Finding the distribution of wake field induced losses in diagnostics structures for realistic machine conditions

Using time domain simulation and combined domain analysis in order to find the loss distribution in structures.

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Diamond light source

Why are we worried?

- In some of our diagnostic structures the wake loss factor is large enough to give uncomfortably large amounts of energy being lost from the beam.
- Current settings imply ~125W lost from the beam at the striplines.
- We have broken a 50W load on a stripline.

Where does it go?

- **Dissipated into the structure**
- **Transmitted down the beam pipe**
- **Transmitted out of measurement ports**

We use an **EM simulation** to distinguish between these conditions
Good for getting a quick idea of what proportion of energy stays in the structure

Our approach

Time domain EM simulation
Excite with bunch
Record wake potential and port mode signals

Wake potential

Combine charge distribution with wake potential

Energy lost from beam

Port signals

Integrate over time and sum over ports and modes

Energy lost into ports

Difference is energy left in structure

Repeat as needed

How do you trust your models?

2 stipulations

- The mesh must be fine enough to have stable results.
- The simulation must have run long enough for the majority of energy to have left the structure.

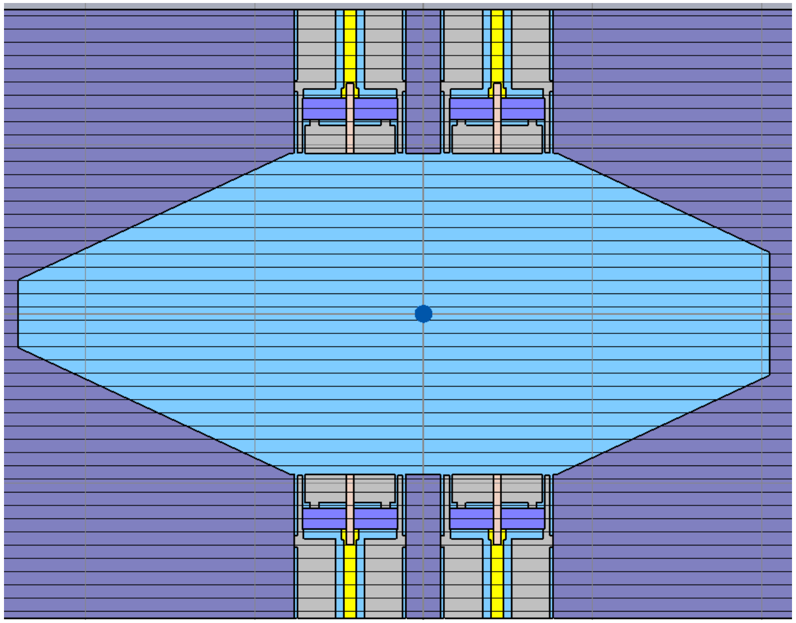
Verification

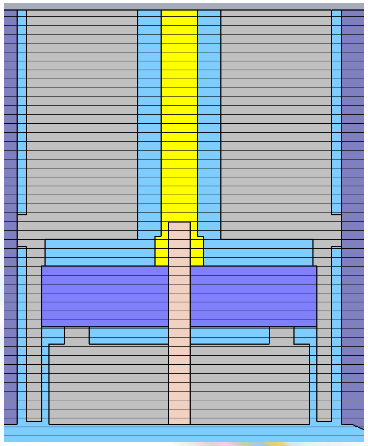
We use both **time** and **frequency** domain analysis to check for model stabilisation and for unphysical results.

- Do the energy / wake potential / port signals decay over time?
- Is more energy emitted from the structure than was lost from the beam?
- Are the Qs stable?

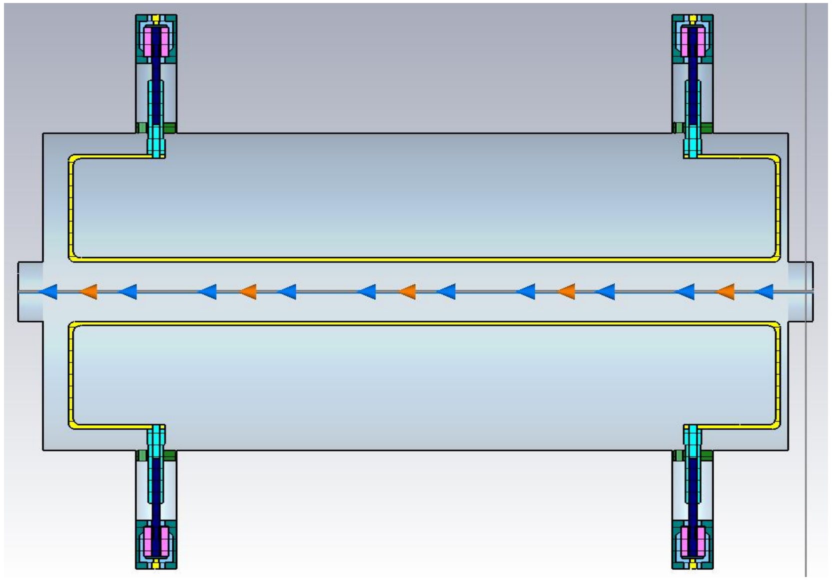
Doing the analysis in both domains also allows for valuable cross checking of the analysis code.

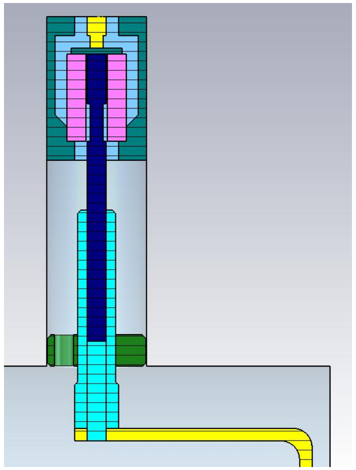
Example: BPM





Example: Stripline





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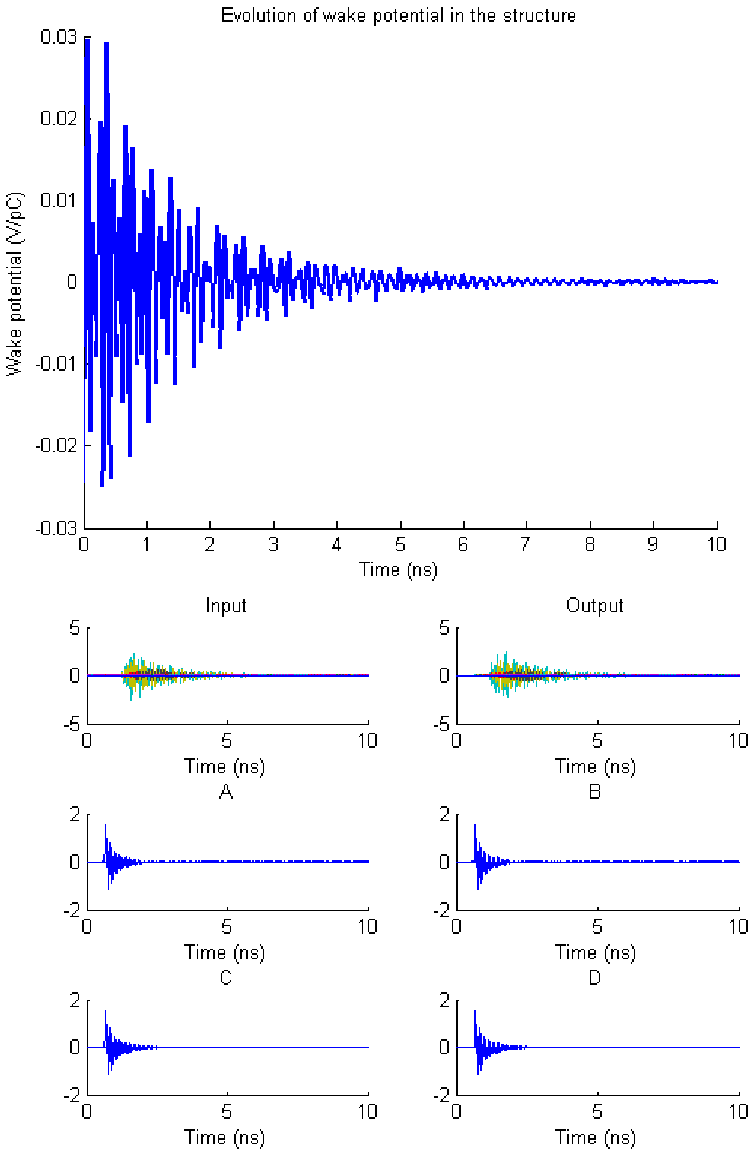
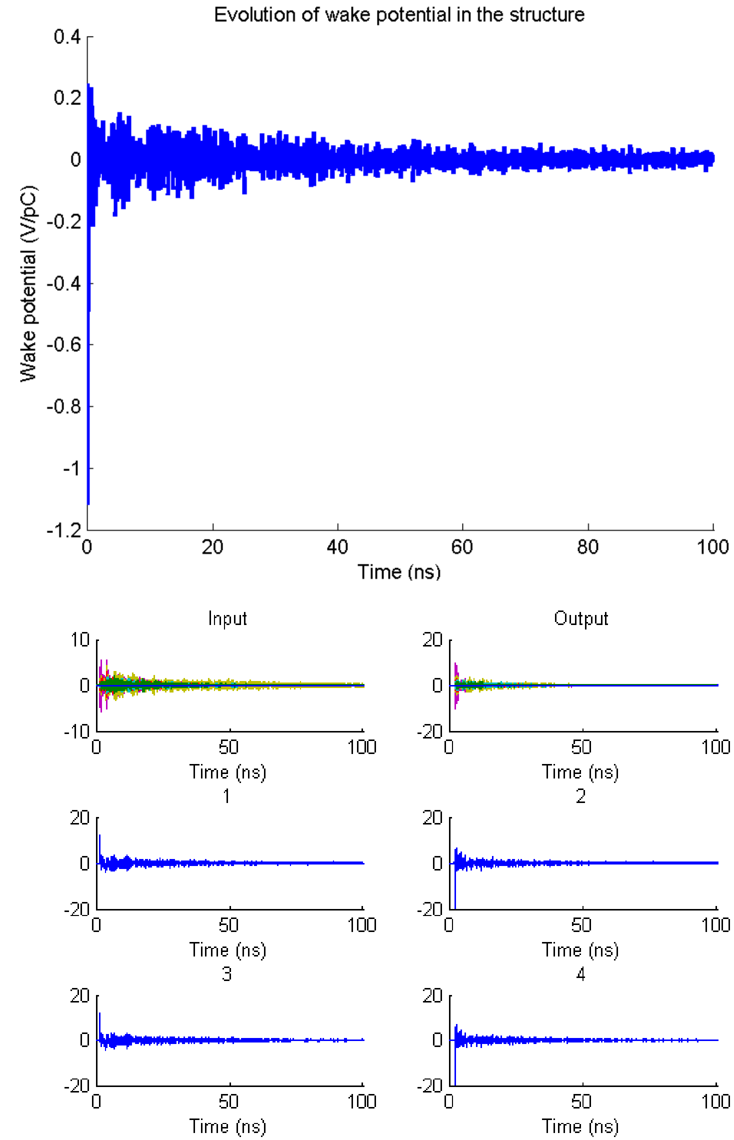


Example:Striplines



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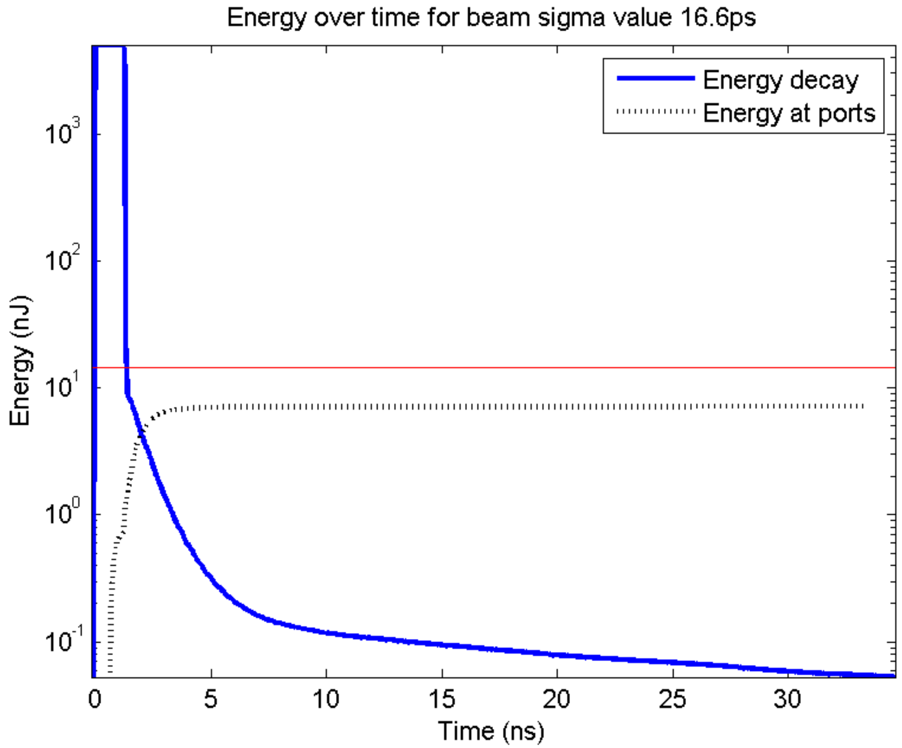

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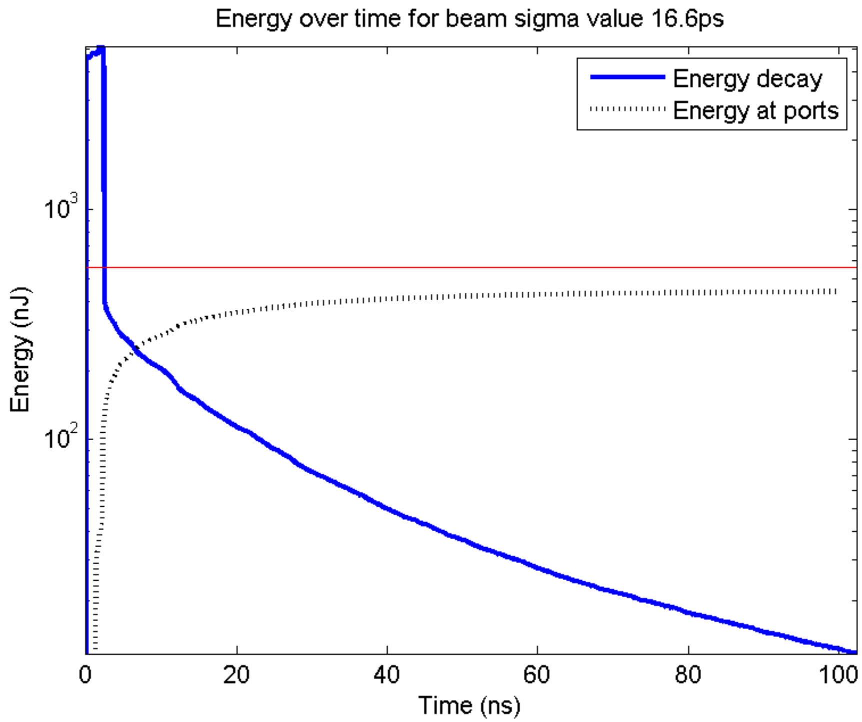

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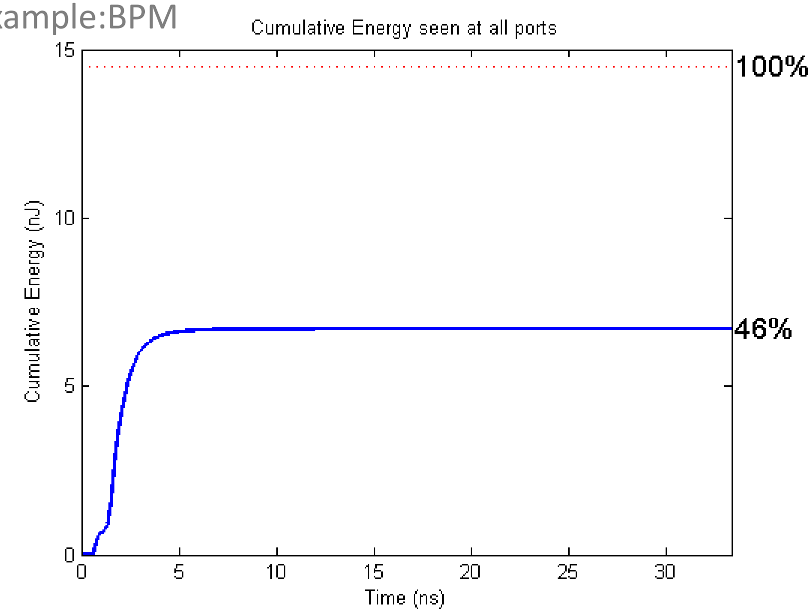

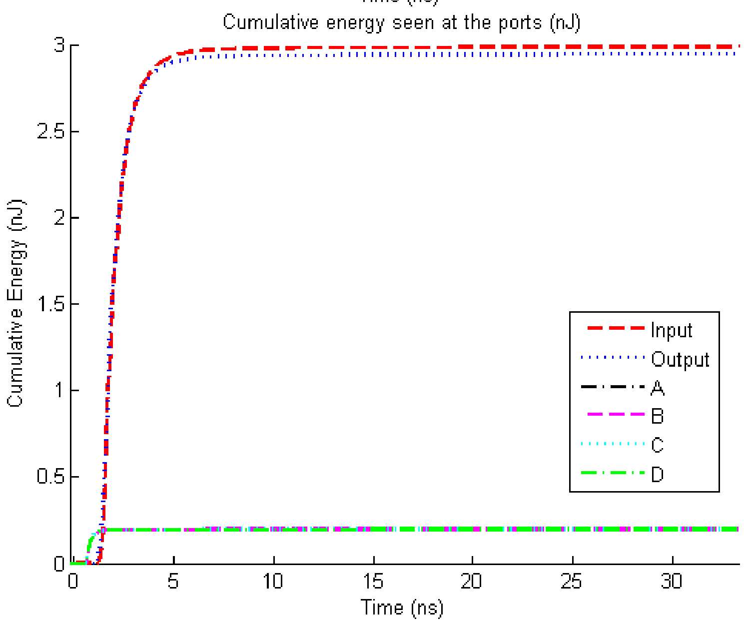

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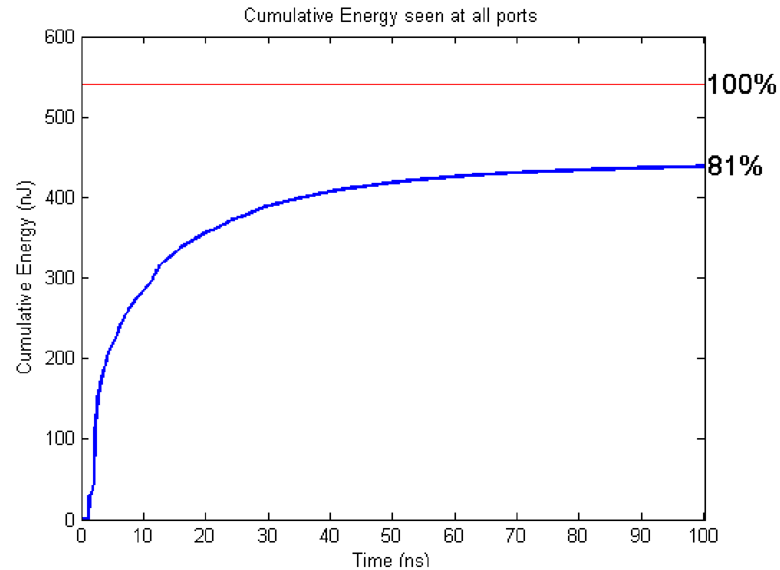
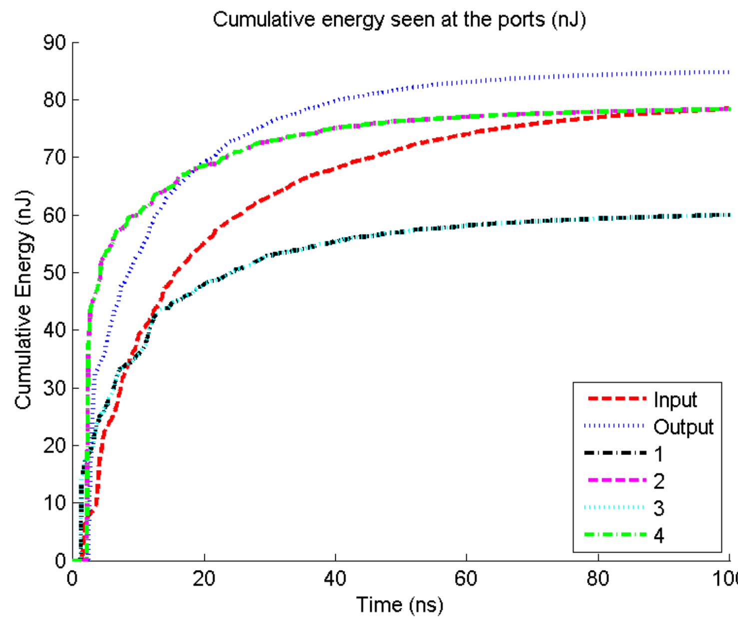
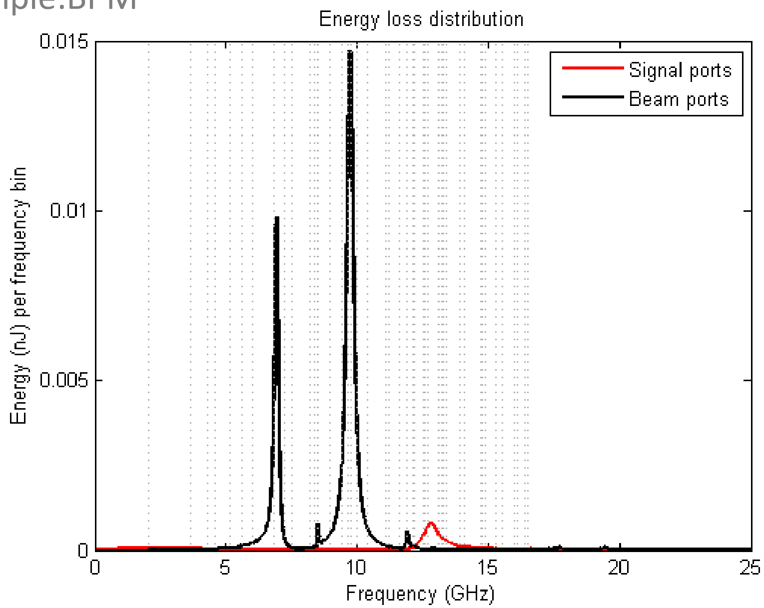
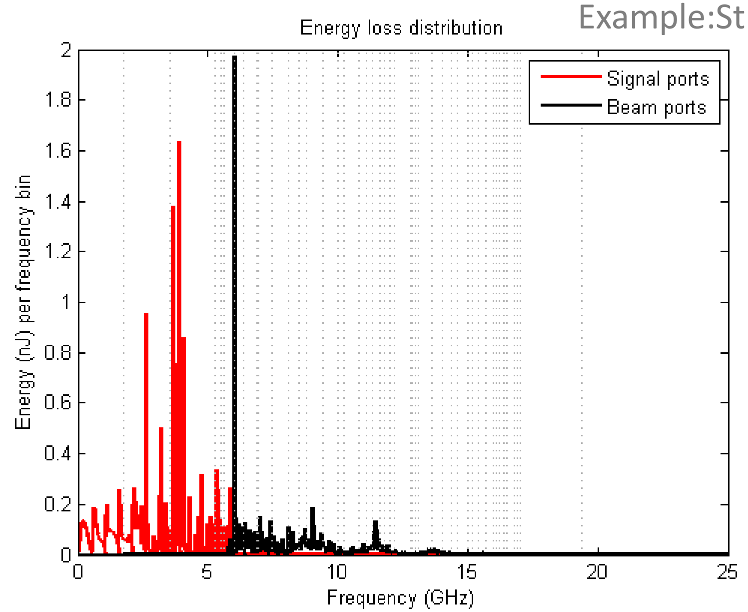


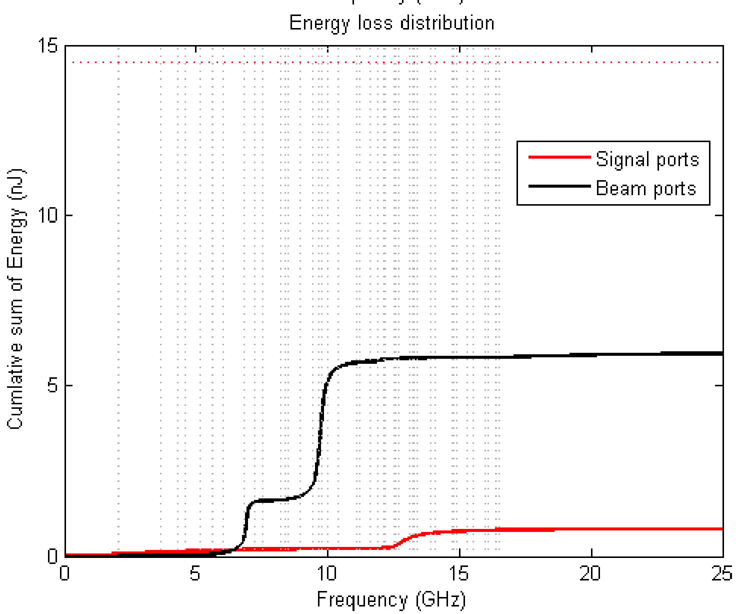


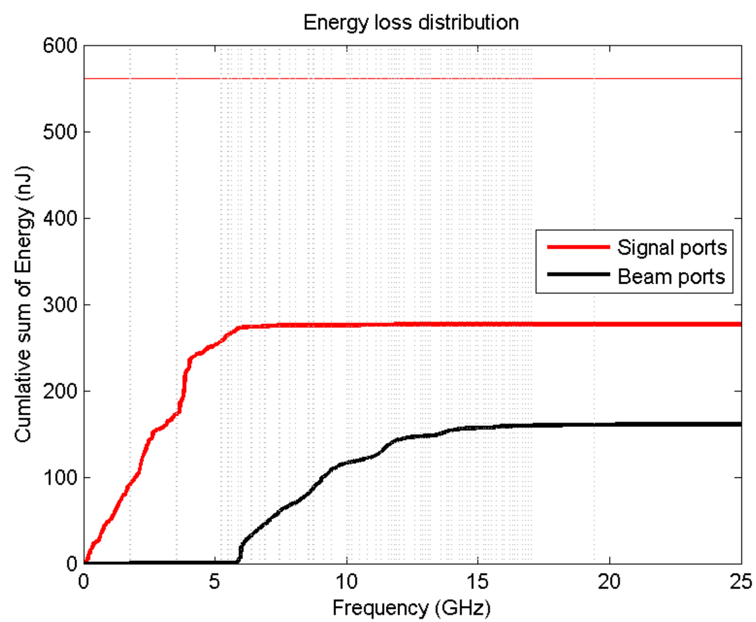
Example:BPM

Example:Striplines









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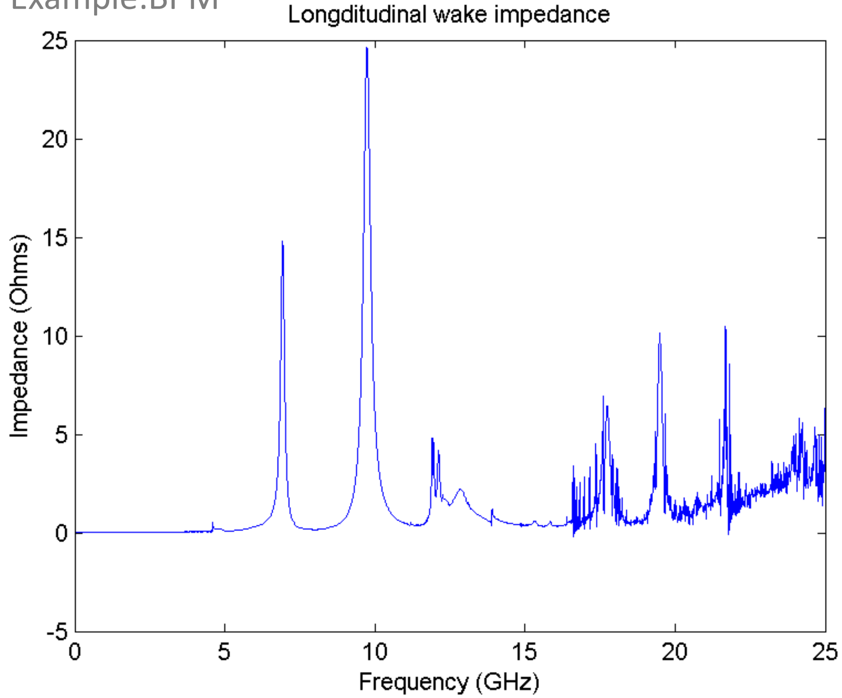

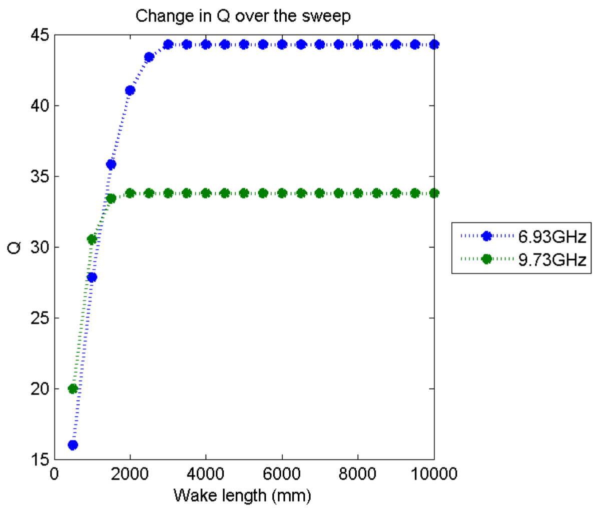

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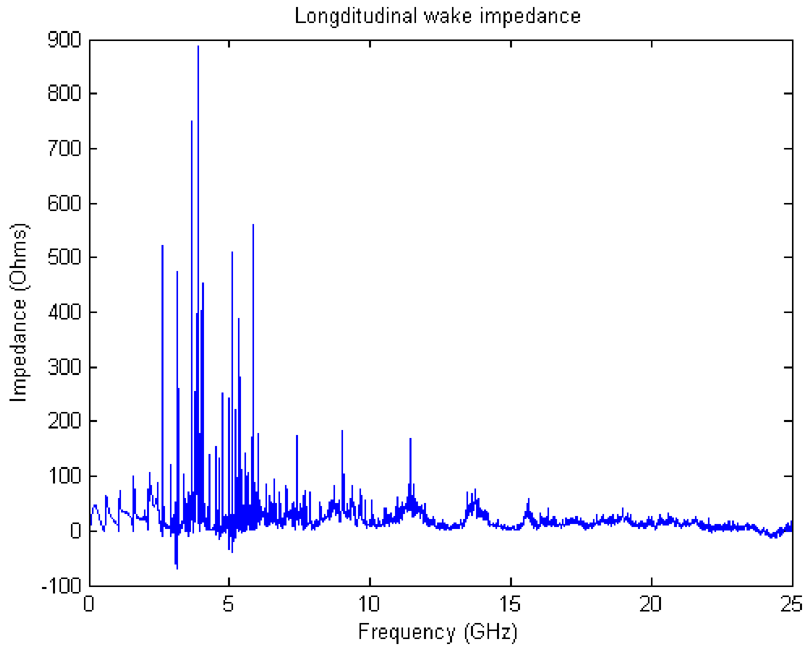
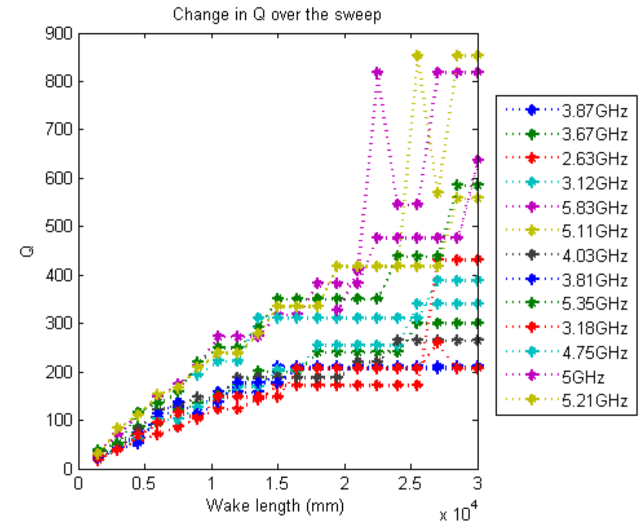




So far:

we can get to a point of trusting that a model is a good representation.

we can find out how much energy is deposited into the structure by a single bunch.

That is not the question we want answered.

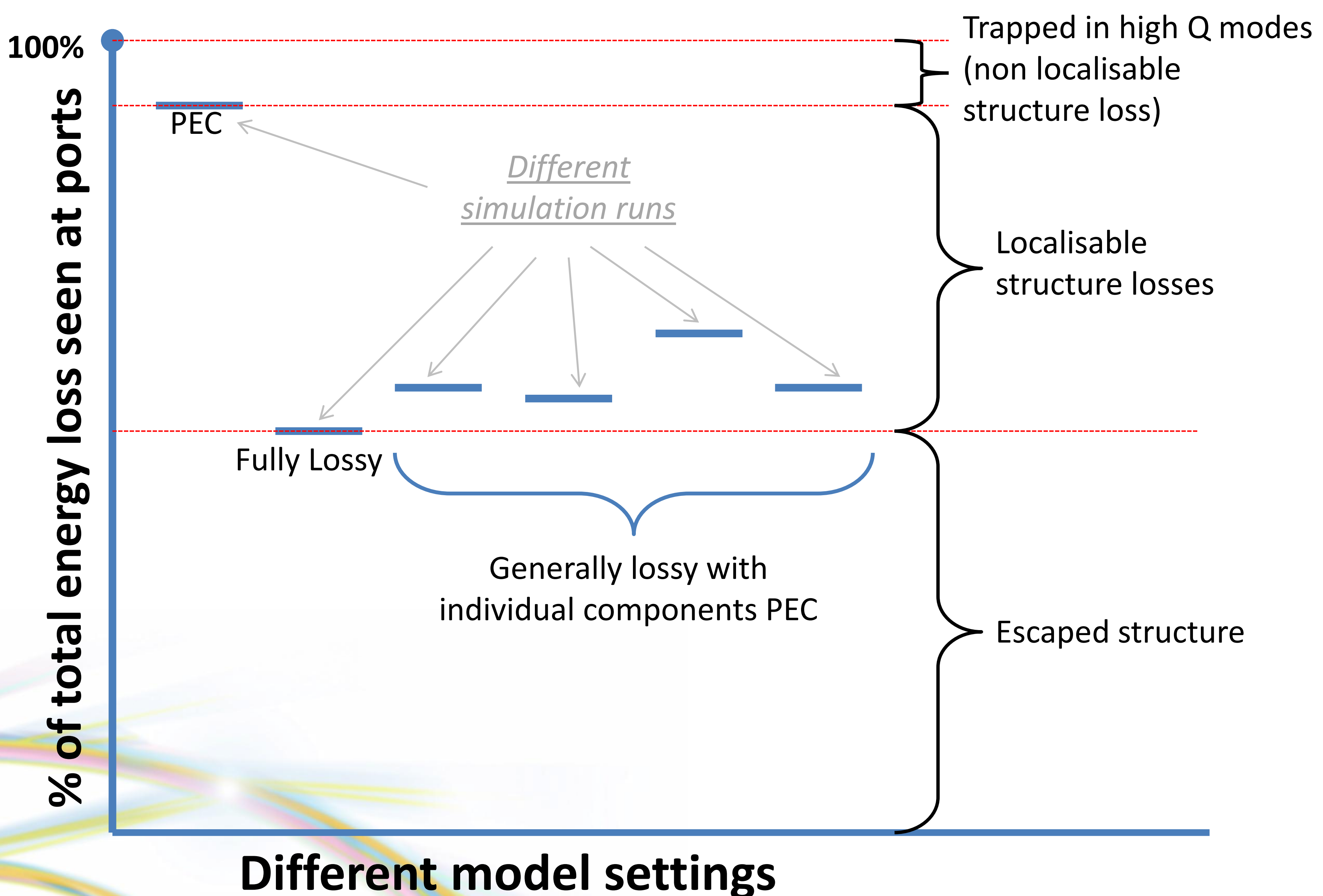
We want to know:

Under normal operating conditions where within the structure does the energy go?

Requires an extension to the analysis

Requires more simulations

One structure… many simulations



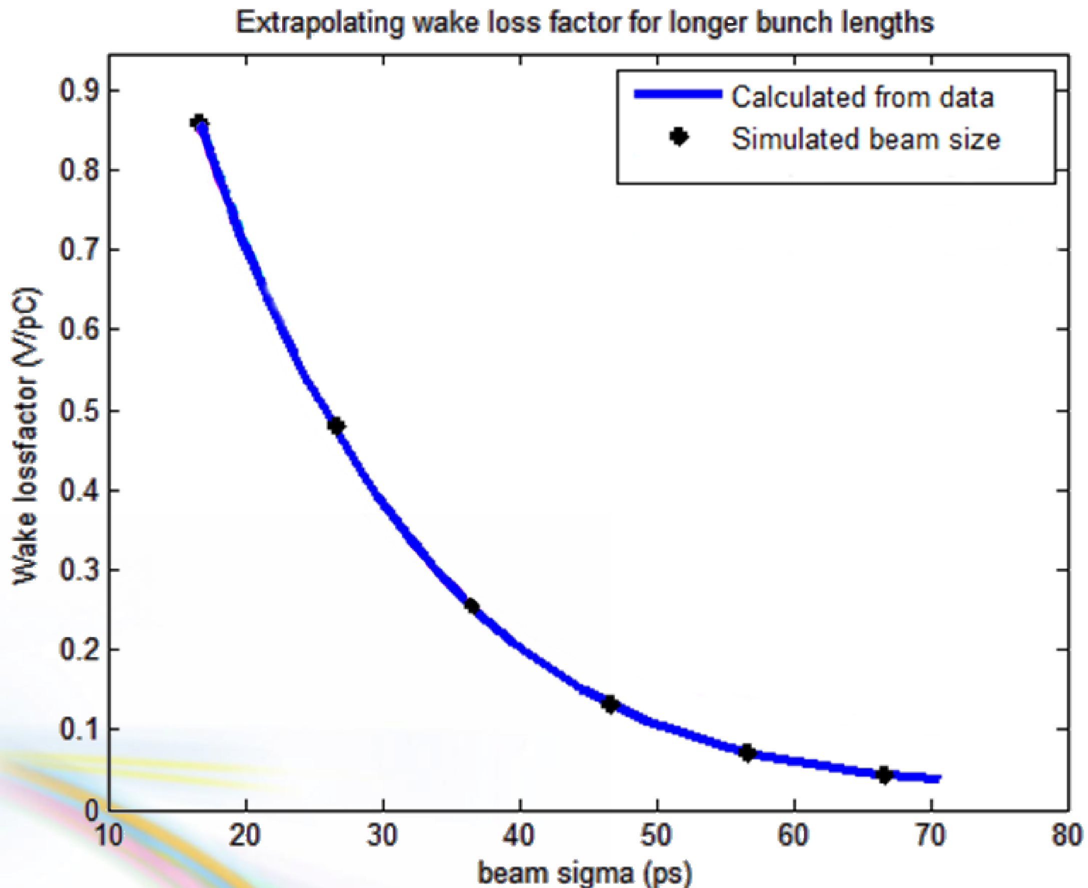
Beyond a single bunch

We have the wake impedance which is the response of the structure **only**.

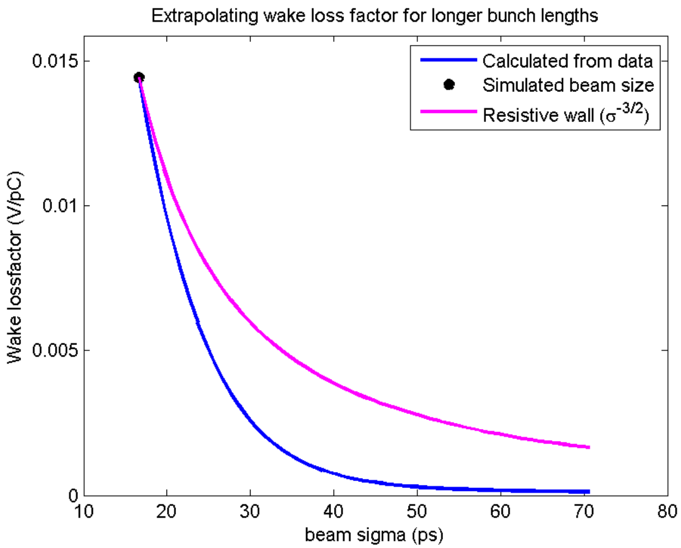
- We can now multiply it with different spectra which allows studies of...
  – multiple bunches
  – Different bunch lengths
  – Machine parameter studies
  – And more...

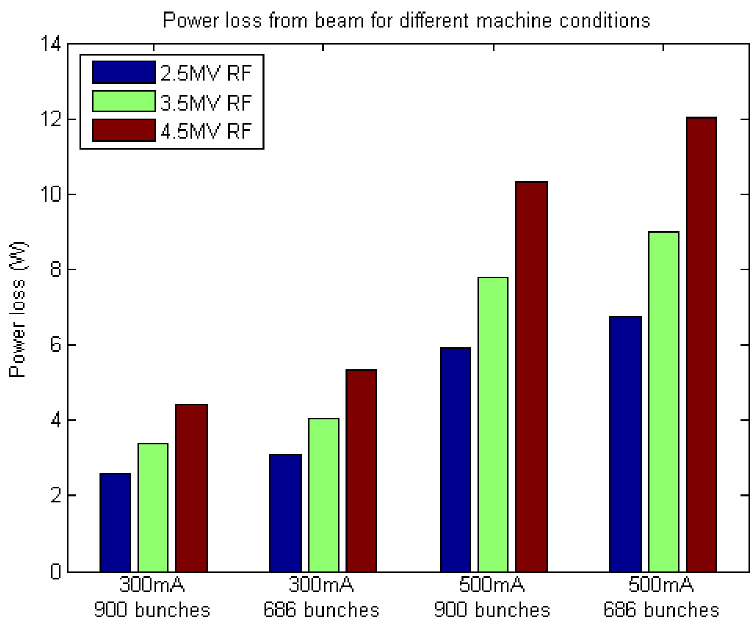
Can we verify this approach?

We can only check single bunch variation ... however the multi bunch extension uses the same technique just with different beam spectra.

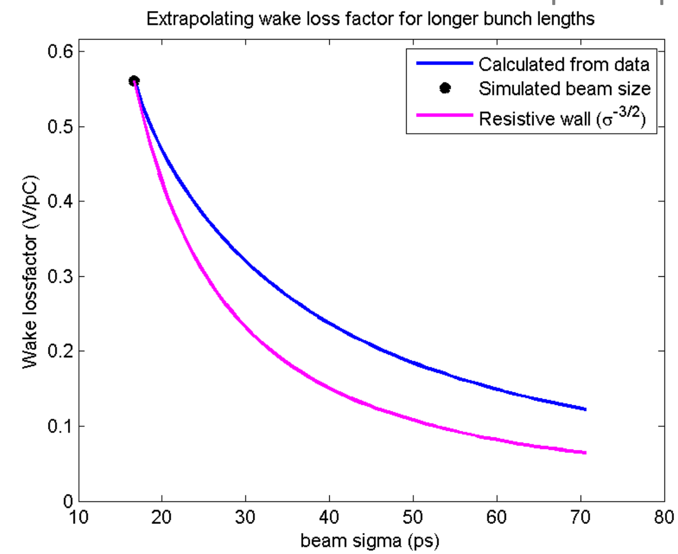


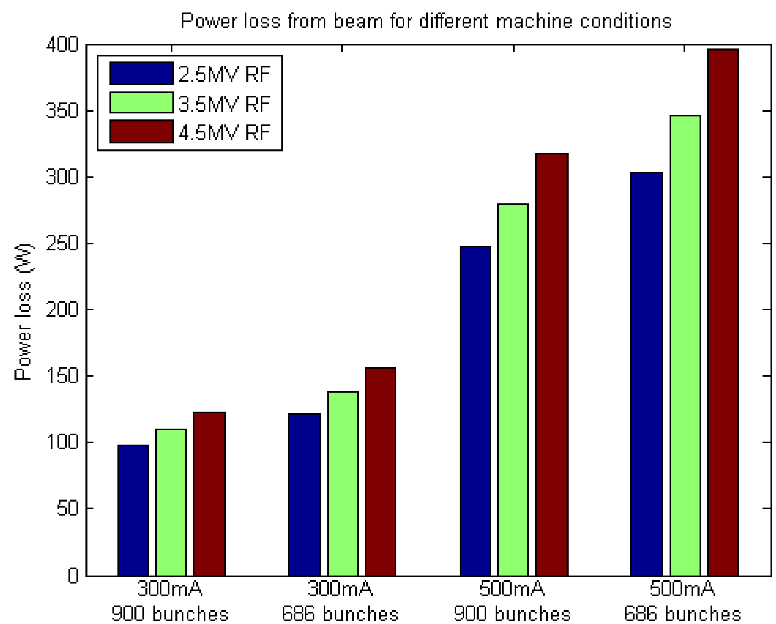
Example:BPM



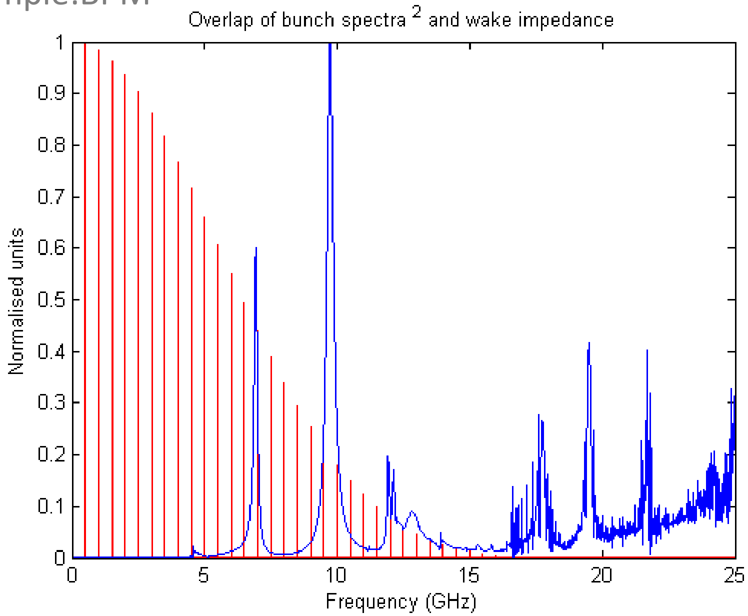


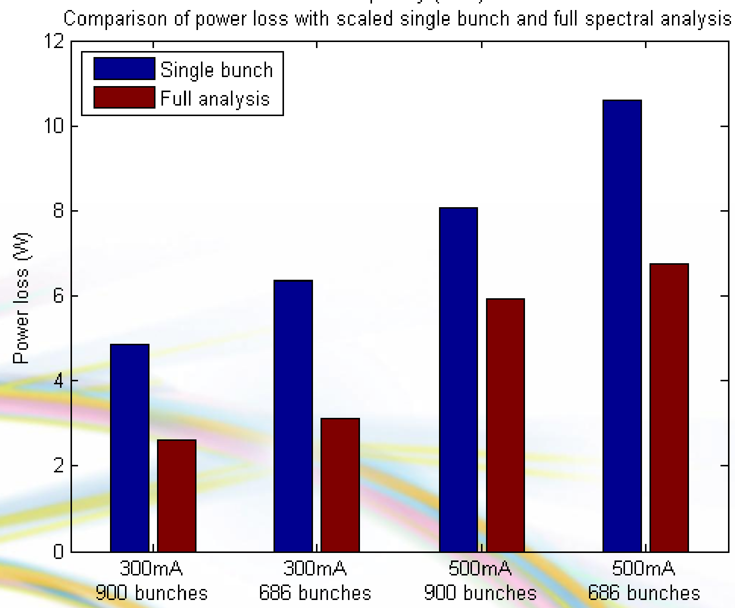
Example:Striplines



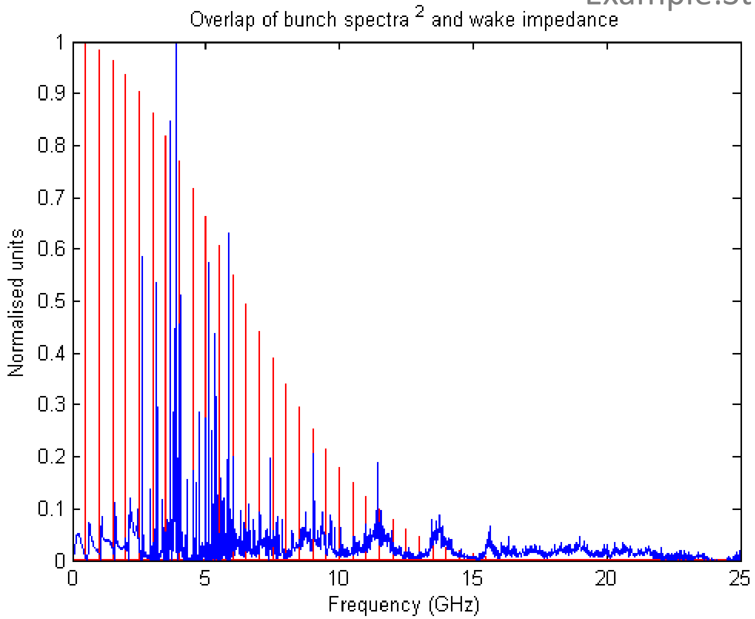


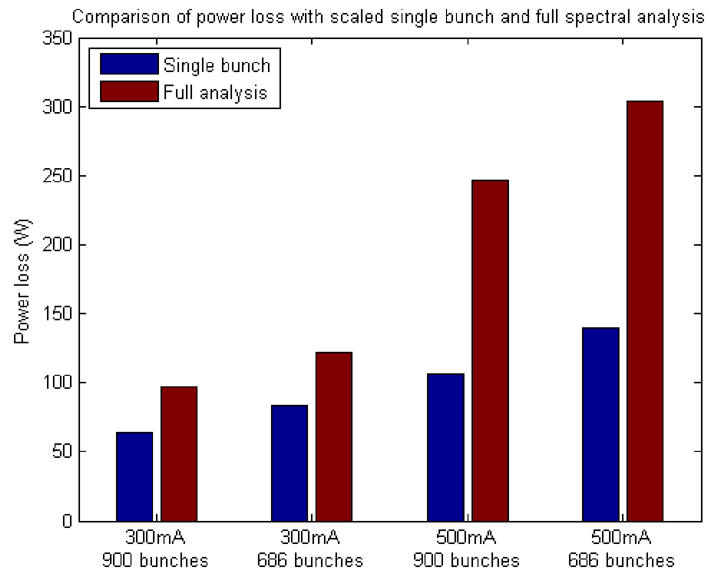
Example:BPM



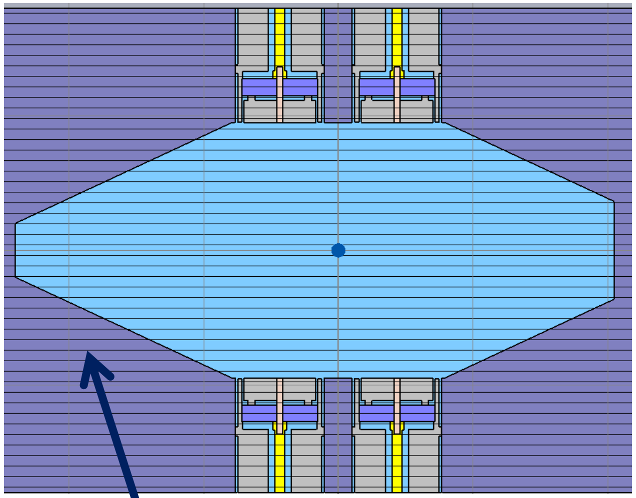


Example:Striplines





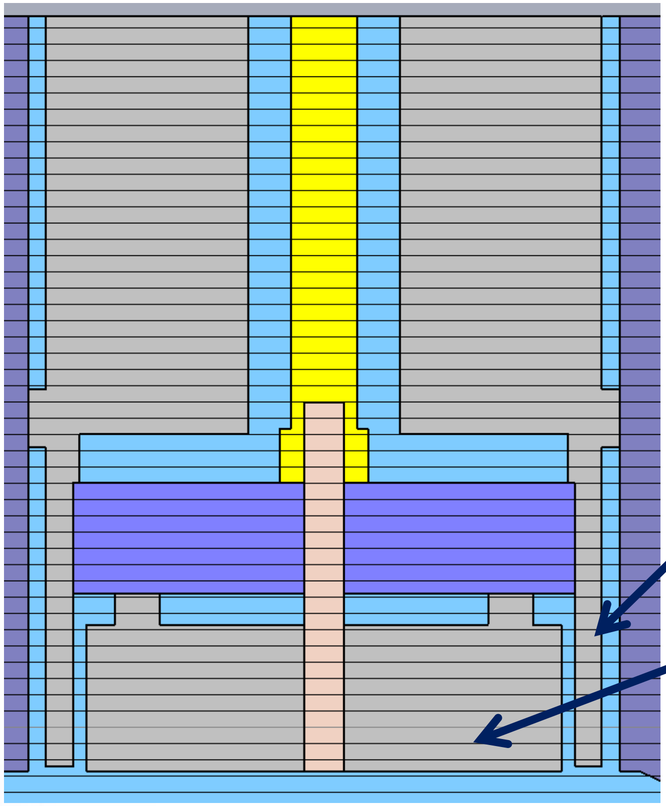
BPM power distribution



289mW/629mW

Power lost into the structure
1.7W @ 300mA 686 bunches
3.7W @ 500mA 686 bunches

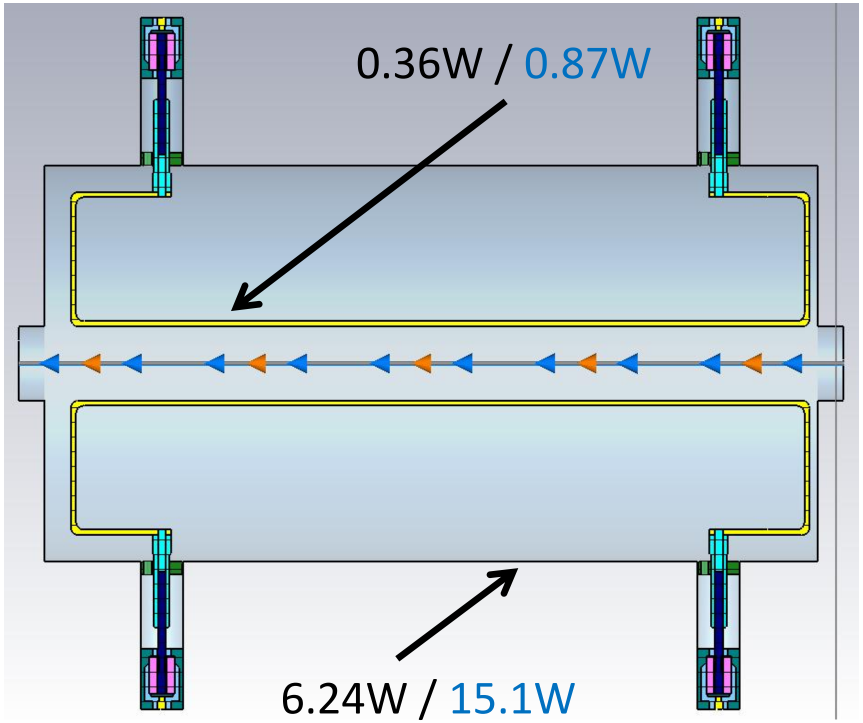
Plus 255mW/555mW delocalised loss

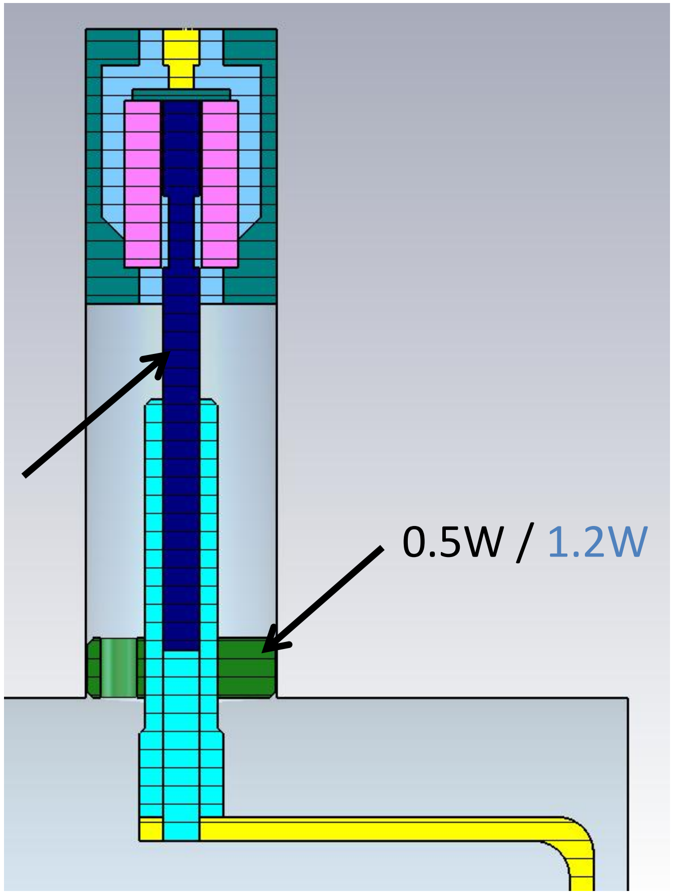


242mW/527mW

38mW/83mW

Stripline power distribution





Power lost into structure
24W @ 300mA 686 bunches
58W @ 500mA 686 bunches

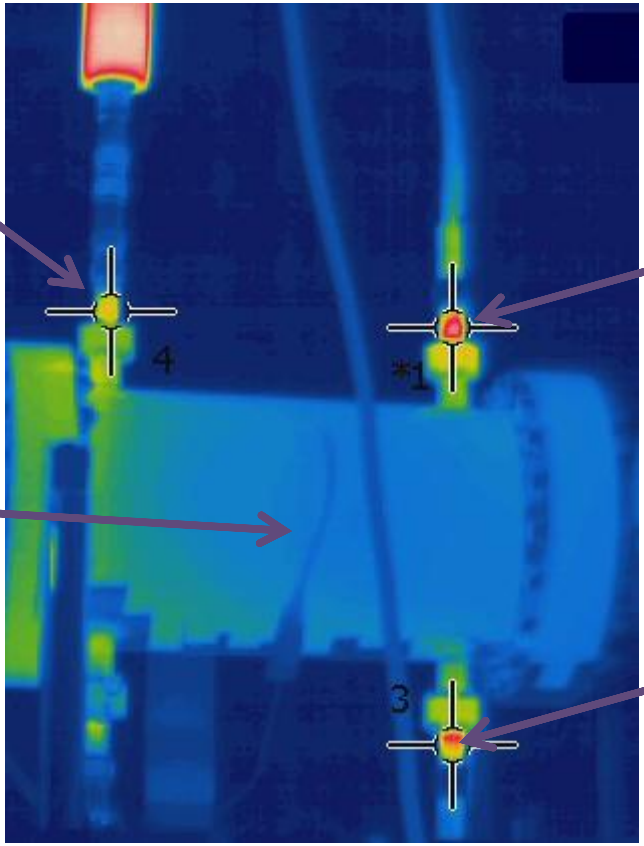
Plus 2.9W / 7W delocalised loss

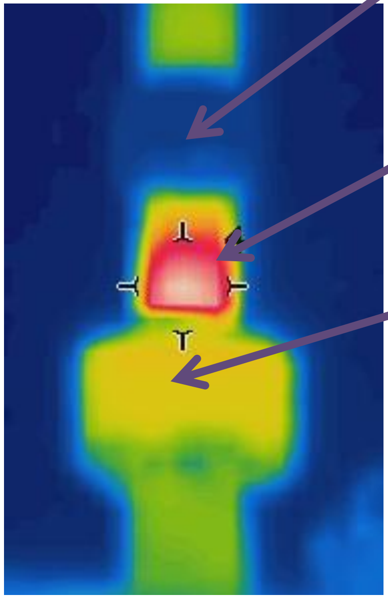
Final thoughts

- For all the currently installed structures tested so far, a large fraction of the ‘lost’ power is sent down the beam pipe. This will act as an additional heat load on nearby structures.
- Once we have energy accounting per mesh cell in the simulations, most of this will be made redundant.

Additional details

Real world measurements





Analysis details – Time domain

$$\text{normalised charge} = \frac{\text{Charge distribution data}}{\text{model charge}}$$

$$\text{wake loss distribution} = \text{normalised charge} * \text{Wake Potential}$$

$$\text{wake loss factor} = -\sum_{\text{time}} \text{wake loss distribution} * \text{time step size}$$

$$\text{loss from bunch} = \text{wake loss factor} * \text{model charge}^2$$

- Port signals

$$\text{energy}_{ports,modes} = \sum_{\text{time}} \text{signals}^2_{ports,modes} * \text{time step size}$$

- By using a cumulative sum one can see the evolution of the power deposition (does it all get dumped quickly, or in a more gradual way).

$$\text{fractional loss down the beam pipe} = \frac{\text{port1 energy} + \text{port2 energy}}{\text{loss from beam}}$$

Analysis details – Frequency domain

- Zero pad in time domain
- FFT time data

$$\text{bunch spectra} = \frac{FFT(\text{charge distribution})}{\text{number of sample points}}$$

$$\text{FFT of scaled wake potential} = \frac{FFT(\text{Wake Potential} * \text{model charge})}{\text{number of sample points}}$$

$$\text{Wake Impedance} = -\Re\left(\frac{\text{FFT of scaled wake potential}}{\text{bunch spectra}}\right)$$

$$\text{bunch power} = \sum_{\text{frequency}} \left(|\text{bunch spectra}|^2 * \text{Wake Impedance}\right)$$

- Zero the wake impedance when the power in the bunch is small.

(combats numerical noise).

$$\text{energy for 1 bunch} = \text{bunch power} * \text{simulation time}$$

$$\text{wake loss factor} = \frac{\text{energy for 1 bunch}}{\text{model charge}^2}$$

Using the ports

$$\text{Total power spectrum} = \sum_{\text{port}} \sum_{\text{mode}} |FFT(\text{port signals})|^2$$

$$\text{Total power from all ports} = \sum_{\text{time}} |\text{Total power spectrum}|$$

Machine parameters to bunch parameters

$$\text{bunch charge} = \frac{\text{beam current}}{\frac{1}{\text{pulse gap}} * \frac{\text{fill pattern}}{936}}$$

$$\sigma = 3.87 + 2.41 \left(\frac{\text{beam current}}{\text{fill pattern}} \right)^{0.81} \sqrt{\frac{2.5}{\text{RF Volts}}}$$

Pulse equations

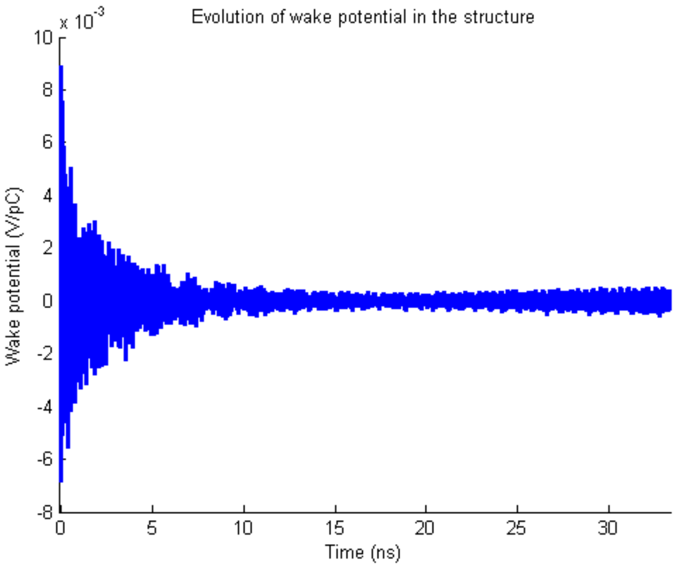
Single pulse

$$\text{pulse} = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{\text{Wake Potential timescale}^2}{2\sigma^2}} \text{model charge}$$

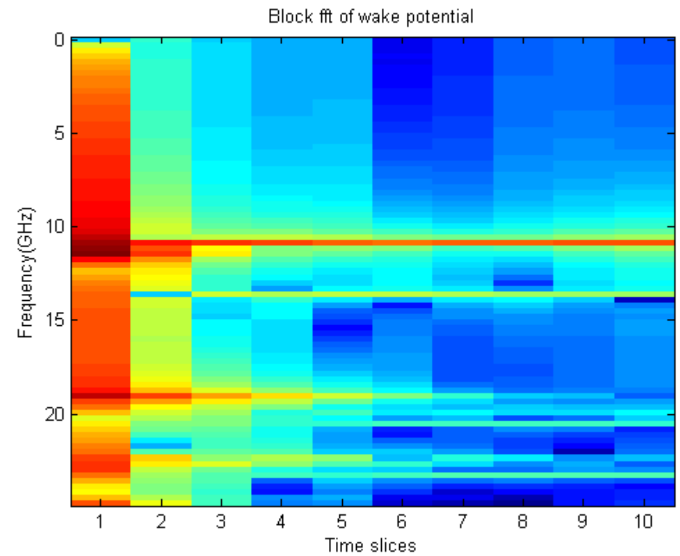
Train

$$\text{pulse} = \sum_{n=1}^{N} \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(\text{Wake Potential timescale} + (\text{gap} * \text{n}))^2}{2\sigma^2}} \text{model charge}$$

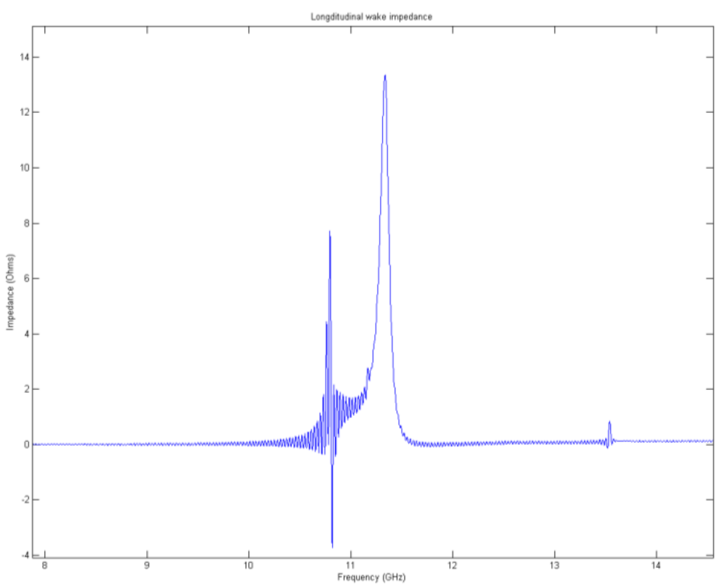
Problems



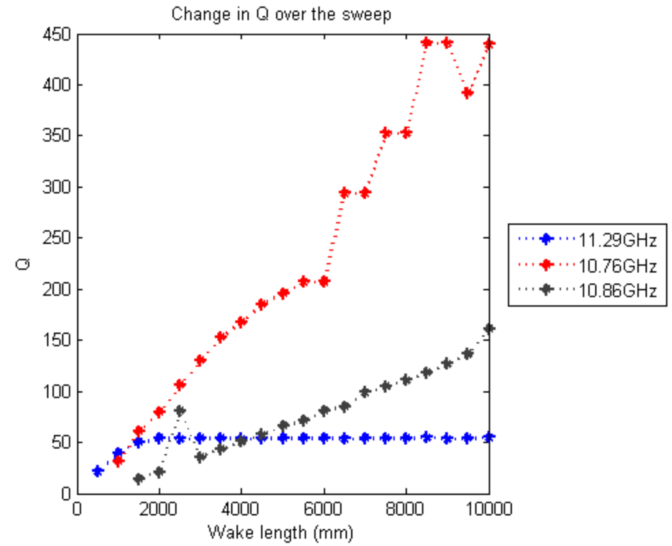
Evolution of wake potential in the structure
x 10^-3
Wake potential (V/pC)
Time (ns)
10
8
6
4
2
0
-2
-4
-6
-8
0
5
10
15
20
25
30



Block fft of wake potential
Frequency(GHz)
Time slices
0
5
10
15
20
1
2
3
4
5
6
7
8
9
10



Longditudinal wake impedance
Impedance (Ohms)
Frequency (GHz)
14
12
10
8
6
4
2
0
-2
-4
8
9
10
11
12
13
14



Change in Q over the sweep
Q
Wake length (mm)
11.29GHz
10.76GHz
10.86GHz
450
400
350
300
250
200
150
100
50
0
0
2000
4000
6000
8000
10000