International Linear Collider

RDR Controls Design Walk-Through

Controls and LLRF EDR Kick-Off Meeting

August 20-22, 2007

Control System Reference Design

- The Control System Reference Design serves several purposes
  - ***Establish a functional and physical model for costing purposes***
  - ***Establish a starting point for engineering design and R&D efforts***
  - ***Communicate our vision of the control system***

Scope of Controls

- Computing Infrastructure
  - *Computer Center*
  - *Business Computing*
  - *Computing Networks*
  - *Desktop Support*
  - *Engineering Support*
  - *Computer Security*
  - *Management*
- Controls System
  - *Central Computers*
  - *On Site Control Room*
  - *Controls Services*
    - Operator Interface
    - Automation
    - Logging
    - databases
    - Data Archival
    - Alarms
    - Diagnostics
- Interfaces to Technical Systems
  - *Front Ends*
    - Hardware
    - software
  - *cabling*
- Protection Systems
  - *Machine Protection*
  - *Personnel Protection*
  - *Beam Containment*
- Network Infrastructure
- Assembly and Testing of Controls Racks

Requirements

- High Availability
  - *Controls System allocation*
    - 2500 hour MTBF
    - 5 hour MTTR
    - 15 hours downtime per year
    - CS availability – 99% to 99.9%
    - Each system 99.999% available
  - *Standardization*
  - *Diagnostic Layer*
- Scalability
  - *~100,000 devices , millions of control points*
- Automation
  - *Sequencing, automatic startup, tuning, etc.*
  - *Slow and Fast Beam Based Feedback*
- Timing and Synchronization
  - *Precision RF Phase References*
  - *0.1% amplitude & 0.1 degree phase stability*
- Remote Operation
  - *Enable Collaborators to participate more fully*

Cost & Technical Drivers

- High Availability
  - *Redundancy*
  - *Automatic failure detection and fail-over*
  - *Remote Diagnosis and Repair*
  - *Long Mean Time to Failure Equipment*
  - *Hot Swap*
- Timing
  - *Tight timing tolerances over long distances*
  - *Correlation of Data from various systems*

Assumptions

- The design model is intended to be technology independent.
- Assumes a high degree of functional and technical standardization
  - *ATCA assumed for FE architecture*
  - *COTS – no fabrication of controls equipment*
- Functional and technical requirements will be placed on the technical systems
  - *limited options for communication interfaces.*
- Greenfield Site to support 2000 users
  - *Manpower Based on Level of Effort at Fermilab*
- Total Cost independent of Site Location
- Equipment Replacement needed over Seven Years

Functional Model

Client Tier

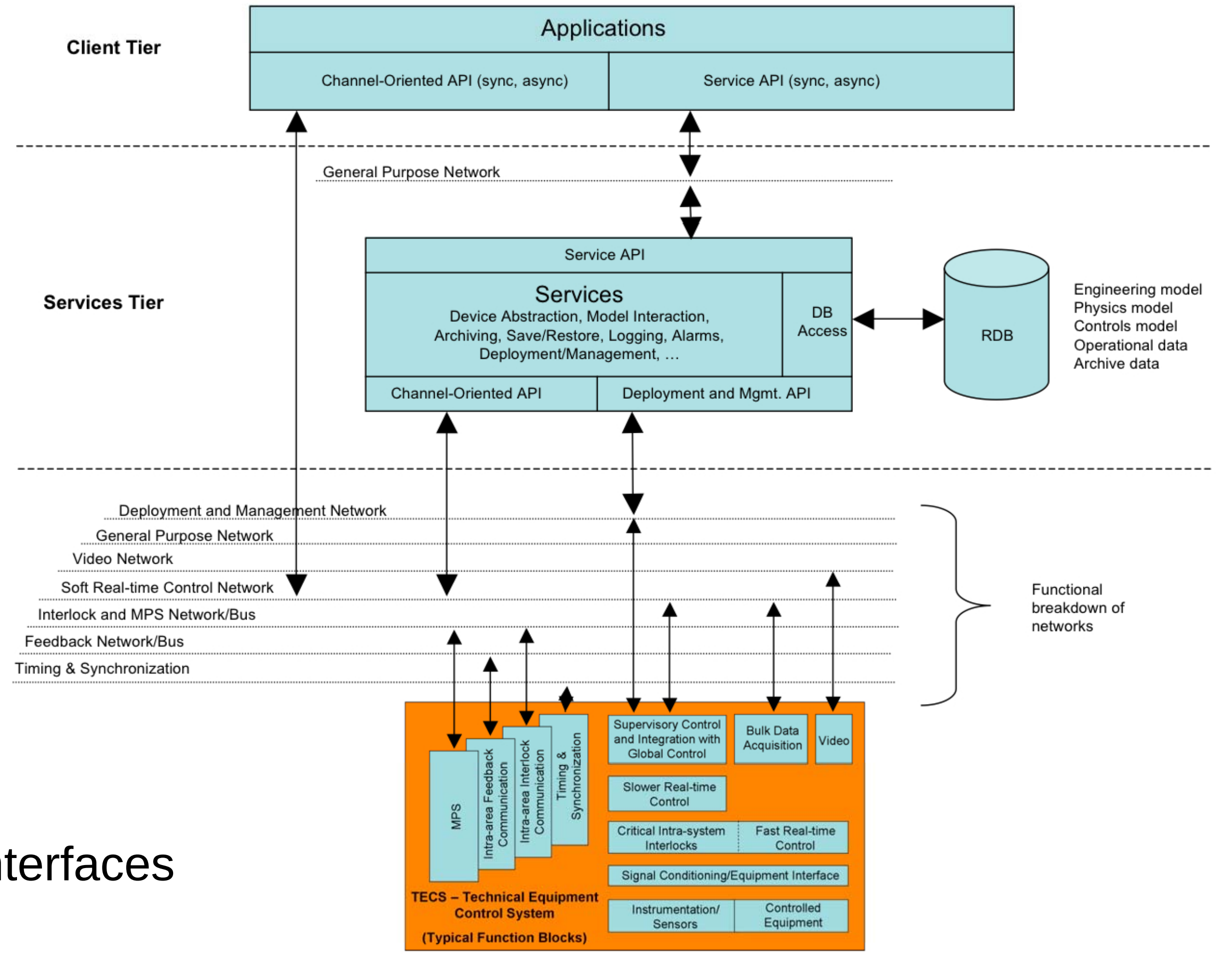
- GUIs
- Scripting

Services Tier

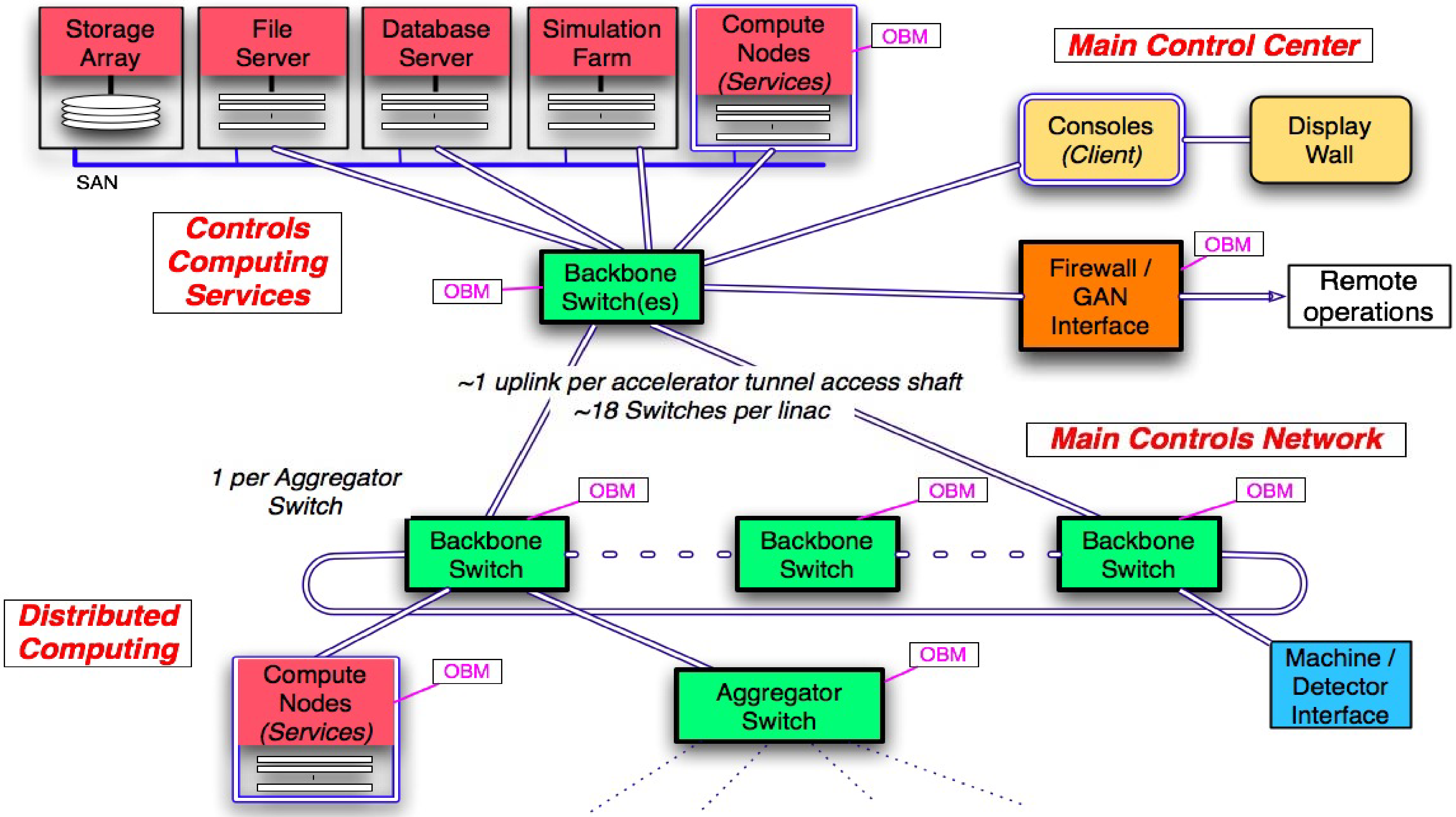
- “Business Logic”
- Device abstraction
- Feedback engine
- State machines
- Online models
- …

Front-End Tier

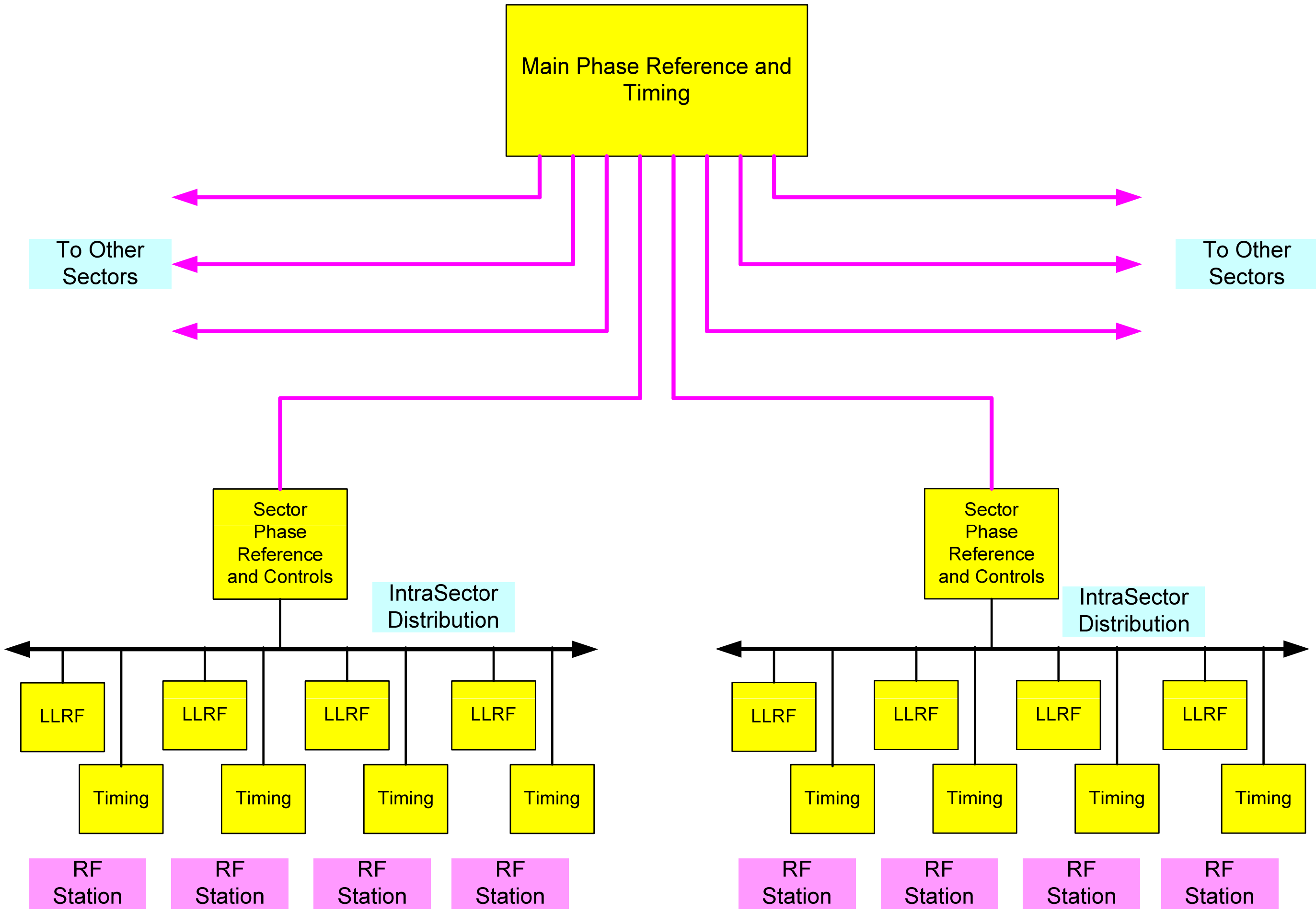
- Technical Systems Interfaces
- Control-point level



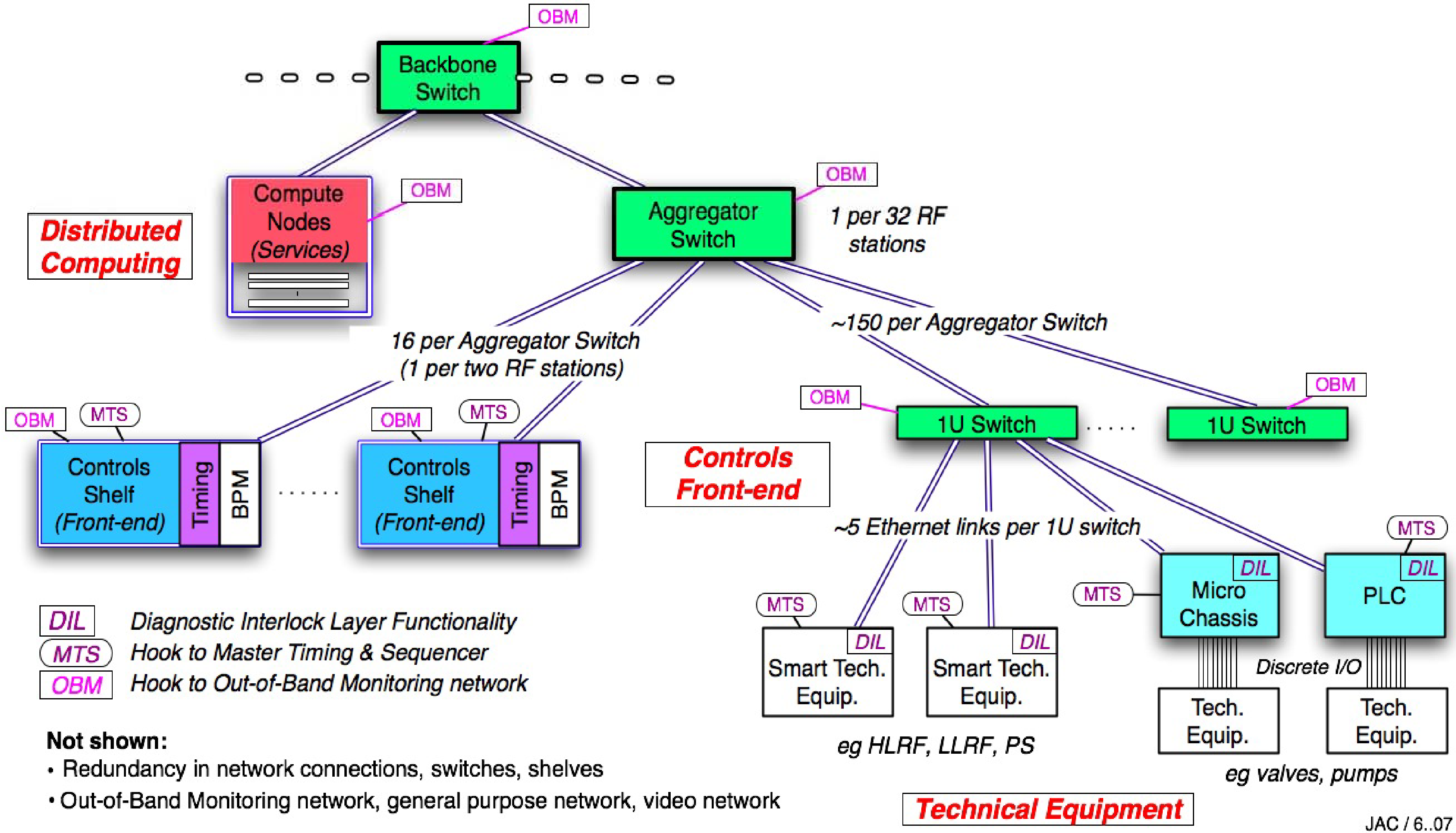
Physical Model (global layer)



Timing System Overview



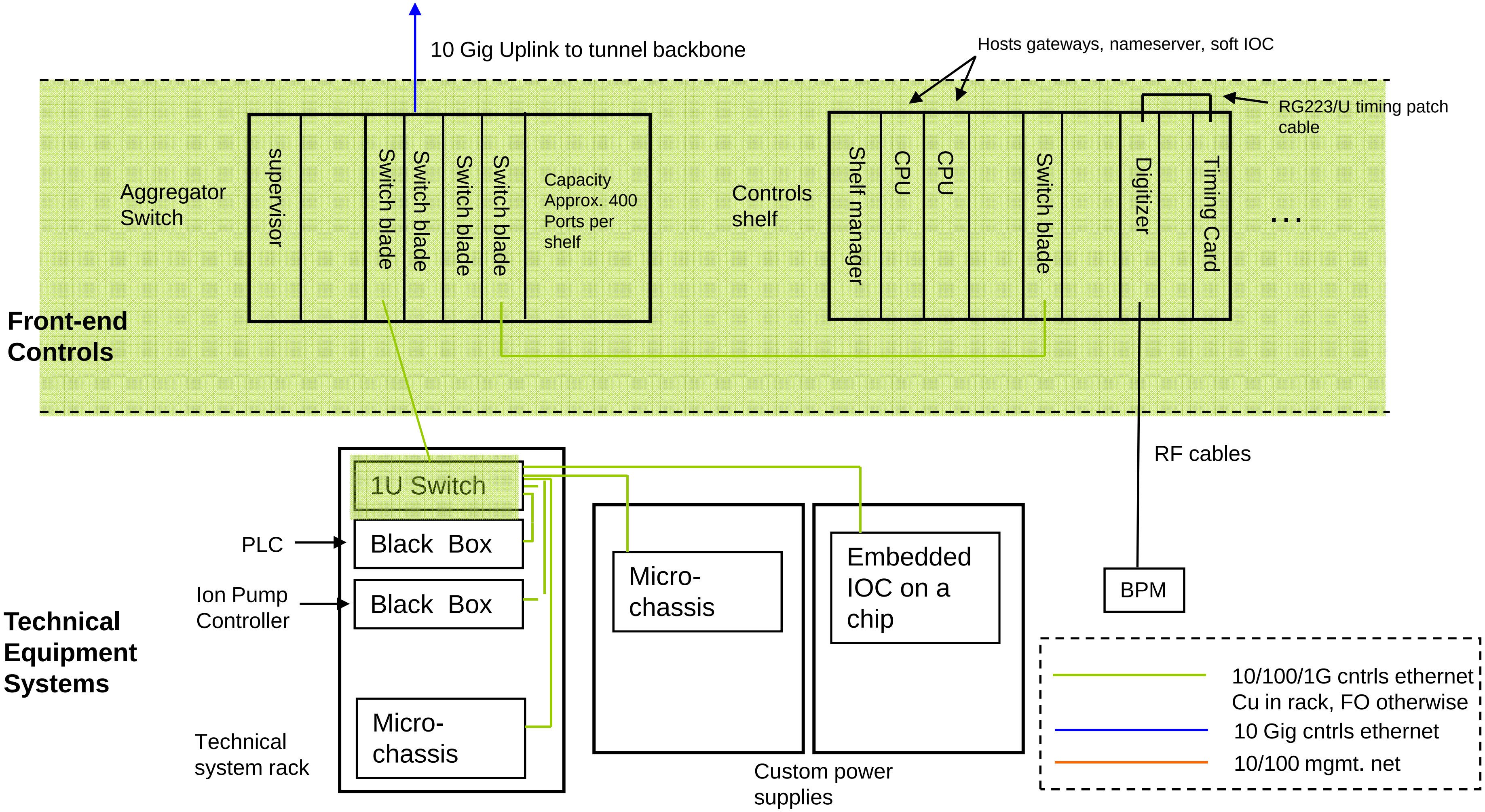
Physical Model (front-end field I/O)



Not shown:

- Redundancy in network connections, switches, shelves
- Out-of-Band Monitoring network, general purpose network, video network

Front-end model



Microsoft Excel - ControlSystem_RDR_Costing_MasterSpreadsheet_25June06.xls

A	B	Risk %	Risk Multiplier
Technical Risk Factors			
	Concept only	15	
	Conceptual Design Phase: some drawings; many sketches	8	
	Preliminary Design > 50 % complete; some analysis complete	4	
	Detailed Design > 50% Done	0	
	No technical issues	0	
Design Risk Factors			
	New design- well beyond current state-of-the-art	15	
	New design- of new technology advances state-of-the-art	10	
	New design- requires some R&D but does not advance the state-of-the-art	8	
	New design- different from established designs or existing technology	6	
	New design- nothing exotic	4	
	Extensive modifications to an existing design	3	
	Minor modifications to an existing design	2	
	Existing design and off-the-shelf hardware	1	
Multipliers	Pushes state of the art in design		2
	Pushes state of the art in manufacture		2
	Both		4
	Neither		1
Cost Risk Factors			
	Engineering judgment	15	
	Top-down estimate from analogous programs	10	
	In-house estimate for item with minimal experience and minimal in-house capability	8	
	In-house estimate for item with minimal experience but related to existing capabilities	6	
	In-house estimate based on previous similar experience	4	
	Vendor quote (or industrial study) with some design sketches	3	
	Vendor quote (or industrial study) with established drawings	2	
	Off-the-shelf or catalog item	1	
Multipliers	Material cost estimate in question		1
	Labor estimate in question		1
	Both		2
Schedule Risk Factors			
	Delays completion of critical path subsystem item	8	
	Delays completion of non-critical path subsystem item	4	
	No schedule impact on any other item	2	

Scope of Global Control System Engineering

- Manpower estimates for all Control System Tasks
  - *Project Management and Administration*
  - *Integration and Testing*
  - *Hardware Design and Testing*
  - *Software Design, Implementation & Testing*
  - *Does NOT include LLRF Engineering*
- M&S for Travel and Misc. expenses

Assumptions

- The Controls System is derived from an existing Framework
- Applications Engineers are assigned to each Technical Area
- No Overhead for managing a globally distributed controls effort

Manpower Counts

Management and Administration	38
Integration and Testing	74
Electronic Engineering	46
Technical Support	98
Control System Global Software	76
Controls Computing	55
Technical Systems Applications	160
Total	547 Person Yrs

Assessment of CS Engineering

- The Control System Design is not complete
- The Project Organization influences overall manpower levels
- These levels were informally reviewed by Controls Managers at other facilities
- Qualitative comparisons with other large facilities (SNS, LHC, NLC, NIF etc.) were useful
- Technical Risk: Medium
  - *Team assembled to do the work is experienced in similar work*

Scope of Global CS Equipment

- CS Computing and Network Infrastructure
- Archival storage
- Local Analysis Farm
- Controls Contribution to Simulation Farm
- One Local Control Center
- Hardware and Software Purchases to Run the facility for seven years

Assumptions

- Only Commercial Off the Shelf Components are used
- Doubling of price/capacity in disk and tape storage is assumed in 4 years (doubling again in 8 years)
- Purchasing 75% of storage in the last 2 years
- Network back bone is 10 Gbps
- Based on existing COTS equipment and vendor roadmaps

Global System Counts

Server Blades		
Archiving/Feedback		140
Monitoring/Diagnostics		88
Central Processing		100
Data Archiving		
Robot		1
Drives		32
Tapes	4 PB	
Disk Cache	1PB	
Other		
Database Machine	Server Class	1
Database Disk	300 TB	
Consoles		50
UPS		4

Assessment of CS Equipment

- Detailed bottoms up understanding of the amount of data is not available now
- Network requirements may not fit within the 10 Gbps assumption
- Technical Risk: Medium
  - *Teams assembled are experienced in similar work*
  - *Based on exiting COTS hardware*

Scope of RF Phase & Timing Distribution

- Master Oscillator
- 5 Hz Fiducial Generation
- Phase Reference Distribution System
- Central Event Generation & Distribution
- Local Timing Trigger Modules & Event Receivers
- Timing modules for Laser Wires, LOLAs, & BDS pulsed magnets and Synchrotron injection/extraction
- Timing and Phase Reference Generation for BCs, Synchrotrons & Electron Source Laser

Assumptions

- Centrally Located Dual Redundant Timing Source
- Distributed via Redundant Fiber to all machine sector nodes
- Timing is Phase-locked to the RF system

Assessment

- Based on Experience gained at SNS and APS
- R&D is required to refine the design
- Many module designs are only conceptual
- Technical Risk:
  - *Phase Reference*
    - Pushes the State-of-the-Art in Design
    - Advances the State-of-the-Art in Technology
  - *Timing*
    - Requires some R&D

Scope of Protection Systems Equipment

- Machine Protection System (MPS)
  - *Beam Loss Monitors*
  - *Beam Abort Systems*
  - *Includes Control and Logic electronics (not sensors, actuators or beam dumps)*
- Beam Containment System (BCS)
  - *Duplicate of MPS to minimize personnel radiation exposure*
- Personnel Protection System (PPS)
  - *Access Control*
    - Door & Gate switches
    - Electronic Control Logic
    - Control and Status panels
  - *Does NOT include*
    - Shielding
    - Gates, beam dumps, etc.

Assumptions

- No design exists for these systems
- Assuming a number of electronics modules per RF station
- PPS based on existing systems using COTS equipment

Assessment

- These Systems are straight forward to Design
- Technical Risk: Low
  - *There is a high level of experience in designing and implementing these systems*

Scope of the Front End Control System Equipment

- Includes controls equipment between technical equipment systems and in-tunnel backbone networking switches.
- Does not include LLRF
  - *Exception: does include LLRF motor controllers…*
- Fundamental function is to “normalize” the many disparate types of equipment and communication protocols into a single control point namespace, carried by a single standard protocol.
- Must enable High Availability, and remote diagnosis and repair
- Must interface to a variety of technical systems

Assumptions

Control of devices accounted for in 1 of 3 ways:

1. *All instrumentation system cards will occupy controls slots.*
   - One exception: cavity bpm digitizers in main linac occupy LLRF slots instead
2. *Most other devices will provide 2 ethernet ports for control.*
3. *10% of all devices will fit neither category and will be run using discrete I/O supplied by a controls micro-chassis.*

Controls Cabling

- All network cabling is redundant
- Some devices require timing signals distributed by a generic timing receiver card (ex. Instrumentation digitizers)
- Intra-rack network cabling is copper, Inter-rack network cabling is multimode fiber-optic. Local timing distribution is RG223/U patch cables.
- Some cable types pre-terminated, others have termination labor accounted for.

Assumptions

- Standard controls shelf contains:
  - *Redundant power supplies*
  - *Shelf manager*
  - *2 CPU's*
  - *2 Switch cards*
  - *Timing receiver*
  - *9 payload slots after above populated*
- Not all shelves, racks, switches will be 100% utilized
  - *A utilization factor applied based on geographic distribution of equipment in given area system*
- 2 other systems are estimated elsewhere but rolled up as a front-end controls cost
  1. *Motor controllers for LLRF in Linac*
  2. *Cryo controls*

Controls Front End Equipment and Device Counts

Controls equipment required…

Components	e- source	e+ source	DR	RTML	Linac	BDS
CPU Card Total	150	248	546	430	650	366
Payload Card Total	445	892	1,962	1,546	1,461	1,317
1U Switch Total	67	831	1,346	708	4,453	951
Switch Blade Total	4	18	29	15	93	20
Telecom Shelf Total	3	4	8	3	36	17
Controls Shelf Total	75	124	273	215	325	183
Rack Total	39	64	141	109	181	100
Cables						
Cat 5E	400	4,982	8,072	4,244	26,713	5702
RG223/U	240	911	3,037	1,600	1,940	1332
Fiber Optic	268	3,324	5,384	2,832	17,812	3804

for control of …

these Area System devices (note: LLRF motor-controllers and cryo not listed here)

ILC Technical Equipment Totals by Category and Area System							
	Area System						
TECS Category	BDS	DR	e-	Linac	e+	RTML	
							Total By Category
Power Supply	654	3866	171	3722	2267	1442	12122
Instrumentation	744	1580	165	2024	749	1418	6680
Vacuum	1787	464	20	6733	219	632	9855
Motor System	234	0	0	0	0	0	234
Feedback system	14	4	5	20	10	4	57
							0
Other	176	0	4	1215	4	48	1447
Total By Area	3609	5914	365	13714	3249	3544	
Total	30395						

Assessment

- Bottoms-up approach worked reasonably well overall, with some challenges:
  - *Negotiated boundary between controls and area system equipment changed over time, and has some special cases*
  - *Ownership of device counts was spread around, making aggregation difficult*
  - *Staying synchronized with area systems difficult, especially given evolving design*
  - *Names and categories for devices varied from area system to area system*
  - *Some very complex devices are counted as 1 device*

Linac Device Counts

Component Type		Total	
Q Magnet	PS	1394	
Corrector Magnet	PS	2324	
Radiation Detector		1686	
Cavity BPM		562	
Machine Protection		562	
Ion Pump		6372	
Vacuum Valve		305.46	
Iso Vac Pump Station		56.2	
Laserwire		12	
Power/Air/Water		597	
Cavity BPM		800	
BLM		650	
Feedback - special		20	
Abort Kicker	PS	2	
pulsed bend	PS	2	
Raster Deflectors	PS	4	
adjustable collimator		18	
fixed ap. collimator		26	
beam dump		2	
PPS stopper		6	

RTML Device Counts

Component Type		Total
Small NC Magnet	PS	750
Large NC Magnet	PS	472
Giant NC Magnet	PS	52
Small SC Magnet	PS	84
Large SC Magnet	PS	56
Giant SC Magnet	PS	4
Feedforward Correctors	PS	8
Abort Kicker	PS	4
pulsed bend	PS	4
Raster Deflectors	PS	8
CM Cavity BPM		56
RT Cavity BPM		496
laserwire		16
wirescanner		0
profile monitor		12
beam phase monitor		6
bunch length monitor		4
adjustable collimator		18
fixed ap. collimator		26
beam dump		4
tune up stopper		0
PPS stopper		0
BLM		800
ion pump		610
vacuum valve		22
Optical monitor		24
LOLA monitor		4
Feedback - special		4

DR Device Counts

Component Type		Total
B Magnet (chained)	Main PS	32
B Magnet (individual)	PS	0
Q Magnet	Main PS	2
	Shunt PS	1646
Q Magnet	PS	0
Skew Q Magnet	PS	0
S Magnet	PS	1008
O Magnet	PS	0
Corrector magnet	PS	900
Septum	PS	8
Stripline Kicker	PS	120
Wiggler	PS	160
	Cryo	160
Magnet mover		0
		0
Cavity BPM (warm)		0
Cavity BPM (cold)		0
Button BPM		1494
LOLA monitor		0
Laserwire		2
BLM		80
Wirescanner		0
Beam current monitor		2
Optical monitor		2
Spectrometer		0
Polarimeter		0
Feedback - special		4
		0
		0
		0
Ion Pump		464

E+ Source Device Counts

Component Type		Total
Quad		206
Sextupole		16
Profile Monitor		0
SC Helical Undulator		1
Drive Laser		1
Bakeout Pump		1
Vacuum Valve		16
RGA		1
Ammeter		1
Ion Pump		200
Neg Pump		1
Dipole		152
Corrector		930
Solenoid		28
Pulsed Magnet		21
Polarimeter		1
Button BPM		309
Wirescanner		8
Bunch Length Monitor		2
Beam Dump		2
Laserwire		2
Feedback - special		10
BLM		400
LOLA monitor		4
Optical monitor		14
Beam current monitor		8
Quadrupole		885
Sextupole		28

E- Source Device Counts

Component Type		Total
Drive Laser		2
Bakeout Pump		2
Vacuum Valve		6
RGA		2
Ammeter		2
Ion Pump		8
Neg Pump		2
Dipole		25
Corrector		26
Solenoid		14
Polarimeter		2
Button BPM		69
Wirescanner		12
Bunch Length Monitor		5
Beam Dump		3
Laserwire		8
Optical monitor		6
LOLA monitor		3
BLM		60
Feedback - special		5
Quadrupole		106
Sextupole		0

BDS Device Counts

Component Type		Total
B Magnet (chained)	Main PS	0
B Magnet (individual)	PS	190
Q Magnet	Main PS	0
	Shunt PS	0
Q Magnet	PS	236
Skew Q Magnet	PS	0
S Magnet	PS	22
O Magnet	PS	14
Corrector magnet	PS	100
Septum	PS	0
Stripline Kicker	PS	92
Wiggler	PS	0
	Cryo	0
Magnet Mover		234
Cavity BPM (warm)		454
Cavity BPM (cold)		0
Button BPM		0
LOLA monitor		4
Laserwire		16
BLM		220
Wirescanner		0
Beam current monitor		16
Optical monitor		22
Spectrometer		8
Polarimeter		4
Feedback - special		14
Beam Dump		8
Muon spoiler		8
Ion Pump		1787
Collimator		160

Scope of Controls/LLRF Relay Rack Assembly & Test

- Engineering and Technical Manpower
- Test Setups & Test Equipment
- Operation and Maintenance of Test Systems

Assumptions

- The Relay Racks will be assembled and tested before installation
- All Crates, modules and cards are manufactured externally
- Assembly Group is self-contained including Engineering, Quality Assurance, and Testing
- Size of an assembly group is based on a build rate of 15 RR/wk over 4 years

Assessment

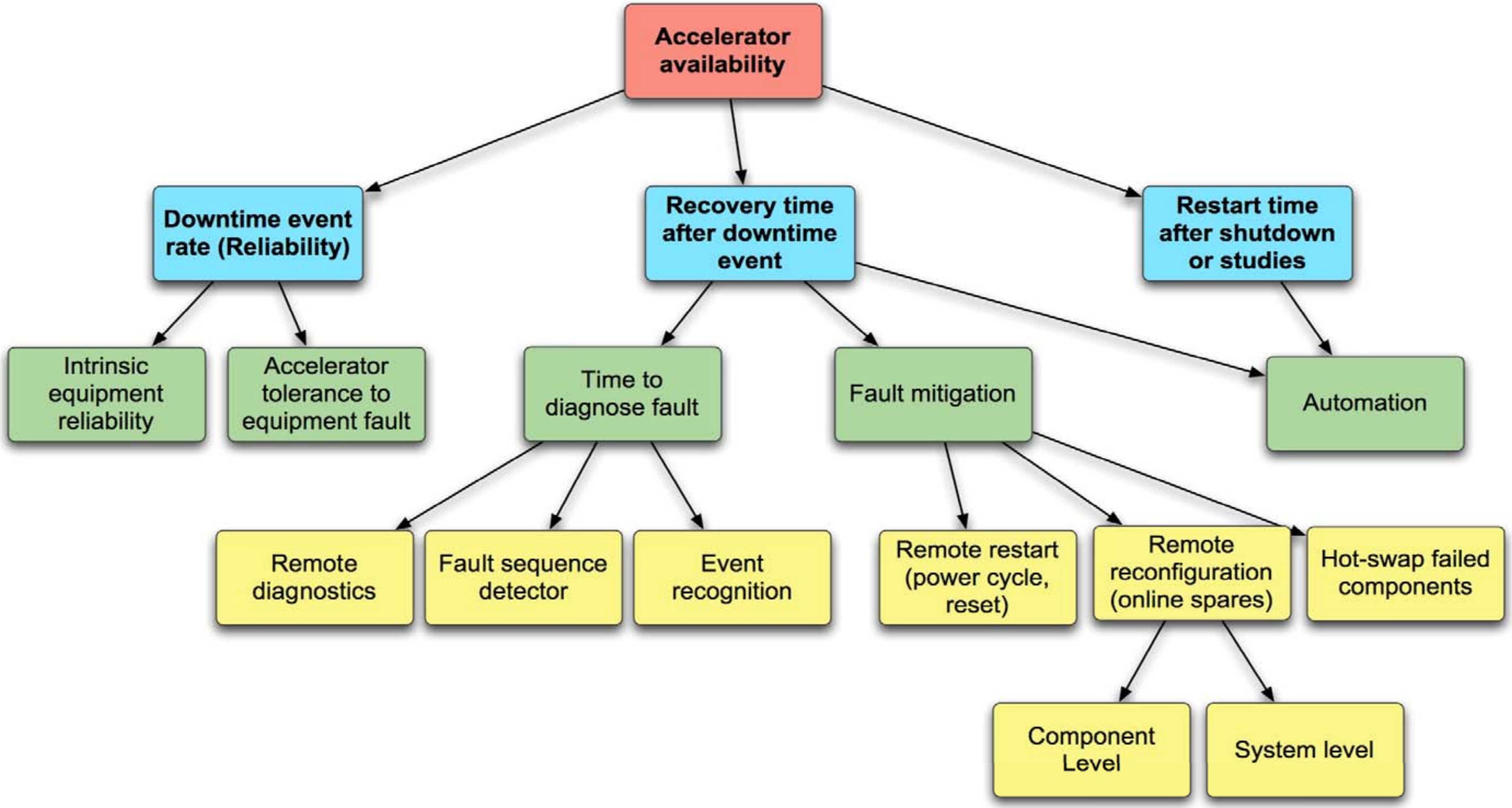
- Total number of RRs and Complexity is not known
- Testing before installation should save time and improve overall quality of the Control System
- Risk: Minimal

Reconciling RDR and BCD

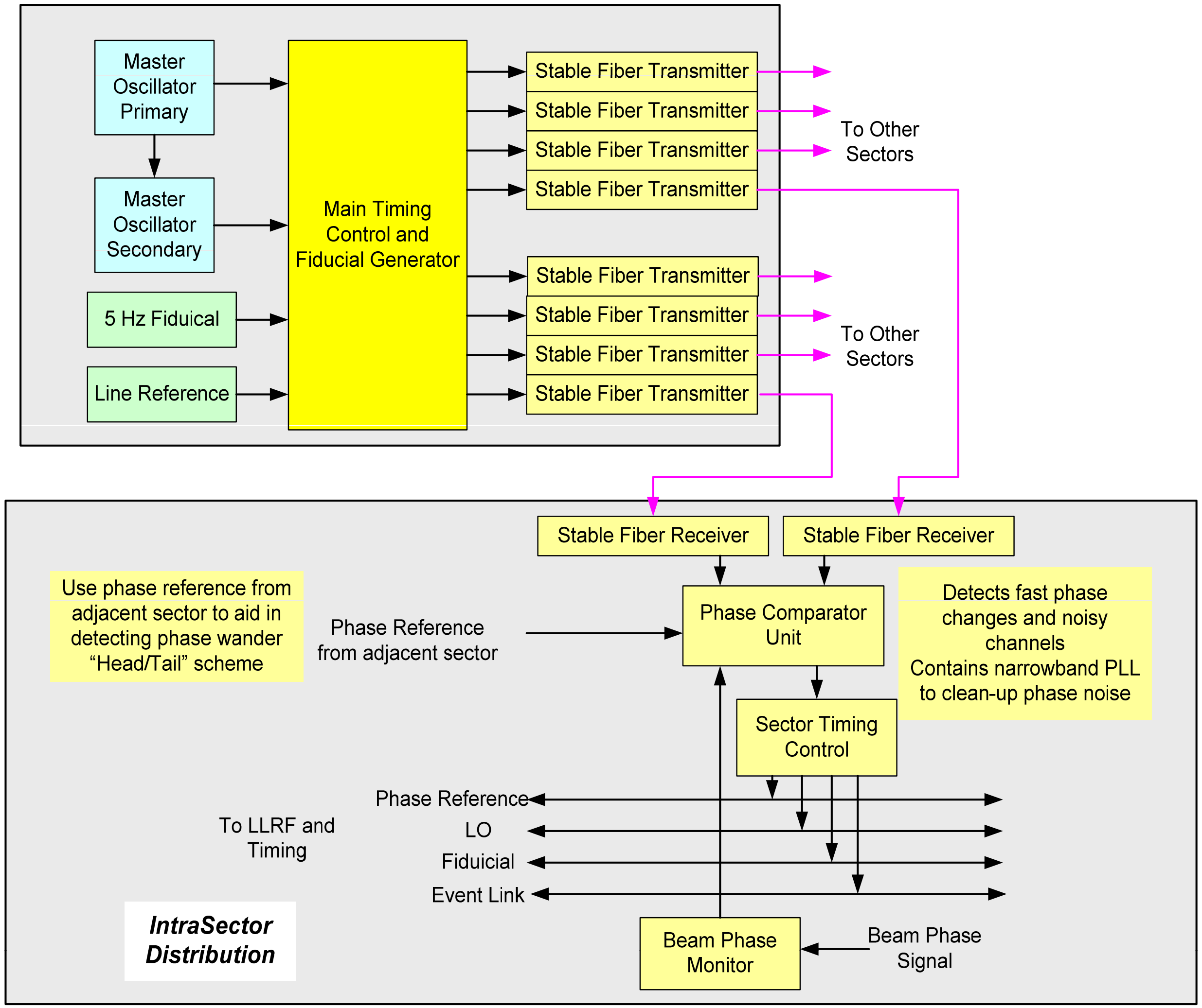
- Differences between RDR and BCD
  - *ATCA is identified as an alternative configuration in the BCD*
  - *The ATCA configuration in the BCD includes robotic equipment replacement not in the RDR*

EXTRA SLIDES

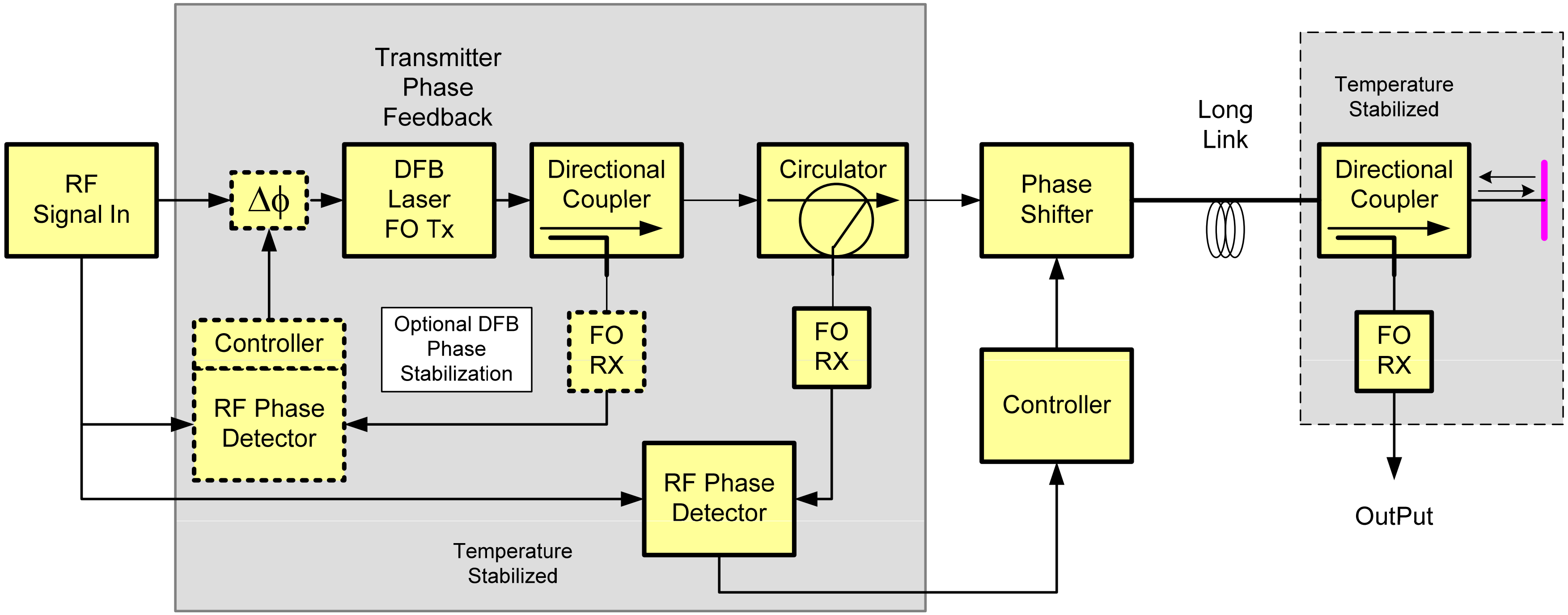
Availability Considerations



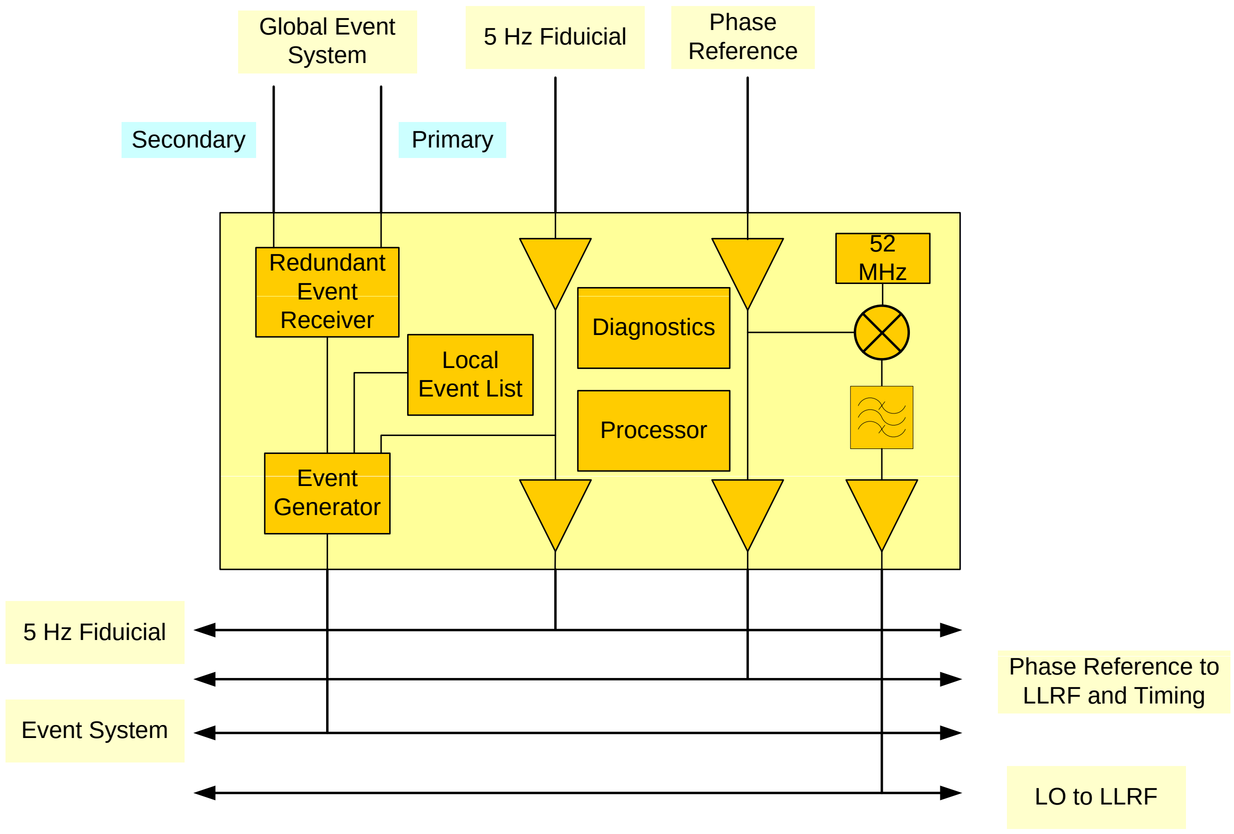
Timing & RF Phase Reference



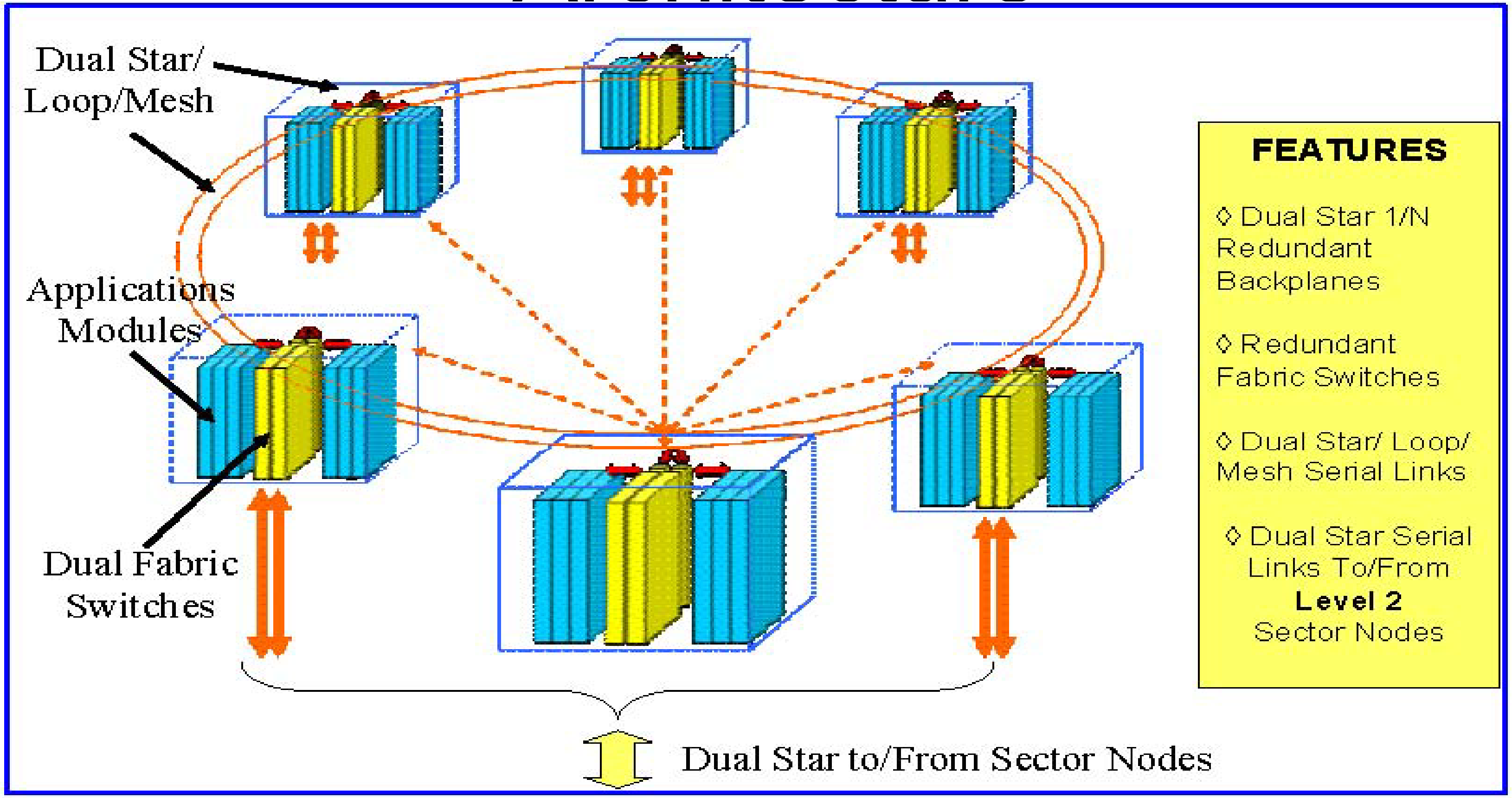
Phased Stabilized Reference Link



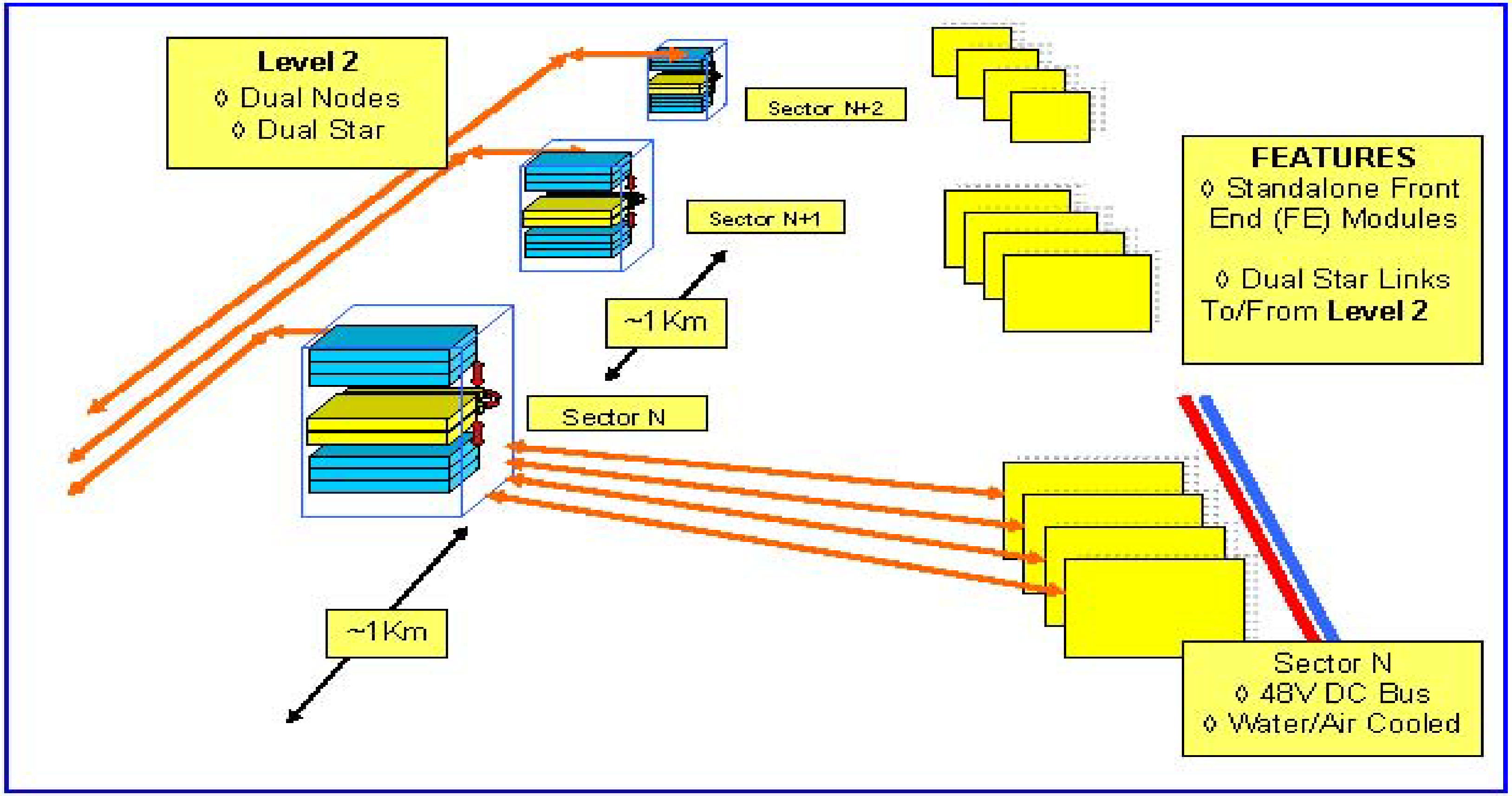
Sector Timing Control Unit



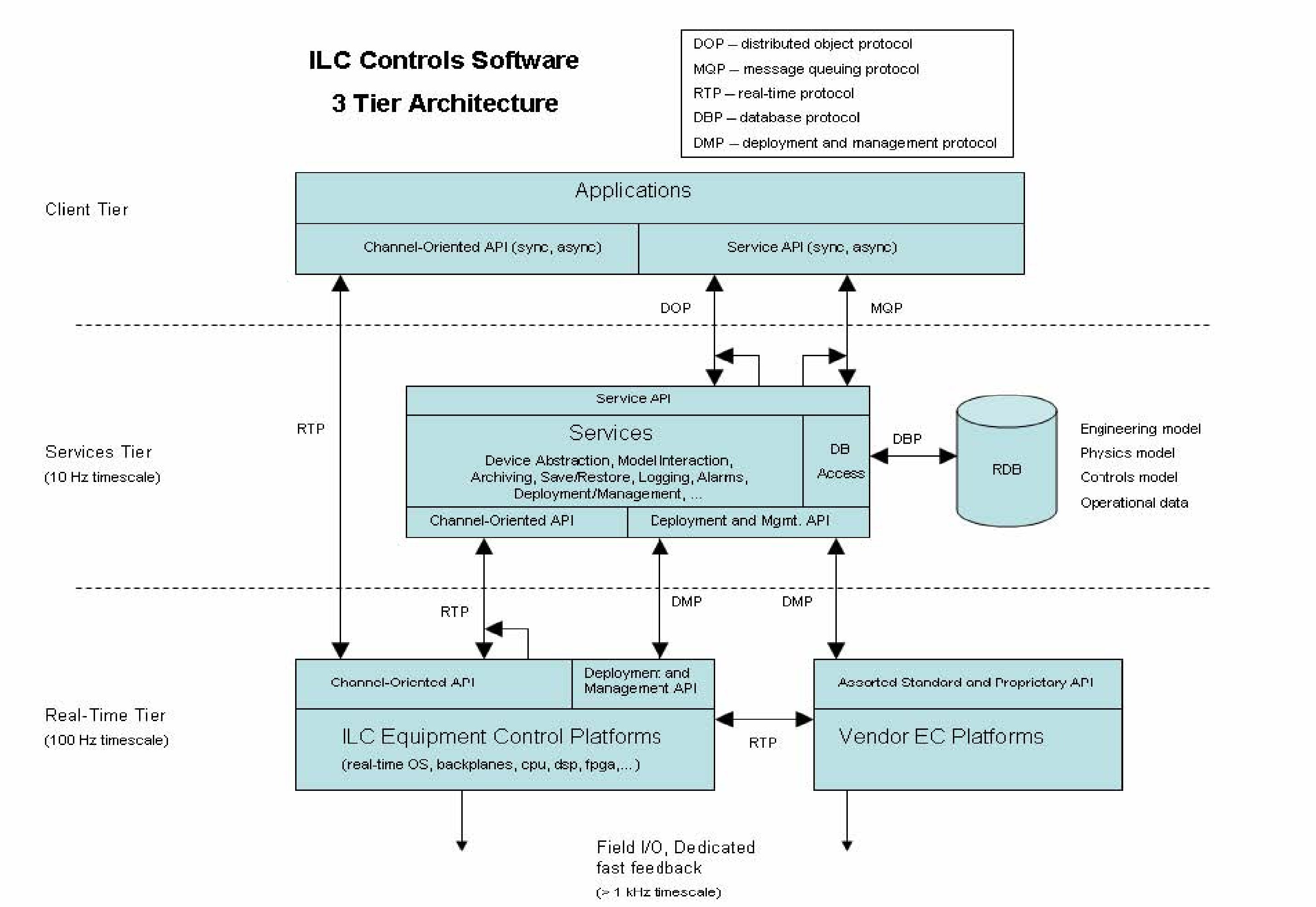
BCD Control Room Cluster Architecture



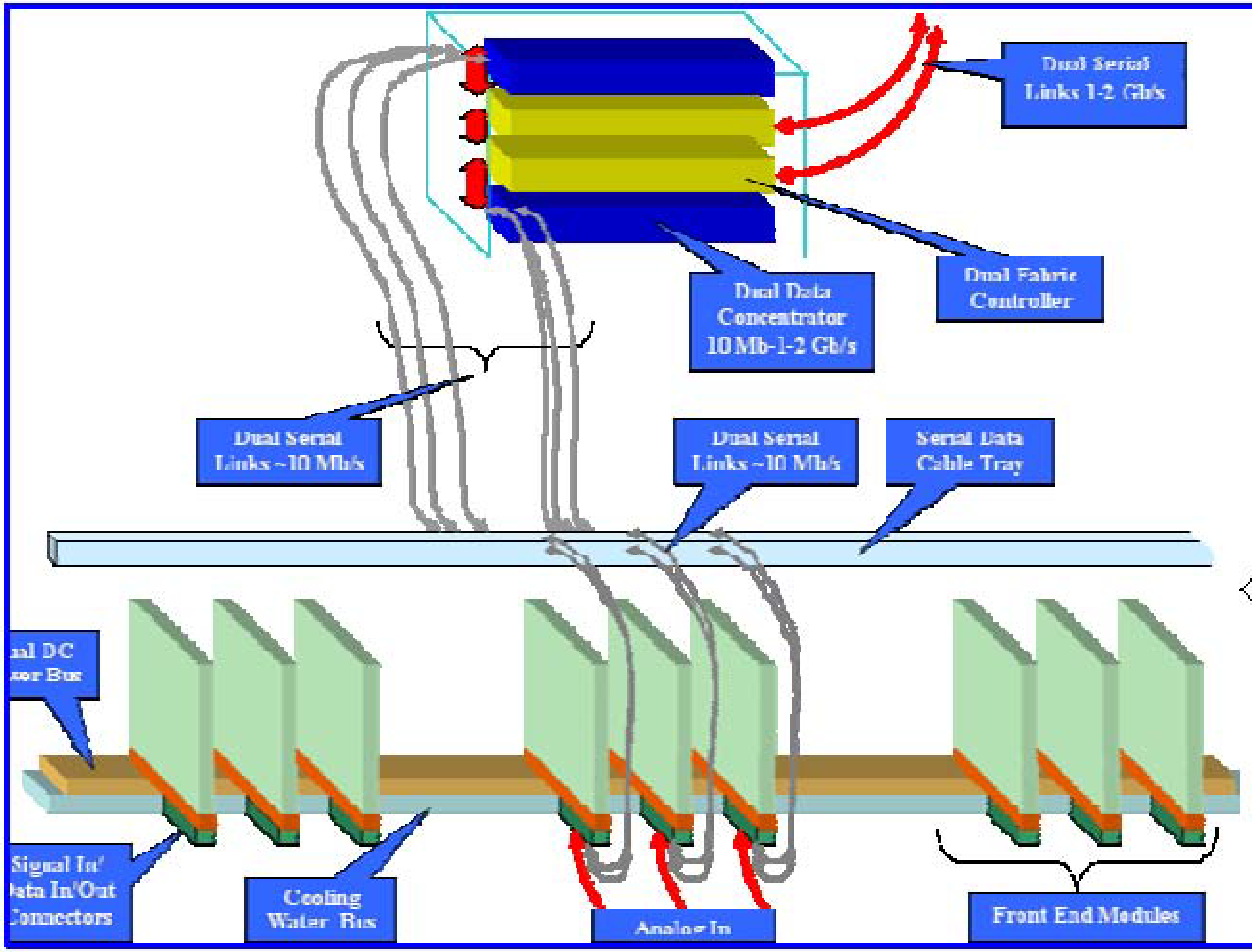
BCD Sector Node Processors & FEs



BCD Software Architecture



BCD Alternative Configuration



- ATCA Style Modules
- Stand-Alone or Cluster
- Dual Redundant Serial I/O, Power
- Robotic Replaceable