R&D studies for the development of a compact transmitter able to mimic the acoustic signature of a UHE neutrino interaction

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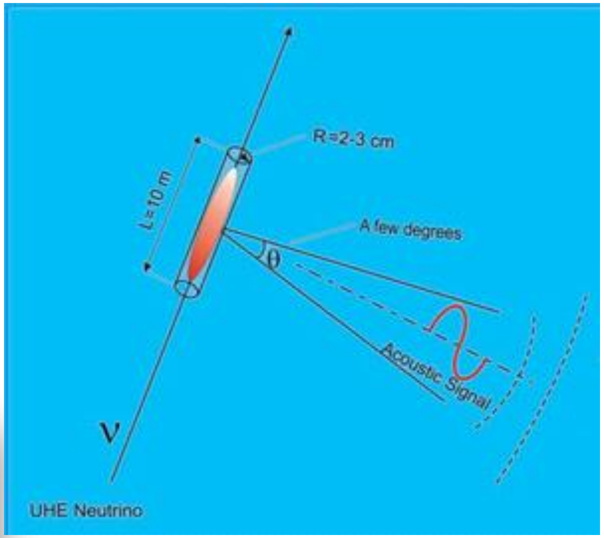
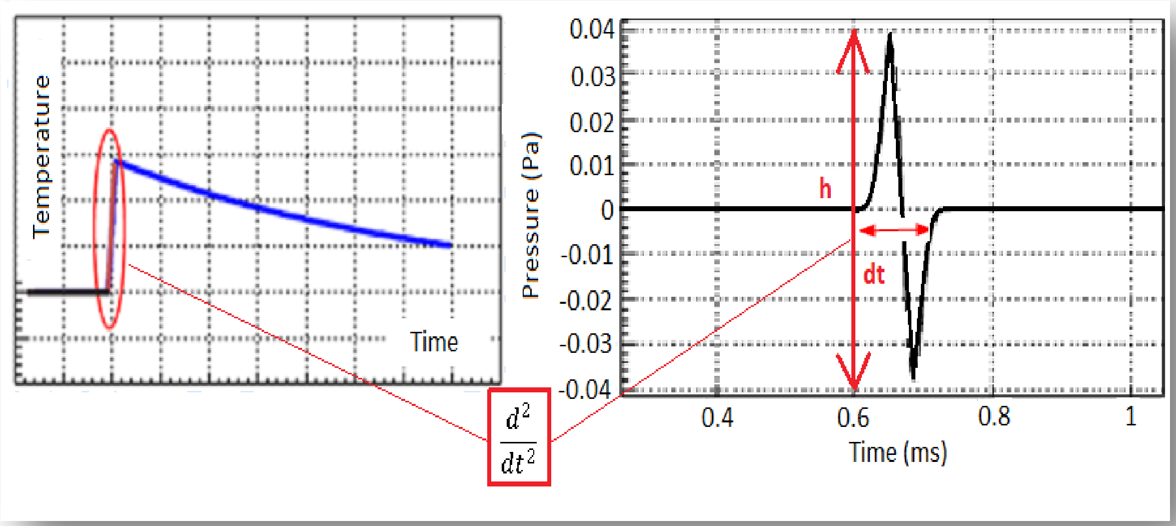
Introduction

When a UHE neutrino interacts with the matter, the energy is deposited fast and locally.

A thermo-acoustic pulse is generated and propagates perpendicularly to the direction of the hadronic shower produced.

The acoustic signal has a bipolar shape in time and a 'pancake' directivity.





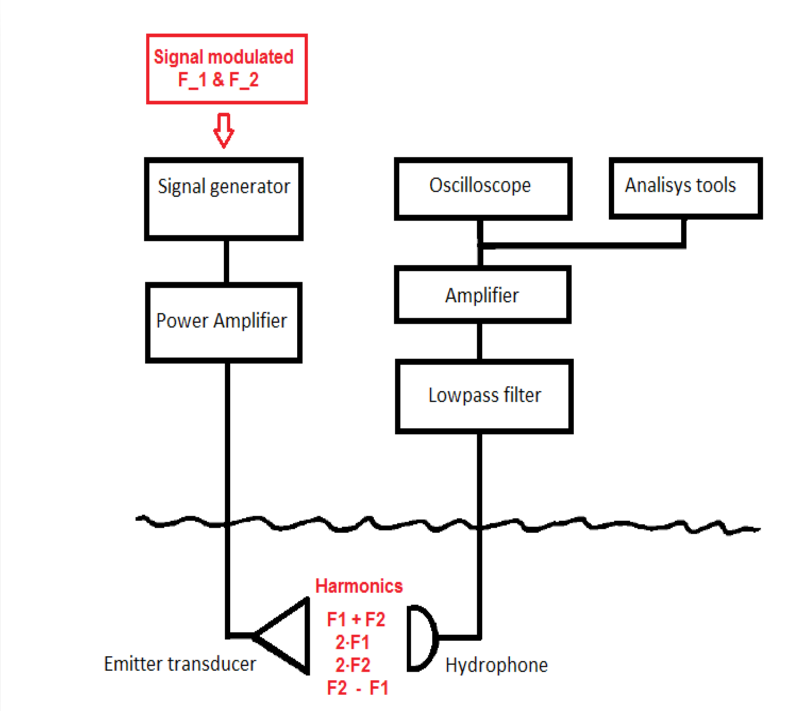
The amplitude of the signal is related with the energy deposed in the medium and the shape of the signal can be parameterized following the second time derivative of the temperature of the medium.

Introduction

- For the acoustic detection of neutrino it is very important to have a good calibrator in order to:
  - Check and monitor the sensitivity.
  - Test the system and the reliability.
- Due to the properties of the acoustic neutrino signal (short bipolar pulse with ‘pancake’ directivity) it is not easy to reproduce it.
- In this work, we extent our previous studies in generating and reproducing neutrino-like signals using parametric acoustic source technique. Mainly, we deal with the cylindrical symmetry of the problem.

Parametric Acoustic Sources

- Parametric acoustic generation is a well known non linear effect studied theoretically at 60's by first time.
- Parametric acoustic generation consist in a non linear effect that occurs along the sound wave path when a transducer is fed with a modulated signal with two close frequencies near to the resonance of emitter.



- Small fraction of energy is converted into new spectral components.
- Larger frequencies are rapidly absorbed in the medium → most interesting harmonic is difference of frequency.
- Secondary signal obtained at low frequency offer the advantage of obtaining secondary beam at low frequency with directivity similar to the primary beam at high frequency.

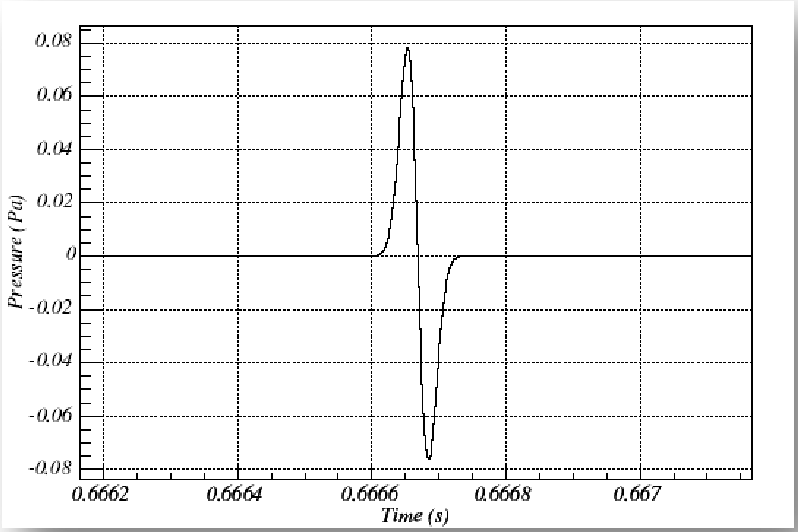
Parametric Acoustic Sources

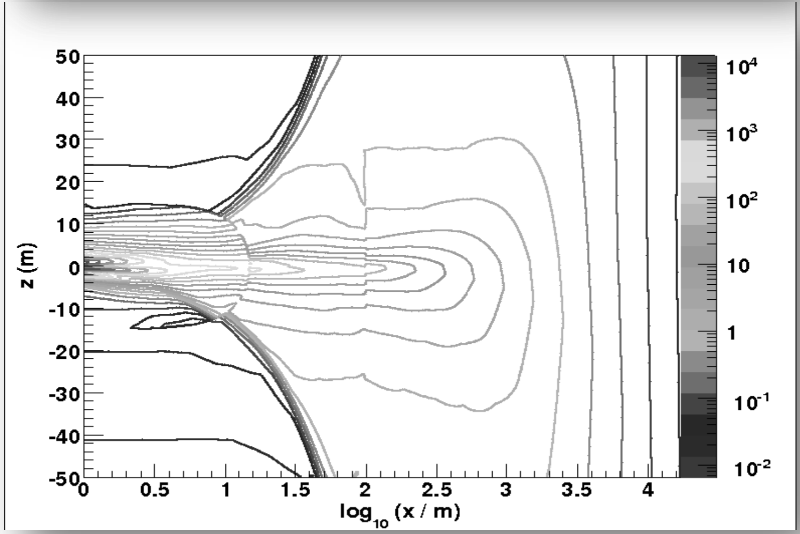
- The parametric acoustic sources has some advantages with respect to traditional linear radiating systems:
  - Opportunity of obtaining narrow directional pattern at small overall dimensions of primary transducer.
    - Absence or low level of side-lobes in a directional pattern on a difference frequency.
    - Broad band of operating frequencies of radiated signals.

- The same effect can be used for transient signals:
  - It is possible to generate a transient signal by a “special modulation” at a larger frequency in such a way that it “interacts” with himself in the medium providing the desired signal due to the difference of f2-f1 frequencies from the spectral content of the short modulated signal

Parametric Acoustic Sources for Neutrino Calibration

- Neutrino acoustic signal is a very directive bipolar transient signal.
- Classical solution to reproduce neutrino-like signal will use a linear array that emits in phase (coherent emission) → long array with many elements → increasing the cost and complexity of the system.
- This technique has the advantage of needing fewer sources due to the fact that secondary beam has similar directivity that the high-frequency primary beam.

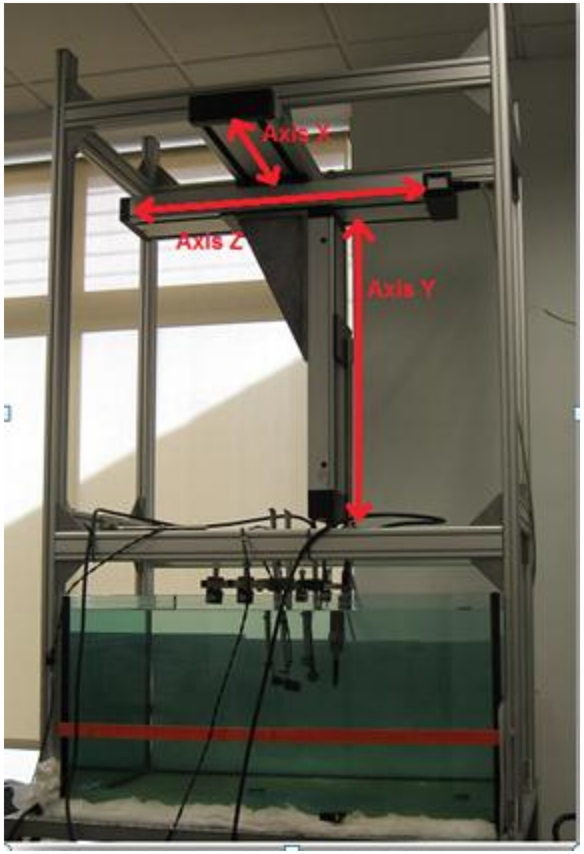




Studies with Parametric Sources (Experimental Setup)

Emitter hydrophone:10 kHz Free Flooded Ring
- 380 kHz frequency resonance used for our studies
- It is usually used at lower frequencies, so it can be used as well as a classical transmitter at low frequency

Receiver hydrophone:ITC-1042
- More sensitive below 100 kHz than for 380 kHz → More sensitive to the bipolar pulse (hardware filtering)



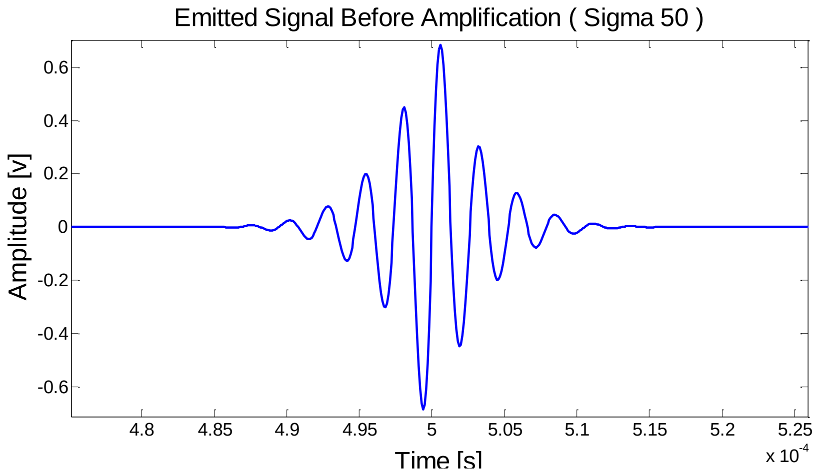
- Emitter hydrophone is fixed, whereas the receiver hydrophone scans along x, y and z axis.
- For each position of z we have done a scan in x and y direction. DAQ with full automatisation of movements and the emission and reception
- Dimension of tank is $\sim 1\ m^3$

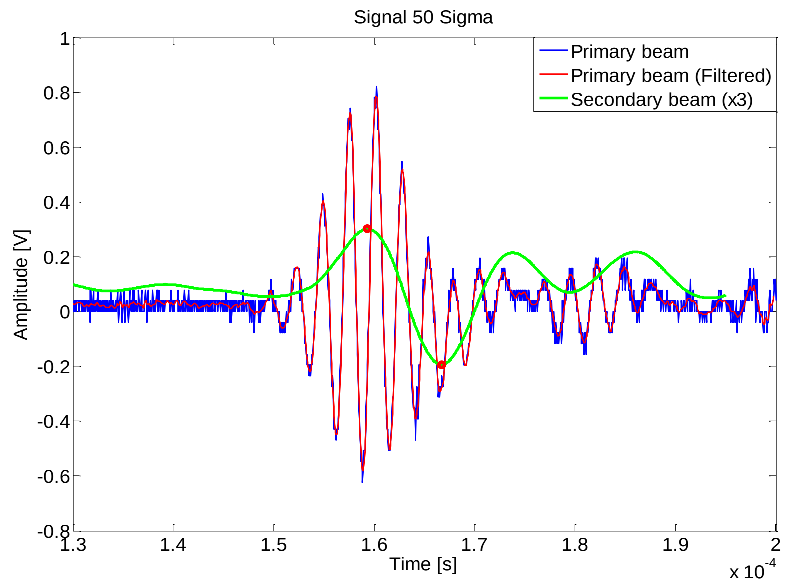
Studies with Parametric Sources

- Modulation of signal for emission calculated from parametric theory:

$$p(x,t)=\left(1+\frac{B}{2\cdot A}\right)\cdot\frac{P^2\cdot S}{16\cdot\pi\cdot\rho\cdot c^4\cdot\alpha\cdot x}\cdot\frac{\delta^2}{\delta t^2}\cdot\left[f\left(t-\frac{x}{c}\right)\right]^2$$

  - Theoretical and experimental studies point that second derivative of the envelope of primary signal is related with secondary non linear beam generated → to obtain a bipolar pulse for p(x,t), we have selected a first time derivative of a Gaussian function.
  - To disentangle the primary and secondary beams we applied different frequency filters
- The goals of these studies are:
  - Extent our previous studies to the case of cylindrical symmetry
  - To characterize the parametric bipolar pulse (shape, amplitude, directivity, generation and attenuation)
  - Put the basis to build a compact neutrino calibrator



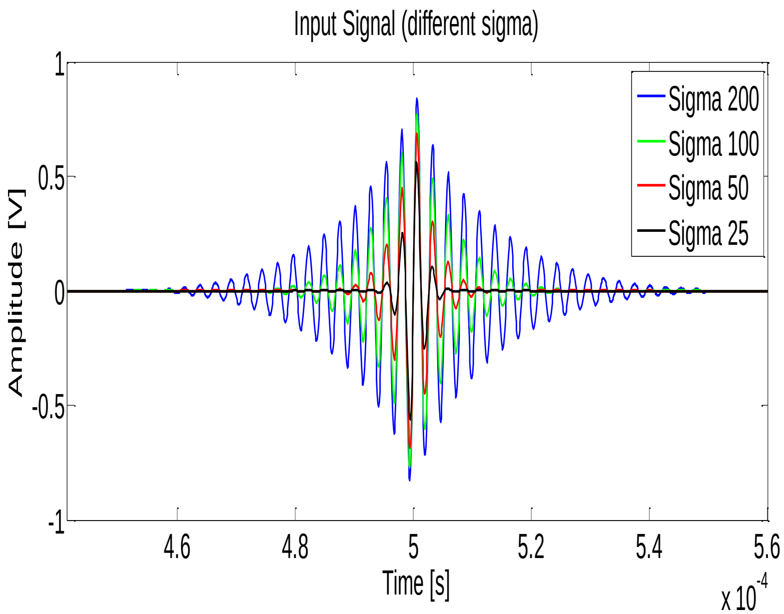


Recorded signal and bipolar pulse

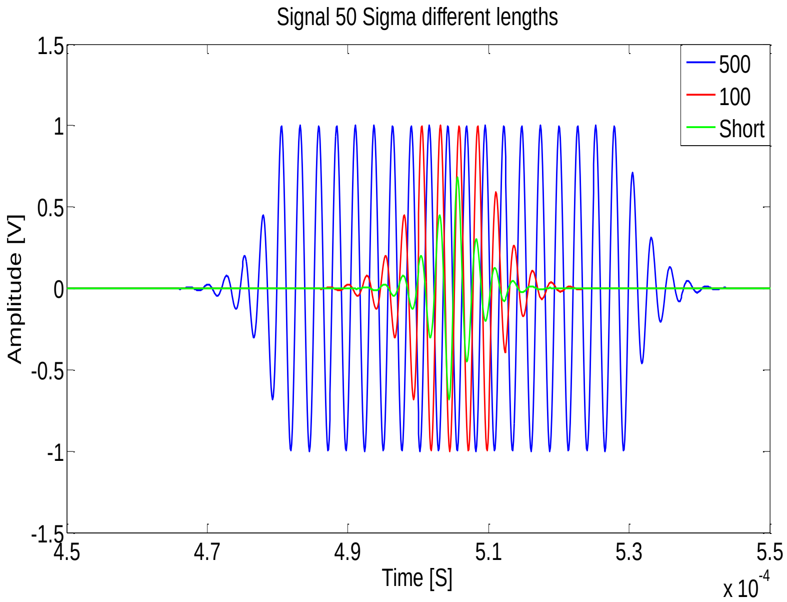
Studies with Parametric Sources (Shape)

- **Study using different set of signals**

Emitted signals with **different width** (different sigma used)



Emitted signals with **different adding time** between the increasing and decreasing amplitude regions

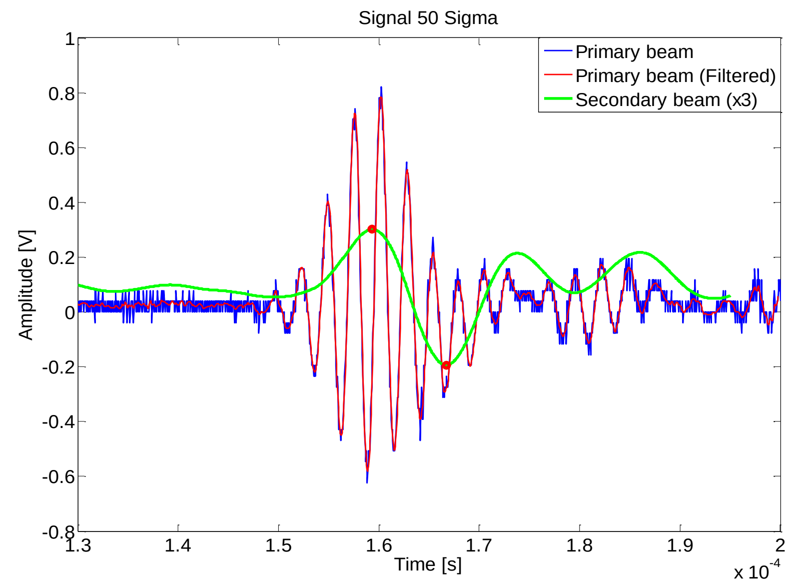


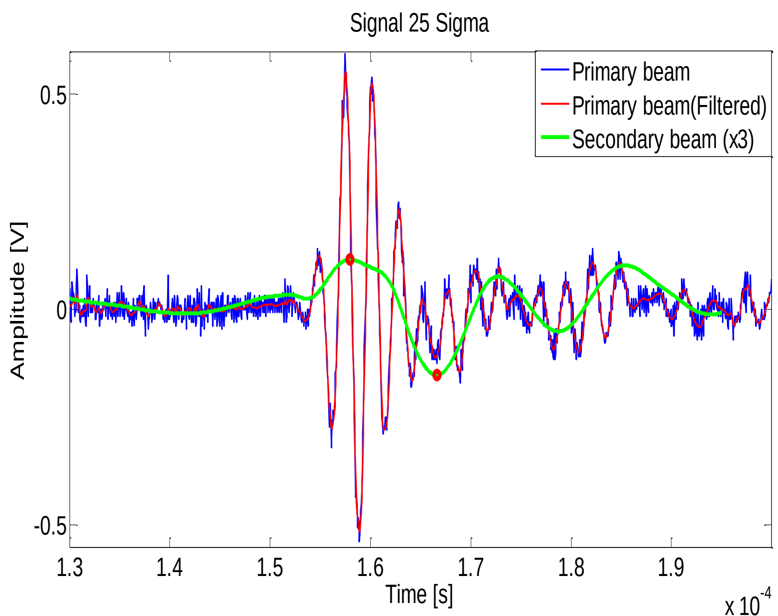
- Emitted signal is studied in order to control generation process of bipolar pulse
  - Which is the influence of sigma and of the length of the signal in final results?

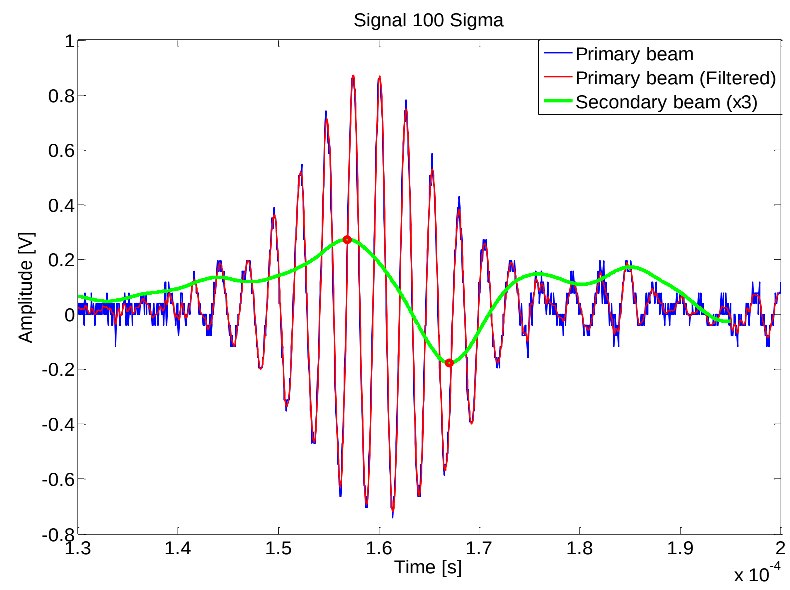
Studies with Parametric Sources (Shape)

- Comparison between the different signals with different widths (sigma):
  - Time between maximum and minimum shown in the table
  - Width of bipolar pulse increases with sigma, as expected (sigma 25 problematic due to the small energy content)

Signal Sigma	25	50	100	200
Δt	7 - 8 μs	7,4 μs	10 μs	11 μs



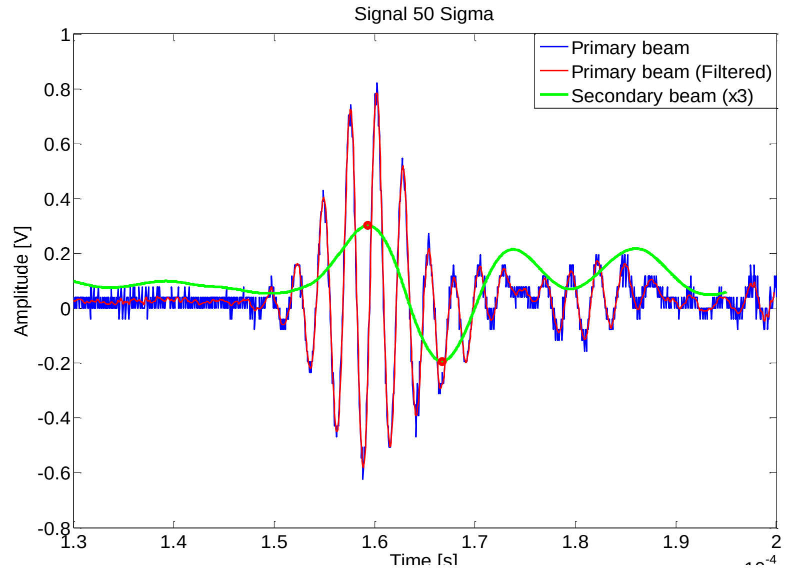


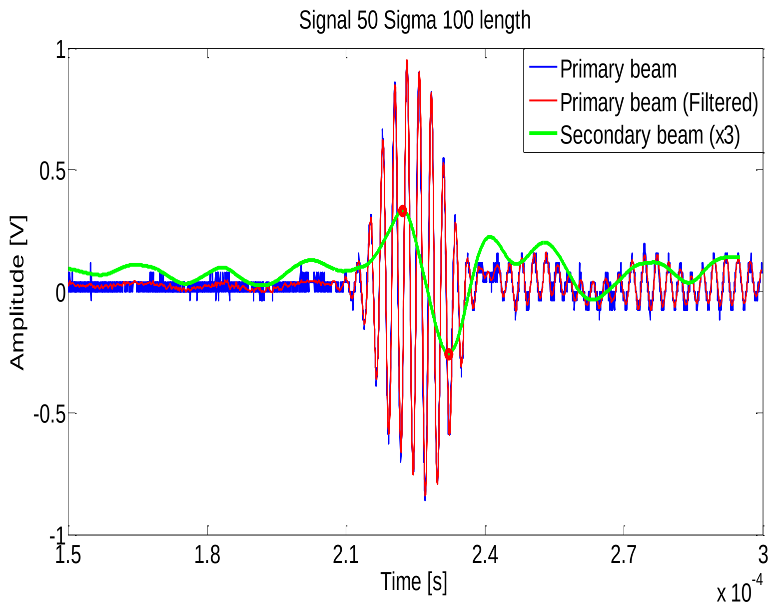


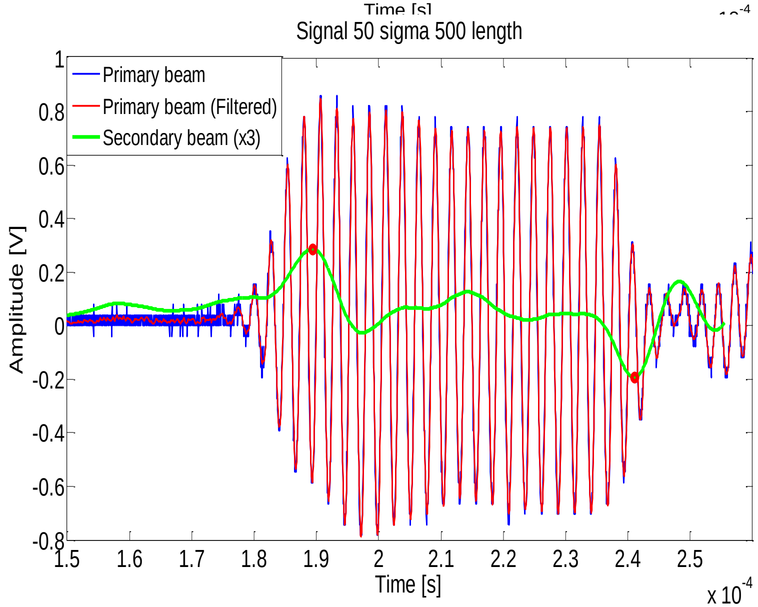
Studies with Parametric Sources (Shape)

- Comparison between the different length signals:
  - Time between maximum and minimum shown in the table
  - The separation of the positive and negative pulse is clearly observed in the 500 length (50 μs) signal

Signal	Short signal	100 length	500 length
Δt	7,4 μs	9,9 μs	52 μs

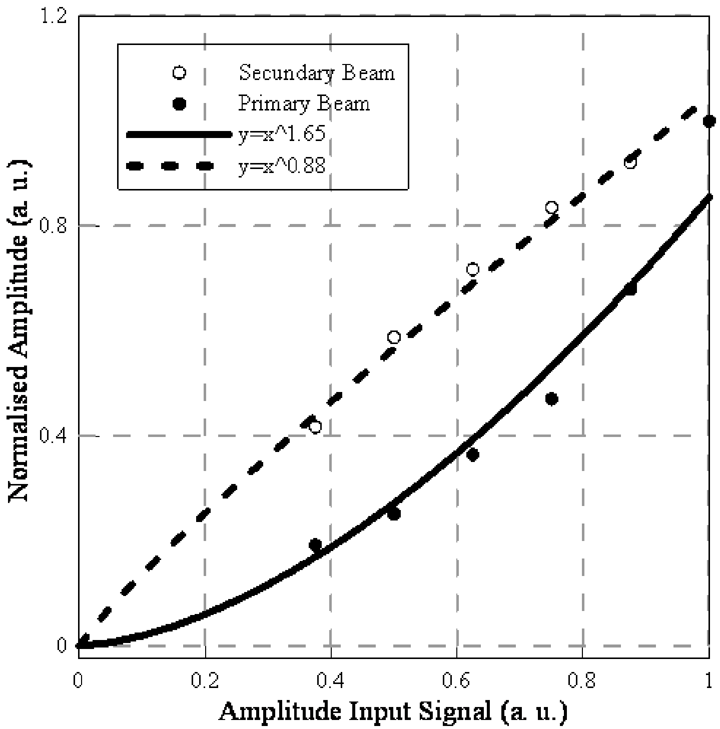


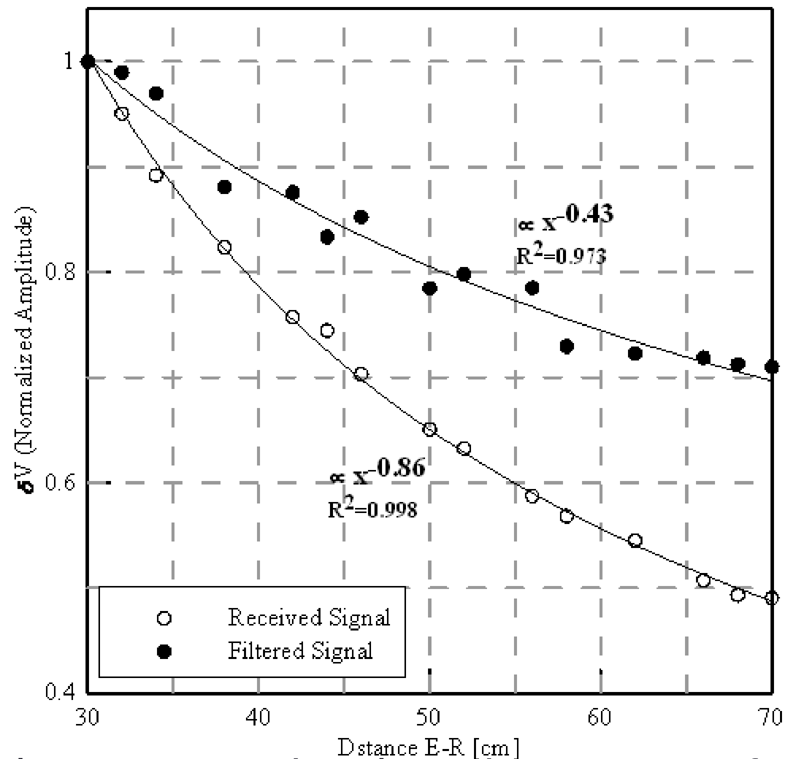




Studies with Parametric Sources (Amplitude)

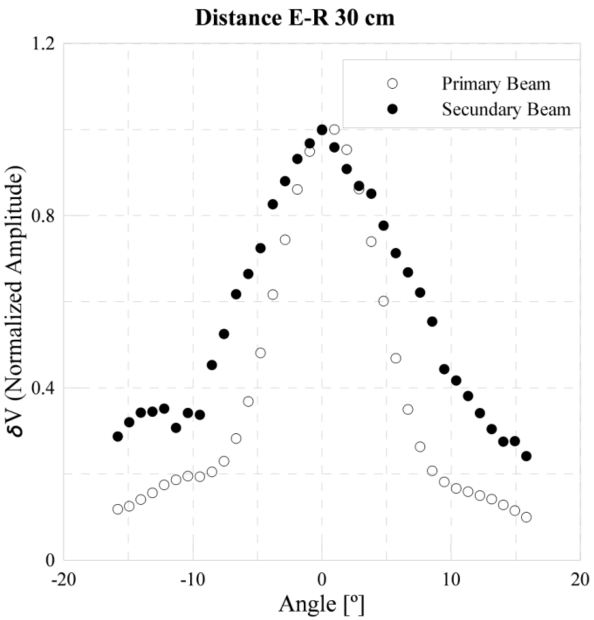
Relationship between the amplitude of the primary and the secondary beam:

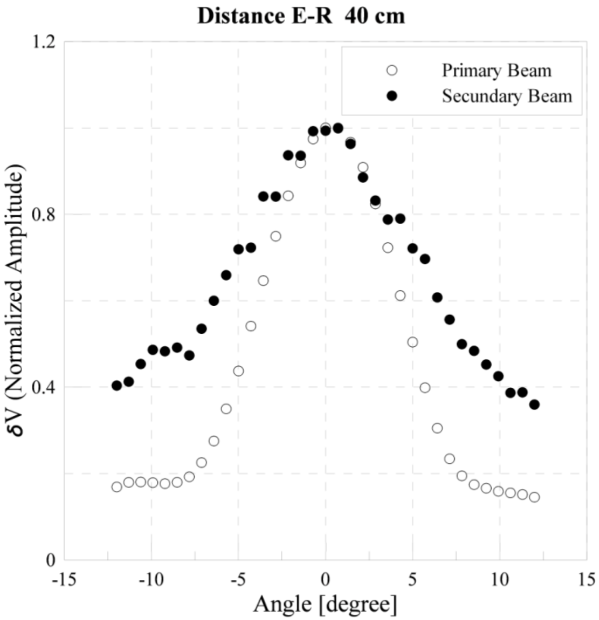


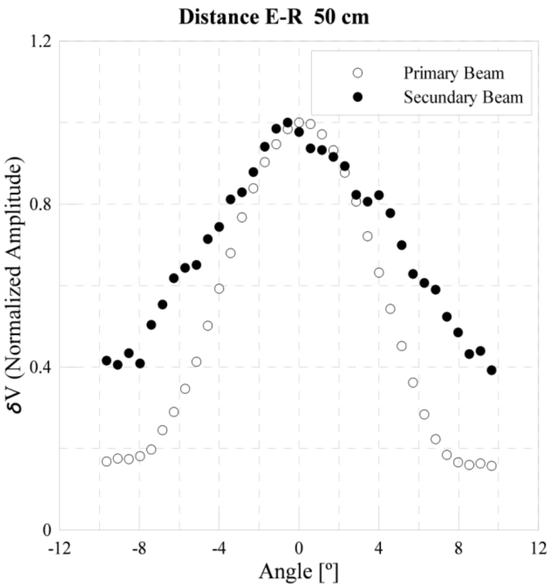


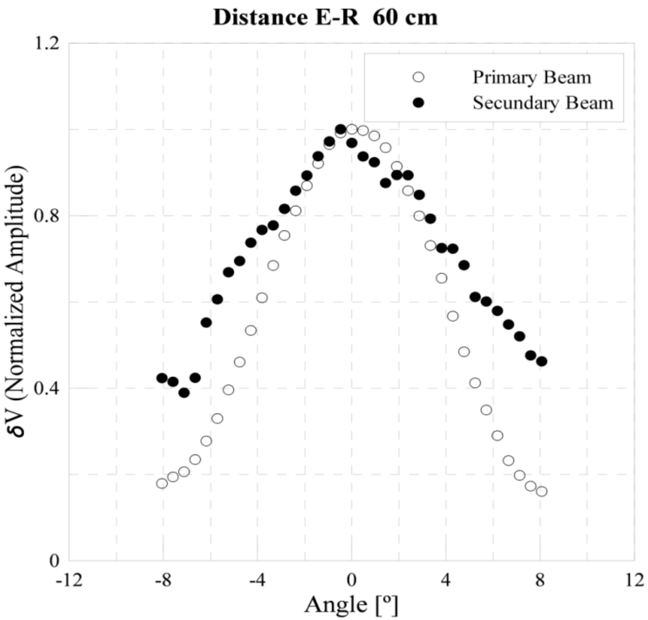
- The amplitude of the secondary beam is almost proportional to the square of the amplitude of the primary beam.
- For short distances the attenuation of the secondary beam is much lower than the primary one. Parametric generation is produced in the medium.
- At distances of about 1 m the amplitude of the bipolar pulse is of the order 10^{-3}-10^{-2} with respect to the amplitude of the primary beam.
- At distances larger than a few hundred meters the bipolar pulse is dominant.

Studies with Parametric Sources (Directivity)

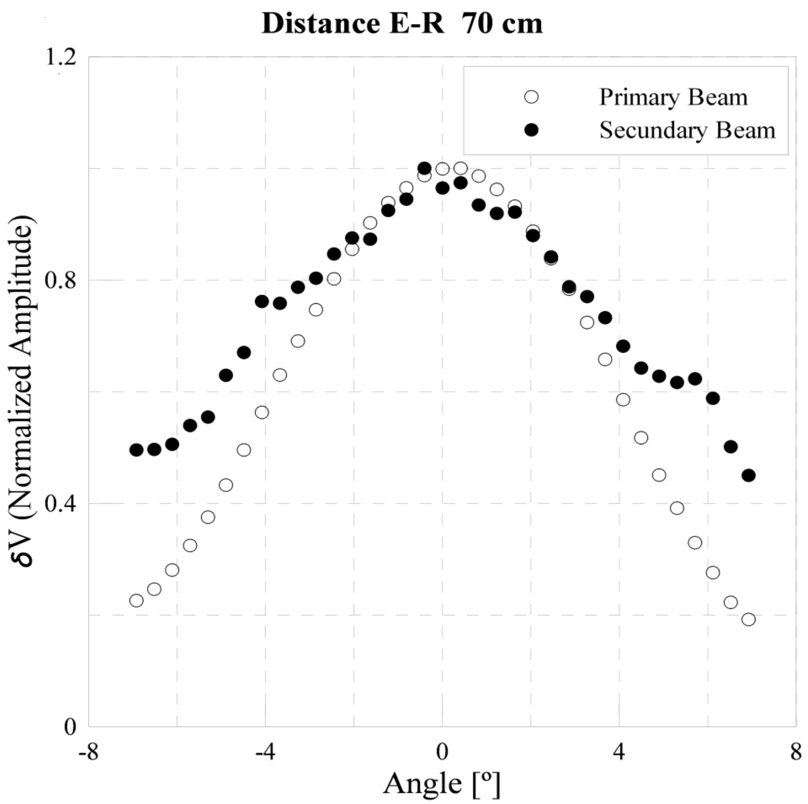








Studies with parametric sources (Directivity)



- Directivity of the secondary bipolar pulse is similar to the directivity of the primary beam
- The whole study done for the case of a transducer with cylindrical symmetry shows that it is possible to build compact neutrino calibrators using the parametric acoustic sources effect.

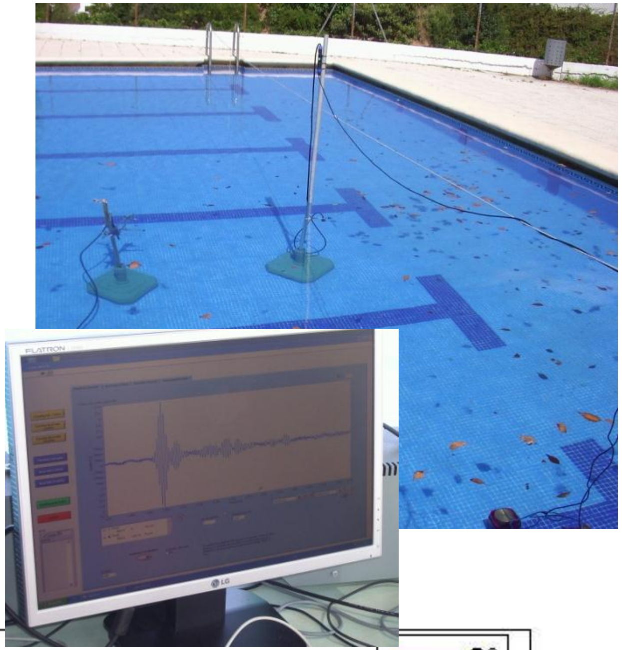
- Measurements at larger distances:
  - Test in a swimming pool (7.5 m)
  - Unfortunately, lot of electronic and mechanic noise makes the analysis difficult
  - Bipolar pulses observed, but more checks needed for a higher reliability.

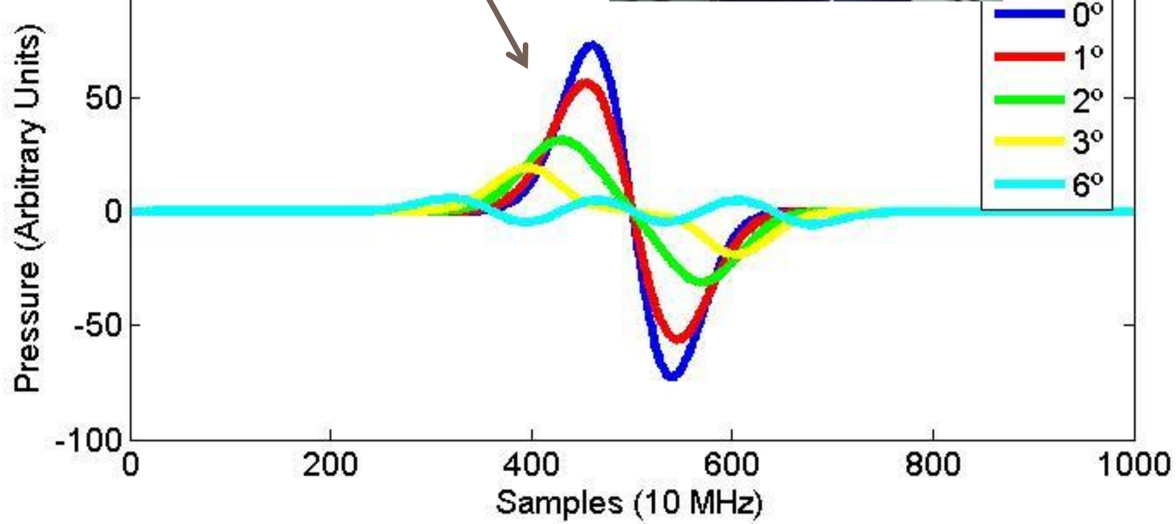
- Transducer studies for a more efficient parametric generation
  - Composite piezoceramics

- Build a compact array giving a 1º pancake directivity:
  - Using 3 of this transducers with a 20 cm separation

- In situ tests of these compact transmitters

Future steps





Conclusions

- We have shown that acoustic parametric sources seems a very good technique to generate neutrino like signals with good directivity using a cylindrical transducer (or a compact array with a few of them).
- Moreover, we are developing a compact acoustic transmitter that could be used for calibration in underwater neutrino telescopes. In situ tests are expected for next year.
- It would be desirable to improve the efficiency of the bipolar pulse generation. For this, a study of different transducers options is foreseen. Ideal solution: to use just one single (and cheap) transducer, which in addition can emit at low frequency for classical calibration as well.