Low Level RF and Controls

Brian Chase - LLRF

Margaret Votava - Controls

Scope of LLRF Projects

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- **Vertical Test Stand**
  - **Cavity testing with automation - analog LLRF (TD/Jlab)**
- **Horizontal Test Stands**
  - **Dressed cavity testing - DESY/FNAL LLRF controller(Simcon)**
    - **Simcon is a 10 channel input VME controller developed for DESY**
- **High Intensity Neutrino Source HINS**
  - **325 MHz, Fast Ferrite Vector Modulator -, LBNL/SNS//FNAL**
- **Coupler Conditioning Stand**
  - **1.3 GHz and 3.9 GHz - rack and stack -> Simcon**
- **NML - Full RF Unit Test - no beam**
  - **3 Cryomodules with 24 cavities - Simcon followed by FNAL design (MFC Module)**
- **NML - Photo Injector Source - beam to test string**
  - **Beam based calibration, beam loading, phase reference line - Simcon**

Key LLRF R&D Issues

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- ILC and HINS require the next generation RF Control System
  - Global 0.1% RMS beam energy regulation
    - Test worst case beam loading of buncher section at NML
    - Can we meet the regulation specs?
  - Multi-cavity regulation per klystron system (26 for ILC, 48 for HINS)
    - Will these schemes work with different cavity gradients?
  - Active Piezo-electric tuner feedback system
    - Can we control the cavity to 10 or 20 Hz?
  - Fast Ferrite Vector Modulator control - HINS
    - Another tough regulation ?
  - Long Haul Phase Reference distribution
    - This looks like it might work on the bench, but can it work for the ILC?
  - Automation to fit the ILC machine scale
    - Self calibration
    - Self diagnostic
    - Global regulation with beam based feedback
    - The ILC will not operate without this automation
  - High reliability, modular, low heat load, and low cost
  - $$$ for large machines

Our Path to Meet these Goals

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- Evolve the 10 channel DESY Simcon system
  - Higher Intermediate Frequency development
  - Fermilab is producing a next version Simcon card to improve noise and bandwidth performance
    - Status: close to production
- Develop a Multi-Channel Field Control Module (MFC)
  - 33 ADC channels, FPGA, DSP, 4 DAC channels
  - High density, low cost, low power and is based on VXI
  - Status: Front-end testing complete, close to production
- Develop the analog RF sections
  - 96 channel receivers
  - Transmitter
  - Master Oscillator
  - Phase Reference Distribution with pulsed reference line

Sources of Perturbations

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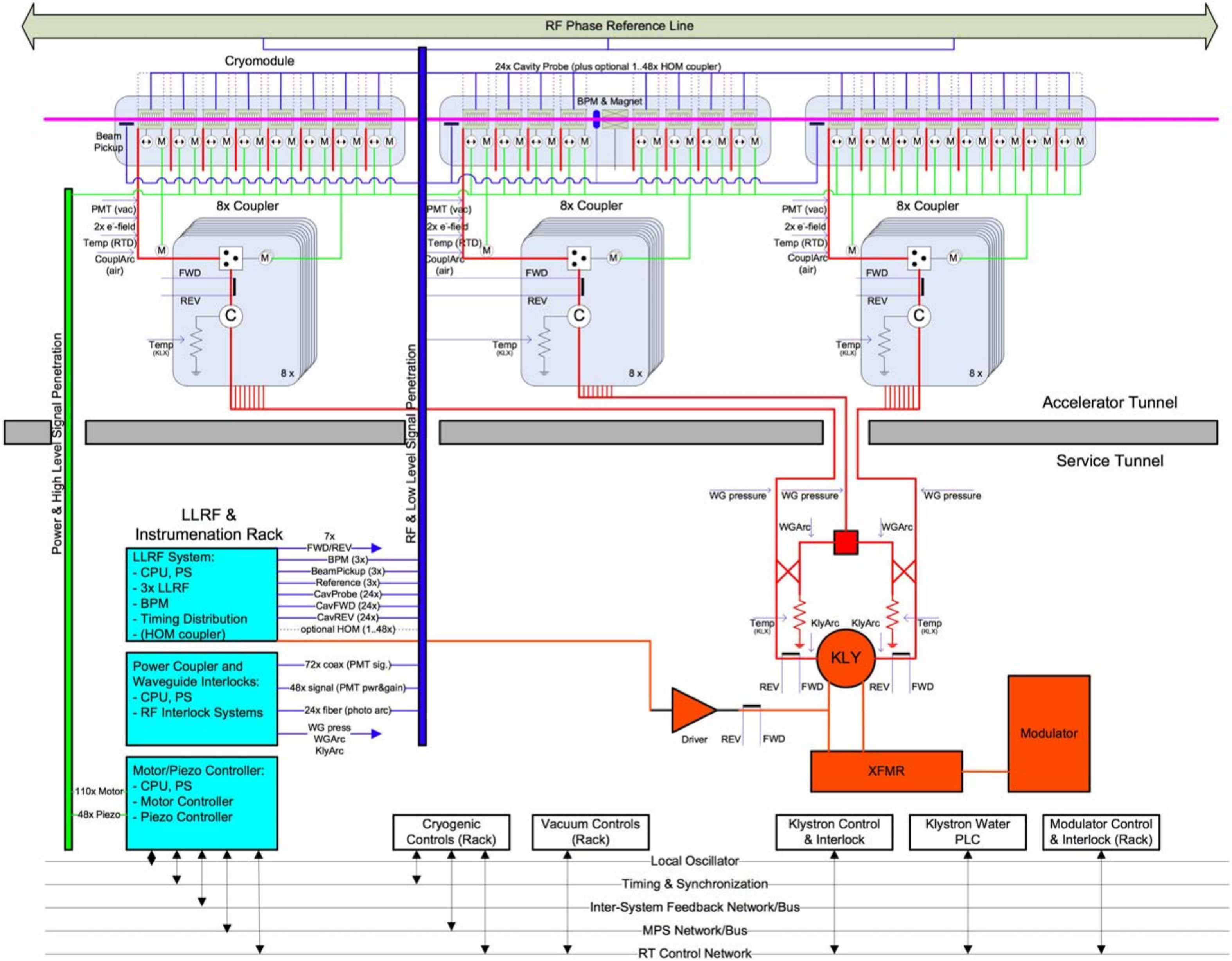
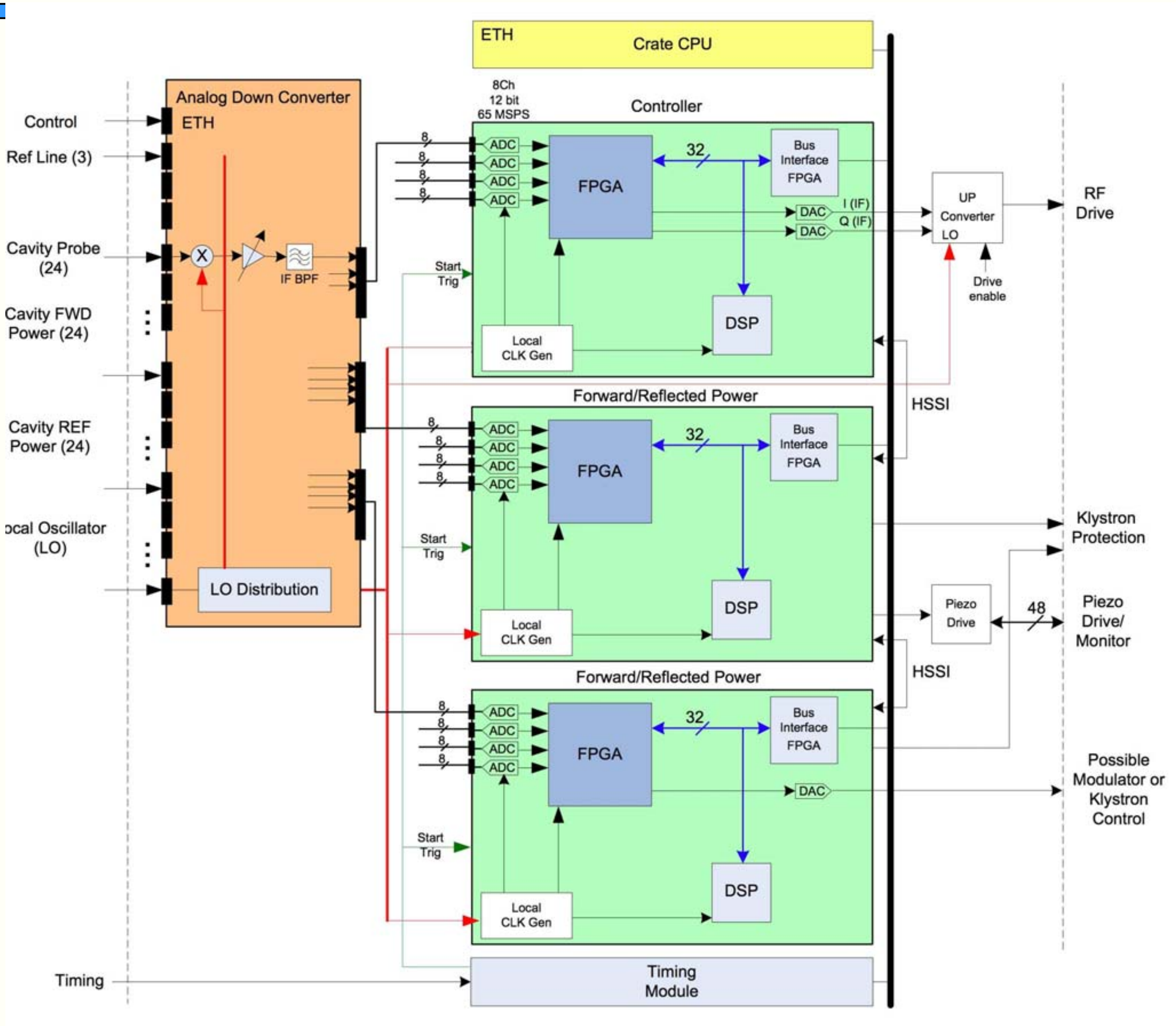
o Beam loading	o Cavity dynamics
- Beam current fluctuations	- cavity filling
- Pulsed beam transients	- settling time of field
- Multipacting and field emission	
- Excitation of HOMs	o Cavity resonance frequency change
- Excitation of other passband modes	- thermal effects (power dependent)
- Wake fields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

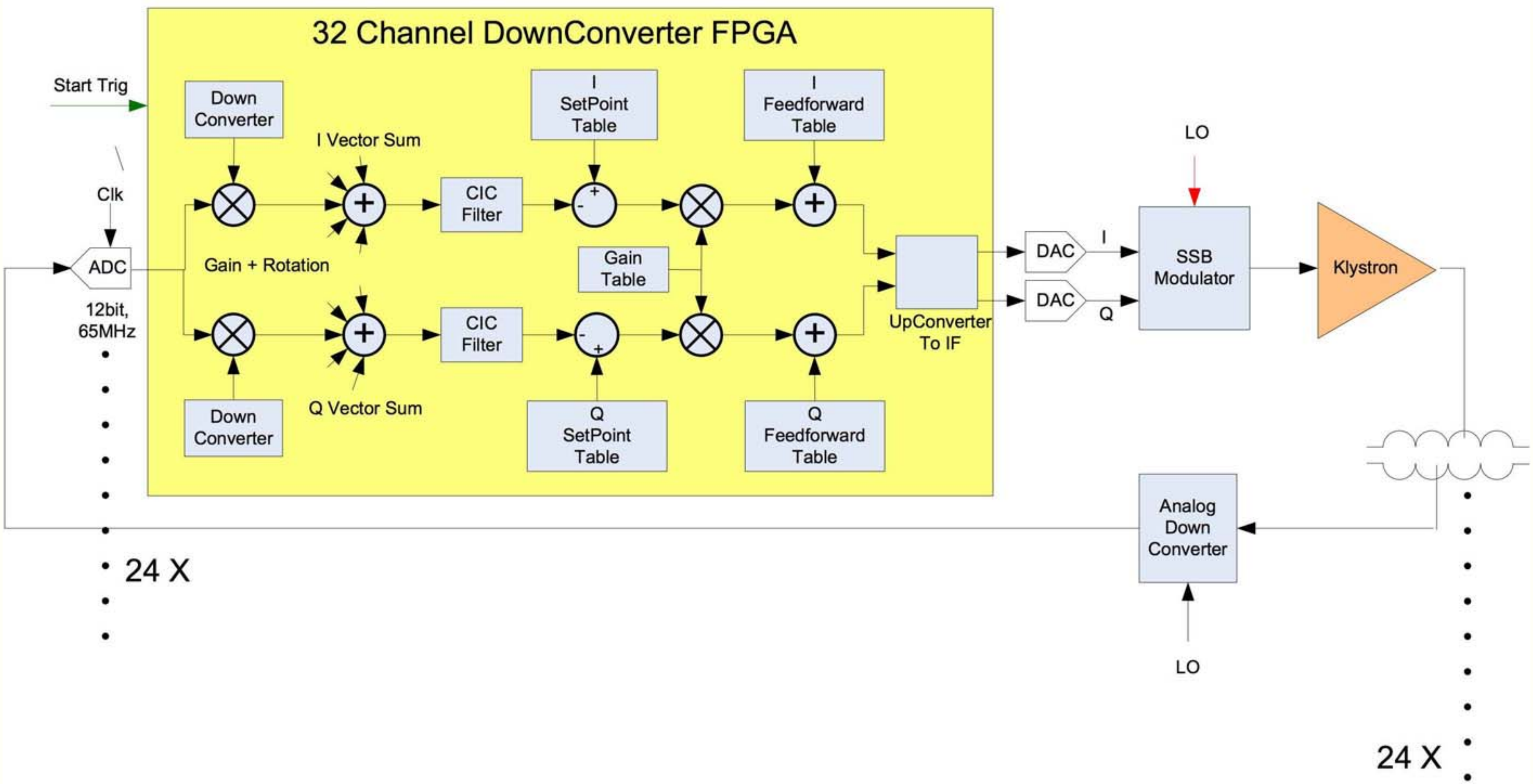
NML with 3 Cryo-modules



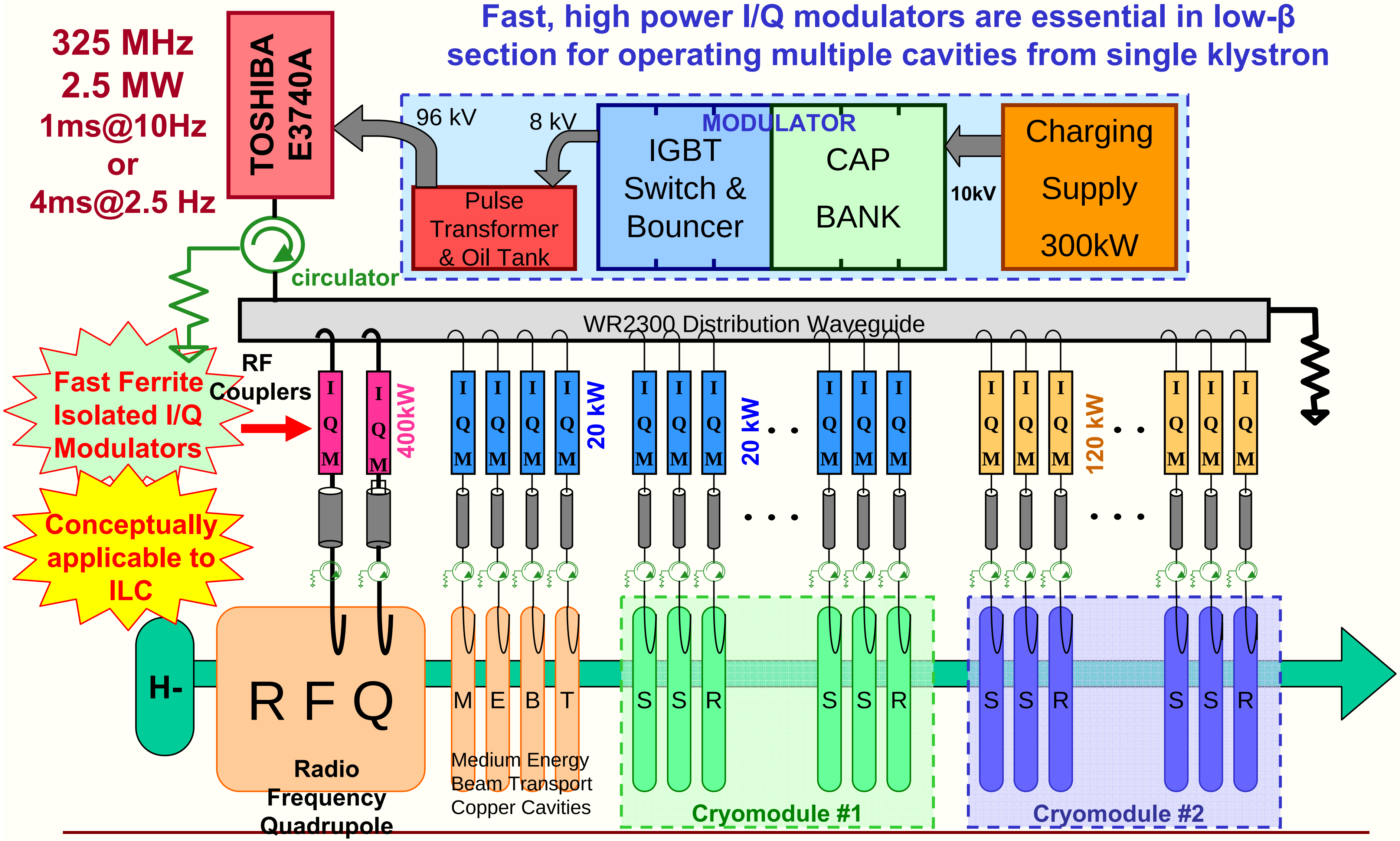
LLRF Rack Detail



3 Cryomodule Field Controller



High Power Amplitude/Phase Control for HINS



Prototype Master Oscillator

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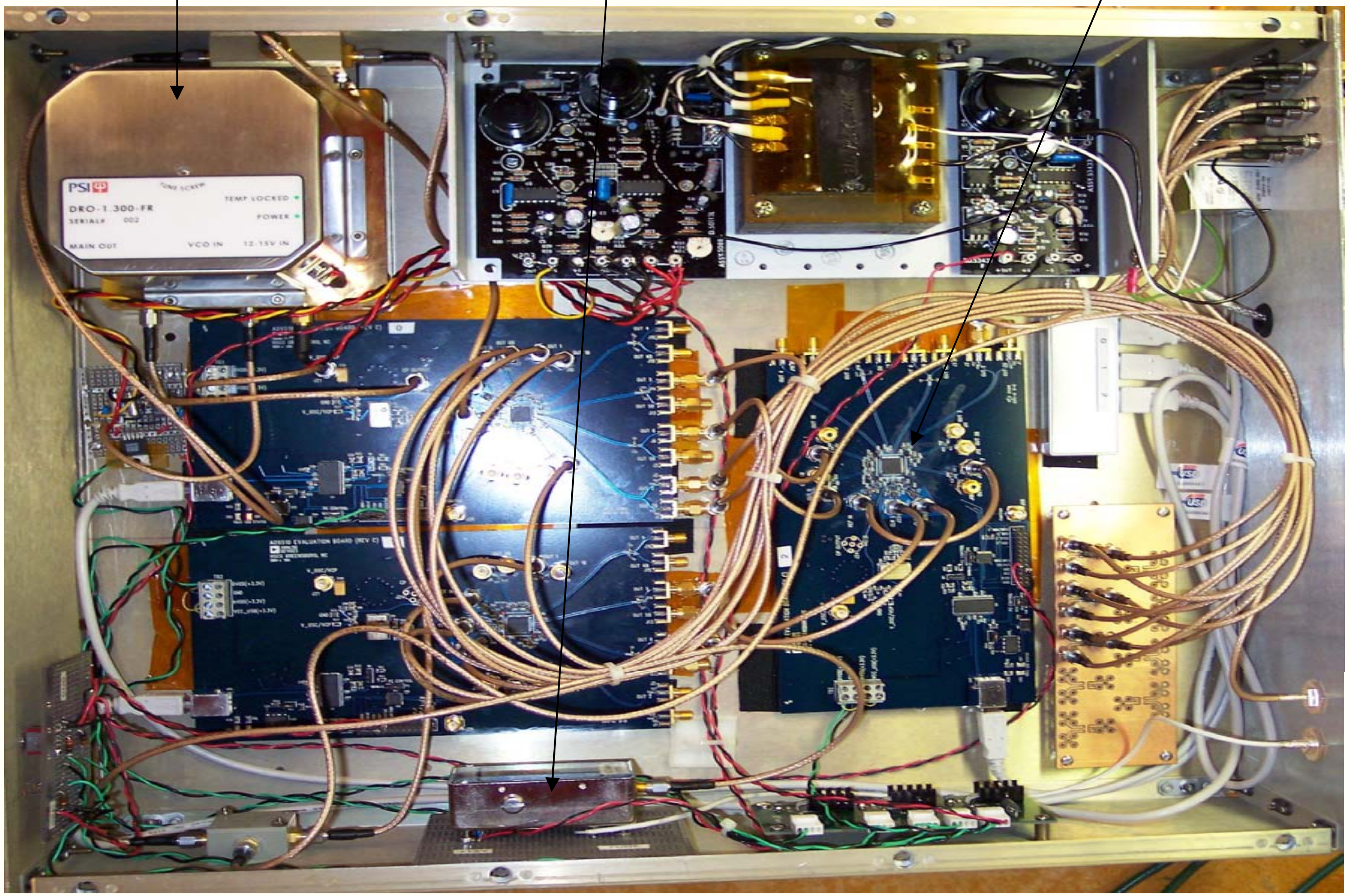
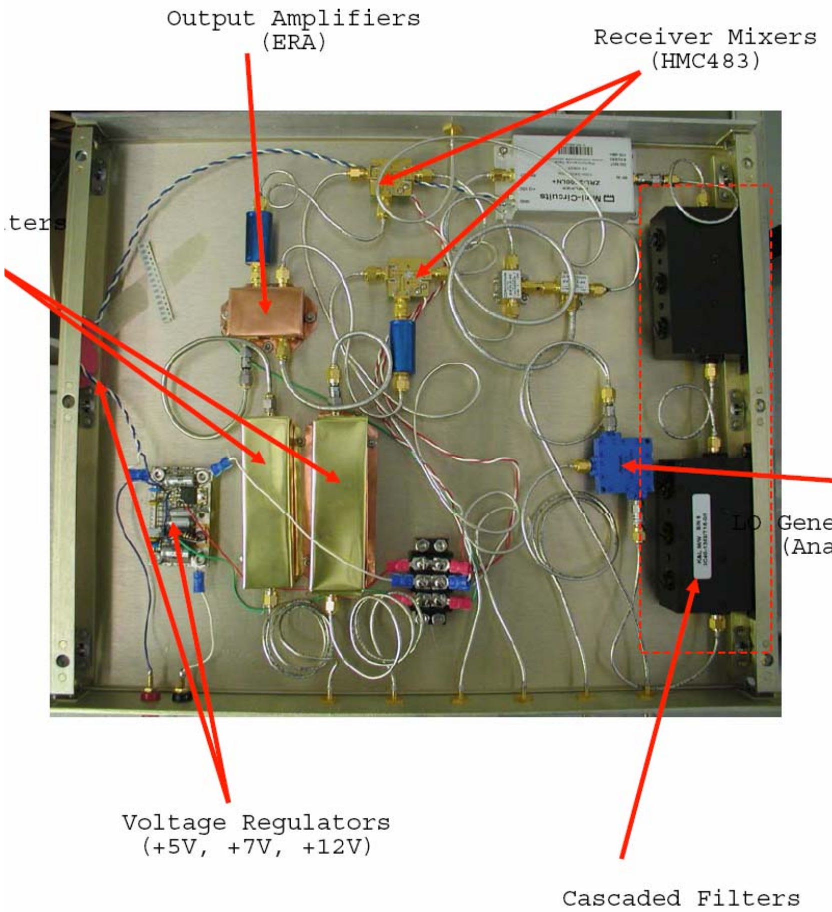
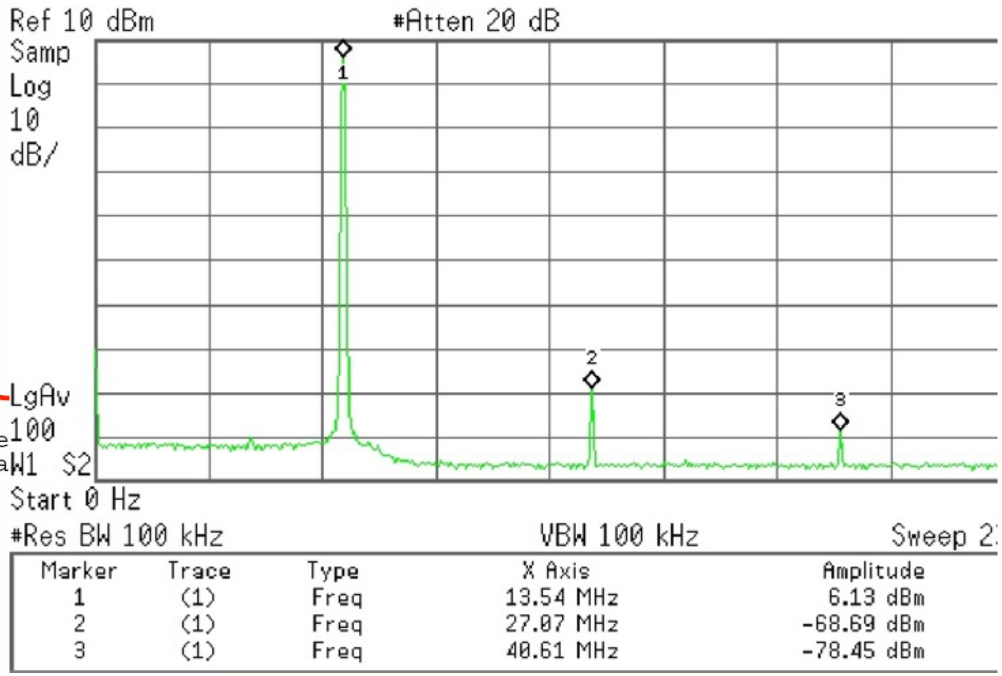
1300 MHz low noise DRO: 10MHz VCXO: Programmable frequency outputs



Prototype LO Gen/Down-converter

1313 MHz Local Oscillator





2nd harmonic -69dBc

CC2 Results with 13 MHz IF

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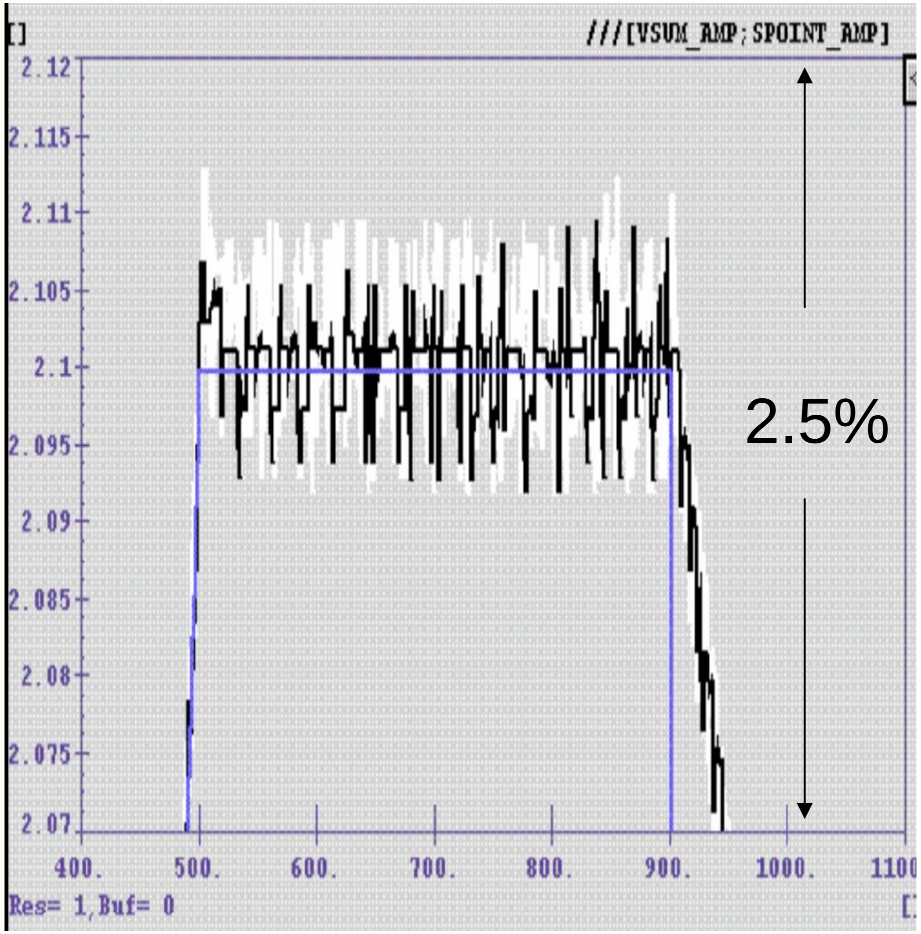
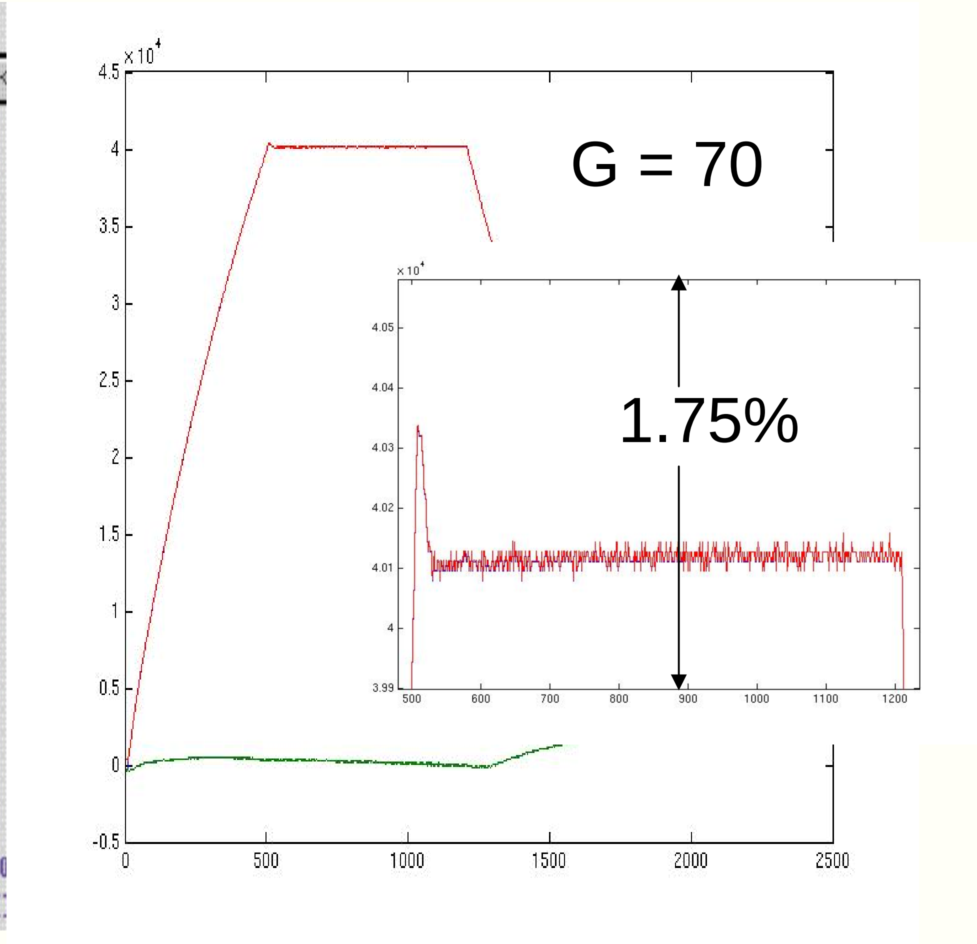




250 kHz IF

13MHz IF

Piezo-electric Control of CC2

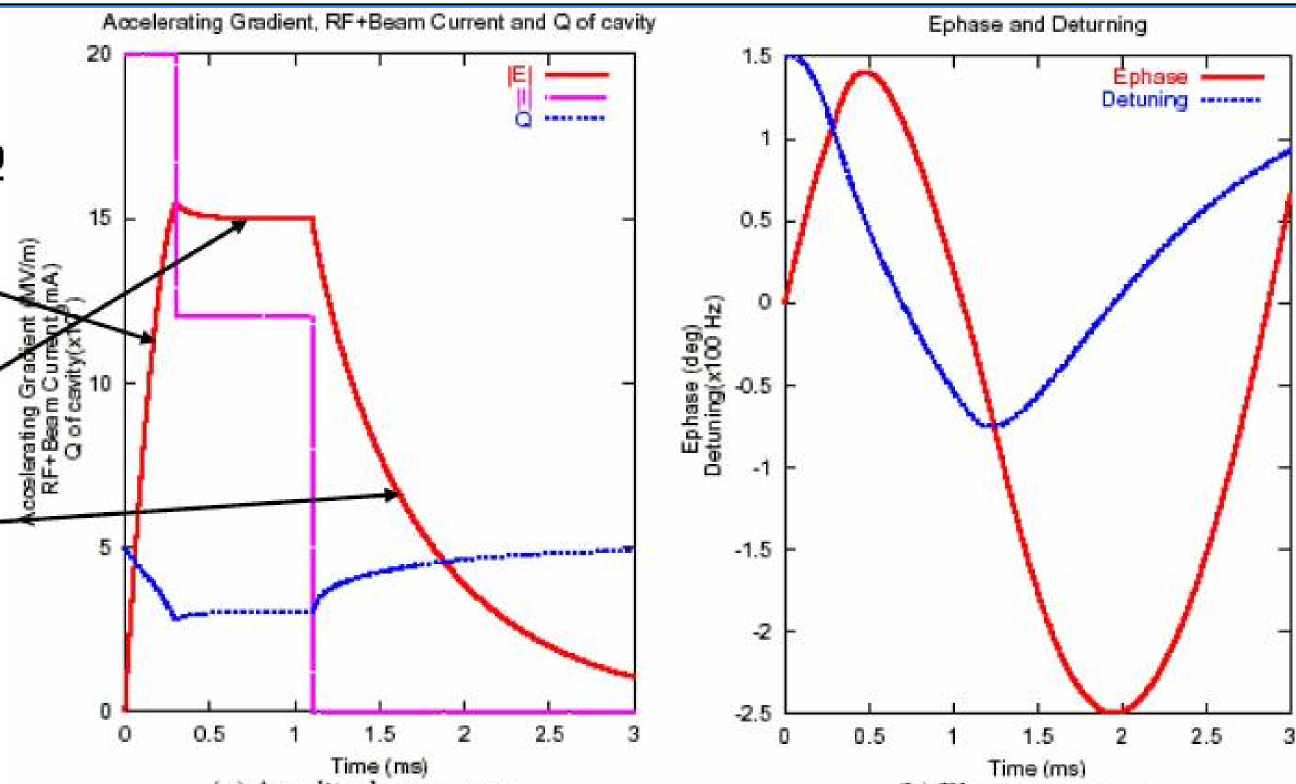
The Piezo-electric actuator counteracts the Lorentz force to maintain the cavity on resonance

Cavity field @ 25 MV/m

Piezo Drive -green
Cavity Probe - Cyan
Reflected Power - Magenta

Real Time Cavity Simulator

Test run of ILC Cavity Simulator (no beam)
1)fill: 0 - 0.3 ms at 20 mA (full power)
2)flat-top: 0.3 -1.1 ms at 12 mA
3)cavity emptying, decay curve shows high Q of cavity.



(a) Amplitude response (b) Phase response

Compare with TESLA cavity measurements:
Shapes are similar, model is working.

IF in these simulations is 50 MHz.

Justin Keung, UPenn

Collaborations

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- Weekly telecom for LLRF
  - FNAL, DESY, Warsaw ELHEP, KEK, ANL, LBNL, SNS, JLAB, INFN, and U of Penn
- Weekly telecom for ILC Controls
  - FNAL, ANL, SLAC, DESY, KEK
- Weekly telecom for ILC HLRF
- Collaborative projects-
  - Controller design for XFEL and ILCTA (DESY, FNAL)
  - Long Haul Phase Reference Line (ANL, FNAL…)
  - HINS LLRF (LBNL, SNS, FNAL)
  - Master Oscillator (DESY, FNAL)
  - Real time Cavity Simulator (U of Penn, DESY, FNAL)
  - Piezo-electric resonance control (INFN, JLAB, FNAL)
  - Data Management (FNAL, ANL)

Staging LLRF and Controls

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- LLRF and Controls may be staged along with other key components
  - BUT…nothing will operate without some version of these systems.
- R&D is manpower intensive
- R&D requires sustained long term effort to meet design goals and to be cost effective
- Growing expertise and training new people in in these systems is critical to the success of any future large SCRF project

Summary

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- New technologies from the telecom industry(ADC,FPGA, etc) allow for the development of the next generation LLRF systems
  - These next generation designs will be very flexible and will apply to light sources and other new machines
- We need these systems to achieve the stated goals of SCRF R&D here at Fermilab
  - The performance of these systems directly affect the performance of the accelerator as a whole.
- Now is the right time to do this development
  - The proposed R&D is key for large scale accelerator projects
- LLRF is on track to support the ILCTA program given the present budget profile

SCRF Control Scope

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- Controls R&D is focused in two areas
  1) R&D to create stable and robust controls system for SCRF R&D program
  2) R&D for ILC Controls
- This request addresses only the SCRF R&D program
- Want to make ourselves available for ILC Controls R&D
  - Control system is recognized critical for ILC success
  - NML is strong site for controls R&D
    - Running with ILC beam parameters (ish)
    - Conveniently located near institutions involved in global controls effort (ANL, FNAL)
    - Close collaborators with others (DESY, SLAC).
  - Not much GDE funding in near term, but will come.

SCRF Control Goals

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1. Provide an operationally stable system for the automatic procedures needed for cavity and cryomodule testing
2. Provide a consistent controls infrastructure for all the facilities: VTS, HTS, NML.
   - VTS controls in the SNS package. Interface to common electronic logbook/data management systems.
3. Provide an infrastructure that can readily integrate components developed at collaborating institutions
4. Provide a work area conducive ILC Controls R&D

These goals are not always compatible.

- Balance needs to be found

SCRF Focus

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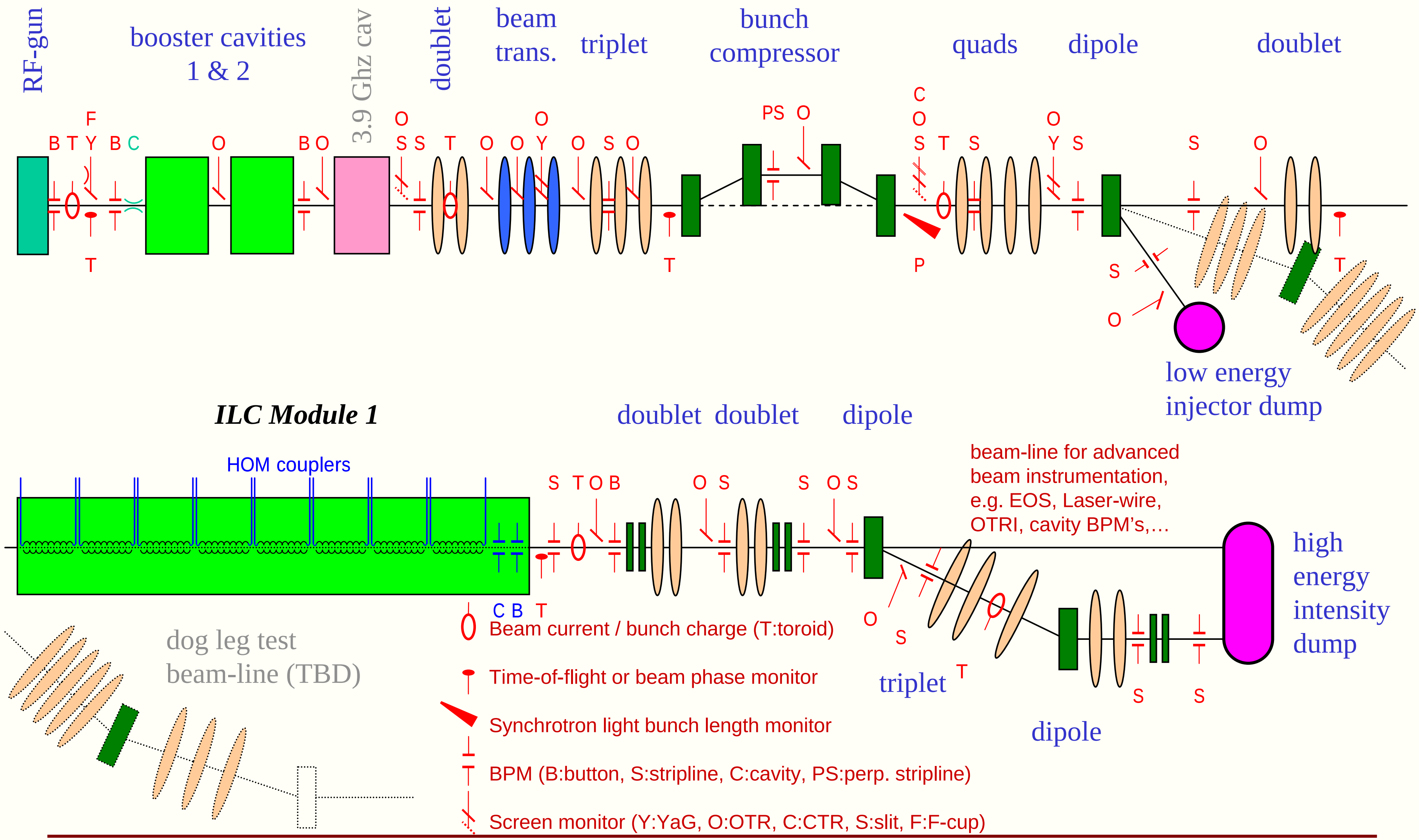
- Infrastructure support
  - Core controls system(s) support, development, and configuration management including code packaging and distribution
    - Controls systems include EPICS, DOOCS and diagnostic systems such as LabView and MatLab
  - Develop cavity data management system
  - Additional component support including system management, electronic logbook, cavity data management system
- Test area specific
  - NML specific development
    - Develop timing and clock system that are required for first beam operation
    - Develop interfaces for new components for instrumentation and control
    - Develop controls interface for ATCA BPMs
    - Develop/configure NML application software
  - HTS/VTS ongoing support – updating processes, and user interfaces as more experience with the cavities is gleaned.

NML Beam Instrumentation



NML Controls Overview

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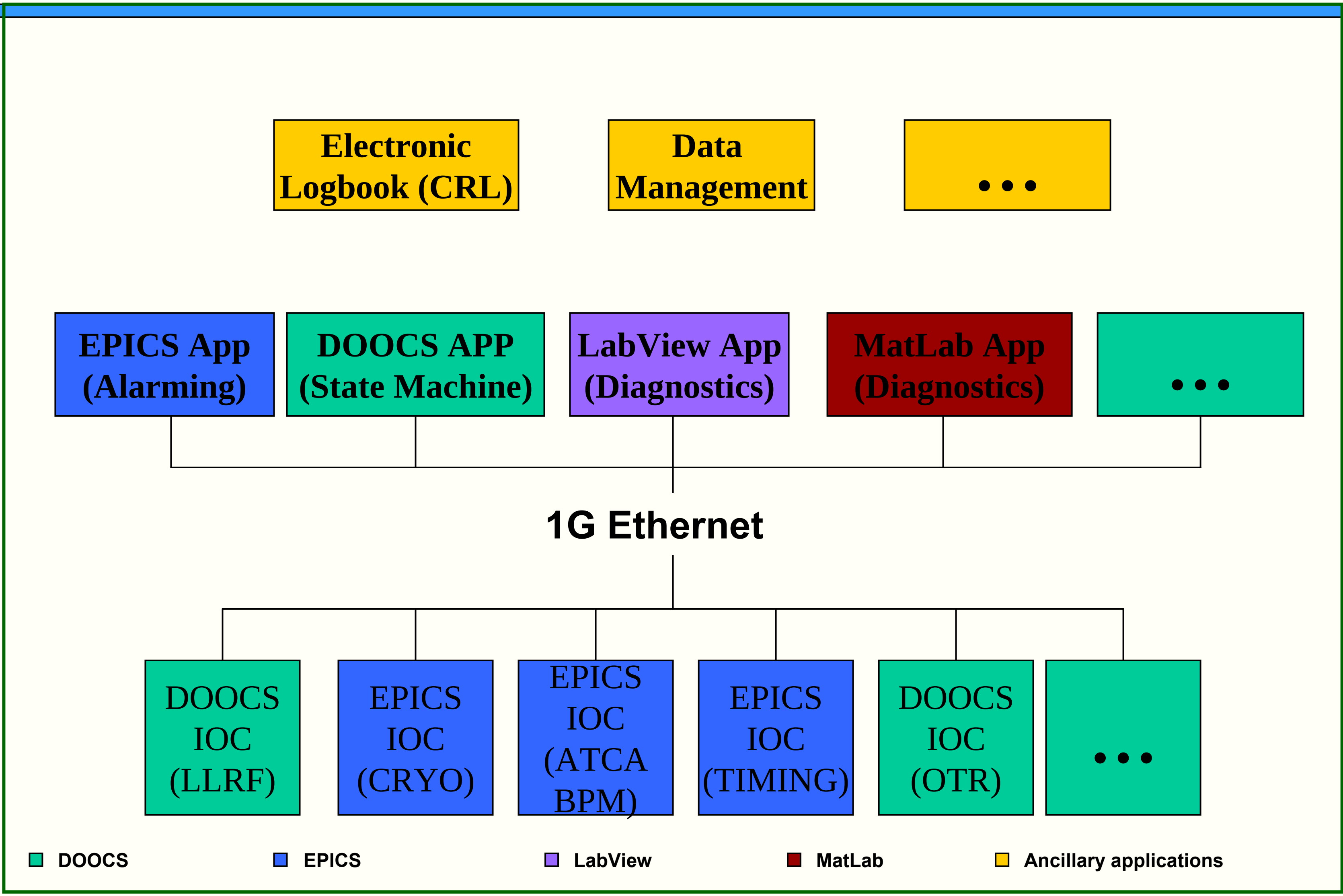

Controls Resources Needed

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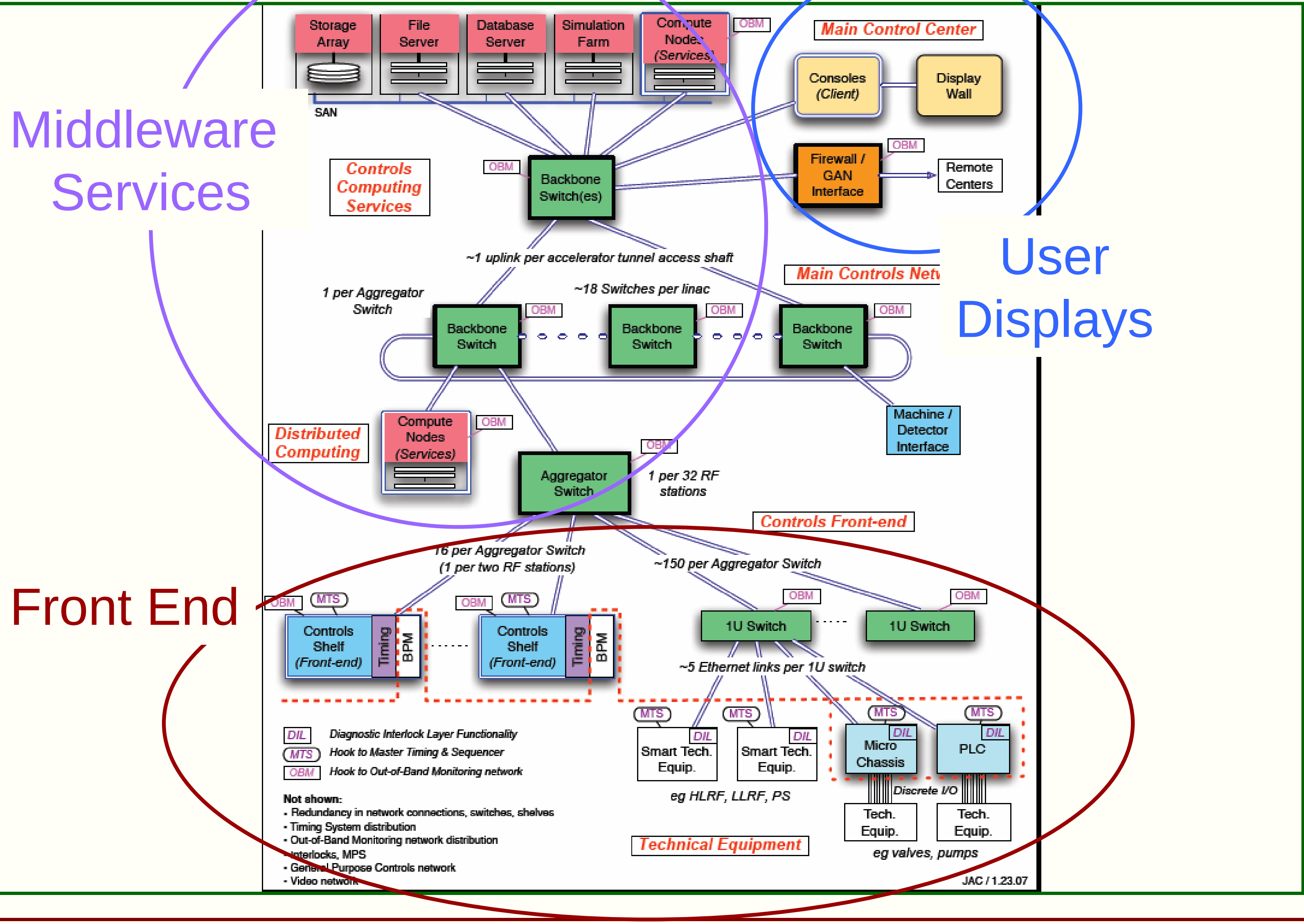
- Labor - ~12 FTE annually
  - Infrastructure support
  - NML specific support
  - HTS/VTS support
  - Cavity Data Management Development (1 year only)
- M&S: ~ $950K
  - Gigabit network infrastructure
  - RF interlocks
  - Event clock/timing system
  - Data acquisition and control (IOCs)
  - Local consoles, archiving, logbook..
  - Control room outfitting
- Detailed costing available in spreadsheet

ILC Overview – from RDR



ILC Controls R&D

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- High Availability
  - Evaluating ATCA as a standard outside of instrumentation
  - Diagnostic Interface Layer
  - Evaluation of high availability software techniques in all layers
  - Standards, standardization, quality assurance
- Timing/feedback
  - Precision timing and RF phase distribution
  - Extensive reliance on automation and beam based feedback
- Controls system studies
  - Conflict Avoidance
  - Fault detection and recovery
- Scalability
  - R&D needed to configure/control/monitor a control system as complex as the ILC.
- Remote operations
  - Provide a framework which is supportive of remote operations R&D such as role based access.