

CEBAF Accelerator Update

Arne Freyberger

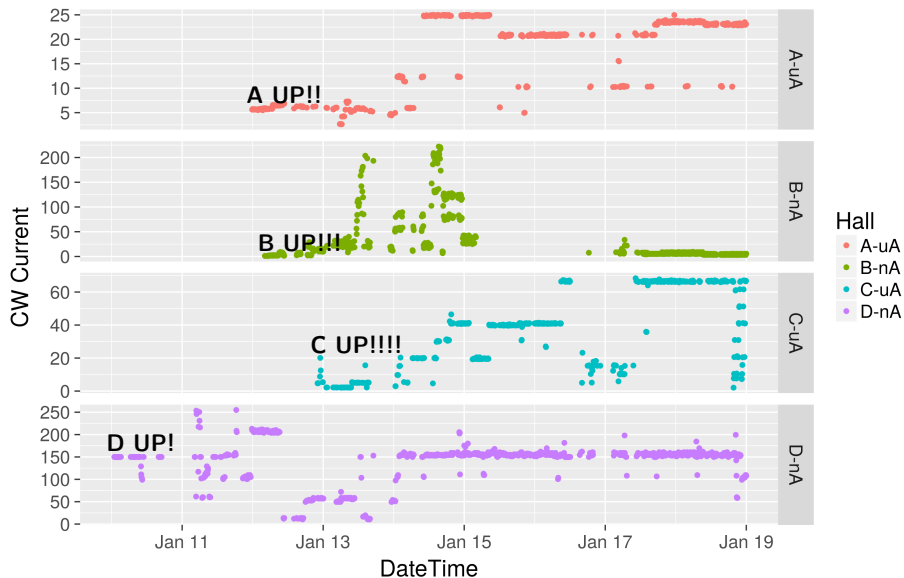
Operations Dept.
Accelerator Division

JLAB

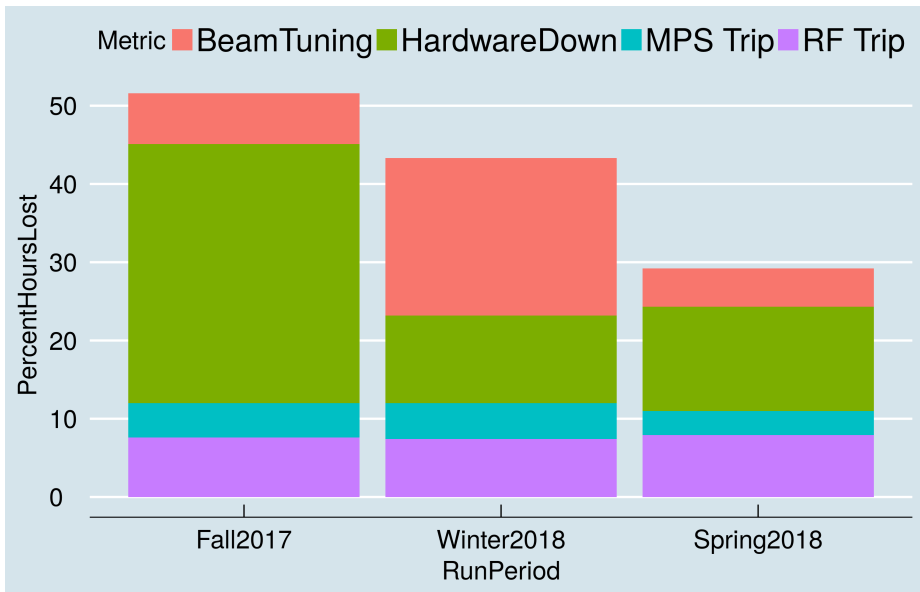
July 15, 2018

Accelerator Operations Department

Four Hall Operations!



Lost Hours: Improving Availability Trend!

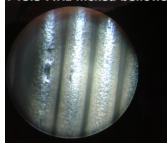


Summer2019: Ongoing Shutdown Activities

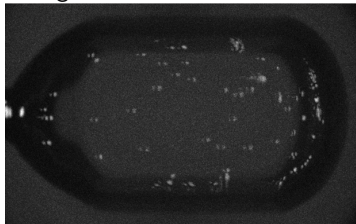
- CHL1 and ESR maintenance
- Repair leak in 5th-pass RF separator (done)
- Detailed analysis of optics data from Spring2018, to identify and correct model error(s)
- Modify Hall-C line to be a near mirror image of Hall-A line
- Gradient maintenance (Helium processing, cryomodule swaps, ...)
 - ▶ LERF F100 module → CEBAF NL23 zone
 - ▶ LERF P1 module → CEBAF NL07 zone
- Grid maintenance: Transformer/Breakers
- Upgrade original 4 GeV box power supplies



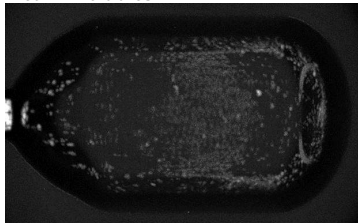
748.5 MHz nicked bellows



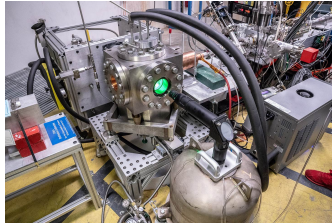
Background:



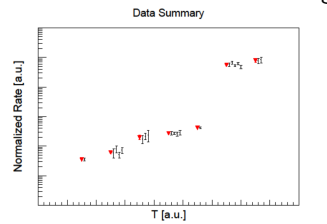
Beam Bubbles!:



Bubble Chamber on the floor:



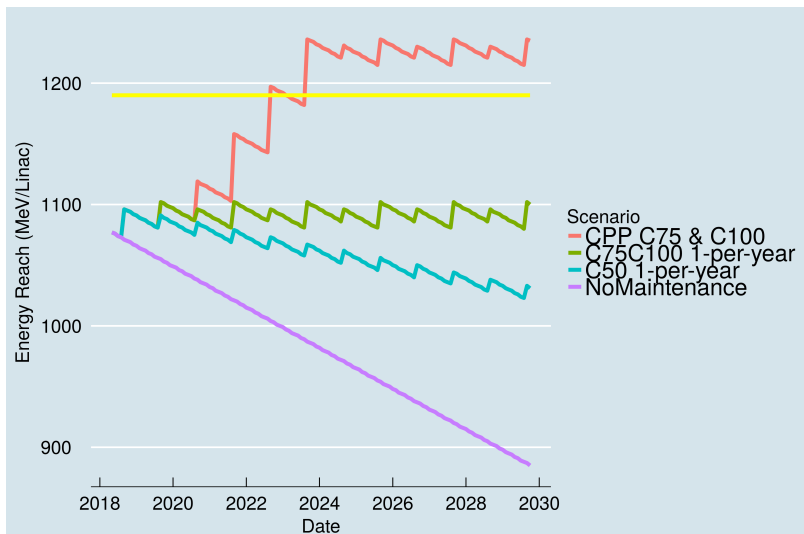
Raw Bubble rate vs beam energy:



Test data being analyzed. Meeting for Physics management in August to discuss readiness for scheduling.

Energy Reach Proposed Plan: C75 & C100-Refurbishment

Goal is to **improve** CEBAF energy capability at 1090 MeV/linac with robust margin by 2022-Oct(FY23).



Hall A

Beam Property	Nominal Value/Range	Temporal Stability over 8 hours
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Hall B

Spot size at target (rms)	Nominal Value/Range
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Angular divergence at target	Nominal Value/Range
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Current [μ Amp]	Nominal Value/Range
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Charge per bunch [fCoul]	Nominal Value/Range
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Bunch repetition rate [MHz]	Nominal Value/Range
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Beam position	Nominal Value/Range
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Energy spread ⁺ (rms)	Nominal Value/Range
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Beam direction	Nominal Value/Range
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Energy range [GeV]	Nominal Value/Range
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Energy accuracy [▽] (rms)	Nominal Value/Range
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Beam polarization [▽]	Nominal Value/Range
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Charge asymmetry [▲]	Nominal Value/Range
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Background beam halo	Nominal Value/Range
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Beam availability (including background beam halo)	Nominal Value/Range
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Beam polarization [▽]	Nominal Value/Range
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Beam availability (including background beam halo)	Nominal Value/Range
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Beam availability (including background beam halo)	Nominal Value/Range
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Beam availability (including background beam halo)	Nominal Value/Range
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12 GeV CEBAF Beam Parameter Tables

Jay Benesch, Alex Bogacz, Arne Freyberger, Yves Robin, Todd Satogata, Riad Suleiman and Michael Tiefenback

Hall C

Beam Property	Nominal Value/Range	Temporal Stability over 8 hours
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Spot size (X/Y) ⁺ at pivot	Nominal Value/Range	Temporal Stability over 8 hours
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Angular divergence at target	Nominal Value/Range	Temporal Stability over 8 hours
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Current [μ Amp]	Nominal Value/Range	Temporal Stability over 8 hours
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Spot size at target ⁺ (rms) [μ m]	Nominal Value/Range	Temporal Stability over 8 hours
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Angular divergence at target	Nominal Value/Range	Temporal Stability over 8 hours
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Current [nAmp]	Nominal Value/Range	Temporal Stability over 8 hours
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Charge per bunch [fCoul]	Nominal Value/Range	Temporal Stability over 8 hours
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Bunch repetition rate [MHz]	Nominal Value/Range	Temporal Stability over 8 hours
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Beam position	Nominal Value/Range	Temporal Stability over 8 hours
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Energy spread ⁺ (rms)	Nominal Value/Range	Temporal Stability over 8 hours
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Beam direction	Nominal Value/Range	Temporal Stability over 8 hours
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Energy range [GeV]	Nominal Value/Range	Temporal Stability over 8 hours
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Energy accuracy [▽] (rms)	Nominal Value/Range	Temporal Stability over 8 hours
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Beam polarization [▽]	Nominal Value/Range	Temporal Stability over 8 hours
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Background beam halo	Nominal Value/Range	Temporal Stability over 8 hours
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Beam availability (including background beam halo)	Nominal Value/Range	Temporal Stability over 8 hours
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'<' - 'not to exceed'

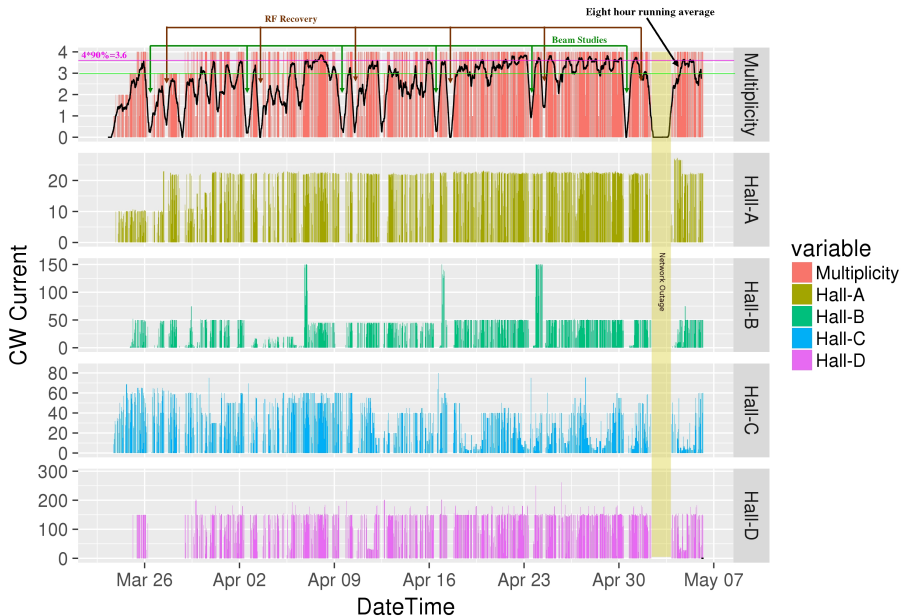
Parity Beam Parameters

Beam Property	Nominal Value/Range	Helicity Correlated 8-hour Average	Maximum Jitter at 30 Hz
Current [μ Amp]	5 – 100 [#]	< 5 ppm	2000 ppm
Energy [GeV]	1 – 11	$\left(\frac{\Delta E}{E}\right) < 15\text{ppb}$ (50 nm@ 35 mm/%)	35 μ m (x-position in center of hall ARC)
Energy spread (rms)	<10 ⁻³	NA	NA
Position x at target	0	<25 nm	15 μ m
Angle x' at target	0	<10 nrad	5 μ rad
Position y at target	0	<25 nm	15 μ m
Angle y' at target	0	<10 nrad	5 μ rad
Spot size at target	100 – 500 μ m ($\sigma_{x,y}$ unrastered) 5 mm x 5 mm (rastered)	$\left(\frac{\Delta \sigma}{\sigma}\right) < 10^{-3}$	NA
Beam polarization [▽]	$P_L > 85\%$ ($P_V, P_H < 1\%$)	NA	NA
Beam halo	<10 ⁻⁴ integrated (> 2 mm from edge of rastered beam)	NA	NA

Beam Delivery Constraints

- 1 Beam energy constrained to a multiple of the energy gain per pass (plus the Injector energy).
 - ▶ Present CEBAF energy reach 2100 MeV/pass, 4% below design 2180 MeV/pass.
- 2 The **total** beam current the Linac can transport is 450 μA .
- 3 The maximum operational beam power to Halls A or C is 900 kW.
- 4 The electron alignment is the identical modulo π for all beams, optimization can be one of the following options:
 - ▶ The alignment is optimized for a single hall (likely a parity experiment) the rest get what they get.
 - ▶ Spin alignment is set to *equalize the pain* across halls desiring polarization. Everyone gets a sub-optimum alignment.
- 5 Passes 1,2,3,4 can only support one hall at a time.
- 6 For 4-hall operation, Hall-D **must** be partnered with another hall on 5th pass. **Preferably Hall A or C.**
 - ▶ During 4-Hall operation there is at most two halls on lower passes.
 - ▶ In other words only two halls (**A-B**, **B-C**, **A-C**) can be supported on lower passes during four hall operation.
 - ▶ Ability to change passes is more constrained then in 6 GeV era.
 - ▶ Changing passes can be more complicated as it may require a change in the Injector (shared slit issue).
- 7 When delivering beam to Hall-D, all 5th pass beams to ABC and Hall-D must be at a 249.5 MHz repetition rate.
 - ▶ Hall-D can only receive 5.5 pass beam
- 8 $\sum_{ABC} (\text{Cryo Loads}) < \text{ESR Capacity}$, supports only one high power target. New ESR will alleviate this constraint (FY22?).

Facility Multiplicity



Fall2018: 2018-08-22 — 2018-12-20

- Three energies: 1050 MeV/linac, 930 MeV/linac, 805 MeV/linac
- 4-hall and 3-hall program
- E12-17-003 requires beam with a very small energy spread

Winter2019: 2019-01-30 — 2019-03-11

- One energy: 1050 MeV/linac, no pass changes
- 4-hall program
- Full power, 900 kW, program

Summer2019: 2019-06-10 — 2019-08-04

- One energy: 450 MeV/linac, no pass changes
- 2-hall program
- Parity experiment in Hall-A, 70 μA , 1-pass
 - * First parity experiment in the 12 GeV era

Fall2019: 2019-10-01 — 2019-12-18

- One energy: 1050 MeV/linac
- 4-hall and 3-hall program
- CReX parity violation experiment in Hall-A
 - * 150 μA → high bunch charge
 - * 1-pass beam

Summer2020+Fall2020: New 2K Coldbox

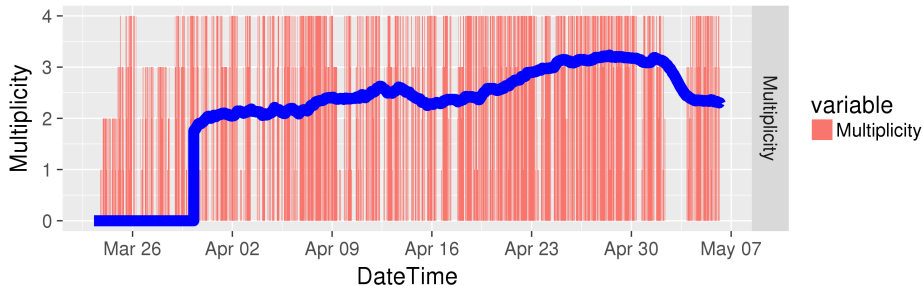
- CEBAF on one Cryo plant for 6 months
 - * Complete and commission the Injector upgrade **or**
 - * Low energy beam operation in parallel with the 2K cold-box commissioning is under evaluation once the cryogenic capabilities are fully understood for this period
- Beam operations with two 2K plants resume 2021-Feb.

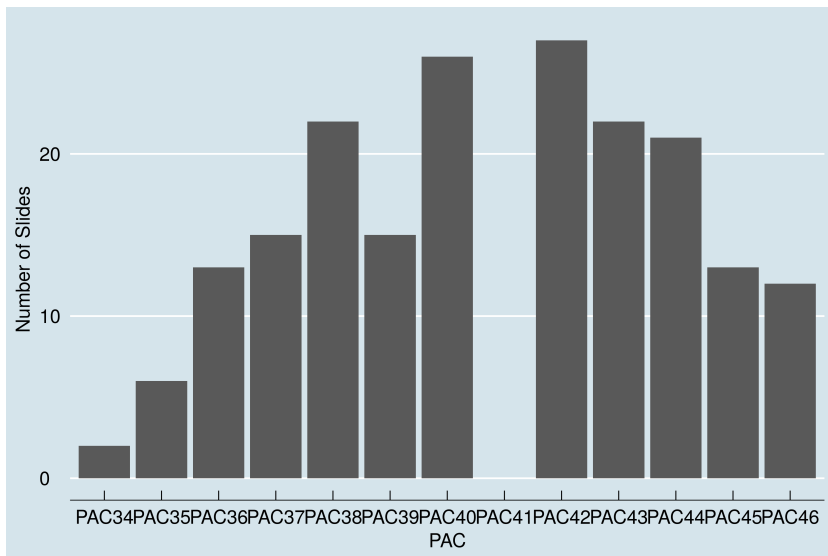
202[1-2]: New End Station Refrigerator (ESR)

- Schedule impact limited to when loads are switched from old ESR to new ESR.

Summary

- Beam availability to date this year has steadily improved
- Accelerator ability to support four halls established
 - ▶ Achieved shift (8h) multiplicity greater than 3.6 ($4 \times 90\%$ (FSD eff))
 - ▶ Achieved **week averaged** multiplicity greater than **3.1** ($4 \times 90\% \times 85\%$ (sch. eff.)) in the final weeks of operation (prior to network outage)
- Achieved full beam power (900 kW)
 - ▶ RF ability to support full beam load established (significant effort)
 - ▶ Identification and mitigation of longitudinal tail as the initial limitation to sustained full power beam delivery
- Energy Reach maintained via weekly *RF recovery days* throughout the run
- Shutdown tasks targeted to build upon the Spring performance





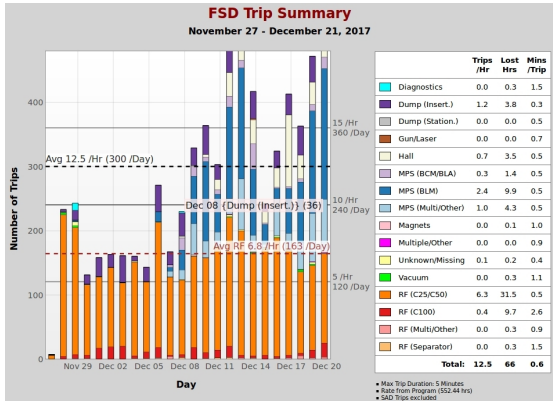
Preceding Activities Operations post Summer2017 shutdown

- $\approx 50\%$ of CEBAF warmed to room temperatures (for maintenance and due to unplanned loss of Cryogenics)

Plan 3 week physics program: establish a four hall Program

Reality 2 weeks of beam delivery, 2-3 hall program

Availability sub 50%, 748.5 MHz RF separators, magnet, ... issues



Accelerator Availability*:	48.4%
Loss Due to Events*:	39.6%
Loss Due to Trips*:	12%
Event Availability*:	60.4%
Trip Availability*:	88%

- Machine setup took longer than expected
- Energy Reach OK, ≈ 7 trips/h
- 748.5 MHz separator challenges, operational near end of run.

Preceding Activities Winter Break, minimal maintenance activities

- CEBAF @2K during break

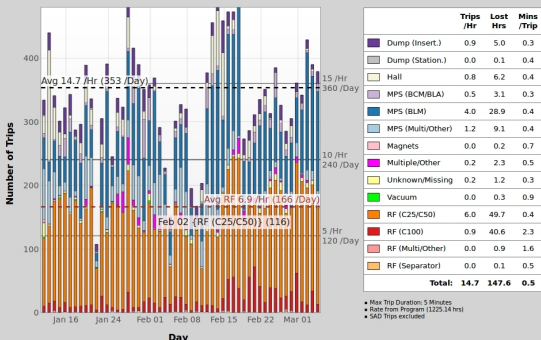
Plan Establish and execute a 3+ hall Program

Reality 3+ halls, unable to sustain high current delivery to Hall-C

Availability improving to 56%, beam tuning, not hardware, dominates the downtime

FSD Trip Summary

January 12 - March 6, 2018



Accelerator Availability*: 55.9%

Loss Due to Events*: 32.1%

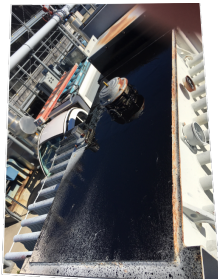
Loss Due to Trips*: 12%

Event Availability*: 67.9%

Trip Availability*: 88%

- Transformer failure on March 5th terminated beam operations
- Energy Reach OK, ≈ 7 trips/h, *trips trending up?*
- Too many MPS (beam loss)

Top of the failed transformer, black is cracked oil the spewed out the top relief port.



Replacement transformer delivered in 5-days!



Maintenance work in parallel with transformer repair and restart of CHL1->SCM system.

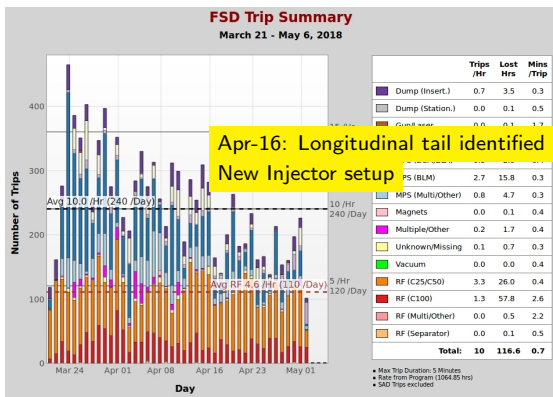
- RF maintenance activities to arrest the trend of increasing RF trip rate.

Preceding Activities Transformer repair and RF maintenance

Plan Continue to execute a 3+ hall Program

Reality 4 hall program

Availability **71%**, best availability to-date in the 12 GeV era



Accelerator Availability*: 70.8%

Loss Due to Events*: 18.2%

Loss Due to Trips*: 11%

Event Availability*: 81.8%

Trip Availability*: 89%

- High current limitation attributed to a longitudinal beam tail
- Reduction of MPS trips
- Energy Reach improved, < 5 trips/h

- CEBAF requires two functioning sub-atmospheric cold-boxes to pumpdown the Linacs to 2 K.
- Both cold-boxes are original 4 GeV equipment:

SCM Original cold-box, in service 1994-1999 and 2013-present

SCN Built out of the SCM spare cold compressors, in service 2000-present

- Two styles of cold-compressors in each cold-box.
- 2015 cold compressor hard landing consumed the only spare cold compressor on the planet (of that style).

End of FY17 funds have been made available to design, fabricate and install a new maintainable cold-box. (early 2021?).

Summary of Considered Options¹:

Option #	Description	Estimated 2K Downtime (Weeks)	Contingency (Weeks)	Expend Increase in Pressure Drop (From Base-Case)	Comments
1	SBR Cold Box Area (CHL Back Porch)	25 ⁺ - Linac Warm-up 'Cold-Drown'	None	> 1.0 mbar	<ul style="list-style-type: none"> Add new 2K Cold Box without permanently disconnecting the existing Cold Boxes. Requires SBR Cold Box Removal. Requires modification of CHL distribution headers. Requires modification of Linac distribution headers (https://www.slac.stanford.edu). Requires permanently tie in SLAC.
2	CHL Oil Processor Area (Bldg. 8 - K100)	30 ⁺	None	> 1.5 mbar	<ul style="list-style-type: none"> Connects to existing (SC1M) Primary Return (PR) header. Requires new PR header to 2K Cold Box. Requires modification of CHL distribution headers.
3	CHL Loading Dock Area (Bldg. 8 - MCB1 Bay)	32 ⁺	None	> 1.0 mbar	<ul style="list-style-type: none"> Connects to existing (SC1M) Primary Return (PR) header. Customer space in loading dock area (prepared for U-Tube operator/plant maintenance). Requires new transfer line to 2K Cold Box.
4	SC1M Area	25	3	> 1.0 mbar	<ul style="list-style-type: none"> Connects to existing (SC1M) Primary Return (PR) header. Requires removal of existing SC1M Cold Box. No modification to distribution piping is necessary. Selected, Base Case.
5	CHL Oil Processor Area (Bldg. 8 - K100, SC2N)	27 ⁺	None	> 1.2 mbar	<ul style="list-style-type: none"> Connects to existing (SC1M) Primary Return (PR) header. Requires new PR header to 2K Cold Box. Requires modification of CHL distribution headers. Requires SC2N AMB/VFD Cabinet Removal.

Option # 4

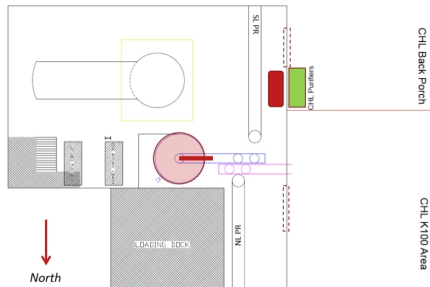
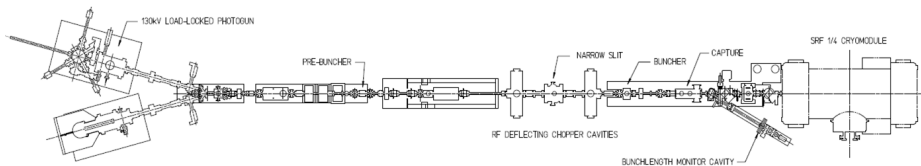


Fig.: CHL CBX Room (1st Floor) Schematic

Injector Upgrade



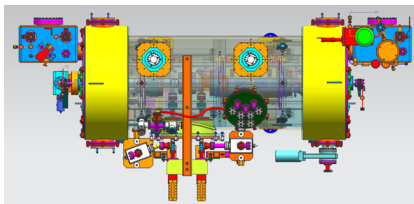
Past Upgrade gun 100 → 130 kV, install 2nd Wien filter, double energy (C100-0) to 123 MeV.

2018 Install and commission 200 kV capable gun and 350 kV HV power supply.

2019 Design, fabricate and test new Wien filter, solenoid magnets and new SRF Booster in the Injector Test Facility

2020 Install and commission in CEBAF, including new Booster:

- Operate gun up to 200 kV
- No X-Y coupling.
- No warm capture



New Booster (aka $\frac{1}{4}$ cryomodule)

- 2-cell capture section+ 7-cell (C100 style) cavity
- Design for up to 10 MeV of energy gain
- Fabrication complete, ready for testing in the Injector Test Facility