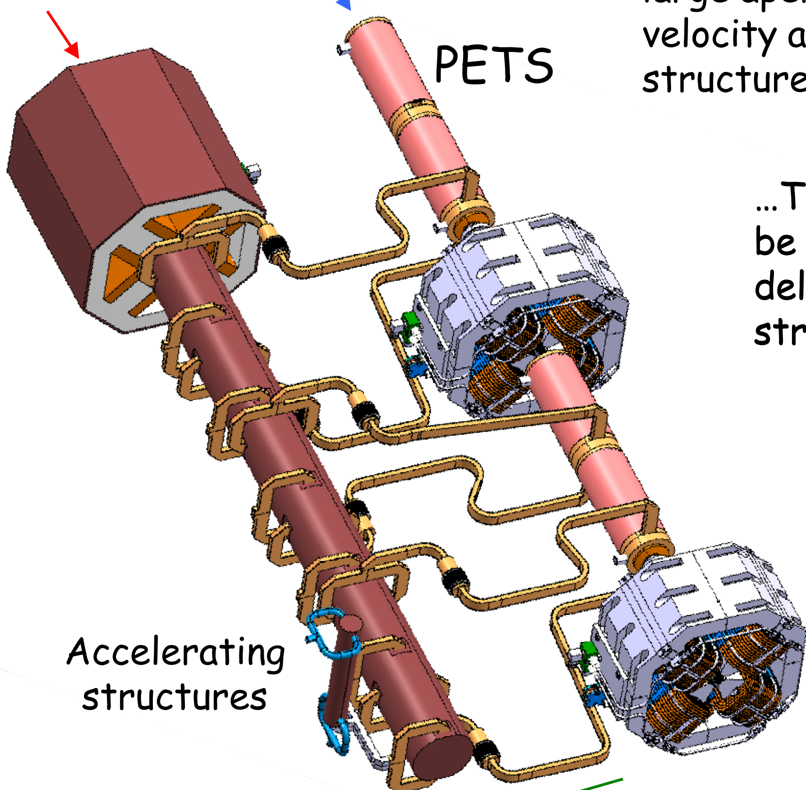
Progress in the PETS development

I. Syratchev

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

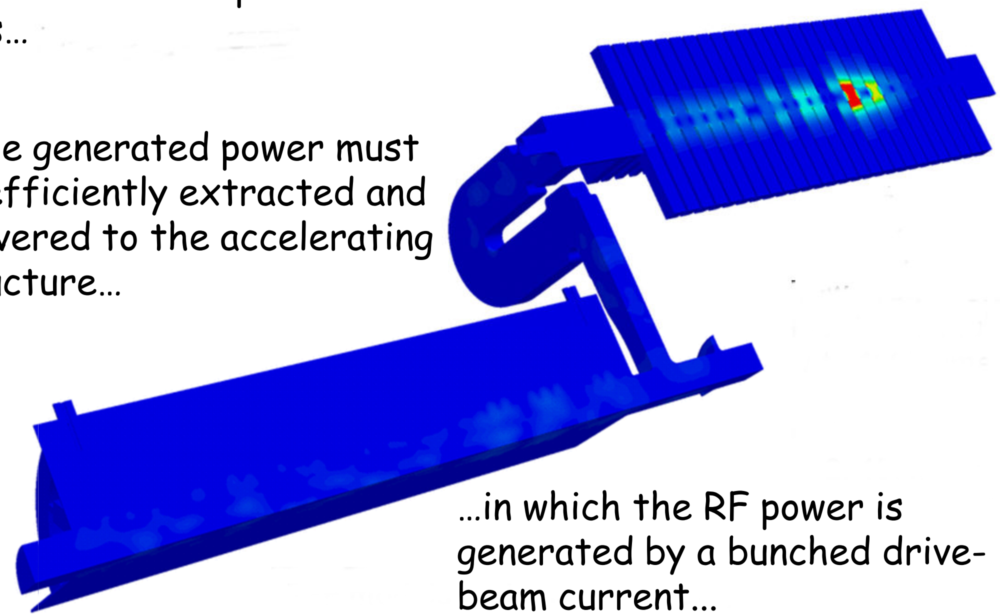


The CLIC Power Extraction and Transfer Structures (PETS) are large aperture, high-group velocity and overmoded periodic structures…

…in which the RF power is generated by a bunched drive-beam current…

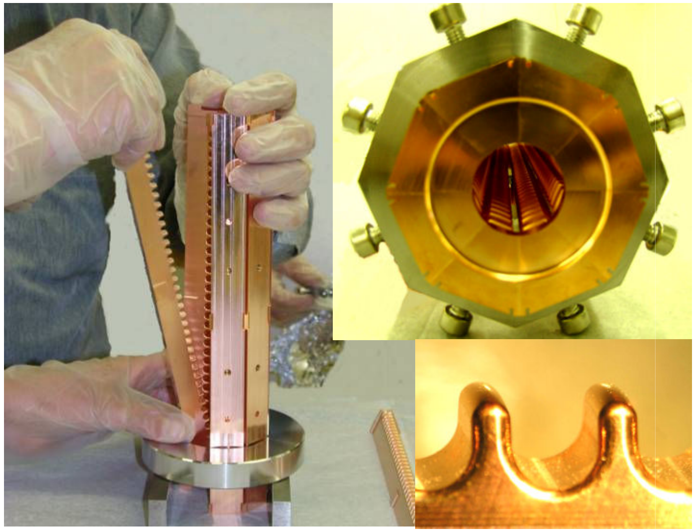
…The generated power must be efficiently extracted and delivered to the accelerating structure…

…to accelerate the main beam.



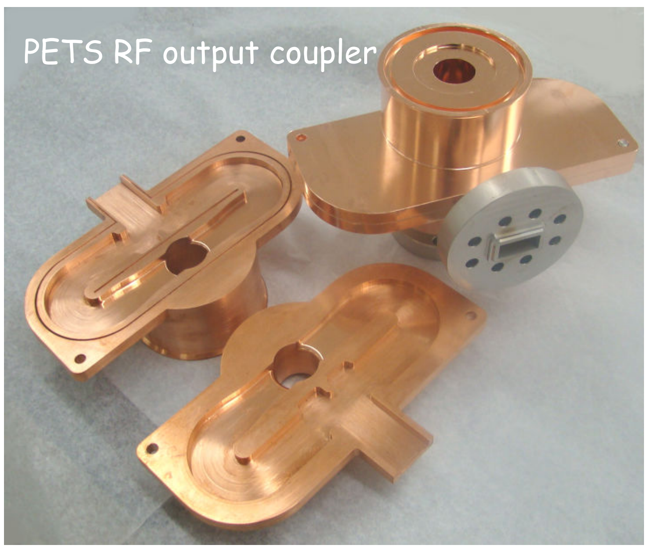
These simulations have been done at SLAC using the T3P – Finite Element EM Time-Domain Code. (A. Candel, SciDAC09, San Diego, Jun 17 2009)

PETS single bar



The PETS should generate 135 MWx240ns pulses from the 100 A drive beam.

In its final configuration, PETS comprises eight identical octants (bars) separated by 2.2 mm wide damping slots. Each of the slot is equipped with RF loads to ensure strong suppression of transverse HOM. The upstream end of the PETS is equipped with a special RF output coupler.



PETS RF output coupler

PETS parameters table

- Frequency = 11.9942 GHz
- Aperture = 23 mm
- Active length = 0.213 (34 cells)
- Period = 6.253 mm (90^0/cell)
- Iris thickness = 2 mm
- Slot width = 2.2 mm
- R/Q = 2222 Ω/m
- V group= 0.459C
- Q = 7200
- E surf. (135 MW)= 56 MV/m
- H surf. (135 MW) = 0.08 MA/m
  (ΔT max (240 ns, Cu) = 1.8 C^0)

PETS development. Experiments.

1. PETS high power tests in the Two Beam Test Stand (TBTS), CERN.

   see also: 'Status and progress of the two-beam test stand ',R. Ruber. 13-Oct-2009 14:35

   'PETS testing in the TBTS', R. Ruber. 15-Oct-2009 09:25

2. PETS high power tests in ASTA, SLAC.

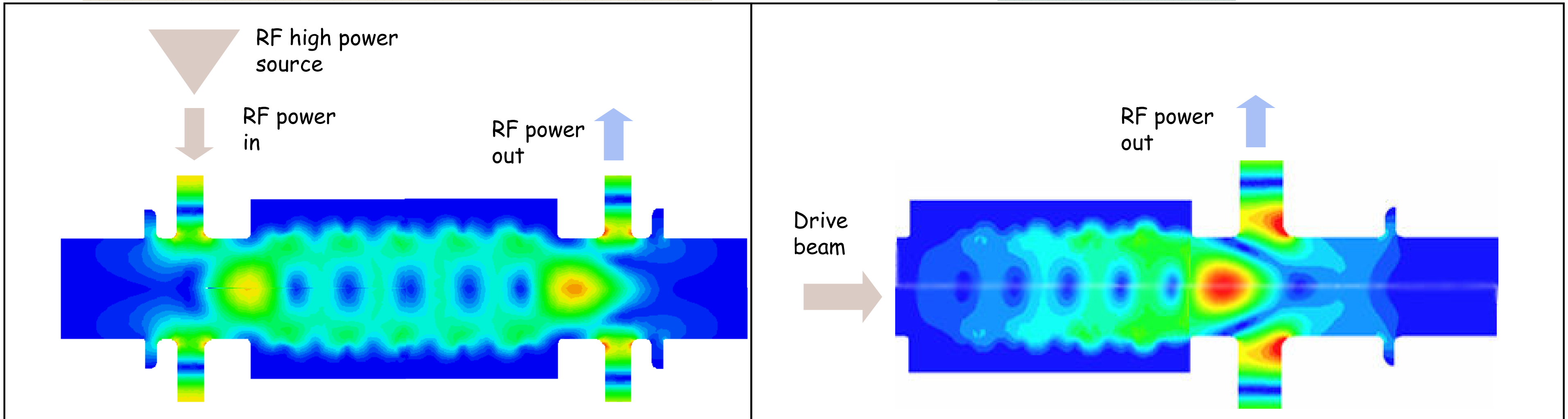
   see also: 'High power tests at SLAC', V. Dolgashev. 15-Oct-2009 10:40

PETS testing program

RF power sources

External RF power source

Drive beam



ASTA (SLAC)

Objective: to understand the limiting factors for the PETS ultimate performance.

- 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: to demonstrate the reliable production of the nominal CLIC RF power level throughout the deceleration of the drive beam.

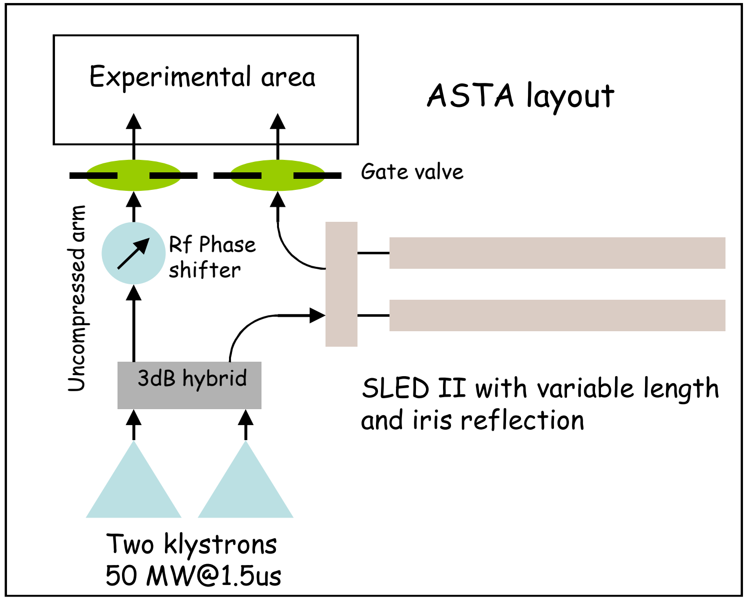
Test beam line (CERN + Collaborations)

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

PETS testing in ASTA

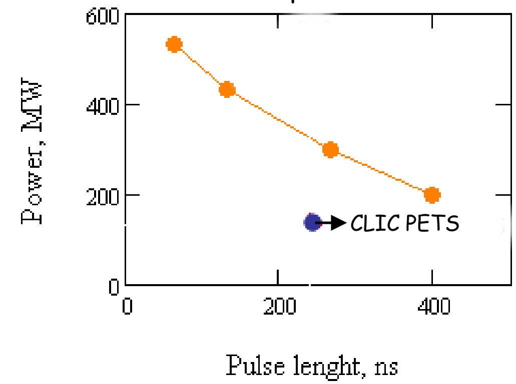
The ASTA pulse compressor with variable delay in delay-lines

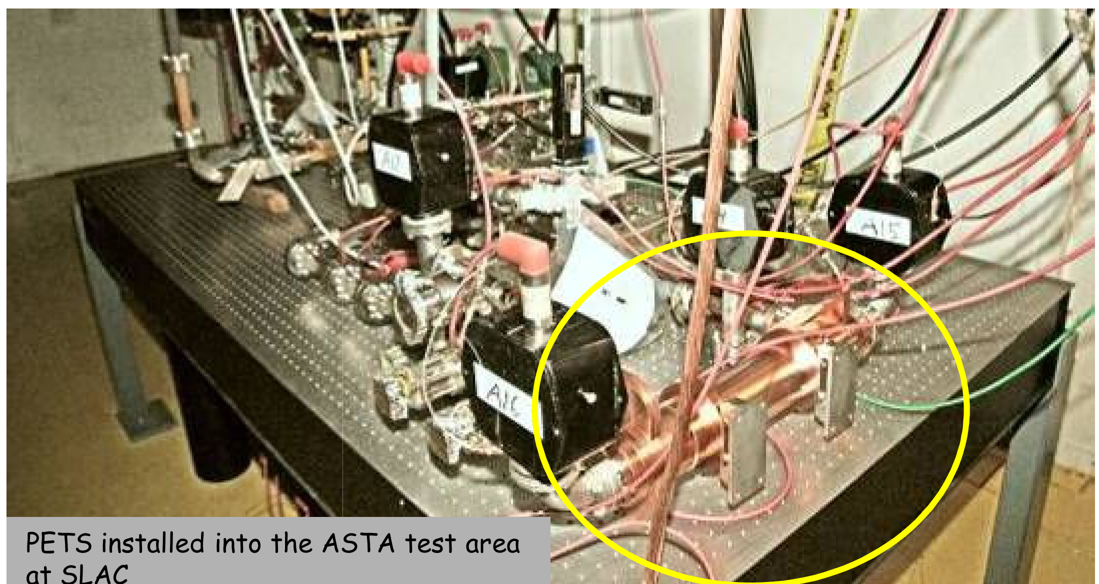
The ASTA pulse compressor with variable iris



ASTA is a new generation general purpose test stand, which will allow processing the various types of the high power RF equipment at X-band. The facility can provide a very versatile pulse length and power level.

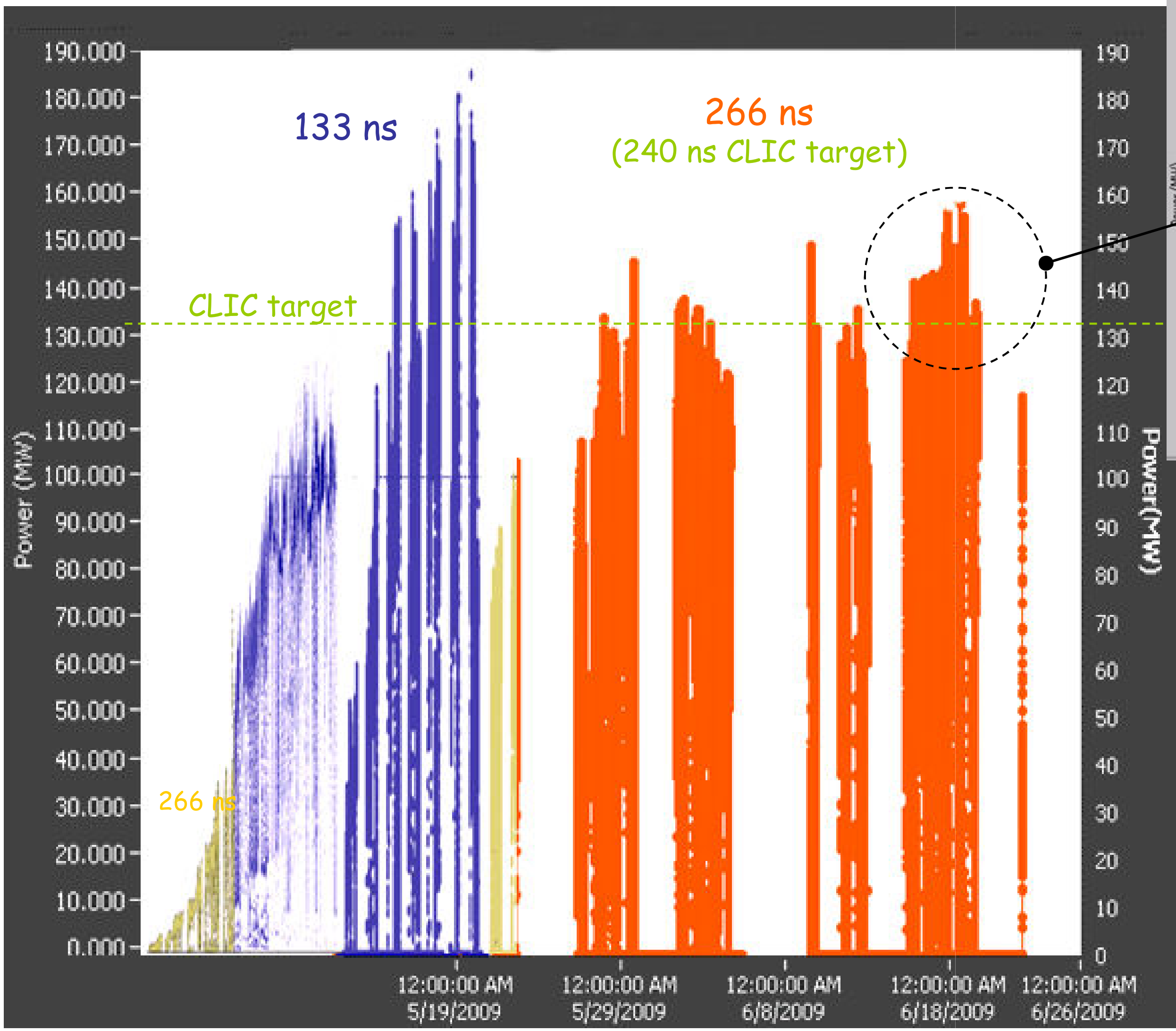
RF pulse @ power in the ASTA compressed arm

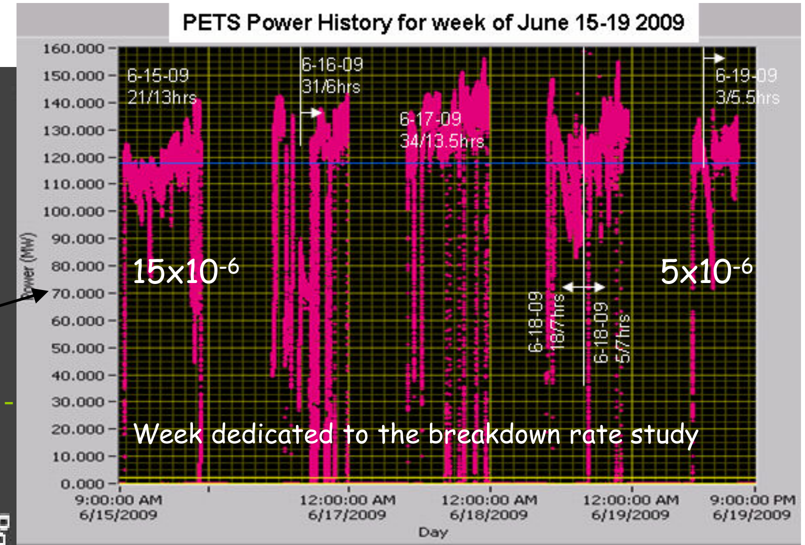




PETS installed into the ASTA test area at SLAC

PETS processing in ASTA (total ~ 300 hours).

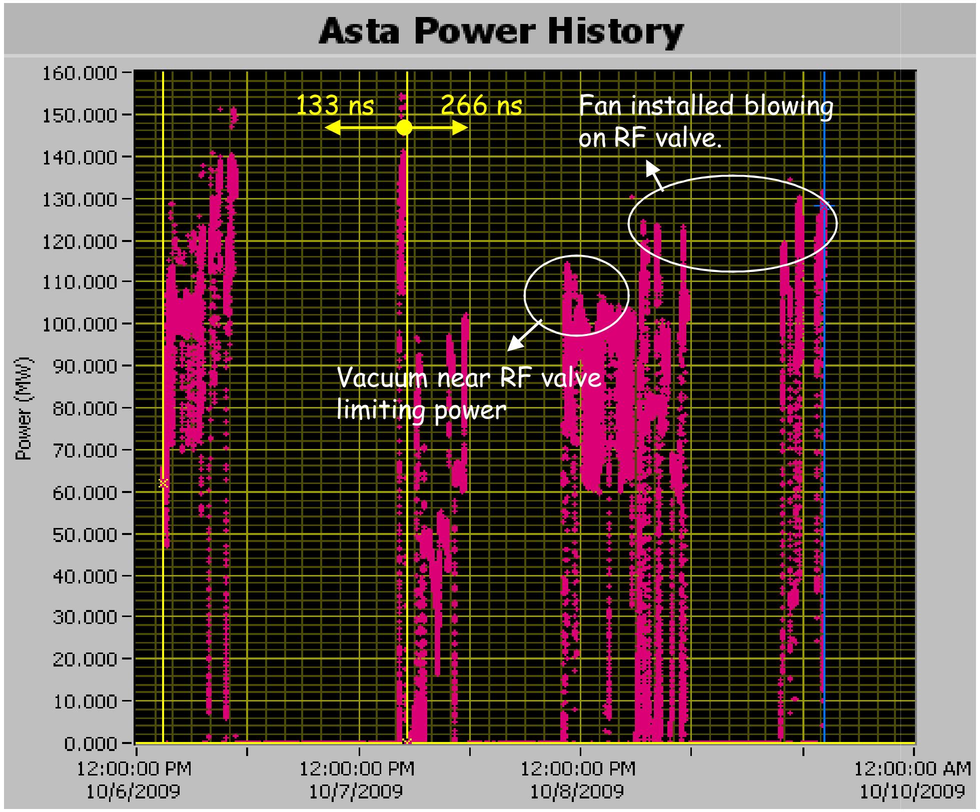


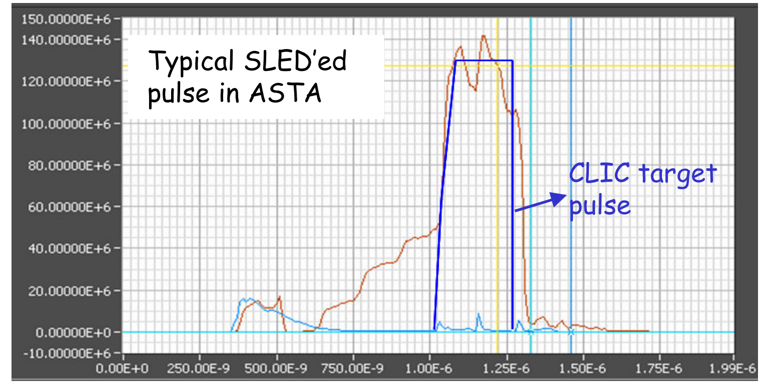


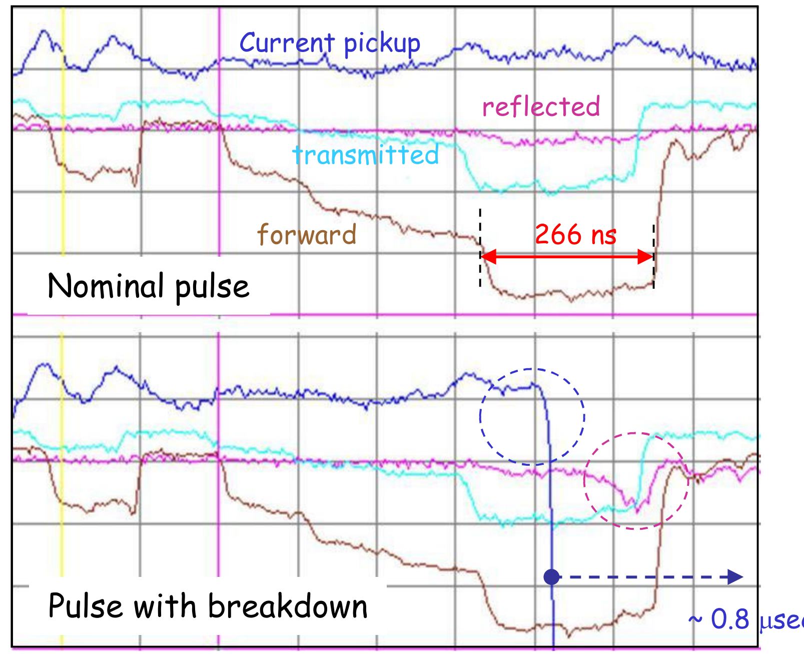
During conditioning the PETS had reached peak power levels up to 180MW (133 ns) and 150 MW(266 ns).

The last day of data (June 2009) shows running at around 125MW average with breakdown rate 0.7 breakdowns/hour, or 5×10^{-6}/pulse/m (cf. to the CLIC target 1×10^{-7}/pulse/m).

After installation of the cooling blocks, the PETS was back into the tests 6 October 2009.







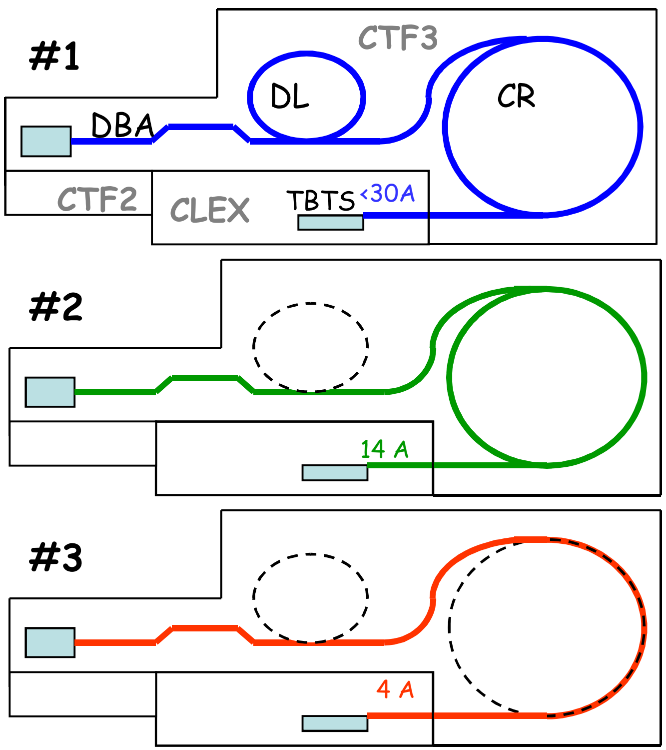
➢ Initial 130ns pulse width processing was quick up to average power 150MW where we changed to the 260ns pulse at ~5pm October 7th.

➢ During processing Oct. 8-9, although we observe breakdowns in PETS, vacuum near "vacuum RF valve" on top of ASTA bunker trips system. Baseline vacuum the near the valve is high.

Jim Lewandowski, 10 October 2009

PETS high power production at CERN (TBTS)

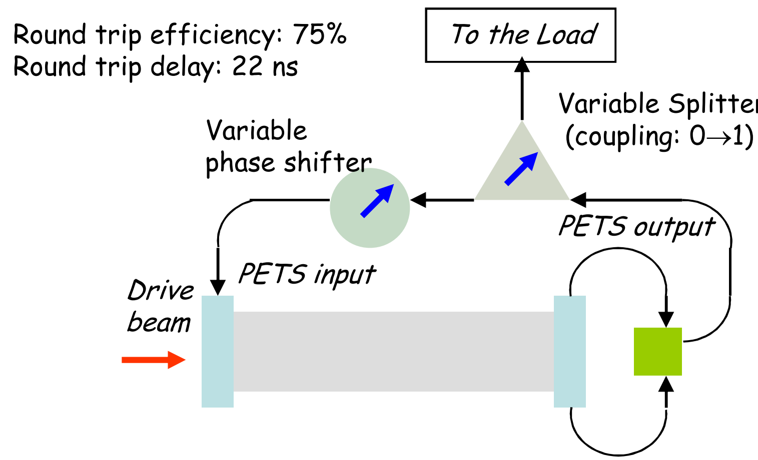
• Different scenarios of the drive beam generation in the CTF3



• To compensate for the lack of current, the active TBTS PETS length was significantly increased: from the original 0.215 m to 1 m.

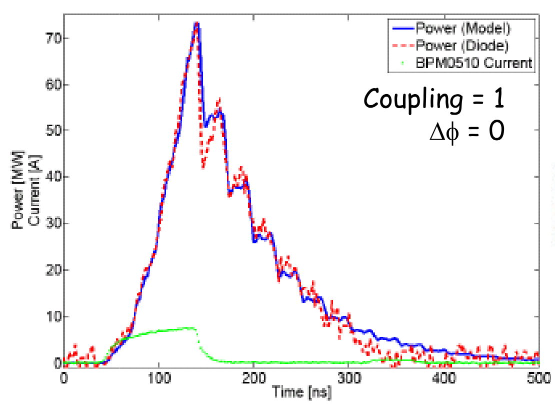
Operation mode	#1	#2	#3	CLIC
Current, A	<30	14	4	101
Pulse length, ns	140	<240	<1200	240
Bunch Frequency, GHz	12	12	3	12
PETS power (12 GHz), MW	<280	61	5	135

• In order to demonstrate the nominal CLIC power level and pulse length, it was decided to implement a different PETS configuration – PETS with external re-circulation.

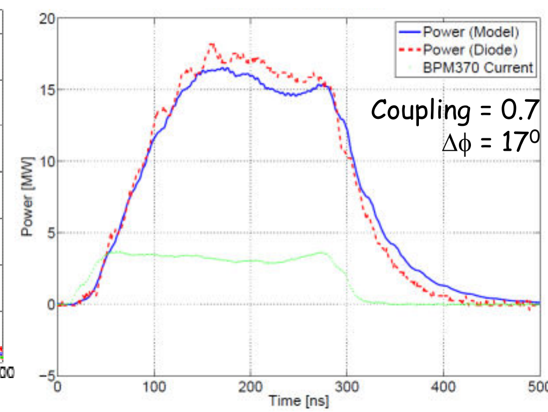


For the fixed parameters of re-circulation (loop delay, coupling, ohmic efficiency and RF phase error) and given pulse shape of the current, the generated RF pulse can be reconstructed/predicted rather well:

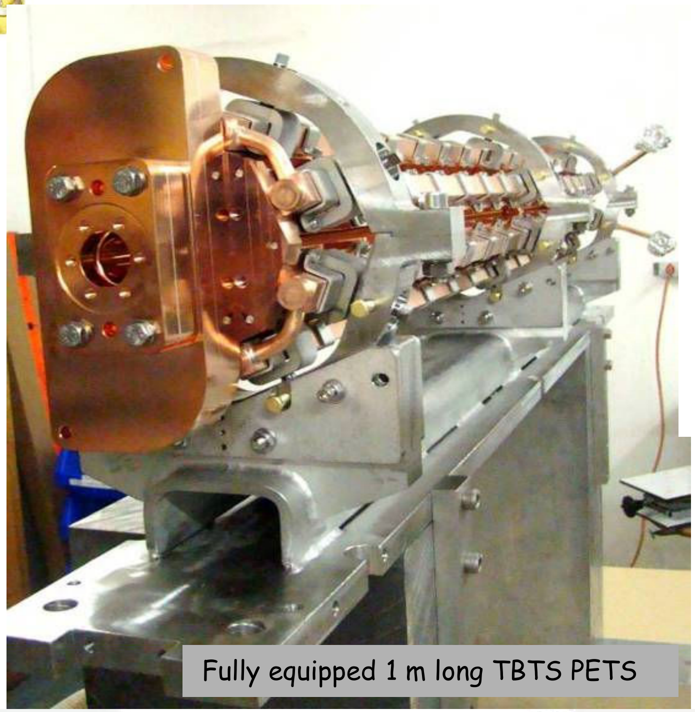
Full re-circulation



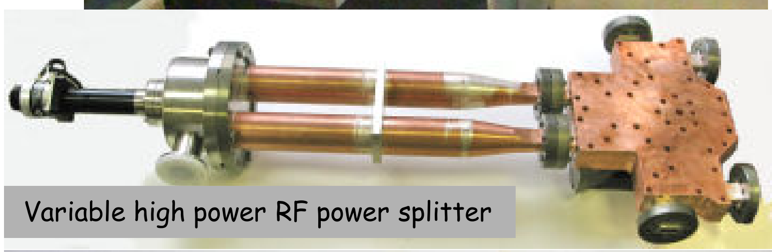
50% re-circulation



PETS high power production at CERN (TBTS)

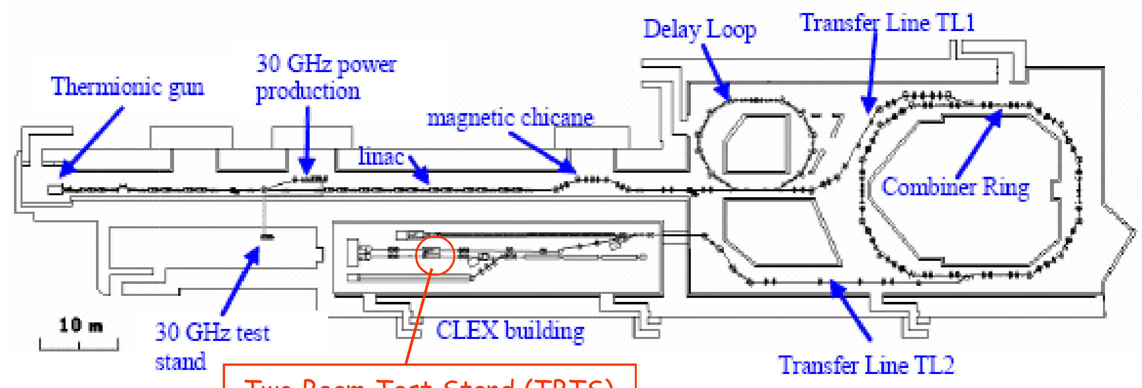


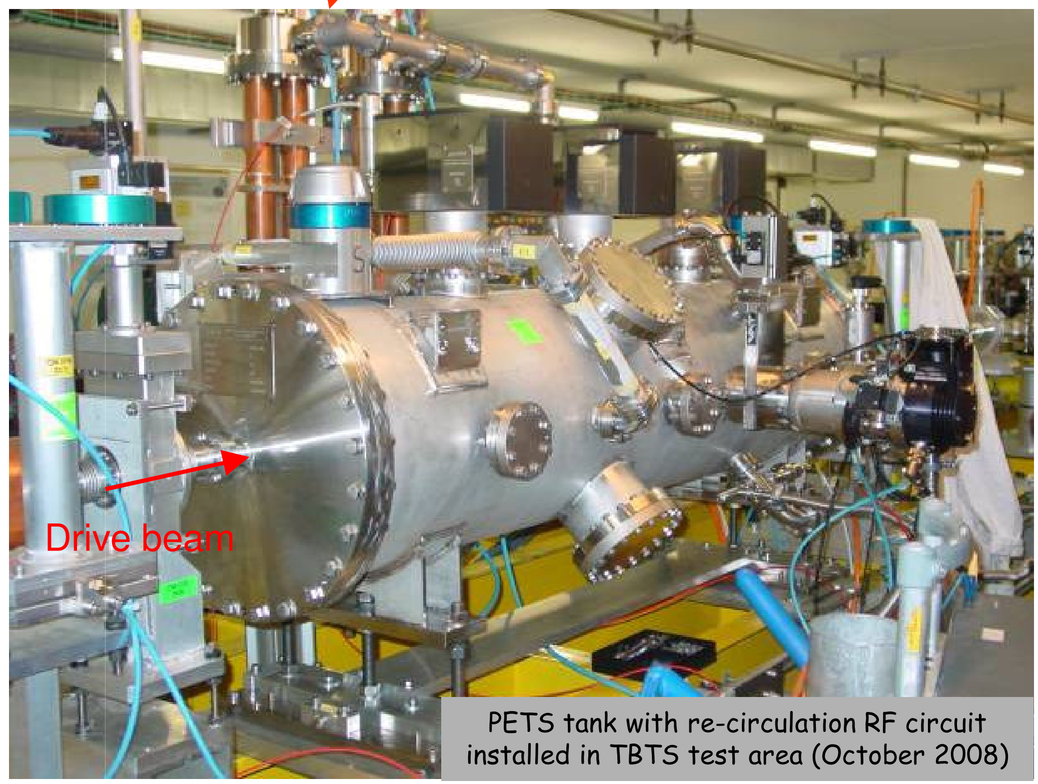
Fully equipped 1 m long TBTS PETS



Variable high power RF power splitter

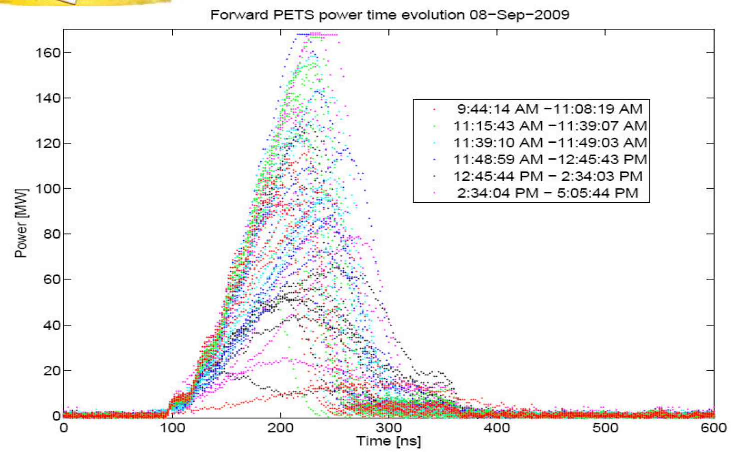
Variable high power RF phase shifter

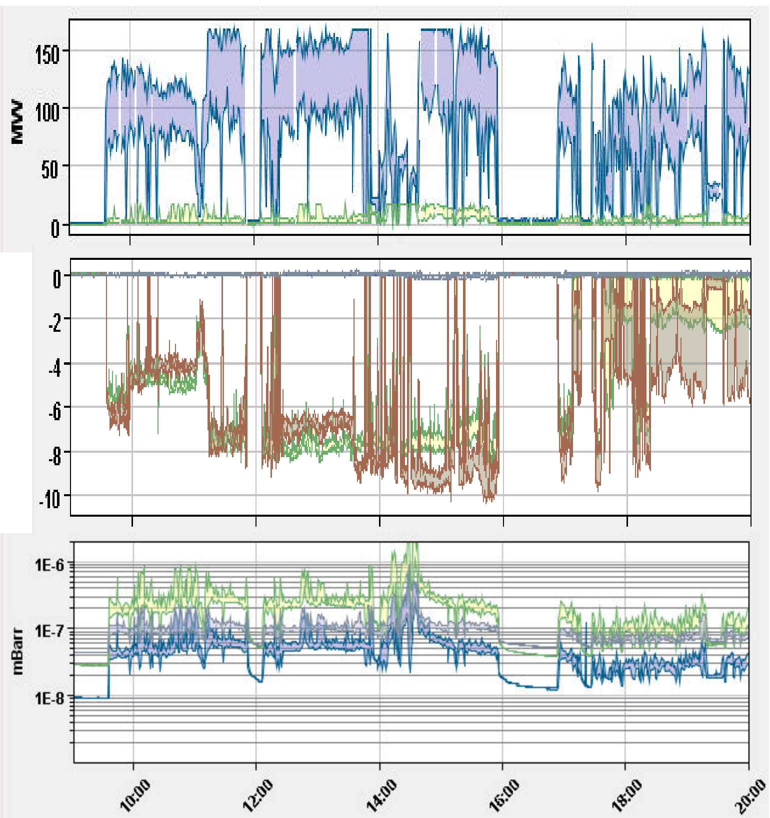




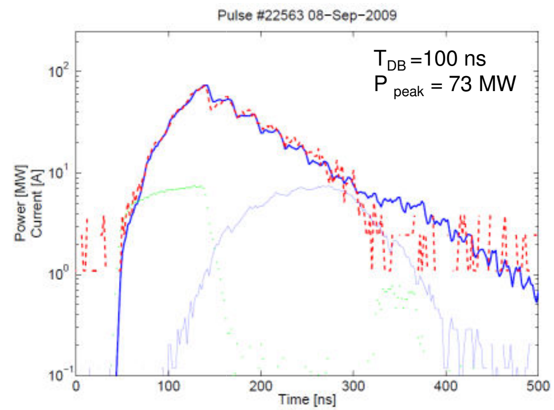
PETS tank with re-circulation RF circuit installed in TBTS test area (October 2008)

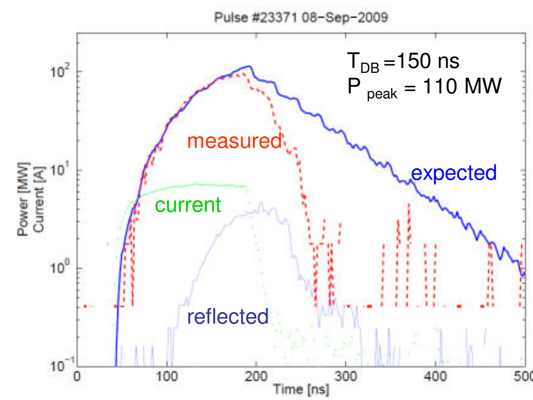
One day at TBTS. 08.09.2009

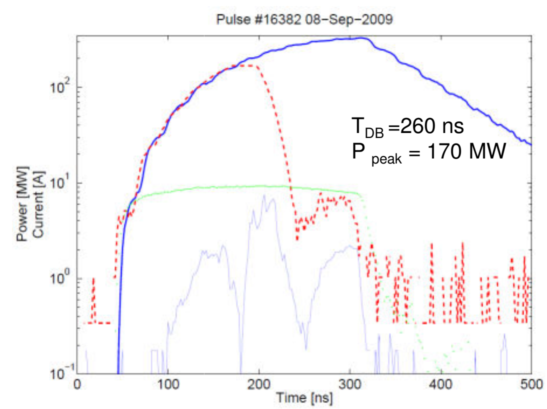




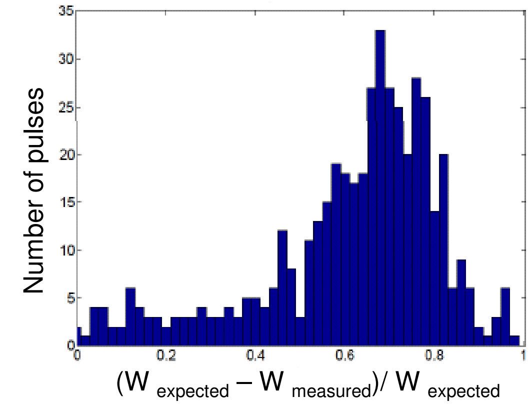
Pulse shortening (full re-circulation)



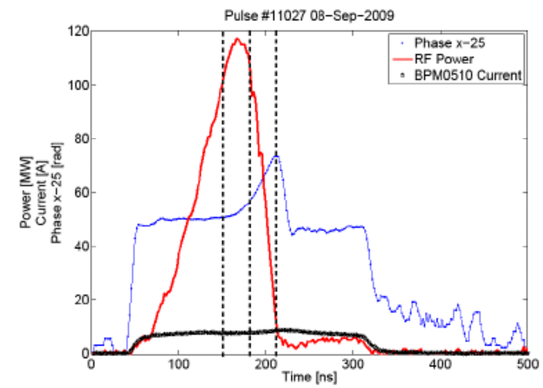




Pulse shortening statistics

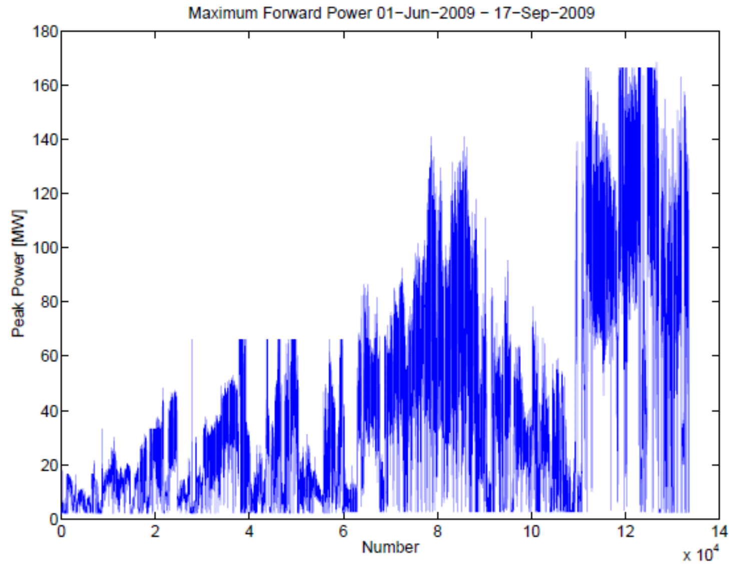


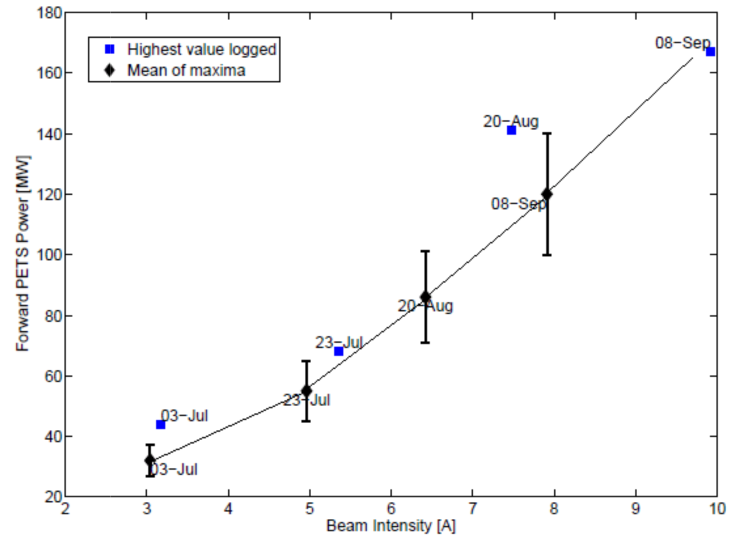
Pulse shortening and RF phase

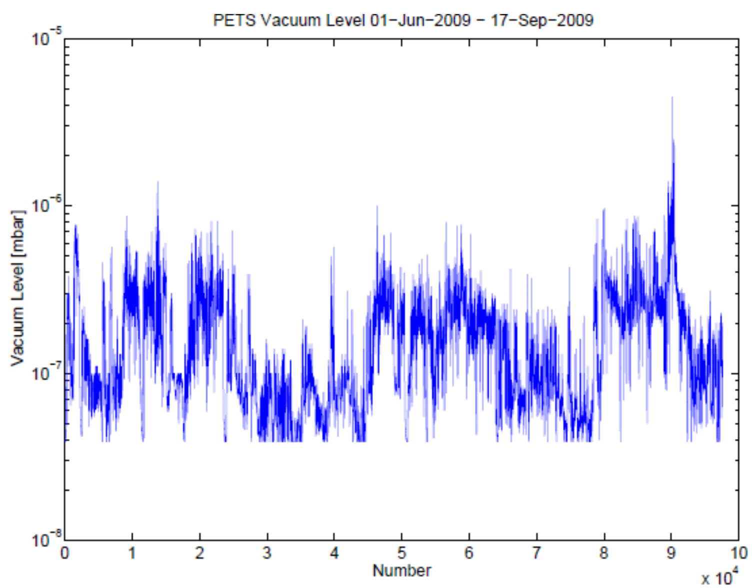


The detailed analysis of the signals gives us a strong indication that in most of the cases when pulse shortening is abrupt, the activity is associated with feedback loop and not the PETS itself.

June-September 2009 PETS TBTS processing history







Discussion.

- In total, 60 hours (~2x10^5 pulses) of the RF power production in the PETS was accumulated. The peak RF power in full recirculation regime was gradually increased from 20MW to ~ 180 MW.
- The processing strategy was rather aggressive, we allowed for the frequent pulse shortening. However, in most of the cases the pulse shortening followed the recirculation parameters transient modification (phase and amplitude) and thus the power production was normally quenched (no missing energy).

Short term 2009/2100 PETS experimental program

ASTA (SLAC)

- To finish PETS processing and to establish solid data point for the PETS breakdown rate performance at the nominal CLIC power: 130 MW x 240 ns (2009)
- To run the next PETS equipped with damping material (2009/2010).

CTF3, Two Beam Test Stand (CERN)

- To process the PETS with re-circulation to the nominal CLIC power.
- To deliver nominal CLIC power to one CLIC accelerating structure, two beam acceleration (2009/2010).
- Demonstration of the PETS ON/OFF operation (2009/2010)

PETS development. Design

1. PETS ON/OF mechanism and RF waveguide components specific to CLIC

   see also: 'PETS on/off mechanism', A. Cappelletti. 14-Oct-2009 09:00

2. PETS transverse HOM damping and drive beam dynamics.

   see also: 'ACE3P time-domain codes applied to CLIC ', A. Candel. 14-Oct-2009 10:15
   ' Drive beam decelerator studies' E. Adli. 13-Oct-2009 12.:05

International Linear Collider. Technical Review Committee
Second Report (2003)

CLIC feasibility issues, Ranking 1.

Reliability

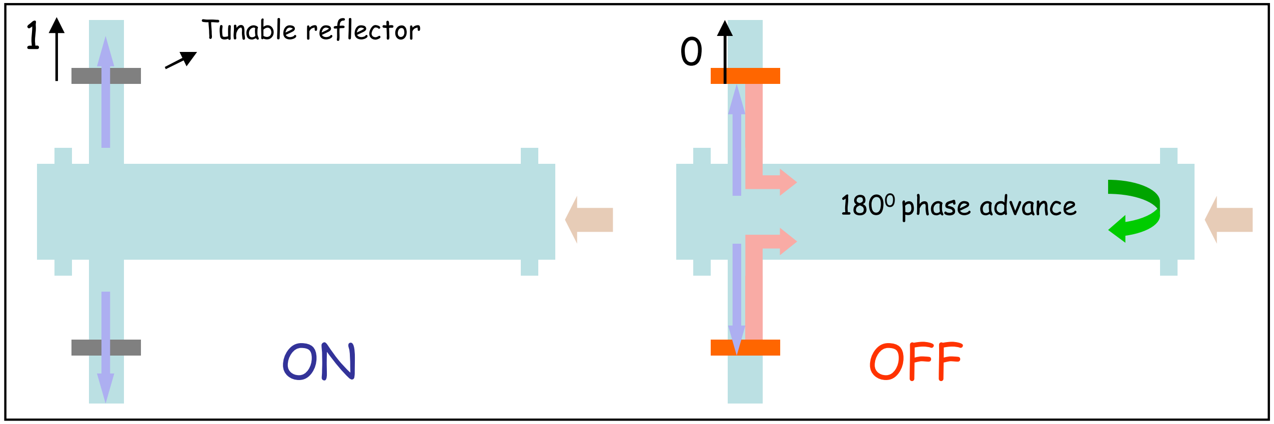
- In the present CLIC design, an entire drive beam section must be turned off on any fault (in particular on any cavity fault). CLIC needs to develop a mechanism to turn off only a few structures in the event of a fault.

- During machine operation the accelerating structure and/or PETS will suffer from the number of RF breakdowns.

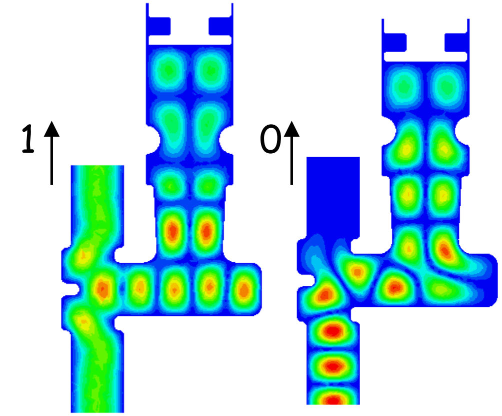
- Currently we have a little information about the actual behavior of the structures at a very low (by design: $<3\times10^{-7}$ /pulse/meter) breakdown trip rate and so it might be necessary to switch the single structure/PETS OFF and re-process it.

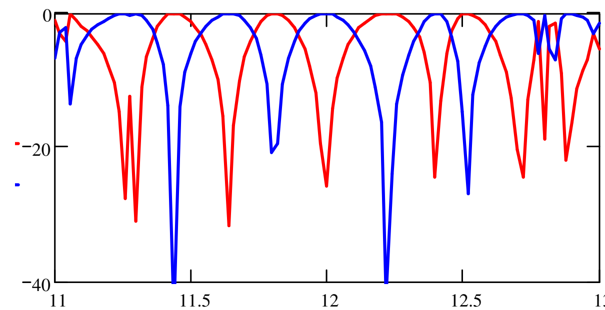
- In order to maintain the operation efficiency we want to do the switching OFF very fast – between the pulses (20 msec).

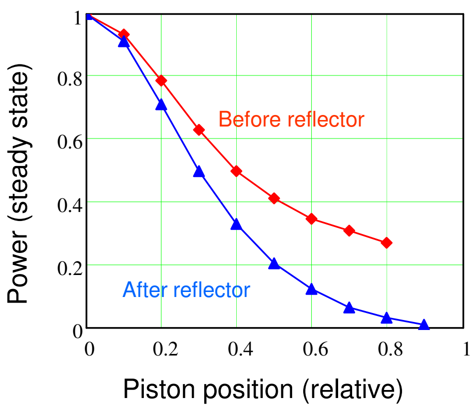
Baseline ON/OFF concept with external commutation and internal re-circulation

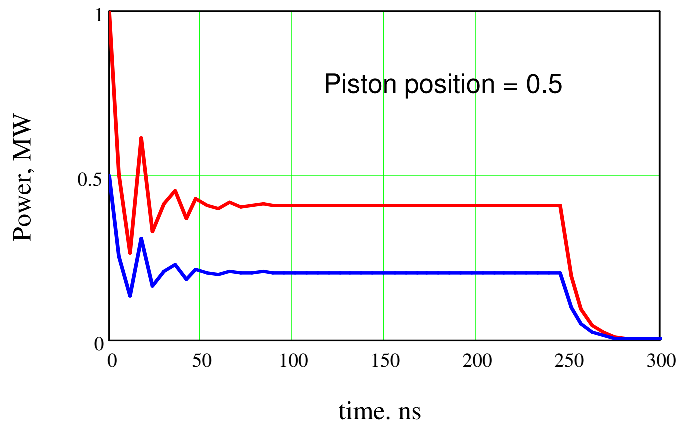


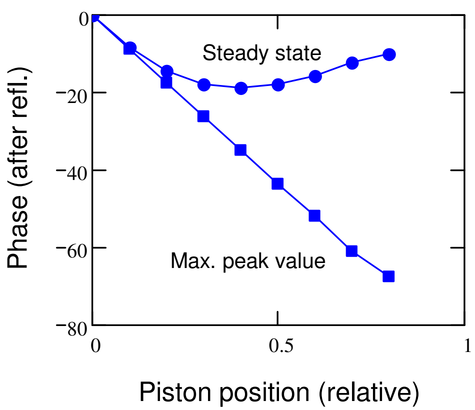
Compact tunable RF reflector design

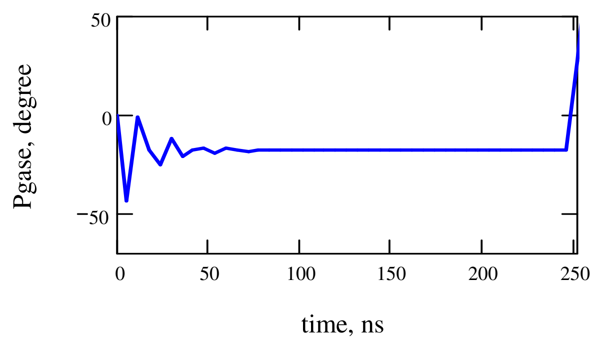




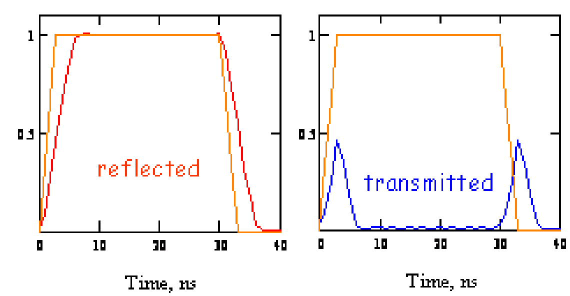








Reflector off position



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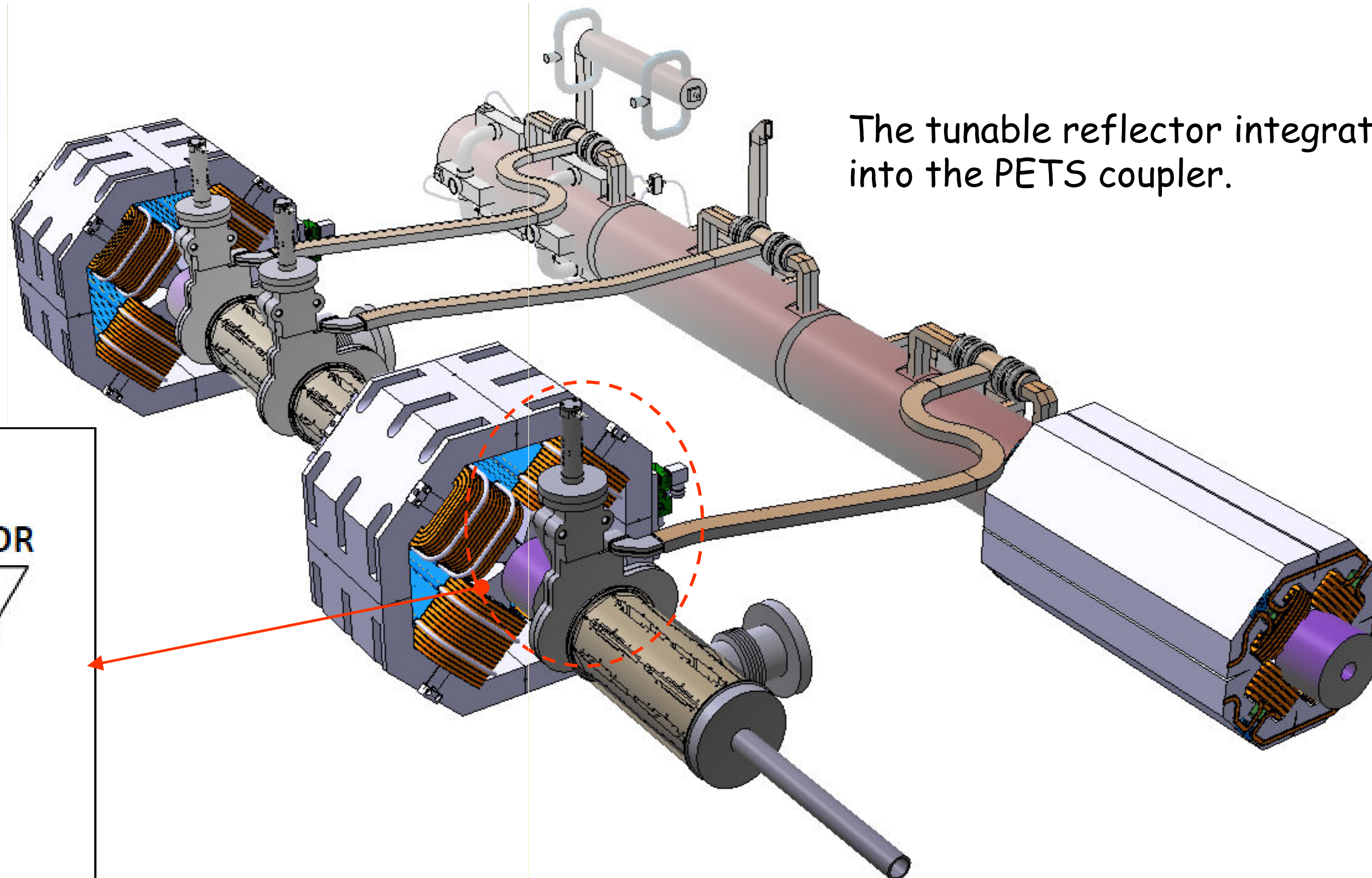
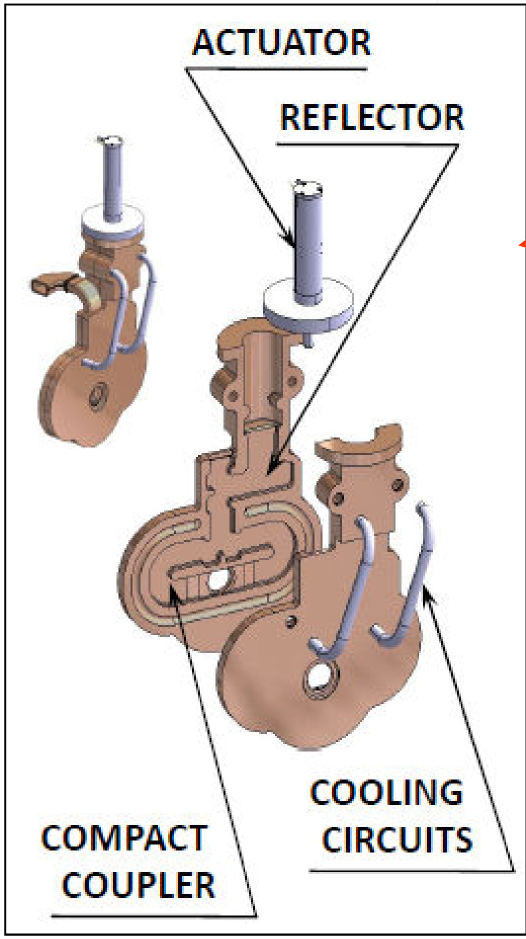
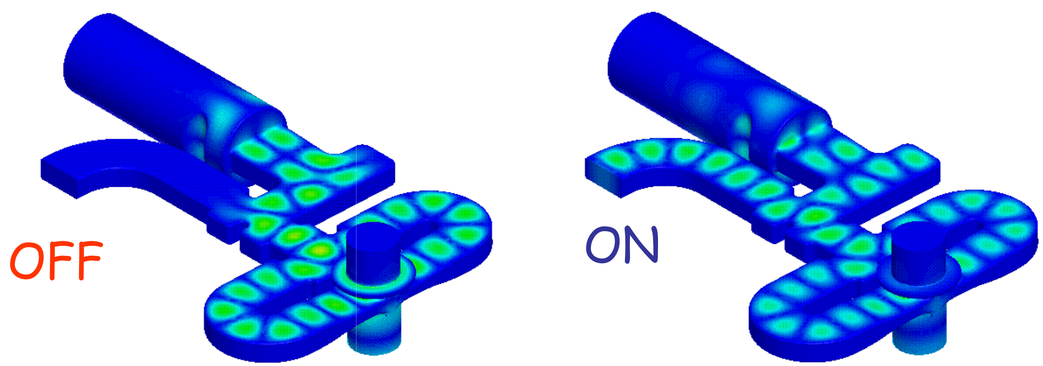
I. Syratchev, CLIC Workshop 2009, CERN

The tunable reflector integrated into the PETS coupler.



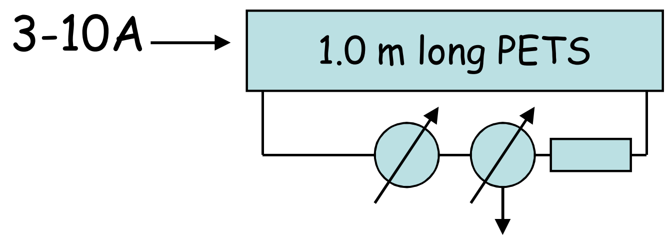




The ON/OFF feasibility demonstration (2009-2010)

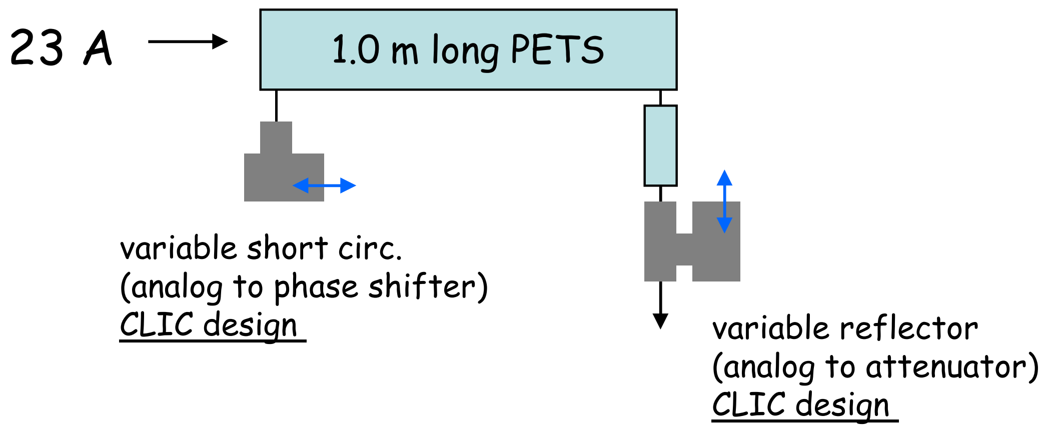
TBTS:

- PETS current configuration (recirculation)

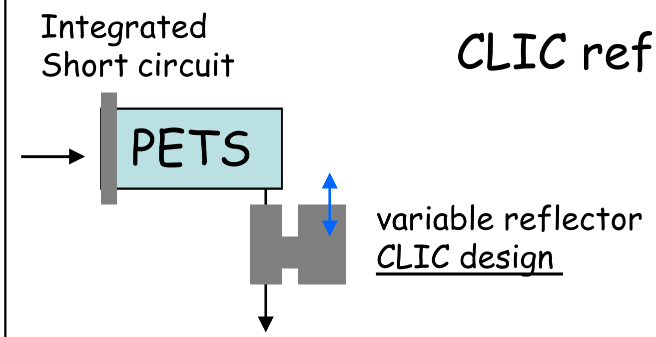


End 2009

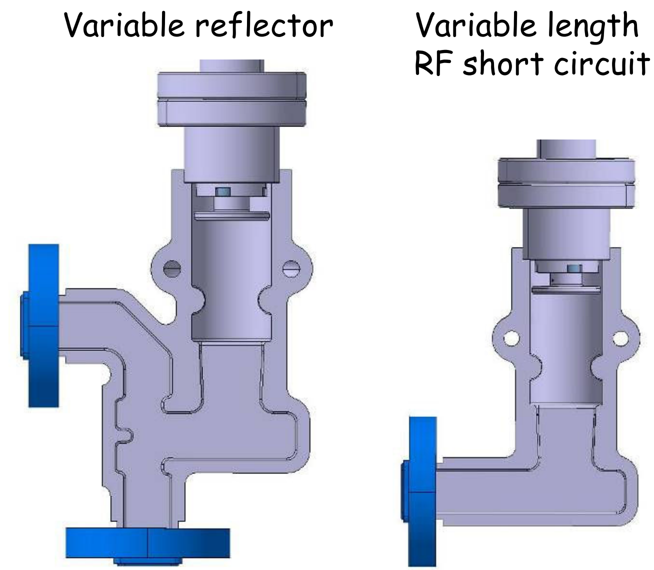
- PETS RF network modification
  (internal recirculation – ON/OFF option)



CLIC reference

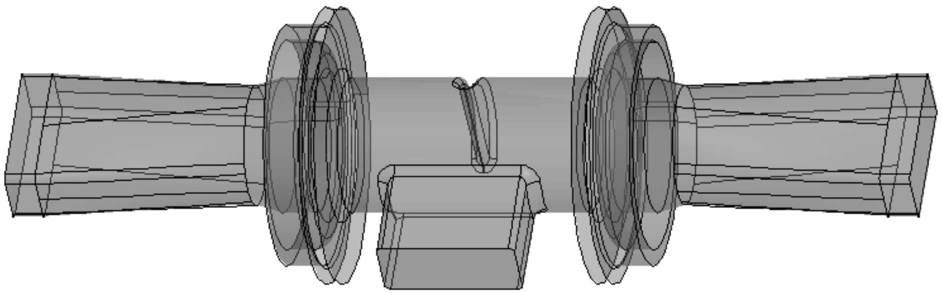


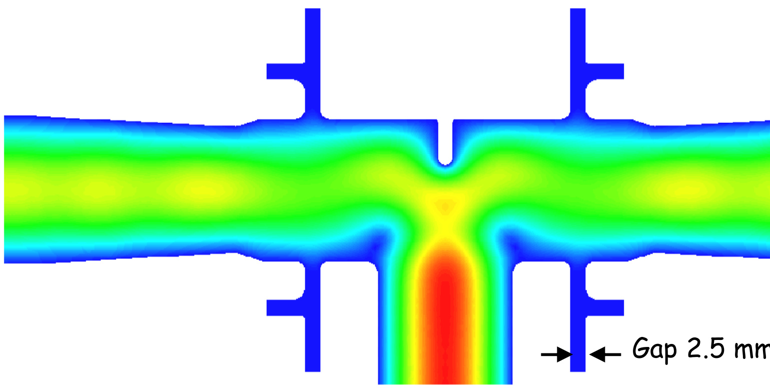
-The ON/FF feasibility demonstration will require full (22.8 A) current.

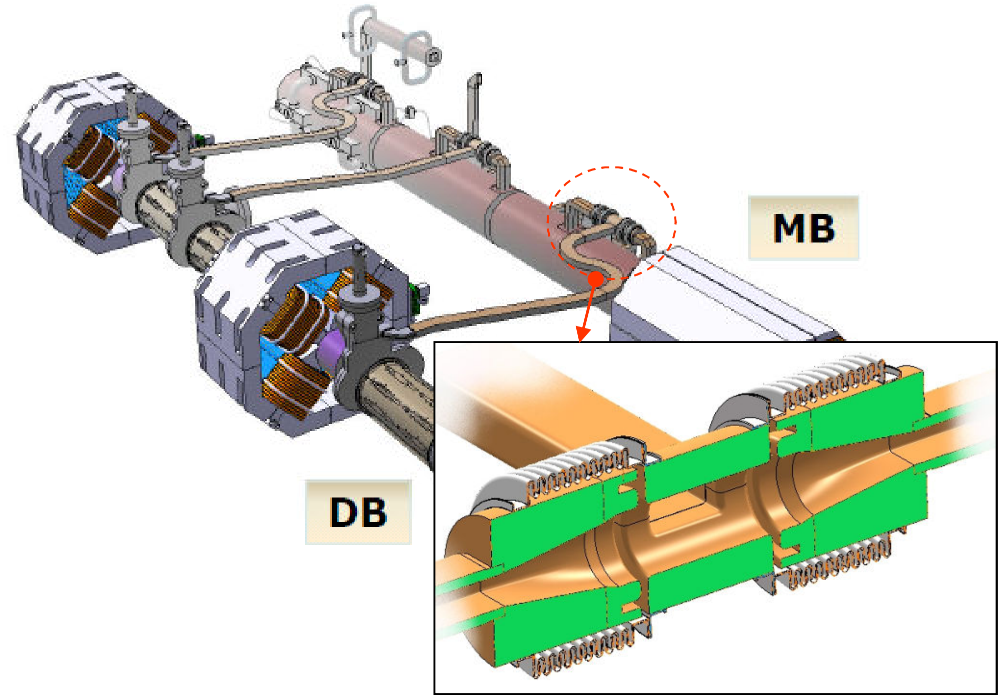


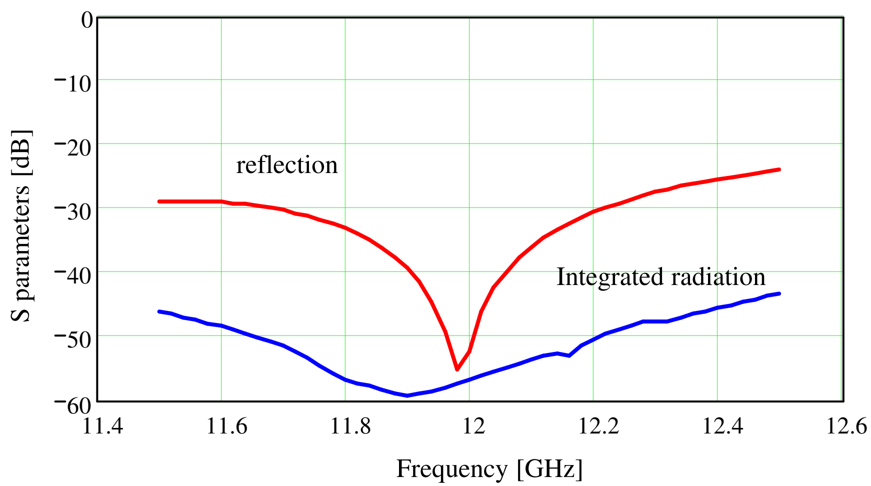
CLIC RF waveguide network

To allow the independent transverse alignment of the two linacs in CLIC, the RF contact free choke mode flanges (CMF) are planned to be used.

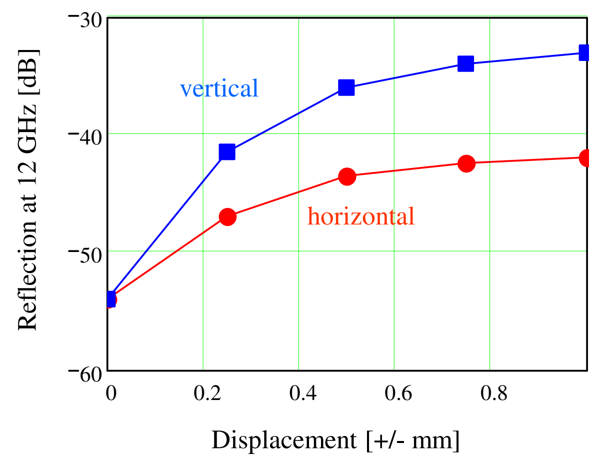




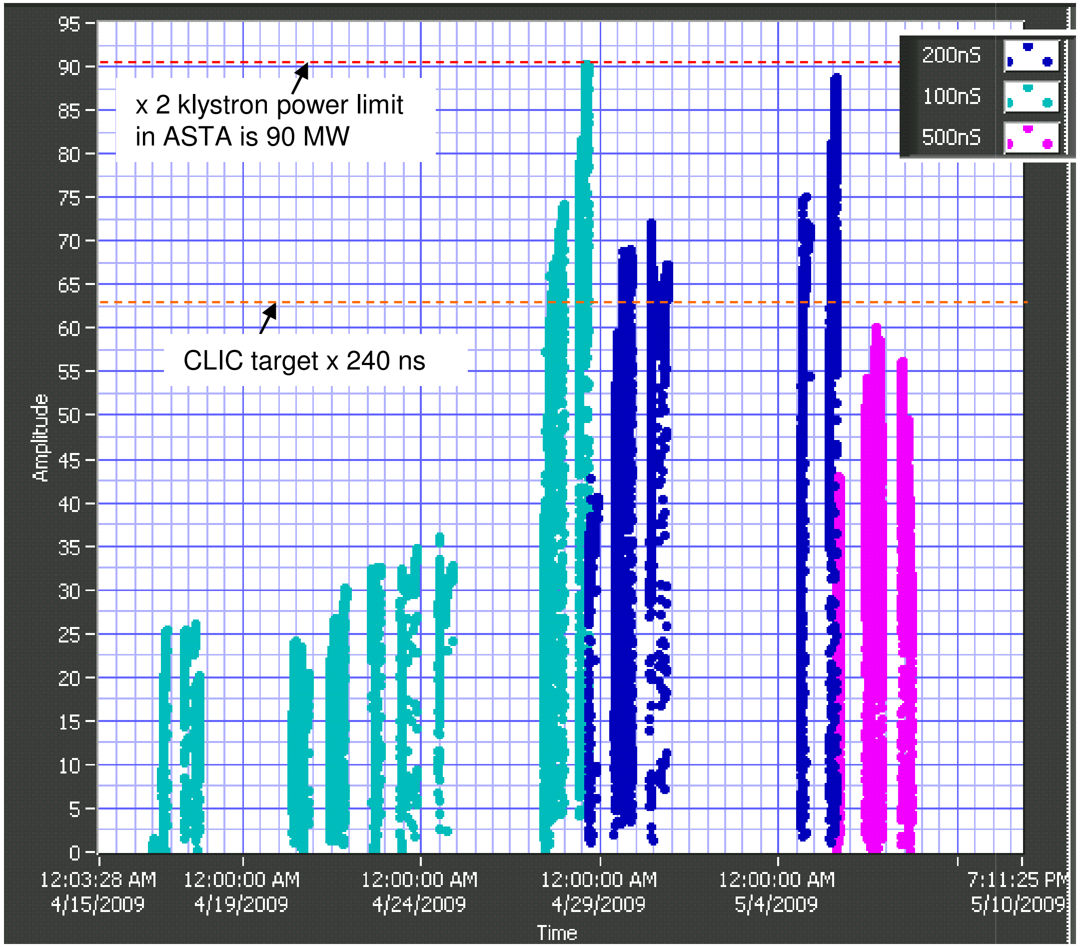




Waveguides transverse displacement in the single choke

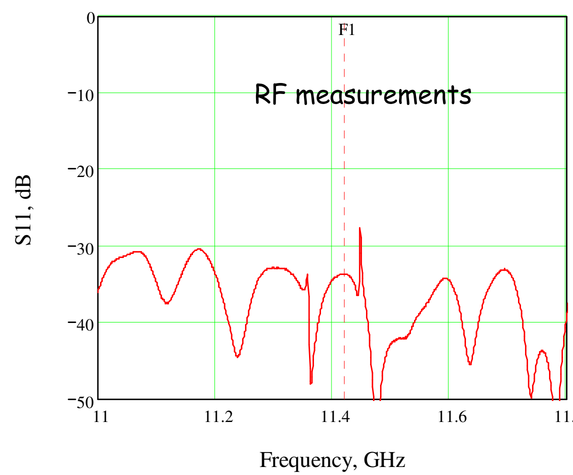


CMF high power tests at SLAC



The choke flange performed well. The achieved peak power levels are above CLIC design values .

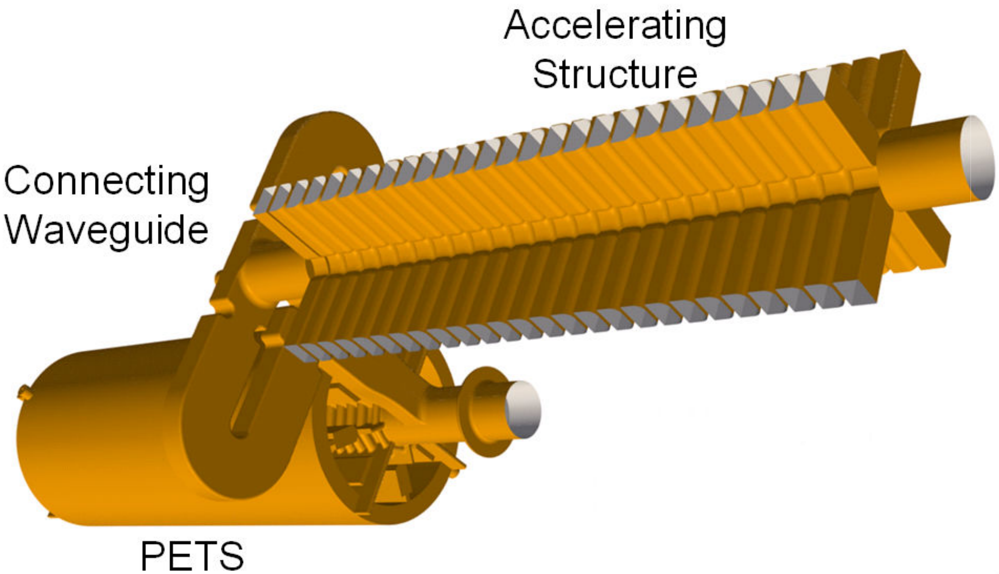
11.424 CMF



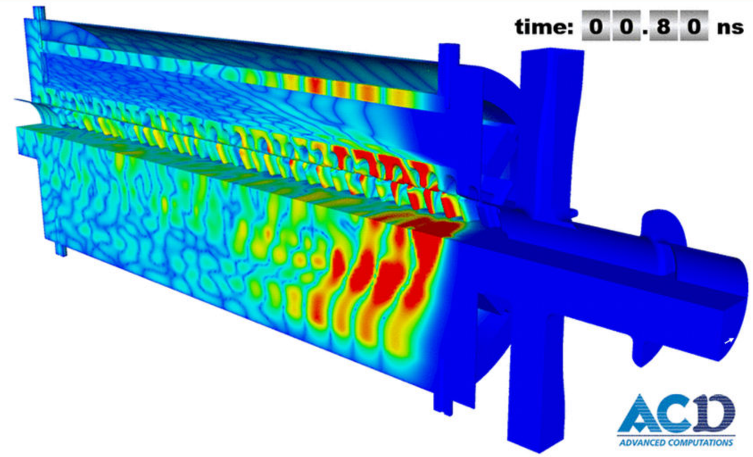
PETS advanced computations. T3P (SLAC)

For the moment, the computer simulation is the only method to study the damping performance in the PETS.

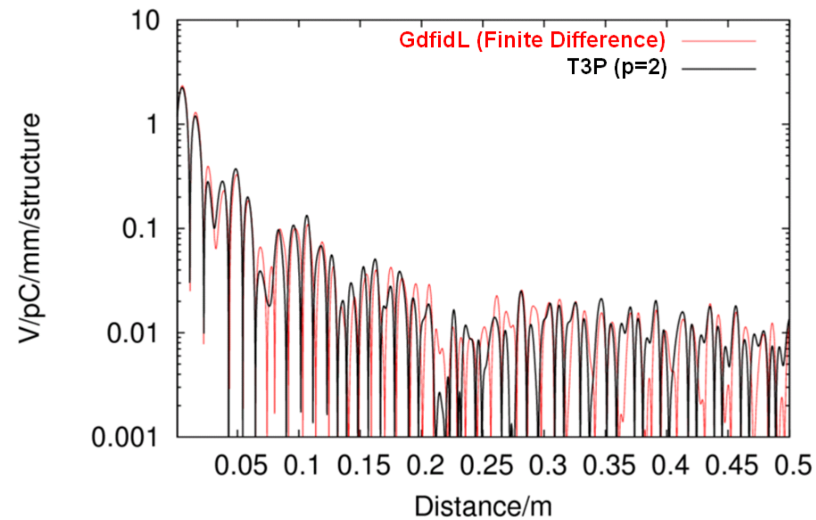
CLIC Coupled Structure Model for T3P



T3P - PETS Wakefield Damping

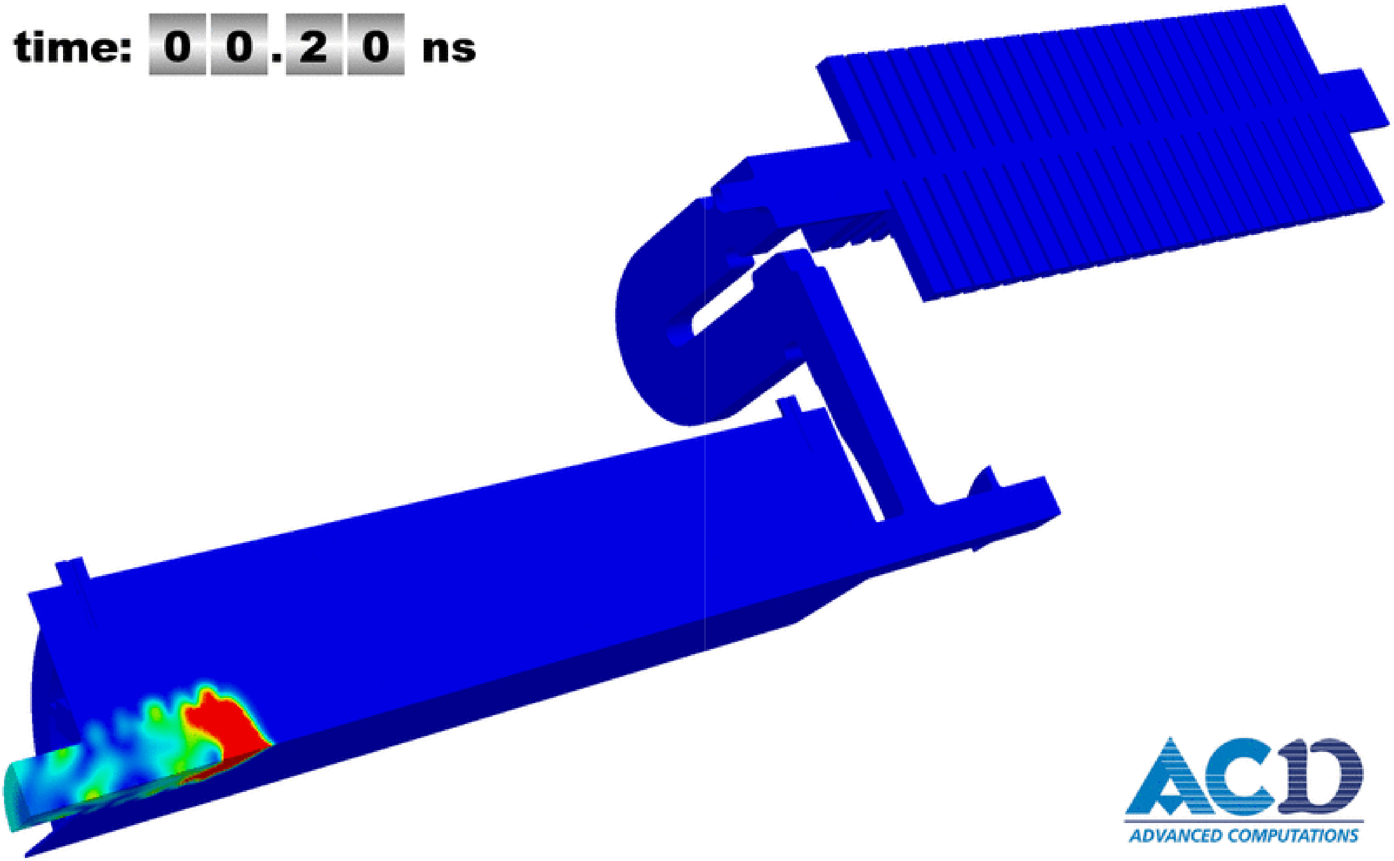


Benchmarking: T3P vs. GdfidL



The computer code T3P developed at SLAC, allows for computation of the wakes/impedances of the very complicated RF structures with unprecedented accuracy.

T3P Simulation of RF Power Transfer



Drive beam stability issues

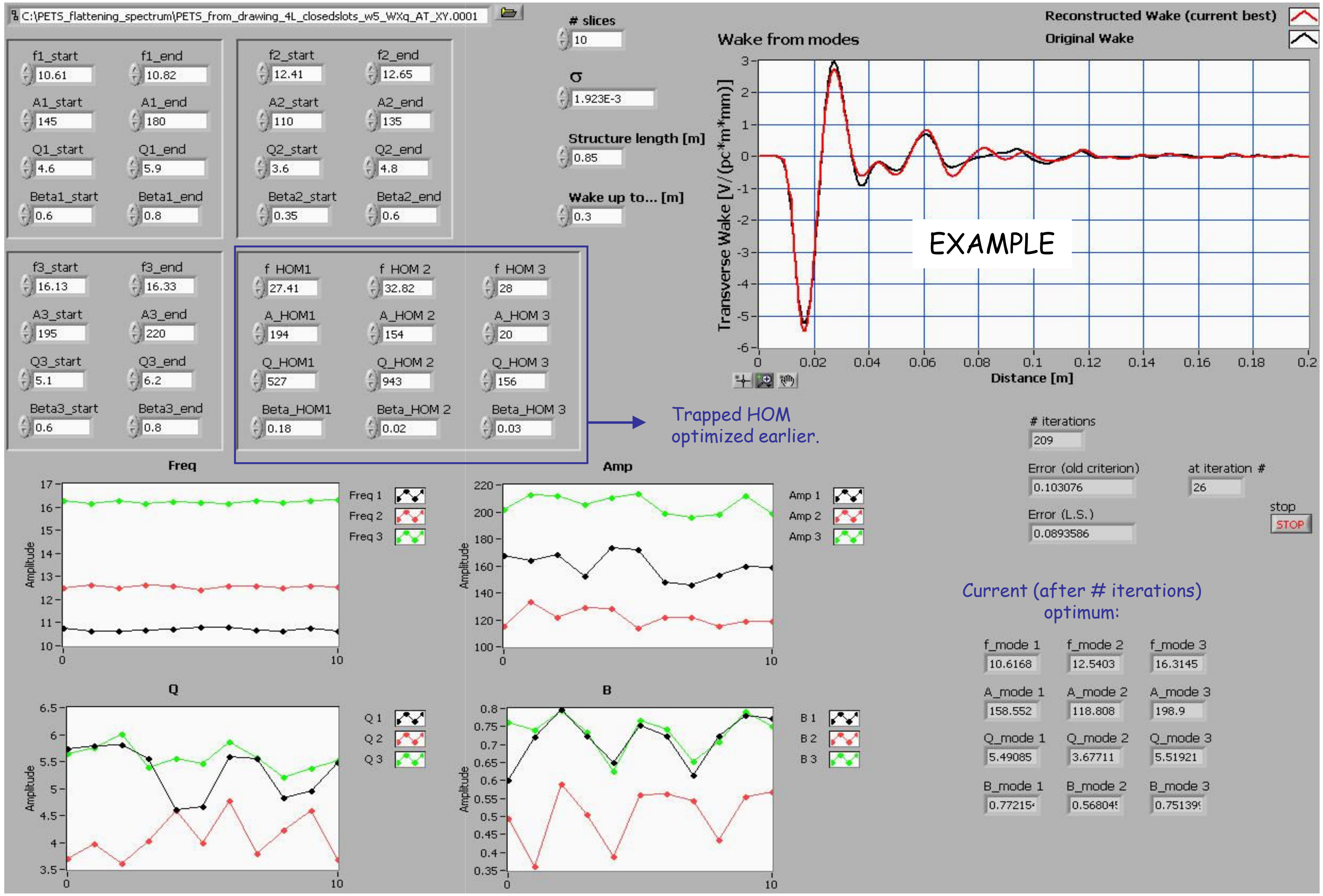
The wake model (PLACET):

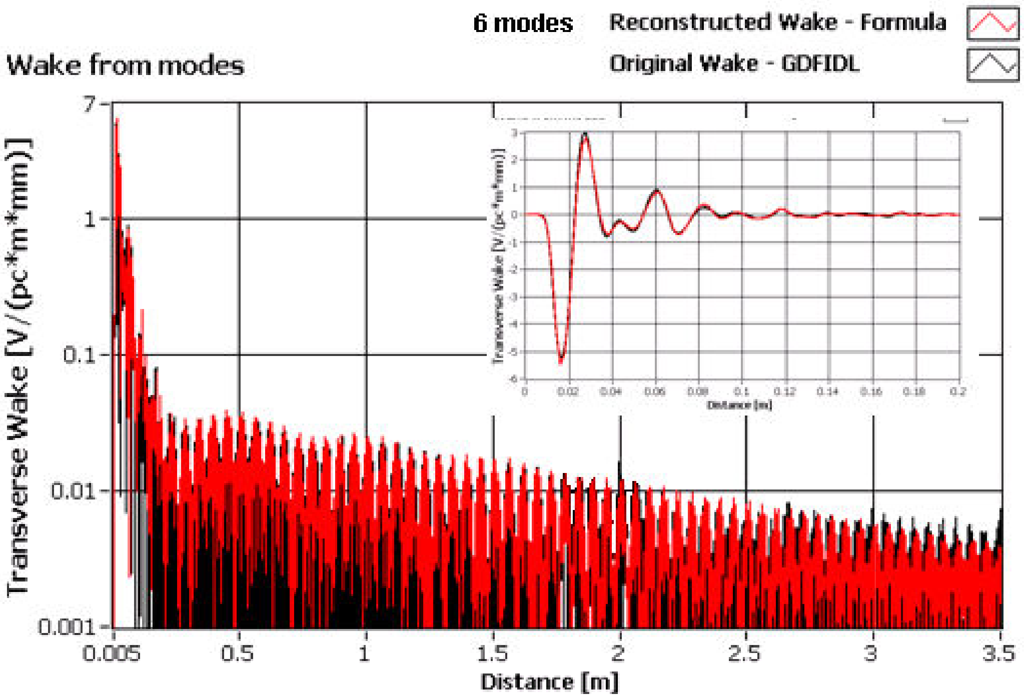
$$W_{\perp_k}(z) = \frac{2K_{\perp_k}}{1-\beta_k}\sin\left(\frac{\omega_k z}{c}\right)e^{-\frac{\omega_k z}{2Q_k(1-\beta_k)c}} \times \left\{1-\frac{\beta_k z}{L(1-\beta_k)}\right\}$$

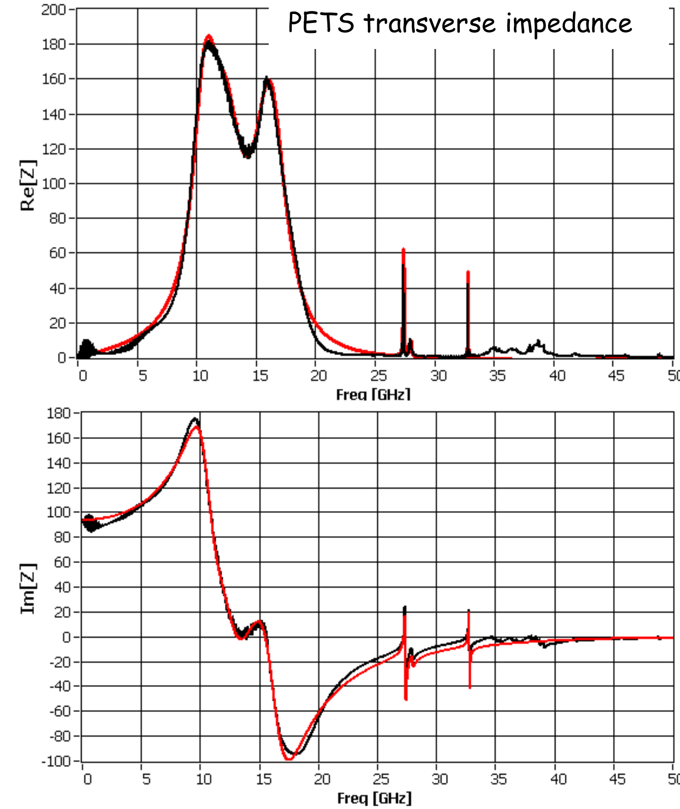
$$W_{\perp_k}(z) = 0, \quad z > L\frac{1-\beta_k}{\beta_k}$$

$$W_{\perp}(z) = \sum_i q_i \times \left(\sum_k W_{\perp_k}\right)$$

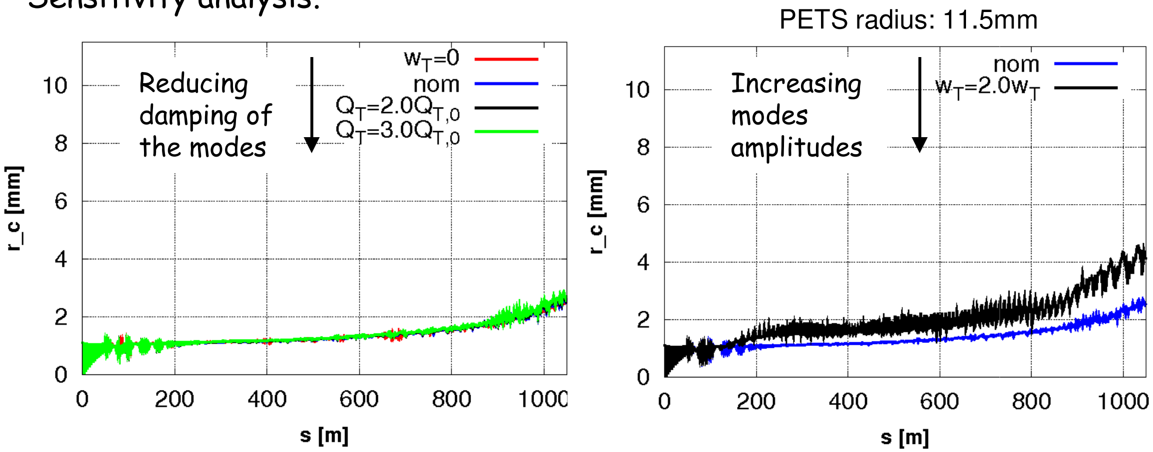
Recently the computer algorithm was developed, which allows reconstruction of the PETS transverse wake simulated by GDFIDL using directly the wake model.







Beam envelope along CLIC decelerator sector simulated in **PLACET**.
Sensitivity analysis.



	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
Freq.	10.72	12.46	16.23	27.41	28	32.82
K (8.247)	1.8768	2.666	3.5844	0.0634	0.02255	0.03368
Q factor	5.9	3.65	5.69	527	156	943
β	0.77	0.44	0.71	0.18	0.03	0.02

The important outcome of this study, is that the system appeared to be quite stable with respect to the changing of the HOM Q-factor (changing of loads material properties for example) and confirmed very stable beam transportation.