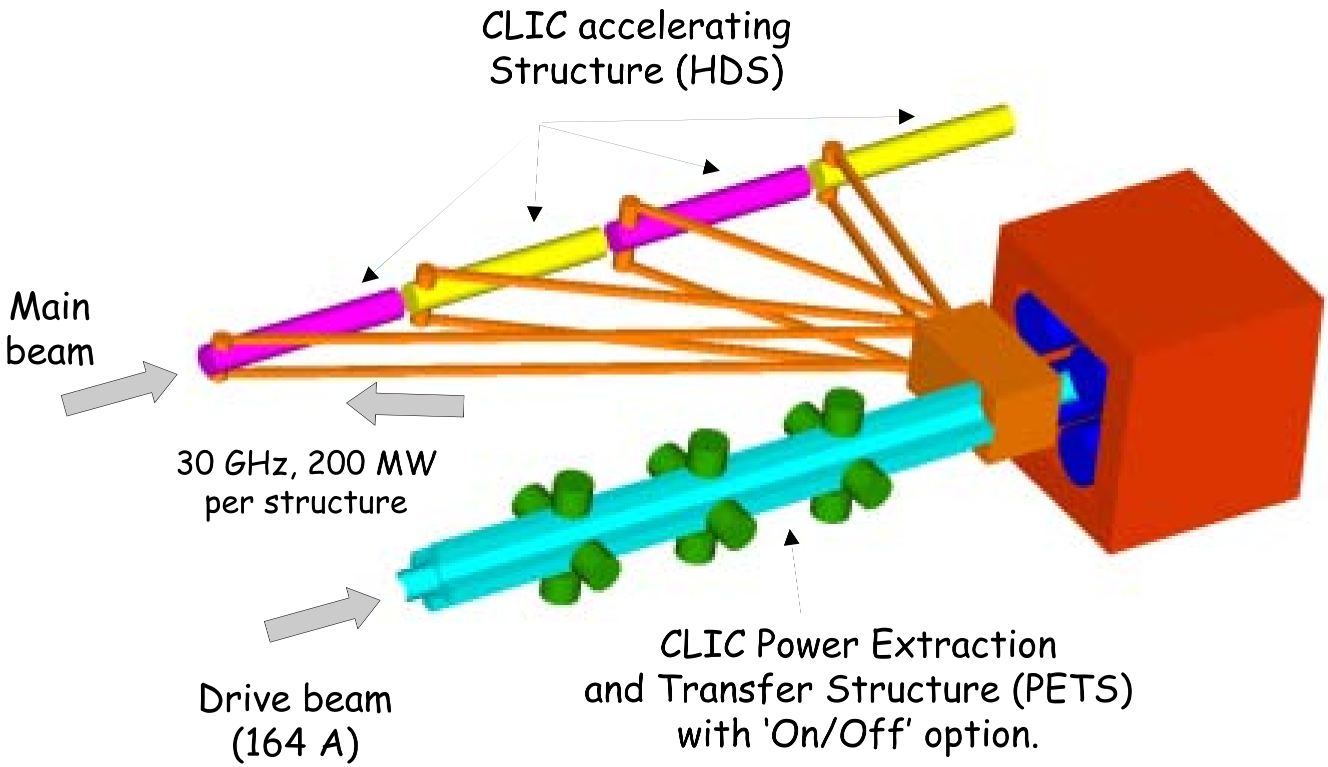
CLIC Power Extraction and Transfer Structure.
(2004)

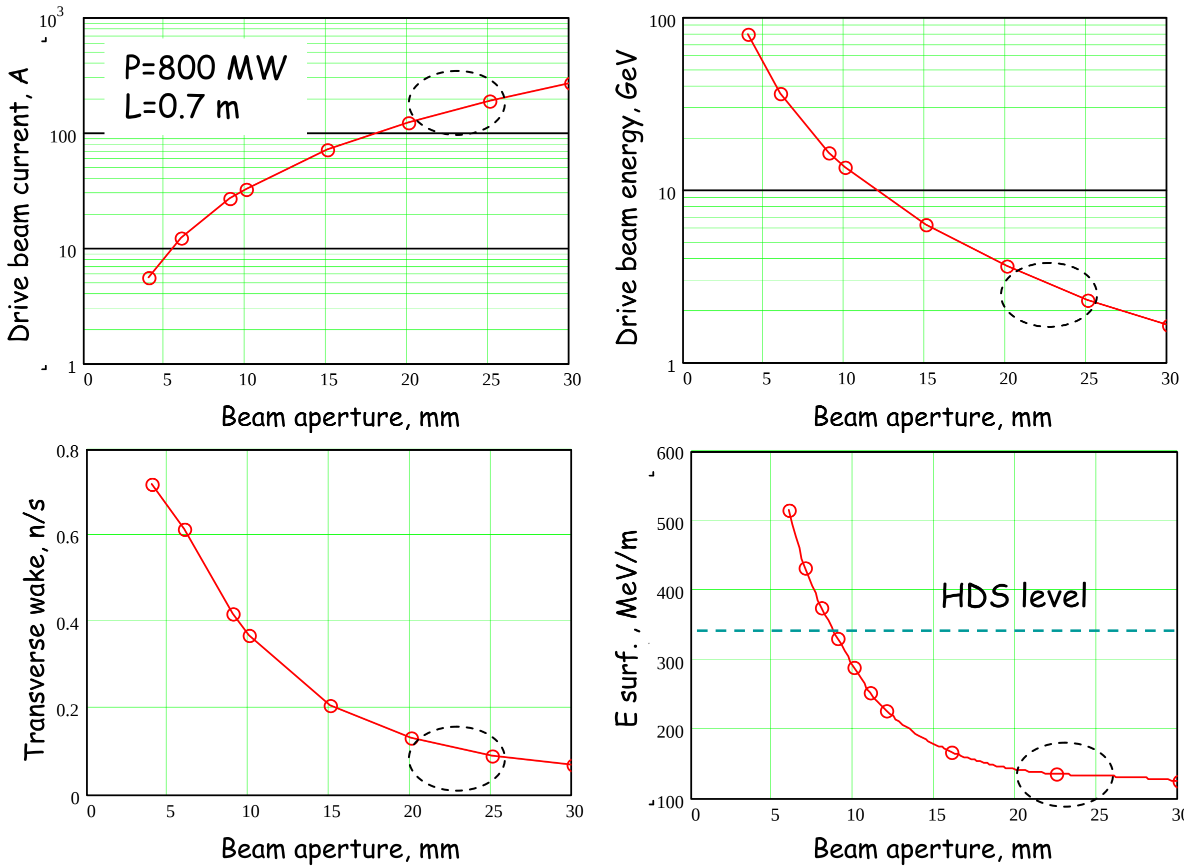
CLIC linac subunit layout:



INTRODUCTION

Mission: PETS should generate 800 MW, 42 ns, 30 GHz RF pulses (8 bunches spacing HDS design). Following present CLIC main linac layout (1 PETS x 4 HDS), the PETS active length should not exceed 0.7m.

Circularly symmetric structures



PETS aperture:

For the given length and RF power of the PETS, beam current scales as:

$$I = \sqrt{\frac{P}{L_{PETS}^2} \cdot \frac{4V_{group}}{R/Q \times \omega}}$$

and transverse wake amplitude:

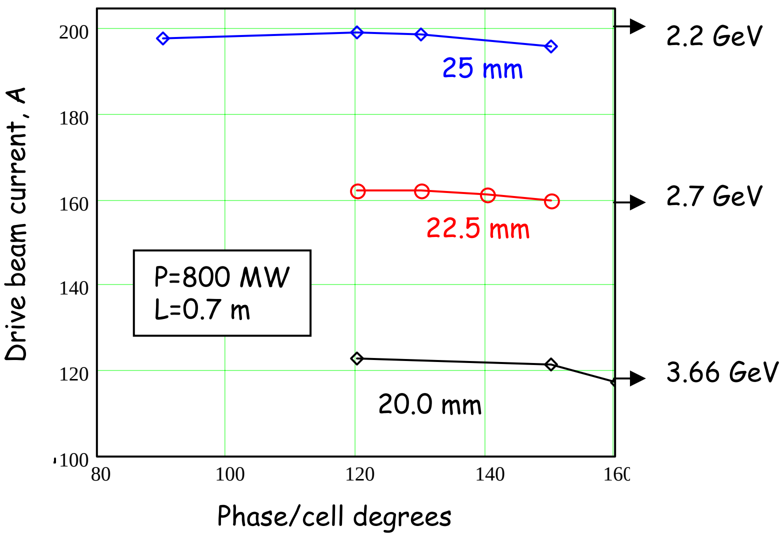
$$W_\perp \approx I \frac{k_\perp}{1-\beta_\perp} \approx \frac{k_\perp}{1-\beta_\perp} \times \sqrt{\frac{V_{group}}{R/Q}}$$

Constraints:

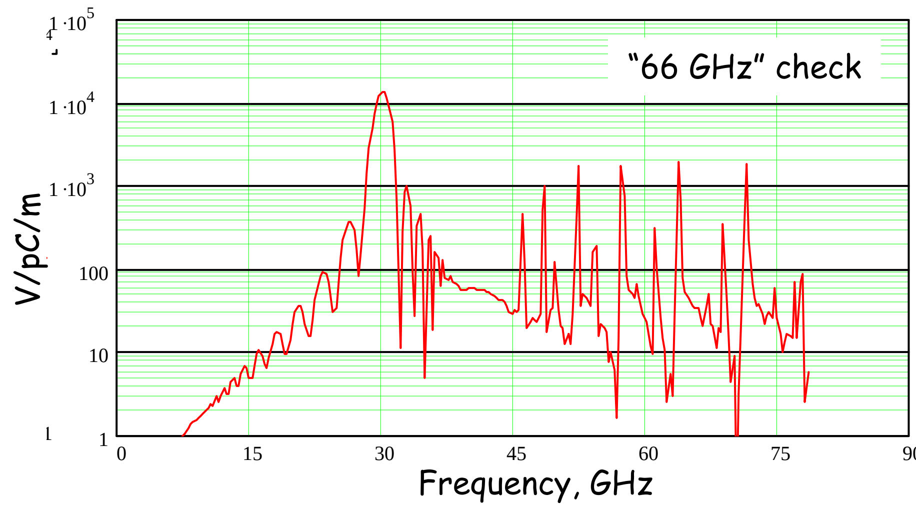
#1. Drive beam accelerator length/cost scales inverse proportionally with the drive beam current.
#2. Combining rings. In general higher energies require larger rings.
#3. PETS reliability. One should not accept a design, when electric surface fields in PETS exceed values of that in a main linac.
#4. Transverse wake in a PETS should be within acceptable level.

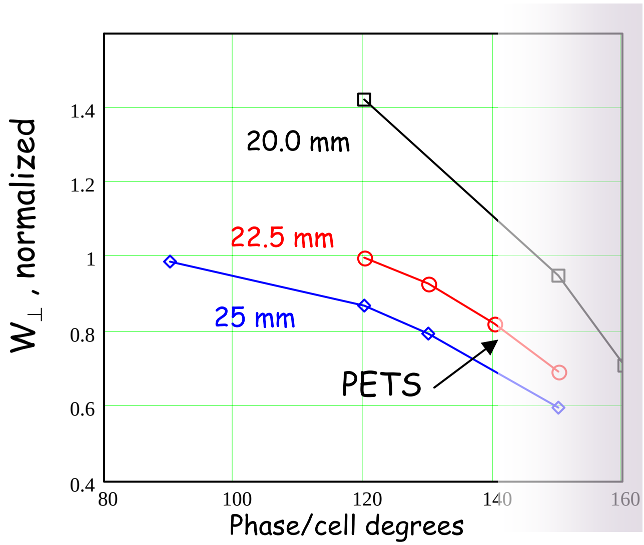
As a compromise, PETS apertures from 20 mm to 25 mm were chosen for detailed study.

Phase advance and aperture



PETS longitudinal impedance (by GDFIDL)



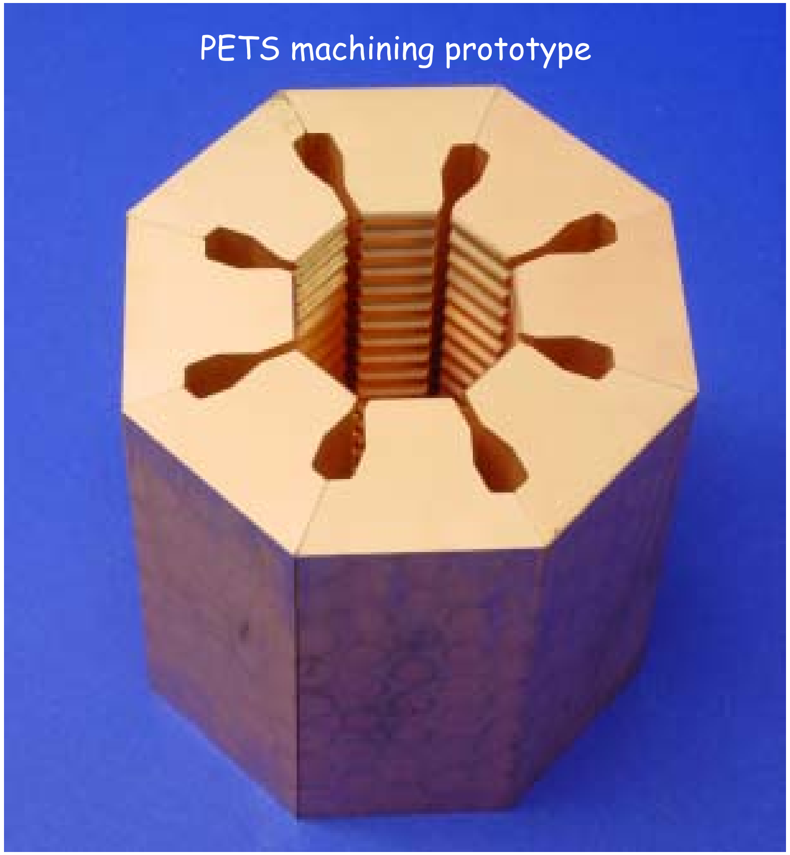


The higher phase advance, the less HOM damping.

PETS parameters:

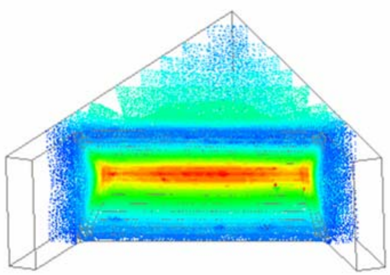
F= 29.9855 GHz
Aperture = 22.5 mm
R/Q = 320.2 Ohm/m
Beta = 0.798 *C*
$\Delta\varphi$/cell = 140⁰
$I_{\text{Drive beam}}$ = 164 A
RF power = 800 MW
Active length = 0.7 m
Damping slots: 8 x 2 mm

CLIC PETS in general

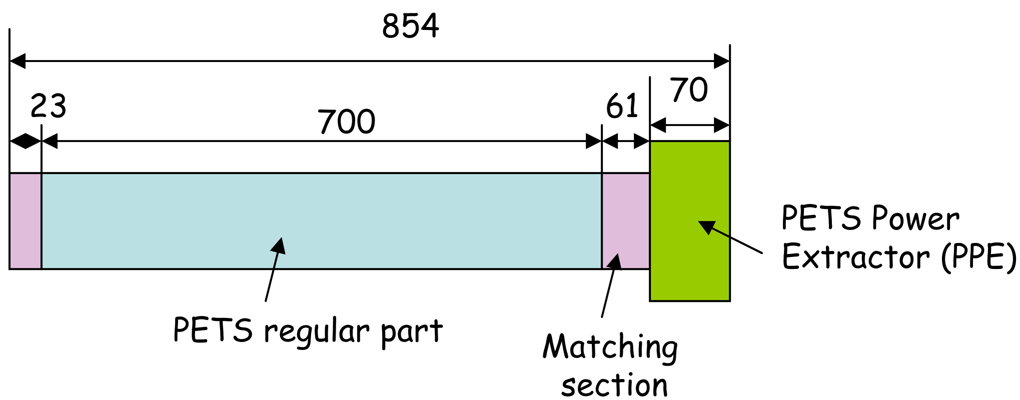


Finally adopted PETS is represented by 22.5 mm diameter circular waveguide with shallow (~1.3 mm deep) sinus-type corrugations with 140^0 phase advance per period (3.8885 mm). Eight HOM damping slots are placed symmetrically around the circumference splitting the whole structure into 8 identical pieces. To simplify the fabrication, the active profile of each of 8 racks was chosen to be flat The damping slot width (2 mm) and slot's rounding radii (0.8 mm) provided quasi-constant surface electric field distribution. This technology is very similar to that was chosen for HDS accelerating structure.
PETS geometry provides certain margins towards active length and RF power to be produced without affecting beam stability along the decelerator.

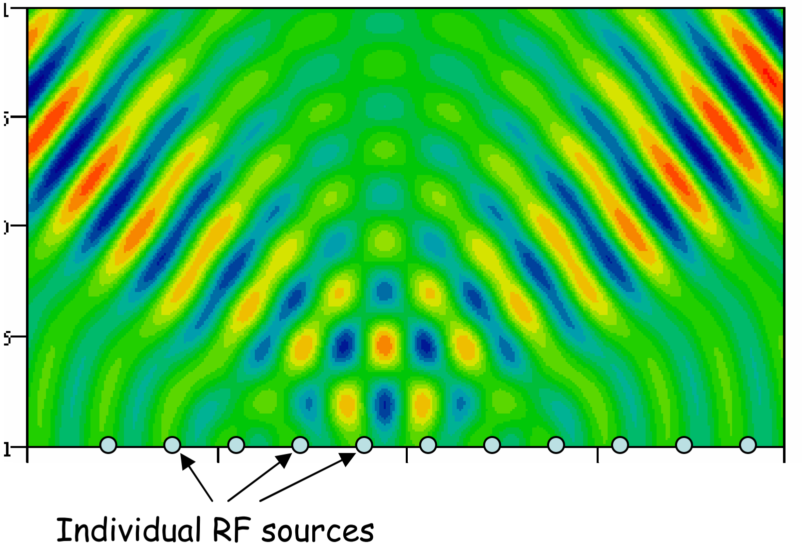
at 800 MW
E_{max} = 135 MV/m
H_{max} =0.22MA/m



PETS architecture



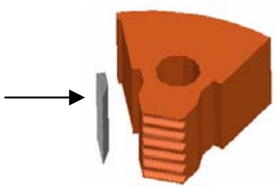
Transverse modes damping in PETS



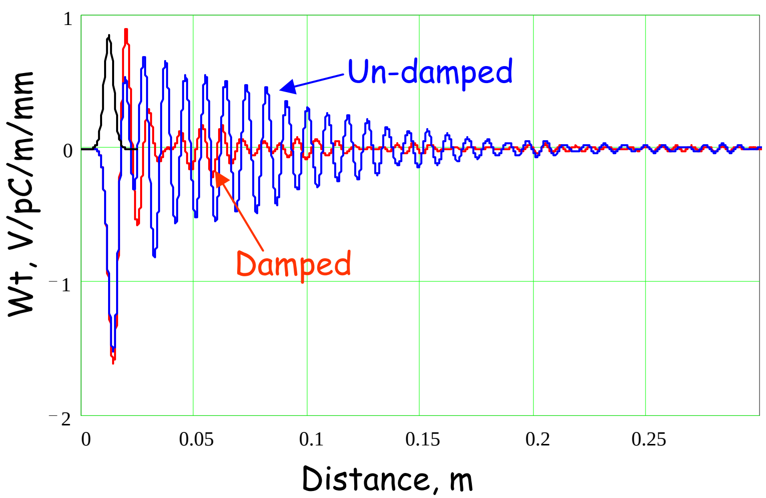
The transverse HOM mode in PETS to taken care of has a frequency and group velocity practically identical to the decelerating one. The only way do damp it is to use its symmetry properties.

Damping mechanism in PETS can be explained as a coherent radiation of many RF sources represented by the individual period of corrugation into the infinite radial slot. The angle of radiation here depends on the phase advance and distance between them. The higher the phase advance, the smaller the angle and less the damping. In any case radiation (damping) is strongest when phase advance and period are matched.

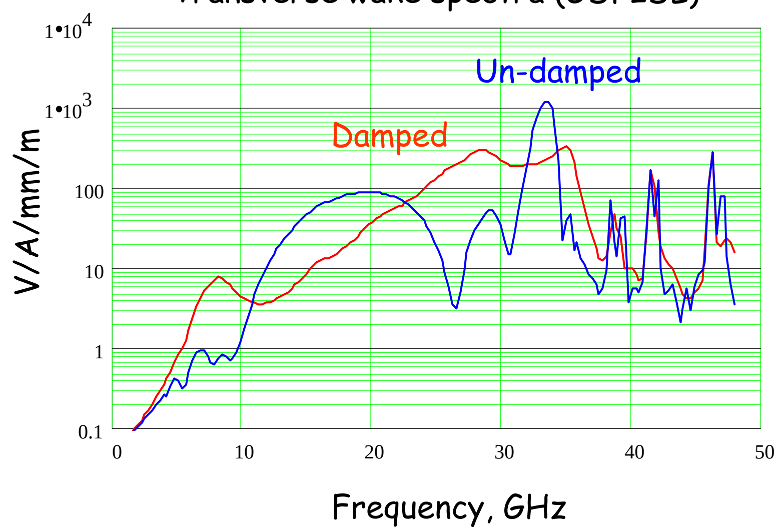
For the practical reason the infinite slot is replaced by the brad-band RF matched load:



Transverse wake amplitude (GDFIDL)

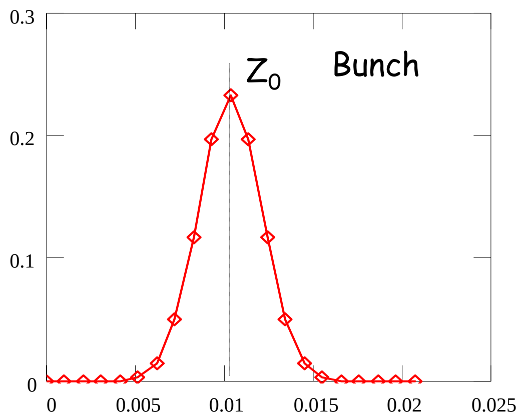


Transverse wake spectra (GDFIDL)



Transverse modes damping in PETS. HFSS versus GDFIDL.

Z_0=5.857σ



Two modes time domain approximation

$$q_i = \exp\left\{-0.5\times\left(\frac{z_i - z_0}{\sigma}\right)^2\right\}\times An \qquad \sum_i q_i = 1$$

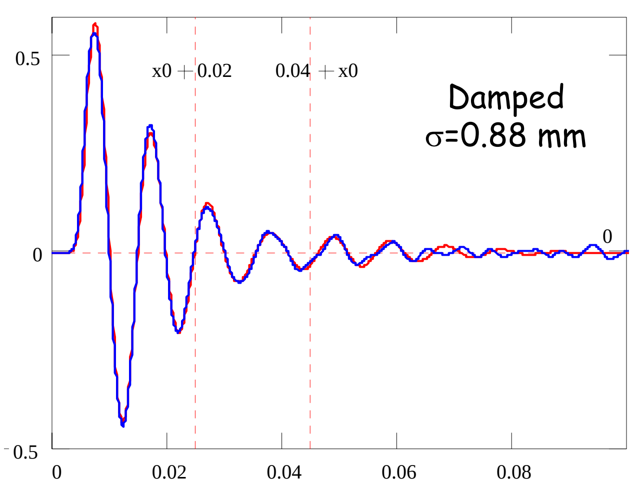
$$W_\perp(z) = \sum_{k,i} 2\times k_{\perp i} q_k \sin\left(\omega_i \frac{z - z_k}{c}\right)\exp\left(-\omega_i \frac{z - z_k}{v_i \times 2\times Q_i}\right)\times\left\{1 - \frac{z - z_0}{Ls\frac{1-\beta}{\beta}}\right\}$$

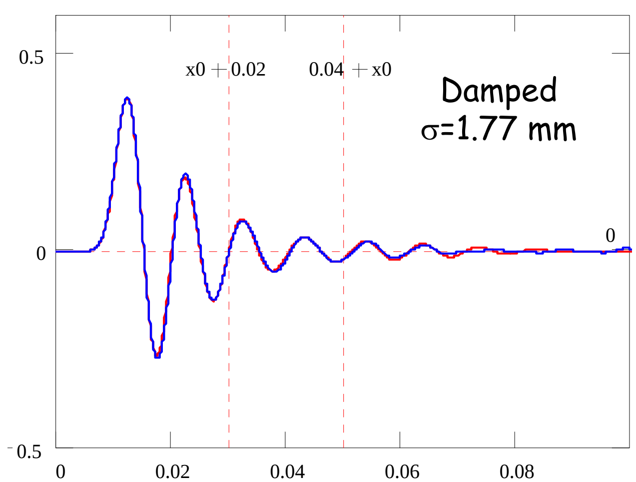
Power extraction

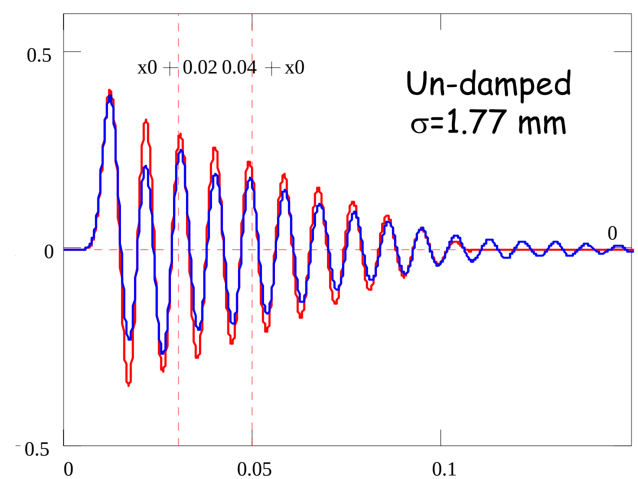
	F, GHz	Q	k, V/pC/mm/m
M1	29.55	8.9(52)	0.27
M2	34.20	9.5(56)	0.12

β=0.87

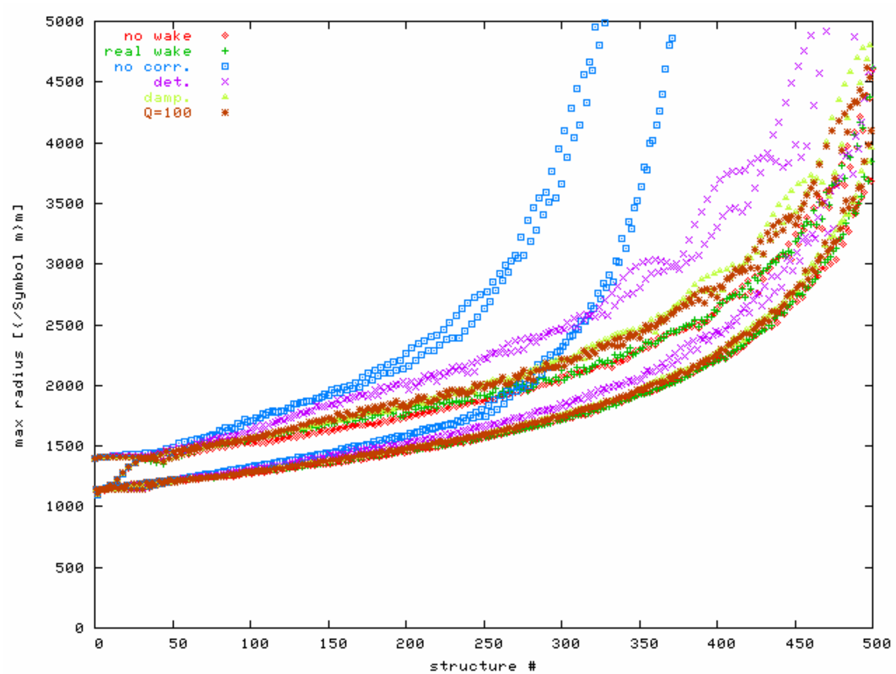
	F, GHz	Q	k, V/pC/mm/m
M0	32.90	10000	0.4

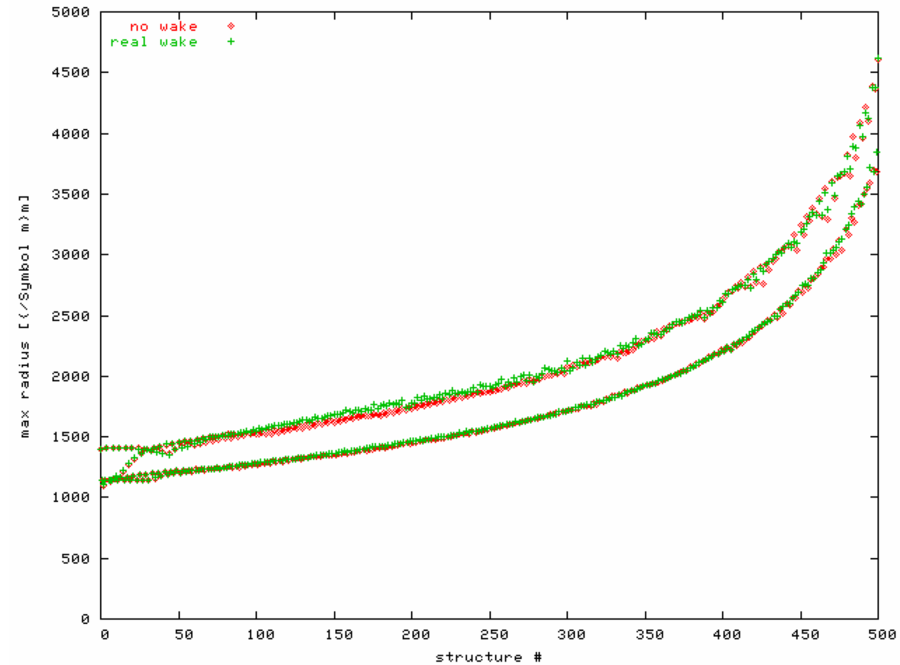






Beam jitter amplification



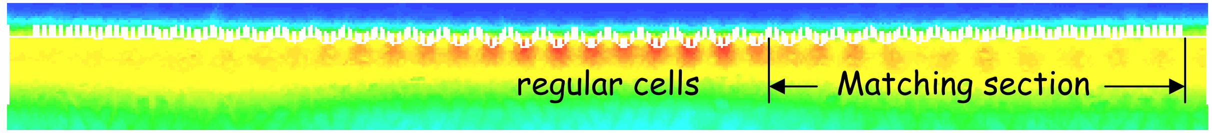


Transverse modes:

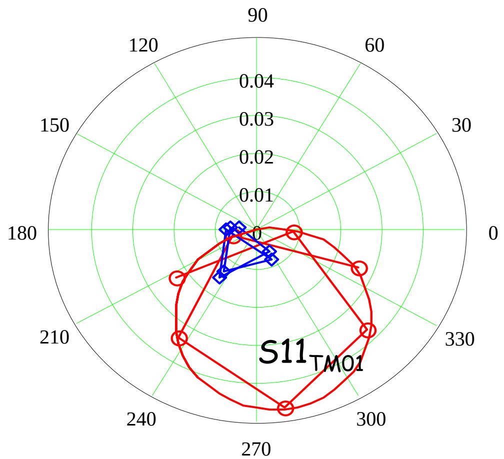
	M1	M2
Kt, V/pC/m/mm	0.904	0.473
F, GHz	27.844	34.915
Beta	0.876 C	0.646 C
Q loaded (HFSS)	40	38

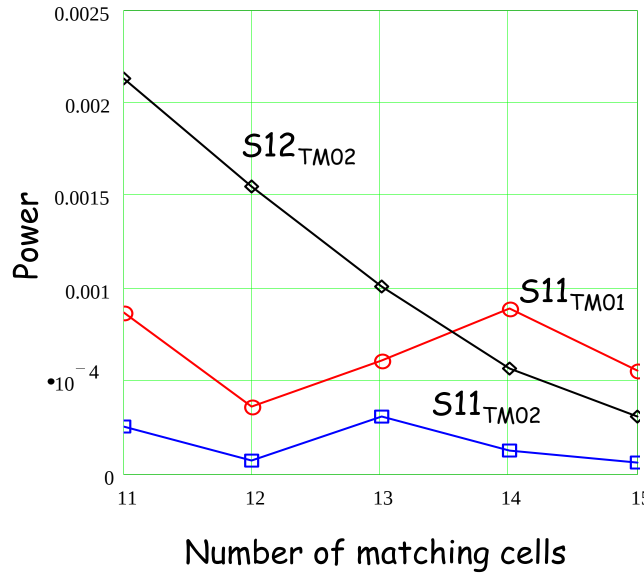
Practically no effect on the beam transport of the transverse HOM can be observed now!

RF power extraction. Adiabatic matching section

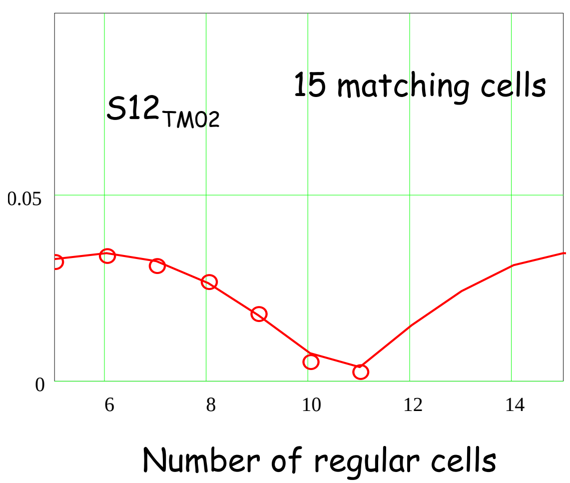


Reflection





Transmition

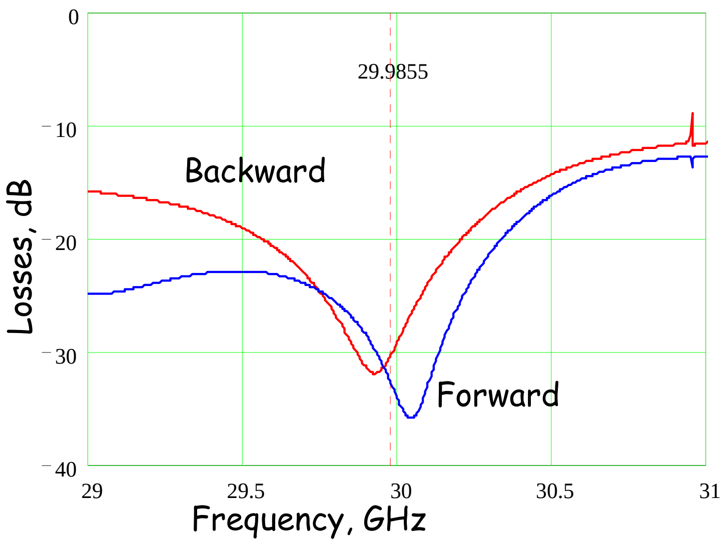


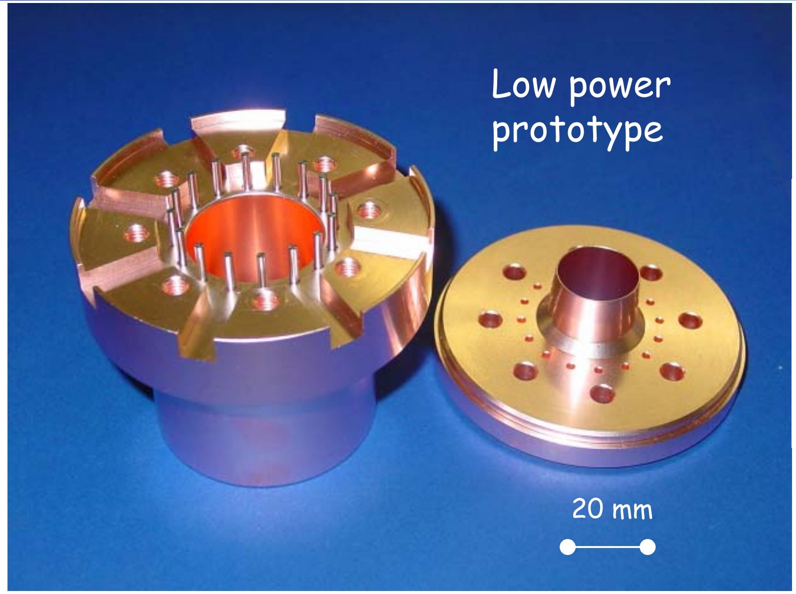
PETS is a very over-moded RF system. Any geometrical perturbation can provoke coupling of the decelerating mode to the number of HOMs. In order to extract RF power into the smooth waveguide efficiently, a long adiabatic section is needed. A number of gradually reduced corrugations (periods) was optimised to bring the reflection and mode conversion to better than – 40 Db. Total length of matching section is 58 mm (15 periods).

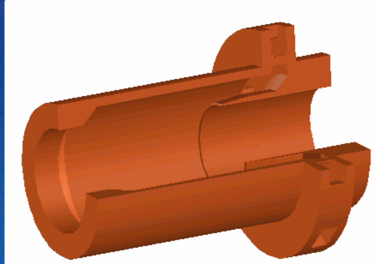
PETS 30 GHz 8 cannel quasi-optical RF power extractor

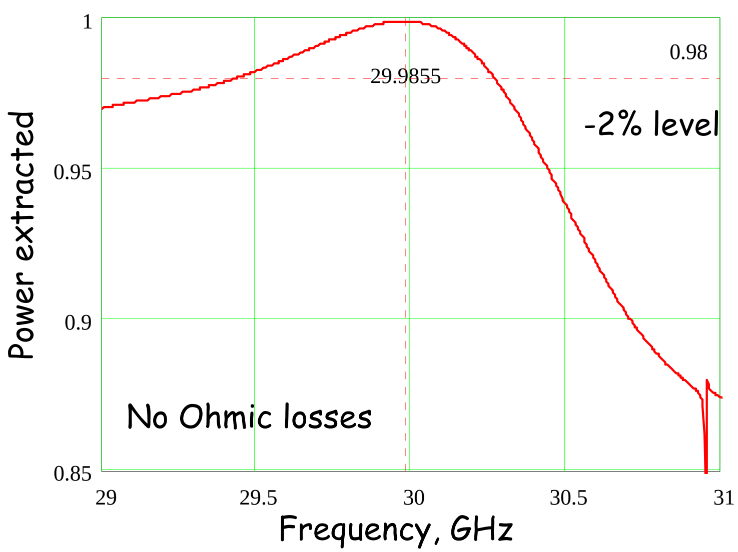
CLIC

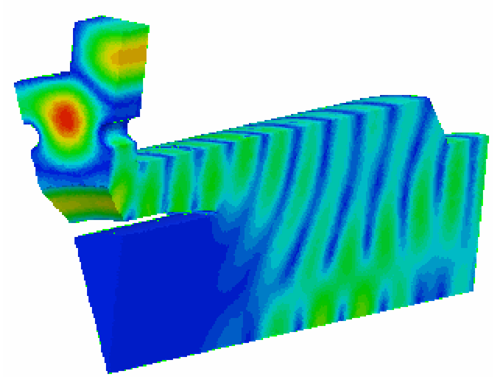
HFSS simulations



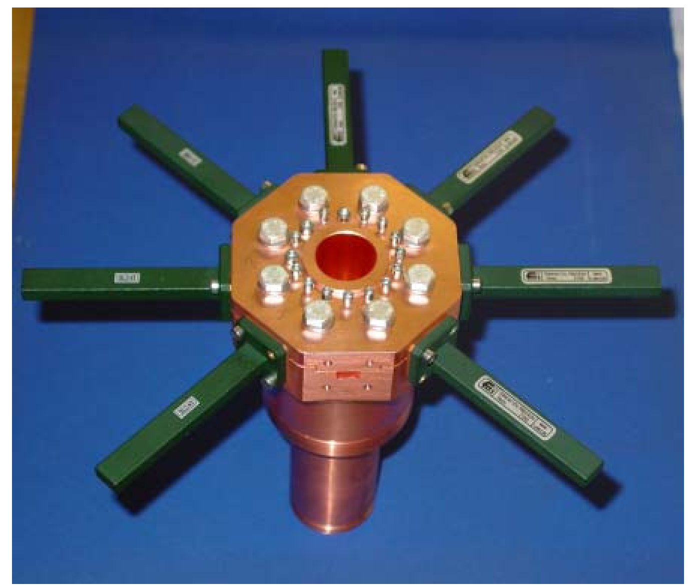




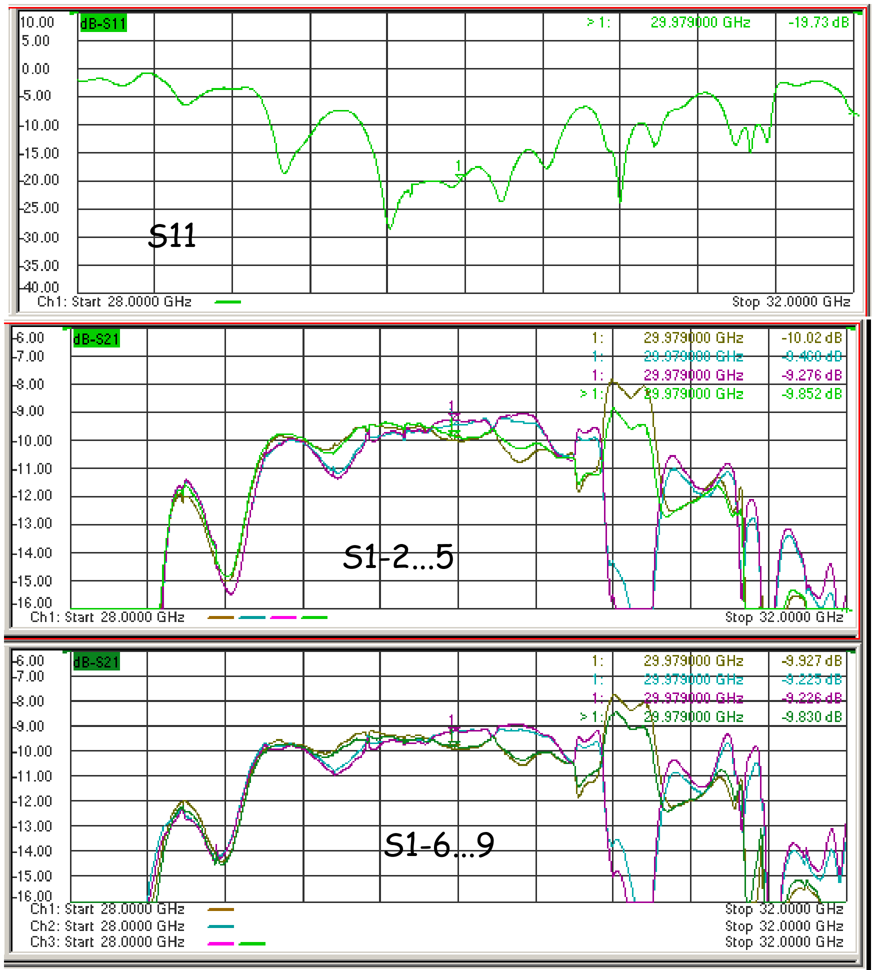




E_{max}: 88 MV/m at 800 MW



Prototype low power RF measurements



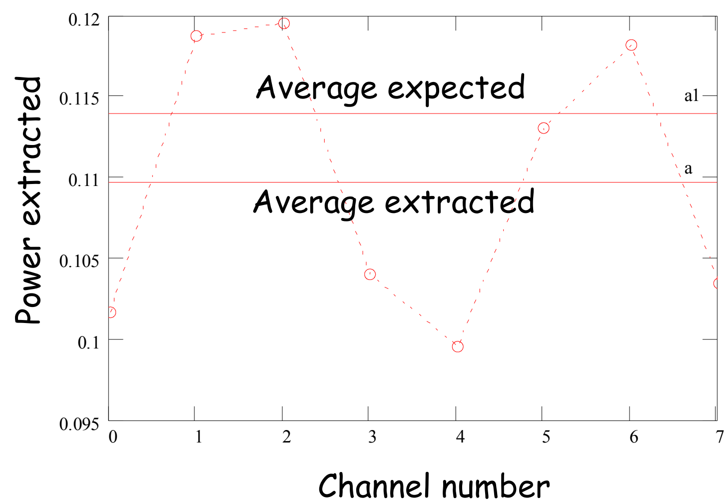
Power budget per channel:

Reflection, E01 mode launcher, Matching transformer

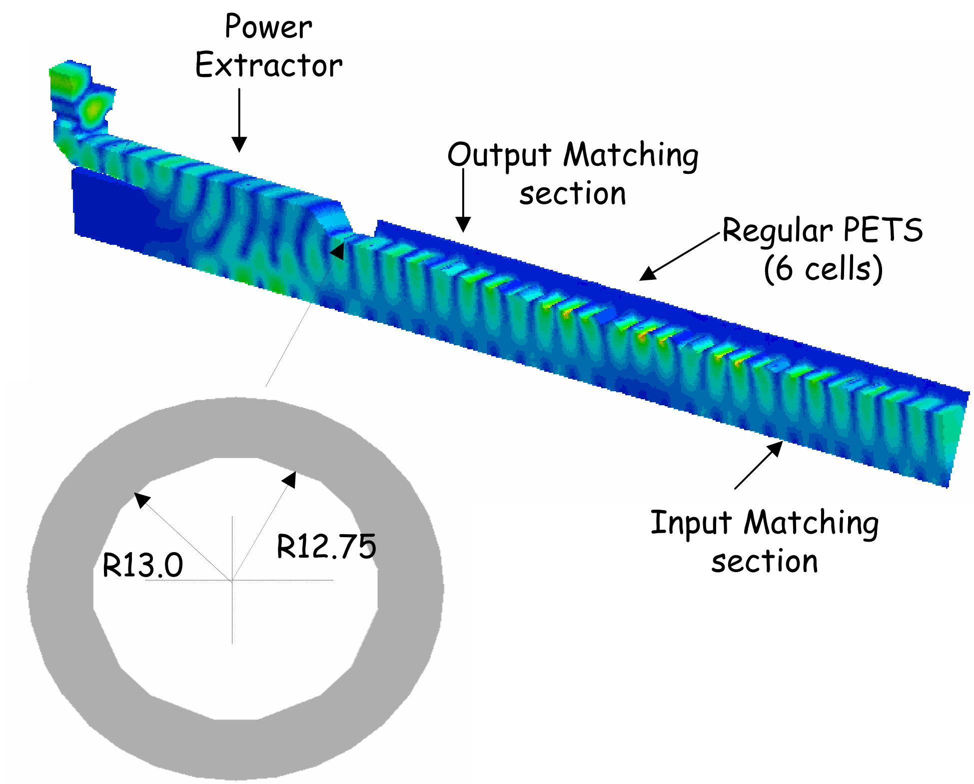
$$P^{Expected}{}_{cannel} = (1-0.011)\times 10^{\frac{-0.36}{10}} \times 10^{\frac{-0.02}{10}} \times 0.125 = 0.113$$

$$Power^{Measured}{}_{channel} = 0.11$$

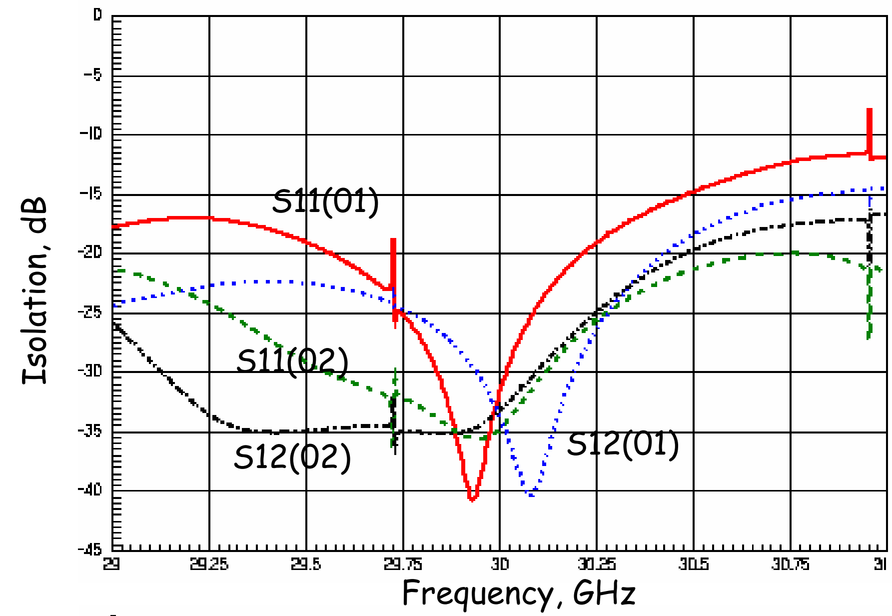
Efficiency: **97.0 %**

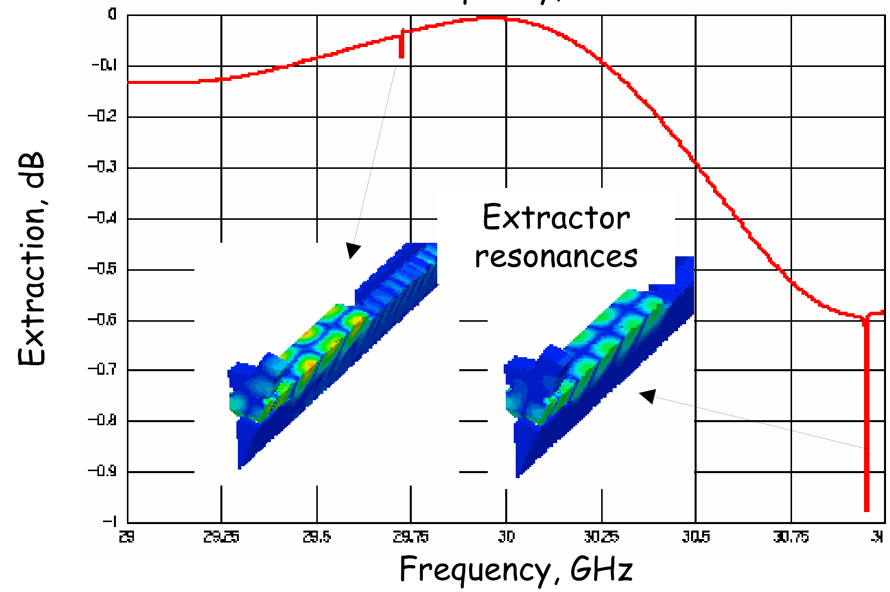


Full geometry HFSS simulation



Matching ring (S 3.0mm)





CLIC PETS ON/OFF principle of operation

Reliability

Ranking 1 (TRC report)

- 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.

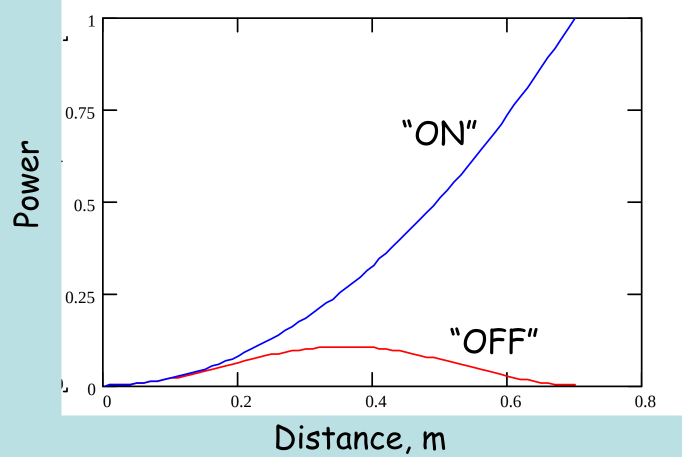
For constant impedance structure, the RF power distribution along the structure can be expressed as:

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

If we need to avoid power production at the end of the structure, than the detuning should be sufficient (without losses) if:

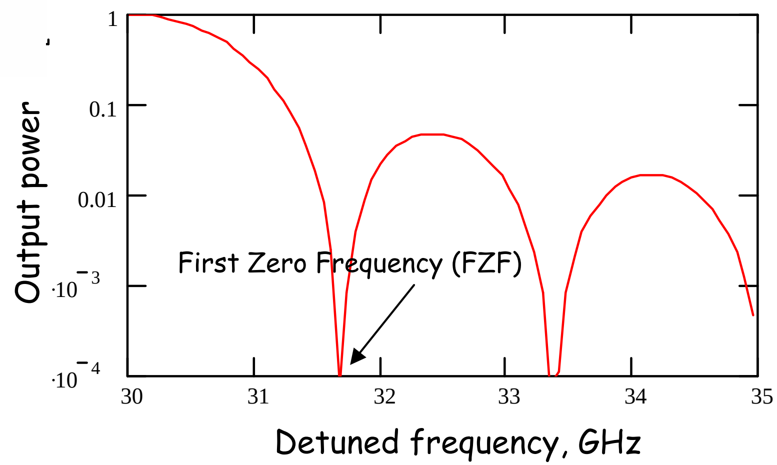
$$F_D=F_0\pm\frac{\beta\times C}{(1-\beta)\times L}$$

Where F_D is a new detuned synchronous frequency, L – length of the structure and β - group velocity. For CLIC PETS F_D = 31.69 GHz:

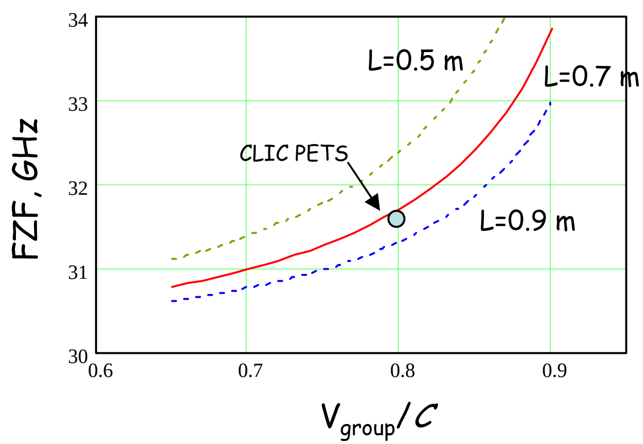


Few examples:

1. Length – 0.7 m, β - 0.798 (CLIC PETS)

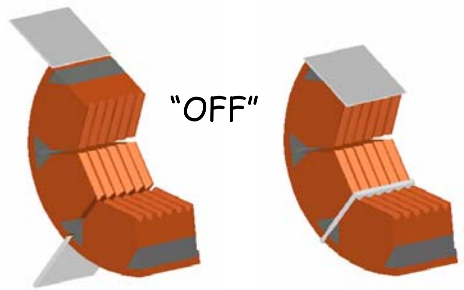


2. FZF versus group velocity and structure length



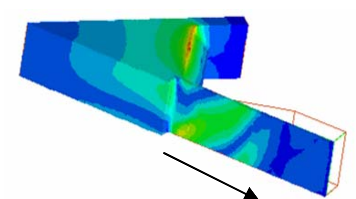
CLIC PETS ON/OFF mechanism description

Ideally, by insertion of 4 (1.6 mm thick) wedges through the damping slots, sufficient PETS synchronous frequency detuning can be achieved:



The need to have a technological (~0.2 mm) slit between the wedge and damping slot unfortunately forces the radiation of generated RF power. This potentially can destroy the RF loads which are not designed for the high power use.
The solution is to introduce another slot along the edge of the wedge. For that we pay by certain field enhancement in a technological slit when the wedge passes its intermediate position.

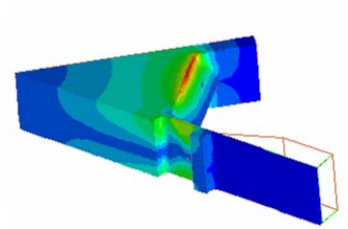
Straight wedge



Radiation

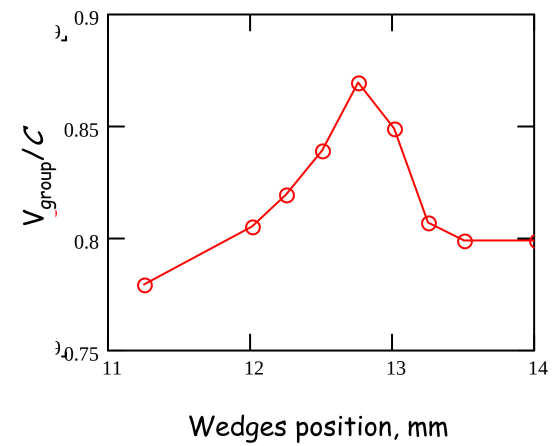
Q_{ext}=105

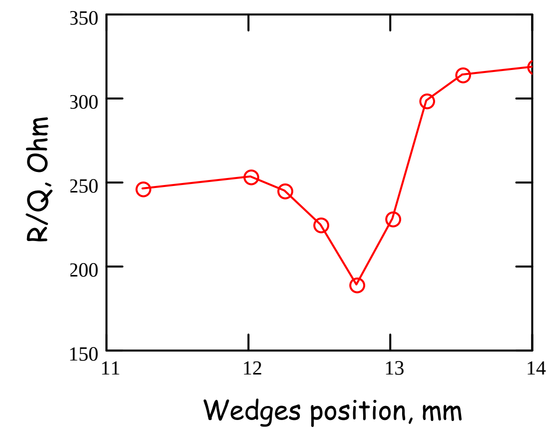
Slotted wedge

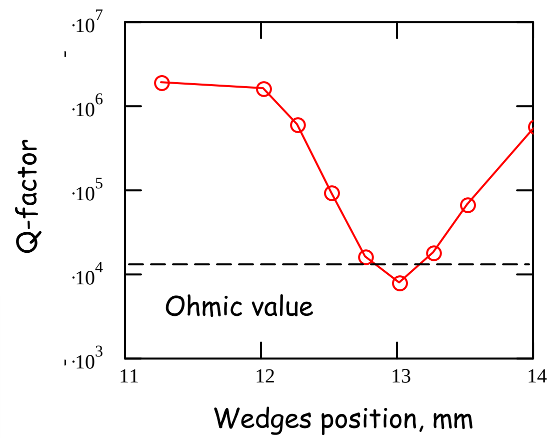


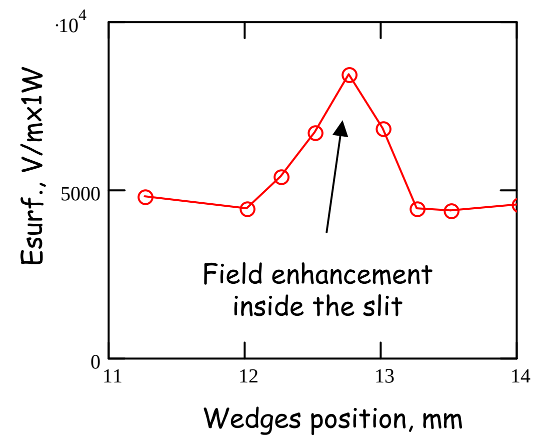
$Q_{ext}=3\times10^6$

PETS parameters evolution during wedges movement.

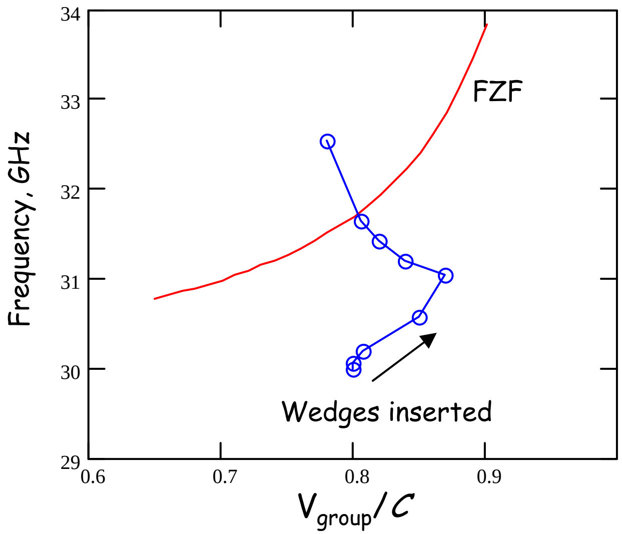


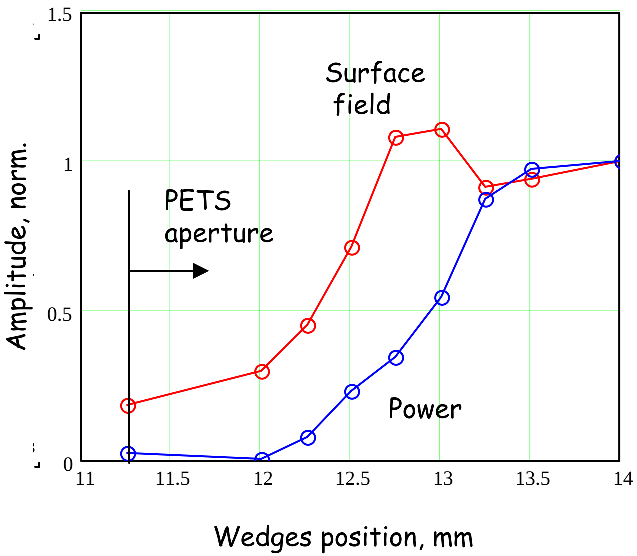




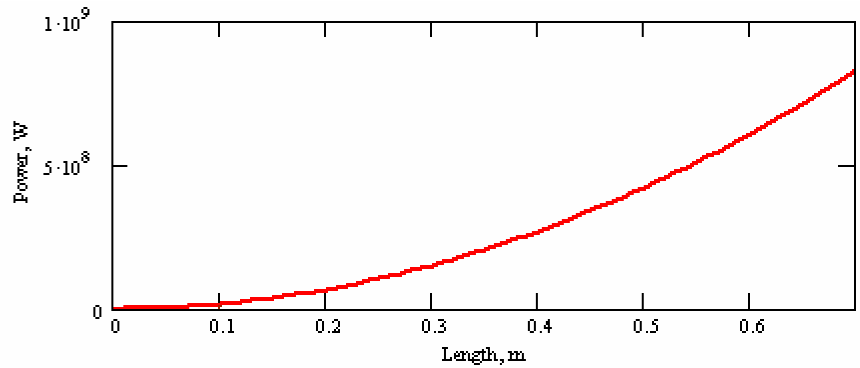


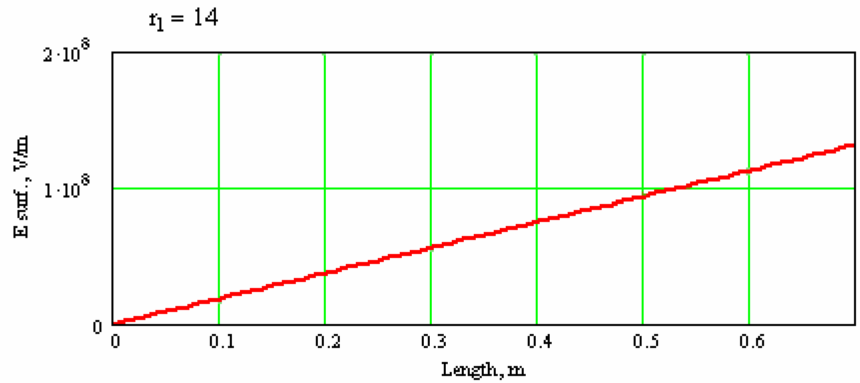
CLIC PETS ON/OFF mechanism description (continued)





Damping animation





The "ON/OFF" operation can be performed with the proposed method. The FZF point is established at a radial position of the wedge of 12.0 mm.

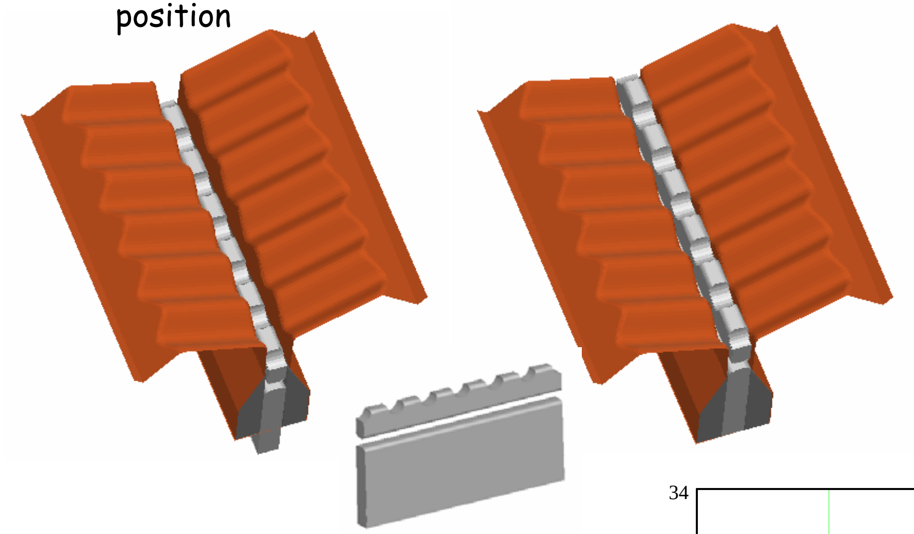
If "variable" attenuation option is required, the danger of undesired field enhancement in a technological slit does appear.

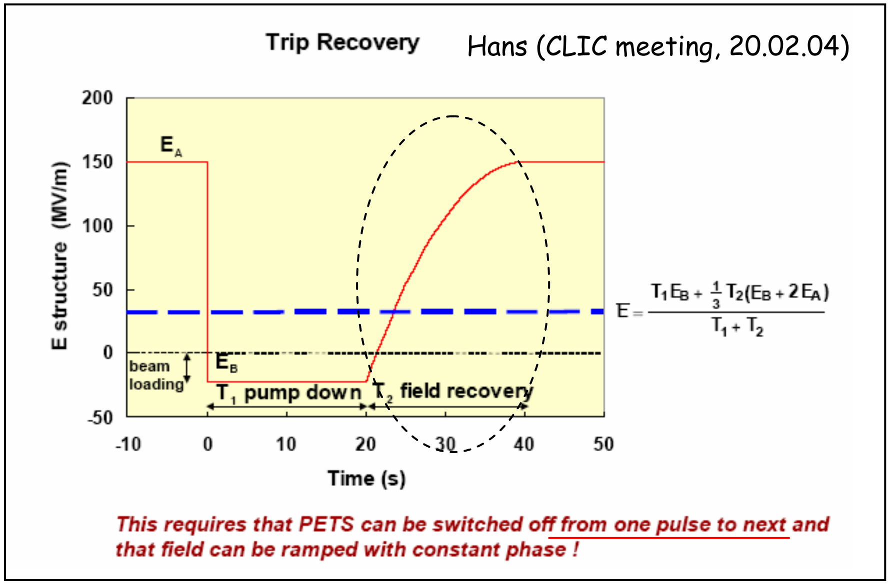
CLIC PETS variable attenuator option. Draft.

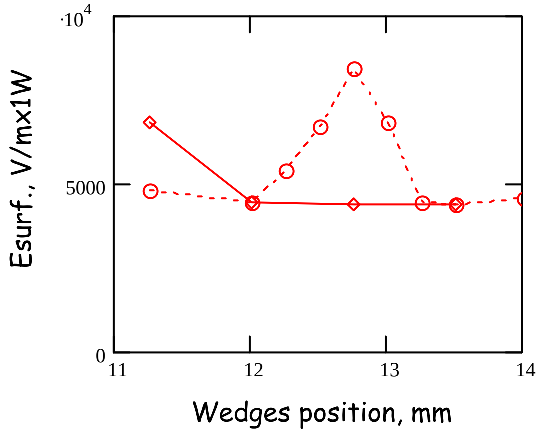
Corrugated slotted wedge

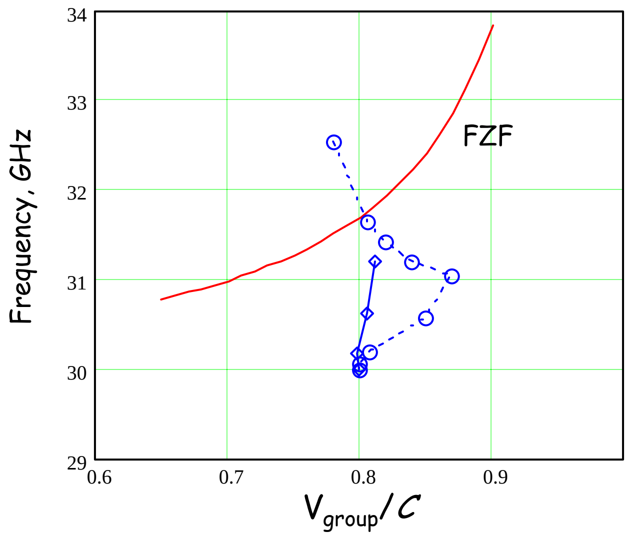
Not very much-"OFF" position

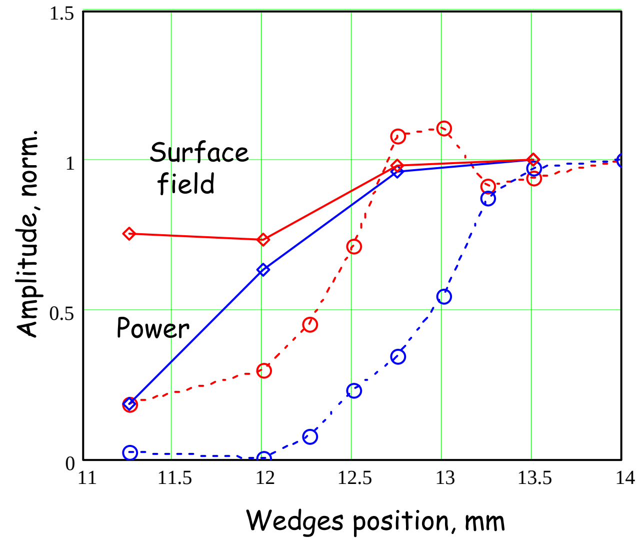
"OFF" position





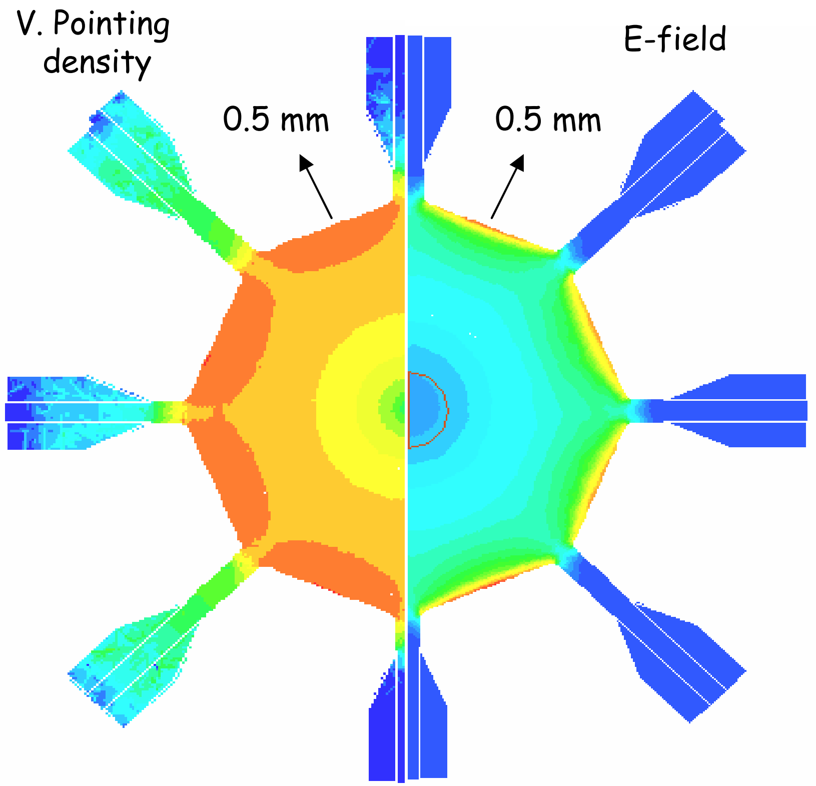


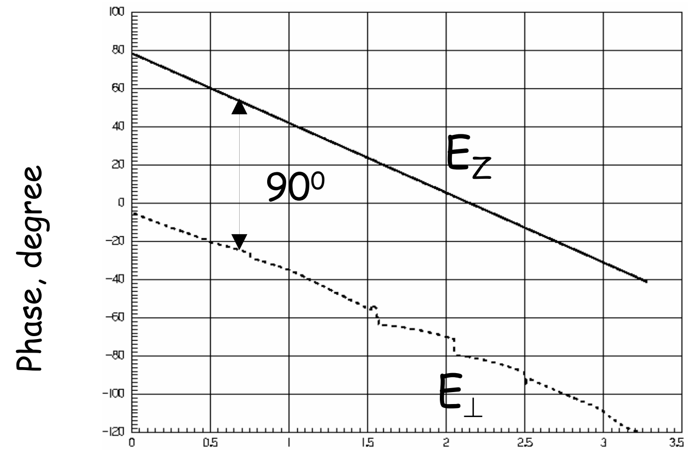


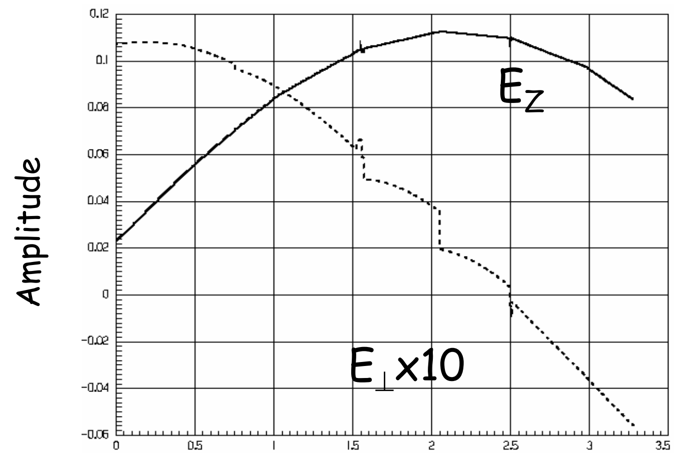


Structure symmetry radial distortion

To simplify the geometry for HFSS, the two adjusted racks were moved by **0.5 mm** in radial direction(see picture).







External Q-factor: 4.8×10^4
Cooper Q-factor: 1.2×10^4

The imperfection in radial positioning of the single rack (within acceptable tolerances) does not create problems neither with power damping, nor with any transverse action on the beam.

Ongoing activity

#1. Structure
The technical drawings of 40 cm PETS full scale prototype are under preparation.
The brazed version of extractor is on a waiting list.

#2. ON/OF mechanism
RF design of the variable option to be finalized (incl. GDFIDL runs).

Future studies

#1. Structure
The use of damping slot for monitoring of the beam position inside PETS.

#2. ON/OF mechanism
Mechanical design for the fast switching should be developed.