CEBAF Status

What has been learned during the Commissioning effort?
Is CEBAF ready and capable of supporting a Physics program?

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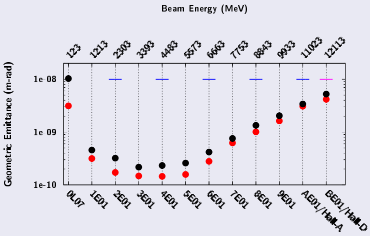
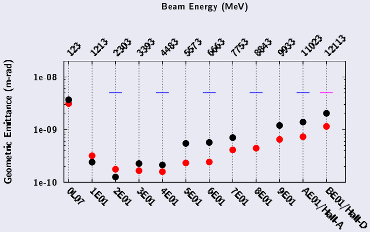
CEBAF Beam Parameters at Design Energy (2.2 GeV/pass)

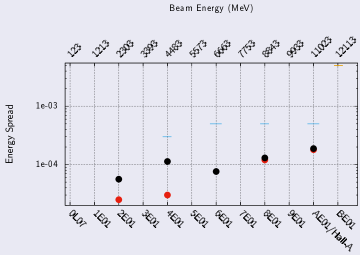
Horizontal emittance: ε_x

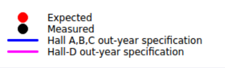


Vertical emittance: ε_y



Energy spread: $\frac{\delta E}{E}$





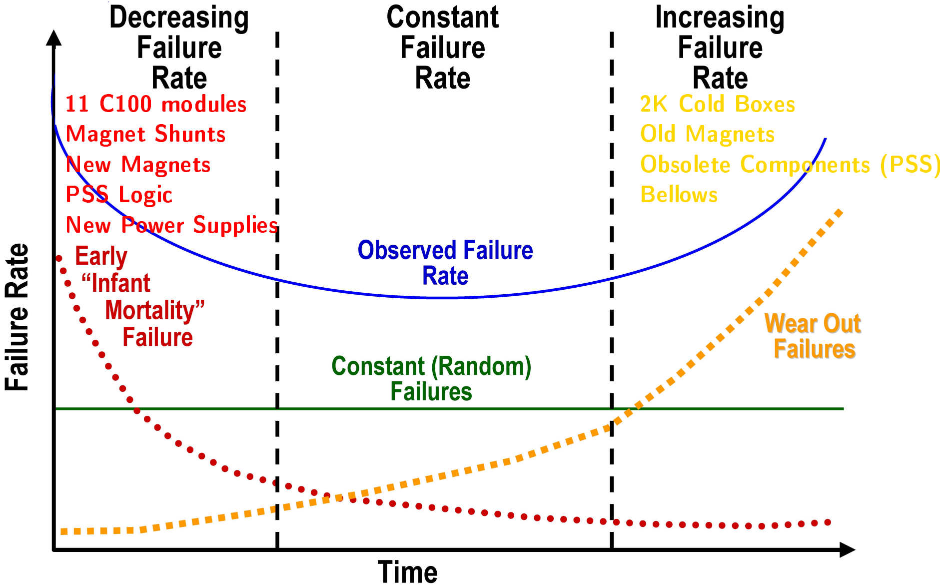
Summary of CEBAF Beam Physics at 12 GeV

- Horizontal transverse emittance is in very good agreement with the design expectations and meets the out-years requirements.
- Vertical transverse emittance meets the out-year requirements but is significantly greater than the expected value. Possibly due to off nominal orbits in the spreader and recombiner sections.
- Upper pass (passes 4 and 5) energy spread is in very good agreement with design expectations and meets out-year specification for all passes except pass-1.
  - Energy spread on the lower passes requires very careful setup and control of RF phasing and bunch length. Not required during these run periods. This is nothing new, careful attention to CEBAF setup was required for experiments requiring very low energy spread. The limit on energy spread is determined by the best one can set and control the RF phase on each cavity.

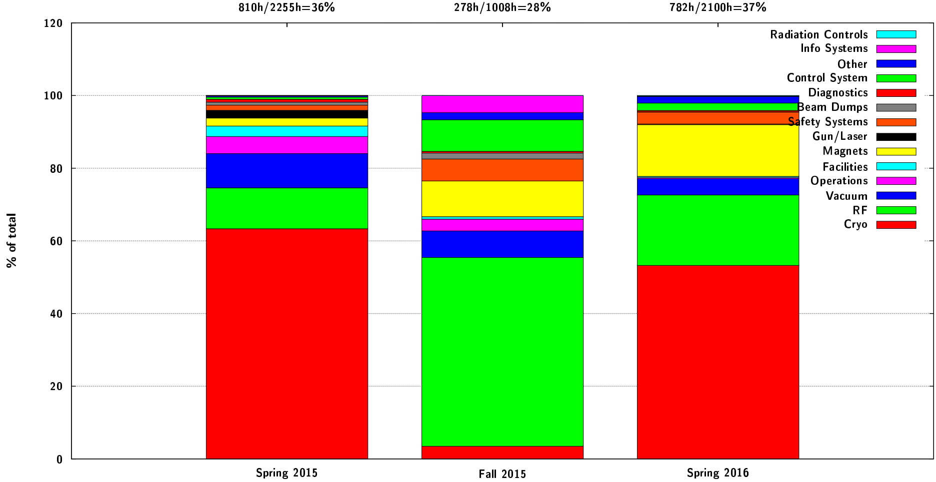
CEBAF design has been validated; the measured beam properties meet the Physics requirements. Emittance and energy spread growth due to synchrotron radiation agrees with the measurements and is well within the CEBAF operation parameters.

Fighting Both Sides of the Bathtub Curve

losing some battles but preparing the win the war.



Hardware downtimes for last three run periods

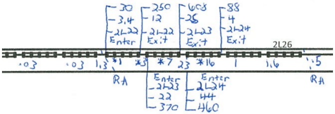


This does not include the **trips** which account for about 6min out of each hour, or 10% additional downtime. And does not include tune-time.

Accelerating System Performance

Fall2015 and Spring2016 were the first 5.5 pass beam operations at the design energy, 1090 MeV/linac. We learned a lot.

- Helium processing in Summer 2015 had a positive effect on the operational gradients of the C20 and C50 (CEBAF original) modules.
- Additional tasks to optimize gradient performance include collecting data for C20 trip models, lowering the LHe pressure to provide more headroom for C100s, continuous improvement on C100 LLRF systems to reduce trip recovery time.
- The high gradients of the C100s are capable of accelerating field emitted electrons to energies above the activation threshold ($\approx$ 10 MeV). Radiation damage is a concern, complicates the ability to access the tunnels for repairs.

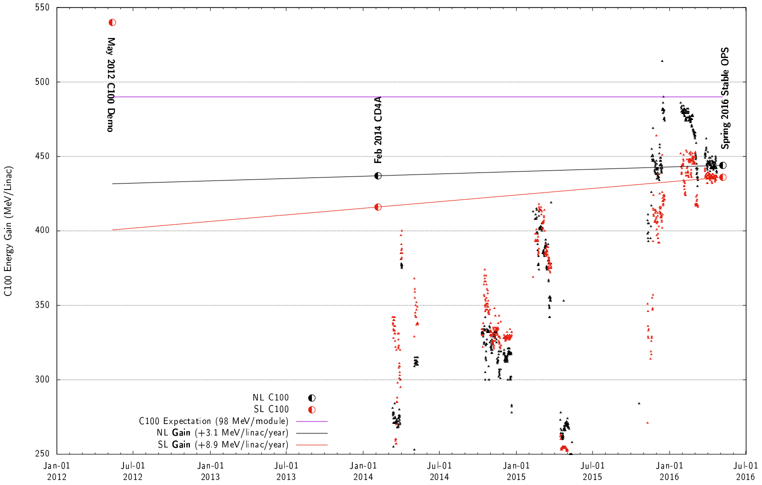


Peak measurement during Spring2016 was 0.8R on contact between C100 modules!

- Energy margin during Spring 2016 beam operations was about 10 MeV/40 MeV in the North and South Linacs respectively.

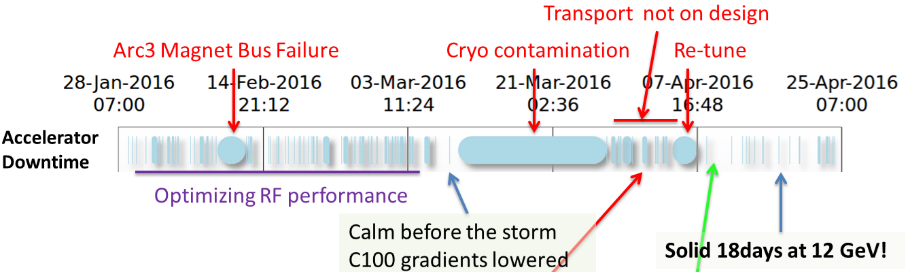
The accelerating system is not capable of supporting the design energy and the desired reliability/availability targets.

C100 Performance (to date)

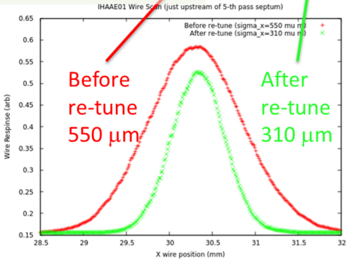


- South Linac C100s improvement from Feb 2014→May2016 due to Helium Processing in Summer 2015.
- C100 energy reach short by about 50 MeV/Linac.

Spring 2016 Beam Operations



- First Physics runs with CEBAF at design energy, 12 GeV to Hall-D, 11 GeV to Hall-A (5-pass).
- 5-pass separation at design energy (11 GeV).
  - 5th pass separation has no margin and requires beam transport to be on-design for robust operation.



Horizontal beam size upstream of 5th pass septum

Accelerator Incident Downtime (Hours) from April 7 - 25, 2016
Transport excluded

Summary

Total Downtime (Hours):	**27.0**
MTTR (Hours):	0.8
Total Suspend (Hours):	22.8
Total Restore (Hours):	4.2
Period Duration (Hours):	422.0

94% CEBAF System Reliability

Reliability Improvement Plans

- CEBAF reliability can be improved.
- Downtime statistics are (un)fortunately rich, which helps identifying weak systems:
- Many improvements were made during operations:
  - RF gradient distribution shifted gradient out of C100s to reduce radiation induced vacuum faults.
  - PSS hardware issues (old/new stuff) debugged and fixed.
  - Wire scanner reliability (old/new stuff) has improved dramatically.
  - Adjustments made to somewhat mitigate vacuum (new stuff) degradation due to field emission. (Clearly more room for improvement here, as shown this past weekend...).
  - ...

Gradient and Reliability Teams

A Gradient Team was formed in Winter 2016 to develop a plan to address accelerating system performance.
A Reliability Team was formed in late Spring 2016 to develop recommendations on improving CEBAF reliability.

Energy Reach versus CEBAF Uptime

Retreat!

In order to provide some gradient margin, lower CEBAF energy to 1050 MeV/linac (based on the requirement to have at least 50 MeV/linac of margin at the end of the year, Spring 2017).

Pass	Beam Energy (MeV)
1	2217
2	4317
3	6417
4	8517
5	10617
5.5	11667

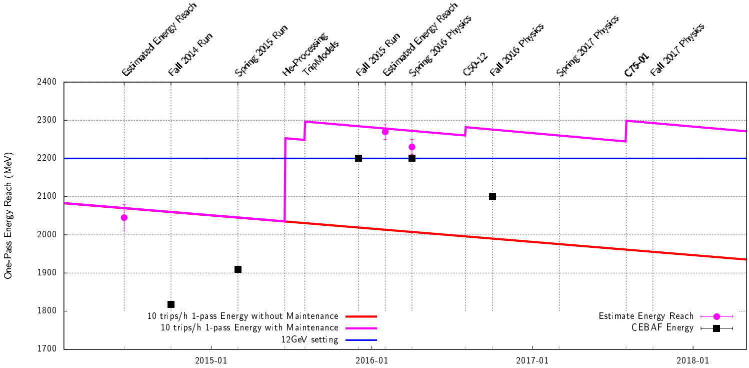
Energies in the upper passes will be slightly lower due to synchrotron radiation losses which are not included in the above table.

50 MeV/linac of gradient margin will permit:

- Problematic (high field emitting) cavities to be turned down (or off).
- Ability to by-pass problematic cavities.
- Ability to absorb a C20/C50 catastrophe (by-pass entire zone) without major impact to the run.

Gradient Improvement and Energy Reach

- Refurbish weakest cryomodules, C50(C75) program.
  - C75 (proposed new refurbishment plan) is a cell replacement for a C20 module with a goal of delivering 75 MeV of energy per module.
- Gradient Team: Operations, SRF and RFpower staff working to develop plans for optimizing gradient system performance, maximum gradient and reliability.



5-pass Separator Improvement Plan

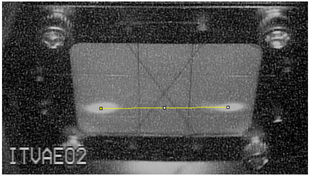
Status

- Maximum kick achieved at 11 GeV is 15.8 mm (design was for 16.5 mm).
  - 4% low at maximum RF power
  - ≈20% more RF power (over expectations) was needed to achieve this separation.

With a careful machine setup, the system can support separation at 11 GeV. But there is no margin. Beam must be perfect and RF power is operated at 100%.

Summer 2016 plans to improve the 5-pass separation margin by ≈ 33%:

Activity	Potential Improvement (%)
Lower Beam Energy	4
Optimize Geometry	9
Replace Weak Cavity with Strong Spare	3
Improve Cooling	4
Increase RF power (IOT)	10
Optimize RF Distribution	3



Four Hall-Ops Plan

750 MHz separators: See previous slide. The concept of sharing a 499 MHz RF train with two 249.5 MHz trains and separate with a 750 MHz system is a success.

- Deficiencies in the RF kick have been measured, plans for mitigating these deficiencies are being developed.

249.5 MHz laser drive: Analog system in place. Three lasers presently on the laser table.

- A 249.5 MHz can bleed through its own 499 MHz chopping slit, resulting in a new source of bleed through to the *other* hall. **In other words, all halls that share 5-pass with Hall-D will bleed through to Hall-D and some bleed through in the other direction**.
- A new higher frequency chopping system would eliminate this bleed through by adding additional slits in the system.

4-laser, 249.5 MHz digital drive: Proto-type in Spring2015. New design is under construction and plan to install Summer2016 and Winter2017.

- Beam tests are planned for Spring2017.

Summer 2016 Schedule

Electrons off a cathode:

PRad 1-pass/2-pass, 1 GeV/2 GeV, low power bill operations. **First use of a window-less target at CEBAF** (May 13→Jun 22).

Hall-C 1-pass, three day checkout of the Hall-C line. Only beam-line that has not seen beam in the 12 GeV era (May 16→May 19).

LERF DarkLight early phase running, (Jun 22 → Sep 02)

Configuration and major summer tasks:

Cryo CEBAF at 2K via CHL2→SC2→NL&SL&LERF to support beam operations and RF tests.

Cryo CEBAF at 4K during cryo maintenance and transition periods. Maintenance planned on CHL1 and SC1 to improve reliability.

C50-12 Install and commission the next (last) C50 module in zone NL12.

4-laser upgrade See previous slide.

750 MHz separator See previous slides.

MYR6T01 Repair 3-pass transport septum magnet that has a leak in one of its coils.

... ...

Fall 2016 Schedule

Oct-01-2016 → Dec-22-2016

Linacs Set to 1050 MeV/linac, 11.6 GeV 5.5-pass energy, 10.6 GeV 5-pass energy.

Hall-A Continuation of DVCS/GMp experiments.

Hall-C 12 GeV project commissioning and demonstration of key performance parameters.

Hall-D First Glue-X experiment production runs.

The trip rate will remain in the 5→10 trips/h range as the gradient margin will likely be used to lower the C100 gradients for improved reliability of the C100 cryomodules.

Summary

Summary

- CEBAF beam parameters at the design energy, 12 GeV, meet the out-year Physics requirements.
  - Measured parameters are near the expected values.
  - Understanding and closing the gap between measured and expected beam parameters is on-going.
- CEBAF Energy margin is insufficient for sustained, robust 2.2 GeV/pass operations.
  - Retreat from design energy, 4%, for Fall2016 and Spring2017 operations.
  - The spare klystron shelf is empty.
  - Energy reach gap will grow, exploring a *C75* module that would arrest the decline and close the gap.
- CEBAF reliability at design energy is lower than the 6 GeV reliability, which is as expected. For $x < 1 \Rightarrow x^2 < x$
  - Cryogenics remains a single point of failure.
  - Brief periods of robust operations have been achieved. Requires proper machine setup, optimized RF setup and vigilance.
- Major pieces of the 4-hall laser/RF-separation systems have been tested and plans are to complete the project in FY17.

The first 12 GeV CEBAF Physics run has just ended. There were many successes and many failures. Through the hard work of all involved the most was made out of a non-ideal situation.