12 GeV CEBAF: Accelerator Systems and Polarized Beams

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Jefferson Lab

Thomas Jefferson National Accelerator Facility

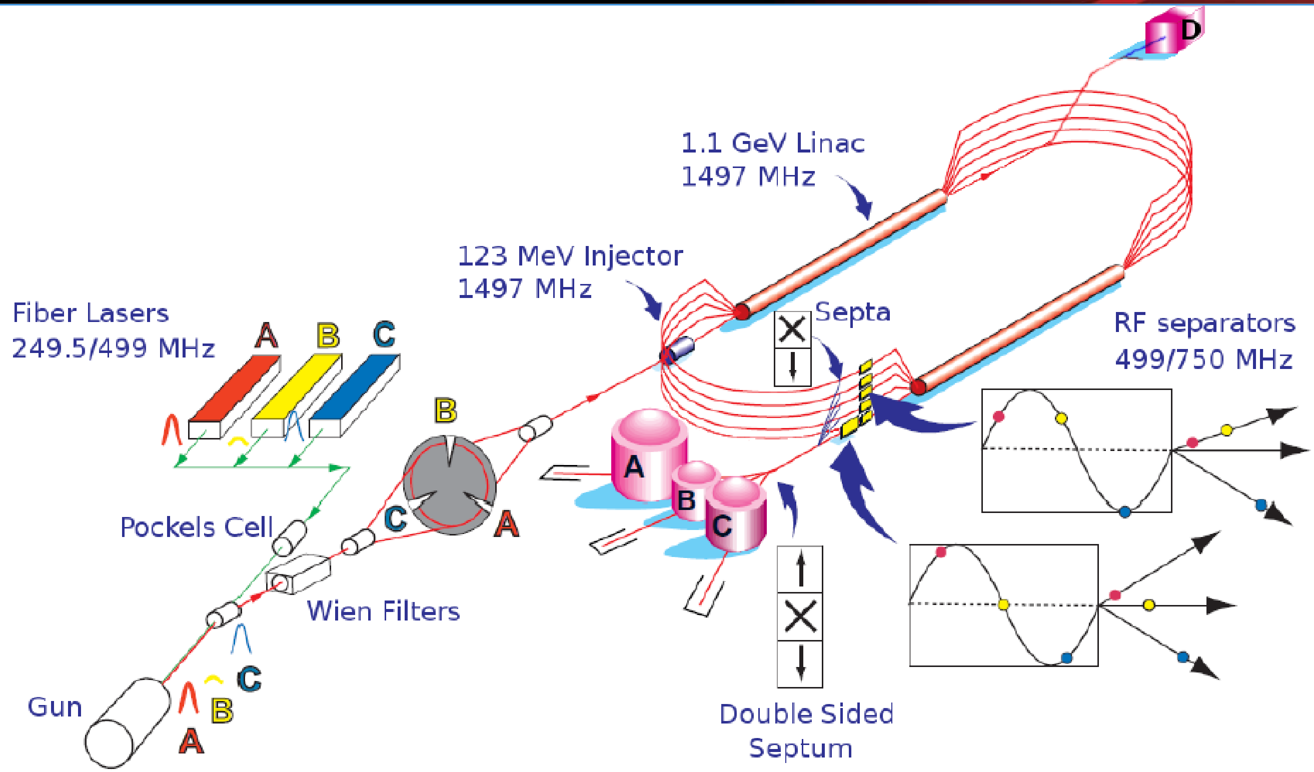
U.S. DEPARTMENT OF ENERGY

JSA

Outline

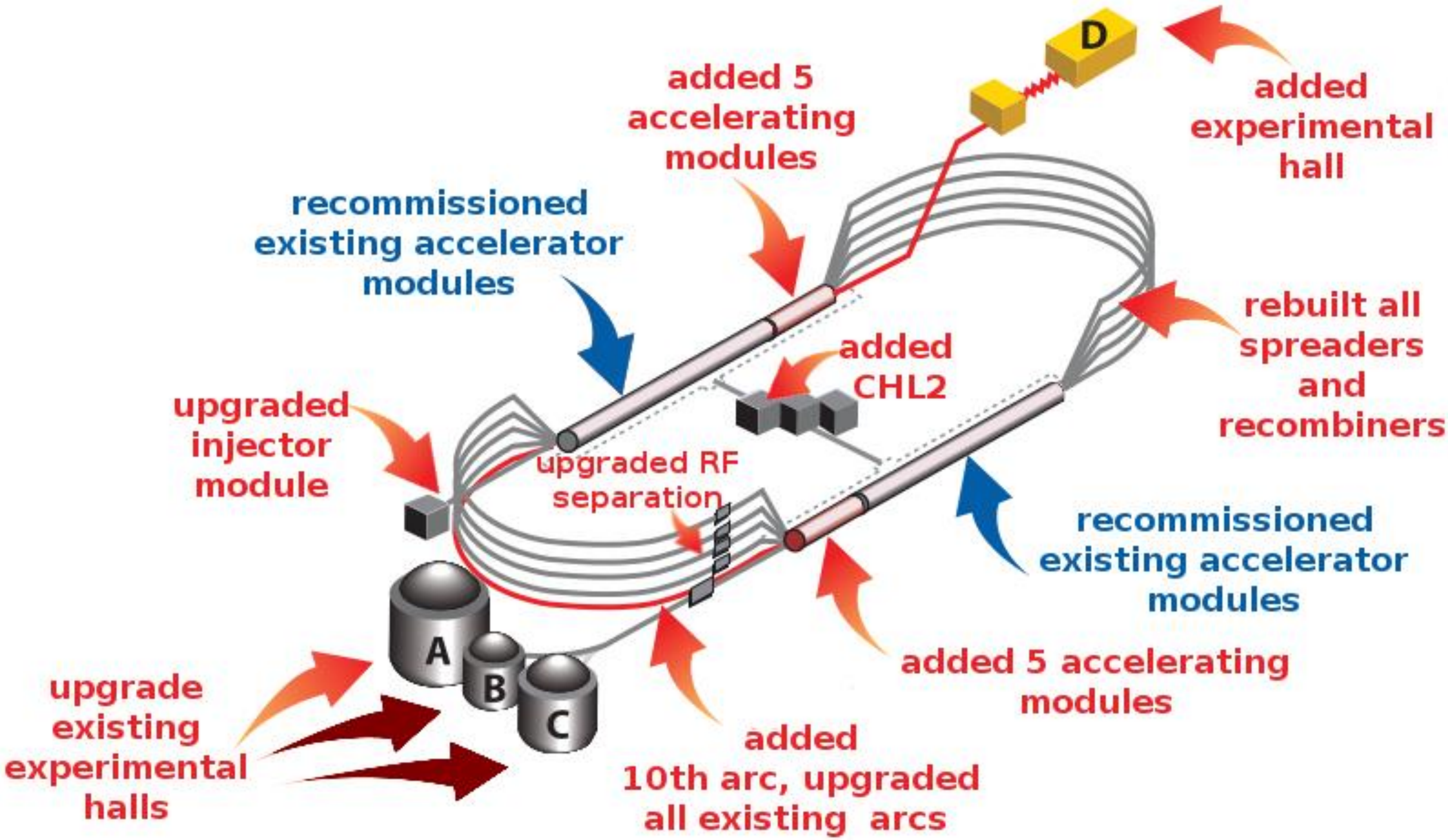
- Overview of 12 GeV CEBAF
- Specific Systems
  - new cryoplant, beamlines, magnets, accelerating cavities, separators, lasers
- Recent Experience
- Future Focus
  - Reliability
  - Gradient
  - Injector Upgrade
  - Injector Test Facility

CEBAF Overview

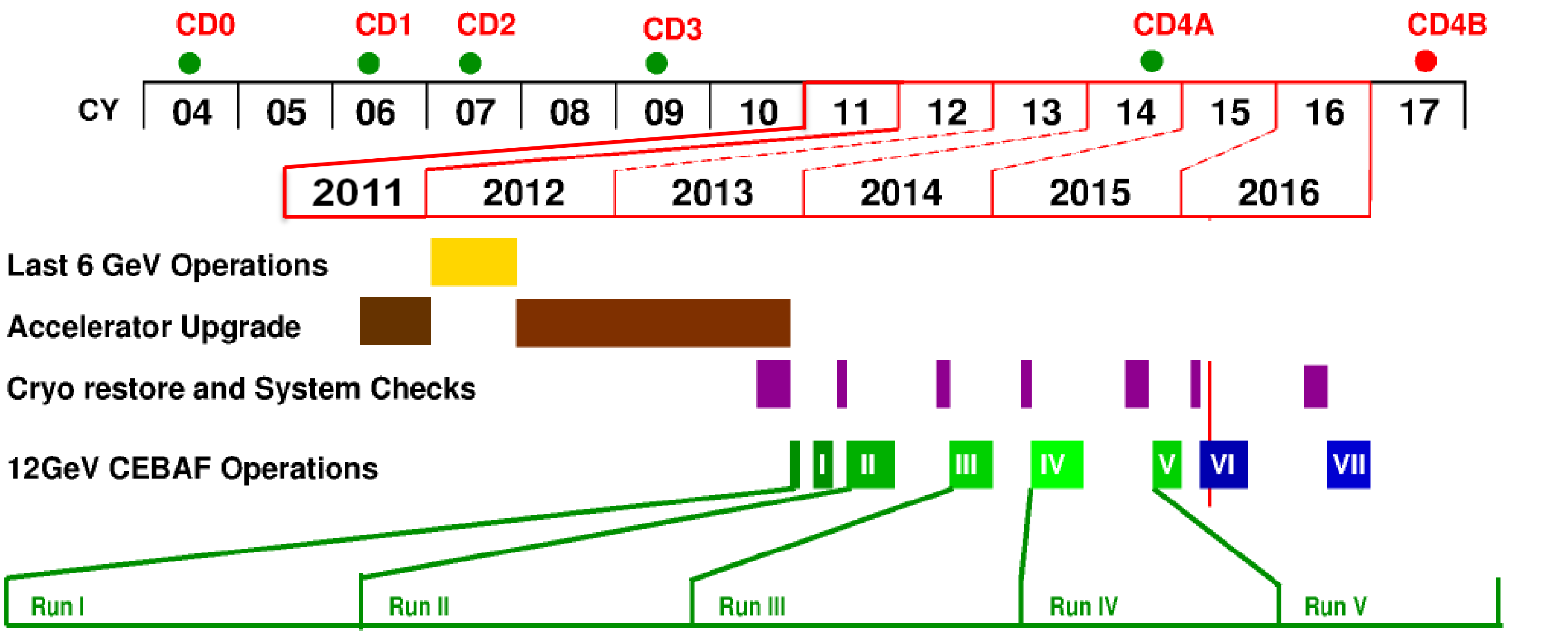


- Maximum (design) energy 12 GeV, 5.5pass Hall-D (11 GeV 5pass for ABC).
- Simultaneous delivery of 85 μA and nA beams: 5 orders of magnitudes in bunch charge.
- Flexible extraction for ABC, 1-5 pass options.
- Polarized electron beam ($P > 85\%$).
- Three 499 MHz or 249.5 MHz beams interleaved resulting 1497MHz pulse structure.
  - Fourth laser upgrade planned for Summer 2016, commissioning Spring 2017.
- CW SRF linacs, 1MW capable.

12 GeV Upgrade Overview



CEBAF 12 GeV Upgrade Schedule



Run I	Run II	Run III	Run IV	Run V
1-pass tune-mode beam	Multi-pass operations	3-Hall operation	3-Hall Operation	Post He Processing
2.2 GeV/pass	2.0 GeV/pass	1.8 GeV/pass	1.9 GeV/pass	**2.2 GeV/pass**
RF trip rate 40-50 trips/h	5.5 pass beam	Hall-D KPP established	5th pass RF-separation	**5.5 pass setup**
~50% Availability	First CW beam		Cold Compressor failure	**12 GeV to D**
				11 GeV to A
			1 GeV/pass	**770kW CW beam**
5 weeks	6 weeks	9 weeks	11 weeks	5 weeks

36 weeks of beam operation to date.

Improved CHL1 New CHL2

Improved CHL1

- Additional sub-atmospheric 2K cold box
- Improved purifier skid
- 420,000 scf He gas storage
- 40,000 gal LN_2 storage
- Improved guard vacuum
- Modifications to original 2K Cold Box:
  - LN_2 gravity fed cooling
  - Removed unreliable, large linac return valve
  - Added flow straighteners and increased volumes between compressors
  - Increased heat exchanger size

New CHL2

- Helium screw-compressors
- Oil removal system
- 10,000 liter helium dewar
- 4 K cold box system
- Integrated computer process control system
- Instrument air system, 60 scfm
- Motor control centers, 4160V/480V
- Gas management and distribution piping
- 77'x 62' building for helium compressors
- 2 x 5MVA , 4160V substation
- Cooling tower system

Beamlines
(magnets, power supplies, beam diagnostics, vacuum lines)

6 GeV beamlines

Recirculation and transport to Halls A, B and C
- 357 major Dipoles (1-3m long)
- 730 Quads (30x30x30cm)
- > 2000 power supplies
- > 700 beam diagnostics
- > 5 km of vacuum line

Reused almost all

Arc 10
- 32 major dipoles (4m long)
- 40 quads (35x30x30cm)
- 81 power supplies
- 32 beam diagnostics
- 0.3 km of vacuum line

Transport to Hall D
- 4 major dipoles (4m long)
- 32 quads (35x30x30cm)
- 97 power supplies
- 44 beam diagnostics
- 0.3 km of vacuum line

All items are copies or variations of previous hardware

Beam Transport: East and West Arcs

- All dipoles changed from “C” to “H”
- Installation occurred during both shutdowns

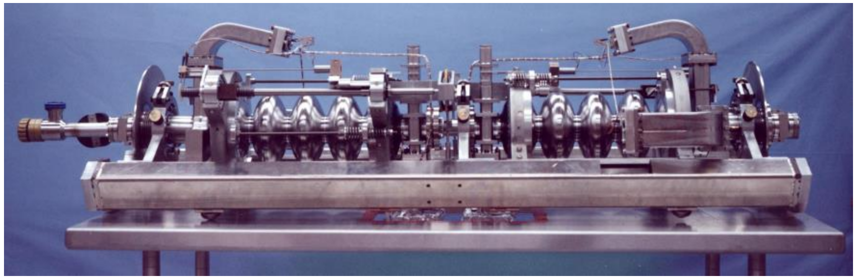
Beam Transport

- Upgraded 5 km of beamline and added ½ km of new beamline
- 256 arc dipoles removed, rebuilt, and re-installed
- All spreaders/recombiners and extraction chicanes fully removed (“broom clean”), reconfigured (including modifying the dipoles), and reinstalled with new stands
- New arc 10 and beamline to Hall D tagger vault
- Above included purchase, mapping, and installation of 230 quadrupoles and 50 new dipoles
- Beamline in Hall D tagger vault plus electron beam dump in tagger vault

Accelerating Cavities at CEBAF

We use both types for 12 GeV nuclear physics

Original CEBAF 5 cell cavity

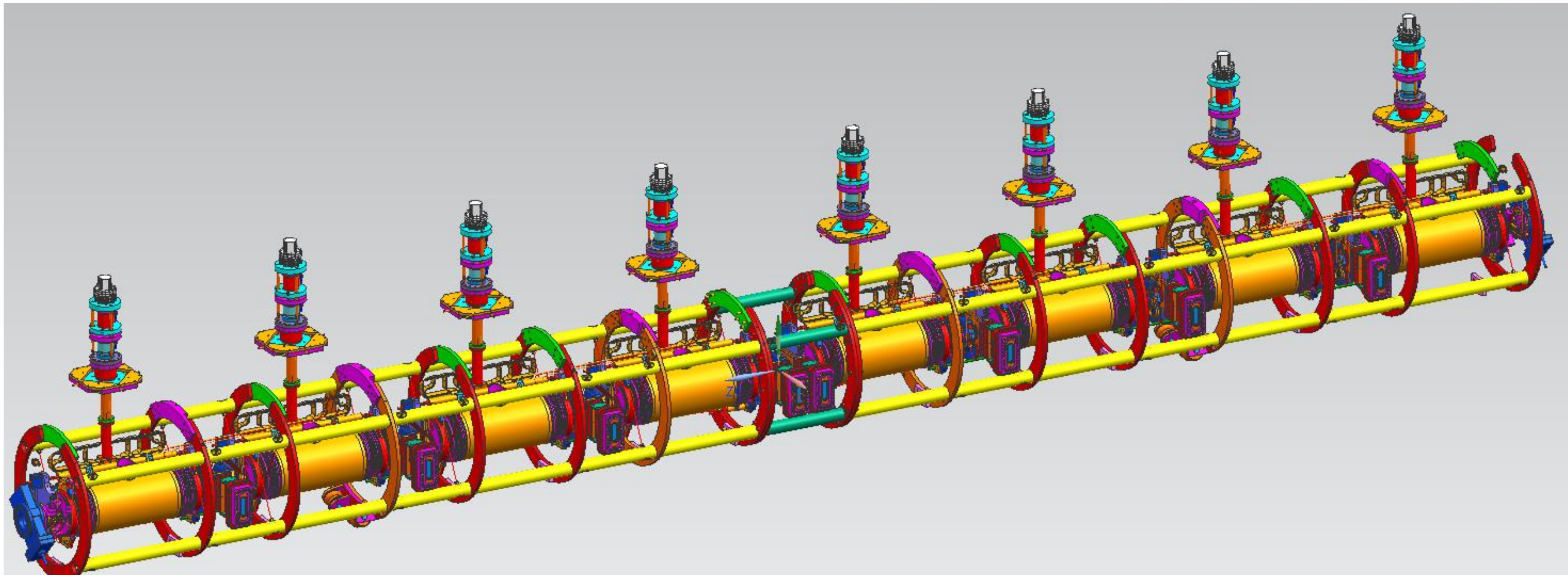


- 5-cell, Cornell-Type
- 338 cavities in 42-1/4 modules
- Design
  - Ea=5 MV/m
  - $Q_0=2.4\times10^9$ @ 5 MV/m
- Achieved after Helium Processing
  - $\langle Ea\rangle=7.5$ MV/m, $\langle Q_0\rangle=5\times10^9$@ 5MV/m
- Achieved after Refurbishing
  - $\langle Ea\rangle=12.5$ MV/m, $\langle Q_0\rangle=5\times10^9$ @ 5MV/m
- Total energy 2 x 600 MV
- 5 kW 2K cooling power
- 5 MW liquefier operation power

CEBAF upgrade cavity

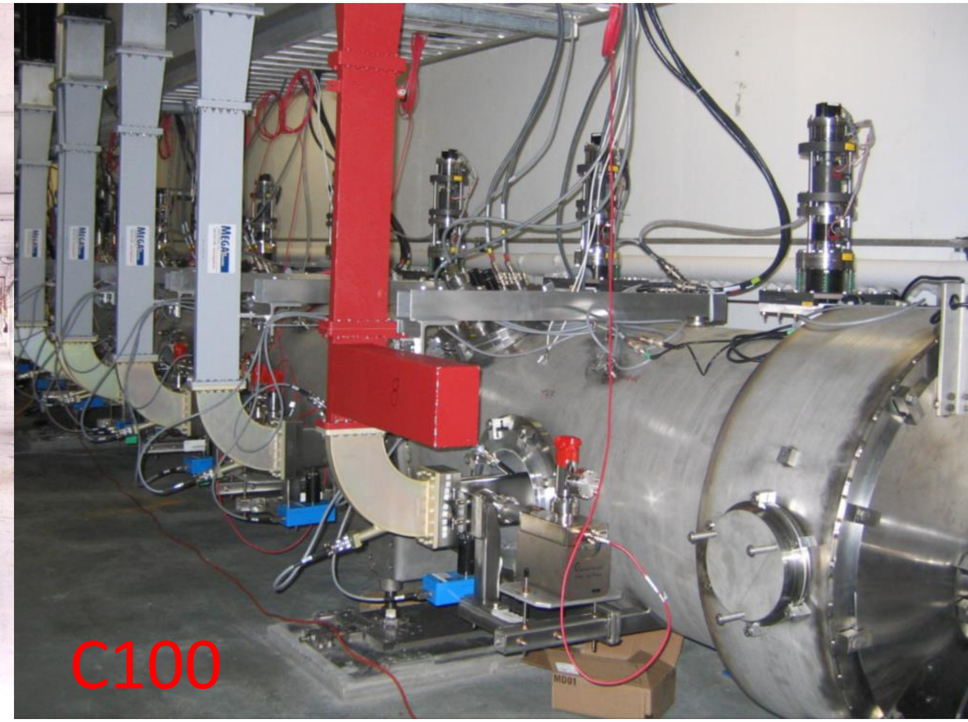
- 7-cell, Low-Loss Shape
- 80+8 cavities in 10+1 modules
- Design
  - Ea=19.2 MV/m
  - $Q_0=7.2\times10^9$ @ 19.2 MV/m
- Achieved
  - $\langle Ea\rangle=22.2$ MV/m
  - $\langle Q0\rangle$ @ 8.1×10^9 @ 19.2 MV/m
- Total energy 2 x 500 MV (+100 MV)
- Requires additional ~ 5 kW 2K cooling power
- Requires additional ~ 5 MW liquefier operation power

C100 Cryomodules



- Eight 7-cell cavities, same cryomodule footprint
- Cavity string suspended within space frame by nitronic rods (think bicycle spokes)
- Different tuners, different response to microphonic resonances
- Higher power klystrons, different low level RF control boards
- Smaller cryostat, different Heat Load/Temperature/Pressure interplay
- Higher levels of field emission

C100 Cryomodules



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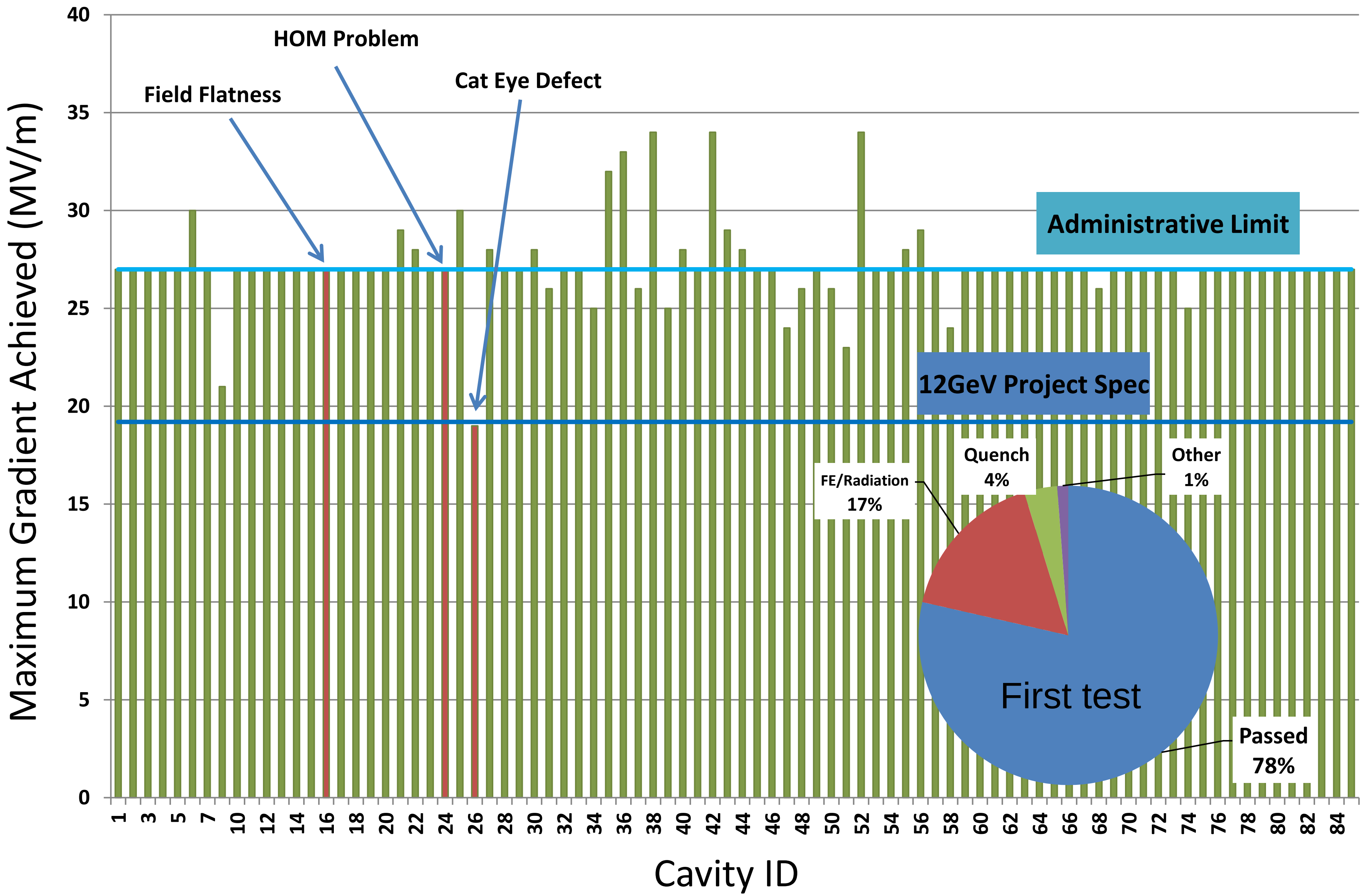
Jefferson Lab 12 GeV C100 Cavity Final E_{max}



C100 Cryomodule Construction

C100-1 and C100-2 in operation; C100-3 and C100-5 in the tunnel (safe storage)

C100-04 - Acceptance testing in progress

C100-06 – Cold mass assembly in progress

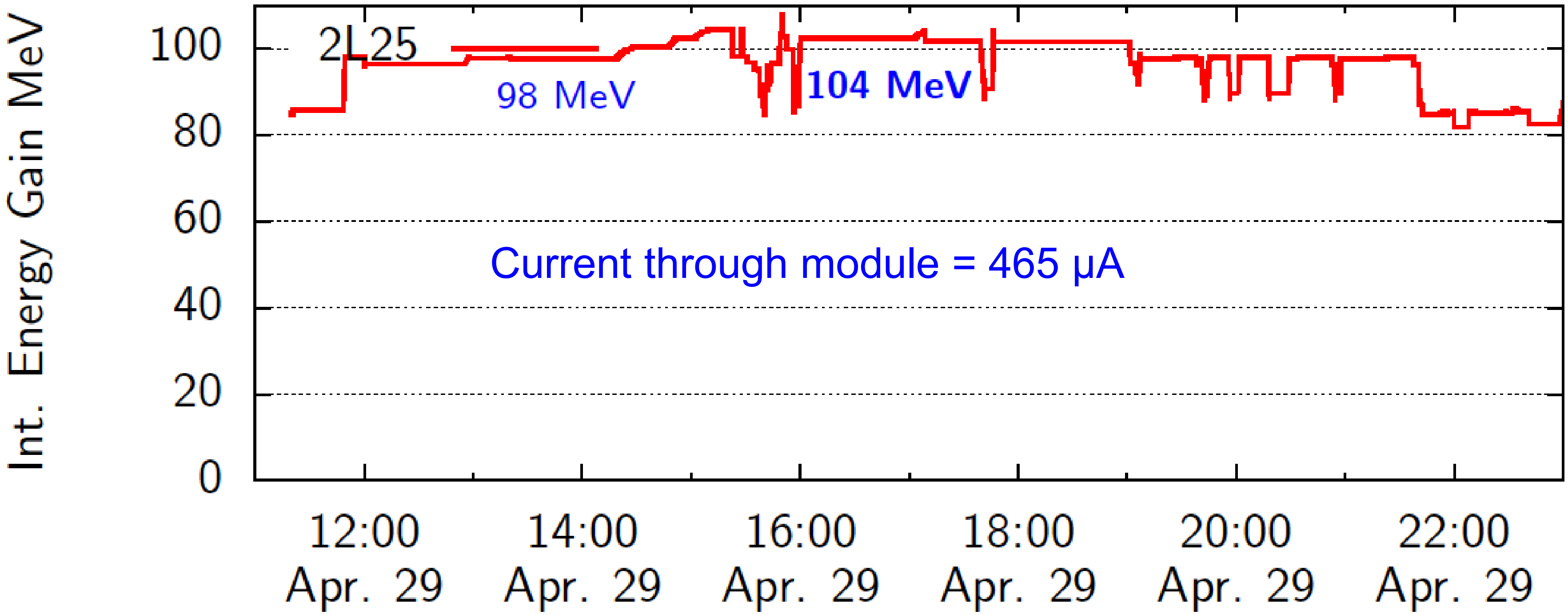
C100-07 – Final assembly in progress

C100-08 - He headers complete

C100-09 – Leak check in progress

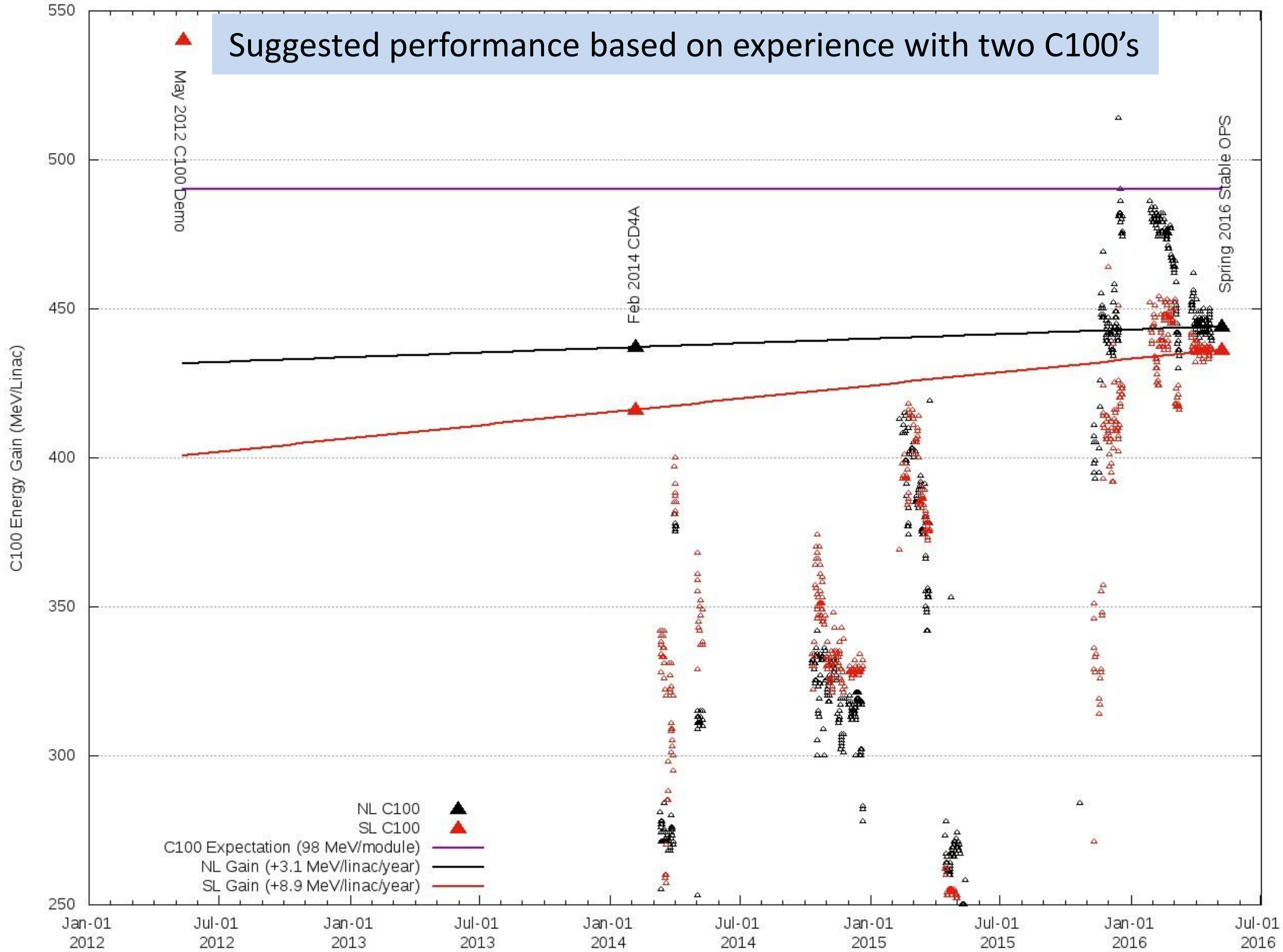
C100-10 – Cavity string assembly complete; staged in cleanroom.

C100 Performance Demonstration

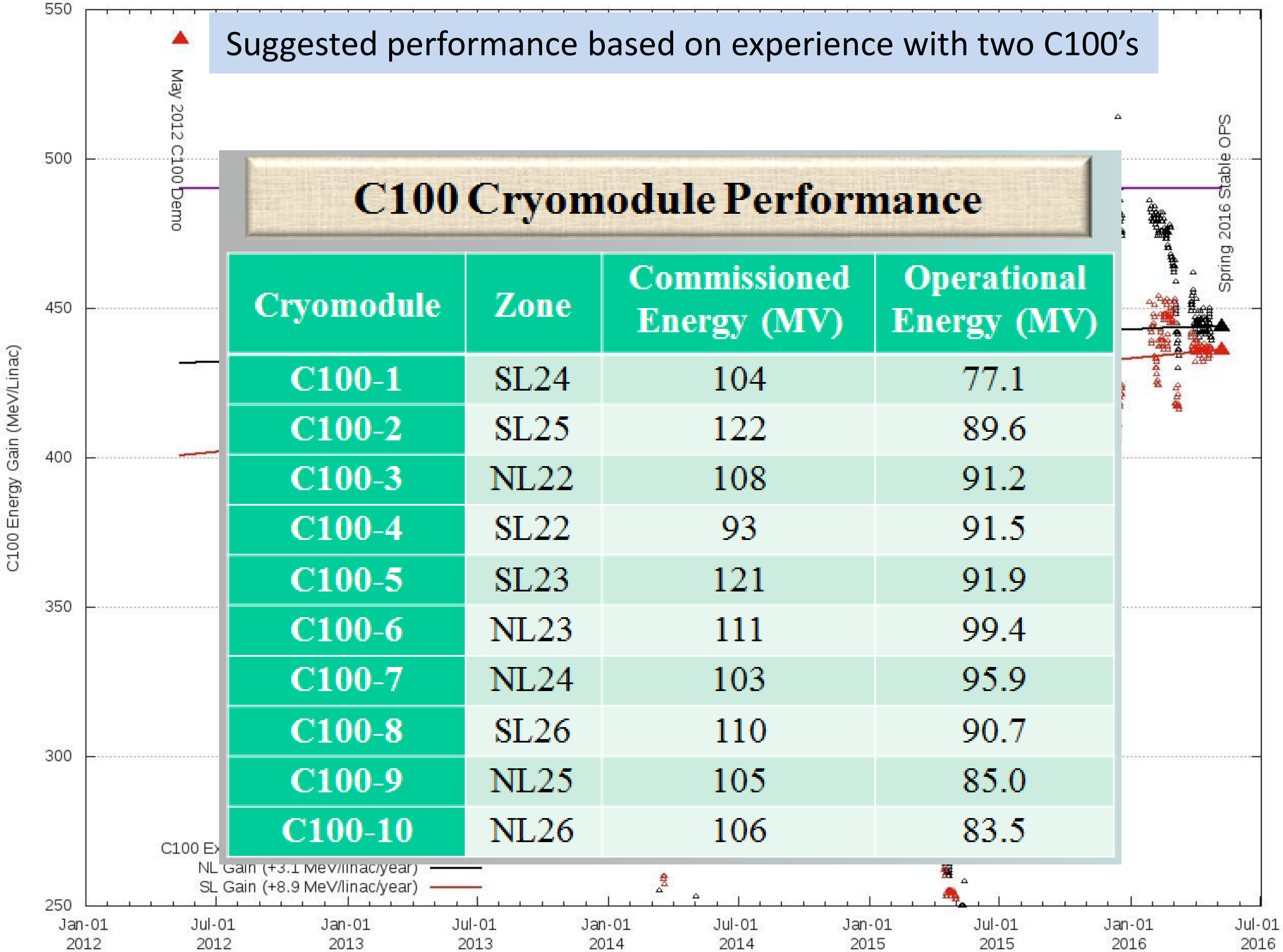


Two C100 cryomodules installed during 6-month down
Operated at nominal specifications during Qweak experiment

C100 Operational Performance with Beam



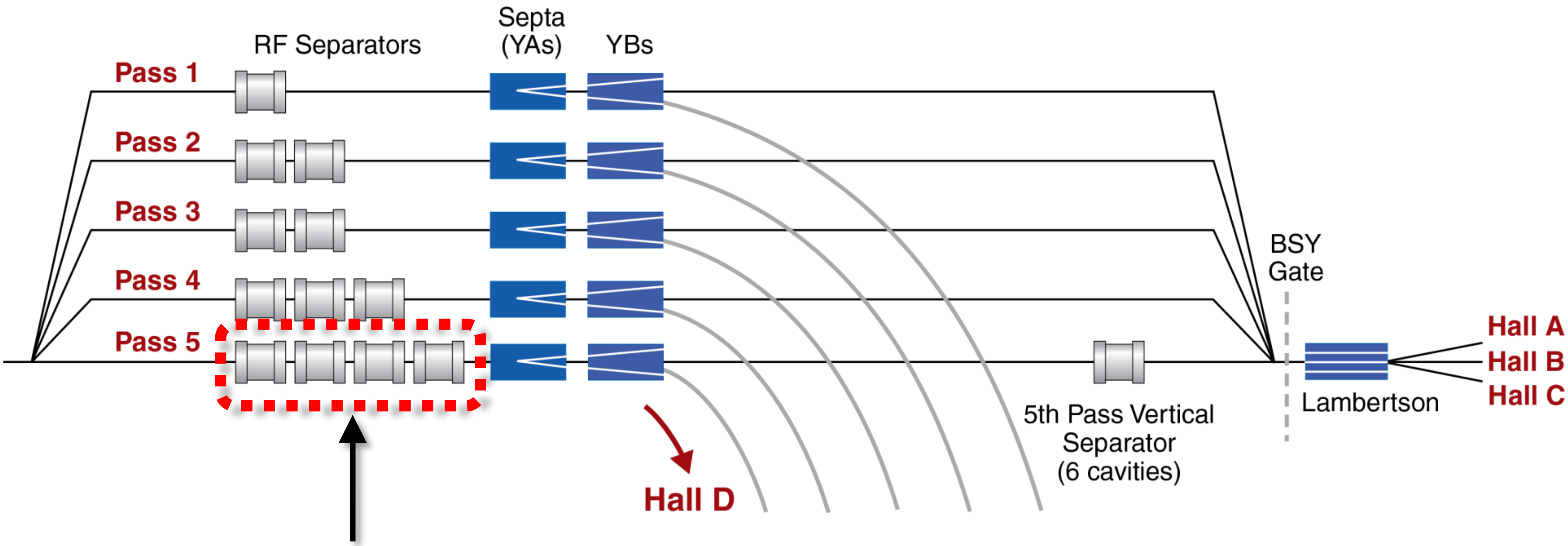
C100 Operational Performance with Beam



C100 Cryomodule Performance

Cryomodule	Zone	Commissioned Energy (MV)	Operational Energy (MV)
C100-1	SL24	104	77.1
C100-2	SL25	122	89.6
C100-3	NL22	108	91.2
C100-4	SL22	93	91.5
C100-5	SL23	121	91.9
C100-6	NL23	111	99.4
C100-7	NL24	103	95.9
C100-8	SL26	110	90.7
C100-9	NL25	105	85.0
C100-10	NL26	106	83.5

5th Pass RF Separation Hardware

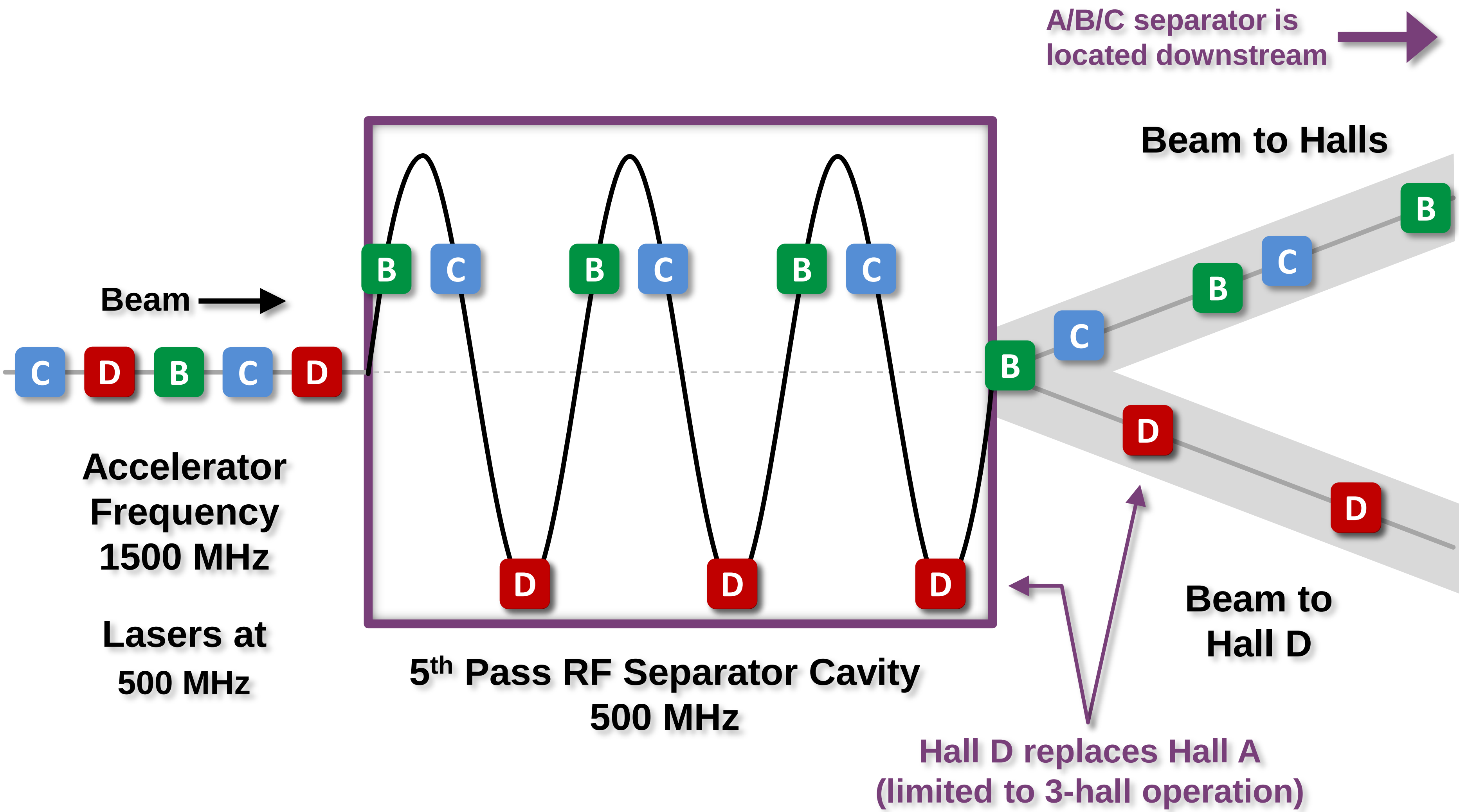


Horizontal 5th Pass Separator (kicks out Hall D for 5.5 pass)

D+2: 500 MHz

D+3: 750 MHz

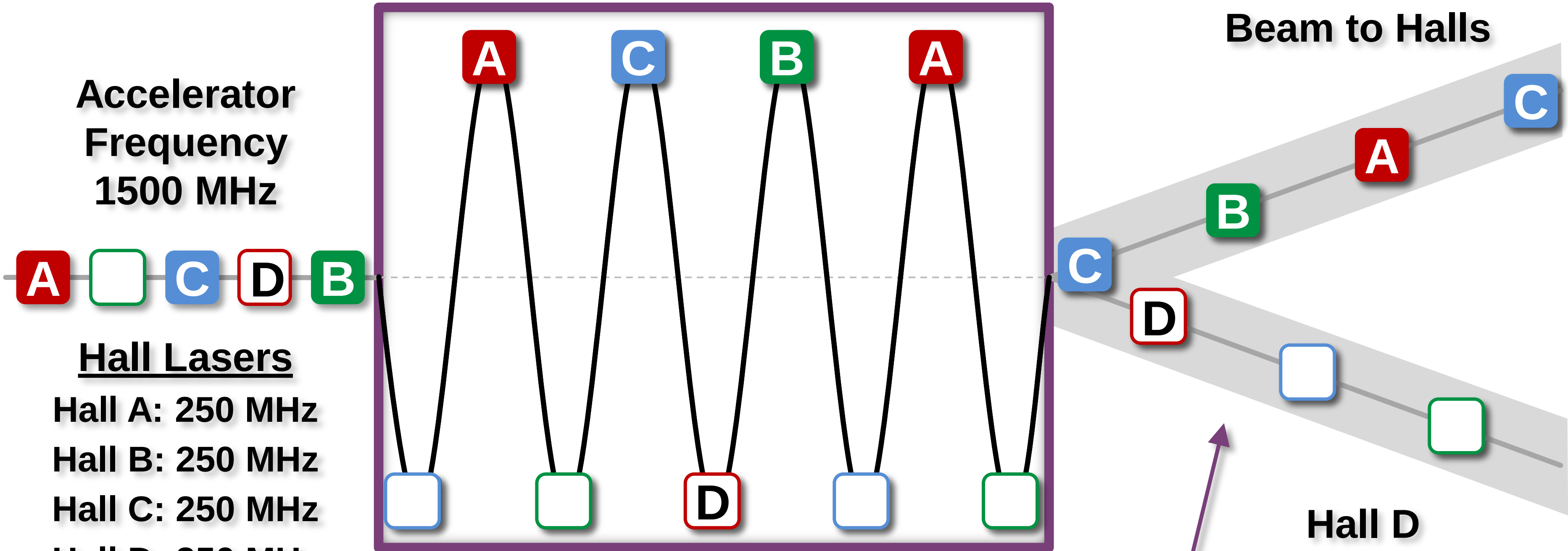
RF Separation – "D + 2"



RF Separation – "D + 3"

A/B/C separator is located downstream

Accelerator Frequency 1500 MHz



Hall D Beam

Hall Lasers

Hall A: 250 MHz

Hall B: 250 MHz

Hall C: 250 MHz

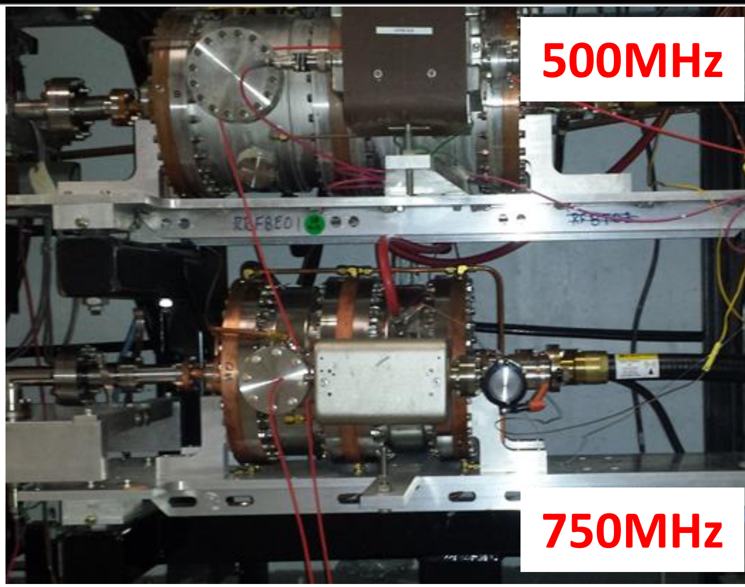
Hall D: 250 MHz

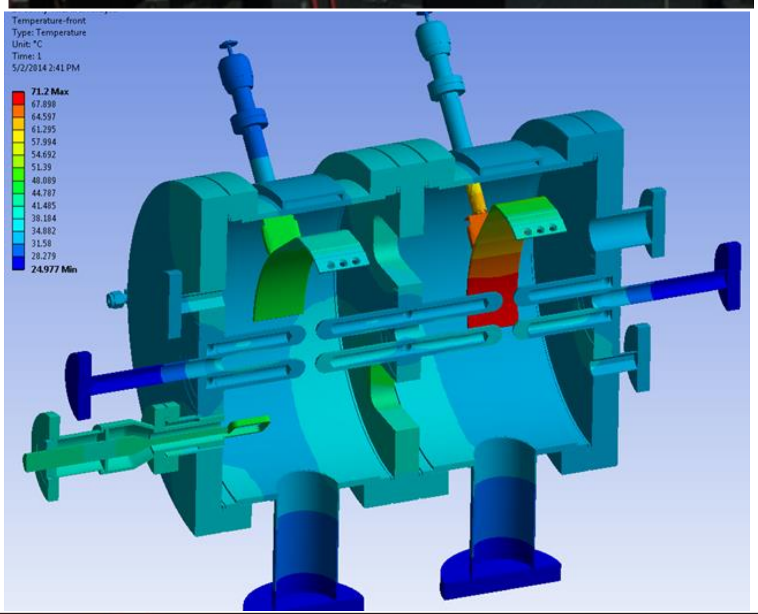
5th Pass RF Separator Cavity 750 MHz

New Hall D laser fills empty buckets at 250 MHz

Four-Hall Operation! (D+3)

750MHz Separation



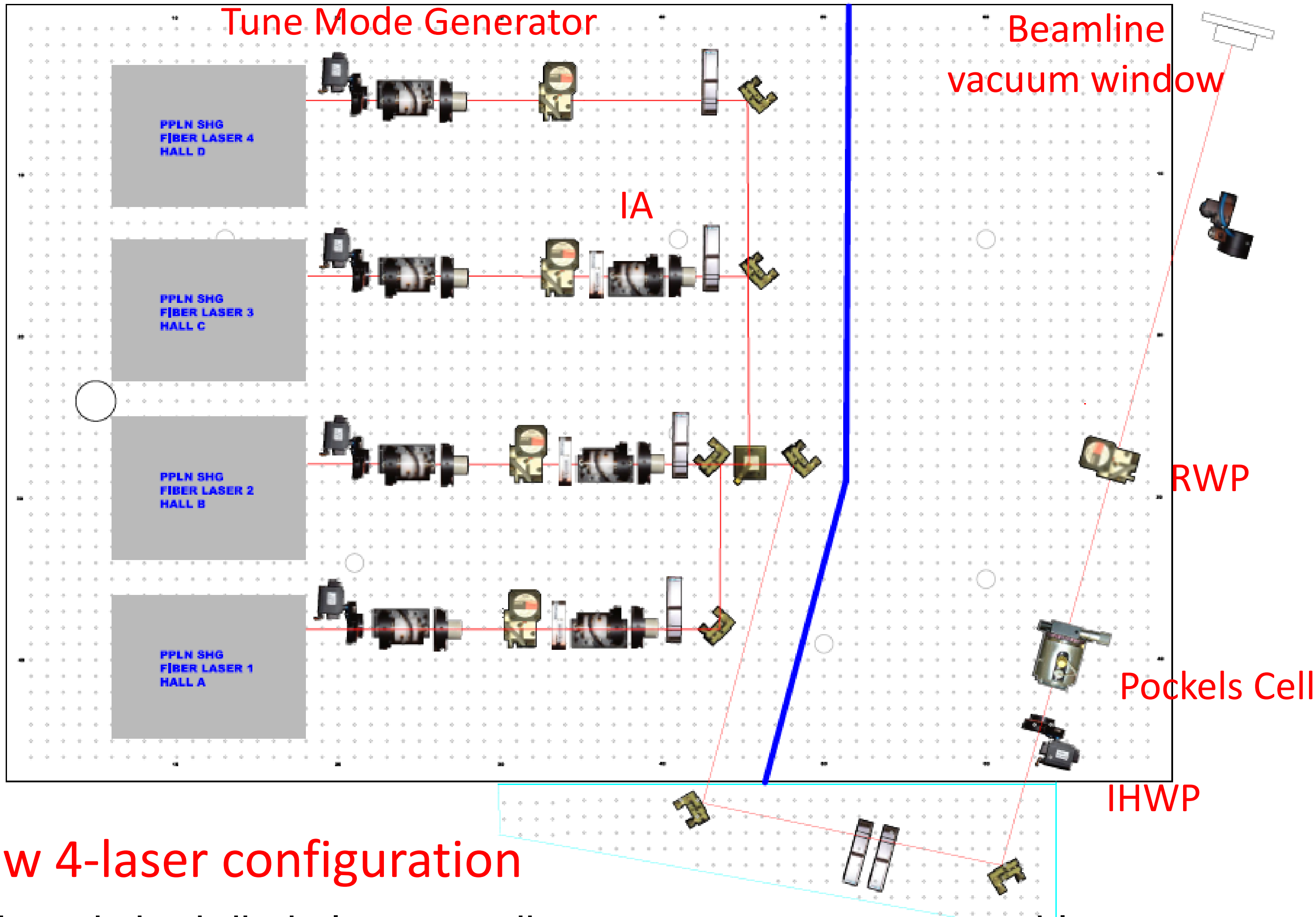


11 GeV maximum beam energy

Improvements were implemented Summer 2016 to increase beam separation:

- Proper cavity placement relative to Lambertson magnets (9% gain in separation)
- Increase IOT power and cooling controls (10% gain)

12 GeV Laser Table: Summer 2016

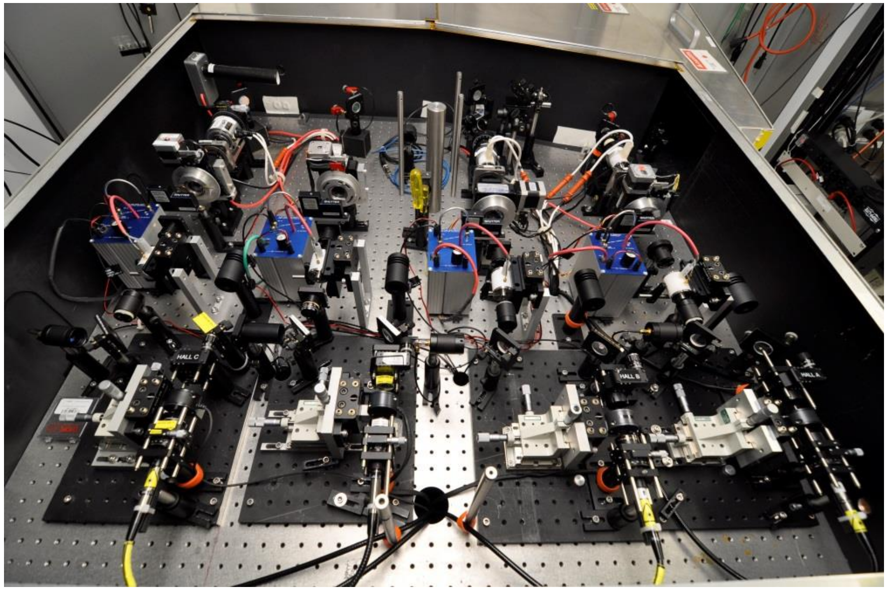


New 4-laser configuration

Gain-switched diode lasers + Fiber Amps + Frequency Doublers

Four Laser Upgrade for CEBAF

Fall 2015 – Spring 2016
- Simultaneous 3-beam operation with either 250/499 MHz rep rate
- Clever firmware solution allowed this with standard 499 MHz laser-RF system

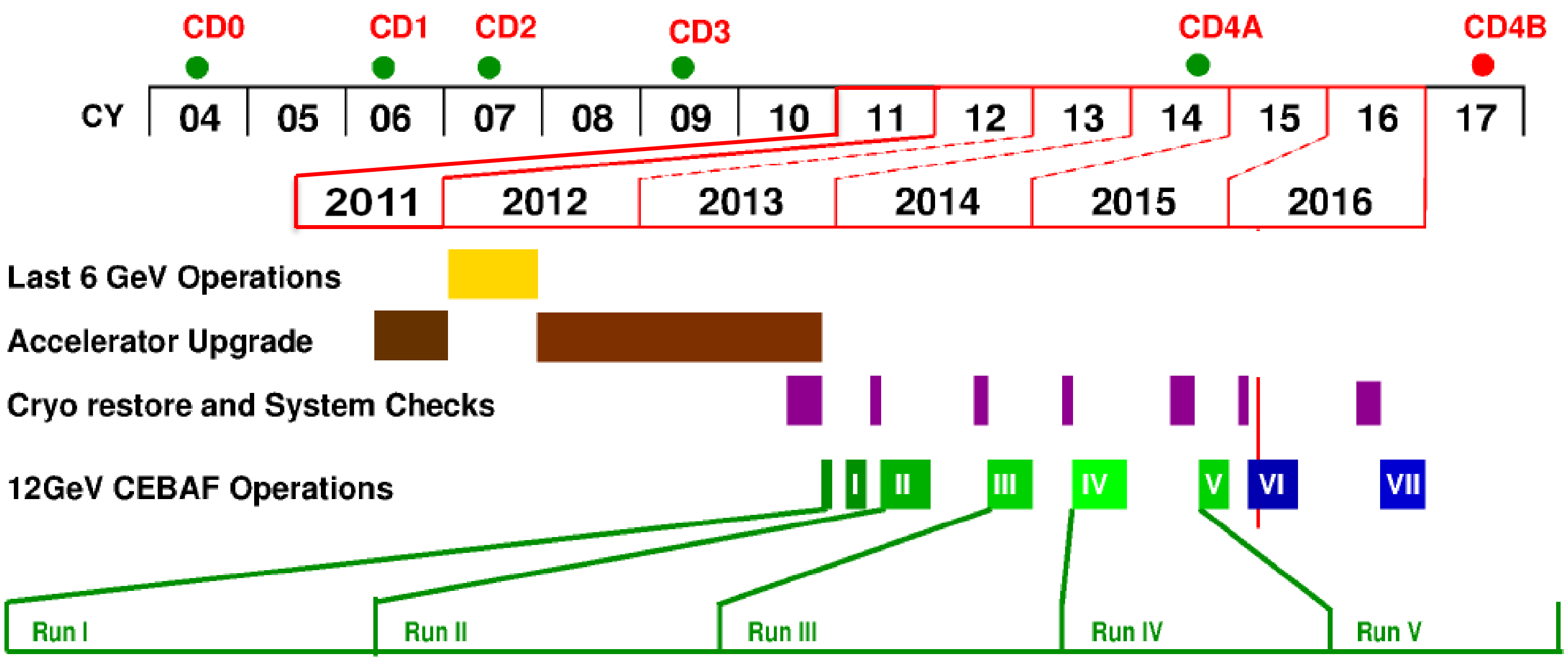


Summer 2016
- Rebuilt laser system, added 4th laser
- Four beams from polarized electron source (chopper photo, right)

Winter 2016
- Planned installation of final 4-laser RF system
- Quick switch between rep rates from MCC, full 360 degree phase adjust

Spring 2017
- Planned 4-beam delivery to 4 Halls

CEBAF 12 GeV Upgrade Schedule



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RF trip rate 40–50 trips/h	5.5 pass beam	Hall–D KPP established	5th pass RF–separation	5.5 pass setup
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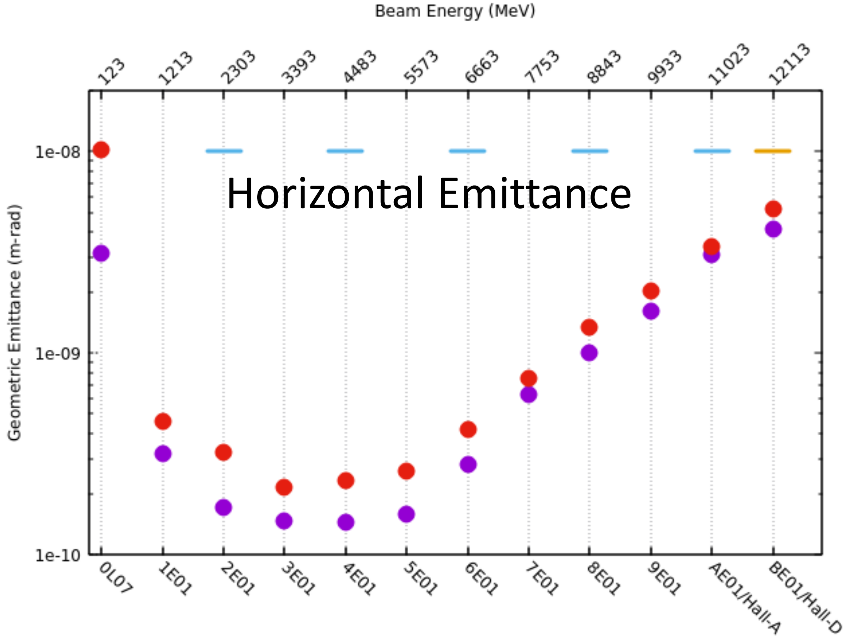
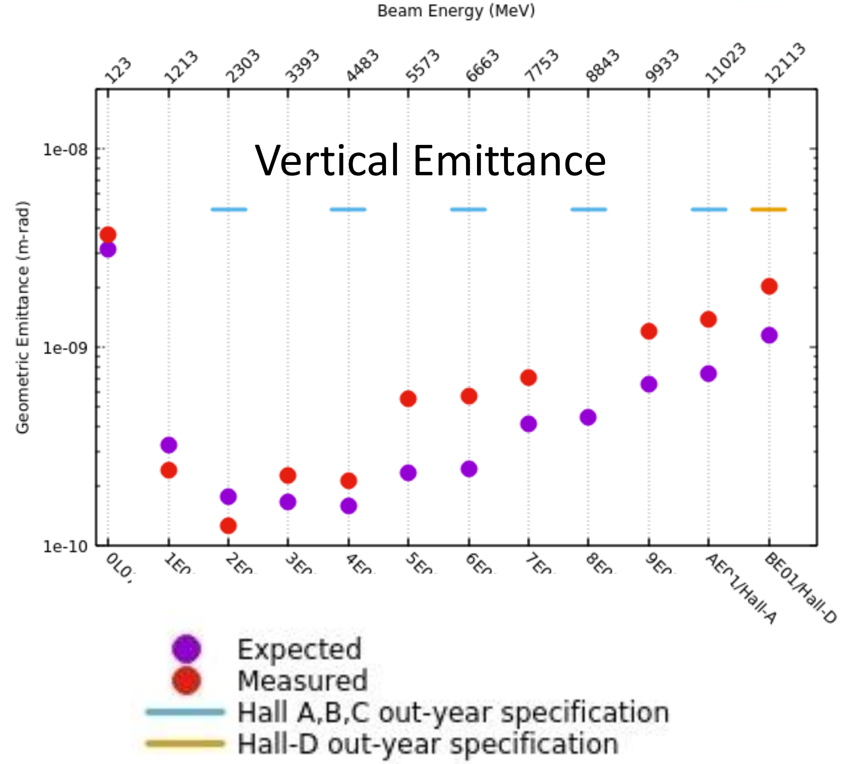
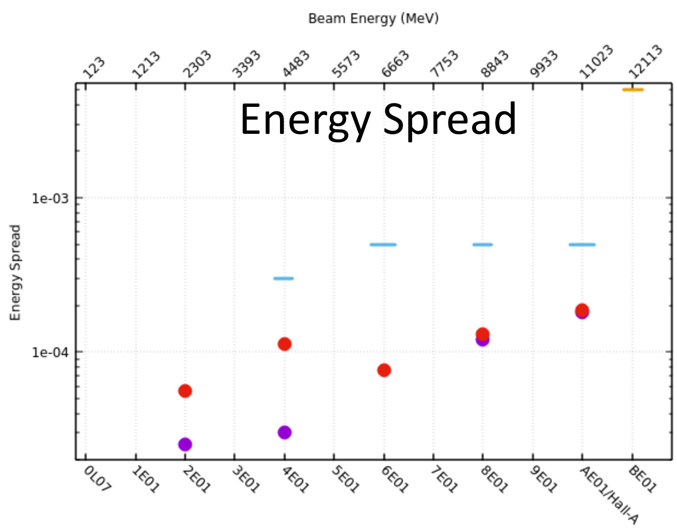
				11 GeV to A
			1 GeV/pass	770kW CW beam
5 weeks	6 weeks	9 weeks	11 weeks	5 weeks

36 weeks of beam operation to date.

Beam Parameters at 12 GeV (2.2 GeV/pass)







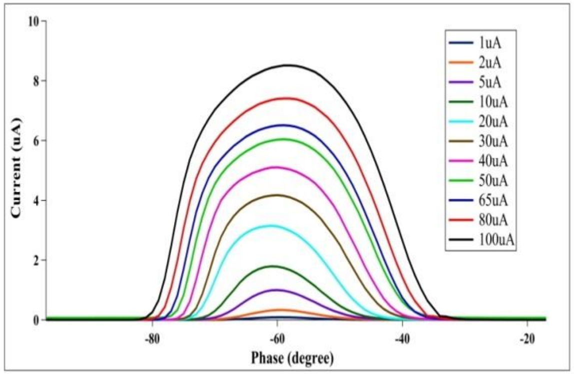
- Beam parameters at 12 GeV meet **out-year** specification
- Growth in emittance/energy spread due to synchrotron radiation - agrees with expectations

Bunchlength Evolution at 12 GeV

TABLE 10: Bunch length results (rms value) summary at all locations

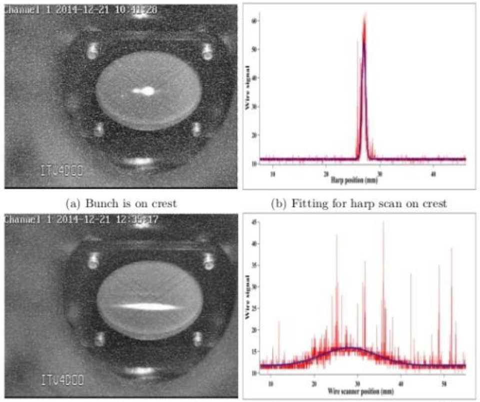
Technique	Location	Beam Energy	Measured	Expected
Brock cavity	A2	130 keV	8.31 ± 0.01 mm	6.8 mm
Slit-scan	Chopper chamber	130 keV	7.16 ± 0.04 mm	7.9 mm
Brock cavity	1D dump	130 keV	10.41 ± 0.04 mm	8.1 mm
Back-phasing	4D dump	102 MeV	80.8 ± 2.0 μm	100 μm
SLM1	Arc1	1052 MeV	91.4 ± 6.5 μm	100 μm
SLM1(compression)	Arc1	1052 MeV	46.1 ± 3.5 μm	56 μm
SLM2	Arc2	2002 MeV	112.8 ± 5.8 μm	100 μm
SLM2(compression)	Arc2	2002 MeV	42.5 ± 5.1 μm	56 μm

Slit Scan @ 130 keV



(a) Slit scan for A-laser at 249.5 MHz

RF Phase Shifts @ 102 MeV



(a) Bunch is on crest (b) Fitting for harp scan on crest

(c) Bunch is off crest by $+90^0$ (d) Fitting for harp scan at $+90^0$

RF Phase Shifts @ 1050 MeV

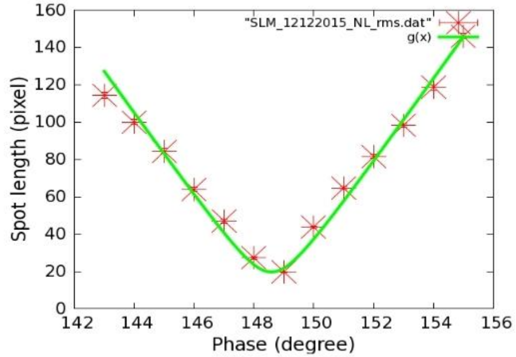


FIG. 58: Hyperbola fitting for Arc1 - rms calculation (CW mode).

FY16 Beam Operations Summary

Fall 2015

- 5 weeks of beam operations at design energy: 12 GeV
  - Measured transverse emittance: **12 GeV CEBAF meets out-year spec**
  - Helium Processing in Summer 2015 helped achieve the design energy
    - Insufficient energy reach margin for reliable operations
  - 5th pass RF separation at design energy established (new 750 MHz separators)

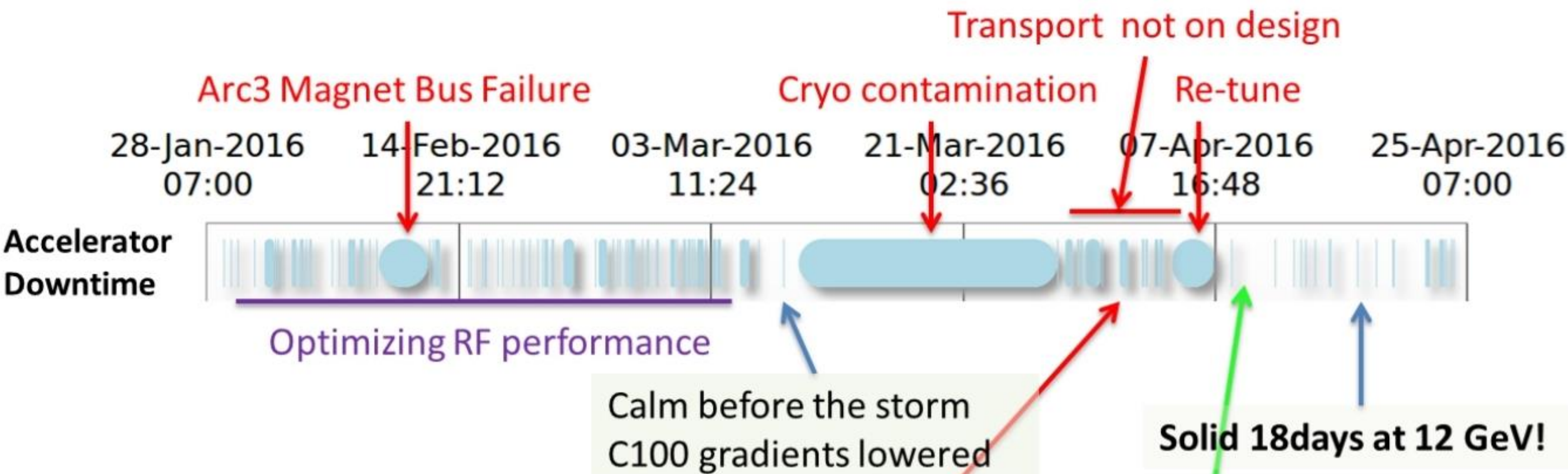
Spring 2016

- 11 weeks planned, 10 weeks actual of beam operations at design energy: 12 GeV
  - DVCS/GMp experiment in Hall-A (passes 2,4,5) **polarization ~ 89%**
  - GlueX engineering run in Hall-D (pass-5.5) **COMPLETED**
  - HPS experiment in Hall-B (pass-1)
- Reliability issues (RF systems, Cryo), more details on next slides

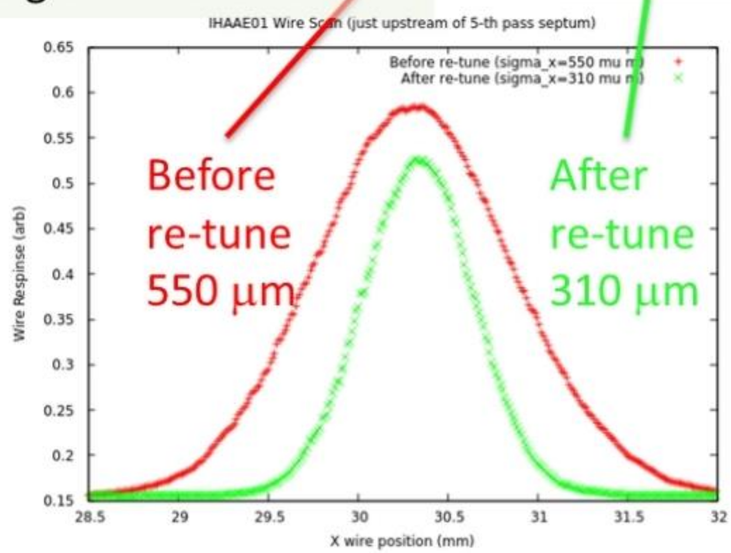
Summer 2016

- 5.5 weeks low power, one CHL configuration at ~50% of design energy
  - PRad experiment in Hall-B (passes 1 & 2) **COMPLETED**
  - Hall-C Beamline checkout (pass 2) **COMPLETED**

Spring 2016 Beam Operations



- First Physics runs with CEBAF at design energy, 12 GeV to Hall-D, 11 GeV to Hall-A (5-pass).
- 5-pass separation at design energy (11 GeV).
  - 5th pass separation has no margin and requires beam transport to be on-design for robust operation.



Horizontal beam size upstream of 5th pass septum

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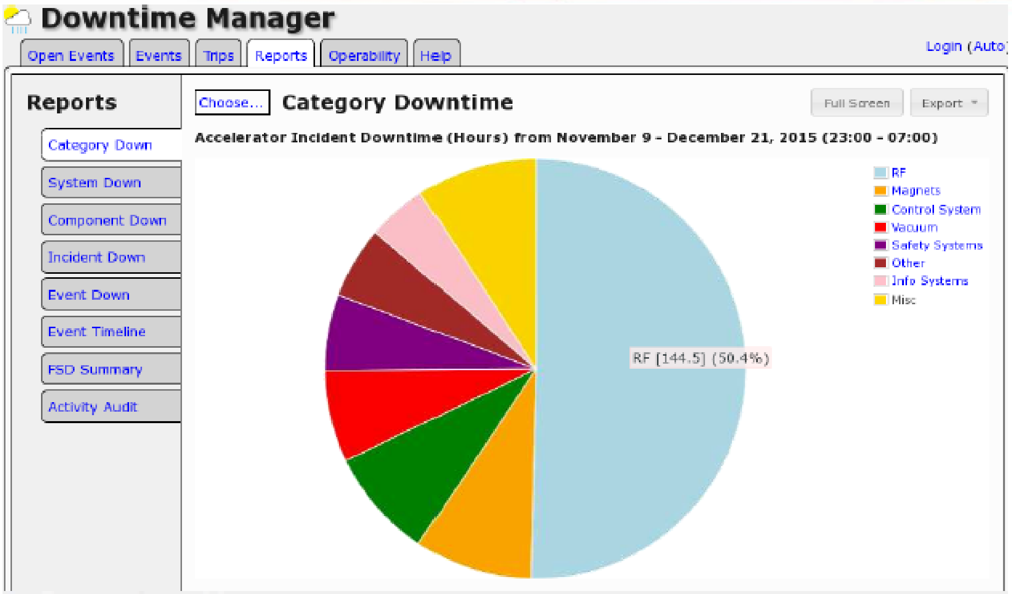
Some Challenges

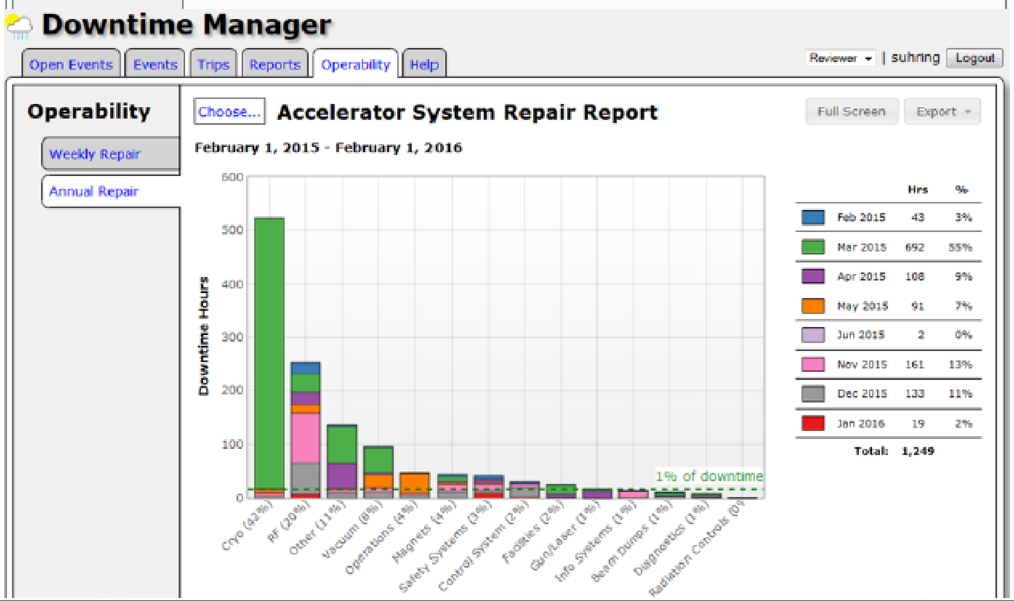
Fall2015: 5w, 2.2 GeV/pass

- Gradient delivery system accounts for half the downtime
- Other systems, Magnets, Control, Vacuum, Safety make up the other half.

Feb. 2015 → Feb. 2016

- Cold Compressor 4 failure: Large Cryo downtime required to reconfigured CEBAF to operate on one CHL.
- RF systems downtime half that of Cryo.





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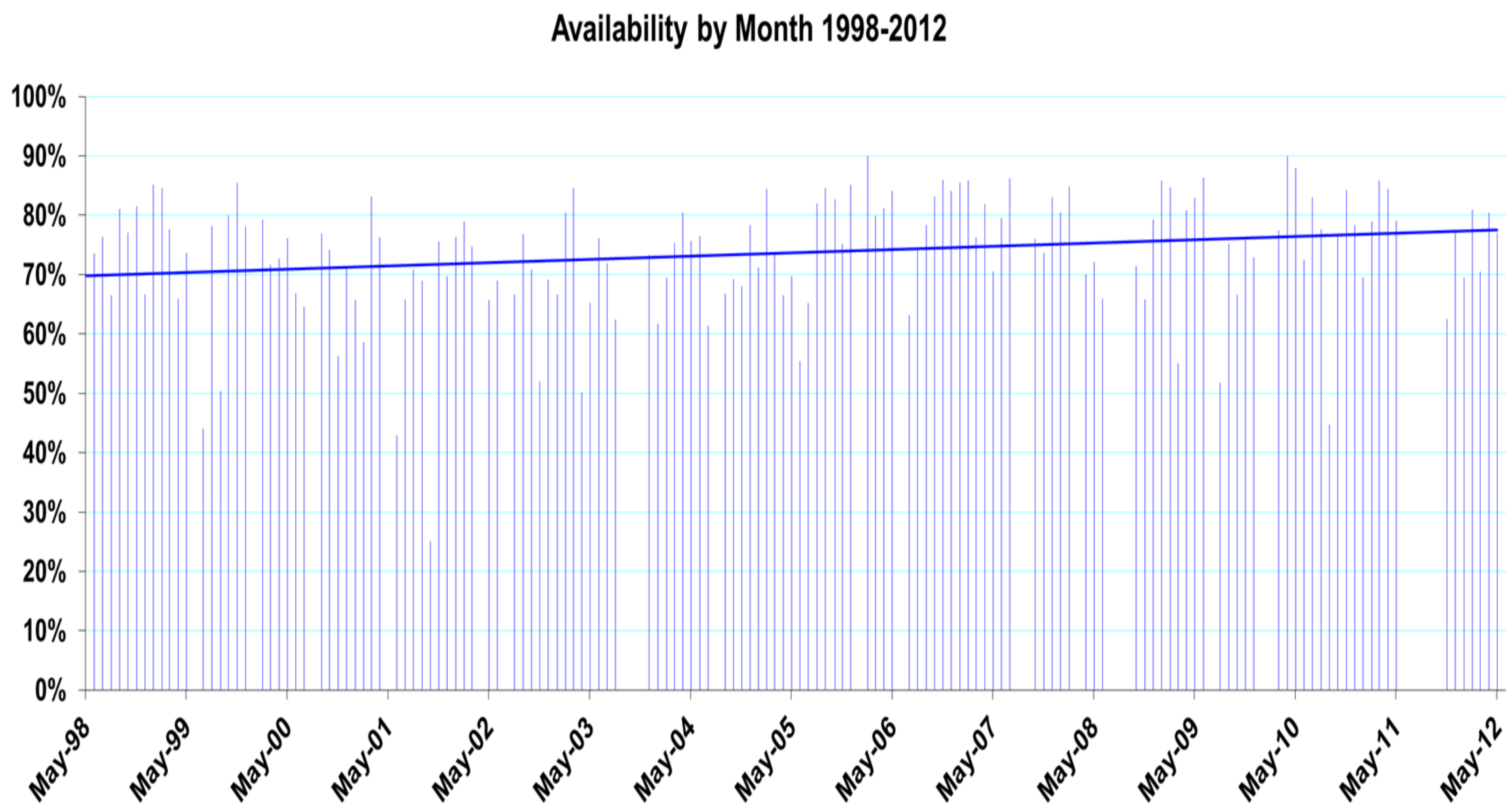
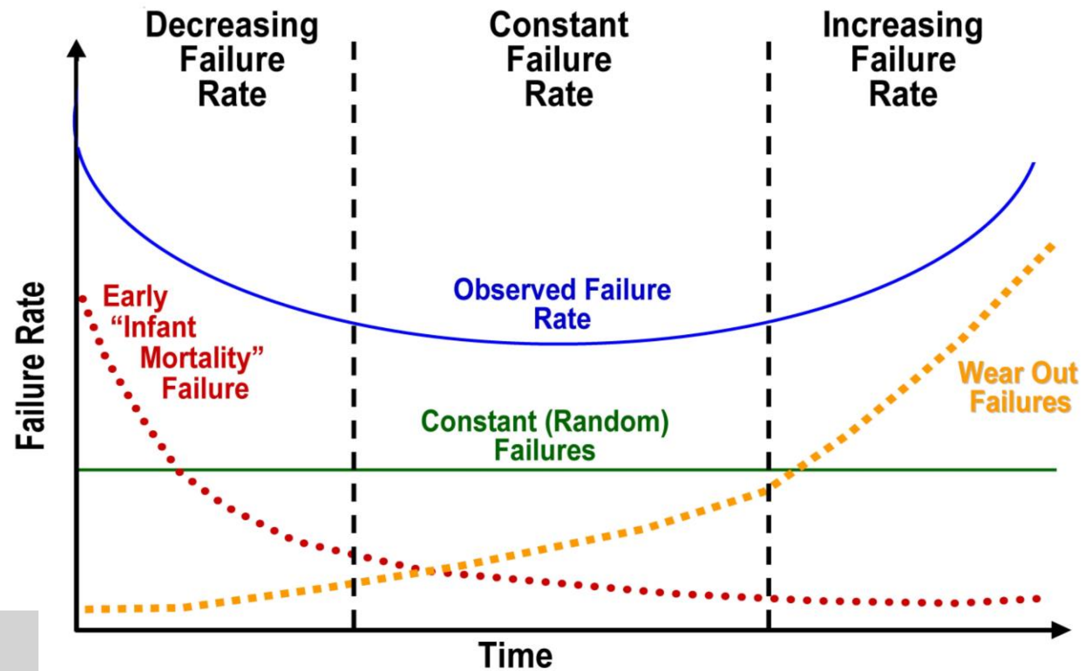
4/6GeV Availability Trend

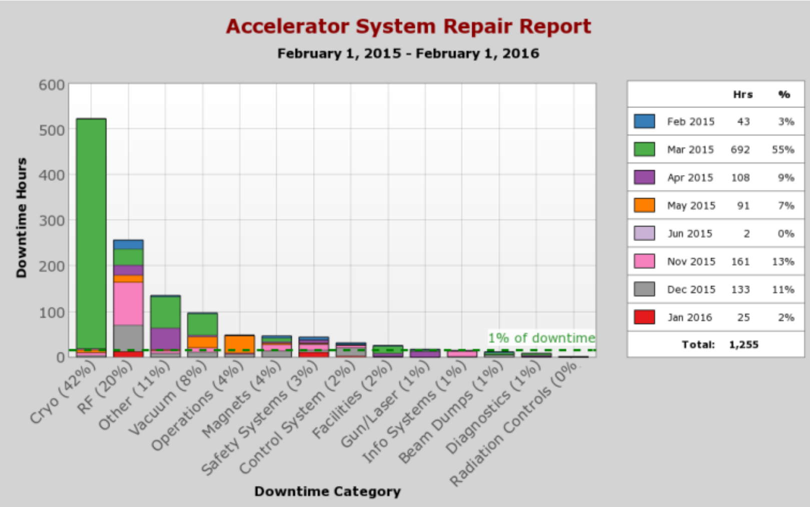


"the good ol' days"

Reliability of Complex Systems

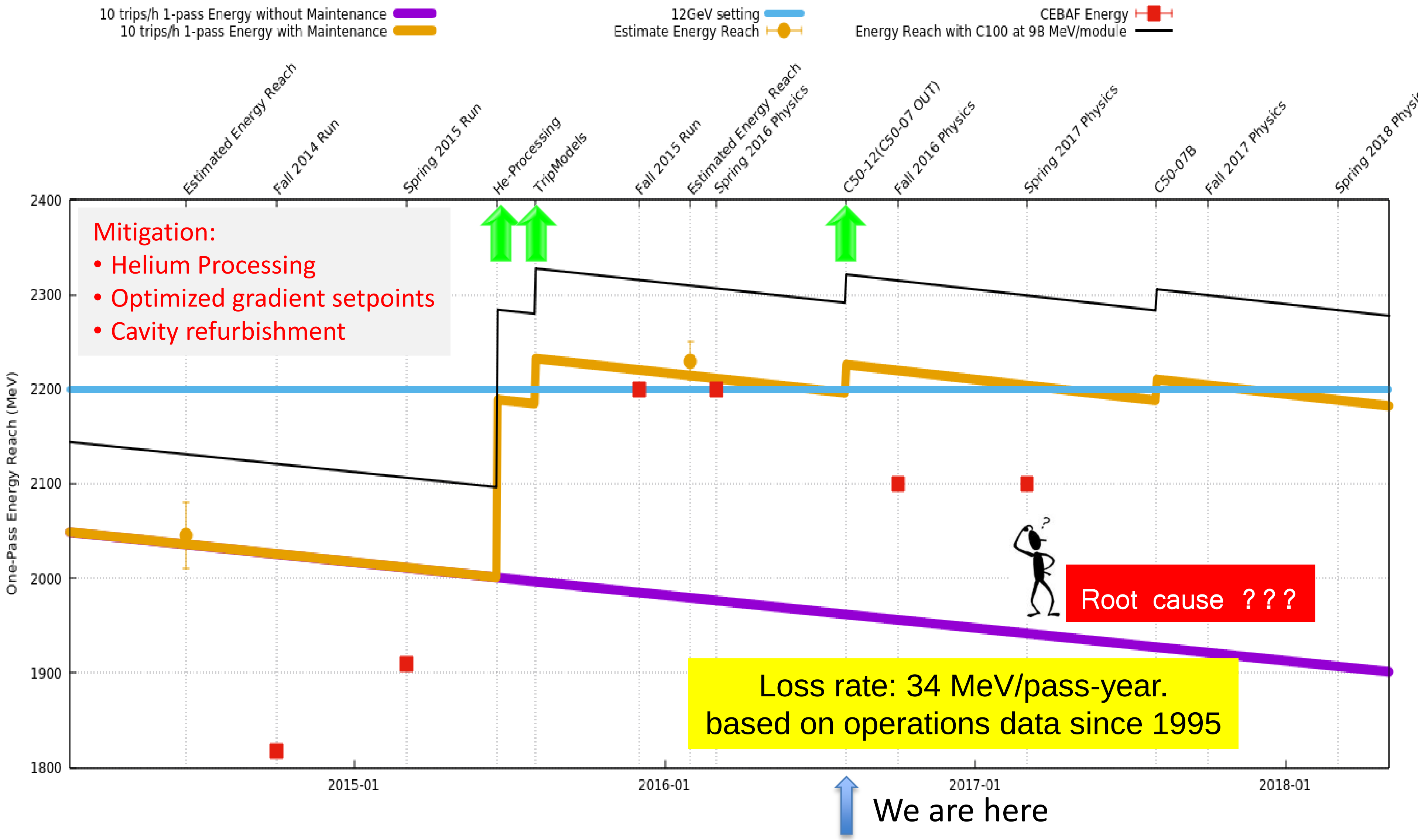
12 GeV CEBAF is a combination of new and old systems: Both sides of the “bathtub curve” - Reliability Team formed





- All downtime events greater than 5 minutes in duration are tracked
- Downtime statistics are presented, reviewed and discussed weekly
- Downtime statistics are used to prioritize near term work and develop annual work plan

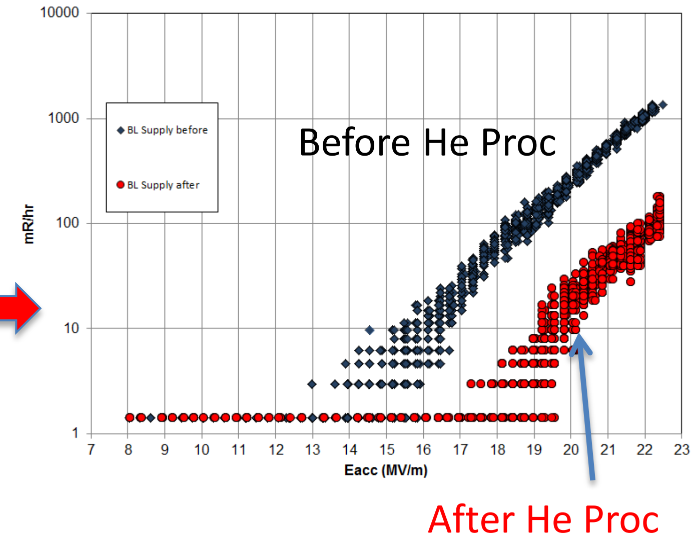
Energy Reach



Helium Processing

- Utilized during 6 GeV era to improve maximum operating gradient of SRF cavities
- Add small amount of gaseous He into the cavity
- Process cavity with RF power, watch for the radiation signature to drop (field emitters extinguished)
- Warm up the cavity to remove the He
- Determine the new maximum operating gradient

Representative gain (~4 MV/m) on one C100 cavity recently Helium processed



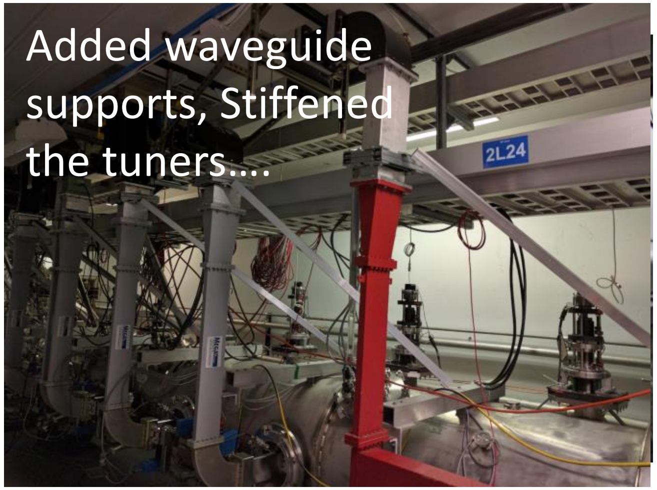
Application	C20 Gain (MV/m)	C50 Gain (MV/m)	C100 Gain (MV/m)
First	**1.2**	1.9	**3.8**
Second	**0.9**	1.4	2.9
Third	**0.7**	1.0	2.2

Table 12: Estimated gains from initial and subsequent applications of Helium processing on the three CEBAF cavity types. **Bold** values are derived from the references, plain text values are a best guess.

C100 Susceptibility to Microphonics

C100 Cavity gradients

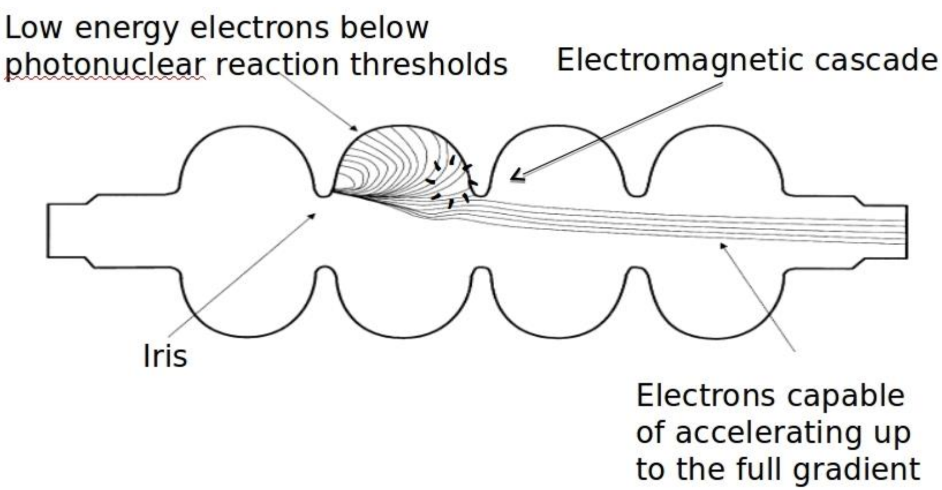
- The drops in figure below show the cavity faulting OFF during the day due to construction and truck traffic (or any low frequency acoustic noise, e.g., fan)
- ESH&Q Building construction halted
- Reason: RF Power could not compensate for the rapid cavity detuning

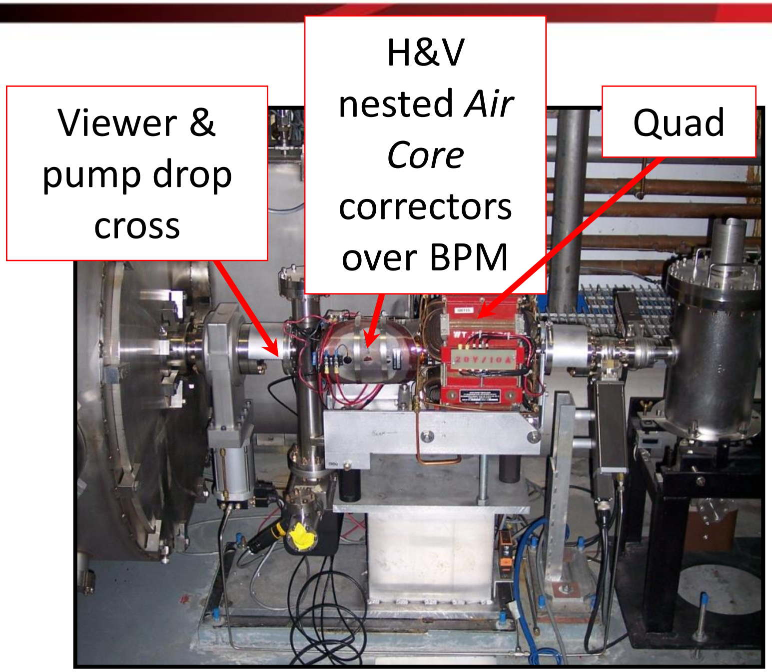


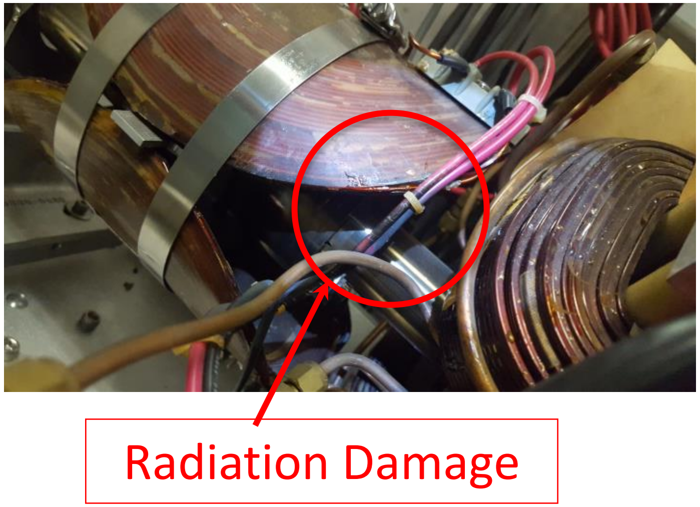
C100 - 0 Cavity Gradients

C100 Operational Experience - Field Emission

- Field emission heats nearby beamline, stimulates gas desorption
- Vacuum pump faults
- Vacuum interlock drops cryomodule out of RF
- Can damage equipment and activate material







Energy Reach

- Gradient insufficient to support reliable 12 GeV operations
  - Average C100 performance below design
    - Gradient Team to solve the problem
- Gradient Degradation (~34 MeV/pass/year)
  - Accumulation of new field emitters, particulate on the cavity surface
    - Identify source of particulate (in progress)
    - Mitigate: Develop the plan, approve the plan, implement
  - C20 refurbishment program (C50->C75) in place until degradation is mitigated
- Radiation Damage of components
  - C100 gradient large enough to accelerate field emitted electrons to energies above Neutron threshold (~10 MeV)
    - Optimize C100 gradient/field emission ratio (Gradient Team)
    - Helium process to reduce field emitter sites
    - Improve particulate control, maintain low FE state post HeProc

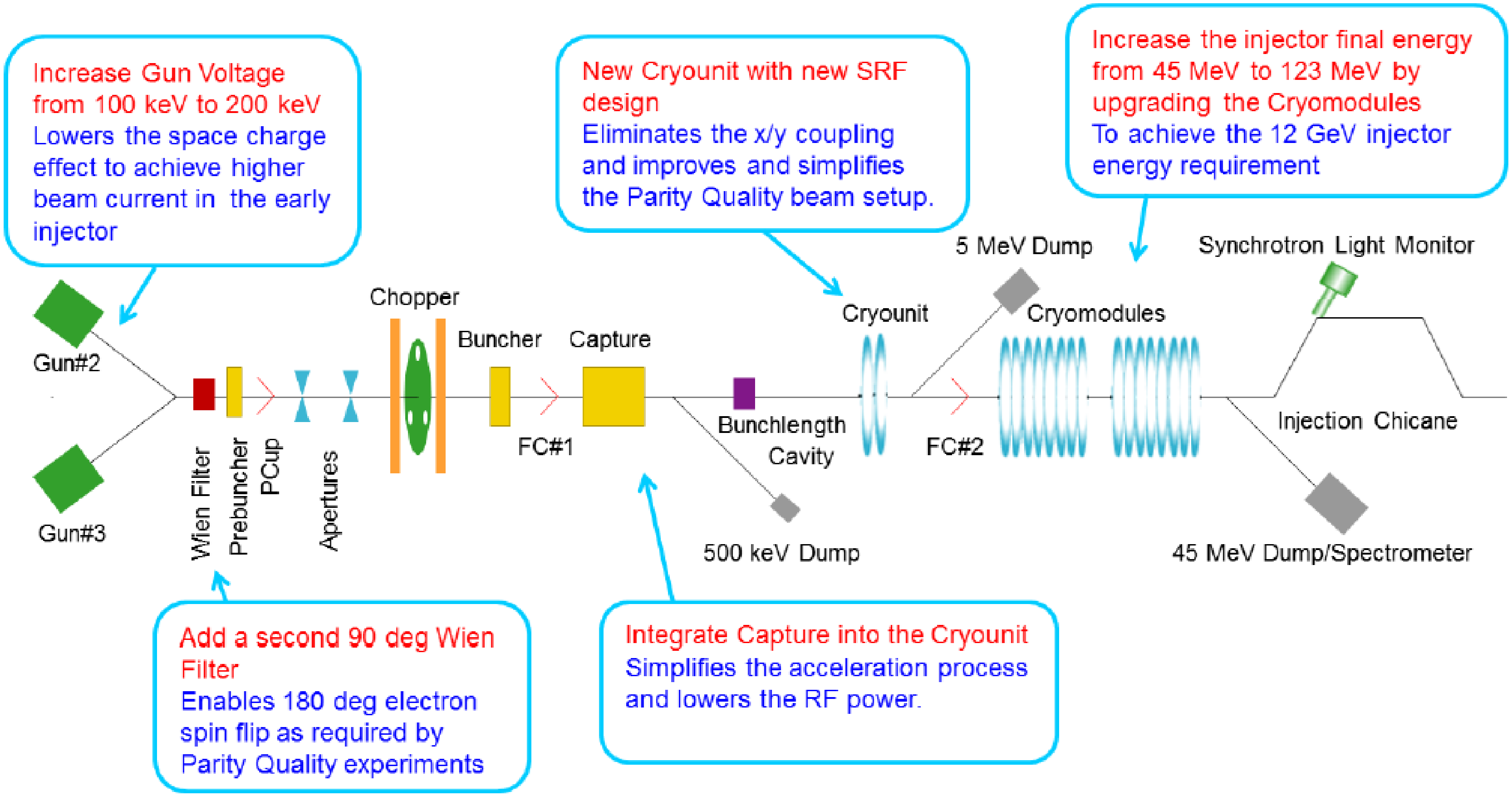
CEBAF Parity Violation Experiments

Experiment	Energy (GeV)	Pol (%)	I (μA)	Target	A_{PV} Expected (ppb)	Charge Asym (ppb)	Position Diff (nm)	Angle Diff (nrad)	Size Diff ($\delta\sigma/\sigma$)
HAPPEx-I (Achieved)	3.3	38.8 68.8	100 40	^{1}H (15 cm)	15,050	200	12	3	
G0-Forward (Achieved)	3	73.7	40	^{1}H (20 cm)	3,000-40,000	300±300	7±4	3±1	
HAPPEx-II (Achieved)	3	87.1	55	^{1}H (20 cm)	1,580	400	2	0.2	
HAPPEx-III (Achieved)	3.484	89.4	100	^{1}H (25 cm)	23,800	200±10	3	0.5±0.1	
PREx-I (Achieved)	1.056	89.2	70	^{208}Pb (0.5 mm)	657±60	85±1	4	1	
QWeak-I (Achieved)	1.155	89	180	^{1}H (35 cm)	281±46	8±15	5±1	0.1±0.02	
QWeak (Analysis In Progress)	1.162	90	180	^{1}H (35 cm)	234±5	<100±10	<2±1	<30±3	$<10^{-4}$
PREx-II (To Be Scheduled, FY18?)	1	90	70	^{208}Pb (0.5mm)	500±15	<100±10	<1±1	<0.3±0.1	$<10^{-4}$
MØLLER (To Be Scheduled, FY21+?)	11	90	85	^{1}H (150 cm)	35.6±0.74	<10±10	<0.5±0.5	<0.05±0.05	$<10^{-4}$

- PREx-II and its cousin, CREx, have requirements similar to QWeak-I. CEBAF can support these experiments without modification.
- Møller PQB requirements order of magnitude more stringent than previous parity experiments.

CEBAF Injector Upgrade

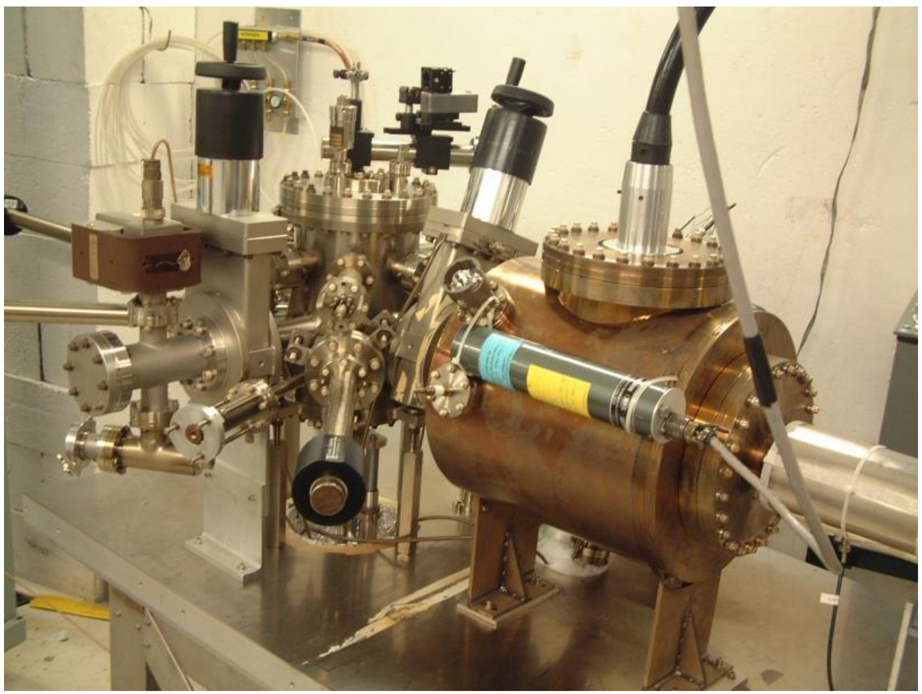
- Upgrade Gun HV to reduce space charge effects, minimize losses, improve A_Q stability.
- Upgrade $\frac{1}{4}$ cryomodule to reduce/eliminate x/y coupling.
- Upgrade all the elements between Gun and $\frac{1}{4}$ for 200 keV beam energy.

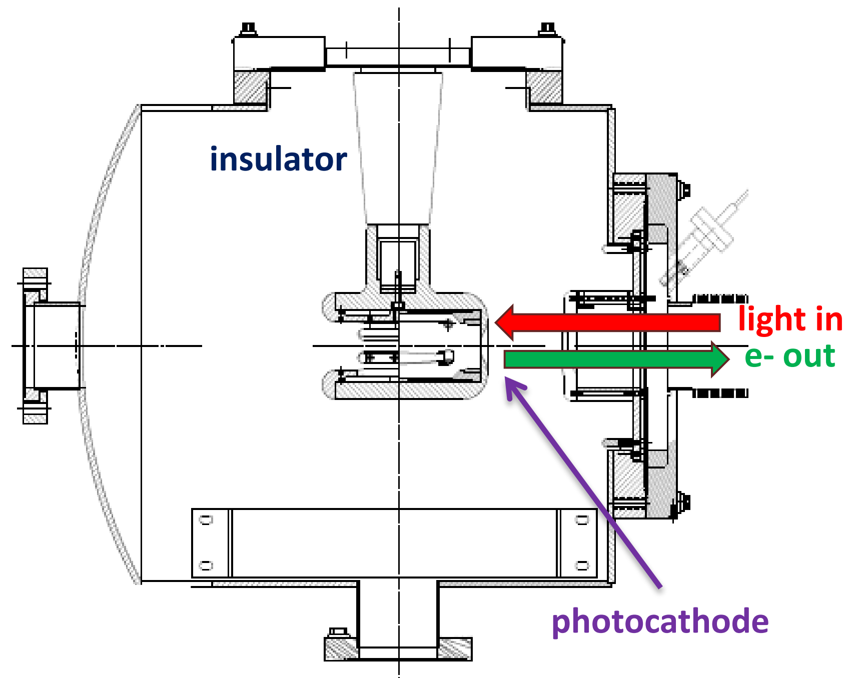


CEBAF – ILC 200 kV Inverted Gun

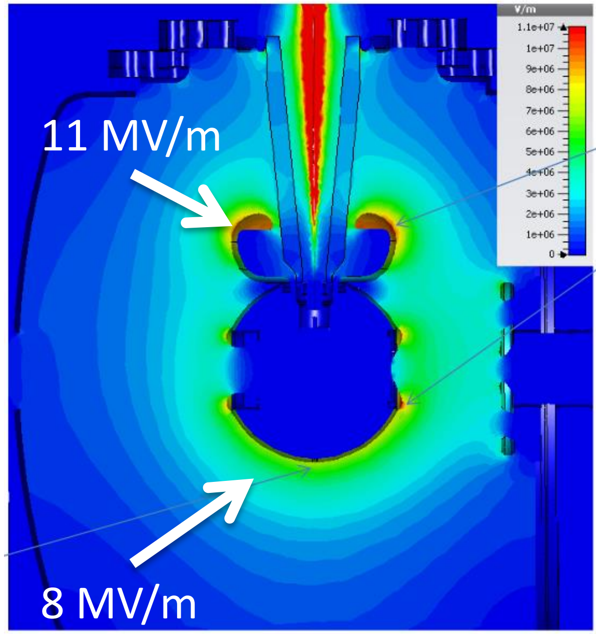
Developed and ready for installation

- Commissioned at Test Cave to 225 kV w/o field emission
- Large Grain Niobium electrode
- But prefer a bit more voltage headroom….

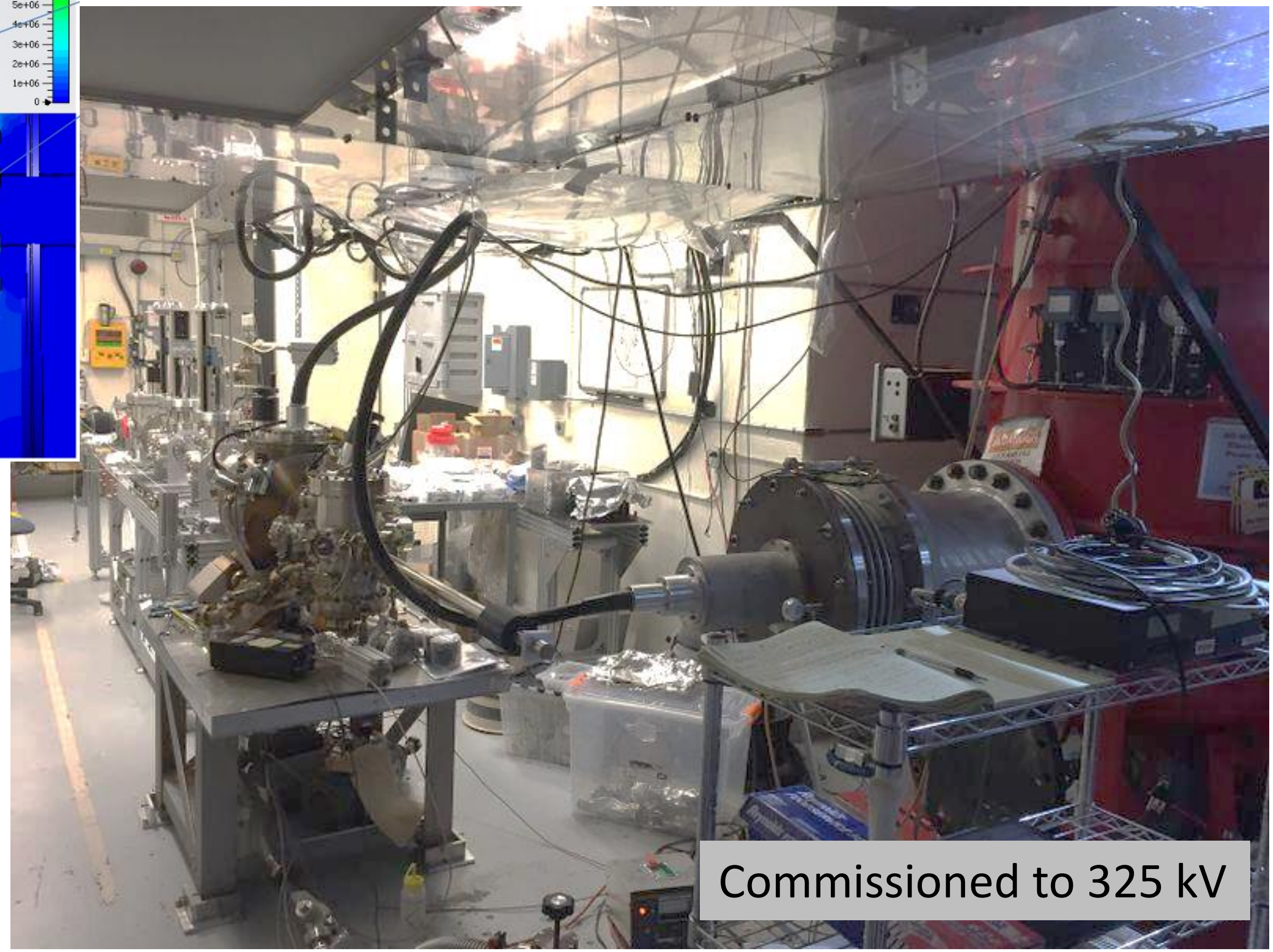




Testing > 300 kV Inverted Guns

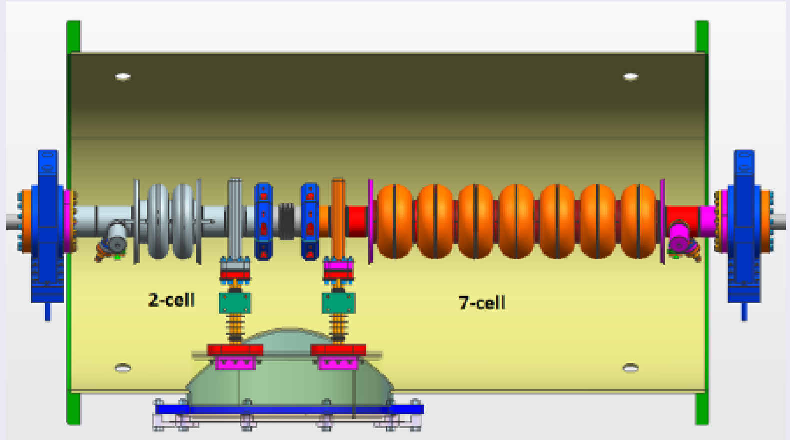


Magnetized beam generation – for electron cooling



CEBAF Injector Upgrade Status

New $\frac{1}{4}$ Cryomodule Design



Done 200kV capable gun installed, need 200+ kV power supply

Done Vertical Wien filter installed

Done C100-0 installed in 0L04 slot, injector 123 MeV capable

Done New $\frac{1}{4}$ cryomodule design

June 2016 New $\frac{1}{4}$ cryomodule fabrication complete

FY16/FY17 New $\frac{1}{4}$ cryomodule commissioning

FY17+ Upgrade and commissioning the elements between gun and $\frac{1}{4}$ cryomodule to support 200keV transport.

CEBAF Injector Upgrade Status

Done	200kV capable gun installed, need 200+ kV power supply
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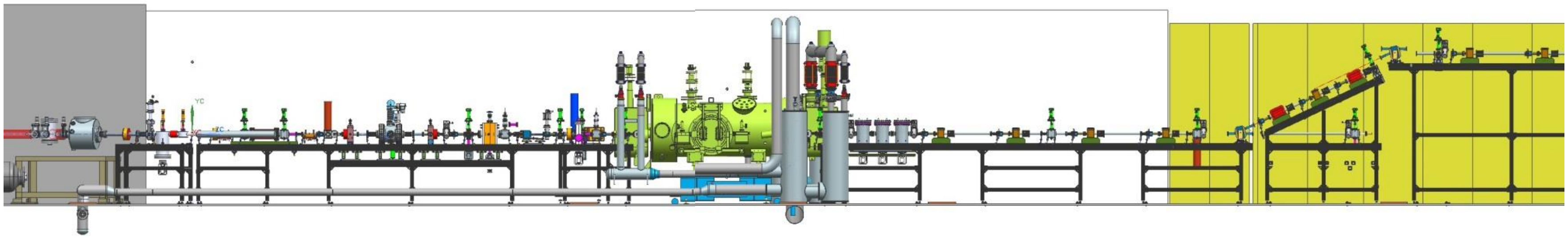
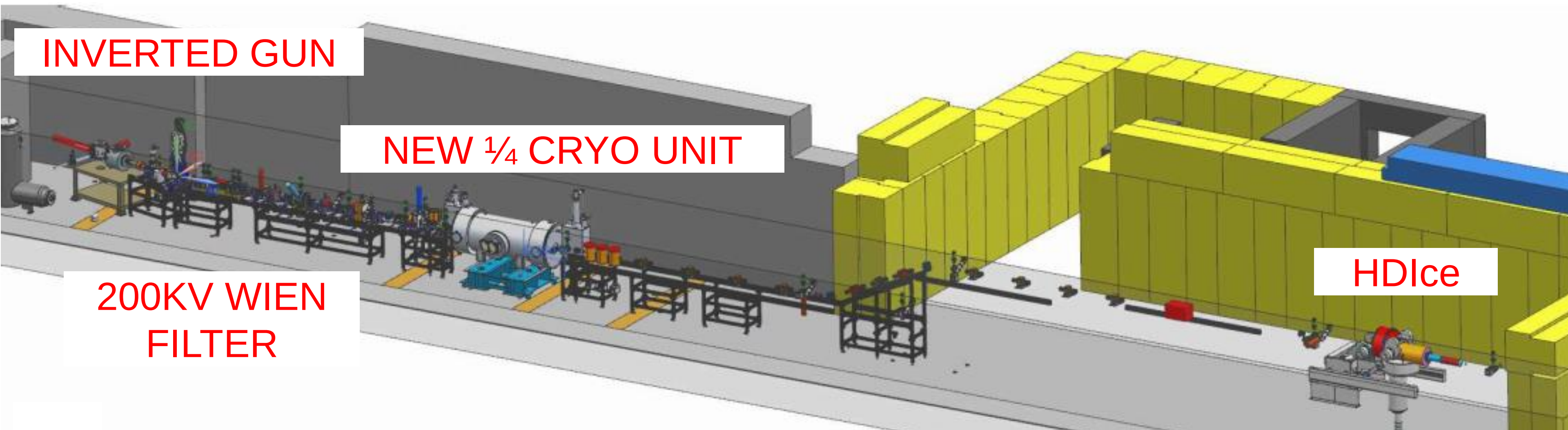
Injector Test Facility

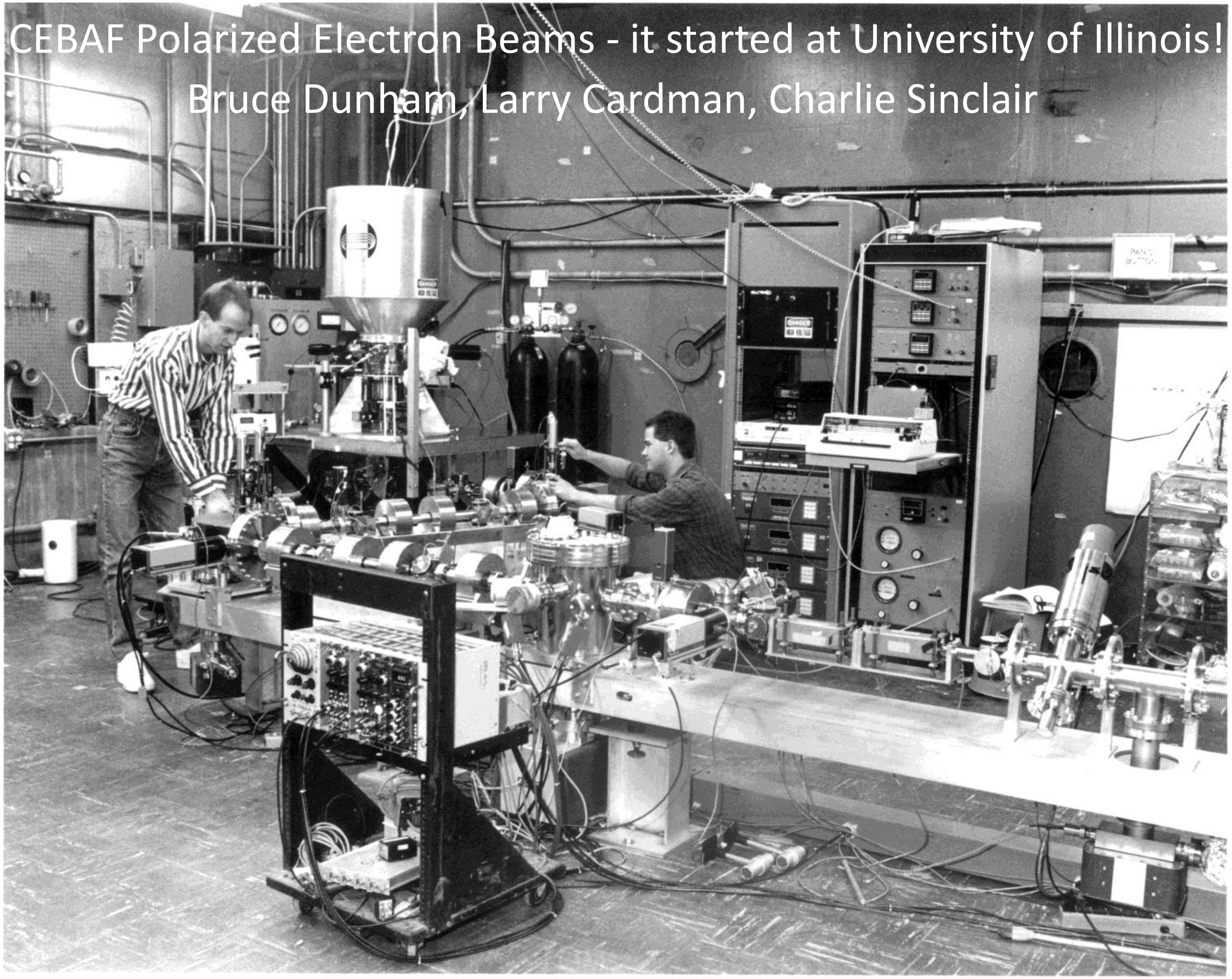




10 MeV accelerator

- Commission HDIce and the new CEBAF injector
- Expect keV operations soon
- New gun and 200 kV Wien Filters at CEBAF during Summer 2017

Thank You


CEBAF Polarized Electron Beams - it started at University of Illinois!
Bruce Dunham, Larry Cardman, Charlie Sinclair

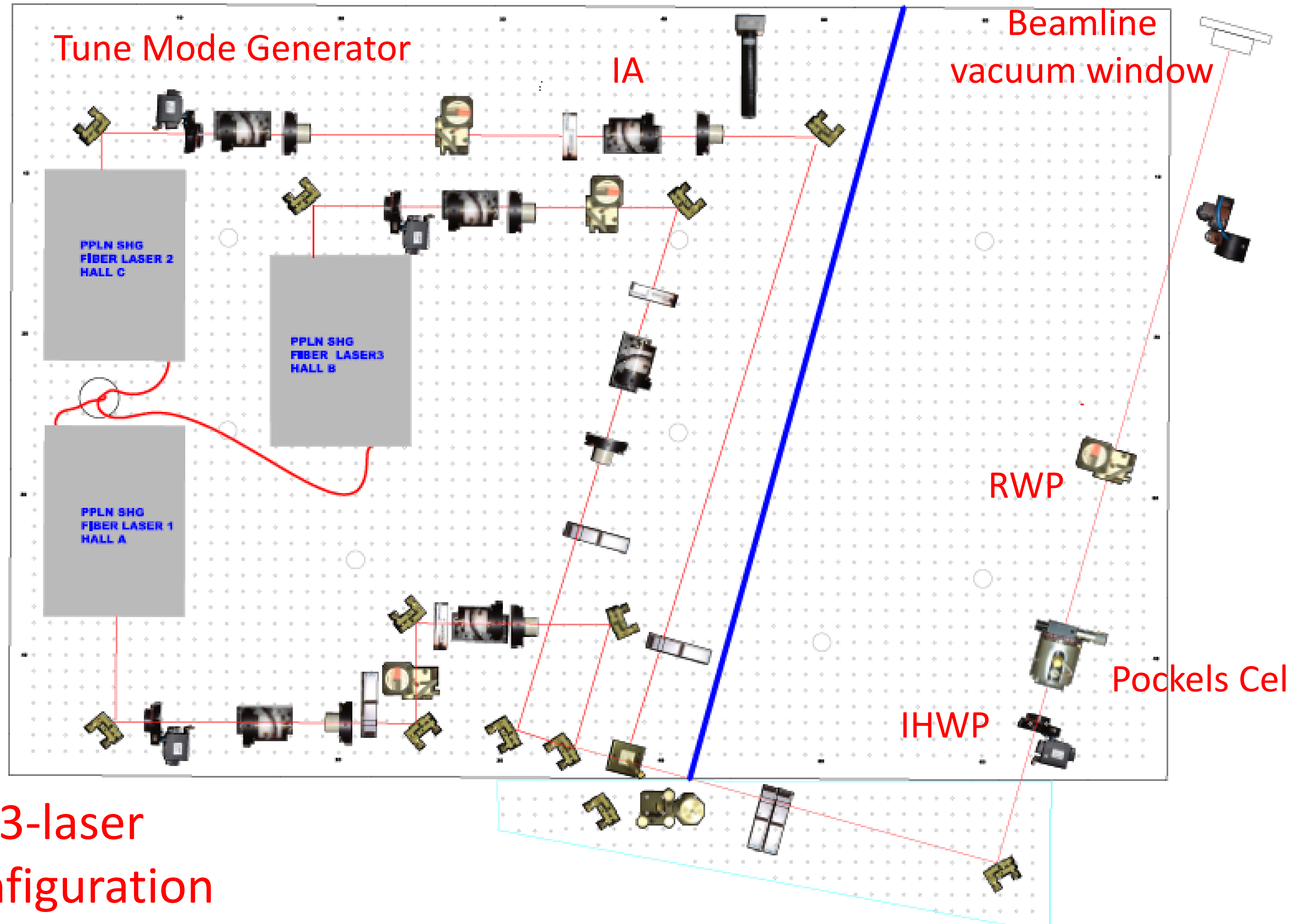
Backup Slides

JLab SPIN topics

More SPIN contributions by JLab source group members and collaborators:

- Wednesday Sept. 27, 9:00, Parallel Session, Yoshitaka Taira, JLab, “High energy X-ray vortex generation using inverse Compton scattering”
- Wednesday Sept. 27, 16:10, Parallel Session VI, Wei Lui, JLab and University of Chinese Academy of Sciences, “Record-level quantum efficiency from high polarization strained GaAs/GaAsP superlattice photocathodes with Distributed Bragg Reflector”
- Thursday, Sept. 29, 15:05 Plenary Session, Joe Grames, Jlab, “Production of Highly Polarized Positrons Using Polarized Electrons at MeV Energies”
- Tuesday Sept. 26, 15:20 Parallel Session, Adeleke Adeyemi, Hampton University, “PEPPo: The Calibration of the PEPPo Polarimeter”
- Parallel Session, Tim Gay, UNL, “High-Precision Mott Polarimetry at the JLab Injector”
- Parallel Session, Charles Hanretty, JLab, “eHD at Jefferson Lab”
- Parallel Session, Richard Talman, Cornell University, “The CEBAF Injection Line as Stern-Gerlach Polarimeter”

6 GeV Laser Table



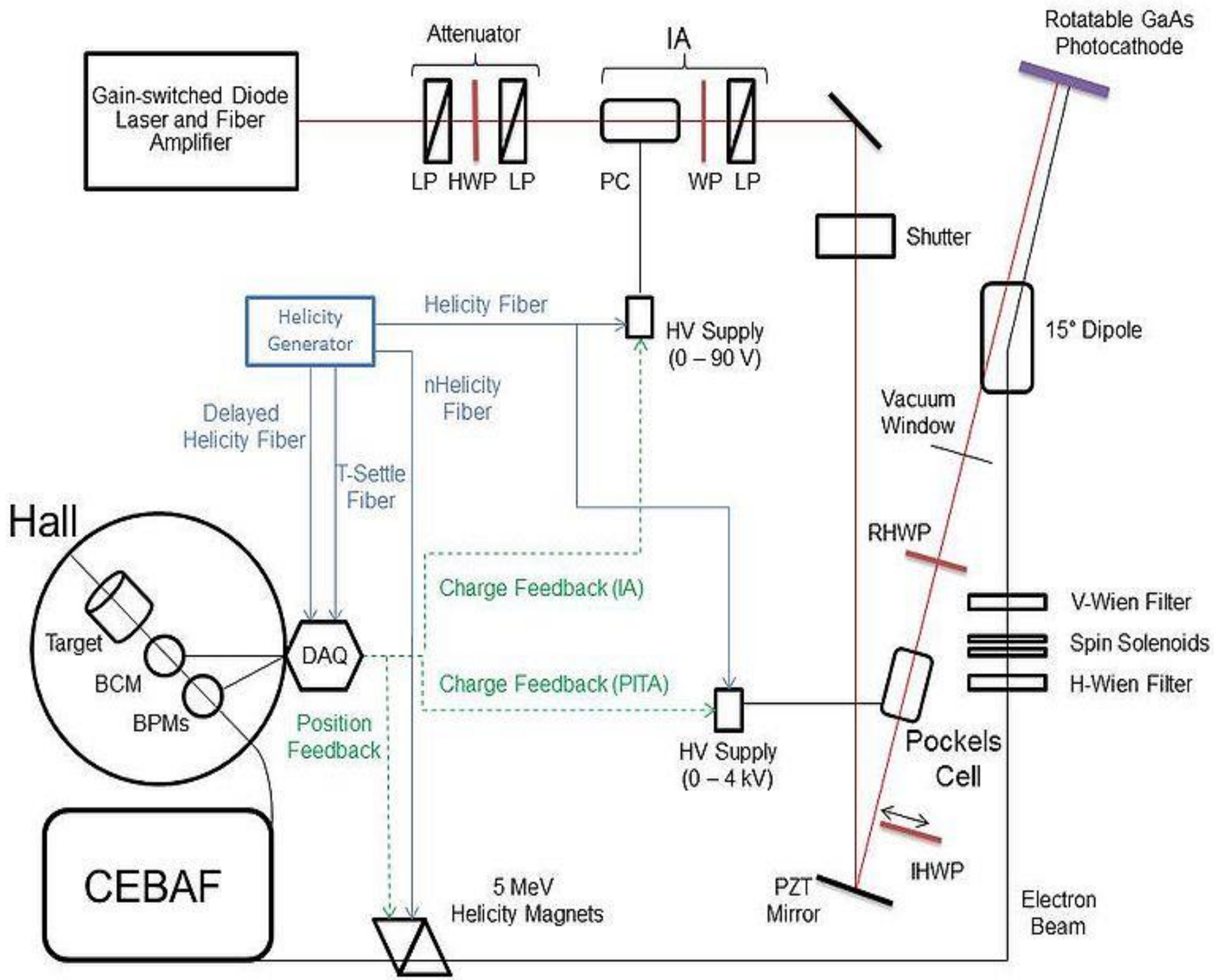
3-laser configuration

CEBAF Polarized Electron Injector

Comprehensive **measurement** and **control** of the electron beam during helicity reversal remains the critical strategy

During Summer 2016 the source laser table will be configured with an additional laser, enabling **simultaneous 4-Hall** capability

Completion of the **Injector Upgrade** includes a **higher voltage gun** and **improved cryounit** to better retain the PQB generated at the source



Issues? Any polarization dependencies?

- Yves Roblin has implemented an ELEGANT model to calculate spin precision with synchrotron radiation (SR) included – standard 6 GeV formula will not work
- Adiabatic Damping: emittance grows but amplitude of betatron oscillations (e.g., helicity-correlated position and angle differences) should still be damped by square root of ratio of momenta
- Beam energy distribution stays symmetric, no energy tails
- Polarization Dependencies (?):
  I. Total SR power depends on transverse polarization, $P_{pol}/P_{unpol} \sim 10^{-4}$
  II. Spin-flip SR (Sokolov–Ternov self-polarization effect) of about

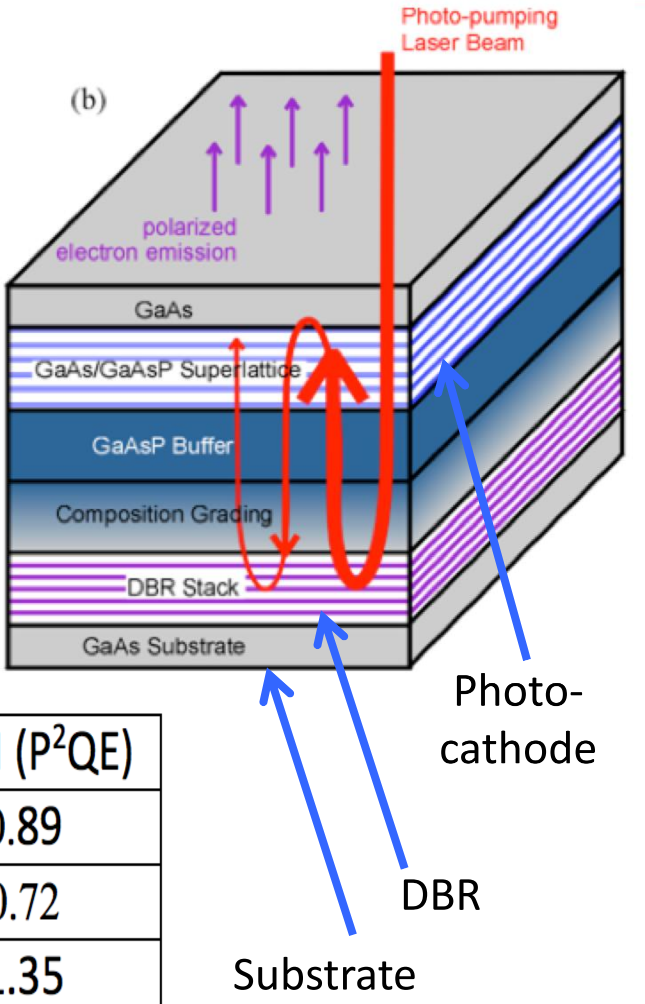
$$\delta pol = \frac{\tau_{JLab}}{\tau_{ST}} = \frac{20\mu s}{113s} \sim 10^{-7}$$

Both cancel with helicity reversal

  III. Total SR power for longitudinal polarized electrons is spin independent but power radiated into space above and below orbital plane is different and thus spin dependent ($A \sim 10^{-5}$) – principle of Spin-Light Polarimeter
    - Helicity-correlated SR → Helicity-correlated emittance growth

World Record High Polarization Photocathode

- 6.4% QE & 84% polarization at 776 nm from strained GaAs/GaAsP superlattice photocathode with GaAsP/AlAsP ***Distributed Bragg Reflector*** (DBR)
- The highest QE & FOM of any reported high polarization photocathode
- Possible to improve both QE & Pol
- SBIR partnership

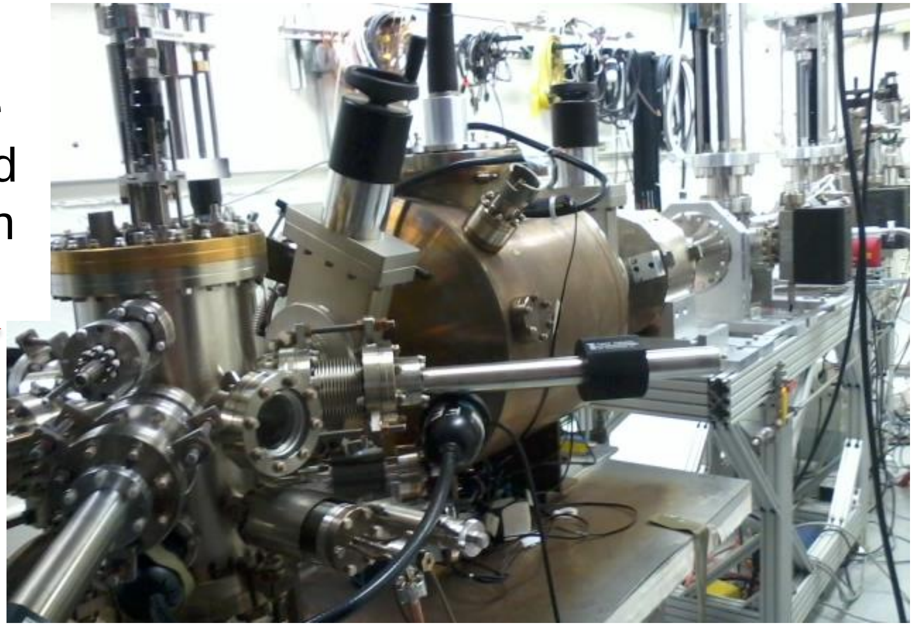


Cathode	Lab	P(%)	QE (%)	FOM (P^2QE)
GaAs-GaAsP	SLAC/SVT	86	1.2	0.89
AlInGaAs-AlGaAs	St. Petersburg	92	0.85	0.72
GaAs-GaAsP	Nagoya	92	1.6	1.35
GaAs-GaAsP/DBR	JLab/SVT	84	6.4	4.52

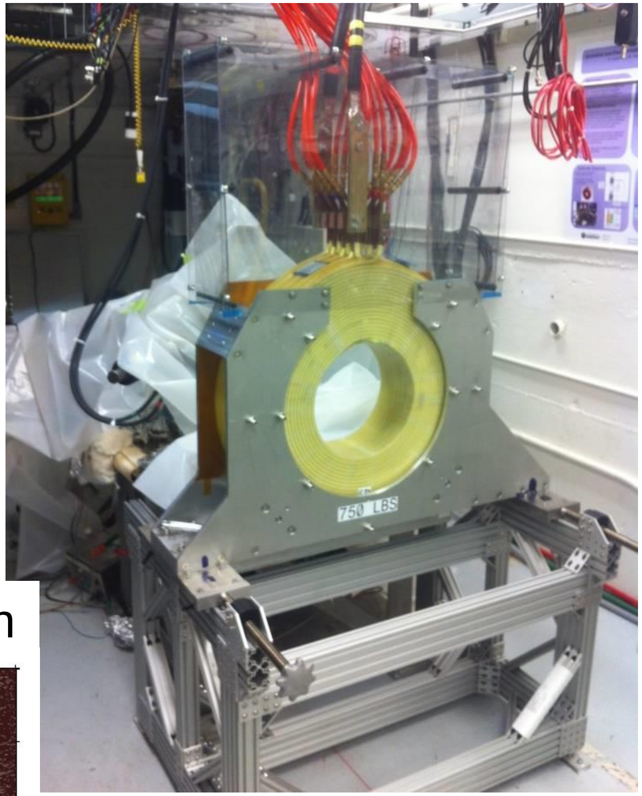
Paper ready for SPIN and APL submission: W. Liu, S. Zhang, M. Stutzman, M. Poelker, Y. Chen, W. Lu, and A. Moy

Magnetized Beam

Rebuilding the alkali-antimonide photocathode deposition chamber

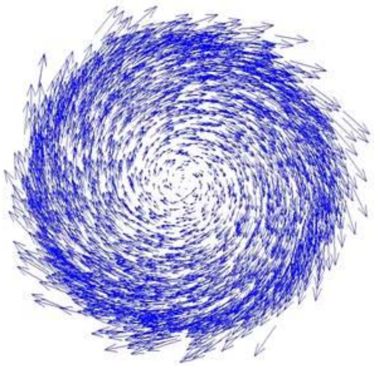


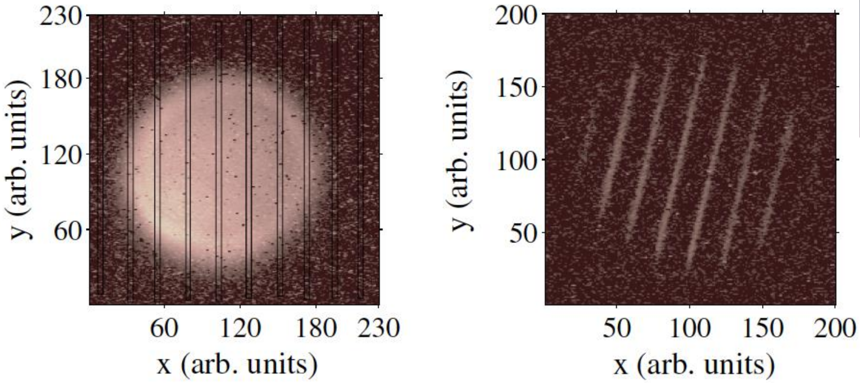
Magnetizing solenoid



Solenoid installed in front of gun table

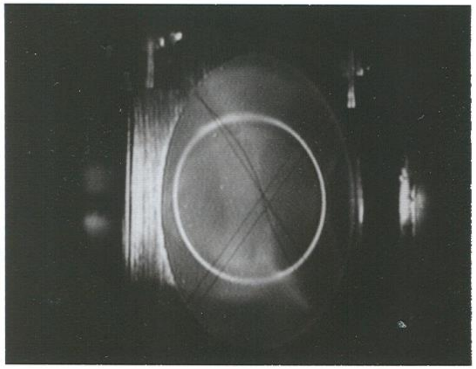
slits used to evaluate magnetization

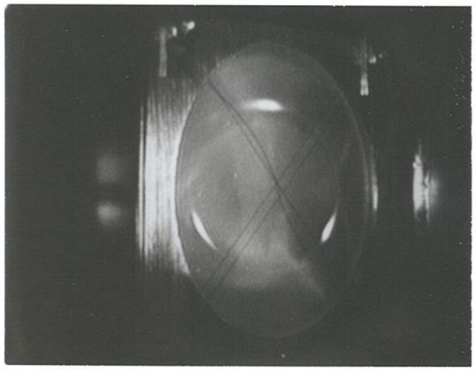


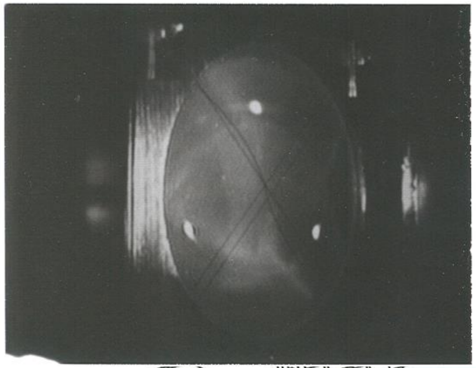


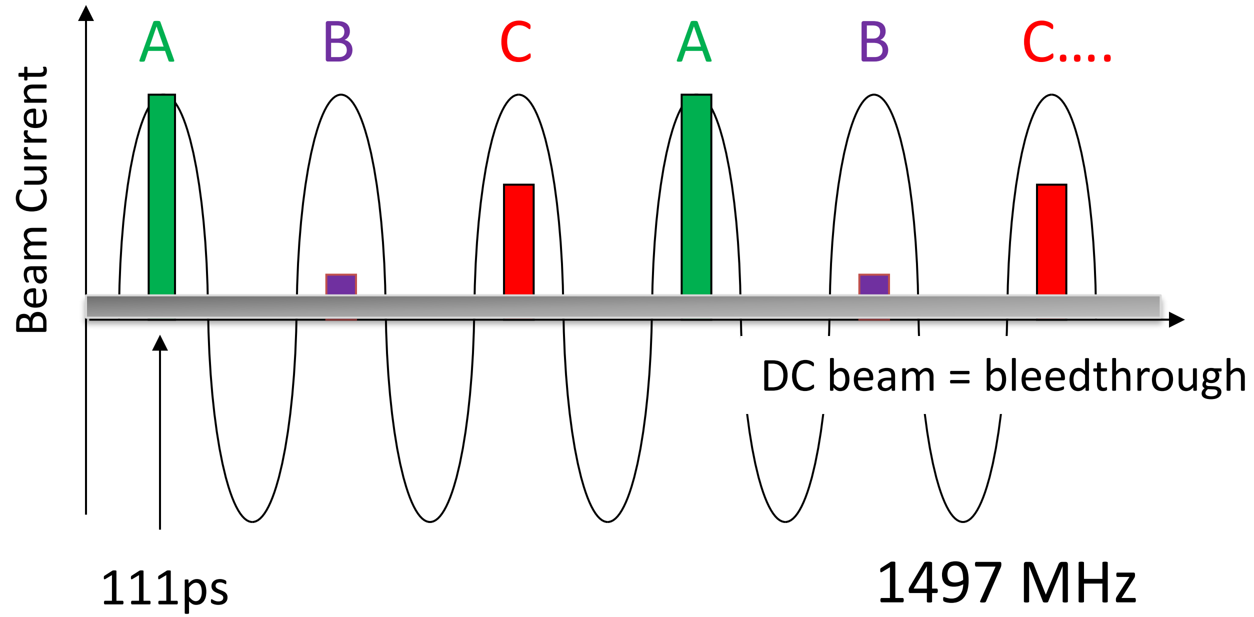
Beam with mechanical angular momentum

…DC Light = bleedthrough…

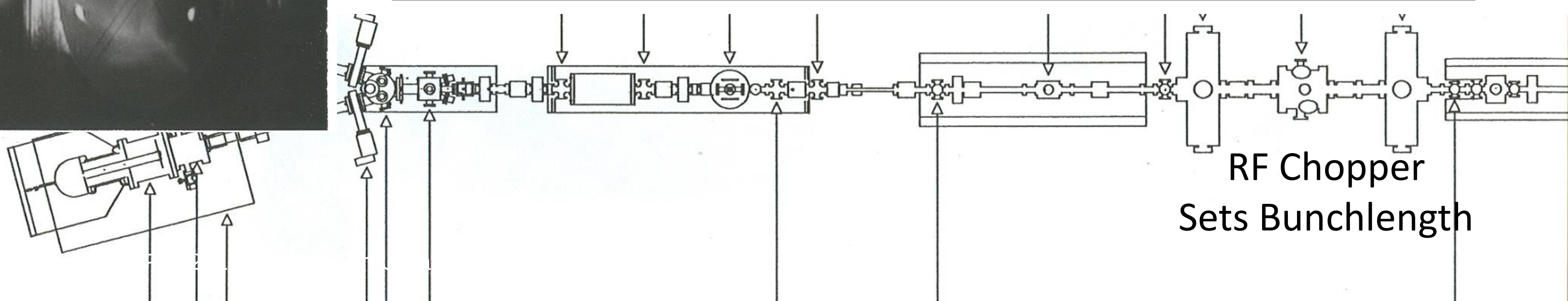








Gain switched laser systems generate some DC light, which bleeds into adjacent chopper slits (and into Hall D bucket). Modelocked lasers generate less bleedthrough, but very reluctant to revisit them….



12 GeV Bleedthrough

- Same as 6 GeV bleedthrough – DC beam bleeding through neighboring chopper slits…
- …and now with 249.5 MHz lasers, bleedthrough can pass through the same slit (what Joe calls self-leakage) producing a bleedthrough bunch 2ns behind "good" bunch.
- Halls expecting 249.5 MHz beam also get beam at 499 MHz
- New 12 GeV bleedthrough problem: Hall D gets beam when their laser is OFF, problematic when radiator is inserted or retracted, can't just close slit
- Solution: turn OFF ALL lasers or insert a beam dump

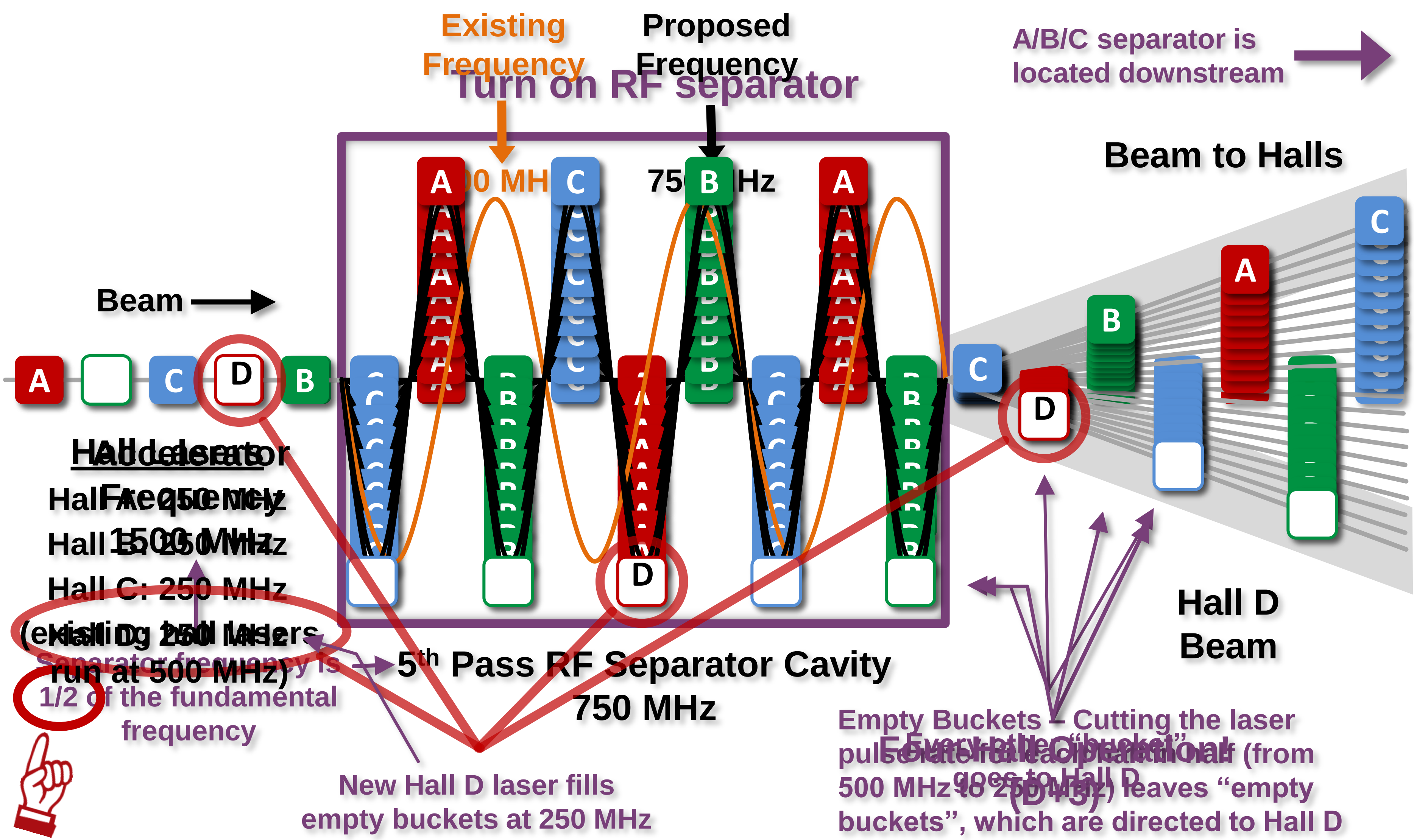
Bleedthrough "Conclusions"

- Bleedthrough electrons originate at the injector chopper, and are delivered to an unintended hall
- Bleedthrough electrons are produced at the photocathode by DC laser light
- Bleedthrough electrons pass through neighboring chopper slits ("old" 6 GeV bleedthrough)
- Now in 12 GeV era with 249.5 MHz lasers, bleedthrough electrons can also pass through the intended hall slit, producing a bleedthrough bunch delayed by 2ns from "good" bunch

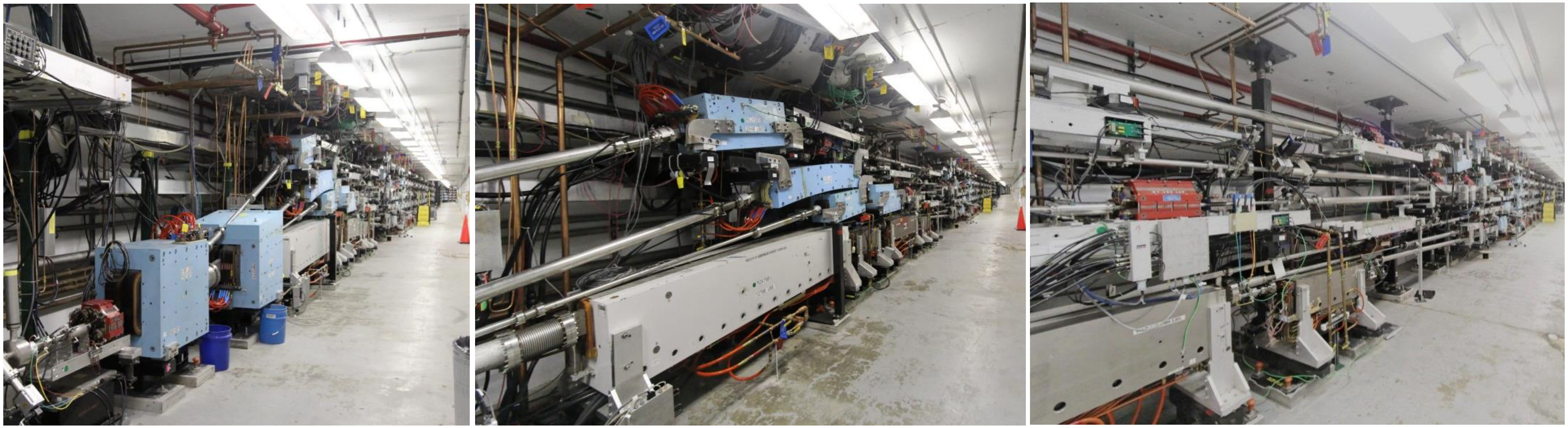
Bleedthrough "Conclusions" continued

- Mostly, bleedthrough is a problem for Hall B – polarization dilution. Solve this problem by extracting ~ 10uA for Hall B and "neck down" their slit
- For 249.5 MHz lasers, the bleedthrough beam that is produced by A, B and C lasers will be delivered to Hall D. Only a problem when Hall D wants to insert or retract their radiator
- Hall D's bleedthrough beam will go to the hall of shared chopper slit., i.e., Hall A or Hall C

RF Separation – Proposed (750 MHz)



Beam Transport: Spreaders and Recombiners



East Spreader

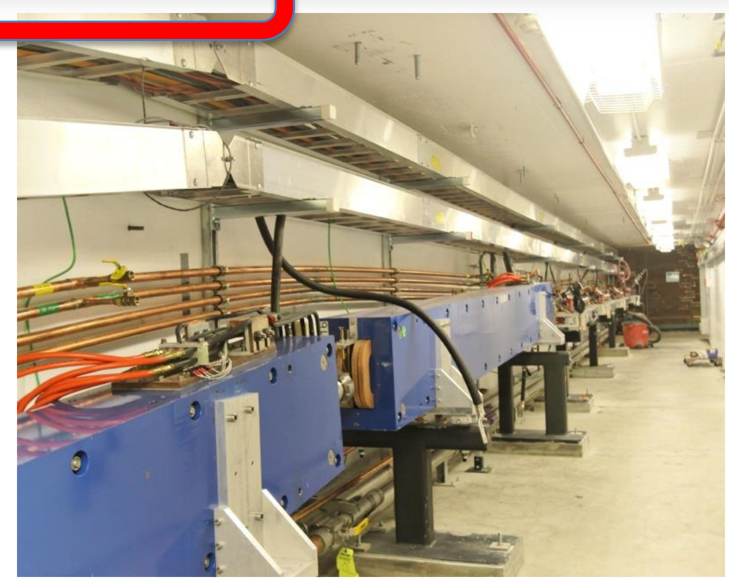
- Spreaders and Recombiners, one each per linac
- Critical CEBAF components, completely rebuilt
- Space constrained, very complicated

Beam Transport: Beamline to Hall D Tagger Vault

Hall D Complex

Hall D Tagger Magnet/Dump

Beam



12 GeV CHL Maximum Capacity

- **Old 6 GeV (CHL1)**
  - Load: 4.25 kW @ 2.1K, 11.65 kW @ 35K
  - Capacity: 4.6 kW @2.1K, 12 kW @ 35K
  - 10 g/s liquefaction @ 4.5K
- **New 12 GeV (CHL1 + new CHL 2)**
  - Load: 7.4 kW @ 2.1K, 14.65 kW @ 35K
  - Capacity: 8.8 kW @ 2.1K, 24 kW @ 35K
  - 10 g/s (CHL 1) plus 15 g/s (CHL 2) of liquefaction