Update on strong-strong beam-beam simulations with 2-cell cavities operated in reversed polarity at the Z

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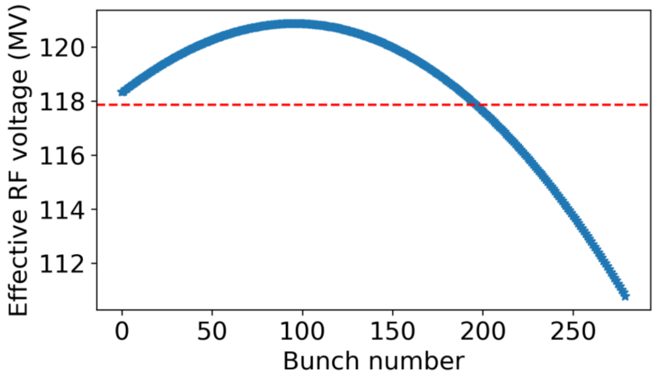
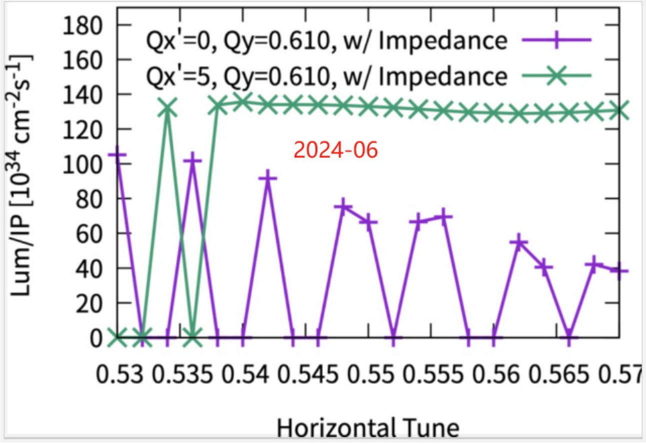
- Reminder about beam loading with RPO
- Instabilities with a higher voltage
- ‘Baseline’ scenario and impact of the voltage spread
- Outlook

Reverse polarity operation of the RF at Z

- Operating with 2-cell cavities in reverse polarity (instead of dedicated single-cell cavities) at the Z leads to a significant spread in voltage for the different bunches along the train due to beam loading
  - High voltage is favourable to reduce the relative bunch-by-bunch voltage spread

Option #	V_{nom} (MV)	V_{min} (MV)	V_{max} (MV)	$Q_{s,nom}$	$Q_{s,min}$	$Q_{s,max}$	$\Delta Q_s / Q_s$
Baseline	88.48	78.86	92.47	0.0311	0.0289	0.0319	10%
1	103.00	94.83	106.43	0.0341	0.0324	0.0347	7%
2	117.86	110.77	120.86	0.0368	0.0355	0.0373	5%
3	132.96	126.71	135.61	0.0394	0.0383	0.0398	4%





- Y. Zhang (M. Migliorati @ FCC 2024) simulations show that at the nominal voltage (79MV), the X-Z instability is well suppressed with a chromaticity of 5 units

X-Z instability with higher voltage

- First simulations featuring higher voltage seemed encouraging (X. Buffat, et al. @ FCC-ee optics meetings 6 and 27 nov. 2024) but were in contradiction with Y. Zhang's simulations which were predicting no stable working points once both horizontal and vertical impedances were included, even at high chromaticity

  → My simulations were inaccurate due to a wrong setup of the effective radiation model in the simplified arc

  → Now they confirm Y. Zhang's findings (more detailed benchmark still ongoing)

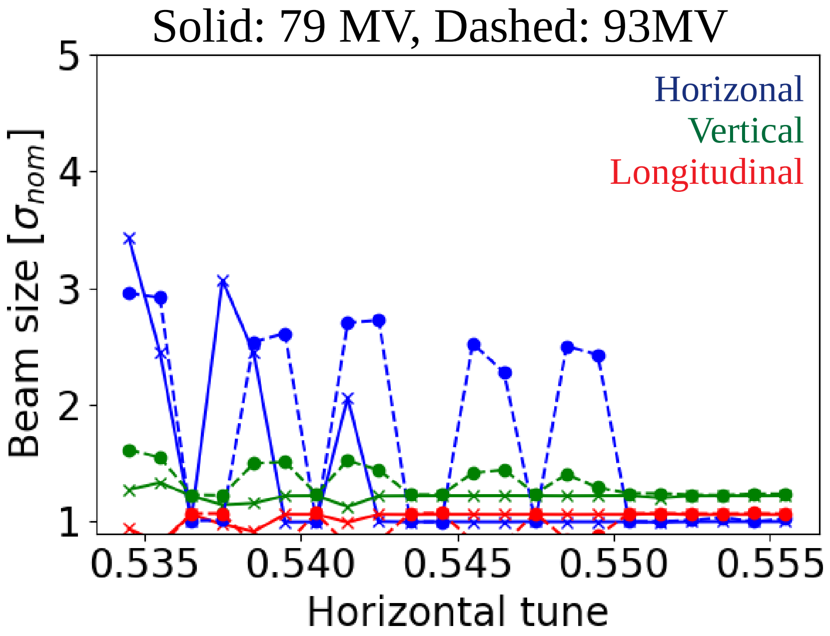
- The mechanism of suppression of the X-Z instability with chromaticity is not well understood and requires further studies

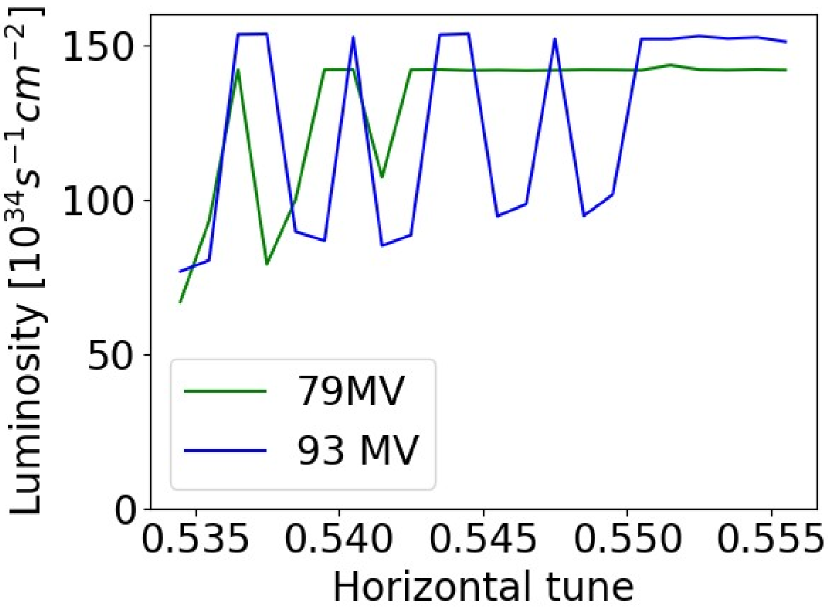
Baseline scenario

Setup:
→ All impedances, no factor 2
→ Chroma x/y: 5 / 2
→ Active damper in both plane with 10 turns damping time

- Lowest voltage corresponds to the current baseline → Compatible with Y. Zhang's result (Active damper does not seem to have a big impact)
- For the bunches featuring the highest voltage, additional instabilities appear

→ Testing now with high chromaticities

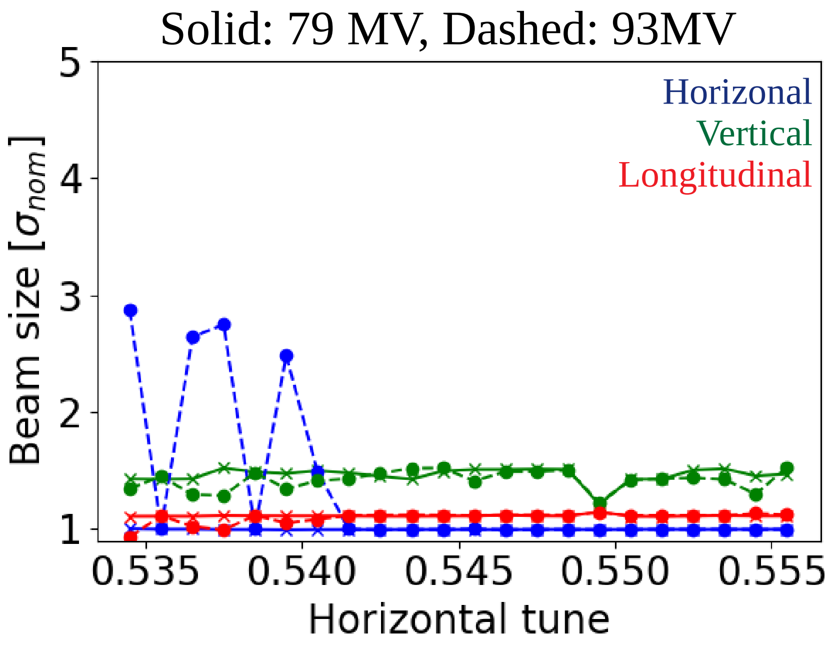


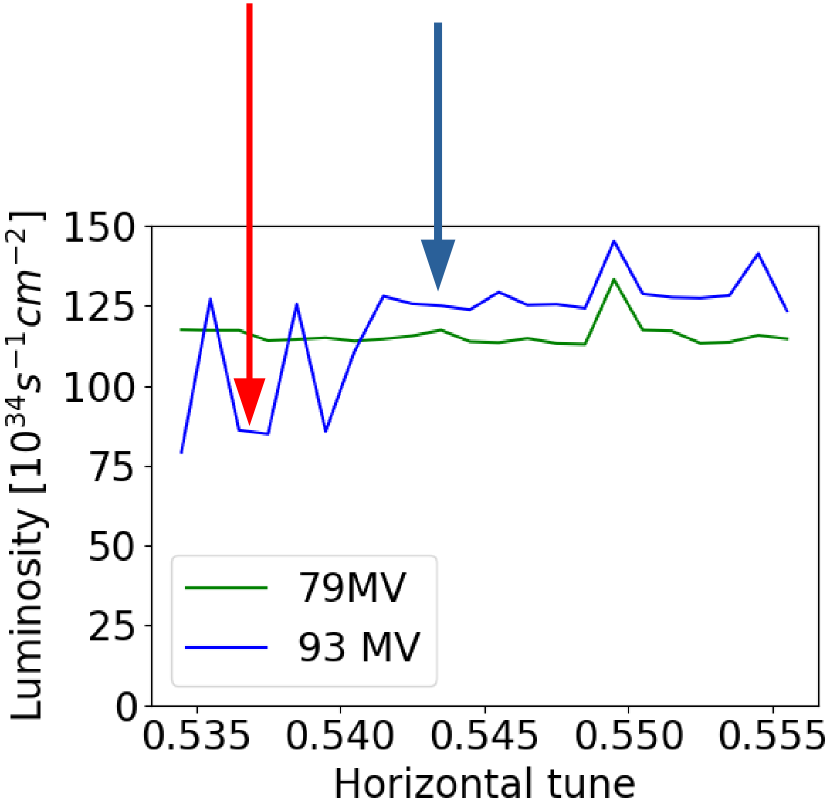


Baseline scenario

Setup:
→ All impedances **multiplied by 2**
→ Chroma x/y: 5 / **5**
→ Active damper in both plane with 10 turns damping time

- With higher impedance and higher vertical chromaticity we find stable working points compatible slightly above the present one

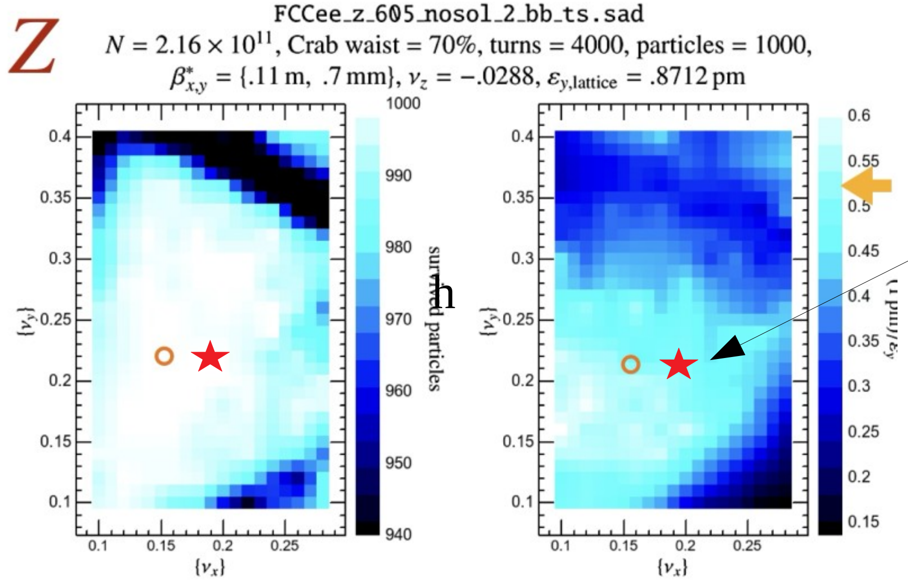




Tune space at Z with ‘baseline’ voltage and 2 cell cavities

79 MV

(K. Oide @ FCC week 2024)



New working point

Conclusion and outlook

- There exists acceptable working points for bunches experiencing significant RF voltage spread due to the 2-cell cavities in RPO only with the lowest voltage considered (88MV → min/max: 79/93 MV)
  - Including impedance margin (2x current model)
  - High chromaticity (5 units in both planes) is required

    → Robustness requires further investigation (e.g. sensitivity to chromaticity changes, asymmetries)

    → Stability during the injection process (intermediate intensities)
- A better understanding of the mitigation of the X-Z instability and of the mode coupling instability of colliding beams in the vertical plane with chromaticity is required (also with 1-cell cavities) to clarify the limits