Ground Motion Studies at Fermi National Accelerator Laboratory

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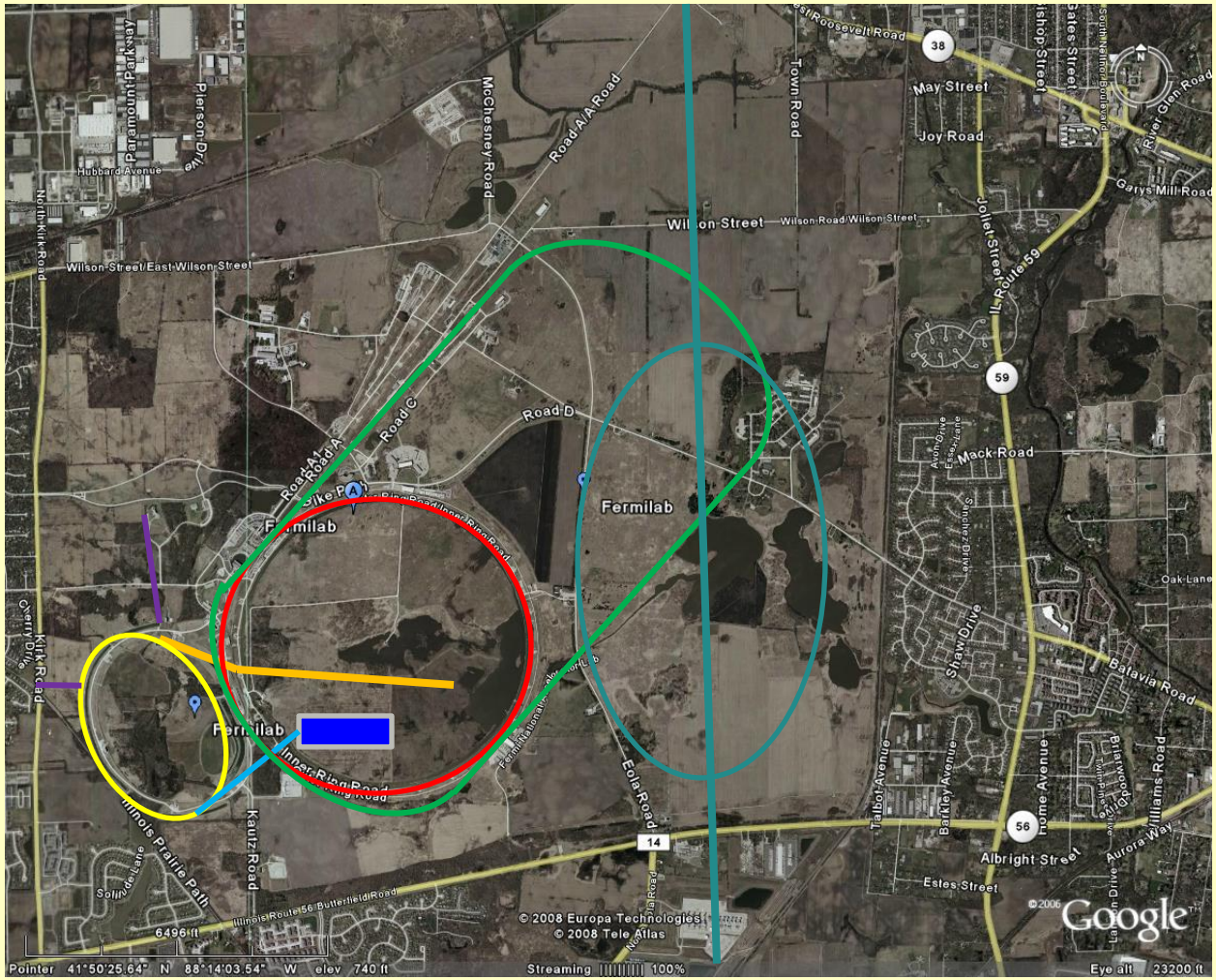
Fermilab

- 64 km (40 miles) due west of Chicago Illinois
- Site is 2752 hectares (6800 acres), 10 sections,
- The complex consists of the LINAC
- The booster and transfer line
- The Main Injector
- Tevatron 1 km radius 9 meters (30 feet) below surface
- There are two detectors one at B0 and one at D0
- There is a rail road at the eastern boundary of the lab

Future Plans at Fermilab



Project X an 8 GeV Superconducting LINAC

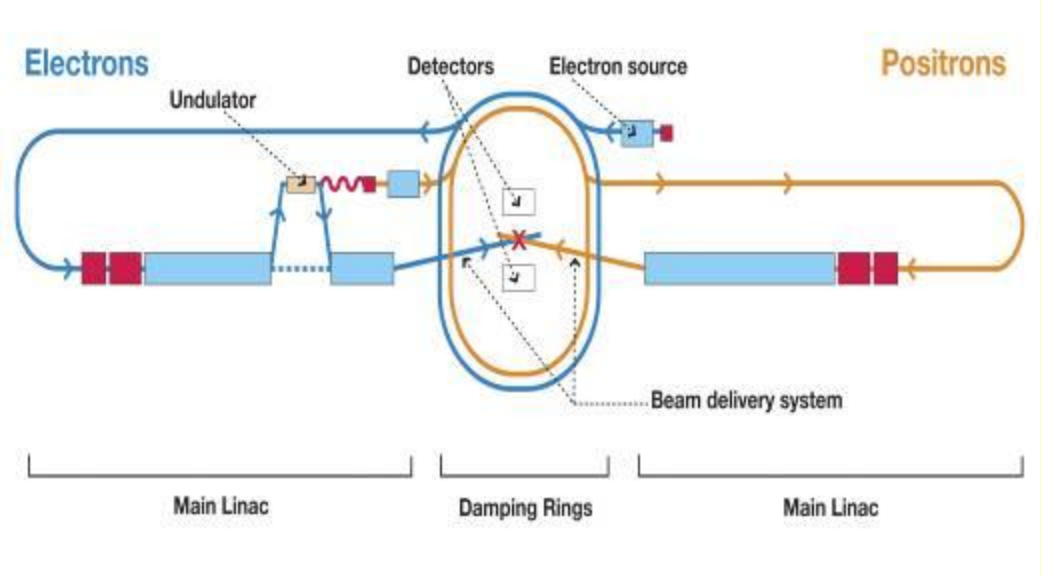
Intense ν beams to NUMI 890 km north and DUSEL 1480 km west

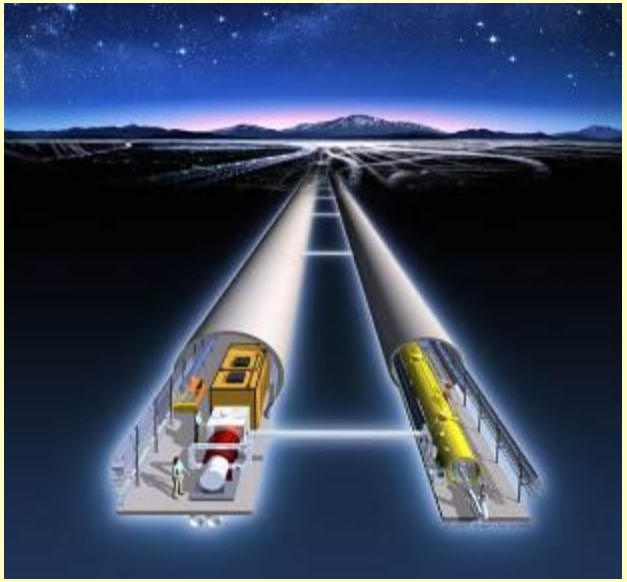
Muon Cooling test facility

Muon Collider

International Linear Collider

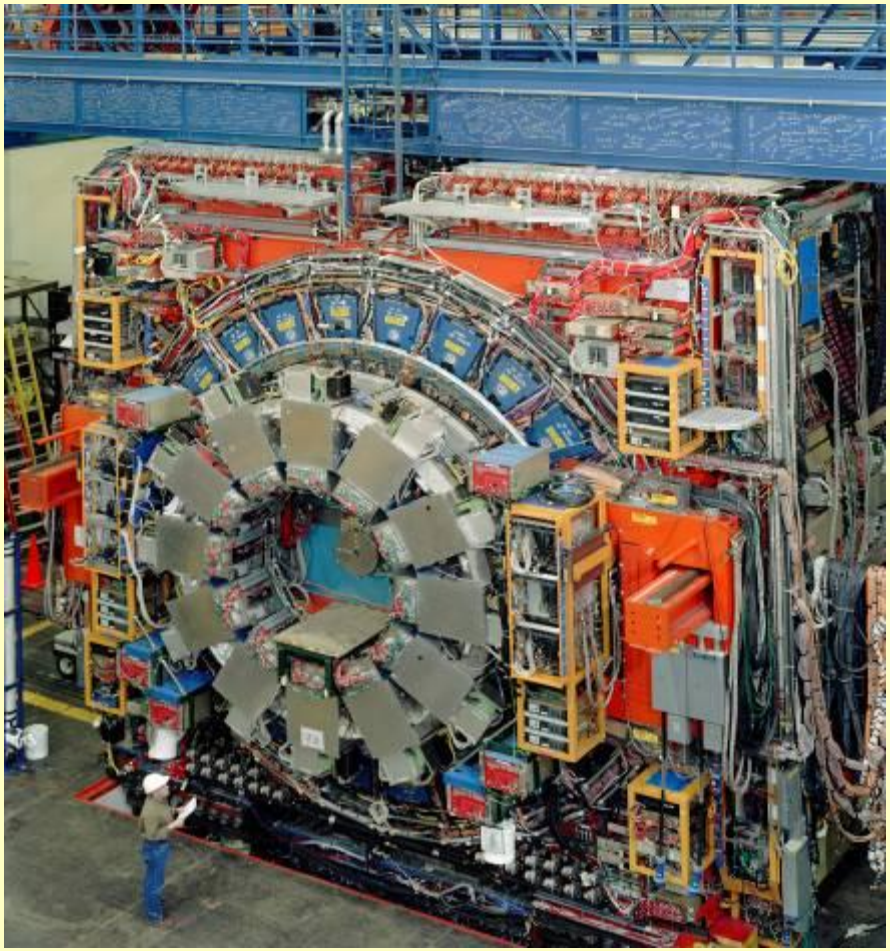
International Linear Collider





Two linear accelerators each 24 km (15 miles) long colliding electrons and positrons. Beam size nanometers (10^{-9} meters). Cultural and natural sources of noise will cause problems such as beam dispersion and lower luminosity (particles /cm^2 sec). Two tunnels are proposed one for the accelerator and the other for power supplies. The US proposed site is at Fermilab in Illinois.

Ground motion at Fermilab



All these accelerators and detectors are sensitive to:

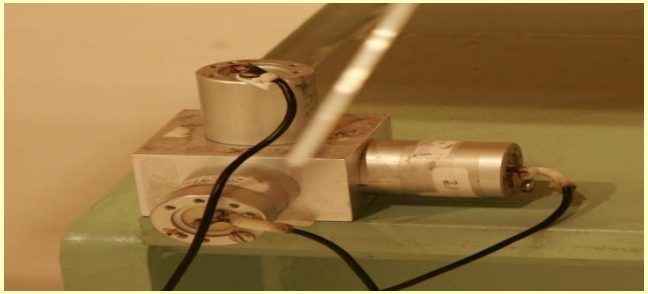
Cultural noise:
traffic, HVAC, cooling water, and, vacuum pumps.

Natural noise:
tides, earthquakes
motion due to ground water

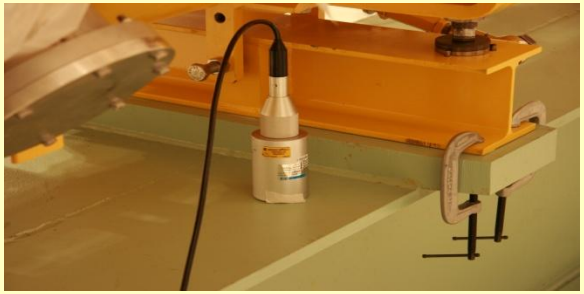
Ways to Monitor Ground Motion

Water levels

BUDKER seismometer



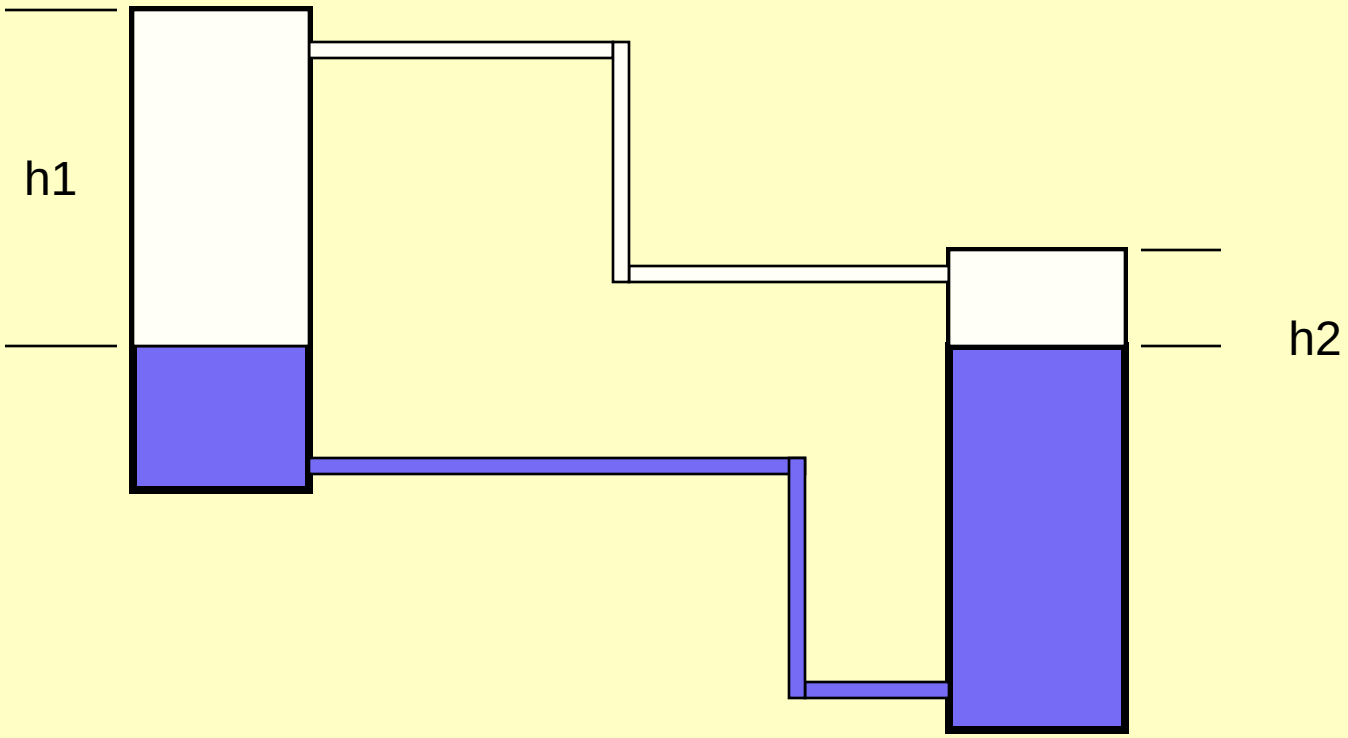
Geophone



Sercel Seismometer

Hydro static water Levels Systems

Water seeks it's own level



Hydro static water Levels Systems

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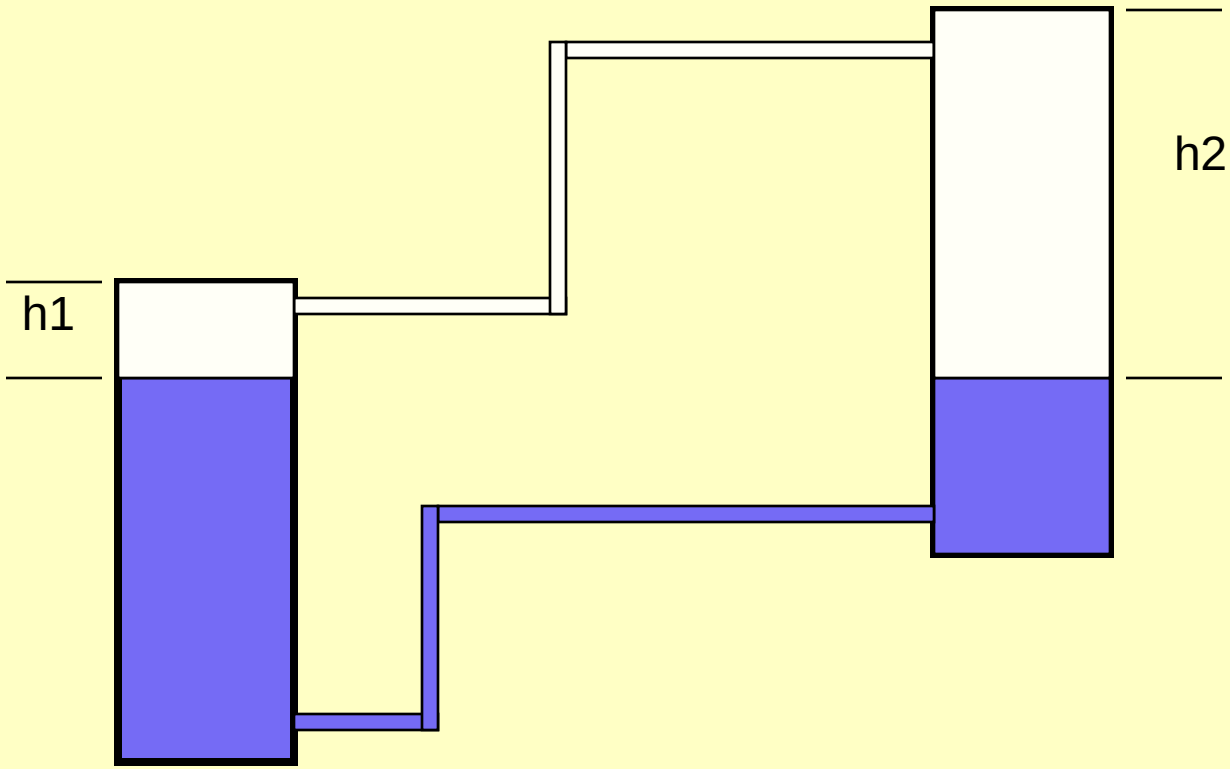


Plumbing

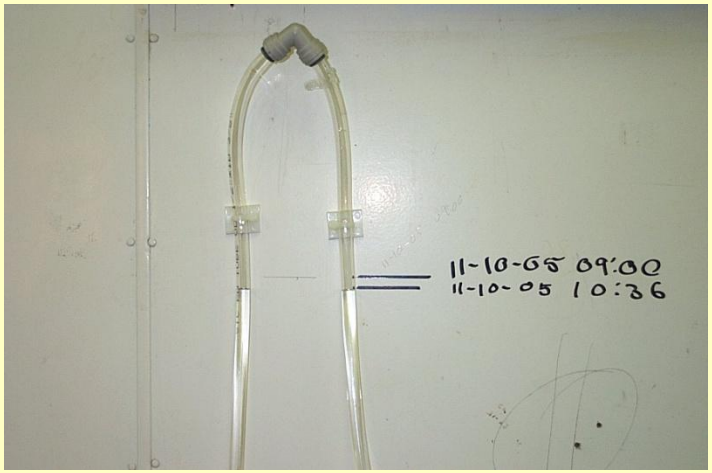
- There are two types of systems
- Fully filled or two pipe systems
  - Two pipes one for water one for air
  - The water pipe can change in elevation i.e. snake around, over and under obstacles
  - Temperature variations can affect data
- Half filled or one pipe system
  - One pipe must be level
  - Problems with air bubbles and water blocks
  - Less dependence on temperature and pressure variation

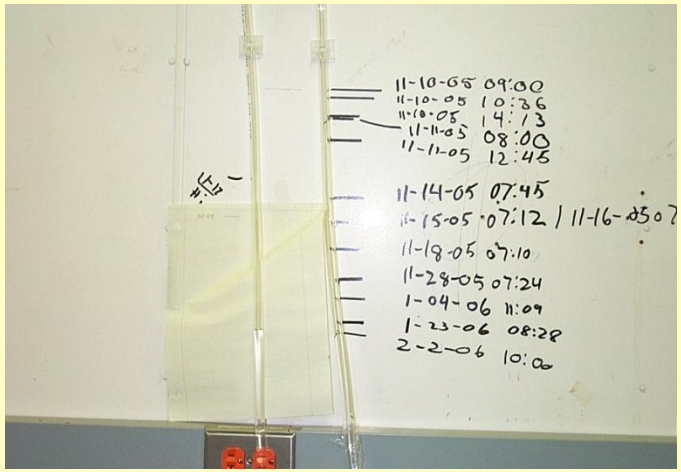
Tubing

Tygon tubing is very attractive to use
It is cheap and clear so you can see bubbles

It absorbs water at a fantastic rate!

This is a test where I filled 152 meters of 12.5 mm dia. Tygon tubing with water and sealed the ends





Within 1.5 hours I lost 1 cm of water

After 3 months I lost more than 30 cm or 74 cc of water

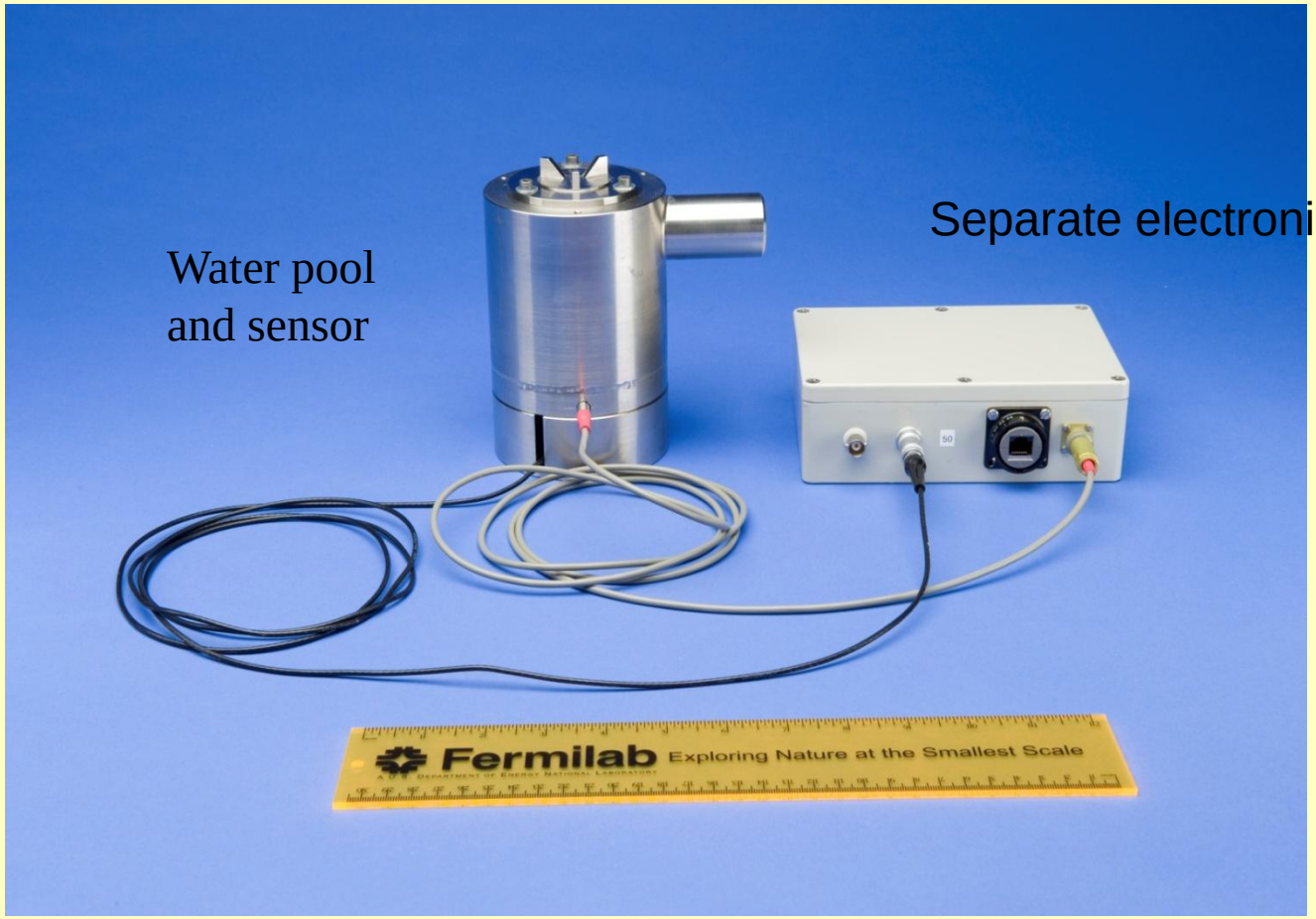
Hydro static water Level Systems HLS

BUDKER sensor
Capacitive pickup
Accuracy 1 micrometer
Cost $1200 per channel

Capacitive sensor Water pool

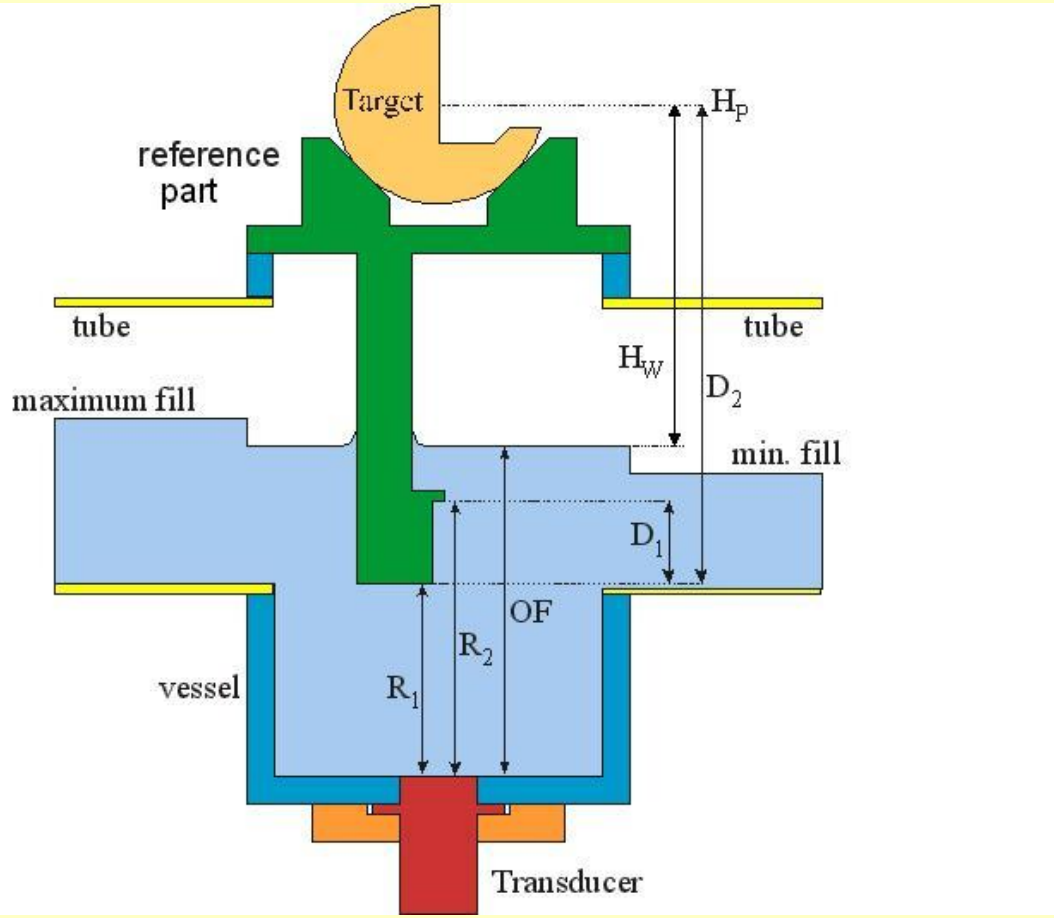
On stand with water and
Air line connections

Ultra Sonic Sensor and Electronics



Ultra sonic sensor better than 1 micrometer resolution $4000 per channel

Schematic of Ultra Sonic Sensor

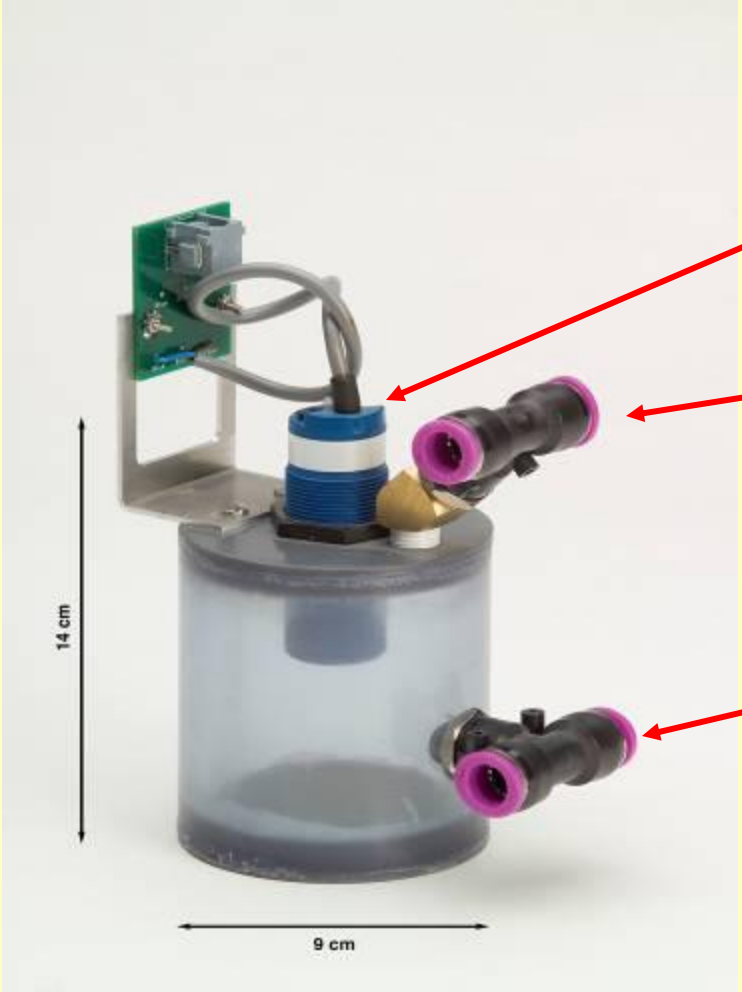


R1 and R2 are Fixed distances used for calibration

OF is water level

Target at top is for alignment

Fermilab HLS sensors



Balluff proximity sensor

Air line

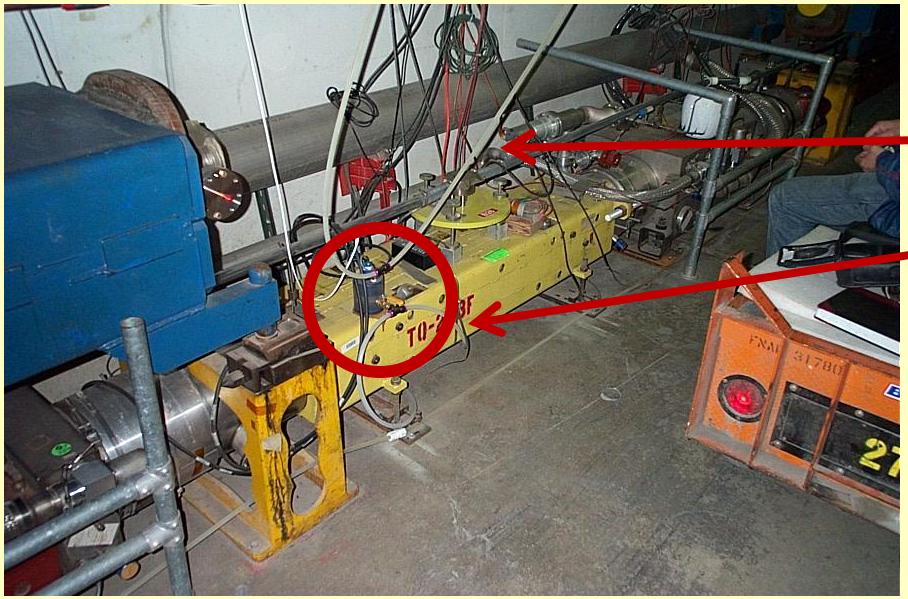
Water line

Accuracy 6 micrometers
Cost $120 - $140 per channel

HLS systems at Fermilab

- 204 Fermilab style sensors one on each quad in the Tevatron
- 7 BUDKER sensors in MINOS hall 100 meters below grade on top of Galena Platteville dolomite – 4 are orientated along a north south line and 3 along an east west line
- 5 sensors in LaFarge mine in North Aurora Illinois 120 meters below ground in Galena Platteville dolomite
- 11 Fermilab sensors in NMS hall
- 9 sensors on the low beta quads at both B0 and D0 collision halls
- 40 sensors on Tevatron quads in B sector (no longer operational)
- 40 sensors in MI-8 beam line (no longer operational)

Tevatron Sensors on Quad



Air Line

Water line

In the circle is a water level pot on a Tevatron quadrupole

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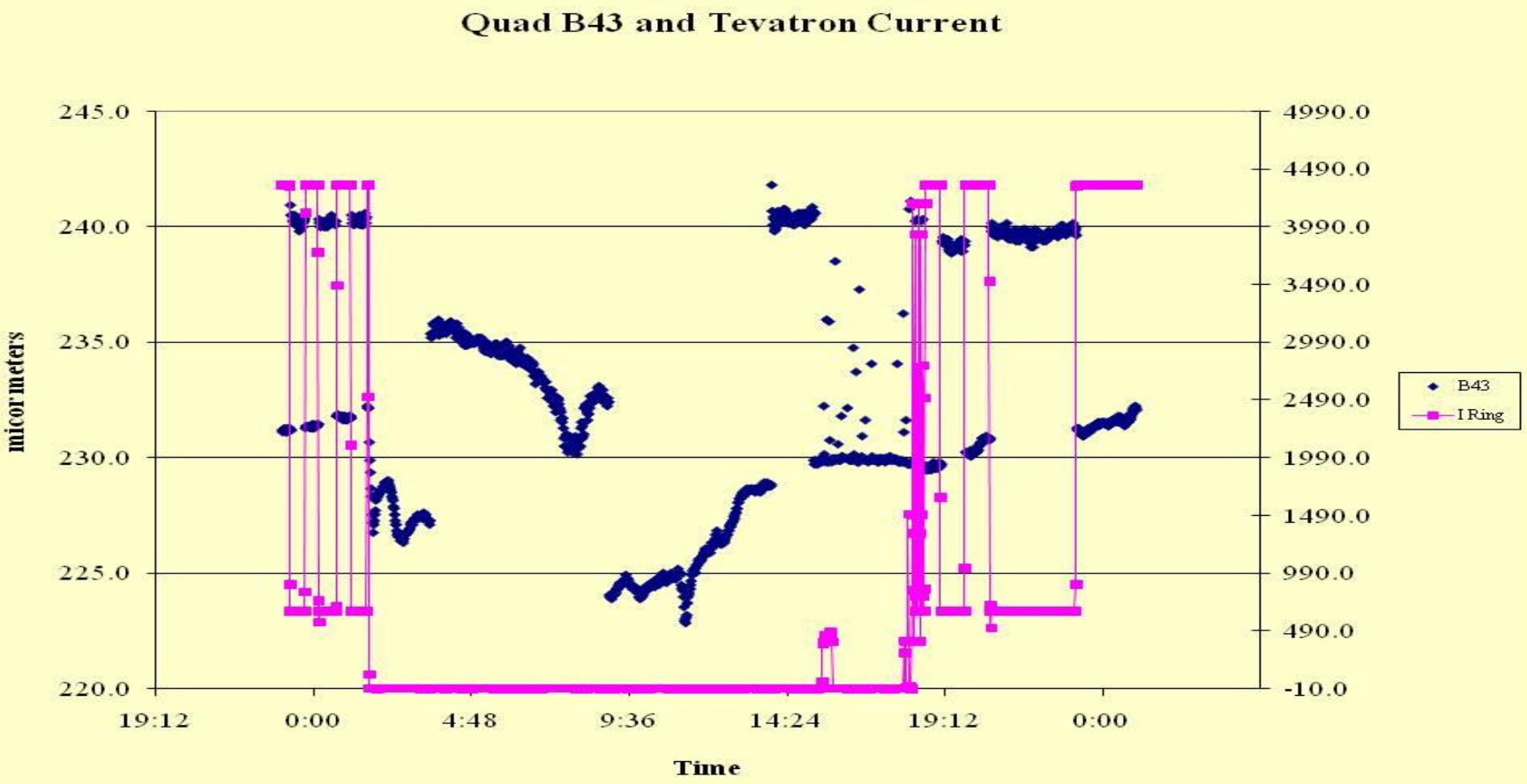
Tevatron Quad Motion During Ramp



Tevatron Quad Movement

MINOS System

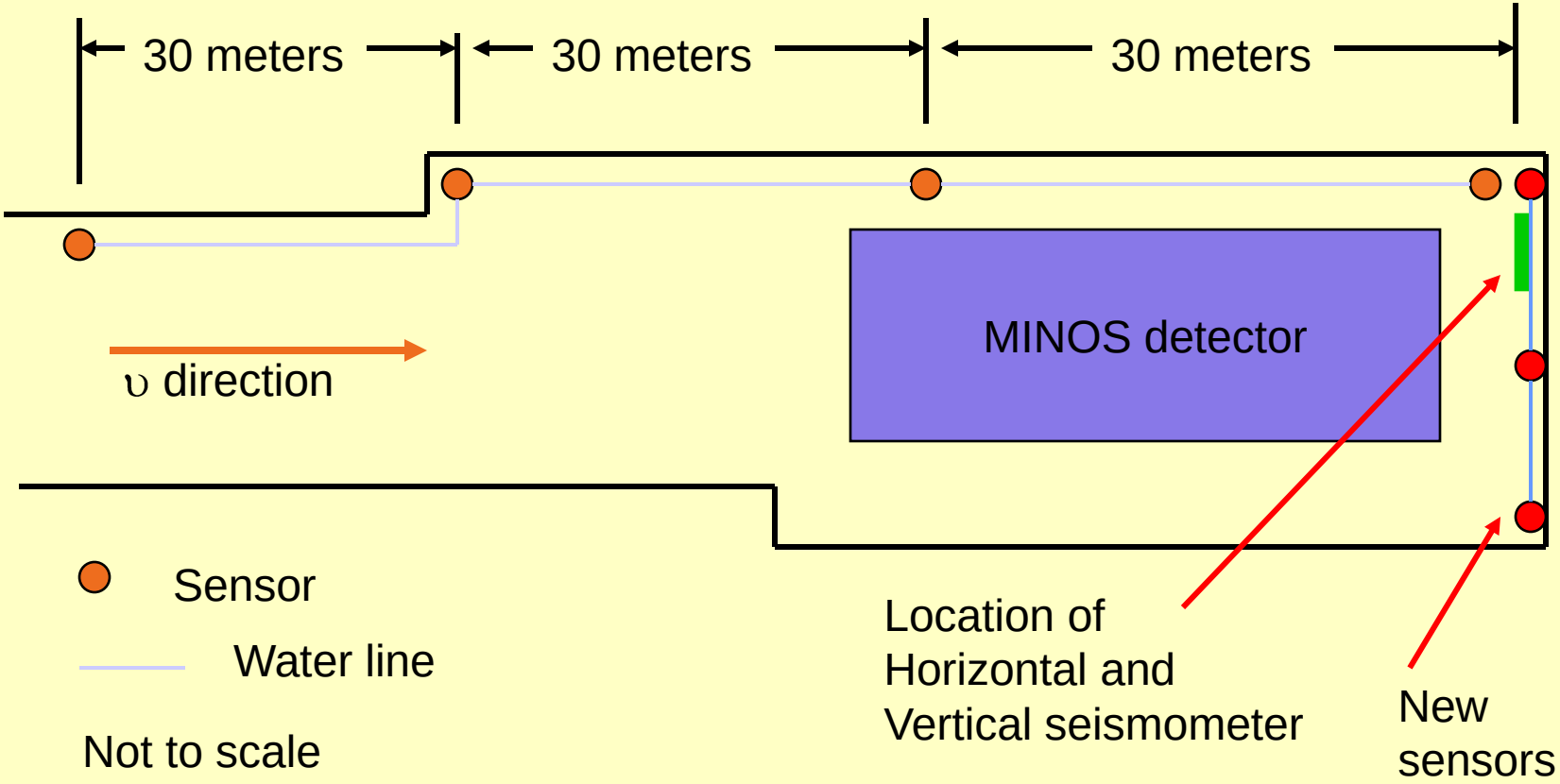
Long base line
Neutrino experiment at
Fermilab - neutrinos are
detected at Fermilab and
Soudan Minnesota 890 km
away

100 meters below
grade on top of
Galena Platteville
Dolomite

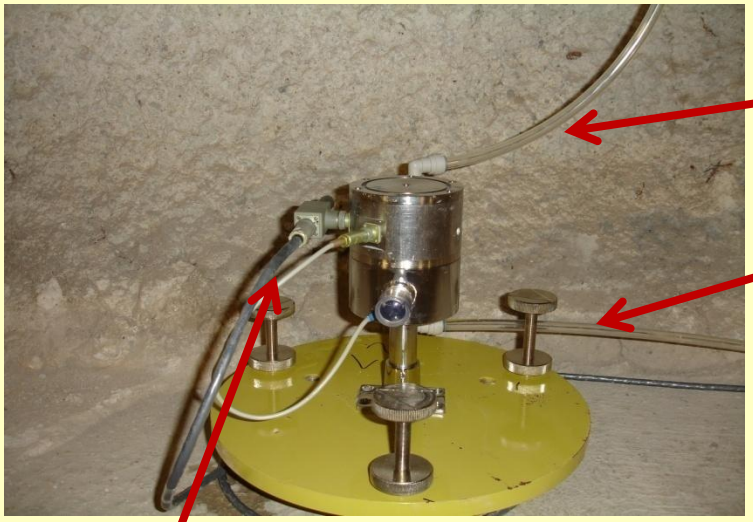
4 sensors 30 meters
apart along western wall
3 sensors 6.7 meters apart
along north wall

Layout of MINOS water level

Depth of floor 100 meters below grade
406 feet above sea level Maquoketa shale



MINOS BUDKER HLS Sensors



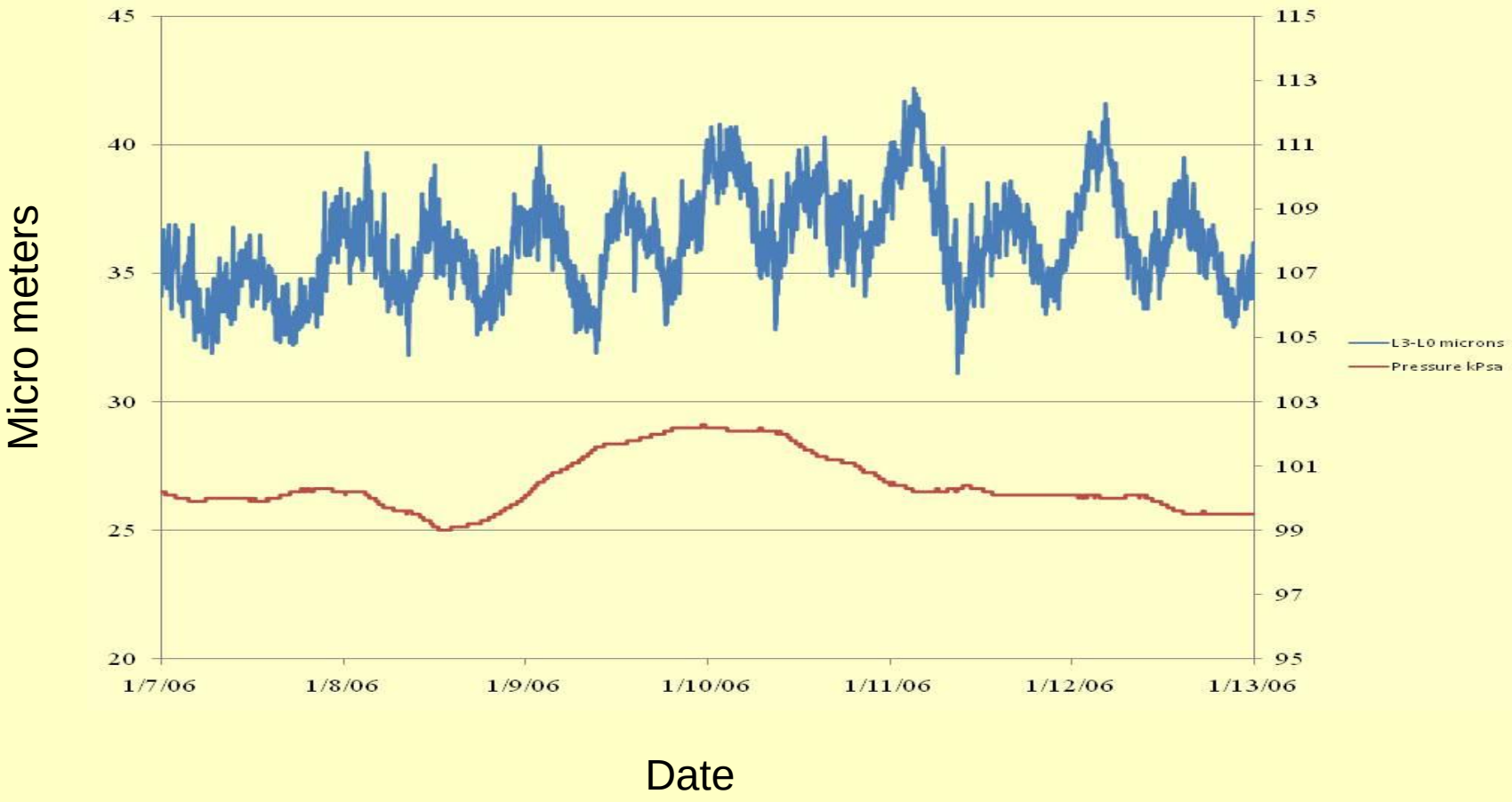
Air Line

Water line

Data Cable

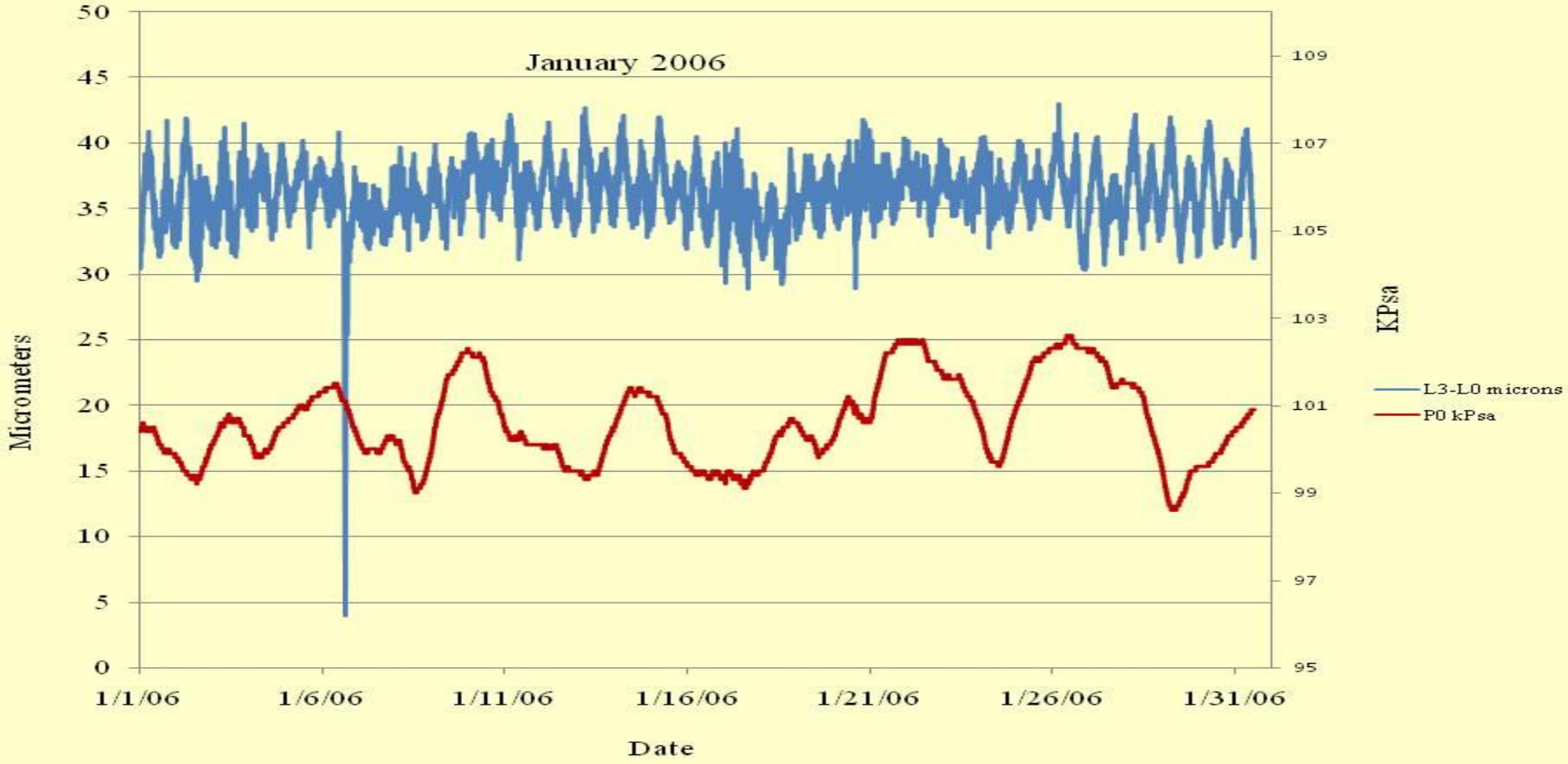
MINOS Tidal Data

Difference in two sensors 90 meters apart



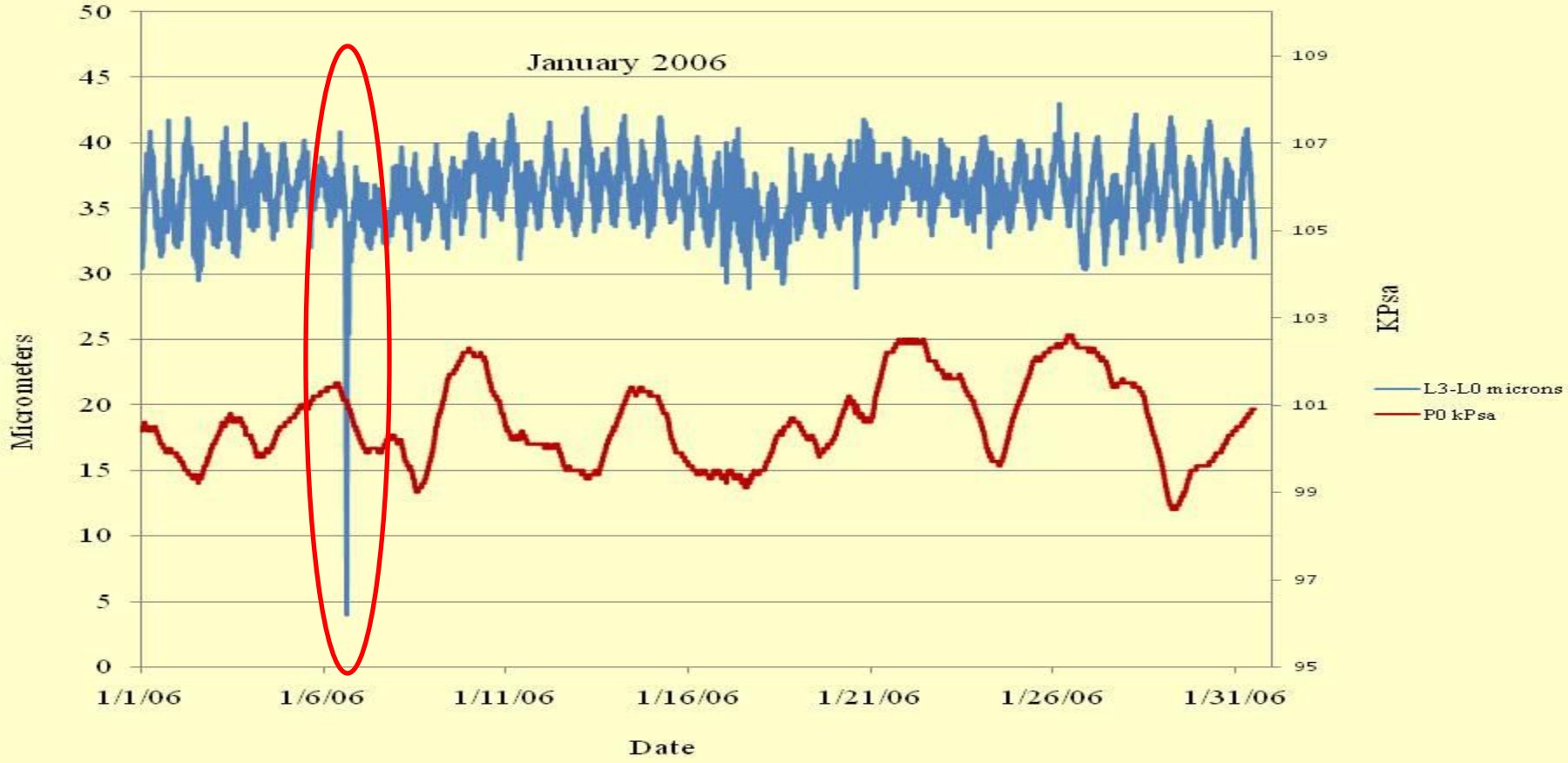
January 2006 MINOS

Difference in two sensors 90 meters apart

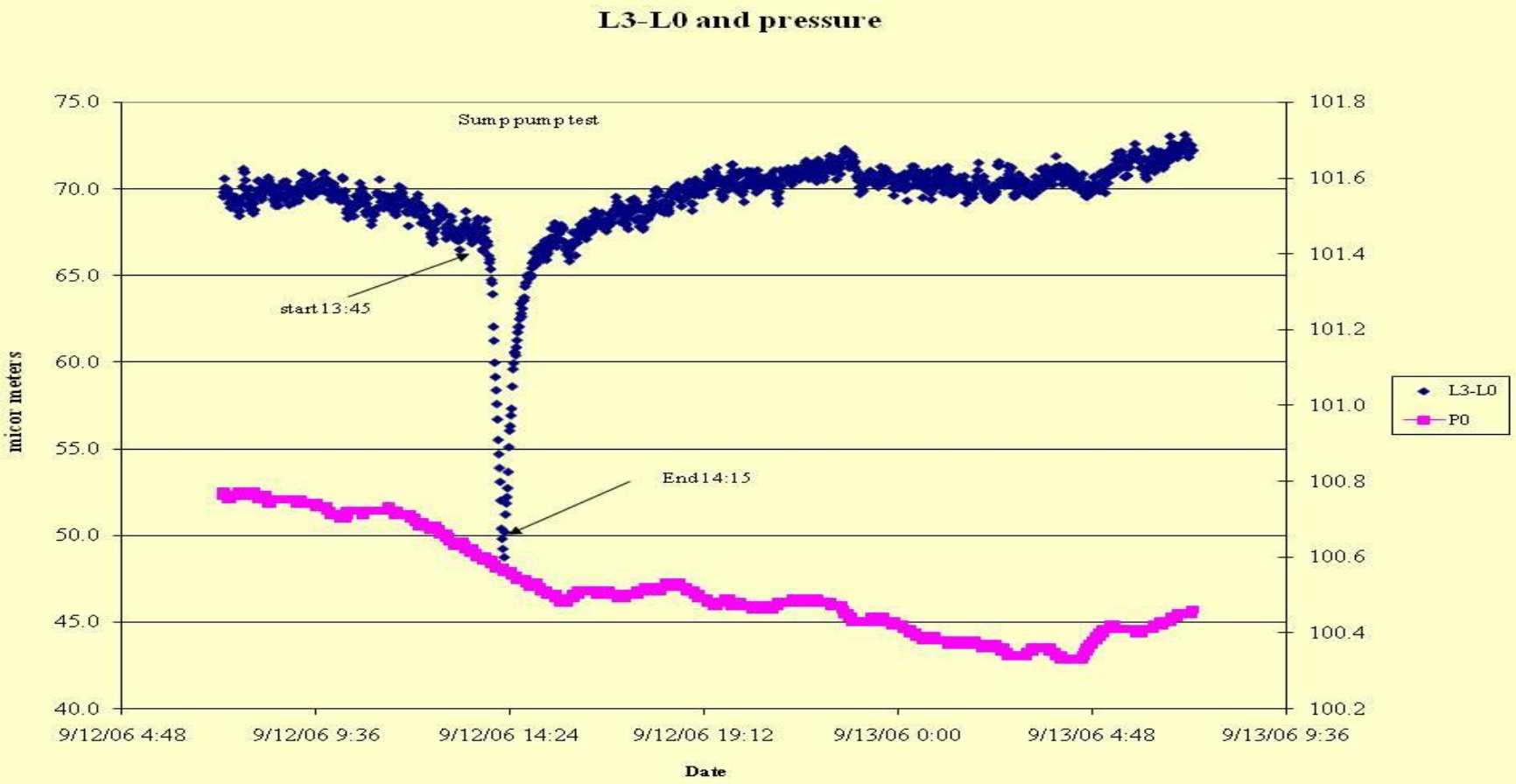


January 2006 MINOS

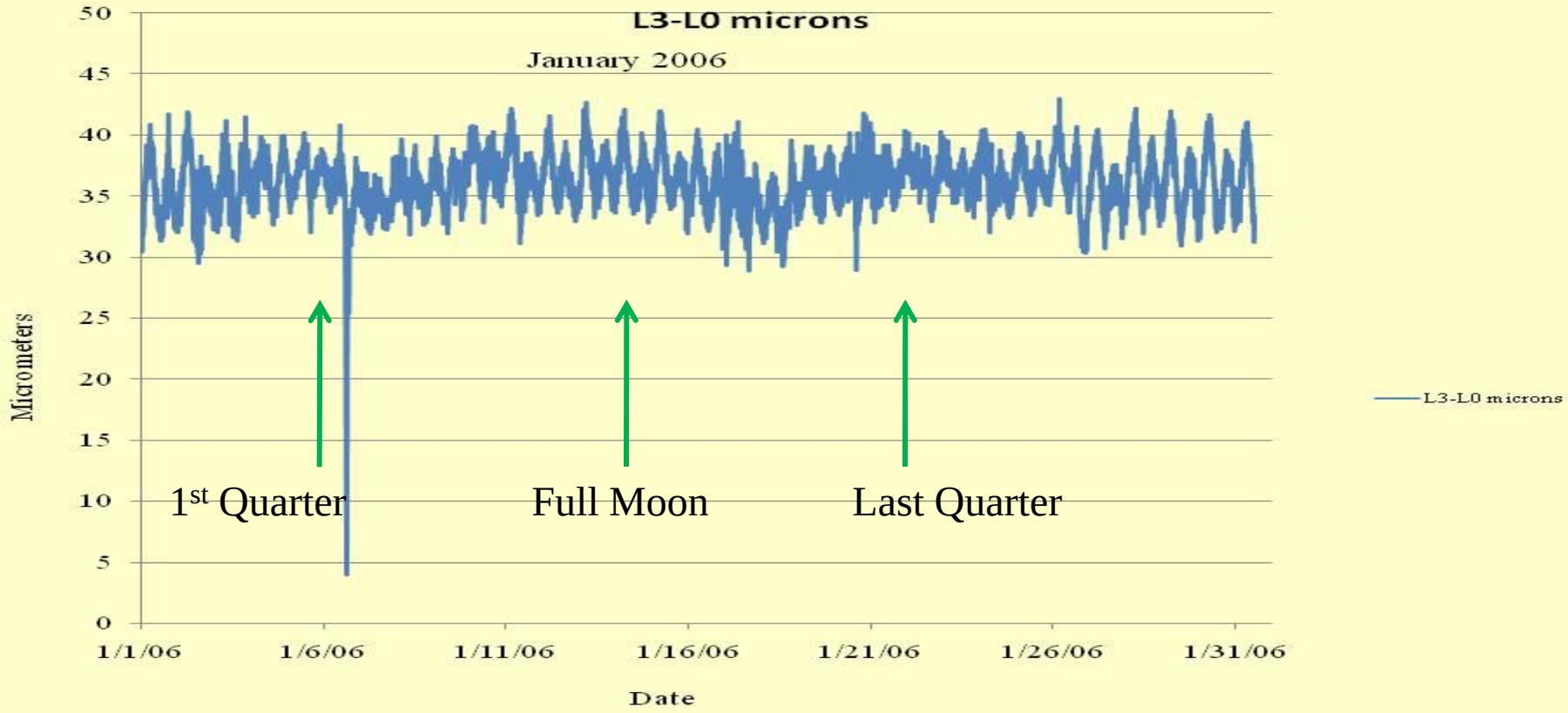
Difference in two sensors 90 meters apart



Sump Pump Test

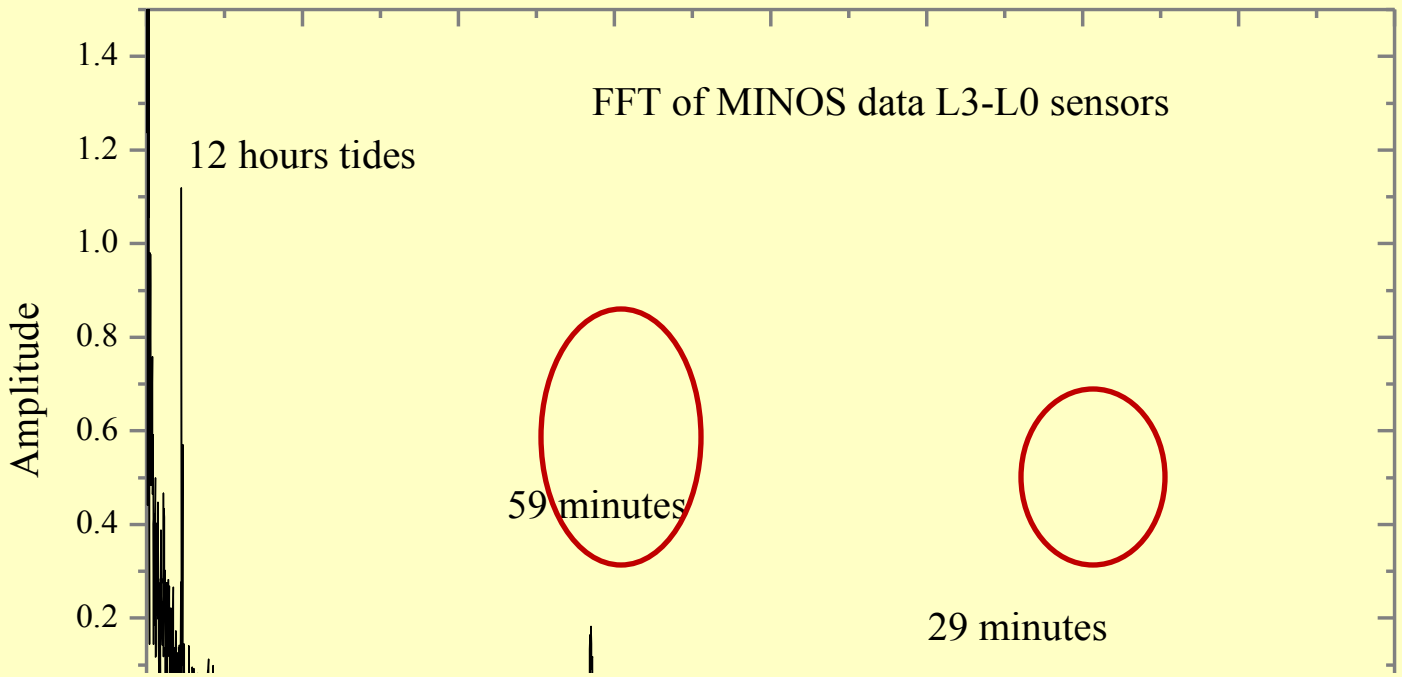


Spring and Neap Tides



FFT of MINOS data difference between two sensors

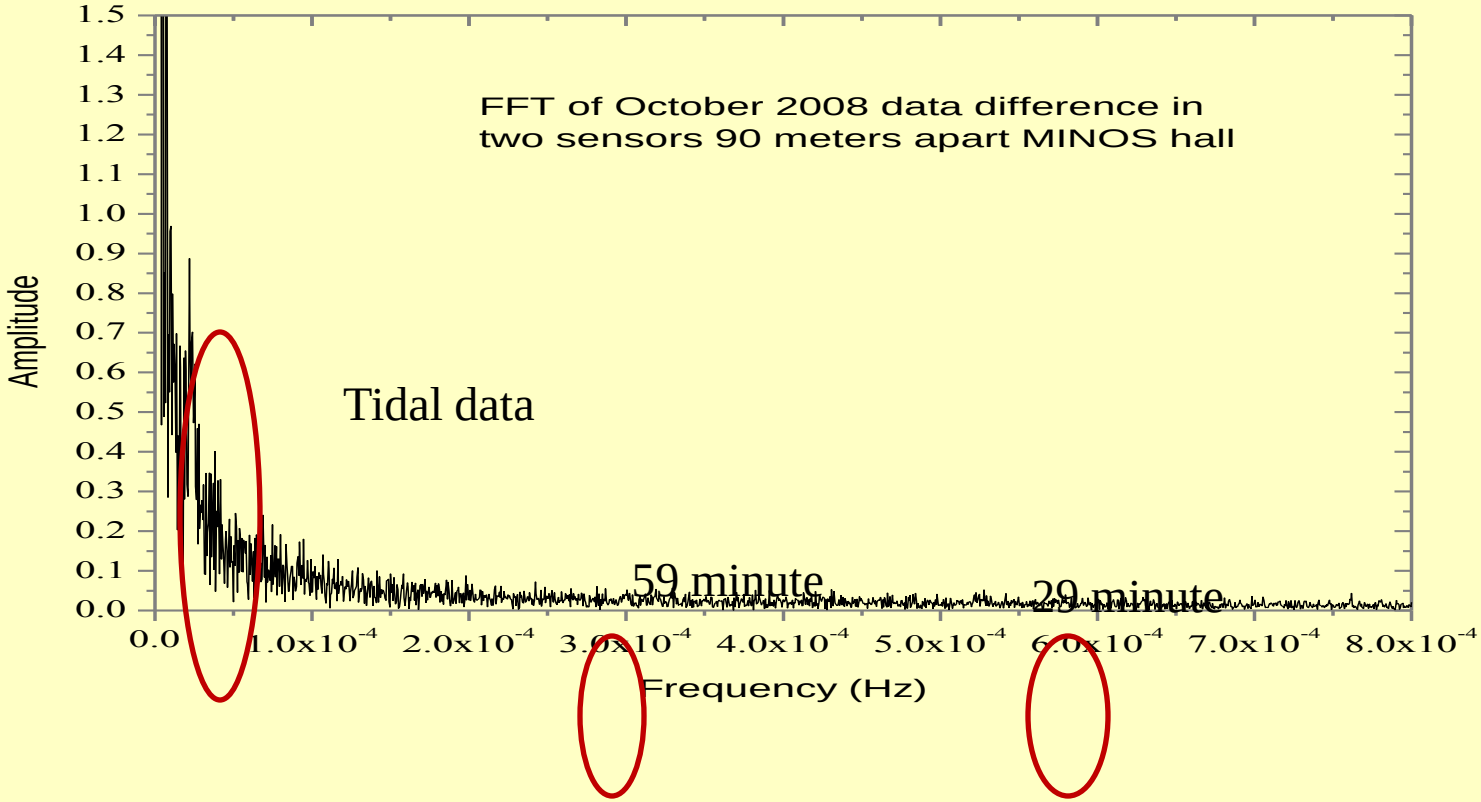
December 2007



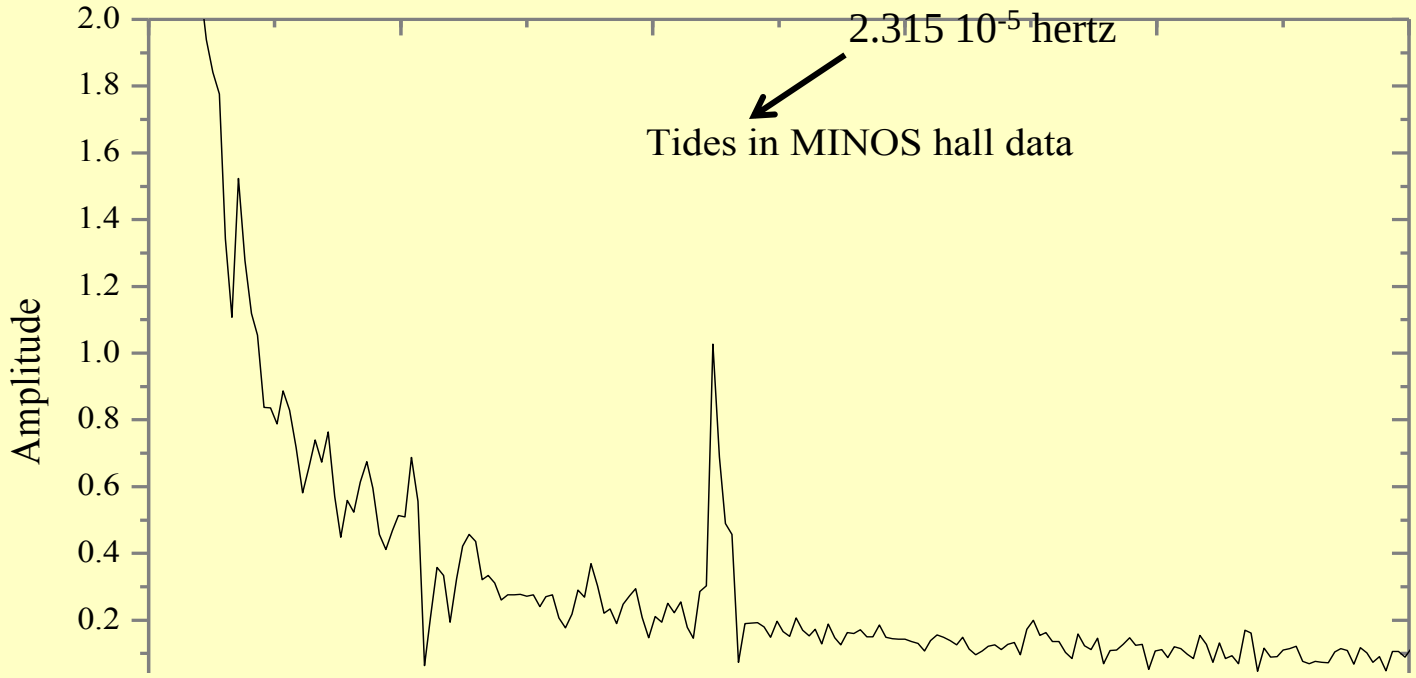
James T Volk IWAA 08

FFT of MINOS data difference between two sensors

October 2008 data

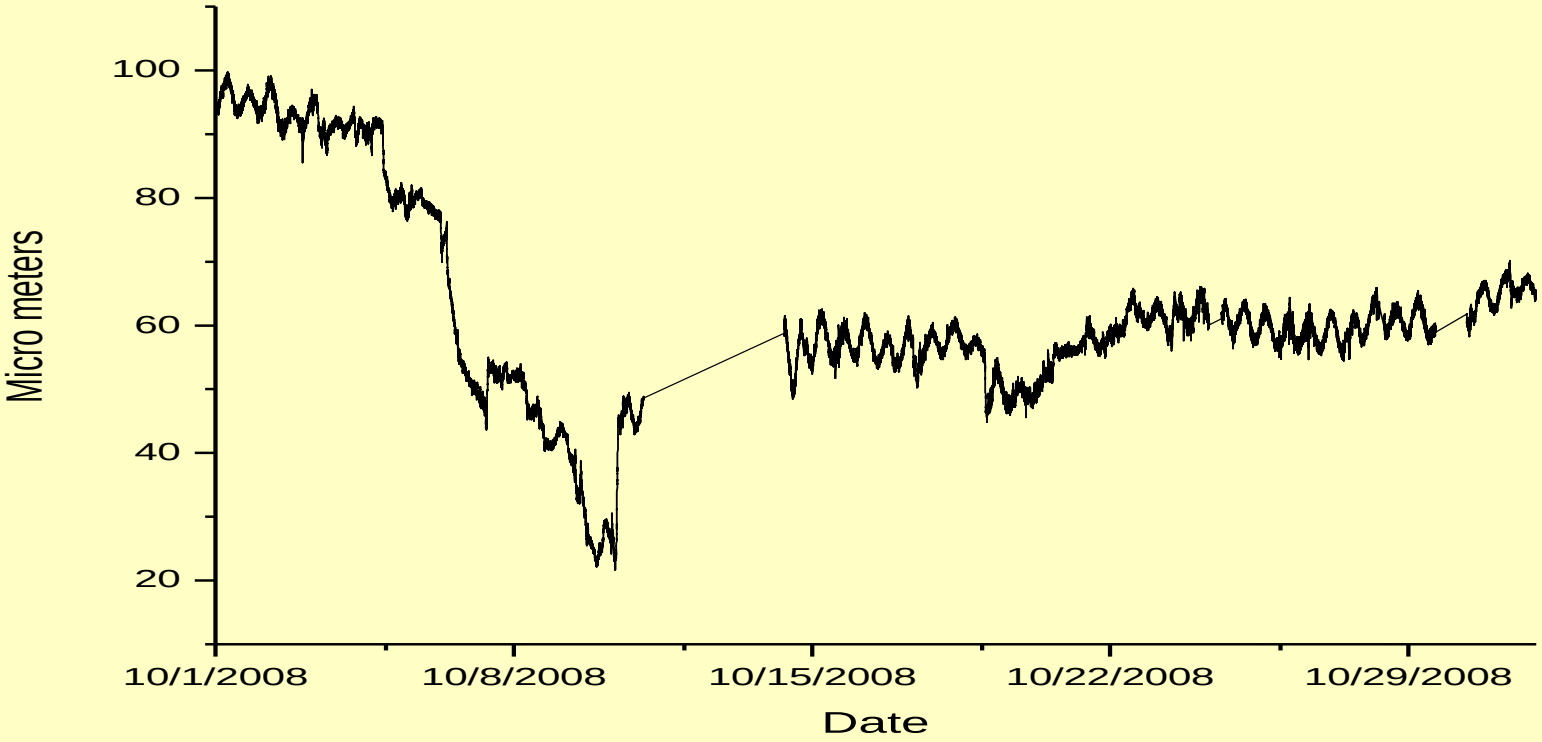


Blow up of FFT showing tide peak



MINOS Hall

Two Sensors 90 meter apart Oct 2008



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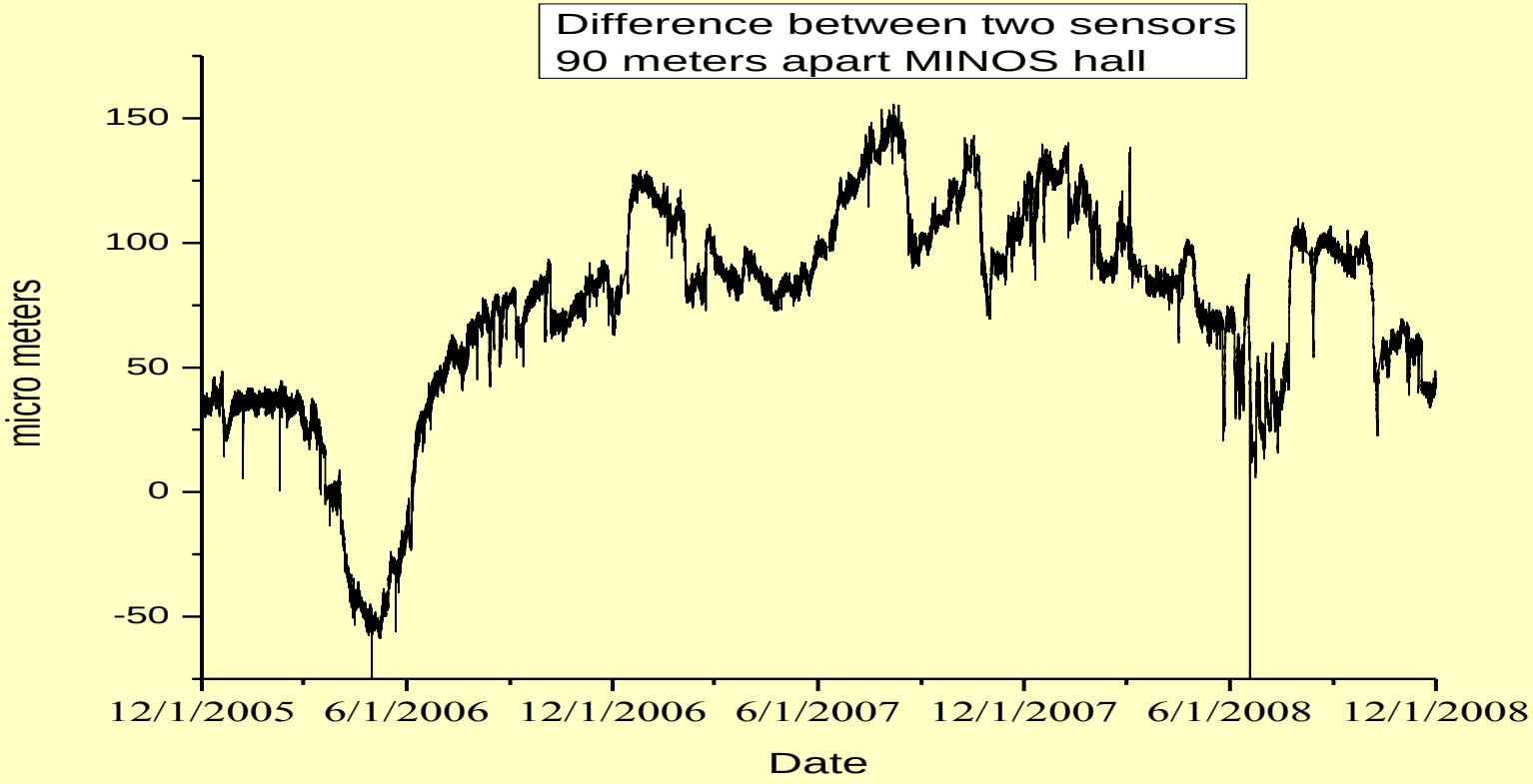
Difference in two sensors 90 meters Apart MINOS hall

36 months of data



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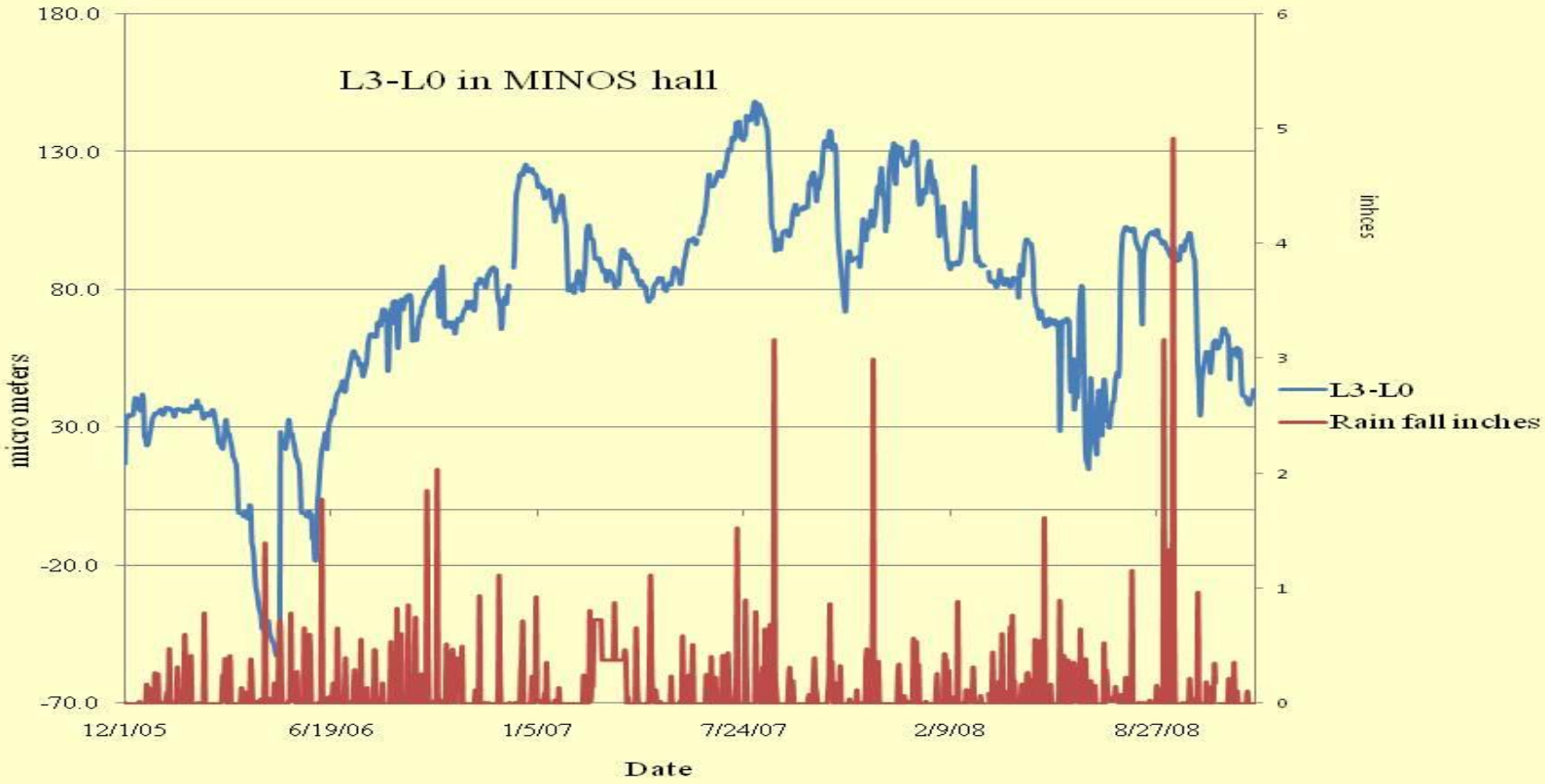
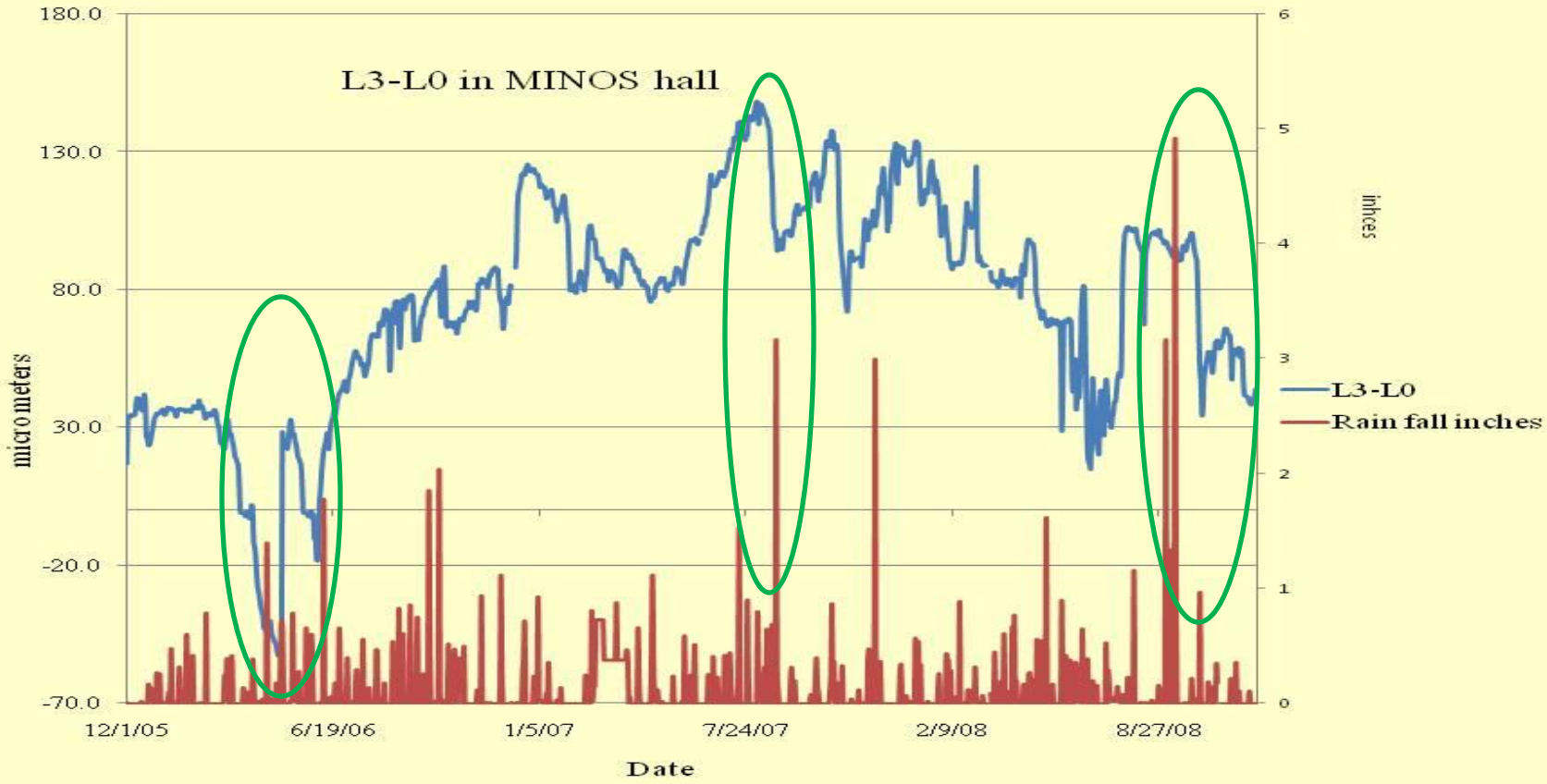
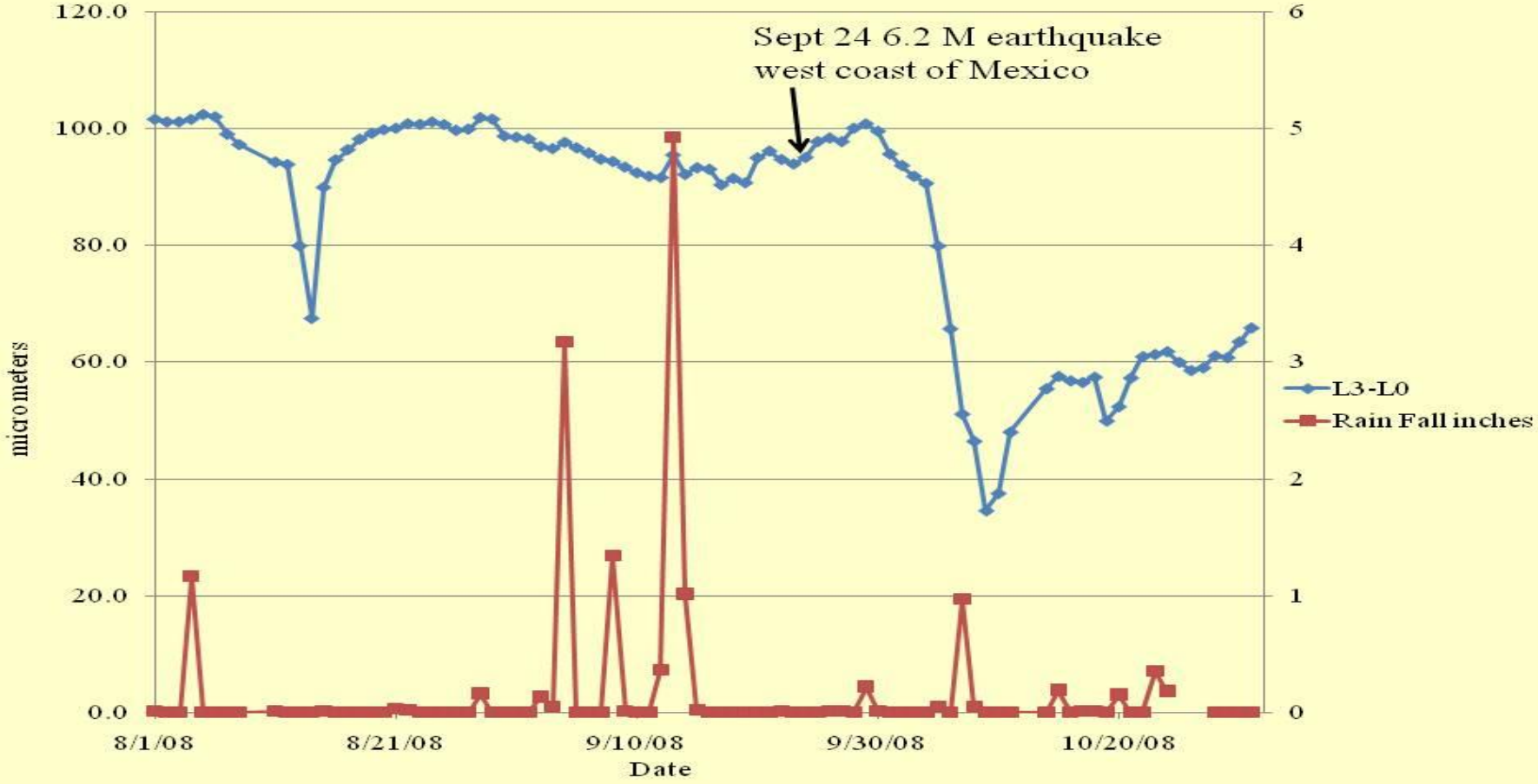
Two sensors 90 meter apart and rain fall in Batavia



Two sensors 90 meter apart and rain fall in Batavia



August 08 through Oct 08 MINOS



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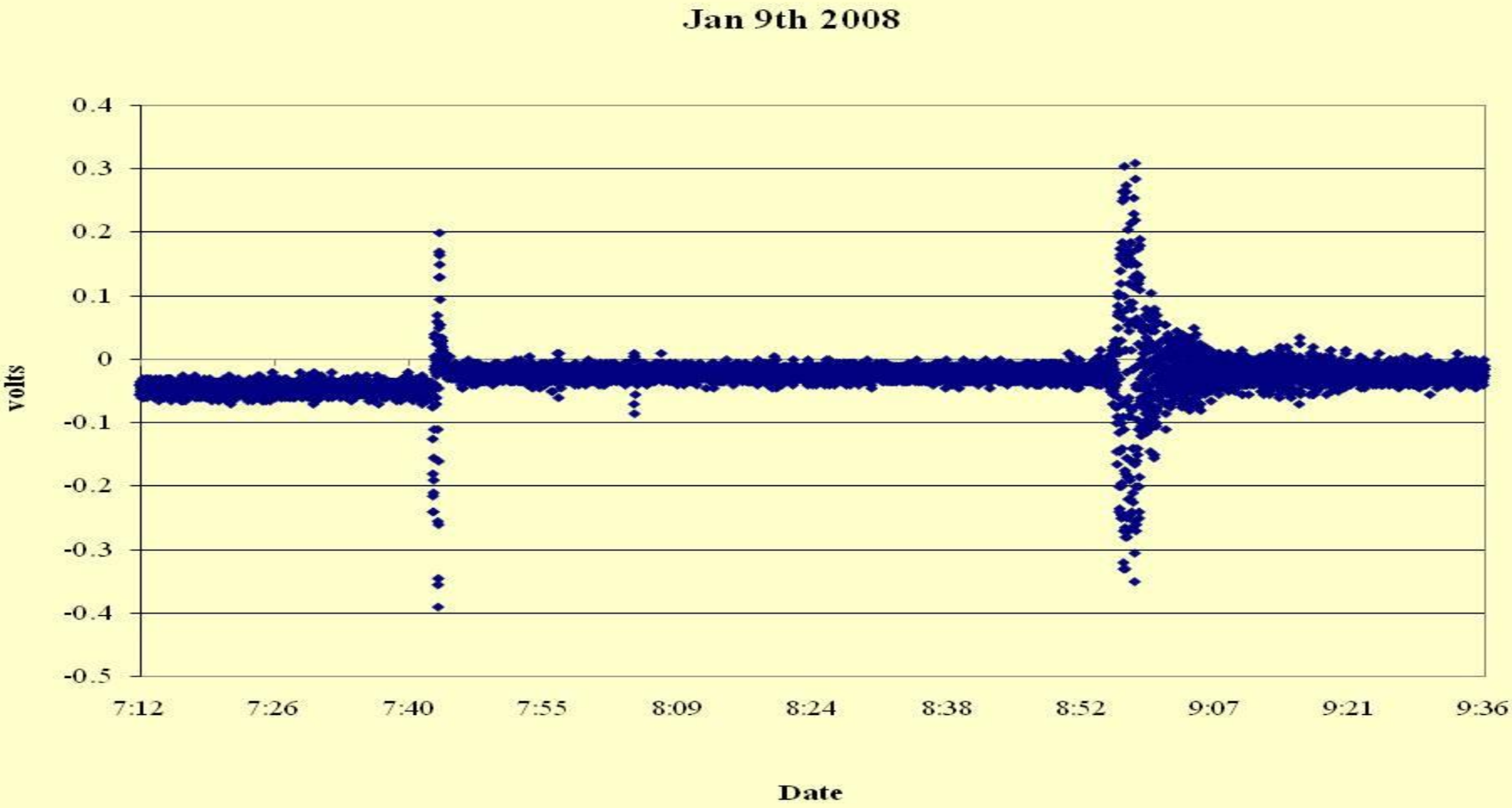
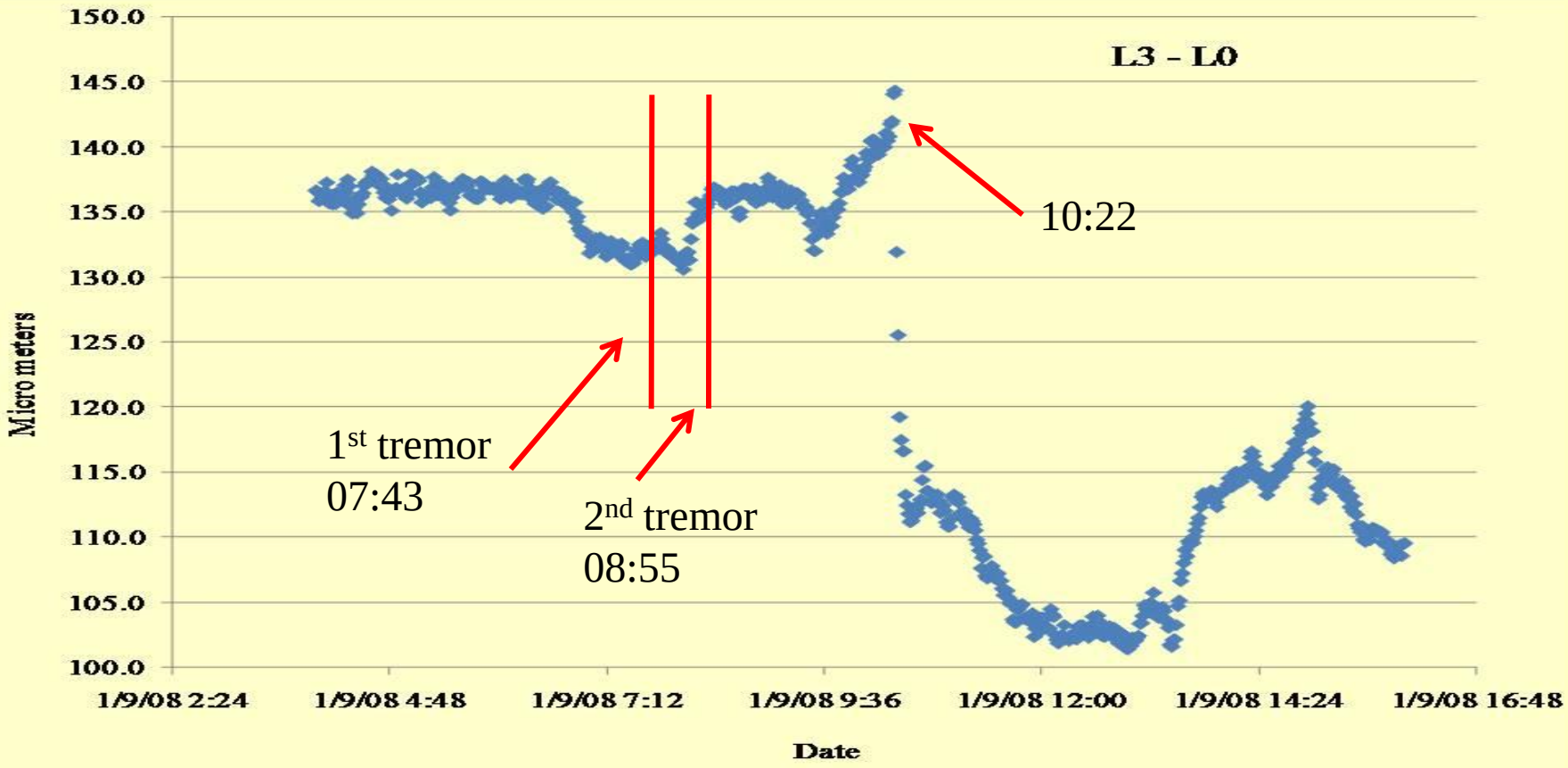
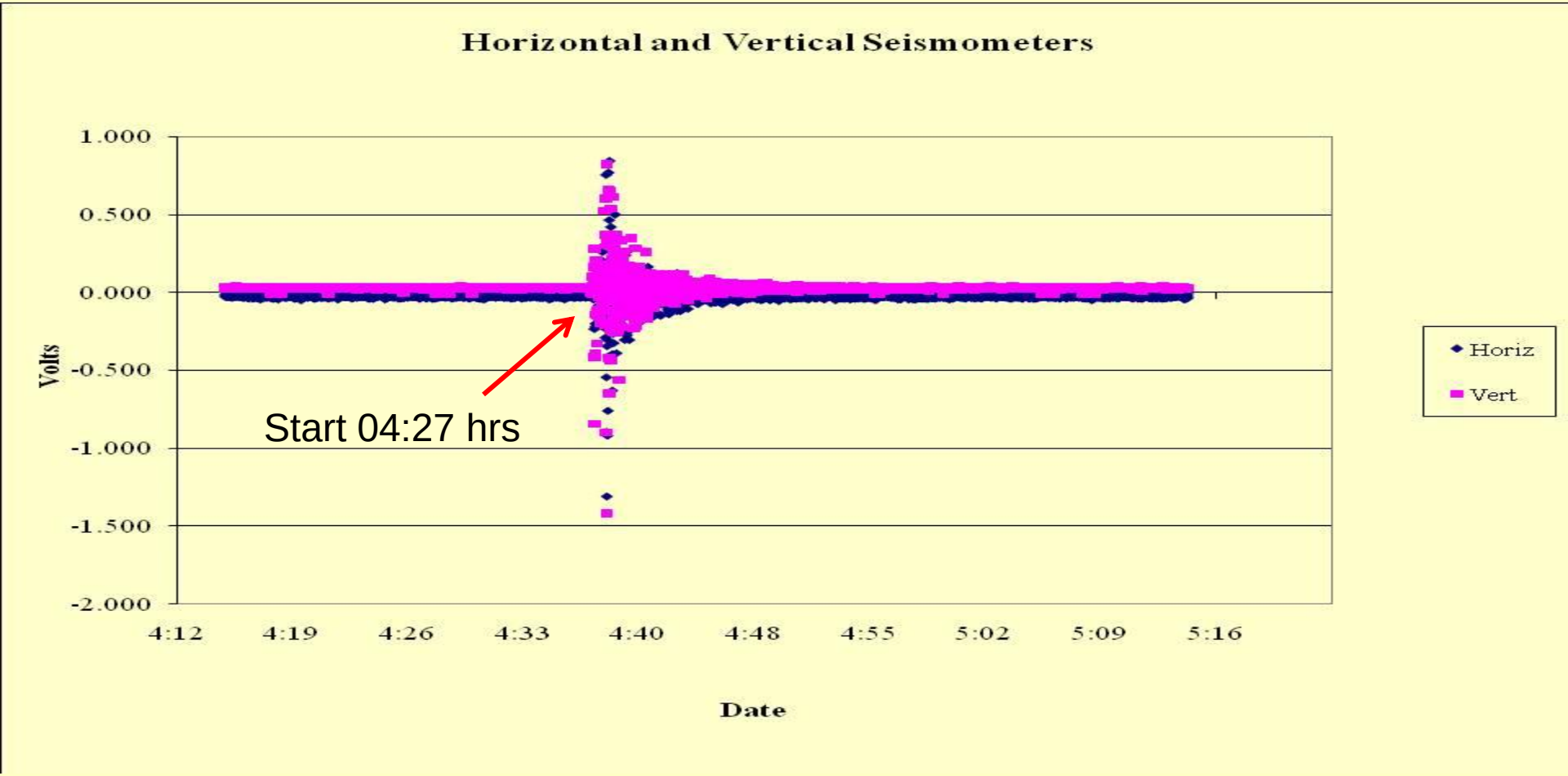
Subsidence and Tremors



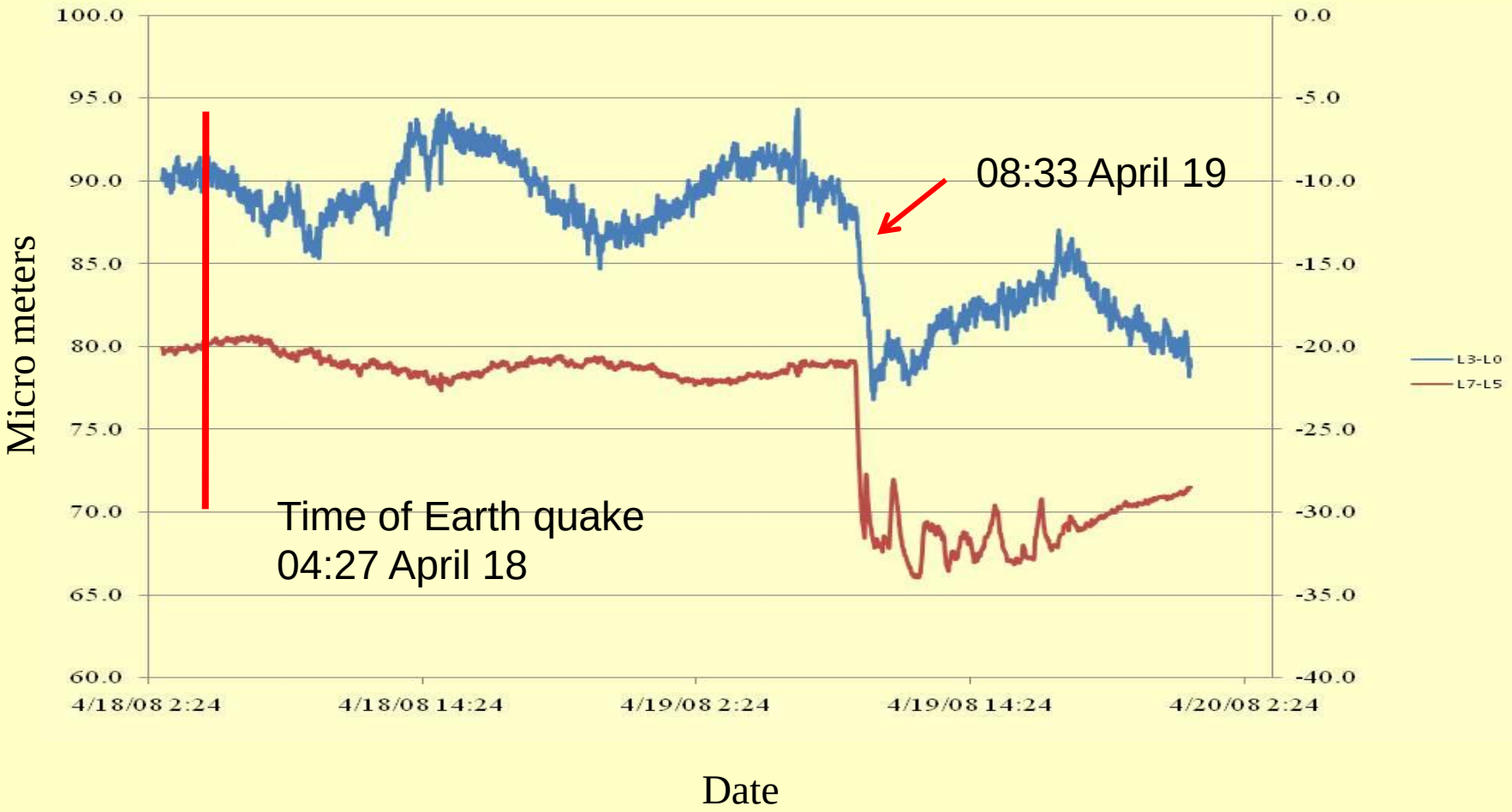
Difference in sensors as showing tilt in floor



Earth quake April 18 at 04:27 hrs CDT 380 km (236 miles) south south east of Fermilab



North South and East West sensors difference MINOS hall



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Ground Motion Data

The data for MINOS and the LaFarge mine are available at
http://dbweb1.fnal.gov:8100/ilc/ILCGroundApp.py/index

```
Measurement_Date,L0,L1,L2,L3,L5,L6,L7,T0,T1,T2,T3,T5,T6,T7,P0
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2008-10-01 00:06:00,7254.852,7554.353,7357.575,7348.481,7759.292,7749.745,25.16,23.3,23.06,21.27,19.88,21.81,21.82,100.63
2008-10-01 00:07:00,7254.9,7553.986,7357.434,7348.769,7759.225,7749.761,25.15,23.3,23.06,21.27,19.87,21.81,21.82,100.63
2008-10-01 00:08:00,7254.837,7553.978,7357.476,7348.451,7759.138,7749.806,25.15,23.3,23.07,21.28,19.88,21.81,21.81,100.63
2008-10-01 00:09:00,7254.805,7553.856,7357.496,7348.445,7759.147,7749.754,25.16,23.3,23.08,21.27,19.88,21.81,21.82,100.63
2008-10-01 00:10:00,7254.619,7554.492,7357.95,7348.795,7759.068,7749.788,25.16,23.3,23.08,21.28,19.87,21.8,21.82,100.63
```

The data are available as a csv or html format
There is a date and time stamp
the 7 level sensors data in micro meters
the 7 temperatures in degrees C
the air pressure in kPsa

LaFarge Mine North Aurora

There is a dolomite mine 7 km from the MINOS hall.
It is in the Galena Platteville layer 125 meters below the surface.
It is room and pillar Construction
There are 5 HLS sensors in an abandoned drift in the mine.

The LaFarge Mine North Aurora Ill

Entrance to mine 3900 meter decline

In the Galena Platteville dolomite 120 meters below grade

If the ILC were built at Fermilab this would be the preferred depth and strata

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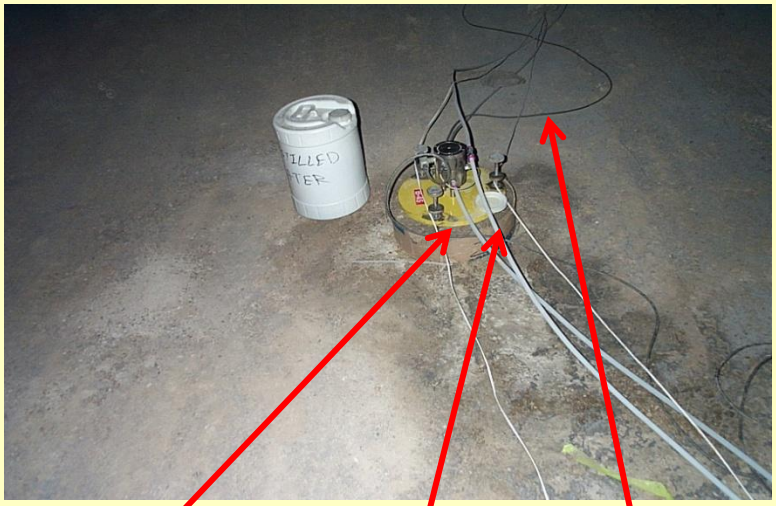
Budker Sensors in South 5 drift

Station 3

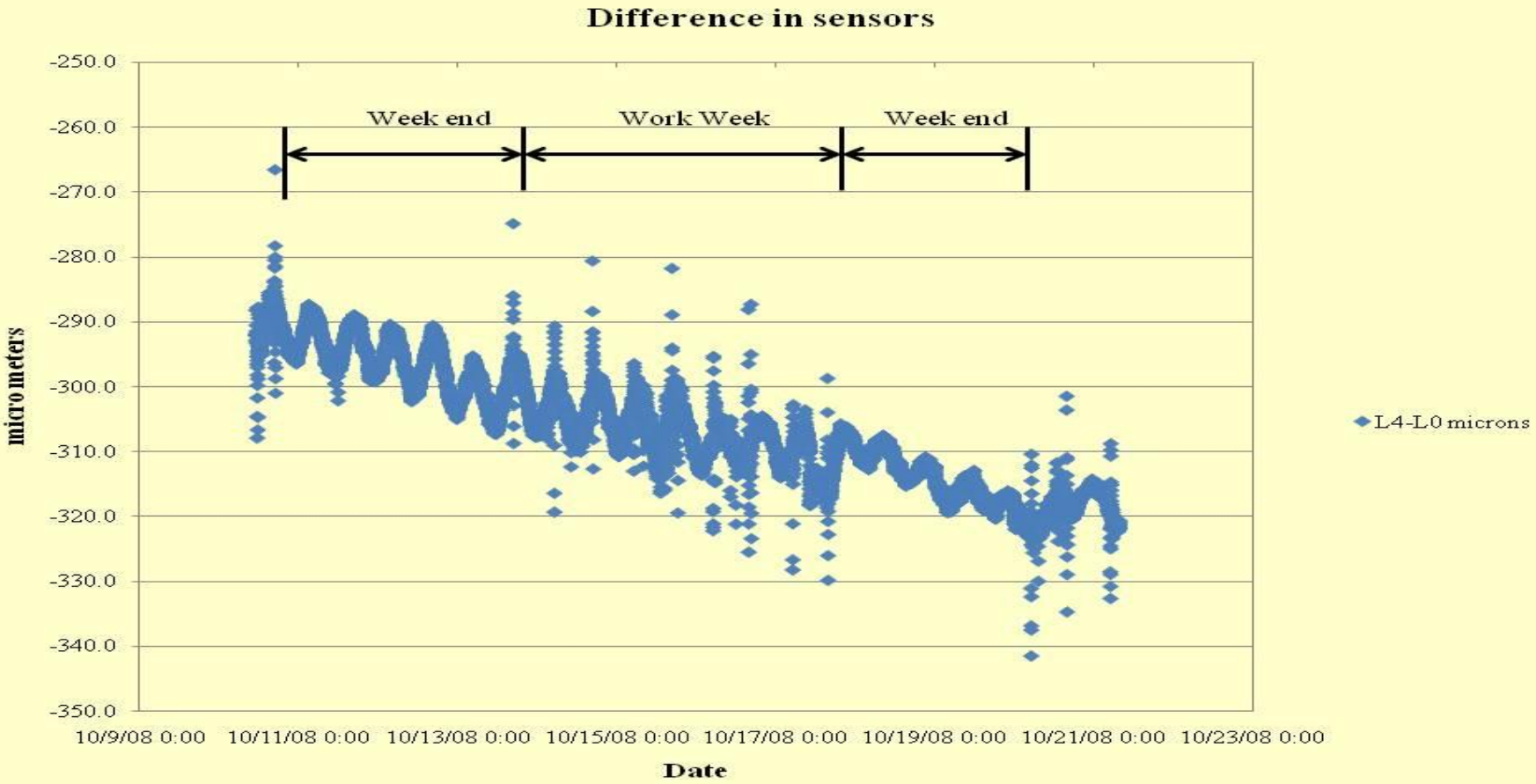


Water line Air line Data cable

Station 4

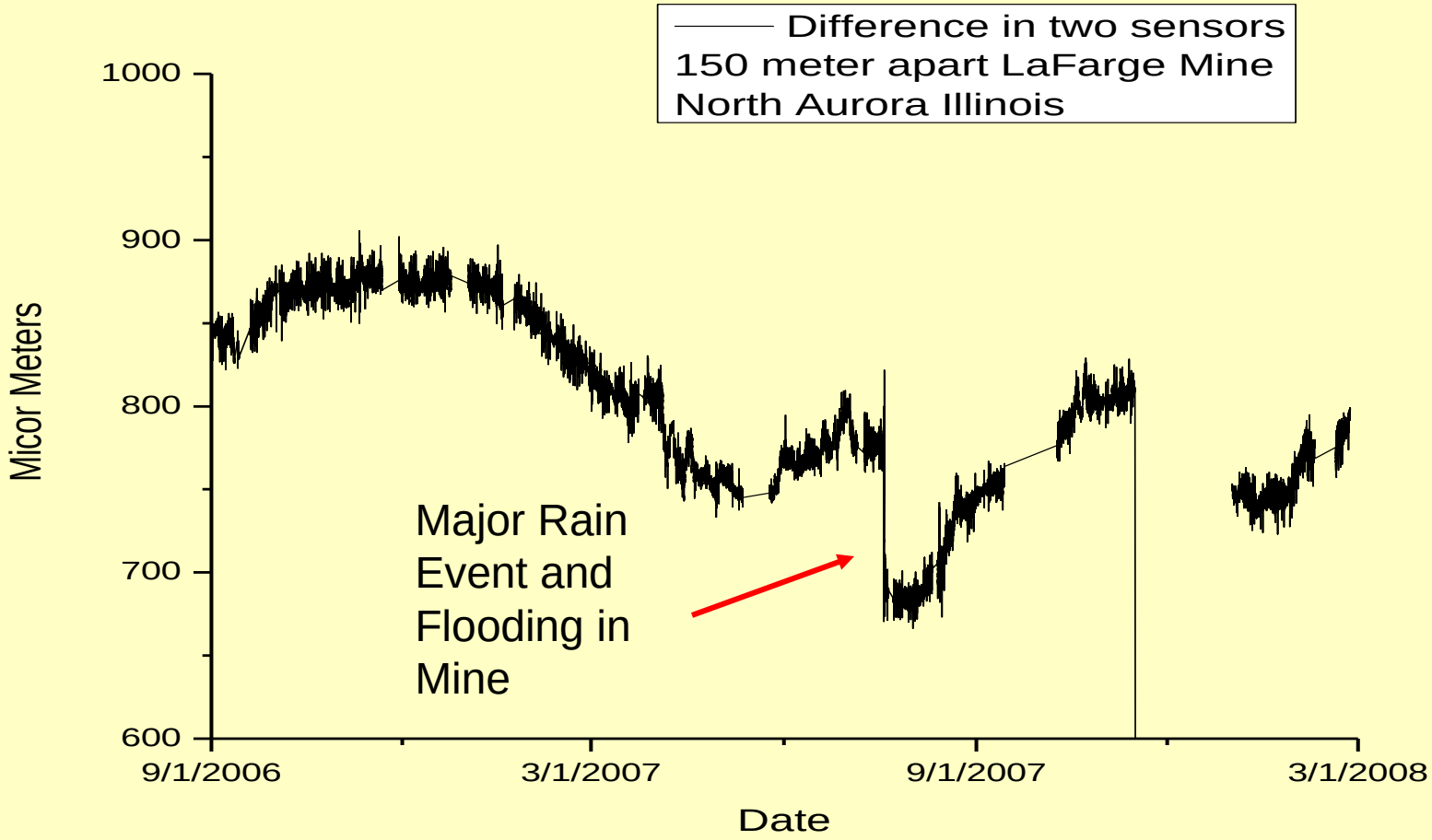
Note built up concrete pillar this is to make up for difference in floor elevation

Difference in two sensors 60 meter apart

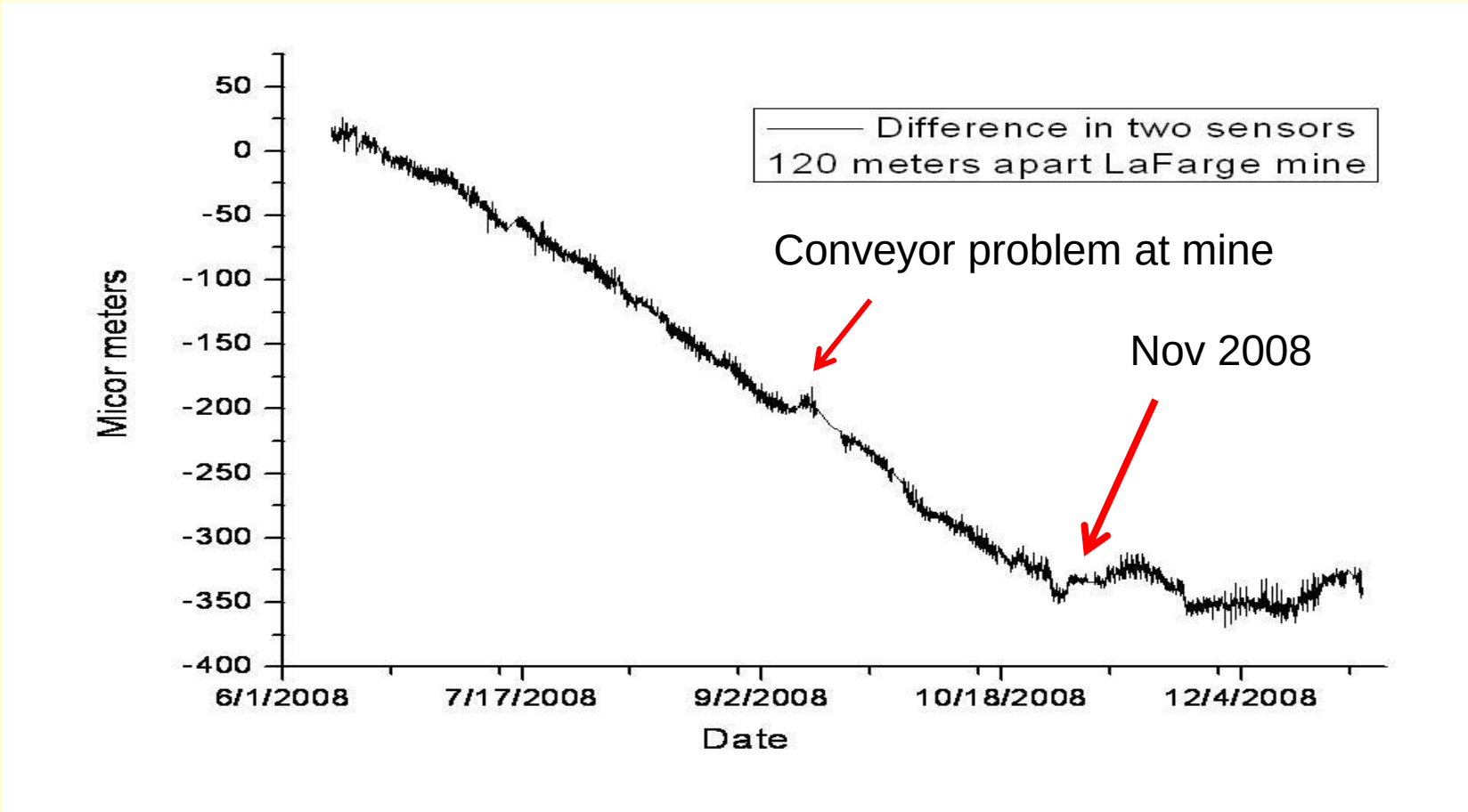


Difference in two sensors150 meters apart

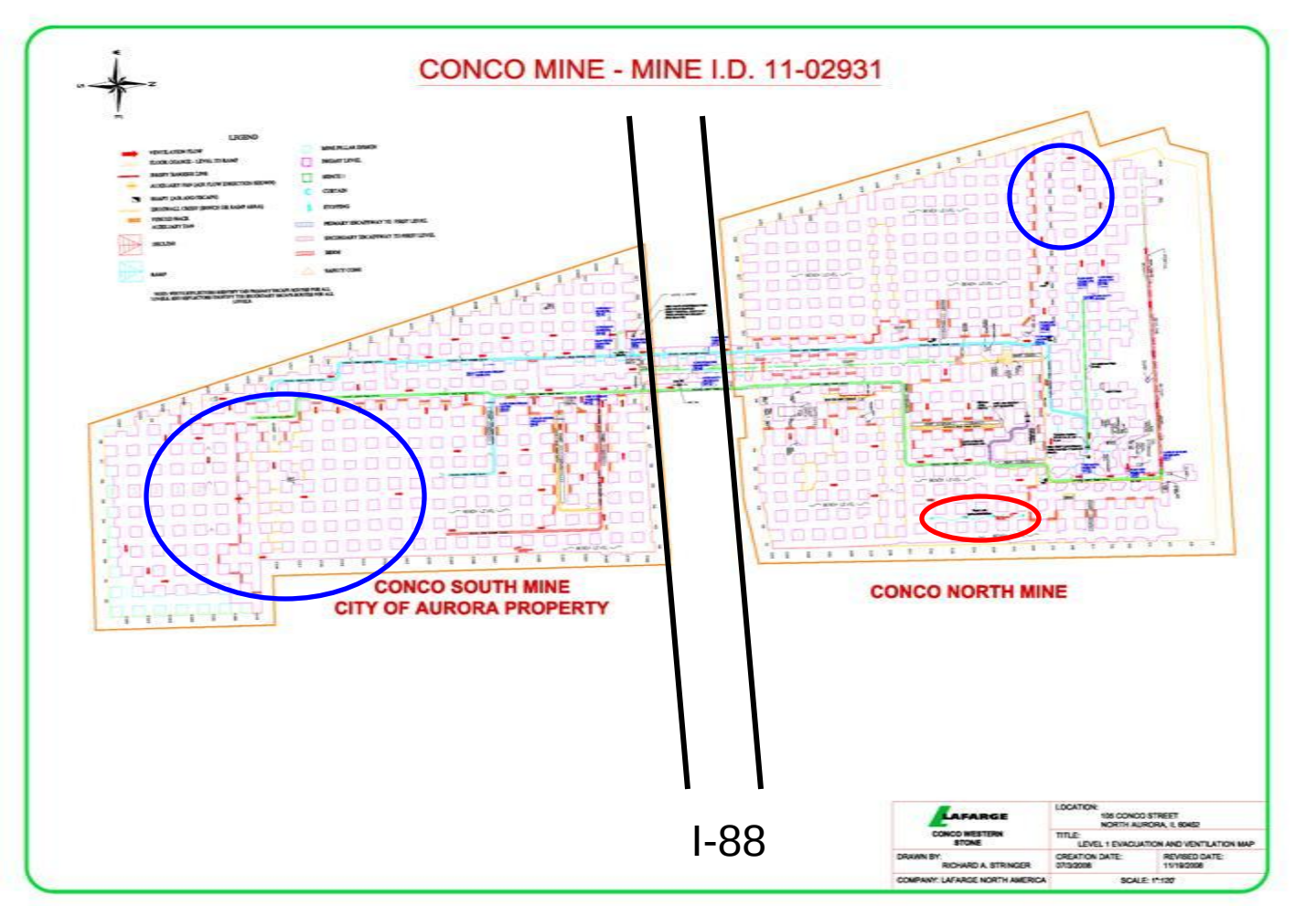
18 months of data



New setup in S5 drift 7 months of data



Layout of LaFarge mine



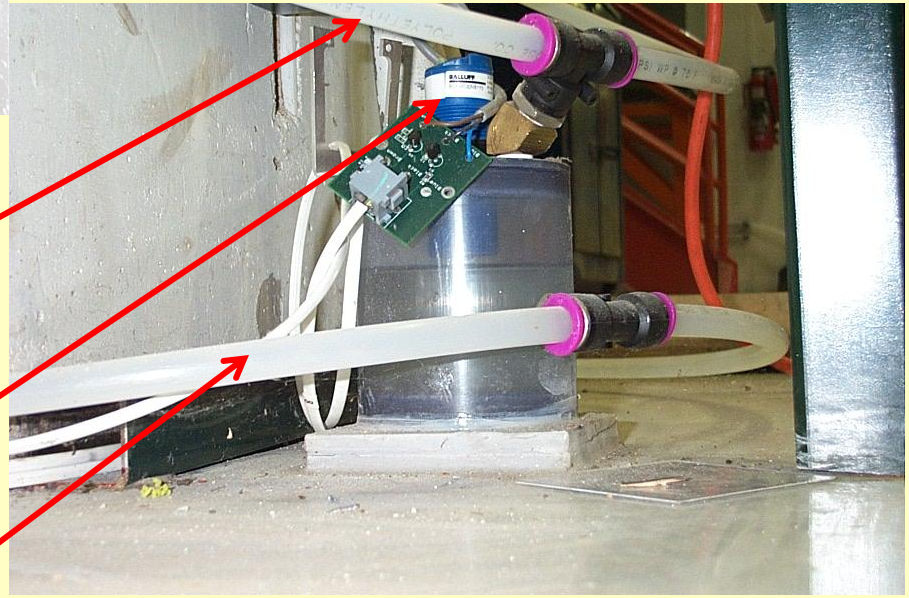
NMS hall

The new test area for the Photo Injector

The first SC RF cavity

Tev style HLS sensors

First sensor with guard



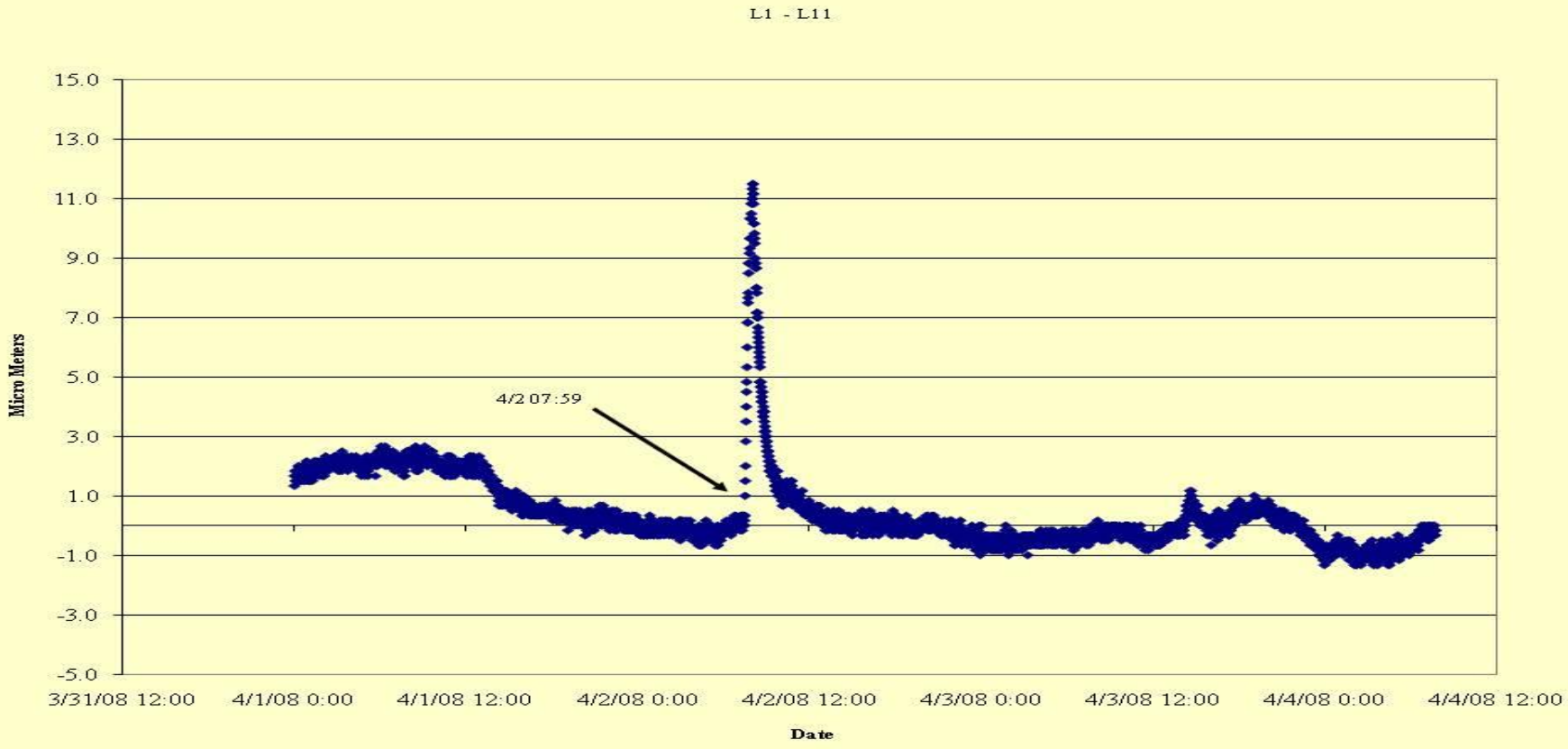
Air line

Sixth sensor

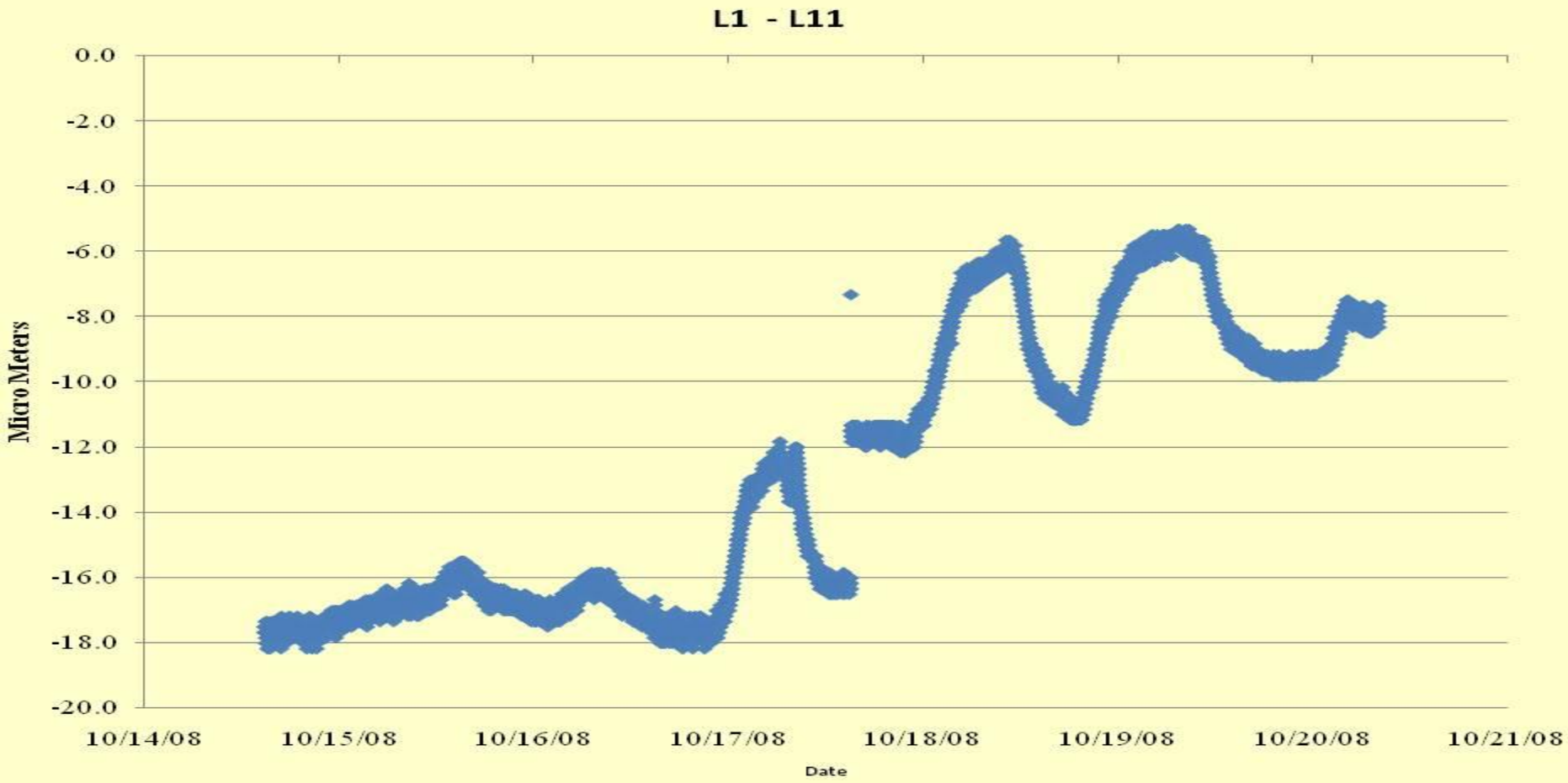
Balluff sensor

Water line

Floor tilt NMS Difference in two sensors 90 meters apart

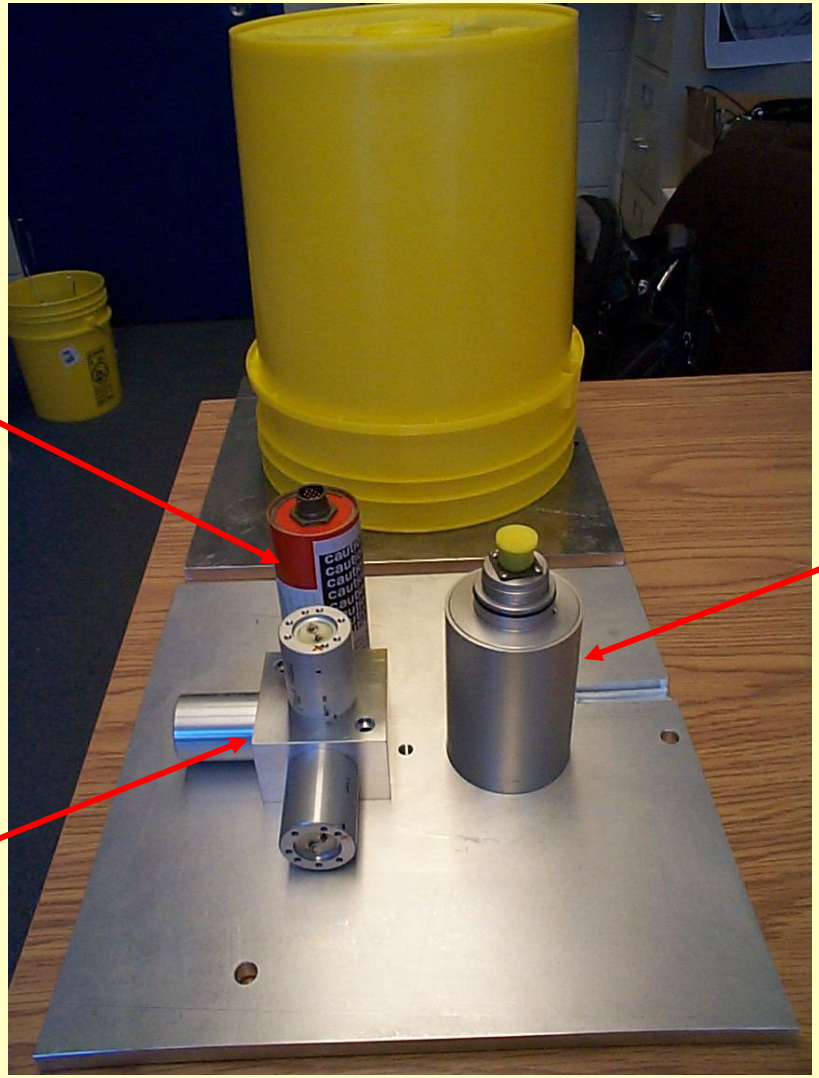


More NMS floor motion data



Meson & NML Seismic Station

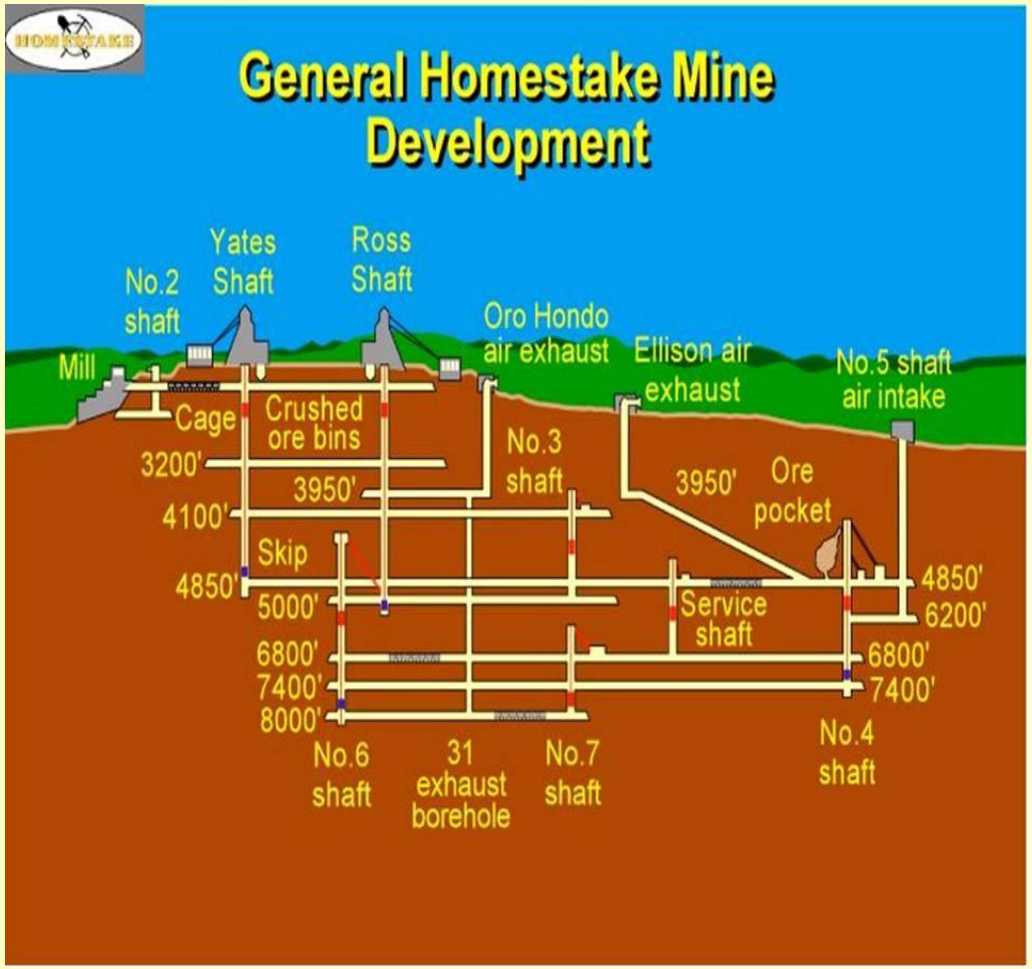
Teledyne Geotech
S-500
Vertical
Short Period
Seismometer
(range down to 1 Hz)



Sercel L-4c
Vertical
Seismometer
(range down to 1 Hz)

Tri-axial Block of
Geophones
(range down to 2 Hz)

DUSEL



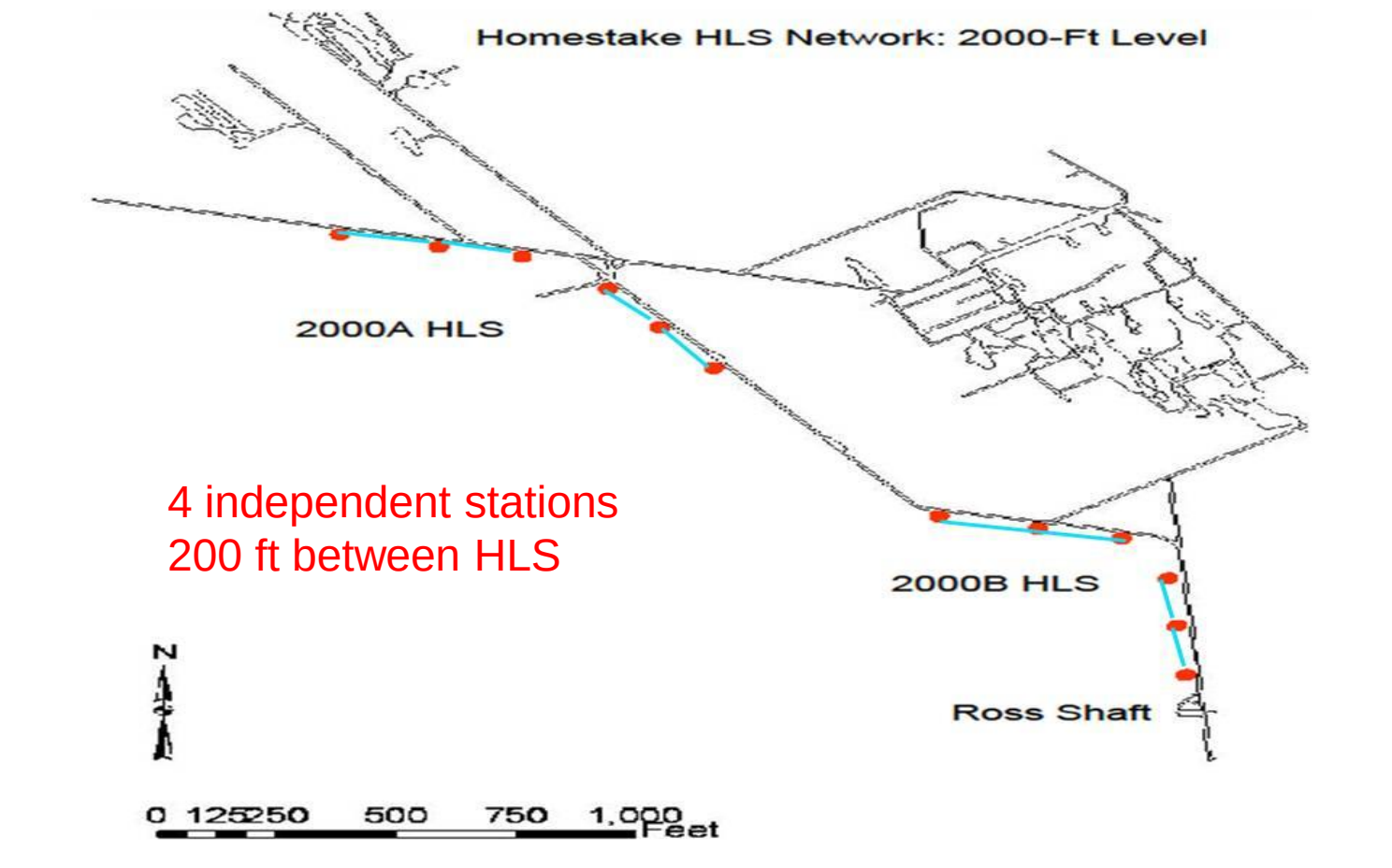
Deep Underground Science and Engineering Lab

In the Homestake
Gold mine in Lead SD

Lowest drifts 8000 ft (2400 meters) flooded to 4850 ft (1470 meters)

In January 2009 there will be 12 Tevatron style HLS installed at 2000 ft
In the summer 12 HLS at the 4100 ft (1242 m) to monitor tilt during dewatering process

HLS layout at 2000 foot level

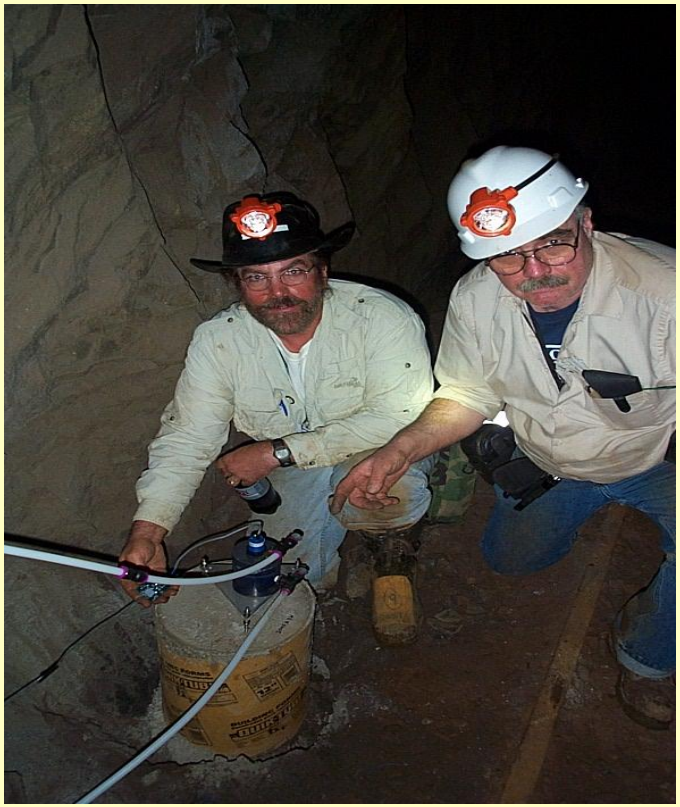


4 independent stations
200 ft between HLS

HLS at DUSEL

Tom Trancynger filling system with water

Jason Van Beek terminating data cable



Larry Stetler of SDSM and Jim Volk

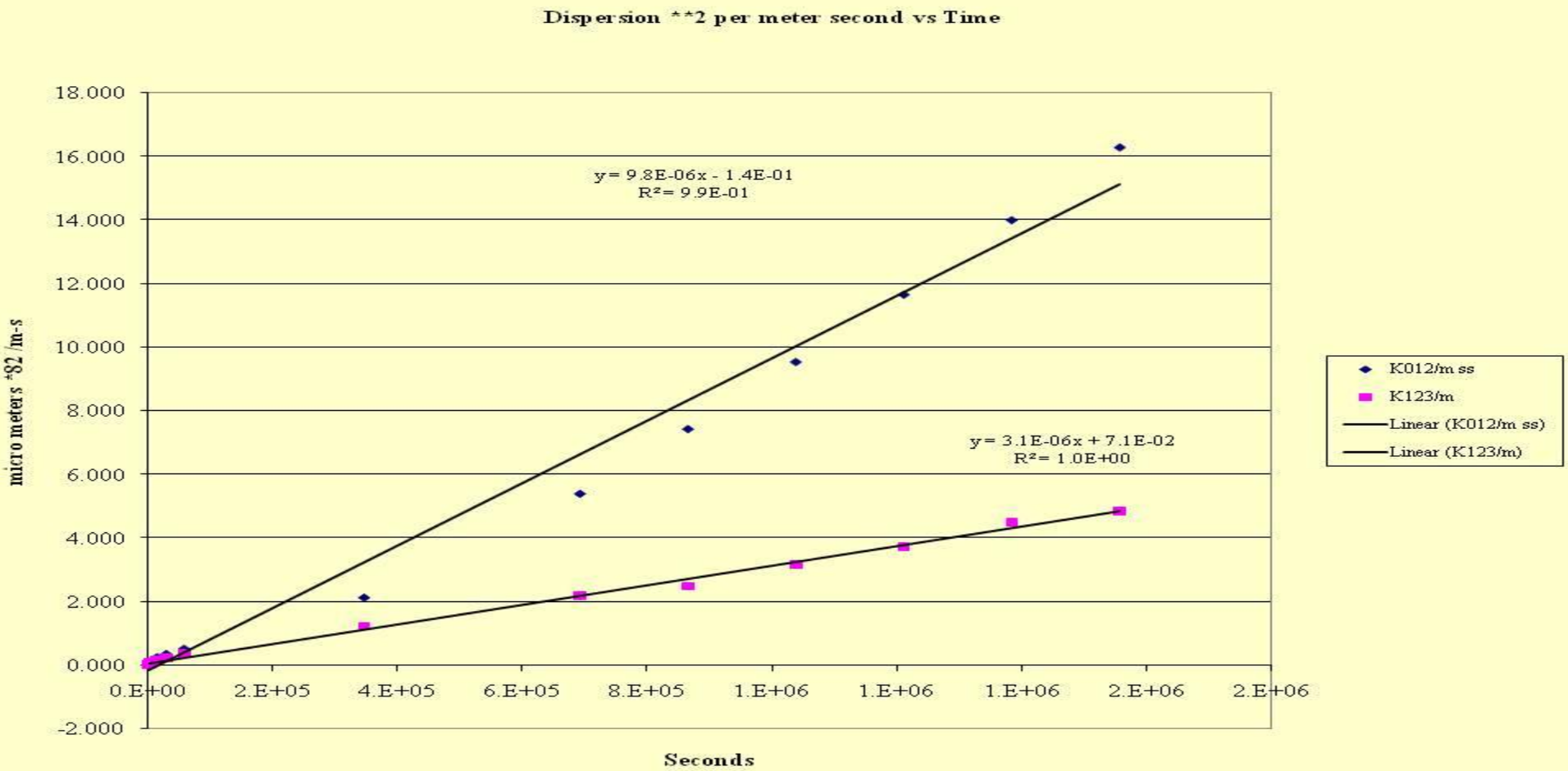
ATL Law

- Motion between two points can be described as <dis**2> = ATL
- Where A is a constant
- T is the time in seconds
- L is length between the points

Calculation of A

- Find the double differences between three sensors
- (D0-D1) – (D1-D2)
- Square the double difference
- Do this for different time slices from 1 minute separation to 14 days separation
- Find the mean of each time slice
- Plot versus time

ATL law extracted from MINOS data for November 2006



J T Volk Fermilab Dec 2008

ATL law results

- Value for A is between $5 * 10^{-6}$ and $1.5 * 10^{-6}$ micro meters ^{2} per m-s
- Need to look at more data it may break down for time spans longer than a few months

EJ&E Rail Road

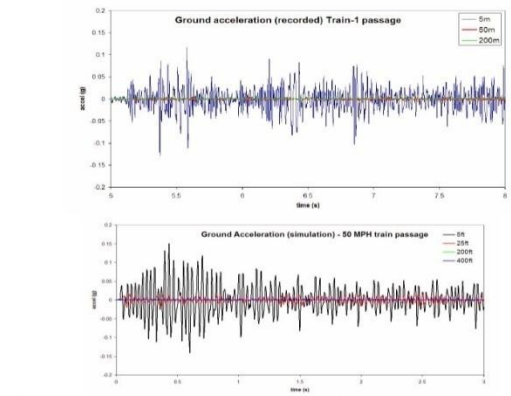


Figure 6.5: Attenuation characteristics of recorded and simulated data on the ground surface at distances from the CN-EJE line.

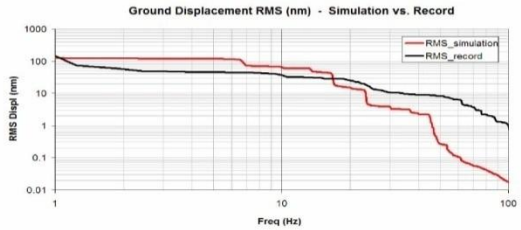


Figure 6.6: Comparison of ground displacement rms between recorded and simulated data for the same distance from track (50m)

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The rail road to the east of site is for sale. As part of the process in the US the site The Surface Transportation Board must do an impact study.

Consultants were hired to model the ground motion due to train passage.

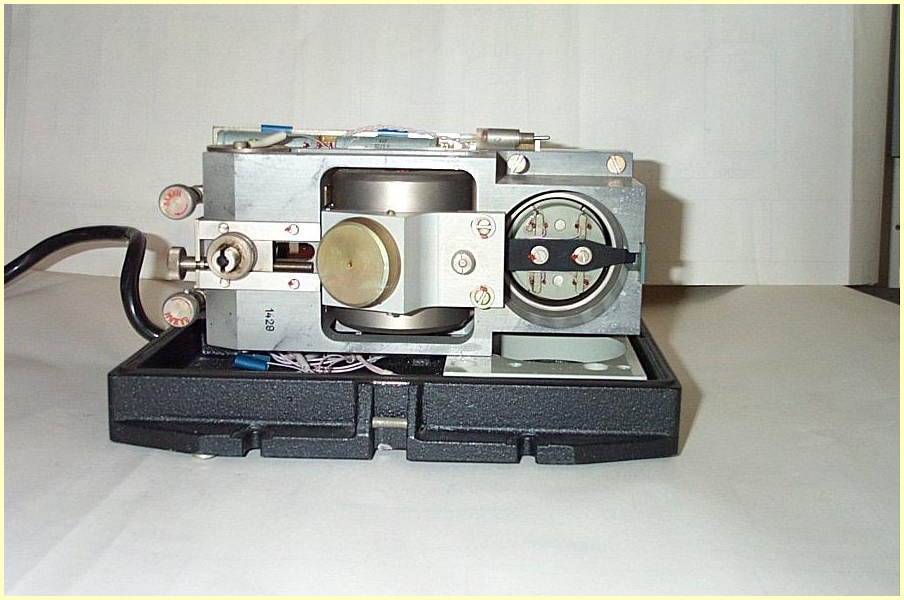
The top graph is ground acceleration as measured by a train traveling 50 mph

The middle graph is the model prediction

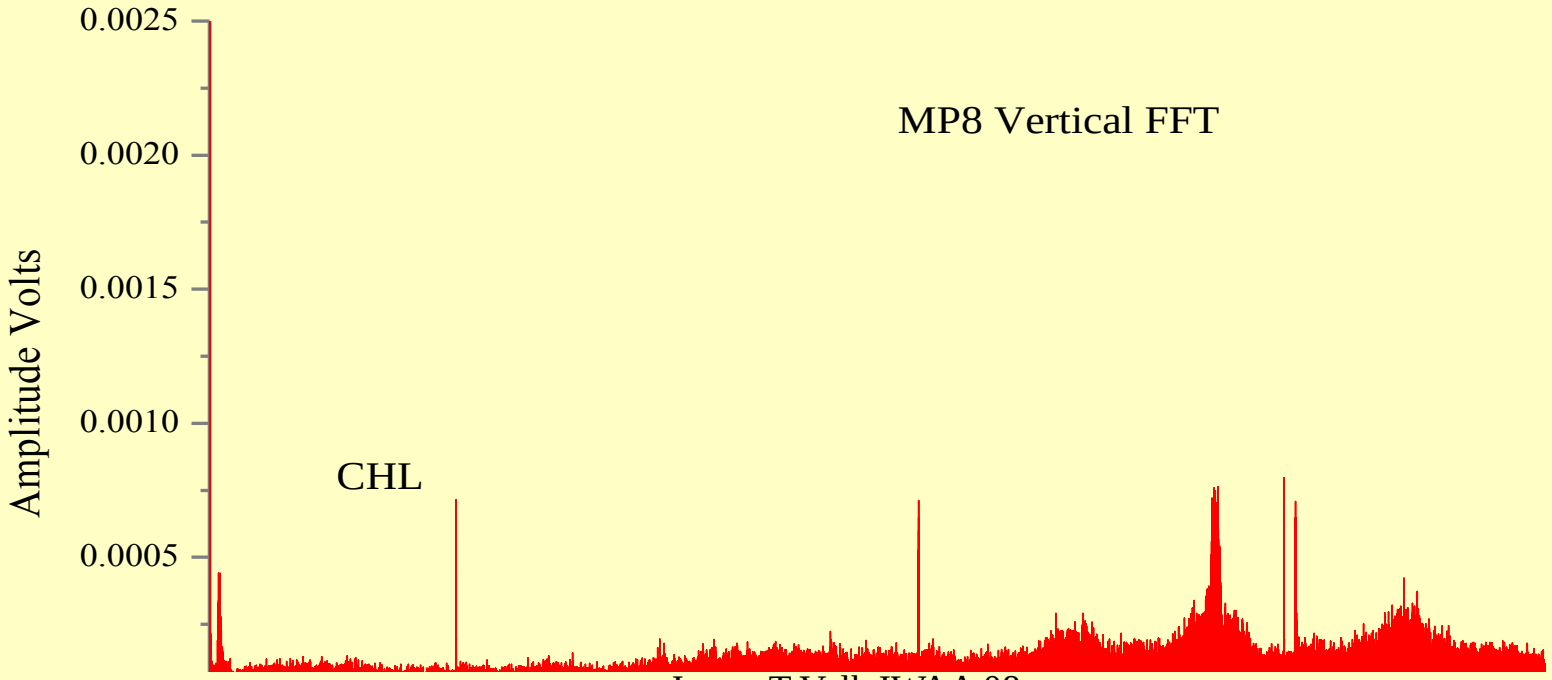
The bottom graph is the power spectrum for the measurements (black) and model (red).

The conclusion is more rail traffic will not adversly affect future accelerators

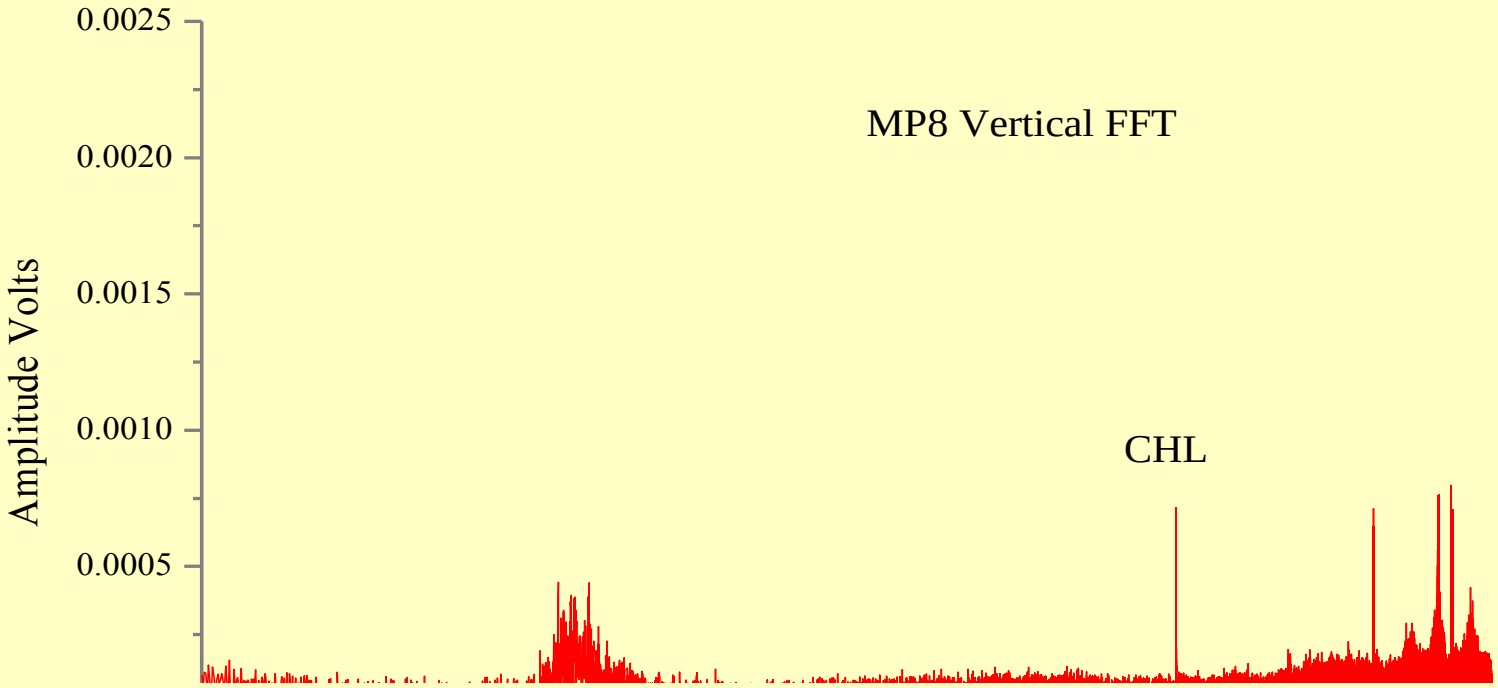
Russian Seismometer



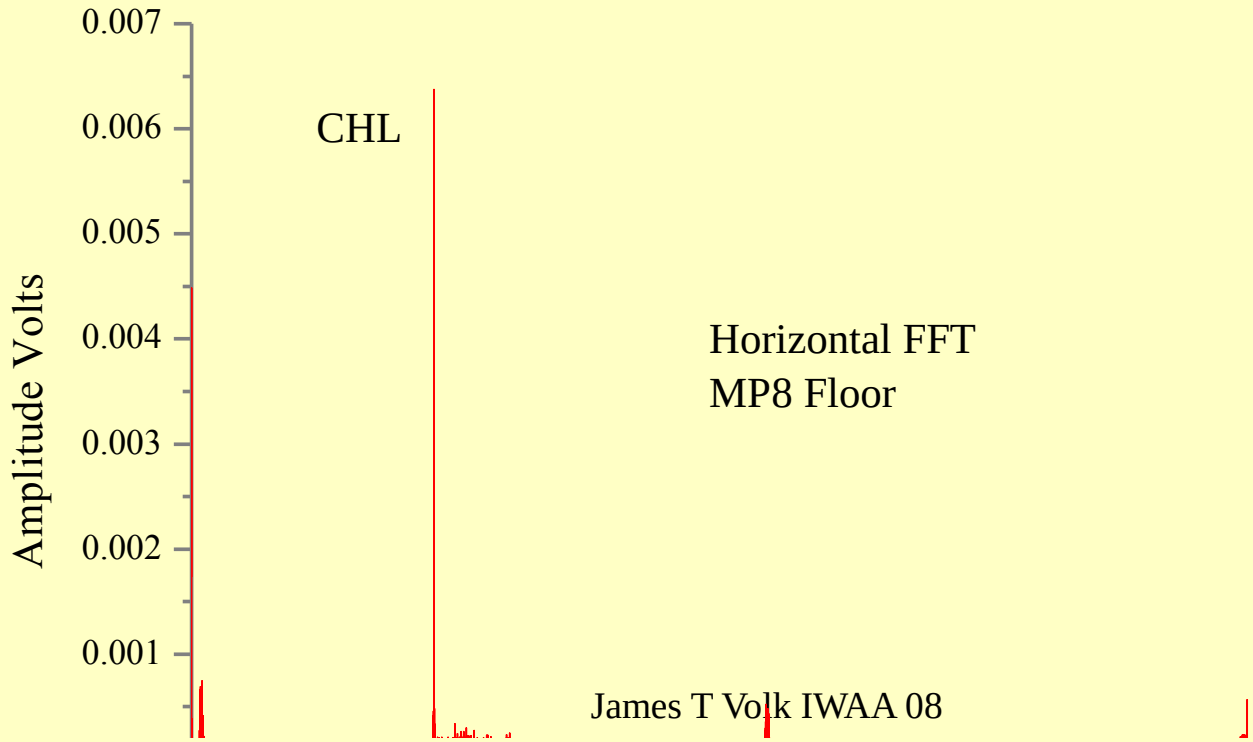
Vertical motion at grade Fermilab



Vertical motion at grade Fermilab log scale



Horizontal motion at grade Fermilab

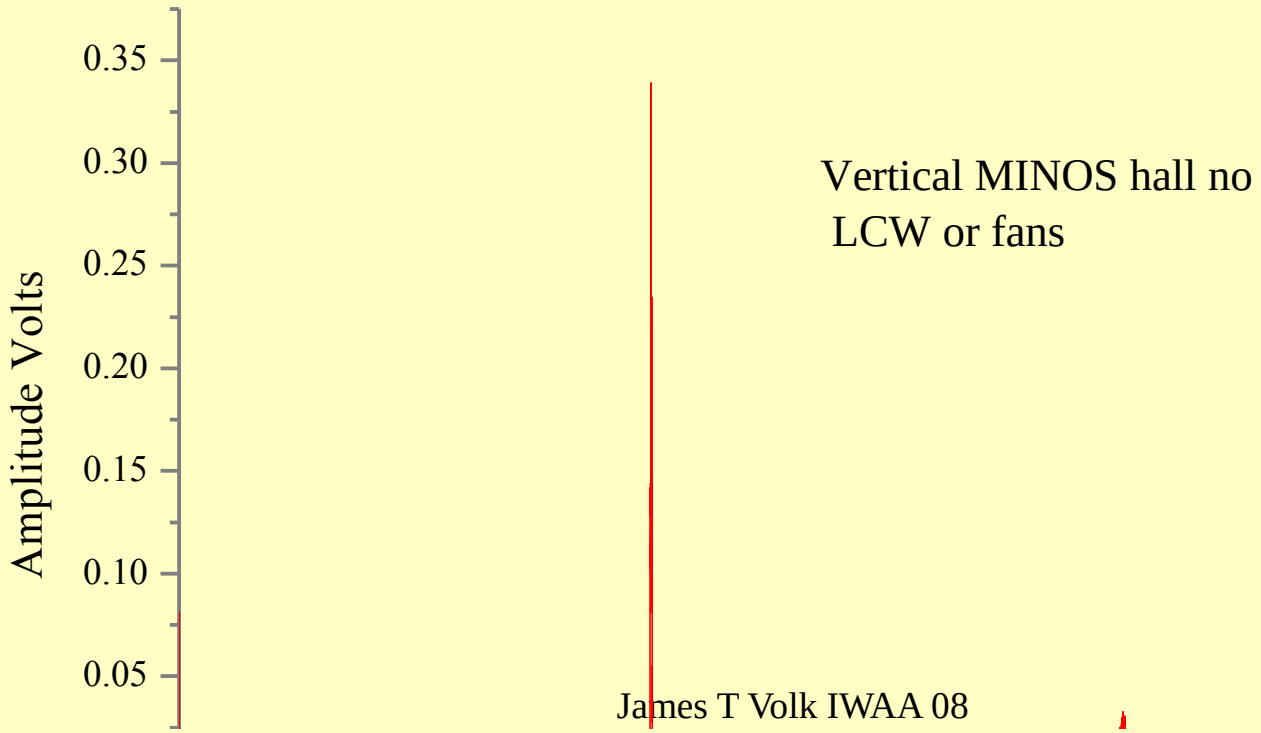


Horizontal motion at grade Fermilab log scale

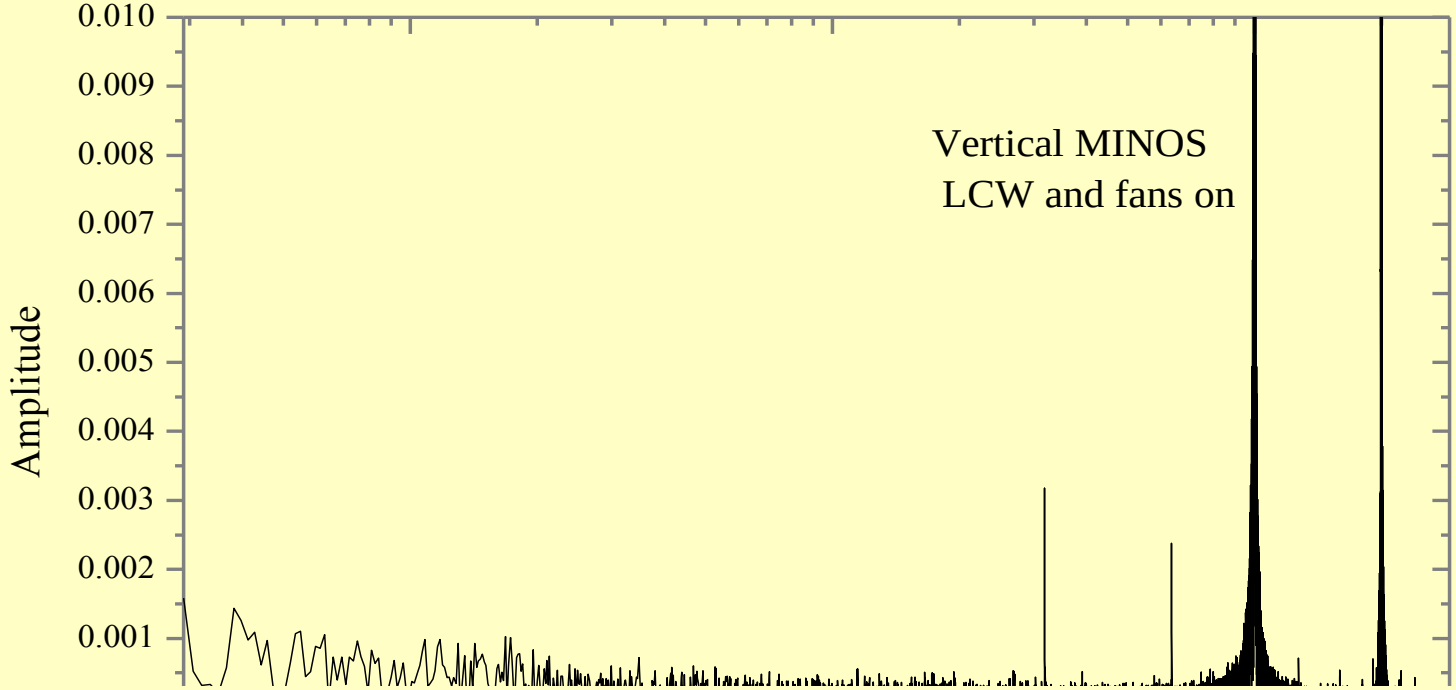
Central Helium Liquifier

Large compressors

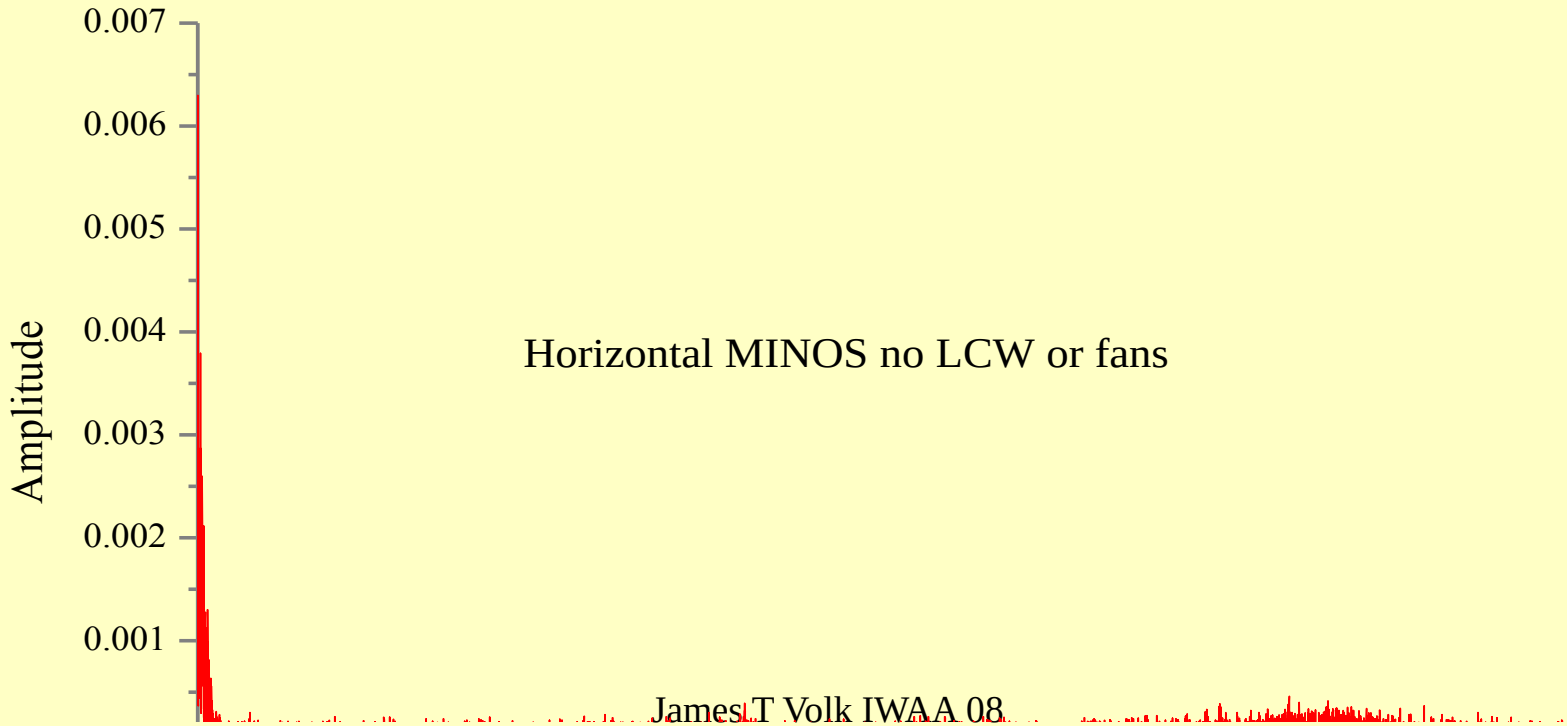
Vertical motion MINOS hall



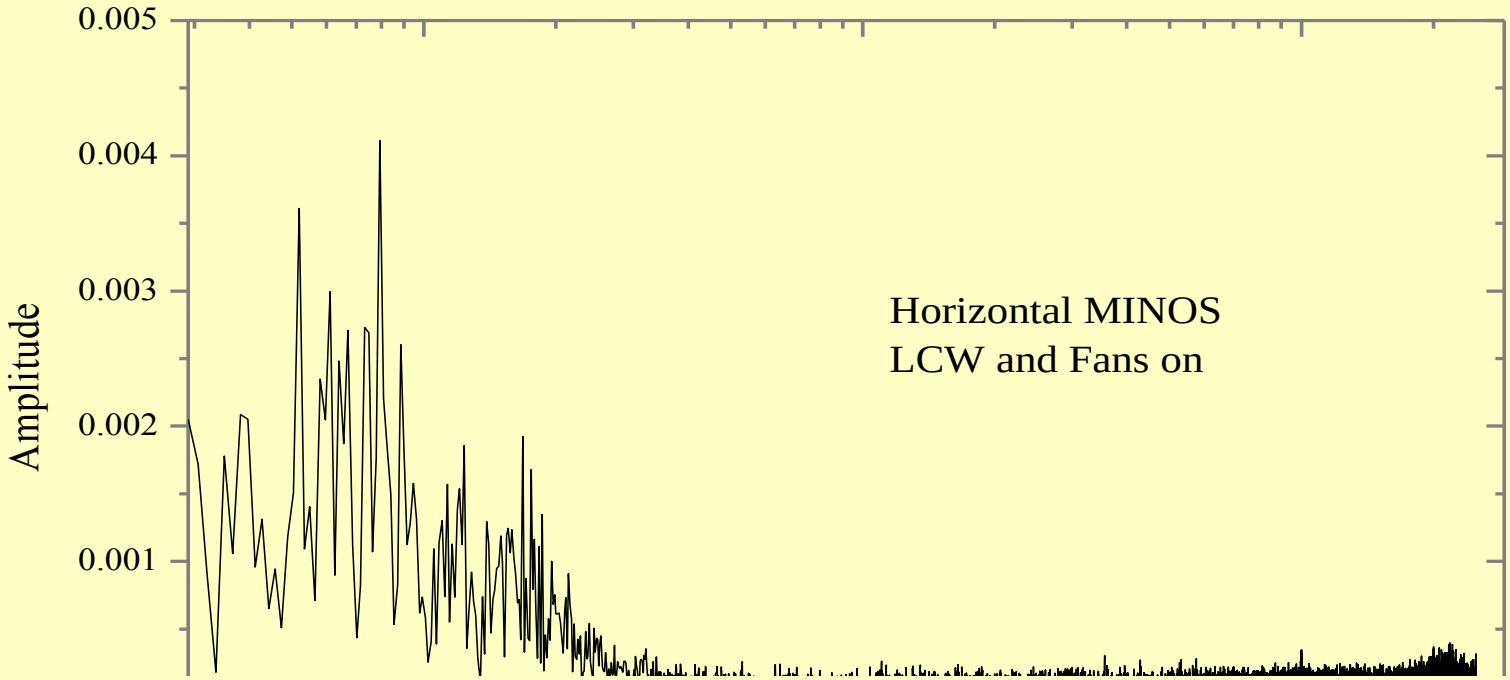
Vertical motion MINOS hall log scale



Horizontal motion MINOS hall

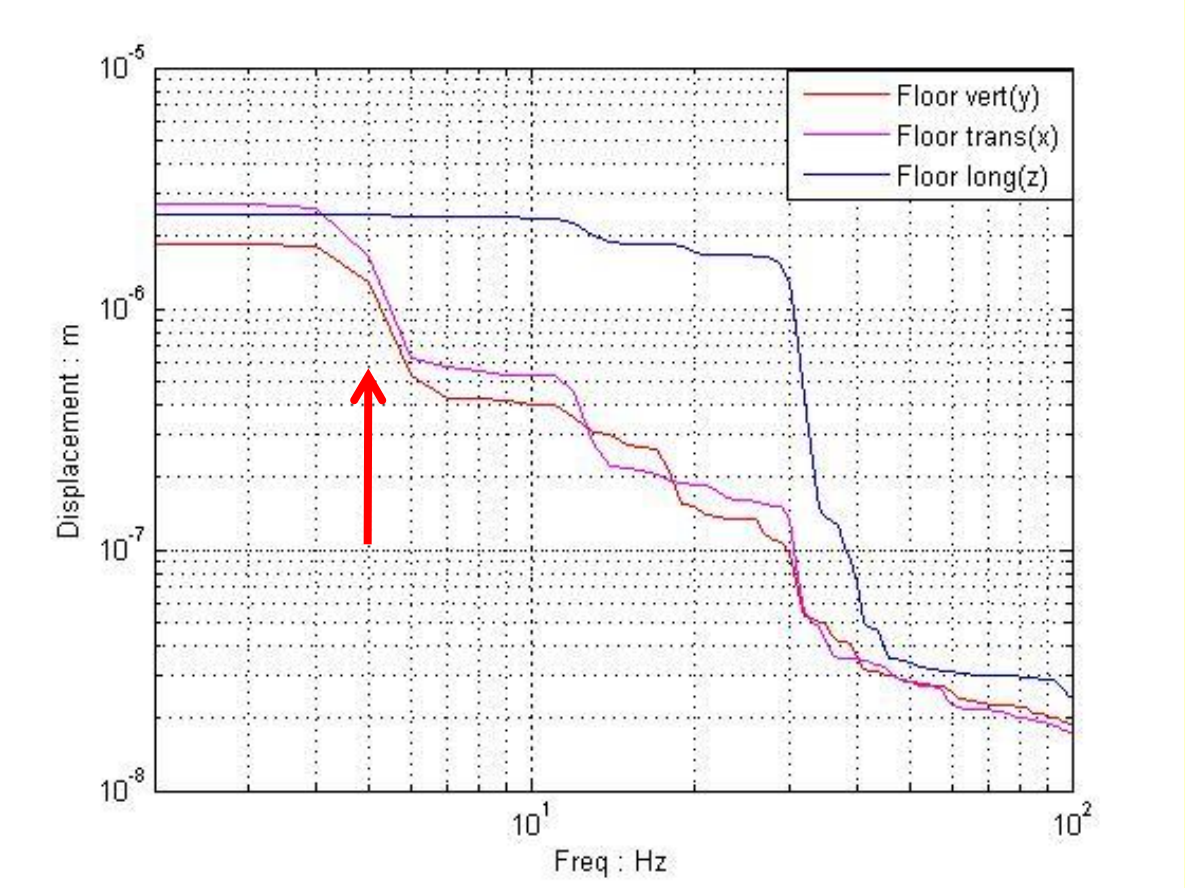


Horizontal motion MINOS hall log scale



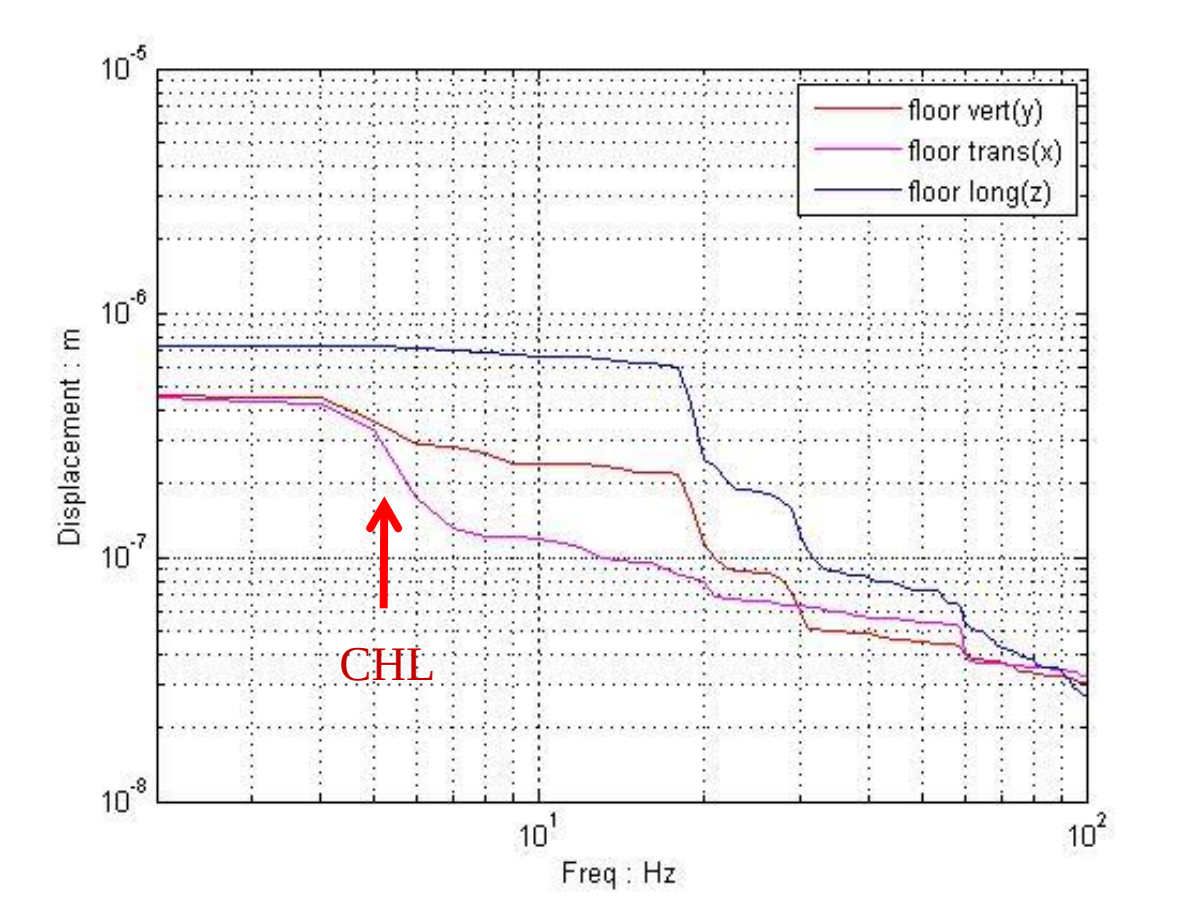
Power Spectrum Meson Floor

CHL vibration

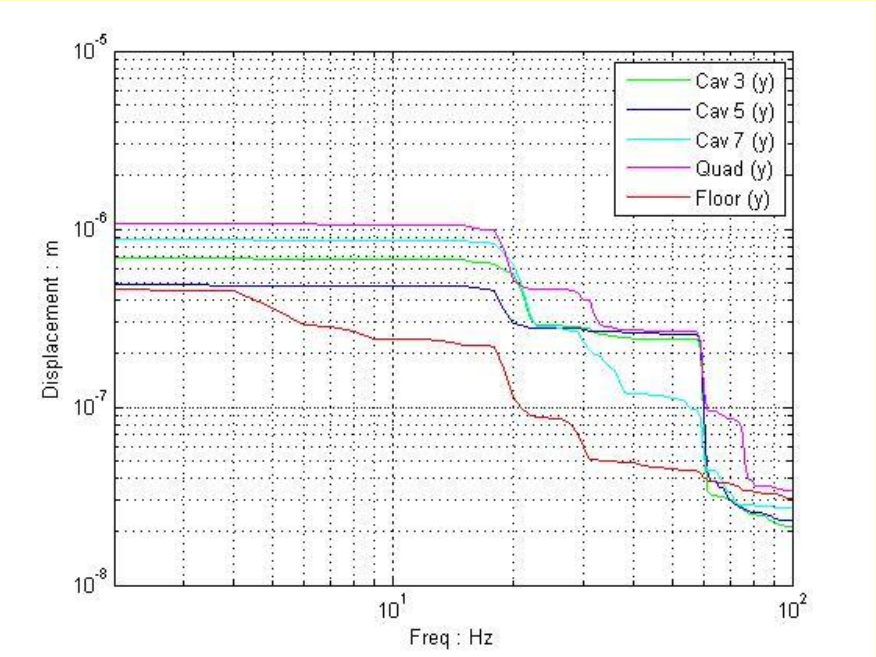


Power Spectrum NMS on floor

5.9 m below grade

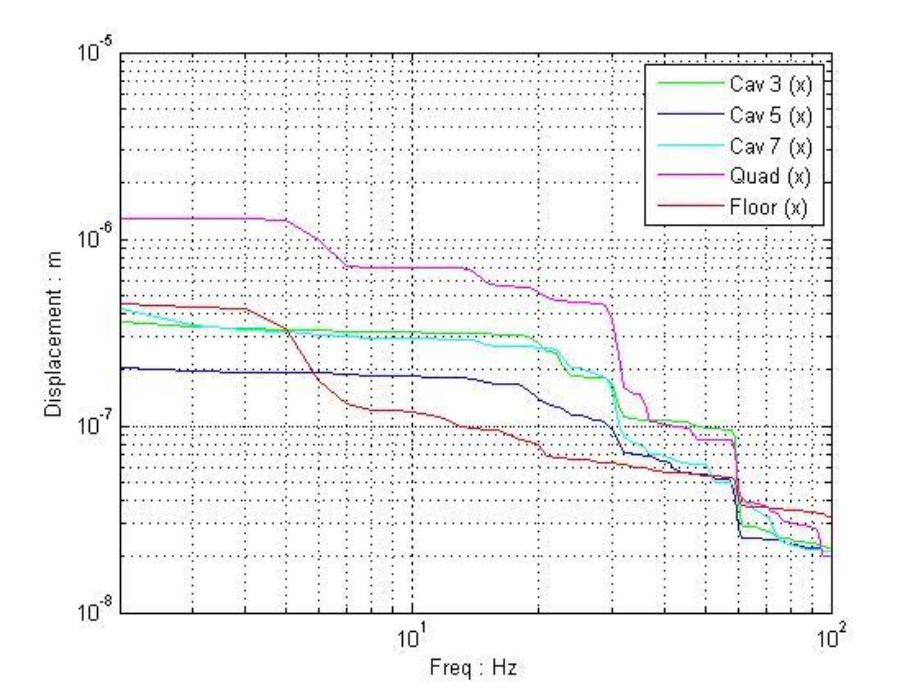


Cryo Modules at Meson Lab



Vertical motion

Horizontal motion



Students Wanted

Joint University - Fermilab Doctoral Program in Accelerator Physics and Technology

Accelerator Physics and Technology is an exciting and challenging field with a growing number of diverse career options ranging from basic research in elementary particles to medical technology. The design, construction and operation of accelerator systems use techniques from physics, electrical and mechanical engineering and computer science.

The Joint University- Fermilab Doctoral Program was established in 1985 as a way to encourage students to pursue a career in accelerator physics and technology by providing research opportunities using facilities and expertise available at Fermilab. The Ph.D. Program works in a joint agreement with universities. Fermilab reimburses the university for the student's salary, provides the research project and supervisors while the student maintains a relationship with their home institution's advisers who oversee the students progress toward the PhD degree from their university.

Graduate students are invited to apply to this program by contacting Roy Rubinstein or Vladimir Shiltsev.

More information concerning accelerator and accelerator technology at Fermilab can be found on the websites of the Accelerator Division, Technical Division and the Computing Division.

http://apc.fnal.gov/programs2/joint_university.shtml

Summary

- There are several HLS system taking data at Fermilab.
- They are accurate and reliable can run for several years.
- They are useful for determining ground motion and tilt.
- The data are available at; http://dbweb1.fnal.gov:8100/ilc/ILCGroundApp.py/index
- There are natural sources of motion: tides, rain fall, earth quakes both large and small.
- There are cultural sources such as sump pumps.
- Plans for new systems in the works.