Upgrade of CEBAF to 12 GeV

Leigh Harwood
(for 12 GeV Accelerator team)

Outline

- Background
- High-level description
- Schedule
- Sub-system descriptions and status
- Summary

CEBAF Science Mission

CEBAF was originally built to establish a deep understanding of the quark/gluon structure of nuclei. (non-perturbative QCD)

The program to date has been highly successful.

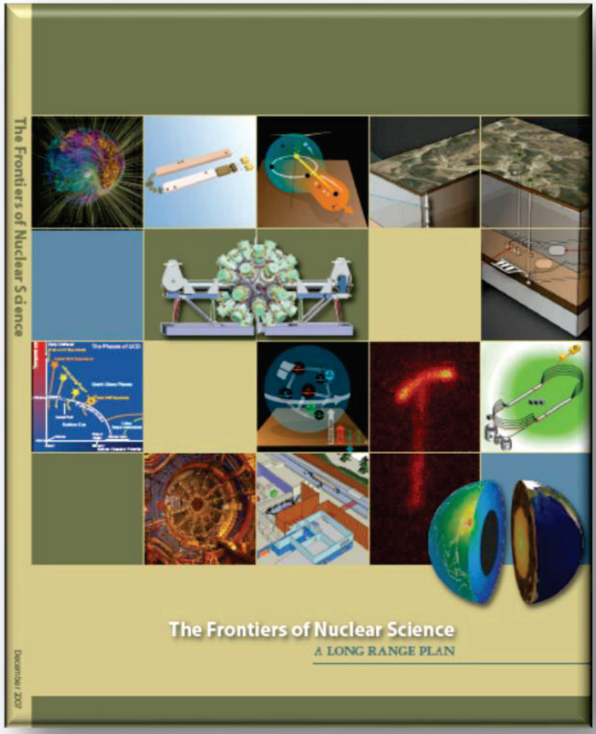
Theoretical initiatives identified critical areas with new opportunities for understanding.

- Explanation for quark confinement (exotic meson spectroscopy)
- Tomography of the nucleus with Generalized Parton Distributions
- Valence quark behavior

Investigating these open questions required doubling the CEBAF beam energy

12 GeV Upgrade Project

Scope of the project includes:
- Doubling the accelerator beam energy
- New experimental Hall and beamline
- Upgrades to existing Experimental Halls



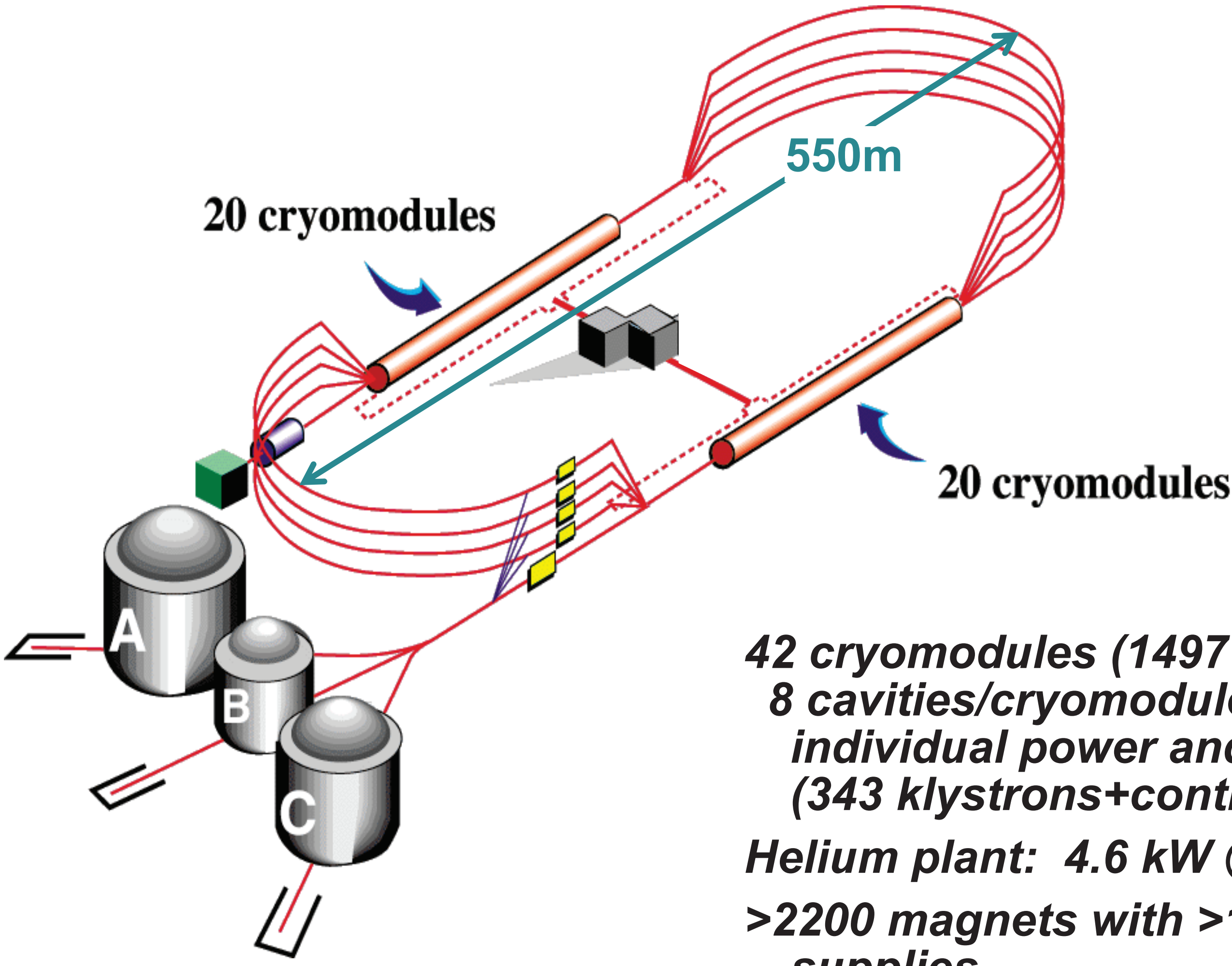
The completion of the 12 GeV Upgrade of CEBAF was ranked the highest priority in the 2007 NSAC Long Range Plan.

This priority was re-iterated in an 2013 NSAC report to DOE/NP

The Upgrade is built on an existing facility:

The vast majority of accelerator and experimental equipment have continued use

6 GeV CEBAF

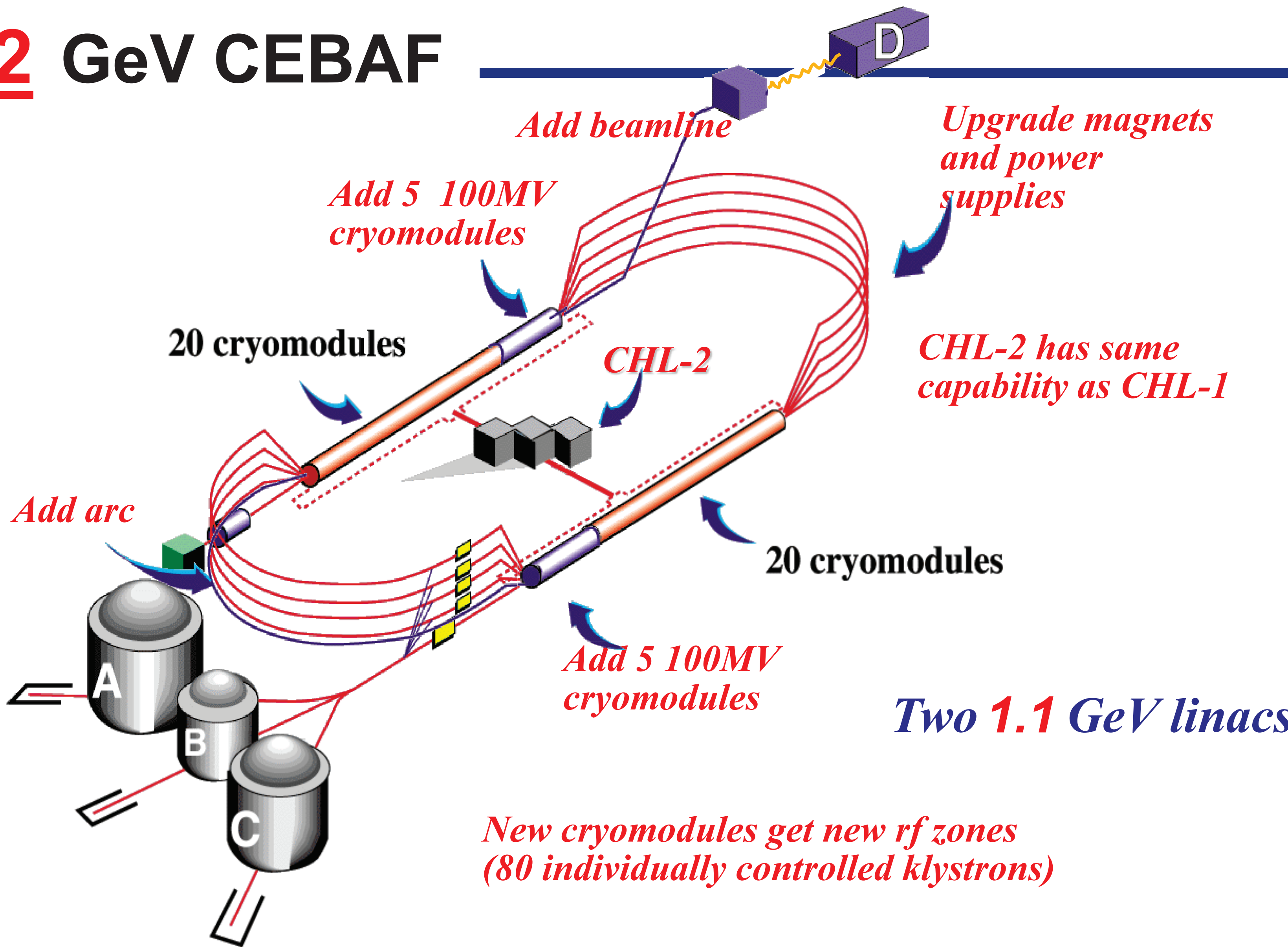


42 cryomodules (1497 MHz, 9m long)
8 cavities/cryomodule with individual power and control (343 klystrons+controls)

Helium plant: 4.6 kW @ 2K

>2200 magnets with >1800 power supplies

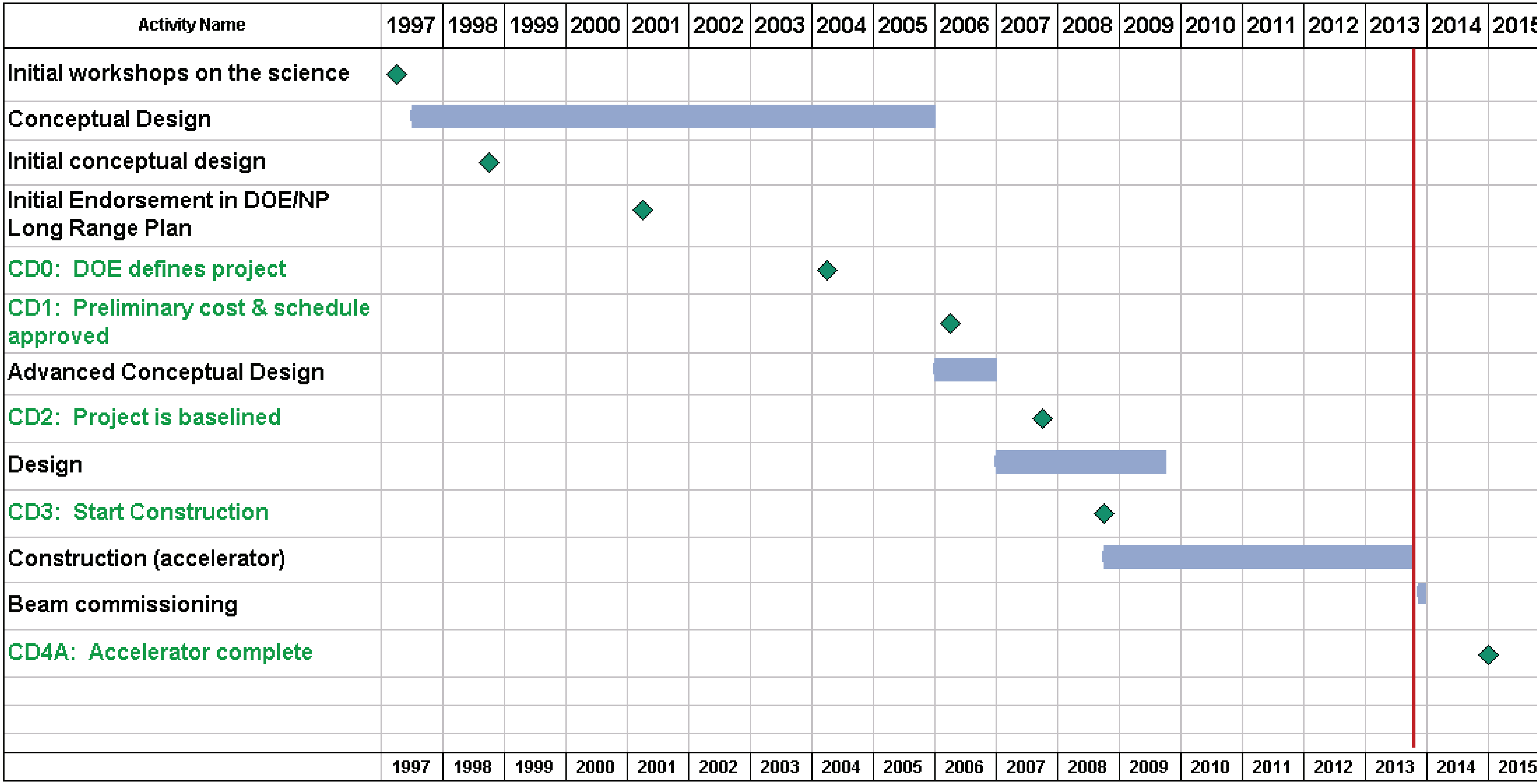
12 GeV CEBAF



*Two **1.1** GeV linacs*

New cryomodules get new rf zones (80 individually controlled klystrons)

Schedule: Long View



Sub-system Descriptions and Status

Cryomodules: Scope & Key Technical Parameters

- Scope: Develop, Design, Fabricate, Install and Check-out 10 Cryomodules (5 new cryomodules per linac)

(The following parameters are for each Cryomodule)

Voltage (Includes 10% reserve):	≥ 98MV (108 MV) (ensemble average in each linac)
Heat budget: (Interface with Cryogenics)	
– 2 K	≤ 300 W
– 50 K	≤ 300 W
Slot Length:	9.8 m
Tuner resolution:	≤ 2 Hz (stepper + PZT)
Fundamental Power Coupler:	7.5/13 kW (Avg/Pk)
Higher Order Mode (HOM) damping:	
– Transverse (R/Q)Qk	$< 2.4 \times 10^{10}$ Ω/m
– Longitudinal (R/Q)Q	$< 6.5 \times 10^{11}$ Ω
Cryomodule Length (Physical)	~8.5m

Cryomodules: Status

	Checked out in tunnel
#1	104 MV
#2	110 MV
#3	118 MV
#4	106 MV
#5	110 MV
#6	108 MV
#7	108 MV
#8	
#9	114 MV
#10	110 MV
Avg	**109 MV**

Avg Q_0 @ 19.2MV = 8.1×10^9

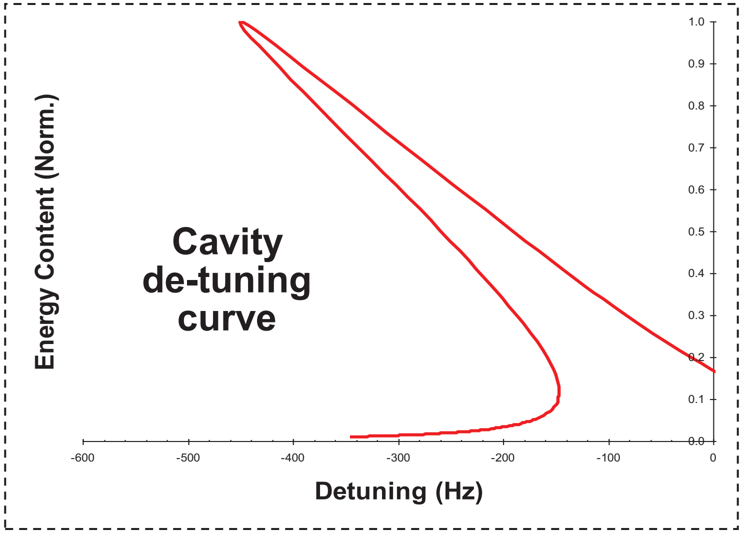
Final C100 installed in linac

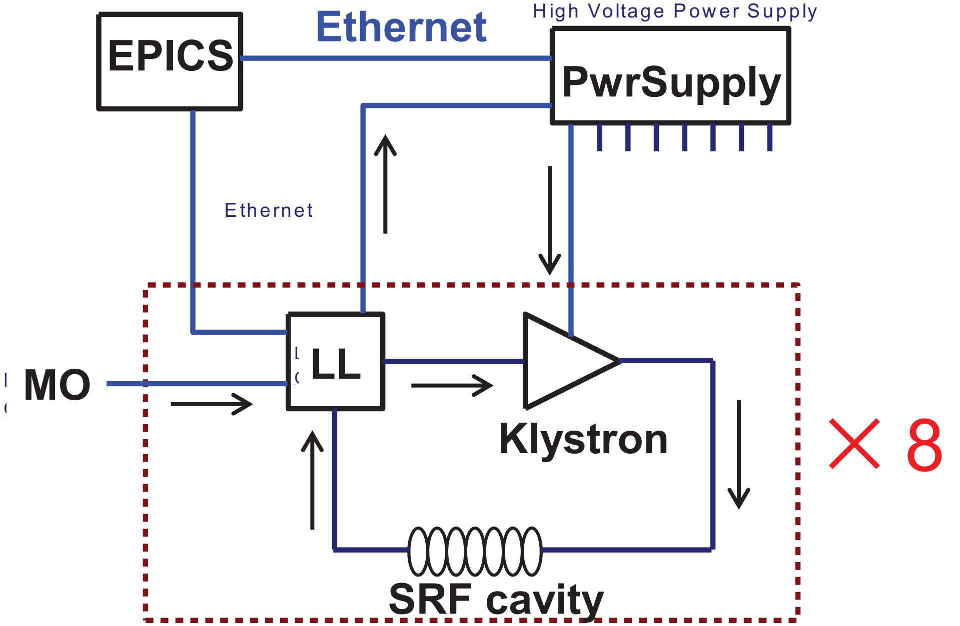
Hogan: WEZAA2

RF: Key Technical Parameters

- **Ten new zones of RF power for new accelerating structures:**
  - Operating Freq: 1497 MHz
  - Eight cavities per zone
    - Individual low-level controls
    - Cavity Q_L: $\geq 2 \times 10^7$
    - Operating Gradients: >17.5 MV/m
    - One cavity per klystron

	Fast (<1sec)	*Slow* (>1sec)
Phase Stability (rms)	0.5º	3.0º
Amplitude (rms)	4.5×10^{-4}	NA





RF details

- Low Level RF
  - Ground-breaking digital solution for cw controls
  - Double-moded
    - Self-Excited Loop (SEL): If phase/amplitude control is not needed
      - Permits cavities to be energized and quickly brought onto resonance. ⇒ Mitigates the double-valued detuning curve.
    - Generator-Driven Resonator: When phase/amplitude control is needed for beam

      Hovater: TUZBA1

      Hoffler: THTB1

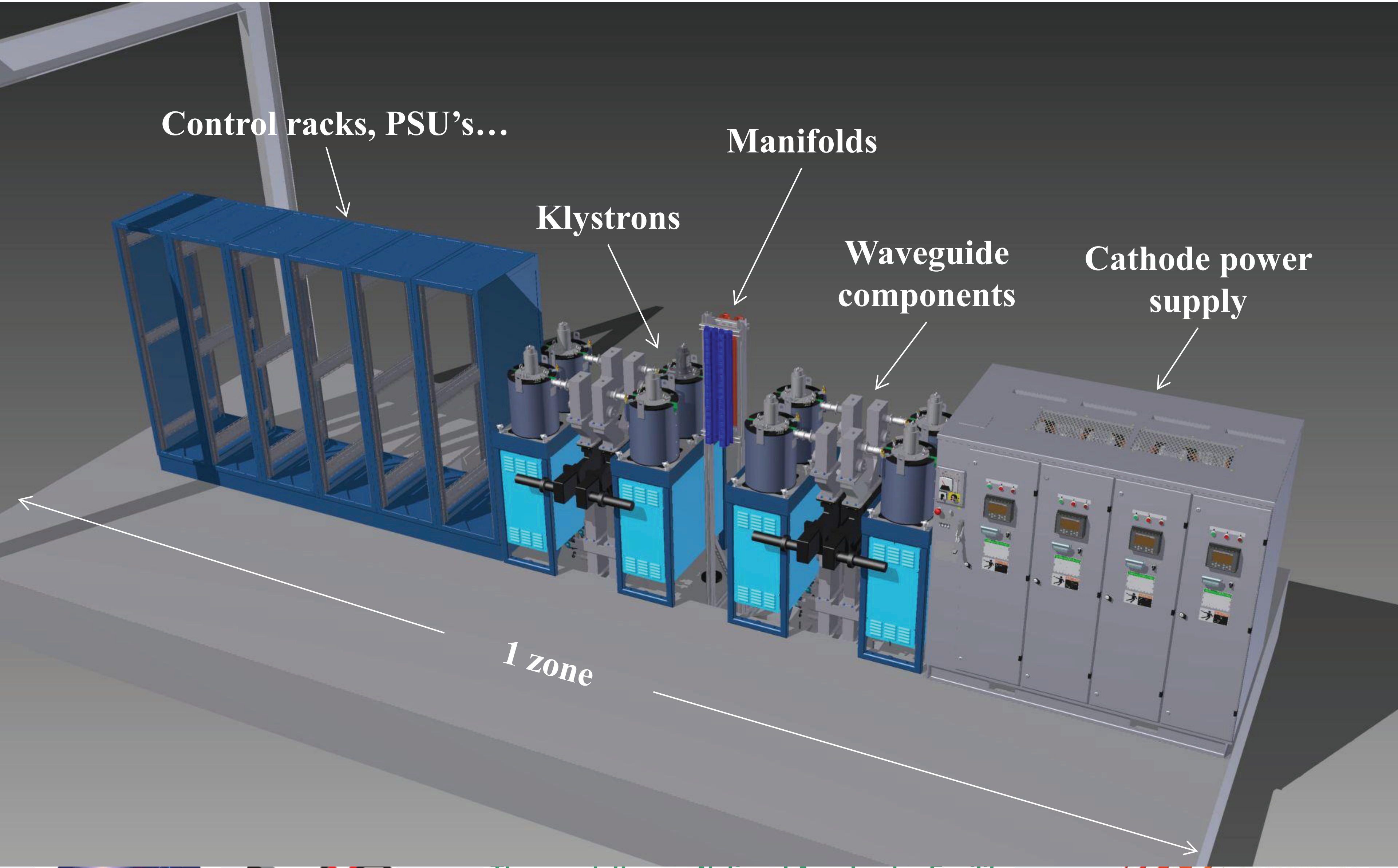
- High power RF
  - New 13kW klystron

  - Only 2 cavities/klystrons per high-power amplifier

    ⇒Improved up time

Installation is complete

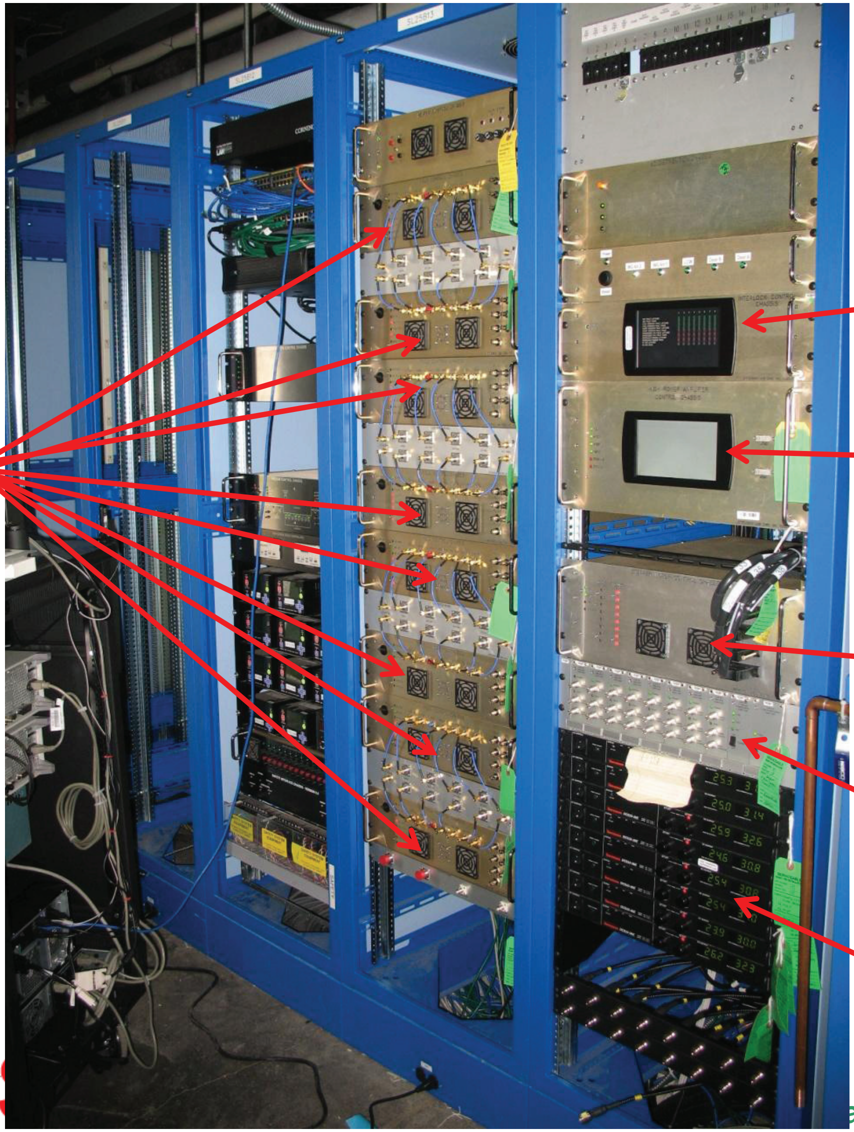
RF: Layout



Control racks, PSU's…
Manifolds
Klystrons
Waveguide components
Cathode power supply
1 zone

RF: LLRF/HPA Control Systems

Field Control Chassis



Cryomodule Interlocks Chassis

High Power Amplifier Control Chassis

Stepper Tuner Control Chassis

Piezo Tuner Amplifier Chassis

Klystron Solenoid Power Supplies

Cryogenics

- **Double the capacity of 2K plant: 4.6kW → 9kW**
  - New 4.5K helium refrigerator: 4.6kW @ 2.1K, 12kW@35K plus 15 g/s of 4.5K liquefaction
  - Modified the cryogenic distribution system for the interconnection of 10 new C100 cryomodules
  - Note: Leveraged an existing 2K coldbox

- **Status**
  - 4.5K coldbox has been accepted
  - Distribution system is complete
  - Commissioning on integrated system is underway

Cryogenics (cont'd)

Lower coldbox

Upper coldbox

Beamlines

- Overall length (excluding linacs)
  - Original: 4.3 km
  - Upgrade: 4.9 km
    - New 10th recirculation arc and beamline to new Hall D
- Original layout retained (including dipole & quad locations)
- Almost all magnets were reused
  - Dipoles
    - Beam energy at any location has increased by ~2x, so $\int BdL$ of dipoles much increase by same ratio
    - Solution: Increase the current in the dipoles by 2x
      - Saturation was beaten by adding more return iron
        - » Changed "C" dipoles to "H"
  - Quads
    - Most reused w/o change
    - ~100 were shifted to higher-current power supplies

Beamlines (cont'd)

Magnets		Major (≥1m) dipoles	Quads	Steering dipoles
Original		452	705	750
Upgrade	Unchanged	27	635	750
	Reworked*	425	0	0
	New	43	114	64

***Reworked: disassembled, insulation replaced, iron modified and/or added, coils reconfigured on some magnets, reassembled, QA'ed and field mapped**

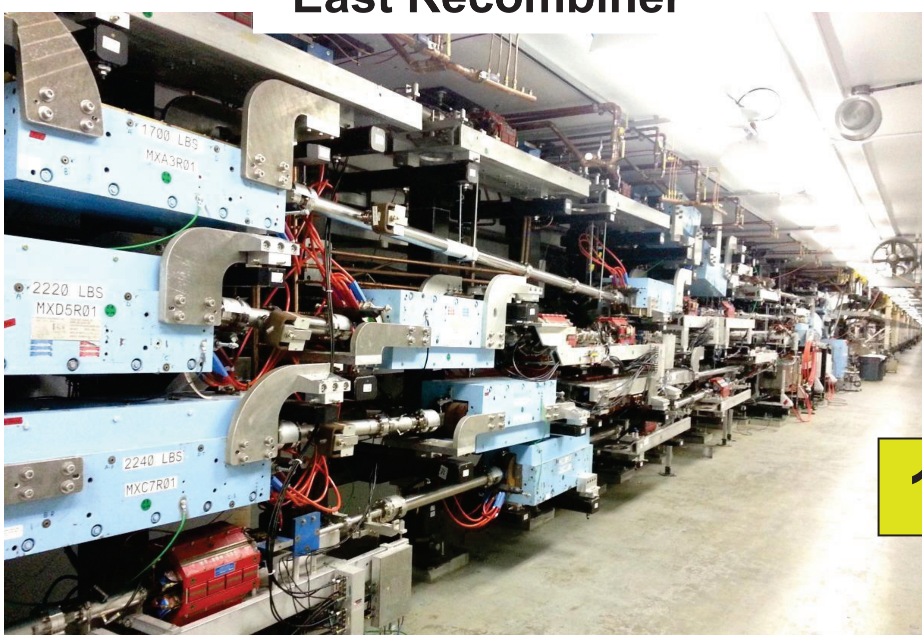
Power supplies		35-260kW	40-1080kW	10A/20V	20A/70V
Original		22		1455	
Upgrade	Reused	9		1322	
	New		15		240

Beamlines (cont'd)

Original

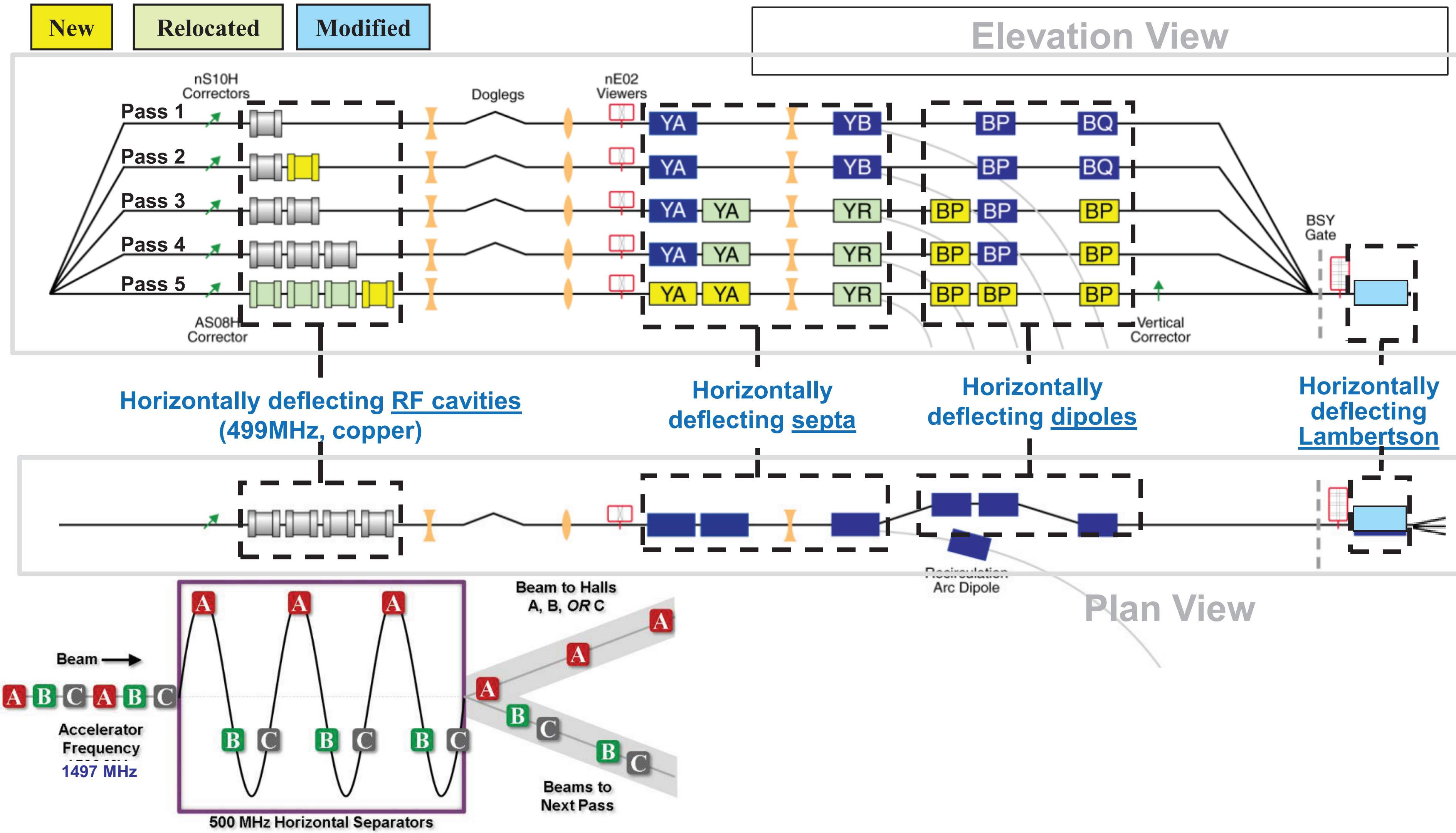
East Recombiner

East Arcs



12GeV

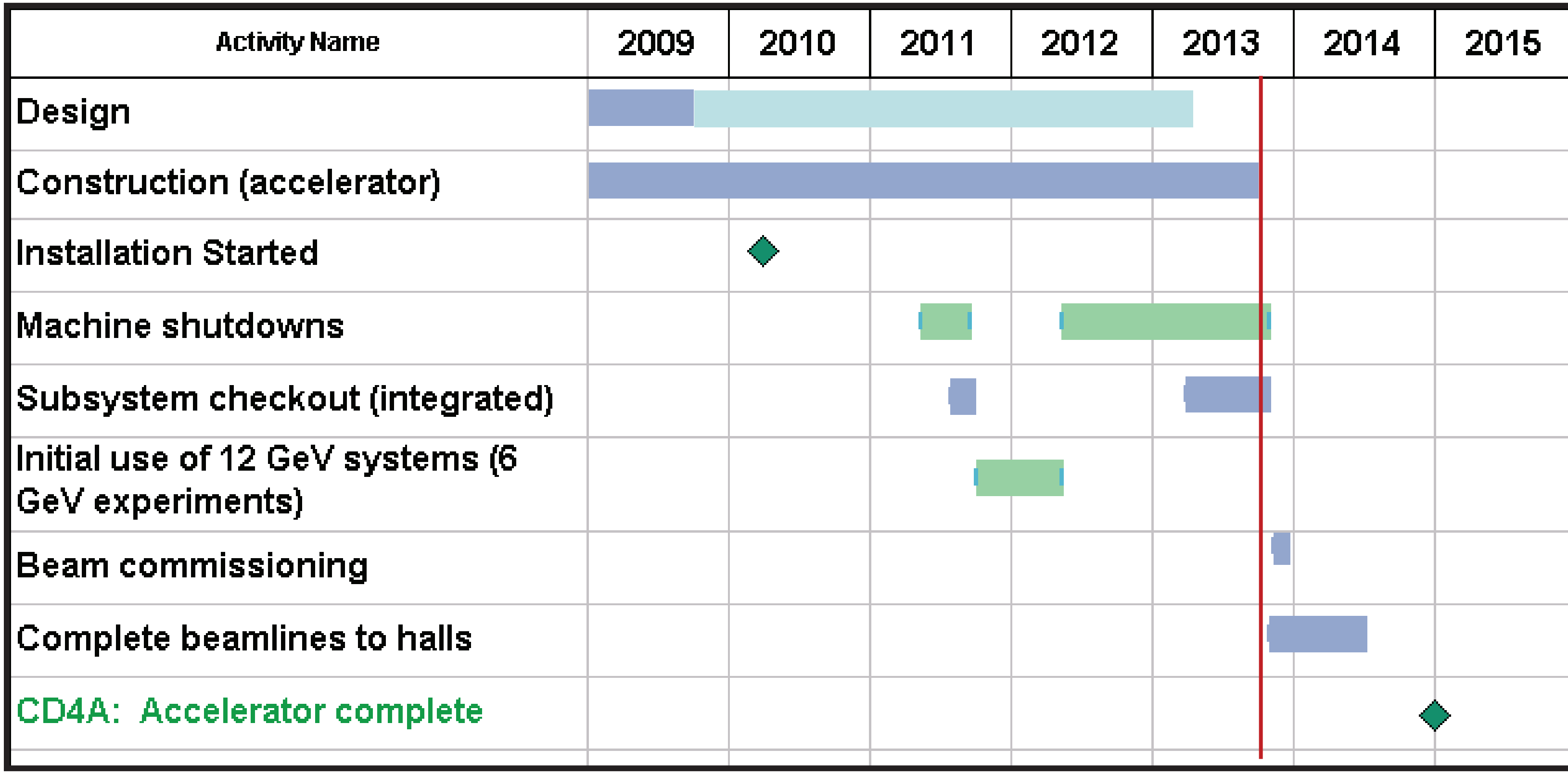
Extraction: Beam to 3 Halls at Once



I&C/Safety

- Added diagnostics and machine protection systems for new beamlines
  - New design for beam position monitor electronics was needed because of obsolescence of components for original
- Expanded network and modify control software for new cryomodule/rf zones, magnet power supplies, and CHL expansion
- Modified control software to incorporate new magnet power supplies and new cryomodule/rf zones
- Expanded personnel safety system to cover new Hall D
- Status
  - Ready for beam commissioning
  - Additions for Hall D will complete in FY14

Schedule: 2009-now

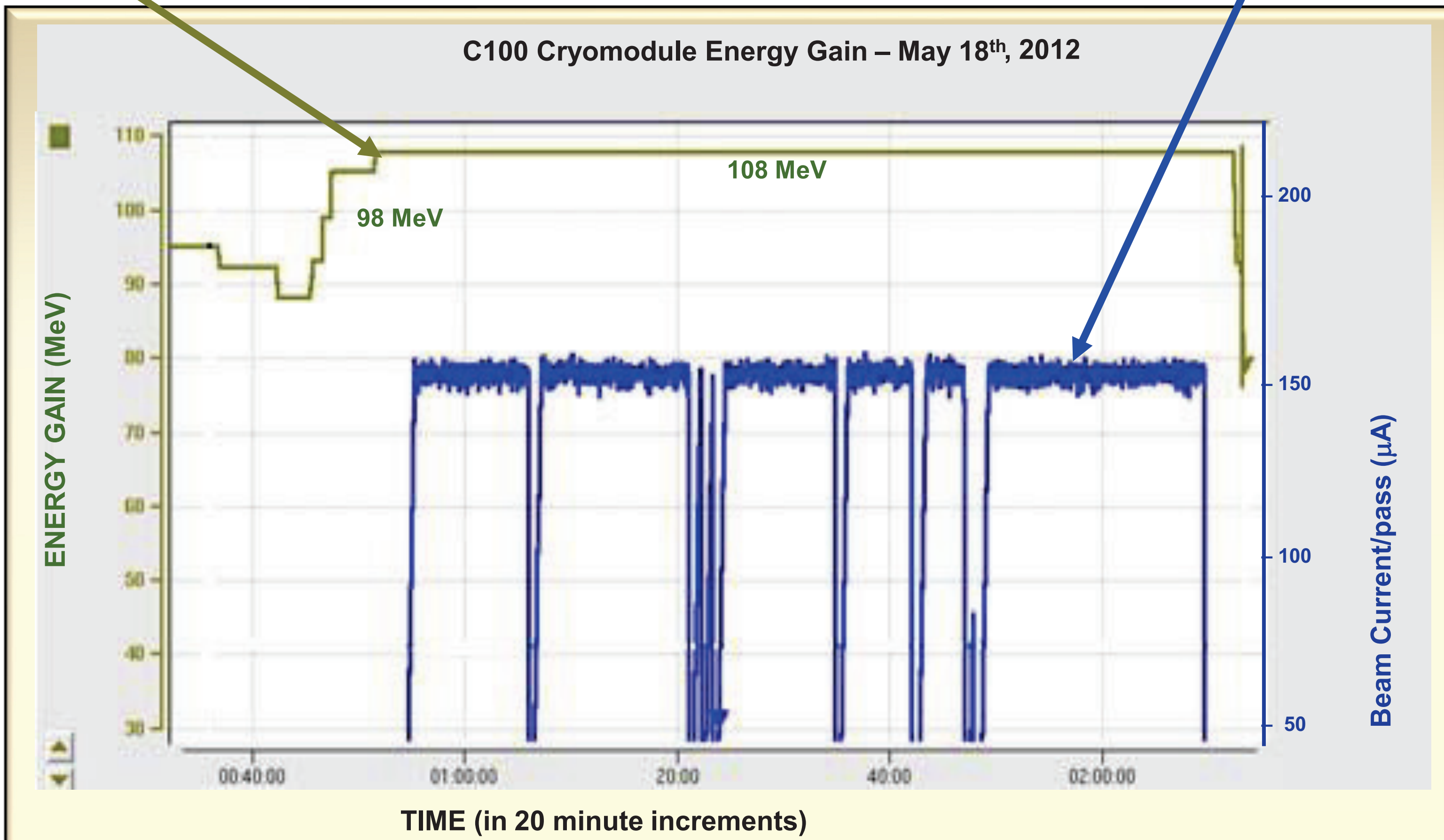


- **FY11 shutdown: Reworked 7 arcs and installed 2 zones of cryomodules & RF**
- **FY12-13 shutdown: Completed accelerator installation for commissioning**

2012: Full Performance of C100 + RF was Demonstrated

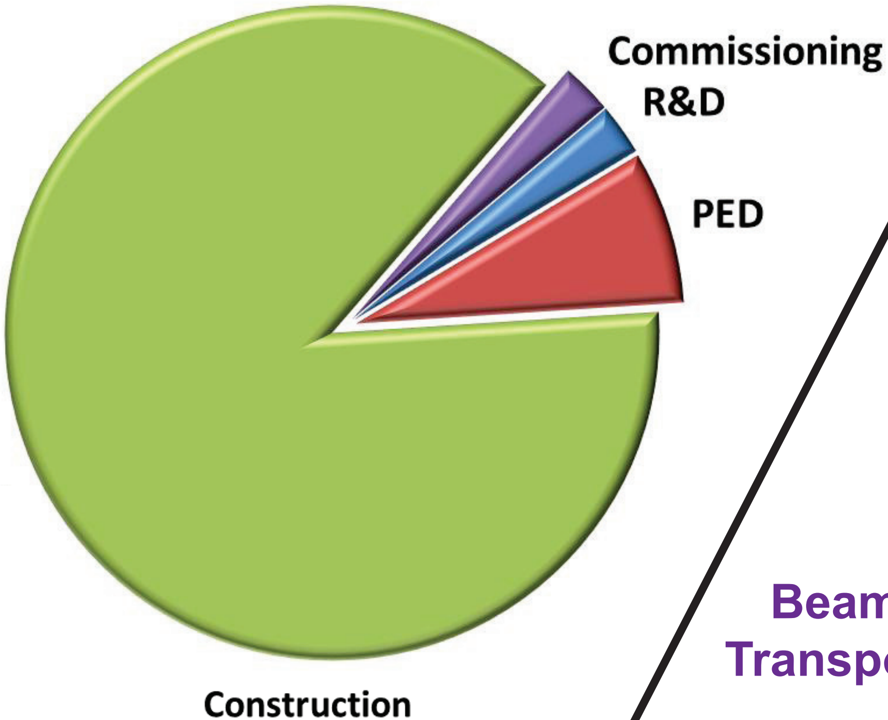
Cryomodule voltage

Total current in linacs: 465 μA

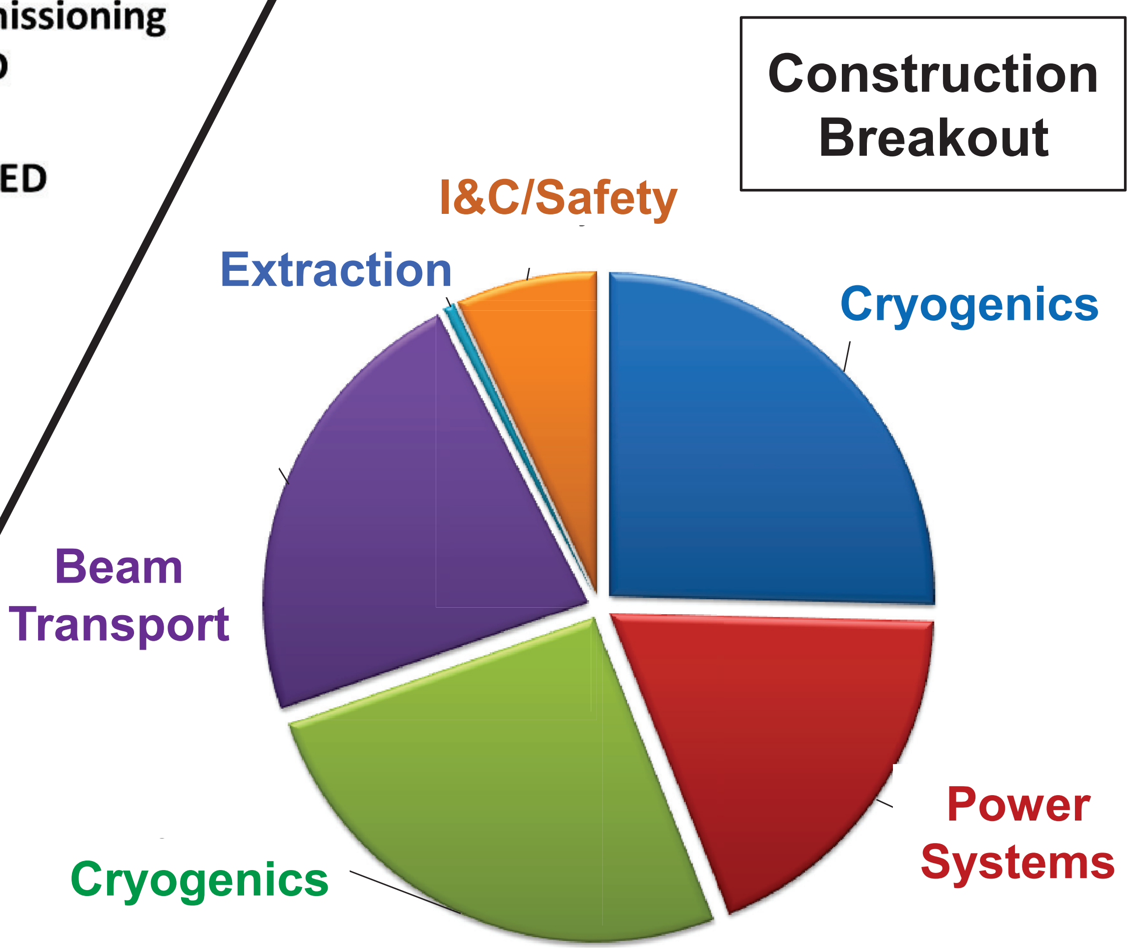


<u>**This is with beam going to the NP experiments**</u>

Costs



Total: $119M



Future

- **What's after 12 GeV?**
- **The NP community is looking towards an Electron-Ion Collider.** Zhang: TUZAA1

Summary

- An exciting research program in the study of the quark structure of nuclei as well as the fundamental question of quark confinement is possible with a 12GeV cw electron beam.
- The CEBAF accelerator has been upgraded to deliver 12 GeV beam.
  - The core of that upgrade was increasing the total linac voltage by 1.0 GV to a total of 2.2 GV.
- All systems have met their defined goals

Beam commissioning is about to start!