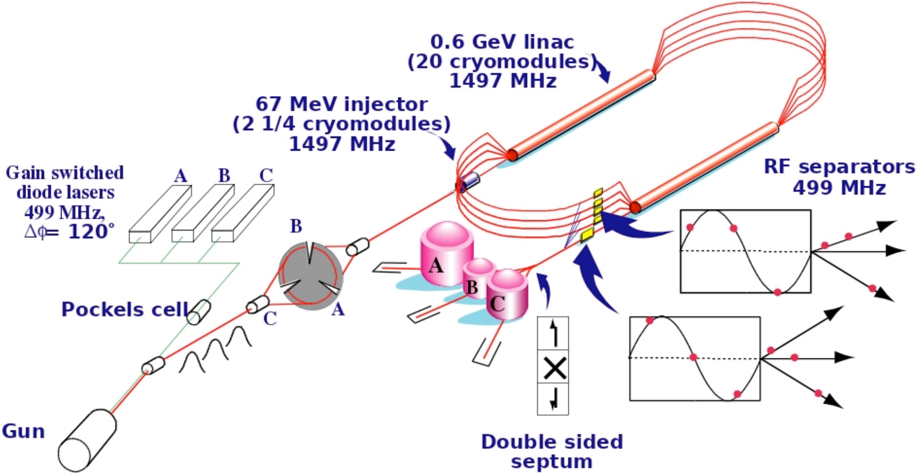
CEBAF Operations

Arne Freyberger
Operations Department
Accelerator Division

JLAB

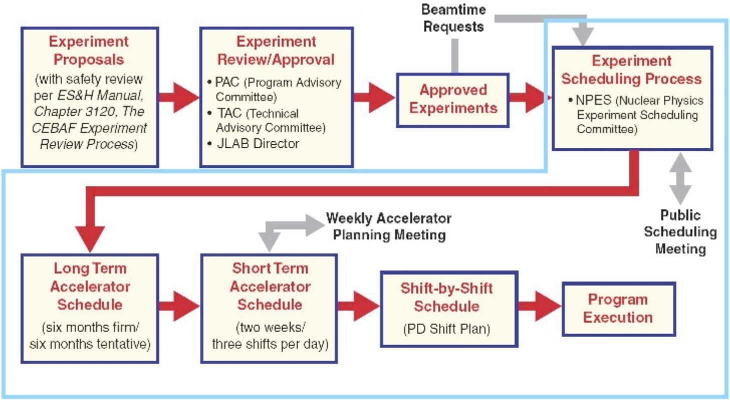
May 9⟶11

6GeV CEBAF Accelerator



- Simultaneously delivery of sub-nA and $\mathcal{O}(100)\mu$A beams
- Beam polarization $> 85\%$
- Momentum spread $\frac{dp}{p} < 3 \times 10^{-5}$
- Parity Quality Beams with nm beam position differences

Operations: Program Flow



- Develop the long term schedule with Physics (TAC, NPES)
- Develop the short term schedule
- Execute the program
  - Work with Physics to optimize the program
  - Develop, measure and track performance metrics
  - Adjust if needed

FY11/FY12 Schedule

CEBAF configuration, energy and pass configuration, has been very stable for FY11 and FY12.

	Energy Changes	Pass Changes	Weeks of Operation
FY10	4	7	35
FY11	0	7	30
FY12	2	7	27†

† FY12 Weeks of operations includes time for beam restoration after the 6-month shutdown.

CEBAF configuration stability due to QWeak presence throughout FY11 and FY12.

	Hall-A	Hall-B	Hall-C
Exp. Configurations	12	8	2

FY11 & FY12 DOE Joule Reports

FY2011 DOE SC PART/Joule Metrics		
Status as of: 24:00 Friday, September 30, 2011	FY11 SC Official Goals and Guidelines	Actual to Date
Delivered Research Hours	4,390	4,305
Delivered Beam Studies Hours	366	256
Delivered Tuning / Restore Hours	244	100
Total Delivered	-	4,661
Expected Delivered Hours	5,000	-
Total / Budgeted	-	93%
Unscheduled Failures	< 632	365
Scheduled Hours	5,618	5,026
Research / Scheduled	88%	86%
Reliability	> 89%	93%
Weeks of Operation	34.3	29.92

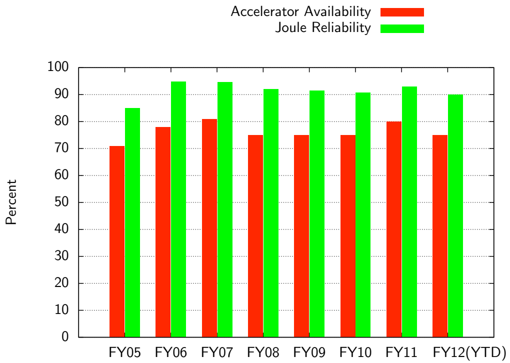
FY2012 DOE SC PART/Joule Metrics		
Status as of: 24:00 Monday, April 30, 2012	FY12 SC Official Goals and Guidelines	Actual to Date
Delivered Research Hours	3,398	3,051
Delivered Beam Studies Hours	283	146
Delivered Tuning / Restore Hours	189	160
Total Delivered	-	3,357
Expected Delivered Hours	3,870	-
Total / Budgeted	-	87%
Unscheduled Failures	< 632	376
Scheduled Hours	4,348	3,733
Research / Scheduled	88%	82%
Reliability	> 89%	90%
Weeks of Operation	26.5	22.22

FY11 Exceeded Reliability goal of 89%

YTD exceeding Reliability goal of 89%

Reliability Joule Metric Reliability $= \frac{\text{Total Delivered}}{\text{Total Scheduled}}$, including Beam Studies and Restoration.

CEBAF Accelerator Availability for Physics



Accelerator Availability for Physics: Fraction of time that the accelerator is ready to deliver beam to Physics users.

Accelerator Availability,FY11(80%) and FY12 YTD(75%), exceed the FY goals (76% and 74%).

System Downtimes: FY12 vs. FY11

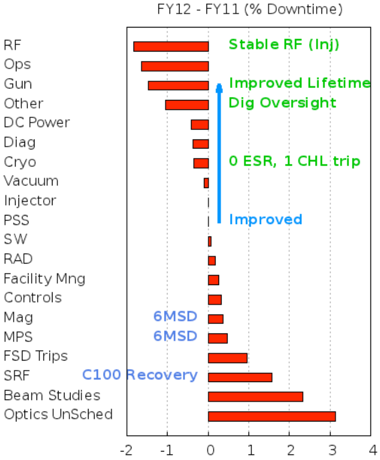
1% Downtime in FY12 (4348 scheduled hours) is equivalent to $\sim$ 2 days of scheduled operation.

Improvements:

- **RF** Injector RF stability
- **Gun** Cathode lifetime, only one heat and activate cycle during FY12 operations.
- **Cryo** One refridgerator trip during FY12 operations.

Systems with Increased Downtime:

- **SRF** C100 fault recovery time
- **Beam Studies** 12 GeV preparations
- **Optics Unscheduled** Tuning for very low beam current program in A&B



1. CEBAF Operations Overview

2. CEBAF Operations Metrics and Performance

3. FY12 CEBAF Beam Delivery Highlights
   - Demanding Experiments in Each End-Station
     - Parity Quality Beam for QWeak
     - g2p/Gep chicane design and commissioning
     - sub-nA beams for HD-ICE
   - Beam Restoration after the 6Month Shutdown(6MSD)
     - 6MSD Work List
     - Initial Beam Restoration Plan
     - Actual Beam Restoration Plan
   - C100
     - BBU
     - C100 Initial Operations
     - 2L25 Gradient Push: April 29
   - FY12 Beam Delivery Summary

4. 12GeV

5. Summary

Parity Quality Beam: Accelerator Perspective

$\overrightarrow{D}$ Number of detected events (normalized) for positive *e* helicity, $\overrightarrow{e}$

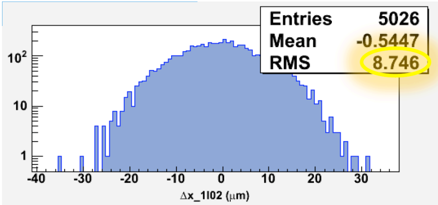
$\overleftarrow{D}$ Number of detected events (normalized) for negative *e* helicity, $\overleftarrow{e}$

$$A_{PV} = \frac{\overrightarrow{D} - \overleftarrow{D}}{\overrightarrow{D} + \overleftarrow{D}} \approx \frac{\text{Weak}}{\text{EM}}$$

This only holds if detector acceptance (or efficiency) is independent of electron spin orientation.

Parity Quality Beam refers to the position, angle and charge differences for the two helicity states averaged over the entire run.

- $\overrightarrow{x} - \overleftarrow{x}$ Position difference at the target, typically in the nm range.
- $\overrightarrow{x}' - \overleftarrow{x}'$ Angle difference at the target, typically in the sub-nrad range.
- $\frac{\overrightarrow{Q} - \overleftarrow{Q}}{\overrightarrow{Q} + \overleftarrow{Q}}$ Charge asymmetry, 100 $\rightarrow$ 10 ppb



Width of asymmetries folds contributions from:

1. Measurement resolution, i.e. new BCM electronics for QWeak
2. Beam stability, $\overrightarrow{\text{helicity}}$ to $\overleftarrow{\text{helicity}}$

Parity Quality Beams at CEBAF

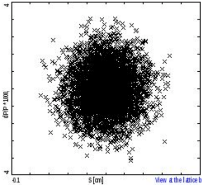
Experiment	Energy (GeV)	I (μA)	Target	A_{PV} (ppb) (Expected)	Maximum Charge Asym (ppb)	Maximum Position Diff (nm)	Maximum Angle Diff (nrad)	Maximum Size Diff ($\delta\sigma/\sigma$)
HAPPEx-II (Achieved)	3.0	55	1H (20cm)	1400	400	1	0.2	
HAPPEx-III (Achieved)	3.484	100	1H (25cm)	16900	200 ± 100	3 ± 3	0.5 ± 0.1	10^{-3}
PREx-I (Achieved)	1.056	100	208Pb (0.5mm)	657 ± 60	100 ± 130	2 ± 3	1	10^{-4}
QWeak-I (Achieved)	1.162	150	1H (35cm)	234 ± 5	-36 ± 14	3.6 ± 0.4(x) -6.9 ± 0.4(y)	-0.22 ± 0.01(x) -0.18 ± 0.02(y)	10^{-4}
QWeak-II (Requirements)	1.162	180	1H (35cm)	234 ± 5	< 100	< 2	< 2	10^{-4}
QWeak-II (Achieved)	1.162	180	1H (35cm)	234 ± 5	-16 ± 13	-0.95 ± 0.06(x) -0.24 ± 0.28(y)	-0.07 ± 0.02(x) -0.06 ± 0.01(y)	10^{-4}
PREx-II (Requirements)	1.0	70	208Pb (0.5mm)	500 ± 15	< 100	$< 1 \pm 1$	0.3 ± 0.12	10^{-4}
Møller (Requirements)	11.0	85	1H (150cm)	35.6 ± 0.7	< 10	$< 0.5 \pm 0.5$	0.05 ± 0.05	10^{-4}

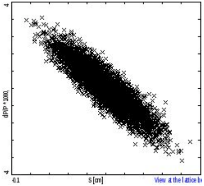
Parity Quality beam parameters meet the QWeak-II stringent requirements and are the best achieved by CEBAF in the 6 GeV era!!

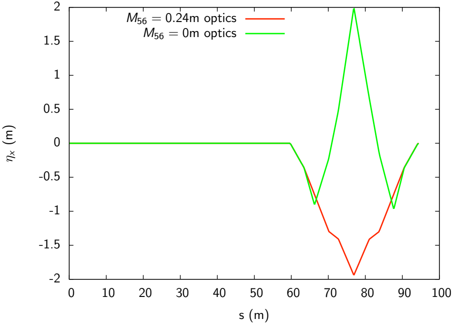
Injection Chicane Longitudinal Dynamics

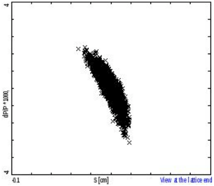
Reduce QWeak sensitivity to long bunch lengths

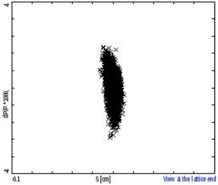
Shorten the bunch length by trading energy spread for bunch length in the injection chicane. Nominal injection chicane optics have $M_{56} = 0$: modified optics such that $M_{56} = 24\text{cm}$.



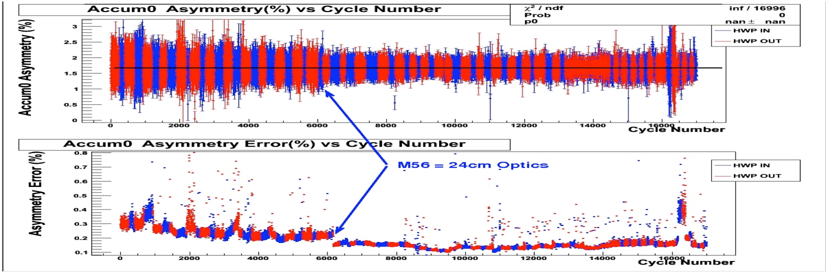




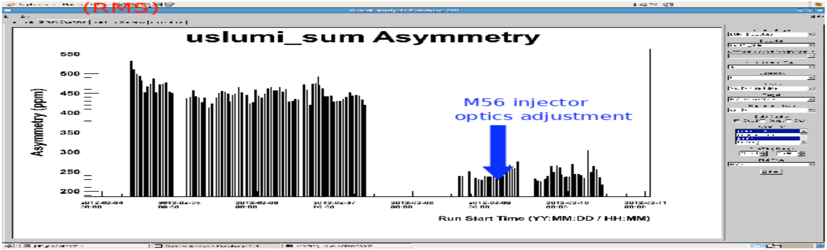




QWeak Asymmetry Widths Improved with $M_{56} = 24\text{cm}$



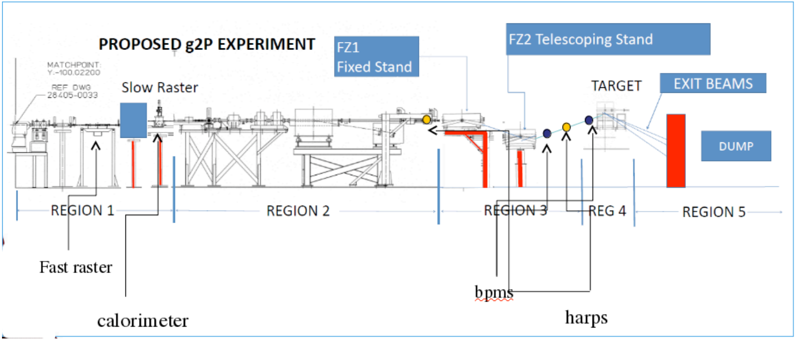
Upstream Luminosity Monitor Asymmetry Width (RMS)



g2p/Gep chicane design and commissioning

Yves Roblin

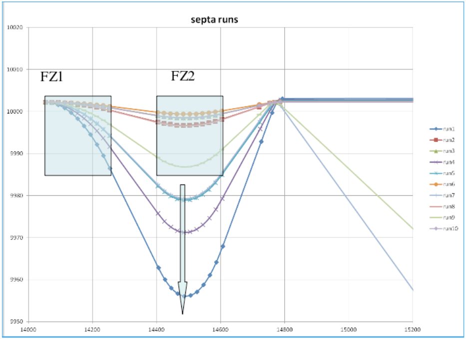
- Major new beamline design and installation for g2p in Hall-A.
- Large, movable, dipole magnet (FZ2) to achieve all Q^2 points.
- New instrumentation for $\mathcal{O}(10)$nA beam operation. (Hall-A beamline diagnostics designed for beam currents $> 5\mu$A.



g2p/Gep chicane design and commissioning

Yves Roblin

- Dipole location for each configuration calculated and transmitted to survey and alignment.
- Configuration change takes ∼4h
- Beam transport established after each move in ∼4h



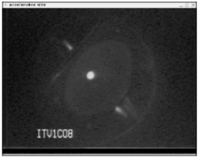
g2p/Gep chicane commissioning

Yves Roblin

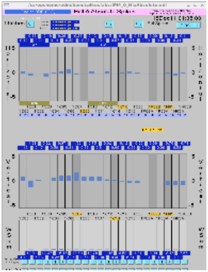
Initial commissioning of line (12/14-12/22)

Beam commissioned in straight-thru.

Halla beam dump



Match into hall A



Match to line done, beam spots on design.
Moller runs were done.
All diagnostics checked, problems identified and being corrected
CW of a few tens of nA delivered for physics detector checks.

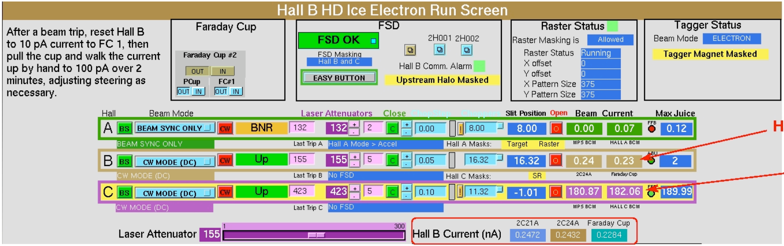
HD-ICE: sub-nA beams

Michael Tiefenback

HD-ICE electron beam test: stable sub-nA electron beam delivered for days to the HD-ICE target.

Tests were in || with QWeak operations:

$$\frac{I_{Hall-B}}{I_{Hall-C}} = 1.4 \times 10^{-7}$$



Hall–B at 23pA

Hall–C at 180uA

Cavity BCM and F–Cup well calibrated

25pA corresponds to about one electron every third 499MHz cycle.

Beam Restoration post 6-month Shutdown

Long down with many activities($\sim$ 500 ATlis work tasks written, reviewed and executed), dominated by 12GeV upgrade tasks:

- **12GeV** Convert Arc8, Arc6, Arc4, Arc2, **Arc9, Arc7 (stretch goal)** dipoles from C-magnets to H-magnets.
- **12GeV** Install, commission and operate two C100 cryomodules
- **12GeV** Connect the NE-stub to the Hall-D transport tunnel
- **12GeV** Upgrade LCW system
- **12GeV** Upgrade to the personnel safety system (PSS)
- **12GeV** Arc Dipole power supplies shuffle
- **12GeV** Camac-VME upgrade in the West Arc
- **NP-OPS** g2p beamline installation (Hall-A)
- **NP-OPS** Hall-C dump maintenance

Work coordinated by the 6MSD team, led by Fulvia Pilat.

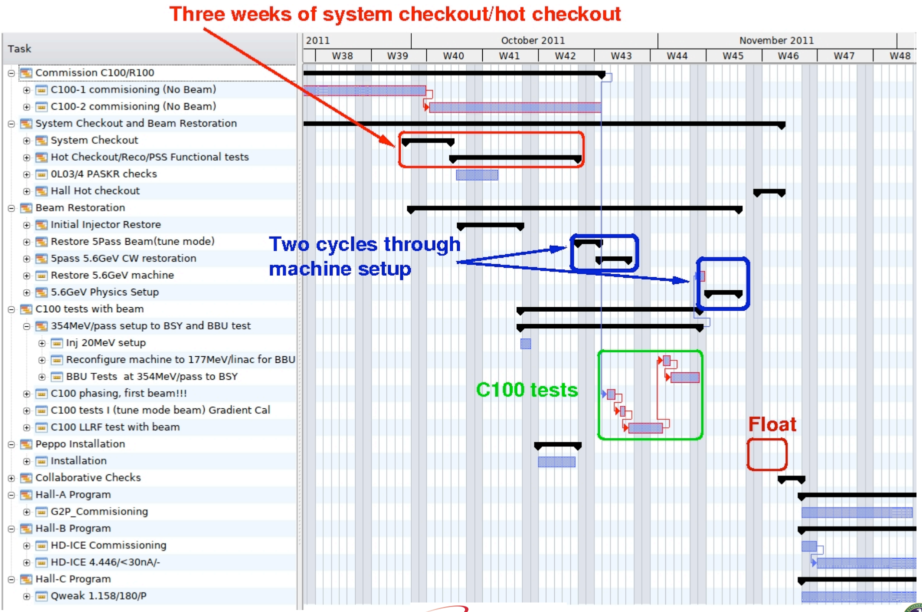
Beam Restoration post 6-month Shutdown

Long down with many activities($\sim$ 500 ATlis work tasks written, reviewed and executed), dominated by 12GeV upgrade tasks:

- Complete Convert Arc8, Arc6, Arc4, Arc2, **Arc9, Arc7** and **Arc5!** dipoles from C-magnets to H-magnets.
- Complete Install, commission and operate two C100 cryomodules
- Complete Connect the NE-stub to the Hall-D transport tunnel
- Complete Upgrade LCW system
- Complete Upgrade to the personnel safety system (PSS)
- Complete Arc Dipole power supplies shuffle
- Complete Camac-VME upgrade in the West Arc
- Complete g2p beamline installation (Hall-A)
- Complete Hall-C dump maintenance

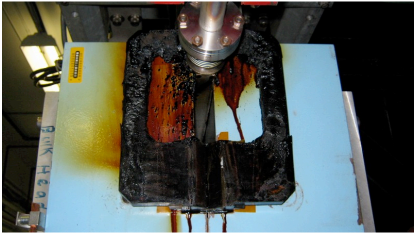
Work coordinated by the 6MSD team, led by Fulvia Pilat.

Original Beam Restoration Plan

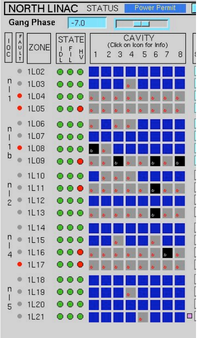


Actual Beam Restoration Plan

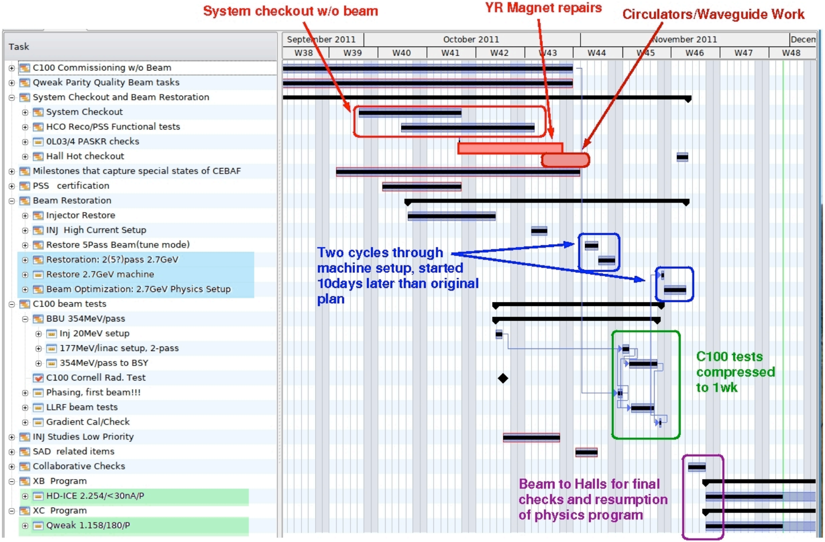
- YR magnet fire, two large septum magnets:
  - Overtemp interlock failure
  - no LCW flow
  - <2wks to install spares



- RF circulator load LCW leaks; CEBAF energy reach compromised
  - Removed, dry and install wet waveguides
  - Leaky loads removed, repaired and installed during Nov/Dec beam delivery.



6MSD Restoration Actual Gantt



Beam for Physics resumes on Nov. 19 2011, the scheduled date.

C100

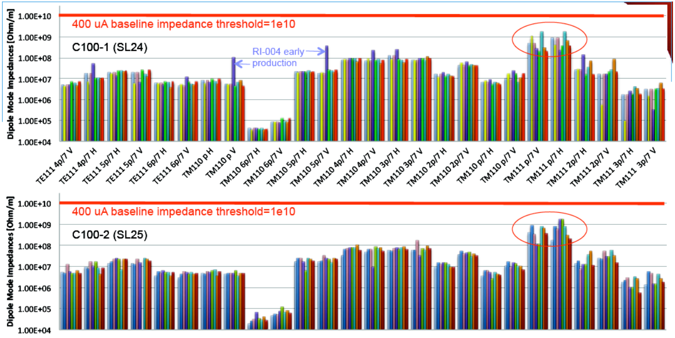
- Two C100 modules installed in the South Linac (zones 2L24 and 2L25)
- Design Parameters:
  - Integrated Gradient: 108MeV (an average of 98MeV/C100 is needed to achieve 12GeV 5.5pass energy)
  - Maximum Beam Current: 465μA
- One Week of dedicated C100 tests with beam before Physics operations in Nov. 2011.

Goals of the one-week test:

- Verify that C100s do not cause beam break up (BBU)
- Digital LLRF controls checkout and commissioning with beam

C100 BBU results

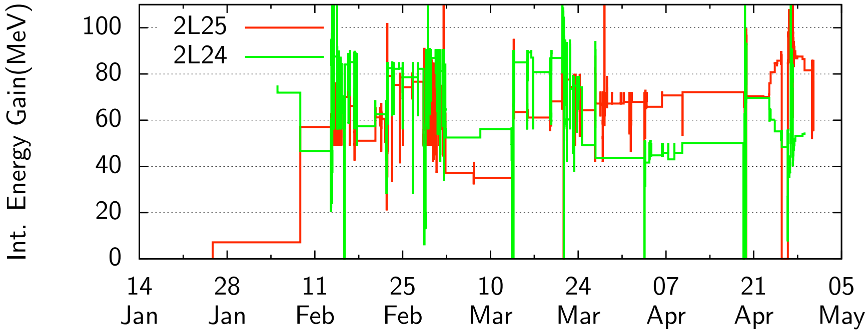
Todd Satogata



C100-1&2 HOM survey and beam-based beam breakup tests (Nov. 2011)

- **No BBU observed during initial beam studies (or subsequent beam operations)**
- Results consistent with design predictions, BBU threshold >5mA
- Large BBU threshold extrapolated with nominal 180μA beam to Hall-C.
- Low frequency TM111 modes of most concern, but well within threshold
- C100 HOM survey and analysis process validated

C100 Timeline

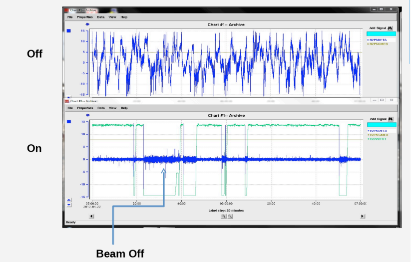


- Dec & Jan worked on Master Oscillator/Digital control issues (no archived data, C100s off during beam delivery for physics)
- By the end of Jan. routine physics operations with C100s operating
- Jan. → April, Data collected, control loops optimized, fault recovery procedures improved.
- Continuous LLRF controls improvement leading up to April 29 gradient push.

C100 data

C. Hovater & C100 team

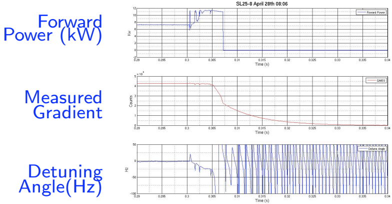
Cavity Detuning Angle: PZT Off vs. On



C100 Faults 2/2- 4/30

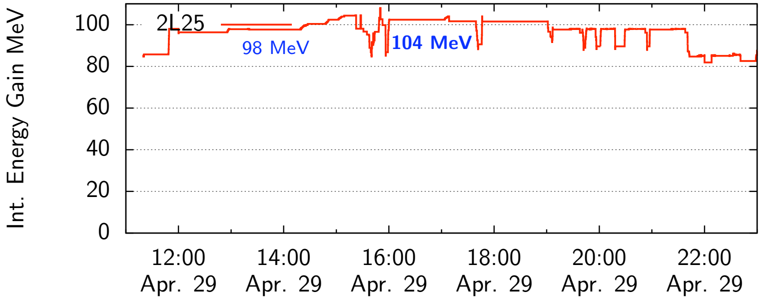
Time Period	Number of Trips	Total Cavitilies	Recovery Time	Average Recovery Time	Notes
2/5 to 3/20	58	410	34.7	0.598	HPA, Beam Vac Issues Dominate
3/21 to 3/26	17	115	7.24	0.426	Beam Line Vacuum Issues Solved
3/27 to 4/3	8	34	1.72	0.215	New firmware for SEL-GDR Transistion
4/4 to 4/9	9	10	0.92	0.115	Reduced number of Cavities at 12 GeV Gradients
4/10 to 4/16	6	12	0.6	0.1	One DC overload pushed the cavity total high
4/17 to 4/23	3	0	0.19	0.095	25-8 Body current (clamp adjusted)
4/23 to 4/30	22	90	6.94	0.315	Does not include 24 hour run

SL25-8 Fault Signature



- Piezo tuners on 2L25 functioning by April
- Fault/trip rate diminishing
- Fault recovery time improving
- Ready for the Gradient Push!

Gradient Push: April 29



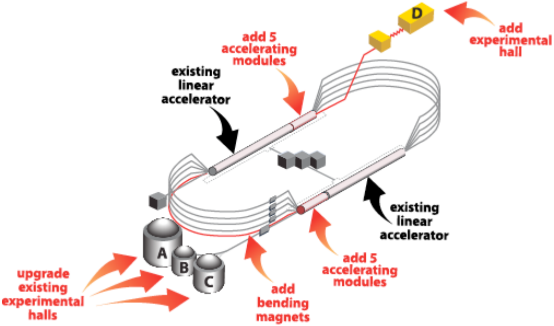
- C100 beam current 465μA (12GeV spec.): Hall-C receiving 3rd-pass beam while g2p/Gep occupies 1st- pass.
- 2L25-cavity-7 gradient limited to 9MV due to window heating.

>98MeV operation, fully beam loaded for hours!!
Max Energy Gain reached: 104MeV
Physics Beam In Use: 50% during this 24h test.

FY12 CEBAF Beam Delivery Summary

- Three hall experimental program successfully executed, one week remaining to end of 6GeV operations.
  - Hall-A: Major beamline modifications, commissioning and operations for g2p/Gep in Hall-A.
  - Hall-B: sub-nA beam for HD-ICE electron operation
  - Hall-C: Parity Quality beam for QWeak
- Successful beam restoration from 6MSD, resumption of physics on schedule.
  - CEBAF Accelerator Reliability and Availability for Physics presently meets or exceeds the FY12 goal.
- Successfully delivered physics quality beam with two C100 cryomodules operational from Feb $\rightarrow$ May
- Successfully operated C100 cryomodule at 104MeV integrated gradient with 465μA of beam current. No evidence of BBU observed.
- New Injector Beamline commissioned for $\overrightarrow{e}^{+}$ production experiment, see talk by Joe Grames.

1. CEBAF Operations Overview
2. CEBAF Operations Metrics and Performance
3. FY12 CEBAF Beam Delivery Highlights
4. 12GeV
   - 12GeV Commissioning Overview
   - Steps Towards 12GeV
   - 12GeV CEBAF Operations: The Initial Years
5. Summary



Commissioning Planning

Accelerator Commissioning Goals

1. Achieve 12GeV CD4 project goals
2. Establish physics quality beam
3. Establish the Machine Model for basis of 12GeV CEBAF operations
4. Develop tools and procedures for routine 12GeV CEBAF operations

- Commissioning plan interleaves NP and 12GeV project funded weeks of operation.
- Assumes hardware has been thoroughly tested and checked out before resumption of beam delivery.
- Thorough review of 4GeV commissioning documents, procedures and initial years of CEBAF operations is used to guide the planning process and time estimates.
- The commissioning plan will be undergoing detailed review and updates during the LSD.

12GeV CEBAF Commissioning Overview

Build upon the 6 GeV toolset, commissioning and operating experience.

New Hardware

- CHL-2
- New Injection chicane
- C100 cryomodules, digital LLRF controls
- Spreader, Recombiner and Transport sections
- RF separators for A,B,C extraction
- Arc10 and Hall-D transport line

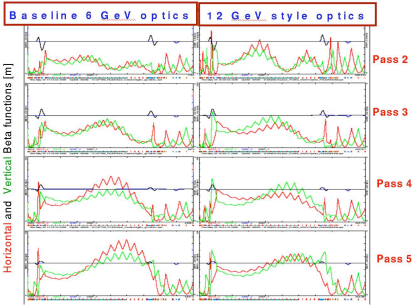
Beam Physics Issues

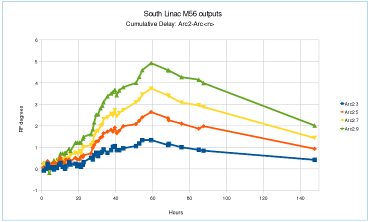
- Synchrotron radiation induced emittance and $\frac{dp}{p}$ growth
- Double Bend Achromat (DBA) Optics in the upper passes, $M_{56} \neq 0$ optics in the upper arcs.
- Globally optimized optics to reduce β (beamsize) on all passes, present optics is optimized for the first pass.

Steps Toward 12GeV

During 6GeV operations Beam Studies time has been used to validate 12GeV design, examples (other than C100) include:

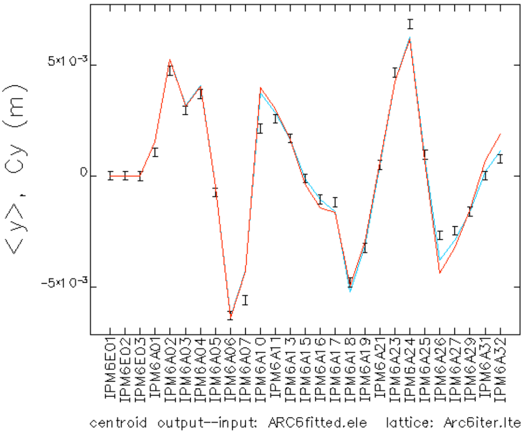
1. 12GeV Globally Optimized Optics: Loaded (Dec. 2005) and successfully delivered (for weeks) physics quality beam.
2. Augment Pathlength control via small adjustments in MO frequencies. This is needed to supplement the pathlength system capacity at the higher beam energies.
3. Induced a temperature change in the Arcs and measured the pathlength change, to estimate the impact of higher temperatures in the tunnel.





Modeling: Beam Based Measurements via LOCO

Y.Roblin



- Uses local orbit kicks at the start of each Arc
- Beam position monitors throughout the Arc
- Iterative fitting allows extraction of average dipole body gradient for that Arc dipole type.
- Arcs 4 & 6 data has been collected, analysis underway
- Remaining ARC data will be collected in the remaining days of 6GeV operation.

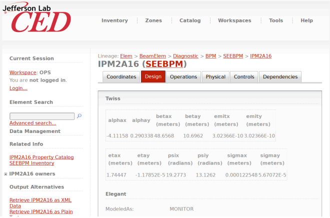
Measured dipole body gradients will be compared with bench measurements and entered into the 12GeV machine model.

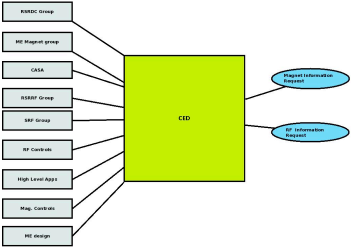
Infrastructure: CEBAF Element Database (CED)

A flexible, scalable database originally designed to capture the 12GeV model.

Status:

- Database schema design complete
- Elements are being populated: RF, Magnets, BPMs, Harps, . . .
- Machine Model parameters are intrinsic to each element that is on the beamline.





Existing Tools are being migrated to use CED as the sole source of information:

LEM	Linac Energy Manager, done and in use now
BEM	Beam Energy Monitor, done and in use now
Matching	Quad scan emittance, TWISS measurement with matching capability, done and in use now

Initial 12GeV Operations: Machine Development

12GeV CEBAF Commissioning Fall 2013 (6wks), Winter/Spring 2014 (13wks) and Fall 2014 (16wks).

Changes to Accelerator Operations during this period.

- 24/7 CASA support in the control room during this period
- Engineering/technical on-site support will be day/swing shift, owl as needed.

Weeks of operation will be used to:

1. Make the new hardware perform as per specification
2. Confront synchrotron radiation effects in the upper passes
3. Establish a scalable (50%→100%) model drivel machine for NP physics
4. Develop procedures and tools for (near) routine CEBAF Operations by end of 2015
5. Work towards exceeding reliability goals

Initial 12GeV Operations: Beams for Physics

First Scheduled Physics Operations: Winter/Spring of 2015

- Beam Quality on lower passes (1,2 and 3) should be near 6GeV CEBAF beam quality as synchrotron radiation effects are minimal on those passes.
  - Recommend initial beam for physics use lower passes
- Beam Quality on the passes 4,5,& 5.5 will always suffer synchrotron radiation effects. Larger emittances, $\frac{dp}{p}$ and beam sizes. The magnitude of this effect depends on the linac energy, central orbit control and envelop matching.

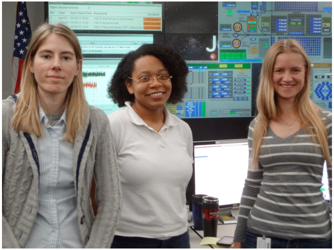
Proposed Initial CEBAF Reliability Goals:

	FY12	FY13	FY14	FY15	FY16	FY17	FY18
Weeks of Operation	26.5	0	24	35	35	35	35
Reliability Goal(%)	89	NA	50	60	70	75	80

CEBAF Reliability in 2005 was 85%, ten years after the start of Physics. The proposed reliability goals are based on a faster ramp since we are commissioning an Upgraded accelerator not a new accelerator.

12 GeV CEBAF OPS Summary

- In addition to completing the 6GeV program, work preparing for the 12GeV commissioning continues.
- C100 commissioning made significant progress in FY12
  - No BBU observed
  - Delivered parity quality beam for months with C100 operational
  - Fault rate and recovery times improved throughout the run
- 12GeV tool development has already started and in some cases are quite mature.
- Commissioning plan has been developed that merges 12GeV project and NP machine development.



CEBAF Operations first ever all women shift, March 30 2012. Crew Chief Amy Comer, Operators Brandi Cade and Anna Shabalina

Summary

FY12 has been a year of significant accomplishments for CEBAF Operations:

- Restoration after the 6MSD
- Major beamline modifications, commissioning and operations for g2p/Gep in Hall-A.
- sub-nA beam delivery over days for HD-ICE electron operation
- Parity Quality beam for QWeak; achieved the best parity quality beam ever for CEBAF
- CEBAF Accelerator Reliability and Availability for Physics presently meets or exceeds the FY12 goal.

Preparation for 12GeV continues and enthusiasm continues to build:

- Successfully delivered physics quality beam with two C100 cryomodules operational from Feb $\rightarrow$ May
- Successfully operated C100 cryomodule at 104MeV integrated gradient with 465μA of beam current. No evidence of BBU observed.