

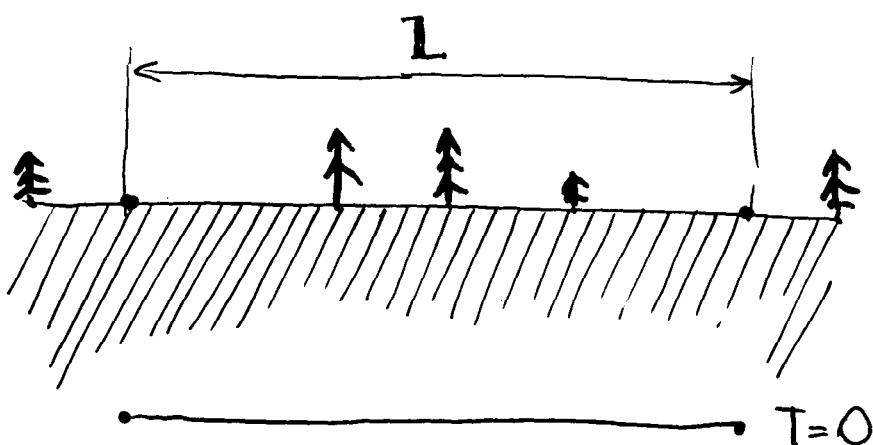
V.Shiltsev (FNAL)

ATL: The Story Continues

1. Introduction: what ATL is about
an example of diffusion
what did we know in 1995
2. Critics so far: R.Pitthan
A.Verdier
others welcome!
3. New data on ATL: SLAC
Japan
LEP orbit diffusion
Fermilab & around

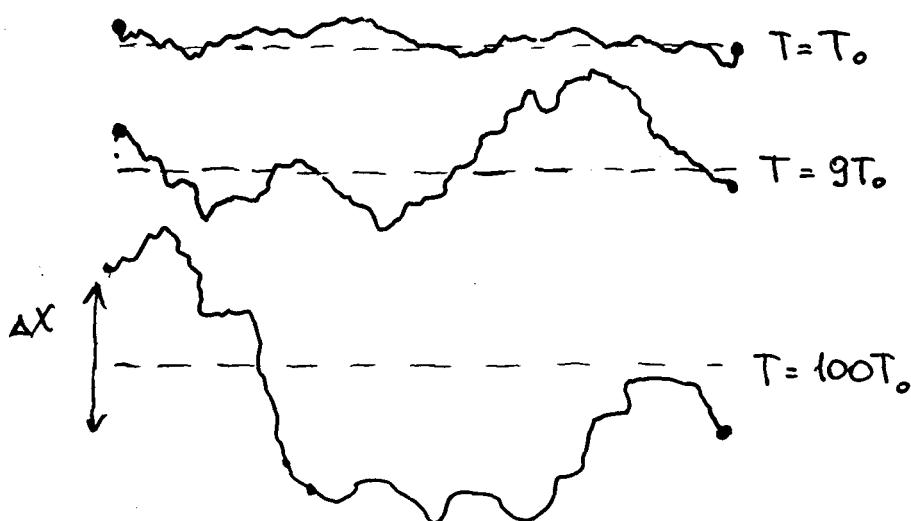
Space-Time Ground Diffusion

- The ATI Law for Accelerators



BESIDES GROUND
MOTION DUE TO:
1) TIDES
2) PRECIPITATION
3) T° VARIATIONS
4) WINDS
5) GROUND WATER
6) ETC.

↓
DIFFUSION (RESIDUAL)



MEAN IN TIME+SPACE

TIME INTERVAL

$$\langle\langle \Delta X^2 \rangle\rangle = A \cdot T \cdot L \quad \leftarrow 1991$$

↑ ↓ ←
 relative DIFFUSIVE SPATIAL
 displacement (AV) COEFFICIENT INTERVAL
 $\Delta X = X_2 - X_1$ $\sim 10^{-5 \pm 1} \frac{\mu\text{m}^2}{\text{s} \cdot \text{m}}$

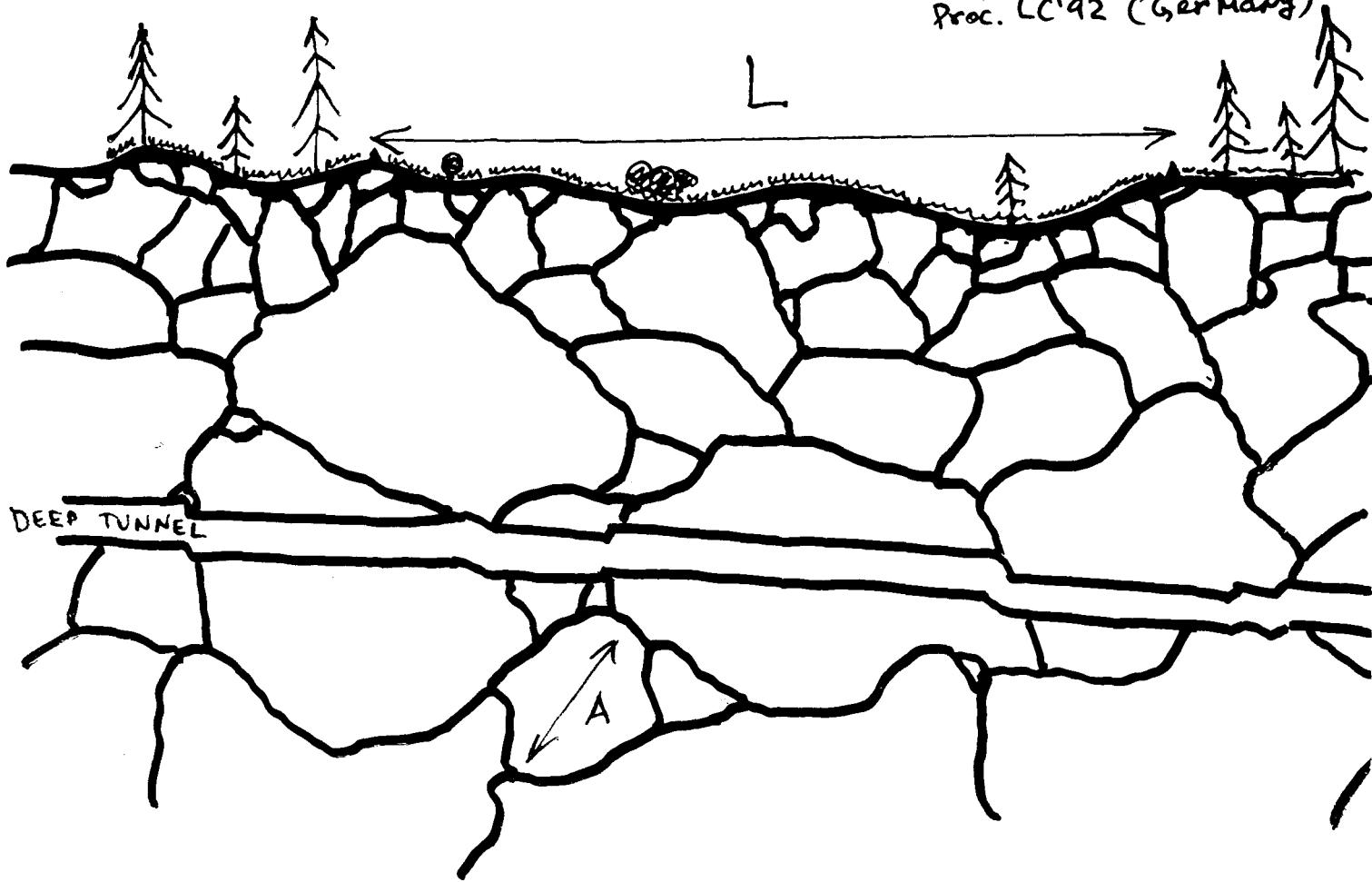
"ATL-law": Underlying Physics

FRACtAL Properties OF GROUND

PARKHOMCHUK, SHILTSEV (1992)

INP 92-31

Proc. LC'92 (Germany)



Number of blocks of size A per UNIT volume:

$$N(A) \propto 1/A^D$$

THE Law of FRACTAL

D - Dimension

(NOT NECESSARy INTEGRe)

The blocks jump with characteristic intervals:

$$\tau(A) \propto A^\delta$$

(TOTALLY, INELASTIC MODEL, subject to improvement)

inverted pendulum

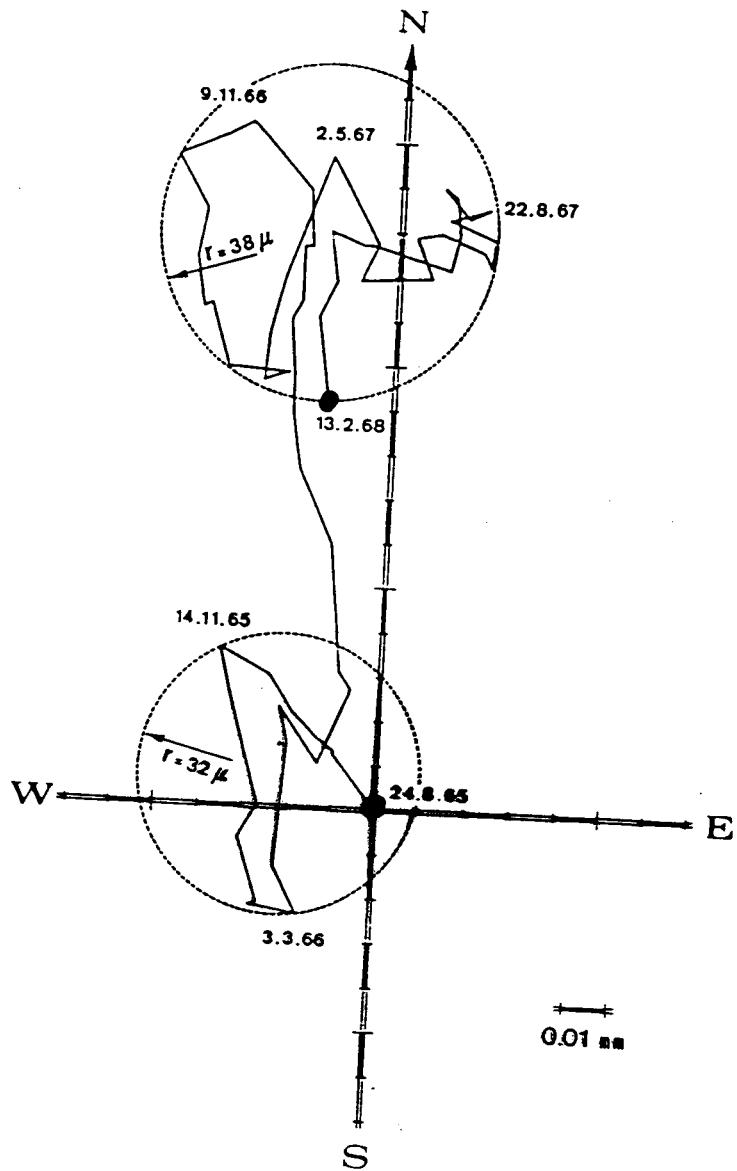
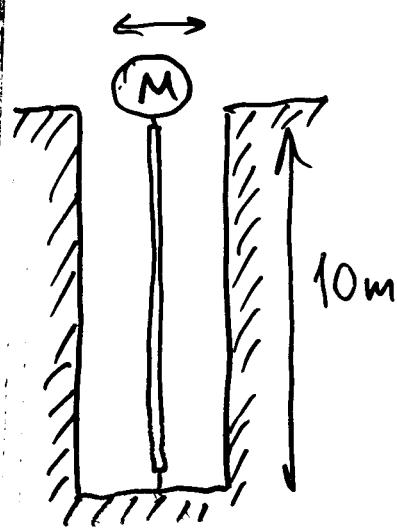
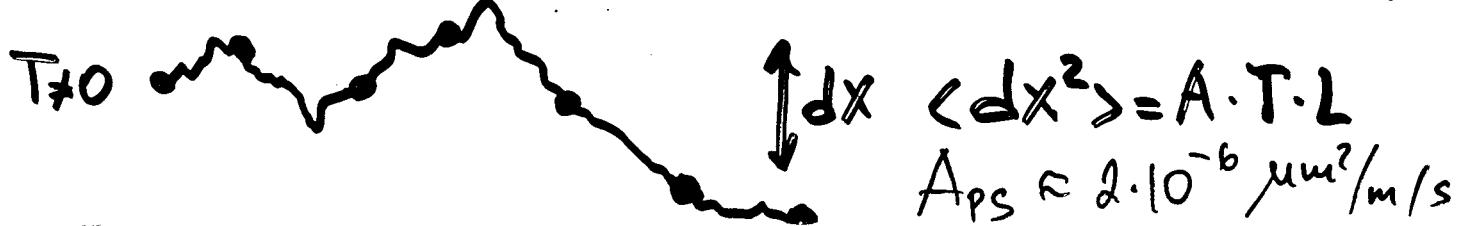


Fig. 7 Horizontal movement of the PS central pillar in 1965 – 1968 (from Ref.[19]).

"ATL-Law" (1991) claims that besides

systematic (regular) motion
tides, linear drifts, pressure
etc → there is diffusion

$T=0$



1995: ATL Summary Table (V. Shiltsev, IWRAA'95)

Table 2: Ground diffusion observations

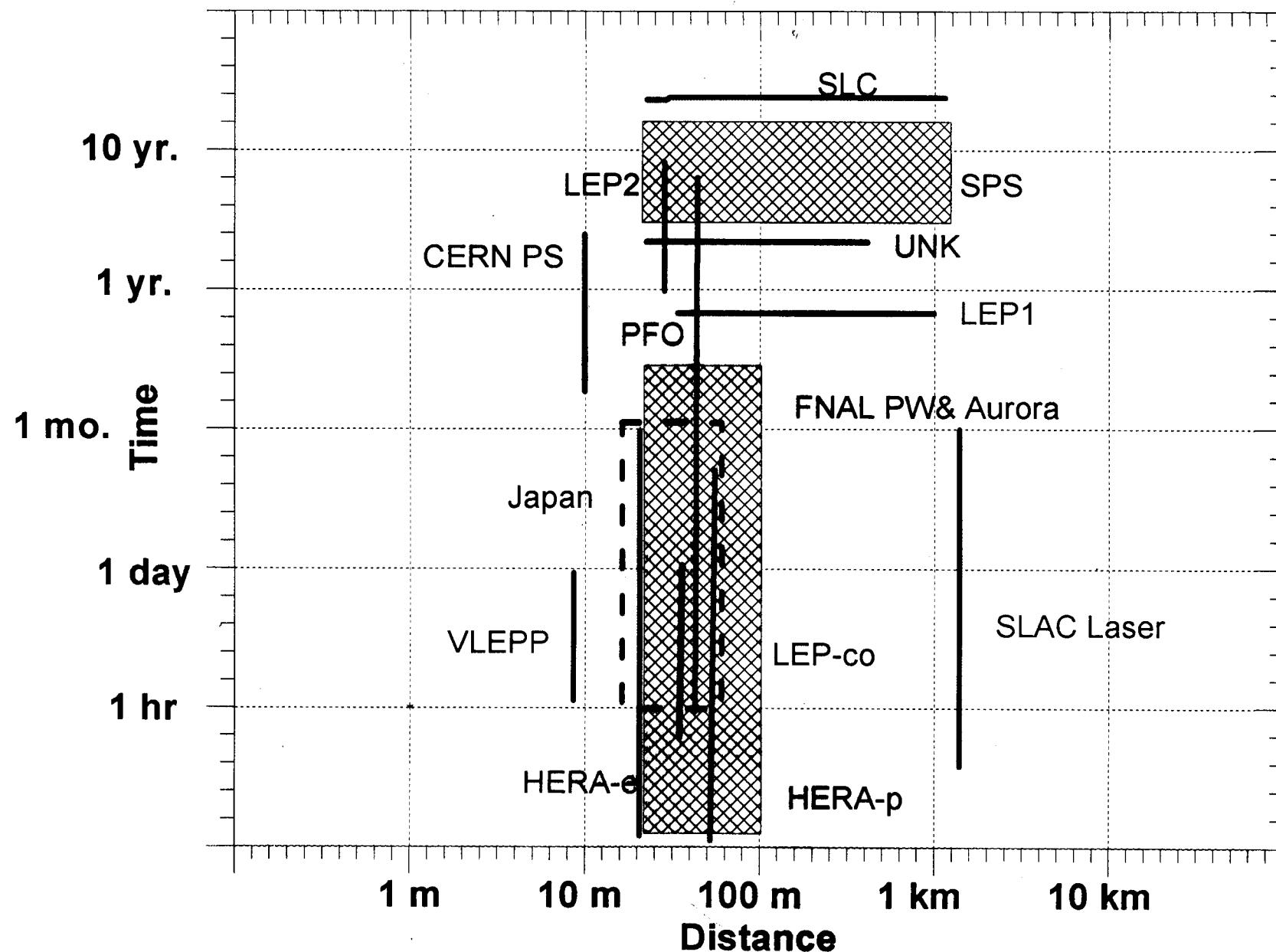
Site	$A, 10^{-5} \frac{\mu\text{m}^2}{\text{s}\cdot\text{m}}$	T	L		Depth
UNK, Protvino	10	2 yr.	50-500 m	V	0 m
UNK, Protvino	10 ± 5	1-10 hrs.	5-10 m	V, H	0 m
SLAC Linac	20 ± 10	17 yr.	50-1000 m	V	0-5 m
SLAC PEP	10 ± 5	20 mos.	20-200 m	V	~ 10
PS pillar	$0.2 \div 0.4$	2.5 yr.	10 m	H	0 m
SPS CERN	$1 \div 1.4$	3-12 yr.	60 m - 2 km	V	~ 20 m
LEP CERN	$0.7 \div 0.9$	9 mos.	40 m - 1 km	V	≥ 30 m
Pinon Flat	0.01	1 yr.	24 m	H	0 m
TRISTAN KEK	$0.5 / 0.04$	4 days	42.5 m / 12.5 m	V	12 m
Sazare mine	$0.001 \div 0.015$	1 week	48 m	V	60 m
Esashi station	0.033 ± 0.005	0-4 yr.	50 m	V	300 m
Orbit of TRISTAN	4.3 ± 3	2 days	~ 20 m	V	12 m
Orbit of HERA- <i>p</i>	1.5 ± 1	1 s - 5 days	~ 50 m	V	~ 25 m
Orbit of HERA- <i>e</i>	0.4 ± 0.1	1 s - 1 month	~ 24 m	V	~ 25 m

* SYSTEMATIC MOTION SEPARATION
 A reduced to 10^{-5}
 (see below)

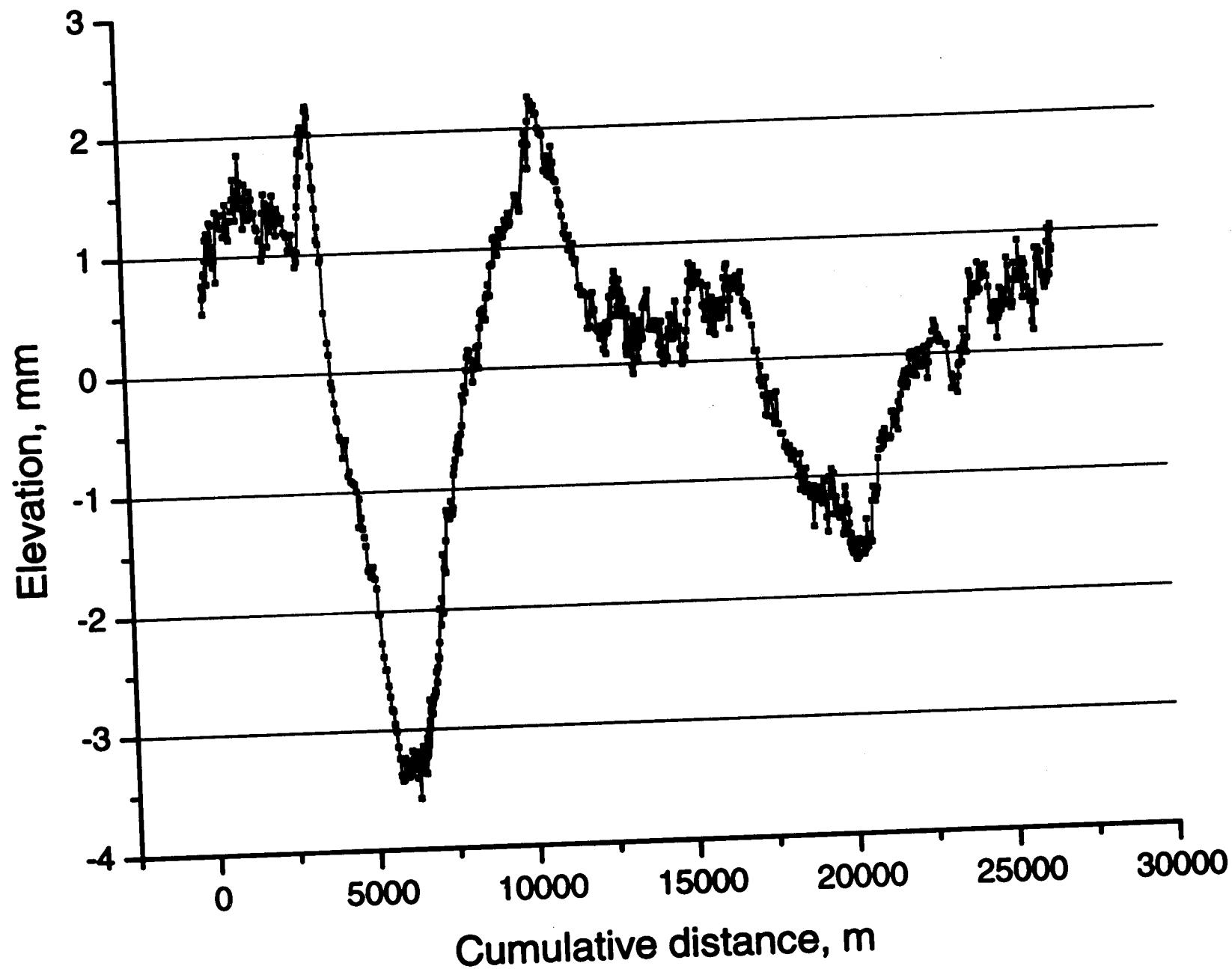
* (see below)

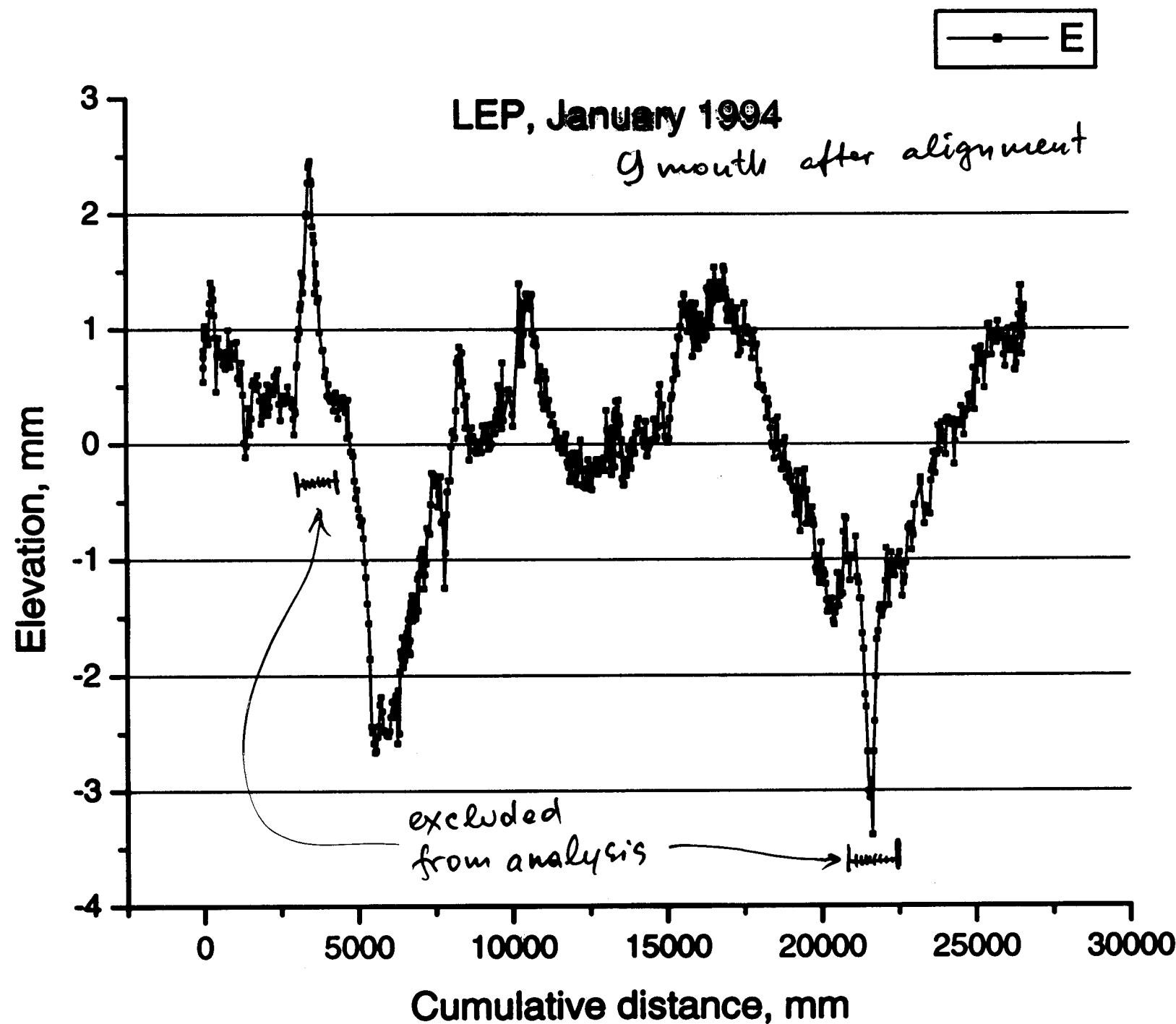
+ & more observations since 1995 (see below)

Ground Diffusion Observations: Region of T and L Intervals



LEP April 1993 (just realigned) D





THAT DASHED LINE actually corresponds to

$$A = 1.4 \cdot 10^{-4} \frac{\mu\text{m}^2}{\text{m} \cdot \text{s}} \quad (\text{e.g. } \sqrt{A \cdot 10 \text{ yrs} \cdot 40 \text{ m}} = 1.32 \text{ mm rms})$$

AND THAT is ≈ 17 times MAX. A ever claimed for LEP!!

RMS of Simple Difference Between Quads in P1

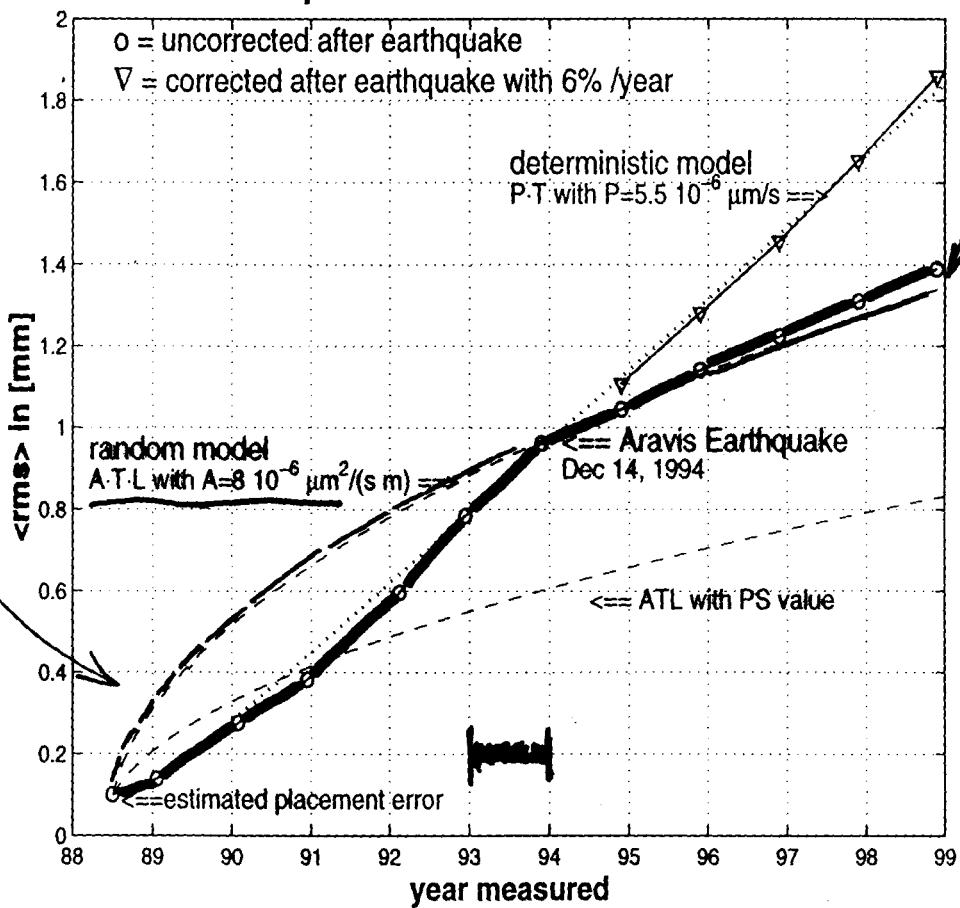
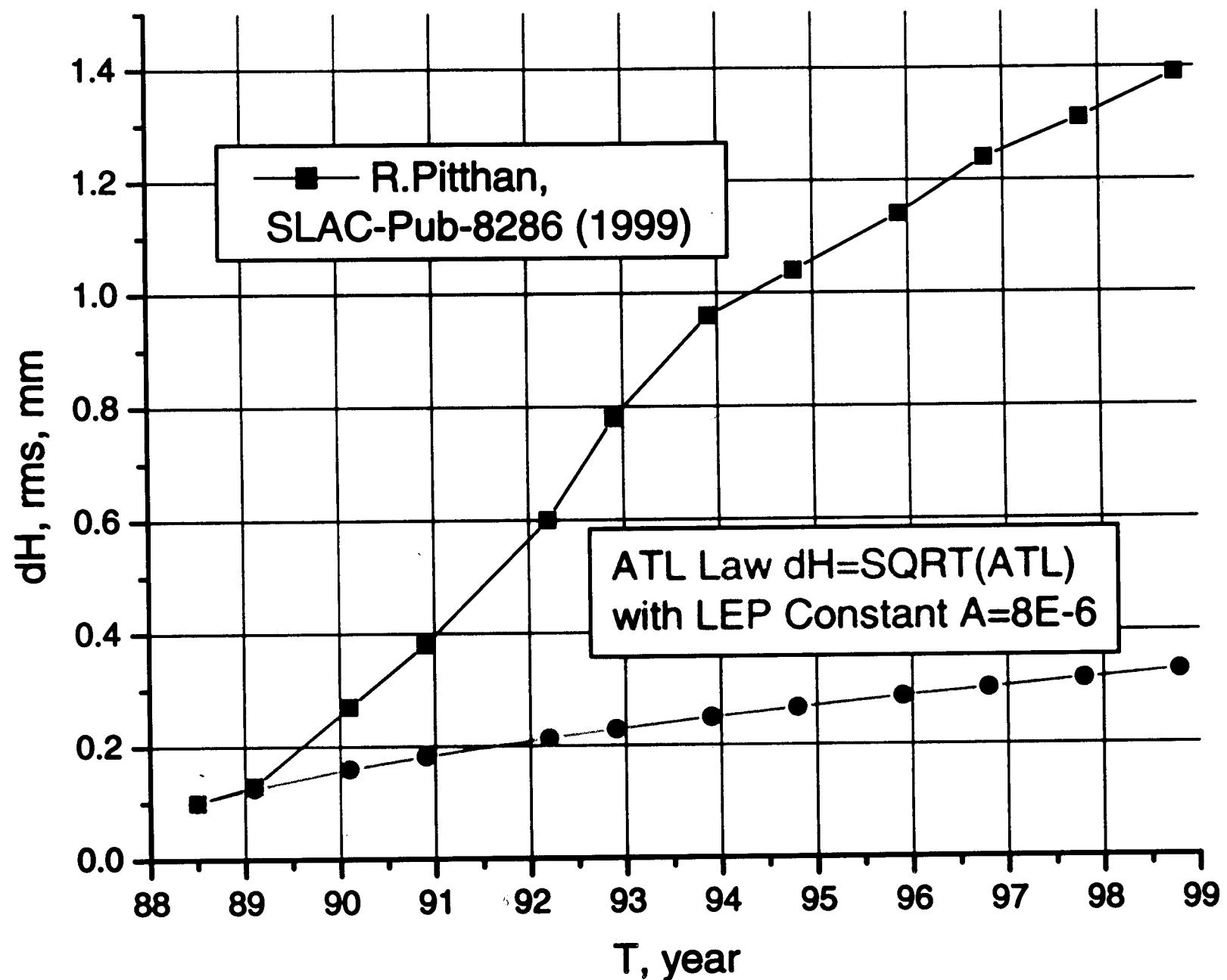


FIGURE 15. Ten-year time dependence for the accumulated rms of magnet off-sets from each other in P1. This busy picture requires explanation. The circles are rms-values calculated by taking the restored difference data as they are. The sharp bend in the curve for the circles in 1994 focused attention on the two groups of curves seen in Figures 12 and 13 and was unexplainable, until the question of an earthquake came up. A fairly large earthquake happened just at the right time to explain the change (December 1994). Two explanations for the mechanism are possible: (1) the tectonic speeds of fault lines was actually changed, making the rms - values grow slower, or (2) a one time change in position of some magnets which was not accounted for in the database because the earthquake happened after the data were taken. The data of Figure 12 support more the second possibility. Rms values are calculated by differences in quadrature. Therefore, in first order a model $(1 + \alpha)^n$, n years passed since the earthquake, seems to be the right Ansatz. From the actual magnet movements by year 10% was estimated for α , a fit gave 12%, resulting in a change of 1.06^n for the change to the rms (∇ symbols in the upper right of the plot).

Comparison of LEP data and ATL prediction



measured.

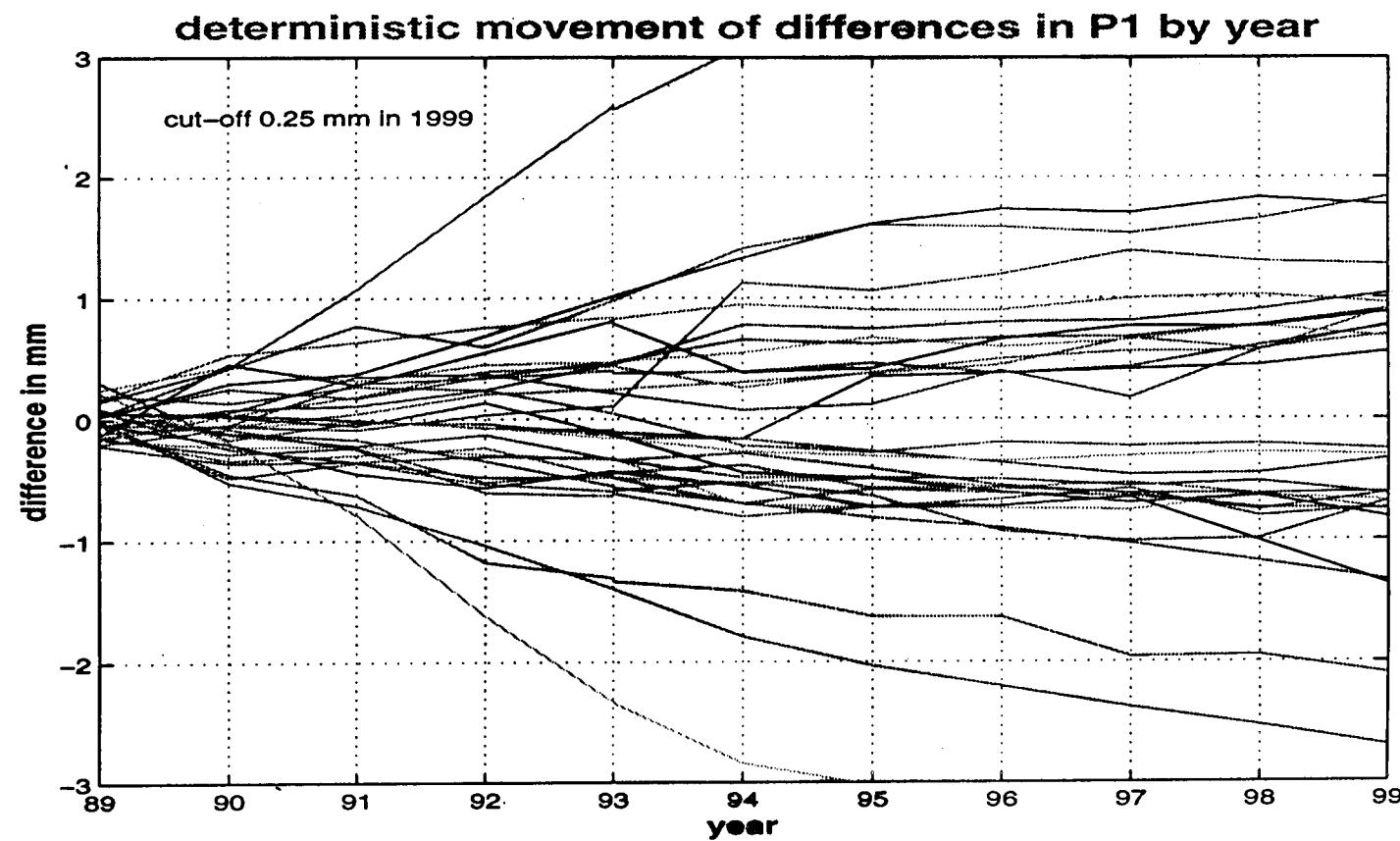
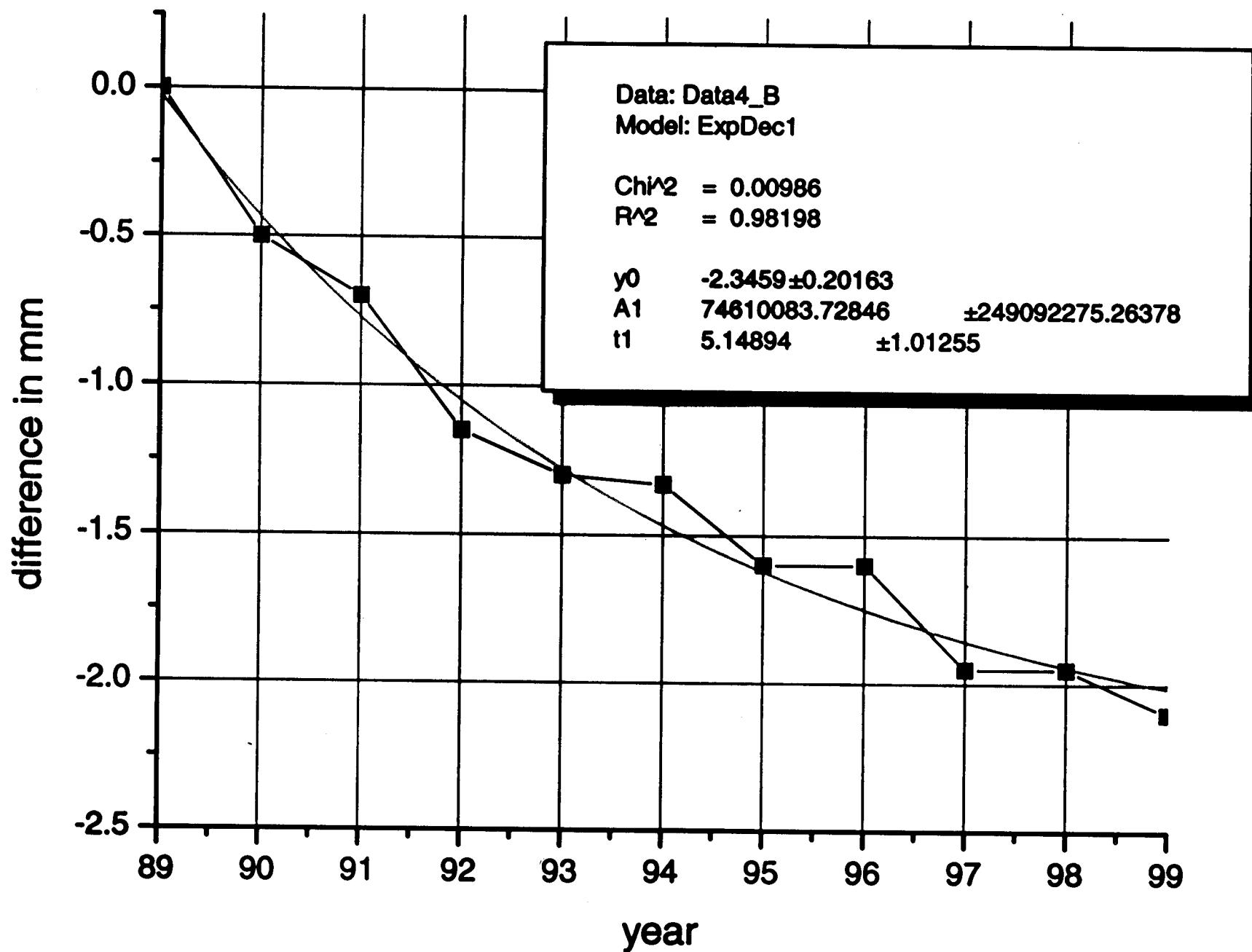
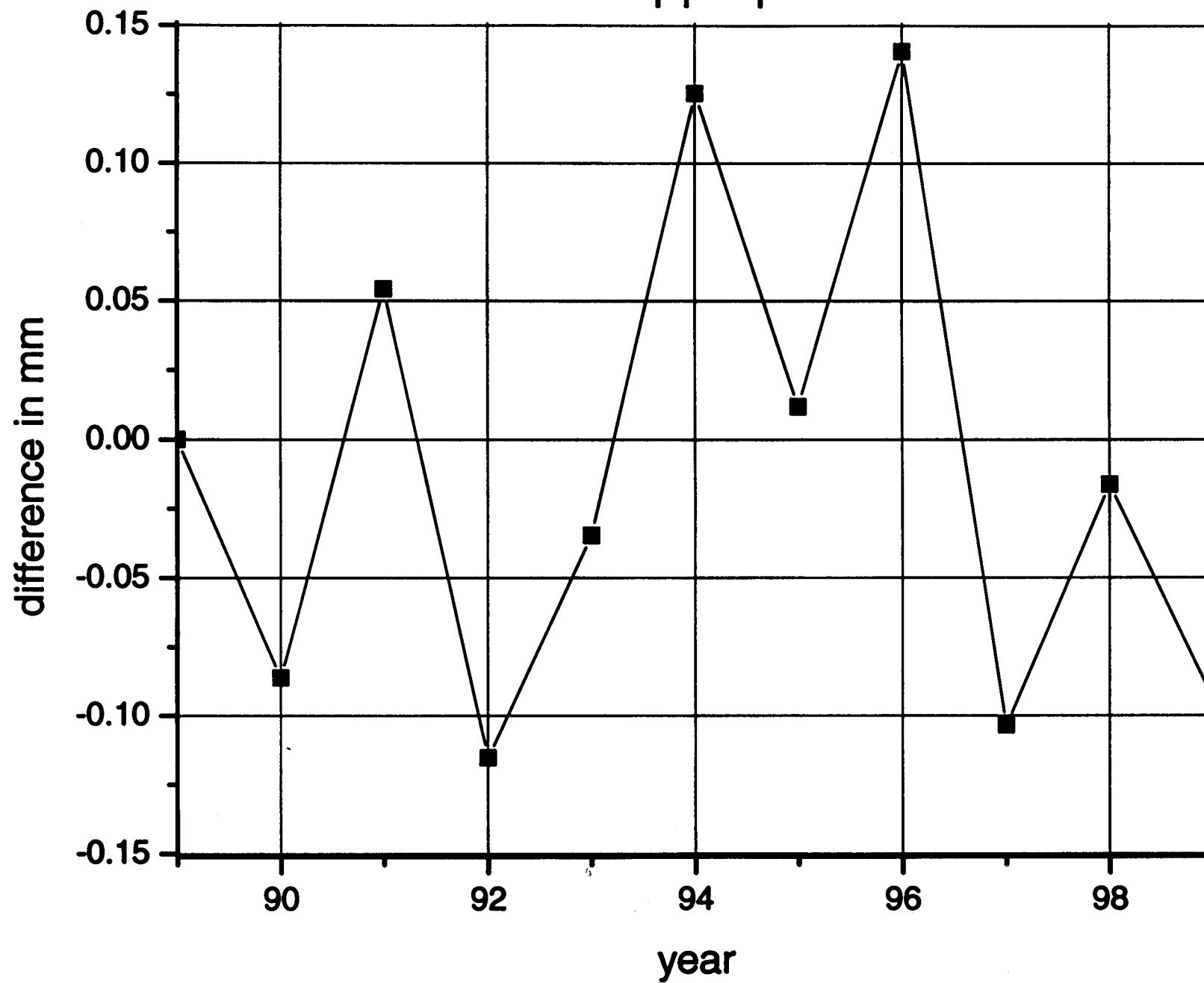


FIGURE 14. From the data of Figure 13 are derived the slopes of movements in mm/year for all magnets with average movements of more than $25 \mu\text{m}/\text{year}$.

One of differences from Fig.14 of SLAC-Pub-8286



**One of differences from Fig.14 of SLAC-Pub-8286
after subtraction of appropriate smooth curve**



SPS Quads Movements 1976-1988

$$\langle A \rangle \approx 1.4 \cdot 10^{-5} \frac{\mu\text{m}^2}{\text{s} \cdot \text{m}} \quad (\text{min } 1.0 \quad \text{max } 4.0)$$

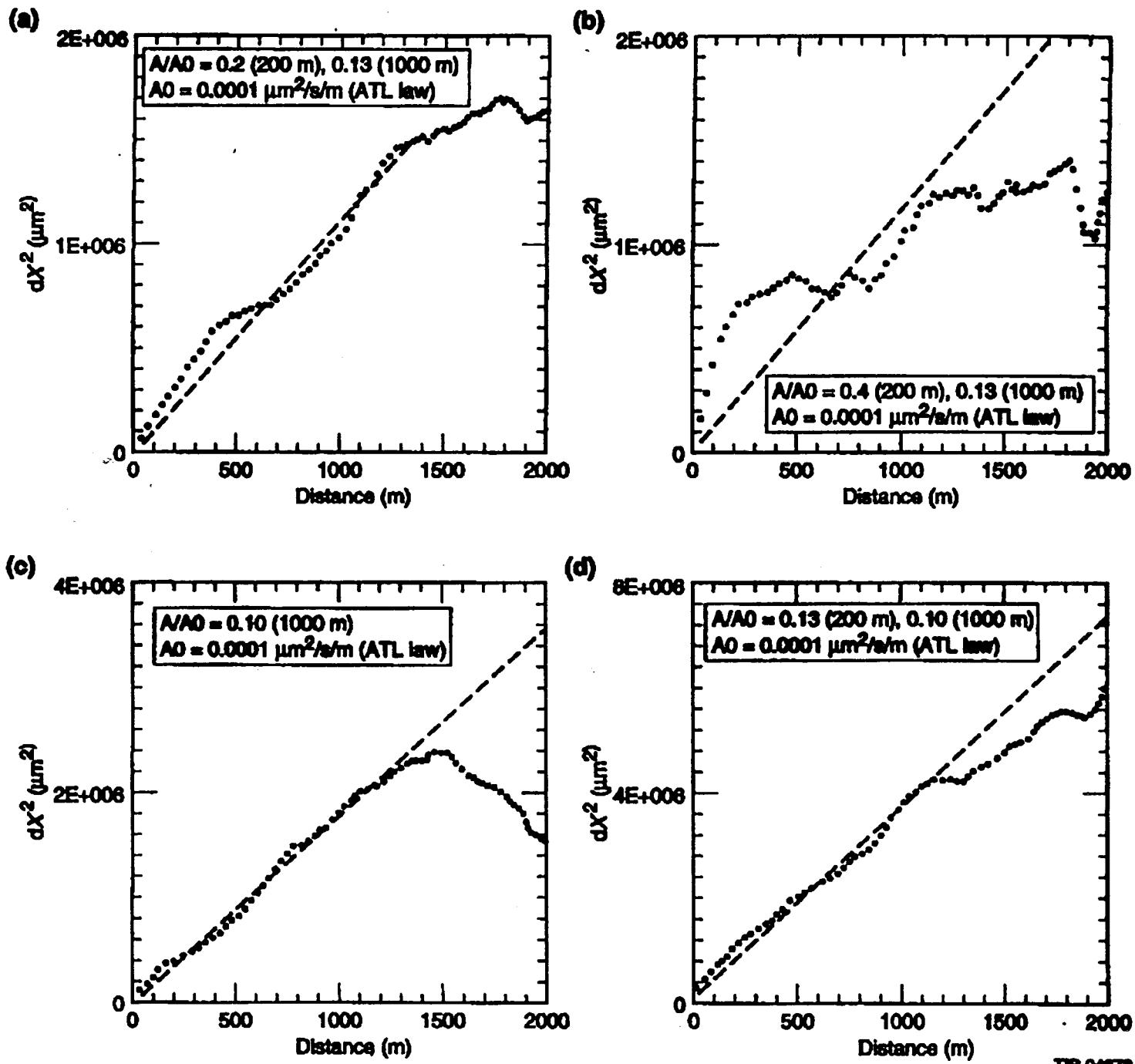


Figure 2. (a) The variance of relative displacements of quads that occurred 1985-1988 vs. distance between quads. (b) The variance of relative displacements of quads that occurred 1988-1991 vs. distance between quads. (c) The variance of relative displacements of quads that occurred 1985-1991 vs. distance between quads. (d) The variance of relative displacements of quads that occurred 1976-1988 vs. distance between quads.

Evidences of Diffusion at CERN

	A, 1e-5 $\mu\text{m}^2/\text{m/s}$	Tmax # of points	Lmax #points	Comments
PS pillar	0.2 - 0.4	30 months ~30 points	10 m 1 point	1965 - 1968 Shiltsev '95 IWAA
SPS alignmt	1.1 ± 0.4	15 years 5 points	2 km 216 points	1976 - 1991 Shiltsev, Stenius 1993
LEP 93-94 alignment	0.8 ± 0.4	9, 6 months 2 points	1 km ~700 points	Shiltsev '95 $S/N \sim 2.4$
LEP 93-99	0.3 ± 0.06	6 years 7 points	$\Delta L = 40 \text{ m}$ ~700 points	Sery '00 (This Workshop)
LEP closed orbit drfits	1.2 ± 0.05	18 hrs ~18 points	$\langle \beta \rangle \sim 40 \text{ m}$ $Q \sim 100$	F.Tecker 1996 L.Vos 1999 (V.Shiltsev '00)

Variance of closed orbit, μm^2

100000

80000

60000

40000

20000

0

0

2

4

6

8

10

12

14

16

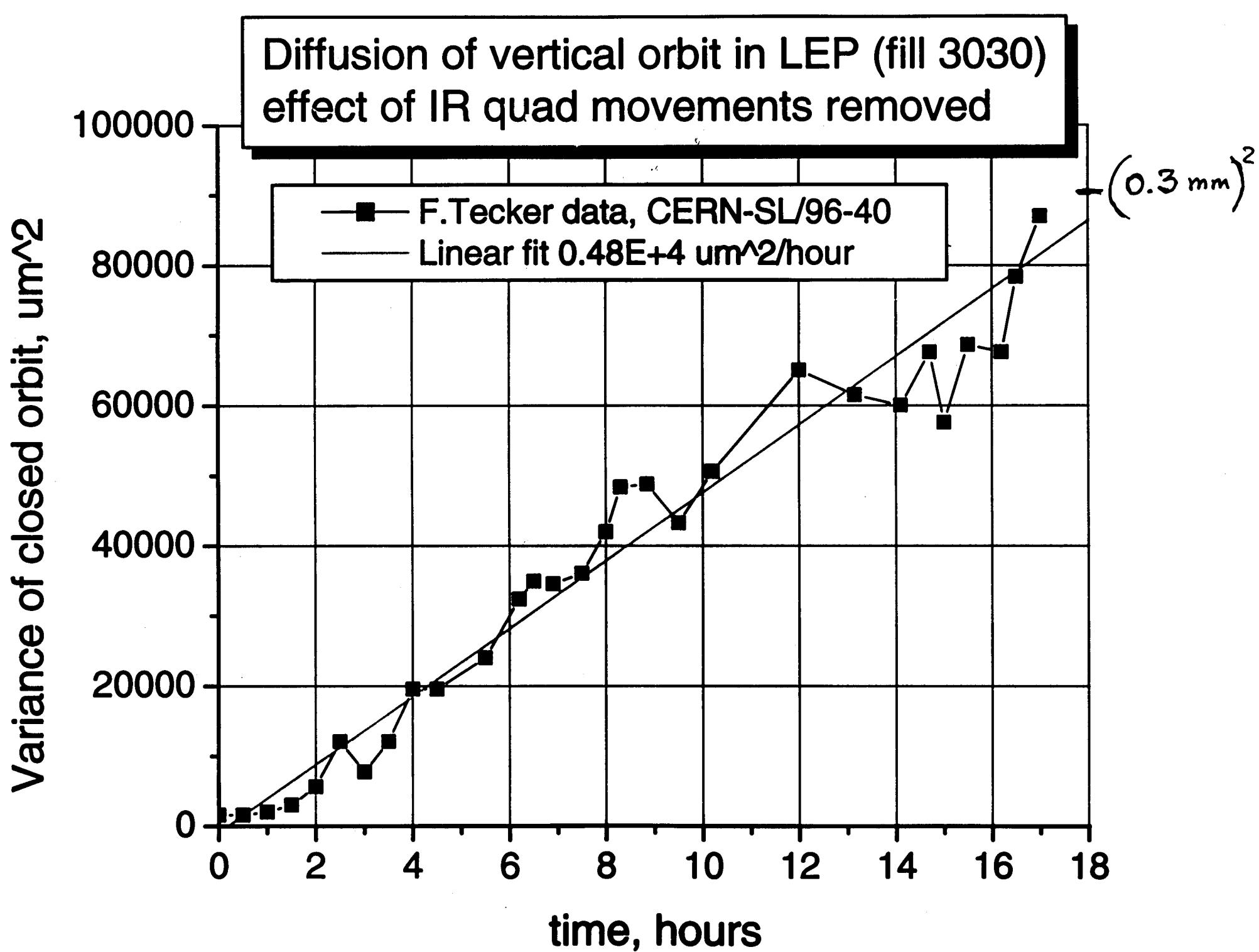
18

time, hours

Diffusion of vertical orbit in LEP (fill 3030)
effect of IR quad movements removed

— ■ — F.Tecker data, CERN-SL/96-40
— — Linear fit $0.48\text{E}+4 \mu\text{m}^2/\text{hour}$

$(0.3 \text{ mm})^2$



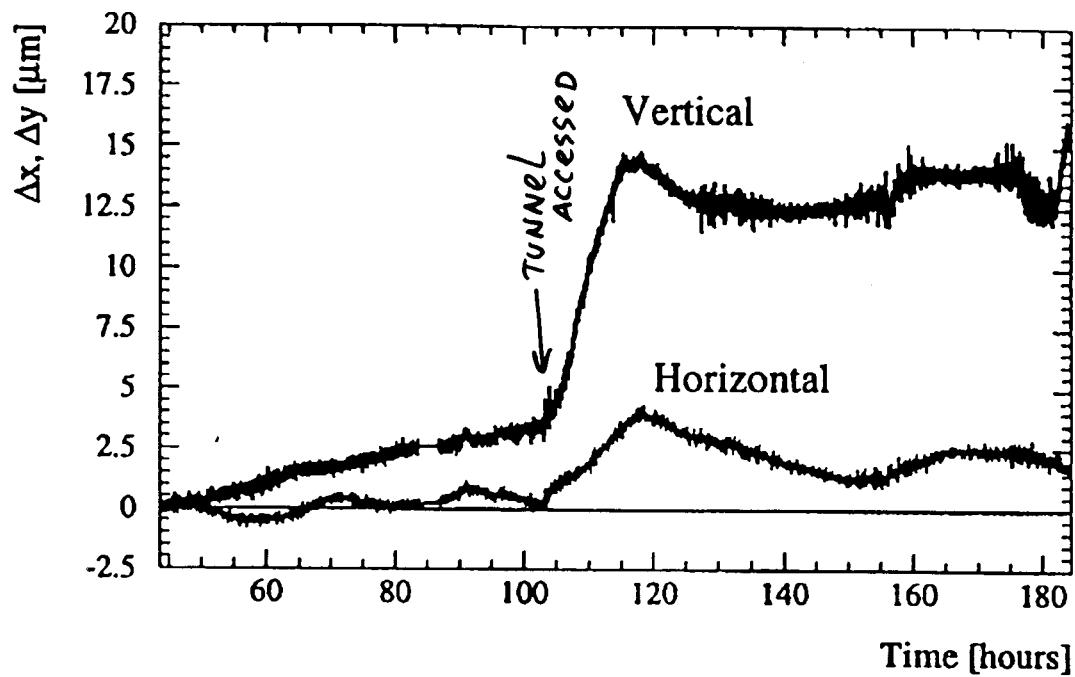


Figure 3: The measured motion Δx , Δy of the middle magnet with respect to the end magnets in section 1.

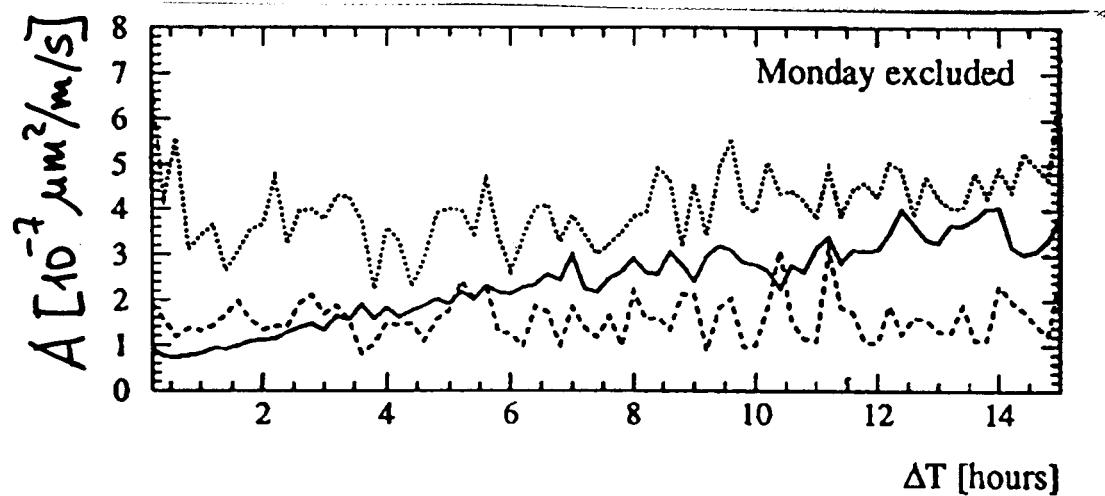


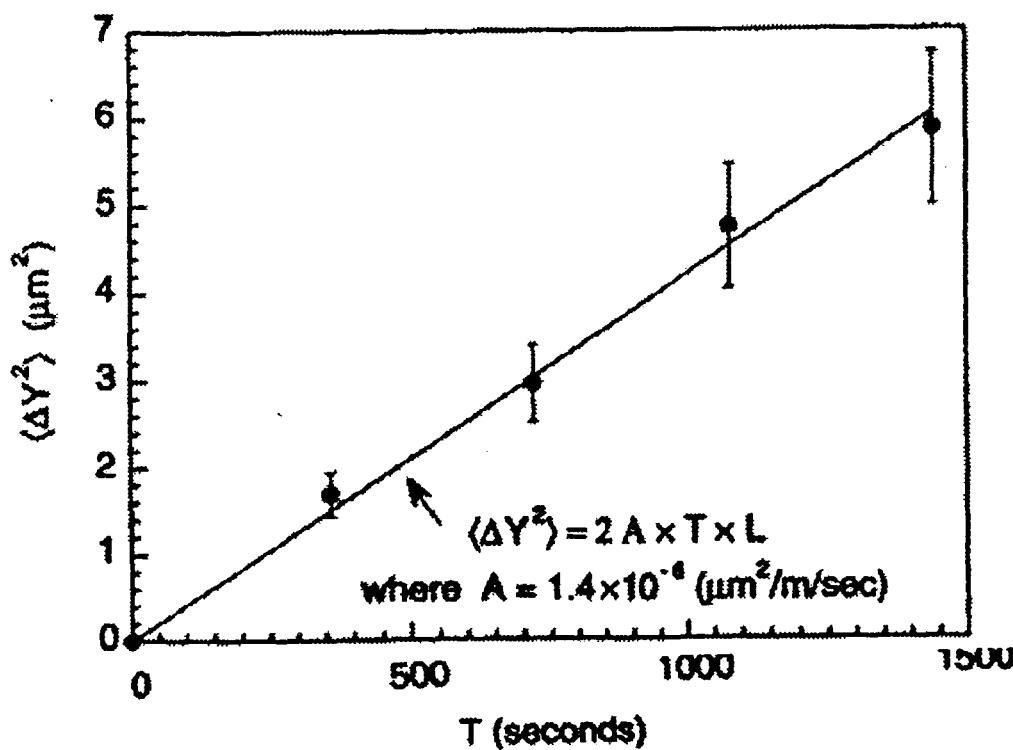
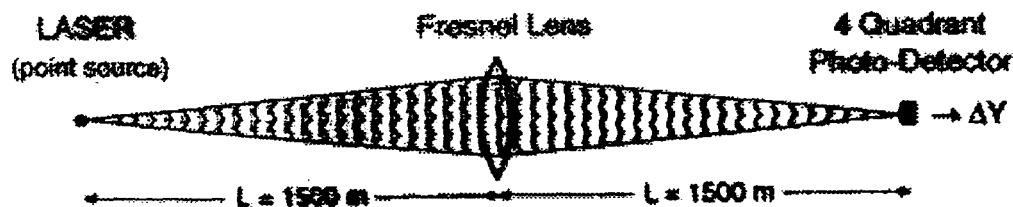
Figure 4: Calculated A constant as a function of the time interval ΔT in the ATL rule. The three different curves refer to the horizontal (solid) and vertical (dotted) data of section 1 and the horizontal data of section 2 (dashed). The upper results include all data. In the lower case the data between 100 and 120 hours (see Fig. 3). was excluded. The perturbing effect of an FFTB access was such eliminated. The A constant was determined over a distance of approximately twice 15 m.

SLOW QUAD MOTION

Characterize by 'ATL' Behavior: $\langle \Delta Y^2 \rangle = A \times \text{Time} \times \text{Length}$

What is A ?

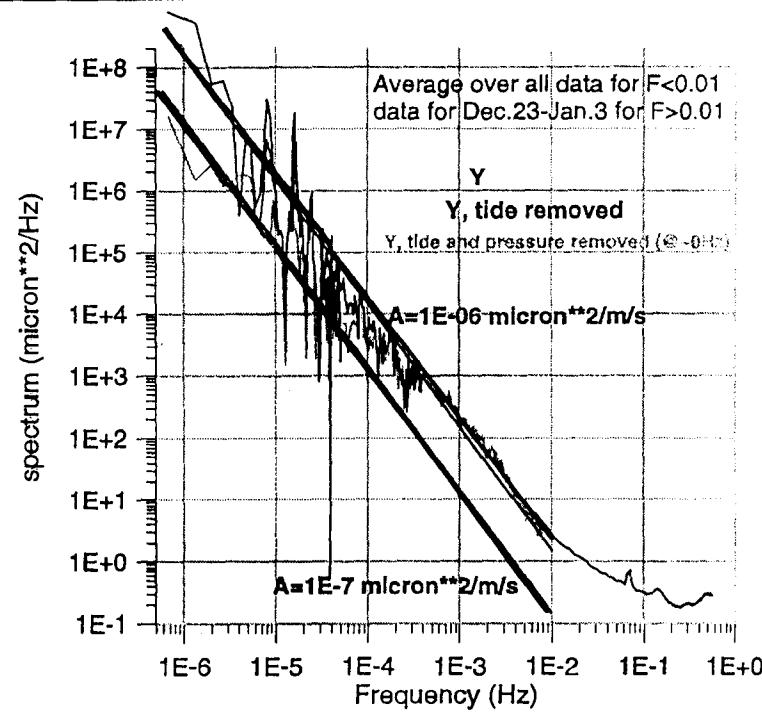
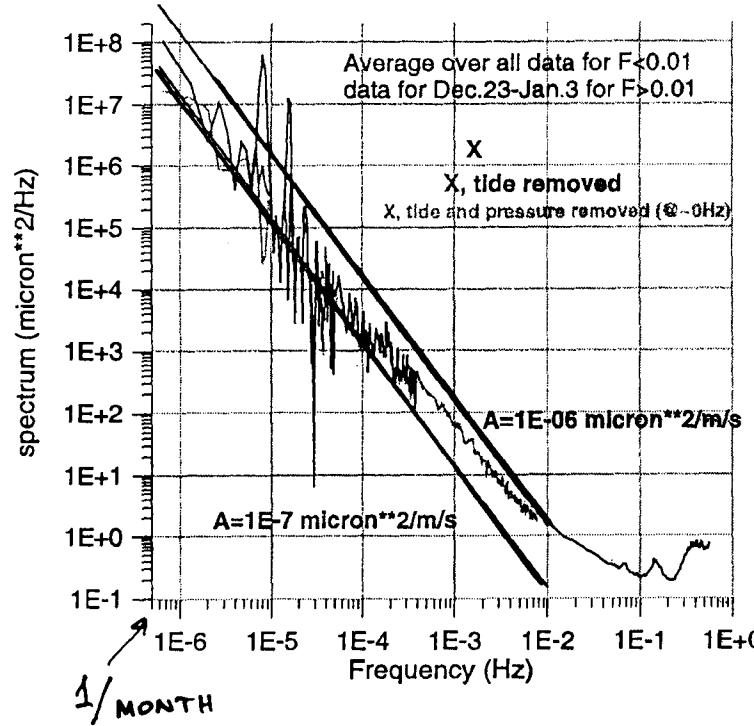
Measurements with SLAC's Linac Laser Alignment System



SLAC Linac Tunnel (1999-2000)

NLC - The Next Linear Collider Project

Tunnel motion. Diffusive in time



- Spectra of tunnel displacements behave as $1/\omega^2$ in wide frequency range, as for the ATL

$$A \approx 10^{-7} - 2 \cdot 10^{-6} \mu\text{m}^2/\text{m/s} \quad \text{in } f \in [10^{-6} \text{ Hz} - 10^{-2} \text{ Hz}]$$

A. Seryi, Proc. Linac 2000
see also NLC MAC (May 2000)

A. Seryi

17 years SLAC tunnel motion = systematic + random

$$d(X, Y)^2 \approx A_s \cdot T^2 \cdot L + A \cdot T \cdot L$$

Seryi, Raubenheimer, Proc. Linac'2000

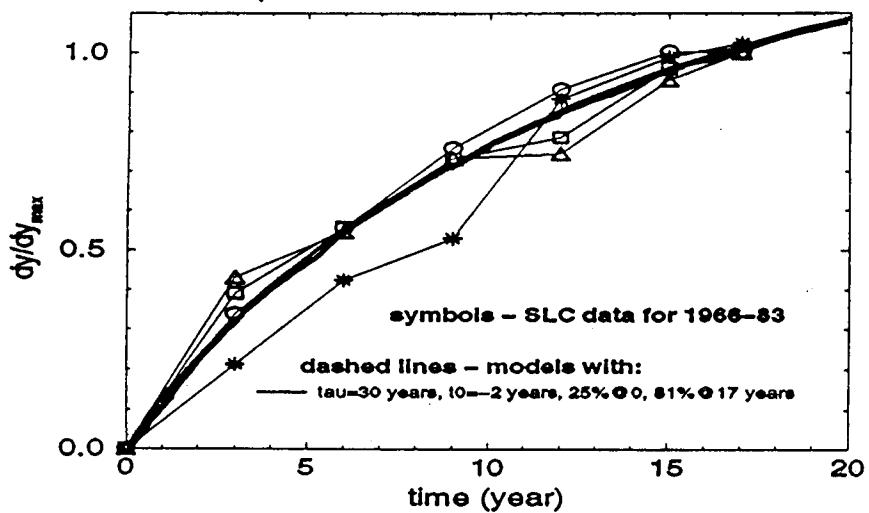
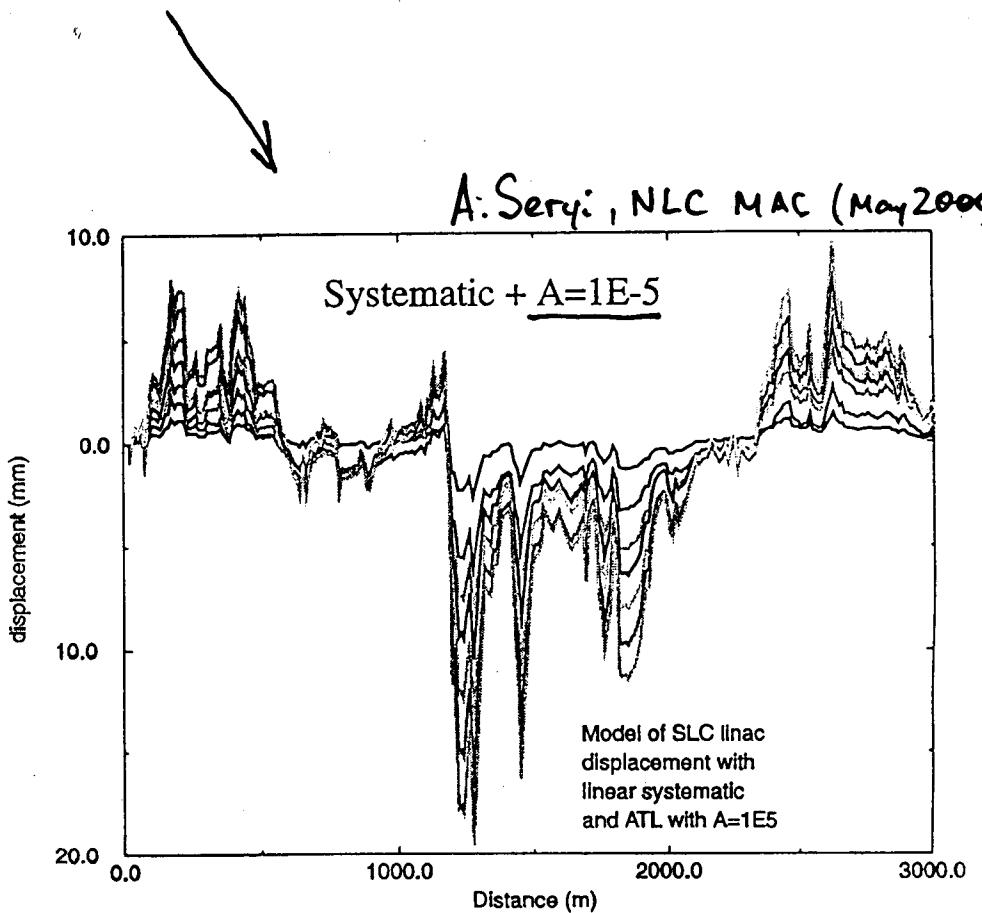


Figure 2: Displacement of some points of SLAC linac tunnel from 1966 through 1983 versus time and the approximation in Eq. (2) with $\tau = 30$ and $t_0 = 2$ years.

$$\frac{\Delta y}{\Delta y_{\max}} \approx 1 - \left(1 - \frac{\sqrt{t/\tau}}{(1 + 2\sqrt{t/\tau})} \right) \exp(-2.36 t/\tau)$$



- The systematic+ATL model

Measurements in Japan

J. Iakeda, et.al. KEK-99/135
 IWAA'99
 EPAC'2000, p.2394

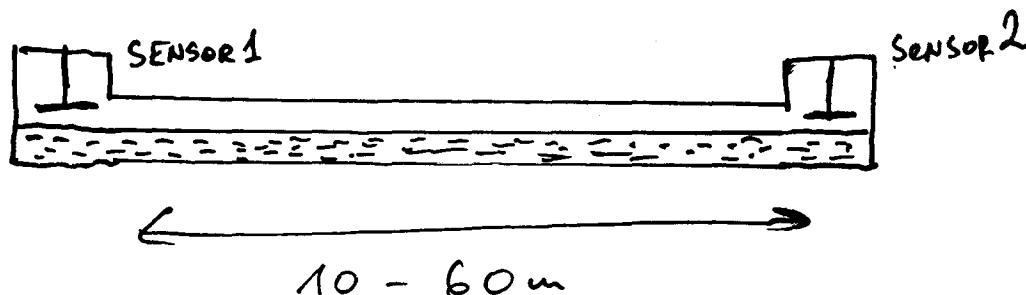


Table 1: ATL coefficient in Japan $10^{-6} \mu\text{m}^2/\text{m/s}$

No	Site Name	A ($\text{nm}^2/\text{m/sec}$)
1	Tunnel of KEKB	4.0E+01
2	Rokkoh-1	3.6E+01
3	Rokkoh-2	3.3E+01
4	Miyazaki	1.5E+01
5	Kamaishi-1	1.4E-01
6	Kamaishi-2	5.7E-02
7	Sazare	5.0E-02
8	Esashi-1	5.7E-03
9	Esashi-2	2.0E-03

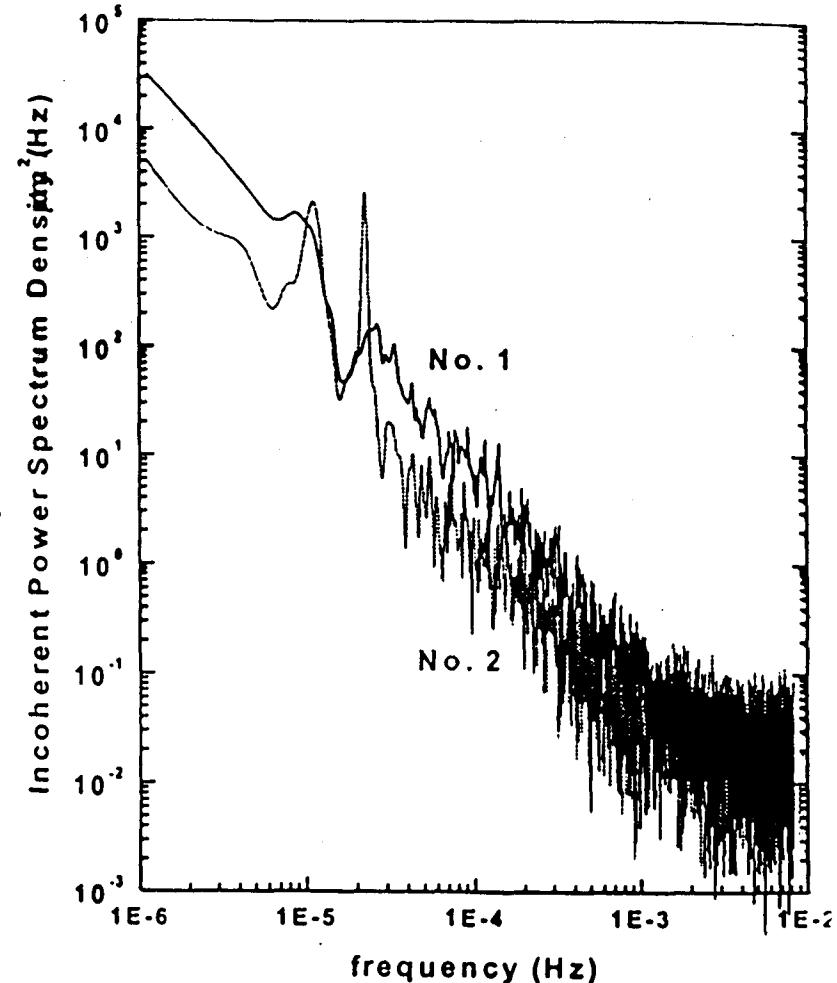
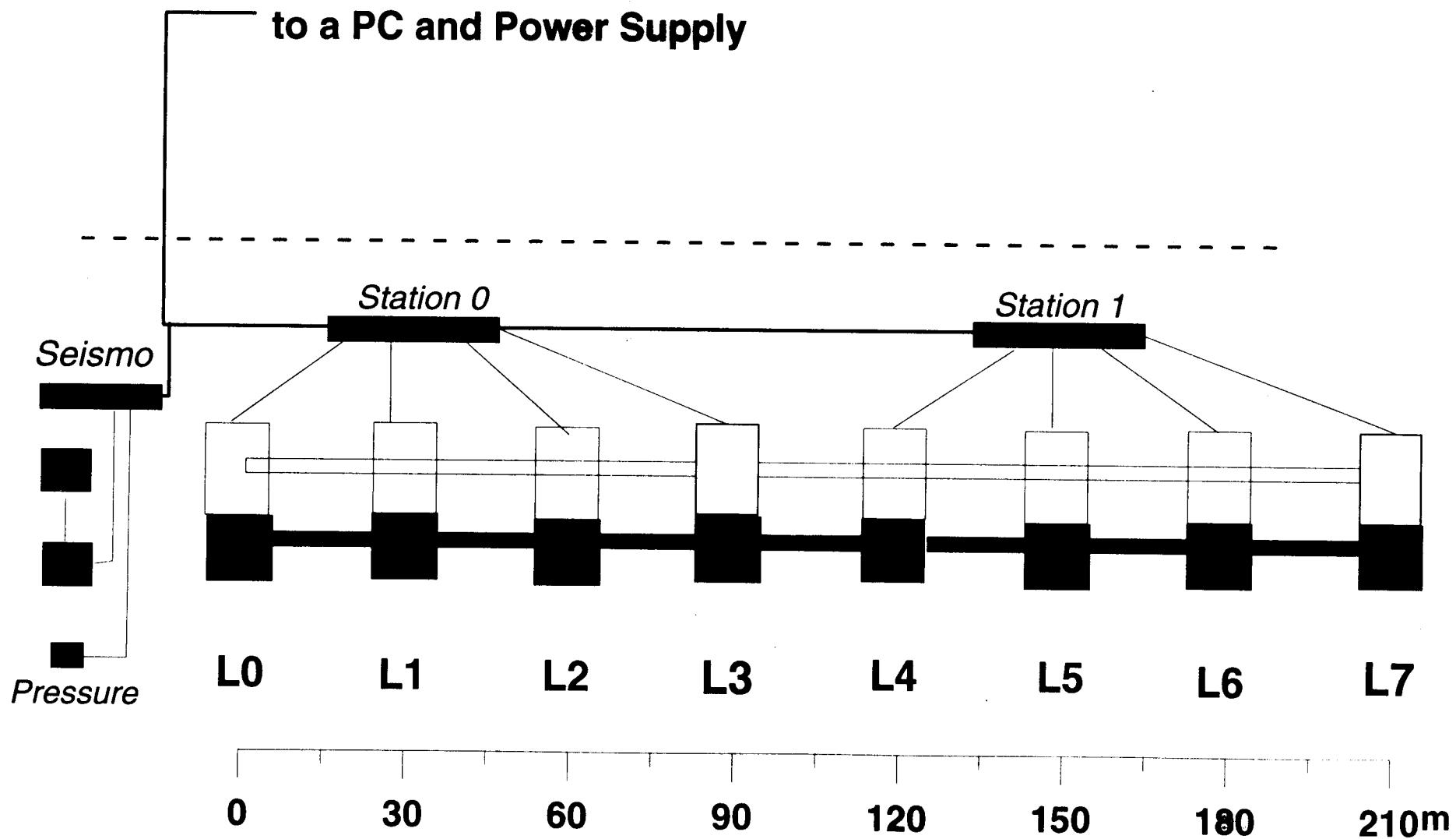
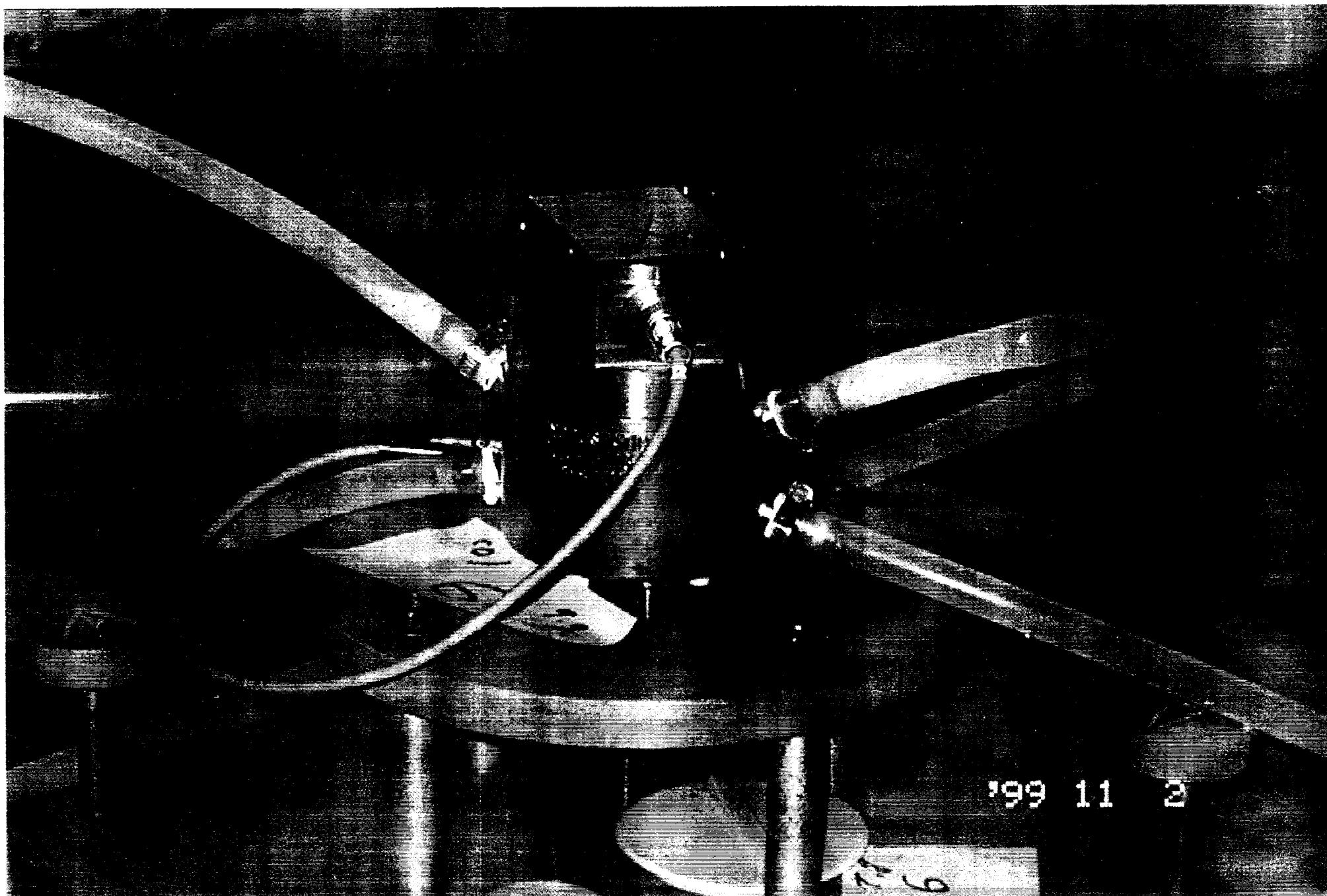


Figure 5: Incoherent spectra obtained in the tunnel of Esashi.
 also reported at IWAA'95 by Shiltsev

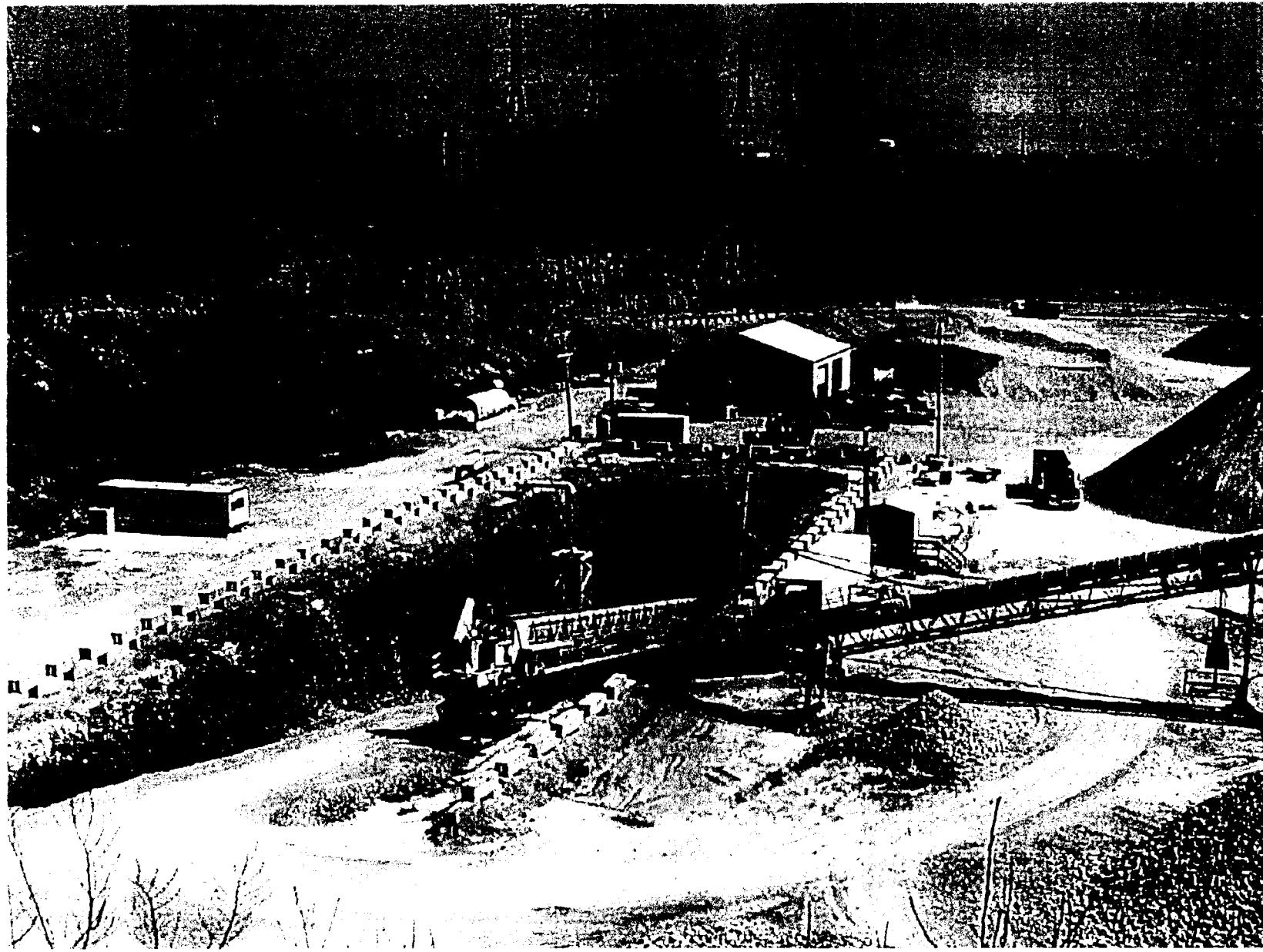
Scheme of Ground Motion Measurements in Aurora Mine and FNAL PW Tunnel



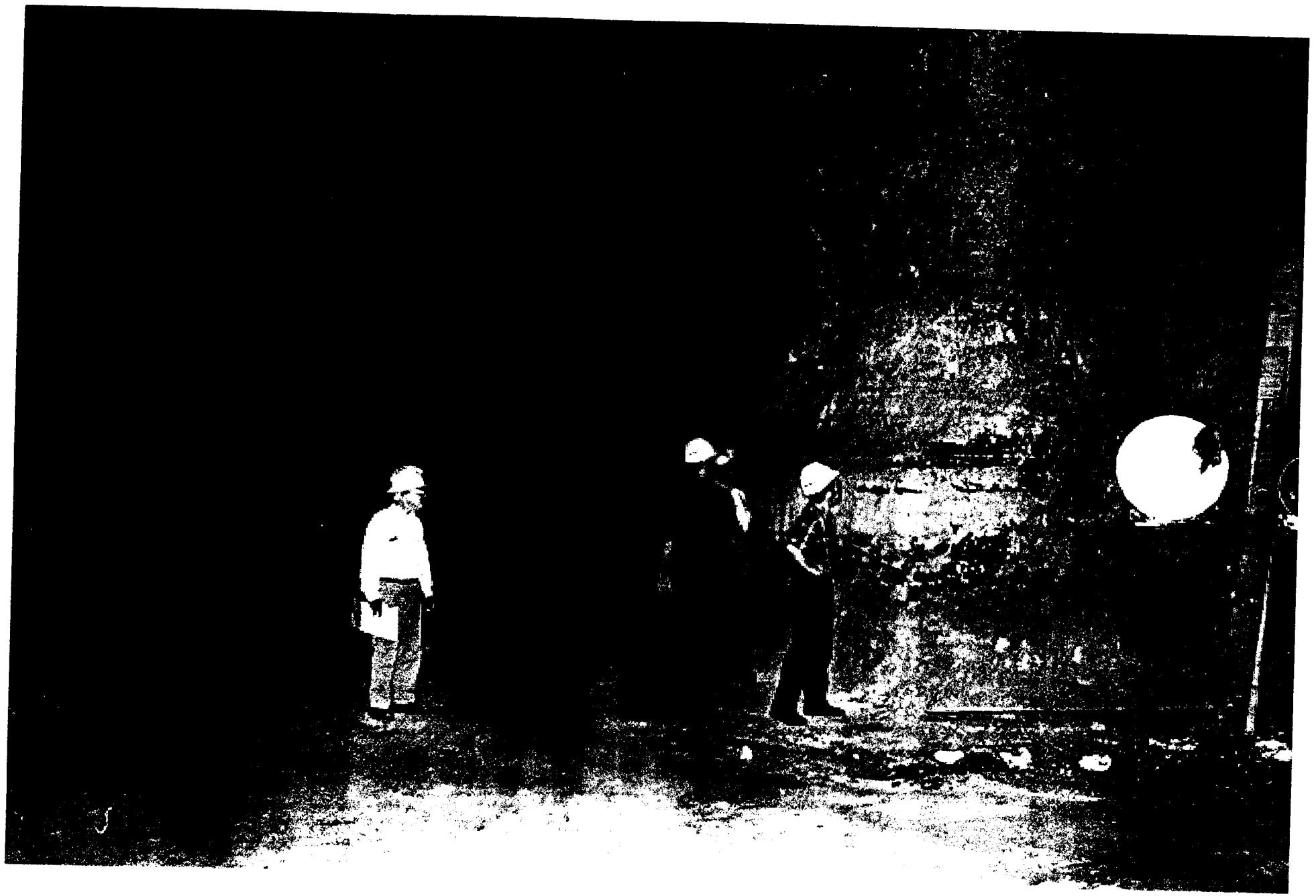
Fogale Nanotech hydrostatic Level sys. test



16 Nov 99 015 ^{AM} Under (closed) pump in condition



Conco-Western mine, Galena-Plattville dolomite
Aurora, IL since 1992



Aurora Mine, 1 day record starting Fri, Oct. 15 19:23

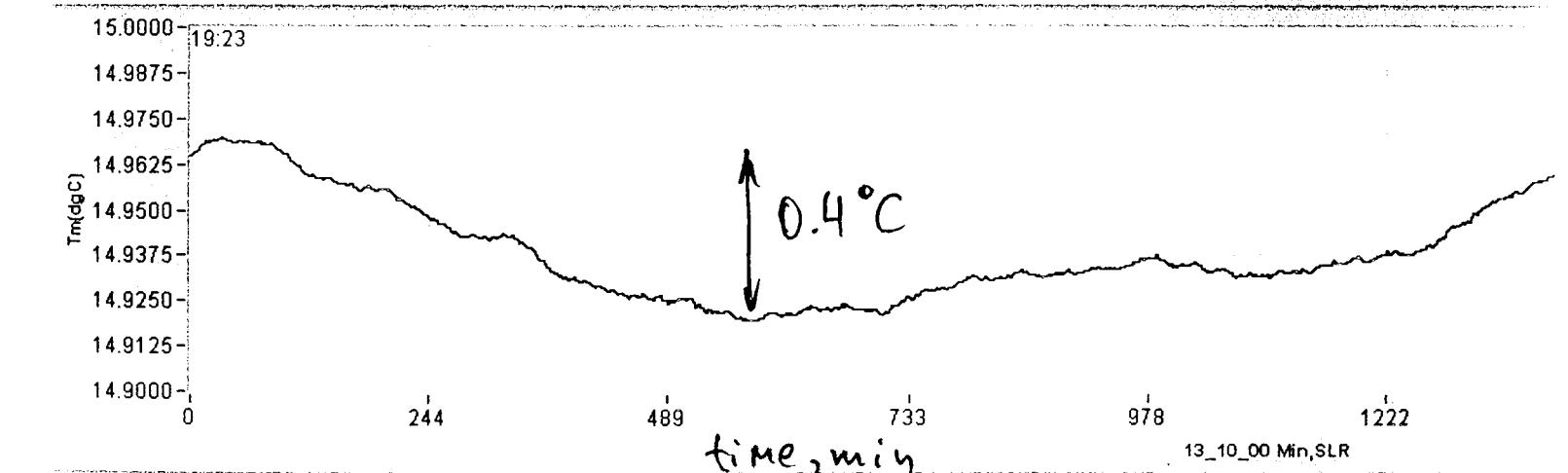
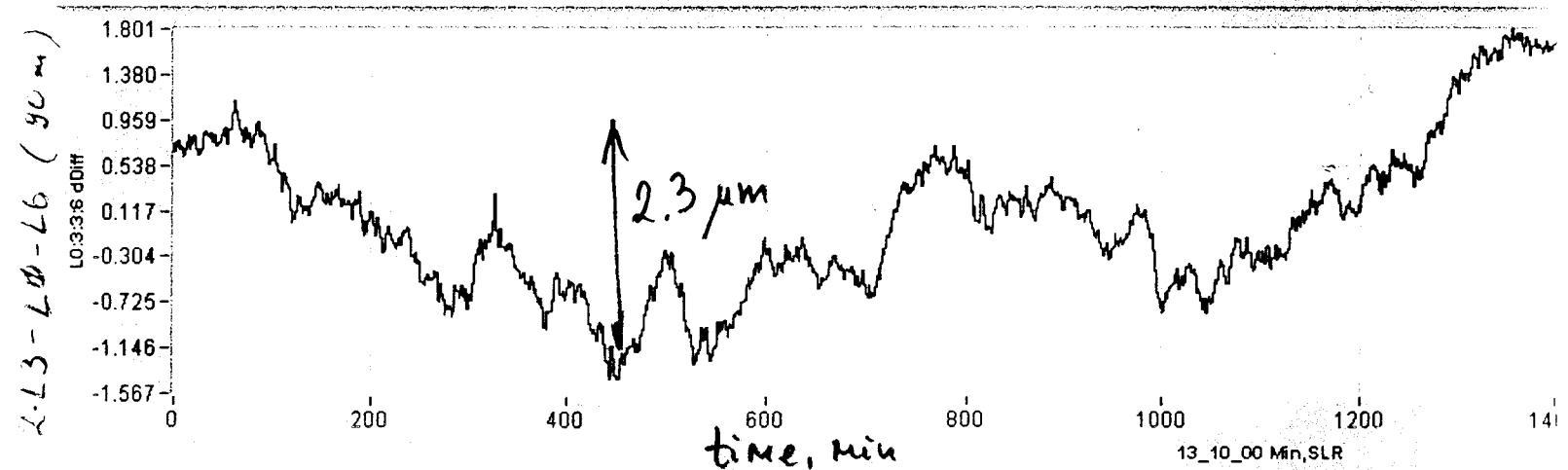
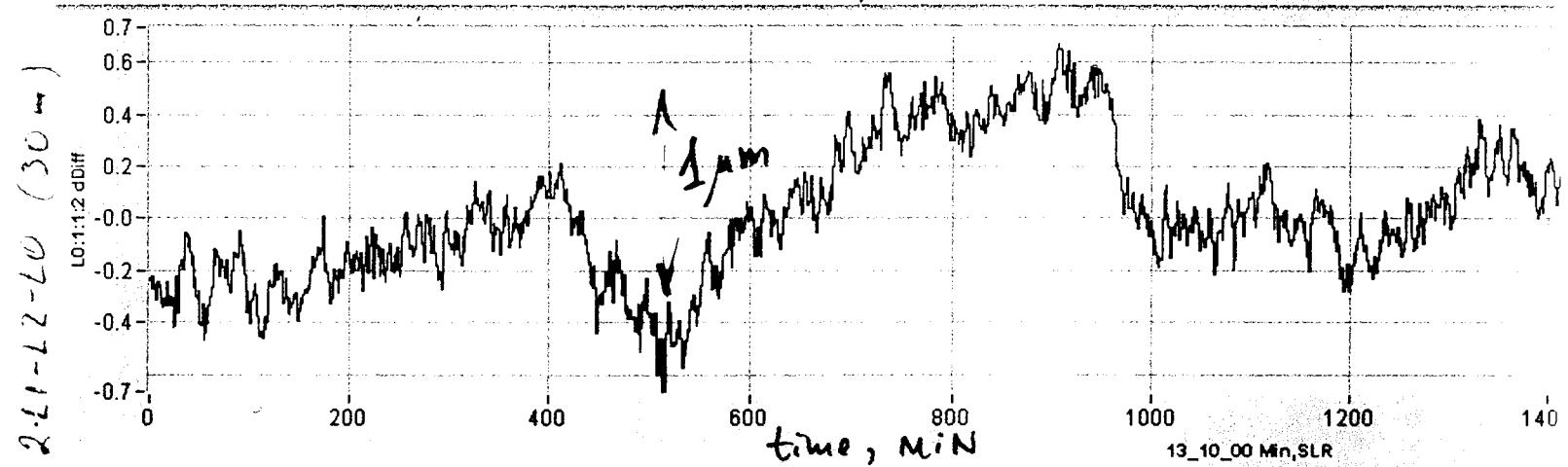
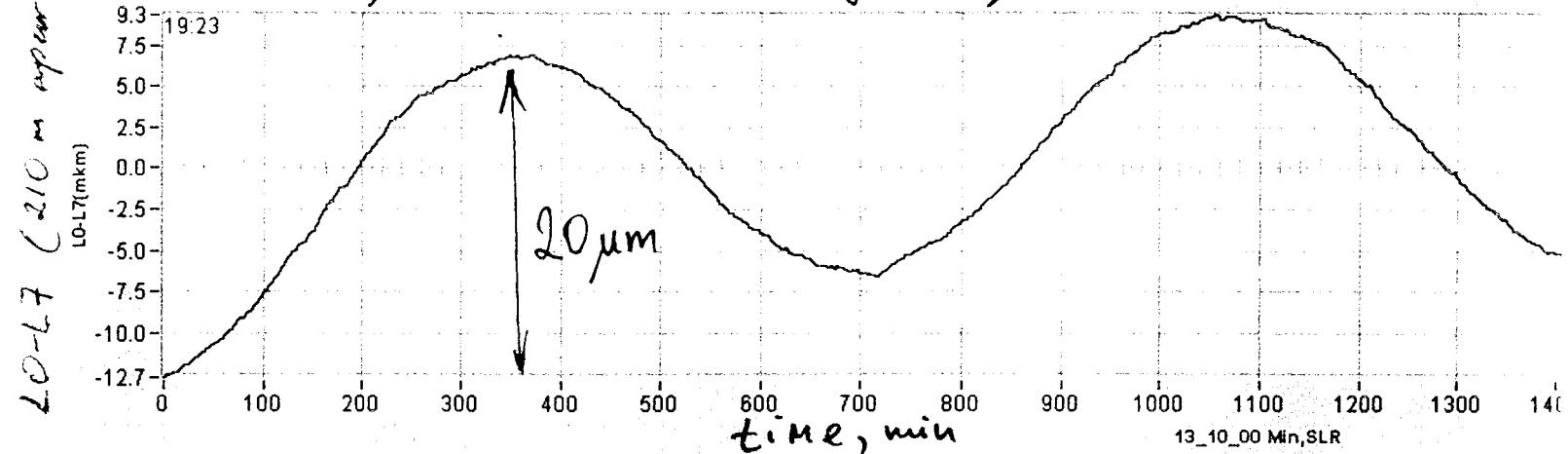
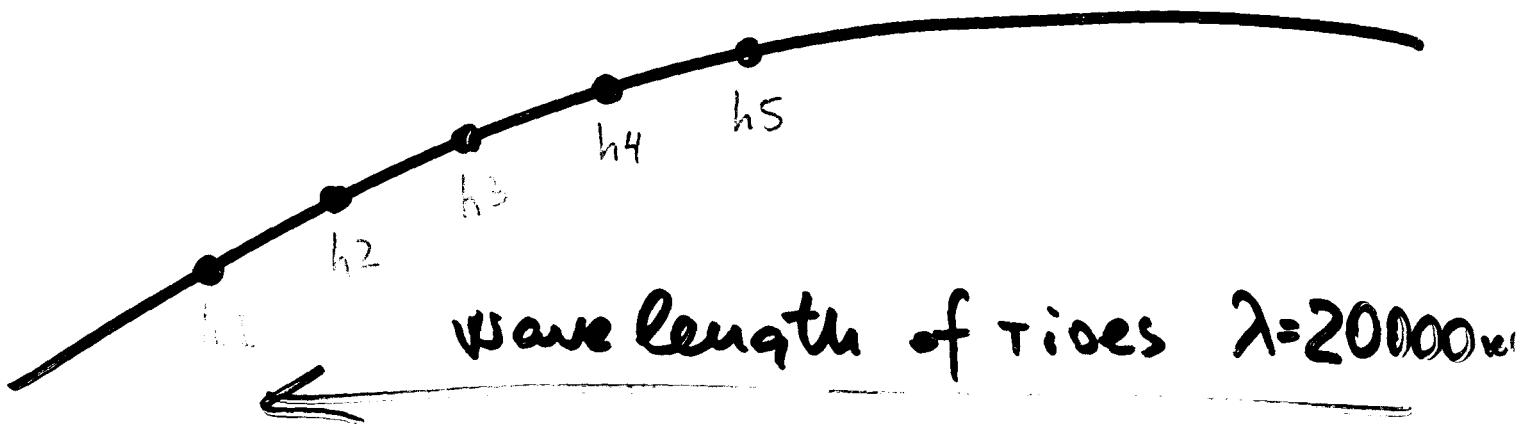


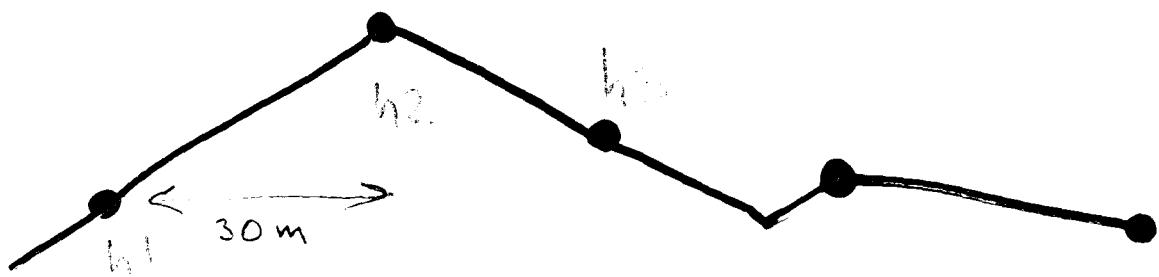
Illustration to middle plot:



$\lambda \gg$ accelerator site
distance between lenses

THAT MOTION IS NOT DANGEROUS!

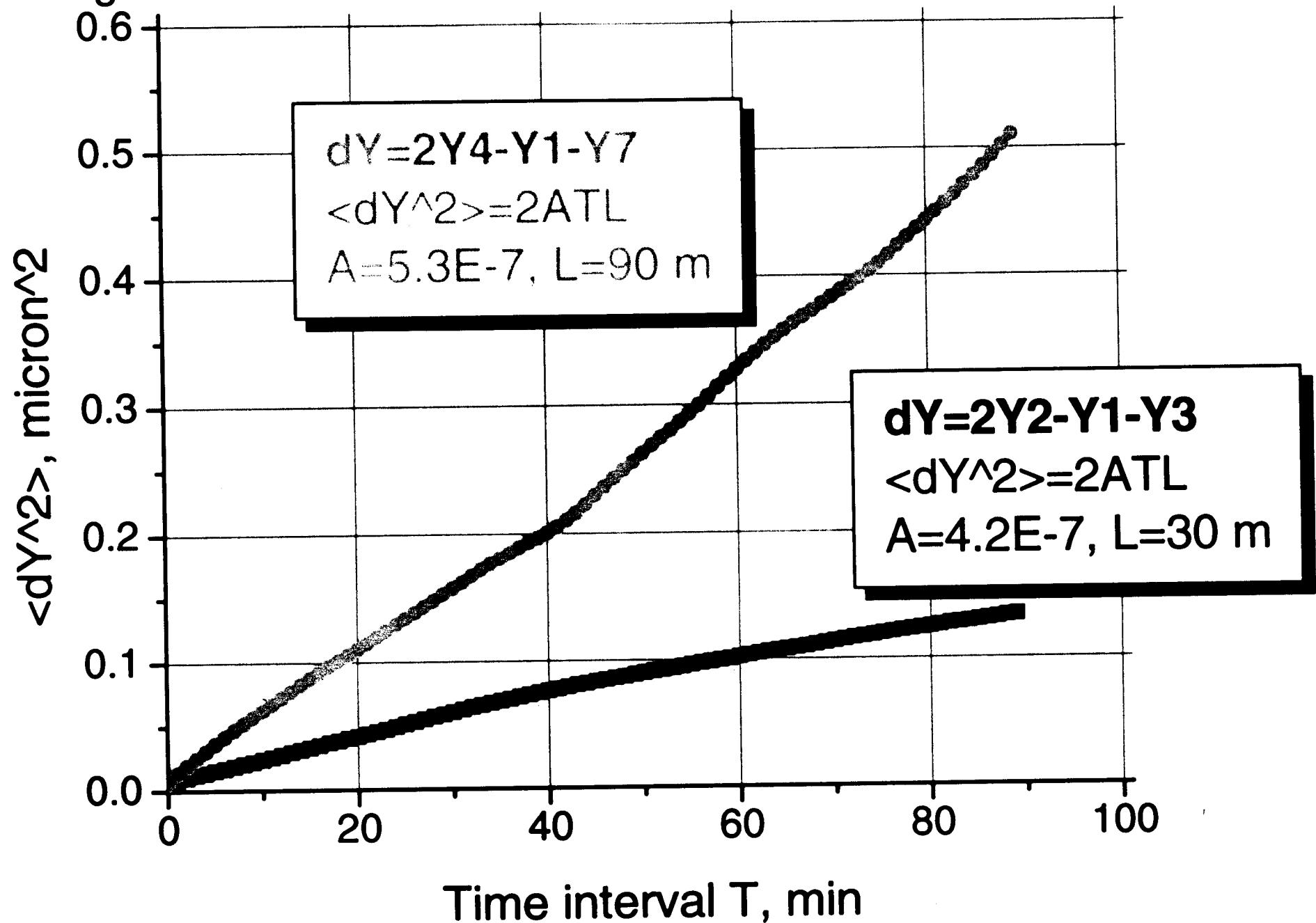
We're interested in fractures:



$$\Delta H = 2 \cdot h_2 - h_1 - h_3$$

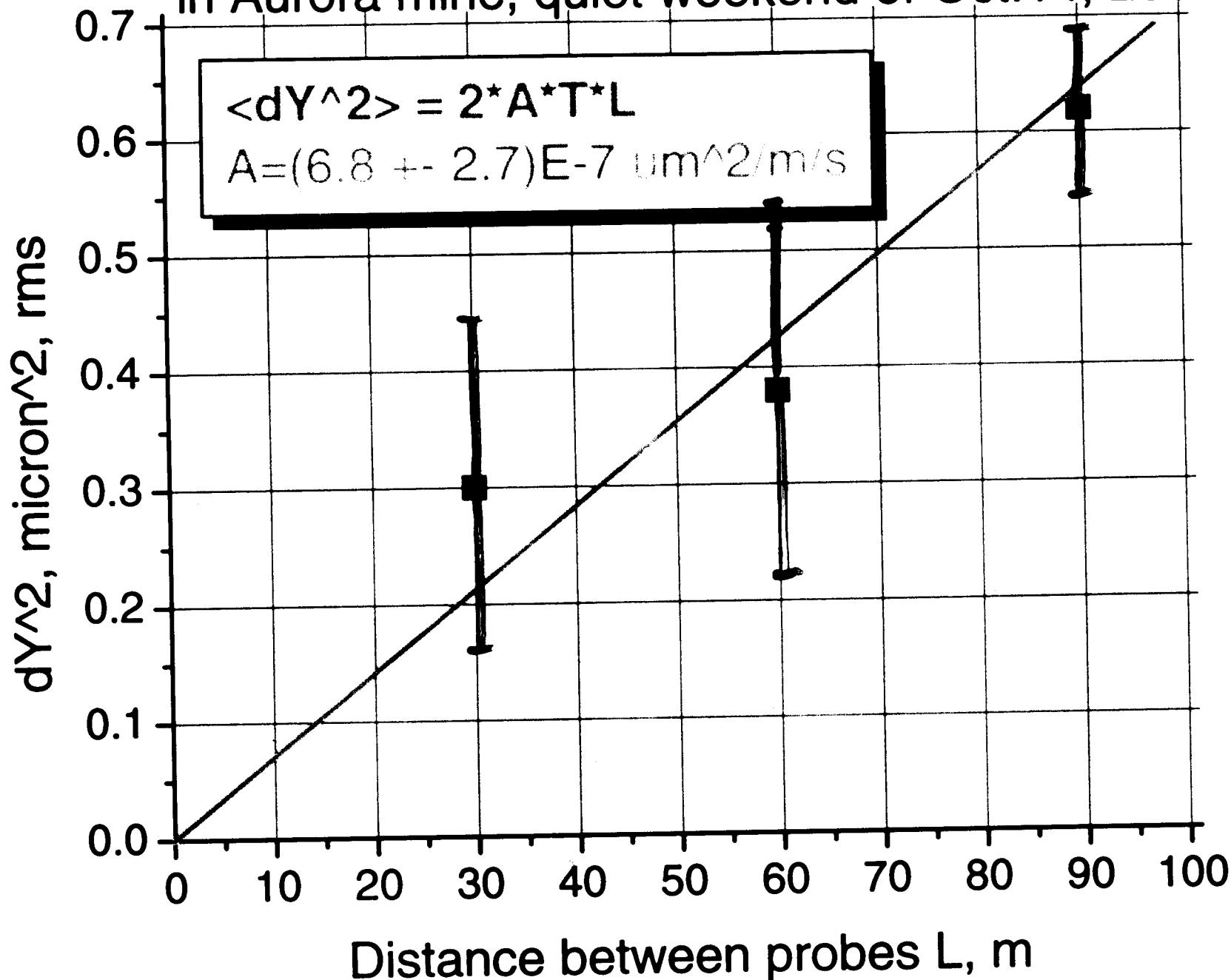
"Quiet" Weekend in Aurora mine (10/13-10/15)

ground diffusion $\langle dY^2 \rangle$ vs Time for distances of 30 and 90 m

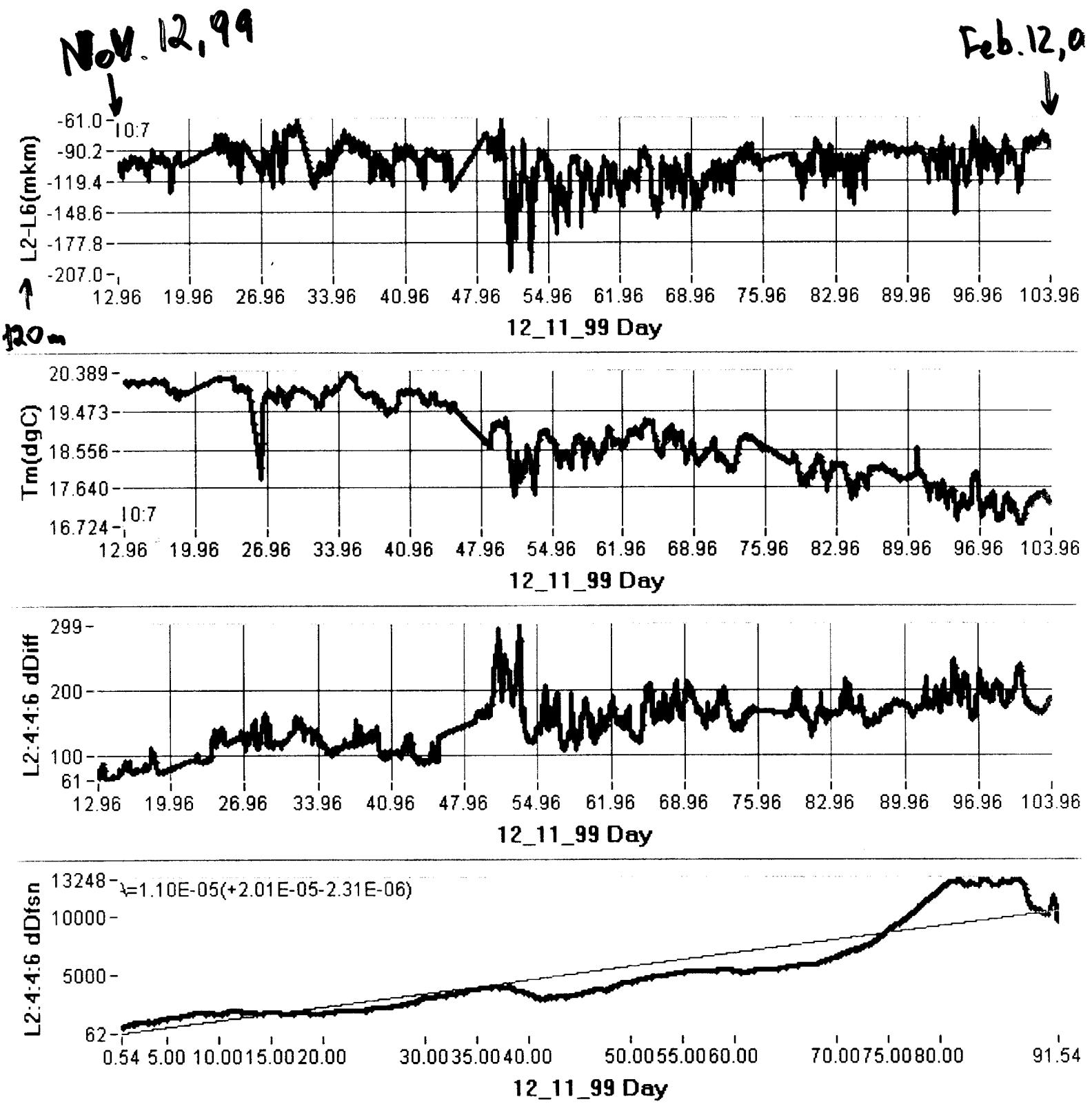


Ground diffusion dY^2 at T=90 min vs L

in Aurora mine, quiet weekend of Oct.14, 2000



PW6-7 tunnel



Summary:

1. slow relative ground motion (min-years) consists of
tides ($\approx 20 \mu\text{m}$ at 200 m $T=1/2$ day),
rare remote earthquakes $10 \mu\text{m}$ at 200 m (30s)
thermal effects ($\approx 5-10 \mu\text{m}/^\circ\text{C}/100\text{m}$ in PW)
air pressure effects ($60 \mu\text{m}/\text{week}/3\text{km}$ at SLAC)
systematic motion ($P_0 C E - 3 \mu\text{m}/\text{day} - \text{site!}$)

and diffusive ground motion

which follows the "ATL-law"

2. At 1995 IWAA 14 observations of the ATL were reported. New evidences since that time:

FFTB wire	$A = (0.2-0.5)E-6 \mu\text{m}^2/\text{m/s}$	in Time
SLC laser system	$A = 1.4E-6$	in Time
Six sites in Japan	$A = (0.06-40)E-6$	in Time
LEP closed orbit	$A = 1.2 E-5$	in Time
LEP 7-yr alignment	$A = 3E-6$	in Time
FNAL PW tunnel	$A = 1E-5$	in Time
SLAC tunnel 17yr	$A = 1E-5$	in T&L
Aurora mine, IL	$A = 0.5E-6$	in T&(may be) L

3. Criticism of the ATL-like phenomena in LEP alignment dat a (so far) seems to be erroneous
4. We plan to carry out wider-scale slow ground motion measurements for NLC with some 20 HLS probes
 - in FNAL MI tunnel
 - in deep Aurora mine
 - in SLAC FFTB tunnel

which should allow to study both spatial and temporal characteristics of the ground movements simultaneously

5

Long Live ATL !