LLRF Operation Experience at FLASH

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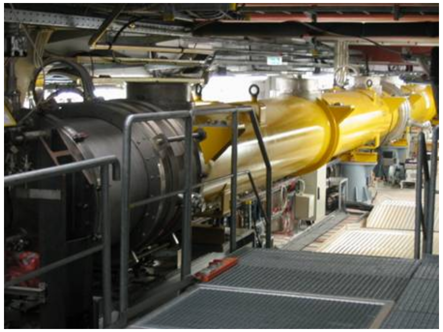
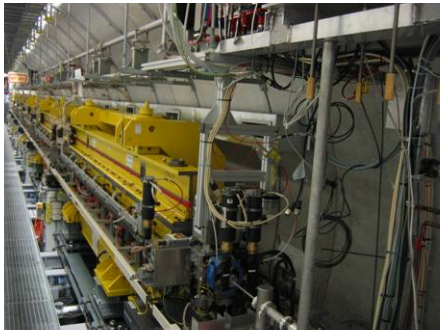
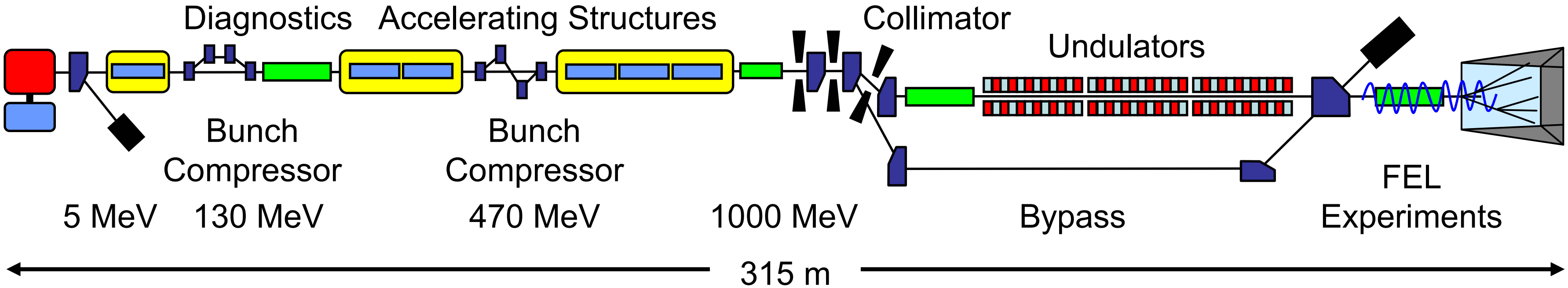
On behalf of LLRF Team

Outline

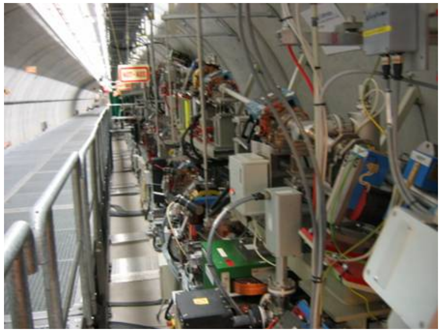
- FLASH LLRF System Status
- Recent Progress
- Operation Experience
- Measured Performance
- Future Plans
- Conclusion

FLASH Overview






Requirements: up to 0.03% for amplitude and 0.03 deg. for phase

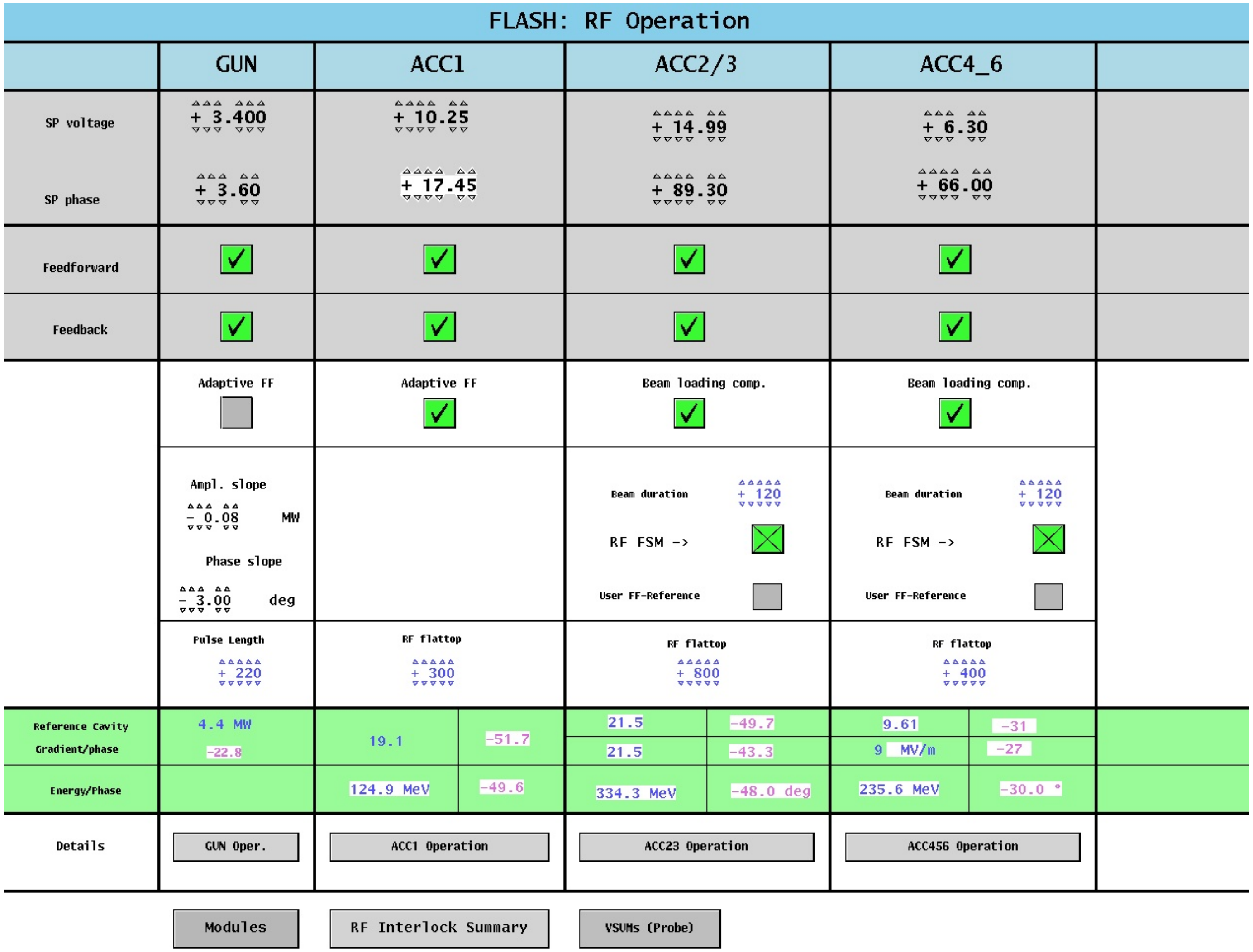
LLRF Controllers used During User Run

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 MHz IF	-	Redundant FF
ACC456	DSP 250 MHz	SIMCON x3 ATCA 54 MHz	Redundant FF

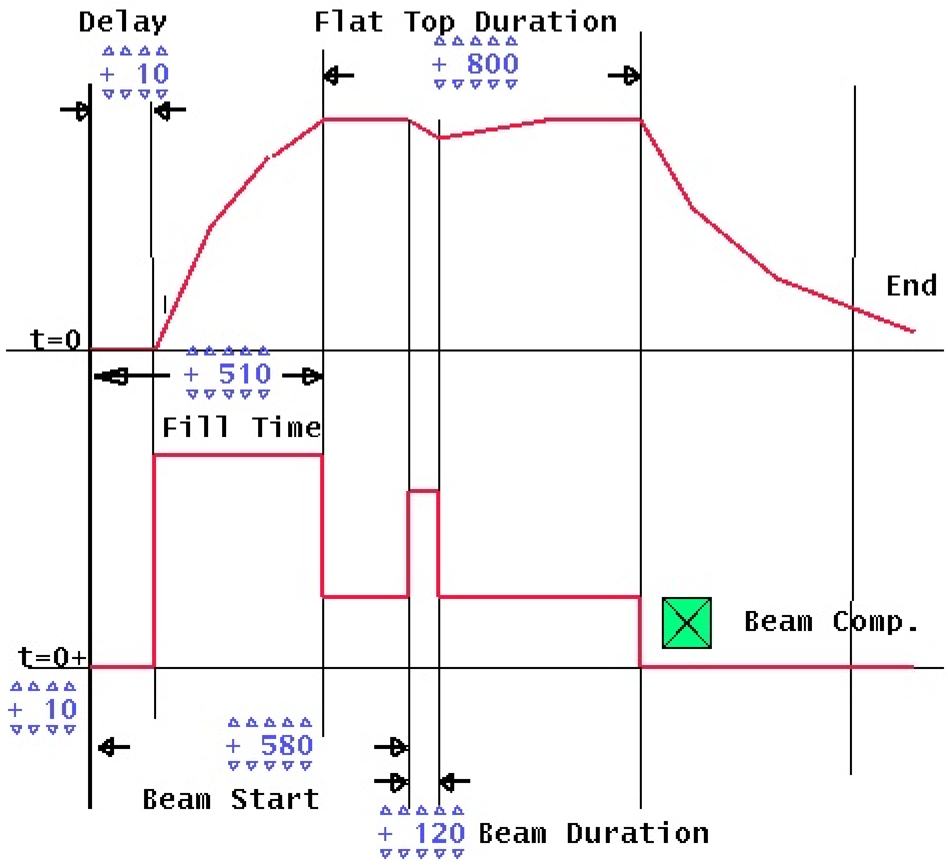
- Monitoring signals for all modules (forward/reflected/probe)

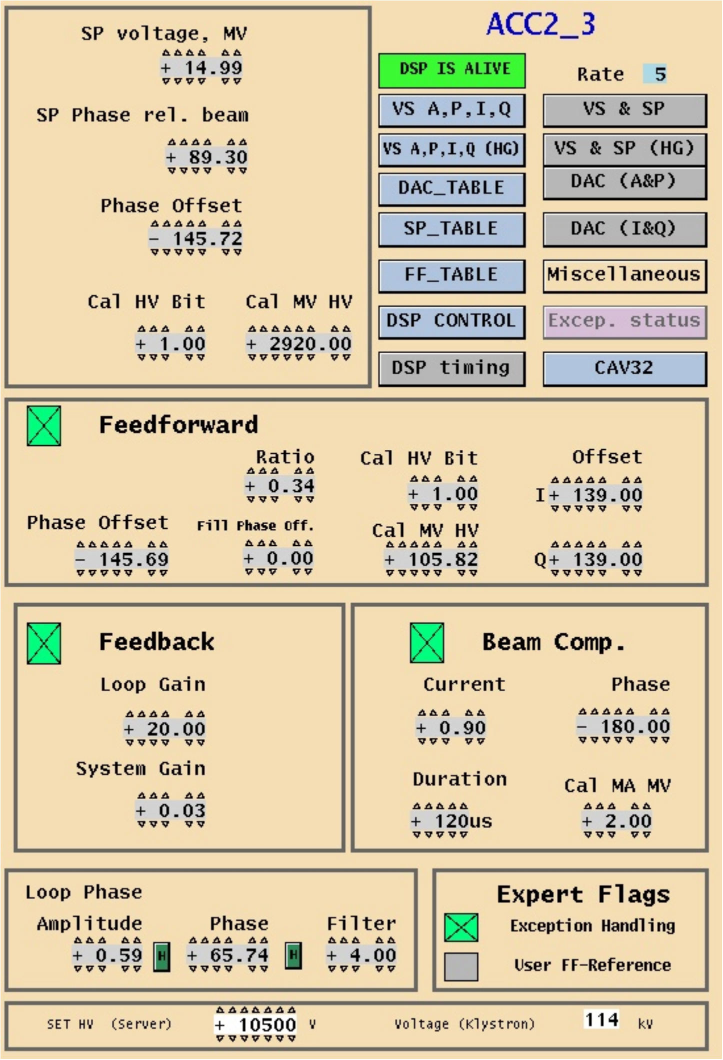
DSP (2000), SIMCON (2006), ATCA (2009)

Operator Interface



Expert Operation





List of Operator and LLRF Expert Functions

Operators:

Setting VS ampl. and phase

Beam loading compensation

Feedback and feedforward

Adaptive feedforward

Feedback gain

Fill and flat top duration

Beam based feedbacks

- Compression (injector)

Slow quench detection

Experts:

Calibration of VS

Energy profile along bunch train

Cavity slow tuning

Lorentz force compensation

Loop phase adjustment

Loop gain calibration

Measurement of beam phase

Gradient calibration

RF power calibration

Incident wave and loaded Q adjustment

Beam based feedbacks

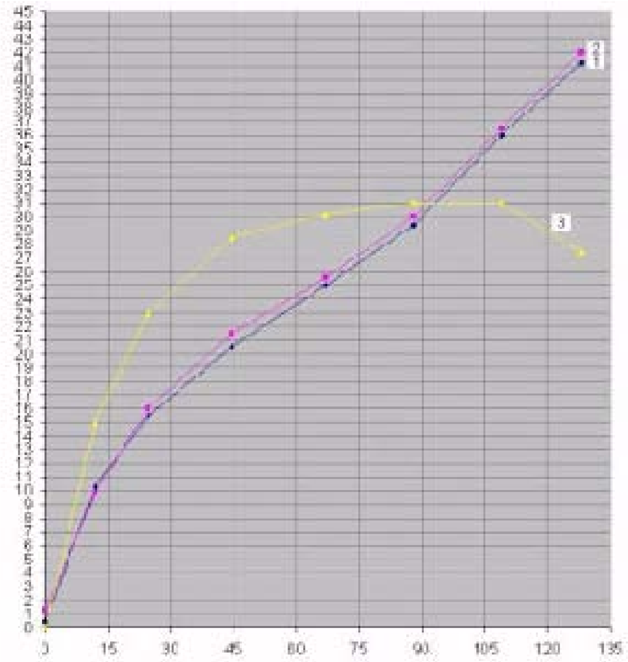
- Bunch arrival (experimental)
- Beam energy (experimental)

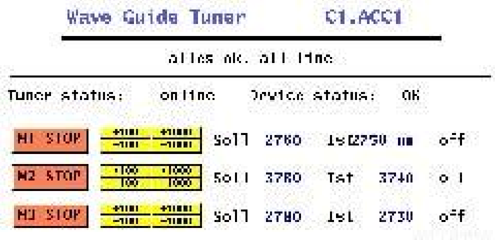
Real time quench detection

Cavity Loaded Q and Phase Adjustment

Motorized three stub waveguide tuners are in use

- Different type of tuners at ACC6
- Phase range up to 120 deg.
- Improvement from ±30° to ±3°

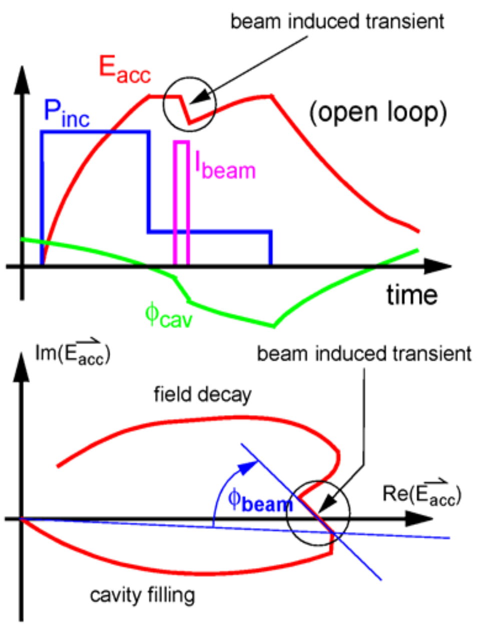




Beam-Based Calibration with Moderate Charge

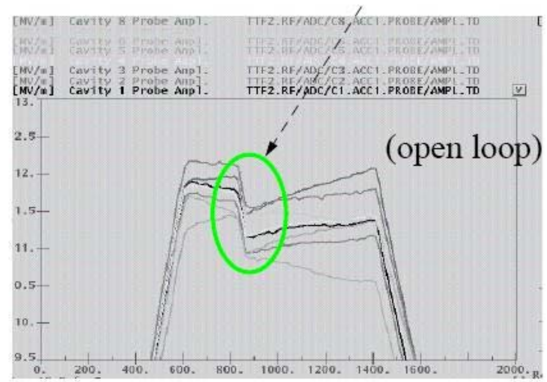
•Preliminary calibration by RF measurement

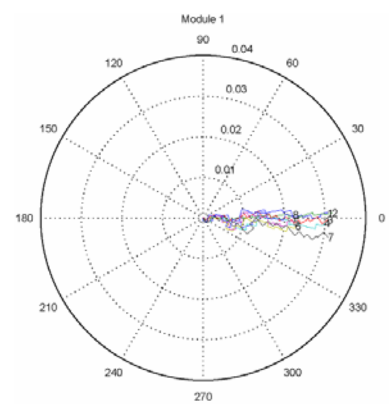
•Good beam requires: requesting 240nC, usually we got 100 -120nC



for $\Delta t \ll \tau_{cav}$:

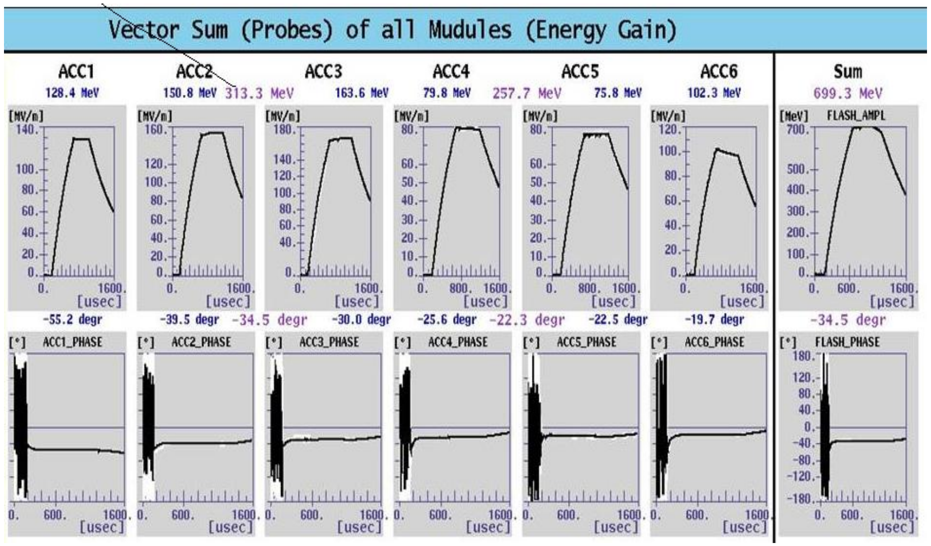
$$\Delta V_{ind} = I \cdot \Delta t \cdot \left(\frac{r}{Q}\right) \cdot \pi \cdot f$$

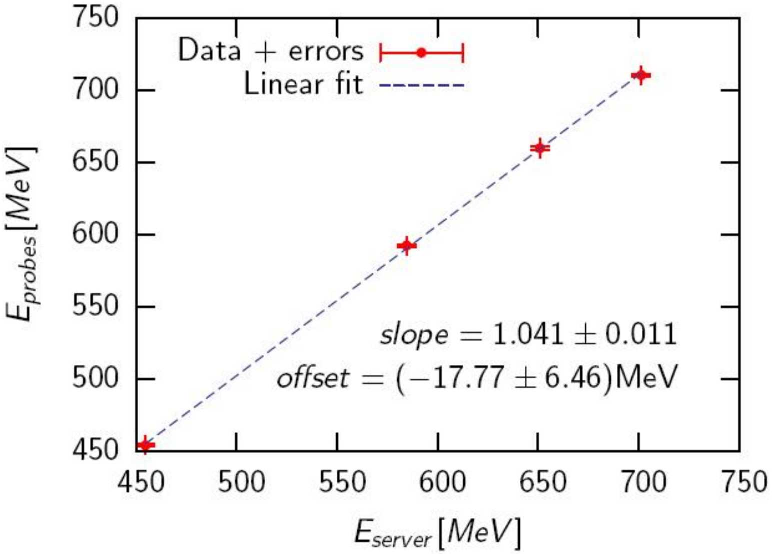




Energy Based Calibration

- Calibration with energy gain measurement by cavity/module detuning
- Different methods are in agreement with ~1%

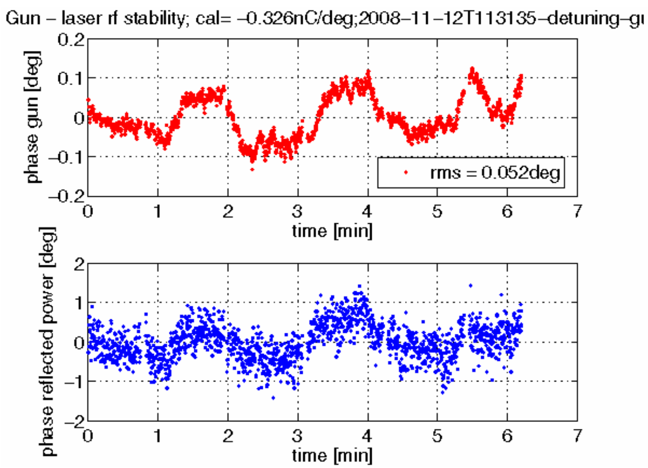




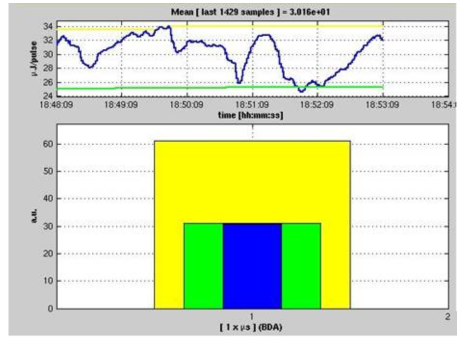
Recent Improvements at FLASH

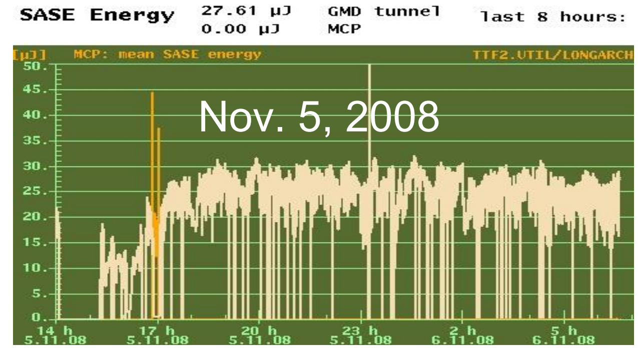
- Master oscillator and distribution
- RF Gun control
- HPRF drive control
- Education of operators
- Improved important expert procedures to be used by selected operators
- Improvements of tools/panels
- Lorentz force compensation
- Feedback gain optimization
- Quench detection
- Offset adjustment
- Adaptive feed forward

RF Gun Stability



Before calibration

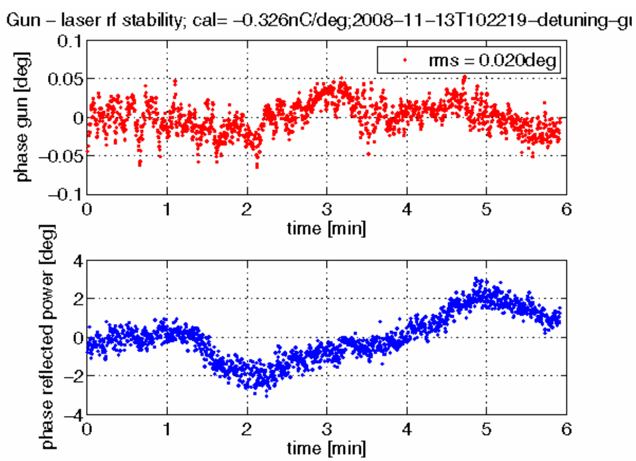




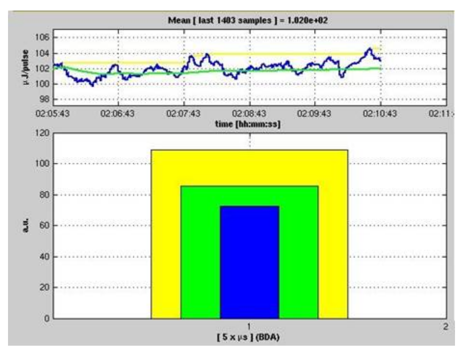
RF Gun field measurement calibration

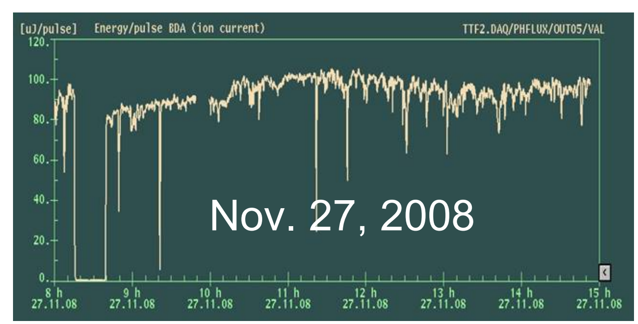
$$U_{trans} = U_{for} + U_{ref}$$

SASE intensity fluctuations down from 25% to a few percent



After calibration

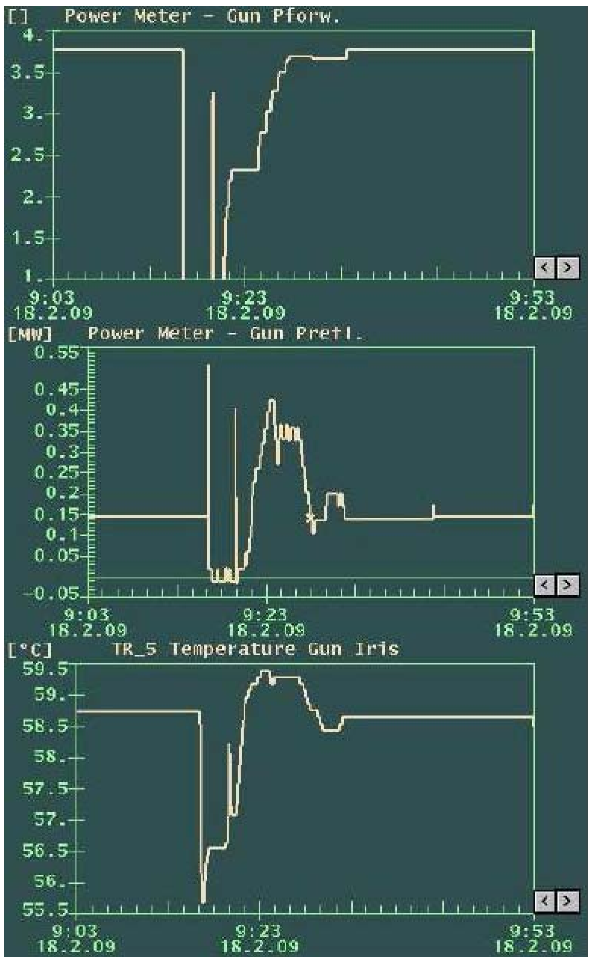




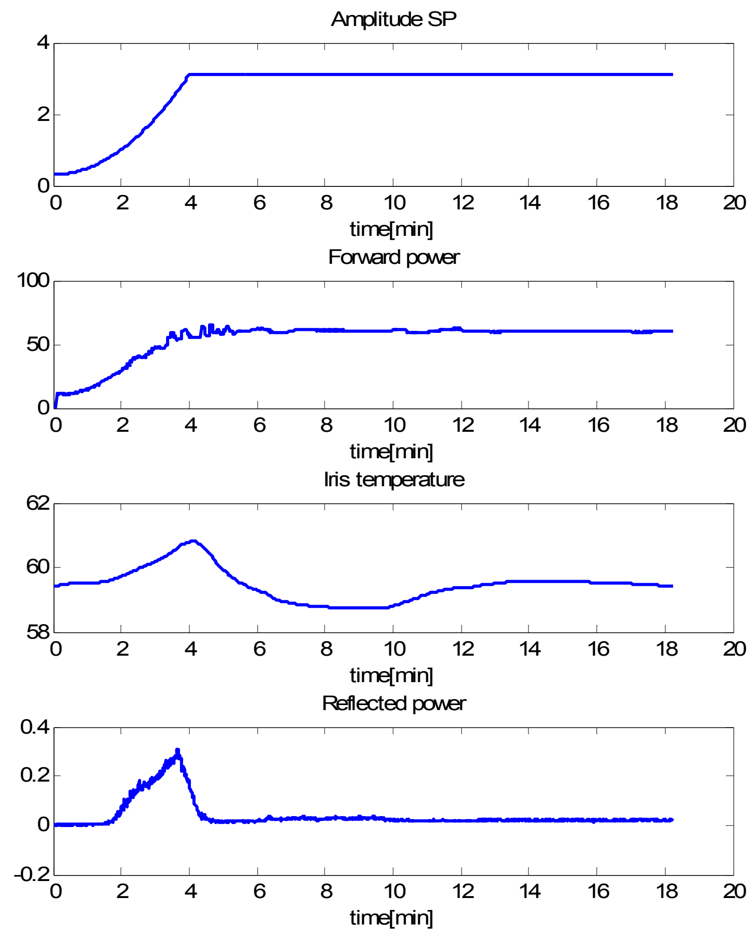
Automatic Gun start-up

Goal: Start-up of the Gun without operator supervision

- Driving the Gun with RF modulated according to the Gun temperature avoiding the excessive reflected power



Manual start-up of the Gun after interlock



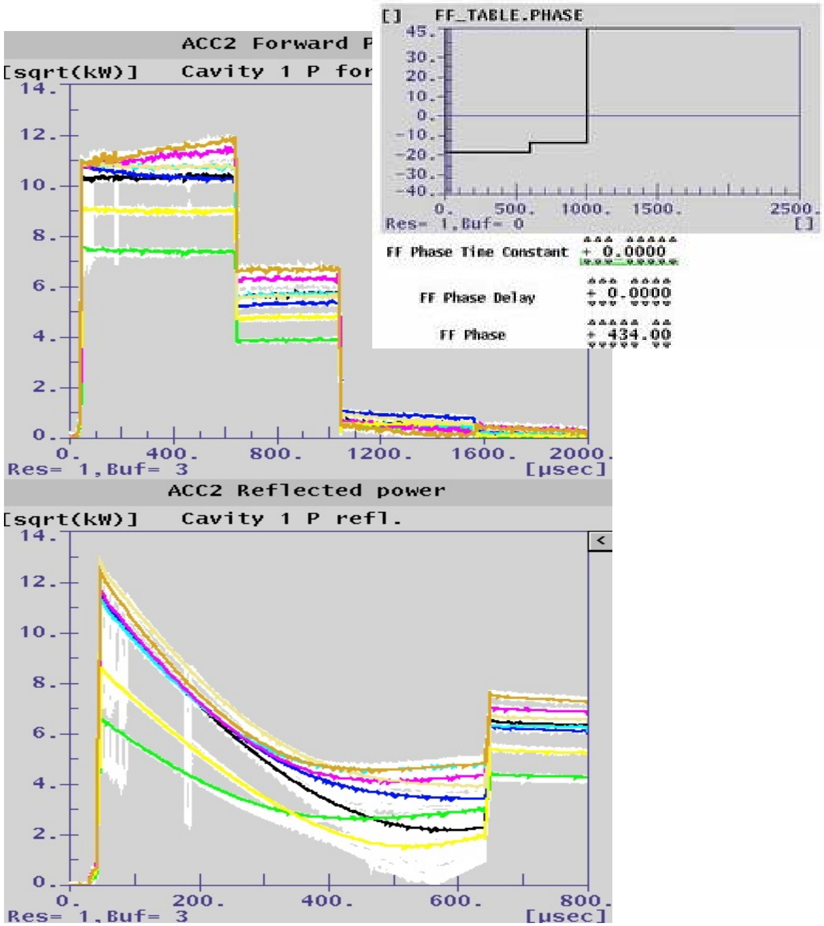
Automatic RF Gun start-up

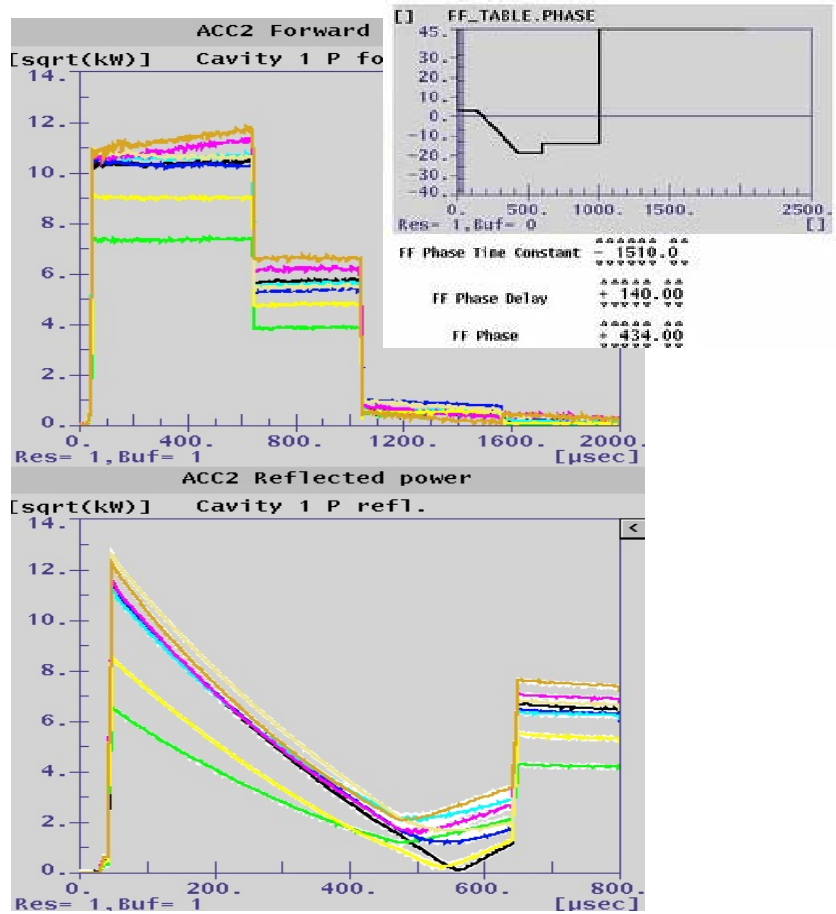
Optimization of HPRF Drive Control

Goal: Efficient use of RF power and reduction of coupler trips

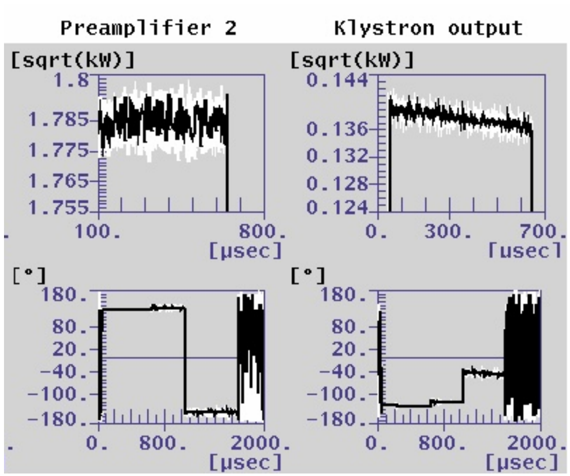
Phase modulation during filling: linear

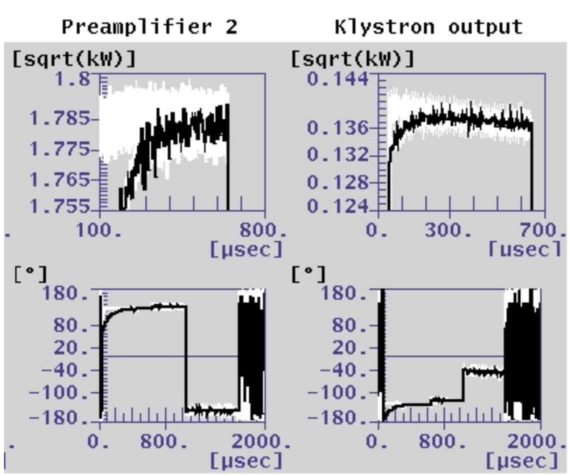
Minimum reflection at the end of filling time has been reached



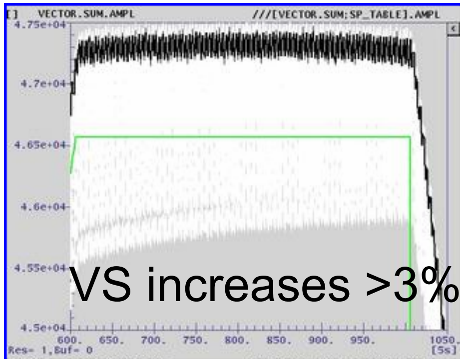


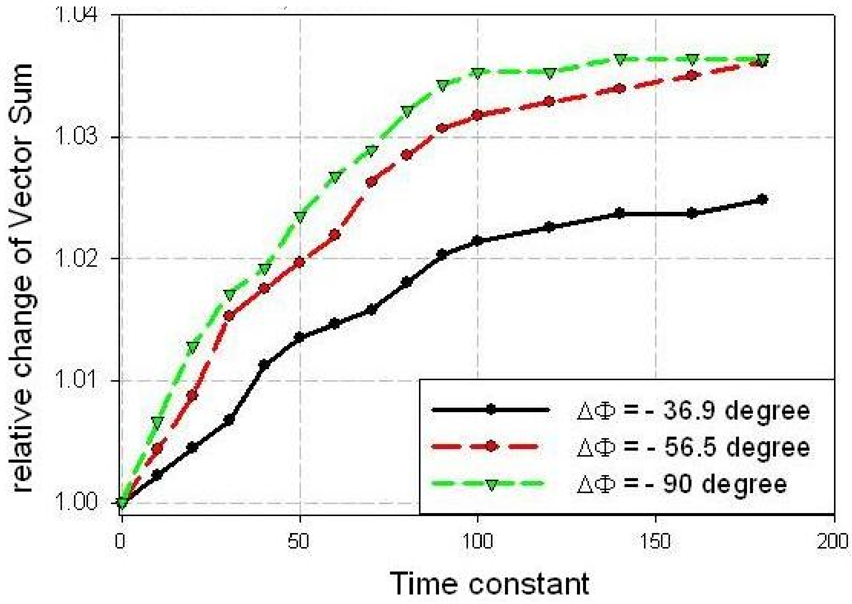
Power Efficiency During Filling

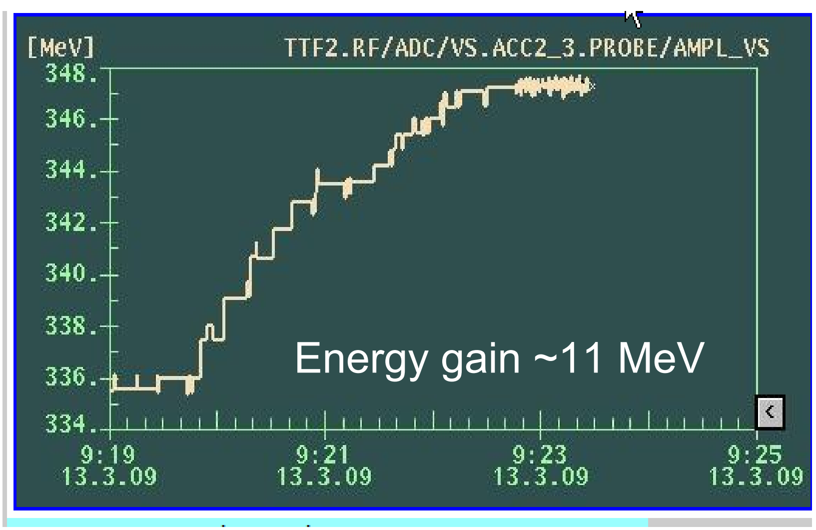




Vector sum by DSP

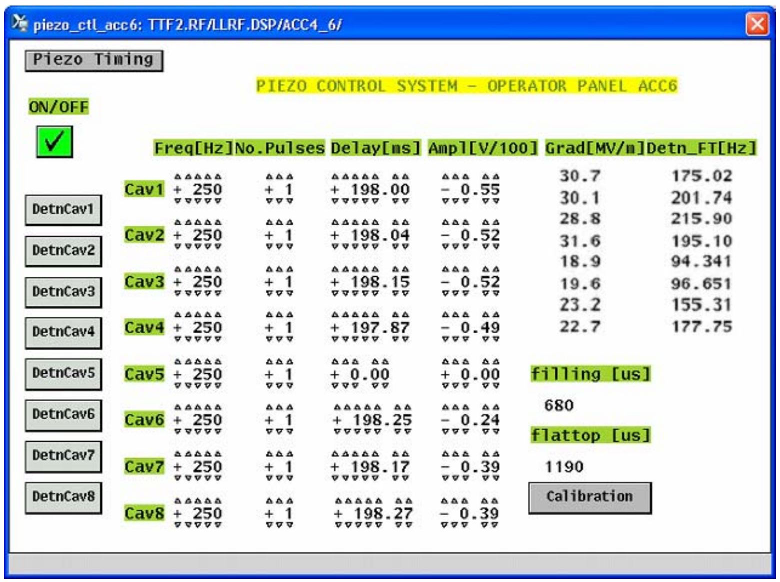


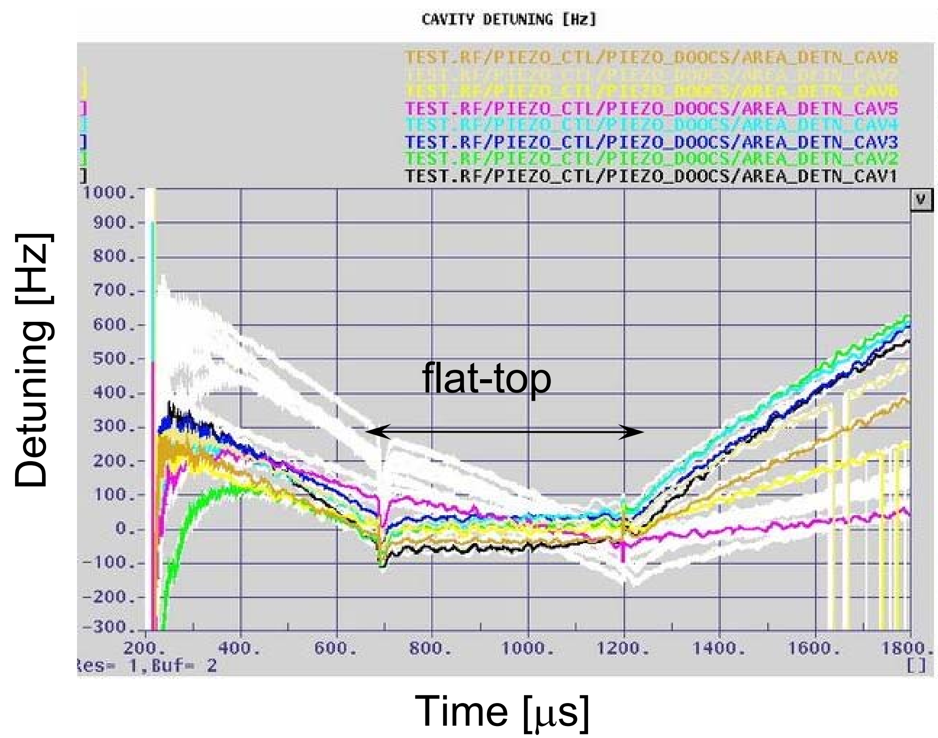




Piezo Control

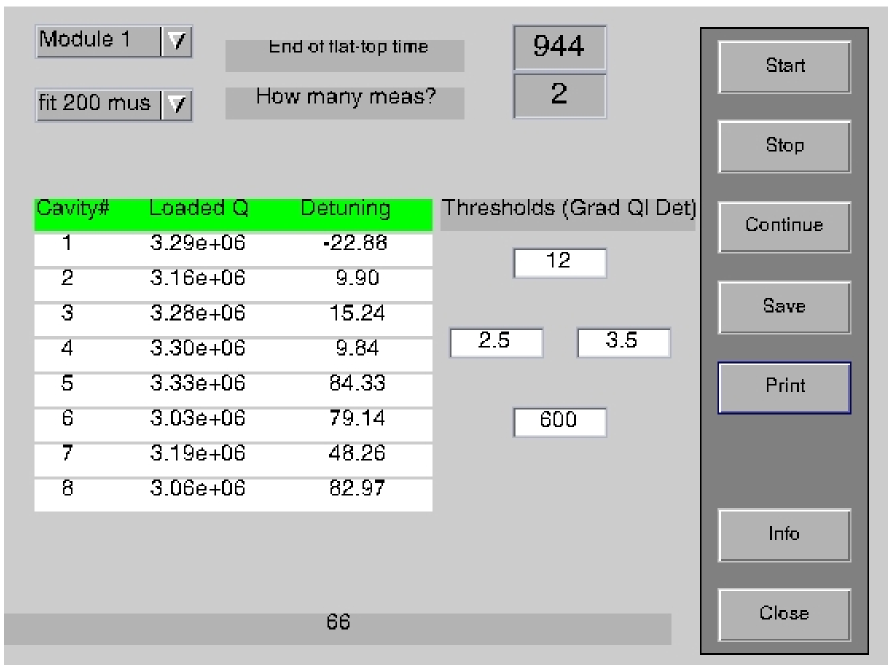
Permanent piezo control system installation at ACC3, ACC5 and ACC6 with operator interface

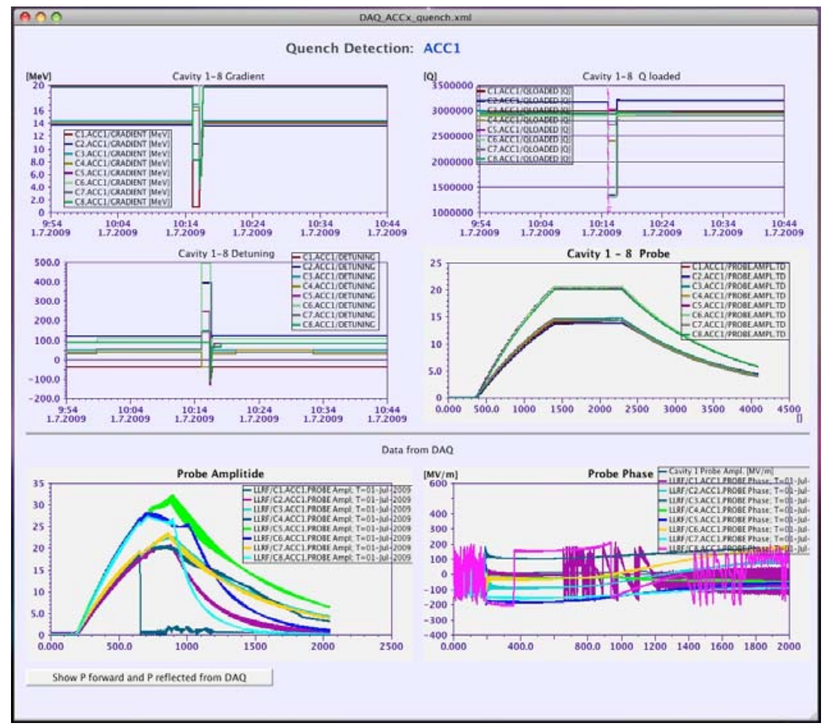




Exception Detection and Handling

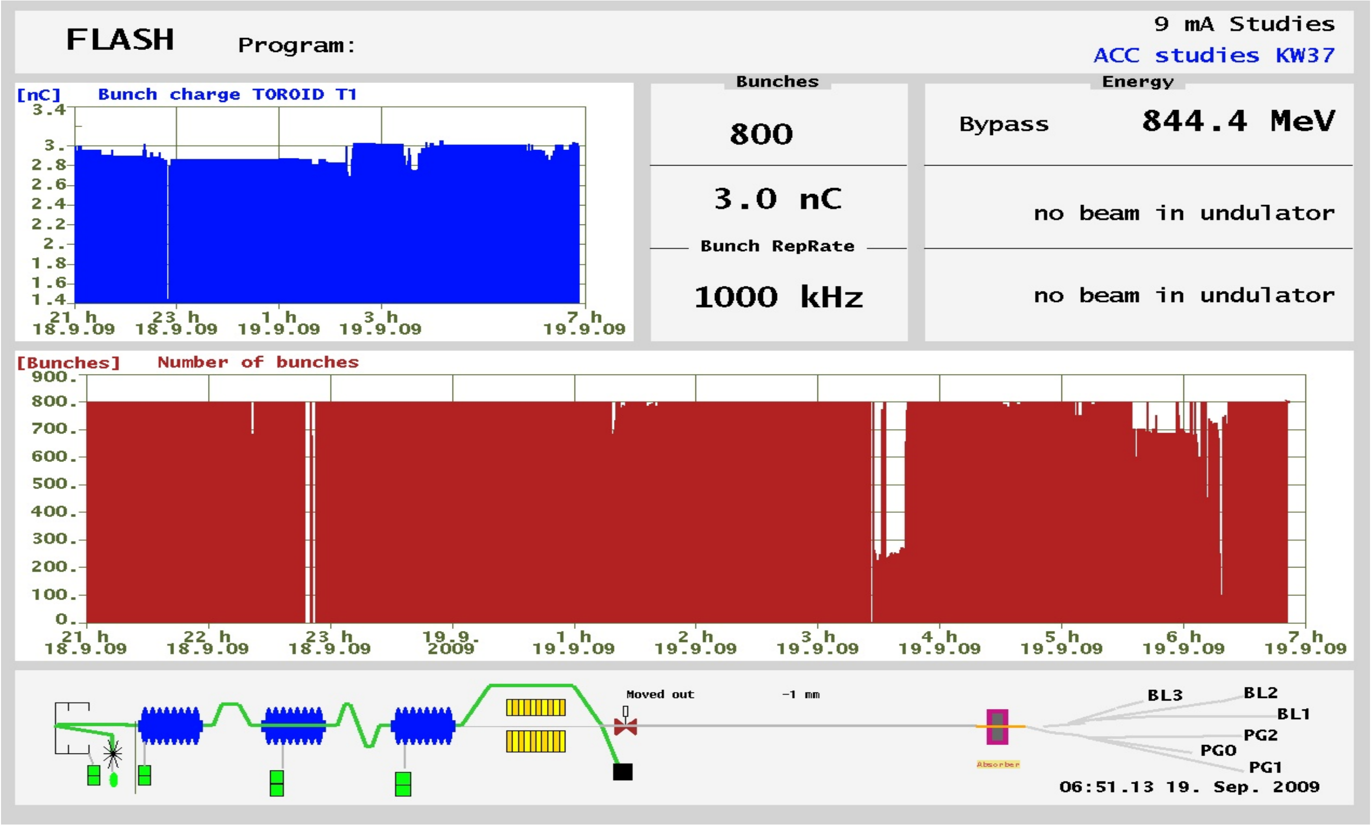
- Fast / slow quench detection
- BIC interlock interface
- DOOCS quench detection middle layer server





ILC 9mA Test

- 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



Typical Problem 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 (wave length) require presence of rf expert

- Loop phase (if klystron HV is changed)
- Feedforward table
- Beam loading compensation
- Feedback gain
- Vector-sum calibration (sometimes)
- Cavity tuning
- Timing (pulse length)

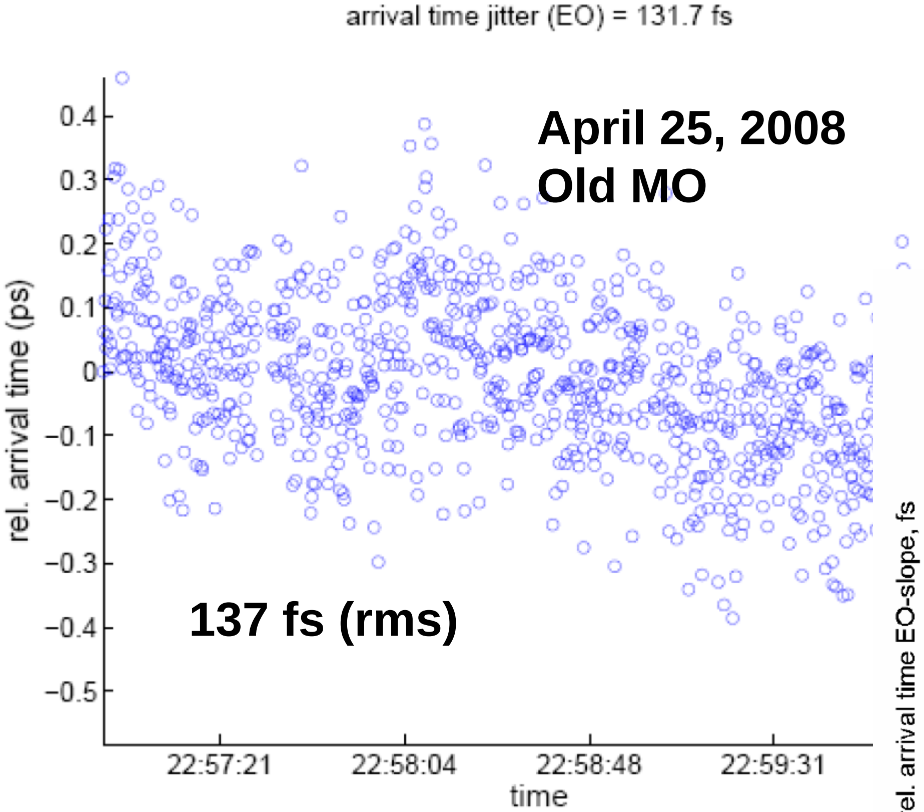
LLRF expert needs to be available several hours per week to help with different types of problems

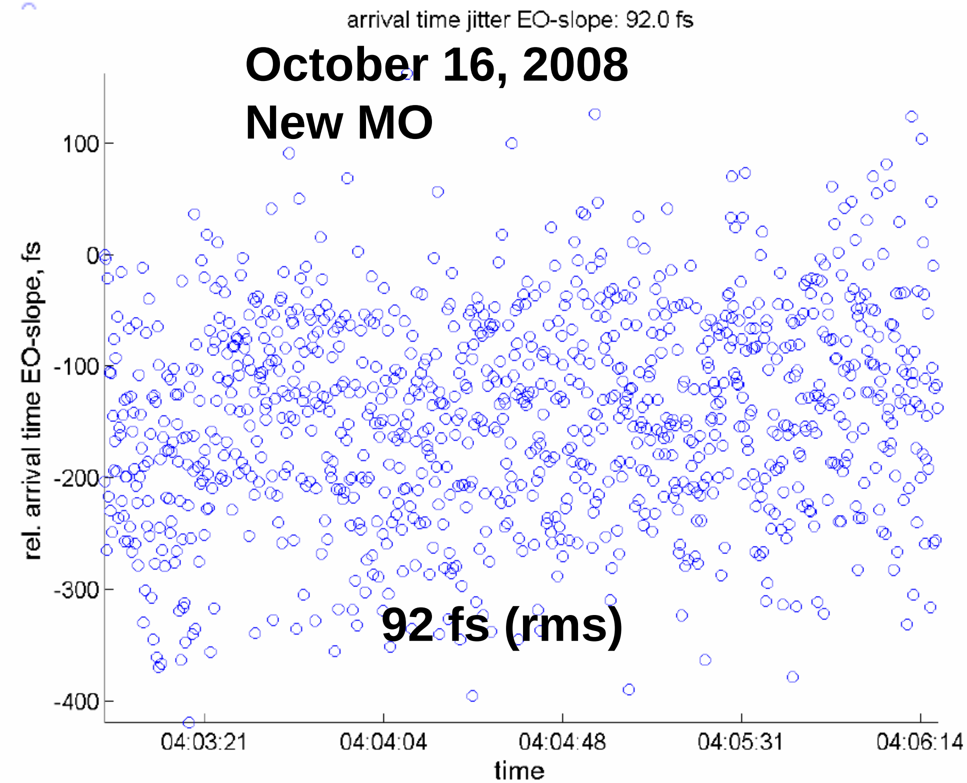
Note 1: Often LLRF is blamed for problems in other systems

Note 2: Sometimes LLRF induced downtime is caused by operator error

Arrival Time Stability with Old and New MO

1000 points in 3 minutes





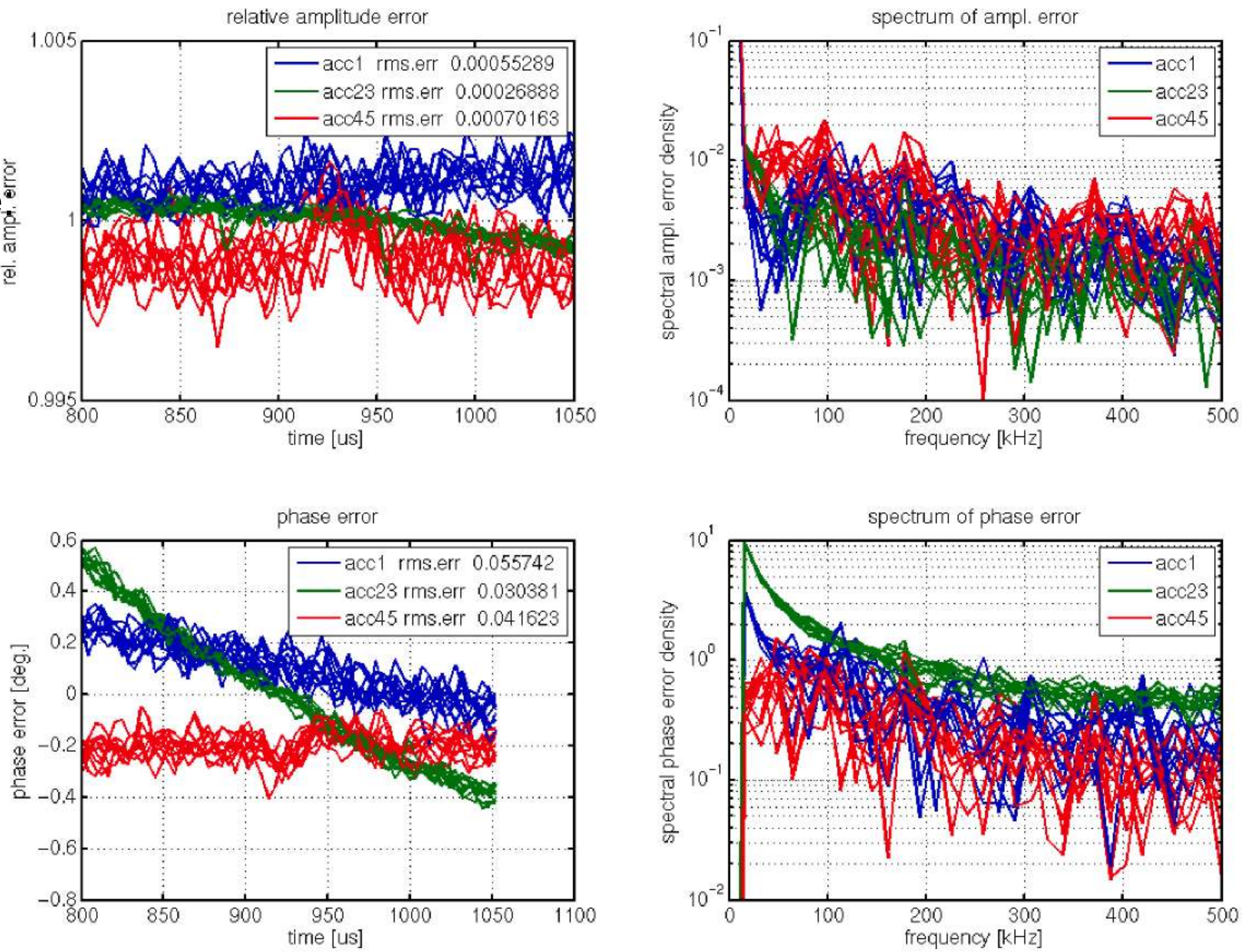
Field Stability in ACC1, ACC23, ACC456

Amplitude:

0.03 %

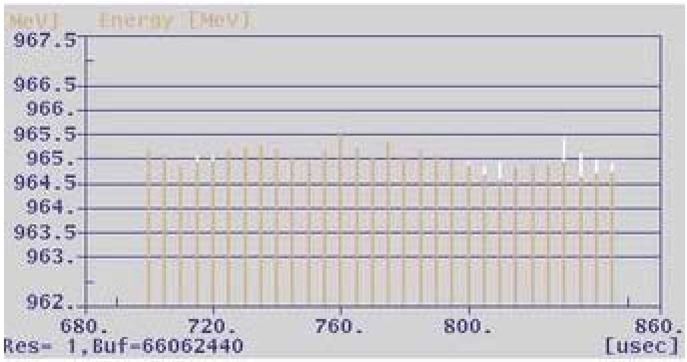
Phase:

0.03 deg.

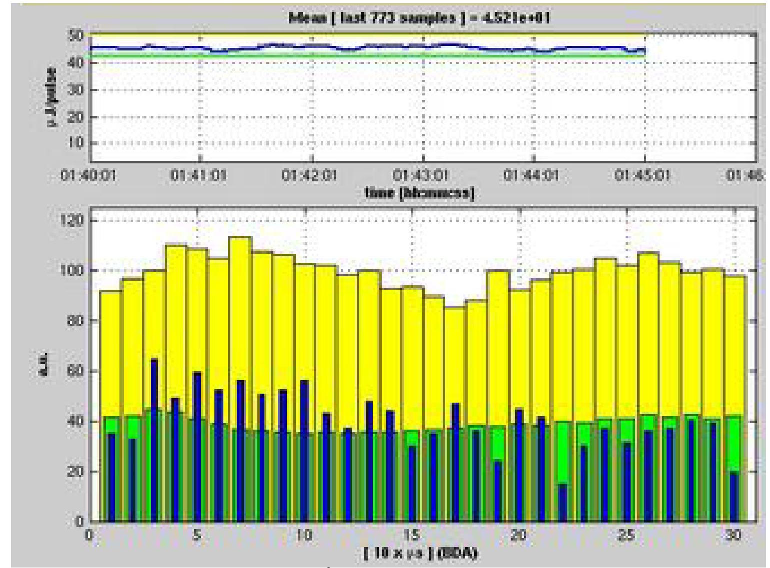


SASE Performance

0.02% rms flatness over pulse train

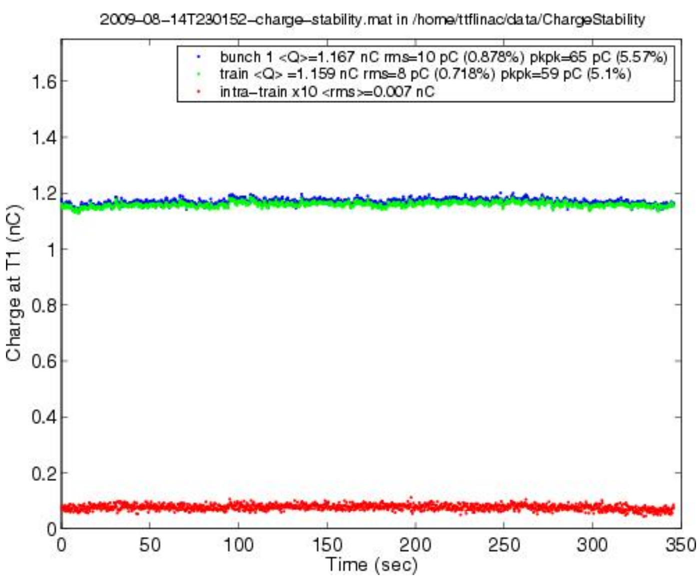


45 μJ for10x10 mm apertures, 100 kHz at 7.02 nm

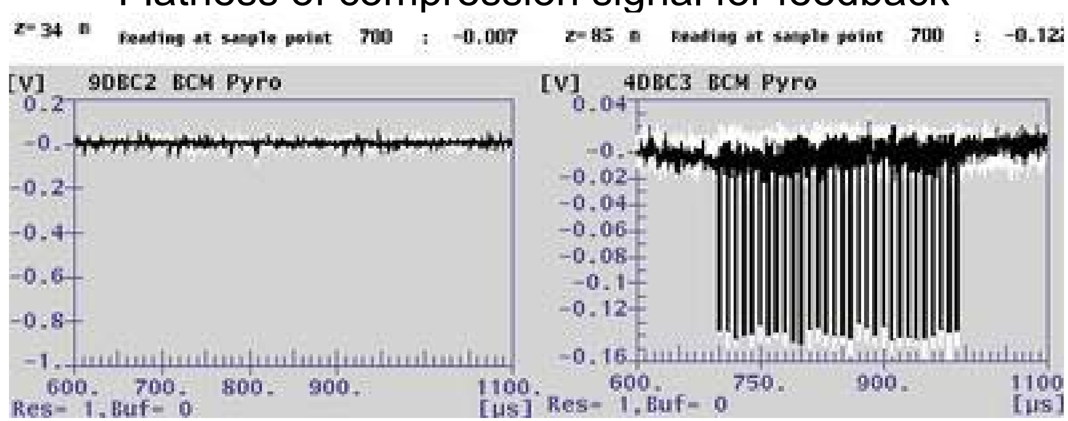


0.9% rms charge fluctuation

7 pC intra train flatness



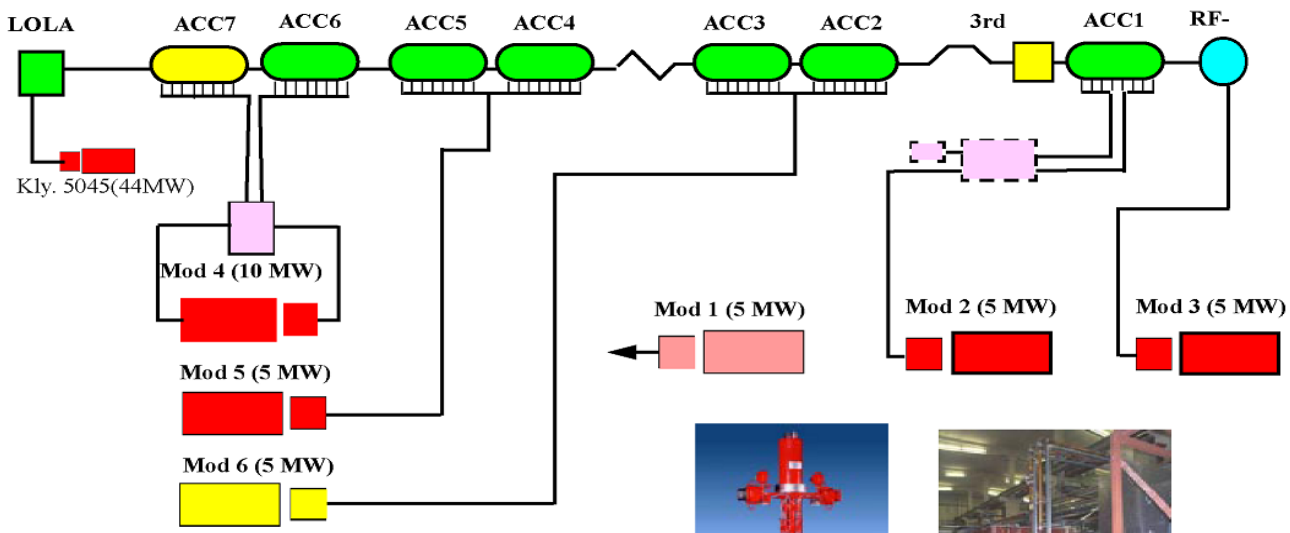
Flatness of compression signal for feedback



Upgrade Plans

RF upgrade in 2009/2010: major modifications

- installation the 3rd harmonic (3.9 GHz) accelerating module
- installation of the 7th accelerating module → energy up to ~ 1.2 GeV ↔ <5 nm
- exchange of the RF gun
- upgrades of RF stations and waveguide distribution



LLRF Installation after FLASH Upgrade

RF System	User operation	Development	Backup
RF Gun	SIMCON	-	DSP
ACC1	SIMCON x1 250 kHz IF	SIMCON x3 54 MHz	DSP 250 kHz
ACC39	SIMCON 54 MHz	-	LIBERA
ACC23	SIMCON x2 54 MHz	-	DSP 250 kHz
ACC45	SIMCON x2 54 MHz	ATCA 54 MHz	DSP 250 kHz
ACC67	SIMCON x2 54 MHz	-	ATCA 54 MHz

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

LLRF Improvement Plans

- Improve long term phase stability (which is of the order of few degrees)
- Improvements to Adaptive feedforward
  - including handling of exceptions, variable beam loading
- RF Gun control
- Automated calibration of vector-sum
- Reproducibility
  - Restoring beam parameters after shutdown or interlock trip
- 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

Conclusion

- RF control performance goals for FLASH achieved
  - 0.03% for amplitude and 0.03 deg. for phase
- User FEL experiments in different fields have been performed successfully with RF feedback only
- The specific needs for improvement of the LLRF at the FLASH user facility have been understood
- In the coming years the LLRF at FLASH will be upgraded to the same systems as planned for the European XFEL
- More diagnostics & Automation are required
- FLASH as a world-wide unique test facility for SCRF technology can be used parallel to user operation with high efficiency