CEBAF 12GeV Commissioning: Status and Plans

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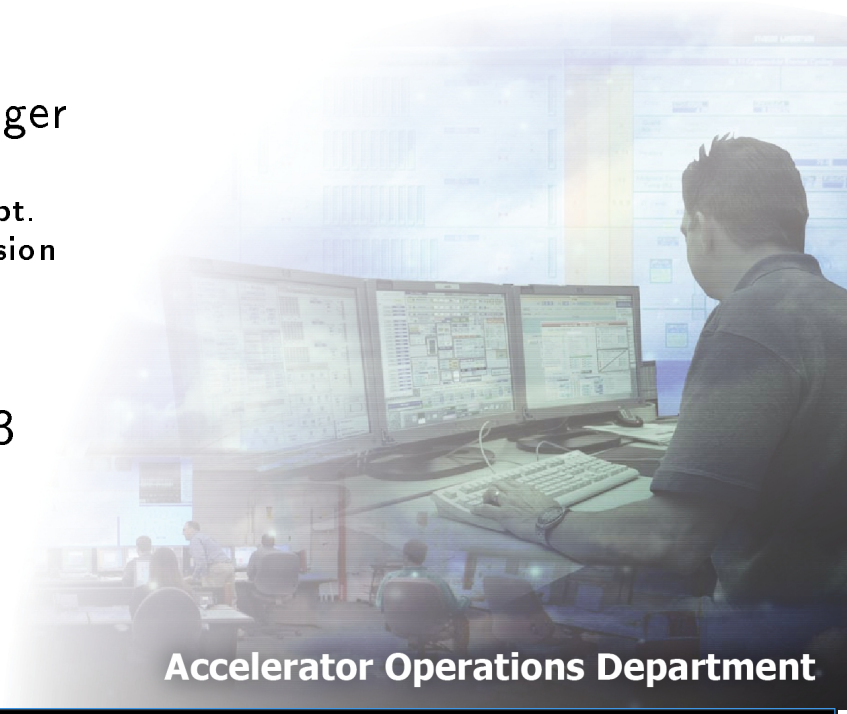
2014-06-03



Accelerator Operations Department

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Talk Outline

1. The Past
   - Timeline
   - Hot Check Out
   - Cryogenics
   - ACC-I & ACC-II Plan, Goals and Accomplishments
2. Lessons Learned
3. Remaining Activities
4. The Future
5. Summary

12GeV CEBAF Timeline: To Date

2009 12GeV Upgrade construction starts in **May** with ground breaking ceremony at the Hall-D site.

2011 First C100 installed in the 2L23 slot in CEBAF, **July**.

2012 C100 module successfully operated at design specifications: 108MeV of energy gain with 465μA of beam loading on **May-18**. (End of 6GeV Operations.)

2013 North and South Linac 2K LHe operations established, **Dec-09** for the first time with two CHL's plants connected to a "split CEBAF".

2013 12GeV CEBAF Beam Commissioning begins **Dec-13**.

2014 Beam successfully transported to the 2R dumplette with 2.2GeV/pass energy gain on **Feb-05**. Establishing RF capability to support 12GeV 5.5pass operation with greater than 50% availability.

2014 Injector achieves 12GeV design energy of 123MeV on **Mar-10**

2014 3-pass beam established to Hall-A **Mar-20**. Multi-pass capability established in the 12GeV era.

2014 **3-pass** CW beam with E$>$ 6GeV established to Hall-A on **Apr-01** and beam-target interactions recorded. First time beam transported to an end-station with energy that exceeds maximum energy set during the 6GeV CEBAF era.

2014 10.5GeV 5.5 pass beam established to Hall-D Tagger dump on **May-07**.

Hot Check Out: Process and Tool

System checkout and tracking at the **element** level. Previously (6GeV era) checkout was tracked at the system level.

Provides one-stop shopping to check the hardware status for all elements up to a specified beam termination.

Two levels of sign off, ✔checked and 👍ready.

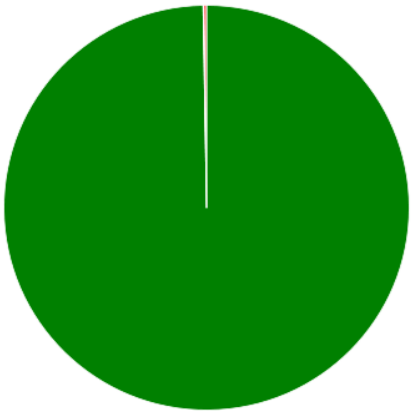
Component View (6533 elements):

Found 6,533 Components in Beam Destination "Beam to Hall D (5.5 pass)"

- CEBAF
  - Beam Dumps
  - Control System
  - Cryo
  - Diagnostics
  - Facilities
  - Gun/Laser
    - Gun
      - Gun HV
        - Gun 2 HV
          - Gun
          - SSG
        - Gun 3 HV
      - Gun Photocathode
    - Laser
  - Info Systems
  - Magnets
  - Operations
  - RF
  - Radiation Controls
  - Safety Systems
  - Vacuum

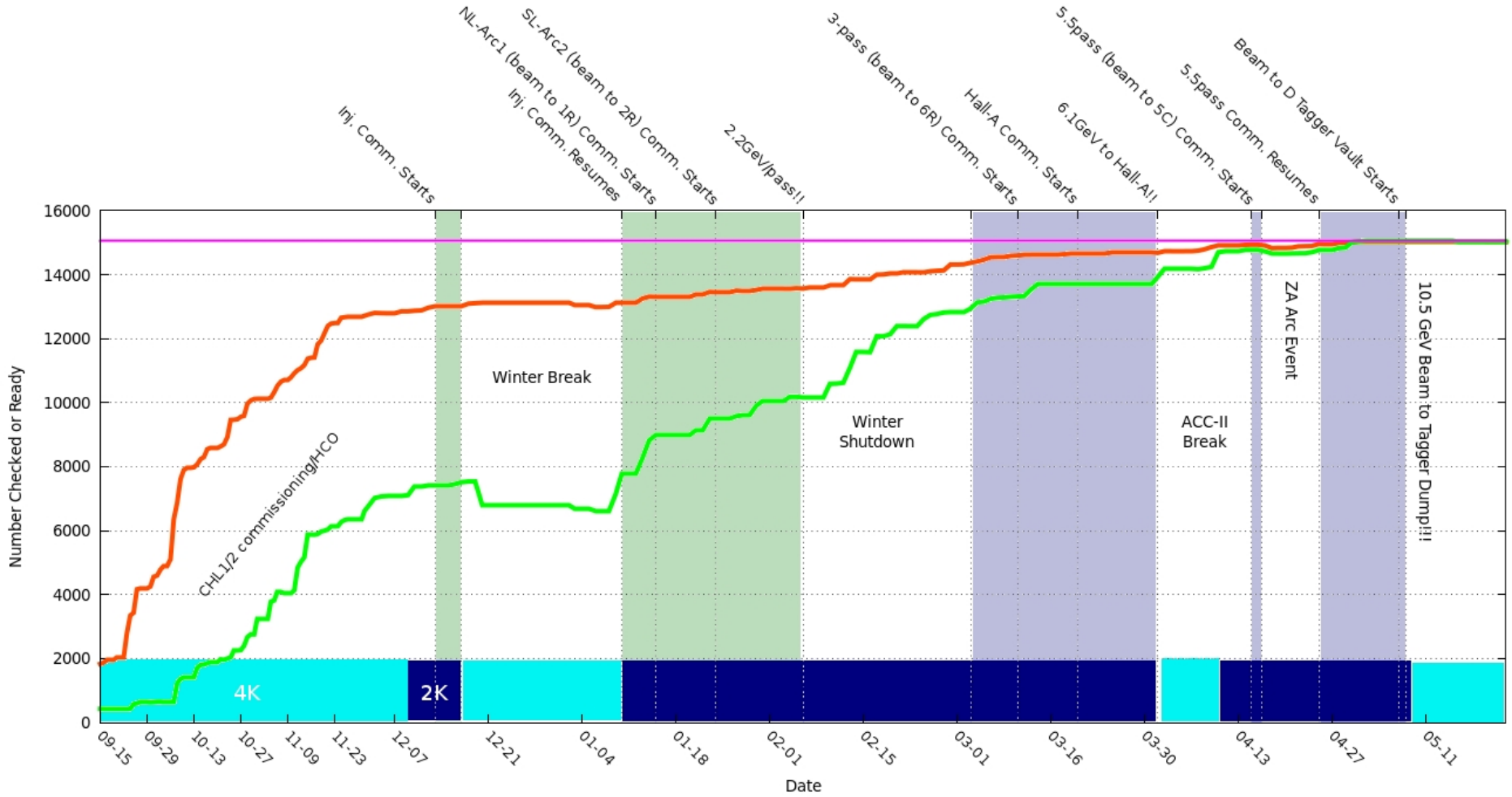
Sign-off View (15059 sign-offs):

Found 15,059 Signoffs in Beam Destination "Beam to Hall D (5.5 pass)" (59 Masked Components)



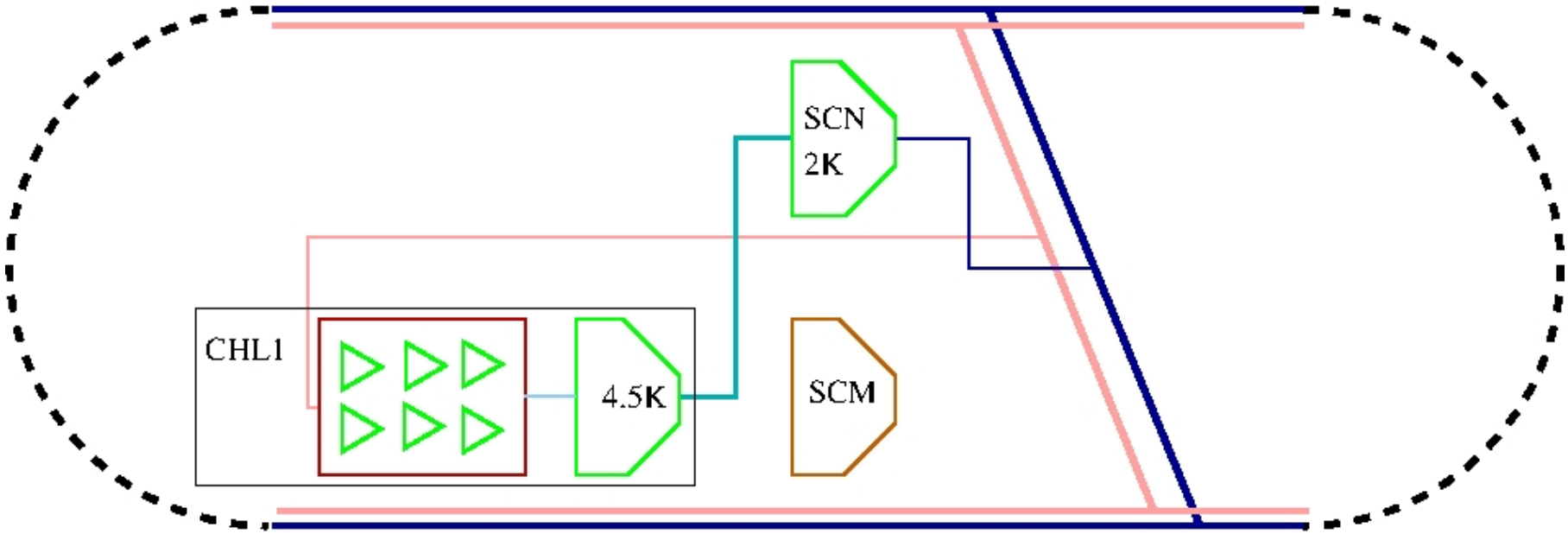
Ready
(~100%)

Hot Check Out and Commissioning Progress



Simultaneous Hot Check Out and Beam Commissioning activities.
Hardware systems barely ahead of the beam.
Very little time with both Linacs @2K for SRF activities due to CHL commissioning and budgetary reasons.

Cryogenic Configuration: 6 GeV era

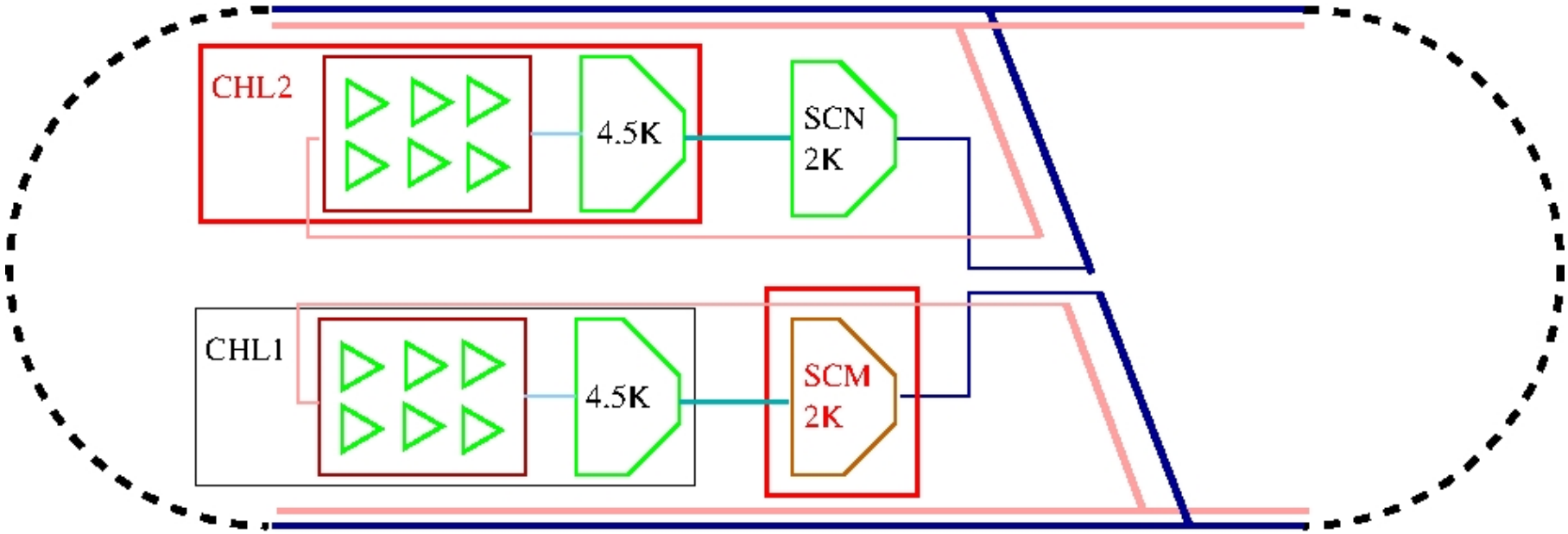


CHL1 Central Helium Liquifier, takes gaseous He and passes it through a series of compressors to make liquid Helium. Liquid accumulates in the 4.5K *coldbox*.

SCN 2K Coldbox. A series of compressors are used to lower the pressure and reduce the Helium temperature. **SCN** is the second 6GeV era coldbox, used since the early 2000s.

SCM original 4GeV CEBAF coldbox, decommissioned early on due to *issues*. Refurbished, but never commissioned or used as of Oct. 2013.

Cryogenic Configuration: 12 GeV era



CHL2 New Central Helium Liquifier

SCM Must be commissioned as if new.

Linacs Linacs are now separated with one CHL-SC pair tied to one Linac. Each Linac presents the equivalent cryogenic load as in the 6GeV era, but with half the Helium volume.

Both Linacs at 2K on separated CHL on Dec. 9th 2013

ACC-I & ACC-II Plan and Goals

Beam Operations

- 19 weeks of operations, divided into two run periods.
- Beam commissioning to start first week in Nov. and end first week of May.
  - Achieved 13weeks of beam operations

Plan and Goals

100% Establish 1-pass 2.2GeV tune-mode beam to 2R dumplet. CD4A Accelerator Project deliverable. (6wks)

100% Establish 3-pass tune-mode beam to Hall-A. Level II 12GeV Project Milestone. (2wks)

100% Hall-A detector checkout. (1wk)

25% Characterize all new magnetic elements up to 3rd pass for 50% to 100% of nominal 12GeV energy. Needed to establish operational procedures required for efficient out-years CEBAF operations. (4wks)

100% Establish 5.5 pass beam in CEBAF, preparing for beam into Hall-D in Fall2015 (CD4B Deliverable, Level-II milestone). (3wks)

20% 4/5/5.5 pass Magnet/Optics characterization. (2wks)

100% Establish first beam to Hall-D tagger vault, Level III 12GeV Project Milestone (**originally planned for Fall2014**). (1wk)

Lessons Learned

1. The Past
2. Lessons Learned
   - The Positives
   - Energy Reach
   - Tunnel Temperature and Power Usage
   - Robust setup, clean transport, CW operations
3. Remaining Activities
4. The Future
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Lessons Learned: Positive

Hot Check Out without Beam

- Very little, negligible, beam time utilized correcting/fixing hardware.
  - Time was spent up-front getting the hardware ready, not sitting in the control room working on creative solutions to unnecessary hardware issues.
  - Handful of polarity and magnetic field map issues, found with beam
  - Some diagnostics, (wire scanners, viewers) required TLC.
  - No magnet shorts or other subtle issues found with beam, it was all "made right" before beam delivery.

Planning and Organization

- Beam Commissioning plan, comprehensive yet flexible to mesh with the dynamic schedule.
- Operations and Accelerator Scientists training robust, it was as if the LSD never happened.
- New concepts/tools required for 12GeV ready for beam operations.

Lessons Learned, New hardware/Tools: Positive

Master Oscillator Frequency shift for pathlength control

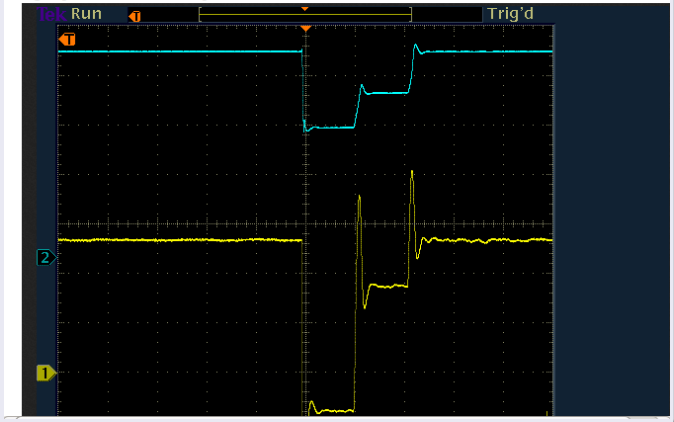
- Planned for as an alternate means of pathlength control in the 12GeV era.
- Need driven due to the limited range of non-upgraded *dog-leg* system
- Frequency adjustment required immediately, Mar-15, due to a ≈2cm shrinkage of CEBAF during the down.
- MO (499MHz) was adjusted by 7.5kHz to account for the smaller CEBAF.

References: 3272007 - M55/M56 Hot Checkout
Backlinks: Follow-up Re: Pathlength

Reacquainting myself with pathlength scope and controls. Quoted precision is 10mV/deg. Present difference between pass-2 and pass-1 is over 400mV or 40degrees!!! Or 2.2cm!!!

We need a rubber band!

Fig. 1 [03/15/2014 09:42:54]



Software Tools: database driven control system

- CEBAF Element Database (CED) defines the CEBAF configuration.
- Used as the starting point for many new tools:
  - Hot Check Out Tool
  - EPICS Control screens are now generated on-the-fly. Change CEBAF configuration → update CED → screens automatically updated.
  - Optics model and tools that rely on the model.
  - More to come, goal is for the entire control system from IOC/EPICS configuration to control screens and High Level applications to be driven by CED.

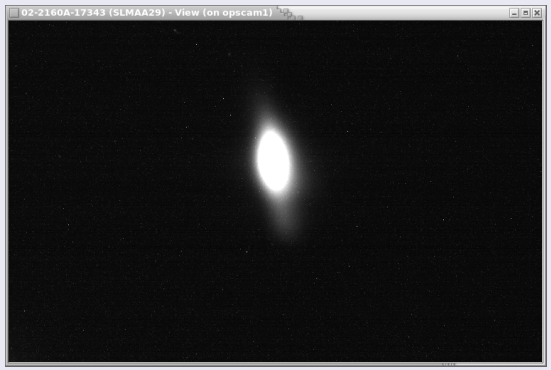
Lessons Learned, New hardware/Tools: Positive

New Beam Position Monitors (BPM) for Hall-D

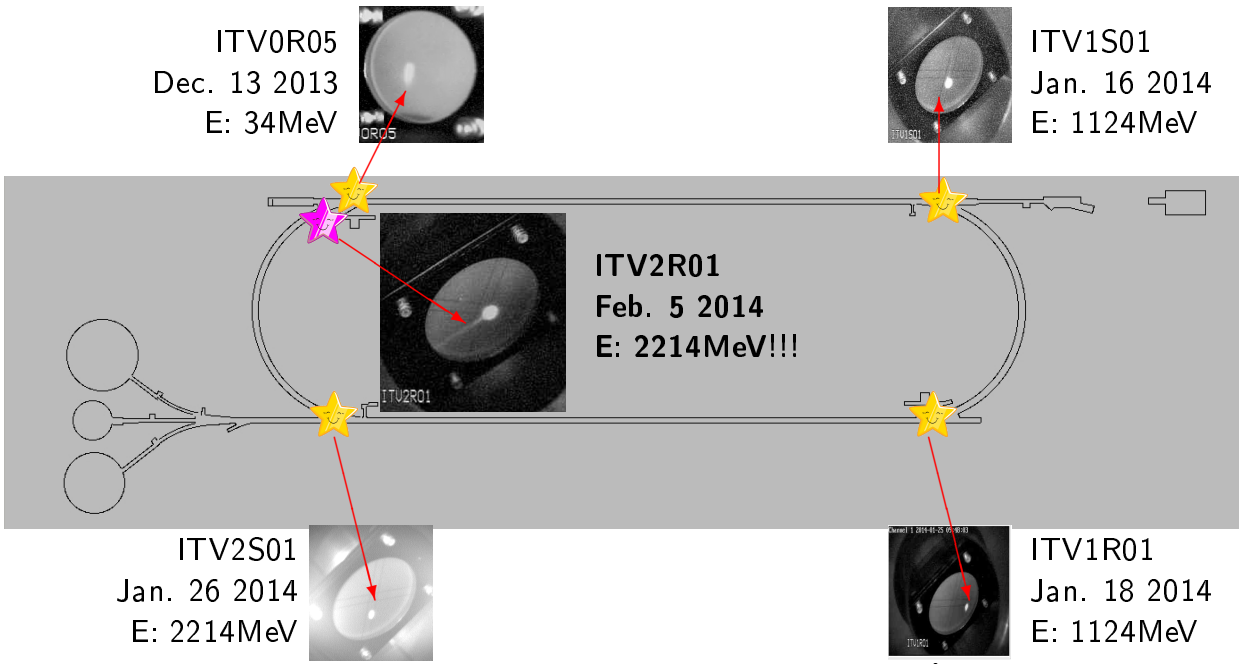
- New stripline design, robust construction technique (no electron beam welding as per the old design).
- New electronics, old design deemed obsolete.
- Worked "out of the box"!!! All timing issues had been roughed in correctly.

New Synchrotron Light Monitors (SLM) in ArcA and 5C line

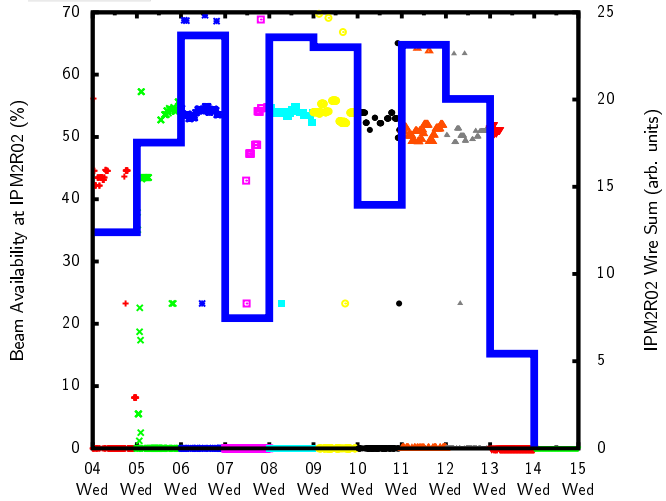
- Copious amount of synchrotron light generated in the upper passes at these high energies
- SLM used to continuously monitor beam size, optics match, energy jitter and energy spread.
- New digital imaging and network will allow for improved real-time image analysis.



Energy Reach: One-pass beam 2.2GeV/pass!!!



- Tune-mode beam, 8h dwell
- Availability measured by presence of beam at BPM just upstream of 2R dumplet.
- Peak availability ≈ 65%, average for 8h period availability >50%.



RF gradients Feb. 5 2.2GeV/pass

RF and ARC1:p/ARC2:p status at: 2014-02-05 09:05

Linac	Type	Ncav	<GMES> (MV)	$GMES_{RMS}$ (MV)	Min-Max (MV)	Egain (MeV)
Inj	C20	10	6.72	0.81	5.86-8.63	33.6
NL	C20	119	7.19	1.64	2.97-11.71	427.6
NL	C50	40	11.03	1.49	6.34-13.45	220.7
NL	C100	38	17.59	2.40	9.80-20.77	467.9
SL	C20	108	7.05	1.40	4.78-10.56	380.7
SL	C50	47	10.06	1.90	6.41-12.36	236.4
SL	C100	40	16.66	2.75	9.70-20.00	466.4

Linac	Egain (MeV)	Σ_E (MeV)	Spectrometer	Momentum (MeV/c)
Injector	33.58	33.58	INJ:p	33.41
North	1116.15	1149.73	Arc1:p	1124.03
South	1083.44	2233.17	Arc2:p	2214.51

Injector Beam Current(IBC0R08): 8.88

Energy Reach Status and Plan

Beam operation to date has provided data on establishing the present energy reach capability of CEBAF. Present energy reach falls short of 12GeV using 6GeV era definitions of "physics quality" beam.

There are a few knobs:

- Permitted downtime for beam to be called "physics quality"
  - 6GeV era requirement was <15trips/h or about a 12.5% downtime.
- Improve the SRF gradient.

Modest improvements to the SRF gradient can be achieved through several approaches:

1. Improve C20 trip models, maximize gradient/minimize trip rate.
   - Due to thermal cycle during LSD all C20 trip models must be determined.
2. C50 program, one C50 refurbishment is in progress. (Net energy gain is about 25MeV per C50/C20 swap)
3. Build more C100s. (Net energy gain is about 75MeV per C100/C20 swap)
4. Helium processing (or plasma processing).

I'm going to reach for both knobs.

RF trip rate for "physics": Strawman

Trips: Any SRF/RF related downtime $\leq$ 5min in duration

Run Period	Dates	Max. 5.5pass Energy	Trip Downtime Goal (% - min/hr)
ACC-III	Fall2014	11 GeV	<20% <12
ACC-IV	Spring2015	11 GeV	<17% <10
Phy-I	Fall2015	12 GeV	<20% <12
Phy-II	Spring2016	12 GeV	<17% <10
Phy-III	Fall2016	12 GeV	<13% <8
Phy-IV	Spring2017	12 GeV	<12% <7
Phy-V	Fall2017	12 GeV	<10% <6
Phy-VI	Spring2018	12 GeV	<10% <6
Ultimate		12 GeV	<5% <3

Non-trip downtime

Run Period	Dates	Max. 5.5pass Energy	Long duration Downtime Goal (%)
ACC-III/Acc-IV	Fall2014-Spring2015	11 GeV	<5%
Phy-I-IV	Fall2016-Spring2017	12 GeV	<4%
Phy-V-VI	Fall2017-Spring2018	12 GeV	<3%

Proposed path for energy reach and trip rate

North Linac

Date	Gradient Gap (act-req) (MeV)	Action	Expected Change (MeV)	Gap post action (act-req) (MeV)
2014-04-02	-60	—	0	-60
2014-10-01	-60	C20 loss (0.5yr,120cav)	-4	-64
2014-10-01	-64	C50 loss (0.5yr,40cav)	-4	-68
2015-08-01	-68	Better Trip models	24	-44
2015-08-01	-44	C20 loss (0.83yr,120cav)	-7	-51
2015-08-01	-51	C50 loss (0.83yr,40cav)	-6	-57
2015-08-01	-57	C50-12 installed	25	-32
2015-08-01	-32	C20 HeProc 7-modules	34	2
2015-08-01	2	C50 HeProc 3-modules	23	25
	25		0	25

He Processing Amount of He processing in the table is the **miminmum** required to achieve the energy reach/trip goals presented.

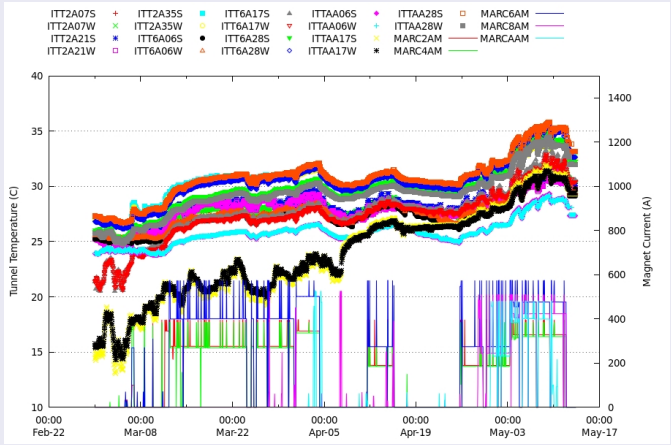
Summer2014 Linacs @4K for budgetary reasons, Helium processing @4K being explored.

Summer2015 Linacs configuration unknown, sufficient time @2K will be required to assess SRF state after He processing @2K or @4K.

Tunnel Temperature and Power Usage

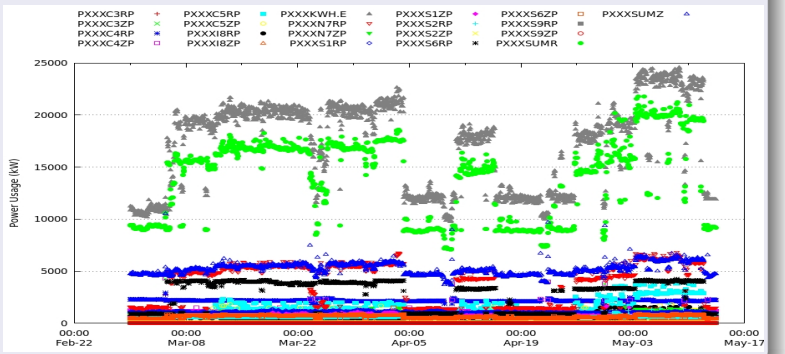
Tunnel Temperature

- Rise at end of plot due to 10.5GeV 5.5pass configuration during the last week of operation.
  - Temperature did not reach equilibrium at this configuration, crude model estimated max of 46C at this energy.
  - 12GeV would be about 30% more power in the magnets (more heat).
- Tunnel electronics rated up to 45C.



Power Usage

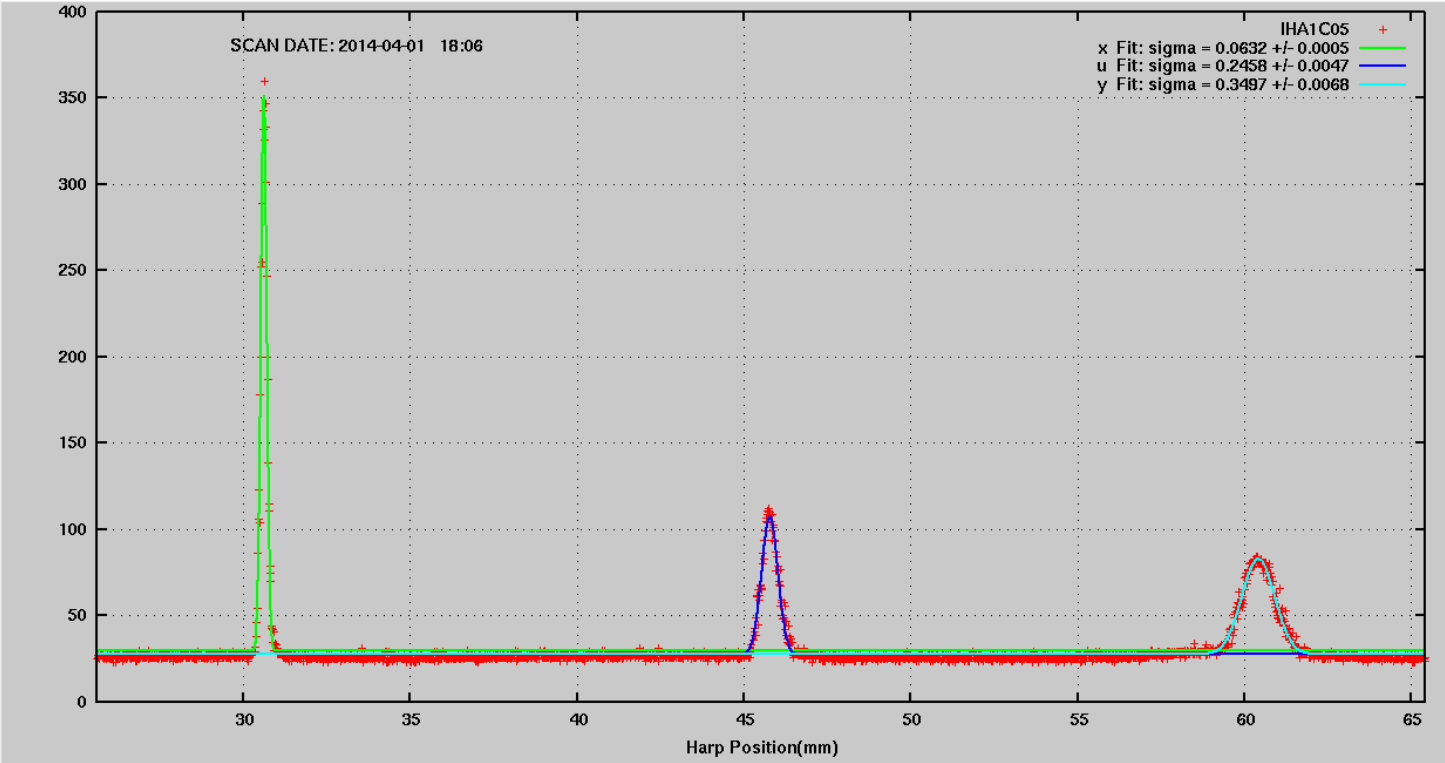
- Peak demand approaching 25MW.
  - 12GeV estimated power demand is ≈28MW.
  - 6GeV era max demand ≈ 18MW.



Beam Optics

- Some data collected at a few energies, analysis in progress.
- Dipole focusing terms (body gradients) need to be well understood to achieve deterministic energy scaling.
- Relied on the nominal 6GeV era process to work through the energy changes.

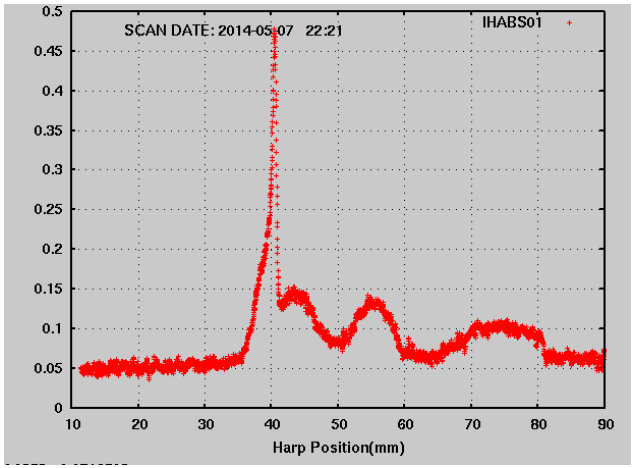
Beam at start of Hall-A line during 6.11GeV setup (Apr-01):



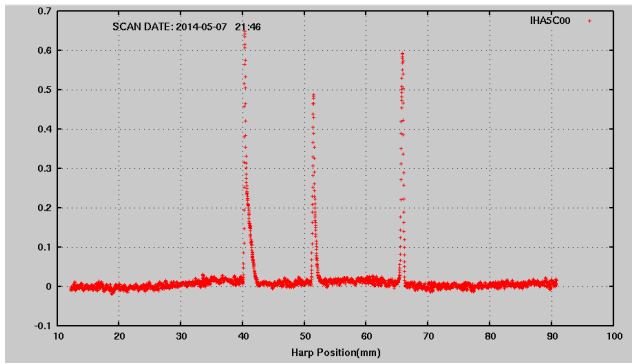
Beam Optics: More profiles, Hall-D

The beam setup to Hall-D was not very good. Beam profiles asymmetric and tails/background presumably from scrapping.

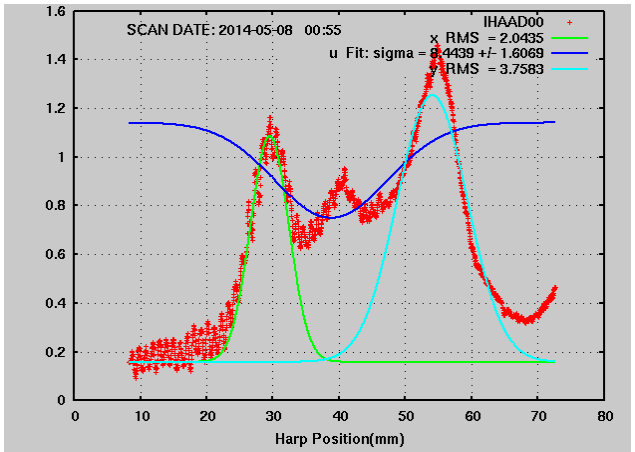
IHABS01: Between the North Linac and start of 5C line, BS: B spreader, after the B (11th) linac.



IHA5C00: Start of the Hall-D transport line (5C).



IHAAD00: In front of the Tagger Vault Dump.



Establishing tune-mode beam to the Tagger Vault verified the hardware installation. Time is needed with the beam to establish a quality extraction and transport. Fall2014!!!!

Remaining Activities

1. The Past
2. Lessons Learned
3. Remaining Activities
   - Remaining Installation
   - Remaining Beam Commissioning Activities
4. The Future
5. Summary

Remaining Installation: Summer2014

RF Separation: 1-4pass

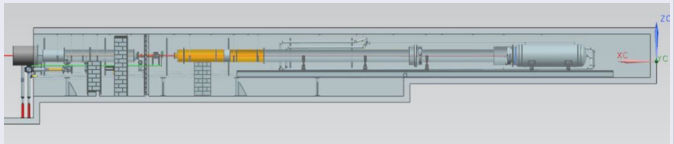
- pass1-4 cavities installed, under vacuum.
- Complete the upgrade of the RF power & controls for 12GeV era beam energies.
- 5-pass separator cavities late2014/early2015, no 5-pass separation until Spring2015.

Dogleg Upgrade

- Upgrade four out of 27 magnets Summer2014.
- Upgrade all power supplies early 2015.
- Restore pathlength adjustment range to near 6GeV range.

High Power Dump Maintenance (Hall-A)

- Improve reliability
- Improve diagnostics



Beam Commissioning Activities: Fall2014

- Beam Switch Yard (BSY) Dump line and BSY dump
  - Provides a CW dump for establishing quality CW beam independent of the Halls.
- Transport Lines:2T,4T,8T,AT
  - Only 3-pass (6T) has been commissioned.
- RF Separation:1-4 pass
  - Multi-beam capability, improved CEBAF efficiency with simultaneous users/programs.
- Energy Scaling, beam model, operational procedures
  - Work towards beam setups that support physics beams (CW).
- CW beam transport.
- 5.5 pass setup with detailed quantification of the synchrotron radiation effects, emittance growth and beam matching.
  - What was the cause of the rough 10.5GeV beam transport to Hall-D?

The Future

1. The Past
2. Lessons Learned
3. Remaining Activities
4. The Future
   - Fall2014 Operations
   - Spring2015 Operations
   - Fall2015/Spring2016 Operations
5. Summary

Fall2014 Plan: 13 wks, $E_{5.5pass} \leq 11$ GeV

- Beam Recovery and establish CW beam to Tagger Vault (2wks)
- Deliver beam for Hall-D detector checkout. CD4B-III Project deliverable. (3wks)
- Establish multiple beam capability in 12GeV CEBAF. Commission 2T,4T,8T,AT transfer lines and pass 1-4 RF separators. Establish multi-hall user program. (4wks)
- Characterize upper pass magnetic elements. Needed to establish operational procedures required for efficient out-years CEBAF operations. (3wks)
- Characterize emittance growth and beam properties in the upper Arc during the first 5.5pass 12GeV beam operations. (1wks)
- With multi-beam capability established; parasitic support of early physics in Hall-A and beam line commissioning in Hall-B. (0 wks)

Winter2015 Shutdown Highlights

- 750MHz separator cavity installation.
- Dog-leg power supply installation.
- He processing SRF cavities.

Spring2015 Plan: 7 wks, $E_{5.5pass} \leq 11$ GeV

- Beam Recovery (1wks)
- Commission new 750MHz horizontal separators and 250MHz laser driver, enables Hall-D + A/B/C on 5-pass (4wks)
- Contingency (2wks)
- Beam for Physics contingent on funding (Nwks, $0 \leq N \leq 10$)

Summer2015 Shutdown Highlights

- Utilities Infrastructure Modernization (UIM) Project: lab wide upgrade to power distribution, cooling towers, network, ...
- SRF Gradient recovery: He processing or Plasma processing.
- C50-12 installation.
- Install tunnel air-conditioning

Fall2015/Spring2016 (FY16) Plan: 20 wks

Highly dependent of FY15 and FY16 budget scenarios.

Fall2015: 7 weeks, $E_{5.5pass} \leq 12$ GeV

- Start of beam operations Nov-02 to allow for UIM work and SRF gradient recovery in Sep/Oct.
- Beam Recovery (1wks)
- 12GeV Optics and procedure finalization, energy scaling and establishing a firm basis for 12GeV CEBAF operations for Physics (6wks)

Spring2016: 13 weeks, $E_{5.5pass} \leq 12$ GeV

- Beam Recovery (1wks)
- Establish beams to B&C in preparation for B&C detector checkout. (4wks)
- Deliver beam in support of Hall-B & C detector checkout. CD4B-III Project deliverable. (3wks)
- Establish Physics quality beam to Hall-D (3wks)
- Support Engineering run in Hall-D/Physics in Hall-A (2wks)
- Additional weeks of beam for Physics contingent on funding (Nwks, $0 \leq N \leq 10$)

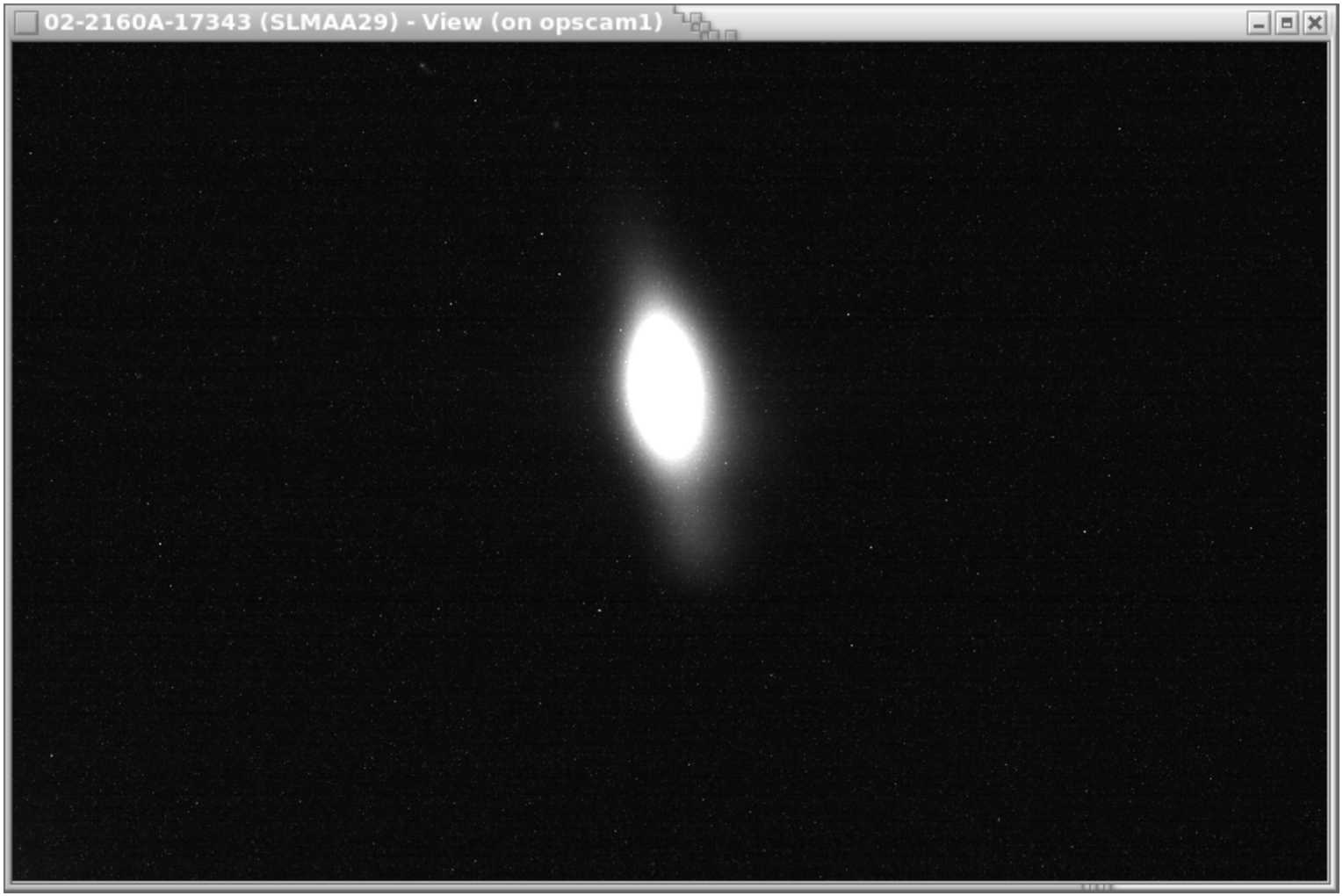
Summary of the Beginning

12GeV CEBAF is a Reality!!!!

- Tremendous progress in a relatively small amount of time with beam in the machine.
- Beam has traversed:
  1. The injector, including the **new R100 cryomodule and injection chi-cane**.
  2. Every Arc including the new **ArcA (the 10th Arc)** and the associated **spreaders and recombiners**.
  3. North Linac **6-times**, South Linac 5-times, all **ten C100 cryomodules commissioned operating**
  4. **6T** & Hall-A line, polarized CW beam to Hall-A dump.
  5. **BS & 5C line, the Tagger Vault, tune-mode beam to the Hall-D dump**
- No show stoppers encountered.
- First steps have been ascended, many more to go!
- Process in place to deal with the unknown unknowns.
- Issues are being identified and actively worked.

12GeV CEBAF is a Reality!!!!

Thank you for your time and attention



Beam image produced by the synchrotron light emitted in ArcA, $E_{beam} = 9.5$ GeV, tune-mode beam.

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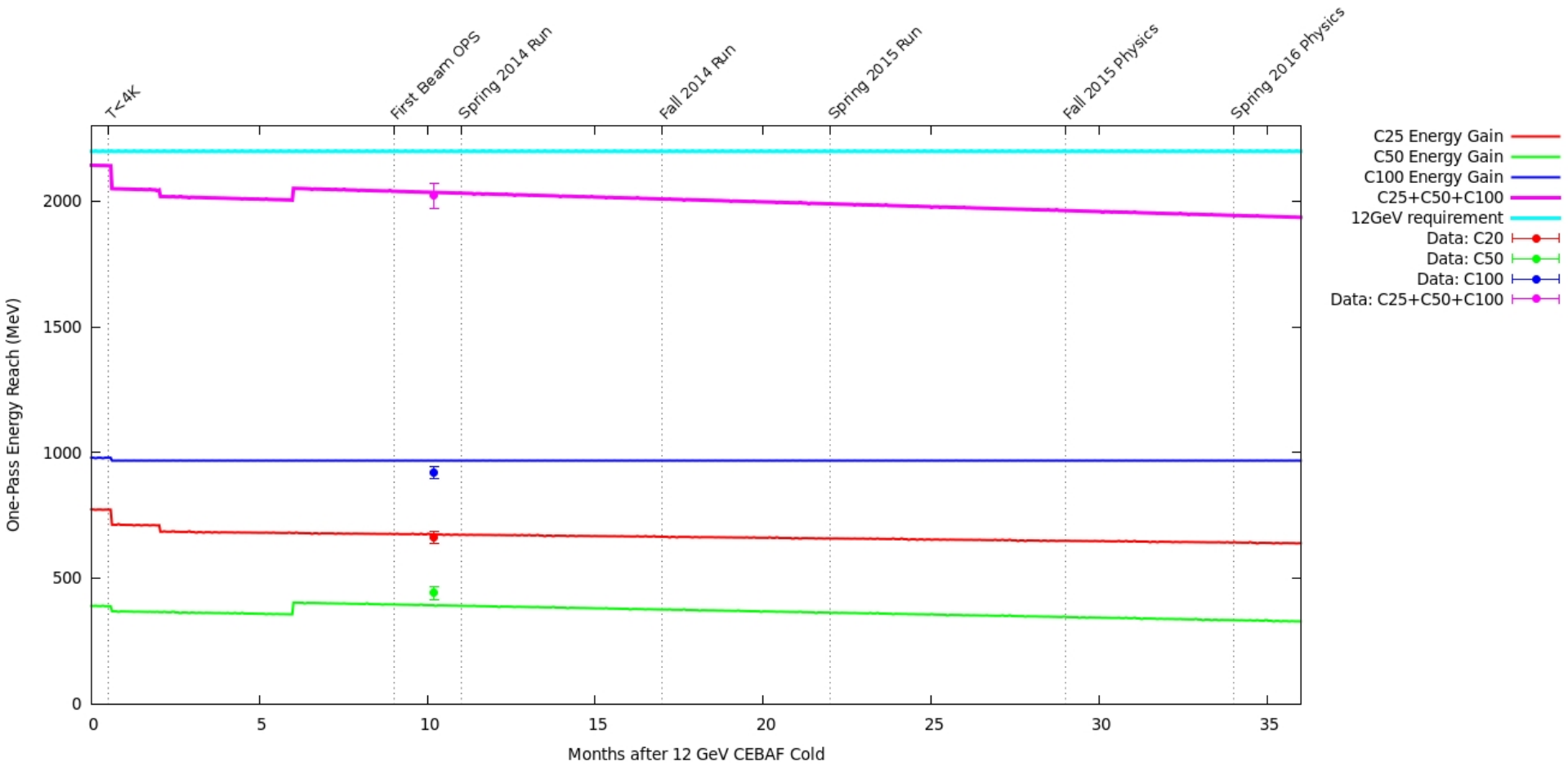
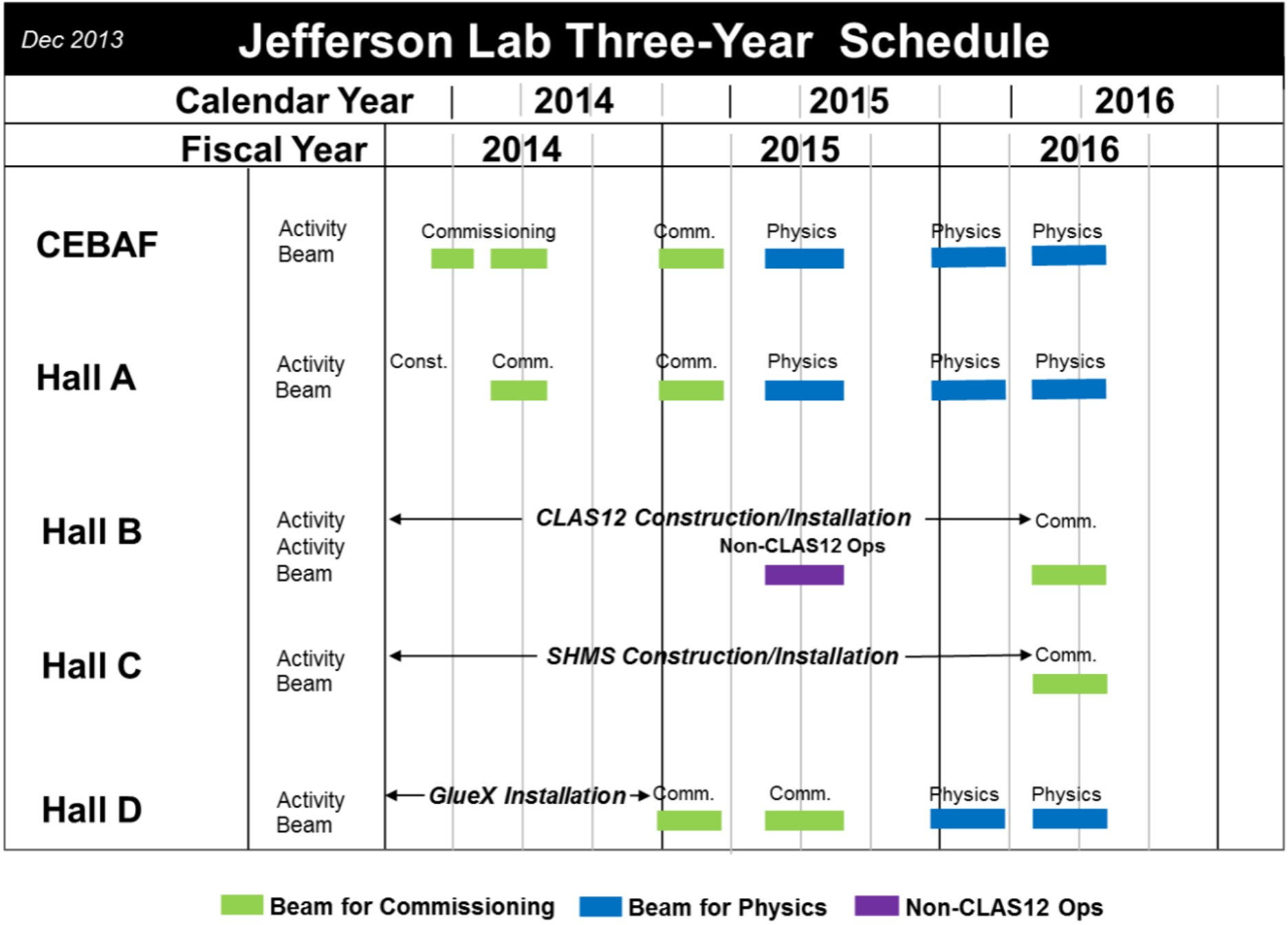
2014 10.5GeV 5.5 pass beam established to Hall-D Tagger dump on **May-07**.

2014 First RF separated beams in 12GeV era on **Nov-??**. Establishes multi-beam capability in the 12GeV era.

Towards CEBAF support of 12GeV Physics




Dec 2013
Jefferson Lab Three-Year Schedule
Calendar Year
2014
2015
2016
Fiscal Year
2014
2015
2016
CEBAF
Activity
Beam
Commissioning
Comm.
Physics
Physics
Physics
Hall A
Activity
Beam
Const.
Comm.
Comm.
Physics
Physics
Physics
Hall B
Activity
Activity
Beam
CLAS12 Construction/Installation
Comm.
Non-CLAS12 Ops
Hall C
Activity
Beam
SHMS Construction/Installation
Comm.
Hall D
Activity
Beam
GlueX Installation
Comm.
Comm.
Physics
Physics
Beam for Commissioning
Beam for Physics
Non-CLAS12 Ops

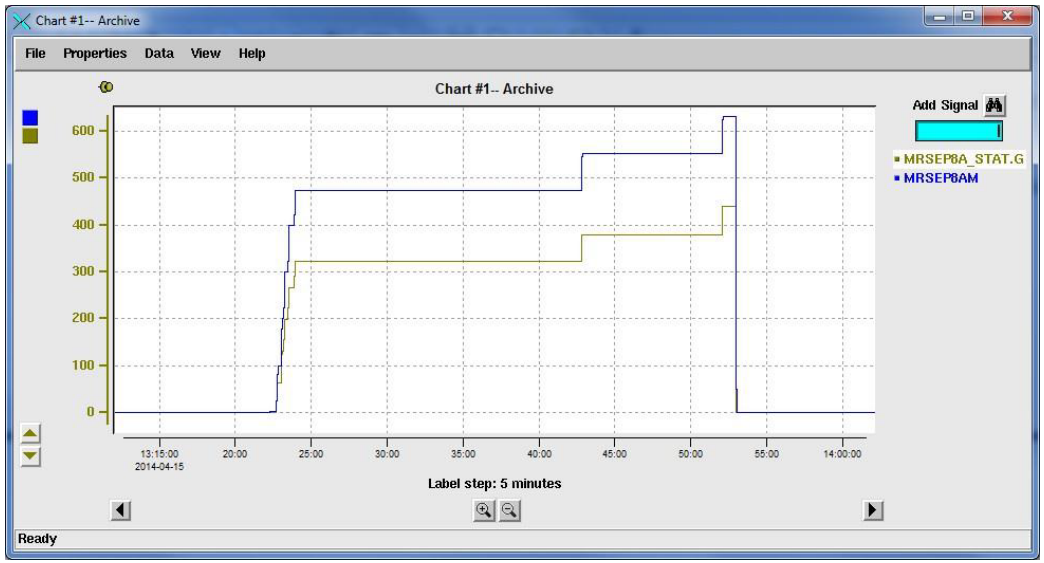
Proposed path for energy reach and trip rate

South Linac

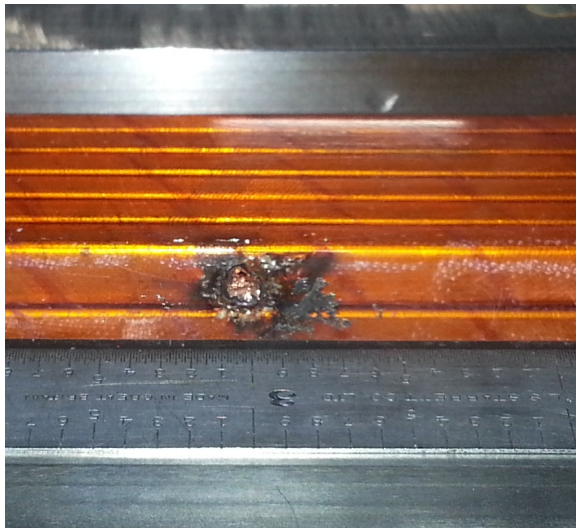
Date	Gradient Gap (act-req) (MeV)	Action	Expected Change (MeV)	Gap post action (act-req) (MeV)
2014-04-02	-70	—	0	-70
2014-10-01	-70	C20 loss (0.5yr,112cav)	-4	-74
2014-10-01	-74	C50 loss (0.5yr,48cav)	-4	-78
2015-08-01	-78	Better Trip models	24	-54
2015-08-01	-54	C100 Controls	23	-31
2015-08-01	-31	C20 loss (0.83yr,112cav)	-7	-38
2015-08-01	-38	C50 loss (0.83yr,48cav)	-7	-45
2015-08-01	-45	C20 HeProc 7-modules	34	-11
2015-08-01	-11	C50 HeProc 3-modules	23	12
	12	C100 HeProc ?modules	23	35

South Linac has the first two C100 modules, these modules are "special". SRF/LLRF is analyzing their performance to date and developing plans to improve their performance through better controls and/or Helium processing.

- @13:53 on April 15 during beam operations there was a loss of vacuum in the second recombiner.
- Loss of vacuum was coincident with a power supply ground fault in the MZAAR03 magnet. Beam was not being transport through MZAAR03 at the time of ground fault and vacuum loss.



ZA Event

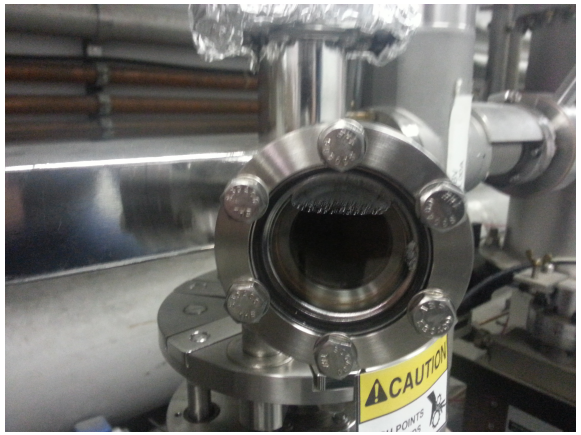


Coil arcing to adjacent vacuum chamber, punches hole in magnet coil, magnet coil spews LCW.

+

Arc drills hole in vacuum chamber, vacuum sucks up LCW.

=



LCW level on an optical viewport.

- What caused the ARC? Magnet had passed full tests in the magnet measurement facility.
- Why was the ARC so persistent? Why didn't the power supply shut off before the coil and vacuum chamber had been damaged?

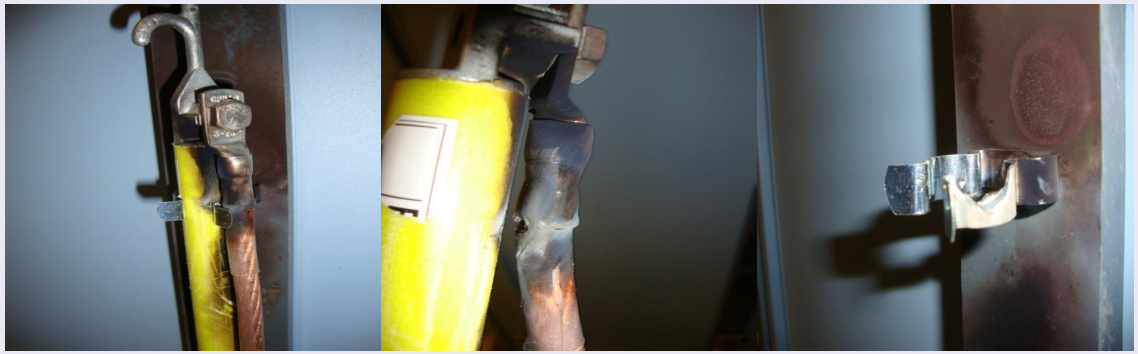
ZA Event: Root and Contributing Causes

Shrapnel between coil and chamber, and coil motion when magnet energized

Well, there's one kind of favor I'll ask of you
Well, there's one kind of favor I'll ask of you
There's just one kind of favor I'll ask of you
You can see that my *tunnel* is kept clean

Power Supply discharge stick inappropriately configured

- Alternate ground path, compromised ground fault detector.
- All new box power supplies have been modified to correct this problem.



ZA Event: Recovery

- Investigation and Repair teams formed within 24h of event.
- Had one spare coil on hand. No spare vacuum chamber.
- Considered using identical ZA in transport line as replacement, but opted for removal and repair.
- Magnet repair and beamline vacuum restoration in parallel, nine days.
- Vacuum chamber repaired by a well conceived and executed patch.
- Commission Advisory Board reviewed preliminary findings from the investigation team and recommended resumption of beam commissioning on Apr-24.

This event consumed the one spare ZA left coil. No spare vacuum chambers are on hand. Lack of spares is a concern going forward. Risk of a major (months) downtime have increased.