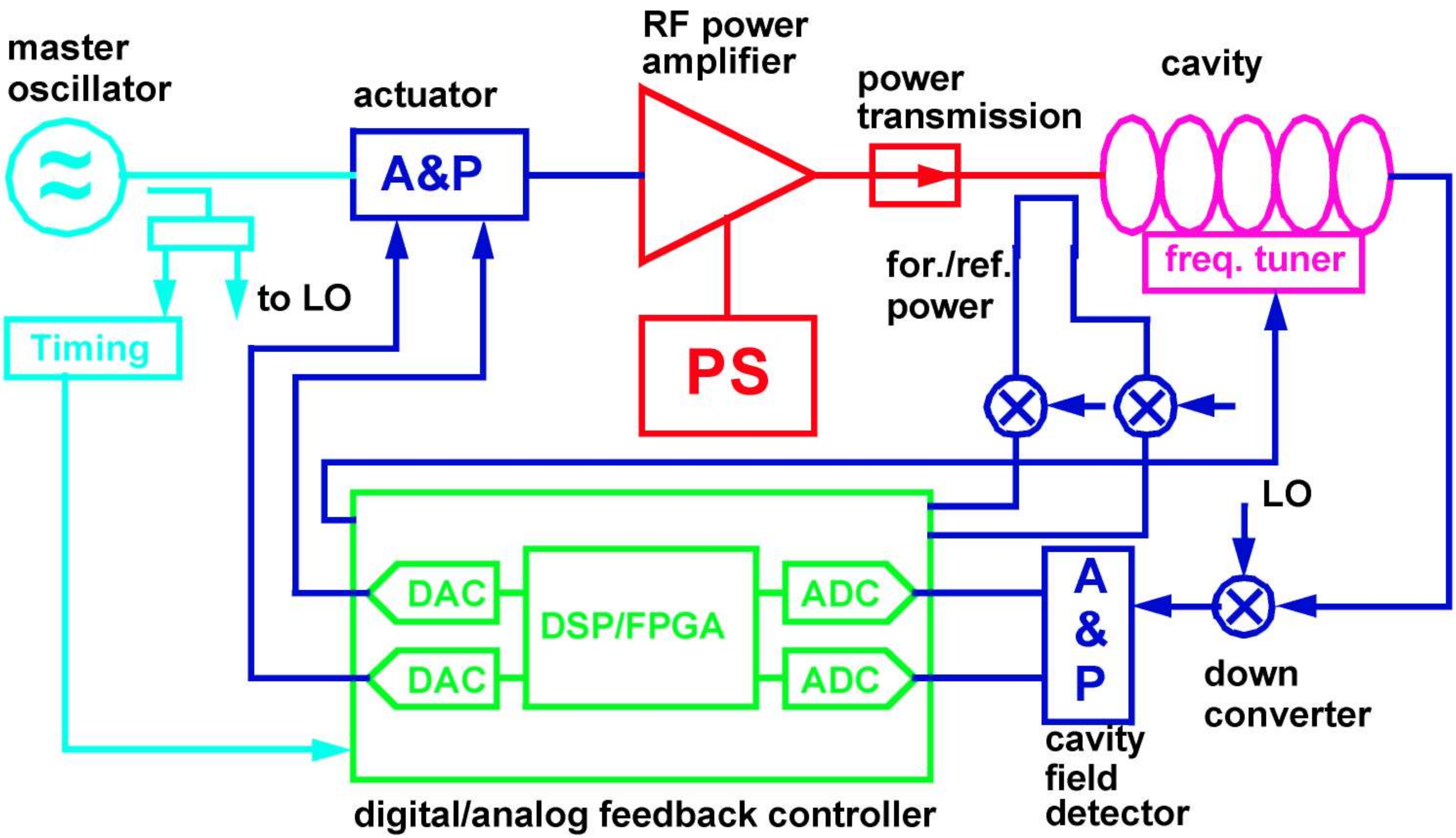
Mutual Benefit of the LLRF Development for ILC and XFEL

S. Simrock, DESY

RF System Architecture (Simplified)



LLRF Requirements for ILC and XFEL

- Maintain Phase and Amplitude of the accelerating field within given tolerances to accelerate a charged particle beam to given parameters
  - up to 0.5% for amplitude and 0.03 deg. for phase for ILC
  - up to 0.02% for amplitude and 0.01 deg. for phase for XFEL

- 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

Requirements

- **Reliability**
  - not more than 1 LLRF system failure / week
  - minimize LLRF induced accelerator downtime
  - Redundancy of LLRF subsystems
  - ...
- **Operability**
  - “One Button” operation (State Machine)
  - Momentum Management system
  - Automated calibration of vector-sum
  - ...
- **Reproducible**
  - Restore beam parameters after shutdown or interlock trip
  - Recover LLRF state after maintenance work
  - ...

Requirements

- **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 24 cavities - within given tolerances
  - Minimize peak power requirements
  - ...

ILC Ampl./Phase Stability Requirements for the Main Linac

	phase tolerance limiting luminosity loss (deg)	phase tol. limiting incr. in energy spread (deg)	amplitude tolerance limiting luminosity loss (%)	amplitude tolerance limiting increase in energy spread (%)
correlated BC phase errors	.24	.35		
uncorrelated BC phase errors	.48	.59		
correlated BC amplitude errors			0.5	1.8
uncorrelated BC amplitude errors			1.6	2.8
correlated linac phase errors	large	.36		
uncorrelated linac phase errors	large	5.6		
correlated linac amplitude errors			large	.07
Uncorr. linac amplitude errors			large	1.05

Summary of tolerances for phase and amplitude control. These tolerances limit the average luminosity loss to <2% and limit the increase in RMS center-of-mass energy spread to <10% of the nominal energy spread.

Ref. Mike Church

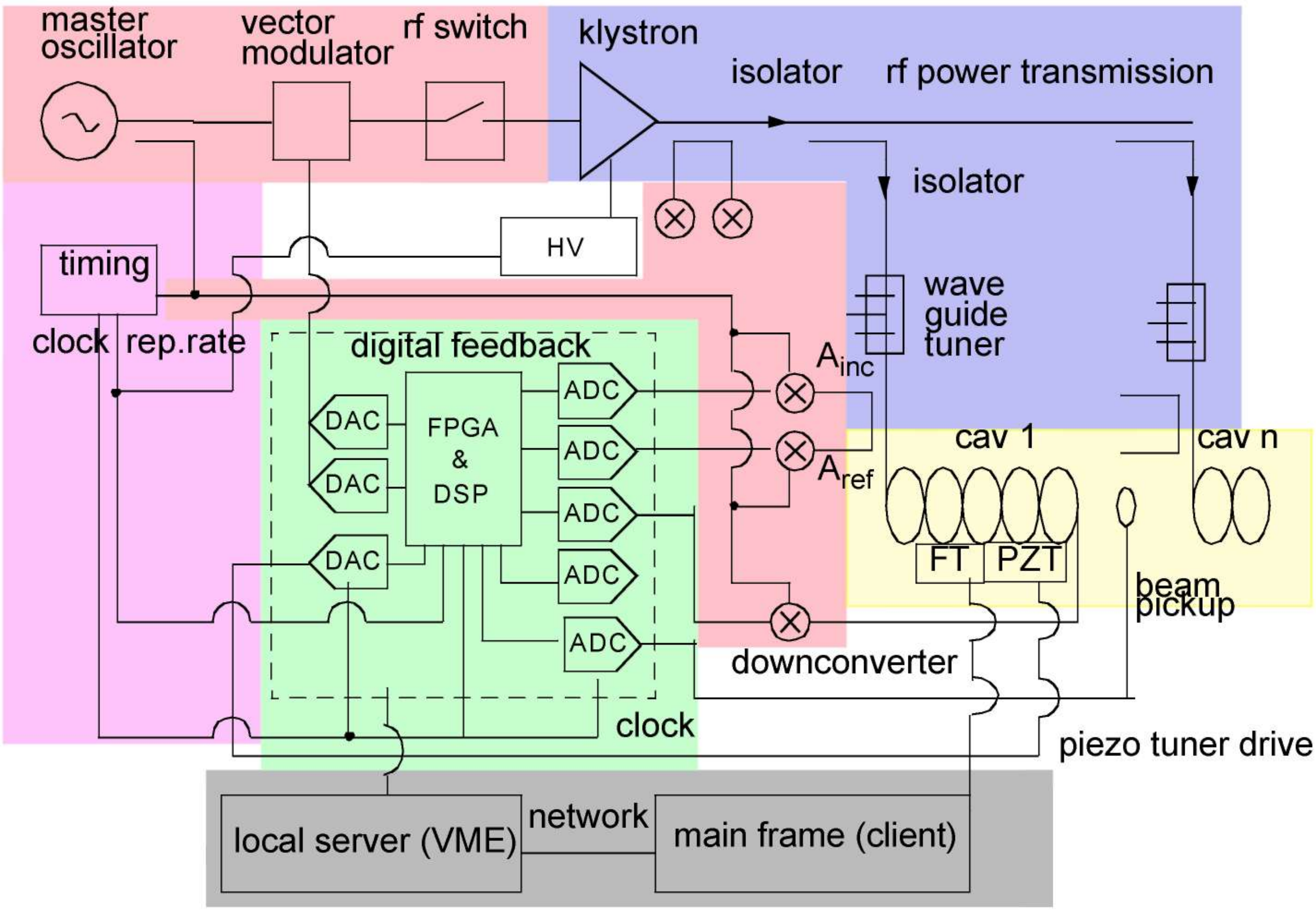
Scope of ILC Main Linac RF

total number of klystrons / cavities per linac	~ 350/ 8,400
per rf station (klystron):	
# cavities / 10 MW klystron	~ 24
# of precision vector receivers (probe, forward, reflected power, reference line, beam)	~90
# piezo actuator drivers / motor tuners	~ 24/24
# waveguide tuner motor controllers	~ 24
# vector-modulators for klystron drive	1
Total # of meas. / control channels per linac	~30,000 / ~30,000

Sources of Perturbations

o Beam loading	o Cavity dynamics
- Beam current fluctuations	- cavity filling
- Pulsed beam transients	- settling time of field
- Multipacting and field emission	
- Excitation of HOMs	o Cavity resonance frequency
- Excitation of other passband	- thermal effects (power
- Wake fields	- Microphonics
	- Lorentz force detuning
o Cavity drive signal	
- HV- Pulse flatness	o Other
- HV PS ripple	- Response of feedback system
- Phase noise from master	- Interlock trips
- Timing signal jitter	- Thermal drifts (electronics,
- Mismatch in power distribution	amplifiers, cables, power
	transmission system)

Architecture of LLRF System

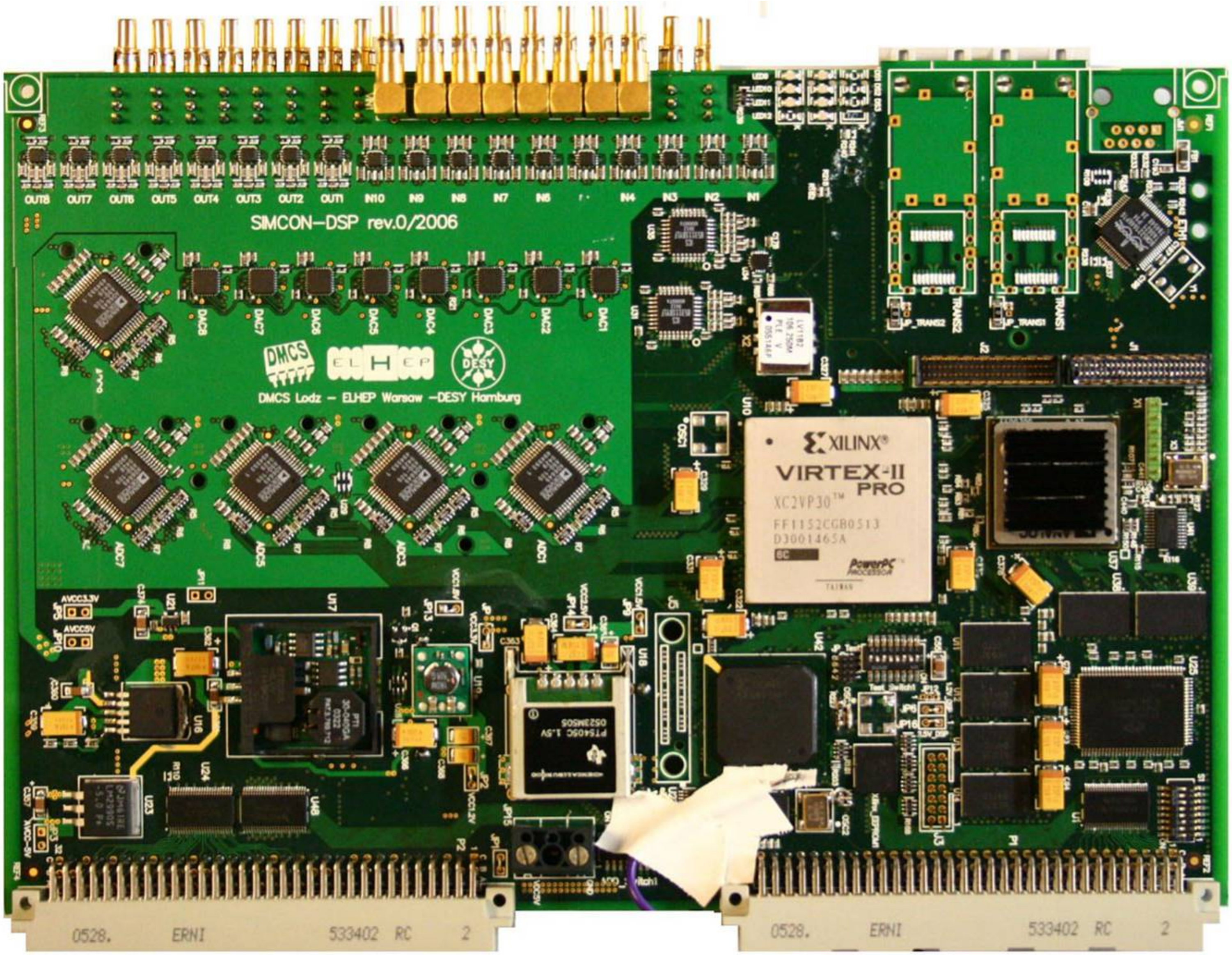


- Topics
  - Vector-Sum Calibration (Ampl. & Phase)
  - Operation close to performance limits
  - Exception Handling
  - Automation of operation
  - Piezo tuner lifetime and dynamic range
  - Optimal field detection and controller (robust)
  - Operation at different gradients
  - Defining stándards for electronics (such as ATCA)
  - Interfaces to other subsystems
  - Reliability

Subsystems Susceptible to Failure

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

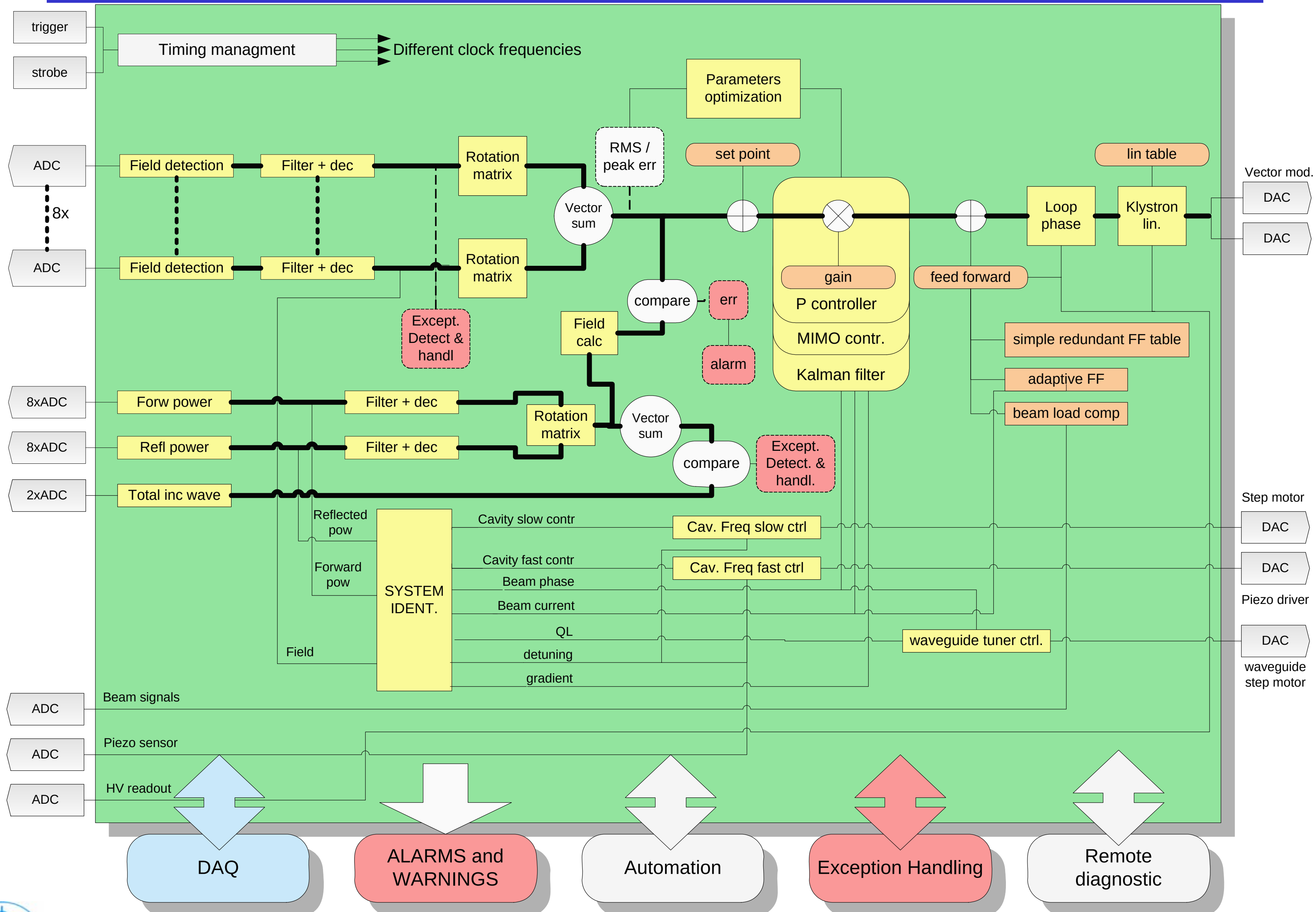
Digital Feedback



Software Modules

- Control Algorithms (Fdbck/ Feedforward)
- Meas. QL and detuning
- Cavity Frequency Control (Fast and Slow)
- Amplitude/Phase Calibration
- Vector-Sum Calibration
- Loop phase and loop gain
- Adaptive Feedforward
- Exception Handling
- Klystron Linearization
- Lorentz Force Compensation

Software Development



- Large number of stations require-
  - System diagnostics must be mostly automated
  - Expert diagnostics must be carried out remotely through the control system
  - Error and fault detection and failure prediction
    - Track klystron gain
  - Self test
    - On reboot and schedule
  - Auto Calibration
    - Built in “Network Analyzer” receiver calibration
    - Klystron linearizer calibration
    - Beam based cavity vector calibration

- ILC
  - Amplitude/phase stability requirements moderate
  - Operates at much higher gradient
    - Lorentz force detuning
    - More rf power to cavities (stress on components)
  - Operates closer to performance limit
    - Closer to klystron saturation
    - Closer to cavity limit (quench, field emission)
  - Two tunnel solution
    - No radiation in service tunnel
    - access to electronics during operation
  - Scale of accelerator 10x larger