

V.Shiltsev (FNAL)

# Vibration Measurements for Accelerators Worldwide

Over last 12 years I did organize/take part/collaborate in a number of ground/magnet vibrations studies at/for various accelerators, including:

1988-1991	VLEPP/UNK	Protvino
1992	VEPP-3	Novosibirsk
1993	SSC	Texas
1994	APS	Argonne, IL
1994	for BESSY-II	Novosibirsk
1995	VEPP-4/VEPP-5	Novosibirsk
1995	HERA/TESLA	Hamburg
1997	Tevatron	Batavia, IL
1999-2000	VLHC/NLC	Illinois

This talk is a brief review of many peoples' work:

## My Co-Authors:

Budker INP (Novosibirsk):	B.Baklakov V.Parkhomchuk A.Seryi A.Sleptsov P.Lebedev V.Lebedev I.Protopopov A.Chupyra S.Singatulin M.Kondaurov
DESY (Hamburg):	J.Rossbach C.Montag
SSCL (Texas):	H.J.Weaver
FNAL(Batavia, IL):	J.Lach

It's my pleasure to use this chance to thank them again (and there are several in this audience), as well as many others who helped us with the studies.

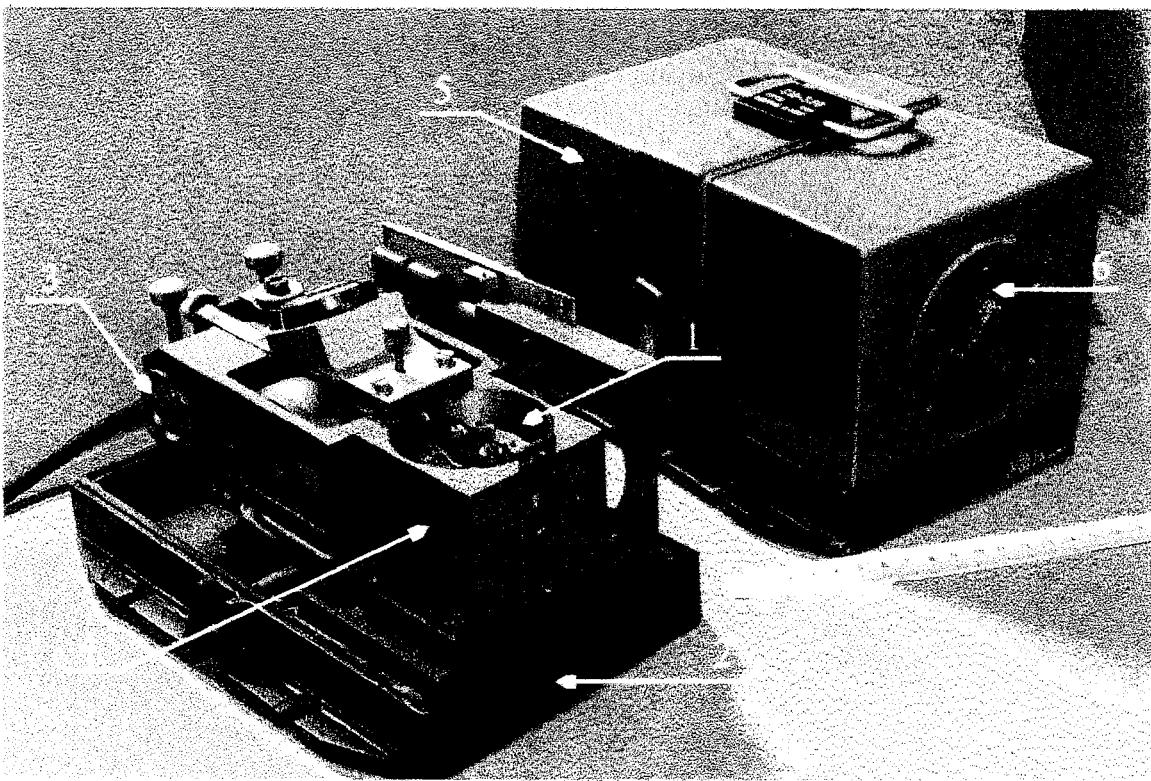


Fig.2. Seismometer of SM3 - KV type.

Here: 1- pendulum with signal and NFS coils, 2 - base of the probe, 3 - springs attaching pendulum to the base, 4 - permanent magnet, 5 - probe box, 6 -window to watch the pendulum.

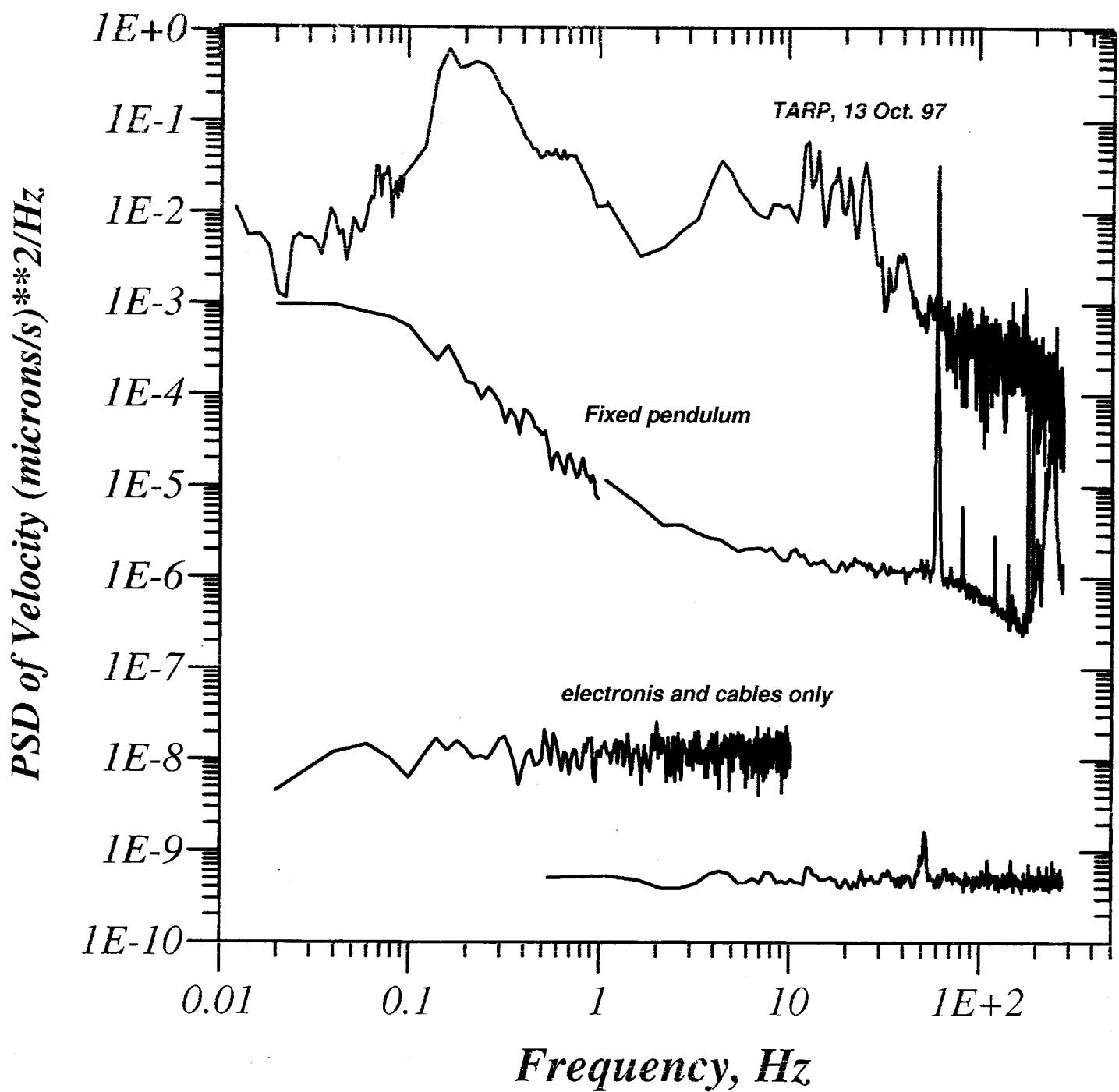
To extend frequency band as low as 0.05 Hz and up to 100 Hz this seismometer was modified by introducing of electronic negative feedback system [2]. This system allows to eliminate influence of intrinsic pendulum resonance at 0.5 Hz, and also improve the linearity , dynamical range and sensitivity of the probe.

The main characteristics of modified SM3-KV probe are summarized in Table 1.

Table 1. Parameters of SM3-KV seismometer.

Type	inductive velocimeter
Working frequency band, Hz	<u>0.05 -100</u>
Reduced pendulum length, mm	84
Pendulum moment of inertia, kG*m <sup>2</sup>	0.0085
Period of free pendulum, s	2
Sensitivity in working frequency range, V*s/m	5 105
Sensitivity of calibration coil, V*s/m	1.8
Dimensions, mm	240x170x145
Temperature range, oC	-10...+40
Working humidity condition at 25 oC	up to 100%
Mass less than, kg	8

The functional diagram of the negative feedback system (NFS) is presented in Fig.3.



PSD of signal and noise  
of SM-3KV geophone

## OTHER INSTRUMENTS USED:

### Low frequency seismometers

SVKD (Russia) 0.003 - 1 Hz

SDE (Russia) 0.001 - 2.3 Hz

CMG-3 (England) 0.003 - 50 Hz

STS-2 (Switzerland) 0.005 - 15 Hz

### High Frequency Accelerometers:

W-731A (Maryland) 10 - 400 Hz

Dytran (USA) 100 - 1000 Hz

TA-2, TA-F (Russia) 100 - 1400 Hz

DN-2, 4, 5 (Russia) 400 - 800 Hz

# NOISE PROPERTIES

Cross correlation spectrum:

$x(t)$  - signal 1

$y(t)$  - signal 2

$$S_{xy}(\omega) = \frac{2}{T} \int_0^T x(t) e^{i\omega t} dt \cdot \int_0^T y(t) e^{-i\omega t} dt$$

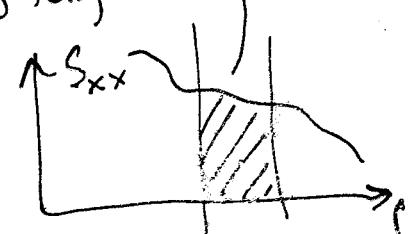
Coherence spectrum:

$$C(\omega) = \frac{|S_{xy}(\omega)|}{\sqrt{S_{xx}(\omega) S_{yy}(\omega)}}; \quad 0 \leq C(\omega) \leq 1$$

Power spectral density (PSD):

$$S_{xx}(f) = \frac{2}{T} \left| \int_0^T x(t) e^{i\omega t} dt \right|^2$$

property:  $\delta x_{r.m.s}^2 [f_1, f_2] = \int_{f_1}^{f_2} S_{xx}(f) df$

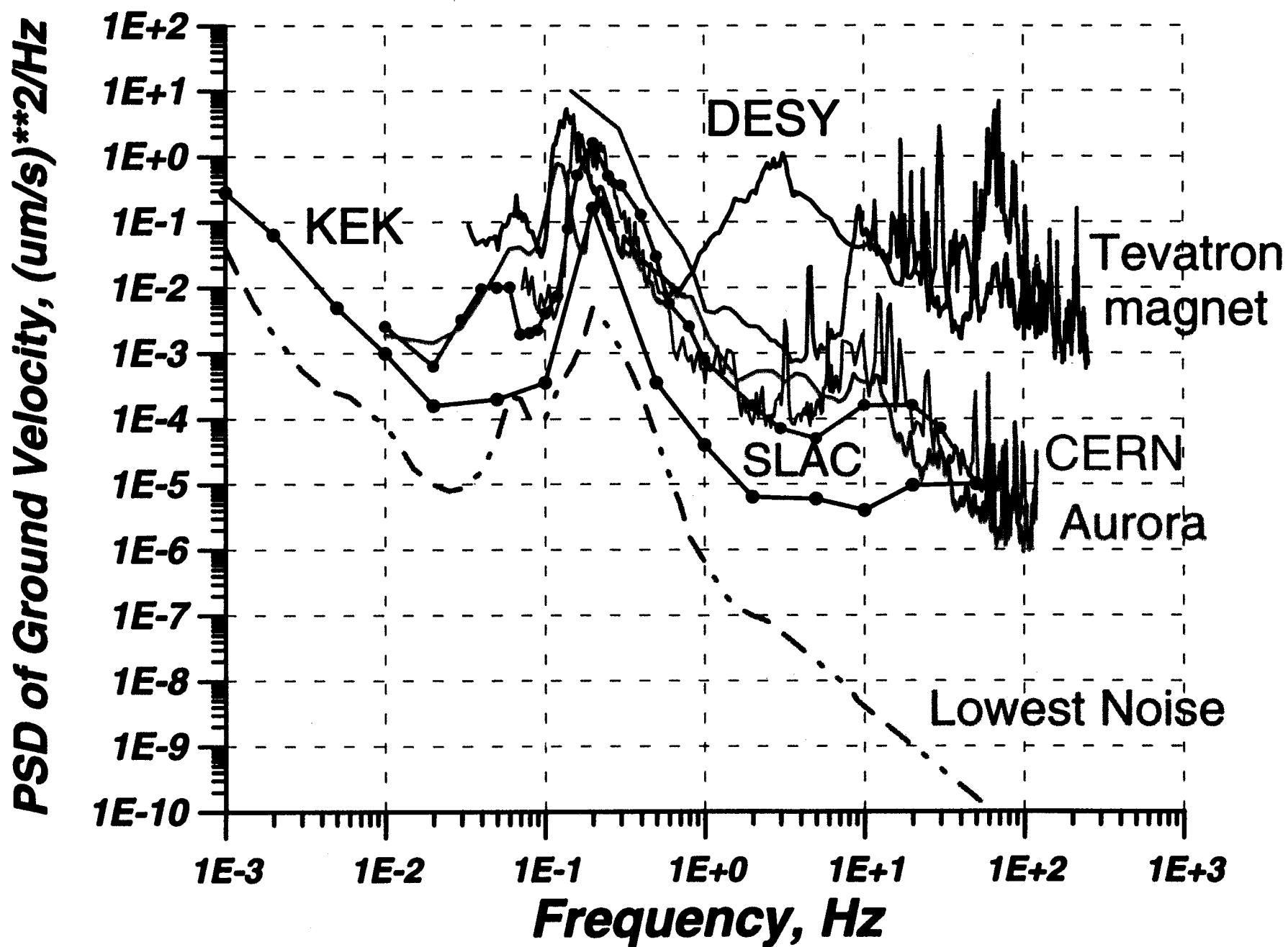


if signal is velocity

then dimension of PSD is

$$\left( \frac{\text{m}}{\text{s}} \right)^2 / \text{Hz}$$

# Ground Motion Spectra at Accelerators and "LowNoise"



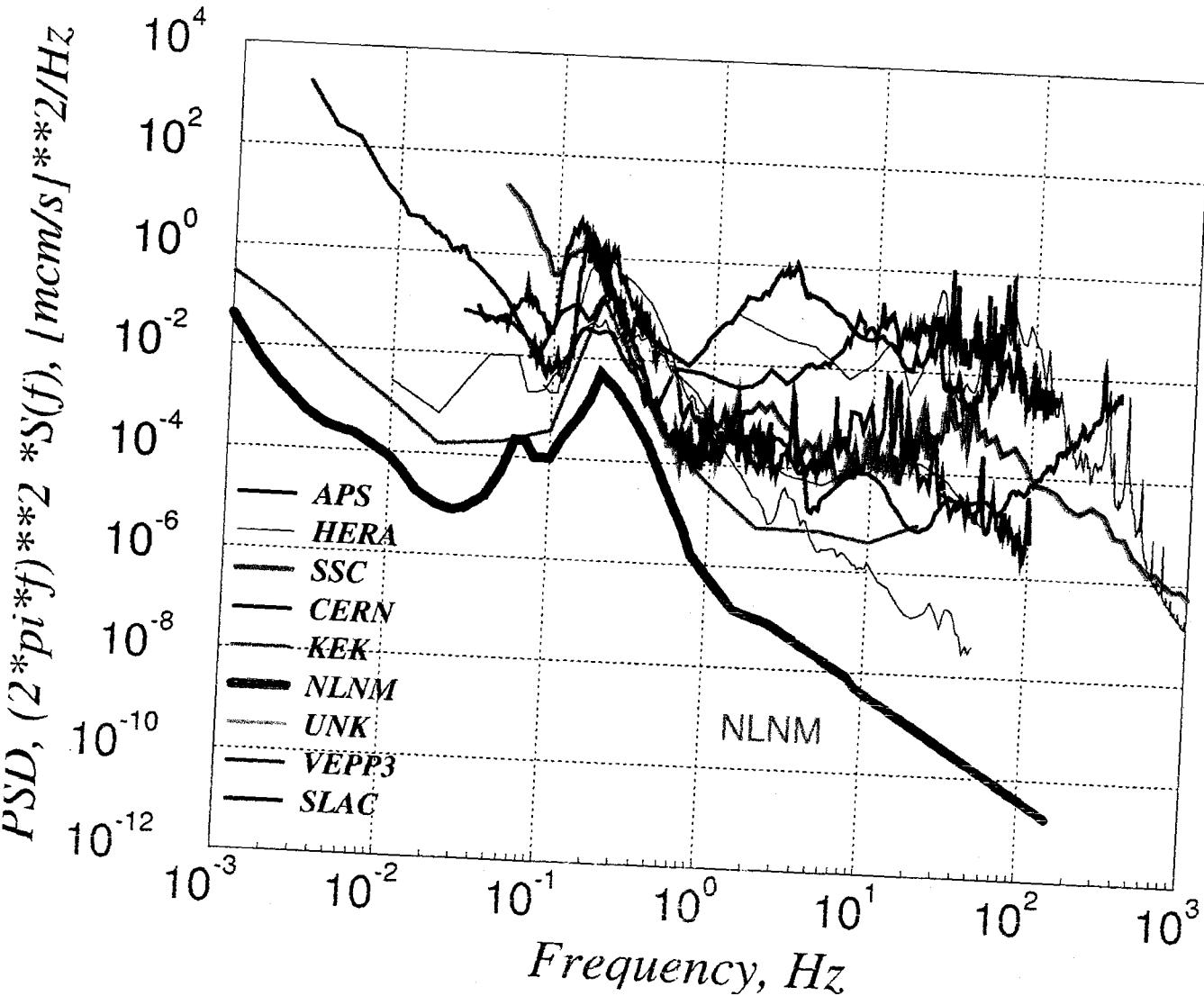
For all sites - first things to study were

- Power Spectral Density (PSD)
- spectra of spatial correlation / coherence

In this presentation, I'll be a little bit more focused on additional / peculiar studies, performed at different sites.

Let's start with spectra:

Rule of thumb  $RMS[\text{nm}] = \frac{20}{f[\text{Hz}]} \text{ and } S_x(f) \propto \frac{1}{f^3}$



# Measurements in UNK tunnel (Protrino, Russia)

Preprint INP 90-88, 91-15

Sov. Zh. Tech. Phys., 63, No. 10 (1993), p 122

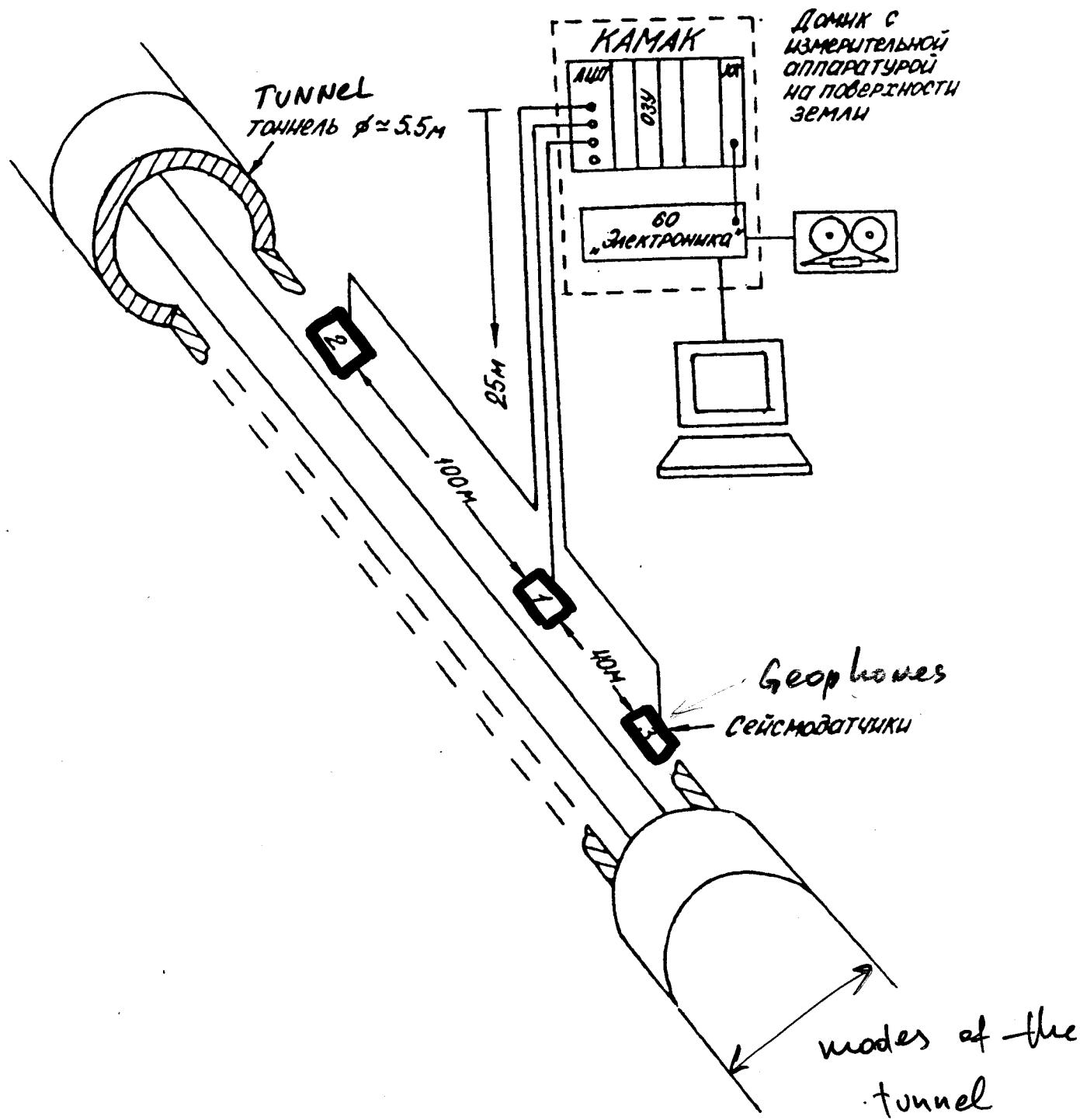


Рис. 1. Схема измерений в тоннеле УНК.

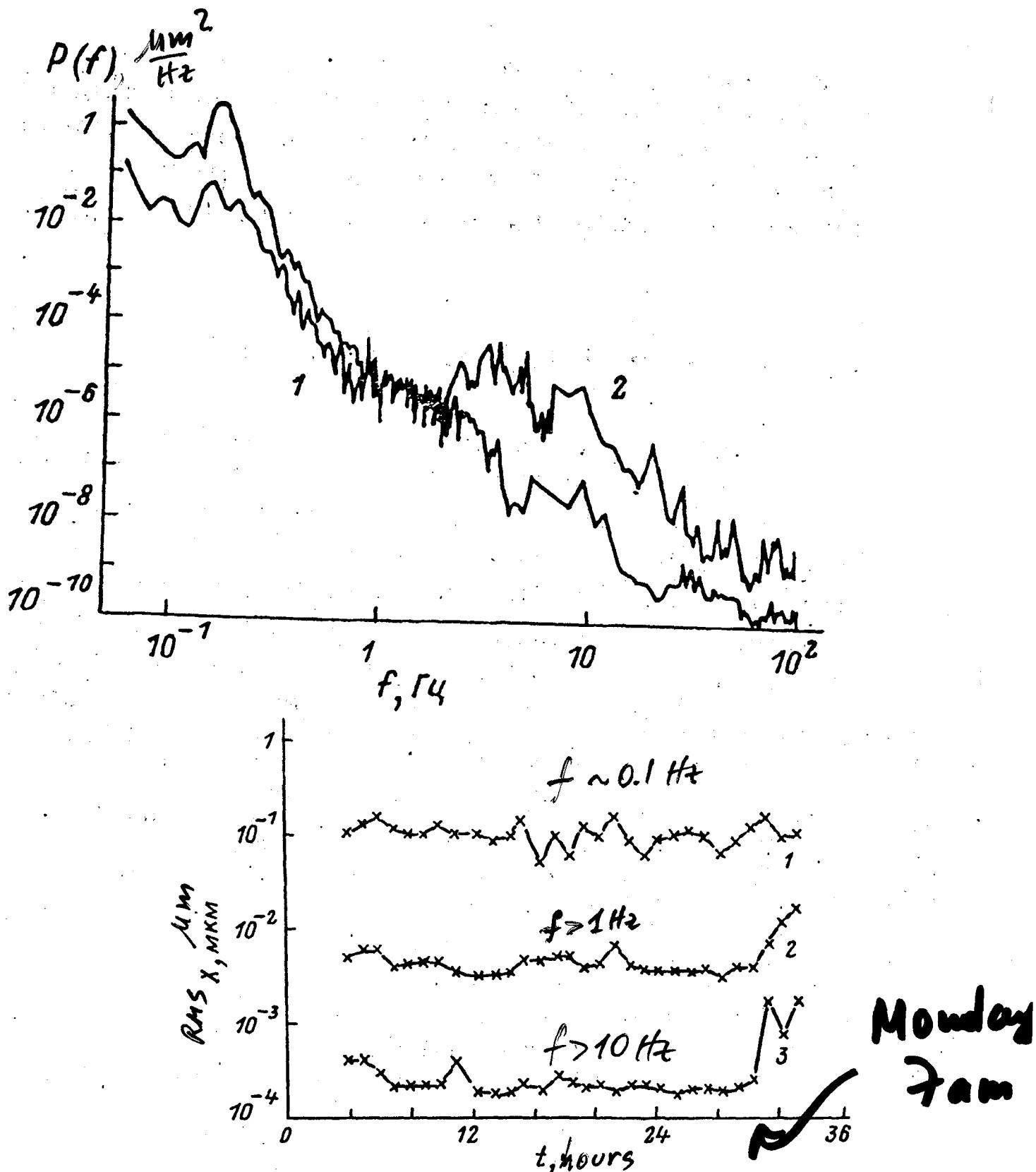


Рис. 2. Среднеквадратичные амплитуды колебаний земли  $X(t)$  в разных частотных диапазонах в зависимости от времени 17-18.06.1990.  
 1 —  $f < 0.1$ , 2 —  $f > 1$ , 3 —  $f > 10 \text{ Гц}$ .

Correlation:

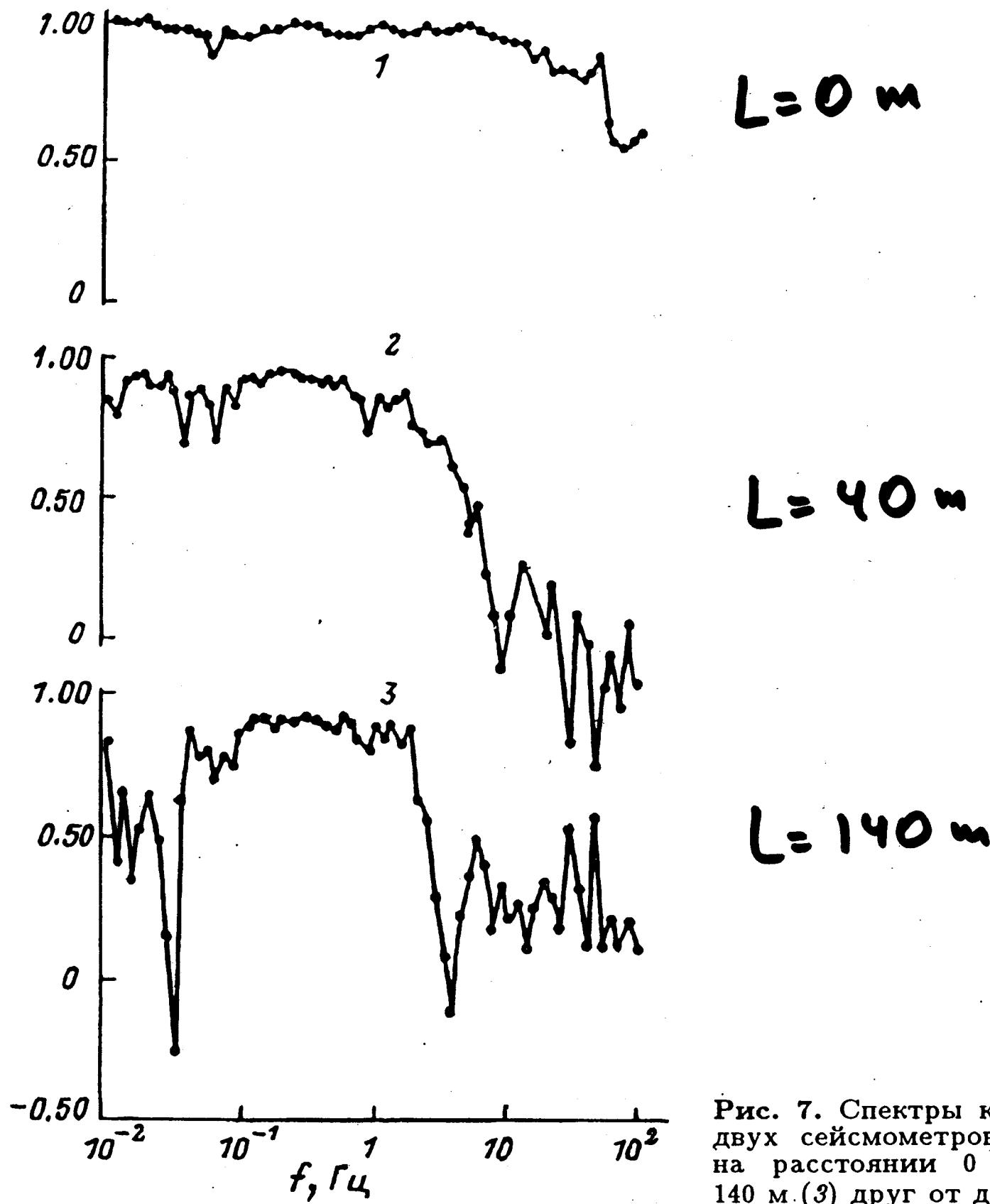


Рис. 7. Спектры коррел двух сейсмометров, нах на расстоянии 0 (1), 140 м. (3) друг от друга.

$V_\lambda \simeq U \cdot (\lambda/L)^{1/3} \cdot (Kolmogorov - Obukhov law)$

$$X \simeq \Delta P \cdot \lambda/E,$$

$$S(X)_f \simeq \rho^2 \cdot U^{22/3} \cdot E^{-2} \cdot L^{-4/3} \cdot f^{-13/3} / 4$$

Correlation between pressure gauge and seismometer

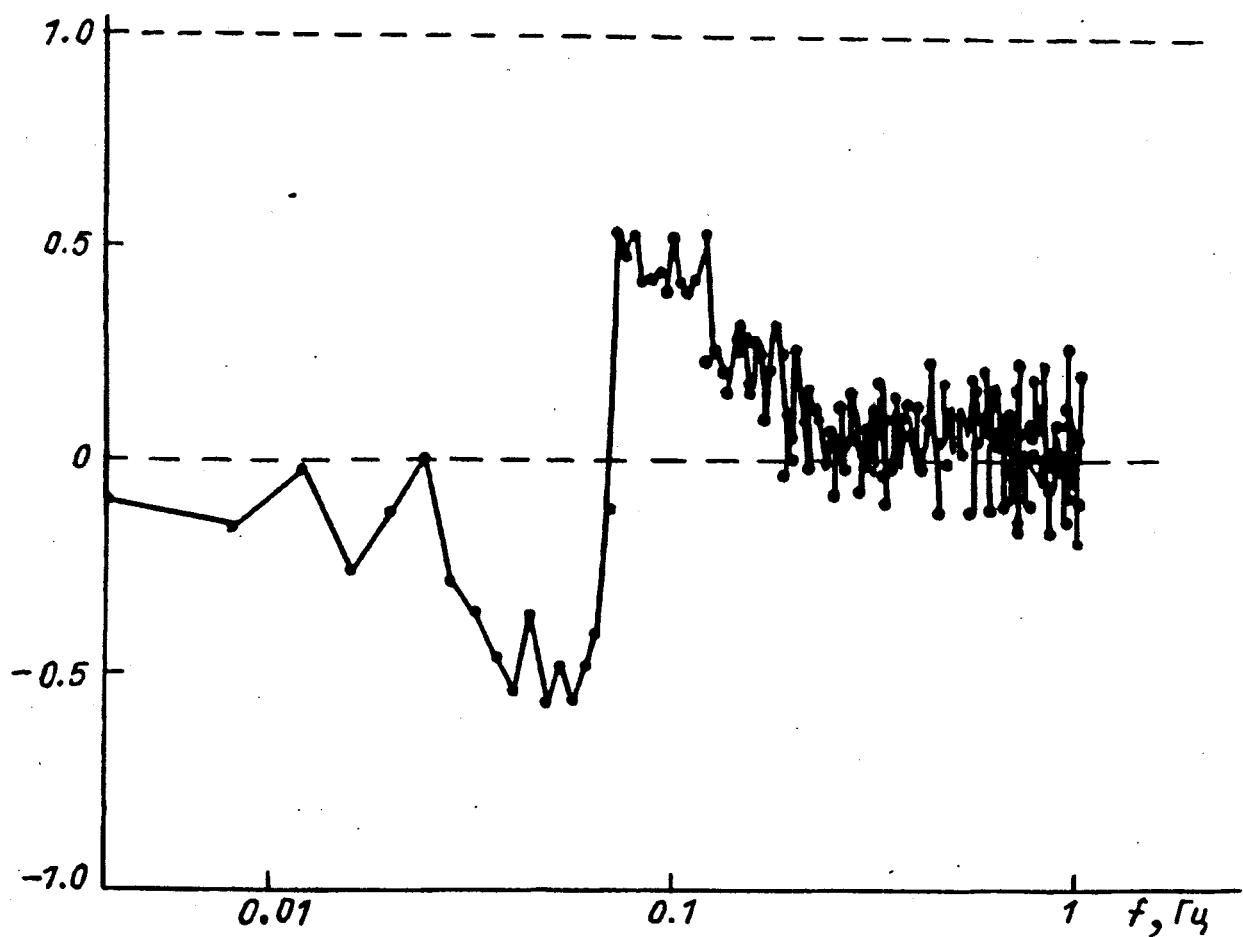


Рис. 4. Частотный спектр корреляции атмосферного давления и сигнала с сейсмометра СВК-Д (11.01.1991).

Beam/Magnets/GROUND VIBRATIONS @ VEPP-3 STORAGE RING

INP 92-39

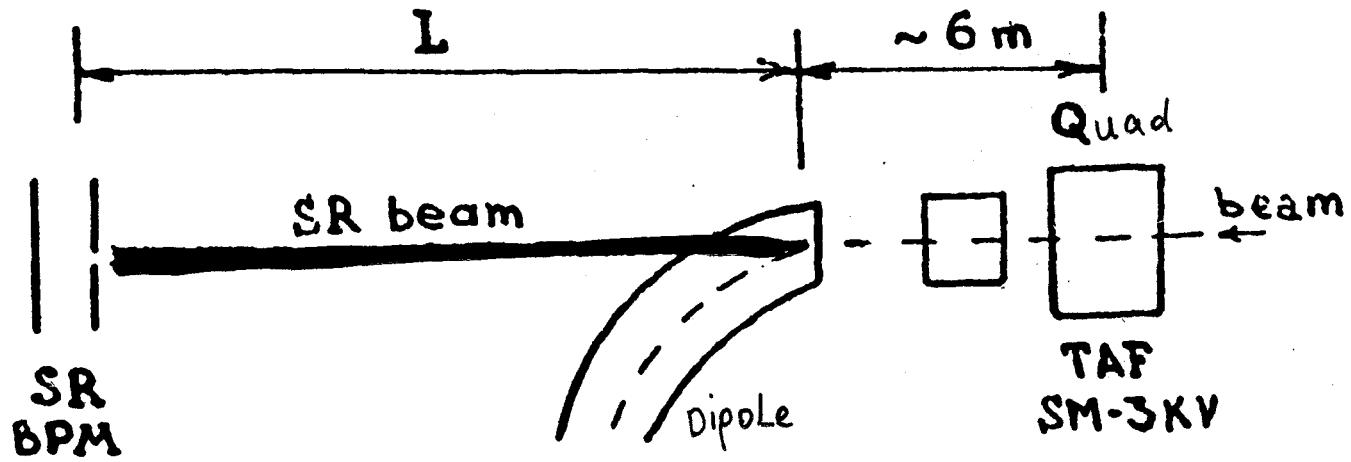
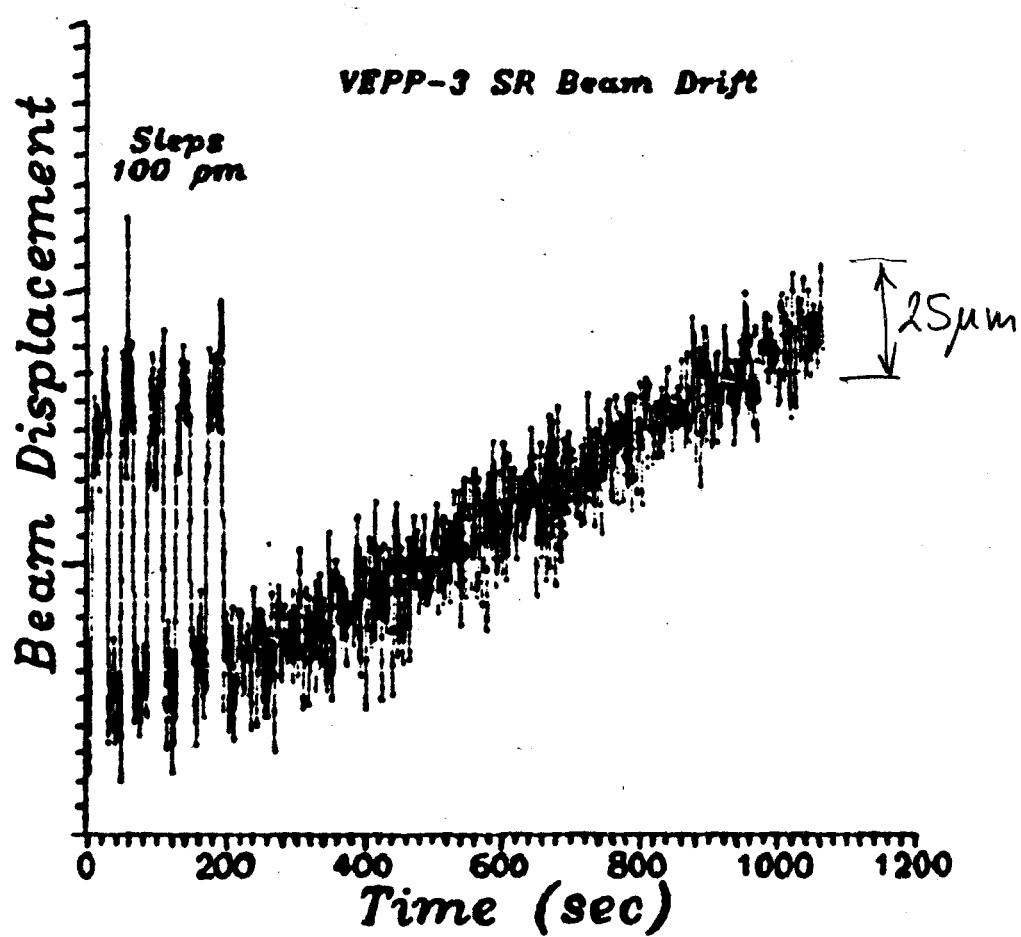
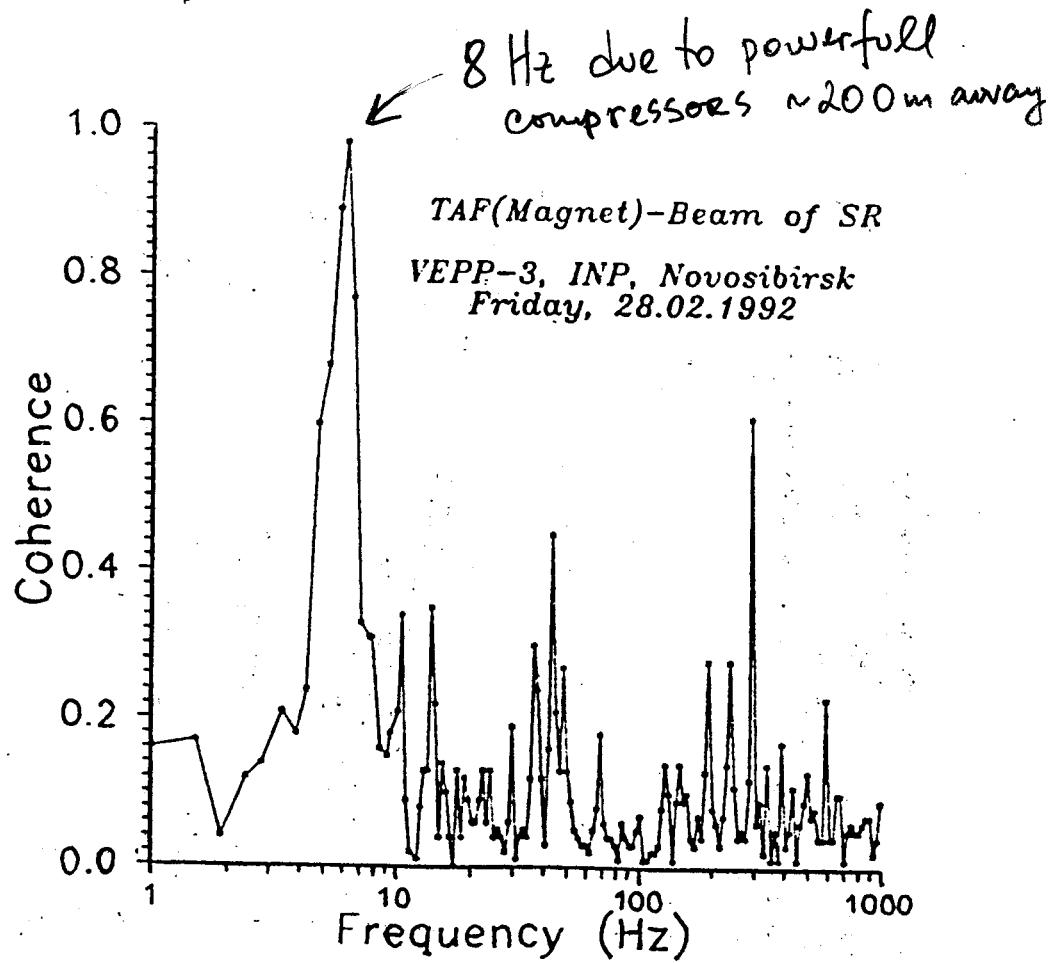
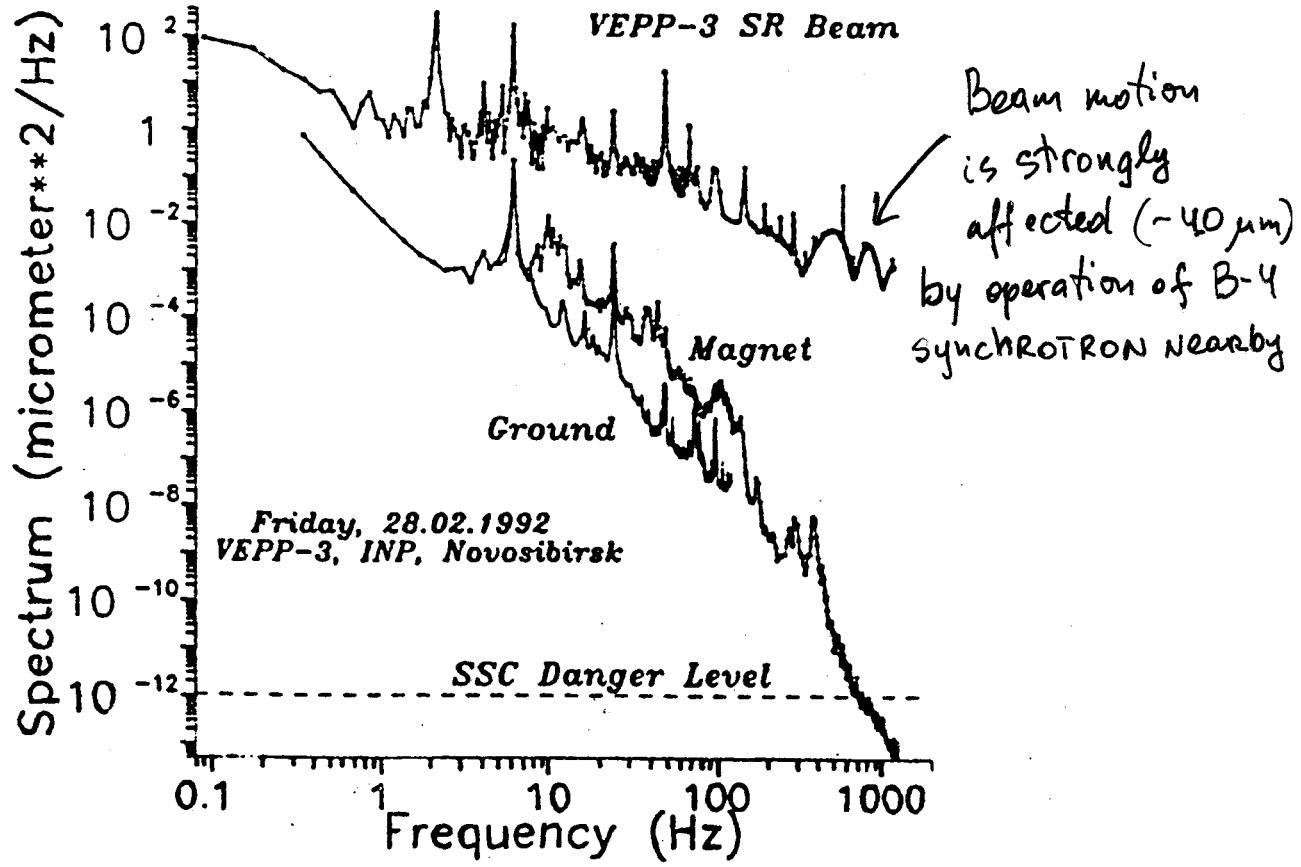


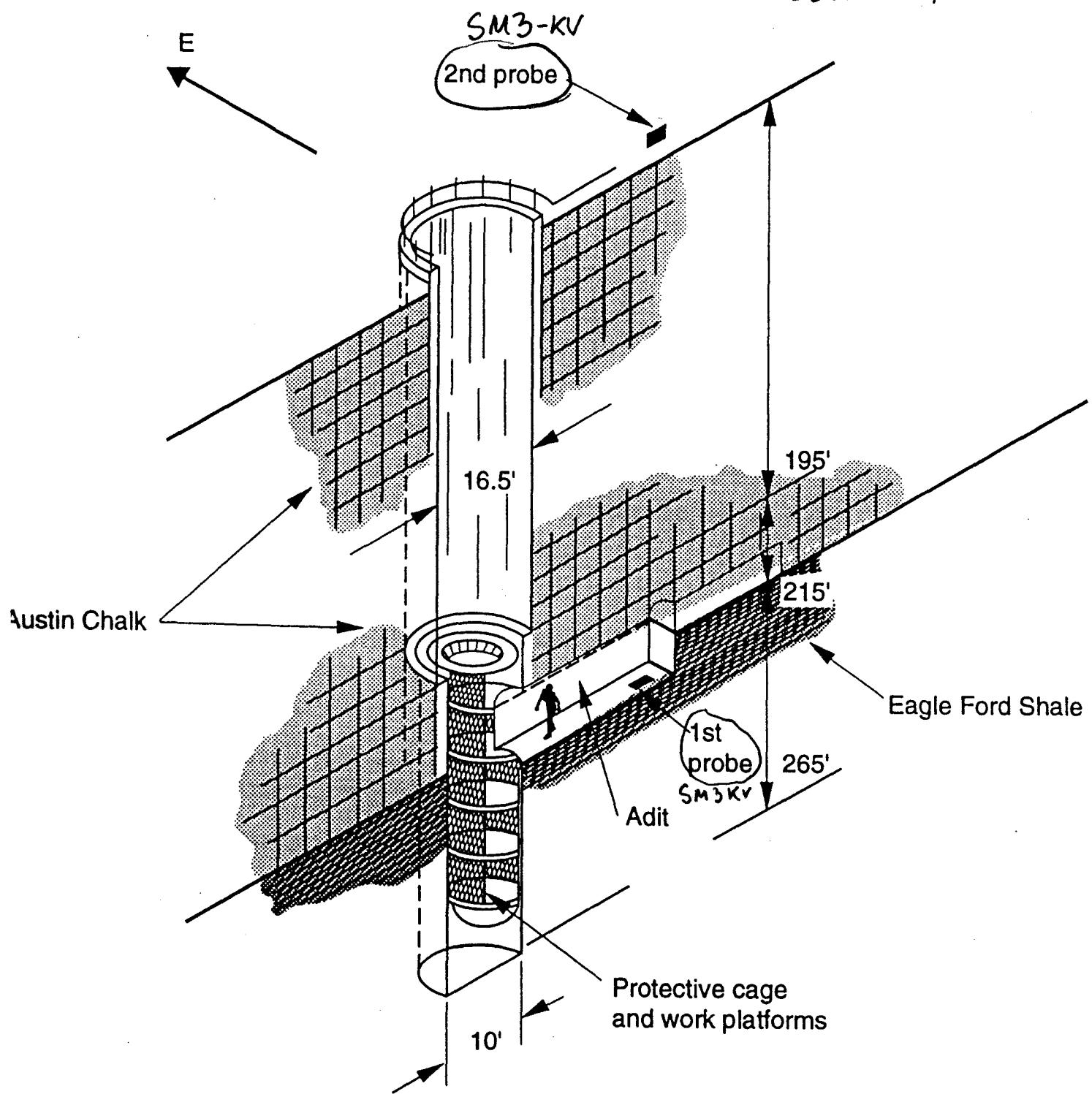
Fig. 1. Layout of the experiment.





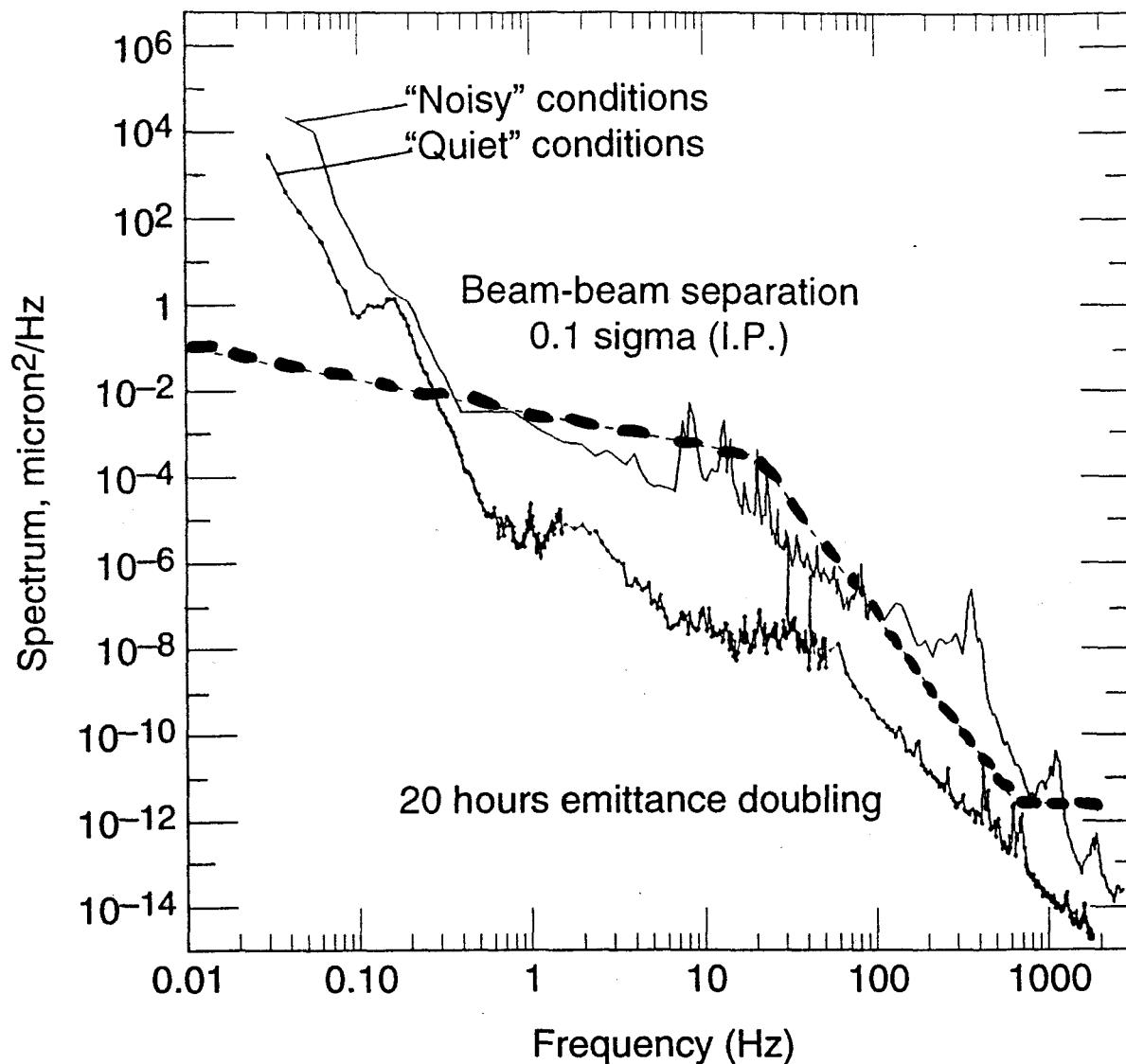
# Ground Motion Measurements at SSCL

AIP Conf. Proc 326 (1995), p 560  
Proc. IEEE PAC'93  
SSCL-622, SSCL-639 (1993)



TIP-04908

Figure 2. View of the SSC Exploratory Shaft and underground experiments.



**Figure 1. Spectral Density of Power of Vibrations in "Quiet" and "Noisy" Conditions (Solid Curves), Reference 6. Dashed lines indicate the level of vibration which cause  $0.1\sigma_{IP}$  beam-beam sep and the SSC emittance doubling after 20 hours of collider operation.**

at  $f=10\text{--}20\text{ Hz}$  "top" signal  $\sim(2\text{--}3)\times$  "bottom"

572 Ground Motion Measurements

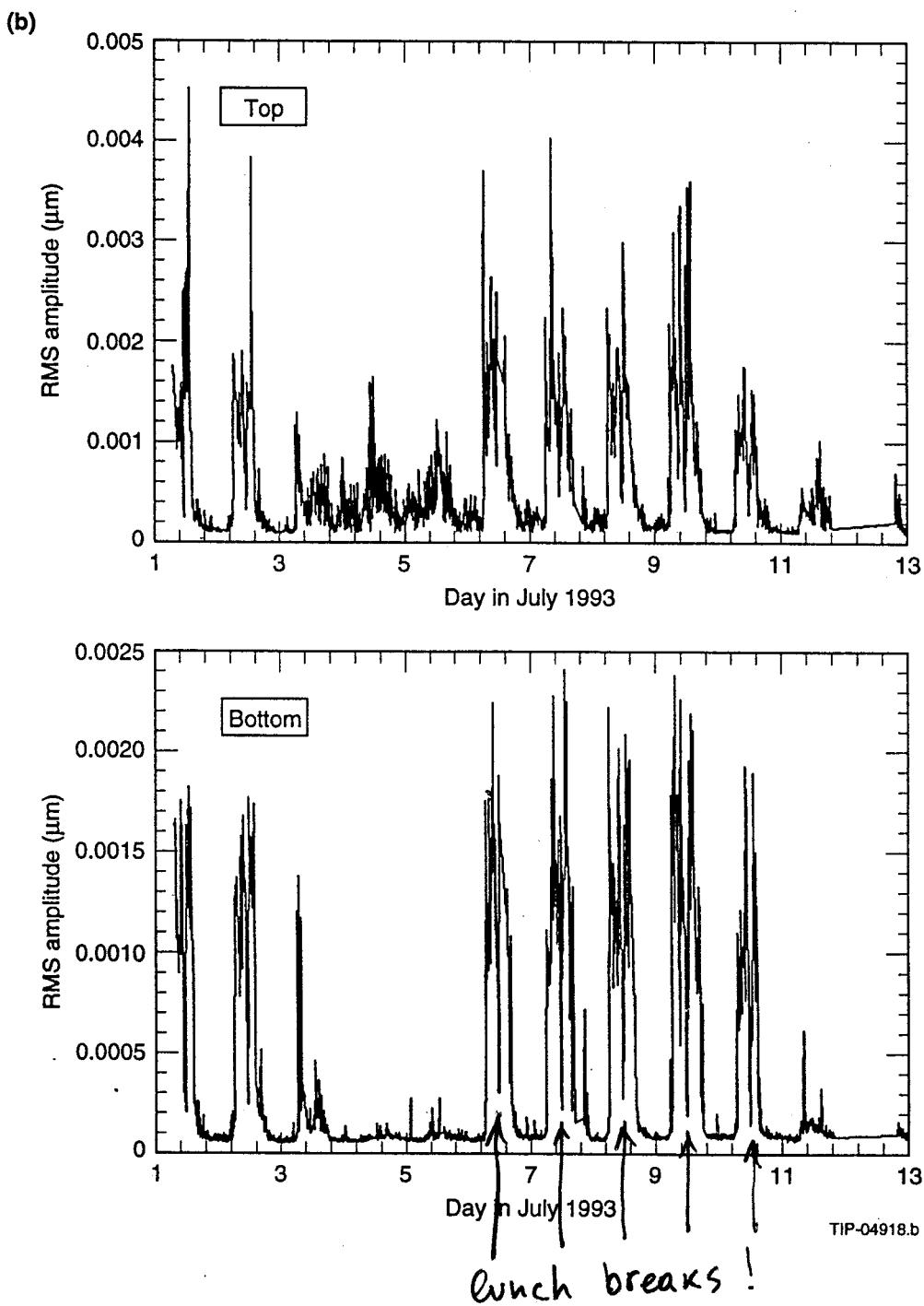
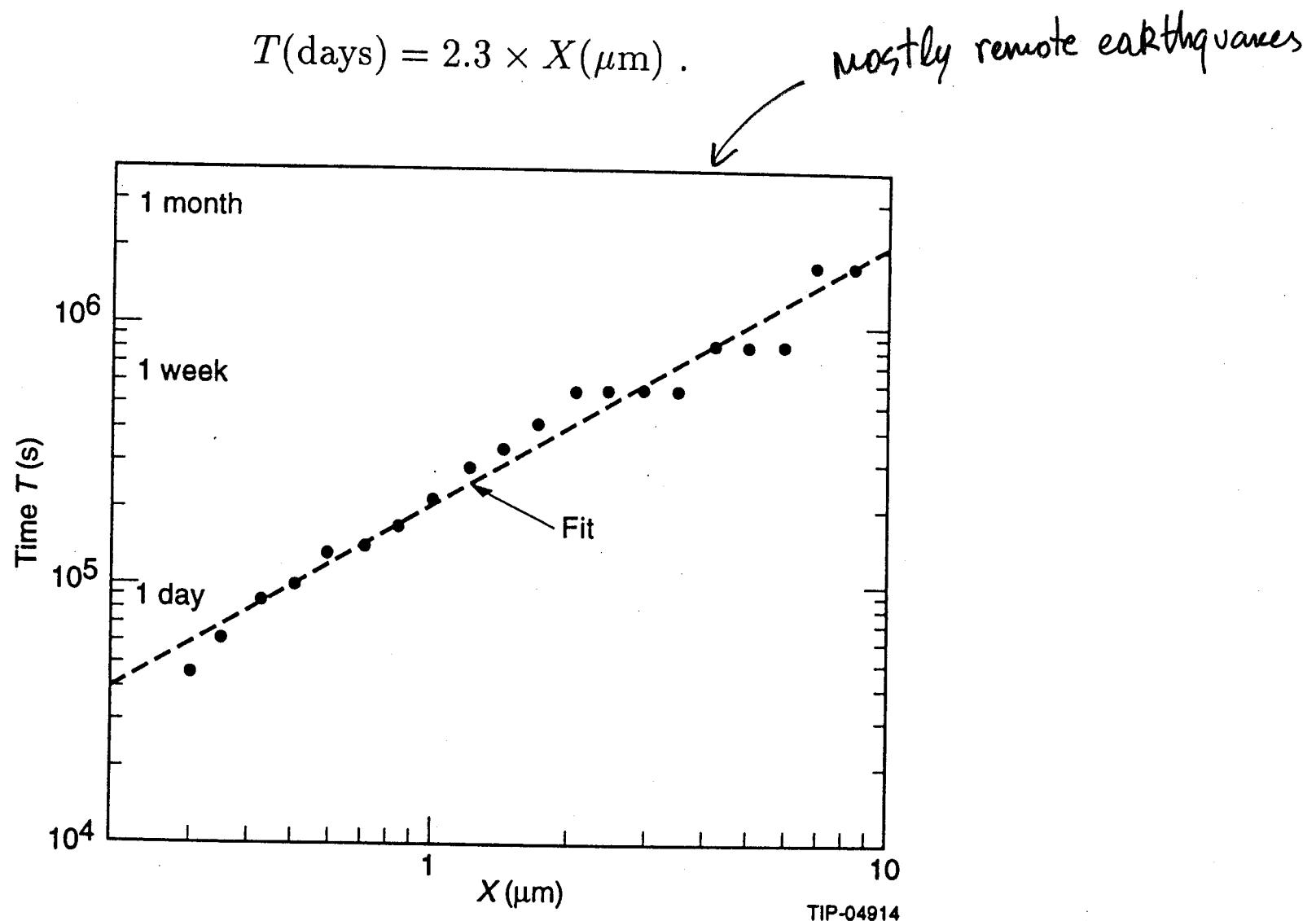


Figure 8(b). Rms value of ground vibrations in frequency band 10–20 Hz in July 1993.

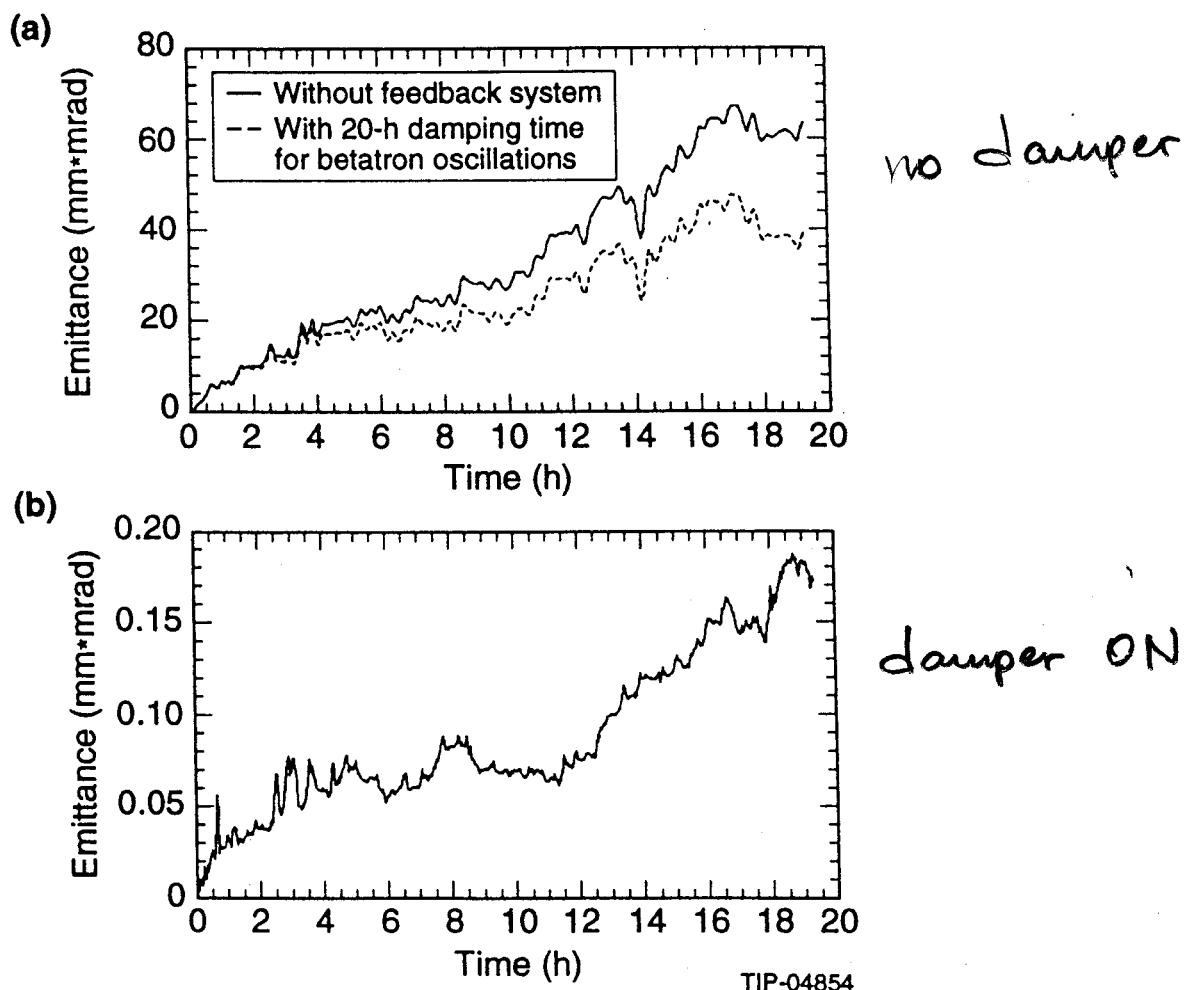
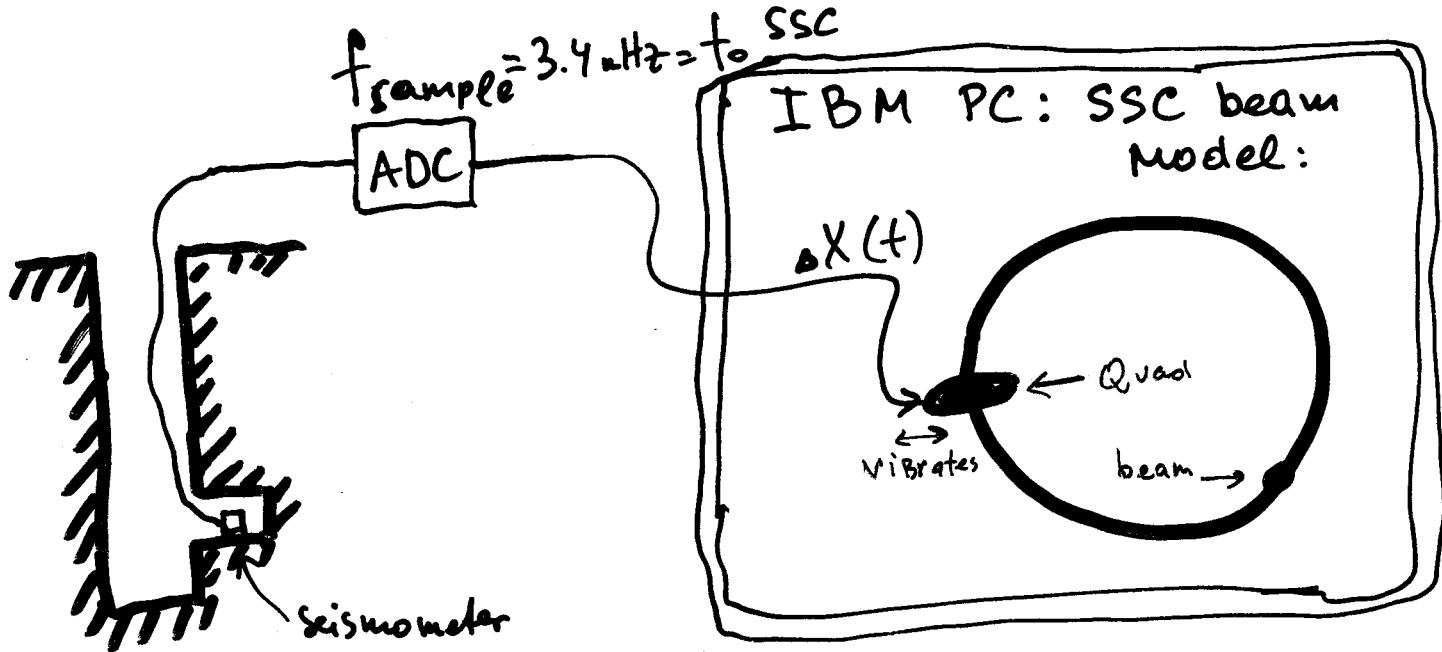
- another example of "Noisy" conditions: one night, a stone ~2 ton fell down from top(ceiling) of the SSC tunnel about 3 miles away. We were the first in the morning who reported that -  
The signal looked very different than at  
"usual" earthquakes.  
NO casualties

The mean time  $T$  between events with amplitudes more than  $X$  grows linearly with  $X$  (see fit in Figure 5):



5. Statistics from August 1993 of large-amplitude events: mean time between events vs. amplitude

# Emittance GROWTH Modeling with Seismometers ON-LINE



TIP-04854

Figure 4. 20-h On-line Simulations of Emittance Growth During Noisy Weekday;  
 (a) Without Feedback System and with 20-h Damping Time;  
 (b) With Feedback System with  $g = 0.05$ .

We also studied Mechanical properties of SSC dipoles:

Major results:

- There are ~10 mechanical resonances with  $Q \sim 5-50$  in these 15-m long dipoles at frequencies up to 70 Hz
- Vibrations of the cold mass are excited by L He flow: about  $1.5\text{Å}$  at  $f = 500-1500\text{Hz}$  @ 40% LHe



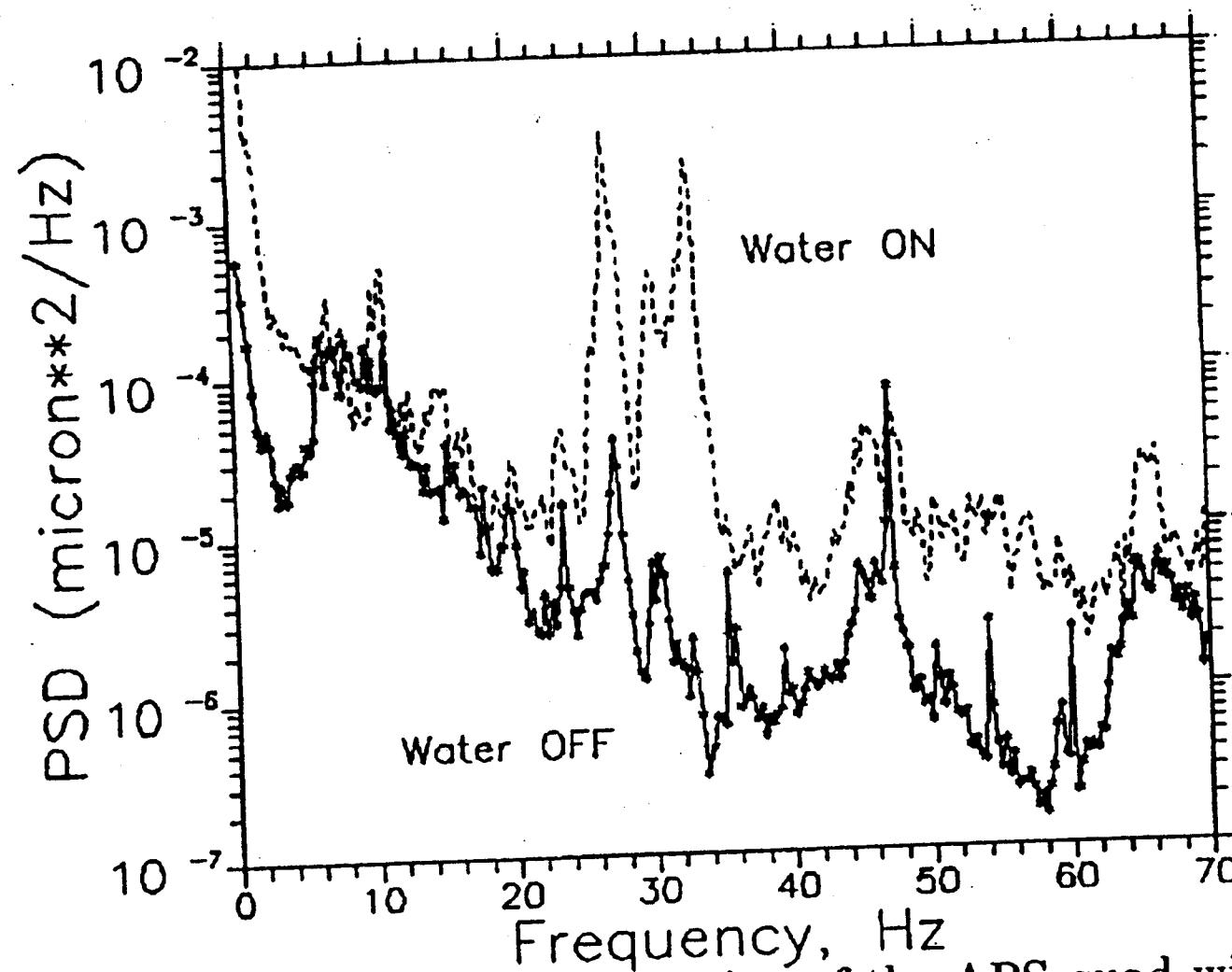


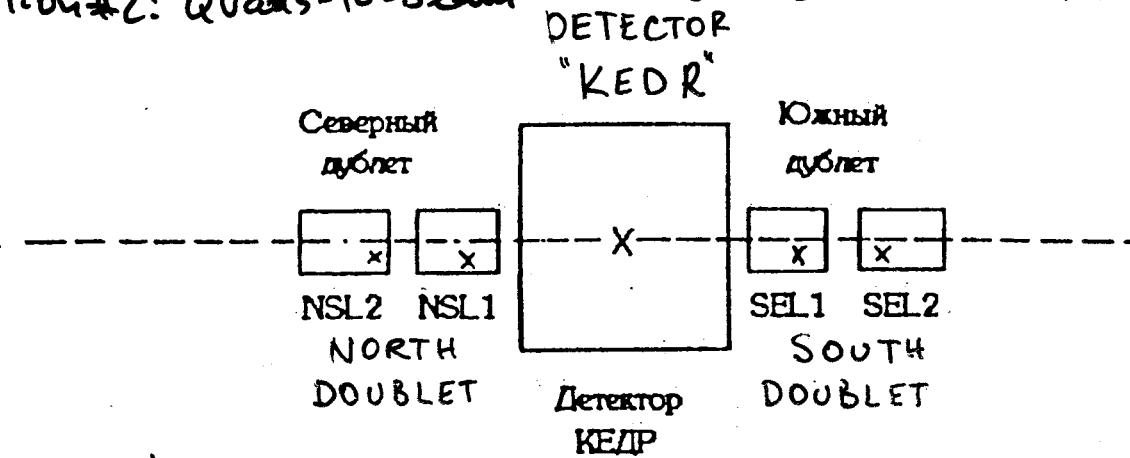
Figure 4. PSD of vertical vibration of the APS quad with cooling water on and off.

Problem:  $\sim 140 \mu\text{m}$  beam motion @ 6.25 Hz

Source: powerful electrical generators  $f = 50 \text{ Hz} / 8 = 6.25 \text{ Hz}$

Amplification #1: floor-to-Quad 30-40 times, about 500 away

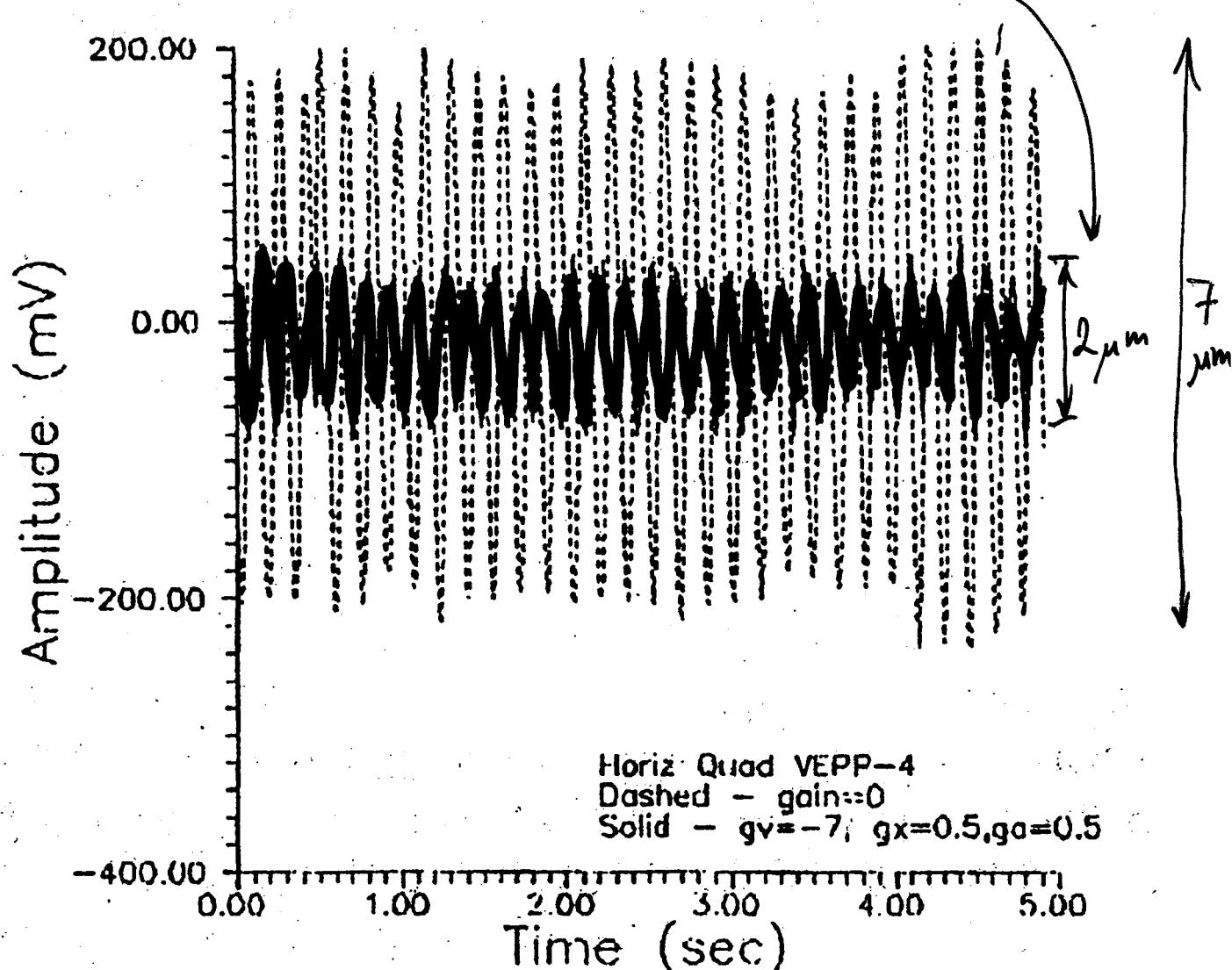
Amplification #2: Quads-to-beam  $\sim 20$  times  $\leftarrow$  resonance @ 6.2 Hz



maximum suppression

achieved  $\sim 2.5$  ( $140 \rightarrow 60 \mu\text{m}$ )

mechanical feedback ON



# DESY HERA Hall West

10:30 07 Oct. 1994, DESY

DESY-HERA 95-06  
(1995)

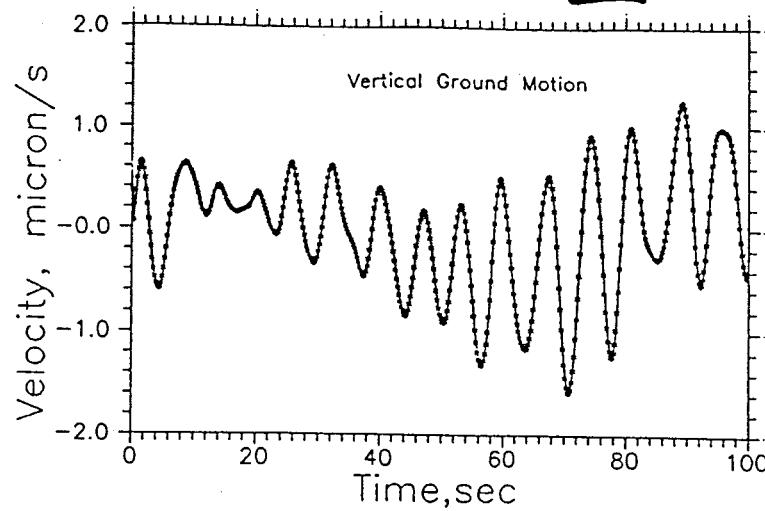


Figure 1:  
c) 100 sec record of vertical ground velocity in HERA Hall West, measured 07.10.1994

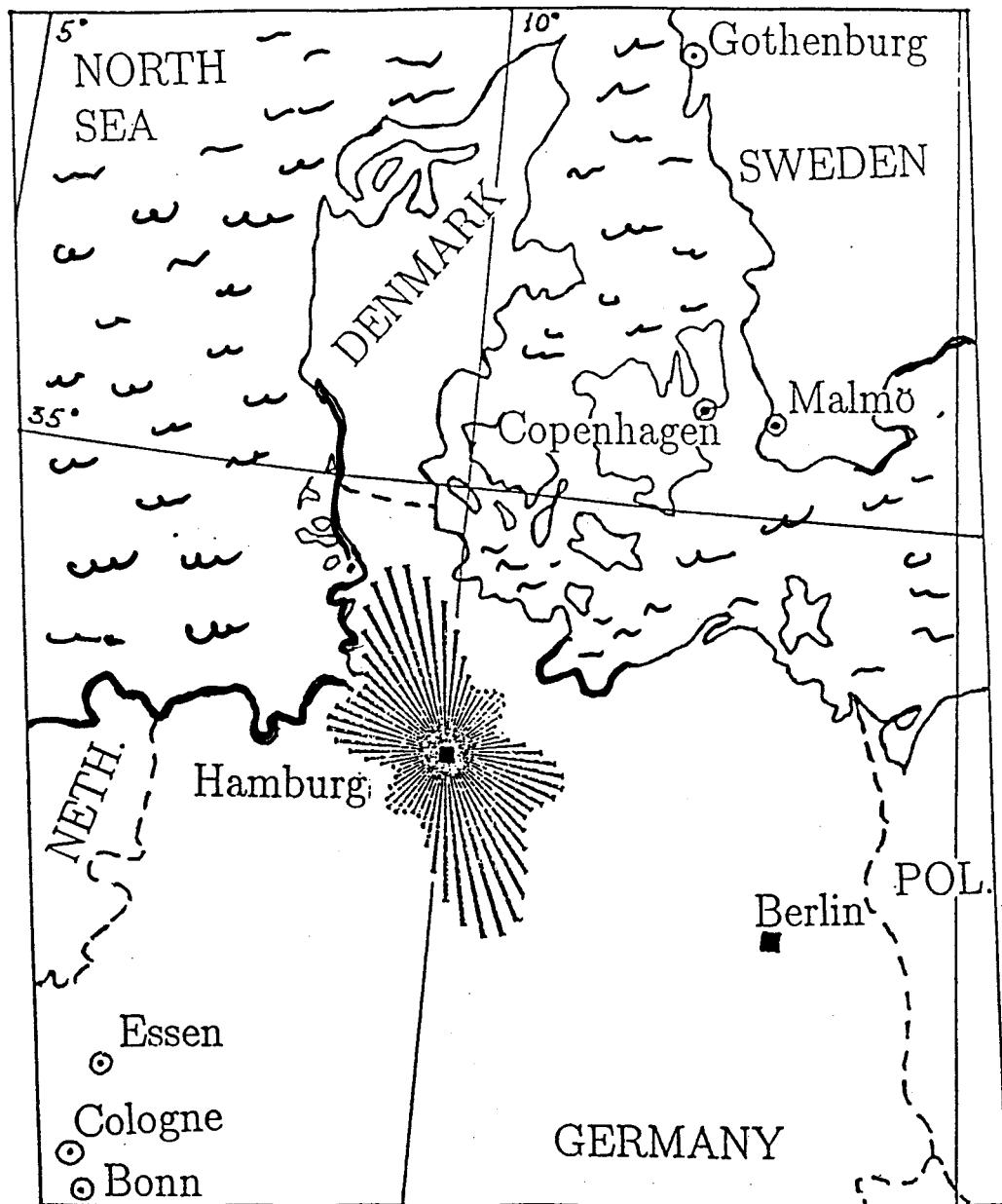


Figure 11:  
b) 0.07 - 0.3 Hz waves in Hamburg (31.08.1994) pointing to the coasts of Denmark

HERA Halls  
floating w.r.t.  
the rest of  
the machine (?)

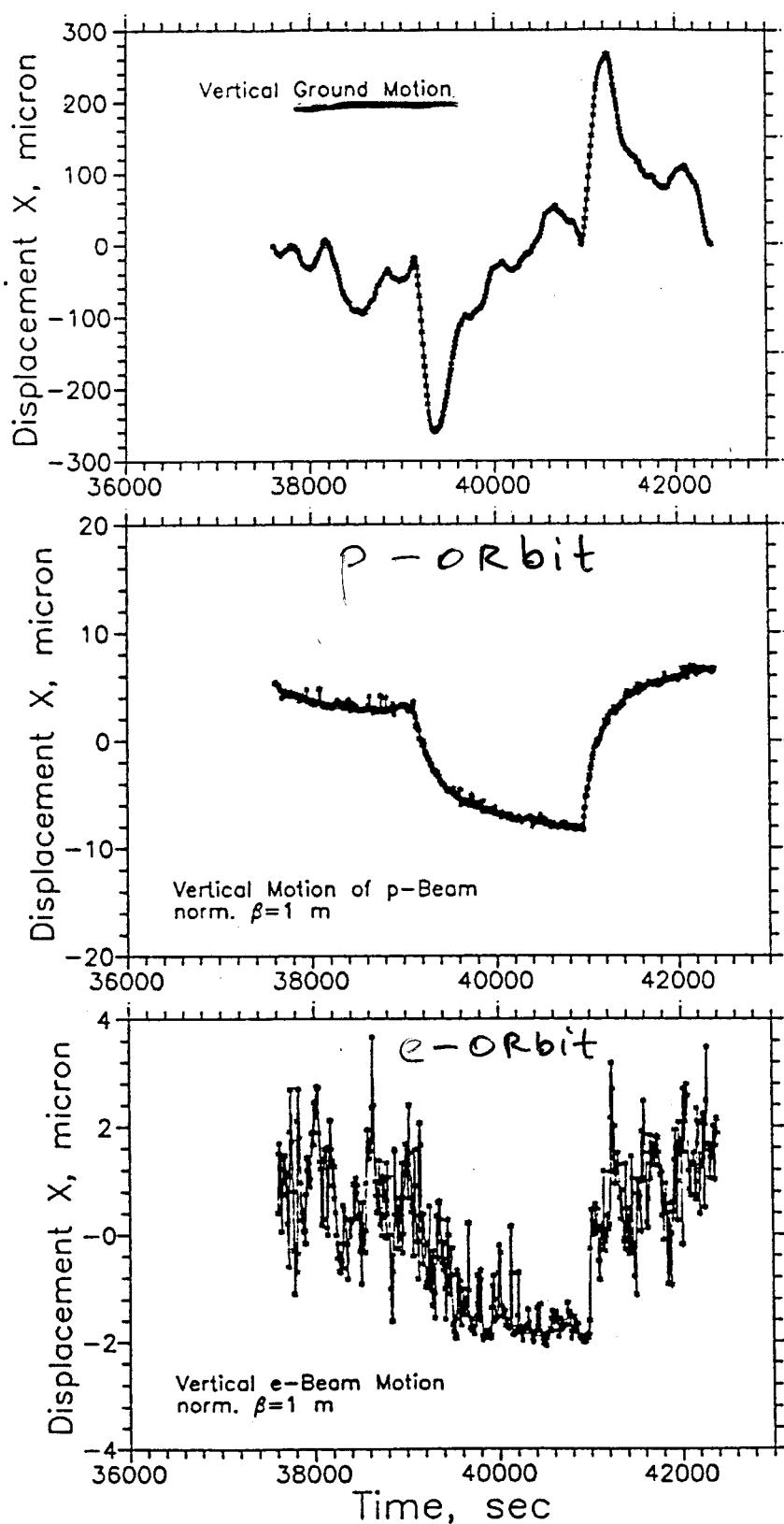
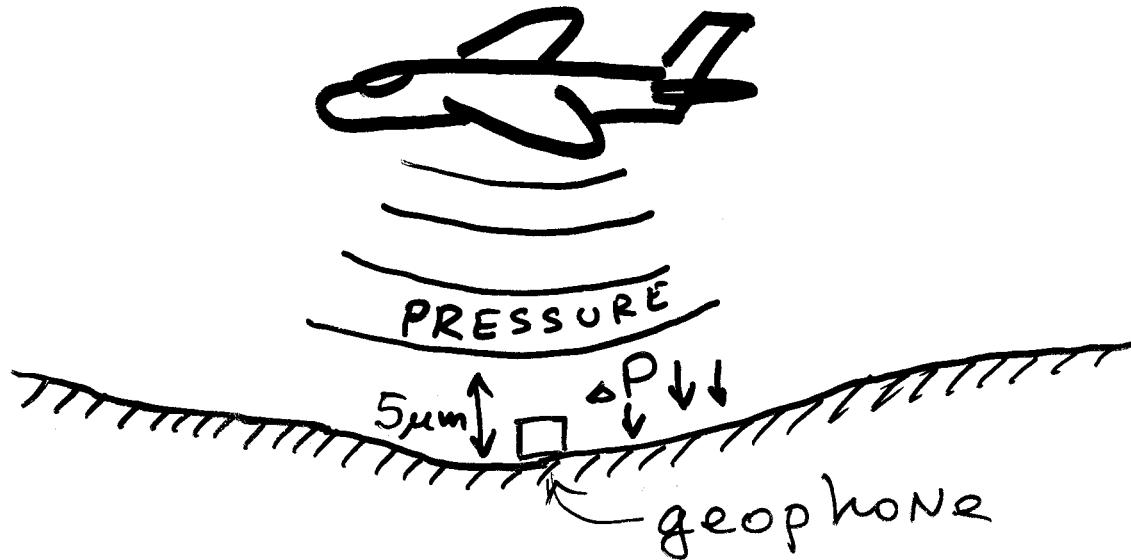


Figure 18:

- Few hours record of simultaneously measured signals:
- Vertical ground displacement
  - Vertical motion of proton beam in HERA
  - Vertical motion of electron beam in HERA

# DISCUSSION WITH GUS VOSS → plane detection system



20:48:40 11 Sept 1994, DESY

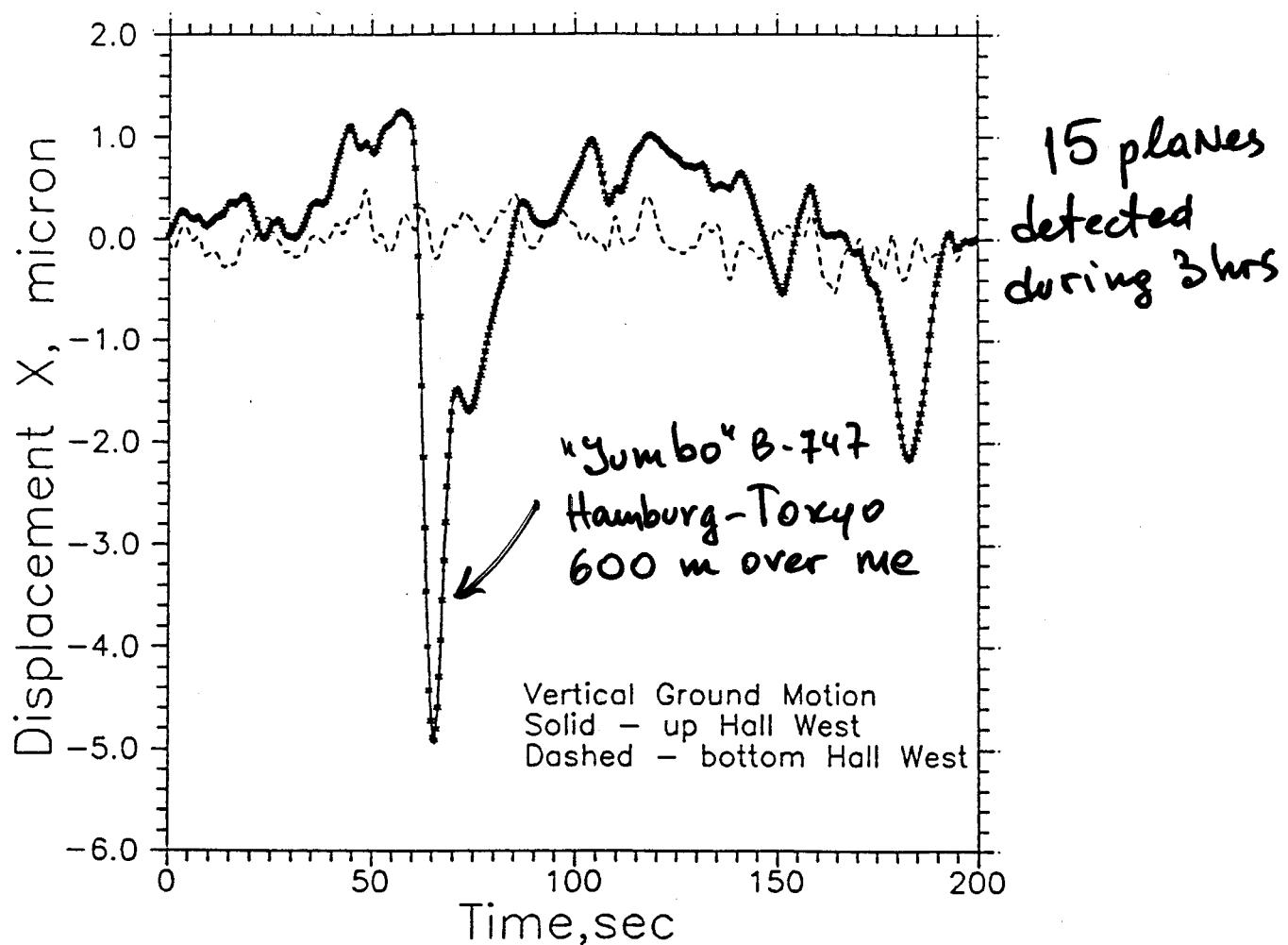
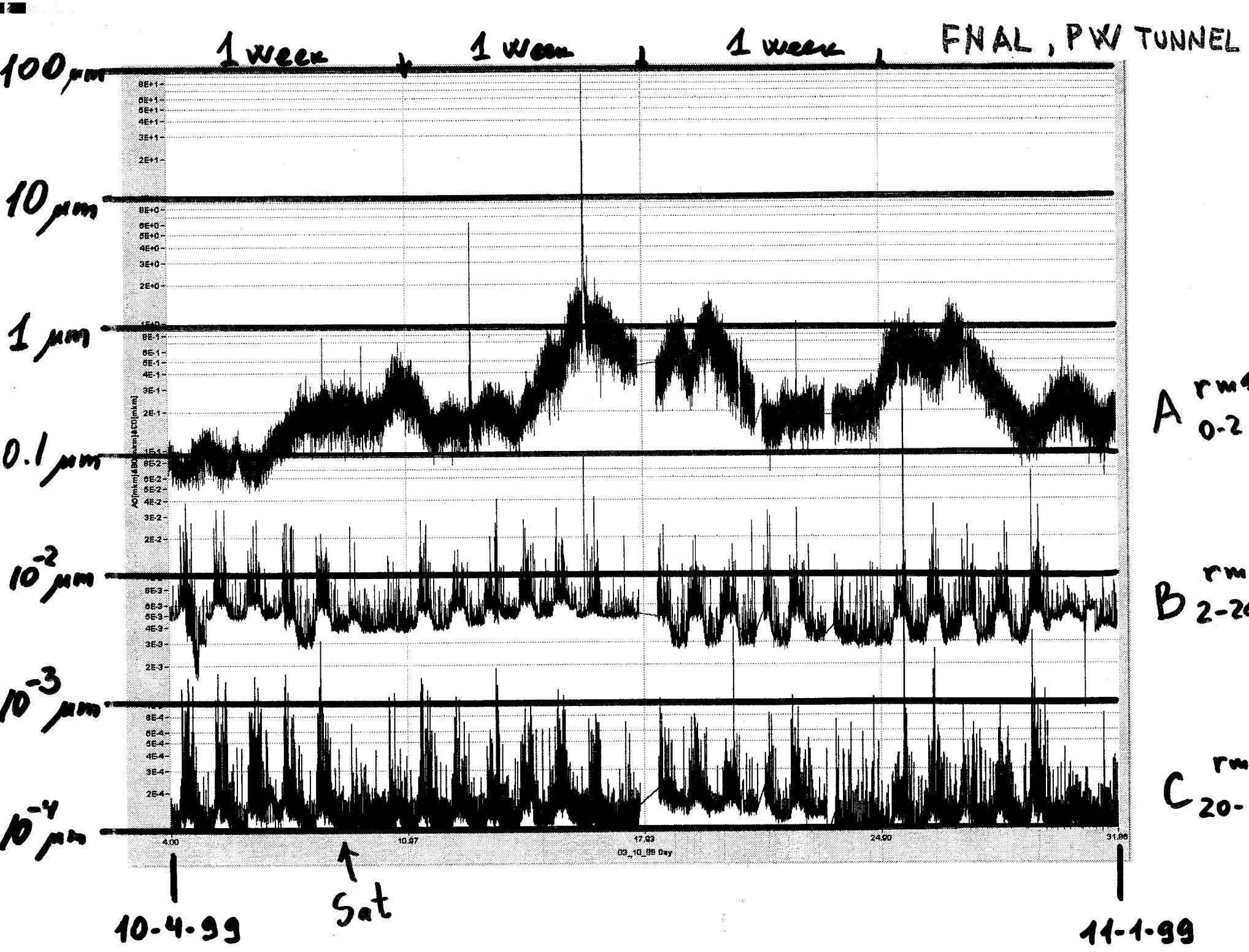


Figure 14:

- a) Vertical ground motion about 0.6 km beneath flying airplane; solid line - on the surface.  
dashed line - on the bottom of HERA Hall West



A rms  
 $0.2-1\ Hz$

B rms  
 $2-20\ Hz$

C rms  
 $20-64\ Hz$

# Tri-Cities Daily Herald

With news from  
Elburn & Wayne

SPORTS

St. Charles  
claims girls  
state golf title

PADDOCK PUBLICATIONS — 128th Year No. 3

Sunday, October 17, 1999

9 Sections

# Powerful quake jolts desert in California

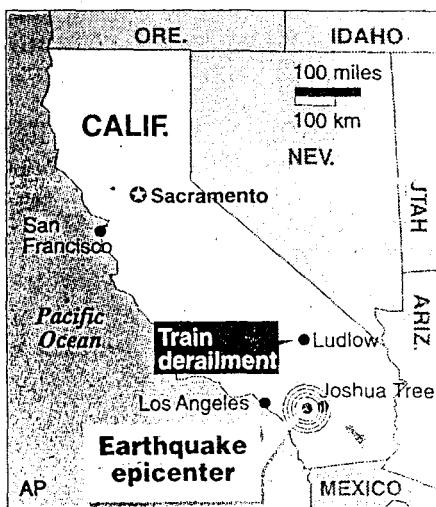
Associated Press

JOSHUA TREE, Calif. — A 7.0-magnitude earthquake in the Mojave Desert shook millions awake in three Western states Saturday, derailing an Amtrak train from Chicago and knocking out power to thousands.

The quake jolted gamblers out of bed in Las Vegas and shook buildings as far away as Phoenix and Tijuana, Mexico. Up to 90,000 customers lost power, mobile homes were knocked off pilings in the desert community of Ludlow and a highway bridge was cracked.

With only a handful of injuries and no deaths, Californians credited location and luck for eluding catastrophe.

"The level of shaking is comparable to what was experienced in Northridge," said Lucy Jones, sci-



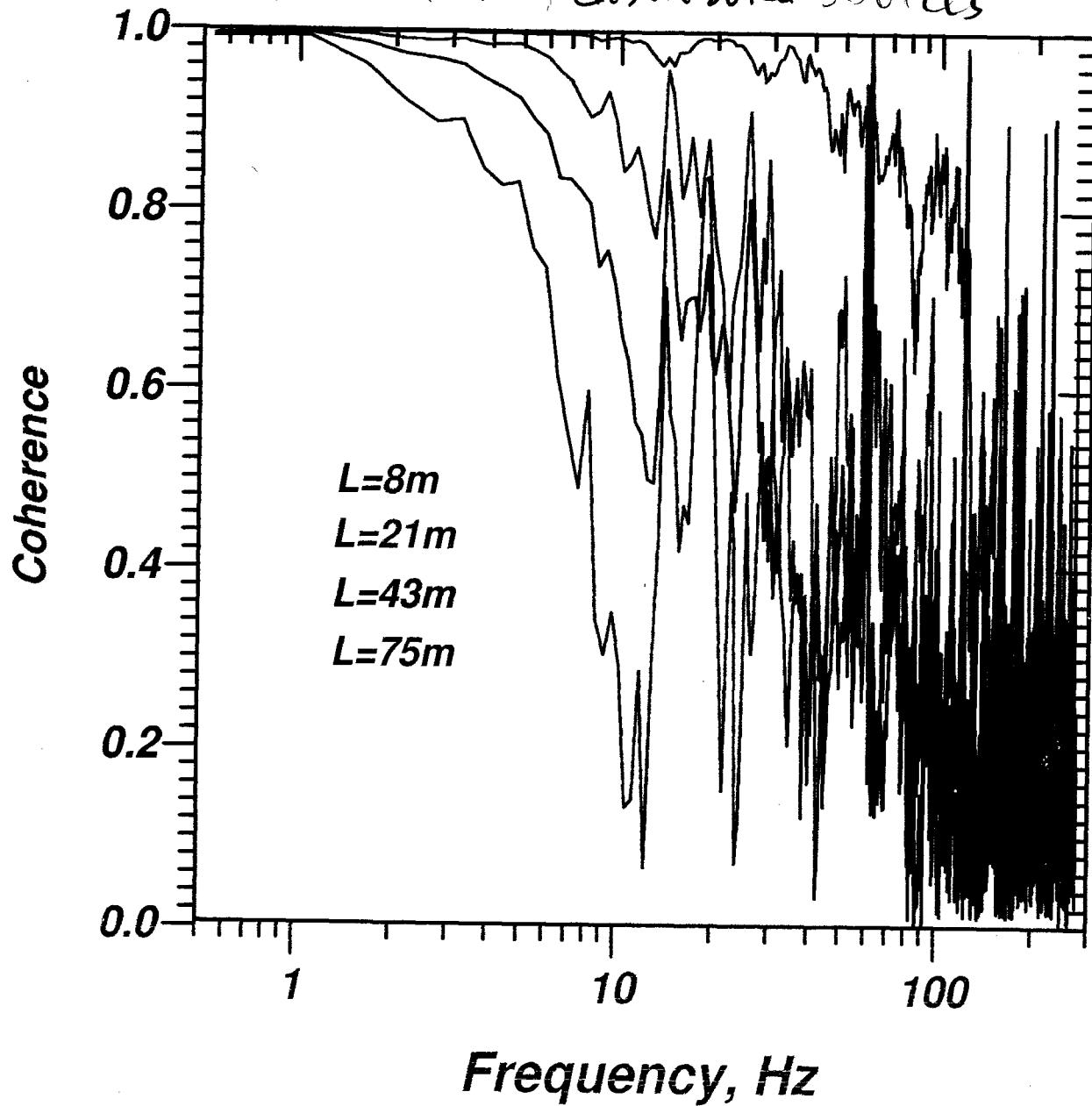
■ Web site tracks stories

B.Barkakov, et.al.

Phys. Rev. ST-AB, 1, 134001 (1998)

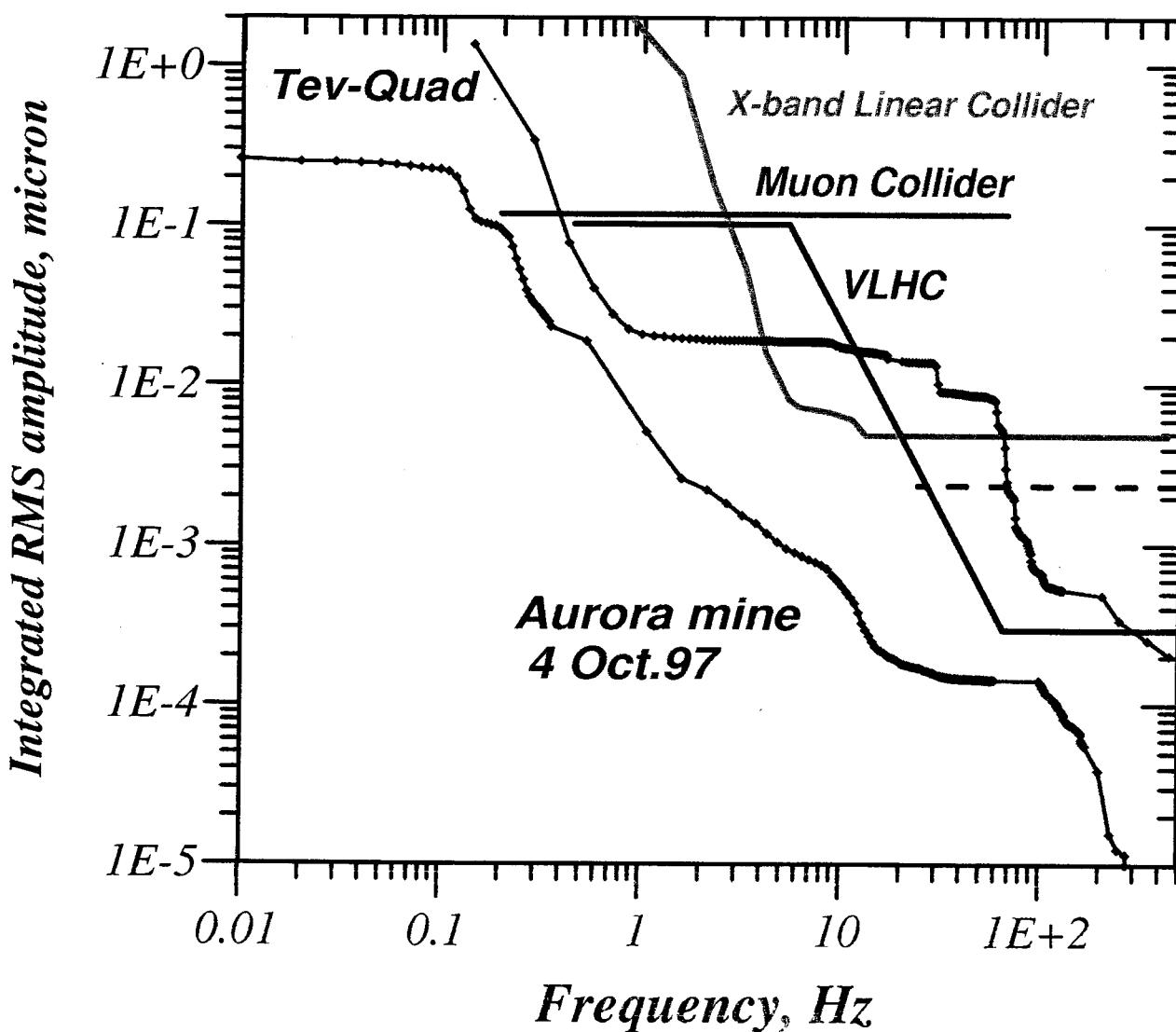
$$C_0(f) = |\mathcal{J}_0(2\pi L f / \sigma(t))|, \sigma(t) = 3800 - 4 \cdot f [\text{Hz}]$$

Model of random uniformly distributed sources



Coherence of vertical ground motion  
in 300-ft deep TARP tunnel (S.Chicago)  
vs frequency and distance btw. probes

- Eola Road project - highway across FNAL site
- The paper was published just in time
- in 1999-2000 more than 30 copies (11 pages, 20 Figs) were distributed among local authorities, managers, politicians
- seems all agree that the highway's impossible
- I bet it's my THE most read and useful paper!



VIBRATION TOLERANCES AND FNAL DATA