Update on RF Layout and LLRF activities for SPL

reported by
Wolfgang Hofle
CERN BE/RF

Acknowledgements and Participation:
S. Chel, G. Devanz, M. Desmons, O. Piquet (CEA Saclay)
P. Pierini, R. Paparella (INFN, Milano)
M. Hernandez Flano, J. Lollierou, D. Valuch
O. Brunner, E. Ciapala, F. Gerigk, J.Tuckmantel (CERN)

This project has received funding from the European Community's Seventh Framework Programe (FP7/2007-2013) under the Grant Agreement nº212114

Outline

Motivation for LLRF simulation

RF layout

Update on the simulations (→ M. Hernandez Flano)

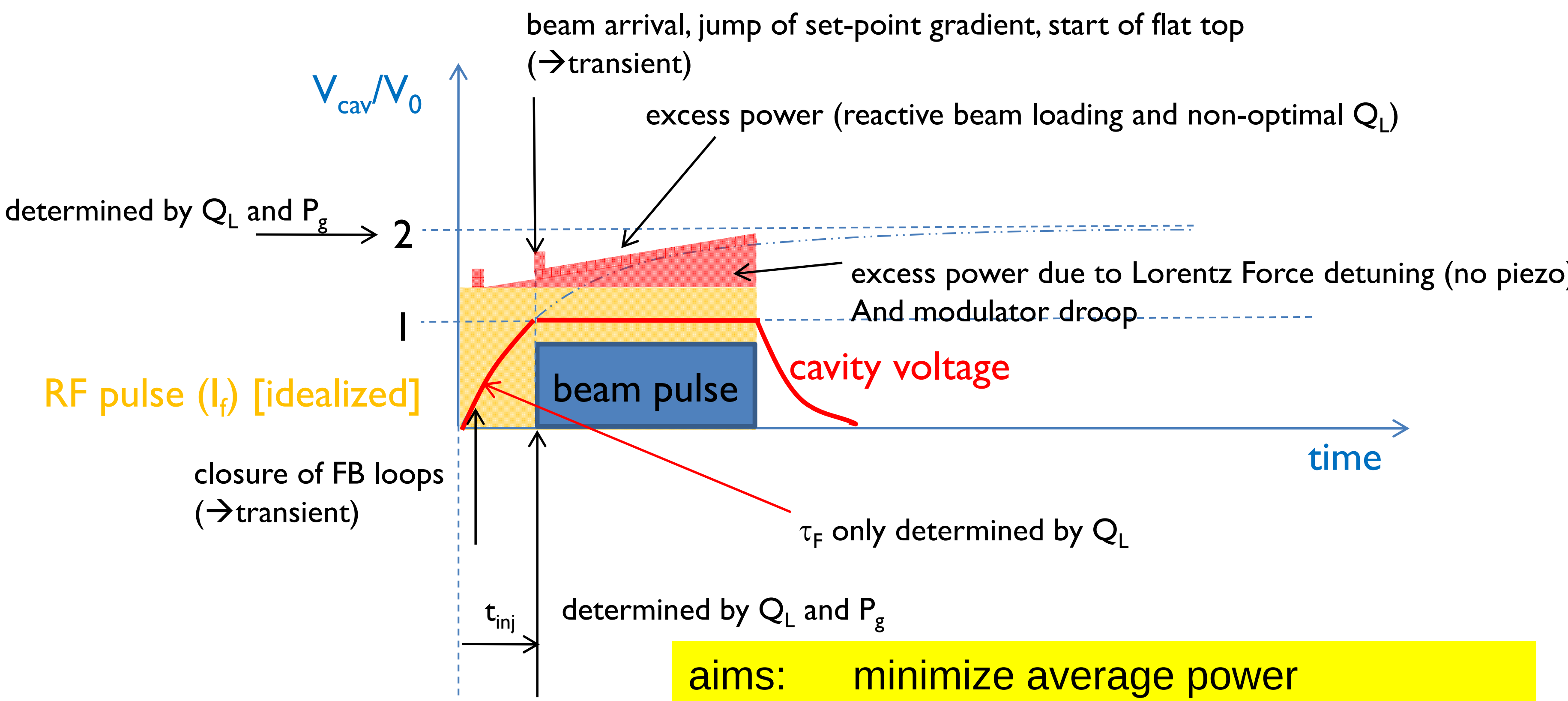
Recent results from tests with piezo compensation at CEA Saclay test stand

Proposal for full LLRF hardware for tests at CEA Saclay

Conclusions

Reminder of principle of pulsed operation

SPL (with beam)



aims: minimize average power
minimize peak and installed power

LLRF (Low Level RF System)

challenges for the LLRF:

- stabilize cavity field in amplitude and phase with minimal power overhead
- keep system stable when pulsing at a high repetition rate (SPL 50 Hz)
- Lorentz-Force detuning
- single klystron for multiple cavities ?

methods:

- use of feedback and feed forward, learning algorithms
- Piezo tuner to counter-act the Lorentz force detuning
- software controlled phasing of cavities

available infrastructure:

- 704 MHz power test stand + cryo infrastructure at CEA Saclay
- β=0.5 cavities and tuners built by CEA and INFN (Milano) under EU-FP6
- high power coupler developed at CEA, Saclay
- LLRF system prototype work on CERN LHC (+LINAC4) LLRF experience

Aims of LLRF simulations

- Determine power overhead using realistic parameters, **new parameters (pulse length now shorter 0.4 ms / 0.8 ms)**

- Test feedback algorithms, **ok, need to move to testing these on real cavity**

- Investigate the impact of errors:

  beam current variation (along pulse and pulse-to-pulse)

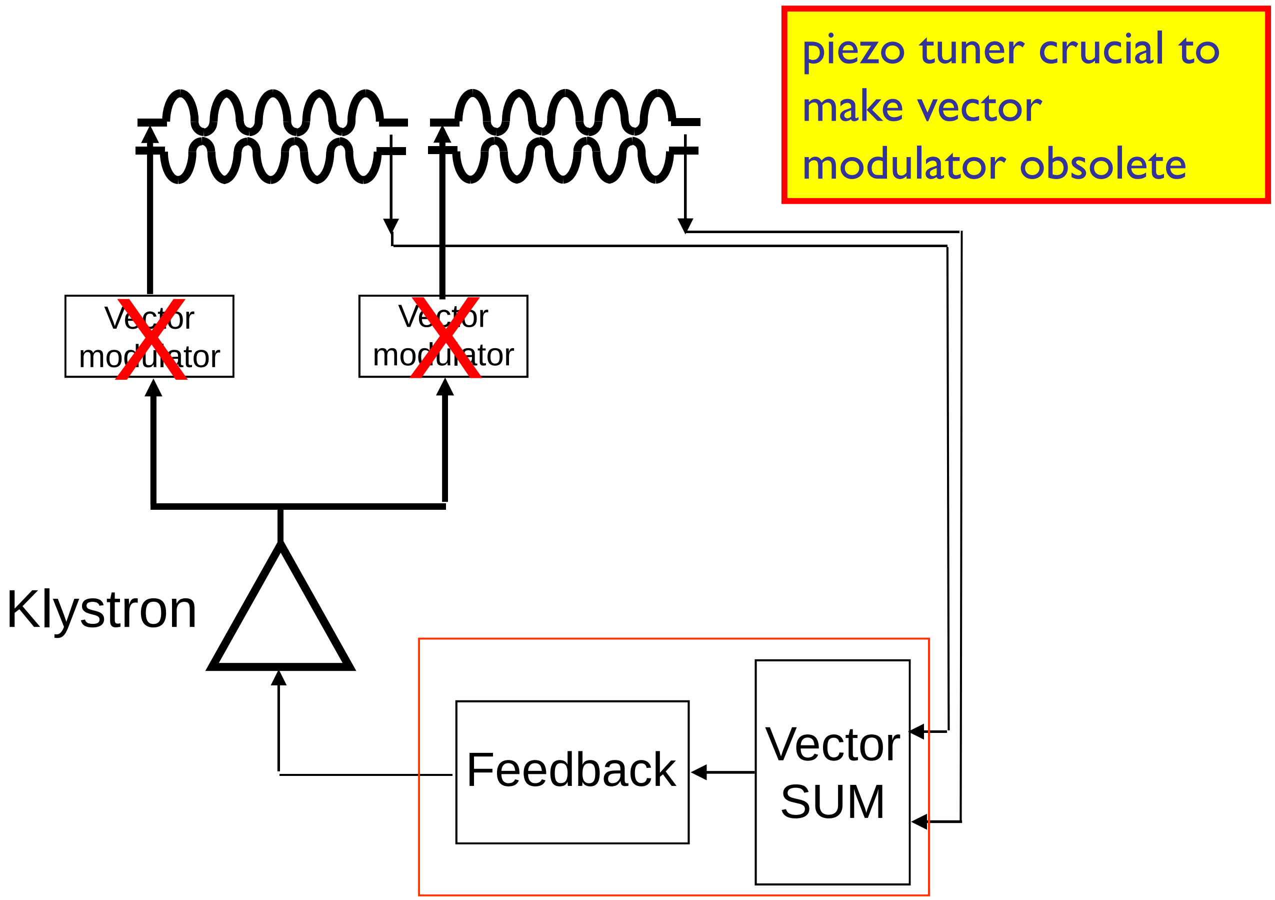
  Q_{ext} variations pulse-to-pulse

  Lorentz force detuning coefficient variations, cavity to cavity

  → use error files to fit model, use model to create sample SPL machines to study the impact (full linac beam dynamics simulation , P. Posocco, **ongoing**)

- Feasibility of optimizations along SPL when beam β is significantly smaller than 1

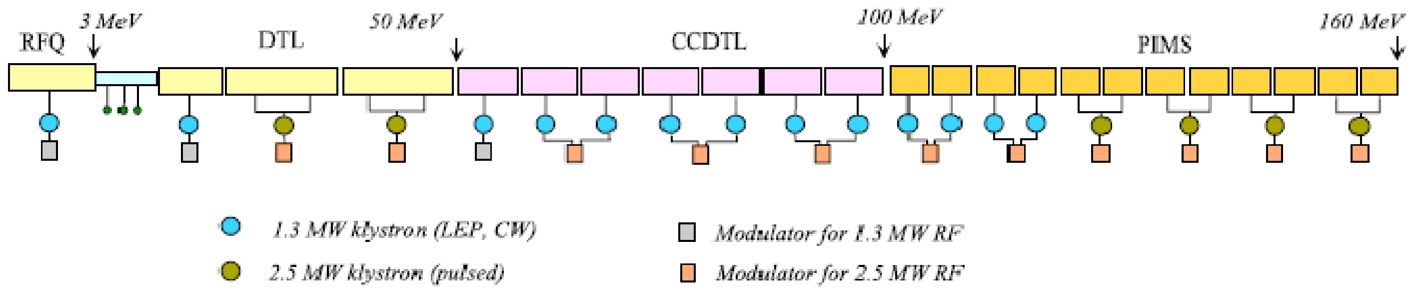
Layout with 2 cavities per klystron



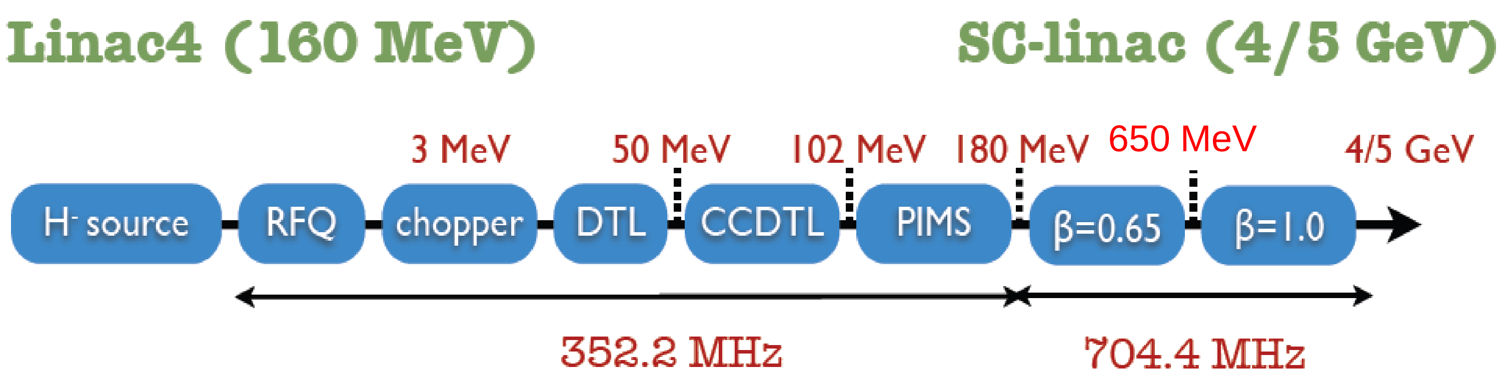
Simulation program developed for LLRF simulations, user interface for 1, 2 and 4 cavities per klystron, for an update see presentation by M. Hernandez Flano

LINAC4 and SPL

Linac4 updated design

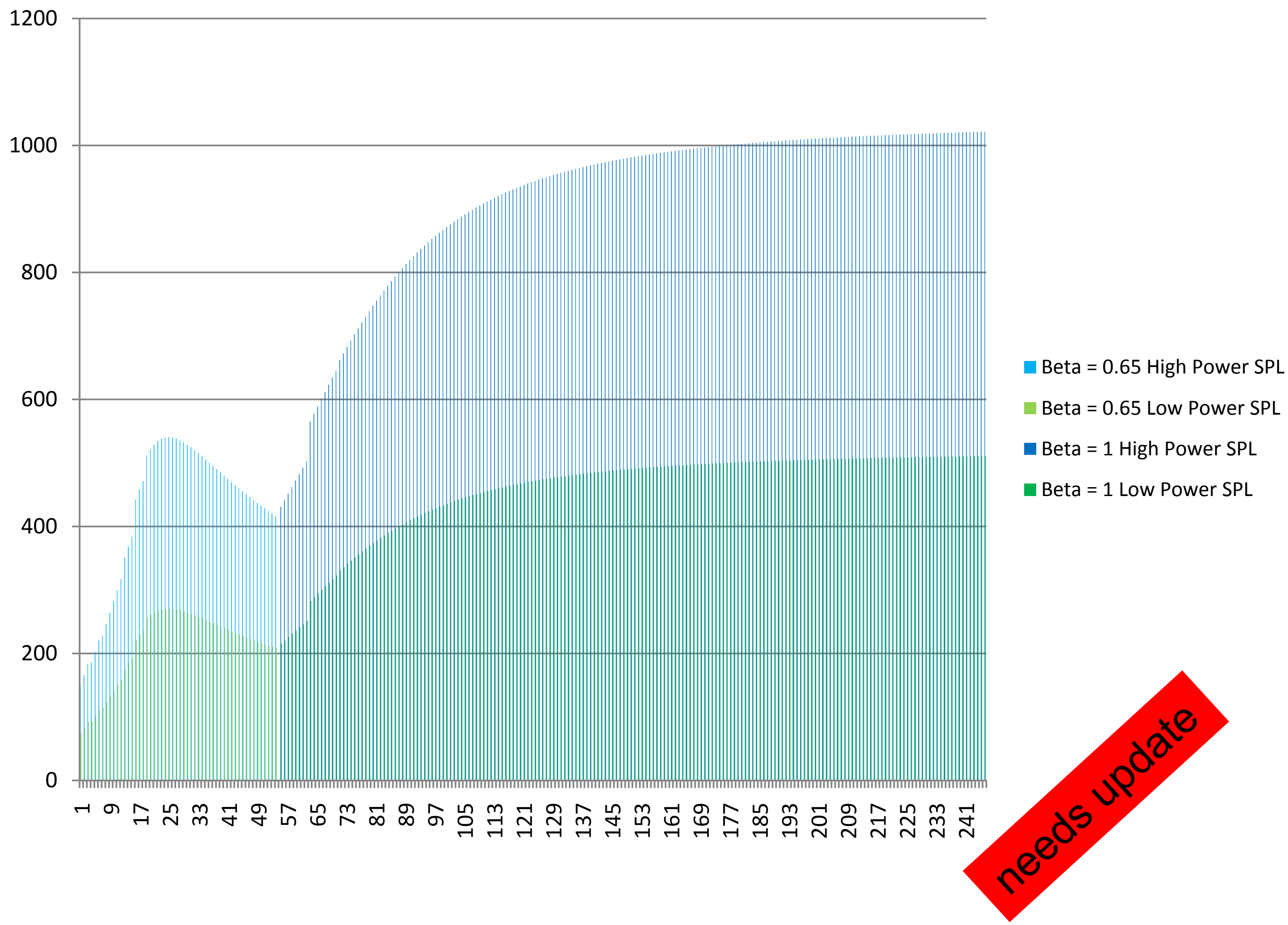


Future extension for SPL, 50 Hz pulsing repetition rate, 20 mA and 40 mA options



Source: LINAC4 / SPL web pages

Optimization along Linac (Q_{ext}), filling time to minimize (peak & installed) power ?



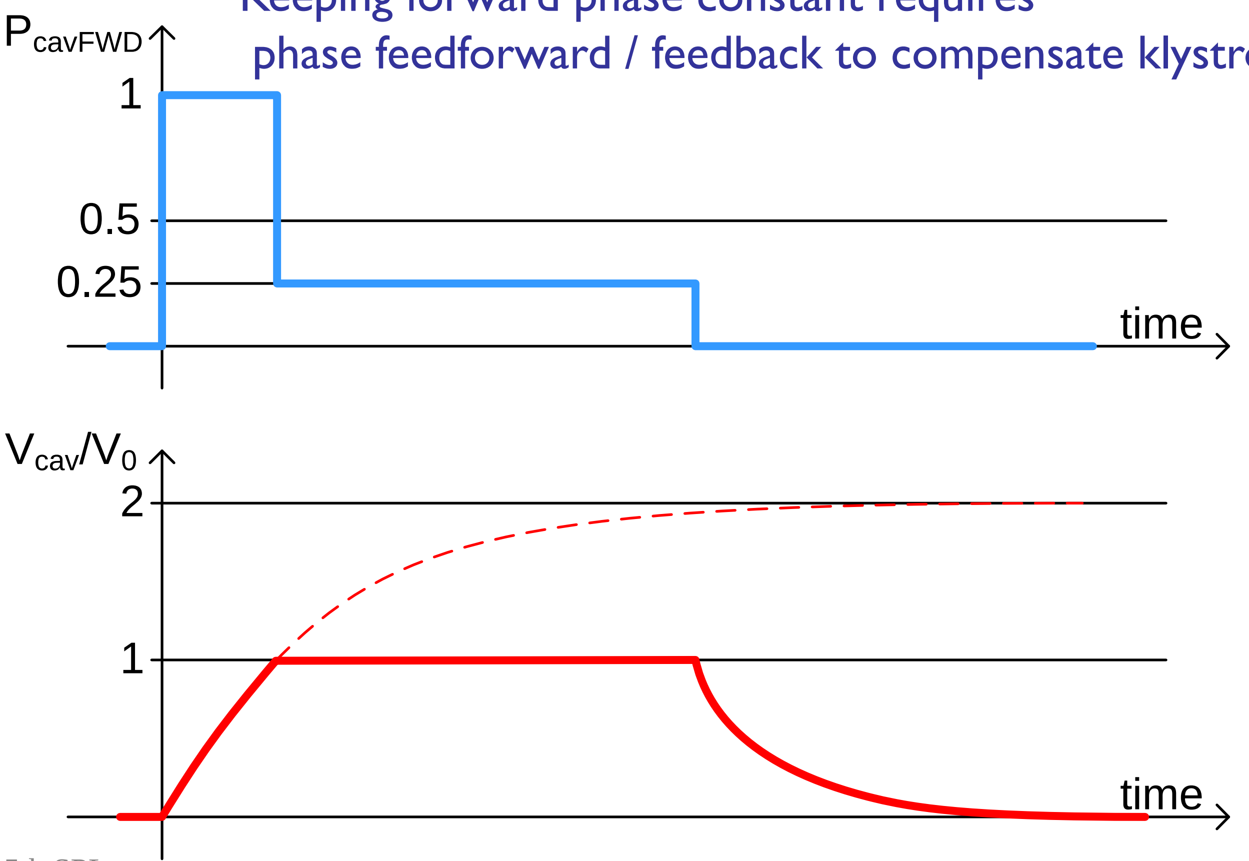
CEA cavity tested and characterized incl. piezo tuner

Frequency [MHz]	704.4
Epk/Eacc	3.36
Bpk/Eacc [mT/(MV/m)]	5.59
r/Q [Ω]	173
G [Ω]	161
Q_0 @ 2K Rs=8 nΩ	$2\ 10^{10}$
Optimal β	0.52
Geometrical β	0.47
Total length [mm]	832
Cavity stiffness [kN/mm]	2.25
Tuning sensitivity Δf/Δl [kHz/mm]	295
K_L @ k_{ext} = 30 kN/mm [Hz/(MV/m)²]	-3.9
Δf @ 12 MV/m, k_{ext} = 30kN/mm [Hz]	-560
K_L with fixed ends	-2.7
K_L with free ends	-20.3

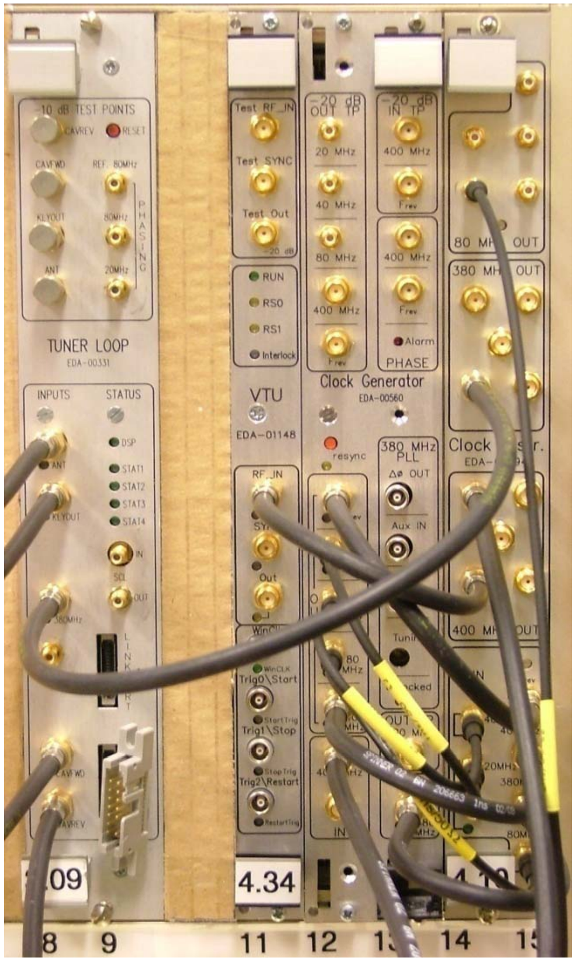
Typical waveforms for tests without beam

- Cavity filling transient without beam for test-stand

Keeping forward phase constant requires
phase feedforward / feedback to compensate klystron phase change



Measurement set-up
for cavity tuner characterization in pulsed mode



modified LHC hardware:
four channels analog down conversion to IF

f_{RF} = 704.4 MHz

f_{LO} = (39/40) f_{RF} = 686.79 MHz

f_{IF} = f_{RF} -f_{LO} = 17.61 MHz

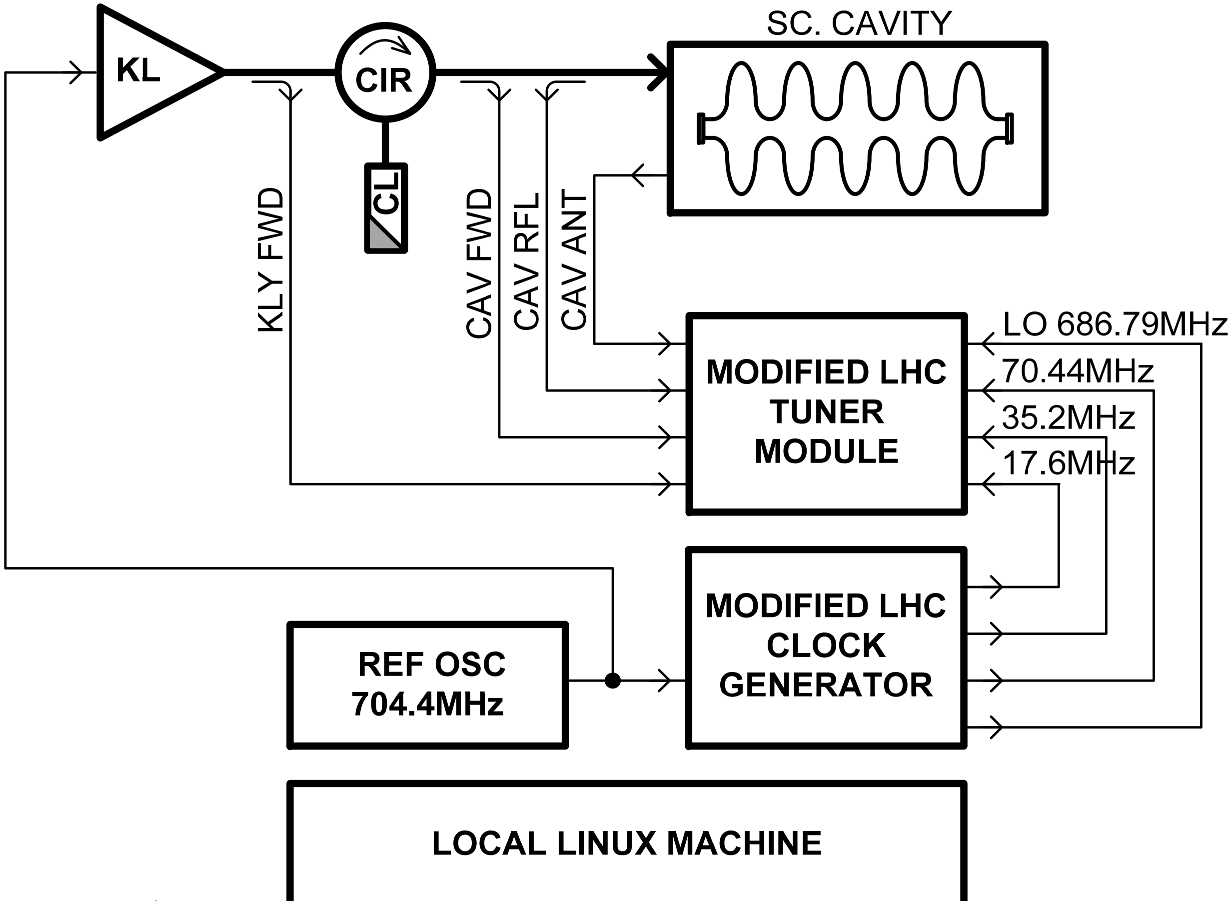
digital IQ demodulation with
sampling at 4xf_{IF} = 70.44 MHz

rate of (I,Q) samples: 17.61 MS/s

actual bandwidth lower and
depending on desired precision

Next steps → evolution to full LLRF system

Test-stand set-up



LO frequency 39/40*RF

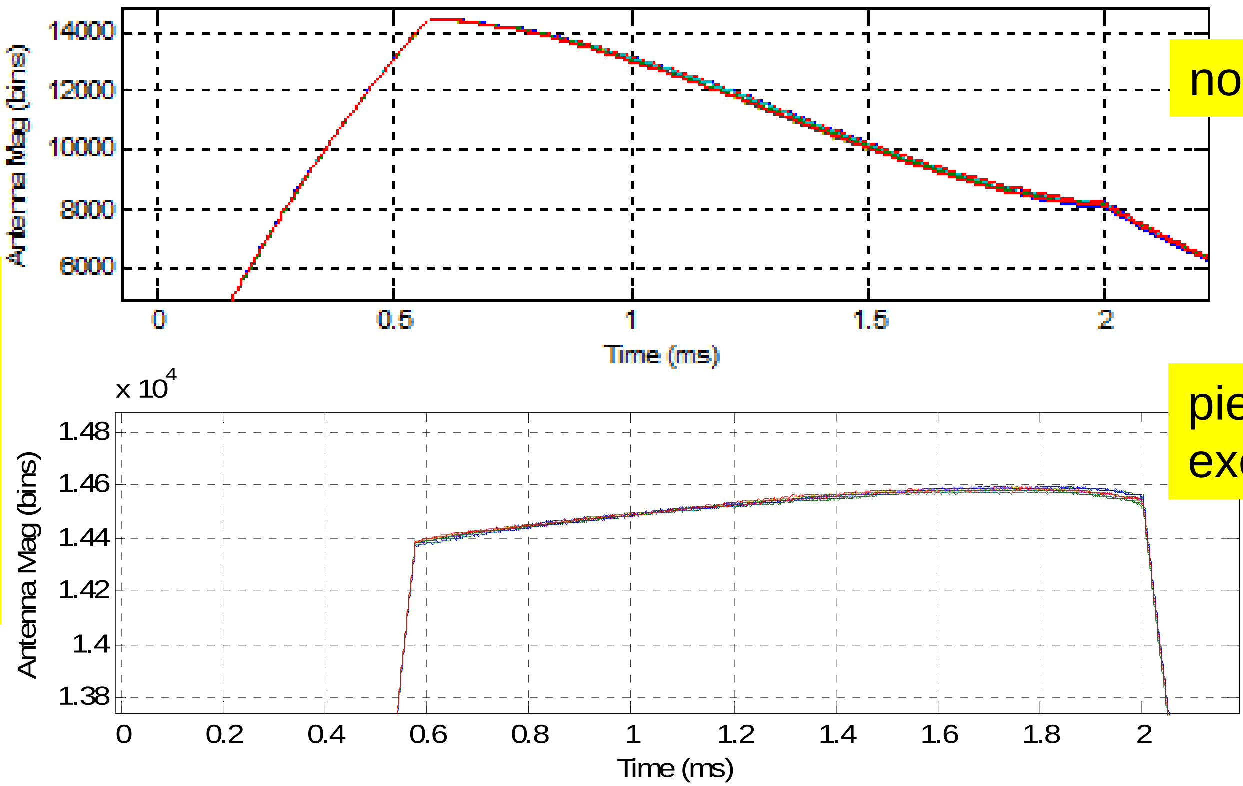
Observation memory 128k data points for each of the four channels

Max. observation rate 35.22 MSps and decimation in powers of two

full rate→ resolution 28.4 ns/point, record length 3.7 ms

down to a resolution of 0.93 ms/point, record length 122 s

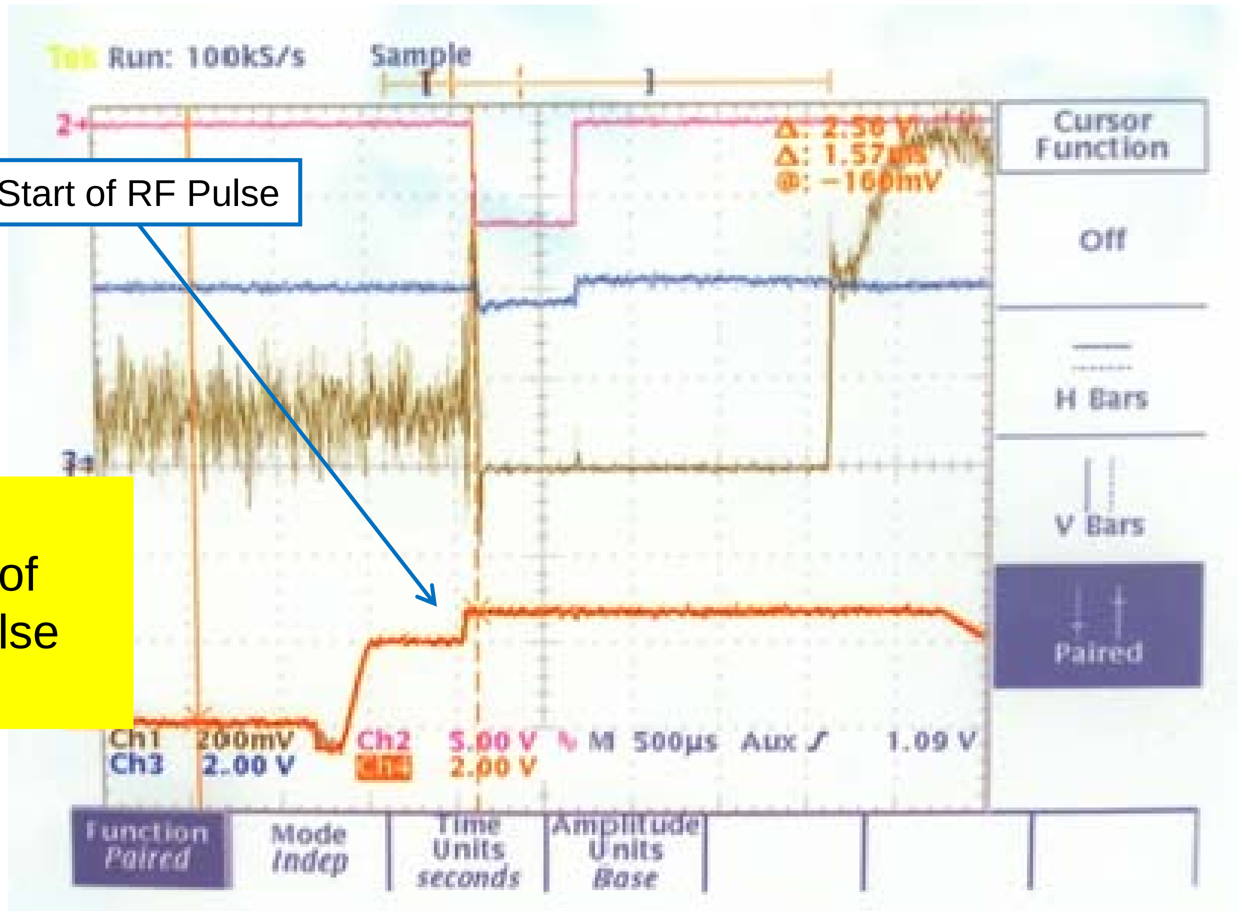
Field flatness with and without piezo compensation (open loop → no RF feedback) acquired with CERN system installed at CEA Saclay



+/- 0.7 %
field flatness
In amplitude
achieved
by using
piezos !

use of piezo minimizes additional RF power needed to further improve the field flatness to the design target of +/- 0.5 %

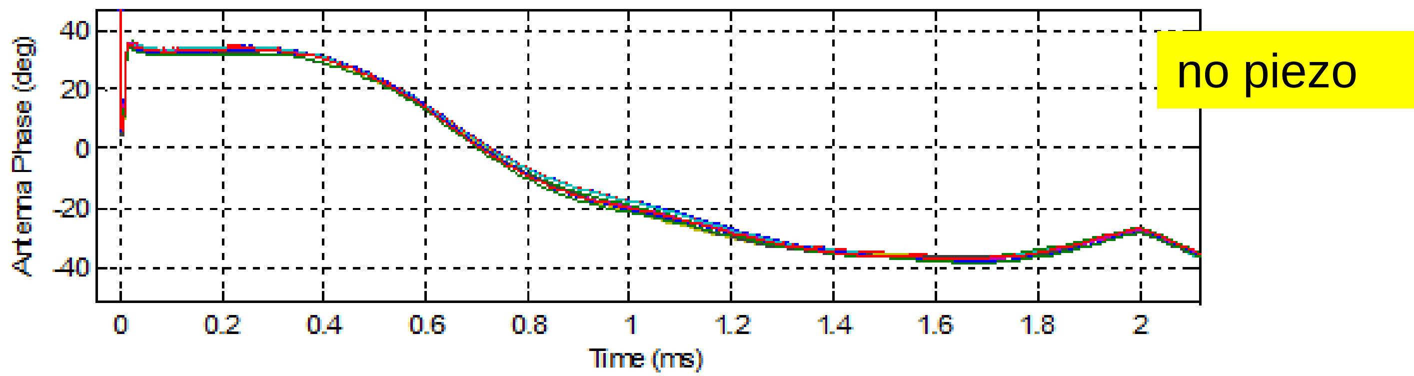
Piezo Excitation

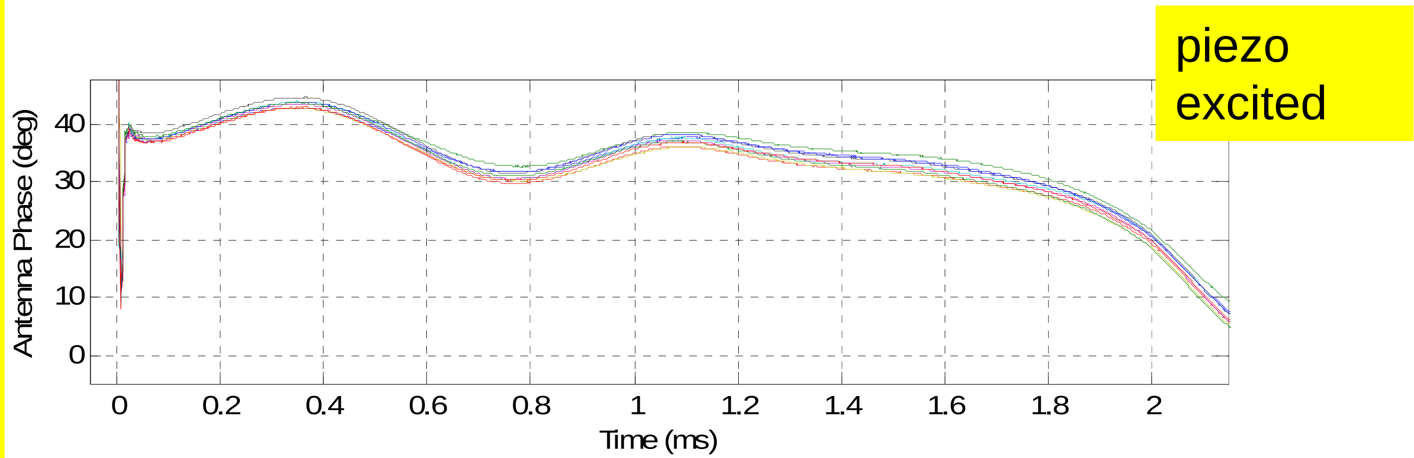


Start of RF Pulse

Manual optimization of excitation pulse for piezo

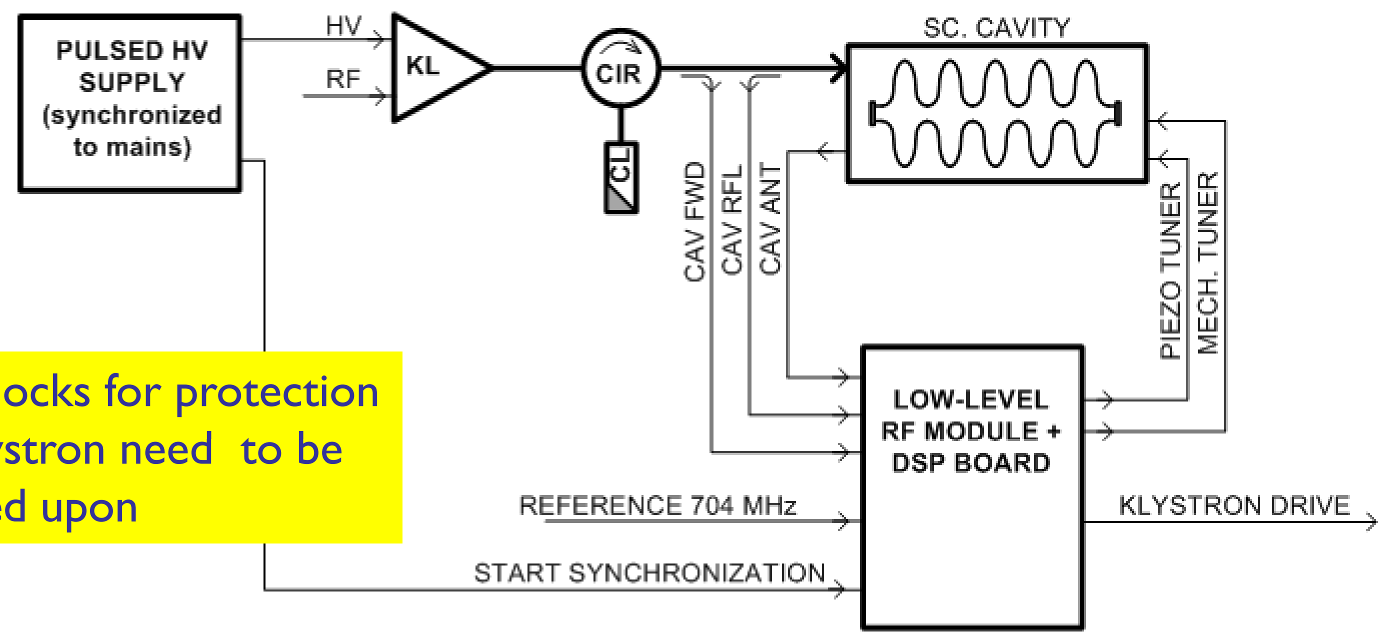
Field flatness for phase, with and without piezo compensation (open loop → no RF feedback)





+/- 8 degrees flatness In phase, achieved by only using piezo ! Needs RF feedback to achieve design goal of +/- 0.5 degrees

Proposed layout for single cavity testing at CEA Saclay with full LLRF system

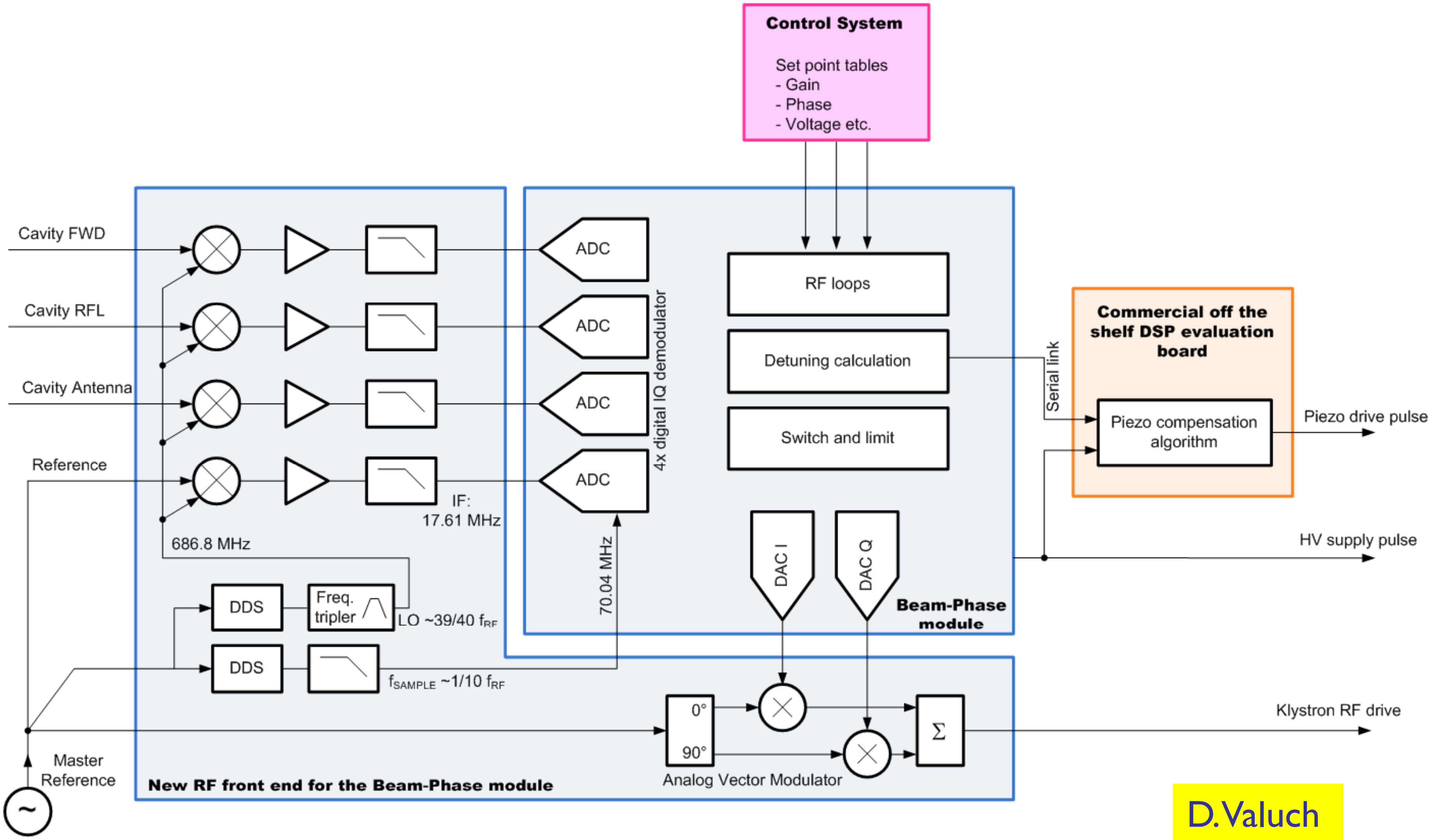


Interlocks for protection of klystron need to be agreed upon

Low level system
The HV supply at Saclay is pulsed and synchronized with mains. Therefore the LL RF system will not be master in generating the Pulses. Instead it will receive the start pulse from the supply and start the RF sequence.

D.Valuch

Consolidated LLRF hardware under development



D.Valuch

Conclusions

new parameters need to be taken into account (shorter pulses of low/high current SPL)

move towards considering the whole accelerator with the different beam β's

parameter variations will have a large impact on required power overhead and performance

test stands indispensible for the development of the LLRF systems, plans exist to build a test stand at CERN for 704 MHz, currently collaboration with CEA Saclay

results with piezo tuner demonstrate its capabilities to keep cavity on tune during the beam passage, essential to minimize the power requirements

having a test stand at CERN would be very important to build up momentum at CERN in the area of LLRF developments