May 2019 Accelerator Update

T. Satogata (Jefferson Lab/ODU) and Mike McCaughan (Jefferson Lab)

- Schedules and Status
  - FY19 Reliability
  - 2019 Spring SAD, Summer Run, and Fall SAD
  - C100-6R status
  - Energy reach for Fall Run (2100 MeV/pass)
- Final focus and beam convergence
- Energy / Energy Spread Monitoring
- 7A SLM installations & Envelope Matching
- TAC runs: Setup and Experience
- Summary

Schedule and Status: 2019

- **FY19 Reliability (Year-to-date)**
- **Spring 2019 SAD**
  - 1L21/2L08 300K thermal cycle to free tuners + leak check.
  - 1L25/1L26 300K thermal cycle to desorb possible contaminants.
  - Performance assessment of all 4 modules.
  - Arc stand survey and realignment + B-Comm relocation. (Vert.)
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  - Hall D off.
  - Parallel Isotope production run at LERF
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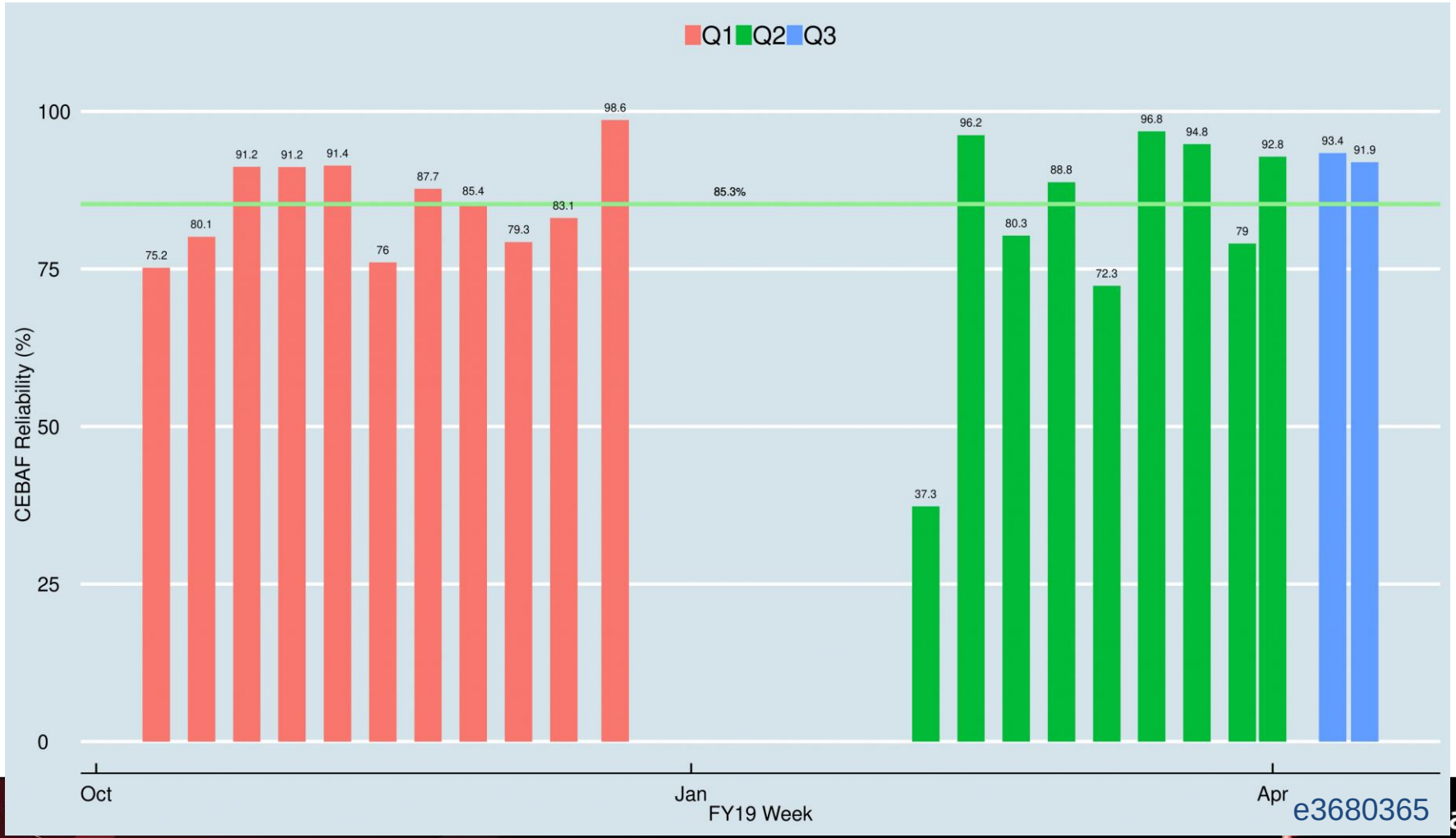
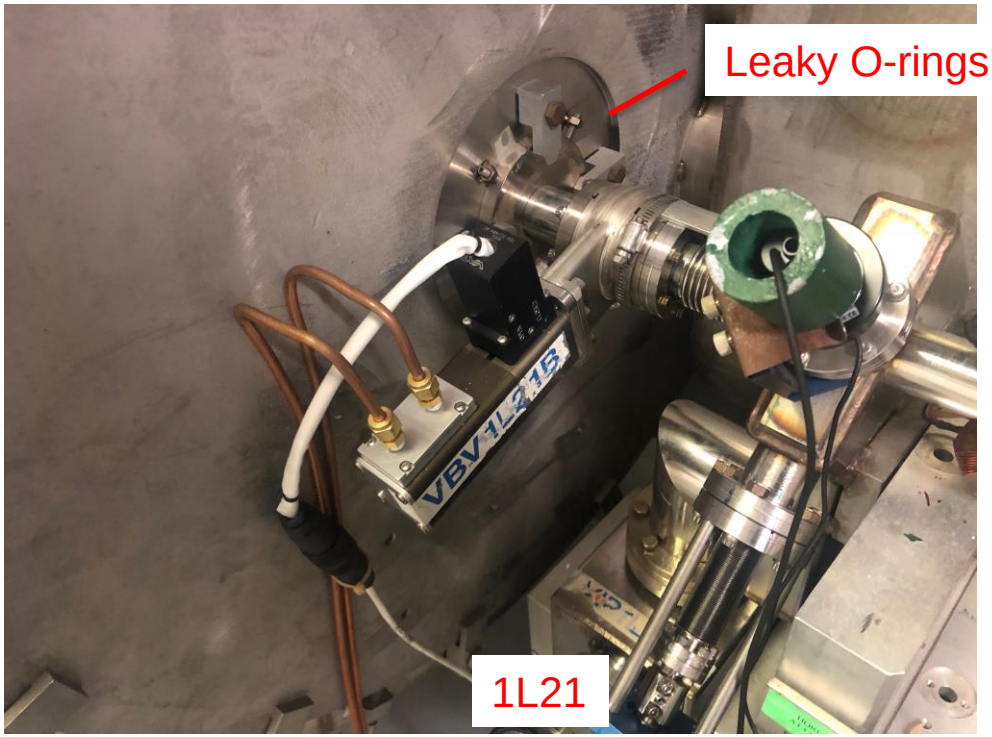
FY19 Reliability [Freyberger]

AVG: 85.3%. Trip impact: starting reliability ~92% & so hardware uptime ~93%. No major downtimes. Notes: Jan. start behind delayed schedule, but hit scheduled research hours – smooth start-up. March drop due to 1L25 flame out/energy change. Beam studies under-subscribed

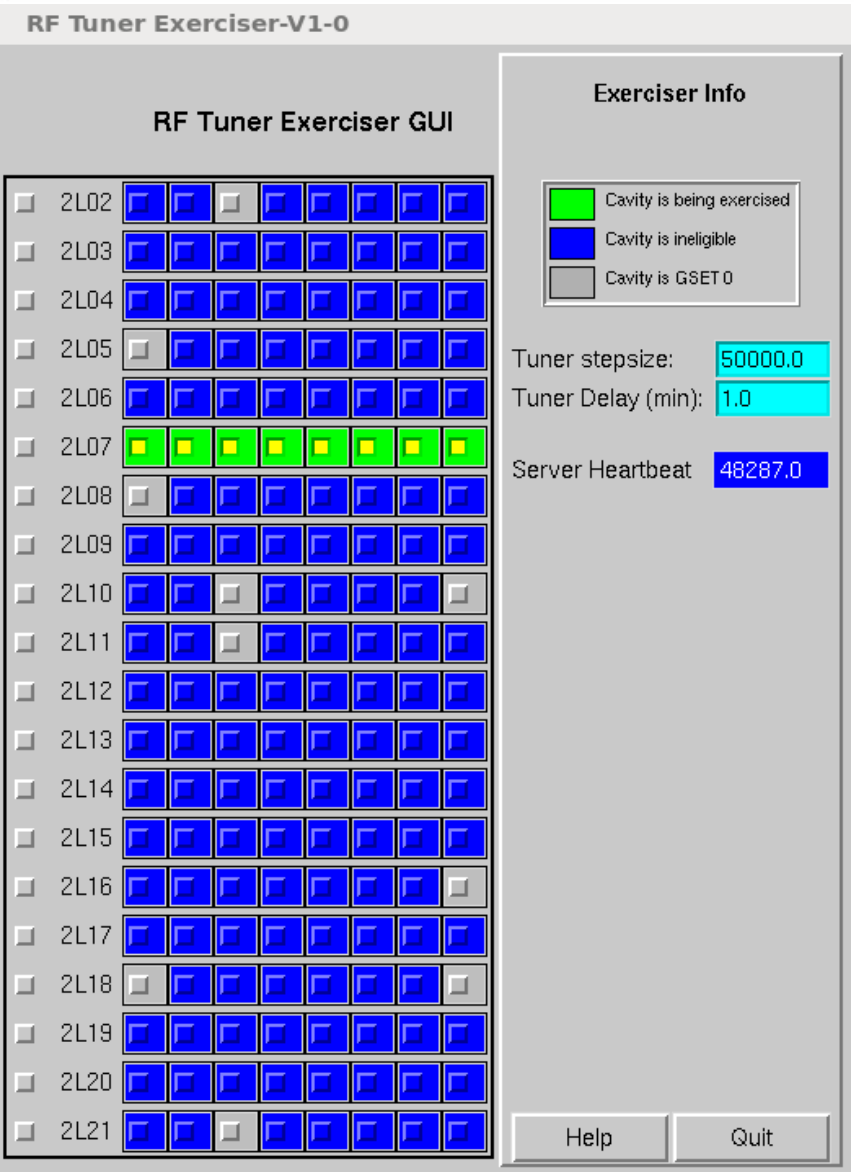


1L21/2L08 Leaky O-rings



- 1L21: 1e-3 Torr leak at D.S. beam pipe O-ring (ATLis 19054)
- 2L08: 1e-5 Torr leak at U.S. beam pipe O-ring (ATLis 19063)
- Modules warmed to 300K; tuners freed.
- Apiezon Q putty applied to seal leaks; passed leak check.

1L21/2L08 Cool Down & Evaluation



Historically:

- Cool downs used tunerExerciser
  - Slewed tuners +/- 50k steps while cooling; harder for tuner in motion to freeze.
  - Usually stopped after cool down.
  - If slow leak persisted, would typically come back days-weeks later and find frozen again.

New Approach:

- Complete Repairs
- Detune Cavities
- Cool Zone
- Let Rest Until Hot Checkout
- Determine if able to tune cavities & recover gradient.

1L21 Performance Assessment

Actual Evaluation with Hot Check Out in early June.

Forecast:

Historic Likely Gains:

Cav 4: +2.5 MV/m

Cav 5: +2.5 MV/m

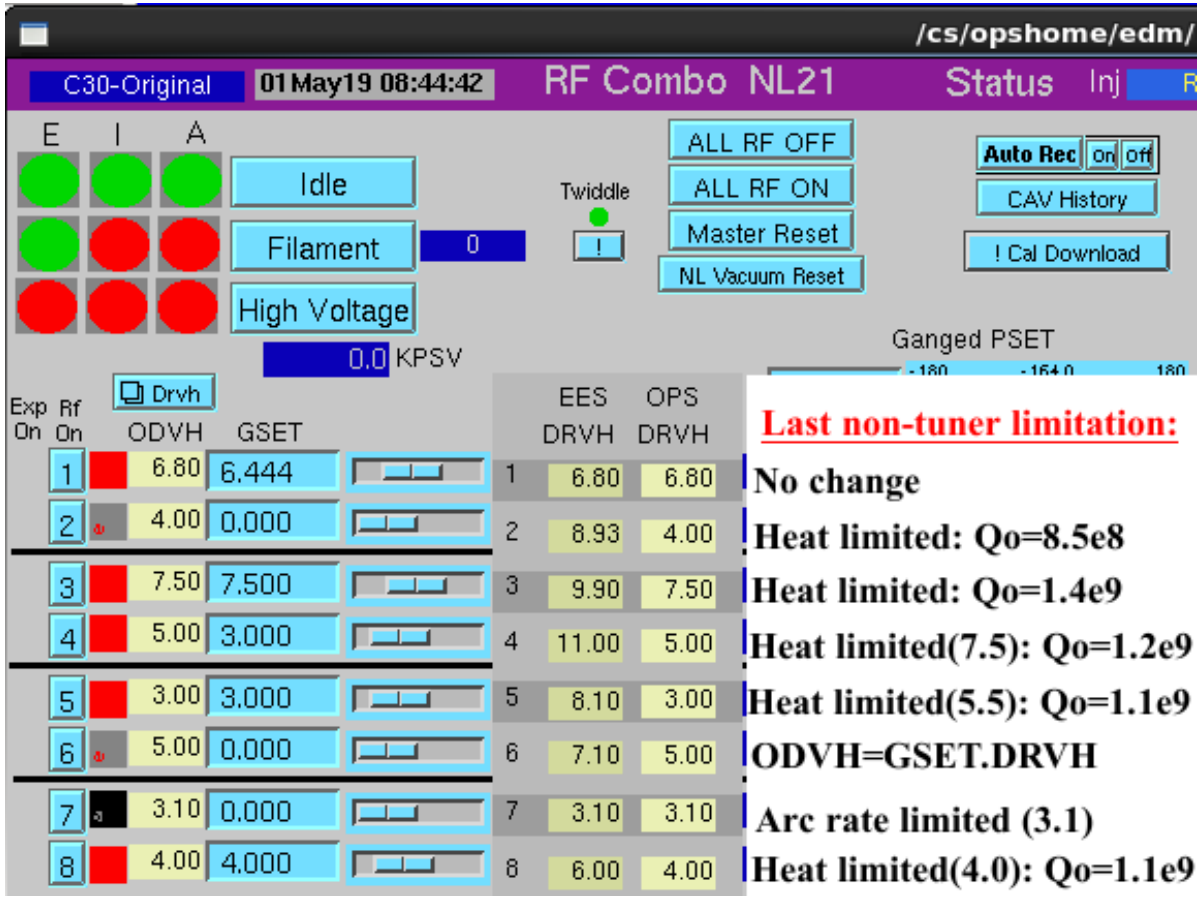
Cav. 6: +7.1 MV/m

Cav. 7: +3.1 MV/m

Possible (Preliminary)

Net: +15.2 MV/m *.5 m

Egain = +7.6 MeV



2L08 Performance Assessment

Actual Evaluation with Hot Check Out in early June.

Forecast:

Historic Likely Gains:

Cav. 1: +5.4 MV/m

Cav. 2: +6.0 MV/m

Cav. 3: +11.2 MV/m

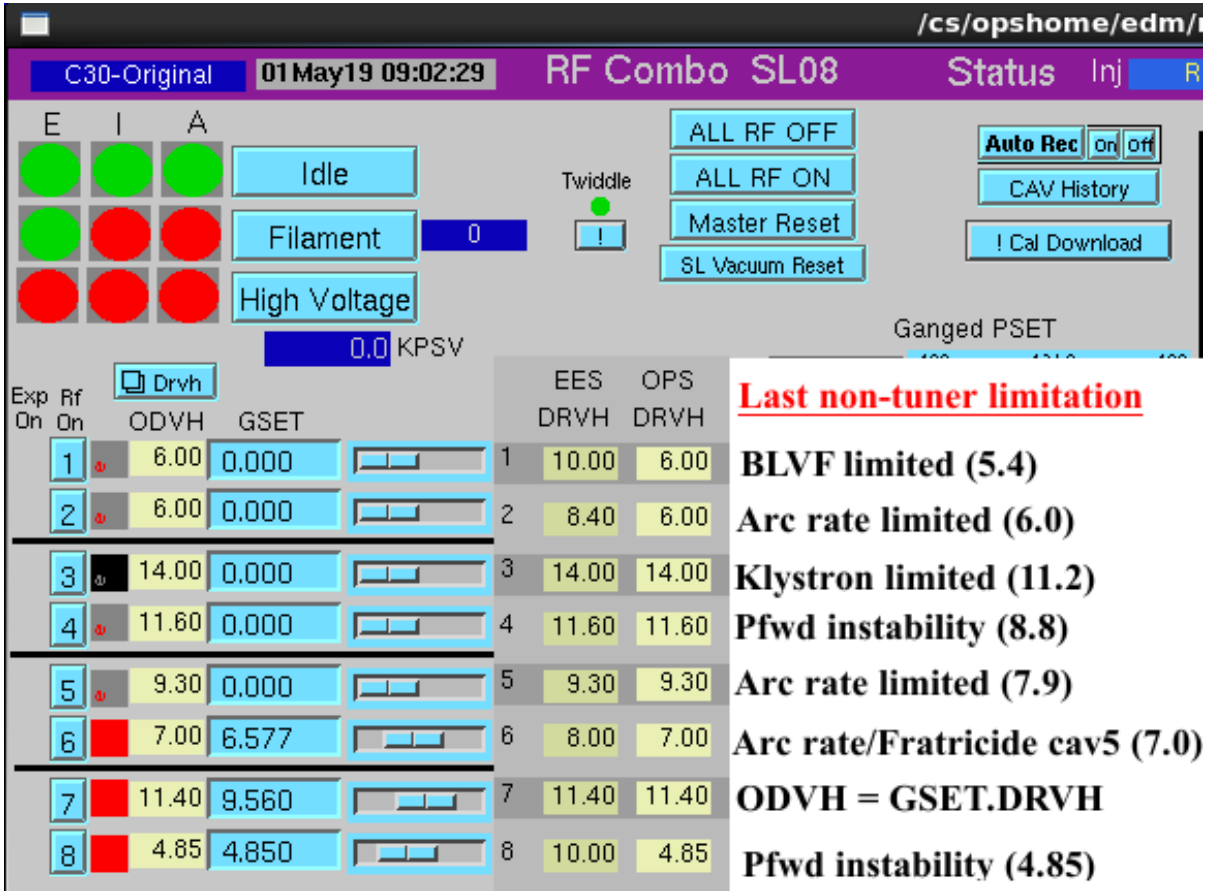
Cav. 4: +8.8 MV/m

Cav. 5: +7.9 MV/m

Possible (Preliminary)

Net: +39.3 MV/m * 0.5m

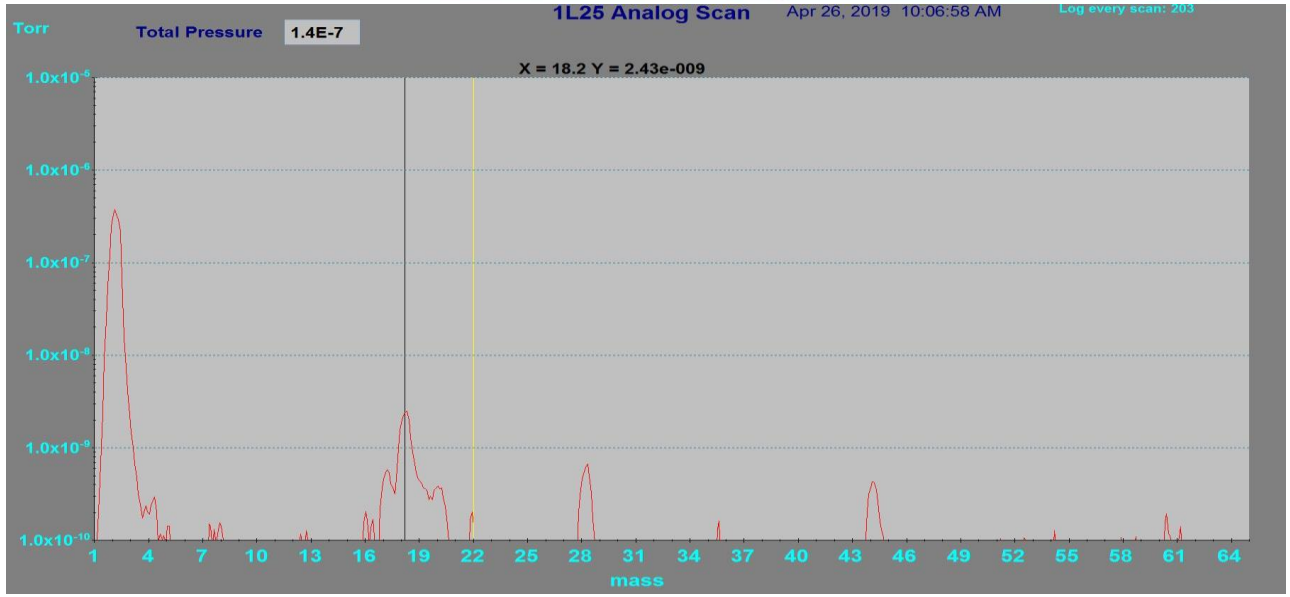
Egain = +19.65 MeV

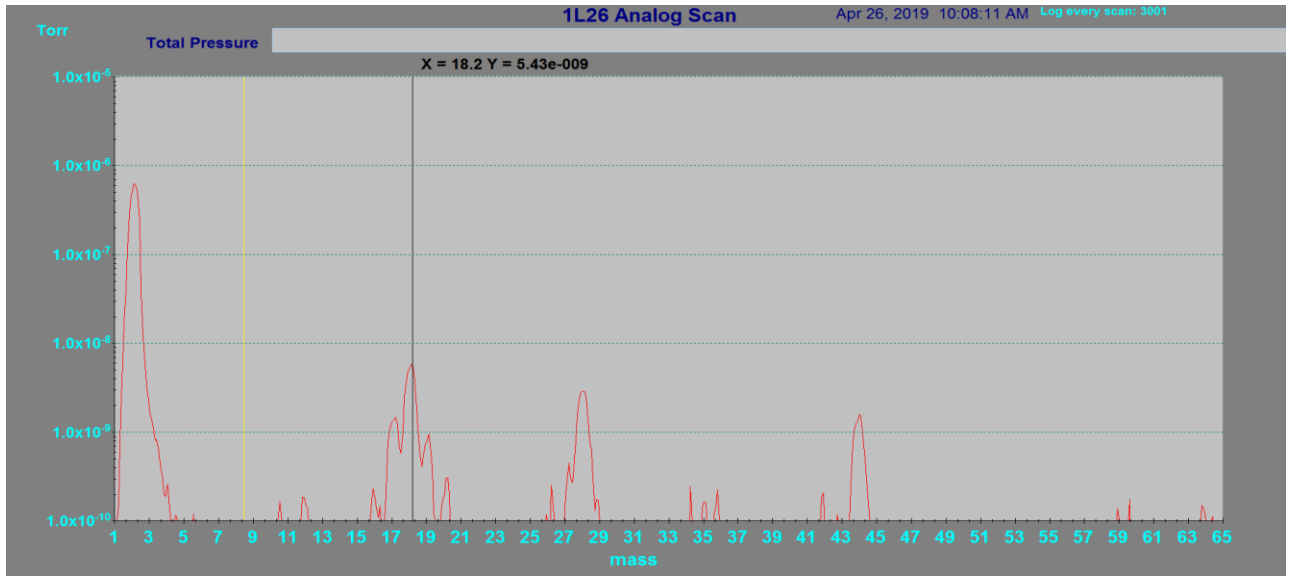


1L25/1L26 4K RGA scan (4/26/19)

- 1L25/1L26 leak checked at 4K and twice at 100K. Window regions and upstream and downstream girders flooded w/ He under ATLis 19066; no window leaks detected. Connector feed-throughs bagged; no leaks detected.
- Turbo valved in to VIP1L25B at 4K & VIP1L26B at ~15K w/ RGA present.
- 300K warm-up in progress. Pressures up to 1E-4 range, no large scale gas evolution.

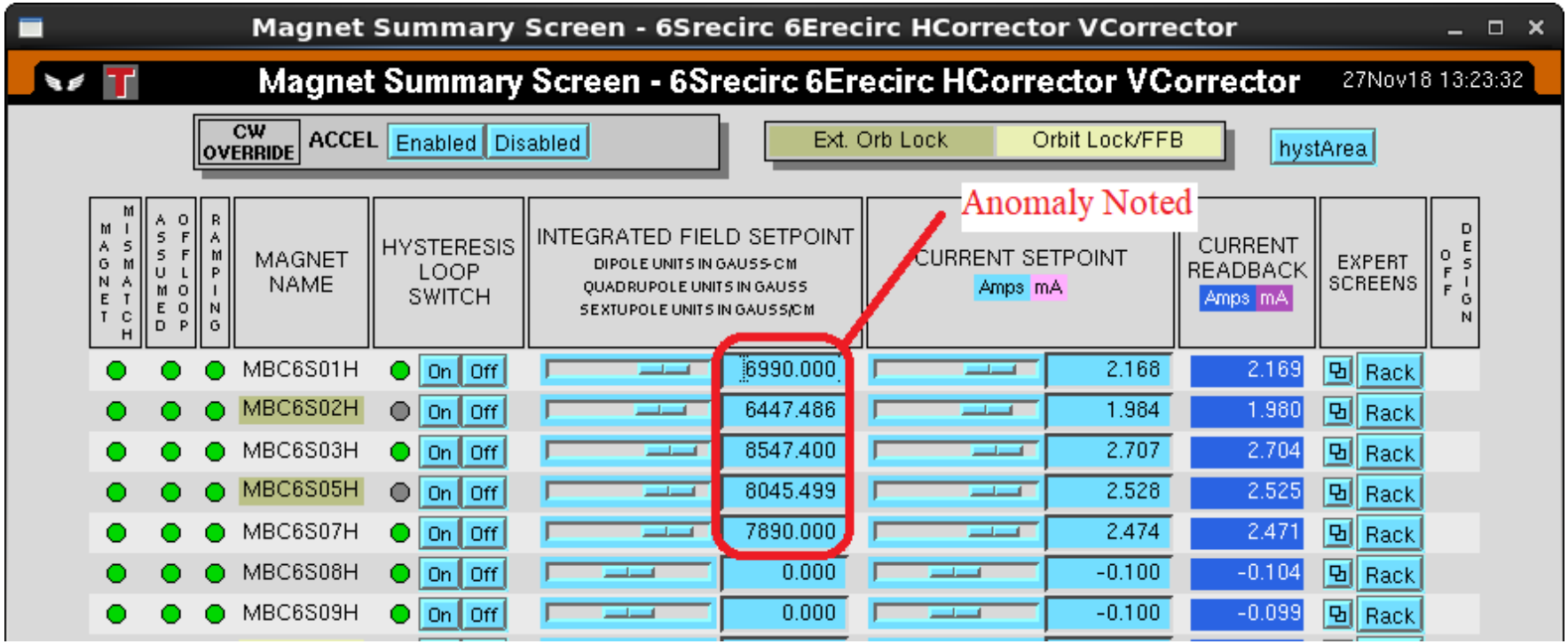
Likely no significant gradient gain.



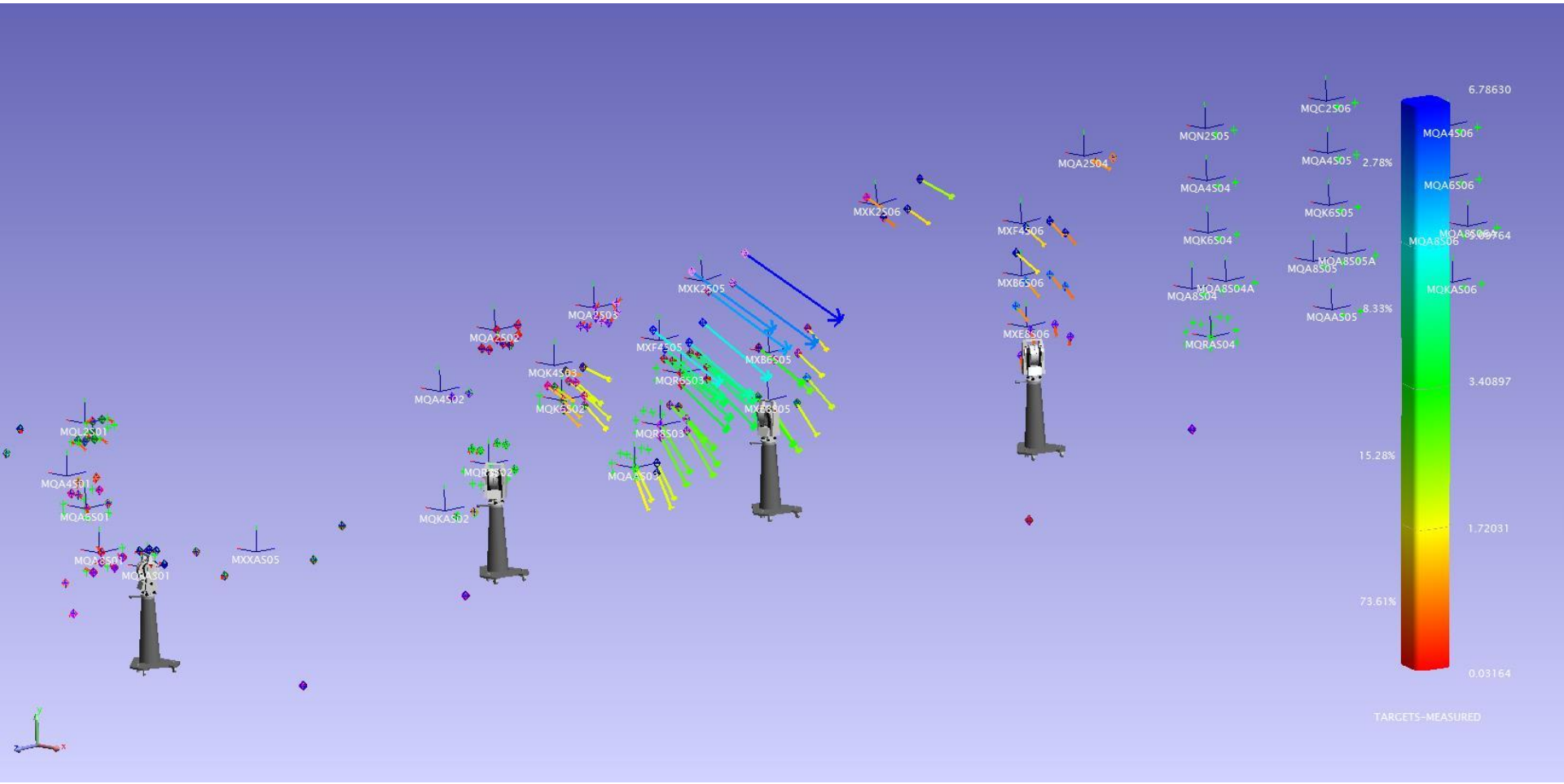


Stand Misalignments

- Discovered initially from an orbit anomaly is 6S region (e3632166); 8S too.
- Due diligence eliminated the normal culprits (missteering, optics errors, etc.)
- Beam based survey (a18645) quantified scale of error (+2.5 mm inboard)
- Physical survey over Winter 18 down turned up very interesting results.



Winter ‘18 Survey Results

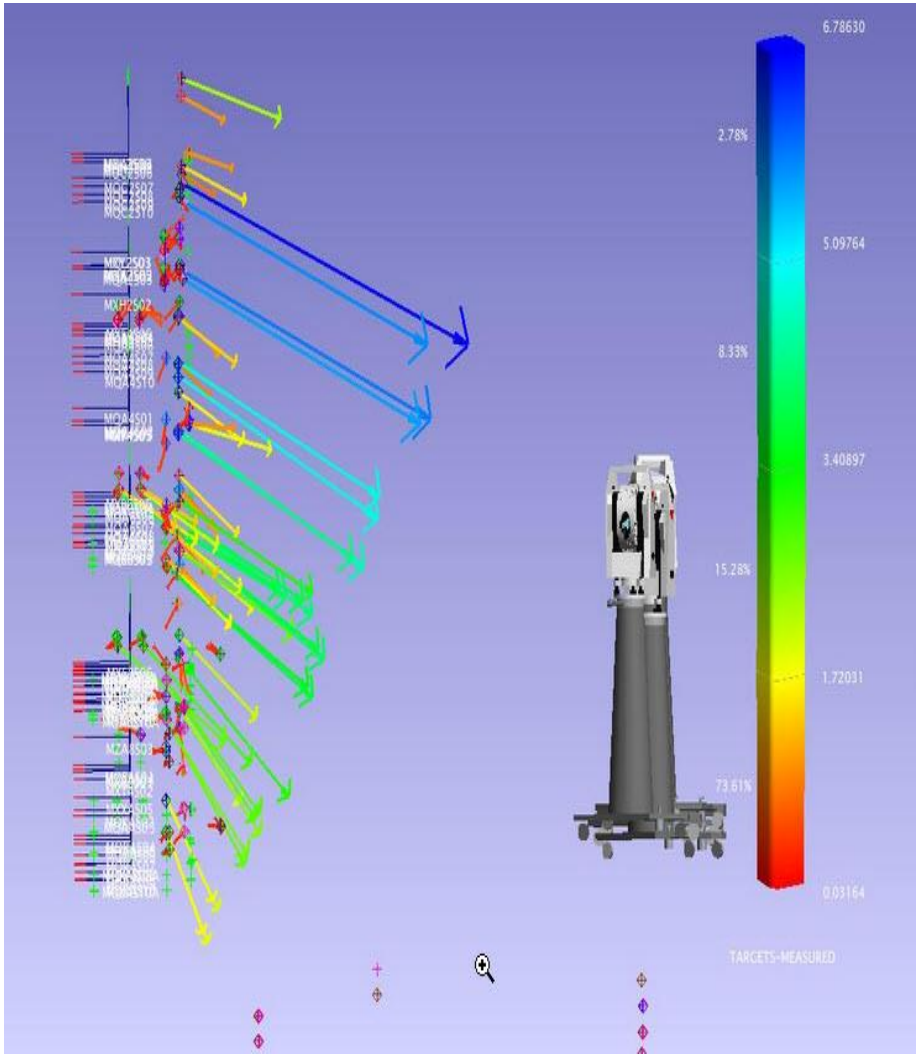


West Spreader Alignment Deviations observed in ATLis 18713 (C. Gould)

Winter 18 Survey Results (cont.)

- Several stands found many mm out of alignment.
- Tops of stands were tilting in towards the aisle.
- Founds nuts securing stands to ceiling were lose / not at torque specification.
- Stands/Stacks realigned, some moving more than 1 cm.
- Gross misalignment checks performed with Bubble level on other stacks revealed more misalignments.

W. Spreader; looking D.S. (A18713/C. Gould)

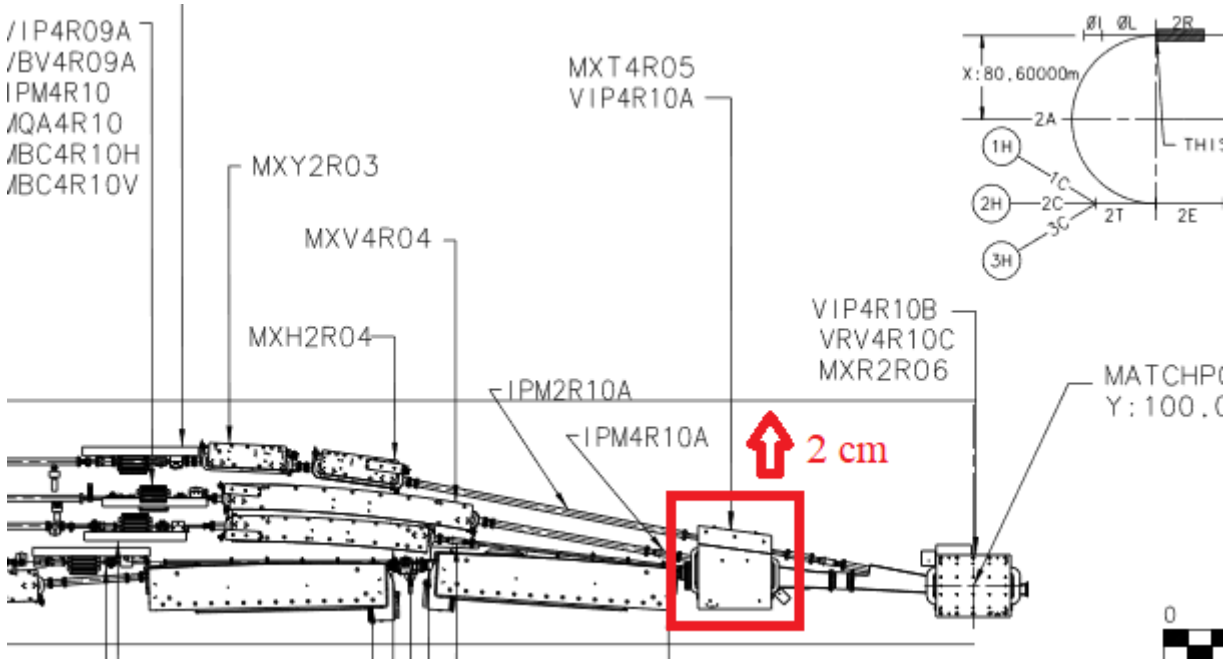


Survey and Alignment

Task re-scoped:

- ATLis 18911: Identify & Correct Misaligned Accelerator Magnets due to Shifting Stands
- ATLis 18733: Stand Ceiling Plate Anchor Tightening and Stand Adjustment

Further stands identified for realignment & torqueing to spec. [110 ft*lb]



MXT4R05/4T05 adjustment up by 2 cm; presently misaligned and inducing multipole effects. [Install Carbon-Steel beam pipe in long down if necessary.]

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C100-06R Installation / Cryomodule Shuffle?

Plans

- Complete C100-06R refurbishment.
- 1L07 LLRF drive system being upgraded to support C-75/100 style zone: opsweb.acc.jlab.org/CSUEApps/atlis/task/18991
- C-1006R with be installed either at the location of F-100 (1L23) or 1L25 (lowest performing C-100).
- Displaced C-100 or F-100 may move to 1L07 position if C-75 not ready, otherwise open for C-75.
- 1L07 module will be removed and the cryostat used to build another C-75 or C-100 style module (At the discretion of Management)

C100-06R Refurbishment Status

C100-06R Status

- The cryomodule was removed from the linac as part of the 2018 summer down and set aside to “cool down”
- Disassembly of the cryomodule completed Nov 2018
  - No signs of radiation damage in components from field emission
- Cavities reprocessed and tested Dec 2018-Feb 2019
  - Field emission free cavities beyond the operational limit after ultra pure high pressure rinsing!
- Cavities met all operational and assembly requirements

C100-06R Plans

- Complete cryomodule assembly by end of July 2019
- Complete cryomodule acceptance test by Labor Day
- **Install and commission in September 2019**

Tony Reilly

Fall Run Energy Reach (2.1 GeV/pass)

Major Gains/Losses:

NL:

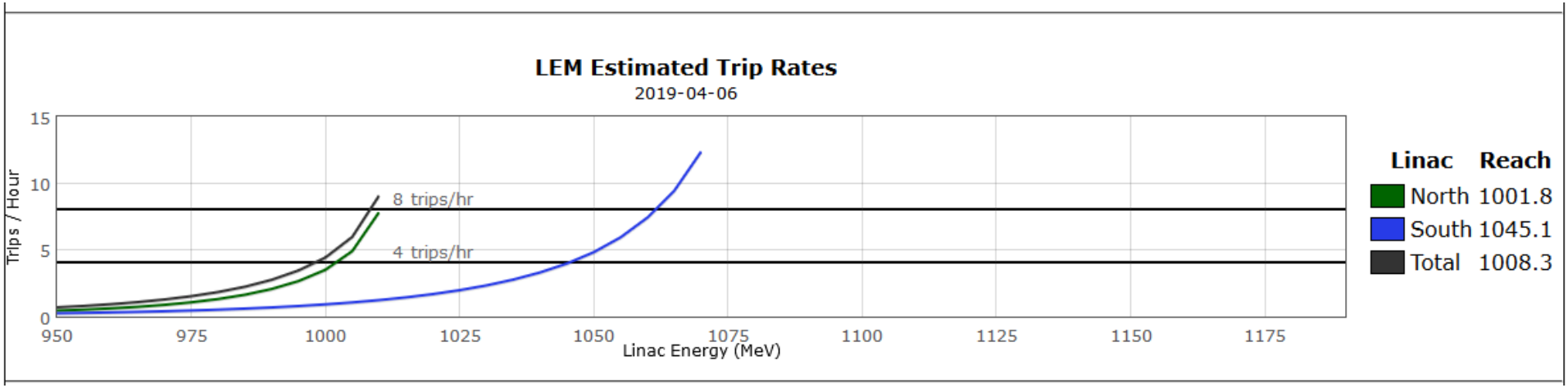
- +7.6 MeV expected from 1L21
- No gains from 1L25/1L26 cryocycle expected directly
- C-100-6R install + module gymnastics likely to gain 30-40 MeV

SL:

- +19.6 MeV expected from 2L08

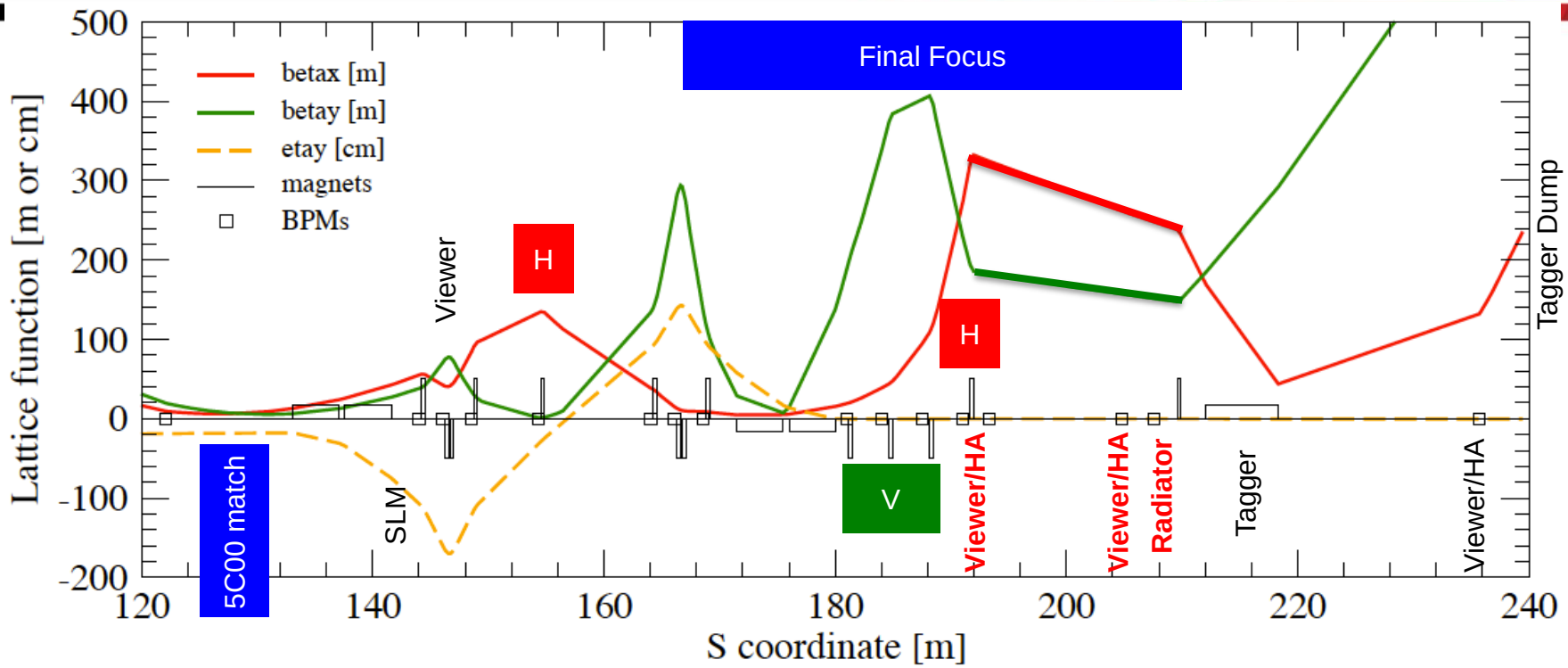
Fault Models still being updated; loss not yet fixed.

Presently, still planning for success.



https://accweb.acc.jlab.org/RFDashboard/energy-reach?start=2019-04-01&end=2019-04-06&diffStart=2019-04-01&diffEnd=2019-04-06&timeUnit=week

Final Focus and Convergence



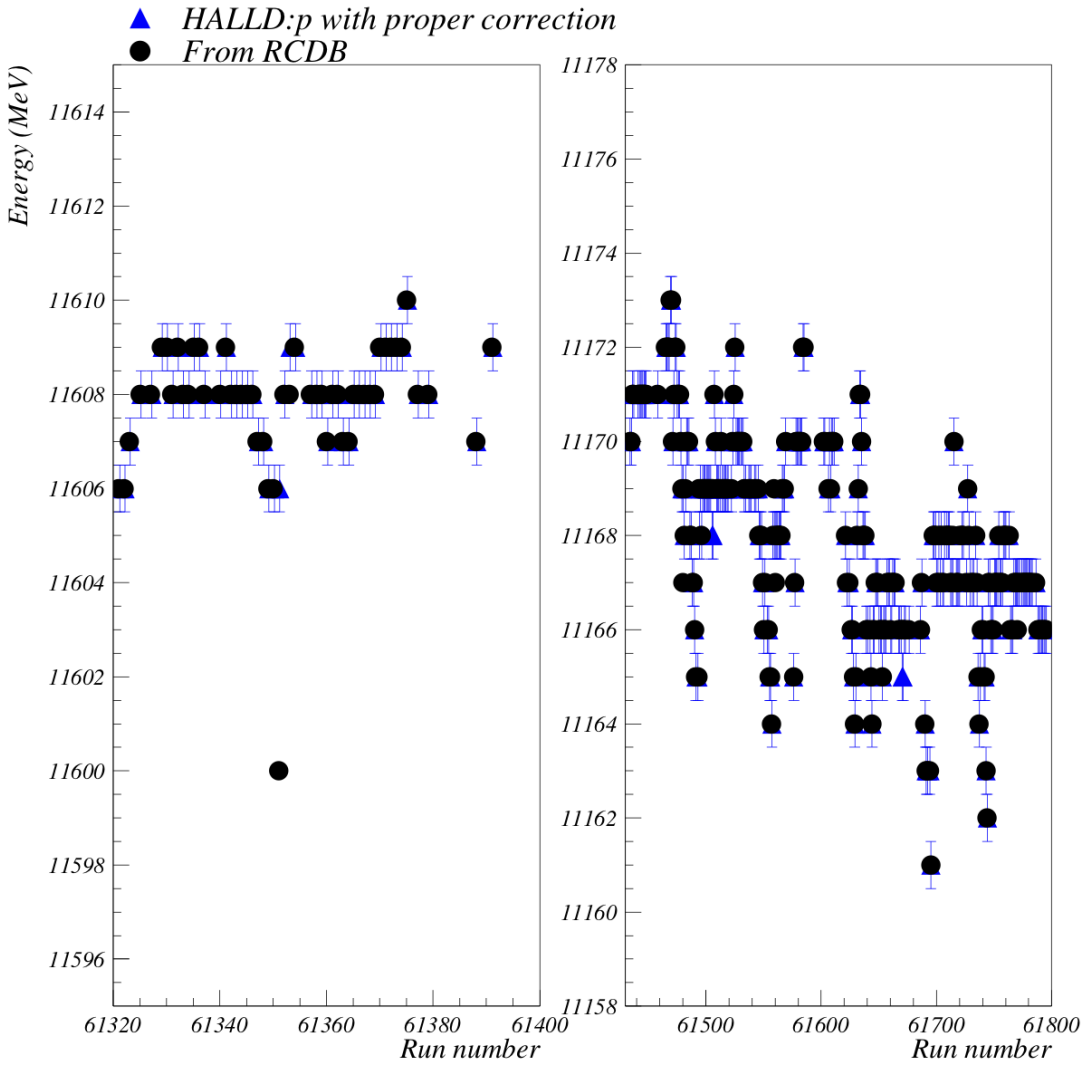
- Final focus
  - Convergence of electron beam ➔ photon beam collimator focus
  - Quite sensitive to even small upstream mismatch
  - Final focus procedure/script reproducibility being addressed
  - 15-30 minutes per iteration: three harp scans, script, resteer
  - 2019 summer student project: redesign optics, improve tolerances

Energy Spread and Monitoring

Energy v. run for PrimEx-eta run 1 (A. Deur, 3675448)

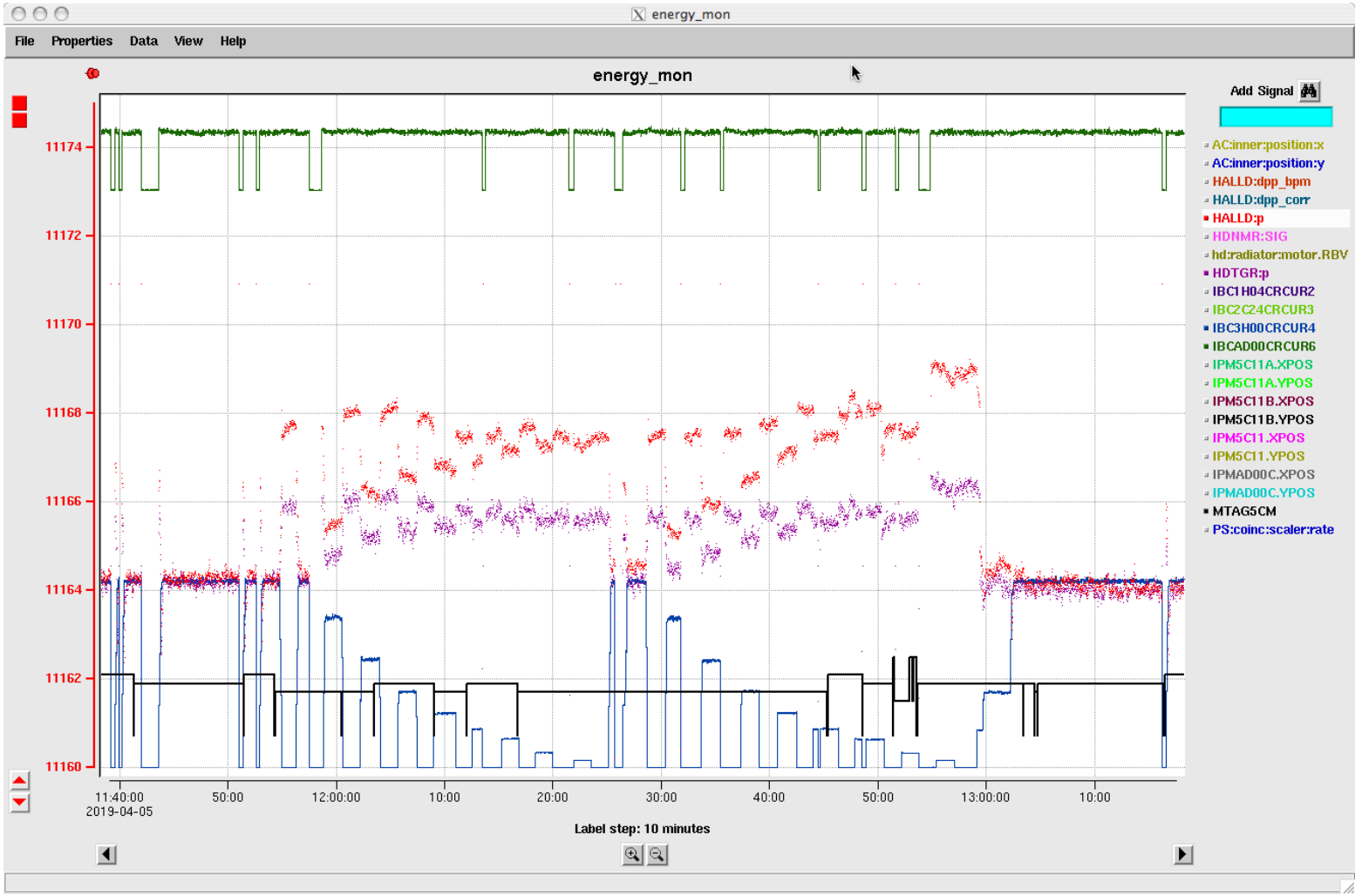
Significant energy shifts:

- Run 61734: 4 MeV jump, HC beam off, no E locks
- Run 61753: 2 MeV jump, Path length drift fix
- Run 61754: 2 MeV jump, HC beam off, no E locks



Energy Spread and Monitoring

Current dependent drift based on highest current hall (C)



A. Deur [3676021]

Energy Spread and Monitoring (Remedies)

- BPMs live in Auto-gain mode (always); beam centroid may vary with different beam paths and currents if not perfectly co-linear (but within machine aperture). Careful machine set-up/ORFP to correct.
- Energy lock idiosyncrasies; dependent on BPM response:
  - Odd arcs: 4 ch. BPMs; ~4uA sensitivity
  - Even arcs: SEE BPMs; $\mathcal{O}$[100s of nA] sensitivity, but increasingly noisy at lower currents
  - Turn locks off with high current hall; try not to rely on auto-suspend
- Path length monitoring – Presently limited to invasive corrections; checked ~1/shift depending on crew and trip rate.
- MOMod system: Online M5,6 / Time-of-flight monitoring. Historically tickled 70 MHz IF frequency with 390 -/+ 7 Hz signal (NL/SL respectively). Combined with 1427 MHz LO to form 1497 MHz RF.

  Considerations:
  - C-100 FCC phase locked loop clock filters at these frequencies, and do not follow well. Notch filtering being explored.
  - Motion of induced frequency to LO will move it out of filtering band (also under consideration/test)
  - Will allow gang phase locks at ~1 degree level & +/- ~0.1mm online path monitoring
- Hall D FFB system energy compensation: Arrange fall beam studies to test D system (NL) in parallel with A/C system (SL) operation.

MJA7A08 SLM Installation

Plan by M. Tiefenback et al. – Install 4 SLMs strategically in Arc to permit rapid envelope matching; 1st install @ MJA7A08 [Low η]

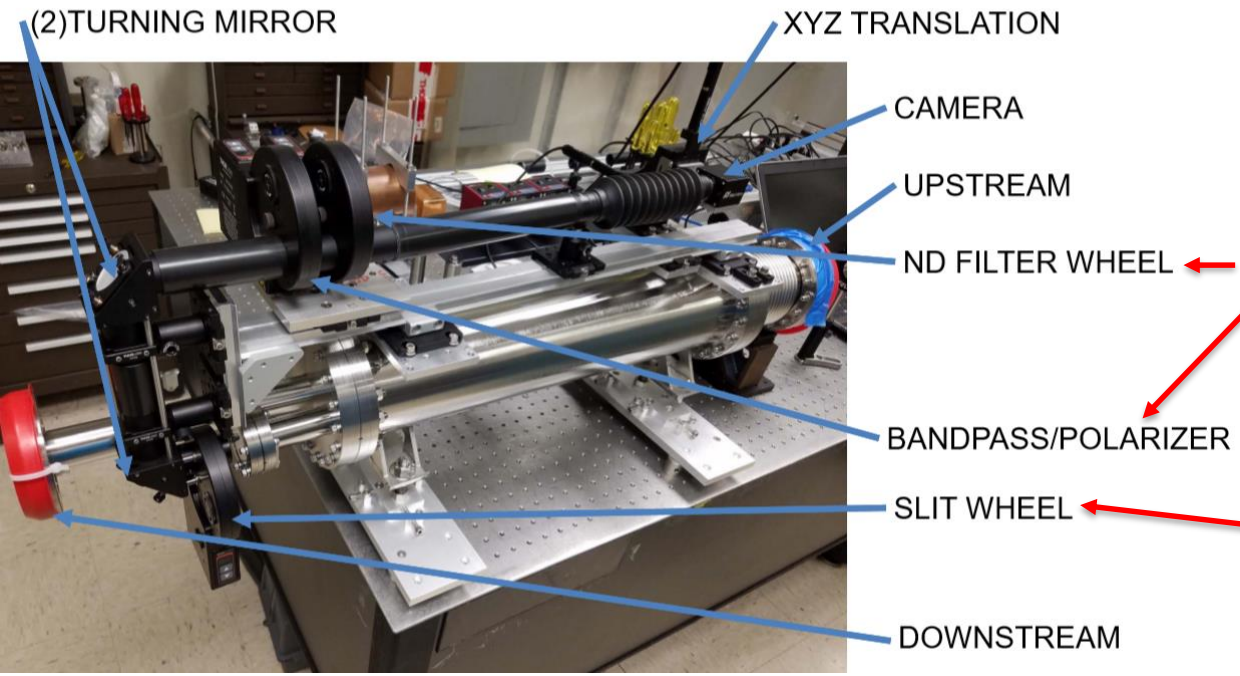
ATLis 18809 & 18889:

- Commission/calibrate 1st diagnostic and replicate. [A16/24/32]
- 7A08 SLM Chambers placed, aligned, leak checked.
- Motor/Signal RG-58 cables dressed/terminated to E301B02
- Interface chassis installed E301B03 w/ 3-D Picomotor controller.
- Digiport server with softioc being installed w/ EPICS controls
- GC-650 camera w/ 3 filter wheels (2 of filters, 1 of apertures)

Hope to gain better controls of Synchrotron Light dominated emittance growth in Arcs 7+ (Better Optics 4th/5th pass and to D)

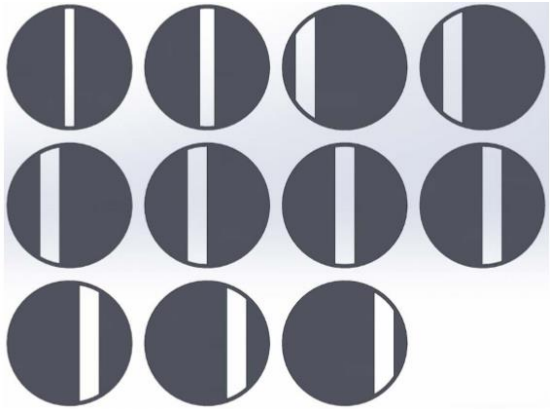
MJA7A08 SLM Installation

OPTICAL HARDWARE

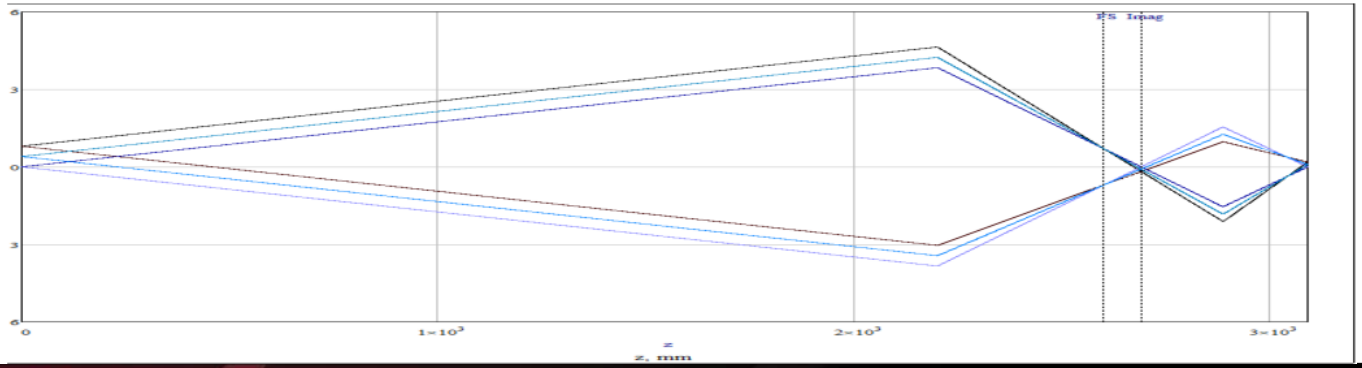


POSITION	2ND WHEEL (6 POS)	3RD WHEEL (12 POS)
1	EMPTY	EMPTY
2	TBD	ND OD 0.1
3	410nm BANDPASS (TL FB410-10)	ND OD 0.2
4	690nm BANDPASS (TL FB690-10)	ND OD 0.3
5	H. POLARIZER (EO 85-919)	ND OD 0.4
6	V. POLARIZER (EO 85-919)	ND OD 0.5
7	-	ND OD 0.6
8	-	ND OD 1.0
9	-	ND OD 1.3
10	-	ND OD 2.0
11	-	ND OD 3.0
12	-	ND OD 4.0

TL – THORLABS EO – EDMUND OPTICS



TWO LENS SYSTEM: 400mm & 100mm FOCAL LENGTH ACHROMATS



Total Absorption Counter (TAC) Running

Spring ‘19 run allowed us to gain significant experience running TAC

- V-wire running w/ 750 um converter [In parallel with Hall C]
  - 2/22-2/24: 10-15 nA TAC running in parallel with Comcal snake scan / commissioning. (Runs 60930-61308)
  - Bleed through / background at several nA level from high current in C
  - Current: 10-15 nA (Slit open) [PS: ~5 Hz/CCAL: 80-100 kHz] (3657310)
  - PID orbit locks at 5C11A / Active Collimator [1e-11 gain] enabled
- 2e-5 amorphous radiator running [Single slit user ops]
  - 3/17-19 with C in restricted access (Runs 61570-61575+61586-61596)
  - 3/17 scrubbed due to unstable positions; corrected by EES-IC 3/18
  - 4/14-15 Comcal snake scan (Runs 61958-62020)
  - Current: 1-2 nA [PS: 5-7 Hz / CCAL: 90 kHz](3669644)
  - PID orbit locks used to establish beam at 5nA. Locks then turned off and current reduced. Positions reported as relatively stable.
  - Slit adjustments as necessary to maintain detector rate

Total Absorption Counter (TAC) Running

Jefferson Lab

Hall D Beam Delivery Procedure

Document Number: MCC-PR-19-002
Revision Number: Rev. 8; May 9, 2019
Technical Custodian: Mike McCaughan
Estimated Time to Perform: Eight hours for initial setup after an energy change

Procedure Overview

This pr
Hall D.
to the H

5.0 Performing a Total Absorption Counter (TAC) Run

NOTE: The following steps presume that

- Section 1.0, page 2 of this procedure has already been completed.
- Production beam delivery to Hall D has already begun.
- The primary collimator is set to either the 3.4 or 5.5 mm hole position with beam going to Hall D.

1. Verify that the beam is locked to the desired positions at >15 nA. The PID locks for IPM5C11B and the active collimator should be engaged at Hall D's desired targets. Allow the orbit to converge to Hall D's desired targets at IPM5C11B (stripline BPM) and the active collimator if necessary.
2. Turn OFF the PID orbit locks for IPM5C11B.

File name: HallD_beam_delivery_proc_rev8.fm Page 20 of 22 MCC-PR-19-002

Procedural revised to include both V-wire and Amorphous radiator running as well as operational lessons learned from the Spring run.

Summary

- Spring 2019 operations saw highs and lows
  - Energy reach continues to be a source of consternation
    - Many RF zones with vacuum / gradient issues in Spring.
  - Despite startup woes, achieved reasonable reliability
    - 12 GeV Asymmetric setup tested relatively successfully
  - Gained lots of experience with the TAC
- Energy Reach
  - Cryocycling / Vacuum work to attempt to regain gradient. [Eval. shortly]
  - C100-06R refurbishment in good shape, on schedule for late 2019
  - Planning for success with 2100 MeV/pass in Fall.
- Machine development in process for improved beam conditions
  - Magnet realignment / Multipole suppression
  - Improved energy spread / optics monitoring & diagnostics
  - CASA examining D-line optics to make improvements

========== Backups ==========

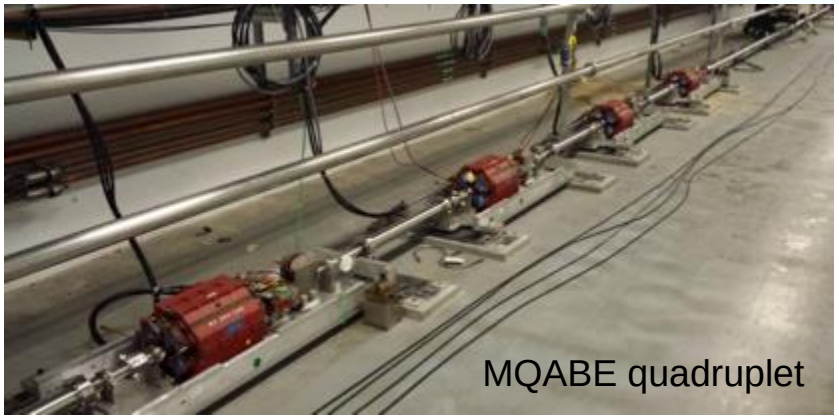
Beam Physics Requirements

Beam/beamline requirements @ 11-12 GeV: Initial requirements

Hall	Emittance	Energy spread (σ)	Spot size (σ)	Halo	Other
A	$\varepsilon_x < 10$ nm-rad, $\varepsilon_y < 5$ nm-rad	0.05% (12 GeV) 0.003% (2-4 GeV)	$\sigma_x < 400$ μm $\sigma_y < 200$ μm ($\sigma_y < 100$ μm, (2-4 GeV))	1×10^{-4} Gaussian integral/pedestal integral	
B	$\varepsilon_x < 10$ nm-rad, $\varepsilon_y < 10$ nm-rad	0.1%	$\sigma_x < 400$ μm $\sigma_y < 400$ μm	2×10^{-4} Gaussian integral/pedestal integral	Beam Position Stability < 200 μm Beam Current Stability $\Delta I/I < 5\%$
C	$\varepsilon_x < 10$ nm-rad, $\varepsilon_y < 10$ nm-rad	0.05%	$\sigma_x < 500$ μm $\sigma_y < 500$ μm	2×10^{-4} Gaussian integral/pedestal integral	Beam Position Stability < 500 μm
D	$\varepsilon_x < 50$ nm-rad, $\varepsilon_y < 10$ nm-rad	<0.5%	At radiator: $\sigma_x < 1550$ μm $\sigma_y < 550$ μm At collimator: $\sigma_x < 540$ μm $\sigma_y < 520$ μm	1×10^{-4} Gaussian integral/pedestal integral	Beam Position Stability < 200 μm 1 nA < Beam Current < 3 μA

From M. Spata

Hall D Transport Line (to insertable dump)



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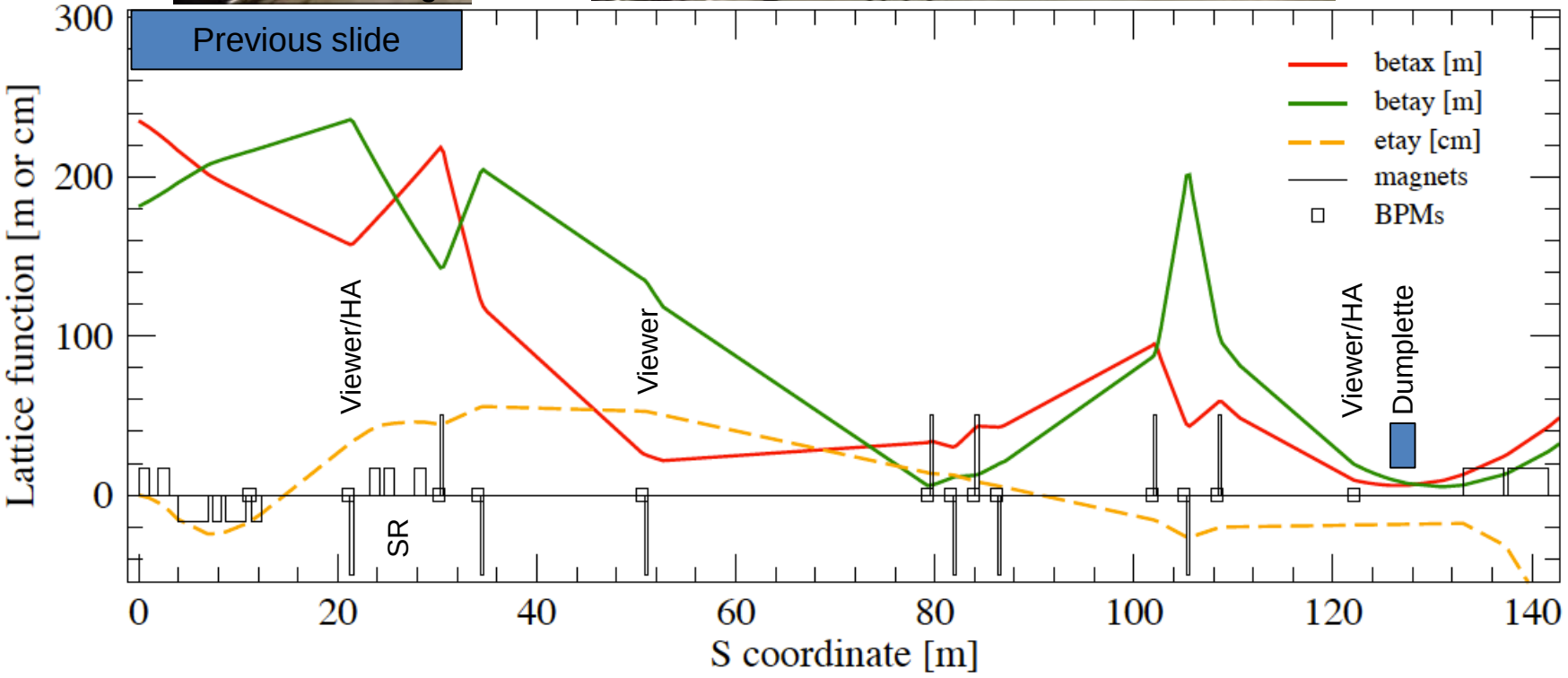
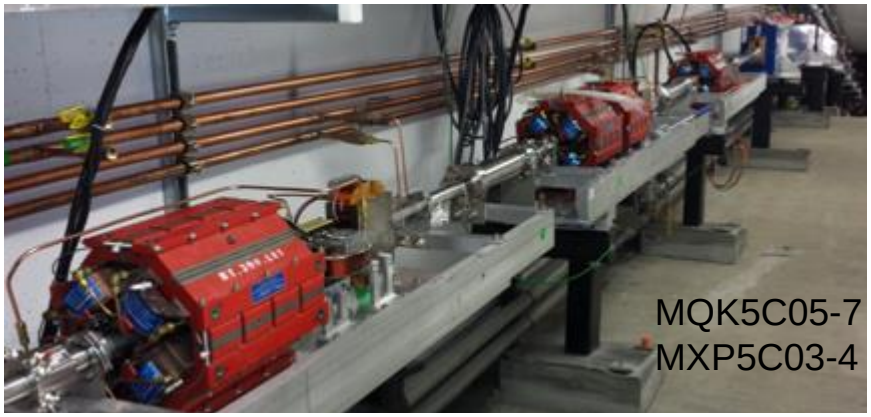
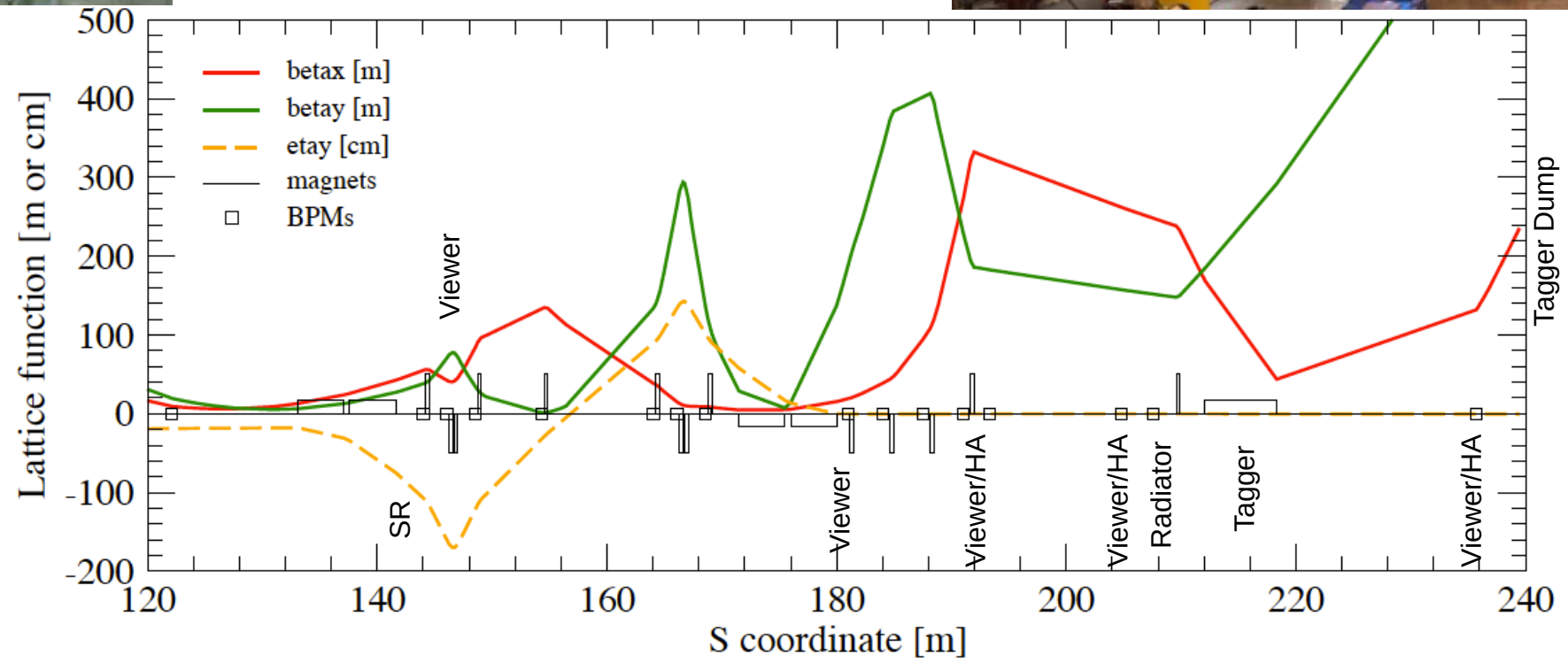
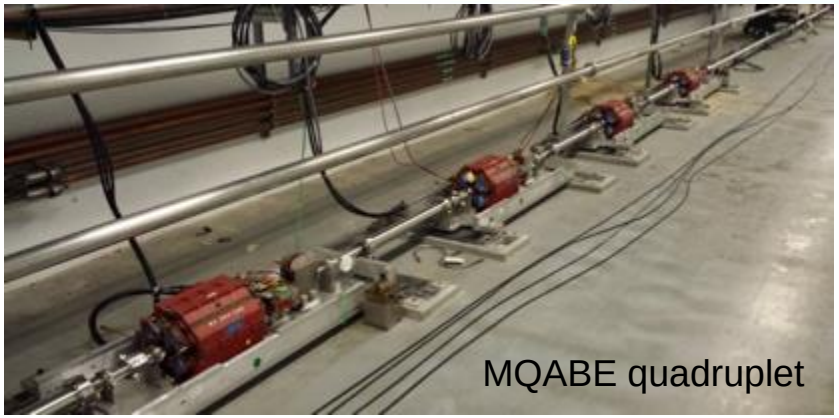


Hall D Transport Line (to tagger dump)





Hall D Extraction Line (labeled)



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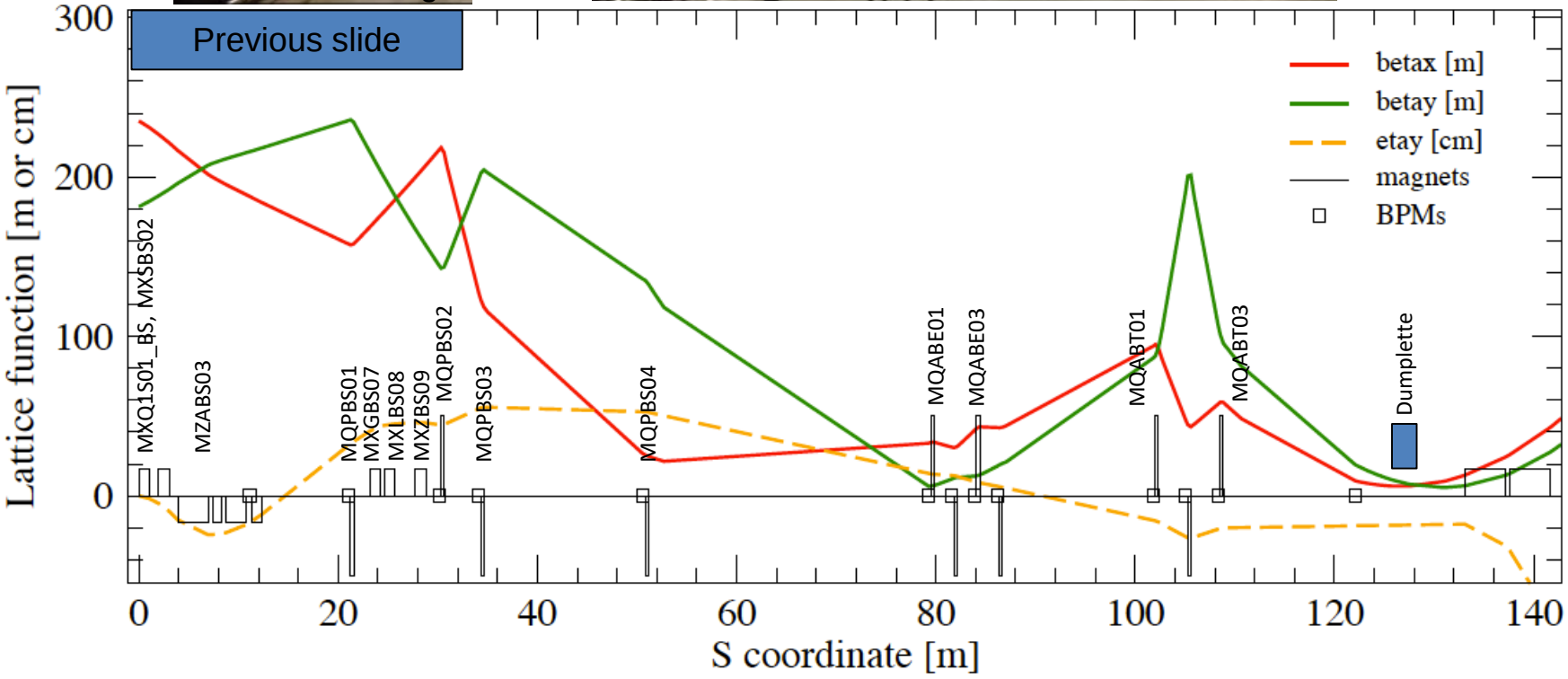


Final Focus Discussion

- Sources of final focusing drift
  - Energy-correlated: Pathlength
    - Thermal drifts in machine and RF phase delays
    - Creates drifts in average energy gain, energy spread
    - Chromatic effects: overall focusing dependence on beam energy
  - Position-correlated: Separation drifts
    - Separator phase drift moves orbits off nominal
    - Modest sensitivity to nonlinear feeddown
- Resolutions
  - Pathlength
    - address with active feedback (MOmod) or routine pathlength
  - Separation drifts
    - address with improved steering setup, modeling improvements
  - BS/5C SLM correlation feedback may still be most robust option
    - beam studies expected later in fall 2018 run

CEBAF Performance Plan

- **Goal**: Operate CEBAF at design energy with adequate margin
  - 1090 MeV/linac with 100 MeV of margin in each linac
  - 100 MeV margin permits entire C100 bypass if necessary
- Emergent problem cavities can be bypassed
  - collect and address during RF recovery days
  - with marginally higher but tolerable trip rates

- **Issues**:
  - Current energy reach 1050 MeV/linac vs 1090 MeV/linac design
  - Energy reach degrades at 34-48 MeV/pass/year
    - JLAB-TN-18-022 and preliminary analysis of 2016-18 operations

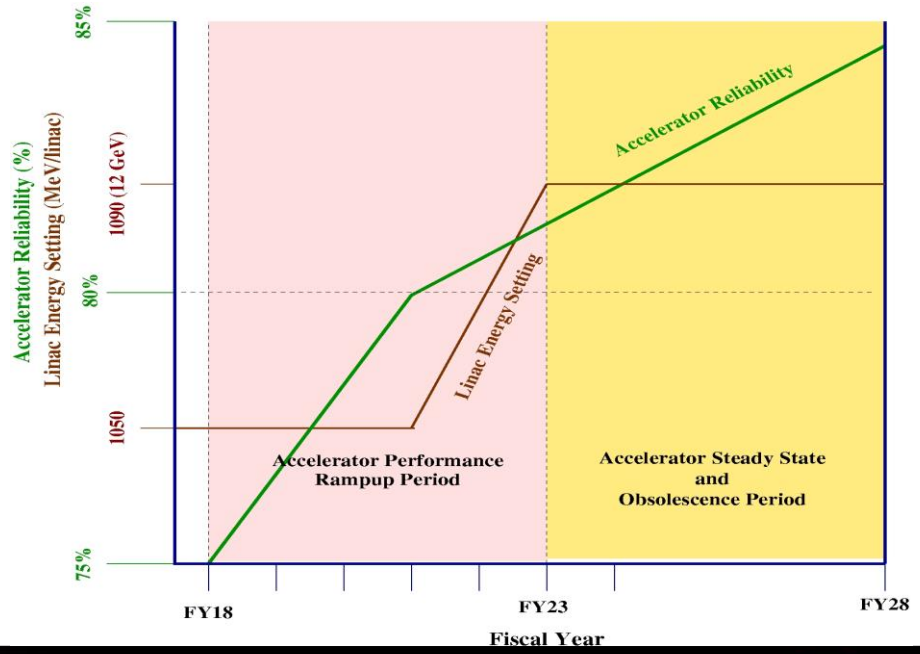
- **Strategy: add gradient, slow or stop degradation**
  - CEBAF Performance Plan

CEBAF Performance Plan

- Long-term strategy
  - Identify and purchase critical spares
  - Replenish consumed spares (e.g. klystrons)
  - Increase energy reach
    - C75: refurbish 8 original C20 modules
    - C100: refurbish modules
    - Particulates: Clean warm girders, upgrade vacuum systems
  - Mitigate obsolescence
- Target: 34 weeks/year ops at >80% reliability

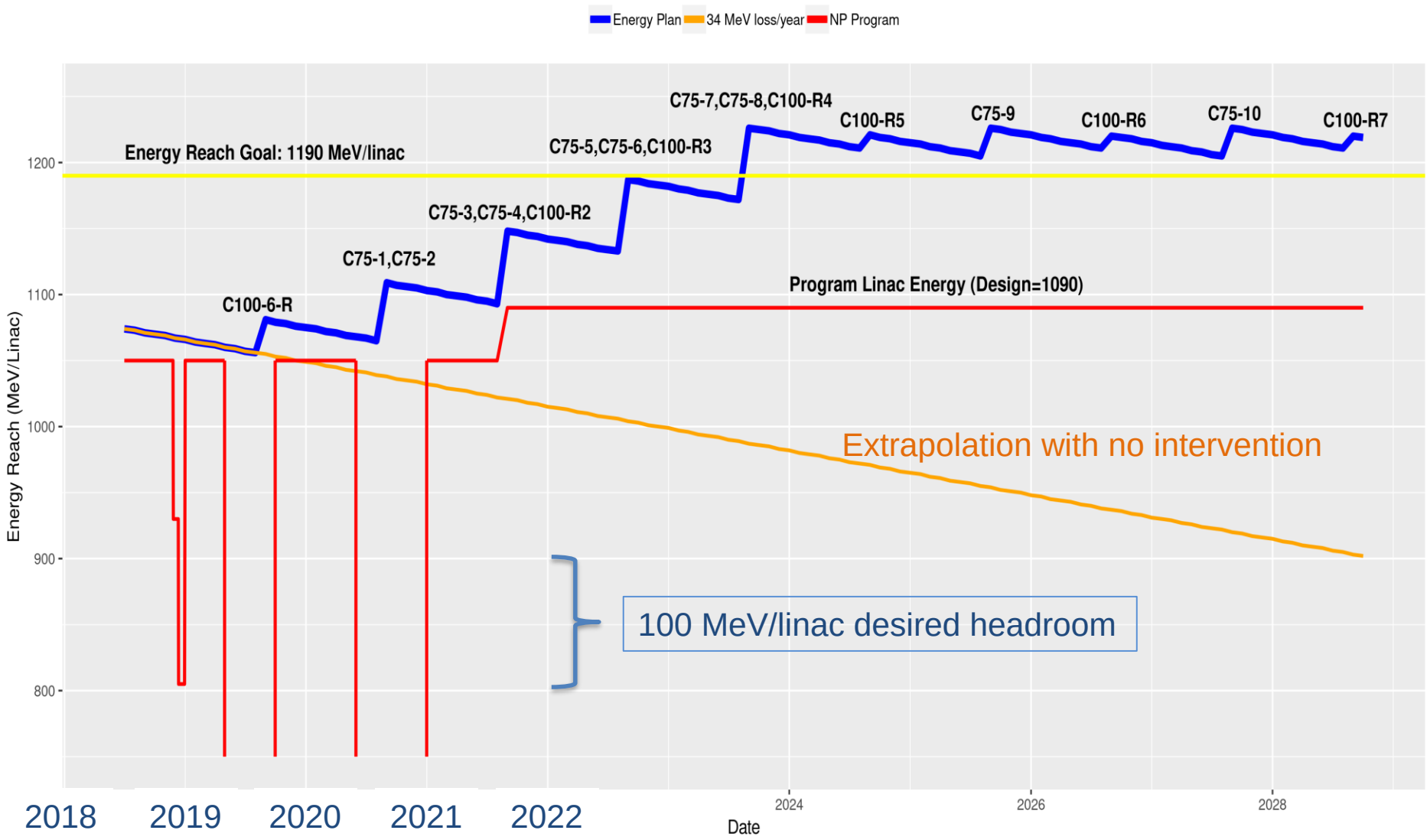
Category	Unit/Metric	Goal
Reliability	%	> 80
Optimal Weeks	weeks-per-year	34
Beam Tuning Hours	h/week	< 8
Peak Hall Multiplicity	Number of halls	4
12 GeV Program Expected Duration	years	20
Linac Design Energy	MeV	1090
Required Linac Energy Margin at start of FY	MeV	> 110
Overall FSD Trip rate	trips/hour	< 15
Overall FSD Trip Downtime	min/hour	< 5
RF Trip rate	trips/hour	< 10
Beam Loss Trip rate	trips/hour	< 5

Table 1: The CEBAF Performance Goals for the 12 GeV CEBAF era.

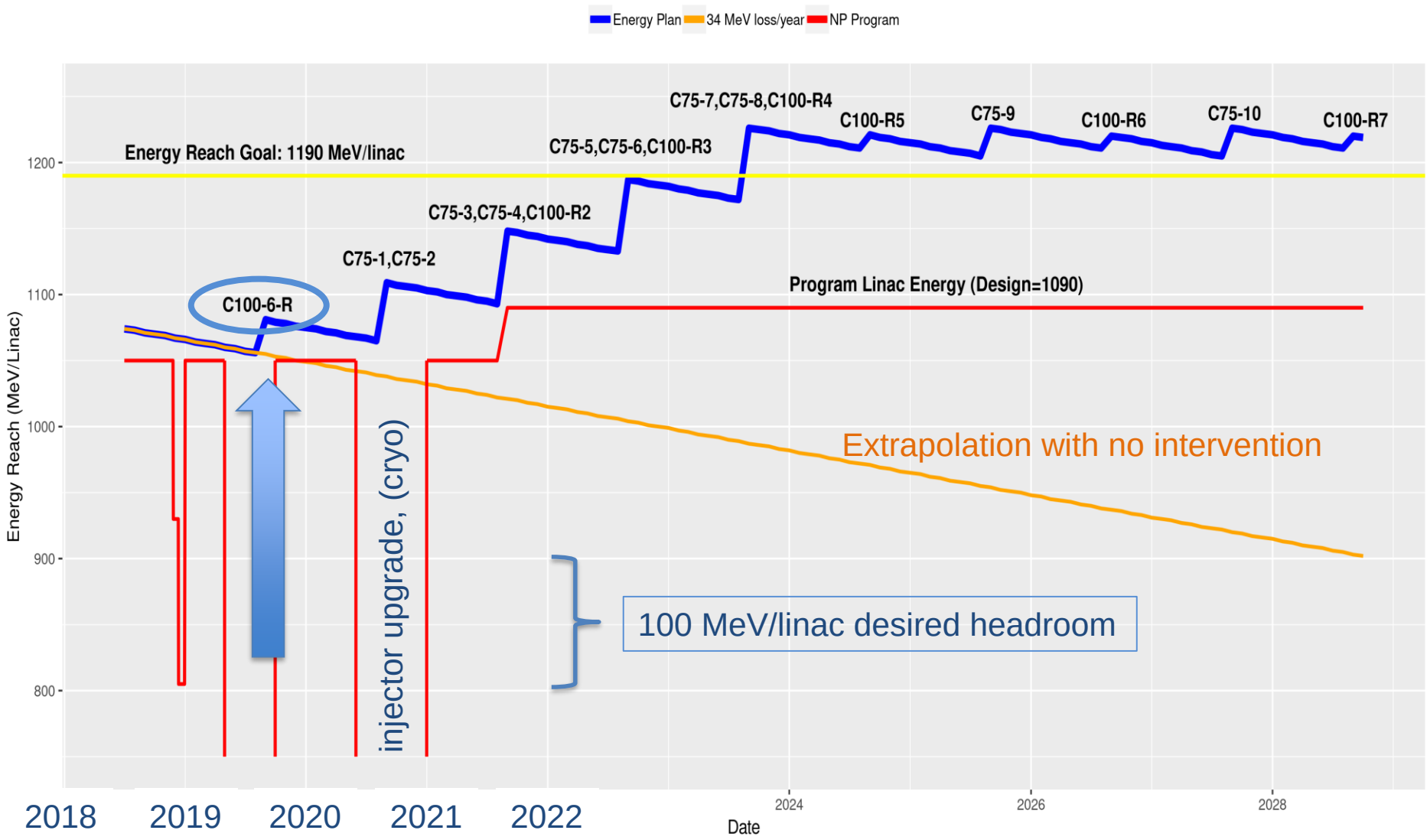


Arne Freyberger/Randy Michaud

Energy Reach Chart



Energy Reach Chart

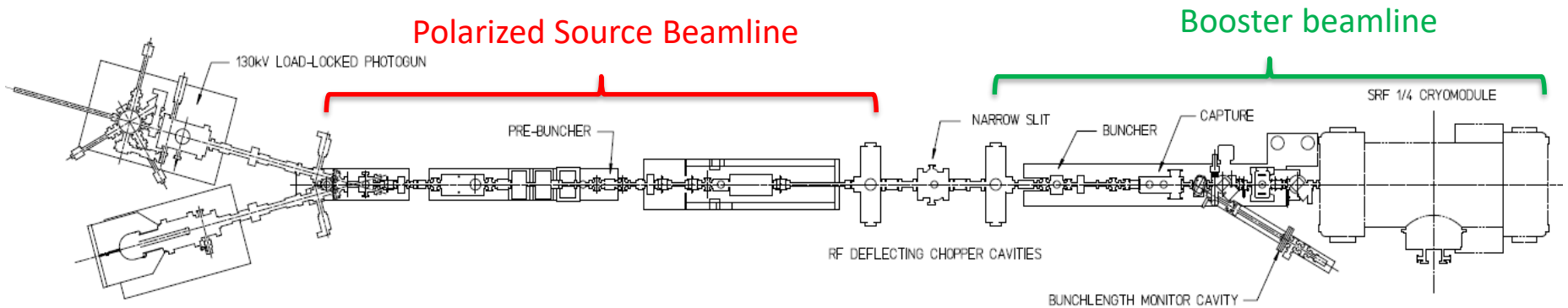


C100-06R VTA Summary – Final

Cavity Number	2011 Q0@20 MV/m	2011 Field Emission Onset (MV/m)	2019 Q0@20 MV/m	2019 Field Emission Onset (MV/m)	Comment
27	Not tested	Not tested	1.00E+10	NA	Pass, FE free Admin limited at 24
39	8.00E+09	15.6	1.00E+10	NA	Pass, FE Free
51	6.60E+09	11	1.00E+10	21	Pass FE onset at 21 MV/m
53	1.26E+10	13.5	1.00E+10	NA	Pass, FE Free
56	1.28E+10	25	1.00E+10	NA	Pass, FE Free
43	8.00E+09	13	1.30E+10	21.5	Pass, FE onset at 21.5 MV/m
47	6.70E+09	12	1.00E+10	NA	Pass, FE Free Admin limted at 24 MV/m
55	7.34E+09	15.5	1.10E+10	NA	Pass, FE Free Admin limited at 24 MV/m

CEBAF Injector Upgrade

- HV gun installed summer 2018; main upgrade May 2020
- Polarized source beamline to be rebuilt
  - two 200 kV Wiens upstream of prebuncher
  - magnet and vacuum improvements (NEG coating)
- Booster beamline to be rebuilt
  - new SRF booster module (replaces existing capture and quarter)
  - may also include improved magnets and diagnostics
- Detailed schedule and component design under development

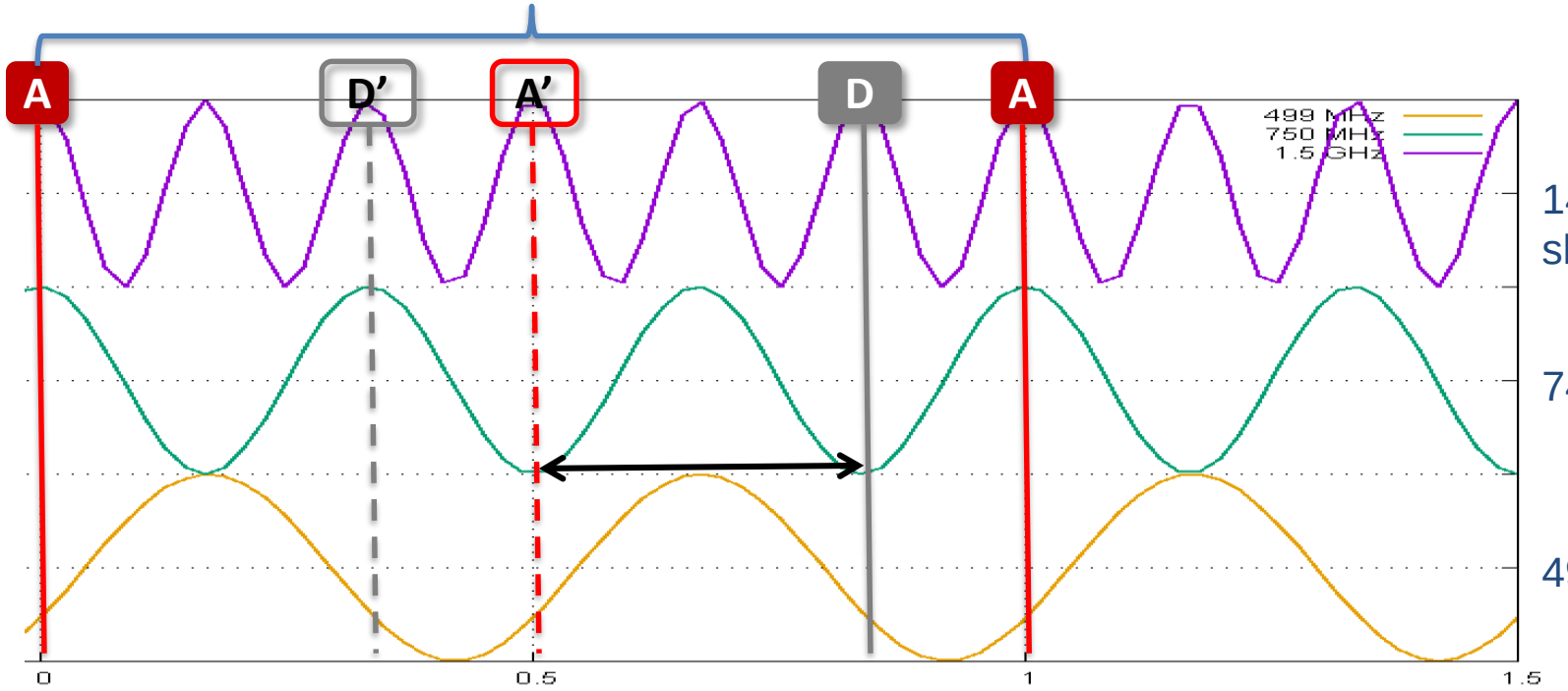


Low-Current Bleedthrough

- o(nA) beams desired for TAC runs, flux calibrations
  - o(nA) bleedthrough from high-current hall operations also routinely observed in Hall D
- What is causing this bleedthrough?
  - Schematic explanation on next slide
  - Only occurs when high current hall (e.g. Hall A) is also operating on 5^{th} pass
  - An intrinsic “feature” of 5^{th} pass RF separation design
    - Beam size not intrinsically different from Hall D beam
    - Cannot eliminate with any changes (e.g. slit) to Hall D slit/laser
- What can be done to resolve it?
  - Coordinate flux calibrations with high-current hall downtime
  - Figure out ways to tolerate it (e.g. V wire, higher currents)
  - Petition to eliminate it at source (e.g. 6-slit chopper)

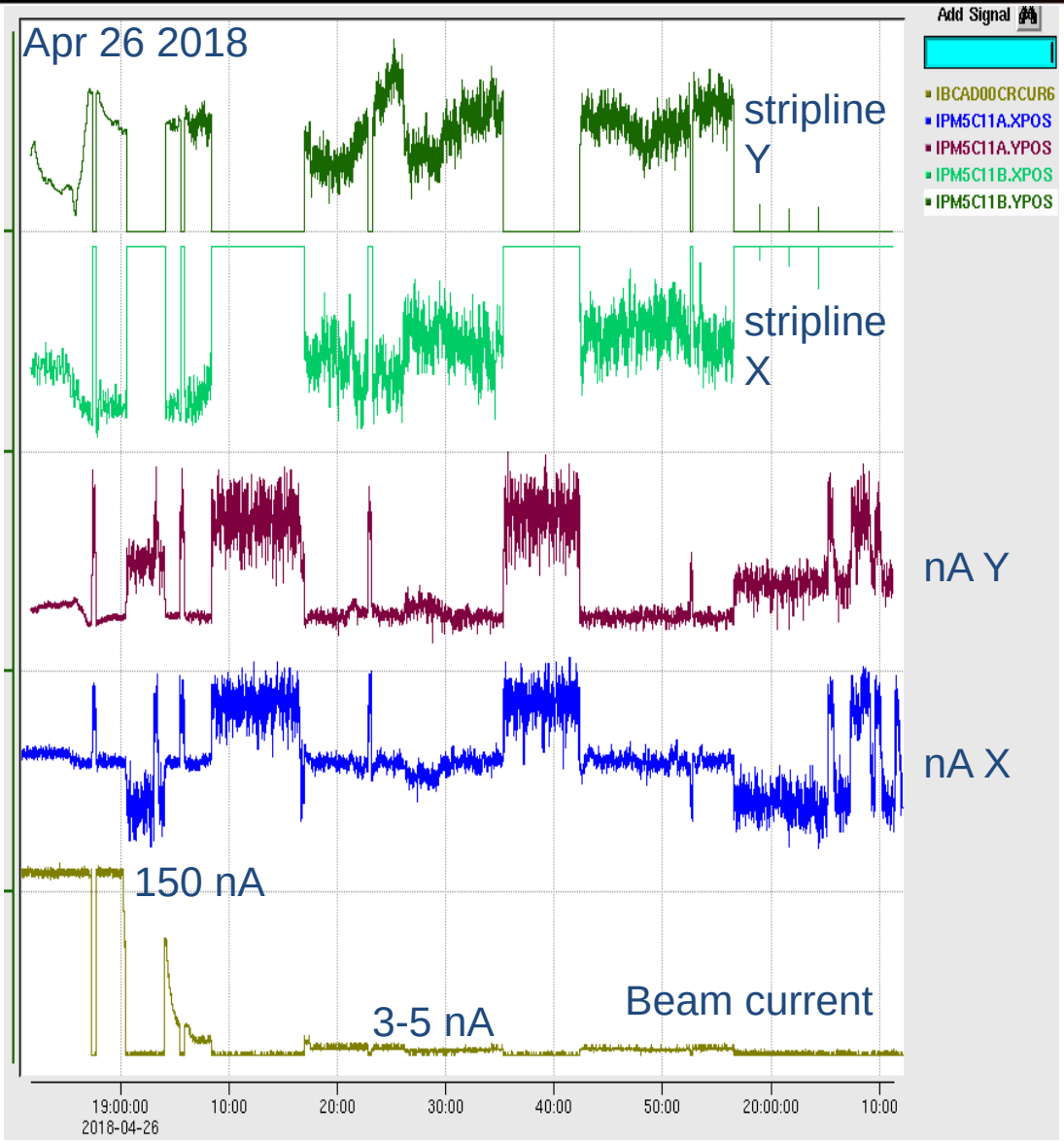
Low-Current Bleedthrough

One 249.5 MHz period (A/D lasers); 2 499 MHz periods (B laser and chopper/slits, omitted)



- Schematic of 748.5 MHz 5th pass separation (green)
  - Hall A also running on 5th pass; both lasers at 249.5 MHz
  - 499 MHz A' "extinction bleedthrough" from A laser goes through A slit
    - But hits 750 MHz separator at same phase as D beam => goes to Hall D
  - Closing D slit / turning off D laser do not eliminate this bleedthrough

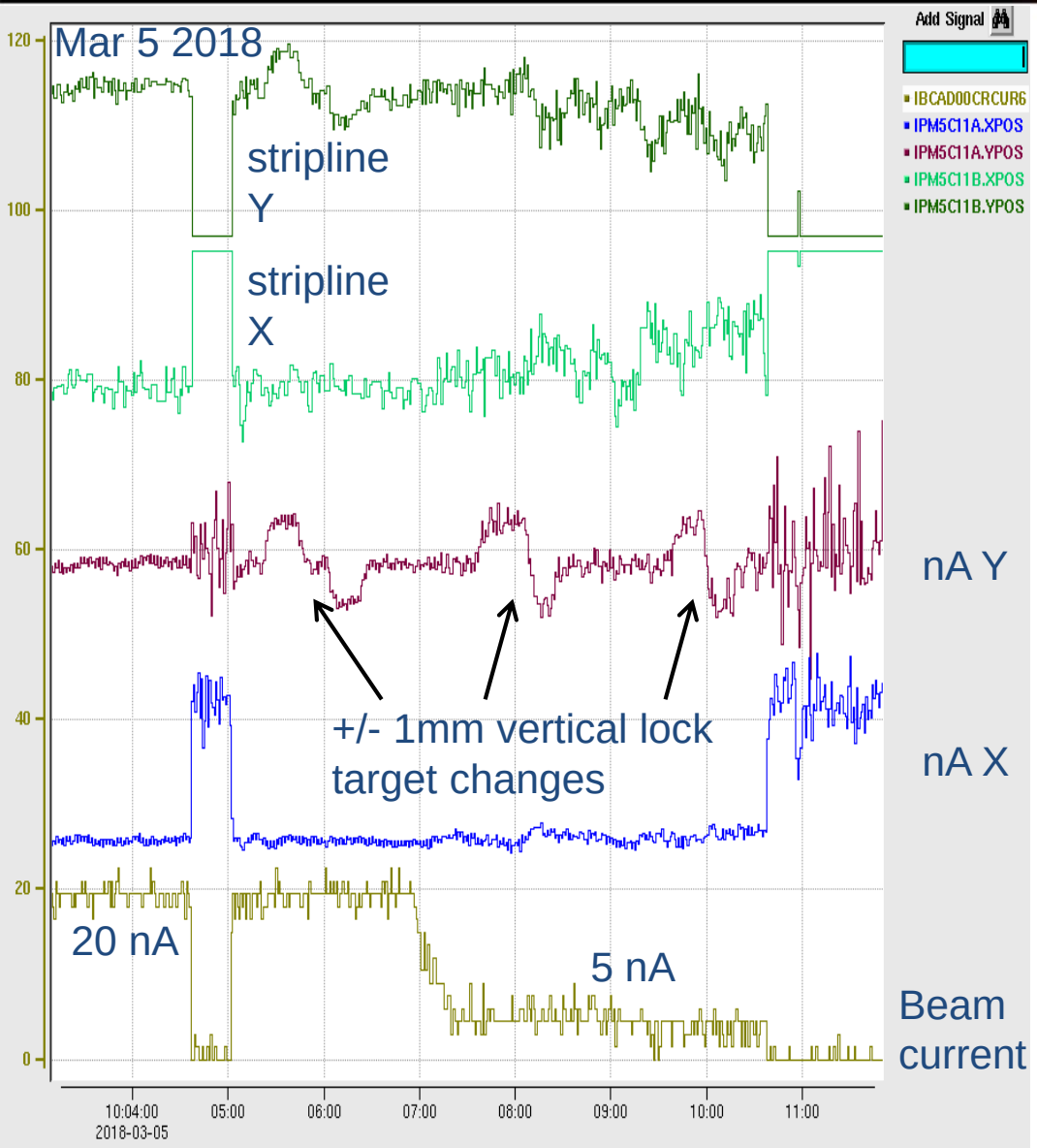
nA BPM Calibration and Locks



- TAC runs require low current operations
- nA BPM IPM5C11A and AC calibrated for orbit locks to o(3 nA)
- https://logbooks.jlab.org/entry/3567813
- o(100 um) lock stability
- o(1 nA) bleedthrough

- Study low-end nA BPM and AC calibrations and behavior
- Optimize PID lock loop gains, sampling intervals

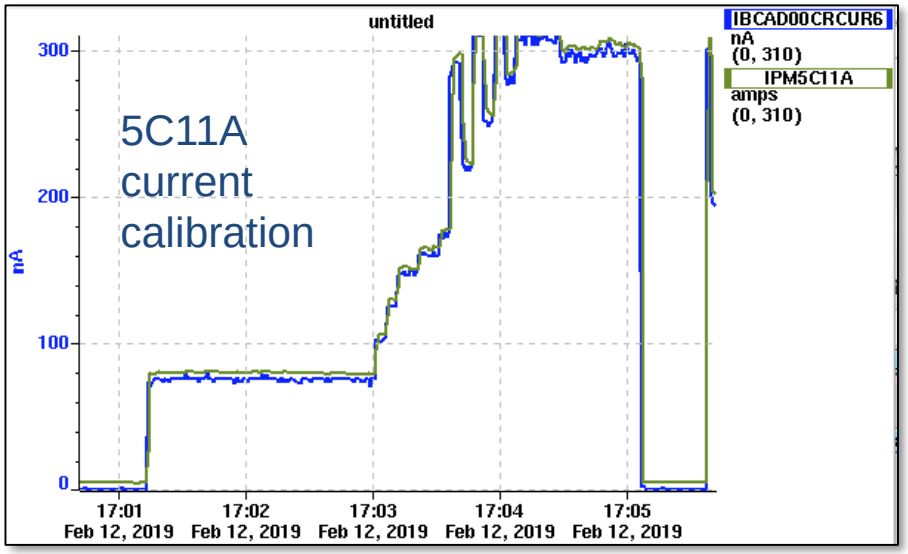
nA BPM Lock Test

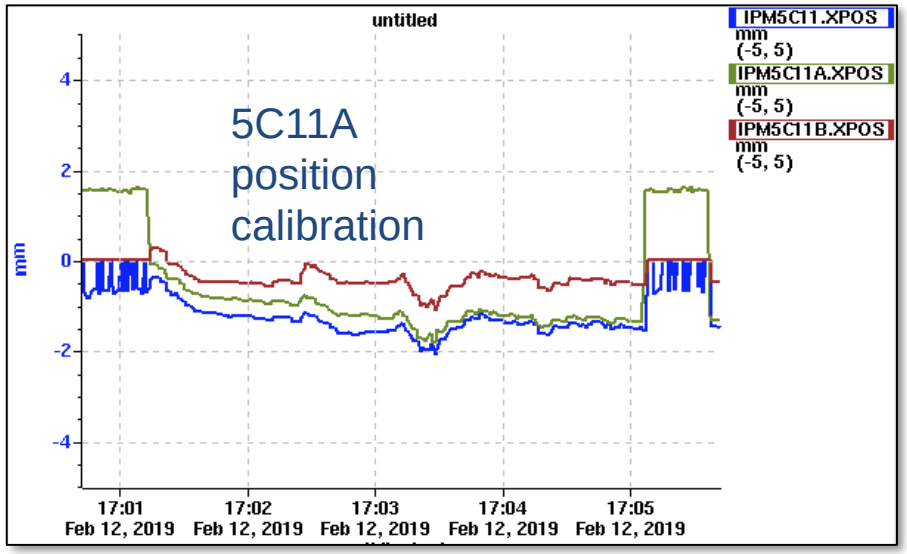


- Checked 5 nA stripline and AC lock stability
- Changed lock target positions by +/-1mm
- Measures response stability and bandwidth (slew rate)
- Striplines work (noisily) at 20 nA but clearly lose tracking at ~10 nA

nA BPM Calibration and Locks

- Calibrated Feb 12 (5C11A) and 13 (AD00) (J. Musson)
  - Low gain setting for nominal 100-300 nA operations
  - Gains can be raised for low-current flux calibrations
- Locks configured to use nA BPMs for position stability
  - Of particular importance when using V wire?
  - No changes since Apr 2018 configuration





AC Calibration Raster Scan

- Active collimator raster scan testing was successful this run
- Apr 20 →
  - reproduce previous results post-Trent departure
  - Good support by Brian Bevins, Chad Seaton, John Musson
- May 1
  - Raster observed working
  - Some X/Y coupling observed