Cebaf energy upgrade program
including re-work of CEBAF cavities

Joe Preble
(for Jefferson Lab)
SRF2007
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
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
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


Two 1.1 GV linacs

Upgrade magnets and power supplies

Add 5 cryomodules

20 cryomodules

Add arc

Add 5 cryomodules

CHL-2

20 cryomodules

Enhanced capabilities in existing Halls

Lower pass beam energies (2.2, 4.4, 6.6 GeV) still available
## Project Planning (w/ Current DOE Guidance)

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Begin construction (CD-3)</td>
<td>Fall 2008</td>
</tr>
<tr>
<td>Accelerator down</td>
<td>Spring 2012 thru Spring 2013</td>
</tr>
<tr>
<td>Accelerator commissioning</td>
<td>Summer 2013</td>
</tr>
<tr>
<td>Re-start research program</td>
<td>Fall 2013</td>
</tr>
<tr>
<td>Start research at 12 GeV</td>
<td>Summer 2014</td>
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12 GeV Schedule

Activity Name

<table>
<thead>
<tr>
<th>Activity Name</th>
<th>FY 04</th>
<th>FY 05</th>
<th>FY 06</th>
<th>FY 07</th>
<th>FY 08</th>
<th>FY 09</th>
<th>FY 10</th>
<th>FY 11</th>
<th>FY 12</th>
<th>FY 13</th>
<th>FY 14</th>
<th>FY 15</th>
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<tr>
<td>Critical Decisions</td>
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<td>1</td>
<td>2</td>
<td>3</td>
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<td>4</td>
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<tr>
<td>Accelerator including Civil</td>
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<tr>
<td>Hall D including Civil</td>
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<td>Hall A</td>
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<td>Hall B</td>
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Legend:
- R&D
- ACD Effort
- FED Effort
- Civil Construction
- Procurement & Assemble
- Installation & Checkout
- Beam Commissioning

# High-level Parameters

<table>
<thead>
<tr>
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<th>Now</th>
<th>Upgrade</th>
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<tbody>
<tr>
<td><strong>ACCELERATOR:</strong></td>
<td></td>
<td></td>
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<tr>
<td>Beam energy</td>
<td>6 GeV</td>
<td>12 GeV</td>
</tr>
<tr>
<td>Voltage of each linac</td>
<td>0.6 GV</td>
<td>1.1 GV</td>
</tr>
<tr>
<td>Number of recirculations</td>
<td>5</td>
<td>5 ½</td>
</tr>
<tr>
<td>Beam power (total program)</td>
<td>1 MW</td>
<td>1 MW</td>
</tr>
<tr>
<td>Beam current (hybrid mesons)</td>
<td>-</td>
<td>5 µA</td>
</tr>
<tr>
<td>Emittance</td>
<td>1 nm-rad</td>
<td>7 nm-rad</td>
</tr>
<tr>
<td>Energy spread</td>
<td>0.01%</td>
<td>0.02%</td>
</tr>
<tr>
<td><strong>CRYOPLANT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.5 kW</td>
<td>9 kW</td>
</tr>
<tr>
<td><strong>EXPERIMENTAL HALLS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>4</td>
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</table>
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
⇒ 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 ⇒ 108 MV / cryomodule
- 8 cavities/cryomodule
- 7 λ/2 cells per cavity
- 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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td><strong>Voltage:</strong></td>
<td>$\geq 108$ MV</td>
</tr>
<tr>
<td>(ensemble average in each linac)</td>
<td></td>
</tr>
<tr>
<td><strong>Heat budget:</strong></td>
<td></td>
</tr>
<tr>
<td>• $2 \text{ K}$</td>
<td>$\leq 300$ W</td>
</tr>
<tr>
<td>• $50 \text{ K}$</td>
<td>$\leq 300$ W</td>
</tr>
<tr>
<td><strong>Slot Length:</strong></td>
<td>9.8 m</td>
</tr>
<tr>
<td><strong>Tuner resolution:</strong></td>
<td>$\leq 2$ Hz</td>
</tr>
<tr>
<td><strong>Fundamental Power Coupler, FPC:</strong></td>
<td>7.5/13 kW</td>
</tr>
<tr>
<td><strong>Higher Order Mode, HOM damping:</strong></td>
<td>$Z &lt; 6 \times 10^8$ $\Omega$/cm$^2$</td>
</tr>
<tr>
<td><strong>Cryomodule Length</strong></td>
<td>$\sim 8.5$ m</td>
</tr>
</tbody>
</table>
C100 Cryomodule

Typical CEBAF end cans

Warm external tuner actuators

FPC

HOM

8 ea 7 cell cavities

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
RF control

High-level performance requirements are the same as 6 GeV

- Amplitude noise: $<1 \times 10^{-4}$
- Phase noise: $<0.2^\circ$

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

- $Q_{\text{external}} \geq 3.2 \times 10^7$
- Stiffness $\approx 1.5 \text{ Hz/(MV/m)}^2$

$\Rightarrow$ 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
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:
• $\geq 19.2$ MV/m at $Q_0 \geq 8 \times 10^9$
  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 \(~ 65 \text{ MeV/yr}\)

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

CEBAF Cavity Processing and Procedure Improvement
1992 Construction & 2006-7 C50 Rework Cavity Tests (same cavities)

Through 10/1/07
C50 Commissioning

Qo vs Eacc C50-01 Commissioning

C50 Cavity Performance as Installed in CEBAF SL04

C50 Cavity Performance as Installed in CEBAF SL16

CEBAF cavity performance before and after C50

Original CEBAF Cryomodule
cw, 50 MV, ½ mA

New Cryomodule Design,
cw, 100 MV, ½ mA

C100