Cebaf energy upgrade program including re-work of CEBAF cavities

Joe Preble

(for Jefferson Lab)

SRF2007

Office of Nuclear Physics
Exploring Nuclear Matter - Quarks to Stars

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Office of Science
U.S. DEPARTMENT OF ENERGY

Operated by Jefferson Science Associates, LLC for the U.S. Dept. Of Energy

Talk Outline

- CEBAF today and the 12 GeV project, machine and Physics programs

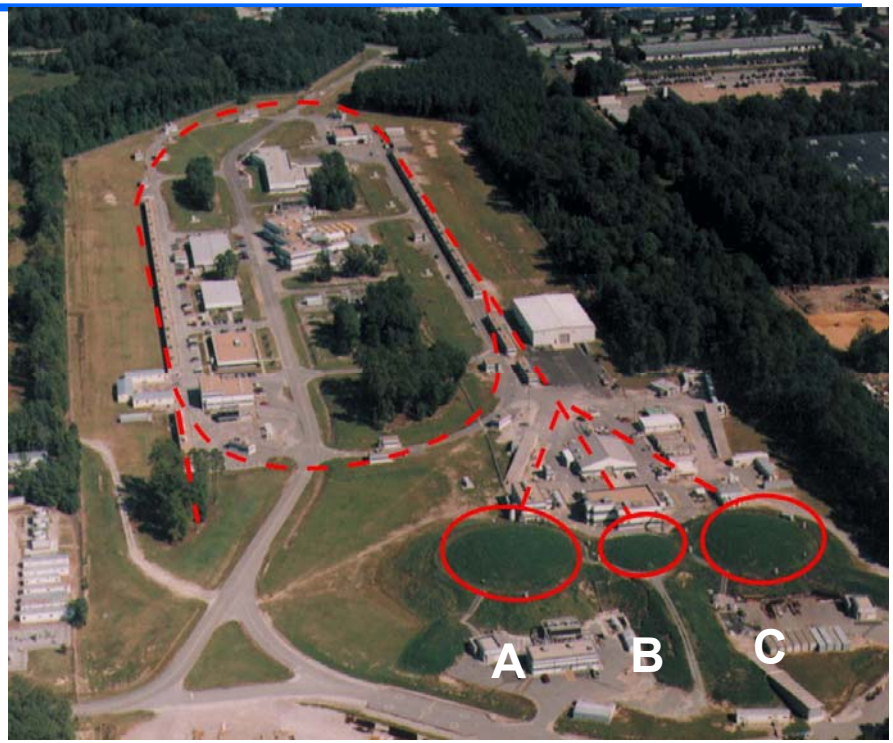
- Upgrade Cryomodule requirements and results

- CEBAF at 6 GeV the building block for 12 GeV, re-work of CEBAF cryomodules

Jefferson Lab Today

2000 member International User Community exploring the quark-gluon structure of matter

A recirculating superconducting linac provides 100% duty factor polarized beams of remarkable quality with energies up to 6 GeV



CEBAF's innovative design allows delivery of beam with independent currents and independent (but correlated) energies to three experimental halls simultaneously

Each of the three halls offers complementary experimental capabilities and allows for large equipment installations to extend scientific reach

Office of Nuclear Physics
Exploring Nuclear Matter - Quarks to Stars

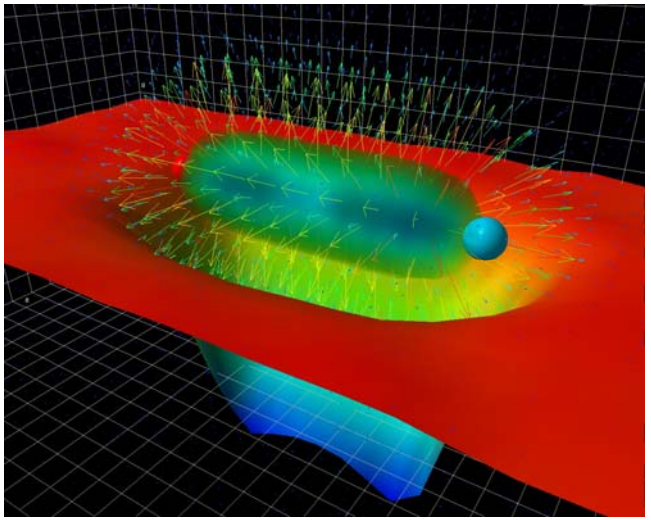
Jefferson Lab
Thomas Jefferson National Accelerator Facility

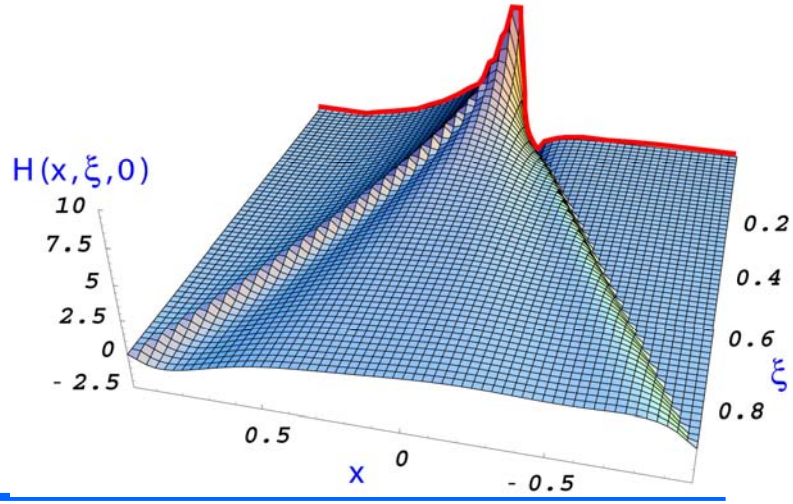
Office of Science
U.S. DEPARTMENT OF ENERGY

Operated by Jefferson Science Associates, LLC for the U.S. Dept. Of Energy

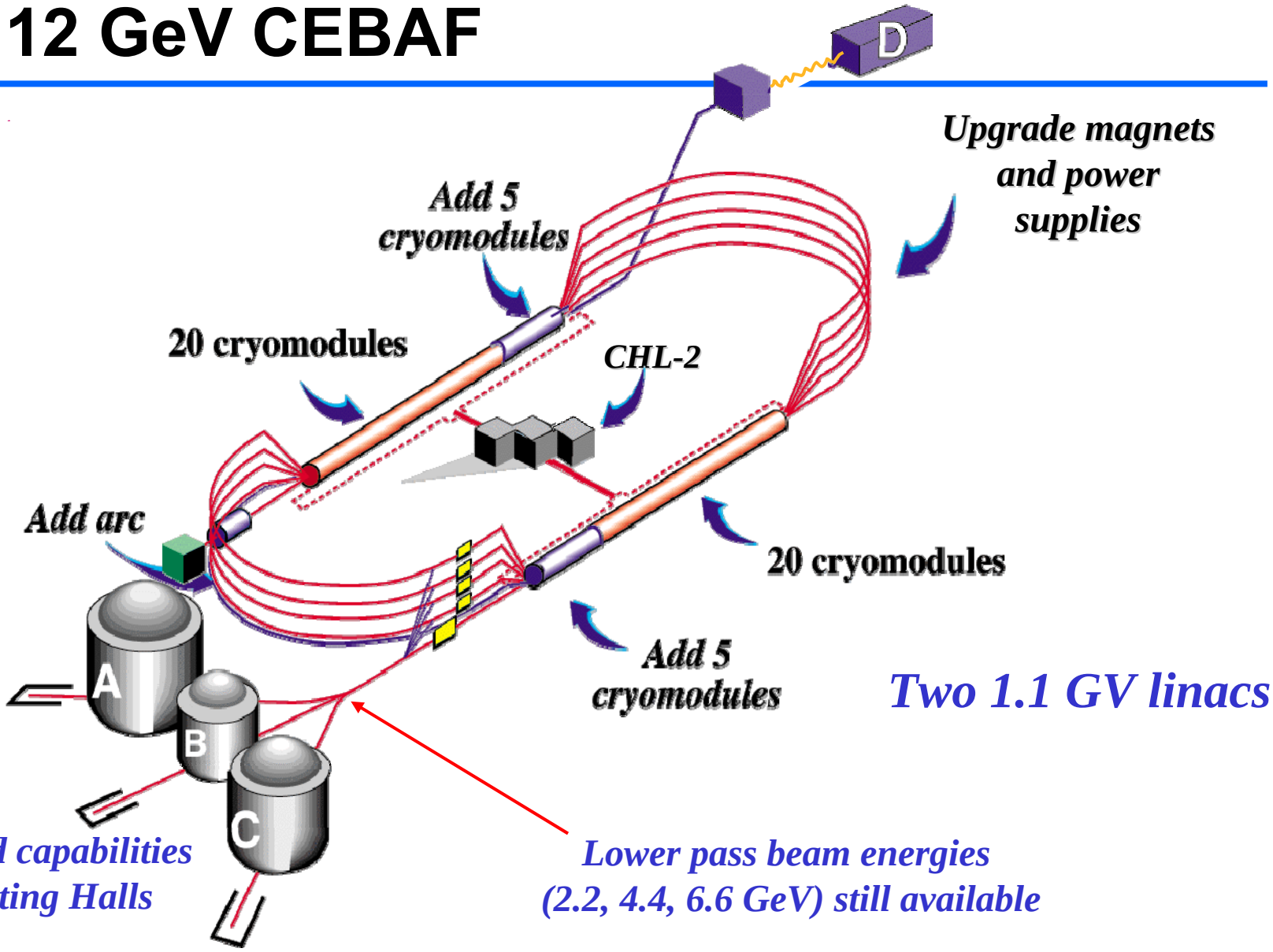
The 12 GeV Upgrade Will Support Breakthrough Programs in Four Areas:

- The experimental study of the confinement of quarks – one of the outstanding questions of the 21st century physics (Hybrid Meson Program)
- Dramatic improvements in our knowledge of the fundamental quark-gluon structure of the nuclear building blocks (GPDs and Valence PDFs)
- Further exploration of the limits of our understanding of nuclei in terms of nucleons and the *N-N* force
- Precision experiments with sensitivity to TeV scale physics beyond the Standard Model
- And other science we can't foresee





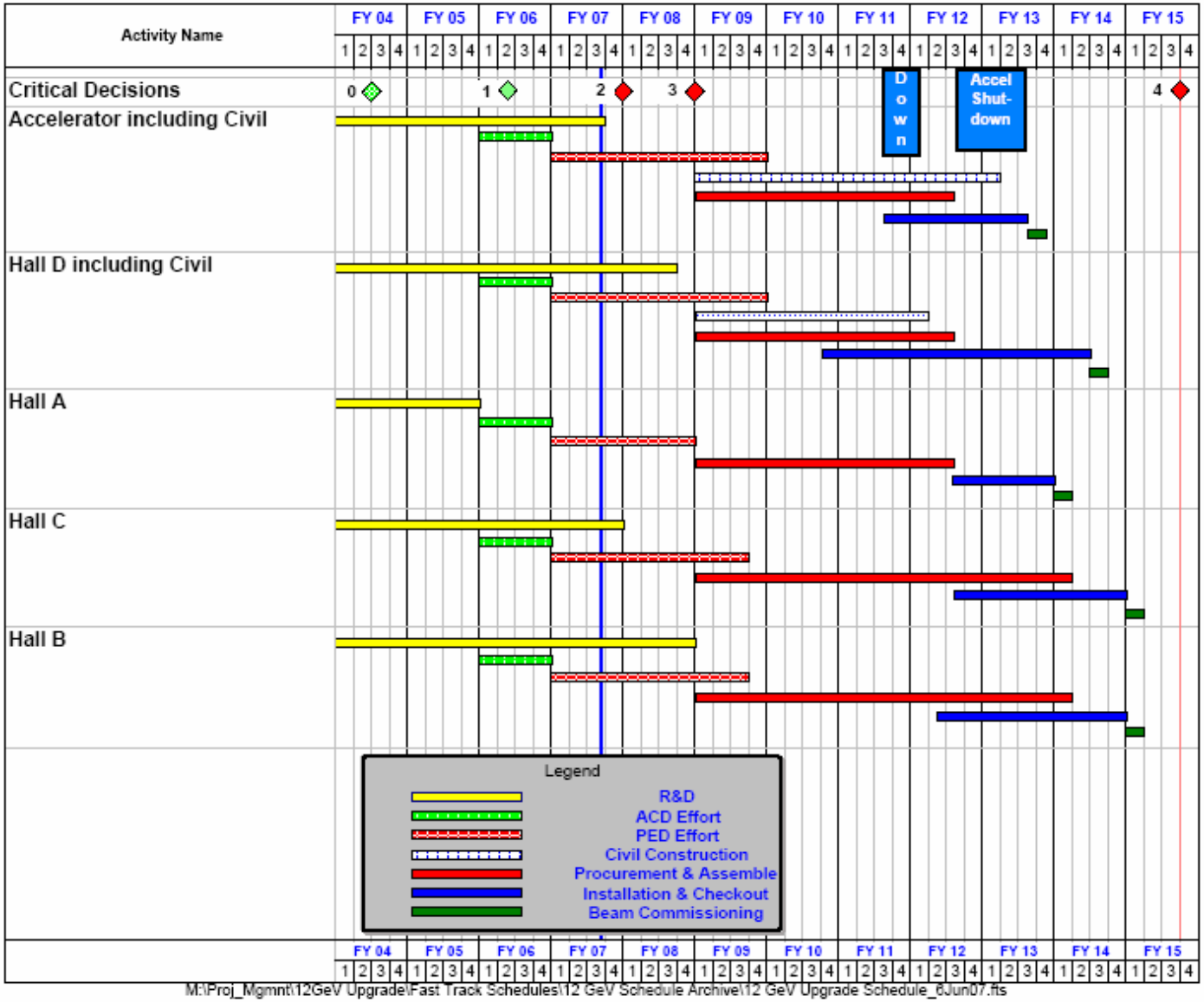
12 GeV CEBAF


D
Upgrade magnets and power supplies
Add 5 cryomodules
20 cryomodules
CHL-2
Add arc
20 cryomodules
Add 5 cryomodules
A
B
C
Two 1.1 GV linacs
Enhanced capabilities in existing Halls
Lower pass beam energies (2.2, 4.4, 6.6 GeV) still available

Project Planning (w/ Current DOE Guidance)

Begin construction (CD-3)	Fall 2008
Accelerator down	Spring 2012 thru Spring 2013
Accelerator commissioning	Summer 2013
Re-start research program	Fall 2013
Start research at 12 GeV	Summer 2014

12 GeV Schedule



High-level Parameters

	Now	Upgrade
ACCELERATOR:		
Beam energy	6 GeV	12 GeV
Voltage of each linac	0.6 GV	1.1 GV
Number of recirculations	5	5 ½
Beam power (total program)	1 MW	1 MW
Beam current (hybrid mesons)	-	5 μA
Emittance	1 nm-rad	7 nm-rad
Energy spread	0.01%	0.02%
CRYOPLANT	4.5 kW	9 kW
EXPERIMENTAL HALLS	3	4

Cryomodule Voltage and Cavity Gradient

What is needed?

Present: 6 GeV / 5 passes = 1.2 GeV / pass = 0.6 GeV / linac

12 GeV: 12 GeV / 5.5 passes = 2.2 GeV / pass = 1.1 GeV / linac

$\Rightarrow$ Need to add 0.5 GV / linac

Adding 0.5 GV / linac

- There are 5 empty zones at the end of each linac
- One 100 MV cryomodule per zone is the obvious solution

"100" MV cryomodules (C100)

- Exact requirement is 98 MV (average for each linac)
- Add ~10% for operational contingency $\Rightarrow$ 108 MV / cryomodule
- 8 cavities/cryomodule
- 7 $\lambda/2$ cells per cavity

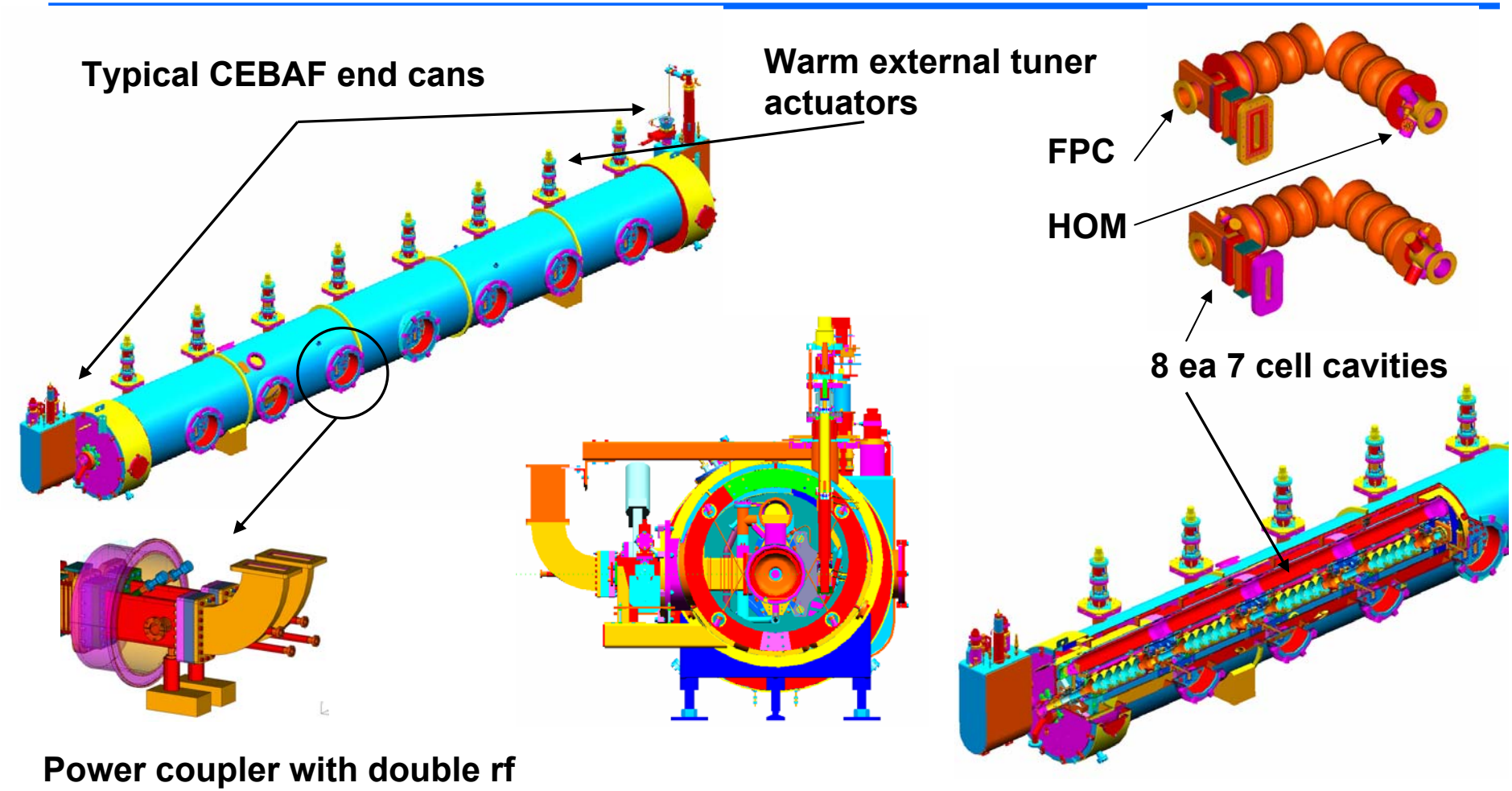
} 5.6m, the current cryomodule length

- 108 MV ÷ 5.6 m = 19.2 MV / m (Original CEBAF Spec. was 5 MV/m We've progressed significantly)

C100 Cryomodule: Key technical parameters

Voltage:	**≥ 108 MV (ensemble average in each linac)**
Heat budget:	
• 2 K	≤ 300 W
• 50 K	≤ 300 W
Slot Length:	**9.8 m**
Tuner resolution:	**≤ 2 Hz**
Fundamental Power Coupler, FPC:	**7.5/13 kW**
Higher Order Mode, HOM damping:	**Z < 6 x 108 Ω/cm2**
Cryomodule Length	**~8.5m**

C100 Cryomodule

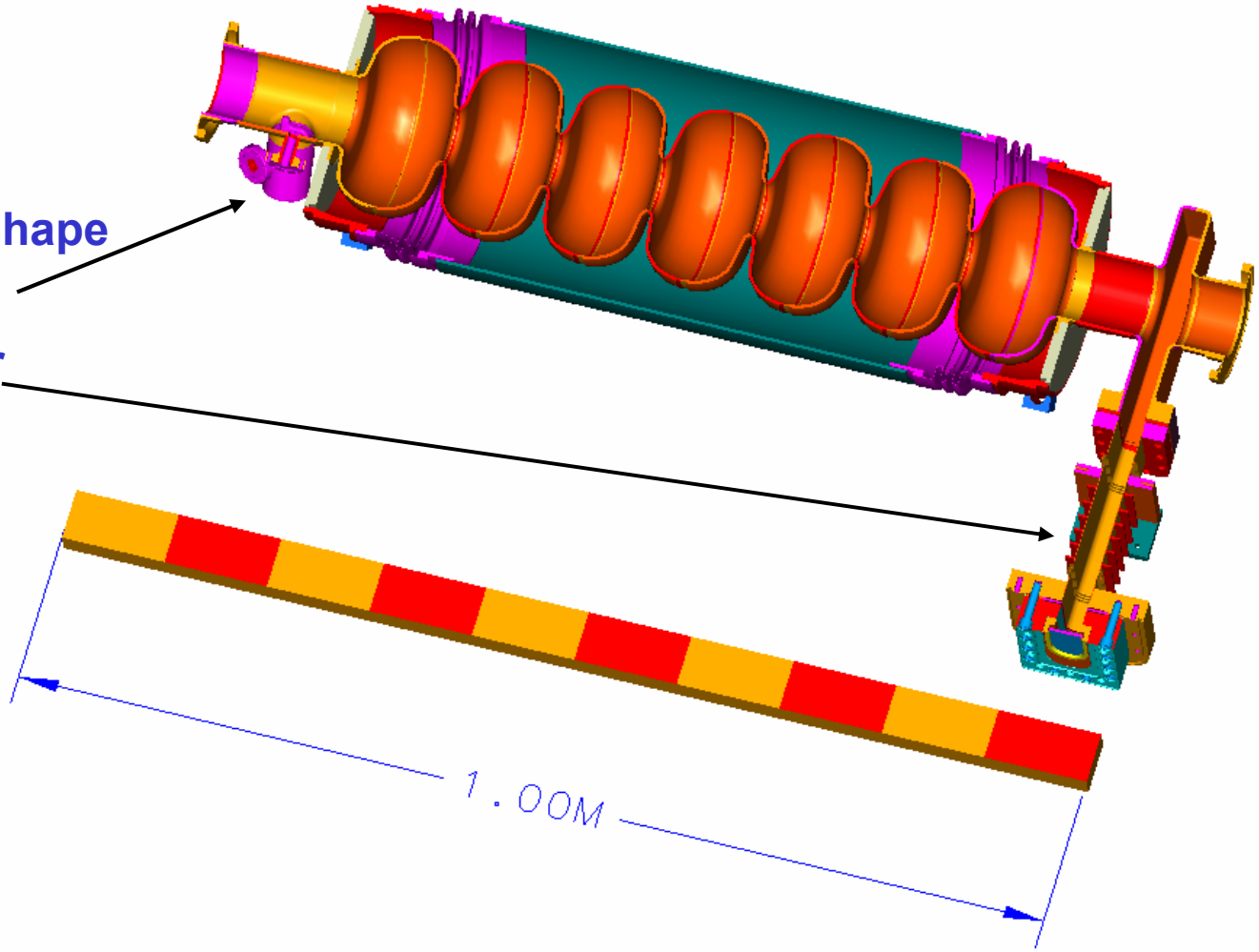


Power coupler with double rf window and interlocks

C100 Cryomodule Cavity

Cavity Design

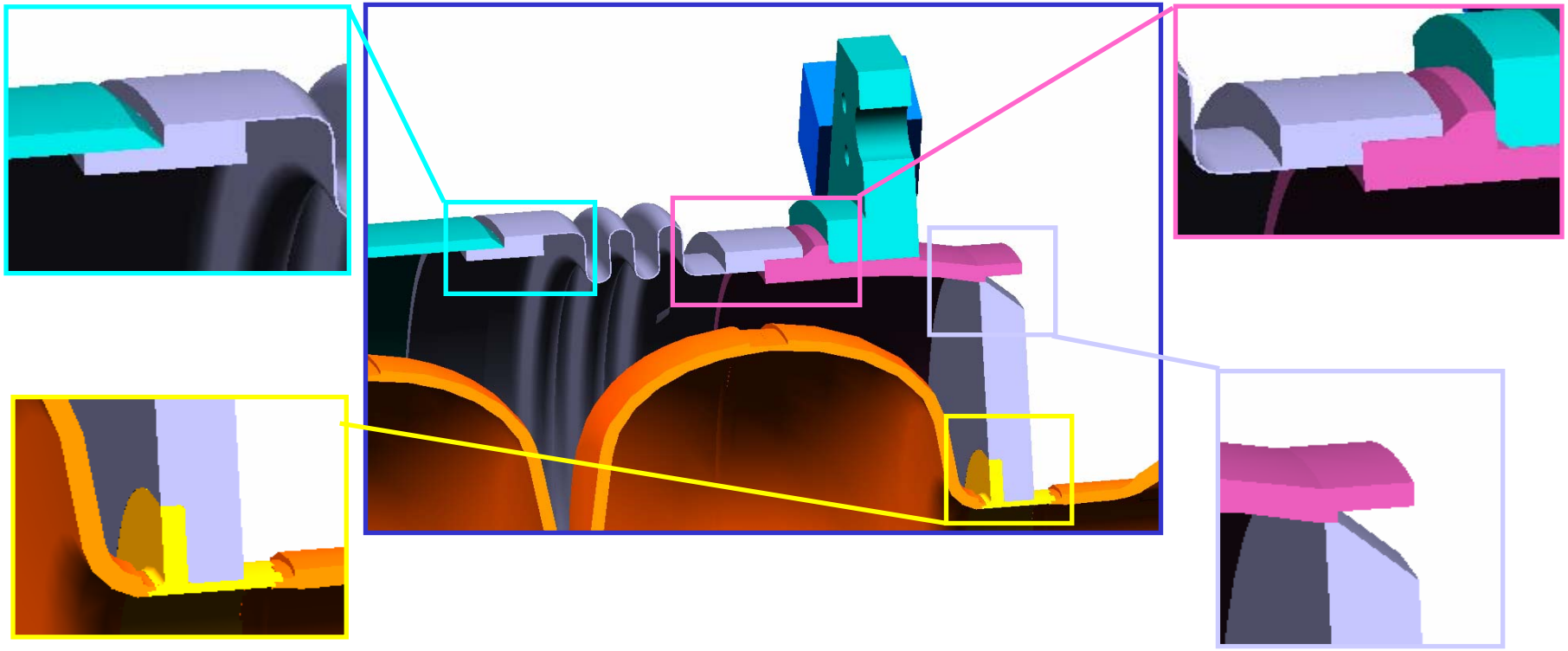
- 7 Cell Low Loss Shape
- 2 HOM Couplers
- Waveguide Power Coupler



C100 Cryomodule Helium Vessel

Redesigned the helium vessel

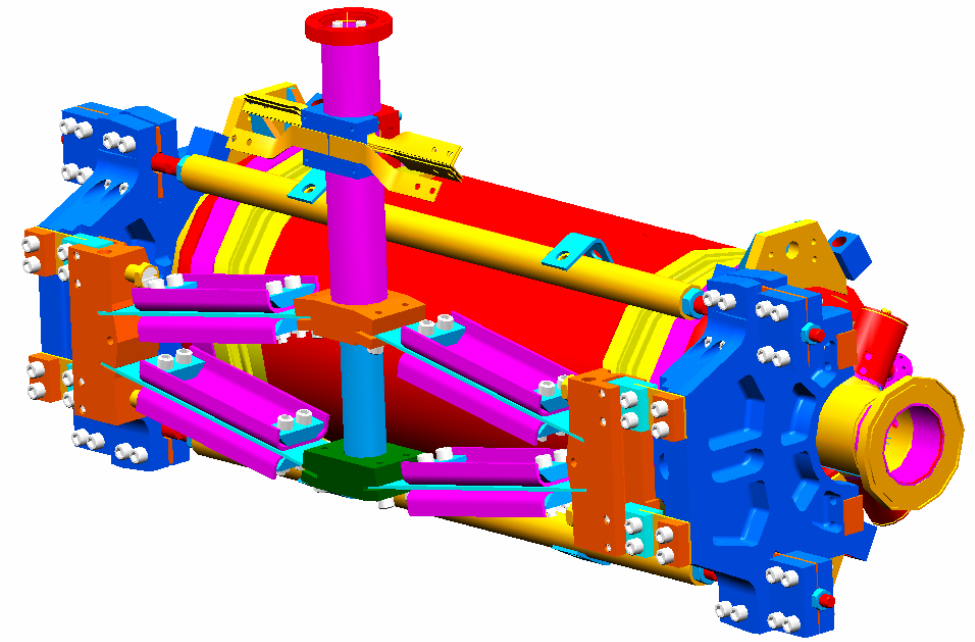
- Incorporate the tuner interface
- Stainless Steel design



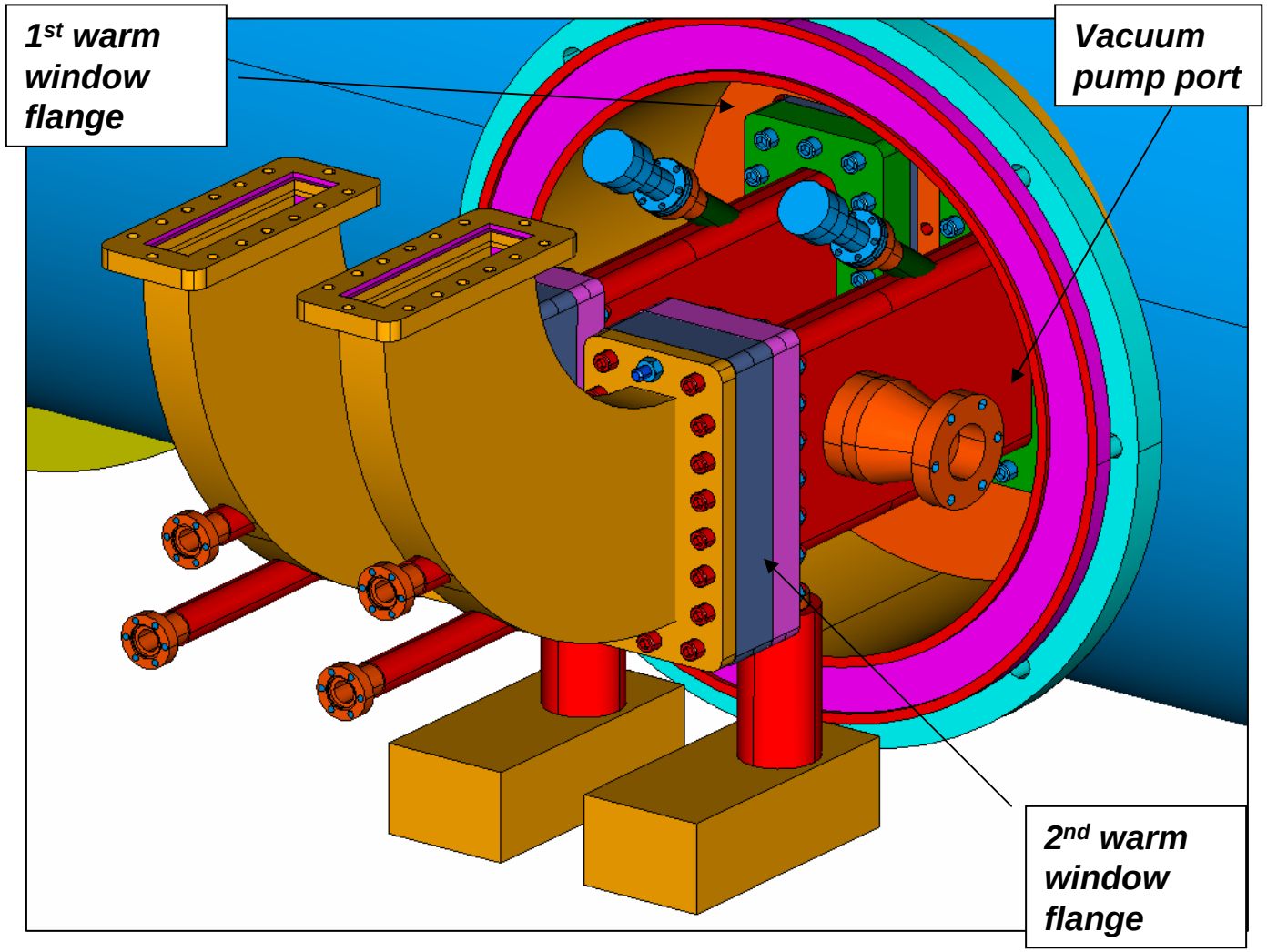
C100 Cryomodule Tuner

The cavity redesign allows us to use a tuner design that is in use in the CEBAF and FEL accelerators.

- **Proven excellent performance for range, resolution and backlash, the LLRF and operators love them**
- **All actuator components are mounted outside the cryostat and can be repaired or replaced without warming the cryomodule**



C100 Cryomodule RF Window R&D



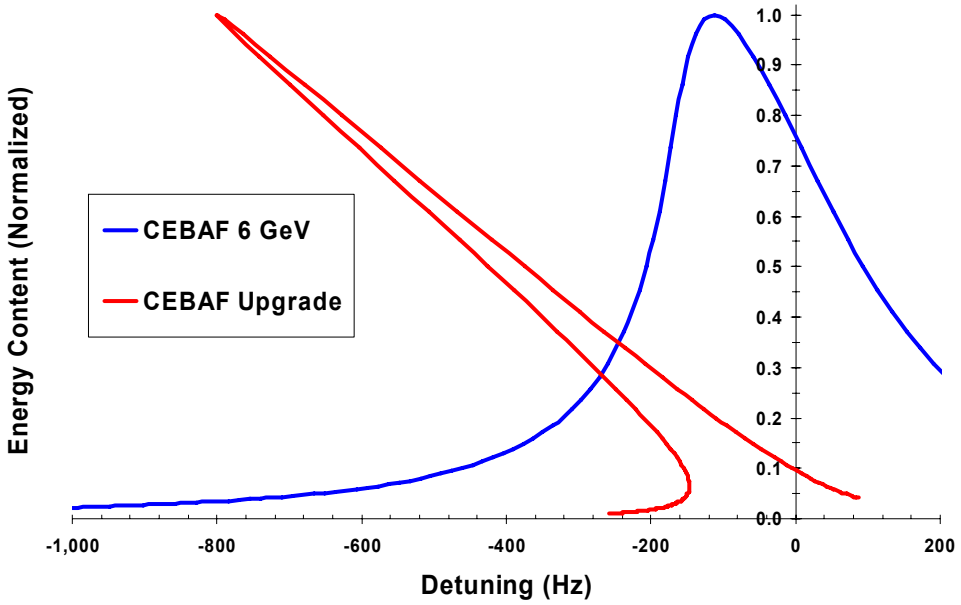
RF control

High-level performance requirements are the same as 6 GeV

- **Amplitude noise: $<1\times10^{-4}$**
- **Phase noise: $<0.2^{o}$**

But: We must deal with narrow bandwidth and large Lorentz detuning

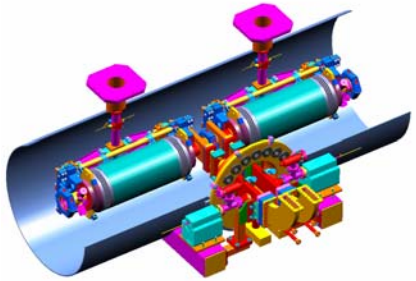
- **$Q_{external} \geq 3.2\times10^{7}$**
- **Stiffness $\approx$ 1.5 Hz/(MV/m)^2**
  - **$\Rightarrow$Very tilted detuning curve**

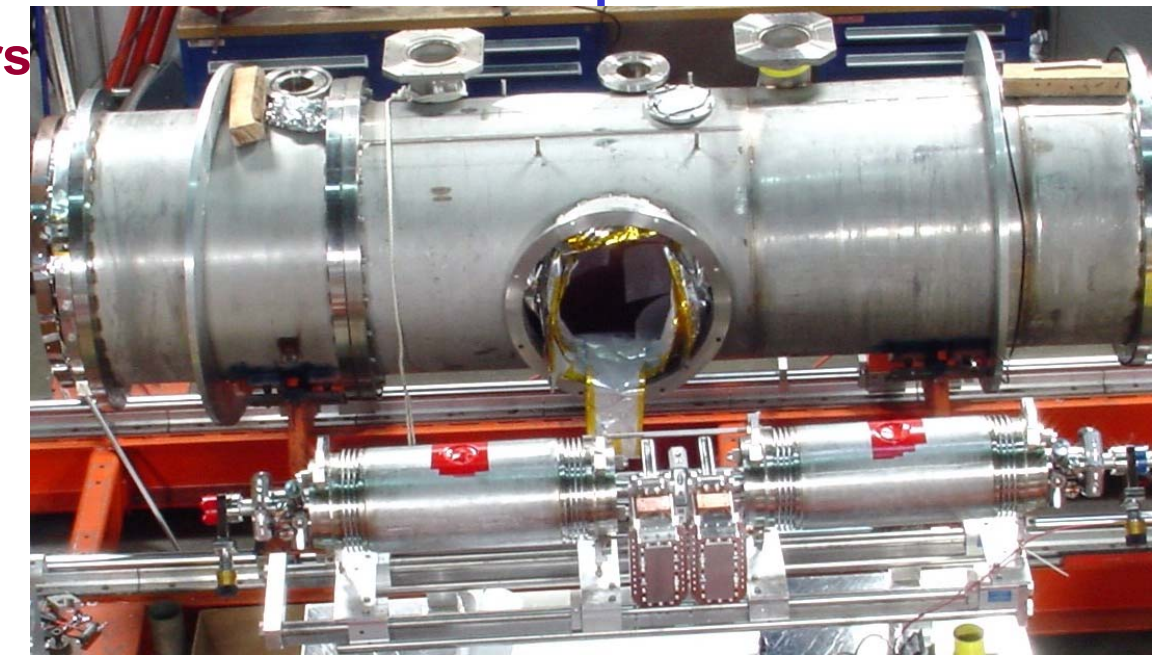


C100 Testing

Developed the plan for a ¼ cryomodule test

- Integrated test in our Horizontal Test Bed (HTB) cryostat
- Thermal conditions, static and dynamic heat loads, temperature gradients, …, will be the same as the full cryomodule design
- Complete design verification of all critical components
  - Cavity HOM Couplers
  - Double window FPC
  - Tuner
  - Helium vessel





SRF Performance

1st cryomodule intended to reach 100 MV (reported at PAC05): Thermal design of the cavity endgroups limited performance Redesign needed (and now completed)

Integrated cryomodule performance with the new design was tested in January, 2007 with a "1/4 cryomodule"

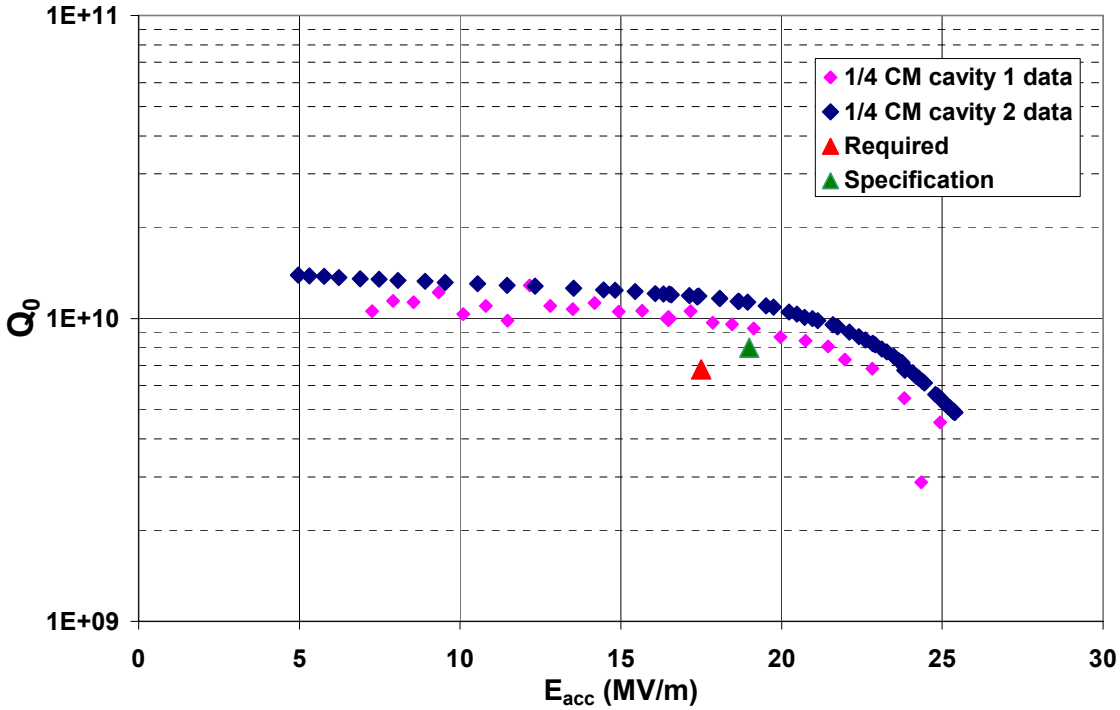
Cavity performance

Cavities achieved:

- **⩾19.2 MV/m at Q_0 ⩾ 8x10 in cw mode**
- **24 MV/m before quench**

Field emission was not an issue

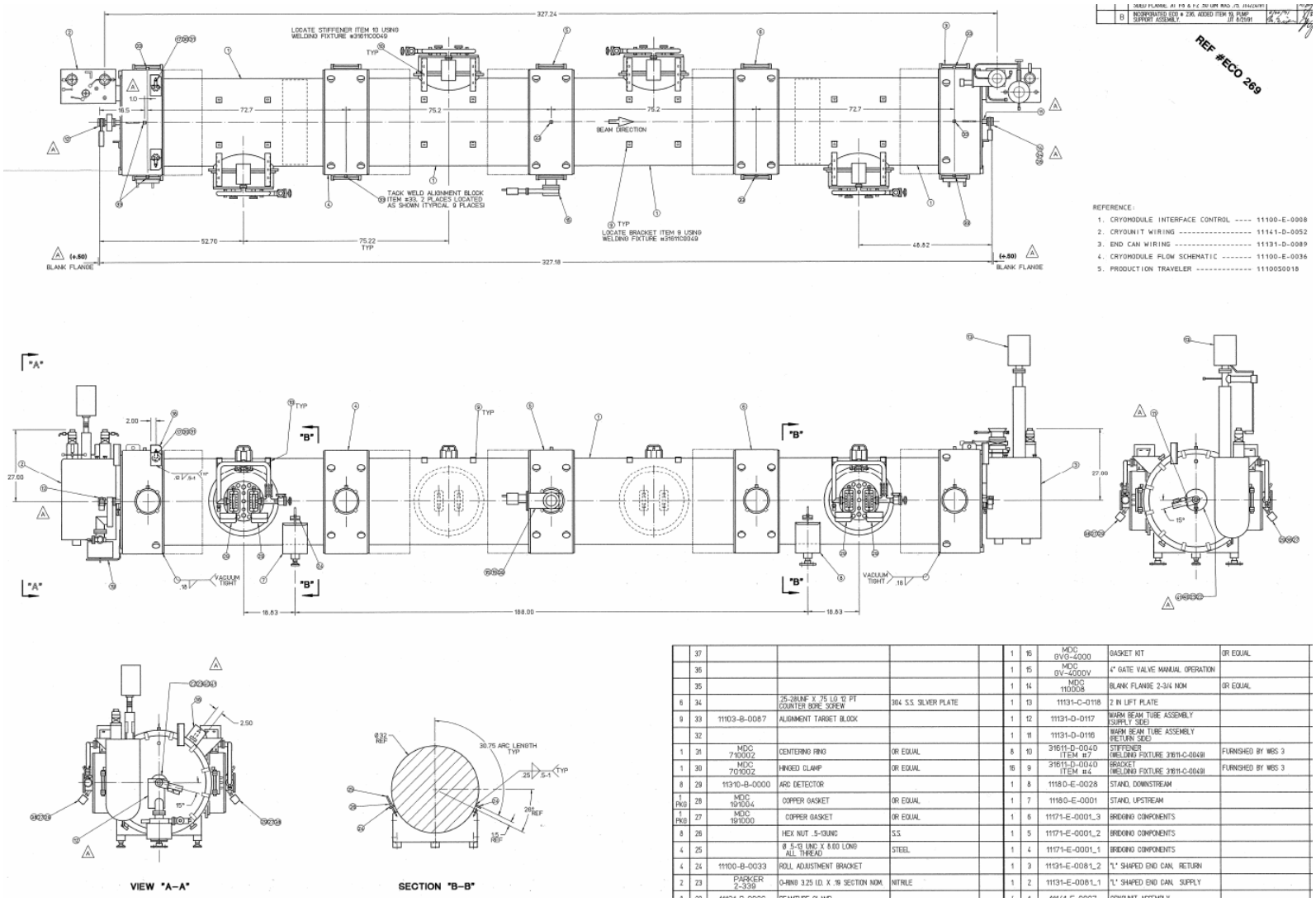
Tuners, windows, etc met or surpassed design requirements



C100 Cryomodule Summary

- A cryomodule appropriate for the CEBAF 12 GeV upgrade has been designed and prototyped.
- Prototype components and assemblies have been built and tested
- All system performance requirements have been met

CEBAF cryomodule re-work, C50



CEBAF re-work, C50

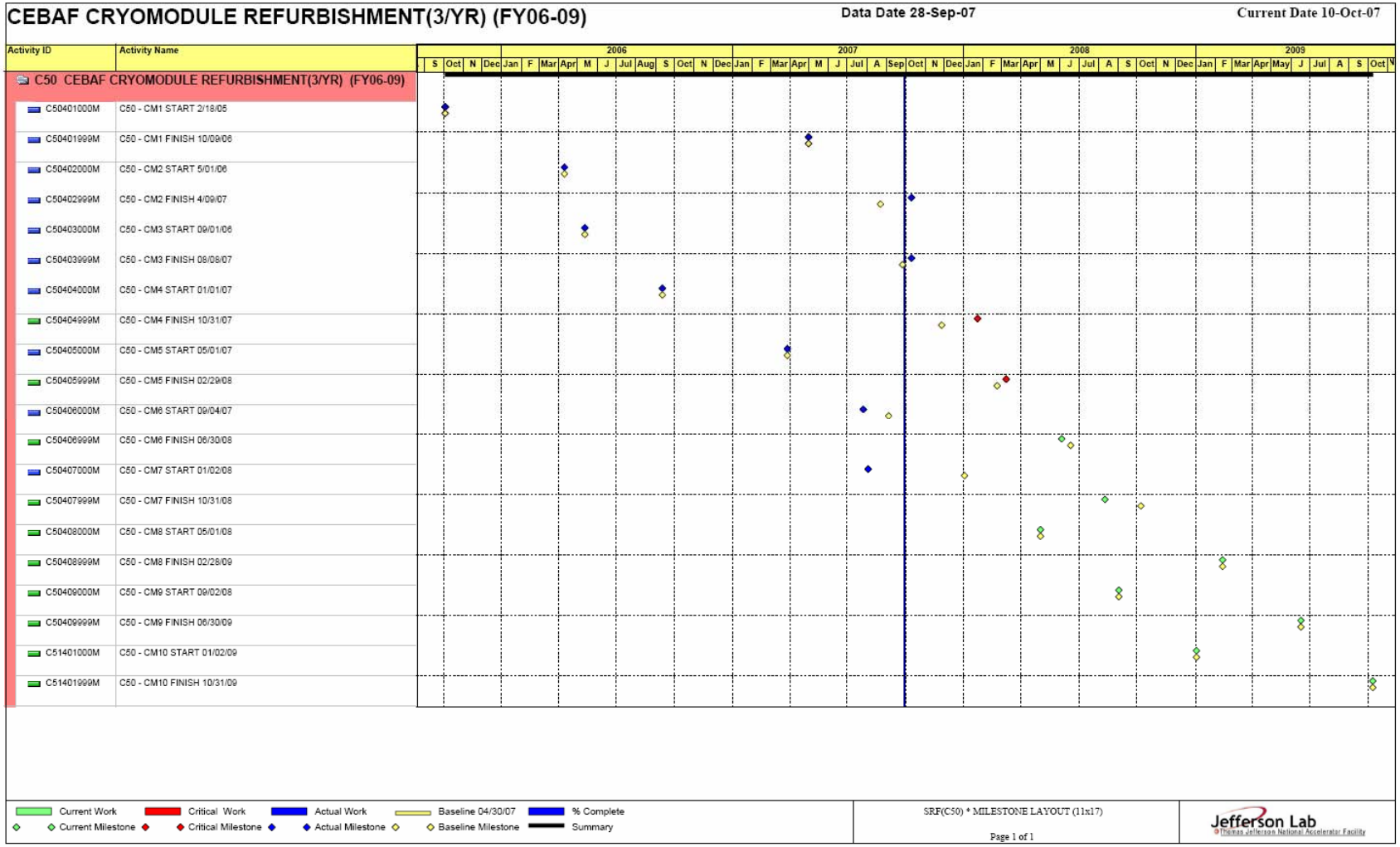
Performance of present CEBAF Linacs has been excellent but does degrade over time.

- **Hurricane power outage resulted in an uncontrolled warm-up of the CEBAF and FEL accelerators**
  - **Lost one complete and one partial cryomodule to helium leaks in vacuum joints**
- **Lost one cryomodule on a planned warm-up**
- **Cavity performance degradation has a yearly effect of ~ 65 MeV/yr**

Requires rework of cryomodules to maintain the 6 GeV capability required for the 12 GeV upgrade and present physics program

Original CEBAF plans were to rebuild 4 cryomodule/yr

C50 Schedule, 10 cryomodules at 3/yr

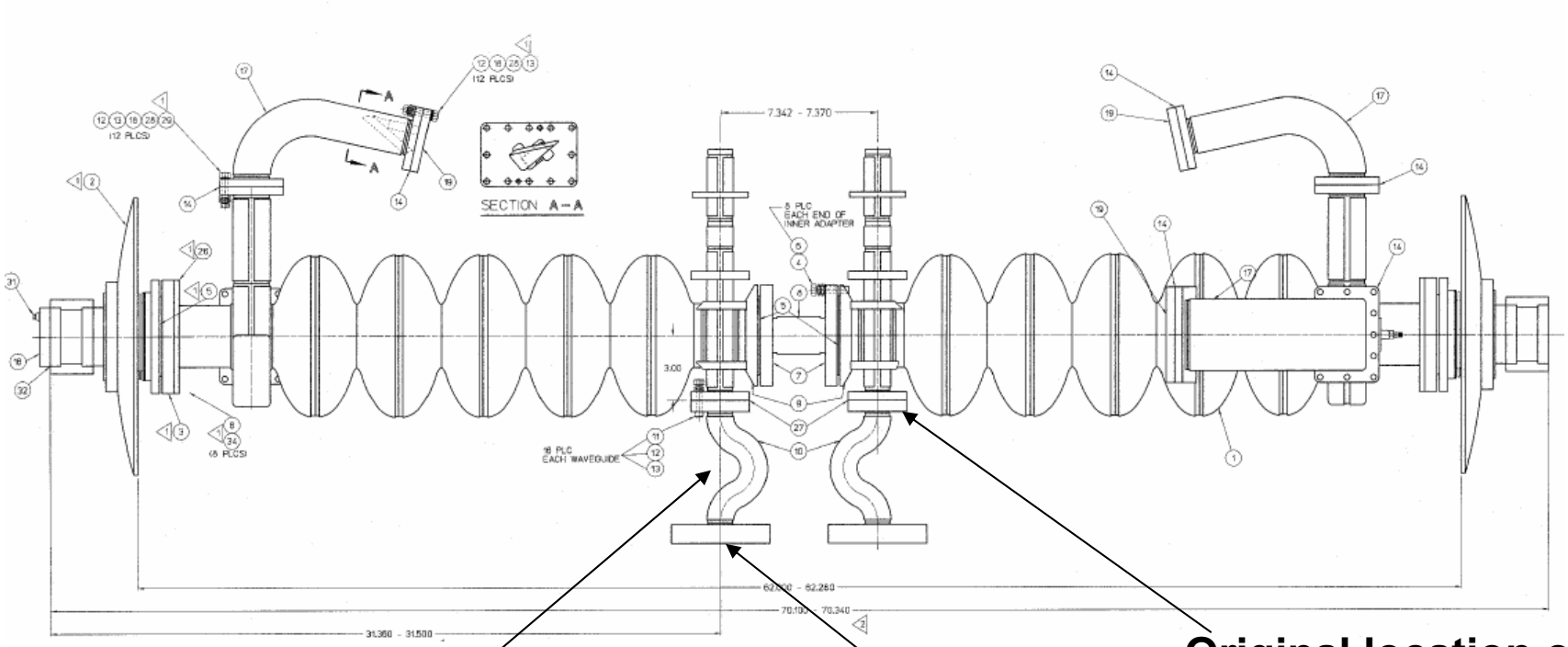


CEBAF re-work, C50 Project

Limited changes to the original CEBAF construction

- **Moved cold ceramic RF window in the power coupler that is the main source of cavity trips in the machine**
- **Added a "dogleg" waveguide to remove line of sight from the beamline to the cold ceramic window**
- **Improved the cavity tuner mechanical linkage to reduce backlash**
- **Changed warm polyethylene RF window to ceramic**
- **Using present "best" practices to process cavities**
  - **Closed Chemistry**
  - **High Pressure Rinsing**
  - **Hydrogen de-gassing**
  - **Controlled clean room procedures**

CEBAF re-work, C50, cavity pair



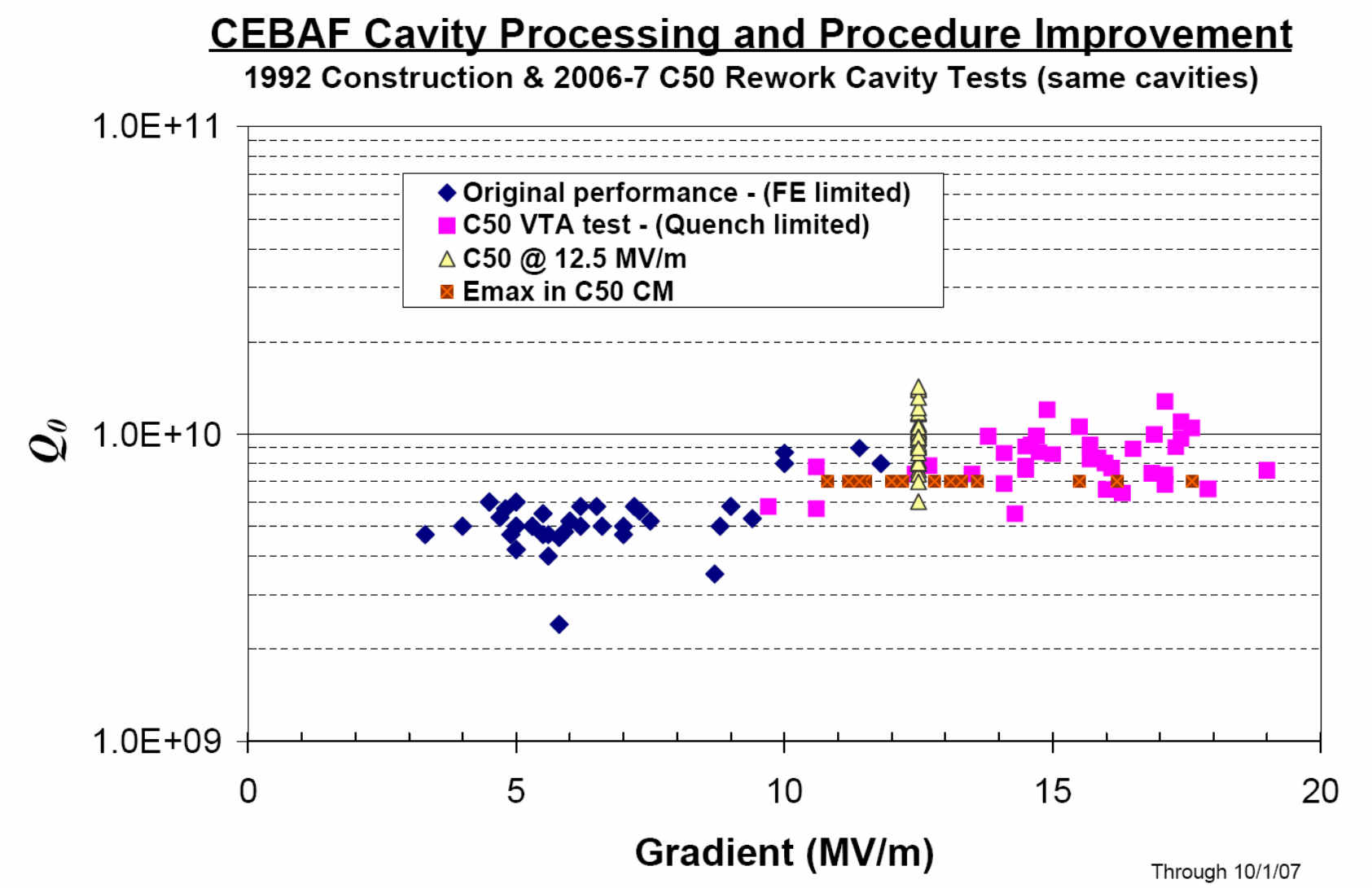
“Dogleg” Fundamental Power Coupler Waveguide

Eliminates power coupler arcing

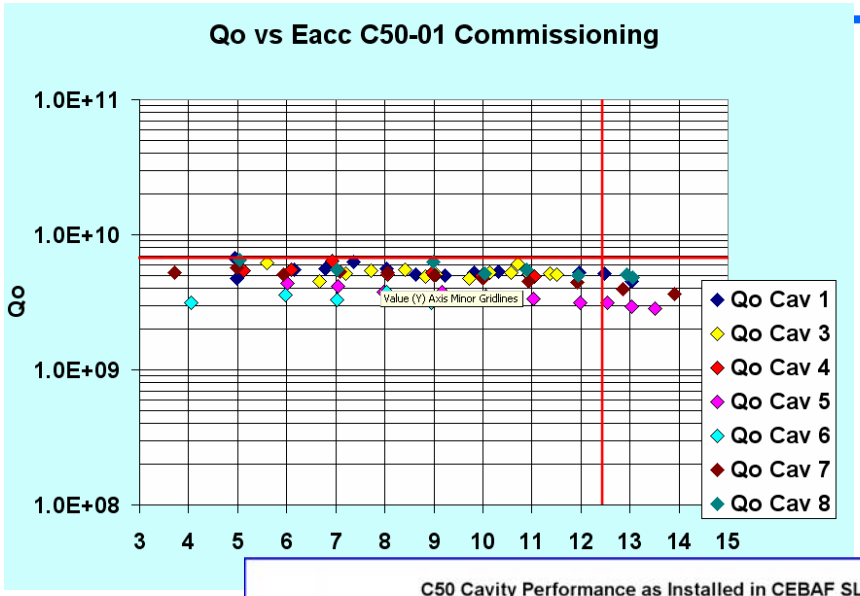
Original location of Ceramic RF window

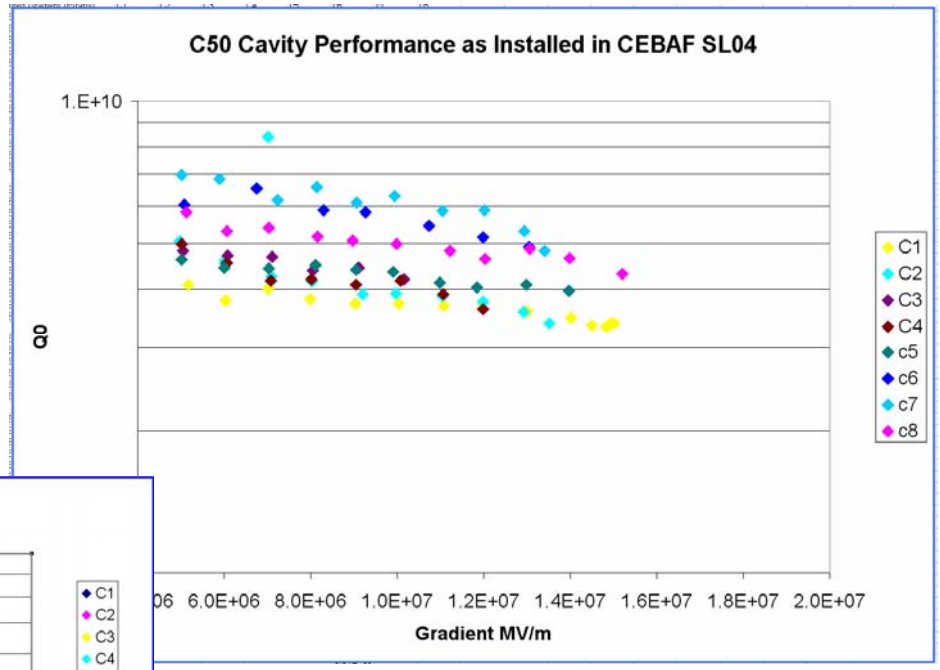
Ceramic RF window is part of the “dogleg” coupler

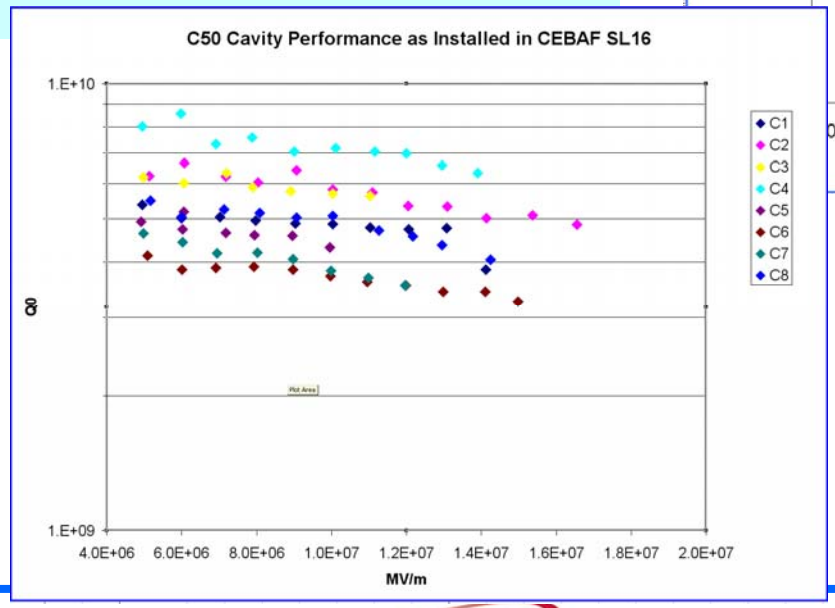
CEBAF cavity performance before and after C50



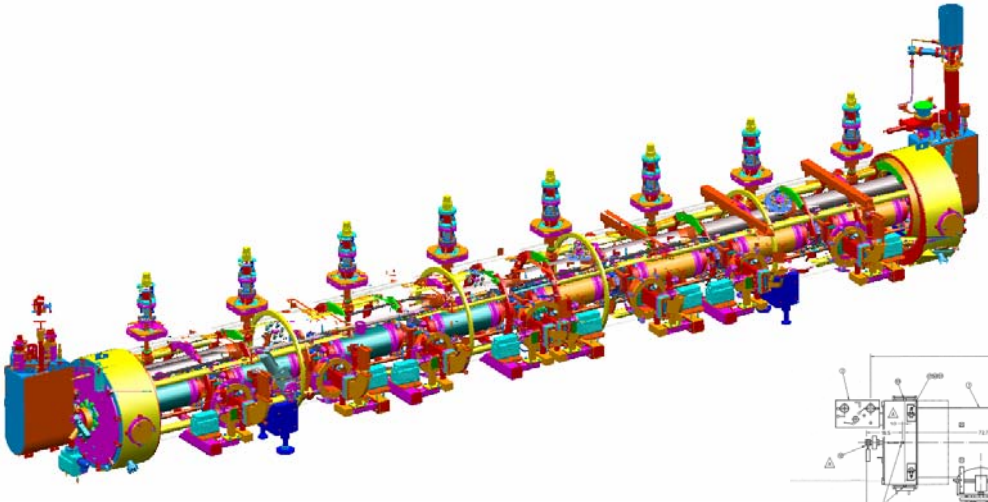
C50 Commissioning



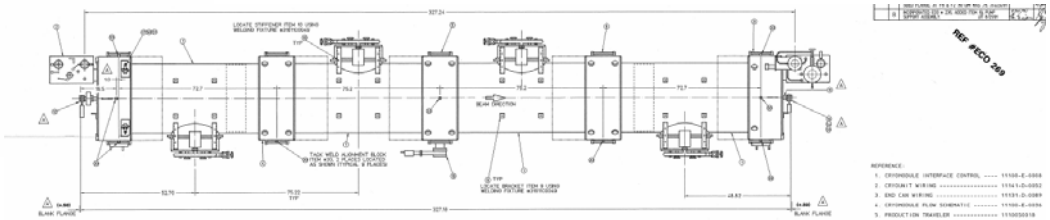




CEBAF cavity performance before and after C50



New Cryomodule Design,
cw, 100 MV, ½ mA
C100



Original CEBAF
Cryomodule
cw, 50 MV, ½ mA
C50