Mitigation for a shorted cavity probe at EuXFEL

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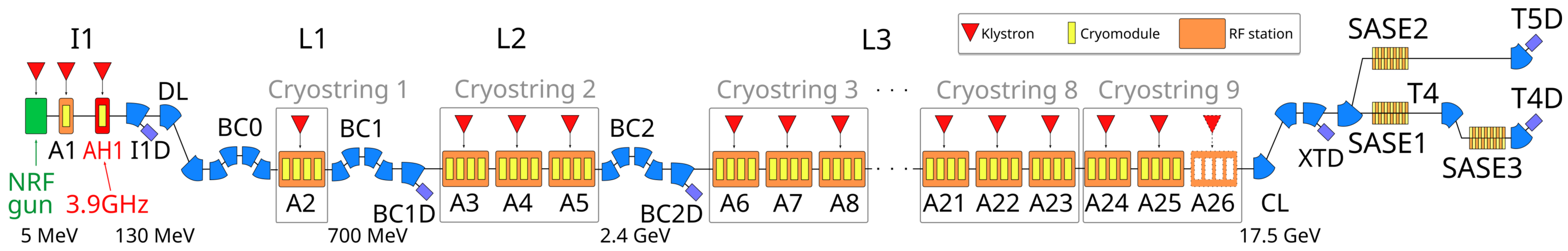
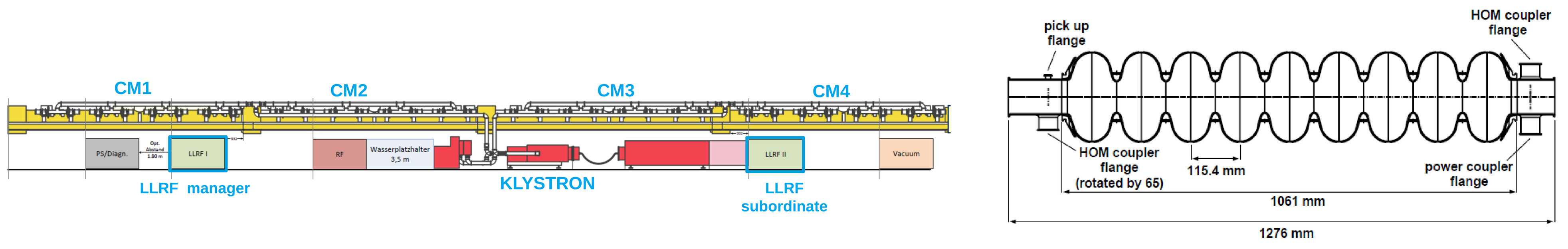
Abstract

Since the commissioning of the European hard X-ray Free-Electron Laser (EuXFEL), one of the 784 superconducting cavities of the linac has a short circuit at the probe connector. For this reason, its signal cannot be used for field regulation. Instead, the signal coming from a high order mode (HOM) coupler antenna is included in the vector sum regulation. This cavity shows a direct impact on the beam arrival time profile along the bunch train. In this work, limitations and operational solutions are described.

EuXFEL

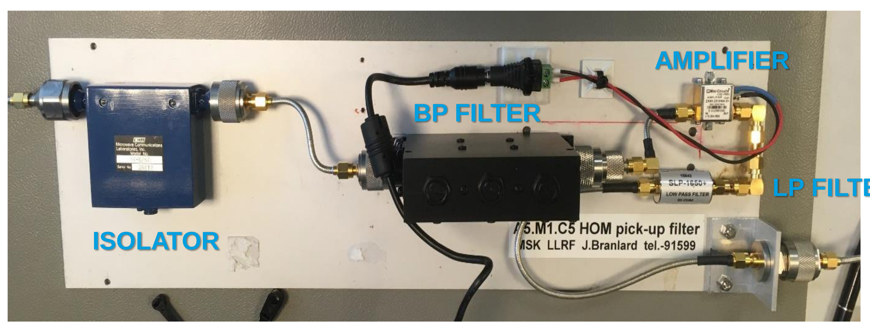
- Hard X-ray free-electron laser for user experiments [1]
- 776 superconducting 1.3 GHz TESLA RF cavities [2] + 8 3.9 GHz SRF cavities [3]
- 3 bunch compression stages (BC0, BC1, BC2) + 10 beam arrival monitors (BAMs)
- Beam arrival time jitter <10 fs adopting LLRF beam based feedback at station A5 (last one upstream BC2), measured at the end of the linac [4]
- The cavity with faulty probe connector is also located at A5 (C1.M1.A5)
- This cavity needs to be included in the vector sum for field control of the RF station [5]
- Spread of ~300 fs generally along the bunch train arrival time
- This might cause the beam based feedback to become unstable (limiters hit and pulse cuts)
- Pre-compensation with amplitude slopes is usually necessary





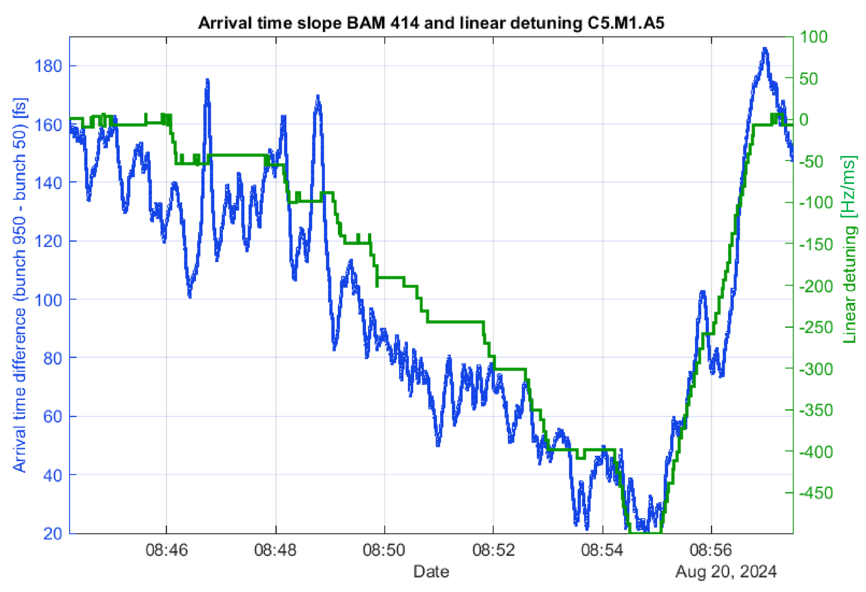
Signal from the HOM coupler

- It is less stable and more damped in comparison with the probe
- it needs to be treated in a special way
- An isolator + band-pass filter + amplifier chain was installed between the cryo-module patch panel and the MTCA downconverter
- Detuning and loaded quality factor computations are affected
- The shape during flat top depends on the bunch train length



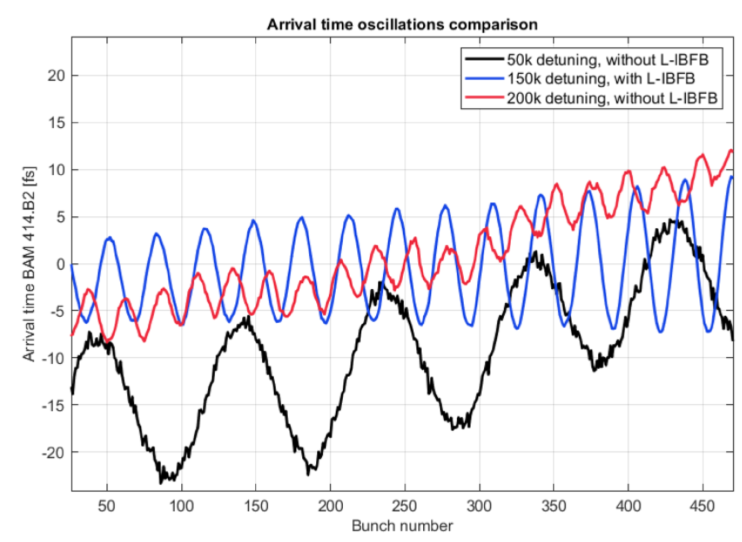
Linear detuning tests

- Detuning the cavity to quantify its impact on the arrival time



Static detuning tests

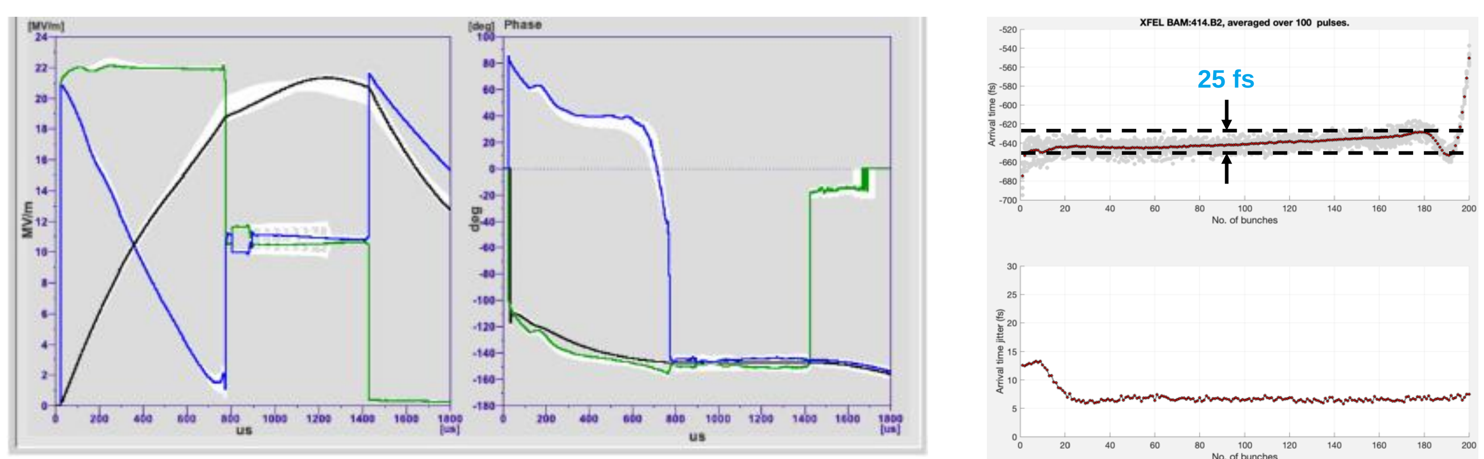
- Oscillations still visible in the arrival time with max motor steps
- Detuning the cavity to its parking position is not satisfactory



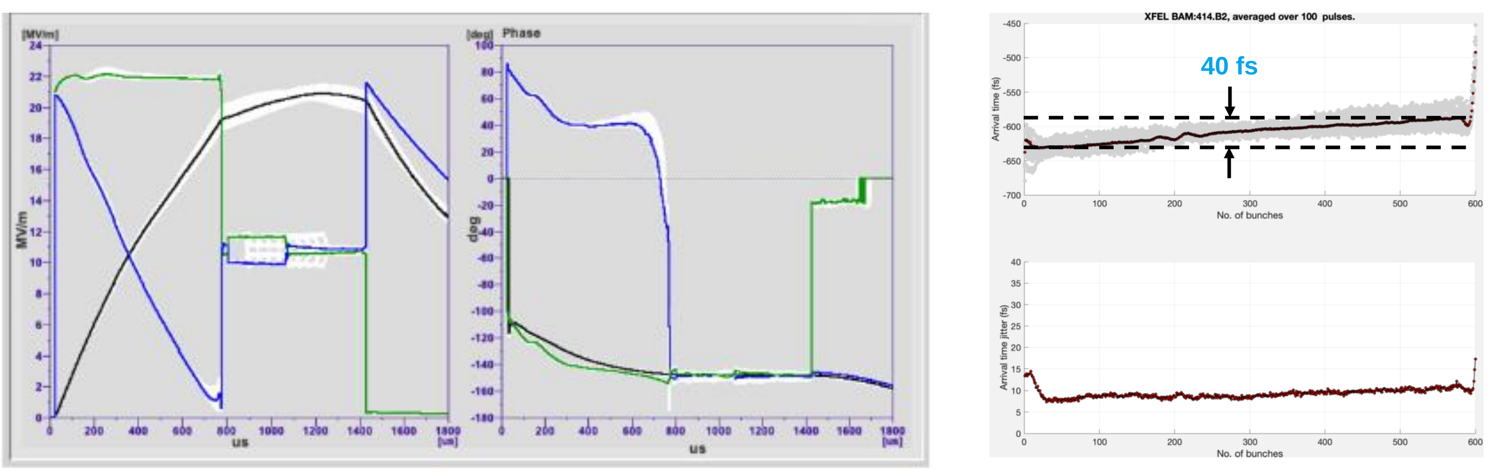
Calibration and beam arrival time measurements

- Calibration performed with beam-transient techniques [6] [7]
- Ql tuning performed minimizing the reflected power at the end of the filling time
- Final tuning of the amplitude calibration coefficient minimizing the impact of the probe amplitude shape on the bunch train arrival time flatness with feedback acting at A2

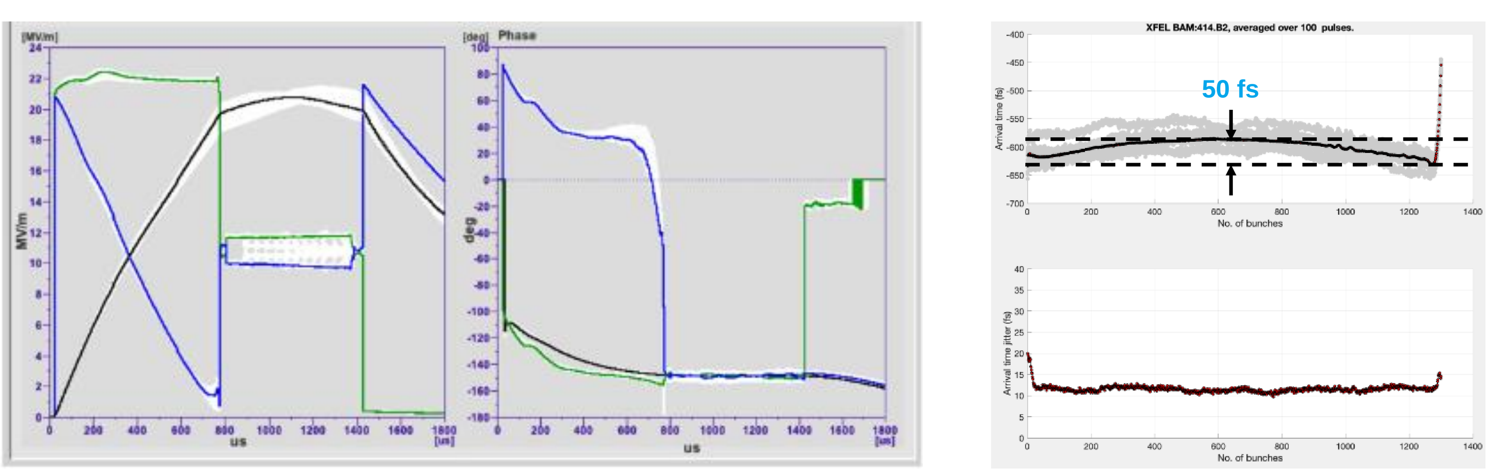
200 bunches



600 bunches



1300 bunches



Summary and outlook

- A spread of ~300 fs is generally visible along the bunch train arrival time
- A superconducting cavity has short-circuited probe at cryogenic temperatures (C5.M1.A5)
- The HOM coupler signal is instead used for field regulation
- Dedicated electronics for signal treatment has been developed
- Detuning tests confirmed that C5.M1.A5 is the root cause of the arrival time spread
- Detuning of the cavity with max motor steps still leaves some oscillations in the arrival time
- Calibrated the cavity with beam-transient techniques
- Amplitude shape that is dependent on the bunch train length
- The max spread in arrival time is minimized from 300 fs to 50 fs
- It corresponds to a max amplitude deviation of 1.4 MV ($\Delta E = \Delta t \cdot c \cdot E/R_{56}$, $R_{56} = -30\ mm$)
- The beam based feedback can deal with it and no amplitude slopes are needed to pre-compensate

- In the future, we can explore the possibility of field regulation via virtual probe [8] [9]
  - Firmware implementation is needed
- Another option is to completely detune the cavity and terminate the waveguide
  - The energy loss would be ~25 MV

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