Subharmonic buncher at 1.5 GHz for CTF3

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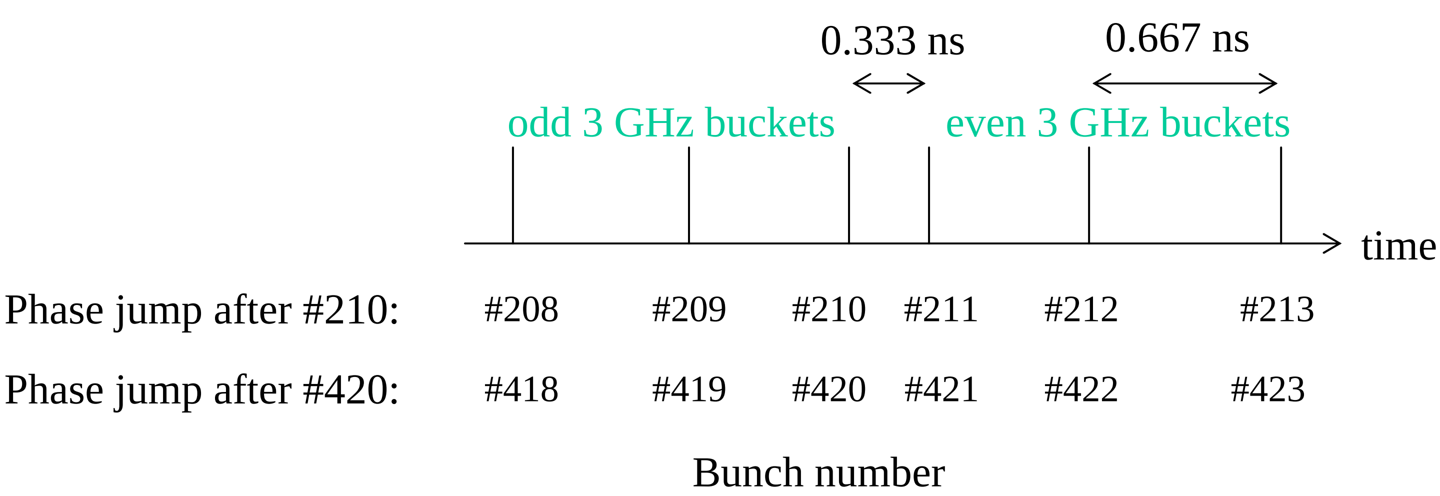
Purpose: a) bunch the beam from the injector with essentially 0.667 ns spacing.

b) using 180 deg. phase jumps all 210 bunches, to halve the spacing to the following bunch, as needed for the CTF3 stacking scheme.



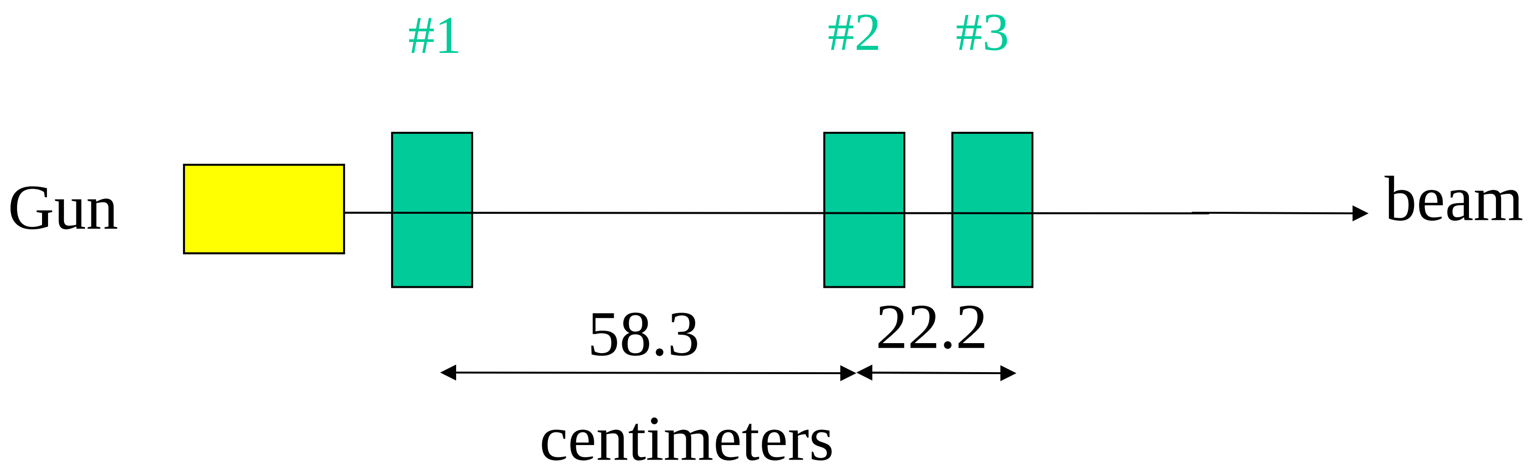
Specification:

-3 identical structures, 20 keV/structure peak accel.

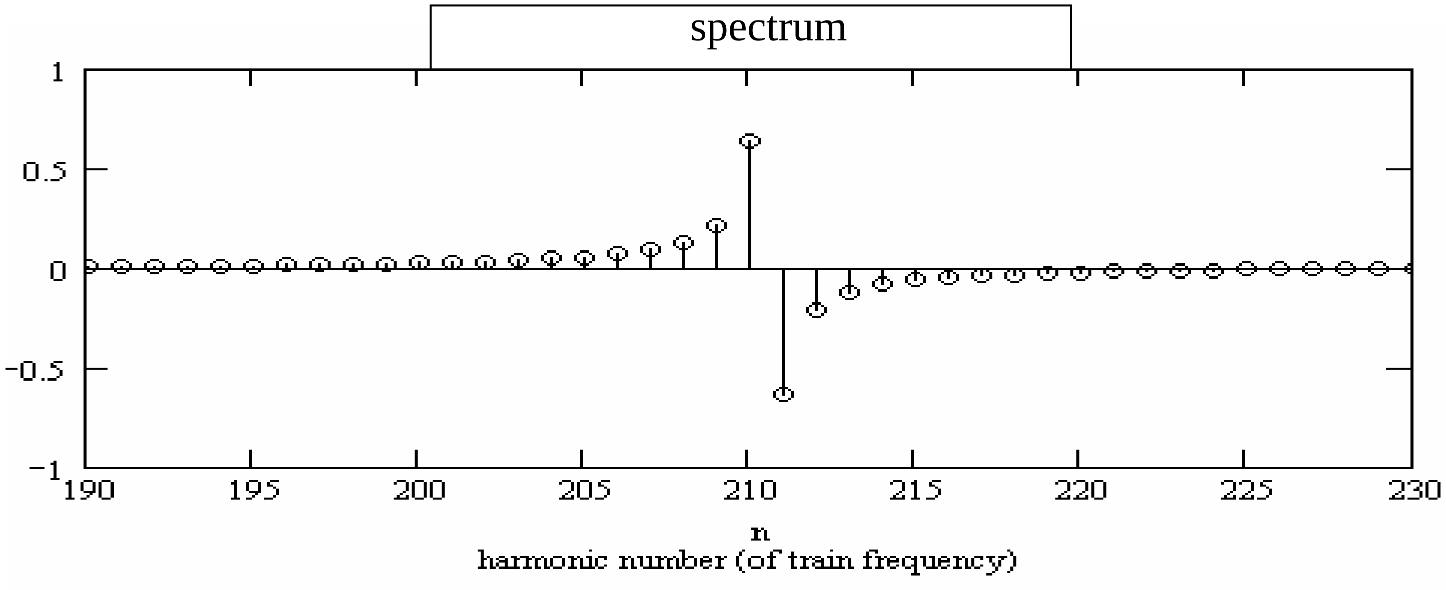
-150 MHz bandwidth for fast phase switching

For large bandwidth short structures with high group velocity are needed

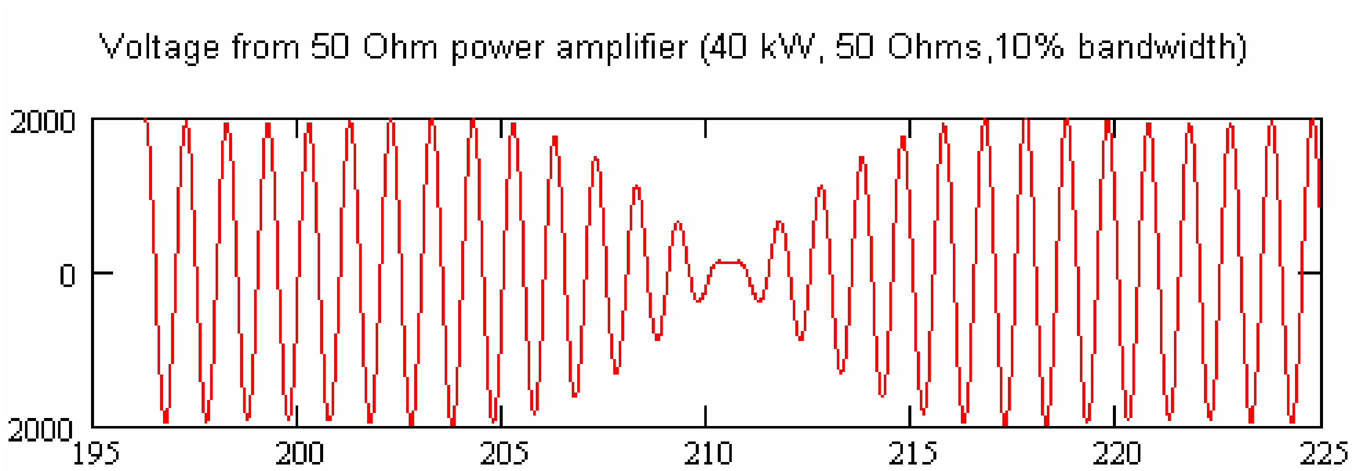
(short fill/drain times).



Spectrum and pulse shape



frequency



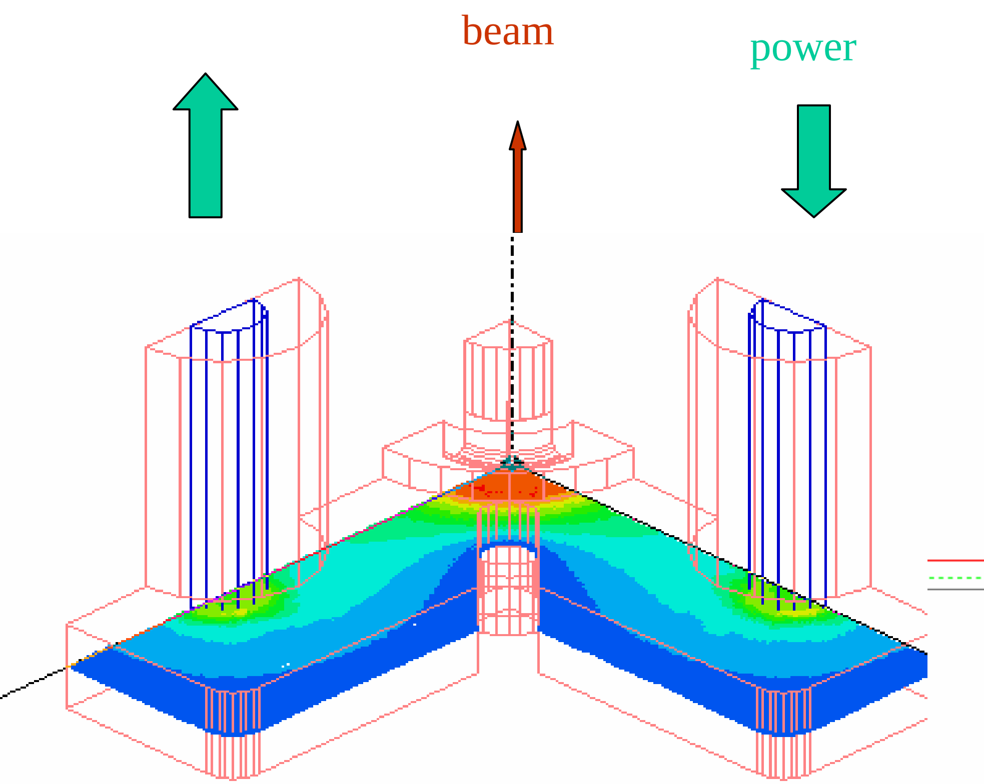
Bunch number

time

Polarity change takes about 10 oscillations after the power amplifier, or 10 bunches!

A) Short waveguide-type structure

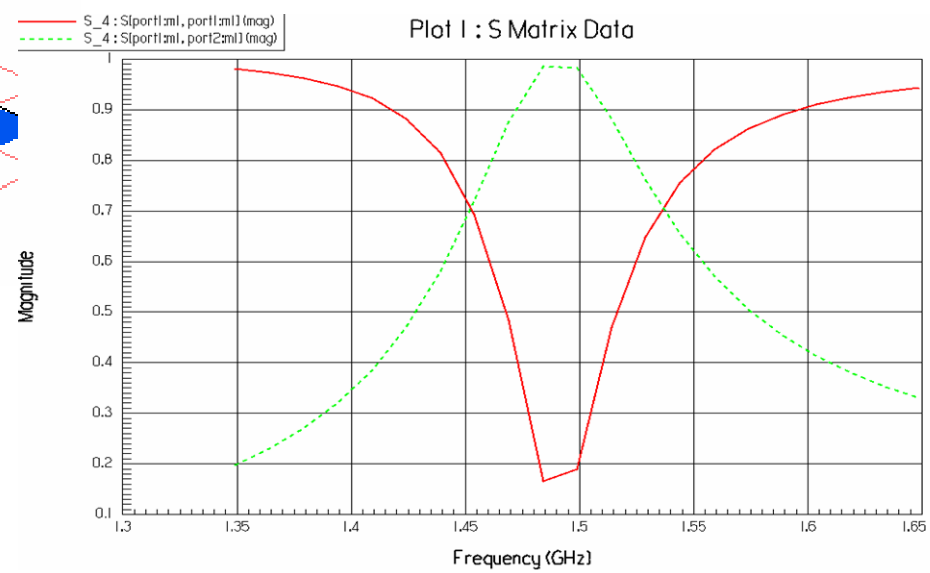
A. Millich G. Carron



Total of 6 structures foreseen,
(pairwise back to back)
R/Q = 69 (circuit), Q = 17.4
10 keV/structure
20 kW/structure

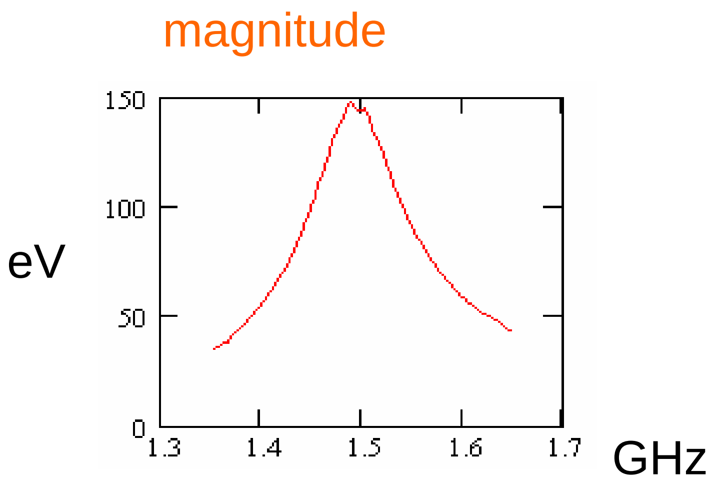
Total power 120 kW

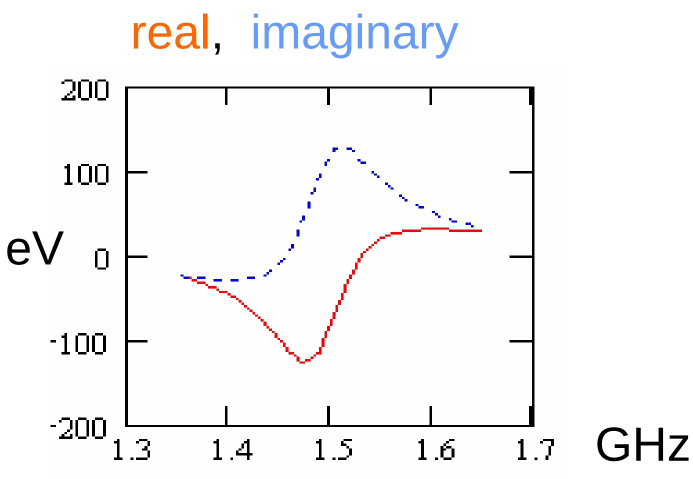
Total 24 vacuum feedthroughs
Aperture = 30 mm diameter



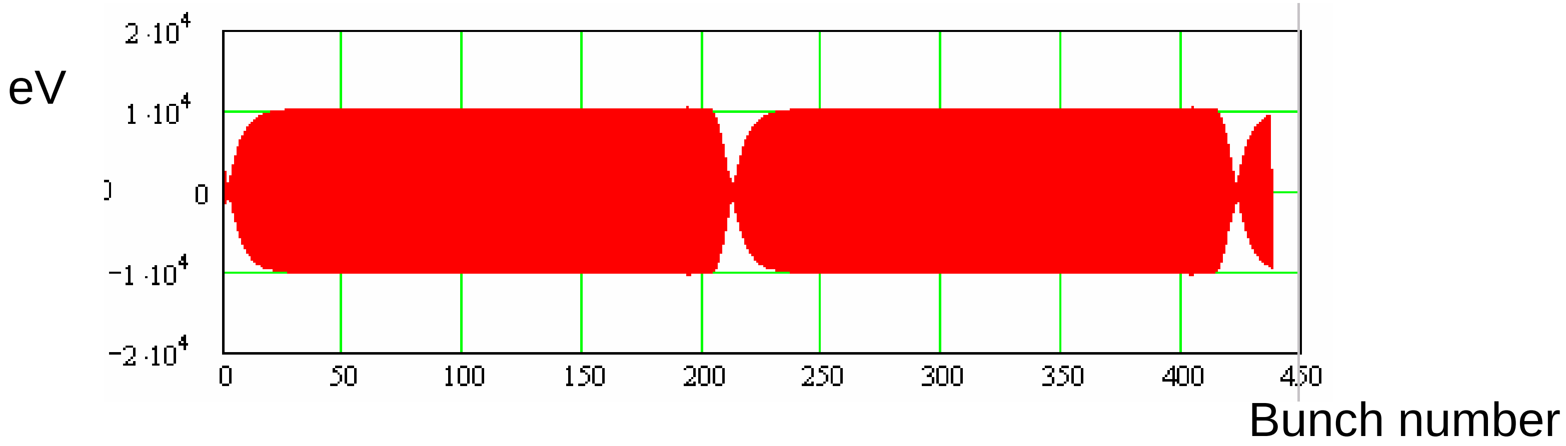
A quarter structure is shown. The power is fed onto the waveguide through coax.line to the right capacitively and exits through coax.. to the left.

eV for 4 W structure input, using HFSS

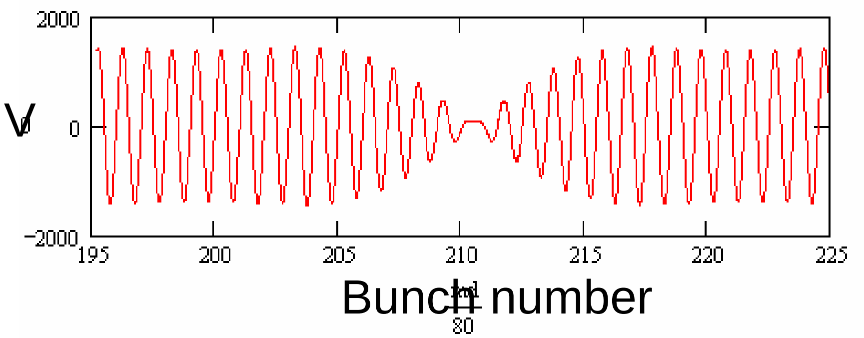




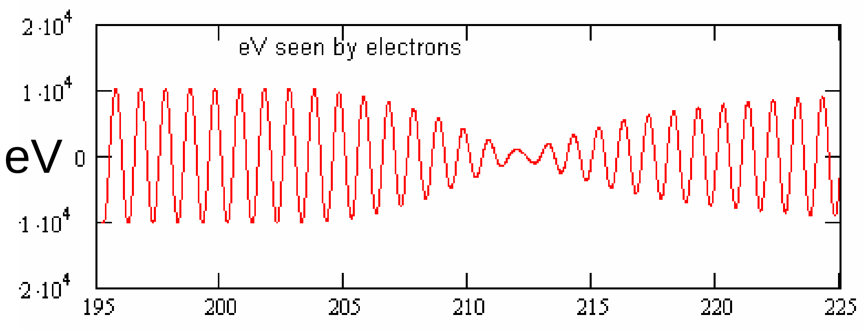
Structure input spectrum (increased to 20 kW, 10 % bandwidth) times above characteristics followed by inverse Fourier transform :



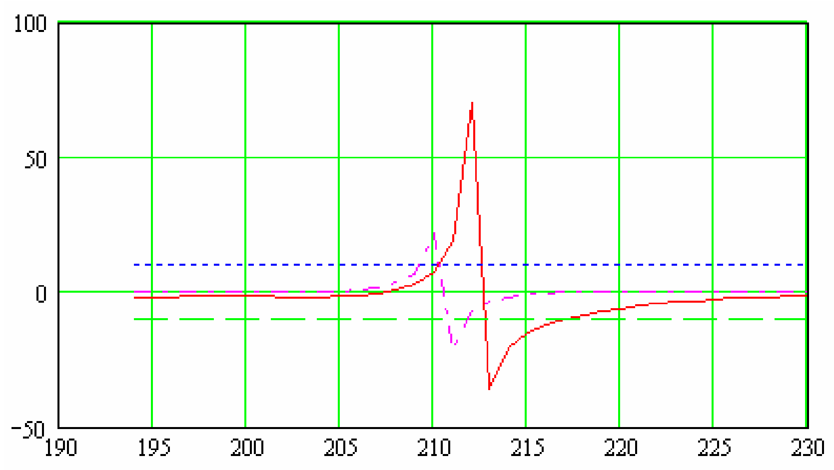
Phase jump in detail



TWT output voltage, 20 kW



eV experienced by beam
(asymmetric wrt 210 th bunch)



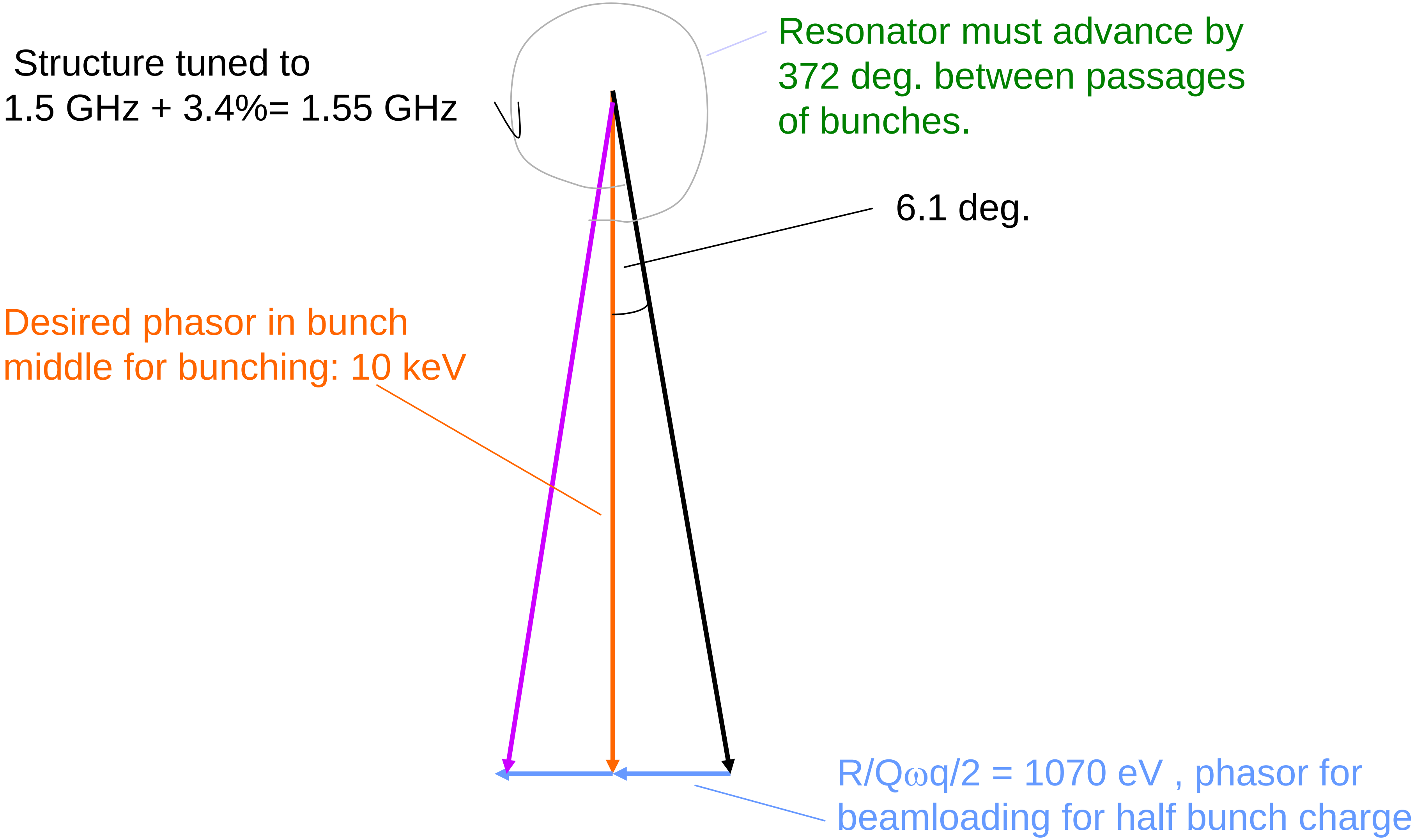
Phase errors around 210 th bunch [degrees]:

TWT output has fast jump

Structure eV have slow jump
> 10 deg. error only for 8 bunches

Beamloading compensation

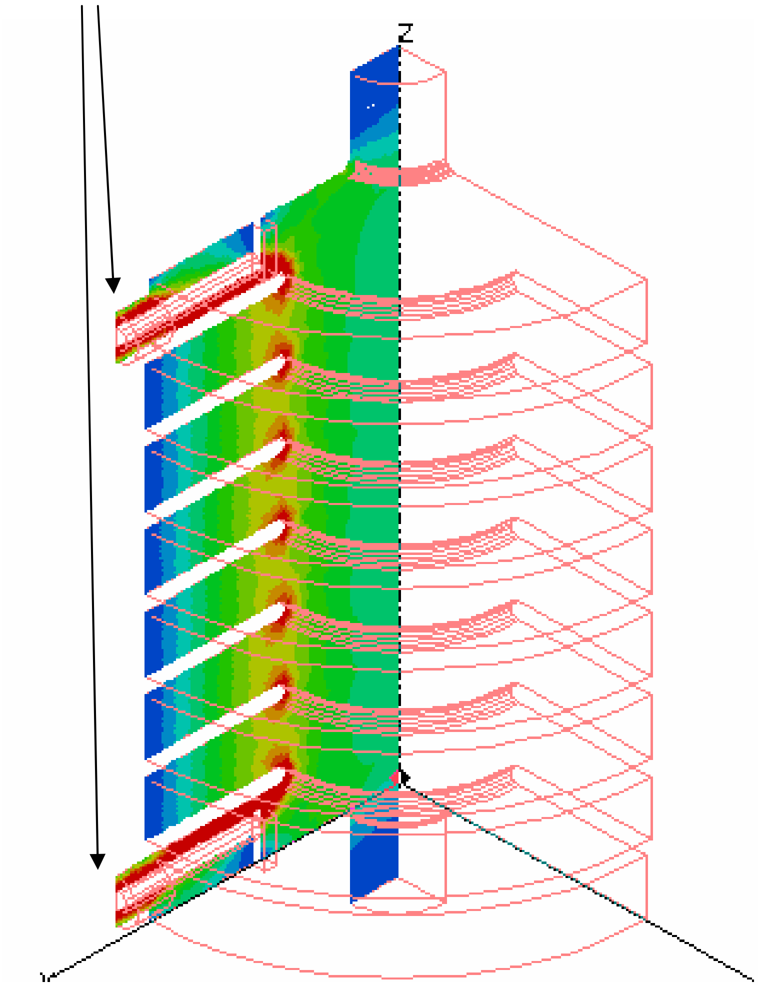
for nominal 5 A beam current case (bunch form factor = 1)



B) Conventional iris-loaded 8 cell structure

(changed to 6-cell structure)

coaxial feeds to coupler loops



length = 26 mm/cell

R/Q = 56 Ohms/structure (circuit)

betagroup = 0.068

fill time = 9.8 ns

drain time = 8.8 ns (or time for passage of ~12 bunches)

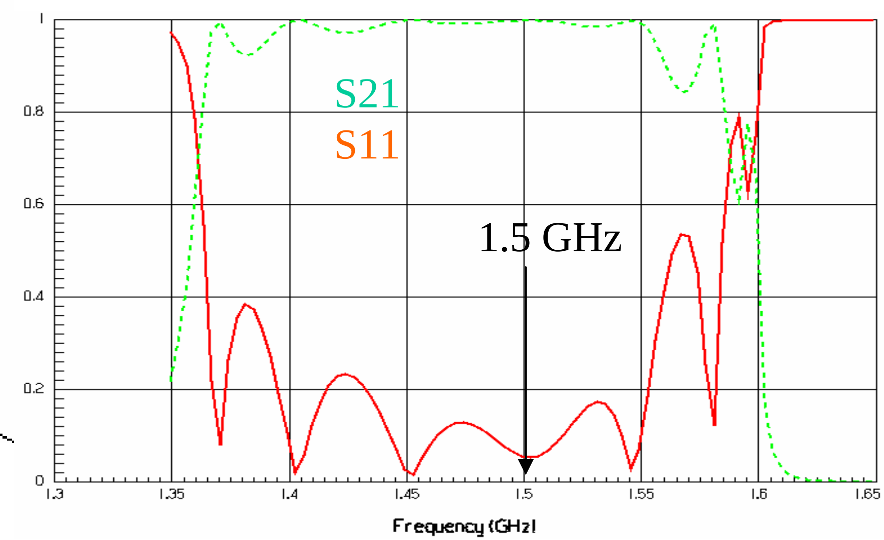
power needed for 20 keV = 40 kW

iris diam. a = 79 mm

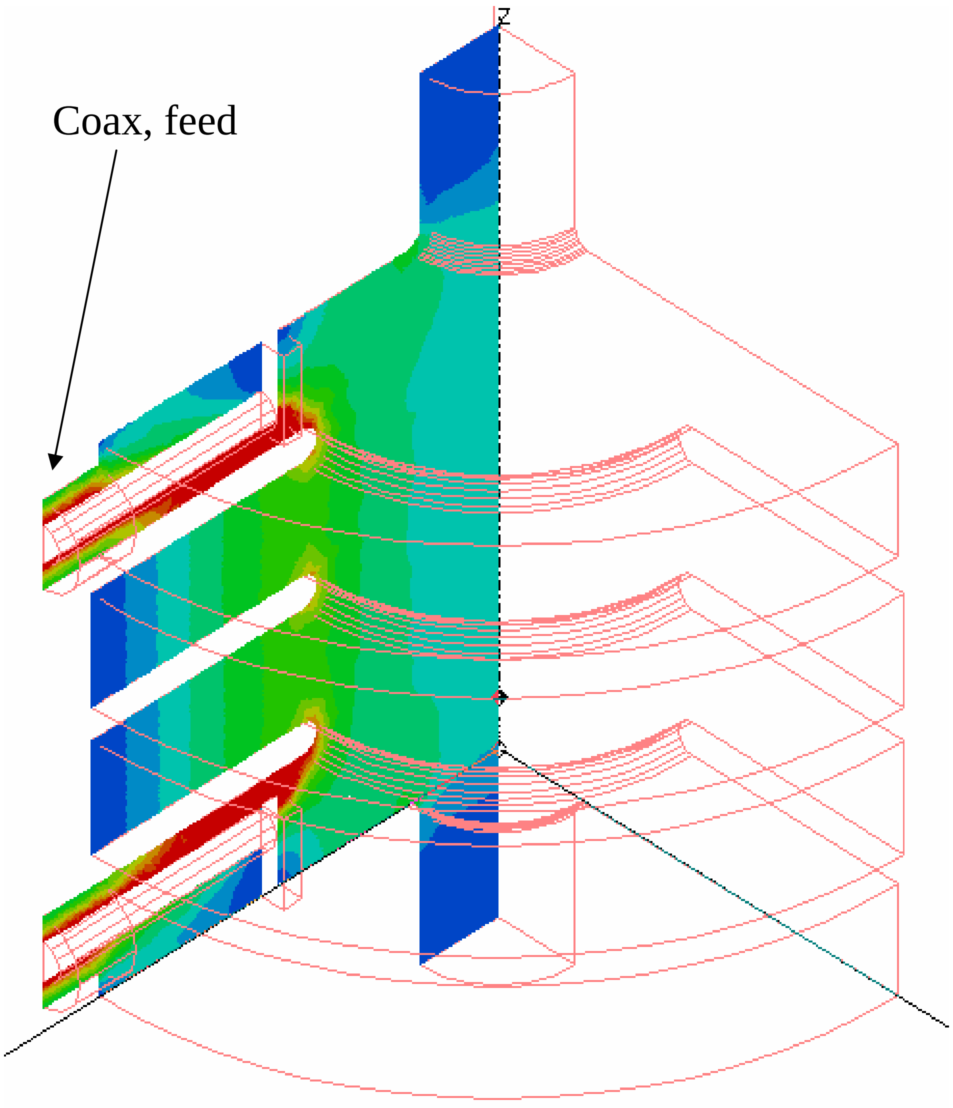
disk thickness = 6 mm

outer cell diam. b = 159 mm

Large bandwidth obtained with 75.5 deg./cell:



C) Short 4-cell conventional structure



length = 26 mm/cell

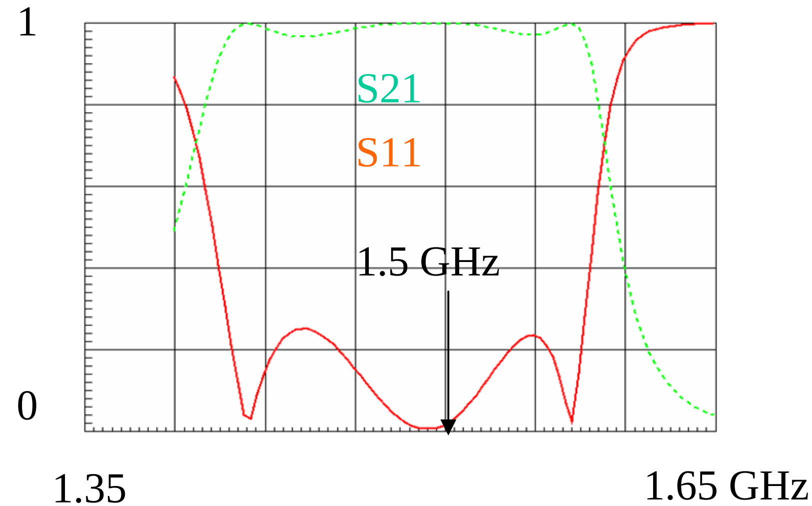
R/Q = 28 Ohms/structure (circuit)

betagroup = 0.068

fill time = 4.9 ns

drain time = 4.4 ns (or time for passage of ~6 bunches)

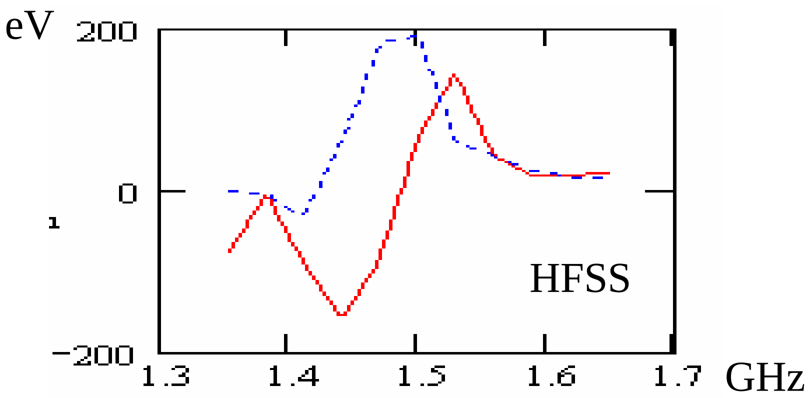
power needed for 20 keV = 160 kW



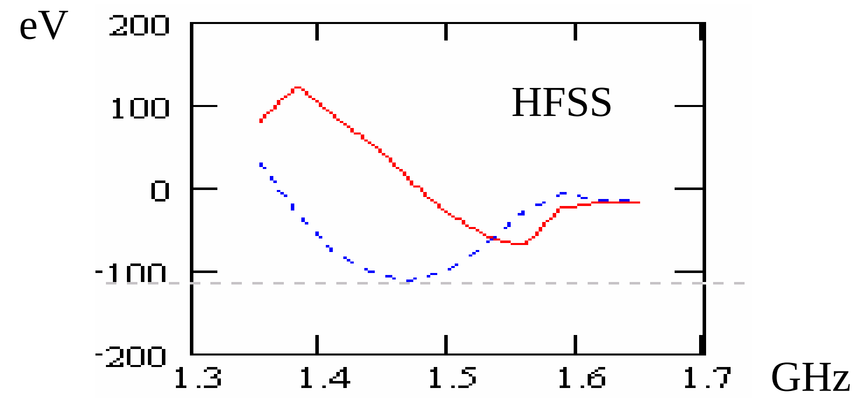
Structure performances

Acceleration for 4 W input versus frequency, complex values, HFSS results:

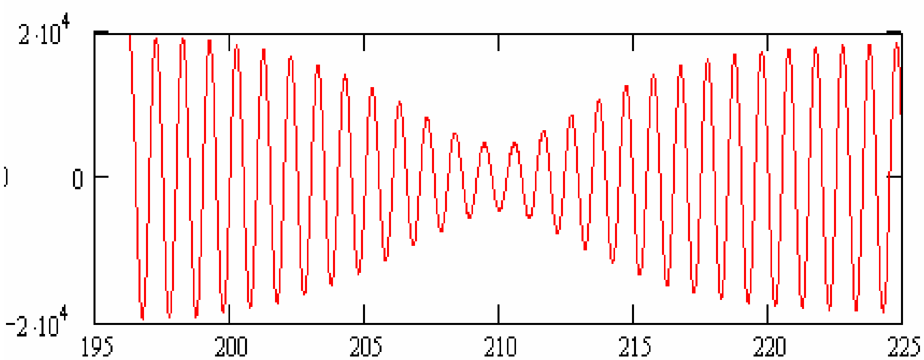
8 cell structure

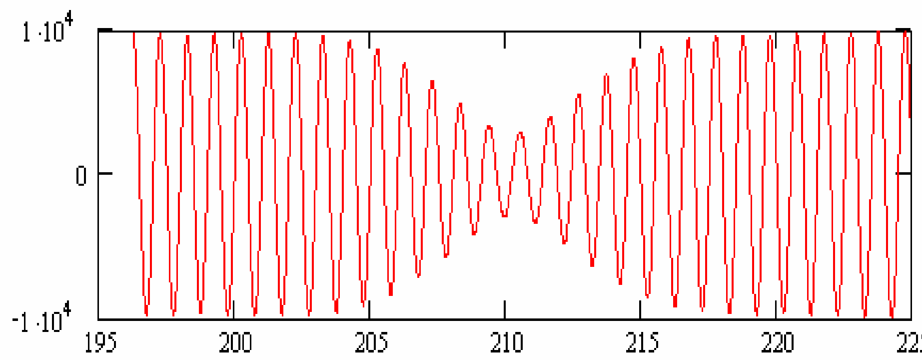


4-cell structure



After multiplication: amplifier output spectrum (40 kW) X structure cheracteristics (as above)



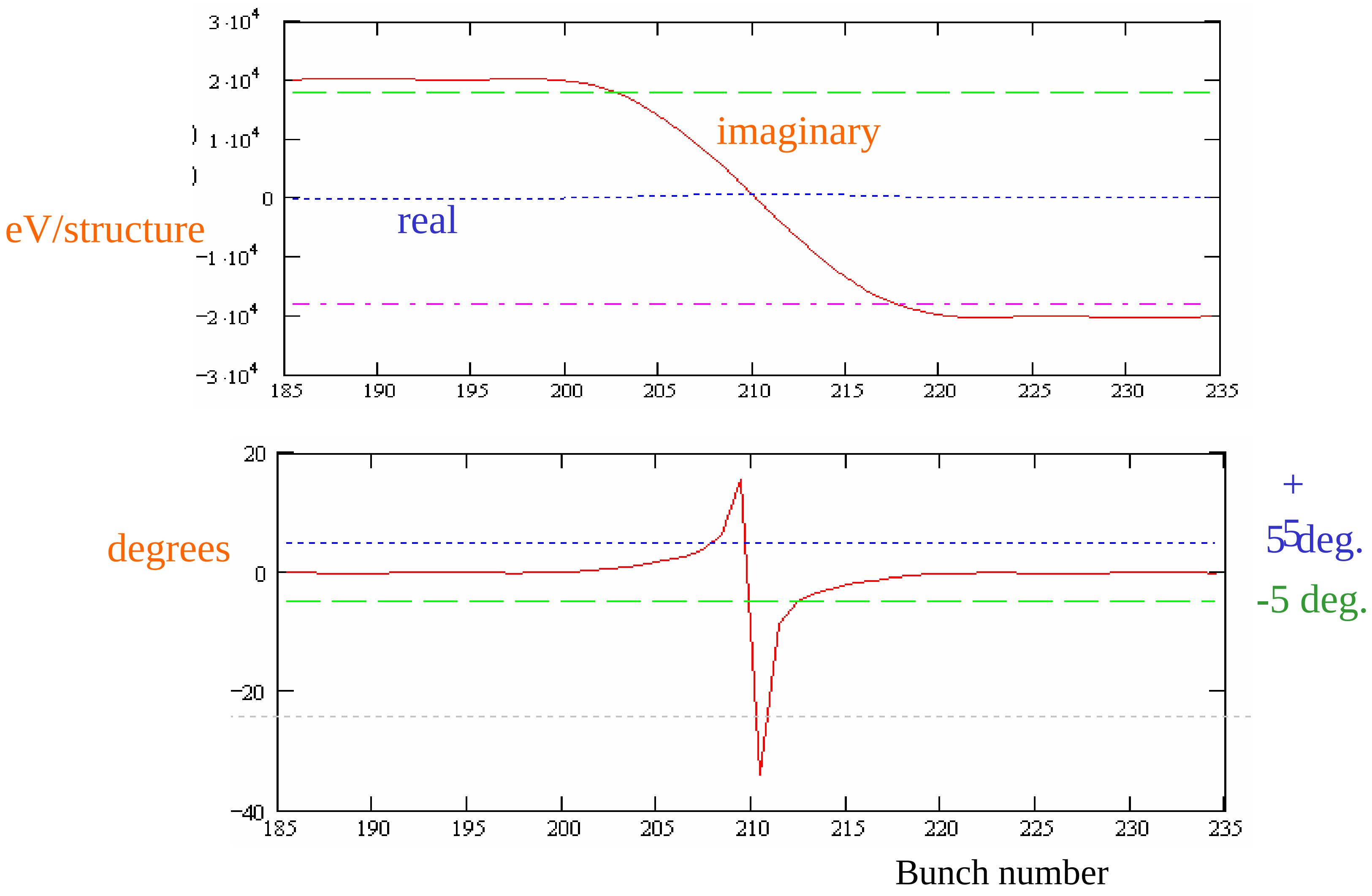


Structure fill and drain time delays are included (beamloading neglected)

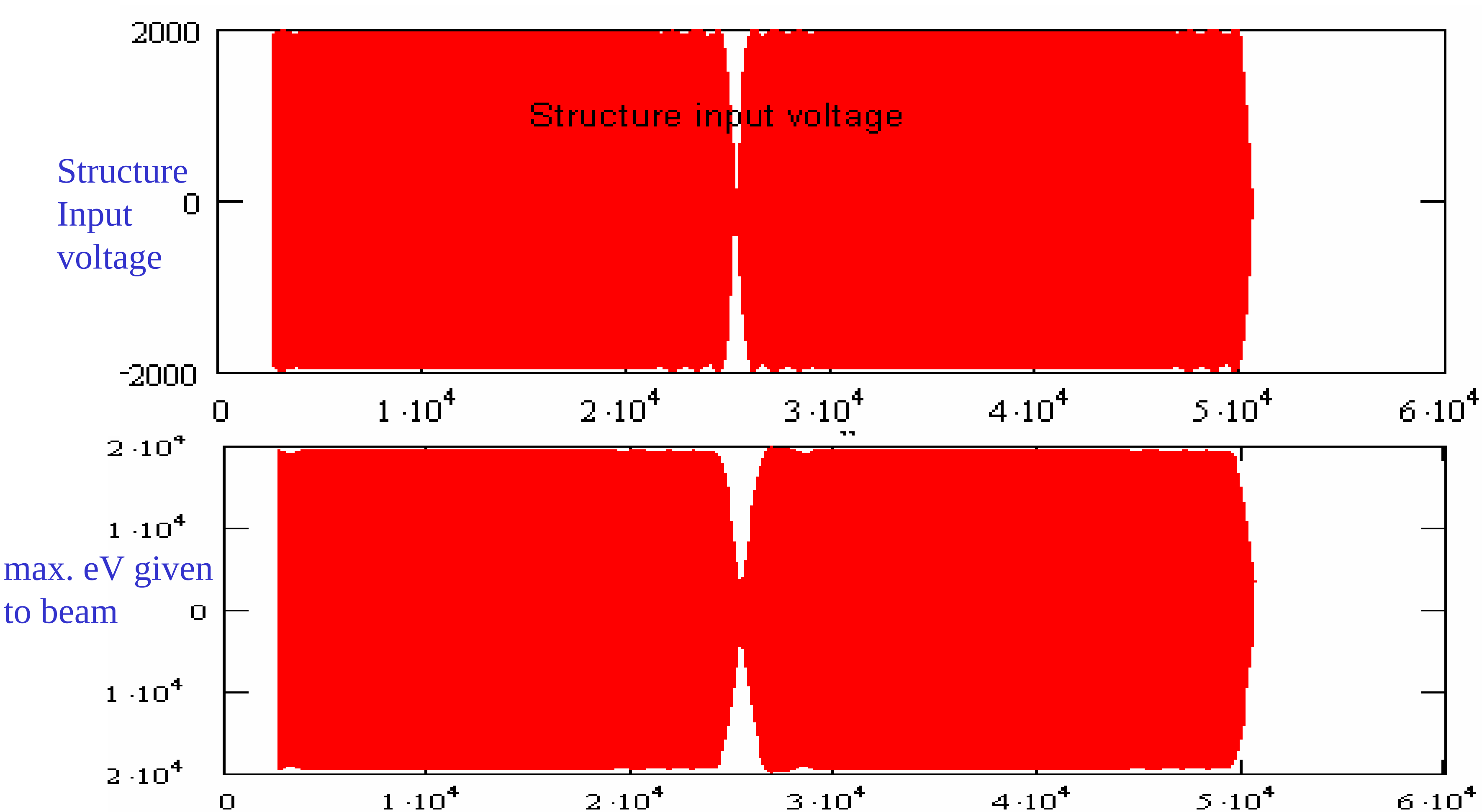
Power needed: 40 kW/structure, 120 kW total

160 kW/structure, 480 kW total

Amplitude and phase at phase jump (no beamloading, 8-cell)



bunching with 8-cell structure

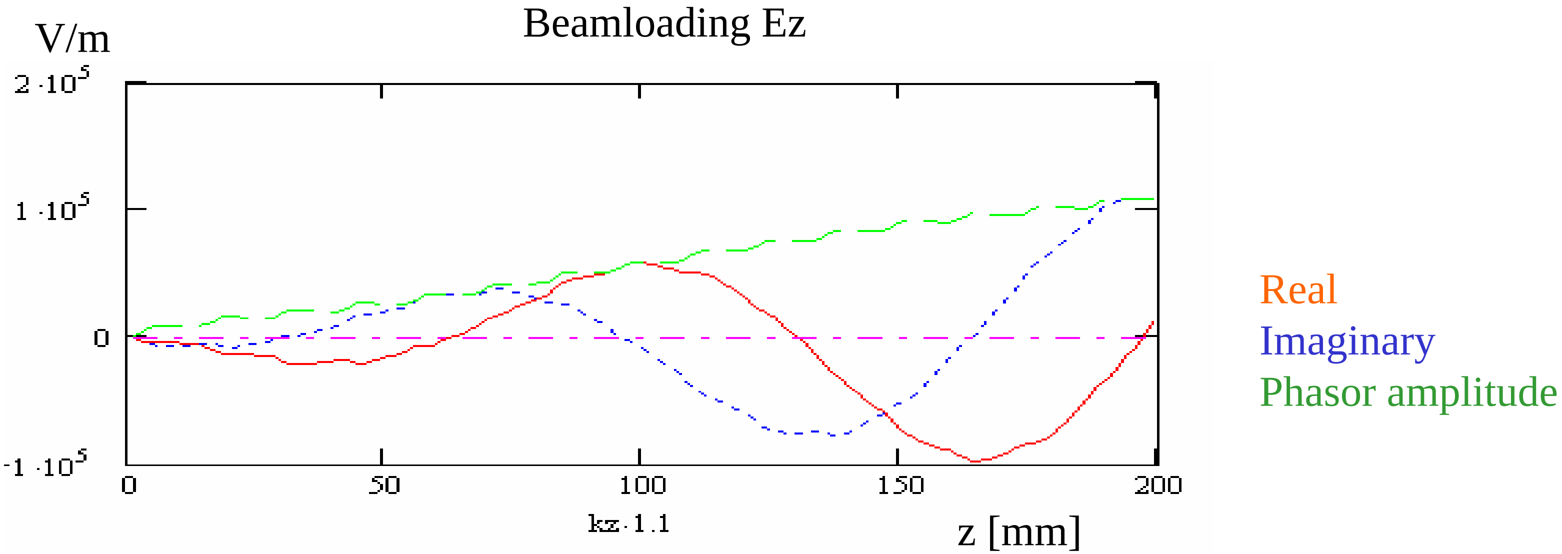


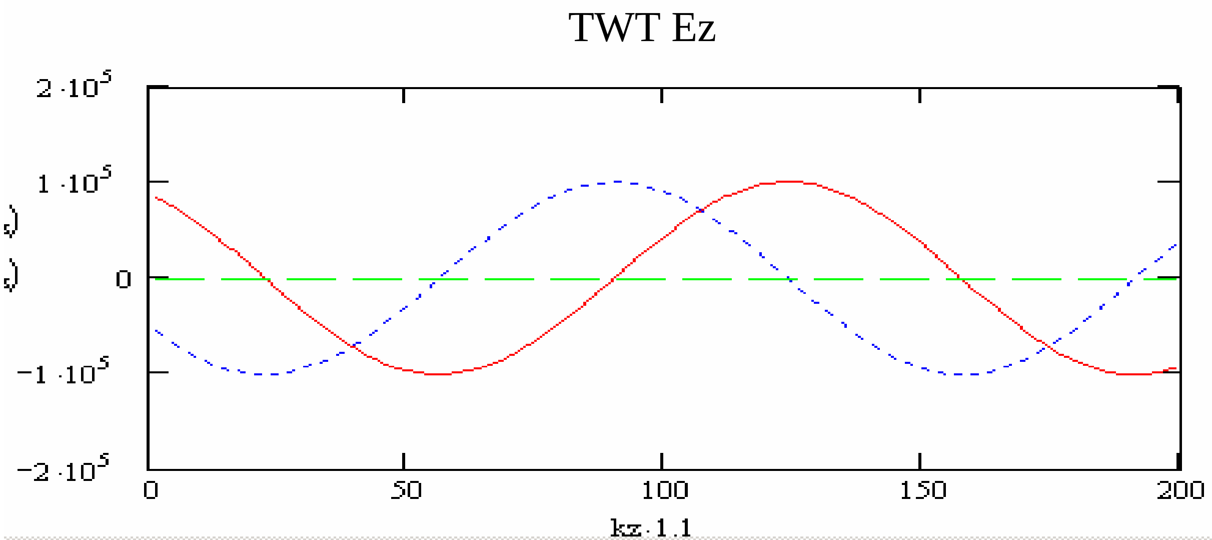
210

→ t

Typical Ez fields in 8-cell structure away from transition

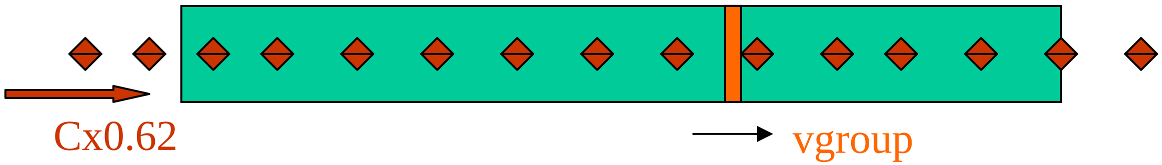
(say, at entry of bunch #105)





Beamloading compensation

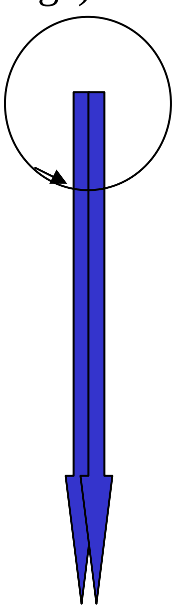
We follow an "rf-energy sample" as it moves with the group velocity in the structure:



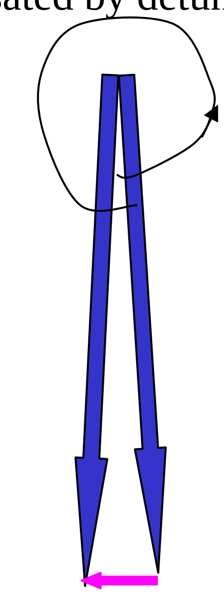
For bunching the bunches traverse the sample when the wave is at zero crossings.
Zero crossings correspond to the wave phasor being positive and purely imaginary.

Phasor analysis shows that the set-up is correct for bunching when between passages of bunches through the moving sample, the Ez phasor turns by an integral number of turns.

With beamloading a negative real phasor = - qωR'/Q x (bunch formfactor) (q = bunch charge) is added at each traversal; it can be compensated by detuning:

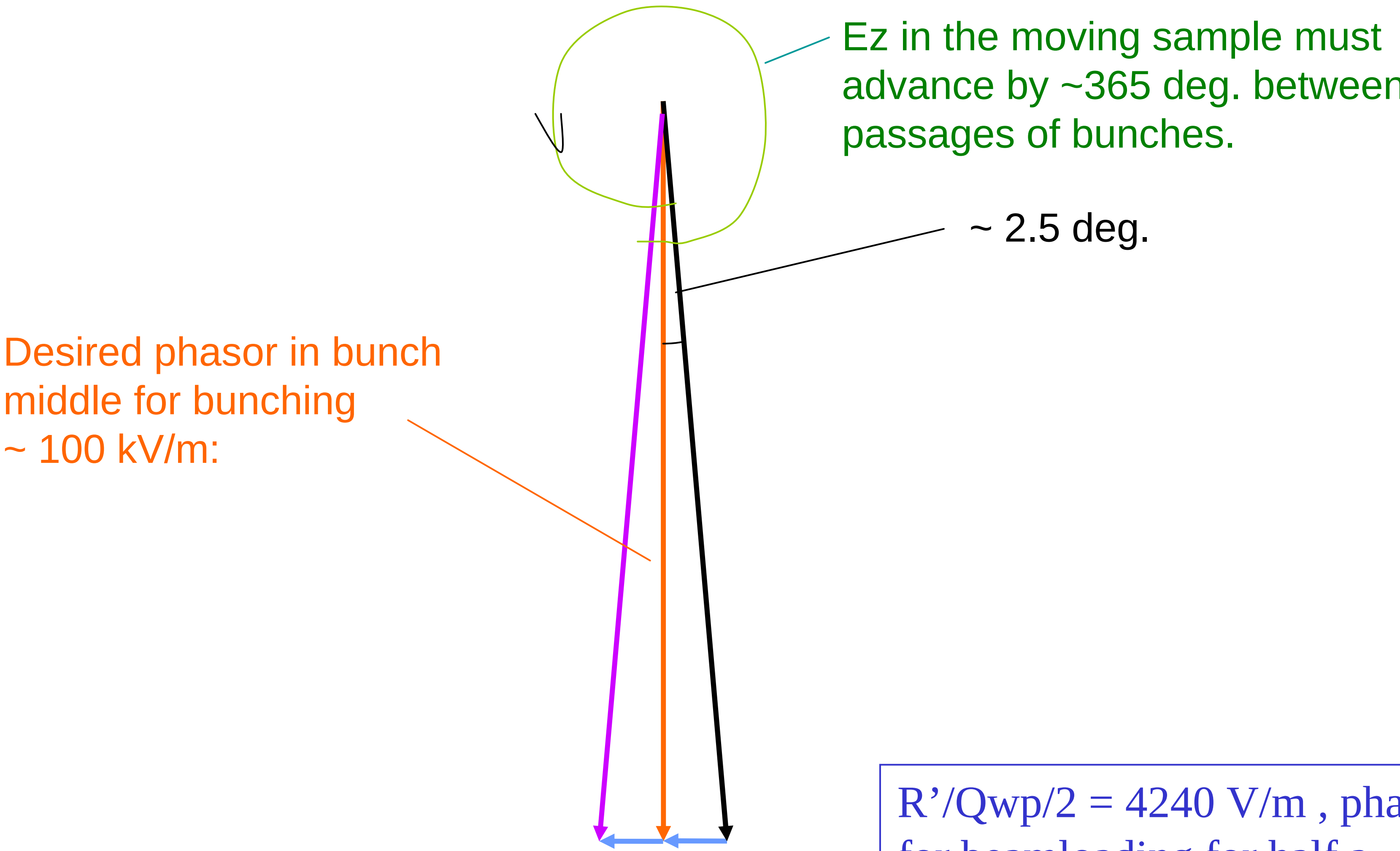


Tuned structure with Ez phasors turning 360 deg. between bunch passages yielding correct bunching phasor at low intensity.



Detuned structure with Ez phasors turning more than 360 deg. between bunch passages yields correct imaginary bunching phasor in presence of beam loading.

Beamloading compensation for nom. Intensity



R’/Qwp/2 = 4240 V/m , phasor for beamloading for half a bunch charge, bunching factor = 1.

Structure detuning

$$e^{j\left[\omega t - \omega z / Vph\right]}$$

The time interval and distance between bunches crossing the sample moving with Vg and a bunch moving with Ve:

$$\Delta t = \frac{1}{f\left(1 - Vg / Ve\right)}$$

$$\Delta z = \Delta tVg$$

The phase between 2 subsequent crossings is:

$$\Delta \varphi = 2\Pi \left[\frac{1 - Vg / Vph}{1 - Vg / Ve}\right]$$

When the phase velocity equals the electron velocity the phase advance is 360 deg.

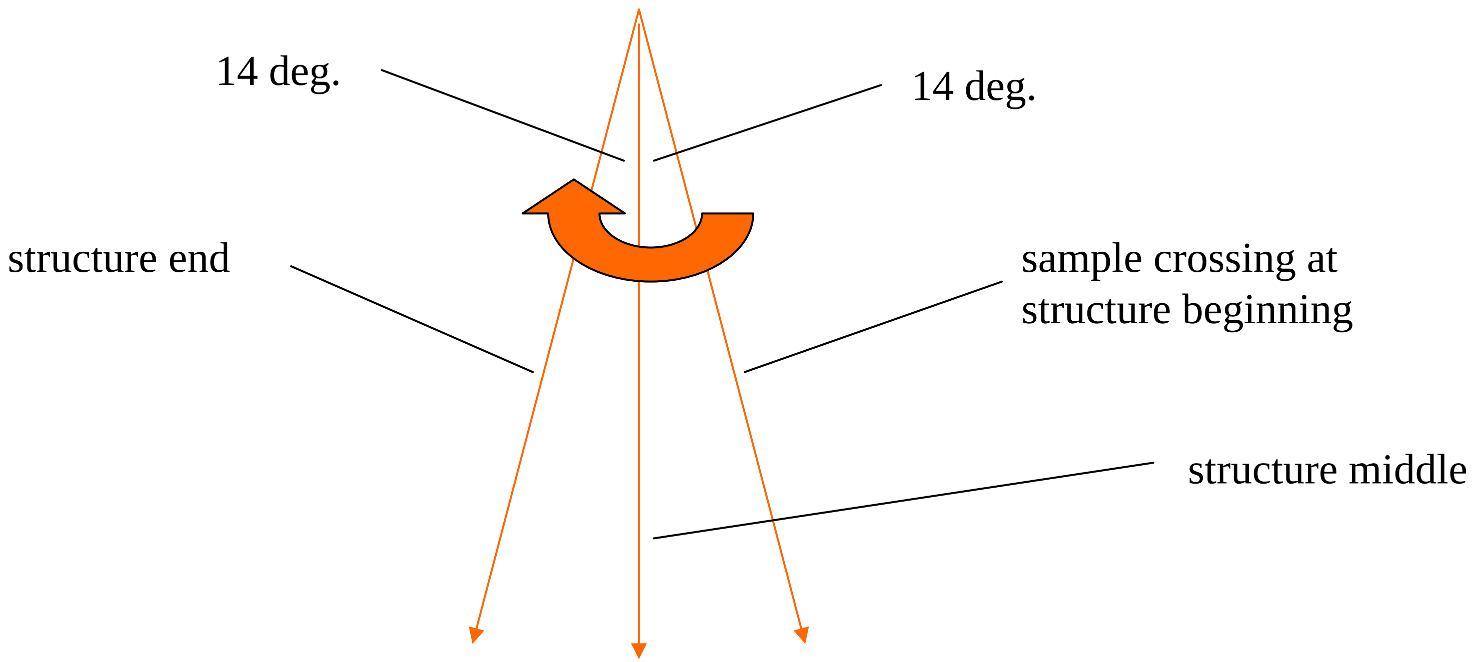
For Vph = 0.71c, instead of 0.62c, the phase advance between crossings reaches the required 365 deg. (66 deg./cell instead of 75.5 deg.).

How to use a fixed detuning for a range of intensities and bunch form factors:

- A) The intensity is too high, say, 7.5 A: the red phasor will turn too slowly between passages through the sample.
- Cure: Phase the input positively (red phasor to the right, 284 deg., for the first sample crossings), such that for the structure middle this phasor is vertical (270 deg.) and at the structure end it is angled to the left (256 deg.).
- B) Intensity low, say 2.5, A: the red phasor turns too fast.
- Cure: Do the opposite phase adjustment at the structure input.

Conclusion: It has been shown with Parmela by Oliver Forstner that the bunching is insignificantly reduced by the occuring small phase deviations between 256 and 284 deg.

- A) The intensity is too high, say, 7.5 A: the red phasor will turn too slowly between passages through the sample.
- Cure: Phase the input positively (red phasor to the right, 284 deg., for the first sample crossings), such that for the structure middle this phasor is vertical (270 deg.) and at the structure end it is angled to the left (256 deg.).

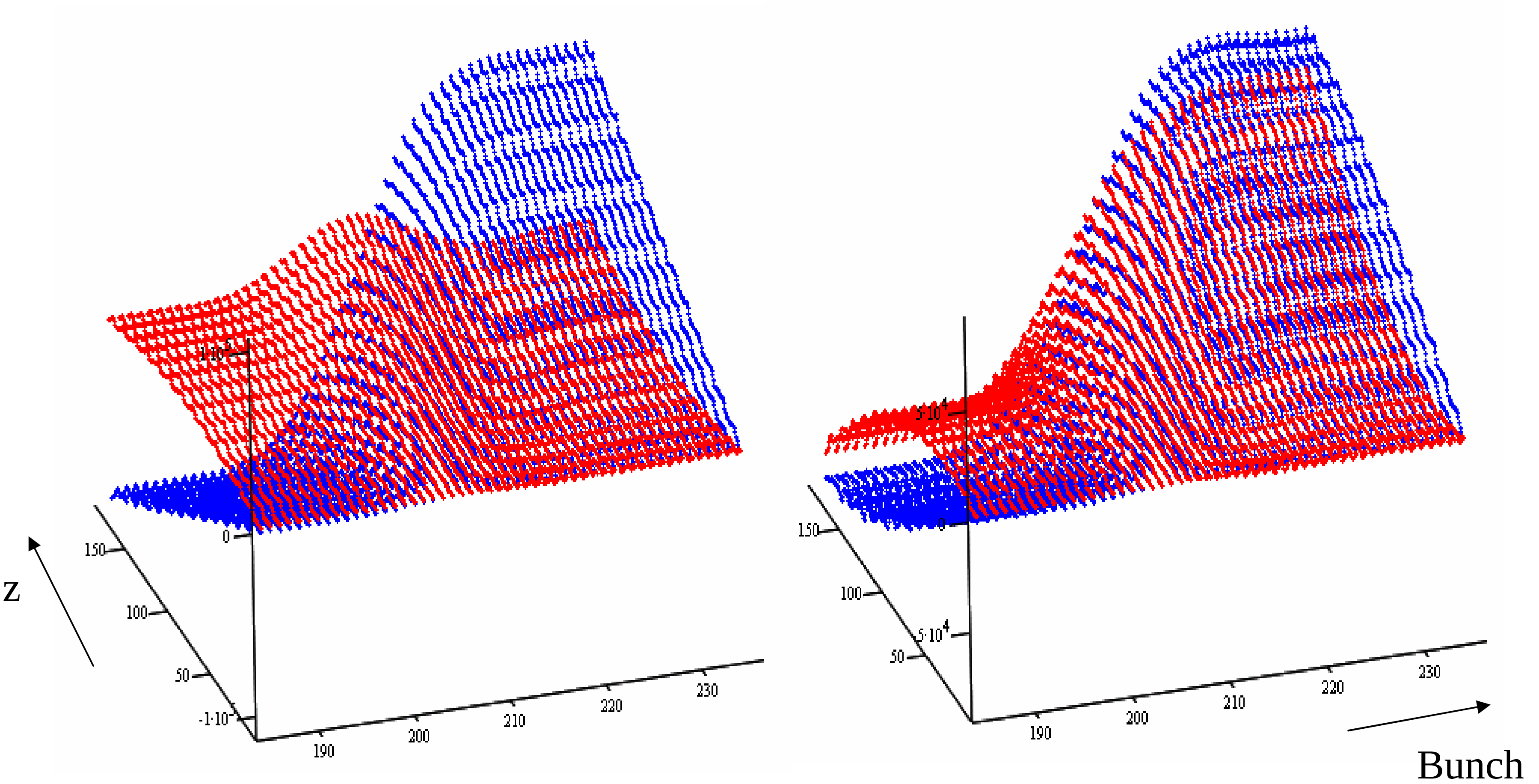


Beamloading Ez fields inside structure at bunch centres during phase jump

Real acc./dec. component

Imag. Bunching/debunching component

Bunching factor = 1, 5A beam current



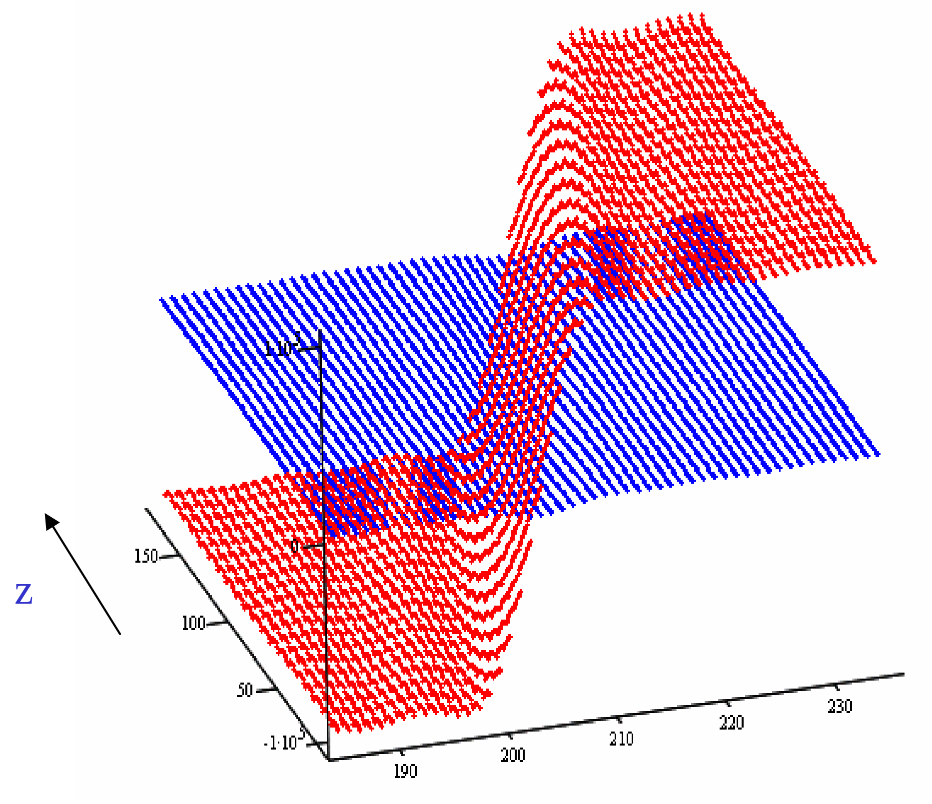
Vph = 0.62c

Vph = 0.71c

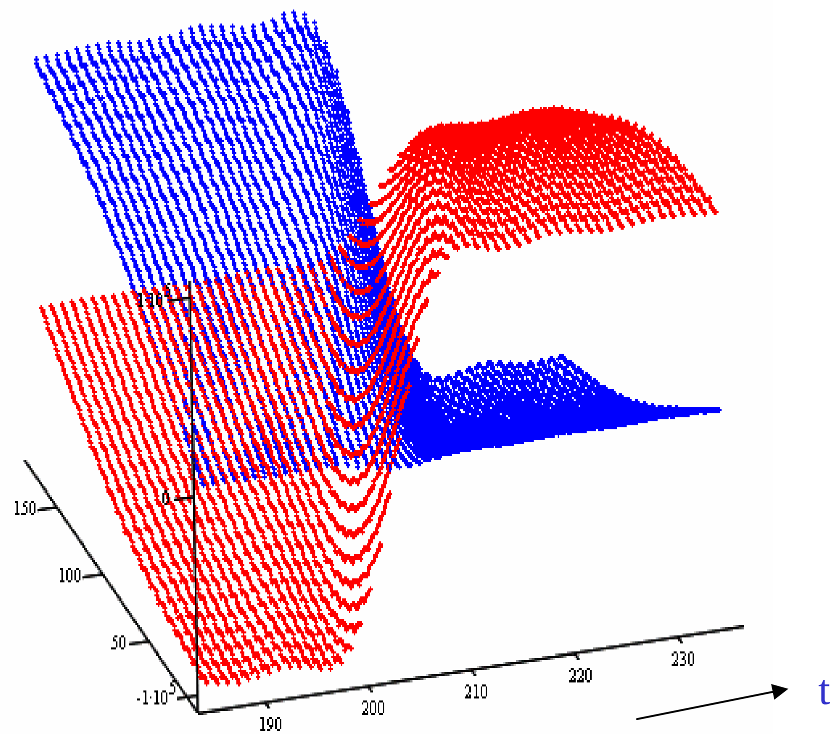
TWT Ez fields inside structure at bunch centres during phase jump

Real acc/dec. component

Imag. Bunching/ debunching component



Vph = 0.62c

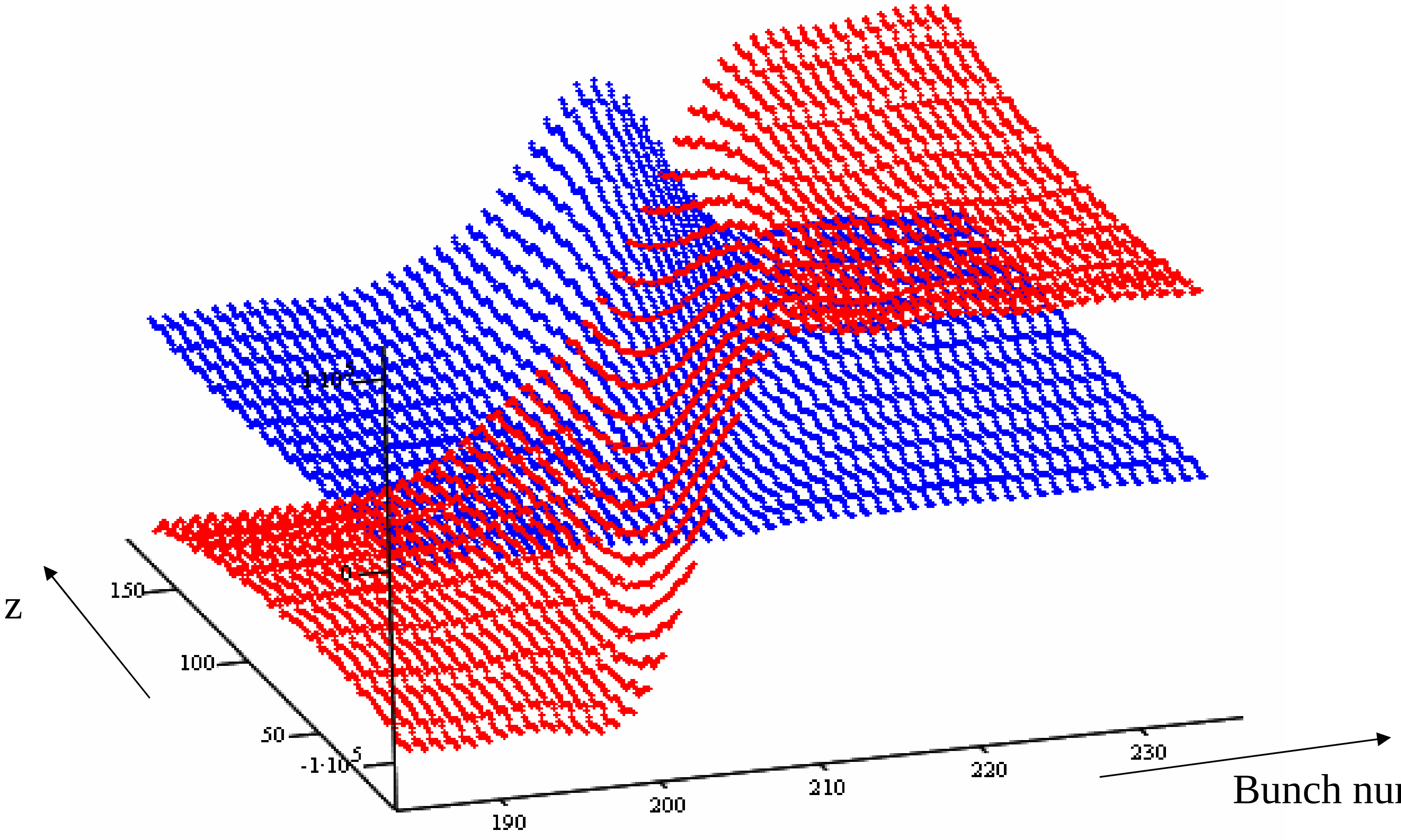


Vph = 0.71c

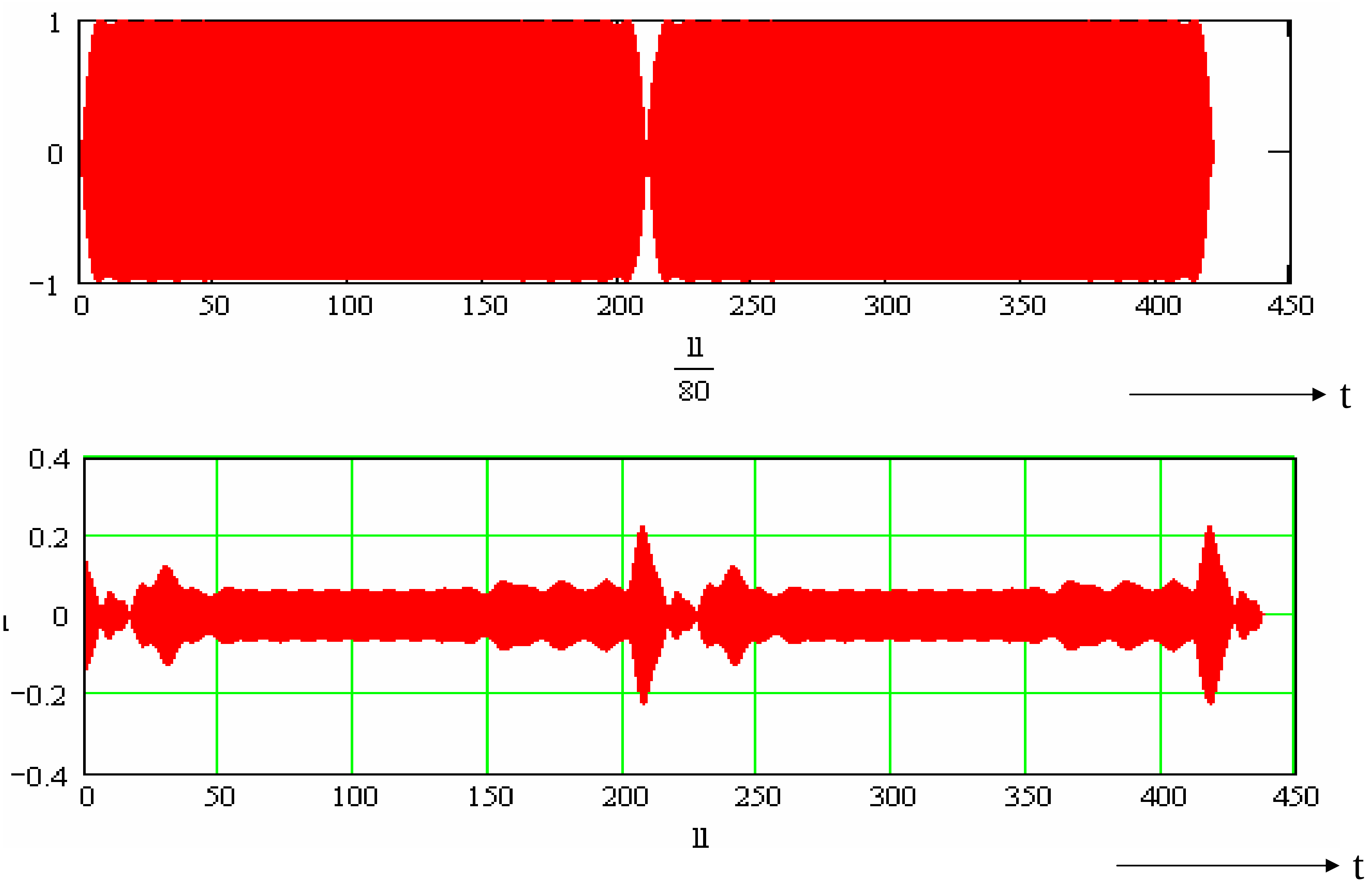
TWT & Beamloading Ez for Vph = 0.694c during phase jump

Real acc./dec. component

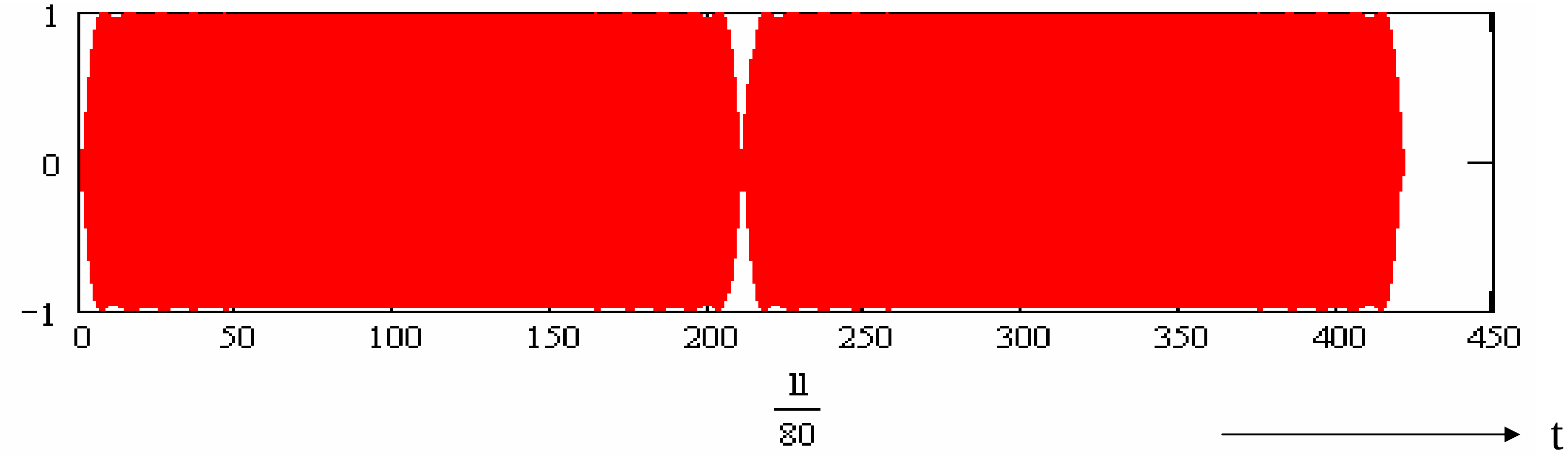
Imaginary bunching/debunching component

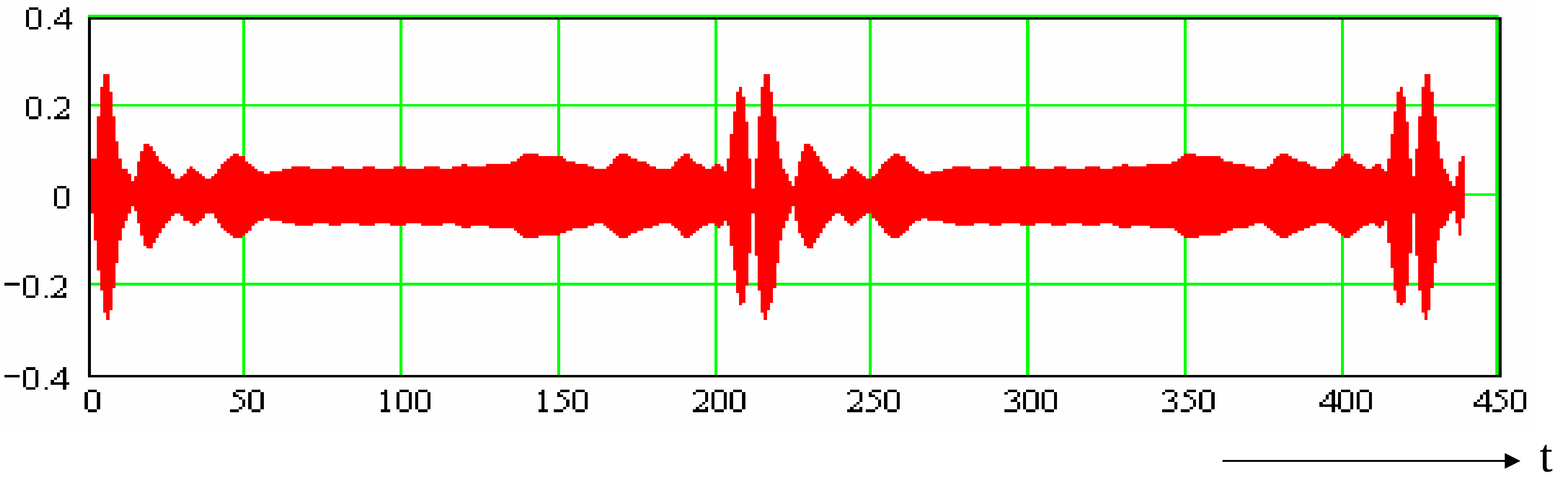


Power amplifier signal and reflected signal from 8-cell structure,

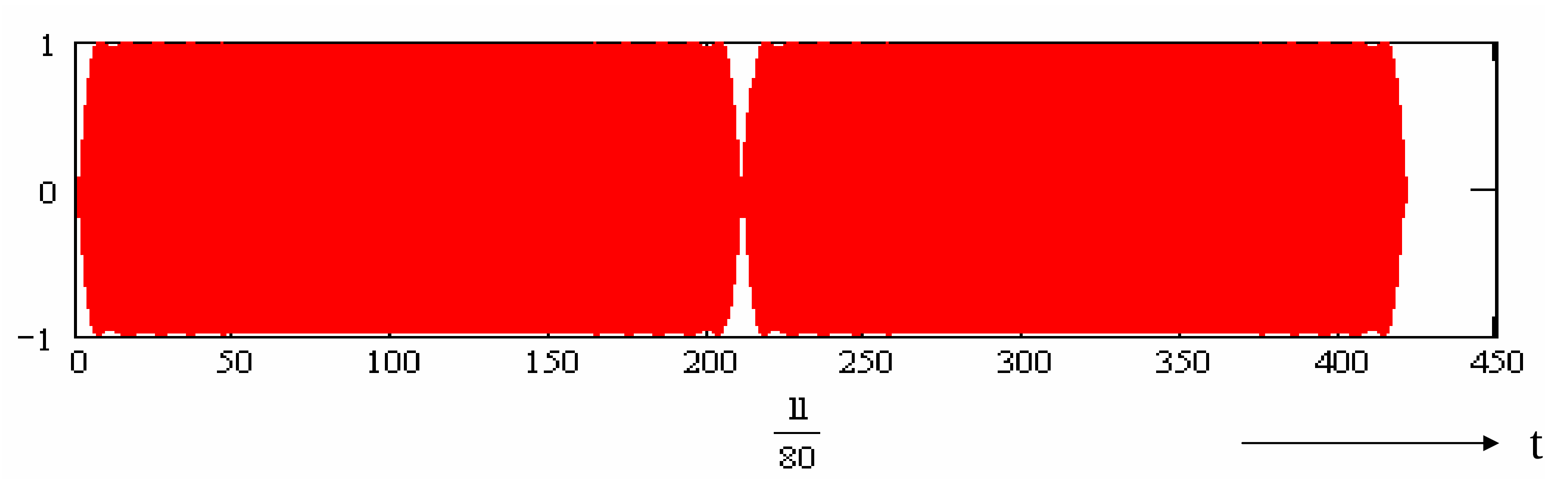


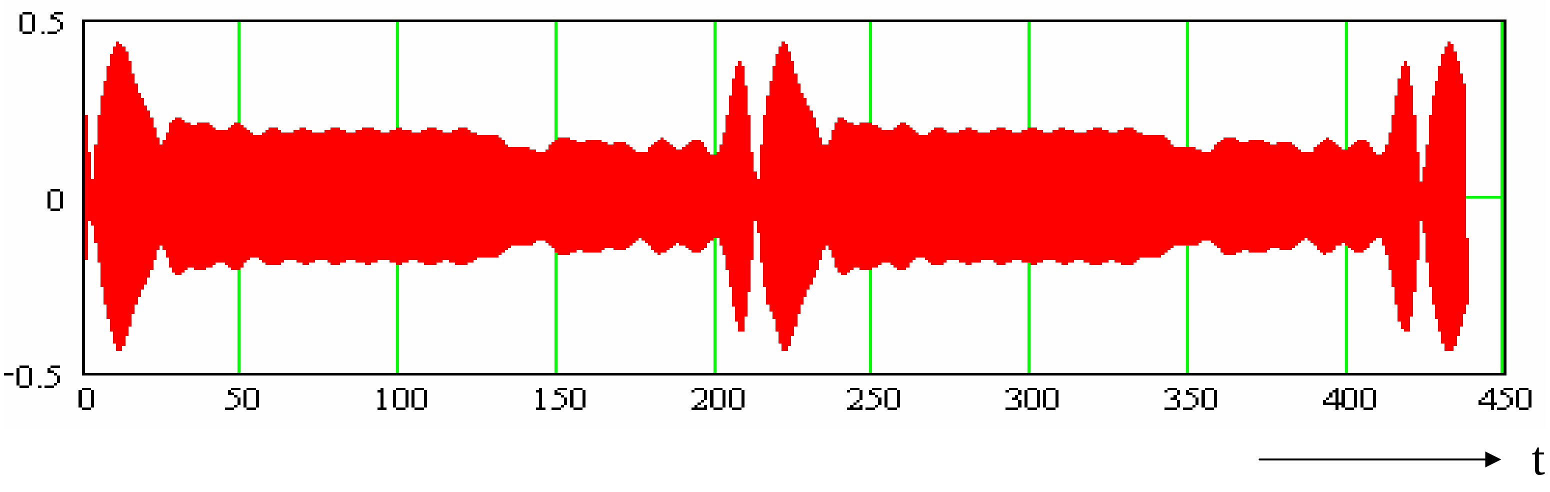
Power amplifier signal and reflected signal from 6-cell structure (non-detuned),



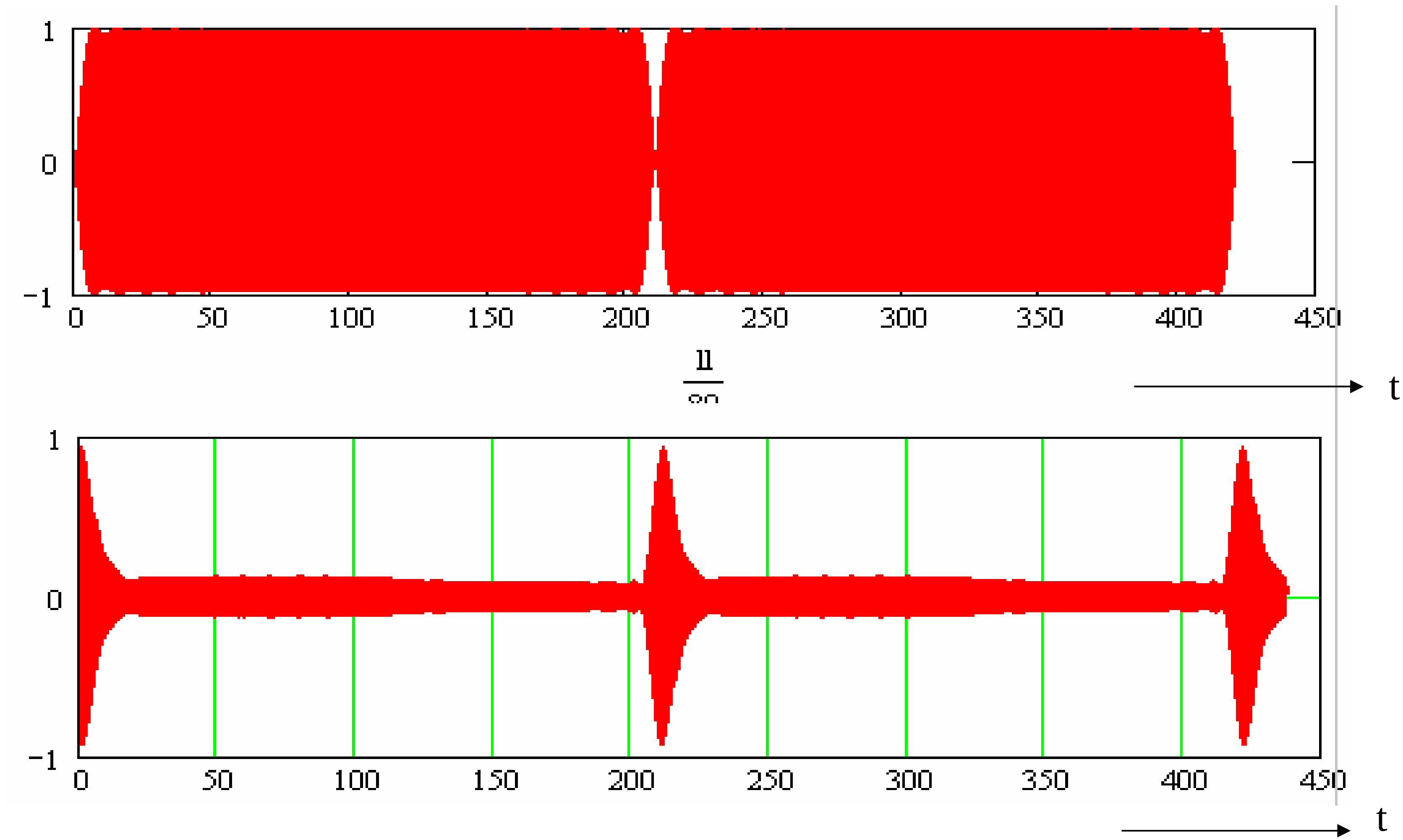


Power amplifier signal and reflected signal from 6-cell structure (detuned),





Power amplifier signal and reflected signal from waveguide structure



Power amplifier tubes

The choice was between:

In case of 4-cell structures or waveguide-type structures

a) Single 750 kW broadband klystron (no spare since too expensive), estimated: 1.6 MCHF modulator available at Cern.

In case of classical 6- or 8-cell structures

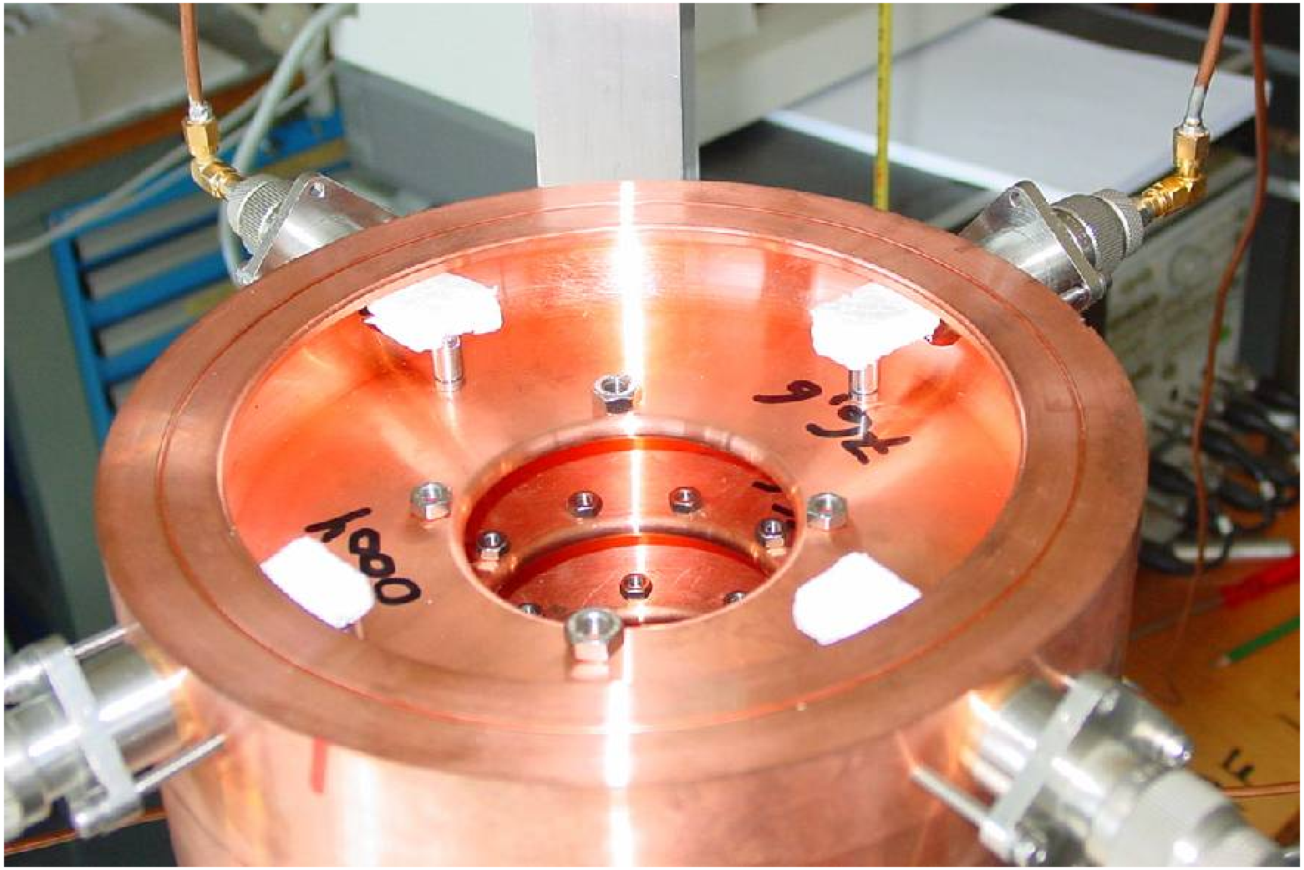
b) Four 40 kW PITOV TWTs $ 114 000 (one spare) power supplies at ~300 000 $.

The cheaper TWT solution was chosen

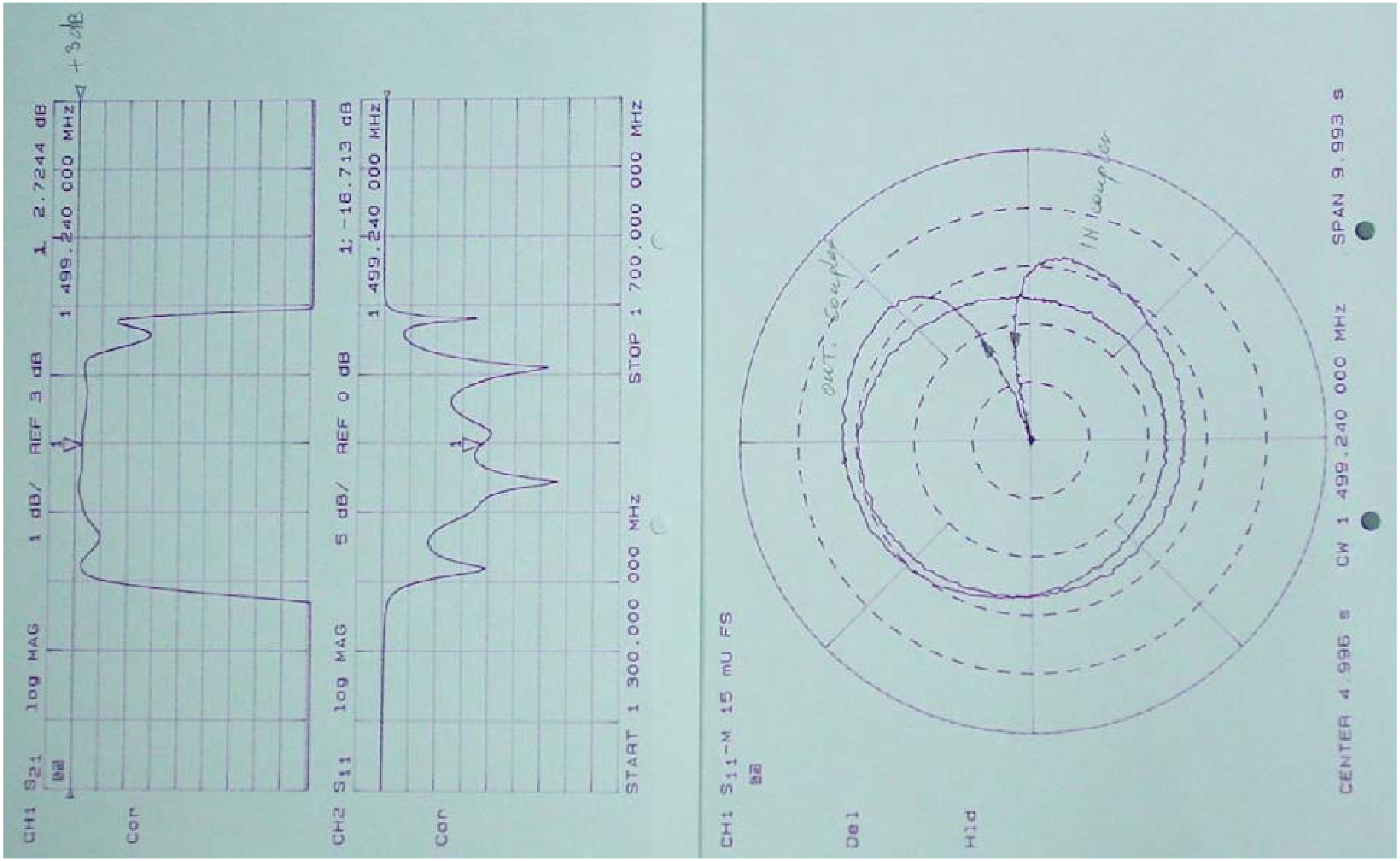
Conclusions

- 1 The three 6-cell structures with a total power need of only 120 kW are able to satisfy the specs at low beam intensities.
- 2 With preadjusted detuning they will also work for a nominal beam current and bunch form factor.
- 3 For a range of currents and form factors reasonable performance can be obtained by phase offsets (this has been shown with Parmela by O. Forstner).

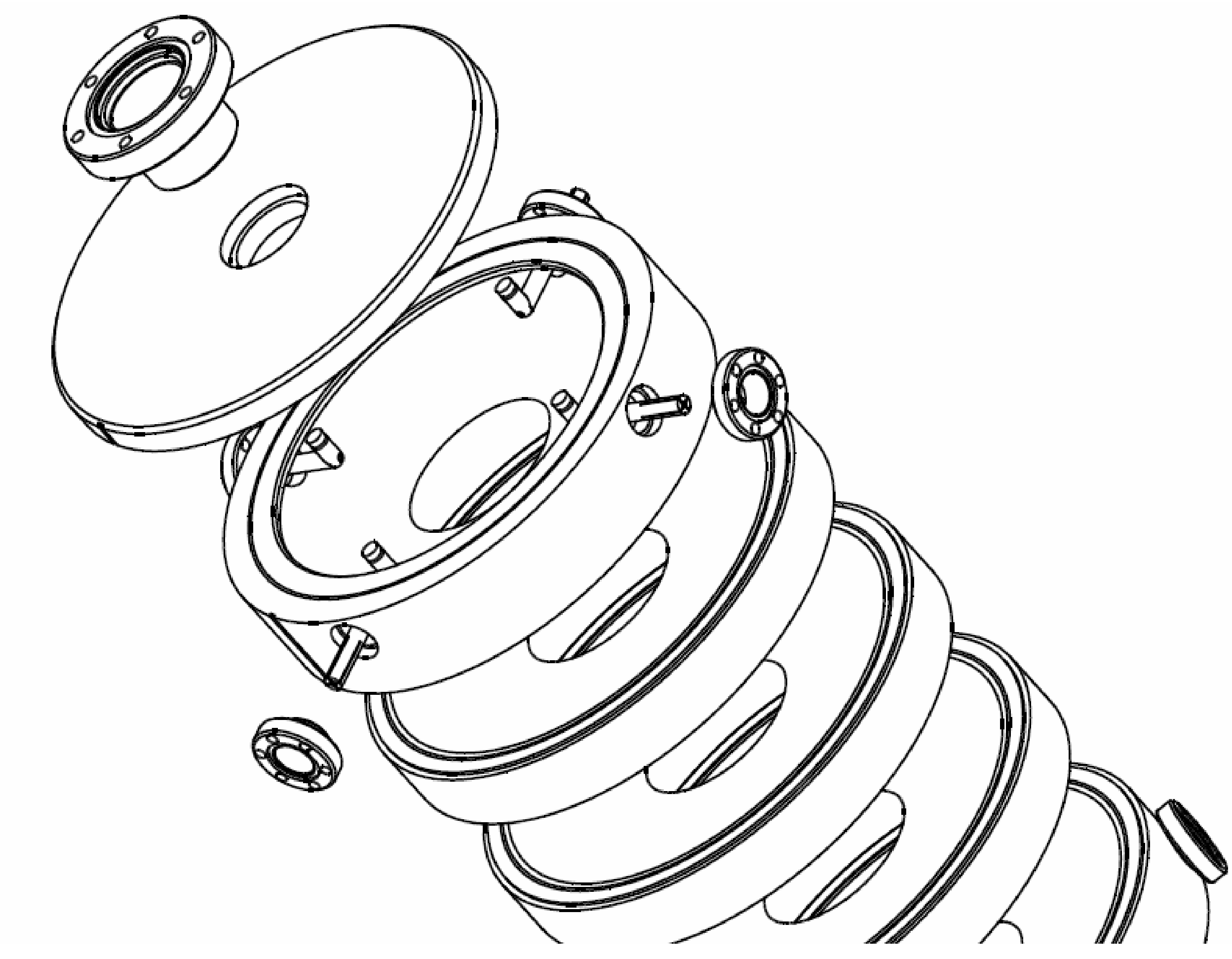
End-coupler with loops and tuning nuts



Transmission/reflection and bead-pull measurements



View before assembly



View of assembled structure with water heaters/coolers and coax. feedthroughs