Superstructures; First Cold Test and Future Applications

DESY:	*C. Albrecht, V. Ayvazyan, R. Bandelmann, T. Büttner, P. Castro, S. Choroba, J. Eschke, B. Faatz, A. Gössel, K. Honkavaara, B. Horst, J. Iversen, K. Jensch, R. Kammering, G. Kreps, D. Kostin, R. Lange, J. Lorkiewicz, A. Matheisen, W.-D. Möller, H.-B. Peters, D. Proch, K. Rehlich, D. Reschke, H. Schlarb, S. Schreiber, J. Sekutowicz, S. Simrock, W. Singer, X. Singer, K. Twarowski, G. Weichert, M. Wendt, G. Wojtkiewicz, K. Zapfe*
Cornell University:	*M. Liepe*
FNAL:	*M. Huening*
INFN-Frascati:	*M. Ferrario*
INS:	*E. Pławski*
INFN-Milano:	*C. Pagani*
SLAC:	*N. Baboi*
Tsinghua University:	*H. Chen, H. Wenhui, C. Tang, S. Zheng*
JLAB:	*P. Kneisel, G. Wu*
Synchrotron SOLEIL:	*C. Thomas*

Motivation

TESLA:

E_{cm} = 500 GeV (upgrade to 800 GeV)

L = 33 km

1752 Cryomodules each housing 12 sc cavities

21024 cavities at E_{acc} = 23.3 MV/m

The questions were (1997):

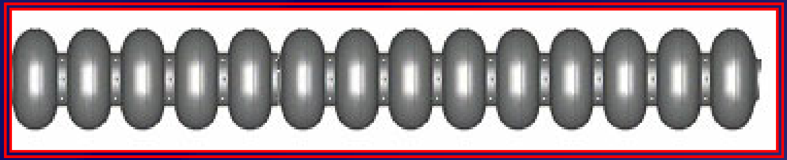
- how we can reduce investment costs of the TESLA main accelerator ?
- can we lower the nominal gradient keeping the length of the tunnel unchanged ?

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

1. Number of FPCs is reduced and thus RF distribution system becomes simpler and less expensive.

2. More accelerating cells can be installed in the tunnel (better filling factor).

We cannot simply add more cells to each 9-cell cavities !!

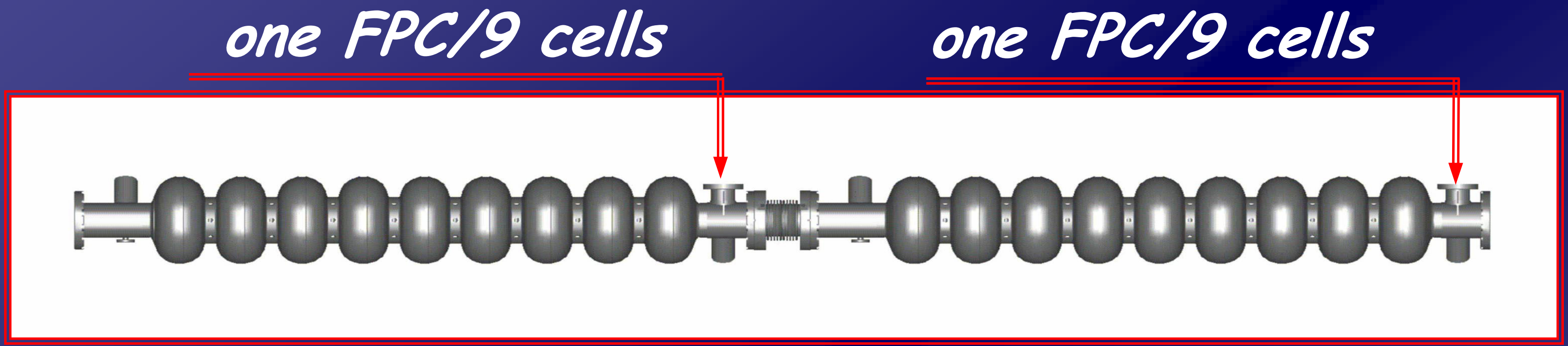


- FM field profile becomes more sensitive to cells' frequency errors : $\Delta A_i/A \propto (N^2/k_{cc})\ \Delta f_i/f$

- Trapping of HOMs increases with N

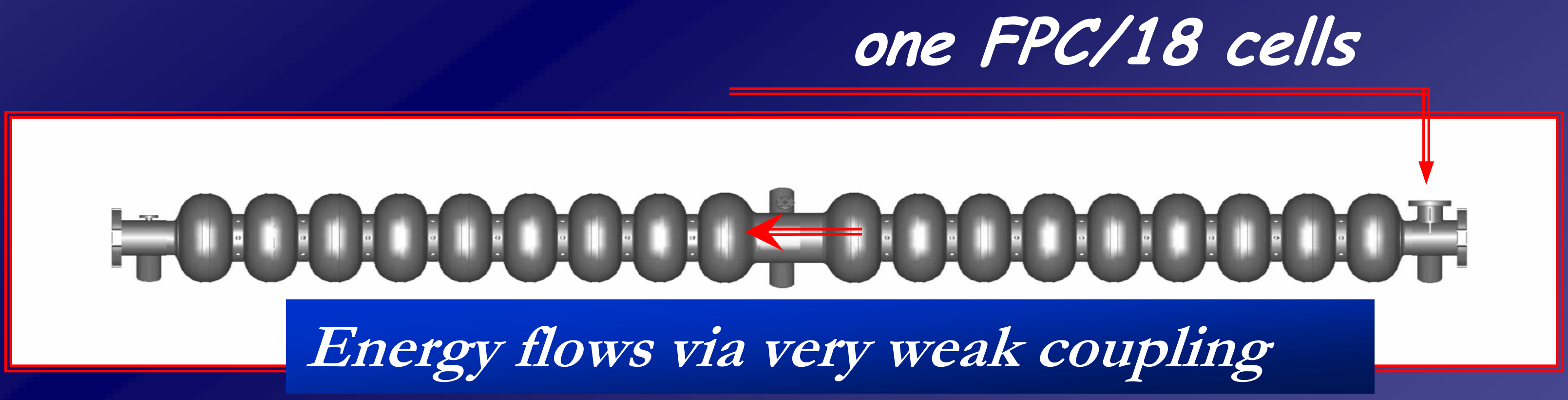
Standard layout:

9-cell structures separated by 286 mm long tube



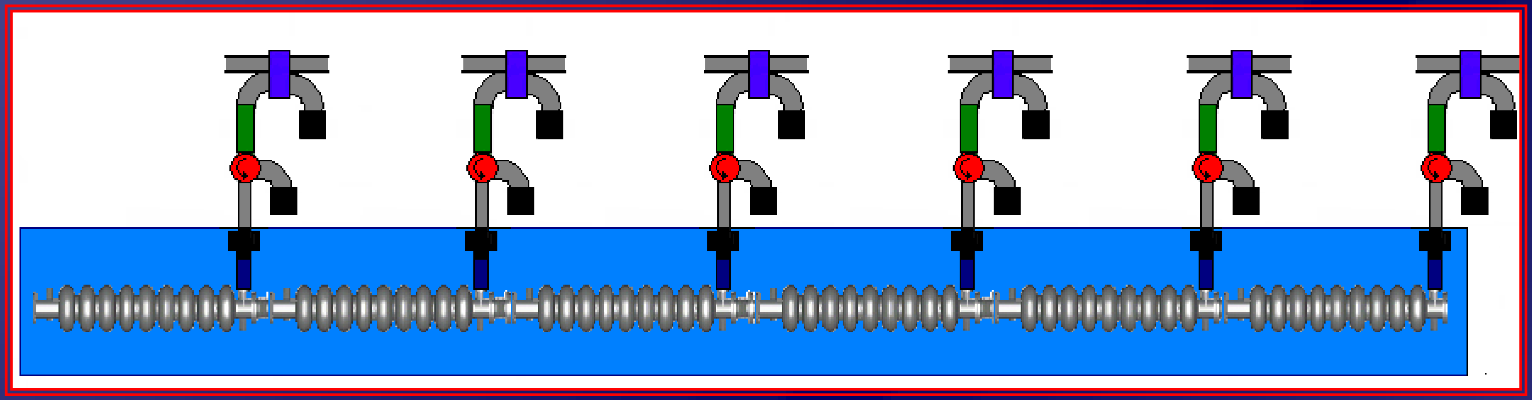
SST layout:

two 9-cell structures coupled by $\lambda/2$ long tube

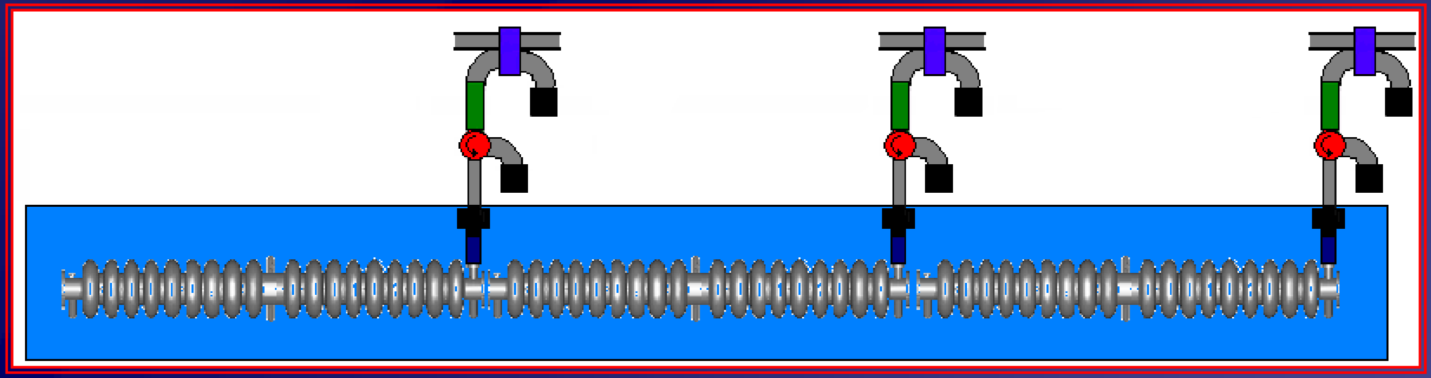


Standard layout:

FPCs, Waveguides
Directional Couplers, Loads, Bends,
Circulators, 3-stub Transformers……

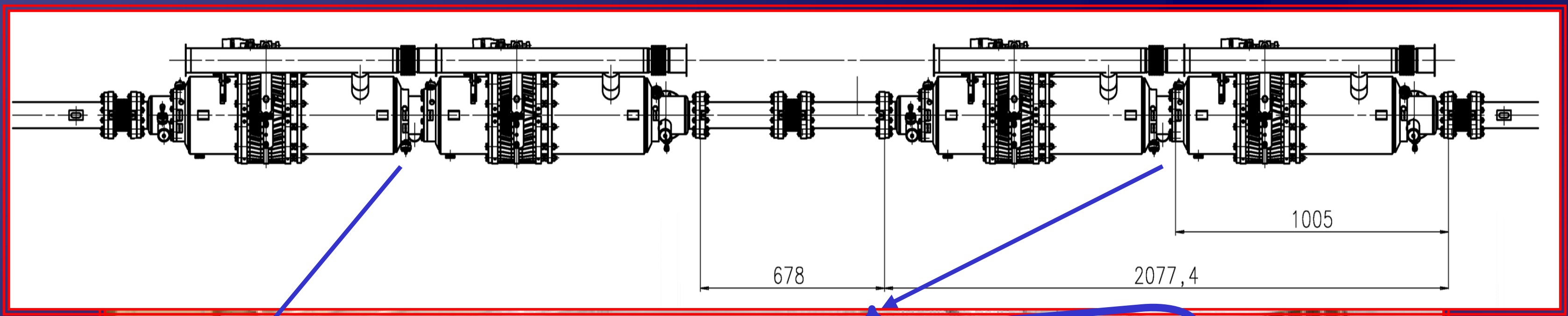


Superstructure layout saves 10000x of all these components



The preparation of the experiment began in 1999.

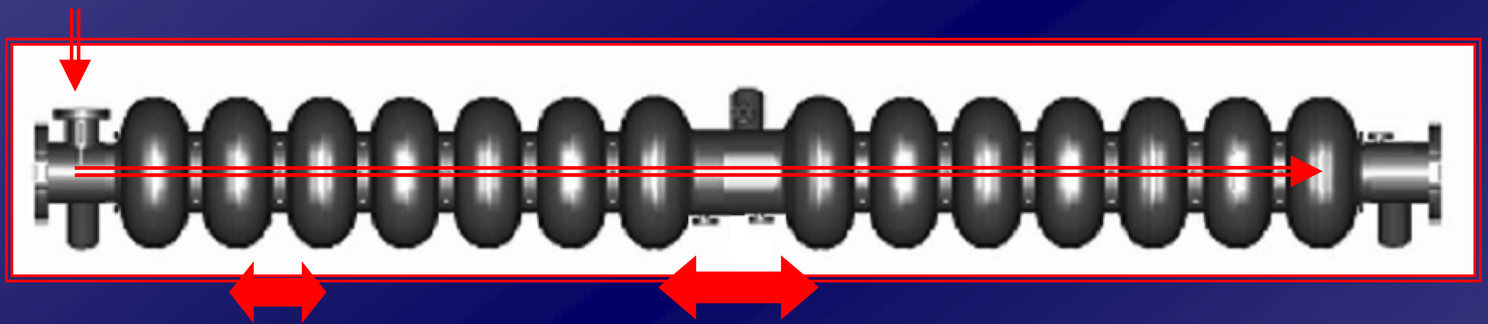
In 2002, two 2x7-cells SSTs were assembled in the cryomodule and installed next to the injector in the TTF linac.



Objectives in the test with beam

1. "proof of principle" experiment

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



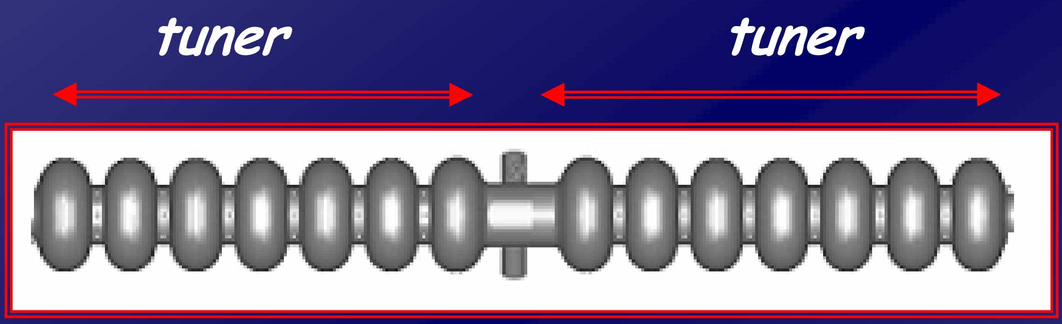
Cell-to-cell coupling ~2 %

Structure-to-structure coupling is only ~0.04 %

2. How good is the damping of HOM's ?

Ad 1. Summary of the energy gain measurement

- Balance of the stored energy in subunits after cool down

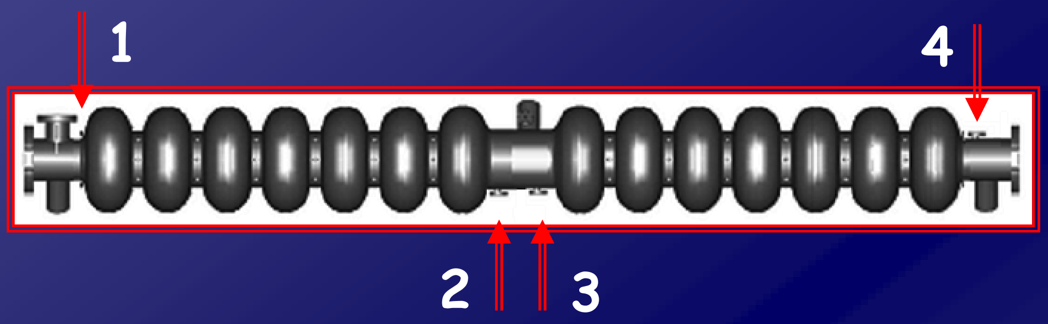


frequency of each subunit was adjusted (we applied the perturbation method):

▼ to get the same $\langle E_{acc} \rangle$ in both subunits

▼ f_{acc}=1.3 GHz

- ***How stable is the gradient during the acceleration ?***



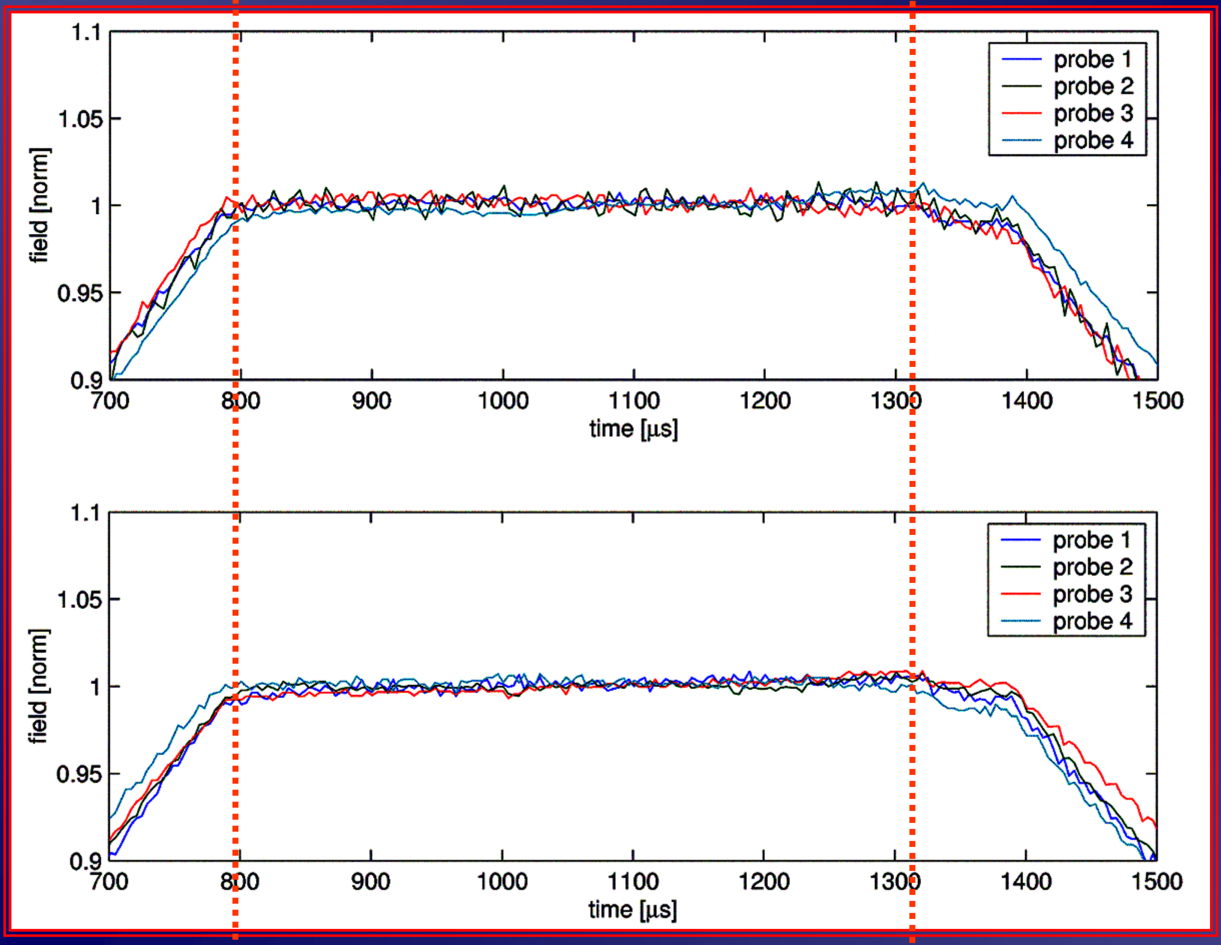
Example:
acceleration of ~530 bunches, q=4 nC at E_{acc}= 15MV/m

Without the re-filling of the stored energy voltage should drop by 45 % during the acceleration

530 µs beam on

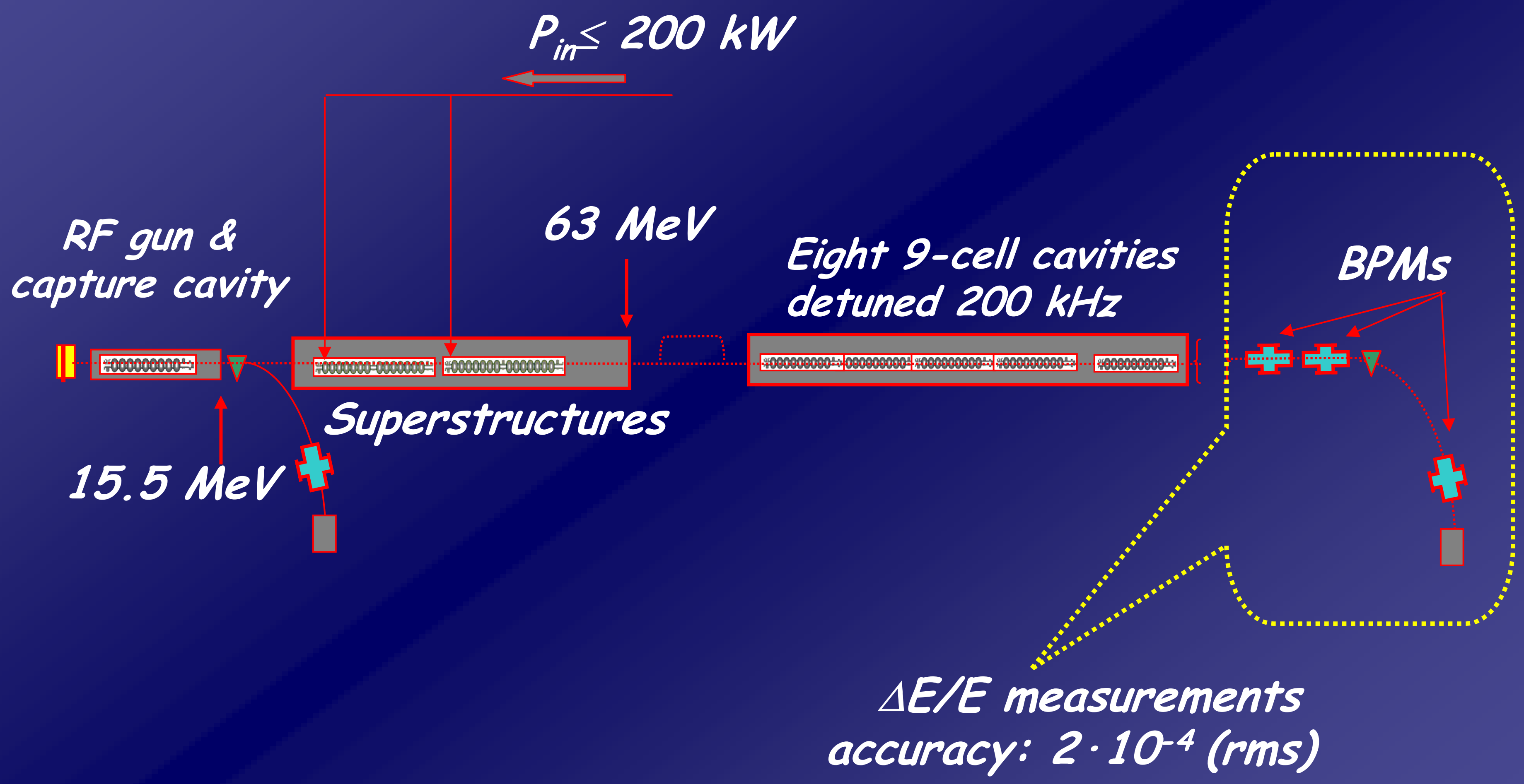
SST_1

SST_2

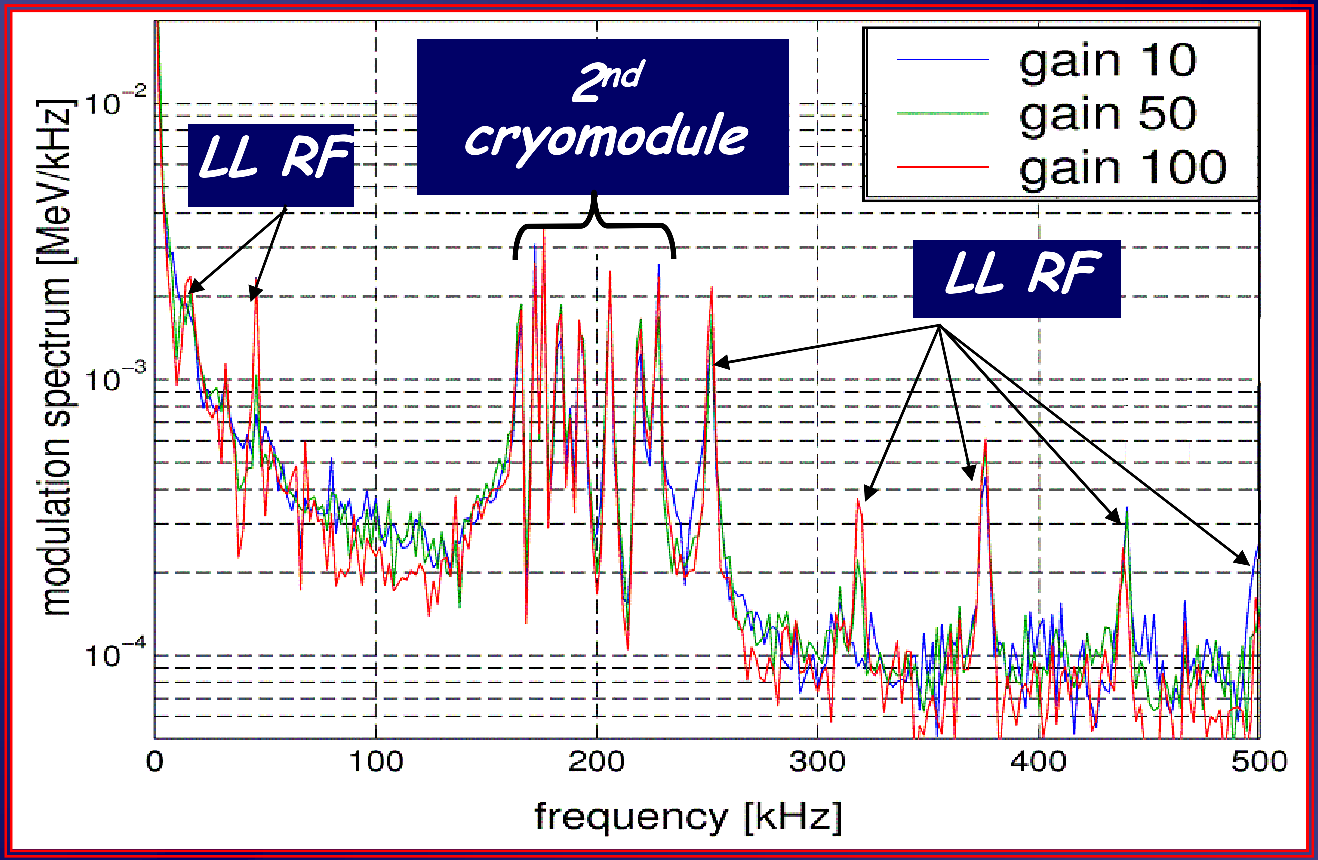


No voltage drop was observed.

- Direct measurements of the energy gain for the whole train of bunches



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



All resonances were caused either by 2nd cryomodule or by Low Level RF-control system

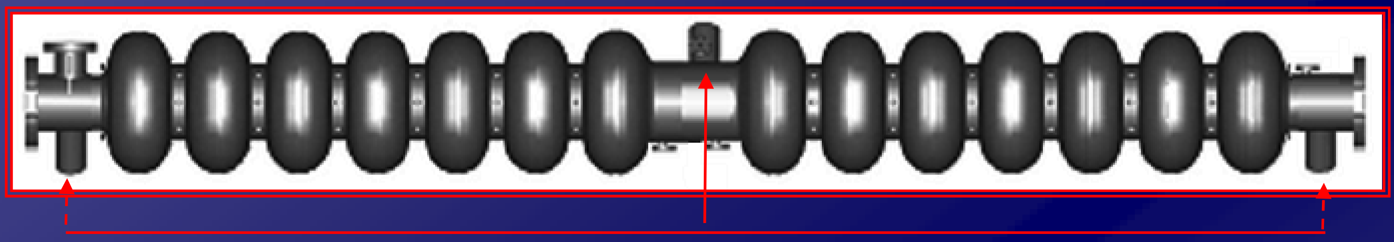
Finally, the measured bunch-to-bunch energy modulation was estimated:

$$\Delta E/E\ (rms) \leq 2 \cdot 10^{-4}$$

The specification for the TESLA collider (TDR)

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

Ad 2. HOM experiment



We applied 3 methods to verify the HOMs' impedance:

$$Z = (R/Q) \cdot Q_{ext}$$

- f and Q_{ext} measurements with Network Analyzers (420 modes up to 3.1 GHz)

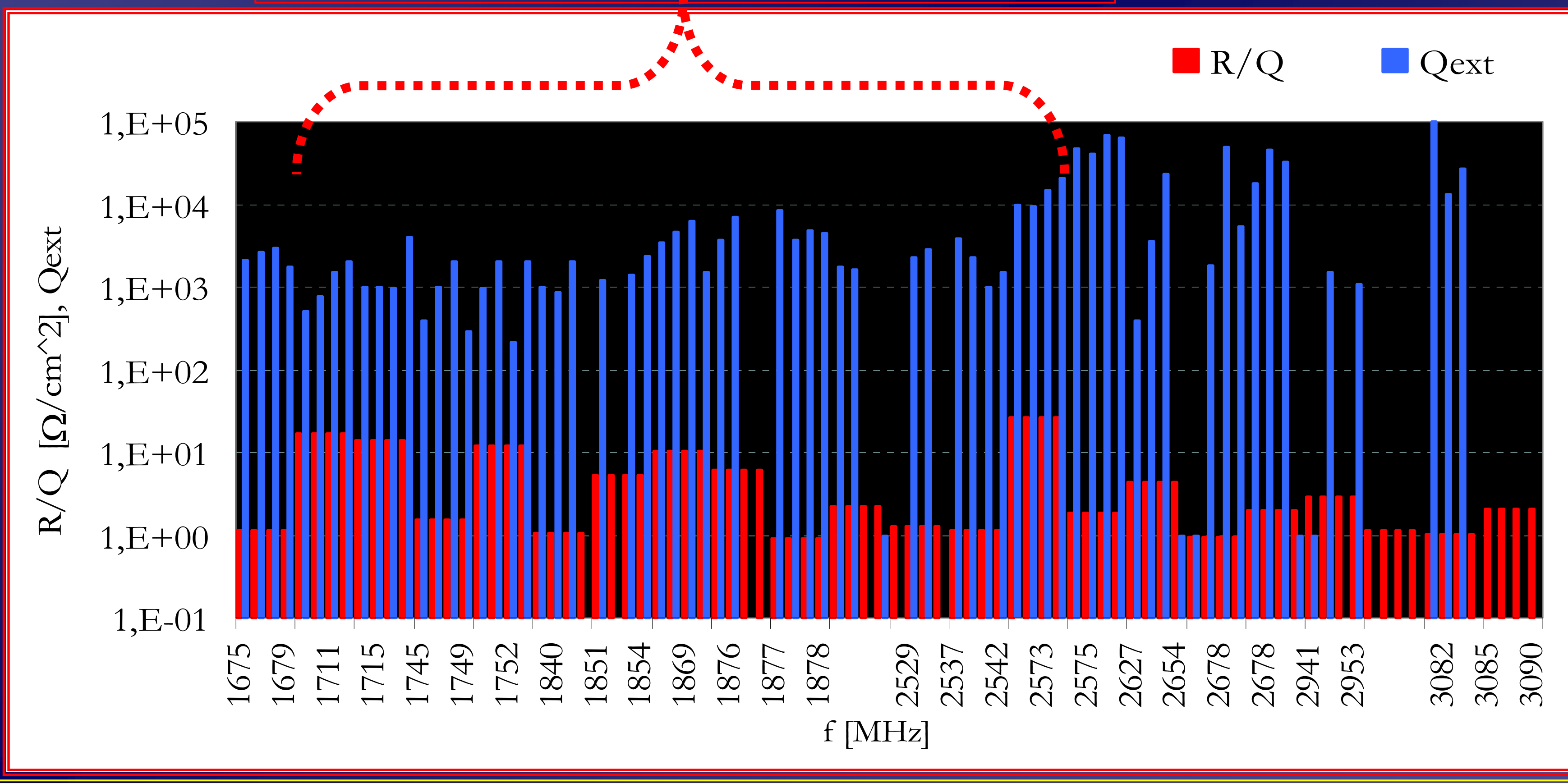
- HOM excitation with external amplifier
- HOM excitation by modulated bunch charge

} *Interaction with beam*

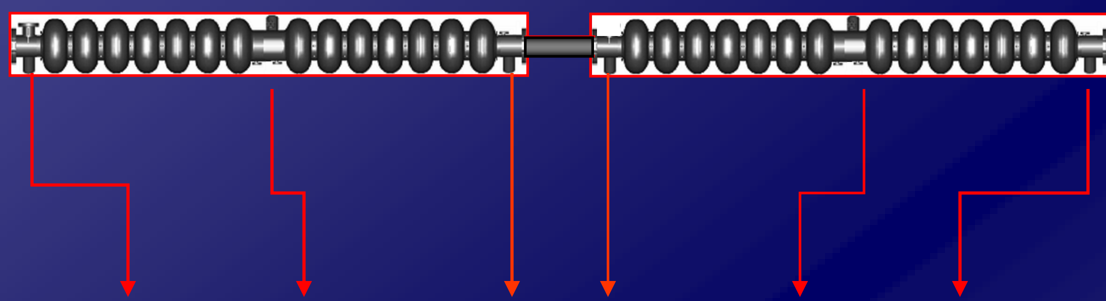
All 3 methods showed that:

damping of dipoles with (R/Q) ≥ 1 Ω/cm² which are relevant for the TESLA beam was by factor 5÷100 better then spec.

Beam Dynamics limit $Q_{ext} \leq 10^5$



Four modes with high Qext (out of 420)



f	SST1			SST2			Qext	R/Q
[MHz]	HOM 1	HOM 2	HOM 3	HOM 1	HOM 2	HOM 3		[Ω/cm^2]
3247.353	o	o	X	X	o	o	2.1E+07	0.200
3076.263	o	o	X	o	o	o	1.4E+07	0.001
3076.154				X			1.2E+07	0.043
3063.370	o	o	X	X	o	X	3.0E+08	0.022

X = seen in HOM coupler,   o = no signal in HOM coupler

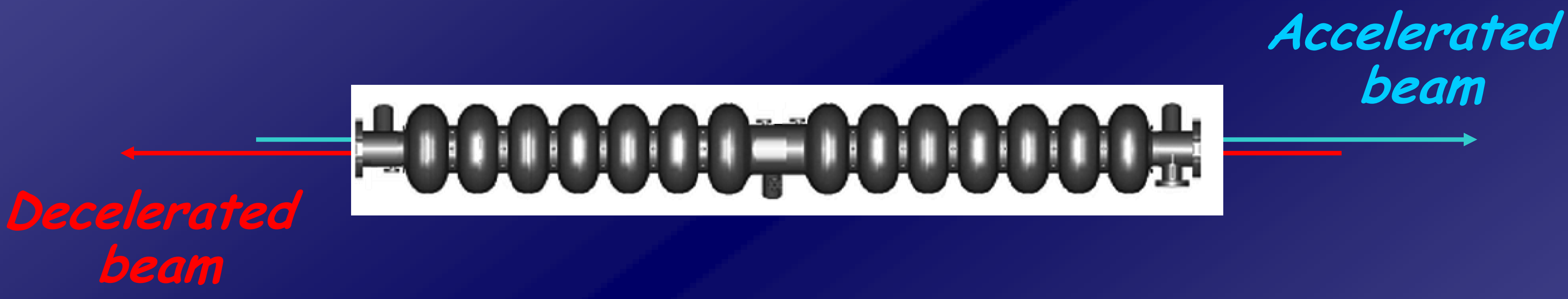
Conclusion from the cold test:

1. The experiment verified that very weakly coupled structures can be used for the acceleration
2. No bunch-to-bunch energy modulation resulting from the weak coupling was observed
3. HOM damping is very good and can be further improved by attaching additional HOM couplers (if needed)
4. Potential cost reduction of accelerators based on sc technology has been proven

Another possible application of superstructures

Energy Recovery Accelerators

What do we expect from a cavity operating in the ER mode ?



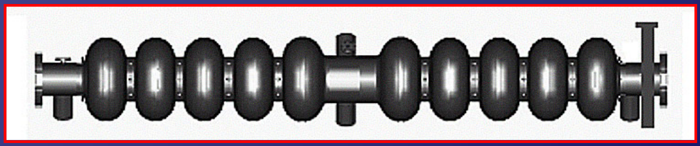
2 beams pass through the cavity → good HOM's suppression

"Small" amount of RF-power transferred to the beam from an external source → one FPC can serve bigger number of cells in a structure

Following this, three applications have been proposed:

1. 10 kW upgrade of the FEL at JLAB: I_{beam} ~ 10 mA

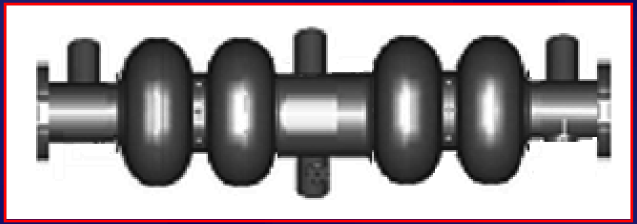
2x5-cell @ 1.5 GHz

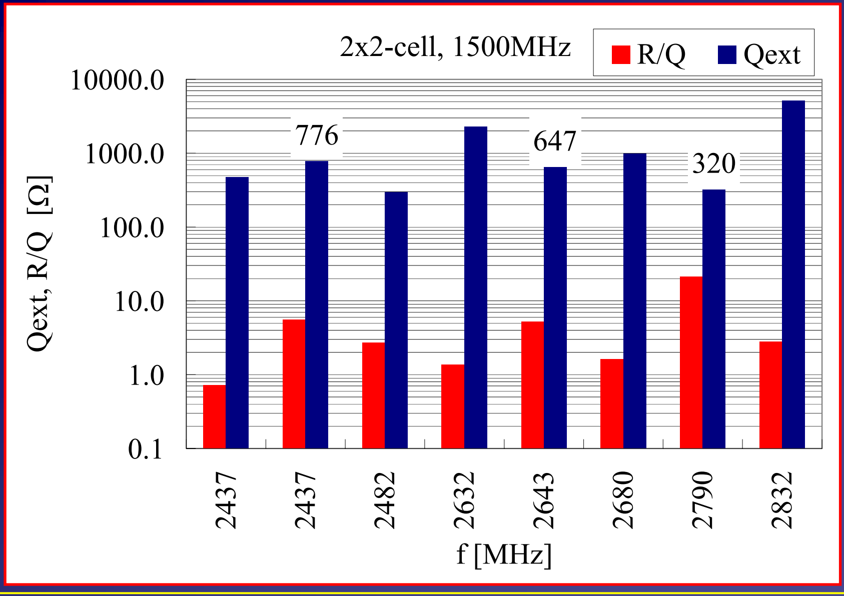


MATBBU simulations showed that I_{beam} threshold increased from 4 mA to 103 mA

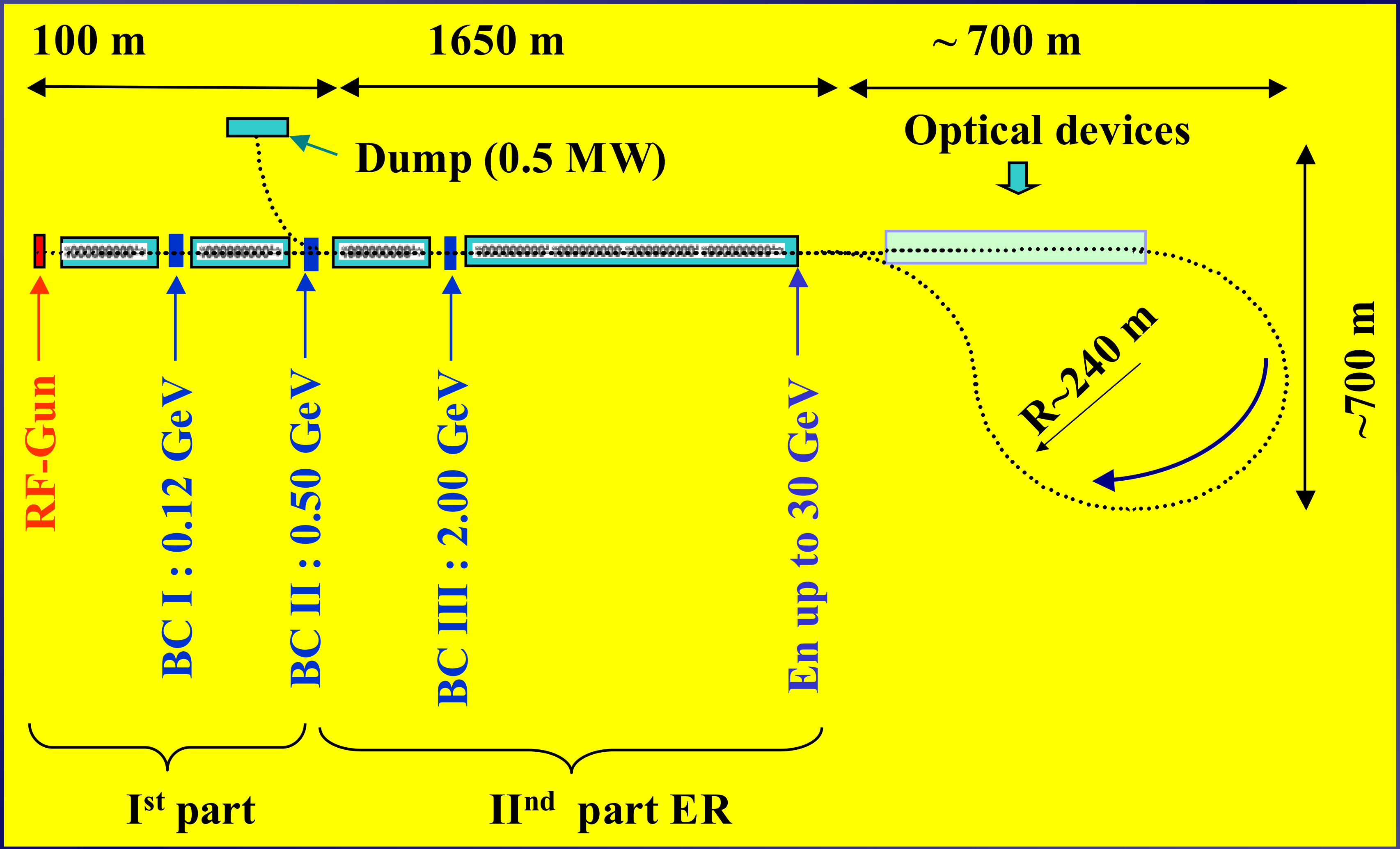
2. Further upgrade of the FEL at JLAB: I_{beam} > 500mA

2x2-cell @ 0.75 GHz



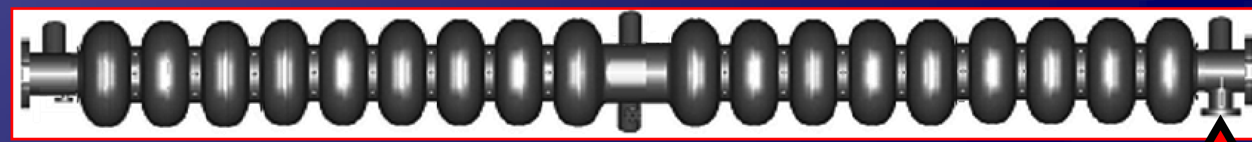


3. CW ER operated XFEL I_{beam} ~ 1 mA



2x9-cell SST

528 SST's



5 kW

ER = 96 %

At 20 GeV ⇒ E_{acc} = 17.8 MV/m @ I_{beam} = 1mA

P_{beam} = 1.5 kW

$P_{in}=P_{beam} + P_{microphonics}$= 1.5 kW +3.5 kW = 5 kW

HOM's damping fulfills spec for the 9 mA TESLA beam, no problem with 1 mA

Overview of SST models

Superstructure	Number of HOM couplers	Qext for the highest (R/Q) mode	I_{beam} [mA]	Status
2x9-cells 1.3 GHz	4	$<5\cdot 10^4$ (dipole)	< 10	Cu model
2x7-cells 1.3 GHz	3	$3\cdot 10^4$ (dipole)		Nb cold tested
2x5-cells 1.5 GHz	4 (+..)	$10^3 \div 10^4$ (dipole)	<100	Cu model
2x2-cells 0.75 GHz	4 (+..)	320 (monopole)	<500	Cu model @ 1.5 GHz