RF-BASED OPTIMISATION OF THE BOOSTER CYCLE

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RF-based optimisation of the booster cycle

1. **RF based-optimisation of the voltage and energy ramps for the Z mode**

2. **Transient beam loading computations**

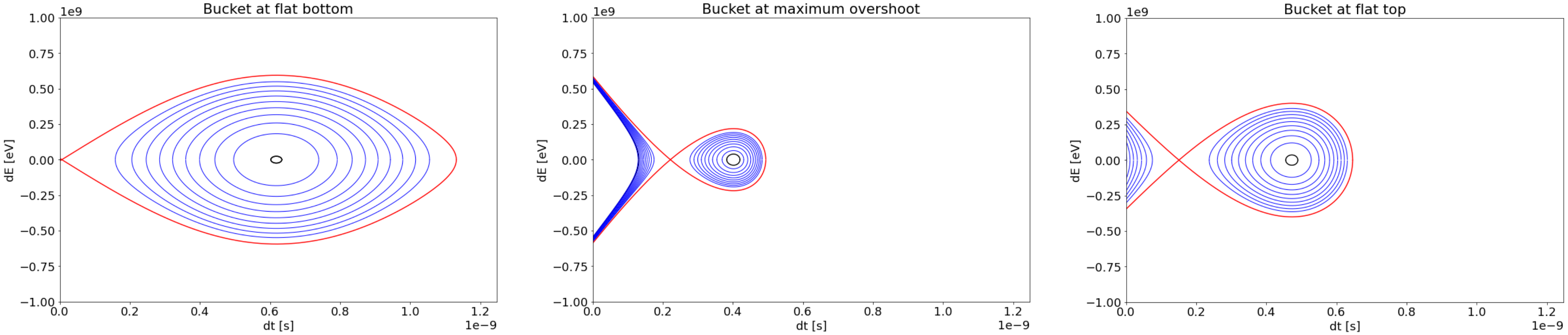
3. **Optimal power calculations**

4. **Update on the CBI due to HOM due to parameter changes.**

Parameter changes relevant to RF

Running mode	Z	W	Higgs	ttbar
Injection energy [GeV]	20			
Extraction energy [GeV]	45.6	80	120	182.5
Momentum compaction	$\mathbf{7.12 \cdot 10^{-6}}$			
Inj. RF voltage [MV]	$\mathbf{50.1}$			
Ext. RF voltage [MV]	$\mathbf{57.2}$	$\mathbf{402}$	$\mathbf{1960}$	$\mathbf{102003}$
Ramp time [s]	$\mathbf{0.706}$	0.75	1.25	2.03
Time spent at FB [s]	$\mathbf{2.8}$	8.9	4.4	0.6
Time spent at FT [s]	$\mathbf{0.1}$	0.1	0.1	0.1
Current [mA]	$\mathbf{14.8}$	$\mathbf{11.8}$	$\mathbf{2.01}$	$\mathbf{0.30}$
Inj. en. loss/turn [MeV]	1.45			
Ext. en. loss/turn [MeV]	40	374	1890	10420
Number of cavities	$\mathbf{8}$	$\mathbf{28}$	$\mathbf{108}$	$\mathbf{540}$

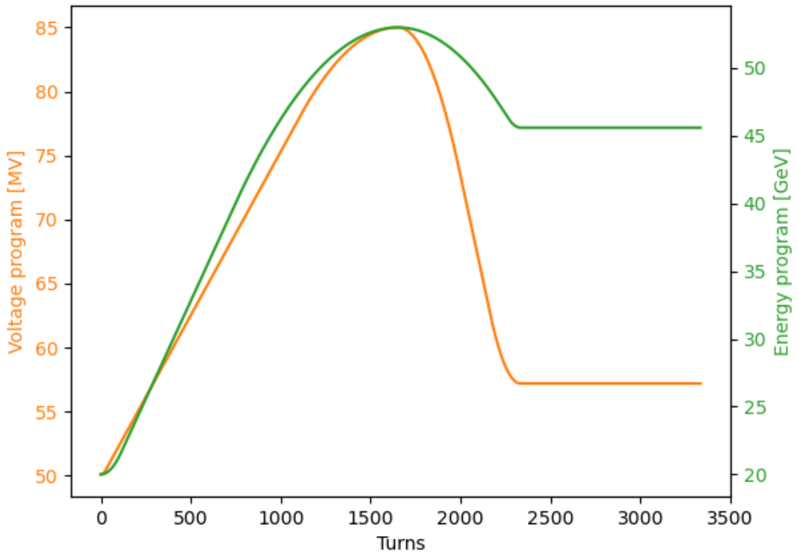
1. Ramp design for the Z mode: boundary conditions

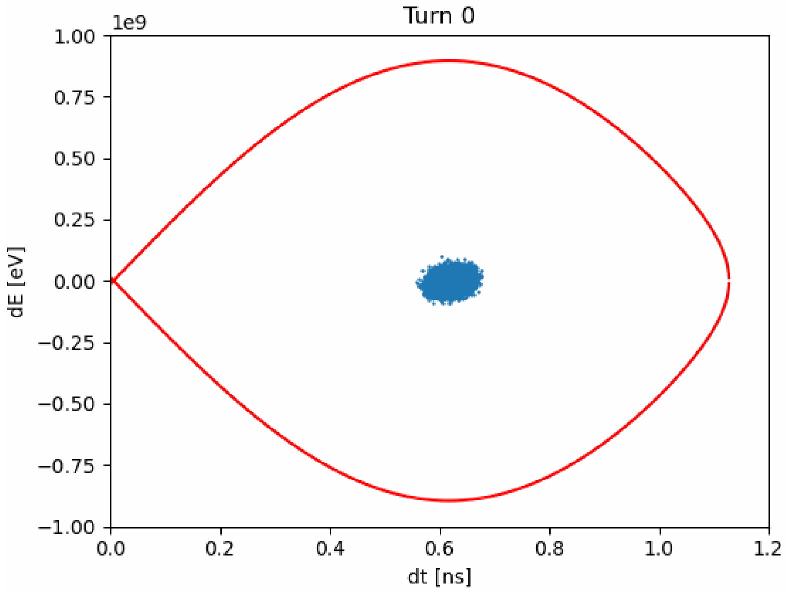


	Flat bottom	Overshoot maximum	Flat top
Energy [GeV]	20	53	45.6
Voltage [MV]	50.1	85	57.2
Damping time in turns	13725 (4 s)	737 (0.22 s)	1158 (0.4 s)
Energy loss per turn [MeV]	1.45	72	40

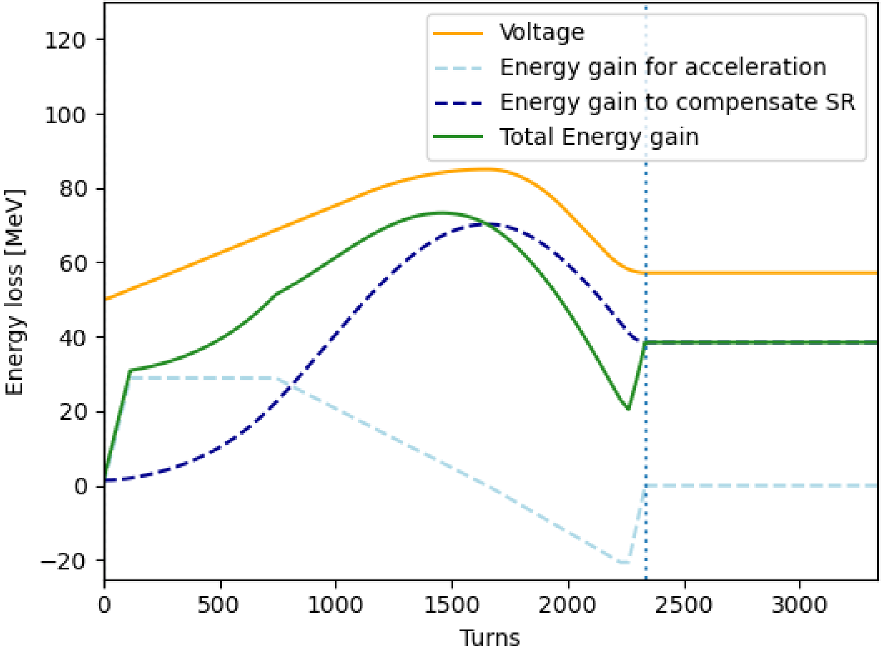
1. Ramp design for the Z mode

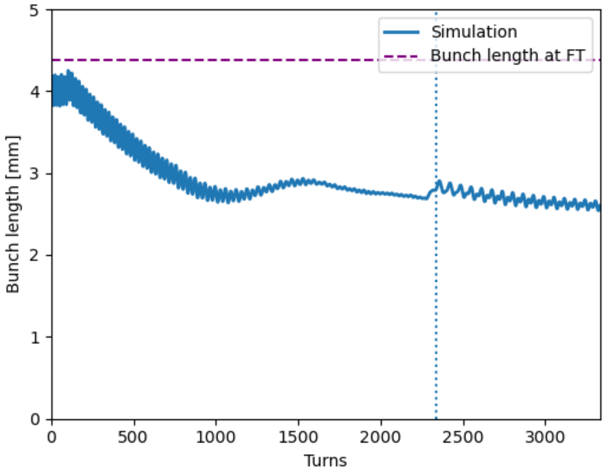
- Inputs: emittance targets at flat top reached thanks to an energy overshoot, voltage at flat top
- Degrees of freedom: energy and voltage ramp shapes
- Tools: use longitudinal tracking to ensure beam stability

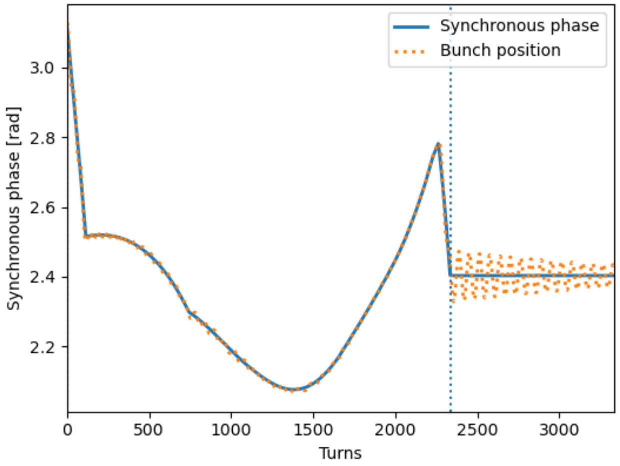




1. Ramp design for the Z mode



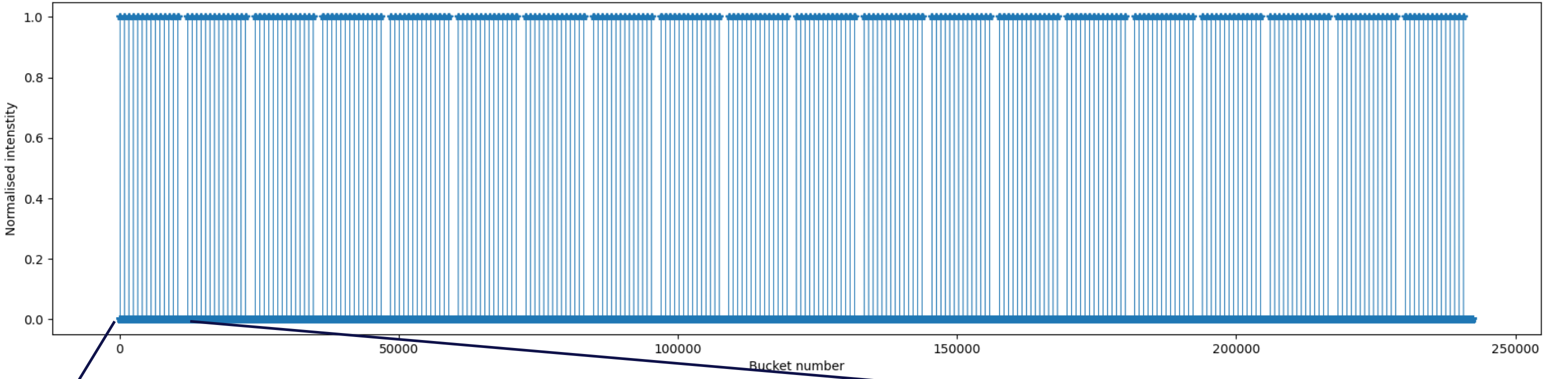




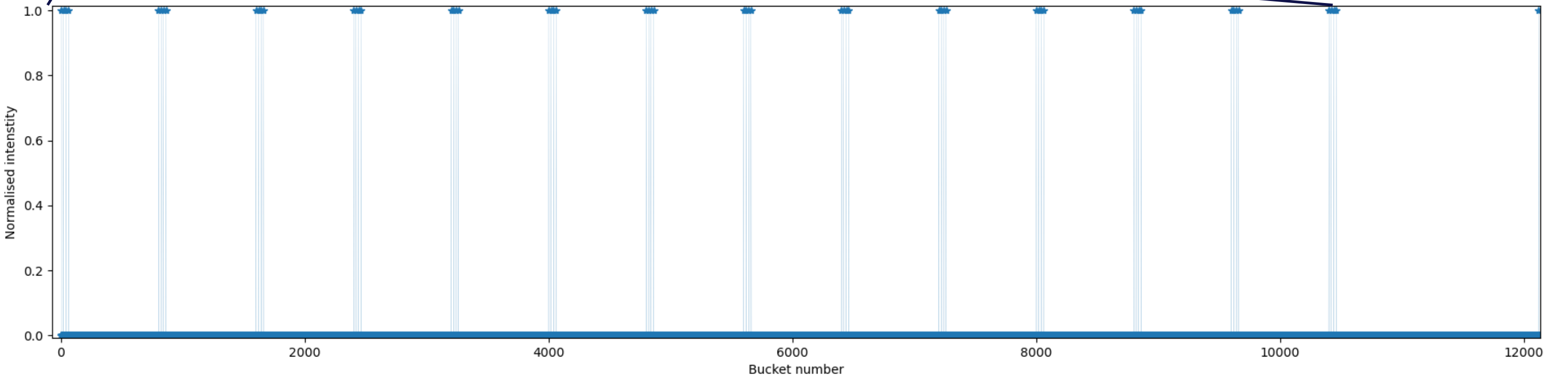
2. Transient beam loading calculations

Current baseline filling scheme, see following presentation by Hannes Bartosik (*Booster and collider filling scheme*) is **maximally and evenly spread** around the ring.

20 trains



of 14x4 bunches

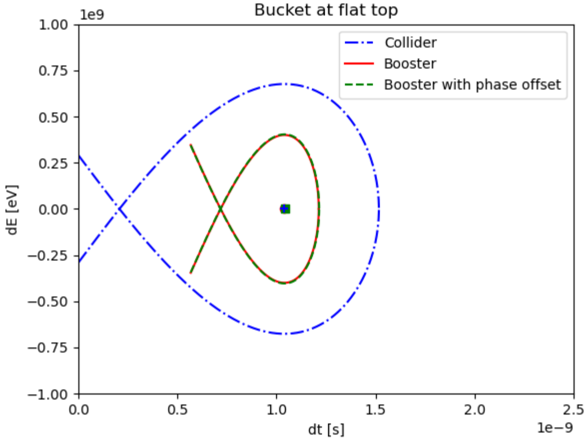


2. Transient beam loading calculations

One can calculate the phase build up:

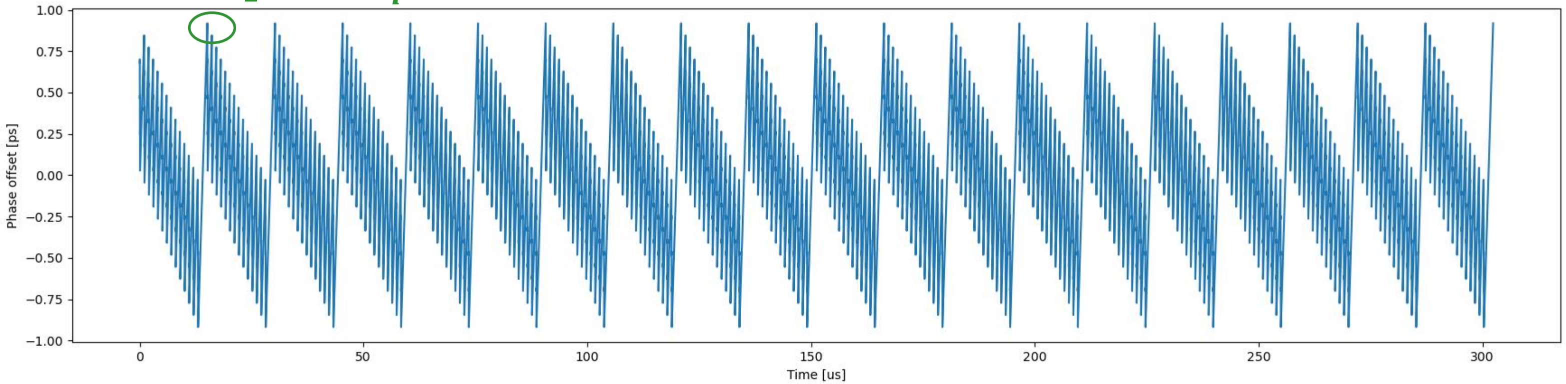
$$\Phi(t) = \frac{\frac{1}{2}\left(\frac{R}{Q}\right)\omega_0}{V} \int_0^{T_{rev}} (< I_b > - I_b(t))\, dt$$

$$< I_b > = \frac{1}{T_{rev}} \int_0^{T_{rev}} I_b(t)\, dt$$



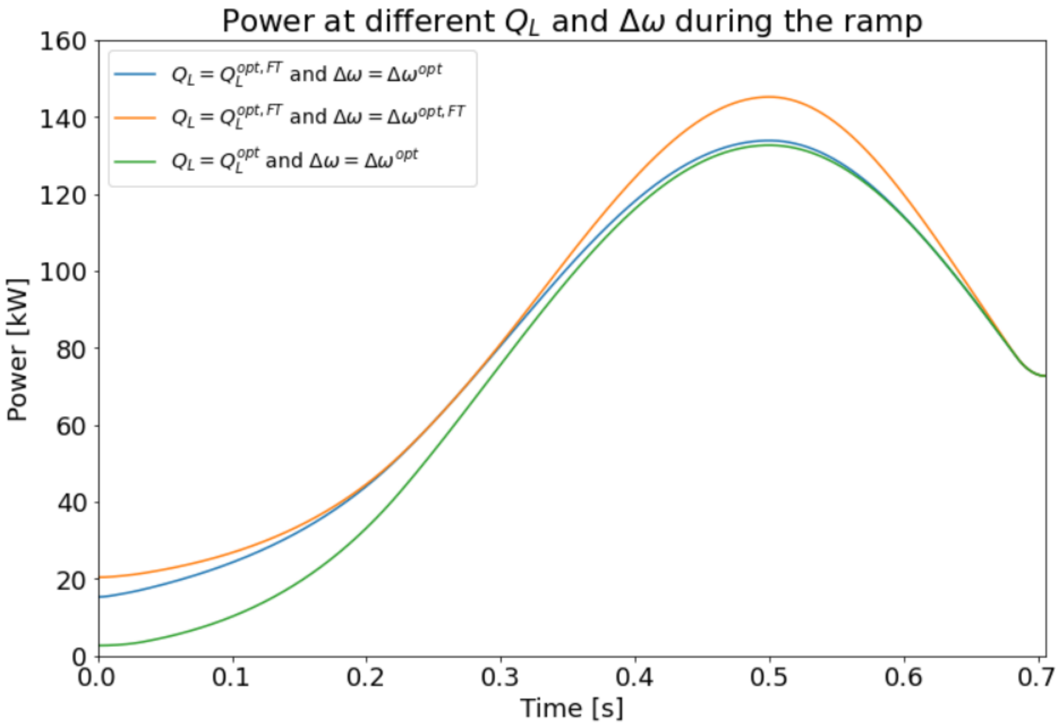
Very low phase offset build-up in the built, ideal for RF

$\Phi\_max < 1\, ps$



Source: https://cas.web.cern.ch/sites/default/files/lectures/slangerup-2019/BeamLoading.pdf

3. Optimised power



See Franck Peauger's presentations *RF designs and RF powering scheme for FCC*.

The power requested is below the limit. There is no need to change the detuning or the Q loaded during the ramp.

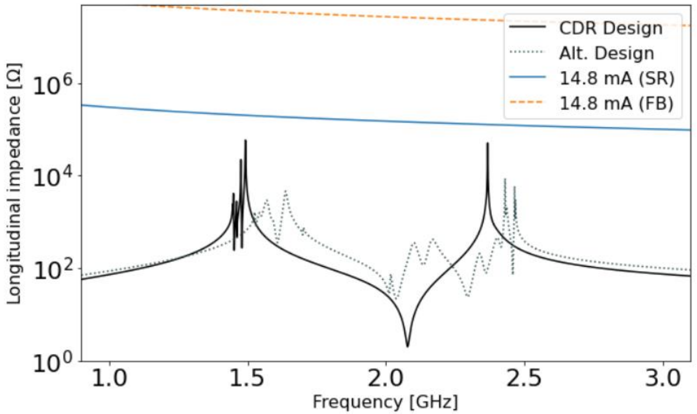
$$P_{g,opt} = \frac{V_{cav}|F_b|I_{b,dc}\cos\phi_s}{2}$$

For short FCC-ee bunches, the form factor can be approximated by :

$$F_b \approx 2\exp\left(-\frac{(\omega_{rf}\sigma)^2}{2}\right)$$

4. Coupled Bunched Instabilities (CBI) due to Higher Order Modes (HOM)

Longitudinal plane

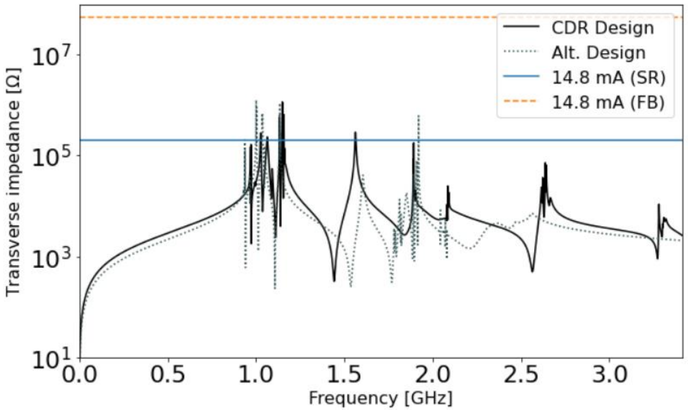


Z operation

$I = 14.8$ mA

8 cavities

Transverse plane



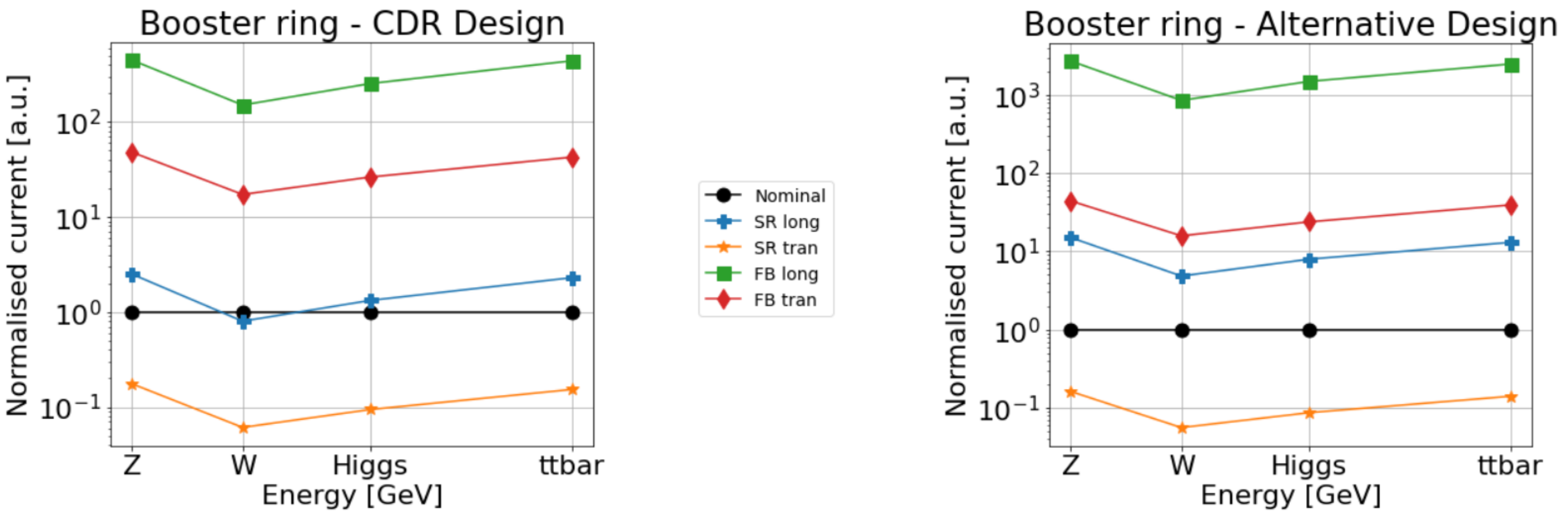
I_{max}	$\tau_{SR}^{\|\|}$ (=4.15 s)	$\tau_{FB}^{\|\|}$ (=23 ms)
Design 1	37 mA	6.6 A
Design 2	222 mA	40 A

CDR Design: Shahnam Z. Gorgi, current CDR scenario, UROS5
Alernative Design: Sosoho-Abasi Udongwo, C3795

I_{max}	$\tau_{SR}^{\perp}$ (=8.3 s)	$\tau_{FB}^{\perp}$(=30ms)
Design 1	2.6 mA	709 mA
Design 2	2.4 mA	652 mA

- Feedback system necessary for both designs in transverse plane
- Alternative Design better than CDR design by factor of 4 in longitudinal plane
- Designs are similar in transverse plane

4. Coupled Bunched Instabilities (CBI) due to Higher Order Modes (HOM)



- **Multi-bunch feedback system** necessary in **transverse** plane for **all modes**.
- Alternative Design better than CDR design in the longitudinal plane.
- Most demanding mode is now **W**, with a multi-bunch FB needed for CDR design.
- These limits were computed with conservative assumptions (100 turns feedback).

Conclusions

1. A doubly parabolic ramp with an energy overshoot was designed in order to reach the emittance targets.

2. The transient beam loading is minimized by the chosen filling scheme.

3. With the newly reduced current at the Z mode, no detuning or loaded Q change schemes are needed to provide enough power to the cavities.

4. With the newly reduced current, the need for less cavities has lowered the coupled bunch instability thresholds due to higher order modes.
   Depending on the cavity design chosen, a multi-turn feedback system will be needed in the longitudinal plane as well as in the transverse plane (unavoidable).