Update of a ground motion generator to study the stabilisation usefulness of ATF2 final focus quadrupoles

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Plan of my presentation

1. Update of the ground motion generator of A. Seryi for ATF2 thanks to ground motion measurements in the ATF2 beam line

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2. Study of the stabilisation usefulness for ATF2 final focus quadrupoles (including final doublets and upstream quadrupoles)

⇕

3. Comparison between simulated and measured relative motion of final doublets to the Shintake Monitor

⇩

4. Conclusion on the achievement of vibration tolerances with the current configuration (rigid fixation to the floor)

1. Update of the ground motion generator of A. Seryi for ATF2 thanks to ground motion measurements in the ATF2 beam line

Introduction

- ✓ Ground motion generator of A. Seryi: Simulation which can reproduce spatial and temporal properties of ground motion

- ✓ Input parameters of the generator can be updated to fit measurements done on various sites in the world

- ✓ Last update done by Y. Renier to fit the generator with measurements done by R. Sugahara in ATF Ring

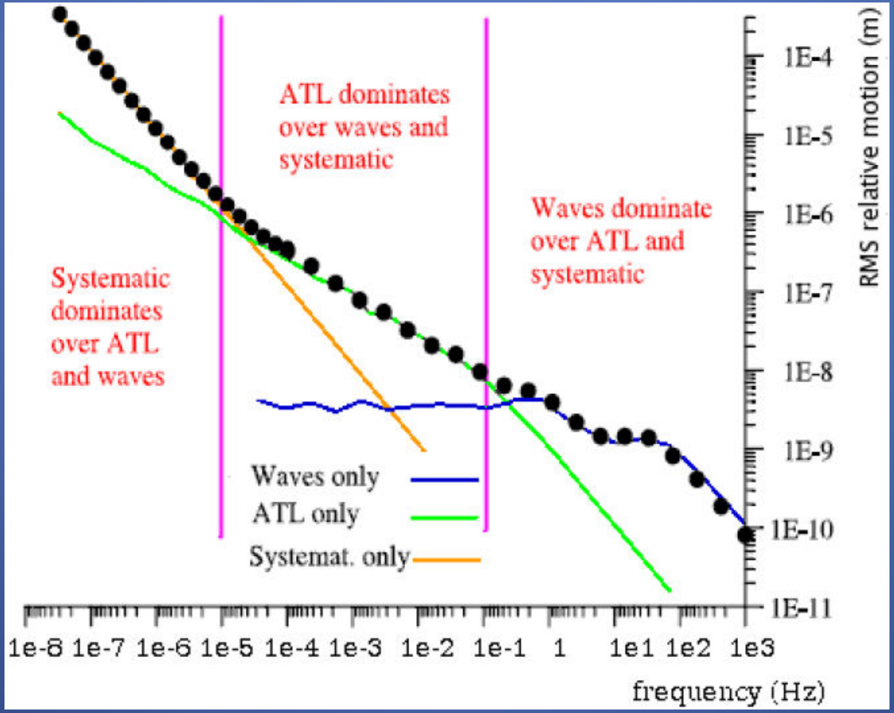
- ✓ Now, continuation of Y. Renier work to have ATF2 ground motion simulations from new measurements done by me in the ATF2 beam line

Y. Renier and all., Tuning of a 2D ground motion generator for ATF2 simulations

Improvment of the fitting method

Description of ground motion

- ✓ **Ground motion can be decomposed in different frequency ranges:**
  - ➢ **Up to 1e-5Hz:** Systematic motion
  - ➢ **From 1e-5Hz up to 0.1Hz:** ATL (diffusion) motion
  - ➢ **From 0.1Hz:** wave-like (propagation) motion



Rms relative motion versus time for L = 30m
for the 2 a.m. SLAC site ground motion model

Principle of the ground motion generator

✓ **Input parameter file of the generator**

```
'Parameter A of the ATL law,        A [m**2/m/s]       '   1.00000E-17
'Parameter B of the PWK,            B [m**2/s**3]      '   5.00000E-18
'Frequency of 1-st peak in PWK,     f1 [Hz]            '   2.00000E-01
'Amplitude of 1-st peak in PWK,     a1 [m**2/Hz]       '   1.00000E-13
'Width of 1-st peak in PWK,         d1 [1]             '   1.10000E+00
'Velocity of 1-st peak in PWK,      v1 [m/s]           '   1.00E+03
'Frequency of 2-nd peak in PWK,     f2 [Hz]            '   2.9000E+00
'Amplitude of 2-nd peak in PWK,     a2 [m**2/Hz]       '   6.00000E-15
'Width of 2-nd peak in PWK,         d2 [1]             '   3.60000E+00
'Velocity of 2-nd peak in PWK,      v2 [m/s]           '   5.5000E+02
'Frequency of 3-rd peak in PWK,     f3 [Hz]            '   10.4000E+00
'Amplitude of 3-rd peak in PWK,     a3 [m**2/Hz]       '   2.60000E-17
'Width of 3-rd peak in PWK,         d3 [1]             '   2.00000E+00
'Velocity of 3-rd peak in PWK,      v3 [m/s]           '   2.5000E+02
'Minimum time,                      Tmin [s]           '   5.00000E-03
'Maximum time,                      Tmax [s]           '   1.00000E+02
'Minimum distance,                  Smin [m]           '   2.00000E-01
'Maximum distance,                  Smax [m]           '   1.00000E+02
'Number of w or k harmonics,        Np   [1]           '      100
'Ampl. of peak in systmat.P,       Q1 [m**3]           '   3.00000E-02
'Wavenumber of peak in syst.P,     rk1 [1/m]           '   2.00000E-03
'Width of peak in system.P,         rkk1 [1]           '   1.00000E+00
'linear or sqrt(t)->exp syst. iwhat_syst (0,1)         '   1
'                              tau_syst [years]        '   30.0000E+00
'(used if ist=1) time gap   tgap_syst [years]          '   2.00000E+00
```

ATL law (diffusion motion)

Wave-like motion: 3waves
amplitude, frequency, width

Update of these parameters since ATF2 ground motion was measured above 0.1Hz

Systematic motion

✓ **Ouput parameter of the generator:** displacement versus time for different beam-line element separations

Update of amplitude, frequency, width parameter

Principle

✓ **In the generator, absolute ground motion (for wave-like motion) is composed of 3 waves and has the dependance in $1/w^4$**

➢ **Theorical formula of absolute ground motion PSD :**

$$p(w) = \sum_{i=1}^{3} \frac{a_i}{1 + \left[d_i (w - w_i) / w_i^2 \right]^4}$$

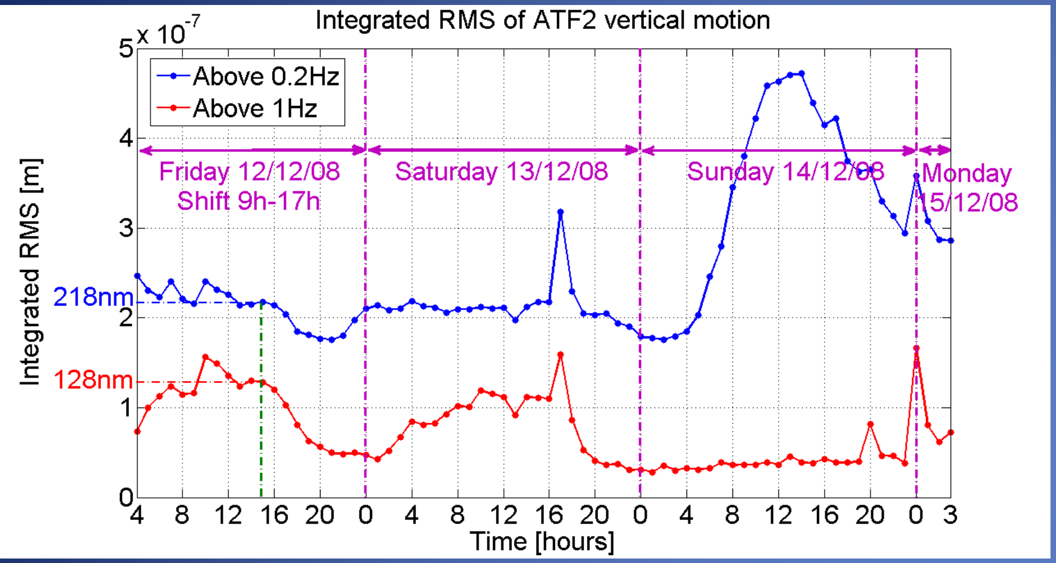
- a_1, a_2, a_3: amplitude of the 3 waves
- w_1, w_2, w_3: frequency of the 3 waves
- d_1, d_2, d_3: width of the 3 waves

✓ **These 9 variables are input parameters of the generator**

➢ **Adjust these 9 parameters to fit the theorical absolute motion PSD with the one measured at ATF2**

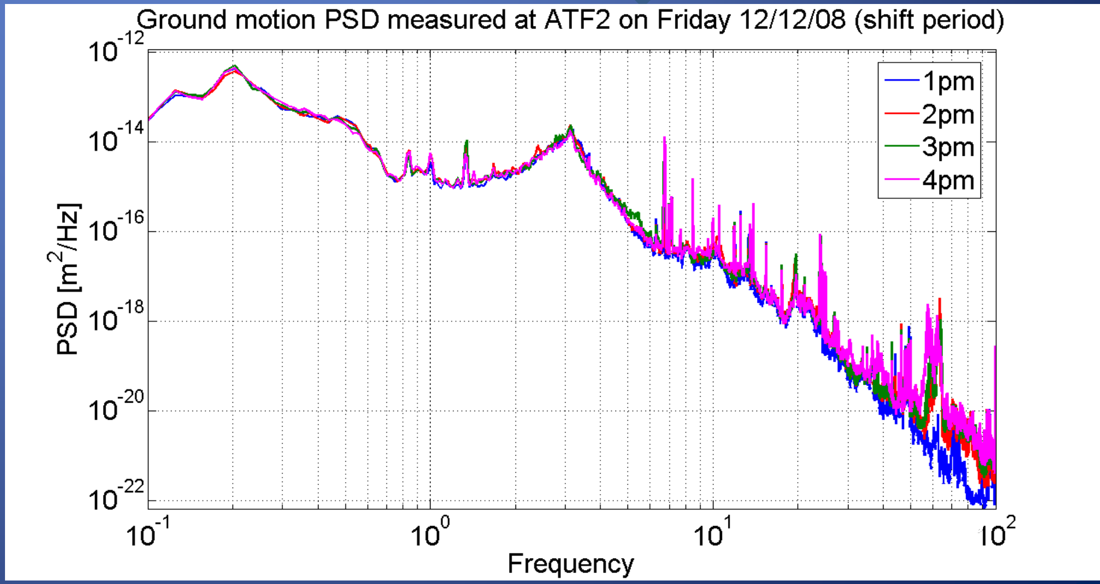
Update of amplitude, frequency, width parameter

Choice of a representative measured ground motion



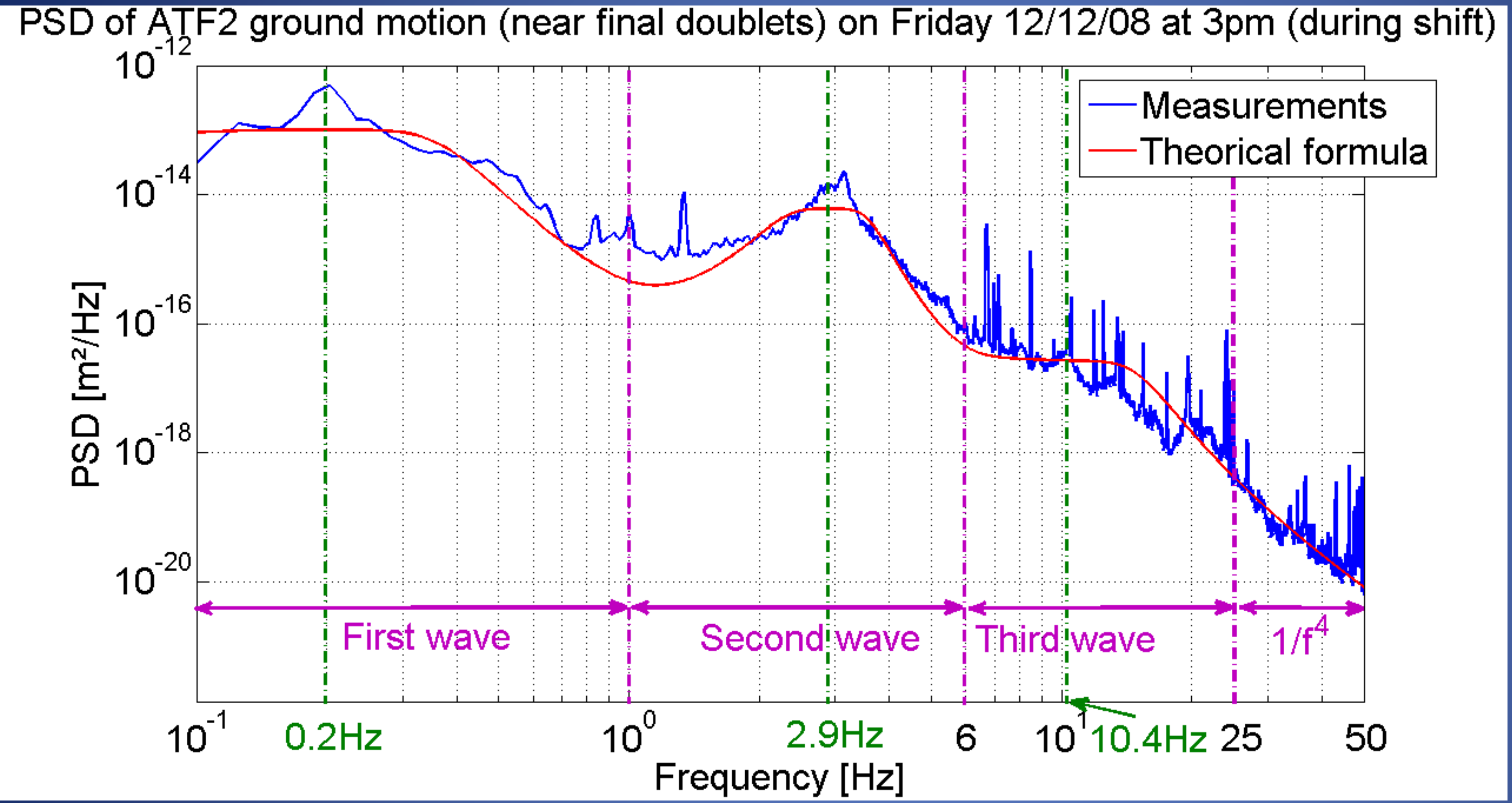
- ✓ **Choice of a high ground motion during shift period**
- ✓ **Friday 12/12/08 at 3pm**
  - → Above 0.2Hz: 218nm
  - → Above 1Hz: 128nm

- ✓ Amplitude almost the same during 4 hours of shift
  - ➢ Choice of ground motion at 3pm representative



Update of amplitude, frequency, width parameter

Absolute ground motion PSD

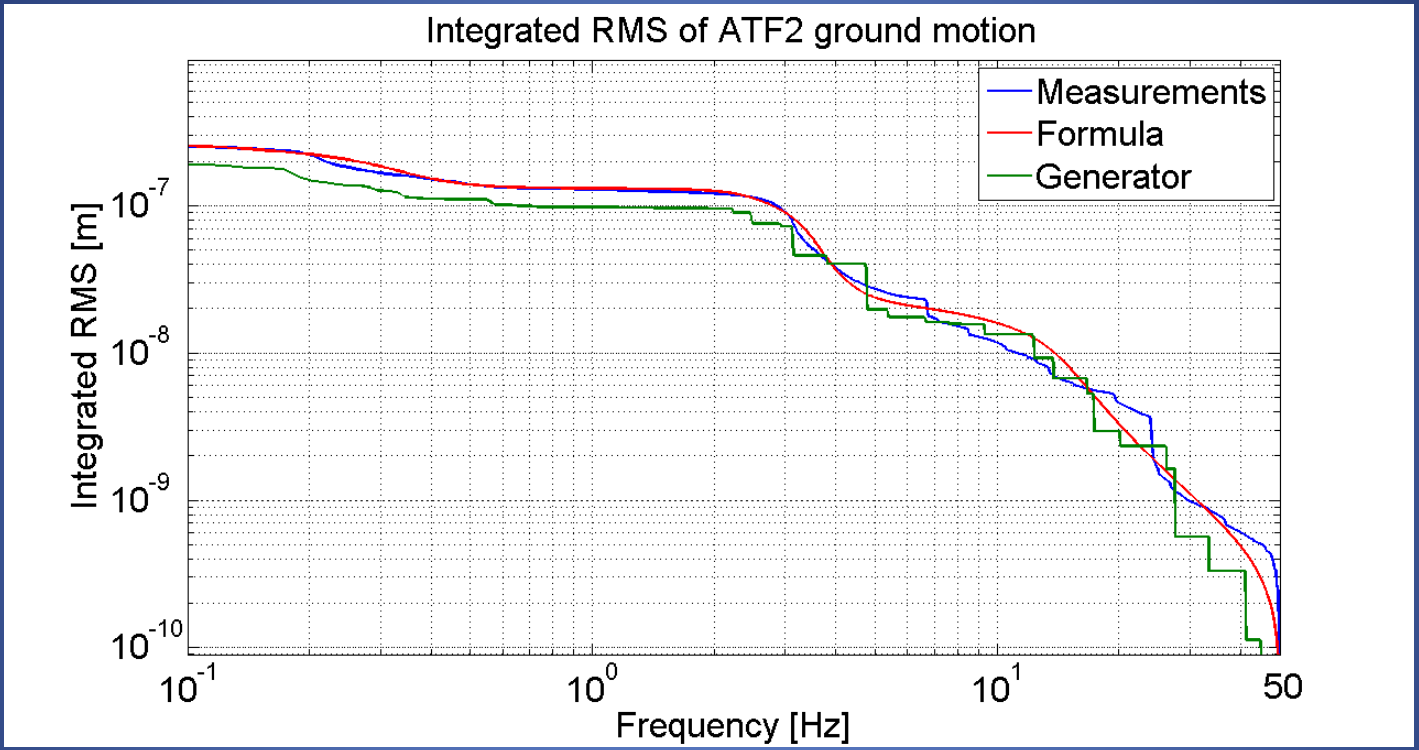


- Good fit of the theorical absolute PSD with the measured one

	1st wave	2nd wave	3rd wave
f [Hz]	0.2	2.9	10.4
a [m^2/Hz]	1.0e-13	6.0e-15	2.6e-17
w []	1.1	3.6	2.0

Update of amplitude, frequency, width parameter

Integrated RMS of ground motion



- Very good fit of the formula with the measurements
- Check: formula and generator give almost the same results (below 3Hz, difference of a factor 1.3)

➔ **Good update of the 9 parameters for the generator**

Update of velocity parameter

Principle

- Last parameters to update: velocity of the three waves (v_1,v_2,v_3)
- Theorical correlation: $c(w,L) = J_0 \frac{wL}{v}$
- Theorical PSD of relative motion: $p(w,L) = 2p(w)[1 - c(w,L)]$

(do not take into account local noise)

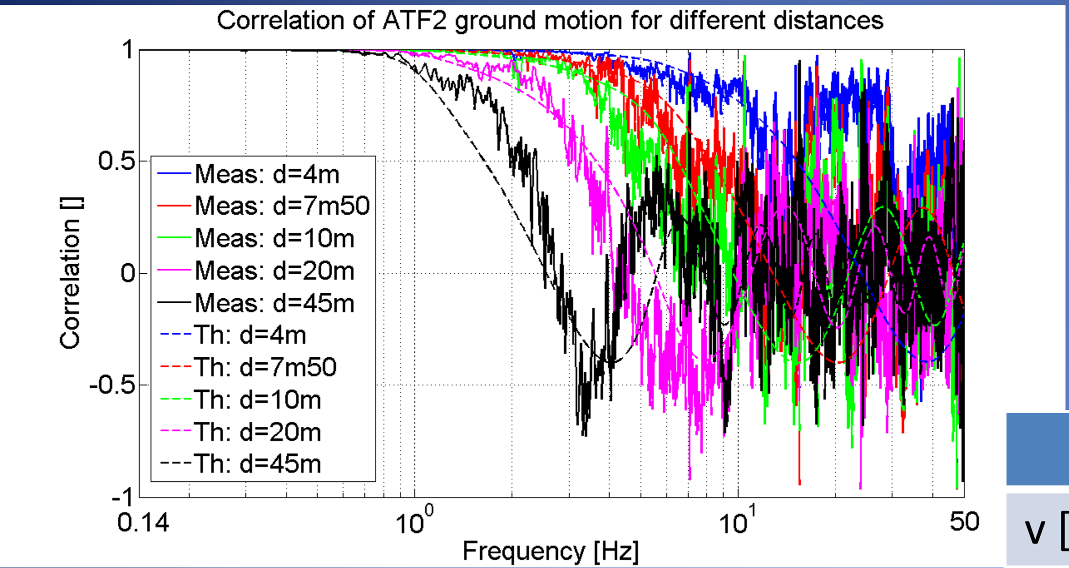
➔ For 3 waves

Adjust v_1, v_2, v_3 to fit the theorical formula with measurements

$$\begin{cases} p(w,L) = 2\sum_{i=1}^{3} \frac{a_i}{1+\left[d_i(w-w_i)/w_i^2\right]^4}\left(1 - J_0 \frac{wL}{v_i}\right) \\ c(w,L) = \dfrac{\sum_{i=1}^{3} \frac{a_i}{1+\left[d_i(w-w_i)/w_i^2\right]^4} J_0 \frac{wL}{v_i}}{\sum_{i=1}^{3} \frac{a_i}{1+\left[d_i(w-w_i)/w_i^2\right]^4}} \end{cases}$$

Update of velocity parameter

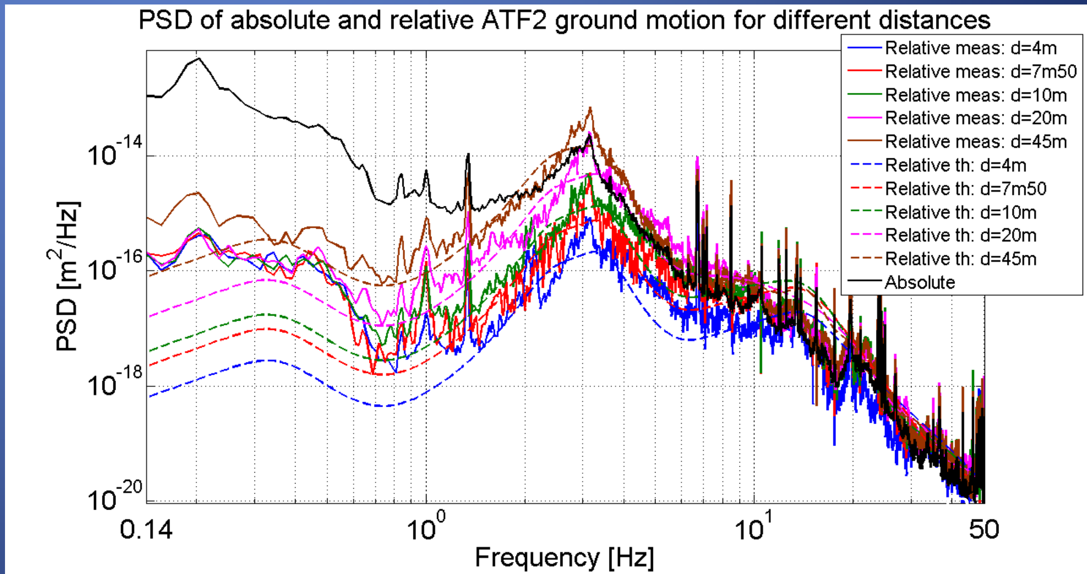
Correlation and PSD for different distances



- ✓ Fall of coherence with the increase of distance
- ✓ Good fit of theorical correlation with the measured one for each distance

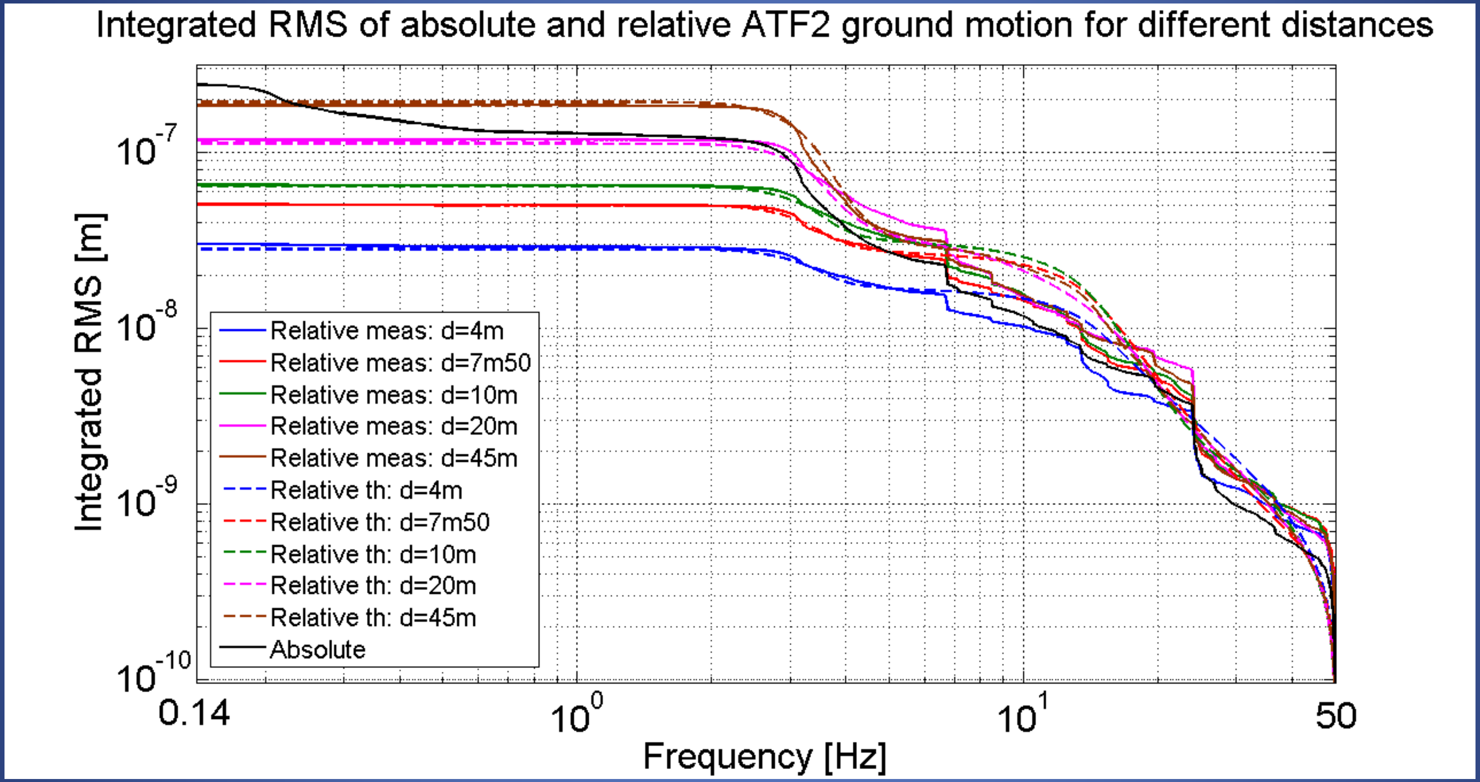
	1st wave	2nd wave	3rd wave
v [m/s]	1000	300	250

- ✓ Increase of the waves amplitude with the increase of distance
- ✓ Good fit of theorical relative PSD with the measured one for each distance



Relative motion

Integrated RMS of absolute/relative motion vs frequency

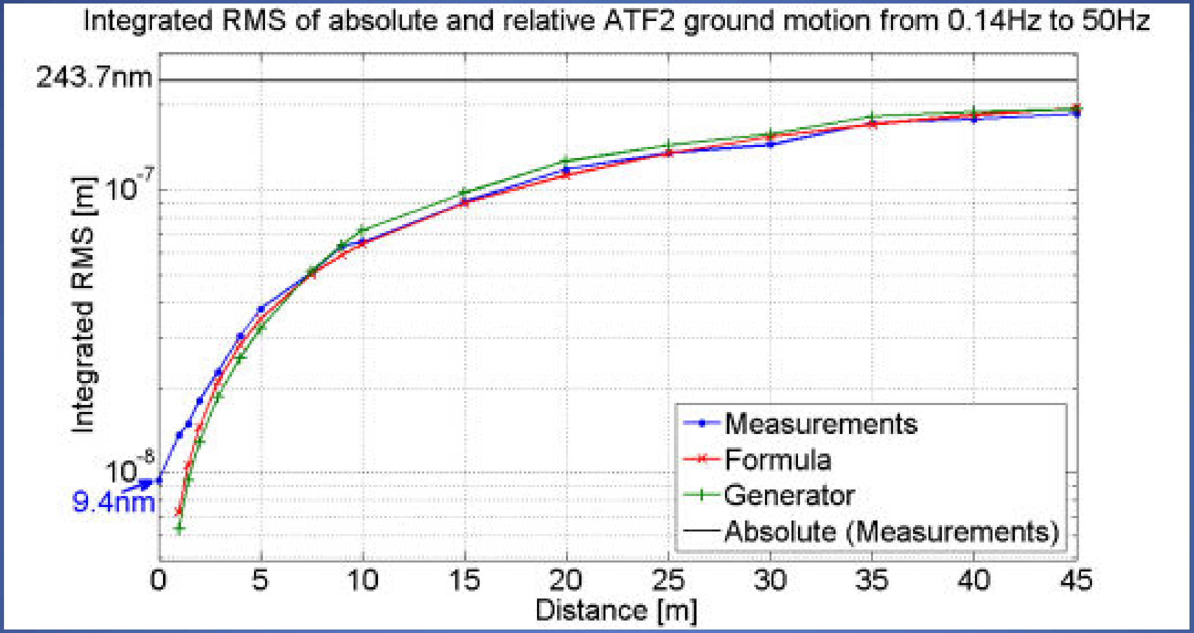


✓ Increase of relative motion with the increase of distance due almost to the second wave (first wave: correlation very good up to 45m)

✓ Very good fit of theorical relative motion with the measured one for each distance

Relative motion

Integrated RMS of absolute/relative motion vs distance



✓ Increase of relative motion with increase of distance up to 190nm at 45m (absolute motion of about 240nm)

✓ Very good agreement simulations /measurements for each distance

➢ Confirmed the quality of the parameter tuning

✓ Below 4m, measured and theoretical RM overestimated due to very high SNR needed and lower correlations than in reality (measurements)

Conclusion and future prospects

- ✓ Parameters well updated for ATF2 ground motion above 0.1Hz
  - ➢ Ground motion generator now ready for ATF2 simulations

- ✓ For the amplitude of waves: update with ground motion measured on shift period during the day
  - ➢ amplitude should be lower the night (worst case taken)

- ✓ Future prospects: measurements of drifts with Sugahara-San thanks to a VHS system
  - ➢ Update of the ATL parameter (A) will be then possible (f<0.1Hz)

2. Study of the stabilisation usefulness for ATF2 final focus quadrupoles

Introduction

Relative motion tolerance between beam and IP: 10nm
(5% accuracy on beam size measurements)

✓ QDO/QF1FF: induce the most beam deflection at the IP when not perfectly aligned (ground motion)

➔ Studies of stabilisation were focused on them

➡ Good ground motion (GM) coherence between QD0/QF1FF and IP

➔ Fixation to the floor: low relative motion between them

✓ Other ATF2 quadrupoles: lower beam deflection

➔ Fixed to the floor even if GM coherence is low (far from IP)

➡ New study: relative motion calculation between beam and IP due to the beam deflection induced by these quads subjected to GM

⬇

Usefulness of a stabilization for these quadrupoles?

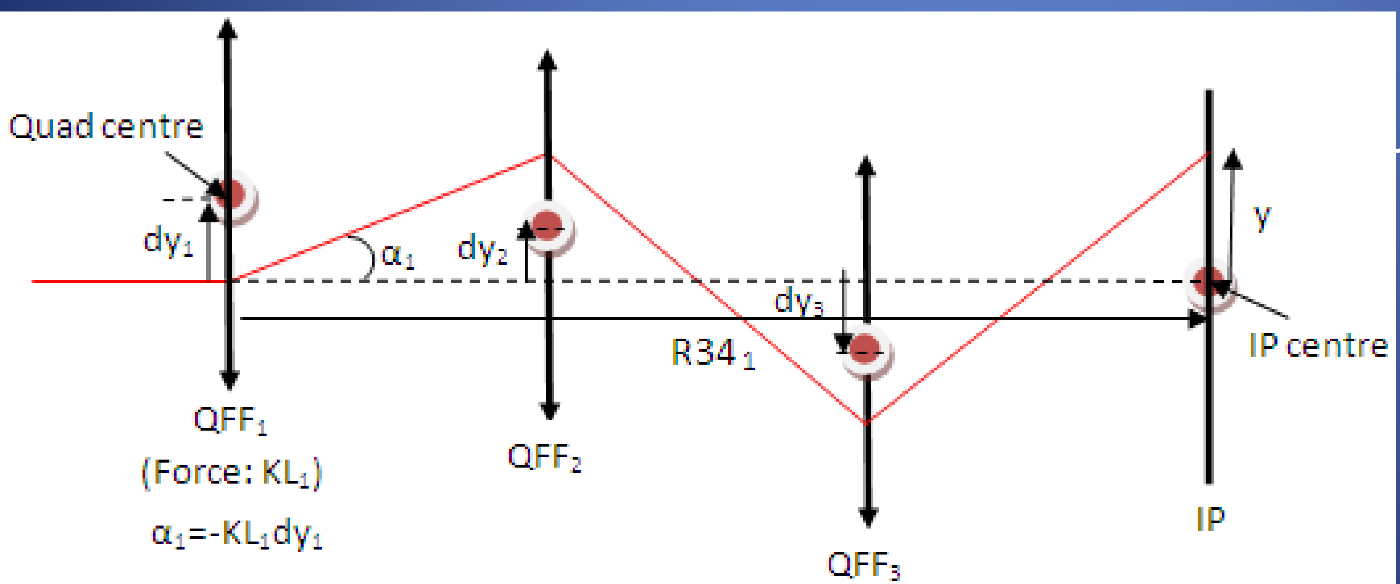
Principle of calculation

1. Use of the ATF2 ground motion generator to have relative motion dyi(t) of each FF quadrupole QFFi to the IP (GM coherence incorporated)

2. Beam relative motion to IP due to QFFi motion: yi(t)=-KLiR34i dyi(t)

3. Beam relative motion to IP due to motion of all quads: y(t)=sum(yi(t))

4. Calculation of the integrated RMS of relative motion Yi(f) and Y(f) to get relative motion from 0.1Hz to 50Hz (sign not given with this calculus)

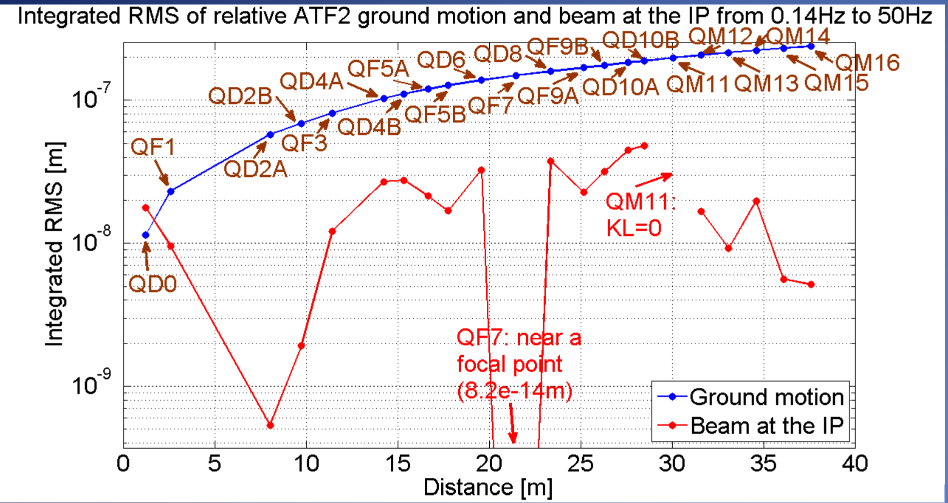


- ✓ *Sign of KL different for QD and QF*
- ✓ *Sign of R34 varies depending on phase advance*
- ✓ *Sign of dy(t) varies*

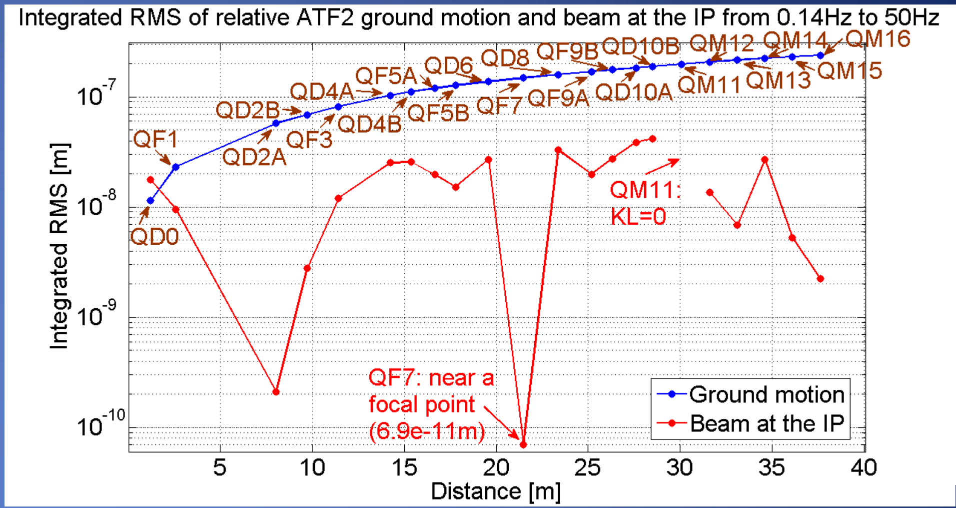
Sign of y(t) varies

Beam relative motion to IP due to jitter of each QFF_i

With the ATF2 nominal lattice



With the CLIC ultra-low β lattice



✓ Increase of relative ground motion to the IP with increase of distance

✓ Beam Relative Motion to IP from 0.1Hz to 50Hz due to motion of:

Beam RM due to:	Nominal	Ultra-low β
QD0/QF1FF (nm)	17.7/9.6	17.7/9.5
QD10A/B (nm)	44.6/48.1	38.7/41.8

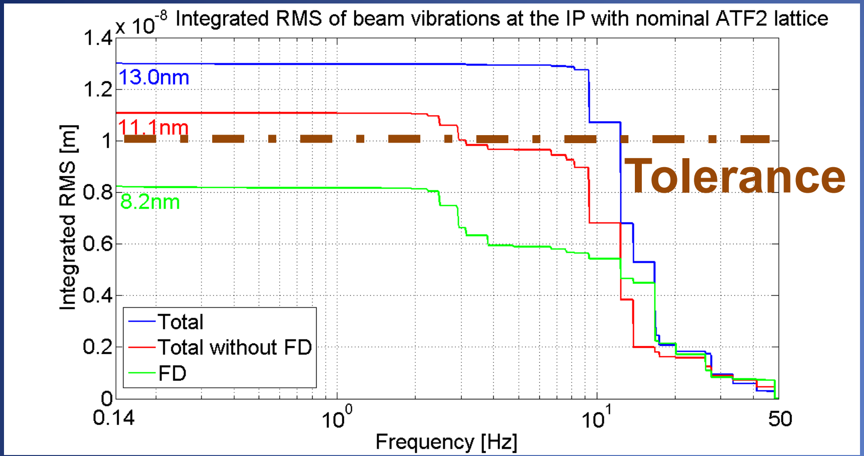
➔ **Low value:** high β but good coherence with the IP

➔ **High value:** due to high β/coherence loss

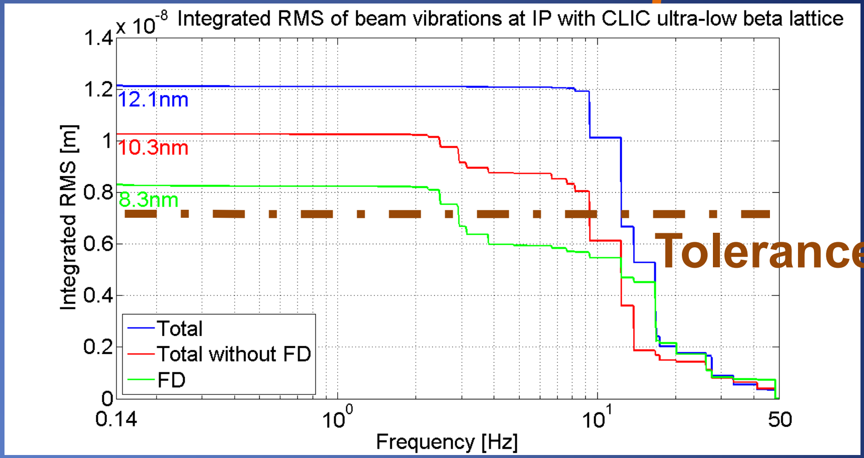
➔ **Necessity to look at beam relative motion due to jitter of all quads**

Beam relative motion to IP due to jitter of all QFF_i

With the ATF2 nominal lattice



With the CLIC ultra-low β lattice



✓ Beam relative motion to IP from 0.1Hz to 50Hz due to jitter of:

Beam RM due to (nm):	Nominal	Ultra-low β
Both QD0/QF1	8.2	8.3
All FF quads except FD	11.1	10.3
All FF quads (tolerance)	13.0 (10)	12.1 (6.8)
Tolerance achievement	Almost OK	Factor 1.8 above

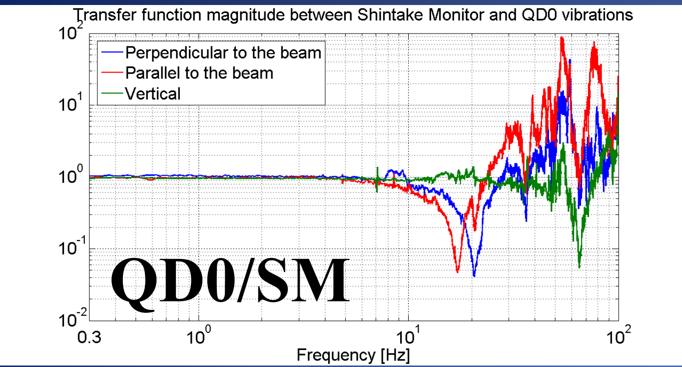
Low: D/F compensation (Both QD0/QF1)

low: lucky compensation (All FF quads except FD; All FF quads)

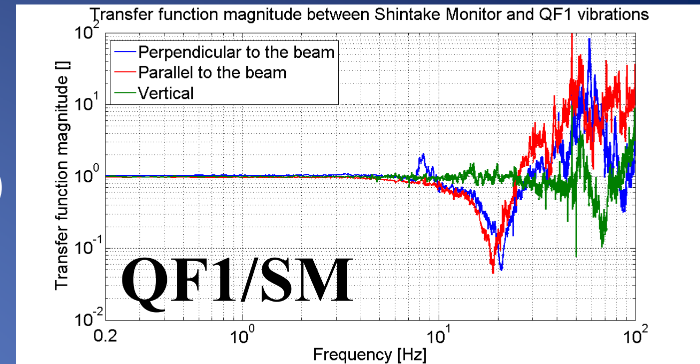
✓ It was checked changing 4 times the generator parameters (slightly and not slightly) that this lucky compensation is robust and not fortuitous

3. Comparison between simulated and measured relative motion of final doublets to the Shintake Monitor

✓ Vibration measurements of transfer function between FD and SM

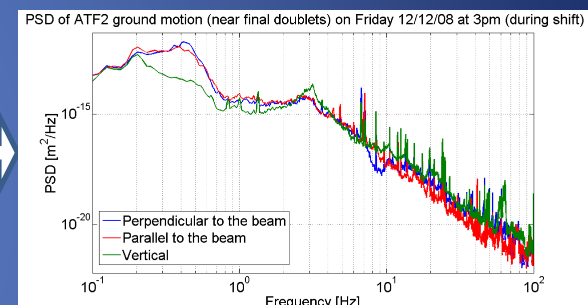


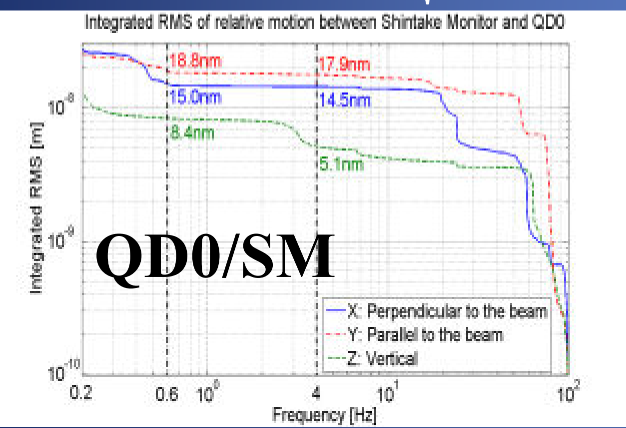
H(k)= Vibration Transfer Function (TF) between FD and SM

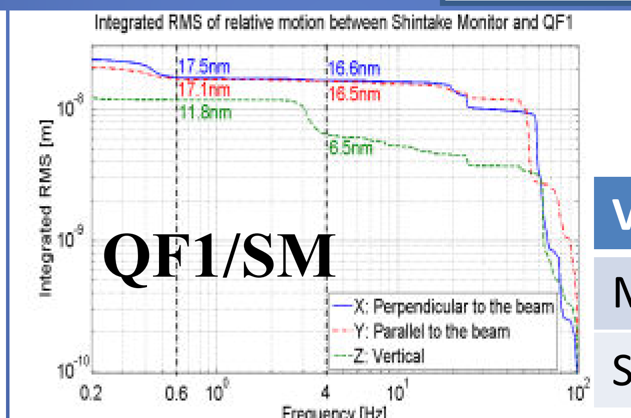


✓ Relative motion calculation by taking the representative GM

$$RMS_{int\,y-x}(k)=\sqrt{\sum_{k_1}^{k_2}\left[H(k)-1\right]\left[H^*(k)-1\right]PSD_x(k)\Delta f}$$







Vertical RM	QD0/SM	QF1/SM
Measured	5.1nm	6.5nm
Simulated	11.4nm	23.1nm

- Below 4Hz: overestimation due to small error on TF measurements (around 1%) amplified by two huge peaks of GM (0.2-0.4Hz and 3.5Hz)
- Difference between measurements and simulations: due to underestimation of correlations by simulations below 4m

Conclusion and future prospects

✓ Jitter of some of FF quads induces separately high RM of beam to IP (up to 50nm for nominal lattice) due to high β and loss of GM coherence

✓ Due to big luck, the sum of these separate effects are well compensated and simulations give a relative motion of the beam to the IP of:

➔ 13.0nm (tolerance:10nm) for the ATF2 nominal lattice

➔ 12.1nm (tolerance: 6.8nm) for the CLIC ultra-low lattice

- Should be much lower since RM of FD to SM well lower in reality (measurements) (correlation underestimation by simulation for d<4m)

✓ Future work:

- Check in simulation this previous assumption by decreasing the distance FD/SM in order to have RM of FD to SM closer to reality

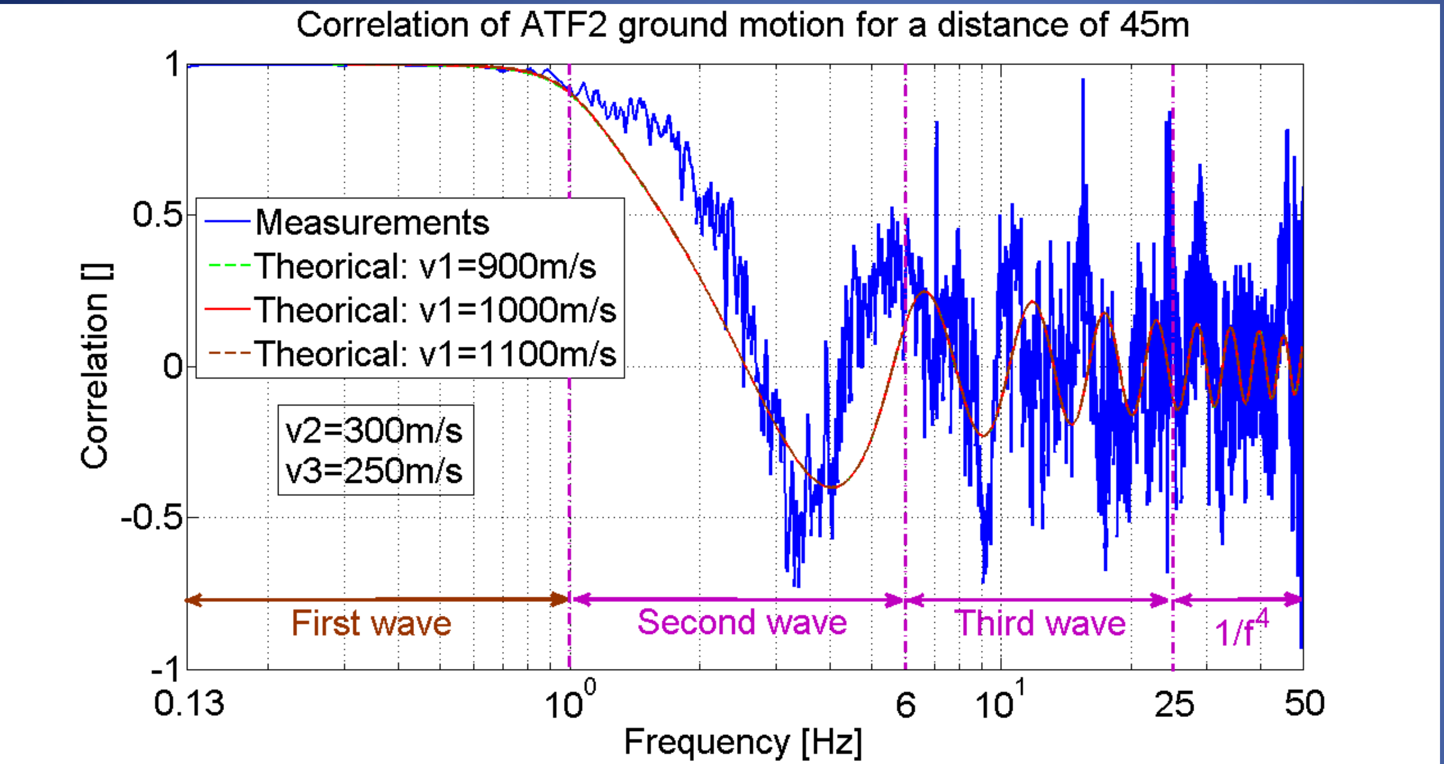
  ➔ **Tolerances (especially the ones of the ultra-low beta lattice which are the most critical) may be achieved**

- Even if stabilisation may not be needed, an active stabilisation will be studied in order to have a prototype for CLIC

ANNEXES

Update of velocity parameter

Fit of the first wave [0.1;1] Hz



✓ v_1=1000m/s (no change)

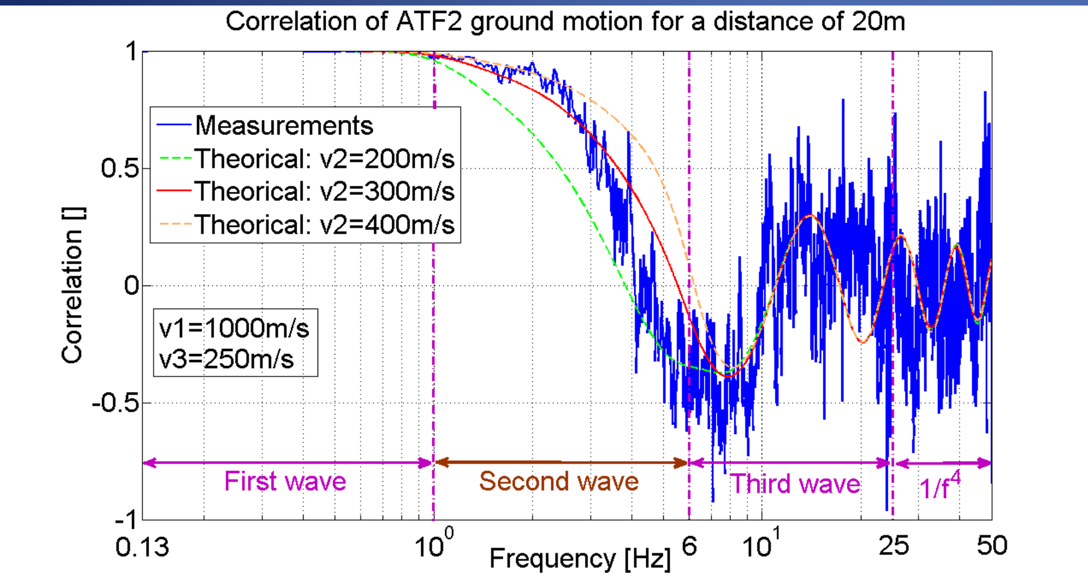
✓ Highest distance taken (45m) in order to see a fall of coherence

✓ But correlation almost at 1 for the first wave

➔ Difficult to obtain a very accurate velocity value but the velocity of 1000m/s choosen for ATF Ring and KEK B works well for ATF2

Update of velocity parameter

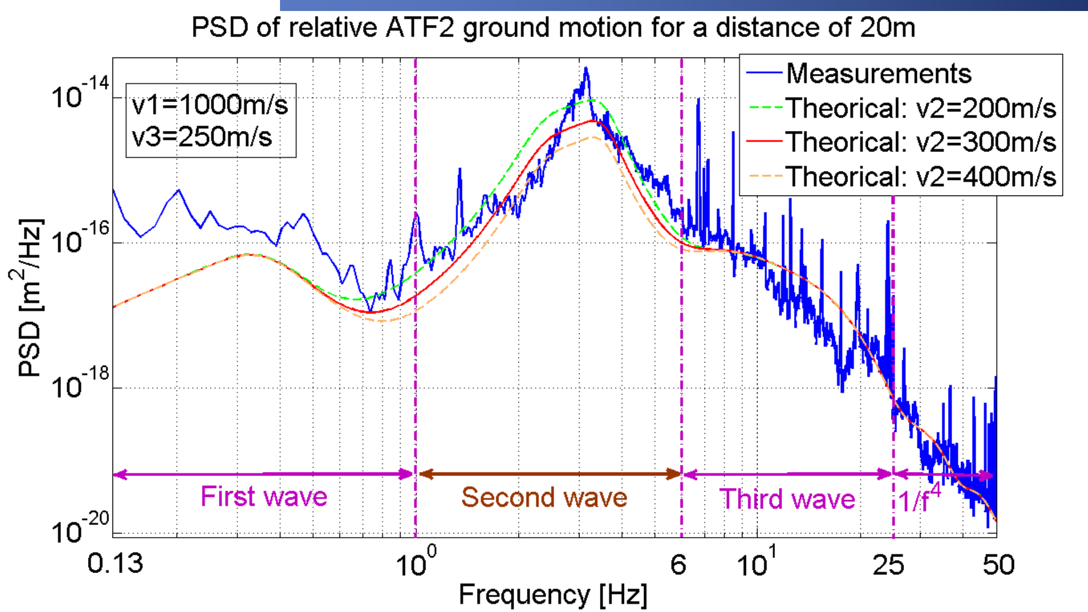
Fit of the second wave [1;6] Hz



✓ Choice of a distance where correlation falls : 20m

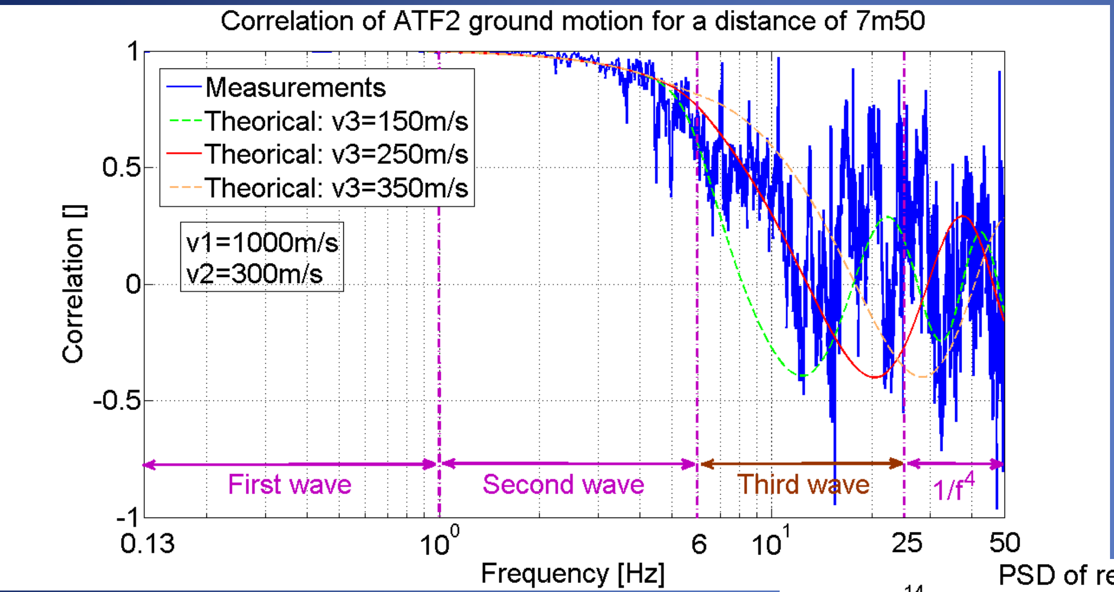
✓ Velocity chosen: v_2=300m/s to fit measurements

✓ Confirmation of the velocity chosen by the good fit of theorical relative PSD with measurements



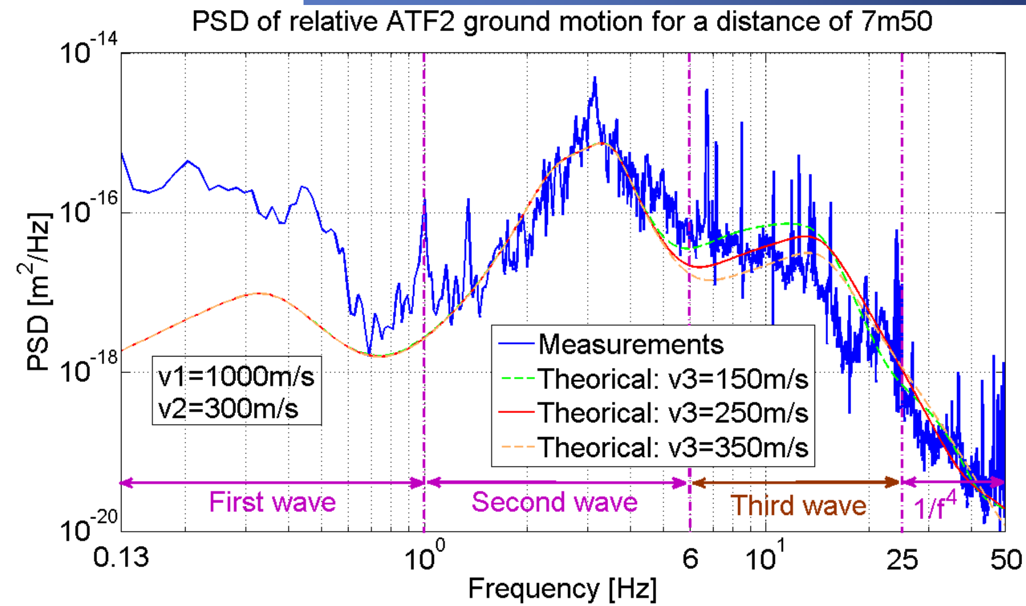
Update of velocity parameter

Fit of the third wave [6; 25] Hz



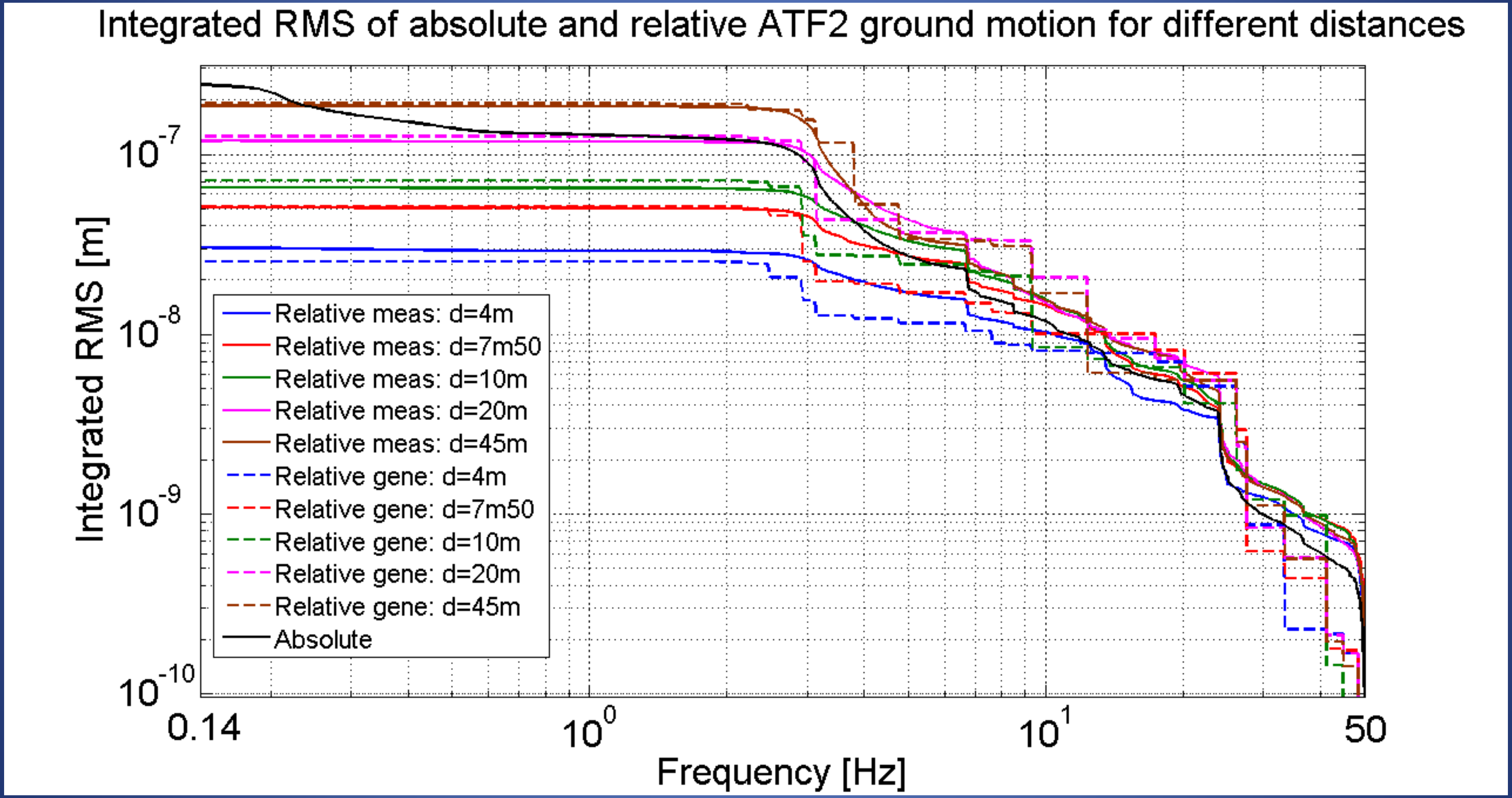
- ✓ Choice of a distance where correlation falls : 7m50
- ✓ Velocity chosen: v_3=250m/s to fit measurements

- ✓ Confirmation of the velocity chosen by the good fit of theorical relative PSD with measurements



Update of velocity parameter

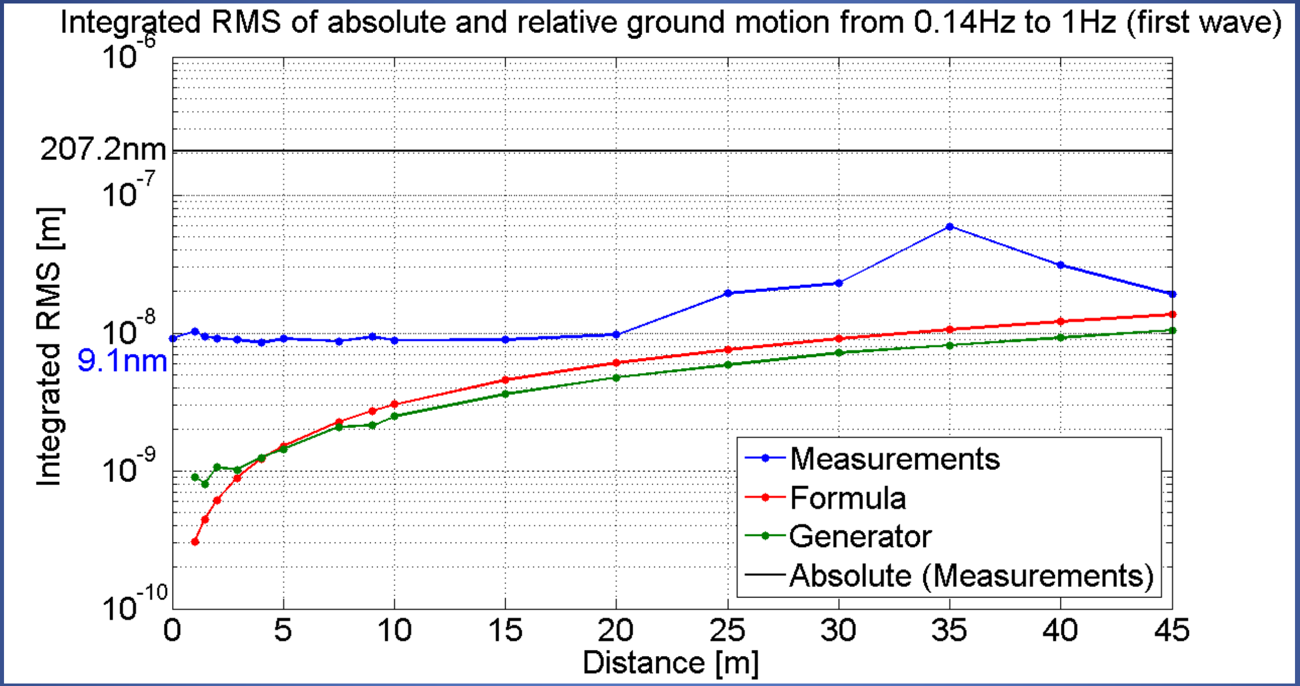
Integrated RMS of absolute and relative motion



✓ Good agreement in terms of relative motion between the generator and the measurements

Update of velocity parameter

Integrated RMS of motion due to the first wave [0.1;1]Hz

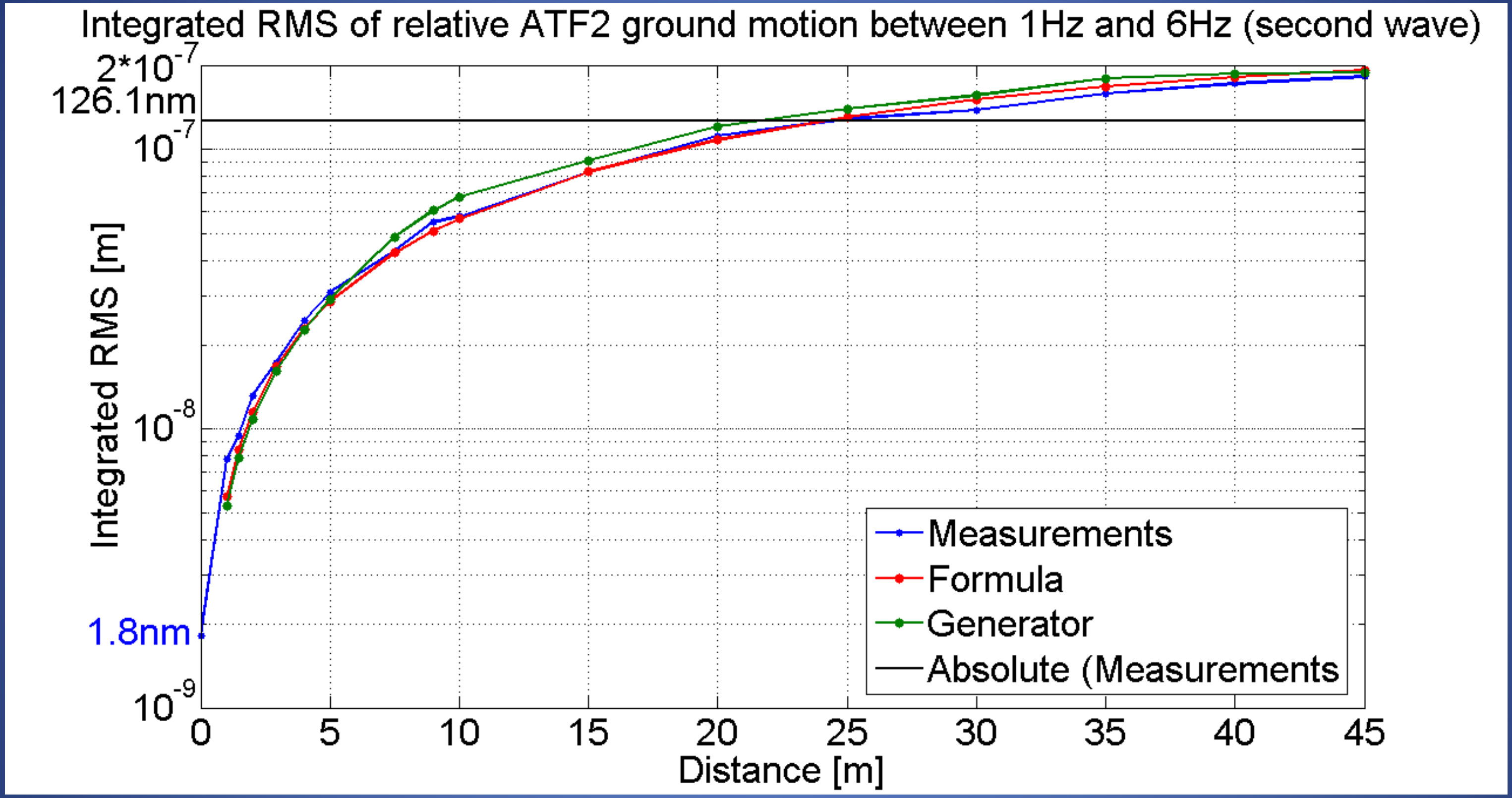


- ✓ Very high absolute motion: 207nm
  - ➔ 0m: relative motion measured= 9.1nm (4% error on correlation)
    - ➔ We have to look at the generator (or formula) results

✓ From 2m92 (QF1) to 45m: generator gives a relative motion which goes only from 1nm to 10nm because of the very good correlation

Update of velocity parameter

Integrated RMS of motion due to the second wave [1;6]Hz



- ✓ Very good fit of the generator (and formula) with measurements
- ✓ Faster increase of relative motion with distance (wave at higher freq)
  - ➢ From 2m92 to 45m: goes from 17nm to 182nm (over absolute motion!!)

Comparison of parameters

	Description	Notation	KEK B model	ATF Ring	ATF2
1st wave	Frequency	f1 [Hz]	0.16	0.16	0.2
	Amplitude	a1 [m^2/Hz]	$4.0*10^{-13}$	$2.0*10^{-12}$	$1.0*10^{-13}$
	Width	d1 [1]	5.0	5.0	1.1
	Velocity	v1 [m/s]	1000	1000	1000
2nd wave	Frequency	f2 [Hz]	2.5	2.5	2.9
	Amplitude	a2 [m^2/Hz]	$3.0*10^{-15}$	$5.0*10^{-15}$	$6.0*10^{-15}$
	Width	d2 [1]	3.0	3.0	3.6
	Velocity	v2 [m/s]	300	300	300
3rd wave	Frequency	f3 [Hz]	9.0	15	10.4
	Amplitude	a3 [m^2/Hz]	$3.0*10^{-17}$	$3.0*10^{-17}$	$2.6*10^{-17}$
	Width	d3 [1]	2.8	2.8	2.0
	Velocity	v3 [m/s]	250	250	250

- ✓ Amplitude, frequency and width changed for the 3 waves
- ✓ Same velocity of the 3 waves

Comparison of different formula for relative motion

Calculation of integrated RMS of relative motion

- ✓ By doing the substraction of temporal data x(t) and y(t)

$$RMS_{\text{int y-x}}(k) = \sqrt{\sum_{k_1}^{k_2} PSD_{x-y}(k)\Delta f}$$

- ✓ With transfer function H(k): in the case of motion amplification

$$RMS_{\text{int y-x}}(k) = \sqrt{\sum_{k_1}^{k_2} [H(k)-1][H^*(k)-1] PSD_x(k)\Delta f}$$

- ✓ With correlation Corr(k) or coherence Coh(k): assumption that x(t) and y(t) same amplitude (same ground motion level at any location)

$$RMS_{\text{int y-x}}(k) = \sqrt{\sum_{k_1}^{k_2} 2PSD_x(k)[1-Corr(k)]\Delta f}$$

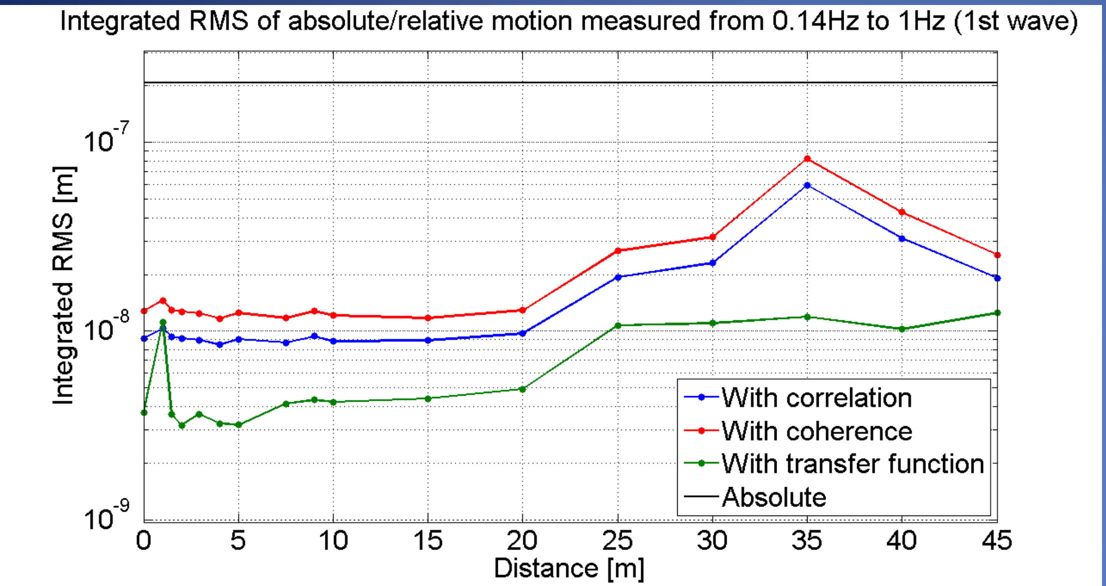
Usually used

In the case of phase difference between sensors

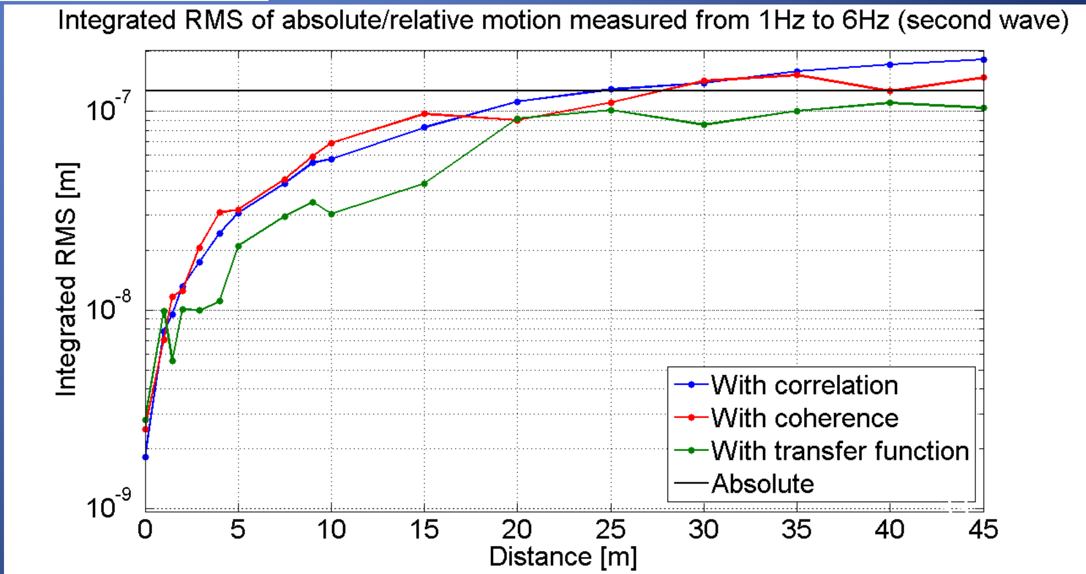
$$RMS_{\text{int y-x}}(k) = \sqrt{\sum_{k_1}^{k_2} 2PSD_x(k)[1-Coh(k)]\Delta f}$$

Comparison of different formula for relative motion

Difference of measurement results between the formula

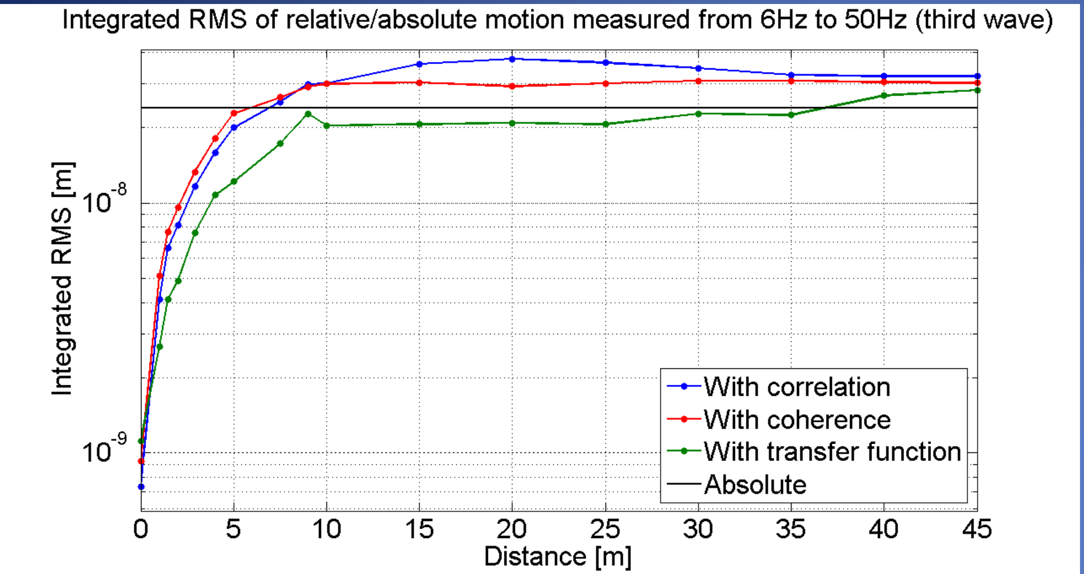


- Seems to have a better signal to noise ratio with the transfer function below 1Hz

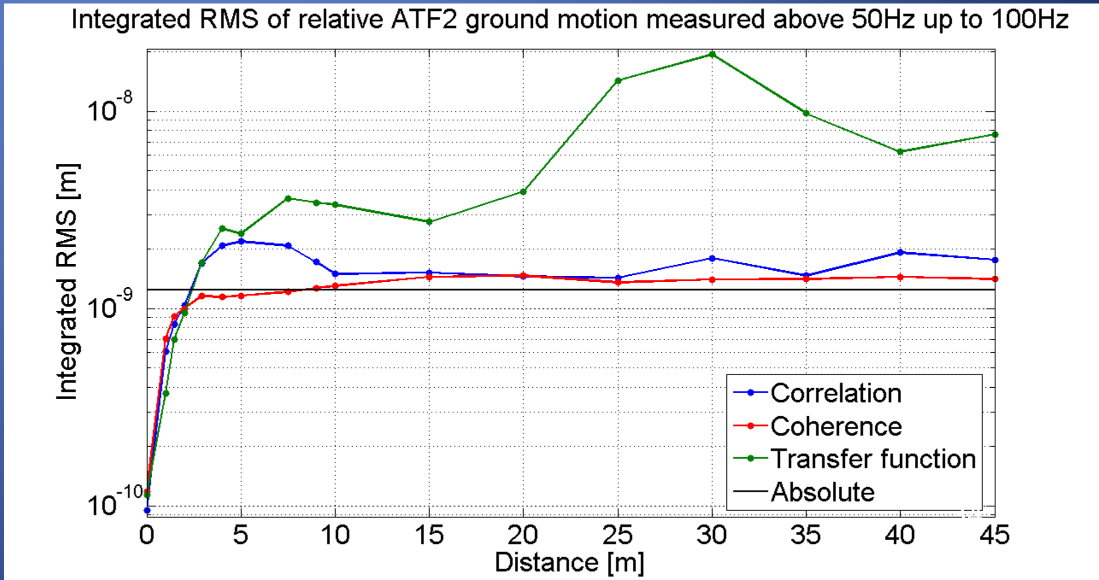


Comparison of different formula for relative motion

Difference of measurement results between the formula

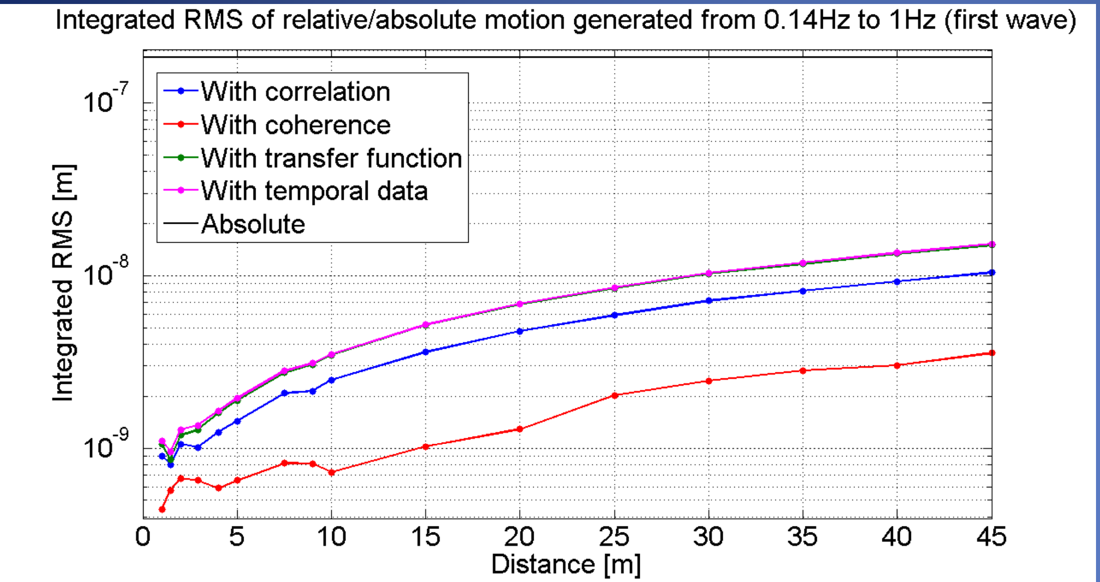


- With transfer function: does not respect the condition sqrt(p(w,L))≤2sqrt(p(w)) above 50Hz



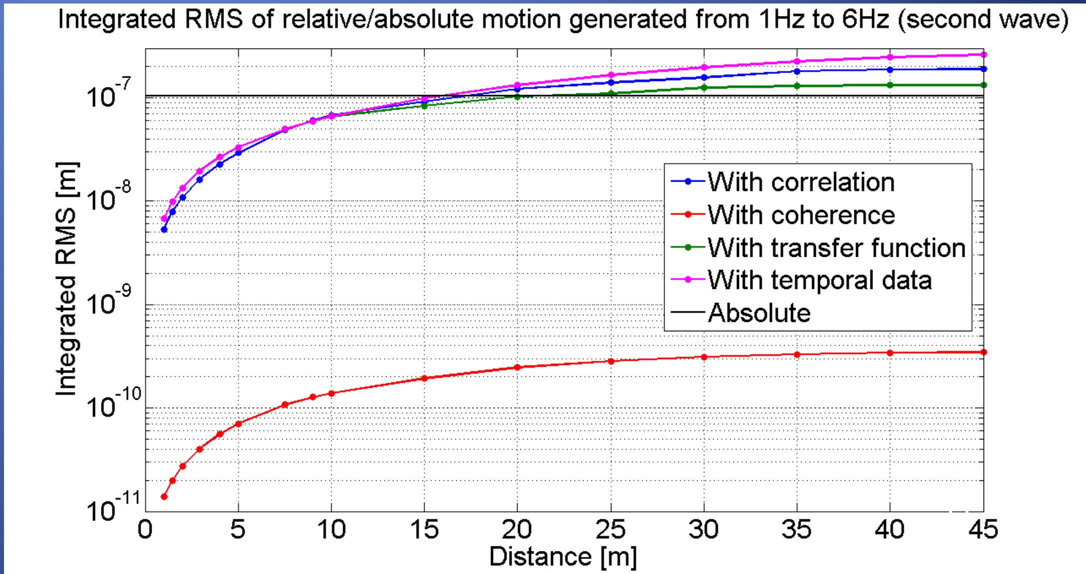
Comparison of different formula for relative motion

Difference of generator results between the formula



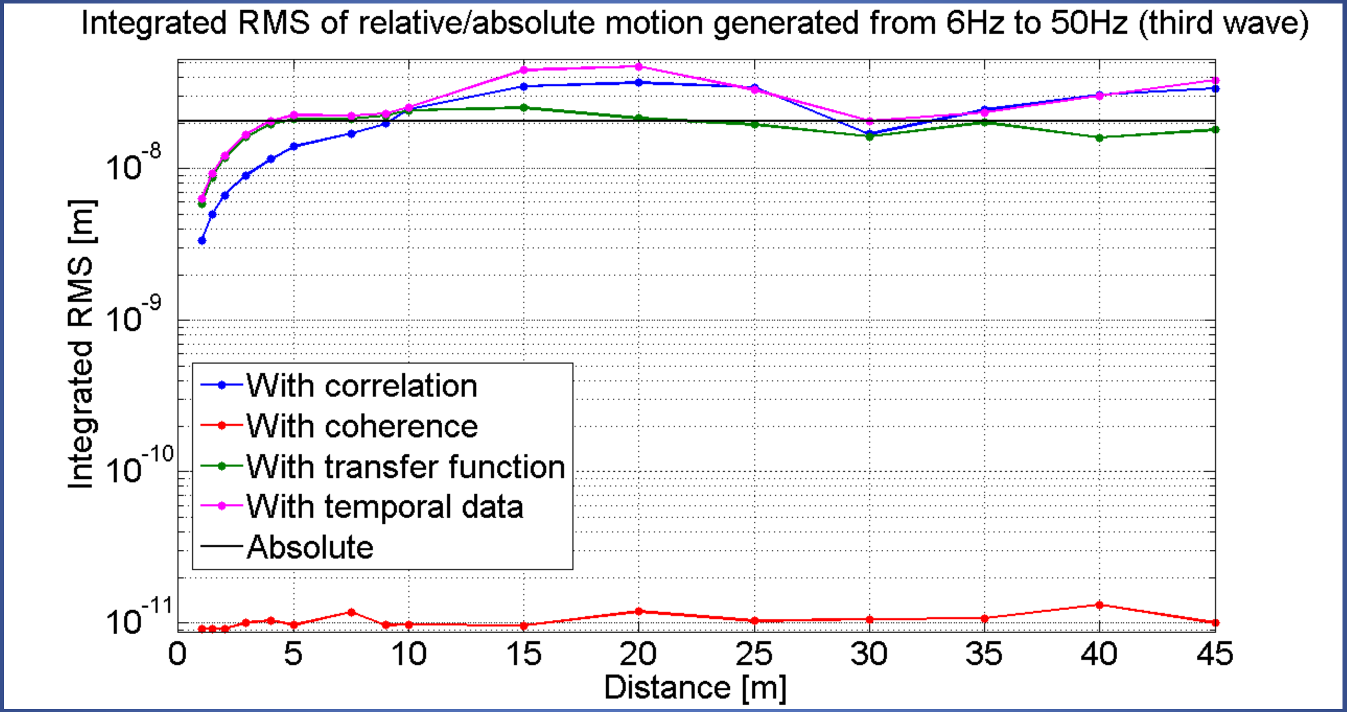
- With coherence: huge underestimation of relative motion

- With temporal data: does not respect the condition sqrt(p(w,L))≤2sqrt(p(w)) from 1Hz to 6Hz
- With coherence: huge underestimation of relative motion



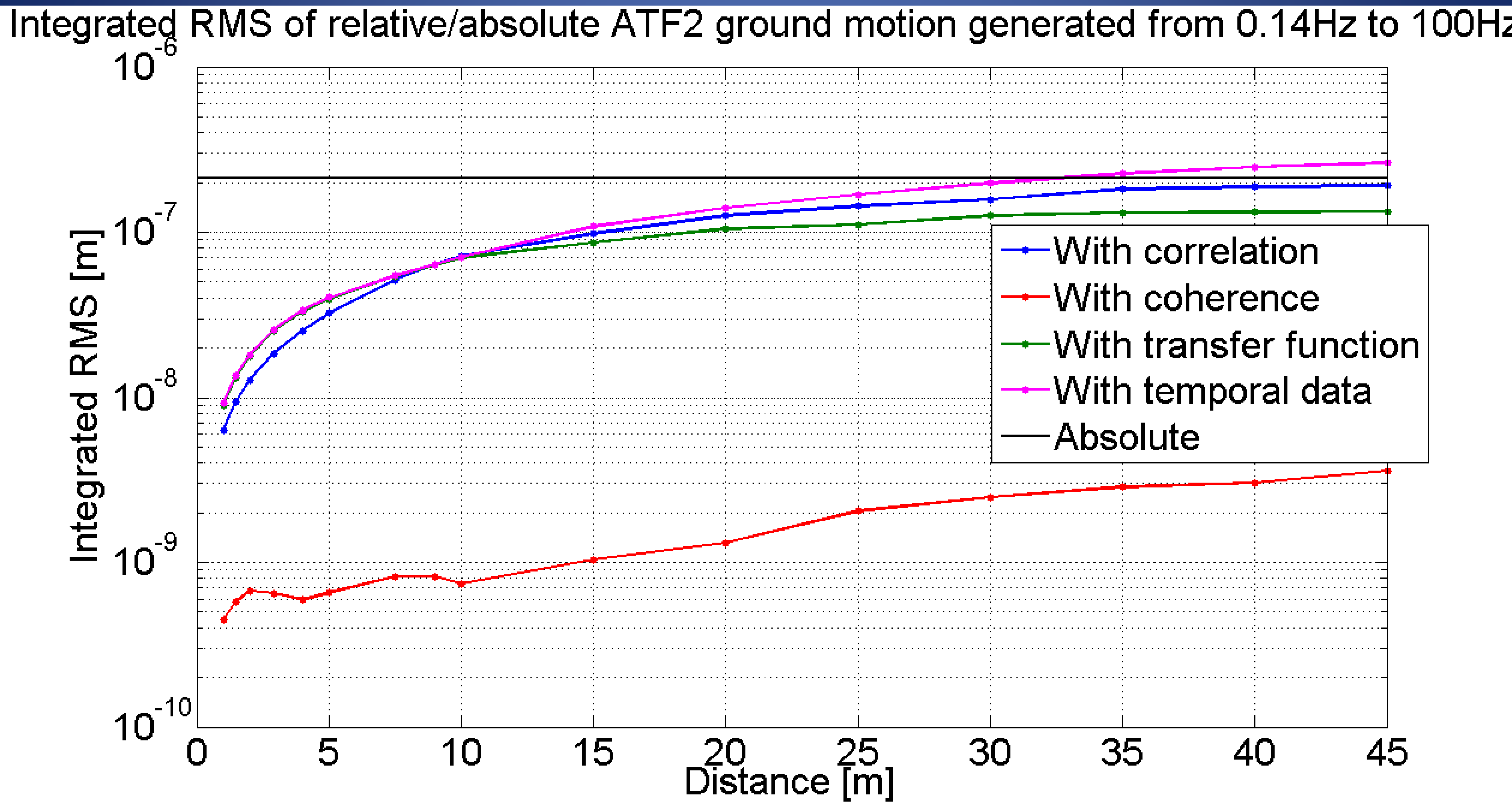
Comparison of different formula for relative motion

Difference of generator results between the formula

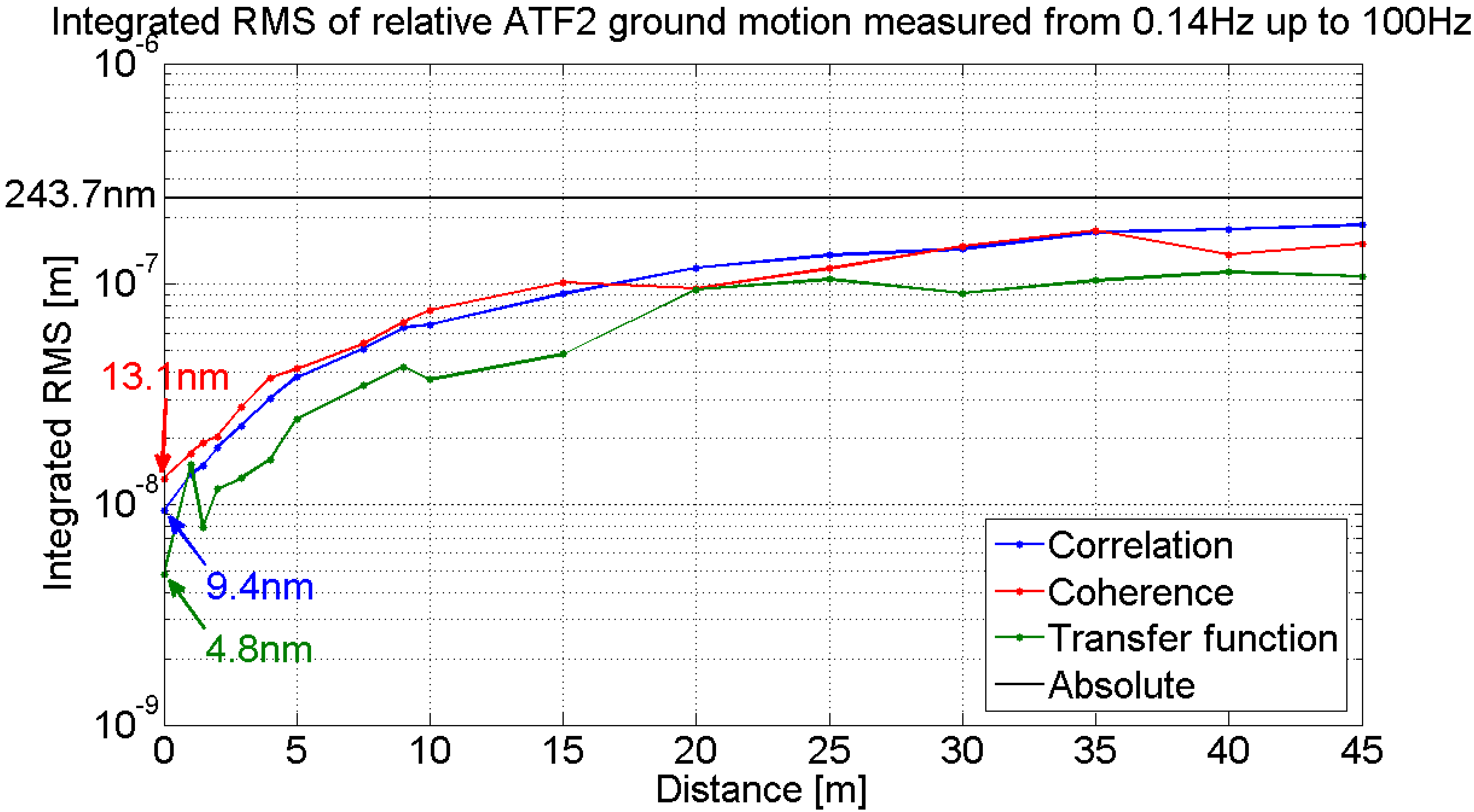


- With coherence: huge underestimation of relative motion

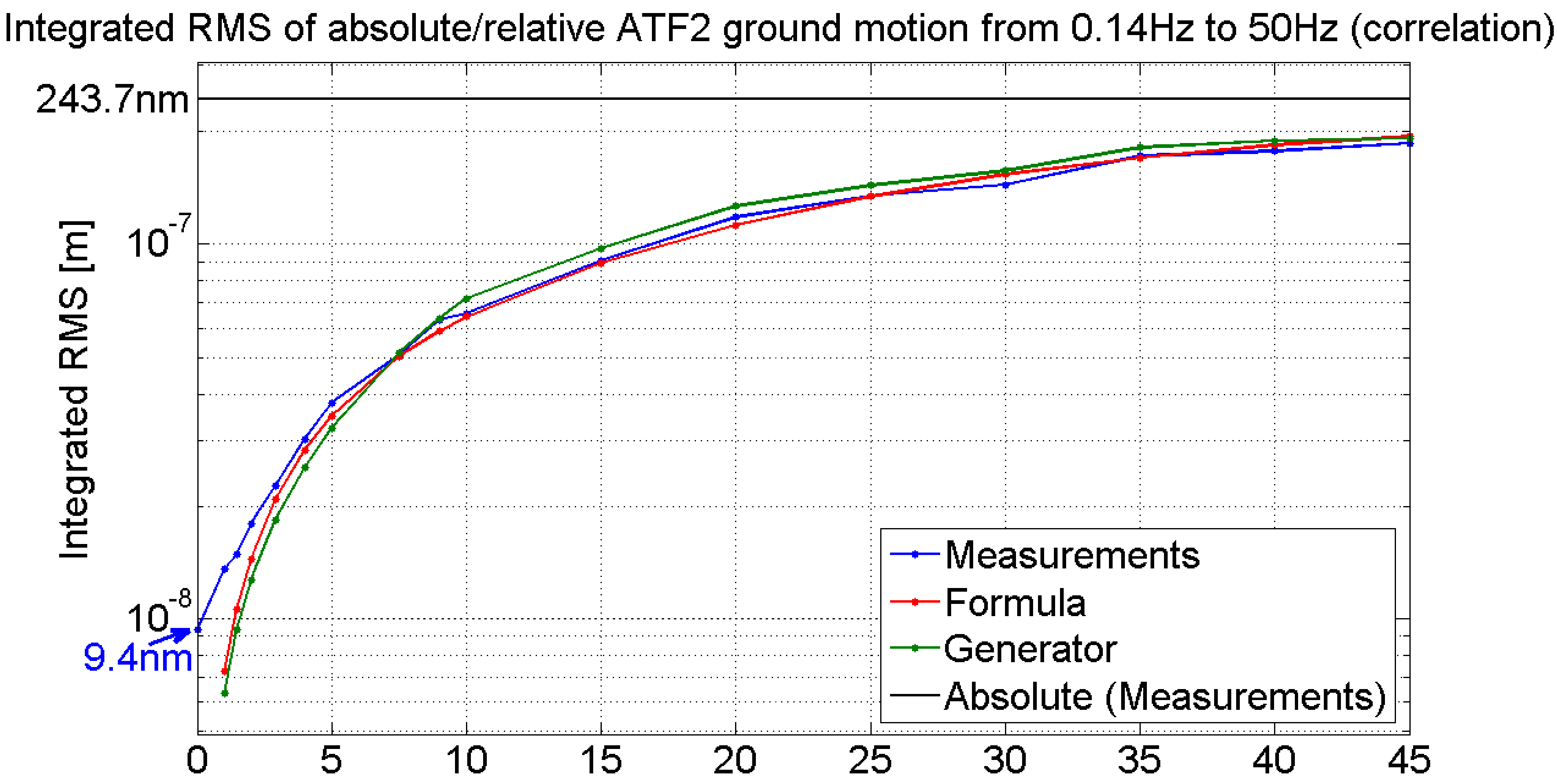
Comparison of different formula for relative motion



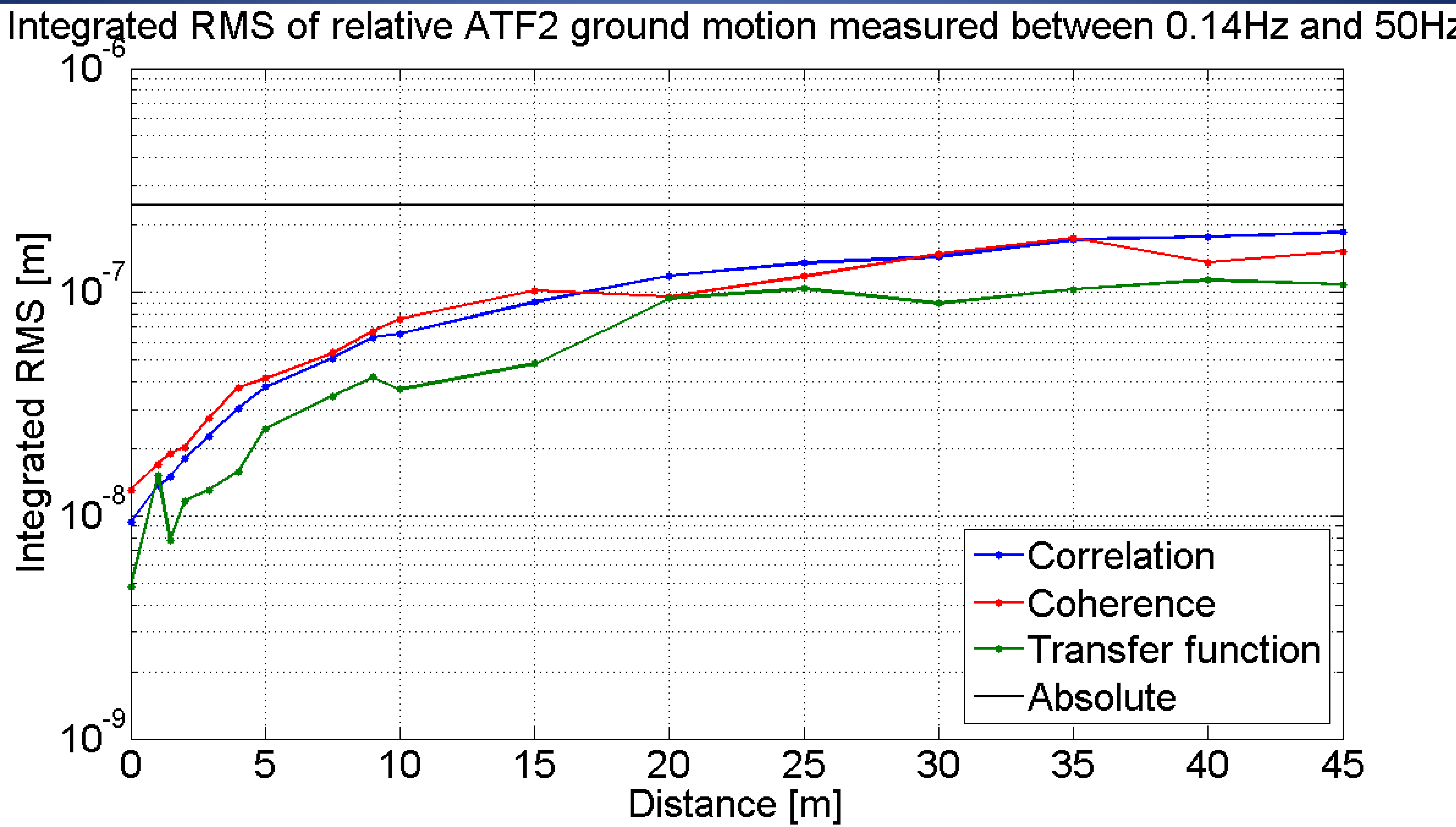
Comparison of different formula for relative motion



Comparison of different formula for relative motion



Comparison of different formula for relative motion



Usefulness of a stabilization for ATF2 final focus quadrupoles?

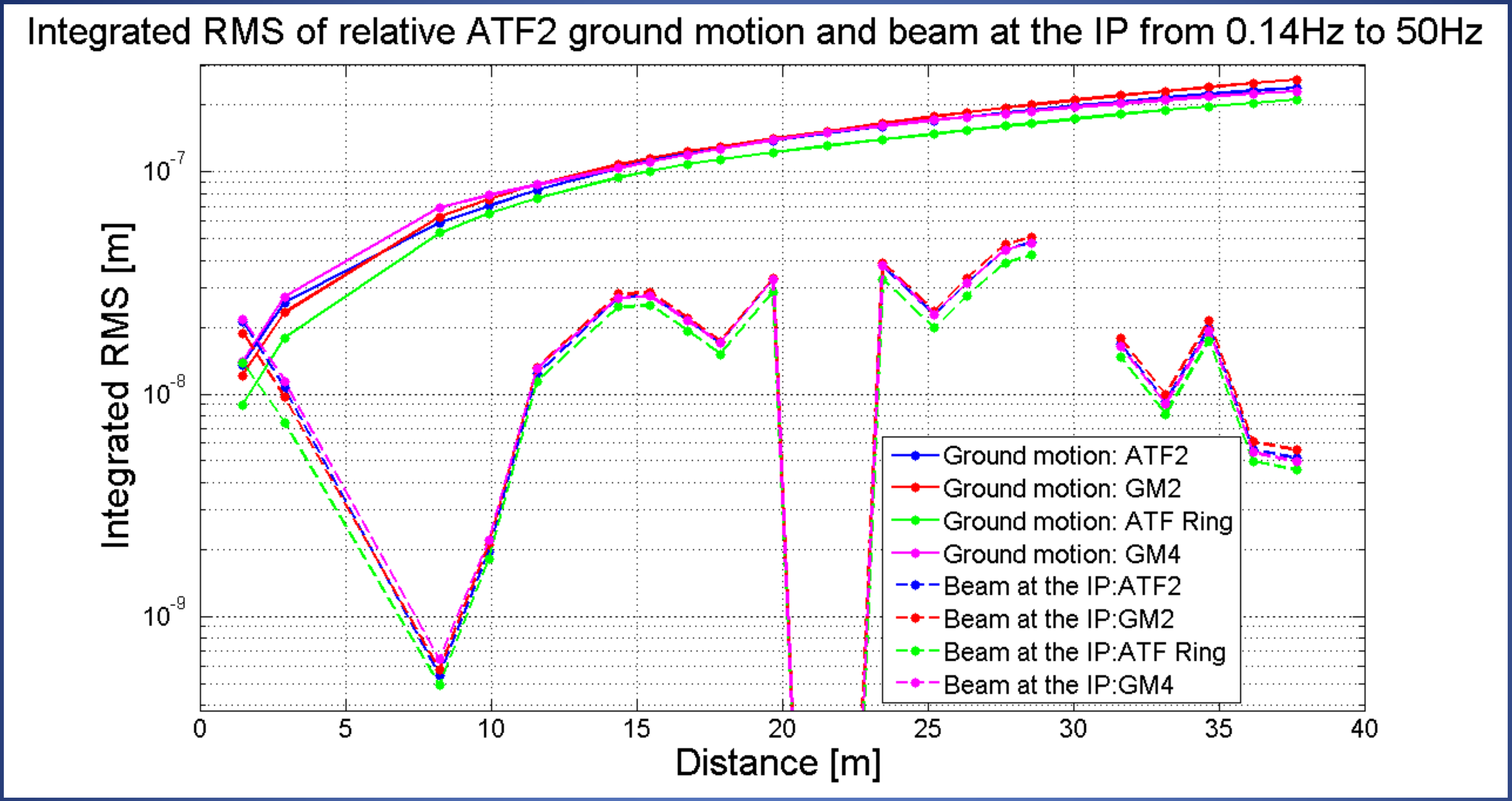
Consistency of results

Ground motion used

	Description	Notation	ATF2	GM2	ATF Ring	GM4
1st wave	Frequency	f1 [Hz]	0.2	0.15	0.1	0.18
	Amplitude	a1 [m^2/Hz]	$1.0*10^{-13}$	$2*10^{-13}$	$2*10^{-12}$	$1.2*10^{-13}$
	Width	d1 [1]	1.1	1.0	5.0	1.0
	Velocity	v1 [m/s]	1000	1000	1000	900
2^{nd} wave	Frequency	f2 [Hz]	2.9	2.4	2.5	2.7
	Amplitude	a2 [m^2/Hz]	$6.0*10^{-15}$	$10*10^{-15}$	$5*10^{-15}$	$6.2*10^{-15}$
	Width	d2 [1]	3.6	3.1	3.0	3.5
	Velocity	v2 [m/s]	300	300	300	280
3rd wave	Frequency	f3 [Hz]	10.4	8.0	15	10.2
	Amplitude	a3 [m^2/Hz]	$2.6*10^{-17}$	$6*10^{-17}$	$3*10^{-17}$	$2.8*10^{-17}$
	Width	d3 [1]	2.0	1.5	2.8	1.9
	Velocity	v3 [m/s]	250	250	250	230

- ATF2: Presented last time: ATF2 GM (reference)
- GM2: Absolute GM higher but same velocity
- ATF Ring: Tuning of Y.Renier for ATF Ring
- GM4: Absolute GM slightly higher and velocity slightly lower

Beam relative motion to IP due to jitter of each QFF_i

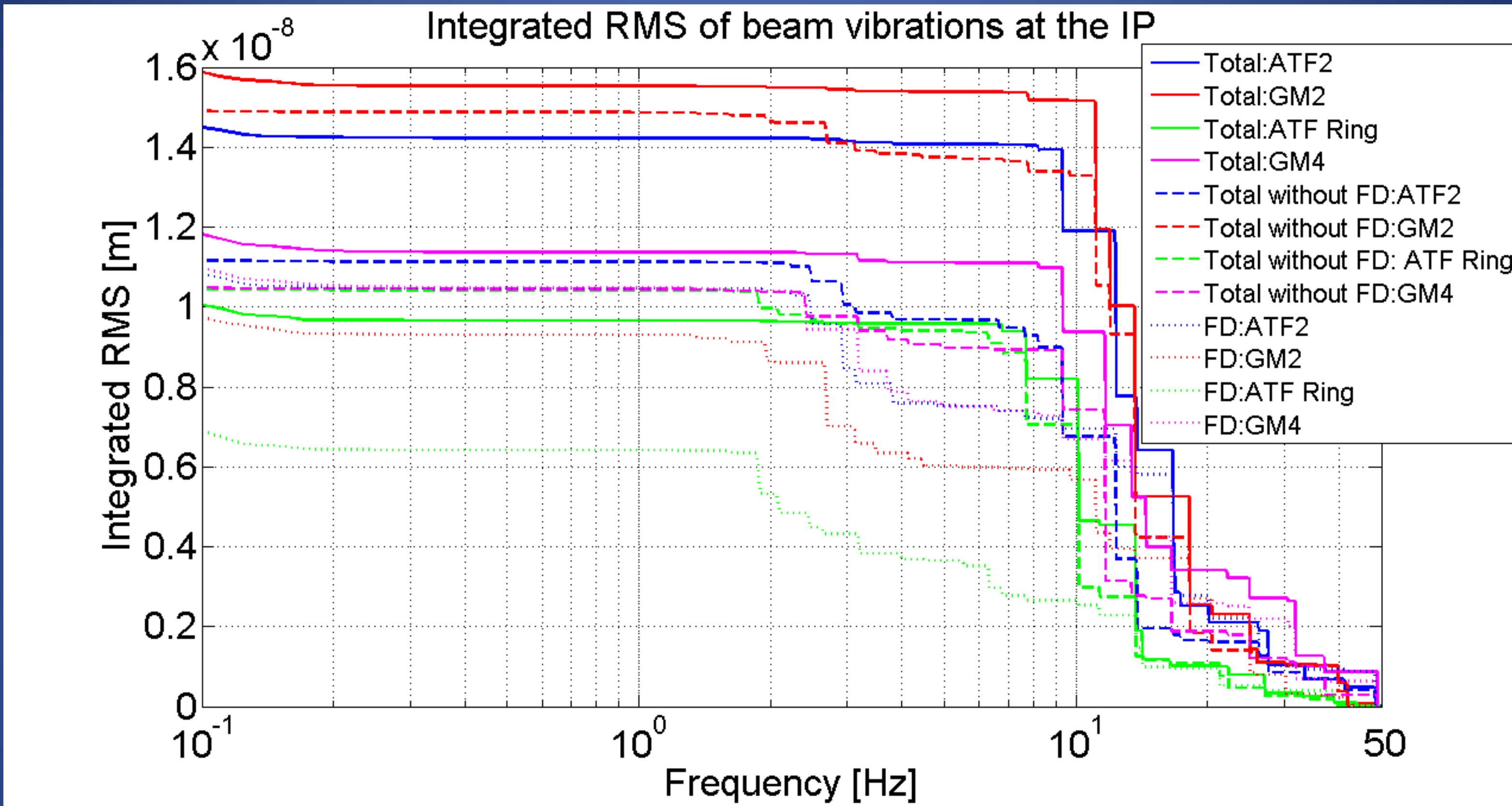


- ✓ Beam relative motion (RM) to IP from 0.1Hz to 50Hz due to motion of:
  - ➢ QD0/QF1FF=around 20nm/10nm (slightly lower for ATF Ring)
  - ➢ QD10A/B=around 45nm/50nm: huge (slightly lower for ATF Ring)

- ✓ GM4 parameters very slightly different from ATF2 ones

➔ very slightly difference in terms of ground and beam relative motion

Beam relative motion to IP due to jitter of all QFF_i



✓ By summing the effect of all the quads motion, lucky compensation on the relative motion beam/IP for 4 different ground motion

➔ **Lucky compensation seems to be well reproductible!!**

Summary

Rel. motion beam/IP (nm)	ATF2	GM2	ATF Ring	GM4
QD0	21.0	18.8	13.8	21.6
QF1	10.7	9.7	7.4	11.4
QD10A	44.7	47.2	39.0	44.5
QD10B	48.2	51.0	42.1	47.8
QD0/QF1	10.5	9.5	6.5	10.5
All QFF except FD	11.1	14.9	10.4	10.7
All QFF	14.3	15.7	9.8	11.5

- ✓ GM4 parameters very slightly different from ATF2 ones
  - ➢ almost same results obtained in terms of relative motion beam/IP
- ✓ Relative motion of ATF Ring slightly lower from ATF2 one
  - ➢ Slightly lower relative motion beam/IP at ATF Ring than at ATF2

➡ **Compensation seems to be not random (good point!!)**