Ultra-High-Energy Neutrino Astonomy From

ACoRνE

A First Year Report

By

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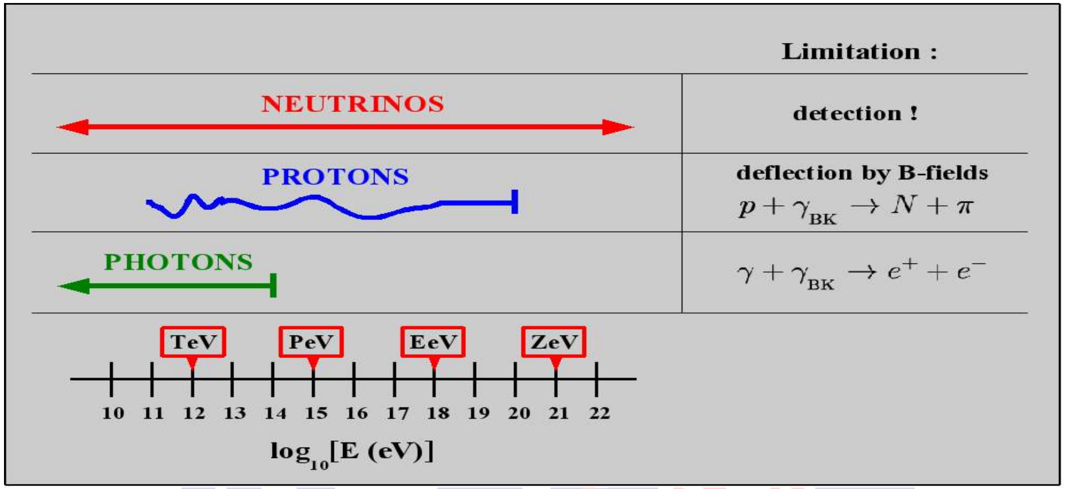
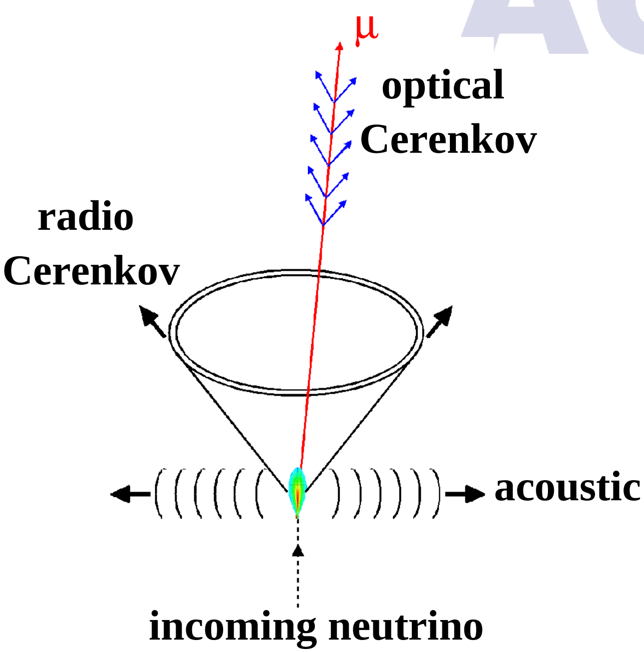
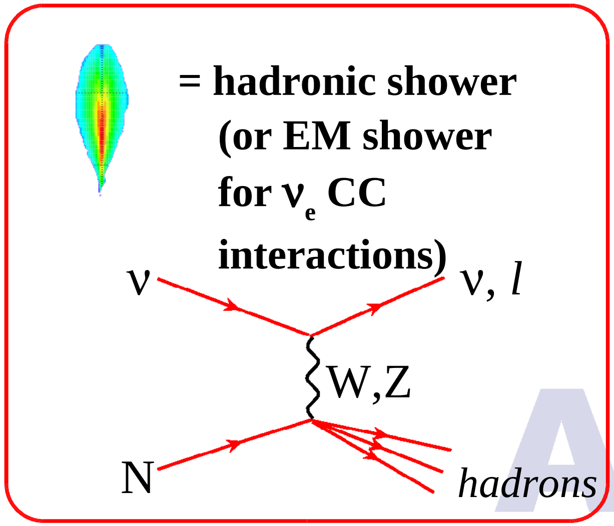
Why Acoustic Neutrinos?

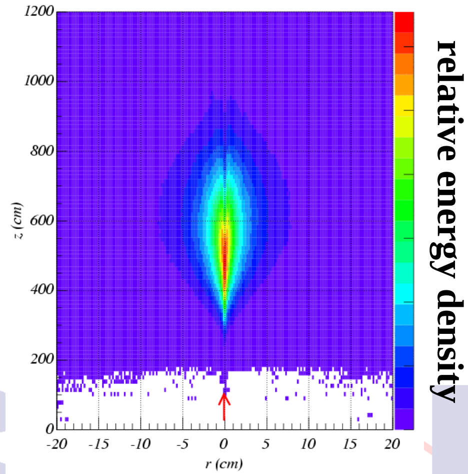


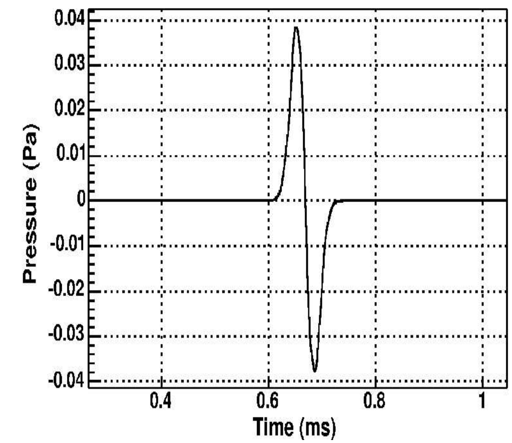


	Attenuation Length		
	water	ice	salt
EM optical (Cerenkov)	~ 50 m	~ 100 m	? (large)
EM radio (0.1-1.0 GHz)	~ 0	~ few km	~ 1 km
Acoustic (10 kHz)	~ 10 km	? (large)	? (large)

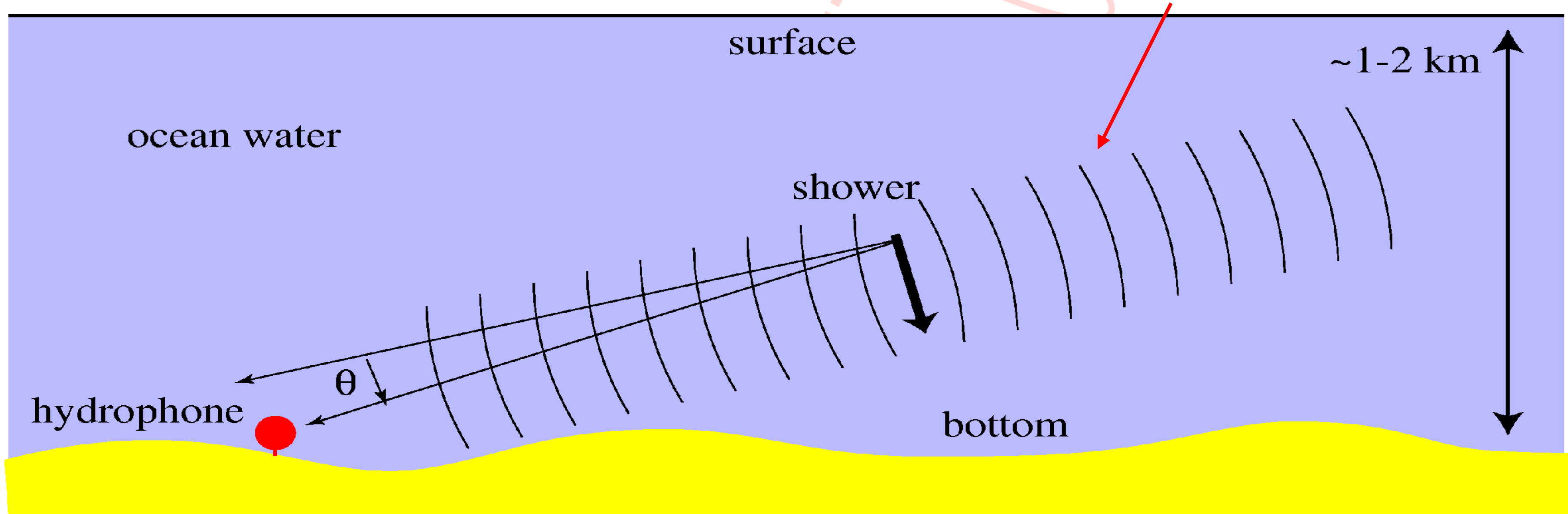
Detection of Acoustic Neutrinos



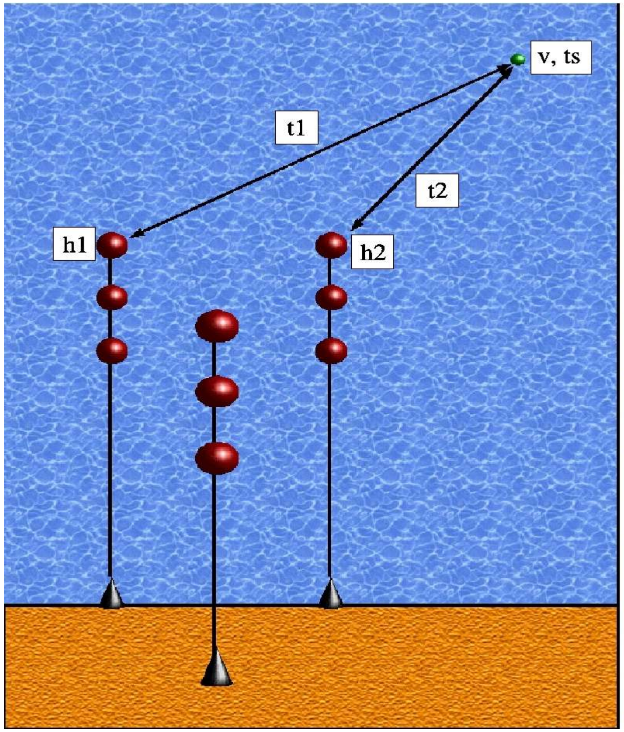




"pancake" propagates ⊥ to shower direction



Vertex Reconstruction



$$|\vec{v}-\vec{r}_i|^2 = c^2(t_i - t_s)$$

$$\vec{v} = M^{-1} \times (\vec{R} + t_s \vec{T})$$

All known

t_s can be also be calculated, but only via a quadratic, i.e. there are two solutions.

Minimum of 4 Hydrophones

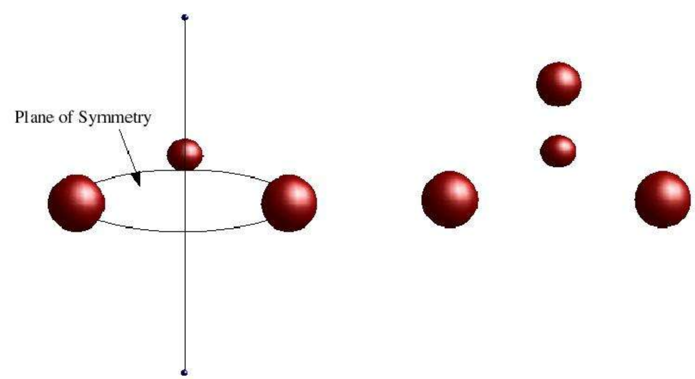
$\vec{v} = (v_x, v_y, v_z)$ = shower location (*vertex*): UNKNOWN

$\vec{r}_i = (x_i, y_i, z_i)$ = location of hydrophone i: KNOWN

t_i = time measured at hydrophone i = KNOWN

t_s = time of shower: UNKNOWN

c = sound of speed : KNOWN



2

$$^{2} = (t_i(actual) - t_i(recon))^2$$

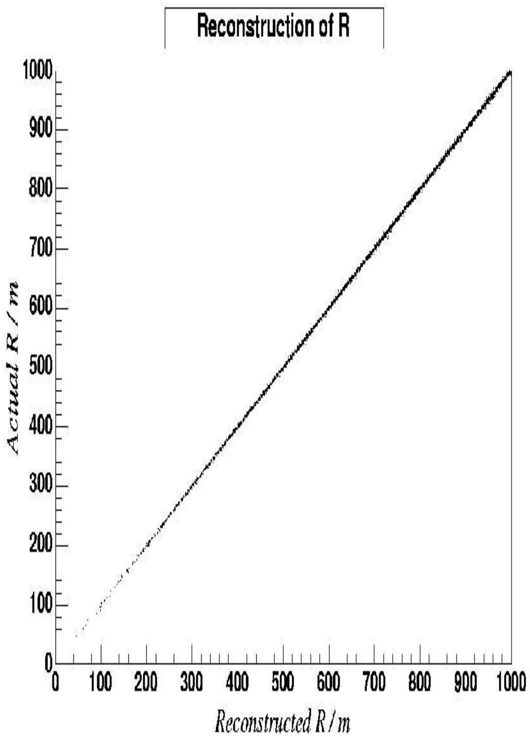
$$t_i(recon) = (t_{\pm s} + (h_i - v_{\pm}))/c$$

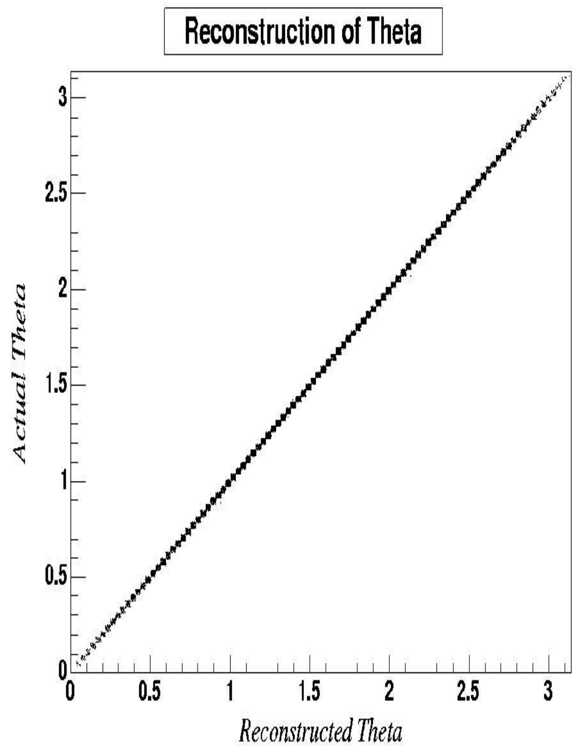
- A way of choosing the solution of the quadratic that corresponds to a real event.
- Take the positive solution, and from the calculated time of interaction, $t_{s,}$ and the calculated vertex, propagate an imaginary wave backwards to hydrophone one using the speed of sound in water. Now repeat for the negative solution.
- We know what time the hydrophone was actually hit, therefore take the solution that most closely matches this time, ie the lowest

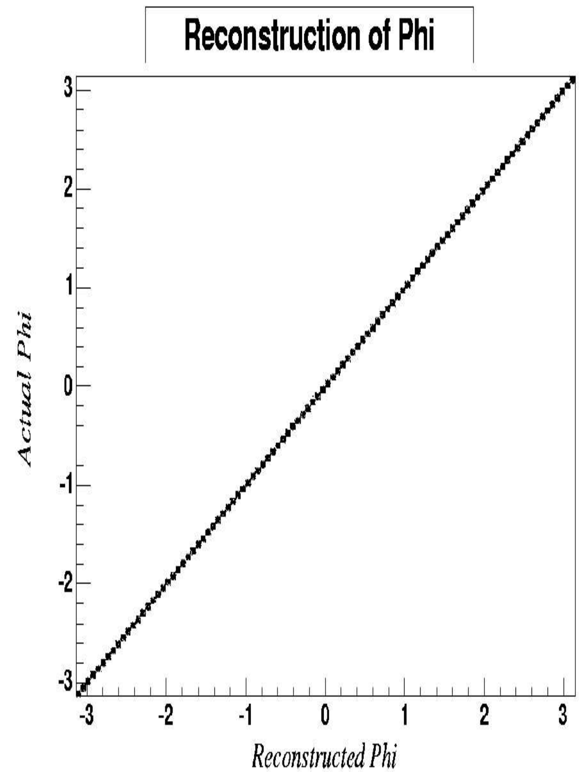
2

Testing the Reconstruction Algorithm

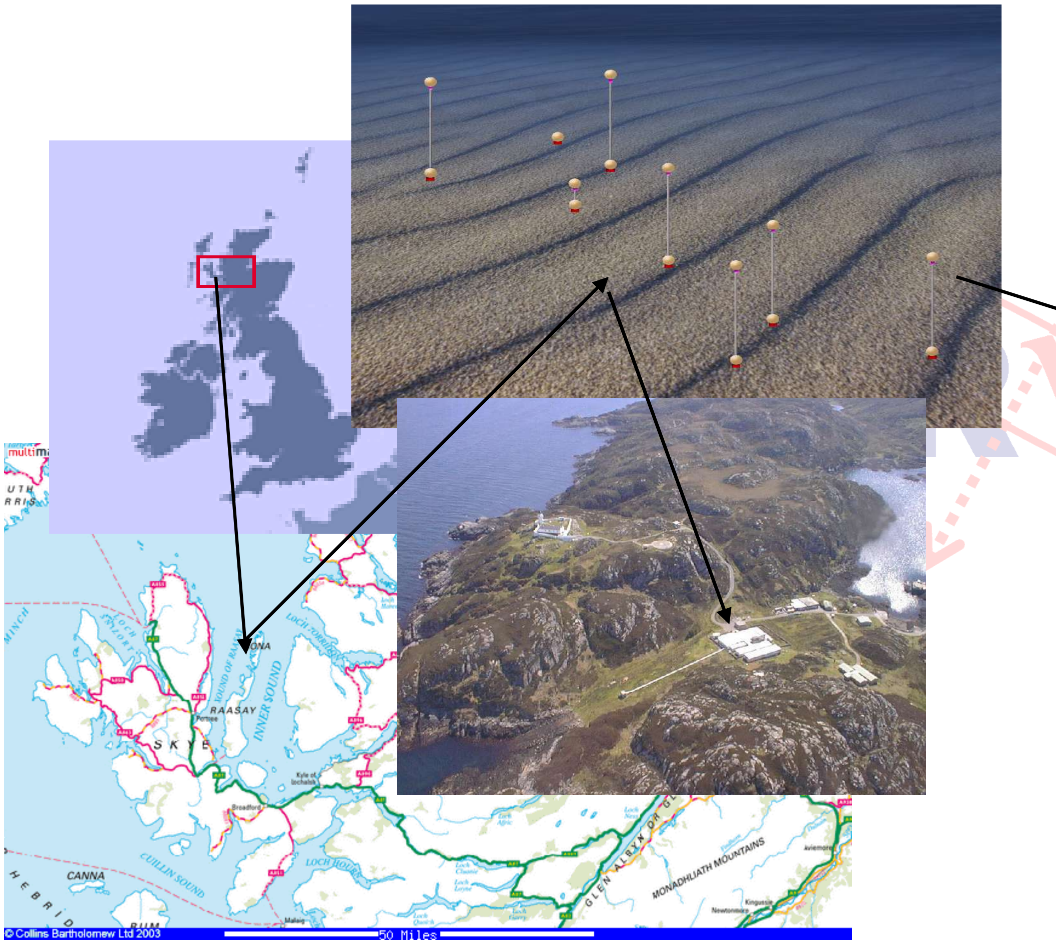
- Use Monte Carlo generate 10000 events in a 1000m radius sphere
- Assume that every hydrophone detects the event, then reconstruct
- Ask how many events reconstruct to within 10m of actual R
- 36 /10000 – 99.64% success



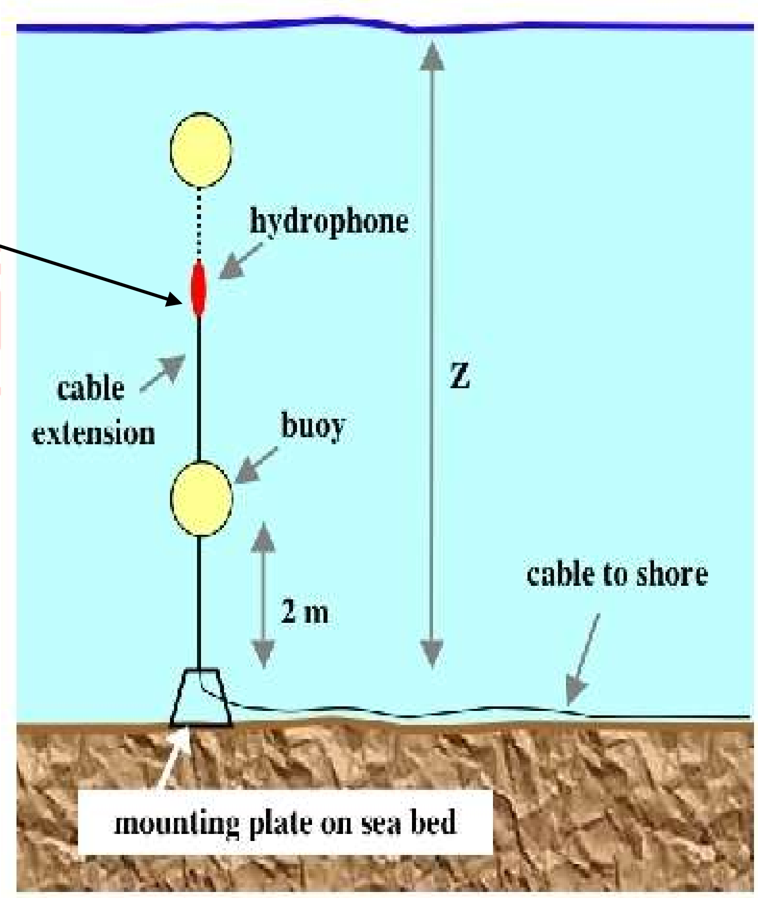




The Rona Array



total cable length =
2m + cable extension + cable to shore



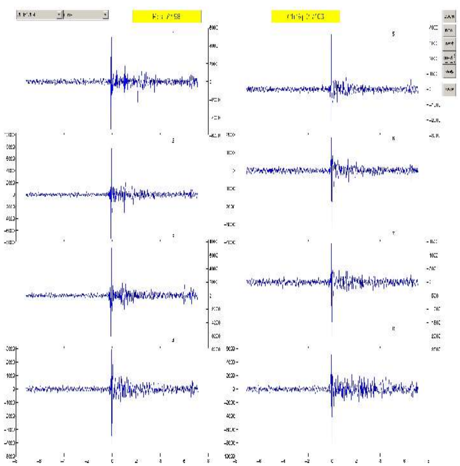
Analysis of Rona Data

- We have now successfully recorded 16 days of consecutive data.
- The initial form is simply 4TB of raw analogue signal from each of the 8 hydrophones
- On this initial analysis is performed:
  - The data is read in 10s blocks and filtered with a distortion free high pass filter. The energy is calculated every 17.85 ms blocks.
  - The top 5 most energetic events in each ten second period are forced to be considered. The events are stored and tagged type 1.
  - The data is then differentiated and the above process repeated. This time the events are tagged type 2.
  - Differentiate again, and now tag as type 3.
  - Finally apply a matched filter, these are type 4 events.

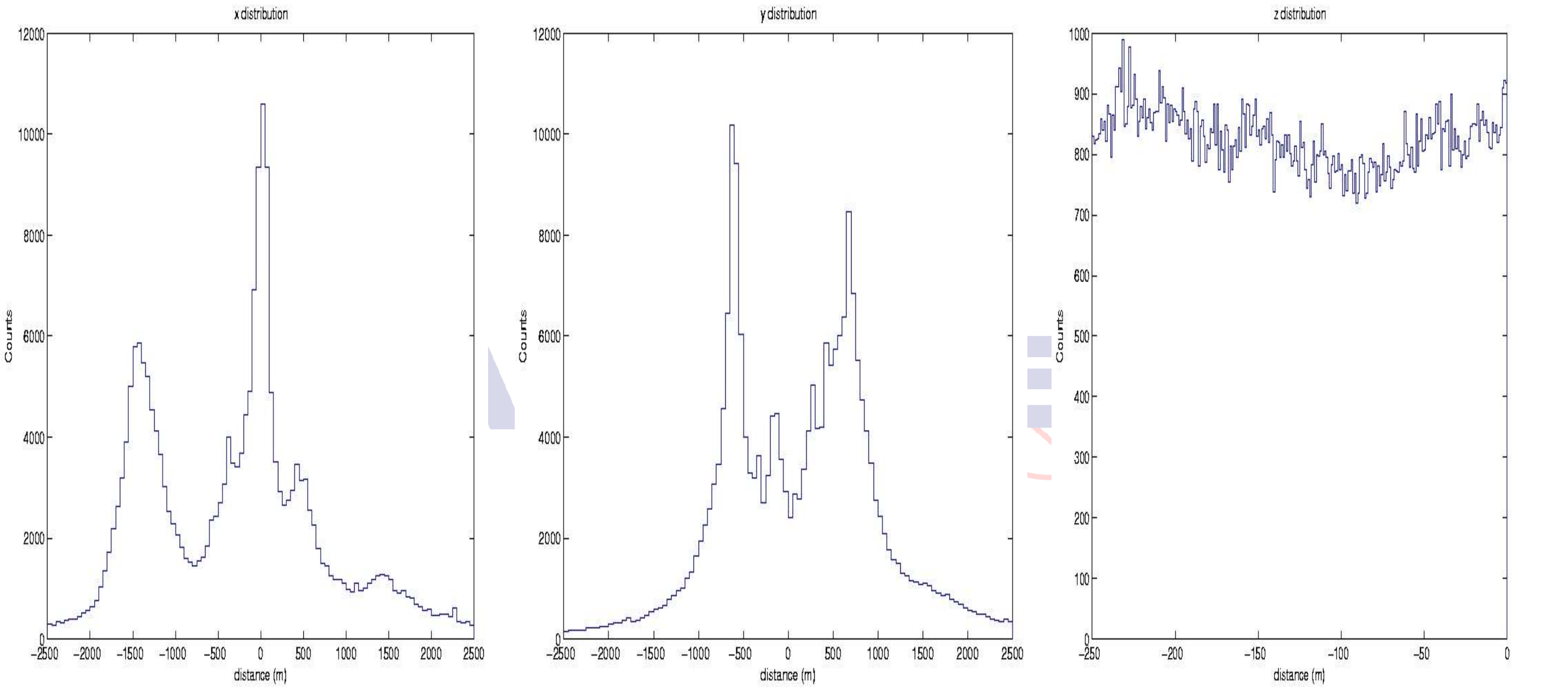
- Give priority to type 4, 3, 2 and then 1 events.
- Remove any duplicates
- Reduces the data down to 40GB

Looking For coincidences

- Each 10 minute is split into 600 bins. Each of the events is then place in the corresponding bin, the bin 0.5s above, and 0.5s below. Duplicates are removed.
- For each window it could be imagined that each hydrophone has been fired more than once. Produces a major combinatorial problem, as we want to consider all events. If each hydrophone is hit just 8, this is 17 million different combinations.
- This problem is greatly reduced by only considering hits of the same trigger type.
- This gives 10^{10} events.
- Now run these events through the reconstruction code and only consider events which reconstruct to a real vertex, in the water volume and with a chi2 of < 100. Note that if an 8 fold coincidence fails, all 7 fold combinations of this are considered, then all 6 etc.
- This gives
  - 123,330 five-fold events
  - 74,839 six-fold events
  - 24,830 seven-fold events
  - 9,555 eight-fold events
  - Giving a total of 232,554 events

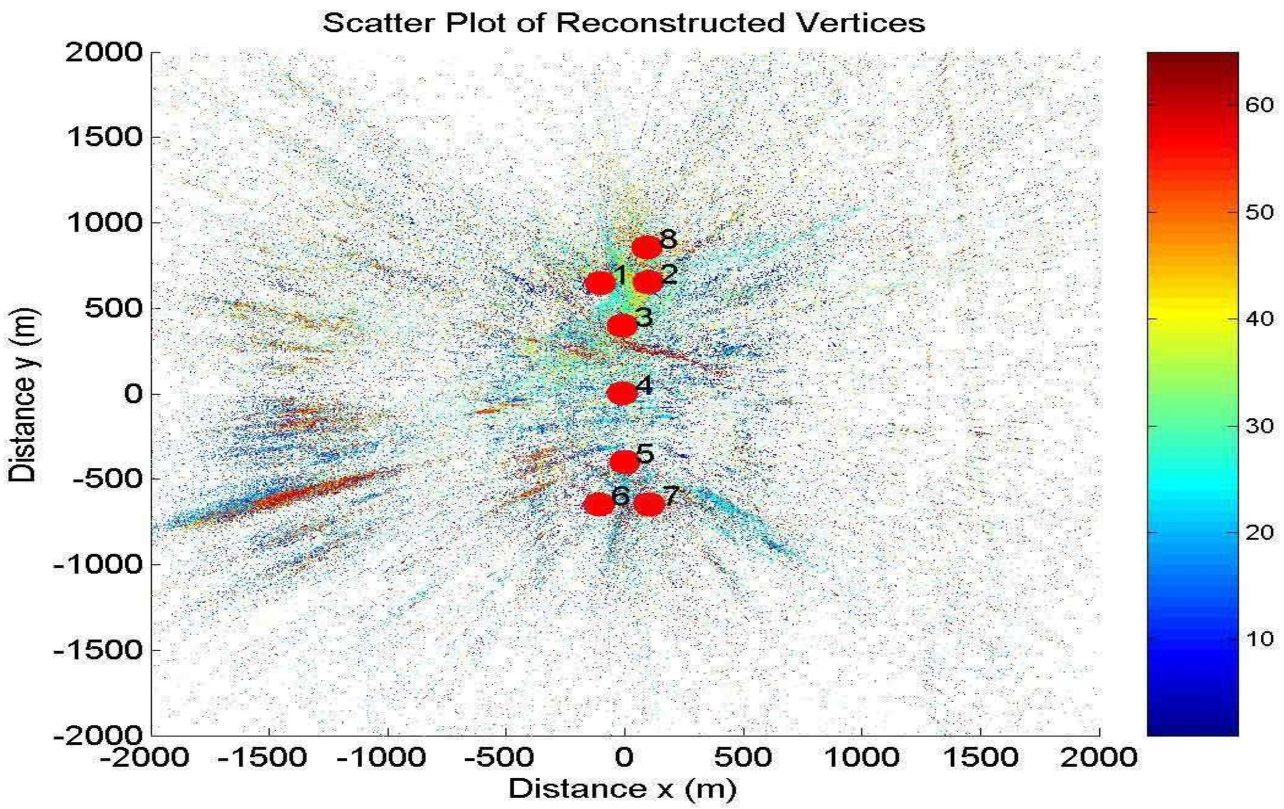


The Results



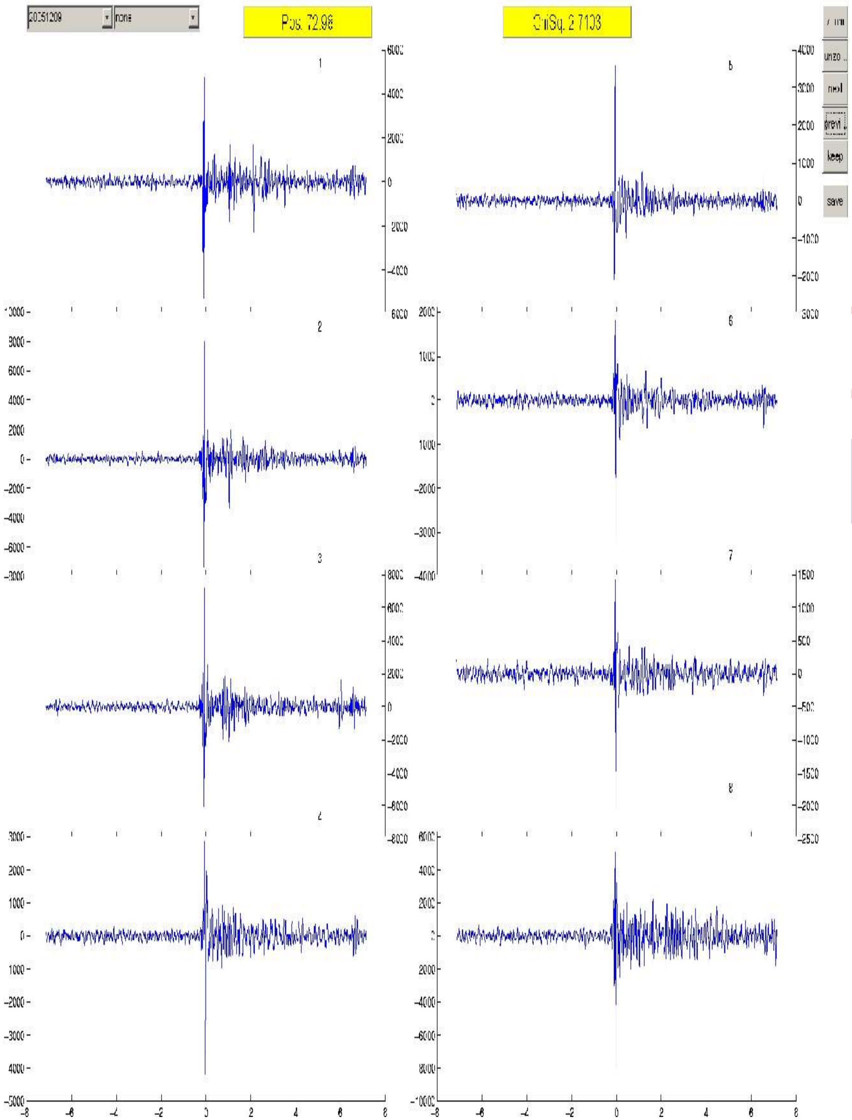
- Would have expected to see a peak in noise at z = 0. But this is not evident here.
- There is definite structure to the x and y distributions, but what causes these?

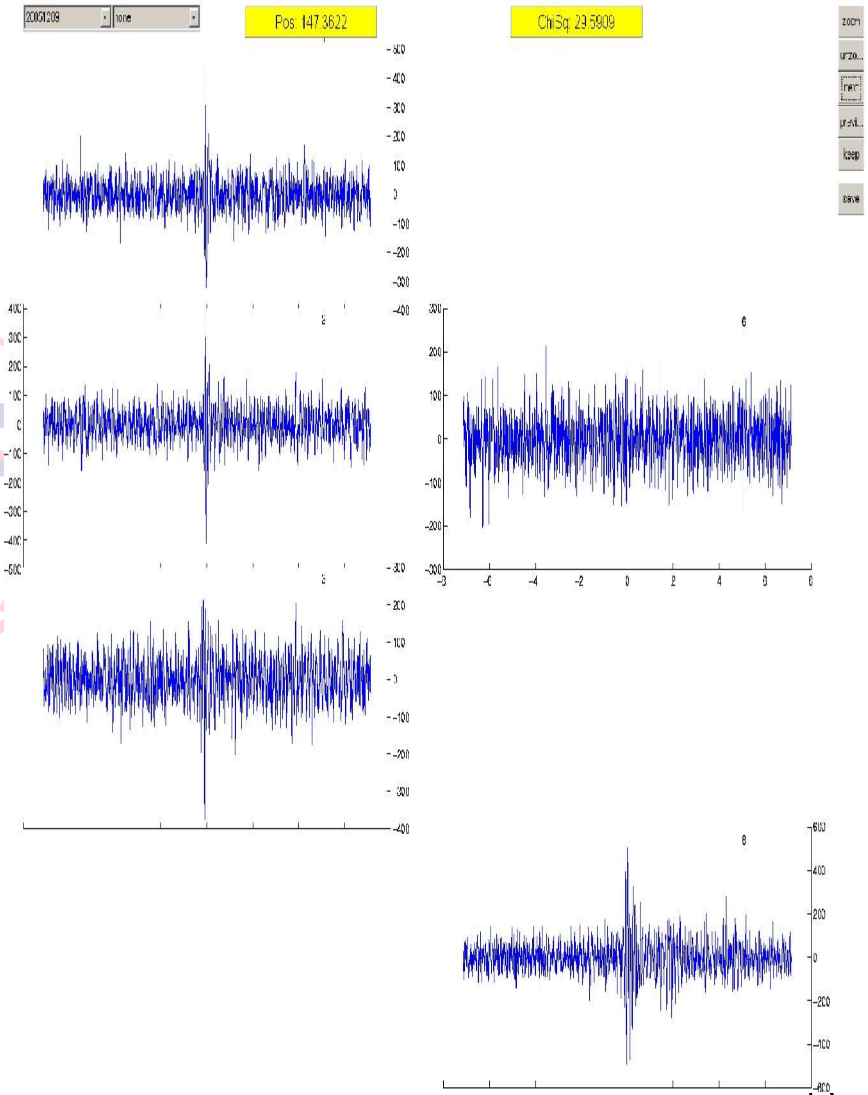
Results 2



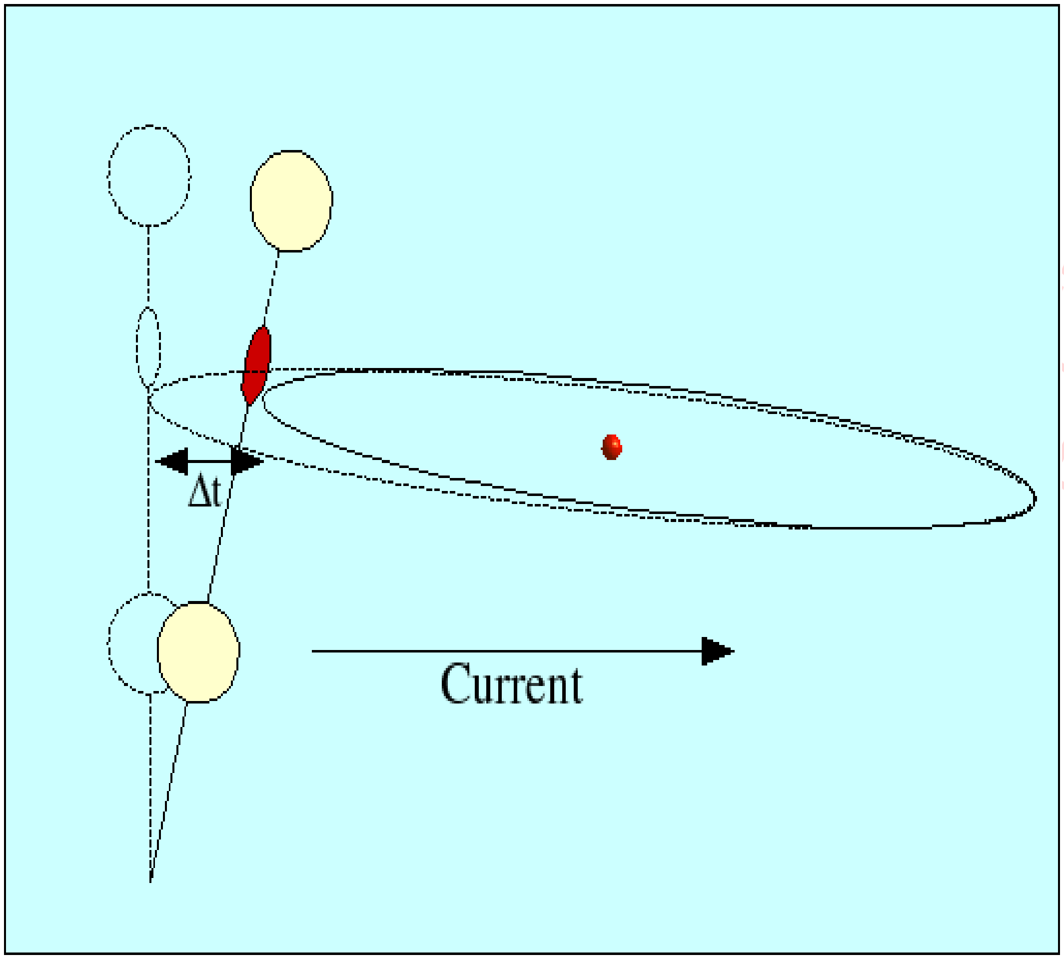
- Clustering and left right asymmetry. Due to sea cliff, bio-noise, or simply a feature of the reconstruction algorithm?
- But data analysis still not complete, estimated that only 10% of the 200,000 events are real.

Event Viewer



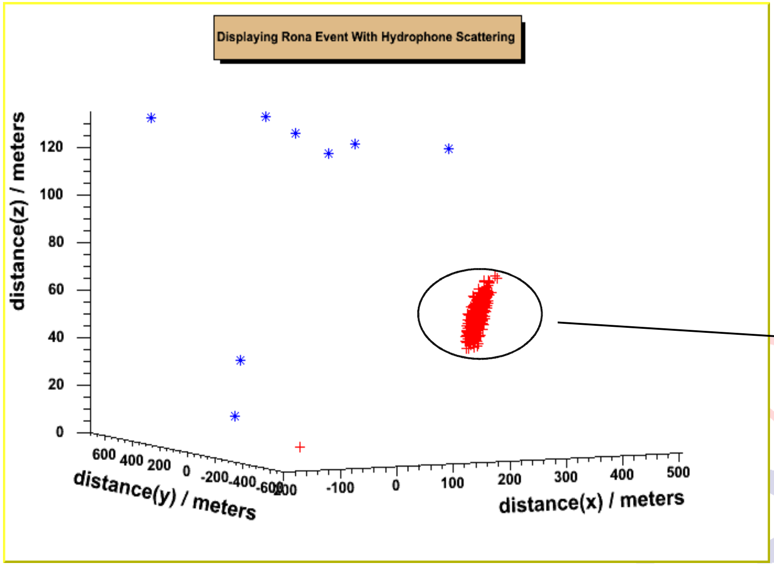


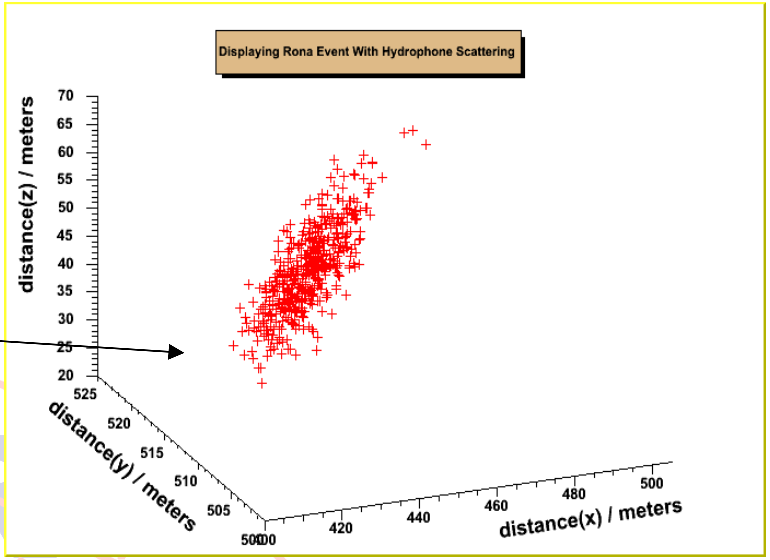
Moving Hydrophones

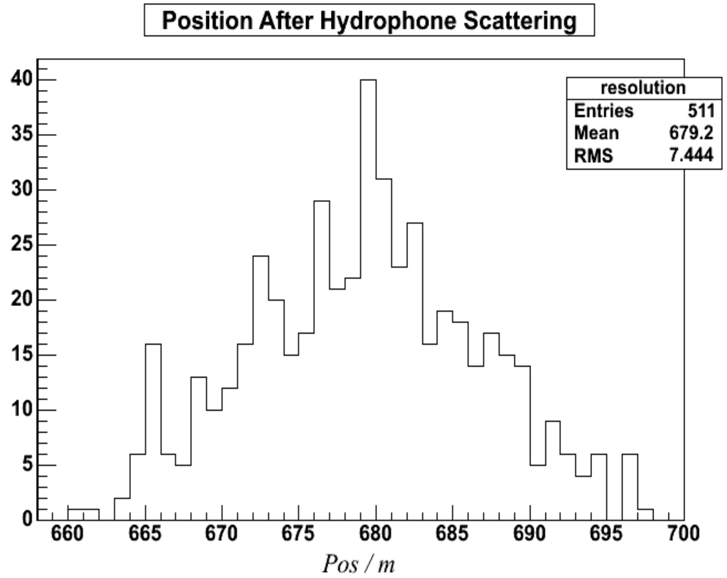


- Consider a hydrophone that has shifted its position by 1m.
- On a string that is 132m long, this corresponds to an angular shift of 7.58×10^{-3} degrees.
- Or a t of $2/3 \times 10^{-3}$ seconds. Well within the sampling rate, 7.14×10^{-6}.

The Effect of a Meter



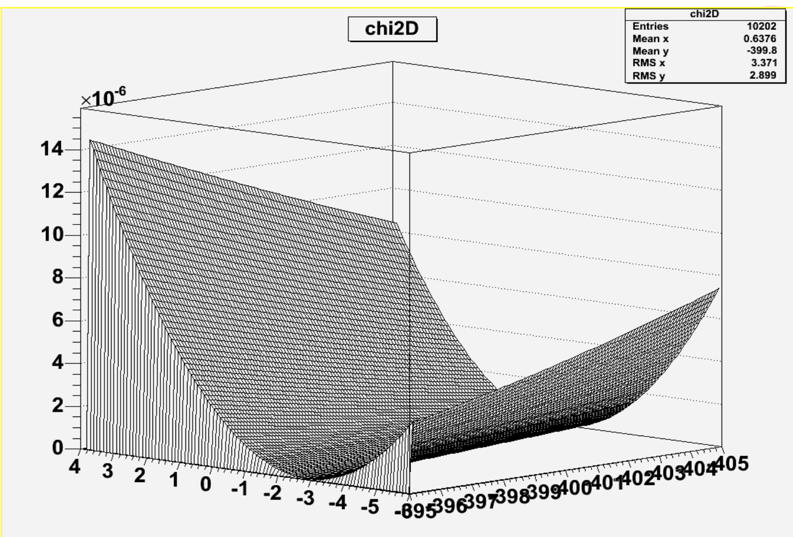


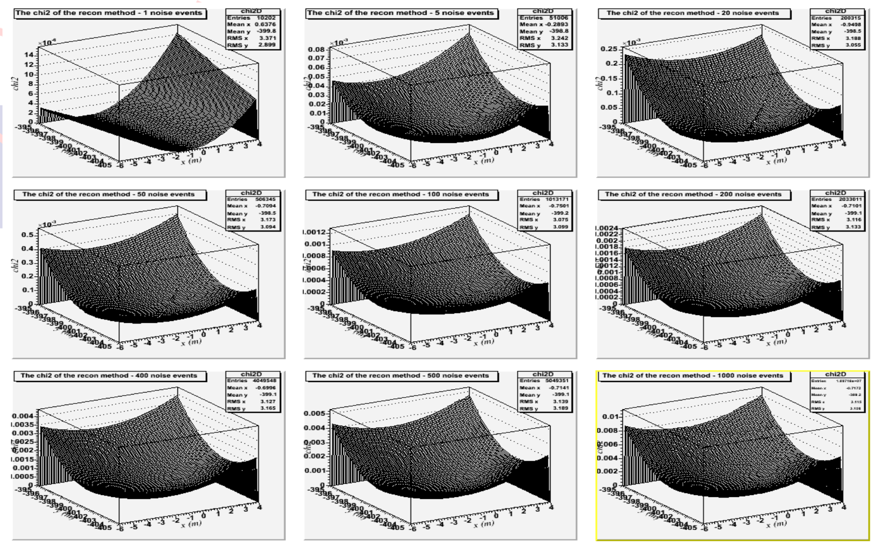


- Using the first golden event, scatter every hydrophone randomly using a Gaussian with a sigma of 1.
- This gives an error on the position of ±10m.
- Can this error be improved?

Optimisation

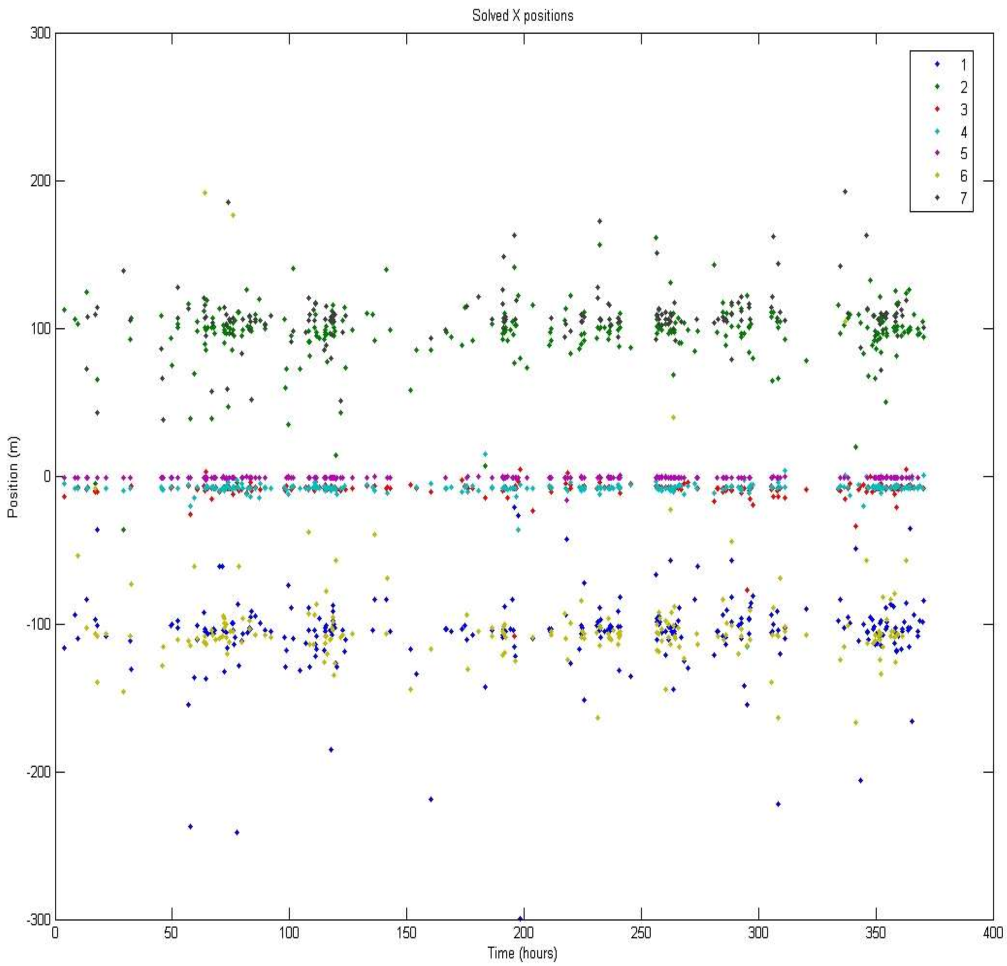
- Fix z and hydrophone 8 (fixed to the sea bed).
- Generate an event, then scatter the free hydrophones.
- Do a multi-parameter fit, minimising on the chi^2.
- One event would never work, as shown by the error surface below.





- Now repeat the above exercise but minimise now on the chi^2 for many noise sources.
- Using the standard Matlab minimiser the answer always converges in < 60s with an error of < 10^{-3}.

Results



- Use this technique on the golden events. Every 10 minute file corresponds to a group of noise sources.
- Do we see the tidal variations or no change? Can we define a function that will feed back into the reconstruction code?
- No, still too many un-real events to draw any conclusions.

Future Work

- Immediate future: -
  - Pattern matching on the ‘golden’ events to only leave real events.
  - FFT on the whole data to look for ships. Can we plot their directory.
  - Can we begin to identify topology, bio noise, even track wildlife
  - Can we then discriminate against it to leave a clean background for a neutrino pulse?

- Less immediate future: -
  - Continued data taking at Rona
  - Better reconstruction algorithms (pointing, energy resolution).
  - Signal processing and background reduction
  - Field work on array calibrations
  - Publishing an upper limit for the flux of UHE neutrinos using acoustic techniques, is acoustic detection feasible?.
  - Design of future arrays, acoustic, or combination of different techniques

Conclusions

- Acoustic detection is necessary for UHE neutrino searches, but the field is still in its infancy.
- With the help of the Rona array, we have taken 2 weeks of continuous data.
- A good start on the data analysis, with many techniques tested and code written.
- But still much work needs to be done.

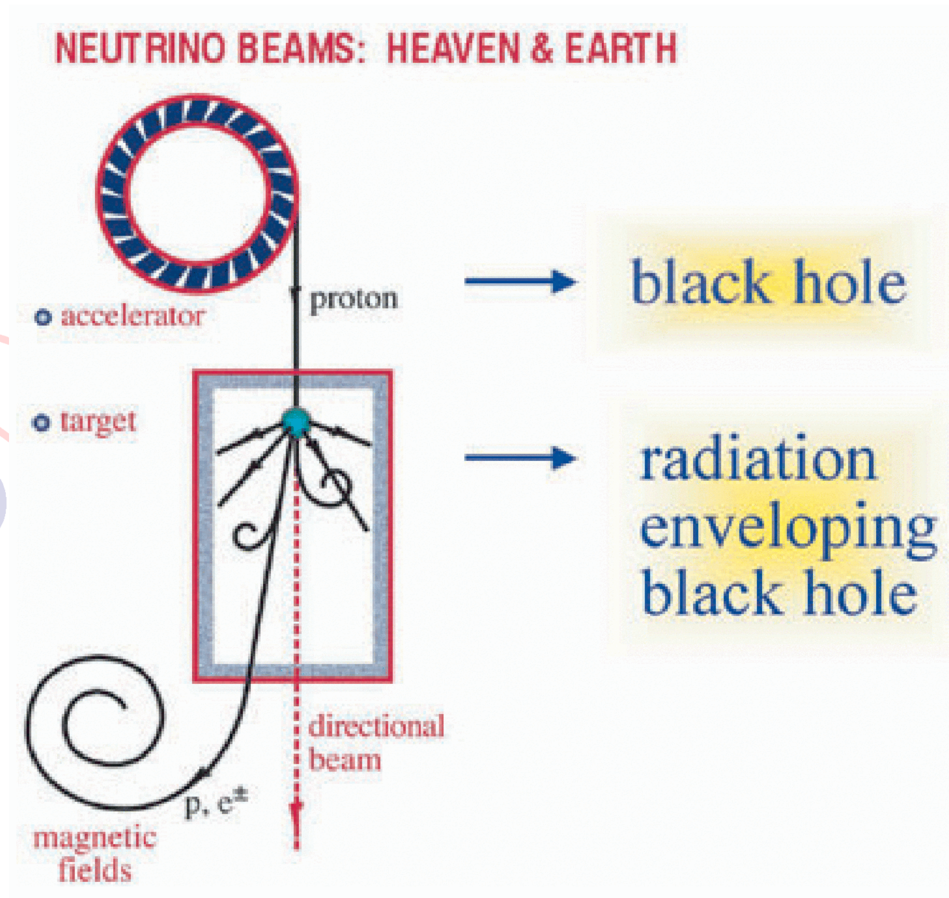
End

Filters

- High Pass filter – Filter low frequency noise, in this case below 2.5kHz
- Differentiation decorrelates noise, making it completely white. Second order differentiation is needed to make the spectrum flat as the spectrum is falling off as $1/f^2$
- Matched filter – Matched in both the phase and the amplitude of the signal and will produce the theoretically optimal signal to noise ratio.

Sources of UHE Neutrinos

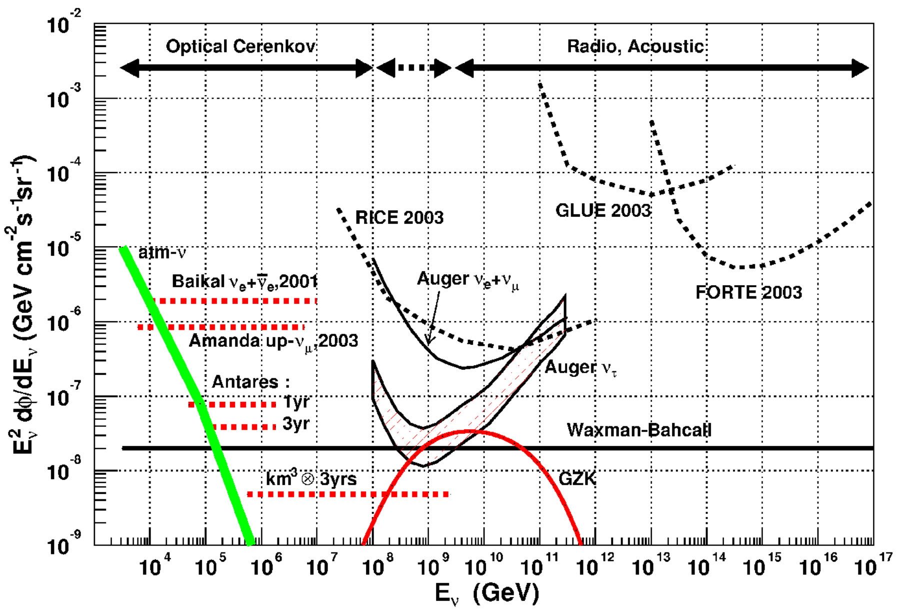
- Protons accelerated in highly energetic environments colliding with the ambient gas.
- AGN
- Gamma ray bursts
- Super novae remnants
- Micro quasars



Halzen & Hooper, 2002

GZK

- Limit of maximum energy of protons of cosmological origin because of (50Mpc) inelastic collision length of particles on cmb.
- Using full model of neutrino interactions on CMB over the full lifetime of the universe, calculations of flux can be made.



$$\hookrightarrow p + e^- + \bar{\nu}_e$$

$$p + \gamma_{CMB} \to \Delta^+ \to n + \pi^+$$

$$\hookrightarrow \mu^+ + \nu_\mu$$

$$\hookrightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

Other Detection Methods

- Optical (AMANDA, ANTERES, ICECUBE) –
  - Look for upward going muons to minimise the noise from neutrinos from cosmic rays hitting the atmosphere.
  - Could detect UHE neutrinos, but not optimal as they have relatively small detection volumes
- Radio (RICE, ANITA, GLUE) –
  - Been demonstrated in lab
  - Km^3 detection volumes
  - Relatively well understood background

Incorporation of all three?