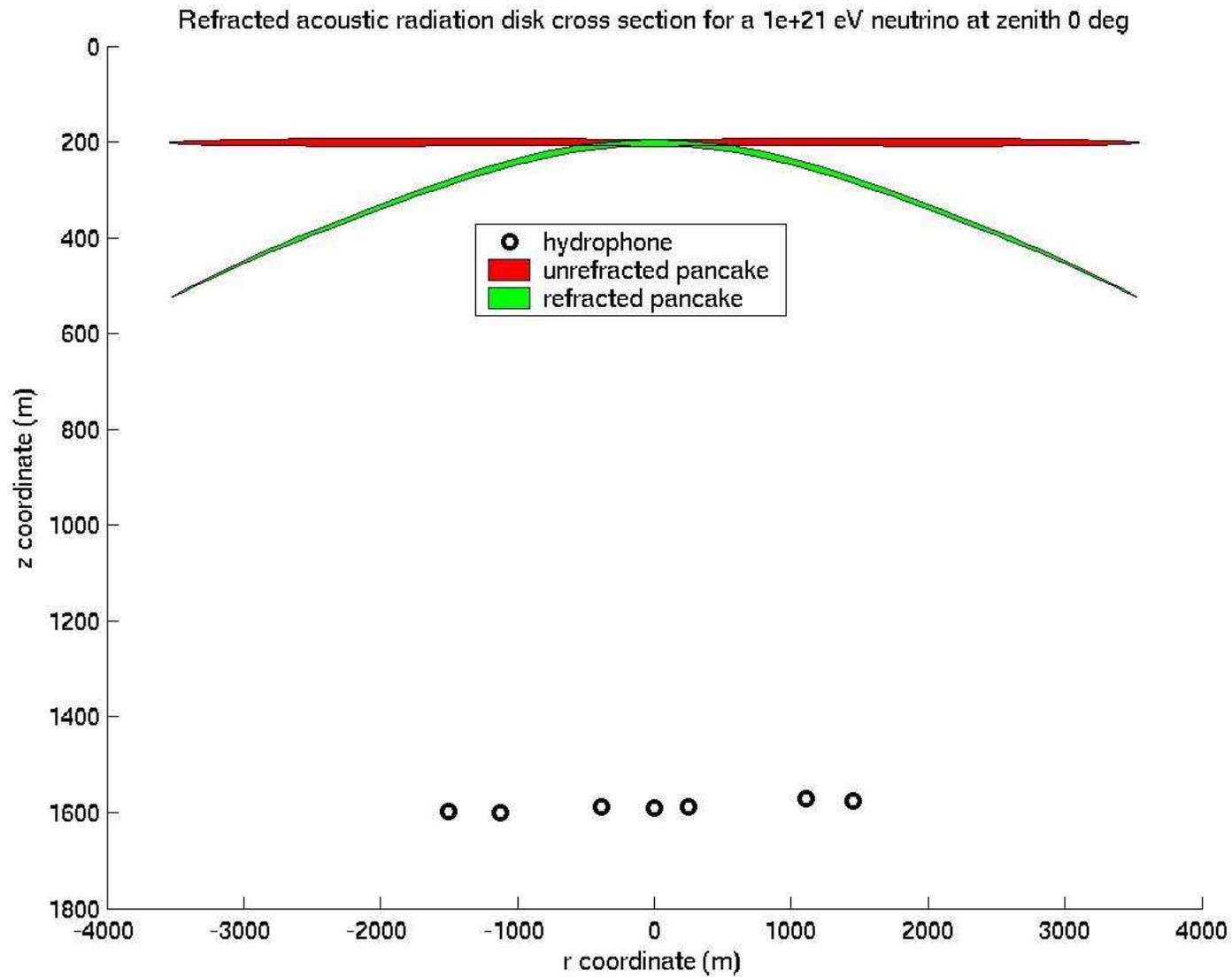
Refracted pancake (detected)
100 m deflection

Refracted acoustic radiation disk cross section for a 1e+21 eV neutrino at zenith 0.5 deg

Legend:
- ○ hydrophone
- unrefracted pancake
- refracted pancake

z coordinate (m) — r coordinate (m)

Localization achieved

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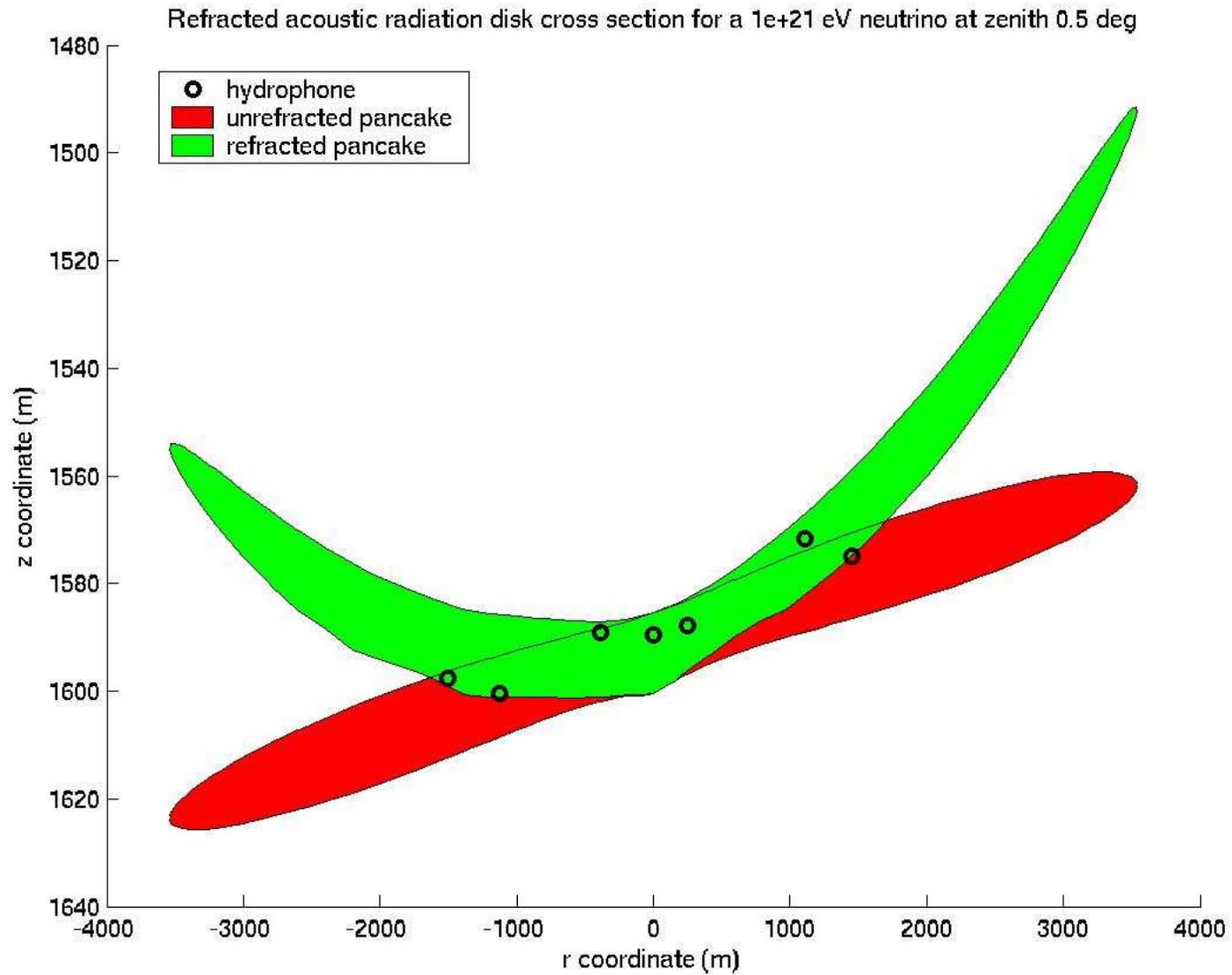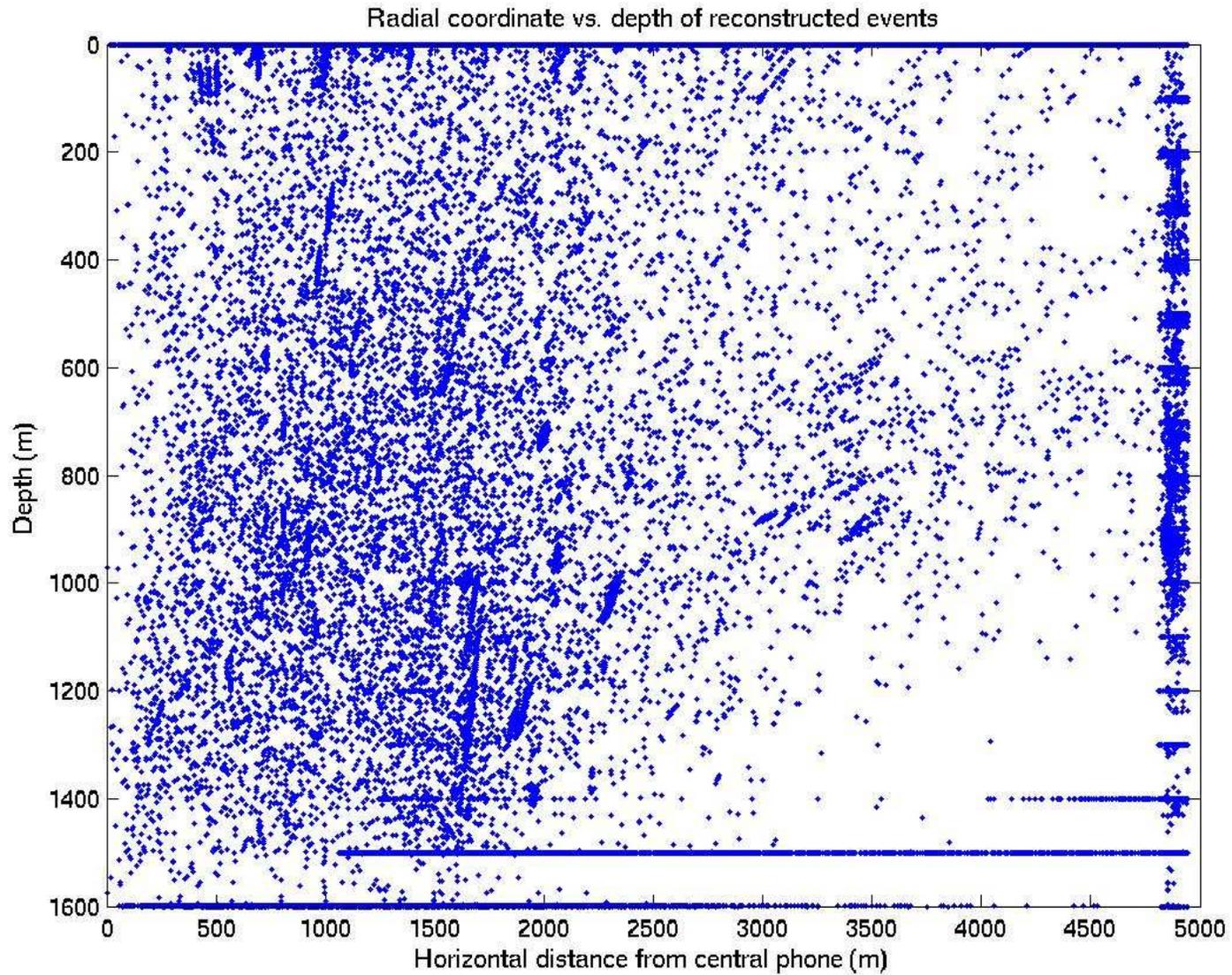
Localization → energy reconstruction

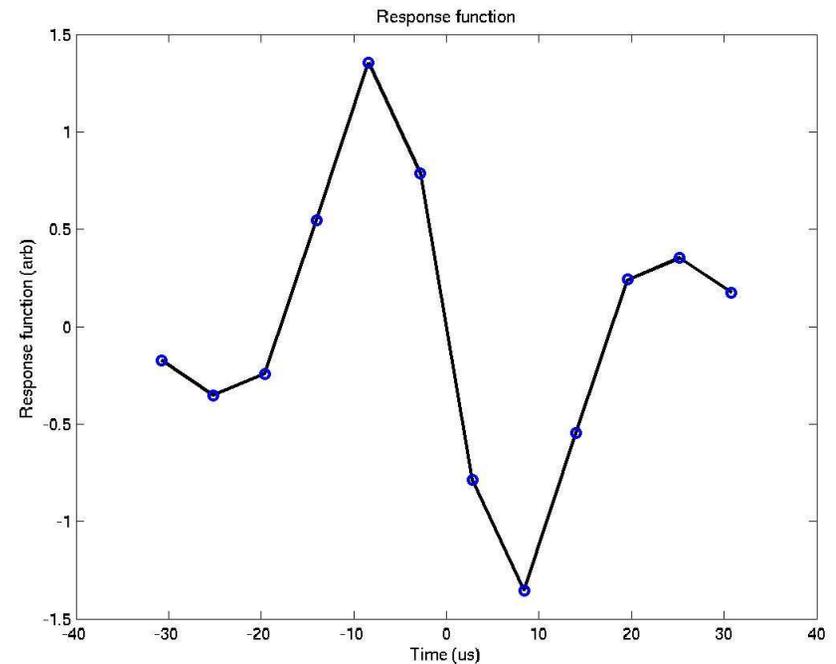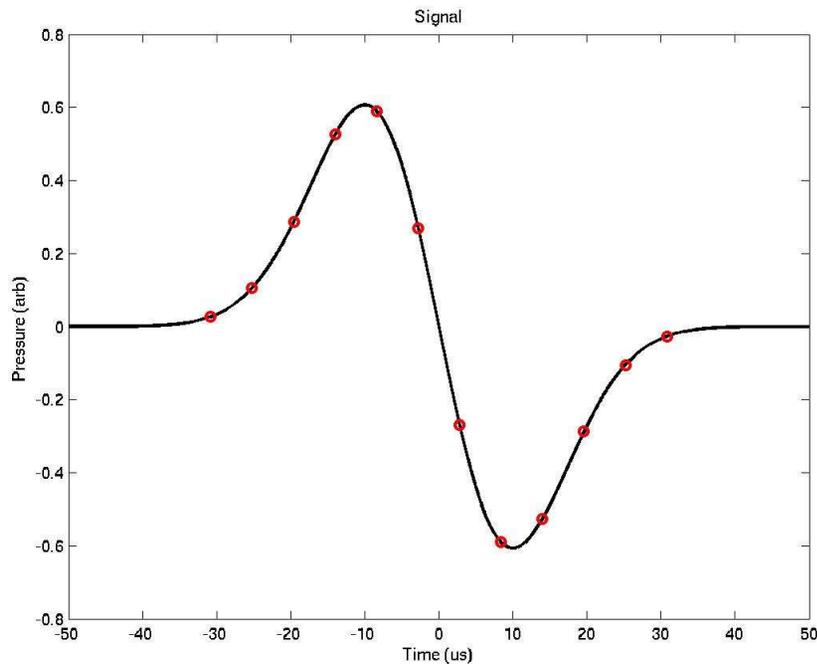Distribution of reconstructed event energies
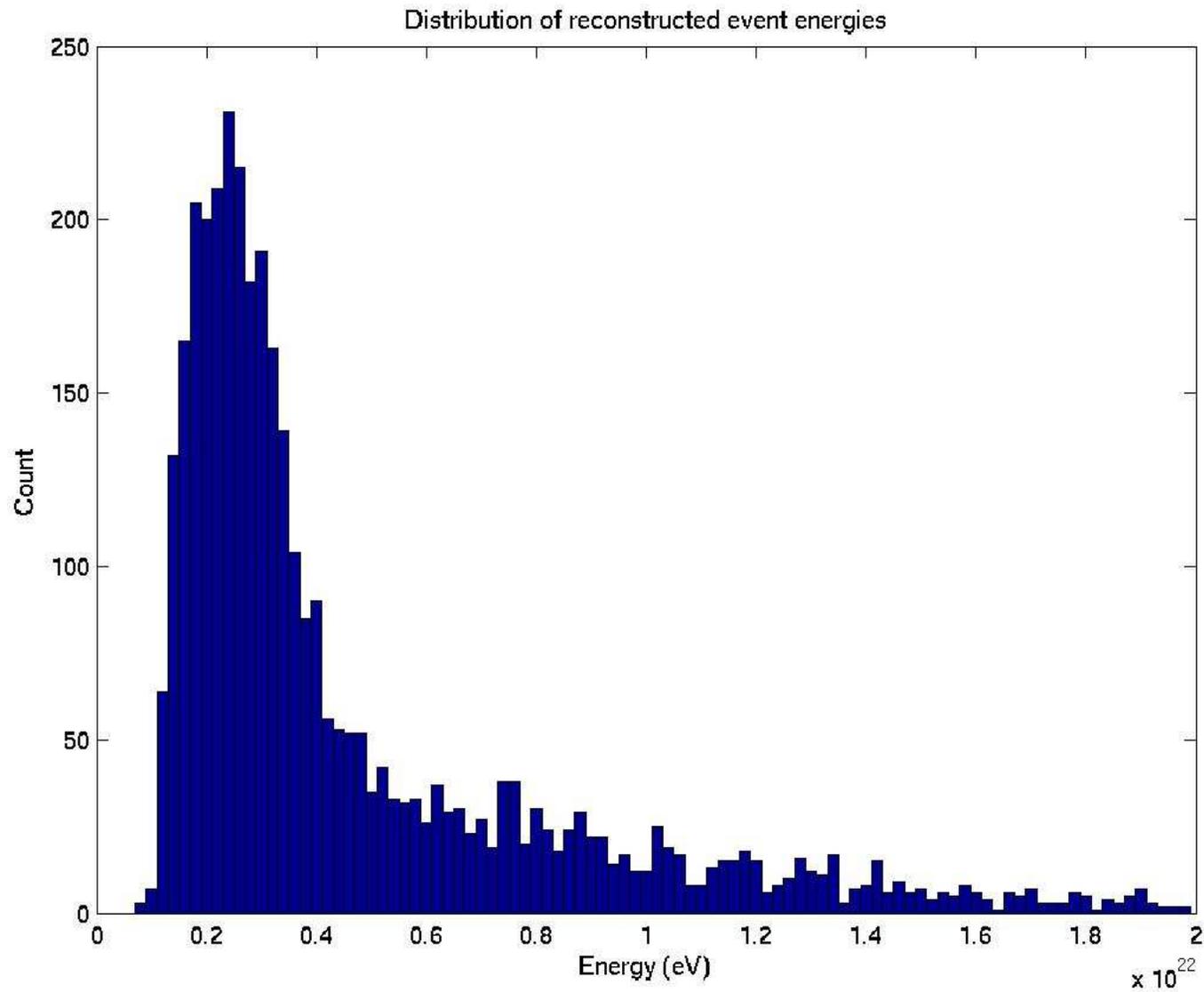
Cut 1: Digital Filter

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

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

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

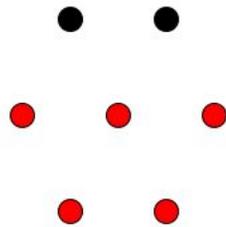$$\tau = 10\ \mu s$$

Cut 3: Five-phone coincidence

Require

1) Events obey causality:
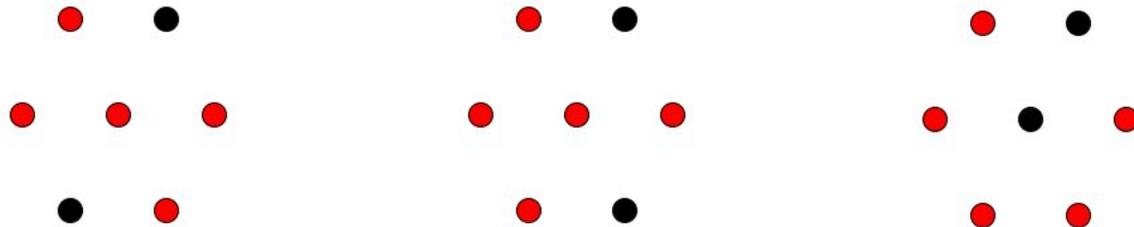   Pairwise, times are within coincidence window: $t_{ij} < c * d_{ij}$

2) Geometry consistent with pancake (2D circle) shape:
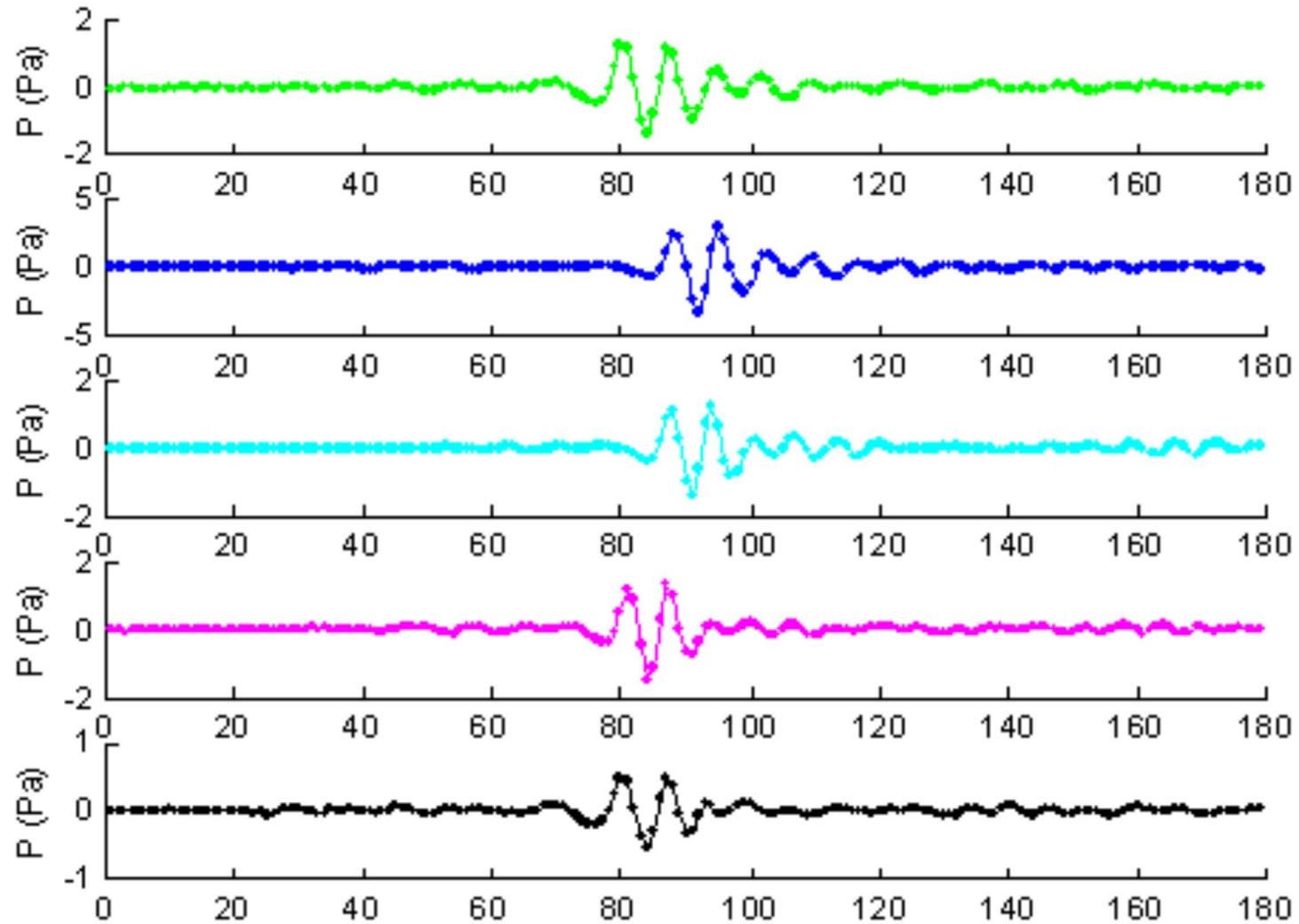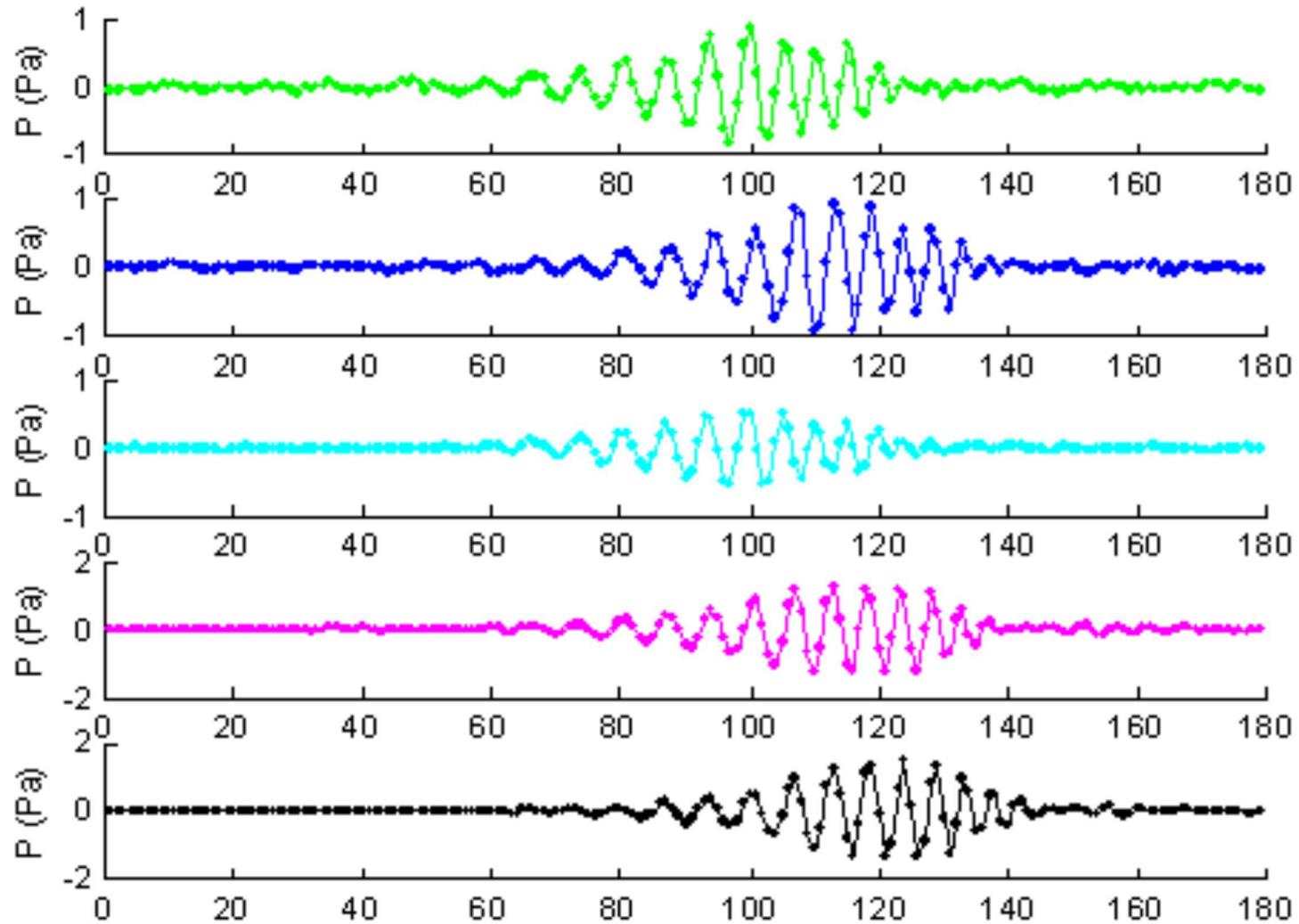
Example of a five-phone event

Example of a five-phone event

Cuts 4a and 4b: Characteristic Frequency and Number of Periods

Stanford University   Justin Vandenbroucke   September 13, 2003
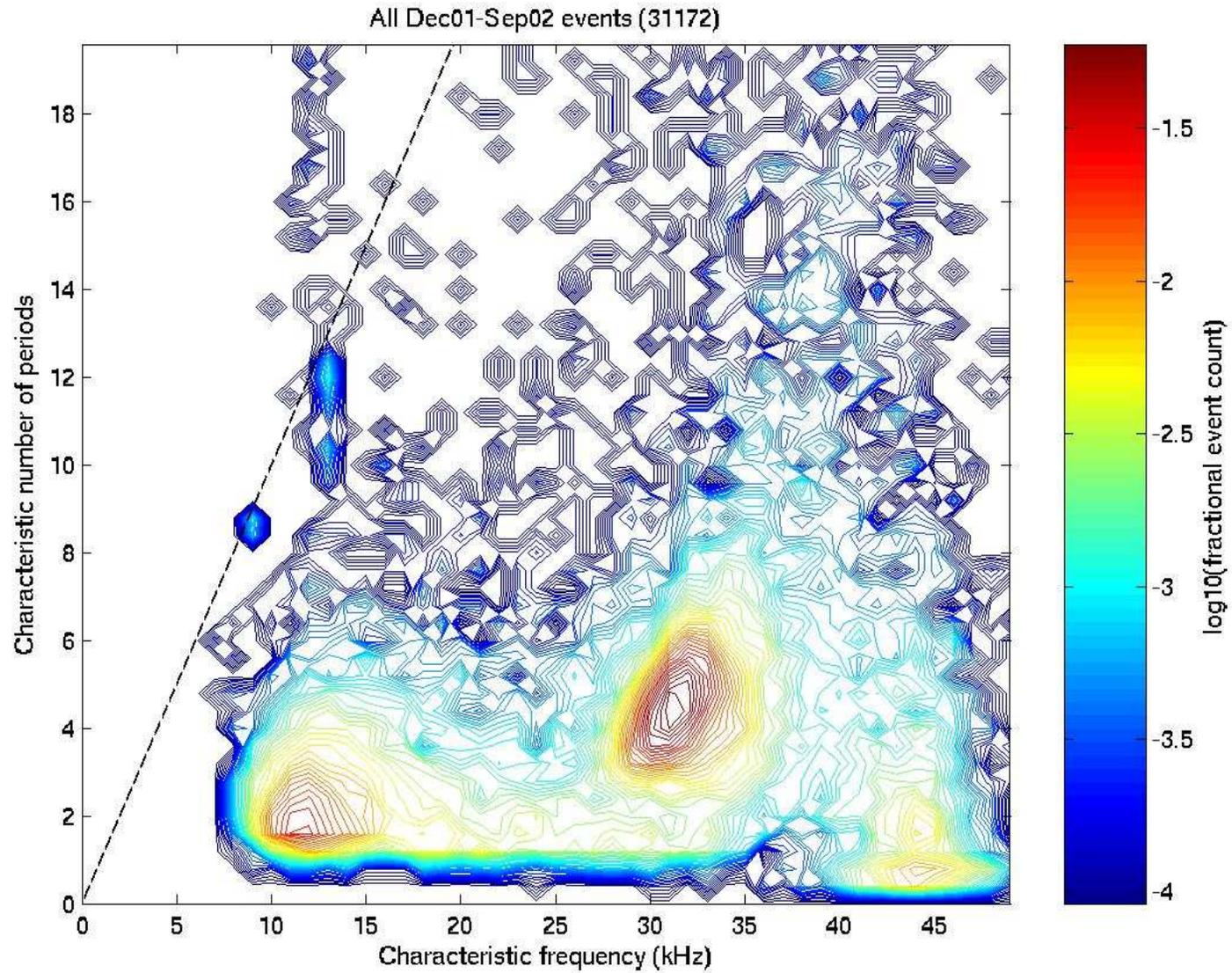
Cut 4c: Diamond Events
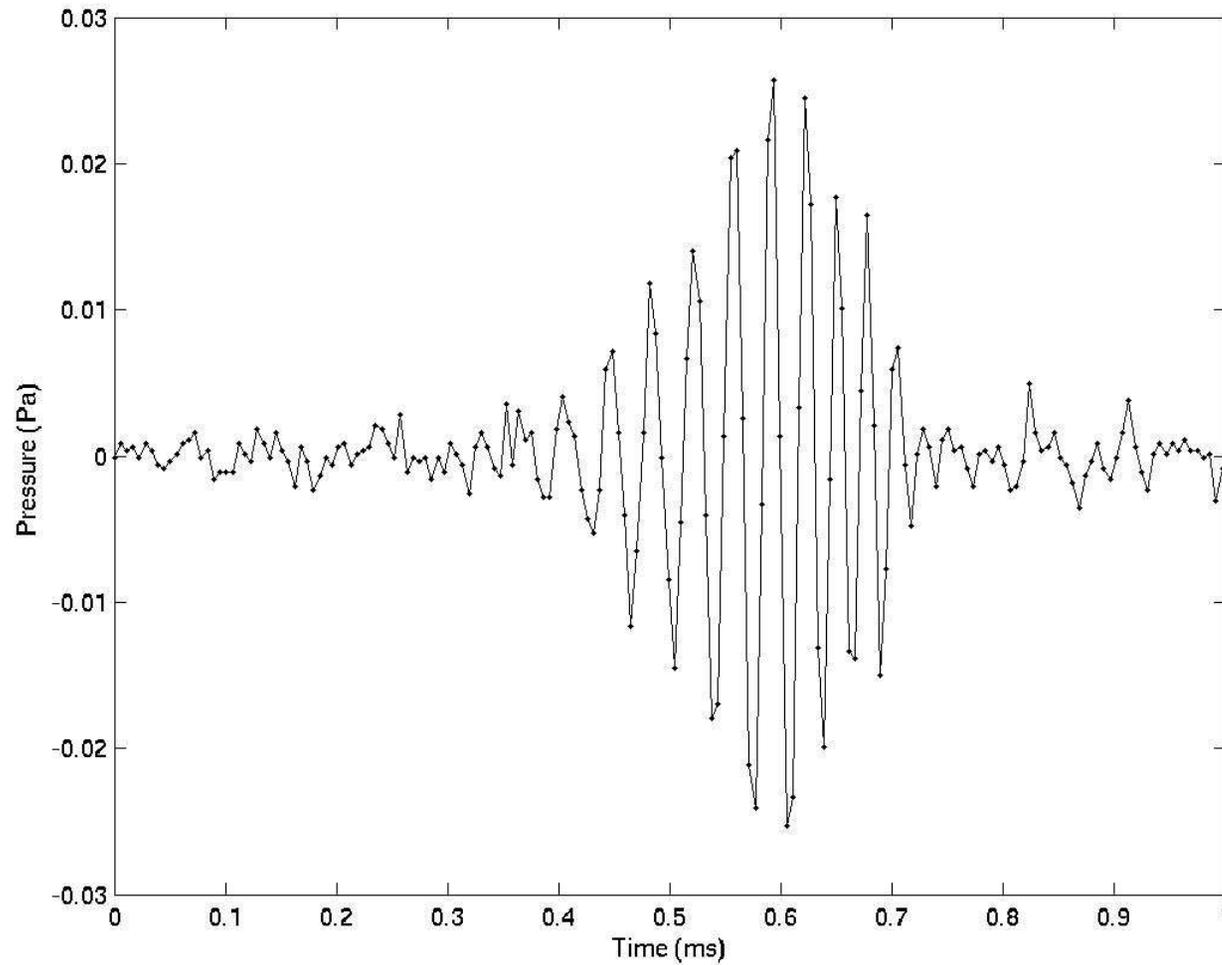
frequent but easily rejected with a matched filter (online?)

Examples of dolphin signals recorded by AUTEC personnel

Cut 5: Adaptive threshold

Livetime at each threshold (total: 122 days)
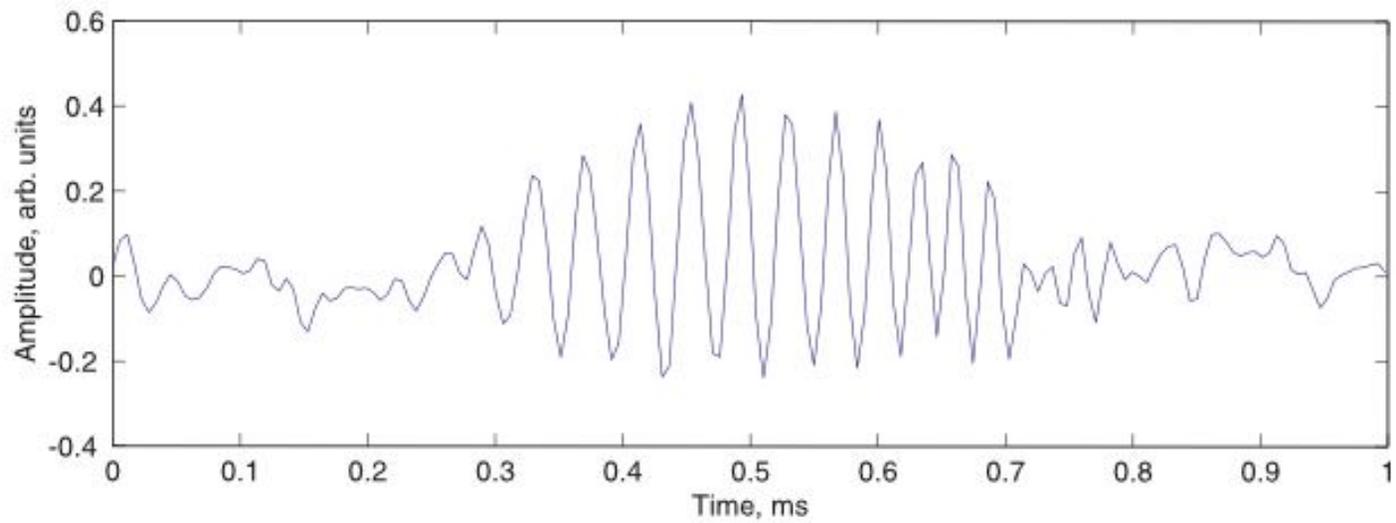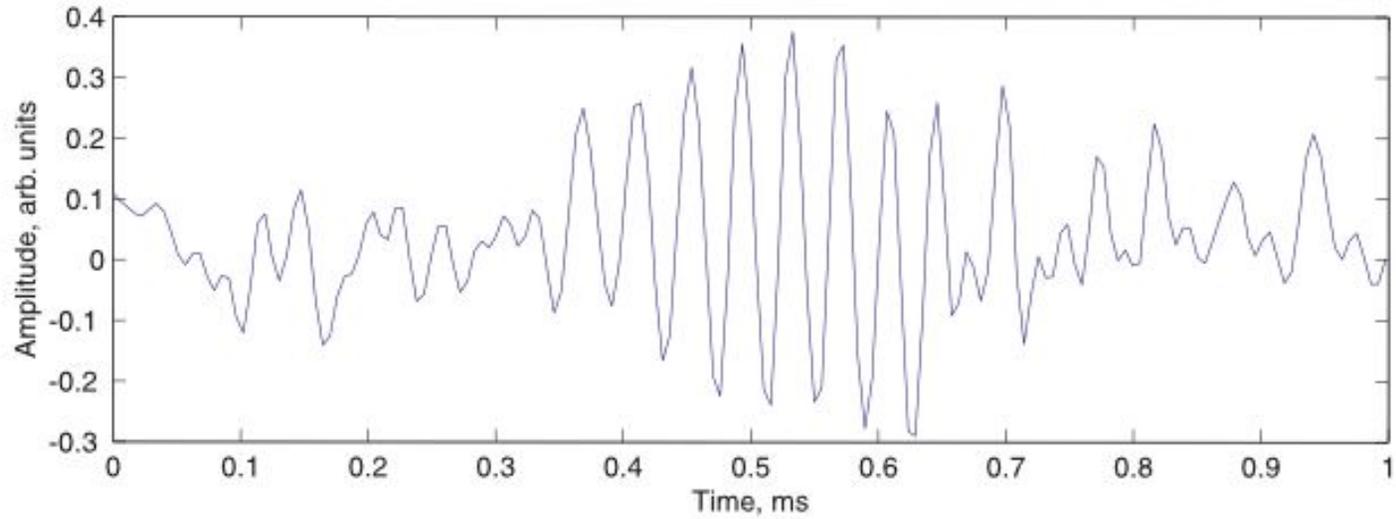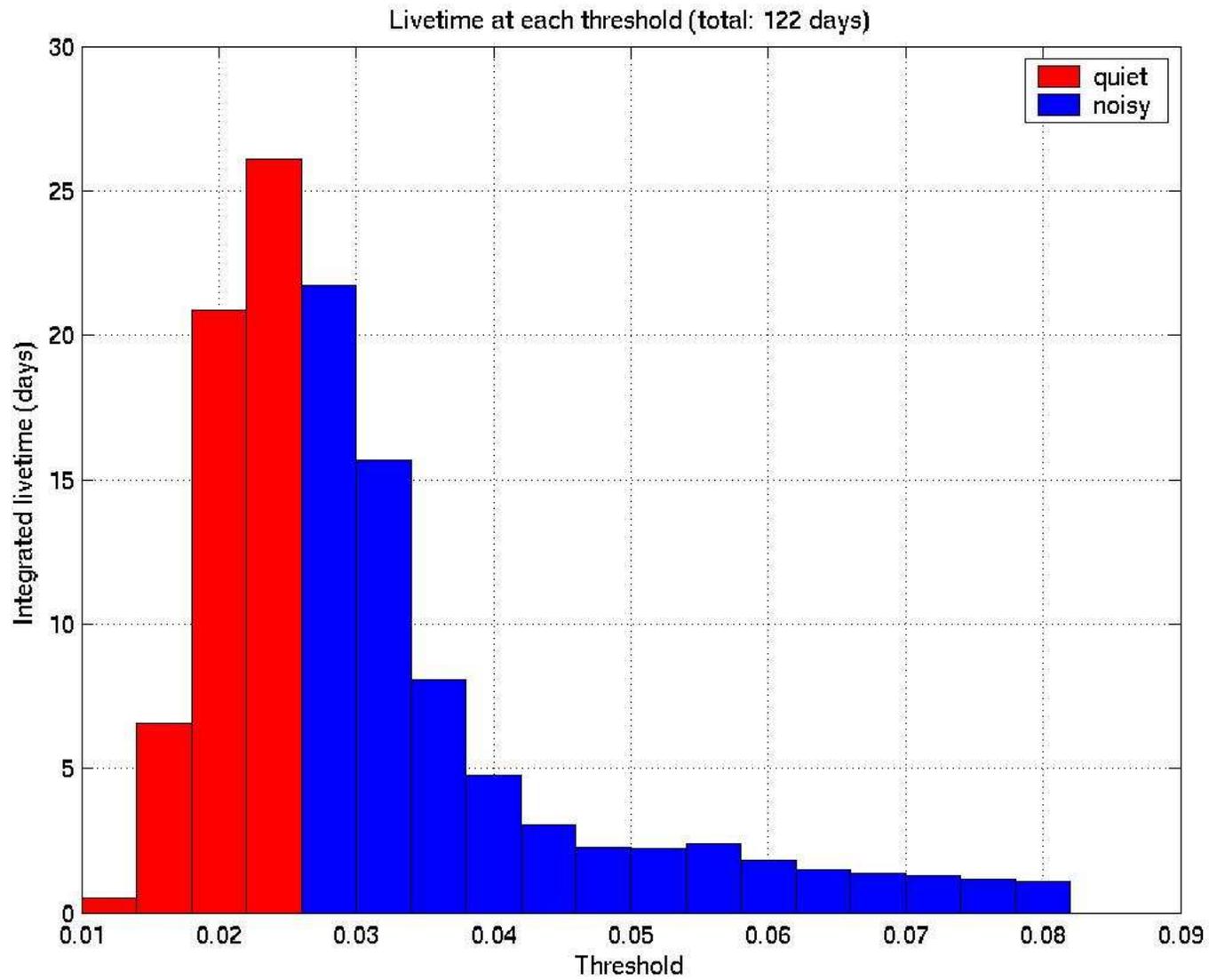
Cut 6: Pancake shape constrains effective volume
(bad news and good news)

Bounding curves for effective volume for various energies (labeled in units of 10^{21} eV)

Cut 7: Threshold crossings

2 threshold crossings, 4 samples above threshold (hour 2001.12.22.12, event 7136)
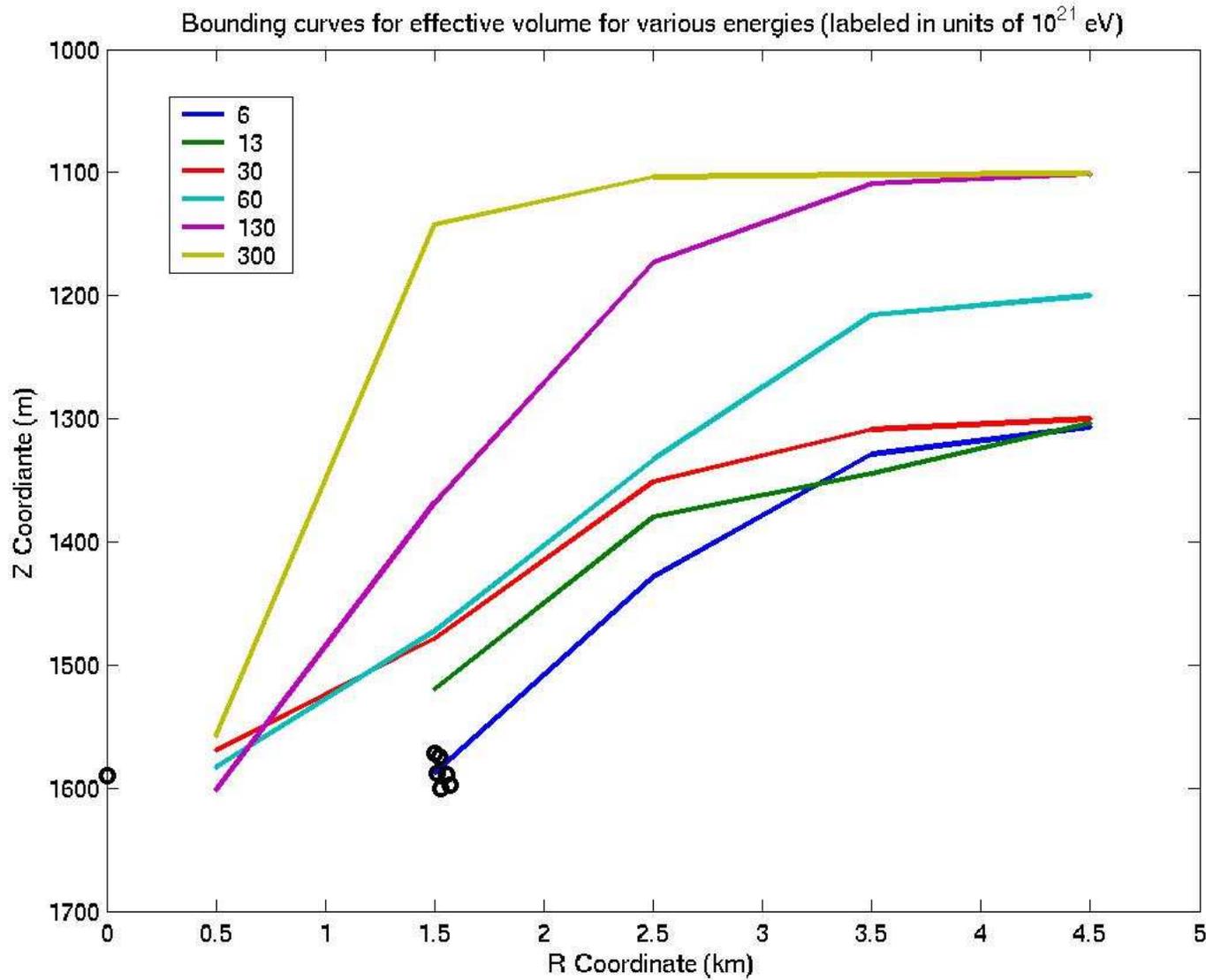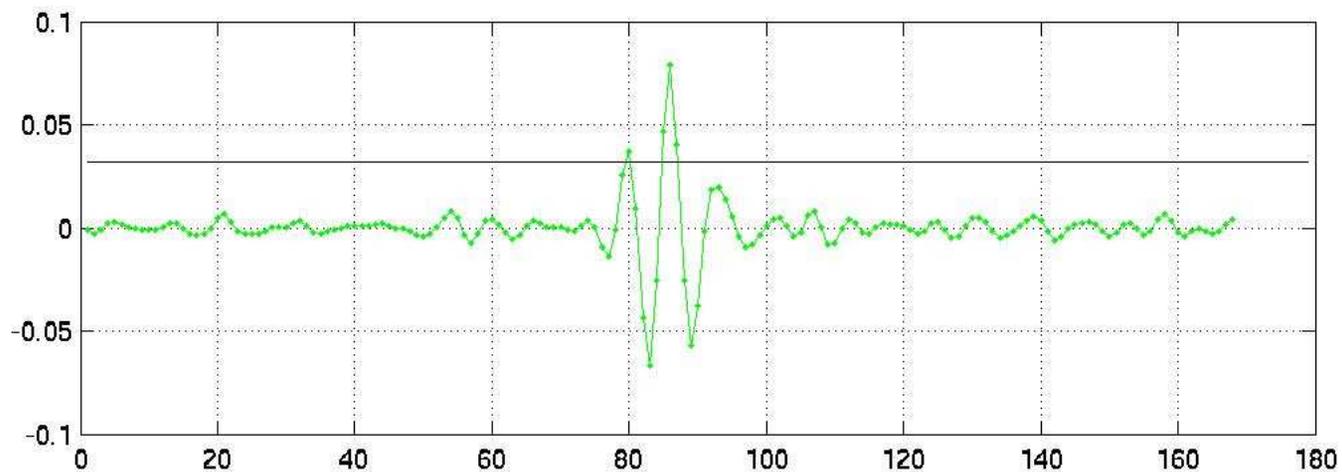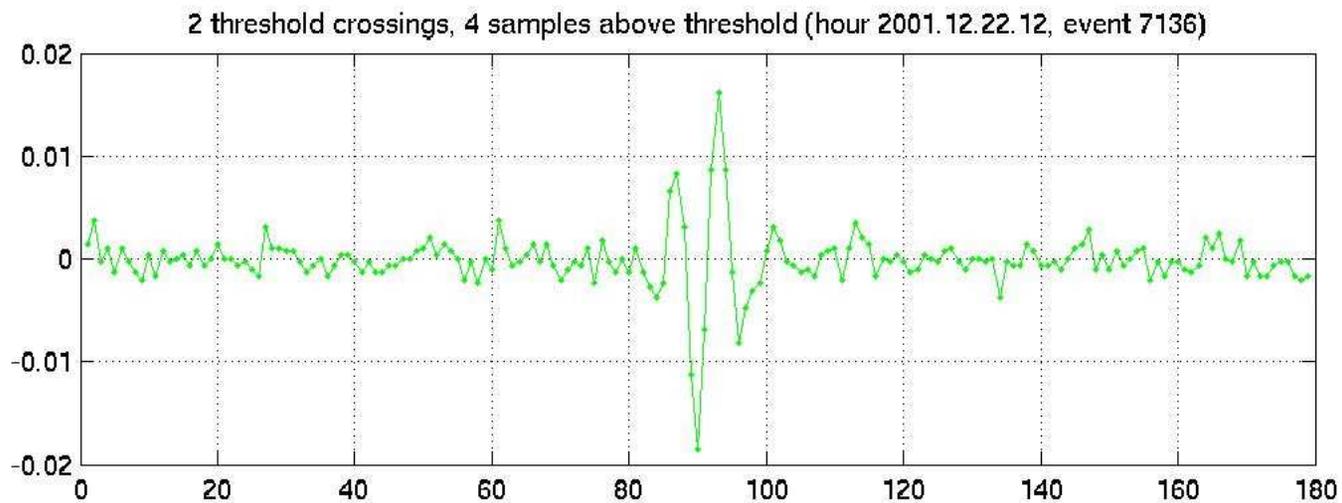
Background rejection

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

(online, offline)

What have we learned?

- Refraction cannot be neglected for > ~ 1 km rays
  - Travel times are not significantly affected, but
  - Arrival direction and radiation envelope are (deflection)
  - Phones on sea floor are bad
  - Ray tracing necessary for localization

- $c_{sound} = c_{light}$ / 200,000 !!
  - Coincidence is a very weak requirement → combinatorics

- 3D localization demonstrated
  - 10 m resolution attained
  - Array geometry important; planar array is worst case
    (but our signal is planar...)
  - Pancake shape a powerful requirement (despite decreased volume)

- Impulsive backgrounds at 10^{21} eV exist but can be rejected

- Energy threshold is very high (10^{21} eV) with 1.5 km spacing and current triggers

What's next?

Analysis
- Rigorous Monte Carlo efficiency check
- Final flux limits

SAUND-II
- More phones, more volume, more computer processing
- Improve adaptive threshold algorithm
- Build coincidences online
- Optimize cut strategy
- Lower energy threshold (one order of magnitude reasonable)
- Push to the Gaussian noise floor

Beyond (other arrays)
- 100-500 m spacing?
- better geometry?
- better noise environment?