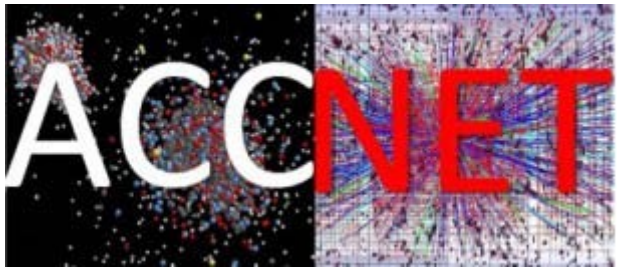
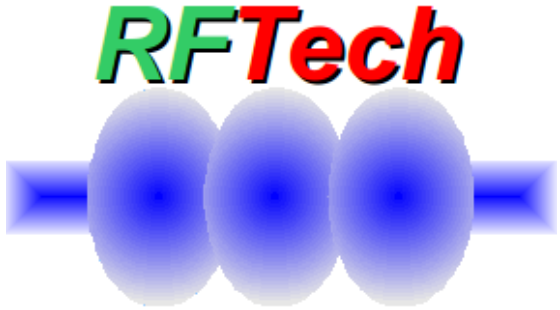
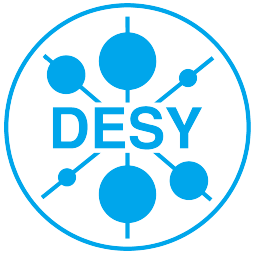




FLASH LLRF system - upgrade and current status

M.Grecki for LLRF team



2nd annual RFTech meeting, PSI Villigen, 1-2 December 2010

Agenda

- FLASH and upgrade 2009/2010
- LLRF control system
  - hardware upgrade
    - previous status
    - upgrade
  - software upgrade
- Conclusion

FLASH

Free-electron LASer in Hamburg

- Single-pass high-gain SASE FEL

  SASE = self-amplified spontaneous emission

- Photon wavelength range from vacuum ultraviolet to soft x-rays
- Free-electron laser user facility since summer 2005
  - 1st period: Jun 2005 –Mar 2007
  - 2nd period: Nov 2007 –Aug 2009
  - 3rd period: Sep 2010 –Sep 2011
- FLASH is also a test bench for the European XFEL and the International Linear Collider (ILC)
- FLASH II, a second undulator beam line is in preparation

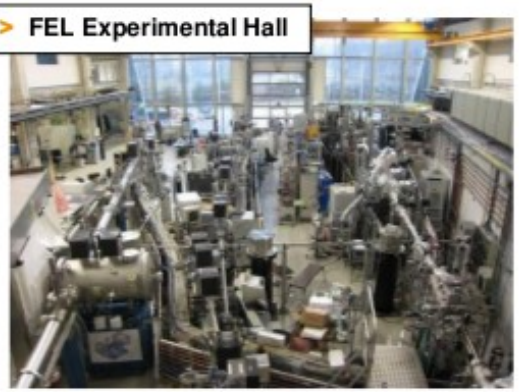
FLASH layout before upgrade

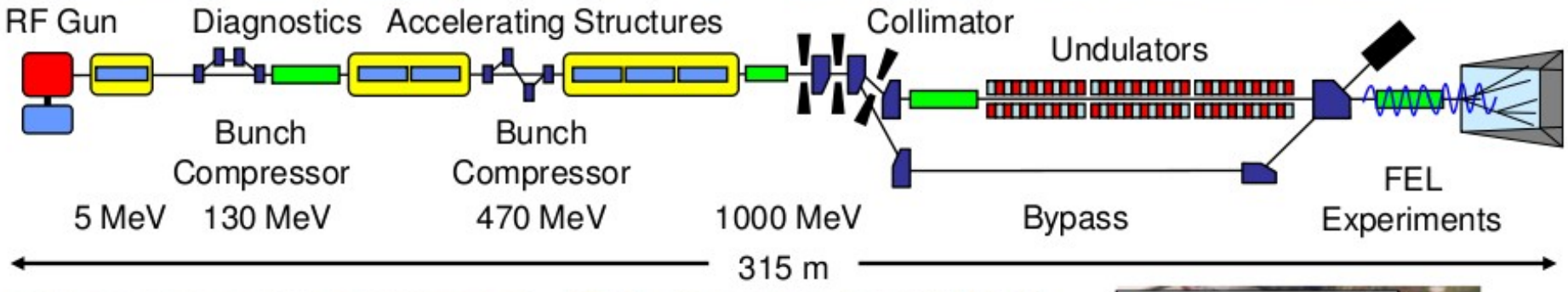
(Sep-2007 – Sep-2009)

- Normal conducting 1.3 GHz RF gun
- Ce_2Te cathode
- Nd:YLF based ps photocathode laser

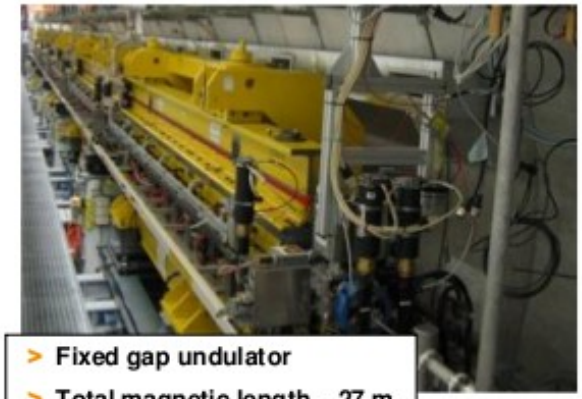
- Collimator section + by-pass line

- FEL Experimental Hall





- TESLA type superconducting accelerating modules
- Each module has eight 9-cell Nb cavities
- RF frequency at 1.3 GHz



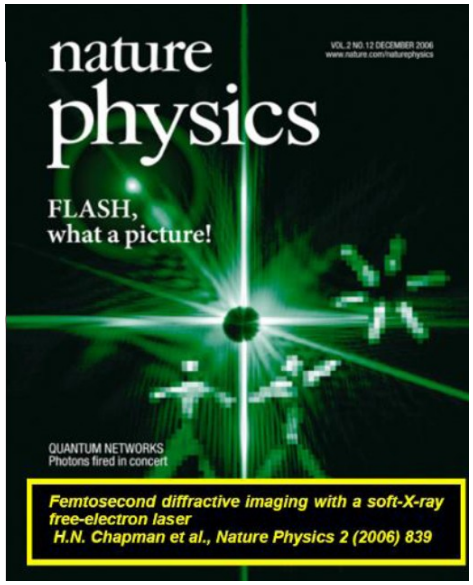
- Fixed gap undulator
- Total magnetic length ~ 27 m
- Permanent NdFeB magnets

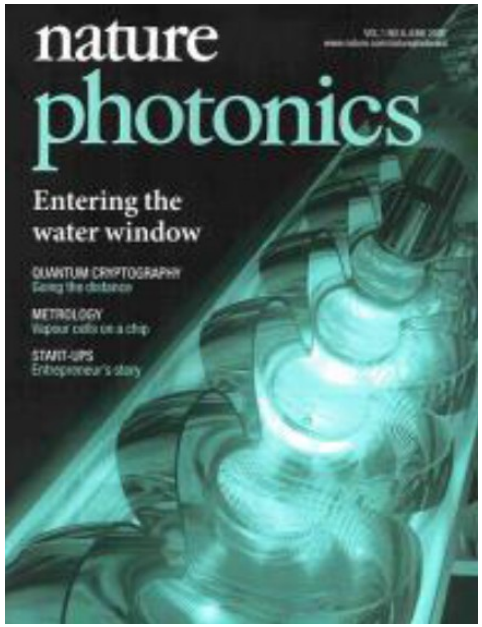
- FEL Experimental Hall

FEL performance 2nd user period

(Nov-2007 –Aug-2009)

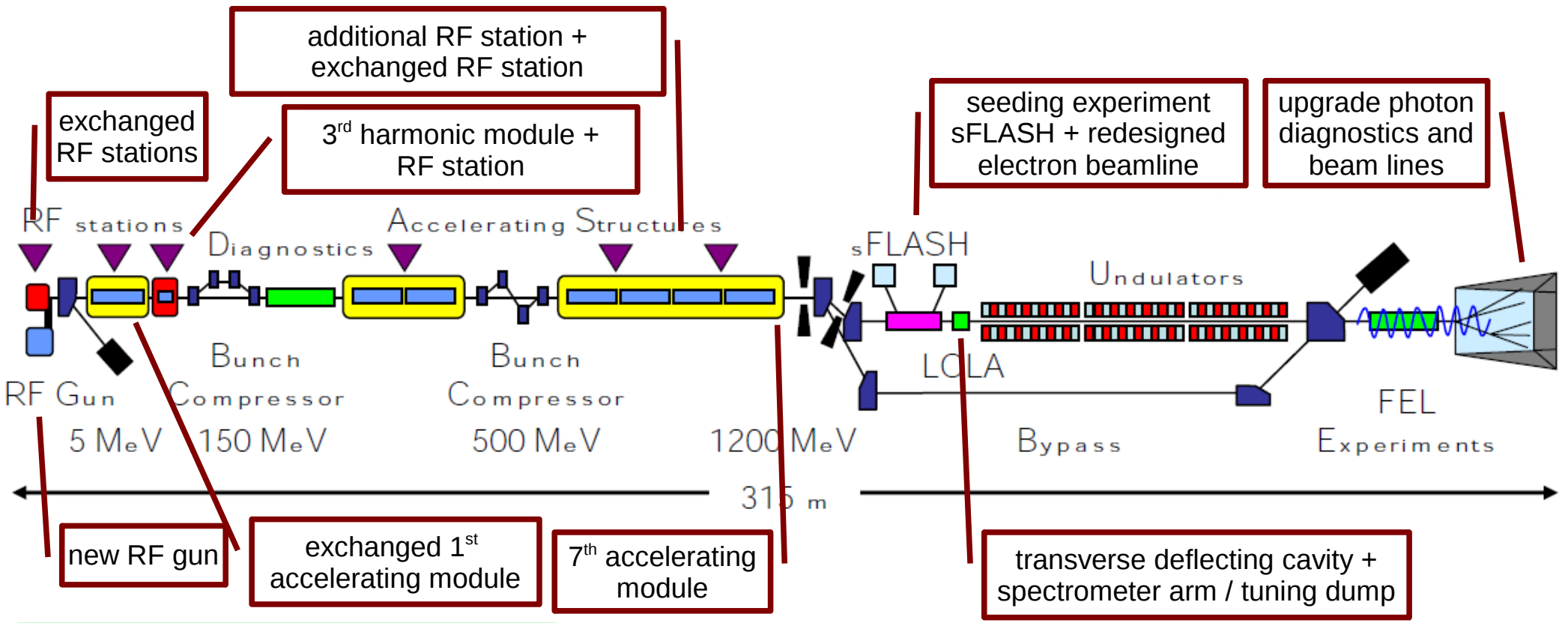
- Typical user operation parameters 2nd user period
  - Wavelength range (fundamental) 6.8 –40.5 nm
  - Average single pulse energy 10 –100 µJ
  - Pulse duration (FWHM) 10 –70 fs
  - Peak power (from av.) 1 –5 GW
  - Average power (example for 500 pulses/sec ~ 15 mW
  - Spectral width (FWHM) ~ 1 %
  - Peak Brilliance 10^{29} –10^{30} * * photons/s/mrad^2/mm^2/0.1%bw





more than 100 publications on photon science at FLASH in high impact journals
http://hasylab.desy.de/facilities/flash/publications/selected_publications

Upgrade 2009 / 2010



additional RF station + exchanged RF station

exchanged RF stations

3rd harmonic module + RF station

seeding experiment sFLASH + redesigned electron beamline

upgrade photon diagnostics and beam lines

new RF gun

exchanged 1st accelerating module

7th accelerating module

transverse deflecting cavity + spectrometer arm / tuning dump

new diode pumped photocathode laser; upgraded old laser systeminstallation

exchanged injector corrector magnets

upgraded magnet controls

maintenance of infrastructure: water supplies, cryogenics

new cabling/layout injector llrf electronics

optimized llrf controls

new synchronization and feedback systems

improved survey and alignment of accelerator components (incl. SASE undulators)

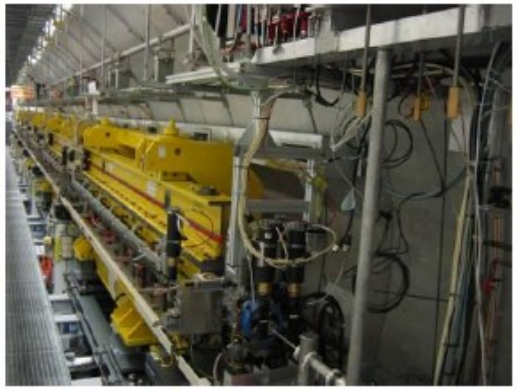
installation of a second master oscillator (as backup)

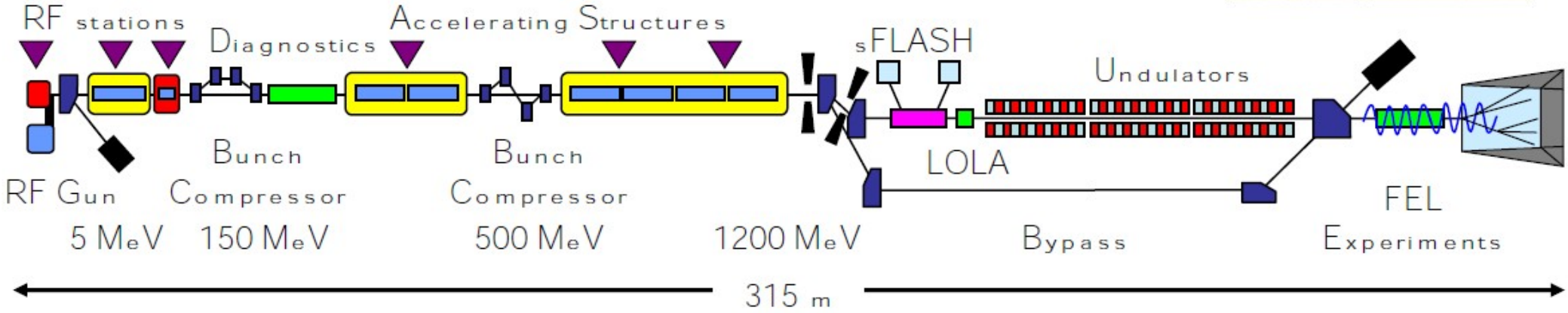
upgraded and optimized waveguide distribution

upgraded personnel interlock and radiation safety systems

Upgrade 2009 / 2010








LLRF upgrade - hardware

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

Master Oscillator

Old hardware platform

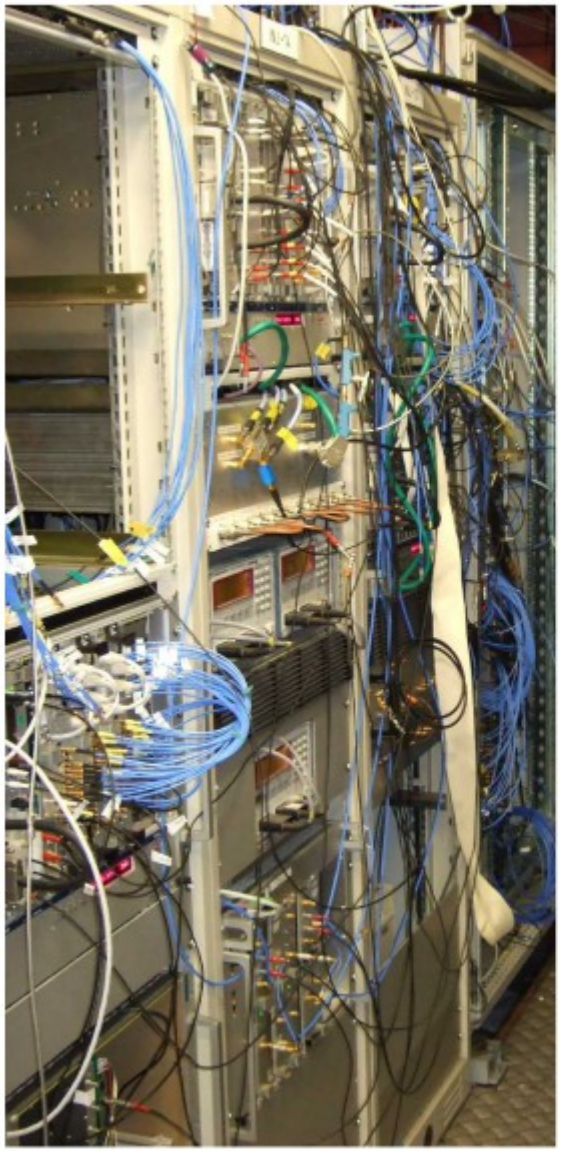
- DSP C67 (2002)
  - 1x C67 DSP for up to 32 cavities
  - 8x Gigalink Interface (4x8ADC, DAC)
  - 1 MHz sampling, 4 microsecond latency

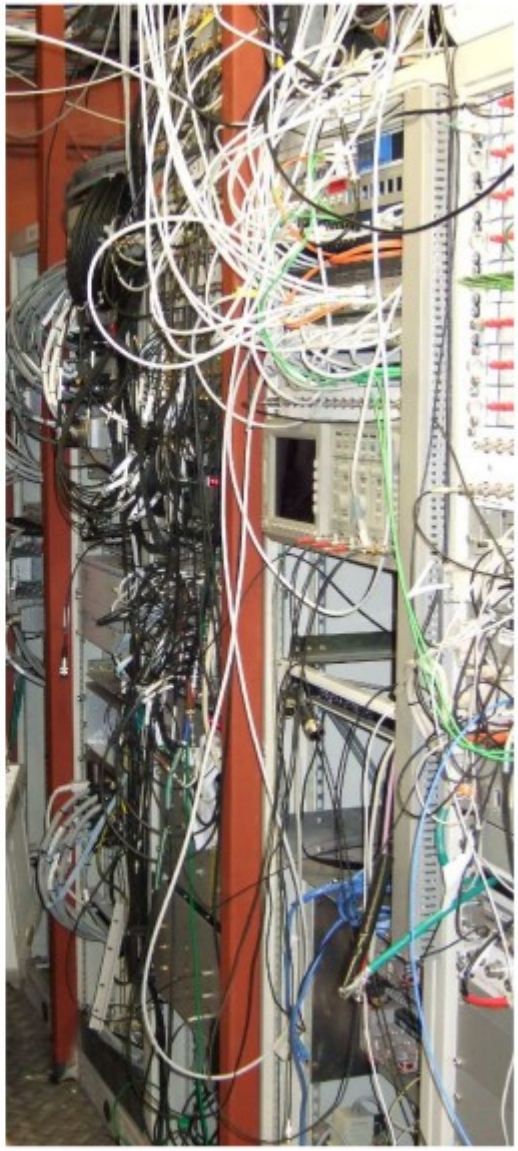
New hardware platform

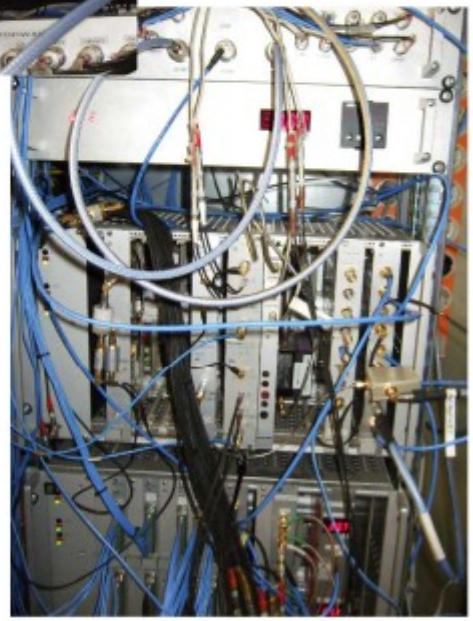
SimconDSP

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

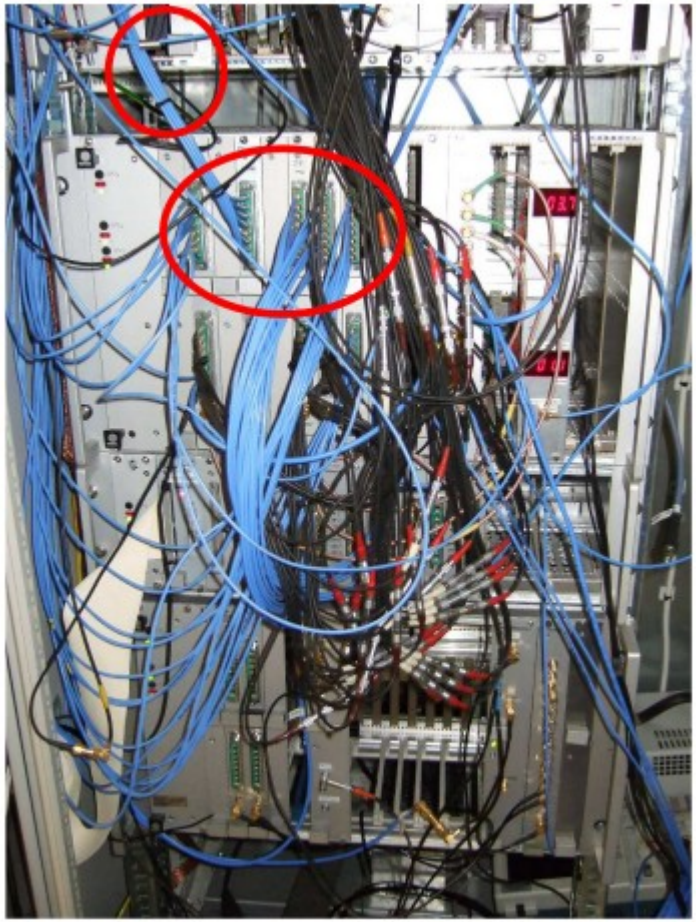
Old Injector Racks

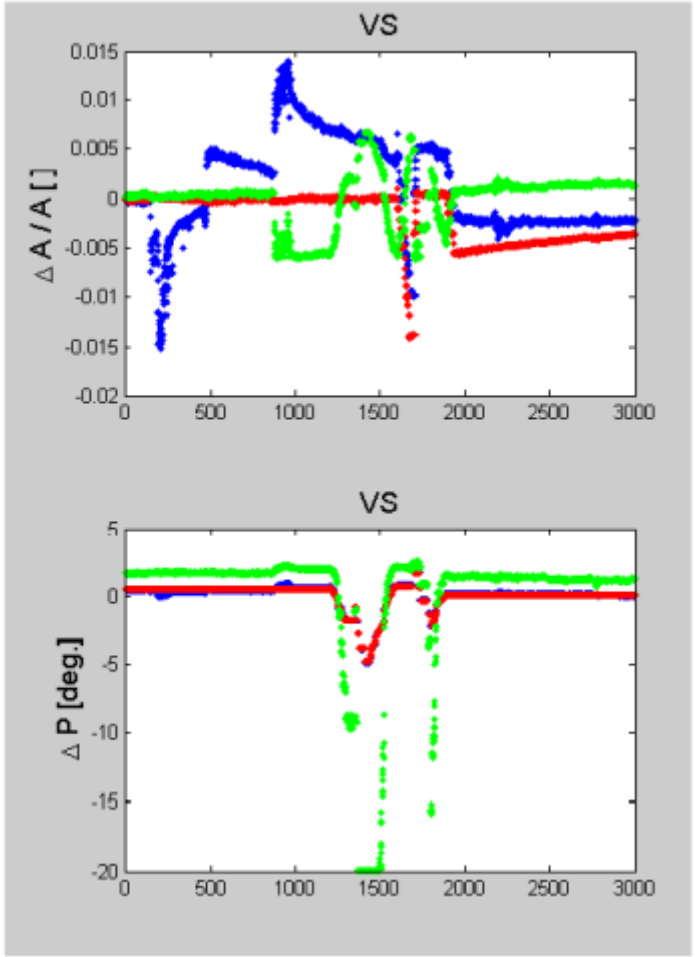






Signal jumps due to poor connections

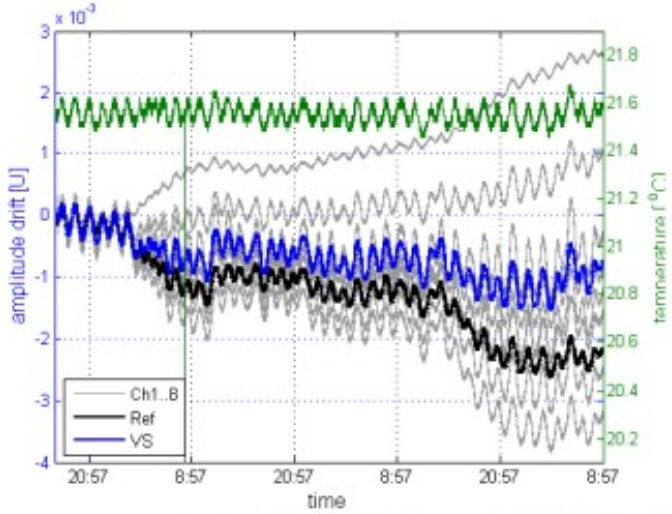




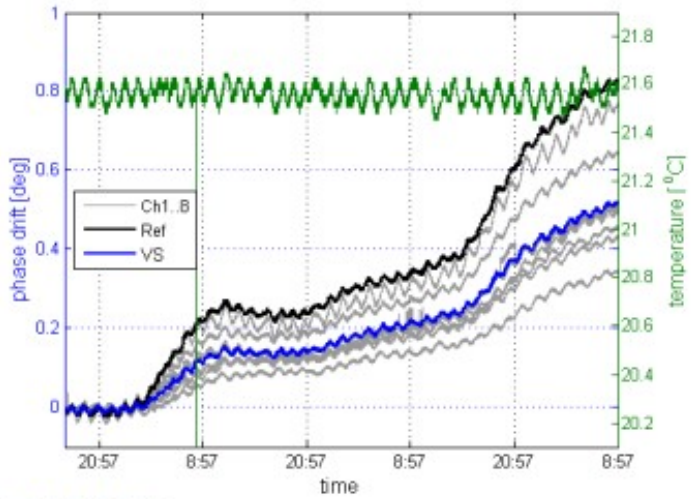
FLASH Seminar, 21.4.2009
"Beam Stability at FLASH – update", F. Ludwig

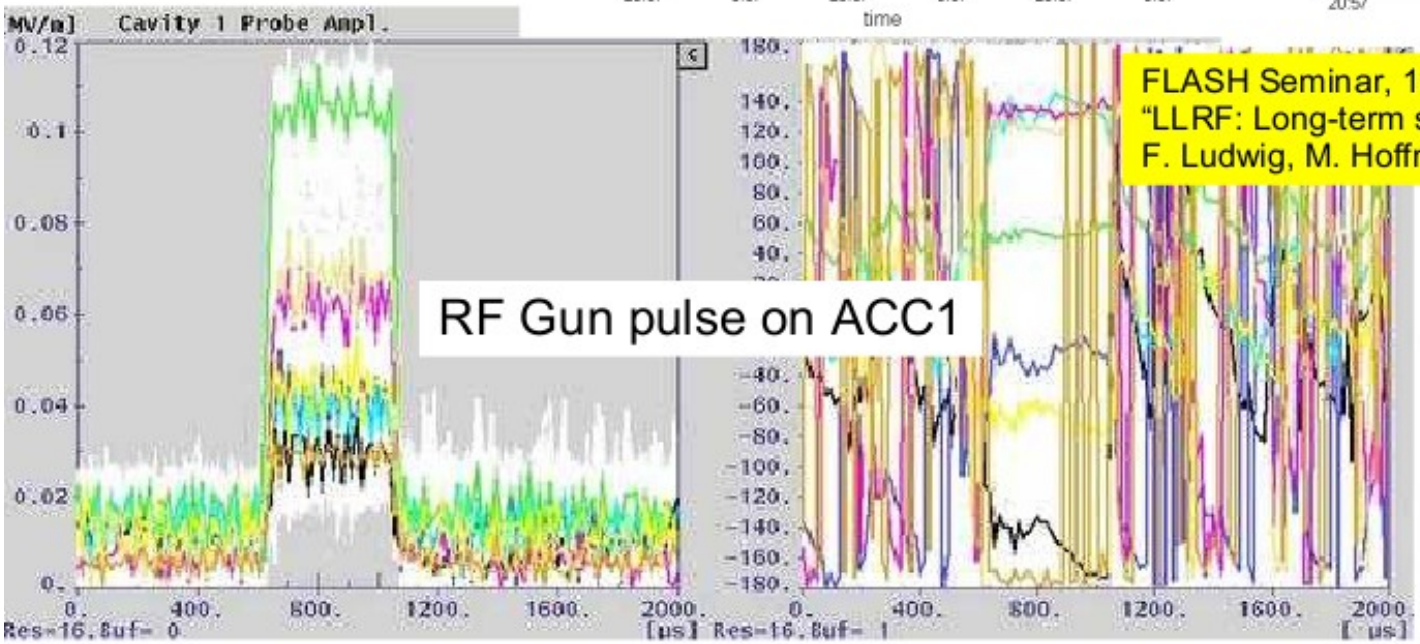
Drifts and crosstalks

- Amplitude Drift :



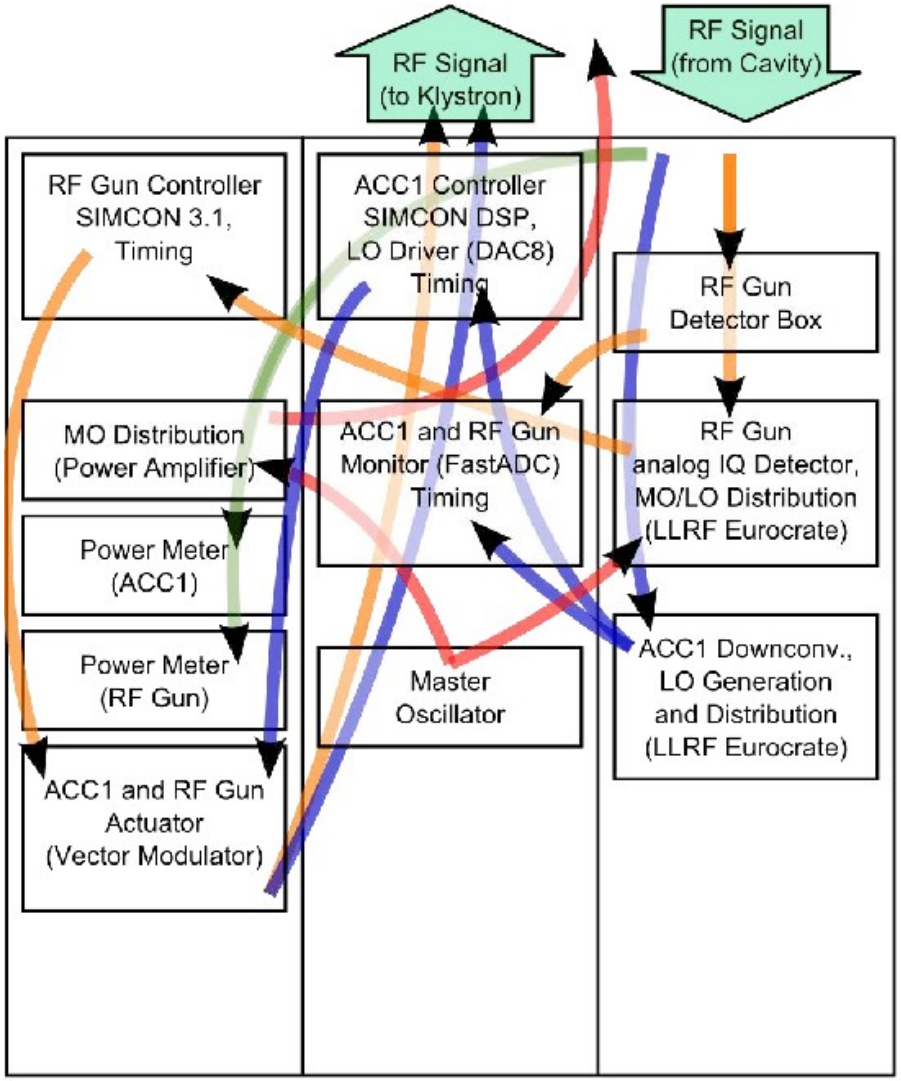
- Phase Drift :



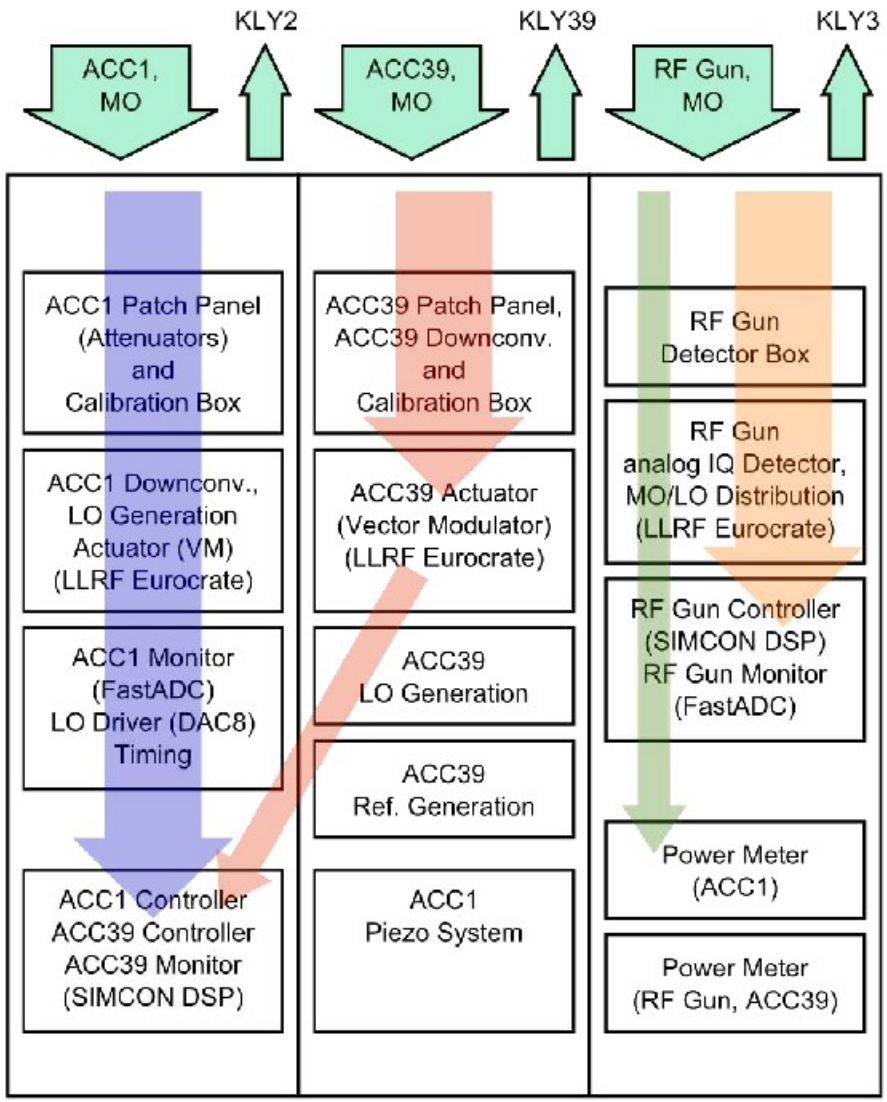


FLASH Seminar, 10.11.2009
"LLRF: Long-term stability improvements of ACC1",
F. Ludwig, M. Hoffmann

Rack reorganization



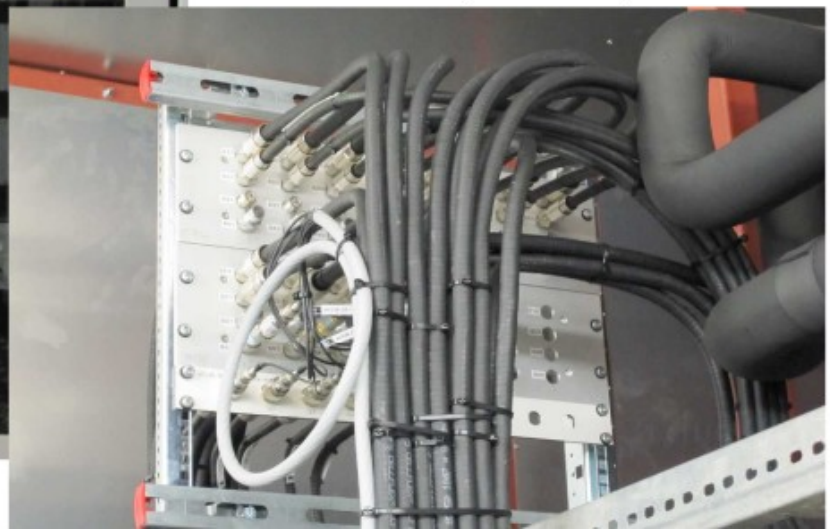
previous



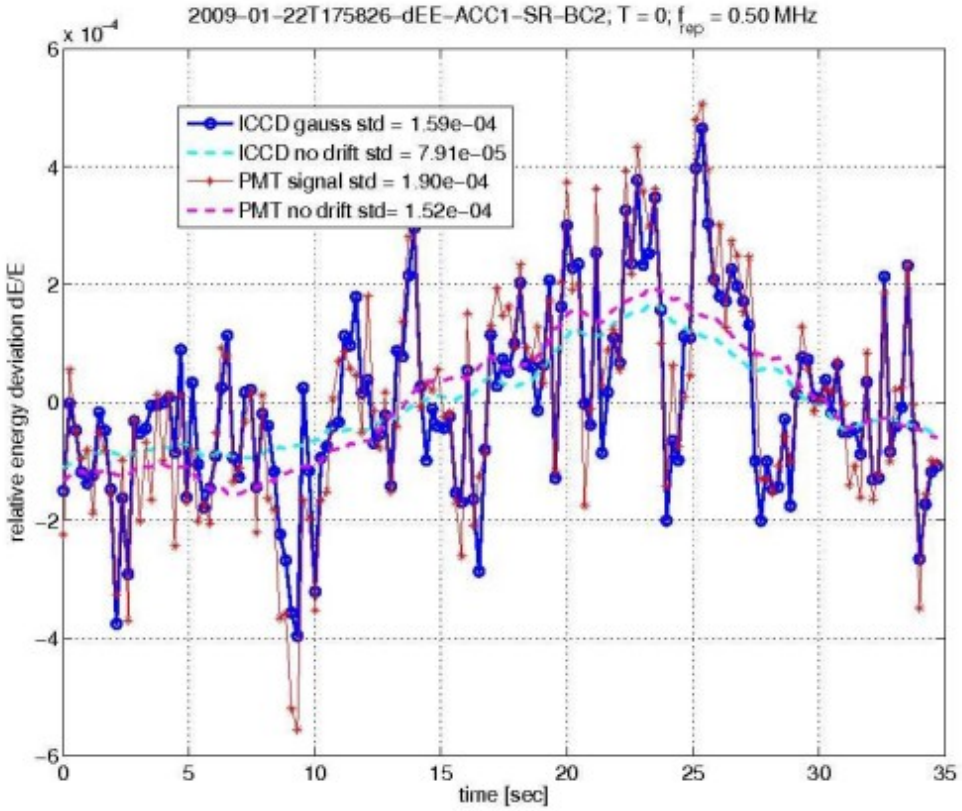
current

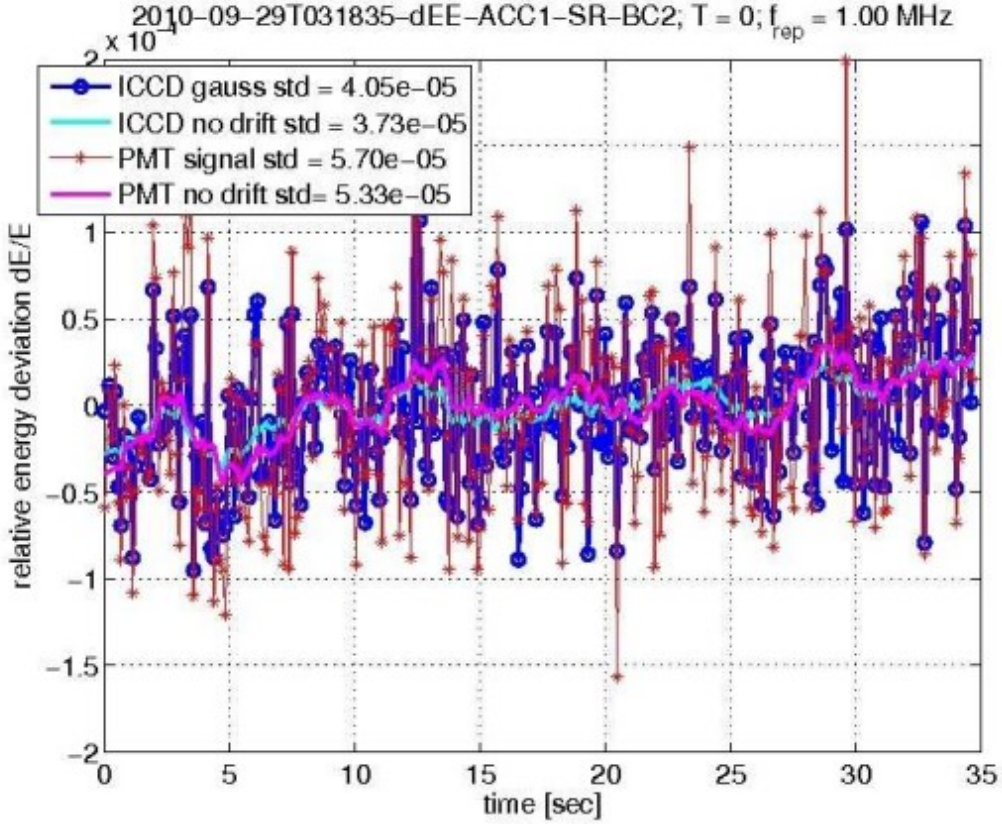
New LLRF Injector Racks

ACC39 patch panel



Energy stability





- FLASH elogbook 22.1.09 18.08h
- ACC1 off-crest
- Typical values of dE/E = 1.5e-4

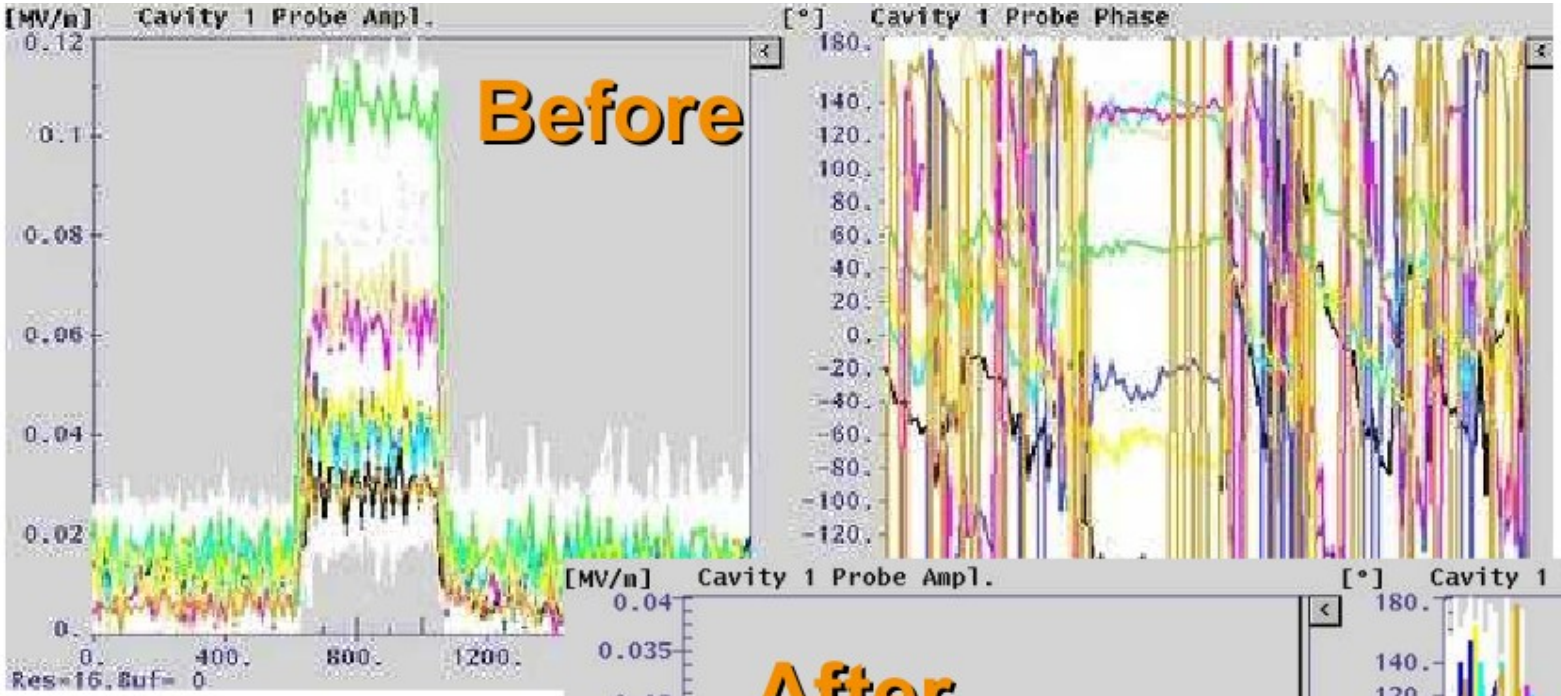
before

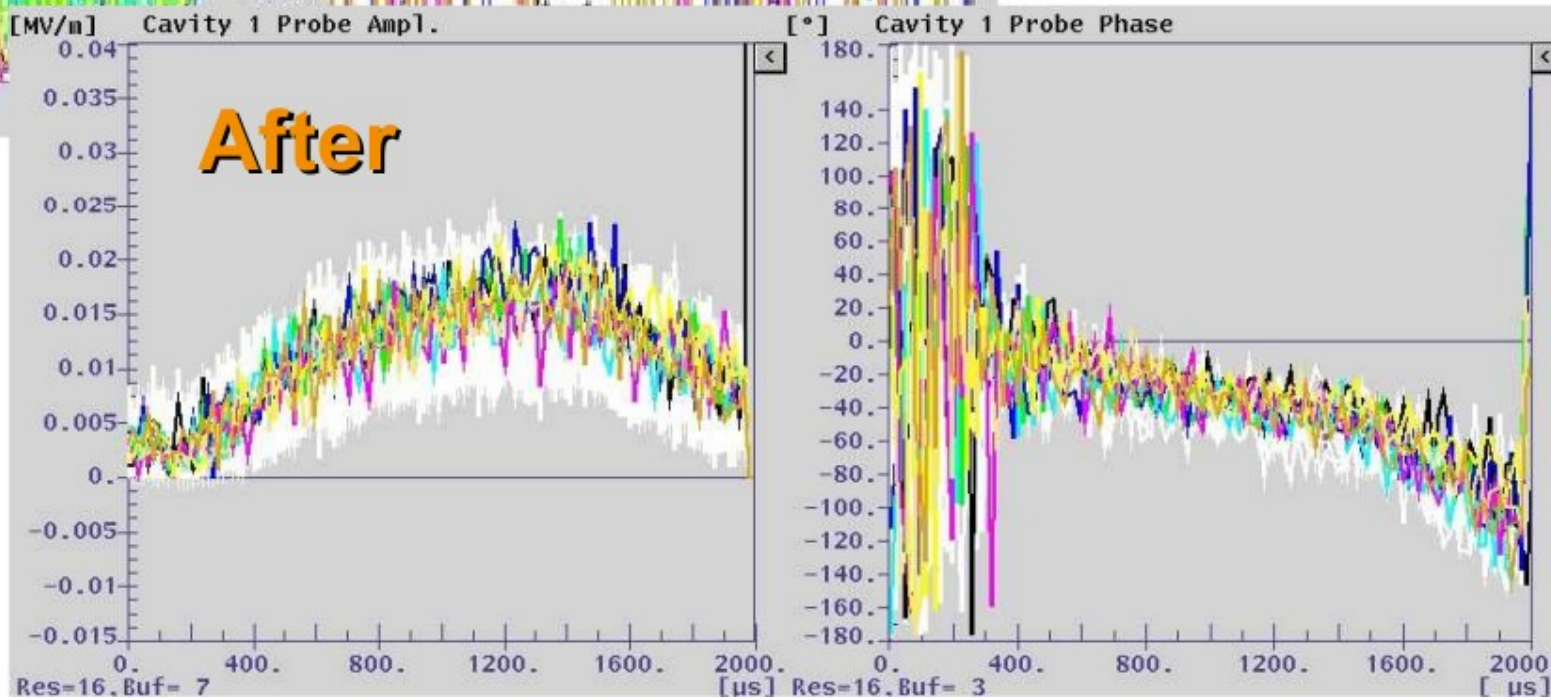
- FLASH elogbook 29.9.10 03.21h
- ACC1, ACC39 on-crest
- Best results: dE/E = 0.5e-4

after

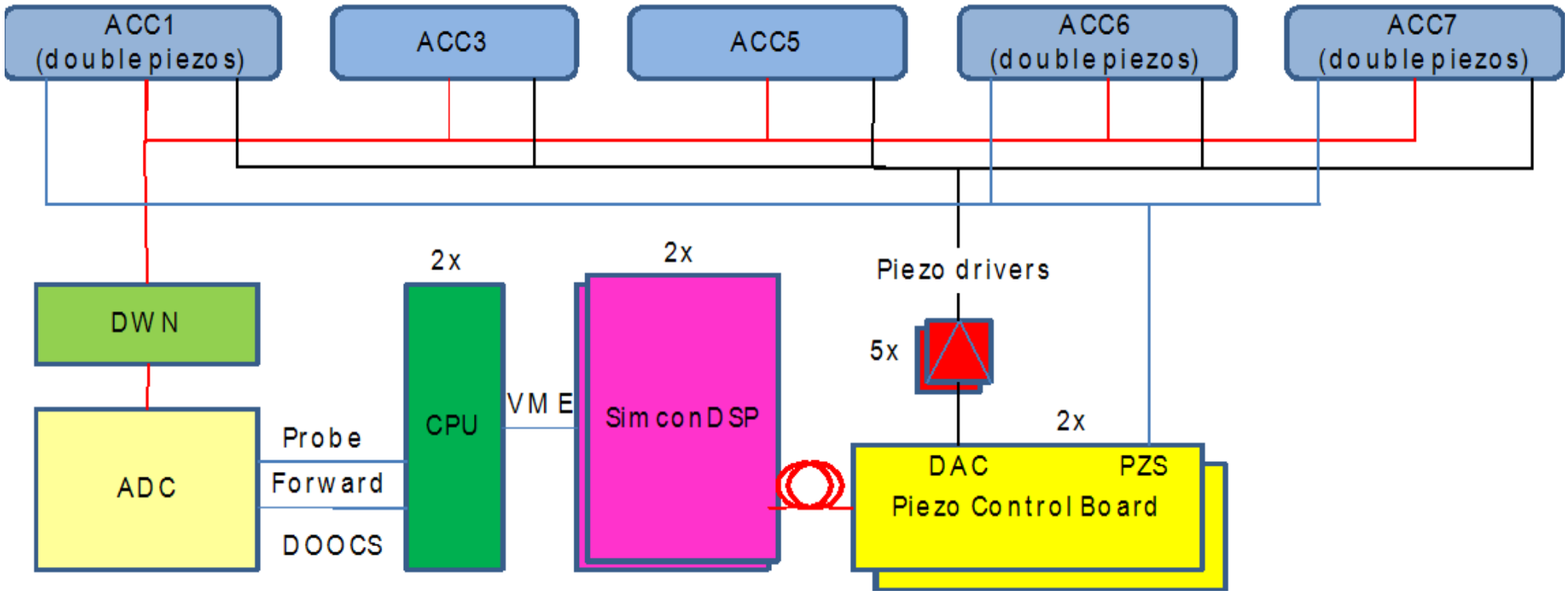
Christopher Gerth, et al.

Crosstalk reduction

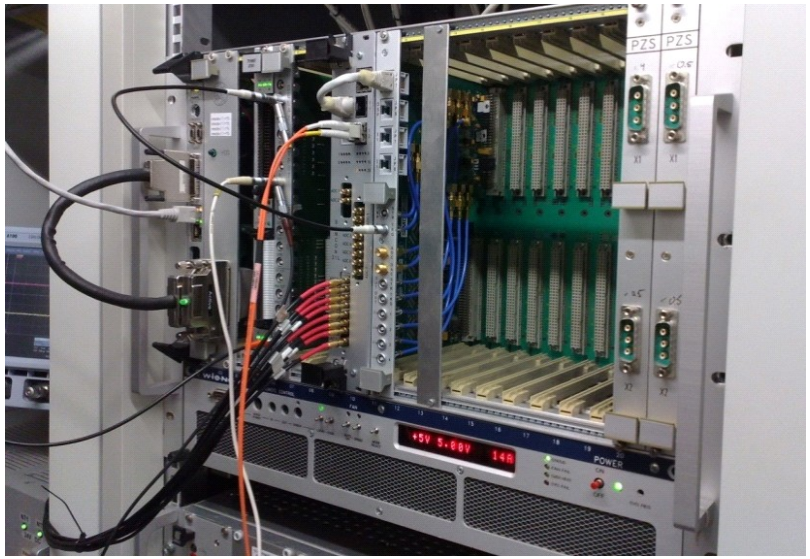


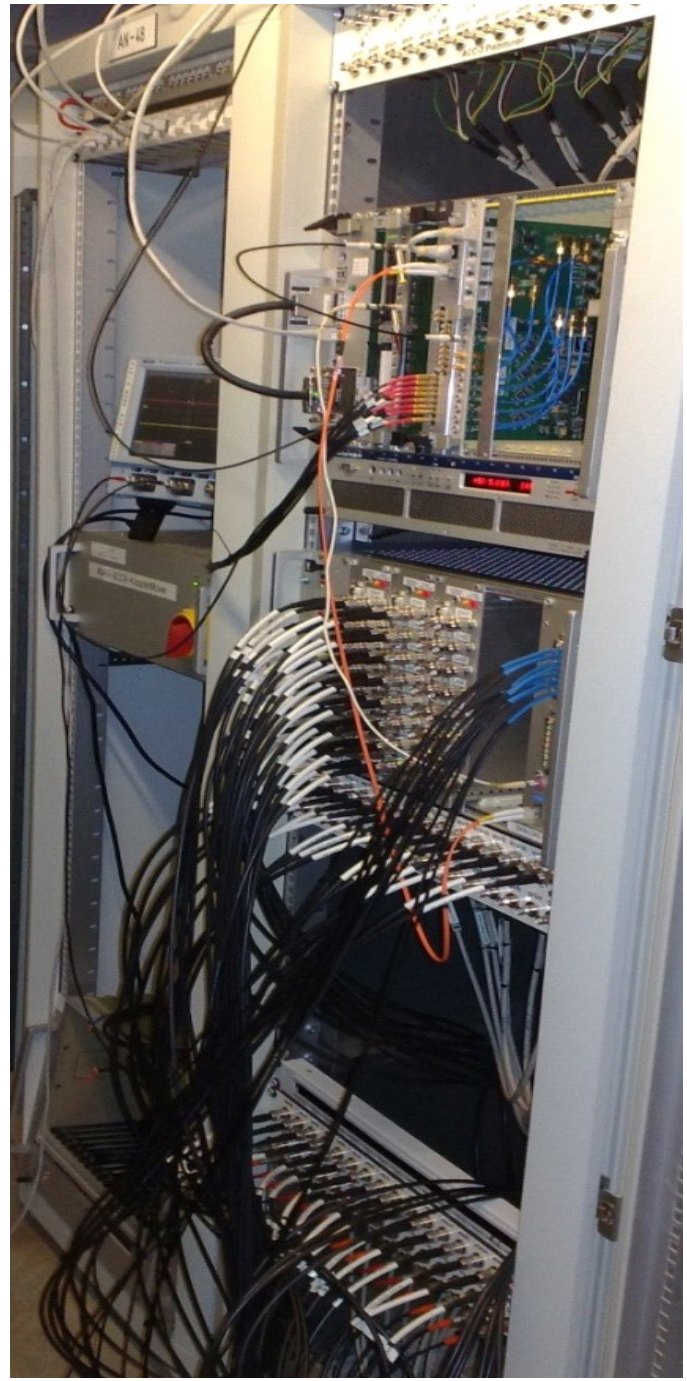


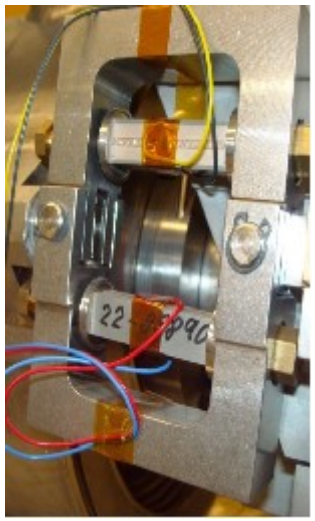
Piezo control system



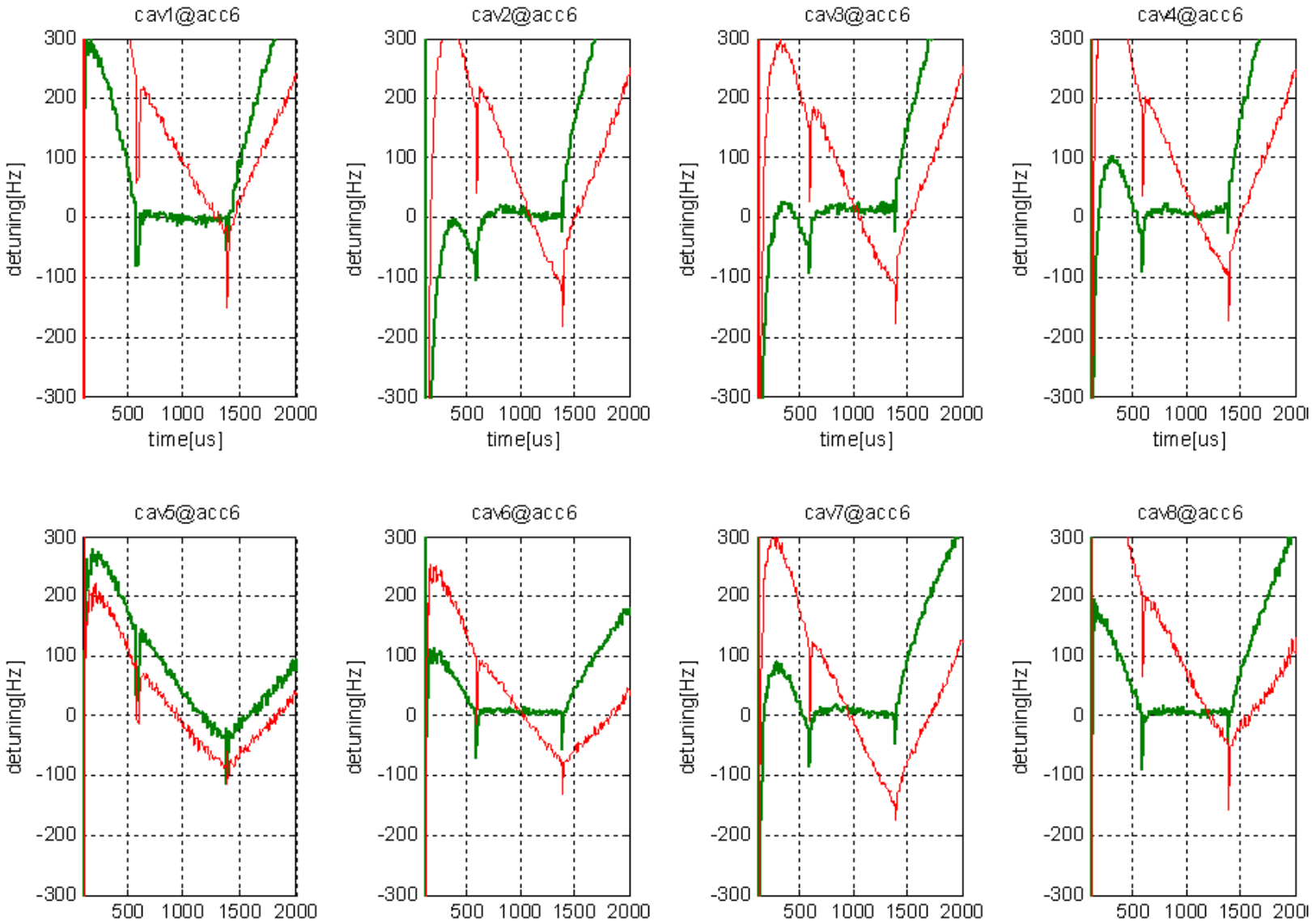
Piezo Control at ACC1,3,5,6,7







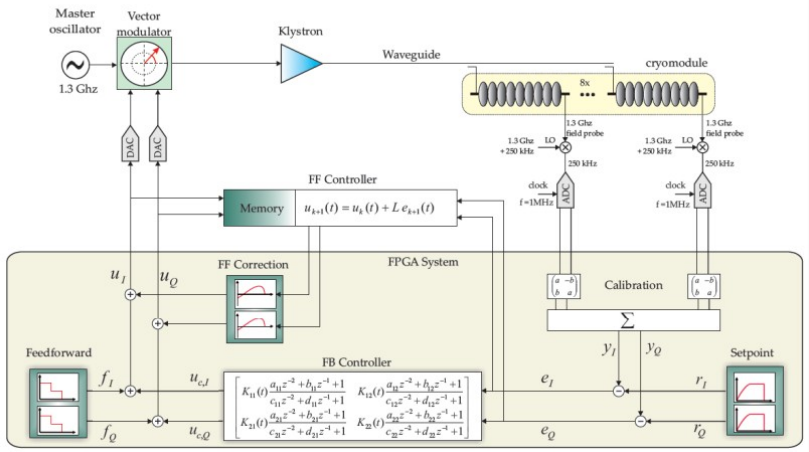
ACC6 (SP = 20 MV/m, rep = 5 Hz)



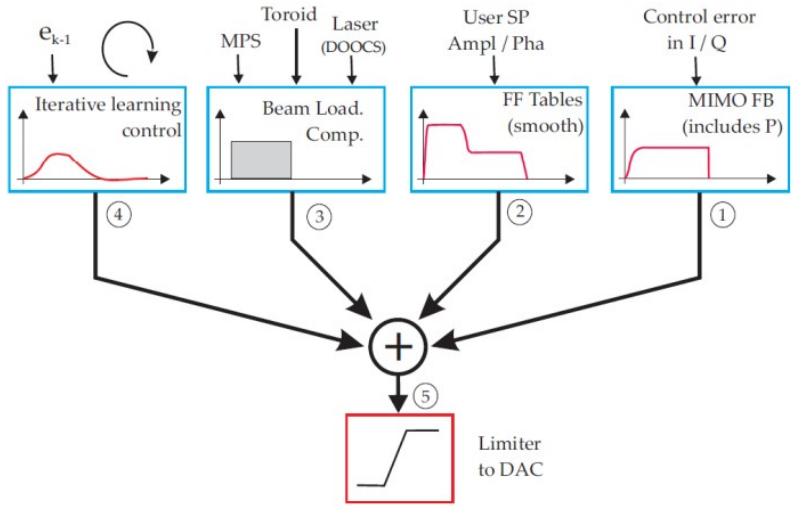
Upgrade LLRF system: FPGA controller firmware

- Upgrade & unified FPGA controller firmware
- Multiple feed forward table (main/beam loading/correction)
- Multiple set point table (main/beam based correction)
- Model based Multiple-In-Multiple-Out (MIMO) controller
- Charge correction & intra-train beam based feedback
- Exception & Error handling, limiters
- Error and status displays

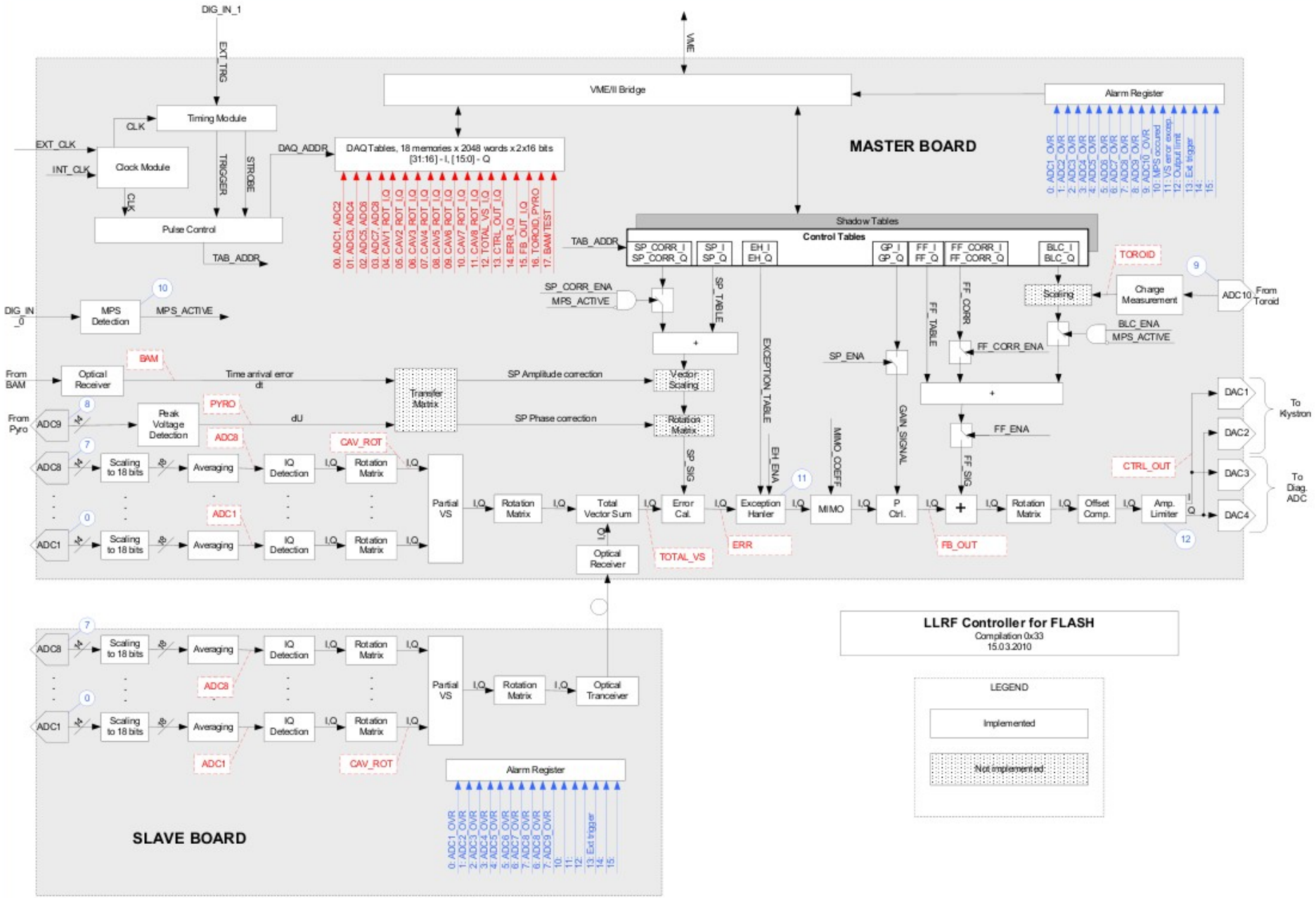
LLRF RF controller schematics



Feed forward table architecture



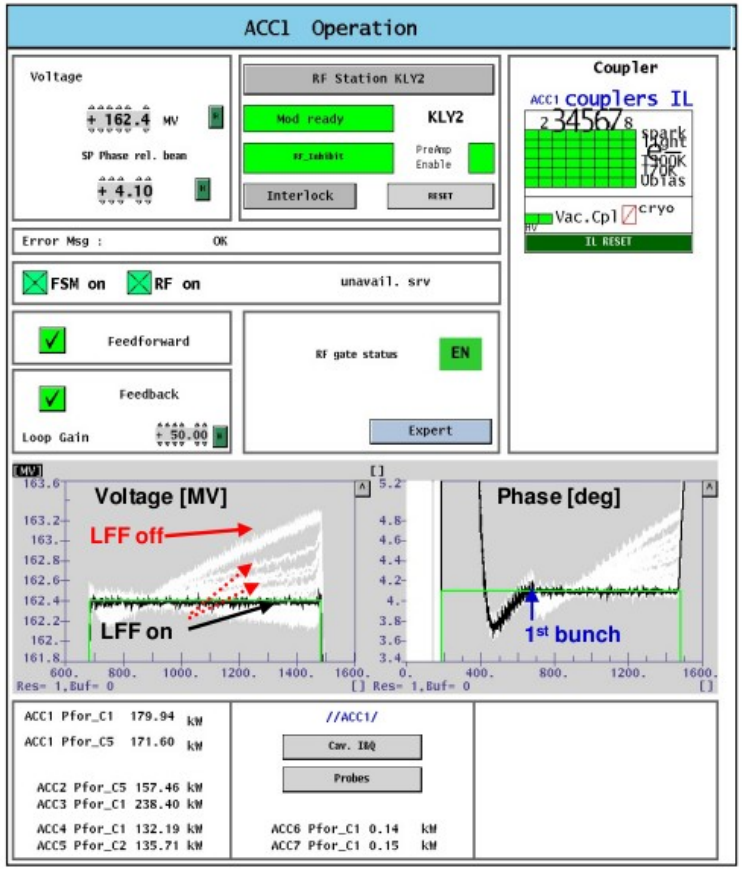
LLRF Field controller firmware



Upgrade LLRF control software

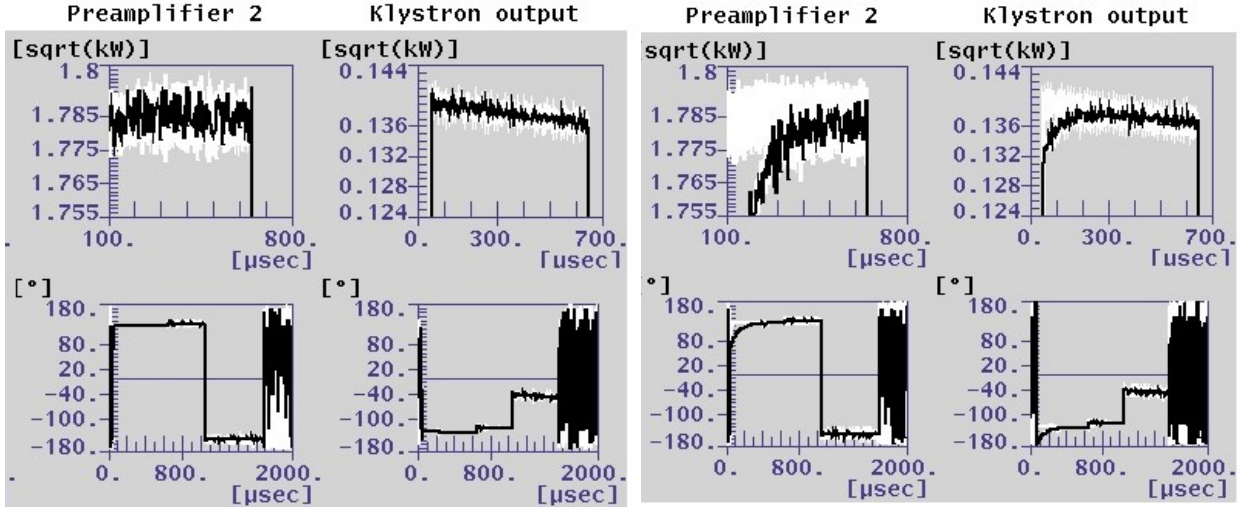
- Unified and new control software
  - New C++ architecture for front-end server
  - Unified naming convention
  - Automatic firmware downloads
  - Finite State Machine for automation
  - High level software: diagnostics, calibration...
  - Integration to data acquisition system
  - Model based learning feed forward (LFF)
  - Loop phase/gain correction
  - Fast piezo control for cavity detuning comp.

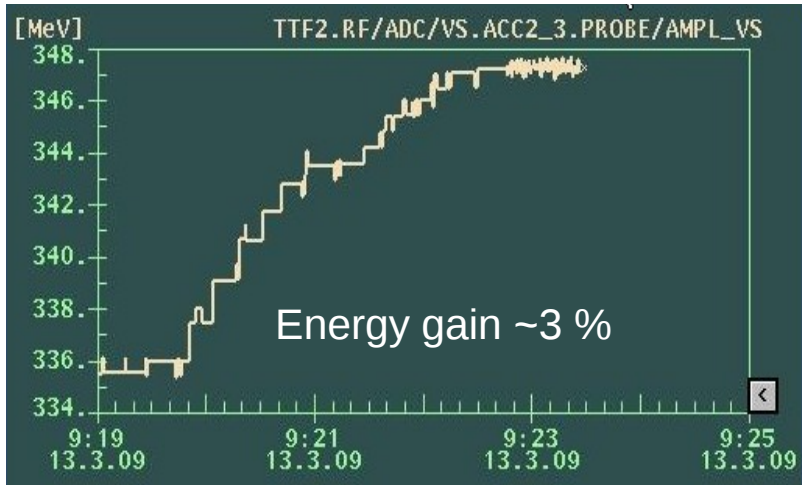
    ... and many more
- Control software ~70 % completed

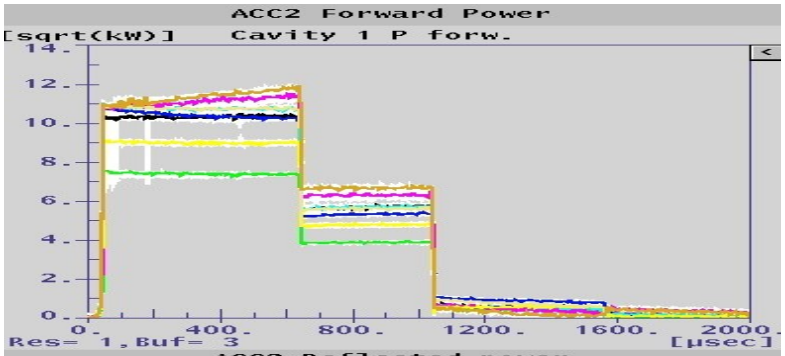


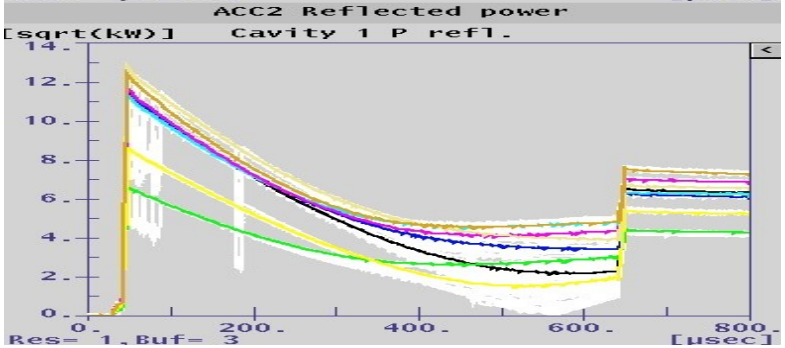
FF Optimization: Phase Modulation

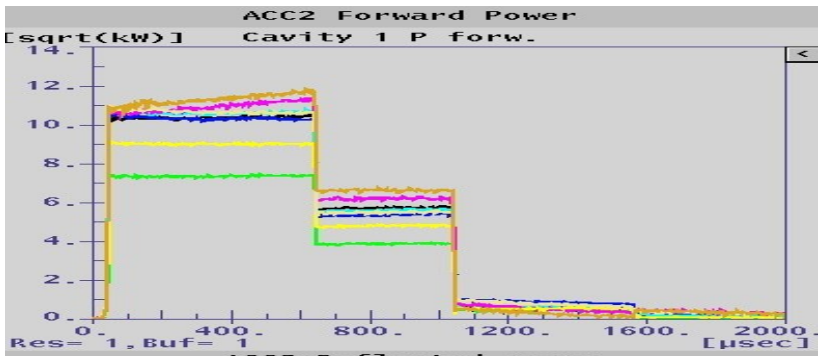
Minimum reflection at the end of filling time has been reached

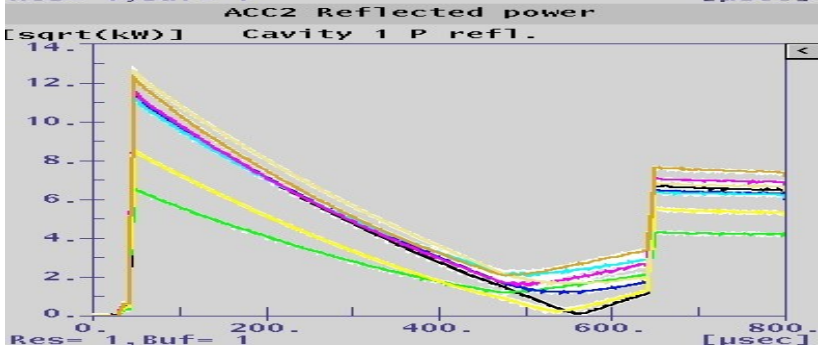






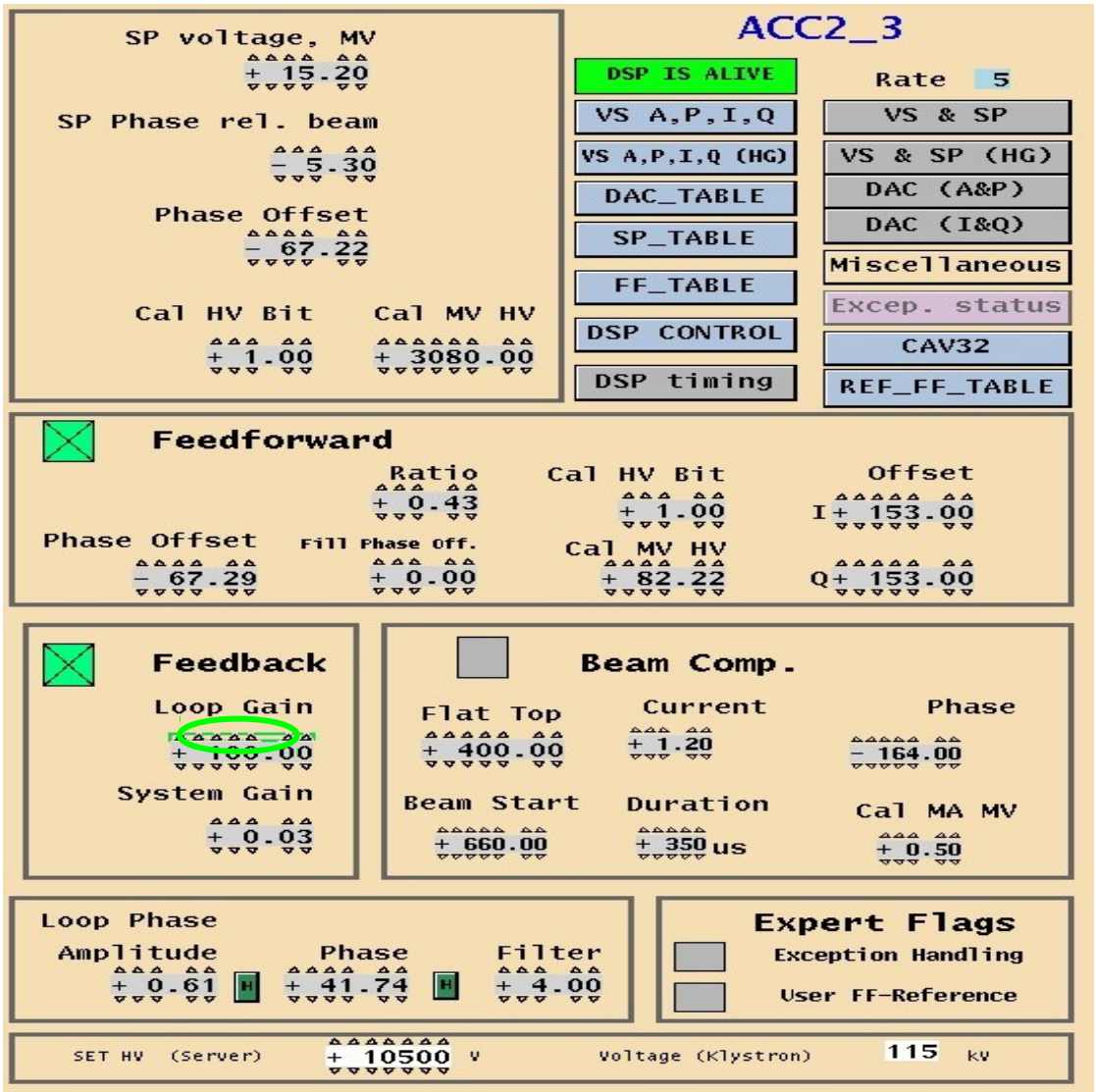


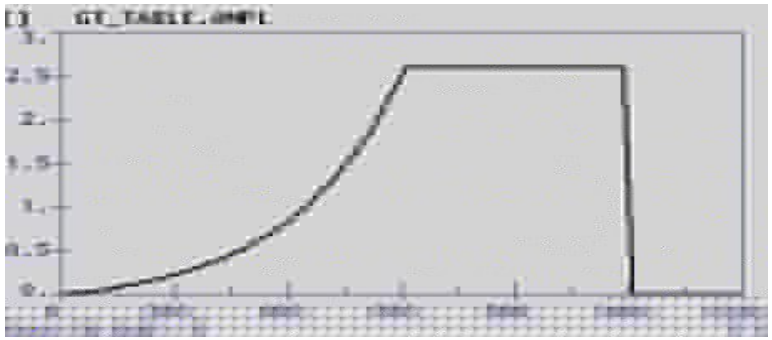


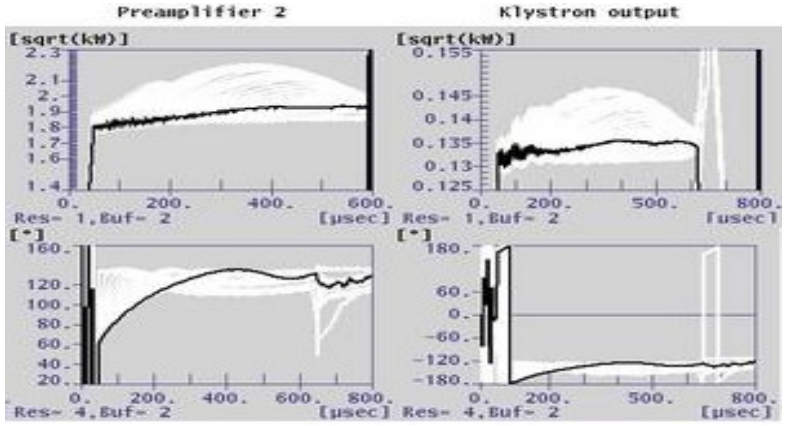


Variable gain

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

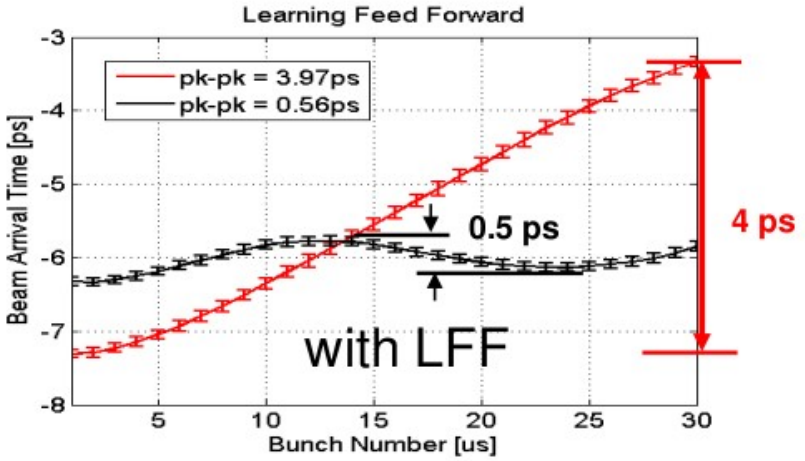


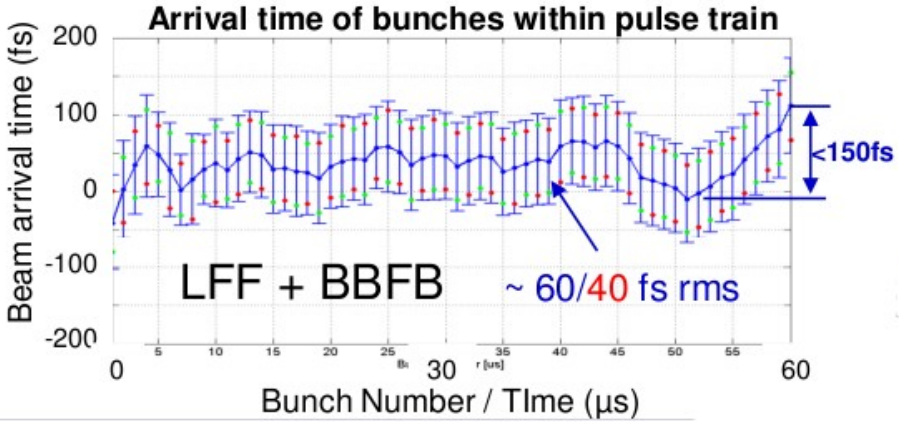


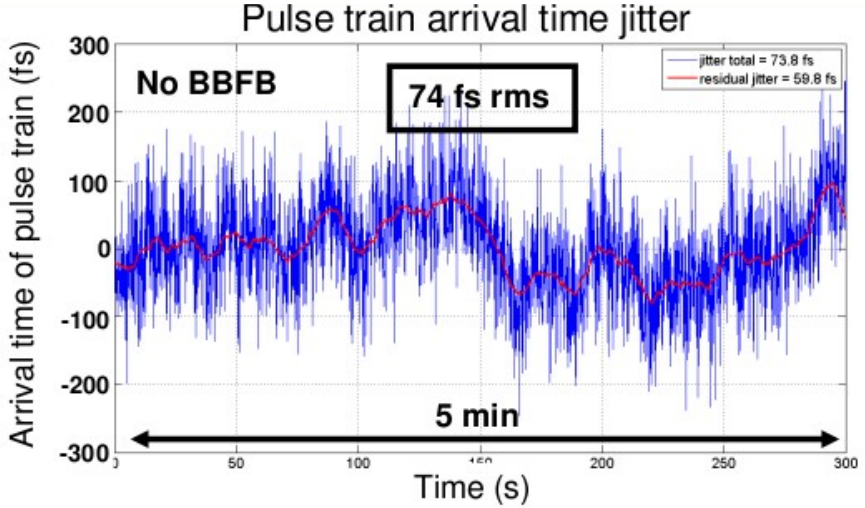


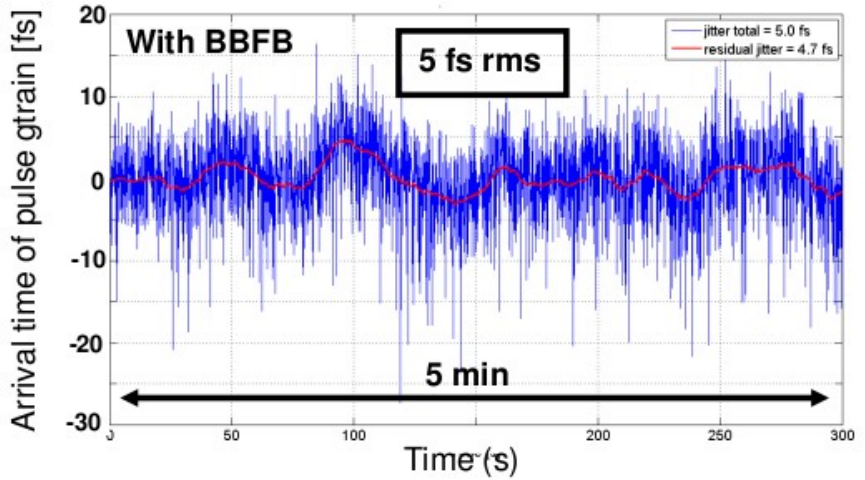
Beam Based Feedback

- Arrival time jitter ds 1st bunch compressor 70 fs rms (5 min) → dE/E (ACC1) < $1 \cdot 10^{-4}$
- Learning feedforward (LFF) and beam based feedbacks (BBFB)



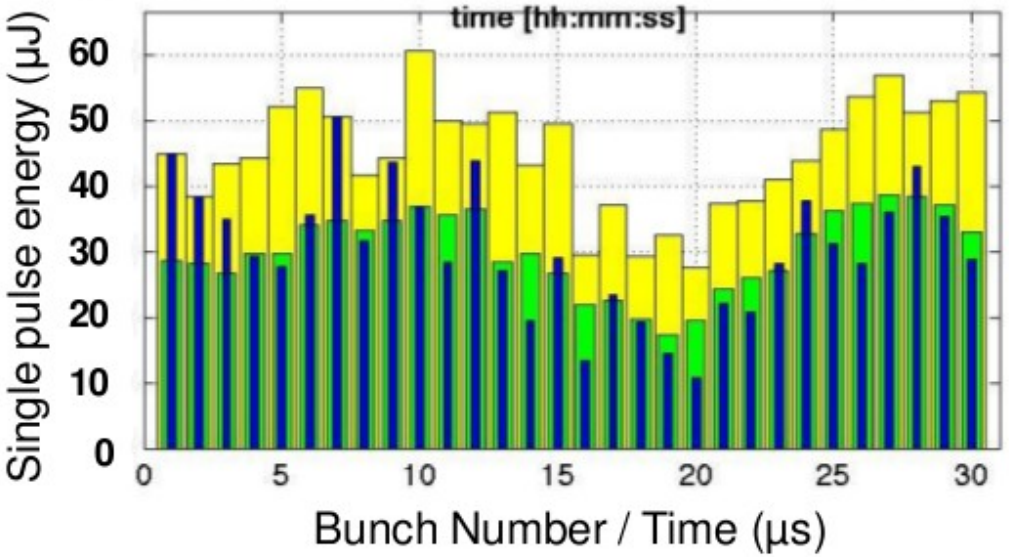




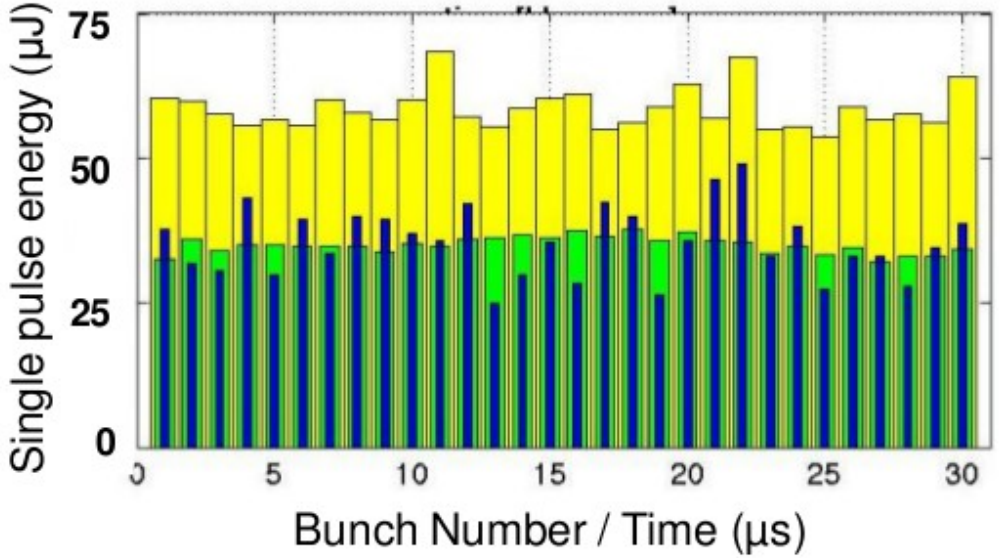


Adaptive Feed Forward

> w/o adaptive feedforward



> adaptive feedforward applied



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.
- Still software development is needed, particularly automation.
- In future FLASH LLRF system should be further upgraded to the same system as applied for XFEL.