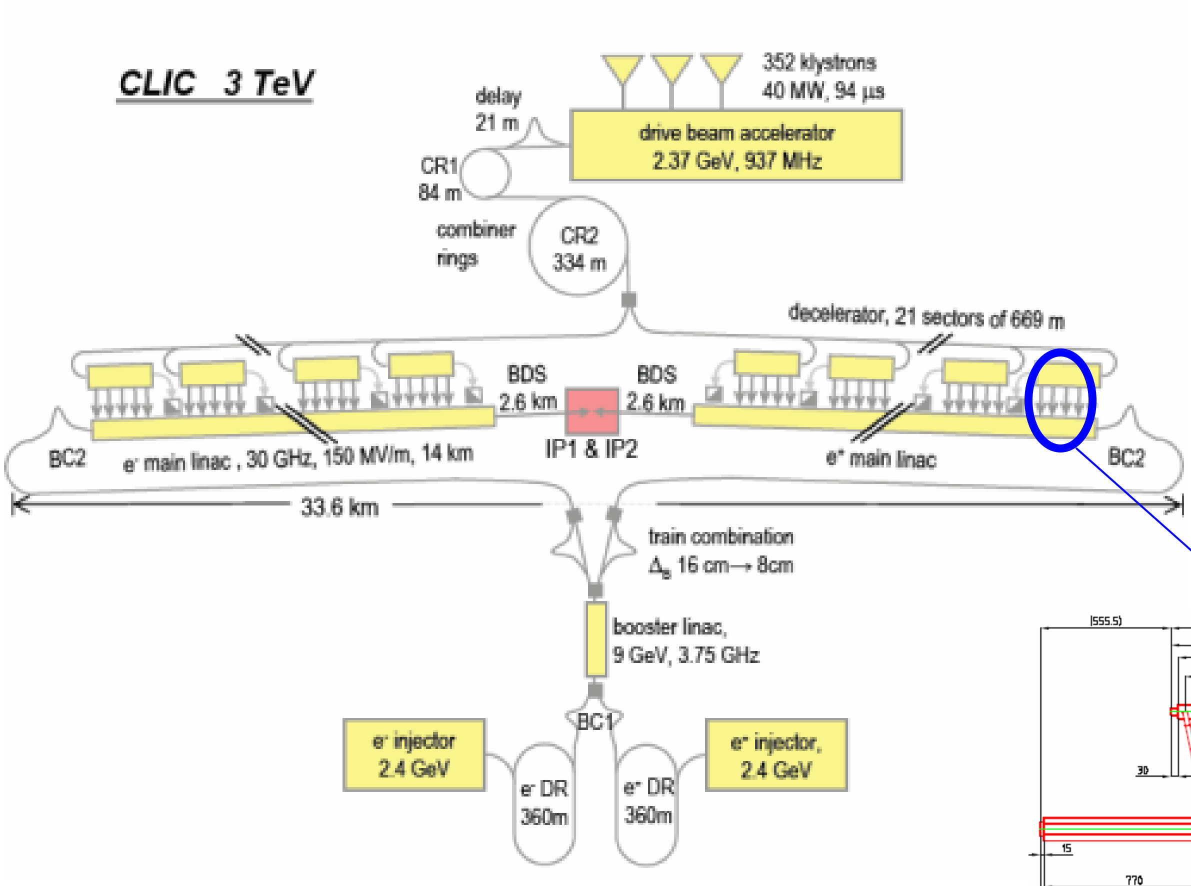
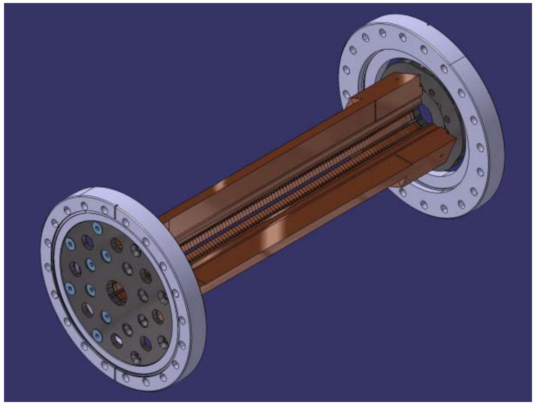
CLIC PETS up-to-date status

Igor Syratchev

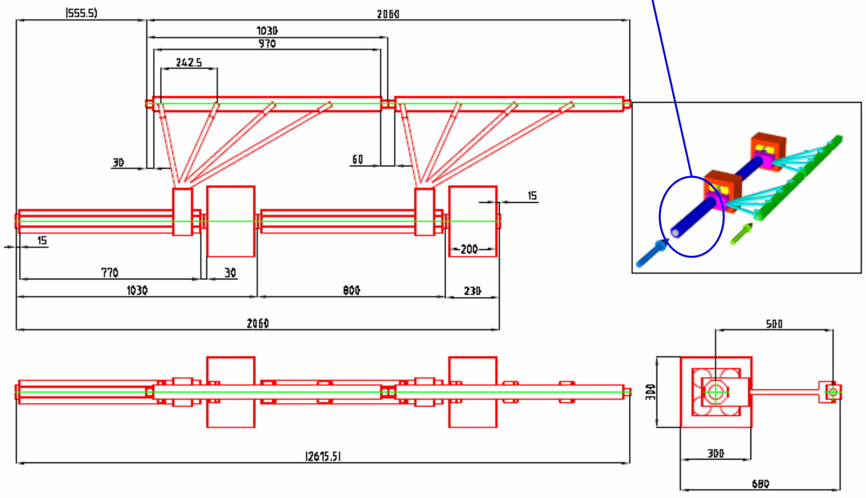
Introduction

CLIC Power Extraction & Transfer structure
PETS



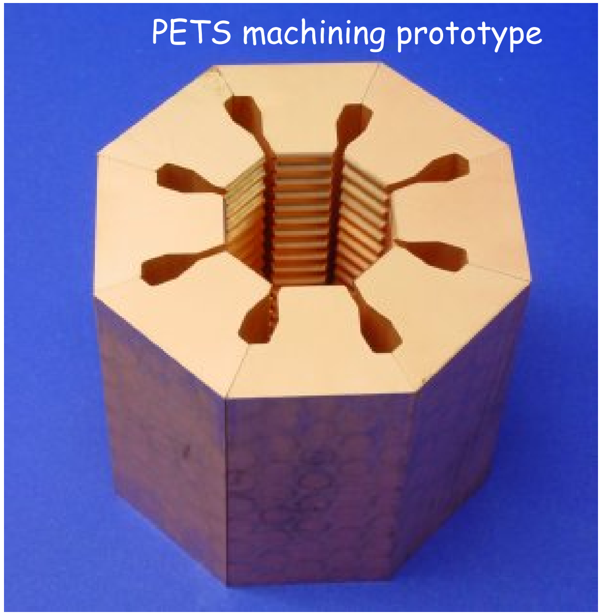


CLIC linac module layout



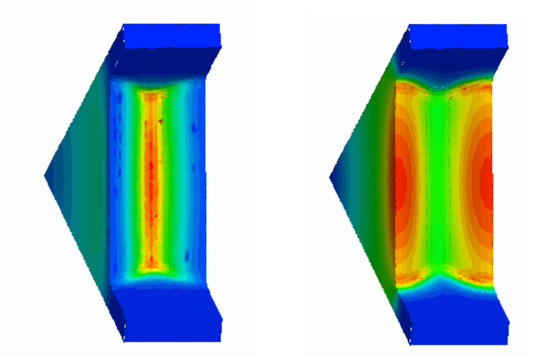
Mission: PETS should generate 650 MW, 70 ns, 30 GHz RF pulses from 15 GHz, 180 A drive beam to provide 150 MW RF power for each of four connected CLIC accelerating structure.

CLIC Power Extraction & Transfer structure


PETS machining prototype

The choice of PETS geometry is a result of multiple compromises between drive beam stability along the whole decelerator sector (~600 m) and the active length of the PETS given by the main linac RF power needs and the layout. Surface electric field, power extraction method, HOM damping, ability to cancel RF power generation if needed, and fabrication technology were all evaluated to ensure a reliable design.

EM filed plots



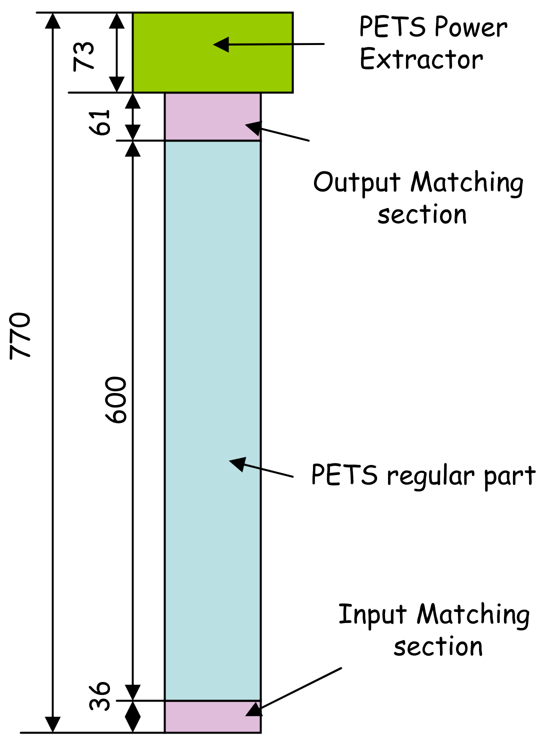
E_{max} = 120 MV/m

H_{max} = 0.2 MA/m
(ΔT = 6.5 ^{0}C)

PETS parameters:

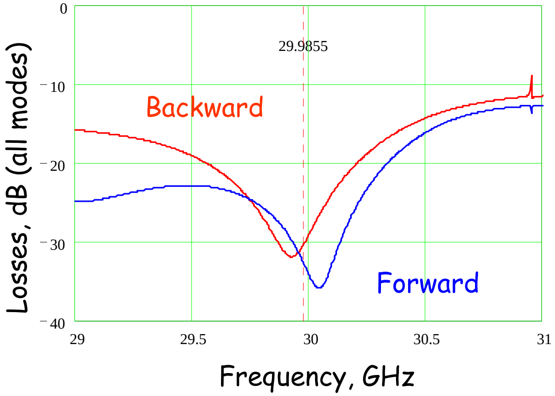
F= 29.9855 GHz
Aperture = 22.5 mm
R/Q = 320.2 Ohm/m
Beta = 0.798 *C*
$\Delta\varphi$/cell = 140^0
Active length = 0.6 m
Total length = 0.77 m
$I_{\text{Drive beam}}$ = 176 A
RF power = 642 MW
Damping slots: 8 x 2 mm
Extraction and transfer efficiency = 94%

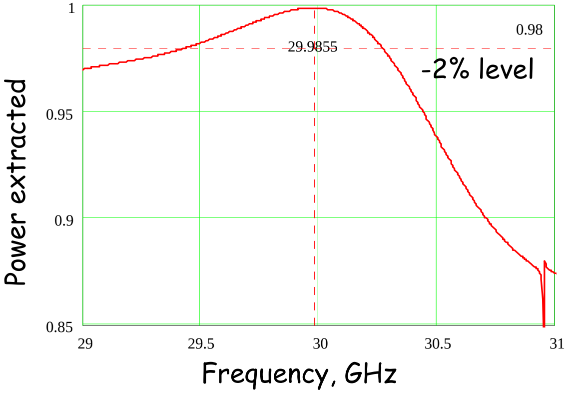
PETS architecture

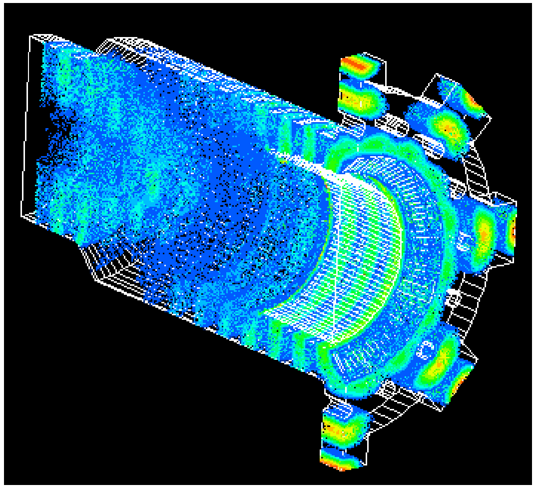


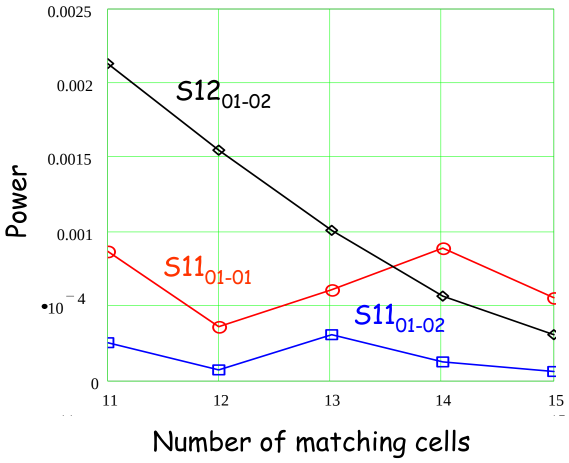
CLIC PETS RF power extractor

The efficient and compact broad-band 8-channel quasi-optical extraction coupler based on the multimode mixing approach has been designed to couple out the power from the CLIC PETS with a simulated (HFSS) efficiency of 99.6%. The total length of the extractor is 70 mm

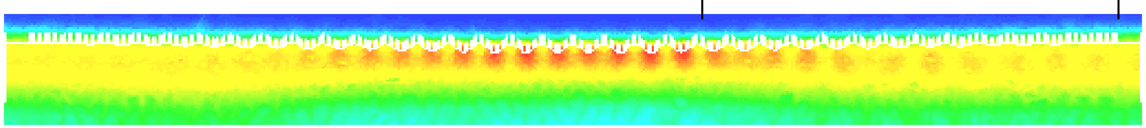




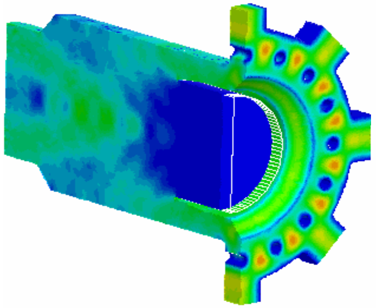


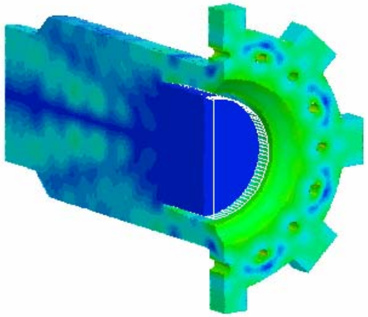


A long adiabatic matching section with a number of gradually reduced corrugations between the active PETS part and the power extractor is needed. The matching section has a total length of 58 mm (15 periods).



E_{max} = 78 MV/m
(1.25 E_{max} in WG)



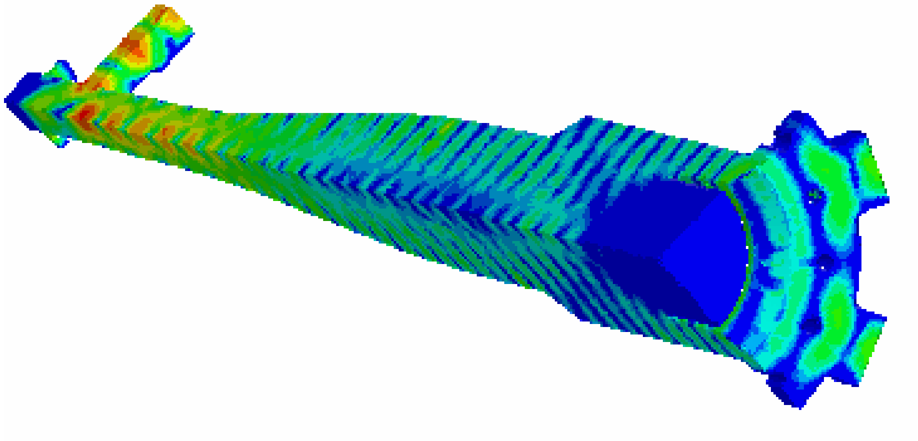


H_{max} = 0.26 MA/m
(ΔT = 11 ^{0}C)

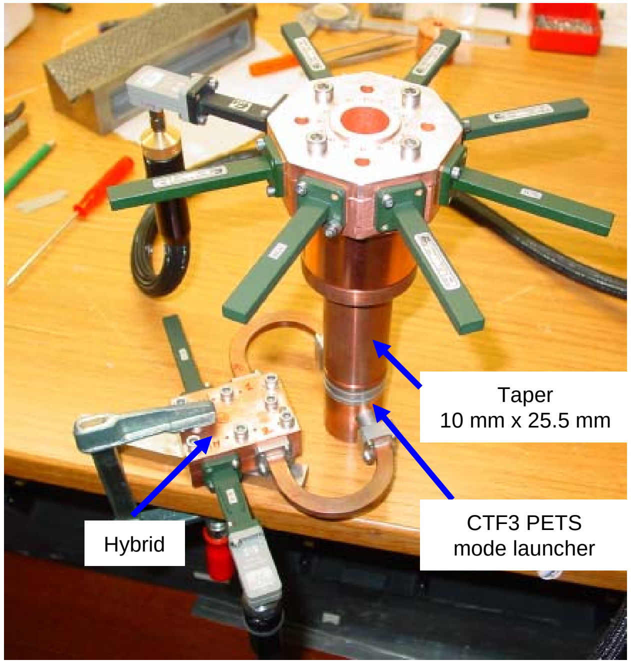
CLIC PETS RF power extractor (continued)

Low RF power prototype of the CLIC PETS Power extractor

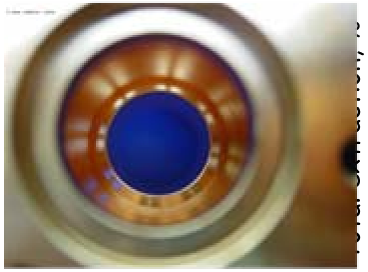
HFSS simulation of the test assembly
(hybrid not included)



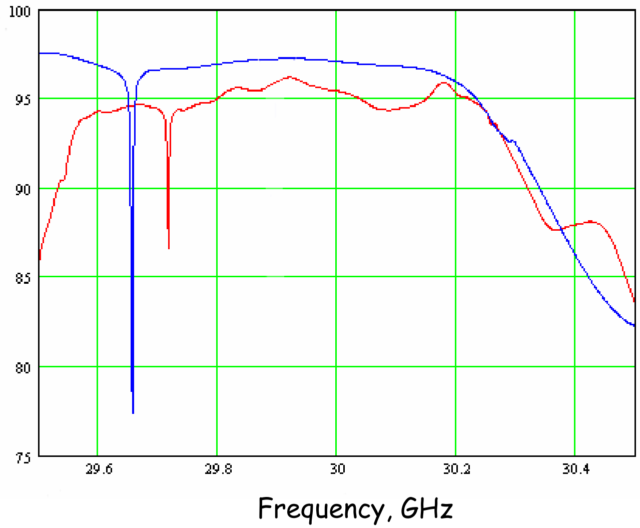
CLIC PETS Power extractor test set-up



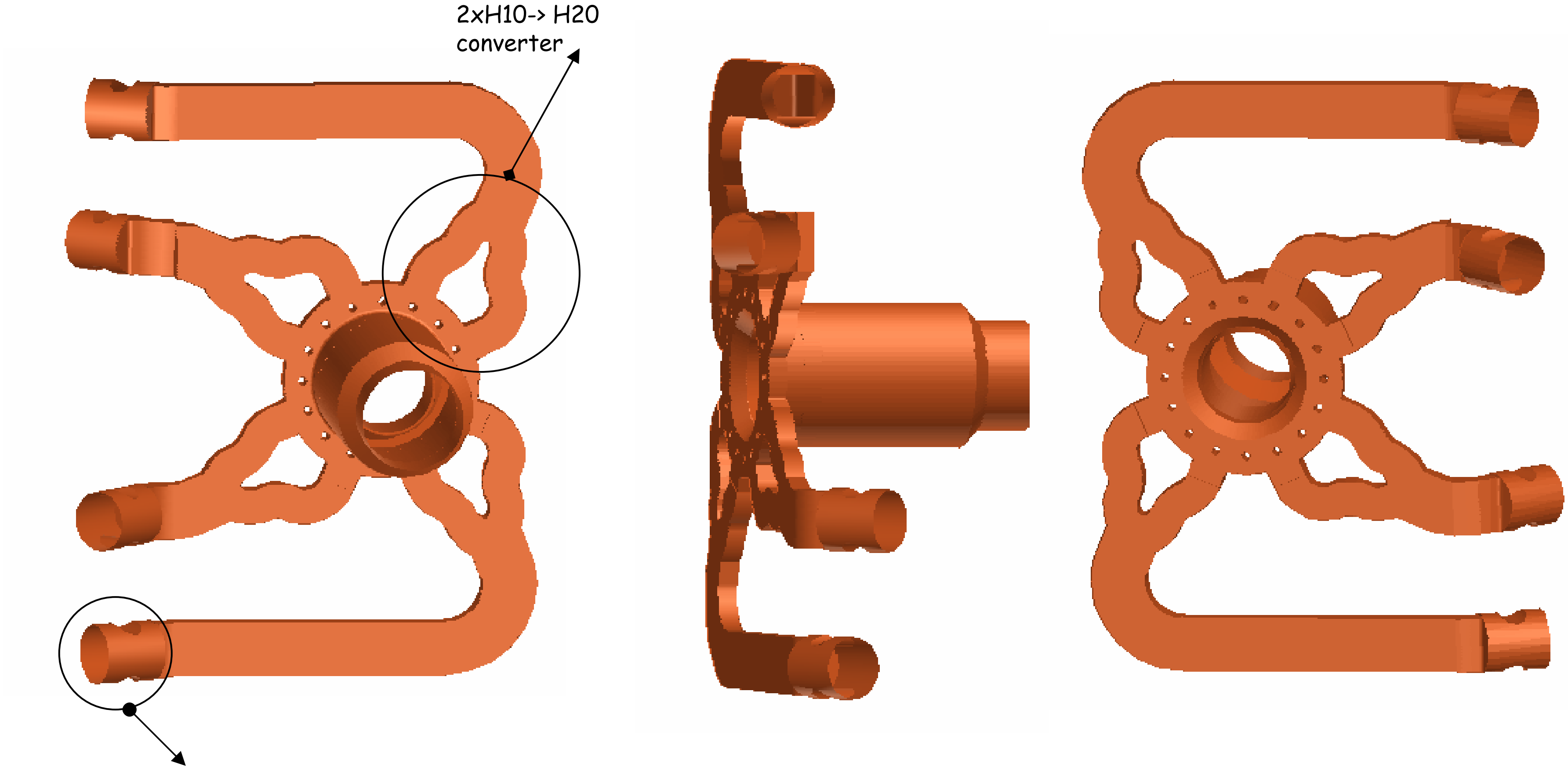
Drive beam eye view



Simulated (blue) and measured (red) extraction efficiency of the CLIC power extractor prototype



CLIC PETS RF power extractor head



2xH10-> H20 converter

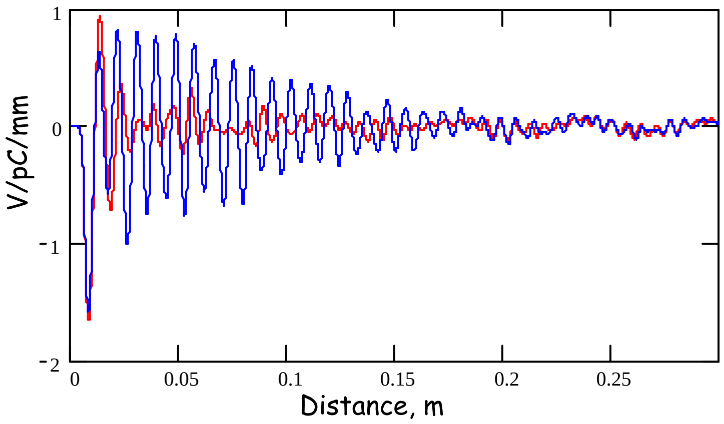
H20-> H01 converter

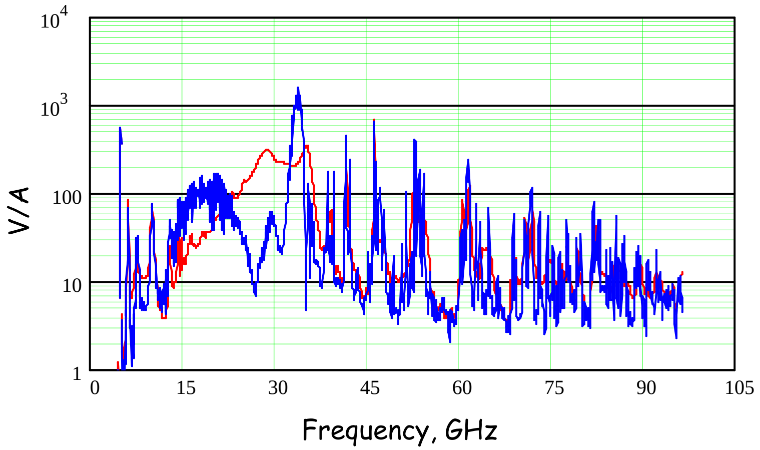
Estimated transfer losses ~ 2.5%!

HOM damping in PETS

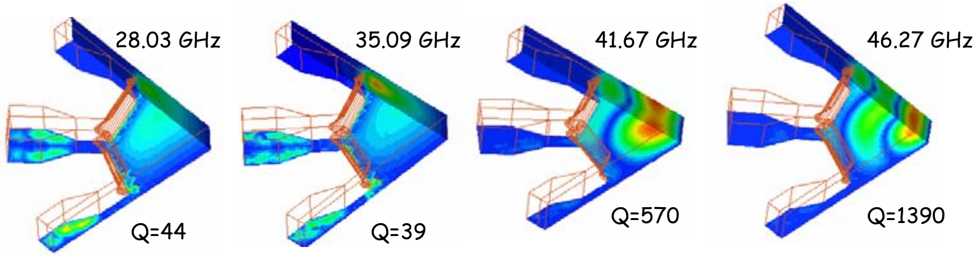
To avoid drive beam losses along the decelerator, the strong suppression of the transverse HOM is absolutely necessary. The most dangerous transverse mode has a frequency and group velocity practically identical to the decelerating one. The only way to damp it is to use its symmetry properties. The damping mechanism of this mode can be explained as a coherent radiation of many RF sources represented by the individual period of the corrugations into eight radial slots terminated by RF loads.

Transverse wake amplitudes and spectra of the full PETS with (red) and without (blue) damping as simulated with GDFIDL.

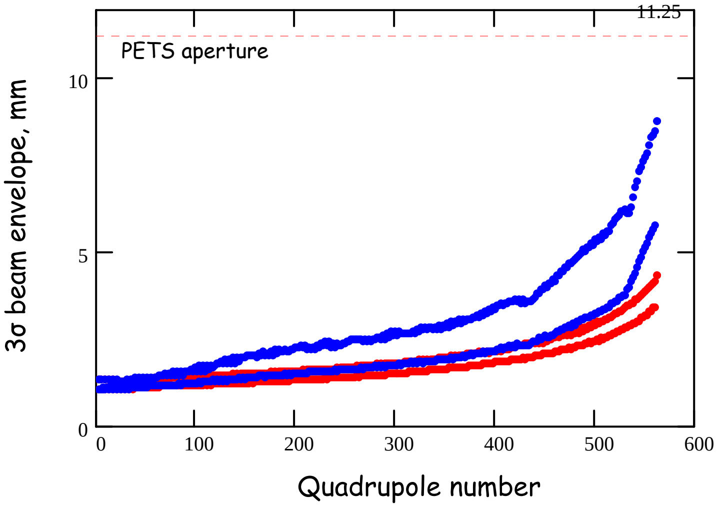




Four modes which bring > 95% contribution to the transverse wake were identified with HFSS. Plots of E_z component for all of them are shown:



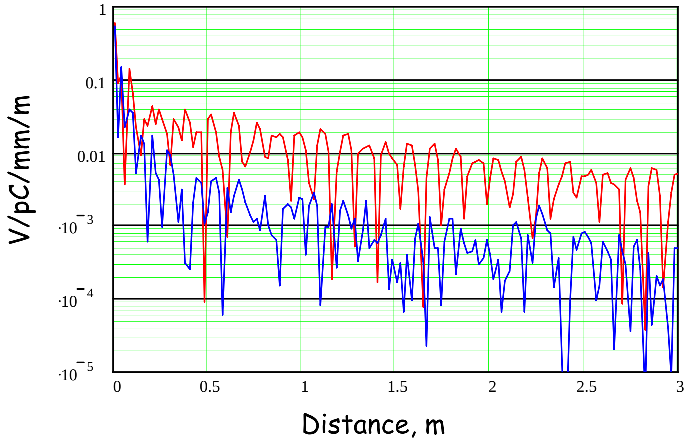
These modes, together with trapped coupler mode at 4.89 GHz, were used to simulate drive beam dynamic along whole the decelerator sector with the code PLACET. Next, the envelopes of a 3σ beam with an initial offset of $\Delta y=0.3\sigma_y$ along the decelerator with (blue) and without (red) transverse wakes are shown.

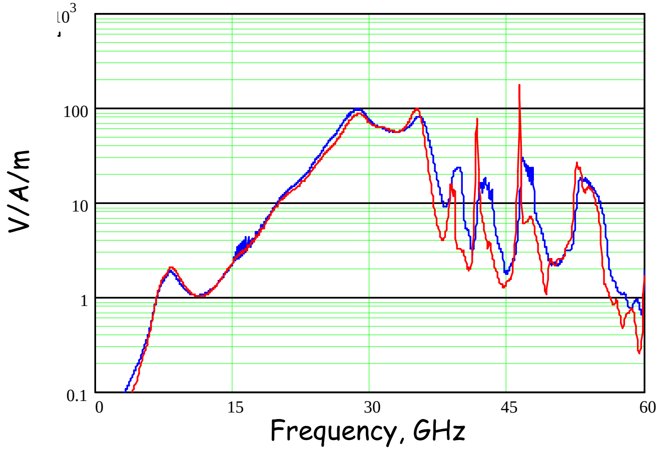


HOM damping & detuning in PETS

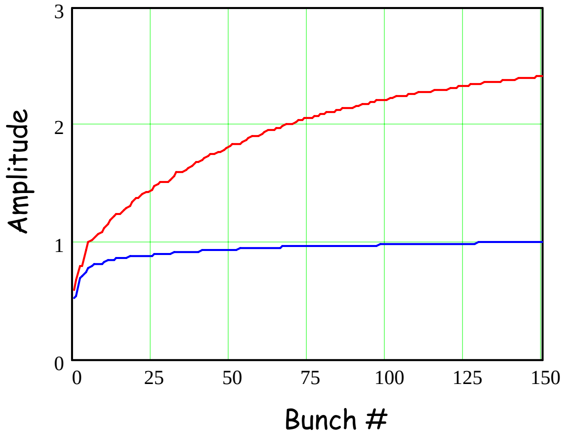
The observed jitter amplification is caused by the third band dipole mode, which have low amplitude but no damping, and by low frequency trapped coupler mode. The frequency detuning via linear variation of the phase advance along PETS from 132 to 140 degrees per cell helps to reduce amplitude of the 3-rd band HOM by factor of ten.

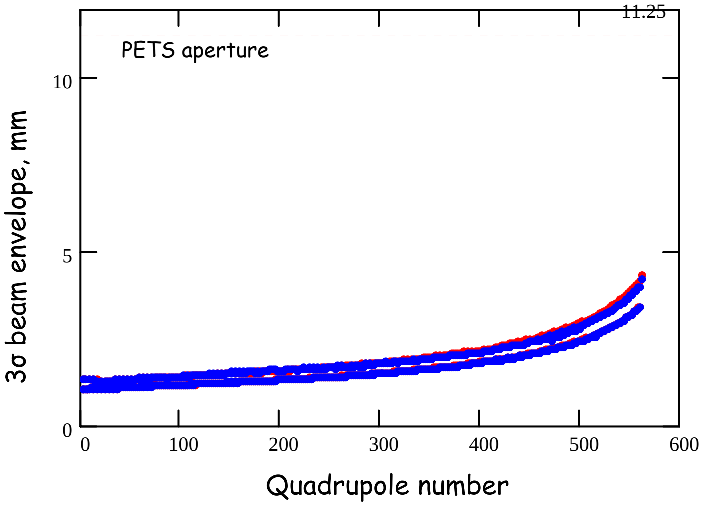
Transverse wake amplitudes and spectra at the positions of bunch cents with (blue) and without (red) detuning as simulated with GDFIDL .



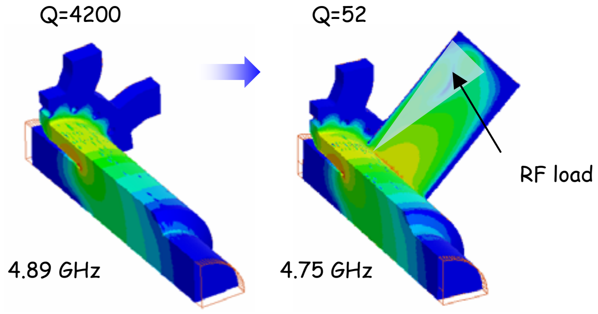


Integrated wake amplitude along the bunch train





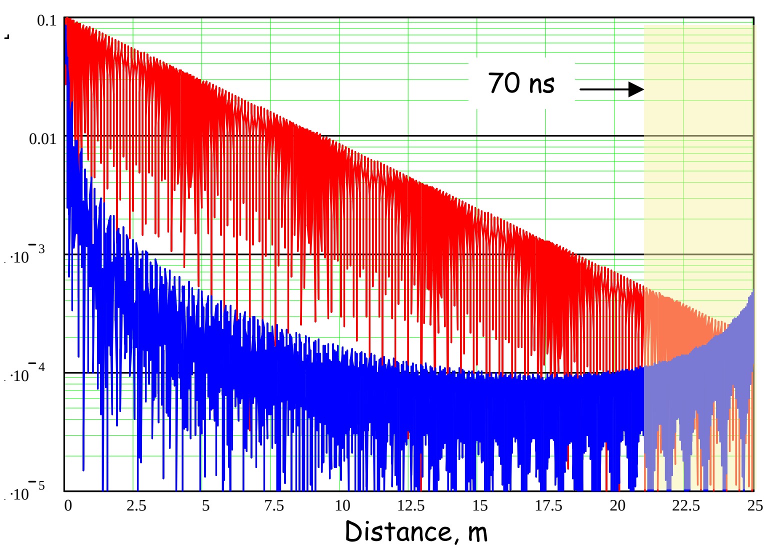
Coupler modes can be suppressed significantly with 4 radial waveguides

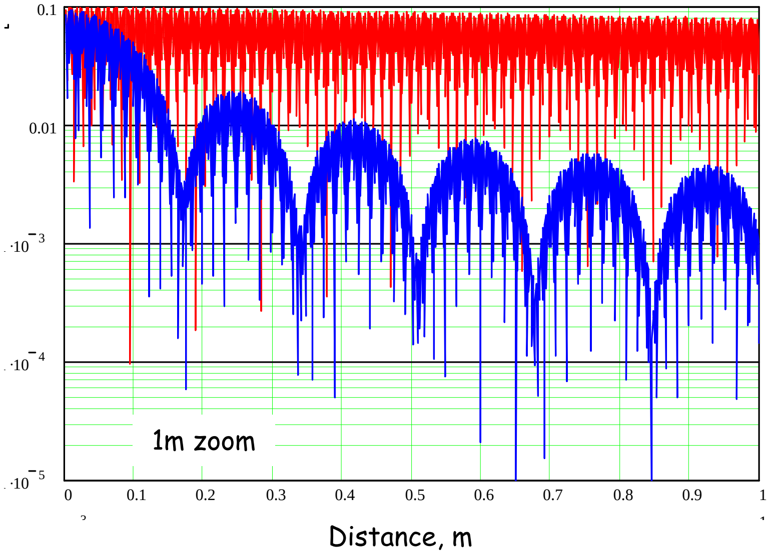


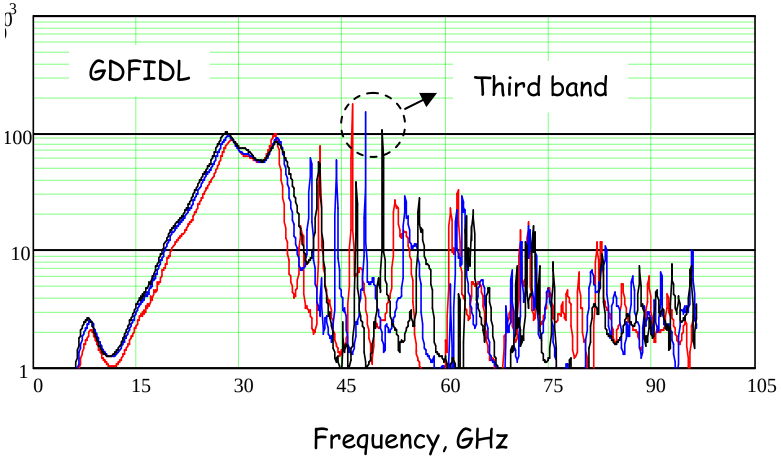
One can see that the transverse HOM have now practically no effect on the beam losses .

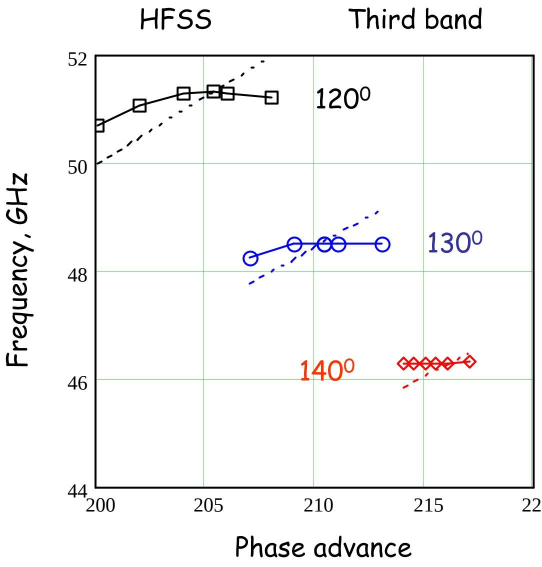
Detuning (more details)

Reconstructed uncoupled wake. First cell 132^0, last cell 140^0, detuning **1.76 GHz**.



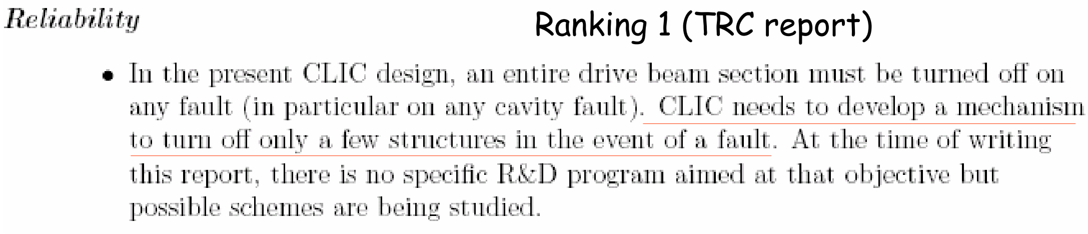






PETS ON/OFF operation

Ranking 1 (TRC report)



Reliability

- In the present CLIC design, an entire drive beam section must be turned off on any fault (in particular on any cavity fault). CLIC needs to develop a mechanism to turn off only a few structures in the event of a fault. At the time of writing this report, there is no specific R&D program aimed at that objective but possible schemes are being studied.

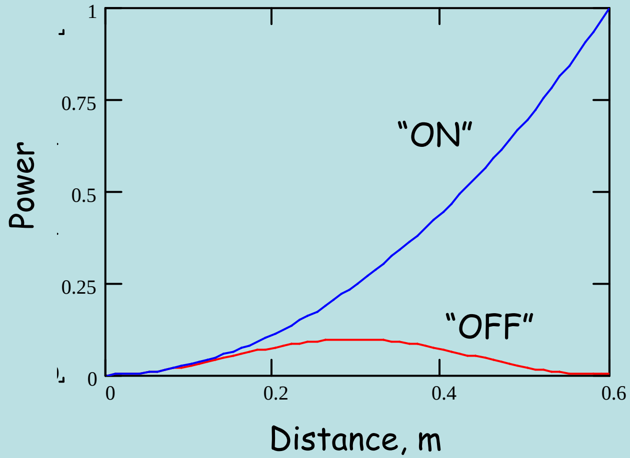
For constant impedance structure, the RF power distribution along the structure can be expressed as:

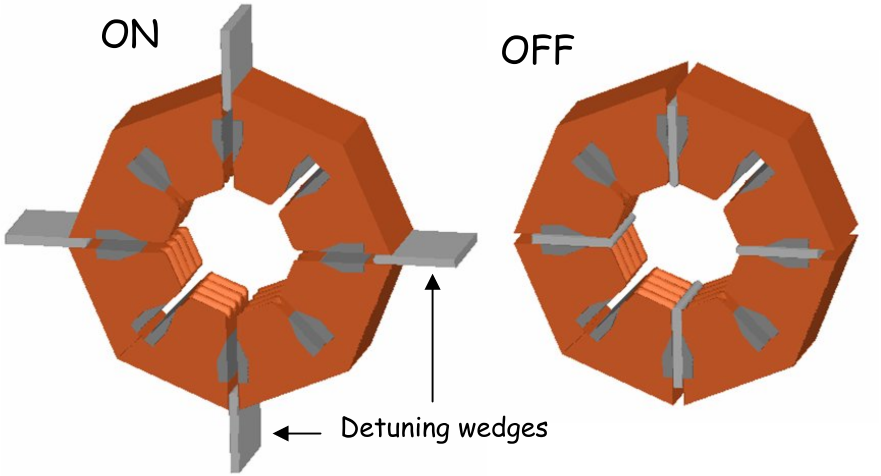
$$P(z) = \frac{R/Q\times I^2\times\omega_D}{4\times\beta\times C}\left(\int_o^z \cos\left(\frac{\omega_D-\omega_0}{2C}\times\frac{1-\beta}{\beta}z\right)\exp\left(-\frac{\omega_D}{2Q\times\beta\times C}z\right)dz\right)^2$$

If we need to avoid power build-up at the end of the structure, then the detuning should be introduced:

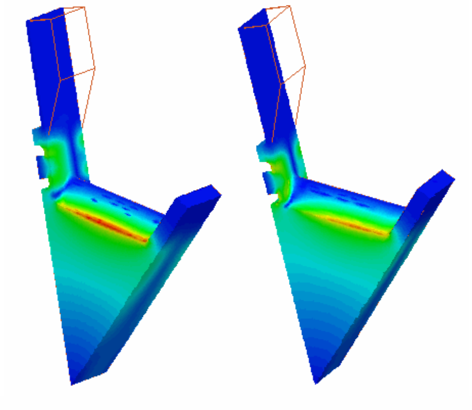
$$F_D = F_0 \pm \frac{\beta\times C}{(1-\beta)\times L}$$

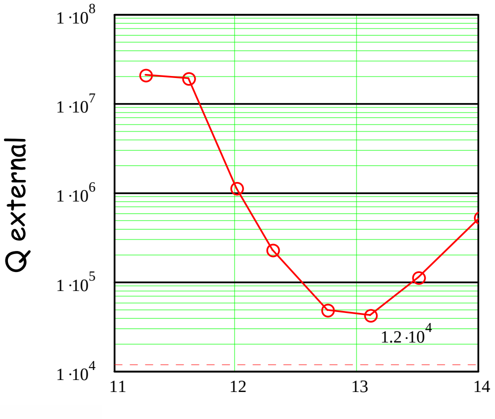
Where F_D is a new detuned synchronous frequency, L – length of the structure and β - group velocity. For CLIC PETS F_D ~ 32 GHz:





We have found that simply by insertion of 4 (1.6 mm thick) wedges through the damping slots, sufficient PETS synchronous frequency detuning can be achieved. To avoid electric field enchantment and power leakage into HOM loads, the wedge designed to have a special profile. This allows to operate in a variable attenuation regime.

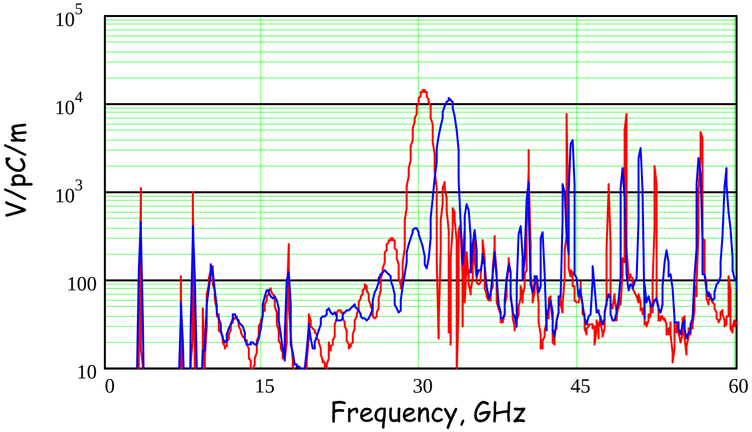




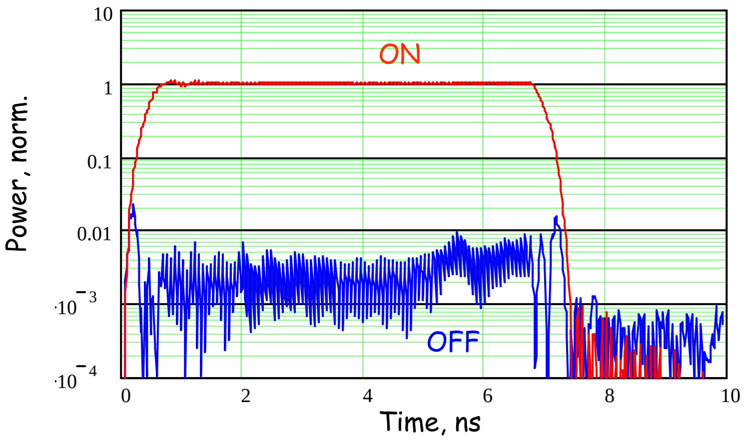
RF power generation and extractor with GDFIDL

Full PETS geometry including matching section and output coupler was simulated with GDFIDL to verify the performance and potential problems. The reconstruction of the output RF power build-up make it possible to reproduce realistic pulse envelopes and to demonstrate ON/OFF capability.

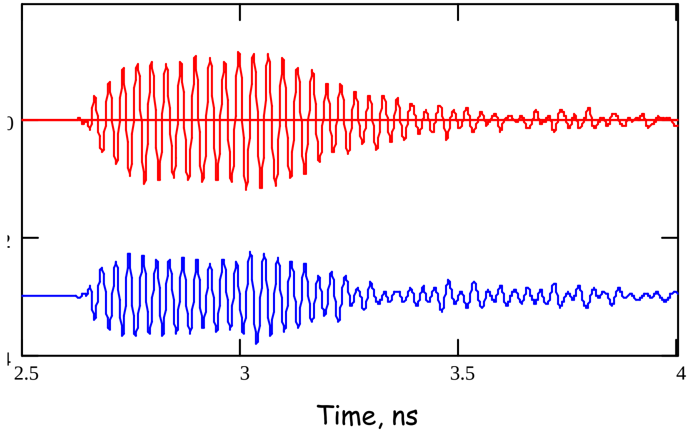
PETS Longitudinal wake. Red-ON, Blue – OFF
(the wedge edge position at r=11.5 mm)



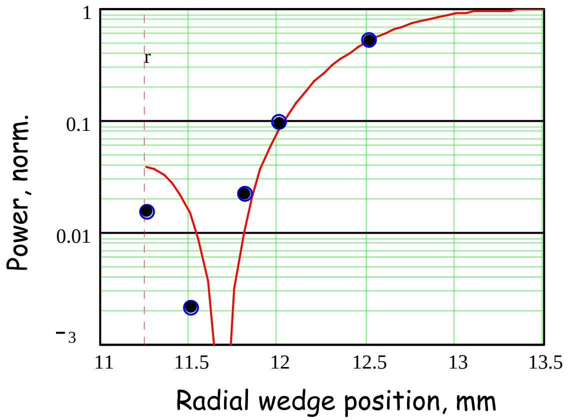
Reconstructed PETS output pulse envelopes
(100 bunches spaced by 2 cm were used).



Voltage induced by single bunch in the output waveguide

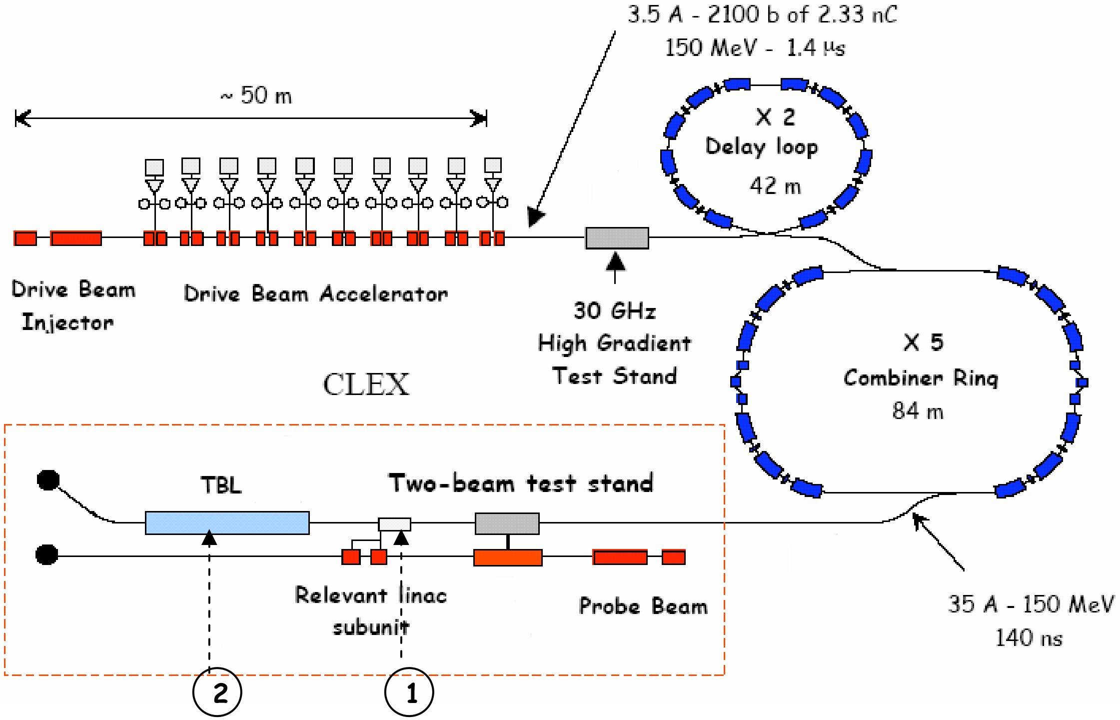


Output power vs. radial wedge position.
Line – HFSS + analytics, Dots – GDFIDL.



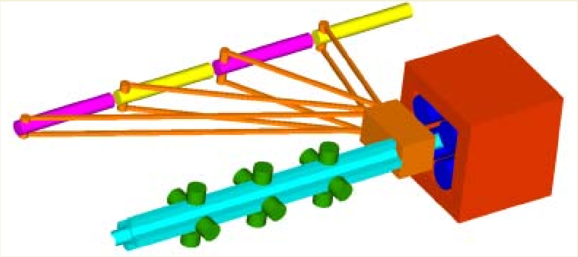
PETS test program 2005-2010

PETS in CTF#3

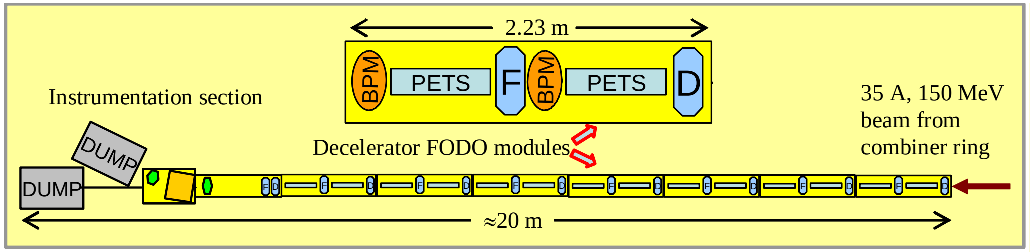


PETS principal locations

1. The International Linear Collider Technical Review Committee has listed “the test of a CLIC relevant linac subunit“ as a **Ranking 2** task for CLIC study.



Since the CTF3 drive beam is only 35 A instead of the 176 A CLIC beam, it will be necessary to use a booster structure to “prime” the CLIC PETS to produce the full power.

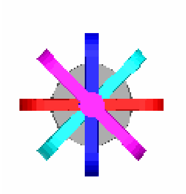


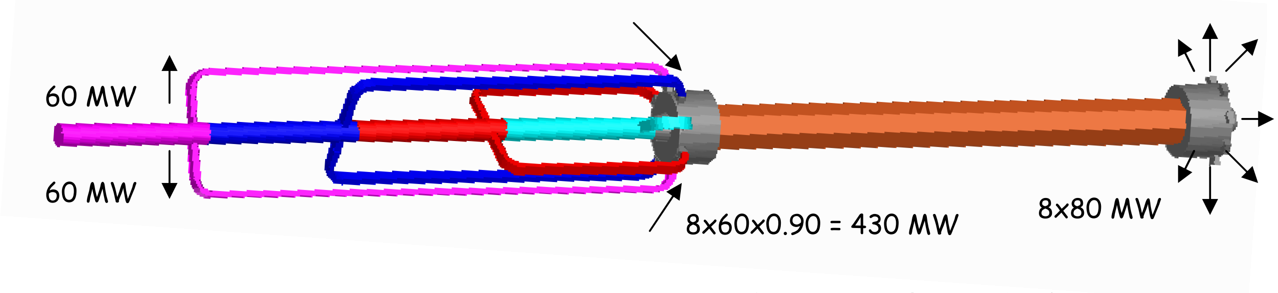
2. The TBL as a scaled model of a CLIC drive beam decelerator sector will give the opportunity to test the operation of such a decelerator and the predictions of the numerical simulation tools which are used for its design.

CLIC relevant linac subunit

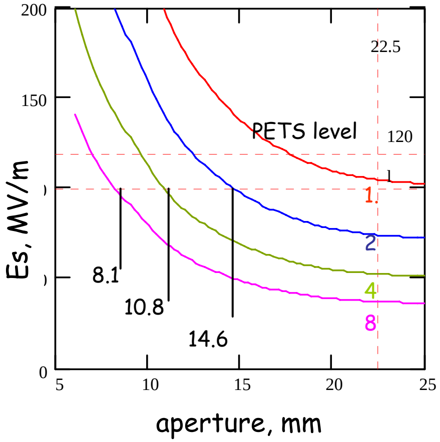
	CTF3 vs.	CLIC
Current, A	35	176
σ, mm	0.4	0.4
Energy, GeV	0.15	2.37
Power, MW	25.4	642
Frequency, GHz	15.	15.

The full power will be generated by CLIC PETS from CTF3 drive beam if extra 430 MW will be used to "prime" it. This could be done using few special booster structures in parallel, so that each of them produces moderate peak power. It is advisable not to exceed the electric surface field level in booster structure compared to that in CLIC PETS. Assuming 90% power transfer efficiency, booster should produce 480 MW.

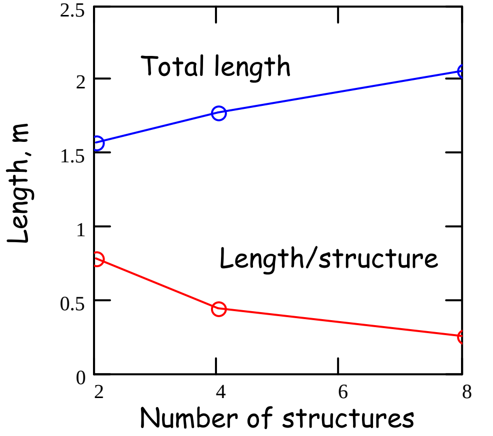




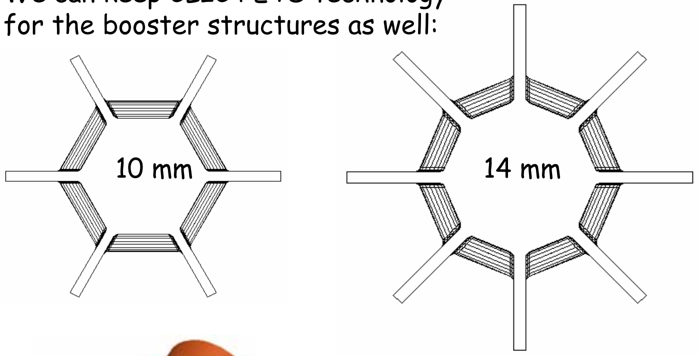
Surface field vs. aperture for different number of booster structures and 480 MW total.



Booster length vs. number of booster structures with 100 MV/m electric surface field limit



We can keep CLIC PETS technology for the booster structures as well:

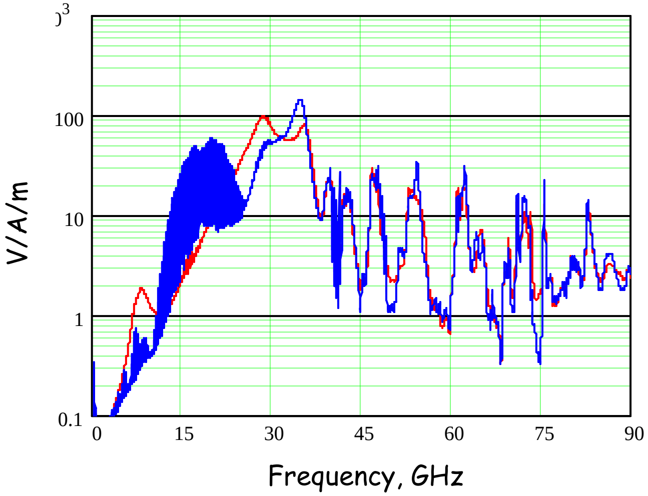


12 mm, 4 way coupler

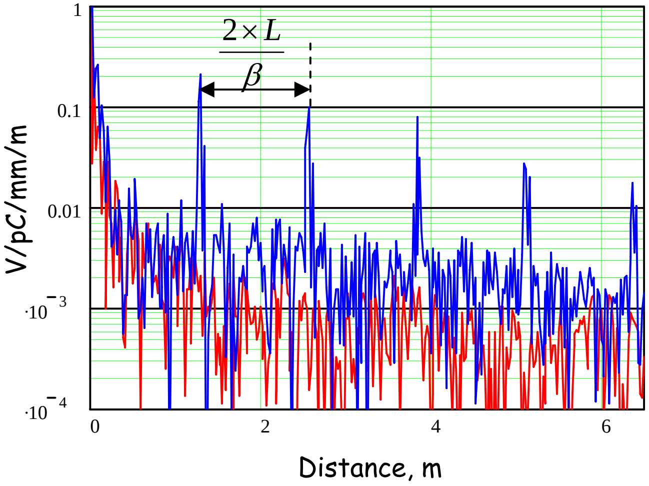
CTF3 like choke stop-band coupler can be adopted to extract power from booster structures with inner diameter up to ~16 mm and number of waveguides as required.

Test Beam Linac

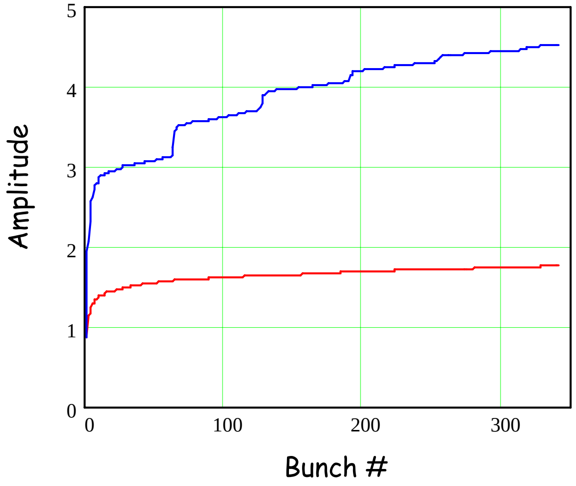
Transverse wake spectra and amplitudes at the positions of bunch centers with 8 loads (red) and 4 loads (blue) as simulated with GDFIDL .



Parameter	Damped (140^0/cell) M0	 M1	 M2	Four loads M0	 M1	 M2
F, GHz	21.108	28.031	35.092	18.269	28.455	34.452
Q	25.6	44.1	39.8	5600	29.6	97.8
V group /C	0.946	0.8883	0.6512	0.95	0.872	0.7388
Wt, V/pc/m/mm	0.59	2.144	0.874	0.532	0.864	1.492



Integrated wake amplitude along the bunch train



Slot mode with only 4 of 8 loads