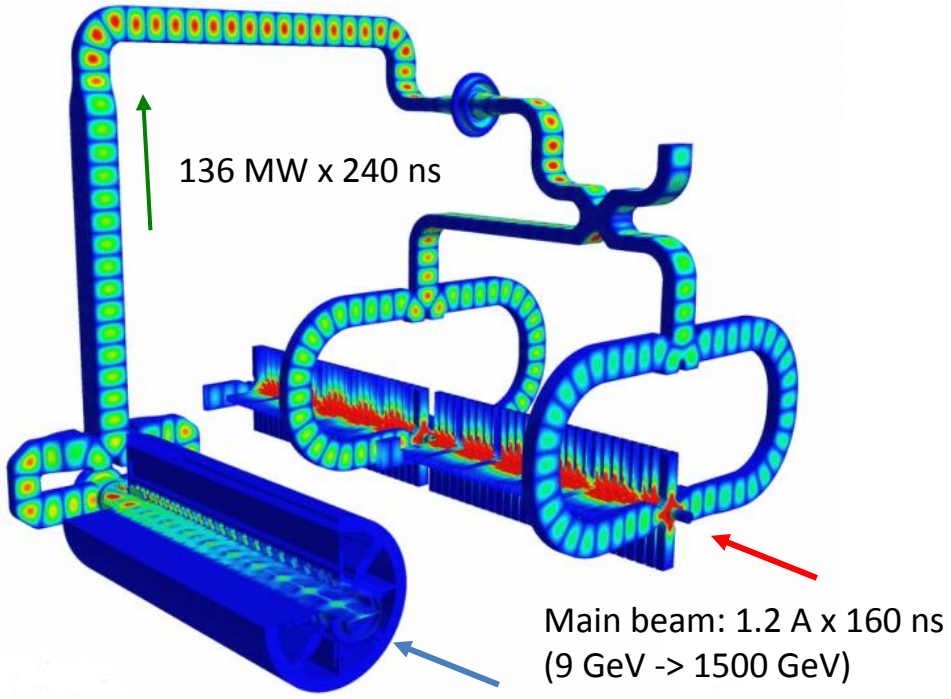
RF POWER PRODUCTION AT THE TWO BEAM TEST STAND AT CERN

I. Syratchev for the CLIC team

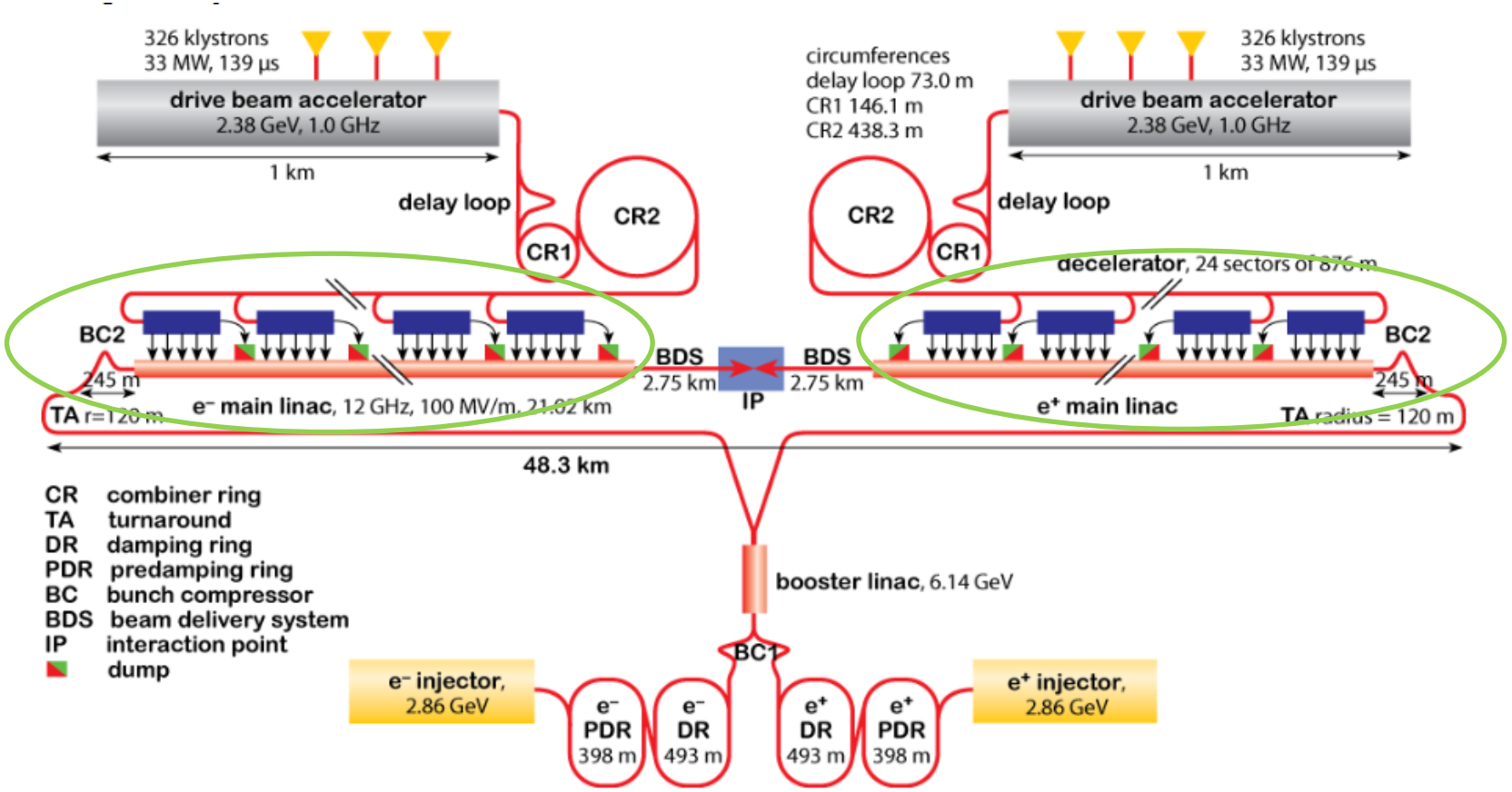
Introduction

Simulated with T3P (SLAC)



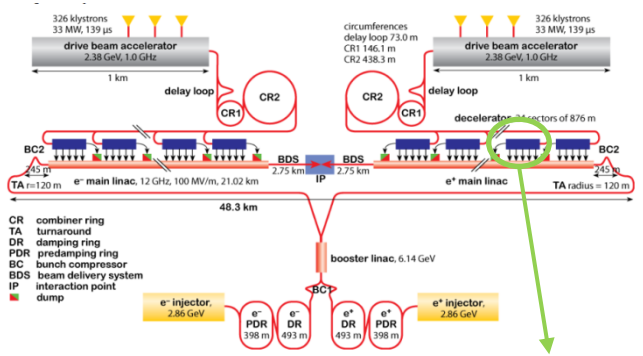
The two beam acceleration is one of the key component of the CLIC scheme, where the RF power is produced via deceleration of the high current, low energy drive beam and then is used to accelerate the low current main beam to high energy.

Introduction

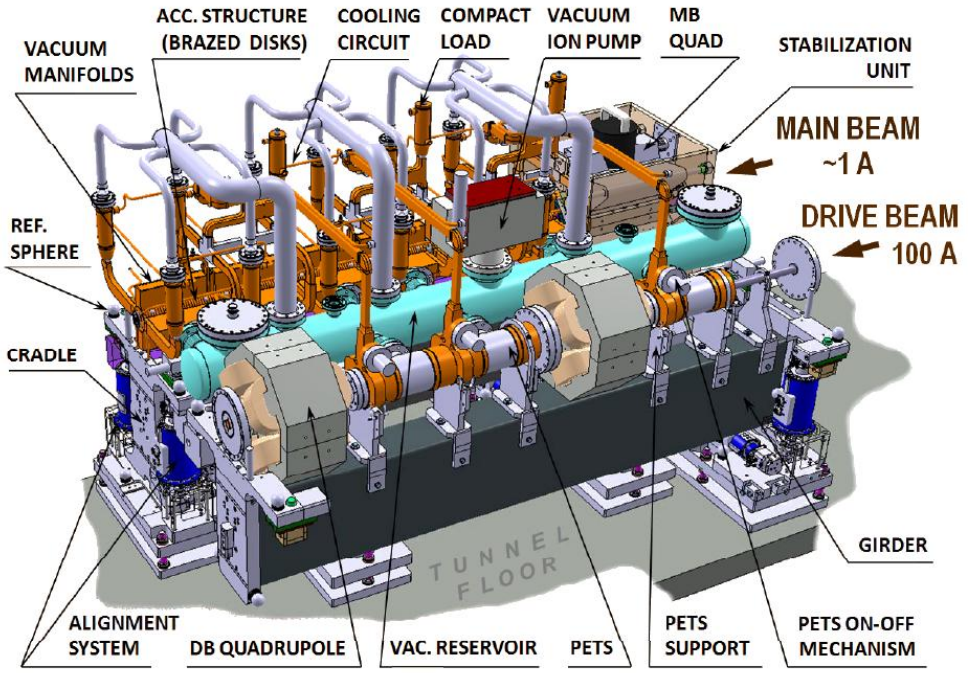


In the CLIC linac, 24 decelerators sectors (each 876 m long) should produce 2.8 TW peak RF power in total, in order to accelerate the main beam to from 9 GeV 1.5 TeV. Notably, the efficiency of the RF power production is 90%.

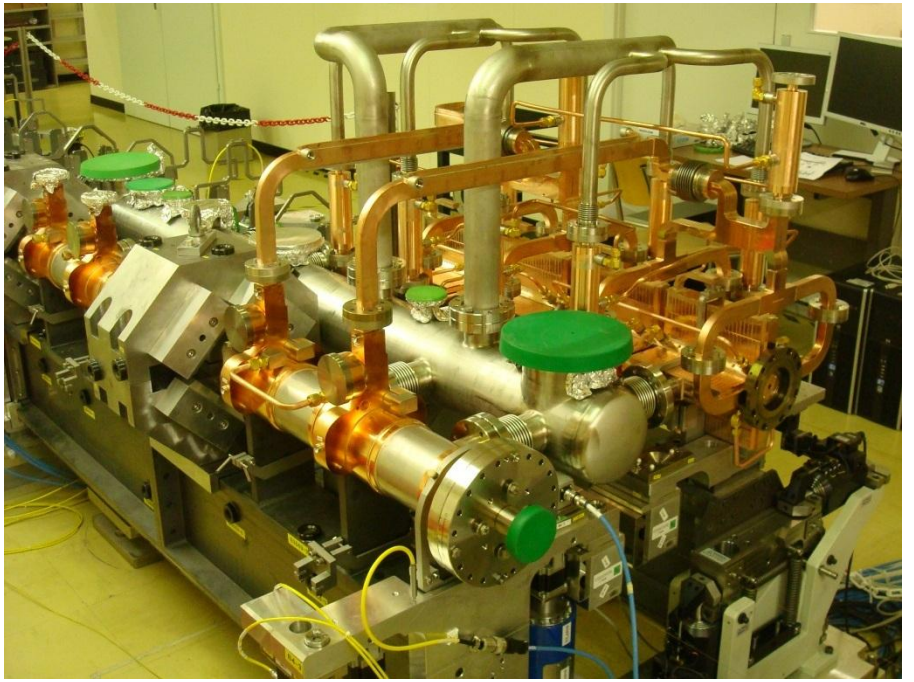
Introduction



Each decelerator sector is comprised of 438 Two-Beam Modules (TBM). The TBM is a complicated installation, where all the accelerator systems and components are integrated in a very compact way.

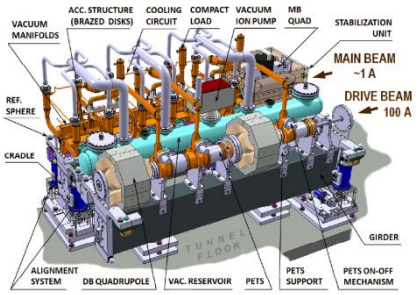


General view of he TBM

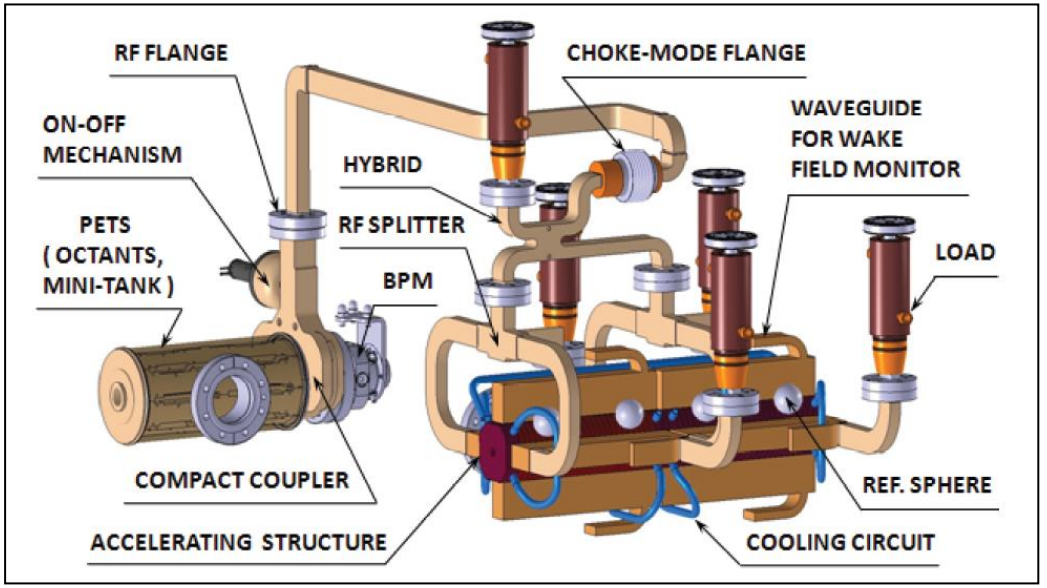


The test (Lab) version of the TBM under installation at CERN

Introduction

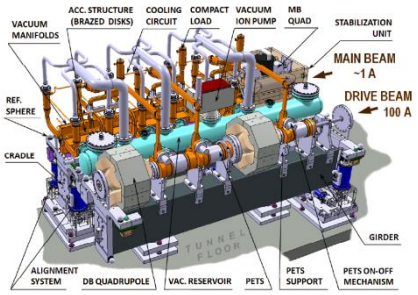


General view of RF unit

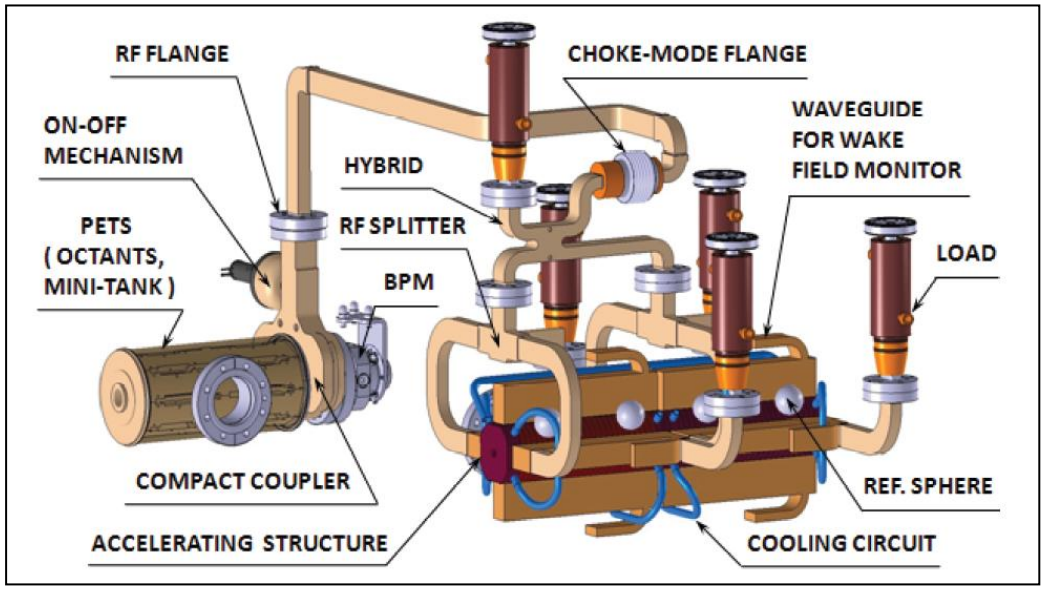


Depending on the its type, each module contains up to 4 RF units. Each RF unit comprises of Power Extraction and Transfer Structure (PETS) and two accelerating structures connected via special RF waveguide network.

Introduction



General view of RF unit



The CLIC PETS is a low impedance, high group velocity iris loaded 0.213 m long structure with a relatively large ($2a/\lambda$=0.92) beam aperture. Each PETS is comprised of eight octants separated by damping slots. Each slot is equipped with damping loads in order to provide the strong damping of the transverse higher order modes. Upstream end of he PETS is equipped with a special power coupler.

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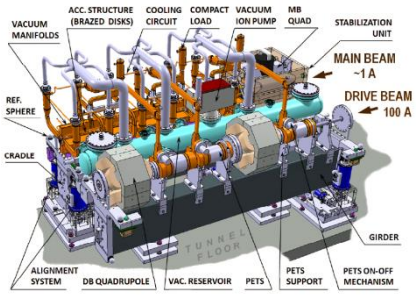
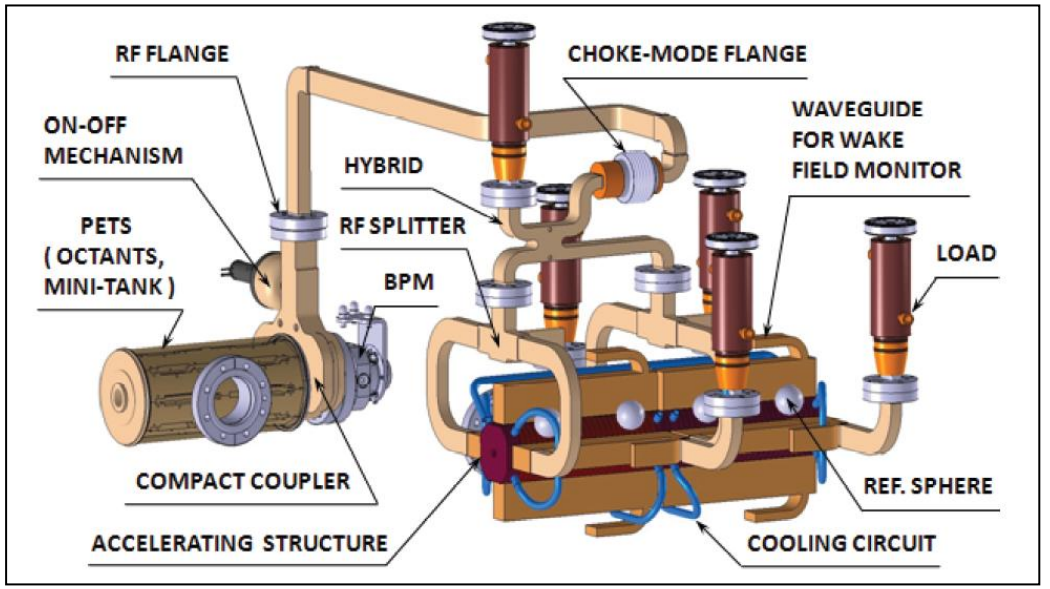


General view of RF unit



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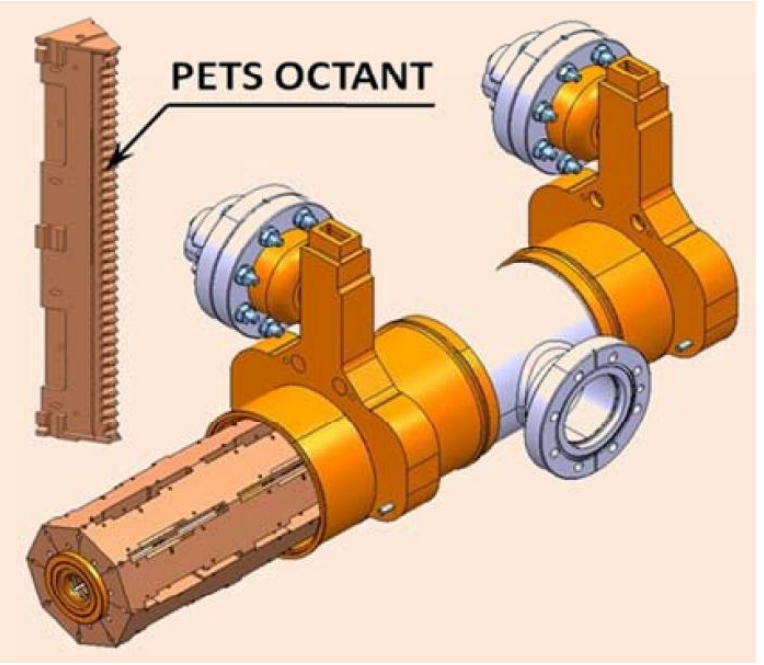


PETS testing program objectives

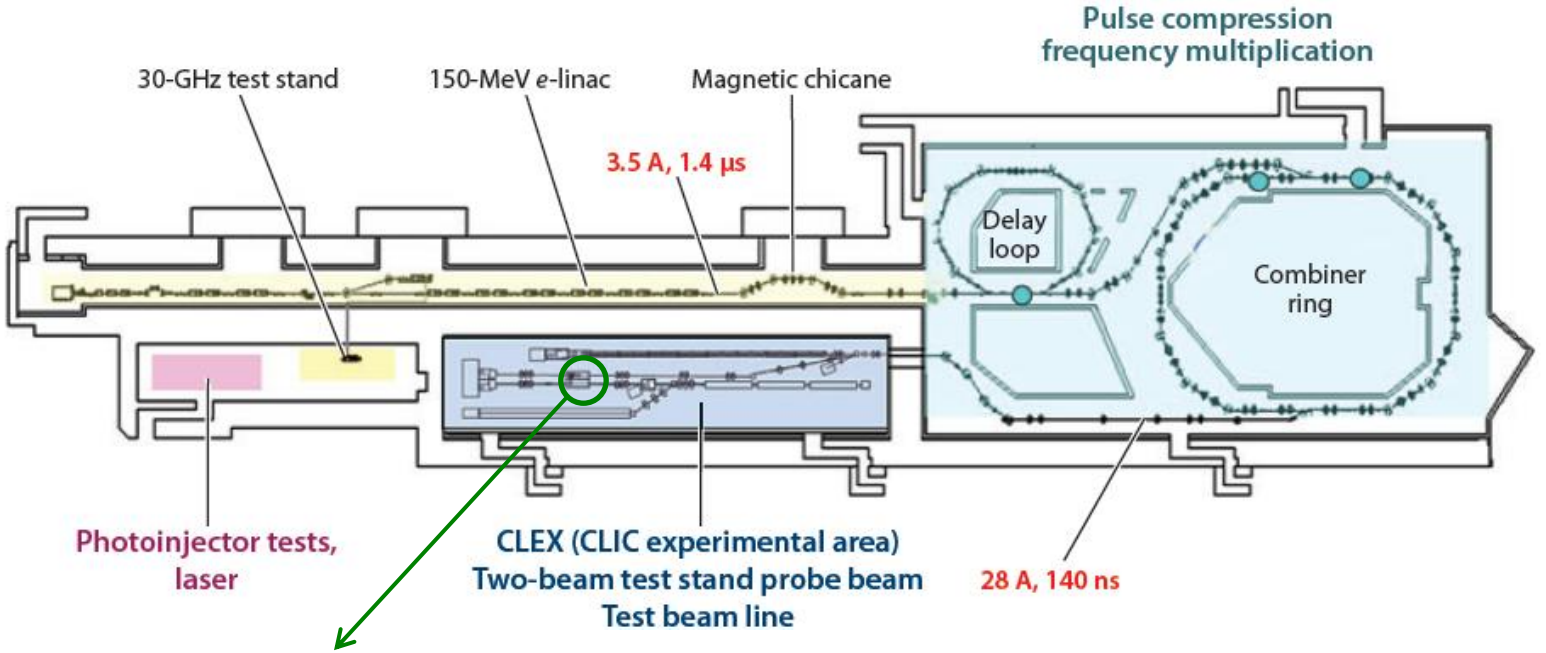
Following extensive working-group discussions within the frame of dedicated workshops and critical scrutiny by the CLIC Advisory Committee 10 feasibility issues have been clearly identified by the CLIC team and the linear collider community. Amongst them, one was related to the RF power production from the drive beam, specifically:

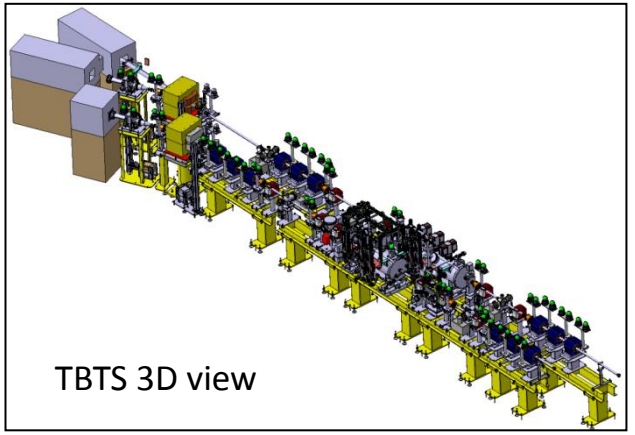
a. A novel power extraction and transfer structure (PETS) that can produce a RF pulse of 136 MW in 246 ns from 12 GHz bunched drive beam and …
b. is equipped with an on-off mechanism either to allow the power to be tuned during operation or to allow conditioning of the structures in parallel with operation in case of problems.

During the period of 2008-2012, a thorough high RF power testing program was conducted at CERN in order to demonstrate experimentally the feasibility of all the issues associated with high RF power generation using the drive beam.

CLIC experimental area

The generation in the PETS of 12 GHz RF power from the drive beam was demonstrated in the CLIC experimental area (CLEX), which is a part of the CLIC Test Facility (CTF3):

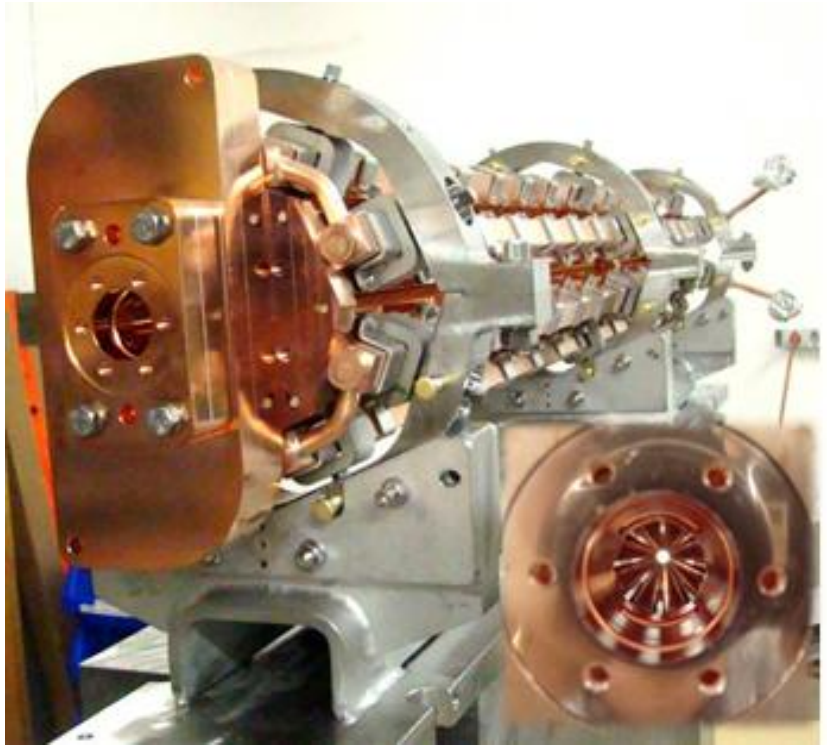




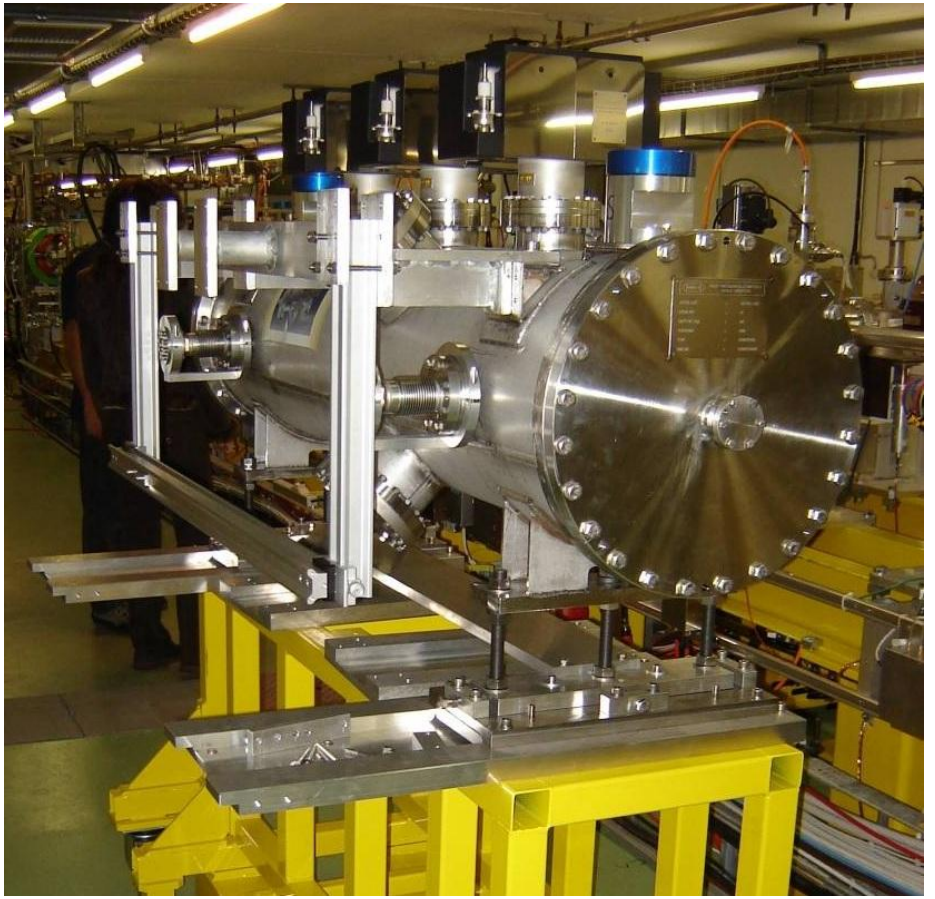
The CLEX is equipped with a number of experiments. One of them is the Two Beam Test Stand (TBTS). The TBTS is a unique and versatile facility where the two-beam acceleration experiments are conducted.

Special TBTS PETS

Because the drive beam current available in CTF3, even with full recombination, will be about four times lower than the CLIC design, to recover the lack of current, the active PETS length was significantly increased from original 0.213 m to 1 m.



The fully assembled, 1 meter TBTS PETS equipped with water cooling channels and power couplers on its girder and ready for the installation into the vacuum tank.



PETS tank upon arrival in the CLEX.

Aspects of the drive beam generation in the CTF3

Different scenarios of the drive beam generation in the CTF3

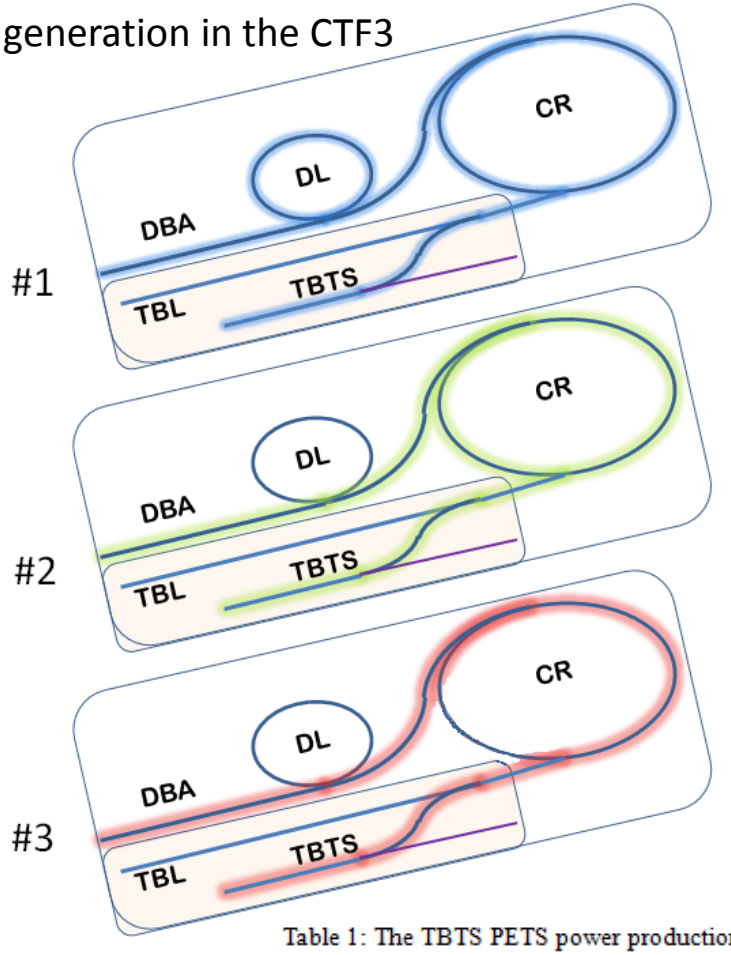
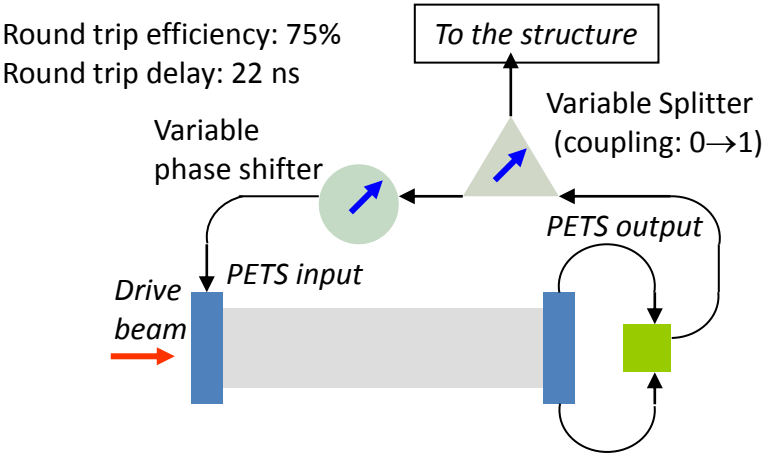


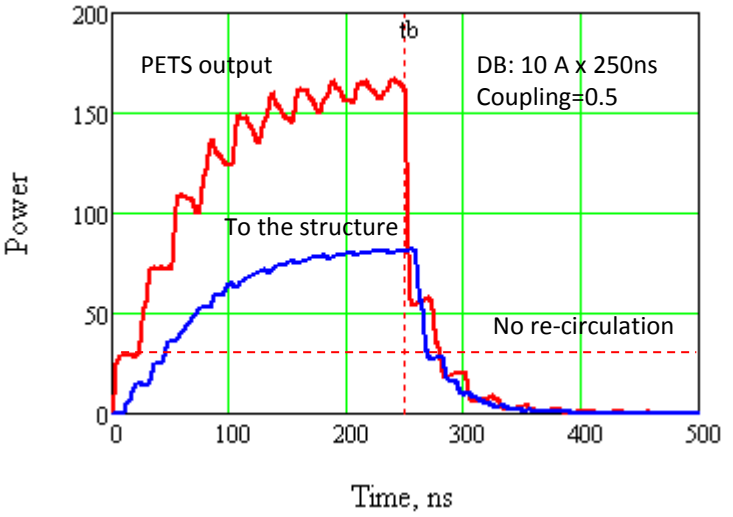
Table 1: The TBTS PETS power production modes

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

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.

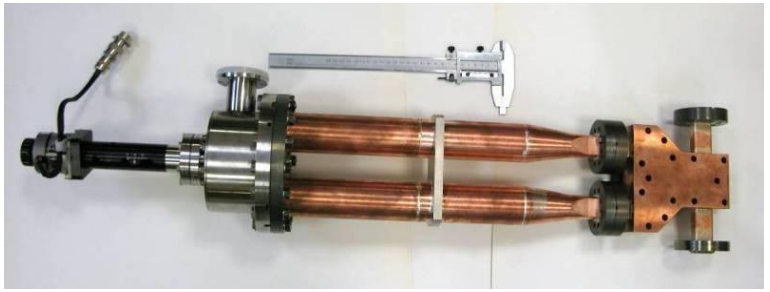


Expected RF power production with re-circulation (computer model):



PETS with re-circulation RF network in the TBTS

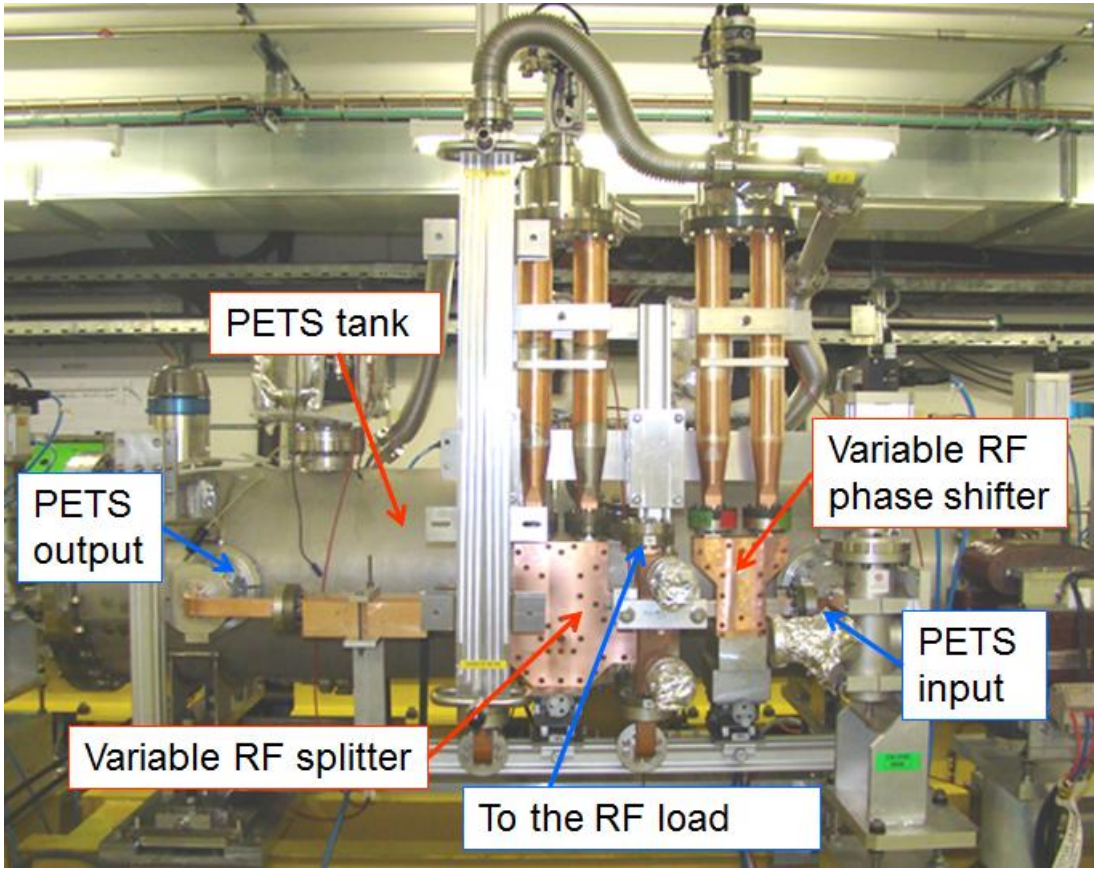
The implementation of re-circulation required development of several special RF components. High RF power variable splitter and variable (2π) RF phase shifter were ordered and received from industry (GYCOM, Russia)



Variable (2π) RF phase shifter

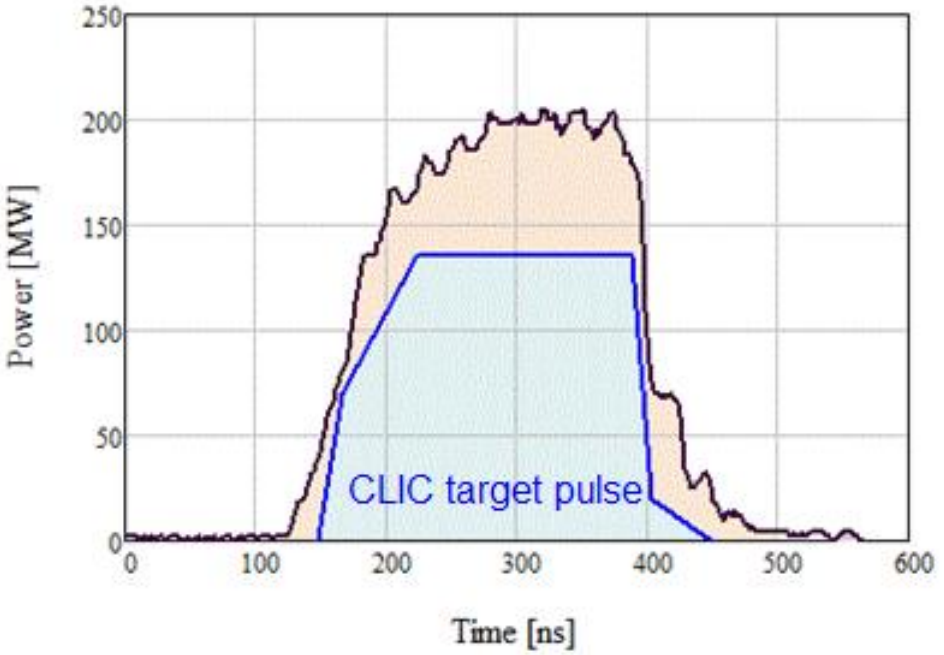
Variable RF power splitter

The PETS tank installed in the TBTS test area (2008)



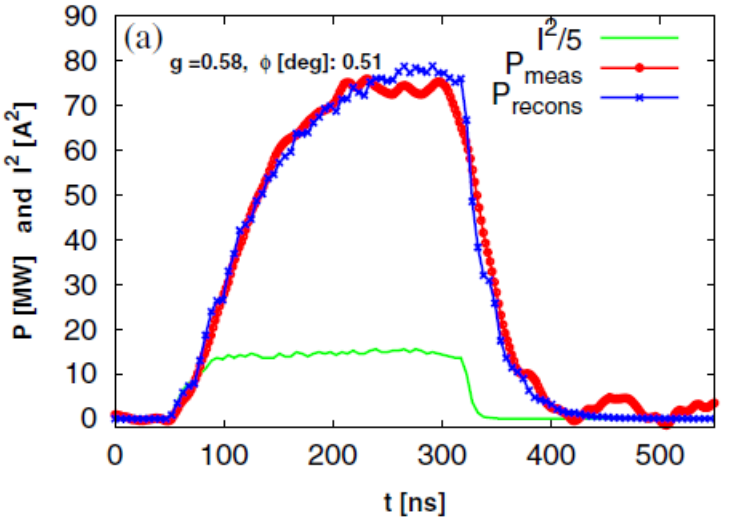
RF Power production at the TBTS

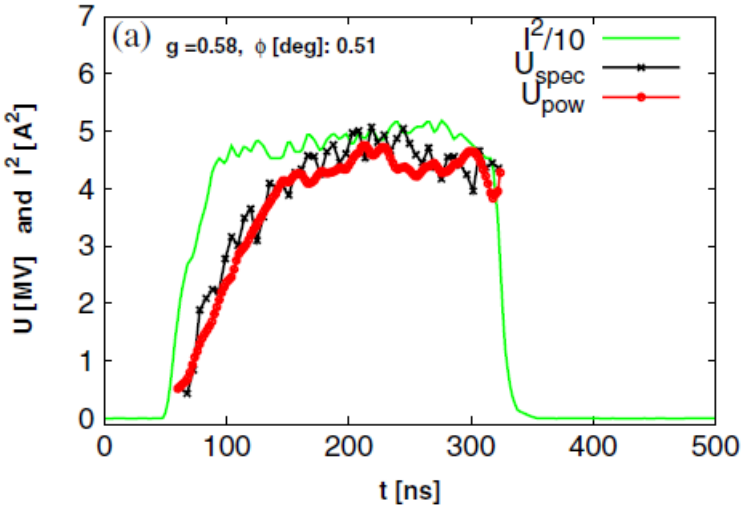
Providing enough margin in drive beam current and pulse length, the CTF3 operation mode 2, together with ~50% re-circulation was chosen as a working point for the PETS power production program. In this configuration, the TBTS PETS was operated until September 2011.



After start up and initial conditioning, PETS was reliably generating RF peak power well in excess of the CLIC nominal value.

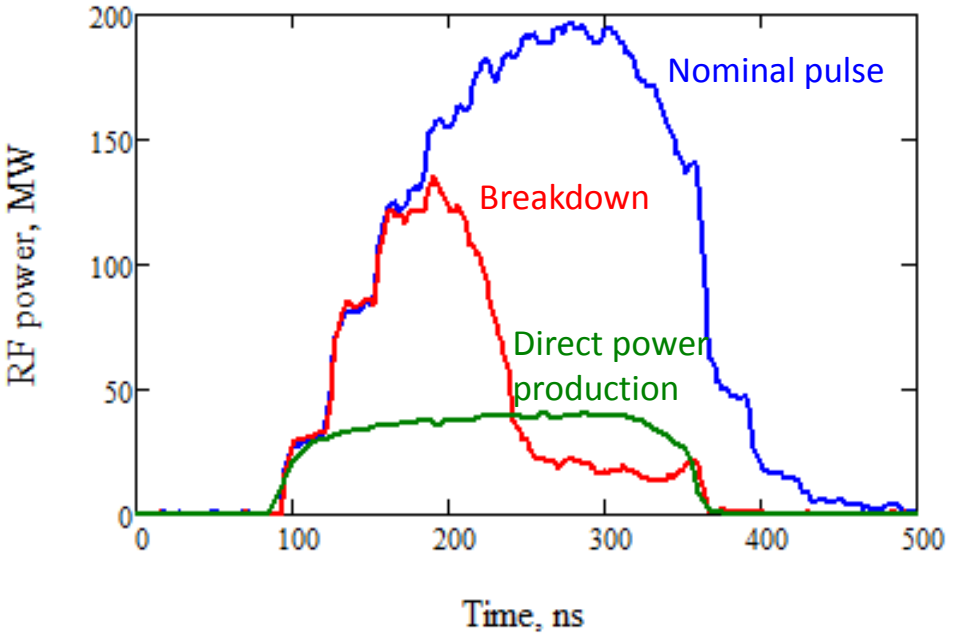
We have developed a number of computer models of varying complexity which accurately reconstruct the processes in the system with re-circulation:





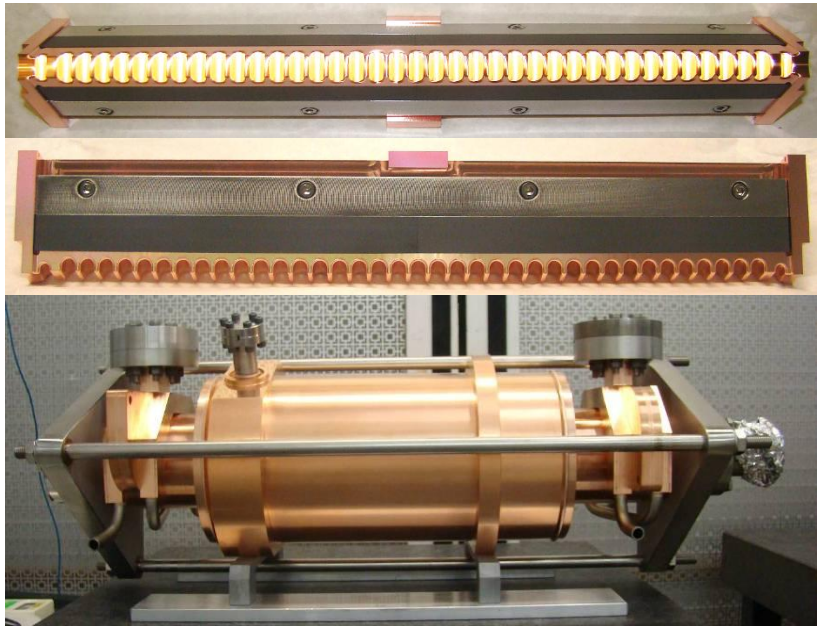
RF breakdown in the system with re-circulation

Typical breakdown pulse envelope



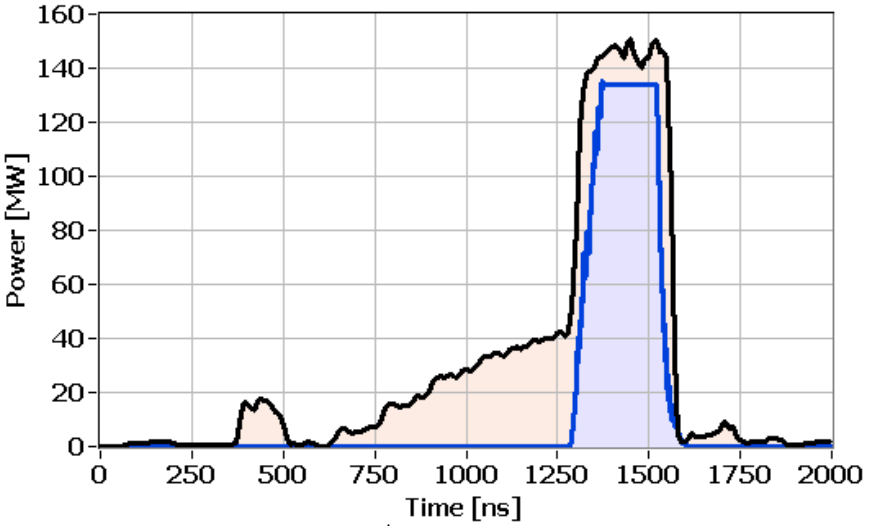
Here we cannot give a firm conclusion about the breakdown trip rate in our experiments in the TBTS, because of insufficient statistics (CTF3 operates at 1 Hz repetition rate) and some difficulties with providing stable drive beam generation during long enough periods. These experiment were done in a different way (see next slide).

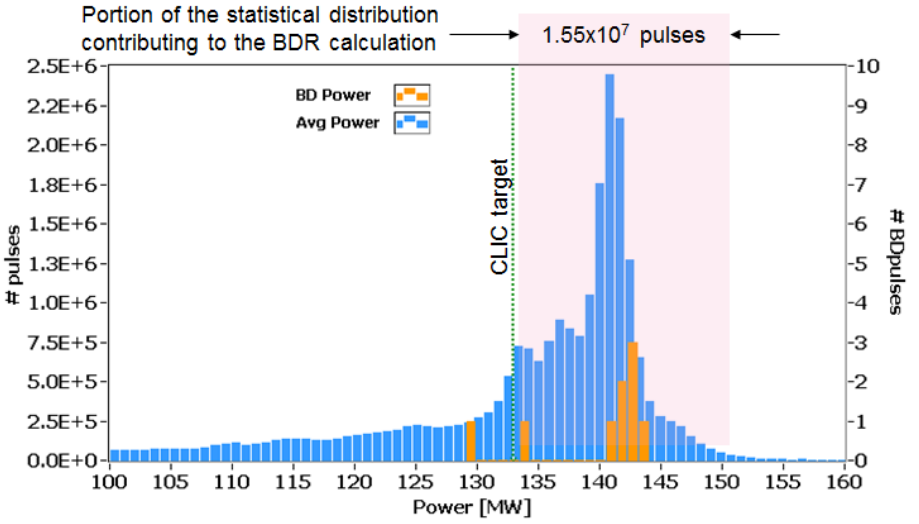
Klystron driven PETS testing at ASTA (SLAC)



Scaled, 11.424 GHz PETS

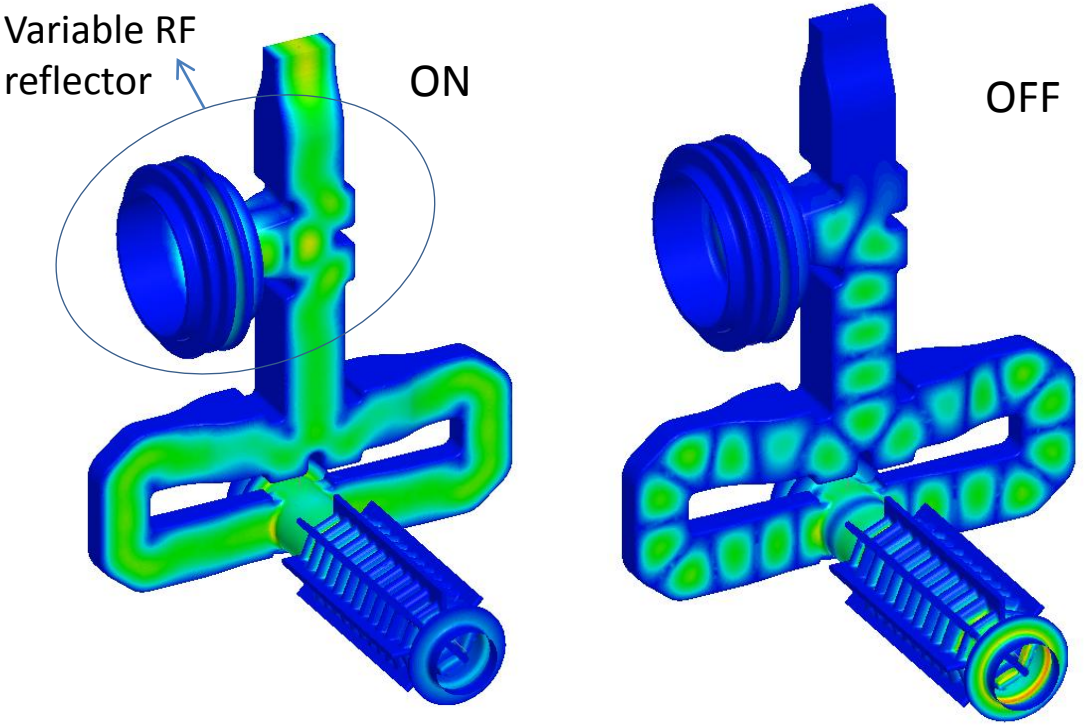
Typical RF pulse shape in ASTA during the last 125 hours of operation at 60 HZ repetition rate.





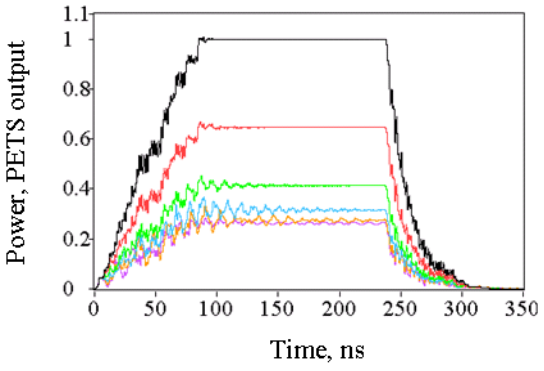
The tests at a fixed power level were ended when the measured breakdown trip rate was close enough to the CLIC specification of 1.0E-7/pulse/m. In the ASTA test, it occurred after 80 hours of operation without breakdown (BDR <2.4E-7/pulse/m).

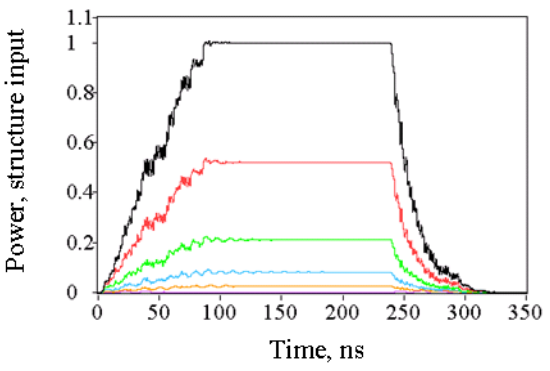
CLIC PETS ON/OFF concept

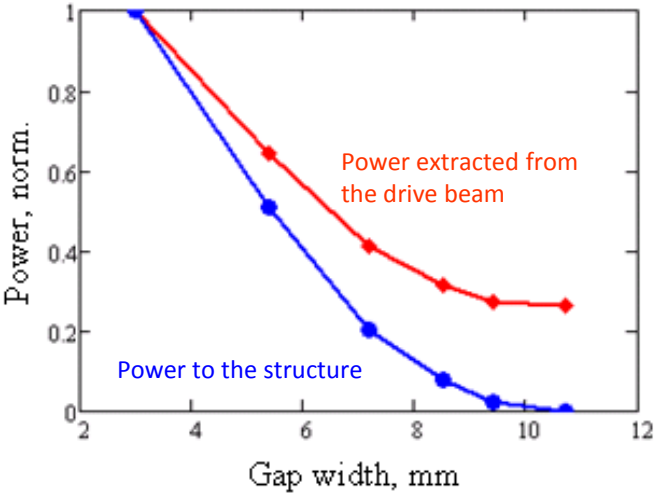


An external high power variable RF reflector is the key component of the system. Providing the whole range of reflections from 0 to 1, it can fully or partially terminate the RF power transfer from the PETS to the accelerating structure.

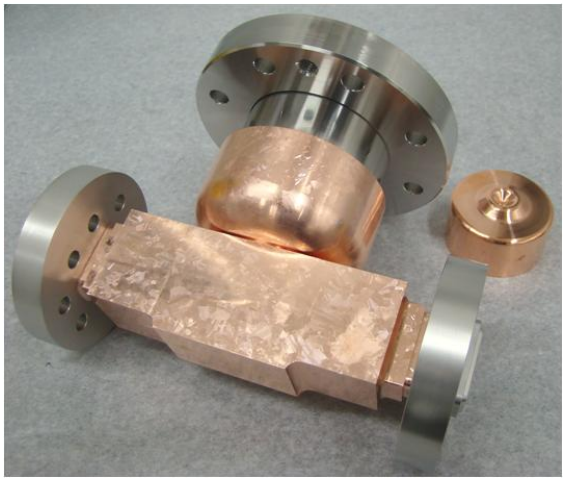
Full model analysis (GDFIDL + HFSS)

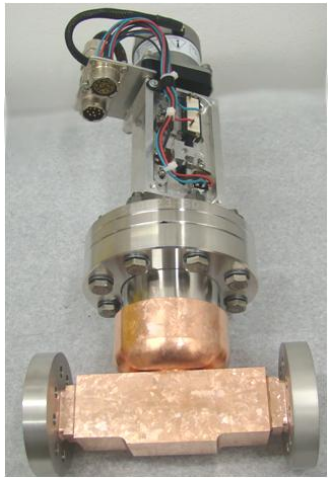




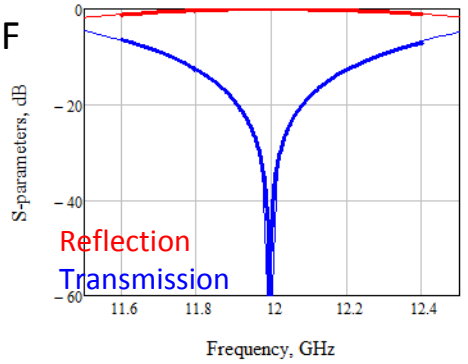


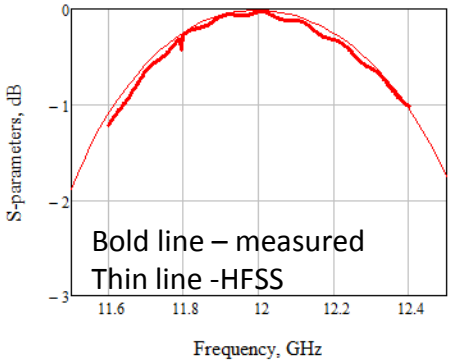
The new variable RF reflector and short circuit

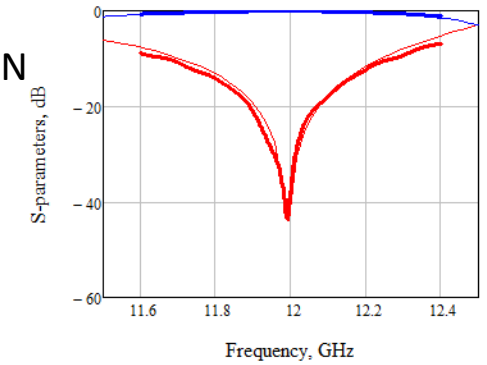


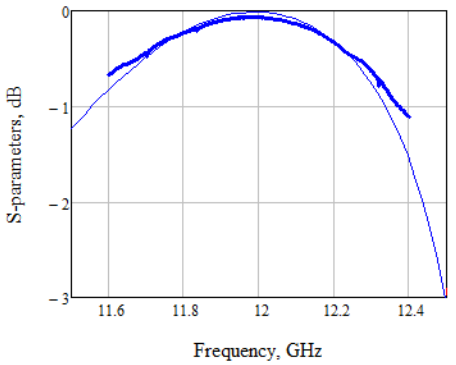
OFF



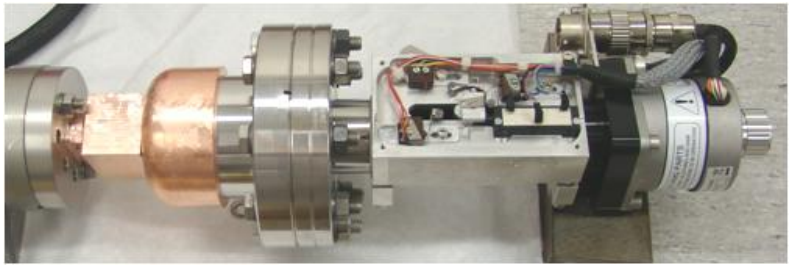


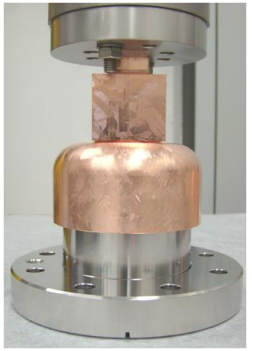
ON

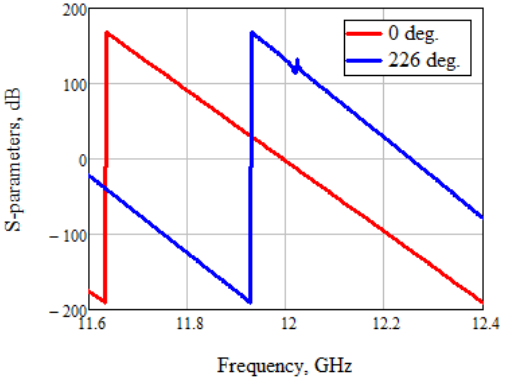




The variable RF short circuit

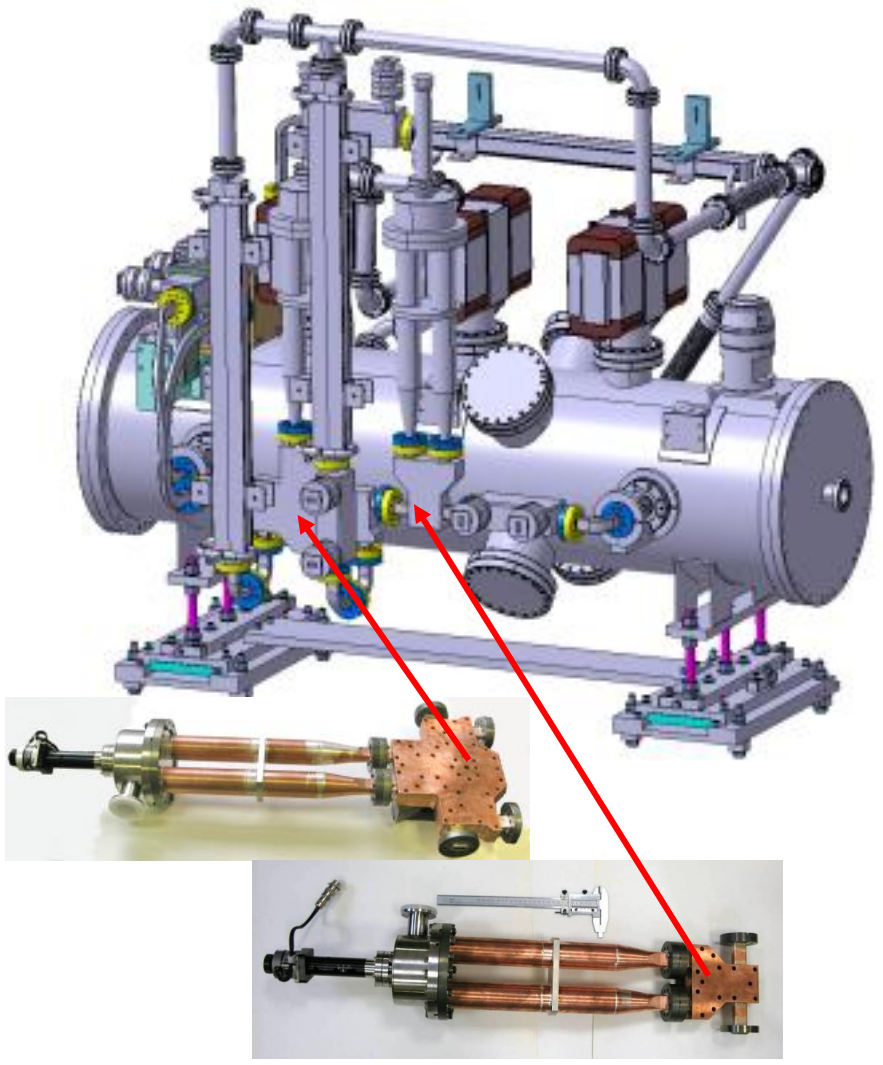




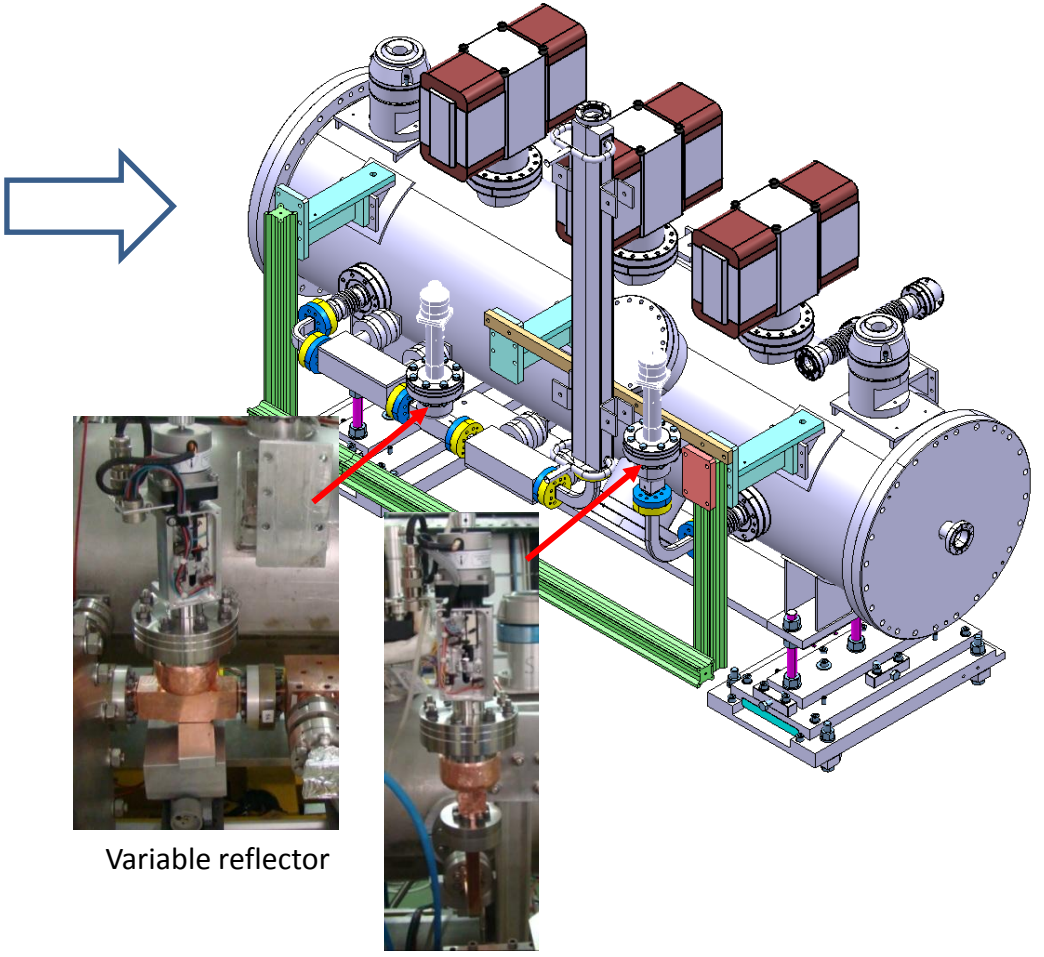


Modification of the TBTS PETS tank layout in 2011.

External recirculation loop



Internal recirculation

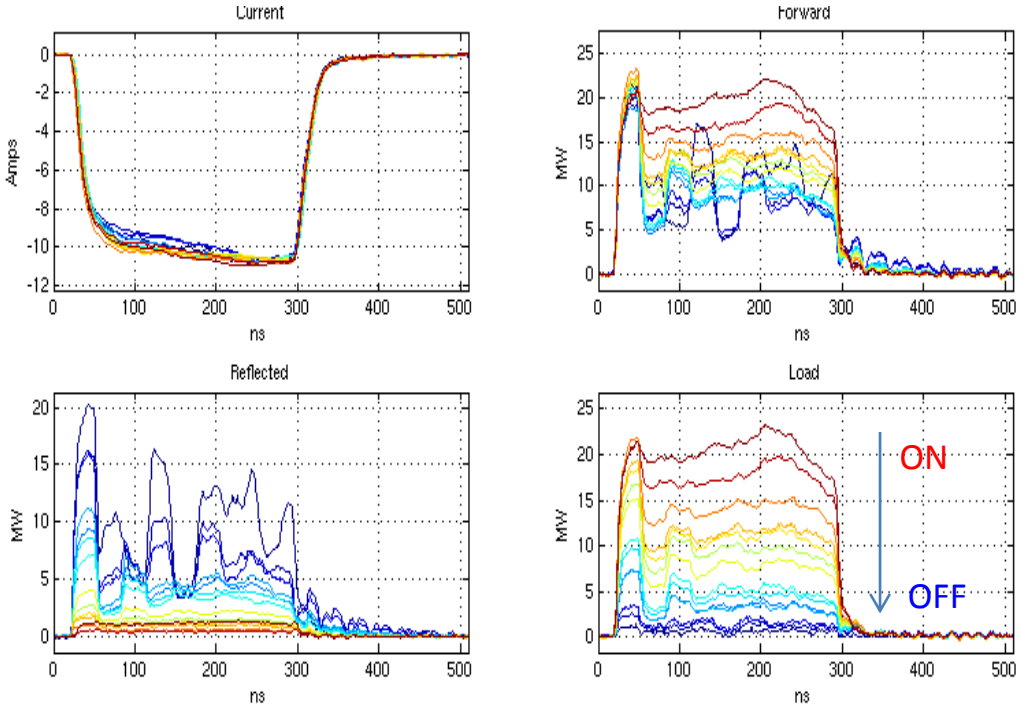


Variable reflector

Variable short circuit

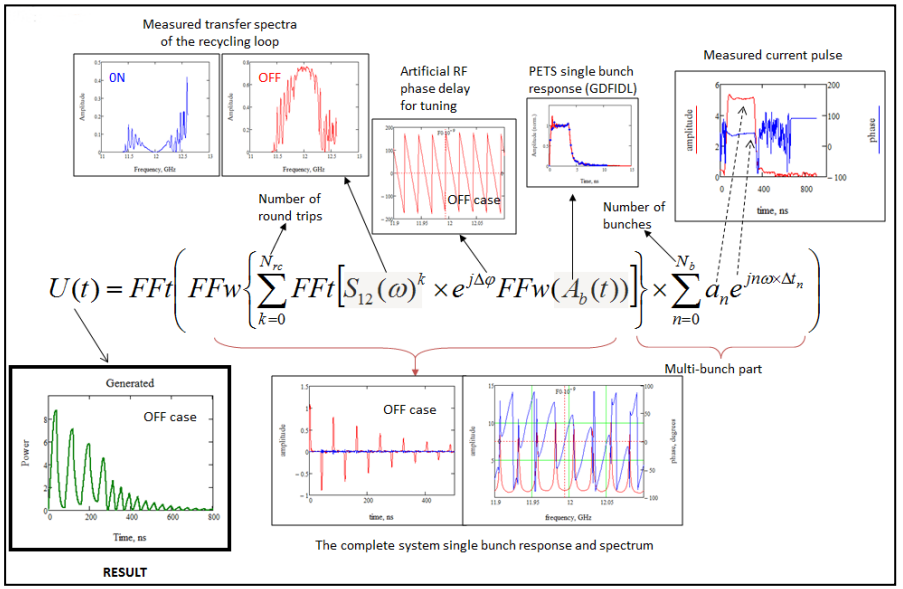
Variable Power splitter and Phase shifter, GYCOM (Russia).

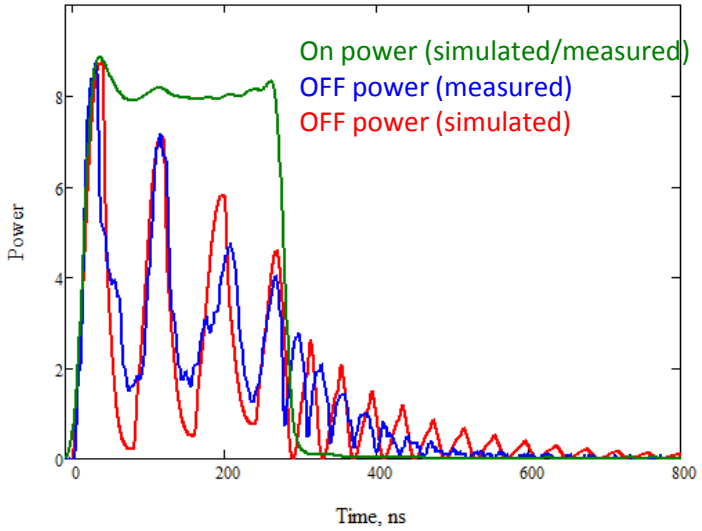
PETS ON/OFF demonstration with beam



During experiments with the beam, the variable reflector settings were changed gradually from full reflection to full transmission. The results were in a good agreement with the system computer modeling, where measured S-parameters of all components were used as an input.

Computer model vs. experiment

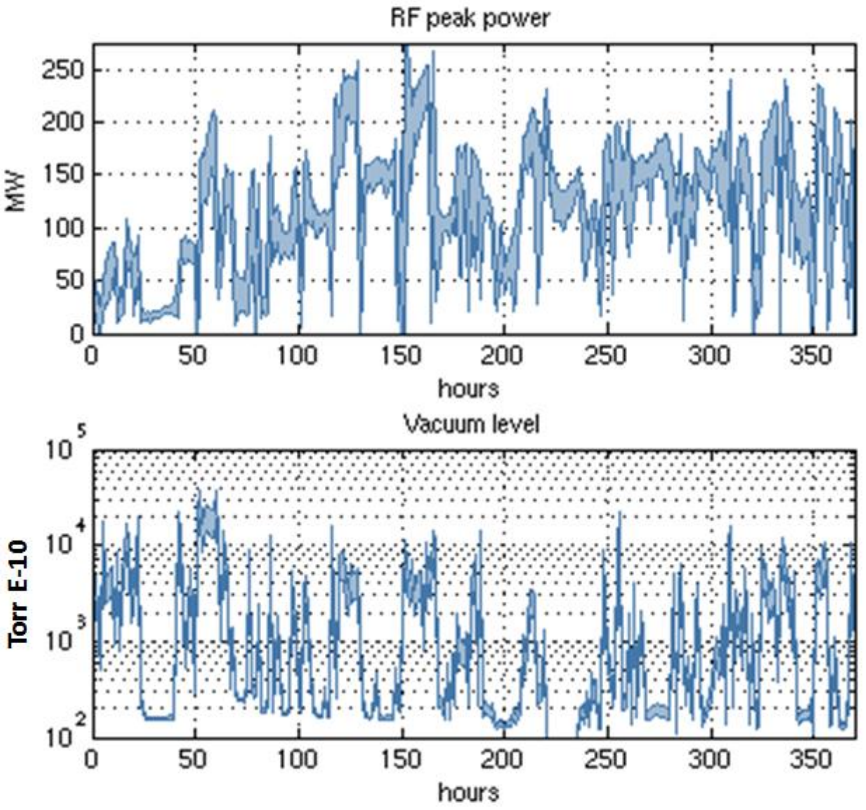




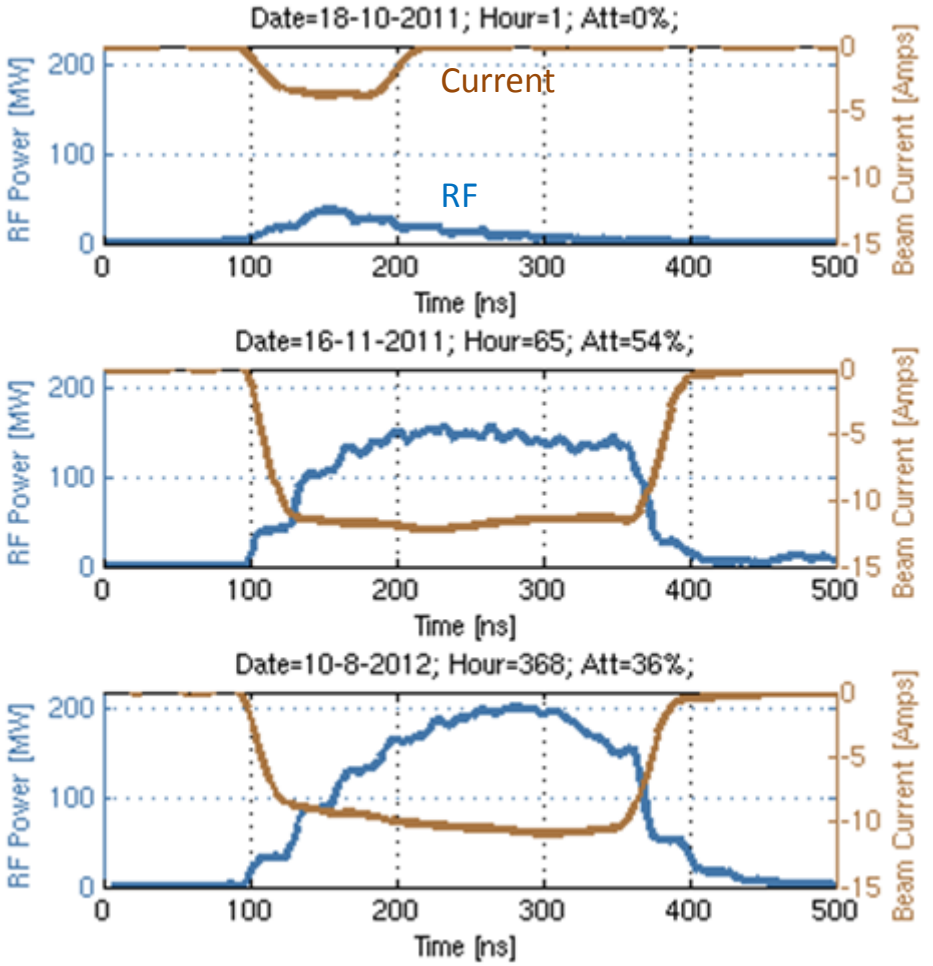
I. Syratchev, CERN, Linac 2012, Tel-Aviv, Israel

PETS ON/OFF high RF power capability demonstration

The PETS ON/OFF operation history



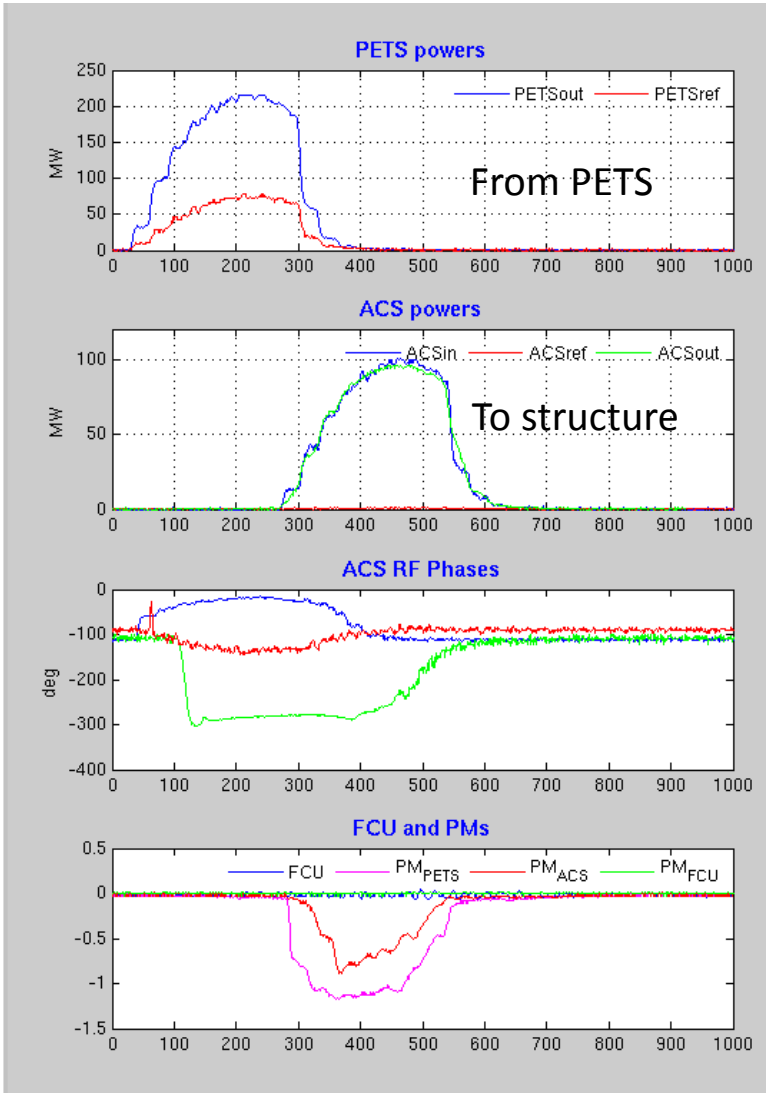
To demonstrate the power capability of the new RF components used in the ON/OFF RF circuit, we set the recirculation loop parameters to their amplification mode.



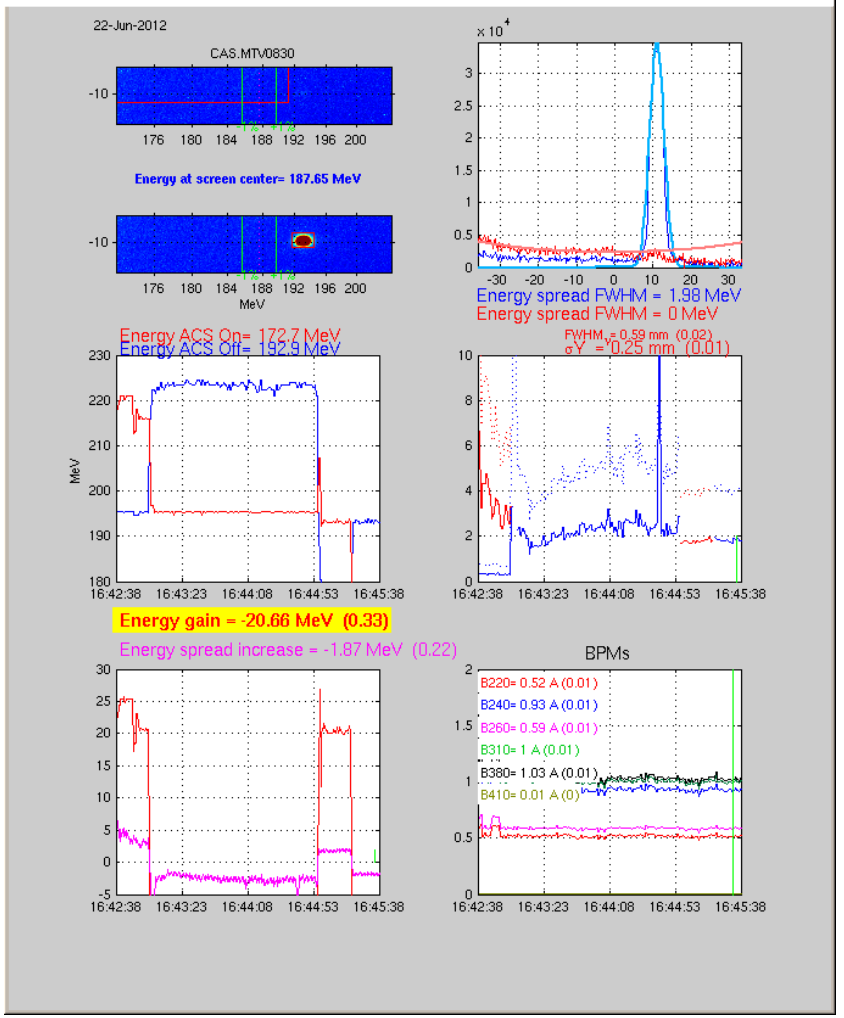
Typical drive beam current and RF power pulses at the different stages of operation.

Two beam acceleration at the TBTS

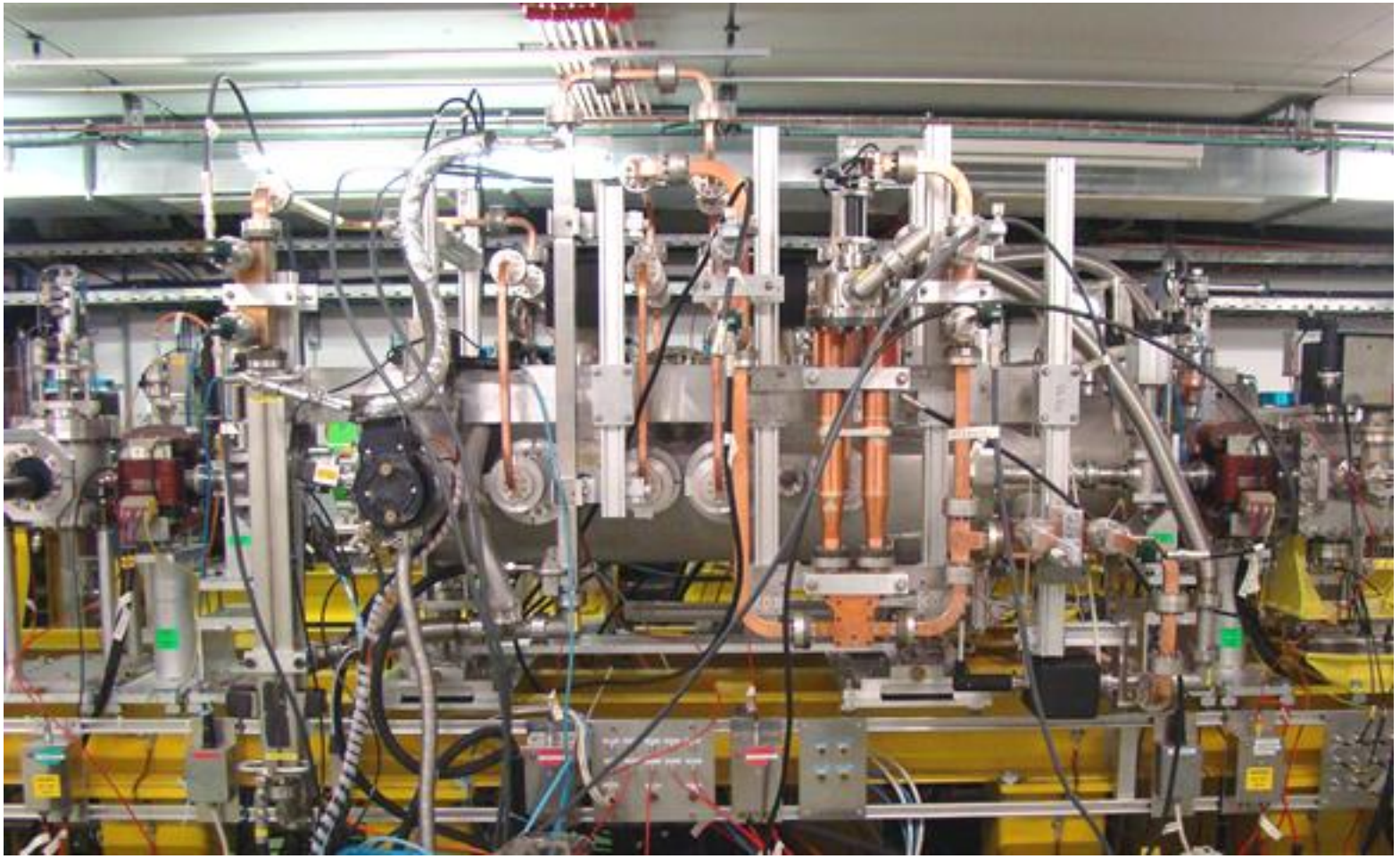
Typical Rf pulses in the system



Two Beam acceleration – 145 MV/m!
(31 MeV gain - about 105 MW input)



TBTS as of today (September 4, 2012)



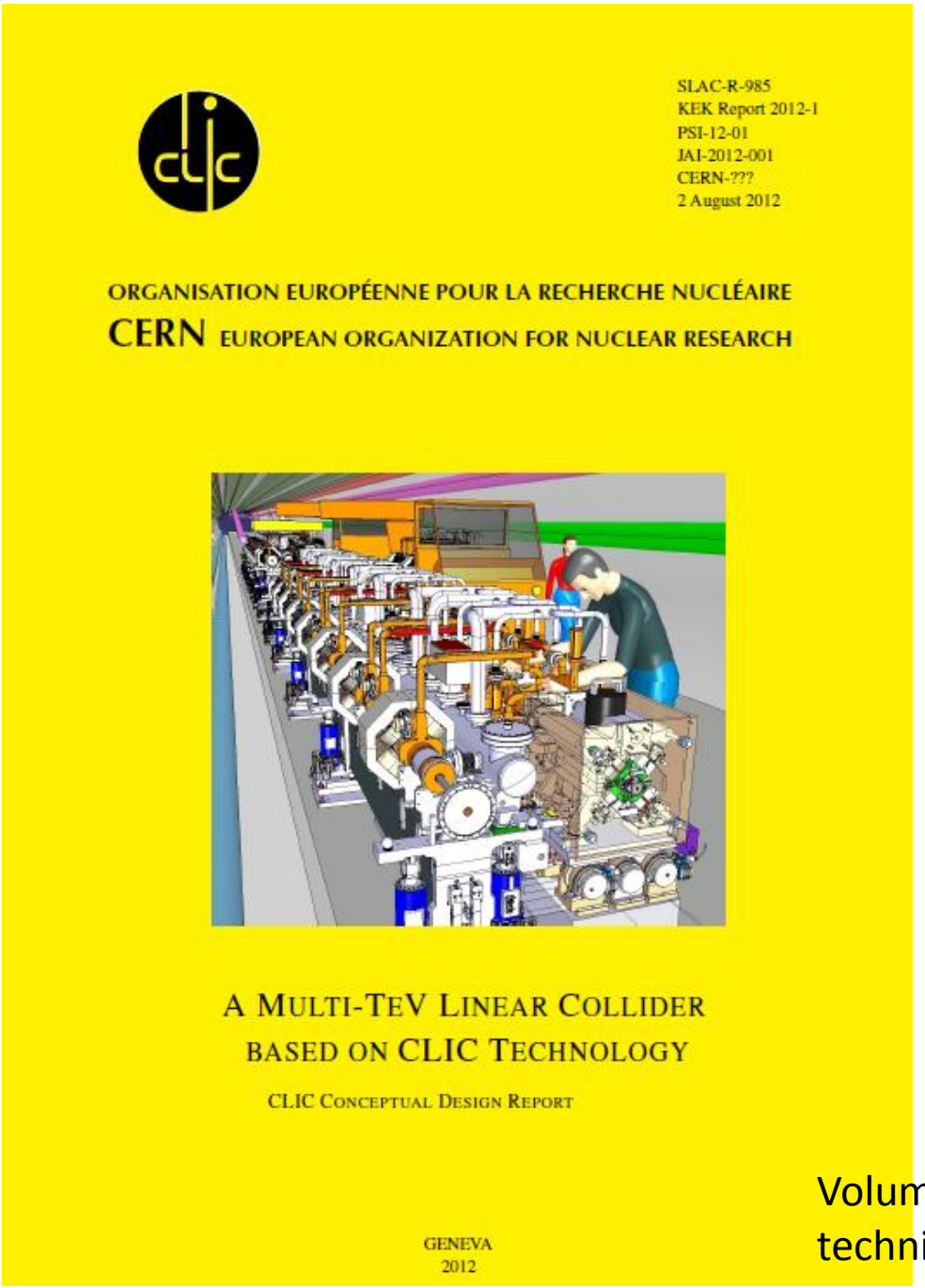
The new tank with <u>two</u> accelerating structures is installed and connected to the PETS

Summary

The feasibility of all the issues associated with high RF power generation using the drive beam was successfully demonstrated in the dedicated testing program that was conducted at CERN during the period of 2008-2012:

- ✓ The scaled, 1 m long, PETS was installed and operated in beam driven mode with external RF re-circulation in order to compensate for the lack of drive beam current and pulse length. The PETS routinely produced RF power with peak levels well in excess of the CLIC specifications.
- ✓ In the klystron driven experiments at ASTA (SLAC), the PETS high power tests at a fixed power level were ended when the measured breakdown trip rate was 2.4E-7/pulse/m. Which is close enough to the CLIC specification of 1.0E-7/pulse/m.
- ✓ The new high RF power variable RF reflector and variable RF short circuit were designed and fabricated. These devices have replaced the external recirculation in the special, 1 m long PETS installed in CTF3. The PETS ON/OFF operational principle and high peak RF power capability were successfully demonstrated in experiments with the CTF3 drive beam.

http://project-clic-cdr.web.cern.ch/project-CLIC-CDR/CDR_Volume1.pdf



"…This report describes the accelerator studies for a future multi - TeV $e^+ e^-$ collider based on the Compact Linear Collider (CLIC) technology…. The focus of CLIC R&D over the last years has been on addressing a set of key feasibility issues that are essential for proving the fundamental validity of the CLIC concept…".

Volume 1 covers the accelerator and technical systems on 812 pages