EFFECT OF VERY LOW FREQUENCY GROUND MOTION ON THE LHC

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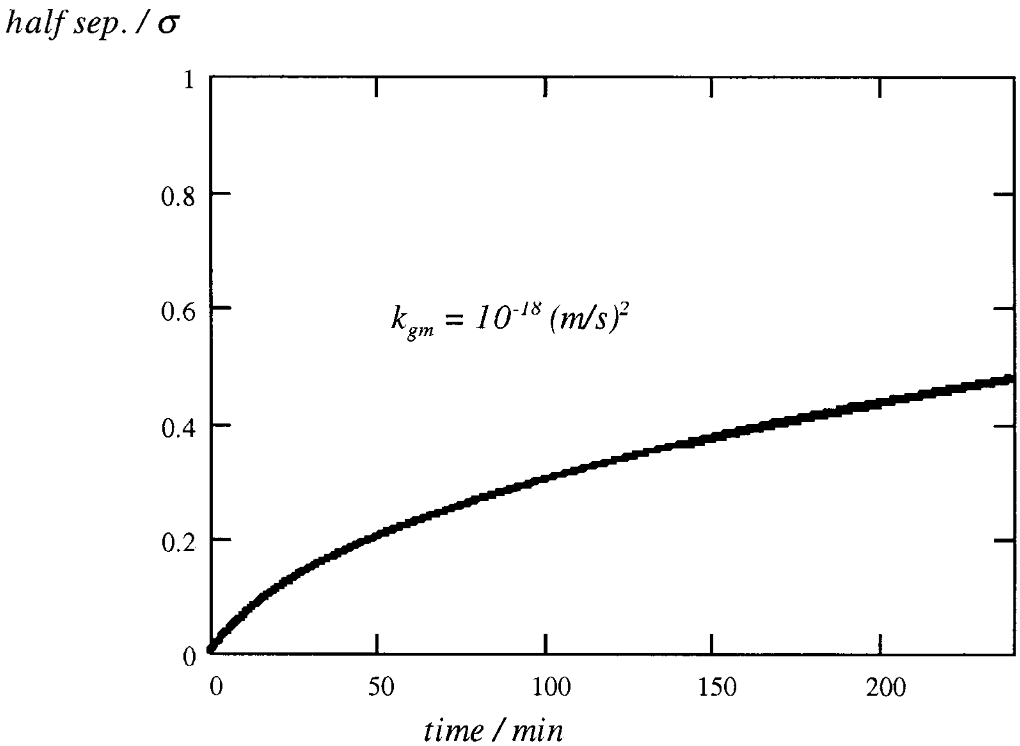
half sep. / σ
1
0.8
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$k_{gm} = 10^{-18}\ (m/s)^2$
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150
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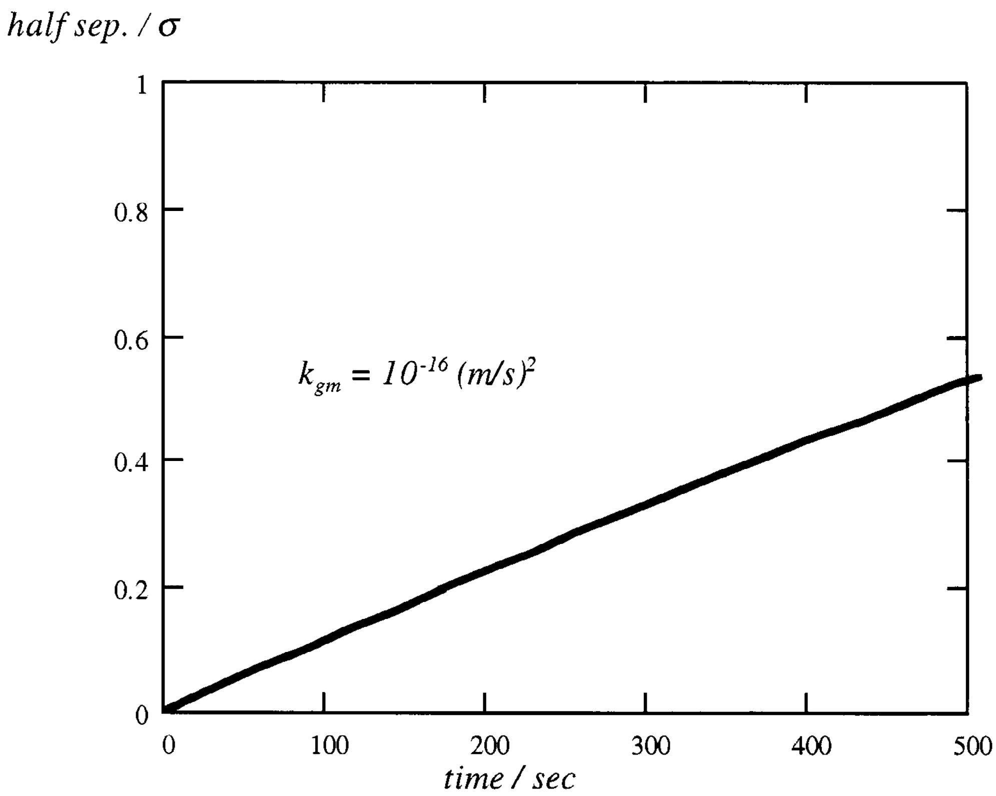
time / min


half sep. / σ
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$k_{gm} = 10^{-16}\ (m/s)^2$
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300
400
500
time / sec

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 in spite of non-negligible optical amplification factor

Introductory remarks

- non-correlated, or partially correlated *movements*, are observed at short distances in spite of much longer wavelengths

- *orbit changes* related to this can be measured in a large machine as LEP (consequences are harmless, single bore)

but, orbits in the LHC of the two constituent rings may wander apart and hence partially separate the beams

===> *loss of luminosity* + *modification of beam-beam interaction* if no adequate correcting action is taken

- direct observation of low frequency non-correlated motion led to formulation of the ***ATL*** scaling law (1991),

  not valid for frequencies above ~ 1 *mHz*

====>

a **model** is proposed based on geo-physical arguments valid for the full frequency range

2 GROUND MOTION MODEL

- **ocean well spectral peak** is <u>*coherent*</u>

the high-pass cut-off frequency of ~0.2 *Hz* together with the speed in water (1.5 kms^{-1}) suggest a limiting wavelength in the oceans of around ~7 *km* ~ depth of the abyssal plain (between 3 and 5.5 *km*)

===> these waves are **surface** waves which will **not contribute** to random motion (difficult to imagine how geological fault structures can cause these waves to loose coherence over a fraction of a wavelength)

- remaining spectrum tends to fall with frequency as f^{-3} above the *ocean hum*

- spectrum falls as f^{-2} well below this frequency (wavelengths involved exceed 25 *km)*

- clear evidence exists on lack of correlation (randomness) of very low frequency noises at distances much less than the wavelength

- ***ATL*** scaling law matches the low frequency f^{-2} slope and states :

the random (integrated) motion between two points is proportional to their distance L while the proportionality factor A depends on the local properties concerning the randomness

<u>However</u>, this scaling law yields <u>non-physical results</u> above a certain frequency: it predicts differential movements that are much larger than the absolute ones

===> a different model is proposed that fulfills two requirements

1 a general formulation of the motion of a single point, in principle valid everywhere

2 take into account local randomnisation of the low frequency earth movements.

2.2 Basic model

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

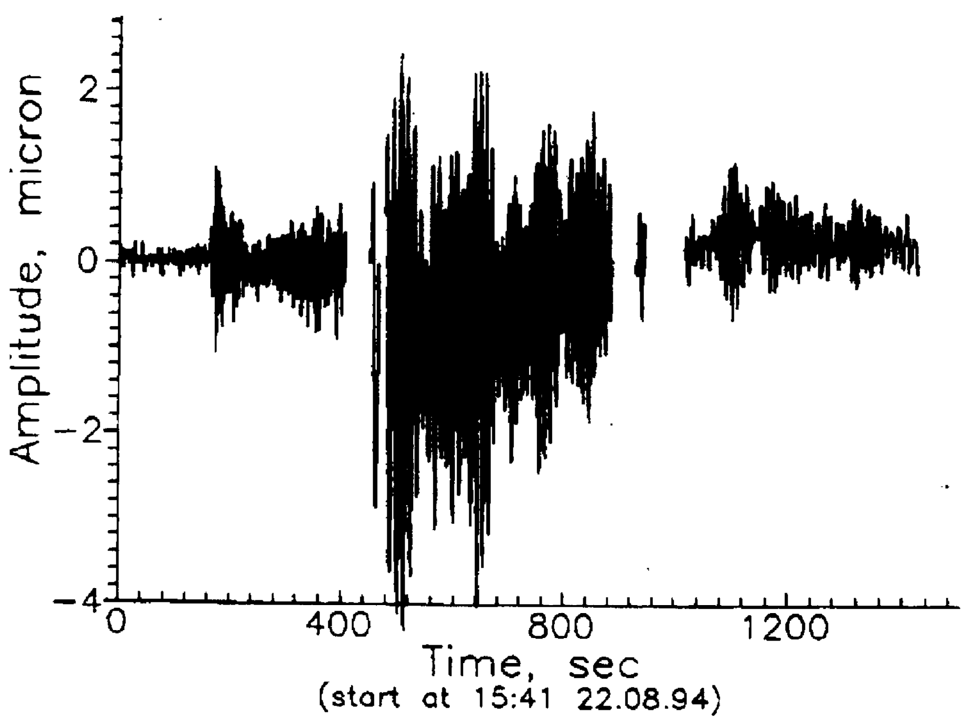
2.2.1 <u>transfer function</u>

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 :

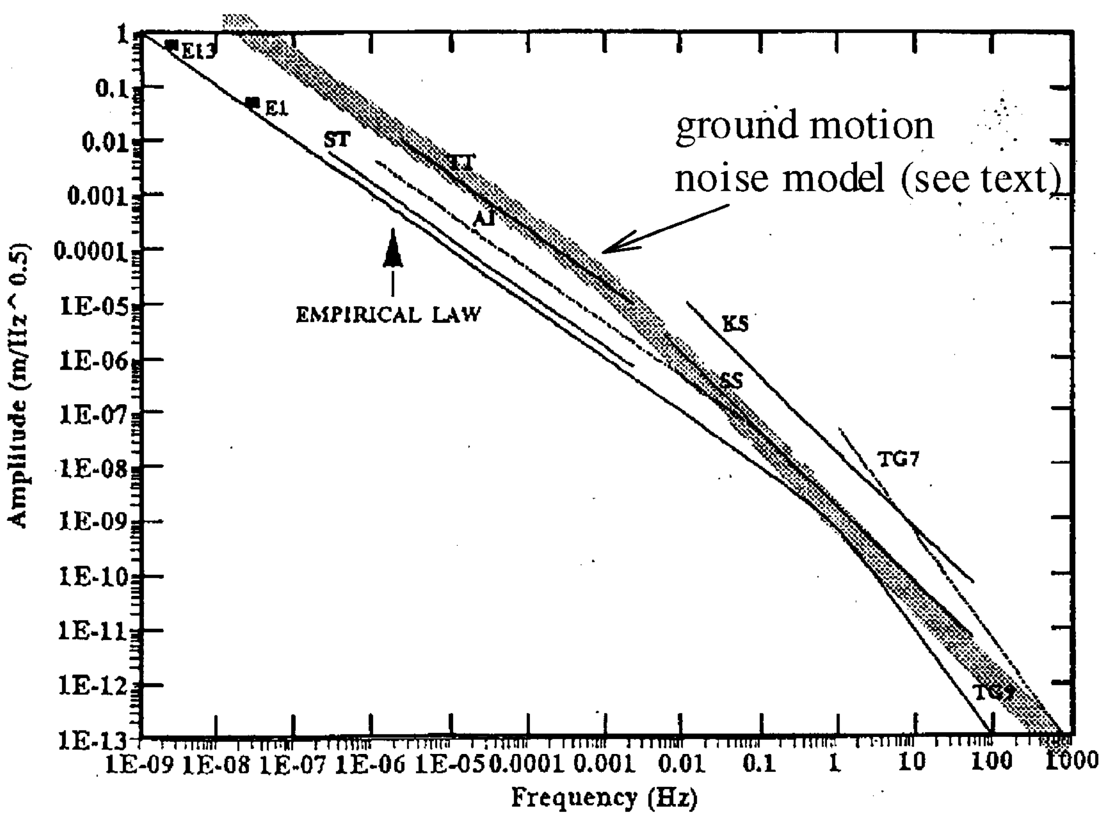
$$\frac{d(x/x_0)^2}{dn} = -\frac{2}{n^3} \propto -\frac{1}{f^3}$$

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 e.a..

2.2 Randomness

- **basic question** :

how can two points, close together (~ 100 *m*, much less than a wavelength : many *km*), move independently?

- **combination of observations may help to explain :**

1 earth quake observations show that depth of the sources is very often ~30 *km* (the ***Moho*** discontinuity)

2 geographical spreading of the sources is very large

3 randomness of differential movement at a given location depends strongly on the **fractured state** of the site (surface behaves as a number of independent blocks excited from below)

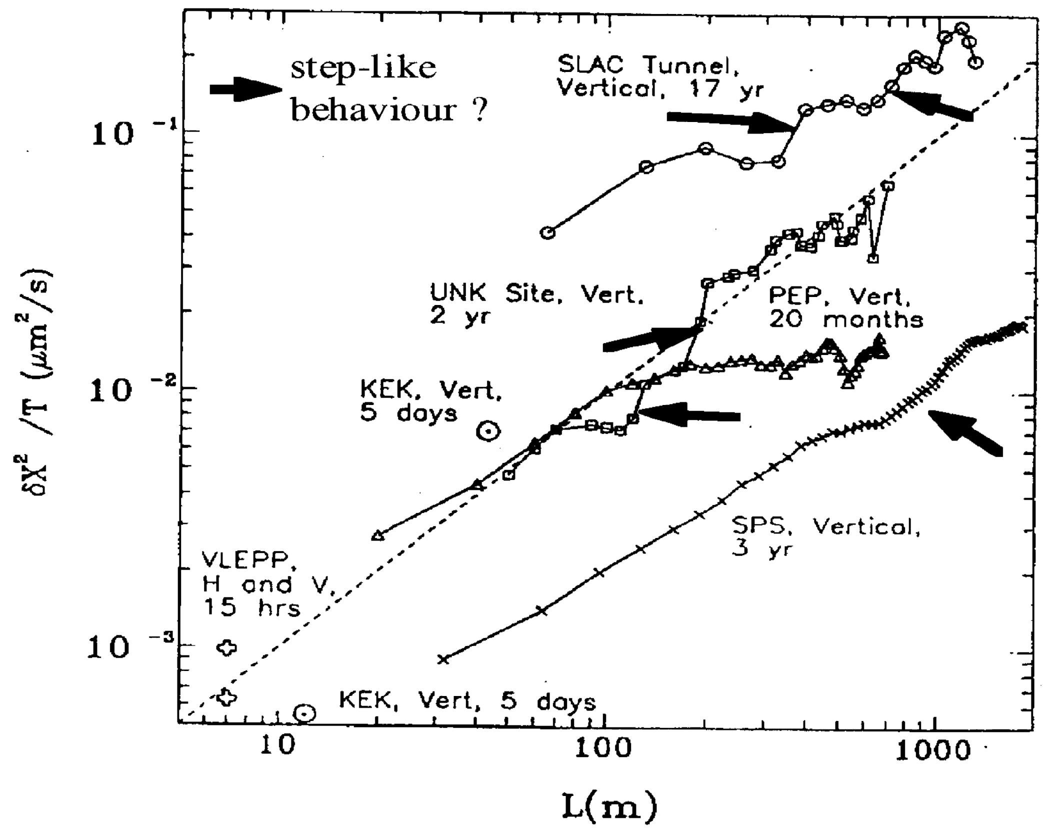
last point borne out clearly by the *experimental observation* on two points on either side of a **construction joint**.

- **introduce the *statistical* notion of coherence length L_{ch} :**

two points at a distance smaller than L_{ch} are **likely** to move ***coherently***, while two points which are further away are **likely** to move ***incoherently***

notion of coherent length is well suited for accelerators where local differences average out

indications about *coherence length* can be found in this figure (Parkhomchuk e.a. 1994) :



Differential movement as a function of distance in a number of machines for a several observation periods.

power of the differential motion seems to jump to larger values **above a given distance (coherence length ?)** in each site

L_{ch} seems to vary from 100...200 *m* (UNK) to 600 *m* (SPS)

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)

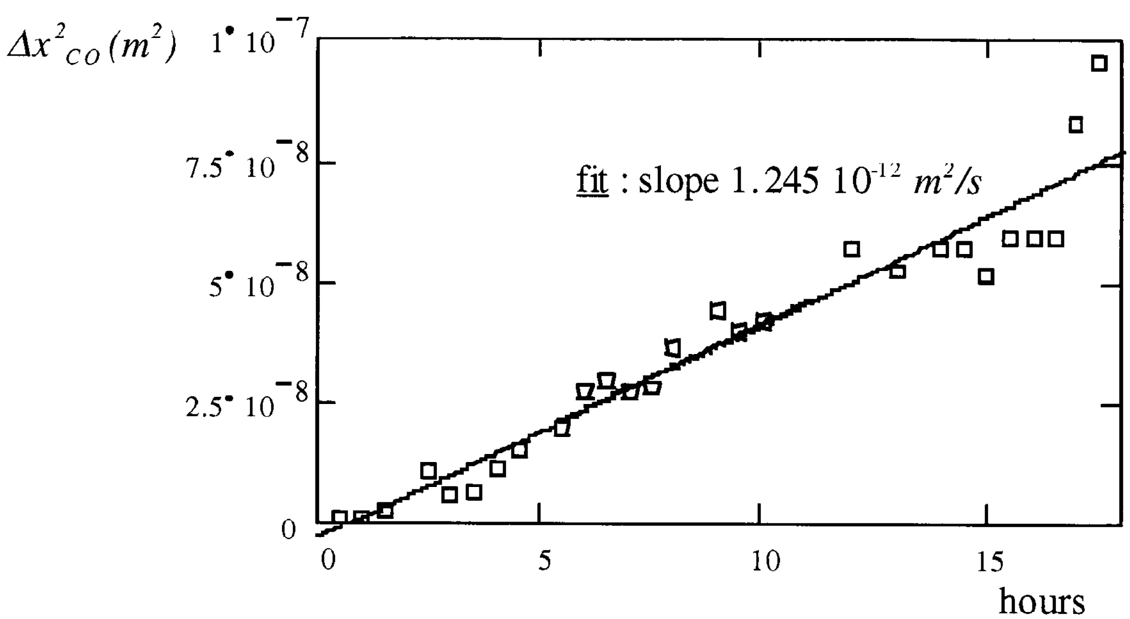
Brinkman & Rossbach (1994)

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

Tecker (1996)

LEP	L_{ch} : 130 m

(known effect supra quads removed)

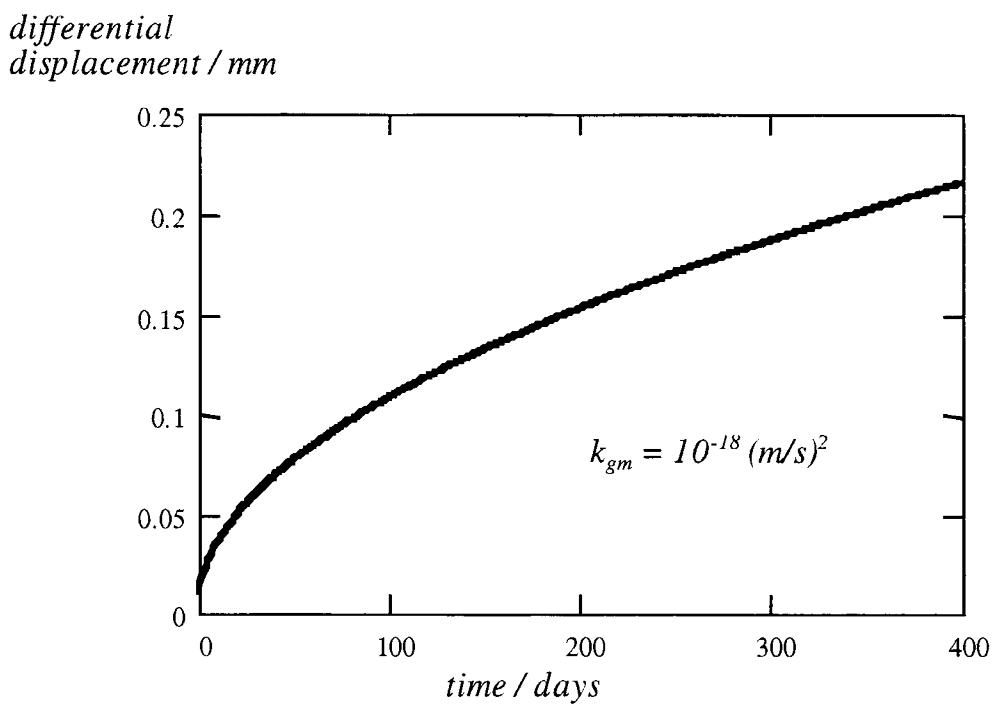


4 APPLICATION TO LHC

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

  spans a **large time/frequency** scale

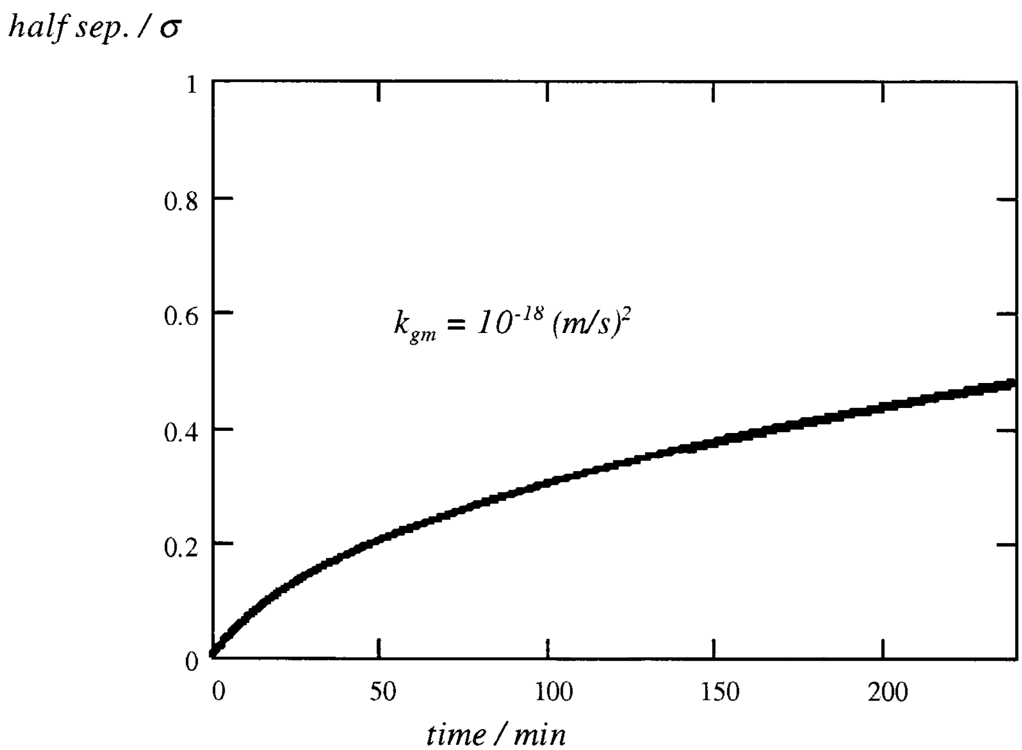
  optimistic example of long term misalignment assuming quiet conditions during 1 year! :



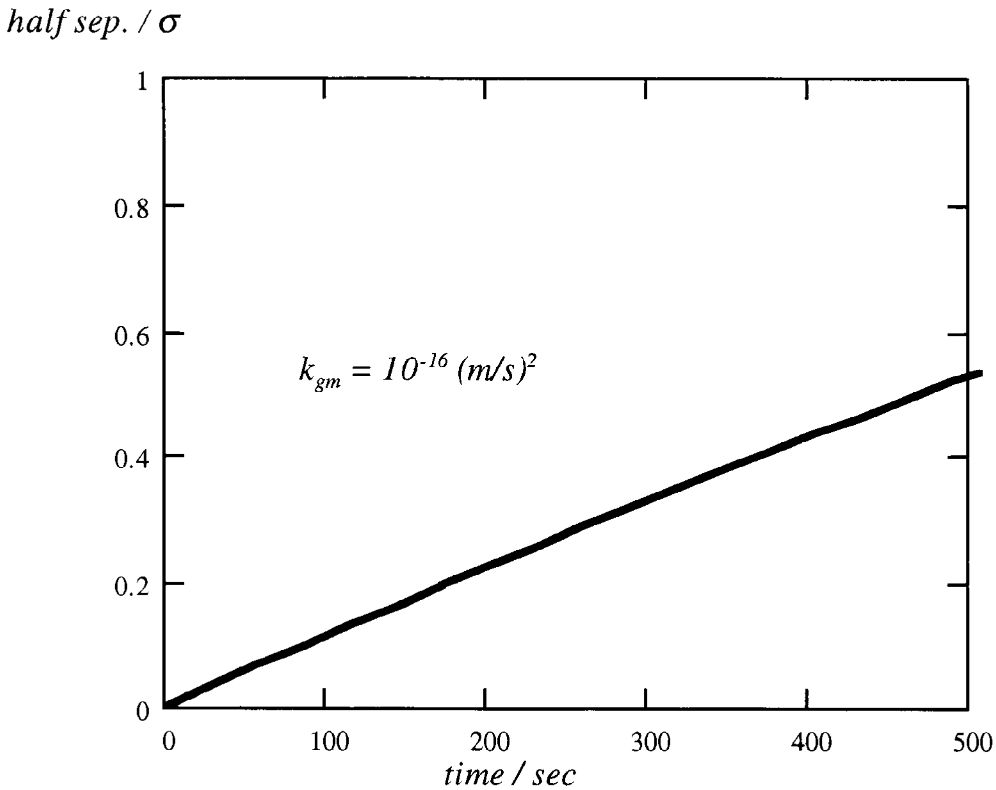
- computation of the *rms* half separation between the beams as a function of time (expressed in terms of the *rms* beam size σ)

Parameters :

β = 183, Kl = 0.03 m $^{-1}$, q = 0.31, N_c = 248 (arc +DS), L_c=*107 m*, L_{ch} = 130 m, transverse emittance 3.75 μradm, 7 *TeV/c*.



- to be expected that **once in a while** the global system is ***highly excited*** ($k_{gm}= 10^{-16}\ m^2/s^2$):



===> procedures must be ready to cope with such a rate of separation

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