Ground Motion Studies at Fermi National Accelerator Laboratory

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- 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

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Future Plans at Fermilab

Project X an 8 GeV Superconducting LINAC

Intense \( \nu \) beams to NUMI 890 km north and DUSEL 1480 km west

Muon Cooling test facility

Muon Collider

International Linear Collider

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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
Hydrostatic water Levels Systems

Water seeks it’s own level

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Water seeks its own level
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
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.
Hydrostatic water Level Systems
HLS

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

Capacitive sensor     Water pool

Air line
Water line
On stand with water and Air line connections

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Ultra Sonic Sensor and Electronics

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

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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

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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)
In the circle is a water level pot on a Tevatron quadrupole.
Tevatron Quad Motion During Ramp

Quad B43 and Tevatron Current

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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

Sensor
Water line
Not to scale

MINOS detector
Location of Horizontal and Vertical seismometer
New sensors

υ direction

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MINOS BUDKER HLS Sensors

Air Line
Water line
Data Cable
MINOS Tidal Data
Difference in two sensors 90 meters apart

Date

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January 2006 MINOS

Difference in two sensors 90 meters apart

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January 2006 MINOS

Difference in two sensors 90 meters apart

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Sump Pump Test

L3-L0 and pressure

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Spring and Neap Tides

![Graph showing tidal variations with marked phases]

1st Quarter  Full Moon  Last Quarter

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FFT of MINOS data difference between two sensors
December 2007

12 hours tides
59 minutes
29 minutes

James T Volk IWAA 08
FFT of MINOS data difference between two sensors
October 2008 data

FFT of October 2008 data difference in two sensors 90 meters apart MINOS hall

Tidal data

59 minute

29 minute

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Blow up of FFT showing tide peak

Tides in MINOS hall data

Amplitude

Frequency (Hz)

2.315 \times 10^{-5} \text{ hertz}

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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

Date
Difference between two sensors
90 meters apart MINOS hall

micro meters

Date

-50
0
50
100
150

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Two sensors 90 meter apart and rain fall in Batavia
Two sensors 90 meter apart and rain fall in Batavia

L3-L0 in MINOS hall

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August 08 through Oct 08 MINOS

Sept 24 6.2 M earthquake west coast of Mexico

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Subsidence and Tremors

Jan 9th 2008

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Difference in sensors as showing tilt in floor

1st tremor
07:43

2nd tremor
08:55

10:22
Earth quake April 18 at 04:27 hrs CDT 380 km (236 miles) south south east of Fermilab

Start 04:27 hrs

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North South and East West sensors difference MINOS hall

Time of Earth quake
04:27 April 18

08:33 April 19

Date

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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
2008-10-01 00:05:00,7255.074,7554.103,7357.6,7348.594,7759.148,7749.771,25.16,23.31,23.06,21.27,19.88,21.81,21.82,100.63
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 00:10:00,7254.619,7554.492,7357.95,7348.795,7759.068,7749.788,25.16,23.3,23.08,21.28,19.87,21.8,21.8,100.63

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

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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

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

Station 4
Difference in two sensors 60 meter apart
Difference in two sensors 150 meters apart
18 months of data

Major Rain Event and Flooding in Mine

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New setup in S5 drift 7 months of data

Conveyor problem at mine

Nov 2008
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

Sixth sensor

Air line

Balluff sensor

Water line

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Floor tilt NMS Difference in two sensors 90 meters apart
More NMS floor motion data

L1 - L11

Micro Meters

Data

10/14/08  10/15/08  10/16/08  10/17/08  10/18/08  10/19/08  10/20/08  10/21/08

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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

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HLS layout at 2000 foot level

4 independent stations
200 ft between HLS

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HLS at DUSEL

Tom Trancynger filling system with water

Larry Stetler of SDSM and Jim Volk

Jason Van Beek terminating data cable
ATL Law

• Motion between two points can be described as $<\text{dis}^{**2}> = \text{ATL}$
• 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

Dispersion $y^2/m$ vs Time

$y = 9.2E-06x - 1.4E-01$
$R^2 = 9.9E-01$

$y = 3.1E-06x + 7.1E-02$
$R^2 = 1.0E+00$

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ATL law results

- Value for A is between $5 \times 10^{-6}$ and $1.5 \times 10^{-6}$ micro meters $^2$ per m-s
- Need to look at more data it may break down for time spans longer than a few months
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 adversely affect future accelerators
Vertical motion at grade Fermilab
Vertical motion at grade Fermilab log scale

MP8 Vertical FFT

CHL

Amplitude Volts

Frequency (Hz)
Horizontal motion at grade Fermilab
Horizontal motion at grade Fermilab log scale
Central Helium Liquifier

Large compressors
Vertical motion MINOS hall

Vertical MINOS hall no LCW or fans
Vertical motion MINOS hall log scale

Vertical MINOS
LCW and fans on
Horizontal motion MINOS hall

Horizontal MINOS no LCW or fans
Horizontal motion MINOS hall log scale

![Graph of Horizontal MINOS with LCW and Fans on]
Power Spectrum Meson Floor

CHL vibration

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Power Spectrum NMS on floor

5.9 m below grade

CHL
Cryo Modules at Meson Lab

Horizontal motion

Vertical motion

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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

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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.

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