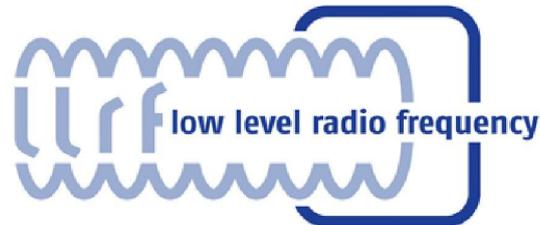


Progress in Low Level RF

M.Grecki & V.Ayvazyan

on behalf of LLRF Team

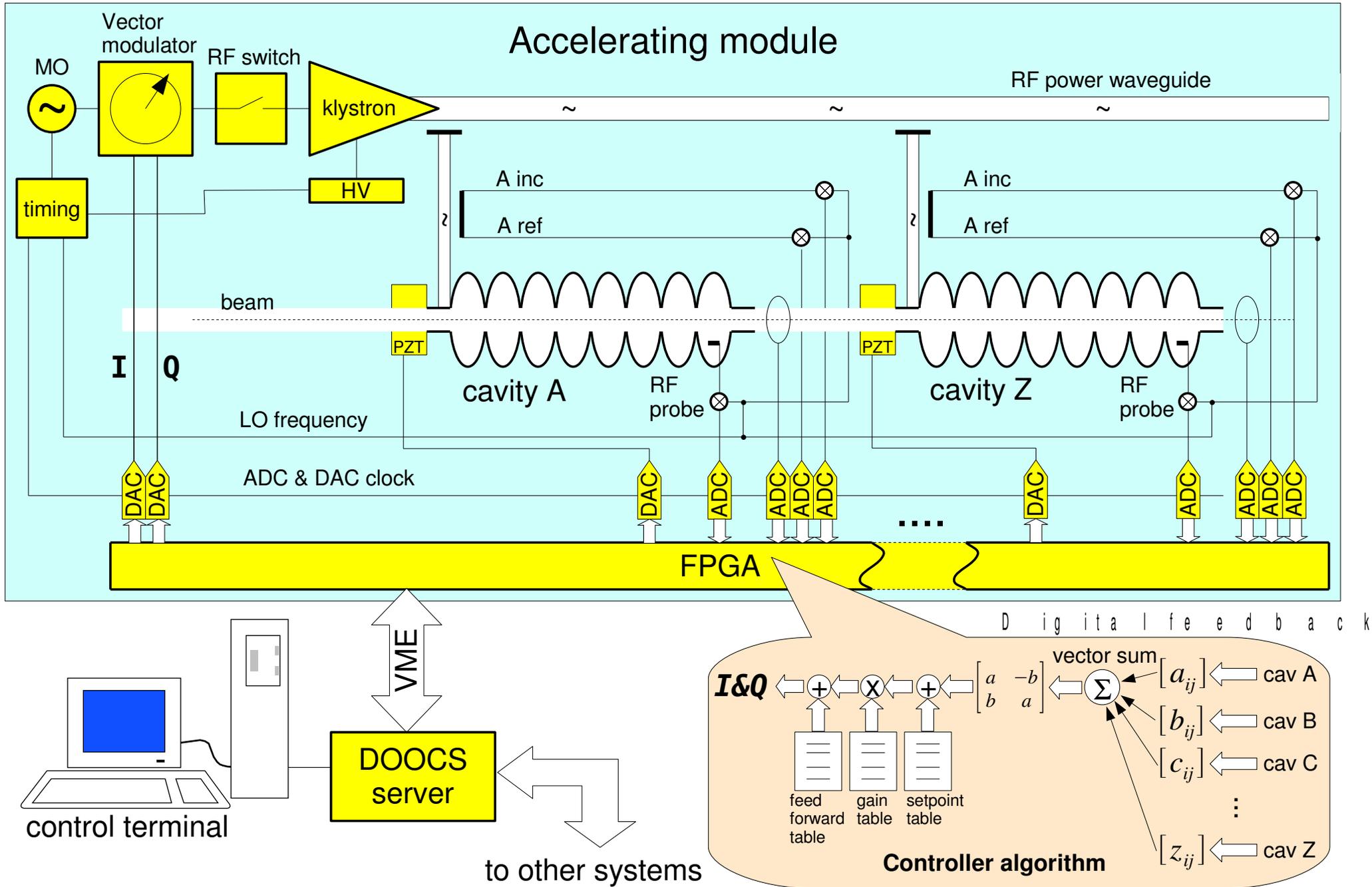


Agenda

- LLRF System at FLASH
- Requirements for LLRF Control
- Development progress
 - hardware
 - software
- Operation Experience
- Future Plans
- Conclusion



LLRF system architecture



RF Control Requirements

- Maintain **Phase** and **Amplitude** of the accelerating field within given tolerances to **accelerate** a charged particle beam (e.g. XFEL: **0.01% for amplitude and 0.01 deg. for phase**)
- Minimize **Power** needed for control
- RF system must be **reproducible, reliable, operable**, and well understood
- Other performance goals
 - **build-in diagnostics** for calibration of gradient and phase, cavity detuning, etc.
 - provide **exception handling** capabilities
 - meet performance goals over **wide range of operating parameters**



Development progress - hardware

- Master Oscillator
 - Redundant MO
 - Local distribution in Cryoannex
- Field control
 - Uniform SimconDSP based LLRF system at FLASH
 - New cabling in GUN, ACC1, ACC39
 - ATCA based LLRF system
- Piezo control
 - Permanent installation at ACC3, ACC5, ACC6, ACC7, ACC1

MO: Ongoing Upgrade

- Installation of the second Master Oscillator (90% done)
- Installation of new 1.3 GHz power amps (higher output power to compensate for cabinet cable losses)
- New subdistribution rack in Hall 3 extension to provide more „tap points“ for MO signals with diagnostics
- Improve DOOCS data acquisition/logging



Master Oscillator



MO1

Distribution

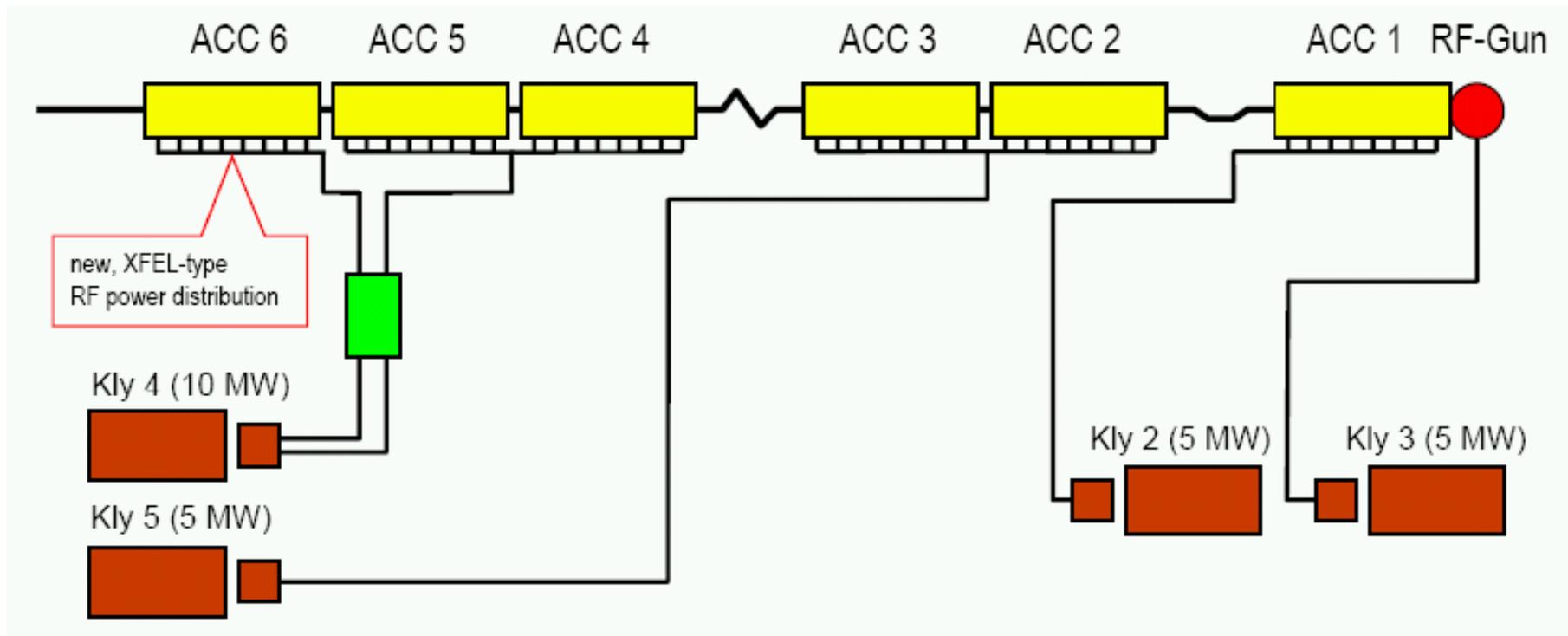


MO2

Subdistribution
in Cryoannex



FLASH before upgrade



LLRF controllers before upgrade

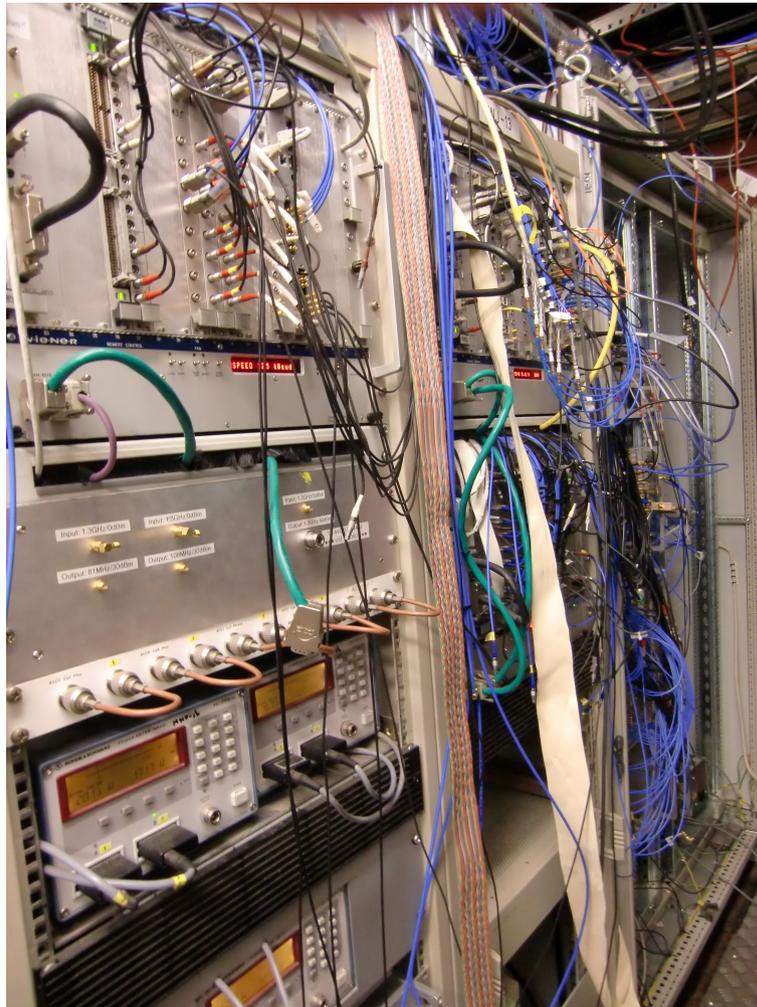
RF System	User operation	Development	Backup
RF Gun	SIMCON 3.1	-	DSP
ACC1	SIMCON DSP 250 kHz IF	SIMCON x3 54 MHz	DSP 250 kHz
ACC23	DSP 250 kHz IF	-	Redundant FF DAC8
ACC456	DSP 250 kHz IF	SIMCON x3 ATCA 54 MHz	Redundant FF DAC8

and monitoring signals for all modules (forward/reflected/probe)

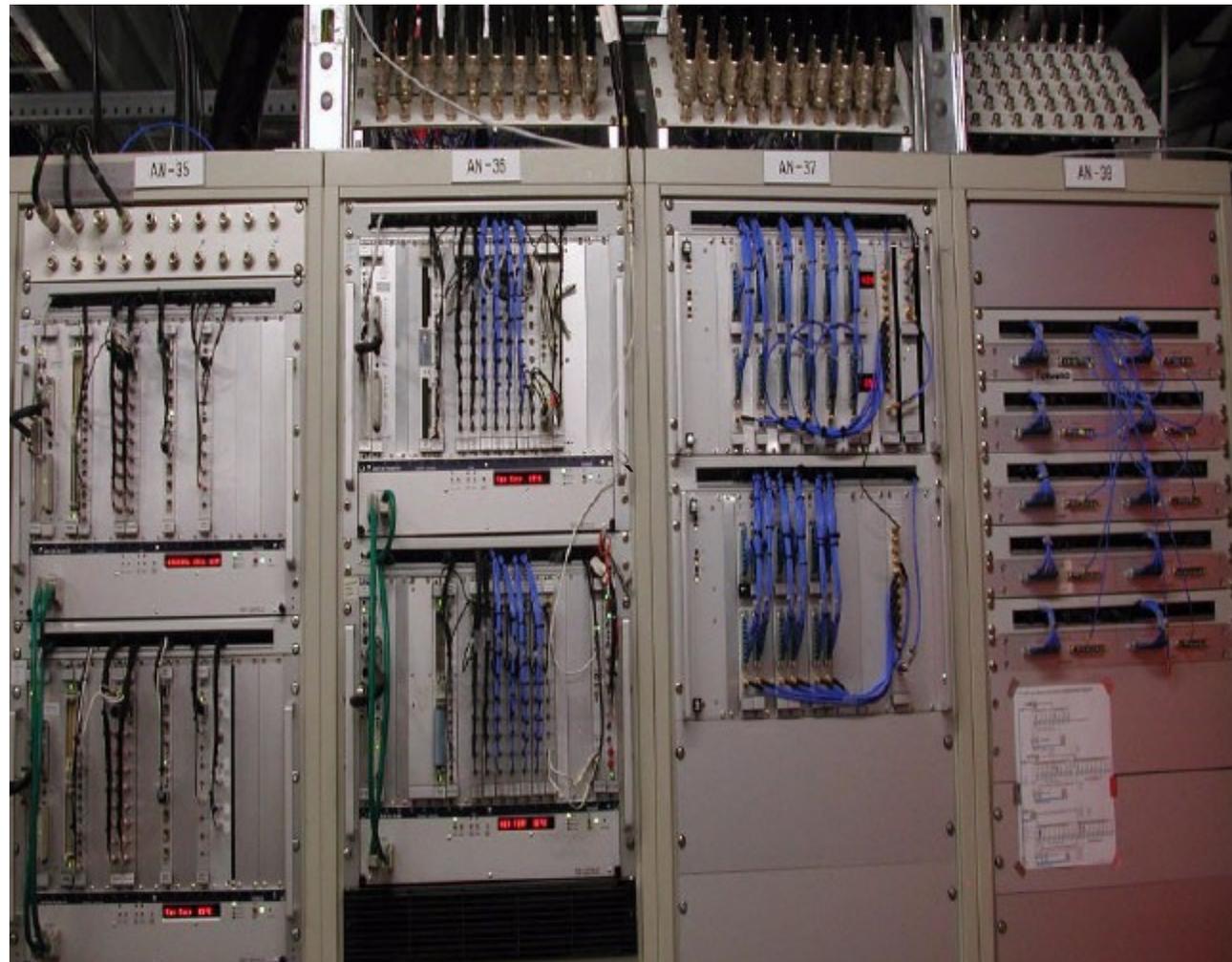
DSP (2000), SIMCON (2006), ATCA (2009)



LLRF installations before upgrade

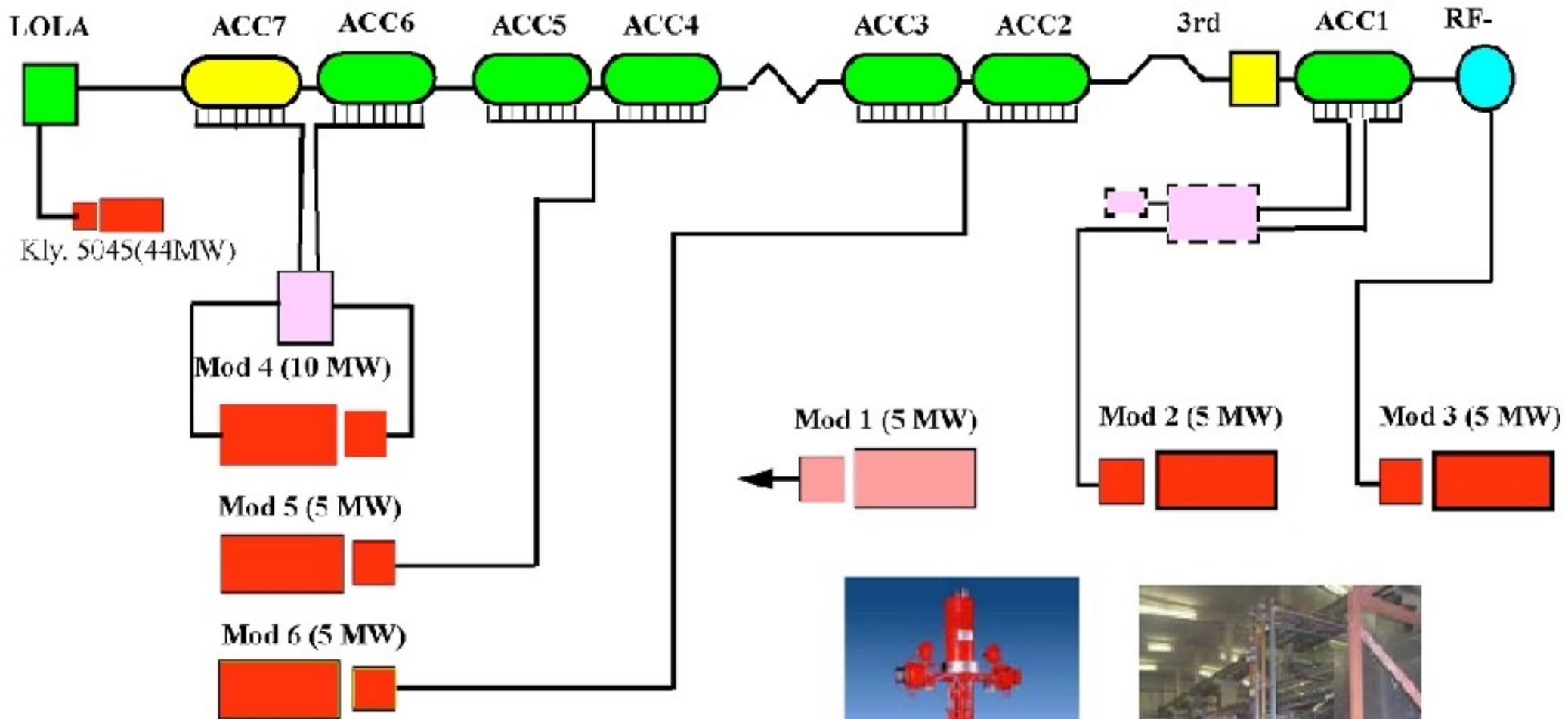


GUN, ACC1



ACC23, ACC456

FLASH after upgrade



LLRF controllers after upgrade

RF System	User operation	Development	Backup
RF Gun	SIMCON	-	DSP
ACC1	SIMCON x1 250 kHz IF	ATCA 54 MHz	DSP 250 kHz
ACC39	SIMCON 54 MHz IF	-	LIBERA
ACC23	SIMCON x2 250 kHz IF	-	DSP 250 kHz
ACC45	SIMCON x2 250 kHz IF	ATCA 54 MHz	DSP 250 kHz
ACC67	SIMCON x2 250 kHz IF	-	ATCA 54 MHz

and monitoring signals for all modules (forward/reflected/probe) DSP
 DSP(2002), SIMCON (2006), ATCA (2009)

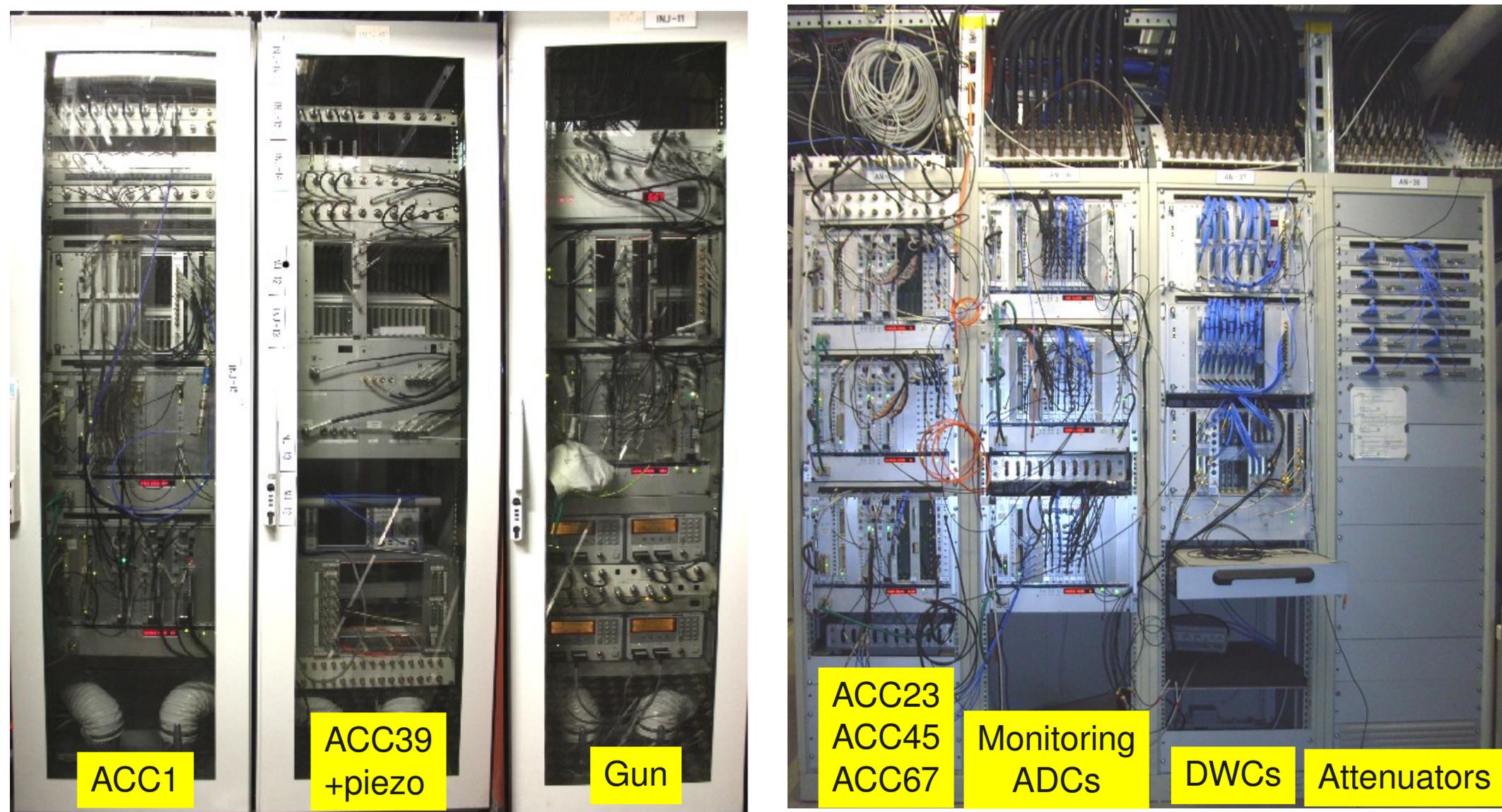


SimconDSP board

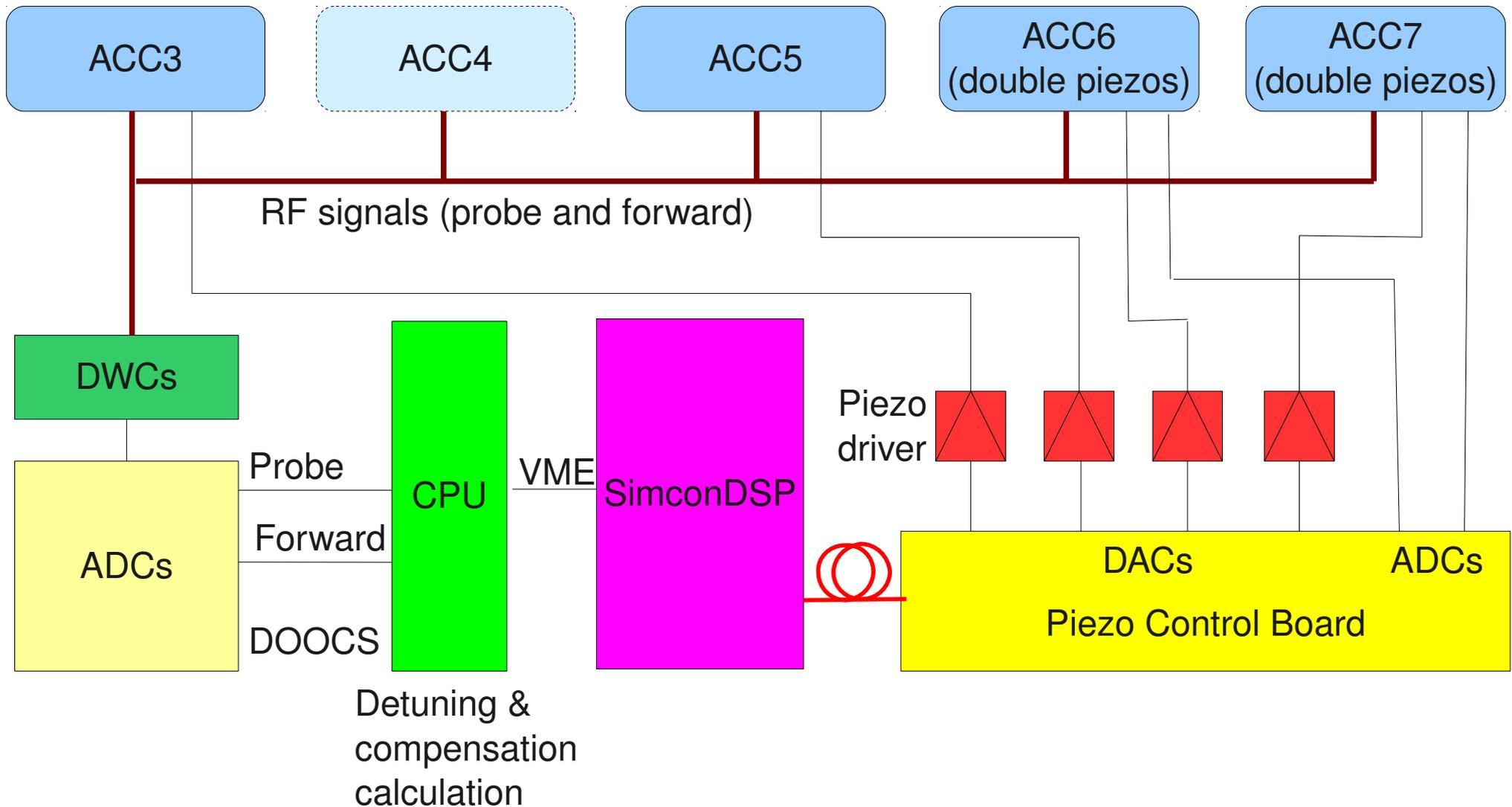
- VME interface
- 10xADC, 8xDAC
- Xilinx Virtex II Pro
(20/30/50), PowerPC
- DSP, Tiger Sharc
- 2 opto gigalinks
- Ethernet



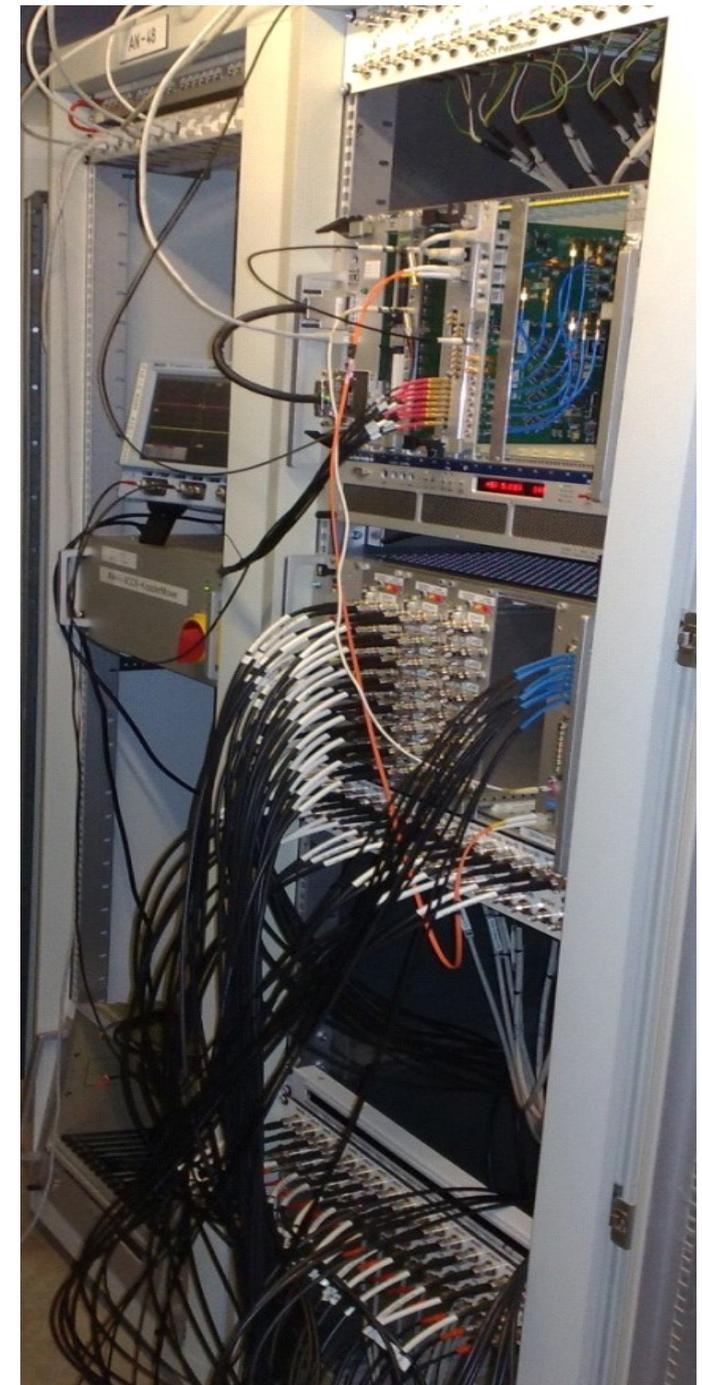
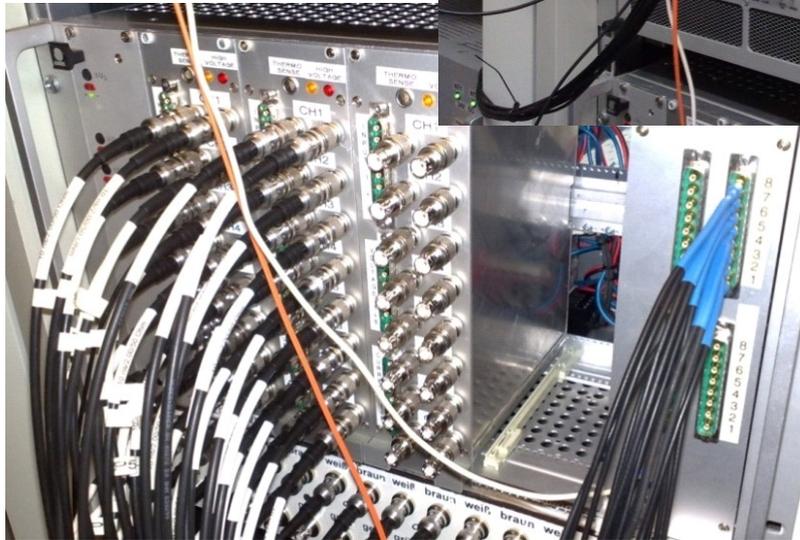
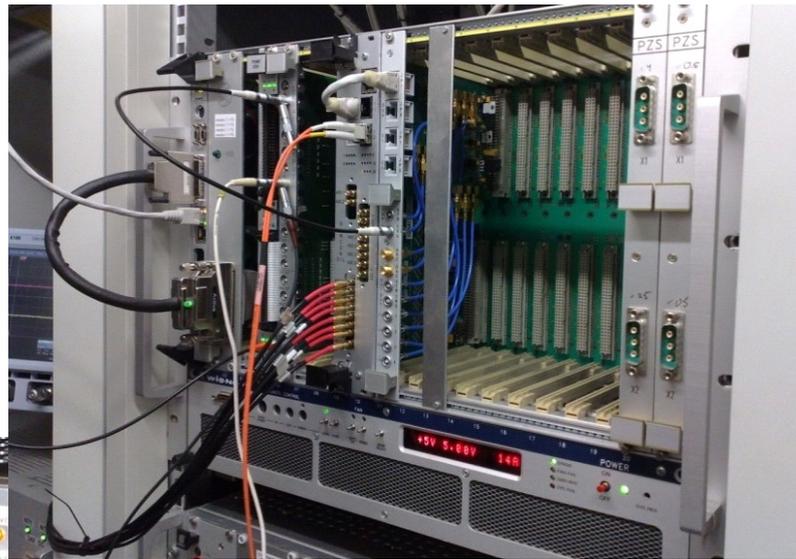
LLRF installations after upgrade



Piezo control at ACC3,5,6,7



Piezo Control at ACC3,5,6,7

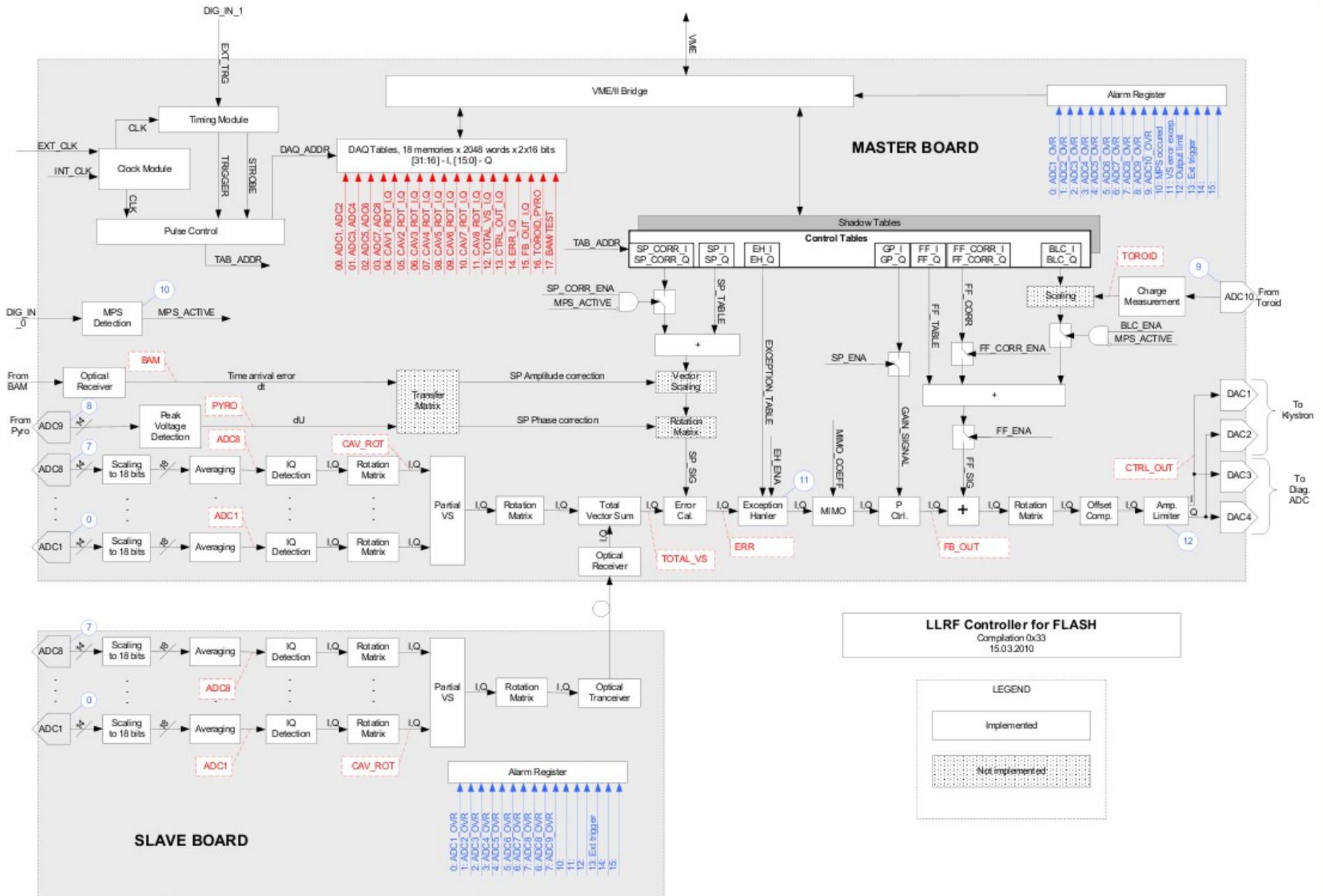


Development progress - software

- New firmware for Simcon
- Feed-forward optimization
- Adaptive feed-forward
- Variable gain
- Gun calibration and automatic start-up
- Manual beam loading
- Exception detection and handling
- Piezo control
- Frequency scan of cavities
- LLRF C++ library



LLRF Field controller firmware



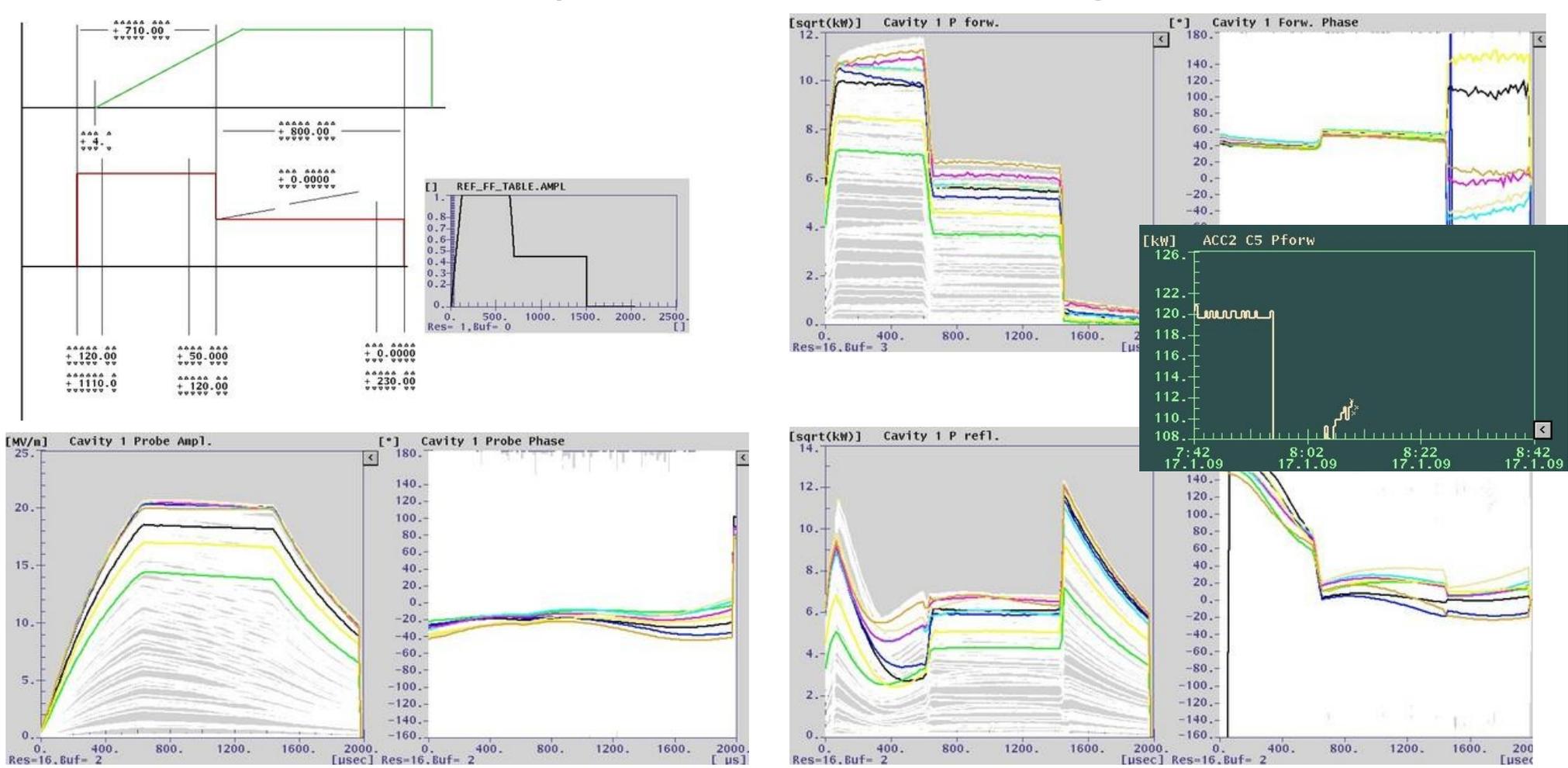
Feed-forward Optimizations

- Minimize the klystron peak power for RF control, avoid unnecessary power overshoots
 - Optimize cavities filling procedure by applying smoothing and phase correction algorithms
- Study the impact of klystron saturation when RF station is operated at high gradient
 - Run accelerating modules almost to the power limit with high gain
 - Minimize klystron & coupler trip rate
 - Maximize energy gain from RF station, keeping the klystron forward power lower



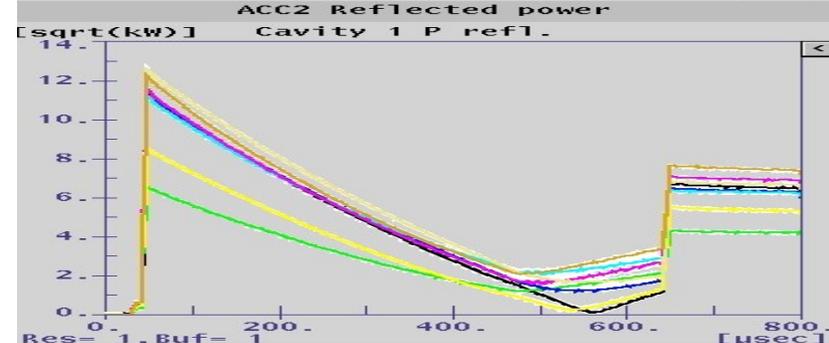
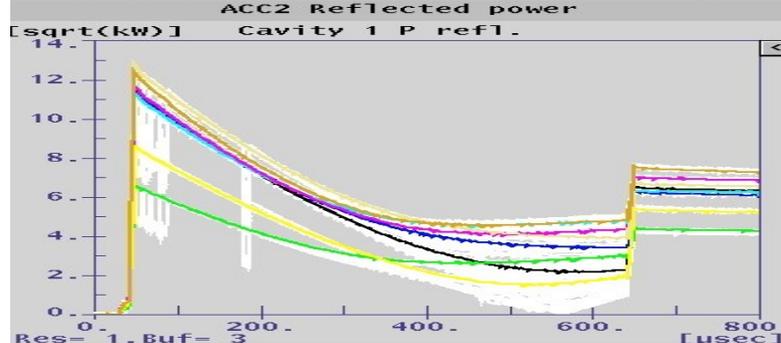
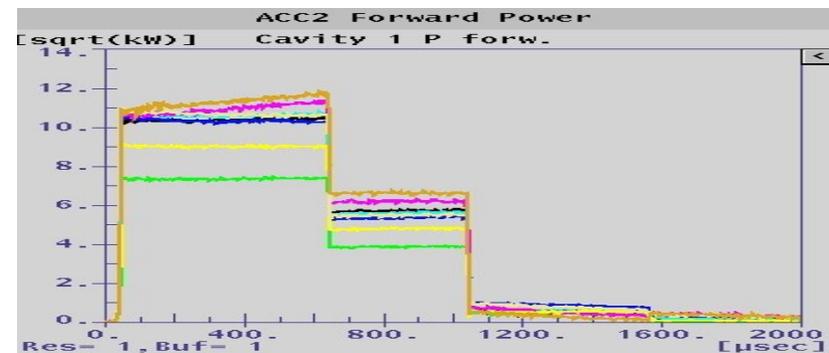
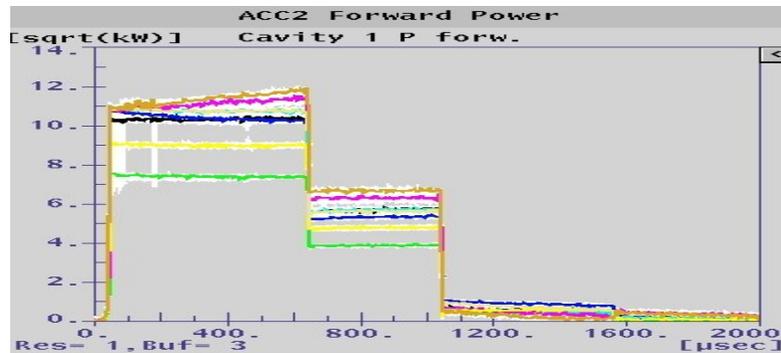
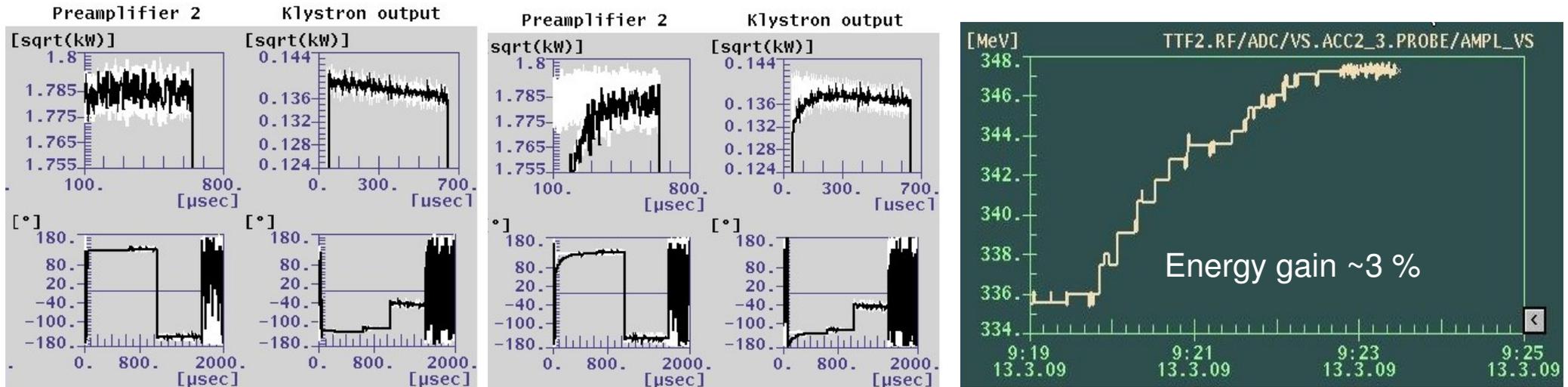
FF Optimization: Smoothing of Forward Power Overshoots

- Smoothed forward power in ACC23 cavities
- White traces show powers before smoothing



FF Optimization: Phase Modulation

Minimum reflection at the end of filling time has been reached



Variable gain

- Running feedback loop with gain of 100 without significant oscillations
- Reduction of ~15% peak forward power required for feedback regulation during filling time

ACC2_3

SP voltage, MV
+15.20

SP Phase rel. beam
-5.30

Phase Offset
-67.22

Cal HV Bit Cal MV HV
+1.00 +3080.00

DSP IS ALIVE Rate 5

VS A,P,I,Q VS & SP

VS A,P,I,Q (HG) VS & SP (HG)

DAC_TABLE DAC (A&P)

SP_TABLE DAC (I&Q)

FF_TABLE Miscellaneous

DSP CONTROL Excep. status

DSP timing CAV32

REF_FF_TABLE REF_FF_TABLE

Feedforward

Ratio +0.43	Cal HV Bit +1.00	Offset I+153.00
Phase Offset -67.29	Fill Phase Off. +0.00	Cal MV HV +82.22
		Q+153.00

Feedback

Loop Gain
+100.00

System Gain
+0.03

Beam Comp.

Flat Top +400.00	Current +1.20	Phase -164.00
Beam Start +660.00	Duration +350 us	Cal MA MV +0.50

Loop Phase

Amplitude +0.61	Phase +41.74	Filter +4.00
--------------------	-----------------	-----------------

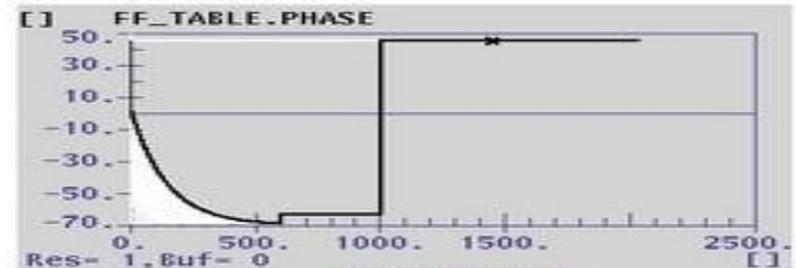
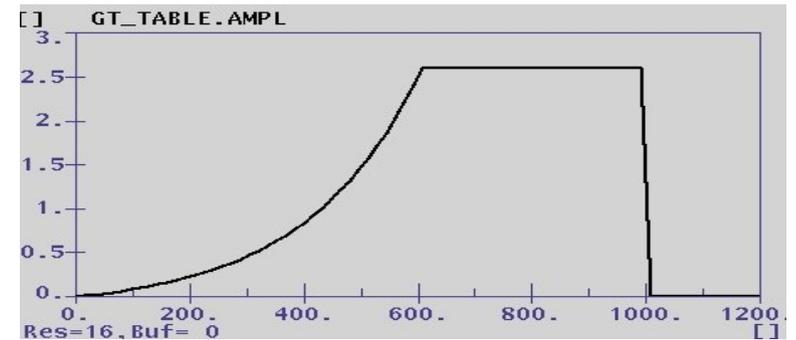
Expert Flags

Exception Handling

User FF-Reference

SET HV (Server) +10500 V

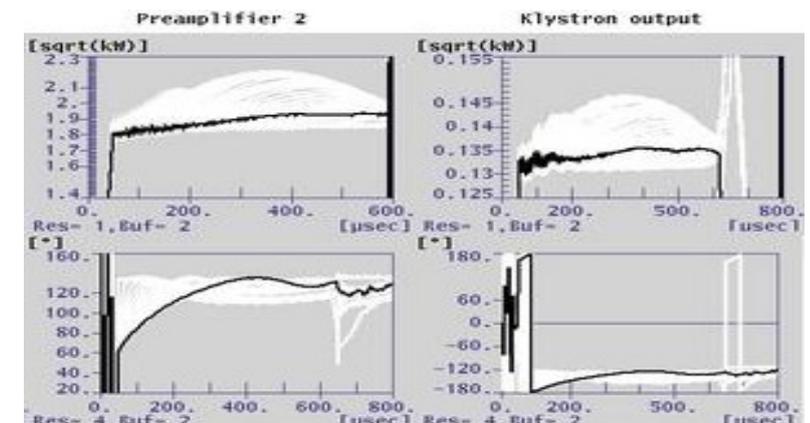
Voltage (Klystron) 115 kV



FF Phase Time Constant +140.00

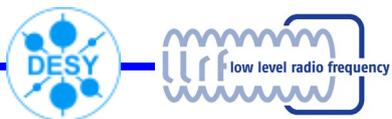
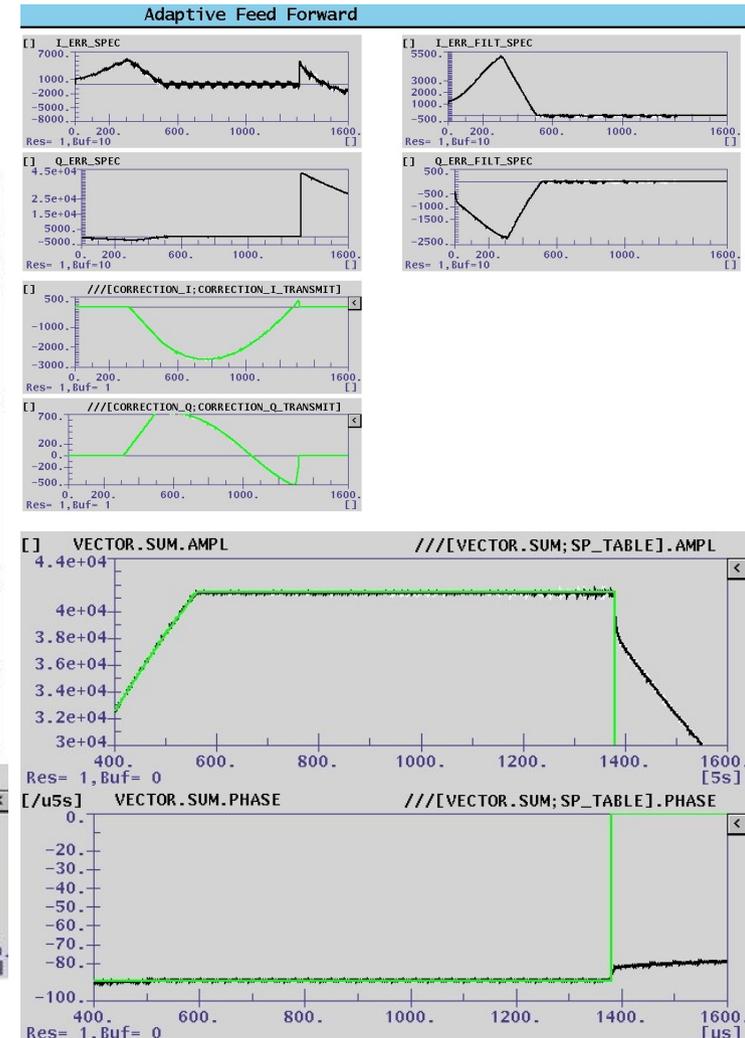
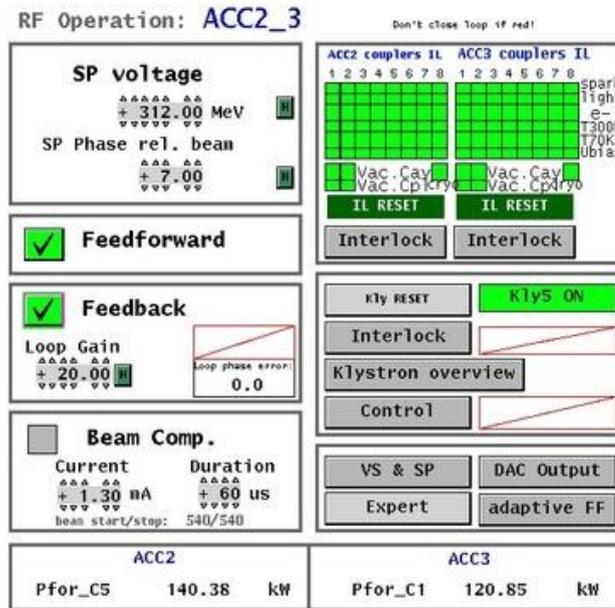
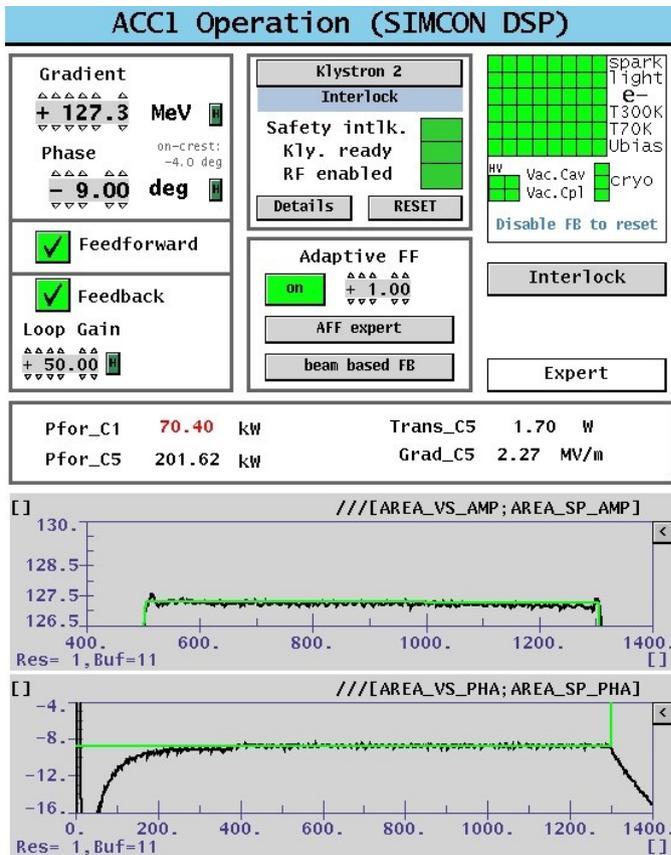
FF Phase Delay +0.0000

FF Phase +600.00



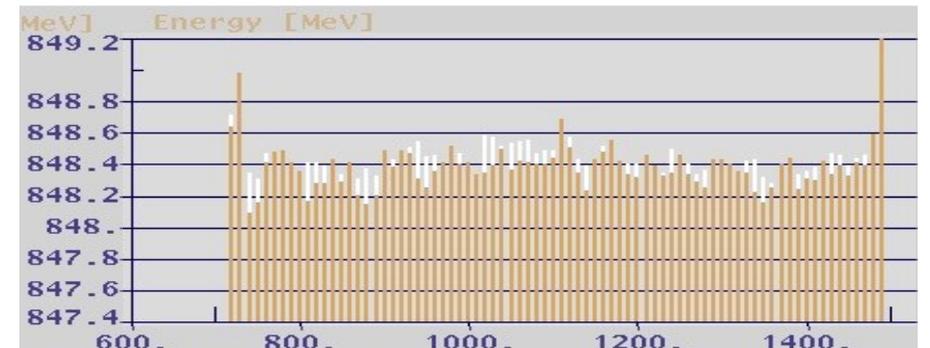
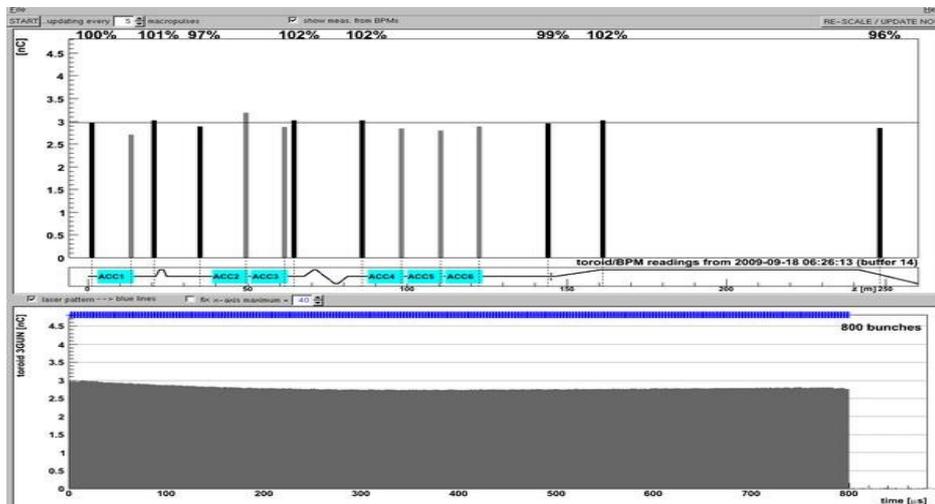
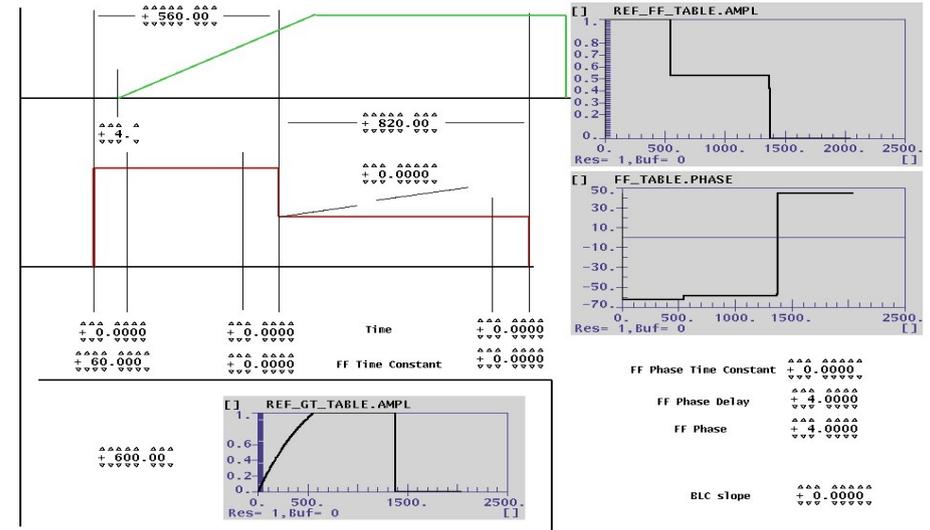
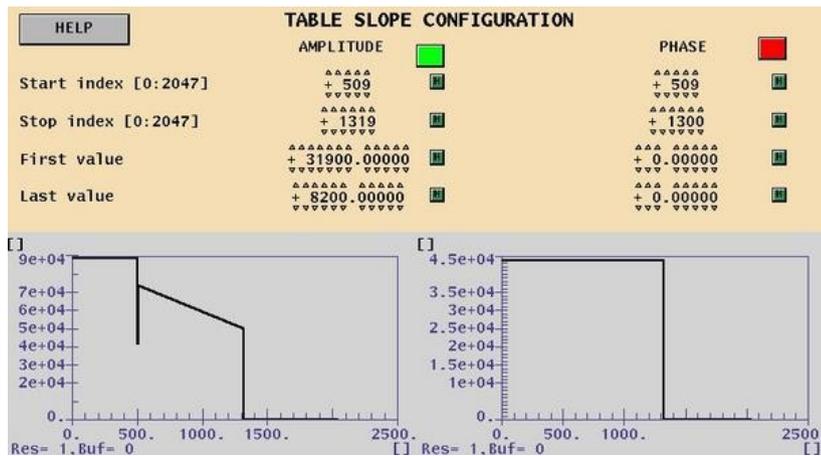
Adaptive FF Performance

Logbook entry (Sep.14, at 7.27): Adaptive feed forward of ACC1 switched on for only a few seconds to build up new corrections. Since the server bug of ACC1 is not yet solved, we stopped the AFF again.

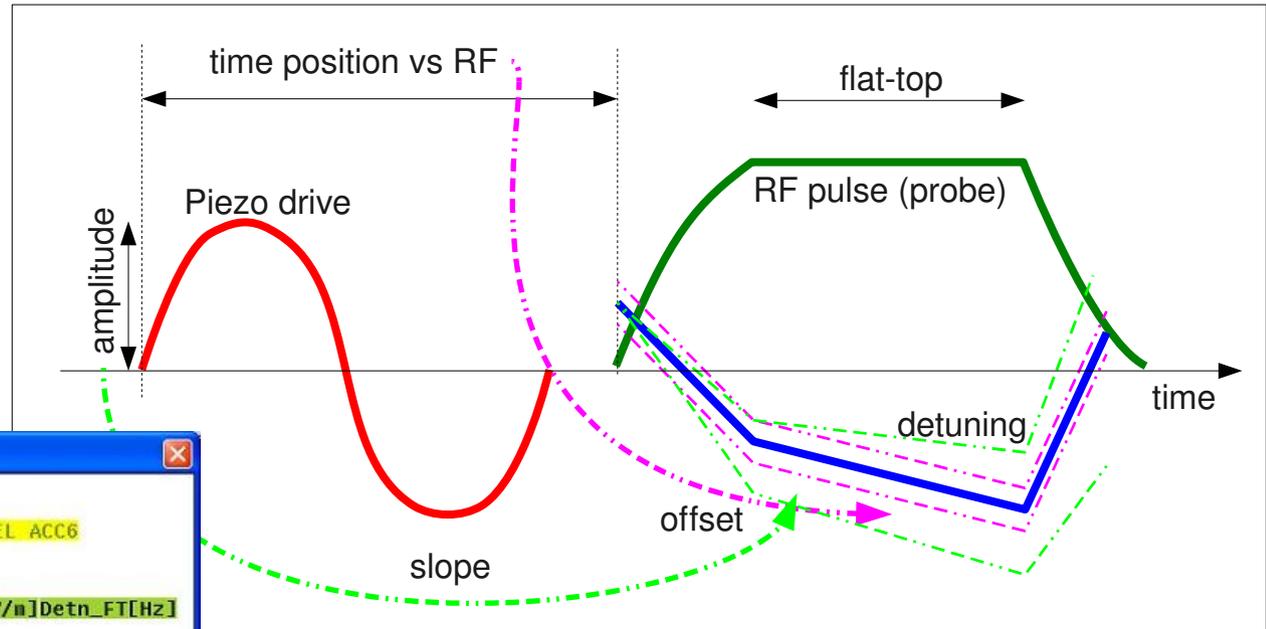


Manual Beam Loading Compensation

- Slope feature in amplitude and phase on beam loading compensation allow to correct energy distribution along the bunch train
- Follow beam profile, pyro and BLM signals



Piezo Control Algorithm



piezo_ctl_acc6: TTF2.RF/LLRF.DSP/ACC4_6/

Piezo Timing

PIEZO CONTROL SYSTEM – OPERATOR PANEL ACC6

ON/OFF

	Freq[Hz]	No. Pulses	Delay[ns]	Amp[V/100]	Grad[MV/n]	Detn_FT[Hz]
DetnCav1	Cav1 + 250	+ 1	+ 198.00	- 0.55	32.9	-12.37
DetnCav2	Cav2 + 250	+ 1	+ 198.04	- 0.52	32.5	-9.657
DetnCav3	Cav3 + 250	+ 1	+ 198.15	- 0.52	31.0	-4.175
DetnCav4	Cav4 + 250	+ 1	+ 197.87	- 0.49	33.4	-8.602
DetnCav5	Cav5 + 250	+ 1	+ 0.00	+ 0.00	18.3	79.493
DetnCav6	Cav6 + 250	+ 1	+ 198.25	- 0.24	24.5	-3.601
DetnCav7	Cav7 + 250	+ 1	+ 198.17	- 0.39	23.4	-13.56
DetnCav8	Cav8 + 250	+ 1	+ 198.27	- 0.39		

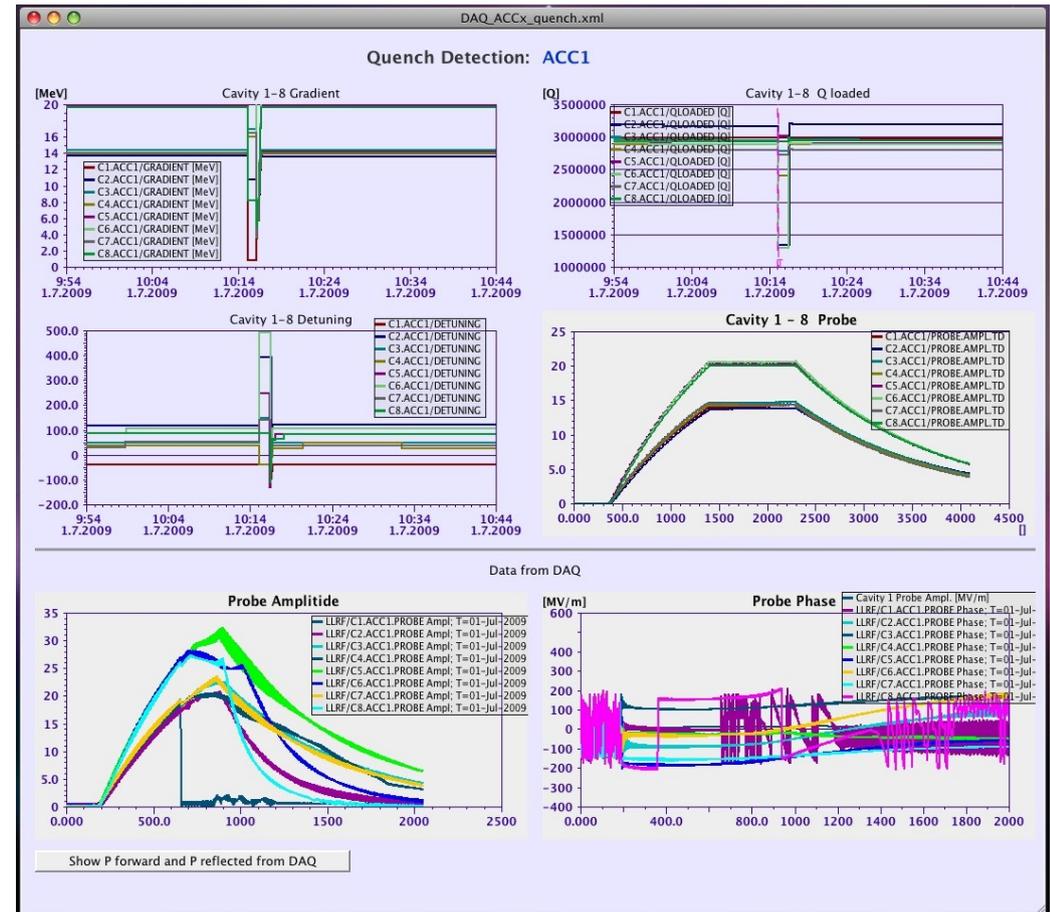
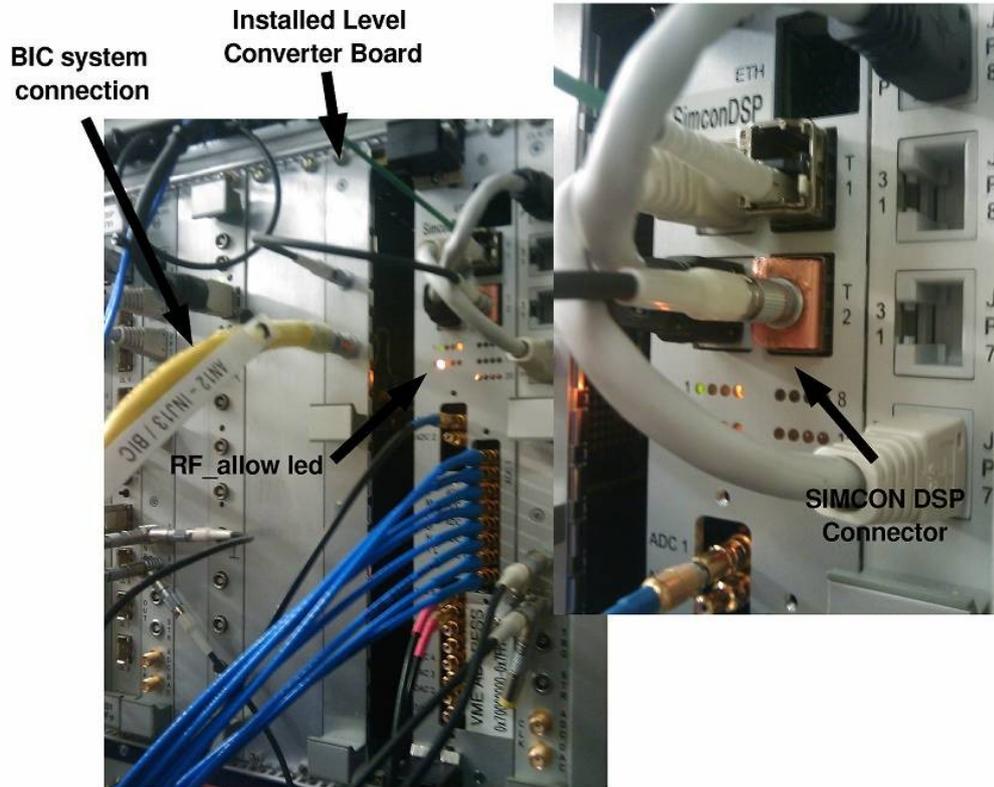
filling [us] 680

flattop [us] 1190

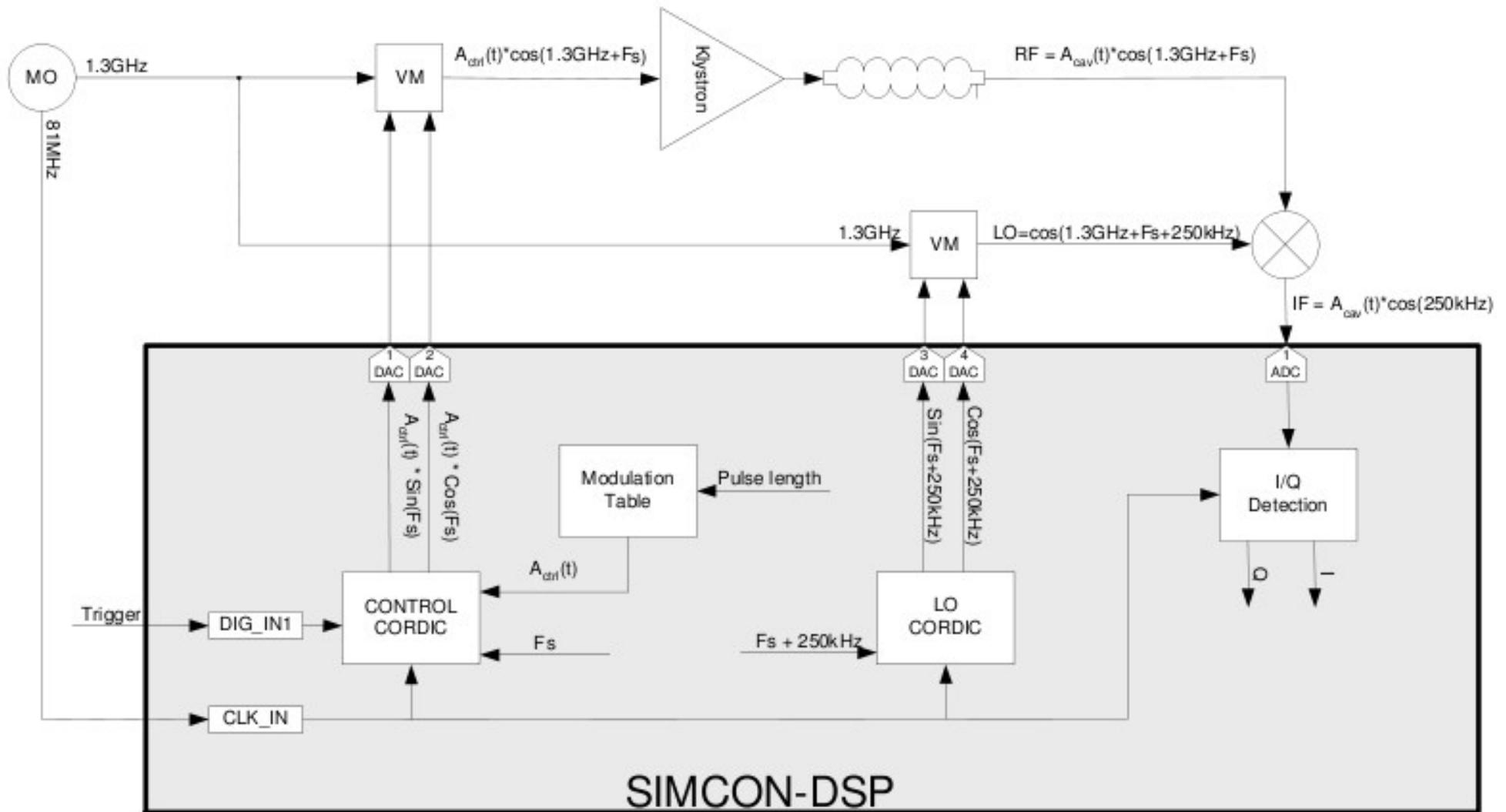
Calibration

Exception Detection and Handling

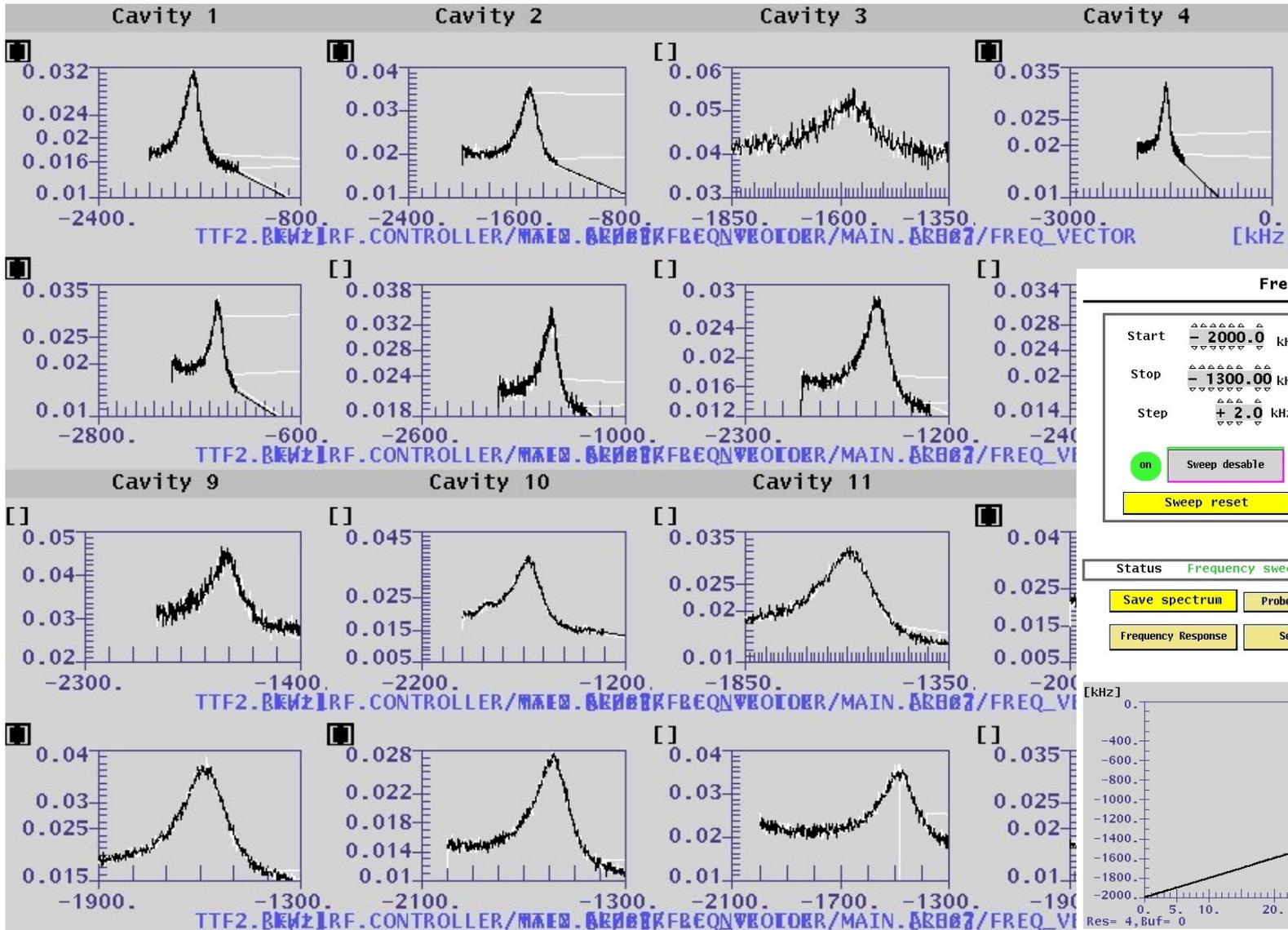
- Fast / slow quench detection
- BIC interlock interface
- DOOCS quench detection middle layer server



Frequency scan of cavities

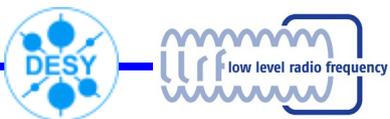


Frequency scan - results



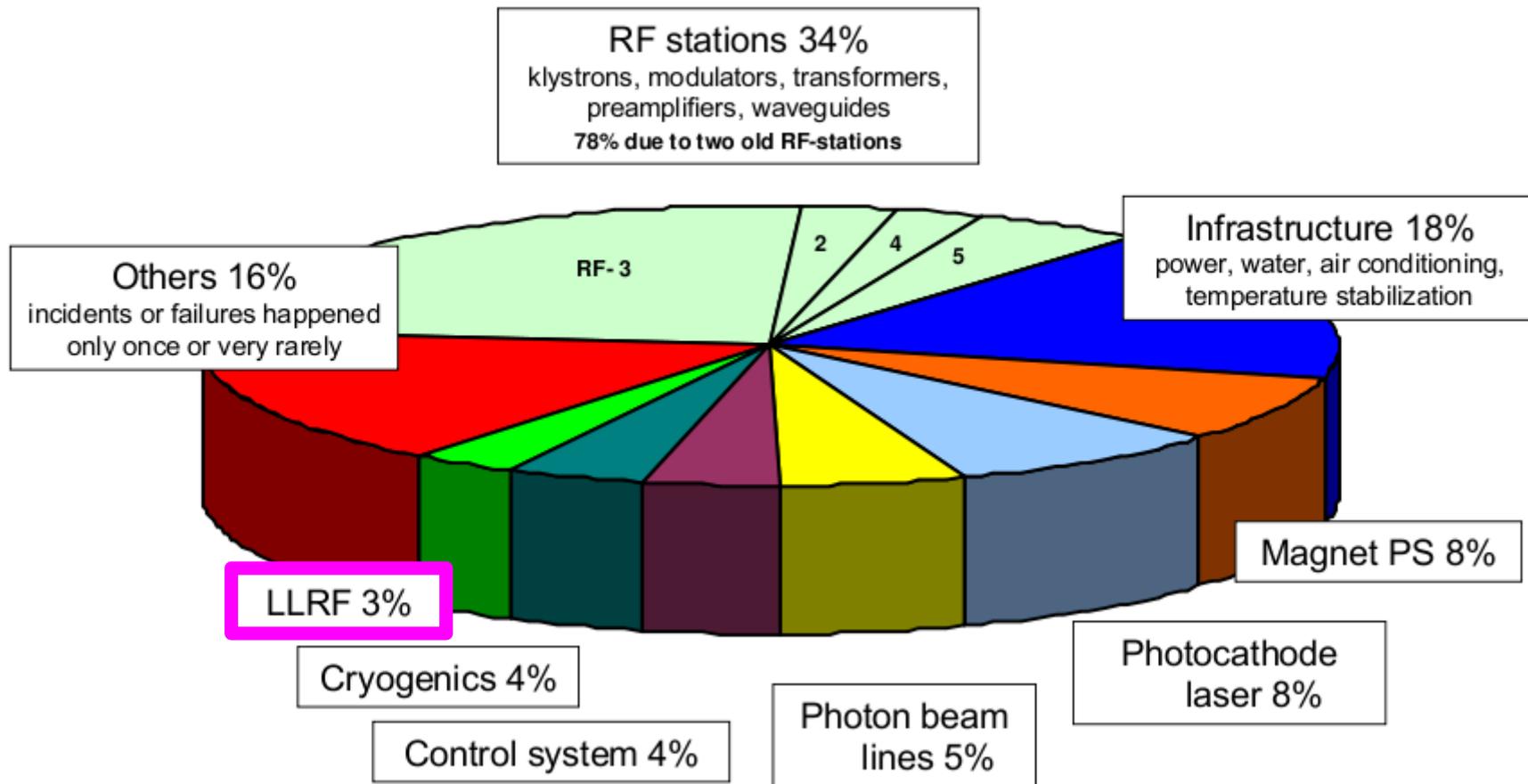
ACC45,
worm conditions

Cav 1	-1704.000
Cav 2	-1556.000
Cav 3	-1628.000
Cav 4	-1626.000
Cav 5	-1562.000
Cav 6	-1646.000
Cav 7	-1656.000
Cav 8	-1550.000
Cav 9	-1758.000
Cav 10	-1724.000
Cav 11	-1652.000
Cav 12	-1720.000
Cav 13	-1638.000
Cav 14	-1634.000
Cav 15	-1526.000
Cav 16	-1704.000



Operation Experience

Total downtime 7%

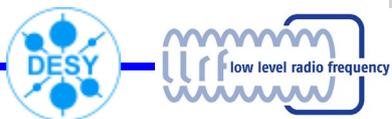
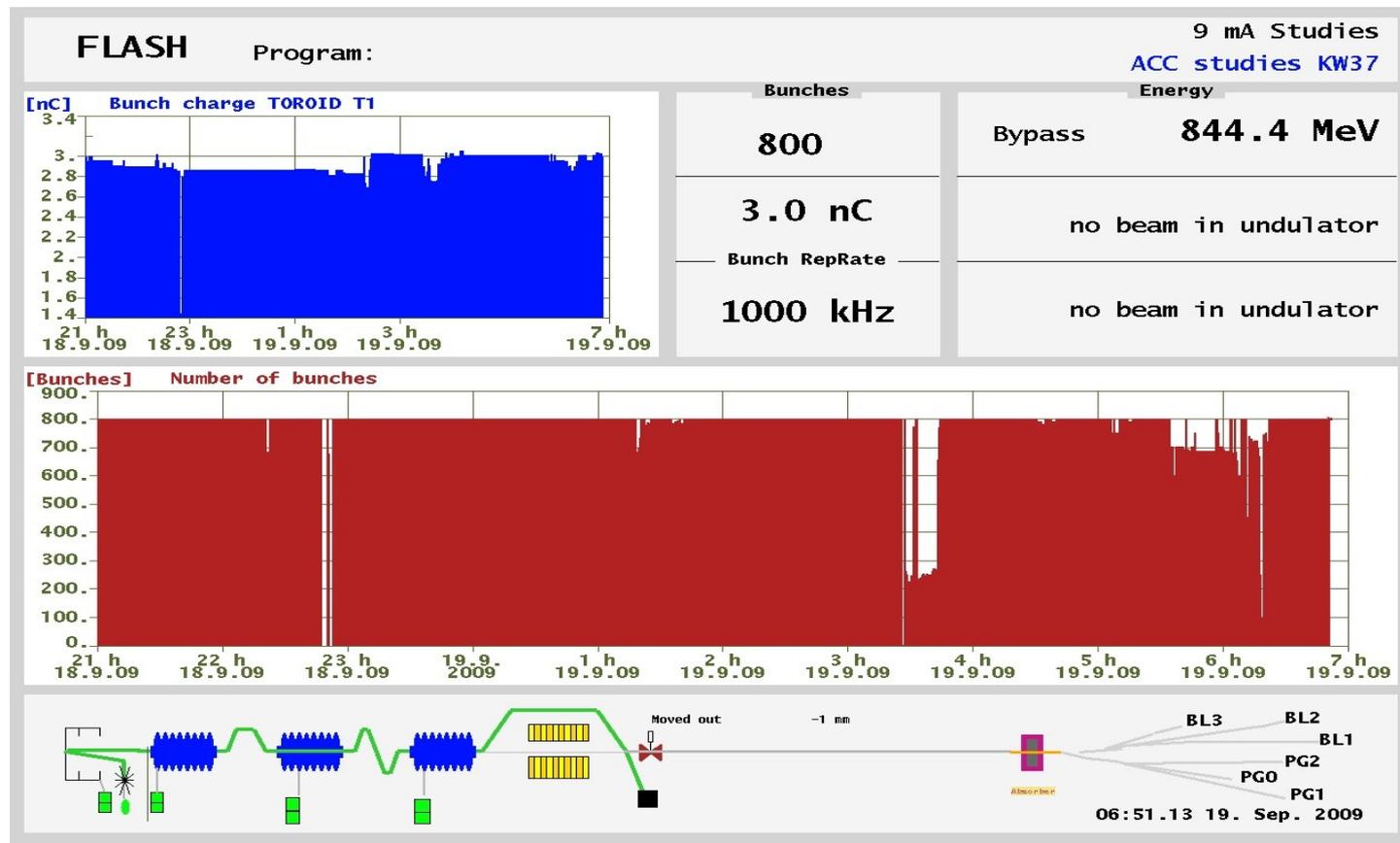


Summary of the 2nd FEL user period at FLASH
2009-10-13 - Katja Honkavaara, DESY



Performance during 9mA studies

- Stable operation at 1MHz beam repetition rate was achieved, resulting in stable 3mA running with a full 800us pulse for over ten contiguous hours.
- Quick start-up after machine access (40 min)
- Several hours of operation at ~9mA but with short trains (300-500us)
- Achieved full pulse length (800us, 2400 bunches) at 6mA for short period



ATCA LLRF system

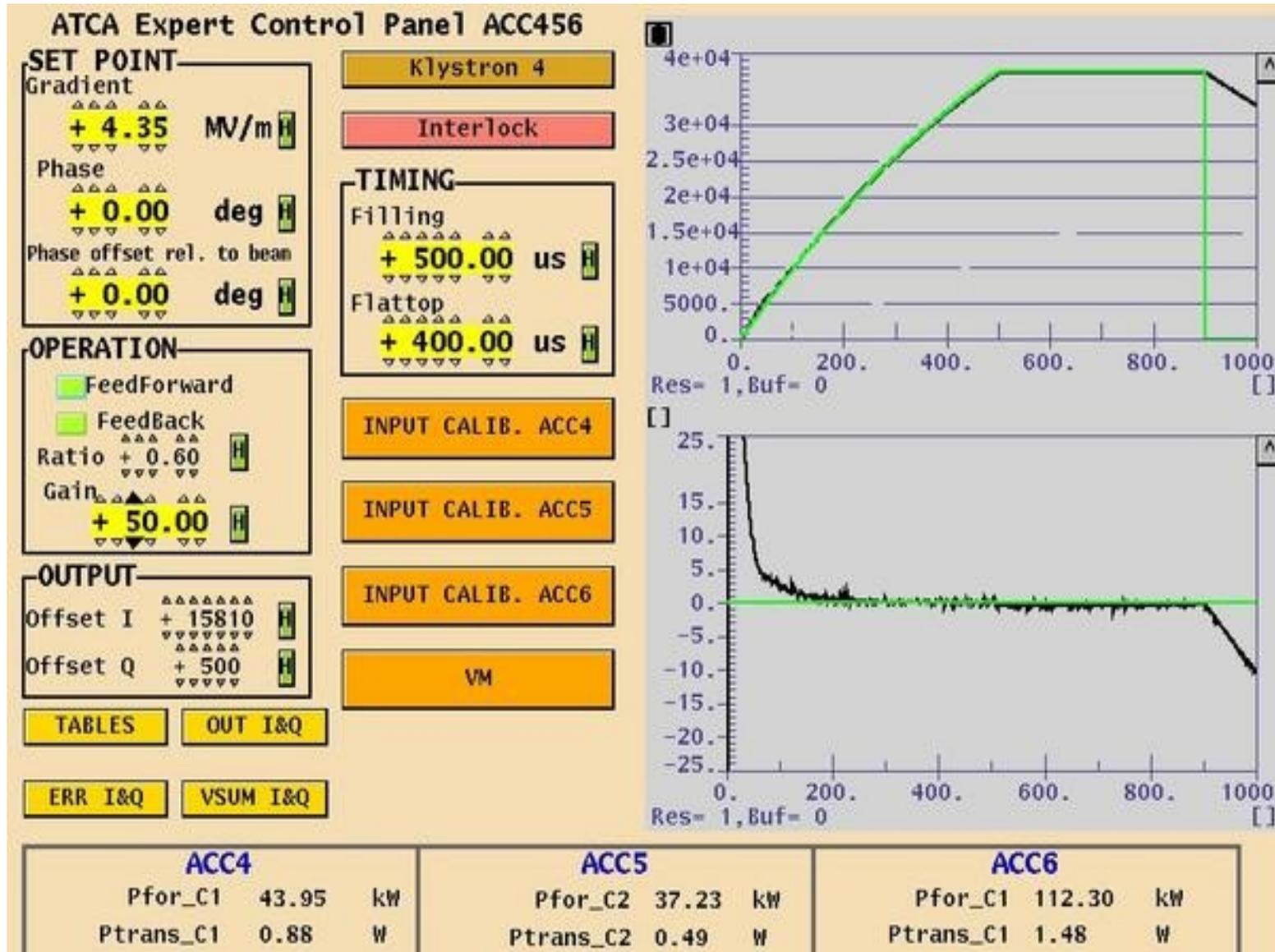


Front view

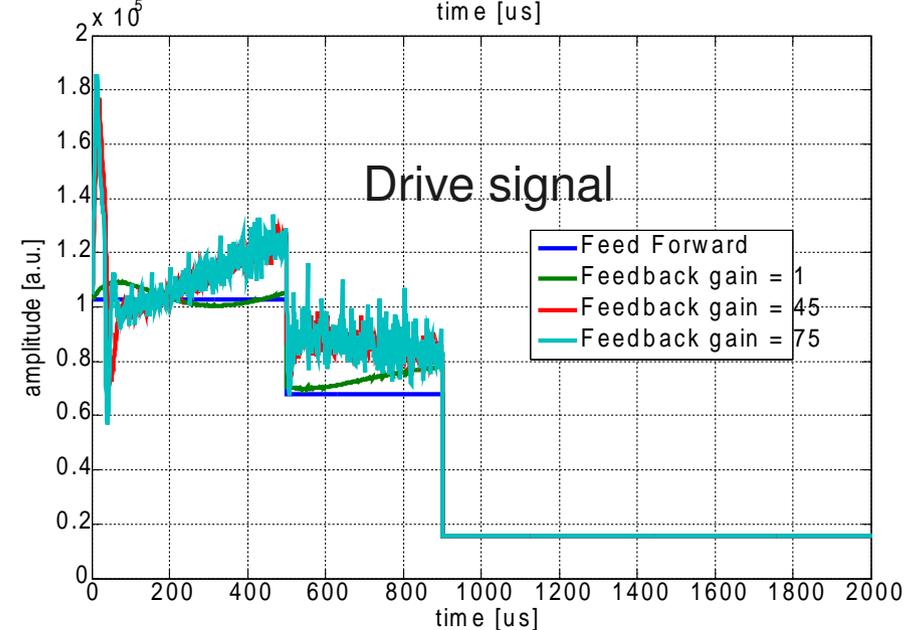
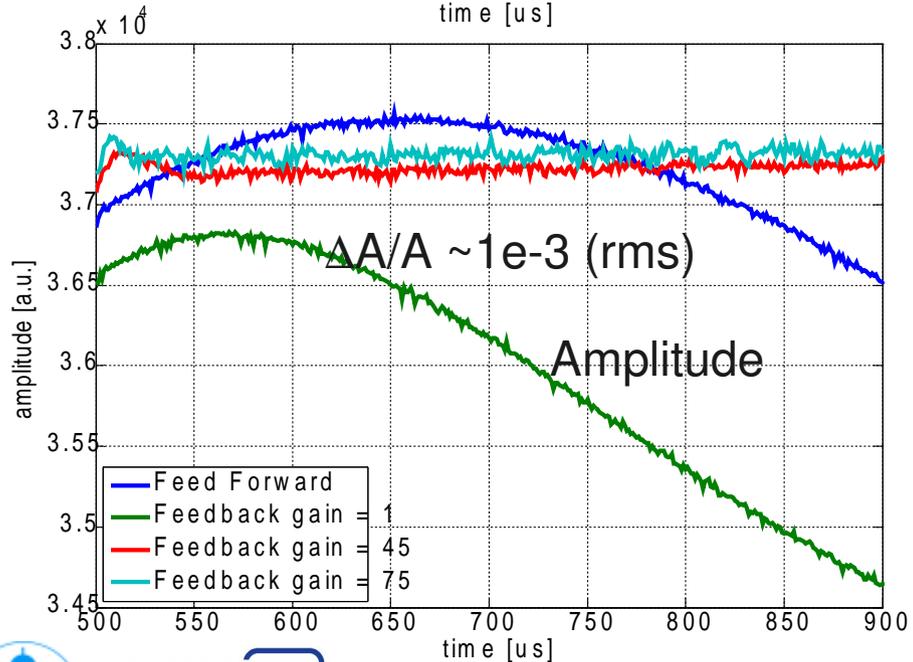
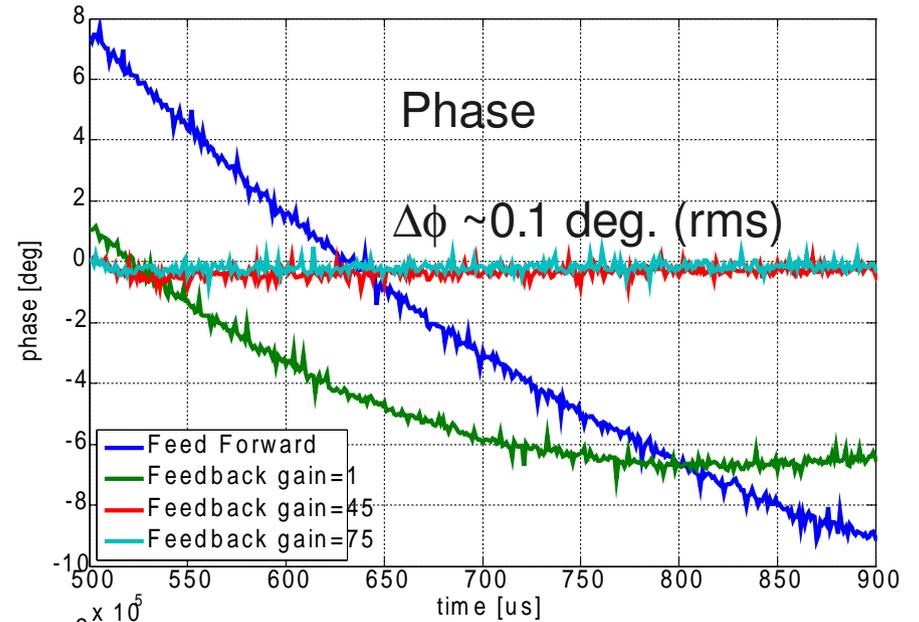
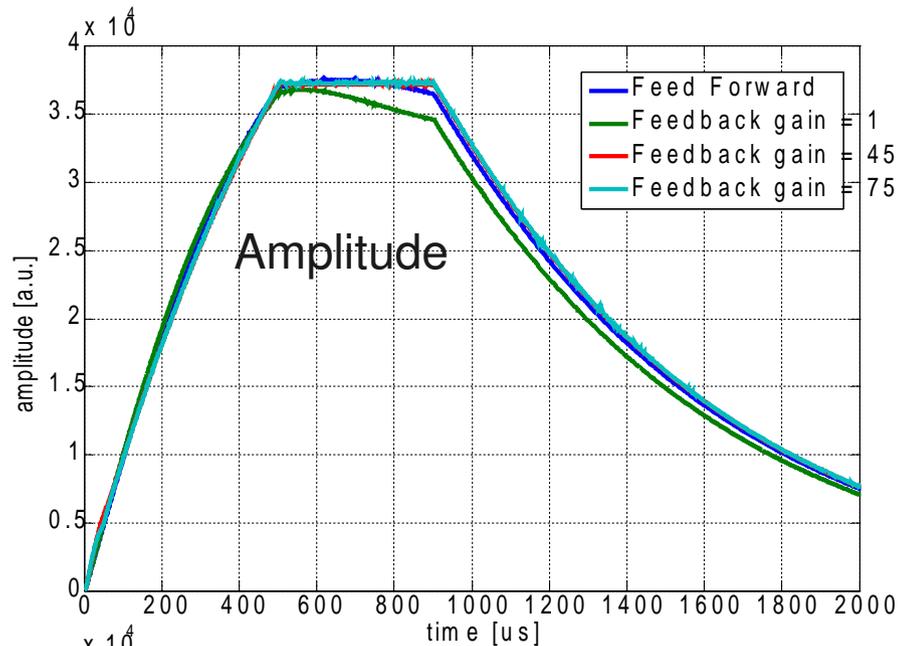


Rear view

Operator Interface



Amplitude and Phase Control

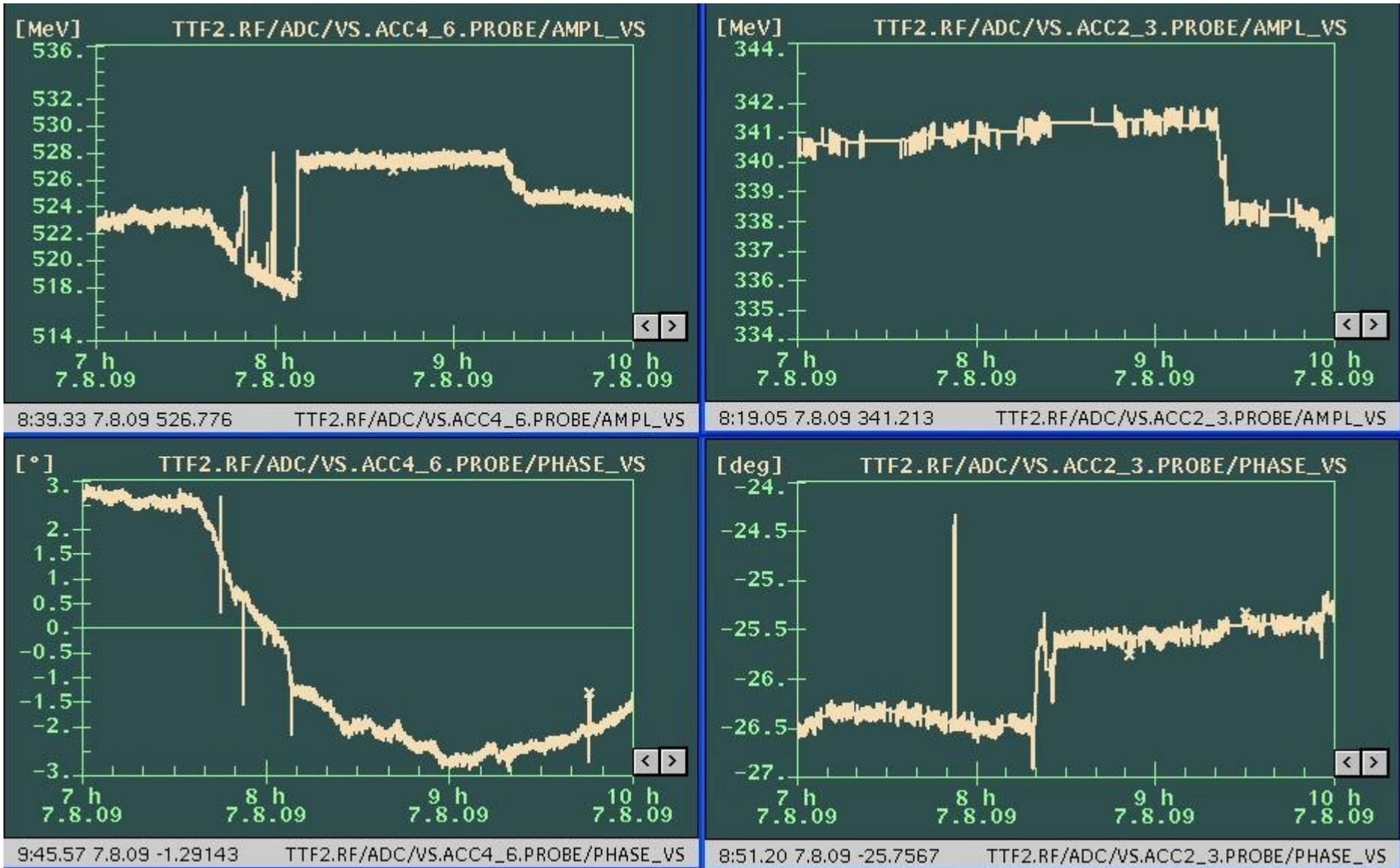


Typical Problems in the LLRF System

- **Phase drifts** of the order of few degree per day.
 - Cables, connectors, MO, downconverter
- **Reproducibility of cavity fields** especially cavity phases with respect to the beam after maintenance period.
- **Large changes of settings require rf expert tuning**
 - Loop phase (if klystron HV is changed)
 - Feedforward table
 - Beam loading compensation
 - Feedback gain
 - Vector-sum calibration (sometimes)
 - Cavity tuning
 - Timing (pulse length)



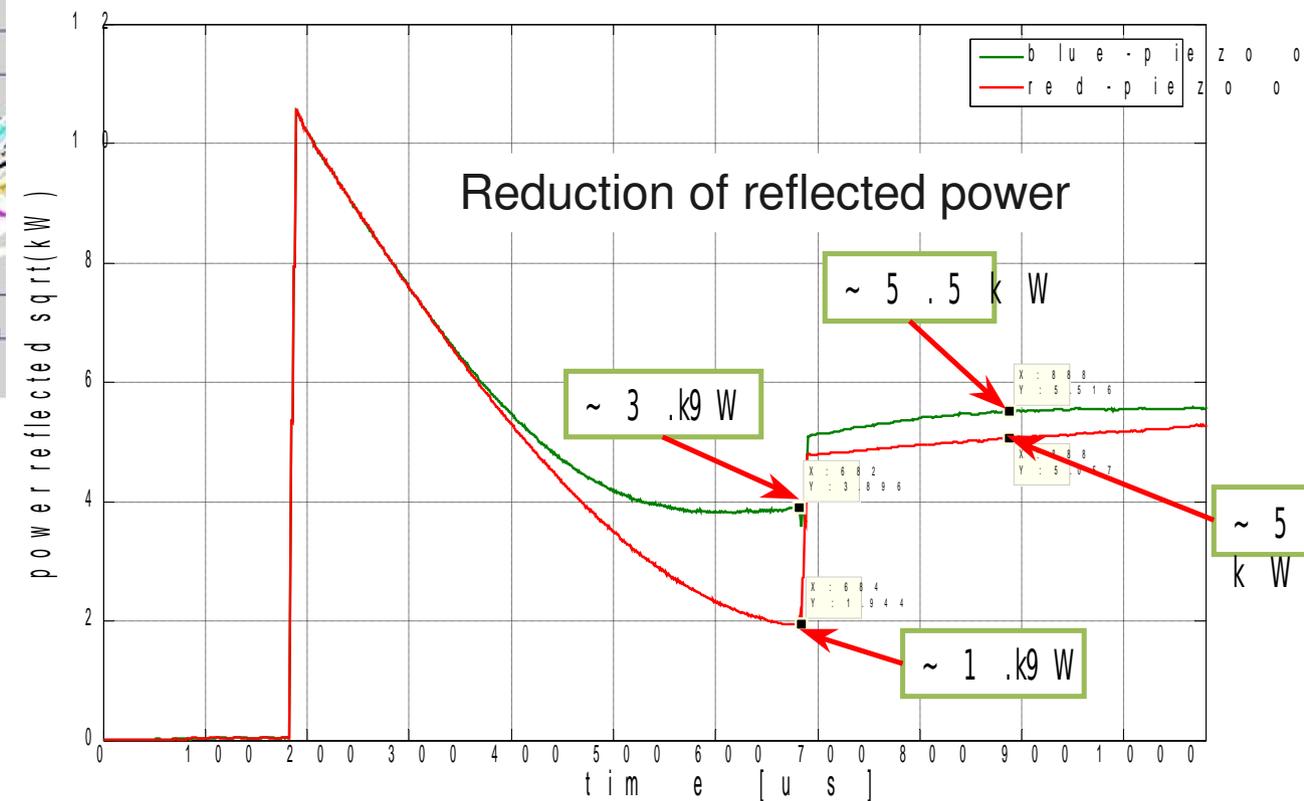
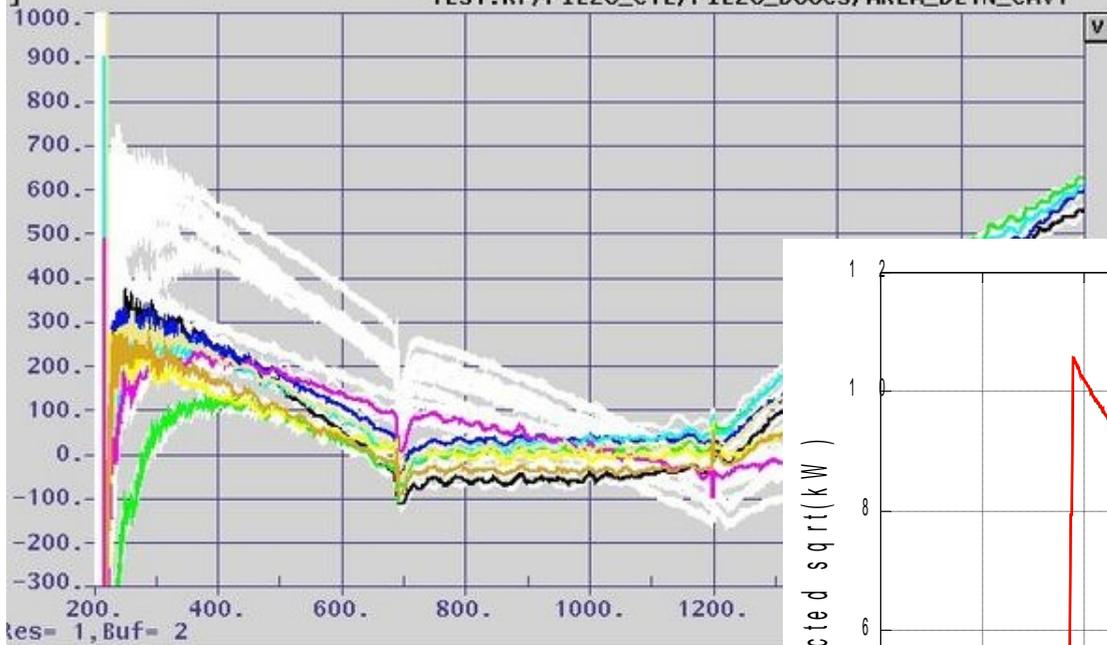
Drifts in ACC23 & ACC456



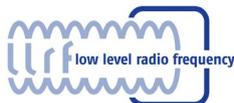
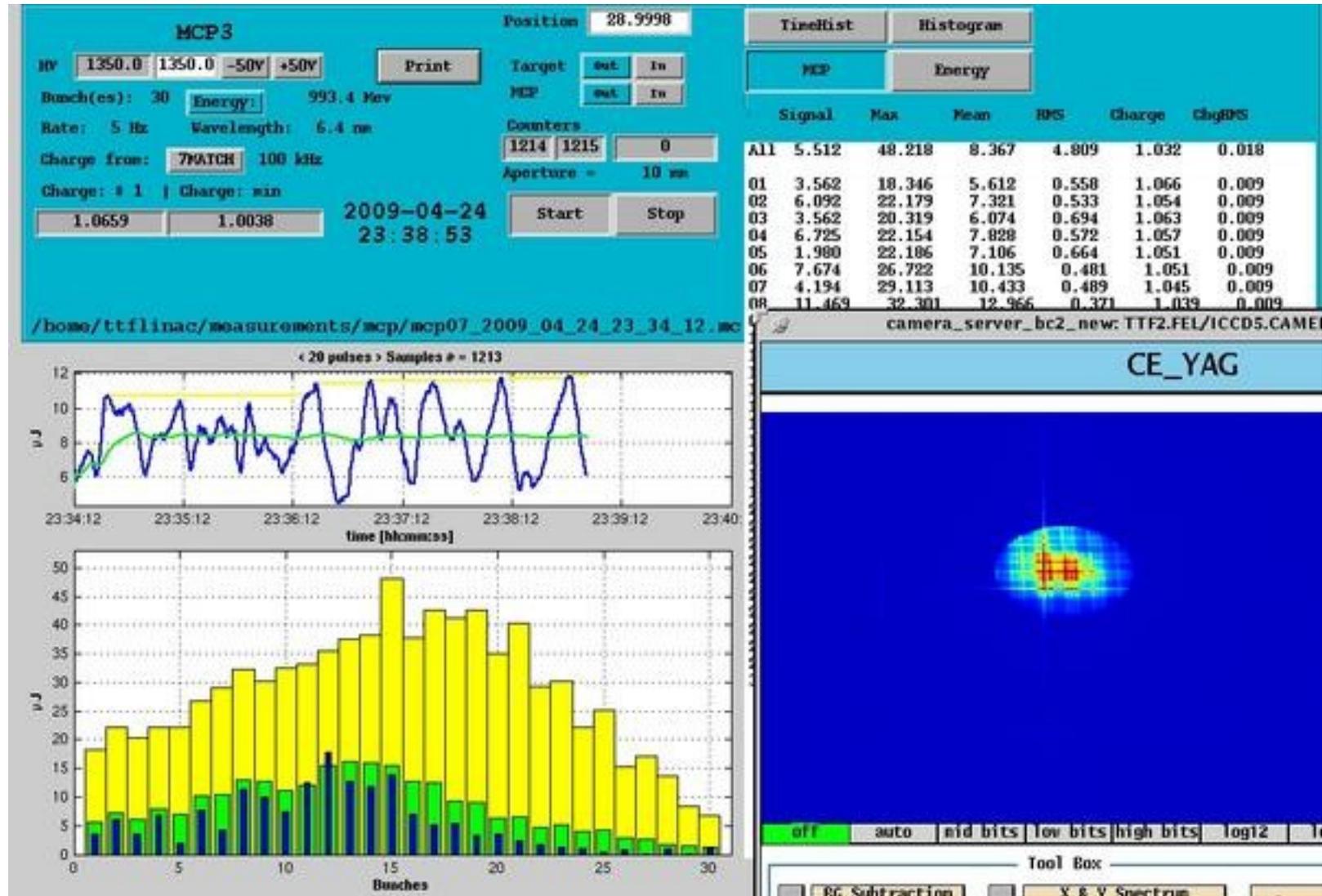
LFD with piezo tuners

CAVITY DETUNING [Hz]

TEST.RF/PIEZO_CTL/PIEZO_DOOCS/AREA_DET_N_CAV8
 TEST.RF/PIEZO_CTL/PIEZO_DOOCS/AREA_DET_N_CAV7
 TEST.RF/PIEZO_CTL/PIEZO_DOOCS/AREA_DET_N_CAV6
 TEST.RF/PIEZO_CTL/PIEZO_DOOCS/AREA_DET_N_CAV5
 TEST.RF/PIEZO_CTL/PIEZO_DOOCS/AREA_DET_N_CAV4
 TEST.RF/PIEZO_CTL/PIEZO_DOOCS/AREA_DET_N_CAV3
 TEST.RF/PIEZO_CTL/PIEZO_DOOCS/AREA_DET_N_CAV2
 TEST.RF/PIEZO_CTL/PIEZO_DOOCS/AREA_DET_N_CAV1



Piezo operation influence on SASE level



LLRF Improvement Plans

- Improve long term phase stability (which is of the order of few degrees)
- Fix problems with adaptive feed-forward / controller server
 - including handling of exceptions, variable beam loading
- RF Gun control (automatic start-up, calibration)
- Automated calibration of vector-sum
- Reproducibility
 - Restoring beam parameters after shutdown or interlock trip
- Slow feedback for pulse train stability (RF and beam based)
- Implement LLRF control system for XFEL at FLASH
 - improve field regulation, operability, availability, reliability
- Automation of LLRF operation
- High gradient and high beam loading require advanced applications
- Documentation



Conclusion

- Substantial part of LLRF hardware at FLASH is upgraded.
- New functionality added to firmware and higher level software.
- Machine operation supported by LLRF during user run and machine studies as well
 - Only 3% of machine downtime due to LLRF
 - RF control performance goals for 9 mA experiment achieved:
 - Stable operation at 1MHz, 3mA, 800 bunches
 - Several hours of operation at ~9mA (with short trains 300-500us)
 - Full pulse length (800us, 2400 bunches) at 6mA (short term)

Thank you for your attention