GROUND MOTION MODEL FOR THE LHC

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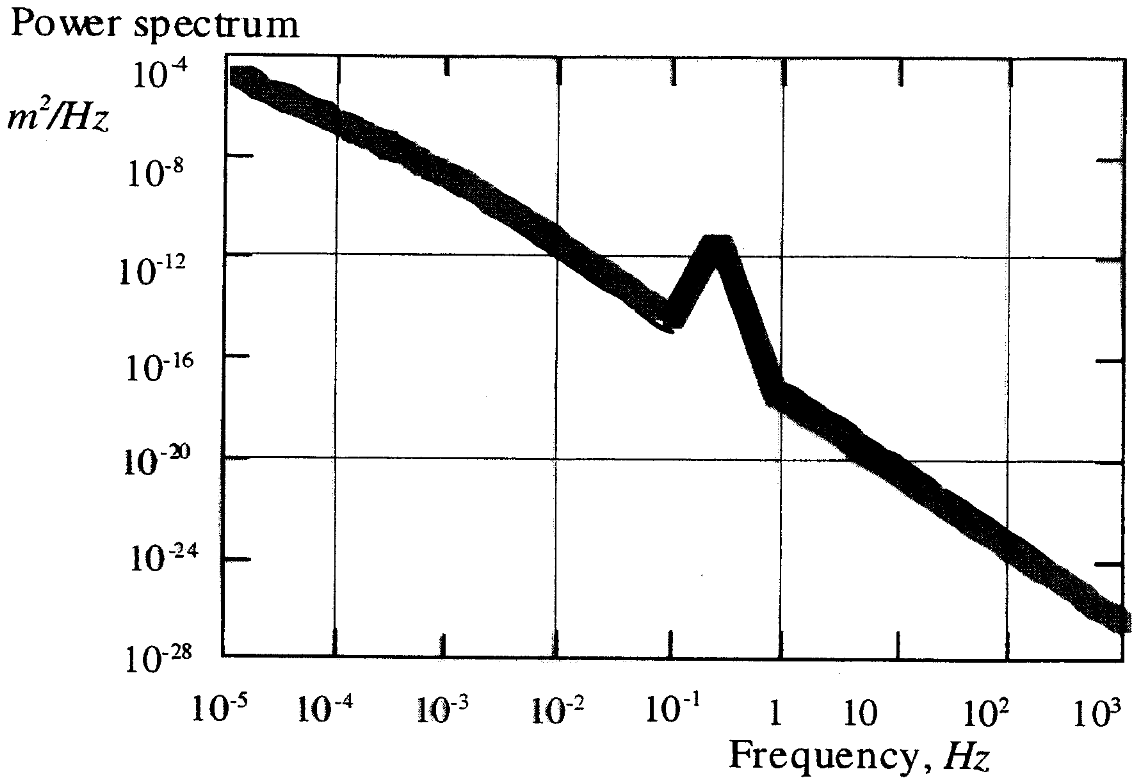
1 INTRODUCTION



(cultural noise taken out)

- power of ground vibrations increases steeply with decreasing frequency

===> possibility of non-negligible orbit deformations if the motion of accelerator quadrupoles is uncorrelated

- what about **plane wave excitation** ?

ground motion wavelength matches the betatron wavelength

===> very **narrow band** effect for frequencies around 1 Hz, ***small spectral power***, small separation effect in LHC < 1/1000 of *rms* beam size

2.2 Basic model

The model consists of a transfer function and a source of excitation

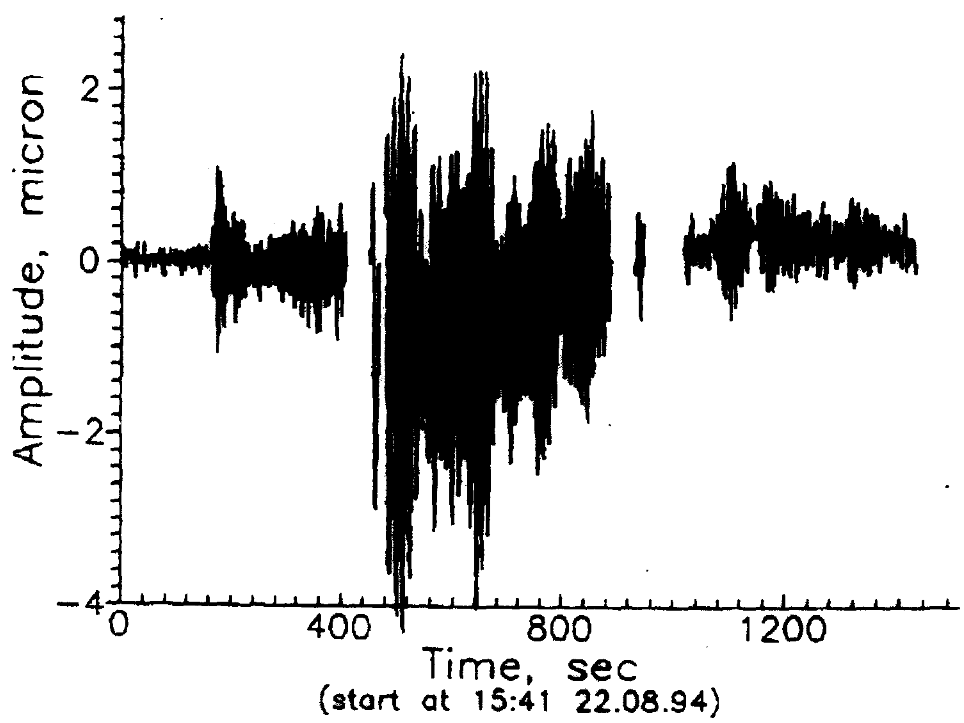
2.2.1 transfer function

maximum seismic length of the earth is ~1500 *s*

seismic '**depth**' of the earth is about 1/3 of this

===> a *cut-off* frequency of f_{co}~*2 mHz*

confirmed by the far away amplitude response of earth quakes:



fast oscillation is the response of the oceans pounding on the continents

amplitude response is not incompatible with a high-pass filter behaviour with a **power** cut-off frequency f_{co} *~1.5 mHz*

note : seismic wave attenuation with distance is very small

2.2.2 source

the obvious source is : *earth quakes!*

the transfer model suggests a source with a f^{-3} frequency slope to reproduce noise spectra

examination of a substantial body of phenomenological material has led to the ***Gütenberg- Richter law*** :

$$\log(n) = -M,$$

n is the number of earth quakes in a given area with a magnitude ***M*** or larger

$$M = \frac{1}{m}\log\left(\frac{x}{x_0}\right)^2$$

x_0 is the lower observation limit of seismographs.

According to *Hamblin m* = 2 so that :

$$\left(\frac{x}{x_0}\right)^2 = \frac{1}{n^2}.$$

The power density of the source can be found by differentiation :

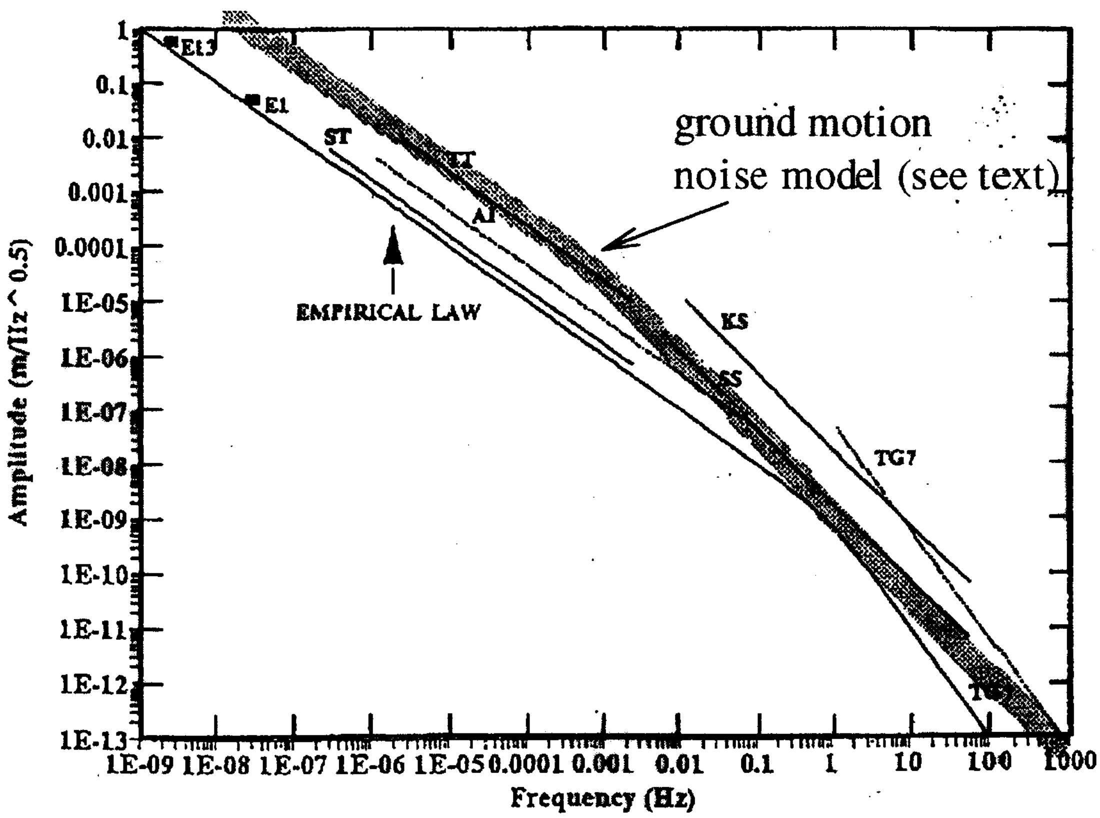
$$\frac{d(x/x_0)^2}{dn} = -\frac{2}{n^3} \propto -\frac{1}{f^3}$$

Combining transfer function and source of vibrations yields the ground motion spectrum :

$$\frac{dx^2}{df}(f) = \frac{k_{gm}}{f^2\sqrt{f_{co}^2 + f^2}}\left[m^2/Hz\right].$$

k_{gm} is a proportionality factor of the source to fit the observed spectral power density. It is a non-local quantity that varies from $\sim 10^{-18}\ m^2/s^2$ to $\sim 10^{-16}\ m^2/s^2$ depending on the state of **global excitation**

Comparison with various observations :



The line marked 'empirical law' is related to the model proposed by Takeda et al.

3 OBSERVATIONS WITH BEAM

coherence length can be determined from orbit measurements assuming an average value for $k_{gm} = 10^{-18}\ m^2/s^2$.

integration noise spectrum yields **displacement2** of a single element :

$$dx^2(t) = \frac{k_{gm}}{f_{co}^2}\left(\sqrt{1+(f_{co}t)^2} - 1\right).$$

orbit deformation : **multiply with an optical amplification** factor :

$$O_A = (\beta Kl/2\sin(\pi q))^2 N$$

β	the optical function at a quadrupole
Kl	integrated focalisation force
N	is the **number** of **uncorrelated** blocks around the accelerator (at the maximum the number of *F* or *D* quadrupoles)

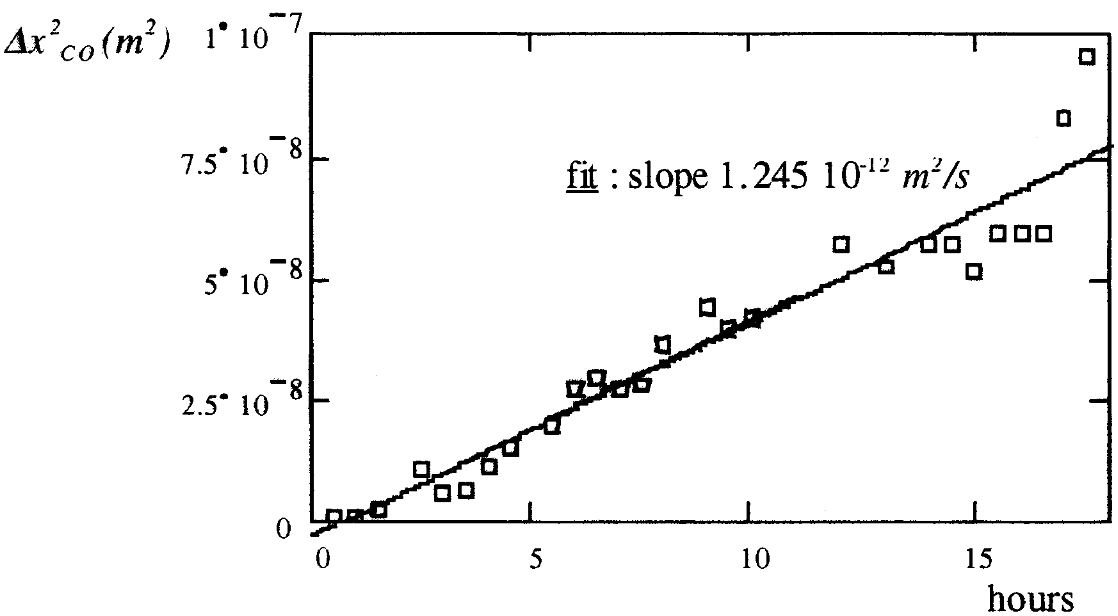
Brinkman & Rossbach (1994)

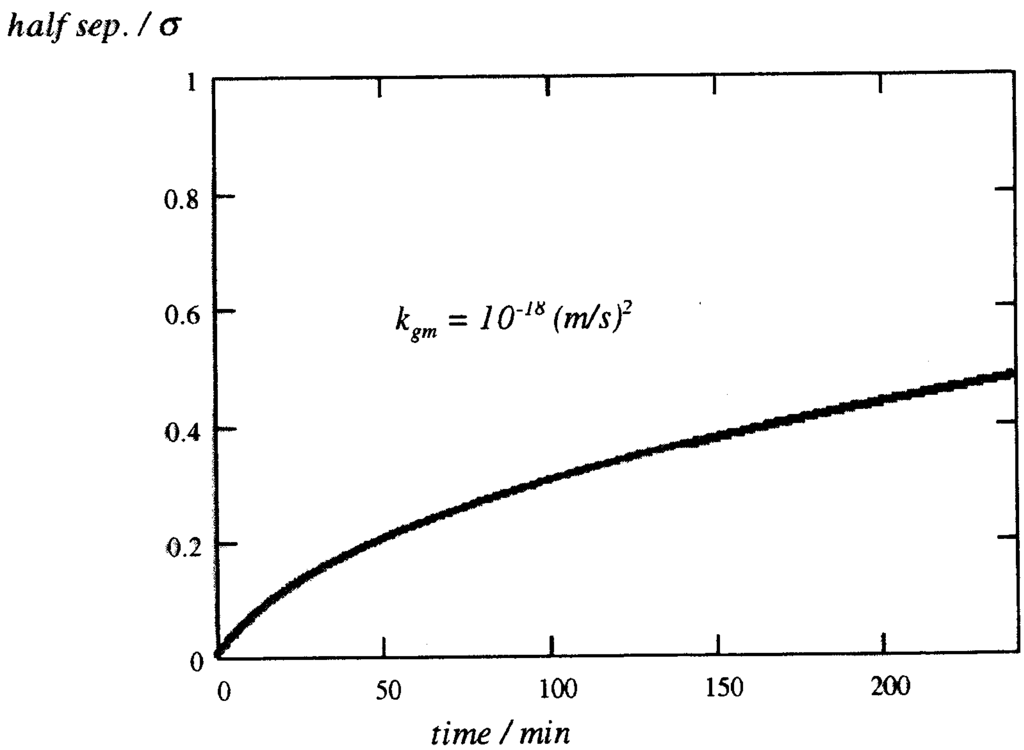
HERA-proton	L_{ch} : 250 *m*
HERA-electron	L_{ch} : 280 *m*

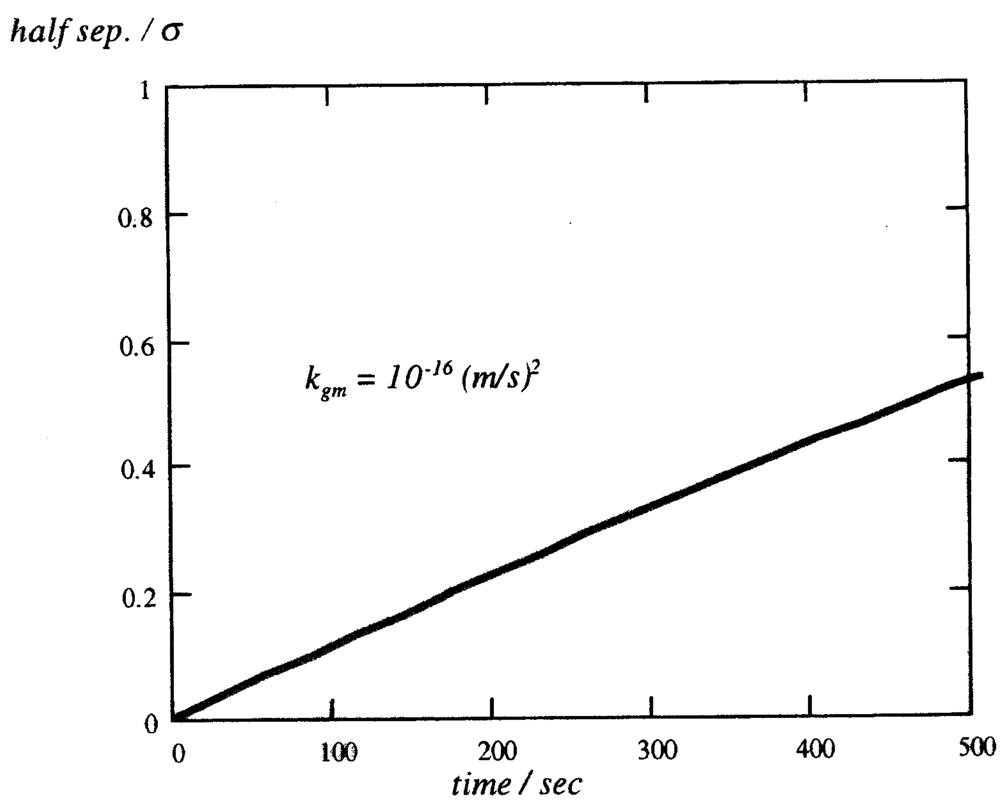
Tecker (1996)

LEP	L_{ch} : 130 *m*

(known effect supra quads removed)




half sep. / σ
1
0.8
0.6
0.4
0.2
0
$k_{gm} = 10^{-18}\ (m/s)^2$
0
50
100
150
200
time / min


half sep. / σ
1
0.8
0.6
0.4
0.2
0
$k_{gm} = 10^{-16}\ (m/s)^2$
0
100
200
300
400
500
time / sec

Problem with the ATL interpretation :

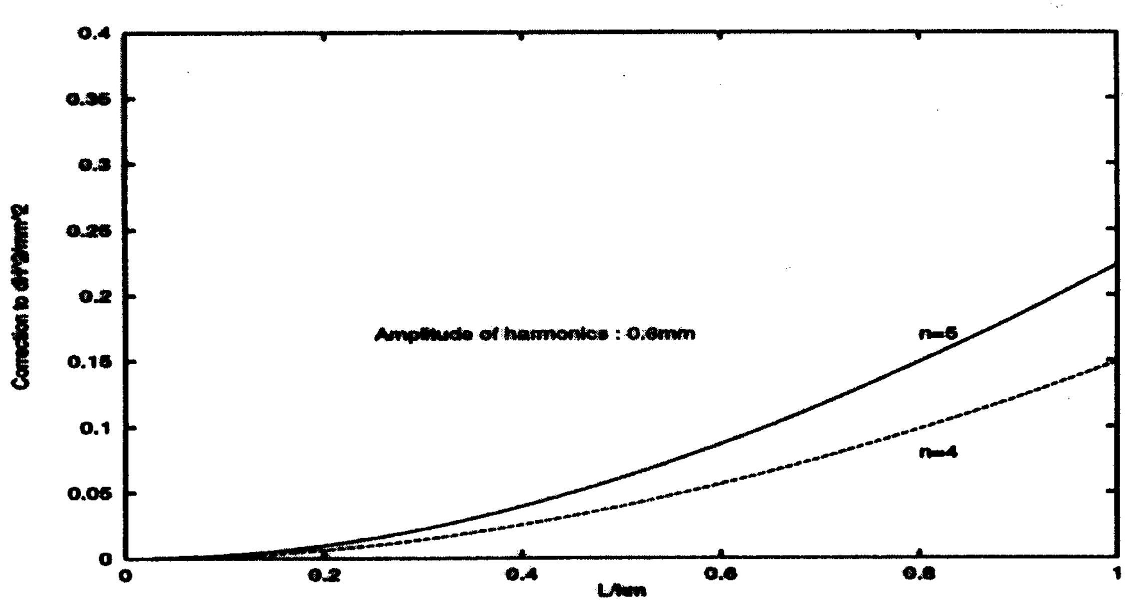
Function $f(s)$ subtracted from the positions $y(s)$

$$dH^2(L) = \int_0^C [y(s+L) - f(s+L) - y(s) + f(s)]^2 ds$$

- the functions $f(s)$ and $y(s)$ are uncorrelated
- the integral of $y(s)$ is zero

$$dH^2(L) = dH_0^2(L) + \int_0^C [f(s+L) - f(s)]^2 ds$$

Harmonic : $f(s) = a \times \sin(2\pi n s/C)$



TO BE KEPT IN MIND FOR THE LHC

Short term :

- **Normal level of excitation : "manual" control**
- **High level of excitation : orbit feedback**

Long term :

- **Alignment data in LHC database for evaluation of annual realignment**
- **Systematic analysis of the closed orbits to detect important motions**