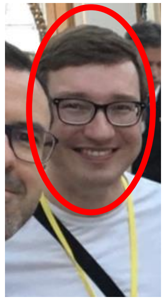
Path towards single RF system for Z, W, ZH

Conditions for using 400 MHz 2-cell for all scenarios, beam dynamics constraints, further studies needed

04-10-2024,

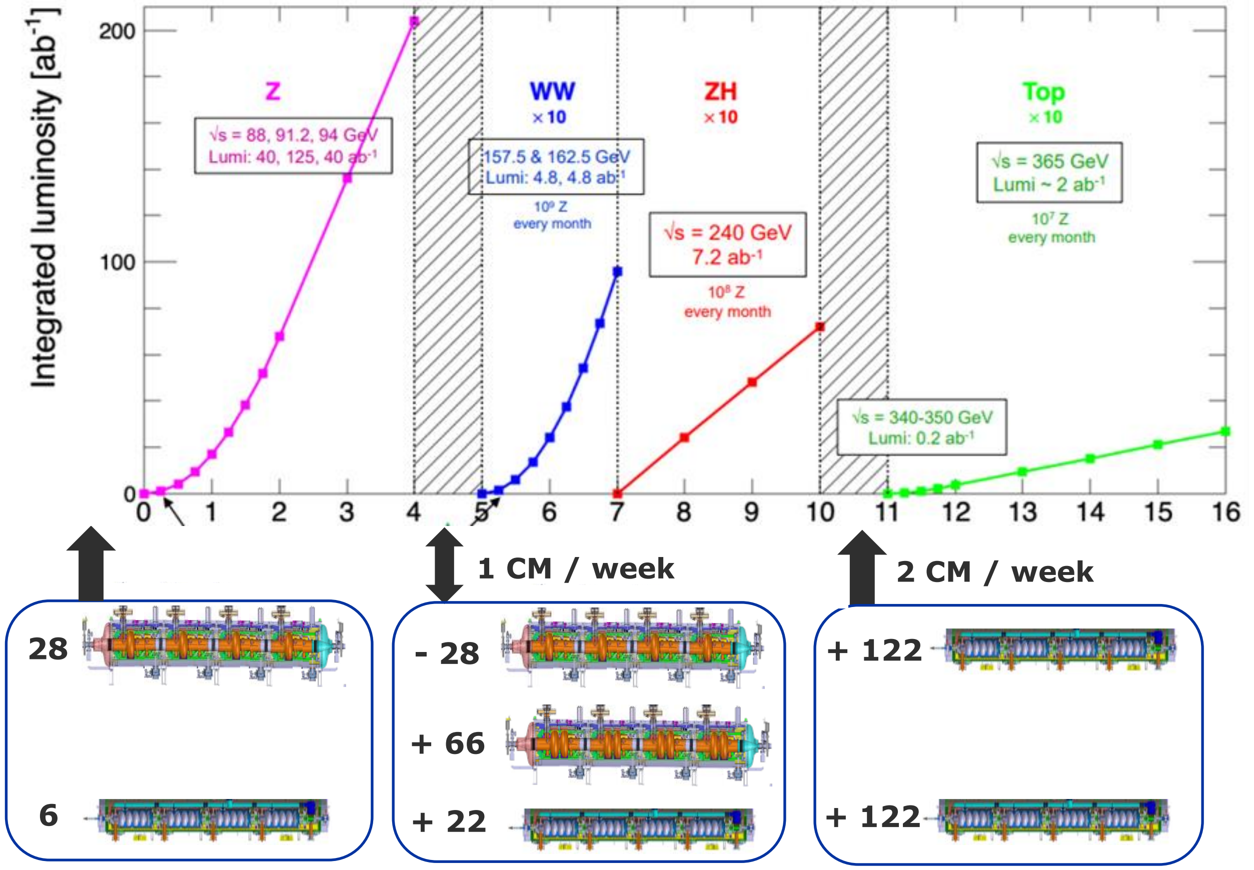
F. Peauger, Ivan Karpov and the R&D SRF team



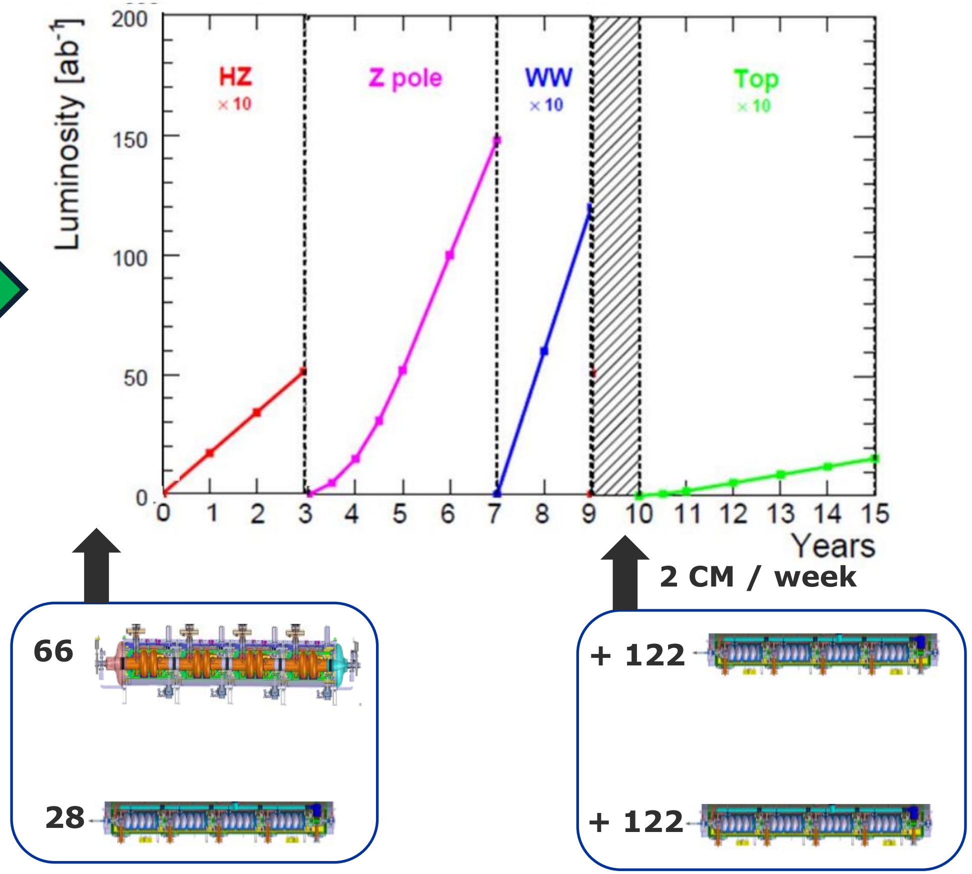
Motivations

Optimisation of the FCCee physics program

Patrick Janot



Guy Wilkinson, University of Oxford, FCC week 2023



Motivations

Major savings for RF activities

Saving on 28 cryomodules and 112 single cell 400 MHz cavities

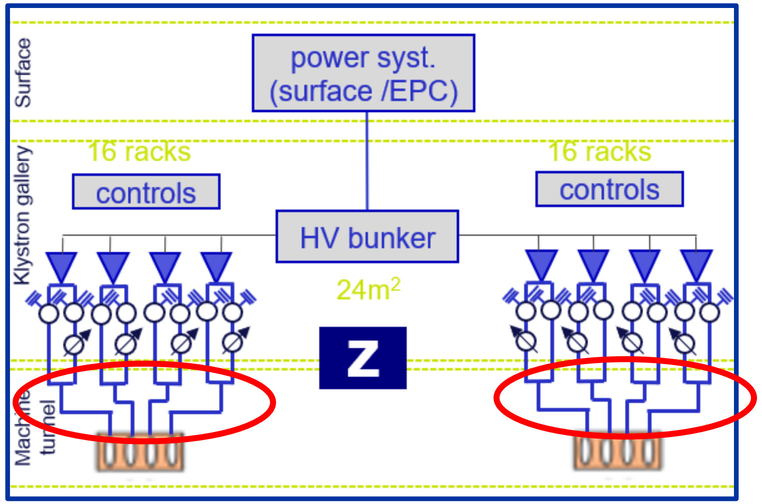
- Developments around Nb/Cu technology will be focused on 2-cell cavities only
- Industrialization process is simplified

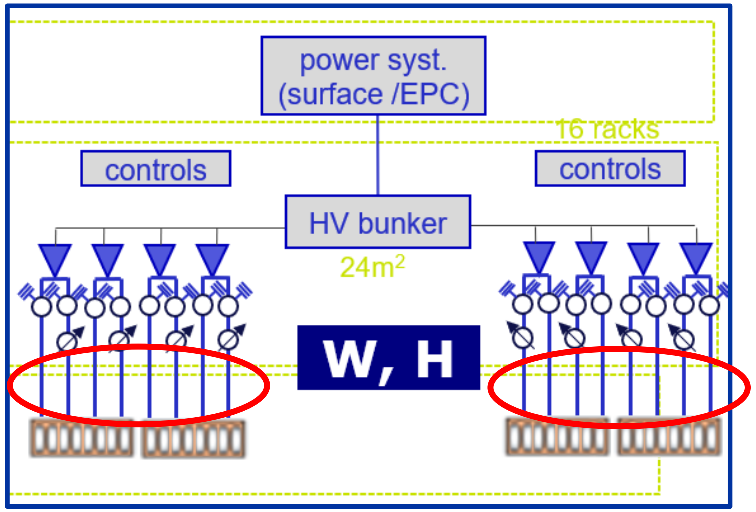
Saving on manpower

- The resources needed to remove and install cryomodules during the first shutdown can be re-affected to other tasks (R&D, …)
- There are always risks to transport cryomodules (particles displacement, accidental venting of cavity volume, mechanical events,…)

Saving on the high power RF re-configuration

- WR2300 rectangular waveguides (straight, flexible, combiners and bends); their implementation in the tunnel and re-configuration for 28 modules is not trivial.

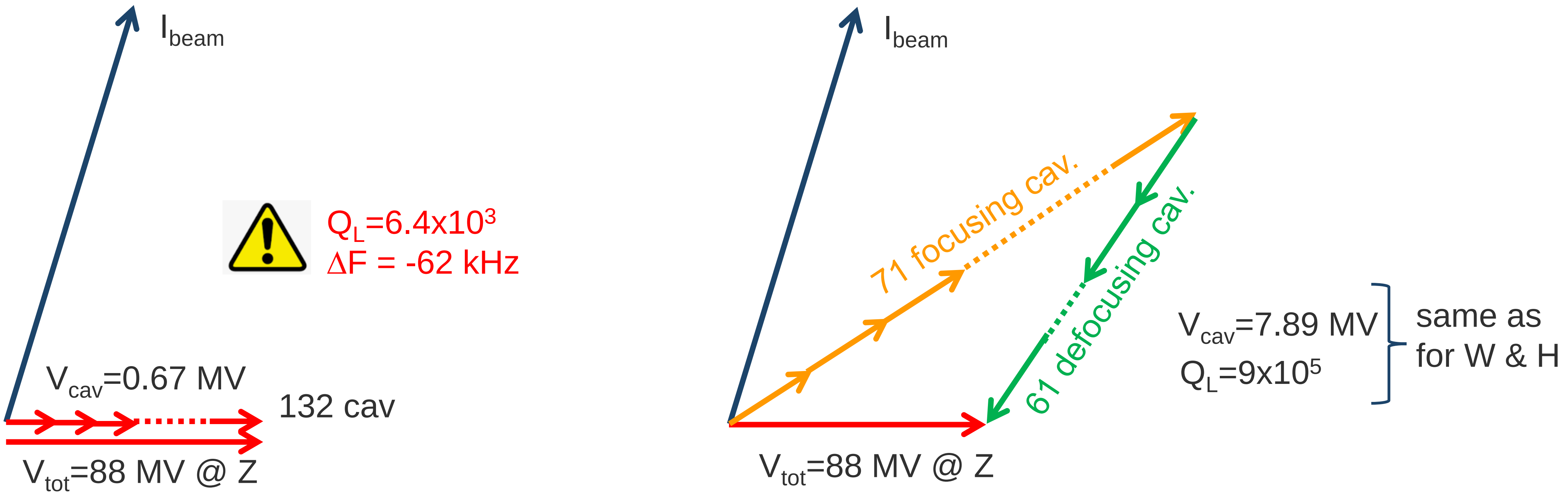




The Reverse Phase Operation (RPO) concept

Reverse phase operation (RPO) mode allows increasing RF cavity voltage *(Y. Morita et al., SRF, 2009)*

- Experimentally verified with high beam loading in KEKB *(Y. Morita et al., IPAC, 2010)*
- Baseline solution for EIC ESR *(e.g., J. Guo et al., IPAC, 2022)*



Items to be checked to validate the RPO option

First idea mid June (during FCC week 2024)

July, August 2024:

- ☑ Coupled-bunch instability due to fundamental mode
- ☑ Coupled-bunch instability due to 0-mode
- ☑ Coupled-bunch instability due to HOM -> additional transverse dampers in LLRF system mandatory
- ☑ Increase of the HOM power 30 to 40 kW per module

22 Aug. 2024 (ATDC#9):

- ☒ Instability due to beam-beam interactions (see next slide)

Sept. 2024:

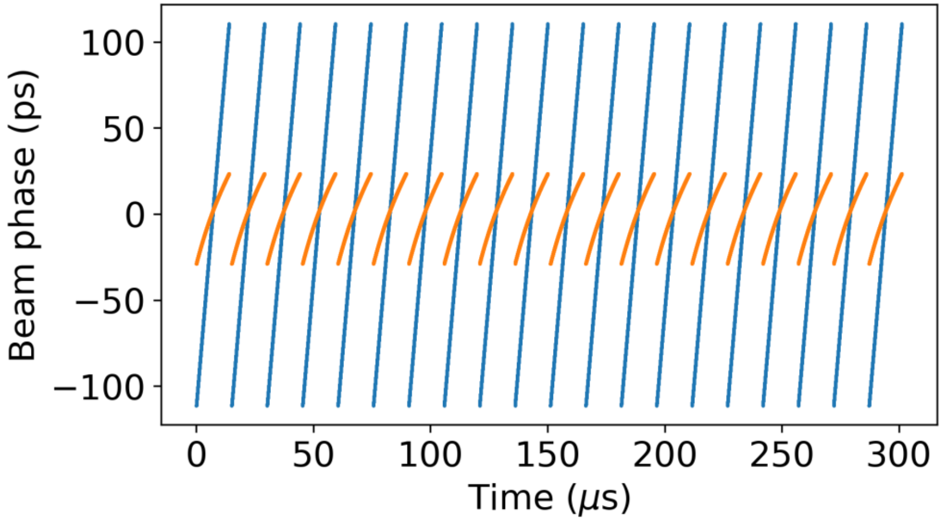
- ☑ Parameters sensitivity to RPO (spread of Q_L, input power)
- ☑ Stability in the booster with all cavities need for H
- ☑ Reduction of RF power per cavity from 1 MW to 400 kW

Oct. 2024:

- ☐ Availability aspects: RPO with tripped cavities
- ☐ Possibility to power two cavities with 1 MW RF power source

Bunch-by-bunch spread of beam parameters due to transient beam loading effects

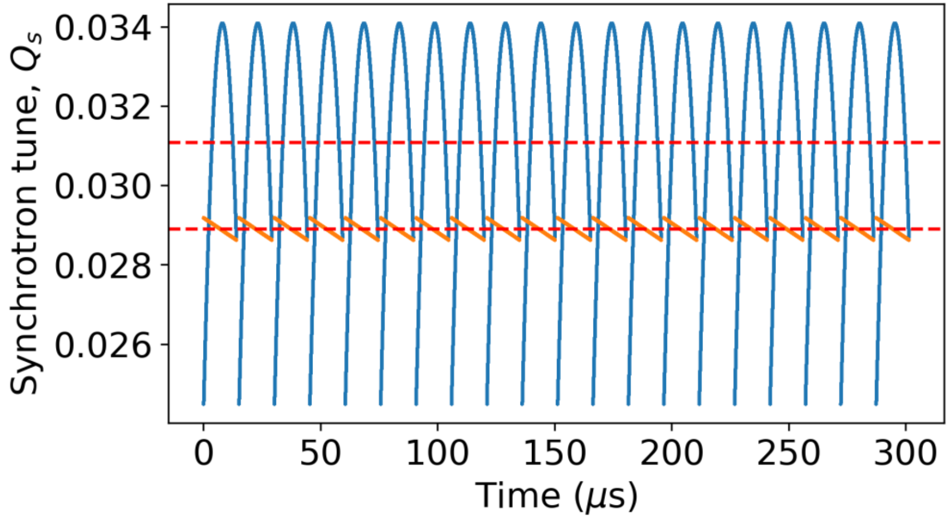
along each of the 20 trains of 560 bunches (1 turn)



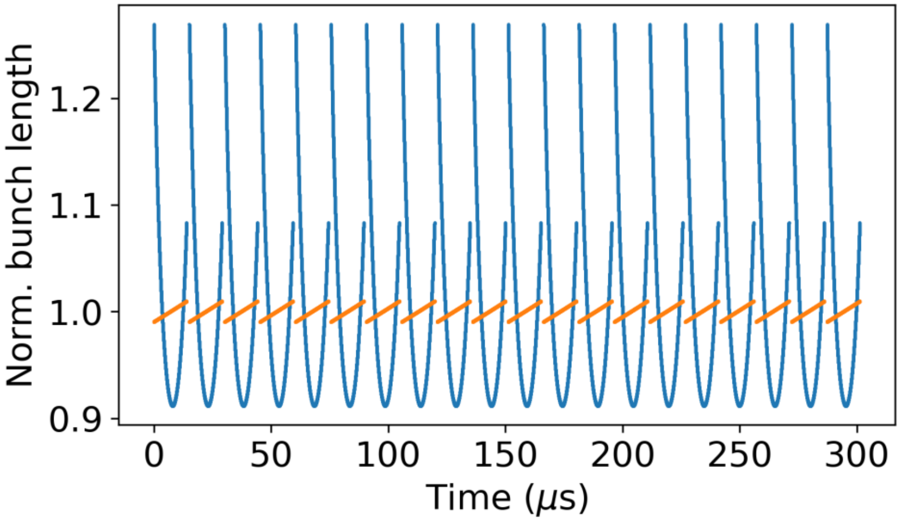
With RPO, peak-to-peak spread of ~30% in synchrotron tune and bunch length can have a significant impact on beam stability

→ We lose a factor of 15 wrt to 1-cell RF system

-21/+9 %



-9/+27 %



Possible solutions

Presented at the Optics meeting last week:
192nd FCC-ee Accelerator Design Meeting & 63rd FCCIS WP2.2 Meeting (26 September 2024) · Indico (cern.ch)

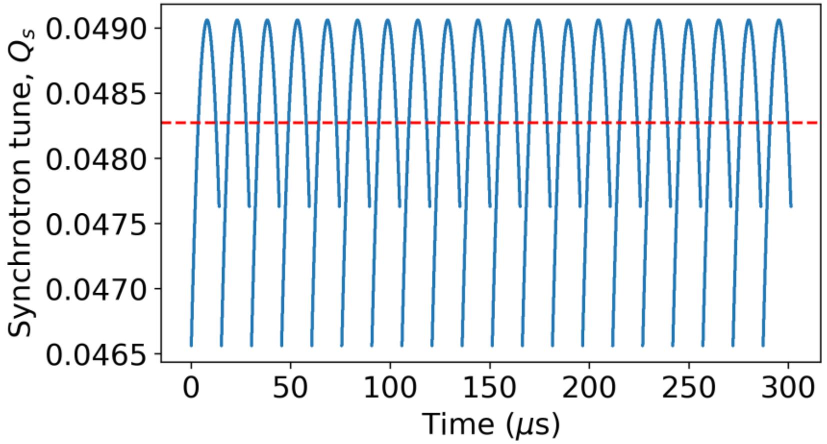
New filling scheme (e.g., 40 trains of 280 bunches)

- Spread is reduced by a factor of ~3
- Gaps become twice shorted (~600 ns) - most likely unfeasible (?) for the extraction system (1 us kicker rise time)

Higher total RF voltage for Z

- From 88 to 195 MV, the Qs spread is reduced from 30 to 5 %

	N_f	N_d	V_{tot} **Z** (MV)	V_{cav} (MV)	Q_L
Current	71	61	88	7.95	9.21e5
Option 2	78	54	195	7.95	9.21e5



Add positive chromaticity

- Promising, see studies from Y. Zhang (IHEP) and shown by M. Migliorati at FCC week 2024

Play with beam current

- To get the same 5% spread of bunch-by-bunch synchrotron tune the current must be reduced to 380 mA. Power reduces to 125 kW.

~1 month of work by beam optics experts (to be confirmed)

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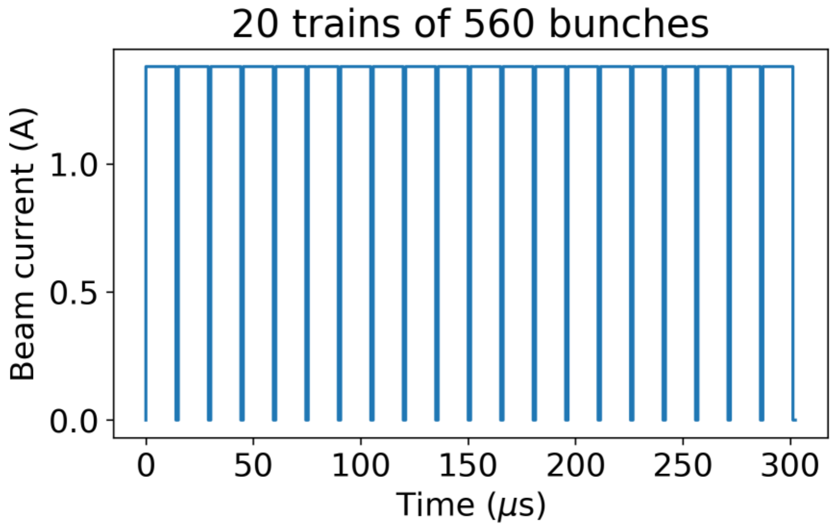
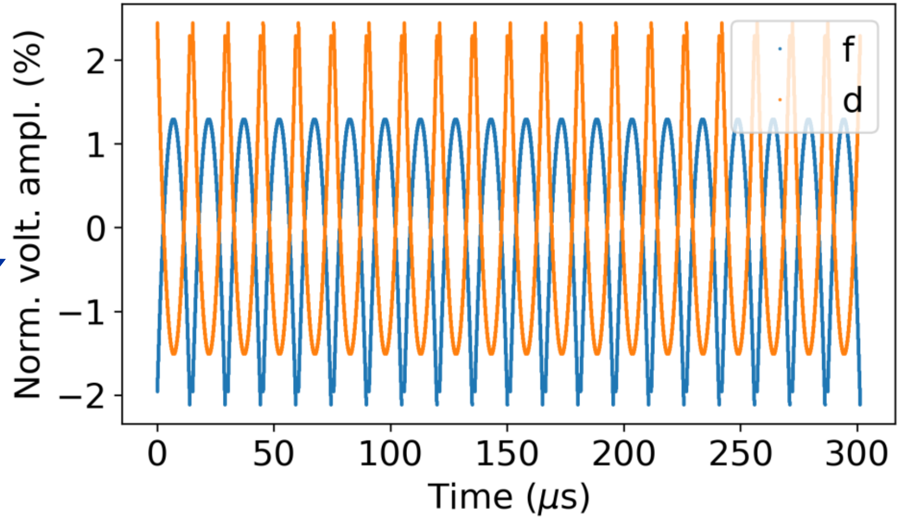
Bunch-by-bunch spread of cavity parameters

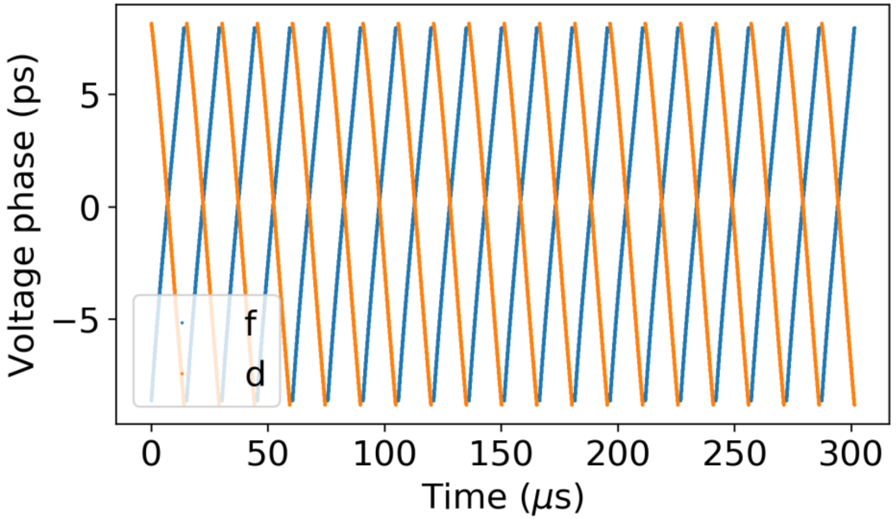
	N_f	N_d	V_{tot} Z (MV)	V_{cav} (MV)	Q_L
Current	71	61	88	7.95	9.21e5



$\frac{a_{Vf,d}}{a_b}$

$\frac{\phi_{f,d}}{a_b}$





Note, the designed rms bunch length is 50 ps (with beamstrahlung)