Requirements for the ATCA based LLRF Evaluation System

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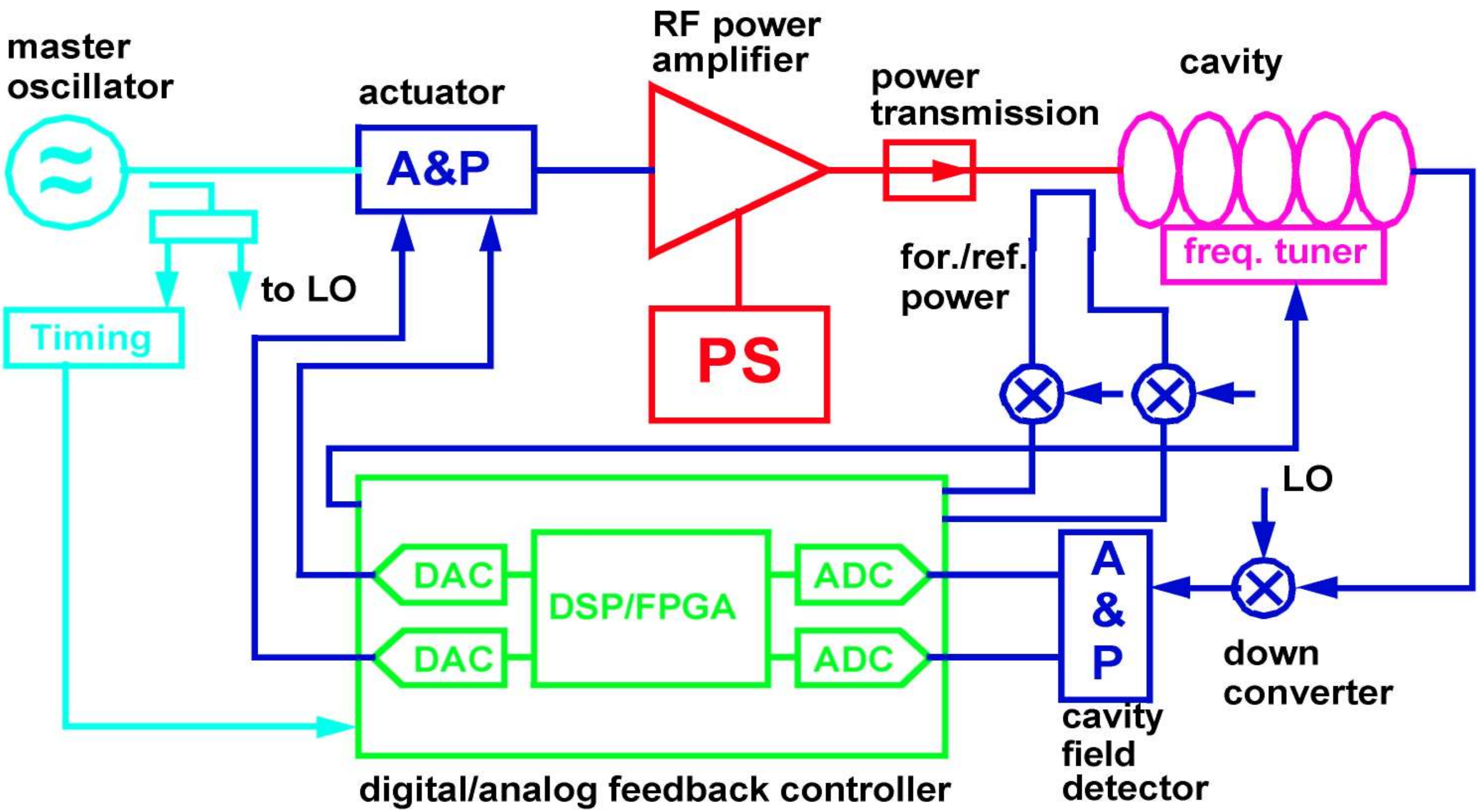
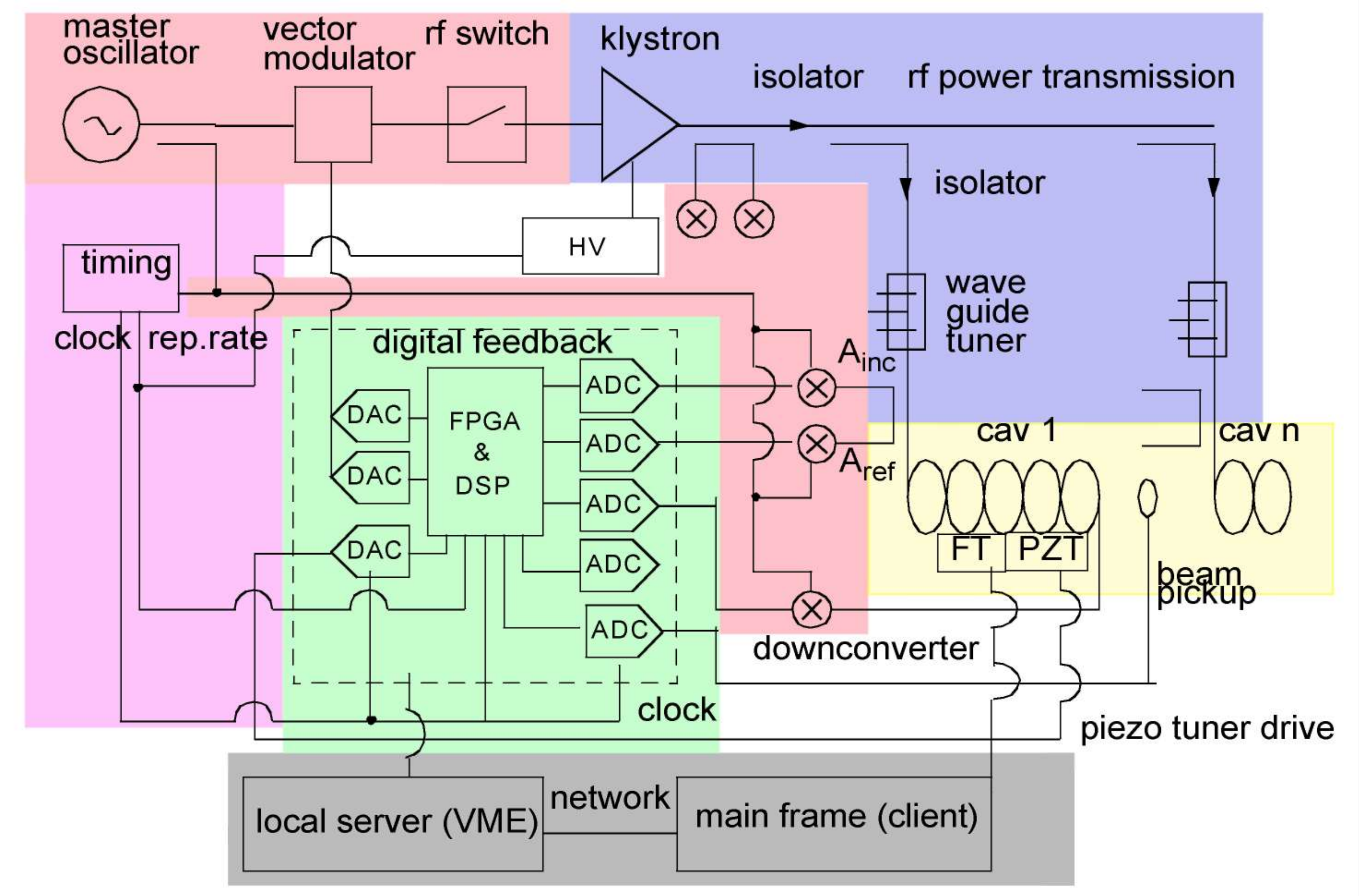
Outline

- Description of the LLRF System
- System Components
- Work Break Down
- Non-functional requirements
- Schedule for Implementation

RF System Architecture



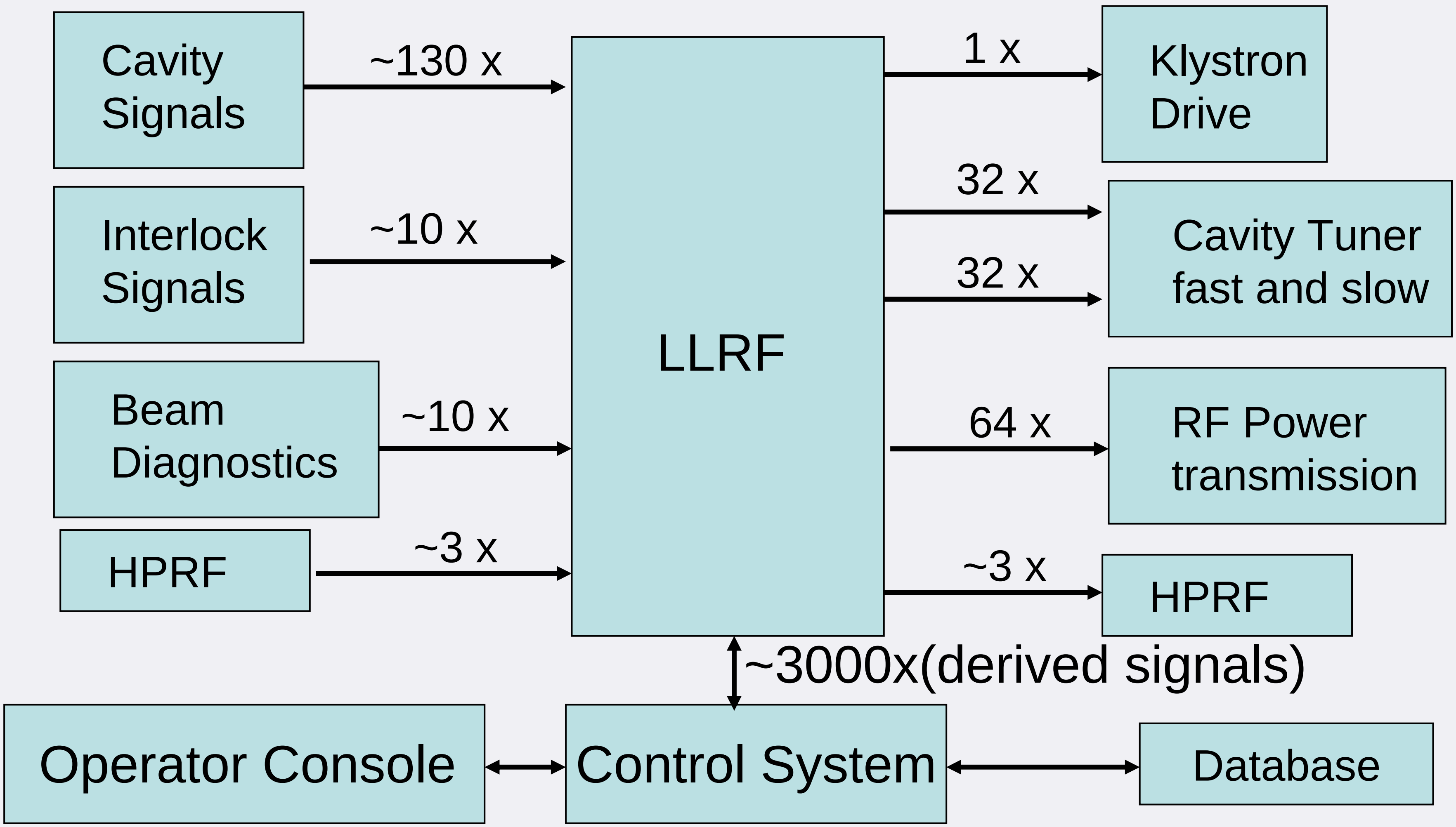
System Architecture Details



Subsystems

o RF phase reference	o Waveguide tuner and controls
- from main driveline	o Cavity resonance control
- LO for downconverter	- slow (motor) tuner
o Timing System	- fast (piezo) tuner
o Vector modulator	o CPU in VME crate
o Downconverter	o Network to local controls
o Digital Control (Fdbck + FF)	o Cabels and connectors
- ADC, DSP, DAC	o Power supply for electronics
- includes exception handling	o Airconditioning in racks
- Redundant simple feedforward	o Software
- Redundant monitoring system	- DSP (FPGA) code
o Transient detection	- Server programs
o Interfaces to other subsystems	- Client programs
- includes interlocks	- LLRF Parameters
	- Finite State Machine

Signal diagram for RF Control (1 RF Station)



RF System Requirements

- Maintain Phase and Amplitude of the accelerating field within given tolerances to accelerate a charged particle beam to given parameters
  - up to 0.02% for amplitude and 0.01 deg. for phase

- Minimimize 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

LLRF Requirements (C'ntd)

- **Availability**
  - not more than 1 LLRF station failure / week
  - SEU tolerant
  - Redundancy of LLRF subsystems
  - ...
- **Operability**
  - "One Button" operation (Automation)
  - Application assist operators and rf experts
  - Automated calibration of vector-sum
  - ...
- **Reproducible**
  - Restore beam parameters after shutdown or interlock trip
  - Recover LLRF state after maintenance work
  - ...

LLRF Requirements (C'ntd)

- **Maintainable**
  - Remote diagnostics of subsystem failure
  - "Hot Swap" Capability
  - Accessible Hardware
  - ...
- **Well Understood**
  - Performance limitations of LLRF fully modelled
  - No unexpected "features"
  - ...
- **Meet (technical) performance goals**
  - Maintain accelerating fields - defined as vector-sum of up to 32 cavities - within given tolerances
  - Minimize peak power requirements
  - ...

Improvement of the FLASH LLRF for the XFEL

- Field regulation :
  - Short term: Improve by factor 3 (0.03 deg. → 0.01 deg.)
  - Phase drifts: Improve by factor 10 (2ps → 0.2 ps)
- Need modular design with high availability (HA):
  - Upgradeability, maintenance
  - Useable by other WP, support collaborative efforts
- Automation (implement applications and exception handling)
- Diagnostics (performance and hardware/software failures)
- Documentation (initially: good requirements are needed, then concepts, design, acceptance tests)

New WBS for LLRF for the XFEL

LLRF Project Management

- Risk Assessment
- Major System Requirements

1. **Hardware**
   - 1.1 MO & distr.
   - 1.2 Digital Feedback
   - 1.3 Field det. & Actuators
   - 1.4 Piezo Control
   - 1.5 Radiation monitoring
   - 1.6 Communication interfaces
2. **Software**
   - 2.1 Controller
   - 2.2 Low Level Applications
   - 2.3 High Level Applications
   - 2.4 Communication protocols
   - 2.5 Control system (DOOCS)
   - 2.6 Global control
3. **Infrastructure Inst/Maint.**
   - 3.1 Cabling
   - 3.2 Racks and crate
   - 3.3 Documentation and Operation Manuals
   - 3.4 QA and QC
   - 3.5 Redundancy, Availability Analysis
   - 3.6 System integration
   - 3.7 Installation in FLASH/MTS/XFEL
4. **Commissioning/ Operation**
   - 4.1 Operation and Evaluation in FLASH/MTS
   - 4.2 Procedures
   - 4.3 Automation
   - 4.4 Diagnostics
   - 4.5 Simulation
5. **Special Topics**
   - 5.1 Transients detection
   - 5.2 WGT Control
   - 5.3 Interfaces to other systems
   - 5.4 Radiation Immunity
   - 5.5 Calibration parameters database

Main LLRF Requirements for the XFEL

1. Provide settability of voltage and phase to the desired values in all 4 quadrants up to a klystron peak power output level of 0.9*P_sat.
2. Maintain stability of voltage and phase of the calibrated and high precision vector-sum of individual rf stations within given tolerances for the range of useable operating parameters.
3. Provide highly stable rf references at specified frequencies at selected locations. Includes calibration reference signals.
4. Provide adequate interfaces to other accelerator subsystems.
5. Diagnose faulty or missing hardware and software and localize areas of functional and technical performance degradation including severeness of degradation. For use by operators and experts.

Main Requirements for the XFEL (Cnt'd)

6. Optimize and/or limit operational and system internal parameters such that the performance function based on rms field stability, accelerator availability, and component lifetime is maximized.
7. Provide a simulation mode, where the klystron-cavity system is replaced by a simulator and which provides performance predictions for planned parameter changes.
8. Provide a high degree of automation of operation to assist the operator and system experts.
9. Provide calibration functions for selected signals.
10. Provide low and high level applications supporting operation and automation.
11. Provide exception detection and handling.
12. Provide operating modes for rf system conditioning (ex. coupler and cavity).
13. Support rf system and accelerator commissioning procedures.

Basic and Advanced Use Cases for RF Station

Basic Use Cases

- Establish moderate RF power and cavity gradients
- Enable and perform measurements of all LLRF relevant signals
- Stabilize fields for beam operation

Advanced Use Cases

- Optimize parameters for best beam stability
- Set parameters to maximize availability during beam operation
- Tune or detune cavity from/to completely detuned state
- Assess performance and performance limitations of rf station
- Diagnose problems and identify the source (hardware/software)
- Detect and handle exceptions

Examples for Scenarios

1. Coarse tuning of cavity resonance with motor tuner
2. Compensate Lorenz force detuning
3. By-pass/un-bypass cavities (to/from completely detuned state)
4. Adjust klystron HV for sufficient power margin
5. Set correct timing
   .. rf gate, rf pulse, klystron HV, flat-top with respect to beam
6. Limit field emission in cavities
7. Apply adaptive feedforward
8. (Re)-start missing or faulty llrf servers
9. (Re)-calibrate rf station
10. Calibrate vector-sum at full beam loading
11. Calibrate downconverter

Non-Functional Requirements

- Field control (up to 0.02% for amplitude, 0.01 deg. for phase)
  - for vector-sum of each rf stations
  - intra-pulse and pulse to pulse (0.03 deg. for several minutes)
  - Long term drifts are corrected by beam based feedback
  - Vector-sum calibration to 1 deg. in phase and 1% in amplitude
  - Adjust incident phase to +- 3 deg.
  - Adjust loaded Q to +- 2%
- Resonance control
  - Coarse tuning (motor tuner) to 0.2 BW
  - Fast tuning (Pietzotuner) to 0.1 BW (LF detuning)
- Calibration of downconverter with reference signal
- Provide frequency and phase reference to llrf and other subsystems.

Non-Functional Requirements (Cnt'd)

- Electronics (racks,crates, boards, and cabling)
  - Crate and board standard compatible with control system
  - Must tolerate moderate levels of radiation (n and gamma)
  - Modular design to facilitate maintenance/upgrades
  - Fulfill european standards for electrical safety
  - Crate cabling only from rear
  - Installation compatible with racks with no rear access
- Interfaces to other subsystems
  - Machine protection and personnel safety
  - Control system
  - HPRF, Cryo, vacuum, cavities, couplers

Crate standard related requirements

- Support ~100 ADC measurement and ~100 DAC control channels with significant data processing capability
  - Sampling rate up to 100 MHz at 14 bit (desired 16) resolution
  - Latency from ADC input to DAC output not to exceed 500 ns (desired < 250 ns)
  - Complex data processing
    - <250 ns for real time feedback in FPGAs
    - 1-10 us for intrapulse measurements
    - <50 ms between pulses
- Support centralized and distributed architecture
  - Requires high bandwidth/low latency communication links
- Scalable

Crate standard related requirements (Cnt'd)

- Modular design
  - Carrier boards with mezzanine cards (5-10 types)
- Maintainable
  - Build-in diagnostics (IPMI, and for all boards)
  - hot-swap
  - Long lifetime of standard and availability of boards
  - Easy access
- Upgradable
- High availability
  - Redundancy supported by hardware and software
  - Rear and front panel IO (few hundred high quality IO channels)

Functional Requirements

- Measurements
  - Signals
  - conditions
  - Components characterization
- Control actions
- Diagnostics
- Warning and fault detection
- Generate events
- Exception detection and handling
- Automation (of operational procedures)

Functional Requirements (Cnt'd)

- Measurements (Examples)
  - Cavity gradient and phase (calibrated)
  - Incident and reflected power (calibrated)
  - Detuning and loaded Q
  - Loop phase and loop gain
  - Klystron linearity characterization
  - Beam phase and beam current
  - System identification
  - …

Functional Requirements (Cnt'd)

- Control actions (Examples)
  - set loop phase, calibrate loop gain
  - set loaded Q and cavity detuning
  - set klystron HV, adjust bouncer timing
  - Calibrate downconverter (every pulse)
  - rf and/or beam inhibit
  - klystron linearization
  - Adaptive feedforward
  - Remote reconfiguration of FPGA
  - …

Functional Requirements (Cnt‘d)

- Exception detection and handling (Examples)
  - Quench
  - Field emission
  - Operational limit exceeded
  - Klystron or drive chain saturated
  - Cavity detuned by more than 1 bandwidth
  - Single event setup (system hangs up or bit-flip)
  - …

Schedule for Software Implementation

- May 08': Basic features needed to demonstrate field control with operation by rf experts
- September 08': Features needed for operation by regular operators and expert tools
- December 08': Basic automation (start-up and fault recovery)