Superstructures

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JLAB

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I. Introduction and Motivation

- high energy sc linear collider
- high current linacs

II. Nb Prototypes

III. Cold test and test with beam

IV. Final Remarks

List of colleagues involved in the projects

SST for TESLA linear collider:

C. Albrecht, N. Baboi, R. Bandelmann, T. Büttner, H. Chen, P. Castro, J. Eschke, M. Ferrario, A. Gössel, M. Huening, B. Horst, J. Iversen, H. Kaiser, G. Kreps, D. Kostin, M. Liepe, R. Lange, J. Lorkiewicz, A. Matheisen, W.-D. Möller, C. Pagani, H.-B. Peters, E. Pławski, D. Proch, K. Rehlich, D. Reschke, H. Schlarb, S. Schreiber, S. Simrock, W. Singer, X. Singer, C. Tang, K. Twarowski, G. Weichert, M. Wendt, H. Wenhui, G. Wojtkiewicz, S. Zheng.

SST for high current linac:

P. Kneisel, C. Thomas, S. Zheng, G. Wu.

I. Introduction and Motivation

The motivation (end 1997) had two components:

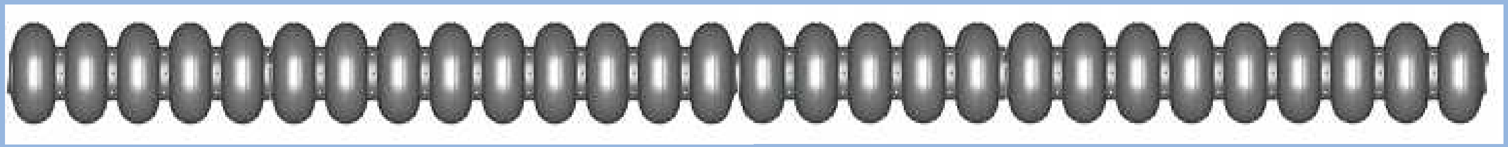
- to lower the investment cost of the TESLA main accelerator
- to lower nominal gradient for already fixed length of the tunnel

⇓

Both goals can be achieved when (N) number of cells/structure increases !

- RF distribution system becomes simpler and less expensive
- more accelerating cells in the tunnel.

We would like to have long structures



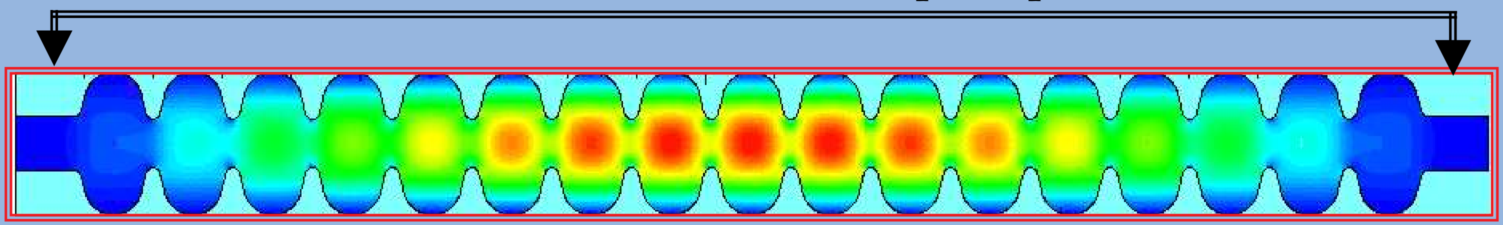
but there are two limits in the number of cells:

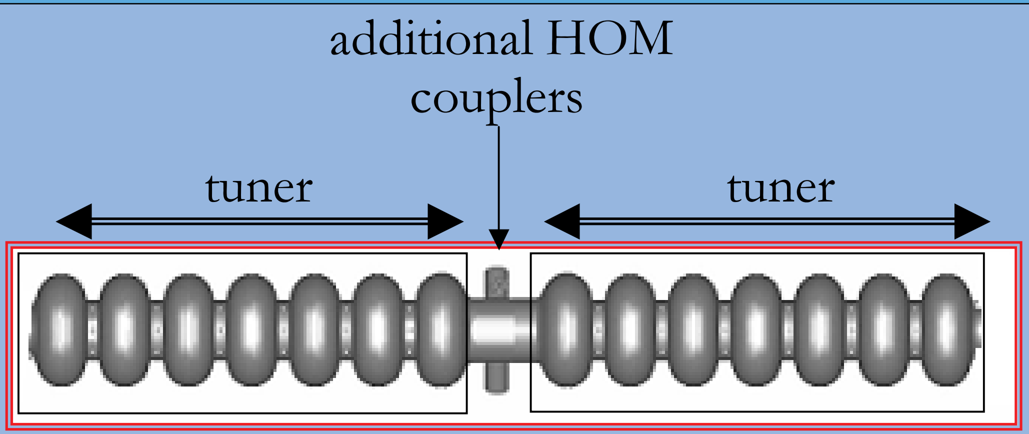
- FM field profile becomes more sensitive to cells' frequency errors :

$$\Delta A_i/A \propto (N^2/k_{cc})\ \Delta f_i/f$$

- Trapping of HOMs increases with N:

no e-m fields at HOM couplers positions



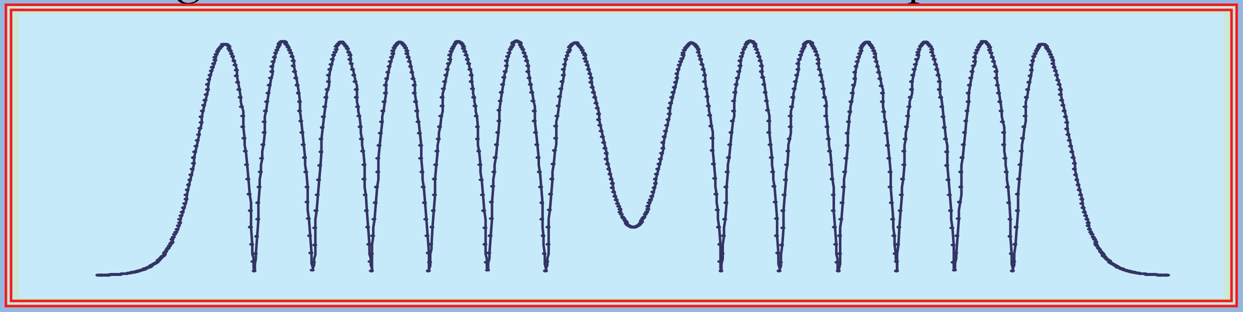


- frequency of each subunit can be adjusted (resolution of cold tuners <1Hz)

$$\Delta A_s/A \propto (N^2/k_{ss})\ \Delta f_s/f$$

- there is enough space to add HOM dampers in the middle of a structure, damping should be at least as good as for an individual subunit

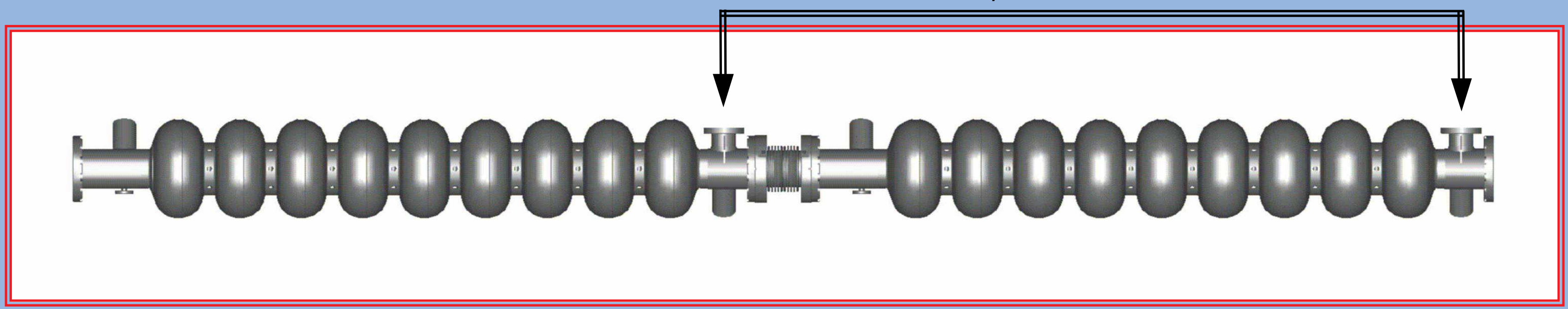
- the accelerating mode is π-0 mode of the TM010 pass-band:



High energy sc linear collider: TESLA

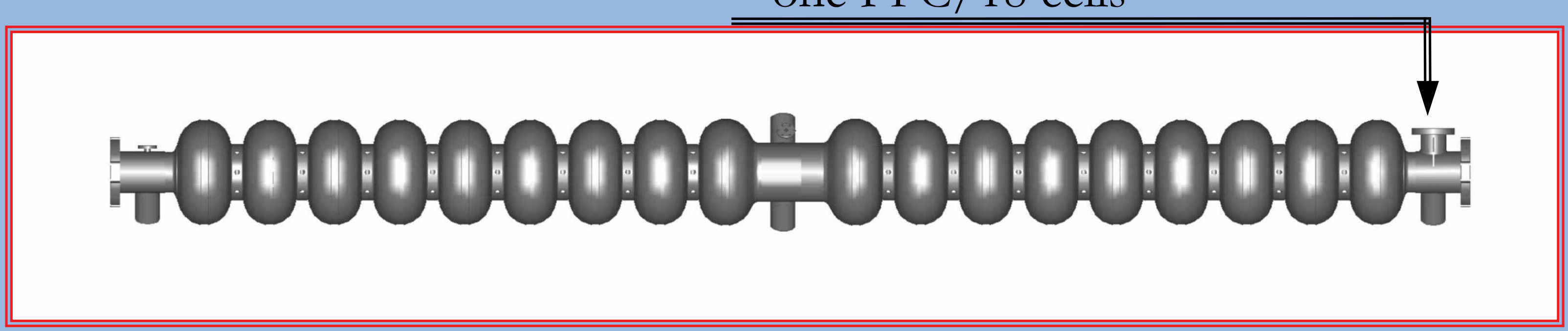
Standard layout: 9-cell structures separated by $3\lambda/2$ long tube

one FPC/9 cells



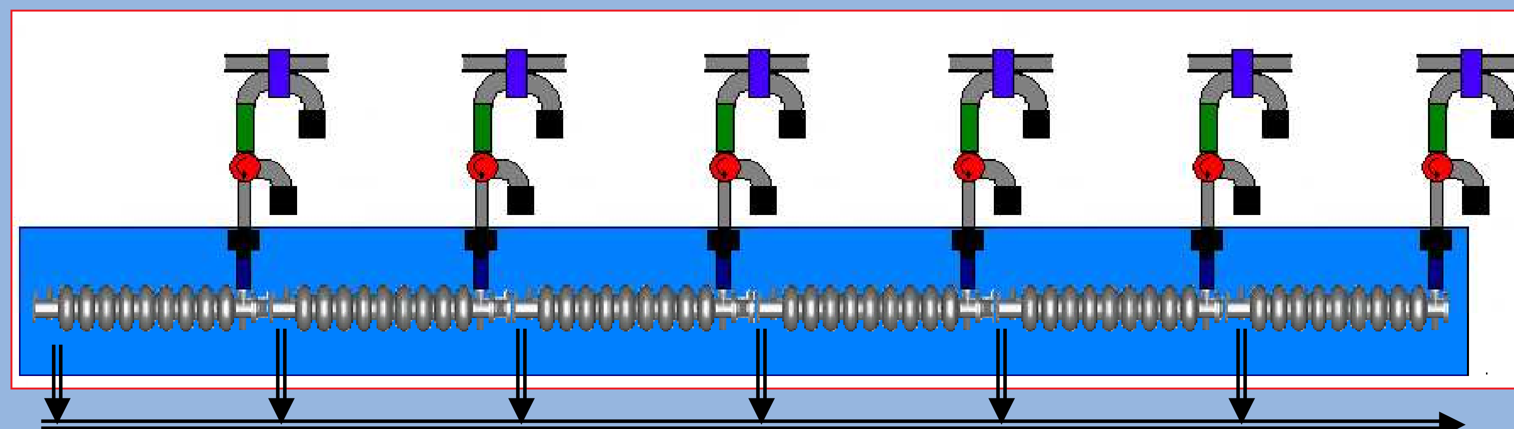
SST layout: Two 9-cell structures coupled by $\lambda/2$ long tube

one FPC/18 cells



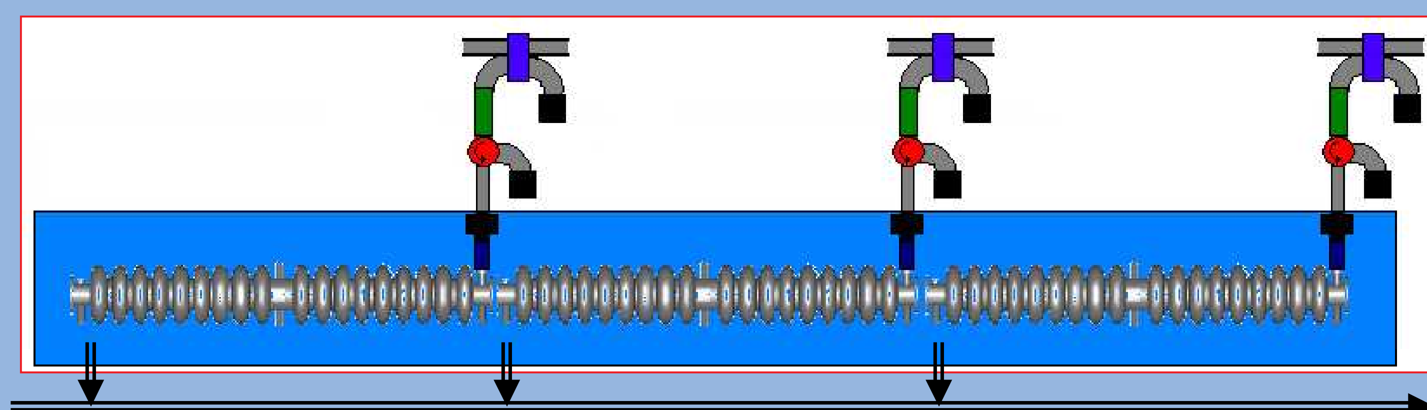
Standard layout

Input Coupler,
Directional Coupler, Loads, Bends,
Circulator, 3-stub Transformer.



RF-control

Superstructure layout



Savings in the investment cost :

10 500 x {

- Input Couplers,
- Directional Couplers,
- Bends,
- Circulators,
- Loads,
- 3-stub Transformers,
- Waveguides
- Electronics for the RF-control,
- ....
- Bellows and flanges,
- Openings in cryomodules.

Better performance:

6% lower gradient for the fixed tunnel length

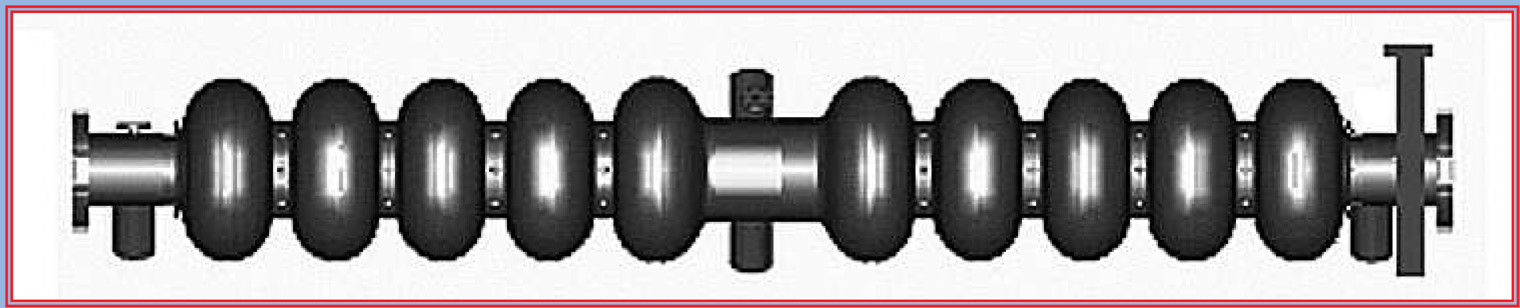
6% (2 km) shorter tunnel for the fixed gradient

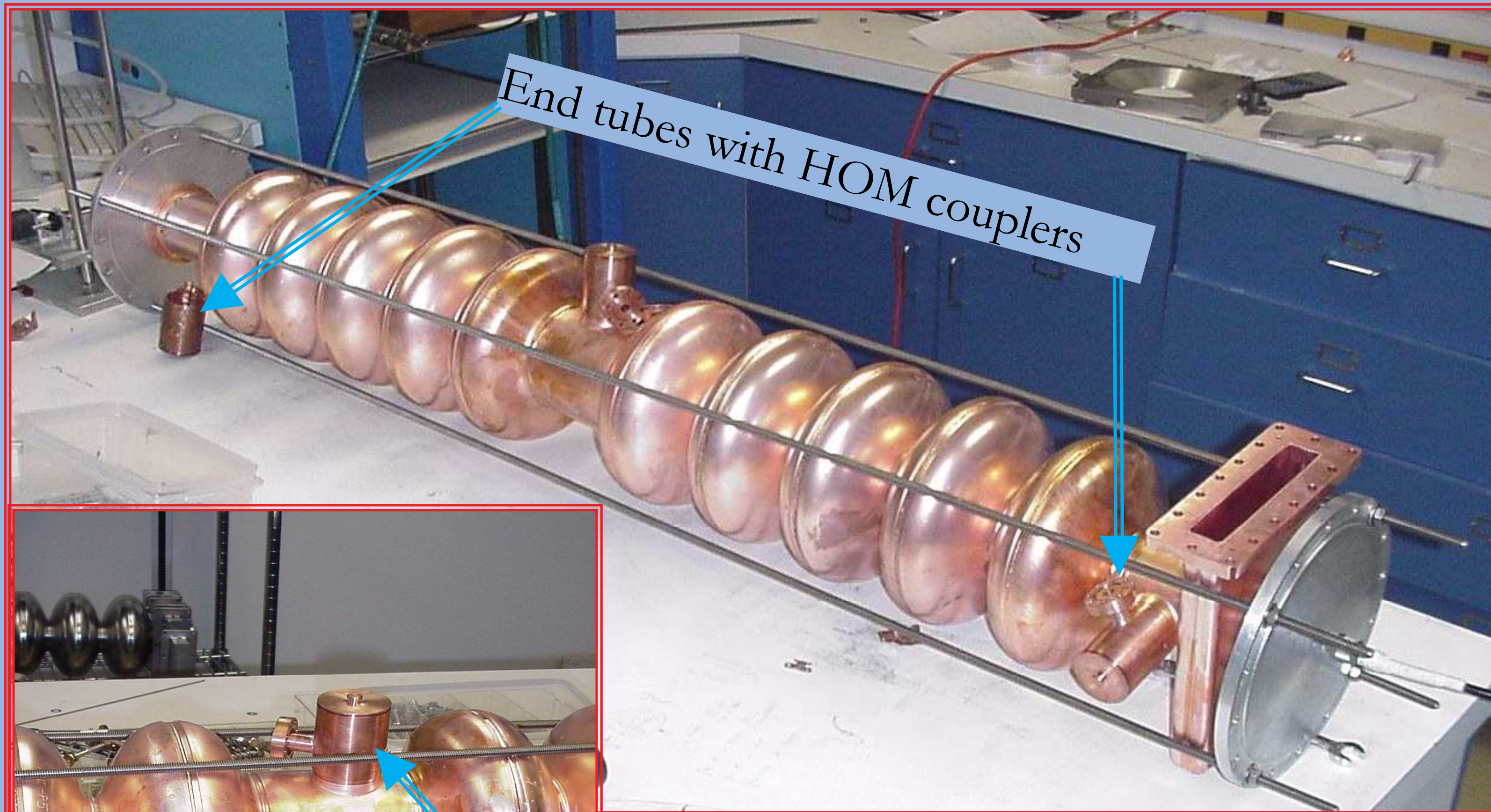
• High current linacs

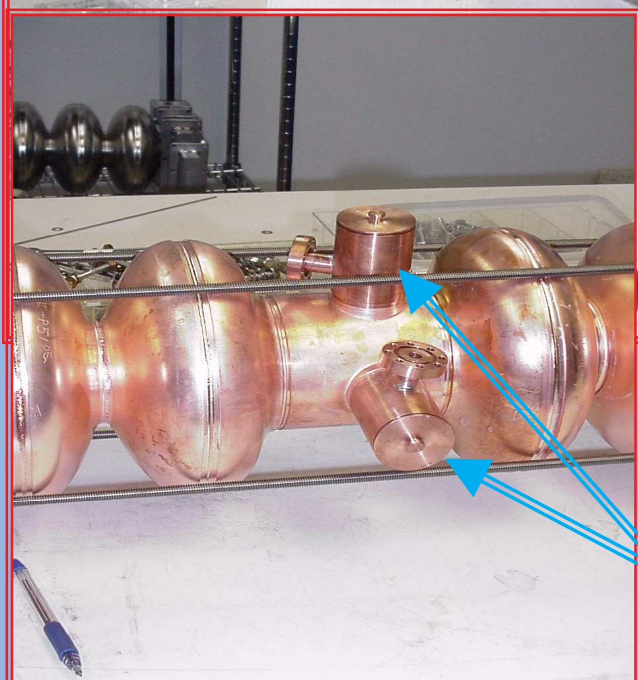
Structures for high current machines must have good damping of HOMs

Example: SST for the FEL upgrade (*JLAB TN-02-034*)

2 x CEBAF-structure (we have more than 30 spare cavities !)

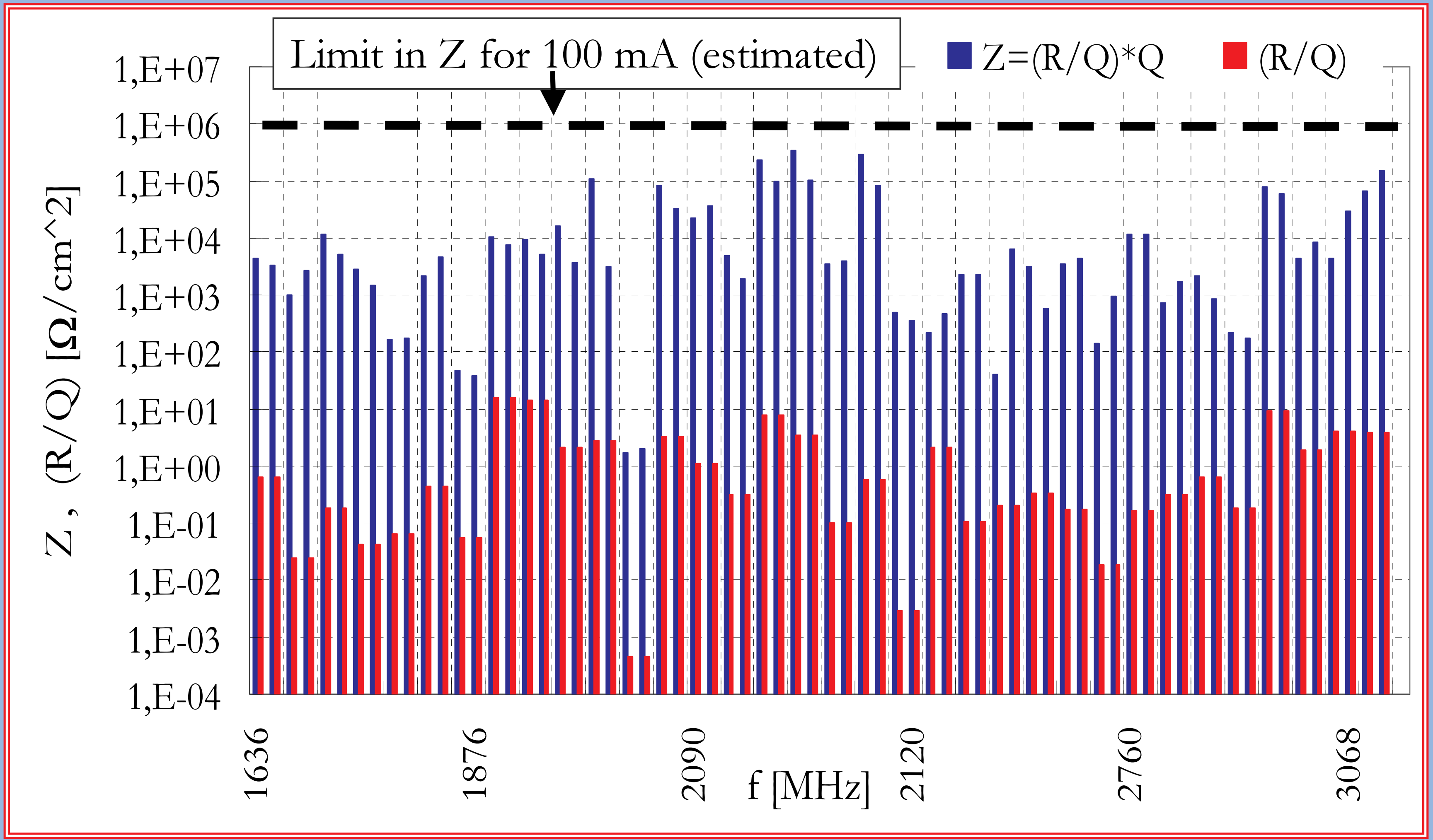






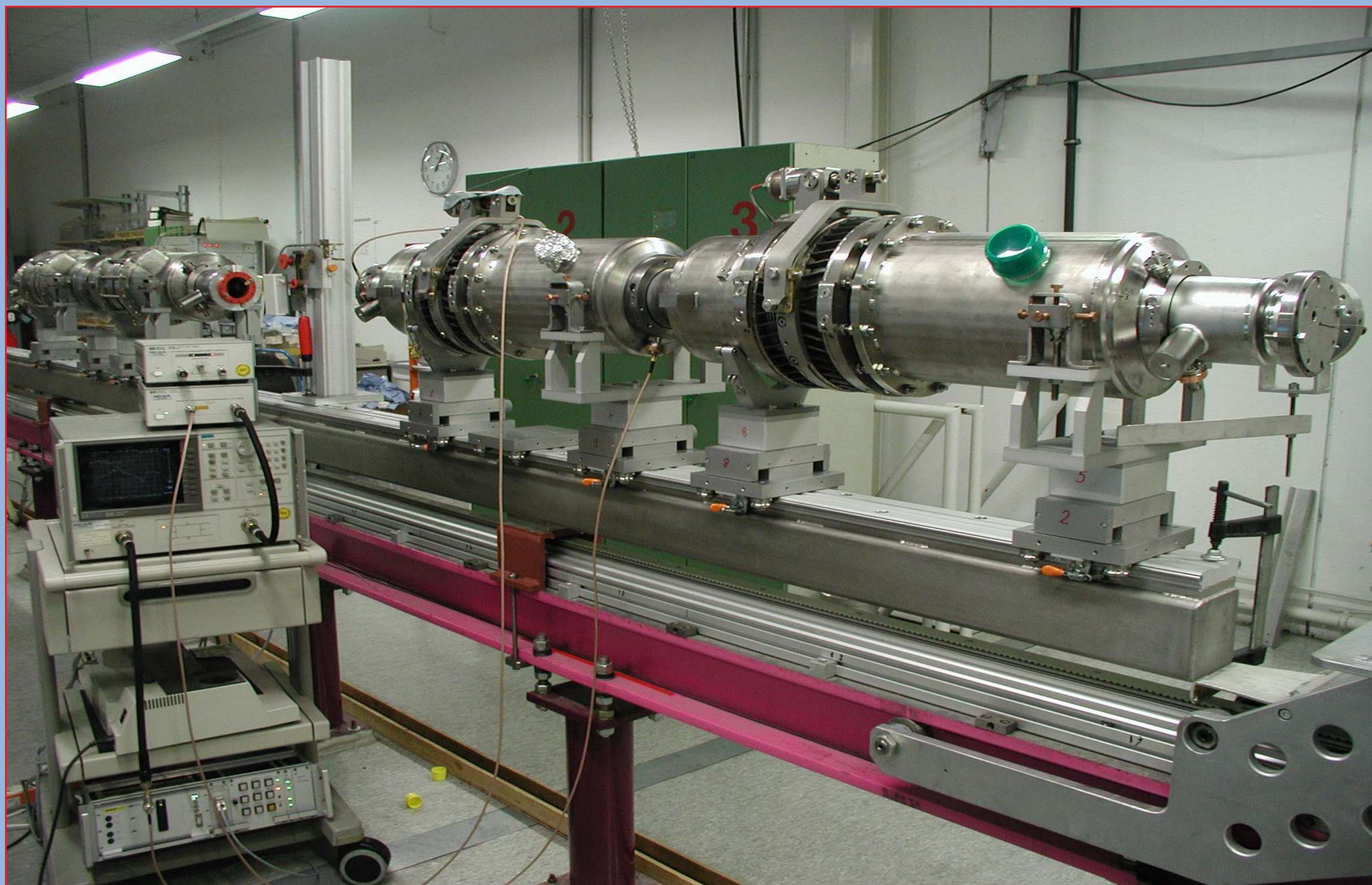
Interconnection with 2 HOM couplers

The damping of parasitic modes is good

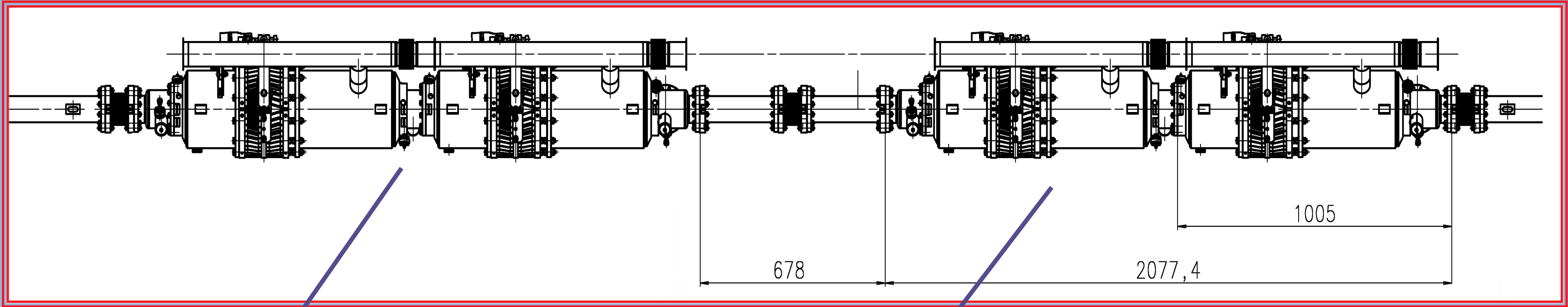


II. Nb Prototypes

2 Nb prototypes of 2 x7cell superstructure have been built at DESY



and assembled in spare standard TTF cryomodule (to keep cost low)

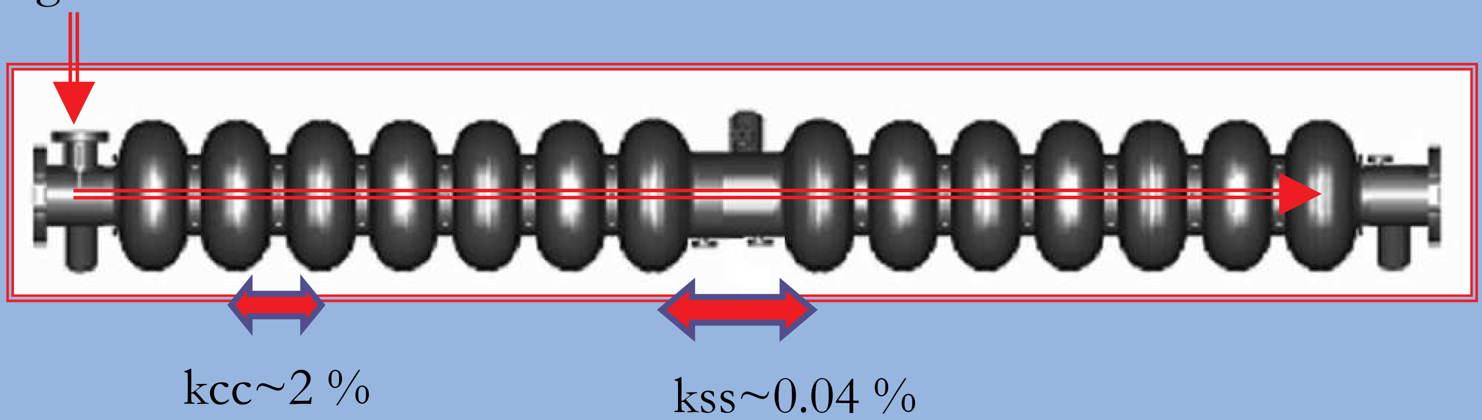


Finally, in May 2002, after 3 years of preparation, the cryomodule was installed in the TTF linac for the cold test.

III. Cold test

1. “proof of principle” experiment to answer the question:

   Is the energy flow via the very week coupling sufficient to keep the energy gain constant for all bunches in the train ?

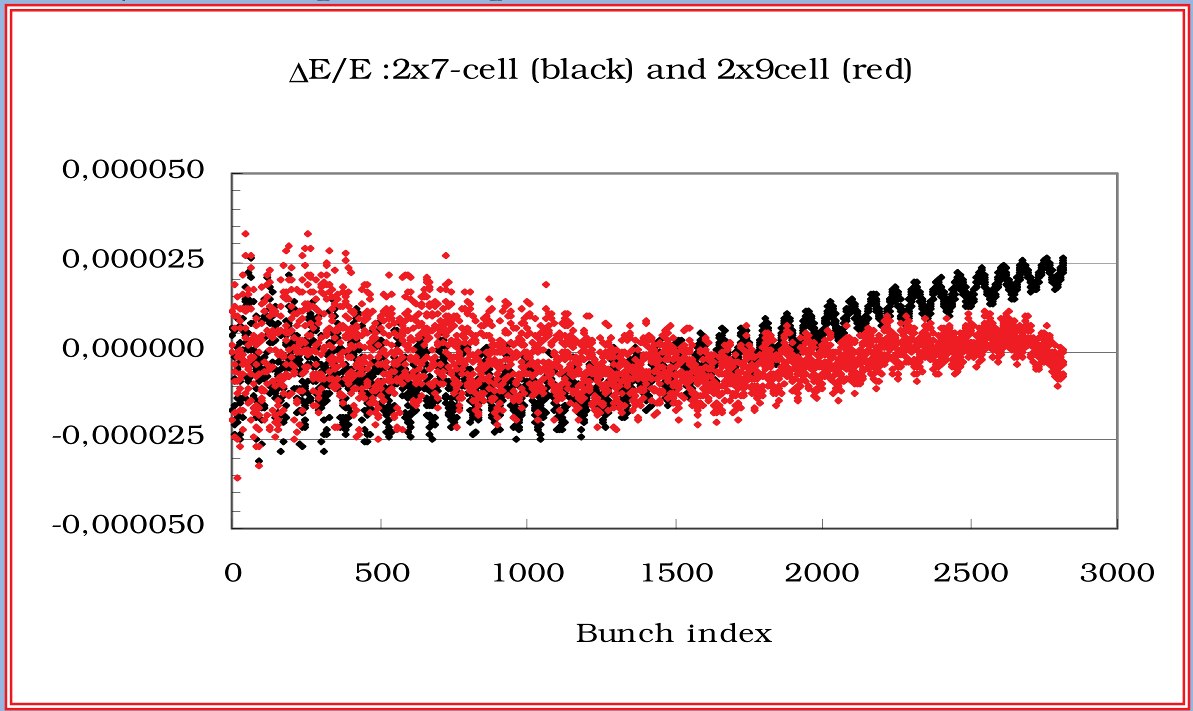


2. How good is damping of HOMs ?

Ad 1. "proof of principle" experiment.

HOMDYN results showed that bunch-to-bunch energy modulation is in the range of $|\Delta E/E| < 4E\text{-}5$ (peak-to-peak).

$\frac{\Delta E}{E}$

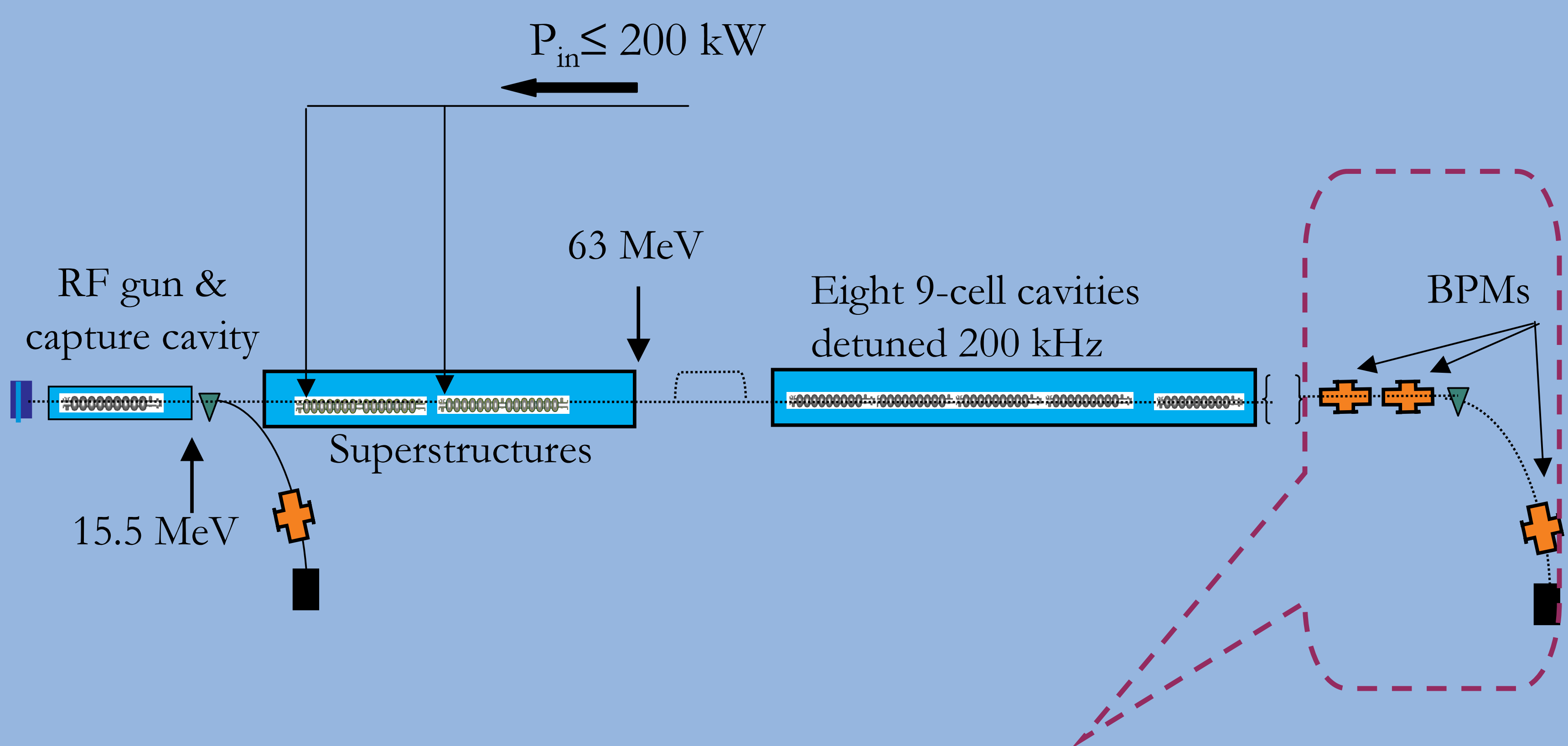


For the new TESLA beam: 2820 bunches, Δt=337 ns

similar result for

the old TESLA (TTF) beam: 800 bunches, Δt=1000 ns.

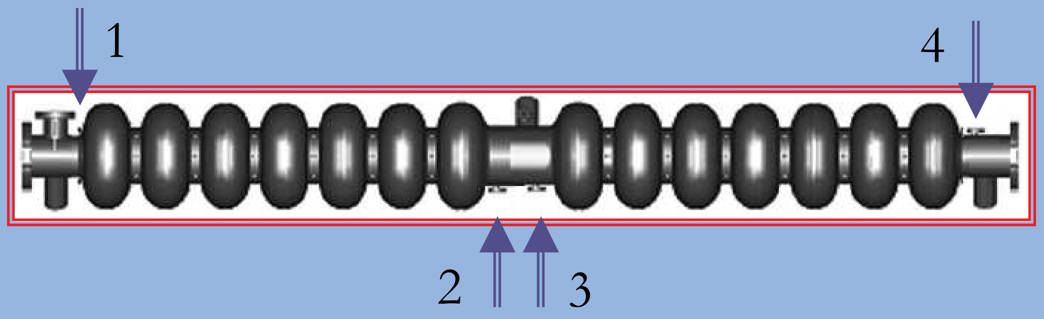
TTF linac for the SST test



ΔE/E measurements
accuracy: $2.5 \div 3.5 \cdot 10^{-4}$ (rms)

not enough to measure the computed modulation

Additionally to the E measurement we measured direct signals of the field probes which are placed near to the end-cells of each sub-unit.



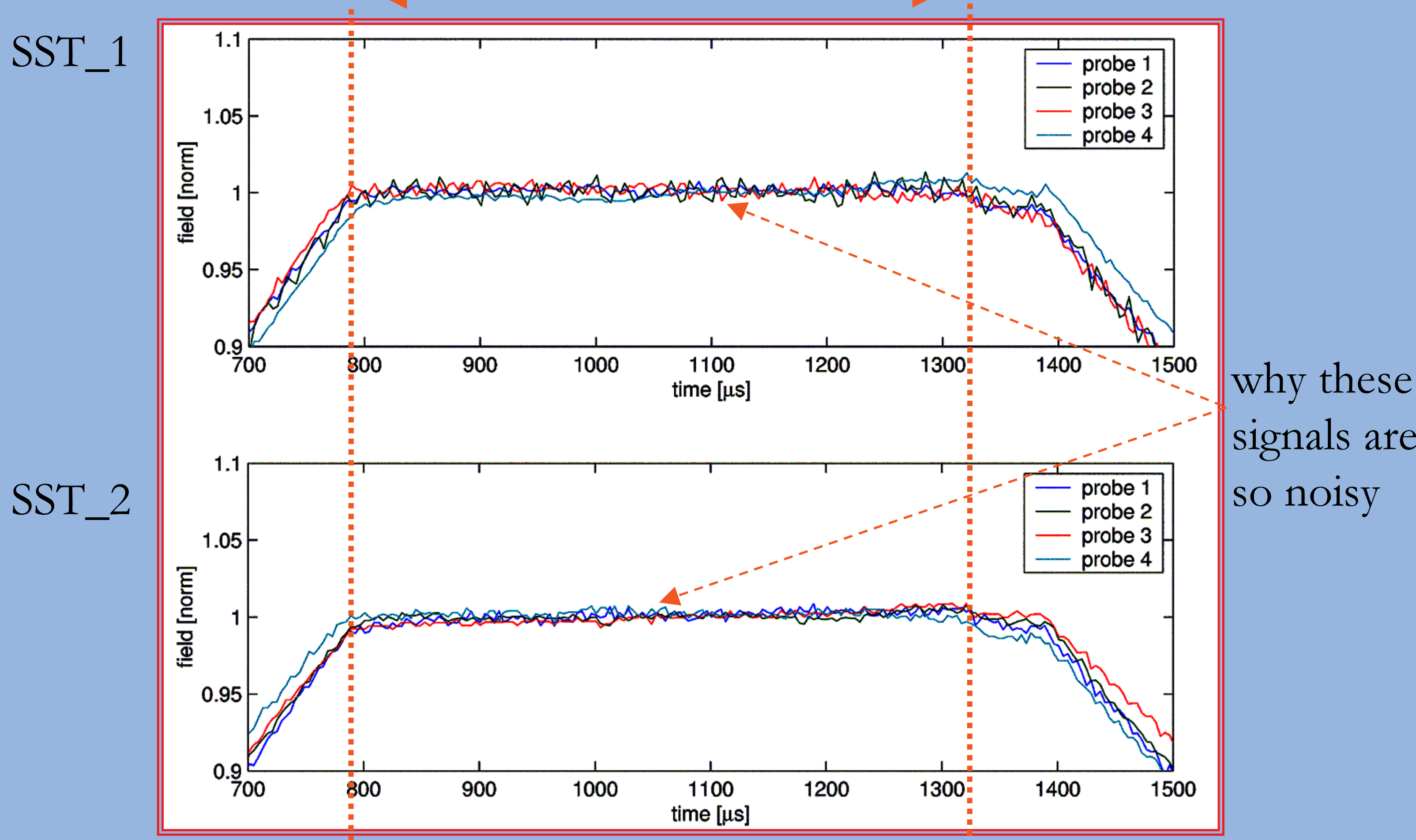
Example: acceleration of ~530 bunches, q=4 nC at Eacc= 15MV/m

The stored energy in each cell at this gradient is **3.2 J**

Without re-filling during the acceleration beam would take from each cell **69%** of the stored energy

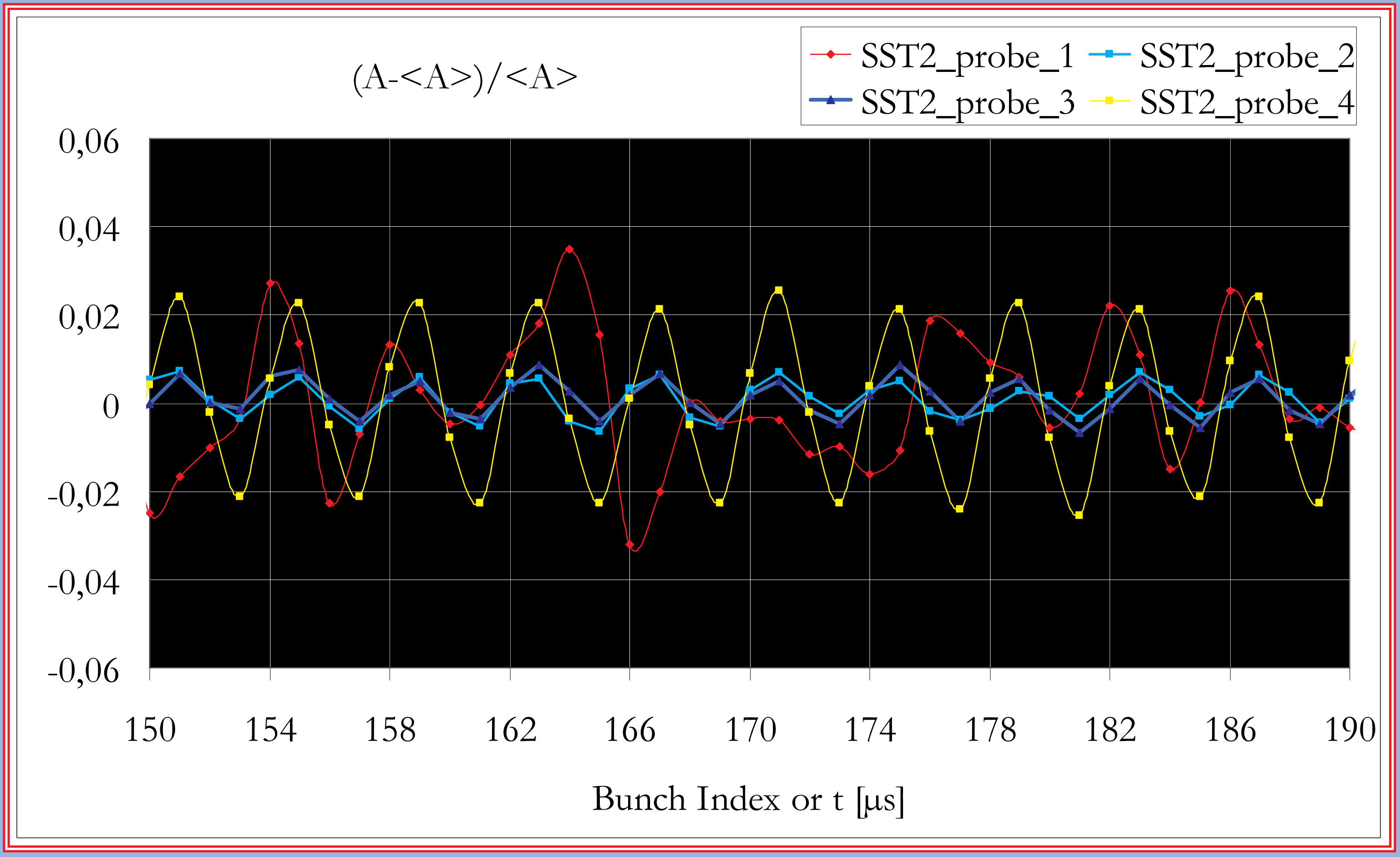
Voltage in the end cells would drop by **45 %** !!!

530 μs beam was on



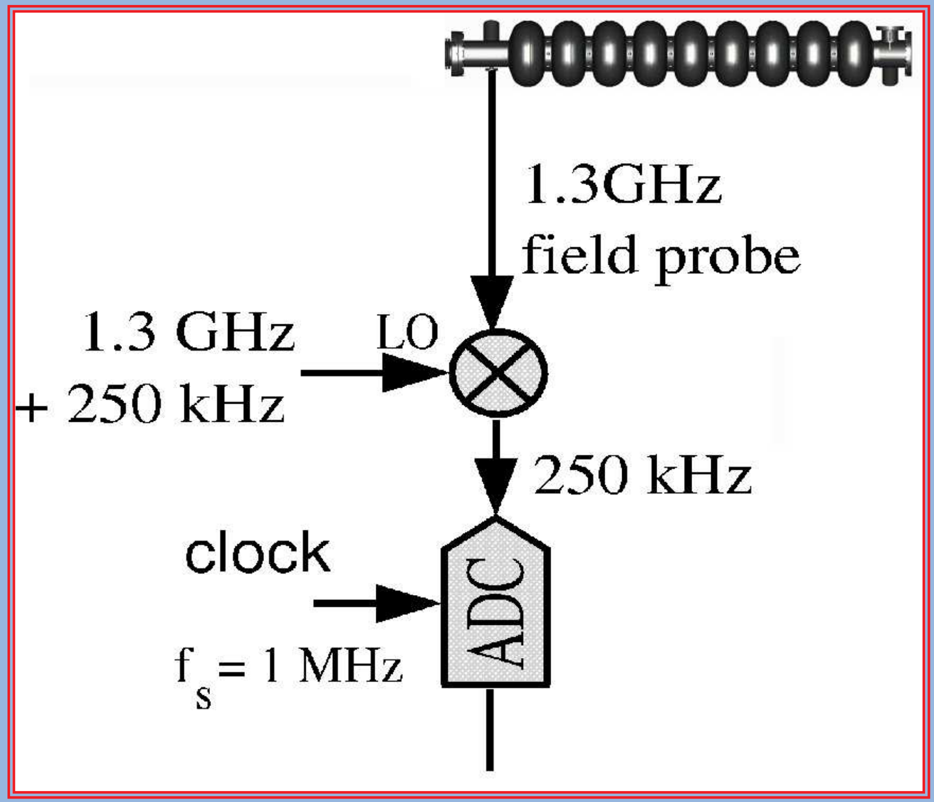
No voltage drop was observed. This was the first hint that SSTs may work, but…

Zoomed signals, beam: 400 bunches/pulse, q=1 nC.



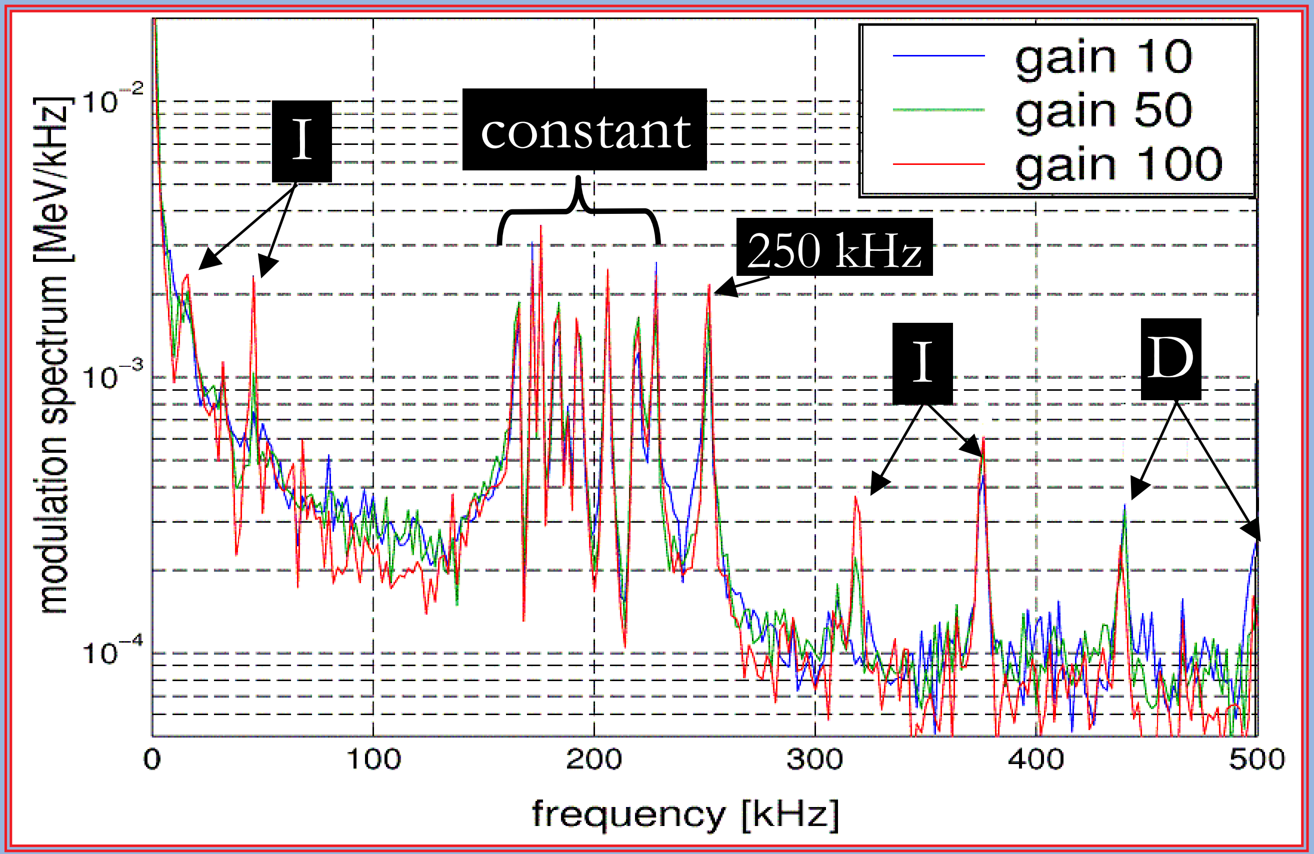
Oscillations had periodicity of 4 µs

and they were caused by the down-converters used for the LLRF



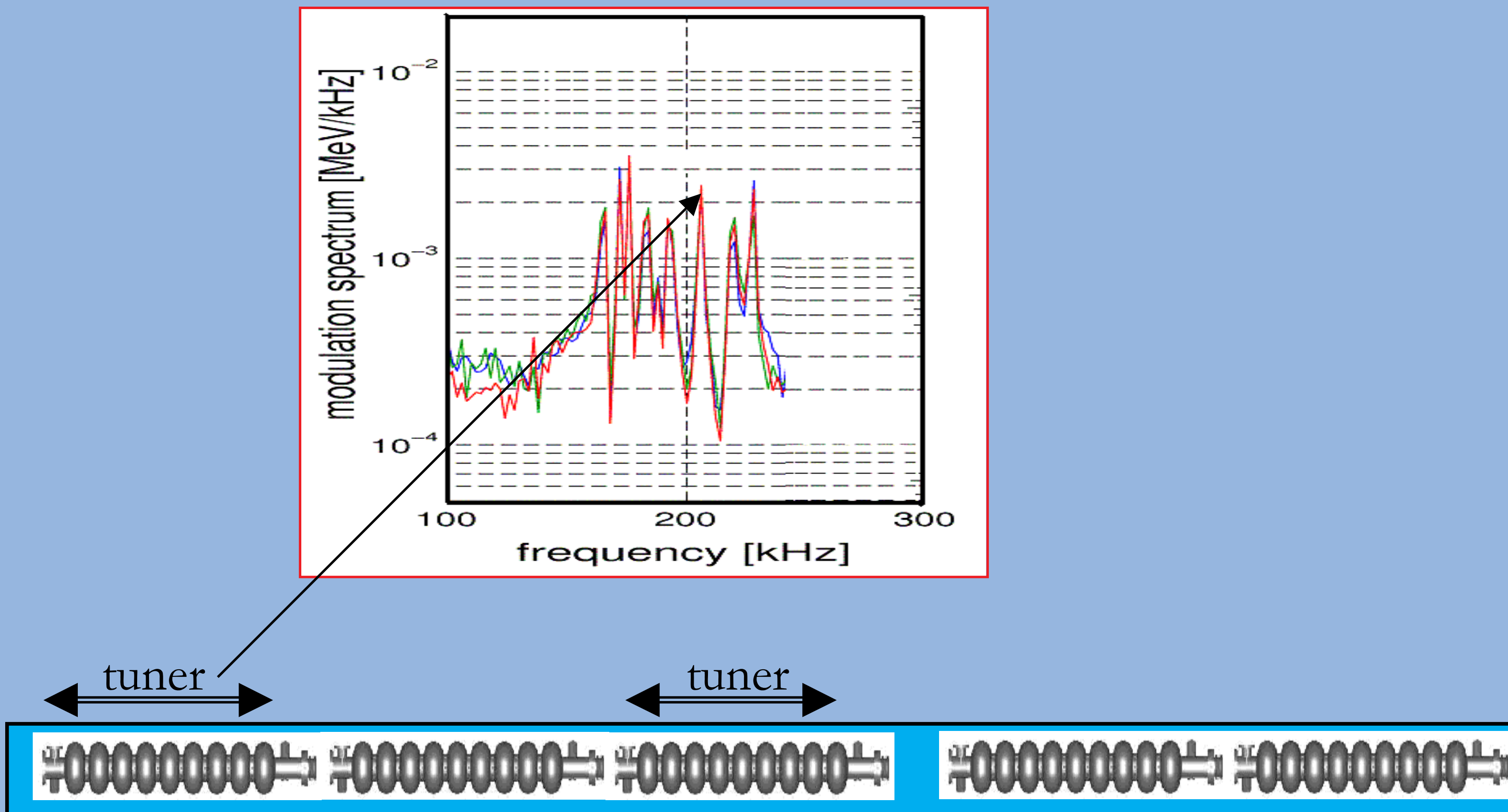
Direct energy measurements at the end of the TTF linac

What is the energy spectrum for the whole macro-pulse ?



Energy modulation for 3 various gains of the feedback loop

The question was: what are these 8 peaks ?



The eight 9-cell cavities of the second cryomodule finally, the measured bunch-to-bunch energy modulation was estimated:

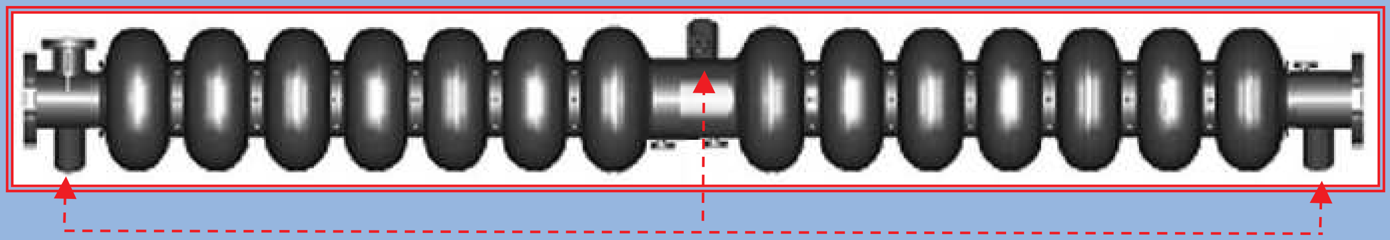
$$\Delta E/E \text{ (rms)} \leq 3.5 \cdot 10^{-4}$$

The specification for the TESLA collider (TDR)

$$\Delta E/E \text{ (rms)} \leq 5 \cdot 10^{-4}$$

Cold test cont

2. How good is the damping of HOMs ?



3 HOM couplers/SST

We applied 3 complementary methods in this test to verify the impedance of parasitic modes: **Z = (R/Q)*Qext**

- f and Qext measurements by means of Network Analyzers
- •• Active HOM excitation
- ••• Charge modulation excitation

- f and Qext measurements by means of Network Analyzers

We measured 420 modes of both SSTs:

dipoles 1st,2nd,3rd,4th and 5th passband (up to 3.1 GHz)

quadrupoles (some of 1st passband)

monopoles (some of TM011 passband)

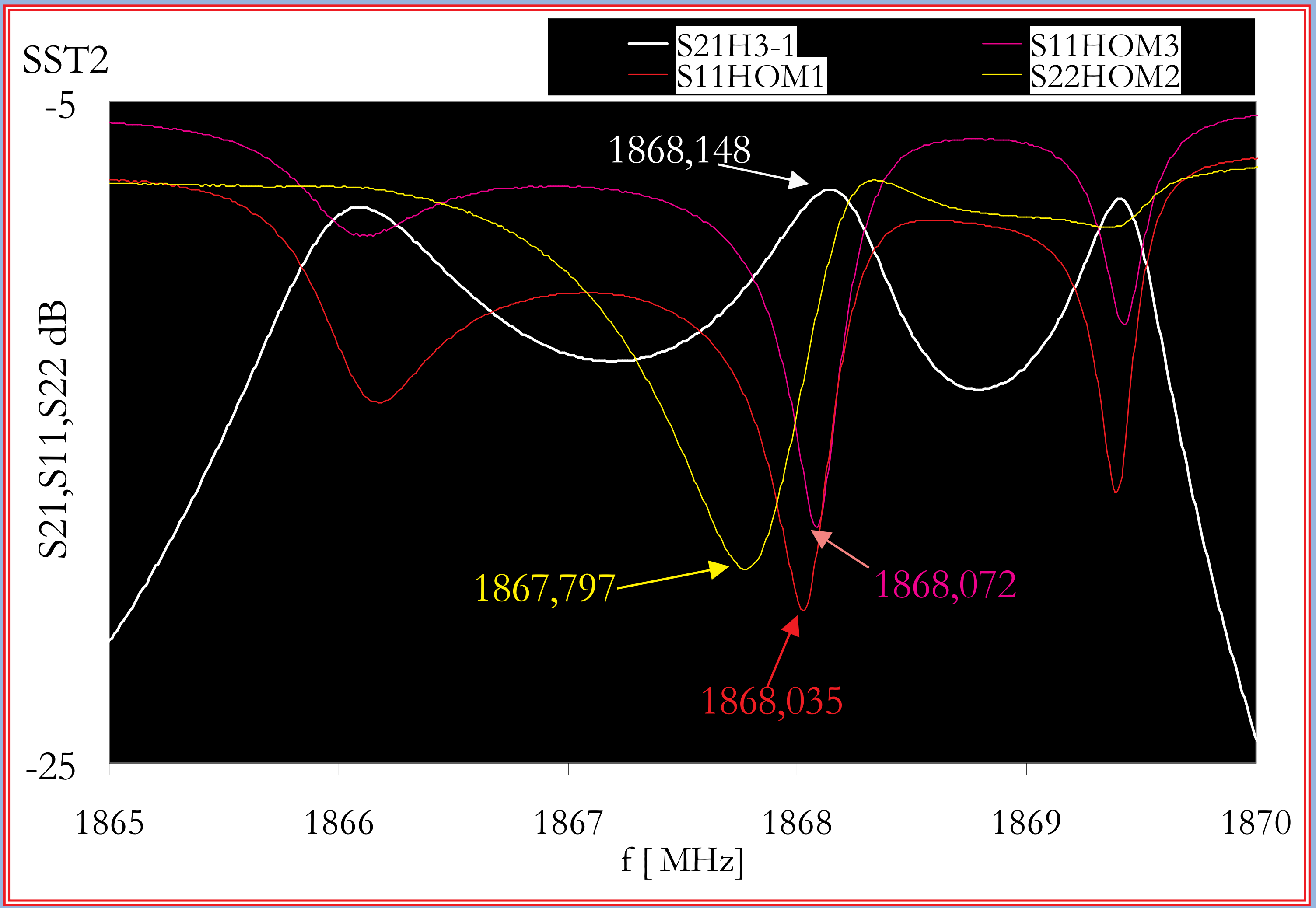
for 58 modes we measured only f.

We cannot identify 70 modes to be a monopole, dipole or quadrupole

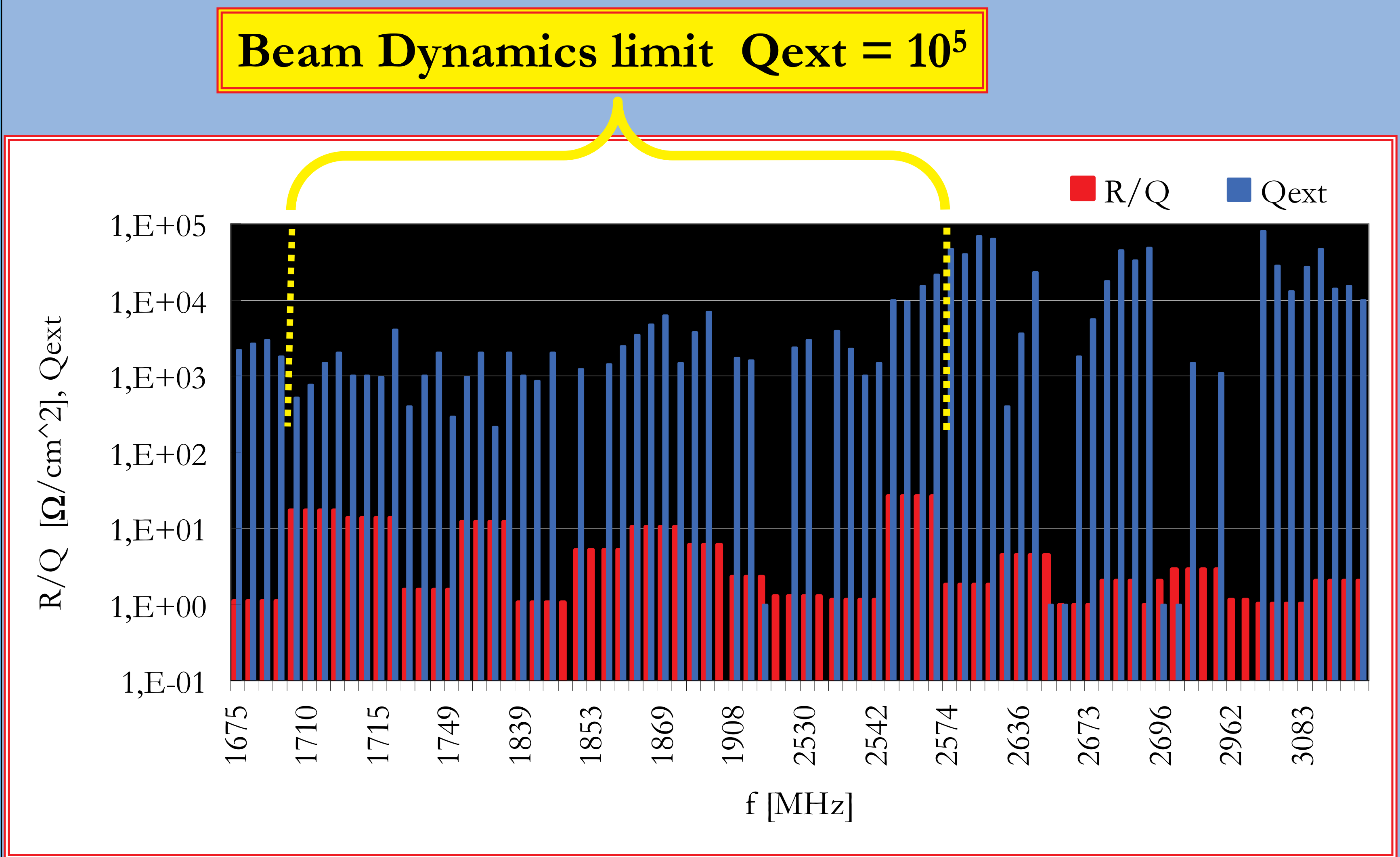
The method does not give information about actual value of (R/Q) !

Frequency errors are big when the Qext is small and when modes overlap

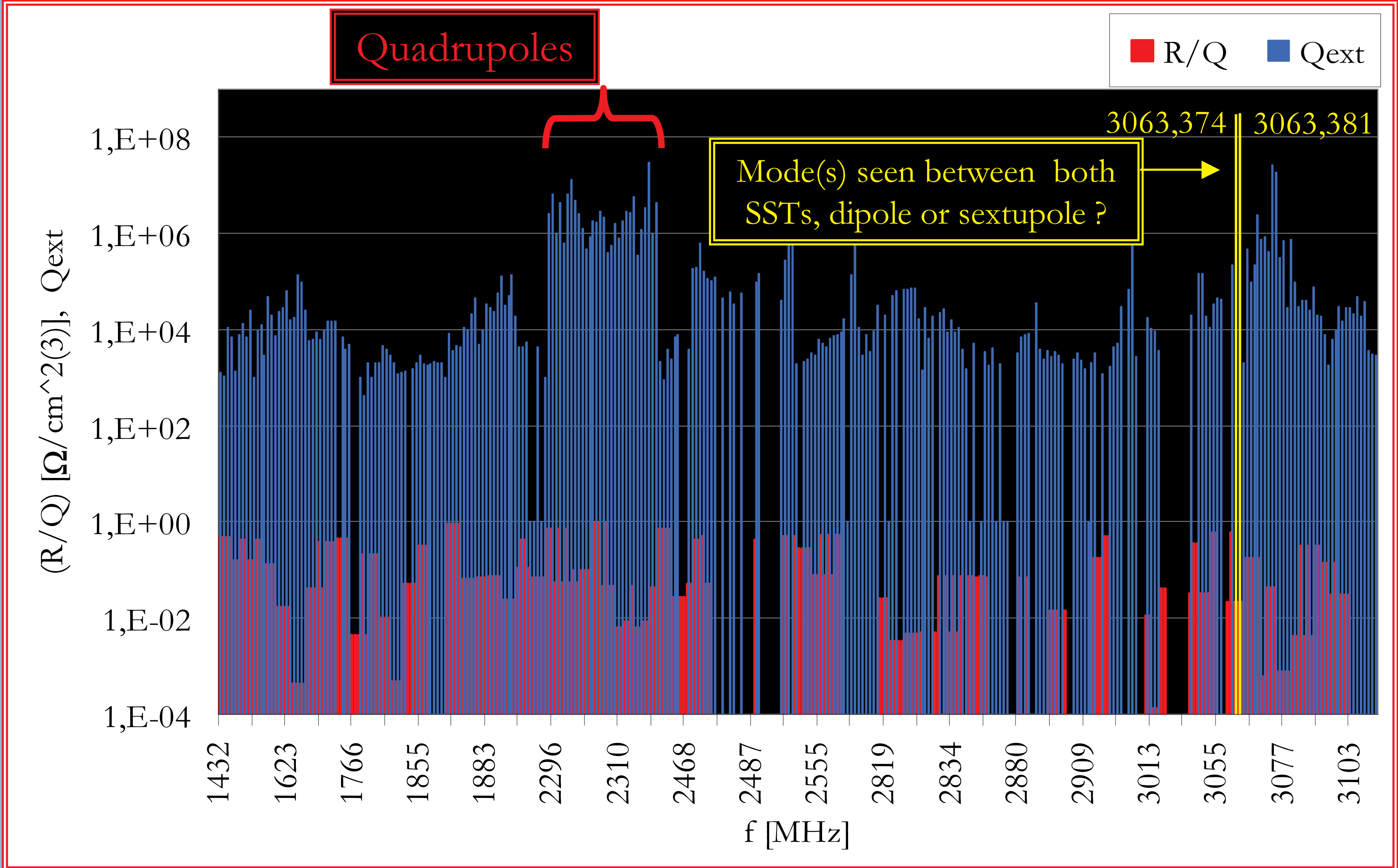
Example: Transmission and 3 reflection signals: Δf = 275 kHz



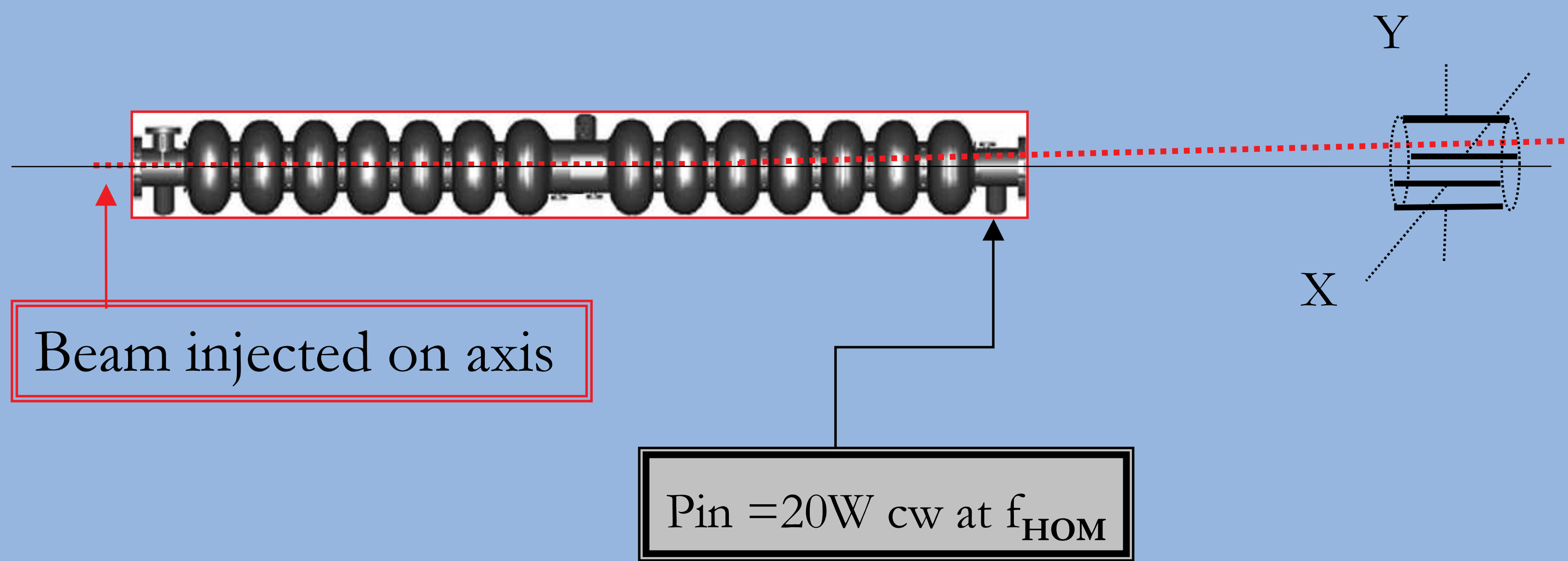
“Dangerous” dipole modes with (R/Q) ≥ 1 Ω/cm²



Dipoles and Quadrupoles with (R/Q)<1Ω/cm^2 (3), and unknown modes of both SSTs



• Active HOM excitation



This method can give all parameters of the excited HOM:

- impedance Z of HOM and (R/Q) when Qext is known
- polarization of HOM
- but it does not work when HOM couplers couple weakly to the mode

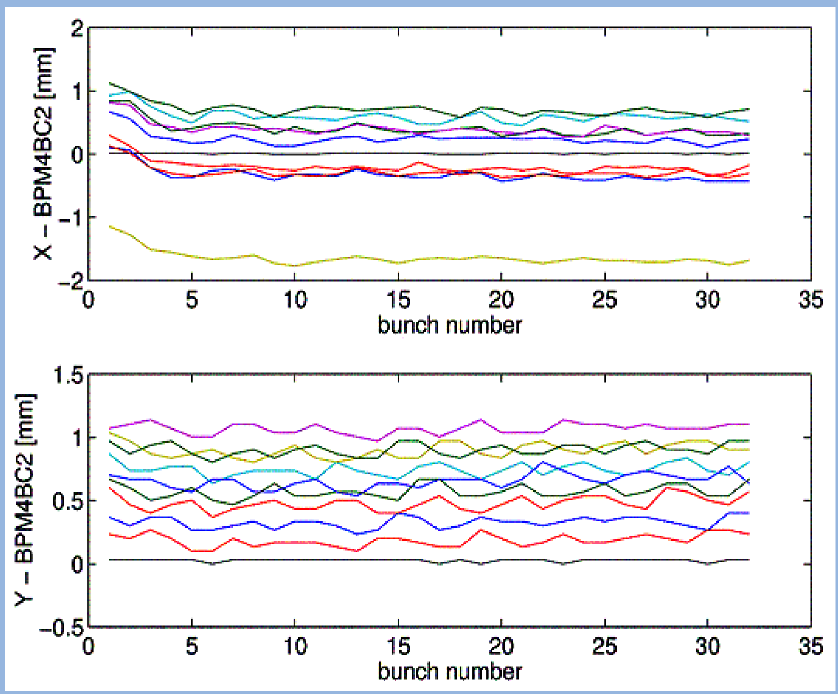
We measured with this method **47 dipoles** (analysis in progress).

Example: Dipole of SST1:

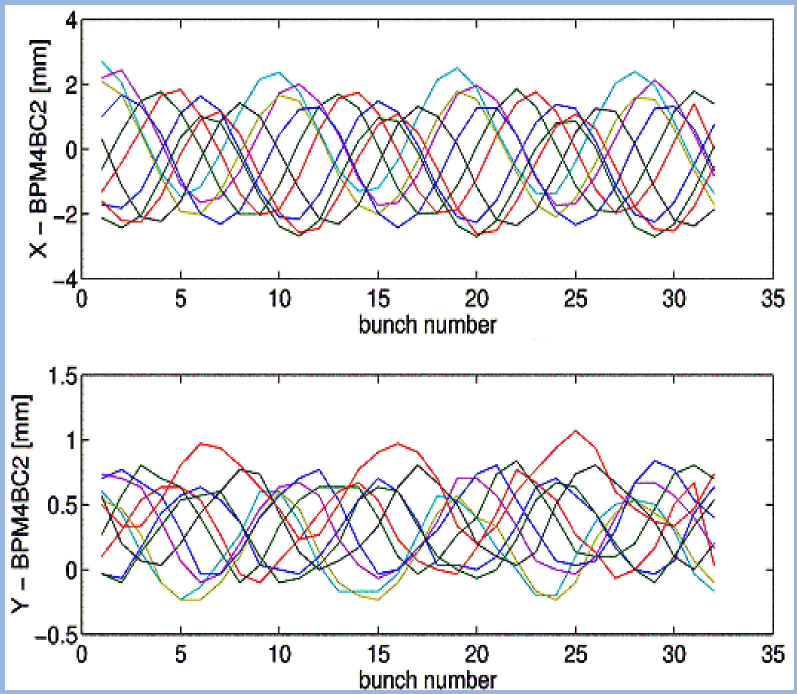
f = 2573.971 MHz, (R/Q) = **27 Ω/cm^2**, Qext = 21000

beam: 1 MHz, 30 bunches, q=2 nC (10 pulses)

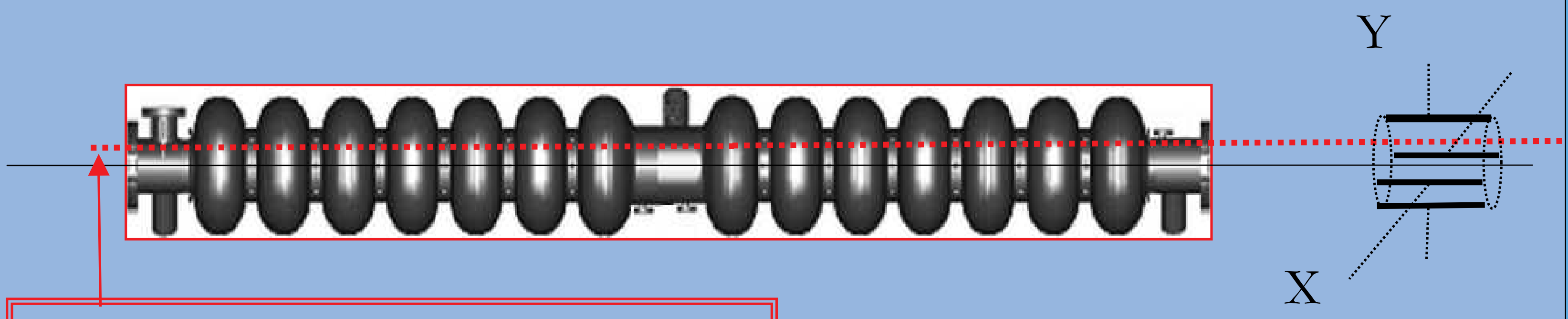
BPM response no excitation



BPM response with the excitation



- Charge modulation excitation



Beam injected off axis, 10 mm

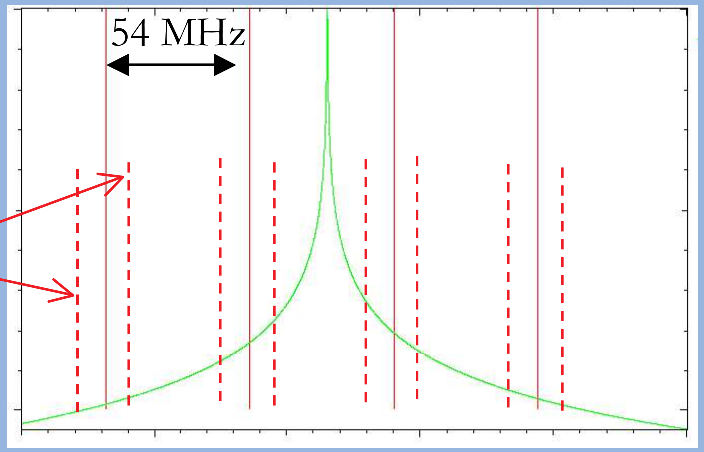
Beam time structure: 54 MHz, q= 40 pC, pulse length 400 µs

The charge was modulated first 200 µs :

f_{mod} = 0.001 ÷ 27 MHz,

80 % modulation depth.

Side band lines: n*54MHz $\pm f_{mod}$

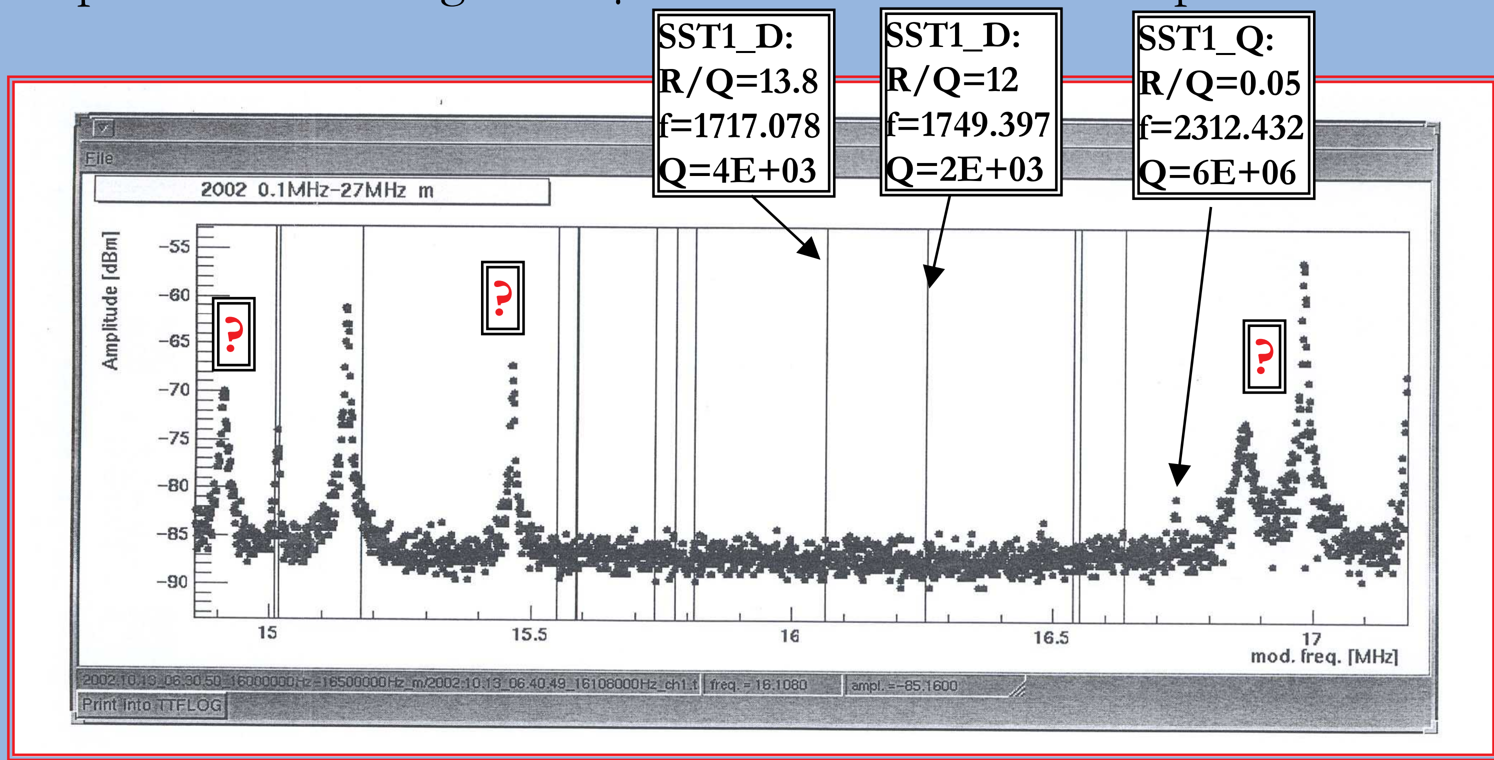


Next 200 µs additional displacement of the beam in the BPM was measured

The method is good to detect poorly damped modes, but

many modes may be excited at the same f_{mod} , so interpretation of data is complicated.

Example of the BPM signal: 15 μs after the modulation stops



? ← These modes are above 3.1 GHz or could be 6-poles (analysis in progress)

IV. Final Remarks

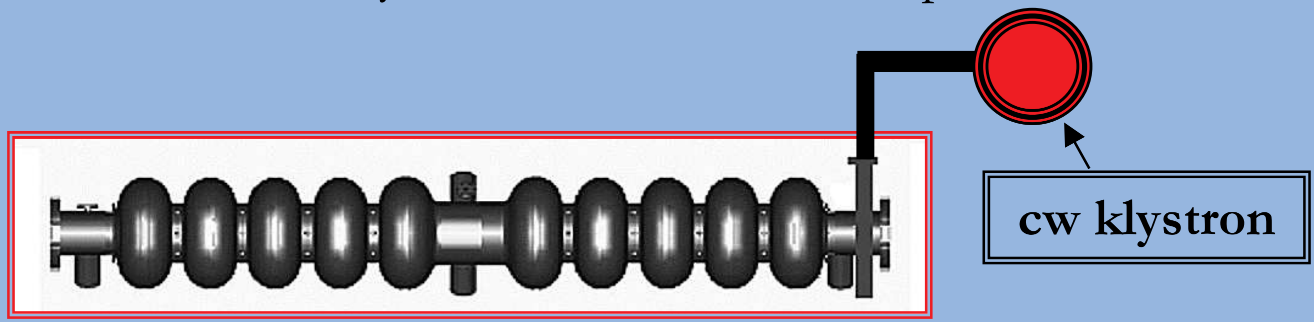
TESLA Collider

- the experiment showed that we can use SST for the TESLA collider
- the investment costs can be cut very effectively
- the Eacc can be reduced from 37 MV/m to 35 MV/m (helpful for 800 GeV)

High current FEL

- SSTs offer very good damping of HOMs: both 2x7-cell and 2x5-cell
- 2x5-cell SST with bigger irises (Original Cornell Shape) has very stable field profile and is relatively simple to manufacture.

• I think we should study more in detail this concept for the FEL linacs



<u>What else was new ?</u>

tuner which is very compact and saves space between cavities (Kaiser, Peters, Pagani)