Ground Motion

Power Spectrum P(f) [m^2/Hz]

f < 0.1 Hz diffusive "ATL"

$f < 10^{-4}$ Hz systematic "AT^2L"

$P(f) = k / f^2$, $k = 1 \sim 100\ nm^2\ Hz$

f > 0.1 Hz elastic "waves"

$P(f) \propto 1 / f^4$

ocean swell 0.2Hz
cultural noises 1~100Hz
crustal resonances 3Hz
μ earthquake

Example of ATL

$\sigma^2 = \langle \Delta y \rangle^2 = A\ T\ L$

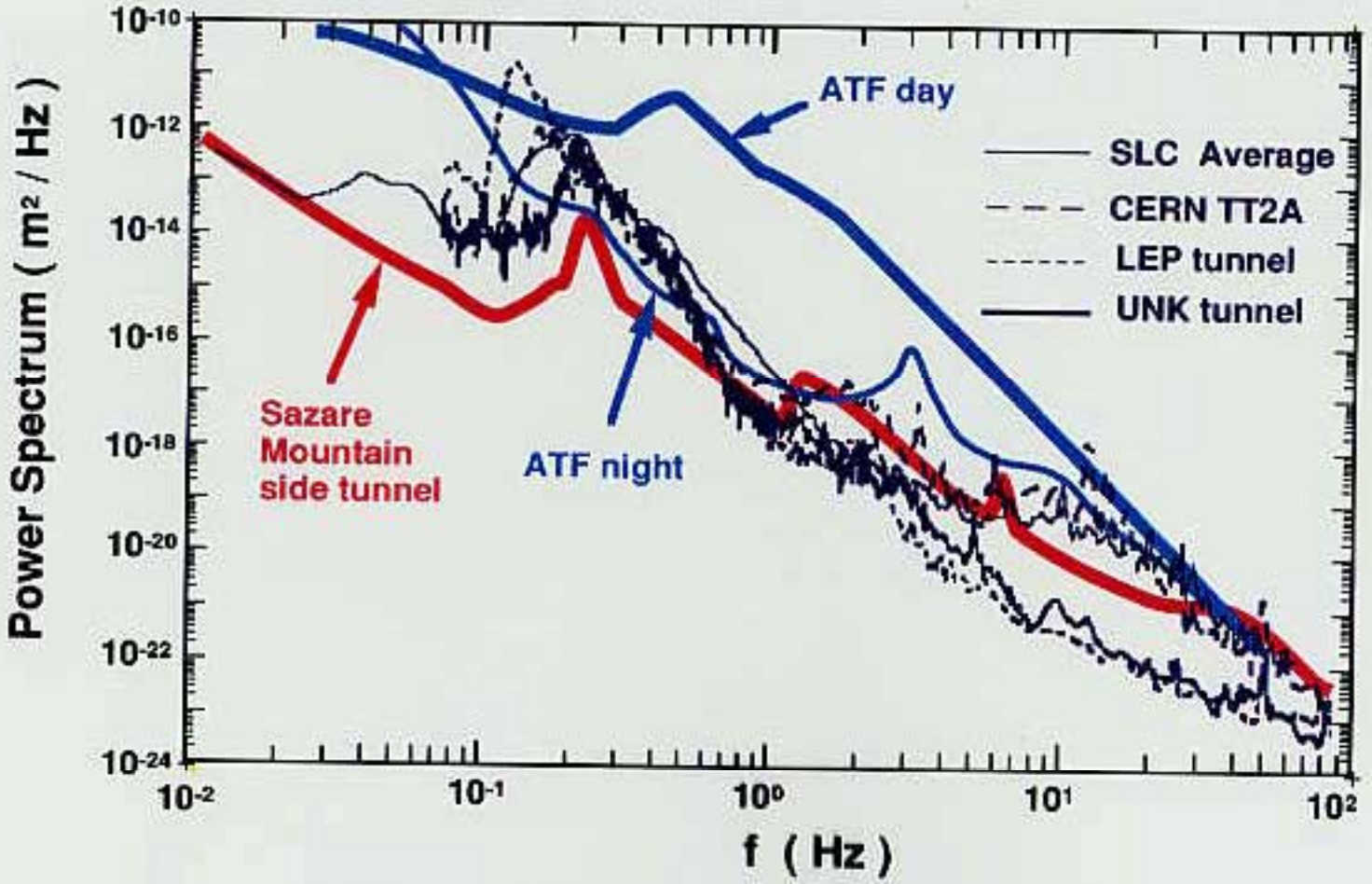
$T = \langle \Delta y \rangle^2 / A\ L$

for QC1,

L is a distance betwen 2 QC1's, L= 4~8.4m,

$\langle \Delta y \rangle^2 = 1\ nm^2$, and $A = 40\ nm^2/m/sec$ at KEK,

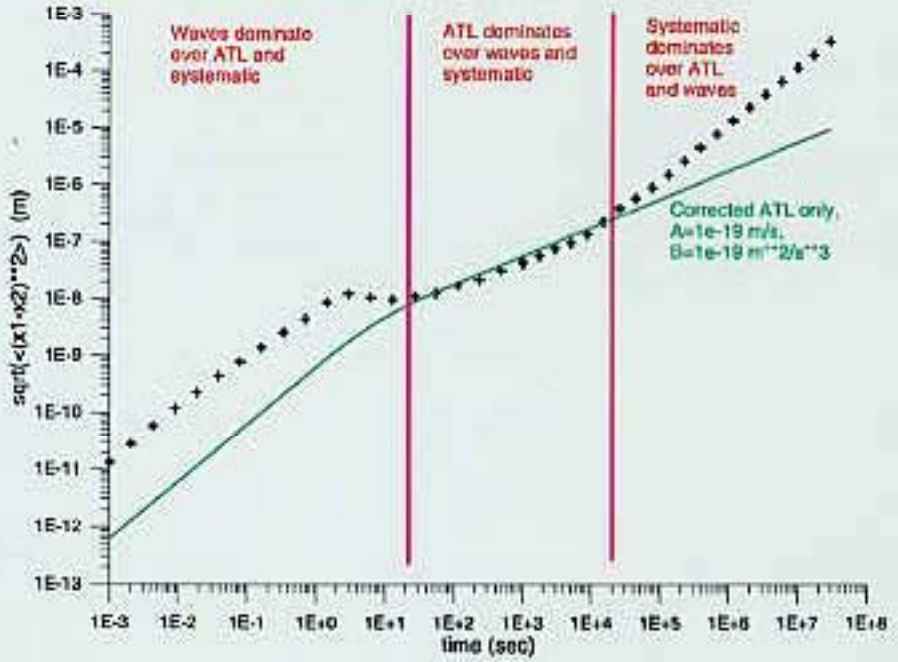
T= 6.25 ~ 2.98msec

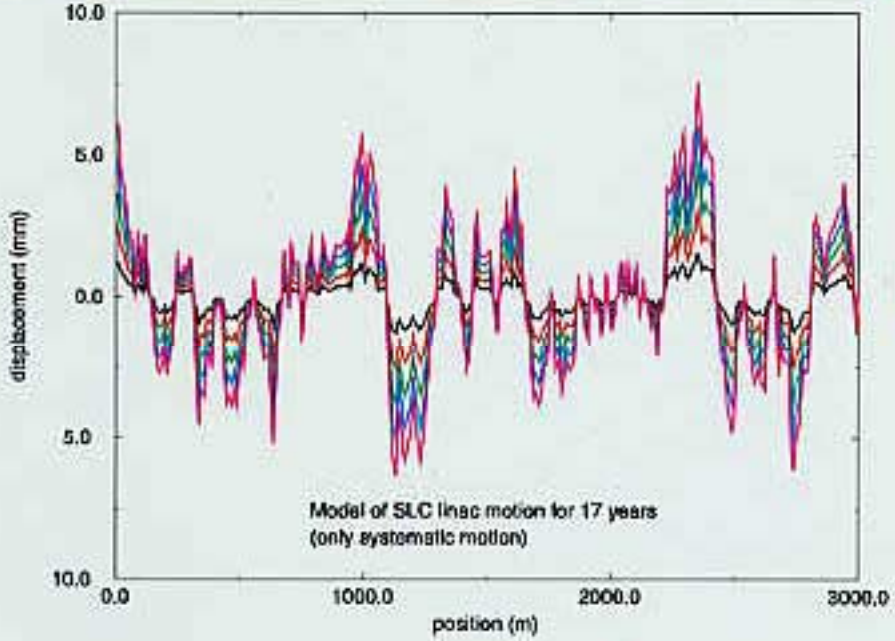

Power Spectrum (m² / Hz)
10-10
10-12
10-14
10-16
10-18
10-20
10-22
10-24
10-2
10-1
100
101
102
f (Hz)
ATF day
SLC Average
CERN TT2A
LEP tunnel
UNK tunnel
Sazare
Mountain
side tunnel
ATF night

Modeling systematic motion

Rms ΔY for ΔL=33m.

Typically systematic motion dominates for t > days-weeks time scale.



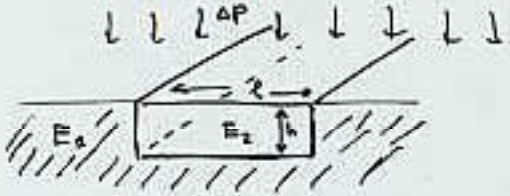


Model of 17 years of linac motion

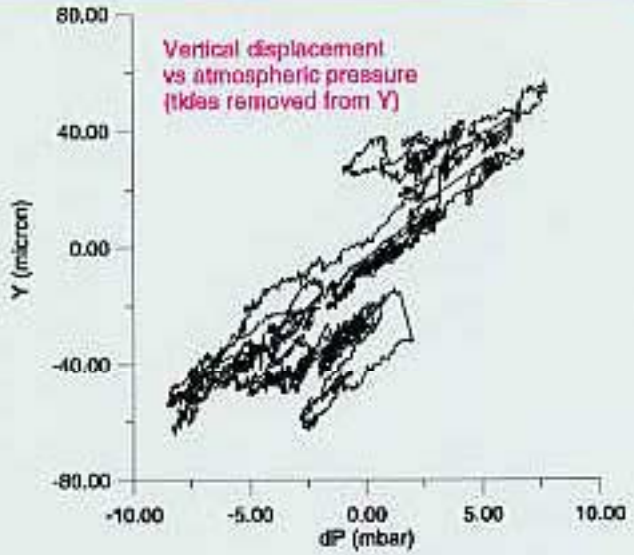
A.Seryi

Influence of atmospheric pressure

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



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

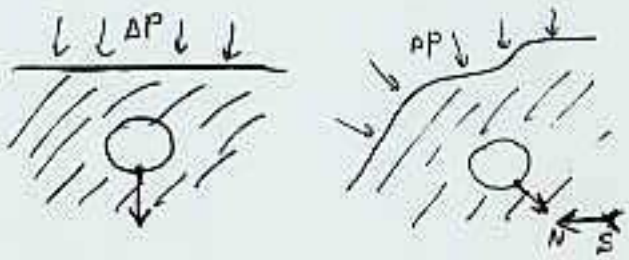


Observed Δh=50μm for ΔP=1000 Pa is consistent with these estimations if $\Delta E/E$~0.5, h~ ℓ~ 100m, α~0.5 and E~10^9 Pa.

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 $\rho=2*10^3$ kg/m^3, we get E= 10^9 Pa



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

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

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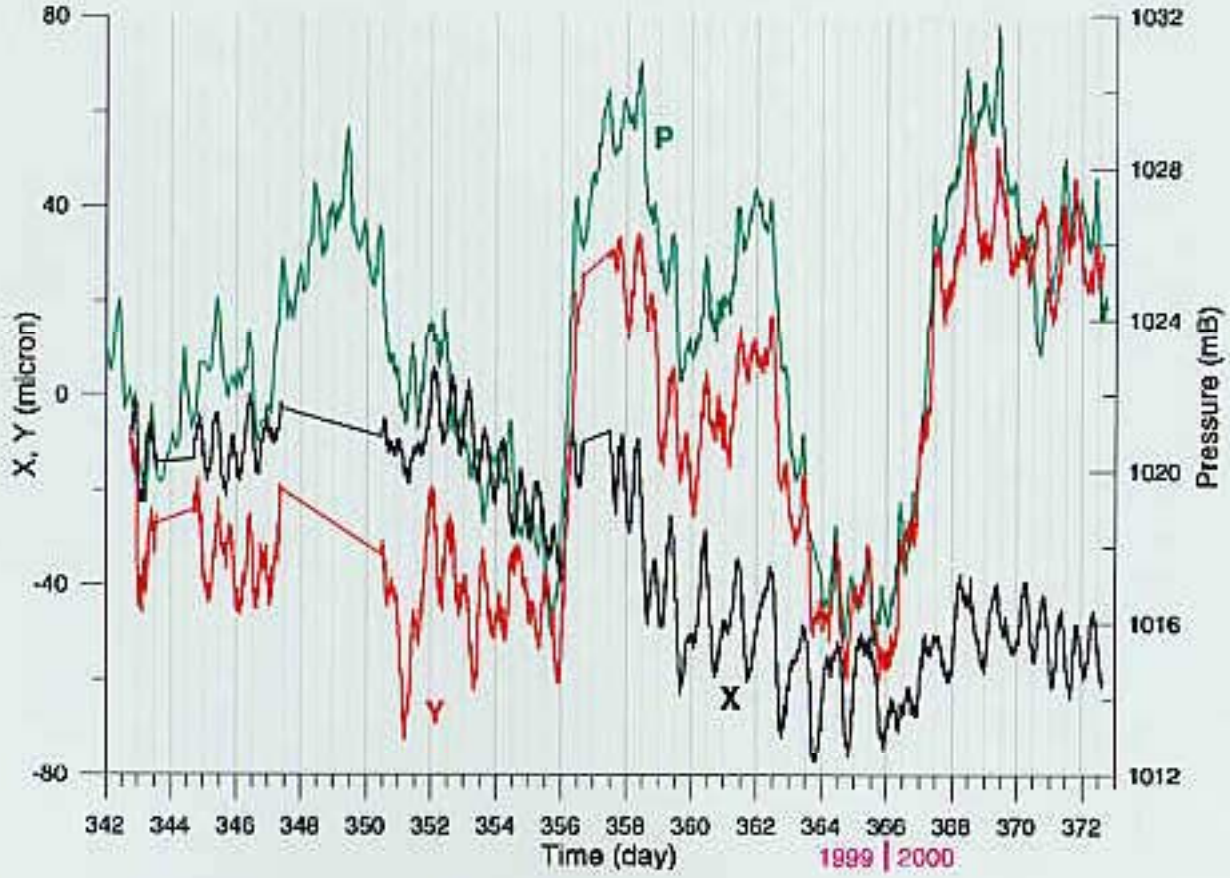
SLAC tunnel drift studies

Unexpected facts:

- **The tidal component of motion is surprisingly big ~10 micron.**
- **Motion has strong correlation with external atmospheric pressure.**



Horizontal and vertical displacement of the SLAC linac tunnel and external atmospheric pressure.

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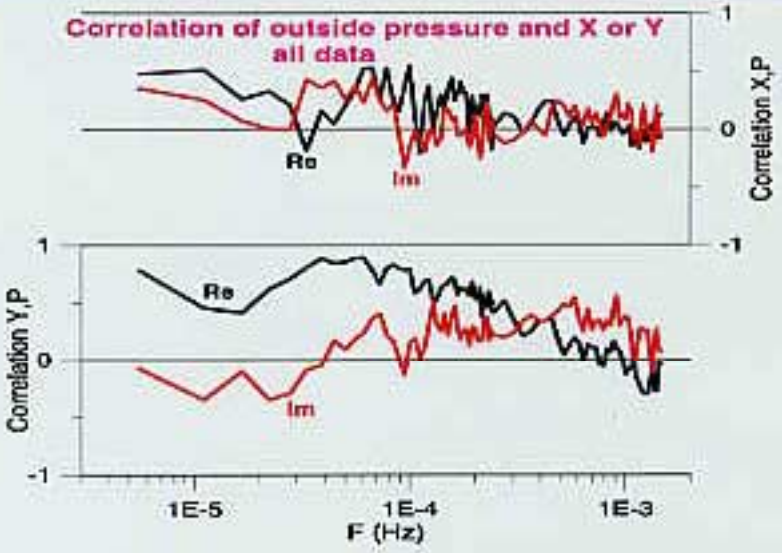
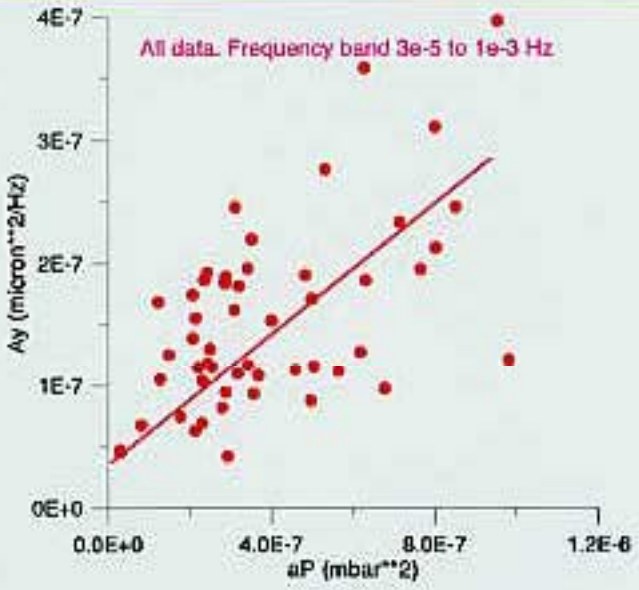
Atmospheric pressure again





"A" vs amplitude of atmospheric pressure spectrum aP.

- Correlation **X or Y and atmospheric pressure** is significant from 10^{-6} up to about 0.003 Hz.
- **Spectra of pressure** also behave as $\sim aP/\omega^2$
- The amplitude of **"A" correlates** with amplitude of **pressure spectrum aP**.
- The **ratio (X/P)** almost **does not depend on frequency** in 10^{-6} -0.003 Hz and is about 6μm/mbar in Y and 2μm/mbar in X.

=> **Spatial λ does not depend on f, but given spectra of landscape/ground properties.**

A.Seryi

"A" versus Young's modulus

Spatial variation of ground and/or landscape + variation of atmospheric pressure is a major cause of diffusive-like motion of the SLAC linac tunnel

The spectra of ground **properties/landscape** vary as $\mathbf{1/k^2}$, the spectra of **pressure** behave as $\mathbf{1/\omega^2}$ and together they give $\mathbf{1/(\omega\, k)^2}$ that is (or mimic) **diffusive motion**

($1/k^2$ justifies extrapolation of 2 mile base measurements to shorter scale)

(Spatial shape of landscape/properties is diffusive in space but stationary in time)
For other mechanisms of diffusive motion this may be different).

For the shallow tunnel, the "A" scales as $1/E^2$ or $1/v^4$!!!

Look for strong media, (higher Young's modulus E or shear velocity v)!

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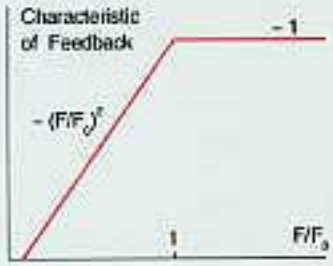
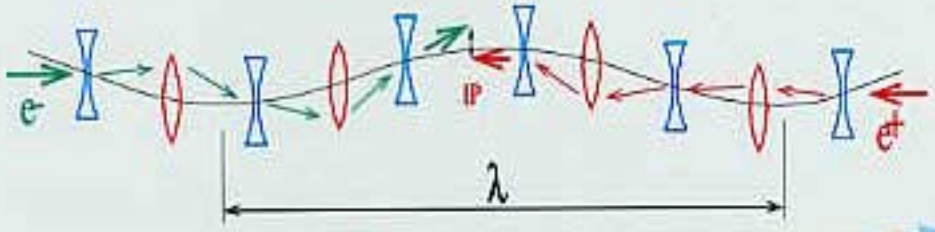
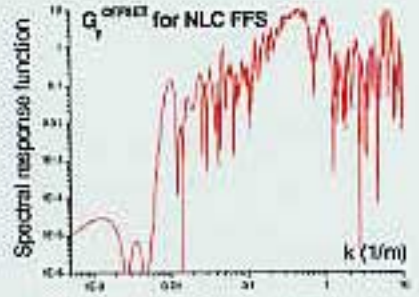
Ground motion induced beam offset at IP







rms beam offset at IP:

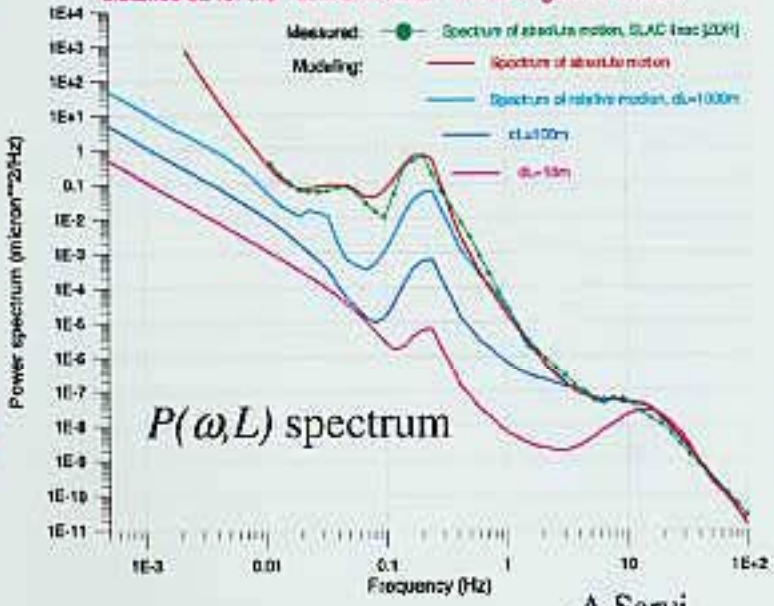
$$\propto \iint P(\omega,k)\cdot G(k)\cdot F(\omega)\cdot dk\cdot d\omega$$

$G(k)$ - spectral response function

$F(\omega)$ - performance of inter-bunch feedback

$P(\omega,k)$ - 2D spectrum of ground motion

Spectra of absolute and relative motion of two points separated by distance dL for the "2am SLAC site" model of ground motion.



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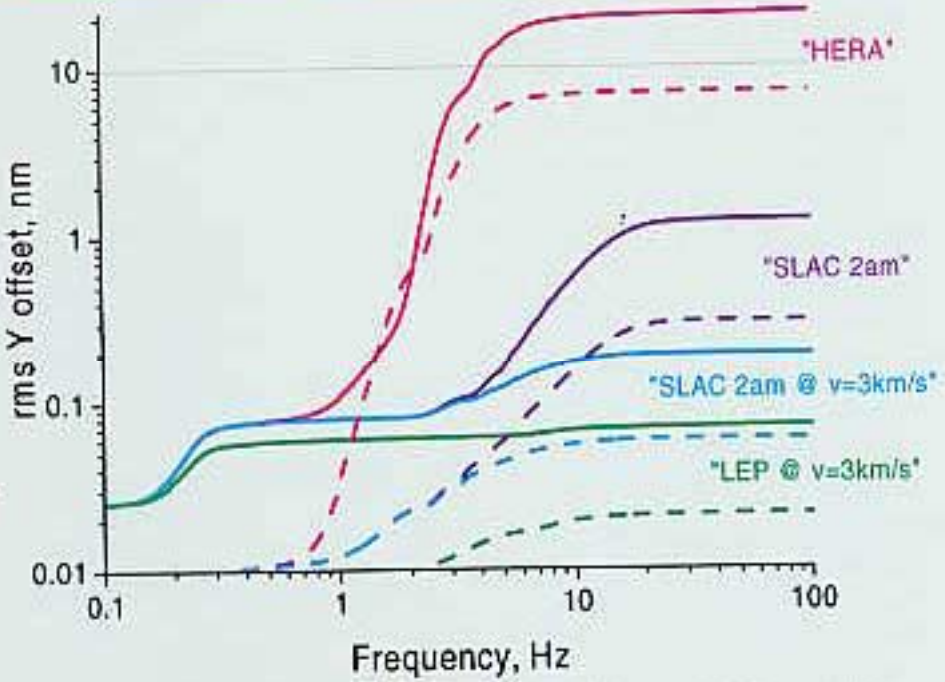
IP beam offset for different GM models

Ground motion models

- **"HERA"** -- noise level as in HERA and SLAC v(f). Extremely noisy, moderate correlation.
- **"SLAC 2am"** -- not too noisy, moderate correlation.
- **"SLAC 2am and v(f)=3km/s"** -- not too noisy, good correlation.
- **"LEP and v(f)=3km/s"** -- extremely quiet, good correlation

Too pessimistic:
"HERA" - noise level did not matter, so nobody care

Too optimistic:
"LEP" - one cannot avoid adding cultural noise in real LC tunnel



IP rms beam offset for different GM models, new FF v.ff01, FD supported 8m from IP.

Need to understand:
what we can do using anti-GM methods,
what will be the noise level in the LC tunnel

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