(Another) Update on Transient Beam Loading from Reverse Phase Operation

Ivan Karpov and Franck Peauger for FCC SRF WP1 with input from:
Hannes Bartosik, Xavier Buffat, Yann Dutheil, Giorgia Favia, Jiquan Guo (JLAB),
Mauro Migliorati (INFN), Katsunobu Oide, Jorg Wenninger, Frank Zimmermann, Mikhail Zobov (INFN)

199th Accelerator Design Meeting & 70th FCCIS WP2.2 Meeting, 12.12.2024

Quick recap

New baseline assumes a common RF system Z, W, and ZH modes
- Reverse phase operation (RPO, *Y. Morita et al., 2009*) mode for Z
- Normal mode for W
- Normal mode for ZH (combined RF system for two beams)

Option #	V_{nom} (MV)	$\Delta Q_s / Q_s$
0	88.48	10%
1	103.00	7%
2	117.86	5%
3	132.96	4%

Transient beam loading with RPO leads to significant variation of effective RF voltage
- After reduction of gap lengths (1.2 → 0.6 μs, G. Favia et al.) several options were considered for spread suppression

→ Only the lowest voltage (option 0) is allowed based on recent transverse stability studies (*slides of X. Buffat*)

This talk:

- Impact of pilot bunches
- Impact of RF feedback

Content

Impact on transient beam loading due to:

- Pilot bunches
- RF feedback

Content

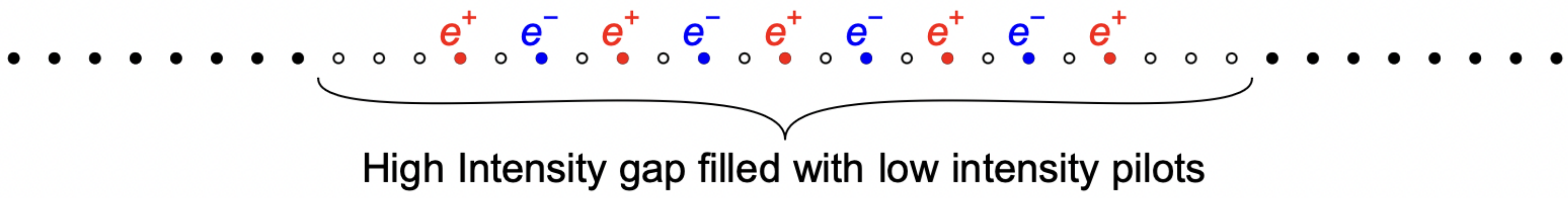
Impact on transient beam loading due to:

- Pilot bunches

- RF feedback

Filling scheme with pilot bunches

Low-intensity non-colliding bunches are need for energy calibration (100-160 bunches per beam)
New alternating filling scheme allows for $20 \cdot 5 + 20 \cdot 4 = 180$ bunches of either type

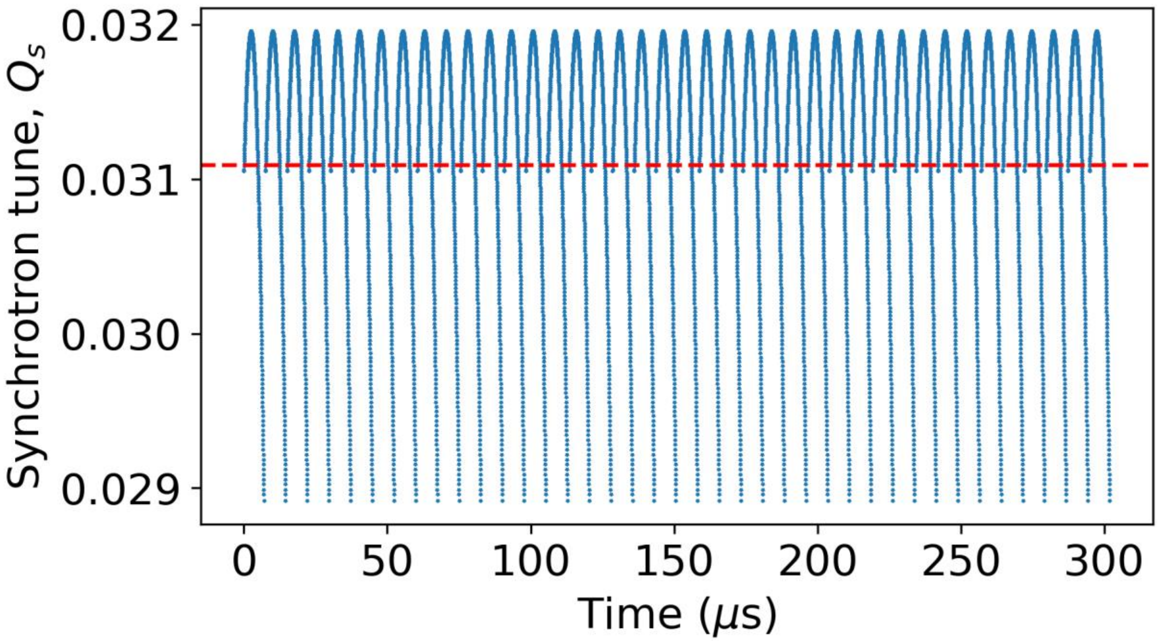


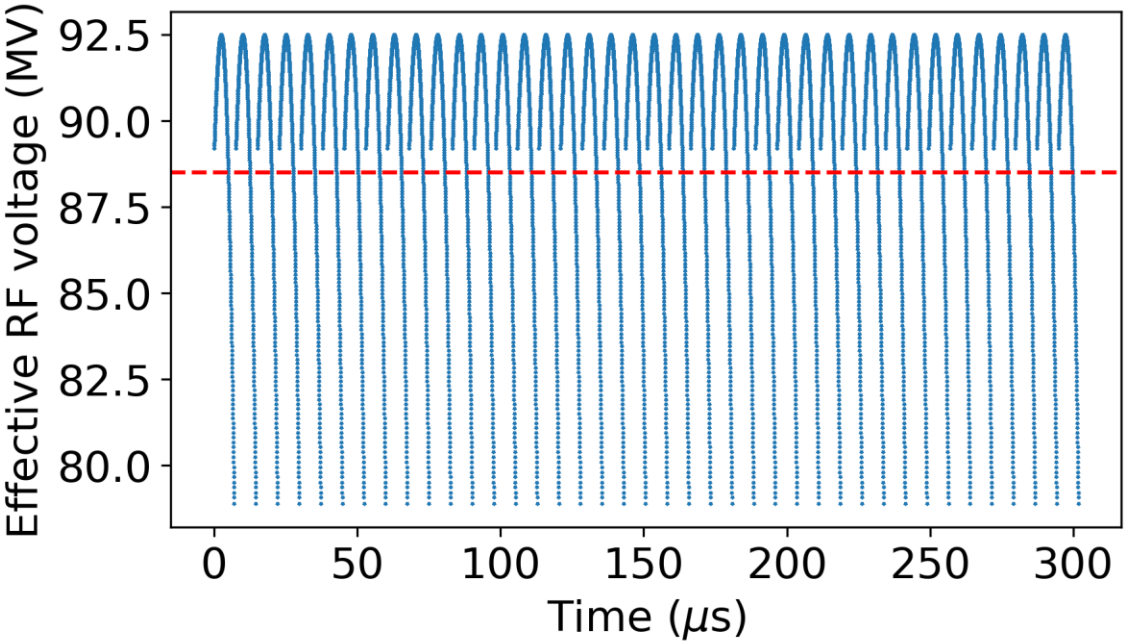
Three options to consider:

- No empty gaps
- One empty gaps (175 + 176 bunches)
- Four equidistant empty gaps ($160 + 164$ bunches)

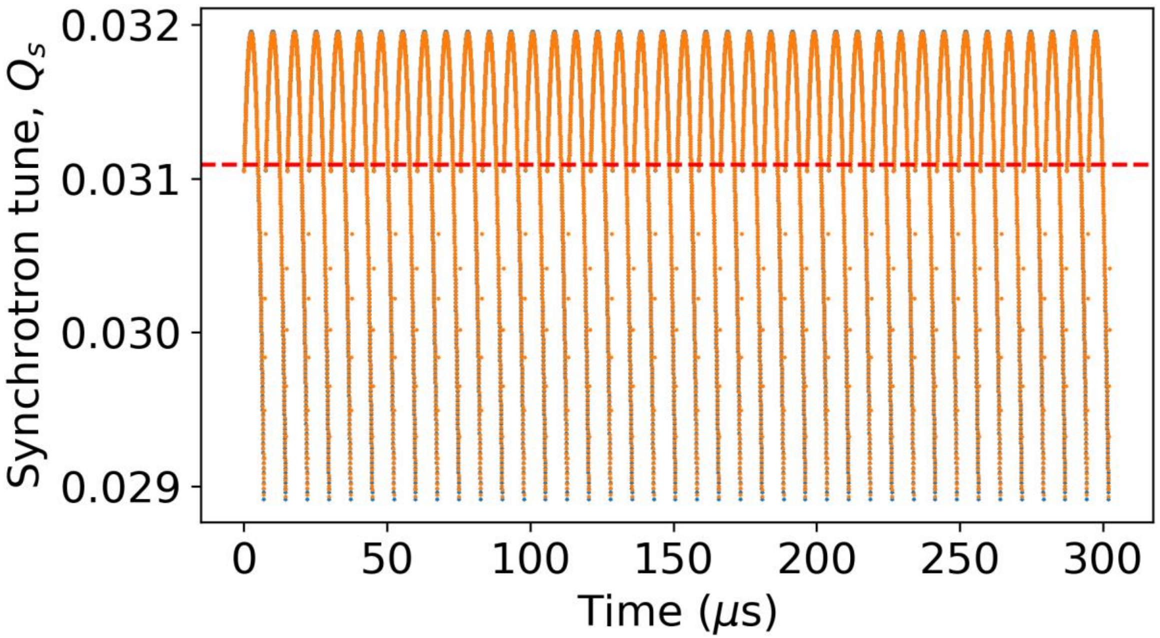
H. Bartosik, C. Carli et al., 8th FCC SAC, 2024

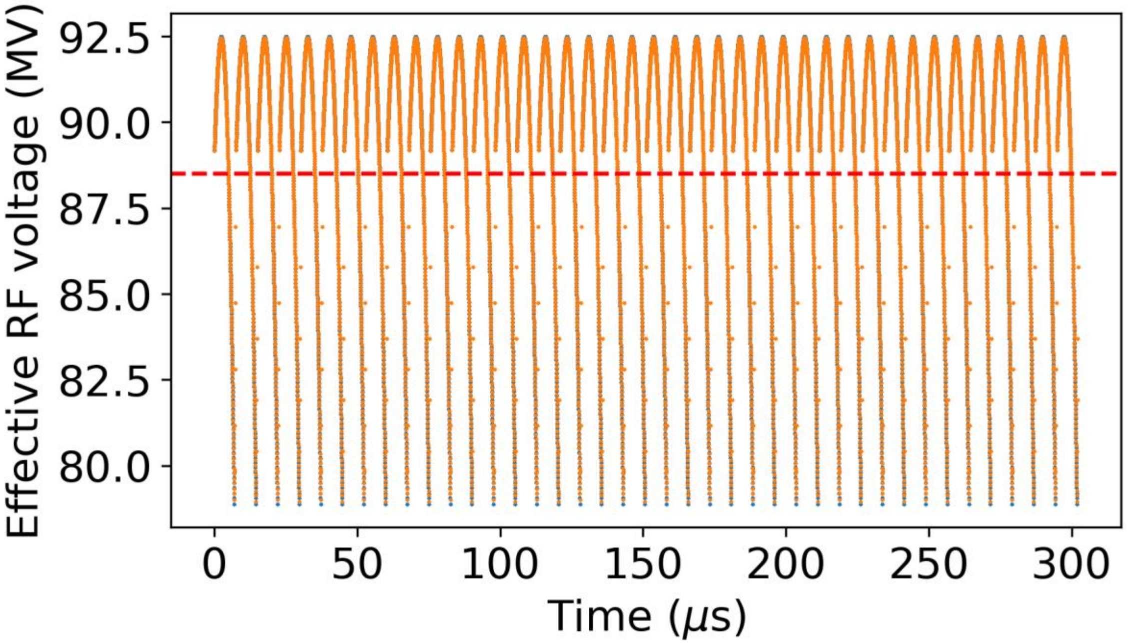
No pilots vs pilots in all gaps



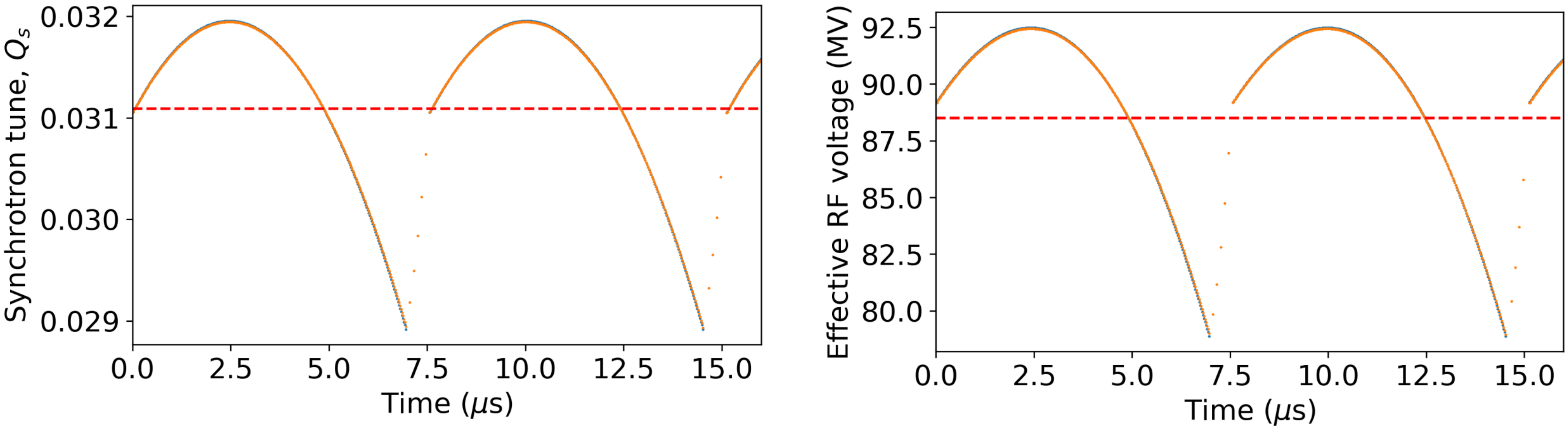


No pilots vs pilots in all gaps





No pilots vs pilots in all gaps



Results from small-signal model for pilot intensity ~1e10

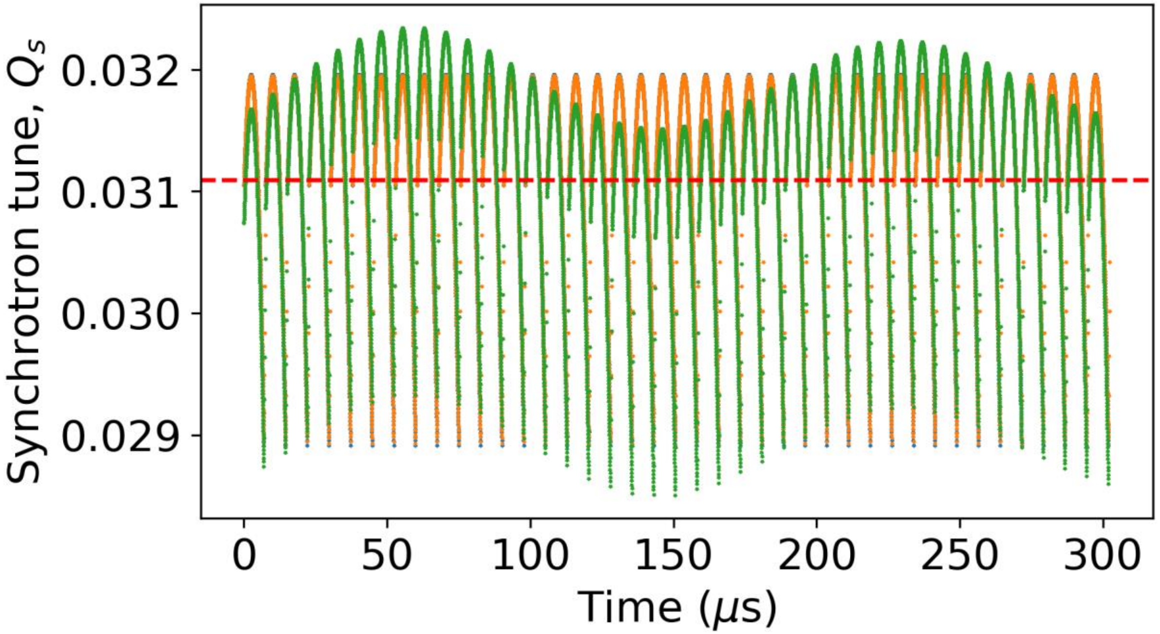
+2.78 -6.99 % - no pilots

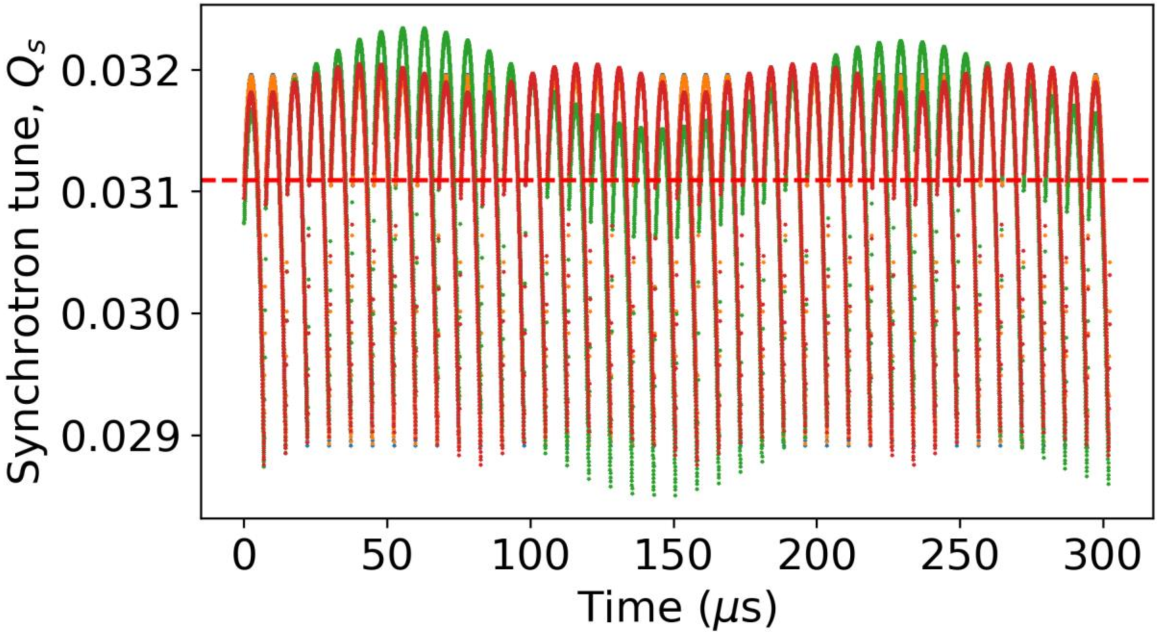
+2.76 -6.93 % - pilots in all gaps

→ Almost no impact on the bunch-by-bunch spread

→ ~5 % spread in Q_s for pilot bunches

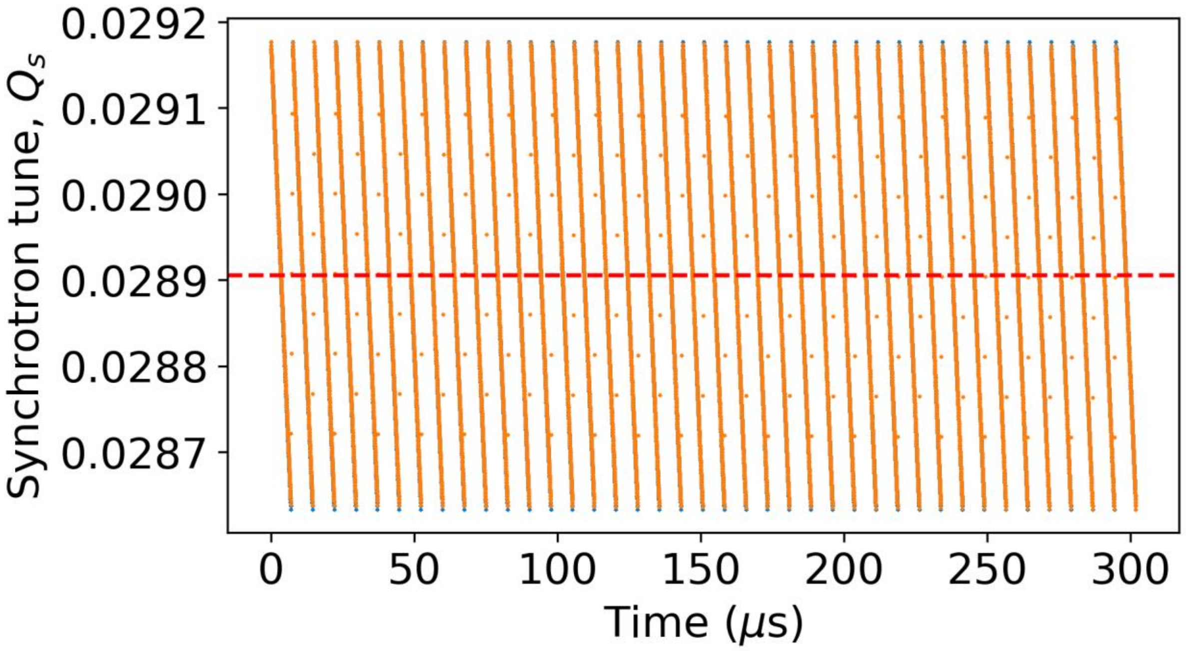
Gaps with missing pilots



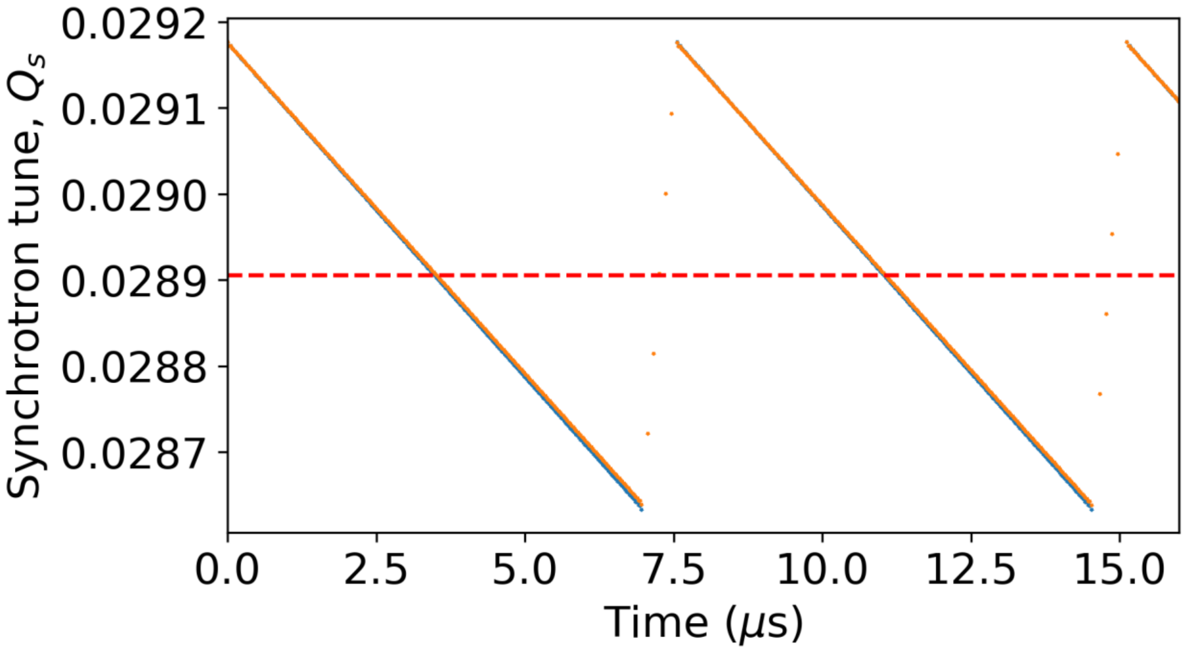


Results from small-signal model for pilot intensity ~1e10
+2.78 -6.99 % - no pilots
+2.76 -6.93 % - pilots in all gaps
+4.02 -8.30 % - one empty gap
+3.07 -7.50 % - four empty gaps
→ Pilot-free gaps enhance transients

Case of single-cell cavities and one empty gap



Case of single-cell cavities and one empty gap



→ Pilots are completely transparent

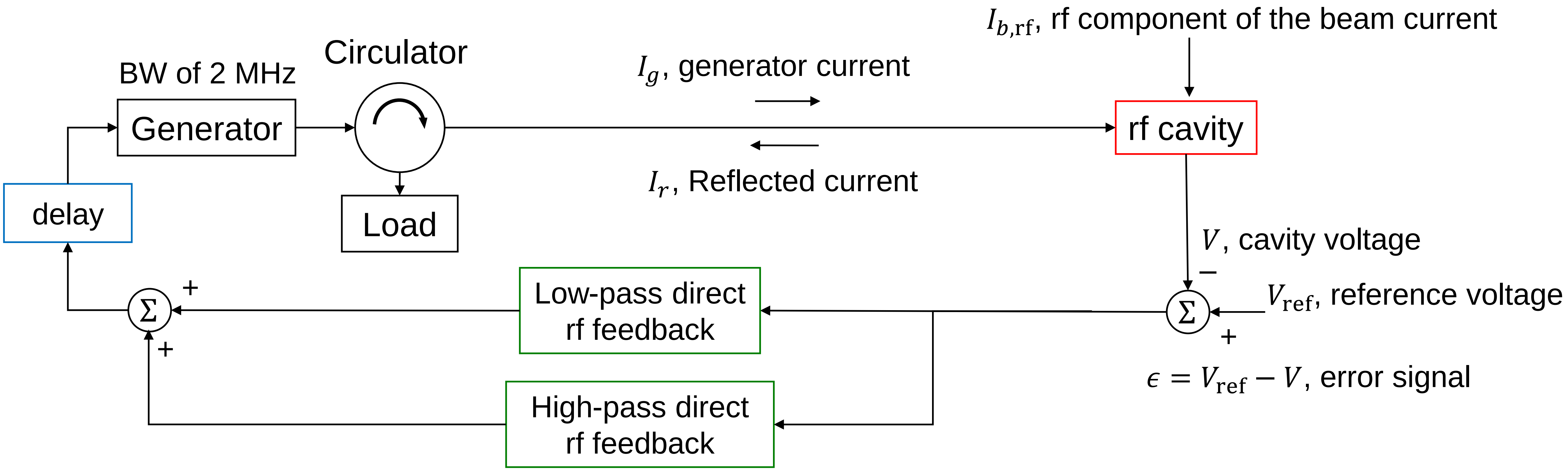
Content

Impact on transient beam loading due to:

- Pilot bunches
- RF feedback

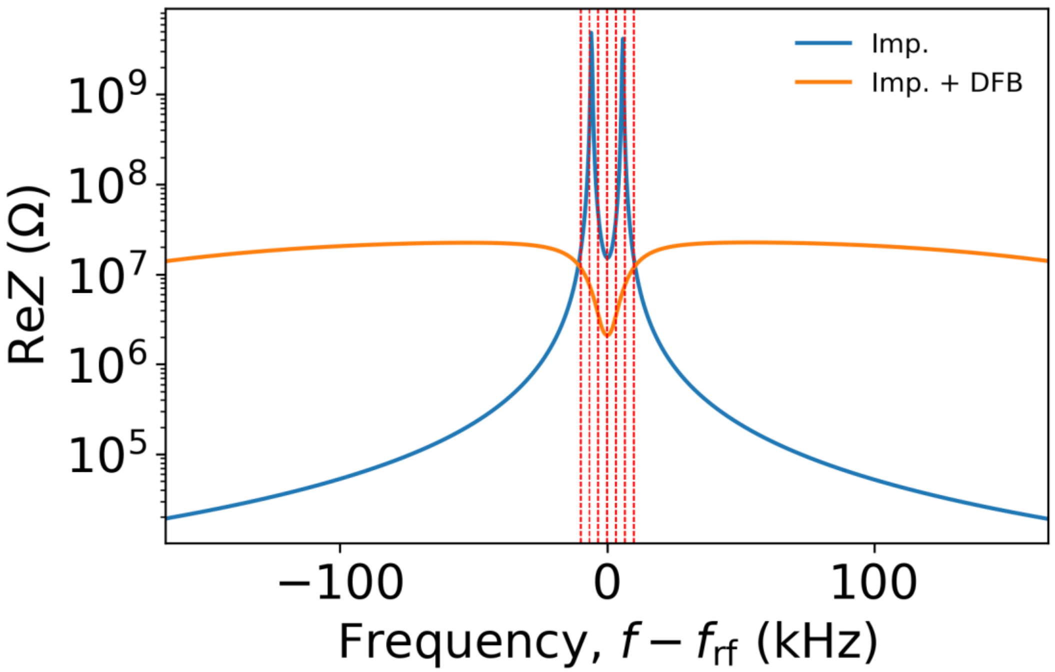
RF system block diagram

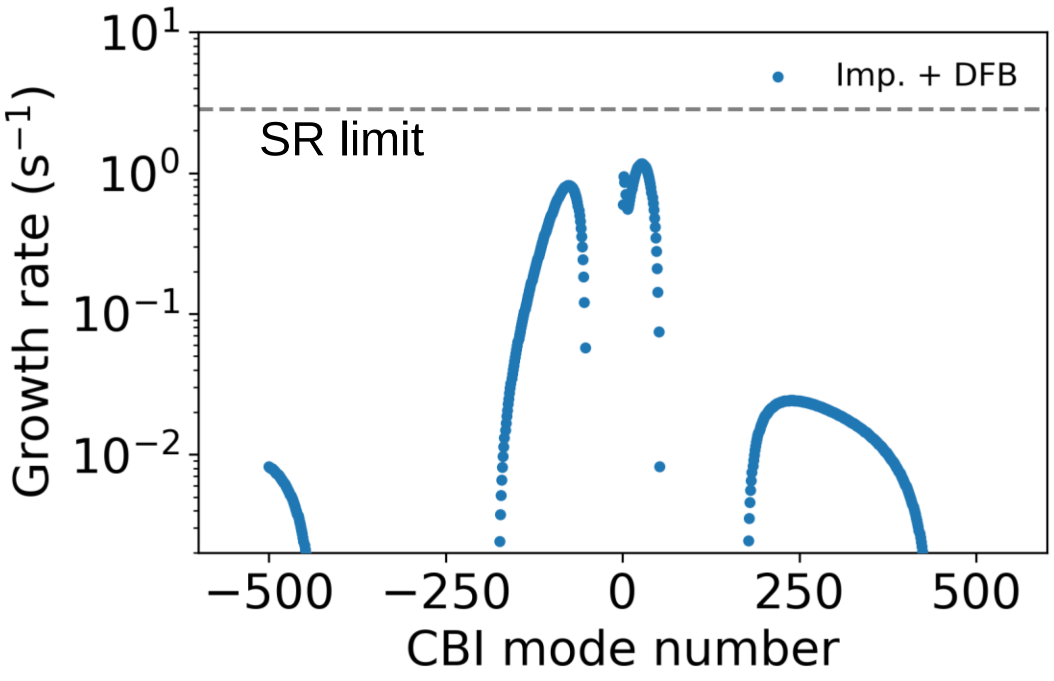
FCC feedback system assumed to be similar to one in the LHC *(P. Baudrenghien et al, 2006)*



Setting adjustments for beam stability

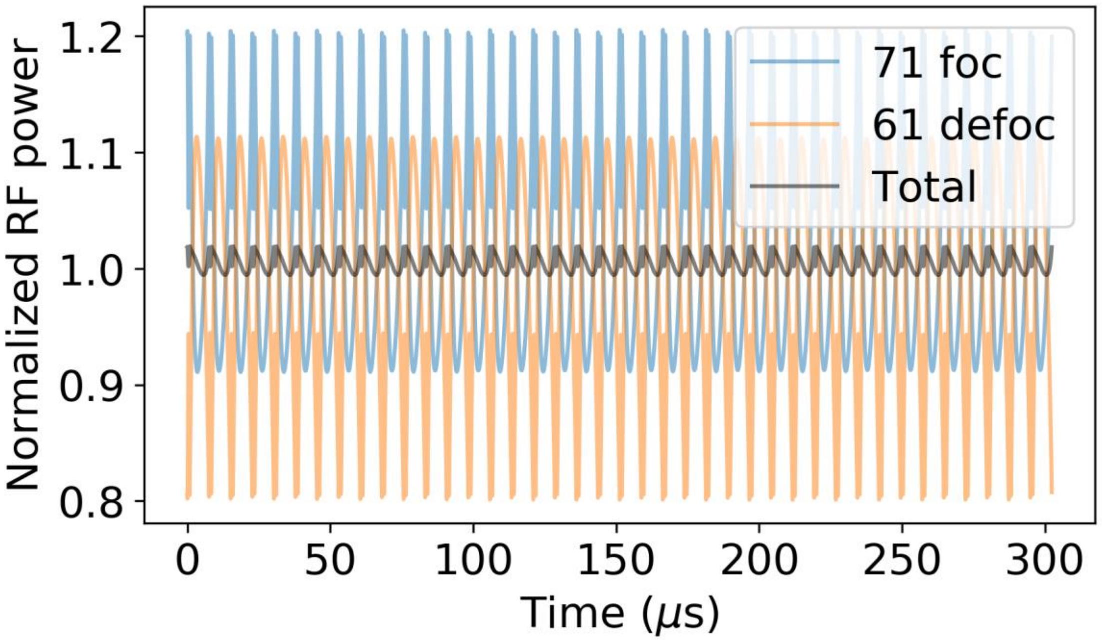
132 2-cell cavities with RPO loop delay of 700 ns, DFB gain 10

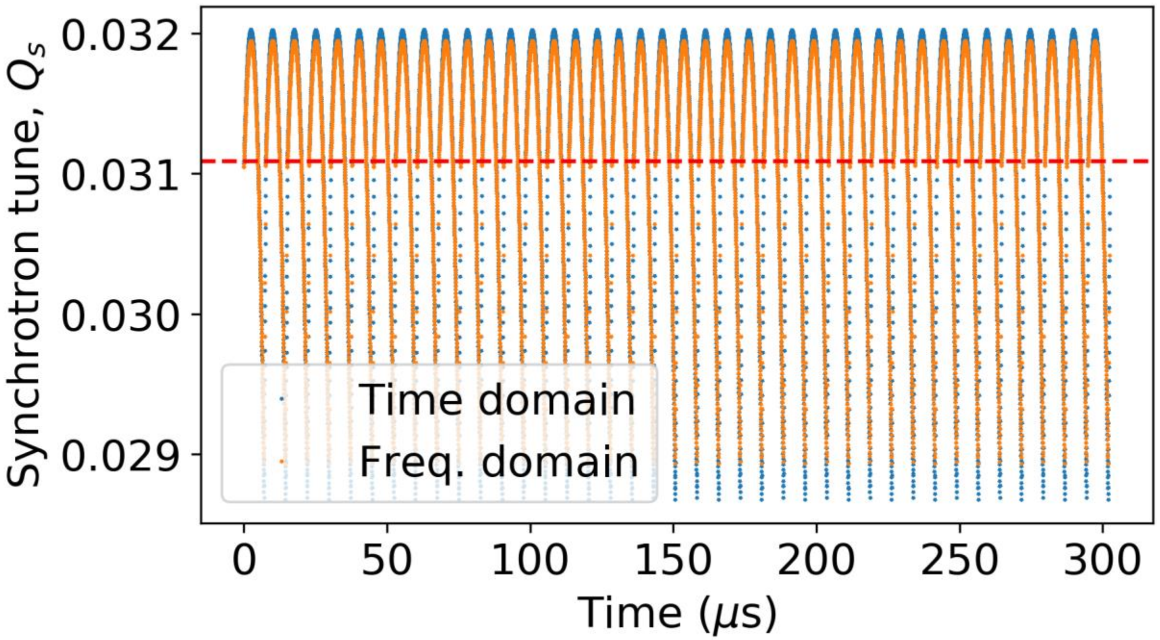




→ Margin of 2.5 with RF voltage of 88 MV

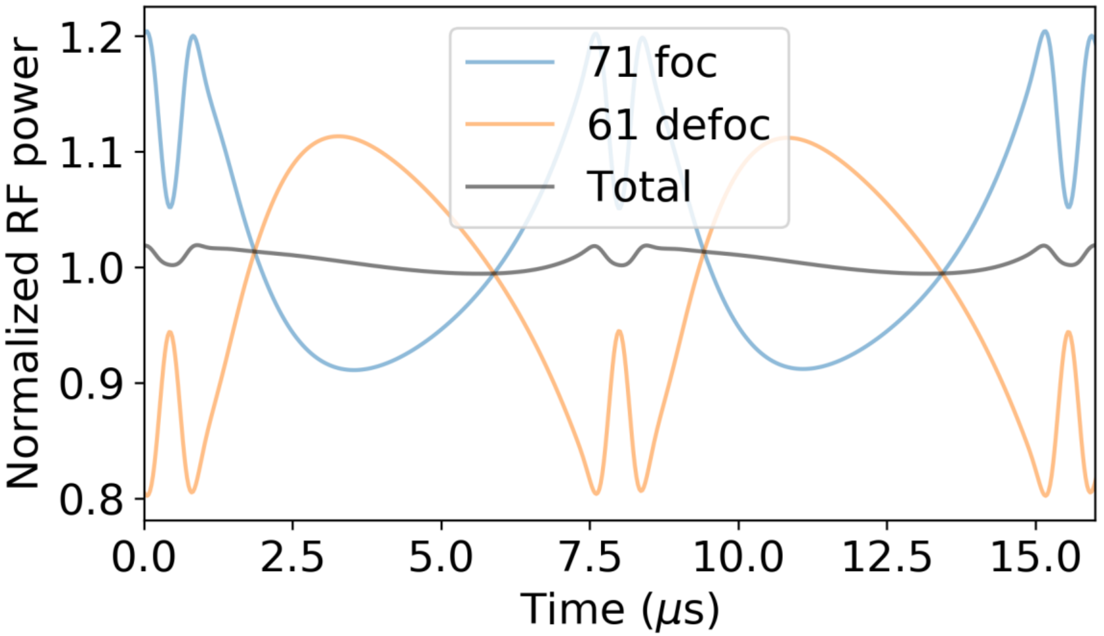
Impact of feedback

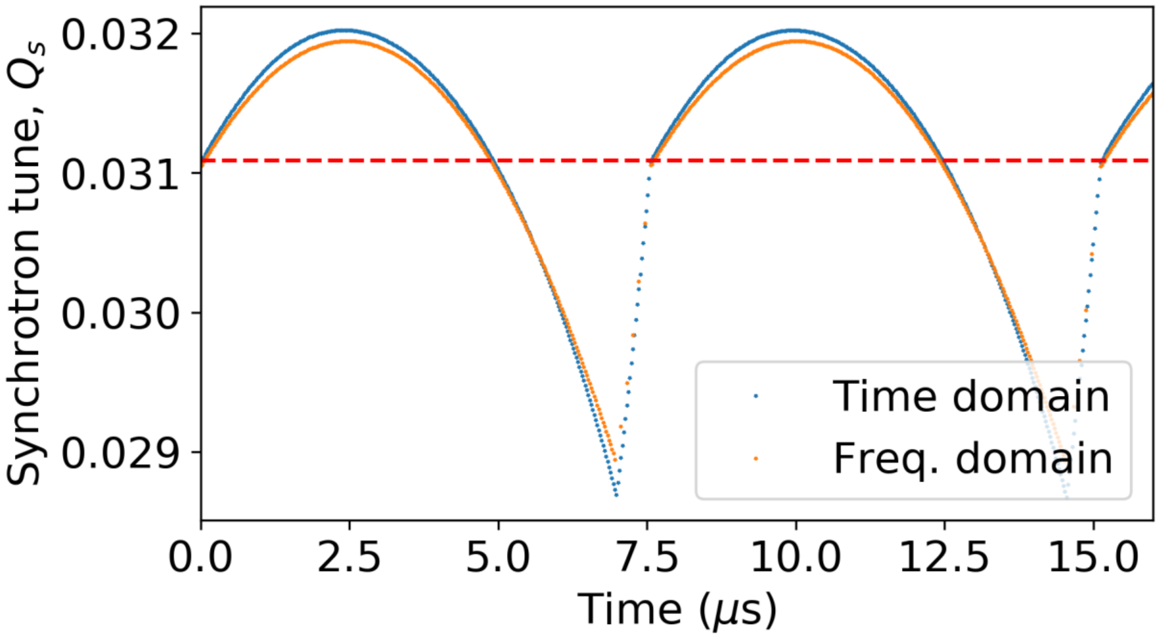




→ ~30% of RF power modulation even for stable operation
→ ~1 % increased spread in Q_s for pilot bunches

Impact of feedback





→ ~30% of RF power modulation even for stable operation
→ ~1 % increased spread in Q_s for pilot bunches
→ Impact on RF power sources discussed in talk of I. Syratchev

Summary

Beam stability constraints required further reduction of total RF voltage for Z mode with Reverse Phase Operation (RPO) mode

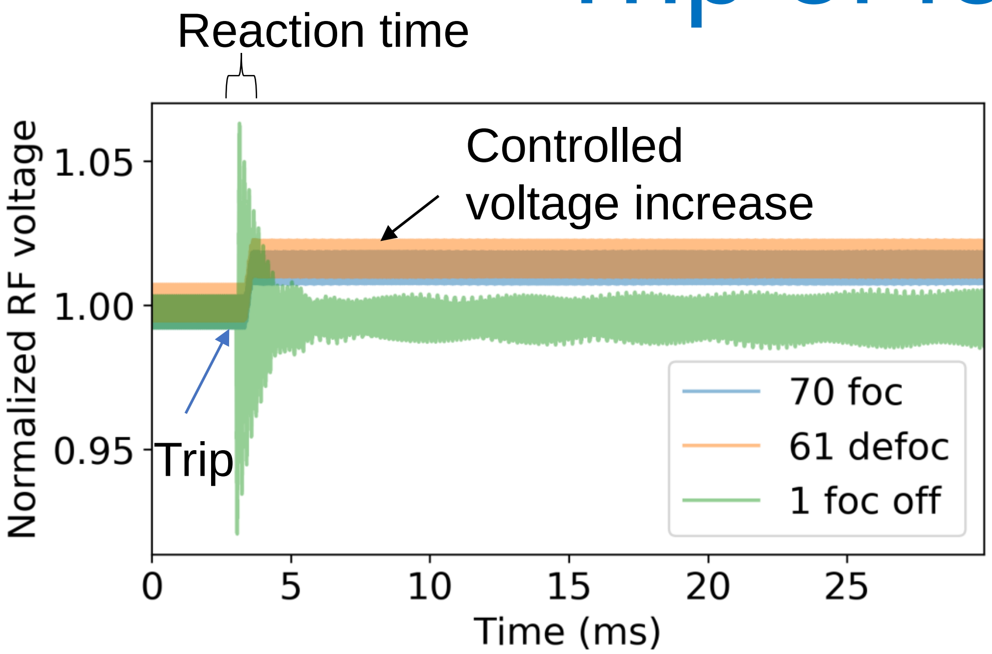
Presence of pilot bunches modifies the synchrotron frequency spread if some gaps remain empty

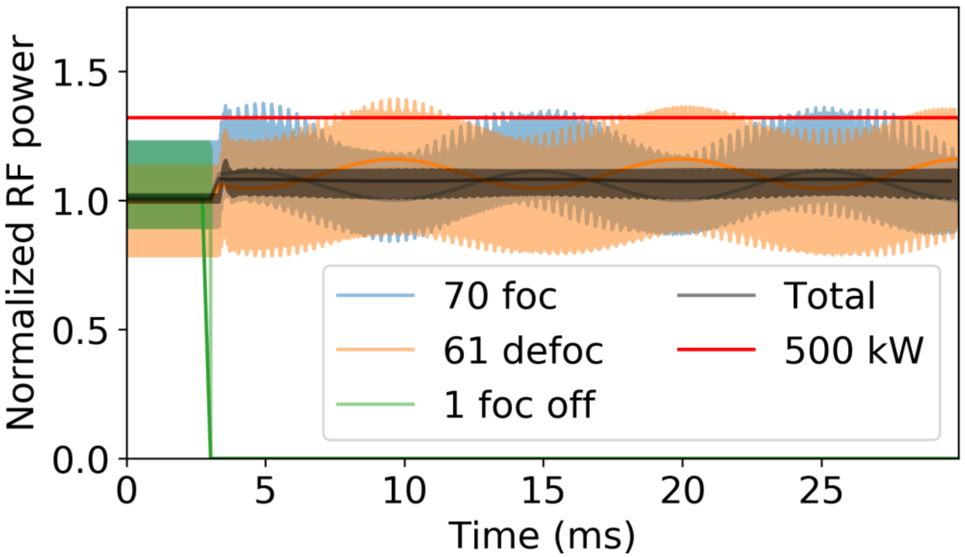
RF feedback with finite gain leads to a small increase of the spread and about 30% RF power transients

Thank you for your attention!

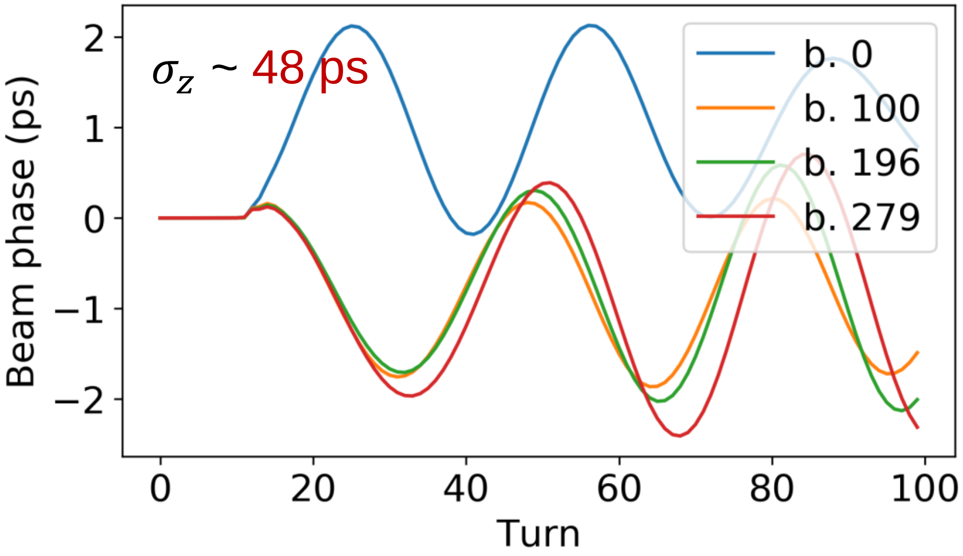
Backup slides

Trip of focusing cavity

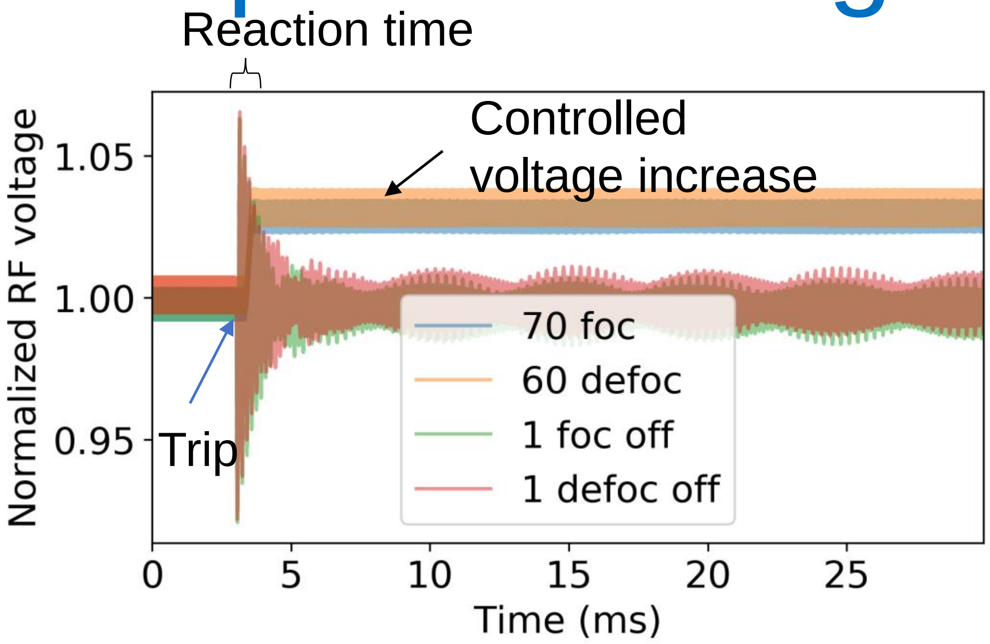


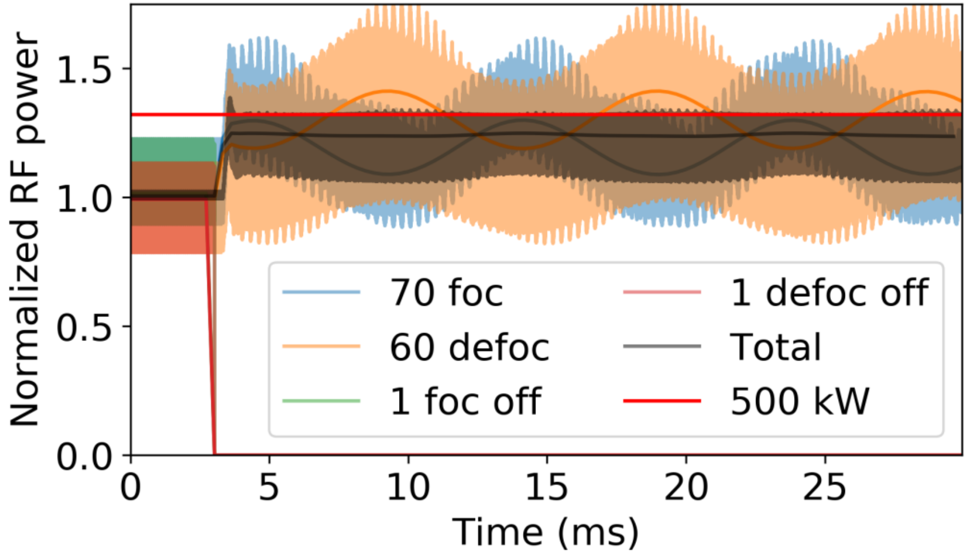


- Short RF voltage transients ~6%
- Peak power of other cavities is modulated at synchrotron frequency (avg. <15%, peak <40%)
- Initial bunch oscillation amplitude is <4% of rms bunch length



Trip of focusing and defocusing cavities





- Short RF voltage transients ~6%
- Peak power of other cavities is modulated at synchrotron frequency (avg. <45%, peak <80%)
- Initial bunch oscillation amplitude is <8% of rms bunch length