Stability issues in CTF3 and their relevance for CLIC. Phase feed-forward.
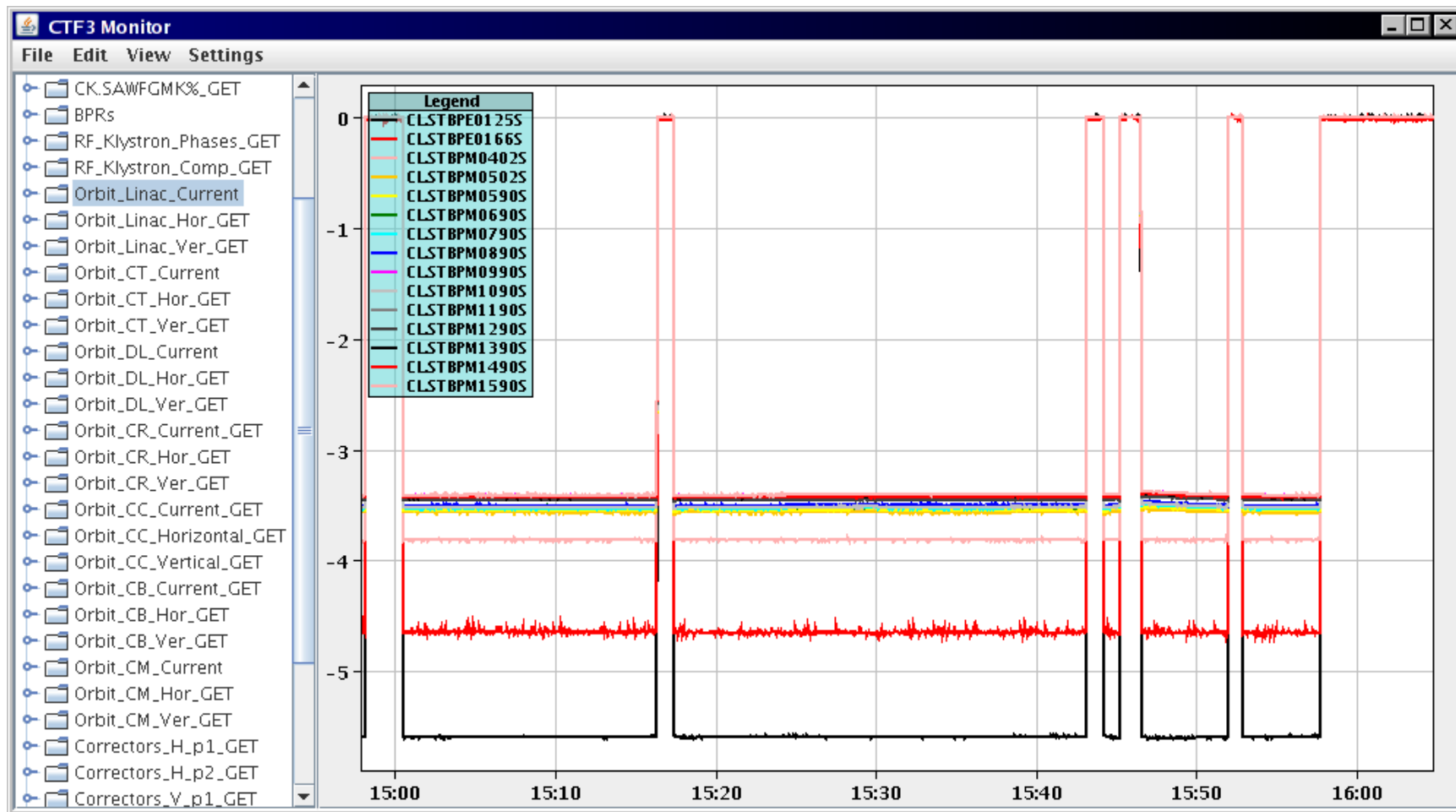
Piotr Skowronski[1],
Tobias Persson [1], Alexey Dubrovskiy [1], Guido Sterbini [1],
Fabio Marcellini [2], David Alesini [2], Andrea Ghigo [2],
Igor Syratchev [1], Alexandra Andersson [1]
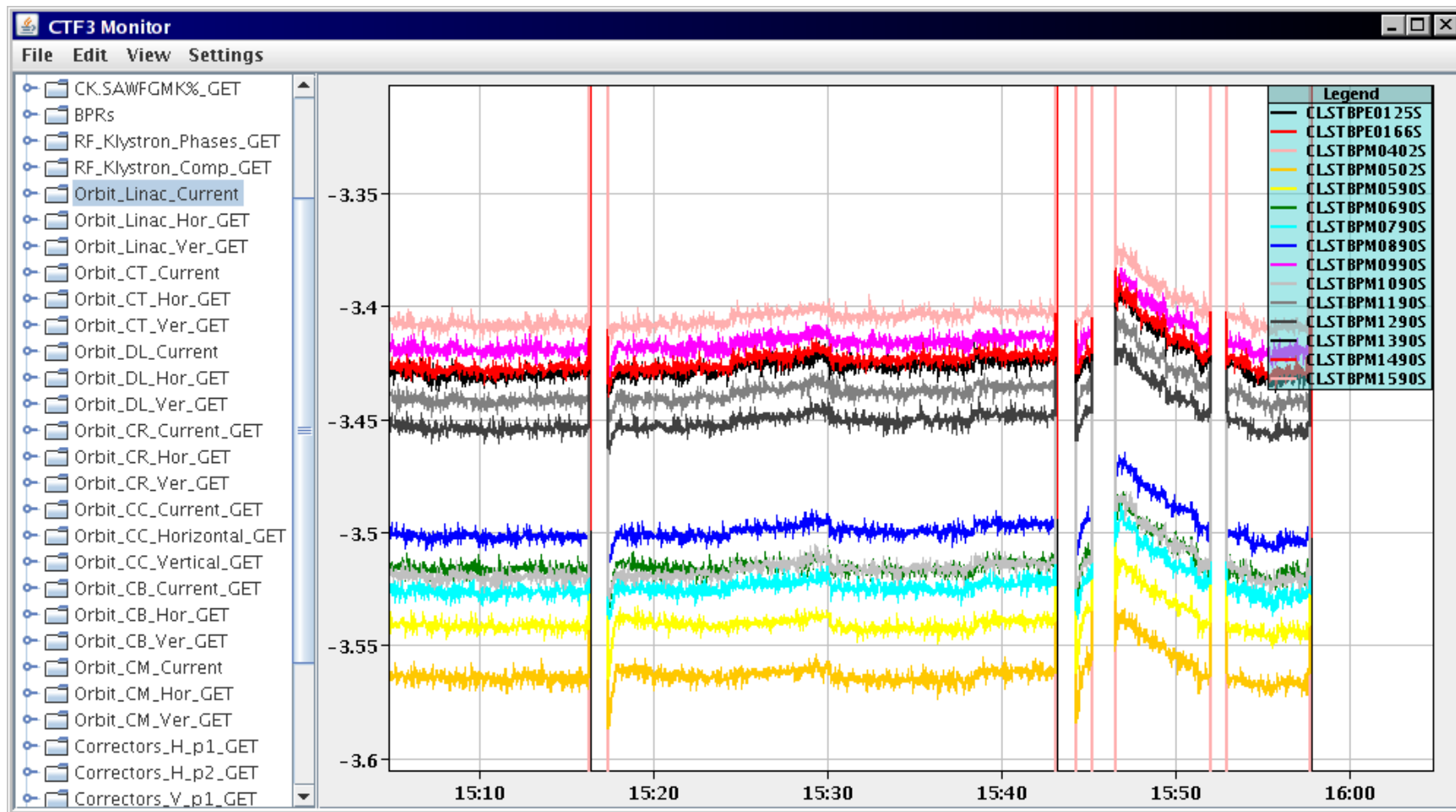
_____

[1] CERN
[2] INFN/LNF, Frascati, Italy

CTF3 stability

- CTF3 was build from LIL/EPA hardware
  - It is not well adjusted to the CTF3 needs, especially in terms of stability
    - Klystrons are running at the limits of their capabilities
    - RF pulse compression system is used
- So, the stability of CTF3 is the issue
- However, we attempt to place countermeasures to achieve as stable beam as we can
- During the last run we have introduced a system to monitor the CTF3 stability
  - Helps to keep the machine in the reference state
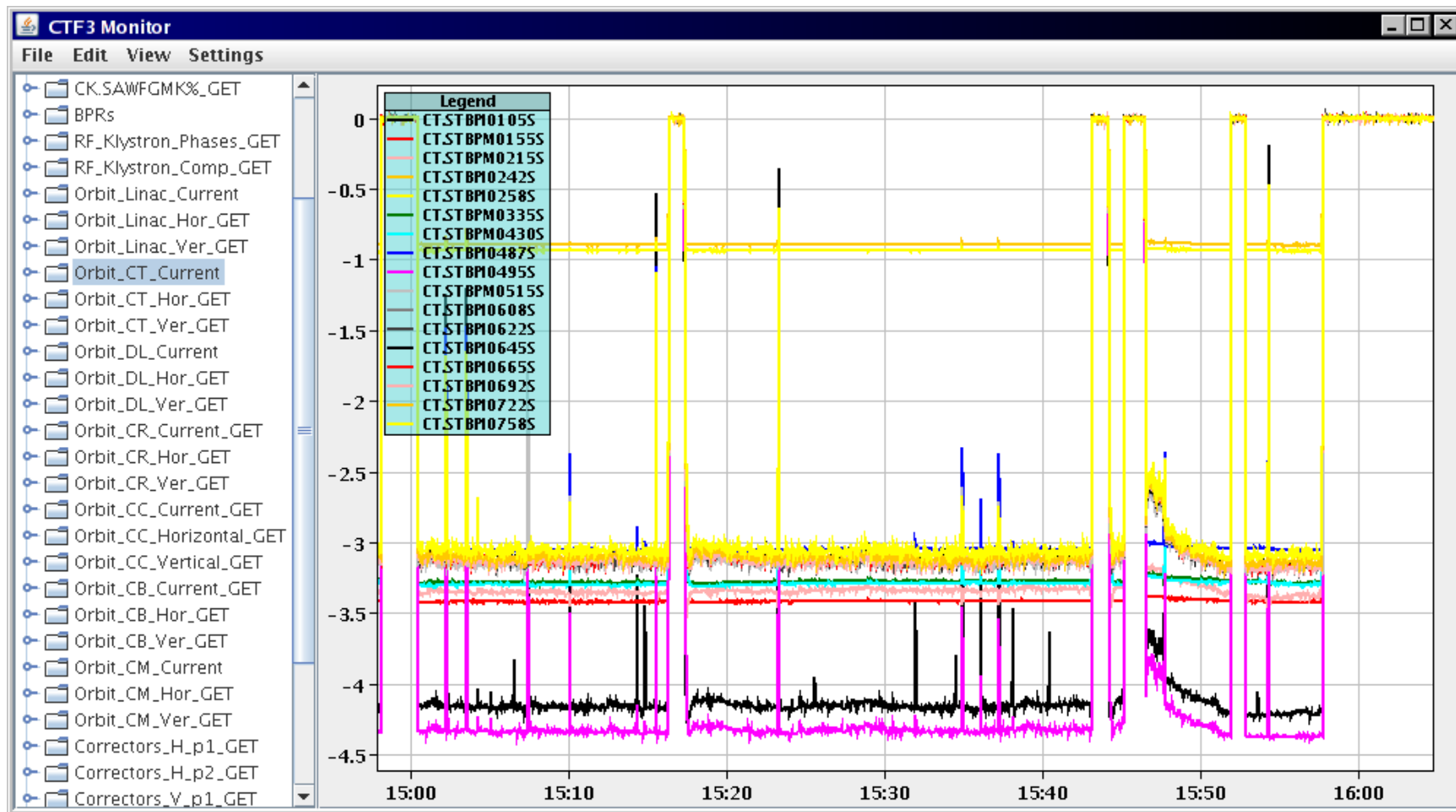 - Allows to find the devices that introduce drifts or jitter
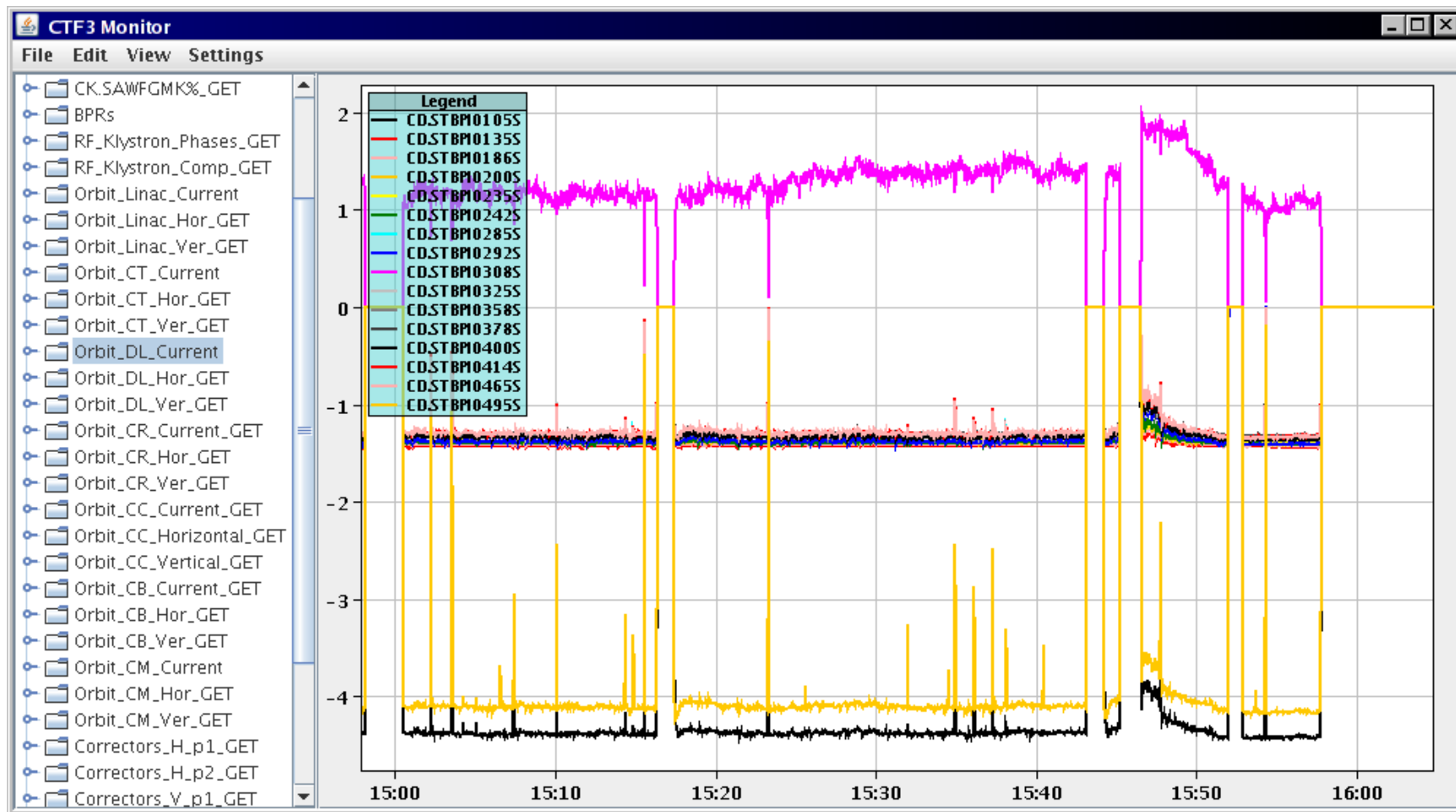
The beam current stability

- ◆ Beam current in Linac
  - ▪ Mean over 1μs

The beam current stability

◆ Beam current in Linac – zoom
  ▪ Mean over 1μs

The beam current stability

- ◆ CT Line
  - ▪ Mean over 1μs

The beam current stability

◆ Delay Loop
  ▪ Mean over 1μs

The beam current stability

◆ Combiner Ring
  ▪ Mean over 1μs

The beam current stability

- ◆ TL2
  - Mean over 0.1μs

Short Term Current Stability

Current Stability (factor 8)
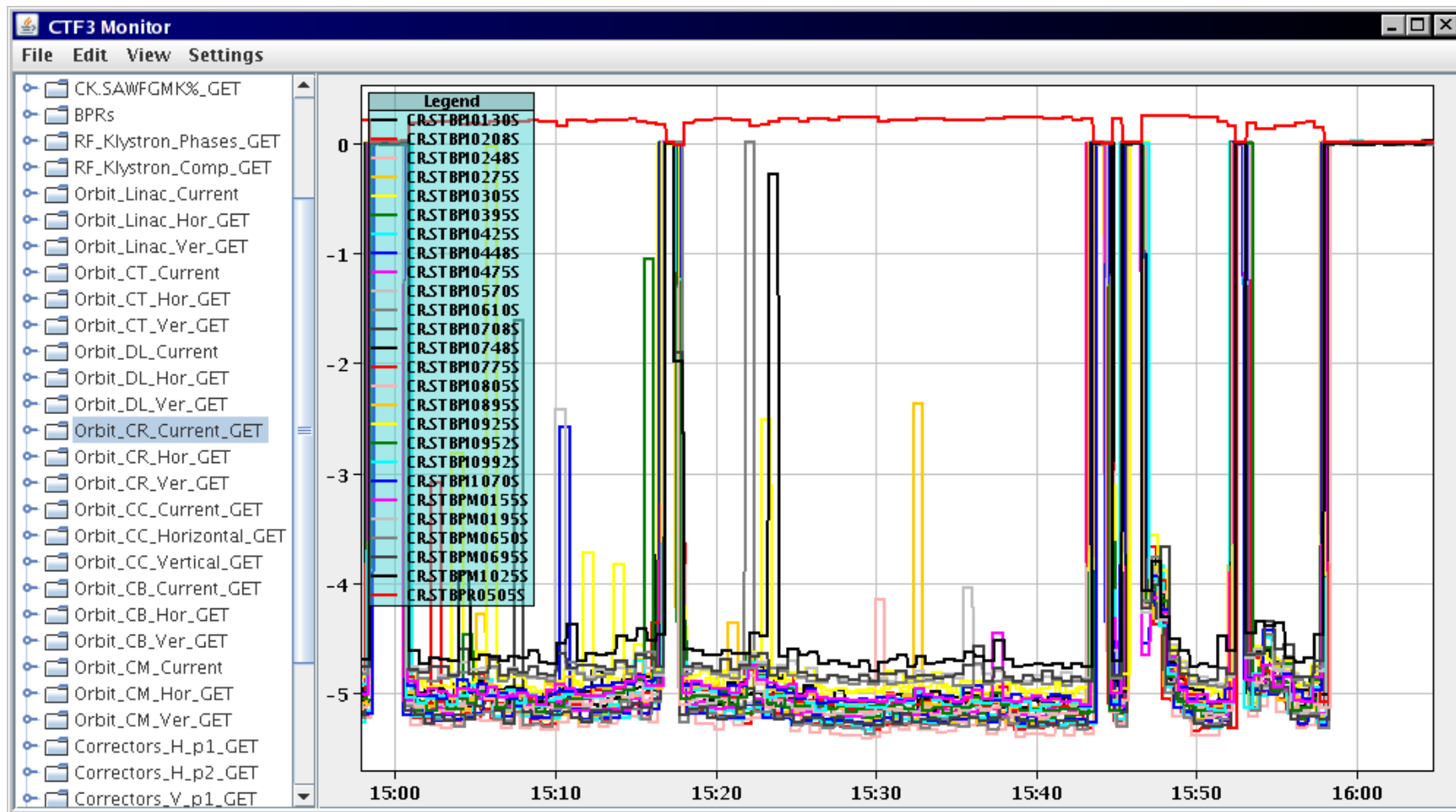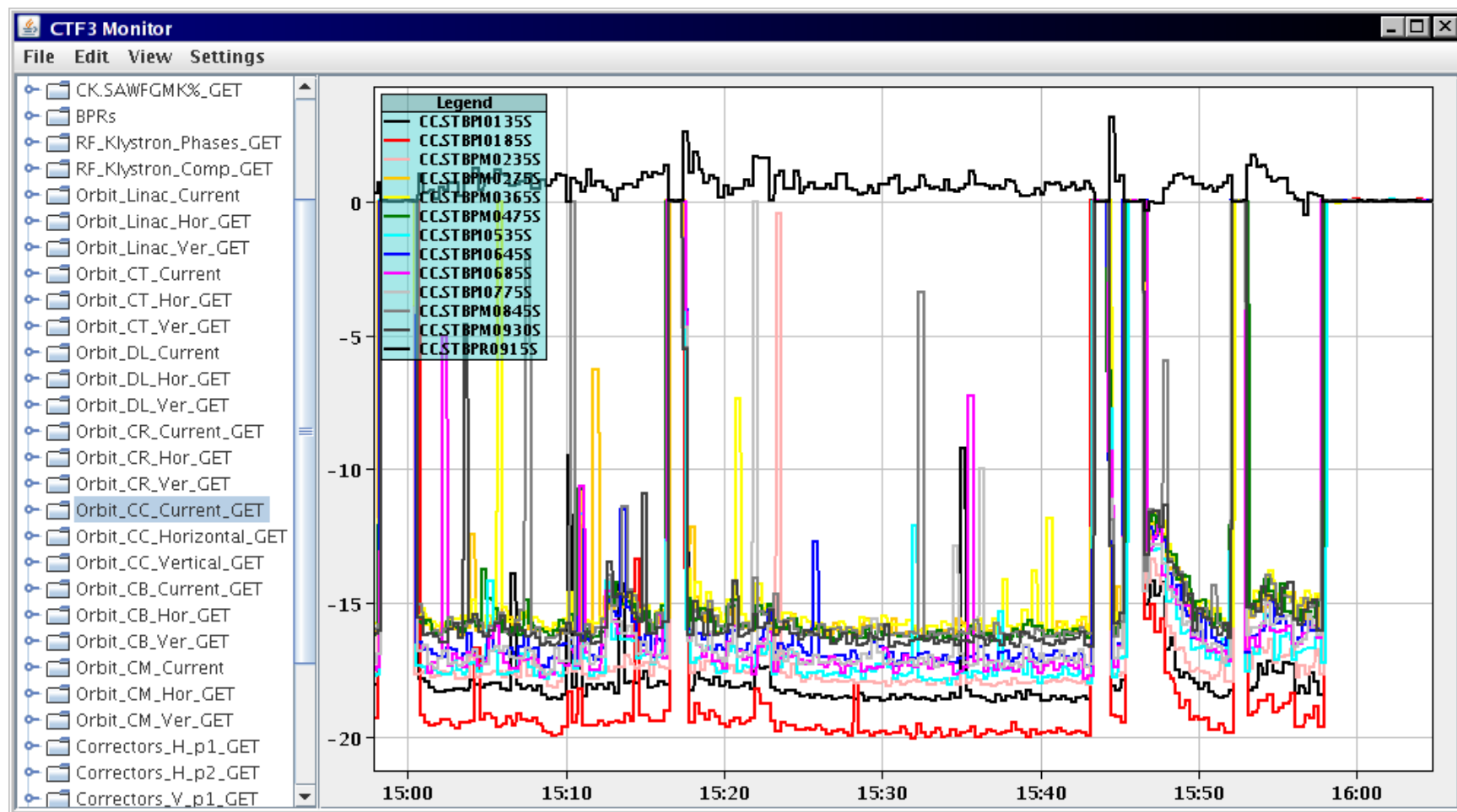
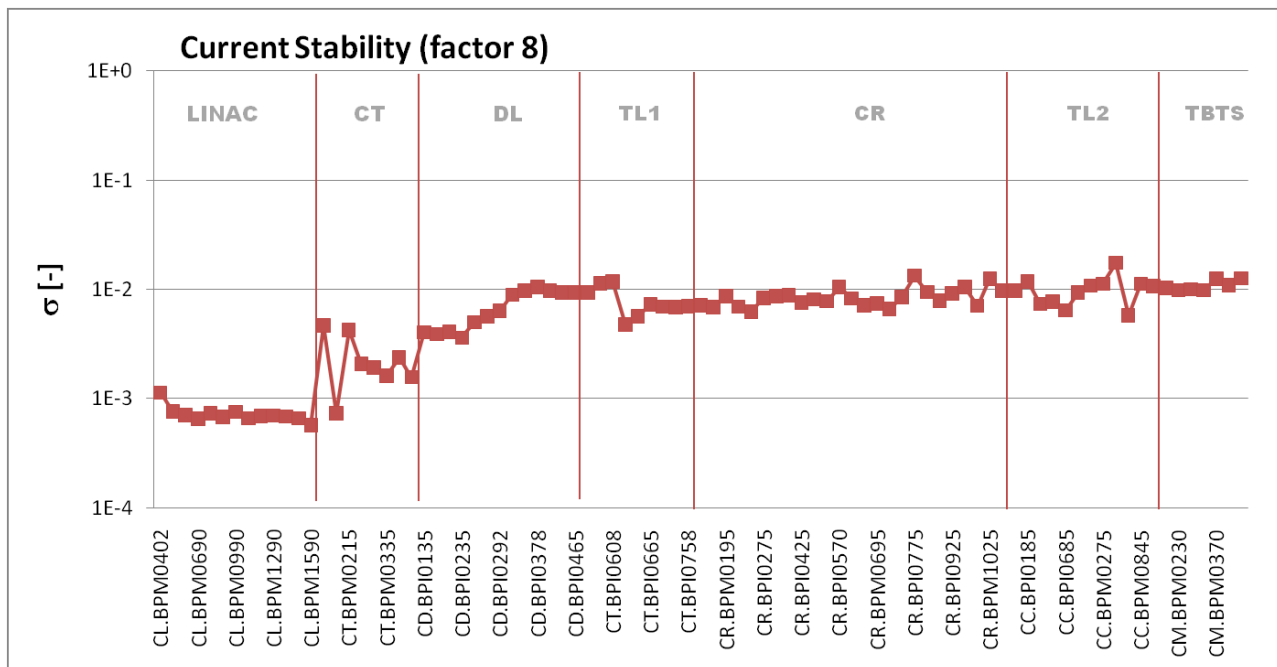- ◈ It is calculated over 20 minutes were no major drift was observed
- ◈ Quoted values are Gaussian fits to the normalized residuals
- ◈ Factor 4 recombination is more stable
  - ▪ Sub-harmonic bunchers are not used
  - ▪ Delay Loop (and its RF deflector) is not used in this case
- ◈ This data represent CTF3 stability as it was towards the end of the last run
  - ▪ The stability monitoring system was put in place only in autumn
  - ▪ With more careful setup better results are achieved

Linac

◆ The measured beam current stability in the linac is 2.5×10^{-4}
- A single BPM measurement is on average around 5×10^{-4}
- We are reaching limits of our BPMs precision
  ◆ The quoted value is obtained taking the sum of all linac BPMs
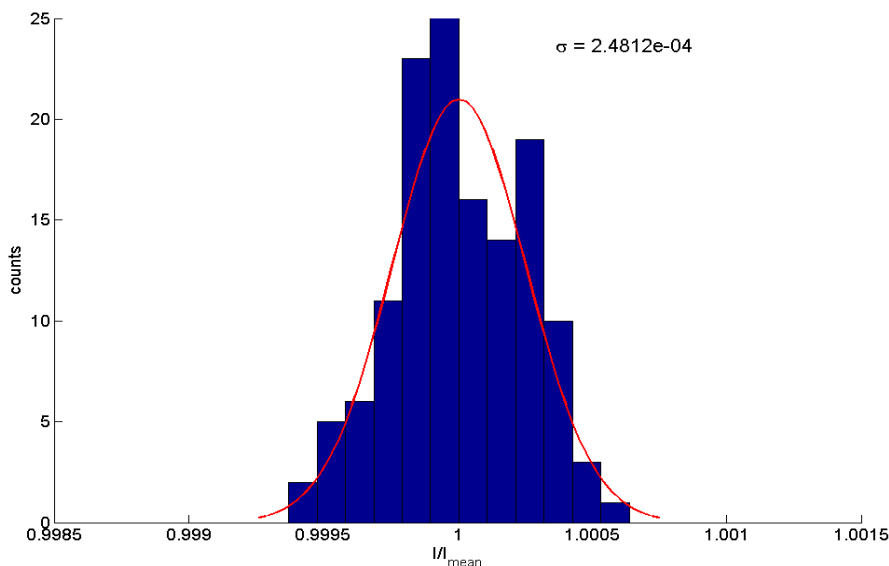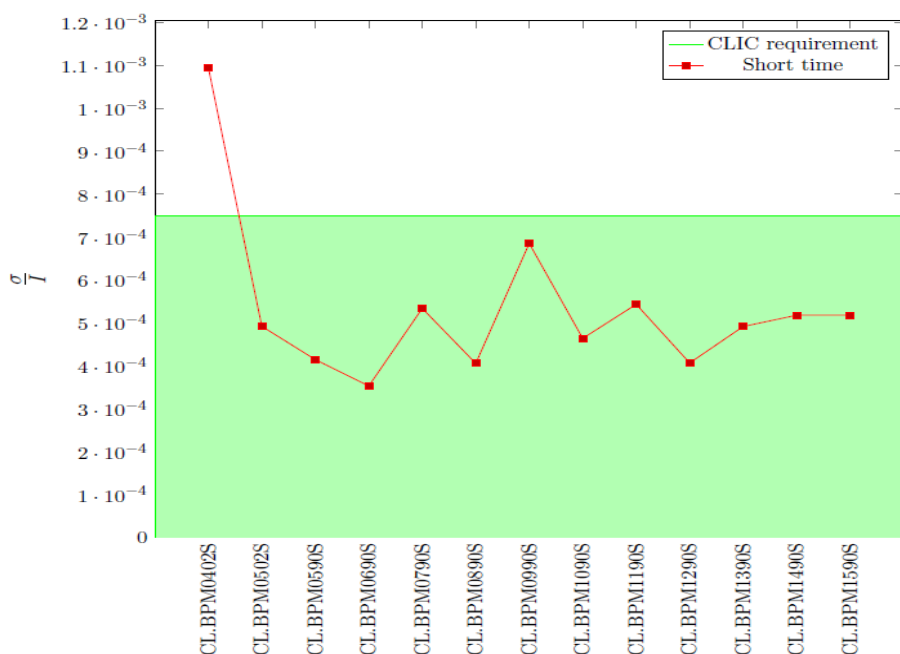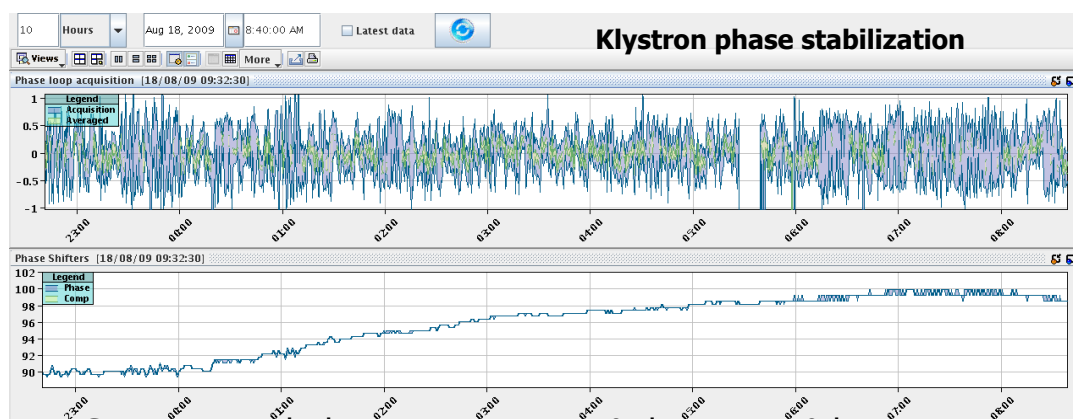
Recombined Beam

- Factor 4 recombined beam reaches current stability of 2.5×10^{-3}
- Improved linac stability thanks to
  - Better gun electronics
  - Feed-back on cathode voltage
  - Use of all BPMs to calculate the value, and over full length of the pulse

Position	Mean [A]	Std. Dev. [A]	Variation [%]
Compressor	-4.078	0.005	0.13 (new: 0.025)
CR (x4)	-15.097	0.038	0.25
DL	-6.277	0.014	0.22
CR (x8)	-25.210	0.254	1.01

- There is still plenty of room for improvements, and we believe it will be possible to reach the CLIC goal in CTF3
  - The beam energy spread will be decreased
    - For example, by more clever adjustments of the phase lags in the injector
      - This way we will be able to use the collimator in the compressor chicane in a more efficient way
      - It will remove energy and energy spread variation along the pulse
  - Closure in the transverse planes can be still improved in the rings
  - Chromaticity and non-linear dispersion will be corrected with sextuples reducing the emittance growth
  - Last year we have put in place tools for stability monitoring
    - The gathered data shall reveal all the important sources of jitter and drifts
    - Appropriate corrections or feed-backs will be put in place
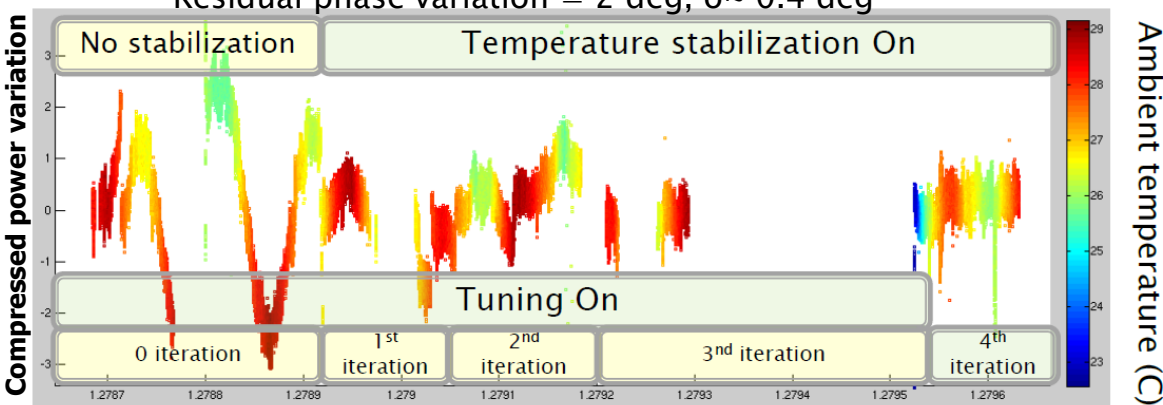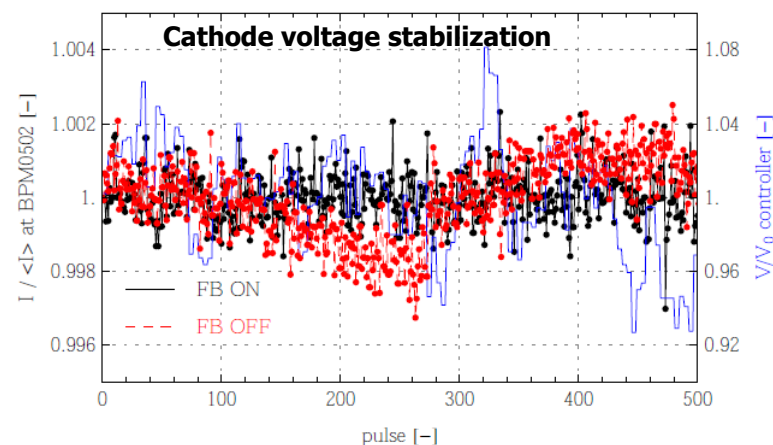
Introduced Feedbacks

- Feed-backs are already put in place for the main sources of the beam drift
  - RF phase stabilization for all klystrons and TWTs
  - Ambient temperature feed-back for RF compression
  - Feed-back on the voltage of the gun cathode

Klystron phase stabilization

Compensated phase variation = 10 deg over 10 hours
Residual phase variation = 2 deg, σ~ 0.4 deg

Cathode voltage stabilization

FB ON
FB OFF

No stabilization — Temperature stabilization On

Tuning On

| 0 iteration | 1st iteration | 2nd iteration | 3nd iteration | 4th iteration |

The total period is ~9 days

Compressed power variation

Ambient temperature (C)

Finding sources of the beam jitter and drift

◆ The data gathered by the CTF3 Monitor allows to find correlations between the beam and readouts of particular devices

- It has confirmed that the beam energy stability is the most important issue and it is driven by the RF fluctuations
- We attempt to
  - ◆ Stabilize the responsible devices where it is possible
  - ◆ Otherwise, implement or improve the feed-backs

phase of klystron 3

pos in the first dispersive pickup

Phase feed-forward
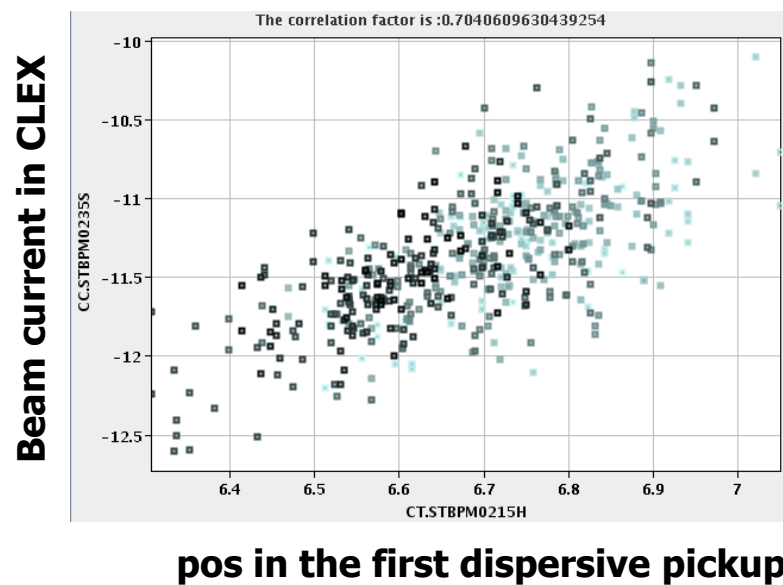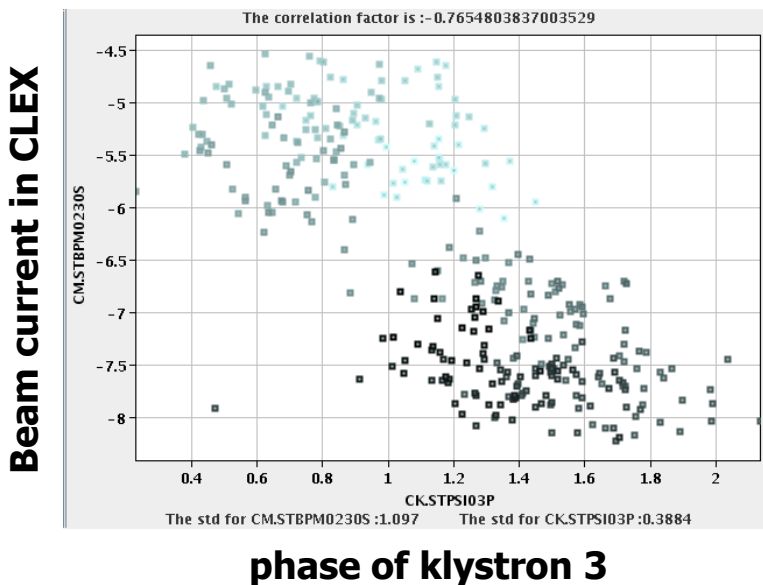
- The stability of the produced 12 GHz RF is at the moment at the level of 5°
  - Adjustments of the optics should improve it at least factor 4
- At CLIC, the phase stability of the drive beam with respect to the main beam should be better than 0.1° at 12GHz
  - To reach it, a feed-forward mechanism is necessary, made of phase monitors and kickers that change TOF in a chicane
  - It development its ongoing and it will be tested in CTF3

The beam phase monitor
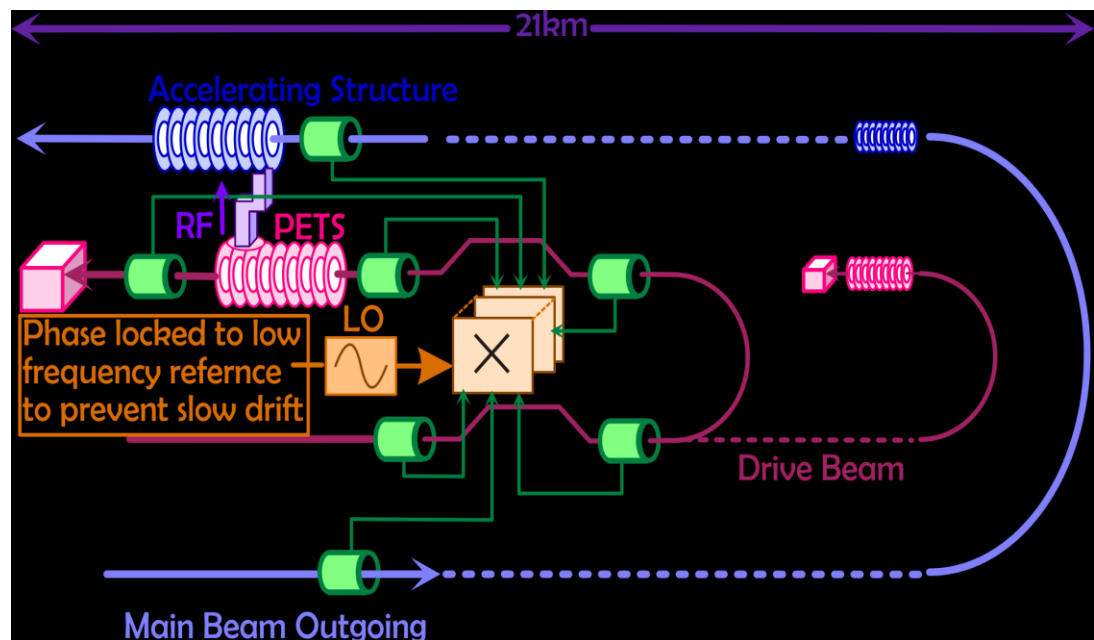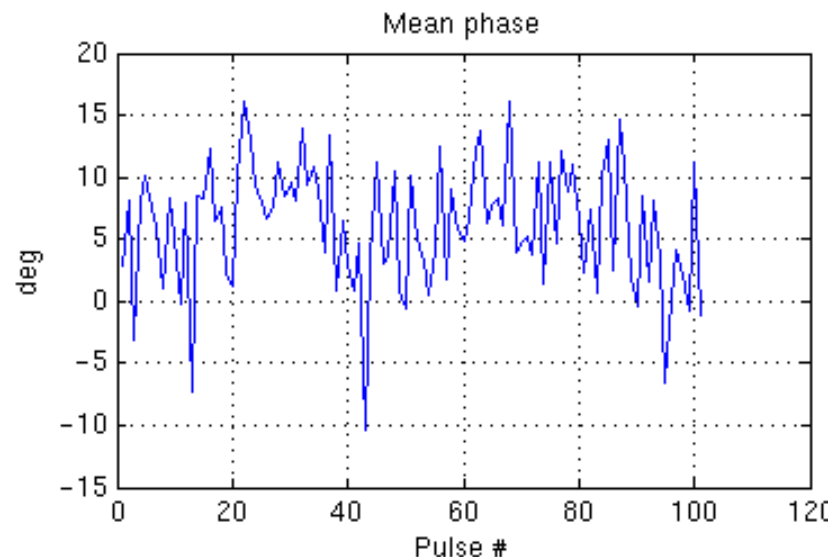
- Mechanical design of the pick-up has been completed and a prototype will be soon realized to check the simulation results and test fabrication techniques.
  - The 12 GHz resonant response of the system at the operating TM01 mode is established placing the notch filters both sides of the pick-ups
  - It is detuned by 200MHz to reduce the signal strength
- The electronics is already implemented for 30GHz detection and it has to be only transferred to 12GHz.
- Design of the kickers has not yet started, but most probably they will follow the concepts developed for the DAFNE injection kickers with tapered strip-lines. Their realization has been already funded.

Conclusions
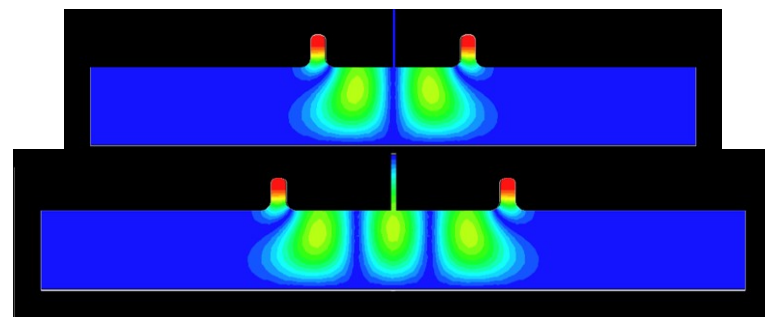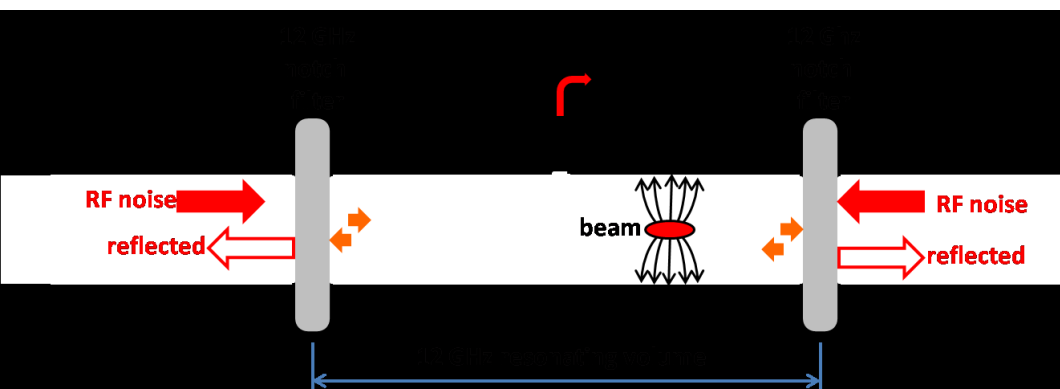
- The beam current at the end of the linac is very stable and it meets the CLIC requirement
- This should be also achieved for the recombined beam soon
- The drive beam phase feed-forward is under development and the system will be tested in CTF3
  - The phase monitor prototype is being fabricated
  - The appropriate kicker will follow soon
- It will be extremely hard to reach all CLIC stability specs in CTF3
  - Its hardware was not designed for that
  - However, we have had already positive surprises, might be there will be more

Backup Slides

CLIC Drive Beam Phase Monitor

Fabio Marcellini, David Alesini, Andrea Ghigo (INFN/LNF, Frascati, Italy)
Igor Syratchev, Alexandra Andersson (CERN, Geneva, Switzerland)

In two beam accelerator scheme the RF power produced in the deceleration of an high current electron drive beam (DB), is sent to 12 GHz RF sections to accelerate the Main Beam (MB). Synchronization of DB respect to MB is mandatory to keep constant the main linac effective gradient and then MB energy.

Single bunch RMS energy spread is $s_E/E \approx 3.5 \times 10^{-3}$. For relative energy variation $s_{jitt}/E < 4 \times 10^{-3}$, the corresponding effective gradient error is $DG/G \approx 4 \times 10^{-3}$ and the coherent error of the RF phase all along the main linac has to not exceed about 0.1º.
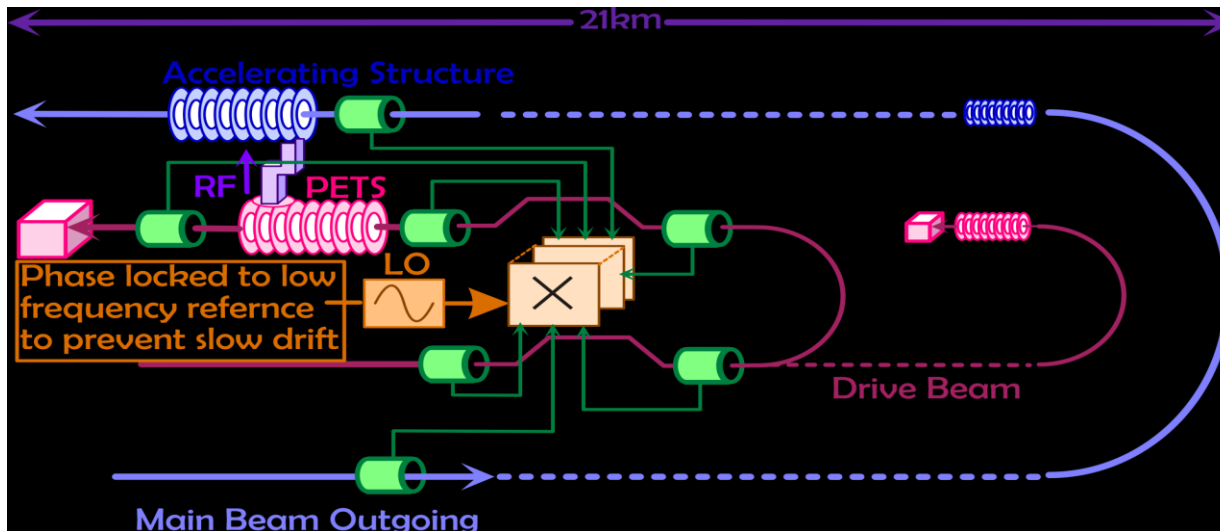

*Overall CLIC layout and the placement of the detectors (green cylinders) in the turnarounds.*

Pick-up design

The beam induced signal is coupled out of the beam pipe through 4 slots equally distributed along the pipe circumference. The slot cut-off frequency is >12GHz then the field intensity at the slot end can be adjusted properly tuning the slot thickness (d) and aperture.

A waveguide is then connected to each slot aperture, followed by a transition to a 50Ω coaxial line (SMA standard). A commercial vacuum feedthrough (MSSI part #853872) is placed in the coaxial section.
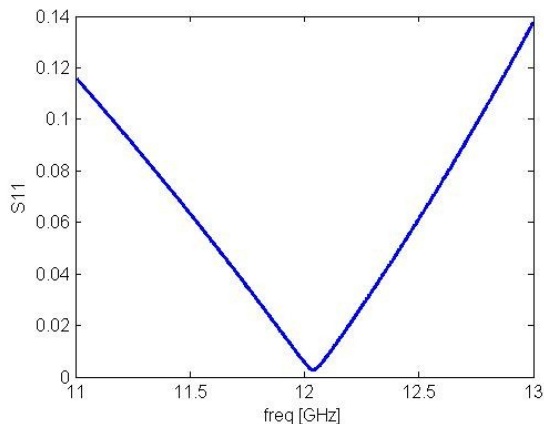
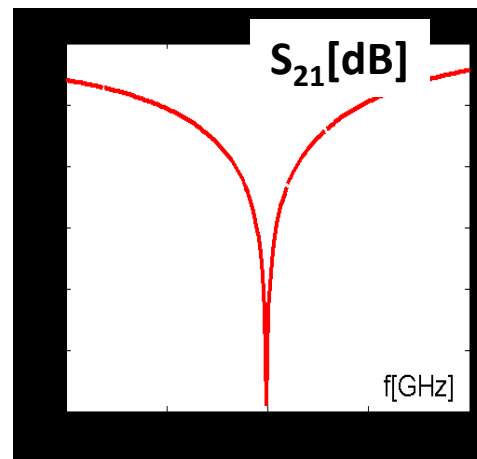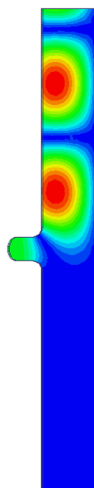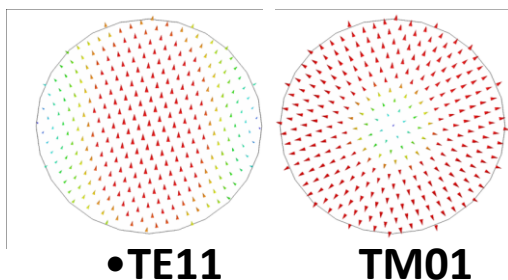*Waveguide to coaxial transition: reflection frequency response .*
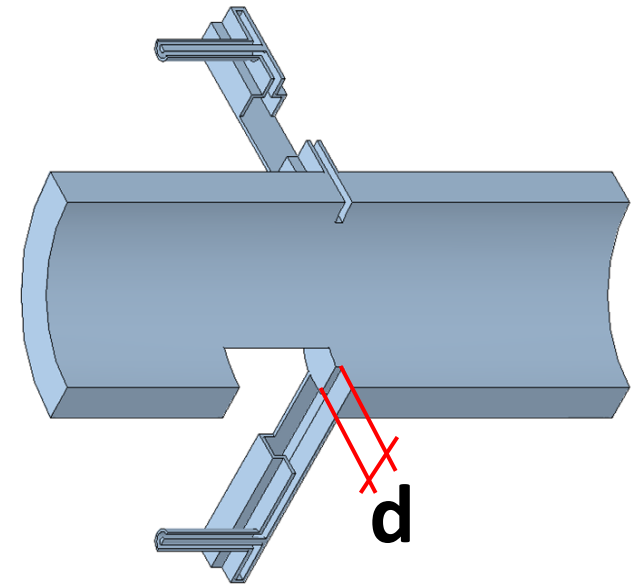
Cut view of the waveguide pick-ups

Rejection of RF noise and wakefield

Rejection of RF noise and beam generated wake fields, at least in the detection frequency range, is done by notch filters.

The notch filter is realized as a bump in the beam pipe. The dimensions of this bump are chosen to reject the 12GHz frequency component of the noise.

$S_{21}[dB]$

f[GHz]

Transmission response of stop-band filter for the

TM_{01} *mode*

The most suitable place for installing and testing the monitor prototype is the CTF3 drive beam chicane region. The pipe radius has been reduced down to 11.5 mm, to limit to only **2** modes (TE_{11} and TM_{01}) propagation at 12 GHz.

•TE11   TM01

•1

•4   •2

•3
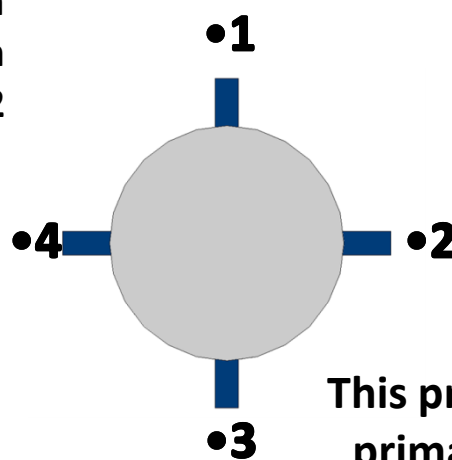
$V1+V2+V3+V4$ $\begin{cases} \neq 0, \text{TM01} \\ = 0 \text{ , TE11} \end{cases}$

This property can be used as a primary mean to reject TE_{11}

•The filter "closed" volume

•The 12 GHz resonant response of the system at the operating TM_{01} mode is established placing the notch filters both sides of the pick-ups, thus providing a kind of closed volume, where the beam generated electromagnetic fields can build up resonantly in the frequency range of the filter rejecting band.
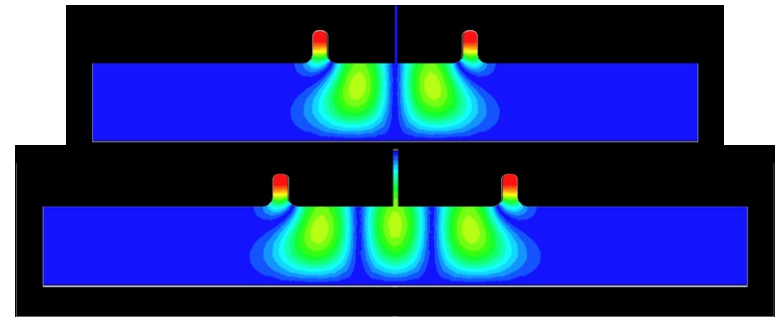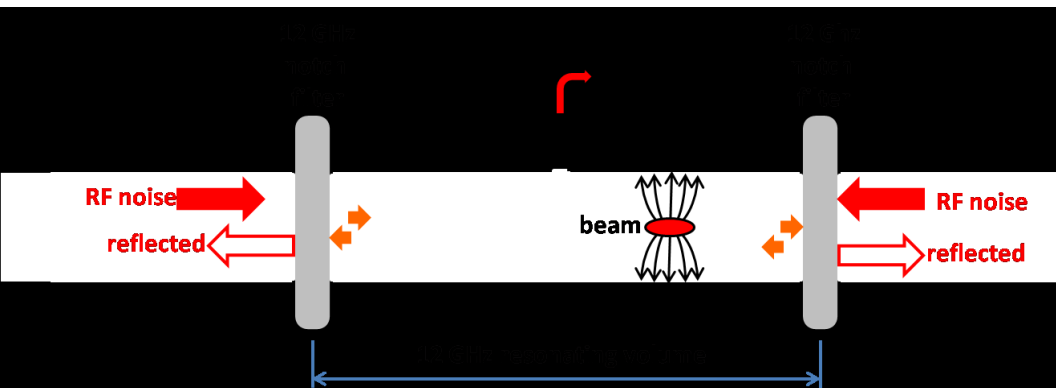
•Within this frequency range the resonating mode can be excited, if the distance between the two notches is equivalent to the integer number (*n*) of the given mode half wavelengths. The amplitude of the signal coupled out can vary from zero (even *n*), to its maximum (odd *n*).

•This condition has been used to set up the amplitudes of the spurious (TE_{11}) mode as close as possible to its minimum.

Q-factor and impedance

On the other side, keeping the resonant conditions of the detecting TM_{01} close enough to its maximum (odd *n)* the typical values obtained from the simulations are Q=7000 and R=60kΩ for a structure build of aluminium. The needs for the drive beam time sampling resolution and the overall restriction for RF power extraction from the drive beam require reducing both the Q-factor and the impedance values.

To reduce Q-factor and impedance:
- **Building of the stainless steel, both the Q-factor and the impedance can be reduced by about a factor of 6;**
- **Coupling the resonating fields to the special external loads, or increasing the coupling to the pick-up waveguide network.**
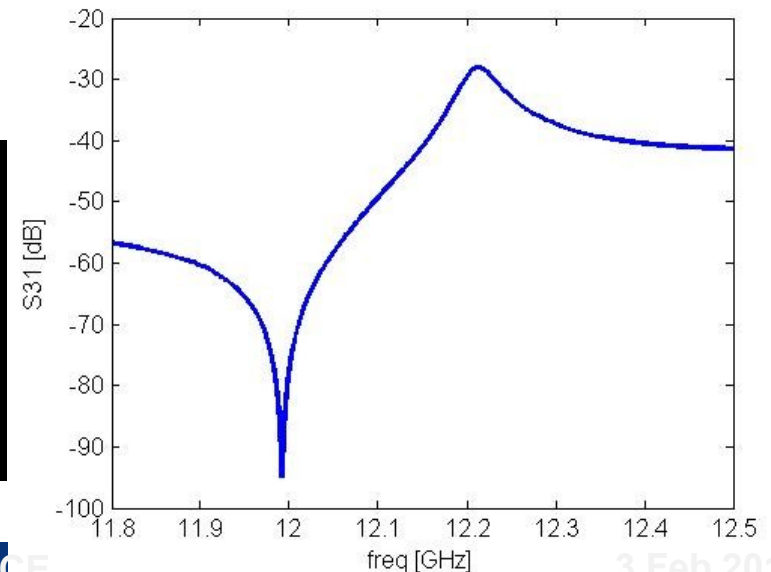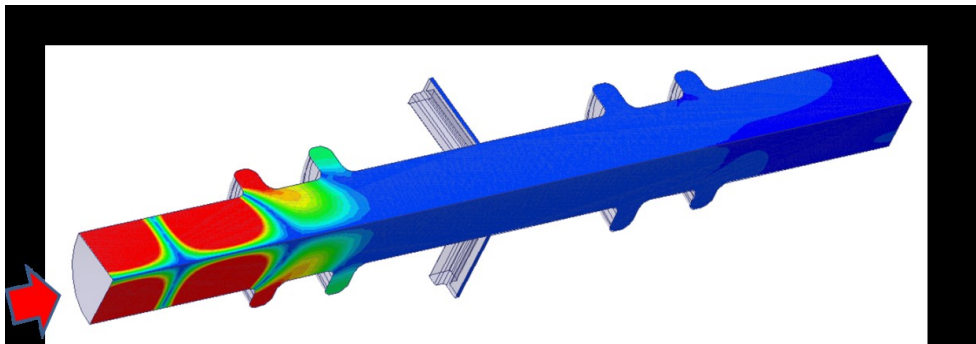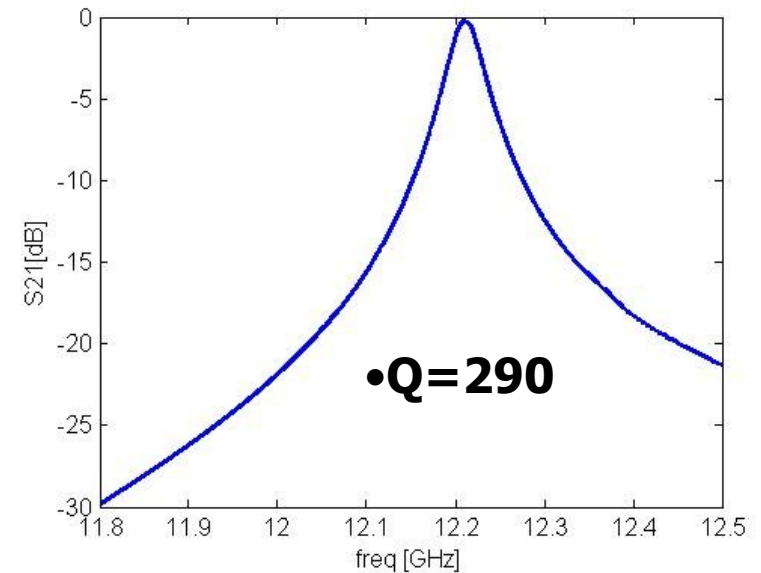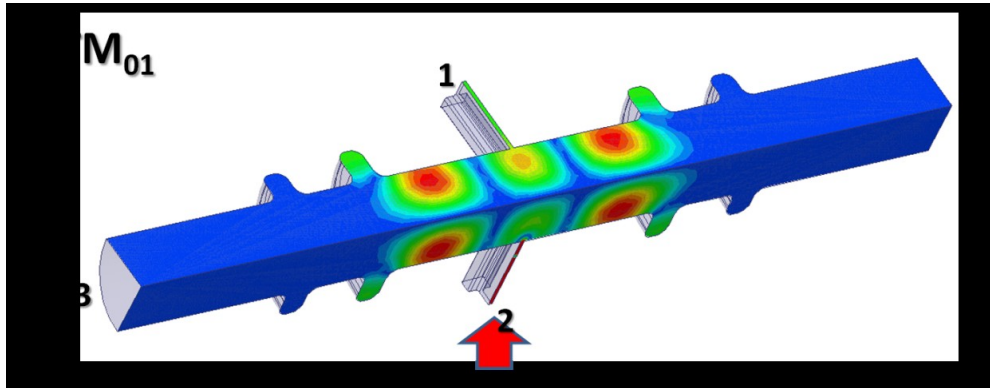- **Appropriate changing of the distance between the notches.**

In the last case, the resonant frequency of the operating TM_{01n} mode can be shifted to a different frequency, where the filter has lower rejection, thus the fields are less sharply contained in the notch delimited volume. The amount of extracted beam power is rather reduced, but still could be enough to detect the proper signal.
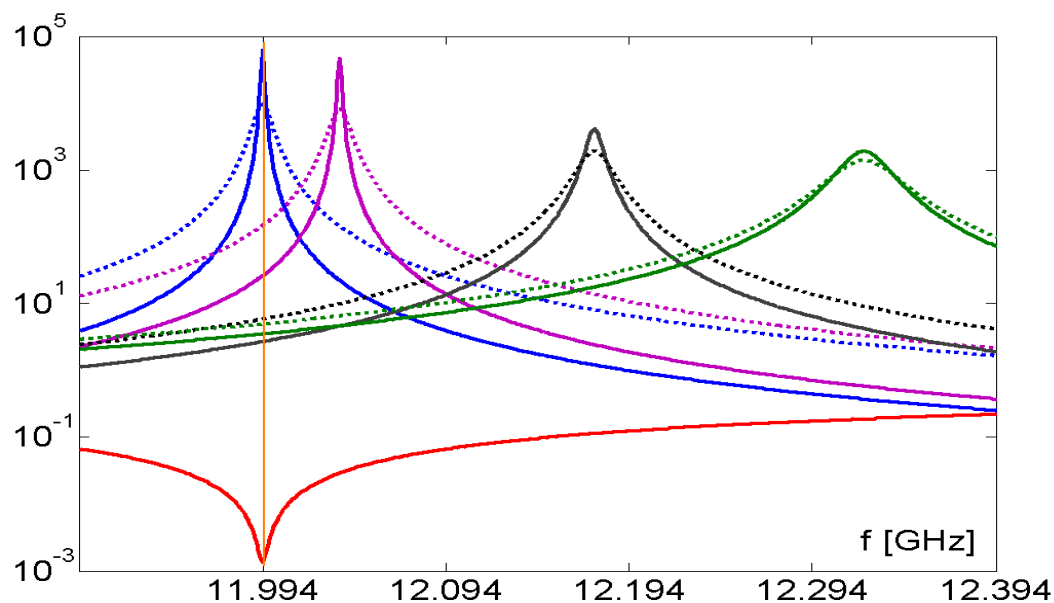
Monitor shunt impedance (vertical scale in Ohm):
no coupling, solid lines,
waveguide coupling (β=5.6 at 12 GHz), dashed lines.
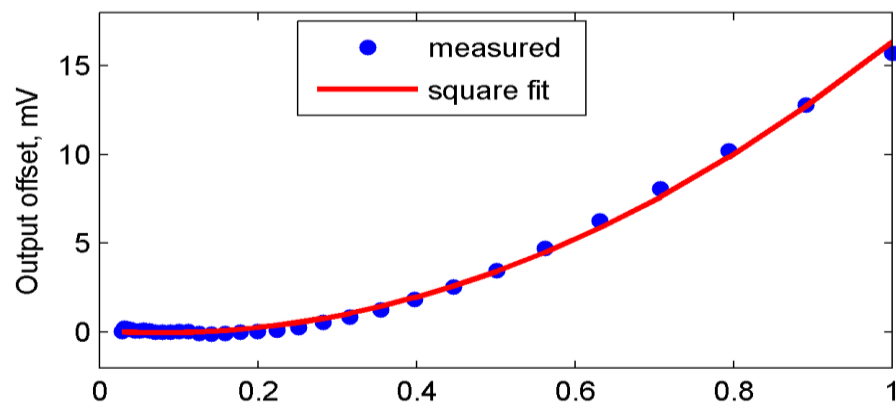*Notch frequency response (solid, red)*

Detuning the resonance frequency of about 200MHz, Q_L=290 has been obtained.

• Q=290

**The mechanical design of the monitor has been also completed.
The manufacture of a stainless steel prototype is in progress.**

Very high resolution and very stable phase reference are required to the detection electronics.

•*Mixer linearity measurements, second order term.*

In the context of XFEL construction femto-second stabilized reference lines are now available over about 1 km. The possibility of extension over 24 km from the central distribution point cannot yet be inferred. However, in CLIC an alternate phase reference, using low phase noise local oscillators (5 fs integrated timing jitter), synchronized to the outgoing main beam rather than a central timing reference, is possible. The time between the passage of the outgoing main beam and the arrival of the drive beam (and the main beam again) is at most 160 μs.

The performance is limited chiefly by device non-linearity and noise. With higher input power, both linearity and noise increase. A parallelization strategy will be used. The input signals from both the local oscillator and phase monitor will be split N ways, and detected on N mixers. The baseband signals will then be added together for an increase in signal to noise ratio. The second order term is the dominant non-linear term. An operating point where its contribution is small enough will be chosen.
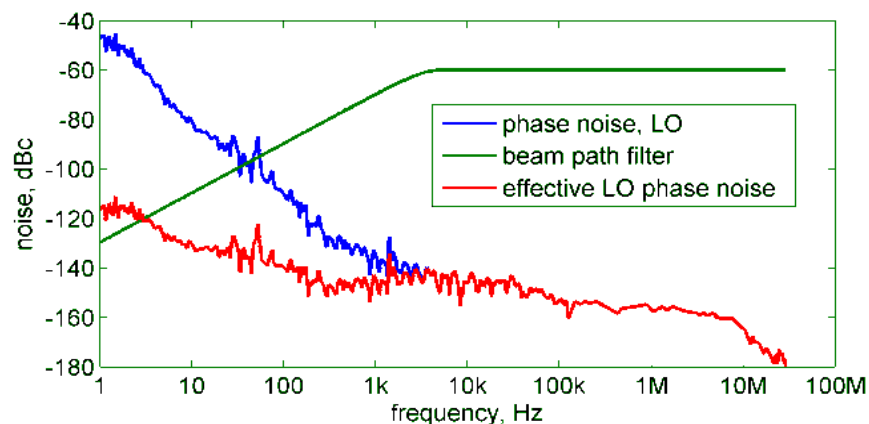
Oscillator timing jitter and beam path filtering.

The monitor to be used in the feed-forward chain to control the synchronization between Main Beam and Drive Beam in CLIC has been conceived and designed to get, at the same time, the desired resolution, low coupling impedance and noise rejection.

The pick-up mechanical design has been completed and a prototype will be soon realized to check the simulation results and test fabrication techniques.

The electronics, already realized in case of 30GHz detection, has to be transferred at 12GHz.

Design of the kickers has not yet started, but they will probably follow the concepts developed for the DAFNE injection kickers with tapered striplines. Their realization has been already funded.

The whole system will be tested in CTF3.

Horizontal

Vertical