Establishing CEBAF Energy for the FY17 Physics Program

Arne Freyberger

2016-03-29

1 Summary

For the NPES scheduling purposes the Fall2016 5.5 pass energy should be set to 11.7 GeV (1053 MeV/linac). This assumes at least one of the options B–G described in this note is executed successfully and assumes that option H, a late C50–12 and approval to take FL03 (SL21)) is not granted, does not happen. In other words, 11.7 GeV requires either C50–12 or FL03(SL21), to be installed in CEBAF by the end of August 2016.

The design energy of 1090 MeV/pass (12 GeV to Hall-D) for the Fall 2016 beam operations is supportable only by removing cryomodules from the LERF and impacting the LERF program.

This note captures some of the data, thoughts and cryomodule configuration options during Summer 2016.

2 Introduction

The upcoming 2016 Fall and 2017 Spring Physics program is nominally at the CEBAF design energy of 1090 MeV/linac or 12.1 GeV (note all the energies listed in this document do not account for the loss of energy due to synchrotron radiation in the upper passes). In addition the upcoming Physics program consists of a series of experiments that utilize the new Tritium target. It is strongly desired to complete these experiments within a 12-month period.

The goal of this note is to establish a sustainable CEBAF energy that has a high probability of being supportable for Physics operations (typically 23 weeks of beam operations between the power bill reads, 34 calendar weeks) to minimize CEBAF setups. The driving term in establishing the sustainable energy is CEBAF reliability. The ultimate goal for CEBAF is a reliability greater than 90%. The best weekly achieved reliability at design energy (12.1 GeV to Hall-D) is in the low 80%.

3 Required Energy Reach Margin for Operations from Oct-May

3.1 Inputs

- Assume a 34 weeks of calendar time between power bill reads.
- Assume insufficient time to install a refurbished/new cryomodule during Winter down.
- Energy loss per linac in 34 weeks is ~11 MeV/linac, due to new field emitters.
- CEBAF Accelerator Reliability target is 90%
- Strongly desire to remain at a single energy for the entire year, reduces setup time.
- Average margin consumption during the run is 5 MeV/week-linac. Does not strongly impact the required energy reach margin as long as there is an 8h RF recovery period every week.
- Peak margin consumption is 80 MeV for an entire C100 module, 30 $\rightarrow$ 40 MeV for an entire C20 module.
  - Absolutely must have 45 MeV/linac margin for a C20/C50 catastrophe
  - Strongly desire to have >100 MeV/linac of margin, without such margin a C100 catastrophe will result in a change in CEBAF energy and possible Physics program.

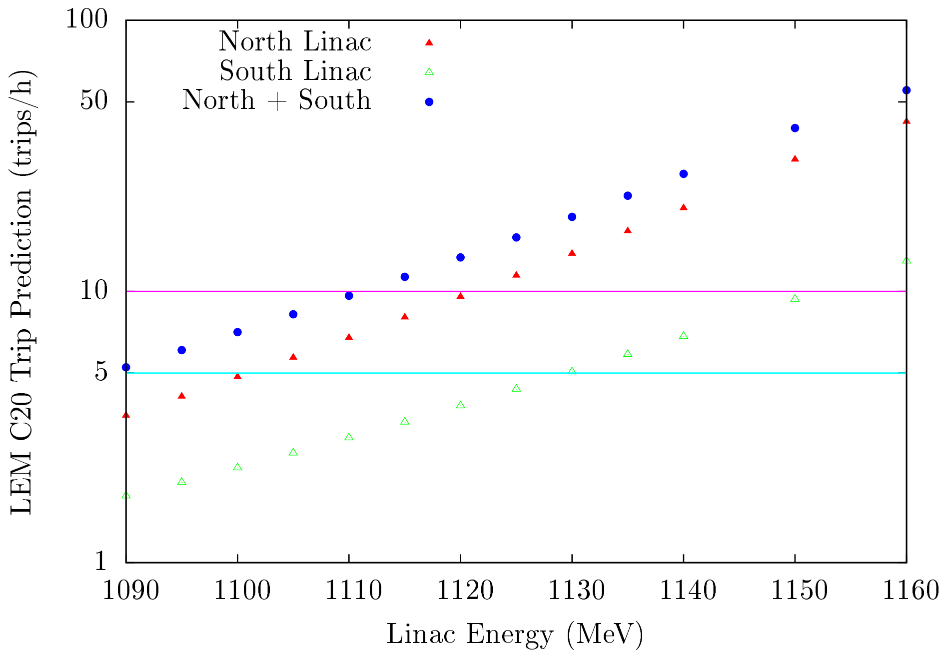
3.2 Required Energy Reach Margin

The energy reach at the start of a year should be at least 60 MeV/linac ($11 + 45 = 56 \sim 60$) above the energy selected for the Physics program.

- **Required Energy Reach margin is 60 MeV/linac**
- Strongly desired Energy Reach margin is 110 MeV/linac

4 Expected Energy Reach Fall2016

4.1 Present Energy Reach



4.1.1 North Linac

The North Linac Energy reach circa March 2016 is about **1100 MeV/linac**, 10 MeV energy margin in the North linac. This evaluation is after the paradigm shift of moving gradient out of the C100s into the C20s. Just prior to the Cryo maintenance, the North Linac was delivering 1090 MeV with a bit less than 10 trips per hour.

4.1.2 South Linac

The South Linac Energy reach circa March 2016 is about **1130 MeV/linac**, or about 40 MeV of energy margin. Just prior to the Cryo maintenance the South linac was delivering 1090 MeV with about 2 trips/h.

4.1.3 Degradation due to New Field Emitters

Field emitter degradation between Mar and Oct will be 12.5 MeV/linac

4.1.4 Predicted Energy Reach on Oct. 1 2016

The energy reach of the presently install SRF/RF system is in the table below. The value that assumes 60 MeV/linac margin is used in the following analysis of supportable energy for the Fall 2016 Physics program.

	North Linac (MeV)	South Linac (MeV)
No added margin	1087.5	1117.5
With 60 MeV/linac or margin	1027.5	1057.5

5 SummerSAD Cryomodule Installation Scenarios

The follow table lists the some of the various options for cryomodule installation during the 2016 Summer shut-down period. Following the table will be a brief description of each options, and the positive and negative impacts on the overall JLab program. Many of the options will result in similar beam energy for the Fall 2016 program and deciding among these options will be based on optimizing the lab's overall program and resources. Options A, B, C, and E support a Fall 2016 program at the design energy, all these options require at least one module from the LERF be moved to CEBAF.

Option	Description	ΔE_{North} (MeV)	ΔE_{South} (MeV)	E_{North} (MeV)	E_{South} (MeV)	E_{pass} (MeV)	$E_{\text{Hall-D}}$ (MeV)
	Design			1090	1090	2180.	12111
A	F100 in NL12, SL21 in SL06 and C50–12 in NL13	74	32	1101.5	1089.5	2191.	12172
B	F100 in NL12, C50–12 in SL06	48	30	1075.5	1087.5	2163.	12017
C	F100 in NL12, SL21 in SL06, (C50–12 is late)	48	32	1075.5	1089.5	2165.	12028
D	SL21 in NL12, C50–12 in SL06	28	30	1055.5	1087.5	2143.	11906
E	SL21 in NL12, F100 in SL06 (C50–12 is late)	28	52	1055.5	1109.5	2165.	12028
F	**C50–12 in NL12 (present plan)**	**26**	**0**	**1053.5**	**1057.5**	**2111.**	**11728**
G	SL21 in NL12 (C50–12 is late)	28	0	1055.5	1057.5	2113.	11739
H	No change in plan and C50 does not come in on time	0	0	1027.5	1057.5	2055.	11417

5.1 Option Details

5.1.1 Option A: F100 in NL12, SL21 in SL06 and C50–12 in NL13

This is the only option that results in supporting operations at design energy with 60 MeV/linac of margin.

1. Implementation Sketch As soon as the summer down starts, warm up FL02(F100) and FL03(SL21) modules, install and commission the modules. Late-July/mid-August install and commission C50–12. If C50–12 is late this changes to Option C,

2. Implications

    - This option does not allow for a LERF run this summer and leaves the LERF in a severely crippled state.
    - Linacs are reasonably balanced.
    - Places a large drain on SRF resources. Might impact LCLS-II schedule.
    - If C50–12 is late, this option becomes Option C.

5.1.2 Option B: F100 in NL12, C50–12 in SL06

This option results in a beam energy about 1% below the design energy.

1. Implementation Sketch As soon as the summer down starts, warm up FL02(F100) module, install and commission the module. Late-July/mid-August install and commission C50–12. If C50–12 is late, switch to Option C.

   In addition to the move of F100 to CEBAF, the FL03(SL21) module will need to be moved to the FL02 slot.

2. Implications

   - This option reduces the LERF energy to about 90 MeV.
   - Linacs are reasonably balanced.
   - If C50–12 is late, this option becomes Option C.

5.1.3 Option C: F100 in NL12, SL21 in SL06, (C50–12 is late)

This is Option A or B with a C50–12 delivery that does not support installation and commissioning in time for the Fall 2016 program. This option has the same energy reach as Option B, to within 1% of the design energy.

1. Implementation Sketch As soon as the summer down starts, warm up FL02(F100) module, install and commission the module. Early-August warm up FL03(SL21) and move to CEBAF, install and commission.

   In addition to the F100 to CEBAF relocation, the FL03(SL21) module will need to be moved to the FL02 slot.

2. Implications

   - This option restricts the LERF Summer operations to June and July.
   - Linacs balancing not quite ideal.

5.1.4 Option D: SL21 in NL12, C50–12 in SL06

1. Implementation Sketch As soon as the summer down starts, warm up FL03(SL21) module, install and commission the module. Late-July/mid-August install and commission C50–12. If C50–12 is late, switch to Option E.

   Energy reach is about 2% below design energy.

2. Implications

   - LERF energy remains above 100 MeV.
   - LERF schedule not impacted, unless C50–12 schedule slips
   - No LERF reshuffle required.
   - Linac balance not ideal.
   - If C50–12 is late, this option becomes Option E.

5.1.5 Option E: SL21 in NL12, F100 in SL06, (C50–12 is late)

This is Option D with a C50–12 delivery that does not support installation and commissioning in time for the Fall 2016 program.

1. Implementation Sketch As soon as the summer down starts, warm up FL03(SL21) module, install and commission the module. Late-July/mid-August warm-up FL02(F100), move, install and commission in SL06 slot.

   Energy reach is about 1% below design energy.
2. Implications
   - LERF energy above 100 MeV.
   - LERF Summer operations limited to June/July
   - Linacs balance not ideal.

5.1.6 Option F: C50–12 in NL12

1. Implementation Sketch Installation and commission C50–12 in NL12 slot. Schedule is presently very tight. Recommendation is to curtail most of the characterization of the module in the Test-Lab: install and commission in the tunnel without Test-Lab qualification.

   Energy reach is 3% below design, 5.5 pass energy of 11.7 GeV.
2. Implications
   - No impact to the LERF
   - Large Schedule risk
   - Linacs balanced
   - If C50–12 is late, this option becomes Option G.

5.1.7 Option G: SL21 in NL12, (C50–12 is late)

This is Option F with a C50–12 delivery that does not support installation and commissioning in time for the Fall 2016 program.

Energy reach is 3% below design, 5.5 pass energy of 11.7 GeV.

1. Implementation Sketch Late-July/mid-August warm-up FL02(SL21), move to CEBAF, install and commission in NL12 slot.
2. Implications
   - This option restricts the LERF operations to June/July.
   - LERF energy remains greater than 100 MeV.
   - Linacs are reasonably balanced.

5.1.8 Option H: No change in plan and C50–12 does not come in on time

1. Implementation Sketch C50–12 does not arrive in time for the Fall 2016 run. Alter program to 11.6 GeV 5.5 pass energy, 6% below design energy.
2. Implications
   - No LERF Impact
   - Linacs balancing not ideal.
   - Late change in CEBAF energy.

6 Linac Energy for NPES scheduling purposes

For the NPES scheduling purposes the Fall2016 5.5 pass energy should be 11.7 GeV (1053 MeV/linac). This assumes at least one of the options (B-G) is executed successfully.

The design energy of 1090 MeV/pass for the Fall 2016 beam operations is supportable only by removing cryomodules from the LERF and impacting the LERF program.

6.1 C50–12 schedule

The C50–12 cryomodule is presently scheduled to be ready in mid July. This schedule is not well align with the Fall 2016 resumption of beam operations, at present there is insuffient time for perform all the commissioning measurements and the schedule may slip. All options that do not have a contingency for if the C50–12 is late are not viable. This leaves the following combinations:

- Option A or B $\rightarrow$ Option C
- Option D $\rightarrow$ E
- Option F $\rightarrow$ G
- Option H

7 SRF/RF/Cryo performance Spring 2016

During the Spring 2016 run the CEBAF energy was set at 1090 MeV/linac, or 12 GeV to Hall-D. Initially the RF gradients were distributed to push the C100s as high as possible and reduce the C20 trip rate. This resulted in low trip rate ($<$5 trips/h), high downtime operations. Typical downtimes during this period were 24-36h of downtime per week of operations, dominated by energy delivery system.

In the first week of March the gradient distribution paradigm was changed to shift gradient out of the C100s into the C20s. The goal was to move as much gradient as possible while maintaining a RF trip rate at less than 10 trips/h. C100 cavities with low onset field emission were targeted for gradient reduction as a large fraction of the SRF/RF downtime is due to poor vacuum from the excessive field emission of the C100 cavities. Most if not all of the gradient relocation was performed on the North Linac.

The analysis of the trip rate and downtime for the week preceding and after the change in gradient distribution follows. As with most analysis on CEBAF operations the change in gradient distribution is not the only change during this two week period. The first week was impacted by a "tornado" event and recover that interrupted beam delivery for a shift or so. The second week was impacted by a CHL1 trip that brought down the South Linac.

7.1 Comparison of Downtimes and Trips between Feb24-Mar02 and Mar02-Mar09

7.1.1 RF trips

date		C20/C50	C100	RF Multi/Other	ALL
	What				
Feb24-Mar02	TripDownTime(h)	2.8	3.3	2.6	8.7
	NumberOfTrips	359	106	197	662
	<Time/Trip> (s)	28	112	48	47
	Trips/h	2.0	0.6	1.2	3.9
Mar02-Mar09	TripDownTime(h)	4.2	3.3	1.3	8.8
	NumberOfTrips	554	114	200	868
	<Time/Trip> (s)	27	104	23	37
	Trips/h	3.3	0.7	1.2	5.2

Mar02-Mar09 had a higher C20 trip rate due to migration of gradient from the C100s to the C20s. But the total downtime was the same. This is mostly due to the faster recovery time of the "Multi/Other" category. An explanation is that the 2nd week Multi/Other had a higher fraction of C20 trips that the 1st week.

7.1.2 Downtimes

date		C20/C50	C100	ALL
	What			
Feb24-Mar02	Downtime (h)	2	12.5	14.5
	NumberOfDowns	6	24	30
	MTTR (min)	20	31	29
Mar02-Mar09	Downtime (h)	2.2	3.1	5.3
	NumberOfDowns	5	6	11
	MTTR (min)	26.4	31	29

C100 related downtimes are much reduced in the Mar02-Mar09 week.

7.2 Possible new cryomodules and CEBAF landing options

7.2.1 New Cryomodule

Module	Energy Gain	Comment
C50–12	48 MeV	Schedule is very tight
FL02(F100)	70 MeV	C100 style waveguides
FL03(SL21)	50 MeV	Old friend, would like to have it back.
FL04	38 MeV	Not desired.

7.2.2 CEBAF underperformers

Module	Energy Gain	Comment
NL12	22 MeV	C50 negative impact of vacuum excursion.
NL13	22 MeV	C20
SL05	18 MeV	Weak performer in a strong linac.