Working Group on Environmental Control

Slow Ground Motion studies at SLAC

Snowmass 2001, July 6
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'Slow' Ground motion at NLC and TESLA

- **Diffusive or ATL motion:** $\Delta X^2 \sim A_D T L$ (minutes-month)
  (T – elapsed time, L – separation between two points)
- **TESLA : Low wakes -> smaller σ_E -> smaller $\Delta\varepsilon$ ($\sim \sigma^2_E$)**

Place	A $\mu m^2/(m{\cdot}s)$
HERA R.Brinkmann, et al.	$\sim 10^{-5}$
FNAL surface V.Shiltsev, et al. TPAH111	$(1\text{-}10)*10^{-6}$
SLAC*	$\sim 5*10^{-7}$
Aurora mine* V.Shiltsev, et al. TPAH111	$(2\text{-}20)*10^{-7}$
Sazare mine S.Takeda, et al.	$\sim 5*10^{-8}$

HERA ← TESLA: Undisruptive realignment ~every month — OK for TESLA

SLAC ← NLC: Undisruptive realignment ~every 5hrs — OK for NLC

Sazare mine ← NLC: Undisruptive realignment ~every 2 days

* Further measurements in Aurora mine, SLAC & FNAL are planned : TPAH116

How to mitigate slow motion?

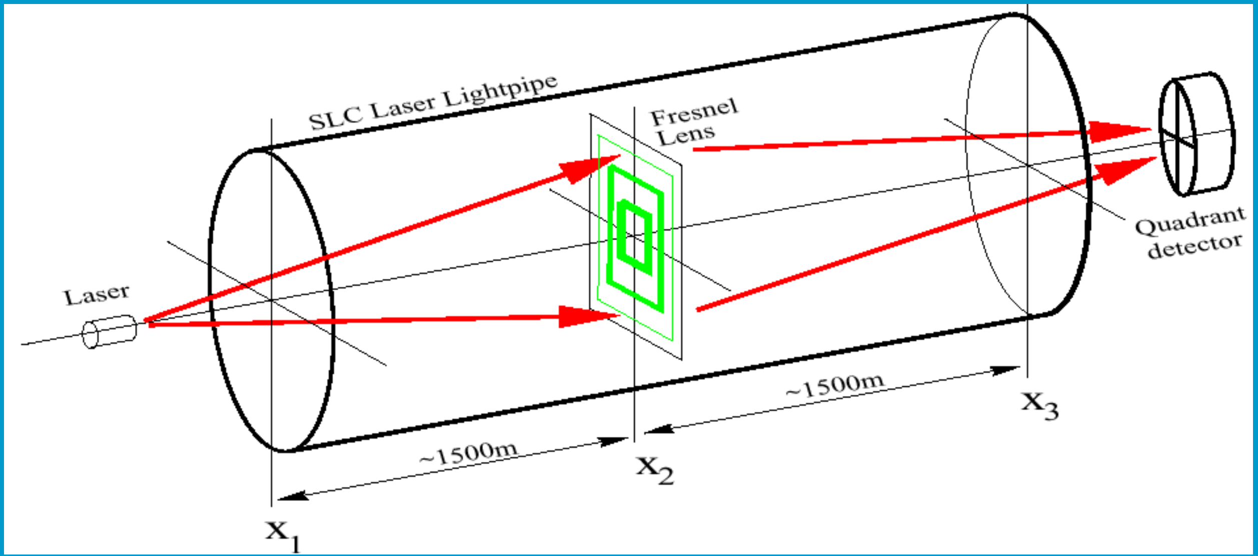
- Can we put more concrete into foundation and forget about slow motion?   This is very unlikely:
  - we care about L~betatron λ~50m, => would need to make strength of foundation equivalent to ~50x50m^2 of soil
    - But poor foundation most probably can increase slow motion!

- Slow motion strongly depends on site and geology
  - Studies at KEK, SLAC, etc., helped to understand mechanisms and behavior of slow motion

- Careful selection of site (depth) – is a way to avoid the problem

SLAC tunnel drift studies

- **Goal: to perform systematic studies of slow tunnel motion**
- **The linac alignment system working in the single Fresnel lens mode allowed submicron resolution**
- **First measurements of this kind were done in November 1995 by C.Adolphsen, G.Bowden and G.Mazaheri for a period of about 48hrs**



Scheme of measurements

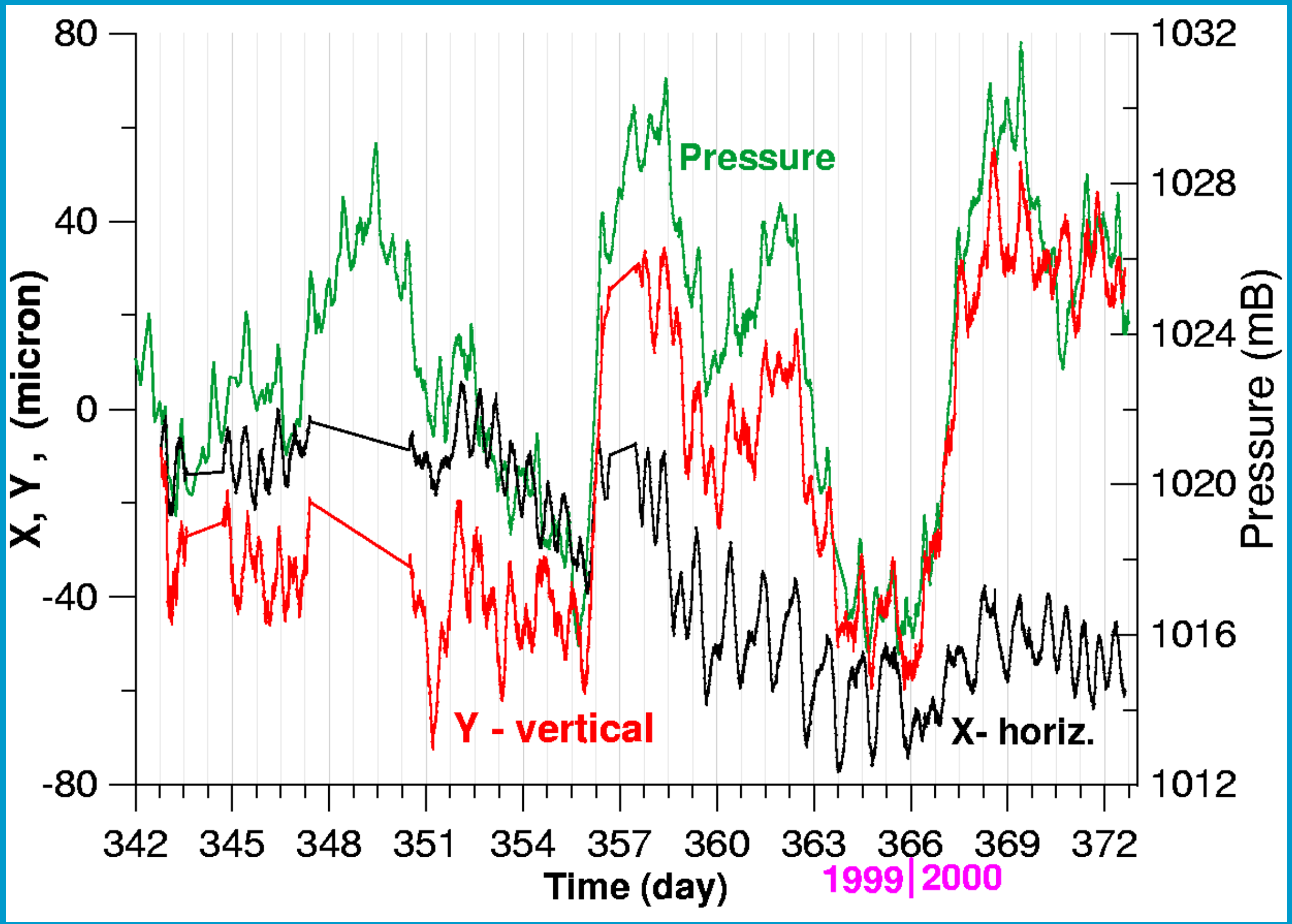
Signals from the quadrant photo detector were combined to determine X and Y relative motion of the tunnel center with respect to its ends.

Slow transverse relative drift of SLC tunnel

SLC tunnel deformation is correlated with atmospheric pressure

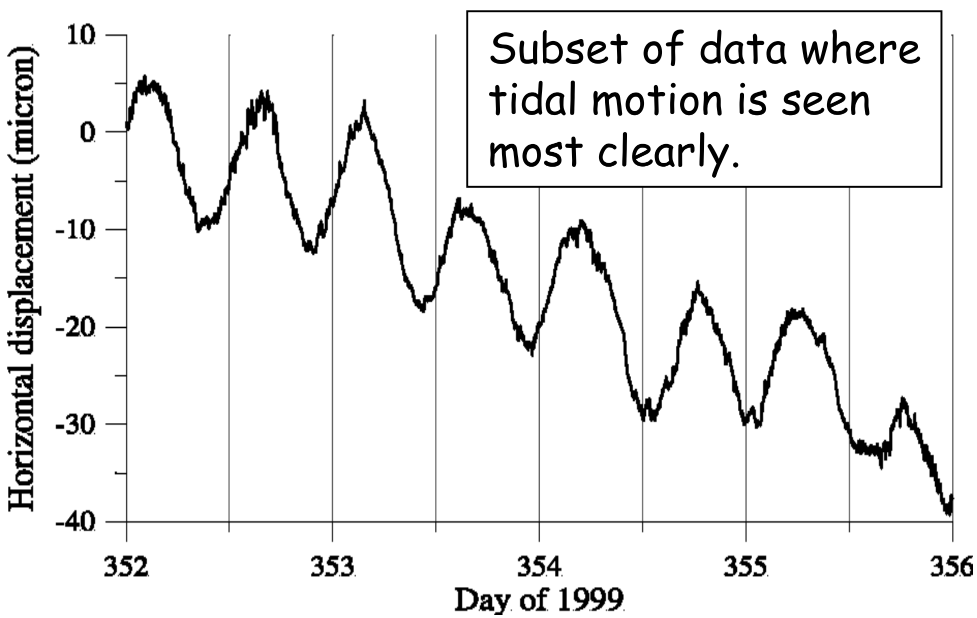
Reason:
landscape and ground property vary along the linac

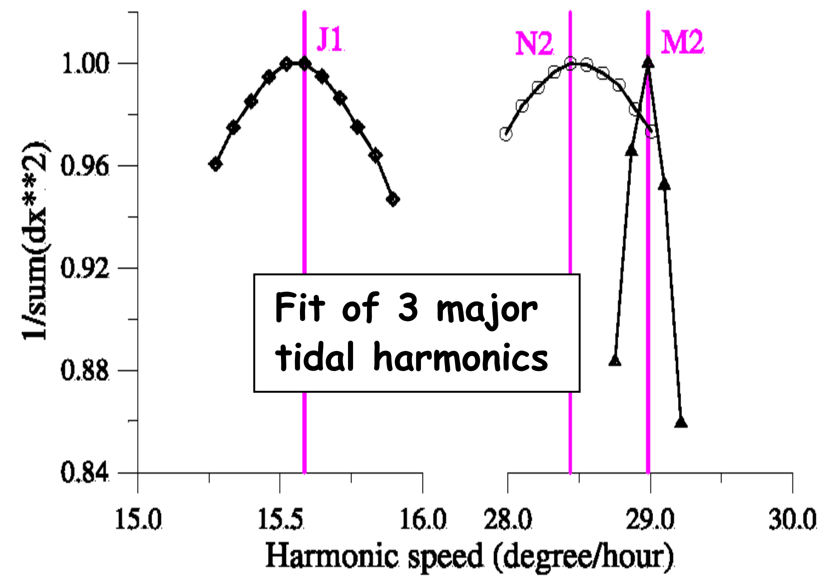
Motion shows diffusive or ATL character



Transverse displacement of the 3 km SLAC linac tunnel (center w. respect to ends) and atmospheric pressure.

Tidal motion of the SLAC linac tunnel





- **Observed tidal motion is ~100 times larger than expected.**

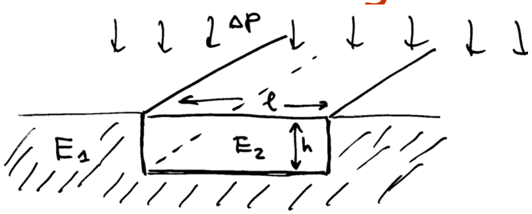
(N.B. the system is not sensitive to change of slope due to tides, but only to change of the curvature)

- **Higher amplitudes are caused by enhancement of tides due to ocean loading in vicinity (~500km) of the shoreline.**

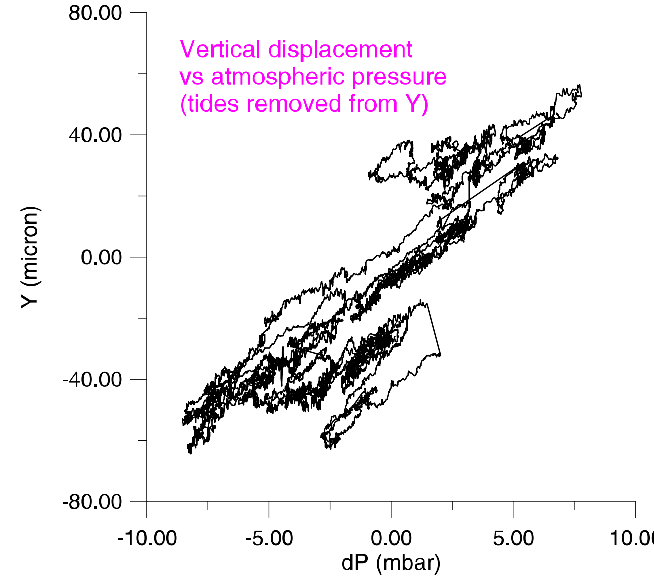
- **Tidal motion is slow, predictable, it has long wavelength and is not a serious problem for a collider.**

Influence of atmospheric pressure

Very slow variation of external atmospheric pressure result in tunnel deformation.
Explanations: landscape and ground property variations along the linac:



$$\Delta h \approx \frac{\Delta P\, h}{E} \frac{\Delta E}{E}$$

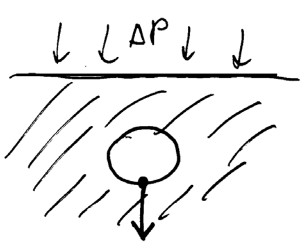


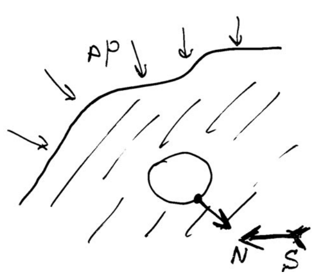
Observed Δh=50μm for ΔP=1000 Pa is consistent with these estimations if ΔE/E~0.5, h~ λ ~ 100m, α~0.5 and E~10^9 Pa.

Assumption E~10^9 Pa is consistent with SLAC correlation measurements.

$$v \approx \sqrt{\frac{E}{2\rho(1+\nu)}}$$

Taking v=500m/s (at ~5Hz, I.e. λ~100m) and ρ=2*10^3 kg/m^3, we get E= 10^9 Pa





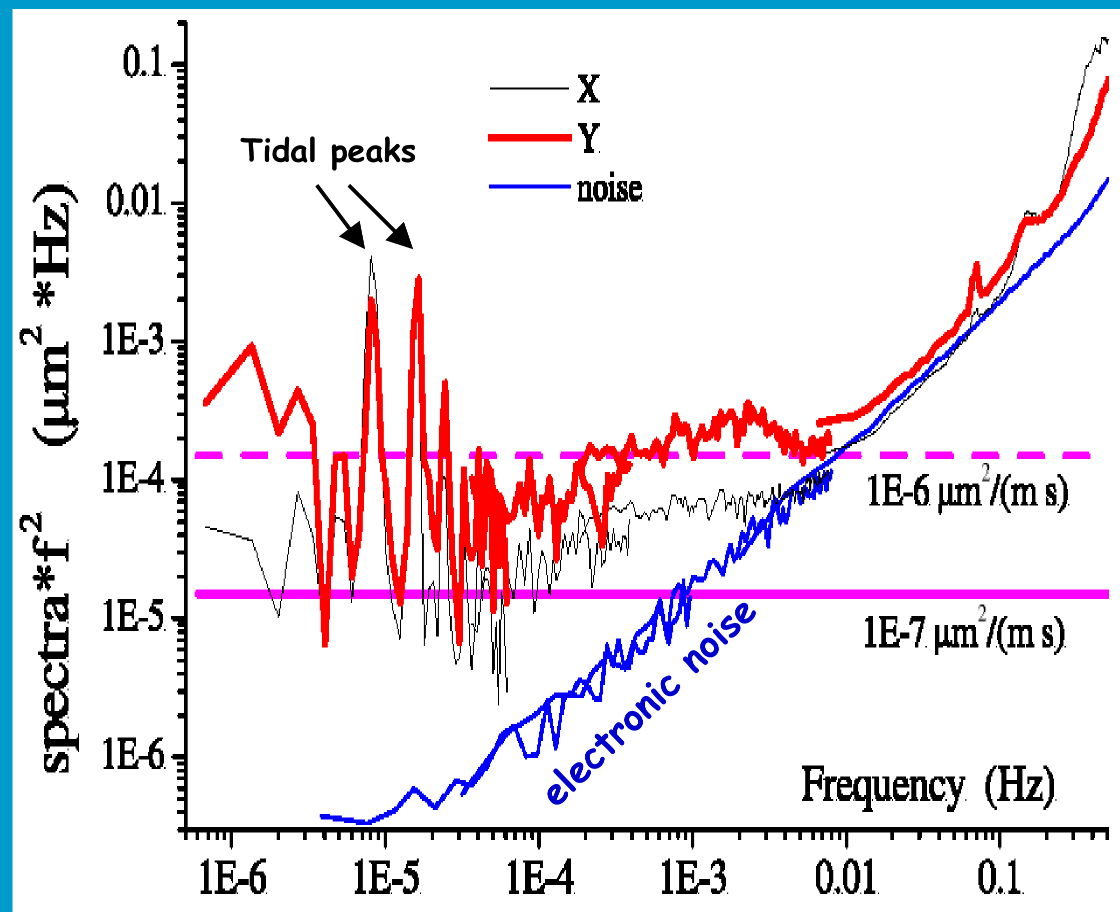
$$\Delta h \approx \frac{\Delta P}{E} \lambda \alpha$$

λ - length of landscape change,
α - variation of the normal angle to the surface

Tunnel motion. Diffusive in time

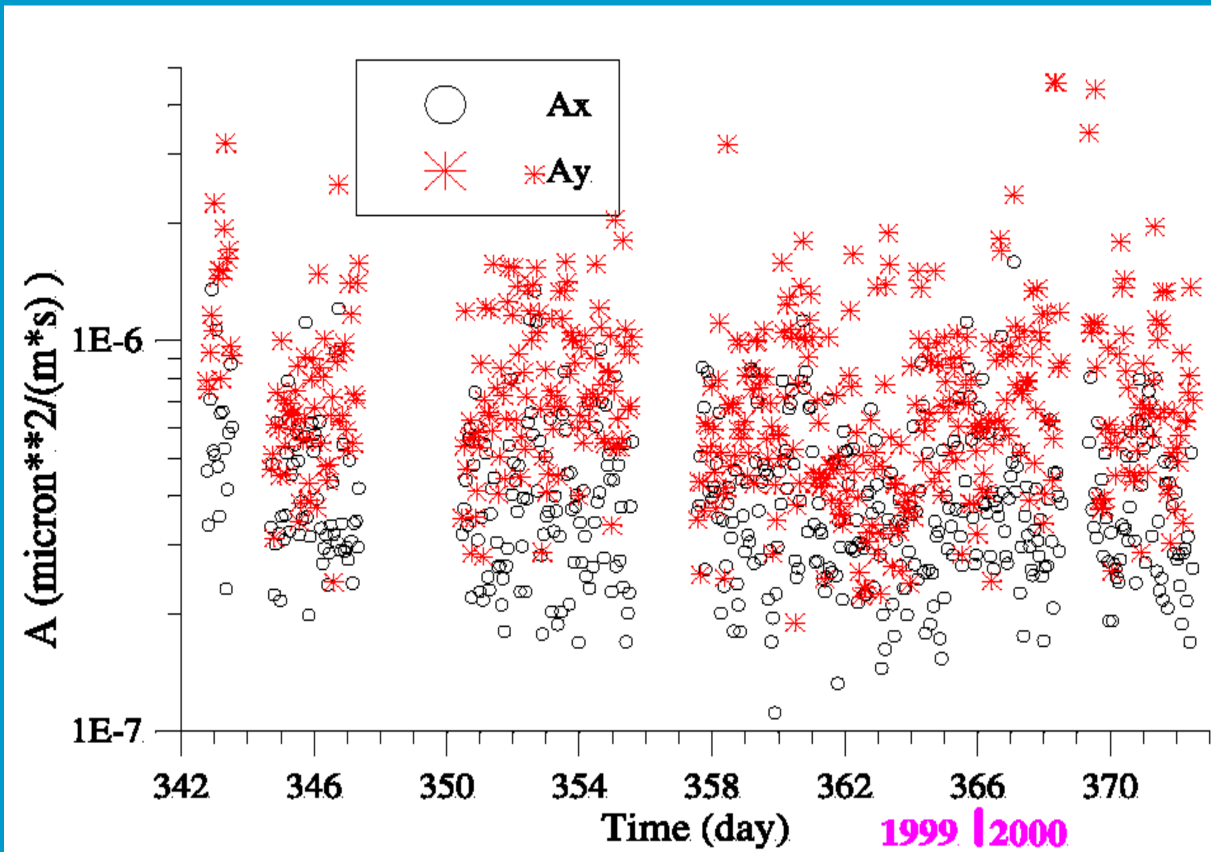
NLC

- **Spectra** of tunnel displacements behave as **$1/\omega^2$** in wide frequency range, as for the ***ATL*** law for which ***$P(\omega,k)=A/(\omega^2 k^2)$***



Electronic noise of the measuring system was evaluated with a light diode fixed directly to quadrant photo detector

Diffusive in time...



Parameter A found in 1999/2000 SLAC measurements.

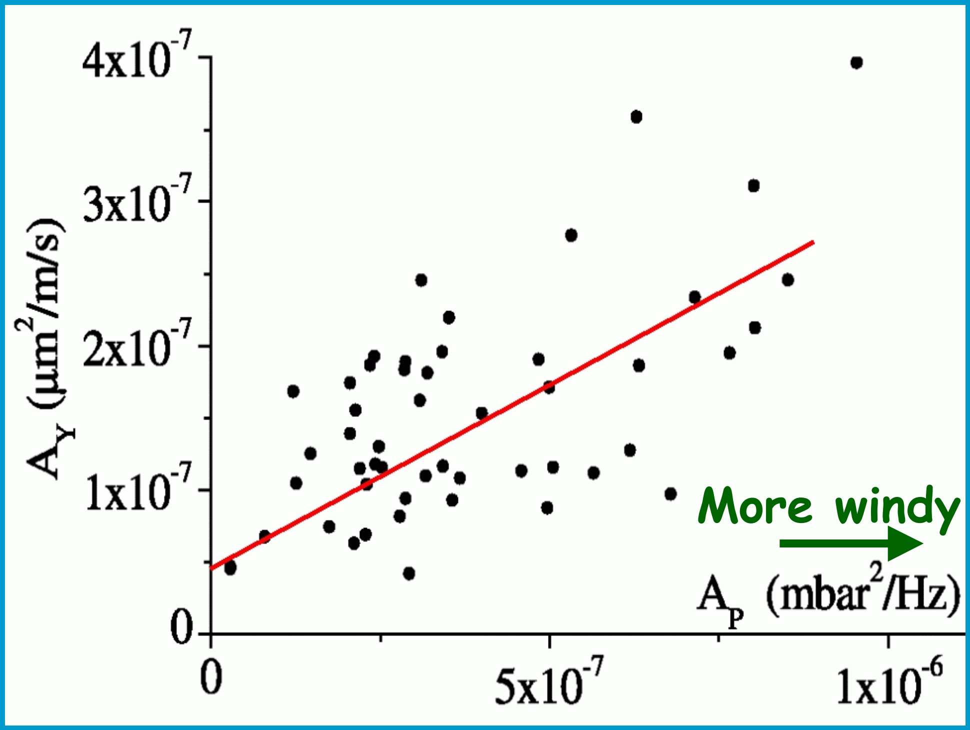
- fit of the spectra to ATL gives A~ 10^{-7} -- $2 \cdot 10^{-6}$ $\mu m^2/m/s$
- "A" is higher for vertical plane.
- The value "A" varies in time. Why?
- The "A" value is consistent with FFTB measurements with stretched wire over 30 m distance

Atmosphere causes "A" of ATL to vary in shallow tunnel

- **Parameter A_D of ATL correlates** with amplitude of **atmospheric pressure variation**

- For **shallow tunnel** the **atmospheric contribution** to A_D **scales as** $1/E^2$
(or as $1/v^4$, v – shear velocity)
=> need **strong ground !**

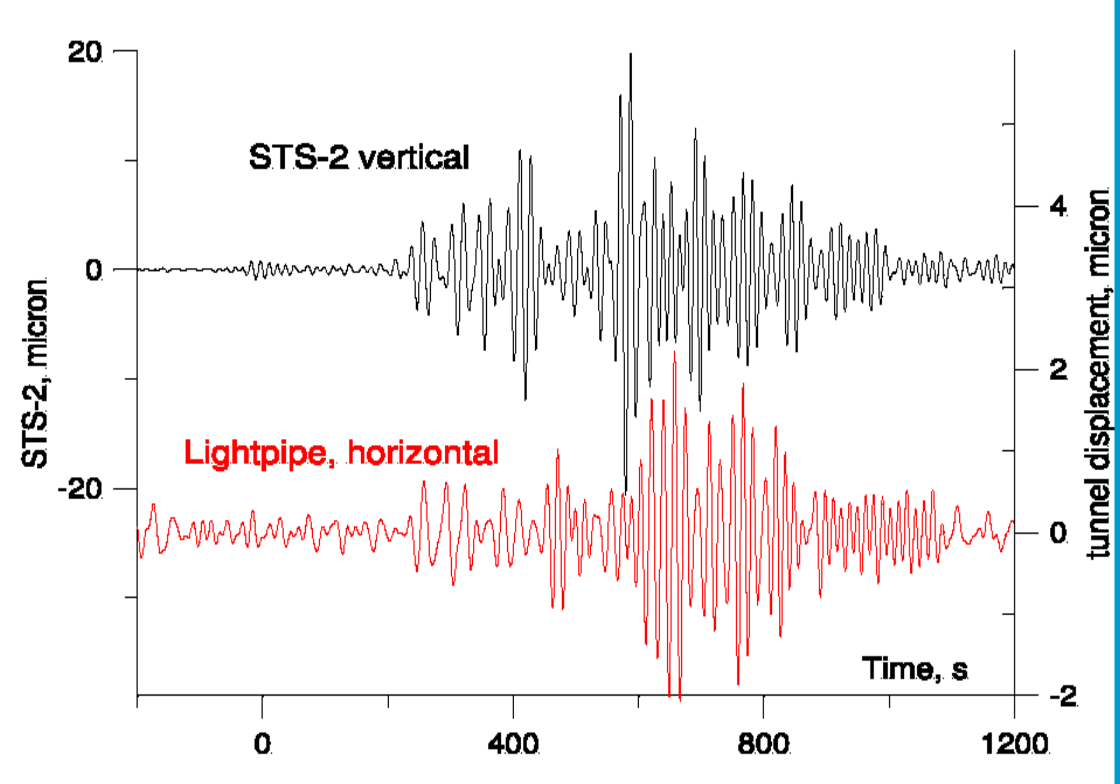
- For **deep tunnel** the **atmospheric contribution** to A_D **vanish**



"A" vs amplitude of atmospheric pressure spectrum A_p (which behaves as A_p/ω^2)

Observation of earthquakes

- Only two earthquakes detected in 3 days
- Ratio of observed absolute to relative motion is consistent with phase velocity 2.5km/s
- I.e. small earthquakes produce smooth deformation



Displacement of the tunnel and displacement measured by STS-2 seismometer during remote earthquake started January 6, 2000 at 02:49:00 local time (supposedly corresponds to 5.8MS earthquake at Alaska happened at 10:42:27 UTC). A passband filter 0.02-0.08Hz has been applied to the data.

'Slow' Diffusive Ground motion vs location

- **Diffusive or ATL motion:** $\Delta X^2 \sim A_D TL$ (minutes-month)
  (T – elapsed time, L – separation between two points)

Place	A µm²/(m.s)	method	~T,L	geology
HERA R.Brinkmann,et al.	~ 10^{-5}	HERA beam	Hrs-month;30m	Glacial till
FNAL surface V.Shiltsev,et al.	~ $(1\text{-}10)*10^{-6}$	double tube HLS	Min-days;10-100m	Glacial till; cut and cover
SLAC* R.Assmann,et al. A.Seryi, et al.	~ $5*10^{-7}$	stretched wire; laser alignment system	Min-hrs;30m Min-days;1500m	Sandstone; cut and cover
Aurora mine* V.Shiltsev,et al.	$(2\text{-}20)*10^{-7}$	double tube HLS	Min-month;10-100m	Dolomite; blasting
Esashi mine S.Takeda,et al.	$2*10^{-9}$	single tube HLS	Min-days;10-100m	Granite, TBM

* Further measurements in Aurora mine, SLAC & FNAL are planned with better HLS system

NLC

Diffusive Ground motion in Japan

[S.Takeda, KEK-99-135]
range ~10-100m, min-days

Place	A $\mu m^2/(m \cdot s)$	geology	tunneling
Tunnel of KEKB	$4*10^{-5}$	Sediment	
Kamaishi II-III	$1.4*10^{-7}$	granite	Slow blasting
Kamaishi I-II	$5.7*10^{-8}$	granite	Slow blasting
Sazare mine	$5*10^{-8}$	Green schist	
Esashi No.1	$5.7*10^{-9}$	granite	drilling
Esashi No.2	$2*10^{-9}$	granite	drilling

"Stability time" between beam-based realignments of a colliders ~1/A

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Very slow (year-to-year) motion

- **Year-to-year** motion observed in tunnels seem to be **systematic** (~linear in time). SLAC, LEP, etc., as found by Rainer Pitthan
- Settlement (SLAC); underground water (LEP)
- Extrapolation of ATL parameter “A” from **year-to-year** measurements to **minute-hour** time scale is **invalid** and result in **overestimation of “A”**.

Systematic motion of SLAC linac shallow tunnel in 1966-1983

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- Year-to-year motion is dominated by systematic component
- Settlement
- Homogeneity of soil is important, but hard to achieve

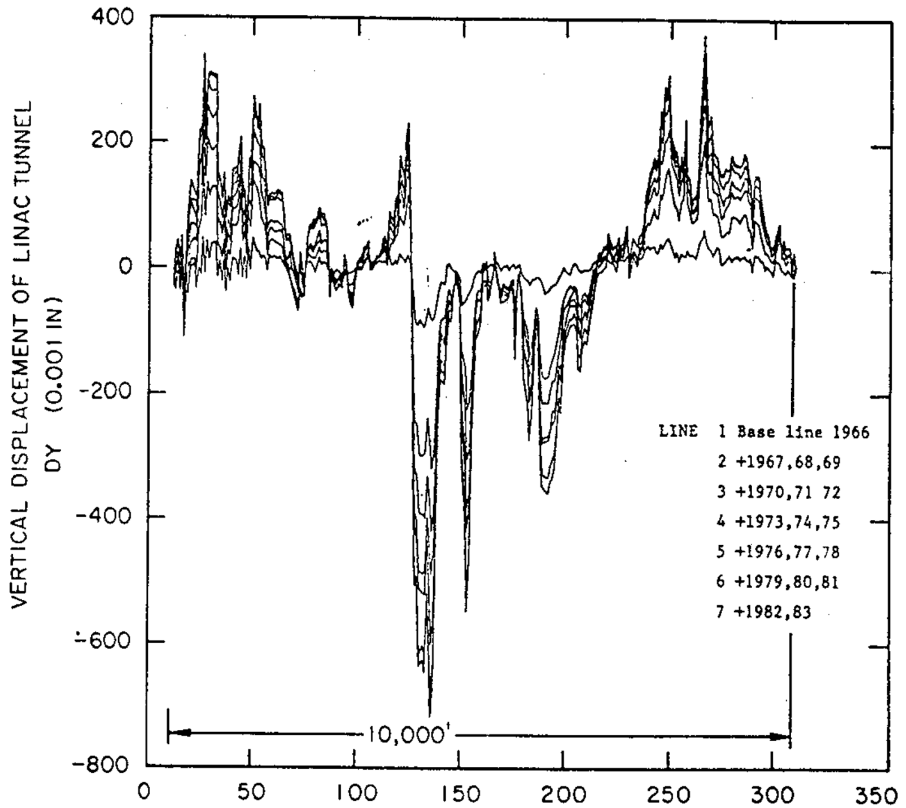


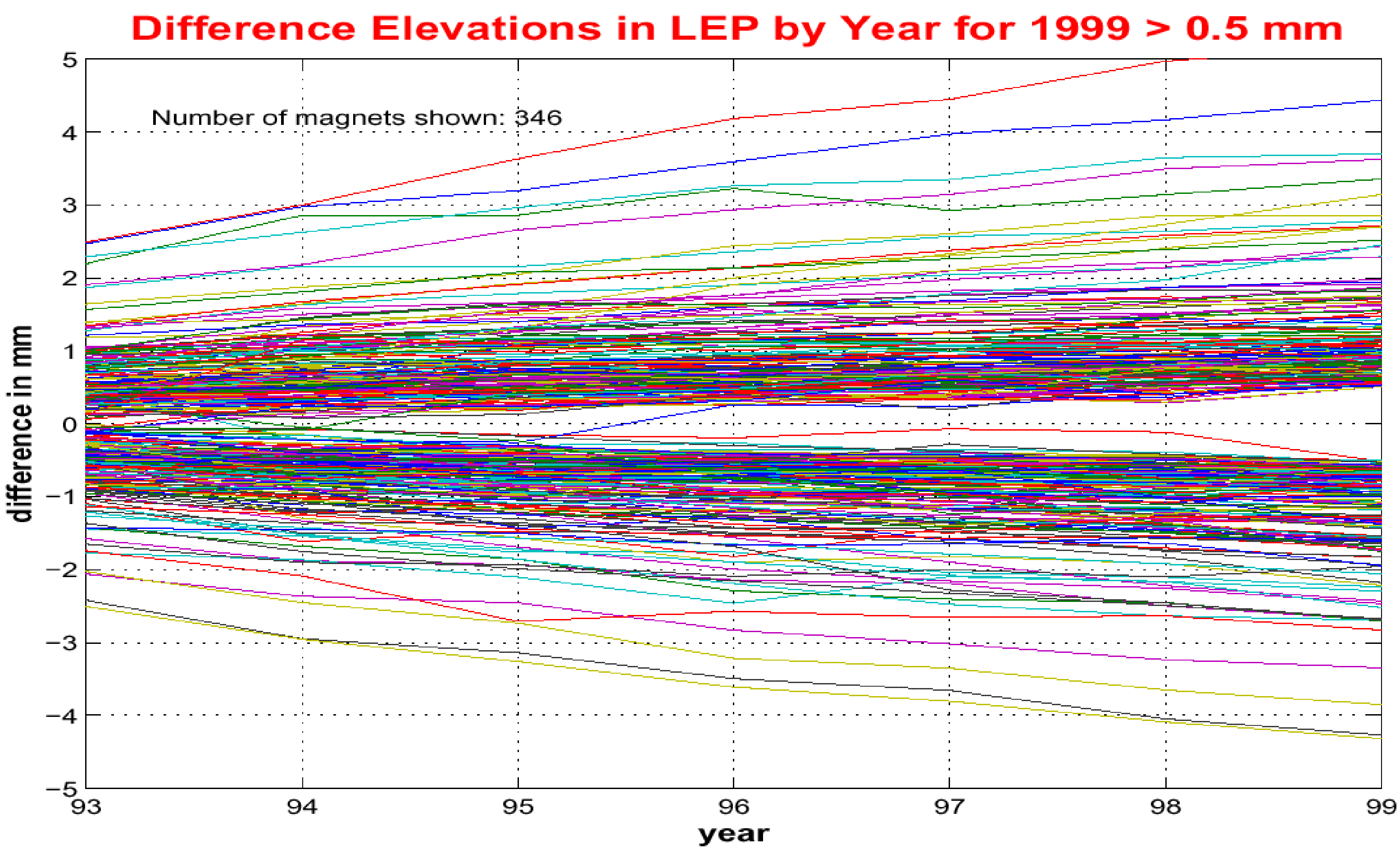
Figure 7: Displacement of the SLAC Linac Tunnel - Vertical.

Vertical displacement of SLAC linac for 17 years

[G.Fischer, M.Mayond 1988]

NLC

Example: Systematic motion at LEP
Difference of position of neighboring quads



Rainer Pitthan, SLAC-PUB-8286, (1999)

Slow motion (minutes - years) summary

- **Diffusive** or **ATL** motion: $\Delta X^2 \sim ATL$ (minutes-month)
- Observed 'A' varies by ~5 orders: 10^{-9} to 10^{-4} $\mu m^2/(m \cdot s)$
  - in some cases due to inappropriate interpretation of year-to-year motion as diffusive rather than systematic
  - parameter 'A' should strongly depend on geology -- reason for the large range
  - 'A' reported to depend on tunnel construction method: blasting/TBM [Shigeru Takeda]

- **Systematic** motion [R.Pitthan] : ~linear in time (month-years)
- **In some cases can be described as ATTL** law :
  - SLAC 17 years motion suggests $\Delta X^2 = A_S T^2 L$ with $A_S \sim 4 \cdot 10^{-12}$ $\mu m^2/(m \cdot s^2)$ for early SLAC

Slow motion questions and recommendations

- Reasons for slow motion
- Dependence on geology, tunneling
- Dependence of slow motion on T, L, regions of validity of models

- Geology: good hard rock is preferable
  - => slow motion has lower amplitude
    - => collider stability time is larger
- Tunneling:
  - => TBM preferable; avoid blasting