# Possibility to detect ground motion at ATF2

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# Headlines

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ATF2

ATF2 Ground Motion

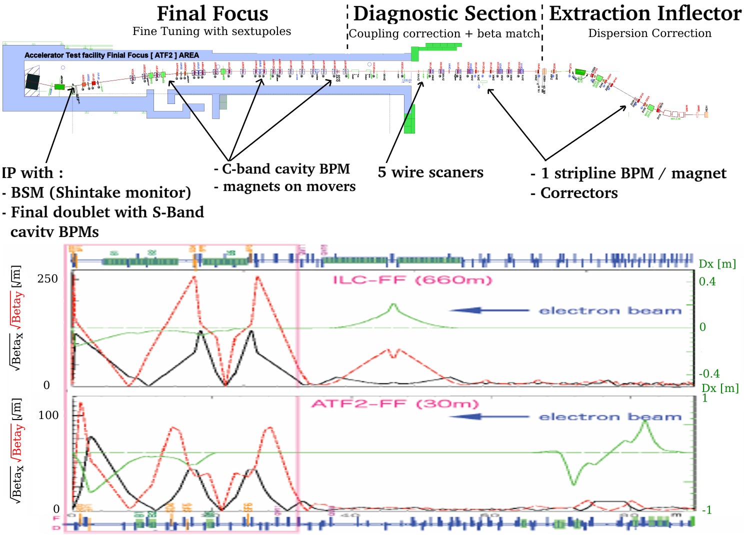
Detection of the Ground Motion Effects

Conclusion and Prospects

Backup Slides

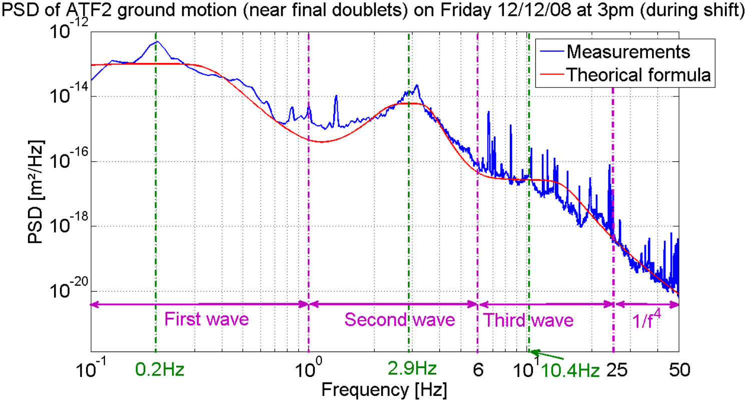
# Introduction

## ATF2 : ILC & CLIC Final Focus Demonstration



# Headlines

# ATF2 Ground Motion Measurements[1]

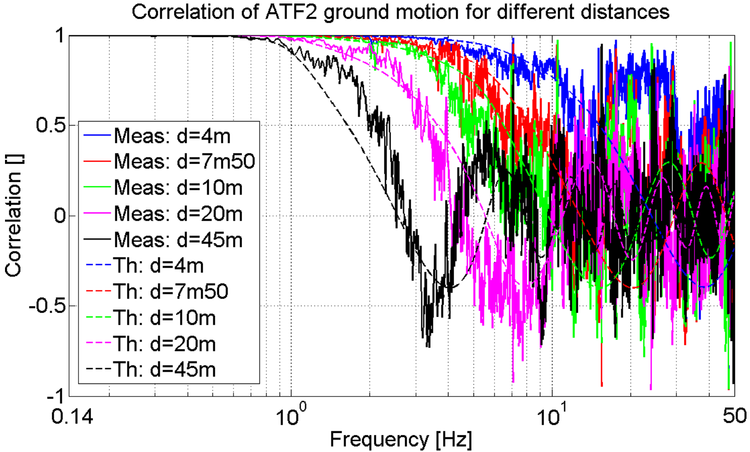



## Power Spectral Density property

$$A^2 = \int_{f=0}^{\infty} p(f)\,\mathrm{d}f \qquad (1)$$

[1]made by B. Bolzon

# ATF2 Ground Motion Measurements[1]

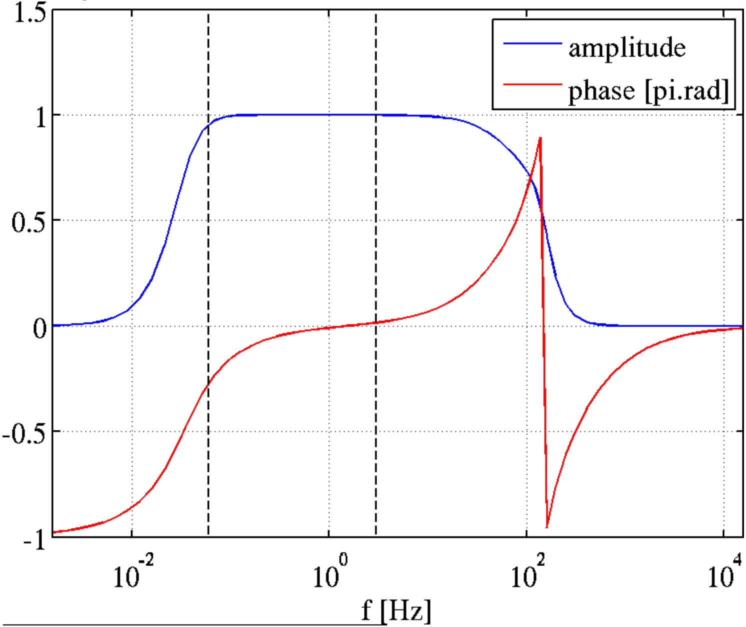



## Coherence definition

$$C(f) = 1 - \frac{p(f, L)}{2 \times p(f)} \quad (2)$$

[1] made by B. Bolzon

# Guralp Seismometer Transfer Function[1]




[1] Courtesy of J. Pfingstner

# Headlines

ATF2

ATF2 Ground Motion

Detection of the Ground Motion Effects

- Simulation
- Jitter determination
- Sextupole-beam offsets
- Injected Beam Offsets
- Results

Conclusion and Prospects

Backup Slides

# Simulation

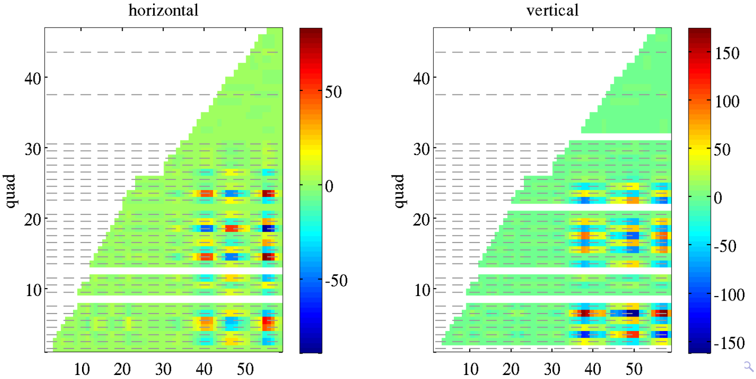
## Conditions

- ATF2 nominal lattice.
- Elements misaligned initially (RMS=100$\mu$m).
- Trajectory is then steered.
- Ground Motion (GM) model based on measurements.
- Elements are displaced by the amount of relative motion compared with the $1^{st}$ element.
- Incoming beam jitter (6 Hz, 100 pulses).
- BPM and sensor noise included.
- Limited number of sensors (Guralp Seismometers).

# Algorithm

## Initialization

- Compute the matrices of the effects of element displacements on BPM readings.
- Find the elements with the higher effects and select them to have GM sensor.
- Put also a sensor on the first and last element.





ATF2 Project
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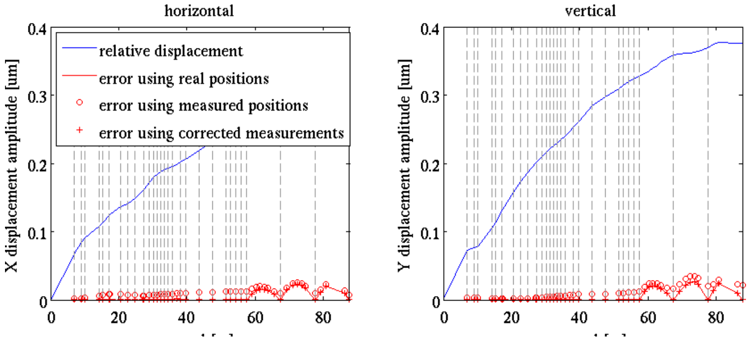
ATF2
ATF2 Ground Motion
Power Spectral Density
Coherence
GM Sensors
Detection of the GM Effects
Simulation
Jitter determination
Sextupole-beam offsets
Injected Beam Offsets
Results
Conclusion and Prospects

# Algorithm

## Algorithm - Each Pulse

- From the measured GM interpolate the displacements of other elements linearly with the distance.
- Subtract induced beam displ. from BPM meas.
- Remove incoming beam jitter from BPM meas.



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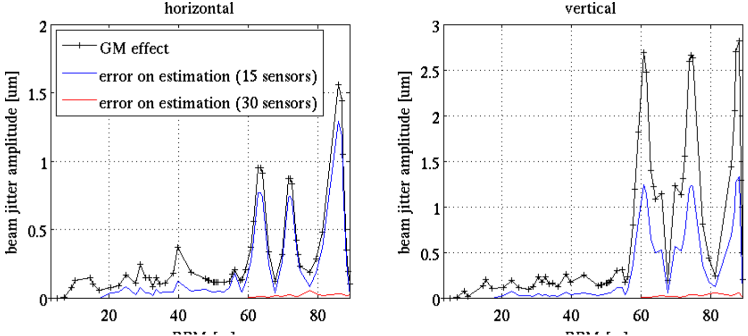

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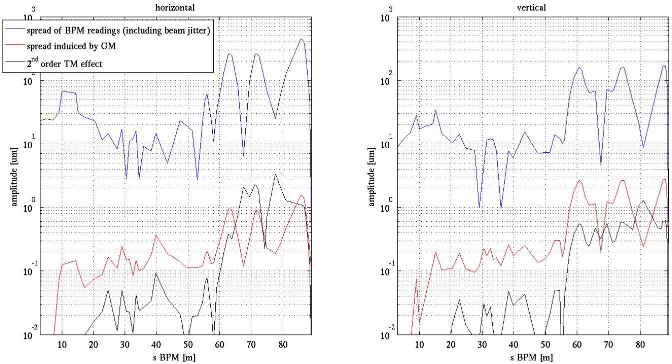


# Transfer Matrices

## Linear case

$XY = TM \times P_{inj}$

$$\begin{pmatrix} X_1 \\ \vdots \\ X_n \\ Y_1 \\ \vdots \\ Y_n \end{pmatrix} = \begin{pmatrix} R_{11}(BPM_1) & \cdots & R_{16}(BPM_1) \\ & \vdots & \\ R_{11}(BPM_n) & \cdots & R_{16}(BPM_n) \\ R_{31}(BPM_1) & \cdots & R_{36}(BPM_1) \\ & \vdots & \\ R_{31}(BPM_n) & \cdots & R_{36}(BPM_n) \end{pmatrix} \times \begin{pmatrix} X \\ X' \\ Y \\ Y' \\ \frac{dE}{E} \end{pmatrix}_{inj}$$

## $2^{nd}$ order case

$XY = TM \times P_{inj} + TM2 \times \{P_{inj}, P_{inj}\}$

$X_1 = R_{11}X + \cdots + R_{16}\frac{dE}{E} + T_{111}XX + \cdots + T_{166}\frac{dE}{E}\frac{dE}{E}$

# Incoming Beam Jitter Determination





## Principle

- Remove mean BPM measurements.
- Subtract GM induced beam displ. from BPM meas.
- Each pulse, fit the 5 parameters at injection ($P_{inj}$). Merit function:

$$\left| XY_{BPM} - < XY_{BPM} > - XY_{GM} - TM \times P_{inj} - TM2 \times \{P_{inj}, P_{inj}\} \right|$$

## Problem

Works great with ideal lattice, not anymore with misalignments. Due to non-linear effects in sextupoles.

# Sextupole-beam offsets determination

## Characterization

TM2 matrices are computed with ideal lattice (beam goes through center of sextupoles).
Using R(sext $\rightarrow$ BPM) and T(sext $\rightarrow$ BPM) :

$$X_{BPM} = R_{11} X_{sext} + \cdots + R_{16} \frac{dE}{E} + T_{111} X_{sext}^2 + T_{166} \frac{dE}{E}^2$$

If we add a constant $X_0$ to $X_{sext}$ , the $\tilde{X}$ variation is :

$$\tilde{X}_{BPM} = \quad R_{11} X_0 + T_{111} X_0^2 + 2 T_{111} X_0 X_{sext} + ... + T_{116} X_0 \frac{dE}{E}$$

New cross terms appear ! dominating ones :

- $\frac{d\tilde{X}_{BPM}}{X_{sext}} \simeq 2 T_{111} \times X_0 \qquad \frac{d\tilde{X}_{BPM}}{Y_{sext}} \simeq 2 T_{133} \times Y_0$
- $\frac{d\tilde{Y}_{BPM}}{X_{sext}} \simeq 2 T_{313} \times Y_0 \qquad \frac{d\tilde{Y}_{BPM}}{Y_{sext}} \simeq 2 T_{313} \times X_0$

# Sextupole-beam offsets determination

## Determination

Considering only the dominant terms, for 1 pulse the effects of beam misalignments in the sextupoles on BPM readings are :

$$\begin{pmatrix} \tilde{X}_1 \\ \vdots \\ \tilde{X}_n \\ \tilde{Y}_1 \\ \vdots \\ \tilde{Y}_n \end{pmatrix} = 2 \begin{pmatrix} T_{111}^{BPM_1} X_{sext1} & \cdots & T_{133}^{BPM_1} Y_{sext5} \\ & \vdots & \\ T_{111}^{BPM_n} X_{sext1} & \cdots & T_{133}^{BPM_n} Y_{sext5} \\ T_{313}^{BPM_1} Y_{sext1} & \cdots & T_{313}^{BPM_1} X_{sext5} \\ & \vdots & \\ T_{313}^{BPM_n} Y_{sext1} & \cdots & T_{313}^{BPM_n} X_{sext5} \end{pmatrix} \times \begin{pmatrix} X_0^{s1} \\ \vdots \\ X_0^{s5} \\ Y_0^{s1} \\ \vdots \\ Y_0^{s5} \end{pmatrix}$$

Solving that equation gives the sextupole-beam offsets. The positions in the sextupoles are determined using the reconstructed parameters at injection.

# Injected Beam Offsets

## Characterization

As for sextupole displacements, non-zero mean injected beam parameters induce new terms in motion equations. Using R(inj → BPM) and T(inj → BPM) :

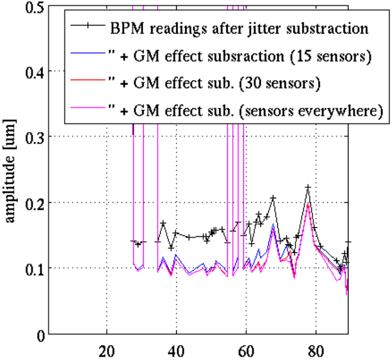
$$\begin{aligned}\tilde{X}_{BPM} = R_{11}X_0 + T_{111}X_0^2 \quad & +2T_{111}X_0X_{inj} + \ldots + T_{116}X_0\frac{dE}{E} \\ & +2T_{121}X_0'X_{inj} + \ldots + T_{126}X_0'\frac{dE}{E} \\ & \vdots \\ & +2T_{161}\frac{dE}{E}_0 X_{inj} + \ldots + T_{166}\frac{dE}{E}_0\frac{dE}{E}\end{aligned}$$

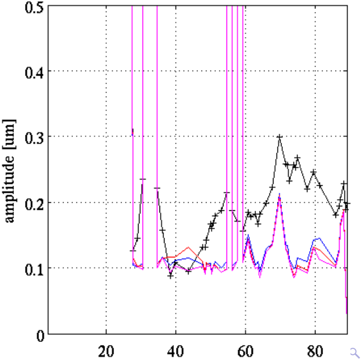
That equation is solved finding $X_0 \cdots \frac{dE}{E}_0$ using the injected beam parameters previously computed.

# Beam Jitter Effects Correction Results

## Principle

- Remove predicted GM effect from BPM readings.
- Remove injection beam jitter.
- Remove non-linear effects.
- Compute injection beam jitter again.
- Look at the RMS of the residuals at each BPM.

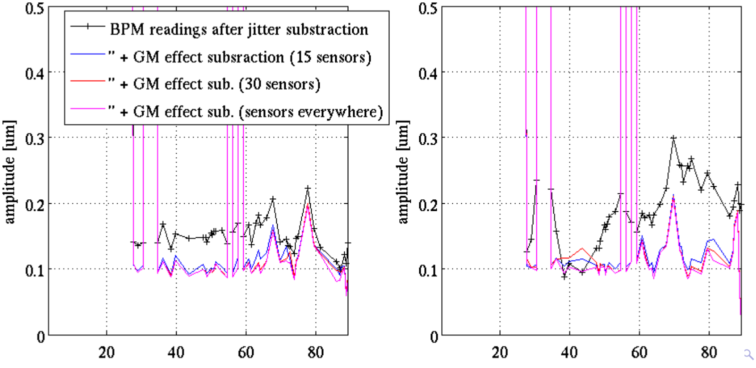


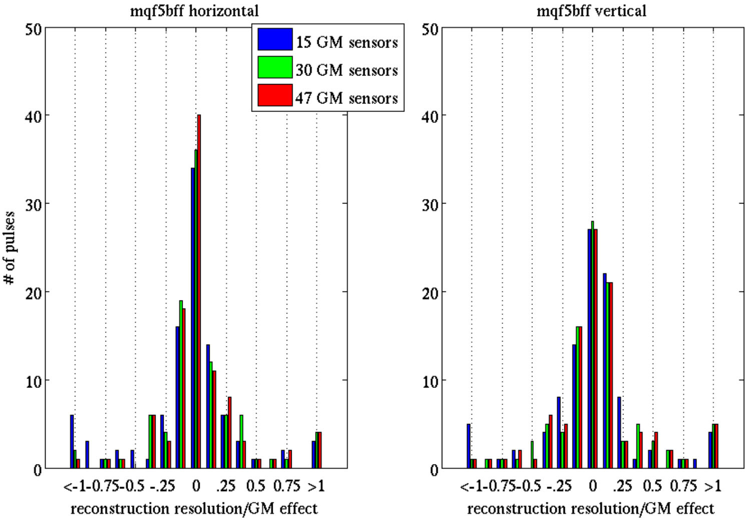
# Beam Jitter Effects Correction Results

## Results

- Only cavity BPMs are precise enough (0.1$\mu$m).
- Residuals are lower subtracting GM effects.
- Works from 15 sensors.
- Sextupole-beam offsets determined at 10s $\mu$m level.
- Higher residuals in FF from errors on jitter.

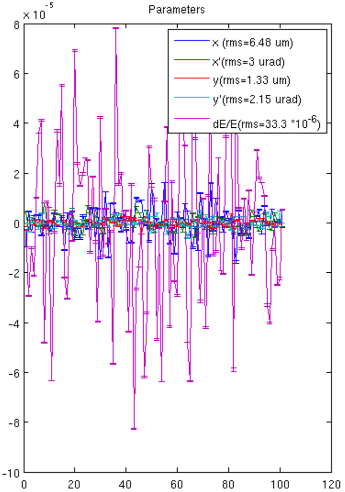


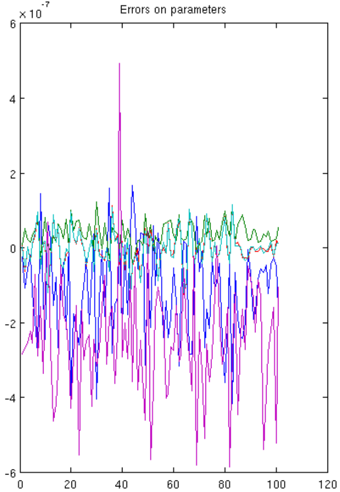
# Ratio of residual over expected GM effect on BPM readings (MQF5BFF s=71m)




Residuals are much lower than GM effects.

# Reconstructed incoming parameters




Parameters are reconstructed with $\simeq$ 1% precision !

# Headlines

# Conclusion & Prospects

## Conclusion

- Beam jitter subtraction is critical.
- With 15 sensors, GM effect is measurable.
- Non-linearities might be used to determine sextupole displacements.

## Prospects

- Errors on magnet fields not considered yet.
- 15 sensors already bought, experimental test.
- Feed forward implementation (in CLIC) is under study. (J. Pfingstner).

# Headlines

# ATF2 Ground Motion Model Parameters Fit[1]



## Model

- Wave Propagation $\Rightarrow$ close enough elements move together.
- 3 Waves with adjusted amplitude, frequency, velocity and width.
- Good agreement with measurements once tuned.

## Parameter table

$$p(f) = \sum_{i=1}^{3} \frac{a_i}{1 + [d_i(\frac{f-f_i}{f_i})^2]^4} \quad (3)$$

$$C(f, L) = J_0\left(\frac{2\pi f L}{v}\right) \quad (4)$$

| | | |
|---|---|---|
| f1 | [Hz] | 0.2 |
| a1 | [m**2/Hz] | 1.0 E-13 |
| d1 | [1] | 1.1 |
| v1 | [m/s] | 1 000 |
| f2 | [Hz] | 2.9 |
| a2 | [m**2/Hz] | 6.0 E-15 |
| d2 | [1] | 3.6 |
| v2 | [m/s] | 550 |
| f3 | [Hz] | 10.4 |
| a3 | [m**2/Hz] | 2.6 E-17 |
| d3 | [1] | 2.0 |
| v3 | [m/s] | 250 |

[1] made by B. Bolzon