Commissioning and Operation of 12 GeV CEBAF

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JLAB Accelerator Operations

Outline

- **Introduction**
  - Jefferson Lab
  - CEBAF
- **12 GeV Upgrade**
  - Gradient
  - Cryogenics
  - Magnets
- **Beam Commissioning**
  - Progress to date
  - Future plans

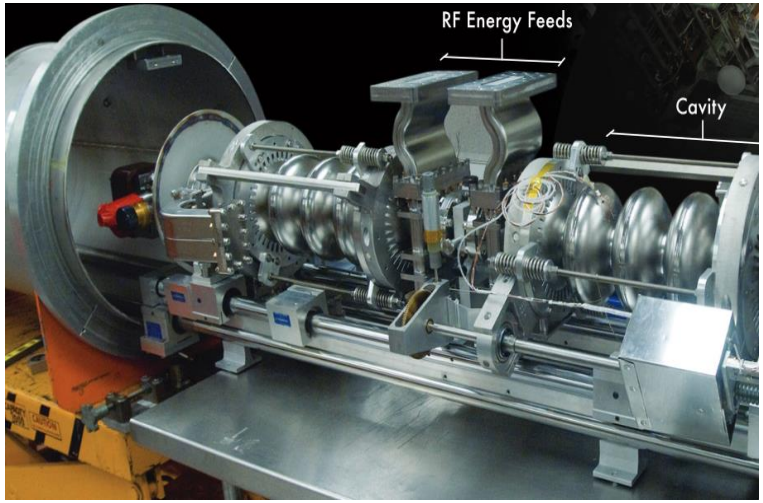
Jefferson Lab

JLAB Research:

- Experimental, computational and theoretical nuclear physics
- Accelerator Science, SRF technologies and FEL
- Radiation detectors and medical imaging
- Cryogenic technology

Continuous **E**lectron **B**eam **A**ccelerator **F**acility (**CEBAF**)

SRF



Cryogenics

CEBAF Timeline

- 1985 CEBAF design changed to use SRF technology
  - First large scale (>40 cryomodules, >320 SRF cavities) implementation of SRF technology
- 1987 **4 GeV** CEBAF green site construction begins
- 1995 CEBAF achieves 4 GeV design energy
- 1996 CEBAF changes its name to Thomas Jefferson National Accelerator Facility (**Jefferson Lab**)
- 1997 All three halls (A, B & C) beam capable
- 2000 CEBAF reaches **6.07 GeV**
- 2012 CEBAF ceases 6 GeV operations
  - 17 years of experiments
  - 15 years of three hall operation
  - 178 completed experiments
  - 1380 Users (480 users from ~29 foreign countries)

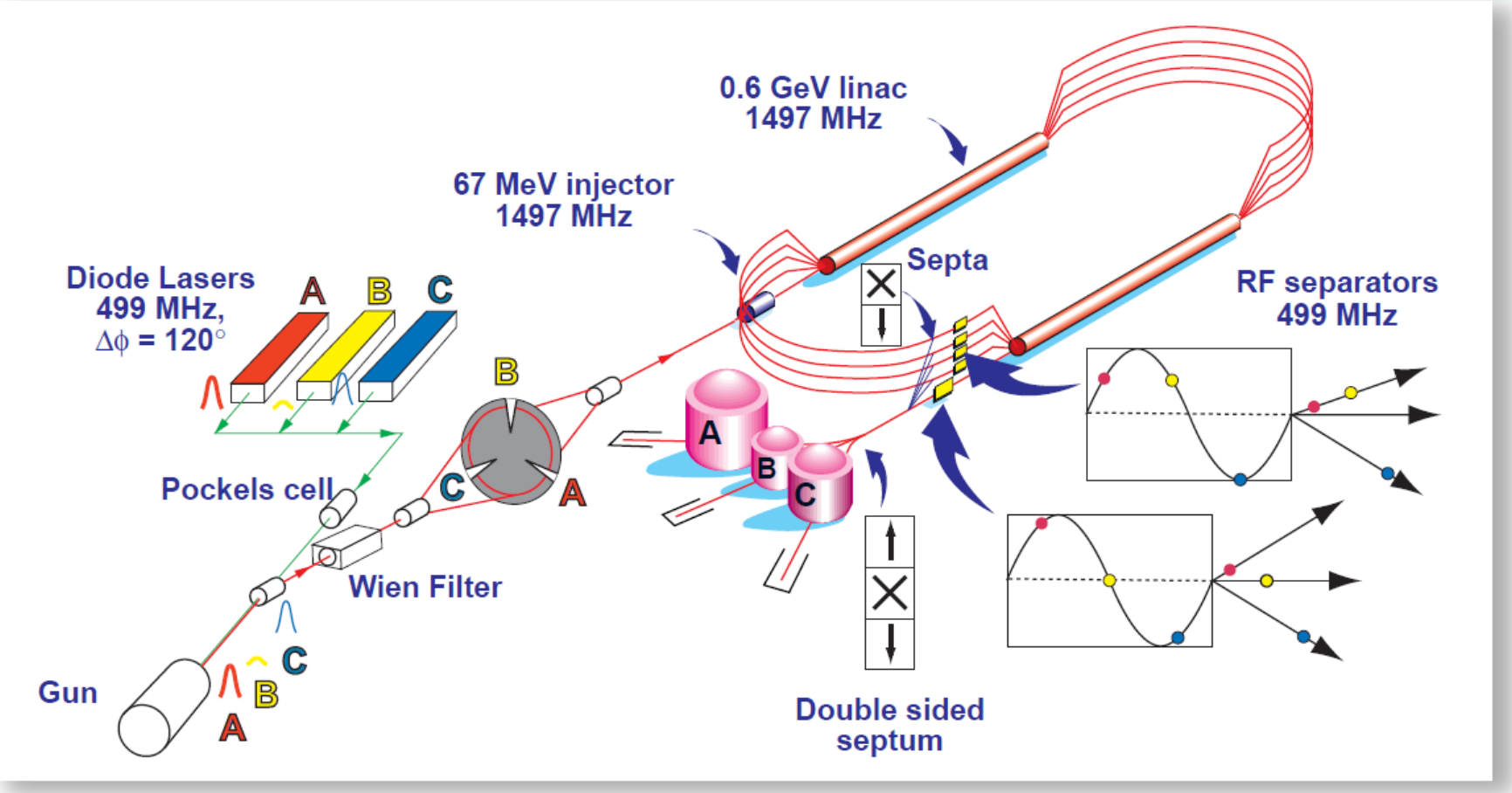

Experimental Hall A


Experimental Hall B


Experimental Hall C


CEBAF Linac

6GeV CEBAF

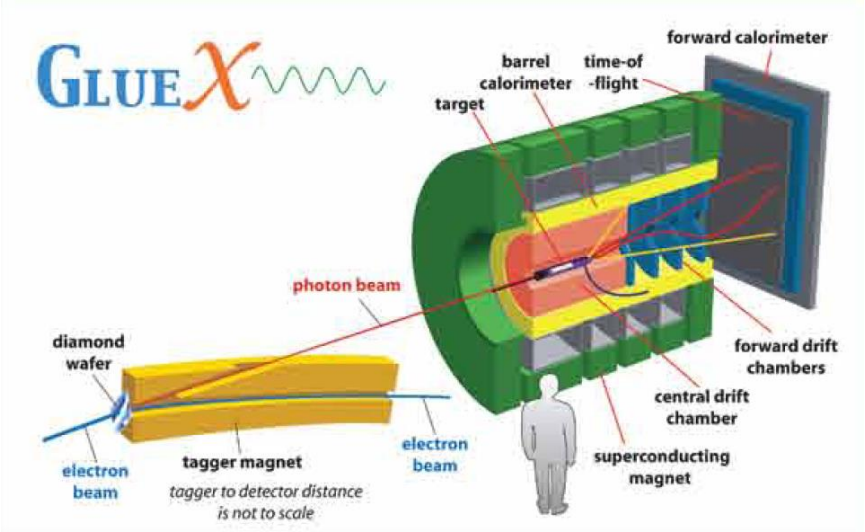


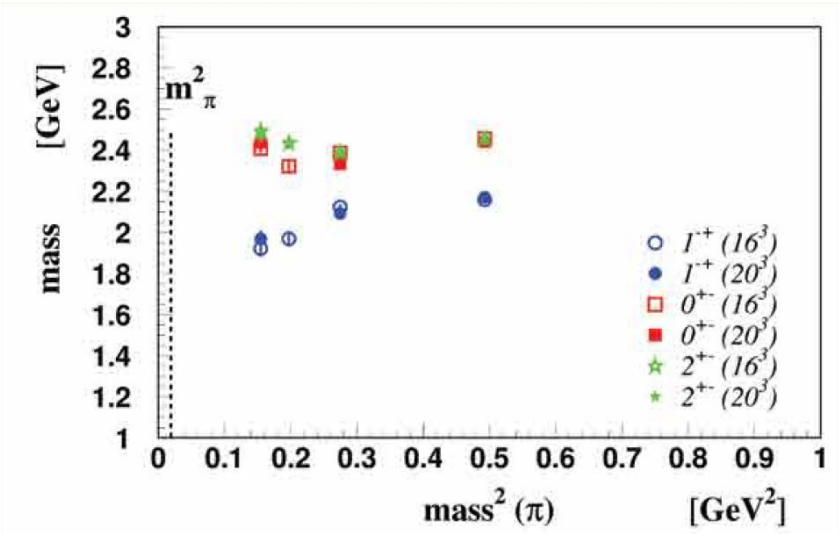
- Warm magnets, superconducting RF
- Beam bunch on each RF phase (1497MHz)
- One revolution takes 4.2 μs
- Up to 5 recirculation passes: an electron is with us for at most 21 μs

- Linacs transport up to 5 different beam energies simultaneously
- Spreader-Arc-Recombiner transport is globally isochronous
- 1MW CW demonstrated

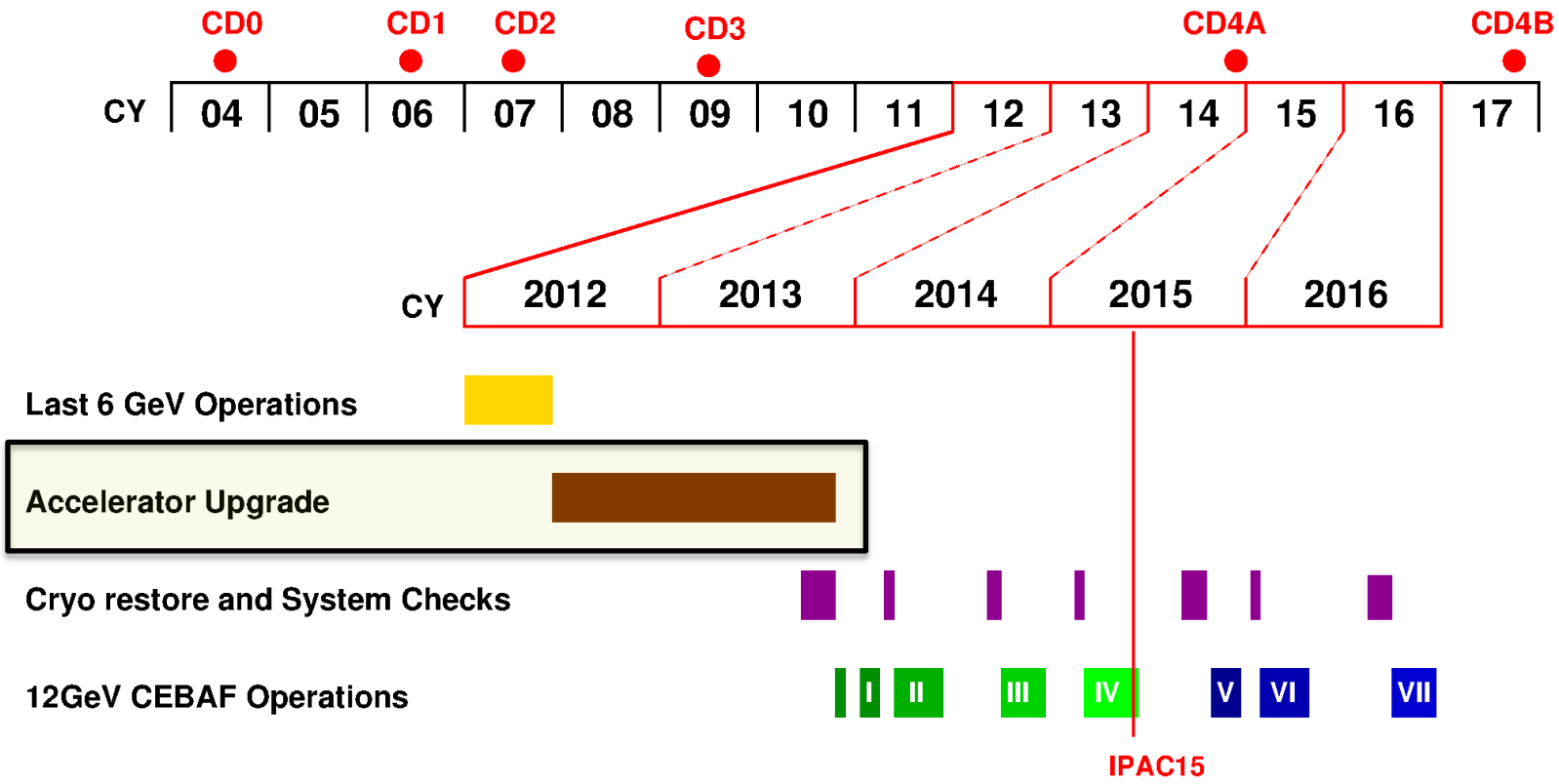
12GeV Upgrade Physics Case

- Quark confinement
  - Exotic meson spectroscopy
  - Production via linearly polarized high energy photons incident on Hydrogen target
    - Coherent bremsstrahlung of a **12 GeV** electron beam incident on a diamond radiator
  - New experimental end-station: **Hall-D**
- Extend nucleon structure & standard model experimental reach in Halls A, B & C



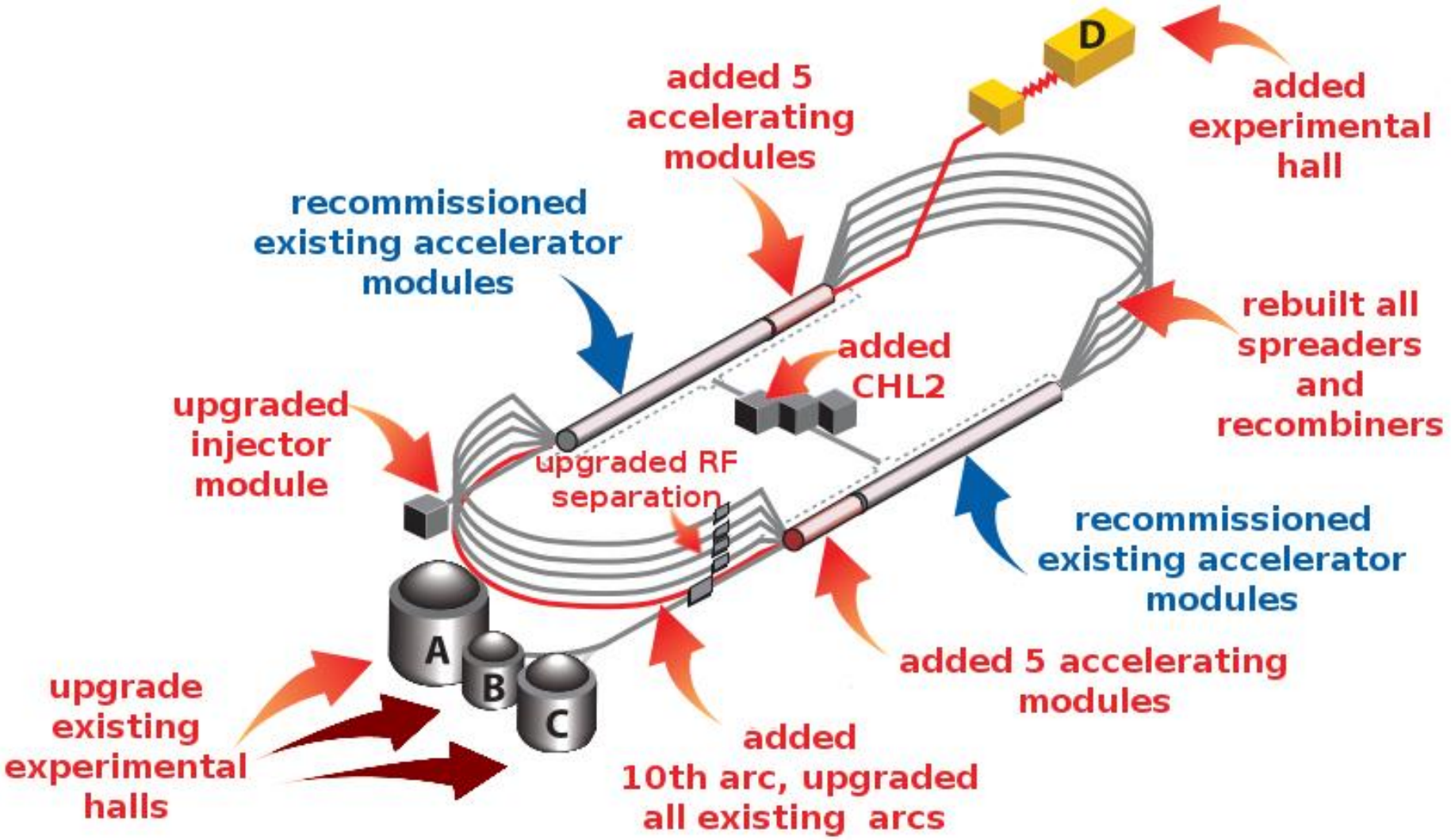


12GeV CEBAF Timeline



CD: Critical Decision

12GeV Upgrade Overview



Beam Parameters

	6 GeV	12GeV
Max. Energy ABC	6 GeV	11 GeV
Max. Energy D	NA	**12 GeV**
Duty Factor	CW	CW
Max. Beam Power	1 MW	1 MW
Bunch Charge (Min-Max)	0.004 fC – 1.3 pC	0.004 fC – 1.3 pC
Hall Repetition Rate Range	31.2 – 499 MHz	31.2 – 499 MHz
Nominal Hall Repetition Rate	499 MHz	**249.5**/499 MHz
Number of Exp. Halls	3	**4**
Max. Number of Passes	5	5.5
Emittance (geometric) at full energy	0.1 nm-rad(X)/0.1 nm-rad(Y)	**3 nm-rad(X)/1 nm-rad(Y)**
Energy Spread at full energy	0.002%	**0.018%**
Polarization	35%(initial), 85%(final)	>85%

Doubling the Energy

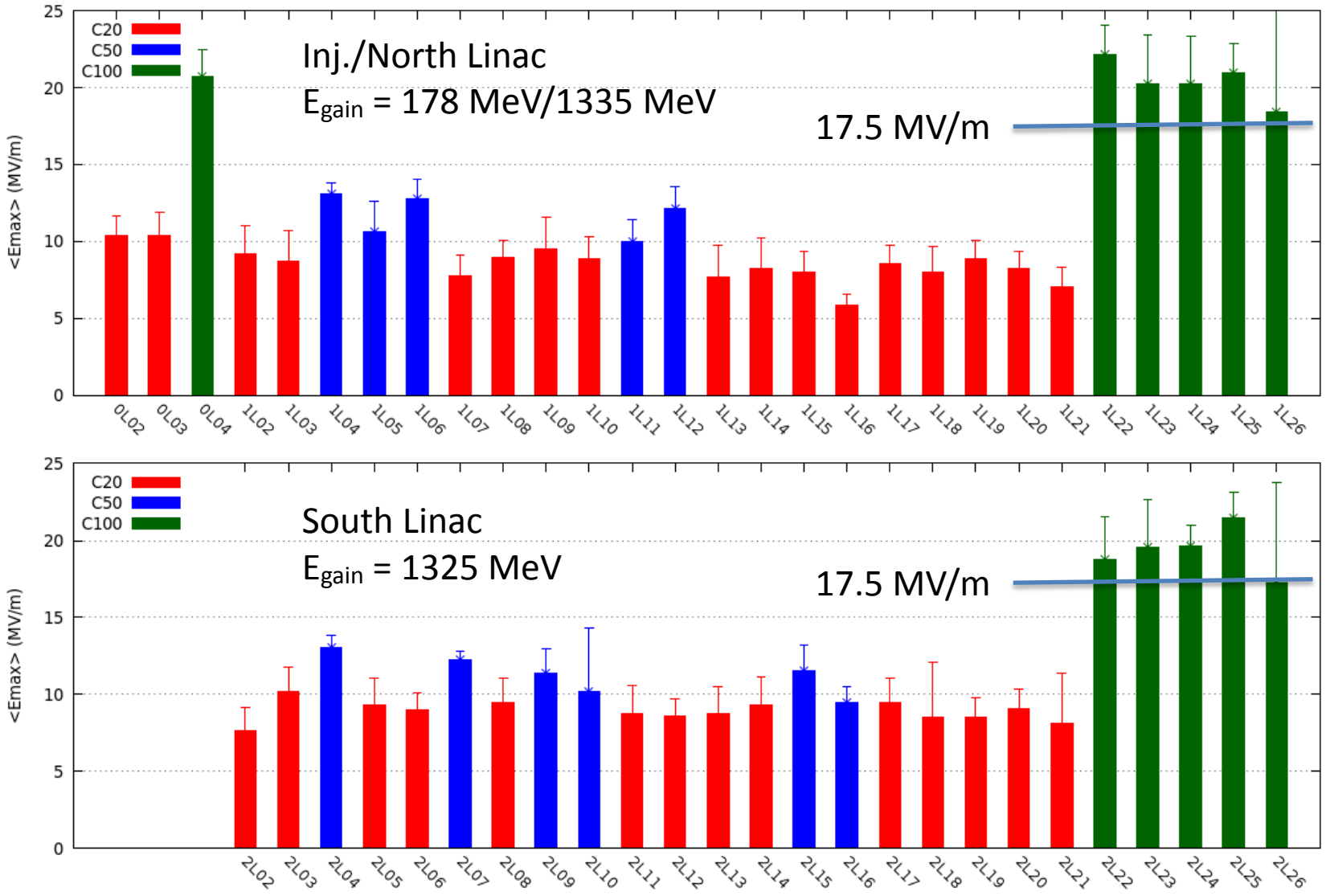
- 6GeV CEBAF: installed SRF provides 1200 MeV/pass of energy gain.
- Add 10th Arc, maximum number of passes now 5.5 (was 5).
- Add 11 new cryomodules with ~ 100 MeV of energy gain per module
  - 5 new modules per linac
  - 1 new module in the Injector

$$E_{Hall-D} = 5.\mathbf{5}\ \boldsymbol{passes}(1200 + 1000)MeV/pass = 12\ GeV$$

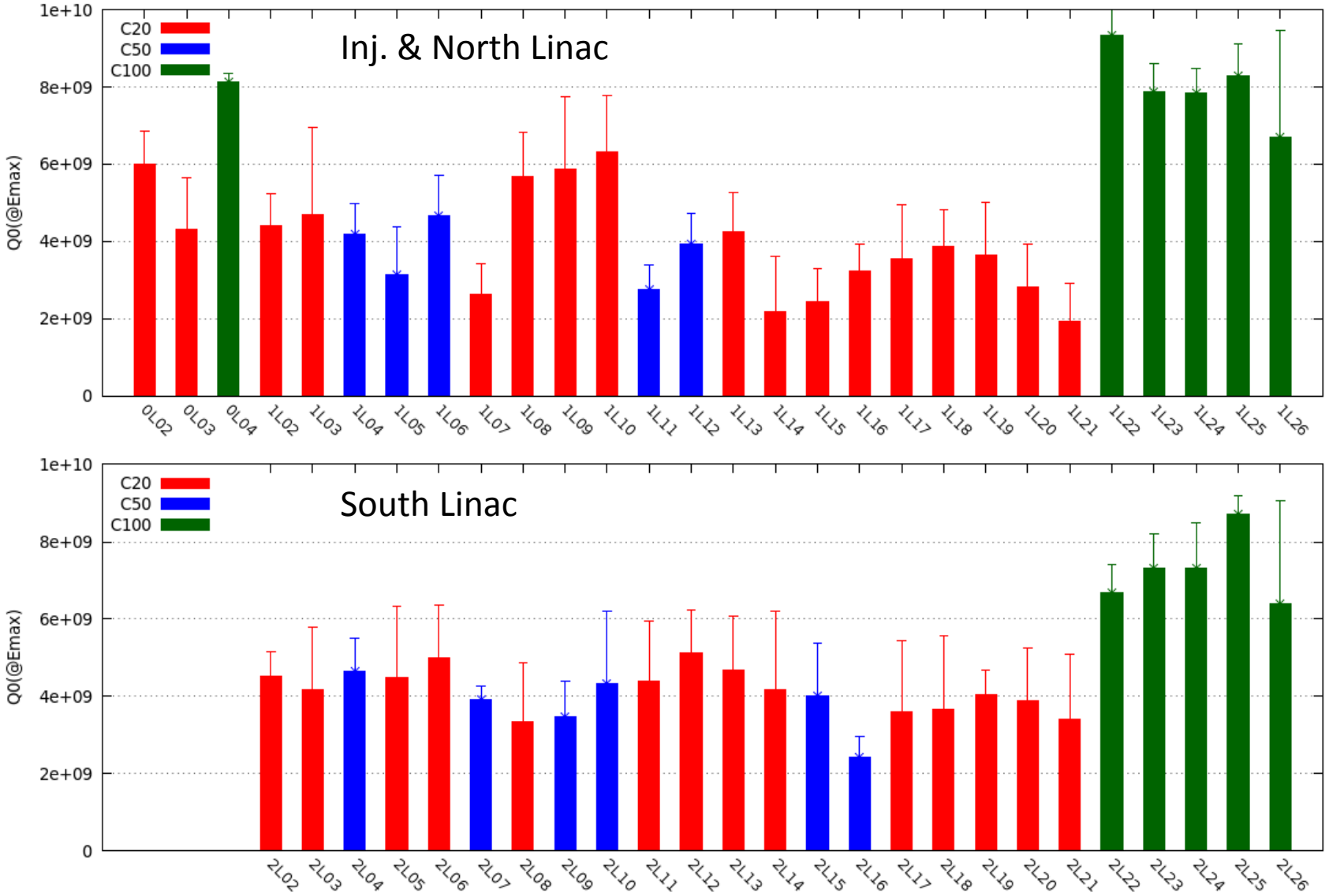
C100

- Each C100 contains 8 7-cell cavities, 1497 MHz, L=0.7 m
- 108 MeV/module (target), 98 MeV/module (required) on average to achieve 12 GeV
- Average target gradient: 19.2 MV/m , average required gradient: 17.5 MV/m.
- Nearly the same form factor as original CEBAF cryomodule

Average Cavity Gradient (per Module)

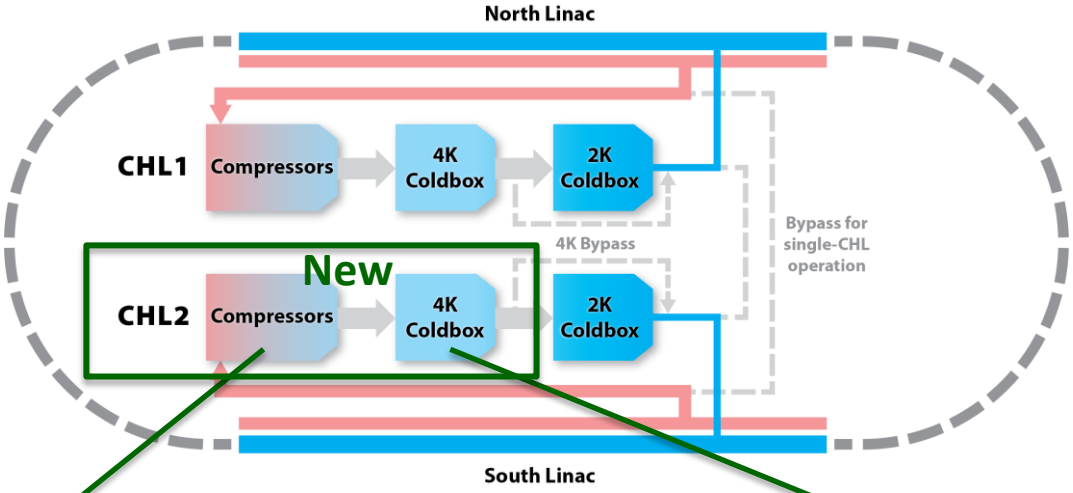


Average Cavity Q_0 (per module)



Cryogenics

CHL1
4.6 kW @2.1 K
250 g/s
5.5 MW



New

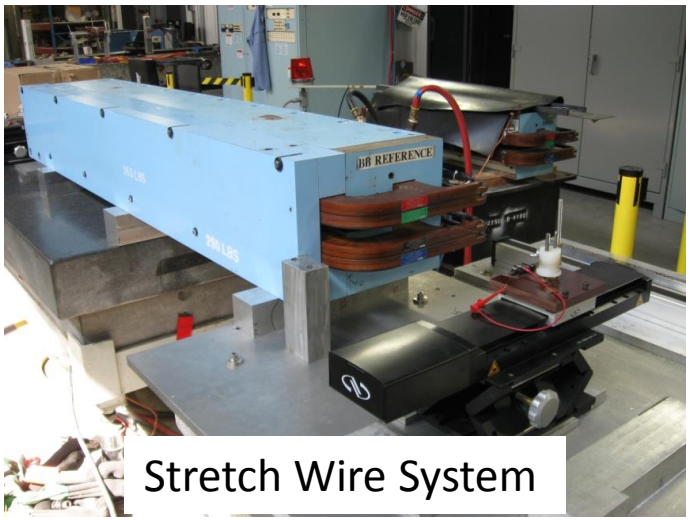
CHL2
4.8 kW @2.1 K
250 g/s
3.8 MW

	Years of Operation
CHL1	1991 – Present
CHL2 (12GeV)	**2013 – Present**
2K Coldbox #1	1994 - 2000 **2013 – Present**
2K Coldbox #2	2000 - Present

Accelerator Magnets

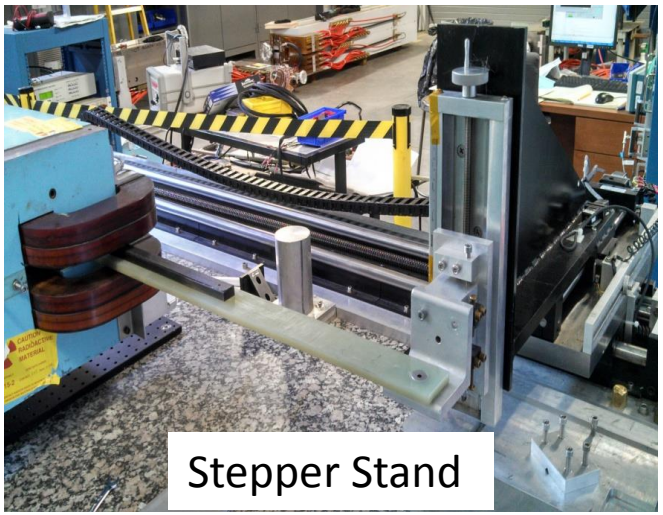
Count	Description
32	New 4m dipole magnets, Arc-10
256	Large dipole refurbishments (add steel and/or new coil packs)
110	Large (>1m) dipole magnets removed and measured
130	New quadrupole magnets
120	New corrector magnets

Excitation Curve: BL measurement



Stretch Wire System

Hall probes: Field quality

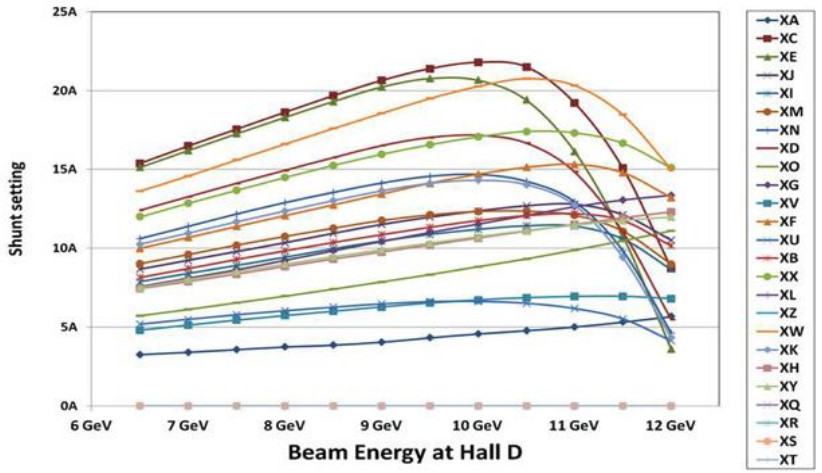


Stepper Stand

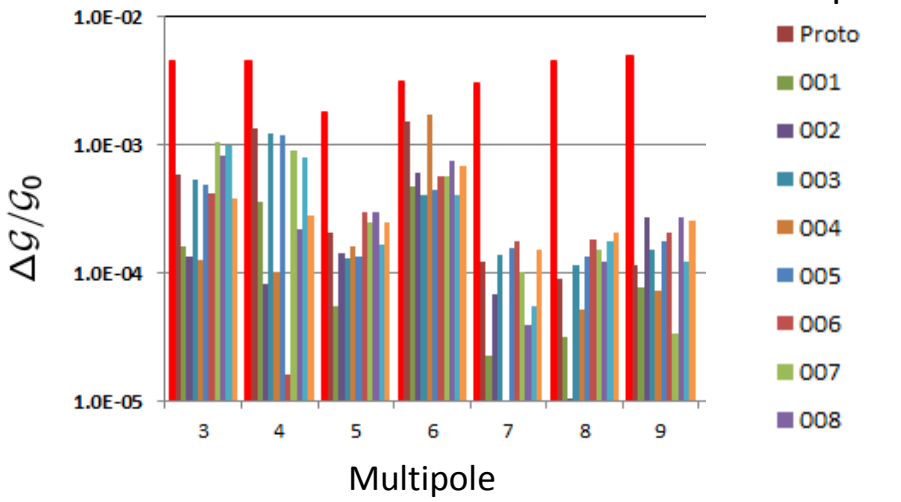
Magnetic Field Measurements

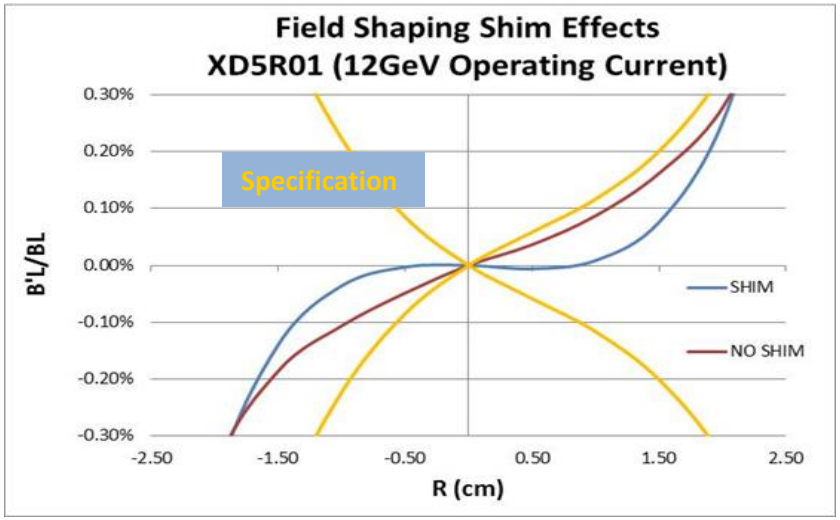
- Excitation curves and measured body gradient entered in database and model
- Shims used to improve field quality beyond specification
- Beam based measurements used to verify and improve the machine model

Spreader/Recombiner Shunt Settings

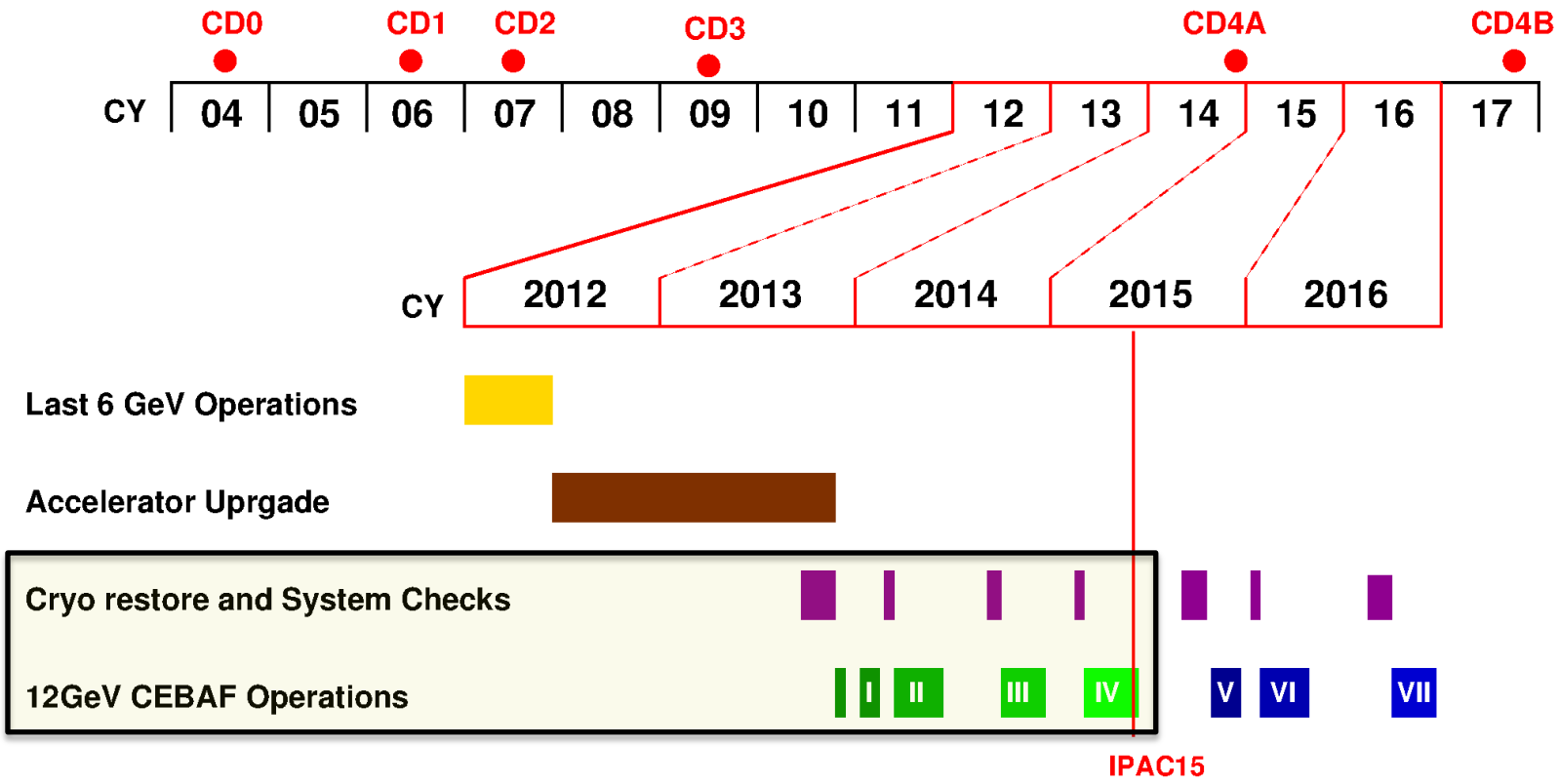


- **QP Quads**





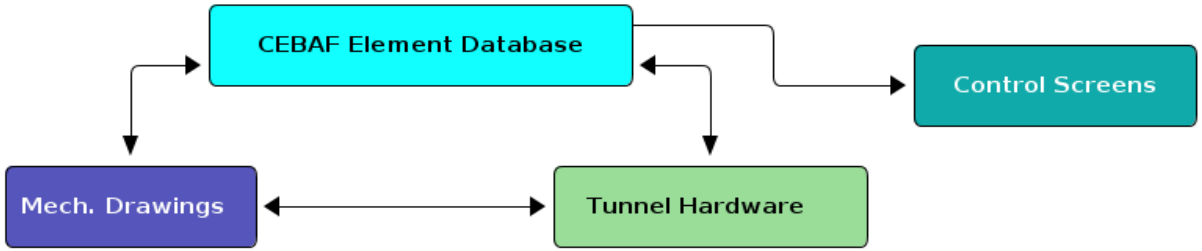
12GeV CEBAF Timeline



CD: Critical Decision

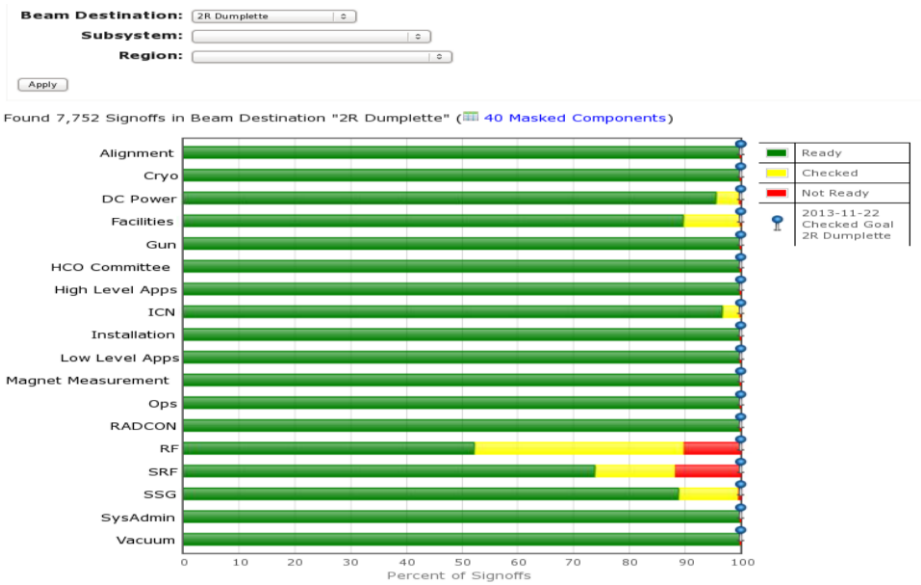
Model Driven, Database Centric

CEBAF **E**lement **D**atabase (**CED**)



CED element definition obtained from varied sources: machine model, magnet measurement, survey and alignment, power supply, control system configuration.

1. The definitive sole oracle for CEBAF configuration.
2. Generates the accelerator model (elegant lattice files).
3. Creates control screens (EPICS).
4. Provides model information for high level applications (orbit & energy locks, beam matching scripts,…).
5. Creates the System checkout (Hot Check Out) lists.
6. And much more.



First Beam Operations

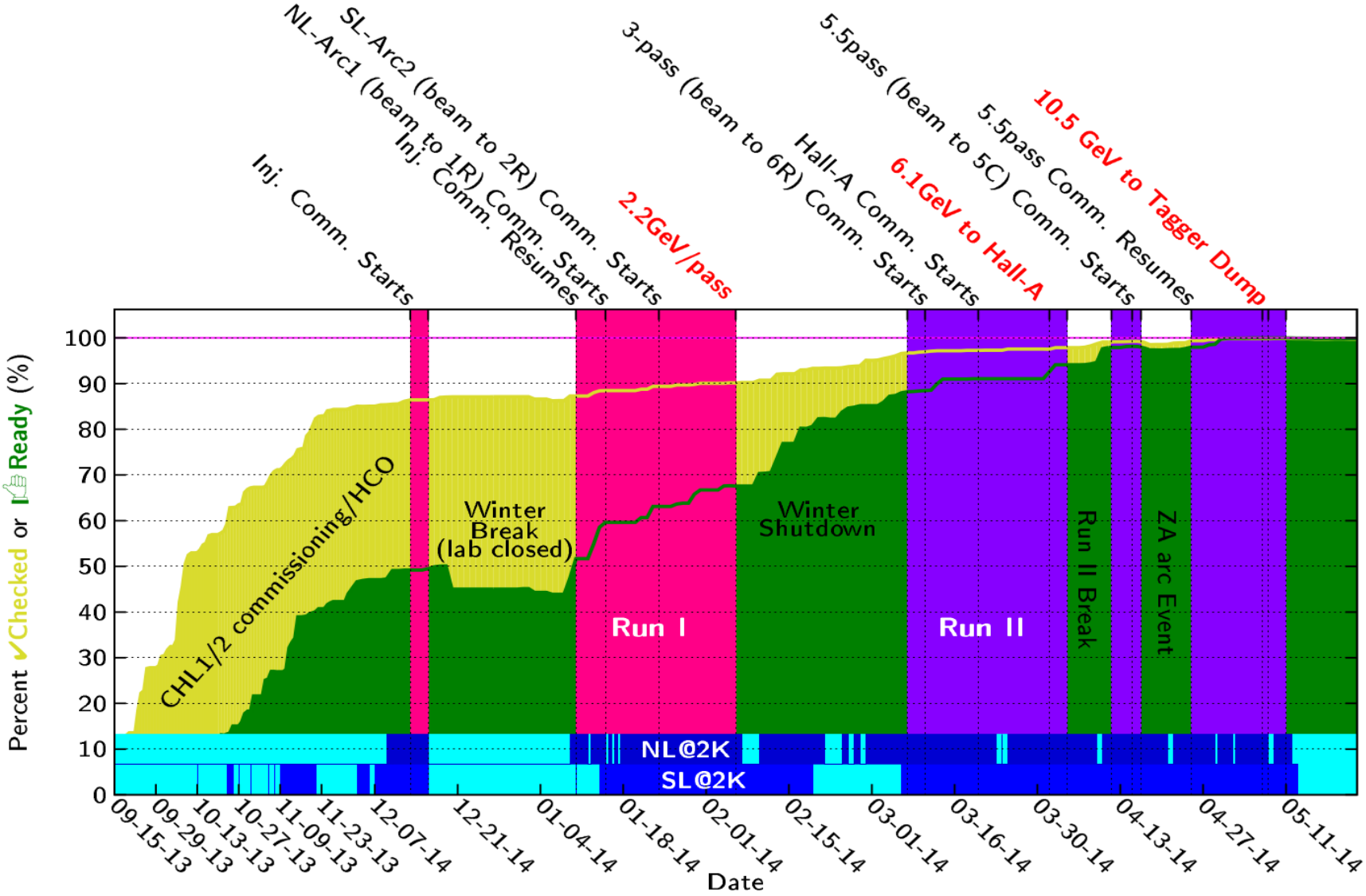
Run I (E_{linac} = 1100 MeV)

- 2013-Dec-13 to 2014-Feb-06
- Establish 1-pass beam
- **Program Goal**: Demonstrate 2.2 GeV/pass of energy gain

Run II (E_{linac} = 1000 MeV)

- 2014-Mar-07 to 2014-May-11
- Demonstrate full injection energy (123 MeV)
- First multi-pass beams in the 12 GeV era
- **Program Goal**: CW operations to Hall-A, 3-pass beam with E>6 GeV
- **Program Goal**: 5.5 pass beam to the Hall-D dumplet

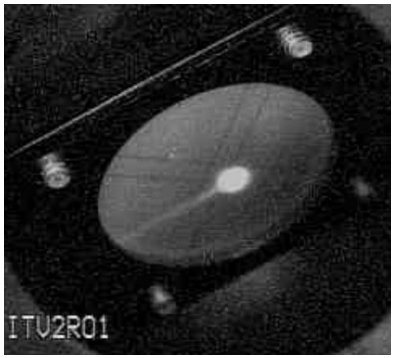
Run I and II Progression



Run I & II: Milestones

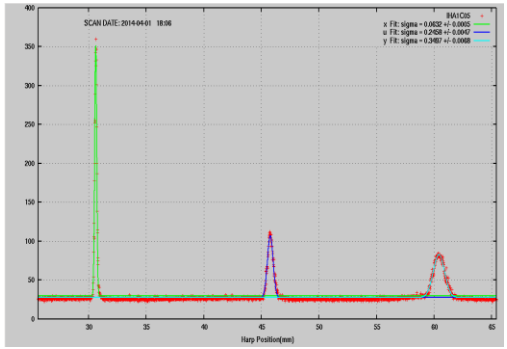
2.2 GeV/pass
2014-02-05

Beam Arc2 viewer



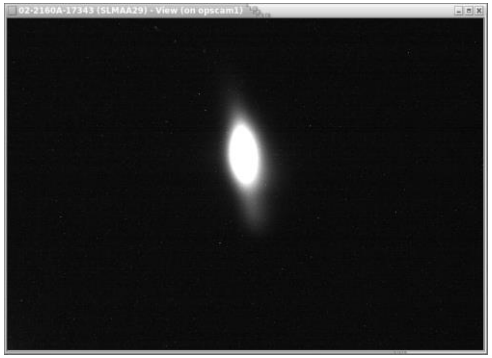
>6 GeV to Hall A
2014-04-01

Beam profile in A line

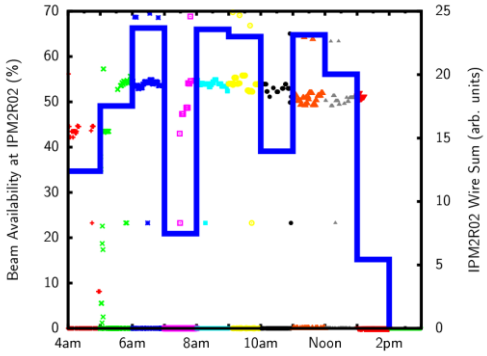


5.5 Pass Beam
2014-05-09

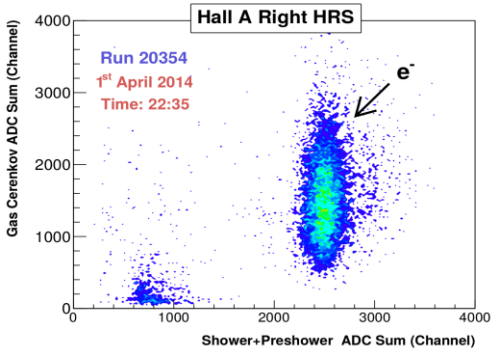
Synchrotron Light in Arc10



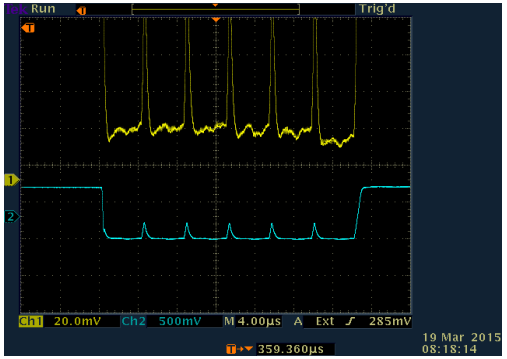
Availability > 50%



Elastic events in A Spectrometer



6-beams in North Linac

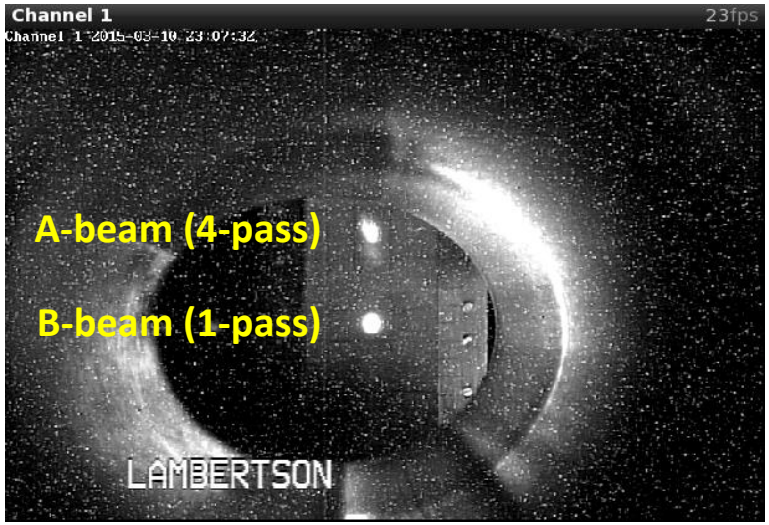


Run III (E_{linac} = 909 MeV)

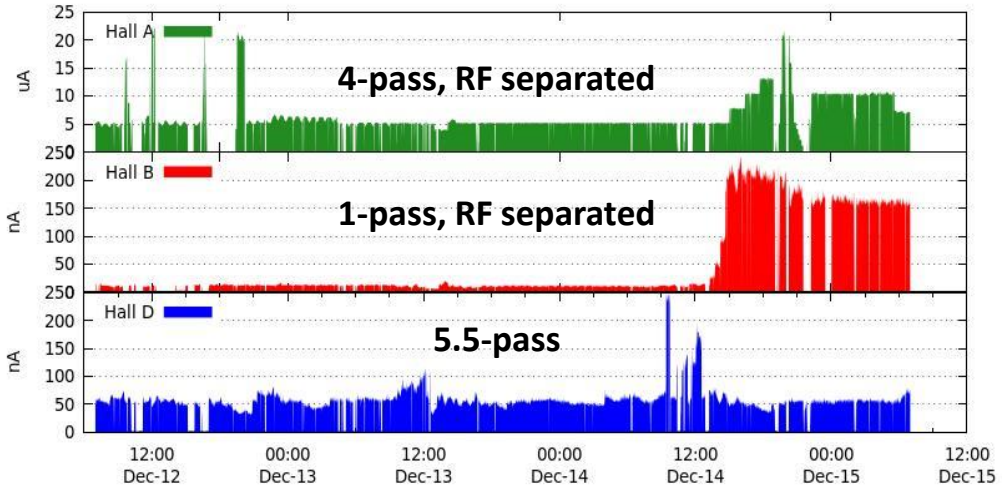
2014-Oct-08 to 2014-Dec-21

- CW beam, E>10 GeV, 5.5pass beam to Hall-D
- First photons into the new experimental hall
- **Program Goal**: Hall-D detector commissioning
- RF separation (1-4 pass), first simultaneous multiple users in the 12GeV era

Separated beams on beam viewer



Sustained 3-Hall operations



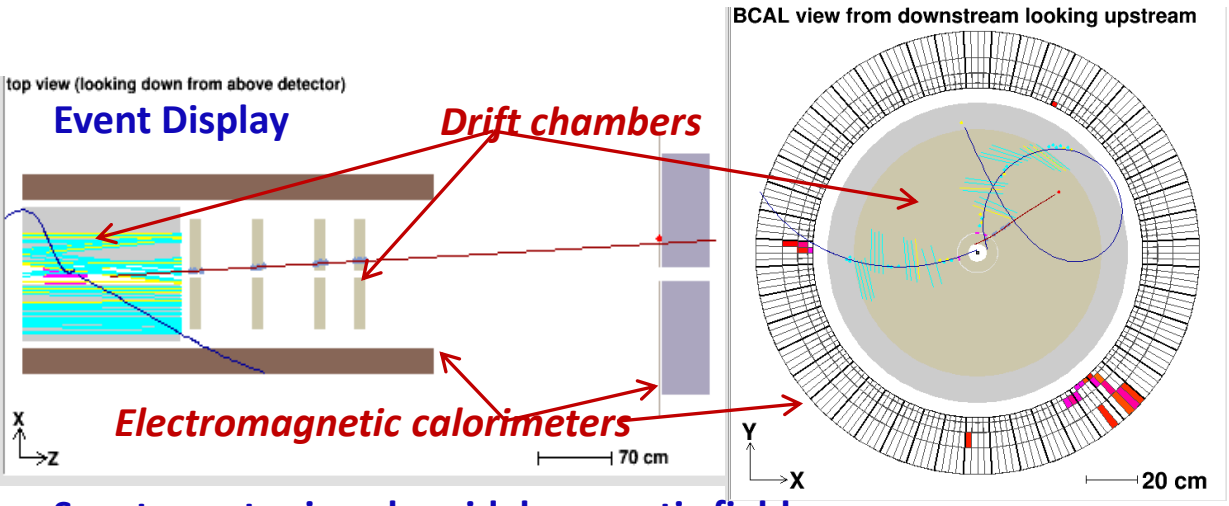
Hall D Commissioning

- Hall D: facility for experiments with linearly polarized photon beam
- Main goal: search for gluonic excitations in light meson spectra (GlueX experiment)
- Photon beam line + large acceptance spectrometer for charged particles & photons
- Commissioning with beam Nov. & Dec. 2014
  - **Program Goals** demonstrated

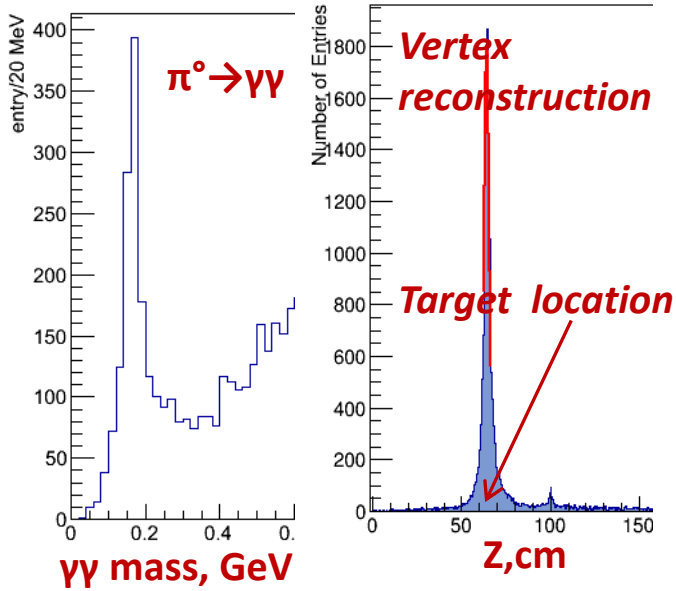
Results with preliminary detector calibration and alignment

Neutral particles reconstruction

Charged particles tracking



Spectrometer in solenoidal magnetic field

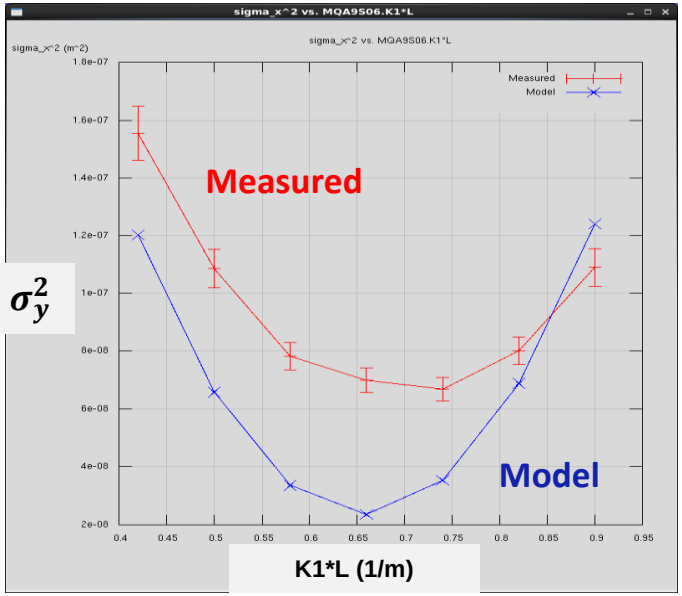


Run IV (E_{linac} = 950 MeV)

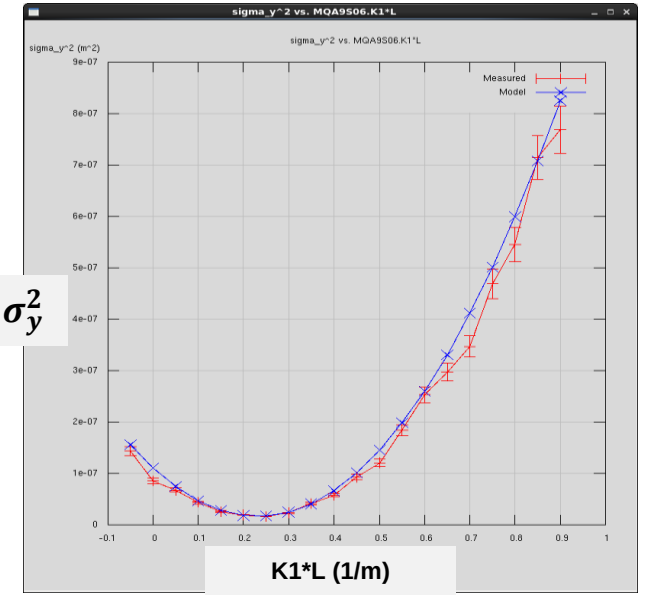
2015-Feb-13 to 2015-May-18

- Commission new 249.5 MHz laser/injector configuration
- Commission new 750 MHz 5-pass separators
- Optics tool development: New beam matching process
- Establish baseline emittance and bunch length evolution
- Support ~5wk “early Physics” Operation

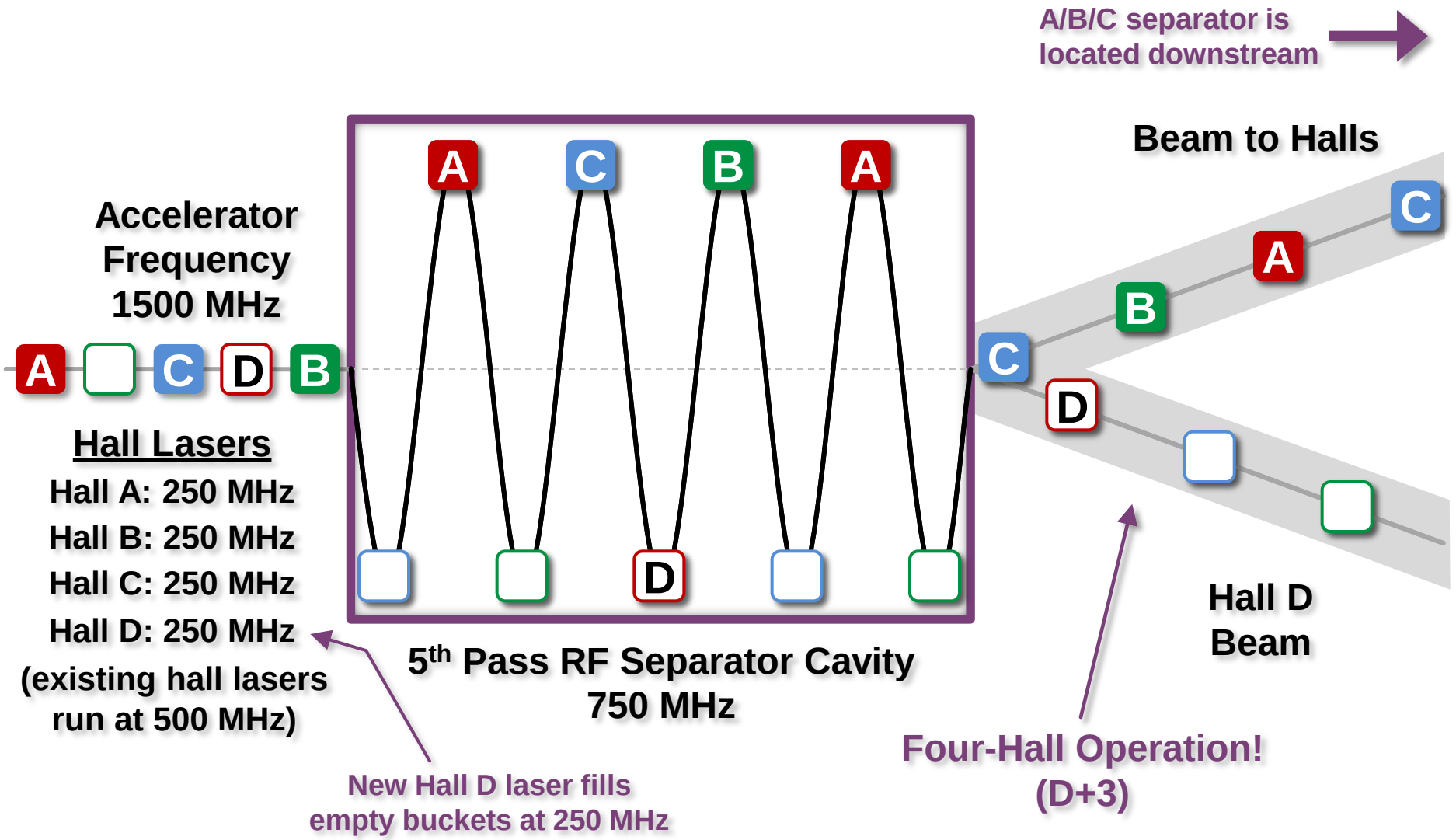
Quad Scan: Before match



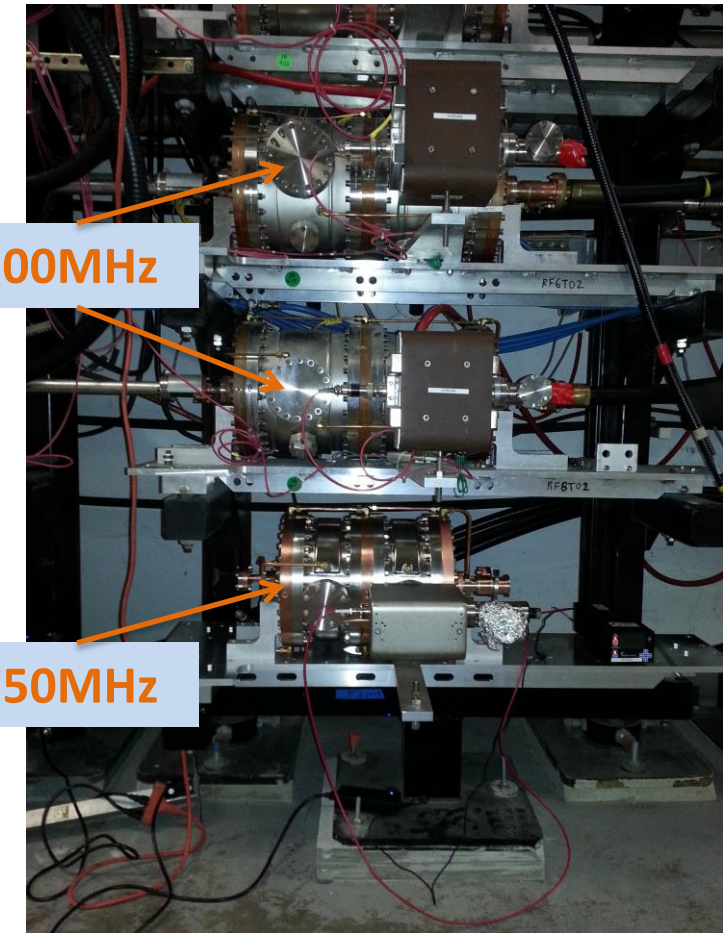
Quad Scan: **After** match



RF Separation – Four Halls



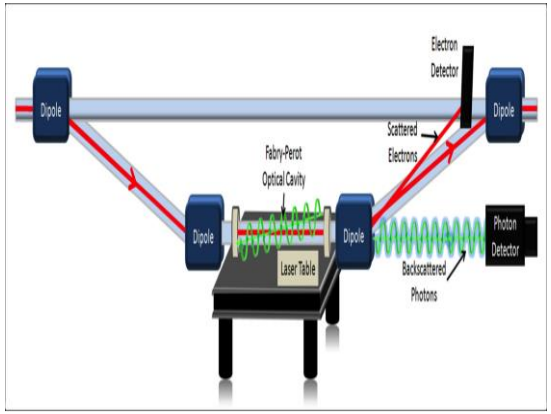
750MHz Separation



A & D beam separated on 5th pass at 9.6 GeV

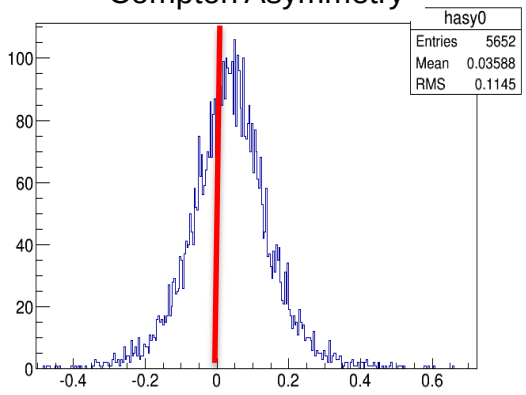
Three Hall Program: (E_{linac}=500 MeV)

Hall-A: Commissioning e- polarimeters

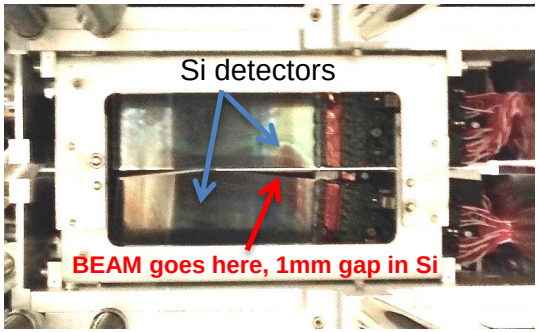


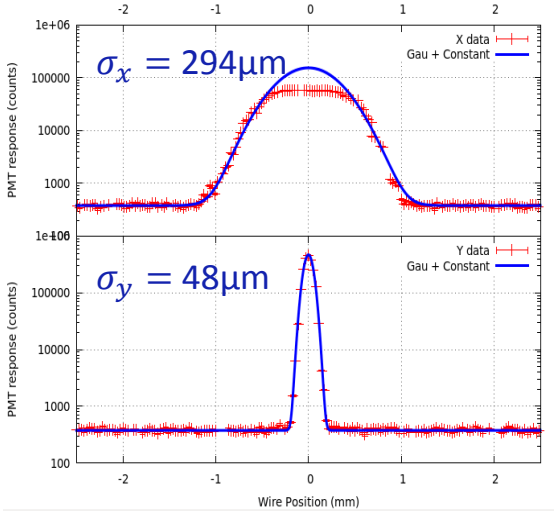
$$A_{Raw} = \frac{N_+ - N_-}{N_+ + N_-}$$

Compton Asymmetry

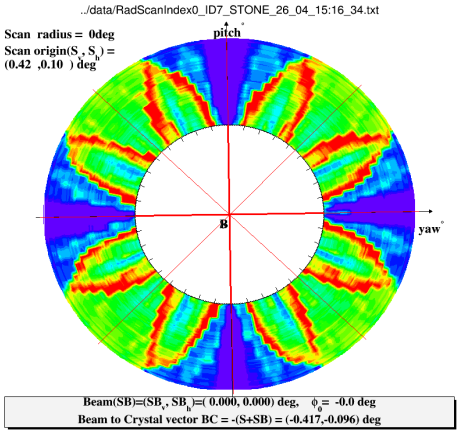


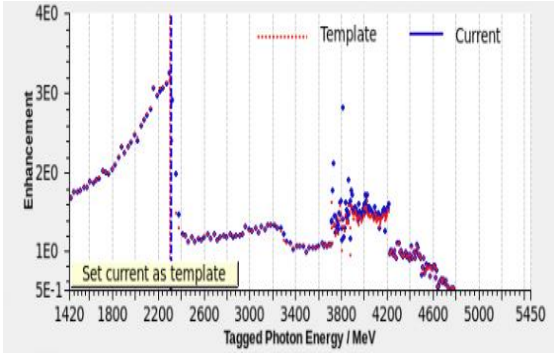
Hall-B: Ribbon beam for dark matter search





Hall-D: First coherent bremsstrahlung spectrum





12GeV Operations: Future

Summer 2015(May-18 to Sept-30): Scheduled Accelerator Down

- Helium process all SRF cavities:
  - Goal: 12 GeV operations at high availability.
- Complete tunnel air-condition:
  - Goal: 35 C at 12 GeV magnet settings (max to date 39 C at 10 GeV).
- Complete pathlength chicane upgrade:
  - Goal: pathlength control range comparable to 6GeV CEBAF era.
- Repair 2K cold box
- Upgrade site power distribution for greater availability, redundancy and flexibility.

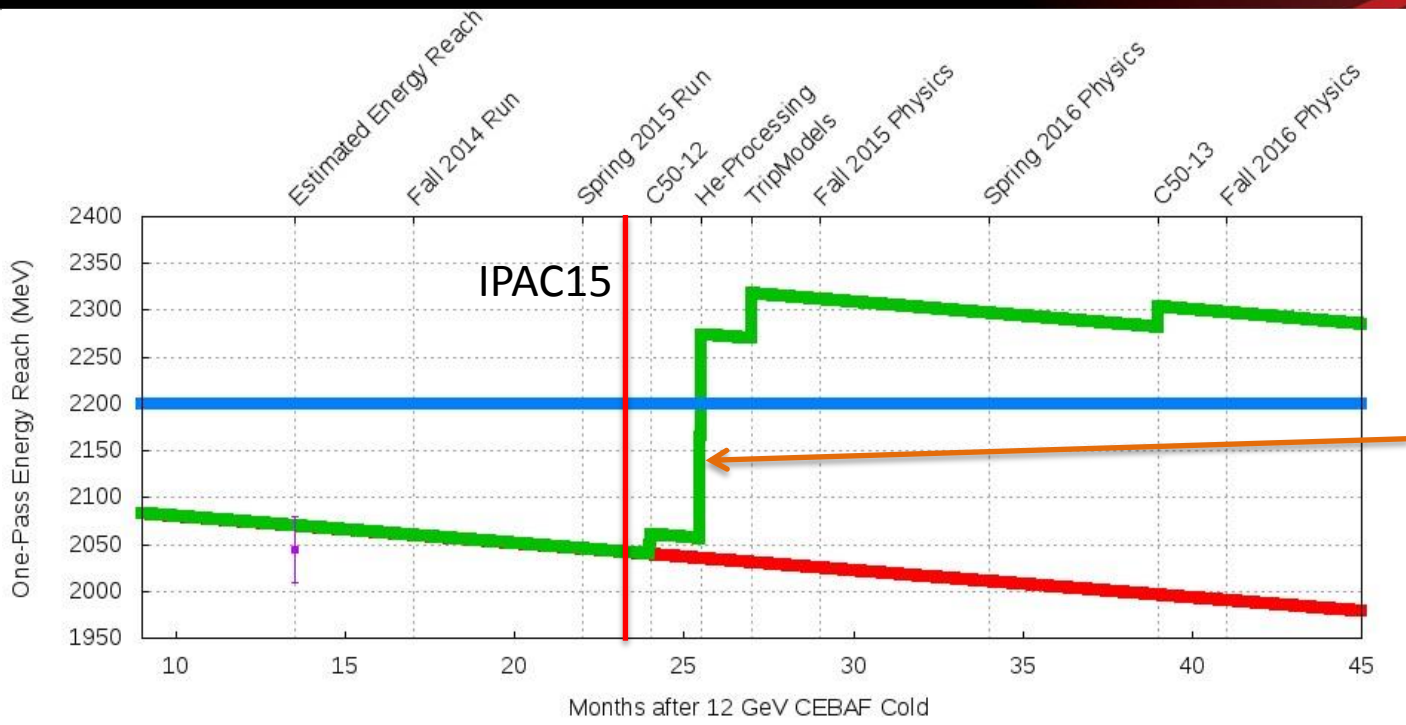
Run V (E_{linac} = 1100 MeV):
2015-Oct-26 to 2015-Dec-21

- Emittance/energy spread growth studies.
- SRF performance optimization at full energy.
  - Minimize trip rate
  - Minimize recovery time
  - Maximize gradient
- Detector commissioning at full energy.

Run VI (E_{linac} = 1100 MeV):
2016-Jan-28 to 2016-Mar-31

- **First Physics runs at 12 GeV energy: Halls A&D**

Gradient Maintenance



Helium processing of all cavities planned for Summer 2015

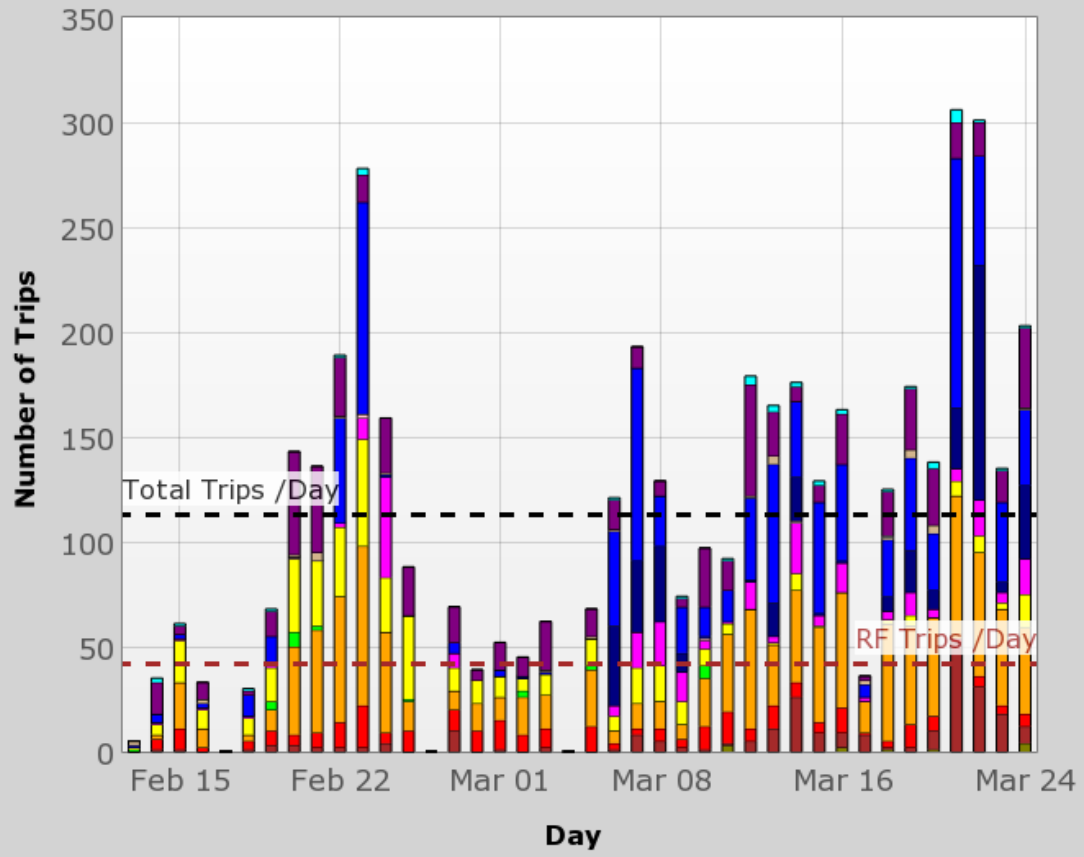
- C20/C50 performance degradation:
  - 0.21 MV/m – year (~34 MeV/pass - year).
  - Cause of degradation is unknown, actively being investigated.
- C100 insufficient data to date to reliably estimate degradation, if any.

- Commissioning vs. Operations cavity performance:
  - $78\% < \frac{Operational\ Gradient}{Commissioning\ Gradient} < 94\%$

Tracking Performance: Beam Trips

Beam Trip Summary

February 13 - March 25, 2015



	Trips /Day	Lost Hrs	Mins /Trip
Diagnostics	1.0	0.4	0.6
Dump (Insert.)	16.4	2.7	0.2
Dump (Station.)	0.0	0.0	0.1
Gun/Laser	0.8	1.4	2.8
MPS (BLM)	24.9	8.9	0.5
MPS (Multi/Other)	9.4	2.4	0.4
Magnets	0.1	0.1	1.6
Multiple/Other	6.5	3.4	0.8
Unknown/Missing	11.3	4.1	0.5
Vacuum	0.7	0.5	1.1
RF (C25/C50)	28.4	6.7	0.4
RF (C100)	6.8	8.6	1.9
RF (Multi/Other)	5.9	4.5	1.1
RF (Separator)	0.3	0.2	1.0
Total:	**112.4**	**43.8**	**0.6**

- Max Trip Duration: 5 Minutes
- Max Types Per Trip: 10

Summary

- 12GeV Project accelerator deliverable (CD-4A) achieved on 2014-July-30, five months ahead of schedule.
  - 12 GeV CEBAF complete!
- 12GeV Project goals for Hall-D detector commissioning achieved on 2014-Dec-11, ahead of schedule.
  - Hall-B & C commissioning scheduled for Fall 2016 in advance of the 12GeV Project date of Sep. 2017 for CD-4B.
- Accelerator effort continues to build towards robust operations and physics quality beam at the 12 GeV design energy.
  - Continue the model driven, database centric approach to beam operations.
  - Helium processing scheduled for Summer 2015, in support of achieving robust 12 GeV operations in Fall 2015.
  - Detector commissioning progressing, getting ready for Physics data in Fall 2015/Spring 2016.

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- External reviewers
- 12GeV Project Management
- JLAB staff from across all divisions and departments

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- Operations staff
- Accelerator Scientists (CASA, CIS, SRF)

Invited Oral:

- **THXB1 CEBAF SRF Performance during Initial 12 GeV Commissioning (Rama Bachimanchi)**

Contributed Oral:

- **WEBC1 12 GeV CEBAF Transverse Emittance Evolution (Todd Satogata)**

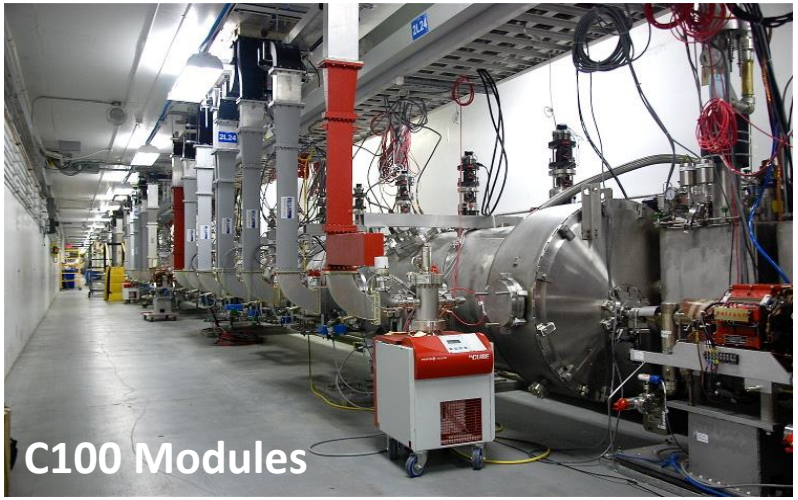
Posters:

- **MOPWI045 Bunch Length Measurements using a Synchrotron Light Monitor (Mahmoud Ali)**
- **MOPWI047 Beamline Insertions Manager at Jefferson Lab (Michael Johnson)**
- **MOPWI048 The CEBAF Element Database and Related Operational Software (Theo Larrieu)**
- **MOPWI049 eDT and Model-based Configuration of 12 GeV CEBAF (Dennis Turner)**
- **TUPMA039 First e-/Photon Commissioning Results for the GlueX Experiment/Hall D at CEBAF (Mike McCaughan)**
- **TUPMA040 Commissioning of the 123 MeV Injector for 12 GeV CEBAF (Yan Wang)**
- **WEPWI026 Vacuum Characterization and Improvement for the Jefferson Lab Polarized Electron Source (Marcy Stutzman)**
- **WEPWI032 Cavity Design, Fabrication and Commission Performance of a 750MHz, 4-rod Separator for CEBAF 4-Hall Beam Delivery System (Haipeng Wang)**
- **WEPWI033 Gain-switched Photocathode Drive Lasers with Variable Repetition Rates for High Current Accelerators (Shukui Zhang)**

STOP HERE

Doubling the Energy

- 10 + 1 C100 modules installed and commissioned.
- All SRF cavities warmed to 300K during cryo upgrade.
- Every cavity characterized post 2K cool-down
  - Q0(E)
  - Emax (Maximum Gradient)
  - Field Emission onset



Linac	Type	N(cavities)	<EmaxOP> (MV/m)	<Q0>	E_{gain} (MeV)
INJ	C20	10	10.38	4.6e9	52
	C100	**8**	**22.58**	**8.1e9**	**126**
				Total E_{gain}	**178**
North Linac	C20	120	8.61	3.9e9	517
	C50	40	11.72	3.7e9	234
	C100	**40**	**20.86**	**8.1e9**	**584**
				Total E_{gain}	**1335**
South Linac	C20	112	9.09	4.3e9	500
	C50	48	11.55	3.8e9	271
	C100	**40**	**19.77**	**7.4e9**	**554**
				Total E_{gain}	**1325**