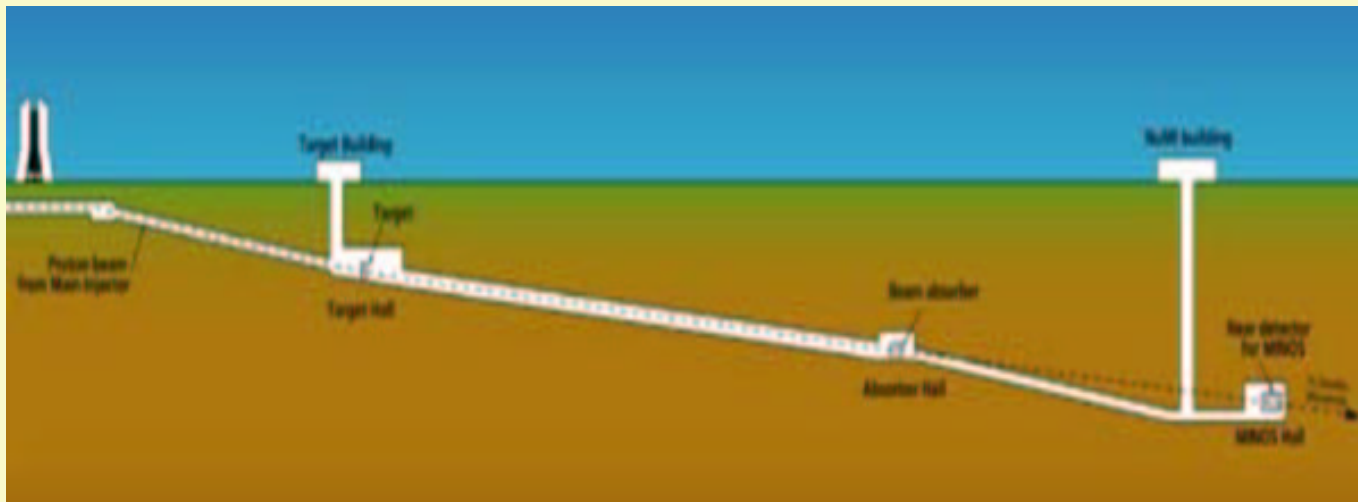# Ground motion measurements in the NuMI tunnel

Michał Szleper
Northwestern University

ICAR Workshop
Argonne, May 19-20, 2004

The project

- Site studies for the LC - measure seismic activity at the FNAL site:

  1. as a function of depth under ground level,

  2. in a wide range of frequencies (e.g., $0.01 - 50\ Hz$),

  3. at various times of the day,

  4. both vertical and horizontal vibrations.

Equipment

- Two broadband seismometers KS2000 from Geotech:

    - measure vibrations in x, y, z,

    - dynamic range $0.01 < f < 50\ Hz$,

- DL-24 portable data recorder,

    - programmable data taking and user defined acquisition frequency.

Offline data analysis

Package of programs for Fourier analysis by A. Seryi (SLAC).

- Power spectral densities from either probe $z_1(t), z_2(t)$:
$$P_{ij}(f) = \int \int z_i(t)z_j(t')e^{-i\omega(t-t')}dtdt',$$

- Correlation between probes:
$$C(f) = <P_{12}>/\sqrt{<P_{11}><P_{22}>},$$

- Measure of intrinsic noise level - power spectrum of the difference:
$$D(f) = |\int[z_1(t) - z_2(t)]e^{-i\omega t}dt|^2,$$

- The average vibration amplitude (RMS of vibration) for $f' > f$:
$$A(f) = \sqrt{\int_{f_{max}}^{f} P_{ii}(f') \, df'}.$$

Before accessing NuMI

Studies of probe performance:

• Test measurements at E4R trailer, Fermilab village (late 2002) and Aurora mine (spring 2003),

• Calibration cross check,

• Effective dynamic range ($f > 0.1\ Hz$),

• Software debugging,

• Comparison with existing measurements (V. Shiltsev) from Aurora mine.
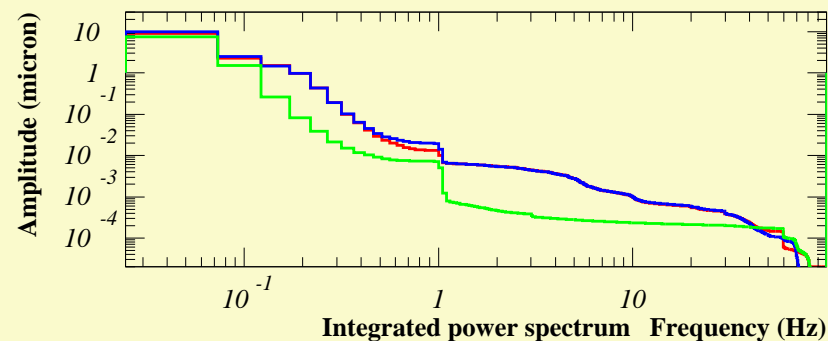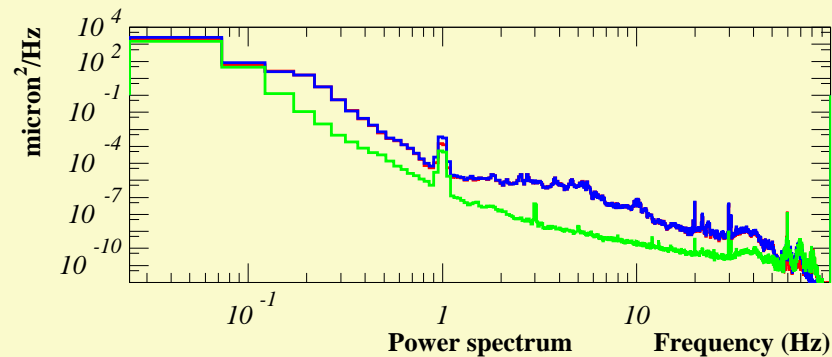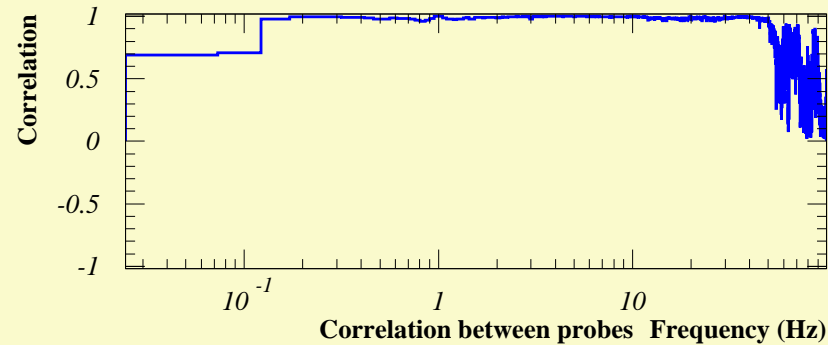
Calendar of measurements @ NuMI

- Two weeks in total - three locations,
- $\sim$ 24 hours with 20 Hz acquisition frequency at each location,
- $\sim$10$\times$30 mins with 100 Hz at each location.

|	
Day 098, Wed Apr 7	Minos hall 100 Hz
Day 099, Thu Apr 8	Minos hall 100 Hz, 20 Hz
Day 100, Fri Apr 9	Minos hall 20 Hz, 100 Hz
Day 101, Sat Apr 10	Minos hall 100 Hz
Day 102, Sun Apr 11	Minos hall 100 Hz
Day 103, Mon Apr 12	Minos hall 100 Hz, Absorber hall 100 Hz
Day 104, Tue Apr 13	Absorber hall 100 Hz
Day 105, Wed Apr 14	Absorber hall 100 Hz, 20 Hz
Day 106, Thu Apr 15	Absorber hall 20 Hz, Target hall 20 Hz
Day 107, Fri Apr 16	Target hall 20 Hz, 100 Hz
Day 108, Sat Apr 17	Target hall 100 Hz
Day 109, Sun Apr 18	Target hall 100 Hz
Day 110, Mon Apr 19	Target hall 20 Hz
Day 111, Tue Apr 20	cleanup

Typical spectra – MINOS hall
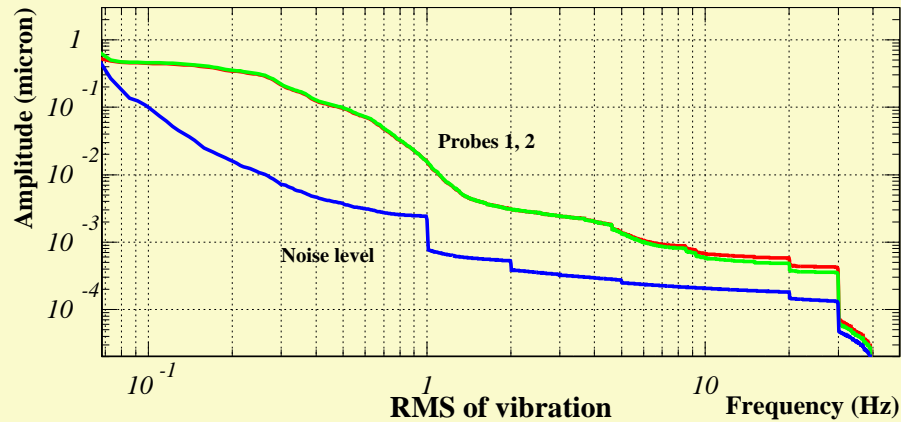

Minos hall, 04/11/04, 03.00 - 03.30
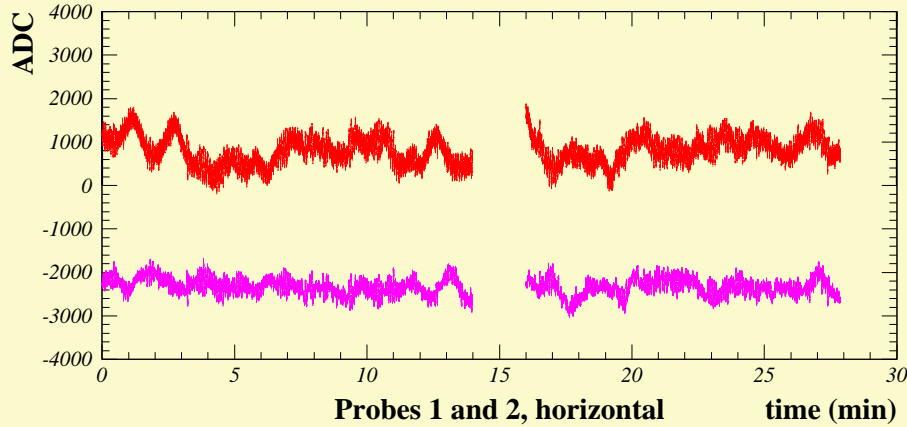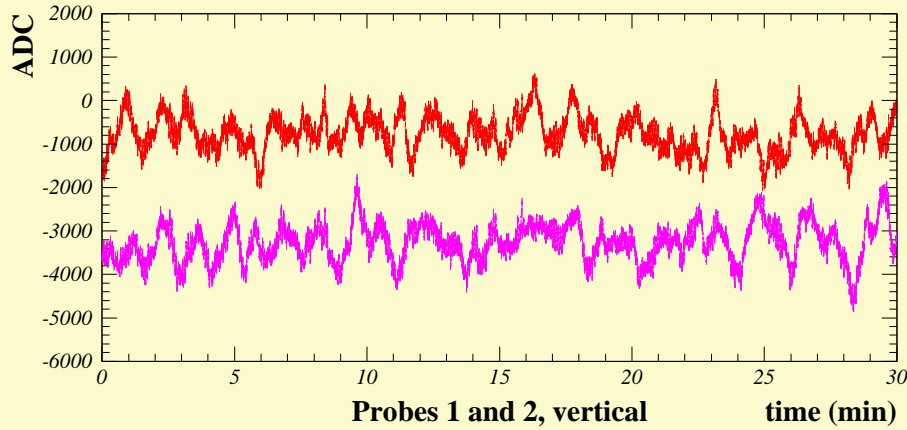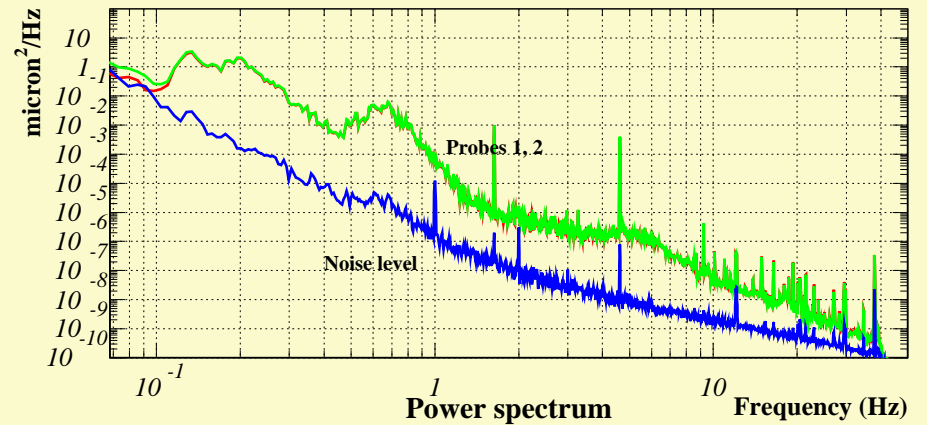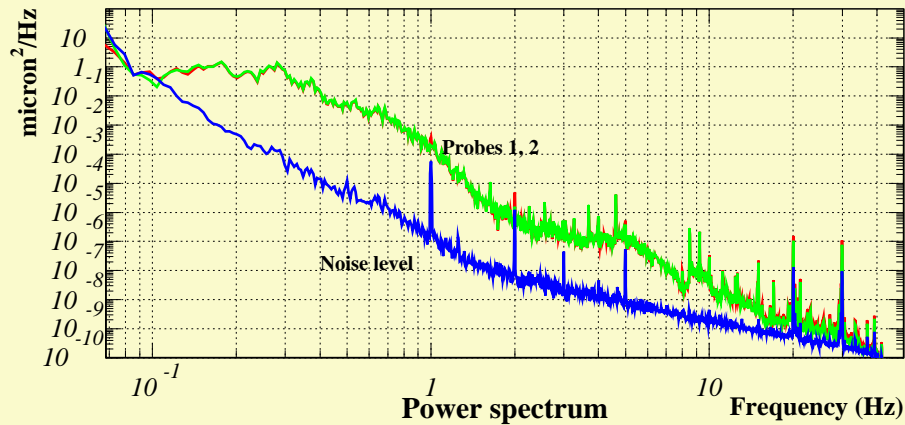
Minos,Day-102,Time-0300,Channels-1,4
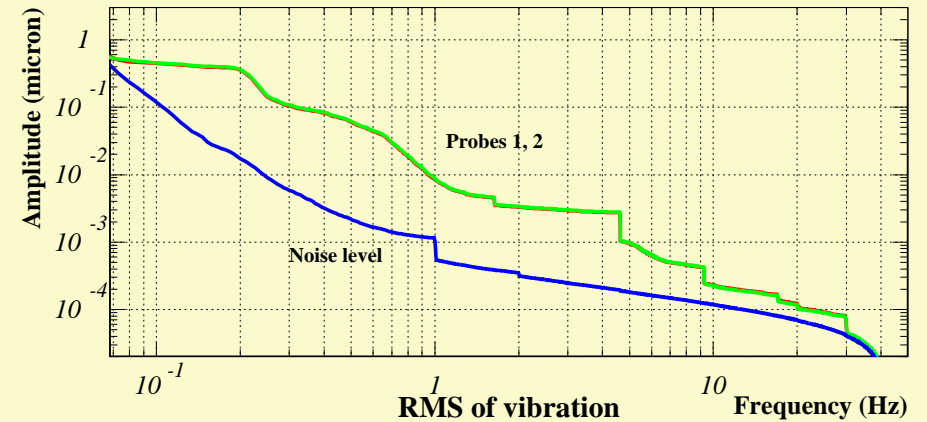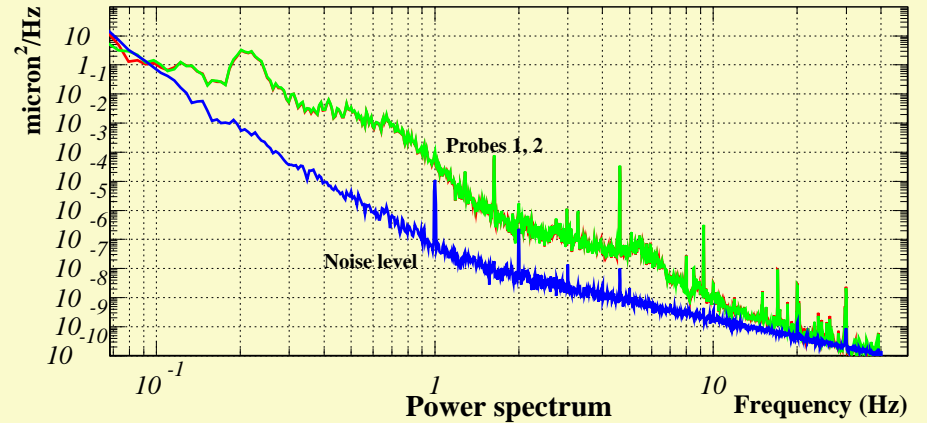
Typical spectra – Absorber and Target

*Absorber,Day-104,Time-0300,Channels-1,4*   *Target,Day-108,Time-0300,Channels-1,4*
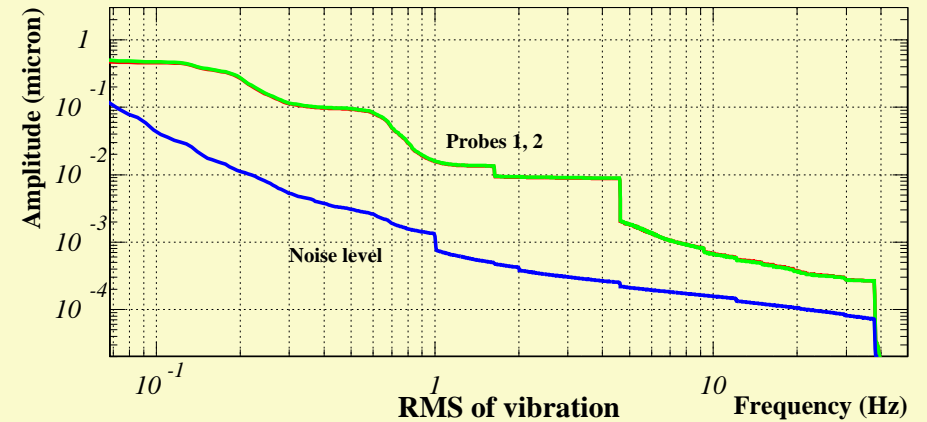
Time averaged spectra

- Periods of corrupted data (low correlation between the probes) removed.
- Power spectral density spectrum computed from every contiguous period of good data.
- Average the two probes (vertical).
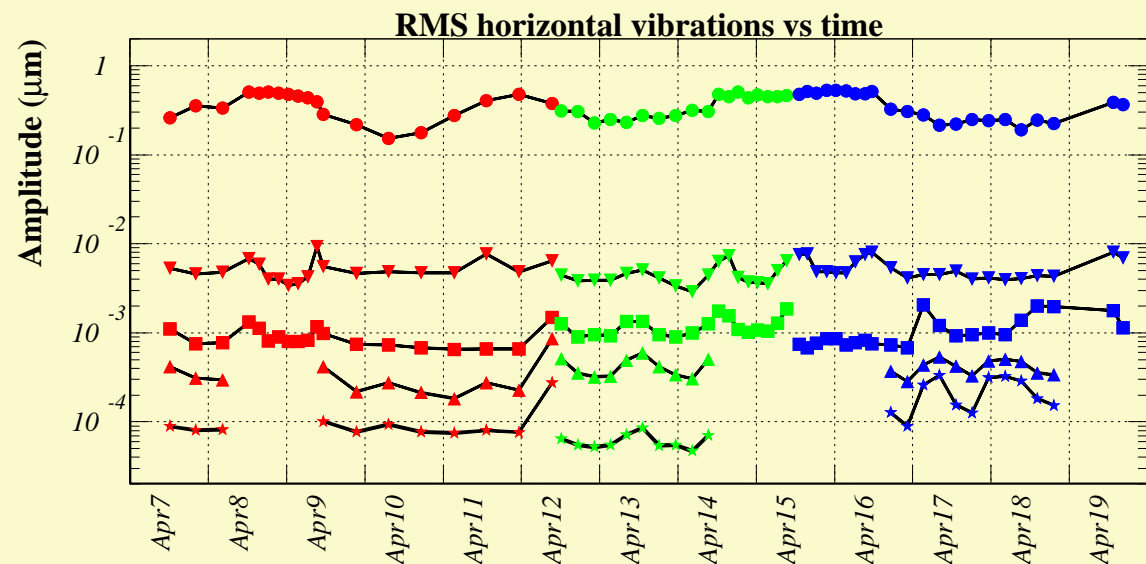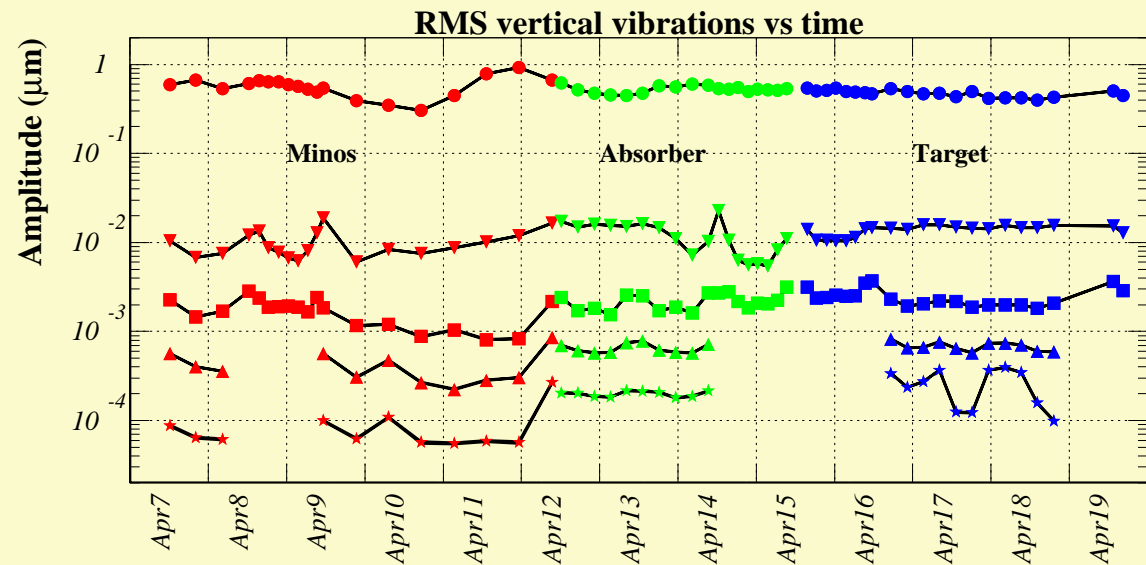- Average spectra measured at different times.

Averaged spectra at Minos, Absorber and Target
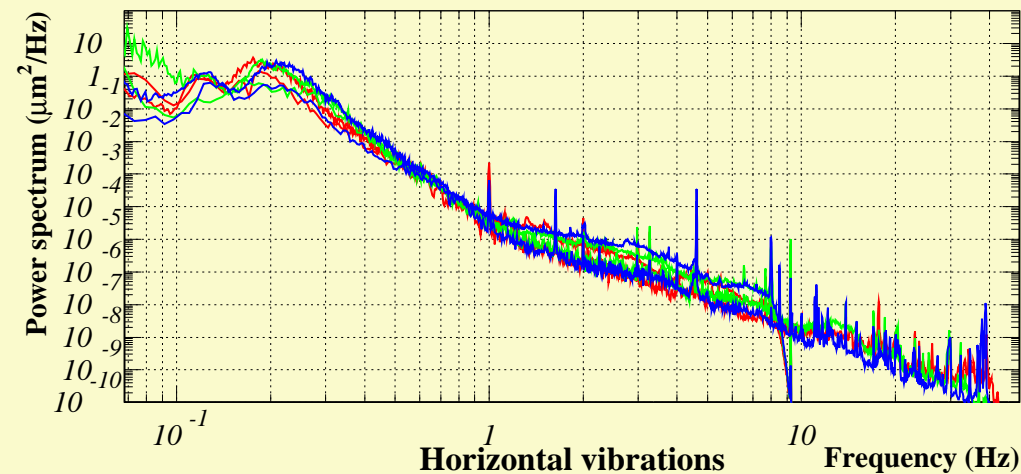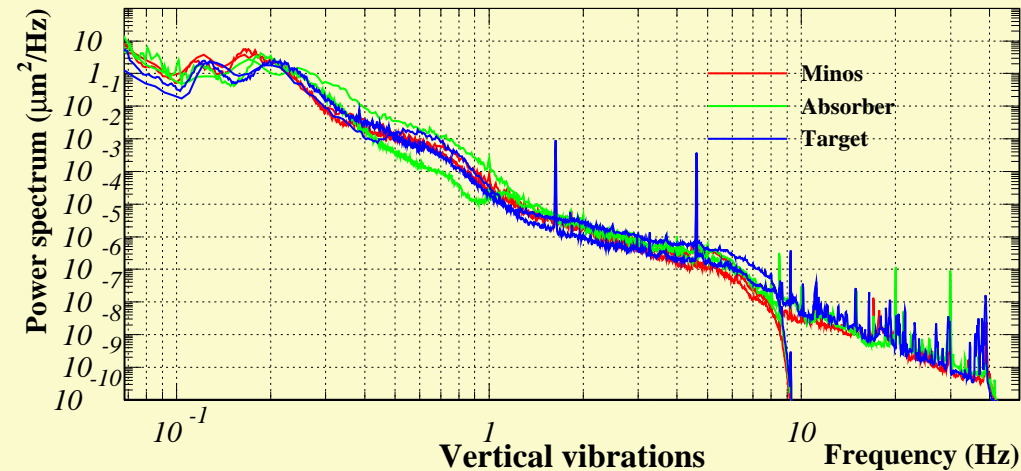
Vibration amplitude vs time

RMS of vibrations in different frequency ranges:

- circles: $0.1-50\ Hz$,
- inv. triangles: $1-50\ Hz$,
- squares: $4.65-50\ Hz$,
- triangles: $10-50\ Hz$,
- stars: $30-50\ Hz$.

RMS vertical vibrations vs time

RMS horizontal vibrations vs time

Summary and outlook

• Ground motion has been taken measured at three different locations in the NuMI tunnel, covering the range $0.1 < f < 50\ Hz$, depths ranging between 200 and 600 ft, and all times of day.

• Data analysis is well in progress. At first look, dependence of seismic activity on depth is small, except for discrete high frequency spikes. Daily variations are more pronounced.

• A more detailed analysis will follow:

    − better understanding of some high frequency spikes, including sources of local in-tunnel vibrations,

    − calculate separate RMS from the spikes (which depend chiefly on what kind of local equipment happened to be turned on) and from the continuous part of the spectrum.

Acknowledgments

I thank Andrei Seryi for his substantial help at every single stage of this project, and in particular for always finding the time answer to my hundreds of annoyingly elementary and naive questions.

I thank the NuMI/MINOS management for granting me access to the tunnel, providing the necessary workspace at each measurement location and for their organizational help.

I thank the management of the Aurora mine for letting me make test measurements in the mine in the spring of 2003, which allowed me to learn a great deal about the equipment and the topic itself.