Wake-Field Monitor testing in CLEX

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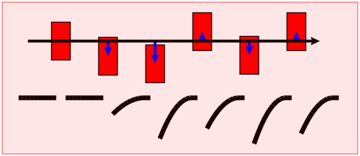
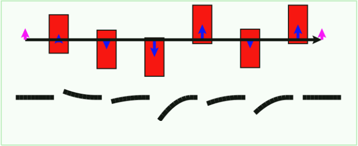
- CLIC is designed with a luminosity of around $\mathcal{L} = 10^{34}/\text{cm}^2/\text{s}$, which requires emittances of
  - $\varepsilon_x = 660$ nm,
  - $\varepsilon_y = 20$ nm.
- An important contributor to emittance growth is **transverse wakefields** in the accelerating structures.
- Therefore, 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 **accuracy is 3.5 μm**. Due to some miscommunication, we have mainly measured the *resolution* so far.
- WFM performance and operating conditions have been tested at the Two-Beam Module (Califes) in the CTF3.

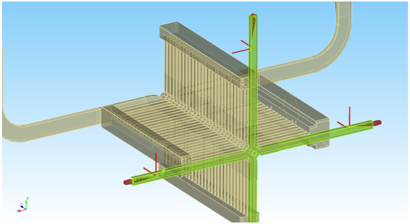


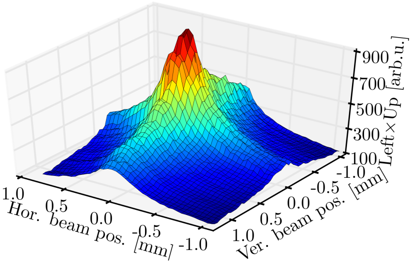


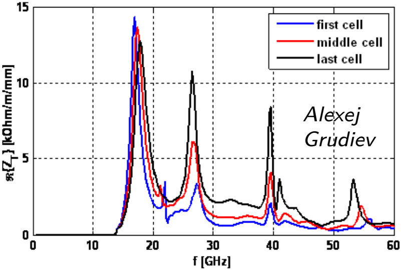
Above: Alignment of a girder to average out transverse wakefield effects.

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).







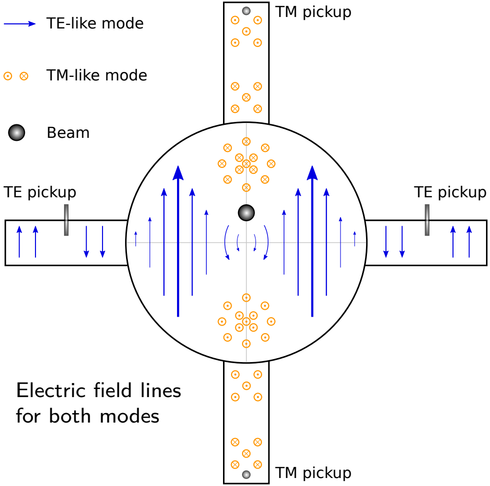
Simulated transverse impedance for non-tapered TD26 structure (GdfidL)

Simplified figure of what the two modes could look like in the cell.

The **TM**-like mode couples to the waveguides in the same plane as the beam offset.

- Asymmetric field distribution ⇒
  The 2 signal pickups can be combined in a hybrid, which removes the monopole component at this frequency.

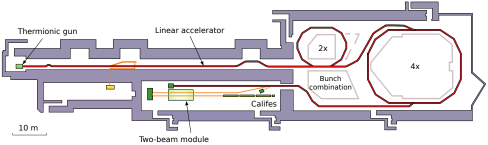
The **TE**-like mode couples to the opposite plane than the beam offset, symmetrically, which removes the possibility of using a hybrid.



Electric field lines for both modes

Experimental setup and methods

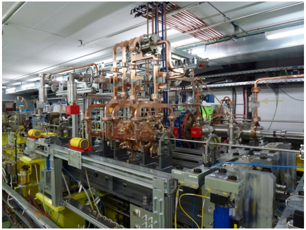
Experimental setup: Two-Beam Module



Califes/Two-Beam Module was a part of CTF3.
This part now turns into CLEAR.

The module can be moved fast with a resolution of 50 µm, with a readback precision of a few microns.

(engineering colleagues can move the actuators online using a special LabVIEW software)



The Two-Beam Module

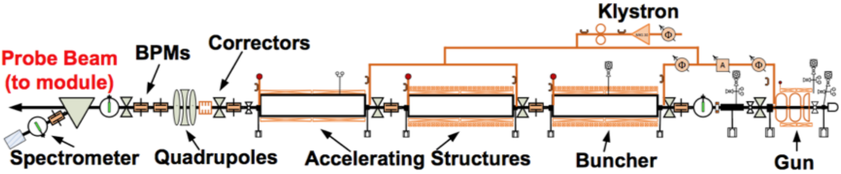
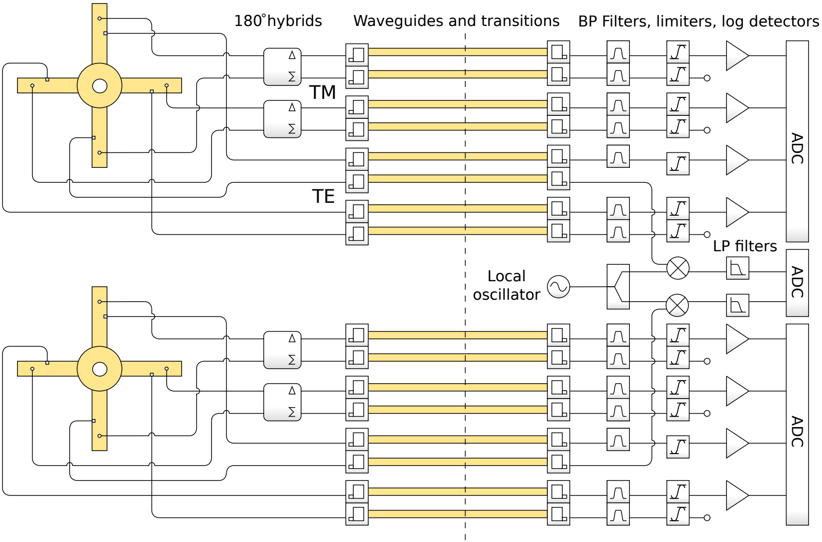
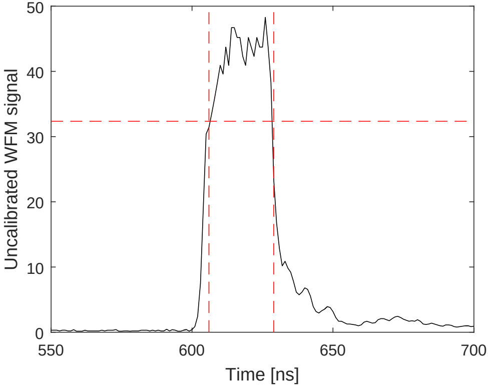


Figure 1: The CALIFES beam line, as installed in the CLIC Test Facility 3

Current WFM Readout System



Signal treatment (i): Integration



Firstly, the raw signals are calibrated for electronics and converted to linear scale.

Then, the pulses are integrated to obtain a single value.
⇒ A threshold of 70 % of the signal maximum is used as a compromise between accuracy and robustness against noise.

Signal treatment (ii): Calibration

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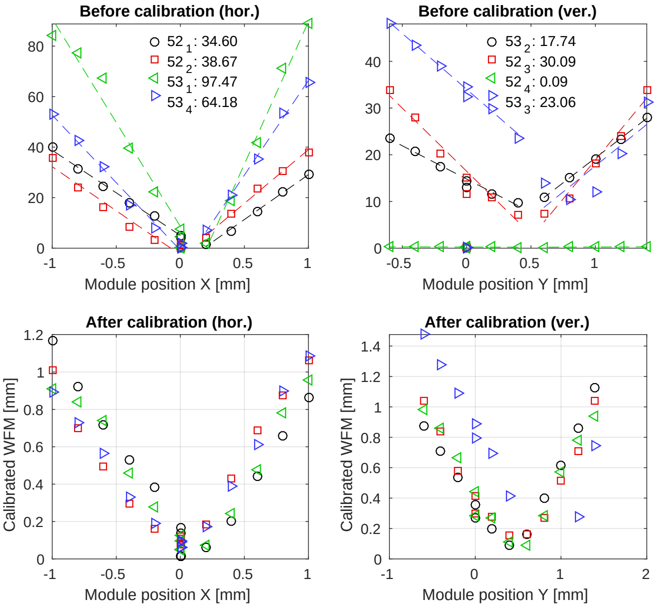


Finally, the single values are calibrated against the known module position.

The points show averages at each measured position (over 50 shots)

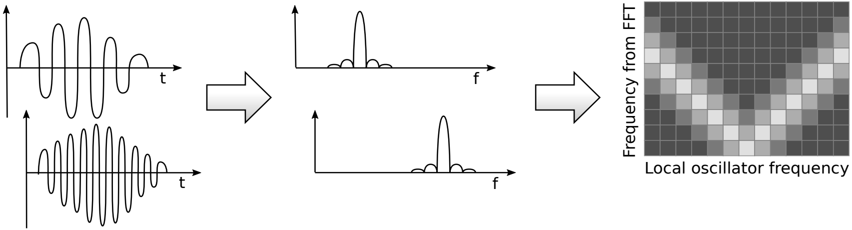
Here:

40 bunches/shot
0.1 nC/bunch

Frequency results

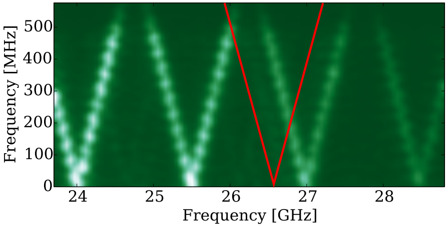
For measuring high frequency spectra, we have used a method we call *downmix scans*.

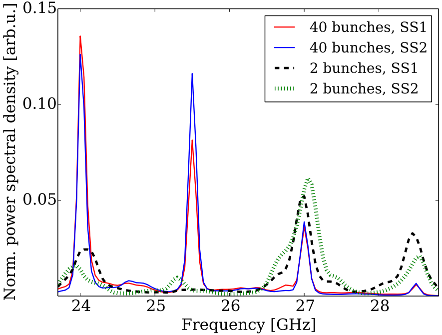
- When mixing a signal with frequency f_0 with a LO at $f_0 + \delta_f$, we are left with a signal peaked at δ_f.
- Changing the LO frequency will move the downmixed peak.
- We can downmix with a large span of frequencies, Fourier transform a mixed signal and obtain a frequency 'image'.



Downmix Scans – Results

- **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.





Resolution estimates

Scatter plots: SS1 Horizontal

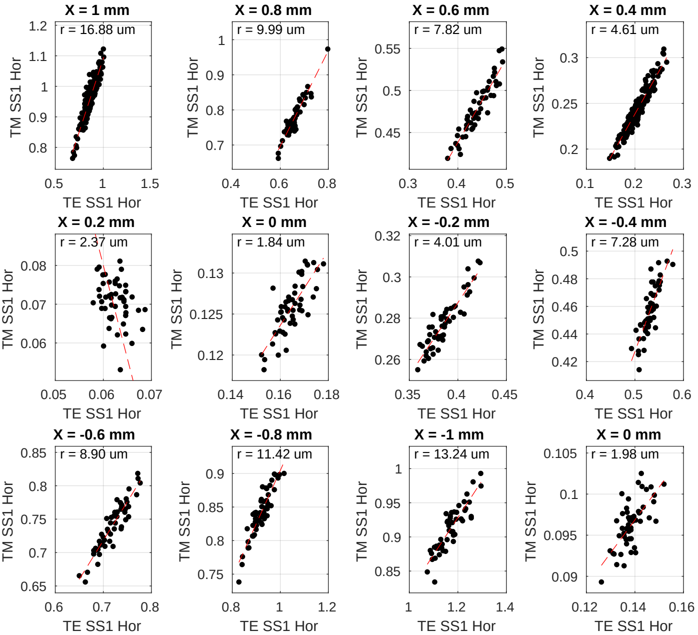
Correlation between the modes for various positions

- 1 structure
- 1 plane

SS1 Horizontal

40 bunches,
0.1 nC per bunch

(Note: Axes correspond to the plane of beam offset, not the location of pickups)



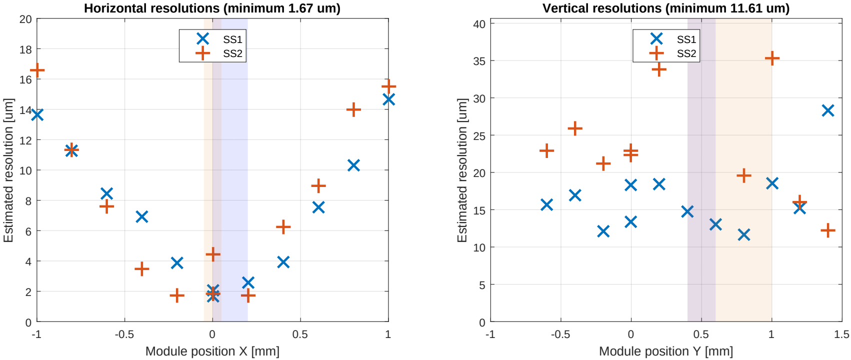
Resolution estimates

All resolution estimates from the last slides combined, for both planes and both structures.

Very good results in horizontal! (1.67 μm compared to required resolution of 3.5 μm)

However, outside the structure centers the resolution gets worse.
Is this due to a common mode?

40 bunches, 0.1 nC per bunch



Possible monopole component / common mode

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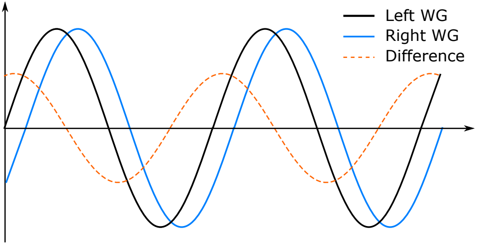
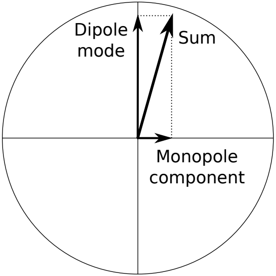
For a hybrid coupler, different cable lengths lead to phase differences which prevent cancellation of the monopole component.

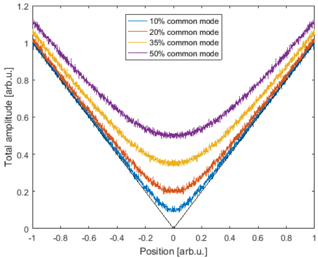
Addition of the interesting dipole component and a constant monopole component can be described by phasors.



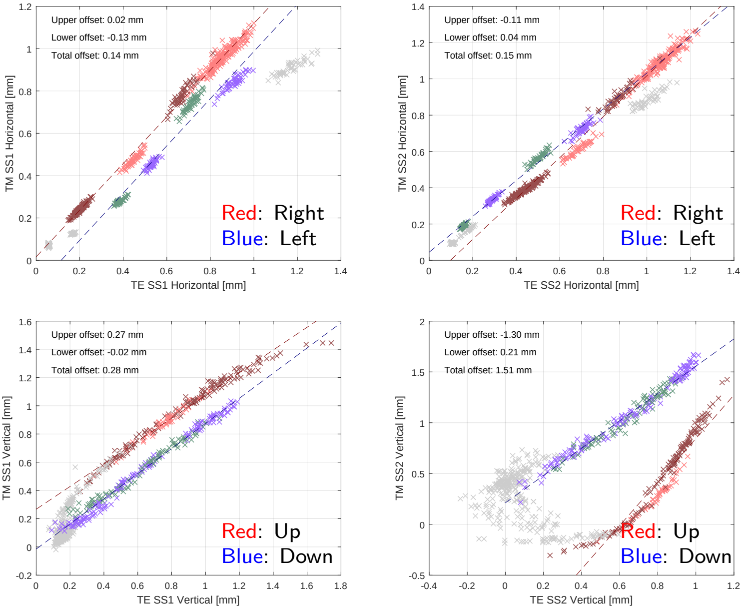


The impedance has a large spectrum and can also give a common mode at the TE-like frequency.

We want to add variable phase shifters everywhere, and a 0° hybrid for the TE pickups.



Different strengths of monopole mode relative to dipole mode



There is not a strictly linear relation between the modes, so they **may not have the same center**.

Can this be explained by a monopole component or phase differences?

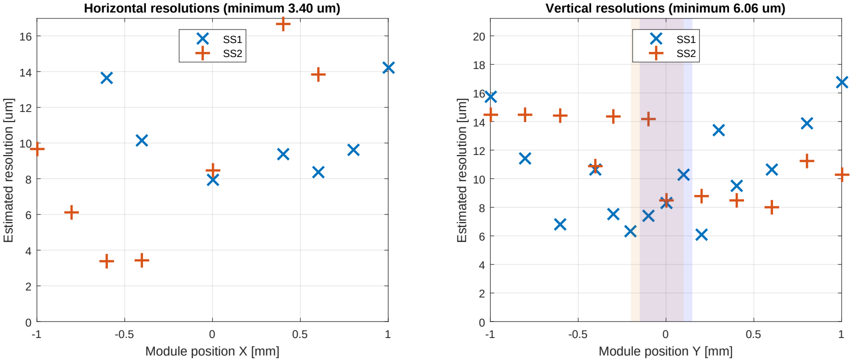
40 bunches, 0.1 nC/bunch

(Note: Axes correspond to the plane of beam offset, not the location of pickups)

Another dataset: Resolutions

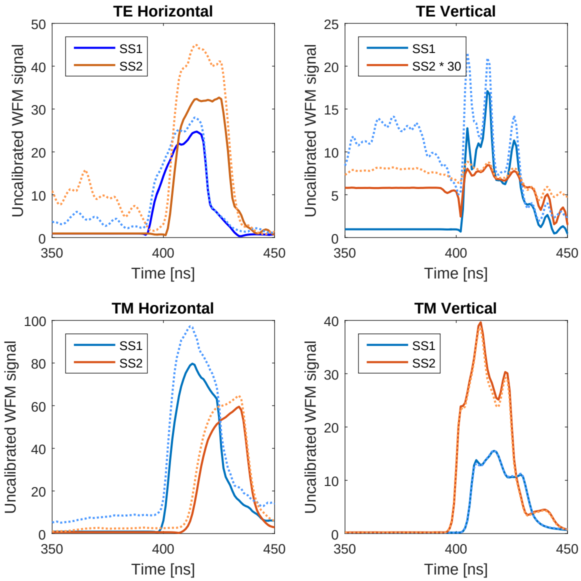
The resolution is still adequate for one structure in the horizontal plane, but the other measurements are not as low.

40 bunches, 0.055 nC per bunch



Drive beam noise

Drive Beam Noise in WFMs



- RF power from a 6 A drive beam injected into the structure.
- Solid lines show signal without drive beam, dotted lines show signal with drive beam.

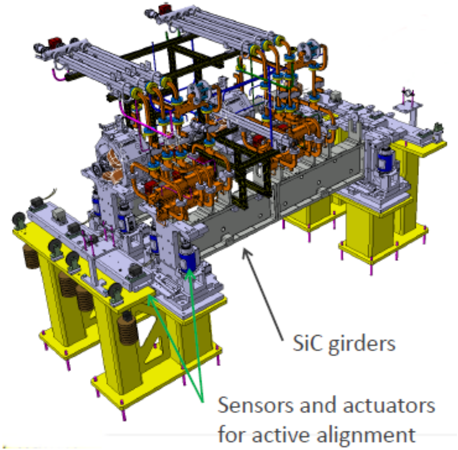
  (averages over 50 shots)
- Probe beam:
  40 bunches
  0.1 nC per bunch
- **TM vertical has negligible DB noise**! TM horizontal sees some, but less than the TE-like mode.

- CLIC Wakefield Monitors have been tested in the two-beam module in Califes.
- Antennas in four damping waveguides measure one TE-like and one TM-like dipole mode for finding the transverse beam position.
- Resolutions satisfying the CLIC target have been measured (**lowest 1.67 μm** for 0.1 nC bunch charge), but
  - This was only measured without drive beam.
  - The resolution seems to get worse outside the center of the structure, but a beam position range of around ±0.4 mm could still be reasonable for the most precise positioning
  - The vertical plane has slightly worse measurements, with the best estimate at 6.06 μm.
  - The better results in the center could be due to an additive **monopole component**
  - The accuracy should be measured in addition to the resolution!
- **Complete suppression of drive beam noise observed for two channels**, however
  - The noise is still unacceptably high and detrimental for precise WFM measurements for the TE-like mode
  - The noise is non-existant for the TM-like mode in the vertical plane
  - The noise situation is not clear for the TM-like mode in the horizontal plane (quite low at the end of the year for one channel)
- The work will continue in CLEAR!
  - Improved experimental setup (phase shifters, new log detectors, 0° hybrids, high precision BPMs nearby etc.)

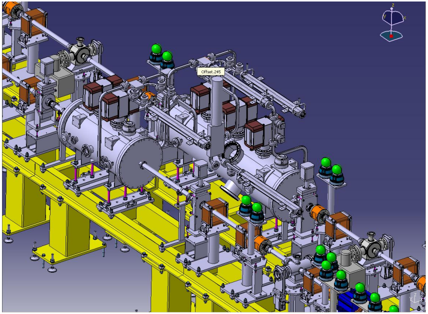
Thank you for your attention!

Extra slides

Mechanical Models of the TBM and the TBTS



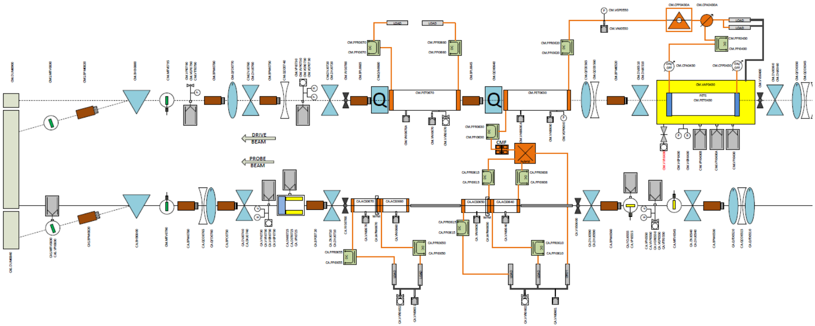
TBM



TBTS

TBM lattice

CLIC TBM INTEGRATION IN CLEX. COMPONENTS



Calibration December (slide 16)

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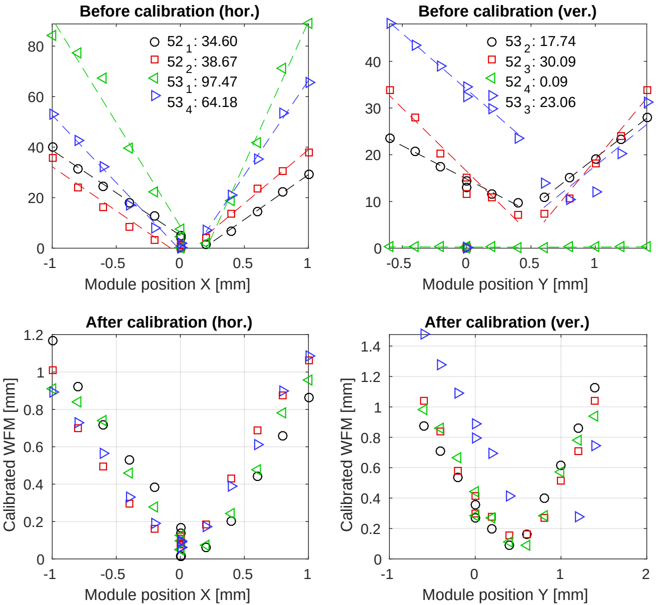
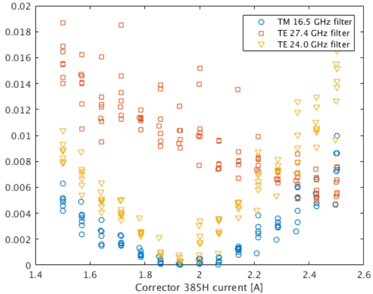


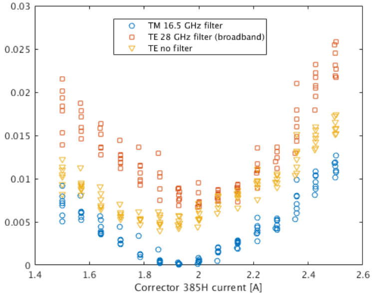
40 bunches/shot
0.055 nC/bunch

Comparison of filters

- Bandpass filters with different pass bands have been tested for the two modes.
- A simultaneous scan using different filters for the same plane and the same structure shows that the 27.4 GHz filters may not be optimal for the TE-like mode.
- The 24.0 GHz filters used in the TBTS have the best performance of the TE filters.
- The 27.4 GHz filters seem worse than not using filters at all.



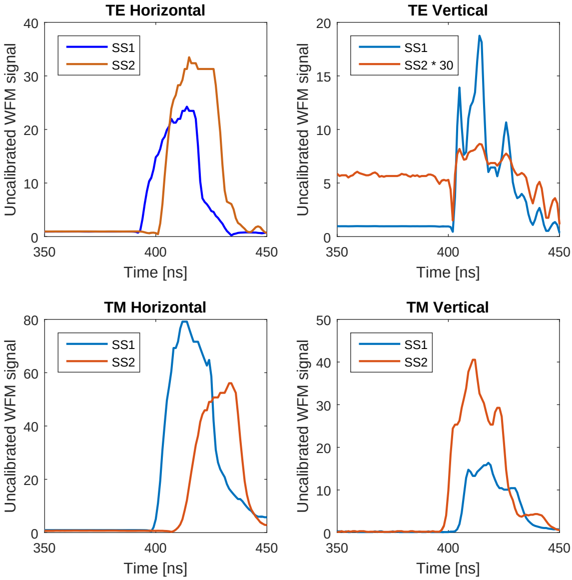
1 A ⇒ 2.6 mm in SS1



1 A ⇒ 2.6 mm in SS1

30 bunches, 0.1 nC per bunch

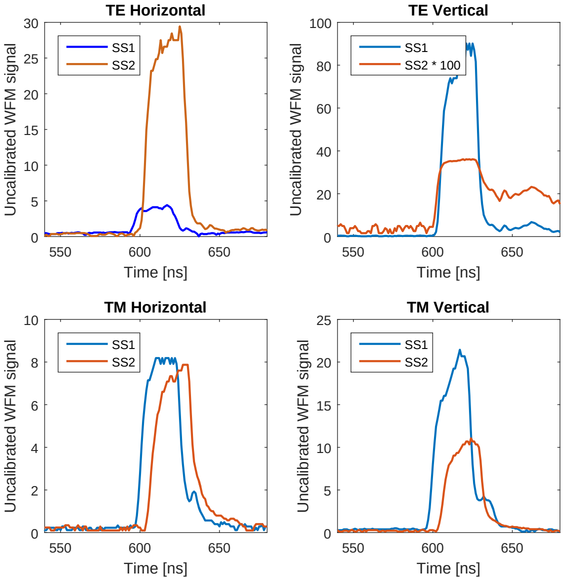
November data set (slide 13): Pulse shapes



Some variation in pulse shapes, but most resemble square pulses.

Strange shape seen here for TE Vertical in SS2, but not an issue in the most recent datasets.

40 bunches,
0.1 nC per bunch



Another set of measurements from a different run, with around half the bunch charge of the other dataset.

- Fairly square shaped pulses here!

40 bunches,
0.055 nC per bunch

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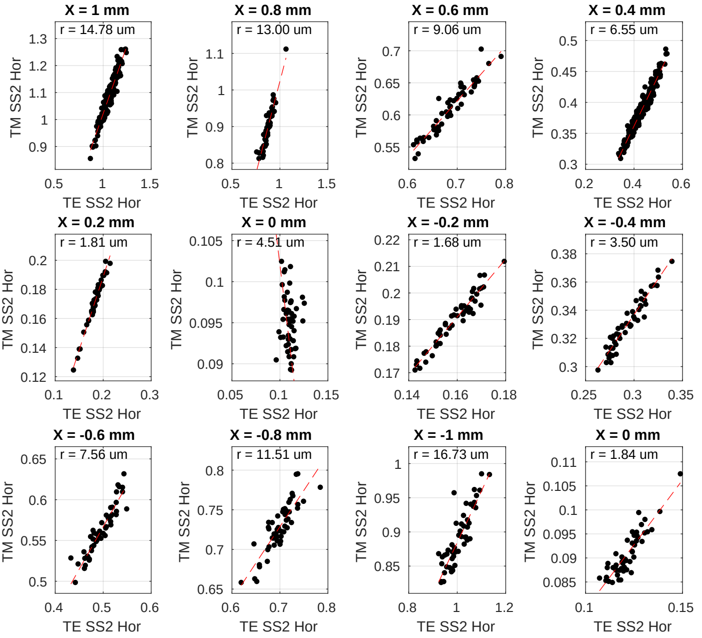
Correlation between the modes for various positions

- 1 structure
- 1 plane

SS2 Horizontal

40 bunches,
0.1 nC per bunch

(Note: Axes correspond to the plane of beam offset, not the location of pickups)



Scatter plots, same data set (slide 13): SS1 Vertical

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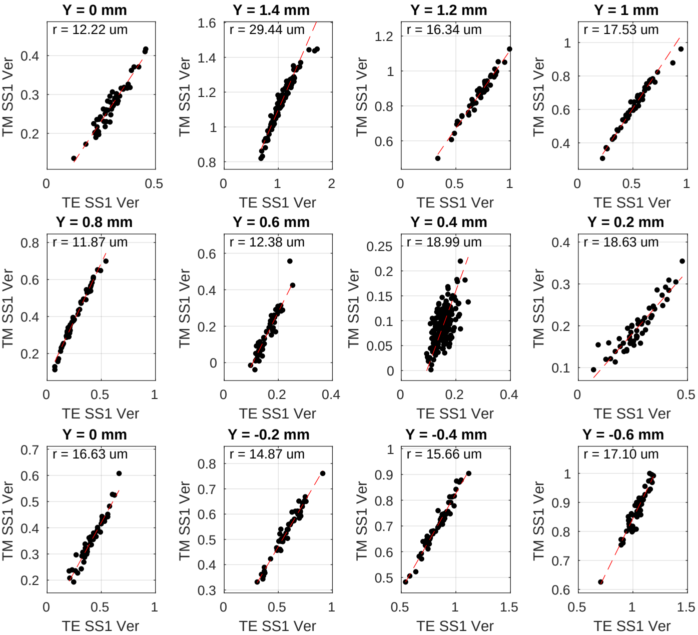
Correlation between the modes for various positions

- 1 structure
- 1 plane

SS1 Vertical

40 bunches,
0.1 nC per bunch

(Note: Axes correspond to the plane of beam offset, not the location of pickups)



Scatter plots, same data set (slide 13): SS2 Vertical

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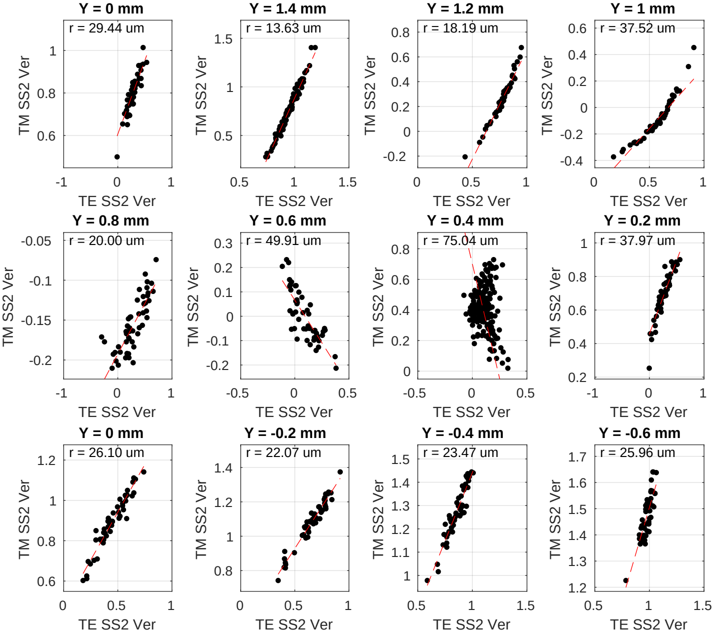
Correlation between the modes for various positions

- 1 structure
- 1 plane

SS2 Vertical

40 bunches,
0.1 nC per bunch

(Note: Axes correspond to the plane of beam offset, not the location of pickups)



Scatter plots December (slide 16): SS1 Horizontal

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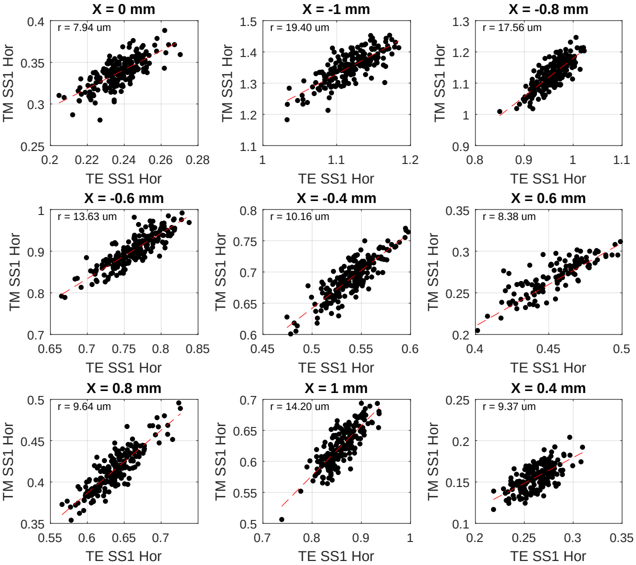
SS1 Horizontal

40 bunches,
0.055 nC/bunch



(Note: Axes correspond to the plane of beam offset, not the location of pickups)

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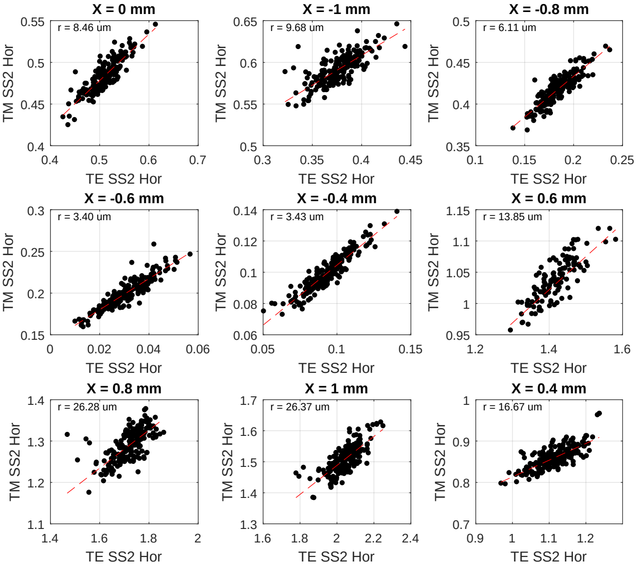
SS2 Horizontal

40 bunches,
0.055 nC/bunch

(Note: Axes correspond to the plane of beam offset, not the location of pickups)



Scatter plots December (slide 16): SS1 Vertical

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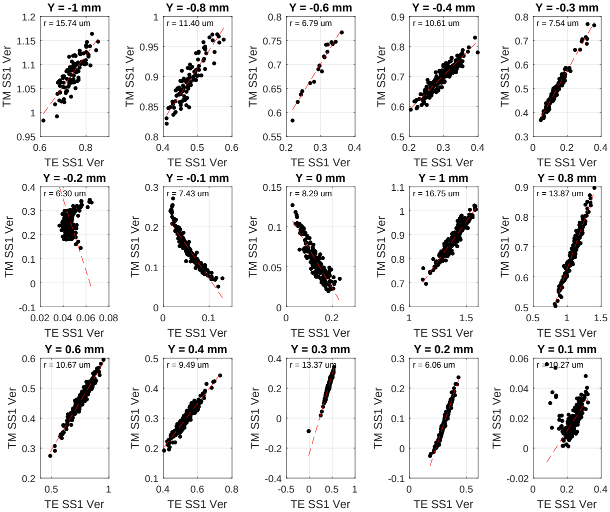
SS1 Vertical

40 bunches,
0.055 nC/bunch



(Note: Axes correspond to the plane of beam offset, not the location of pickups)

Scatter plots December (slide 16): SS2 Vertical

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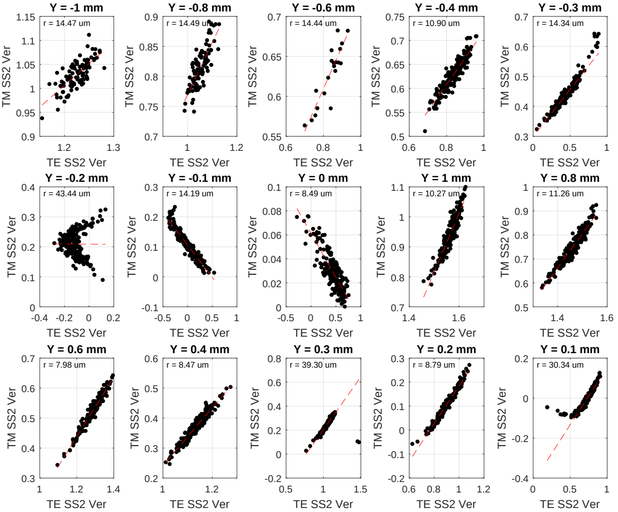
SS2 Vertical

40 bunches,
0.055 nC/bunch

(Note: Axes correspond to the plane of beam offset, not the location of pickups)



Scatter plots December (slide 16): Everything together

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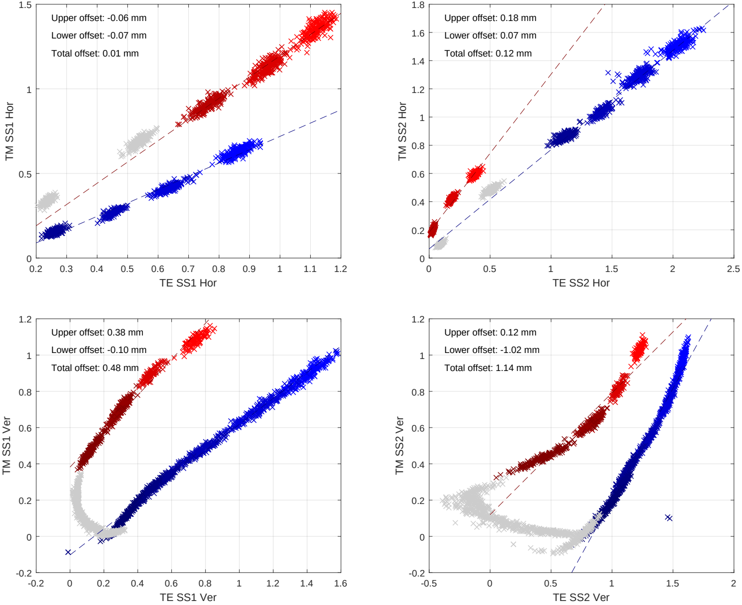

There is not a strictly linear relation between the modes, so they may not have the same center.

Why?

40 bunches, 0.055 nC per bunch