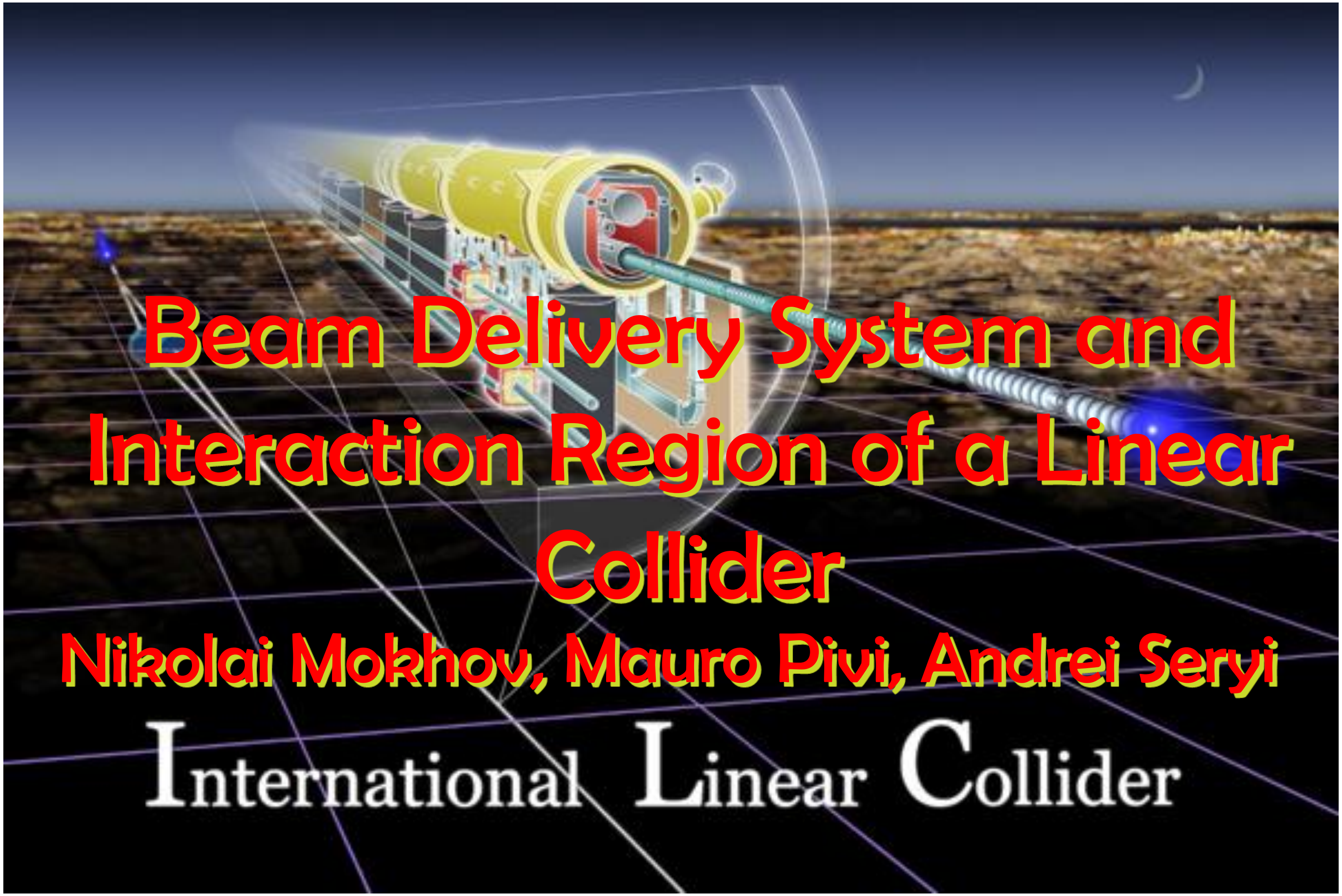
Beam Delivery System and Interaction Region of a Linear Collider

Nikolai Mokhov, Mauro Pivi, Andrei Seryi



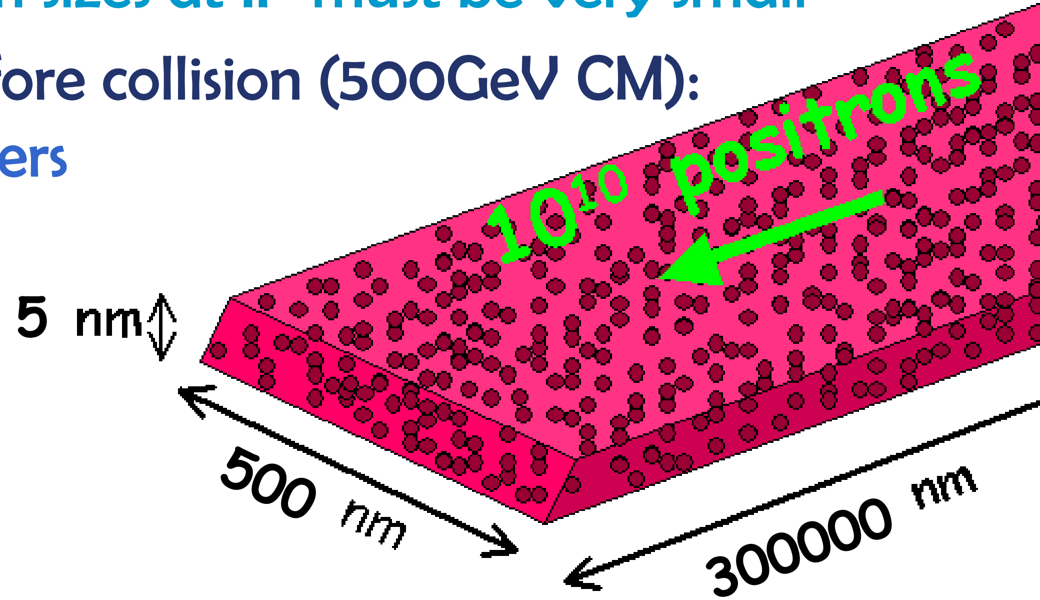
The US Particle Accelerator School
January, 2011 in Norfolk, Virginia

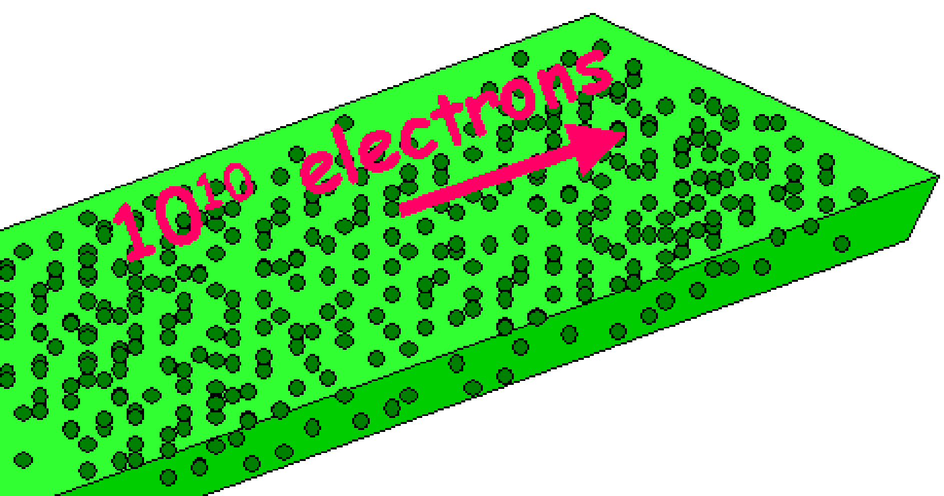
STABILITY Lecture

How to get Luminosity

- To increase probability of direct e^+e^- collisions (**luminosity**) and birth of new particles, beam sizes at IP must be very small
- E.g., ILC beam sizes just before collision (500GeV CM):
  500 * 5 * 300000 nanometers
  (x y z)

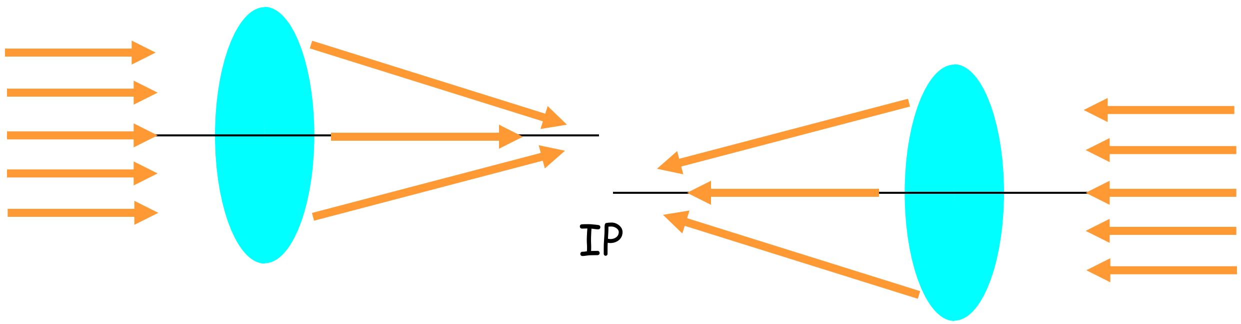
Vertical size is smallest





$$L = \frac{f_{rep}}{4\pi} \frac{n_b N^2}{\sigma_x \sigma_y} H_D$$

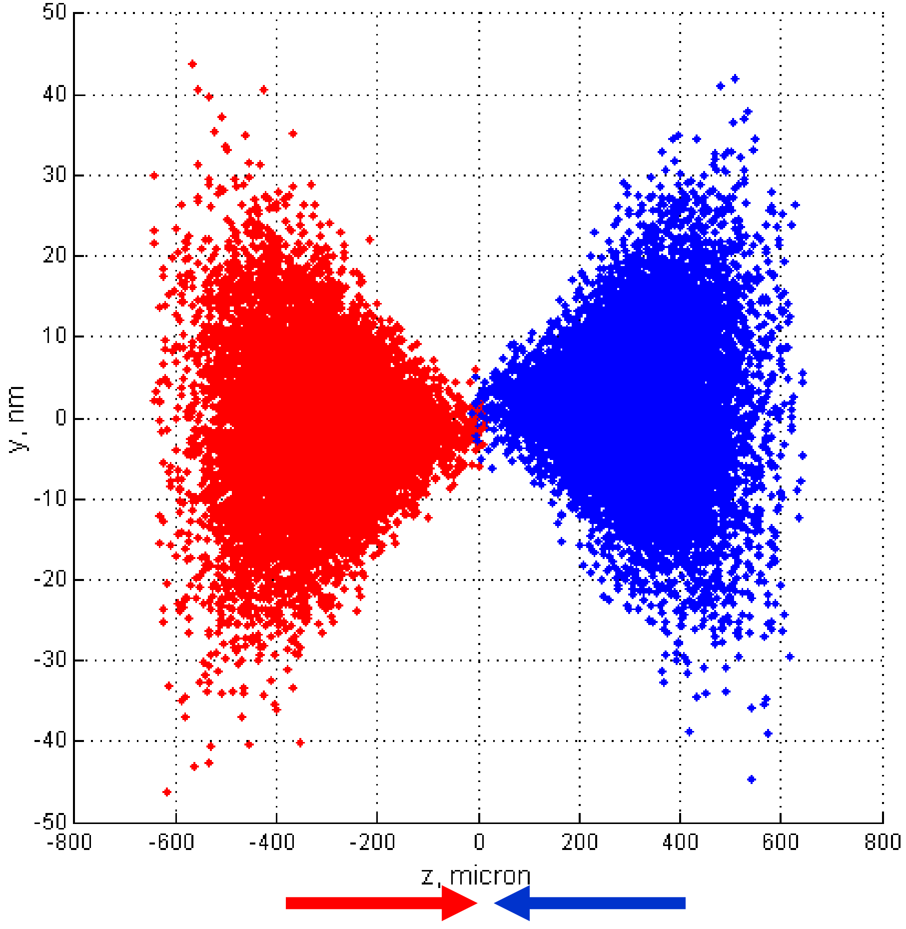
Stability – tolerance to FD motion

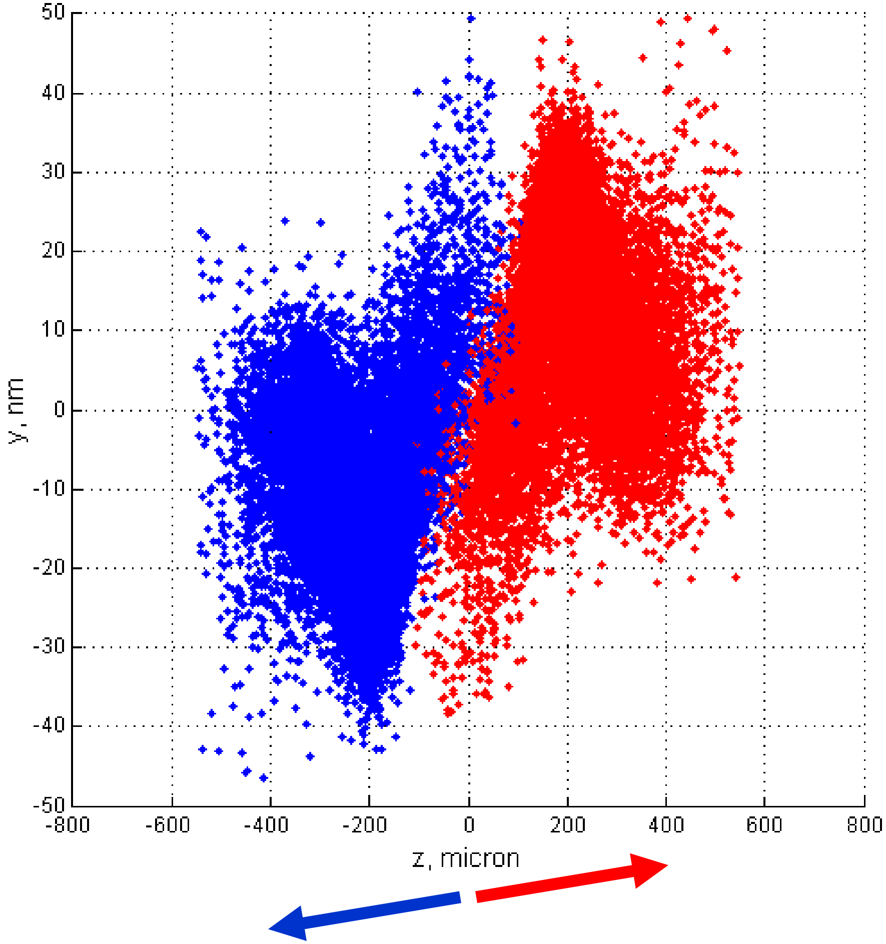


- Displacement of FD by dY cause displacement of the beam at IP by the same amount
- Therefore, stability of FD need to be maintained with a fraction of nanometer accuracy
- How would we detect such small offsets of FD or beams?
    - Using Beam- beam deflection !

- How misalignments and ground motion influence beam offset?

Beam-beam deflection





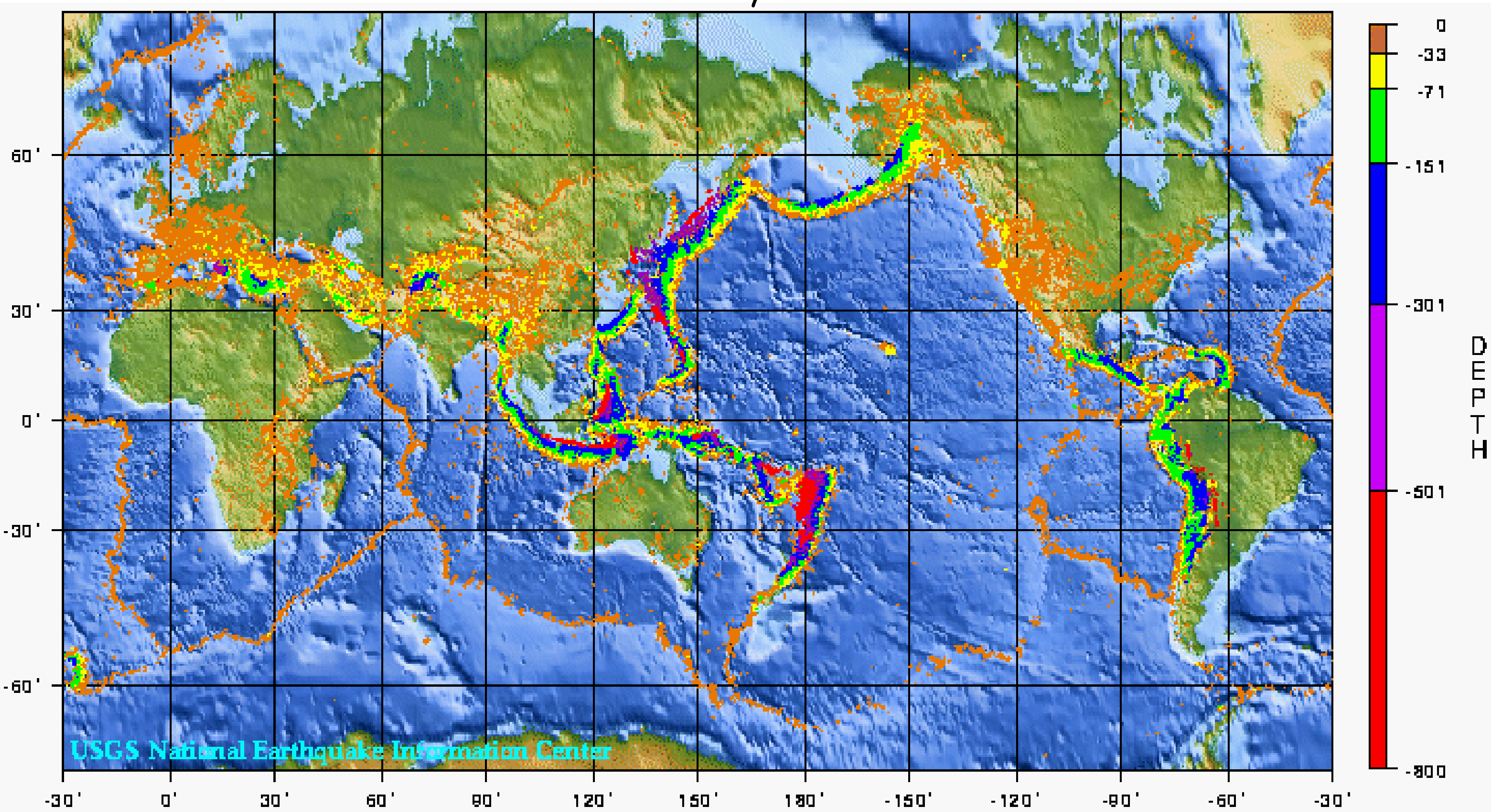
Sub nm offsets at IP cause large well detectable offsets (micron scale) of the beam a few meters downstream

What can cause misalignments of FD and other quads?

- Initial installation errors
  – But if static, can eventually correct them out
- Non-static effects, such as ground motion (natural or human produced)
  – In this lecture, we will try to learn how to evaluate effect of ground motion and misalignment on linear collider

not so much about earthquakes...

World Seismicity: 1975-1995

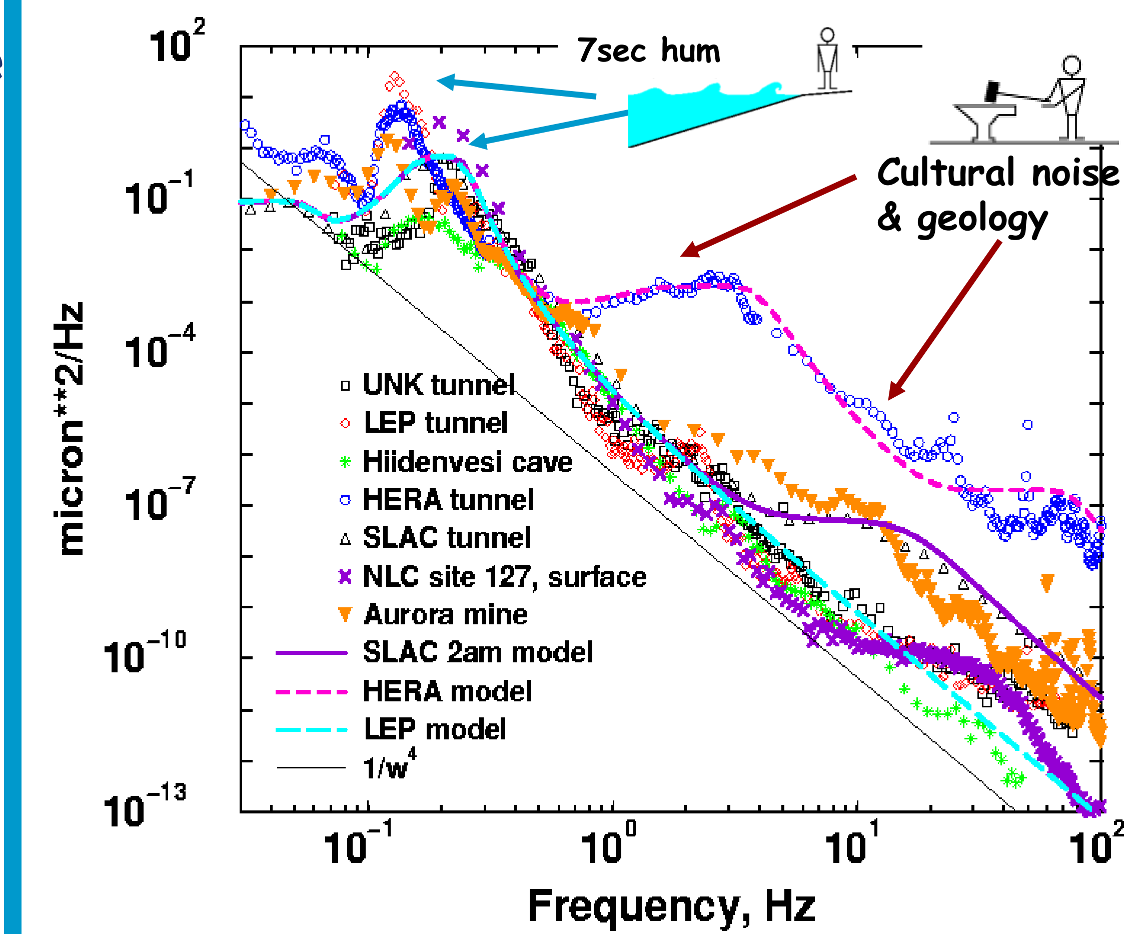


Random signal & Power spectra

- Periodic signals can be characterized by amplitude (e.g. μm) and frequency
- Random signals described by PSD (Power Spectral Density) which usually have units like (m^2/Hz)
- The way to make sense of PSD amplitude is to *by frequency range and take

Ever-present ground motion and vibration and its effect on LC

- Fundamental – decrease as $1/\omega^4$
- Quiet & noisy sites/conditions
- Cultural noise & geology very important
- Motion is small at high frequencies…
- How small?



Power spectral density of absolute position
data from different labs 1989 - 2001

Natural ground motion is small *at high frequencies*

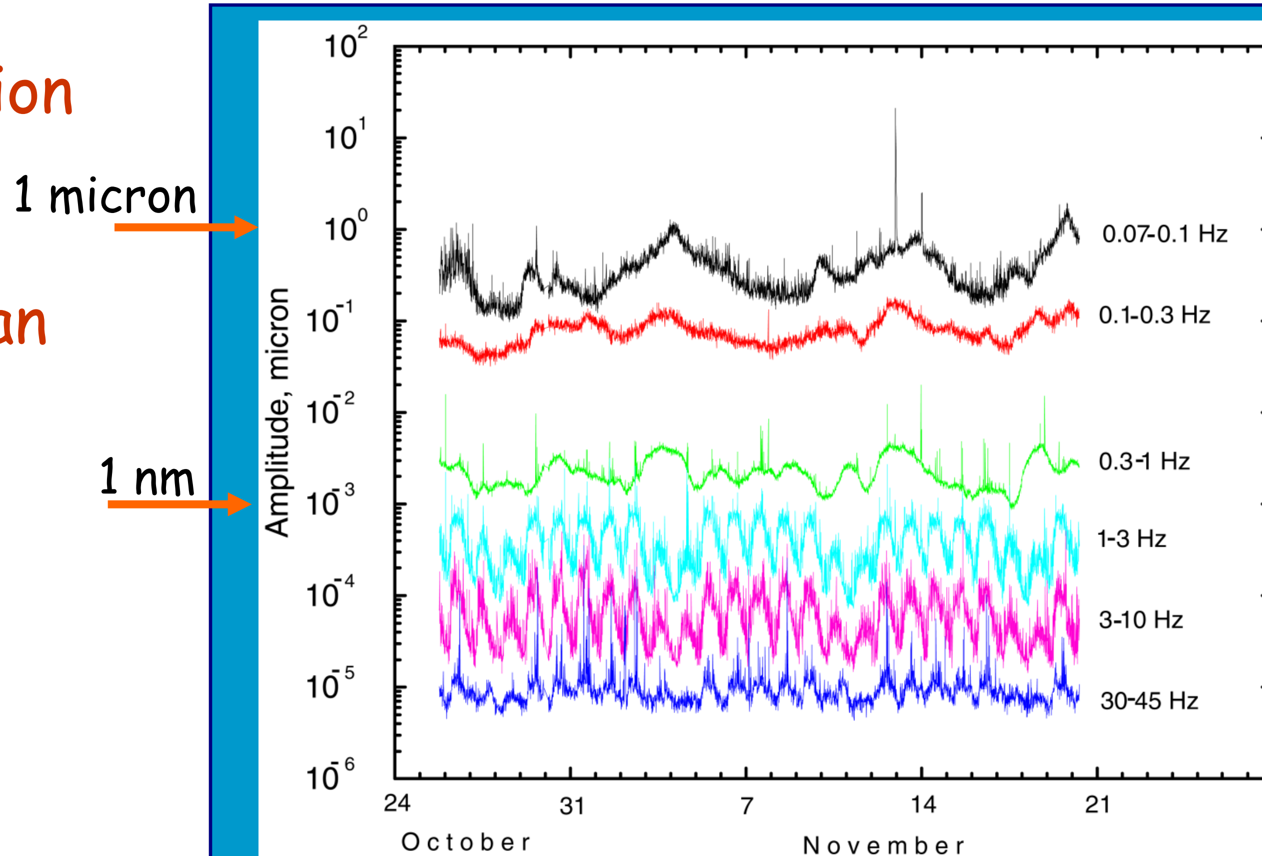
At F>1 Hz the motion can be < 1nm

(I.e. much less than beam size in LC)

Is it OK?

What about low frequency motion?

It is much larger…

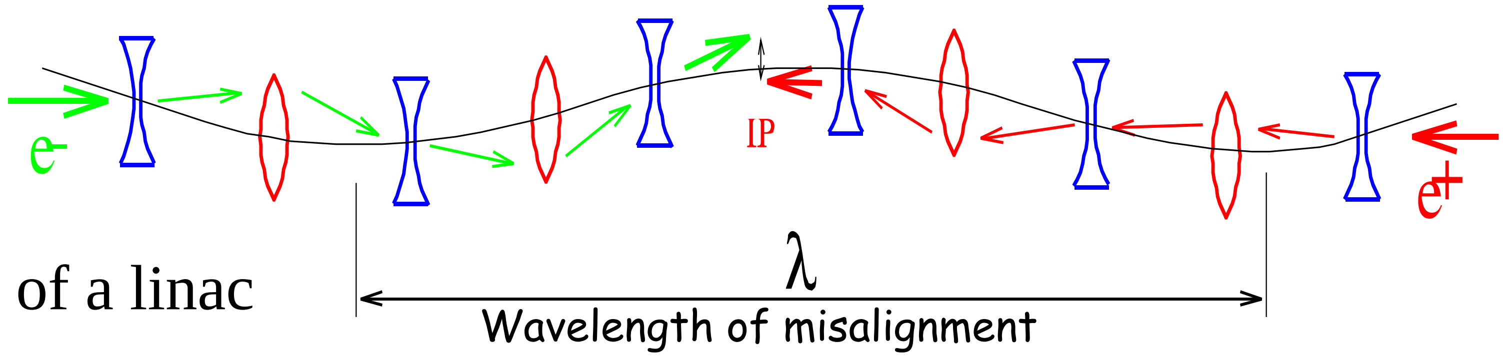


Rms displacement in different frequency bands. Hiidenvesy cave, Finland

Ground motion in time and space

- To find out whether large slow ground motion relevant or not…
- One need to compare
  - Frequency of motion with repetition rate of collider
  - Spatial wavelength of motion with focusing wavelength of collider

Snapshot of a linac



Two effects of ground motion in Linear Colliders

frequency

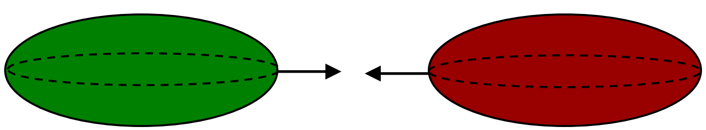
'slow motion'

'fast motion'

$F_c \sim F_{rep}/20$

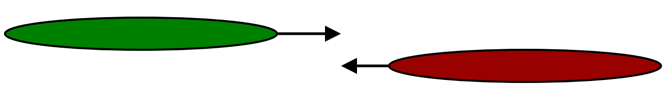
Beam offset due to **slow motion** can be compensated by feedback

May result only in beam emittance growth



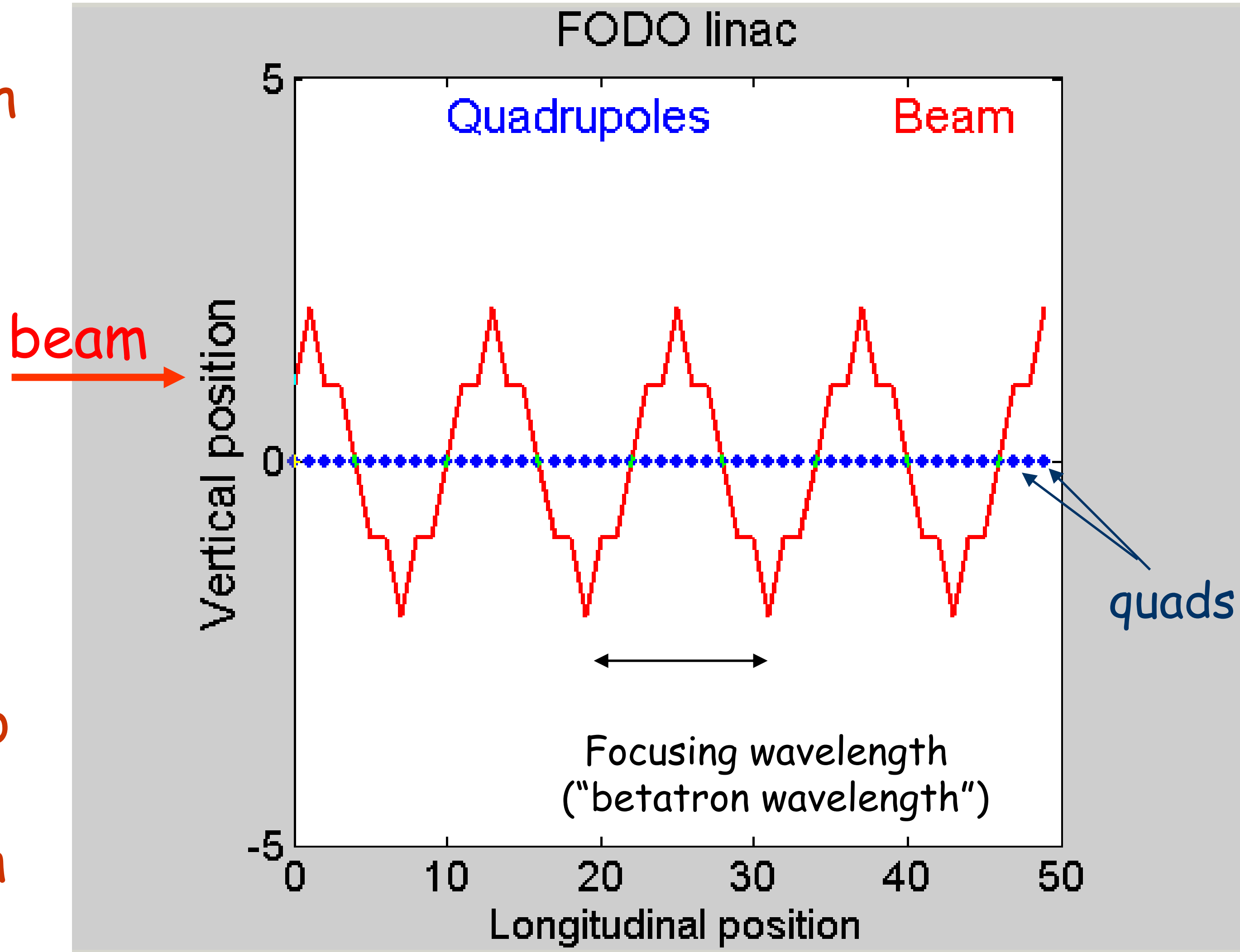
Beam offset cannot be corrected by a pulse-to-pulse feedback operating at the F_{rep}

Causes beam offsets at the IP



Focusing wavelength of a FODO linac

FODO linac with beam entering with an offset



Betatron wavelength is to be compared with wavelength of misalignment

Movie of a Misaligned FODO linac

next page

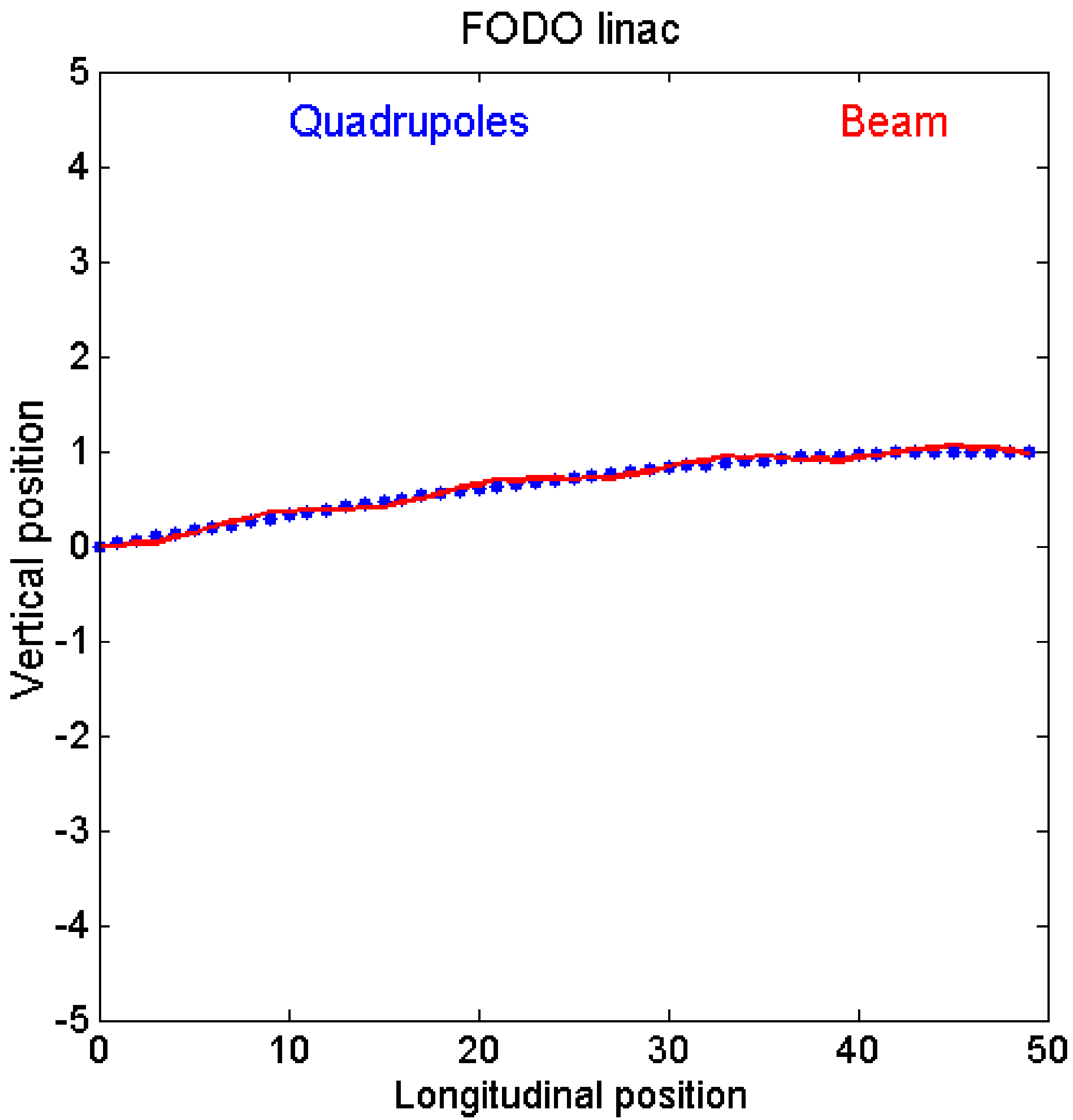
Note the following:

Beam follows the linac if misalignment is more smooth than betatron wavelength

Resonance if wavelength of misalignment ~ focusing wavelength

Spectral response function – how much beam motion due to misalignment with certain wavelength

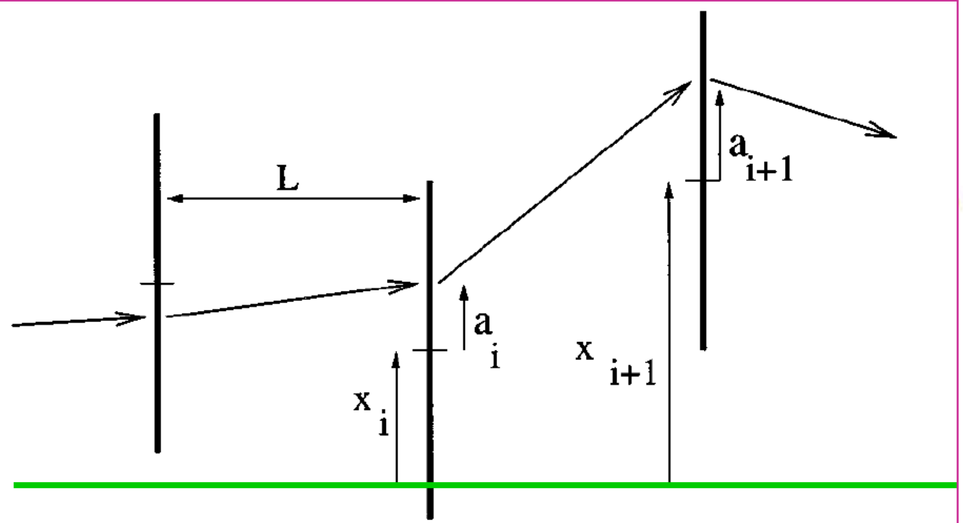
Below, we will try to understand this behavior step by step…



FODO linac
Quadrupoles
Beam
Vertical position
Longitudinal position
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
10
20
30
40
50

How to predict orbit motion or chromatic dilution

Let's consider a beamline consisting of misaligned quadrupoles with position $\mathbf{x_i(t)=x(t,s_i)}$ of the **i**-th element measured with respect to a reference line. Here $\mathbf{s_i}$ is longitudinal position of the quads.
If $\mathbf{x_{abs}(t,s)}$ is a coordinate measured in an inertial frame and the reference line passes through the entrance, than $\mathbf{x(t,s)= x_{abs}(t,s)- x_{abs}(t,0)}$. We also assume that at $\mathbf{t=0}$ the quads were aligned $\mathbf{x(0,s)=0}$.



Misaligned quads. Here $\mathbf{x_i}$ is quad displacement relative to reference line, and $\mathbf{a_i}$ is BPM readings.

We are interested to find the beam offset at the exit $\mathbf{x_*}$ or the dispersion $\boldsymbol{\eta_x}$, produced by misaligned quadrupoles. Let's assume that $\mathbf{b_i}$ and $\mathbf{d_i}$ are the first derivatives of the beam offset and beam dispersion at the exit versus displacement of the element **i**. Then the final offset, measured with respect to the reference line, and dispersion are given by summation over all elements:

$$x_*(t) = R_{11}\, x_{inj}(t) + R_{12}\, x'_{inj}(t) + \sum_{i=1}^{N} b_i\, x_i(t)$$

$$\eta_x(t) = T_{116}\, x_{inj}(t) + T_{126}\, x'_{inj}(t) + \sum_{i=1}^{N} d_i\, x_i(t)$$

Is it clear why there is no $\mathbf{a_i}$ in this formula?

Where **N** is the total number of quads, **R** and **T** are 1st and 2nd order matrices of the total beamline, and we also took into account nonzero position and angle of the injected beam at the entrance.

Predicting orbit motion and chromatic dilution … random case

Let's assume now that the beam is injected along the reference line, then:

$$x_*(t) = \sum_{i=1}^{N} b_i \; x_i(t) \qquad\qquad \eta_x(t) = \sum_{i=1}^{N} d_i \; x_i(t)$$

Assume that quads misalignments, averaged over many cases, is zero. Let's find the nonzero variance

$$\langle x_*^2(t) \rangle = \sum_{i=1}^{N} \sum_{j=1}^{N} b_i \; b_j \langle x_i(t) \cdot x_j(t) \rangle \qquad\qquad \langle \eta_x^2(t) \rangle = \sum_{i=1}^{N} \sum_{j=1}^{N} d_i \; d_j \langle x_i(t) \cdot x_j(t) \rangle$$

Let's first consider a very simple case.
In case of **random** uncorrelated misalignment we have $\langle x_j(t) \cdot x_j(t) \rangle = \sigma_x^2 \; \delta_{ij}$ (σ_x is rms misalignment, not the beam size)

So that, for example $\langle x_*^2(t) \rangle = \sigma_x^2 \sum_{i=1}^{N} b_i^2$ And similar for dispersion

Now we would like to know what are these **b** and **d** coefficients.

Predicting x_* and η … what are these b_i and d_i coefficients

Let's consider a thin lens approximation. In this case, transfer matrix of **i**-th quadrupole is $\begin{pmatrix} 1 & 0 \\ -K_i & 1 \end{pmatrix}$ (**K**>0 for focusing and **K**<0 for defocusing)

A quad displaced by $\mathbf{x_i}$ produces an angular kick $\boldsymbol{\theta=K_i x_i}$ and the resulting offset at the exit will be $x_* = r_{12}^i K_i x_i$ Where r_{12}^i is the element of transfer matrix from i-th element to the exit

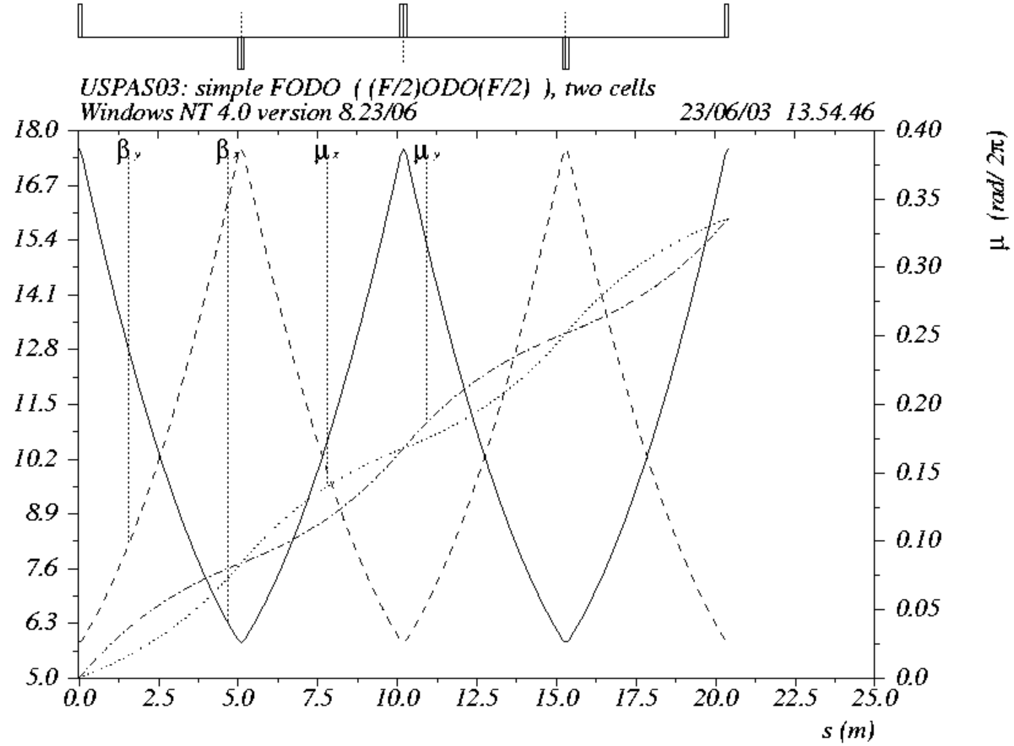
The coefficient $\mathbf{b_i}$ is therefore $b_i = r_{12}^i K_i$

The coefficient $\mathbf{d_i}$ is the derivative of $\mathbf{d_i}$ with respect to energy deviation $\boldsymbol{\delta}$:

$$d_i = \frac{d}{d\delta}\left(r_{12}^i K_i\right) = \frac{d}{d\delta}\left(r_{12}^i \frac{K_i(0)}{1+\delta}\right)$$

Which is equal to $d_i = -K_i\left(r_{12}^i - t_{126}^i\right)$ Where t_{126}^i is the 2nd order transfer matrix from i-th element to the exit

Transfer matrices for FODO linac



Let's consider a FODO linac… No, let's consider, for better symmetry, a (F/2 O D O F/2) linac. Example is shown in the figure on the right side.

The quadrupole strength is $\mathbf{K_i = K\,(-1)^{i+1}}$ (ignoring that first quad is half the length). The position of the quadrupoles is $\mathbf{S_i = (i-1)L}$ where L is quad spacing.

The betatron phase advance μ per FODO cell is given by

$$2\sin\left(\frac{\mu}{2}\right) = |K|\,L$$

The matrix element r_{12}^{i} from the i-th quad to the exit (N-th quad) is

$$r_{12}^{i} = \sqrt{\beta_i\,\beta_N}\,\sin(\Psi_i)$$

Where Ψ_i is the phase advance from i-th quad and exit. Obviously,

$$\Psi_i = \frac{\mu}{2}(N-i)$$

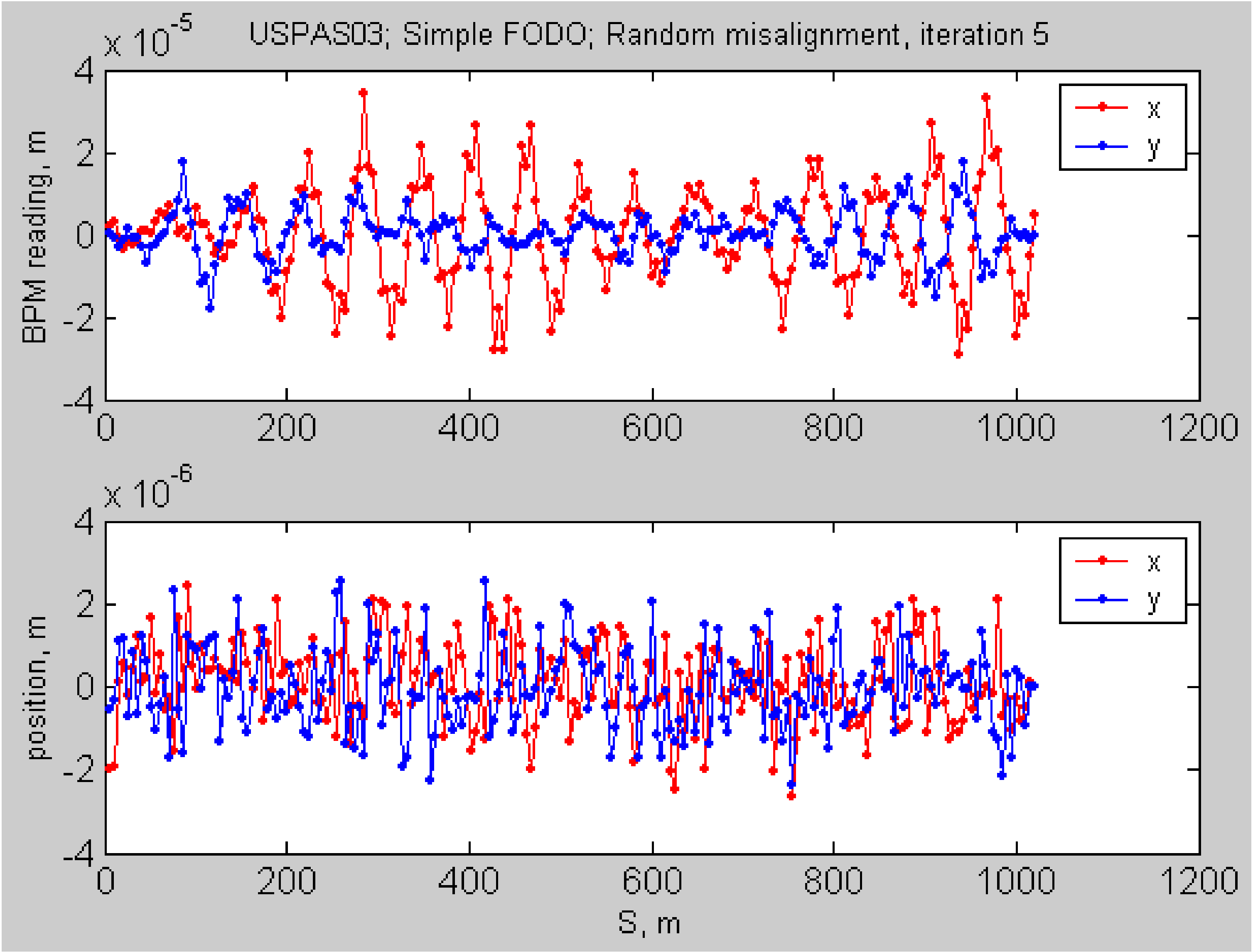
And here β_i and β_N are beta-functions in the quads. For such regular FODO, the min and max values of beta-functions (achieved in quads) are

$$\beta_{\max,\ \min} = \frac{L}{\tan\left(\frac{\mu}{2}\right)\left[1 \mp \sin\left(\frac{\mu}{2}\right)\right]}$$

Since the energy dependence comes mostly from the phase advance (it has large factor of N) and the beta-function variation can be neglected, the second order coefficients are given by

$$t_{126}^{i} \approx -r_{12}^{i}\,(N-i)\,\tan\left(\frac{\mu}{2}\right)\frac{1}{\tan(\Psi_i)}$$

Example of random misalignments of FODO linac



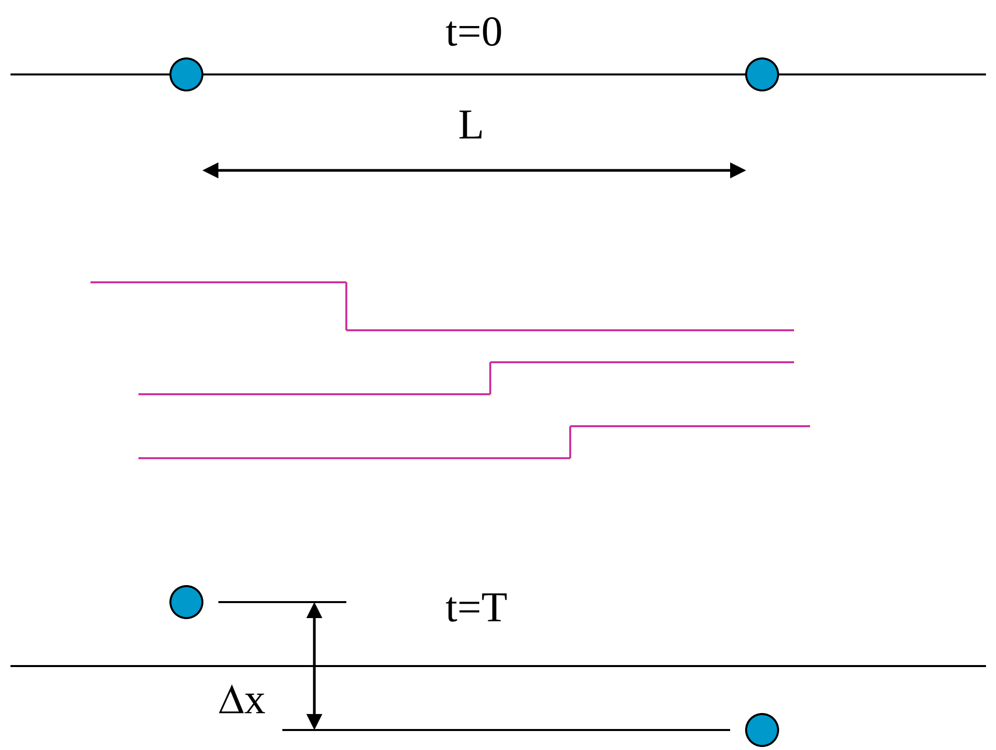
Example of misalignments and orbits

Random… is it possible?

- Now you have everything to calculate **b** and **d** coefficients and find, for example, the rms of the orbit motion at the exit for the simplest case – completely random uncorrelated misalignments.
- Completely random and uncorrelated means that misalignments of two neighboring points, even infinitesimally close to each other, would be completely independent.
- If we would assume that such random and uncorrelated behavior occur in time also, I.e. for any infinitesimally small Dt the misalignments will be random (no “memory” in the system) then it would be obvious that such situation is physically impossible. Simply because its spectrum correspond to white noise, I.e. goes to infinite frequencies, thus having infinite energy.
- We have to assume that things do not get changed infinitely fast, nor in space, neither in time. I.e., there is some correlation with previous moments of time, or with neighboring points in space.
- Let’s consider the random walk (drunk sailor). In this case, together with randomness, there is certain memory in this process: the sailor makes the next step relative to the position he is at the present point.
- Extension of random walk model to multiple points in space and time is described by the “ATL law” [B.Baklakov, V.Parkhomchuk, A.Seryi, V.Shiltsev, et al, 1991].

The ATL motion

According to “ATL law” (rule, model, etc.), misalignment of two points separated by a distance L after time T is given by $\Delta X^2 \sim ATL$ where **A** is a coefficient which may depend on many parameters, such as site geology, etc., if we are talking about ground motion. (The ATL-kind of motion can occur in other areas of physics as well.)



Such ATL motion would occur, for example, if step-like misalignments occur between points 1 and 2 and the number of such misalignments is proportional to elapsed time and separation between point. You then see that the average misalignment is zero, but the rms is given by the ATL rule.

Can you show this?

ATL ground measurements will be discussed later. Let’s now discuss orbit motion in the linac for ATL ground motion.

Predicting orbit motion and chromatic dilution … ATL case

So, we would like to calculate $\langle x_*^2(t) \rangle = \sum_{i=1}^{N} \sum_{j=1}^{N} b_i \, b_j \langle x_i(t) \cdot x_j(t) \rangle$ for ATL case.

Let's rewrite ATL motion definition. Assume that there is an inertial reference frame, where coordinates of our linac are $\mathbf{x_{abs}(t,s)}$. Let's assume that at t=0 the linac was perfectly aligned, and let's define misalignment with respect to this original positions as $x(t, s) = x_{abs}(t, s) - x_{abs}(t = 0, s)$

The ATL rule can then be written as: $\langle \left(x(t, s + L) - x(t, s)\right)^2 \rangle = A \cdot t \cdot L$

Take into account that beam goes through the entrance (where s=0) without offset and write: $x_i = x(t, s_i) - x(t,0)$ $\quad x_j = x(t, s_j) - x(t,0)$

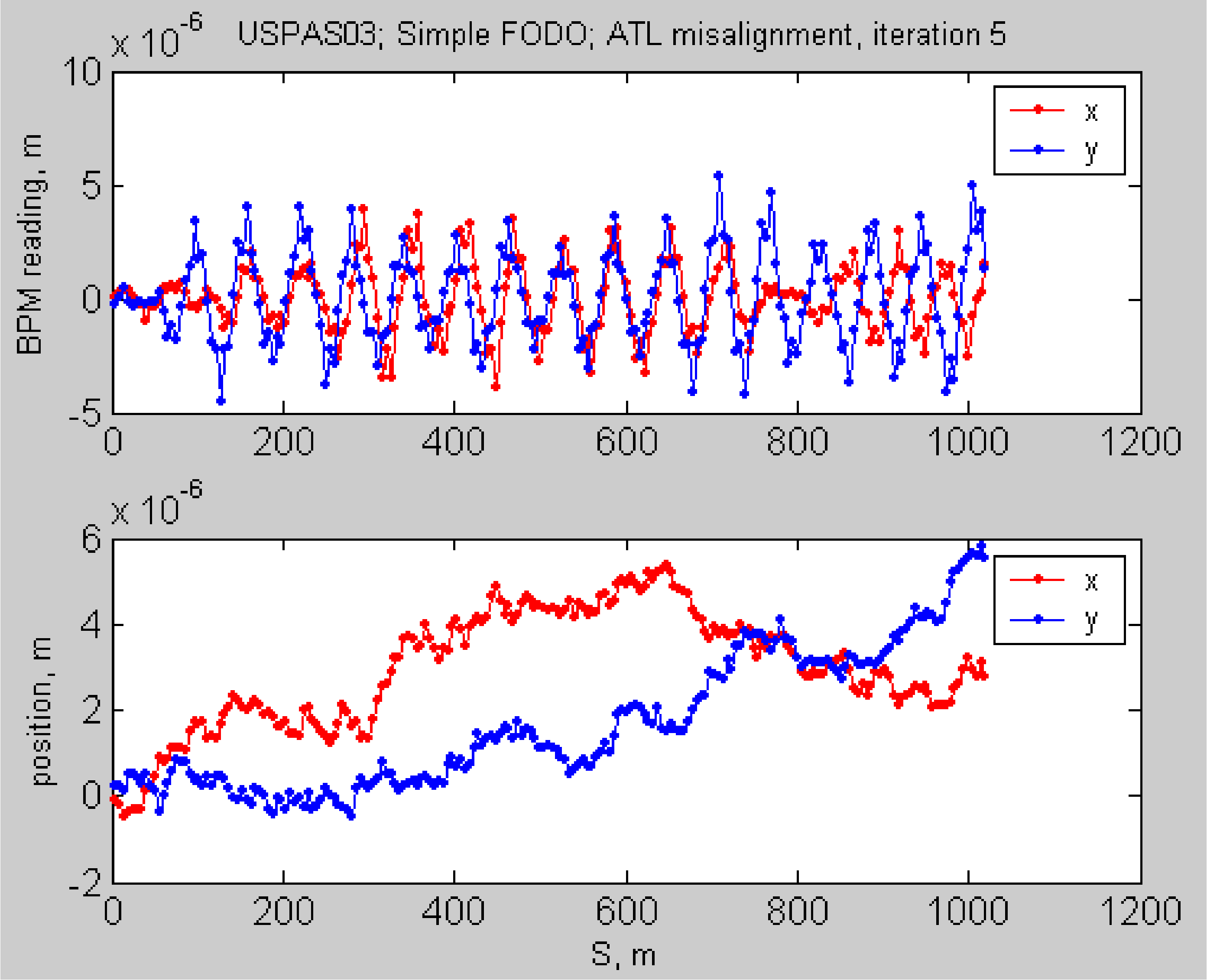
Then rewrite $\mathbf{x_i x_j}$ term as $x_i x_j = \frac{1}{2}\left[\left(x(t, s_i) - x(t,0)\right)^2 + \left(x(t, s_j) - x(t,0)\right)^2 - \left(x(t, s_i) - x(t, s_j)\right)^2\right]$

Now use ATL rule and get $\langle x_i x_j \rangle = \frac{1}{2} \cdot A \cdot t \cdot \left(|s_i| + |s_i| - |s_i - s_j| \right)$

Taking into account $\mathbf{S_i = (i - 1)L}$ we have the final result for the rms exit orbit motion in ATL case:

$$\langle x_*^2(t) \rangle = \frac{A \cdot t \cdot L}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} b_i b_j \left((i-1) + (j-1) - |i - j|\right)$$

Example of ATL misalignments of FODO linac

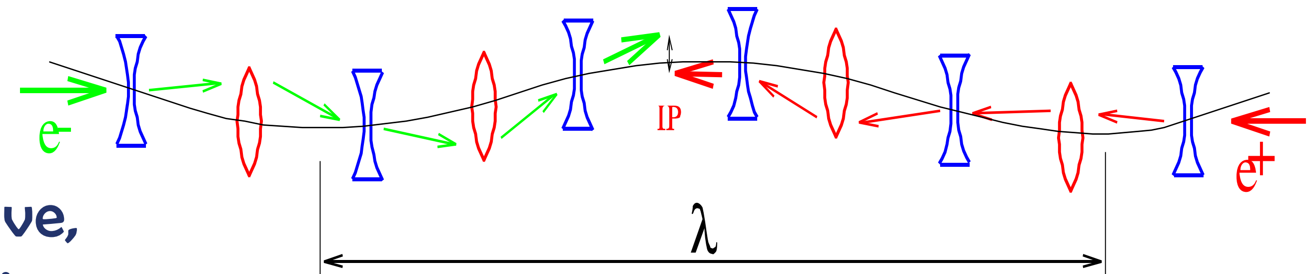


Example of misalignments and orbits

Slow and fast motion, again

- We know how to evaluate effect of ATL motion
- This motion is slow
- What about fast motion?
- Its correlation?
- Measured data?

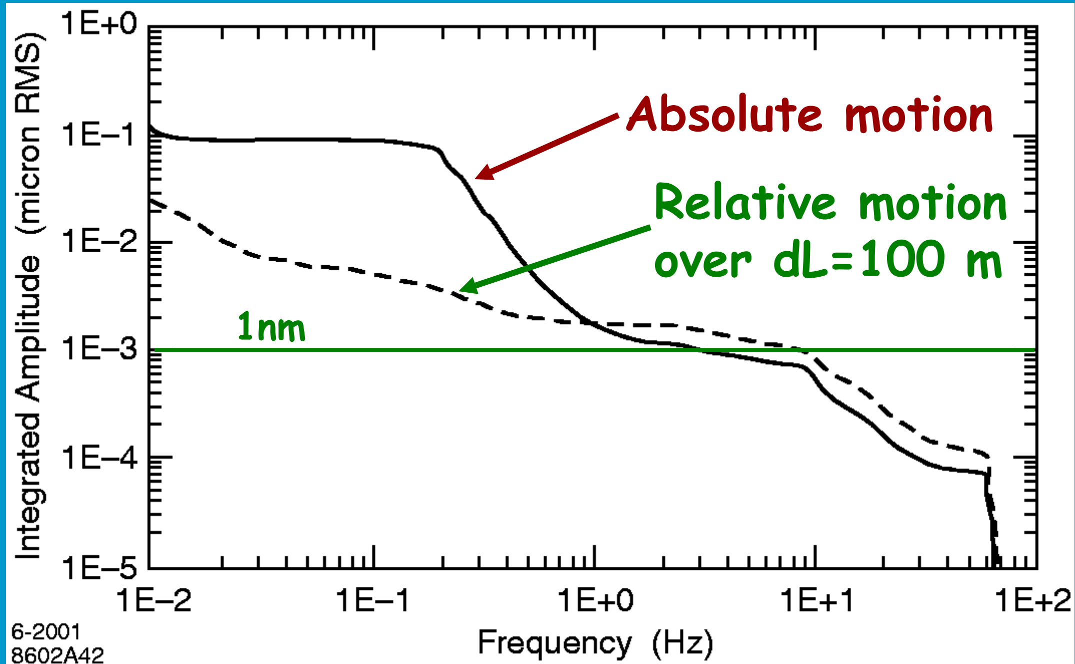
Correlation: relative motion of two elements with respect to their absolute motion



- Care about relative, not absolute motion

- Beneficial to have good correlation (longer wavelength)

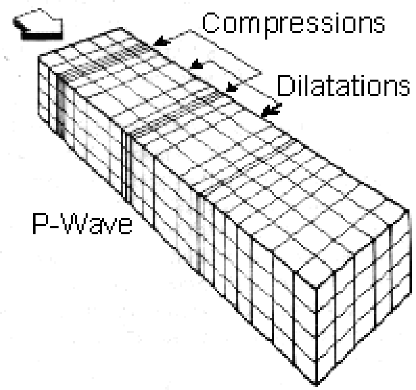
- Relative motion can be much smaller than absolute



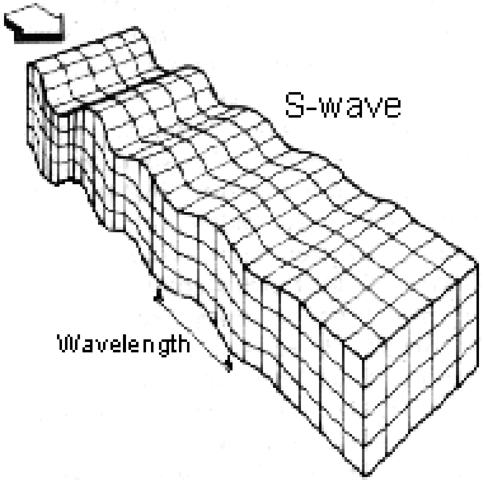
Integrated (for $F>F_o$) spectra. SLC tunnel @ SLAC

Correlation of ground motion depends on velocity of waves (and distribution of sources in space)

P-wave, (primary wave, dilatational wave, compression wave)
Longitudinal wave. Can travel trough liquid part of earth.



Velocity of propagation $$v_P = \sqrt{\frac{\lambda + 2G}{\rho}}$$



S-wave, (secondary wave, distortional wave, shear wave)
Transverse wave. Can not travel trough liquid part of earth

Velocity of propagation $$v_S = \sqrt{\frac{G}{\rho}}$$ typically $$v_S \approx \frac{v_P}{2}$$

Here ρ- density, G and λ - Lame constants: $$G = \frac{E}{2(1+\nu)} \qquad \lambda = \frac{\nu E}{(1+\nu)(1-2\nu)}$$

E-Young's modulus, ν - Poisson ratio

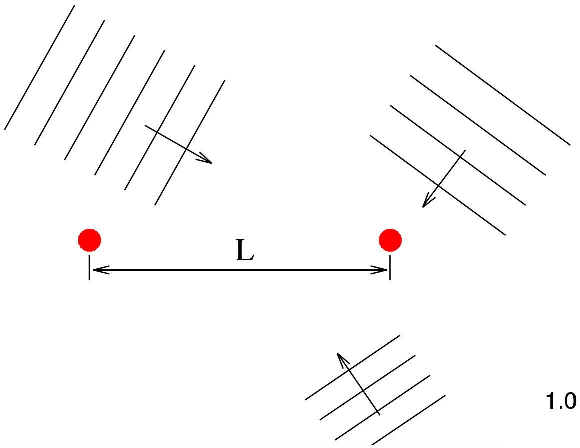
Correlation measurements and interpretation

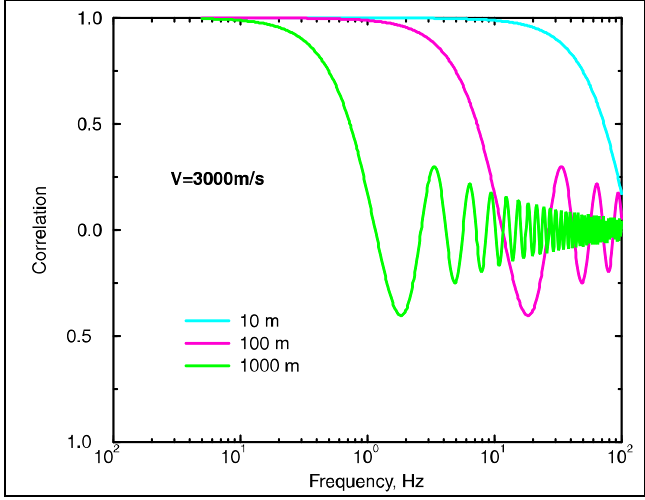
In a model of pane wave propagating on surface

correlation = $\langle \cos(\omega \Delta L / v \cos(\theta)) \rangle_\theta$ =

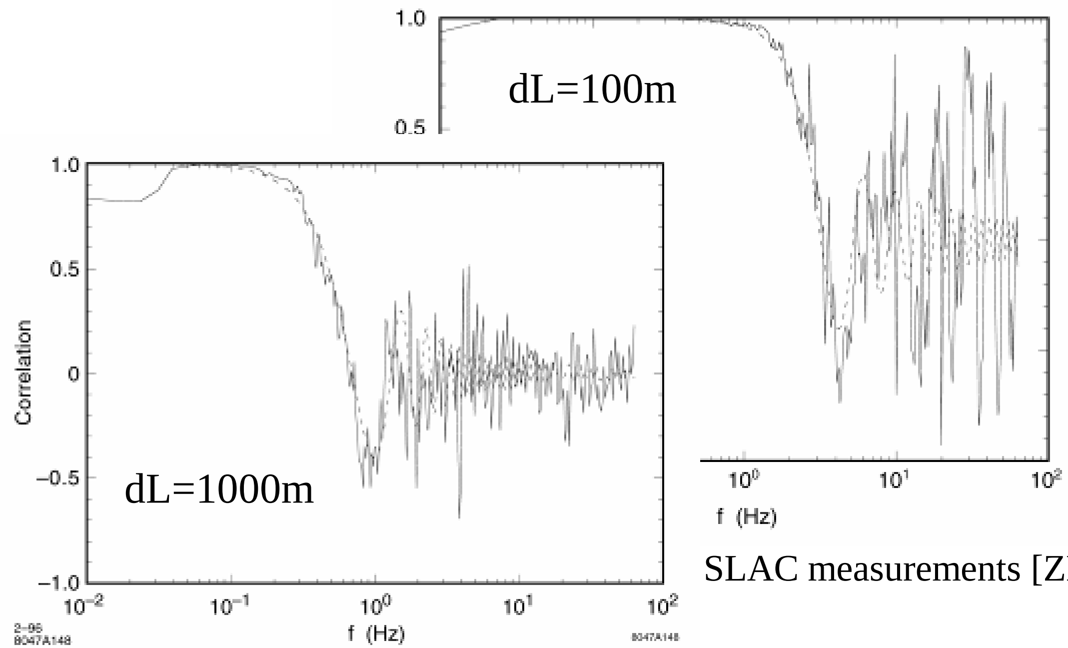
$= J_0(\omega \Delta L / v)$

where **v**- phase velocity

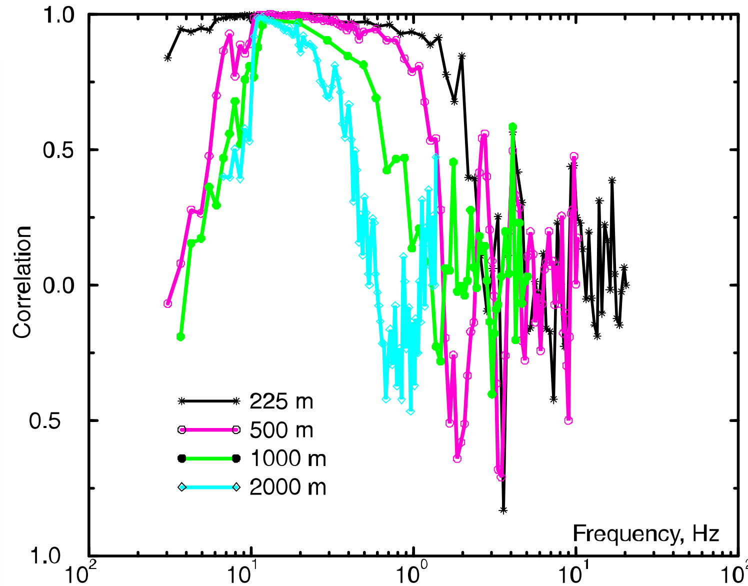




Theoretical curves

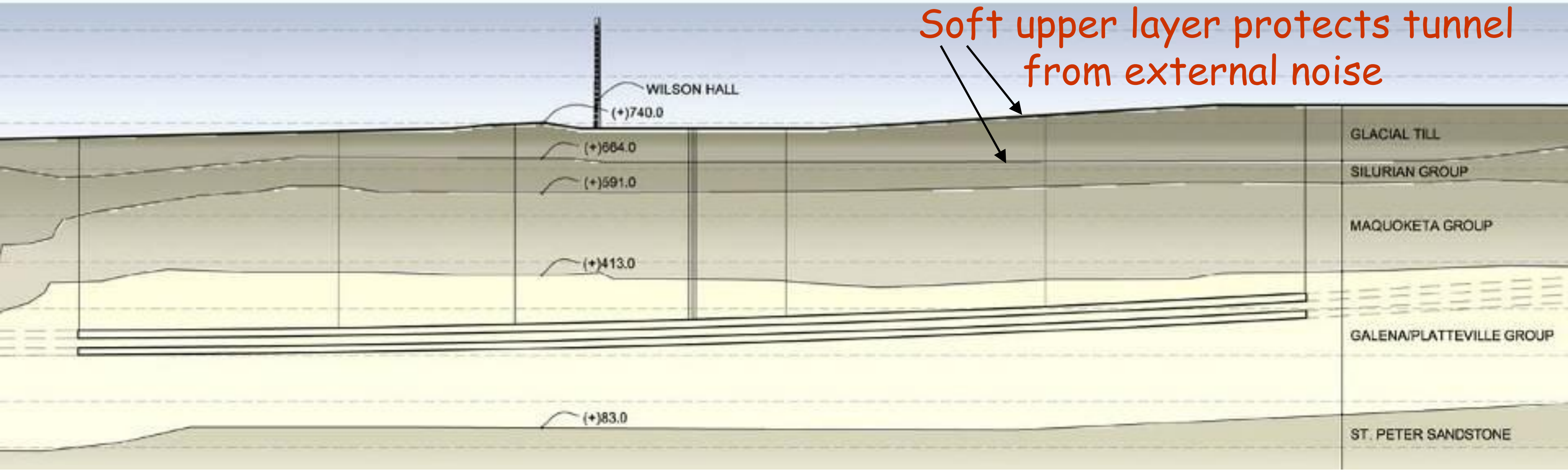


SLAC measurements [ZDR]



LEP measurements

Fermilab site



- Tunnel can be placed ~100m deep in geologically (almost) perfect Galena Platteville dolomite platform
- Top ground layer is soft – this increase isolation from external noises

Predicting orbit motion for arbitrary misalignments

So, we would like to calculate, for example, $\langle x_*^2(t)\rangle = \sum_{i=1}^{N}\sum_{j=1}^{N} d_i\, d_j \langle x_i(t)\cdot x_j(t)\rangle$ in case of arbitrary properties of misalignments

One can introduce the spatial harmonics **x(t,k)** of wave number **k=2π/λ**, with λ being he spatial period of displacements:

$$x(t,k)=\int_{-\mathcal{L}/2}^{\mathcal{L}/2} x(t,s)e^{-iks}ds$$

The displacement x(t,s) can be written using the back transformation:

$$x(t,s)=\int_{-\infty}^{\infty} x(t,k)(e^{iks}-1)\frac{dk}{2\pi}$$

which ensures that at the entrance **x(t,s=0)=0**.

Then the variance of dispersion is

$$\langle\eta_x^2(t)\rangle=\sum_i\sum_j d_i d_j\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\langle x(t,k_1)x^*(t,k_2)\rangle(e^{ik_1s_i}-1)(e^{-ik_2s_j}-1)\frac{dk_1}{2\pi}\frac{dk_2}{2\pi}$$

We can rewrite it as

$$\langle\eta_x^2(t)\rangle=\sum_i\sum_j d_i d_j\int_{-\infty}^{\infty}P(t,k)(e^{iks_i}-1)(e^{-iks_j}-1)\frac{dk}{2\pi}$$

Where we defined the spatial power spectrum of displacements **x(t,s)** as

$$P(t,k)=\lim_{\mathcal{L}\to\infty}\frac{1}{\mathcal{L}}x(t,k)x^*(t,k) = \lim_{\mathcal{L}\to\infty}\frac{1}{\mathcal{L}}\left|\int_{-\mathcal{L}/2}^{\mathcal{L}/2}x(t,s)e^{-iks}ds\right|^2$$

Predicting orbit motion for arbitrary misalignments

So, we see that we can write the variance of dispersion (and very similar for the offset) in such a way, that the lattice properties and displacement properties are separated:

$$\langle \eta_x^2(t) \rangle = \int_{-\infty}^{\infty} P(t,k)\, G(k) \frac{dk}{2\pi}$$

Here G(k) is the so-called spectral response function of the considered transport line (in terms of dispersion):

$$G(k) = g_c^2(k) + g_s^2(k)$$

where

$$g_c(k) = \sum_{i=1}^{N} d_i [\cos(k s_i) - 1] \qquad \text{and} \qquad g_s(k) = \sum_{i=1}^{N} d_i \sin(k s_i)$$

The spectral function for the offset will be the same, but $\mathbf{d_i}$ substituted by $\mathbf{b_i}$

2-D spectra of ground motion

Arbitrary ground motion can be fully described, for a linear collider, by a 2-D power spectrum **P(ω,k)**

If a 2-D spectrum of ground motion is given, the spatial power spectrum **P(t,k)** can be found as

$$P(t,k)=\int_{-\infty}^{\infty} P(\omega,k)2[1-\cos(\omega t)]\frac{d\omega}{2\pi}$$

Example of 2-D spectrum for ATL motion: $P(\omega,k)=\frac{A}{\omega^2 k^2}$ And for **P(t,k)** : $P(t,k)=\frac{A\cdot t}{k^2}$

The 2-D spectrum can be used to find variance of misalignment. Again, assume that there is an inertial reference frame, where coordinates of our linac are $\mathbf{x_{abs}(t,s)}$. And assume that at t=0 the linac was perfectly aligned, and that misalignment with respect to this original positions is $x(t,s)=x_{abs}(t,s)-x_{abs}(t=0,s)$, its variance is given by

$$\left\langle \left(x(t,s+L)-x(t,s)\right)^2 \right\rangle = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} P(\omega,k)\, 2\cdot[1-\cos(\omega t)]\; 2\cdot[1-\cos(kL)]\; \frac{d\omega}{2\pi}\frac{dk}{2\pi}$$

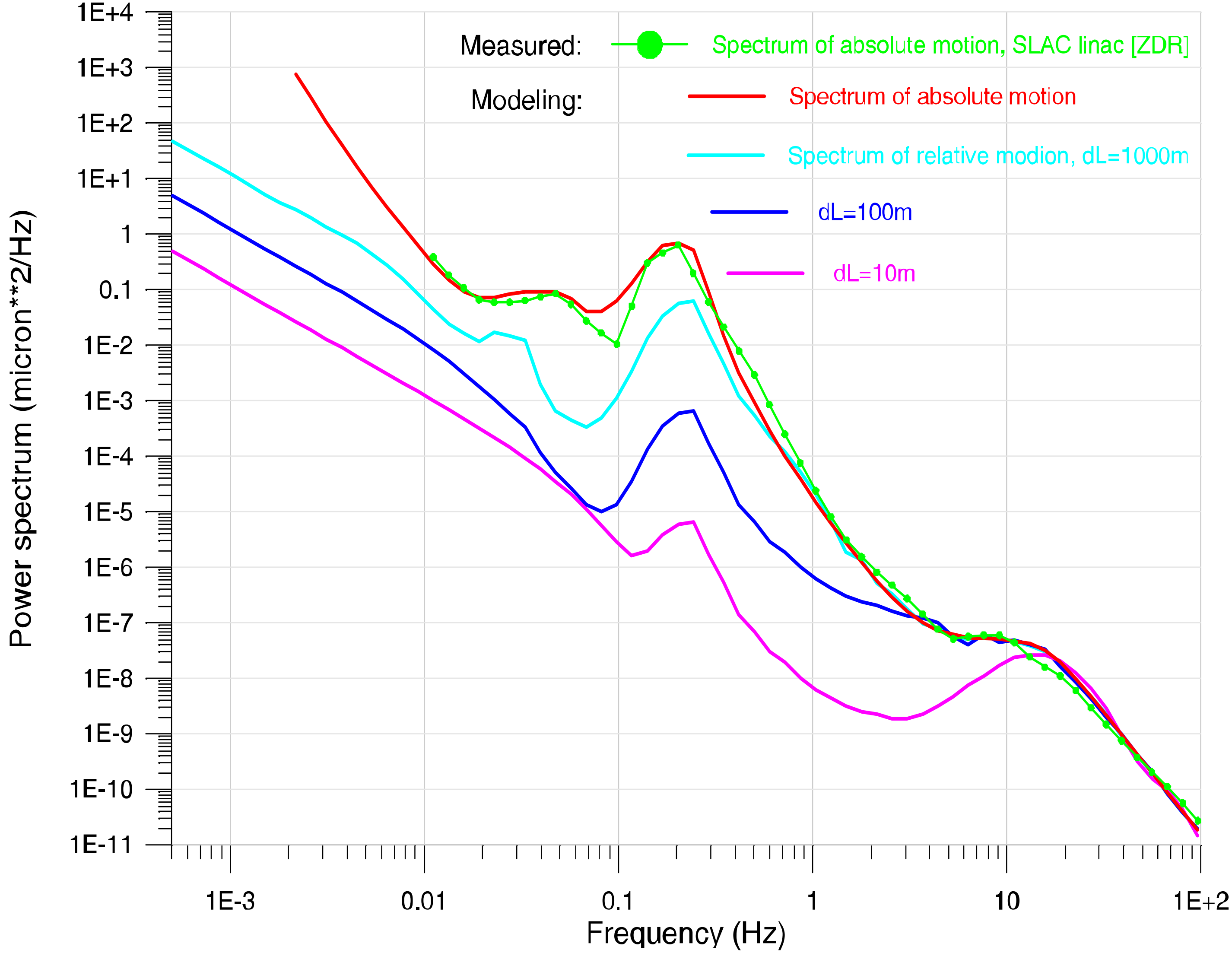
You can easily verify, for example, that for ATL spectrum it gives the ATL formula

The (directly measurable !) spectrum of relative motion is given by

$$\rho(\omega,L)=\int_{-\infty}^{\infty} P(\omega,k)2[1-\cos(kL)]dk/2\pi$$

Example of P(ω,L) spectrum (model)

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



Behavior of spectral functions

Remember that before assuming that beams injected without offset we wrote that

$$x_*(t) = R_{11}\, x_{inj}(t) + R_{12}\, x'_{inj}(t) + \sum_{i=1}^{N} b_i\, x_i(t) \qquad \eta_x(t) = T_{116}\, x_{inj}(t) + T_{126}\, x'_{inj}(t) + \sum_{i=1}^{N} d_i\, x_i(t)$$

It is easy to show that the coefficients b (and d) follow certain rules, which can be found in the next way. By considering a rigid displacement of the whole beam line, it is easy to find the identity

$$\sum_{i=1}^{N} b_i = 1 - R_{11} \qquad \text{and} \qquad \sum_{i=1}^{N} d_i = -T_{116}$$

On the other hand, one can show by tilting the whole beamline by a constant angle that the coefficients satisfy for thin lenses the following identity:

$$\sum_{i=1}^{N} b_i s_i + R_{12} = s_{exit} \qquad \text{and} \qquad \sum_{i=1}^{N} d_i s_i + T_{126} = 0$$

$$g_c(k) = \sum_{i=1}^{N} d_i [\cos(k s_i) - 1]$$

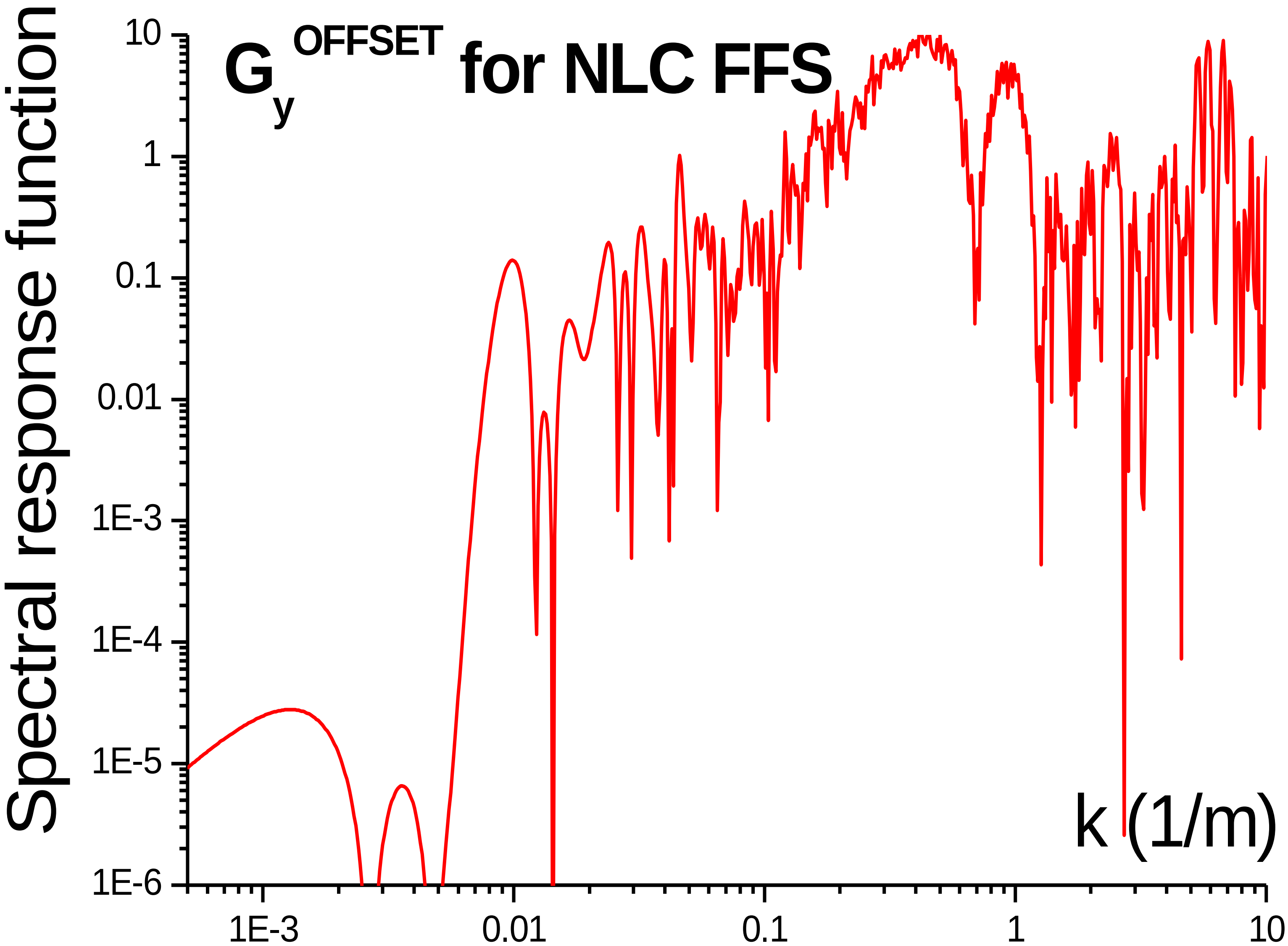
$$g_s(k) = \sum_{i=1}^{N} d_i \sin(k s_i)$$

These rules allow to find behavior of the spectral functions at small k:

$$g_c(k \to 0) \approx O(k^2) \qquad g_s(k \to 0) \approx -k \cdot R_{12} + O(k^3)$$

You see that if R_{12} is zero, effect of long wavelength is suppressed as k^2

Example of spectral response function



Slow motion (**minutes - years**)

- **Diffusive** or **ATL** motion: $\Delta X^2 \sim ATL$
  (T – elapsed time, L – separation between two points)
  (minutes-month)
- Observed 'A' varies by ~5 orders: 10^{-9} to 10^{-4} $\mu m^2/(m \cdot s)$
  - **parameter 'A' should strongly depend on geology -- reason for the large range**
  - **Range comfortable for NLC: A <** 10^{-6} $\mu m^2/(m \cdot s)$
    Very soft boundary! Observed A at sites similar to NLC deep tunnel sites is several times or much smaller.
- **Systematic** motion: ~linear in time (month-years), similar spatial characteristics
- **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 but short λ ground motion

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

Place	A $\mu m^2/(m{\cdot}s)$
HERA	$\sim 10^{-5}$
FNAL surface	$\sim$ 1-few*10^{-6}
SLAC*	$\sim 5{*}10^{-7}$
Aurora mine*	$\sim 2{*}10^{-7}$
Sazare mine	$\sim 10^{-8}$

~20μm displacement over 20m in one month

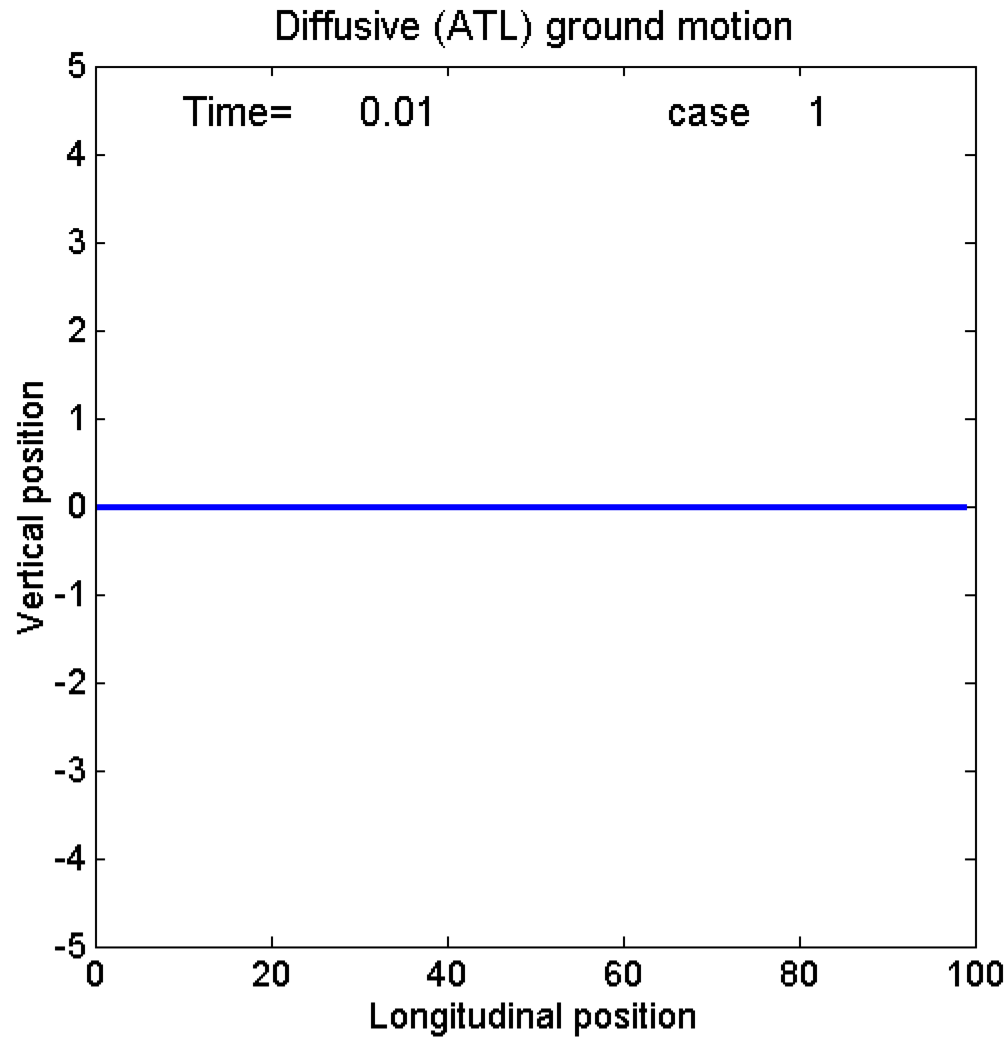
How diffusive ATL motion looks like?

- Movie of simulated ATL motion

- Note that it starts rather fast

- $X^2 \sim L$

- and it can change direction...

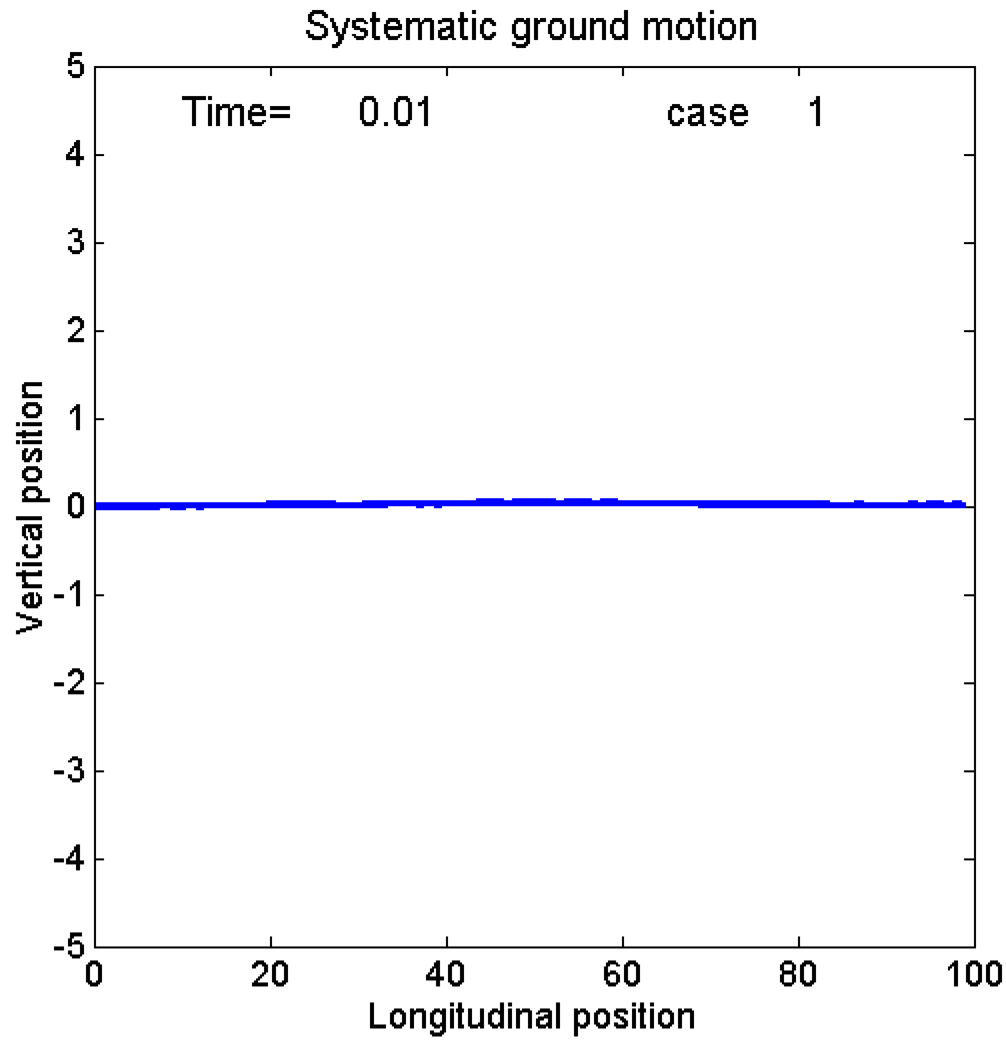


How systematic motion looks like?

- Movie of simulated systematic motion

- Note that final shape may be the same as from ATL

- And it may resemble...



And in billion years...

Systematic motion
SLAC linac tunnel in 1966-1983

- Year-to-year motion is dominated by systematic component

- Settlement...

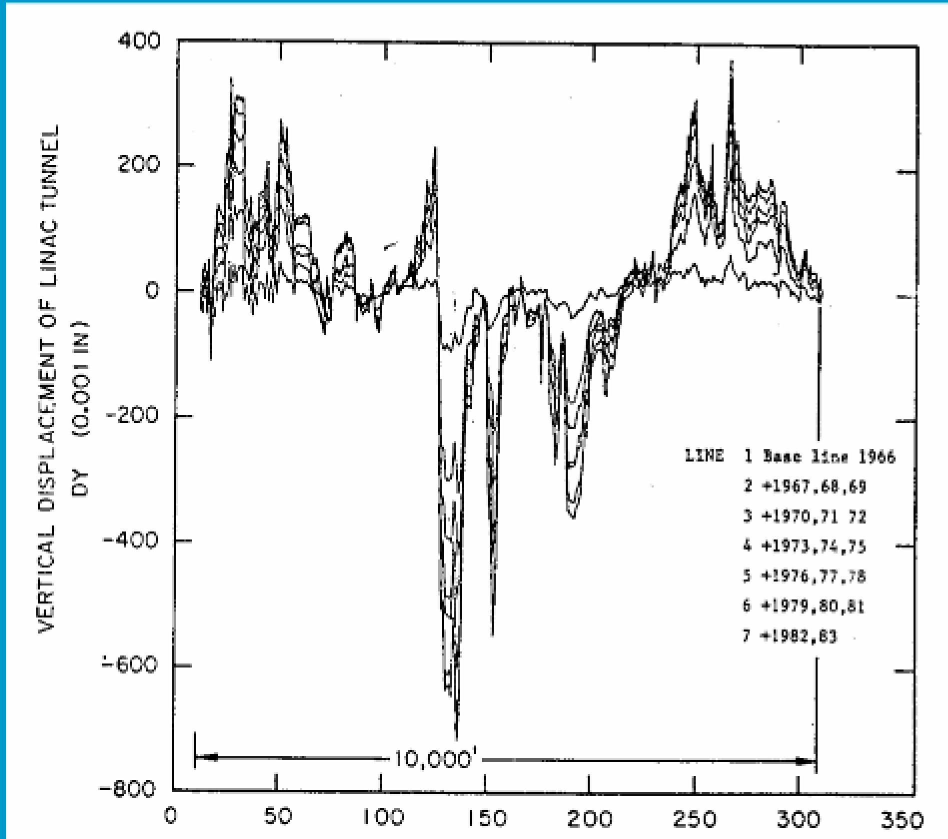


Figure 7: Displacement of the SLAC Linac Tunnel - Vertical.

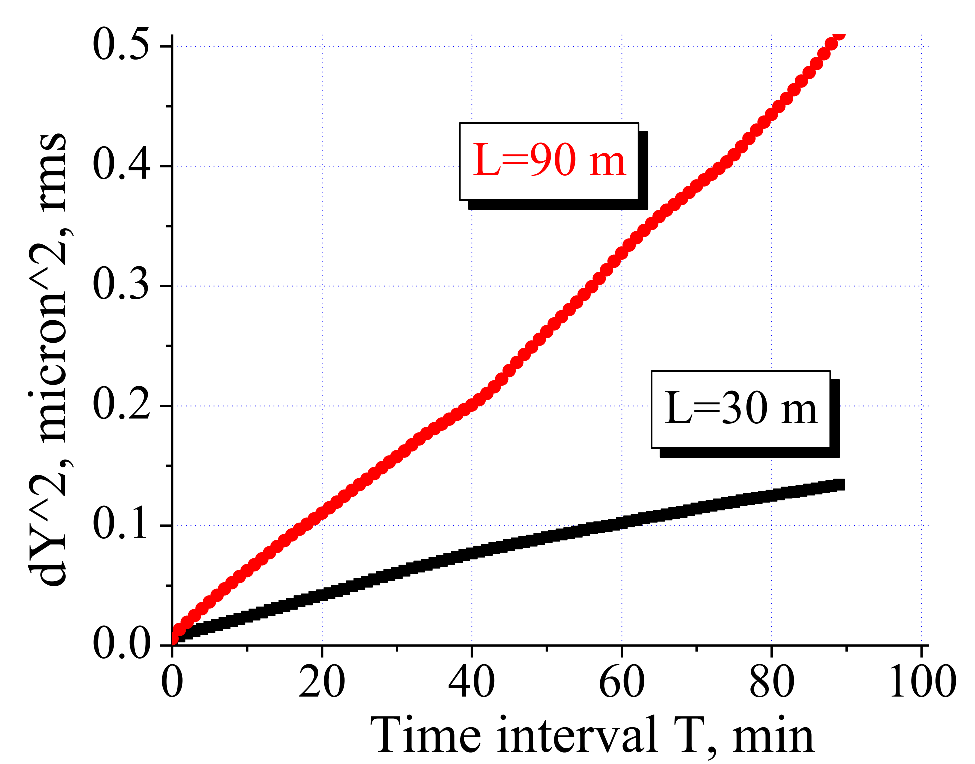
Vertical displacement of SLAC linac for 17 years

Slow motion
example: Aurora mine

- Slow motion in Aurora mine exhibit ATL behavior

- Here A~ $5*10^{-7}$ $\mu m^2/m/s$

  (similar value was observed at SLAC tunnel)



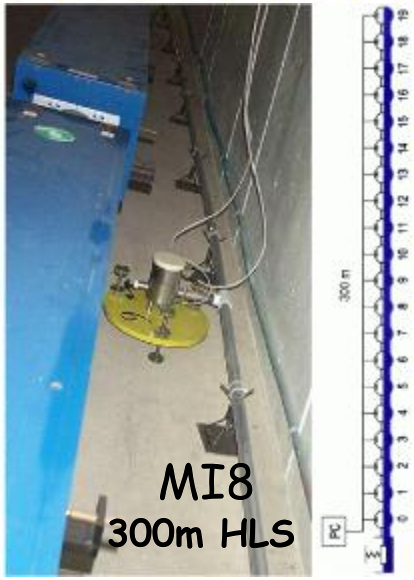
Slow motion in Aurora mine. Measured by hydrostatic level system.

Slow motion study (BINP-FNAL-SLAC)

NLC

Diffusion coefficients ***A*** [10^{-7} $\mu m^2/(m{\cdot}s)$]:
- **(10-100)** for MI8 shallow tunnel in glacial till (in absence of dominating cultural motion);
- **~3** or below in deep Aurora mine in dolomite and in SLAC shallow tunnel in sandstone

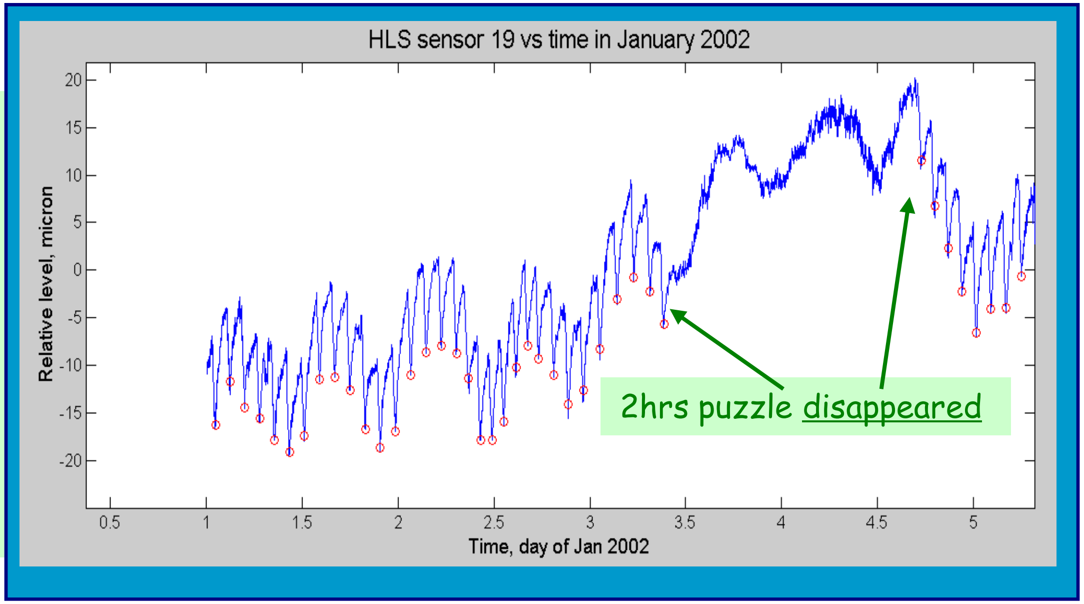
Shallow tunnel in sedimentary/glacial geology – is a risk factor, both because of higher diffusive motion, and because of possibility of cultural slow motion.



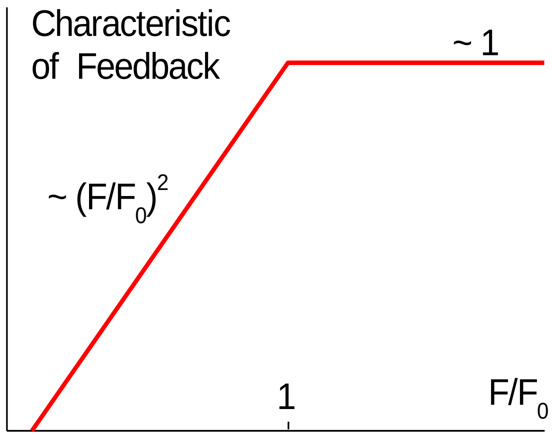
Cultural effects on slow motion:
"2hour puzzle" – 10 μm motion occurring near one of the ends of the system

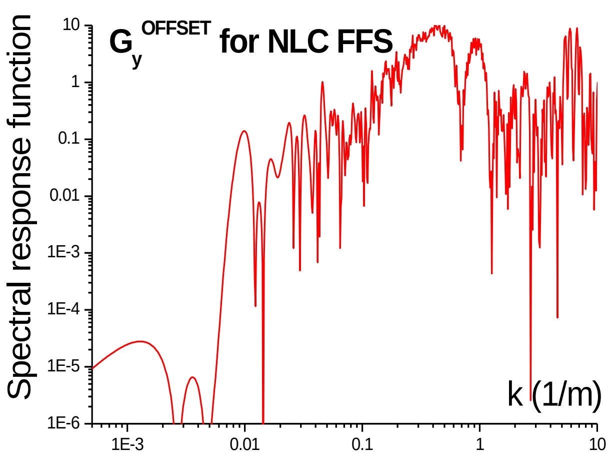
Reason: domestic water well which slowly and periodically change ground water pressure and cause ground to move

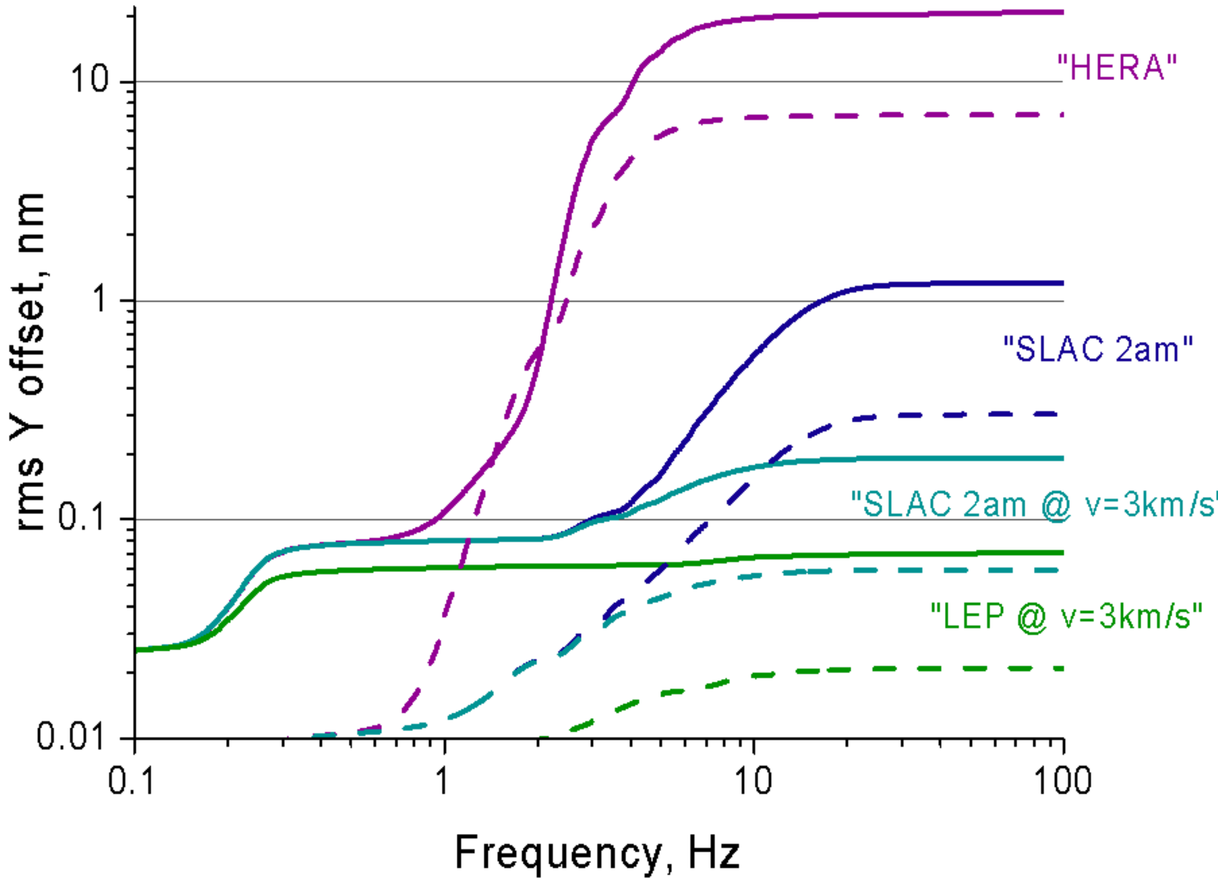
Large amplitude, rather short period, bad correlation – nasty for a collider



Beam offset at the IP of NLC FF for different GM models



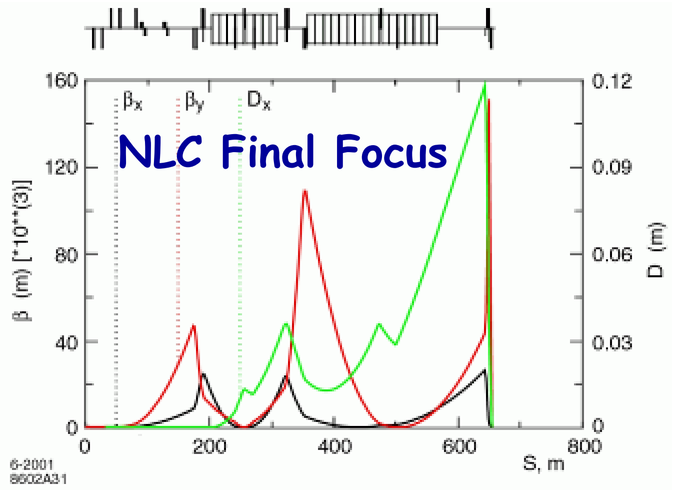


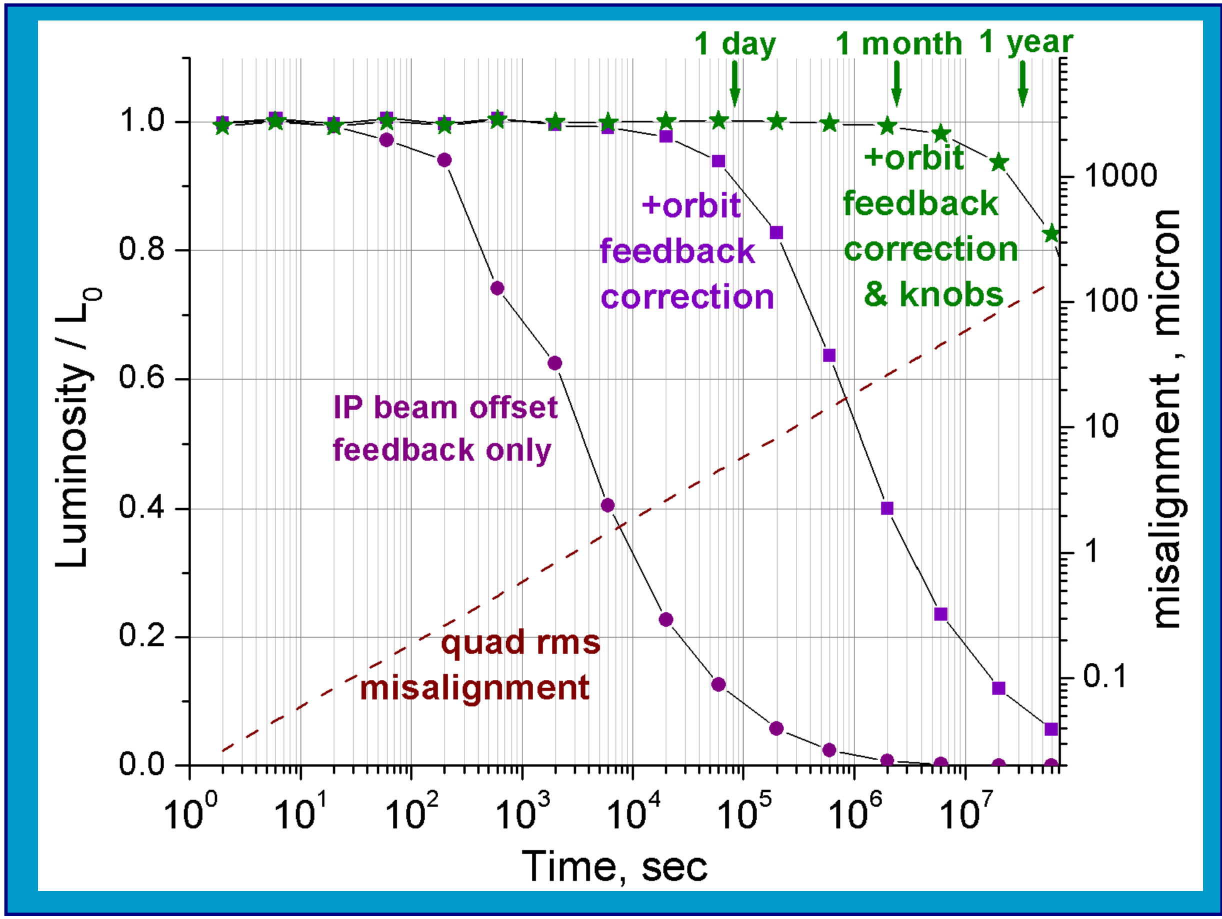


rms beam offset at IP: $\propto \iint P(\omega, k) \cdot G(k) \cdot F(\omega) \cdot dk \cdot d\omega$

Simulations of feedbacks and Final Focus knobs

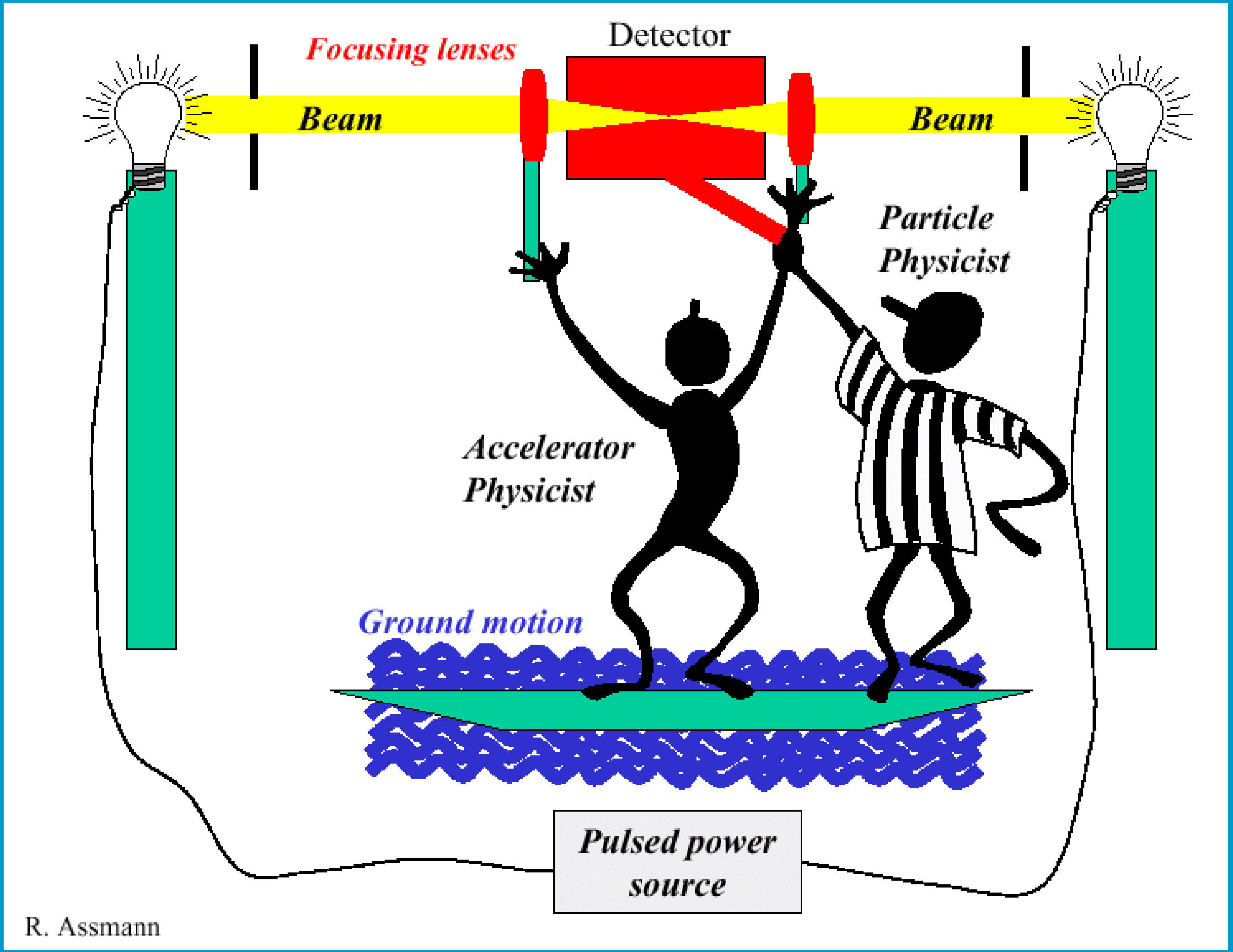
IP feedback, orbit feedback and dithering knobs suppress luminosity loss caused by ground motion





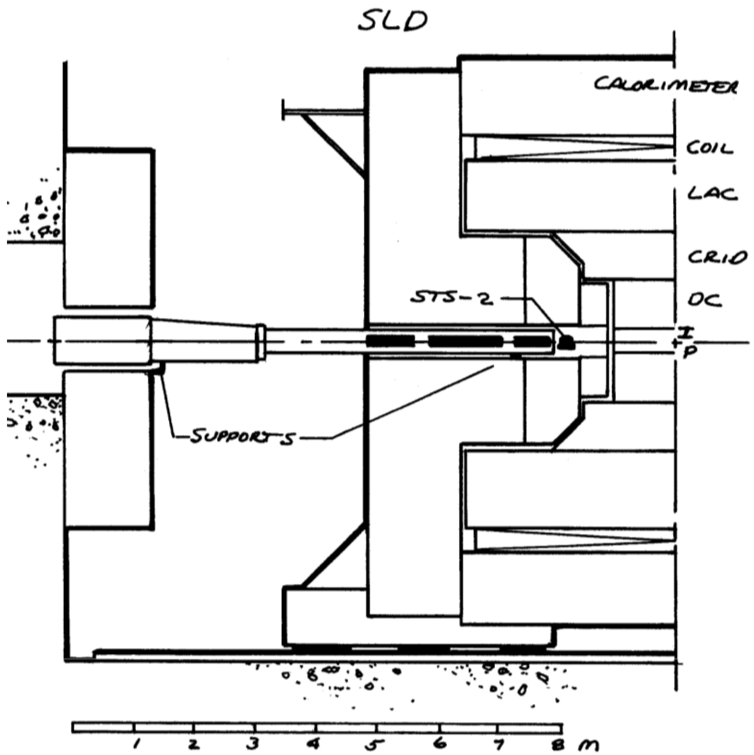
- Ground motion with $A=5*10^{-7}$ $\mu m^2/m/s$
- Simulated with MONCHOU

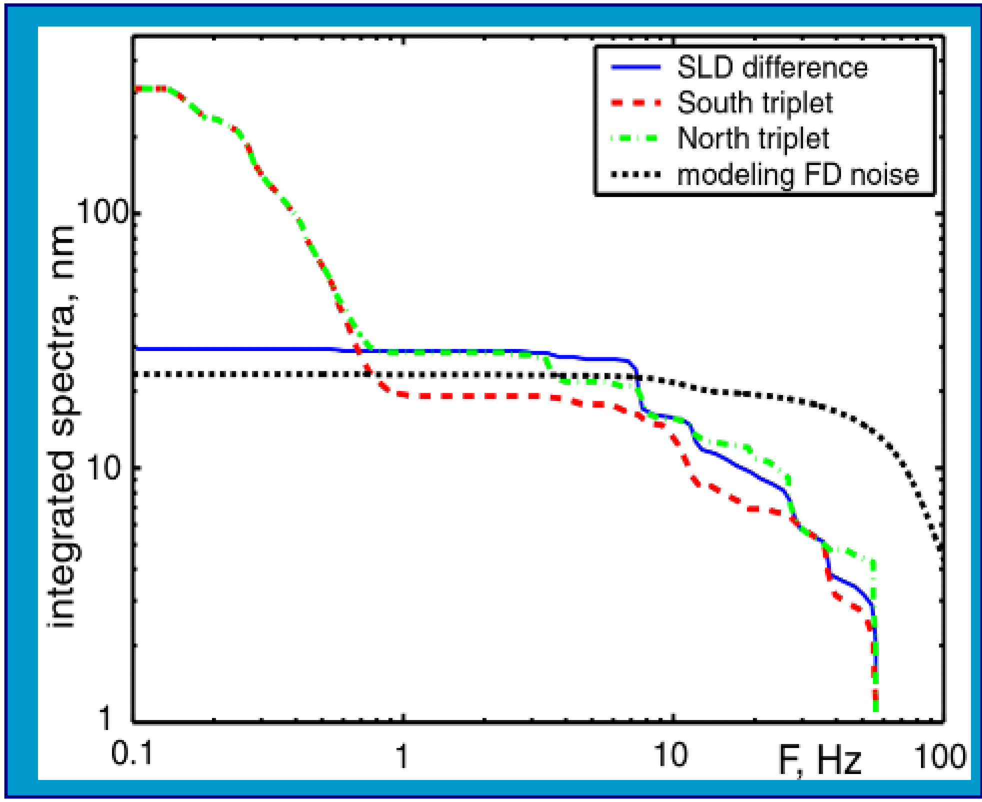
Detector complicates reaching FD stability



Cartoon from Ralph Assmann (CERN)

Detector is a noisy ground !

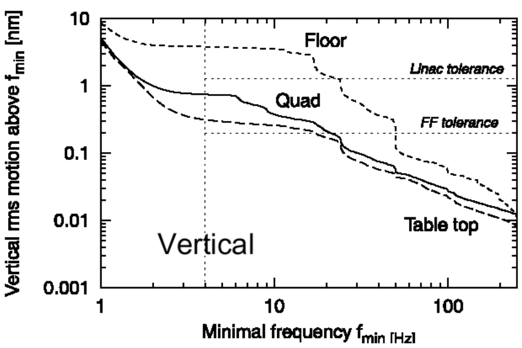




Measured ~30nm relative motion between South and North final triplets of SLC final focus. The NLC detector will be designed to be more quiet. But in modeling we pessimistically assume the amplitude as observed at SLD

CLIC stability study

Quadrupole vibration:



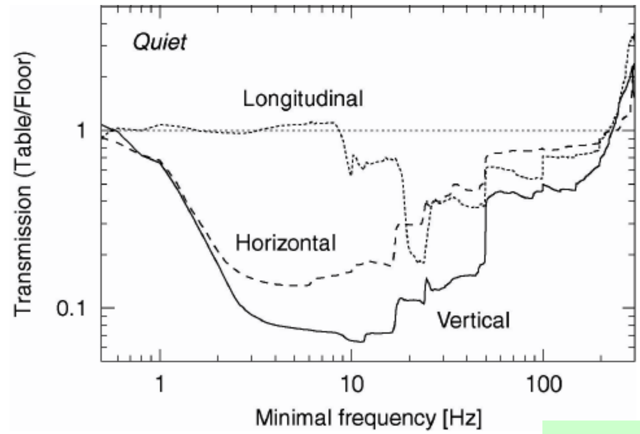
On magnet top:

X: (0.4 ± 0.1) nm

Y: (0.9 ± 0.1) nm
(0.3 nm on table top)

Z: (3.2 ± 0.4) nm

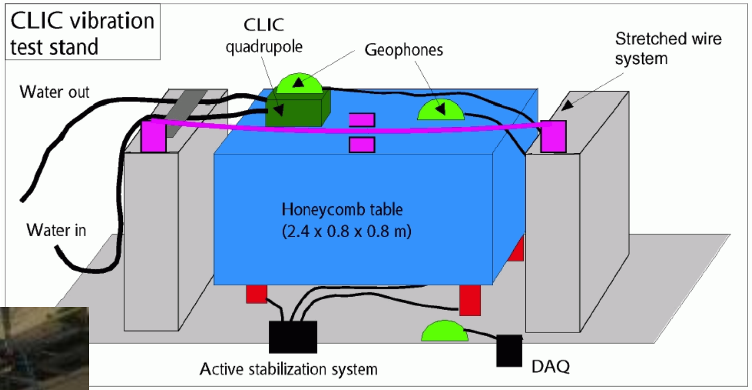
without cooling water.



With nominal flow of cooling water:

Y: (1.3 ± 0.2) nm

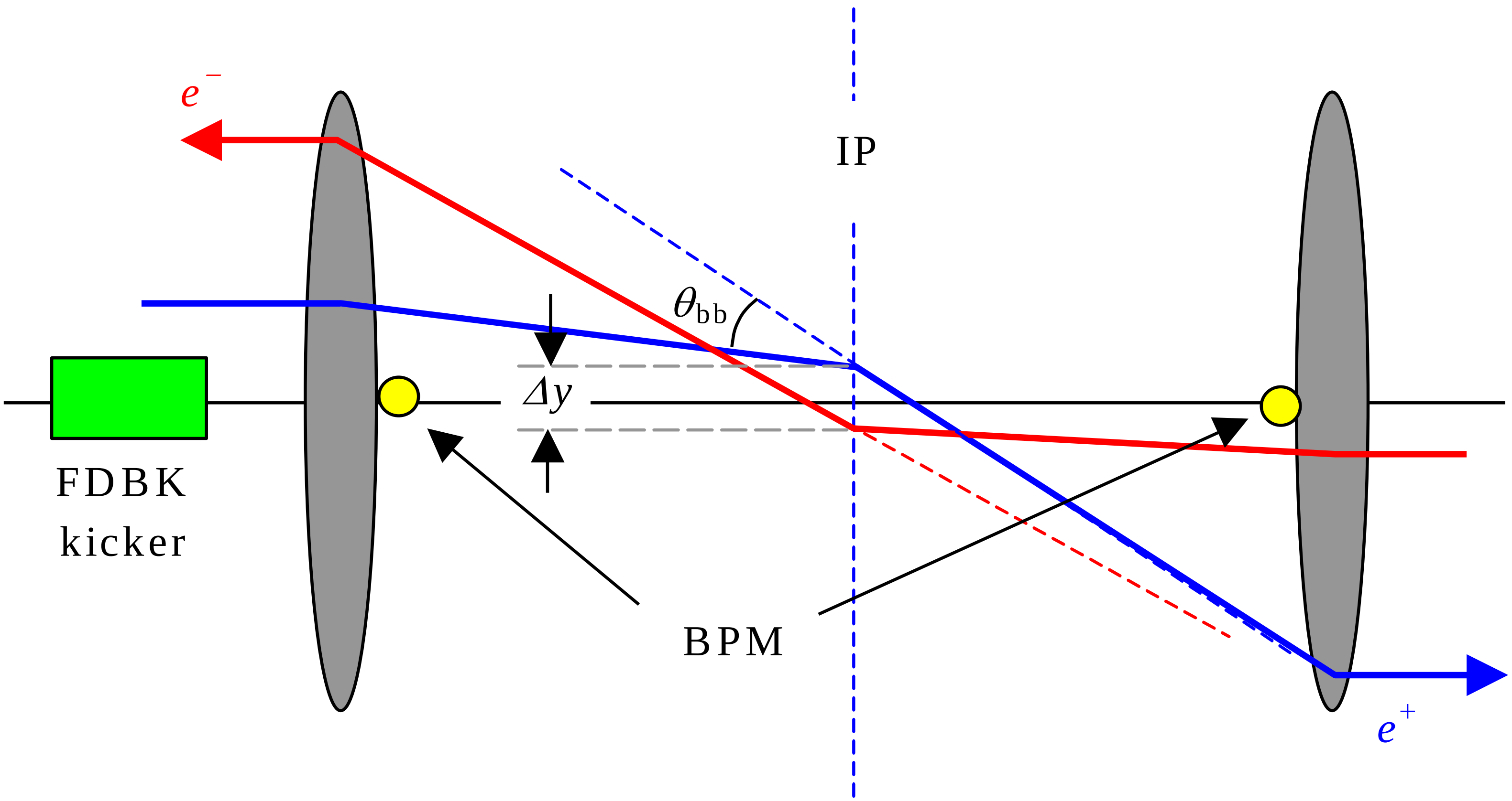
Tight vertical linac tolerance demonstrated!



Using commercial STAICIS 2000 (TMC) achieved 1nm stability of a CLIC quadrupole

Nonmagnetic sensors, detector friendly design, would be needed in real system

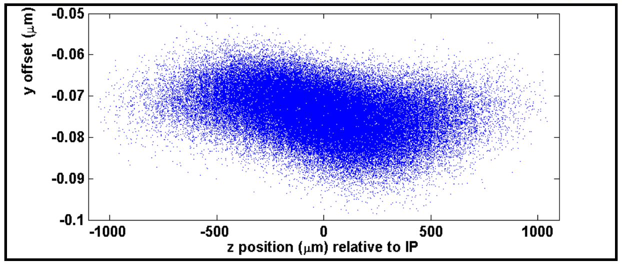
Beam-Beam orbit feedback

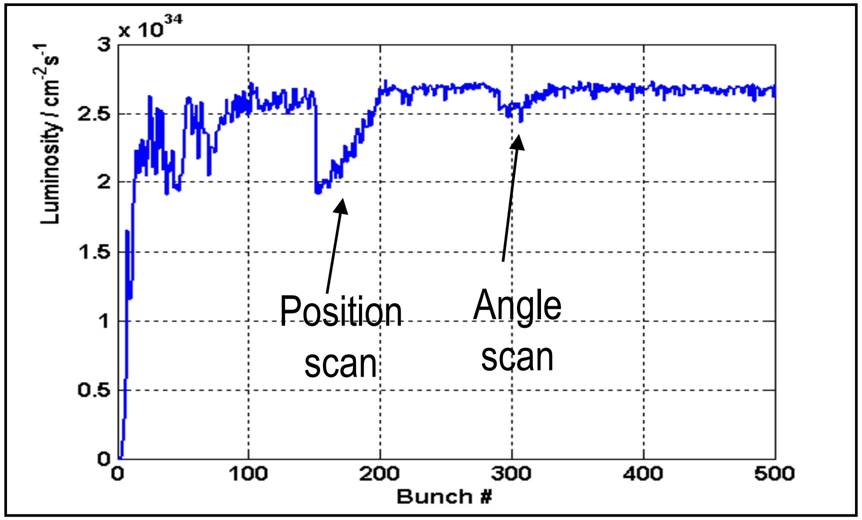


use strong beam-beam kick to keep beams colliding

ILC intratrain simulation

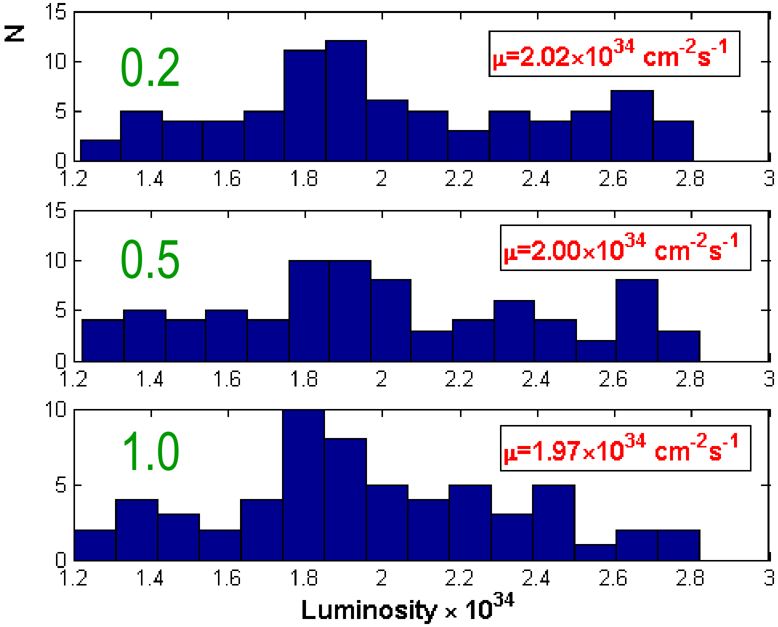
ILC intratrain feedback (IP position and angle optimization), simulated with realistic errors in the linac and “banana” bunches, show Lumi ~2e34 (2/3 of design). Studies continue.





Luminosity through bunch train showing effects of position/angle scans (small). Noisy for first ~100 bunches (HOM’s).

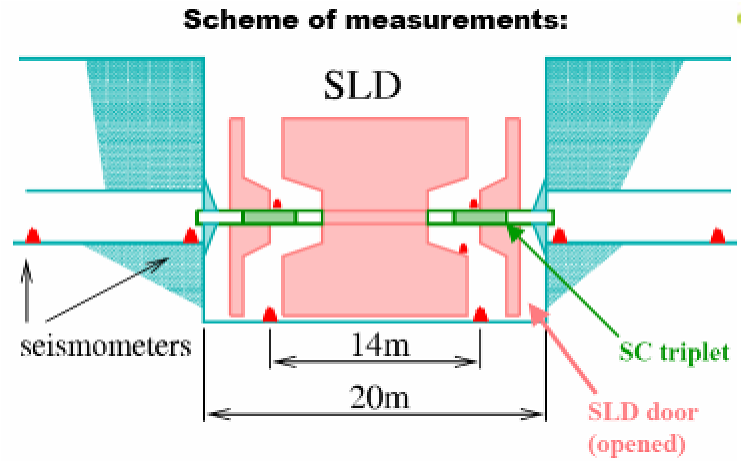
Luminosity for ~100 seeds / run

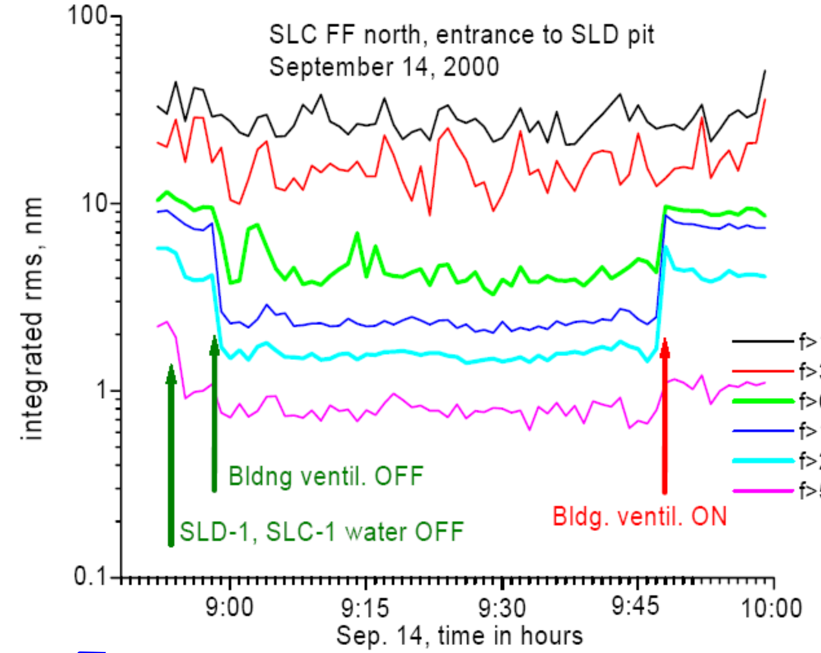


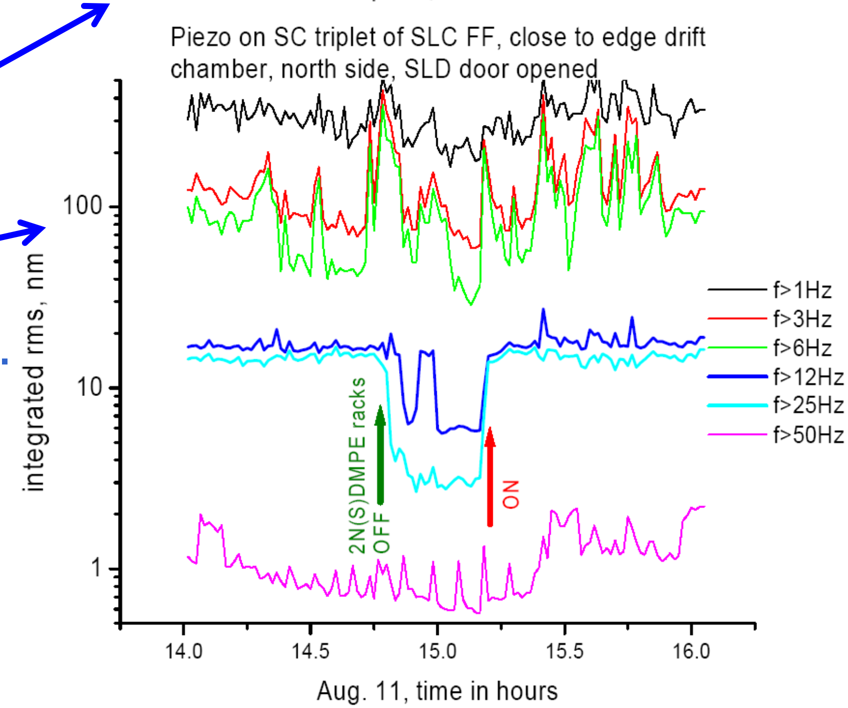
Injection Error (RMS/σ_y): 0.2, 0.5, 1.0

[Glen White]

Vibrations at detector





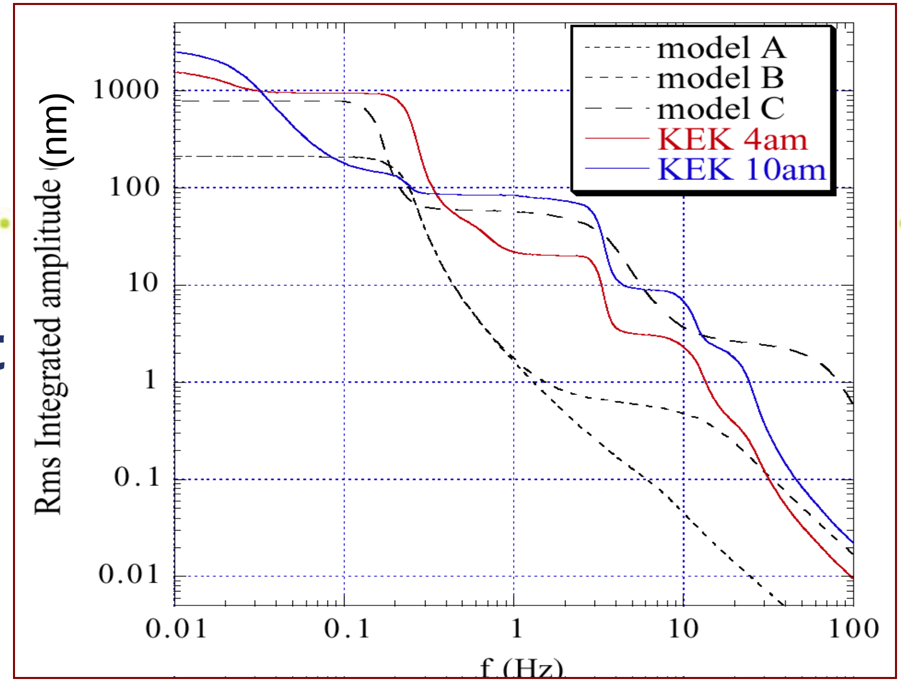


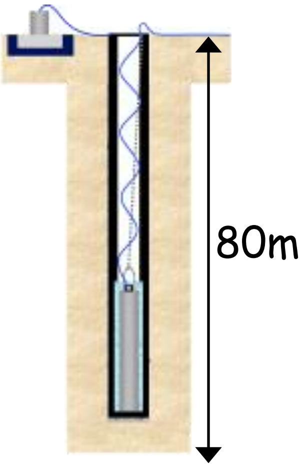
- Floor noise in SLD pit and FF tunnel mostly affected by building ventilation and water compressor station
- Vibration on detector mostly driven by on-SLD door mounted racks, pumps, etc.

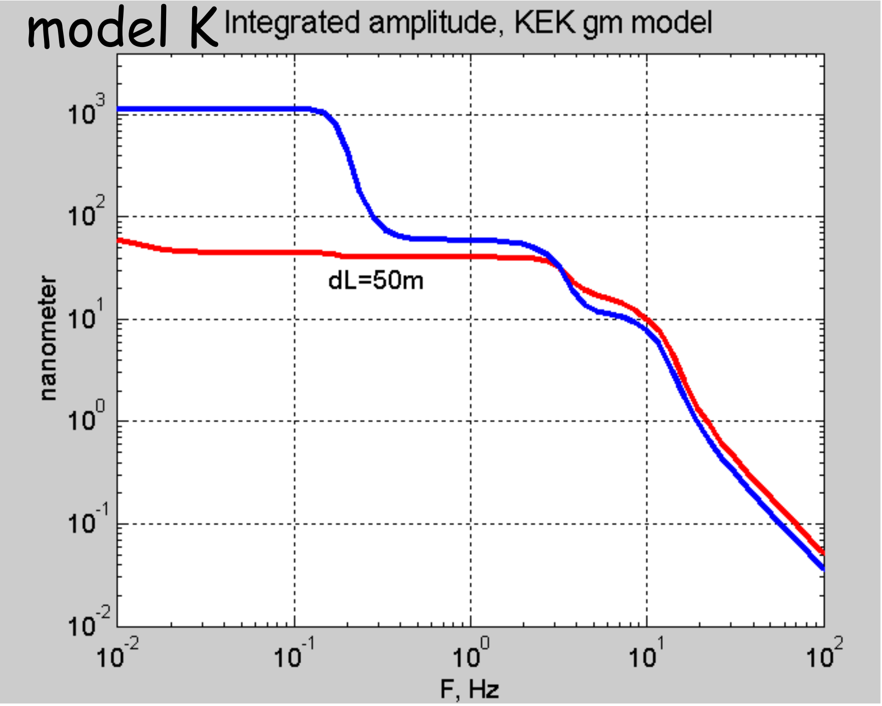
- This shows that it may be needed to place noisy detector equipment on separate platform nearby

Model K

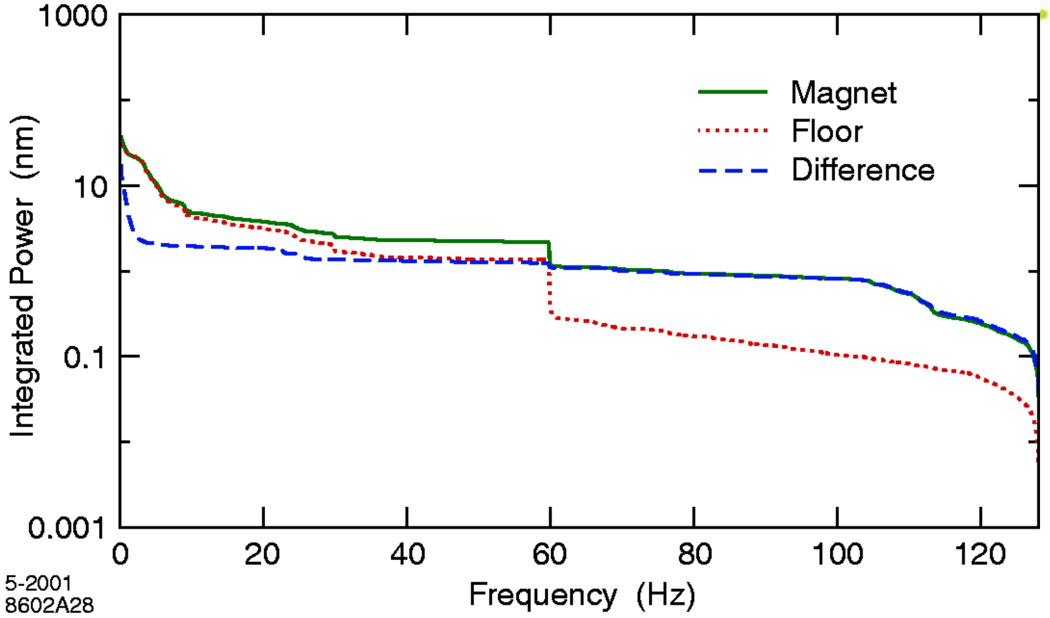
- Based on measurements at KEK, in a borehole near Higashi-Odori, Toshiaki Tauchi et al.
- del C in 1-10Hz,
  above 20Hz







10 nm goal for BDS component jitter



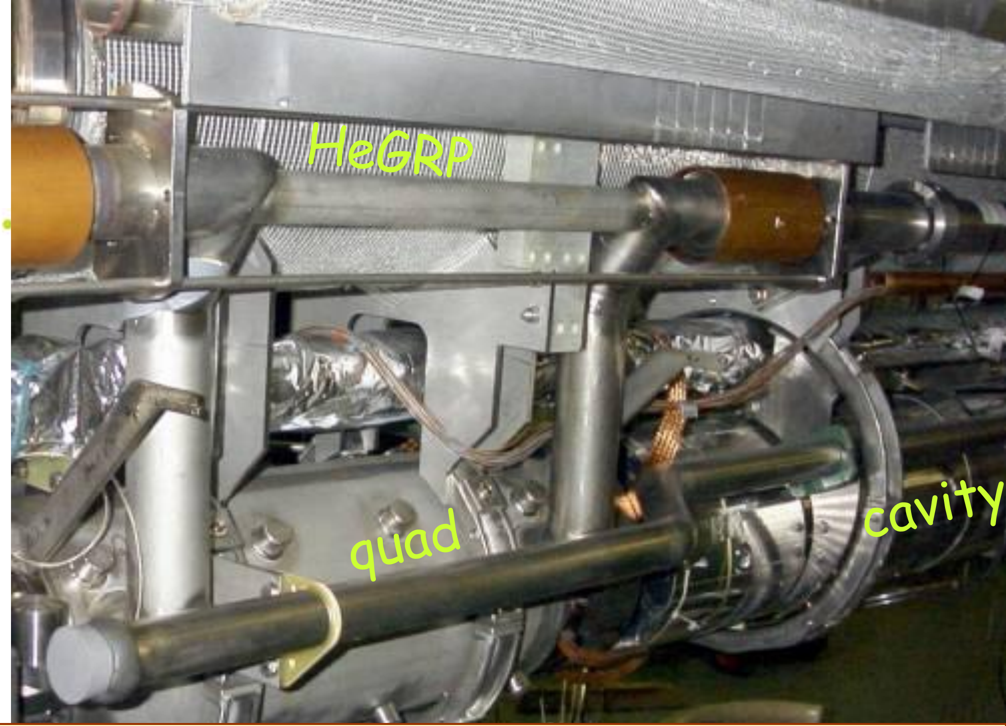
- FFTB quad
  - Small (~2nm at 5Hz) difference to ground (on movers, with water flow, etc.)
  - Lower frequency is relevant for 5Hz machine (0.2-0.5Hz) but was not studied accurately
  - The 10nm goal may be achievable (for BDS area in gm B to B*3)

ILC linac quad stability

TTF cryomodules, since ~1995, were equipped with vibration sensors.

Studies at TTF were ongoing in September 2002 [1]. At that time there was still big uncertainty in the measured data, due to not well determined calibration at cold temperature, issues with sensor grounding, measured spectrum being limited to <100Hz, etc.

[1] Private communication with DESY engineers Heiner Brueck and Erwin Gadwinkel.



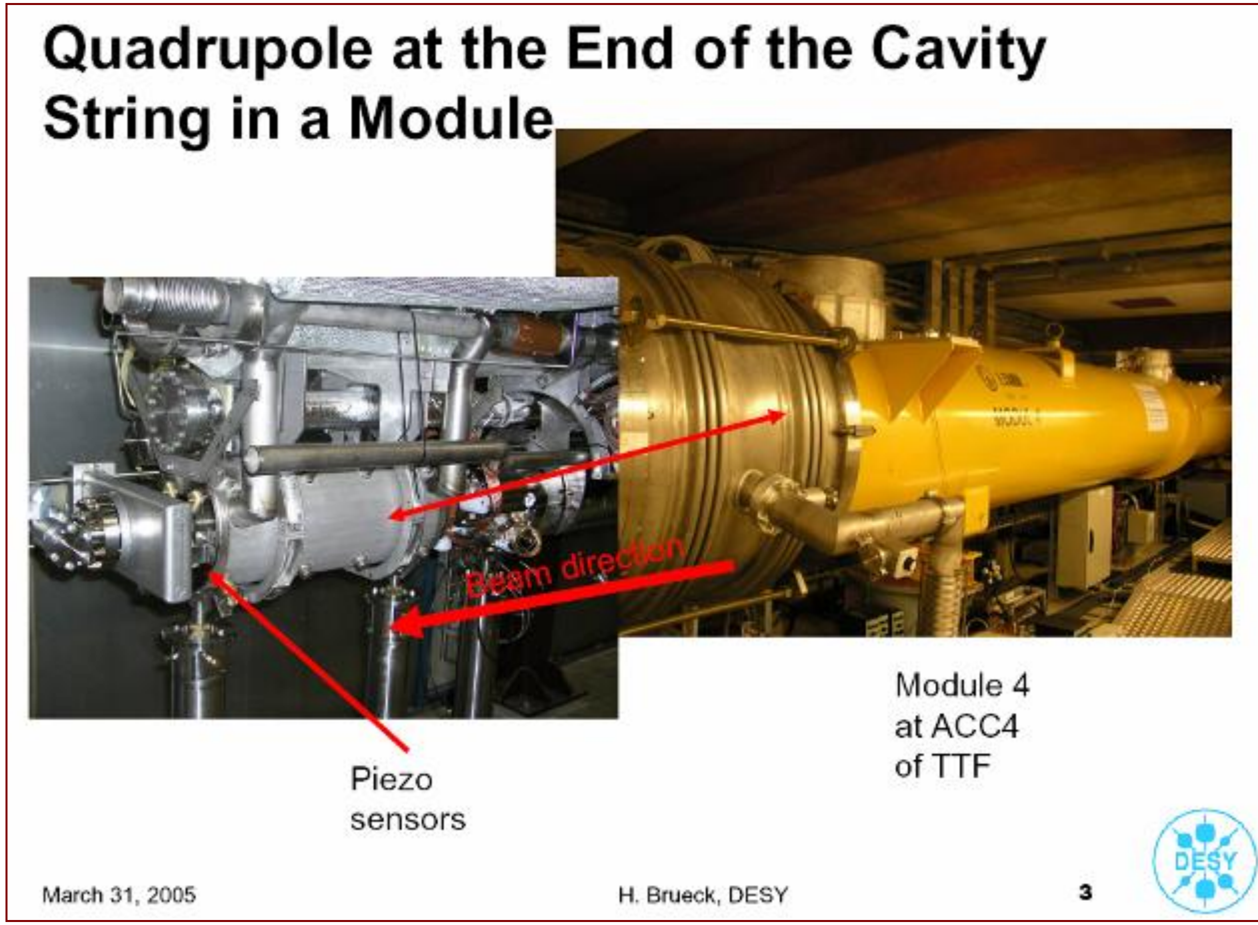
TRC R2 :
"A sufficiently detailed prototype of the main linac module (girder or cryomodule with quadrupole) must be developed to provide information about on-girder sources of vibration."

- Recent progress in studies of quad stability in cryomodules
  - use of piezo sensors
  - use of wire position system

Most Recent results on cryo-module stability were presented at E-ILC meeting, January 2007, by R. Amirikas, A. Bertolini, W. Bialowons

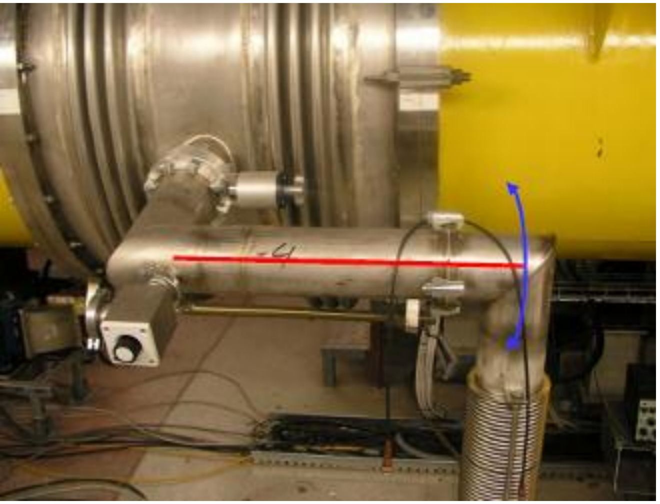
Vibration study at TTF in cold

- Heiner Brueck et al., TESLA Meeting, Hamburg 03/31/2005
  - Piezo sensors (cold) at the quad, in X and Y directions
  - Sensors on top of the module, on ground, support, +geophone



Heiner Brueck, et al.

TTF vibration study – pump modification

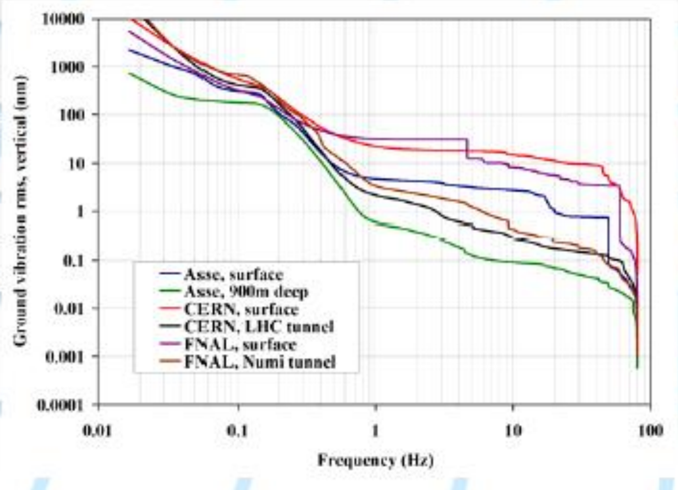


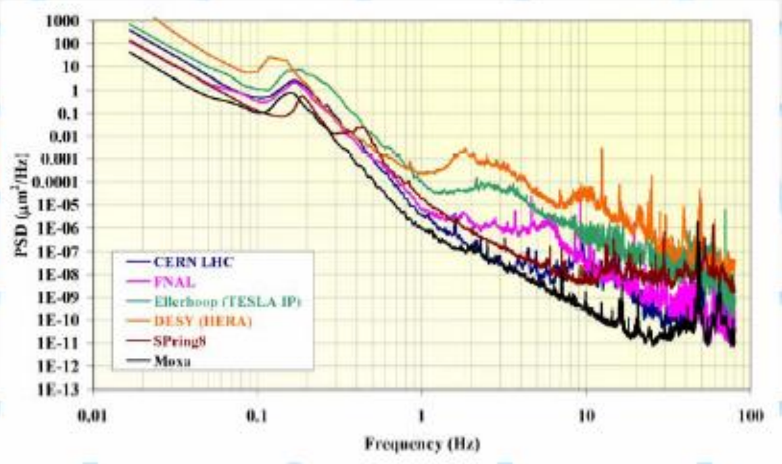
- Decouple pump from cryomodule, use flexible pipe and foam under the pump

Heiner Brueck, et al.

Overview of Our Research Program & Vibration Studies of a XFEL/ILC Cryomodule at Room Temperature

R. Amirikas, A. Bertolini, W. Bialowons

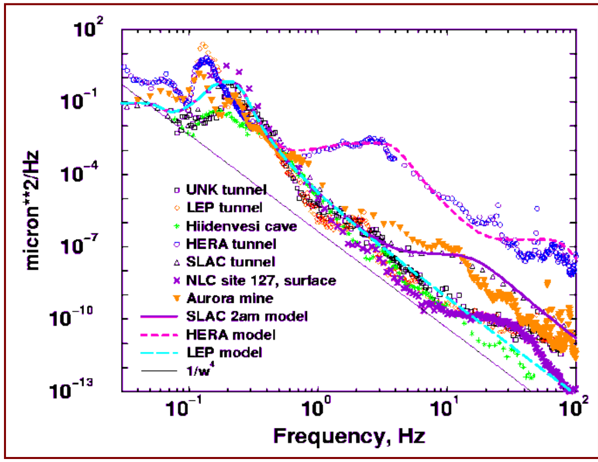


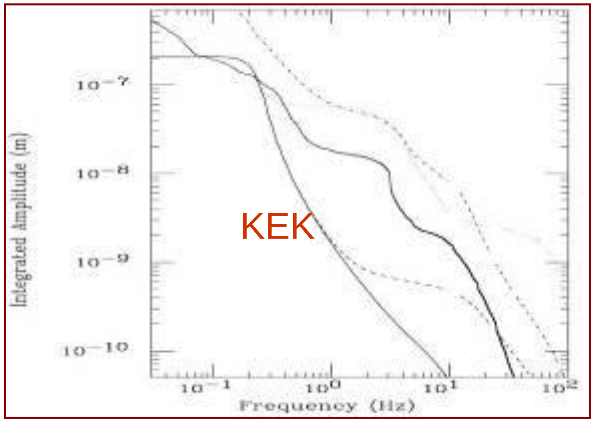


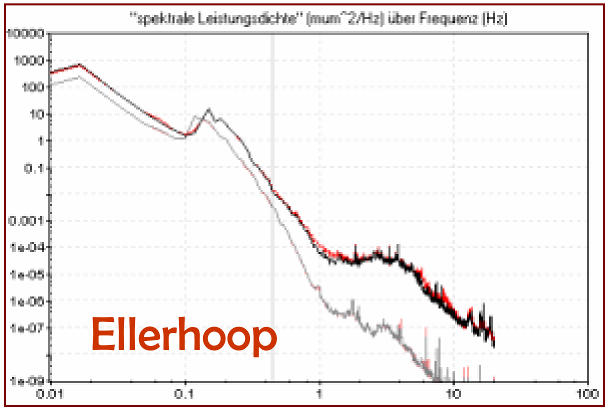
DESY

Site stability studies

- Many places around the world

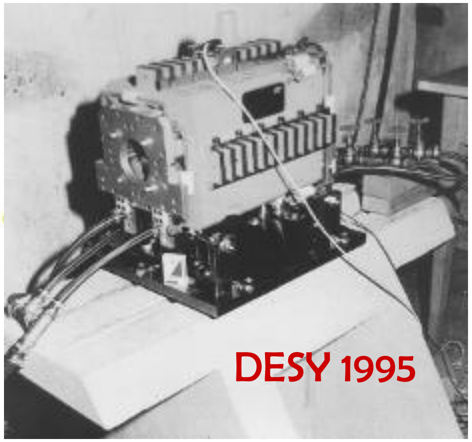


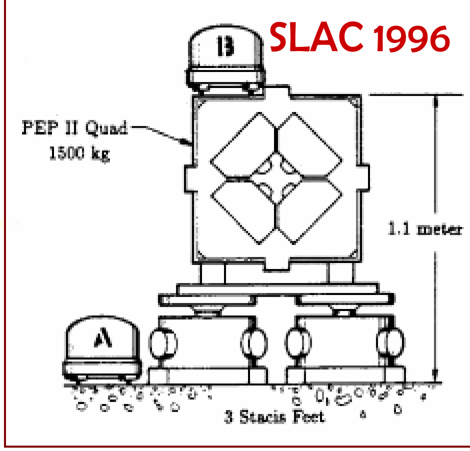


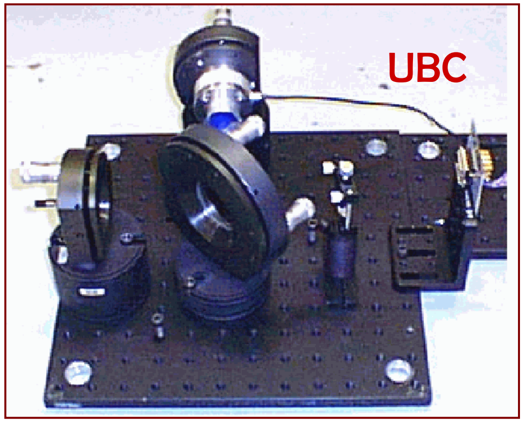


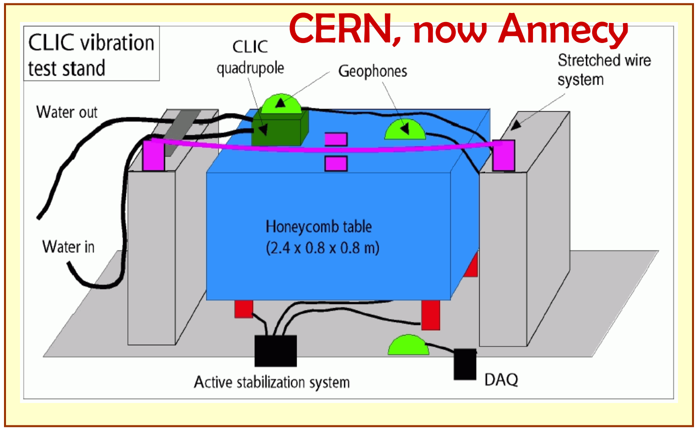
Stabilization studies

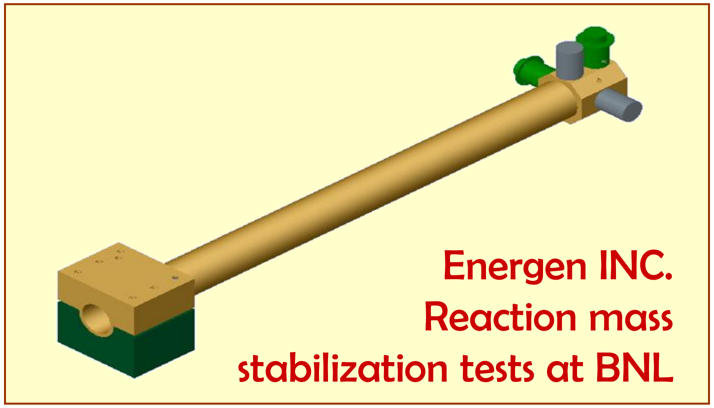
- Experience invaluable
- Components of developed hardware may be applicable





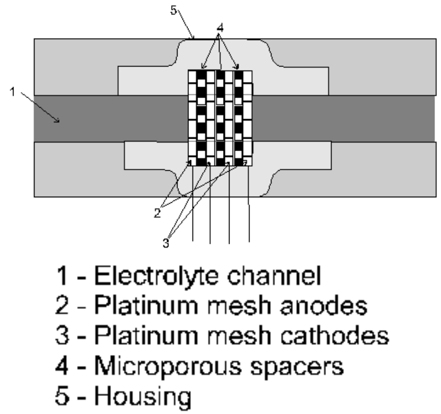


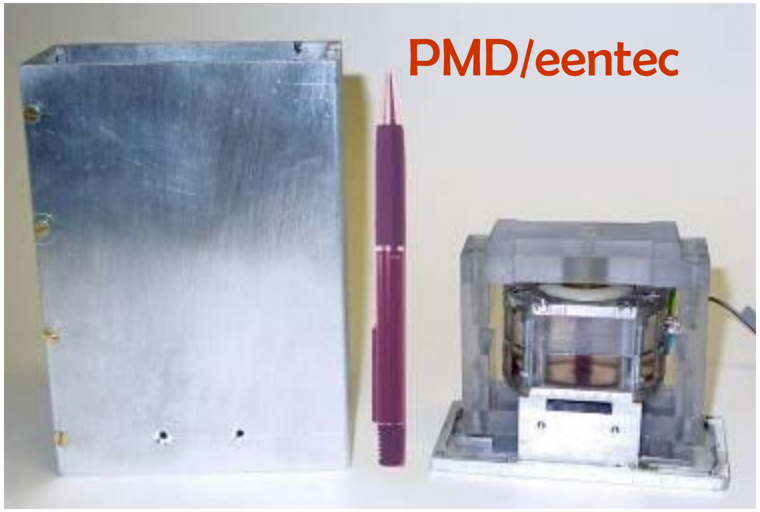




Development of sensors for IR

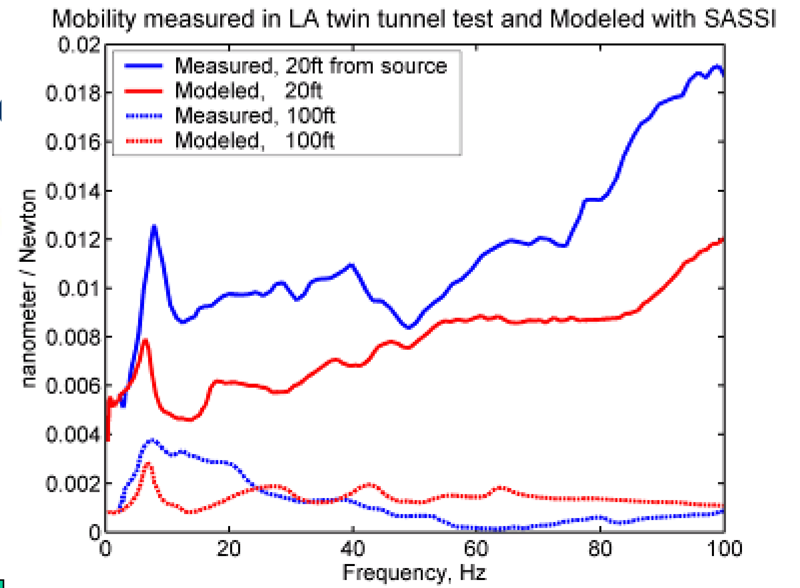
- Nonmagnetic inertial seismometers
  - SLAC home built – low noise, as good as Mark4 geophone or better
  - Molecular Electronic Transfer sensor – low noise, tested in 1.2T field, but cannot be cooled
- Interferometer methods
- Will need to use these or more advanced sensors to monitor FD motion



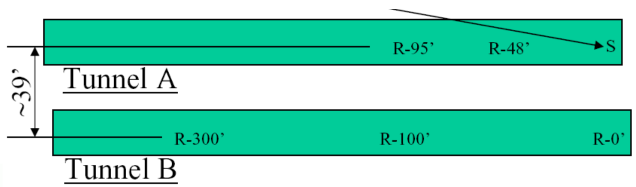


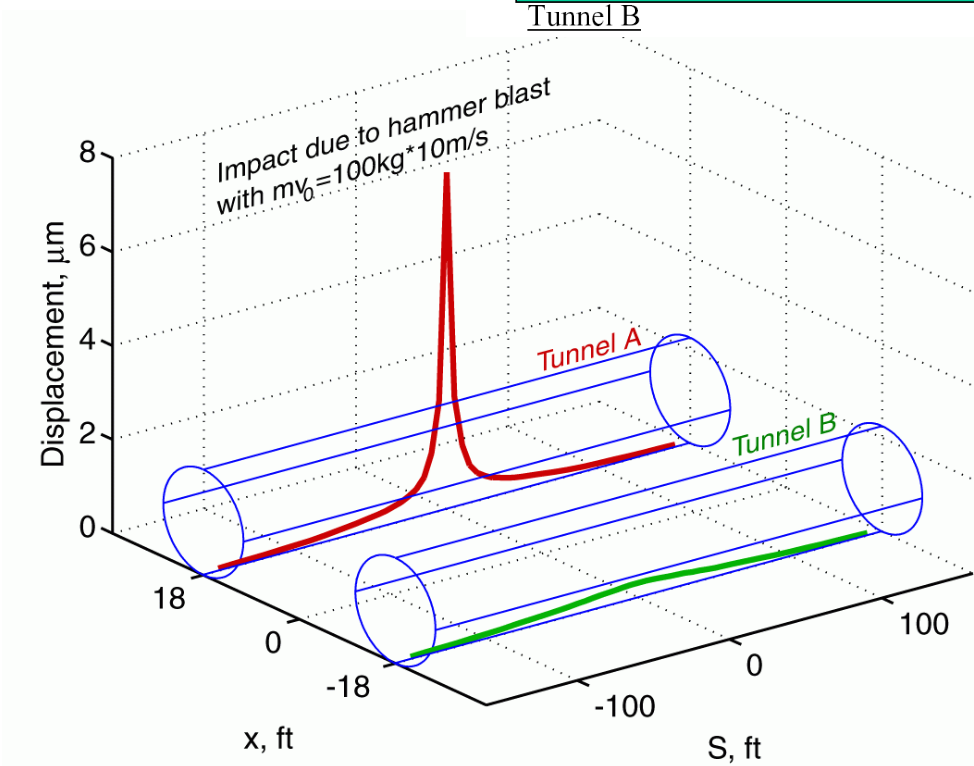
Vibration tr

- LA twin tunnel: between tunnels and from surface (figs shown)
- Results are valuable for ILC



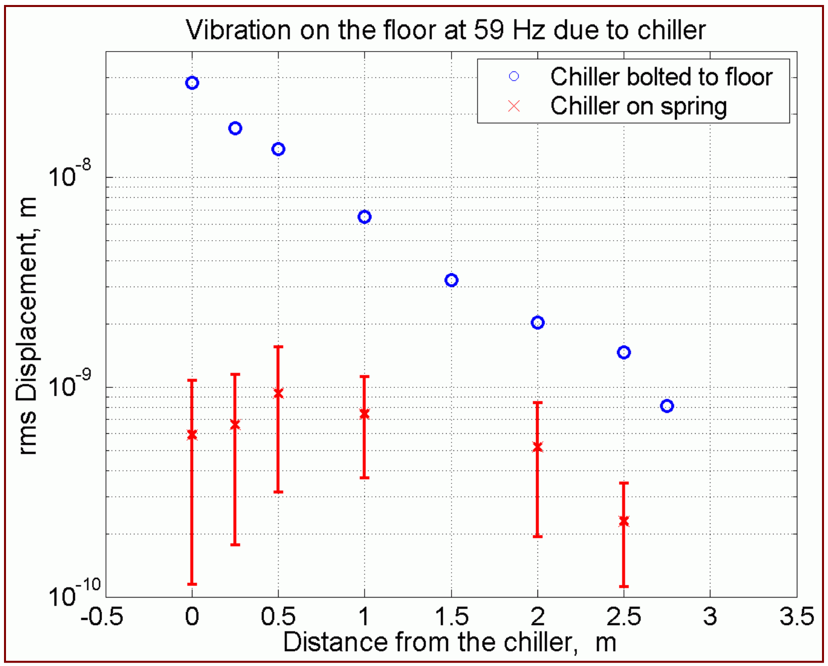
Mobility (response / driving force) measured in LA metro twin tunnel test and modeled with 3D code SASSI.





Vibration isolation of vibration sources

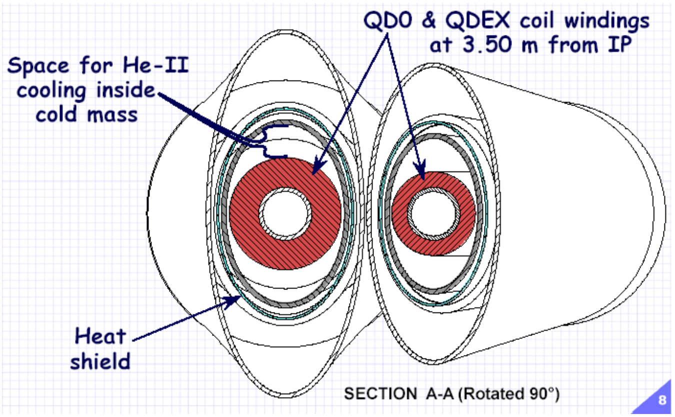
- Should be a standard practice for ILC

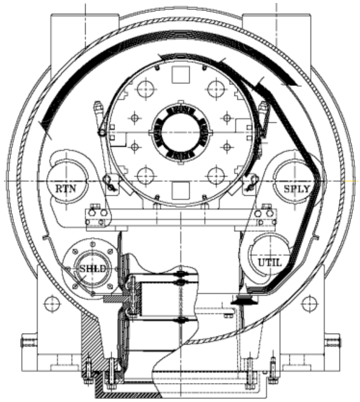


Vibration on the floor vs distance.
For chiller on springs, its vibration effects are indistinguishable on the floor.

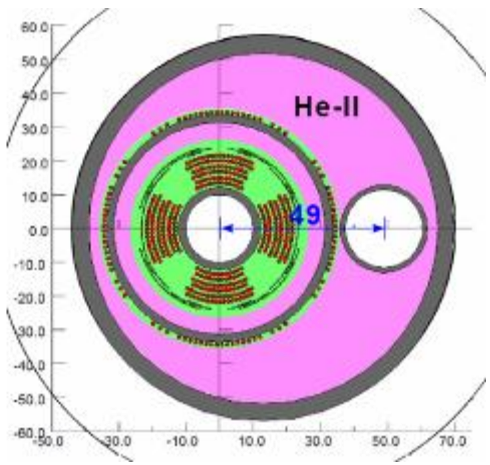
FD magnet stability

- Stability of FD magnets need to be studied
- BNL preparing to measure stability of compact SC quads
- First results with CQS quad will be presented – encouraging results
- Annecy group is aimed to study FD stability (simulation & experiments) with BNL FD design
- Studies at ATF2 ?





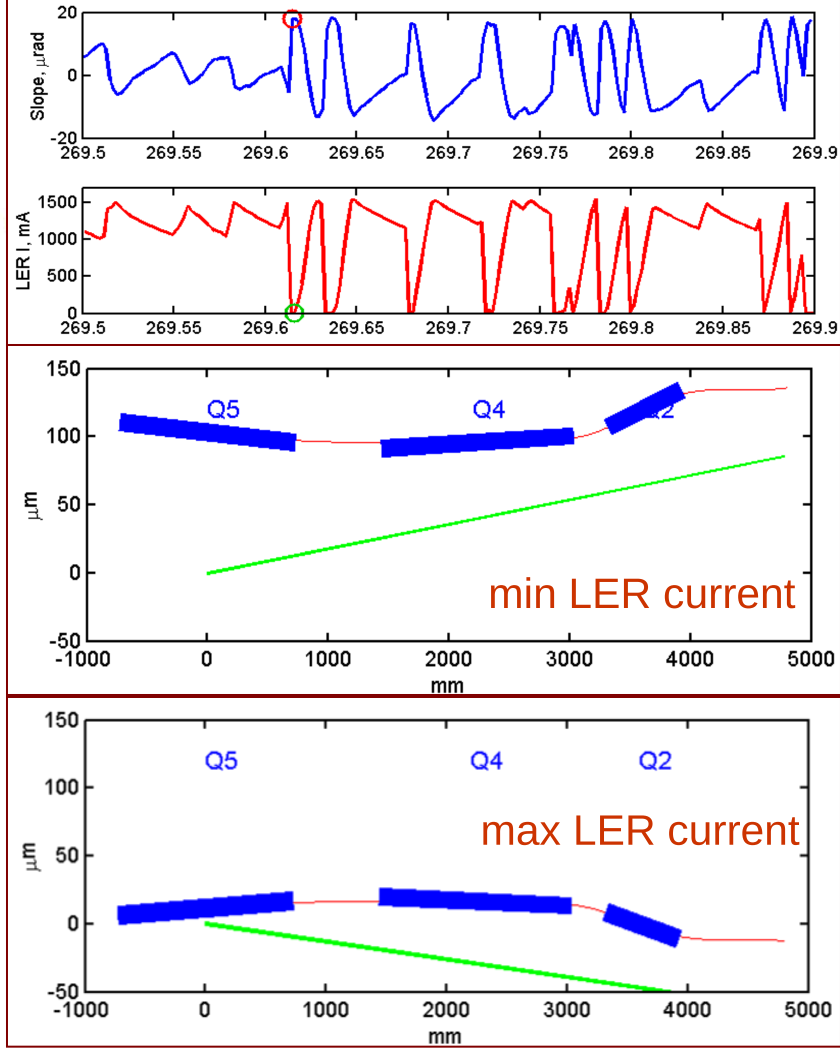
RHIC CQS



Evolution of FD design with compact quads, B.Parker et al

IR stability

- Vibration is not the only concern
  - Temperature stability?
  - Wakes heating the IR chamber and deforming it? During 1ms?
  - SR should be well masked in IR, but may it cause deformations in other parts of BDS?
  - Example of PEP-II: IR heated by SR from LER and is moving by 0.1 mm as e+ current vary



Current of Low Energy Ring, slope of the girder measured by HLS and wire, and reconstructed position of FD magnets for min and max LER current