Some initial thoughts on the decay-ring RF system

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Setting the scene:

- Ring circumference: 6911.6 m = 23.05 μs
- Harmonic numbers: 40 MHz: 924
  80 MHz: 1848
- Bunch charge: 10 · 3.7E12 e = 5.9 μC (!)
- Beam current:
  237 A during batch (20 bunches, 500 ns),
  5.1 A average (924 buckets, 23 μs).

Problems: very heavy and very transient beam loading!

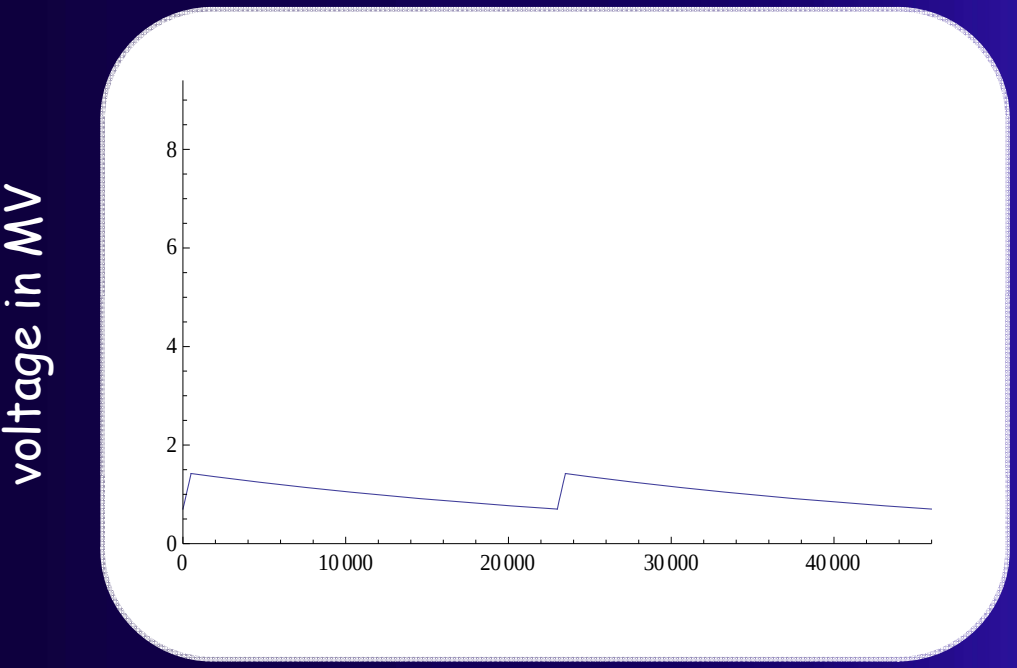
First, let's just look at a cavity from the beam (without any RF amplifier):

… now imagine a cavity with (just) a 100 kΩ shunt impedance!

- For short bunches, the RF component of the beam current is I_B = 474 A.
  (compare: LHC beam in PS: 2.1 A)
- In 100 kΩ, this current would induce an RF voltage of 47 MV in steady state!
- Of course, for a high Q cavity, this steady state would not be reached during 20 bunches, but the induced voltage would behave (solution periodic with 23 μs) like:

Induced voltage

assuming R = 100 kΩ and Q = 4000



It should not surprise that the average induced voltage is around 1 MV, i.e. 100 kΩ · 10.2 A

But: what about the power?

- However, if these 100 kΩ were real, the power lost in to them would be

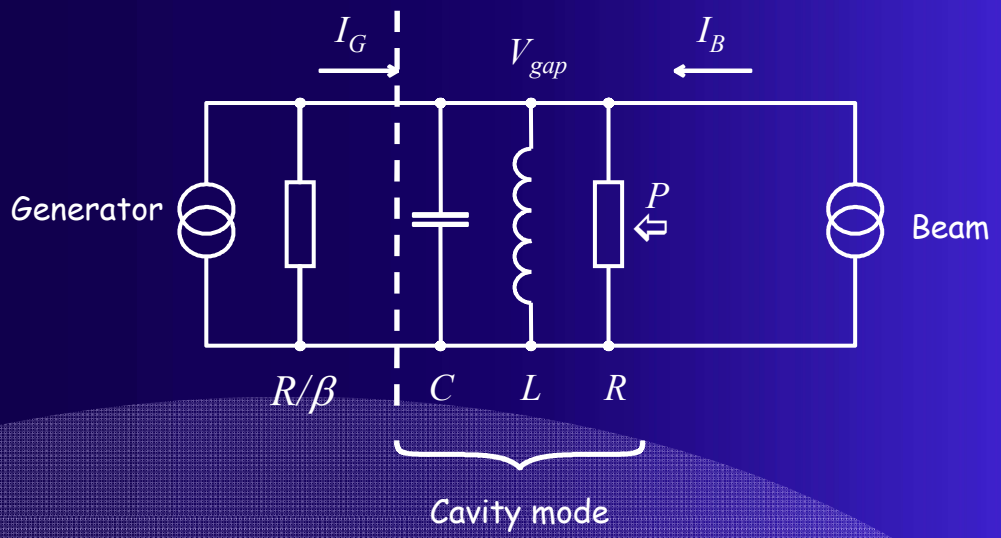
$$0.5 \cdot 10.2\ A \cdot 1.02\ MV = 5.2\ MW$$

... which of course would mean that the beam power would be lost rapidly!

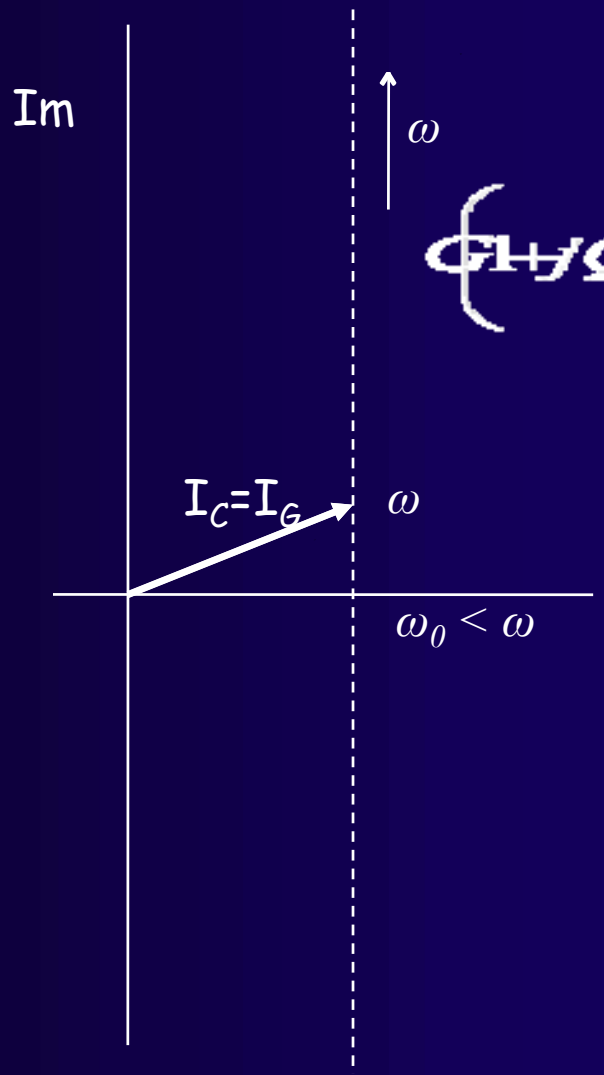
(20 MJ are stored in the beam)

- ... and if it were a reactive impedance? Then the beam could induce by itself the voltage necessary! From the power balance this works, but it would make the beam (Robinson) unstable.

Now let's see cavity and beam from the amplifier:



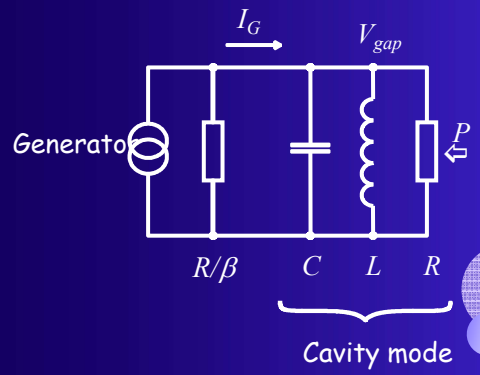
- The beam current shall be in quadrature to the gap voltage – it should be a "reactive", i.e. a "non-resistive" current.
- This means that there is no net power flow to or from the beam.
- Above transition, in the stable point of the stationary bucket this current is inductive.
- This current can be compensated by tuning the cavity down, e.g. by adding a parallel C.
- The relative detuning should be $\frac{R/\beta}{Q_{ext}}$.
- In this case, the generator would only have to deliver the power lost in the cavity (high Q preferable!)



no beam, some mismatch

$$\left[\quad\right]$$

Re (direction of V_{gap})



Im

ω

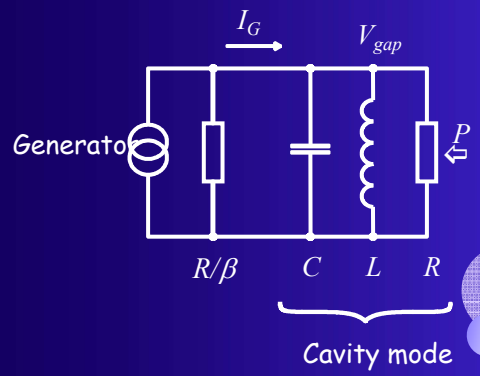
no beam, tuned to match

$$G_{1+\beta}\left[\frac{\omega}{\omega}\right]$$

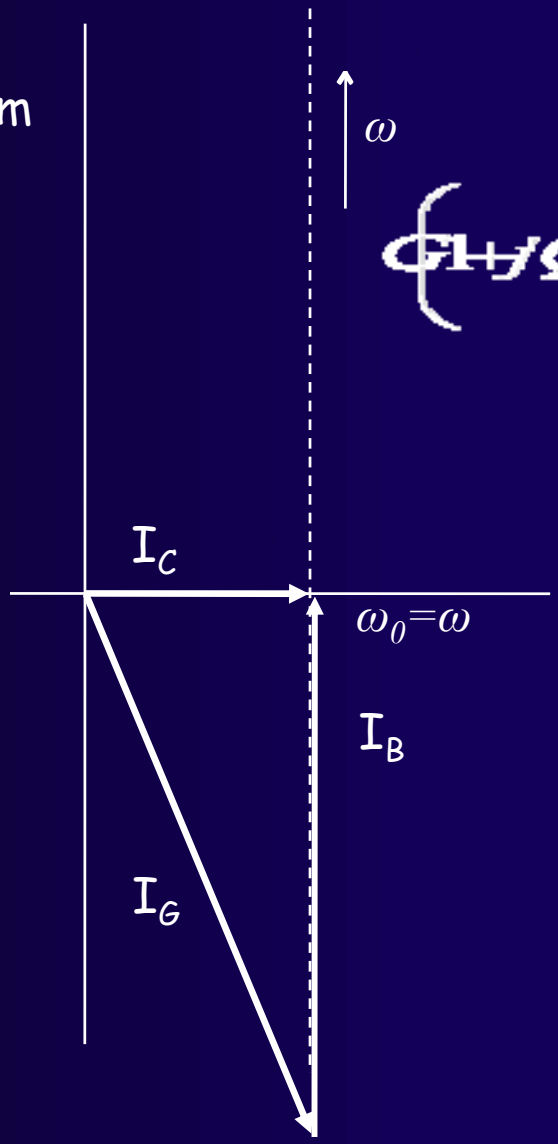
$I_C=I_G$

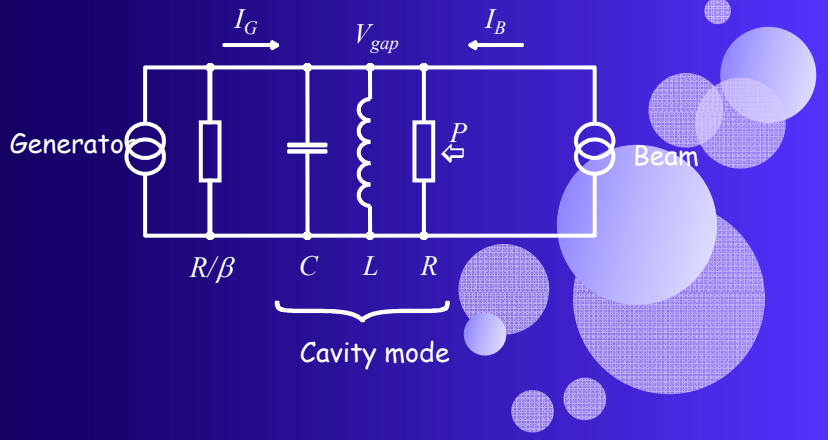
$\omega_0=\omega$

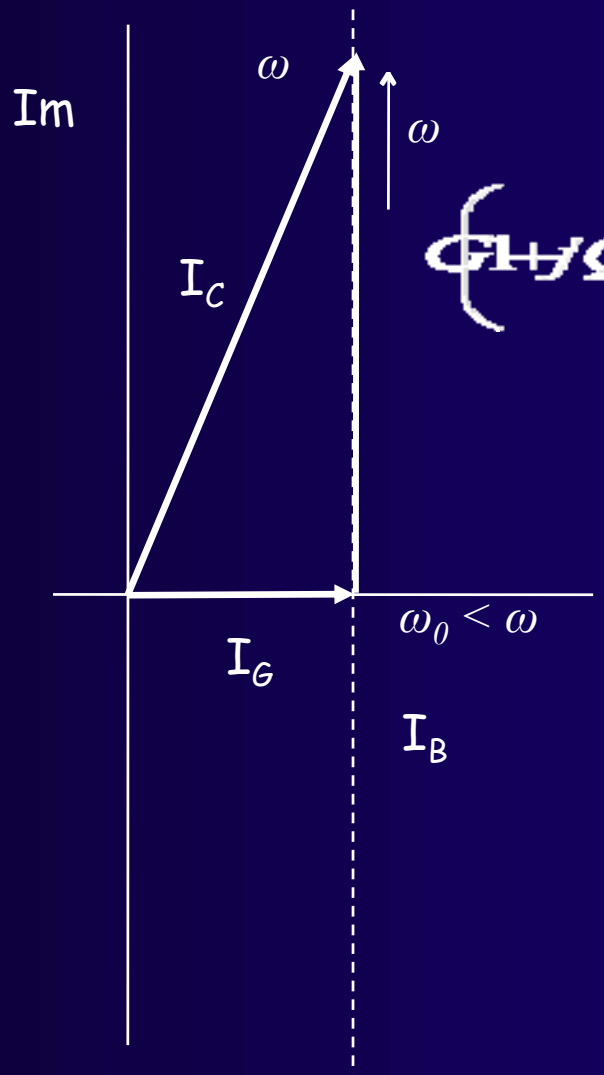
Re



beam on, matching lost

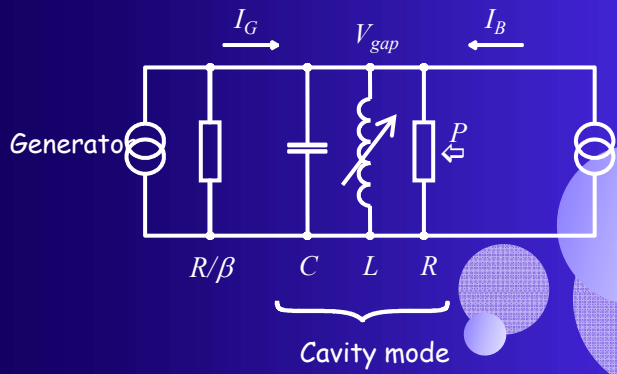


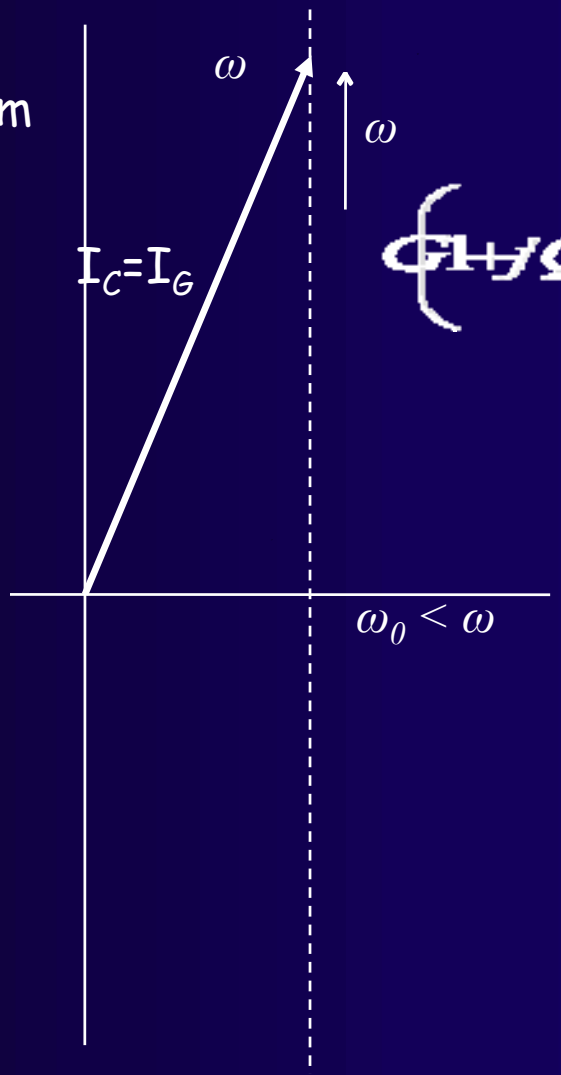




beam on, matching to beam

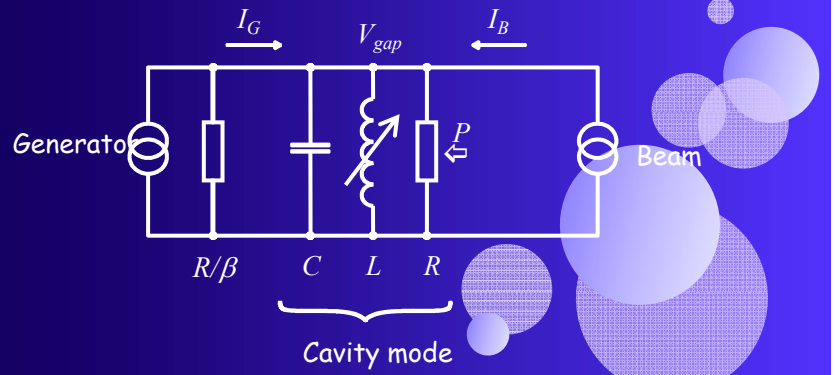
$$G_{1+j\left(\frac{\omega}{\omega}\right)}$$

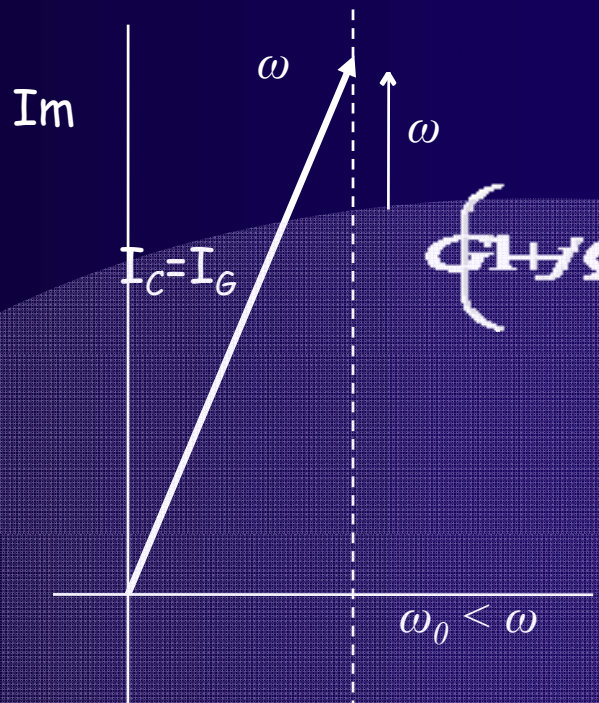




beam off, sudden mismatch

$$\left[1+j\left(\frac{\omega}{\omega}-\frac{\omega}{\omega}\right)\right]$$





beam off, sudden mismatch

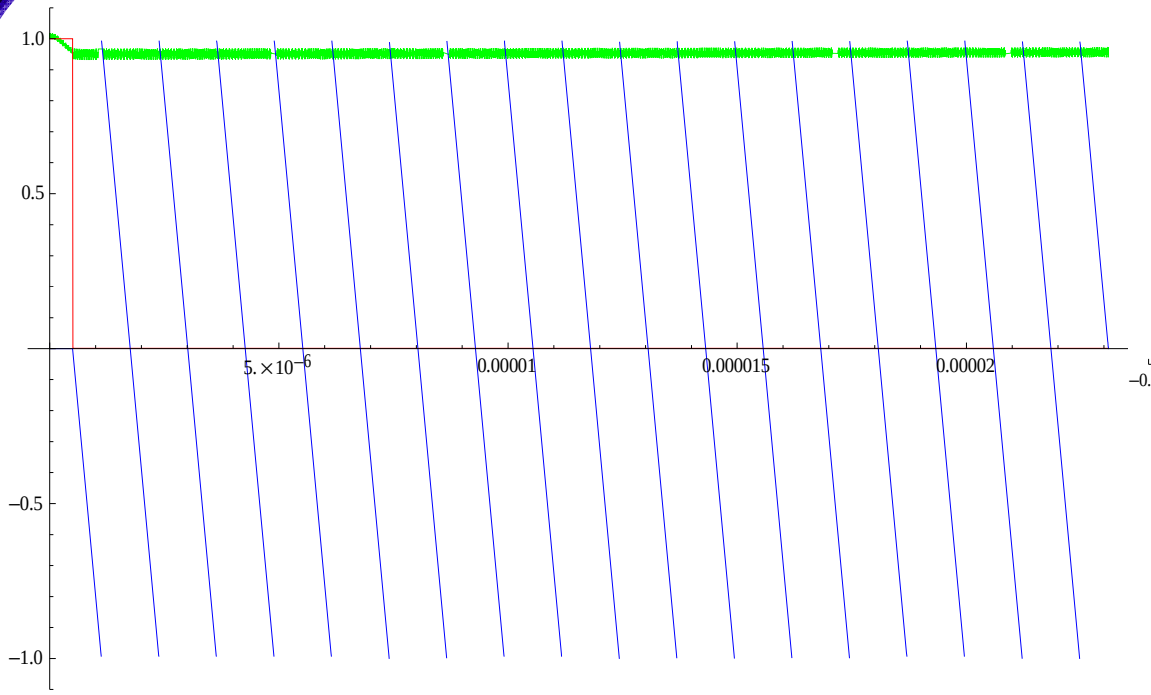
$$\left[\begin{matrix} \omega & \omega \\ \omega & \omega \end{matrix}\right]$$

- In absence of the beam, one could allow an arbitrary gap voltage.
- For example, one could continue to feed power at $\omega_0 < \omega$ where the cavity is tuned.
- But 23 μs later, phase & amplitude must be correct again!

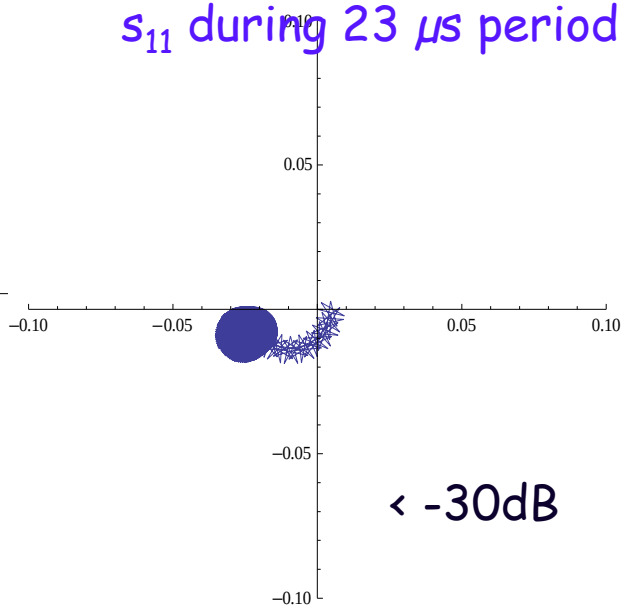
For example:

- Q: 20 000, R: 500 kΩ, V_{gap}: 300 kV, I_B: 474 A
- f: 40 MHz (h: 924), beam on 20 periods (500 ns)
- result: f_0 : 39.218 MHz
- Integrated phase slip: (40-39.218) · 0.025 · 904 turns = 17.67 turns; chose closest integer (18) …
- … so in absence of beam, feed f_{opt}: 39.203 MHz!
- The RF power amplifier has to deliver 90 kW in this example.

Result of transient analysis:



s_{11} during 23 μs period



< -30dB

Blue: phase of drive current in units of π (corresponding to frequency offset)

Green: gap voltage in units of 300 kV

Red: total current in units of 474 A

Summary:

- Not conclusive yet – only first ideas – more work is needed!
- The heavy transient beam loading is unprecedented.
- Since there is no net energy transfer to the beam, the problem might be solved using a linear phase modulation in the absence of the beam, mimicking detuning – this could reduce gap transients.
- A high Q cavity (S.C.?) would be preferable.