MCC Operations
What goes into delivering beam at CEBAF

Unfortunately, delivering continuous, high-power, physics quality electron beam on-target is not as simple as flipping a light switch. Many interconnected systems are in play, and that is before thinking about delivering multiple beams simultaneously to four experimental endstations. Presented in this talk will be an overview of MCC Operations systems, routine procedures, and common obstacles to achieving high up-time.
Outline

1) Overview of 12 GeV CEBAF
2) Systems Ops Operate or Interface With
   A) Facilities
   B) Cryogenics
   C) Computing Infrastructure
   D) Information
   E) Source
   F) Magnets
   G) RF
   H) Diagnostic
   I) Safety
   J) Software
3) Common Obstacles to Beam Delivery
   A) Hardware Failure / Malfunction
   B) Beam is Trippy, Cause Known
   C) Accelerator Setup
   D) Beam is Trippy, Cause Unknown
4) Routine Procedures (do we get this far?)
   A) Quantum Efficiency
   B) Target Change
   C) Ion Chamber Calibration
12 GeV 4-Hall CEBAF (after 2023 SAD)

MCC Operations – What goes into delivering beam at CEBAF

- Pre-Injector
  - Vertical Wein filter
  - Spin flipper solenoids
  - Horizontal Wein filter
  - Prebuncher cavity
  - Chopping cavities
  - Slits (Master, A/B/C)
  - De-chopping cavities
  - Buncher cavity
    - Booster CM

- 200 keV Polarized Gun

- Booster CM

- mcc_operations_beam_delivery_at_cebaf_diagram.png
MCC Operations – What goes into delivering beam at CEBAF

9/22/22: Administrative limit for total power to A and C raised from 1 MW to 1.3 MW.

11/24/22: Owl shift touched ~975kW = 45uA to A3; 65uA to C5
CEBAF Source Configurations

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Systems Ops Operate or Interface With

- **System vs Utility or Infrastructure**
  - Electricity often regarded as a utility
  - Cryogenics – system of utility?
  - Beamline Vacuum – system or utility?

- **System vs Information Tool**
  - Beam Time Accounting – *overall a system with tools to interface with?*

- **System Readiness Tool / Hot Checkout System**
  - **System vs Utility vs Tool – Ops regularly interfaces with them all =>**

  *Let’s not get bogged down in semantics*
Facilities Systems

- Fire Protection System
  - In tunnel and Halls: Very Early Smoke Detection Apparatus (VESDA)
- Instrument Air System – 60 psi N2
- HVAC Systems
  - Site chilled water loop
  - Dehumification systems
  - Fans – general ventilation and equipment/rack
- LCW (Low Conductivity Water) System
- AC Distribution (electricity)
  - Substations
  - Switchboards
- Drains and Disposals
  - Groundwater pumping
  - Hall A/C Dump tritium disposal
Cryogenic Systems

- Cryogenics (Utilities?)
  - CHL1, CHL2, ESR, HDR, CTF

MCC Operations – What goes into delivering beam at CEBAF
Computing Infrastructure

- Accelerator Computing Environment (ACE) SysAdmins
  - Network Switches, Gateways, UPSs, Remote Reboot Switches, User Consoles
  - Servers – Alarm, Archive, Authentication, Database, File, Name, Web

- ~Software / Controls Software Group Systems Team / Low Level Apps
  - EPICS I/O Controllers = IOCs – ~450+ in total
    - Some owned by Cryo, Halls
    - Mostly Motorola VME
  - Control Crates (Modular Crate Electronics)
    - Usually owned by Instrumentation & Controls (I&C)
    - Sometimes owned by Cryo or RF
    - Some flavors = VME (Versa Module Eurocard), CAMAC (Computer Automated Measurement and Control), NIM (Nuclear Instrumentation Module)
Information Systems

- Accelerator Software
  - Beam Time Accounting (BTA)
  - Beam Time Manager (BTM)
  - Hot Checkout / System Readiness (HCO)
  - Beam Authorization (BA)
  - Program Deputy Shift Plans
  - CEBAF Element Database (CED)
    - LED, UED
  - Laser Configuration Manager
  - Downtime Manager (DTM)
  - Accelerator Task List (ATLis)
  - Waveform Browser

- JLab / Computer Center
  - Operational Safety Procedure (OSP)
  - Run Readiness Certificate
  - Radiation Safety Assessment Document (RSAD)
  - Experiment Safety Assessment Document (ESAD)
  - Conduct of Operations (COO)
  - Radiation Work Permits (RWP)

- Operations
  - Ops Restrictions
  - Accelerator Bypassed Interlock Log (ABIL)
  - Ops Problem Reporting (Ops-PR)
  - Web On-Call
  - MCC Docs

How to determine max current that can be delivered to a Hall on a specific target?

- What is the maximum current the target can take? Ops Restrictions
- What is the maximum allowed current in Hall? Beam Authorization
- What is the radiation budget allotted? RSAD

There is room for improvement...
Source Group Systems

(aka Center for Injector Sources (CIS), formerly Electron Gun Group (EGG))

- Lasers – seeds, pre-amps, amps, Service Catch-All Module (SCAM)
- Laser Table – RTP Cell, IHWP, RHWP, Pockels Cell
- Gun – HV, SF6, GaAs photocathode
- Mott polarimeter, Wein filters
- Helicity and parity controls
- Chopping apertures/slits
- Front-end apertures, cups, vacuum
Magnets

- DC Power for power supplies, connections
  - 10A trim system = trim cards, racks, utility chassis, bulk power supplies
  - 20A trim power supplies
  - Shunt modules
  - Box Power supplies and their many varieties
- Mechanical Install for LCW and installation
- Survey and Alignment for… (self-explanatory)
- Magnet Measurement for field maps
- Software (Low Level Apps) for Controls
- CASA for design settings
- Software (High Level Apps) for managing, downloading, and comparing with design

<table>
<thead>
<tr>
<th>Magnet Type</th>
<th>Count (from CED), Excluding Unpowered</th>
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</thead>
<tbody>
<tr>
<td>Dipole</td>
<td>482</td>
</tr>
<tr>
<td>Corrector</td>
<td>1029</td>
</tr>
<tr>
<td>DiagKicker (raster, FFB corr, 30Hz)</td>
<td>48</td>
</tr>
<tr>
<td>Quadrupole</td>
<td>854</td>
</tr>
<tr>
<td>Solenoid</td>
<td>13</td>
</tr>
<tr>
<td>Thin Septa</td>
<td>8</td>
</tr>
<tr>
<td>Total Magnets</td>
<td>2434</td>
</tr>
</tbody>
</table>
RF Systems

Warm RF
- Lasers, Prebuncher, Choppers, Buncher
- 499MHz Separators (Pass 1-4 Horizontal, Pass 5 Vertical)
- 750MHz Separator (Pass 5 Horizontal)

Cold RF
- (incoming) Booster
- Cryomodules

Other RF Systems
- Master Oscillator

<table>
<thead>
<tr>
<th>Cryomodule Type</th>
<th>Count (from CED)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Booster (one 0.12m cavity, one 0.7m cavities)</td>
<td>1</td>
</tr>
<tr>
<td>C25 (eight 0.5m cavities)</td>
<td>26</td>
</tr>
<tr>
<td>C50 (eight 0.5m cavities)</td>
<td>11</td>
</tr>
<tr>
<td>C75 (eight 0.5m cavities)</td>
<td>2</td>
</tr>
<tr>
<td>C100 (eight 0.7m cavities)</td>
<td>12</td>
</tr>
</tbody>
</table>
Cryomodule Example – 1L14

MCC Operations – What goes into delivering beam at CEBAF
Diagnostic Systems – I&C

- **Beamline Cavities** – Beam Position Monitors (1041), Beam Current Monitors (28), M56/Pathlength (2), Yao/Bunchlength (1)
- **Actuated** – Viewers (153), Harps (59), Dumplettes (16), Faraday Cups (5), Apertures (4), Pucks (2)
- **Radiative** – Synchrotron Light Monitors (11), (diagnostic) Beam Loss Monitors (103 vs 68 MPS)

**Systems**
- 30Hz System – Function Generator, Correctors, RF Vernier
- Beam Loss Accounting – BCMs
- Fast Feedback – iron-core correctors, RF lock zone, air-core correctors, RF Vernier, Fast DAQ
Vacuum

• Beamline vacuum (not around Cryomodules)
  • Vacuum itself – Vacuum group
  • Pumps, valves, gauges, interlocks and logic – I&C
  • Except for first ~10m of beamline in Injector – CIS

• Cryomodule-related
  • Beamline through cryomodule
    • Vacuum itself – Vacuum group
    • Instrumentation functionality – I&C
    • Interlock/trip thresholds – SRF
  • Cryomodule Insulating Vacuum
    • Vacuum itself, interlock thresholds – SRF
    • Instrumentation functionality – I&C
  • Cavity Waveguide Vacuum
    • Vacuum itself, interlock thresholds – SRF
    • Instrumentation functionality – I&C
    • PSS loss of pressure interlock – SSG

<table>
<thead>
<tr>
<th>Vacuum Device</th>
<th>Count (from CED), excluding Unpowered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion Pumps</td>
<td>953</td>
</tr>
<tr>
<td>NEG Pumps</td>
<td>8</td>
</tr>
<tr>
<td>Turbo Pumps</td>
<td>28</td>
</tr>
<tr>
<td>Cold Cathode Gauges</td>
<td>64</td>
</tr>
<tr>
<td>Pirani Gauges</td>
<td>48</td>
</tr>
<tr>
<td>Thermocouple Gauges</td>
<td>60</td>
</tr>
<tr>
<td>Beamline Valves</td>
<td>226</td>
</tr>
<tr>
<td>Fast Valves</td>
<td>14</td>
</tr>
</tbody>
</table>
Safety Systems

- Personnel Safety
  - Personnel Safety System (PSS) – SSG
  - Electrical – DC Power, RF, CIS
  - Prompt and Microwave Radiation – RadCon, RF, CIS
- Oxygen Deficiency Hazard (ODH) – SSG
- Fire Protection – Facilities
- Machine Protection Systems (MPS)
  - Fast Shutdown Detection (FSD) – SSG
    - Beam Loss Monitors (BLMs)
    - Cryomodules, RF separators, Warm Cavities
    - Ion Chambers
    - Halo Monitors
    - Vacuum valves / interlocks
  - Beam Envelope Limit (BELS) – SSG
  - Beam Loss Accounting (BLA) – I&C
# Software

## High Level Applications
- FSD Masking Tool
- FSD Fault Panel
- Fast Optics (FOPT)
- Linac Energy Manager (LEM)
- Alarm Handler
- iCalibrate
- harpFitter
- Phaser
- hystArea
- Injector Steering Script
- LaserFreek
- RF Fault Viewer
- RF HealthCheck
- RF Analyzer
- RF Fast Reset
- OrbitSnaps

## Ops Applications
- Box Supply Cycling
- RF On/Off
- adViewer
- CHIME
- Twiddle

## CASA Applications
- Electronic Download Tool (eDT)
- Dogleg Calculator
- Courant Snyder
- Spin Doctor
- ArcSteer
- Quad Scan Utility (qsUtility)
- RayTrace

## Low Level Applications
- Extensible Display Manager (EDM) Screens
- Channel Access
- CDEV Lock Server
  - Generic PID/Matrix Locks
  - Orbit Locks
  - Current Locks
- Energy Locks
- Beam Energy Monitor (BEM)
- All-saver
- EPICS Alarm Handler and CMLog
- Mya Archiver
- IOC Watchdog
- FastSEE Diagnostics
- BPM Calibration
2/3 of Time, Ops is First Responders to System Malfunctions / Trips / Failures

- Ops provides troubleshooting and initial diagnosis of *many* systems when experts aren’t on-site.
- Taken alone, few systems are terribly complicated, handful of failure modes. Put together => multi-dimensional rich failure space.
- Determining which system expert to contact is not always straightforward (and that’s before delineating between Hall-owned and Accelerator-owned hardware).
- More beneficial to Operators than expert in-depth knowledge of select systems is some exposure and understanding of many systems and how they interconnect.
Common Obstacles to Delivering Beam

The best shifts are when all Halls are getting beam at desired parameters, with few trips and high up-time.

- Beam Tripped, Unable to be Restored => Hardware Malfunction or Failure
  - Provide initial troubleshooting and diagnosis
  - Create Downtime Incident for suspected hardware
  - Contact System Experts as-needed
- Beam is trippy / cannot reach desired currents
  - Cause known / understood => take corrective action
    - Hardware failure / malfunctioning, repair / rectify
    - Setup degraded, execute appropriate beam routine / procedure
  - (most likely) Exact cause unknown
    - Investigate / Troubleshoot
- In both cases, balance beam delivery against troubleshooting / investigation / repair efforts
Beam is Trippy, Cause Known – Examples from Last Run

- 1L12-2 Tuner Frozen close to resonance
  - Cannot be de-tuned to prevent beam draining
  - Beam current/power dependent
  - Drifted in and out of resonance
    - When close, push RF power into it
    - Some weeks, handful of adjustments
    - Other weeks, shift-ly adjustments
  - Fixed during ‘22-’23 “Winter Break”

- 0I02 YAG Viewer screen charging up and discharging
  - Resulted in ~mm drift in Injector, followed by instantaneous snap backs upon discharge
  - Beam current/power dependent
  - Most detrimental to Hall B current stability
  - Fixed during SAD’23 (but may not be only early Injector element charging up and discharging, Vertical Wein when HV Off suspected as well)

- Why not fixed earlier? Balancing Time...
Sometimes They Don’t Trip Much, Then They Halt the Program

- 2L07 Insulating Vacuum leak
  - Eventually, leak will become so bad that keeping the module cold will over-tax the CHL => Zone must be turned off.
  - CM swap entails ~weeks extension to SAD – deferred

- BSY Recombiner/Transport Vacuum
  - ~1/4 of nT* VIPs disabled from nT06 down
  - Number of pumps down => hi-potting fruitless, need more time than a maintenance day to recover vacuum = SAD’23 activity
Before we get into Beam is Trippy, Cause Unknown... Beam Beam Delivery for Physics, Accelerator Beam Setup!

- Injector Setup – Ops and Injector Group
  - Polarization
  - Bunchlength
  - Chopper
  - Transmission optimization
  - Injector Energy
  - Initial Optics
- Cold Start-Up Procedure – Ops
  - Phase up linacs
  - Steer beam first time through Spreaders, Doglegs, and Recombiners
  - Establish beam to 3R, 1.5 passes

- Optics Restoration and Finalization Procedure (ORFP)
  - Pull (n-1)R dumplette and steer (n)R dumplette
  - Correct pathlength up to (n)R
  - Correct dp/p < 5e-4 in Arc(n)
  - Correct Horizontal Dispersion coming out of (n-1)A
  - Correct Vertical Dispersion coming out of (n-1)R
  - FOPT to (n)R. Compare to CS traces.
  - Correct betatron match coming out of (n-1)R using DiffX/Y “ballpark” procedure or RayTrace
  - Correct Vertical Dispersion in (n)A
  - Correct M56 for (n-1)A
  - Re-check horizontal dispersion coming out of (n-1)A. Iterate between M56 and dispersion as needed.
  - Match at (n)E using qsUtility
  - After downloading match, viewer walk for Arc(n).
  - Aperture scan
  - Take another FOPT. If good, all-save.
Accelerator Beam Setup before Physics

- Injector Setup – few shifts to few days
- Cold Start-Up – handful of shifts
- ORFP – ~4hrs for each arc
  - Lower passes/arcs typically take longer to setup compared to higher passes/arcs
  - Beam becomes more rigid as it gains energy, fewer ways in which it can be mis-steered or mis-setup and still transport
- Beam Extraction Procedure – RF or magnetic extraction
- Hall Setup Procedures, first to dumplettes
- All tune-mode up until this point*, 1.5% duty cycle, BLMs usually masked

* Except for parts of the Injector setup

Ready to Send Beam into Halls for Setup

- Hall Setup Procedures interleaved with Counting House setups – raster, target and/or collimator centering
- Start with tune, eventually switching to CW for...
  - Ion Chamber Calibrations
  - Beam Loss Accounting BCM Calibrations
- First CW throughout whole machine rarely works right off the bat – BLM trips!
  - Tight aperture? Re-visit steering, pathlength, gangphase
  - Injector Setup?
  - RF loading? Identify struggling cavities (if RF trips, at least you know where to focus)
Beam is Trippy, Cause Unknown

- FSD trips mostly radiative diagnostics – halo counters, ion chambers, BLMs
- A Common Troubleshooting Approach –
  - RF beam loading at higher currents – check RF throughout machine using RF HealthCheck, RF Analyzer, Waveform Browser with highest stable current achievable
    - Sometimes you identify a struggling cavity and can correct
    - Sometimes you can’t correct that cavity and have to re-visit gradient distribution to lessen its ill-effects on beam
  - Steering / Scraping
    - Check individual orbits in stable CW, tune
    - Pathlength, gangphase, RF Separation
    - Locks behaving as expected?
  - Optics (transverse)
    - FOPT and manual use of 30Hz
    - Harp swipes
  - Optics (longitudinal)
    - Use 0L04 phase to optimize bunch
    - Bunchlength measurement
Beam is Trippy, Cause Unknown

- From the Injector or from RF?
  - Injector clipping?
    Charging/discharging?
  - RF beam loading?
- Fast transient? Do fast diagnostics see it (e.g. FastSEE BPMs)?
  - RF Separator regulation?
  - Chopper centering?
- Ghost in the system?
  - Magnet trim rack silently not reporting errors, but otherwise functioning as expected (SA01B07)
  - Is the device tripping with no beam? (IIC3H04)
  - Ion pump out-gassing and beam interaction resulting in radiation picked up by BLMs?(8E02 BLM)
Beam is Trippy, Cause Unknown, Days of Investigation

- Can we try to identify the problem device by removing it from setup?
- Diagnostics radiation survey of beamline reveal anything?
- System checks…

- We don’t always find a smoking gun for why beam is tripping
- Sometimes something occurs on a maintenance day and the trippiness subsides
- Tracking beam trippiness is not trivial, can’t be tackled by a single individual (although Jay Benesch will try)
- Invest in more expensive diagnostics that may reveal issue? No guarantees, and so a hard sell

- In Archiver, we have 100,000s signals
- Using AI/ML to analyze these signals for patterns when beam is inexplicably trippy an ongoing effort
- Archiver signal analysis ripe with opportunity – we will take all the help we can get!
Think of a question later?

moser @ jlab . org
Routine Procedures – Quantum Efficiency Measurement

MCC Operations – What goes into delivering beam at CEBAF
Routine Procedures – Target Change in A/C

• Target and Highest Current expected needed
• Ops checks –
  - Operational Restrictions and Beam Authorization (and sometimes RSAD)
• Ops Sets –
  - MaxJuice (over-current protection)
  - Ion Chamber Trip Thresholds
  - Raster size
  - Current/orbit lock parameters
## Routine Procedures – Radiator Change in D

### Hall D Radiator Change Procedure

#### Setup (Preparing to move the radiator or goinometer)

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Verify Beam is Off to Hall D</td>
</tr>
<tr>
<td>2</td>
<td>Inhibit CW to Hall D</td>
</tr>
<tr>
<td>3</td>
<td>Insert Dumplette Out</td>
</tr>
<tr>
<td>4</td>
<td>Unrestrict Gun Mask Requests</td>
</tr>
<tr>
<td>5</td>
<td>Mask Radiator</td>
</tr>
<tr>
<td>6</td>
<td>Call Hall D, tell them that they can move the radiator.</td>
</tr>
</tbody>
</table>

#### Backout (Preparing to resume beam delivery)

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Unmask Radiator</td>
</tr>
<tr>
<td>2</td>
<td>Restrict Gun Mask Requests</td>
</tr>
<tr>
<td>3</td>
<td>Verify Beam is Off to Hall D</td>
</tr>
<tr>
<td>4</td>
<td>Retract Dumplette Out</td>
</tr>
<tr>
<td>5</td>
<td>Enable CW to Hall D</td>
</tr>
<tr>
<td>6</td>
<td>Adjust Ion Chambers and Maxjuice</td>
</tr>
</tbody>
</table>

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### Technical Notes

- **TAC Runs**: 50nA, N/A, N/A, N/A
- **Beamline**
  - **Admin Limit**: 3000nA, N/A, N/A, N/A
  - GlueX Phase I Fall 2018 E12-06102 nA of 3 shifts for tests
- **Dumplette Limit**
  - AD00 electron beam dump limit: N/A, 60kW, N/A, N/A
  - Technical limit for the AD00. The por

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**MCC Operations – What goes into delivering beam at CEBAF**

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**Jefferson Lab**
Routine Procedures – Ion Chamber Calibration

https://logbooks.jlab.org/entry/4139563