ESRF 6 GeV energy variations : slow & fast & permanent measurement & analysis of their cause

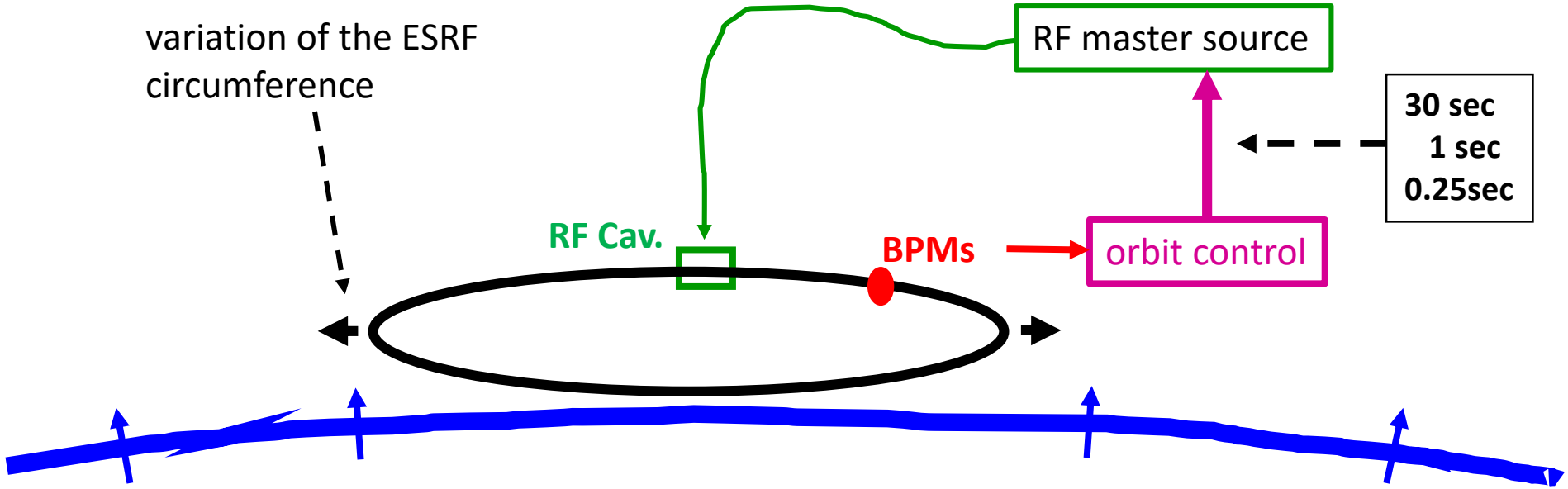
1) Recall of the relation between : - **circumference of the Ring,**
   - **the RF-frequency**
   - **the energy of the electrons**

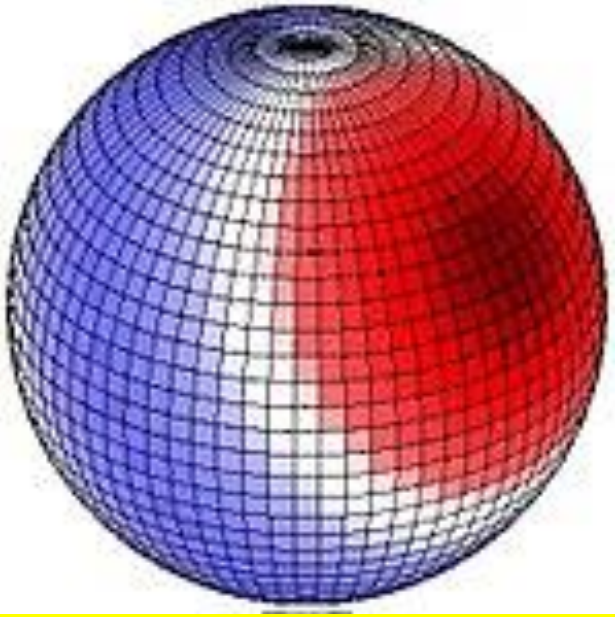
2) Permanent energy variations and their **measurements (over many hours & days)** :
   - using **the BPMs** (the 128 in **dispersive sections**)
   - using the "Energy-Monitor" → **X-rays from 3-pole-wiggler**

3) Verifications on the **real stability** of the **RF-Master-source**

4) Effect of an increase of the RF frequency control (1 to 4Hz)

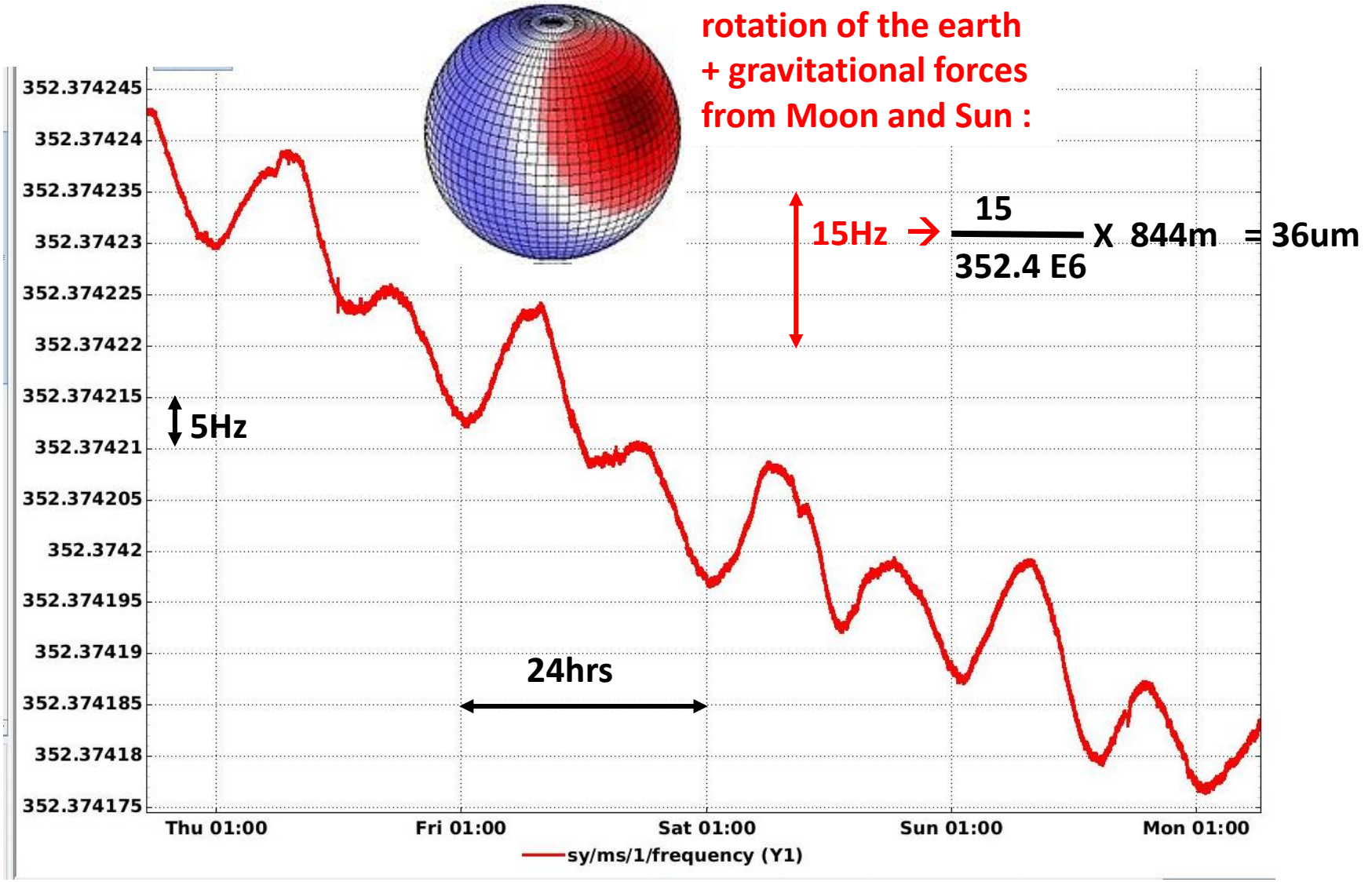
5) Conclusions





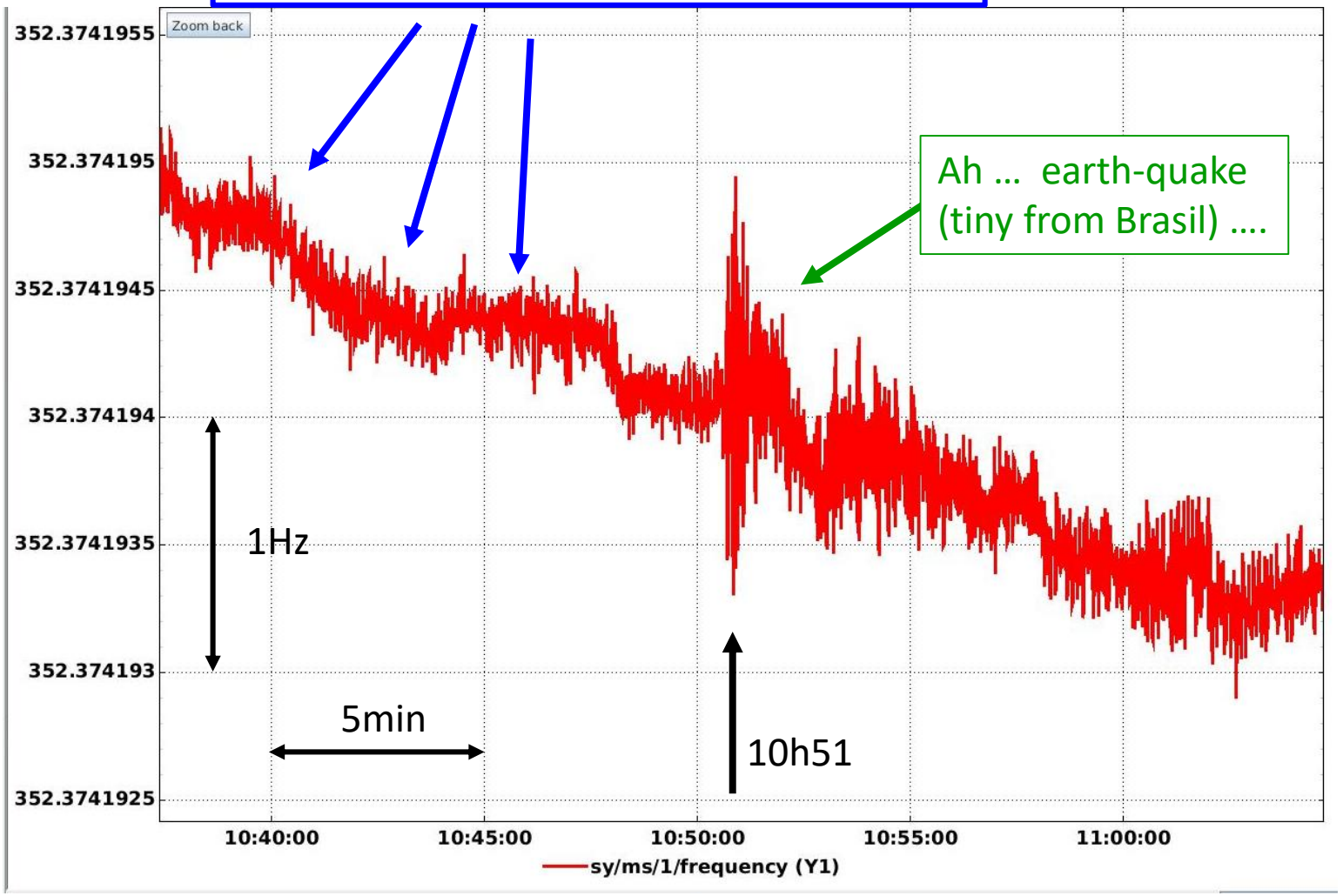
rotation of the earth
+ gravitational forces
from Moon and Sun :

the RF-frequency is adjusted permanently so to match a changing circumference, thereby keeping the 6GeV energy stable



RF-frequency is adjusted
to match a changing circumference,
→ keeping the 6GeV energy stable

please note the **nervousness**
of these frequency adjustments …. **WHY ?**

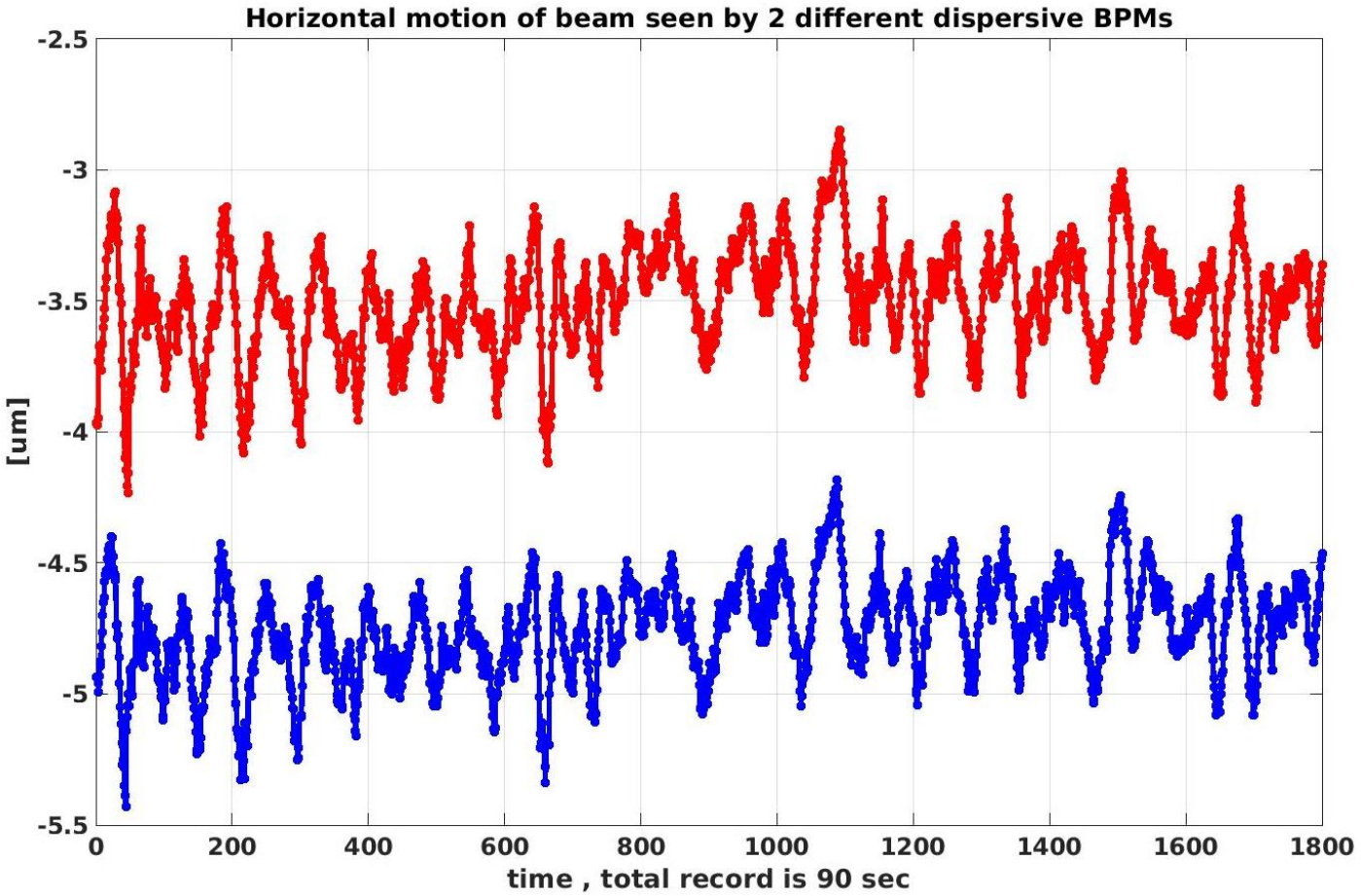


2) permanent energy variations and their measurements (over many hours & days) :

-A- using the BPMs (the 128 in dispersive sections)

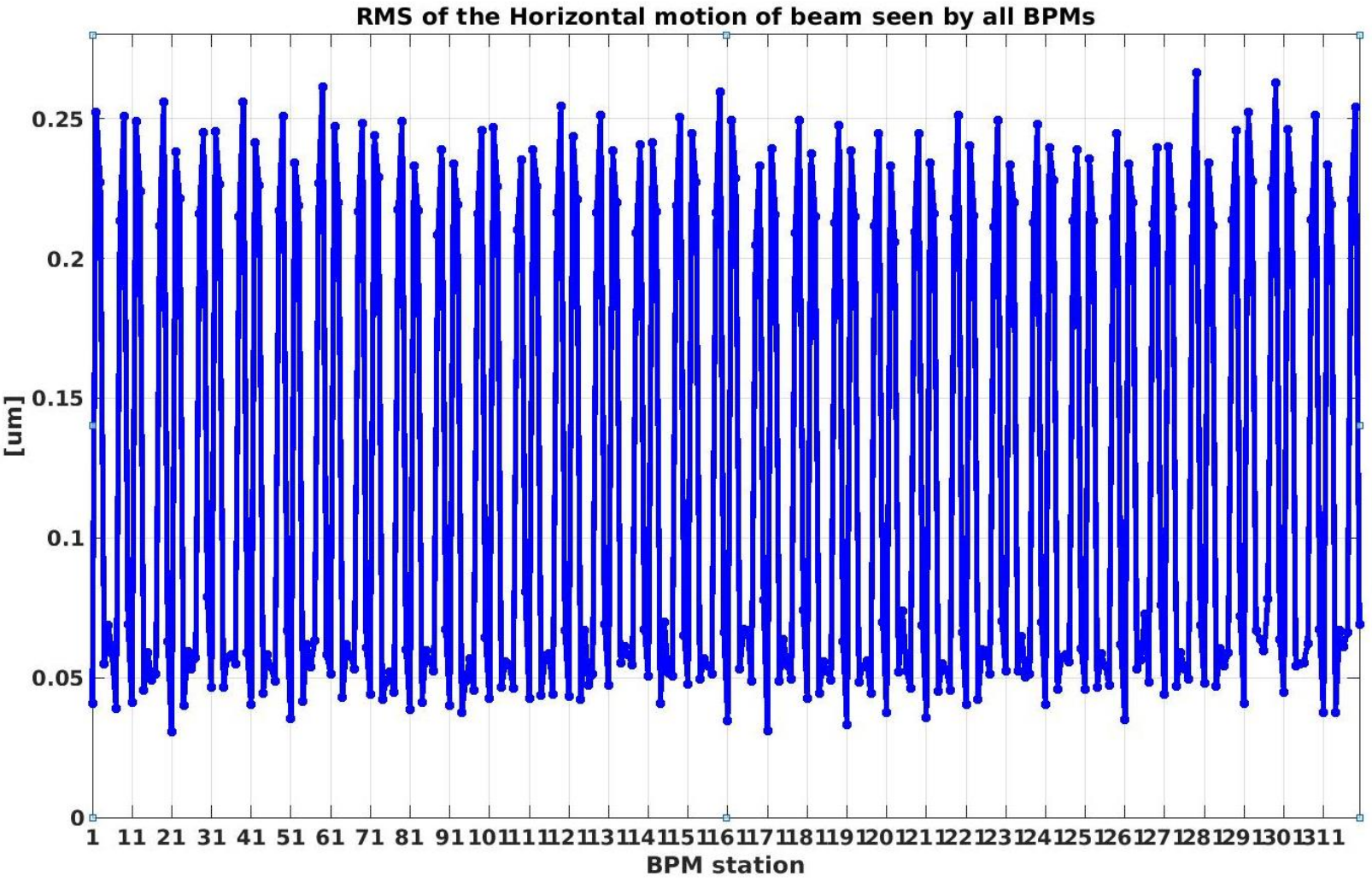
-B- using the "Energy-Monitor" → X-rays from 3-pole-wiggler

-A- (BPMs)



record=90sec, sampling at 20Hz, BPM-bandwidth 6Hz

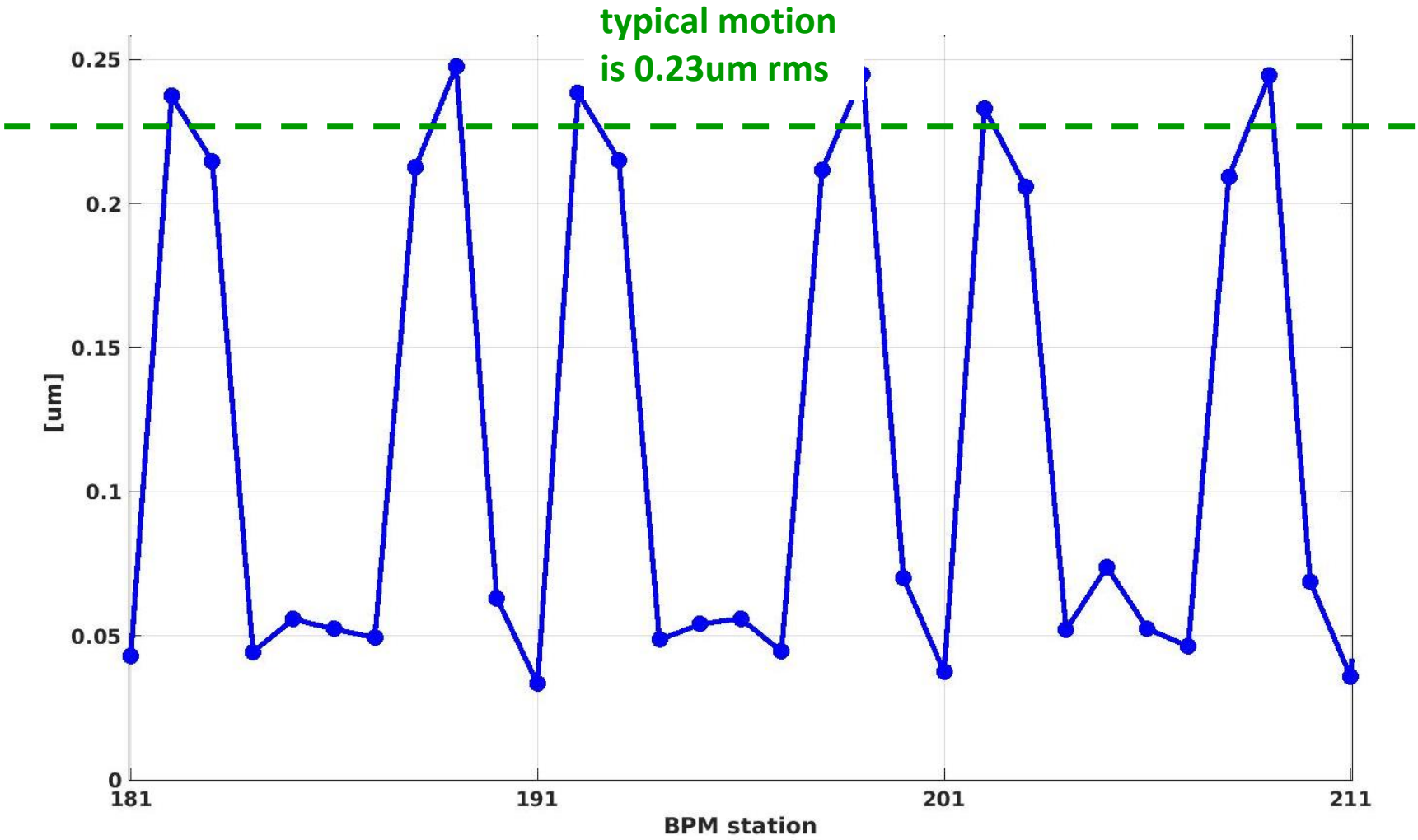
-A- (BPMs)



only slow freq. control (30sec)

record=90sec, sampling at 20Hz, BPM-bandwidth 6Hz

-A- (BPMs)

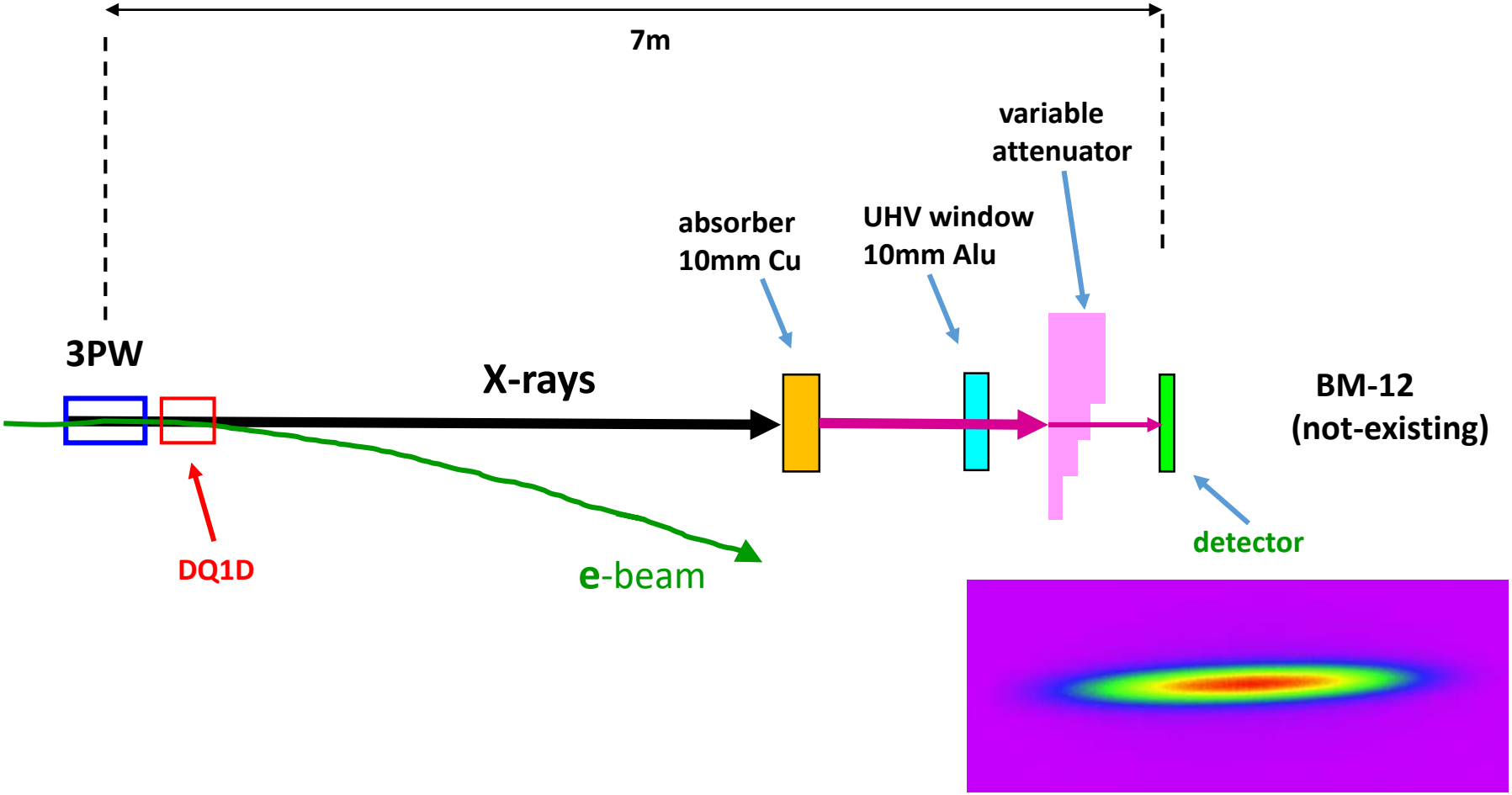


record=90sec, sampling at 20Hz, BPM-bandwidth 6Hz

only slow freq. control (30sec)

-B- X-rays

simplified lay-out of the BM-12 X-ray Diagnostics (top-view)



these X-rays are of high energy (200KeV)
and their flux is very sensitive to electron energy variations
thus useable for a MCF (momentum compaction factor) measurement
→ *presentation by Laura Torino at DEELS in 2018 (DLS, UK)*

relation of Frf , E , momentum-compaction-factor (mcf)

$\delta Frf / Frf = -mcf \times \delta E / E$

$\delta E = - (E \times \delta Frf) / (mcf \times Frf)$

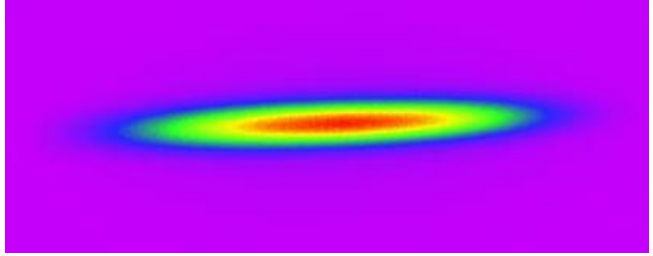
mcf = 8.5 10-5
Frf = 3.52 10+8
E = 6 10+9

for δFrf of 1Hz : δE= 0.2 MeV = 0.00333% of 6GeV

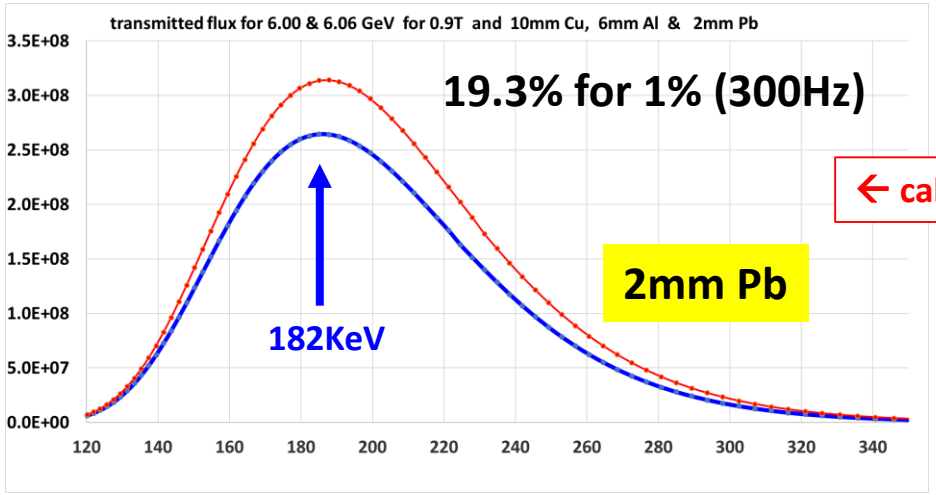
300Hz δFrf is needed to produce
1% of variation of the 6GeV energy

-B- X-rays

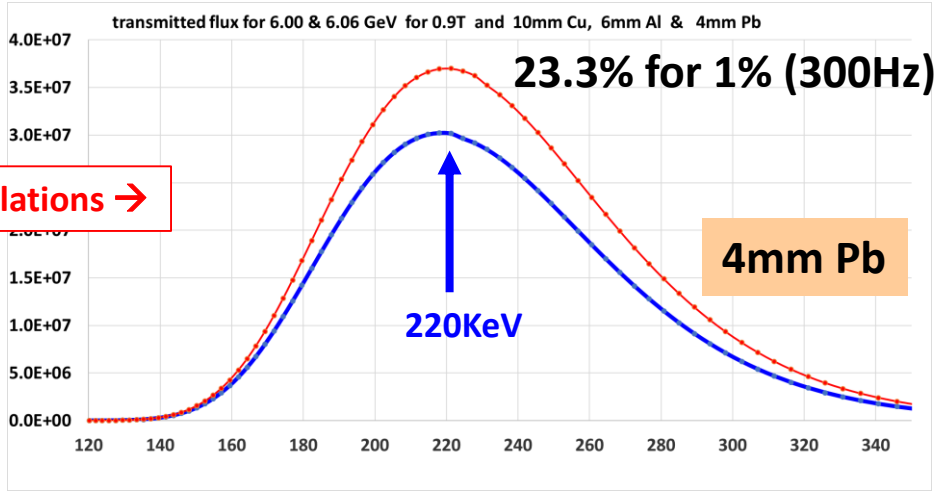
measurements at 4.5mA

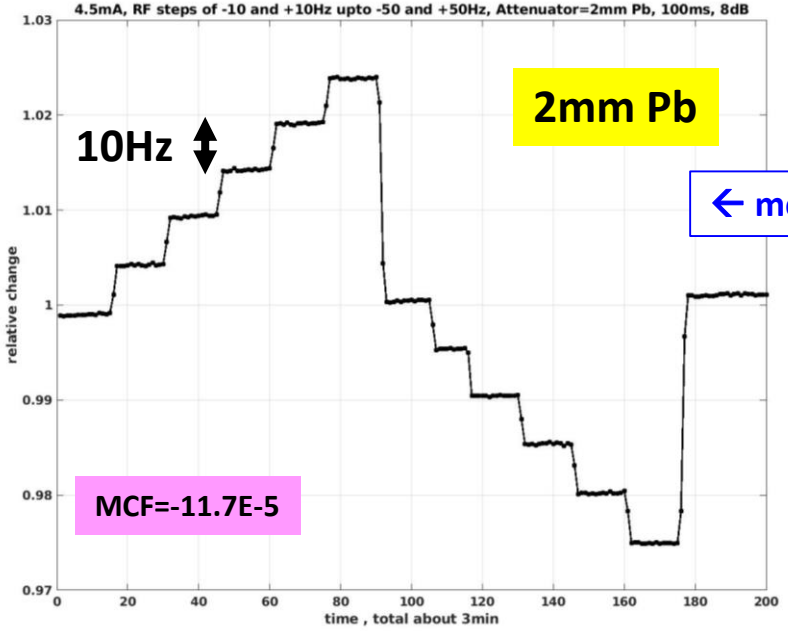


MCF-model=-8.5E-5

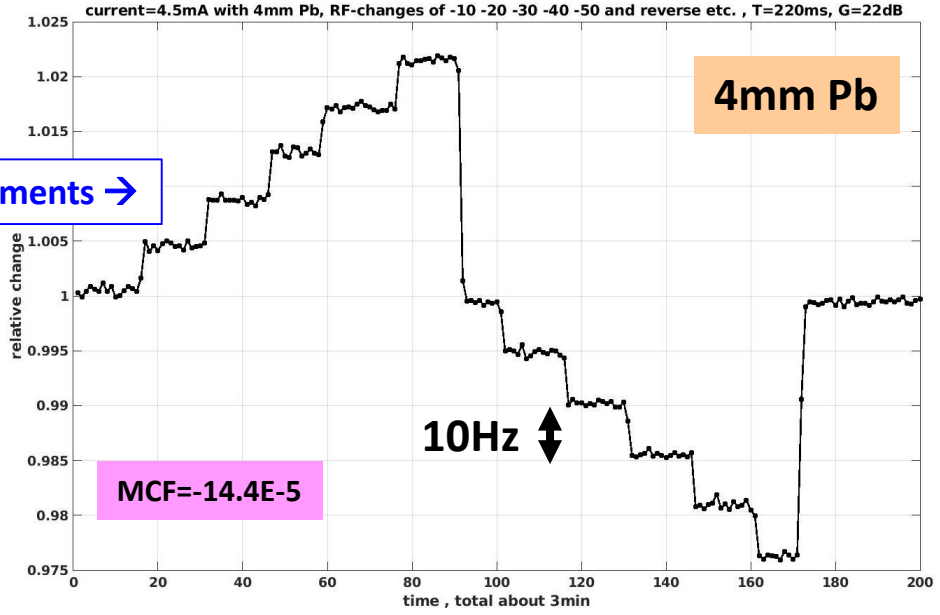


← calculations →





← measurements →



Measurement over many hours -- > two frequency spectra of :

A) the hor. motion of the 128 BPMs in the dispersive sections

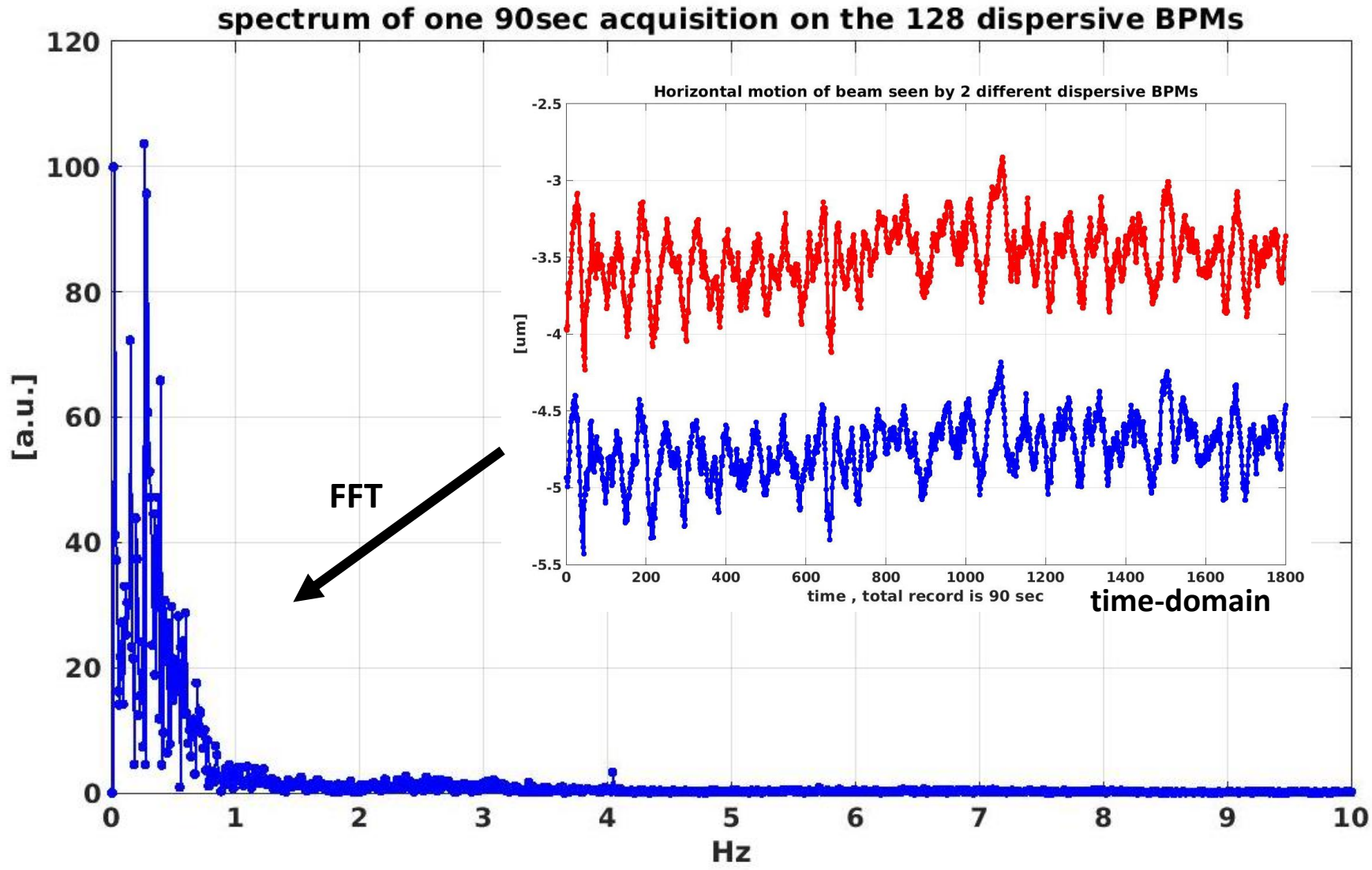
B) the energy fluctuation as detected by this hard X-ray detector

for A) the Hpos-history of the 320 BPMs were read-out, which constitutes 90sec of data at 20Hz.
only the 128 dispersive BPMs are retained, and on each of these 128 a spectrum was calculated,
and the 128 spectra were averaged → which yields a spectrum limited to 10Hz.

for B) the camera was operated at 12Hz,
images were read-out at this rate during 90sec and the intensity of the signal calculated in each acquisition.
then the slow slope of that 12 x 90 data set was removed (due to the slow decay of current)
and then the fft is calculated → which yields a spectrum limited to 6Hz

The above was repeated every 90sec, for e.g. 400 times for 10hrs of record.
The two independent spectra obtained are shown in next slides.

There is a striking correlation between these curves showing a distinct bump of these
Energy variations in the 0.2 to 0.8Hz range.

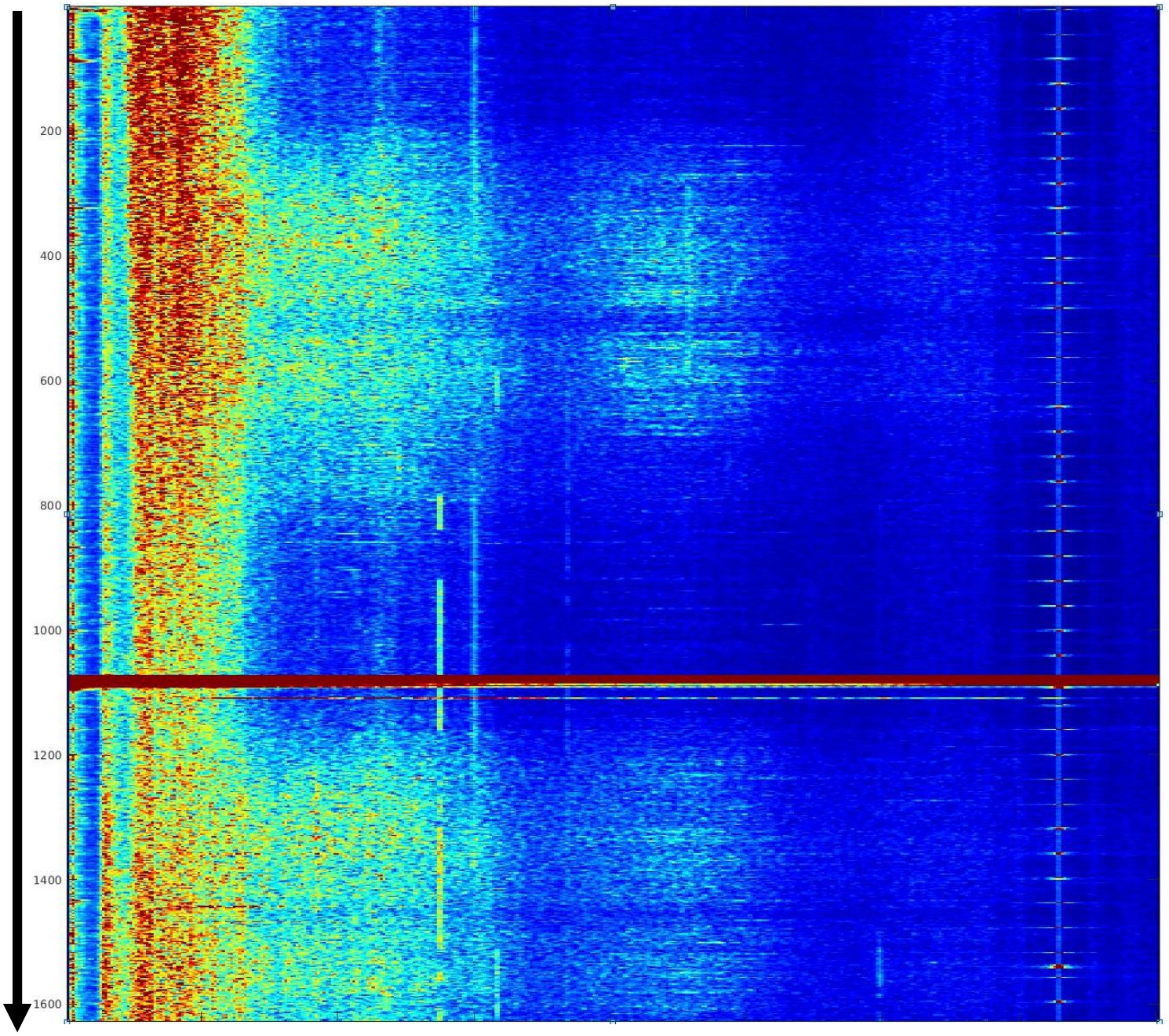


this is a single shot (90sec) measurement

this can be repeated over many hours & days !

-A- (BPMs)

dispersive BPMs

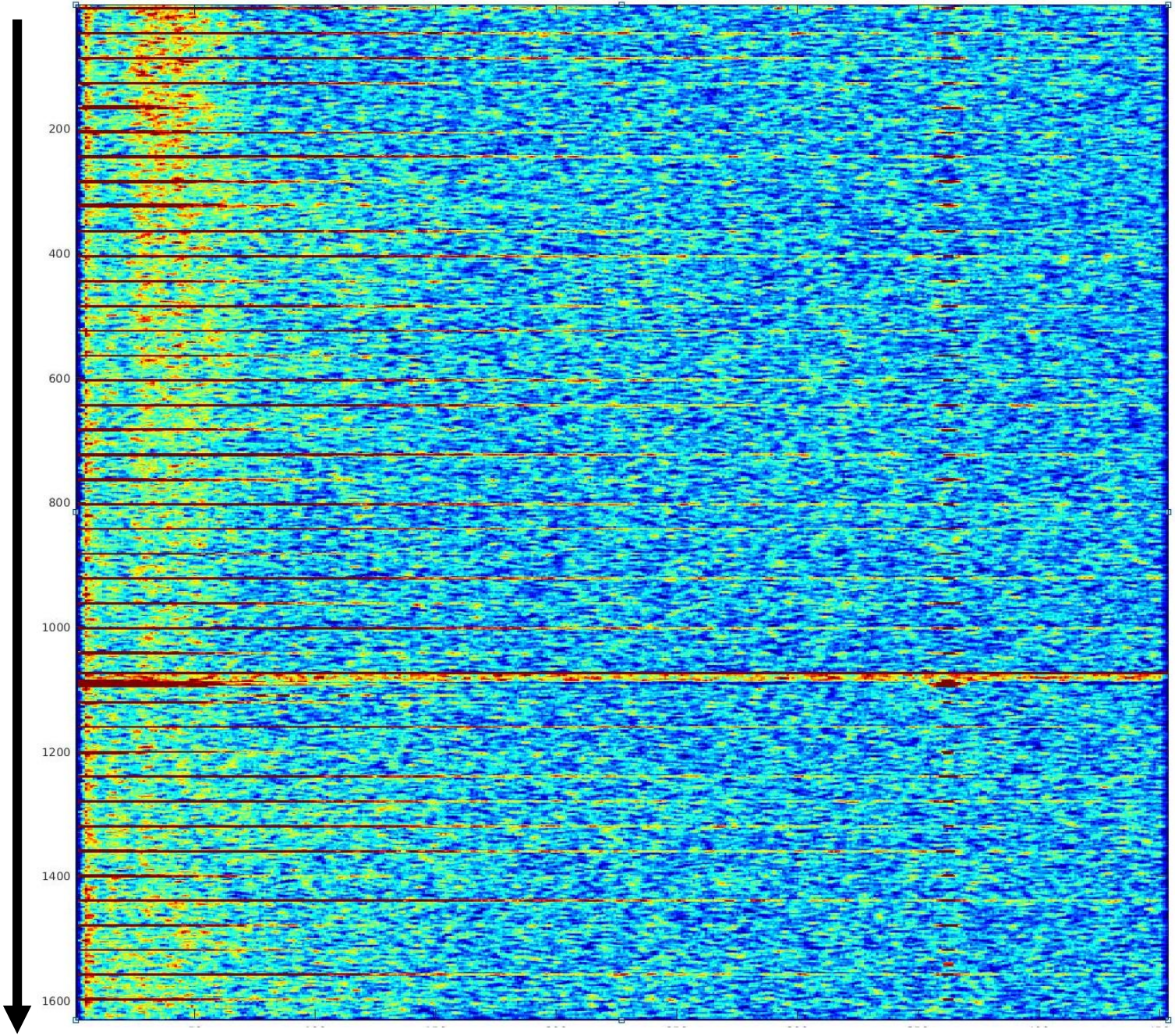


each line
is the spectrum
measured
in 1.5min

from hard
X-rays

time
40hrs

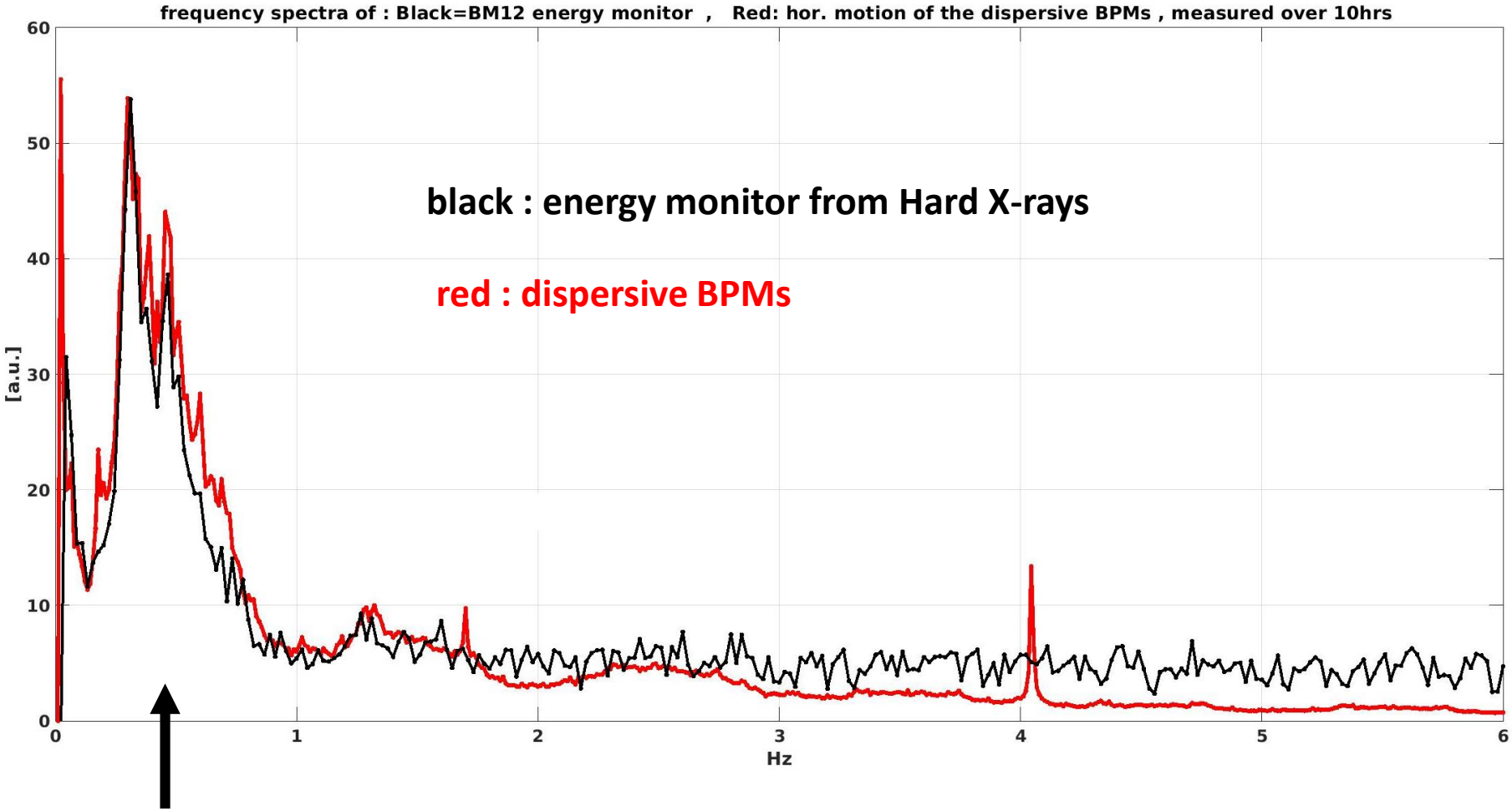
each line
is the spectrum
measured
in 1.5min



0 1 2 3 4

spectra of the hor. motion [Hz]

excellent agreement between 2 independent systems



strong bump in 0.2 to 0.8Hz range

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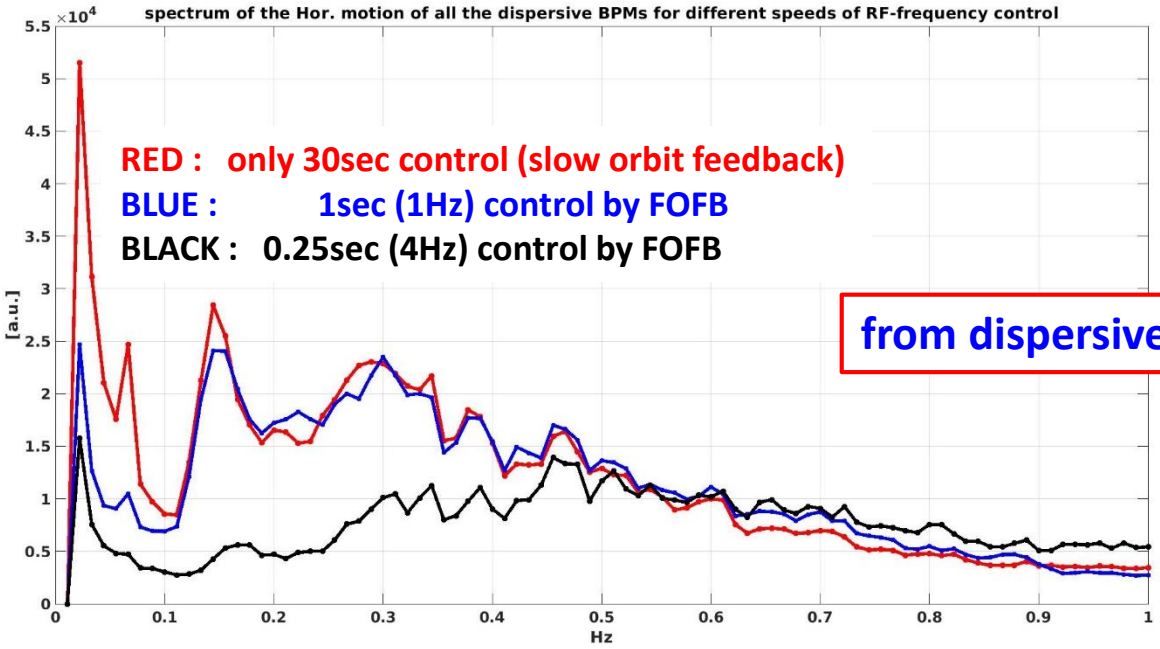
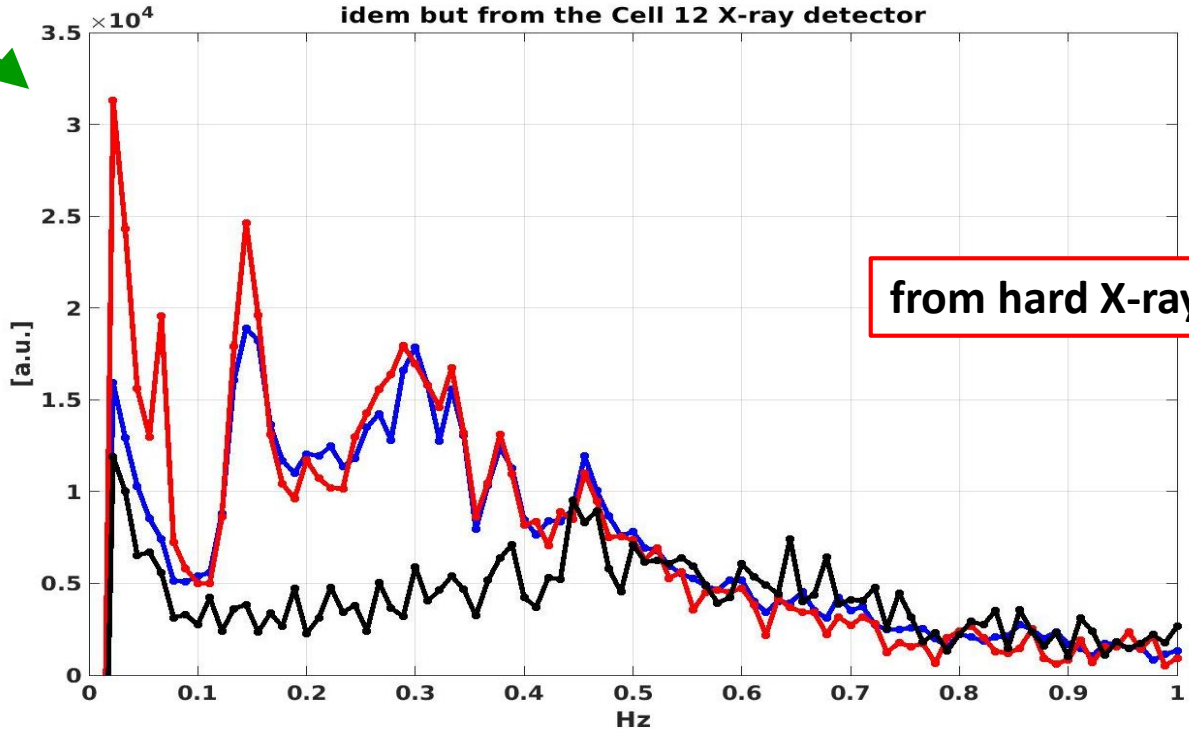
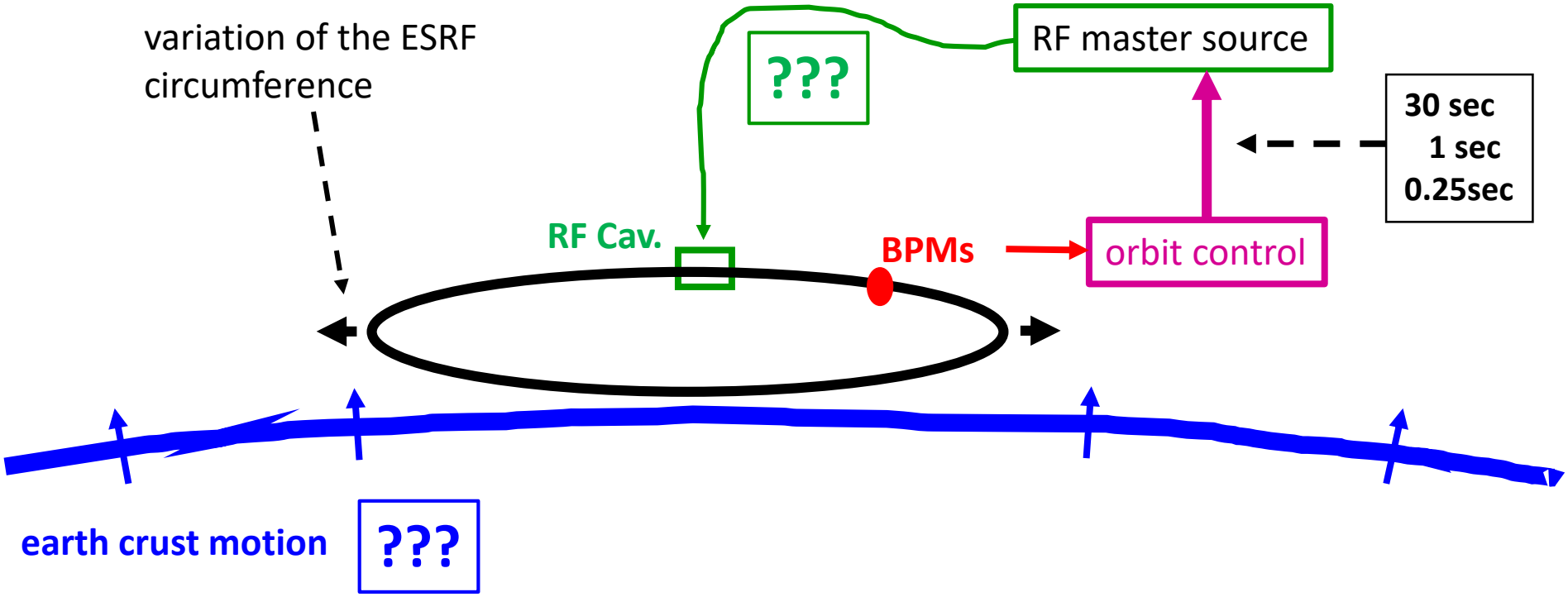


from dispersive BPMs

excellent agreement
between
2 independent systems

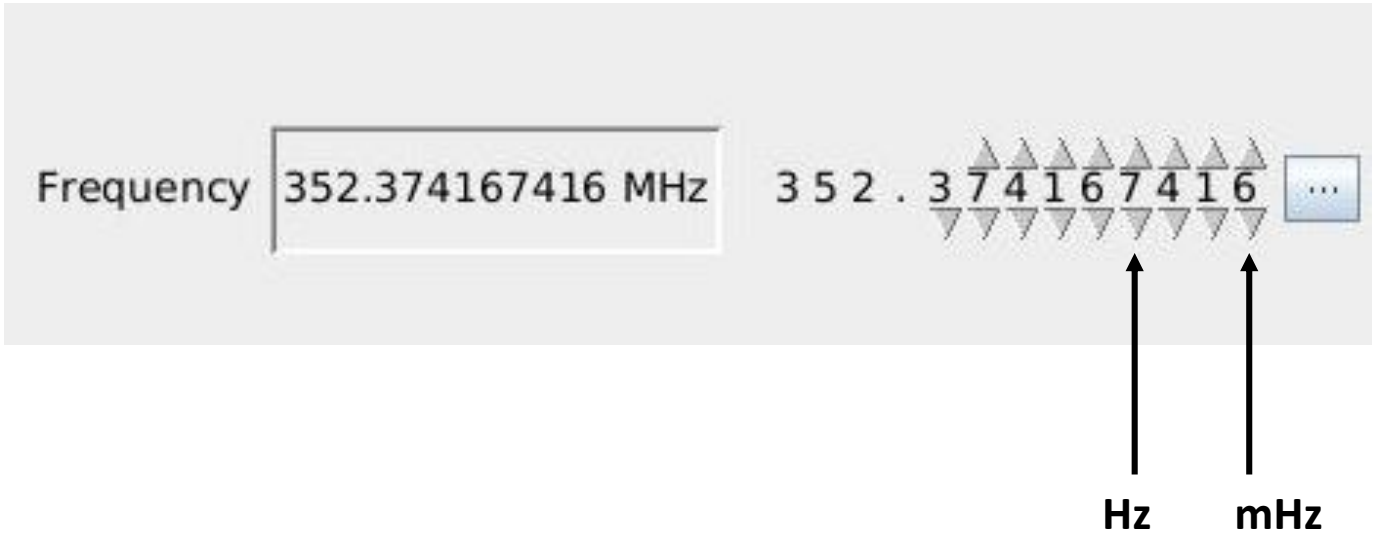


from hard X-rays



what is causing these (permanent) vibrations ???

the Master Source or seismic vibrations ???



ideal world :
***perfectly* stable !**

micro-Hz

352374167.416000 Hz

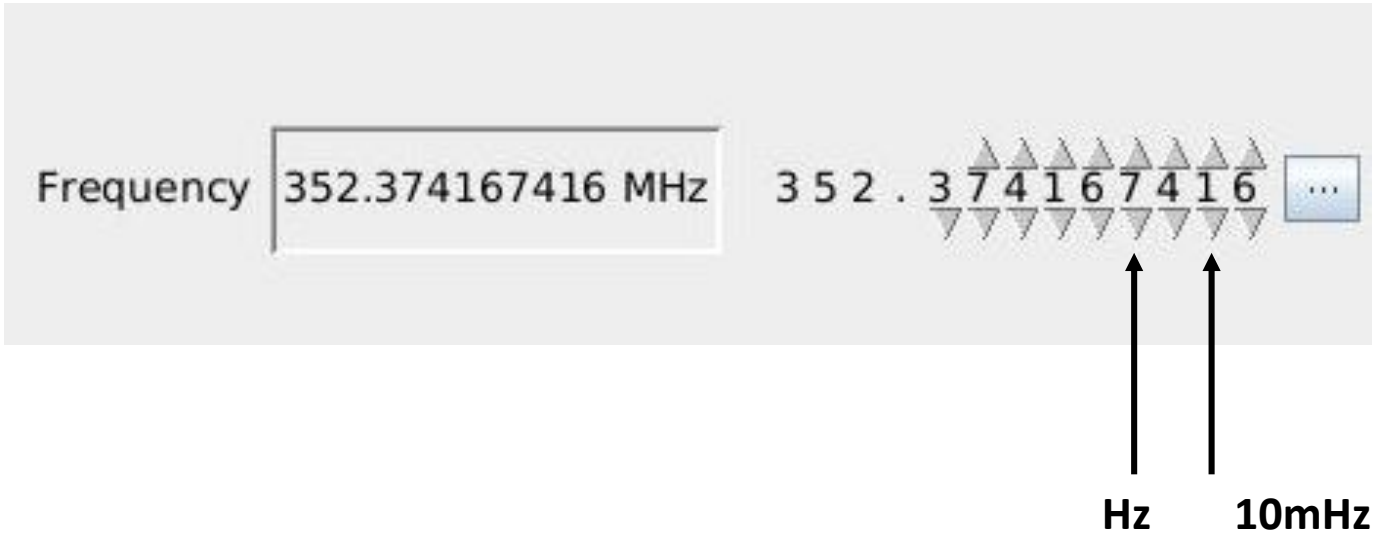
real world
stability

10 milli-Hz

?? difficult to measure & know

3 sec

time



ideal world :
***perfect* response !**

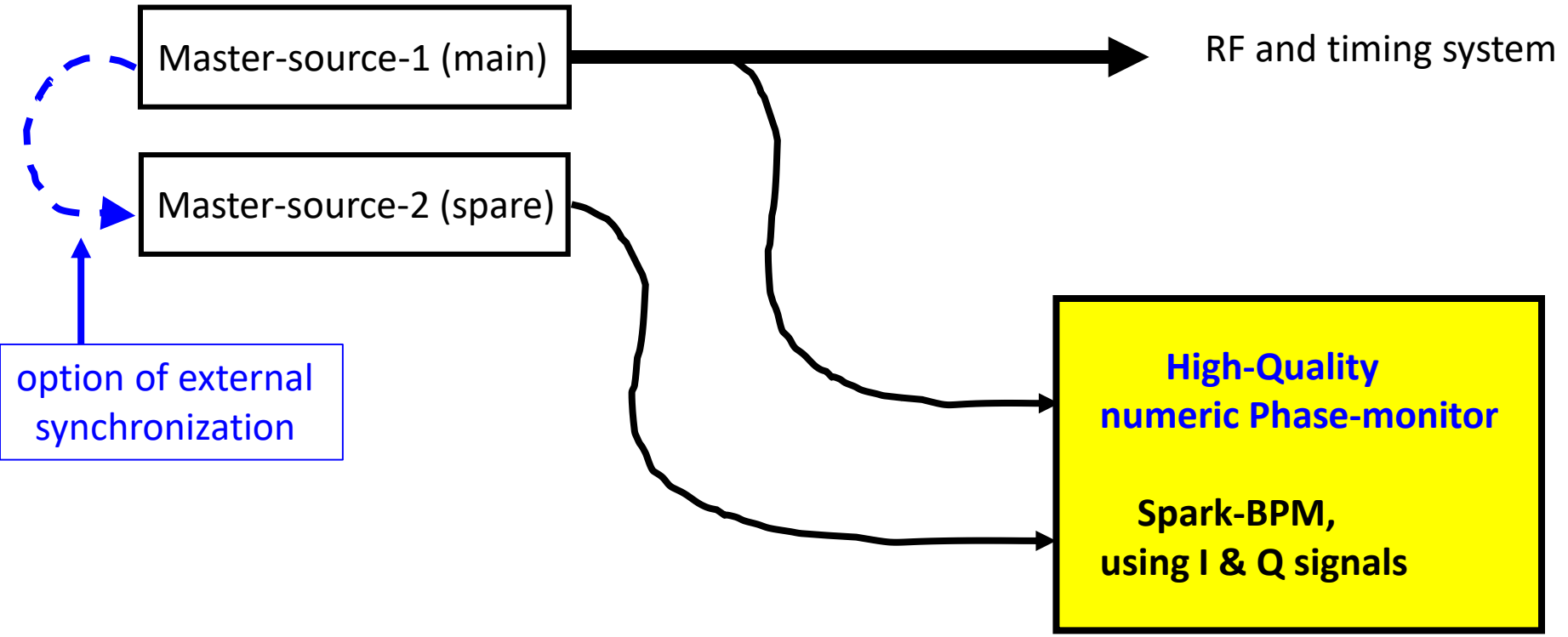
10 mHz

real world response

?? difficult to measure & know …

time

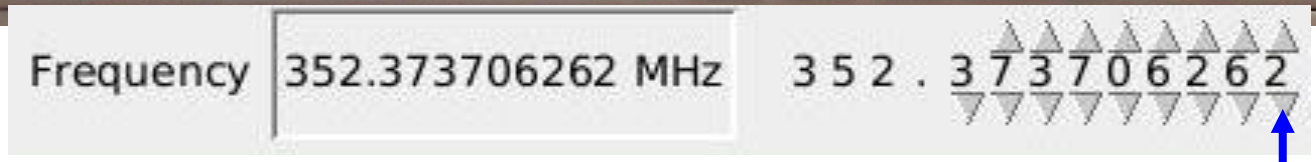
3) Verifications on the real stability of the RF-Master-source



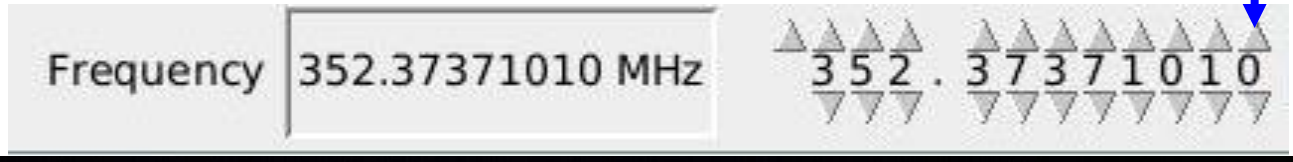
presented at IBIC 2013, DLS, Oxford, UK
B.Joly, K.Scheidt

main
master-source

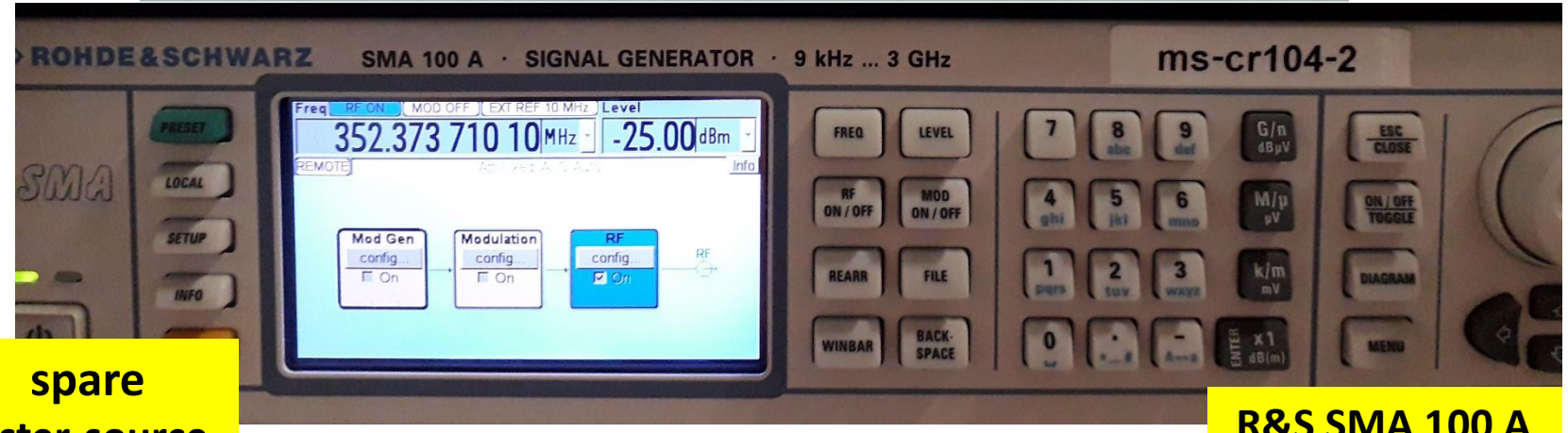
R&S SMA 100 B



1 milli Hz

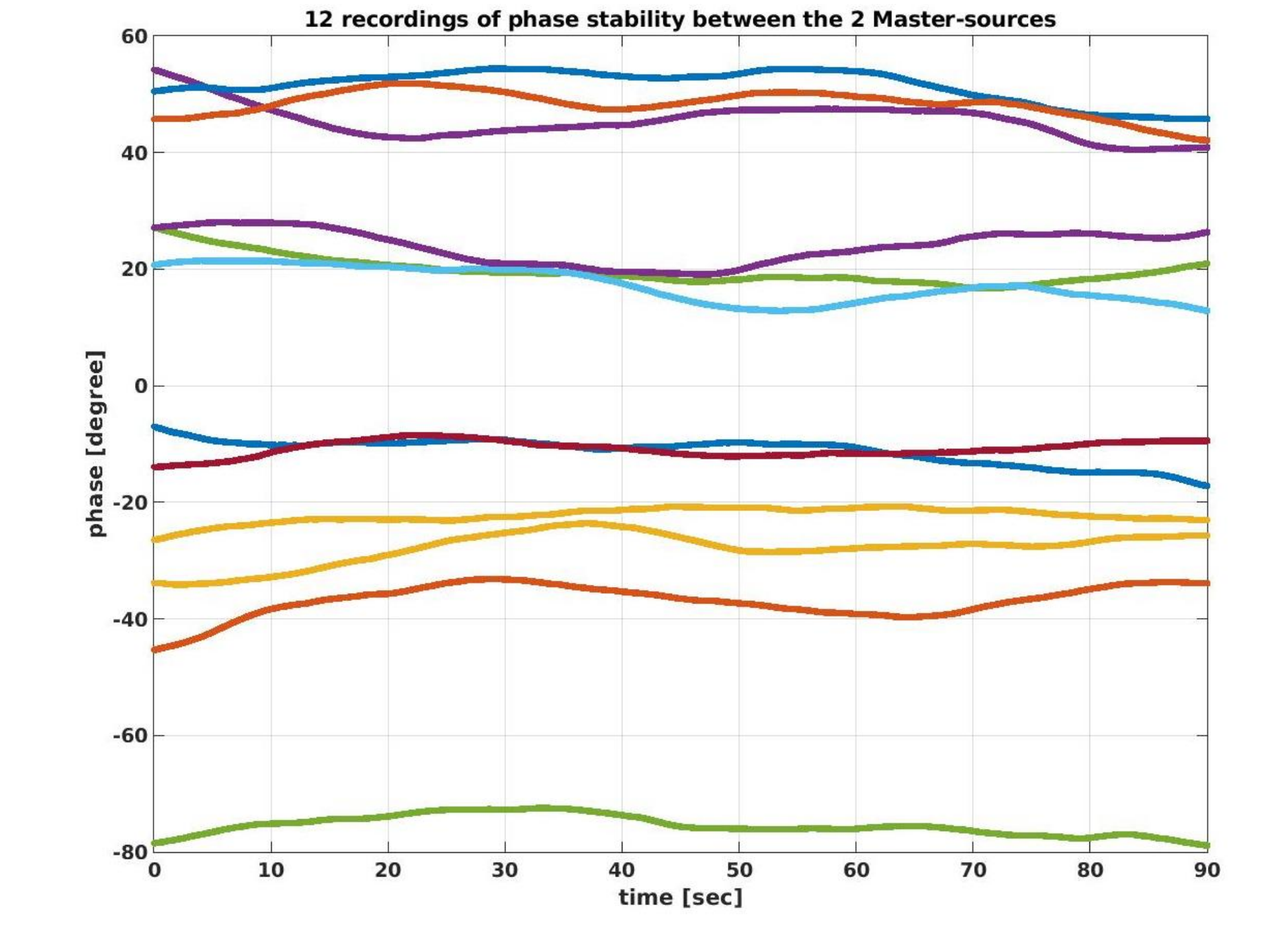


10 milli Hz



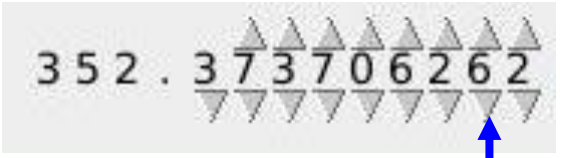
spare
master-source

R&S SMA 100 A

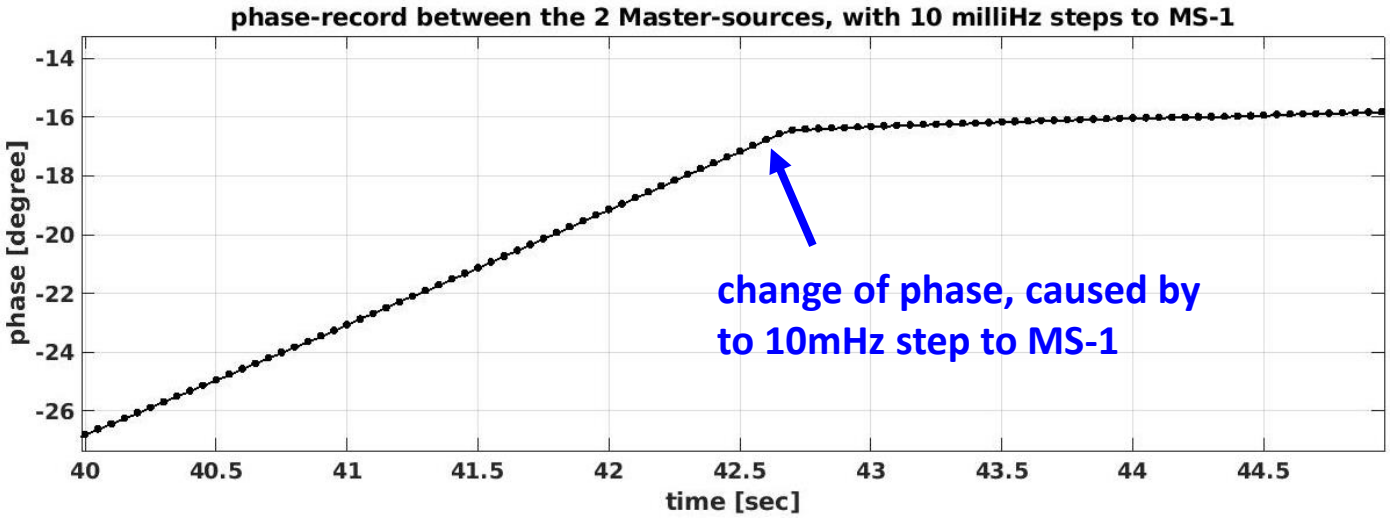

12 recordings of phase stability between the 2 Master-sources
phase [degree]
time [sec]
60
40
20
0
-20
-40
-60
-80
0
10
20
30
40
50
60
70
80
90

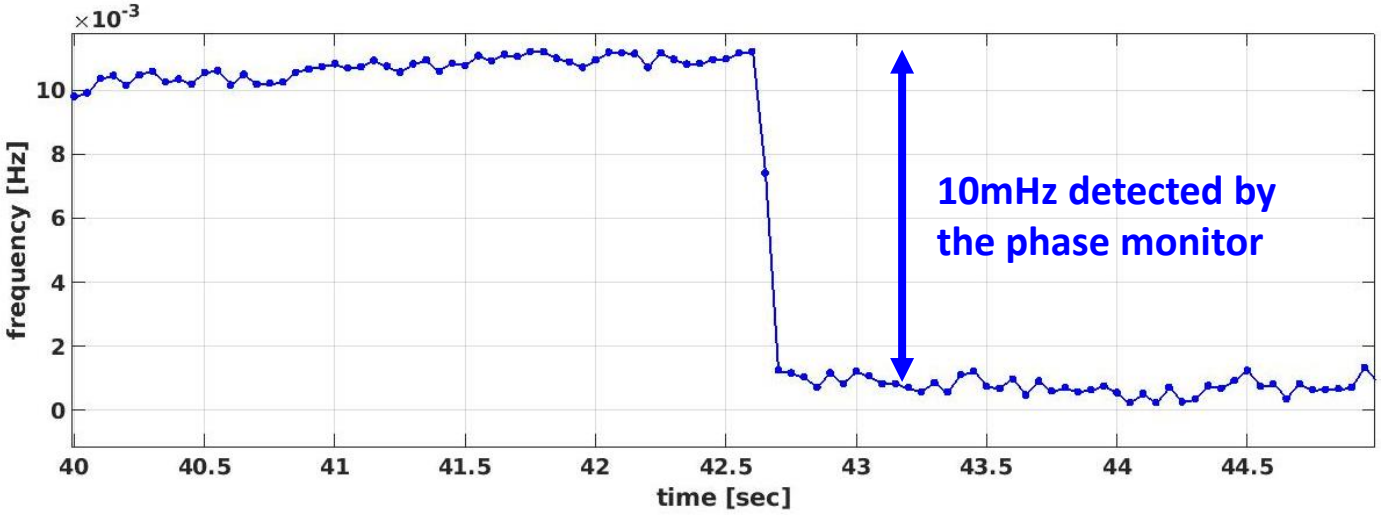
phase variation Versus difference in frequency :

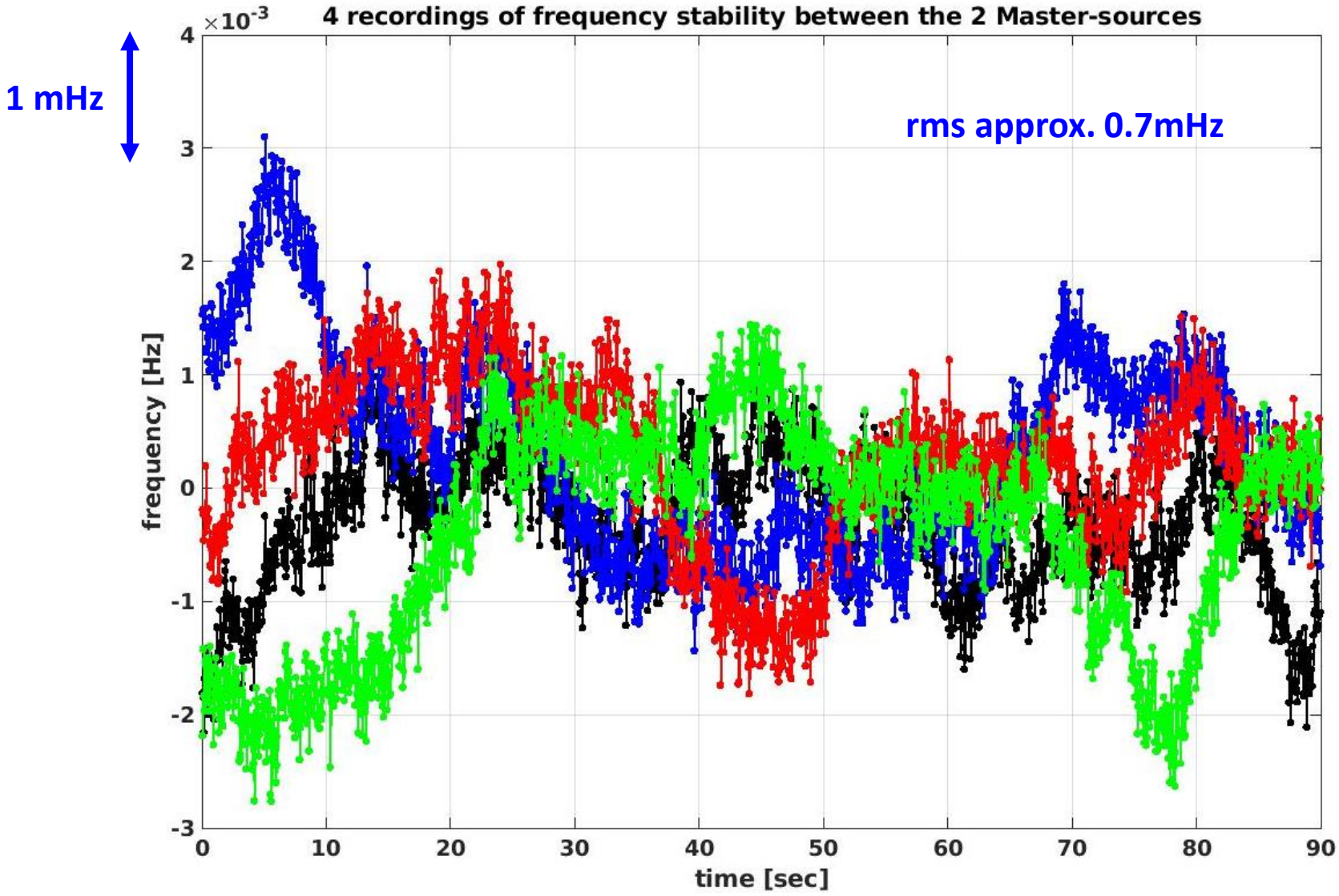
$$\frac{\delta \text{ phase}}{\delta t} = f1 - f2$$



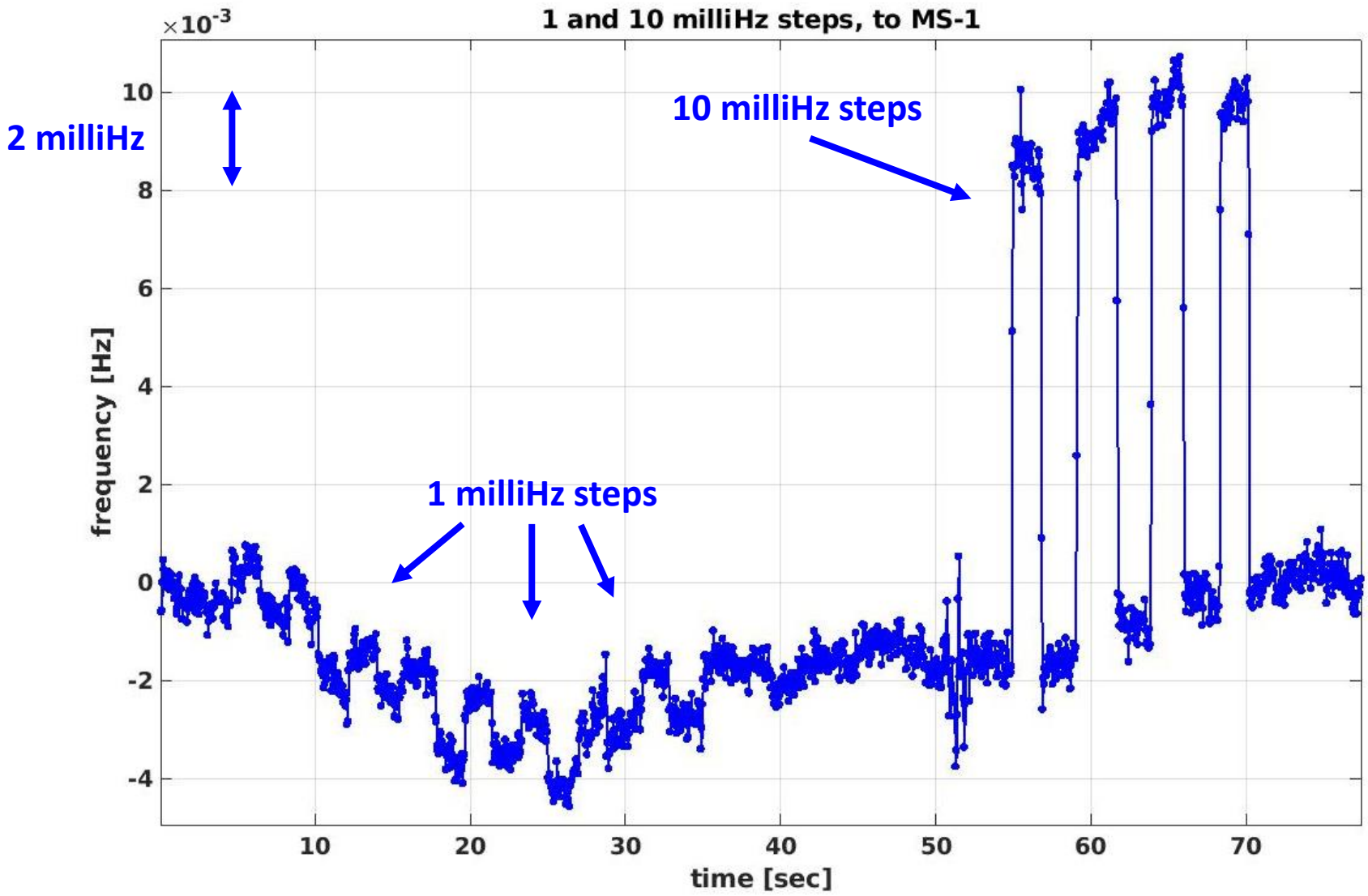
10 milli Hz



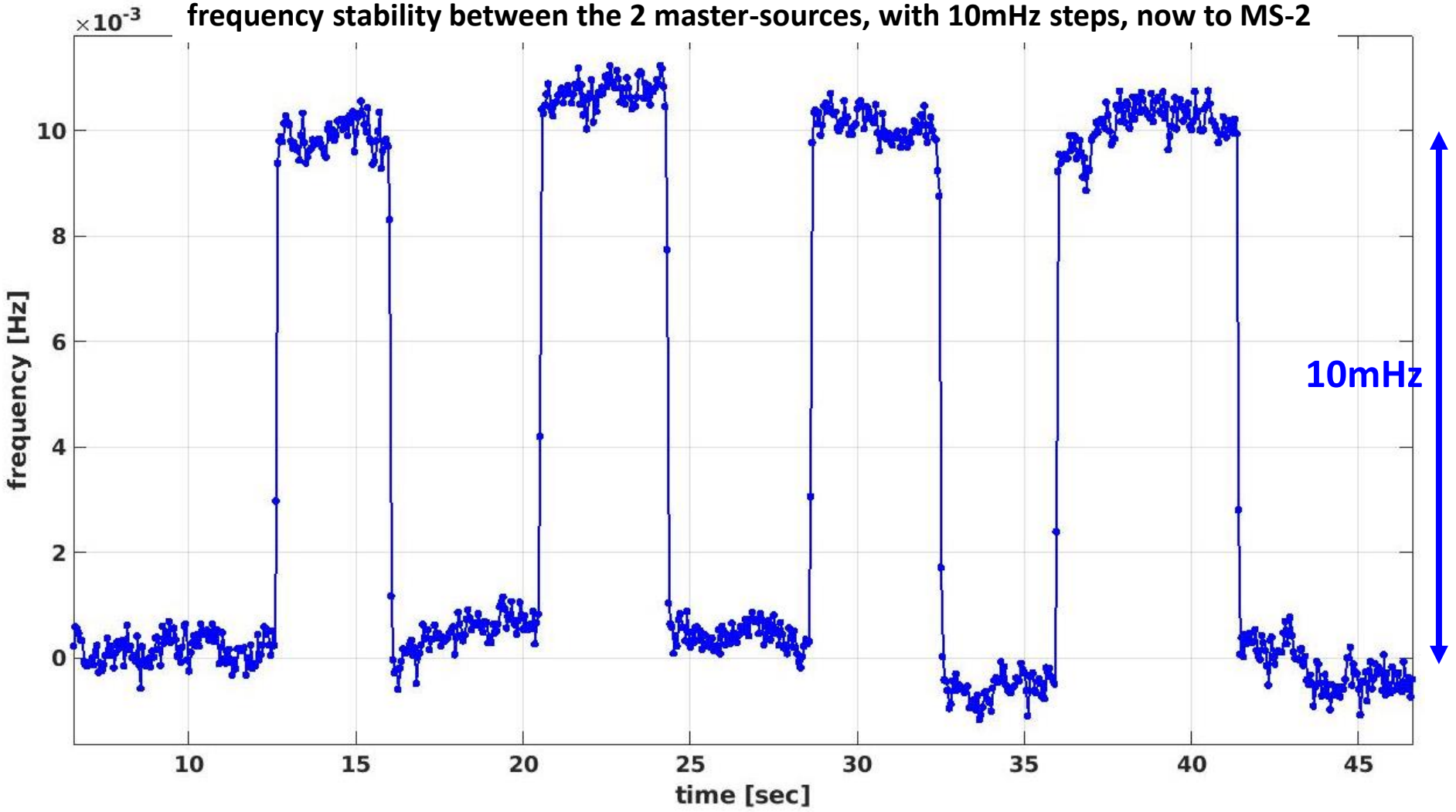




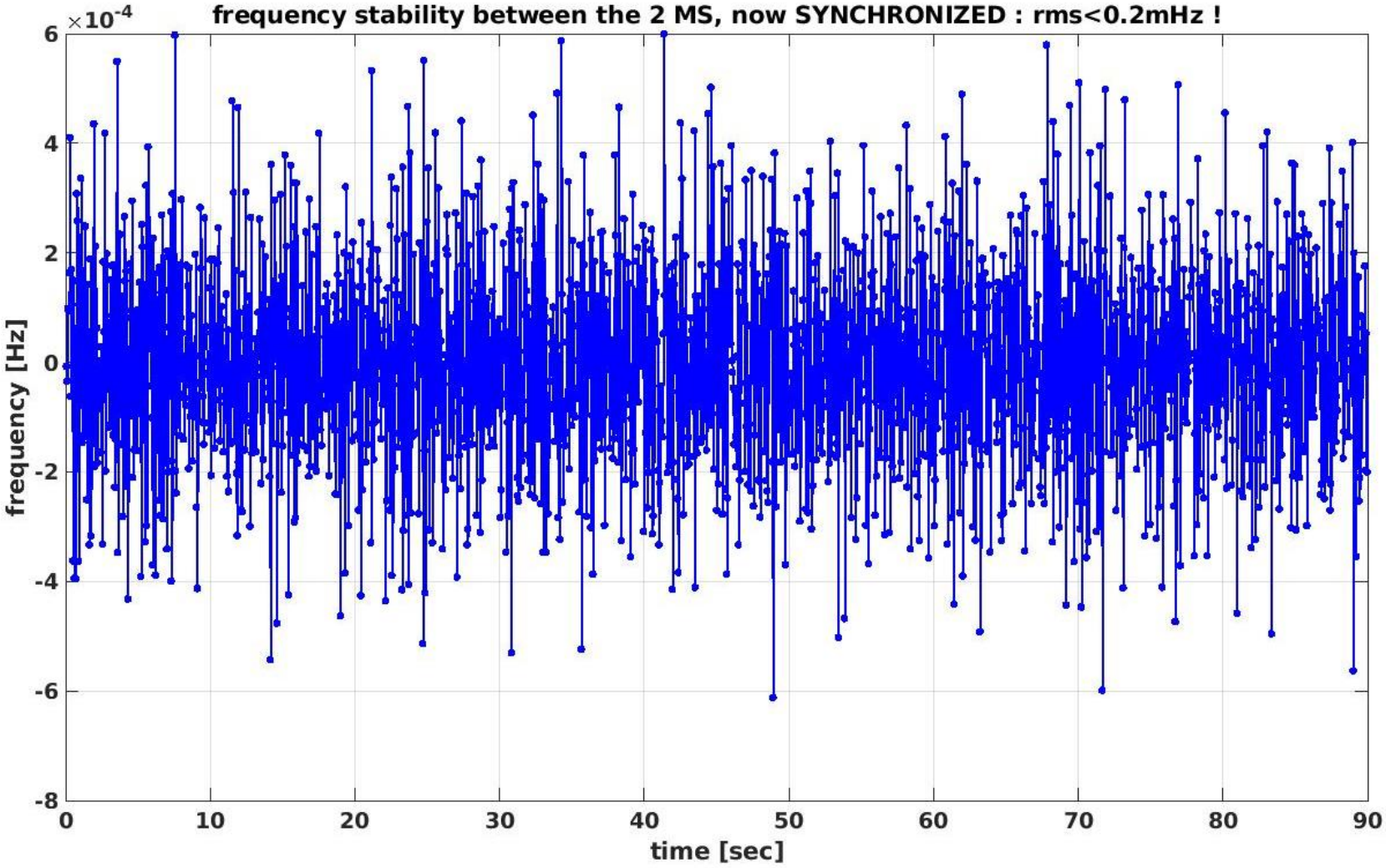
MS-1 and MS-2 both free-running, i.e. NO external synchro (yet)


1 and 10 milliHz steps, to MS-1
×10^-3
2 milliHz
10 milliHz steps
1 milliHz steps
frequency [Hz]
time [sec]
10
8
6
4
2
0
-2
-4
10
20
30
40
50
60
70

frequency stability between the 2 master-sources, with 10mHz steps, now to MS-2



MS-1 and MS-2 both free-running, i.e. NO external synchro (yet)

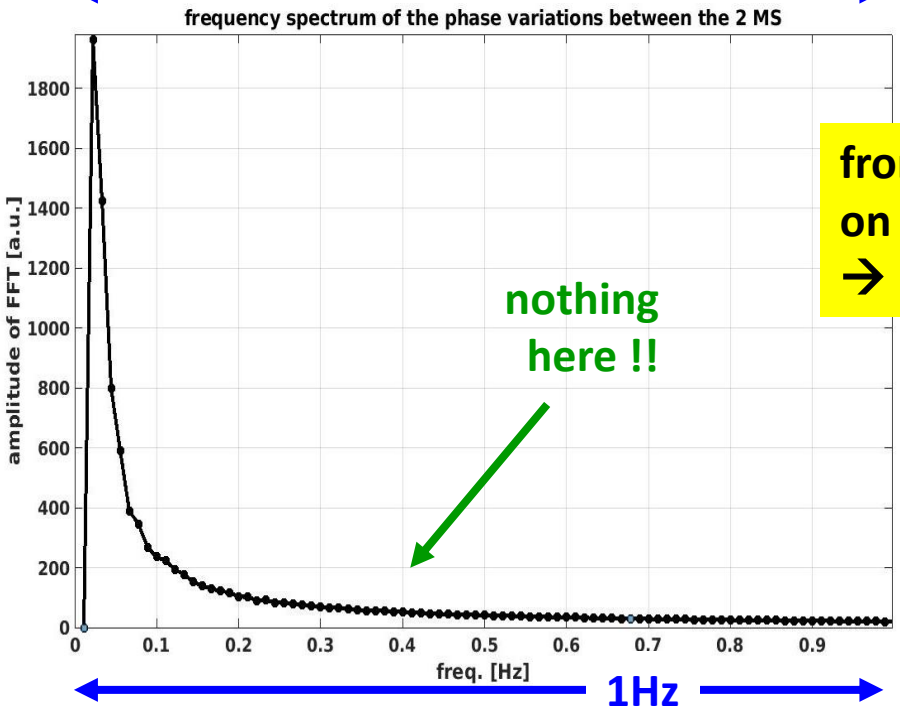


MS-2 is now ext. synchronized to MS-1 → rms is better than 0.2mHz

seen on the beam

what is causing this bump ?

1Hz



nothing here !!

1Hz

from MS lab. checks on its freq. stability
→ MS is OK !

Conclusion : the energy fluctuations are caused by external events, that affect the circumference of the beam path

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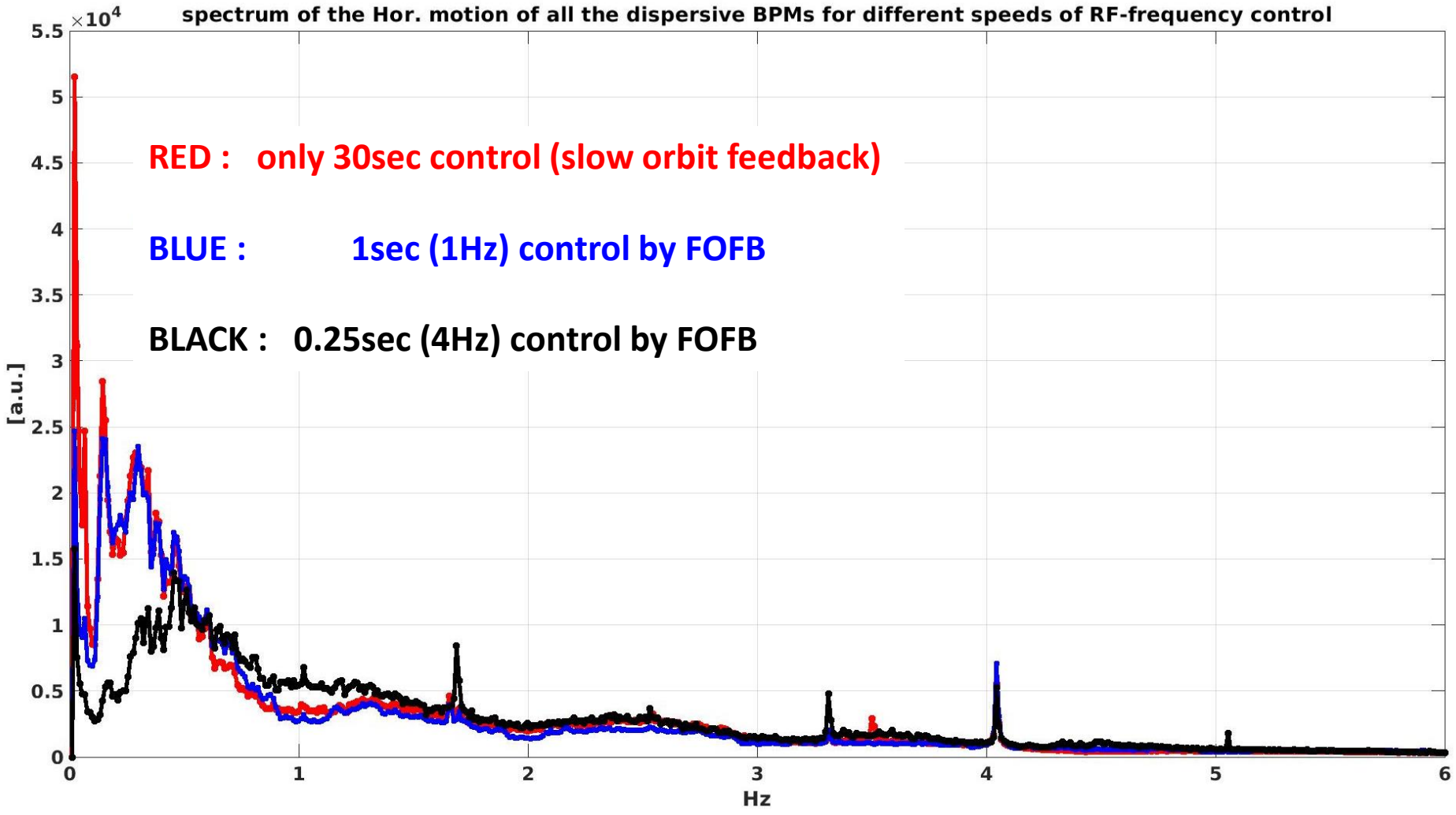
spectrum of the Hor. motion of all the dispersive BPMs for different speeds of RF-frequency control
×10^4
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
[a.u.]
0
1
2
3
4
5
6
Hz
RED : only 30sec control (slow orbit feedback)
BLUE : 1sec (1Hz) control by FOFB
BLACK : 0.25sec (4Hz) control by FOFB

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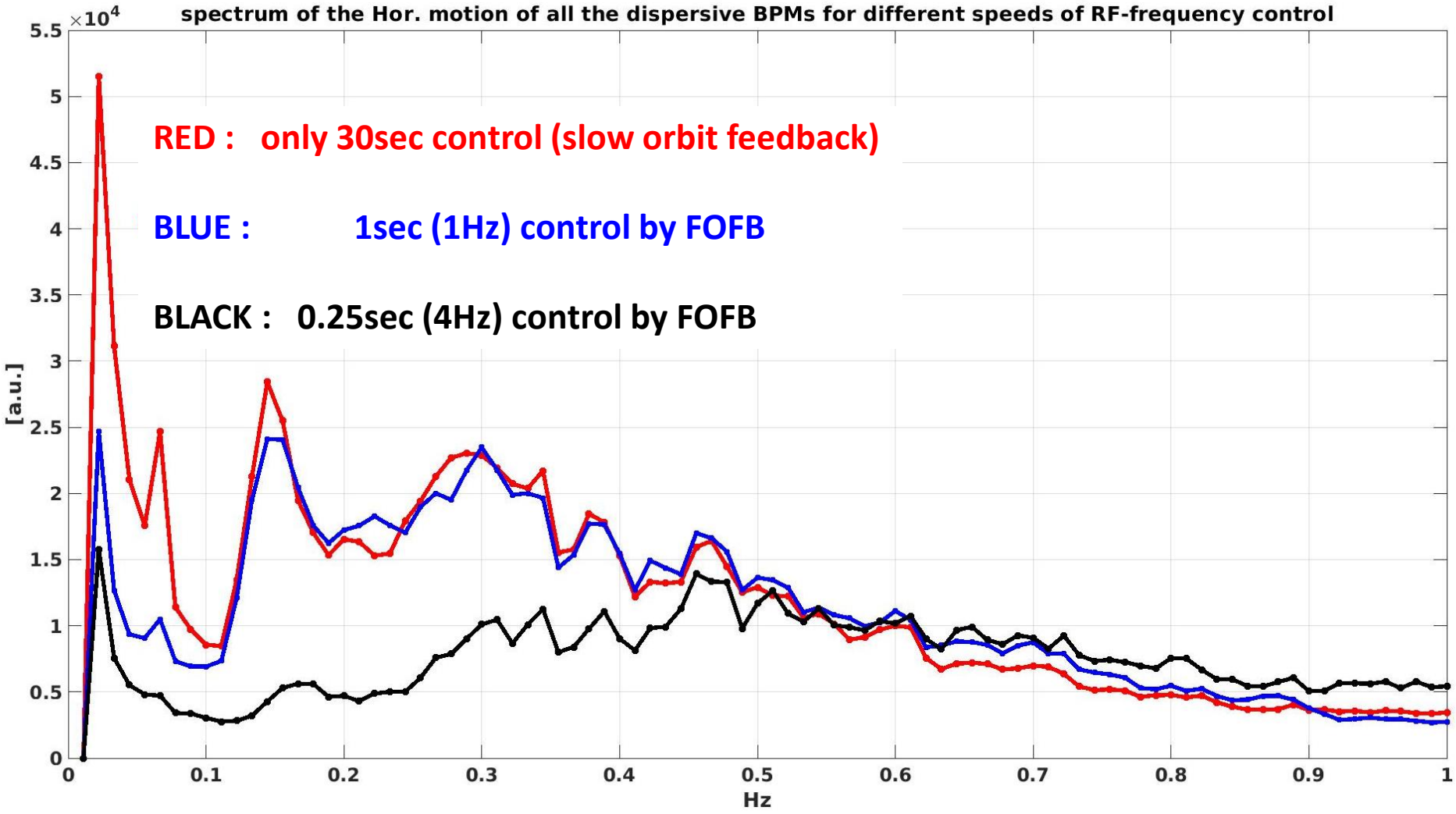

spectrum of the Hor. motion of all the dispersive BPMs for different speeds of RF-frequency control
×10^4
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
[a.u.]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Hz
RED : only 30sec control (slow orbit feedback)
BLUE : 1sec (1Hz) control by FOFB
BLACK : 0.25sec (4Hz) control by FOFB

can we put a number on the strength of these energy fluctuations ?

$$\frac{-\,dFrf / Frf}{dE / E} = mcf = 8.5\ E\text{-}5\ \text{(model)}$$

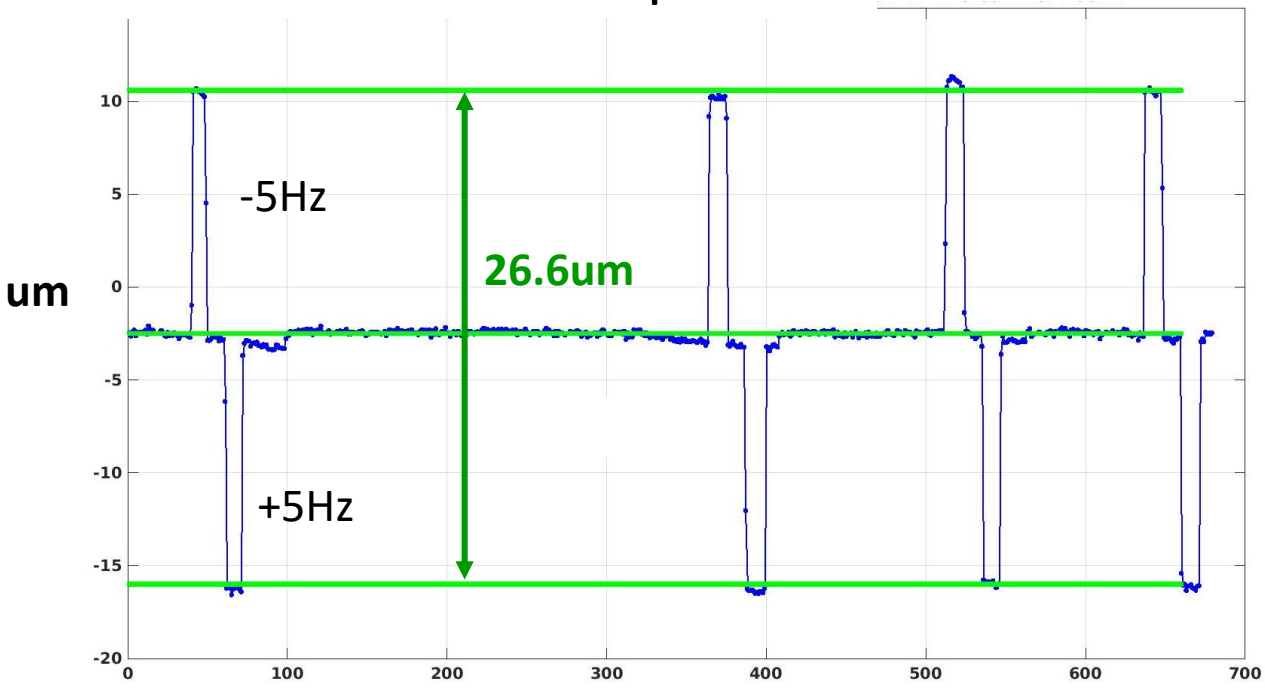
mcf = momentum compaction factor

typical motion, without fast frequency control, is 0.23um rms

rms energy fluctuation = (0.23 / 26.6) **X** (10 / 352.4E6) **X** (1 / 8.5 E-5) = **3 E-6**

the *'normal'* energy spread of EBS is **1.2 E-3**

average of all 128 dispersive BPMs,
delta=26.6um for 10Hz RF-freq. excursion



conclusions & future perspectives

the ESRF is subject to permanent seismic vibrations

their spectra is in the 0.2 to 1Hz range (1 to 5sec period)

they cause slight energy variations of about 3 E-6 that can be detected and in a clear correlated manner by 2 independent methods

This 3 E-6 variation is small to the natural energy spread (1.2 E-3), but is it therefore totally negligible to the users … ??

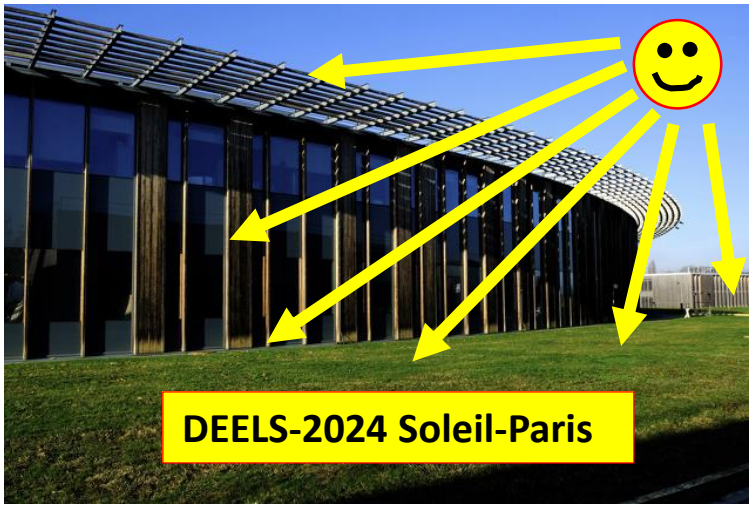
the amplitude of these vibrations seems correlated (24hrs cycle, weekday-weekends) with human activity (traffic etc.) in the Grenoble area

operating the control of the RF-master at higher frequency (soon at 4Hz) can reduce these energy vibrations

<u>points to be raised with other light sources :</u>

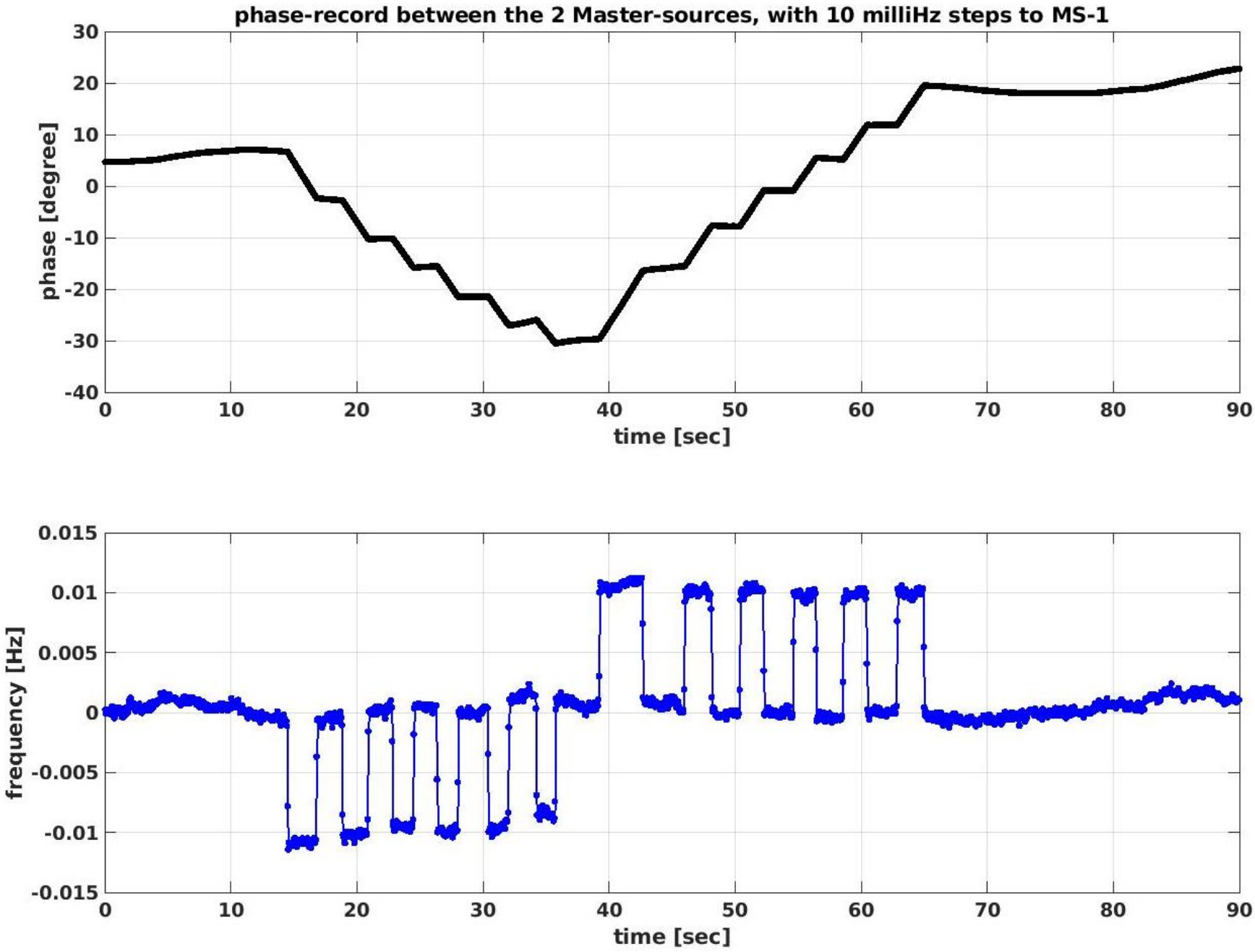
they all have performing BPMs and in dispersive sections,
so they could also do this very easy measurement
we can then compare the “quality” of ground support of different light sources

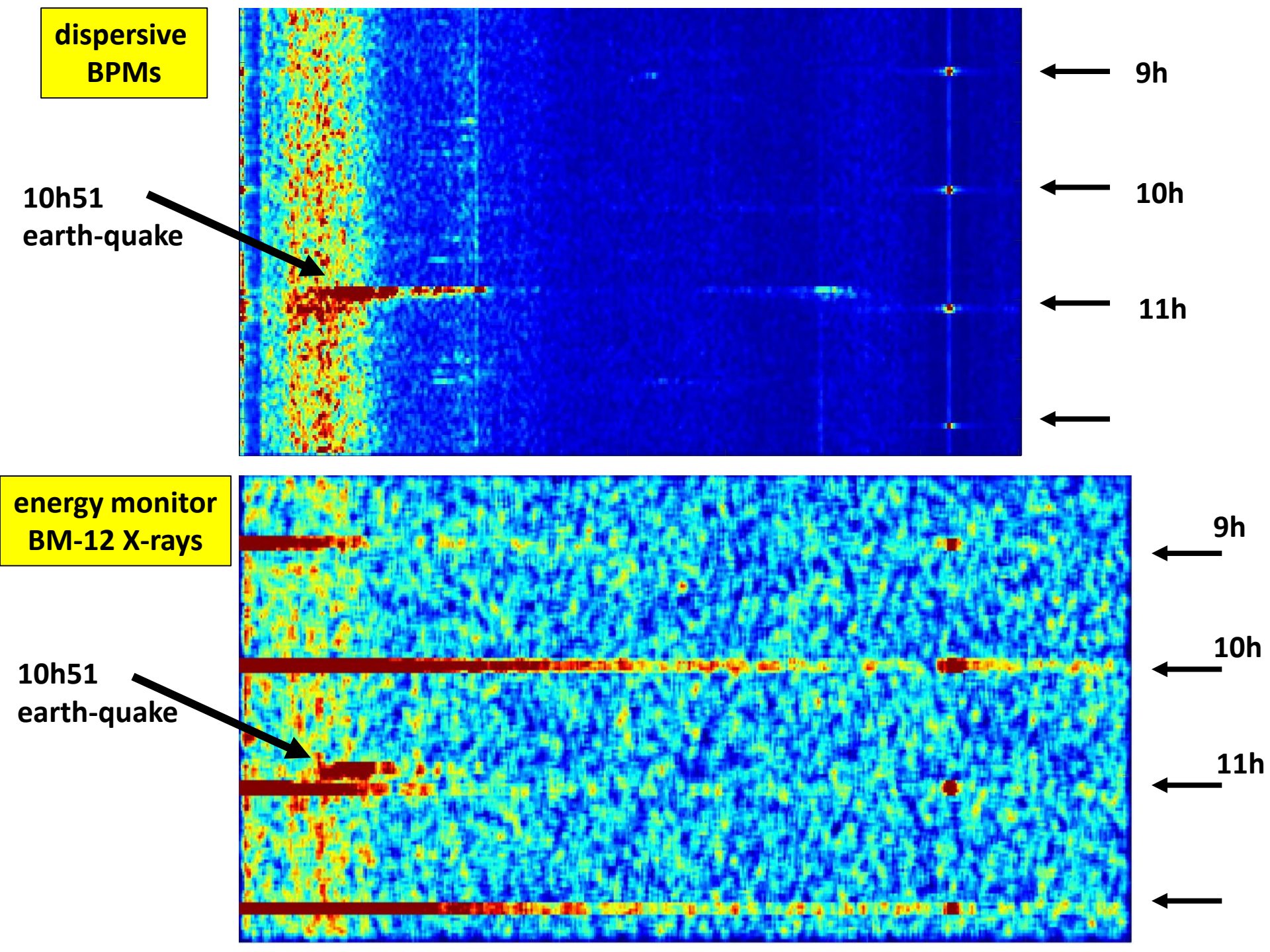
Thank you for your attention !



How do you control/manage/measure the energy stability of your ring ?

back-up slides


phase-record between the 2 Master-sources, with 10 milliHz steps to MS-1
phase [degree]
time [sec]
frequency [Hz]
time [sec]


dispersive
BPMs
10h51
earth-quake
9h
10h
11h
energy monitor
BM-12 X-rays
10h51
earth-quake
9h
10h
11h