High Availability Electronics Standards

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ILC R&D Project

Stanford Linear Accelerator Center

LECC September 25 2006

Outline

- ## Introduction
  - ILC Motivation for High Availability (HA) Design
- ## New Industry HA Standard Systems
  - Potential Accelerator & Detector Applications
- ## ILC HA Electronics R&D Initiatives
  - Controls & Instrumentation Standards, Diagnostics Layer, Magnet & RF Power
- ## Summary & Acknowledgments

Introduction
ILC Motivation for
High Availability (HA)
Design

Introduction
ILC Project Status

- R&D programs nearing end of 2nd decade!
- Technology choice made 2004 for Cold RF
- Global organization Asia, Americas, Europe Regions
- Regional R&D programs began coordination 2005
- Electronics, other Technical Systems groups formed to develop Costs, R&D programs for machine Areas
- Highest R&D priority given to highest cost items: Superconducting cavities, RF and civil engineering
- First Draft Costs for all Baseline Conceptual Designs submitted for Vancouver July 06 GDE meeting
- *∗∗Full cost estimate and Reference Design Report (RDR) to be completed end 2006 ∗∗*

Introduction
Controls & Instrumentation (C&I) Status

- C&I slowly being addressed since cost estimate is "only" ~5% total ILC budget

- Top priority: R&D on RF technologies to prove feasibility of RF design. (Still have major performance, cost issues)

- Attitude: *"Controls is simple so let's wait"*.

- *BUT:* Due to size and complexity ILC demands systems that break much less often than current machines.

- Impact: New urgency to C&I, other electronics R&D.

- *Goals:*
  - *Develop HA designs for all electronics, machine system architectures.*
  - *Performance high, costs low.*

Introduction
Availability Challenge

- 1. Availability simulations show Accelerator performance with current systems (based on PEP + 2-Mile Linac experience, other machines) would result in ~20% availability for ILC. *(Ref. USLCTOS Report, March 2004, Ch. 4, Availability Subcommittee, T.M. Himel, Task Leader)*

  – Current PEP availability advertised at 85% BUT

    - Does not count "scheduled downtime", tuning, recovery from trips, machine development time downtimes for the detector
    - Linac injector system failures masked by "coasting beams"; Linac fails often even while working far below capacity

  – Actual uptime *for Detector* is much less. *It's integrated Luminosity vs. time that truly defines Availability.*

Introduction
Why Worse than LHC?

1. ILC a "One-Shot" machine
2. Every component must function perfectly on every pulse for sustained beam-beam collisions at design luminosity
3. No stored beams to buffer source or Damping Ring interrupts as in stored beam machines; single failures mean instant beam loss
4. Loss of a single Main Linac quad degrades performance; simultaneous loss of two destroys collisions
5. Colliding micron-sized beams demand unprecedented beam emittance, steering and focus control
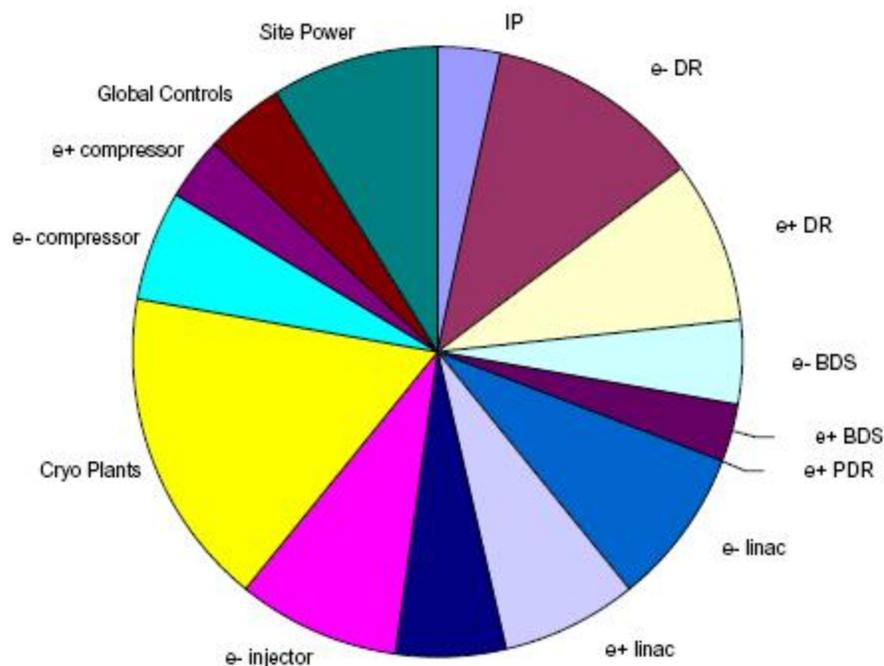
Introduction
Availability Simulations

- Tom Himel developed simulator *Availism* for ILC; benchmarked on some real machines.
- Conclusion: Using historic design approaches of 3 km SLAC linac, ILC uptime will be *less than 20%.*
- Himel calculated required MTBF improvement needed for key components to achieve 85% up-time (A=0.85).
- "ILC is 10X larger and will be 10X worse. In other words it won't work".
- *Subsystem MTBF Improvement Factors of 3-50 times are required.*
- http://www.slac.stanford.edu/~tmh/availalbility/

Introduction
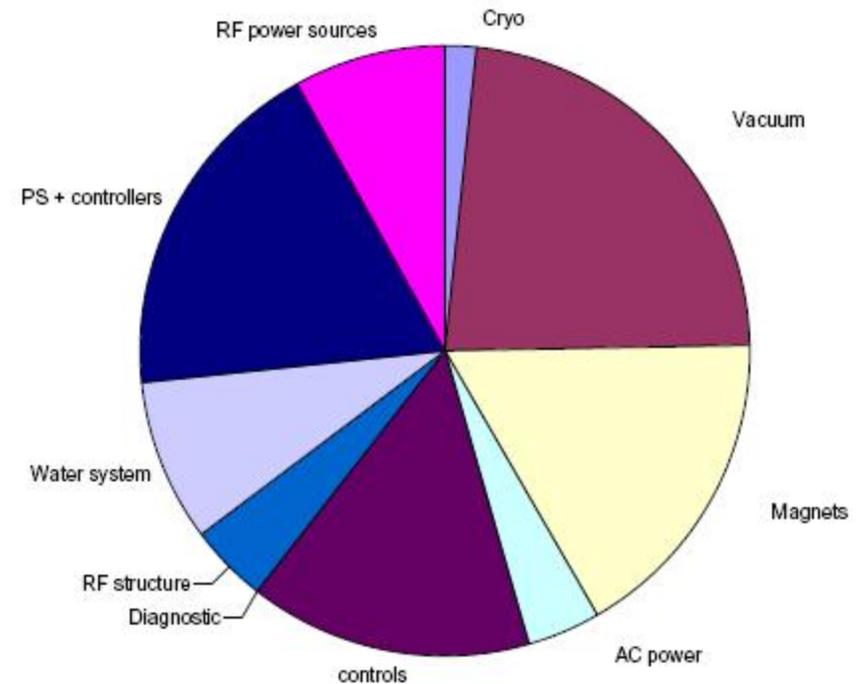# Cold 2-Tunnel Simulation A=0.85

Linac + DR Systems

Area Systems

Figure 4.4.1.2: Downtime summary for run Cold2 (2 tunnel, undulator e^+ source, version B MTBFs). The top chart divides it by region while the bottom chart divides the linac and DR downtimes by system.

Ref. USLCTOS Ch 4

Introduction
MTBF Improvement for A=0.85

Table 4.4.1.3: Version B MTBFs that were needed to get the Cold 2 tunnel LC with an undulator e^+ source to a budgeted downtime of 15%. Note that this level of detail has only been done for the linac and main damping rings. Note that for device = "energy overhead", the energy overhead was increased rather than make all the devices contributing to the energy more reliable. Also, for the sensitivity check in the last column, the energy overhead was decreased by 2%. The cost of increasing that energy overhead is directly estimated without the use of the power law formula. The cavity tuners and cavity piezo tuners designs both require opening the cryostat to effect repairs and had over 50 failures per year. This is an unreasonable amount of work even for the 3 month shutdown. The tuners will either have to be made very reliable (probably via redundancy) or their failure prone components made replaceable without warm-up. . The cost increase for the first 5 klystrons and related hardware assumes the RF power sources are made redundant with high power switches to select which source is used.

Device	Nominal MTBF (hours)	Factor improve-ment over nominal needed	Source of nominal MTBF	# of devices	Rough total cost for devices (% of total LC)	Very rough cost increase (% of total LC)	Increase in down time (%) if MTBF is 10 x worse
all water cooled magnets	1×10^6	10	SLAC SLC had 5×10^5 Fermilab main injector had 2×10^6	2800	1.4	.69	5.0
Large power supply controllers	1×10^5	40	SLAC SLC had 8×10^4	600	.10	.08	1.2
Large power supplies	2×10^5	10	Fermilab main injector had 6×10^4. TESLA design with redundant regulators estimated at 2×10^5	600	.13	.06	1.9
All electronics modules	1×10^5	3	Commonly used number for electronics modules	25000	.81	.18	3.8
Linac controls local backbone	1×10^5	9	Commonly used number for electronics modules	600	.05	.02	0.8
Vacuum valve controllers	1.9×10^5	5	SLAC SLC had 1.9×10^5 for valves + controllers. Most failures were the controllers	300	.05	.02	1.3
Flow switches	2.5×10^5	10	SLAC SLC had 2.2×10^5	1700	.03	.02	1.8
Water instrumentation	3×10^4	3	SLAC SLC had 3.5×10^4 Fermilab main injector had 5.6×10^4	330	.02	.003	1.2
AC power distribution - small	3.6×10^5	10	SLAC SLC had 3.6×10^5	700	.02	.008	1.1
first 5 klystrons and related hardware (should be done with redundancy)	varied	20		10		.08	0.4
Cavity tuner - see caption for details	1×10^4	50	SLAC SLC magnet movers had 5×10^5. Assume tuner is similar as it is a mechanical stepping motor	18000	.63	.63	0.1
Vacuum pumps on the insulating vacuum	1×10^5	6	guess	150	.03	.01	1.6
Linac energy overhead	2%	1%	Energy overhead increased from 2% to 3%			.32	5.0
Total cost						2.1	

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Introduction
Some *Availism* Results

- Lent strong support to need for 2nd (parallel service) tunnel

  – All active equipment accessible for repair while beams running

  – Minimal MTTR is as important as high MTBF

  $$[A=(MTBF-MTTR)/MTBF => 1 \text{ if } MTTR => 0]$$

- Quantified needed improvements in each subsystem

- Supported directions already underway for stronger electronics systems for ALL major subsystems
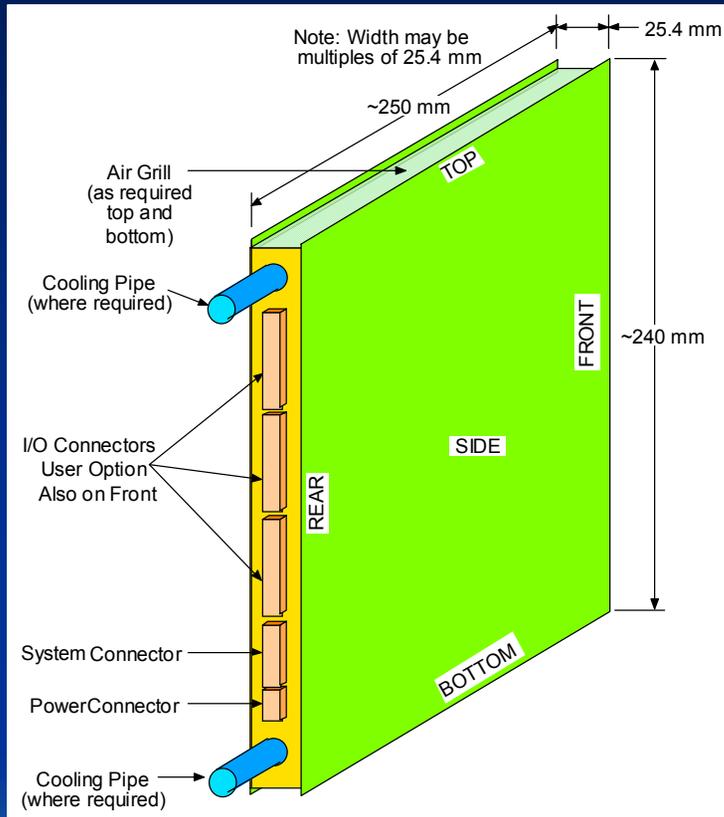
New Standards Modular HA Industry Systems

New Standards
What's Wrong with Present Systems?

- Legacy modular card standards with parallel backplanes obsolete as new systems for ILC
  - Not designed for HA
  - Dense crate clusters not ideal for 40 km machine – forces long cable plant vs. independent module close to pickup or actuator
  - Parallel bus structures pose single-point failure for many modules.
  - Since today parallel buses largely imbedded into "systems on a chip" parallel backplanes no longer optimum or necessary.
  - Imbedded serial gigabit communication now industry standard; wavelength division multiplexing on fiber also available, cheap.
- *Industry emphasis: Evolving Open Standard platforms integrating design of crates, cards, communications, power, cooling, intelligent diagnostics.*

New Standards
VSO Future Concept* Circa 2000

Note: Width may be multiples of 25.4 mm

25.4 mm

~250 mm

TOP

Air Grill (as required top and bottom)

Cooling Pipe (where required)

FRONT

~240 mm

I/O Connectors User Option Also on Front

REAR

SIDE

System Connector

PowerConnector

BOTTOM

Cooling Pipe (where required)

- All data connections 2.5-4.5 GHz Serial on Backplane
- No parallel data bus
- Front panel connections Optional
- Hot-Swappable
- Liquid cooling with airflow Grills top & bottom

*Slide from a talk on the future of instrument standards at the last NIM/ESONE meeting at NSS in Lyon, *Nov. 2000*

Courtesy VSO VME Standards Organization & R.W. Downing

Flexibility & Imbedded Intelligence
Potential Stand-Alone module: 48V in, Fiber in/out data & timing, Analog IO in rear for hot-swap. Could place anywhere along accelerator or in a crate-like cluster

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New Standards
2004: Introduction of ATCA*

- Telecom Industry Open Standard
- Driven by $10B/year server and switching market
- Crate (Shelf) system designed for "5-9's "
- A=0.99999 = Downtime of 5 min/year
- All Gigabit serial Dual Star or Mesh backplane
- Dual controllers, 48V PS, hot swappable,
- 200W/module air cooled, 3+1 Fans hot swappable
- Shelf Manager controls failover, power metering, hot swap
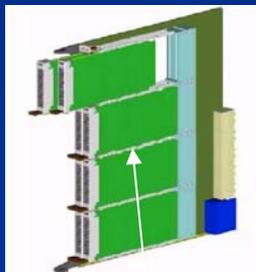
Mezzanine Cards – Hot Swappable
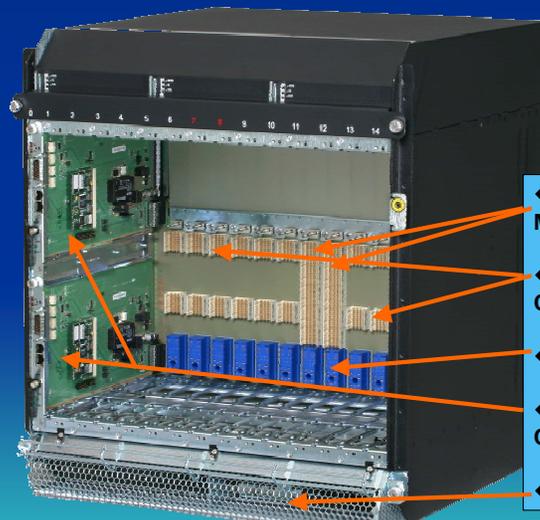
◆ **Dual Network Switch Module Locations**

◆ **Dual Star Fabric Connectors**

◆ **48V DC Power Plugs**

◆ **Redundant Shelf Manager Cards**

◆ **Fan area**

◆ Fan Rear Exhaust Area

◆ Shelf Manager Card Connection

◆ Fabric Cabling Area

◆ Fabric Interface Card Slots

◆ Power Converters

Advanced Telecom Computing Architecture

New Standards Applications to C&I
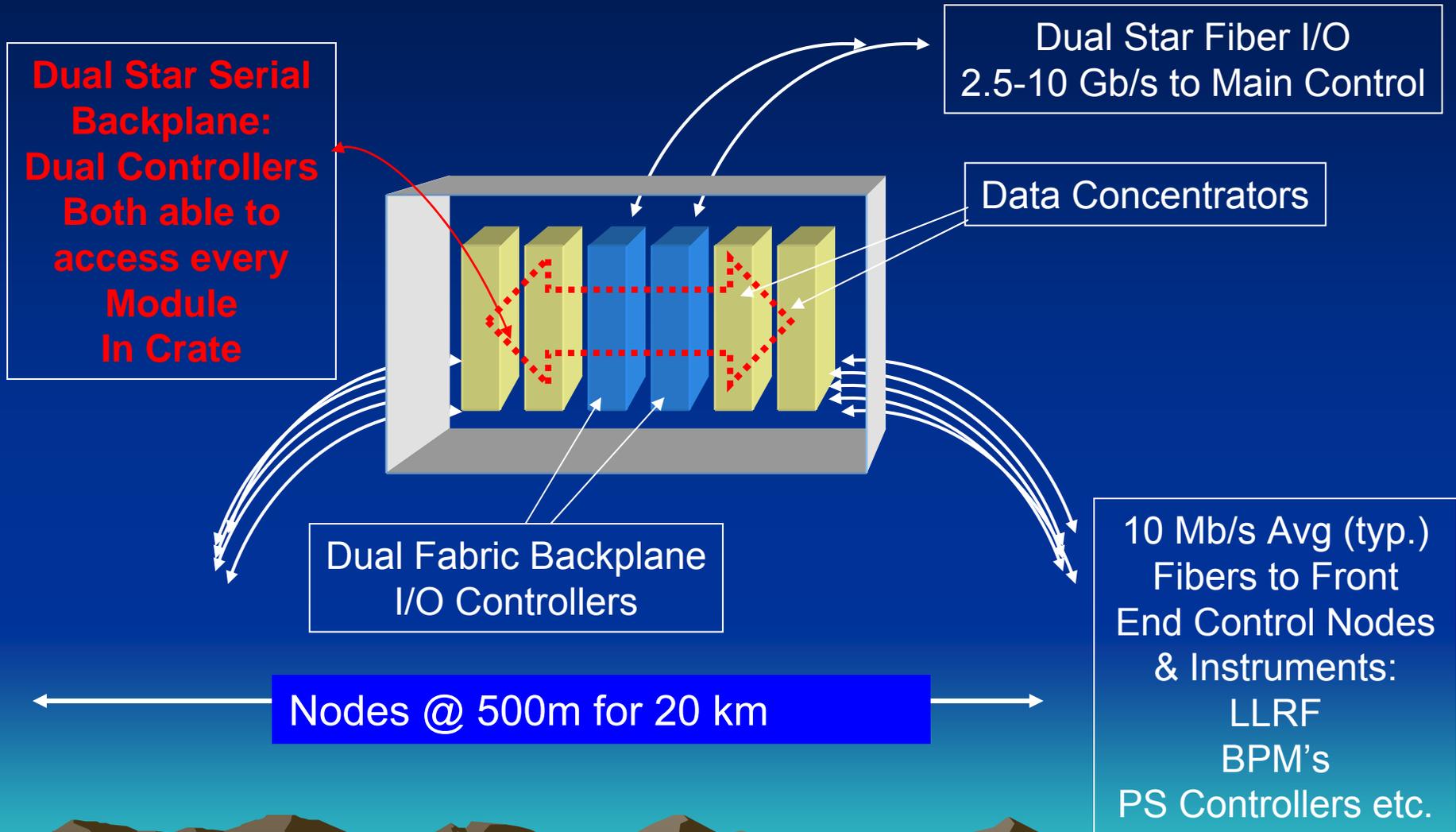
New Standards
Central Control System HA Farm
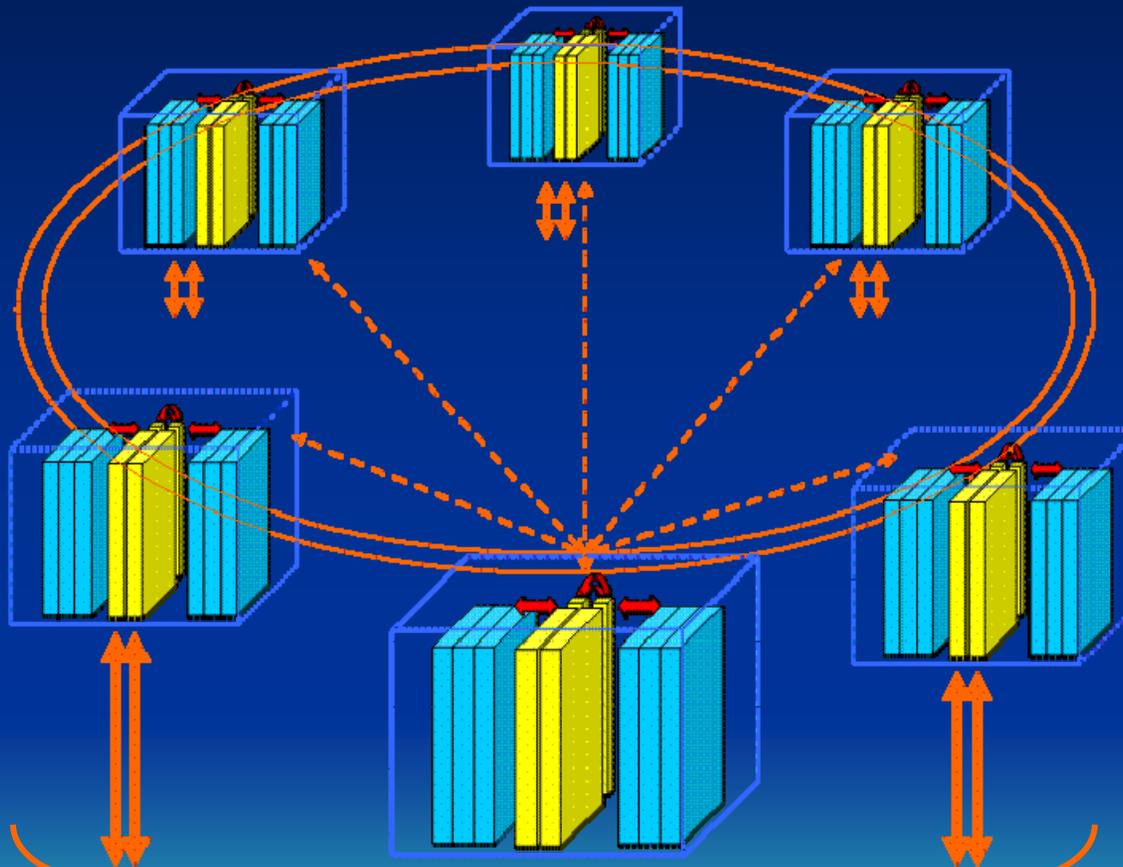
FEATURES

◊ Dual Star 1/N Redundant Backplanes

◊ Redundant Fabric Switches

◊ Dual Star/ Loop/ Mesh Serial Links

◊ Dual Star Serial Links To/From **Level 2** Sector Nodes

Dual Star Data + Timing & Phase References To Sector Nodes. Auto-Failover Hwe/Swe

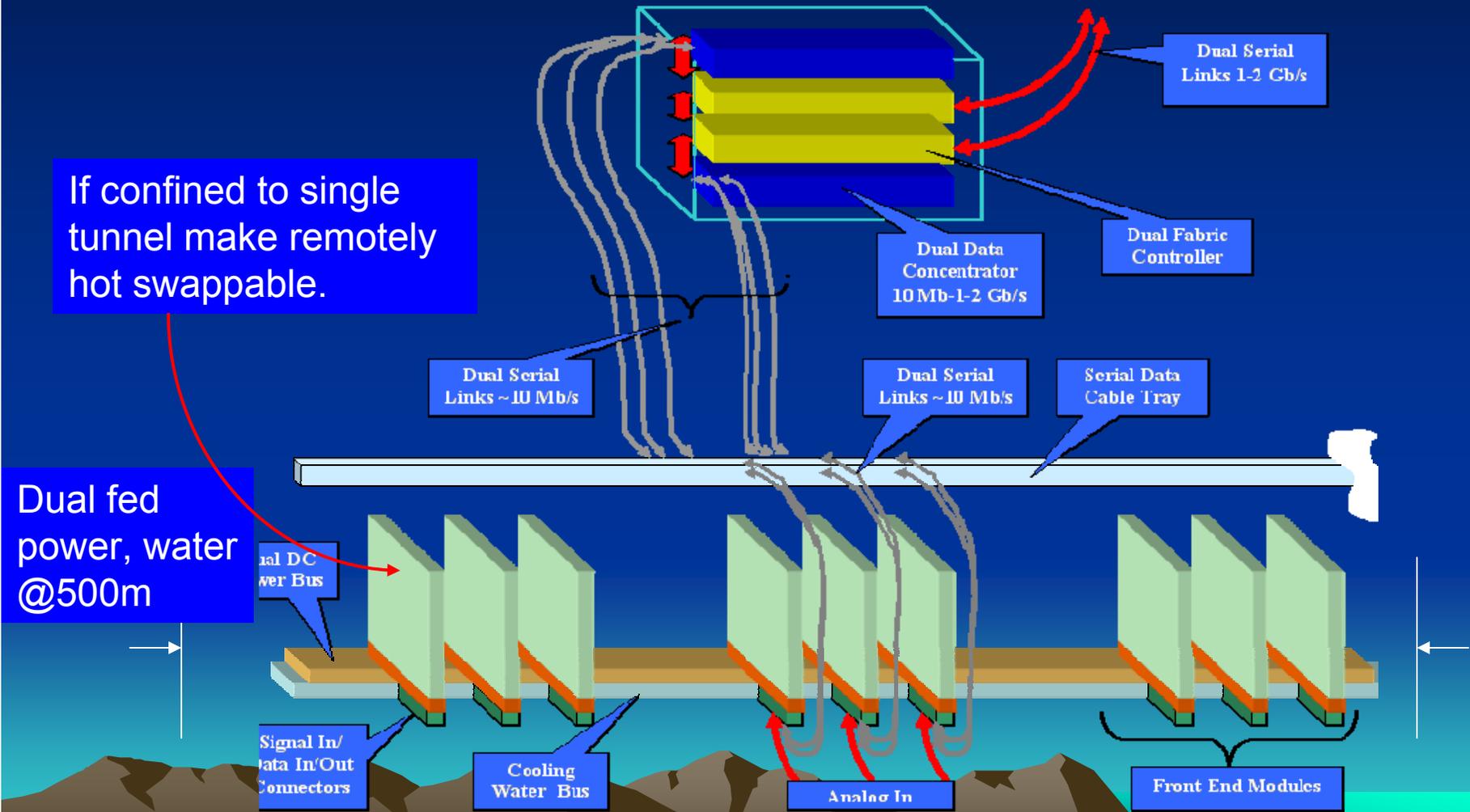# New Standards
Level 2 Sector Nodes to FEB's

Dual Star Fiber I/O
2.5-10 Gb/s to Main Control

Dual Star Serial Backplane: Dual Controllers Both able to access every Module In Crate

Data Concentrators

Dual Fabric Backplane
I/O Controllers

10 Mb/s Avg (typ.)
Fibers to Front
End Control Nodes
& Instruments:
LLRF
BPM's
PS Controllers etc.

Nodes @ 500m for 20 km

New Standards
Front End Instrumentation

- Candidates: Typical custom designs now built in CAMAC, VME or VXI
  - Beam position monitors
  - LLRF modules
  - Low voltage modular power supplies & controllers
  - Beam instrumentation
  - Vacuum instrumentation
  - Temperature monitoring
  - Any data acquisition & control instrument module that is not standard COTS (commercial off-the-shelf)
  - Controls communication interfaces all systems

New Standards
Accelerator Front End Concept

New Standards
ATCA Front End Potential

- Board Size:
  - ATCA is close in size to VXI, derived from VME for instrument market. Well proven as useful form factor

- 2 Modes:
  - Channel layout directly on board
  - Layout on Mezzanine boards
  - Mezzanine advantage: Easier to update technology on revised drop-in board
  - Mezzanine independently hot-swappable

- Restrictions:
  - Prefer all analog & digital inputs on rear panel for hot-swap. Connector issues through Rear Transition Module (RTM) need to be solved.
  - Fabric connector itself a candidate; 5 GHz+ digital BW, shielded twisted pair

New Standards
Board Level Power Systems

- New processors/logic IC's demand voltages to 0.75V at currents to 100A

- Drivers needed very close to loads (POL's, Point-of-Load)

- Primary system supply is 48VDC to minimize size of conductors

- Convert 48VDV on-board using industry standard stackable "bricks"

- *Standard pinouts, multiple suppliers*

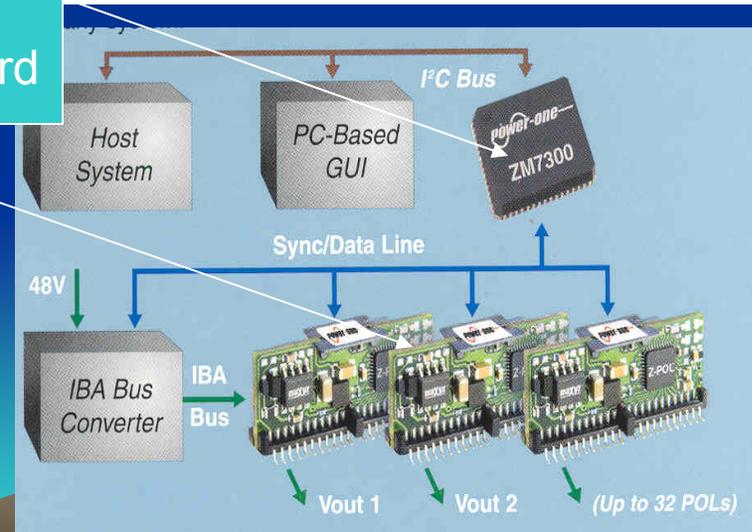- Power chip sets include intelligent controllers to set up, monitor sequencing, V and I levels, report faults, isolate faulty units.

Courtesy Power One Corp.

New Standards
Board Level Power Systems (2)

AC in

Intermediate
Bus Converter
(8-12VDC)

Brick – Foot prints

Dual Shelf PS

To Other
Cards via
Backplane

ATCA Card

48VDC
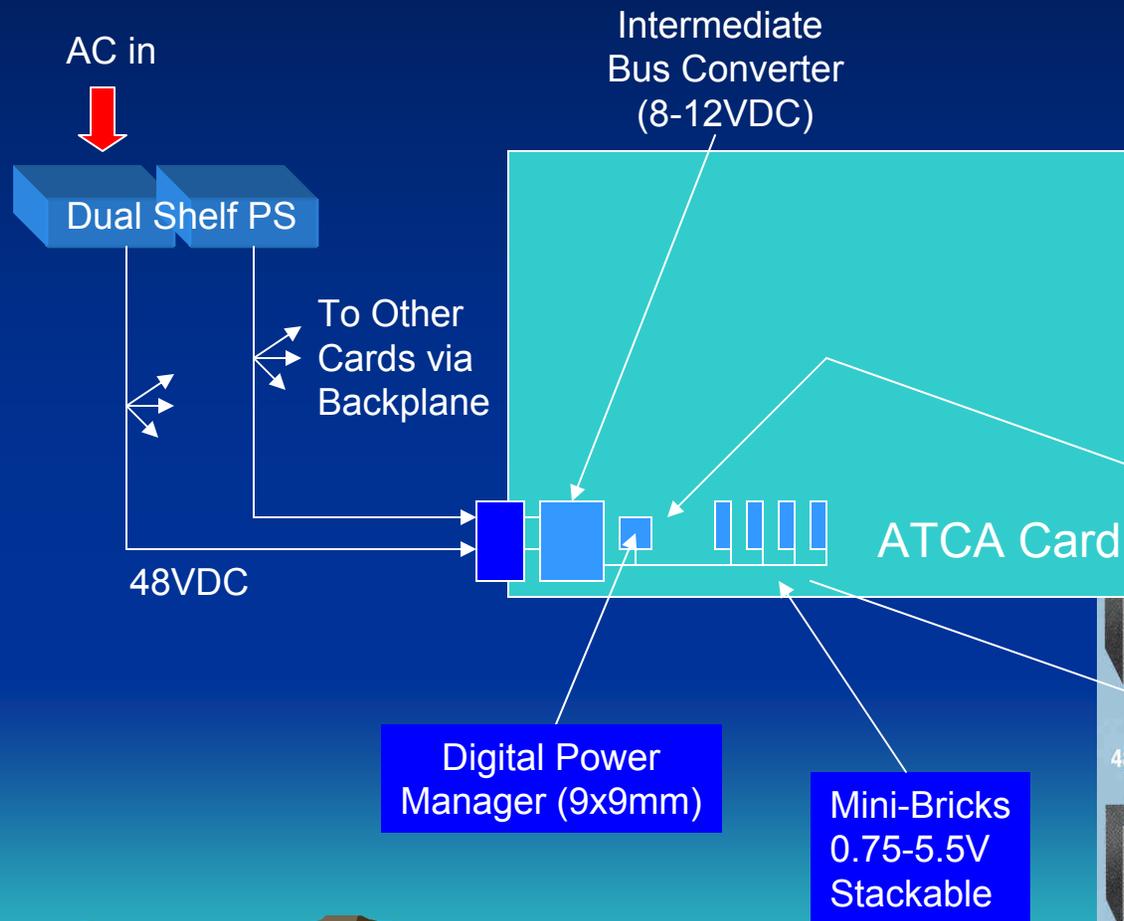
- Brick foot prints are open standards – anyone can make Brick DCDC Converters

Name	Size	Introduction
Half	2.3" x 2.4"	1980s
Quarter	2.3" x 1.45"	1990s
Eighth	2.3" x 0.9"	2002
Sixteenth	1.3" x 0.9"	2005

Digital Power
Manager (9x9mm)

Mini-Bricks
0.75-5.5V
Stackable

I²C Bus

Host
System

PC-Based
GUI

power-one
ZM7300

Sync/Data Line

48V

IBA Bus
Converter

IBA
Bus

Z-POL

Vout 1   Vout 2   (Up to 32 POLs)

New Standards
Applicability to Detectors

- *High level crate-based systems and modules*:
  - ATCA widely applicable in standard form to high level Trigger-DAQ processing systems
  - COTS processors, switches available from multiple vendors
  - Multi-Gb/s serial fabric interface built into backplane, customizable by vendors
  - Large and growing vendor base for all products including custom DAQ designs

- *Board communications and programmable logic:*
  - Design on sub-modules, mezzanine cards for ease of future upgrades.

New Standards Applicability to Detectors (2)

- *Internal Custom Form Factor Boards:*
  - HA architectures, design principles of redundancy and shelf fault management should be employed
- *Board-Level Power Conversion:*
  - Good selection of COTS board-level power converters, management systems available; take advantage of commercial HA products in custom designs.
  - *Urgent* to develop new radiation, magnetic field tolerant designs of similar power conversion products using industry standard footprints.

New Standards
Detectors - Suggested Guidelines

- *Make HA Architectures Mandatory in System Design Phase*
  - Perform reliability, failure mode analysis, MTBF & Availability analysis for all subsystems

- *Strive for Accessibility to Minimize MTTR*
  - In design phase strive to negotiate for accessibility to critical N+1 redundant components within detectors, particularly power and protection systems.

ILC HA Electronics Initiatives

- Controls & Instrumentation Standards
- Diagnostics Layer
- Magnet & RF Power

HA Electronics Initiatives General Goals

- From *Availism*, subsystem component MTBF's need to improve to millions of hours in some cases
- HA Methodology
  - N+1 modular design redundancy
  - Automatic fail-over strategies wherever possible
  - Rapid replacement of failed parts, ideally by hot-swap
- Main HA design constraints:
  - Avoid undue complexity esp. in software
  - Keep incremental costs of design, hardware & software to minimum

Controls, Timing, RF Reference Distribution, Low Level RF

- Redundant architectures planned for all critical controls nodes, communications links: Data, Timing, RF Phase Reference
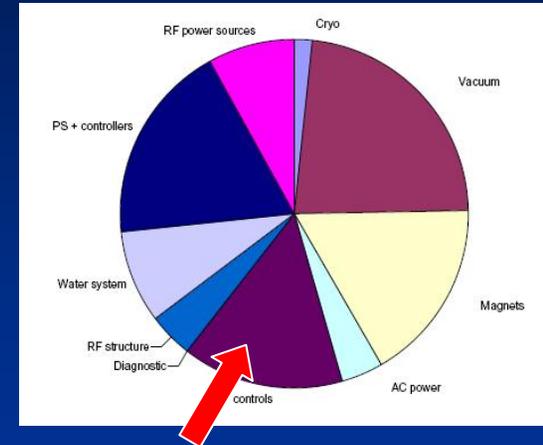
- Low level RF not necessarily redundant due to 3% Station redundancy but should be designed for low MTTR, hot swap of failed modules or sub-units to minimize interruption.

ATCA Standards Studies

- Purchased ATCA starter kits of crates, switches, controllers for hardware-software evaluation. Work underway in collaboration with University of Illinois at Urbana. Testing all features with goal of developing engineering systems for participating labs (Currently SLAC, ANL, FNAL, DESY)

- Investigating ATCA adapter card for VME to speed testing with experimental DAQ systems. Some commercial DAQ modules available but very few.

- FNAL developing high resolution fast ADC module.

- ANL leading Global Controls team for GDE. Developed HA concept models for all hardware and software; developed project costs.

- ANL investigating HA software options, commercial sources.

ILC HA Electronics Initiatives
Diagnostics Layer

- Build new layer into all systems as in ATCA Shelf Manager
  - Imbedded hardware, software to manage redundancy, failover modes, machine interrupt prevention strategies
  - Include set point monitoring, slow and fast waveform capture…
- Intelligent Diagnostics & Fault Management
  - Apply to all modular power control systems
  - Controls & monitoring from Main Control
  - Predict, evade faults & machine trips
  - Report actions to MCC, Maintenance
  - *Goal: Test on prototype systems in FY07-09*

Example: Marx Modulator Diagnostic Processor

- Low power unit runs on cell control power floating up to 120kV

Marx Cell Front View 1 of 14

Marx Cell Rear View DP Mounting

Fiber Optics

Control System Computer

Ground Control Station (16 Ch)
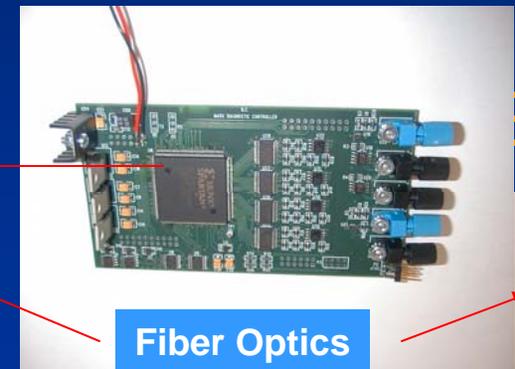
Marx Cell Controller Details
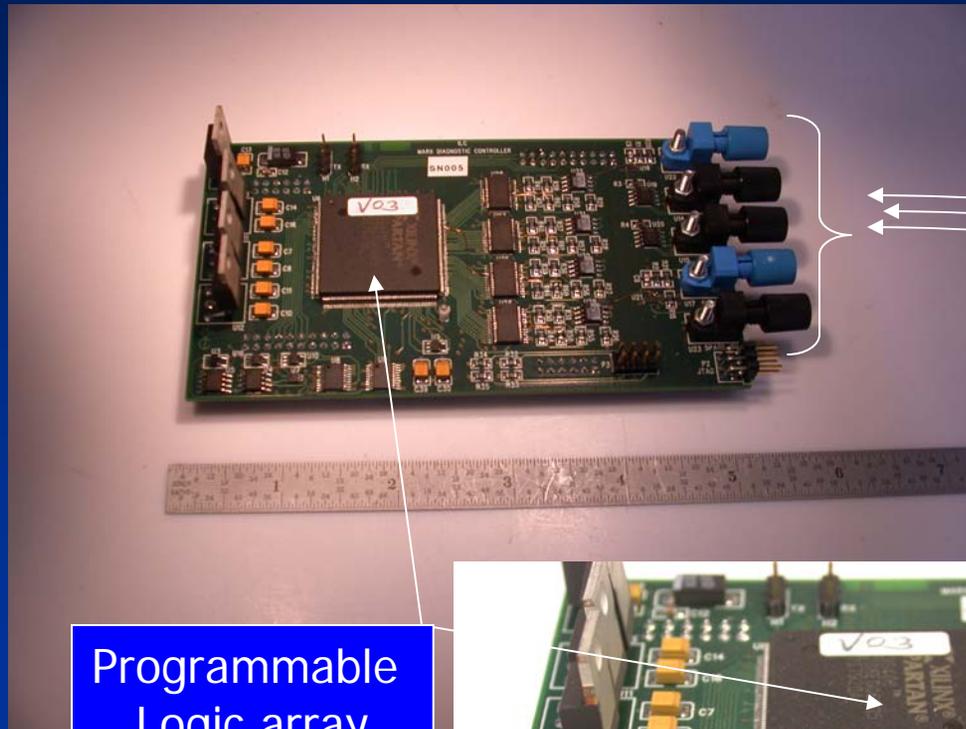
Dual Fiber Optic Timing & Data Links

Programmable Logic array

Duplex Timing & Data Channels Each Cell (Mounted on Rear)
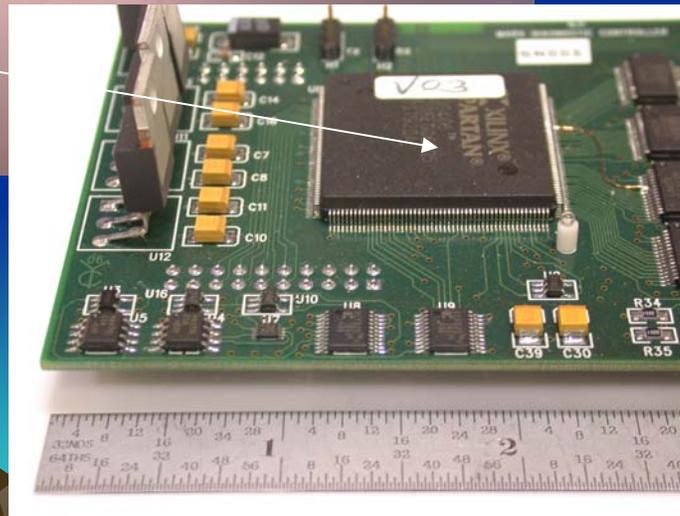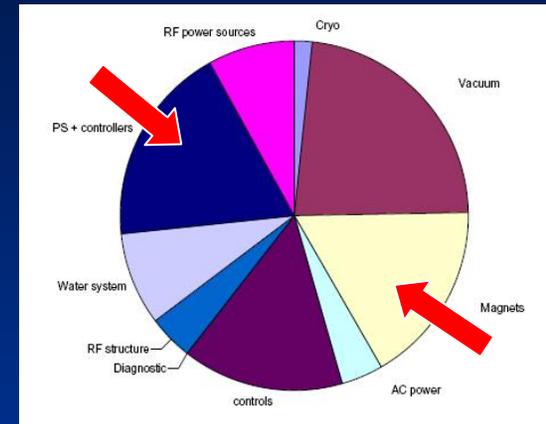
16 Ch Ground Station

HA Magnet & RF Power Systems

Magnet Power & Control Systems

- ## Traditional System

Magnet
Load

Controller

Switching PS

- ## New System

Dual Redundant Controllers

Dual Bulks

Dual 48VDC Lines
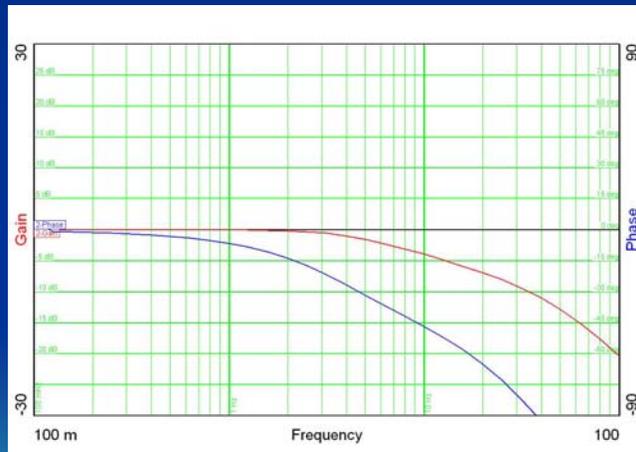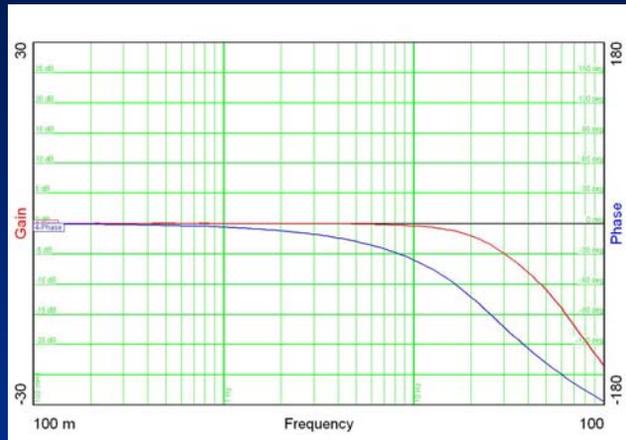
N+1 Redundant
Modules
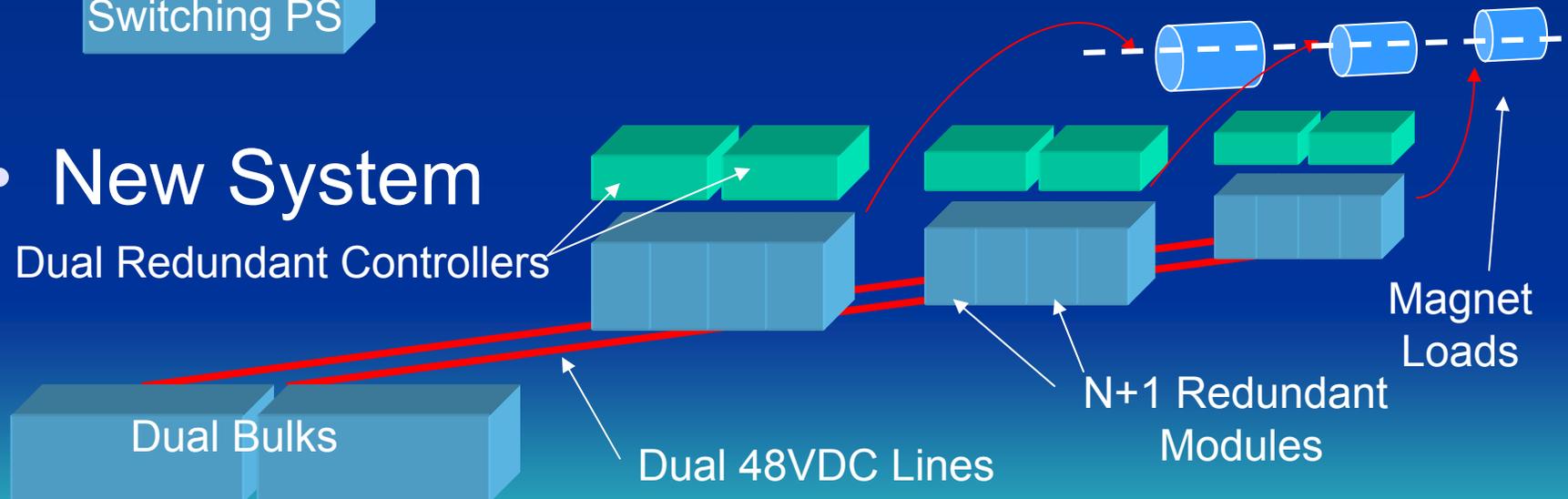
Magnet
Loads

Magnet PS Prototype

- Approx. 18,000 magnets & supplies in all systems
- For A~0.99 require modular n/N, Dual Bulk, Dual Controller
- Improved MTBF magnets, water systems, cable connections etc.
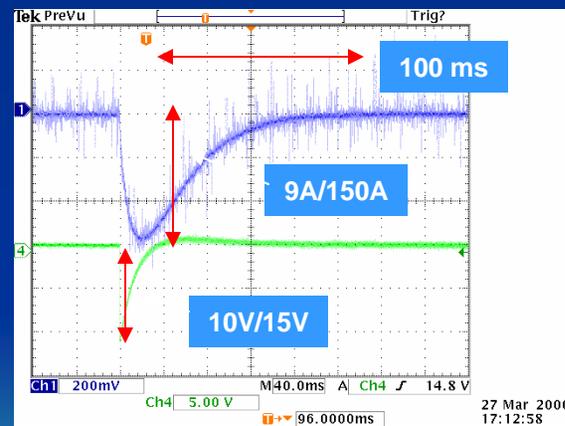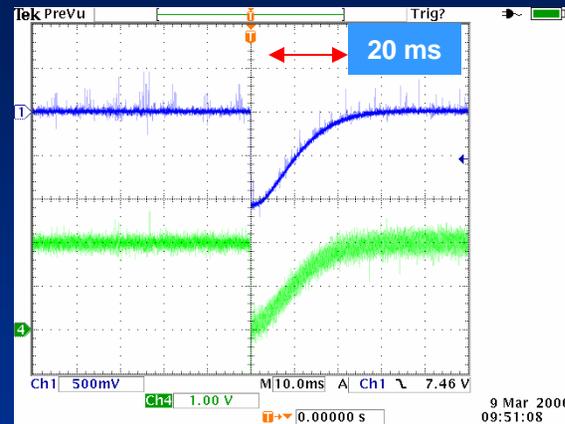- FY06-08 Goals: Demonstrate all HA features on multi-unit test system.

AC In/Out

Serial I/O (5x2)

5 Parallel 1.25 KW Modules

DC Out

- •1/N parallel modules for DC magnet supply (4+1 shown)
- •Independent dual controller
- •Diagnostics each module
- •Overall load current feedback

Backplane

Embedded PSDC's

Ethernet Controller

100mΩ Resistive Load

Test Magnet

Bulk Supply & Modules

P. Bellomo & B. Lam
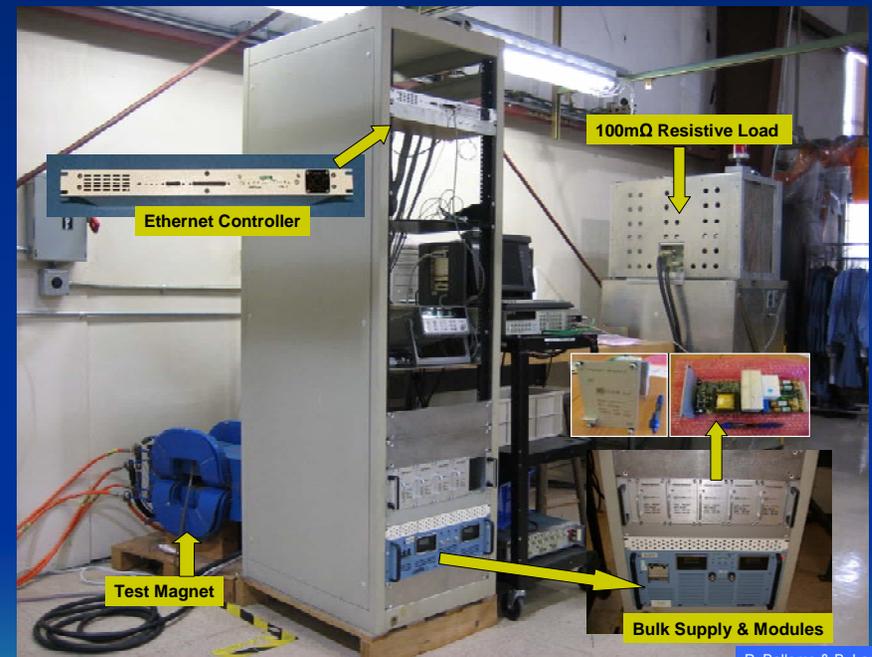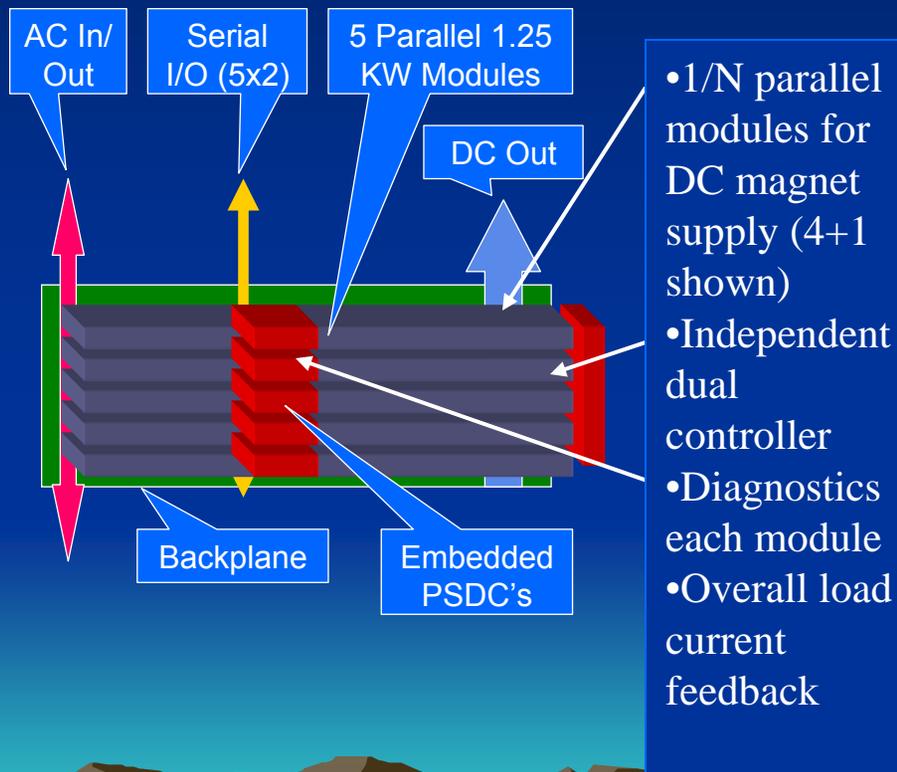
Prototype Test N+1 Auto-Failover

N+1 PS Performance

Frequency Response

Transient Recovery
1 Module Switched Off

8-Hour Stability @150A

20 ms

5ppm   8 Hrs

Module Current Sharing

100 ms

9A/150A

10V/15V

1 Percent

Top: Resistive Load, A, Φ
Bottom: Magnet Load + 100mΩ, A, Φ

Top: Resistive Load, 10 ms/cm
Bottom: Magnet Load +100mΩ, 40 ms/cm
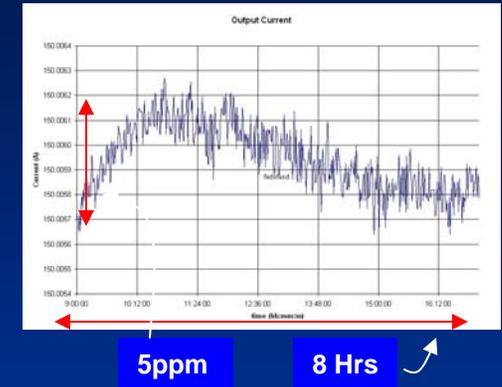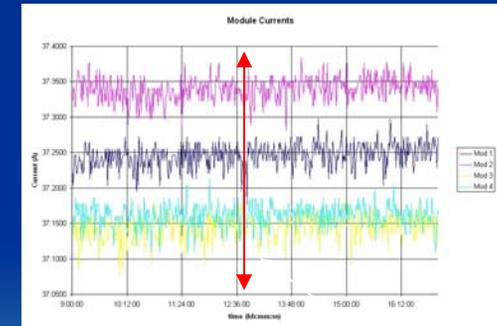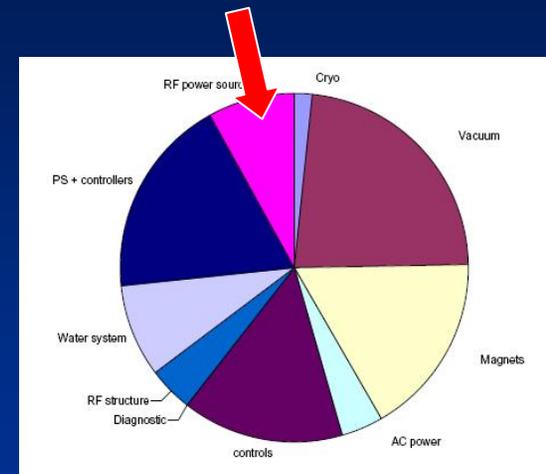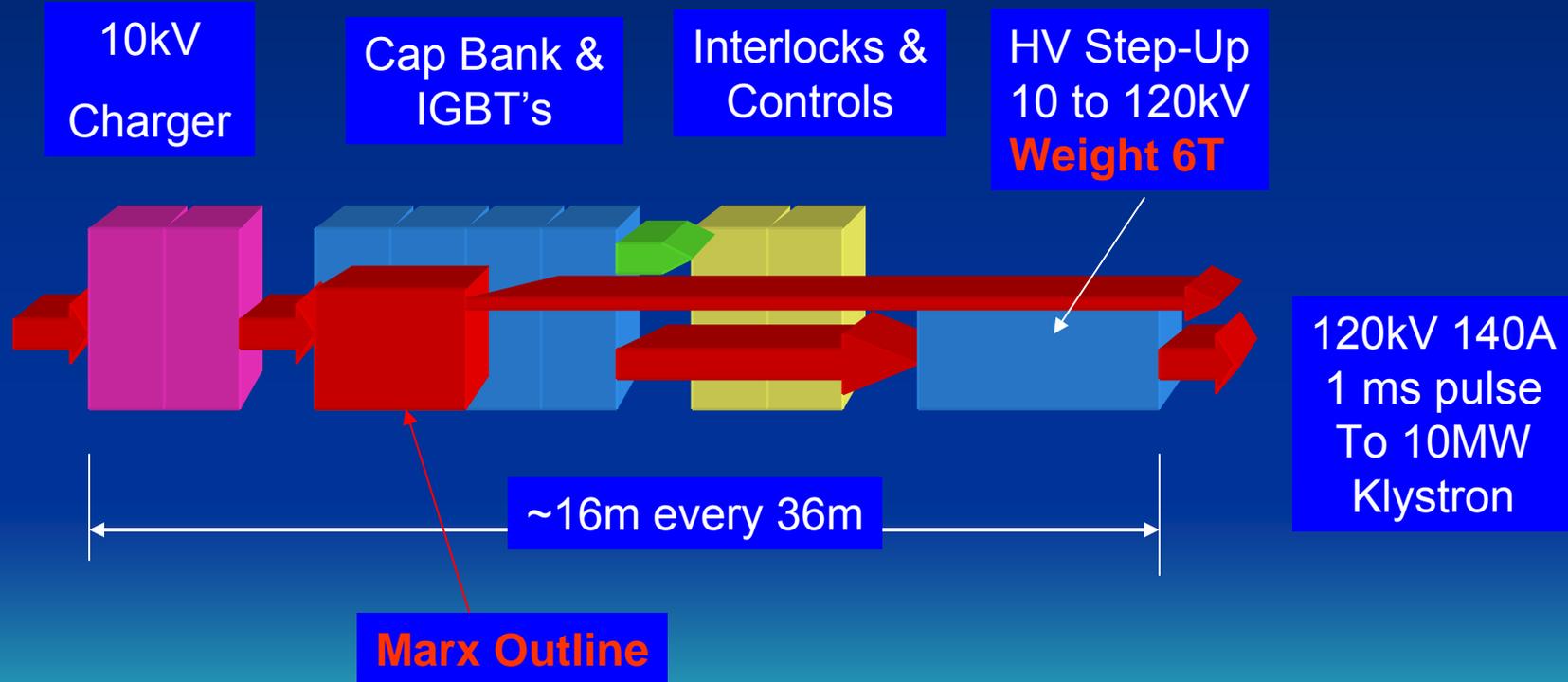
HA RF Power Systems

- RF Power Source consists of:
  - Modulator & Charger
  - Klystron & associated supplies
  - Waveguide distribution
  - Low Level RF system
  - Local Control systems
  - Protection and interlocks
  - Overall diagnostic controller
- System is about 12-15% of Total Project Cost
- *Modulator is highest cost component*

Current Baseline Modulator Compared w/ R&D Design

10kV Charger

Cap Bank & IGBT's

Interlocks & Controls

HV Step-Up 10 to 120kV **Weight 6T**

120kV 140A 1 ms pulse To 10MW Klystron

~16m every 36m

Marx Outline

New HA Modulator Development

- Radical departure from traditional 10kV capacitor bank single switch design with multi-ton step-up transformer to 120kV

- All solid state electronic voltage stack, no transformer, direct out at 120kV 140A

- Air cooled inside water-cooled cabinet
  – Easily replaceable circuit boards (low MTTR)

- Redundant N+1 design at three levels:
  – *1. Cells*
  – *2. IGBT Switch Arrays on each cell*
  – *3. Full RF Station*

Marx Assembly Overview

Fine Vernier (1)

120 kV Output Cable
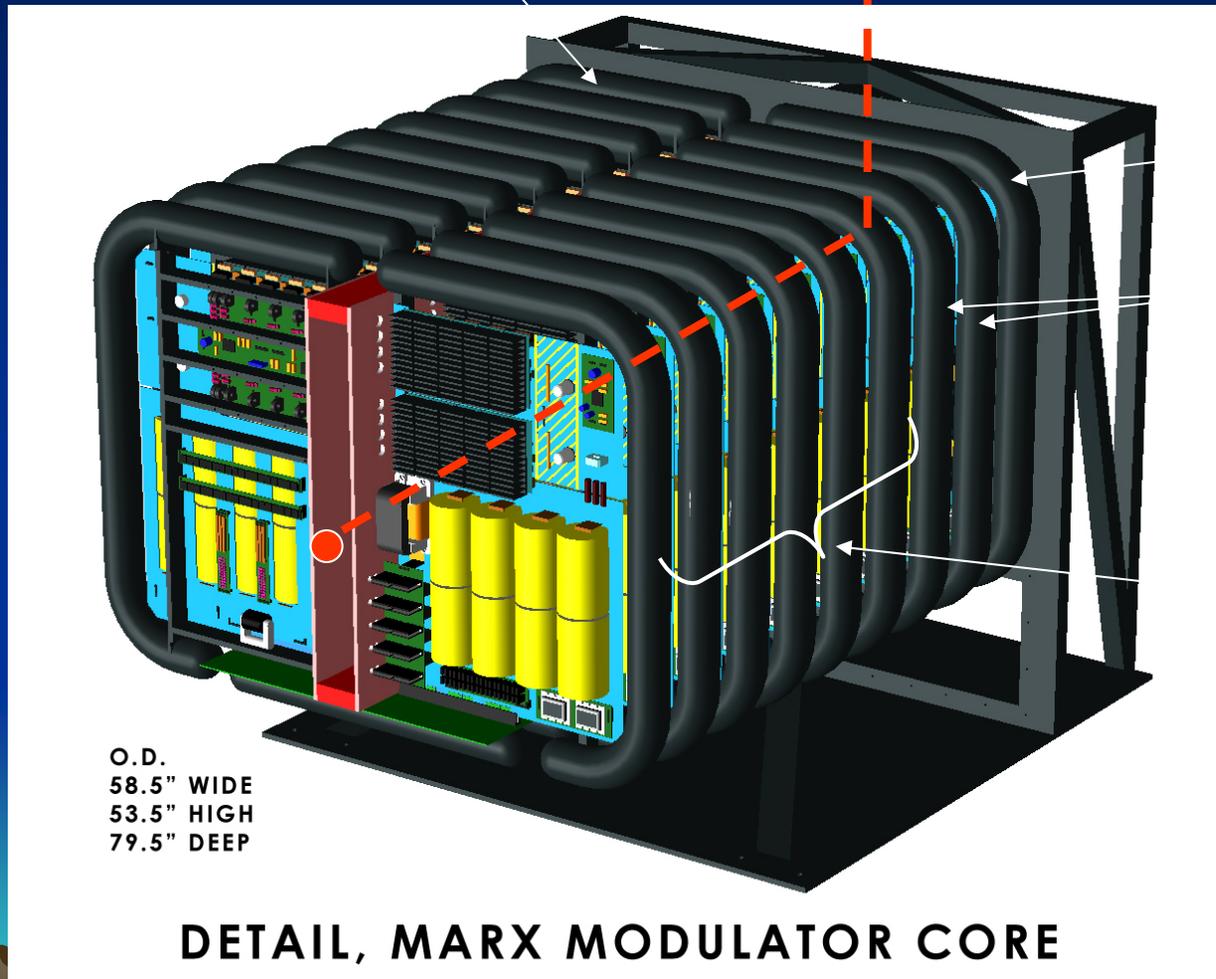
Buck Regulator Cell (1)
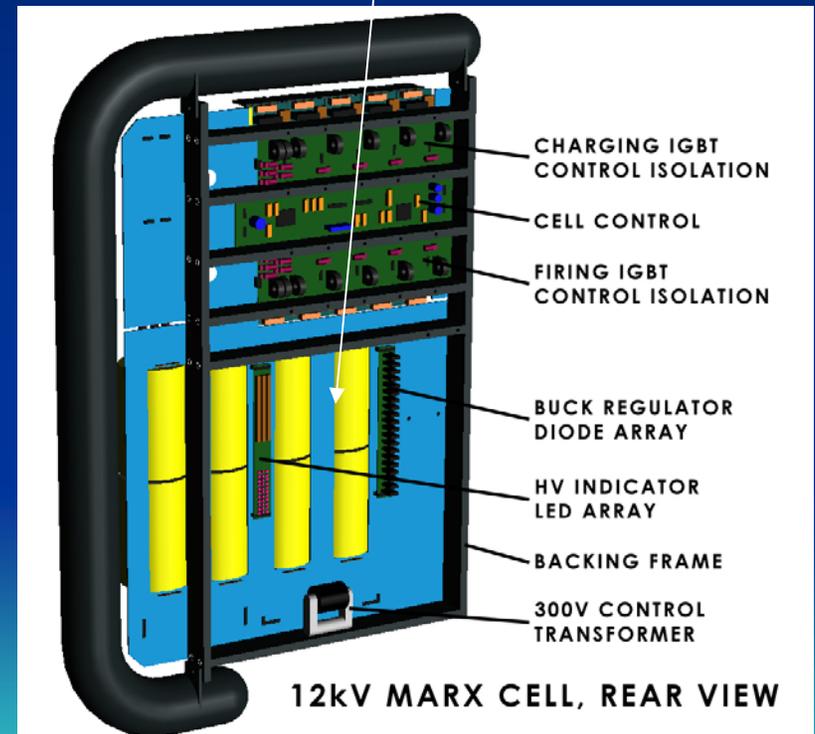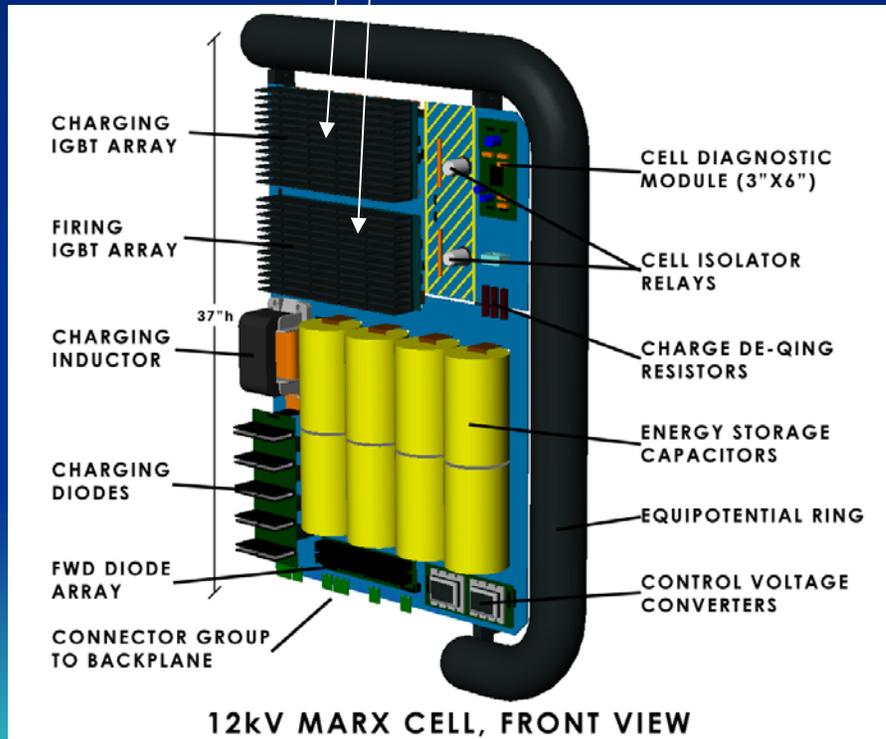
Coarse Vernier (3+1 Redundancy)

12 kV Cells (10+2 Redundancy)
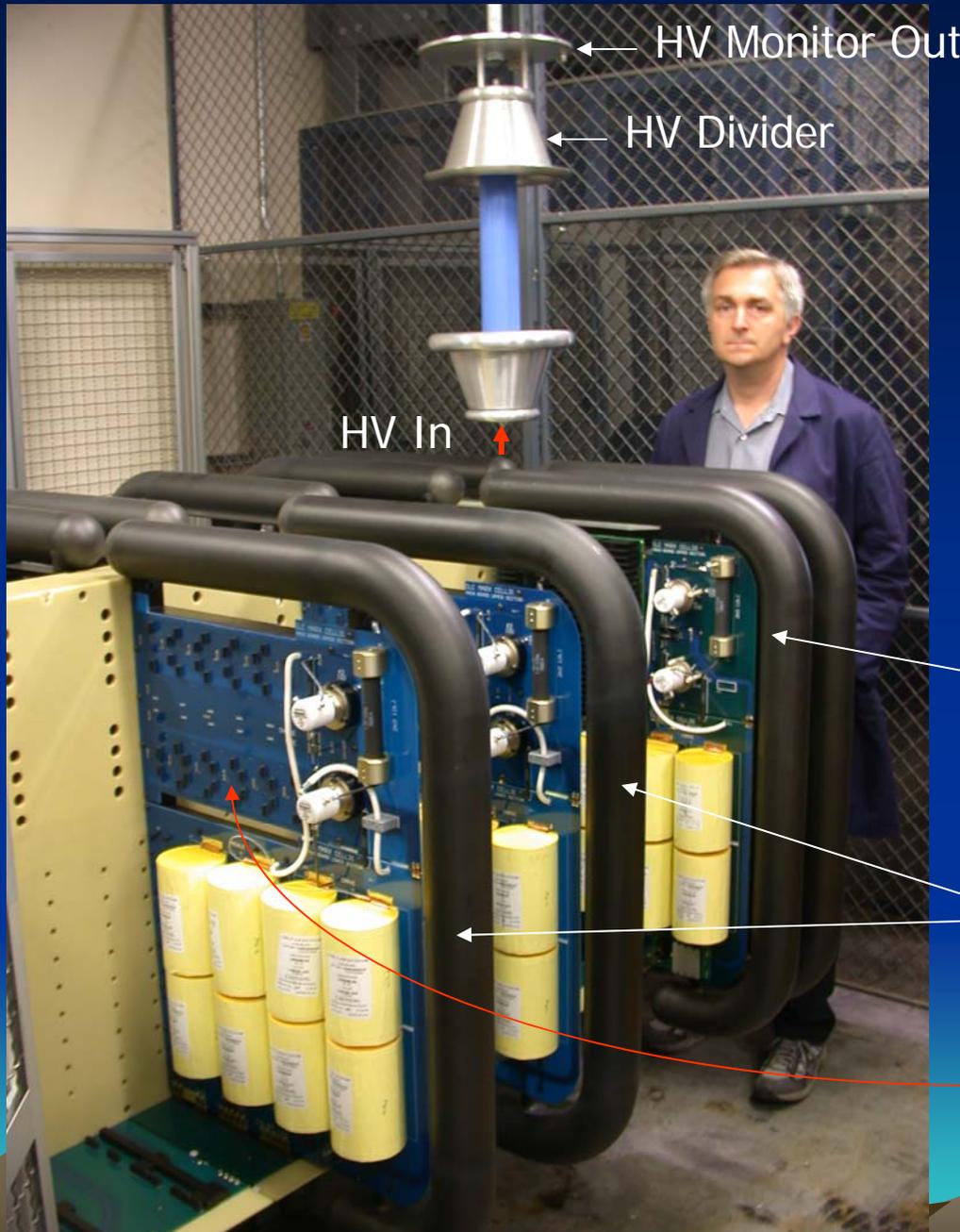
~610+20 (3%) Unit redundancy (Main Linacs)

O.D.
58.5" WIDE
53.5" HIGH
79.5" DEEP

DETAIL, MARX MODULATOR CORE

12 kV Cell Detail

4+1 Redundant Switch Arrays for charge, discharge

6+2 Redundant Capacitors

12kV MARX CELL, FRONT VIEW

- CHARGING IGBT ARRAY
- FIRING IGBT ARRAY
- CHARGING INDUCTOR
- CHARGING DIODES
- FWD DIODE ARRAY
- CONNECTOR GROUP TO BACKPLANE
- 37"h
- CELL DIAGNOSTIC MODULE (3"X6")
- CELL ISOLATOR RELAYS
- CHARGE DE-QING RESISTORS
- ENERGY STORAGE CAPACITORS
- EQUIPOTENTIAL RING
- CONTROL VOLTAGE CONVERTERS

12kV MARX CELL, REAR VIEW

- CHARGING IGBT CONTROL ISOLATION
- CELL CONTROL
- FIRING IGBT CONTROL ISOLATION
- BUCK REGULATOR DIODE ARRAY
- HV INDICATOR LED ARRAY
- BACKING FRAME
- 300V CONTROL TRANSFORMER

First Marx Production Cells

HV Monitor Out

HV Divider

HV In

Tested Prototype Cell

First 2 Production Cells under initial test

IGBT subassembly plugs

Summary

- The ILC is firmly committed to the HA design for all systems, not just electronic.
- Work in controls and instrumentation has been dormant while larger issues are solved and assuming ILC continues to grow must accelerate for success to be possible. The window of opportunity is only a few more years.
- The ATCA concepts of intelligent management of redundant systems are being applied in all electronics areas where HA is essential.
- Applying HA standard solutions across many future projects requires a much broader inter-lab and inter-project collaboration which would be very beneficial to all participants.

ATCA Workshops

- *ATCA Industry Forum schedule mid-October 2006 in San Jose CA. See PICMG website.*

- *HA Electronics Session or Workshop planned at RT2007 in May at FNAL (M. Votava of FNAL, General Chair. See website for details)*

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