CEBAF Accelerator Update

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With grateful thanks
for input from many others

Major Topics

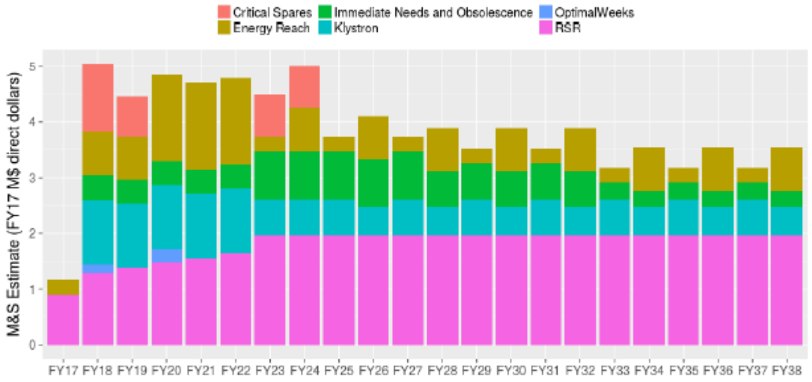
- CEBAF Performance Plan
- CEBAF Energy Reach
- Cryogenics
- Injector
- Magnets
- Optics
- Bits & Pieces

CEBAF Performance Plan (CPP)

JLAB-TN-17-022

Strategy to improve CEBAF performance through:

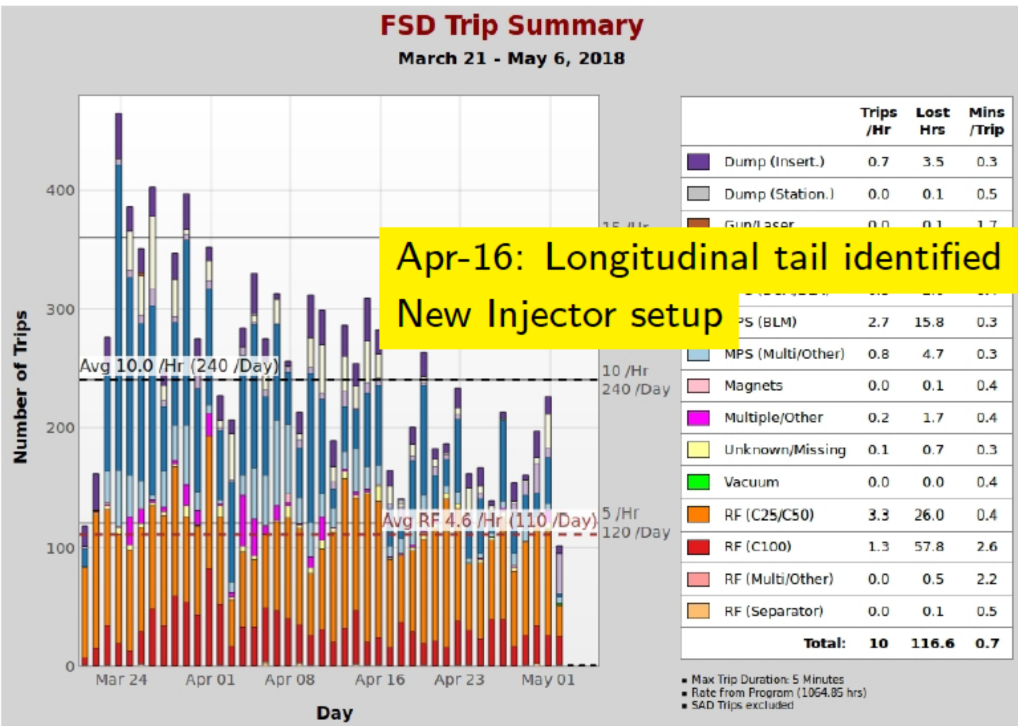
1. Purchase Critical Spares to mitigate the impact of single point failures.
2. Replenish consumed hardware spares (i.e. Klystrons)
3. Increase Energy Reach to support design energy with robust energy margin.
   - C75 Refurbish 8 original C20 modules, including new cavities and digital controls.
   - 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).



Spring2018 Operations: **(Where we've just been)**

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

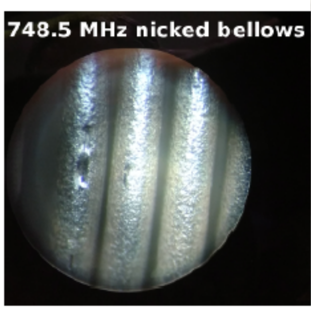


Accelerator Availability*:	**70.8%**
Loss Due to Events*:	18.2%
Loss Due to Trips*:	11%
Event Availability*:	81.8%
Trip Availability*:	89%

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

Summer2018: Shutdown Activities – What's Happening NOW?

- 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 → CEBAF NL23 zone
  - LERF P1 module → CEBAF NL07 zone
- Grid maintenance: Transformer/Breakers
- Upgrade original 4 GeV box power supplies



Energy Reach Plans: Where We Intend to Go

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).

Date	FY	Proposed Linac Energy Setting for FY $\frac{\text{MeV}}{\text{linac}}$	Linac Margin $\frac{\text{MeV}}{\text{linac}}$	Rebuilt cryomodules completed in FY	Comment
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: What, Why, When?

- 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[i]:

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[†] + Linac Warm-up / Cool-Down[3]	None	> 1.0 mbar	• Adds 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 (*Linac warm-up*). • Requires permanently tie to SLinac.
2	CHL Oil Processor Area (Bldg. 8 – K100)	30[†]	None	> 1.5 mbar	• Connects to existing (SC1/M) 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 Room)	32[†]	None	> 1.0 mbar	• Connects to existing (SC1/M) Primary Return (PR) header. • Consumes space in loading dock area (required for U-Tube operation/plant maintenance). • 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. • Requires removal of existing SC1/M Cold Box. • No modification to distribution piping is necessary. • Selected, Best Case
5	CHL Oil Processor Area (Bldg. 8 – K100, SC2/N)	27[†]	None	> 1.2 mbar	• Connects to existing (SC2/N) Primary Return (PR) header. • Requires new PR header to 2K Cold Box. • Requires modification of CHL distribution headers. • Requires SC2/N AMB/VFD Cabinet Removal

Option # 4

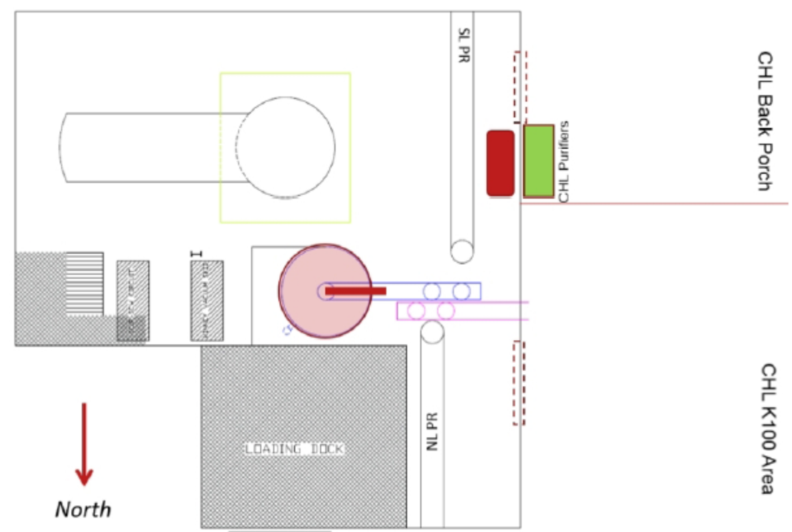
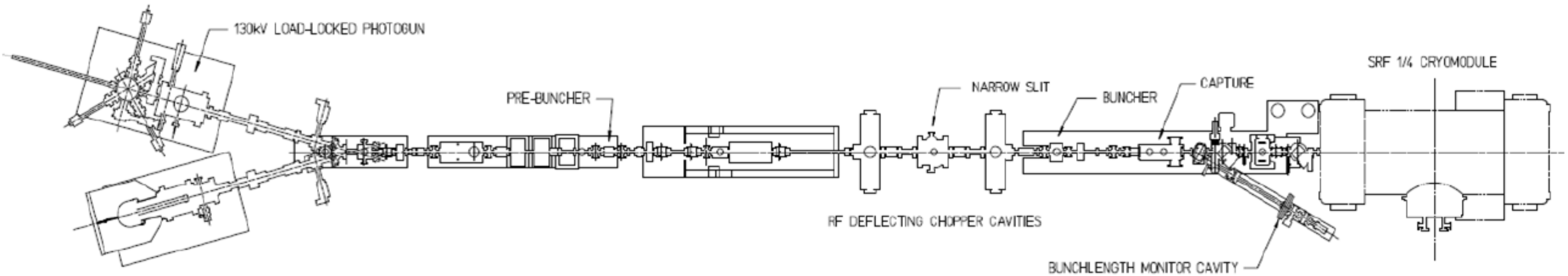
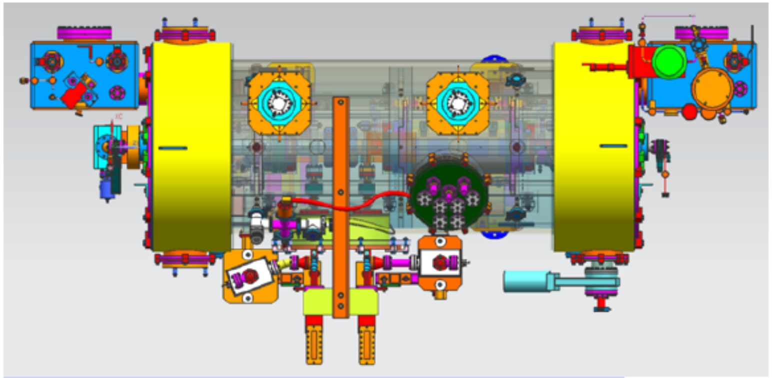


Fig.: CHL CBX Room (1st Floor) Schematic

(Perhaps complete during 2020?)

Injector Upgrade





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

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

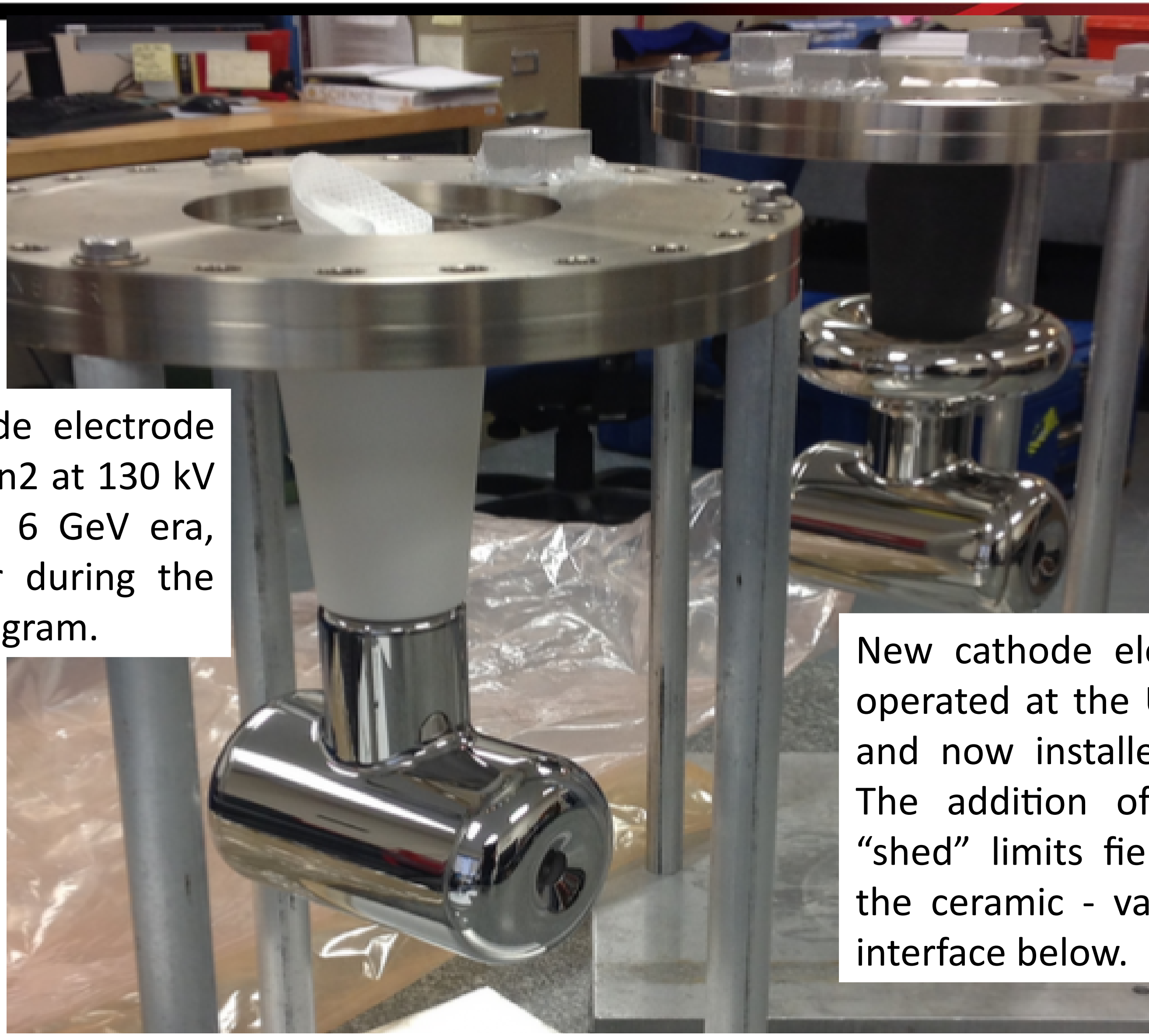
2018 Install and commission 200 kV capable gun and 350 kV HV power supply.

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

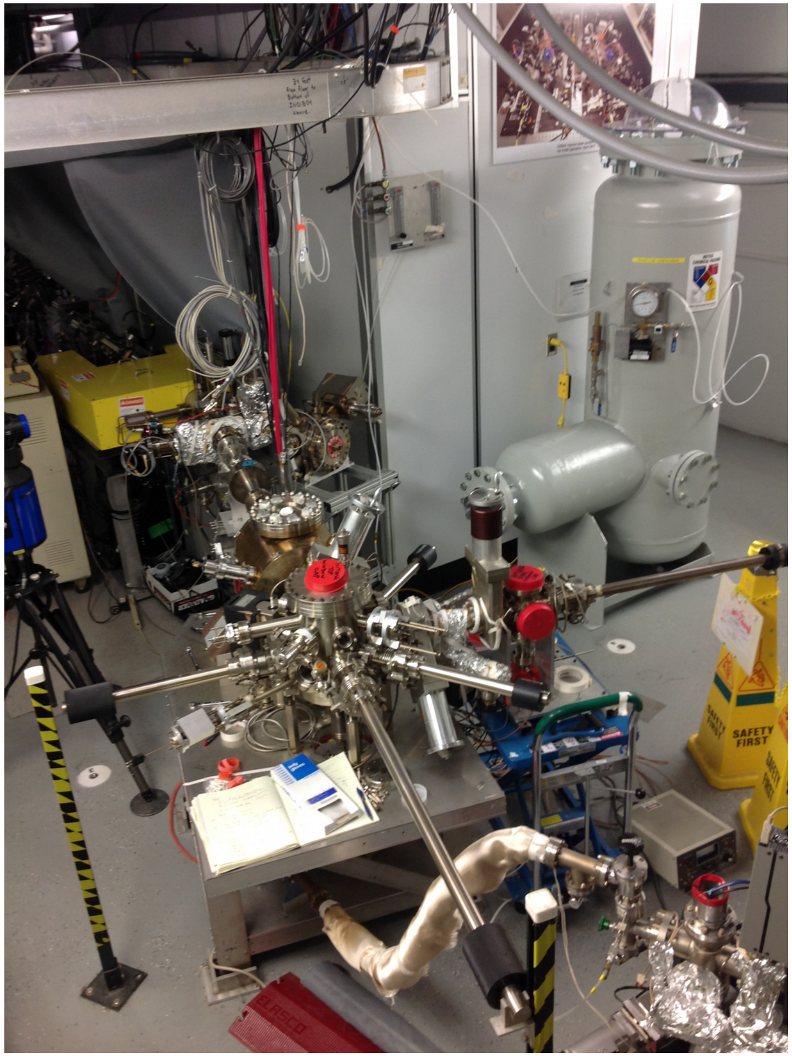
Gun2 Electrodes (May 2018)



The cathode electrode used in Gun2 at 130 kV during the 6 GeV era, and so far during the 12 GeV program.

New cathode electrode, first operated at the UITF @ 200kV and now installed in Gun2. The addition of the annular "shed" limits field gradient at the ceramic - vacuum - metal interface below.

Summer 2018 SAD Status



May – June

- ✓ Replaced Gun2 with an electrode optimized to reach 200 kV
- ✓ Replaced 150kV PS with a 350 kV PS that now sits beside Gun2 in SF_6 tank
- ✓ Added two new BPM's to the NEG tube just downstream of Gun2

June – July

- ✓ Conditioned Gun2 electrode for beam tests to 180 kV (limited time this SAD)
- ✓ Tested magnets, PSS kicker and chopper w/ 180 keV beam for higher voltage operation
- ✓ Restored Gun2 operation for 130 kV and delivered beam to FC2 at 6.3 MeV
- ✓ High polarization photocathode used during Spring run activated and ready in Gun2
- Injector setup scheduled for early August

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 μA, 1-pass
  - First parity experiment in the 12 GeV era

Future Schedule: Fall2019→ (Coordination required for cryo upgrades)

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

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) (1.5 kW capacity upgraded to 4 kW)

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

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 (includi		

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

Magnet News

- Significant magnet power supply upgrades (mentioned in slide 5 – “box” power supplies)
- Full-system quadrupole and corrector inductance survey is complete
- Two more wiring errors caught last week: MQK5C06, MQPAA13
  - Inductance shift from any wiring error is proportionally large
  - Relatively easy to verify with the correct tool
- Final data review ongoing

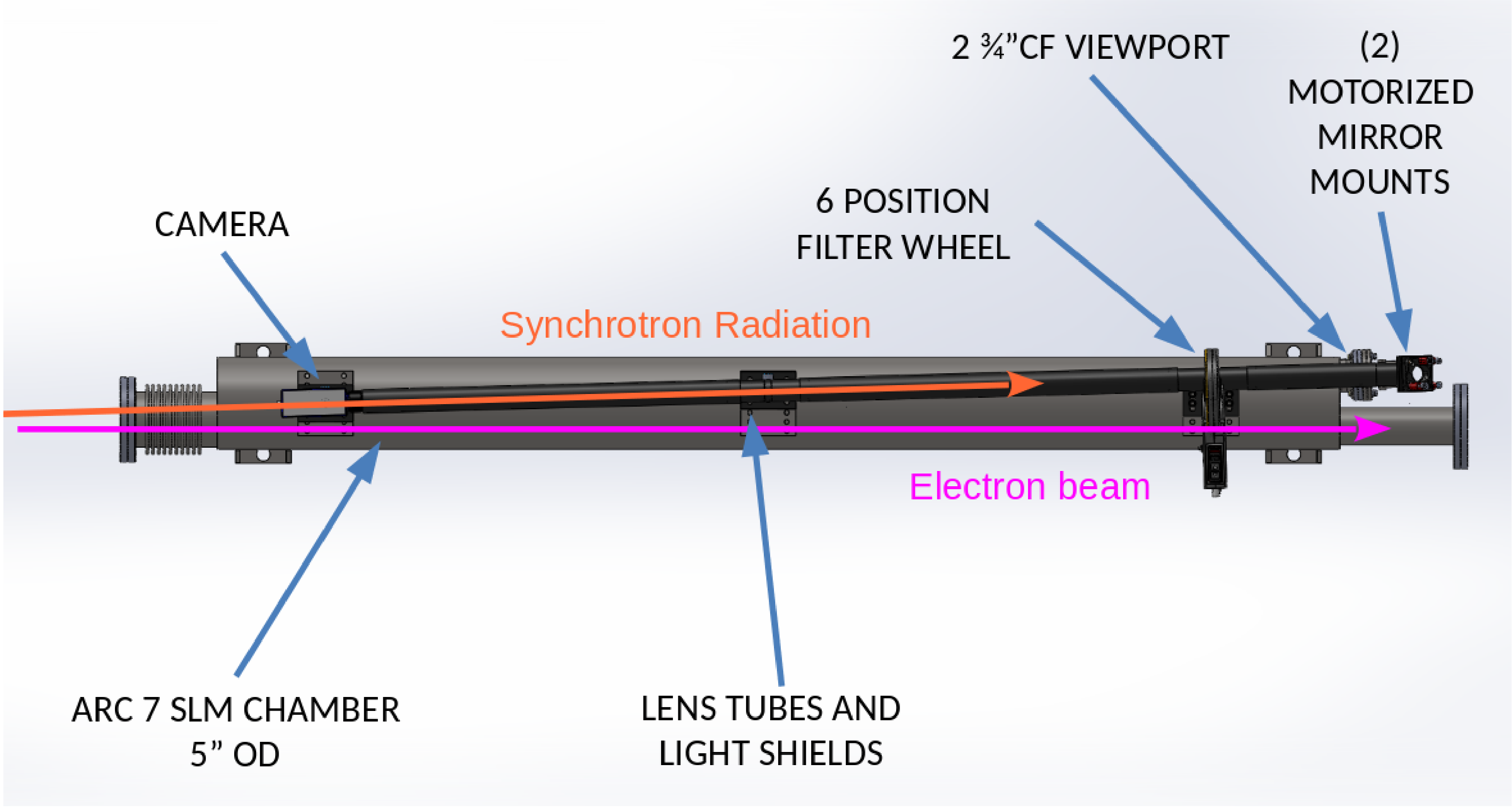
Accelerator Optics Updates – Hall C

- Restoring original Hall C transport arc (3C line) quadrupoles
- High-energy emittance growth was unnecessarily large in final transport lines with 6 GeV optics
- Reduced peak dispersion in these lines reduces emittance growth and beam size on-target
- (Hall A line had retained/upgraded all quads and provided the test bed for the lower emittance optics)

Optics and Procedure Updates

- Setup procedure is being modified to integrate differential trajectory data from accelerator BPMs
- Better data on beam envelope propagation in linacs (esp. North Linac) makes setup more reliable across linacs
- Preparing for multiple Synchrotron Light Monitor beam profile measurements in a single arc. Goals:
  - Rapid, strongly convergent process to match beam envelope in arcs, minimizing emittance growth
  - Noninvasive imaging of beam in accelerator high arcs should provide early problem identification
- Investigating direct imaging of Synchrotron Radiation X-rays in Hall A and C transport lines

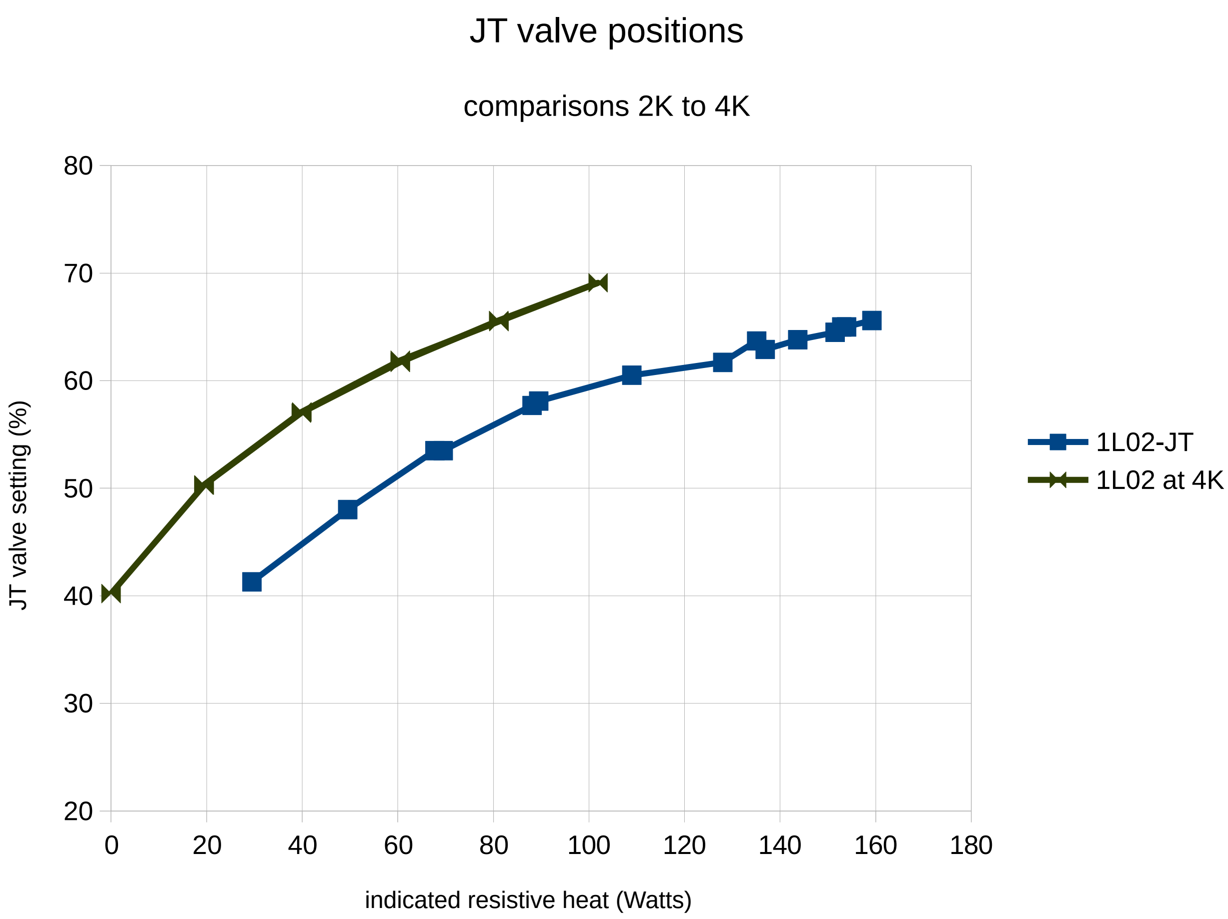
ARC 7 SLM CHAMBER



“Systems Integration” – SRF and Cryo

- CHL requires relatively constant He mass flow for stability of sub-atmospheric centrifugal compressors
- Heat load into cryomodules has been estimated from gradient using approximate, constant “Q_0” values
- This provides poor modeling of ome heat loads, particularly in the North Linac, and controlled access shut-downs of SRF result in fluctuating mass flow
- We are currently calibrating the cryo Joule-Thomson (JT) valves against cryomodule resistive heaters
- Rather than compute heat load from GSET and Q0 values, simply read off the total SRF heat from the JT equilibrium values during operation.
- As a side benefit, variable “static” heat load may be visible

“Systems Integration” II – SRF/Cryo JT Valve Cal.



North Linac 1L02 JT valve equilibrium position vs. resistive heat at 2K and 4K (constant liquid level)

4K data were gathered to compare against 2K data as a consistency check. An extra 30W unexpected heat load appears at 4K

Upon search, it may be due to a) increased shield temp or b) H_2 or He pressure increase in the insulating vac

Summary

- Accelerator Performance Plan work progresses
- Spring 2018 performance was very promising
- Bunch tails limiting current were identified using optical analysis of SLM data
- Published experimental schedule supports time blocks needed for machine upgrades: CHL (in progress) and ESR (in planning)
- Unexpected hardware issues (magnets, etc) are being cleared up and stable operation at 1050 MeV per linac appears maintainable
- Full 1090 MeV/linac operation is expected for FY22