CEBAF Overview

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Accelerator Operations

- What is a CEBAF?
- Mission
- Timeline
- Machine Overview
- Injector
- Linear Accelerators
- Recirculation Arcs
- Extraction Systems
- Beam Specifications
- Beam Operations and Safety
- 12 GeV Upgrade

What is CEBAF?

Prior to 1996 Jefferson Lab was called CEBAF.
Continuous **E**lectron **B**eam **A**ccelerator **F**acility.
It is now the Thomas Jefferson National Accelerator Facility or Jefferson Lab.
Jefferson Lab is a basic nuclear physics research laboratory operated for the US Department of Energy by the Jefferson Science Association, LLC.

Mission Statement

Jefferson Lab, a forefront U.S. Department of Energy nuclear physics research facility, provides world-class, unique research capabilities and innovative technologies to serve an international scientific user community.

Specifically, the laboratory's mission is to:

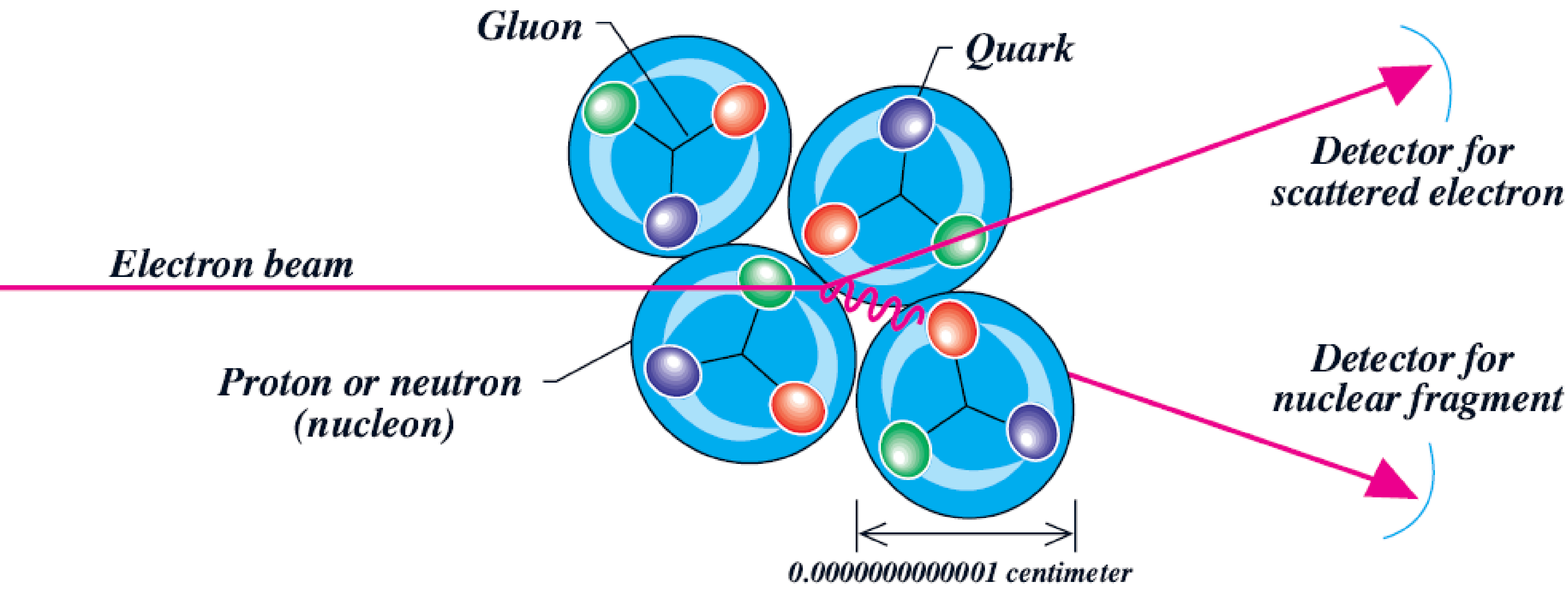
Deliver discovery-caliber research by exploring the atomic nucleus and it's fundamental constituents, including tests of their interactions;

Apply advanced particle accelerator, detector and other technologies to develop new basic research capabilities and to address the challenges of modern society;

Advance knowledge of science and technology through education and public outreach and;

Provide responsible and effective stewardship of resources.

Electrons and Nucleus Collide!



CEBAF Overview Timeline

- 1984 - DOE provides funding for new facility
- 1987 - Construction Begins on CEBAF
- 1995 - First Physics Experiments Begin
- 1997 - 4 GeV Three-Hall Simultaneous Operations
- 2004 -12 GeV Upgrade Development Team Formed
- 2004 - Engineering/Design of 12 GeV Machine Begins
- 2005 - C-50 Program to Reach 6 GeV Begins
- May 18th 2012 8:18 – Began the Long Shut Down (LSD)
- 2012 & 2013 - 12 GeV Installation work
- Late 2013 – Began 12 GeV Commissioning
- May 7th 2014 – 5.5-pass beam on the Hall D Tagger Dump

CEBAF Overview Aerial View

- 5.5-pass Electron Accelerator
- Four user facilities (A, B, C, D)
- Photo Injector
- Two 1497 MHz Linacs
- Two Recirculation Arcs
- Dynamic Physics Program Requiring Frequent Energy & Pass Changes
- >90% Polarization
- Small Helicity-Correlated Beam Asymmetries

CEBAF Overview CEBAF Tunnel

- The circumference of the tunnel is ~7/8 mile (1.4 km).
- Two superconducting linacs (linear accelerator), each ~1/4 mile long.
- The base of the tunnel is 30’ below the surface.
- The tunnel is 10’ high and 13.5’ wide.

CEBAF Overview   Tunnel with Beamlines

Beamline Under Vaccum

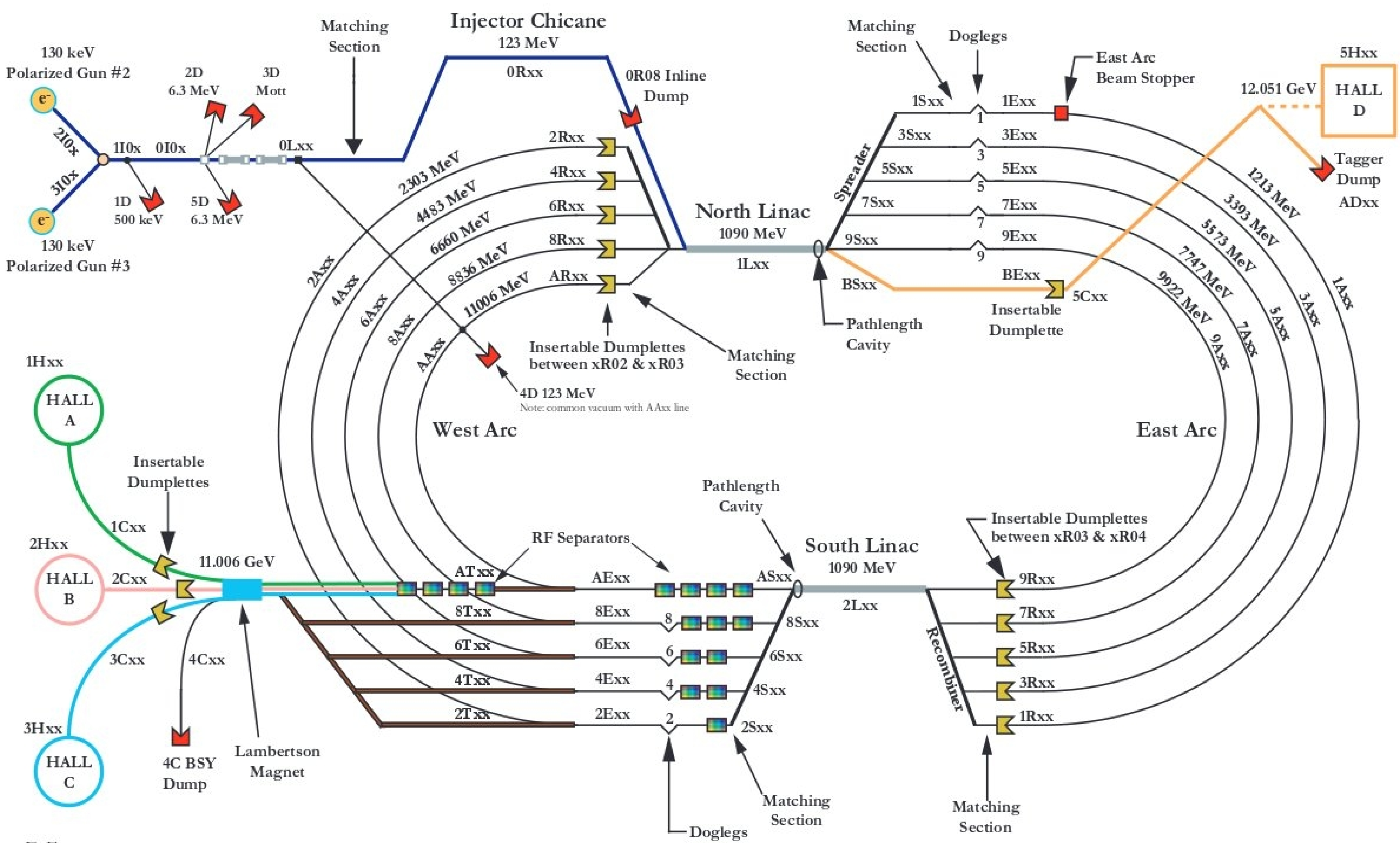
- Beamlines are made of stainless steel with diameters from 1 inch to 24 inches.

- They are under high vacuum ranging from 10^{-6} to 10^{-11} torr. (Outer space ranges from 10^{-6} near Earth to 10^{-17} in deep space)

- There are ~450 ion vacuum pumps in the arcs spaced ~ 8m apart.

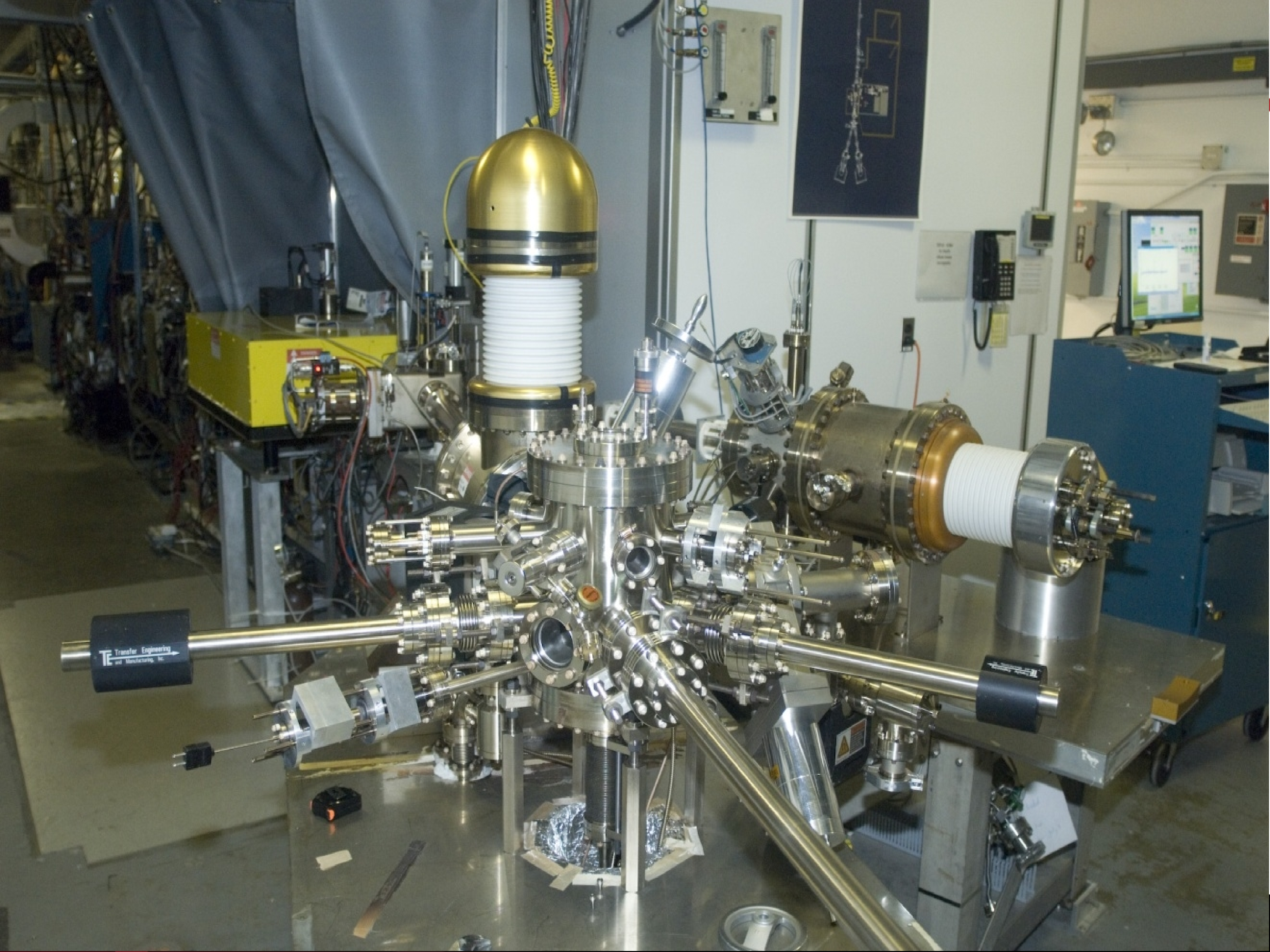
- Fast acting and slow acting valves isolate regions of the beamline for maintenance and automatic leak isolation.

CEBAF Overview CEBAF Beamline



Synchronous Photoinjection

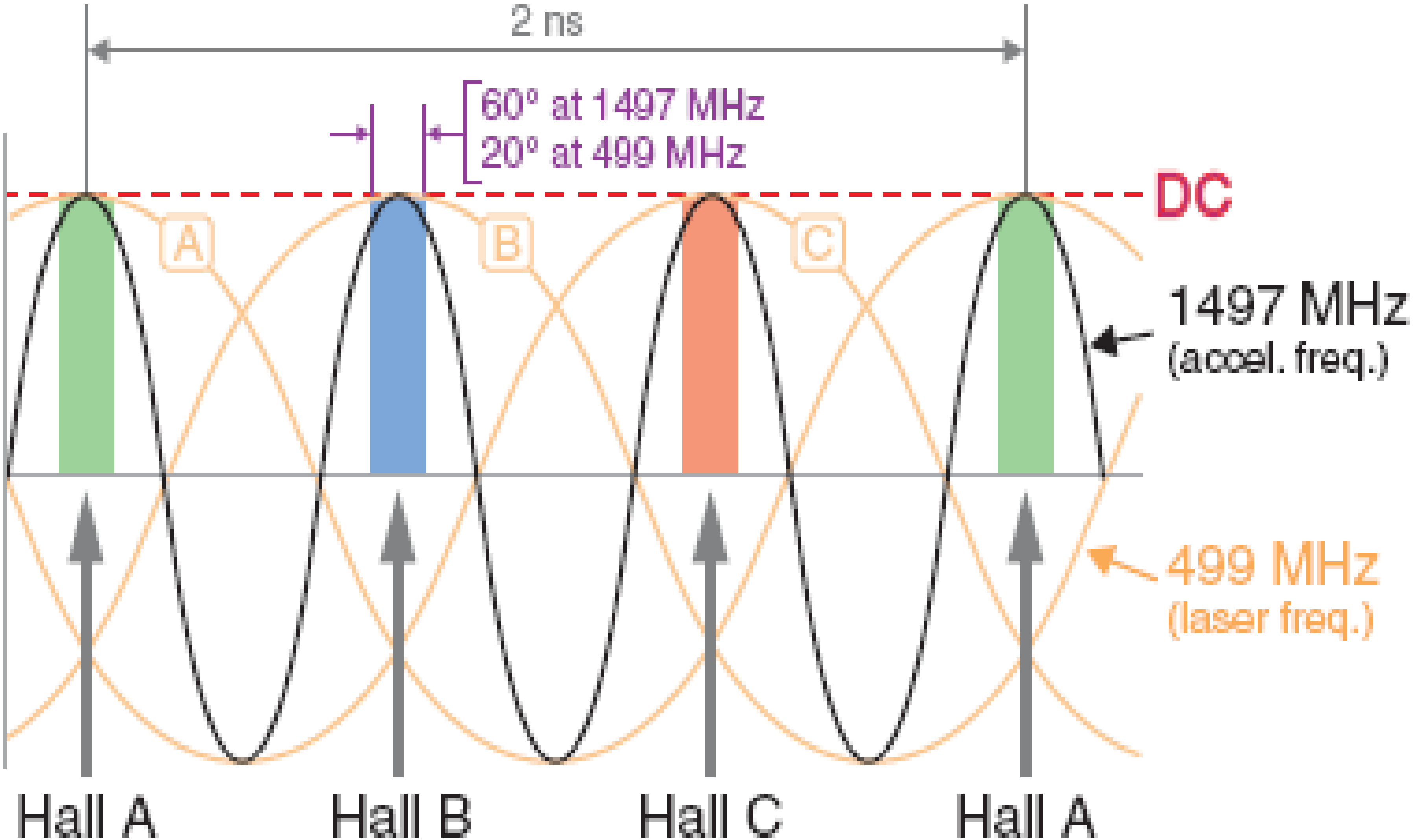
- Light in the near-infrared range shines on a Gallium Arsenide photocathode releasing electrons through the photoelectric effect.
- A high negative charge of -130kV on the cathode repels them into the beam line.
- There are two electron guns in the injector. One to use and the other as an installed spare.
- The in use gun incorporates a load-locked design. Magnetic manipulators allow the cathode wafer to be removed from the main gun chamber for cleaning, cesiation, or change out while maintaining the ultra high vacuum in the main chamber.


Transfer Engineering

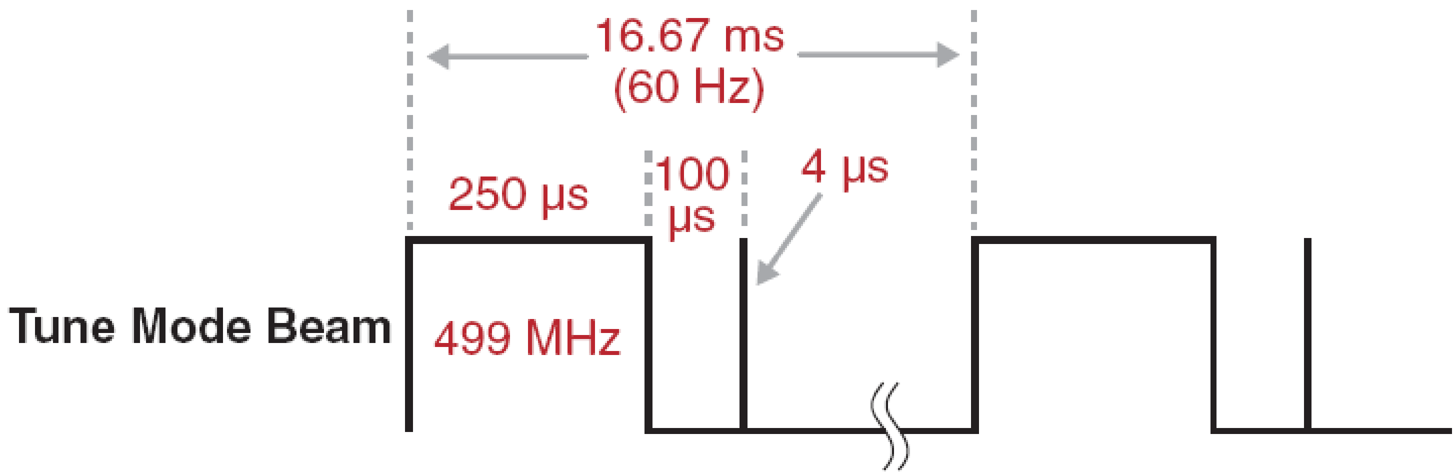
Synchronous Photoinjection

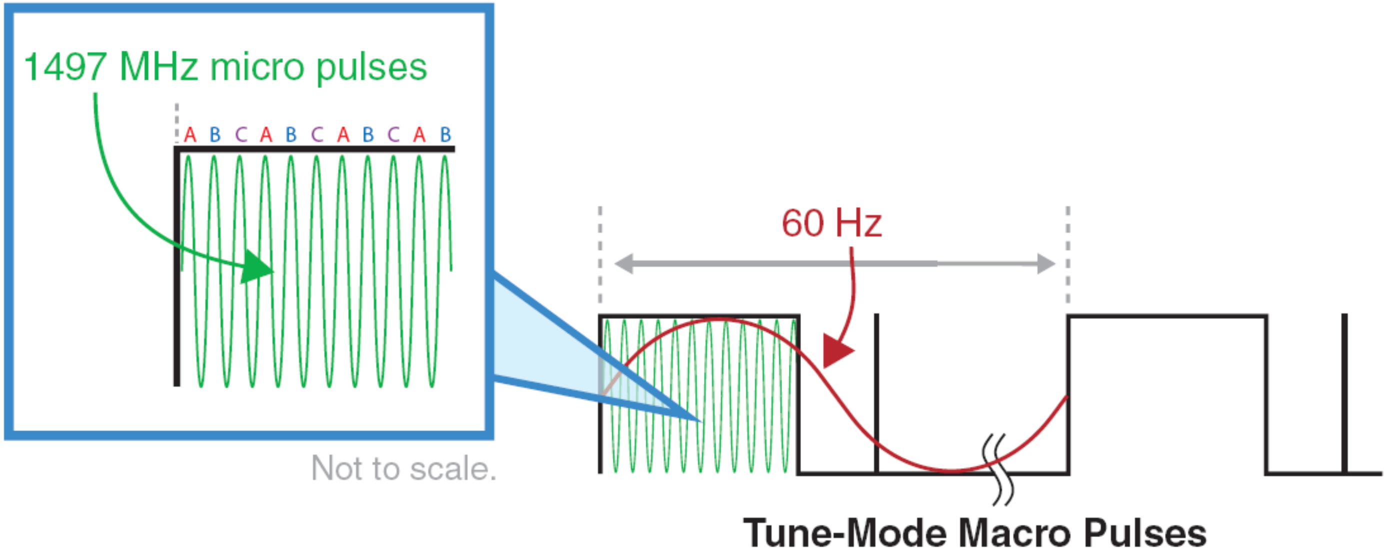
- The light that shines on the photocathode is pulsed at 499 MHz. The pulses are 40 – 50 ps in length.
- 499 MHz is a sub-harmonic of the fundamental accelerator operating frequency 1497 MHz
- During three-hall operations, three separate 499 MHz lasers—one for each hall—are used to generate three interlaced electron beams.
- Continuous Wave Beam for Physics (CW)
- Pulsed beam for optics tuning (Tune)

Continuous Beam Formation



CEBAF Overview   Tune Mode (Pulsed) Beam Formation

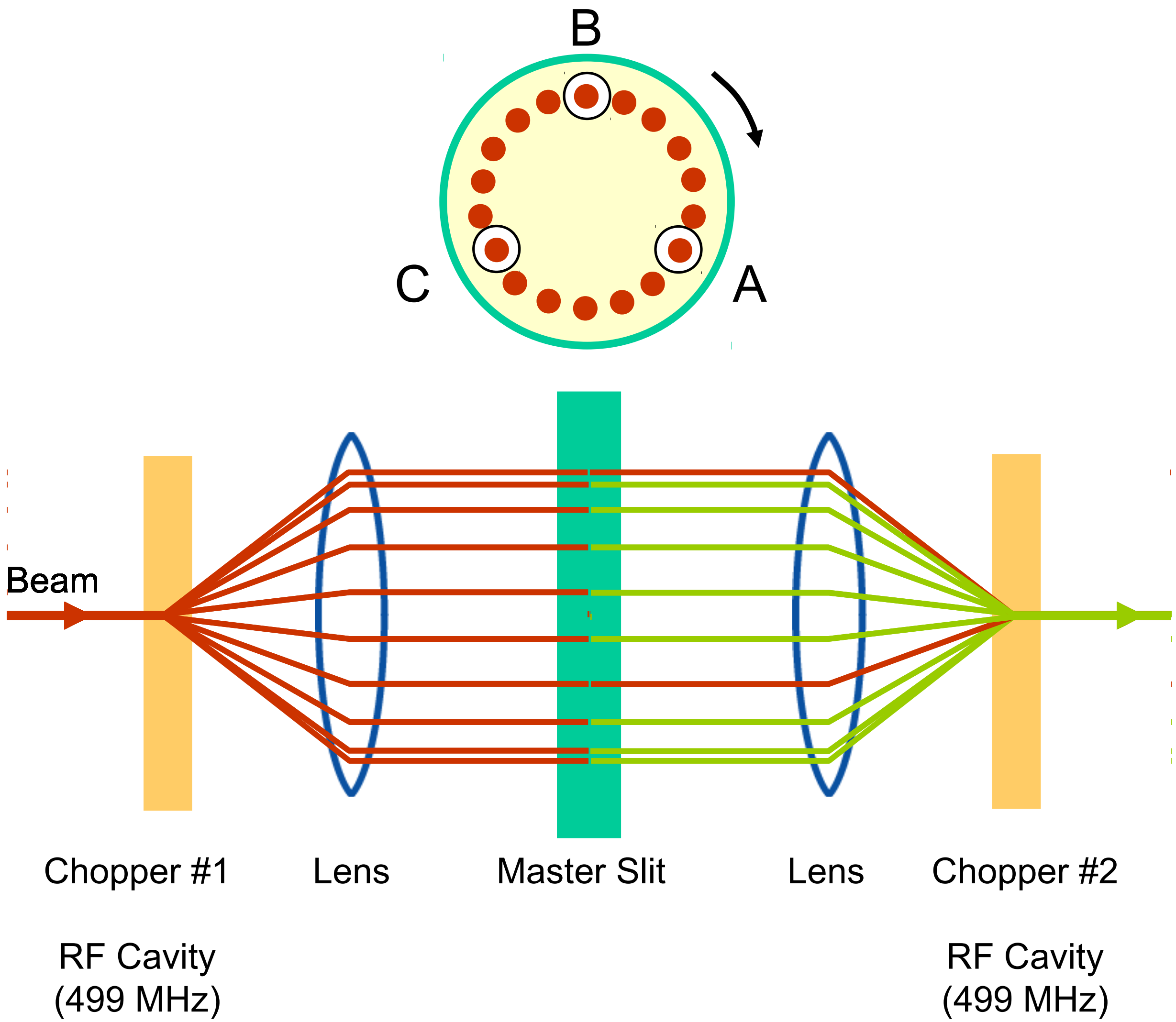




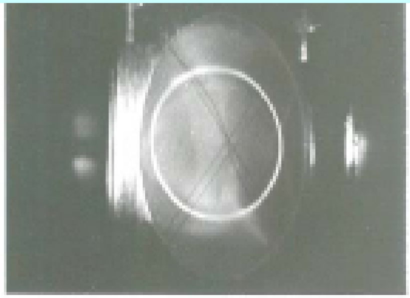
Chopping System

- Electron bunches from the 130 kV photocathode gun is sent through a 499 MHz chopper cavity
- Transverse orthogonal magnetic fields rotate the beam in a circle of ~1.5 cm radius
- Slits at 0°, 120° and 240° degrees allow bunches of electrons to pass
- Chopper slits and laser intensity are individually controlled to regulate currents for Halls A, B & C
- The three beams are recombined by another 499 MHz chopper cavity
- 40 – 50ps pulses grow longitudinally to 50 – 90ps bunches by the time they get to the chopper. >110 ps can not fit through chopper slit. A Pre-buncher compresses bunches to fit in chopper.

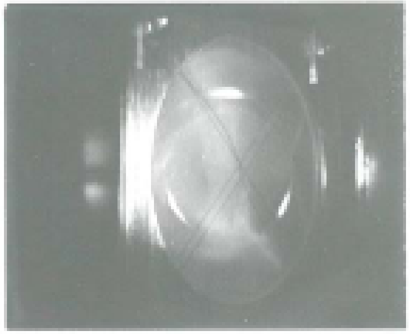
Chopping System



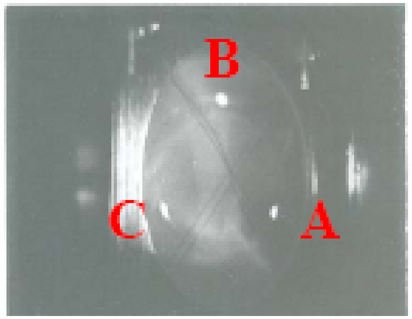
Shared Injector Chopper



DC Light, Most beam thrown away



Three independent RF-Pulsed lasers



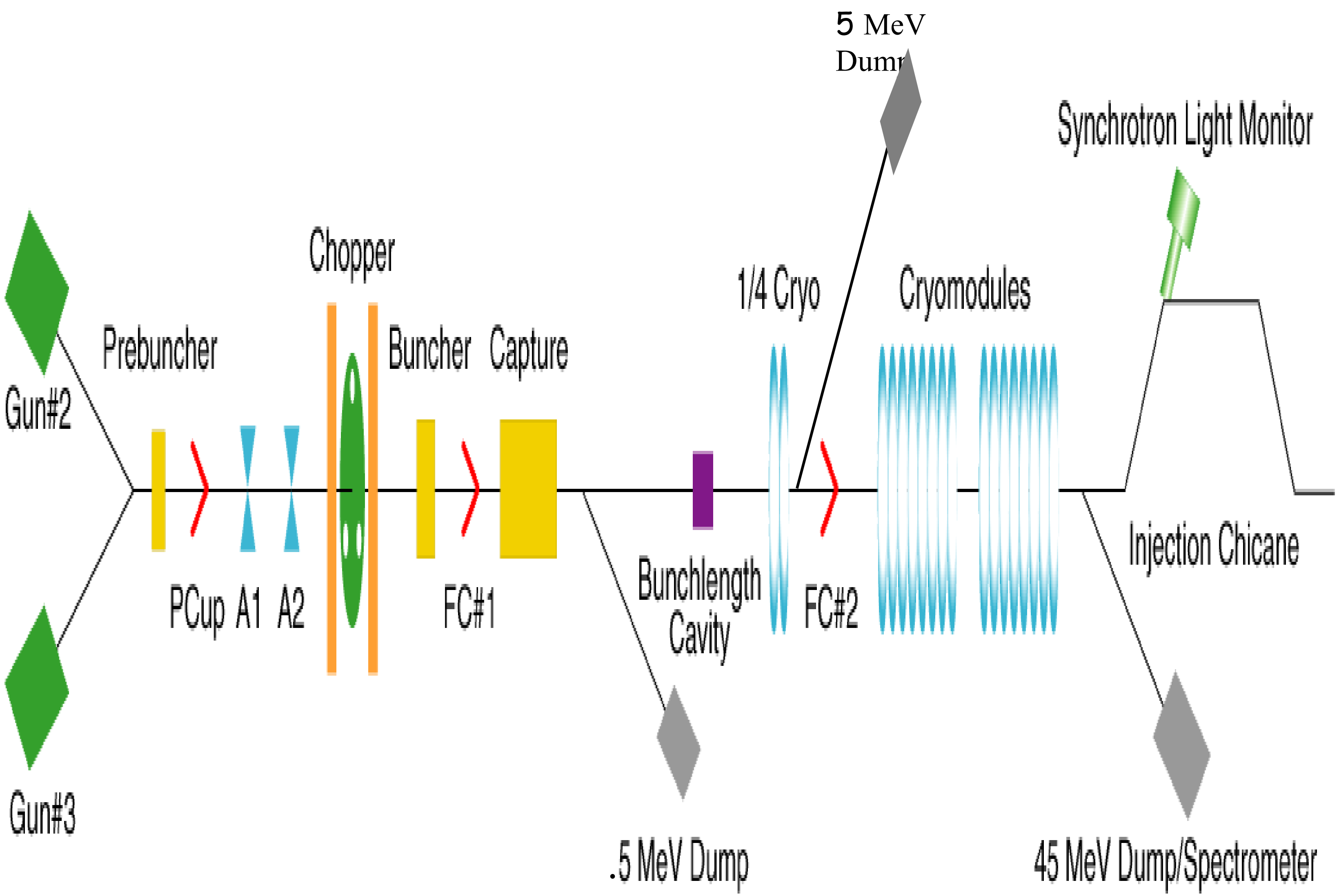
Now add prebuncher

Efficient beam extraction prolongs operating lifetime of photogun.

Lasers with GHz pulse repetition rates have been hard to come by

Lasers don't turn completely OFF between pulses: Leakage (aka crosstalk, bleedthrough)

CEFAF Overview Injector Layout



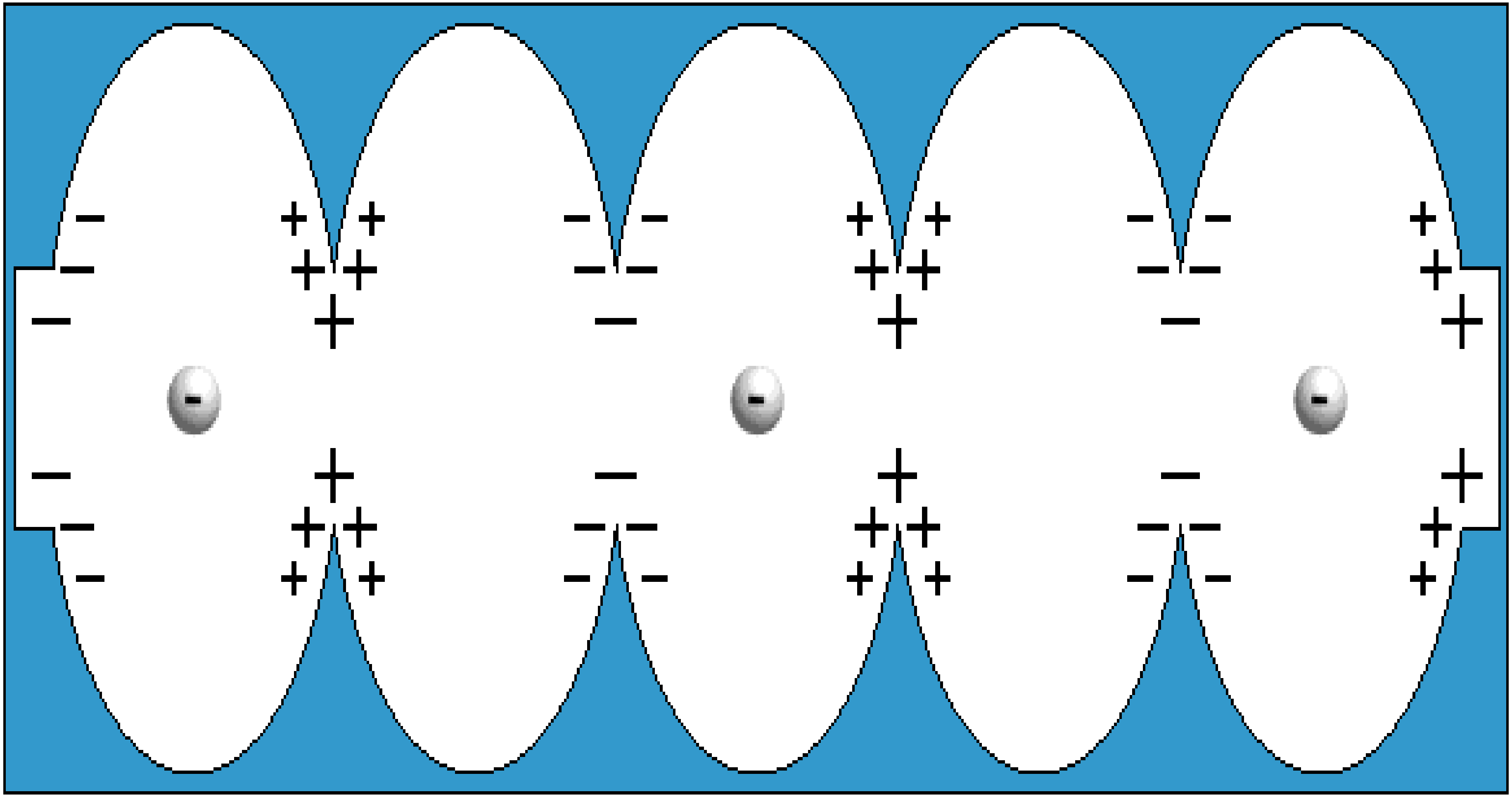
Acceleration of Electrons

- The electrons gain energy by placing negative charges behind them and positive charges in front of them. Devices we call cavities are used to set up these charges.

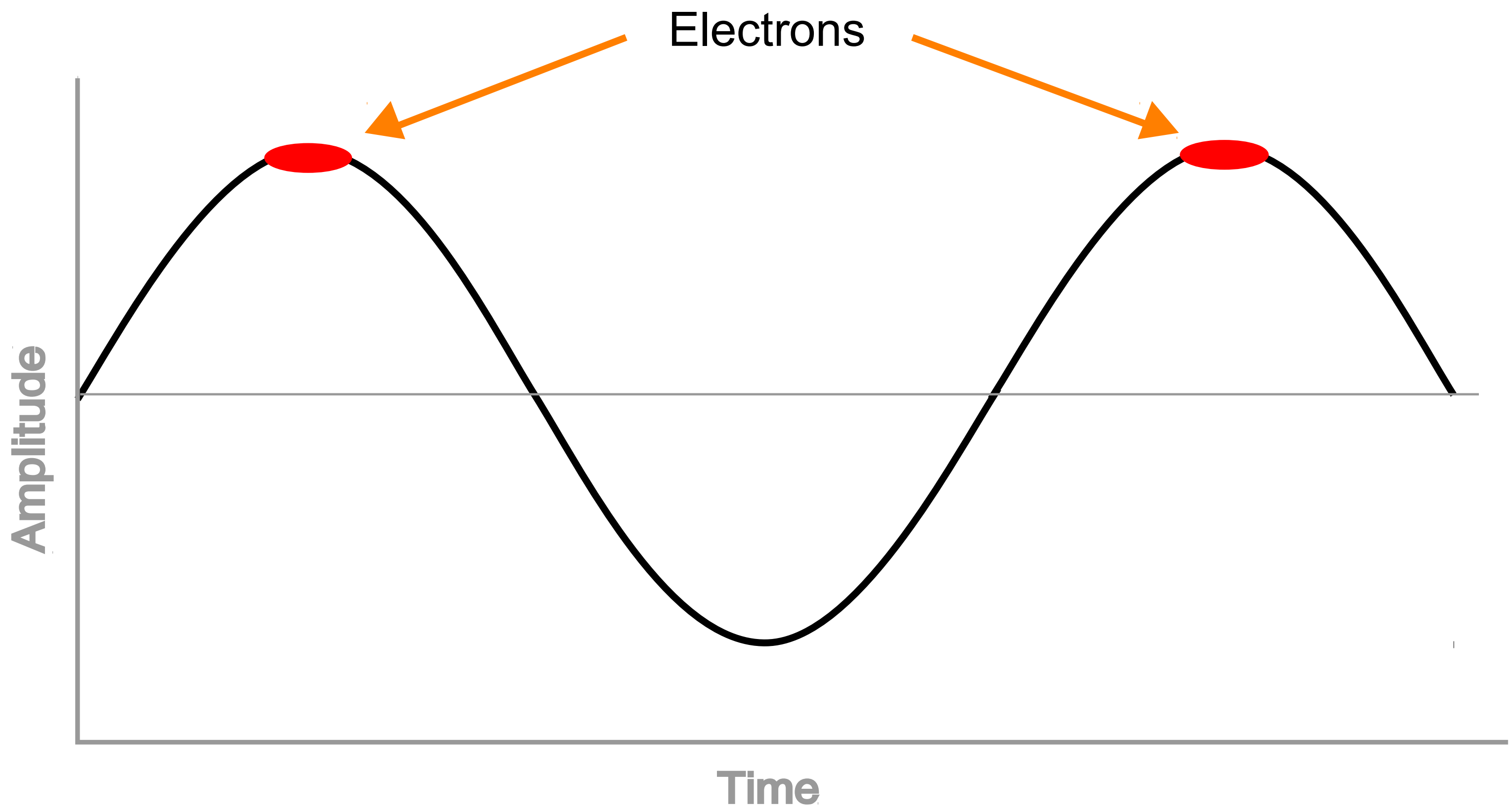
- Cavities are hollow shells with multiple cells made from niobium. Jefferson Lab's accelerator uses 418 cavities. Microwaves are directed into the cavities to create the electric charges (fields).

- The frequency used is 1497 MHz. (499MHz x 3)

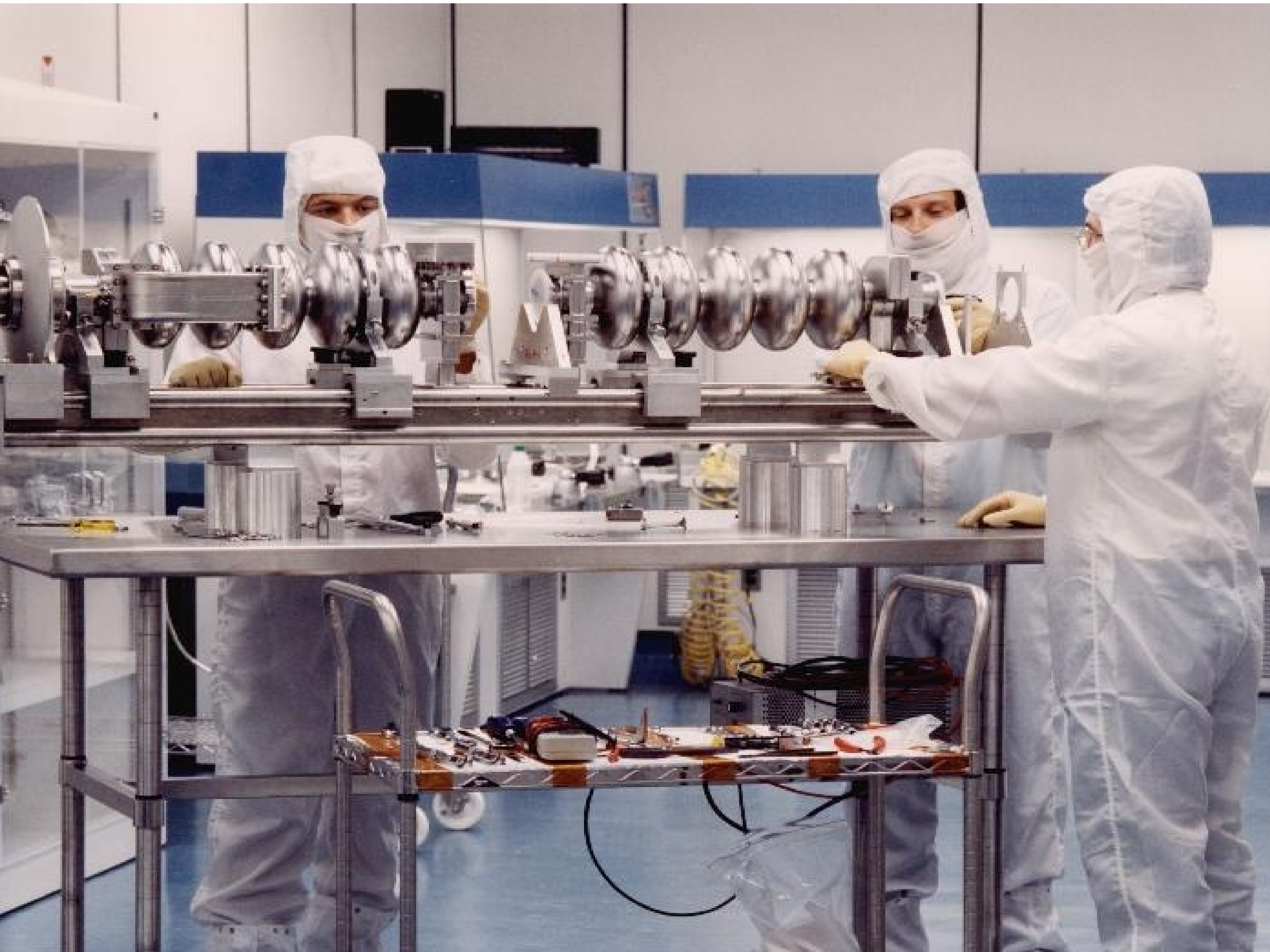
CEBAF Overview   Acceleration of Electrons

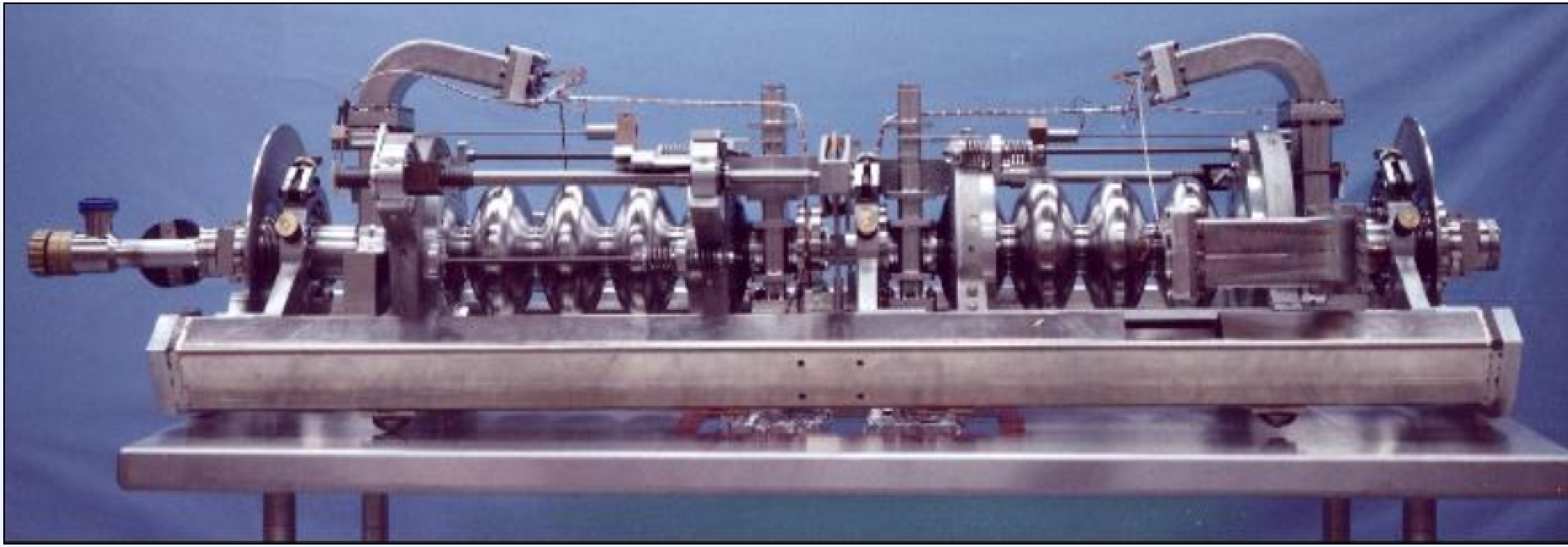


Acceleration of Electrons

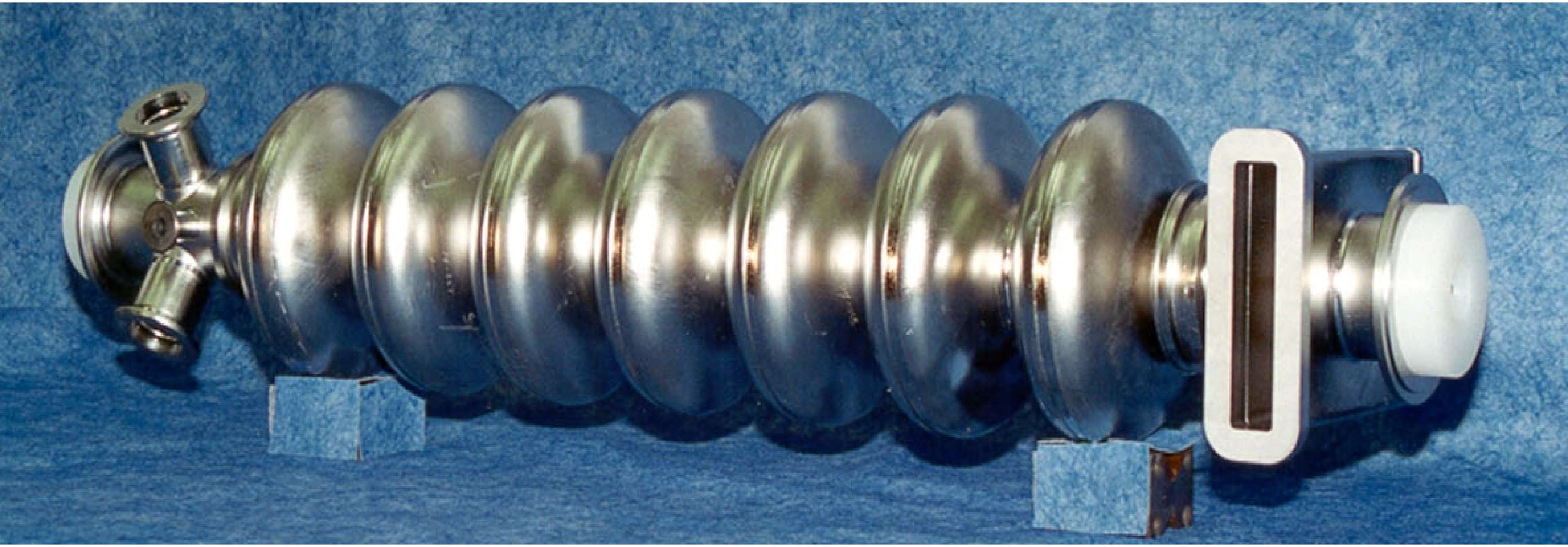


Beam gains energy when it goes through the cavities





7-cell 1497 MHz Niobium SRF Cavity for CEBAF



Superconductive Cavities

- The normal conducting cavities cannot be efficiently operated at high powers due to the heat generated.
- The heat would lower the efficiency or melt the cavities.
- When niobium is cooled to very low temperatures, it loses all electrical resistance and becomes a superconductor.
- Superconductors have no electrical resistance, electrical currents flowing through them do not lose any energy and do not produce any waste heat.
- The use of superconductive niobium cavities allows CEBAF to operate very efficiently.

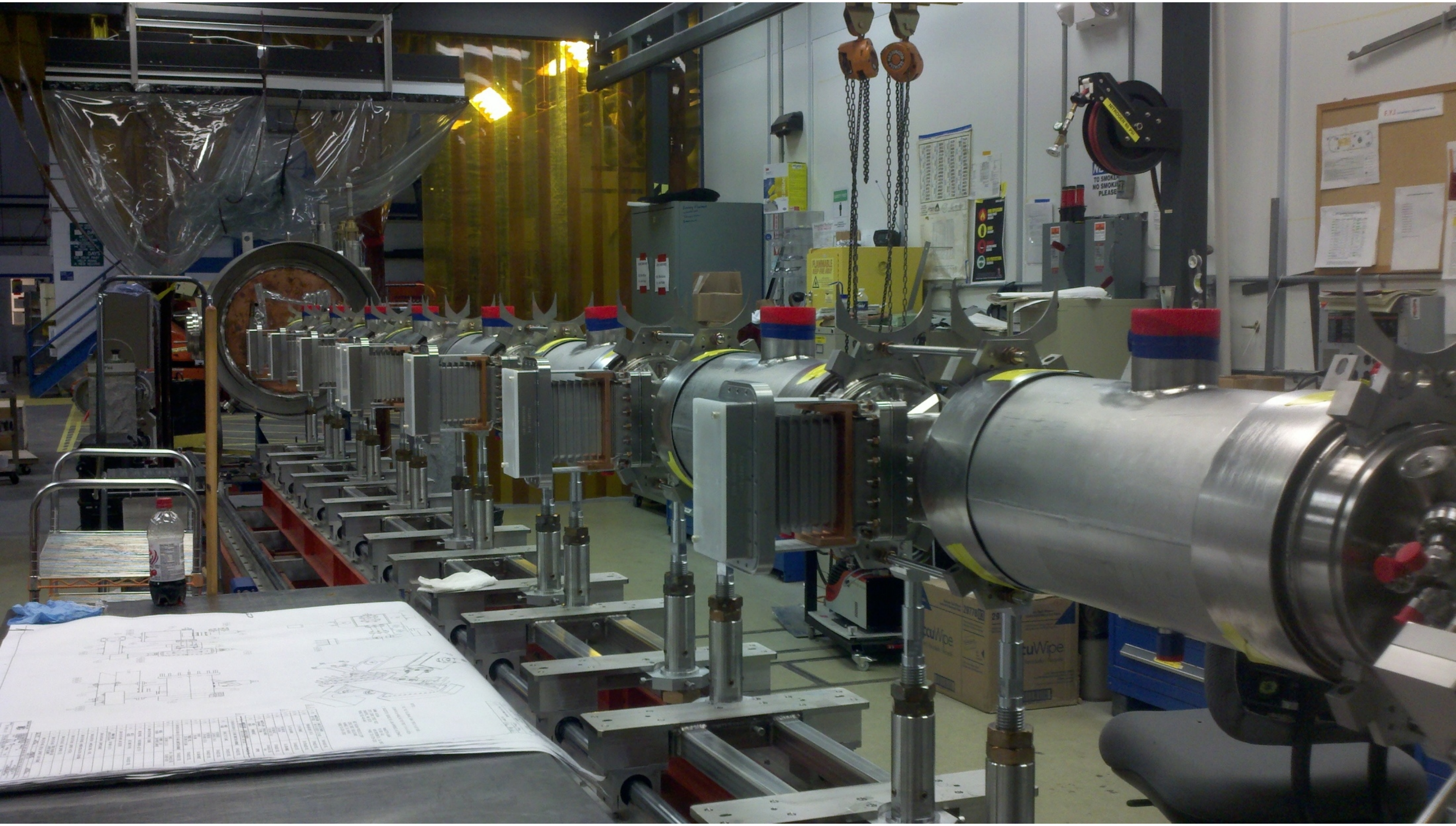
In order for niobium to become superconductive, it must be cooled by being immersed in a bath of liquid helium at a temperature of -271°C (-456°F).

This is only 2°C above absolute zero. (2°K)

The cavities and liquid helium are shielded from the heat of the outside world inside large, very well insulated containers called cryomodules.

Cryomodules use a combination of insulating methods:

- An insulating vacuum (convection)
- Layers of superinsulation (radiant)
- Thermal shield and thermal clamps (conduction)



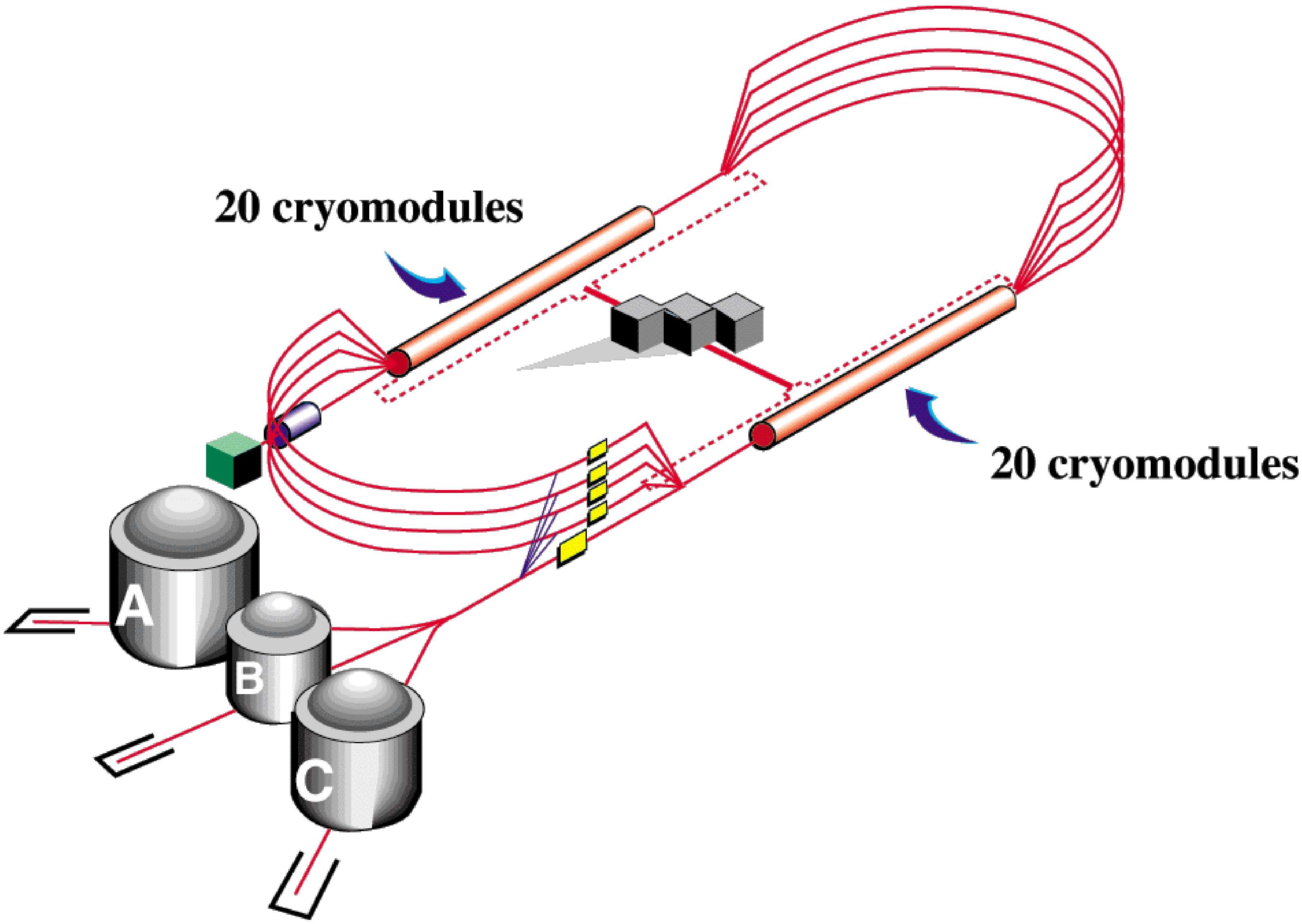
CEBAF Overview Cryomodules

Cryomodules

- There are eight RF cavities in each crymodule
- Cost ~$1 million per crymodule during construction
- There are 52 and1/4 cryomodules
- Inside modules, the RF cavities sit in a bath of 400 gallons of liquid helium cooled to 2 Kelvin.

- Central Helium Liquifier (CHL) cools the helium to a super cold high pressure gas.
- The CHL is the world’s largest 2K liquid helium refrigerator.
- The cryogenic system holds ~17000 gallons of liquid helium.
- The CHL runs continuously 24/7.

CEBAF Beamline



CEBAF Overview Magnets

- Magnets steer, focus and defocus electron beam.
- There are about 2200 magnets in CEBAF
- Heaviest magnet is about 20,000 pounds.
- Magnets can be powered up to ~700 Amps.

CEBAF Overview Arcs

- Recirculation arcs transport the beam between linacs
- Low energy beam at the top
- High energy beam at the bottom
- 16 or 32 dipoles powered in series are used to complete the 180 degree bend

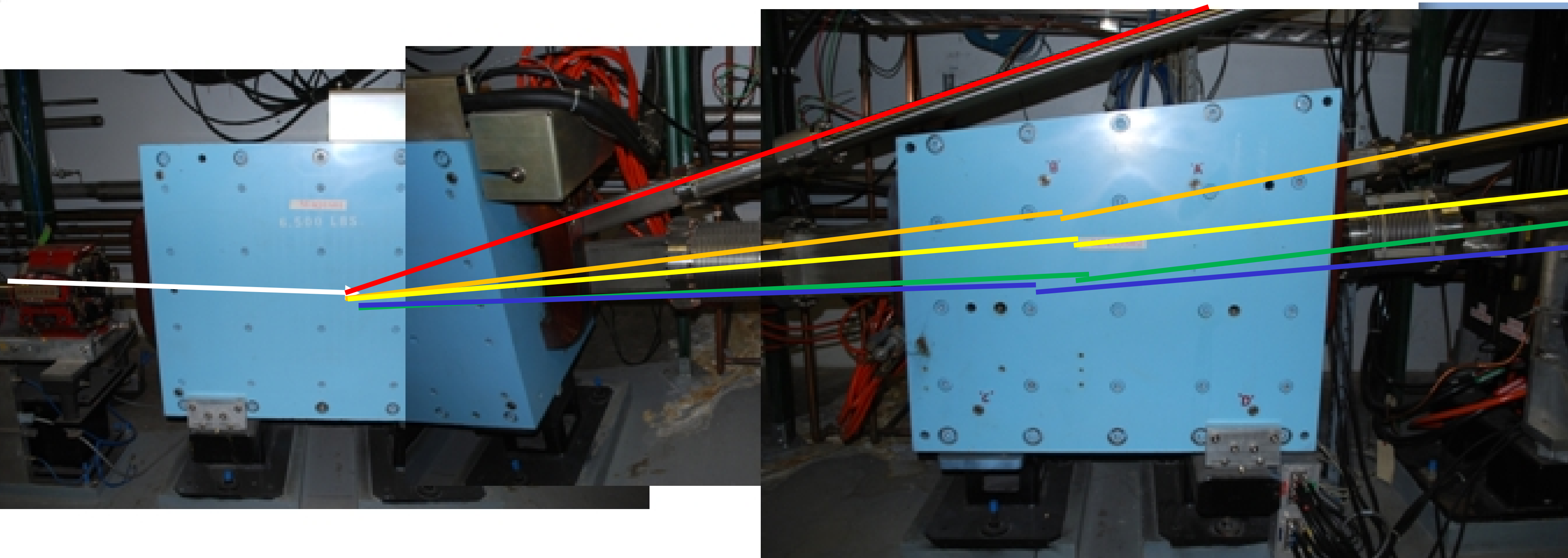
CEBAF Overview 6 GeV Arc Magnets

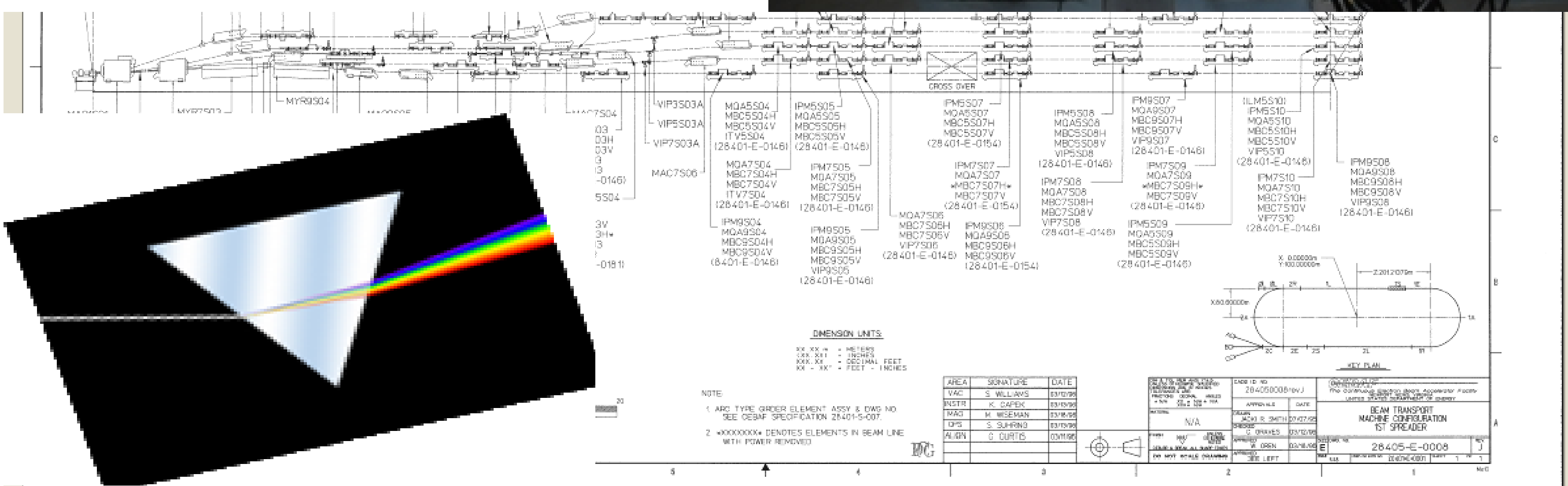
CEFAF Overview   12 GeV Arc Magnets

Prototype dipole with added H-Steel

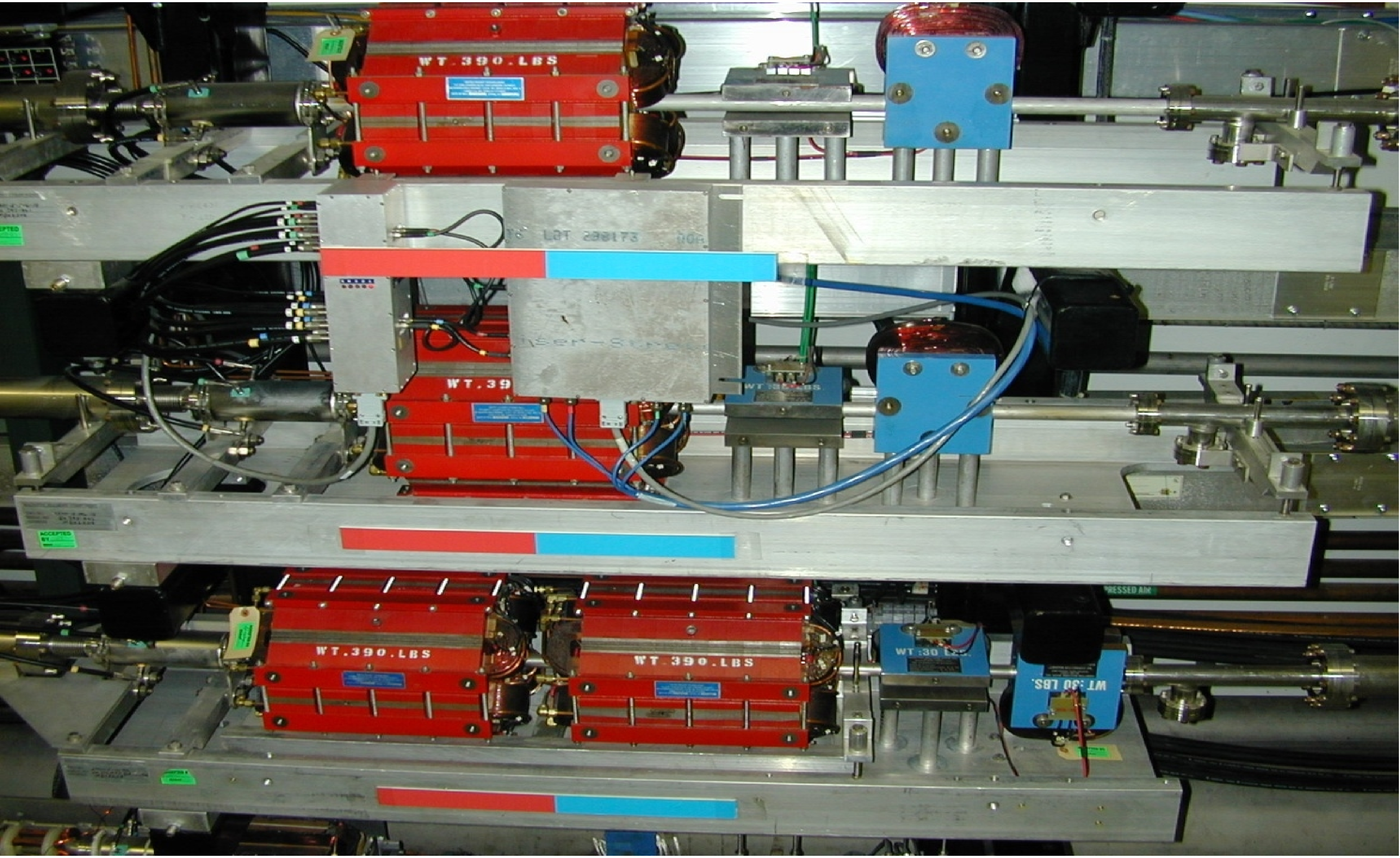
- Spreader and Recombiner sections of the machine connect linear accelerators to recirculation arcs.
- The beam is separated into it's discrete energies.
- Each arc has magnets sized and powered to bend it's energy beam in the same radius.

Spreader Magnets / Recombiners do the same thing in reverse





CEBAF Overview   Beamline Girders



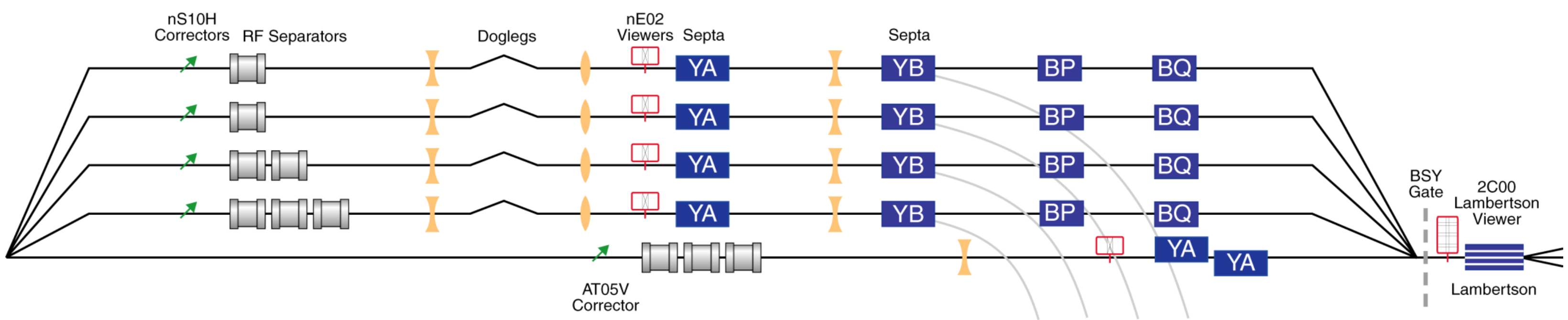
Jefferson Lab

Extraction of Beam

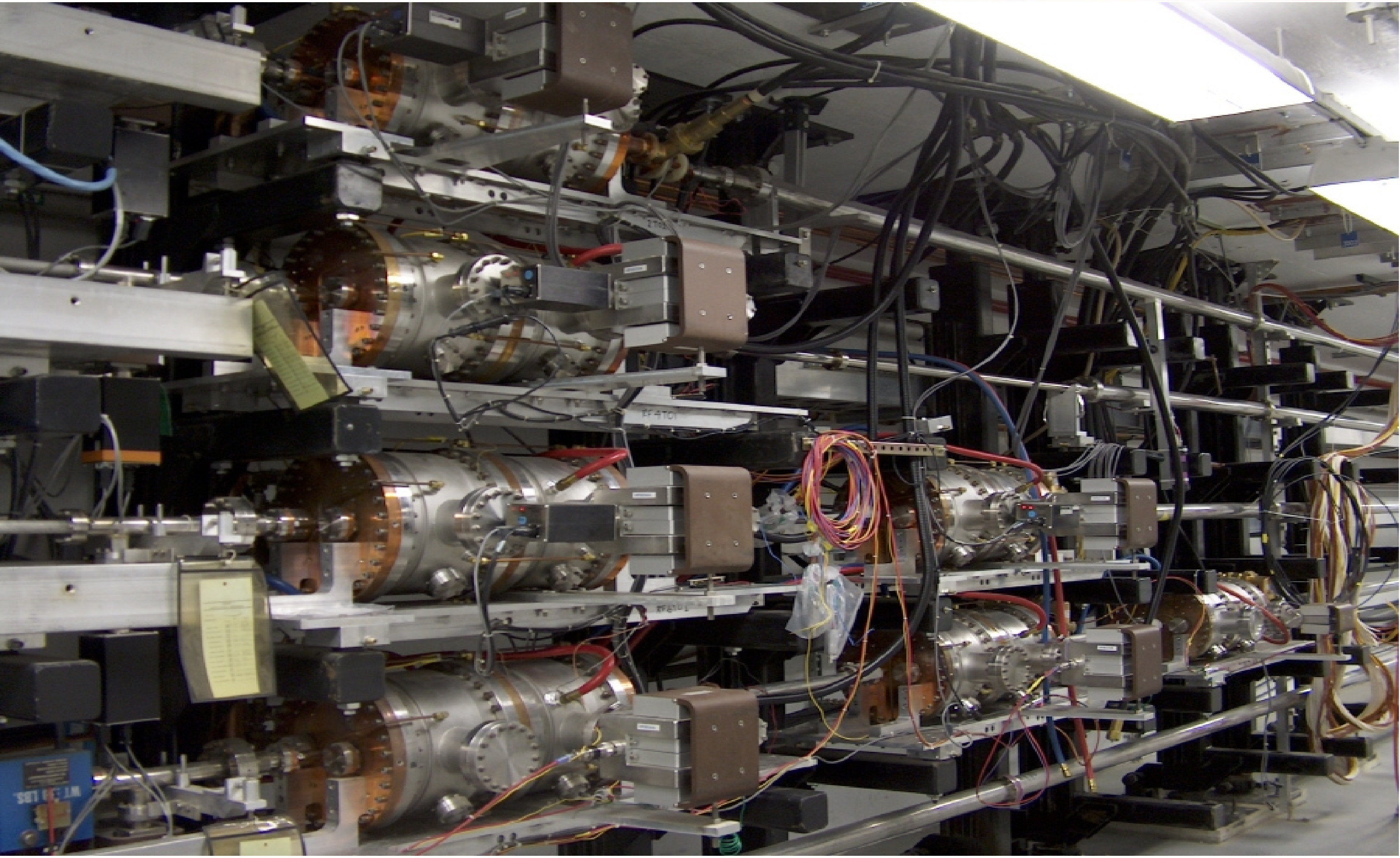
- Any single experimental hall can receive beam from the first four passes
- All three halls may receive beam from the fifth pass
- Time-dependent transverse kicks are applied to the microbunch structure to selectively direct beams along the correct path
- Accomplished with RF Separator cavities operating at 499 MHz
- Also use dipoles and quadrupoles at fixed field strengths to change the path of the beam

CEBAF Overview Extraction of Beam

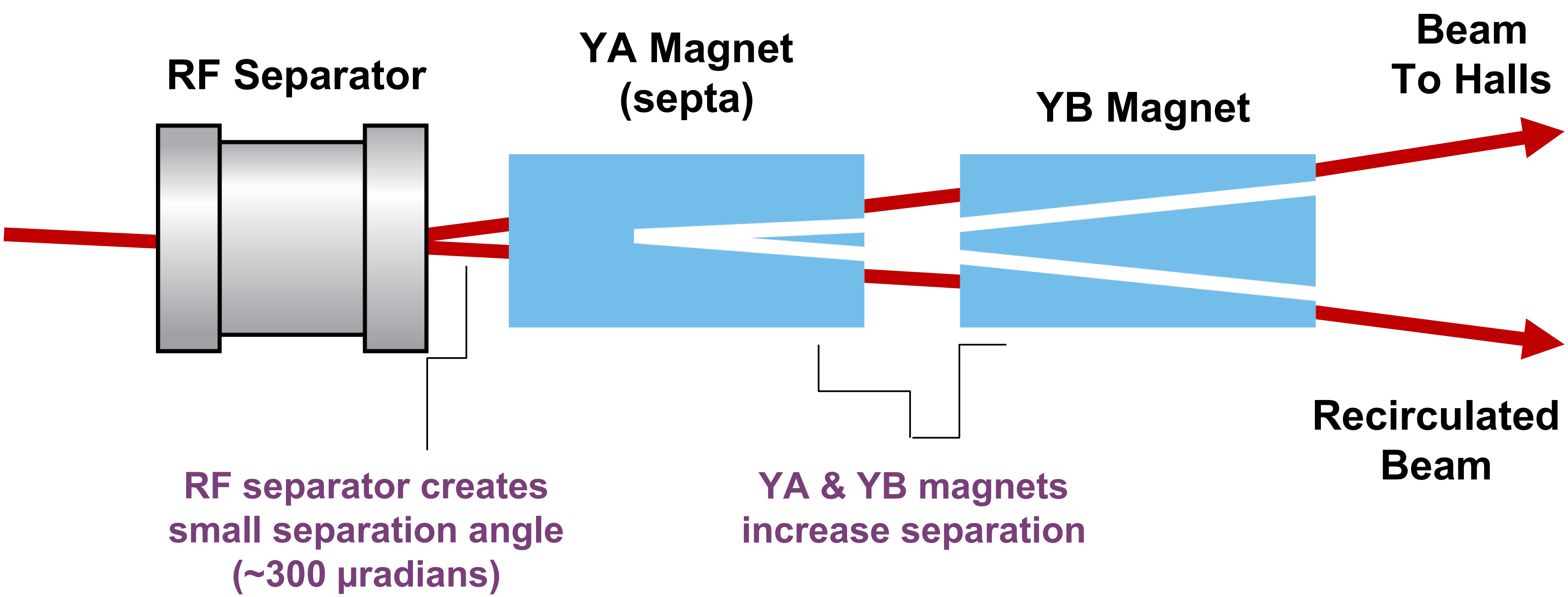
- Extraction system consists of RF Separators, Septa and Dipole magnets
- 1-4 pass uses horizontal separation to deflect one beam to halls A, B or C
- 5th pass uses vertical separation and all 3 halls can have the maximum energy at the same time



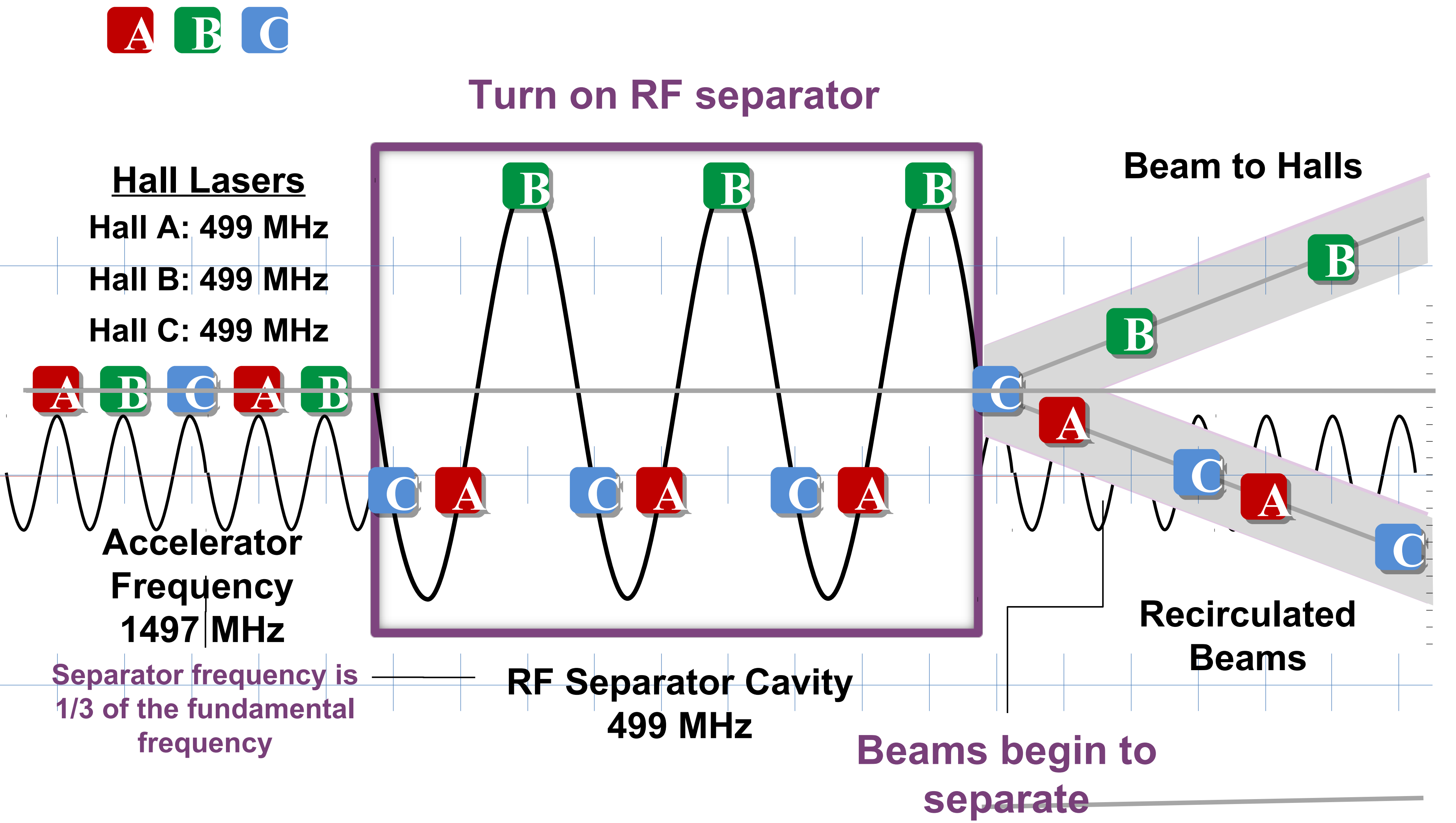
CEBAF Overview Beam Separators



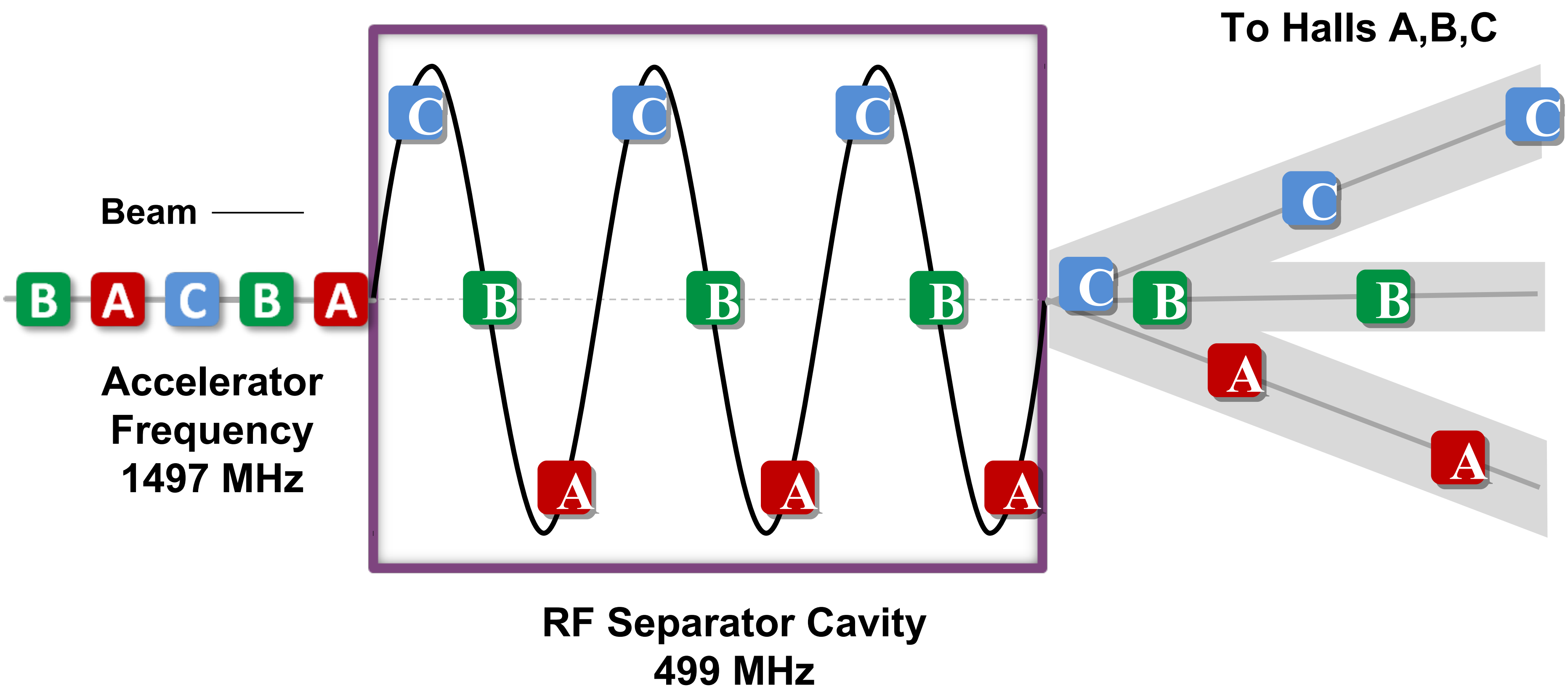
RF Separation Basics



RF Separation – Existing (499 MHz)



Halls A,B,C 5th Pass Vertical Separation



Just name a few:

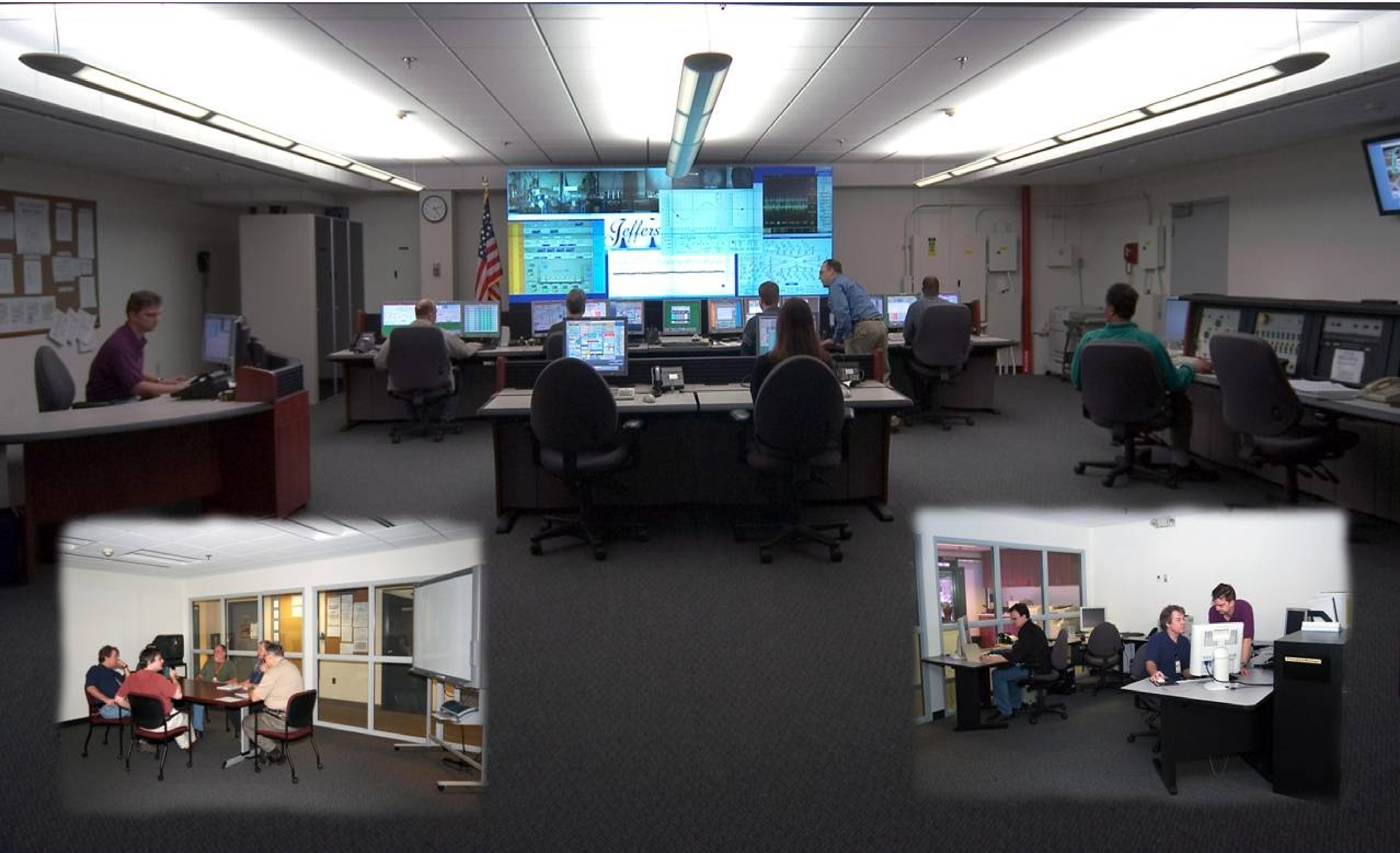
- Beam Energy: up to 12 GeV
- Energy Stability: ~ E-5
- Beam Current Range: a few pA to 200 uA.
- Current Stability: < a few percent
- Beam position Stability: -/+ 0.1 mm
- Beam polarization: ~85%

- Beam operations are conducted in the Machine Control Center (MCC) by the Operations personnel using the control software called Extensible Display Manager (EMD).

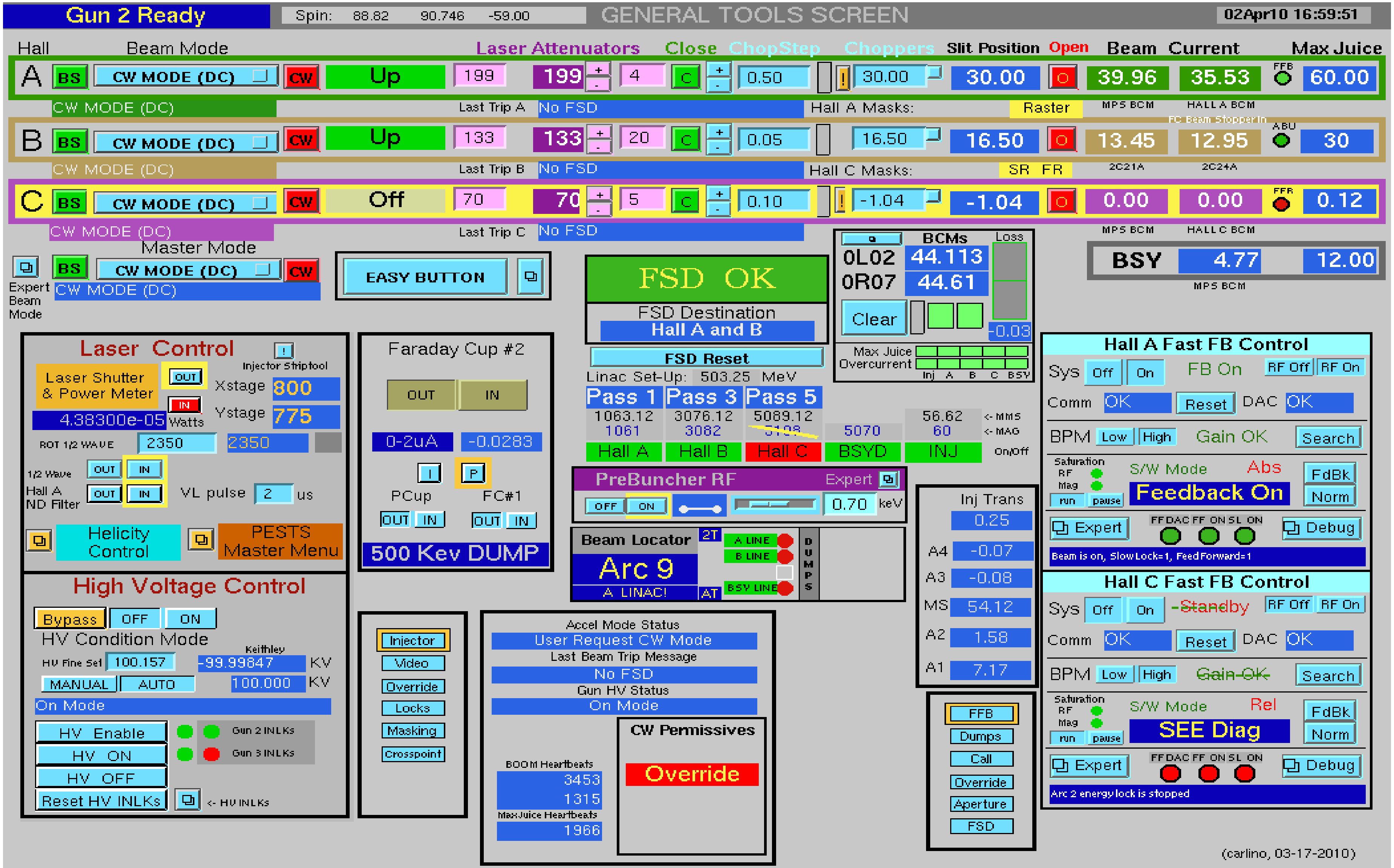
- Any request for machine parameter changes must go to the MCC, and the Operations personnel will do the changes.

- The MCC is staffed 24/7 during beam operations.

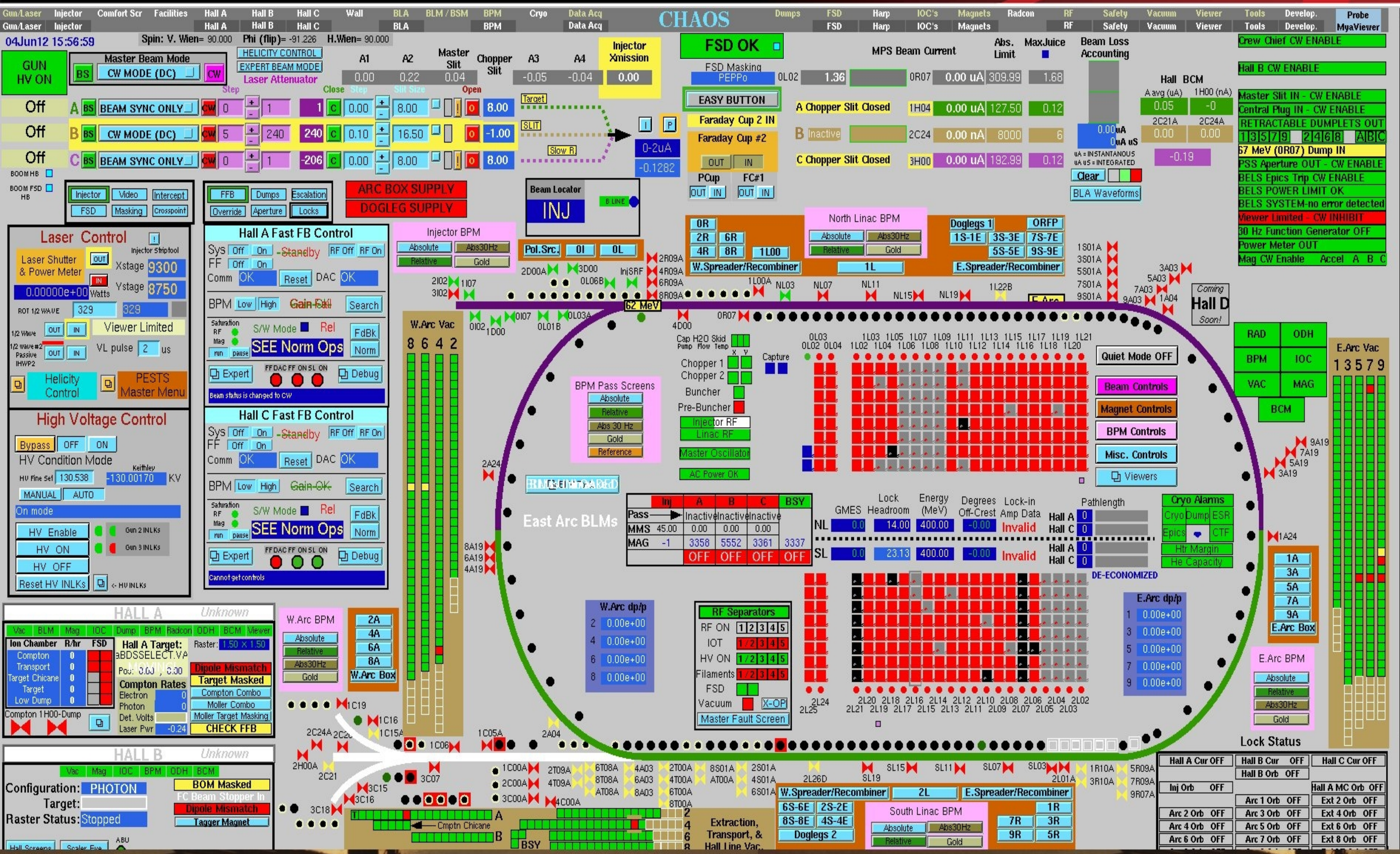
CEBAF Overview Machine Control Center



CEBAF Overview How to Control the Beam



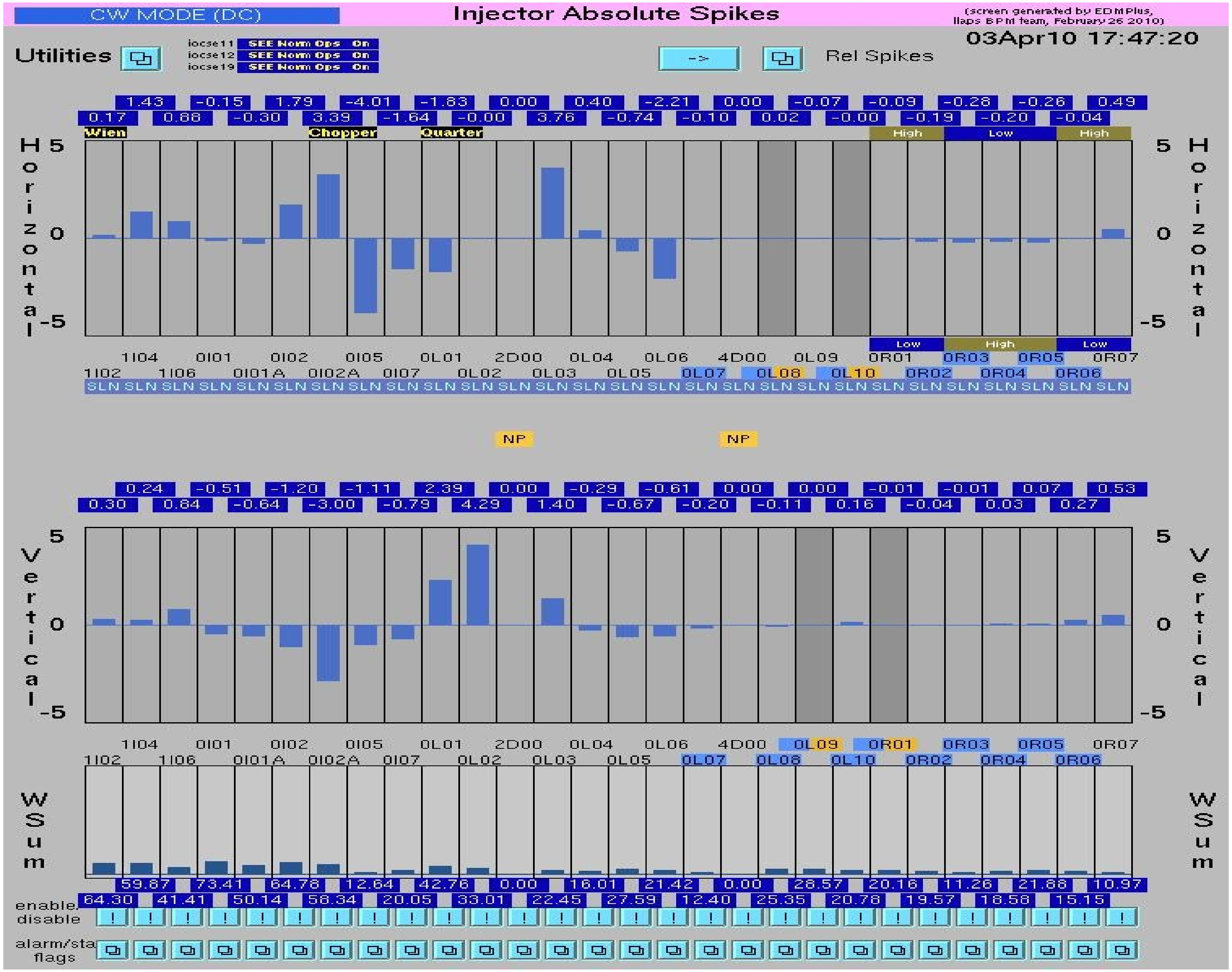
CHAOS

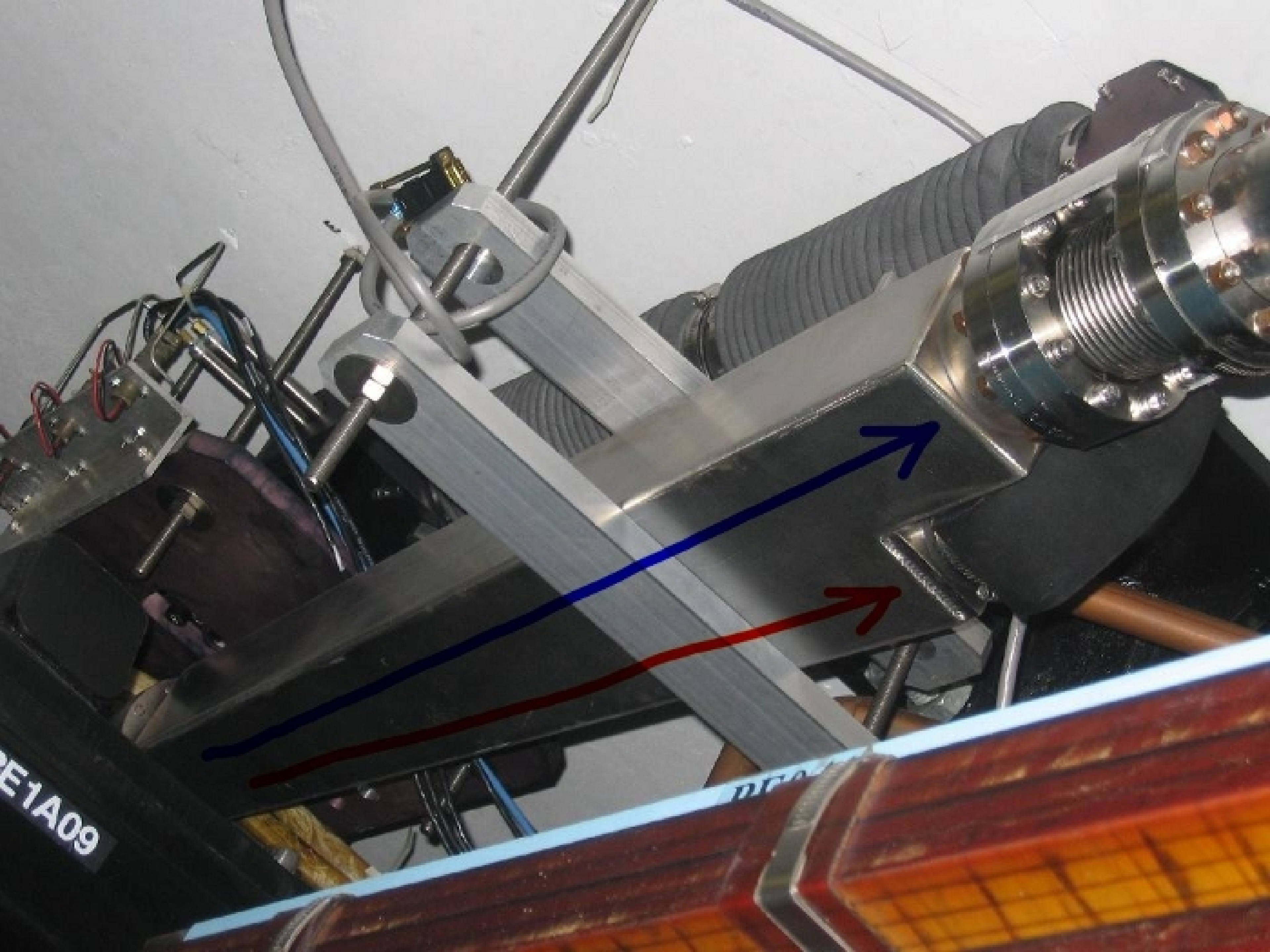


CHAOS
04Jun12 15:56:59
GUN HV ON
Master Beam Mode
CW MODE (DC)
BEAM SYNC ONLY
HELICITY CONTROL
EXPERT BEAM MODE
Laser Attenuator
Master Slit
Chopper Slit
Injector Xmission
FSD OK
FSD Masking
EASY BUTTON
Faraday Cup 2 IN
Faraday Cup #2
MPS Beam Current
Abs. Limit
MaxJuice
Beam Loss Accounting
Hall BCM
Crew Chief CW ENABLE
Hall B CW ENABLE
Master Slit IN - CW ENABLE
Central Plug IN - CW ENABLE
RETRACTABLE DUMPLETS OUT
PSS Aperture OUT - CW ENABLE
BELS Epics Trip CW ENABLE
BELS POWER LIMIT OK
BELS SYSTEM-no error detected
Viewer Limited - CW INHIBIT
30 Hz Function Generator OFF
Power Meter OUT
ARC BOX SUPPLY
DOGLEG SUPPLY
Beam Locator
INJ
Laser Control
Laser Shutter & Power Meter
Viewer Limited
Helicity Control
PESTS Master Menu
High Voltage Control
HV Condition Mode
HV Enable
HV ON
HV OFF
Reset HV INLKs
Hall A Fast FB Control
Hall C Fast FB Control
SEE Norm Ops
Injector BPM
North Linac BPM
W.Spreader/Recombiner
E.Spreader/Recombiner
62 MeV
W.Arc Vac
BPM Pass Screens
East Arc BLMs
Quiet Mode OFF
Beam Controls
Magnet Controls
BPM Controls
Misc. Controls
Viewers
Coming Hall D Soon!
E.Arc Vac
Cryo Alarms
DE-ECONOMIZED
RF Separators
Master Fault Screen
W.Arc BPM
W.Arc dp/p
E.Arc dp/p
E.Arc BPM
Lock Status
HALL A Unknown
HALL B Unknown
Hall A Target:
Compton Rates
Configuration: PHOTON
Target:
Raster Status: Stopped
BOM Masked
Tagger Magnet
South Linac BPM
Doglegs 2
Extraction, Transport, & Hall Line Vac.

- Energy locks, orbit locks and current locks (feedback loops) are used to keep beam stable.
- Operations personnel monitor the beam using various diagnostic tools like beam position monitors (BPM), beam current monitors (BCM), beam loss monitors (BLM), synchrotron light monitors (SLM).
- Beam Position Monitors sense the electrons passing four small antenna arranged within the beampipe to obtain an X & Y position.
- Synchrotron Light Monitors provide a non-invasive relative image of the beam.

CEBAF Overview Beam Position Monitors

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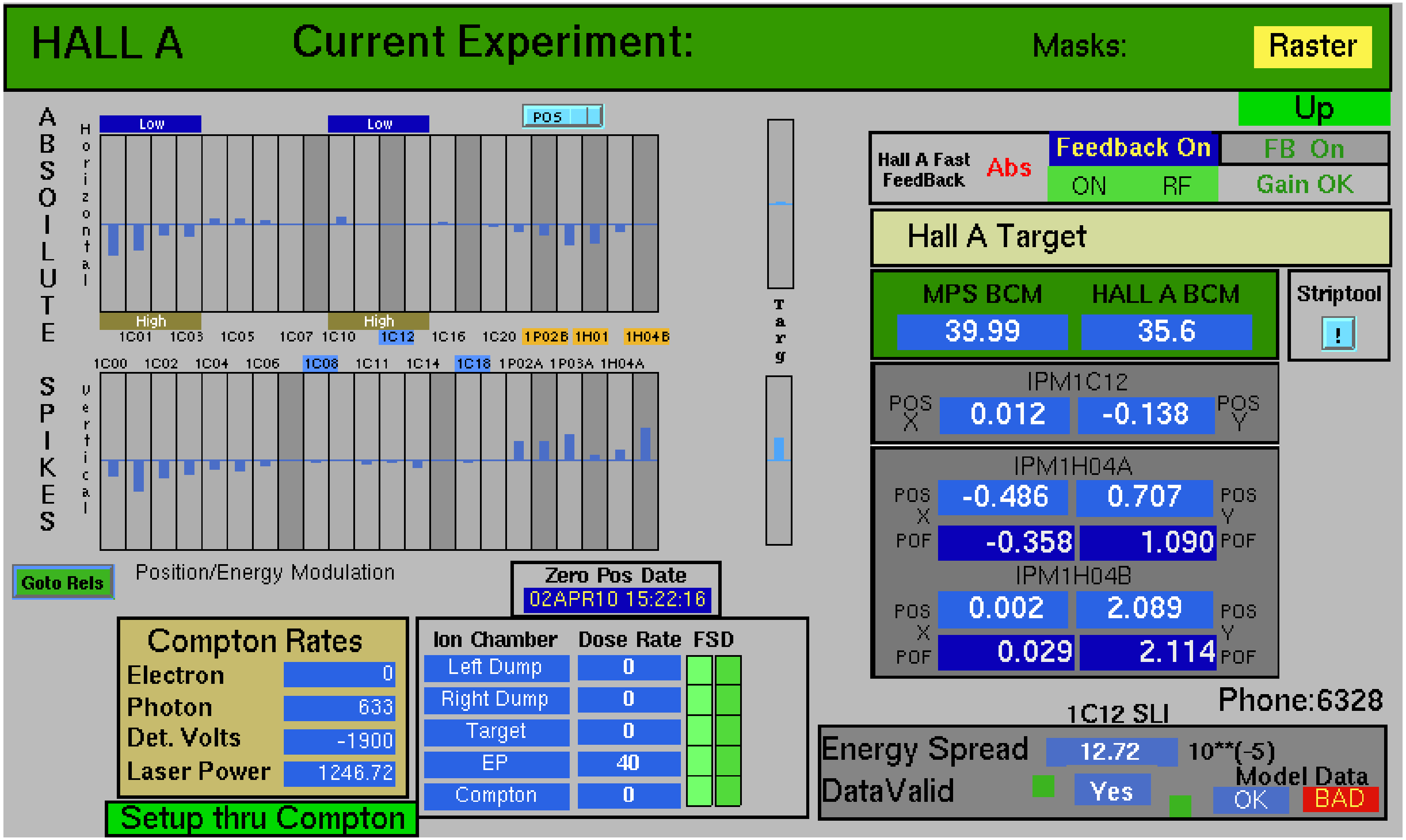
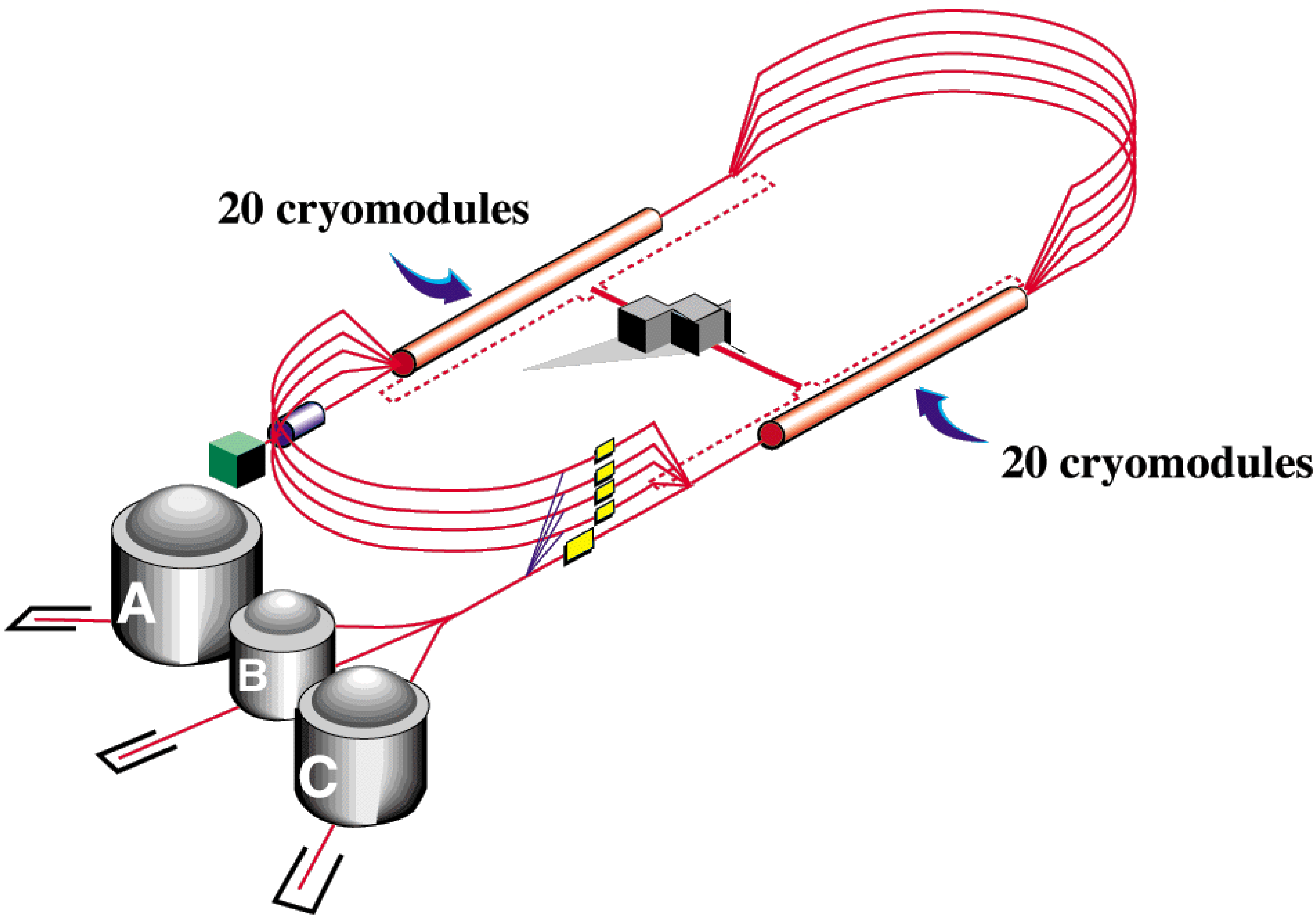
CEBAF Overview   Synchrotron Light Monitor

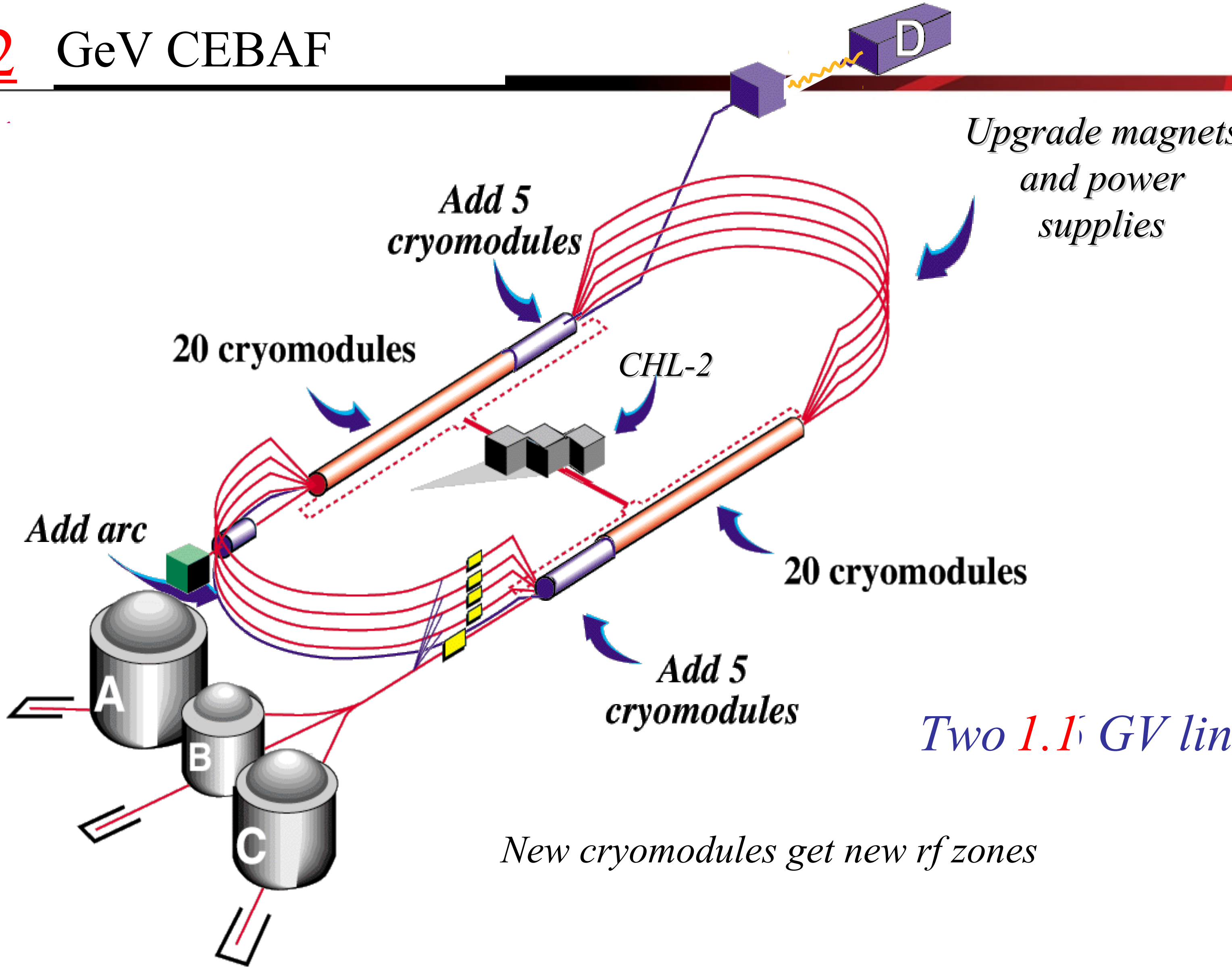
CEBAF Overview   Hall A Beam



CEBAF Overview pre-12 GeV Upgrade



12 GeV CEBAF



Two 1.1 GV linacs

New cryomodules get new rf zones

Questions?

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