Status of Wakefield Monitor Experiments at the CLIC Test Facility

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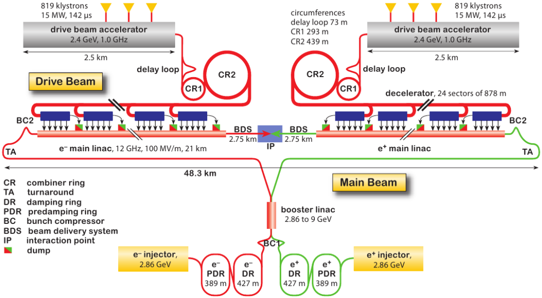
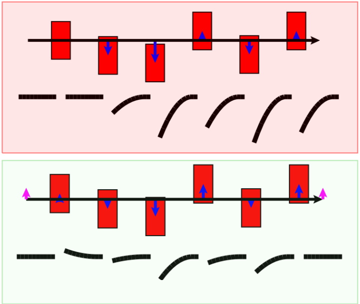
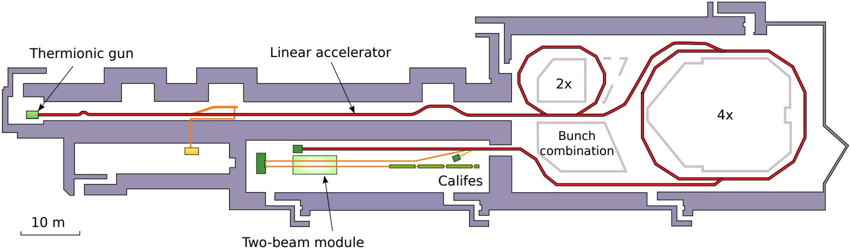
Introduction

- The proposed e^+e^- collider CLIC is designed with a luminosity of around $\mathcal{L} = 10^{34}/\text{cm}^2/\text{s}$.
- This requires emittances of
  - $\varepsilon_x = 660$ nm,
  - $\varepsilon_y = 20$ nm.
- An important contributor to emittance growth is **transverse wakefields** in the accelerating structures.
- Therefore, the structures are equipped with Wakefield Monitors (**WFMs**) for **measuring the transverse beam position in the structures**.
- Simulations show that the emittance growth has an acceptable level if the WFM resolution is **3.5** µ**m**.
- WFM performance and operating conditions are tested at CERN.







A large part is the drive beam generation

- Fully loaded acceleration.
- Bunch combination in a delay loop and a combiner ring, up to a factor 8.
- Many experiments including phase feed-forward, beam energy extraction, instrumentation etc.
- Will shut down Dec. 2016.

The Califes linac emulates the CLIC main beam

- Two-beam acceleration
- Instrumentation tests, external users like ESA, etc.
- May continue past 2016

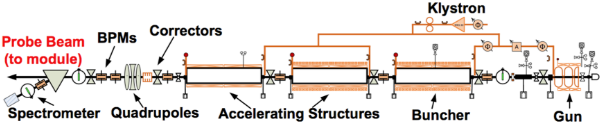


Figure 1: The CALIFES beam line, as installed in the CLIC Test Facility 3

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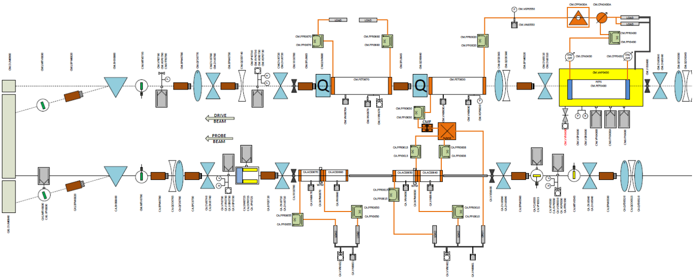
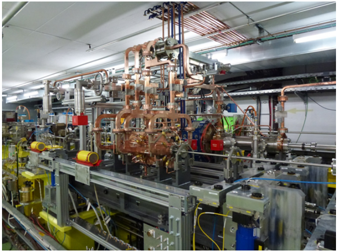
A prototype CLIC Module is installed, which uses the CTF3 drive beam to accelerate the probe beam in Califes

CLIC TBM INTEGRATION IN CLEX. COMPONENTS

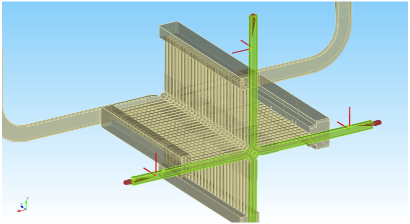


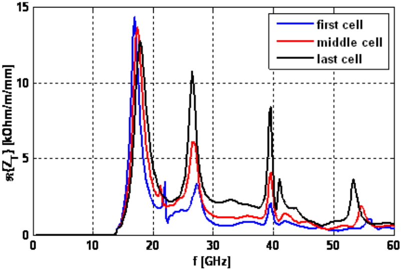


Beam parameters	Values
Beam energy	80–220 MeV
Relative energy spread	1 %
Bunch charge	0.01–1 nC
Acceleration frequency	3 GHz
Normalized emittances	2–70 µm
Repetition rate	0.83–5 Hz
Bunches per train	1–150
Bunch frequency	1.5 GHz
WFM signals	16

Wake Field Monitors (WFMs)

- **WFMs**: Precise determination of the beam position in accelerating structures.
- Four HOM damping waveguides with antennas are used for measuring dipole modes (which depend on the beam position).
- Four TD26 structures are installed in the module prototype in CTF3.
- A TE-like mode at 27.3 GHz and a TM-like mode at 16.9 GHz are expected from simulations (picked up with antennas on different sides of the waveguides).





Simulated transverse impedance for non-tapered TD26 structure (GdfidL)

Current WFM Readout System

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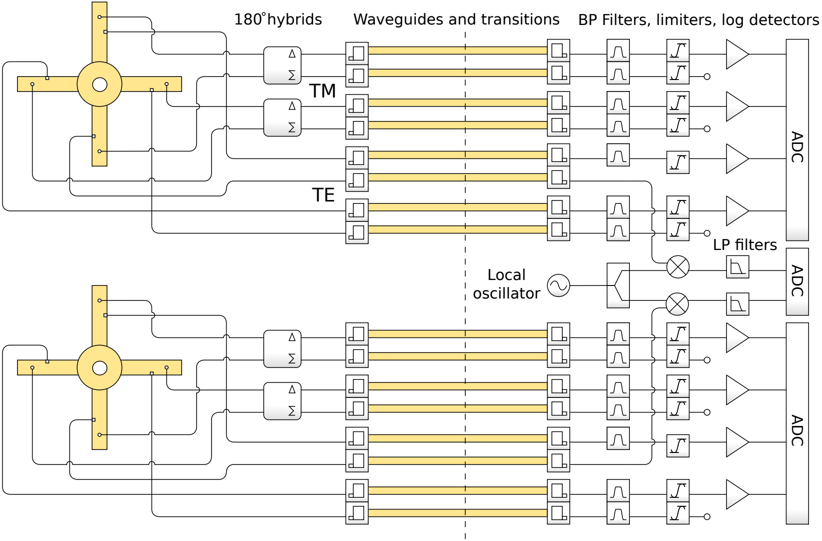

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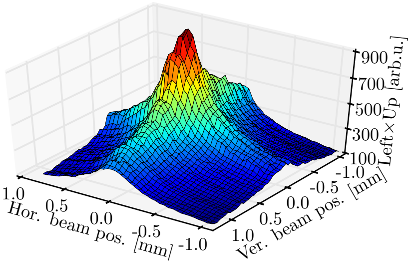
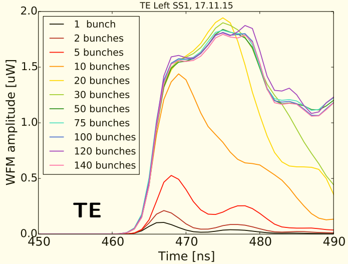
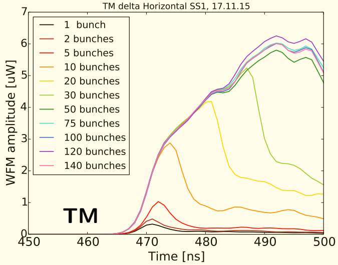
- The module including WFMs was commissioned in early 2015, and behaves as expected.
- Below: A position scan in both transverse planes, where signals in both planes are multiplied to find the structure center.







Signal buildup until steady-state depending on the number of bunches (0.17 nC per bunch)

Downmix Scans – Method

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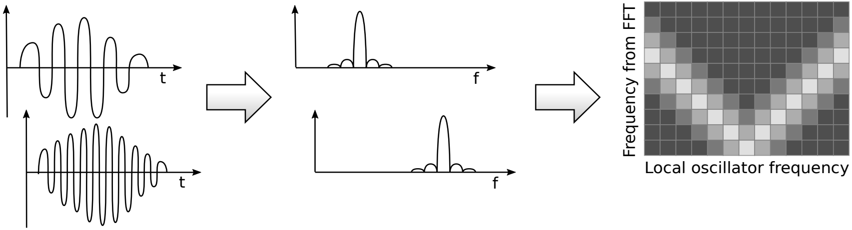
For measuring high frequency spectra, we have used a method we call *downmix scans*.

- When mixing a signal with frequency f_0 with a LO at $f_0 + \delta_f$, we are left with a signal peaked at δ_f.
- Changing the LO frequency will move the downmixed peak.
- We can downmix with a large span of frequencies, Fourier transform a mixed signal and obtain a frequency 'image'.



Downmix Scans – Results

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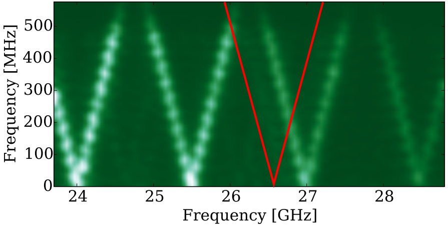
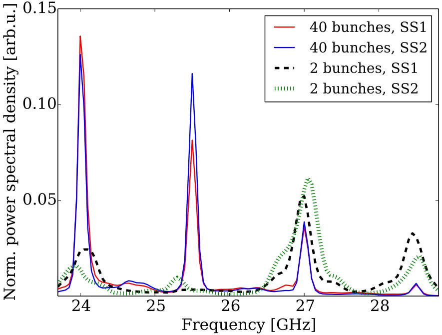
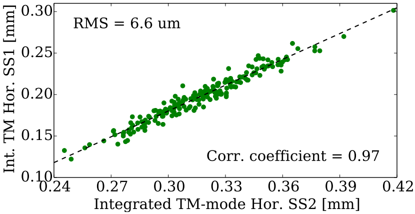
- **Upper right**: A frequency image of a WFM signal for the TE-like mode, scanned from 23.7 to 28.8 GHz.
- For each frequency we can
  - Apply an **image mask** with 2 lines that make up a 'V' with the correct angle (fixed).
  - Multiply and average with the frequency image.
- **Lower right**: Spectra obtained with this method.
  - Spectra for 2 bunches (0.8 nC per bunch) are similar to the simulated single-bunch spectrum.
  - Spectra for 40 bunches (0.35 nC per bunch) have peaks at integers of the bunch frequency at 1.5 GHz.
- For CLIC, the number of bunches during machine tuning should take into account the WFM spectra.





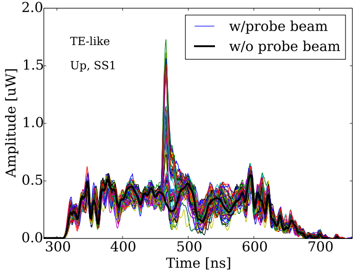
WFM Resolution Estimates – Simple Analysis

- A simple estimation of resolution can be done by comparing measured to expected position, or comparing two signals.
- **Right**: 200 shots of TM-like mode in the horizontal plane, comparing two accelerating structures.
- Obtained RMS of **6.6 μm**, however the TE-like mode had a spread of 15 μm and all vertical signals had a spread of around 20 μm.

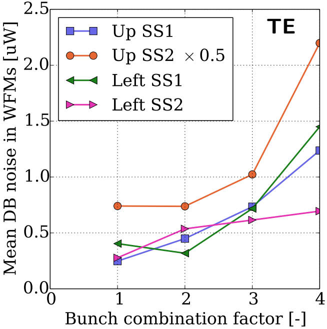


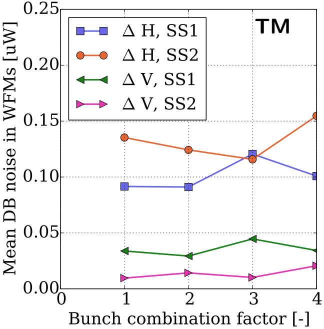
50 bunches, 0.42 nC per bunch

Drive Beam Noise in WFMs (2015)



- In the early commissioning, a large amount of RF noise was seen coming from the drive beam.
- The noise increased with the drive beam current, and the TE-like mode had much more noise than the TM-like mode.





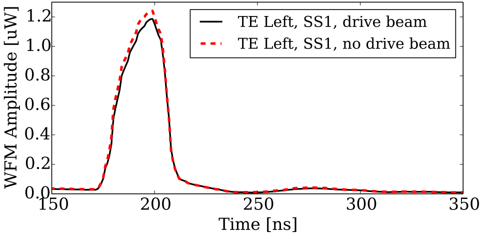
Steps taken:

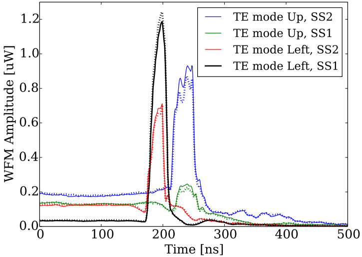
- Careful grounding of accelerating structures
- Recabling with high performance cables

This significantly reduced the noise level.

Current Noise Level in WFM Signals

- After the steps to improve noise, we cannot see any significant effect from the drive beam on the WFM signals.
- There is still some noise that likely comes from the Califes klystron, and this should be removed as well by shielding etc.





WFM Resolution Estimates – SVD

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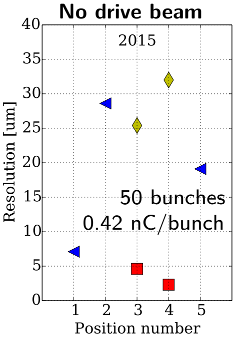
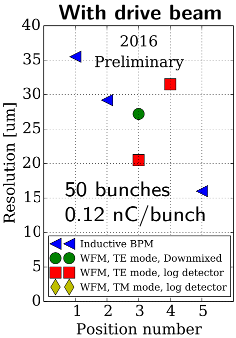
- We can do a more careful resolution analysis using *model independent analysis* with *singular value decomposition* (SVD).
- The first 2 singular values in our analysis represent dispersion/drifts of the machine, and are removed.
- **Right**: Using the same data as before, we obtain resolutions of 2.3 and 4.6 μm for the TE-like mode.
- However, the TM-like mode is here worse, and seems to drive an eigenmode of their own.





- **Left**: Recently, there were a few hours with drive beam in the module.
- A similar SVD analysis gives 20–30 μm resolutions for the WFMs.
- However, **the same is the case for all recent data** (also without drive beam), so there must be another cause that must be discovered!
- Also, here we have low statistics with 200 shots.

For CLIC, a cost-effective readout system should be found due to the 140,000 WFM devices. We consider

- Log detectors
- Downmixing system
- Diodes
- IQ demodulators
- Electro-optical system

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Conclusion

- CLIC Wakefield Monitors are tested in the Califes beamline in the CTF3.
- Antennas in four damping waveguides measure one TE-like and one TM-like dipole mode for finding the transverse beam position.
- 'Downmix frequency scans' have been used for finding high frequency spectra.
  - The simulated single-bunch structure impedance was seen with 2 bunches.
  - However, for many bunches there are **peaks at harmonics of the bunch frequency**.
- At first there was a large amount of noise when the drive beam was operated, however this has now been heavily reduced. Some noise from the Califes klystron remains, but should be reduced as well.
- The best resolution found without drive beam in the module was **2.7 μm**.
- With drive beam the recently measured WFM resolution is 20–30 μm, however, this is preliminary and further work is required. Also more statistics should be taken with the SVD analysis.

Thank you for your attention!