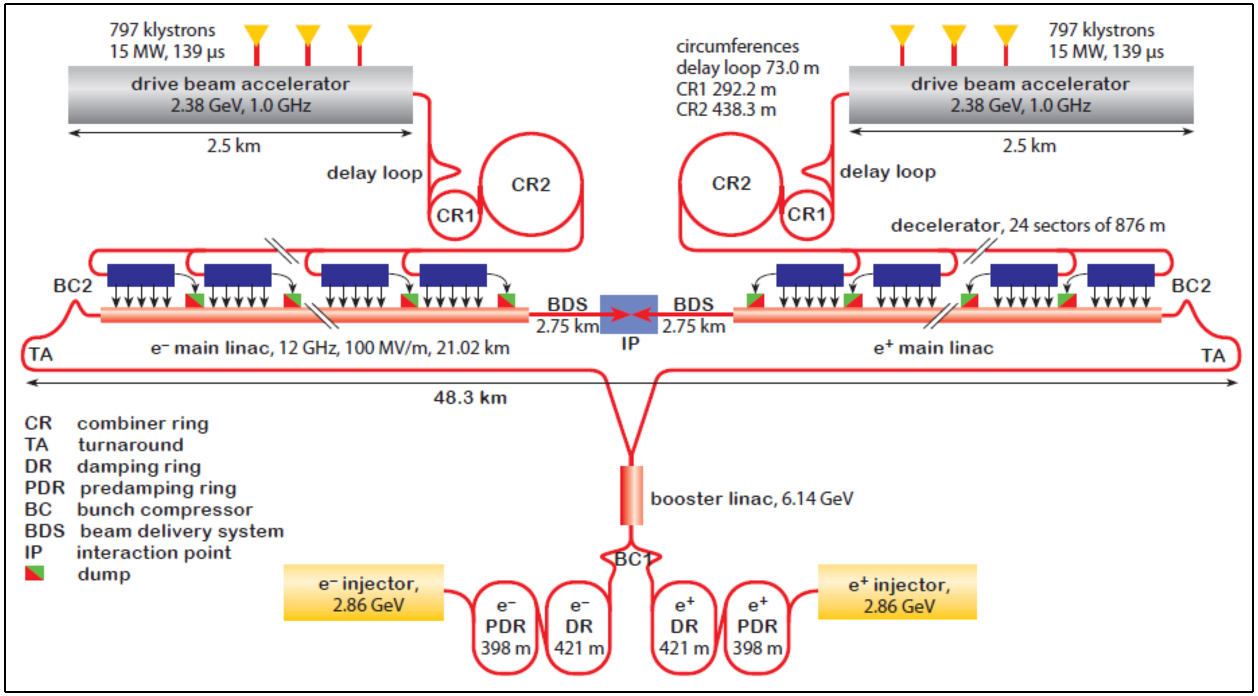
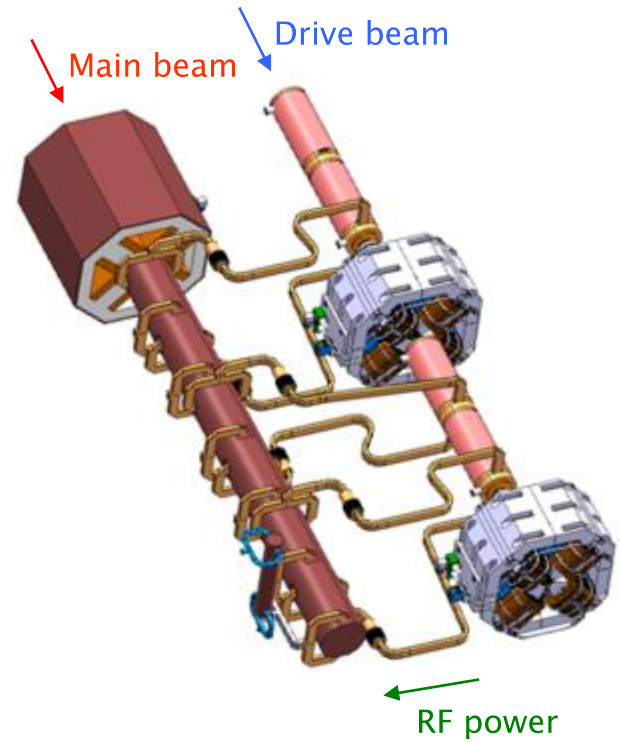
The CLIC Power Extraction and Transfer Structure

International Workshop on Linear Colliders

Alessandro Cappelletti for the CLIC team, 20th Oct 2010

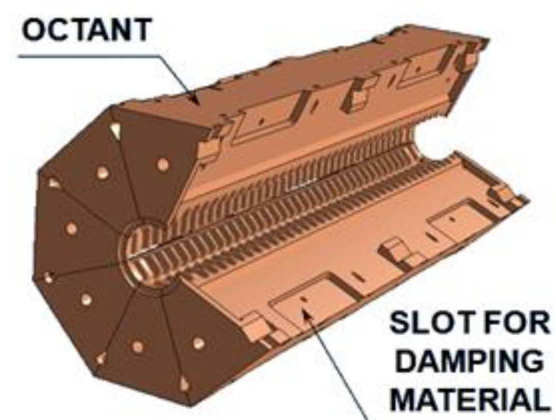
CLIC layout

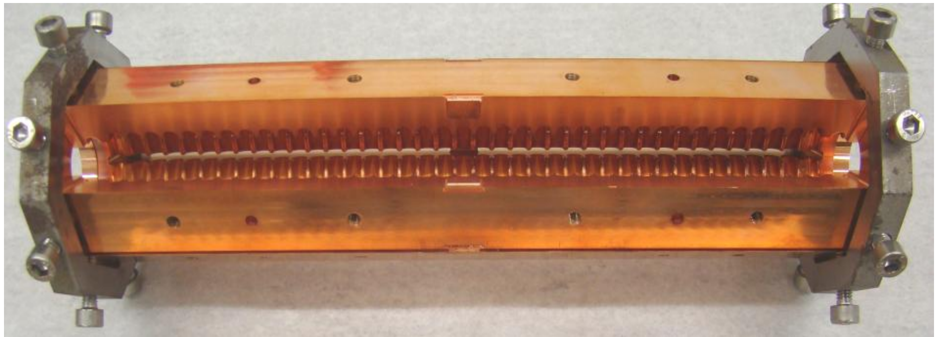


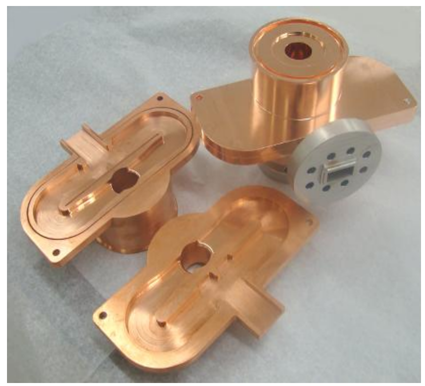


A fundamental element of the CLIC concept is two-beam acceleration, where RF power is extracted from a high-current, low-energy beam in order to accelerate the low-current main beam to high energy.

PETS

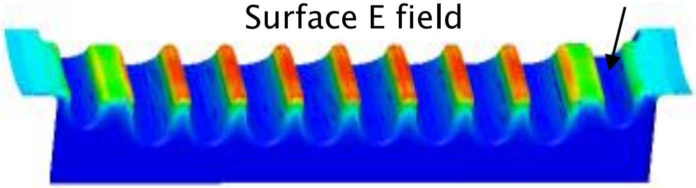




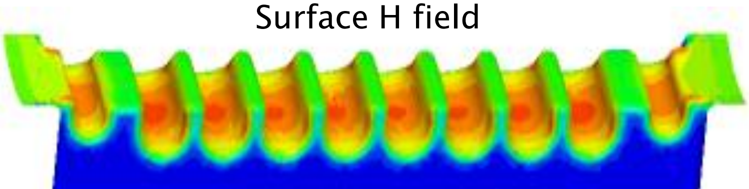


Special matching cell

Surface E field



Surface H field



Specific features:

1. Large aperture
2. High V_g
3. Overmoded
4. 8-slot HOM damping
5. High peak RF power (135 MW)
6. High current (100 A)
7. Low surface E field
8. Special coupler
9. Milling technology
10. Body assembly with clamping

PETS parameters

- Frequency = 11.9942 GHz
- Aperture = 23 mm
- Active length = 0.213m (34 cells)
- Period = 6.253 mm (90^0/cell)
- Iris thickness = 2 mm
- Slot width = 2.2 mm
- R/Q = 2222 Ω/m
- V_g= 0.459C
- Q = 7200
- E surf. (135 MW)= 56 MV/m
- H surf. (135 MW) = 0.08 MA/m

For the fixed phase advance and iris thickness: $\dfrac{R/Q}{V_{gr}} = a^{-2} C_G$

Design input parameters

$$P = I^2 L^2 F_b^{\,2} \omega_0 \frac{R/Q}{V_g 4}$$

PETS design

$$L = \frac{(L_{struc} \times n - L_T)}{m} - L_{extr}(a)$$

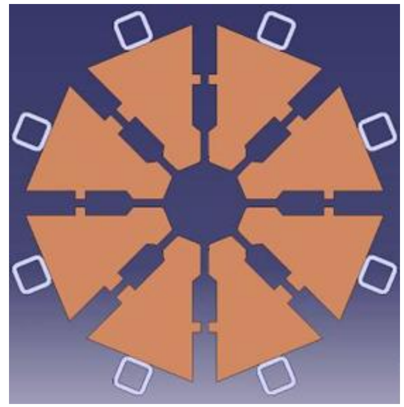
$$P = P_{struc} \times \frac{n}{m} \qquad I^2 F_b^2 \omega_0 = C_I$$

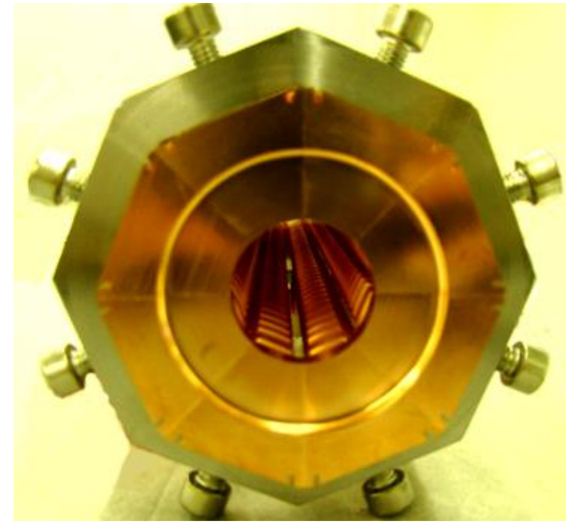
$$a = B \times m^{1/2} (L_{Av} - L_{extr}(a) m)$$

$$L_{Av} = L_{struc} \times n - L_T$$

$$B = \frac{C_I C_G}{4 P_{struc} n}$$

1. For the chosen layout (L_{UNIT}) and the number of PETS per unit, the aperture is uniquely defined (a/λ=0.46).
2. A bigger aperture favors beam dynamics.

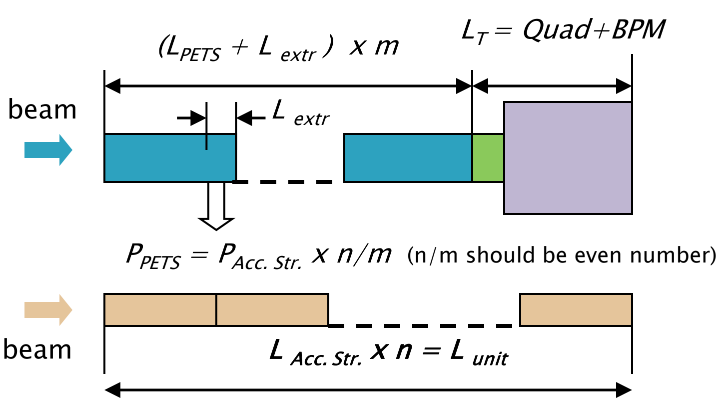


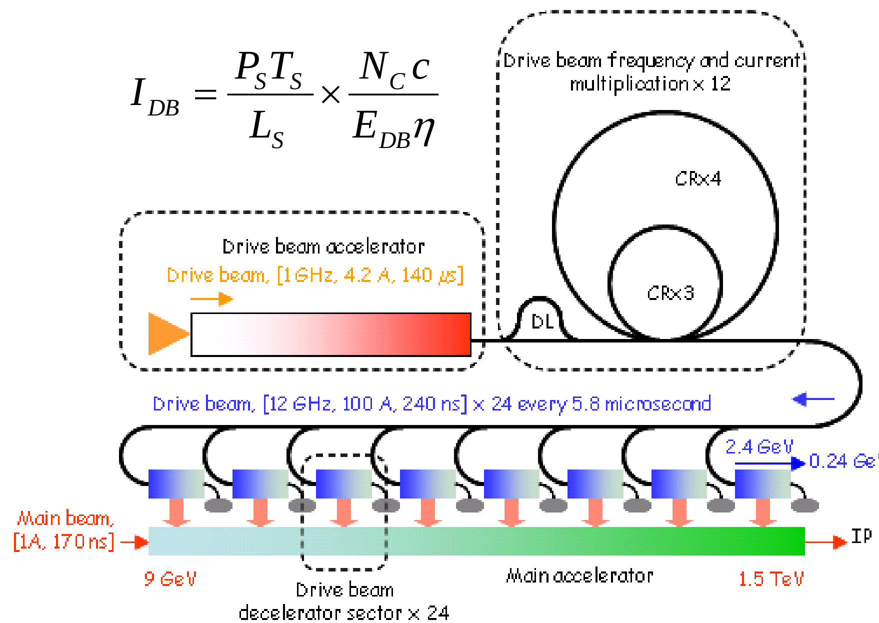


P – RF power, determined by accelerating structure needs and module layout.
I – Drive beam current
L – Active length of the PETS, limited by the module layout
$\mathbf{F_b}$ – single bunch form factor (≈ 1)

$$I_{DB} = \frac{P_S T_S}{L_S} \times \frac{N_C c}{E_{DB} \eta}$$

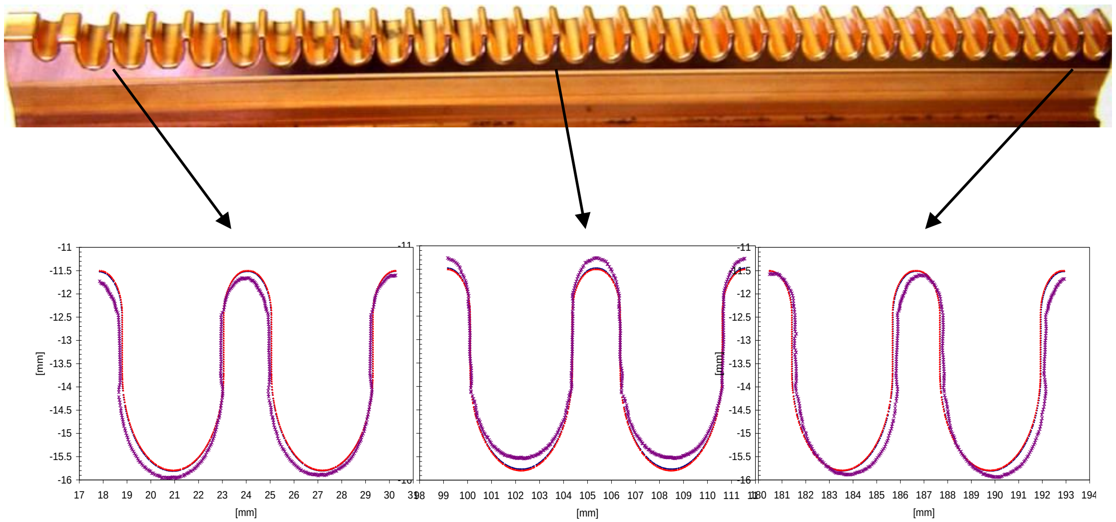
CLIC sub-unit layout:

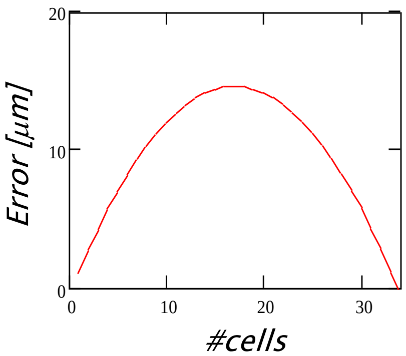




PETS machining and tolerances issues

PETS machining test bar





Fabrication and assembly errors can detune the PETS synchronous frequency and affect the power production.

Metrology results translated into frequency error:

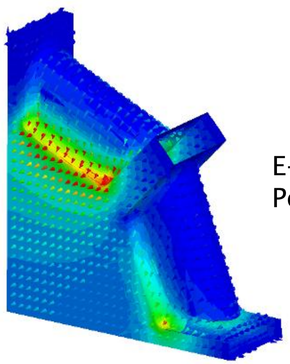
$$P = I^2 F_b^2 \omega_0 \frac{R/Q}{V_g 4} \left| \underbrace{\int_0^L \exp\left(i \frac{\Delta\omega}{2c} \frac{1-\beta}{\beta} z \right) dz}_{99.97\%L} \right|^2$$

A fabrication accuracy of ±20 μm is sufficient and can be achieved with conventional 3D milling machines.

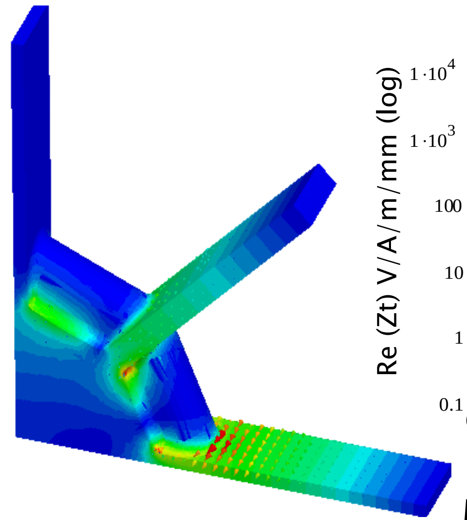
If the hypothetical PETS were made of such 8 identical bars, the expected power losses would be 0.03%; impedance, V_g and frequency wouldn't be significantly affected.

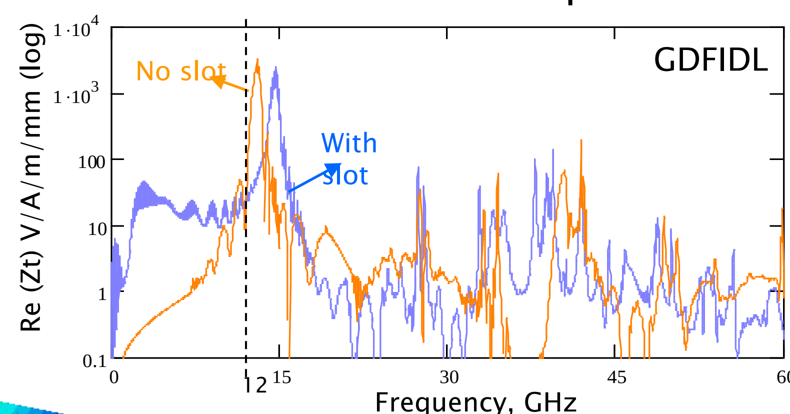
HOM issues

In big aperture structures, the frequency of the transverse modes is rather close to the operating one. The only way to damp it is to use its symmetry properties.

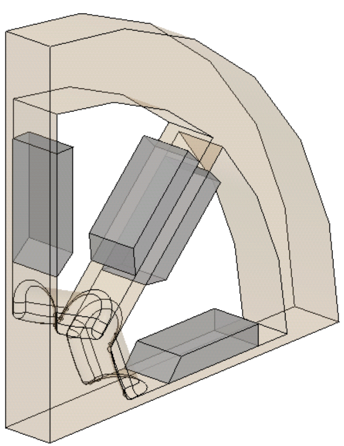


E-field (color maps) and
Poynting vectors (arrows):





With the longitudinal slots, the transverse mode field pattern is heavily distorted. The new, TEM-like nature of the mode significantly increases the group velocity.



To perform the HOM damping, we introduce the radial impedance gradient in the slot to create the radial component of the Poynting vector by putting the lossy dielectric material close to the slot opening.

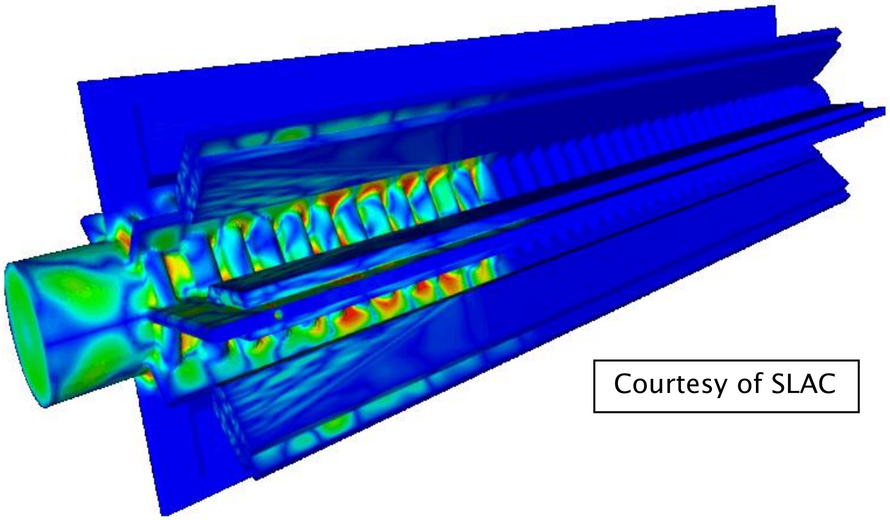
The proper choice of the load configuration with respect to the material properties makes it possible to couple the slot mode to a number of heavily loaded modes in dielectric.

The transverse wake damping in PETS. GDFIDL field animation (by W. Bruns)

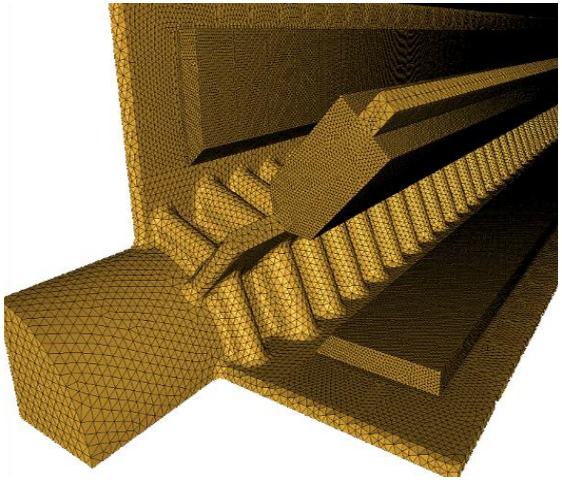
The PETS equipped with ceramic loads without losses ($tg\delta = 0$)

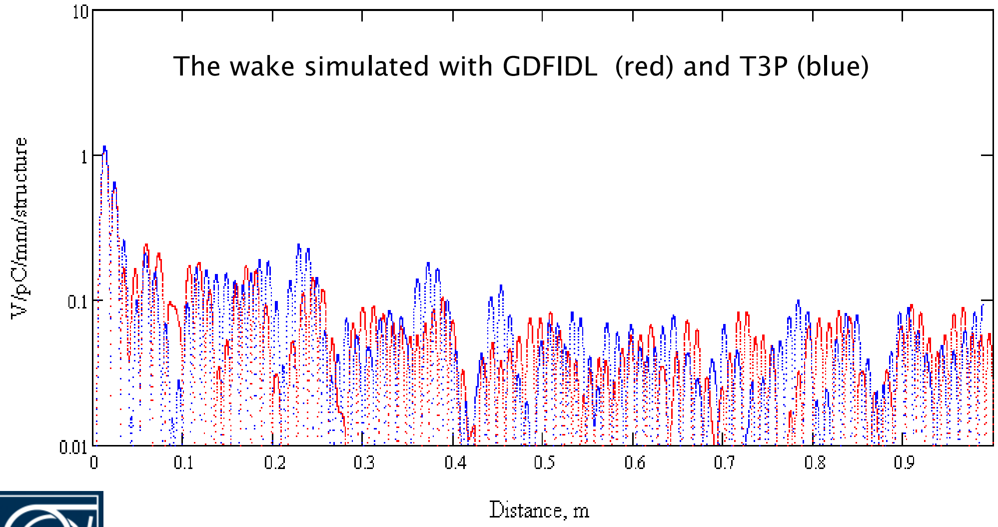
The PETS equipped with ceramic loads with losses ($tg\delta = 0.32$)

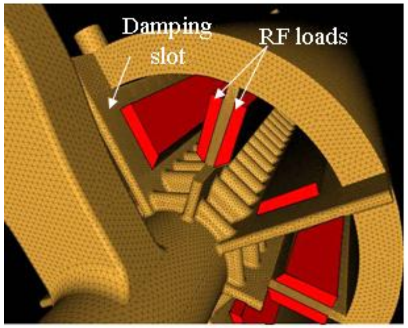
PETS computations expansion: T3P

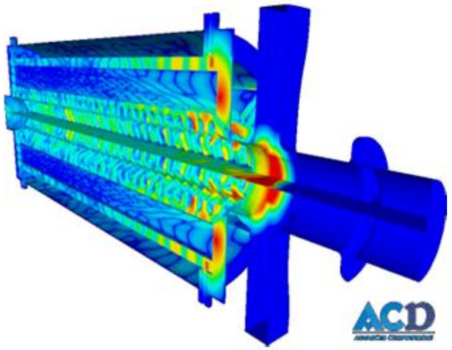


Computer simulation is the only method to study the damping performance in the PETS. Benchmarking with different codes is extremely beneficial.









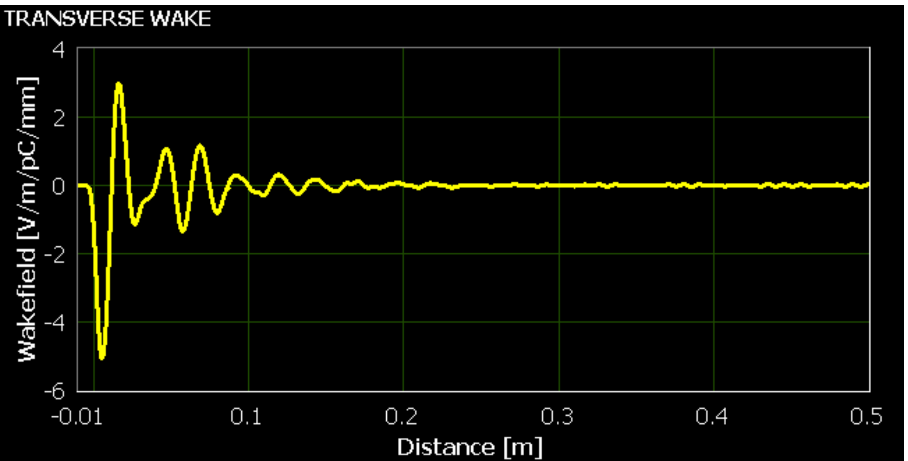
HOM study approach

While the fundamental mode induced by the monopole moment provides RF power, the HOM induced by higher order beam moments lead to unwanted effects (see "Overview and Beam Physics", E. Adli).

The analytical expression for a single HOM is well known:

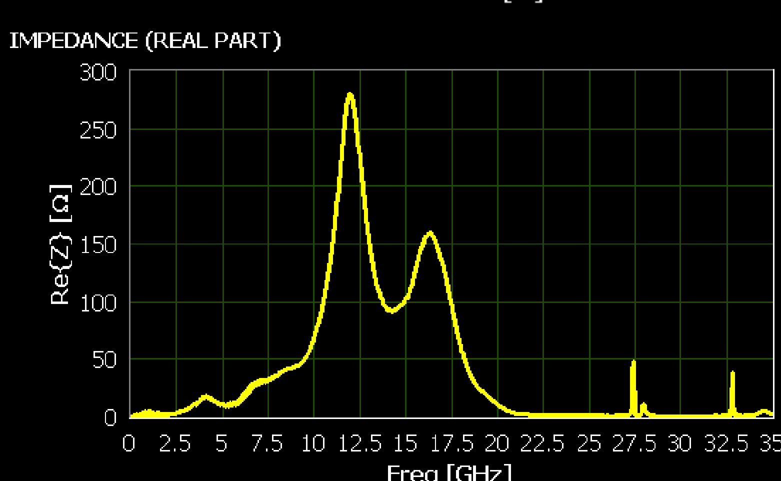
$$W_{\perp}(z) = 2q \times K_{\perp} \sin\left(\frac{\omega z}{c}\right) e^{-\frac{\omega z}{2Q(1-\beta)c}} \times \left\{1 - \frac{\beta z}{L(1-\beta)}\right\}$$

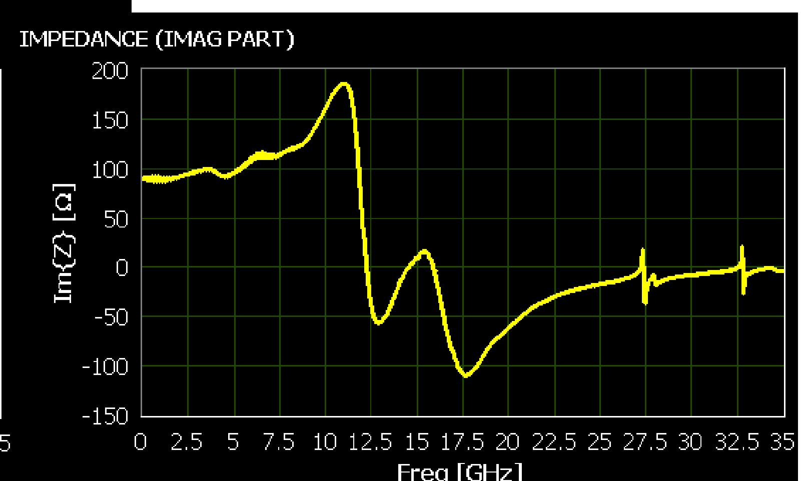
A mode is uniquely identified by a set of 4 parameters:
ω, K, Q, β



Wake potential carried out by computer simulation. It is what the superposition of single modes results in.

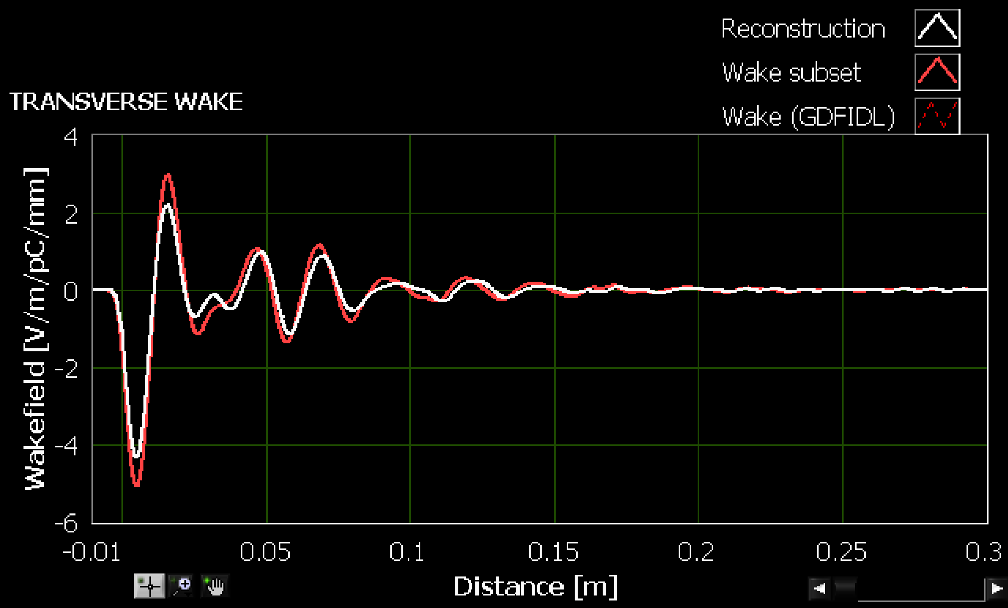
$$W_{\perp}(z) \xrightarrow{\mathfrak{I}} Z(f)$$

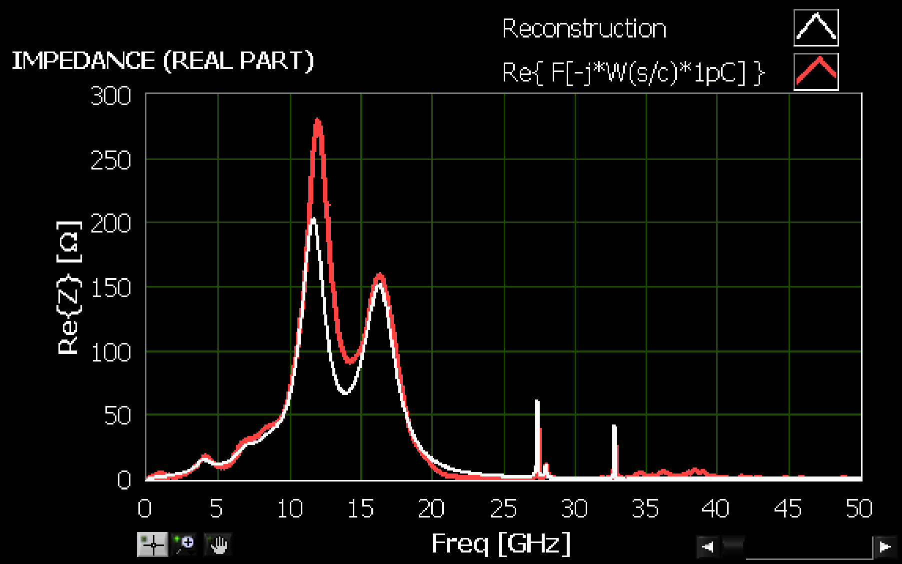




We need to extract the parameters sets for the single modes

TWO-STEP APPROACH…

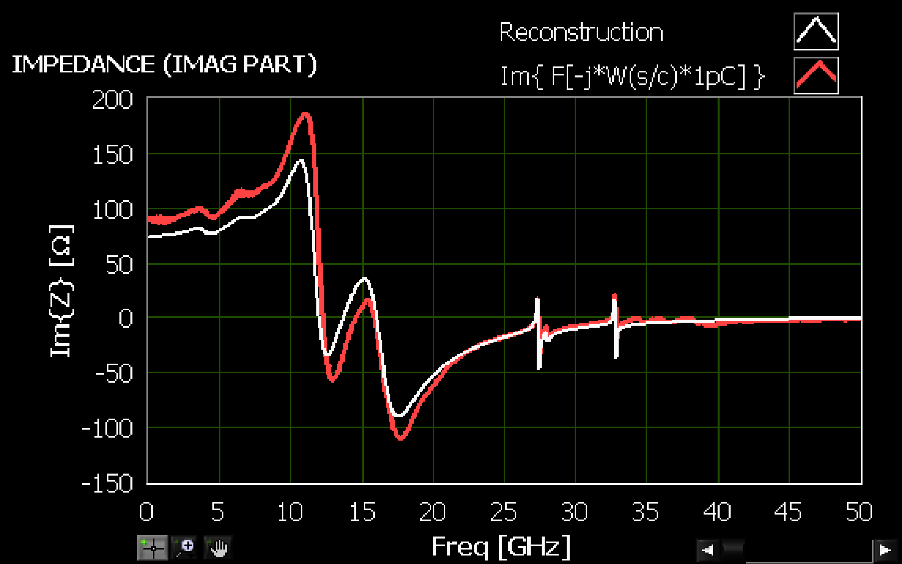




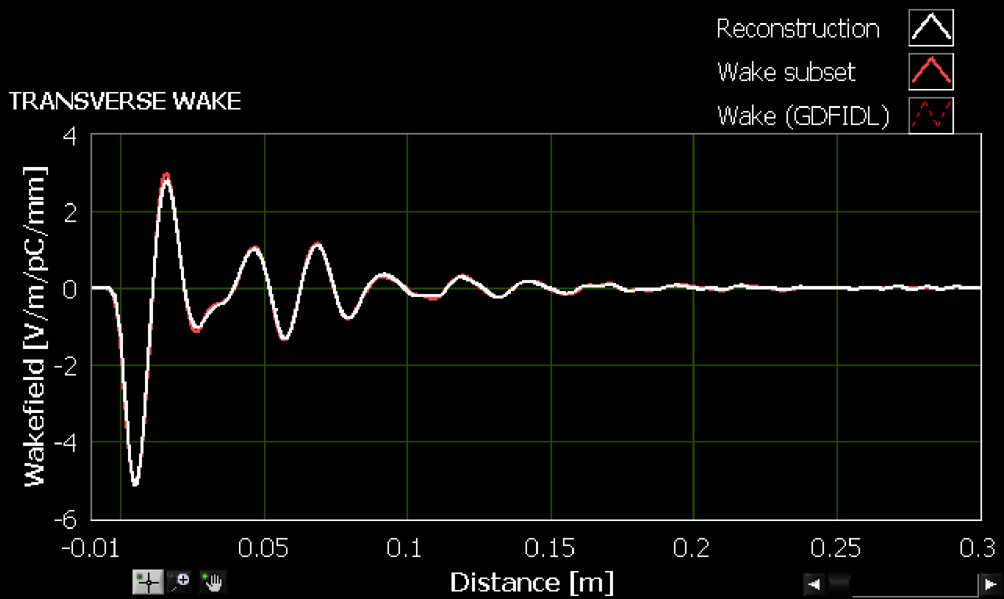
Wake Start: -0.011 | Wake End: 3.500 | Log Y? | Windowing coeff.: 0.002 | STOP

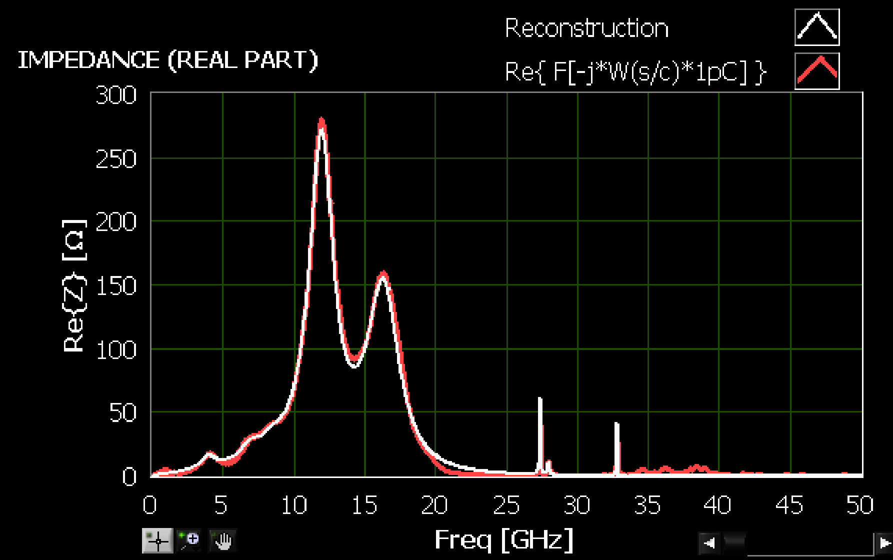
	Freq [GHz]	Amp	Q - factor	β
#1	3.95	10.10	3.40	0.43
#2	6.92	13.64	5.50	0.67
#3	8.50	13.00	5.00	0.70
#4	11.71	250.20	6.82	0.67
#5	16.40	195.00	6.30	0.56
#6	27.41	194.00	527.00	0.18
#7	28.00	20.00	156.00	0.03
#8	32.82	154.00	943.00	0.02

MODES



1. INITIAL GUESS





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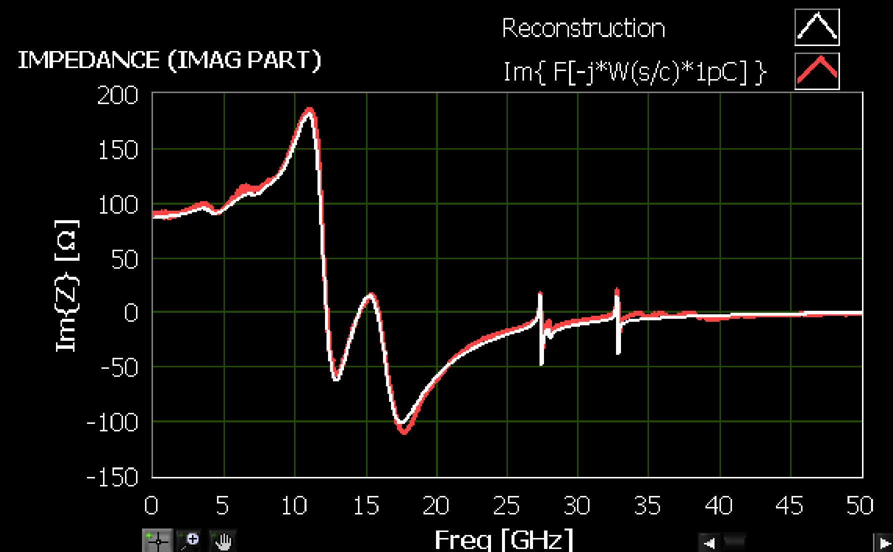
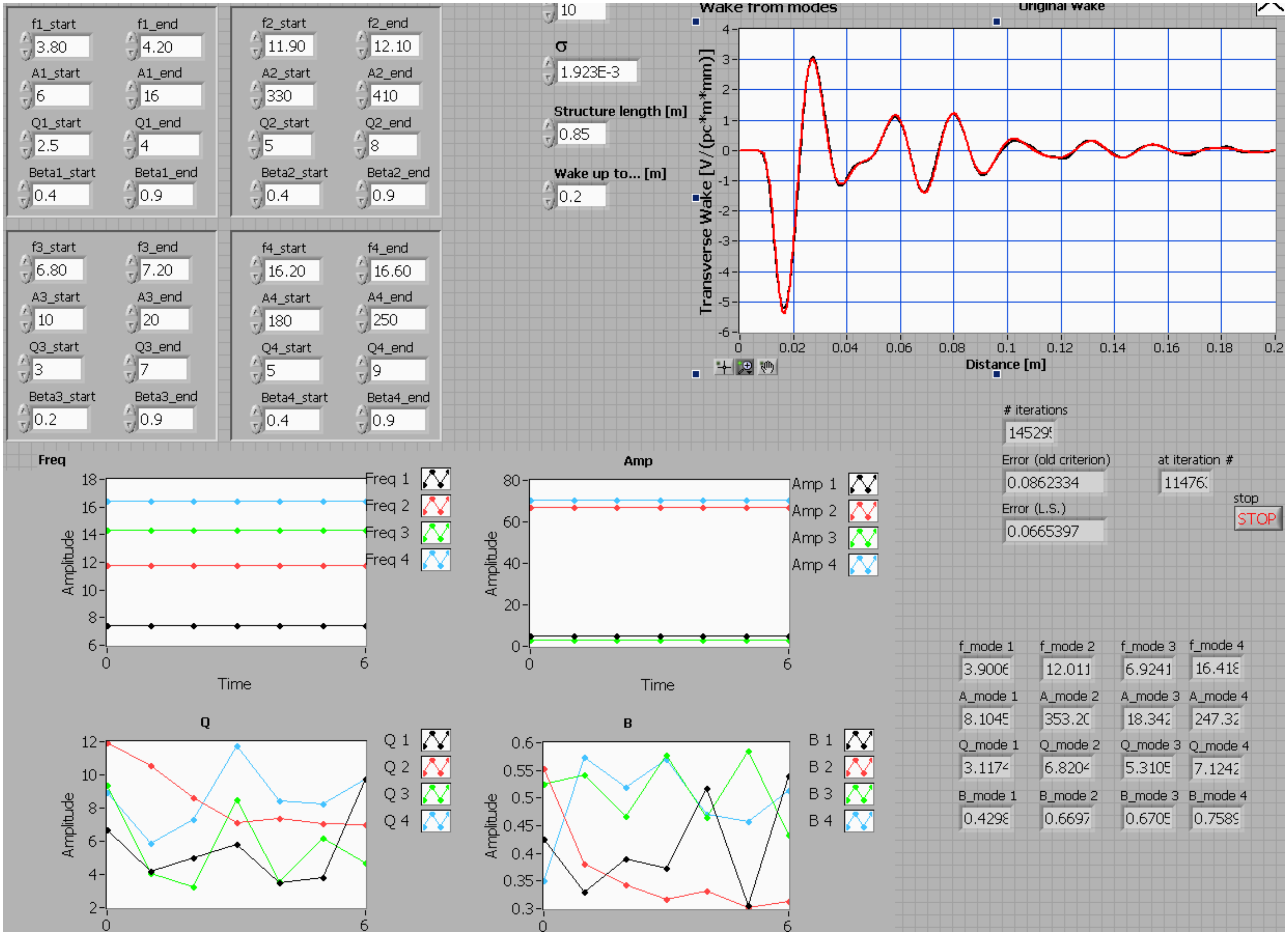
MODES



2. BRUTE FORCE REFINEMENT

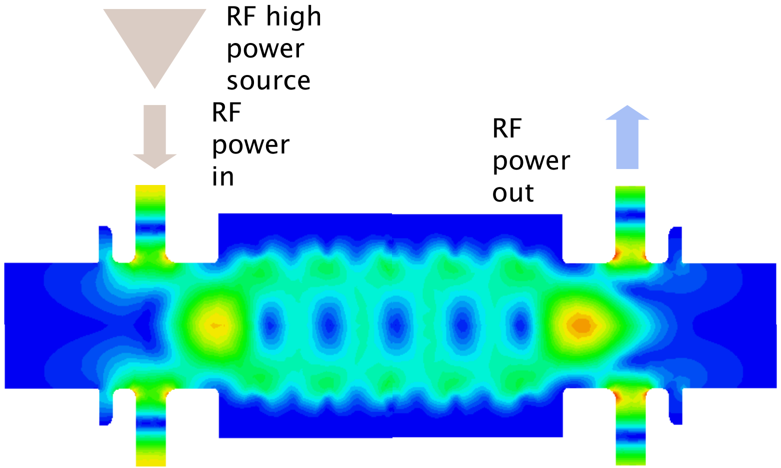


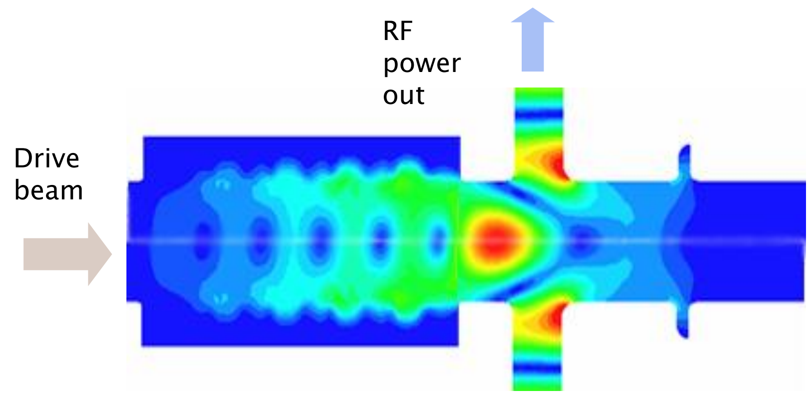
PETS testing program

RF power sources

External RF power source

Drive beam*





ASTA (SLAC)

Objective: understanding the limiting factors for the PETS ultimate performance and breakdown trip rate.

- Access to the very high power levels (300 MW) and nominal CLIC pulse length.
- High repetition rate – 60 Hz.

CTF3 (CERN + Collaborations)

Two beam test stand (CERN + Collaborations)

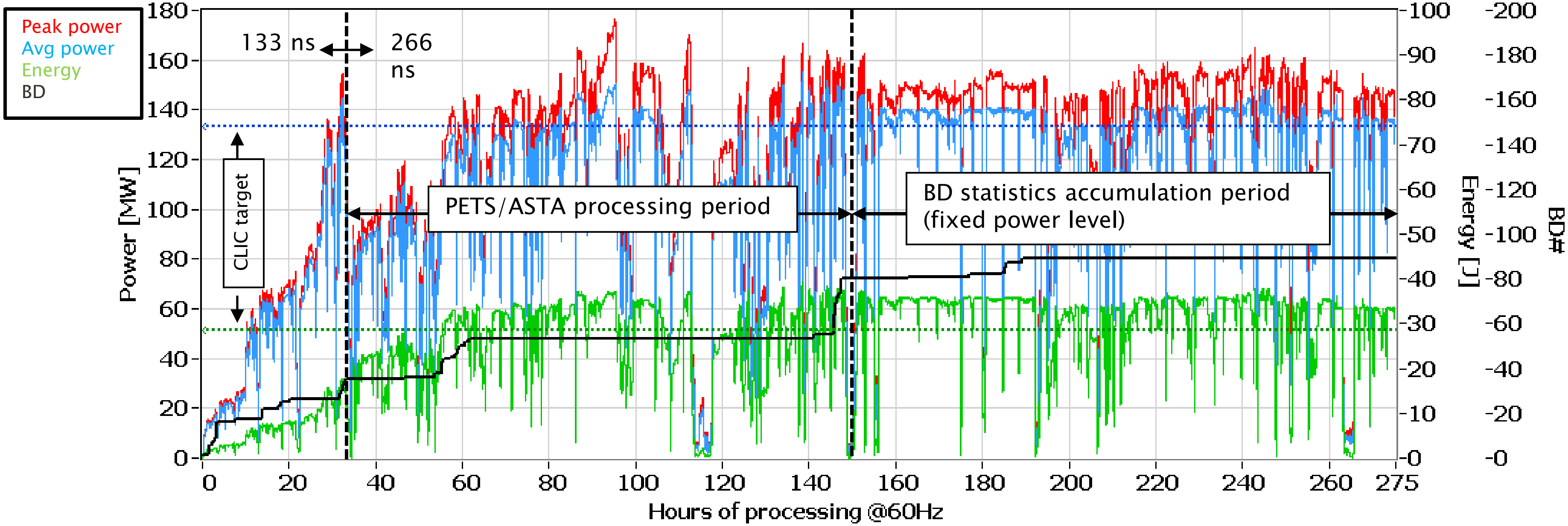
Objective: demonstrating the reliable production of the nominal CLIC RF power level throughout the deceleration of the drive beam.

Test beam line (CERN + Collaborations)

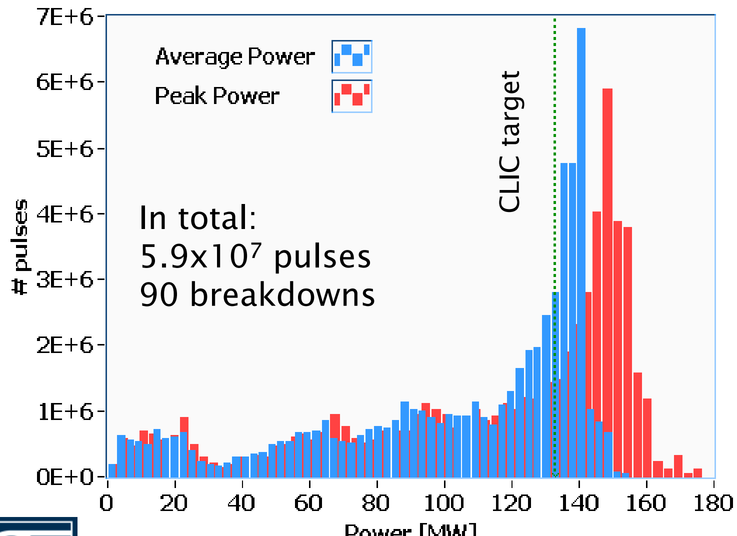
Objective: to demonstrate the stable, without losses, beam transportation in presence of the strong (50%) deceleration.

*See I. Syratchev's and E. Adli's presentations

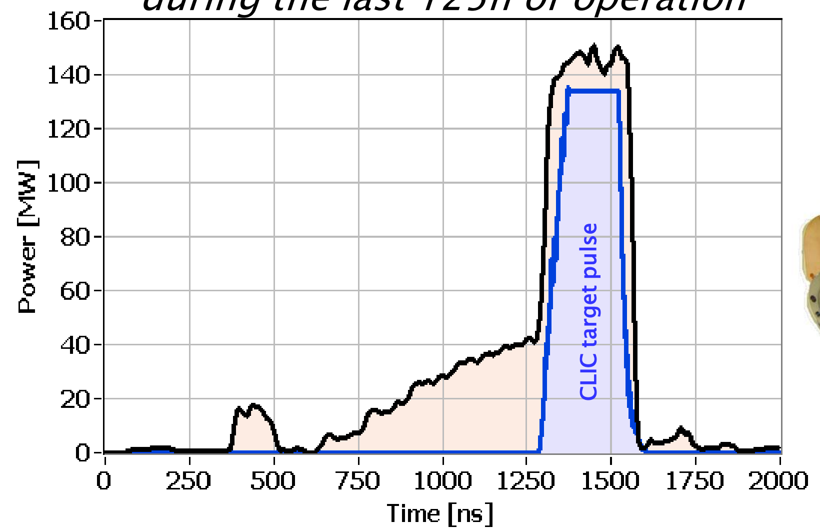
PETS high RF power testing @ SLAC (2010)



Average and peak power distributions

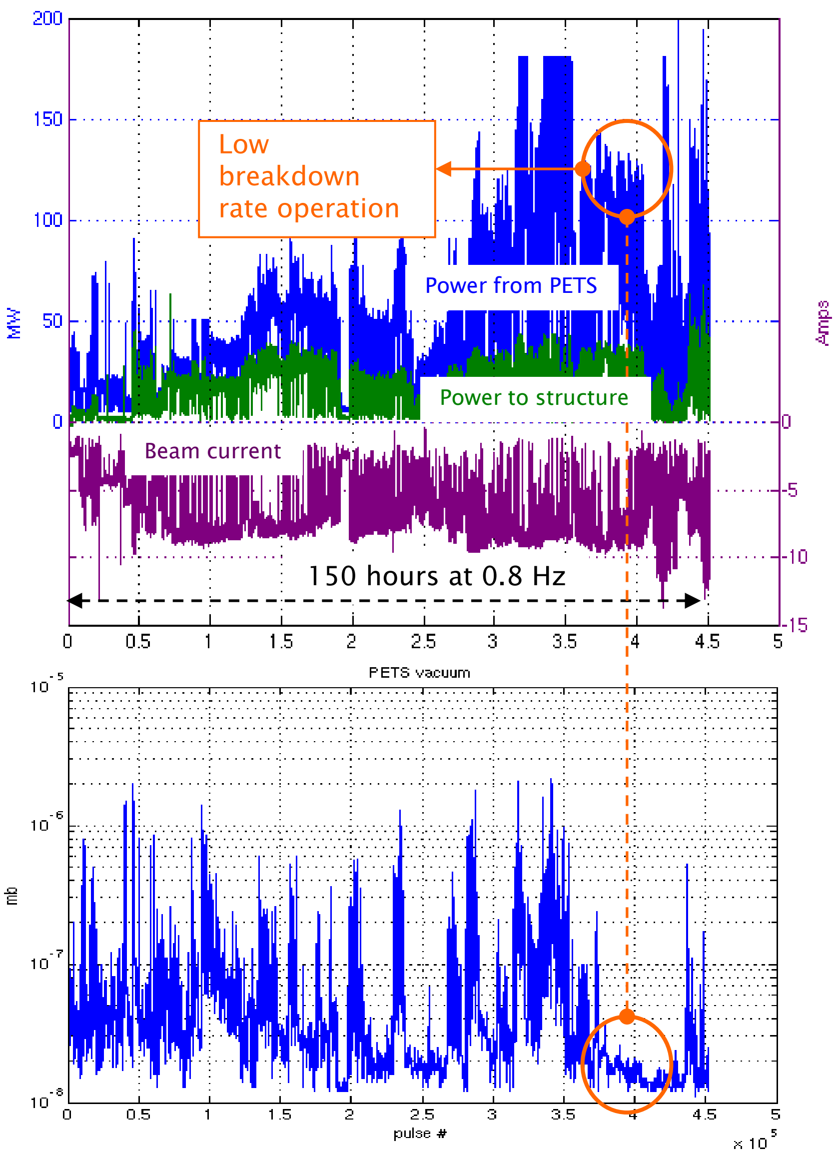


Typical RF pulse shape in ASTA during the last 125h of operation

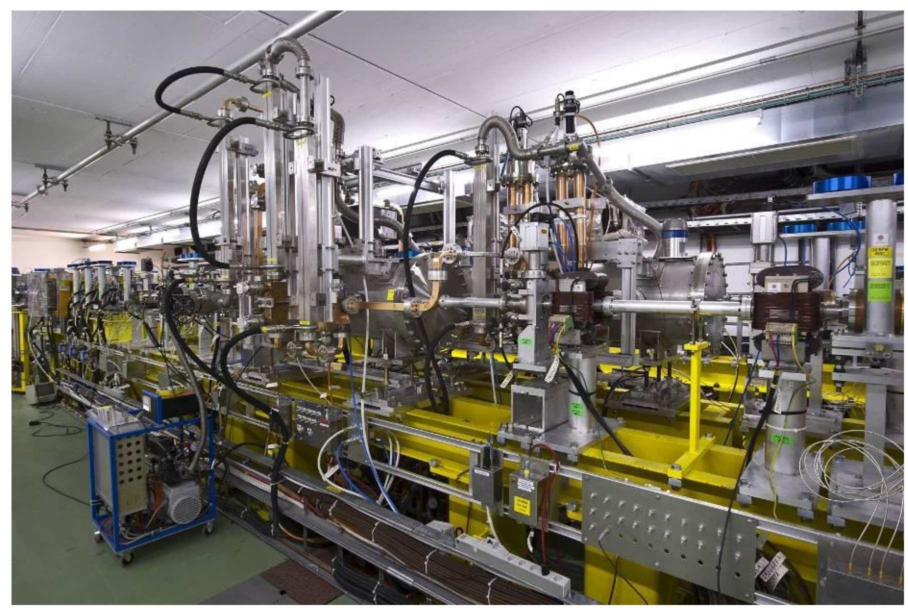


After 80h of operation with no breakdown: BDR $<1.2\times10^{-7}$/pulse/PETS

PETS power production inTBTS



PETS consistently produces required RF power for the accelerating structure processing and the two beam acceleration experiments.



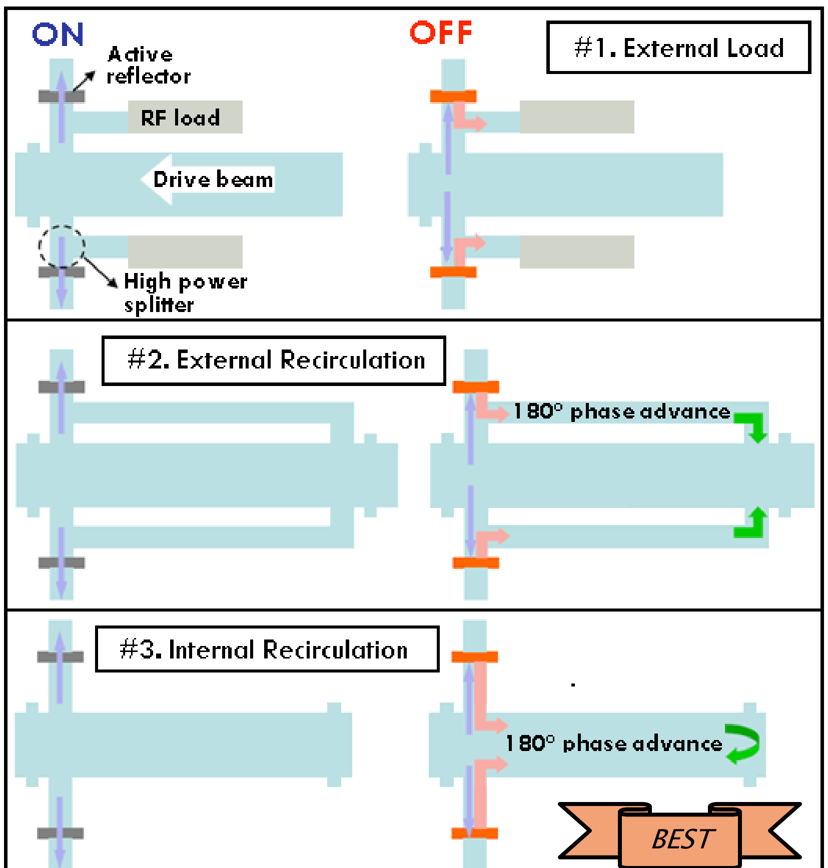
PETS ON–OFF operation

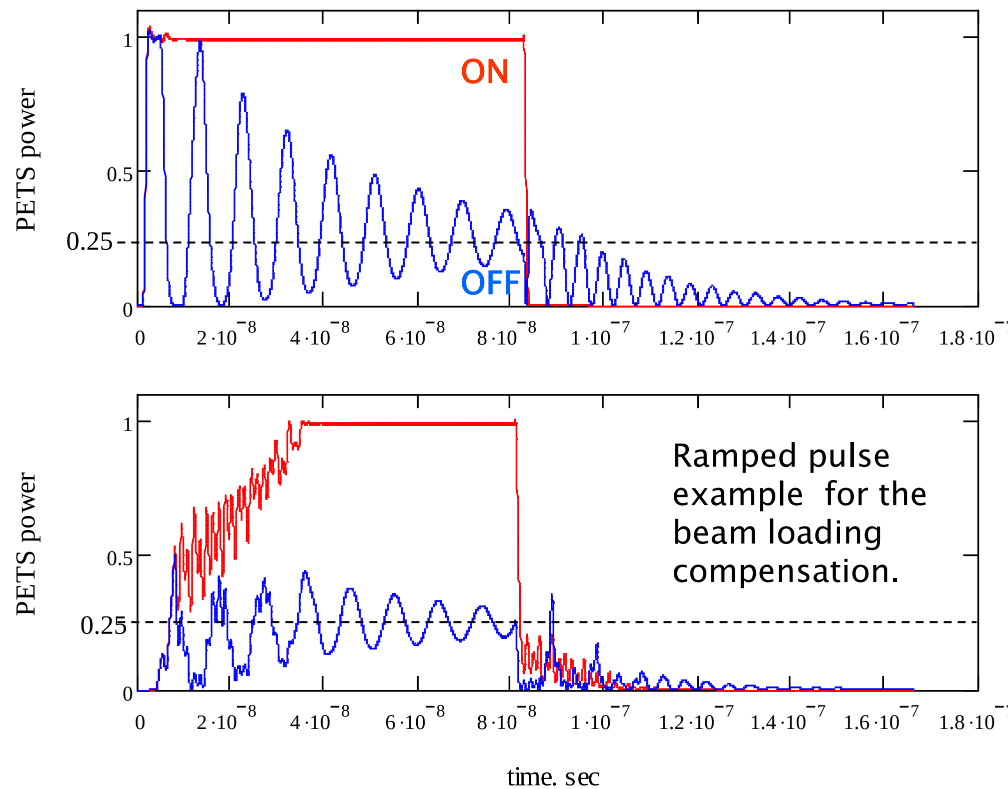
ILC, Technical Review Committee, 2003. CLIC feasibility issues, Ranking 1.

Reliability

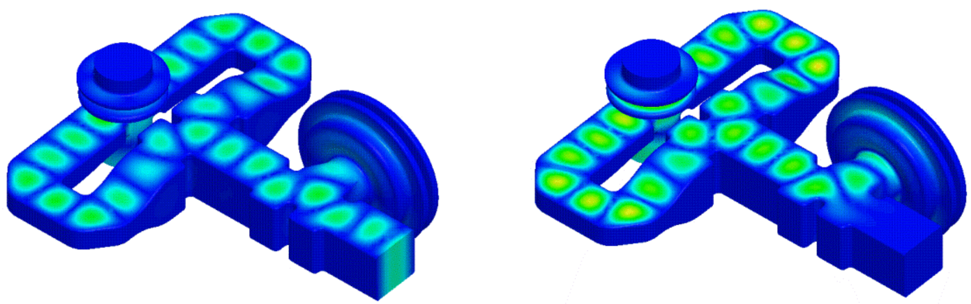
- In the present CLIC design, an entire drive beam section must be turned off on any fault. <u>CLIC needs to develop a mechanism to turn off only a few structures</u> in the event of a fault

Possible solutions

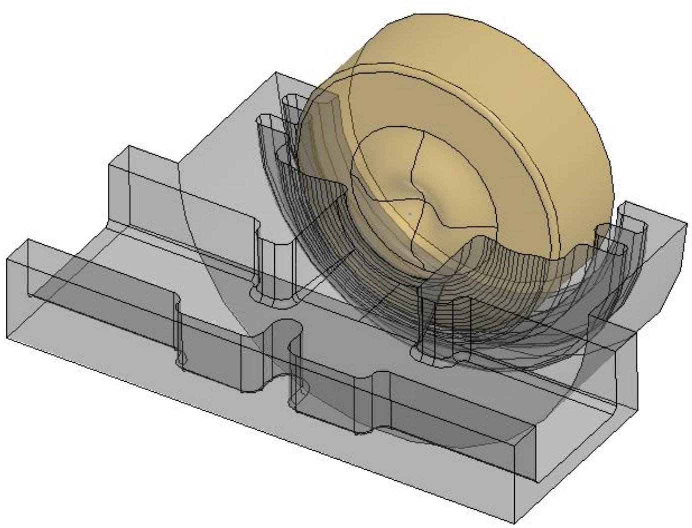


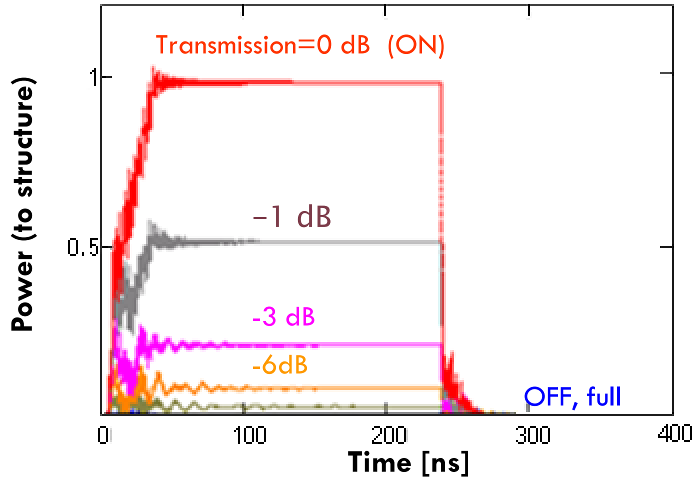


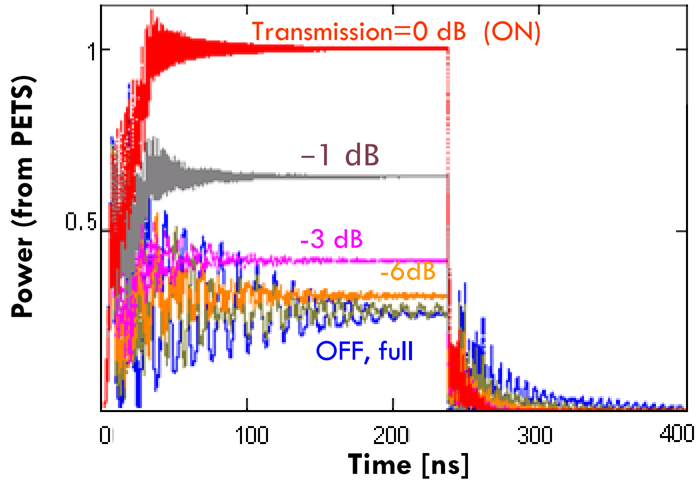
PETS ON-OFF operation

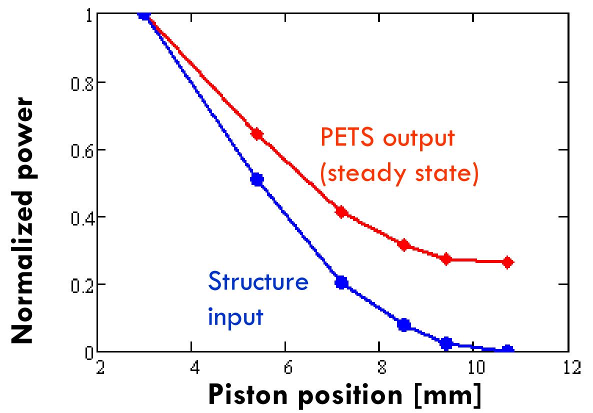


- extremely broad band (~4 GHz)
- low surface electric field (< 45 MV/m)
- reduced actuators stroke (~λ/4)
- contact-free

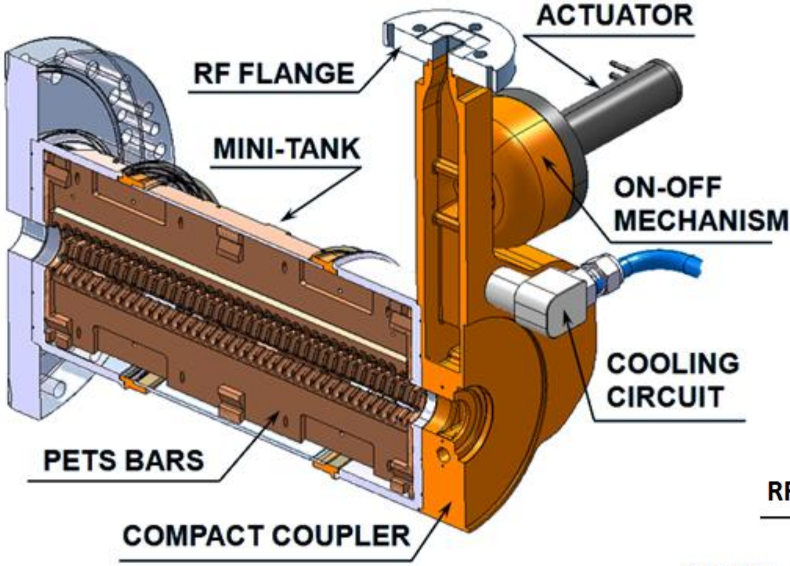




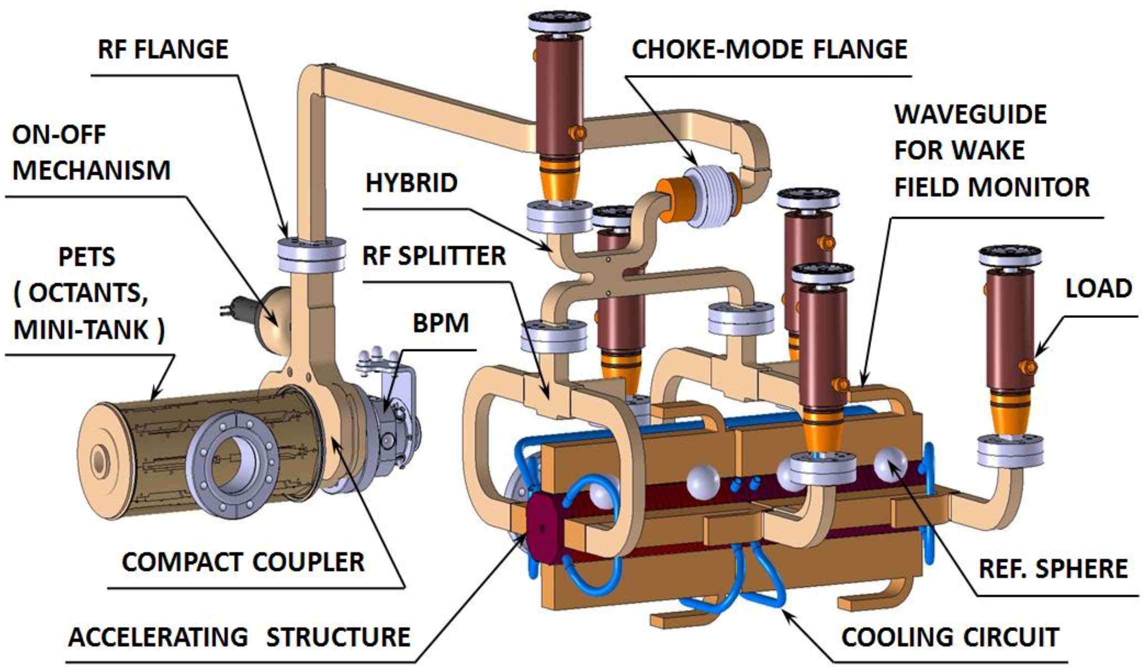




RF network layout*



See A. Samoshkin's presentation



Remarks and future plans

- So far, 2 PETS for SLAC testing and 2 PETS for CERN testing have been built. More will be coming in the next months (/years).
- Simulation codes have become fundamental in the whole design & improvement process. We're constantly looking to increase our computational capabilities.
- In the framework of our feasibility study, the test results proved that PETS performed well with respect to the requirements…
- … which will be important for our Conceptual Design Report (due by the end of the year).