Overview
Multi Bunch Beam Dynamics at XFEL

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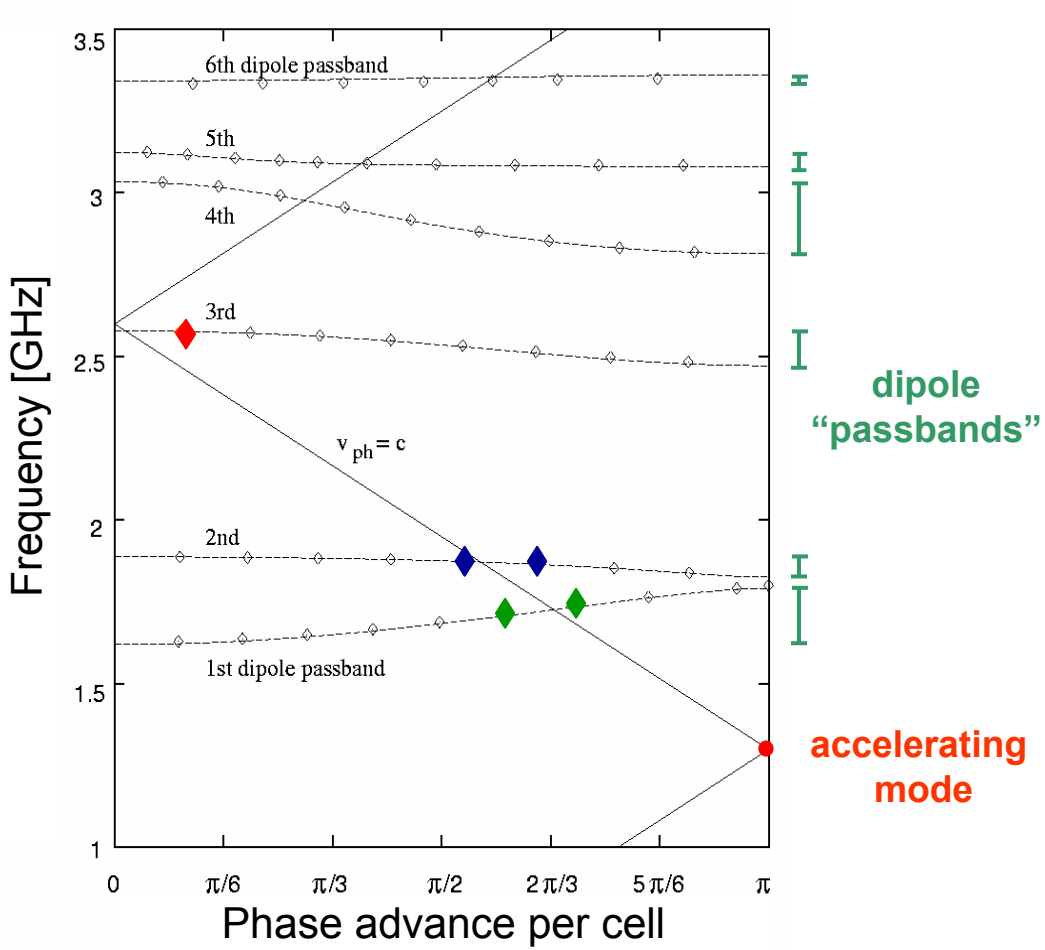
What has been done on Studies of MB Dynamics at XFEL?

- Most dangerous modes found
- Damping by HOM Couplers foreseen
- Multi Bunch Beam Dynamics Simulations with Mafia-L

Problematic Modes

Dipole passbands

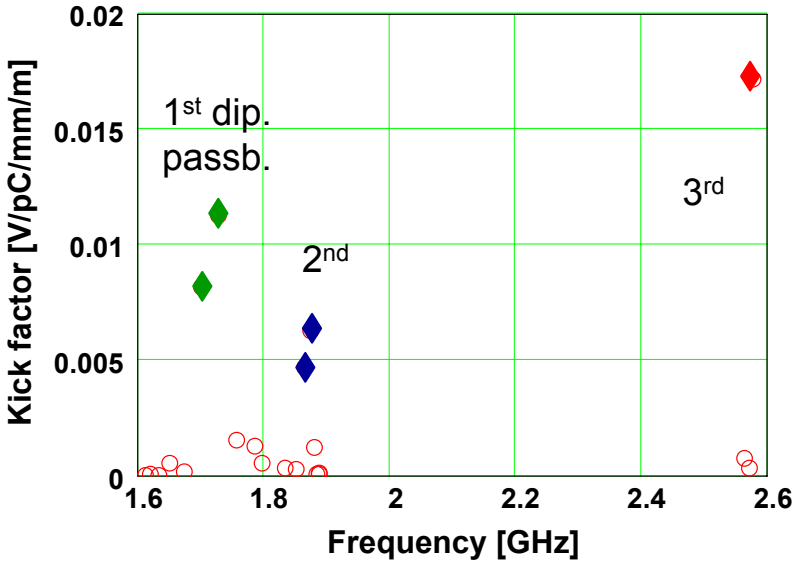


dipole "passbands"

accelerating mode

- Trapped in the cavity
- Ring for a long time
- Have a high kick factor

Five modes with high kick factors below the cut off frequency found

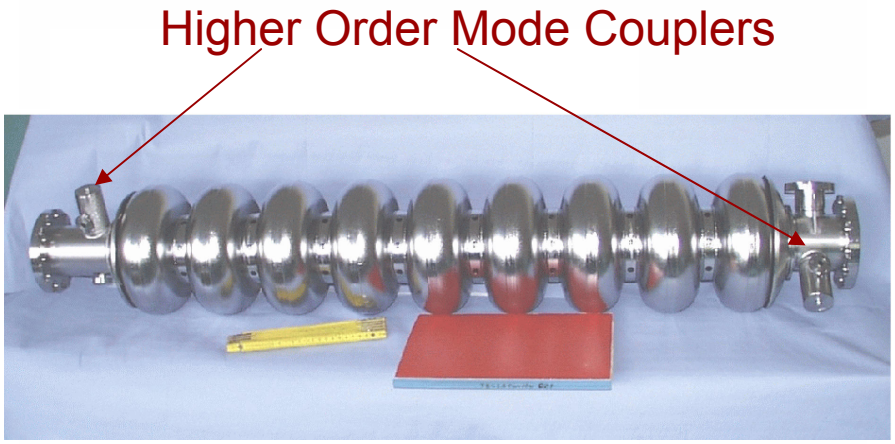


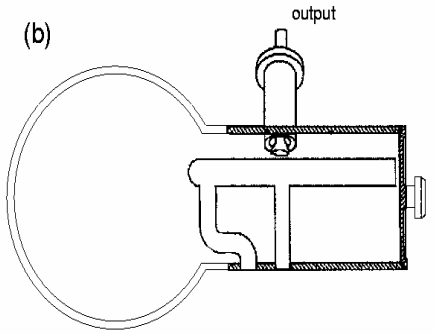
Damping

- The TESLA cavities have superconducting walls
- the resonant modes ring in the cavity for a long time
- the energy stored in each mode is absorbed very slowly in the walls; the amplitude of each resonant field decays in time like

$$\exp\left(-\frac{1}{\tau_n}\frac{\zeta}{c}\right) = \exp\left(-\frac{\omega_n}{2Q_n}\frac{\zeta}{c}\right)$$

  - quality factor $Q \sim 10^9$
  - damping time $\tau = 2Q/\omega \sim 0.1\text{s}$





The Q of these modes is reduced from 10^9 to below 10^5.

Simulations: Assumptions

- Decouple single bunch effect from multi-bunch effects
- Neglect wakes in the 3.9 GHz cavities
- Consider
  - dipole modes from passbands 1,2, and strongest in passband 3;
  - also 3 strongest monopole modes
- Use MAFIA-L

Accelerating cavities

Detuning among cavities

0.1 % rms

Misalignment:

500 μm rms

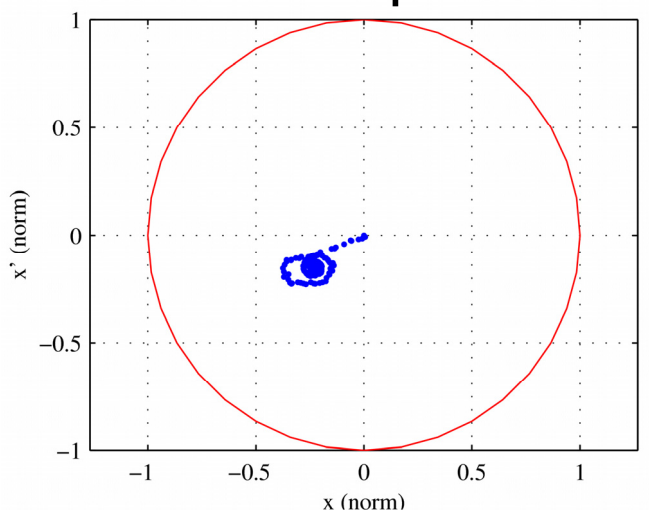
Beam

Inject beam on axis

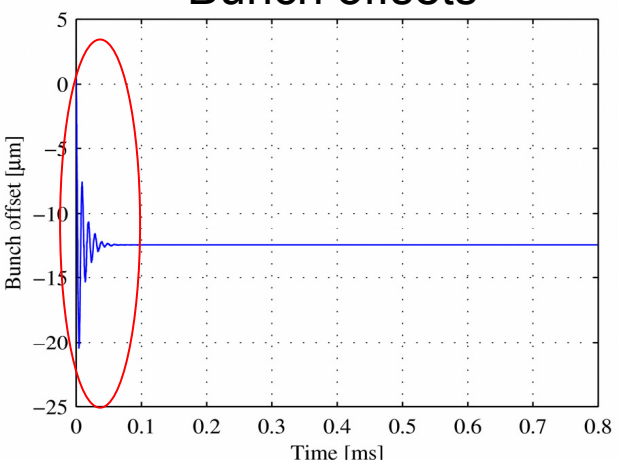
Simulations Results -Transverse

- Reference bunch train
  - Spacing: 200ns
  - Train length: 800 μs
  - Energy: 20 GeV
- emittance averaged over 100 linacs

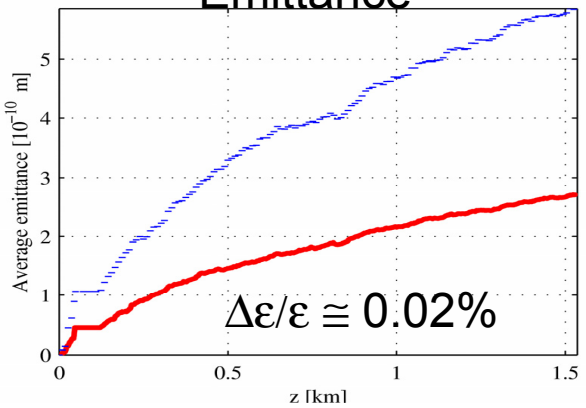
Phase space



Bunch offsets

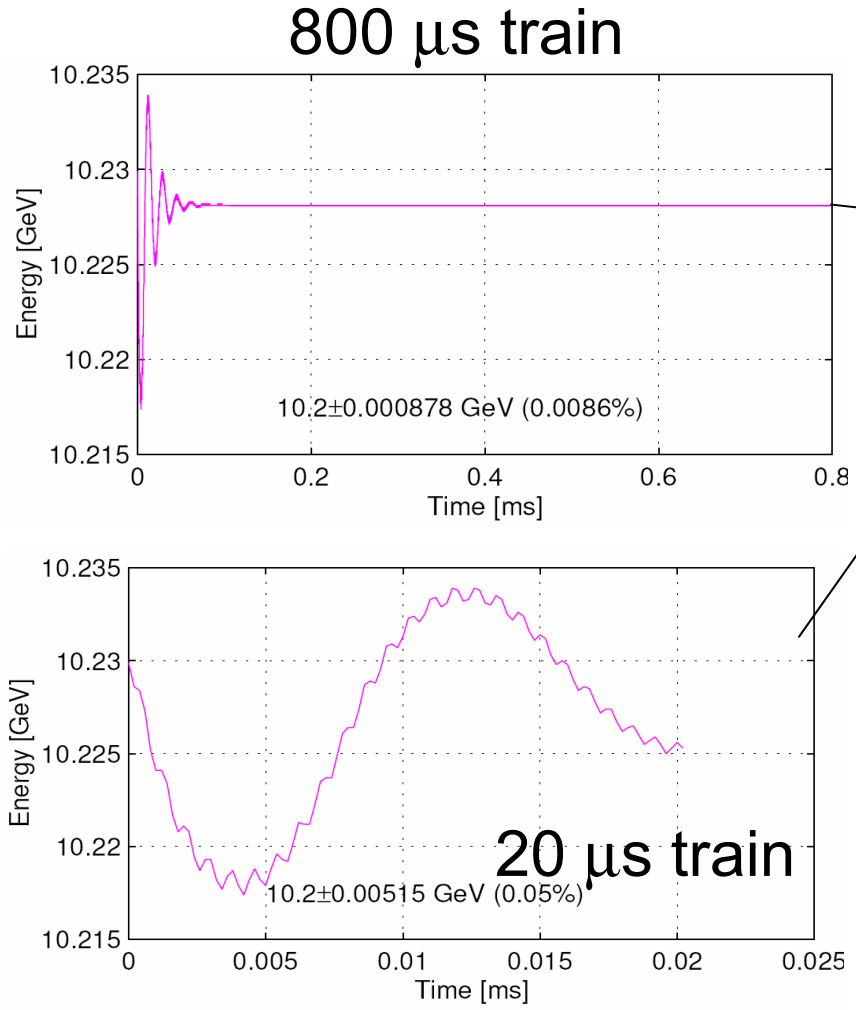


Emittance



- Higher emittance for short bunch trains, low spacing and low energy
- Due to detuning the emittance growth drops from 10^3 % to below 5%

Simulations Results - Longitudinal

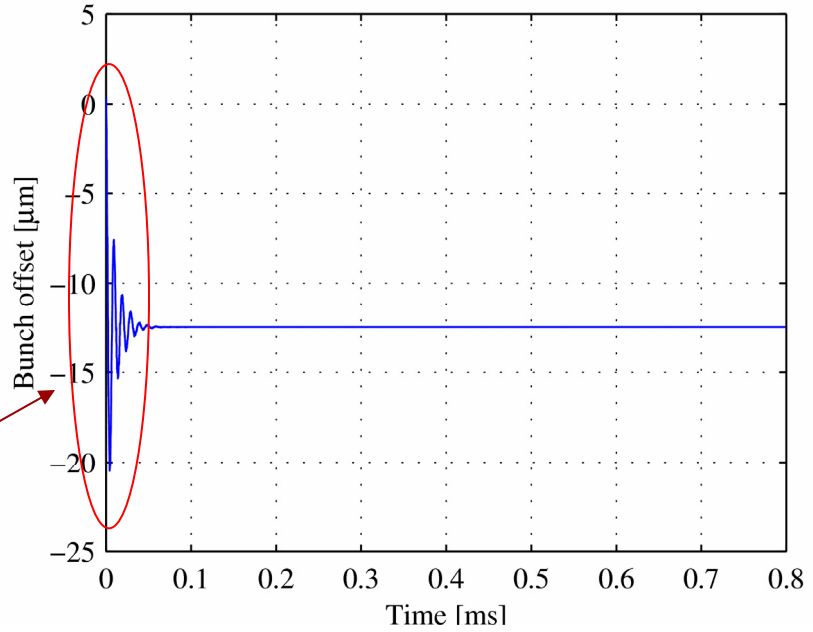


- RMS energy spread
  - 0.88 MeV @ 800 μs length
  - 2.25 MeV @ 120 μs
  - 5.15 MeV @ 20 μs
- Peak-to-peak energy spread
  - 17 MeV @ 200 ns spacing
  - 7 MeV @ 400 μs

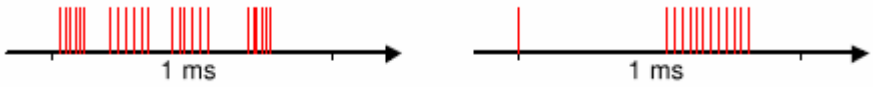
Bunch energy converges at the tail of a train

What could be done to minimize the MB wakefields effects

- For many XFEL applications the beam quality as obtained form these simulations may be good enough
- For best quality
  - Kick away the first part of the beam
  - This will reduce transverse multi-bunch emittance to 0
  - The multi-bunch energy spread will be eliminated as well



- For various beam patterns
  - Form patterns from long tail, as needed; e.g.



- Alternative
  - Correct beam offsets with fast intra-beam feedback
  - This is possible due to the fact that beam pattern is almost identical from bunch to bunch
  - Energy spread may be compensated by the RF system

Summary

- Some modes from the 1^{st} 2^{nd} and 3^{rd} dipole pass bands may affect the multi bunch beam dynamics at XFEL
- Due to HOM Couplers the quality factor of these modes is damped from 10^9 to below 10^5.
- The cavities misalignment may cause the emittance growth. However this growth is expected to be suppressed rather well by the cavity detuning.
- Simulations:

  - higher emittance for short bunch trains, low spacing and low energy
  - bunch energy and offset converges for the tail of the train under natural conditions.
- Problematic head of the bunch train can be either kicked away or corrected by intra beam feedback.
- Still not investigated:

  - the modes from 4 dipole pass band
  - certain bunch patterns.