Inferring the Temperature of Bubble Chambers

By Measuring the Speed of Sound

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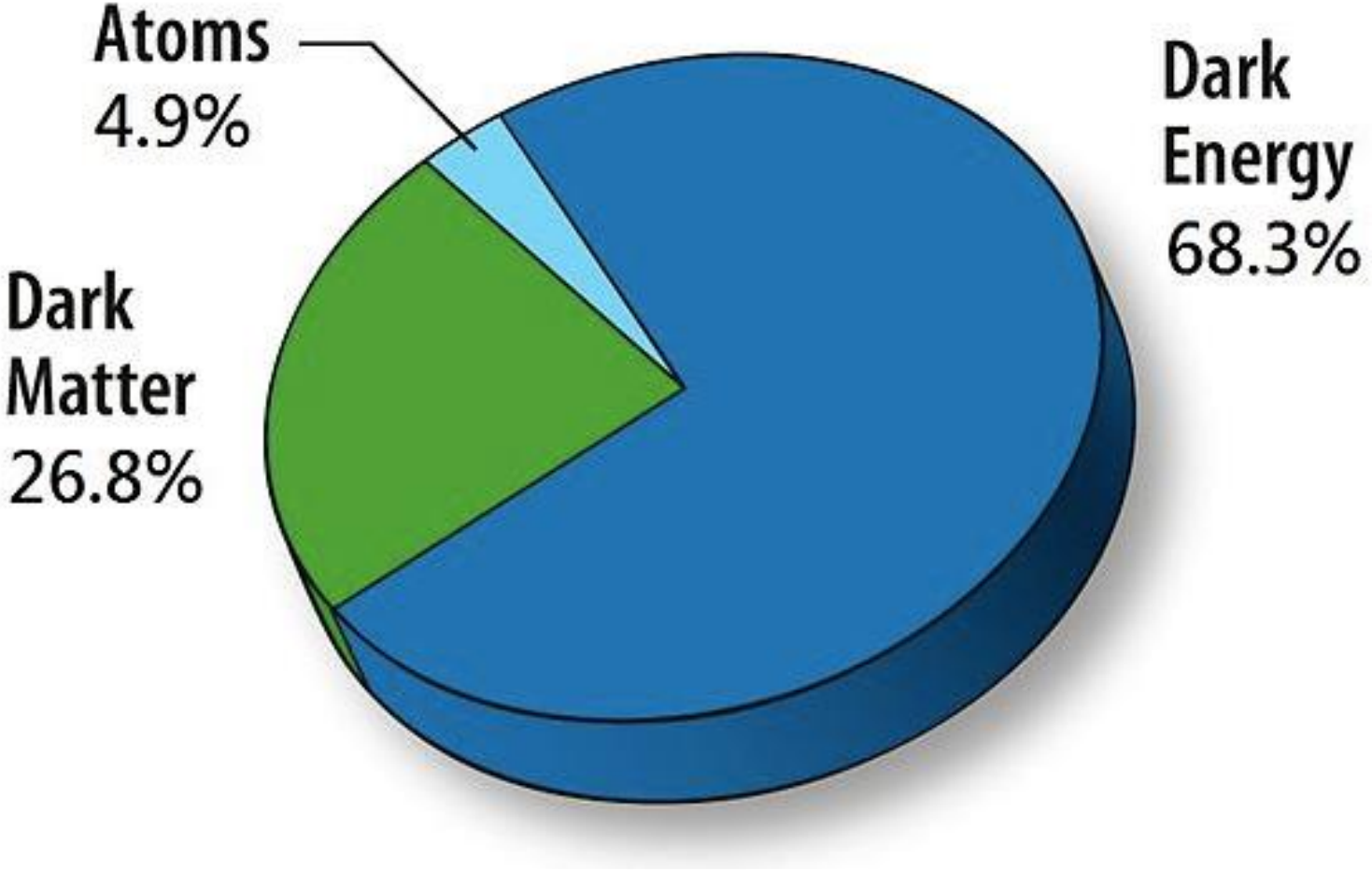
Dark Matter

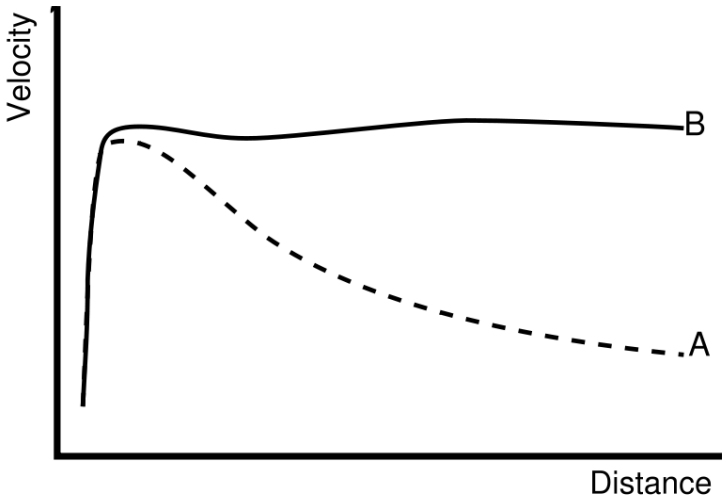

Atoms
4.9%
Dark
Energy
68.3%
Dark
Matter
26.8%

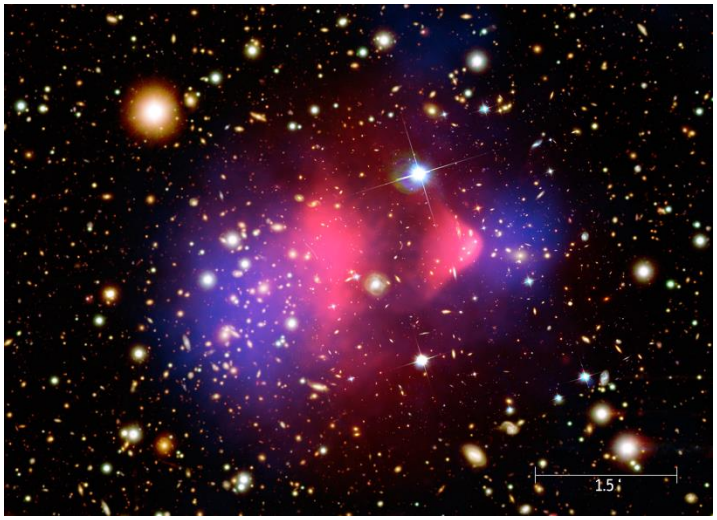
Dark Matter

"nonluminous material that is postulated to exist in space"

- Galaxy Rotation Curves
- Gravitational Lensing ("Bullet Cluster")
- Cosmic Microwave Background

→ ***Missing Mass***

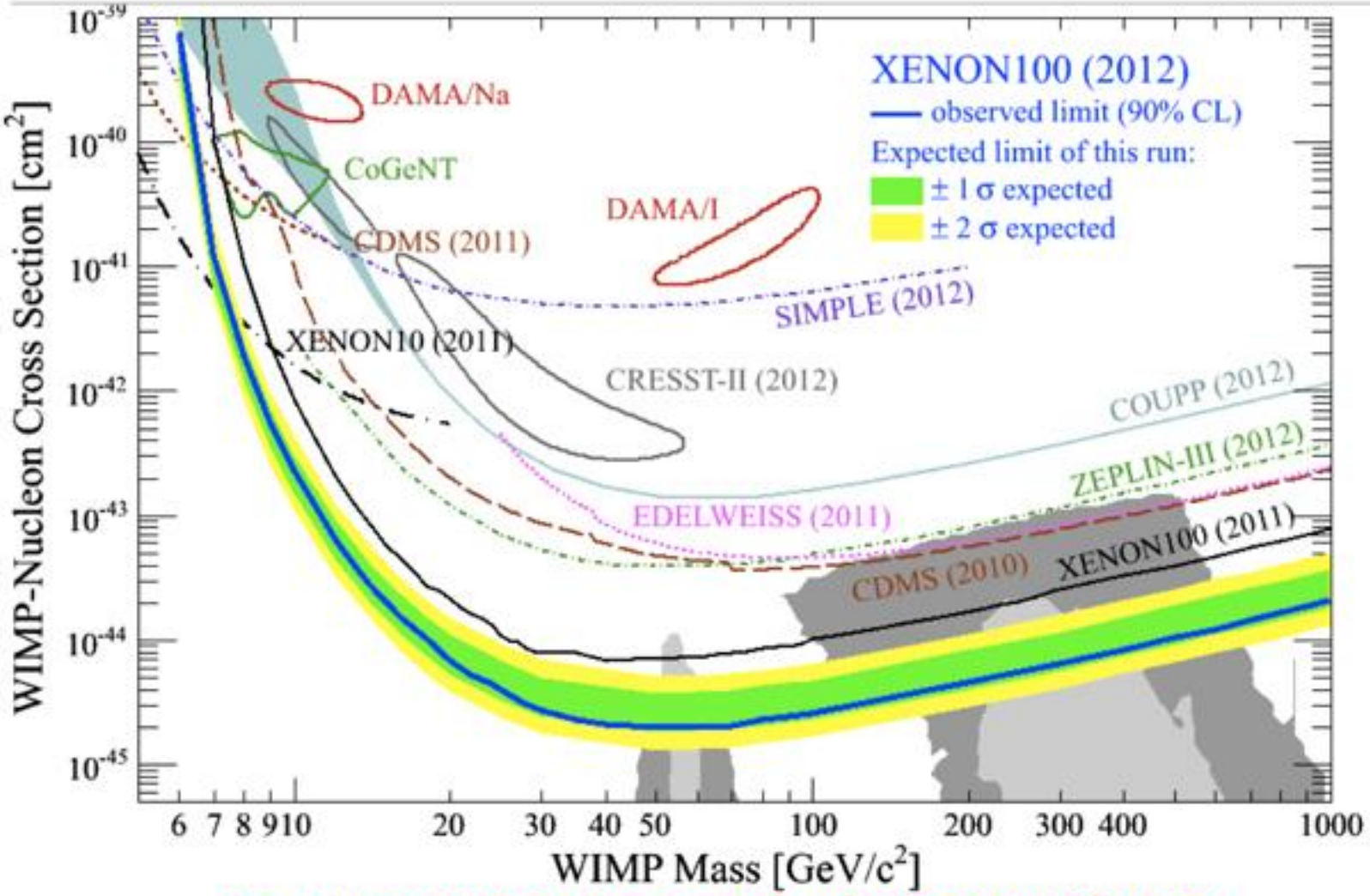




Dark Matter Detection

- WIMPs
  - "Weakly interacting massive particles"
- Indirect Detection

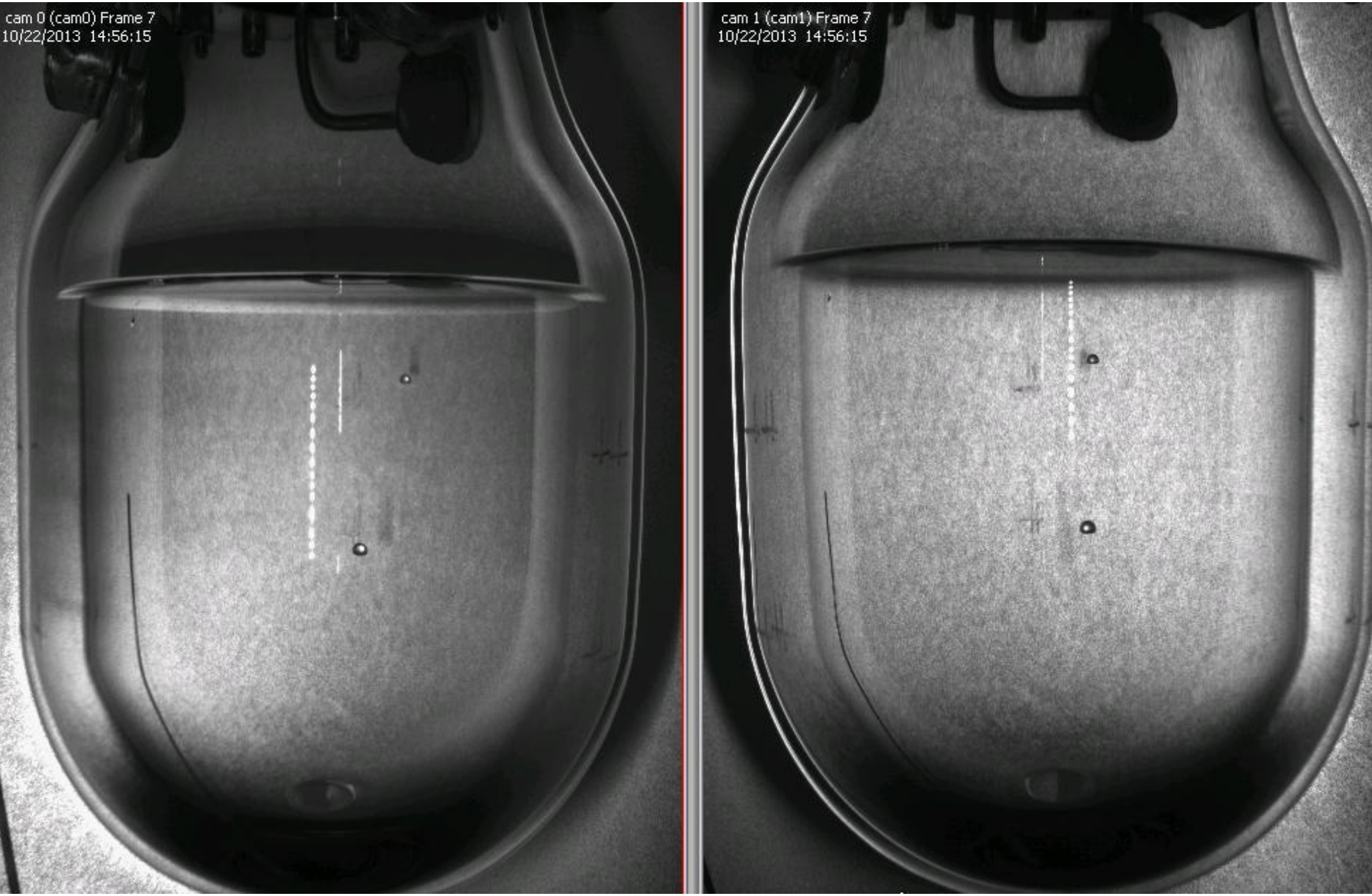
- Direct Detection



Upper Limit (90% C.L.) is 2 x 10^{-45} cm^2 for 55 GeV/c^2 WIMP

Bubble Chambers

- Super Heated Fluid
- Particle Interaction → Nuclear Recoil
- Dark Matter Detection?

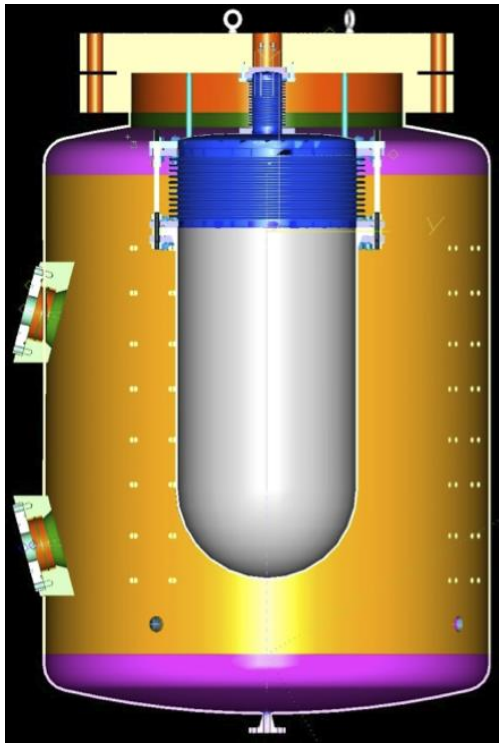

cam 0 (cam0) Frame 7
10/22/2013 14:56:15
cam 1 (cam1) Frame 7
10/22/2013 14:56:15

Temperature Problem

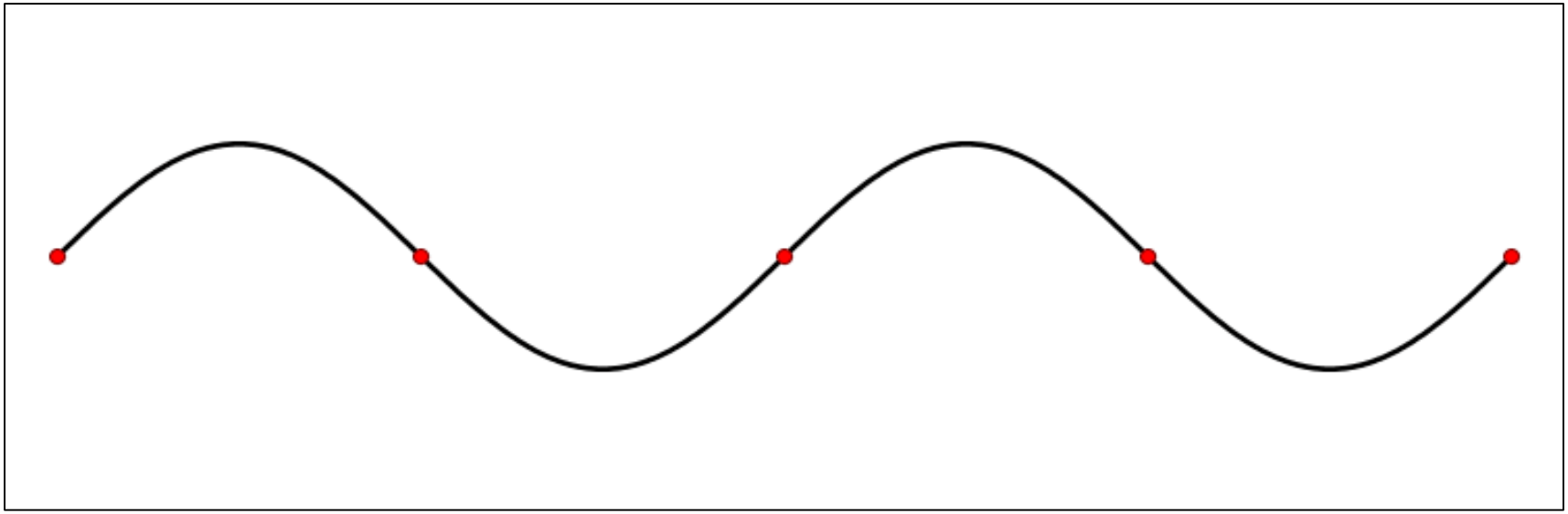
- Temperature crucial parameter
  - Energy threshold for nuclear recoil

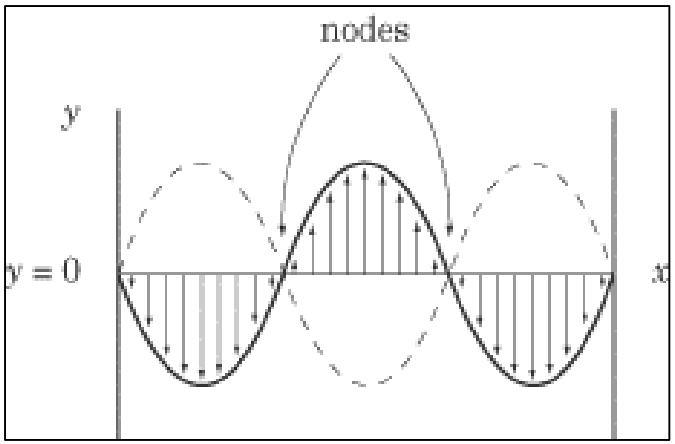
- Cannot insert temperature probe
- Measure temp of fluid around chamber
  - → Bigger chambers, more error

What do we do???

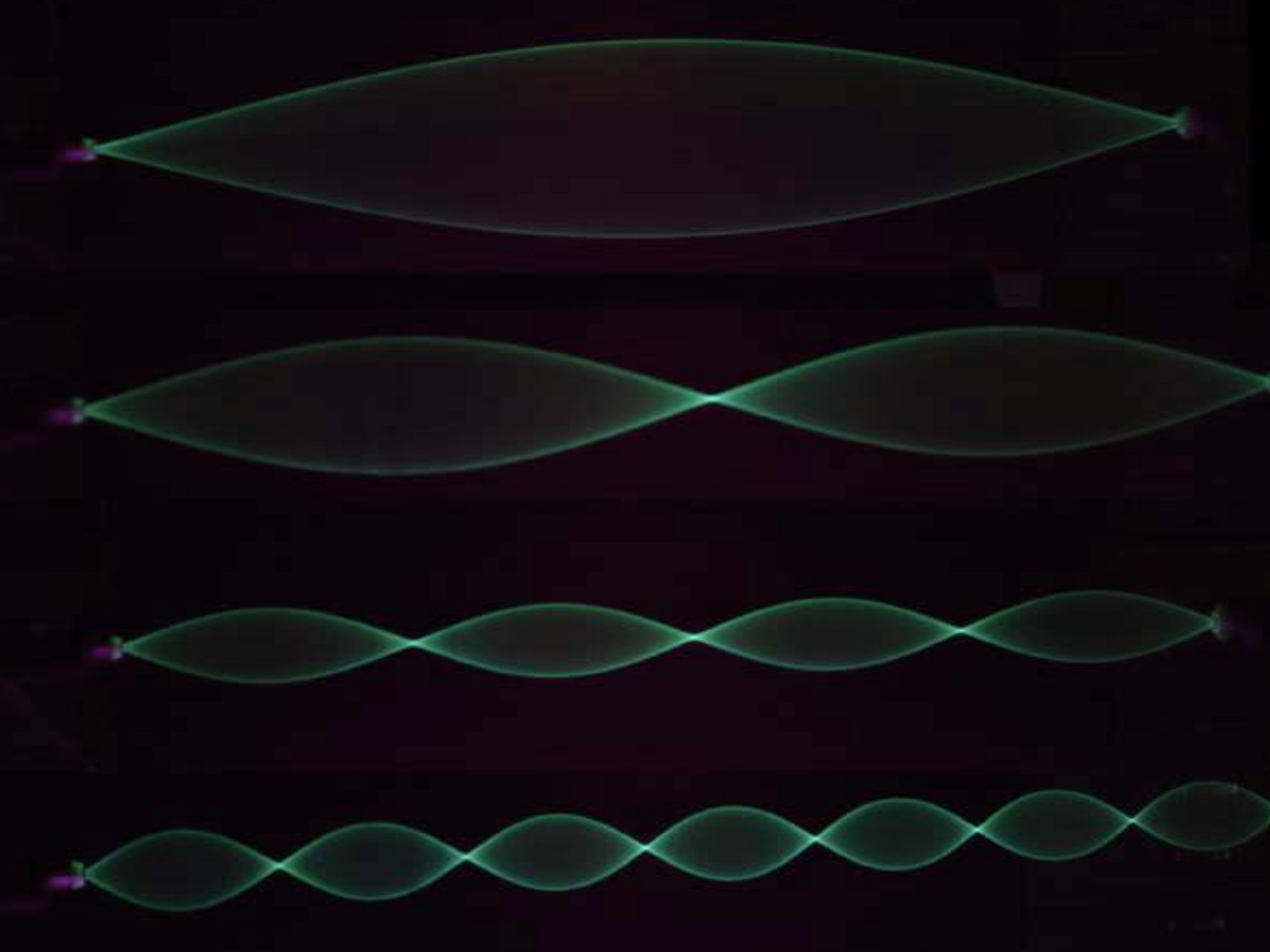


Standing Wave





Resonance

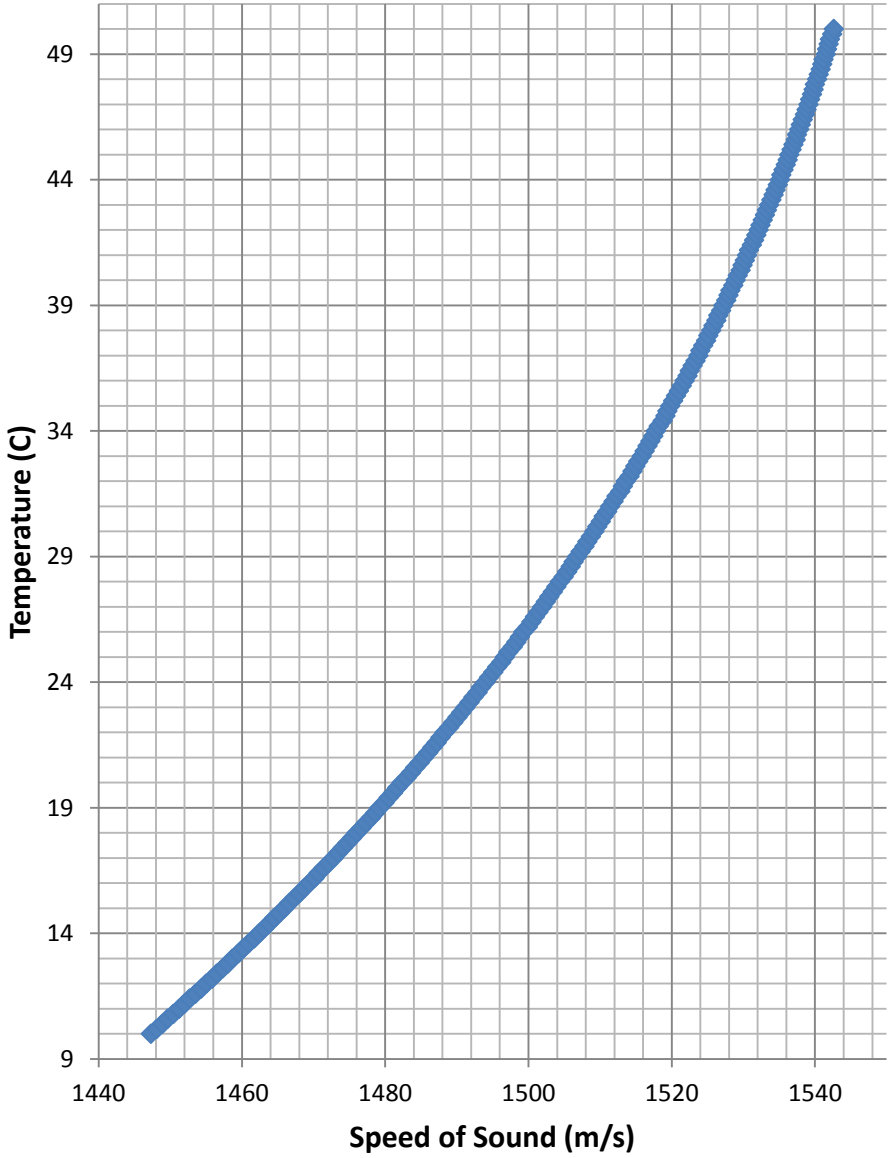


Resonance Frequency!

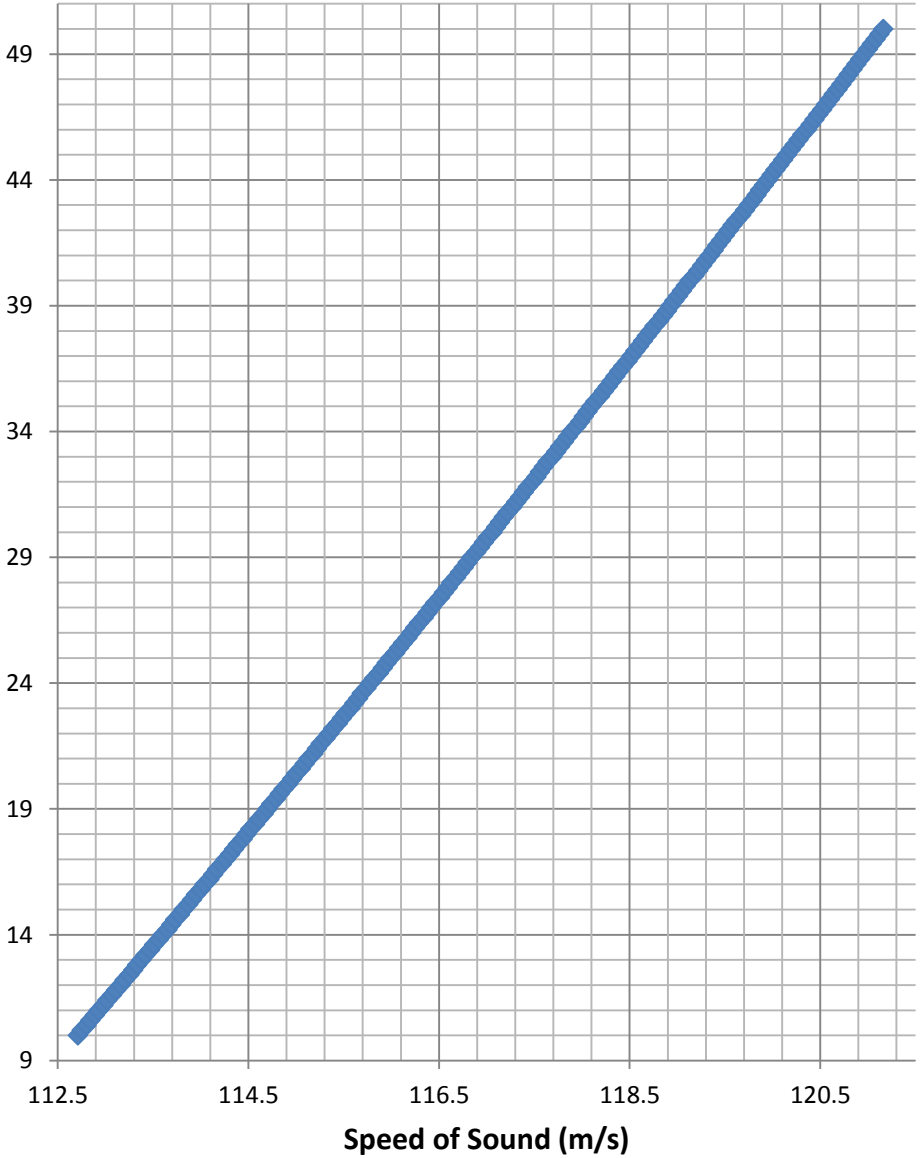
Piezoelectric microphones detect acoustic pressure of system

→Temperature
→ Density
→ Speed of Sound
→ Resonance Frequency

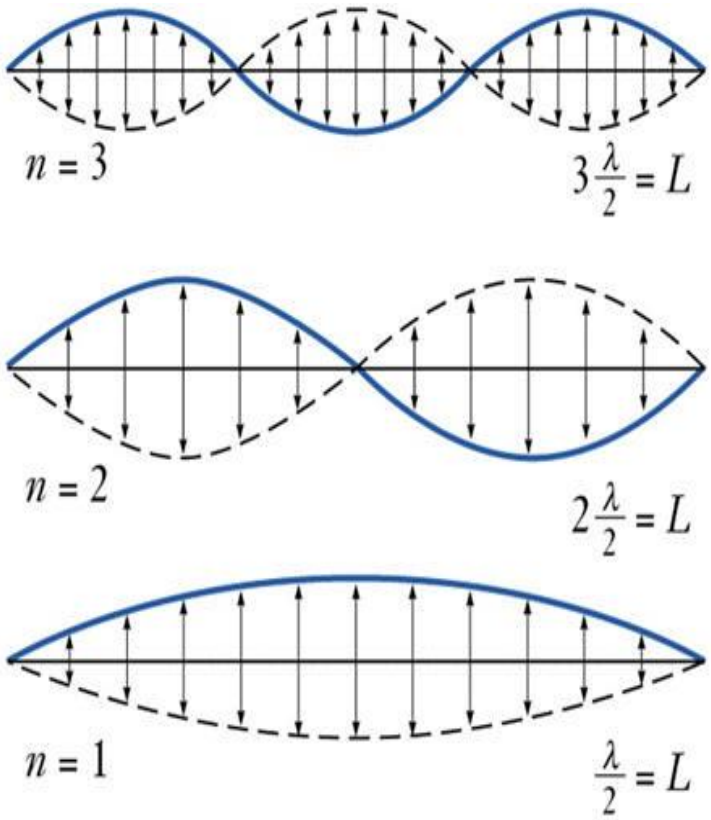
Temperature vs Speed of Sound in Water at 1 atm



Temperature vs Speed of Sound in Octafluoropropane at 1atm



$$f = \frac{v}{2 * pi}\sqrt{\left(\frac{\ell}{L_x}\right)^2 + \left(\frac{m}{L_y}\right)^2 + \left(\frac{n}{L_z}\right)^2}$$

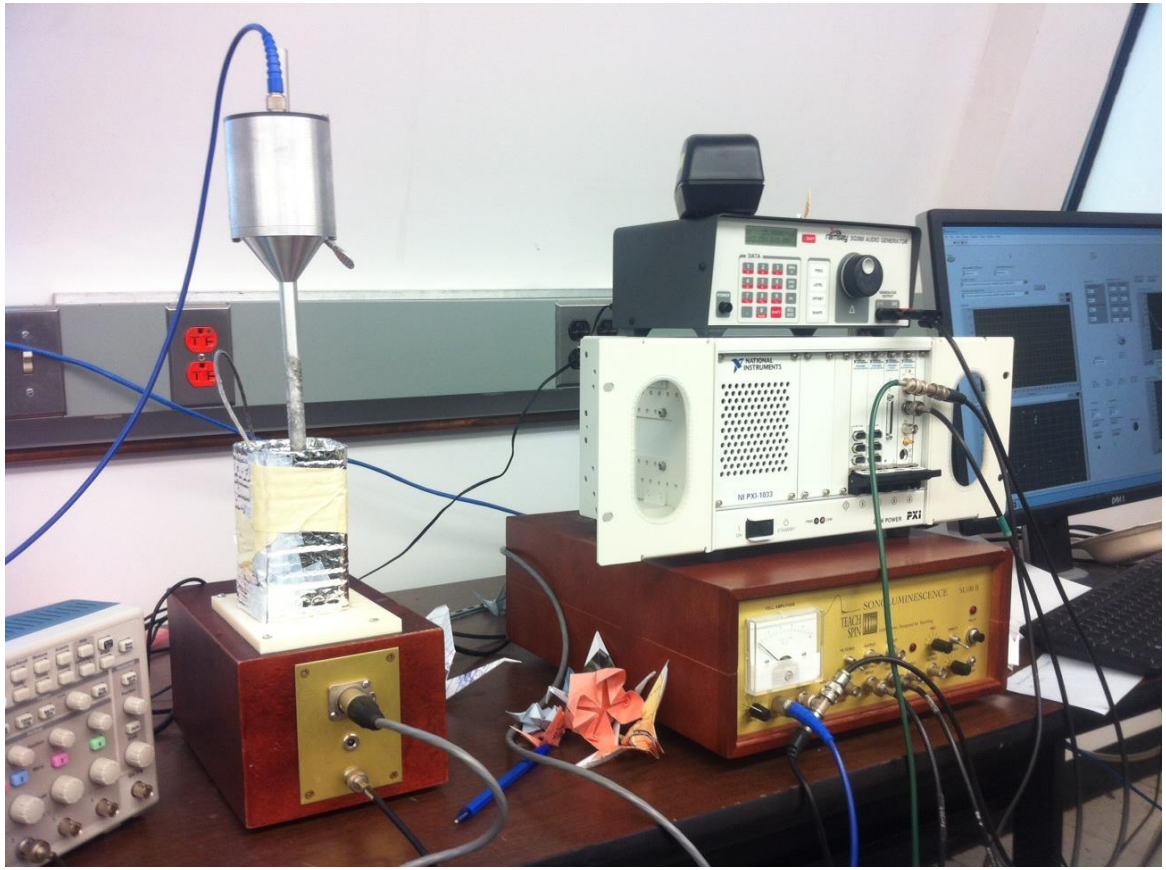


f = resonance frequency

v = speed of sound

l,m,n = # half wavelengths in x,y,z direction

Lx,Ly,Lz = dimensions in x,y,z direction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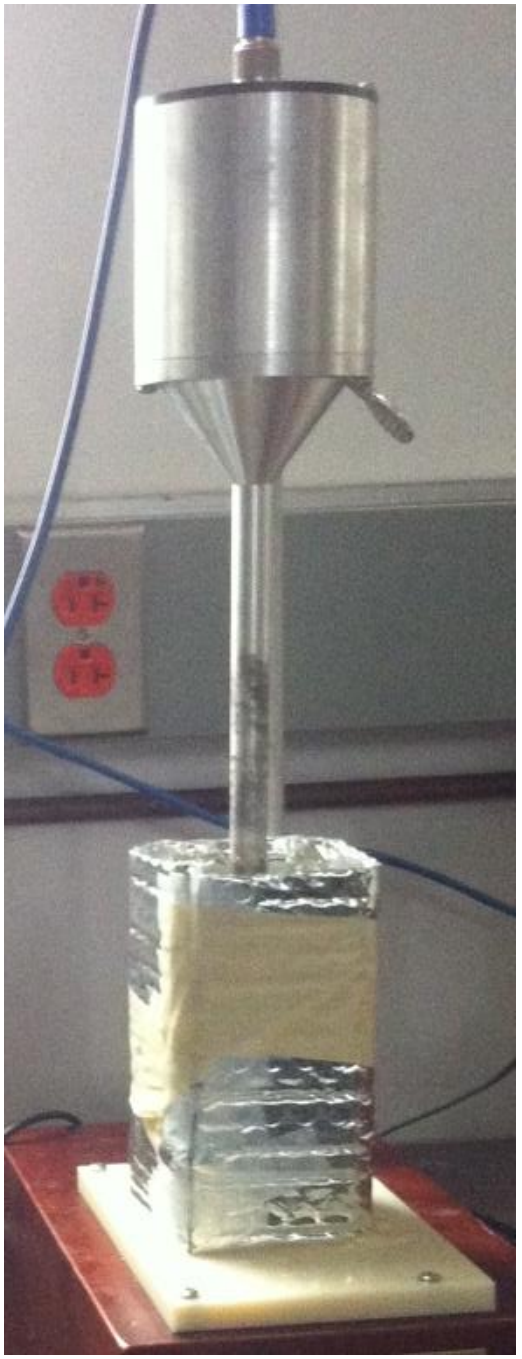
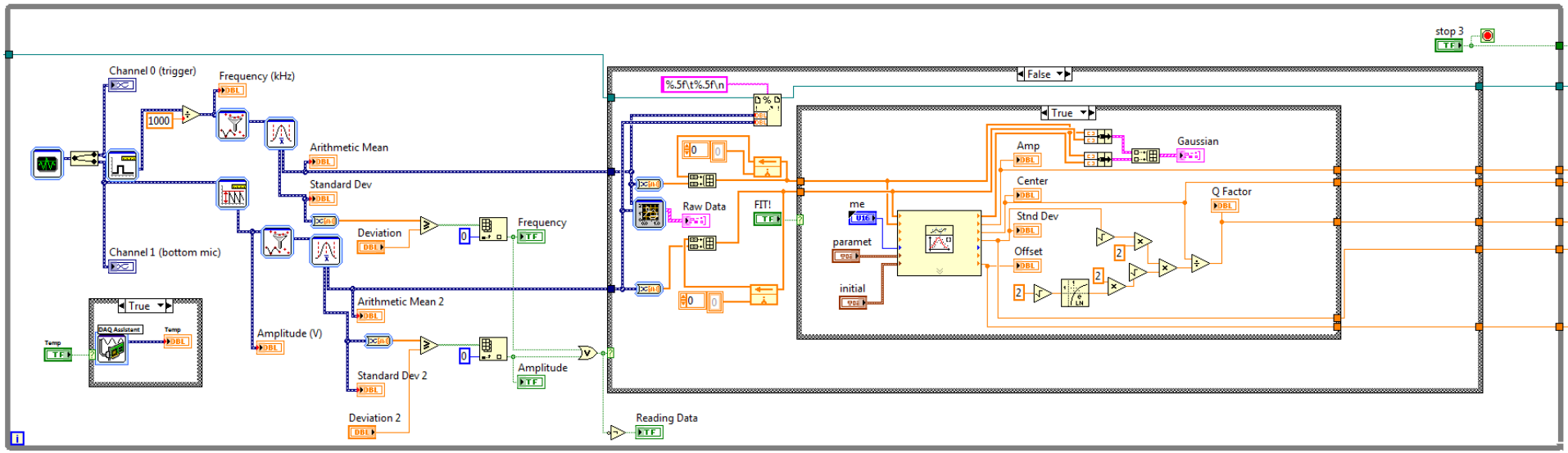



Channel 0 (trigger)
Frequency (kHz)
1000
Arithmetic Mean
Standard Dev
Deviation
Frequency
Channel 1 (bottom mic)
True
DAQ Assistant
Temp
Amplitude (V)
Arithmetic Mean 2
Standard Dev 2
Deviation 2
Amplitude
Reading Data
%.5f\t%.5f\n
Raw Data
FIT!
False
True
me
paramet
initial
Amp
Gaussian
Center
Stnd Dev
Offset
Q Factor
stop 3

data operation (0:open)
create

fit operation (0:open) 2
create

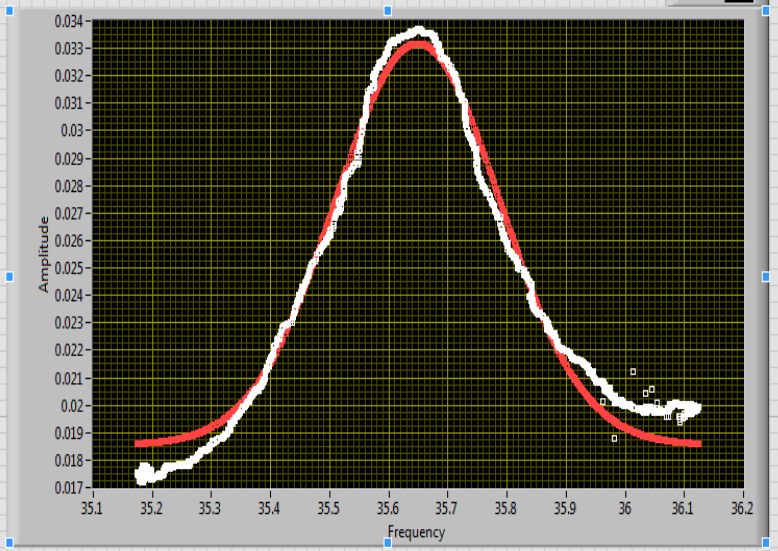
file path XY data
C:\Users\madeline\Documents\LabVIEW Data\TestData46.txt

STOP

file path temp/gaus funct
C:\Users\madeline\Documents\LabVIEW Data\FitData46.txt

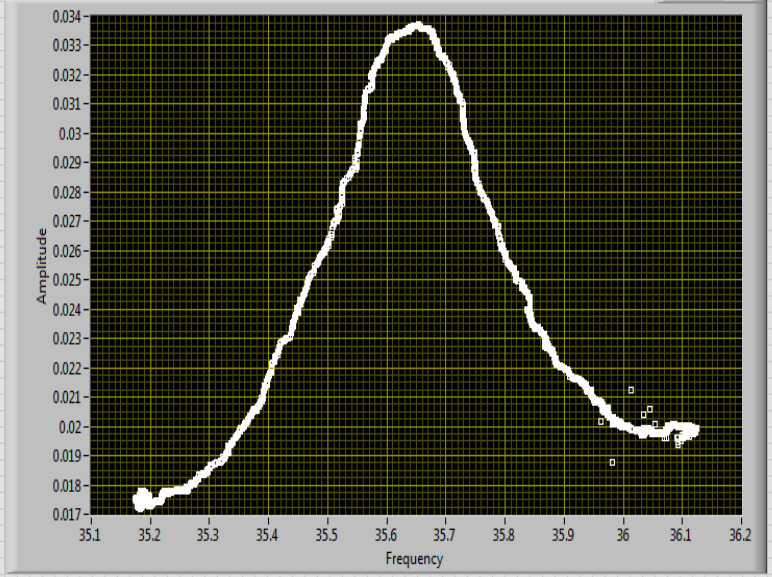
Plot 0
Plot 1

Gaussian



Raw Data

Plot 0



initial quess 2

initial amplitude
NaN

initial center
NaN

initial standard deviation
NaN

offset
NaN

parameter bounds 2

amp min
0

amp max
Inf

center min
-Inf

center max
Inf

deviation min
-Inf

deviation max
Inf

offset min
0

offset max
1

FIT!

method 2
Least Square

Q Factor
57.2755

Offset
0.018551

Amp
0.014620

Center
35.6487

Stnd Dev
0.139722

Frequency

Deviation
1.1

Arithmetic Mean
35.1795

Standard Dev
0.0811347

Amplitude

Deviation 2
1.003

Arithmetic Mean 2
0.0172368

Standard Dev 2
0.0018043

Reading Data

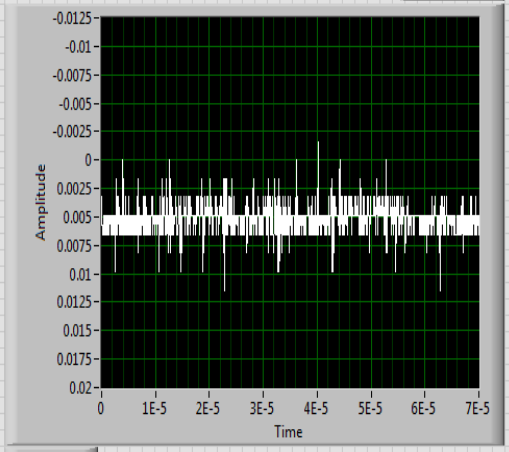
Amplitude (V)
0.014704359

Frequency (kHz)
35.1914414

Temp (C)
18.912

Channel 1 (bottom mic)

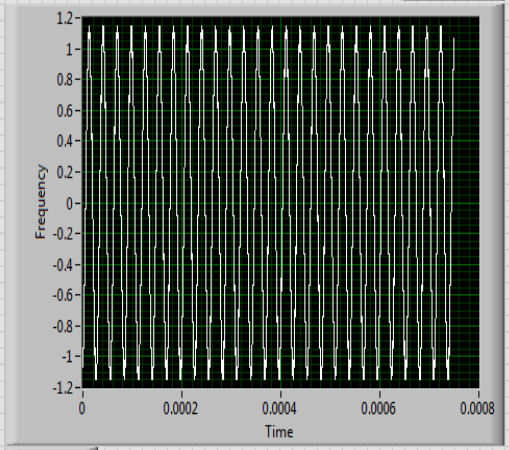
Plot 0



Time
Amplitude

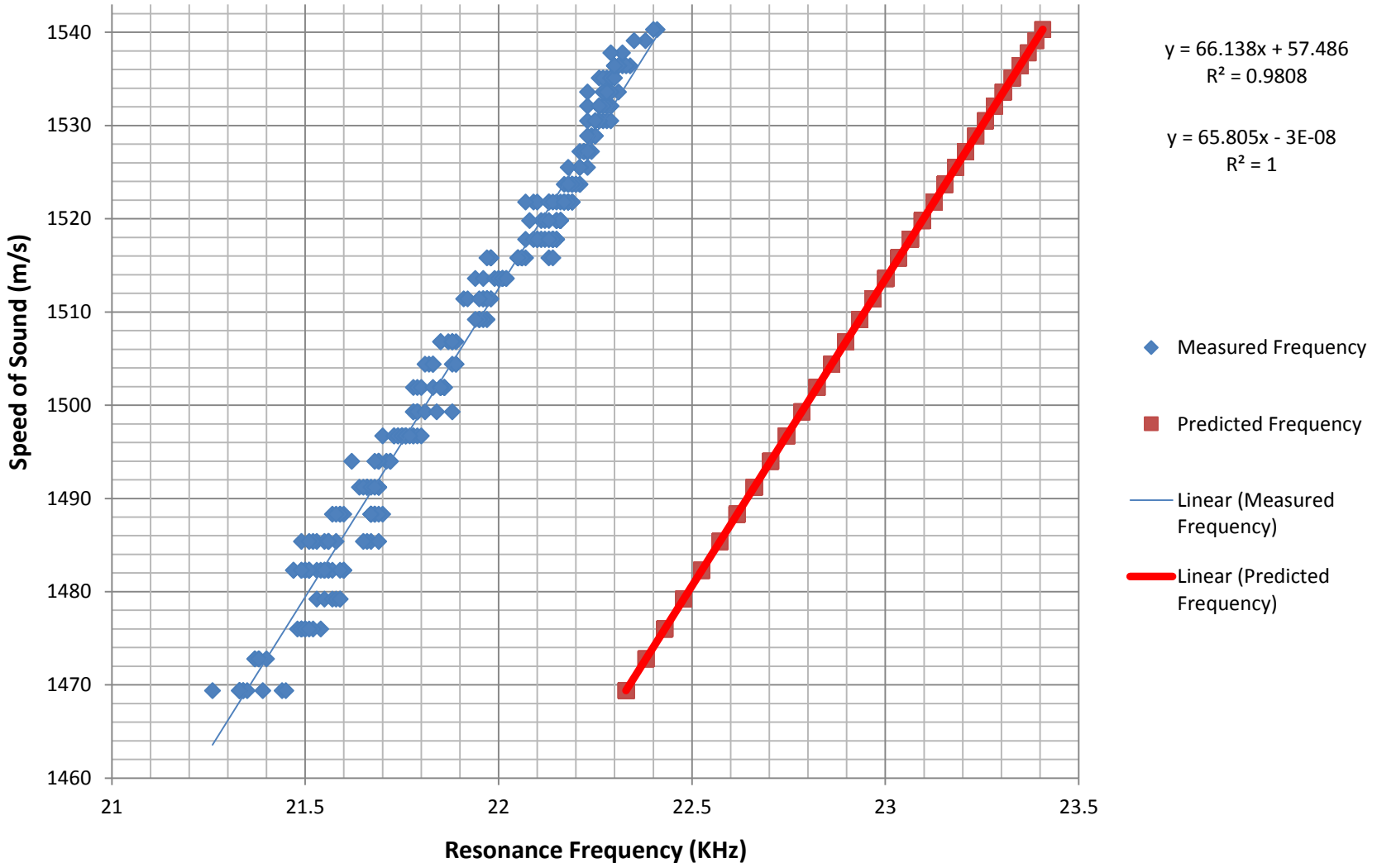
Channel 0 (trigger)

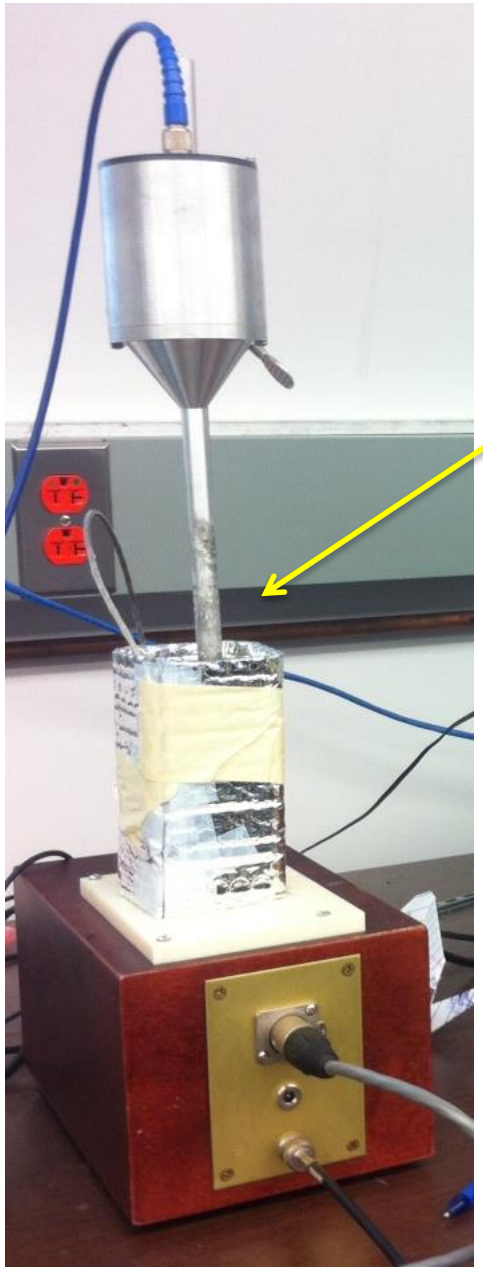
Plot 0



Time
Frequency

Speed of Sound vs Peak Resonance Frequency of a 112 Three Dimensional Standing Wave in water

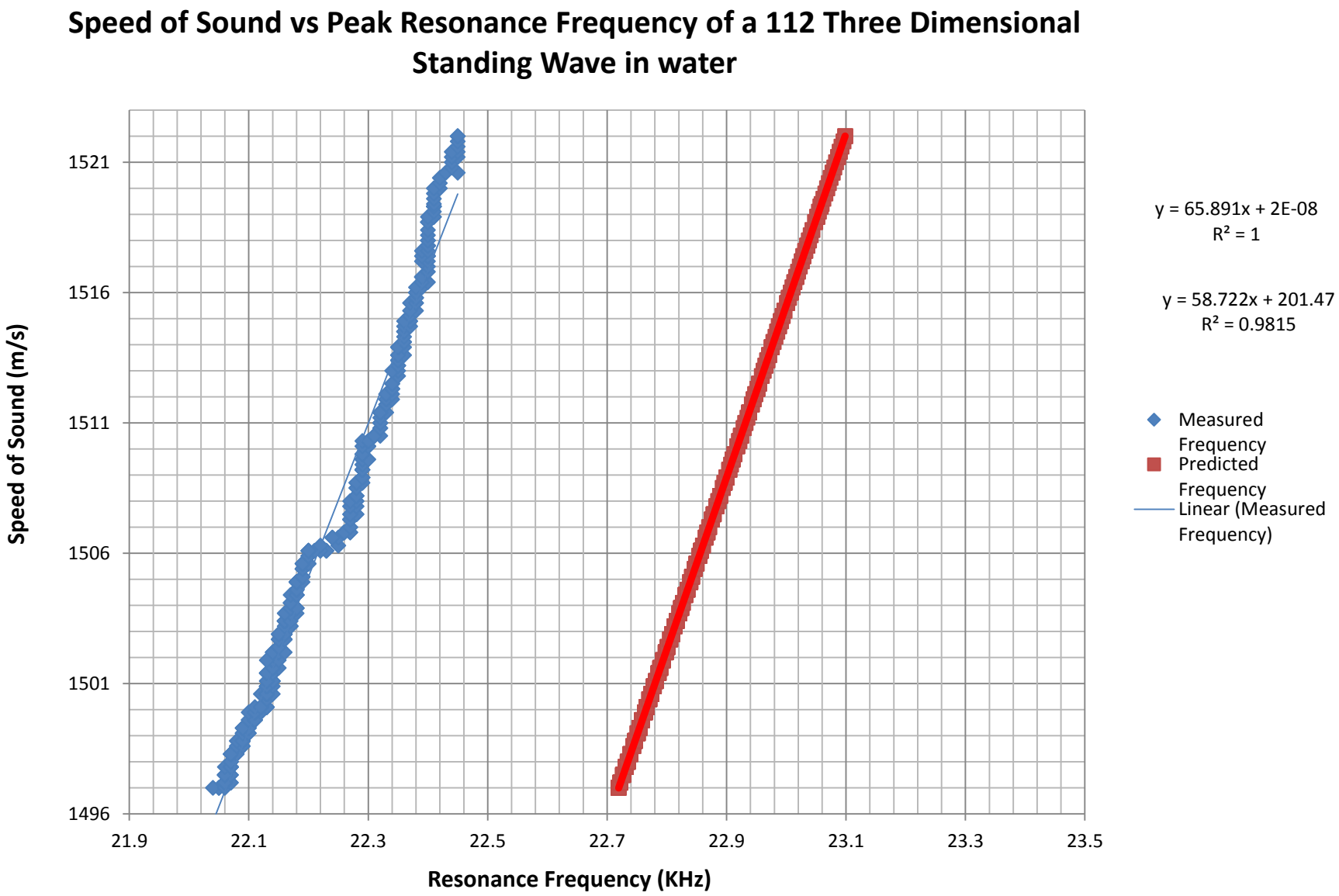




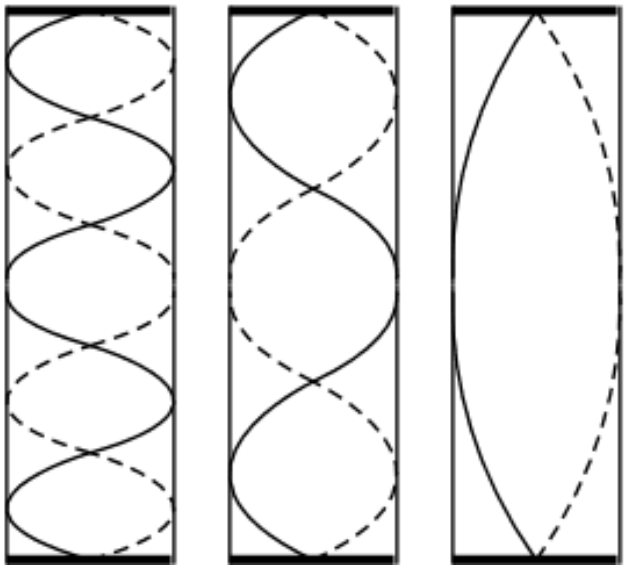
Scatter a result of shifting driver

This is clearly crooked

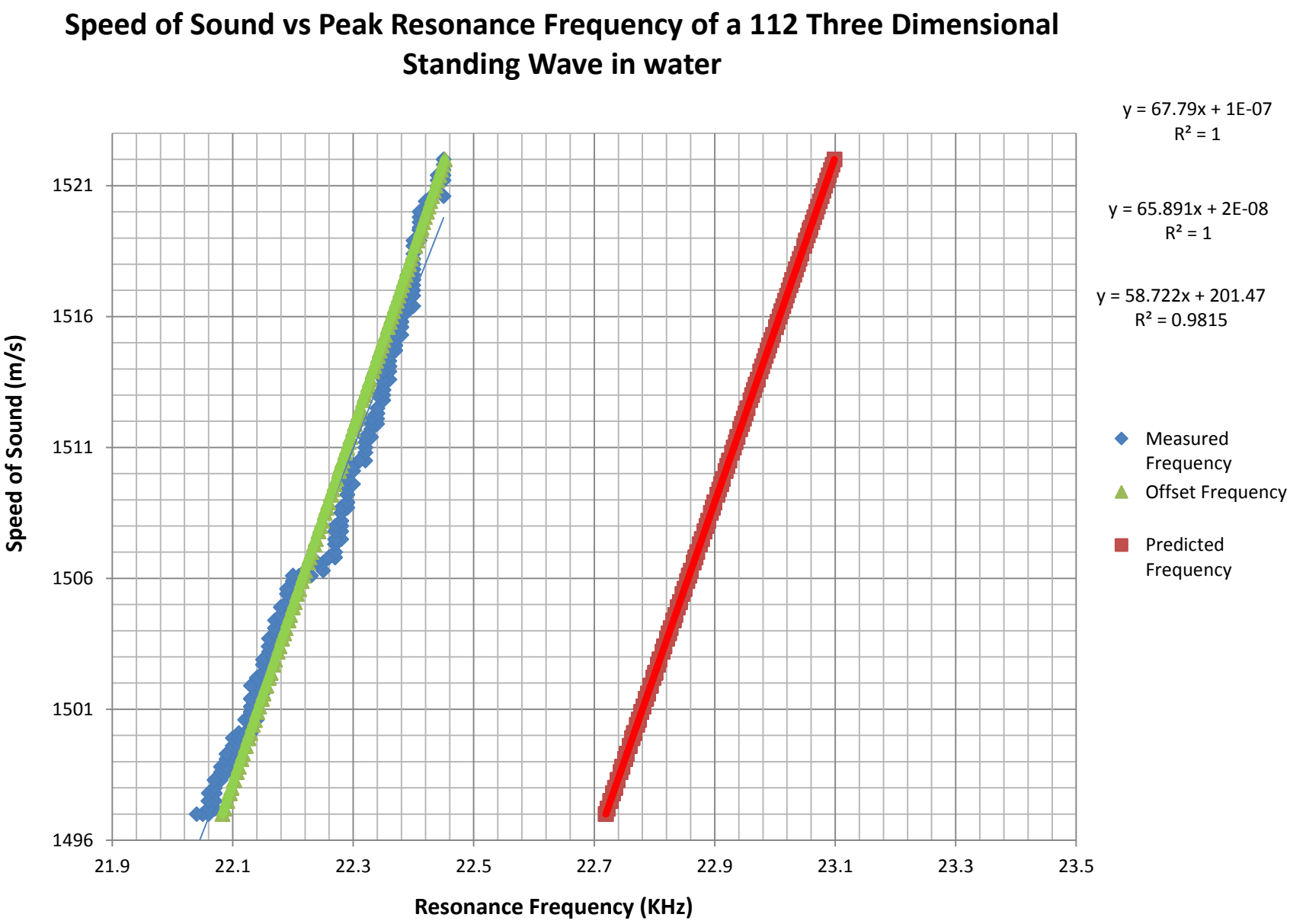
→ Correct by not changing the water during a test


Speed of Sound vs Peak Resonance Frequency of a 112 Three Dimensional Standing Wave in water
Speed of Sound (m/s)
1521
1516
1511
1506
1501
1496
21.9
22.1
22.3
22.5
22.7
22.9
23.1
23.3
23.5
Resonance Frequency (KHz)
y = 65.891x + 2E-08
R² = 1
y = 58.722x + 201.47
R² = 0.9815
Measured Frequency
Predicted Frequency
Linear (Measured Frequency)

$$f = \frac{v}{2 * pi}\sqrt{\left(\frac{\ell}{L_x}\right)^2 + \left(\frac{m}{L_y}\right)^2 + \left(\frac{n}{L_z}\right)^2}$$



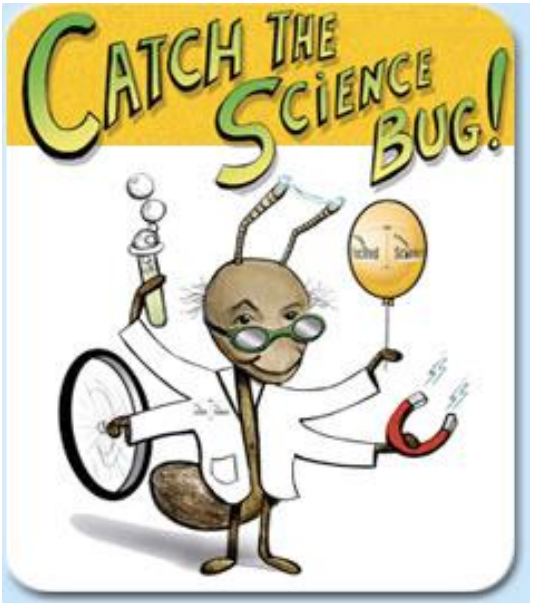
- Not perfectly rigid boundaries
  → *Open top!*
- Dimensions L_x, L_y, and **especially** L_z may vary
- Positions of **nodes** change


Speed of Sound vs Peak Resonance Frequency of a 112 Three Dimensional Standing Wave in water
y = 67.79x + 1E-07
R² = 1
y = 65.891x + 2E-08
R² = 1
y = 58.722x + 201.47
R² = 0.9815
Measured Frequency
Offset Frequency
Predicted Frequency
Speed of Sound (m/s)
1521
1516
1511
1506
1501
1496
21.9
22.1
22.3
22.5
22.7
22.9
23.1
23.3
23.5
Resonance Frequency (KHz)

Further Experimentation

- *Change geometry, fluid*
- *Greater precision, account for systematic errors*
- *Generate frequencies in chamber*

Personal Experience



- HUGE amount of independence
- Confidence!
  - To ask or not to ask
- How not to give up even when *nothing works*
  - ("Our code finally works! Oh, no wait, it doesn't work. Oh hey we fixed it! Oh nope now there's a new problem…")
- Bitten by the research bug?

Thank you!!!

- Mike Crisler
- Chris Stoughton, George Dzurickso, Ian Mcnair
- Eric Dahl, Pranjali Rathi, Brian Zhou
- Family, friends, teachers
- and…

Thank you for making this an unforgettable experience!