# CEBAF Accelerator Update

Arne Freyberger

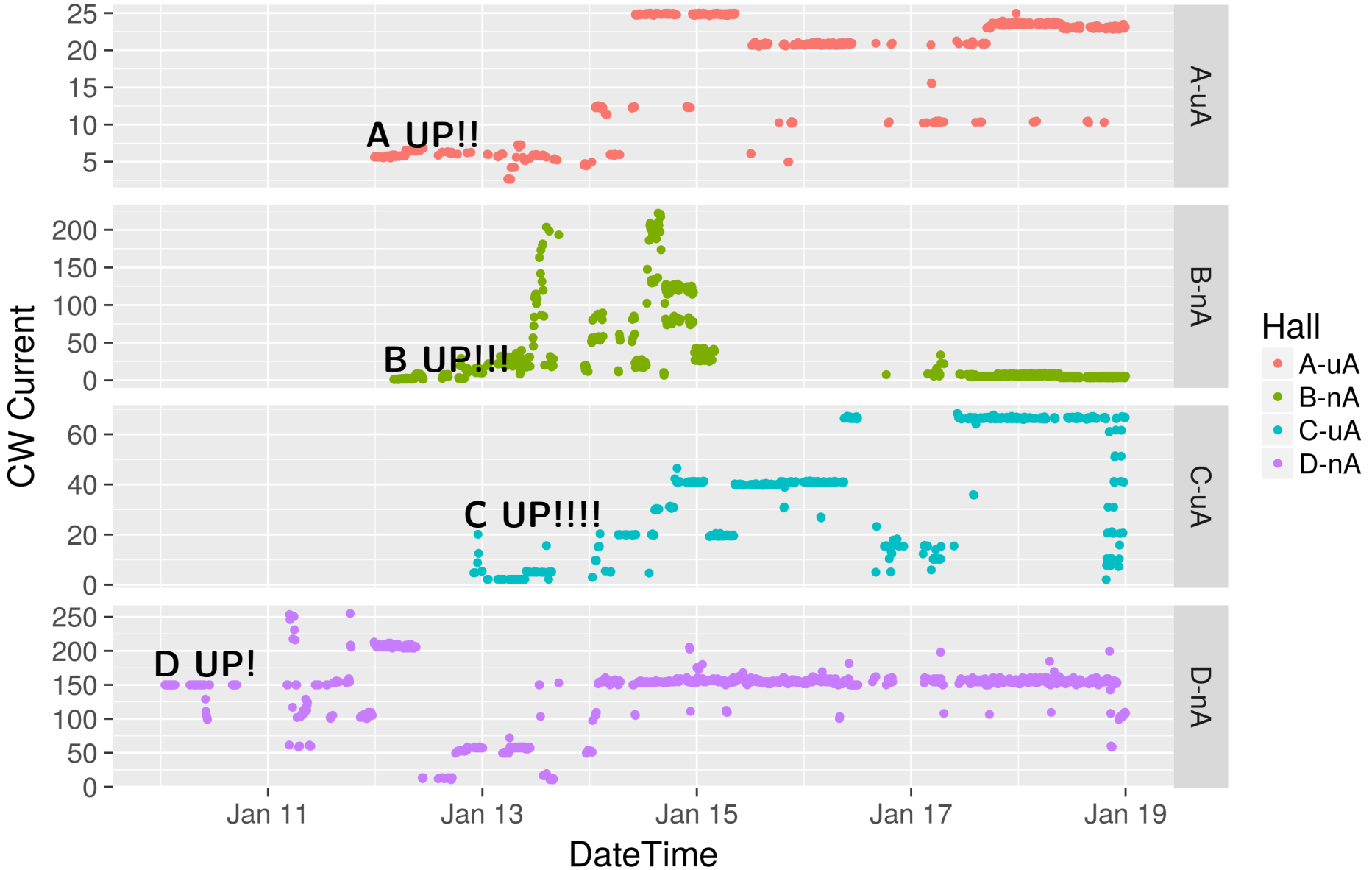
Operations Dept.
Accelerator Division

JLAB

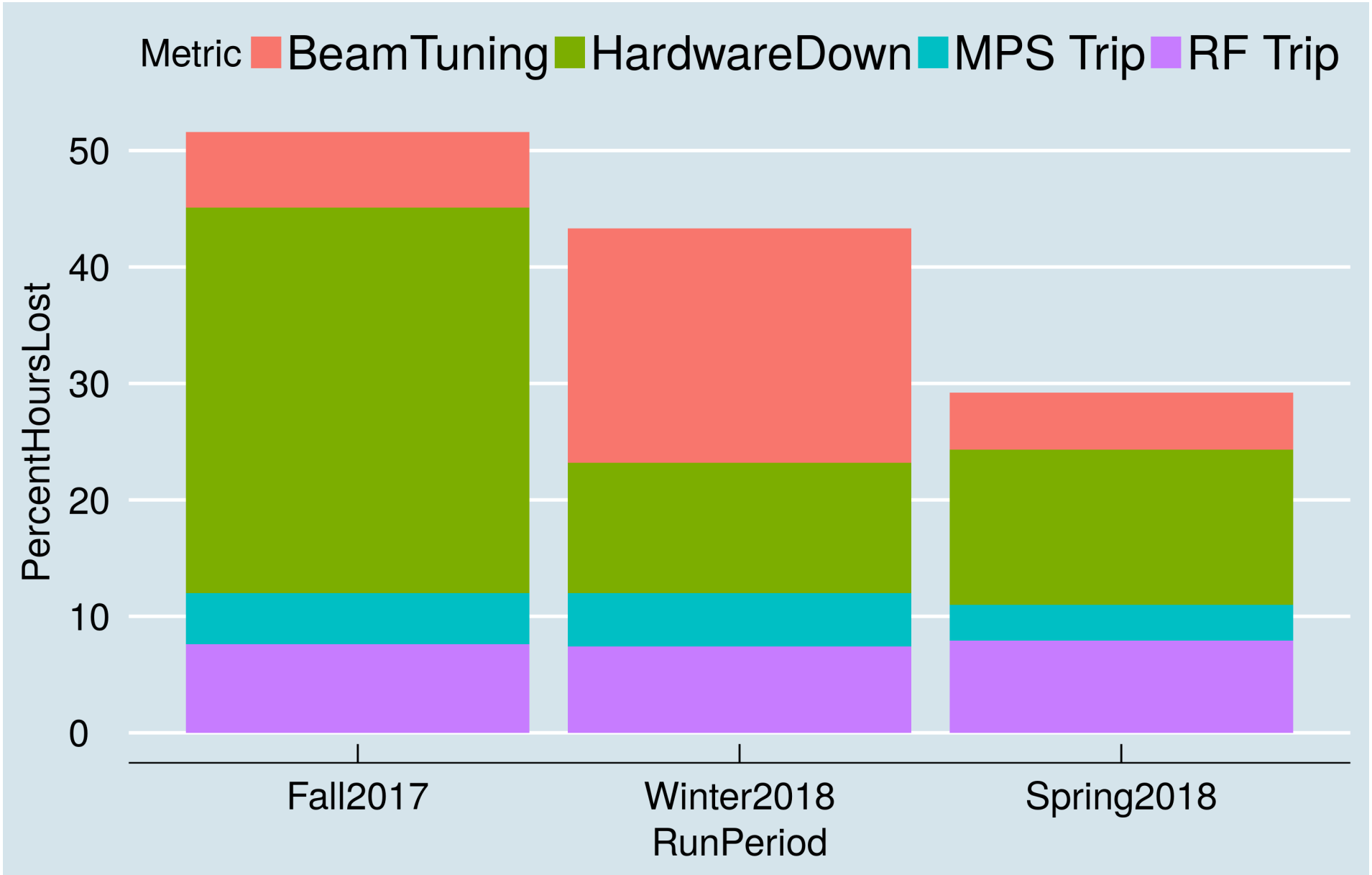
June 20, 2018

# FY18 Operations (to-date)

# Four Hall Operations!

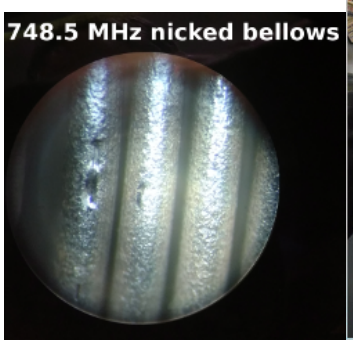


# Lost Hours: Evolution



# Summer2019: Ongoing Shutdown Activities

- CHL1 and ESR maintenance
- Repair leak in $5^{th}$-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 $\rightarrow$ CEBAF NL23 zone
  - LERF P1 module $\rightarrow$ CEBAF NL07 zone
- Grid maintenance: Transformer/Breakers
- Upgrade original 4 GeV box power supplies

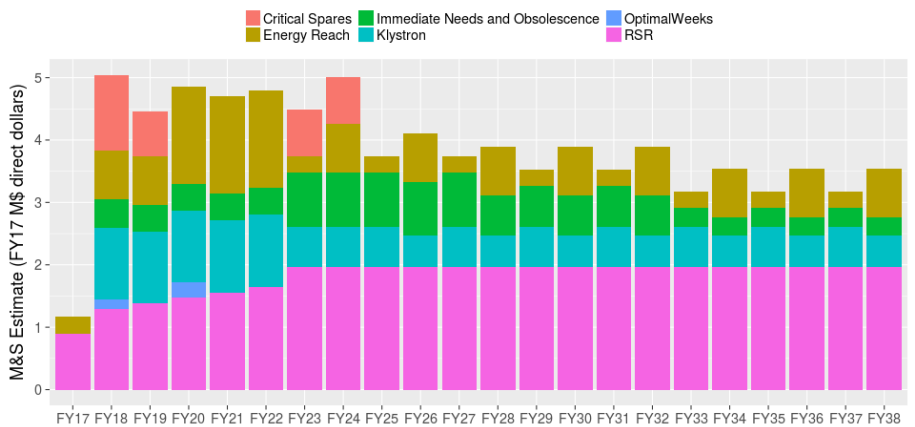





# CEBAF Performance Plan (CPP)

Strategy to improve CEBAF performance through:

1. Purchase Critical Spares to mitigate the impact of single point failures.
2. Replenish consumed hardware spares (i.e. Klystrons)
3. Increase Energy Reach to support design energy with robust energy margin.
   - C75 Refurbish 8 original C20 modules, including new cavities and digital controls.
   - C100 Develop and execute C100 refurbishment plan
   - Particulate Control Clean warm girder regions and upgrade vacuum systems
4. Upgrade original CEBAF hardware to mitigate obsolescence issues in a timely manner (ie. before it becomes an issue)
5. Procure equipment to minimize future maintenance duration (to support up to 35 weeks-per-year of operation).

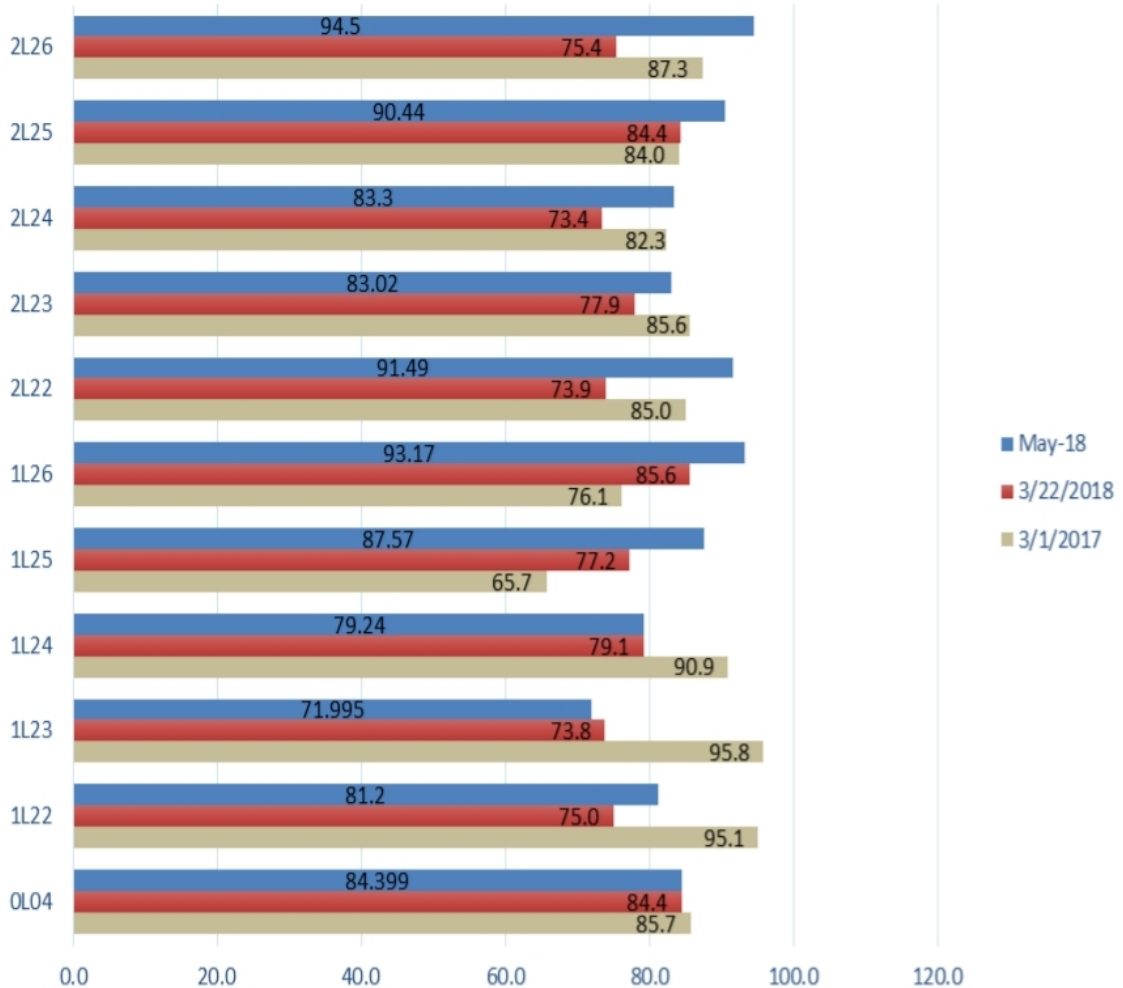


# Energy Reach: C100 Status

- Started on March 23
- South up 18.6MeV/m from 2017
  - gradient was just sitting there, sad and forgotten
- North down 10.5MeV/m from 2017
  - cryo events, vacuum, FE

| MeV/m | Total | North | South |
|---|---|---|---|
| March 2017 | 933.5 | 423.6 | 424.2 |
| March 2018 | 860.1 | 390.8 | 384.9 |
| May 2018 | 940.5 | 413.2 | 442.8 |

- North is up 22.4 MeV/m from the start
- South is up 58 MeV/m




Energy reach: NL 1079MeV; SL 1080MeV

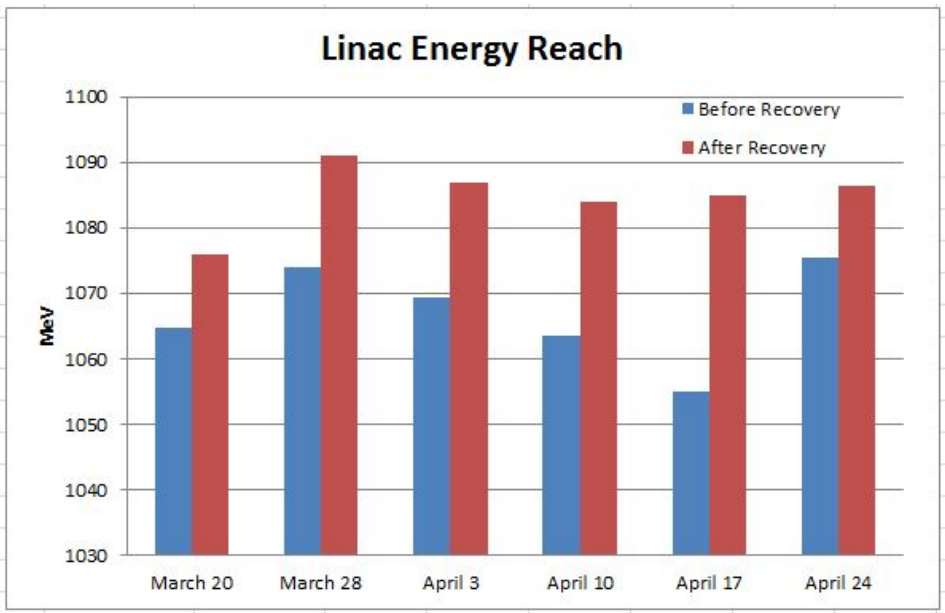
Slide: Anna Solopova

# RF Recovery Days

During beam delivery cavity gradients can sometimes be lowered or turned off due to:

- Perceived excessive trip rate
- Difficulty recovering the cavity after a trip
- Hardware failures

Planned work during RF recovery day is to *recover* gradient so that the RF margin remains in the positive range.




Graphic: Ken Baggett

# Energy Reach: Plans

## Near Term: Summer2018

Goal is to **maintain** CEBAF energy capability at 1050 MeV/linac for the next run.

- Install the LERF **F100** in NL23 slot. C100 style cryomodule.
- Install the LERF **P1** in NL07 slot. P1: First post-C20 cryomodule
- Helium process poorest performing cavities
- Thermal cycle NL C100s to remove frozen gases
- Install rad-hard turbo pumps on insulating vacuum space

## Long Term

Goal is to **improve** CEBAF energy capability at 1090 MeV/linac with robust margin by 2021-Oct(FY22).

| | FY | Proposed Linac Energy Setting for FY | Linac Margin | Rebuilt cryomodules completed in FY | Comment |
|---|---|---|---|---|---|
| Date | | $\frac{\text{MeV}}{\text{linac}}$ | $\frac{\text{MeV}}{\text{linac}}$ | | |
| 2017-10-01 | FY18 | 1050 | 25 | F100, P1 | Install Two FEL hot modules |
| **2018-10-01** | FY19 | 1050 | 31 | **C75-1** | **First C75 Installed Summer 2019** |
| 2019-10-01 | FY20 | 1050 | 37 | **C75-2**/C100-Refurb-1 | First C100 Refurbed module installed |
| 2020-10-01 | FY21 | 1050 | 50 | **C75-3**/**C75-4**/C100-Refurb-2 | **First year of two C75s** |
| 2021-10-01 | FY22 | 1090 | 36 | **C75-5**/**C75-6**/C100-Refurb-3 | |
| 2022-10-01 | FY23 | 1090 | 72 | **C75-7**/**C75-8**/C100-Refurb-4 | |

# New 2K ColdBox

- 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 Options[1]:**

| Option # | Description | Estimated 2K Downtime (Weeks) | Contingency (Weeks) | Expected Increase in Pressure Drop (From Base-line[2]) | Comments |
|---|---|---|---|---|---|
| 1 | SBR Cold Box Area (CHL Back Porch) | 26[7] + Linac Warm-up / Cool-Down[3] | None | > 1.0 mbar | ▪ Adds new 2K Cold Box without permanently disconnecting the existing Cold Boxes.<br>▪ Requires SBR Cold Box Removal.<br>▪ Requires modification of CHL distribution headers.<br>▪ Requires modification of Linac distribution headers (*Linac warm-up*).<br>▪ Requires permanently tie to SLinac. |
| 2 | CHL Oil Processor Area (Bldg. 8 – K100) | 30[7] | None | > 1.5 mbar | ▪ Connects to existing (SC1/M) Primary Return (PR) header.<br>▪ Requires new PR header to 2K Cold Box.<br>▪ Requires modification of CHL distribution headers. |
| 3 | CHL Loading Dock Area (Bldg. 8 – MCB1 Room) | 32[7] | None | > 1.0 mbar | ▪ Connects to existing (SC1/M) Primary Return (PR) header.<br>▪ Consumes space in loading dock area (required for U-Tube operation/plant maintenance).<br>▪ Requires new transfer line to SC1/M vacuum shell. |
| 4 | SC1/M Area | 25 | 3 | ~ 0.1 mbar | ▪ Connects to existing (SC1/M) Primary Return (PR) header.<br>▪ Requires removal of existing SC1/M Cold Box.<br>▪ No modification to distribution piping is necessary.<br>▪ Selected, Best Case |
| 5 | CHL Oil Processor Area (Bldg. 8 – K100, SC2/N) | 27[7] | None | > 1.2 mbar | ▪ Connects to existing (SC2/N) Primary Return (PR) header.<br>▪ Requires new PR header to 2K Cold Box.<br>▪ Requires modification of CHL distribution headers.<br>▪ Requires SC2/N AMB/VFD Cabinet Removal |

**Option # 4**

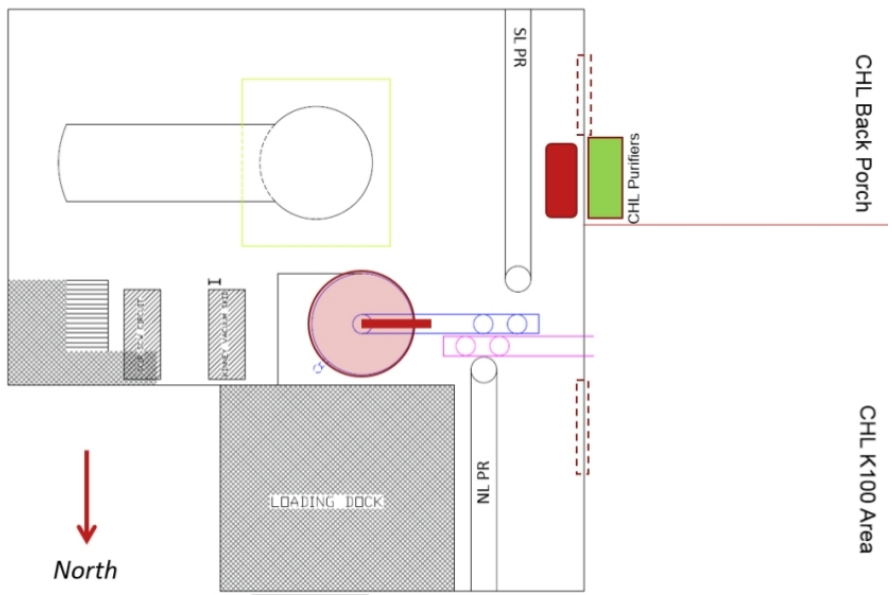
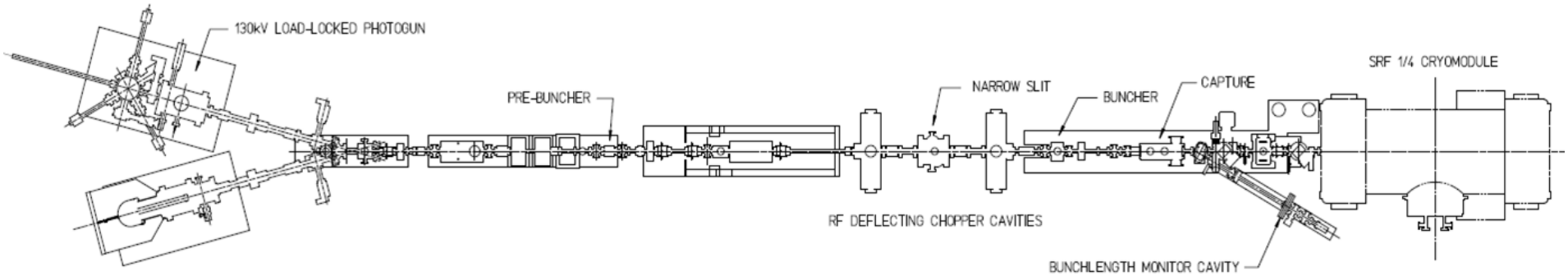



Fig.: CHL CBX Room (1st Floor) Schematic

# Injector Upgrade

# Injector Upgrade



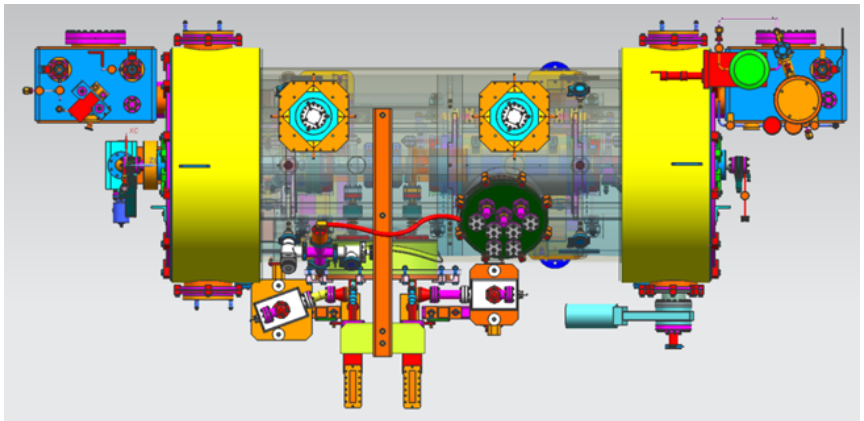

Past Upgrade gun 100 $\rightarrow$ 130 kV, install $2^{nd}$ Wien filter, double energy (C100-0) to 123 MeV.

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

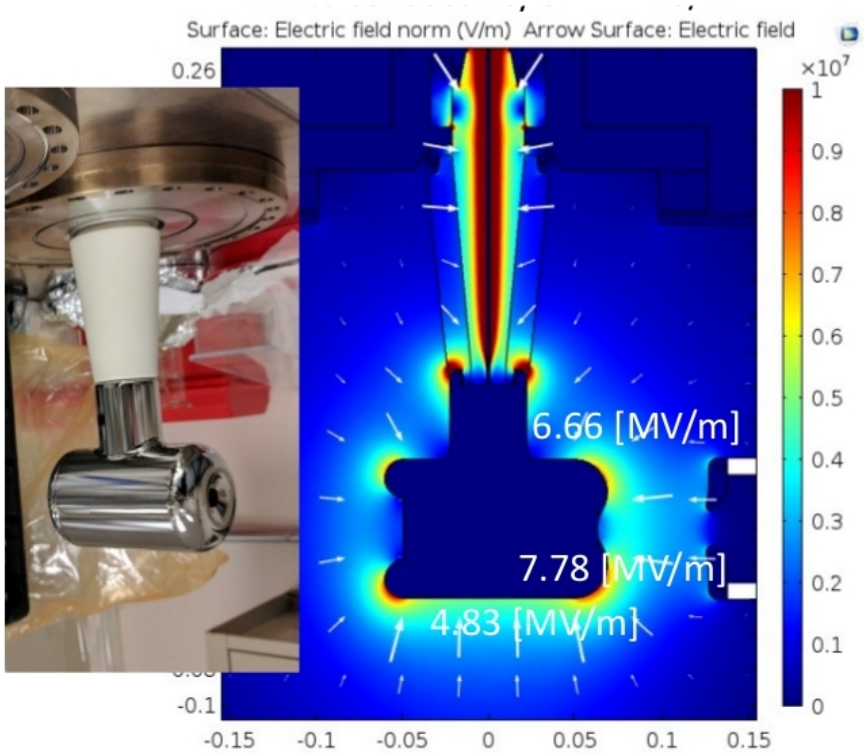


New Booster (aka $\frac{1}{4}$ *cryomodule*)

- 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

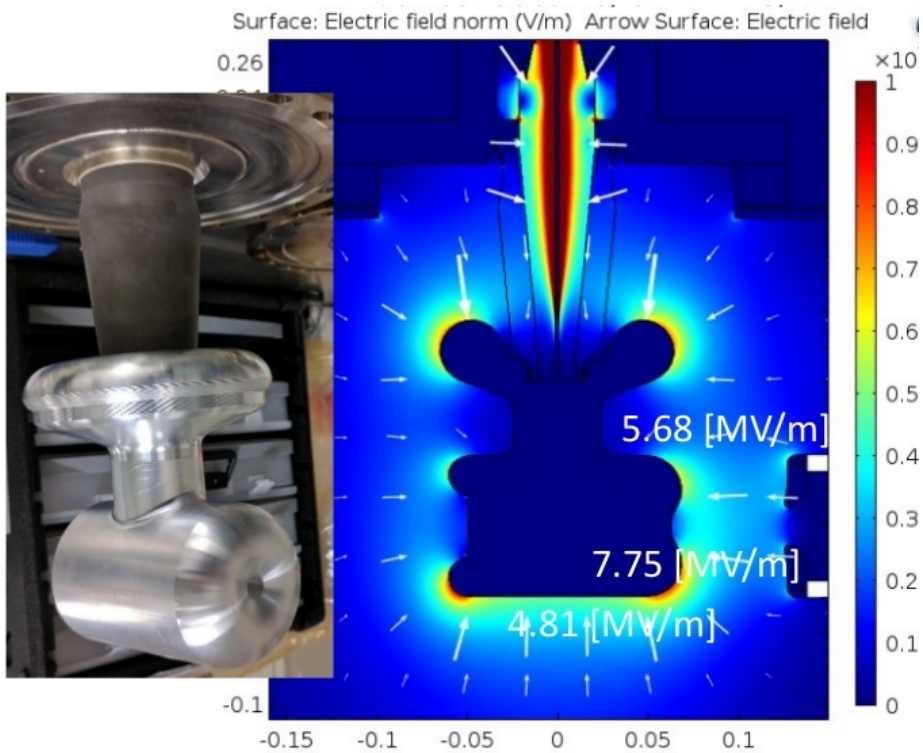
# 200 kV Gun: New Cathode Design

## CEBAF Existing Gun @ 200 kV




- Pure alumina insulator
- No triple point shielding

## CEBAF Upgrade Gun @ 200kV



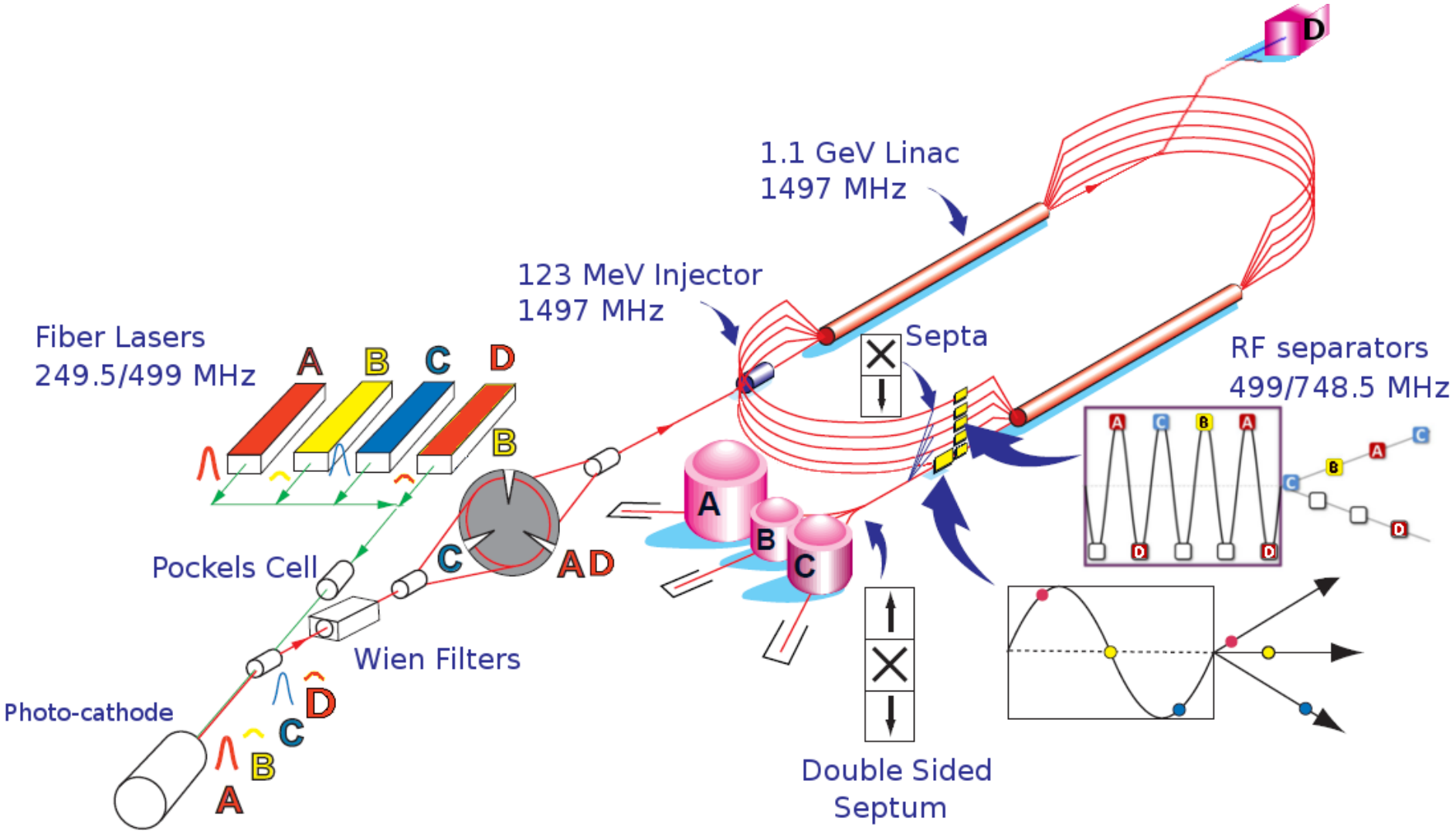

- Mildly conductive alumina insulator for charge dissipation
- Triple point shielding to prevent arcing across HV plug

Work of G. Palacios, C.H. Garci

# Future Schedule

# Fall Halls: Laser Table to RF separation

Concept: Reza Kazimi



# Beam Parameters

JLAB-TN-18-022

JLAB-TN-18-022
31 March 2018

## 12 GeV CEBAF Beam Parameter Tables

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

### Hall A

| Beam Property | Nominal Value/Range | Temporal Stability over 8 hours |
|---|---|---|
| Spot size at target (rms ) | | |
| Angular divergence at ta | | |
| Current [μAmp] | | |
| Charge per bunch [fCoul] | | |
| Bunch repetition rate [M | | |
| Beam position | | |
| Energy spread♠ (rms ) | | |
| Beam direction | | |
| Energy range [GeV] | | |
| Energy accuracy♥ (rms ) | | |
| Beam polarization▽ | | |
| Charge asymmmetry▲ | | |
| Background beam halo | | |
| Beam availability (includ | | |

### Hall B

| Beam Property | Nominal Value/Range |
|---|---|
| Spot size measured by 2H01 | |
| Angular divergence at target | |
| Current [nAmp] | |
| Charge per bunch [fCoul] | |
| Bunch repetition rate [MHz] | |
| Beam position♣ | |
| Energy spread♠ (rms ) | |
| Beam direction | |
| Energy range [GeV] | |
| Energy accuracy♥ (rms ) | |
| Charge asymmmetry▲ | |
| Background beam halo | |
| Beam polarization▽ | |
| Beam availability (including | |

### Hall C

| Beam Property | Nominal Value/Range | Temporal Stability over 8 hours |
|---|---|---|
| Spot size (X/Y)♦ at pivot ( | | |
| Angular divergence at tar | | |
| Current [μAmp] | | |
| Charge per bunch [fCoul] | | |
| Bunch repetition rate [M | | |
| Beam position | | |
| Energy spread♠ (rms ) | | |
| Beam direction | | |
| Energy range [GeV] | | |
| Energy accuracy♥ (rms ) | | |
| Beam polarization▽ | | |
| Charge asymmmetry▲ | | |
| Background beam halo | | |
| Beam availability (includi | | |

### Hall D

| Beam Property | Nominal Value/Range | Temporal Stability over 8 hours |
|---|---|---|
| Spot size at target♦ (rms ) [μm] | Horizontal < 1000 | Horizontal ~ 100 |
| Angular divergence at | | |
| Current [nAmp] | | |
| Charge per bunch [fCo | | |
| Bunch repetition rate [ | | |
| Beam position | | |
| Energy spread♠ (rms ) | | |
| Beam direction | | |
| Energy range [GeV] | | |
| Energy accuracy♥ (rms | | |
| Background beam halo | | |
| Beam availability (incl | | |

'<' – 'not to exceed'

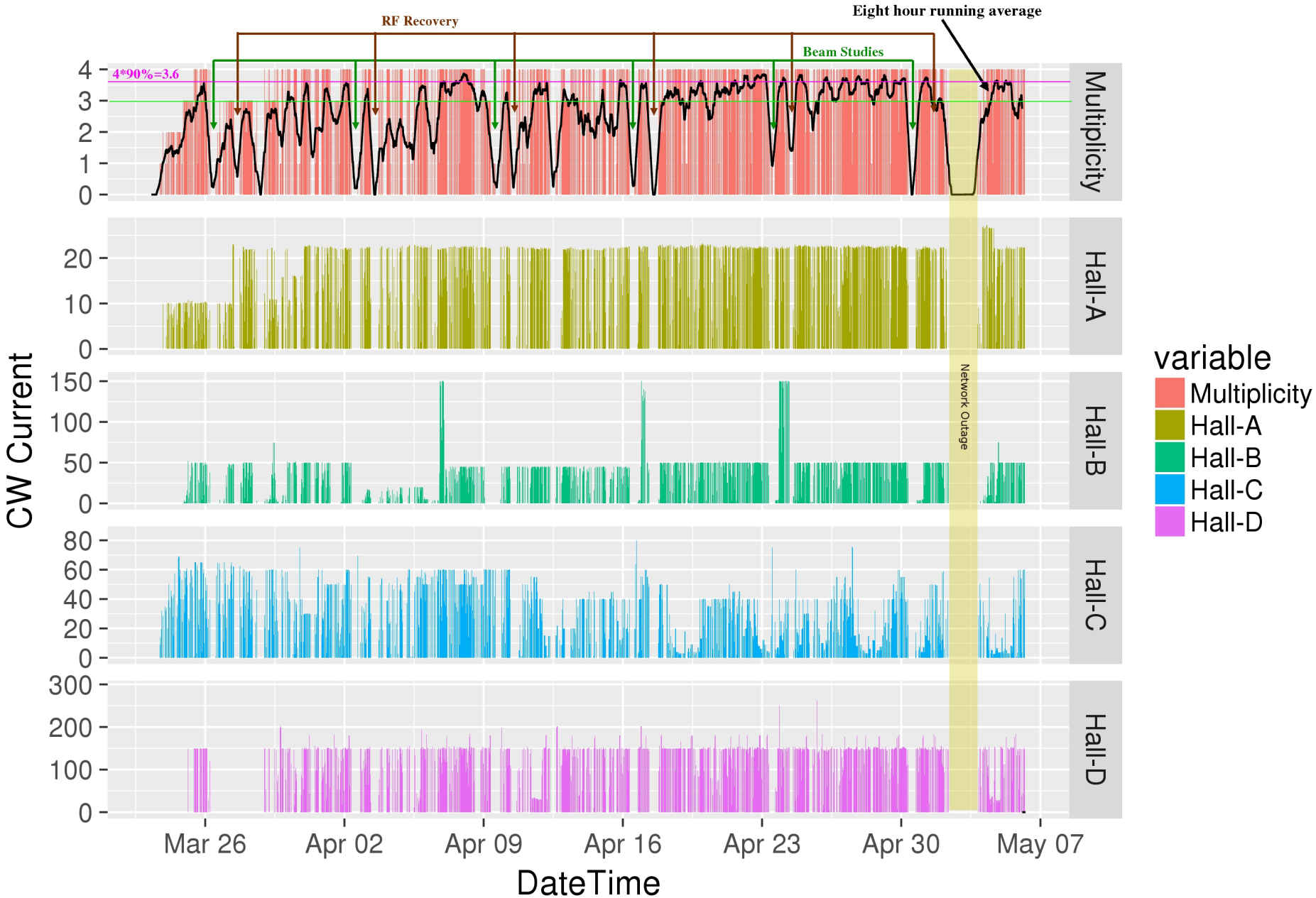
### Parity Beam Parameters

| Beam Property | Nominal Value/Range | Helicity Correlated 8-hour Average | Maximum Jitter at 30 Hz |
|---|---|---|---|
| Current [μAmp] | 5 – 100# | < 5 ppm | 2000 ppm |
| Energy [GeV] | 1 – 11 | $\left(\frac{\Delta E}{E}\right) < 15$ppb (50 nm@ 35 mm/%) | 35 μm (x-position in center of hall ARC) |
| Energy spread (rms) | $<10^{-3}$ | NA | NA |
| Position x at target | 0 | <25 nm | 15 μm |
| Angle x' at target | 0 | <10 nrad | 5 μrad |
| Position y at target | 0 | <25 nm | 15 μm |
| Angle y' at target | 0 | <10 nrad | 5 μrad |
| Spot size at target | 100 – 500 μm ($\sigma_{x,y}$ 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 $\mu$A.
3. The maximum operational beam power to Halls A or C is 900 kW.
4. The electron alignment is the identical modulo $\pi$ 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 $5^{th}$ 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 $5^{th}$ 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

# Facility Multiplicity



# Future Schedule: Fall2018-Summer2019

## 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 $\mu$A, 1-pass
  - First parity experiment in the 12 GeV era

# Future Schedule: Fall2019→

## 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 $\mu$A → high bunch charge
  * 1-pass beam

## Summer+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.

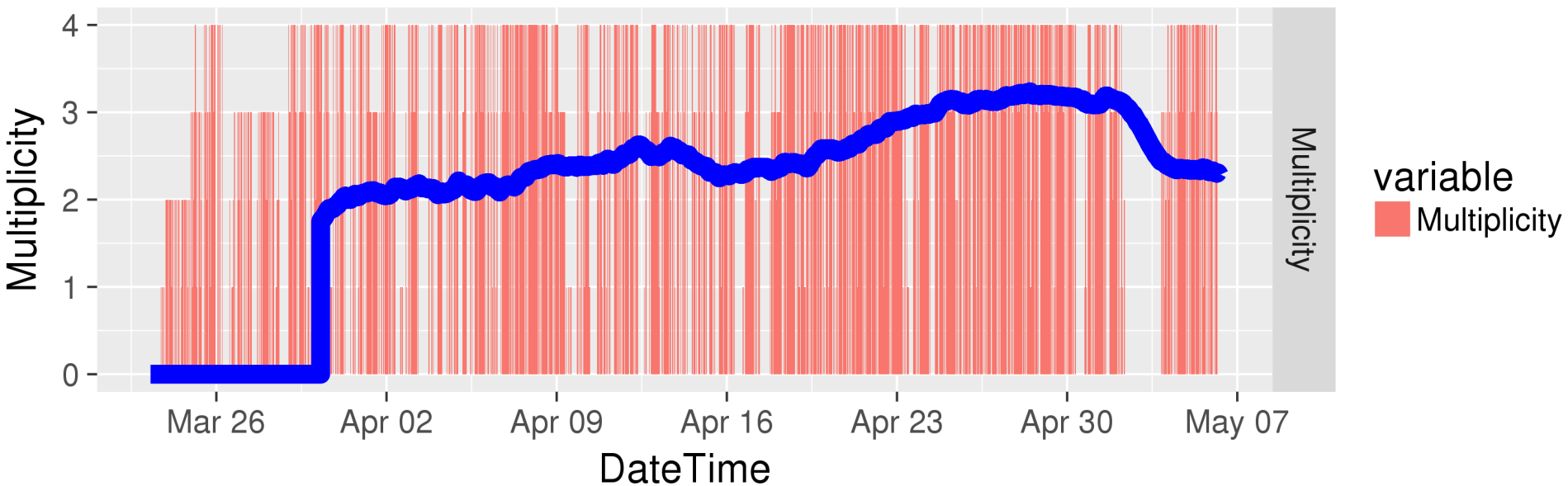
## 202[1-2]: New End Station Refrigerator (ESR)

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

# Summary

# 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



# Stop!

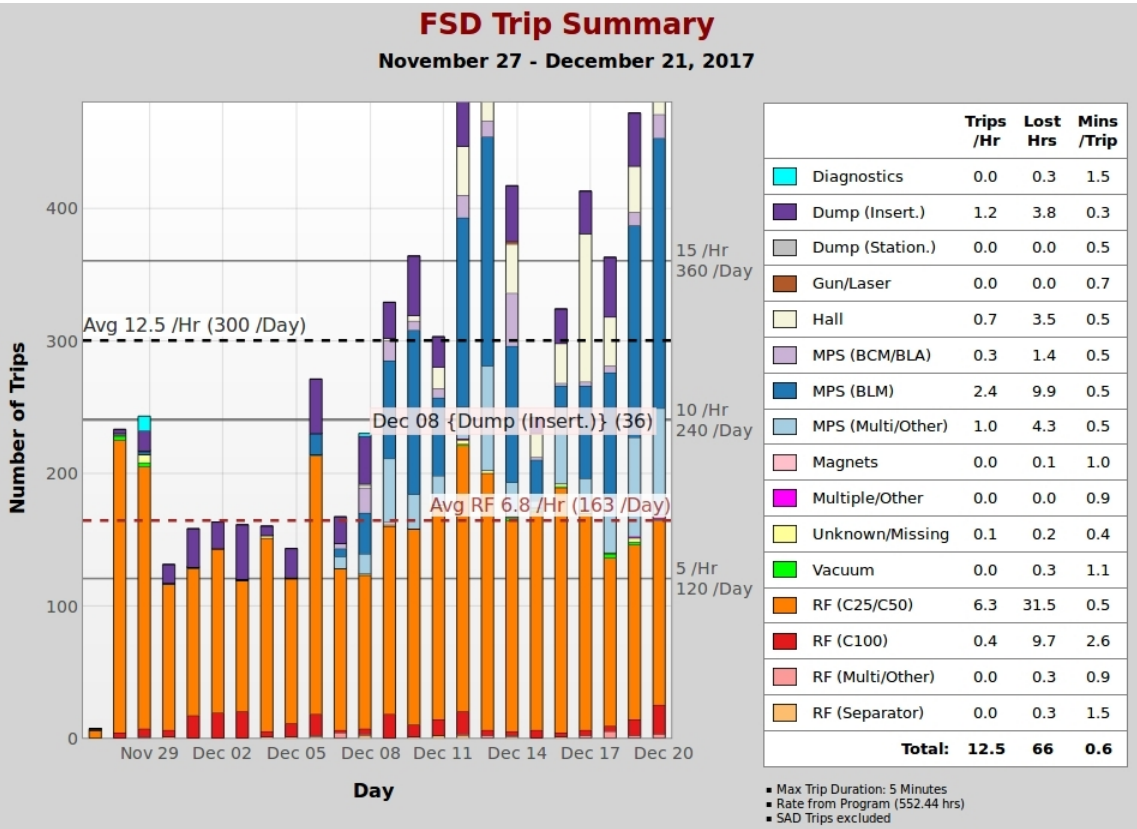
# Fall2017 Beam Operations
## 2017-11-27 — 2017-12-21: 1050 MeV/linac

**Preceding Activities** Operations post Summer2017 shutdown
- ≈ 50% of CEBAF warmed to room temperatures (for maintenance and due to unplanned loss of Cryogens)

**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.

# Winter2018 Operations

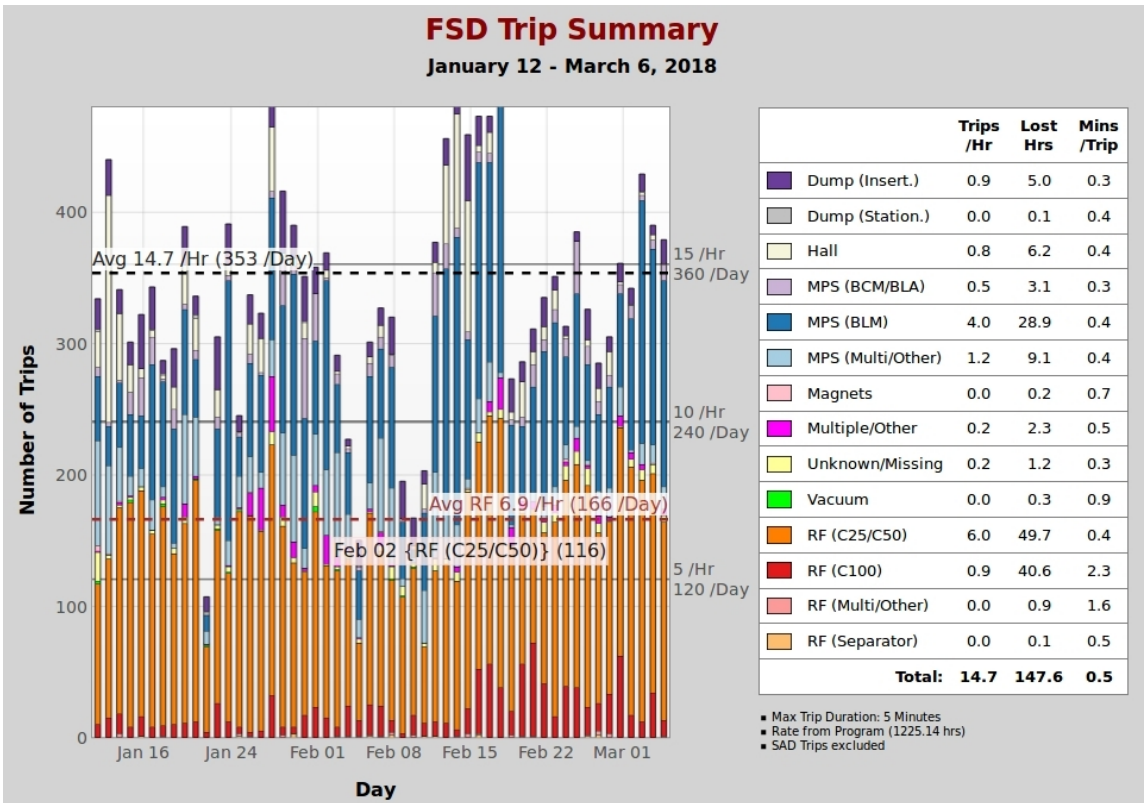
## 2018-01-09 — ~~2018-03-23~~ 2018-03-05: 1050 MeV/linac

**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




| | Trips /Hr | Lost Hrs | Mins /Trip |
|---|---|---|---|
| Dump (Insert.) | 0.9 | 5.0 | 0.3 |
| Dump (Station.) | 0.0 | 0.1 | 0.4 |
| Hall | 0.8 | 6.2 | 0.4 |
| MPS (BCM/BLA) | 0.5 | 3.1 | 0.3 |
| MPS (BLM) | 4.0 | 28.9 | 0.4 |
| MPS (Multi/Other) | 1.2 | 9.1 | 0.4 |
| Magnets | 0.0 | 0.2 | 0.7 |
| Multiple/Other | 0.2 | 2.3 | 0.5 |
| Unknown/Missing | 0.2 | 1.2 | 0.3 |
| Vacuum | 0.0 | 0.3 | 0.9 |
| RF (C25/C50) | 6.0 | 49.7 | 0.4 |
| RF (C100) | 0.9 | 40.6 | 2.3 |
| RF (Multi/Other) | 0.0 | 0.9 | 1.6 |
| RF (Separator) | 0.0 | 0.1 | 0.5 |
| **Total:** | **14.7** | **147.6** | **0.5** |

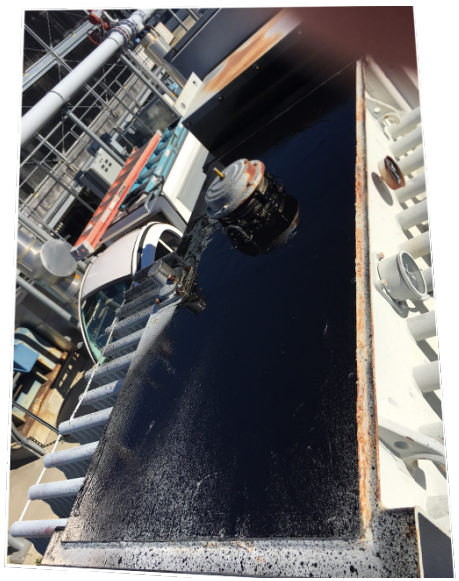
| | |
|---|---|
| **Accelerator Availability*:** | **55.9%** |
| **Loss Due to Events*:** | 32.1% |
| **Loss Due to Trips*:** | 12% |
| **Event Availability*:** | 67.9% |
| **Trip Availability*:** | 88% |

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

# Technical Stop: Transformer Failure and Repair

**2018-03-05 – 2018-03-21**

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.

# Spring2018 Operations: Continuation and Extenstion

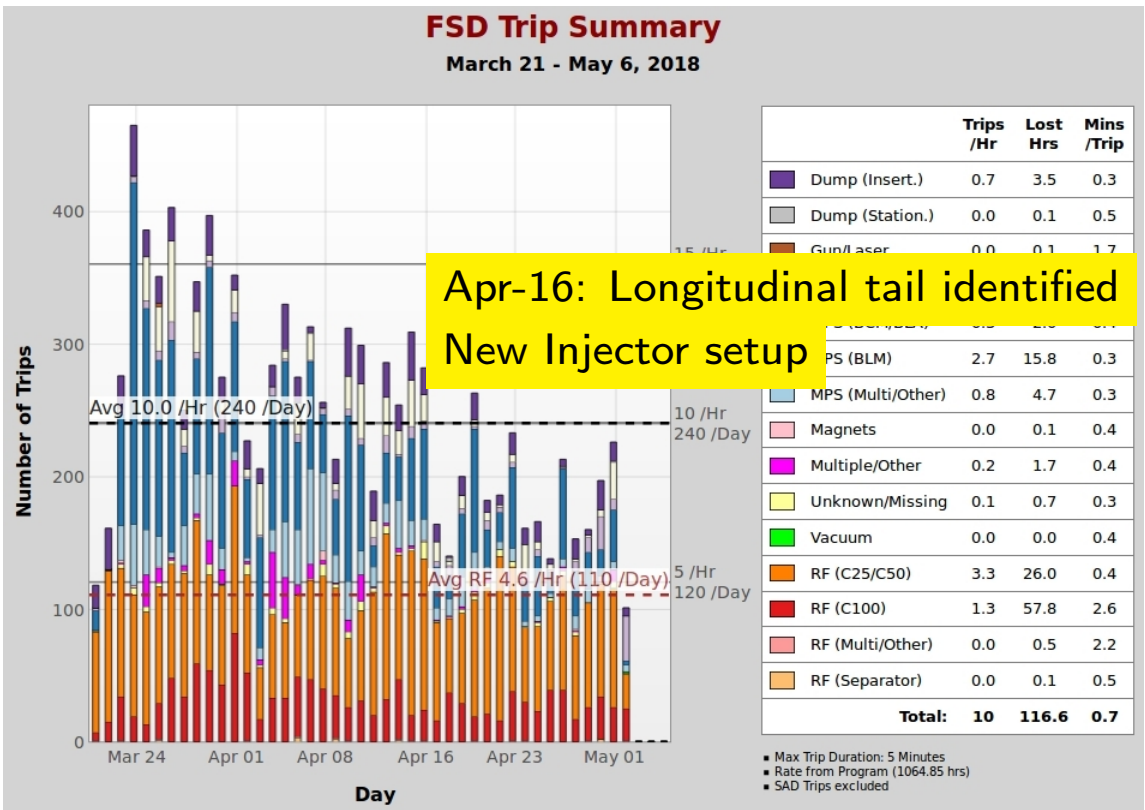
## 2018-03-21 — 2018-05-06: 1050 MeV/linac

**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




| | Trips /Hr | Lost Hrs | Mins /Trip |
|---|---|---|---|
| Dump (Insert.) | 0.7 | 3.5 | 0.3 |
| Dump (Station.) | 0.0 | 0.1 | 0.5 |
| Gun/Laser | 0.0 | 0.1 | 1.7 |
| PS (BLM) | 2.7 | 15.8 | 0.3 |
| MPS (Multi/Other) | 0.8 | 4.7 | 0.3 |
| Magnets | 0.0 | 0.1 | 0.4 |
| Multiple/Other | 0.2 | 1.7 | 0.4 |
| Unknown/Missing | 0.1 | 0.7 | 0.3 |
| Vacuum | 0.0 | 0.0 | 0.4 |
| RF (C25/C50) | 3.3 | 26.0 | 0.4 |
| RF (C100) | 1.3 | 57.8 | 2.6 |
| RF (Multi/Other) | 0.0 | 0.5 | 2.2 |
| RF (Separator) | 0.0 | 0.1 | 0.5 |
| **Total:** | **10** | **116.6** | **0.7** |

| | |
|---|---|
| **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