Status of high-power X-band RF systems development at CERN

I .Syratchev

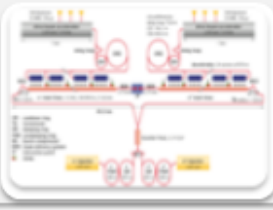
CLIC Project Implementation Plan 2012-16

S. Steinar, https://indico.cern.ch/conferenceDisplay.py?confId=239376

Define the scope, strategy and cost of the project implementation

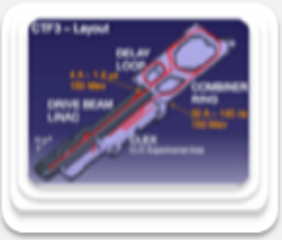
LHC data crucial – also at nominal energy, re-baselinimg studies ongoing (375 GeV, ~1.5 TeV, 3 TeV) – including more work on a klystron based initial phase

Costs, power, scheduling, site, etc.



Define and keep an up-to-date optimized overall baseline design that can achieve the scope within a reasonable schedule, budget and risk.

Overall design and system optimization, activities across all parts of the machine from sources to beam-dump, links to technical developments and system verification activities



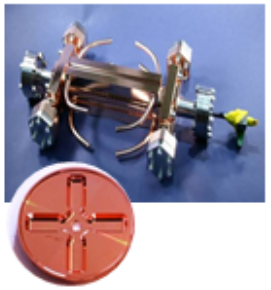
Identify and carry out system tests and programs to address the key performance and operation goals and mitigate risks associated to the project implementation.

Priorities are the measurements in: CTF3+, ATF, FACET and related to the CLIC Drive Beam Injector studies, addressing the issues of drive-beam stability, beam-loading experiments, RF power generation and two beam acceleration with complete modules, as well as beam based alignment/beam delivery system/final focus studies.

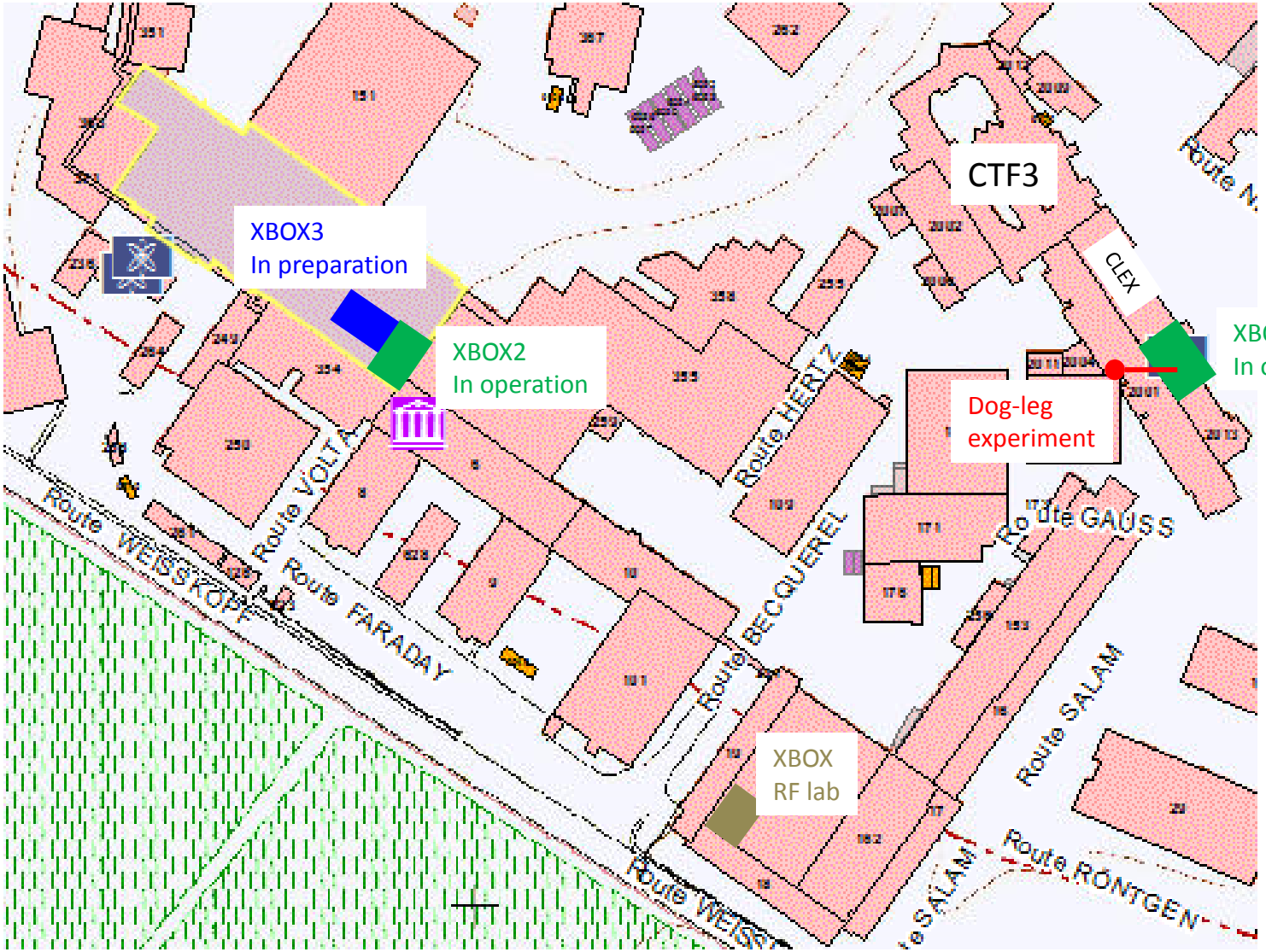
Develop the technical design basis. i.e. move toward a technical design for crucial items of the machine – X-band as well as all other parts.

Priorities are the modulators/klystrons, module/structure development including significantly more testing facilities, and alignment/stability studies.

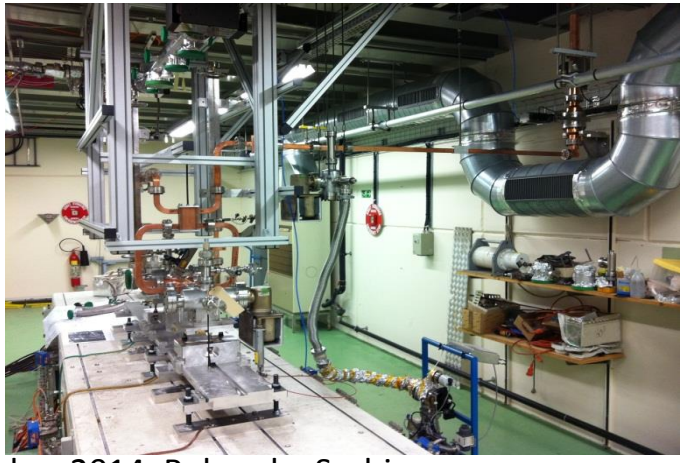
A number of specific instrumentation and technical system studies.

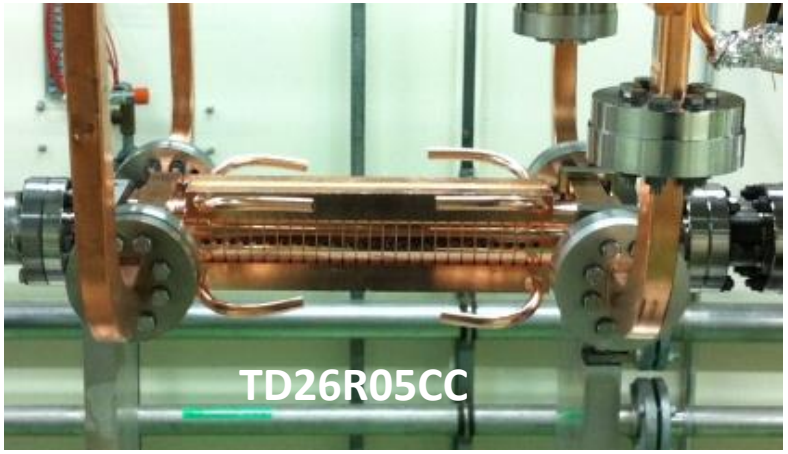


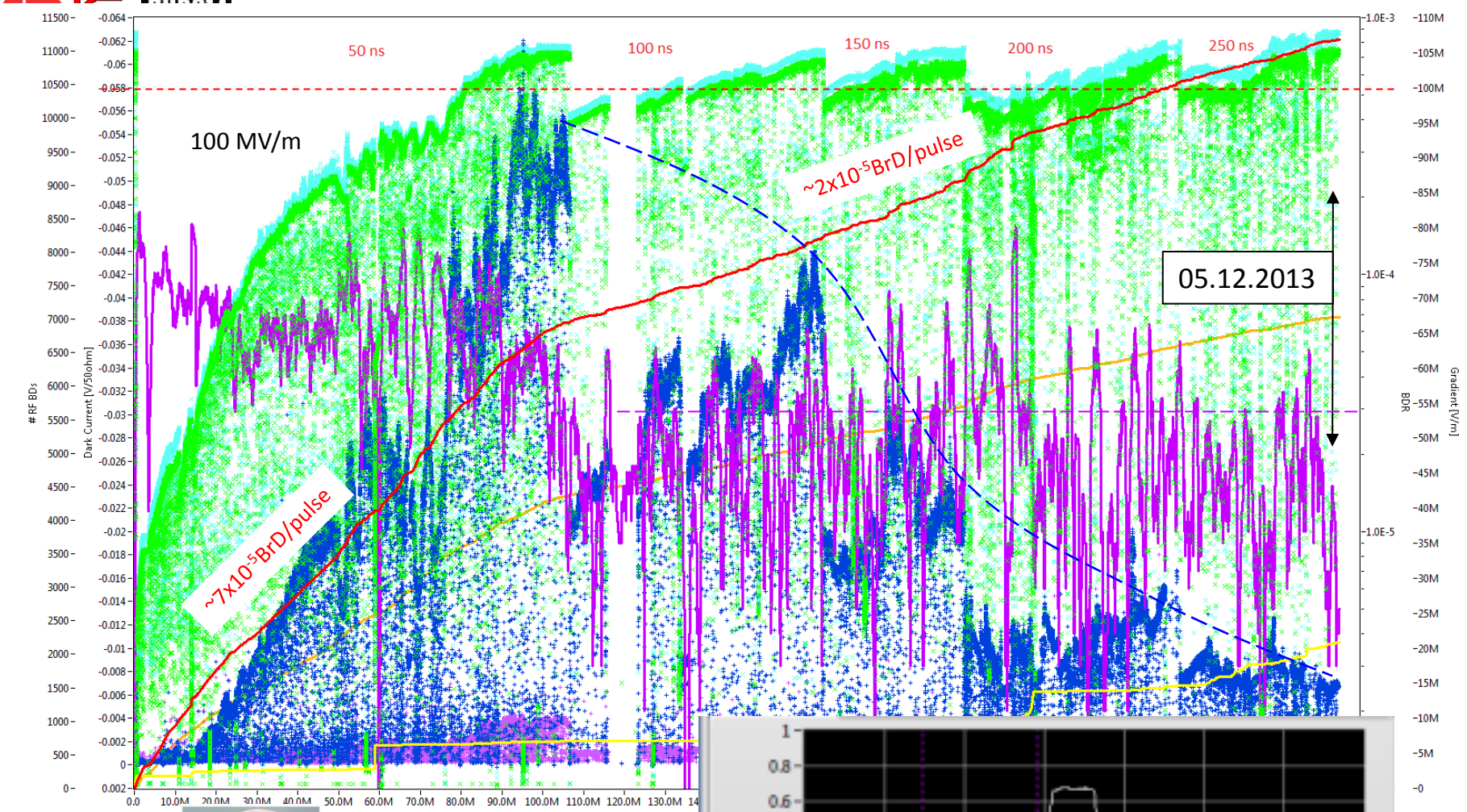
XBOX'es on the CERN map

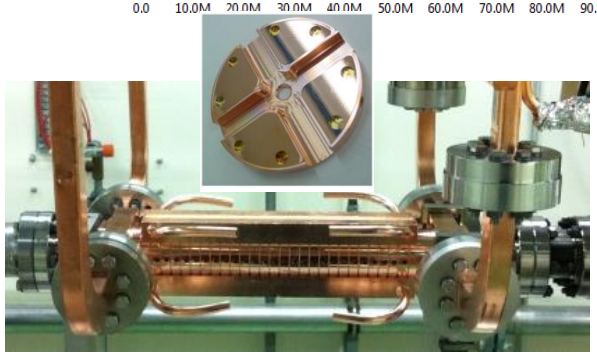


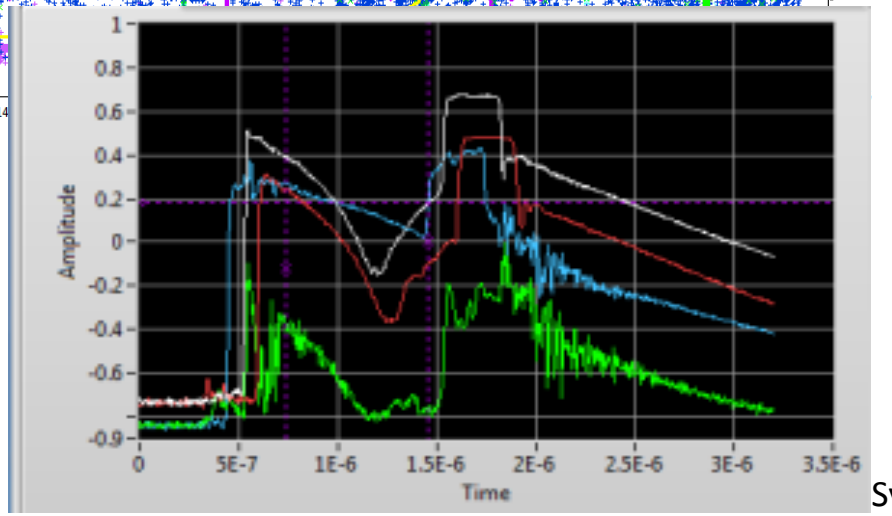
XBOX1 is up and running for almost 3 years





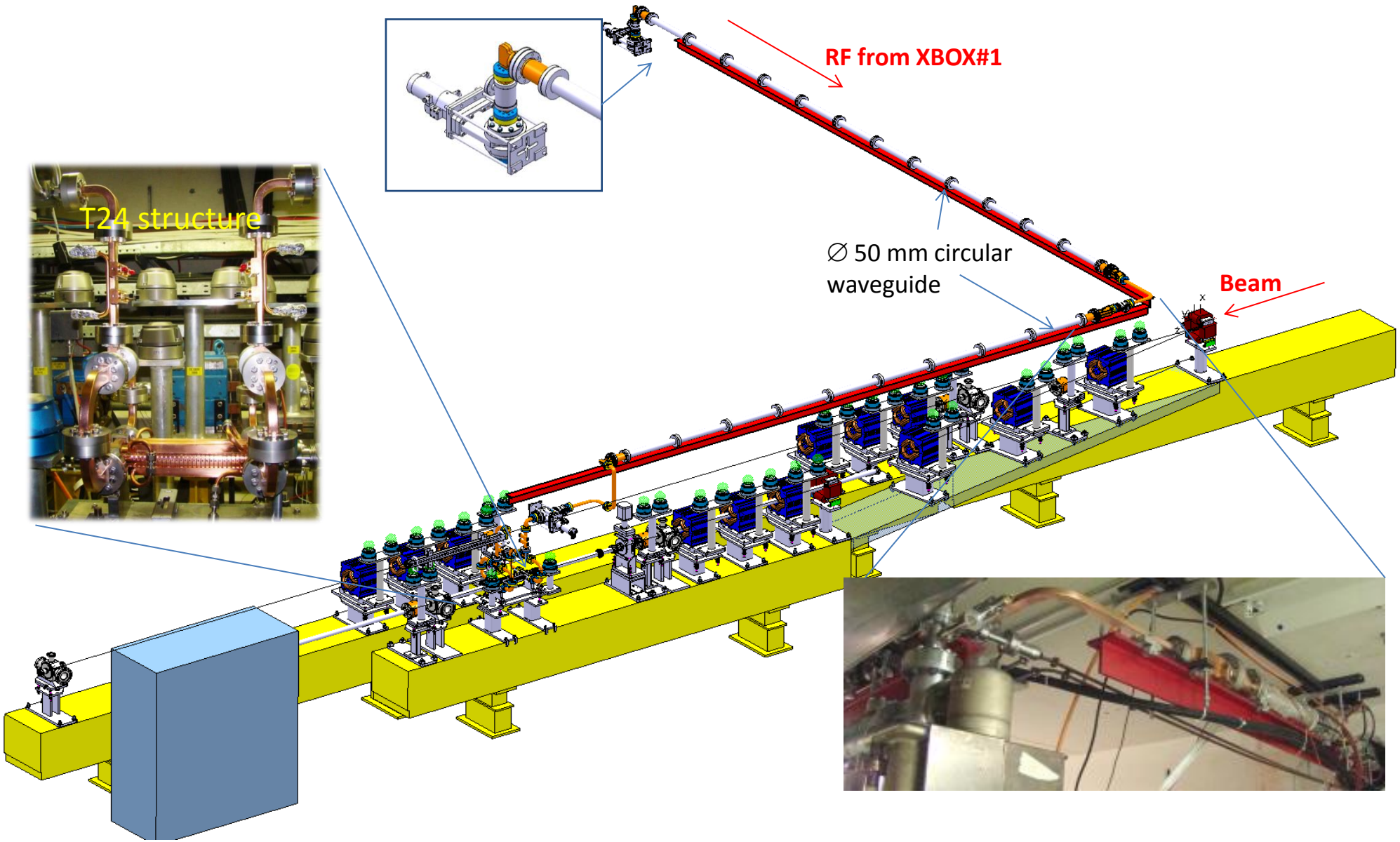

50 ns
100 ns
150 ns
200 ns
250 ns
100 MV/m
~2x10-5BrD/pulse
~7x10-5BrD/pulse
05.12.2013
RF BDs
Dark Current [V/50ohm]
BDR
Gradient [V/m]
REF
KREF
Average Gradient
BDR
DC1 Average
DC2 average
Cluster REF
Beam Axis IPs
Manifold IPs
Peak Gradient
Loadside win
IP before PC
IP after PC
Circ WG gallery
Gun
Collector
Tubeside win
Pulses
294.96M
Equivalent hours @ 50Hz
1639
REF breakdowns
11168
cluster BD
7035
BDR Total
3.8E-5
BDR cluster
2.4E-5
Start
13:00 19/07/13
End
22:00 03/12/13
delta BD (s)
30
KREF breakdowns
2172



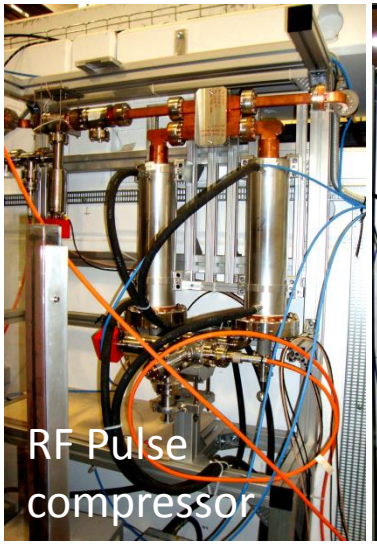

Amplitude
Time

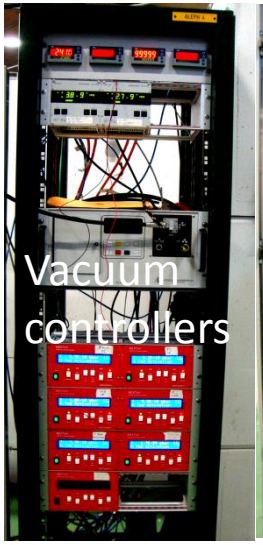
The first commercial (CPI) 50 MW 12 GHz klystron is in operation in XBOX#1 since June 2014

Dog-leg test RF network layout (overall measured RF transfer efficiency ~0.67)



High RF power X-band test station XBOX#2



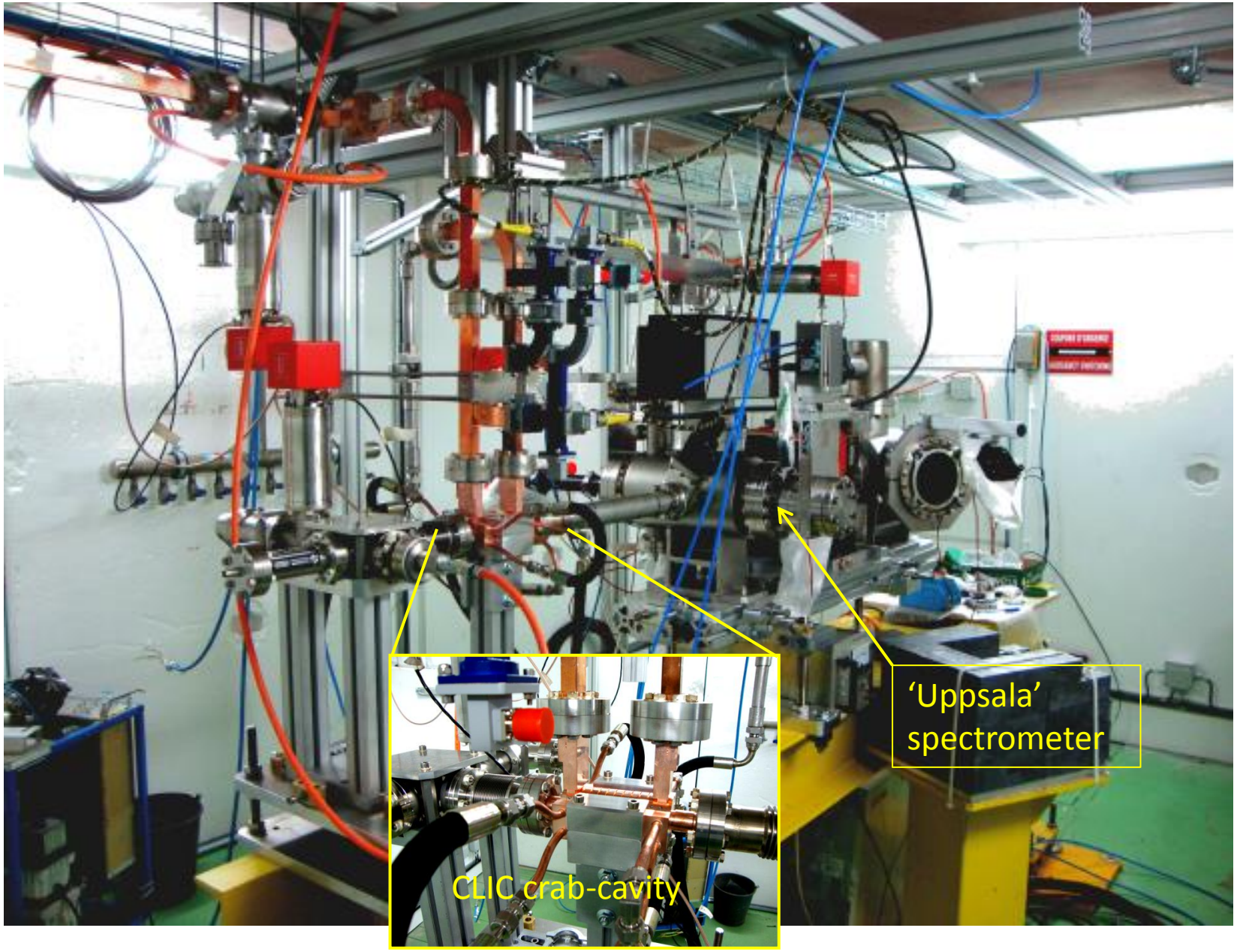


PXI (LabVIEW) based LLRF architecture fox XBOX2

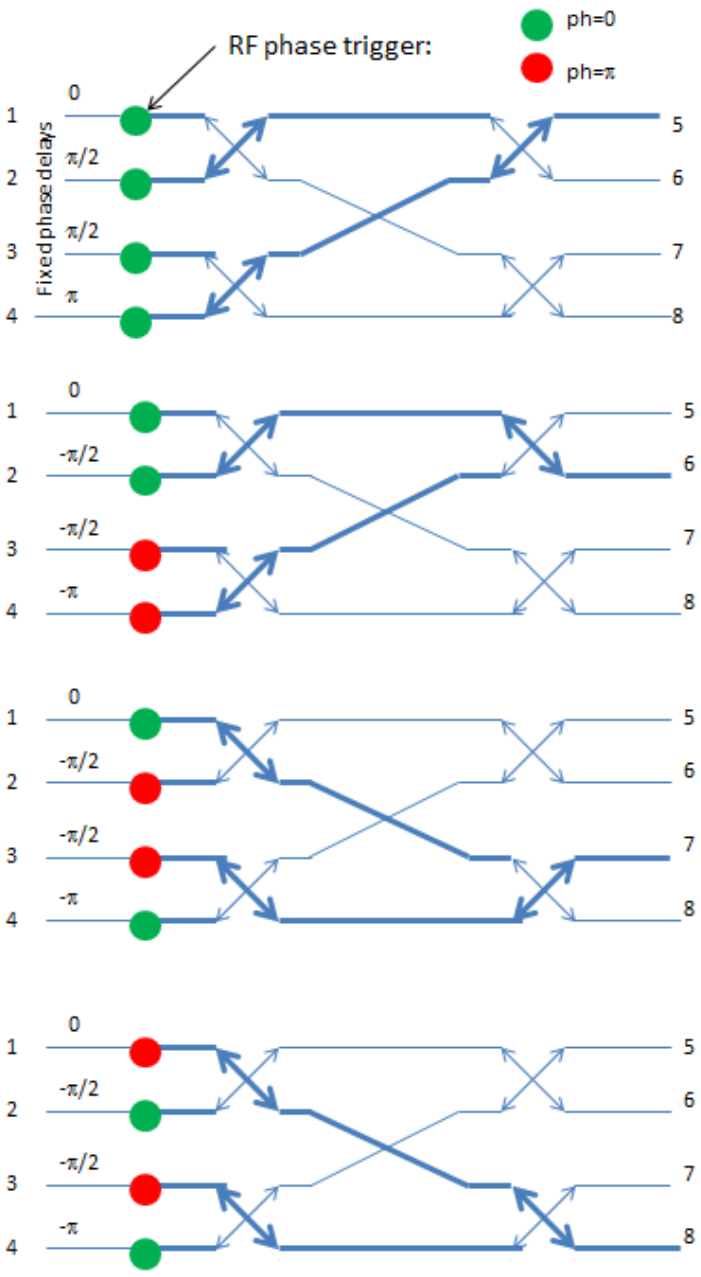
Glossary: PXI - **P**CI e**X**tensions for **I**nstrumentation

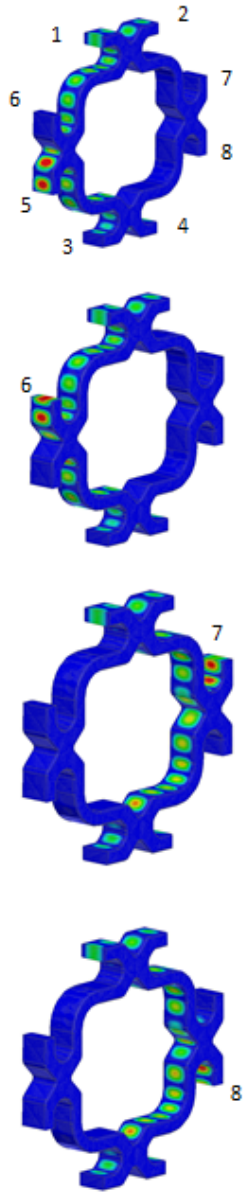
PCI - **P**eripheral **C**omponent **I**nterconnect

Inside of XBOX#2 test area

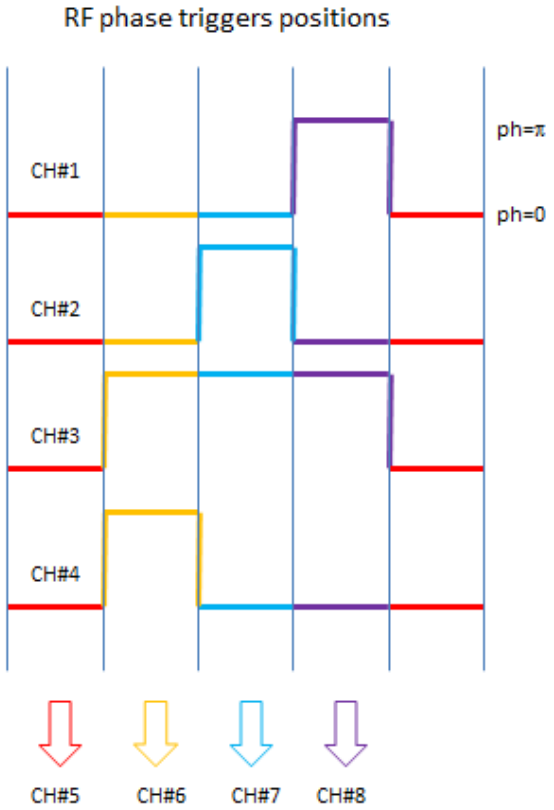


Basics of XBOX3 operation

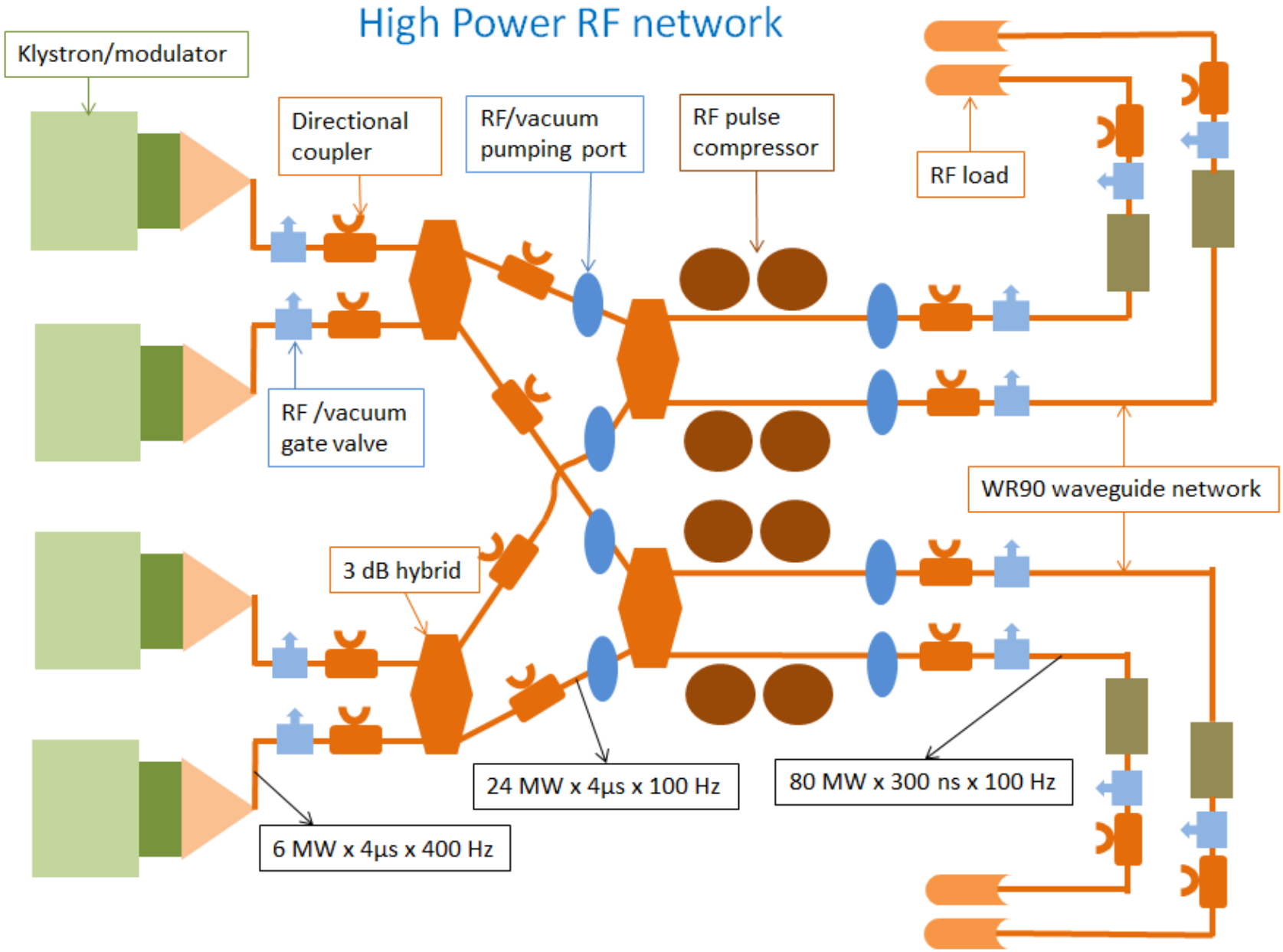




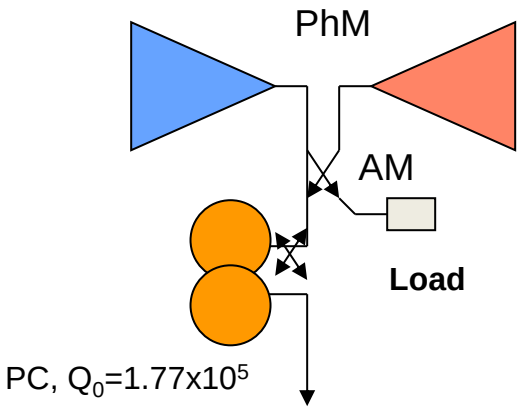
Klystrons commutation using LLRF phase triggers.

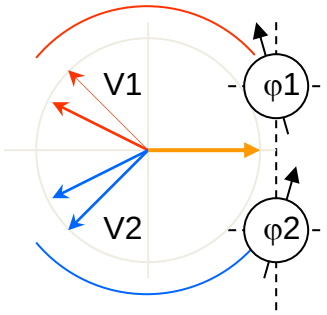


By RF phase manipulation of klystrons (each running at 400 Hz) we can established 4 testing slots running at 100 Hz each.

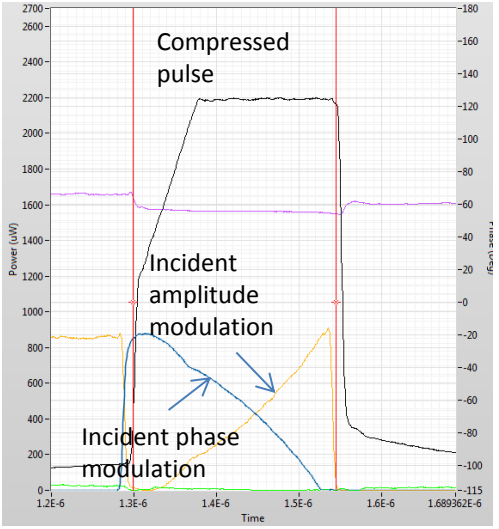

High Power RF network
Klystron/modulator
Directional coupler
RF/vacuum pumping port
RF pulse compressor
RF load
RF /vacuum gate valve
WR90 waveguide network
3 dB hybrid
24 MW x 4µs x 100 Hz
80 MW x 300 ns x 100 Hz
6 MW x 4µs x 400 Hz

Manipulating the RF pulse using phase modulation of the klystrons pair and Pulse Compression.

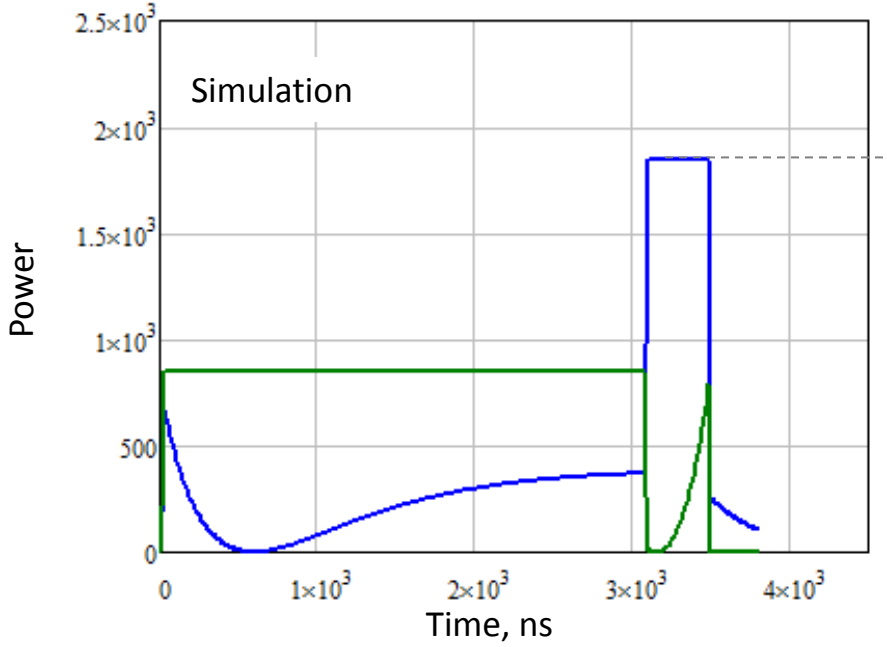


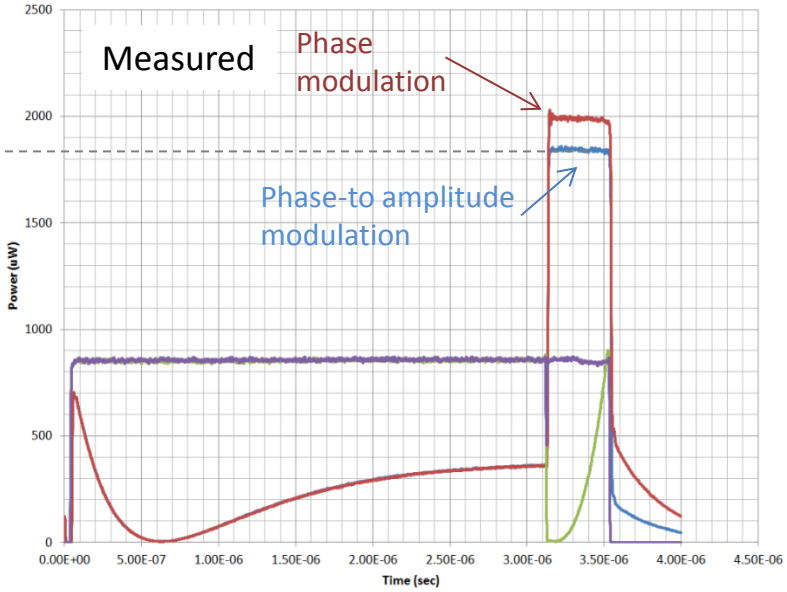


Making CLIC pulse shape with two klystrons



3.5 μs -> 400 ns

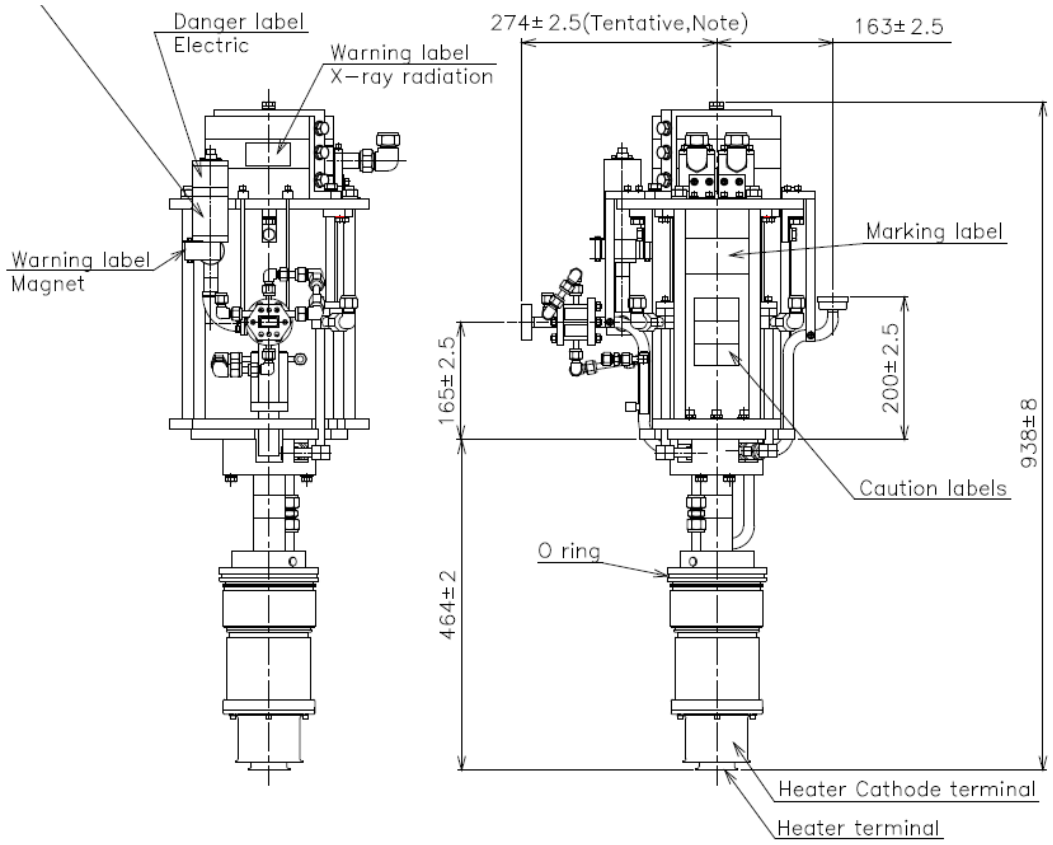




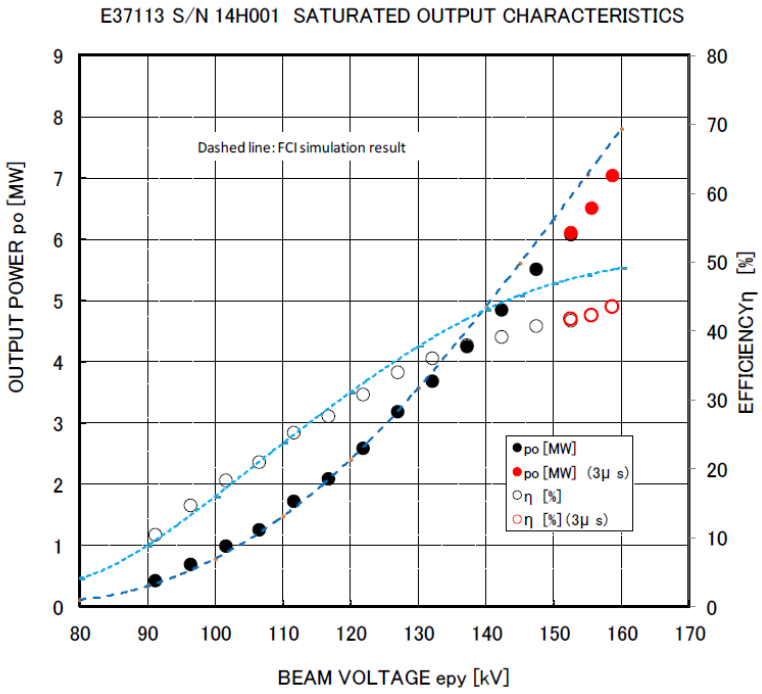
Design:

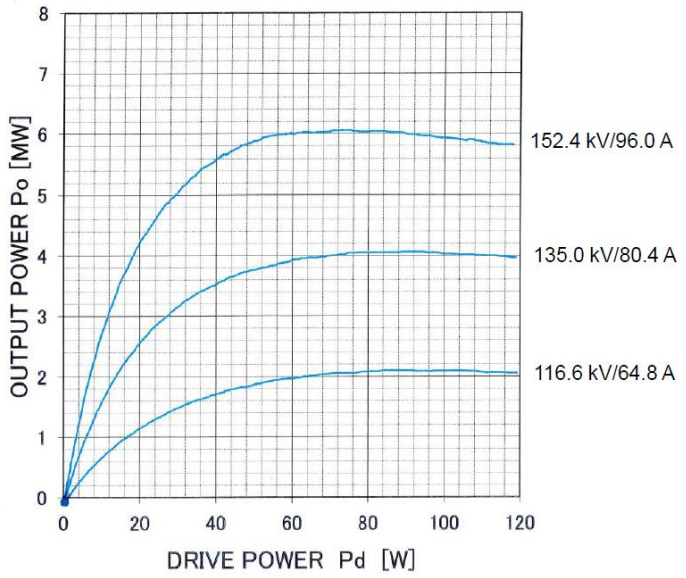
Peak power: 6 MW
Beam Voltage: 150 kV
Beam current: 90 A
Average power: 12.4 kW
Efficiency: 47.5%

TOSHIBA
Leading Innovation



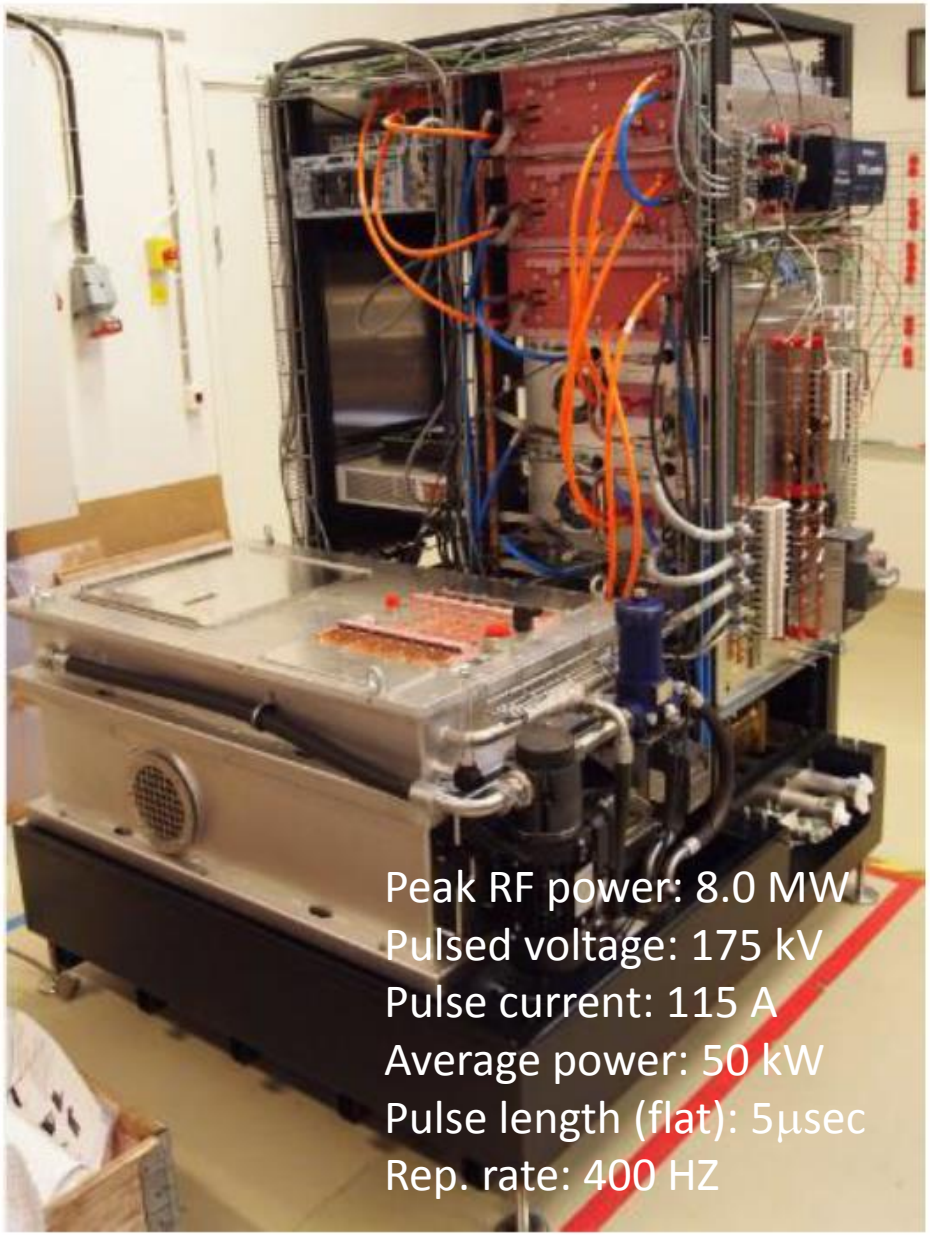
Factory tests results



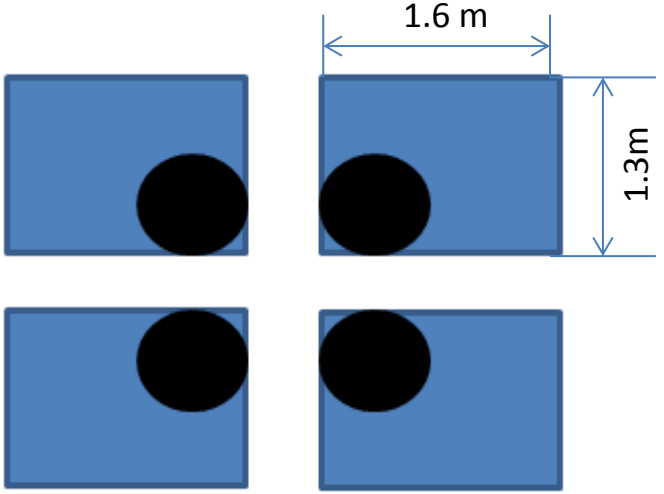


- 4 turn-key 6 MW, 11.9942 GHz power stations (klystron/modulator) have been ordered from industry.
- The first unit is scheduled to arrive at CERN in October 2014. The full delivery will be completed before July 2015.

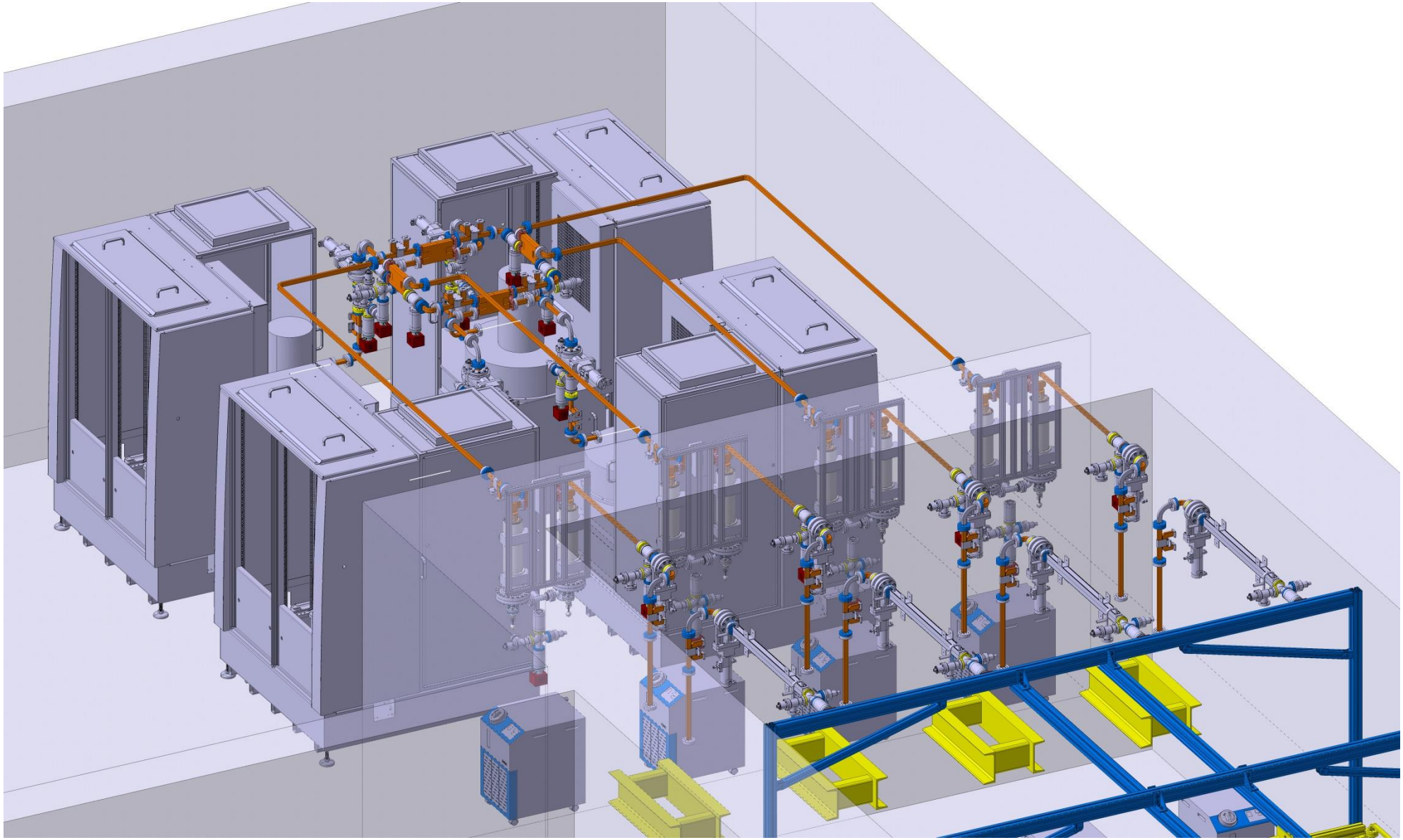
Modified K1 ScandiNova modulator



- Doubled width oil tank. To facilitate installation of the Toshiba klystron which has rather wide (∅ 0.7 m) solenoid.
- Additional cabinet (comes for free). It can be used for Klystron RF driver amplifier, Solenoid PS, Ion Pump PS etc.
- New Control System that will simplify integration of external parts and offer a lot of new features.
- Flexible design (klystrons positioning) to minimize the length of RF waveguide circuit:

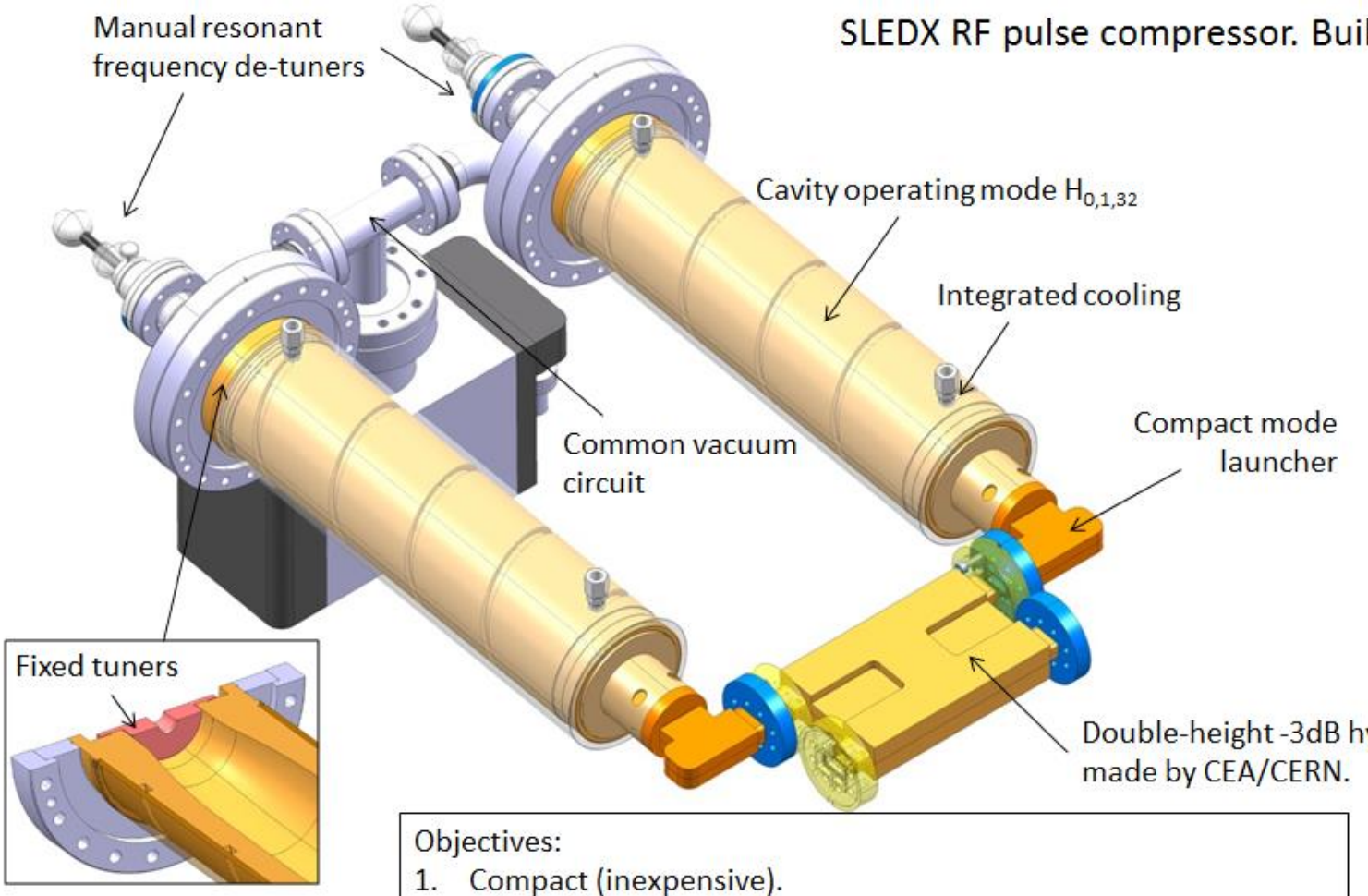


3D layout/integration of XBOX3



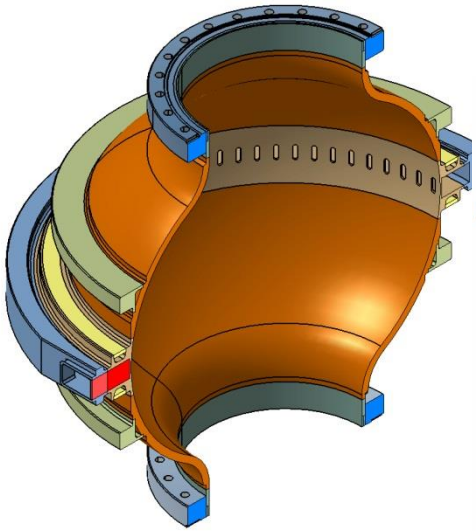

XBOX2
bunker roof
XBOX3 area

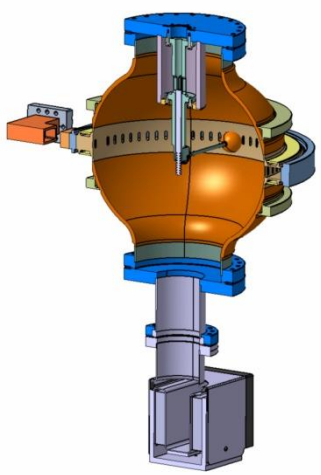
SLEDX RF pulse compressor. Built at CERN.

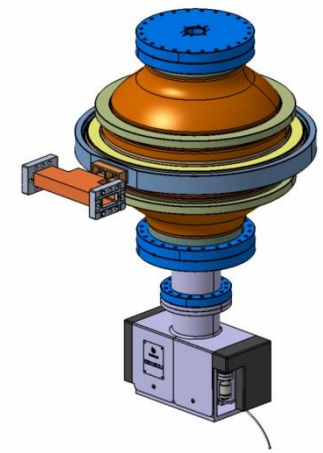


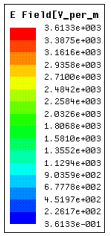
Objectives:
1. Compact (inexpensive).
2. Relaxed fabrication tolerances.
3. Fixed frequency tuners (frequency control by temperature).
4. Detuning option.

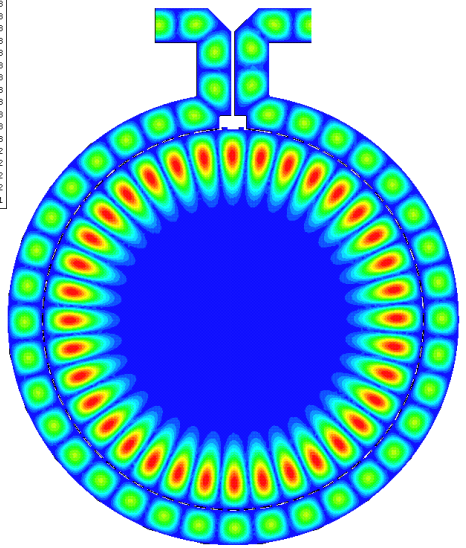
Barrel open cavity pulse compressor (BOC)

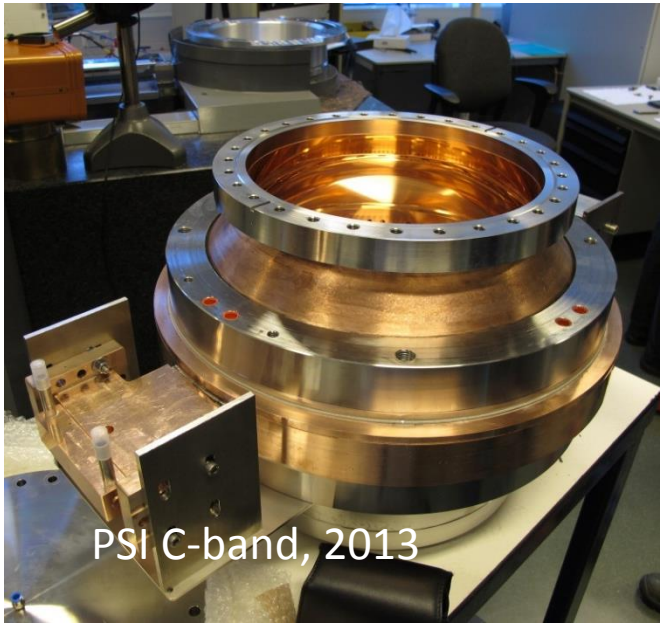






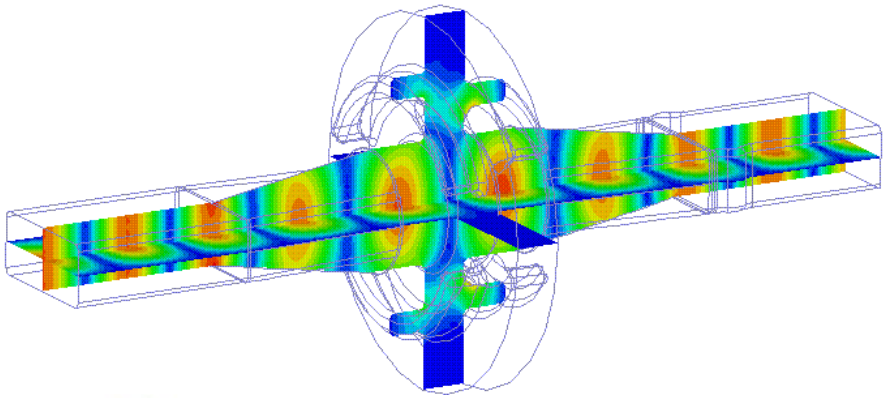


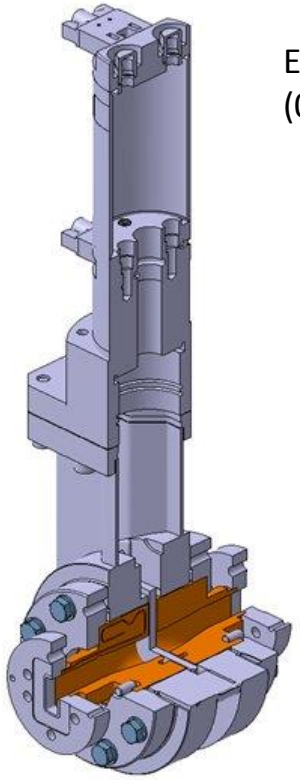




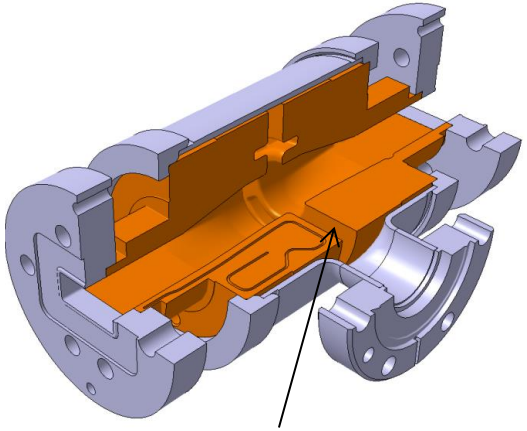
Compact RF/vacuum gate valve and vacuum pumping port

Doubled-choke WG joint

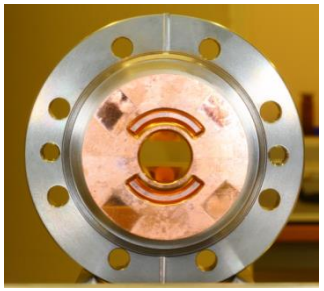


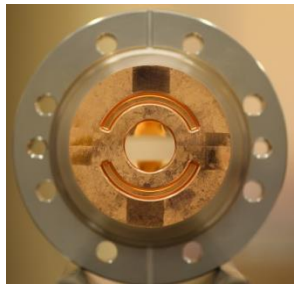


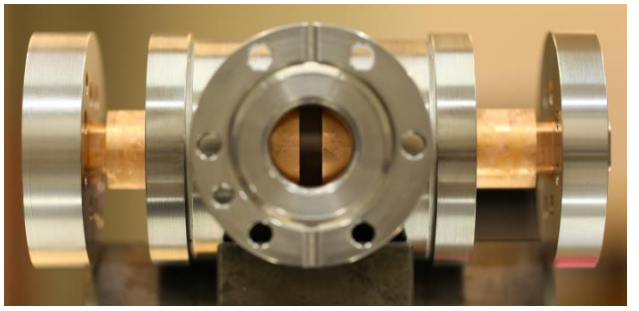
$E_{choke/max}$ (100 MW)=23.7 MV/m
($0.75 \times E_{max}$ in WR90)

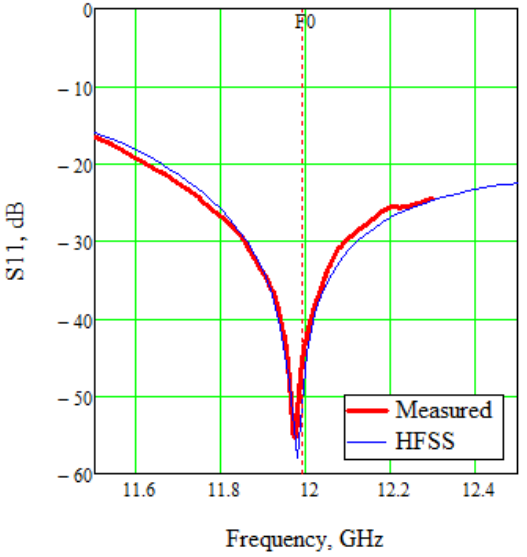


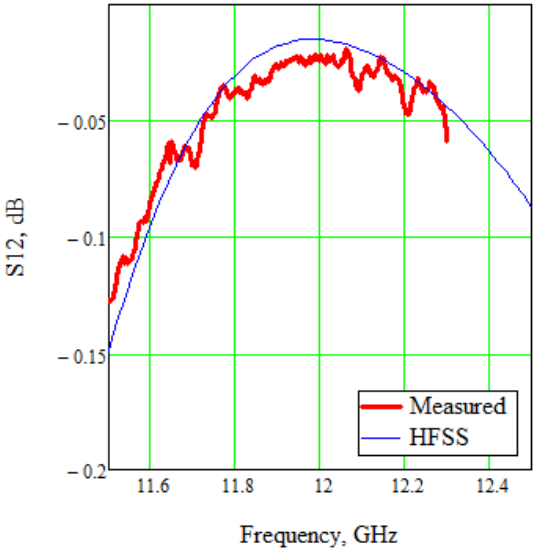
Slot width: 7mm



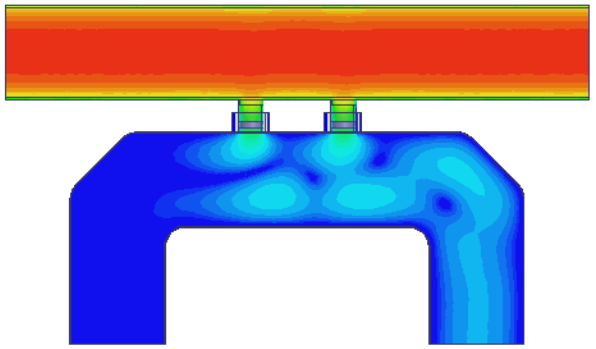


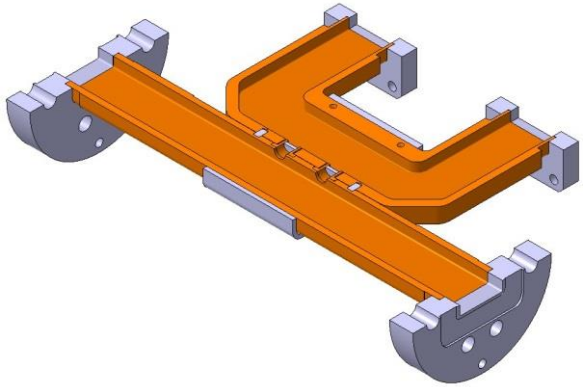


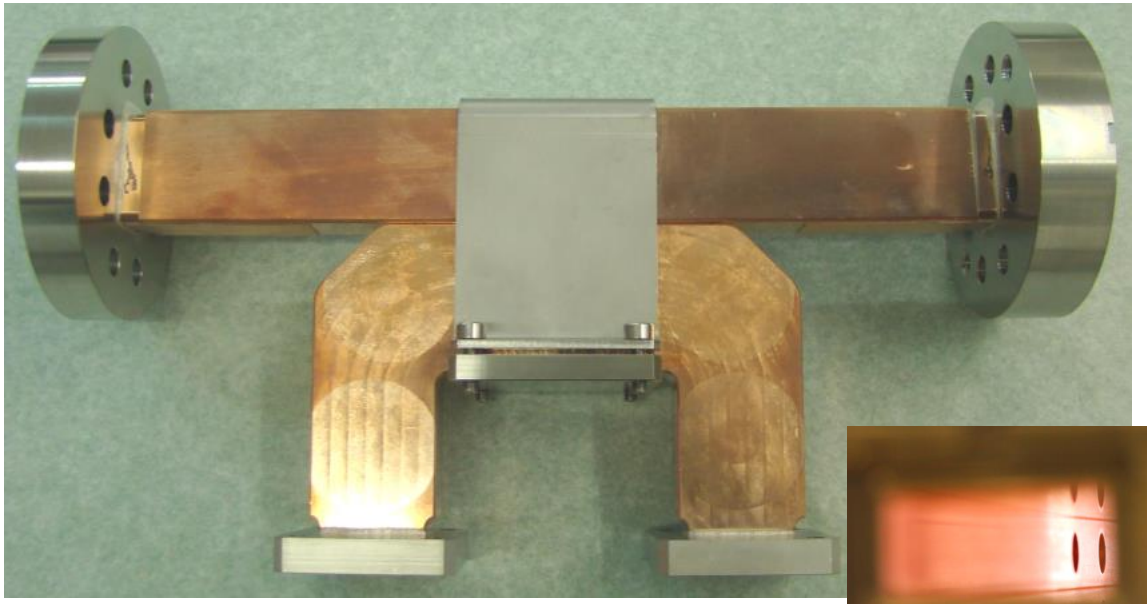


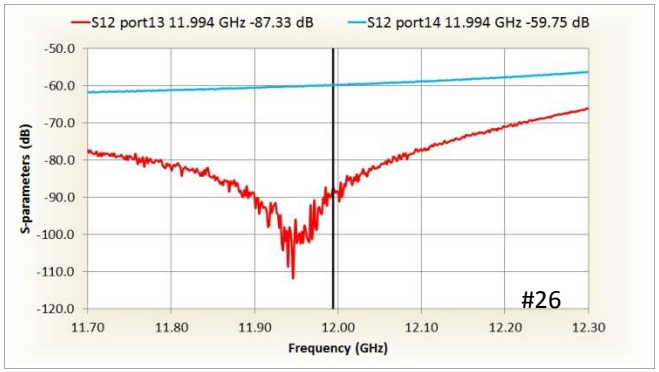


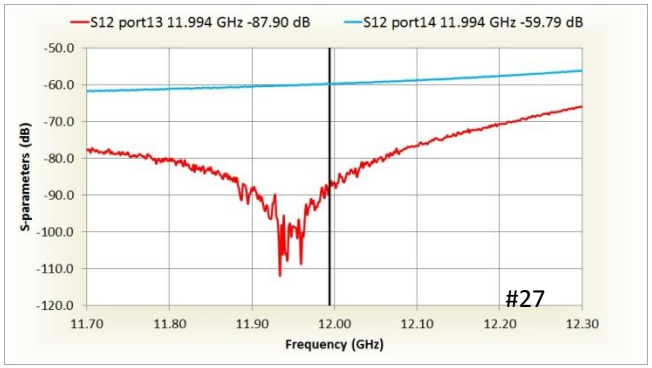
‘Simple’ -60 dB directional coupler

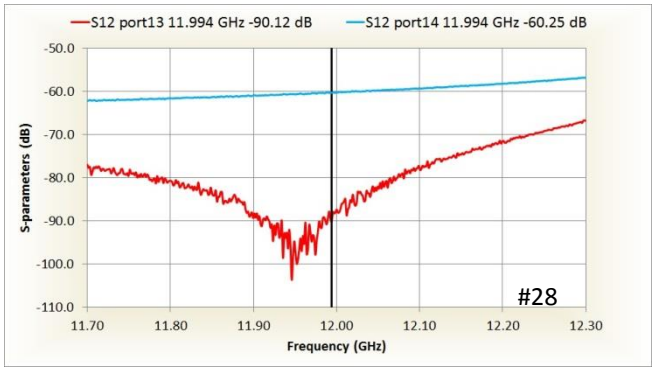




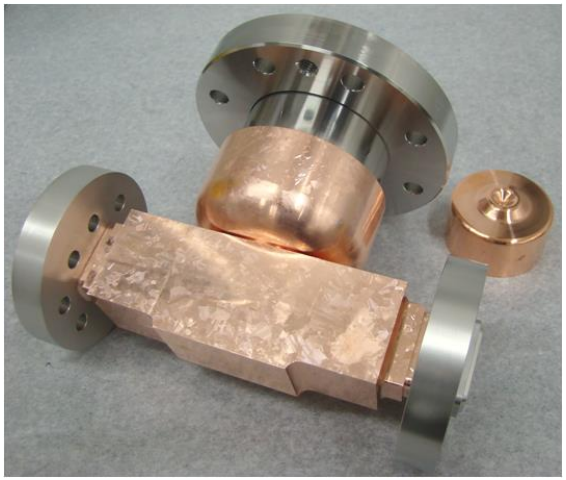


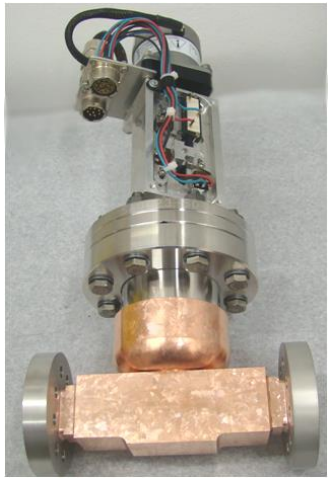




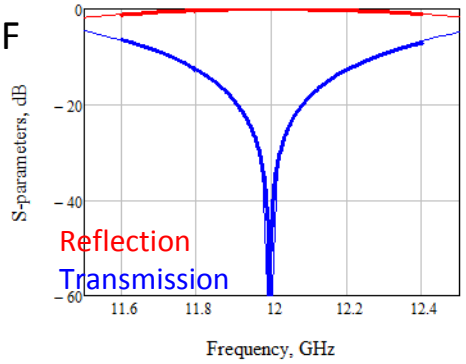


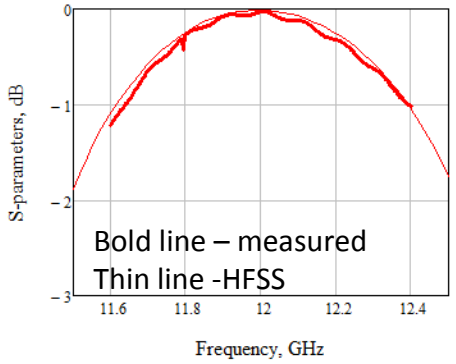
The variable (mechanically) RF reflector.



OFF





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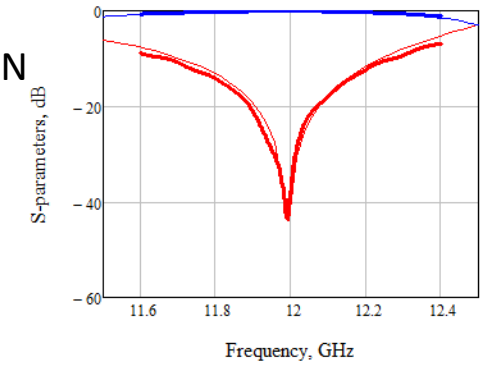
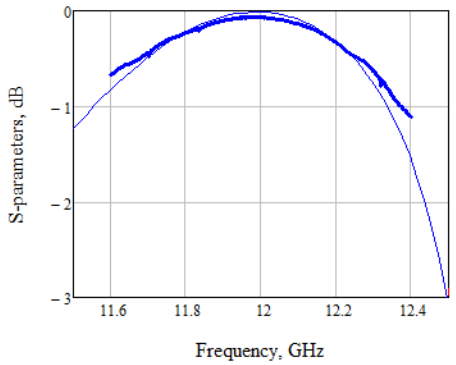
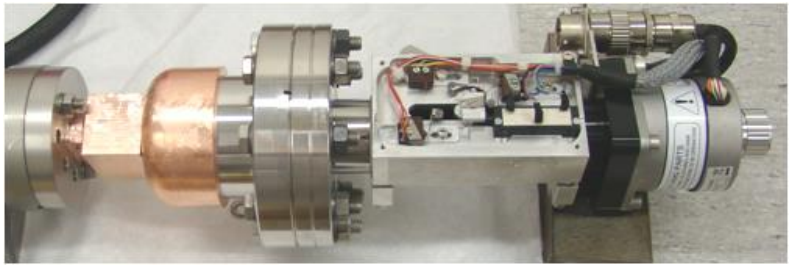
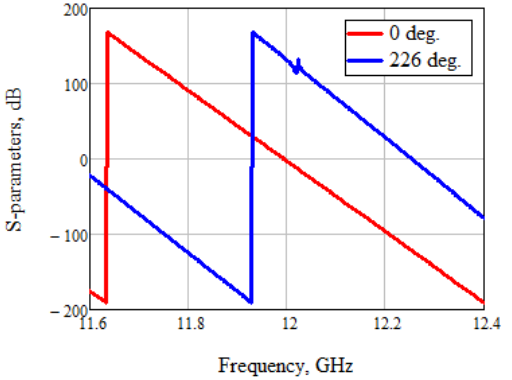




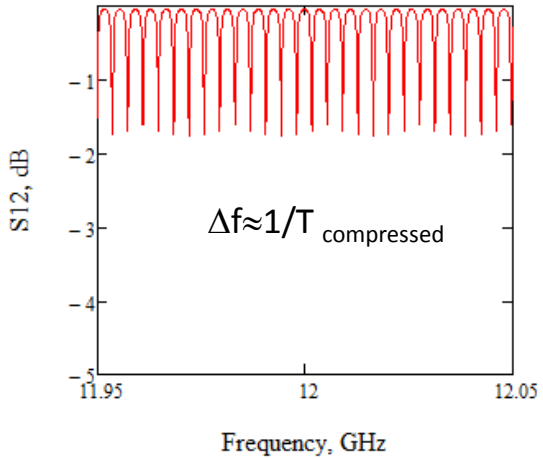
The variable RF short circuit

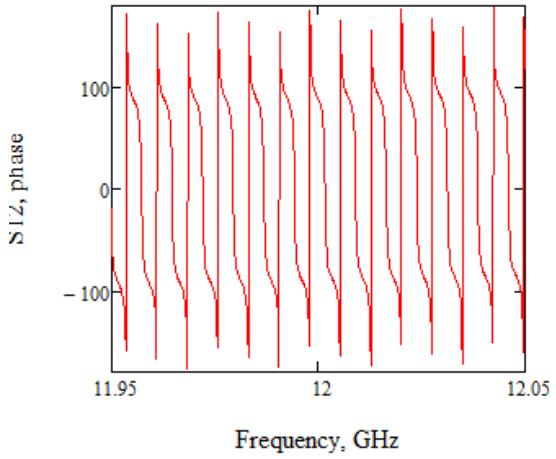




SLEDII transmission spectrum

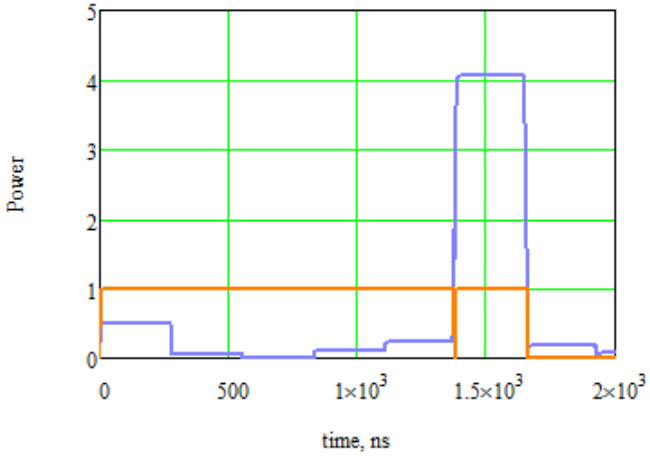
2 x 41.5 m, ∅ 77 mm

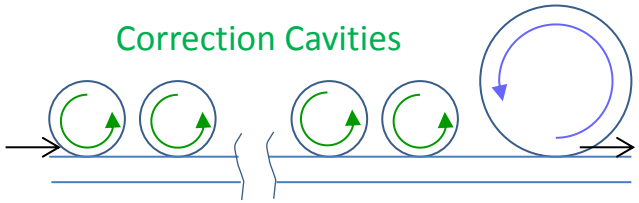




Basic principle (S. Kazakov, 1992)

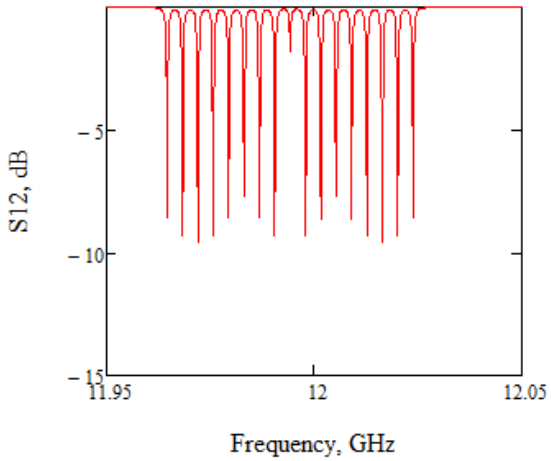
Compression

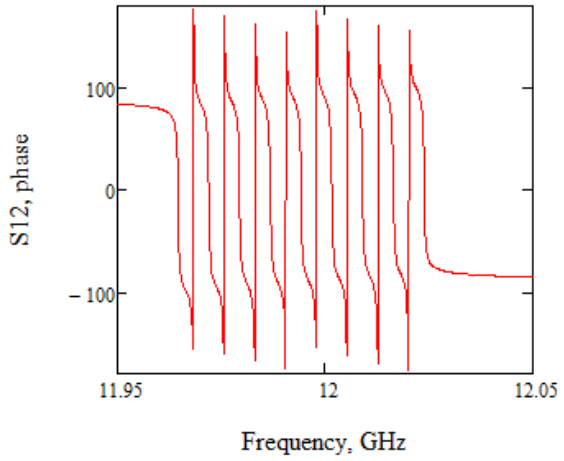


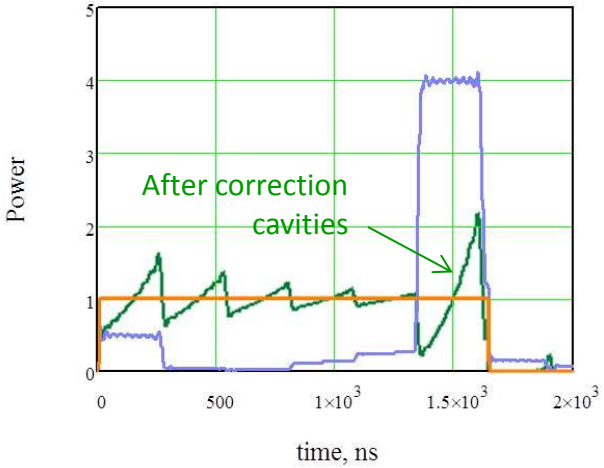


N_c=16, Q^S_0=3x10^5, Q^C_0=0.85x10^5

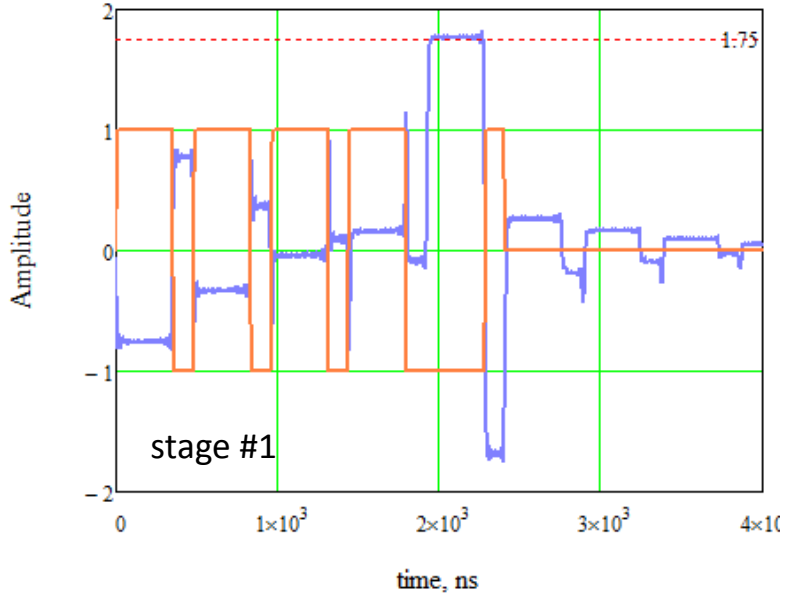
- The spectrum lines of long waveguide can be partially imitated by limited number of individual correction cavities.
- Only storage cavity should provide high Q-factor.
- Loaded Q-factor for all the cavities should be equal (flat top)

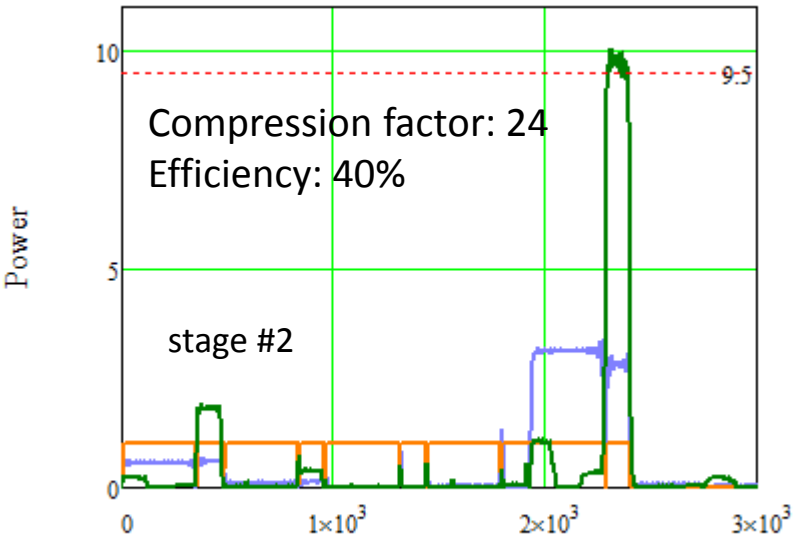


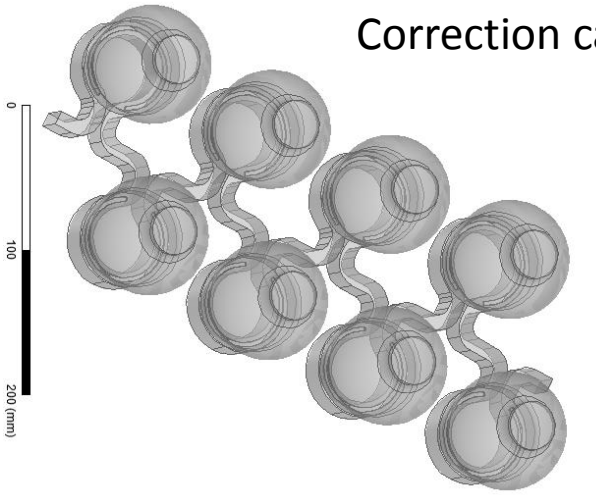




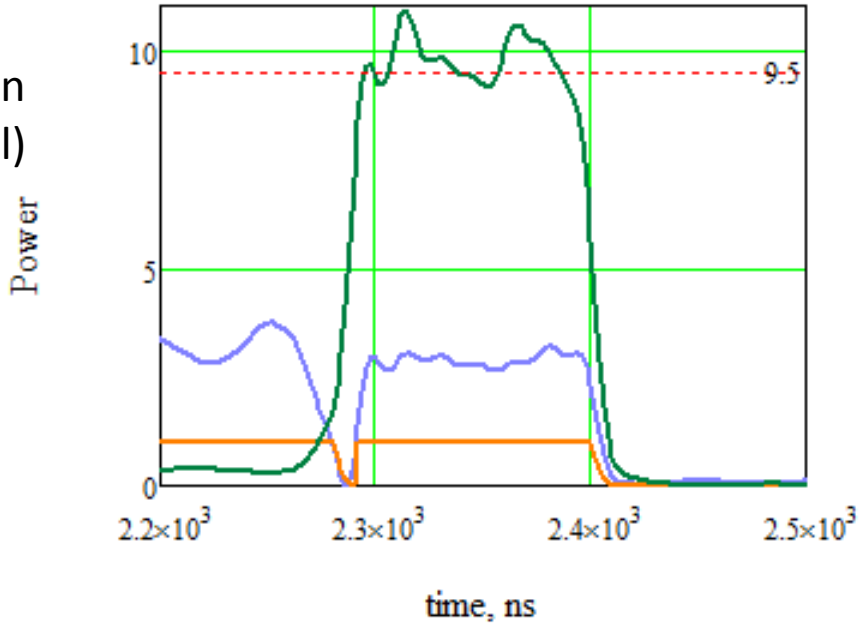
Two stages of RF pulse compression





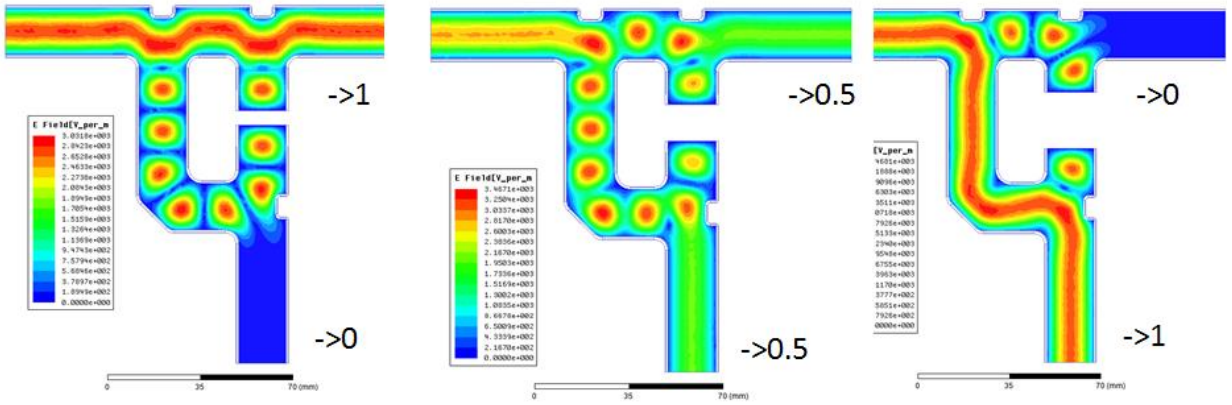


Correction cavities chain
(24 in total)



Compact inline distribution system. Original idea and design by Hao Zha.

Arbitrary coupling splitter concept:



Max 33 MV/m at 100 MW RF peak power