C^3 main linac beam dynamics

250 GeV beam dynamics

Wei-Hou Tan, Zenghai Li, Emilio Nanni

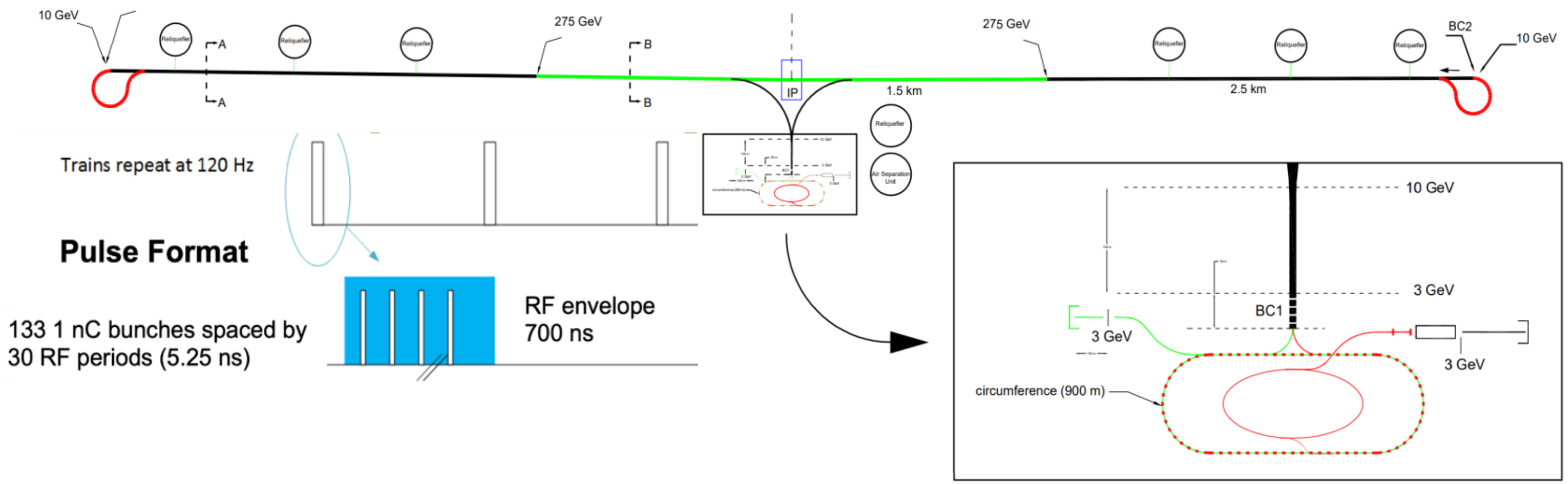
2024-02-13

SLAC NATIONAL ACCELERATOR LABORATORY

Los Alamos NATIONAL LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

The Cool Copper Collider (C^3)

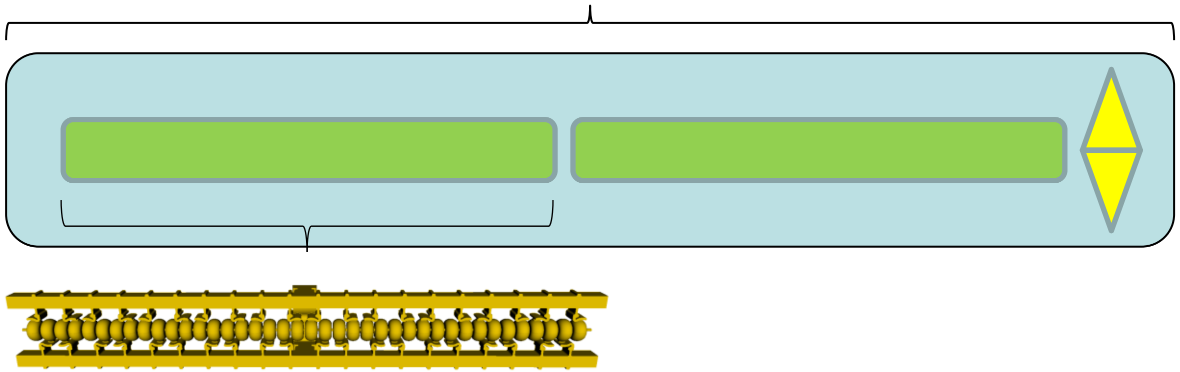


Parameter	Value
Cryocooled temperature	77 K
Length	8 km
Center of mass energy	250 GeV
Number of bunches	133
Charge per bunch	1 nC
Bunch spacing	5.25 ns (30 RF cycles)
Field gradient	70 MV/m

C^3 main linac

- Total length: 2.3-kilometer
- C^3 main linac consists of
  - 253 cryomodules
  - 4 rafts in each cryomodule, 2.3-meter each
  - 2 RF structures in each raft, 1-meter each
  - 1 quad in each raft, 0.15-meter each

2.3-meter raft



40 cells RF structure

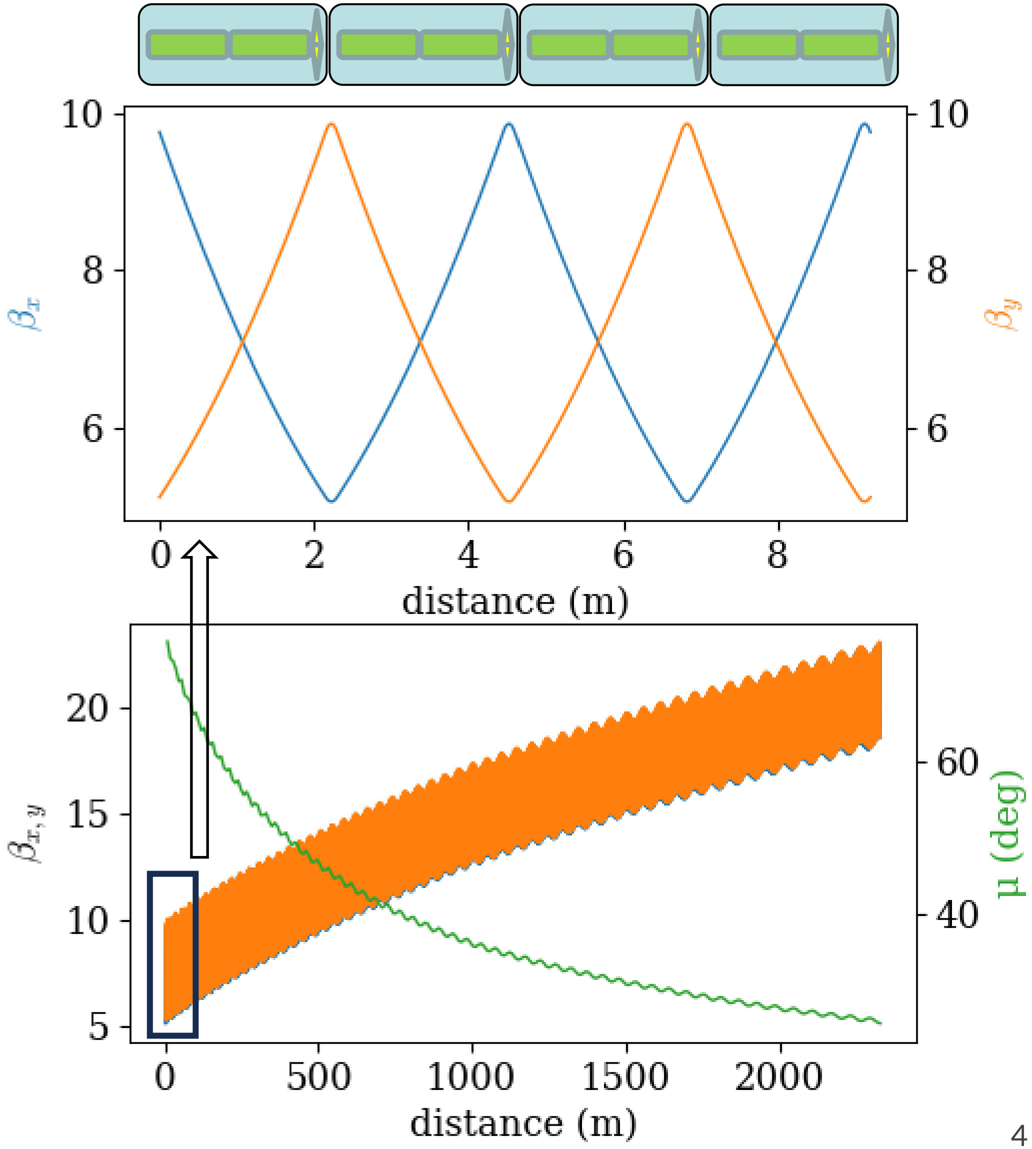
Parameter	Initial value	Target value
Beam energy	10 GeV	125 GeV
Emittance x, y	775, 10 nm	900, 20 nm
Energy spread	1.5%	0.36%
Bunch length	100 µm	100 µm
Charge, # of bunches	1 nC, 133	1 nC, 133
Bunch spacing	5.25 ns (30 RF cycles)	N/A
Field gradient	70 MV/m	N/A
RF frequency	5.712 GHz, C-band	N/A
Quad length	15 cm	N/A

C^3 main linac beam optics

- FODO lattice with logarithmic phase advance

$$\tan\frac{\mu_n}{2} = \tan\frac{\mu_1}{2}\left(\frac{\gamma_1}{\gamma_n}\right)^{0.5}$$

$$K_{1,n}L_n = K_{1,1}L_1\left(\frac{\sin\mu_n/2}{\sin\mu_1/2}\right)$$

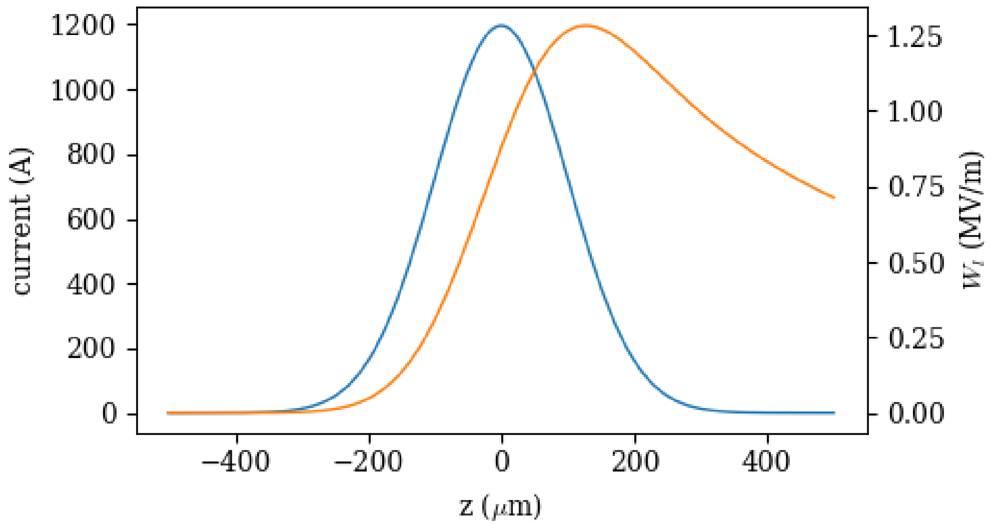


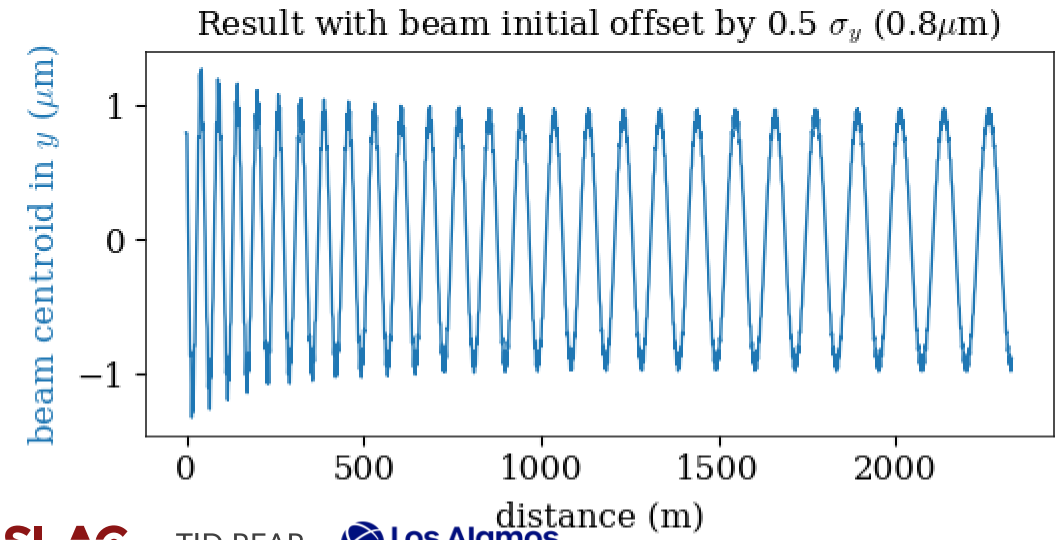
1

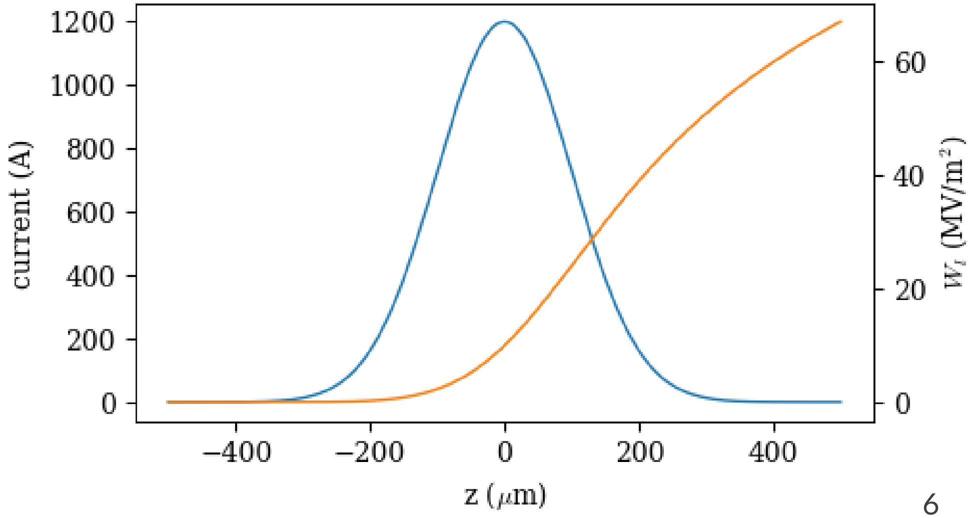
Single bunch beam dynamics

Short range wakefields

- Short range wakefields are included
- Aperture radius is 3.55 mm
- Beam is accelerated off-crest to provide chirp for BNS damping

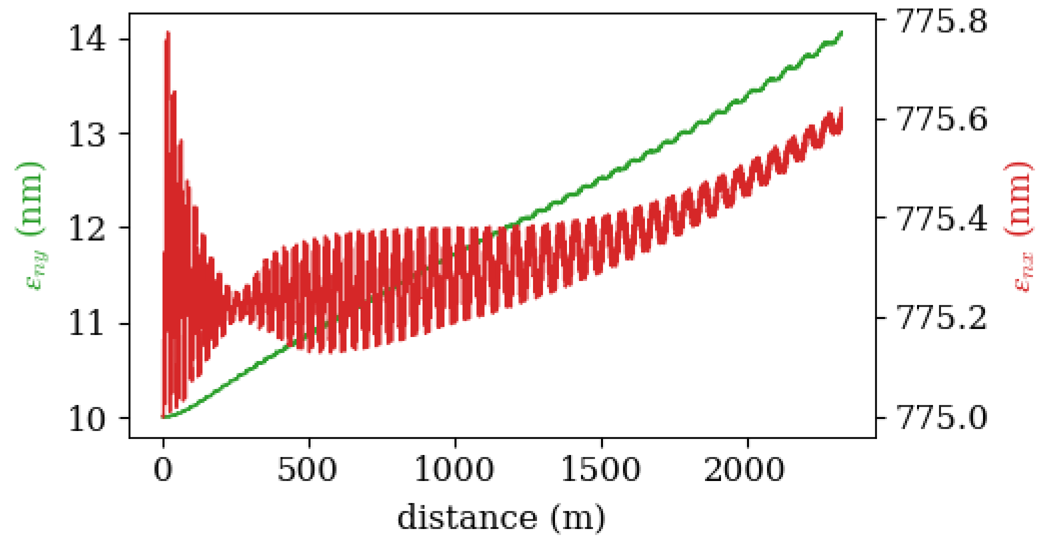


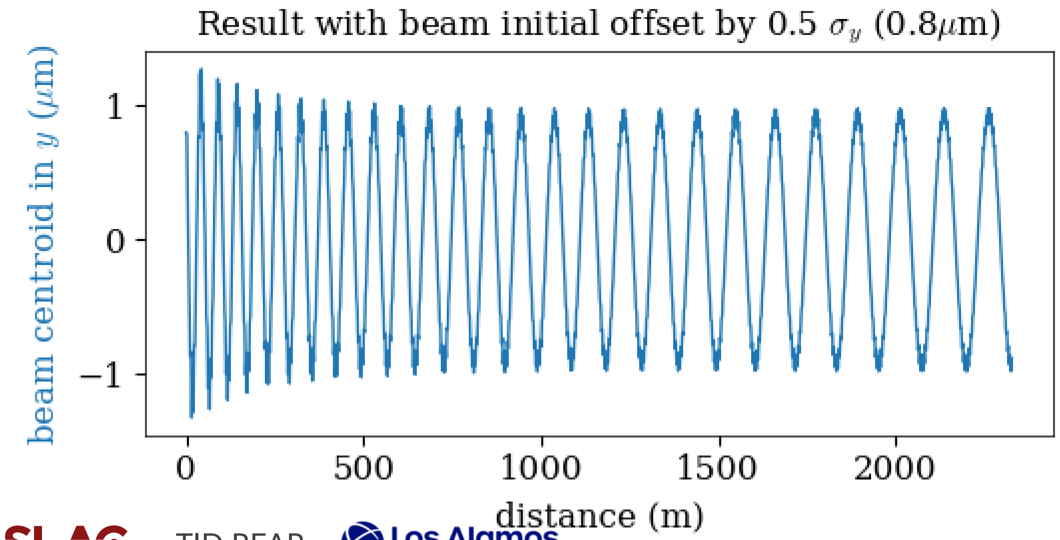


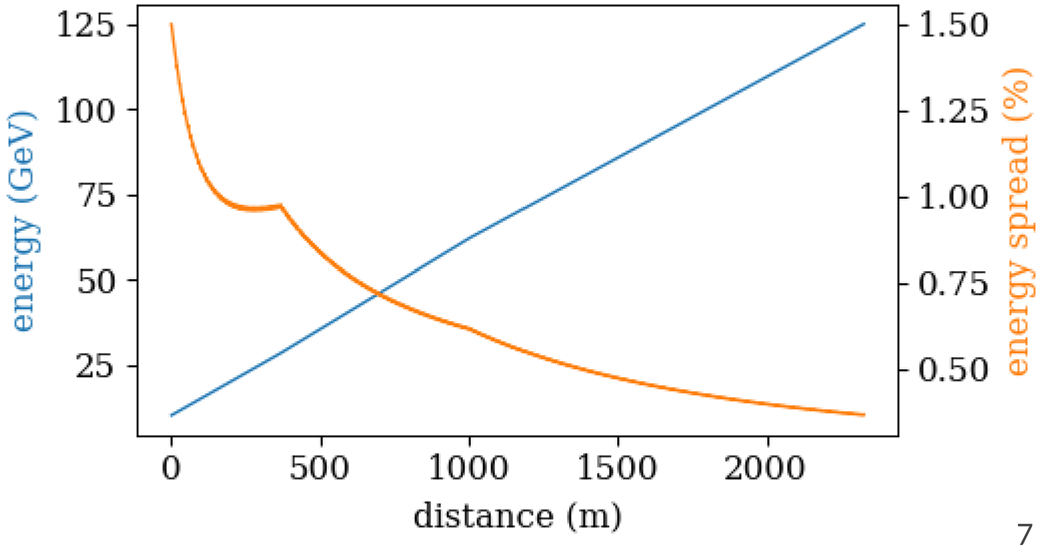


C3 single bunch tracking

- Single bunch tracking example

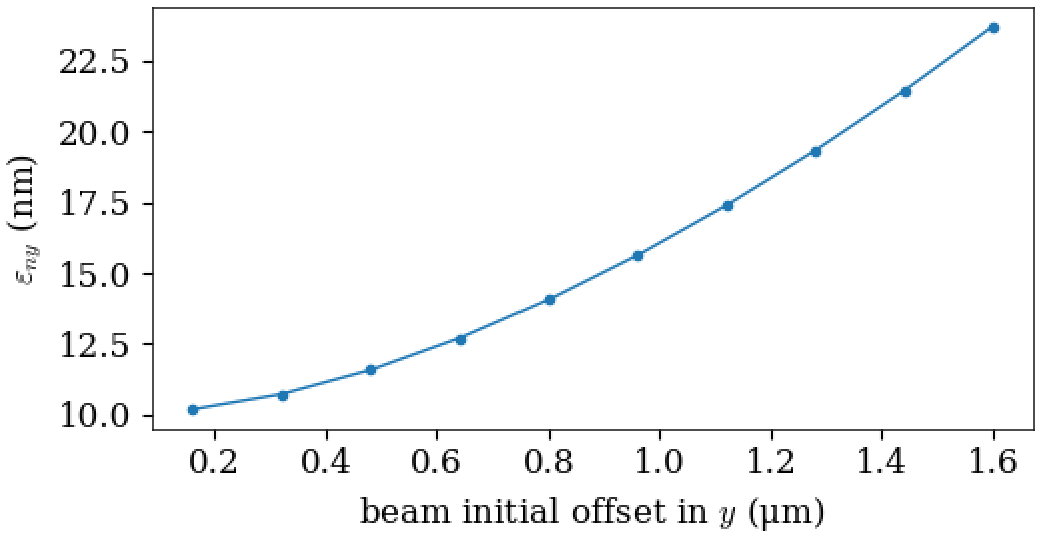






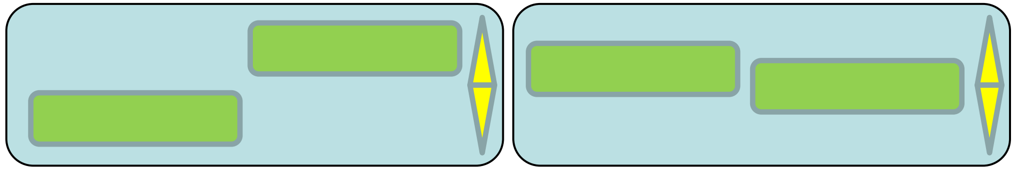
C^3 single bunch tracking

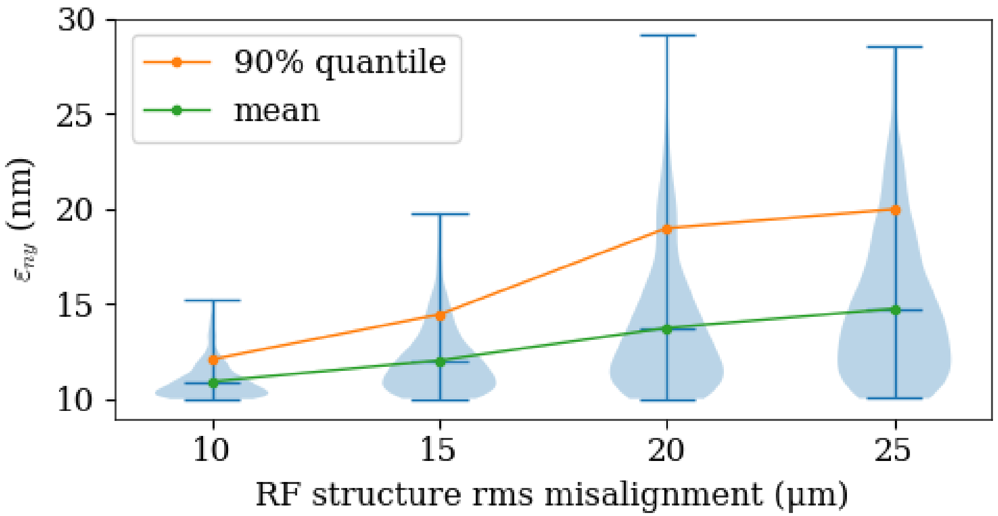
- Beam initial alignment needs to be smaller than 0.4 micron for 10% emittance growth



Vibration tolerance

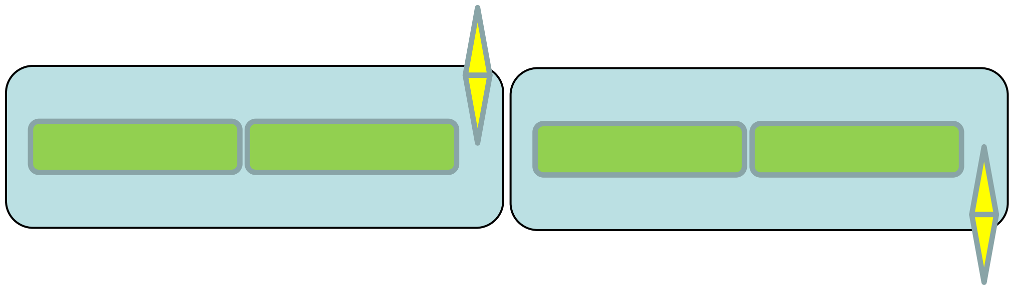
- Vibration tolerance studies were performed using ELEGANT simulations
- Random misalignment of beamline elements were inserted to investigate vibration tolerance
- RF structure vibration tolerance needs 10 μm

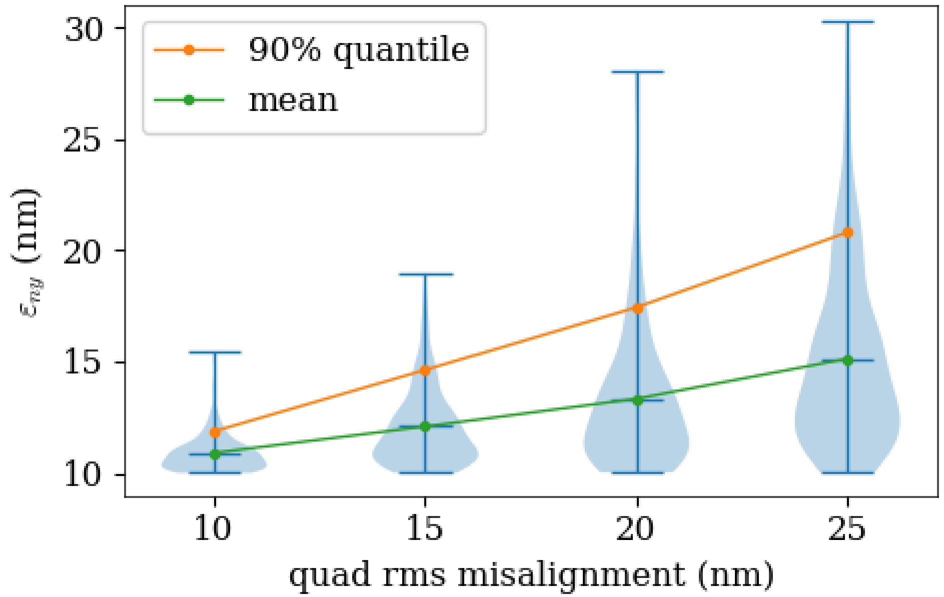




Vibration tolerance

- Vibration tolerance studies were performed using ELEGANT simulations
- Random misalignment of beamline elements were inserted to investigate vibration tolerance
- Quadrupole vibration tolerance needs down to 10 nm



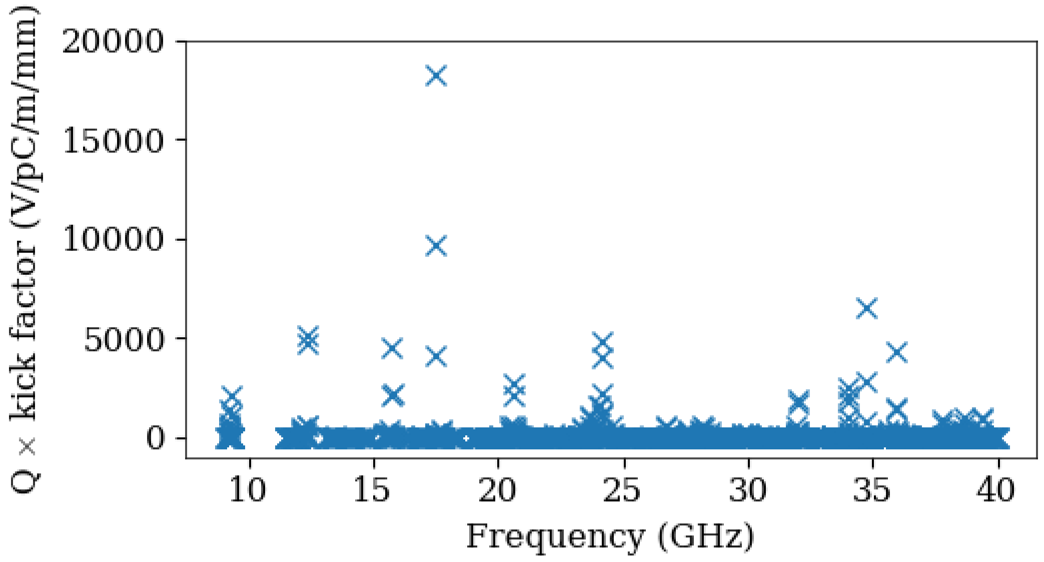


2

Multi bunches beam dynamics

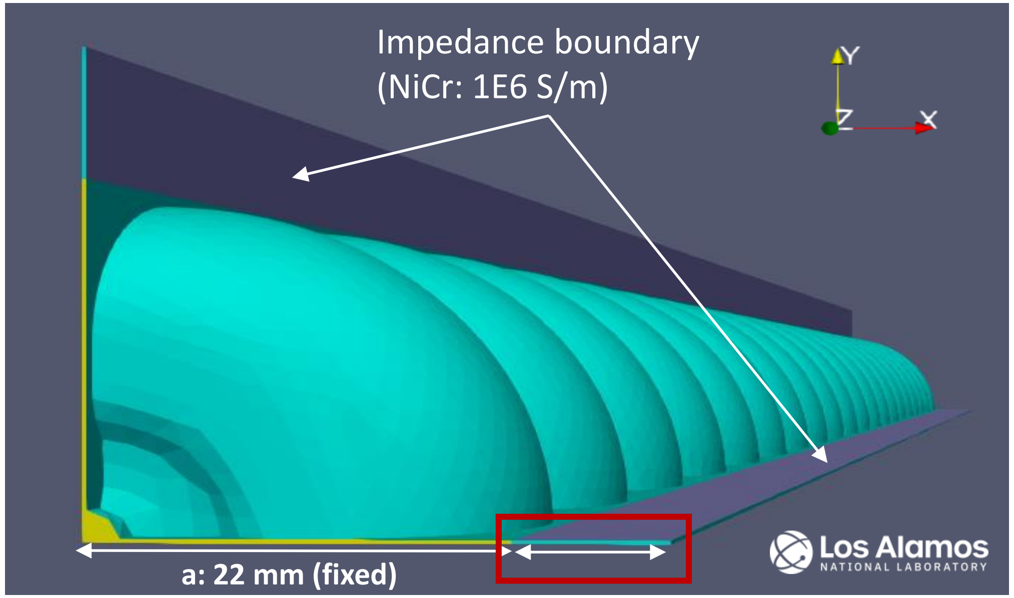
Long-range wakefields

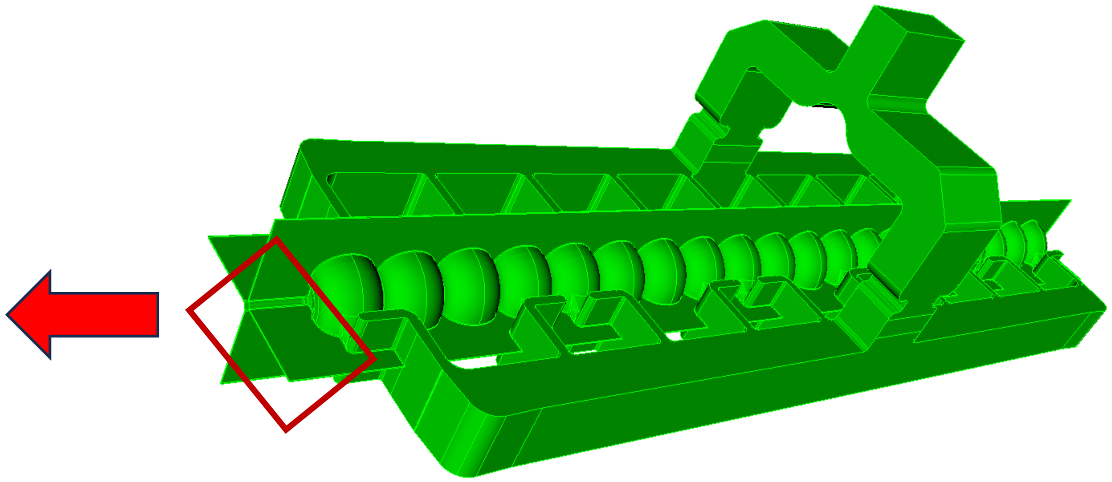
- Long-range higher-order modes (HOMs) wakefields are causing emittance growth along the bunch train
- Notably the transverse wakefields
- The current slot damping result is provided by Dongsoon Kim from LANL



Long-range wakefields damping

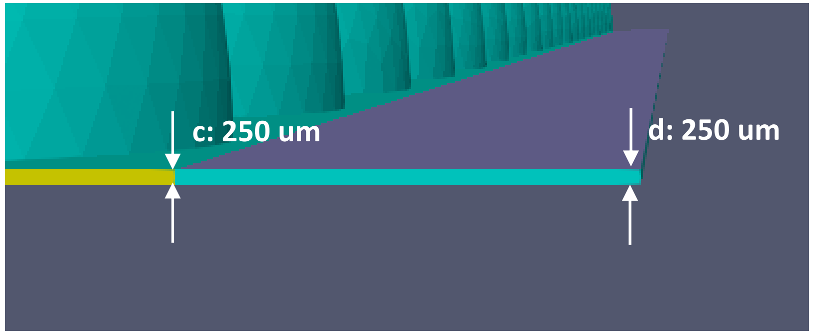
- Waveguide slot with NiCr absorbers is used to provide damping
- Courtesy of Dongsung Kim, Haoran Xu, Evgenya Simakov from LANL

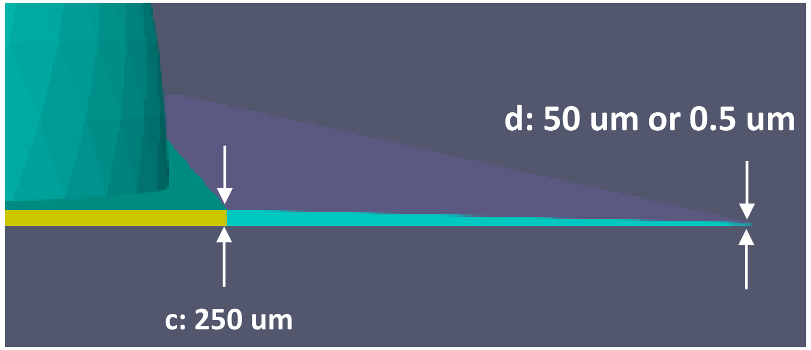


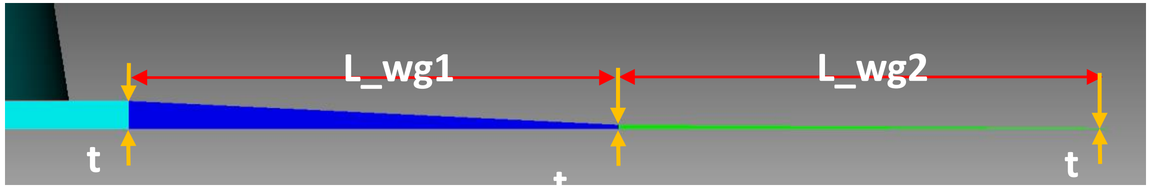


Long-range wakefields damping

- Three designs for damping slot were explored
  1. Single waveguide slot
  2. Single, tapered waveguide slot
  3. Two, tapered waveguide slot



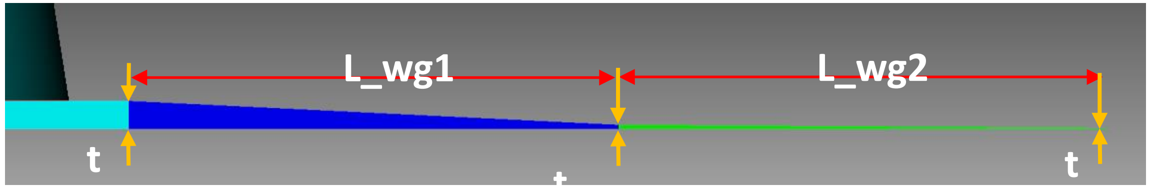




Multi bunches beam dynamics

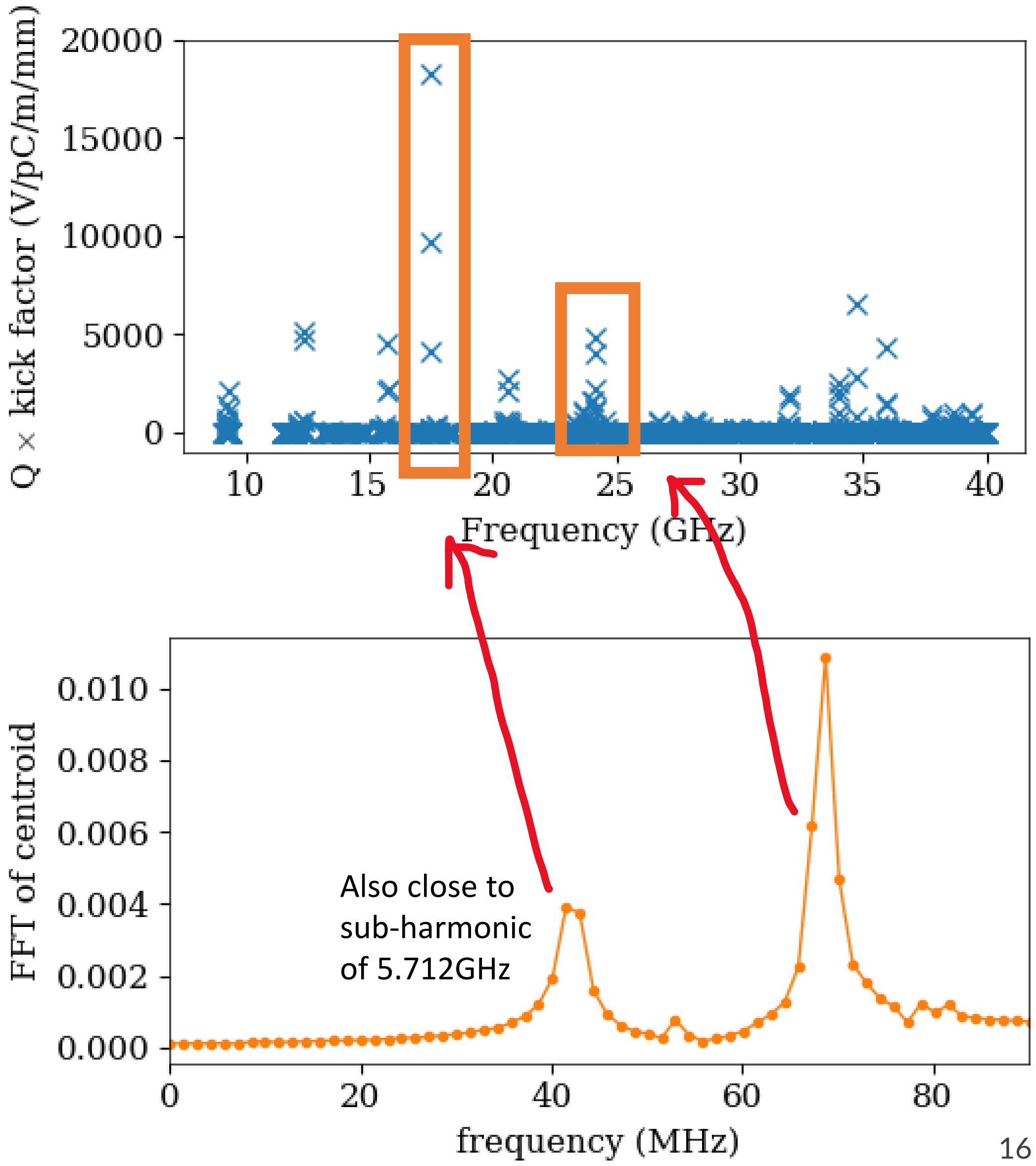
- Two, tapered waveguide slot
- Elegant simulations
- Only long-range transverse wakefields
- Assume perfectly aligned lattice
- Bunches are misaligned randomly with 0.3 µm RMS
- Identify frequency bands that need detuning or further damping
- Estimate the required detuning width

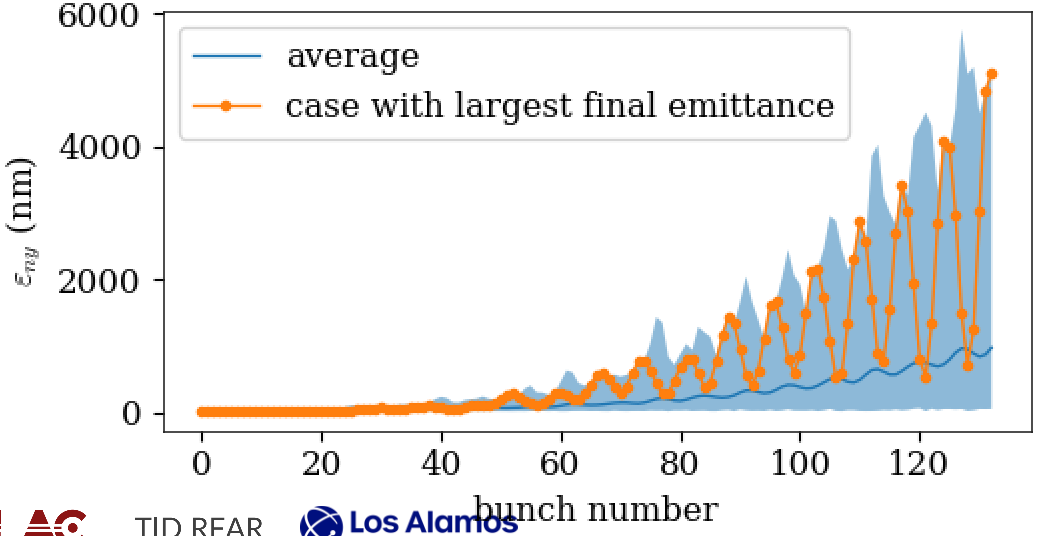
Parameter	Initial value	Target value
Beam energy	10 GeV	125 GeV
Emittance x, y	775, 10 nm	900, 20 nm
Bunch length	100 µm	100 µm
Charge, # of bunches	1 nC, 133	1 nC, 133
Bunch spacing	5.25 ns (30 RF cycles)	N/A



Identify frequency bands that need detuning

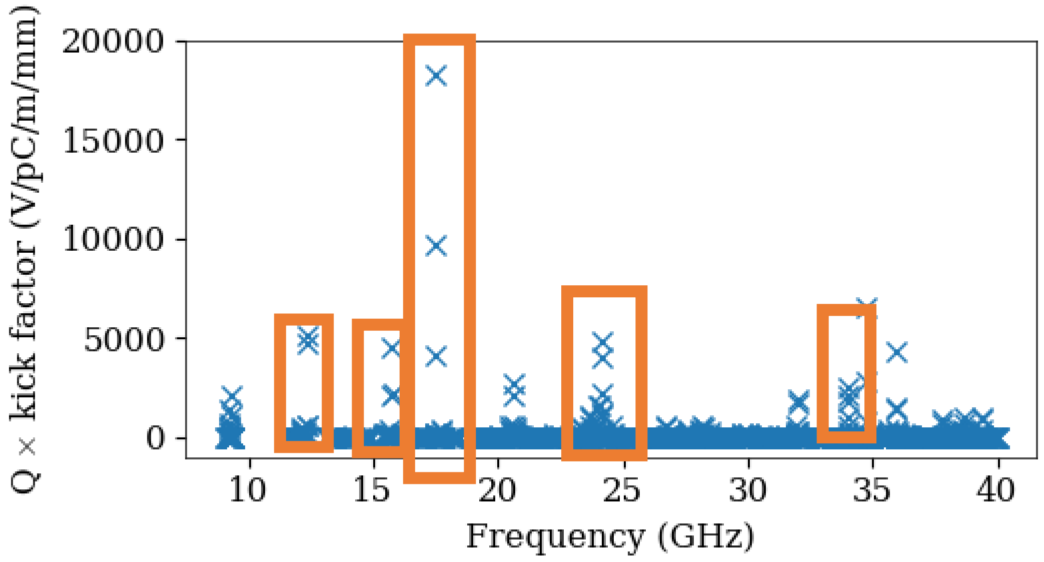
- Emittance growth along the bunch train
- Bunches oscillate at sub-harmonic of 17.4 GHz and 24.1 GHz bands





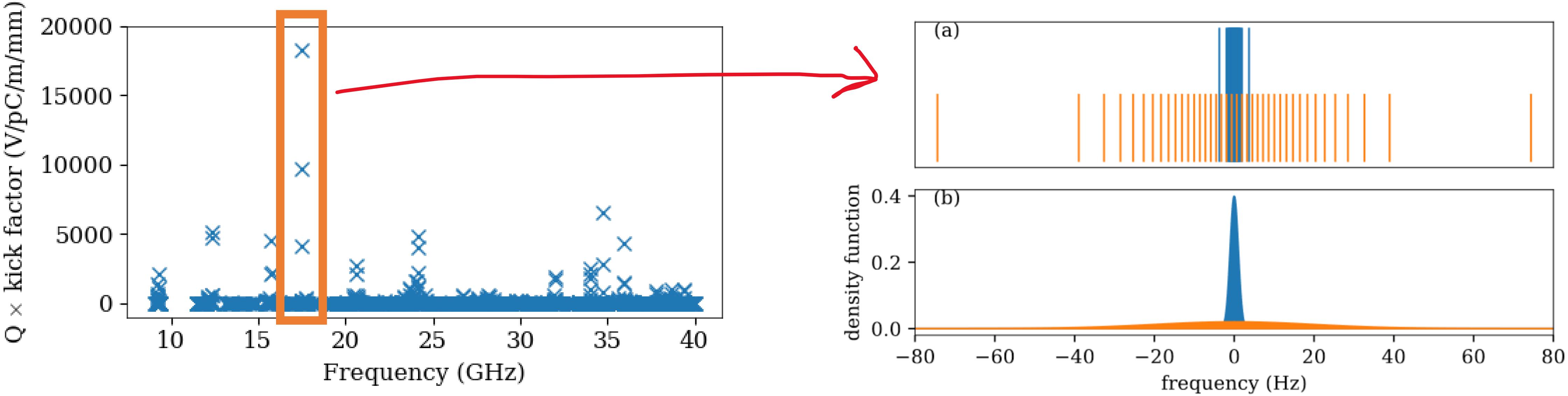
Identify frequency bands that need detuning

- Five frequency bands were identified
- Gaussian detuning were applied to investigate the required frequency width to suppress the emittance growth



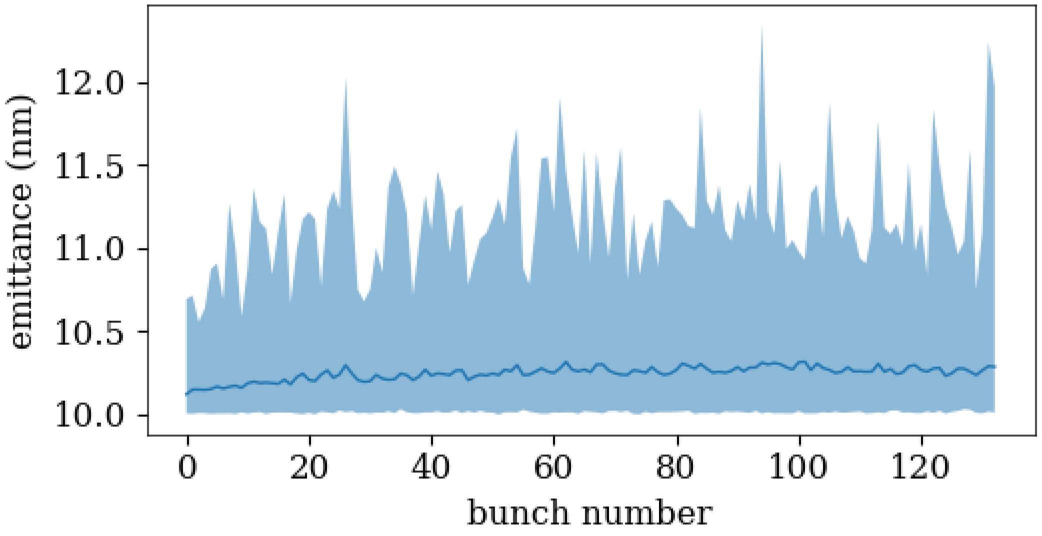
Gaussian detuning

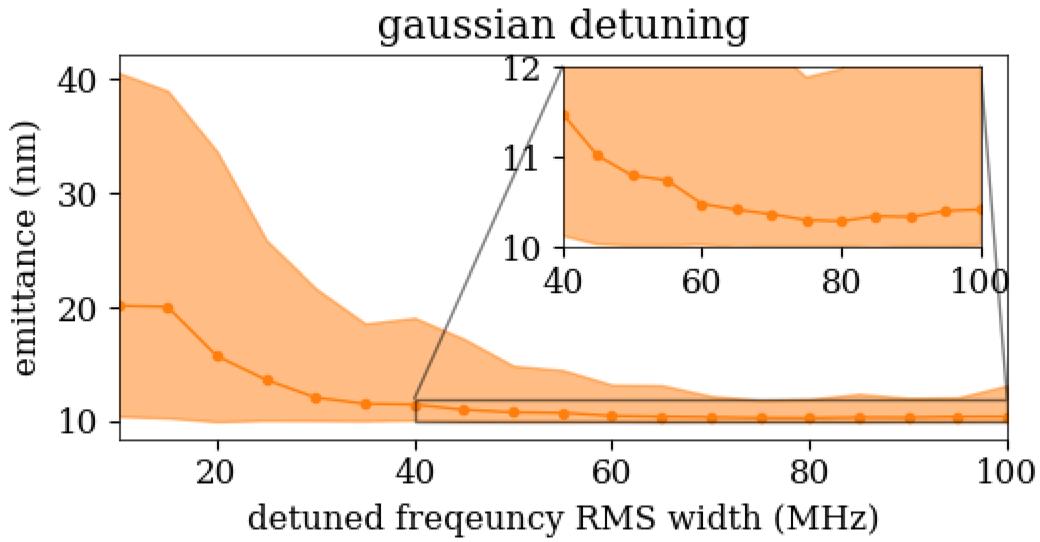
- Gaussian detuning were applied to investigate the required frequency width to suppress the emittance growth



Multi bunches beam dynamics with detuning

- Emittance growth can be suppressed
- 40 to 80 MHz rms frequency width is needed for detuning





Summary

- Single bunch beam dynamics
  - Vibration tolerance for RF structure and Quads are identified
  - Studies on raft vibration will be conducted
- Multi bunches beam dynamics
  - Frequency bands that are detrimental to emittance are identified
  - The amount of detuning were estimated using Gaussian detuning
  - Results will be used to refine the design of the RF structure

Acknowledgement

- Some of these works were done by Glen White
- Dongsung Kim, Haoran Xu, Evgenya Simikov from LANL
- Thanks to Michael Borland and Robert Soliday from ANL for the support on Elegant simulations
- Simulations were performed at SLAC S3DF and NERSC facilities