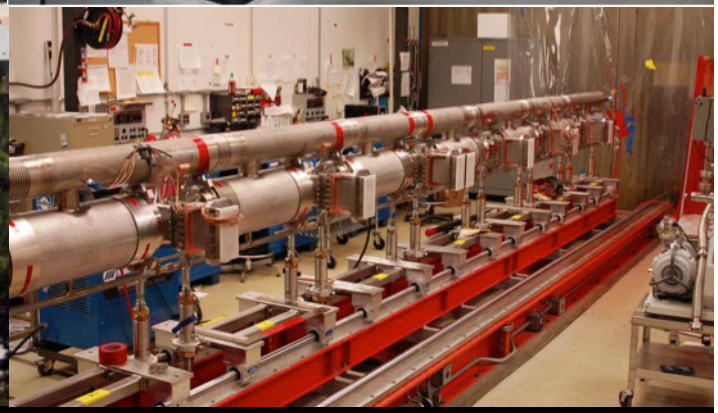
U.S. DEPARTMENT OF ENERGY

JSA

Commissioning and Status of the CEBAF 12 GeV Upgrade at Jefferson Lab

Todd Satogata / Center for Advanced Studies of Accelerators



APS physics

April 11-14 2015

Jefferson Lab

Thomas Jefferson National Accelerator Facility

Outline

- Introduction to **Jefferson Lab** and the **CEBAF 12 GeV Upgrade**
- 12 GeV Commissioning and Project **Preparations**
- 12 GeV Commissioning **Results** and **Timeline**
- 12 GeV **Future Run Plans** and **Physics**

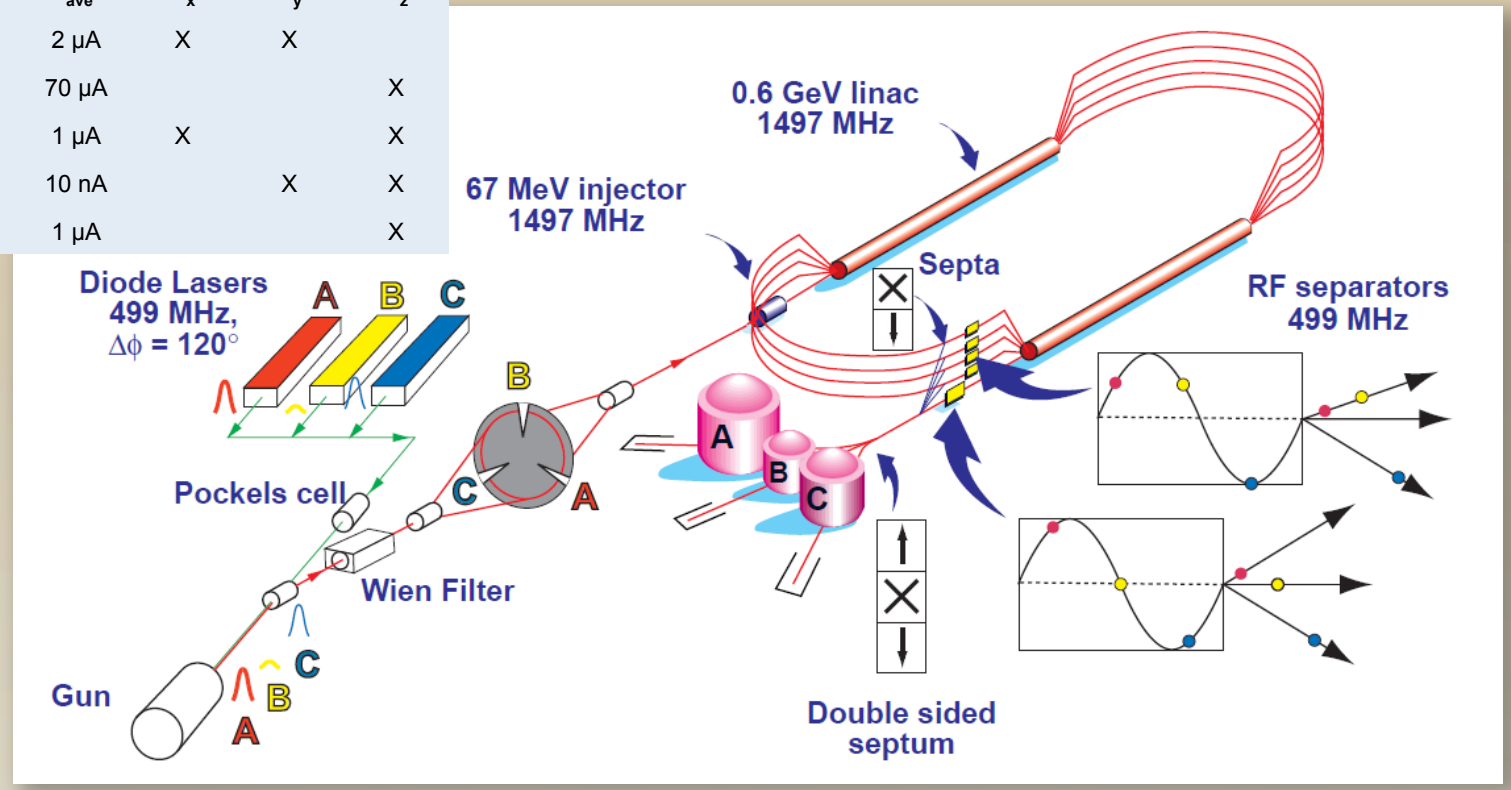
Jefferson Lab

- Location of **CEBAF** (the Continuous Electron Beam Accelerator Facility)
  - Operating since 1995; 1300+ users in 170+ experiments
  - Produces ~1/3 of US Ph.D.s in Nuclear Physics
- **SRF Institute** is active leader in **SRF technology**
  - Including CEBAF 12 GeV upgrade SRF development (with RI)
- Leadership in development of **polarized electron sources**
- **Accelerator physics** and **diagnostics development**
- **K-12 Science Education** program serves as national model

- 169 acre site with 80+ buildings, 700+ ksf
- 760+ FTEs with 20+ joint faculty
- Annual budget: $180M, mostly through DOE ONP

6 GeV CEBAF Overview

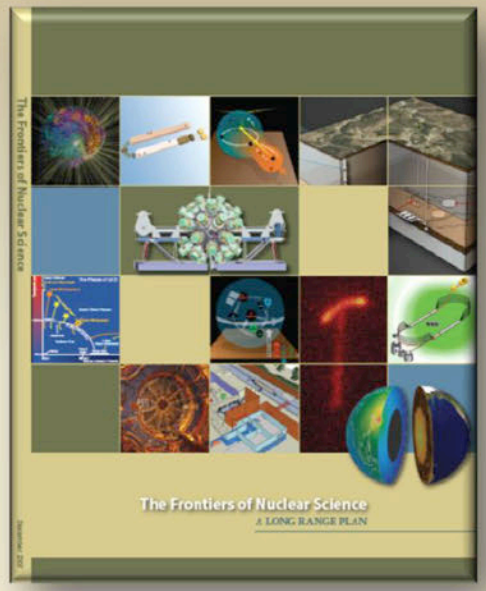
Polarimeter	I_{ave}	P_x	P_y	P_z
Injector Mott	2 μA	X	X	
Hall A Compton	70 μA			X
Hall A Moller	1 μA	X		X
Hall B Moller	10 nA		X	X
Hall C Moller	1 μA			X



First large **high power (MW) CW recirculating electron linac** based on **SRF**
Capabilities: 5 passes, multiple beam energies / intensities / polarizations
3 experimental halls running simultaneously

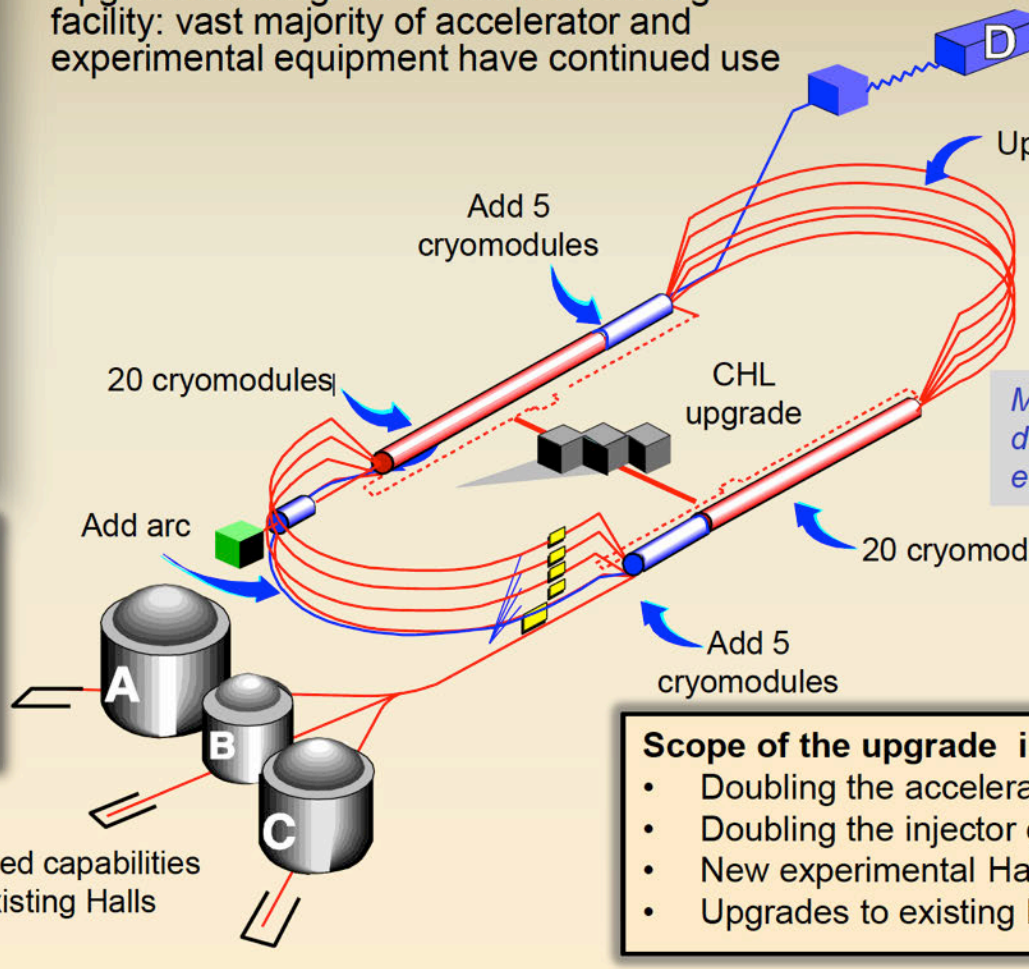
12 GeV Upgrade: proposed in late 1990s ➔ approved and funded in 2004

Scope of 12 GeV Upgrade



The completion of the 12 GeV Upgrade of CEBAF was ranked the highest priority in the 2007 NSAC Long Range Plan.

Upgrade is designed to build on existing facility: vast majority of accelerator and experimental equipment have continued use



Maintain capability to deliver lower pass beam energies: ***2.2, 4.4, 6.6….***

Scope of the upgrade includes:

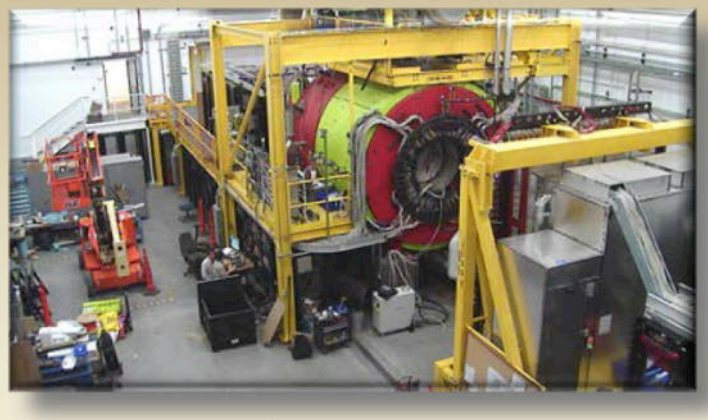
- Doubling the accelerator beam energy
- Doubling the injector energy
- New experimental Hall and beam-lines
- Upgrades to existing Experimental Halls

6 GeV to 12 GeV Parameters

	6 GeV Operations	12 GeV Design/Requirements
Energy to Halls A,B,C / D	6 GeV	11 GeV / 12 GeV
Number of passes for Halls A,B,C / D	5	5 / 5.5 (add a tenth arc)
Duty Factor	CW, 499 Mhz	CW 499 Mhz, 250 Mhz
Max. Current to Halls A+ C / B	200 μA / 5 μA	
Max. Current to Halls A+C / B+D		85 μA / 5 μA
Max. Beam Power	1 MW	1 MW
Emittance at max. energy (geometric, rms): x, y	1 nm-rad, 1 nm-rad	10 nm-rad, 2 nm-rad
Energy spread at max. energy (rms)	2.5×10^{-5}	5×10^{-4} / 5×10^{-3}
Bunch length (rms)	0.2 ps	~1 ps
Polarization	80%	80%

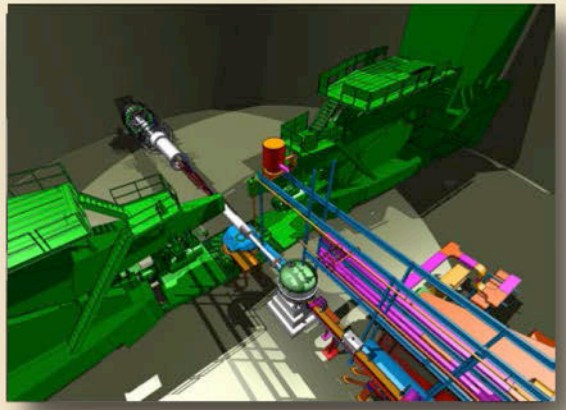
12 GeV Scientific Capabilities

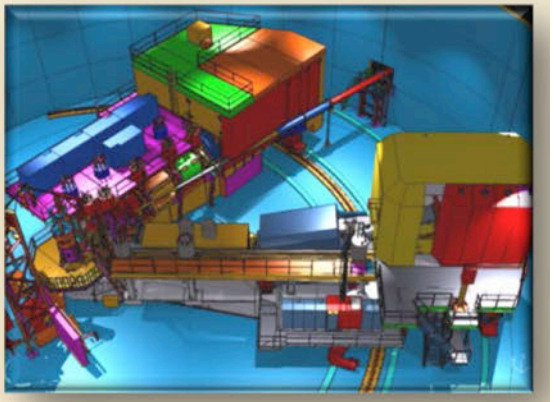
Hall D – exploring origin of confinement by studying exotic mesons



Hall B – understanding nucleon structure via generalized parton distributions

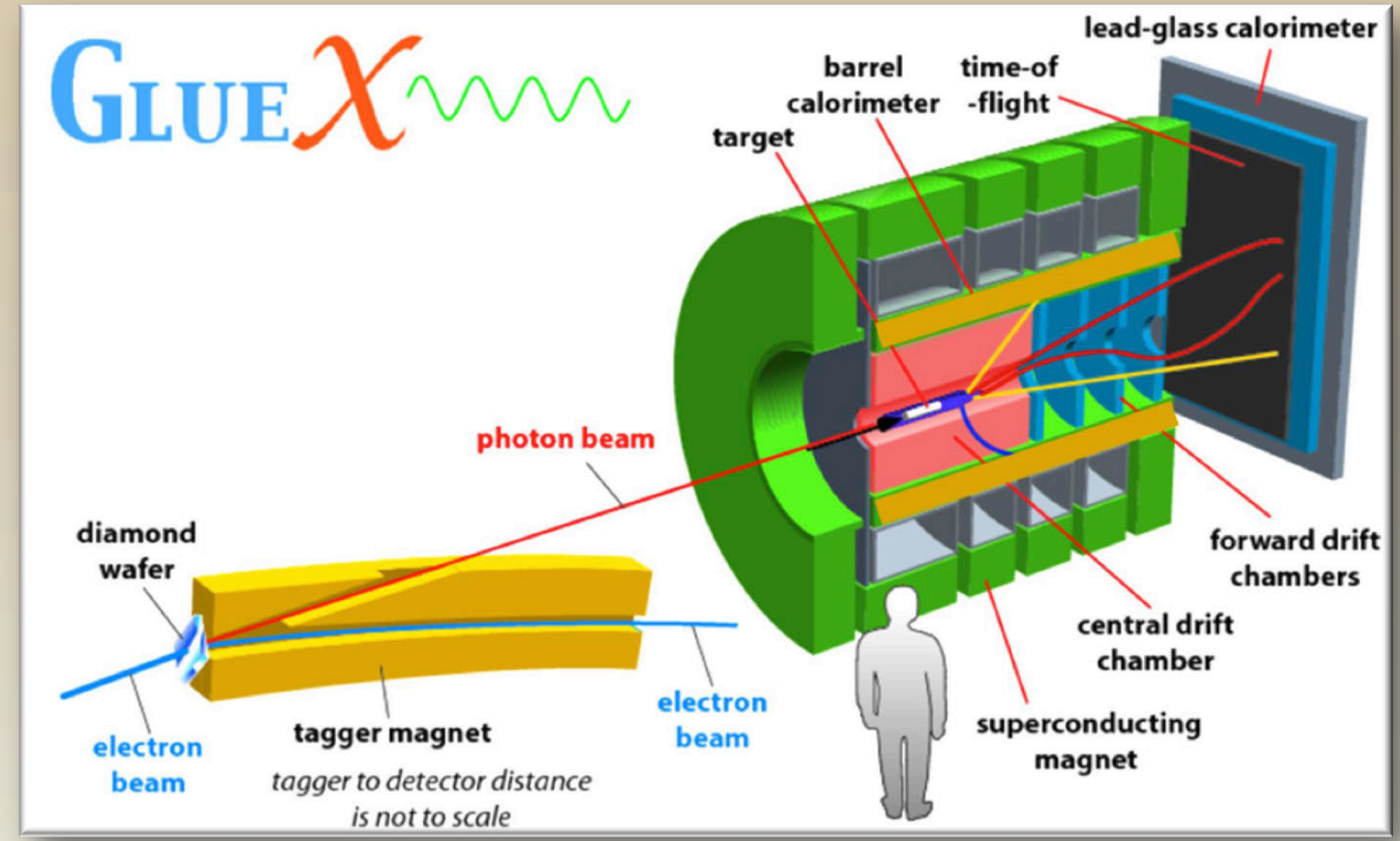
Hall C – precision determination of valence quark properties in nucleons and nuclei





Hall A –form factors, future new experiments (e.g., SoLID and MOLLER)

Hall D: GlueX


GLUEX
lead-glass calorimeter
barrel calorimeter
time-of -flight
target
photon beam
diamond wafer
forward drift chambers
central drift chamber
superconducting magnet
electron beam
tagger magnet
electron beam
tagger to detector distance is not to scale

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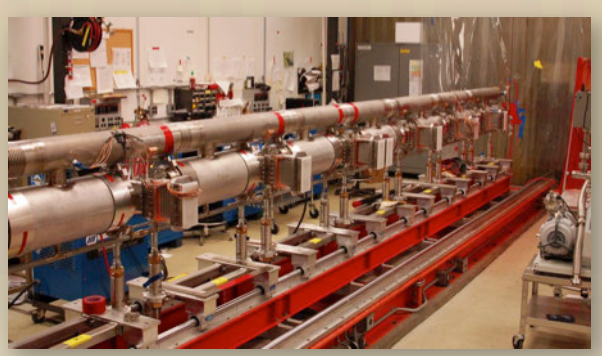
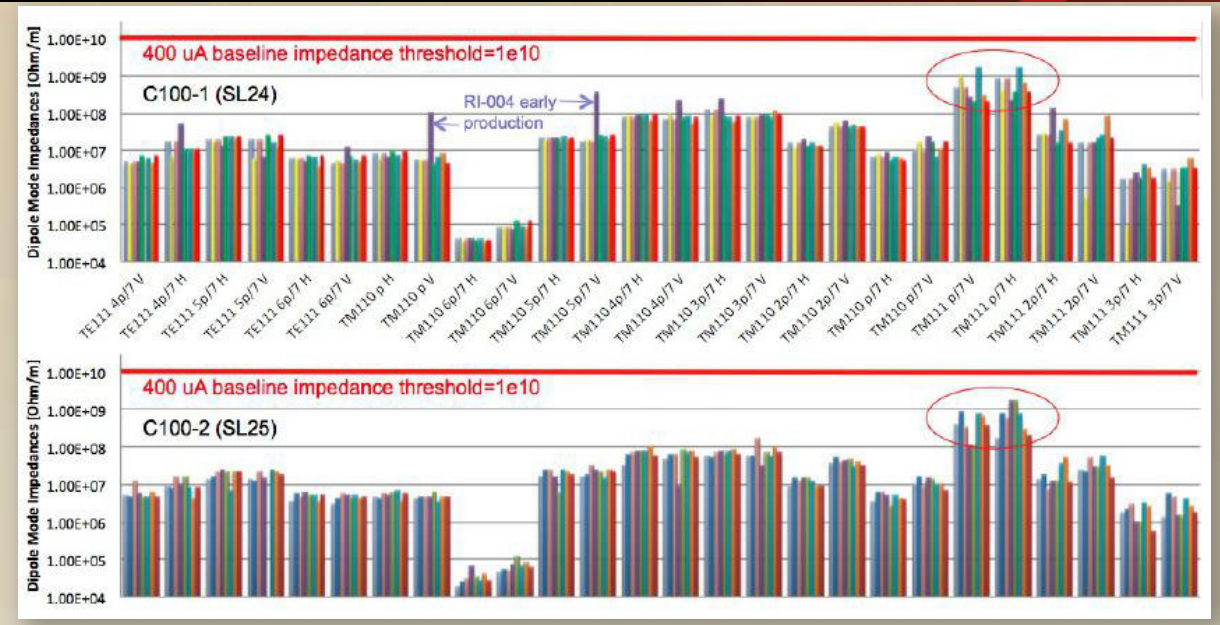
RF/Cryomodule Design/Production



- C100 cryomodule: **8 7-cell cavities, 1497 MHz**
  - Designed for **108 MV/cryomodule**; 98 MV/module needed for 12 GeV
- Cavities produced with industry (Research Instruments)
- Assembly and 18-step qualification testing at Jefferson Lab
  - Electropolishing production process derived from ILC R&D

- Design gradient: **19.2 MV/m** average
- Operational limits: **~25 MV/m** (klystron-limited)
  - Cavity Qs are BCS-limited, average heat load **29 W/cavity**
  - Active piezo microphonics feedback, 120° HOM dampers

Cryomodule Tests and Performance

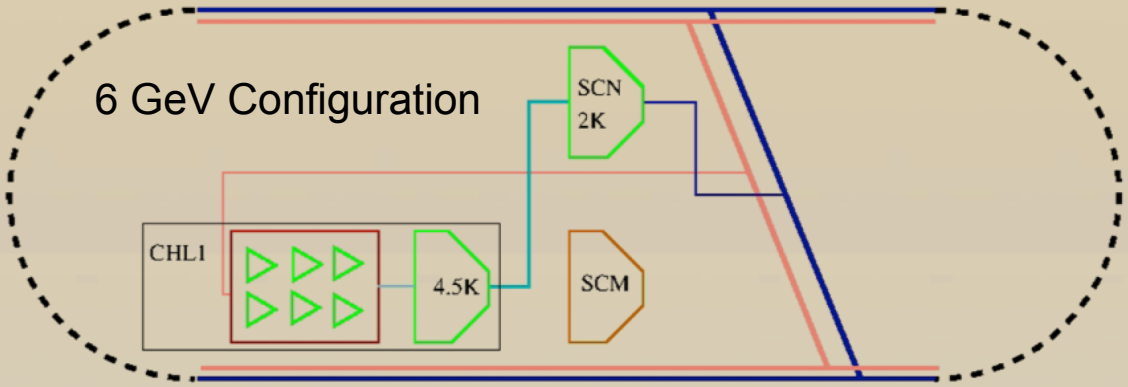


C100-1 and C100-2 HOM survey from CMTF

Show HOM impedances well below conservative threshold

- All cavities and cryomodules were **acceptance tested** in CMTF/tunnel
  - Measure tuning, HOMs, max gradient, field emission, Q_0, microphonics and heat loads
- **HOM survey** (TE111, TM110, TM111) via BTF and beam tests
  - BBU threshold over 10x maximum expected beam loading
  - Early commissioning beam tests with worst-case optics: no BBU seen

Cryogenics



6 GeV CEBAF cryogenics
SCM/SCN are 2k coldboxes with series of compressors

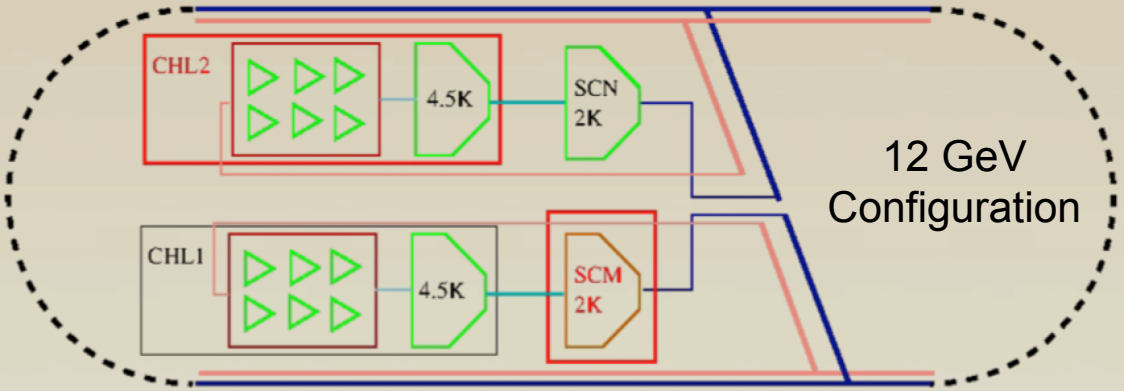
SCM: original 4 GeV coldbox, refurbished but not used in 6 GeV

SCN: second 6 GeV coldbox

12 GeV project

Add new CHL2 central liquifier
Recommission SCM coldbox
Separate CHL-SC pairs for each linac

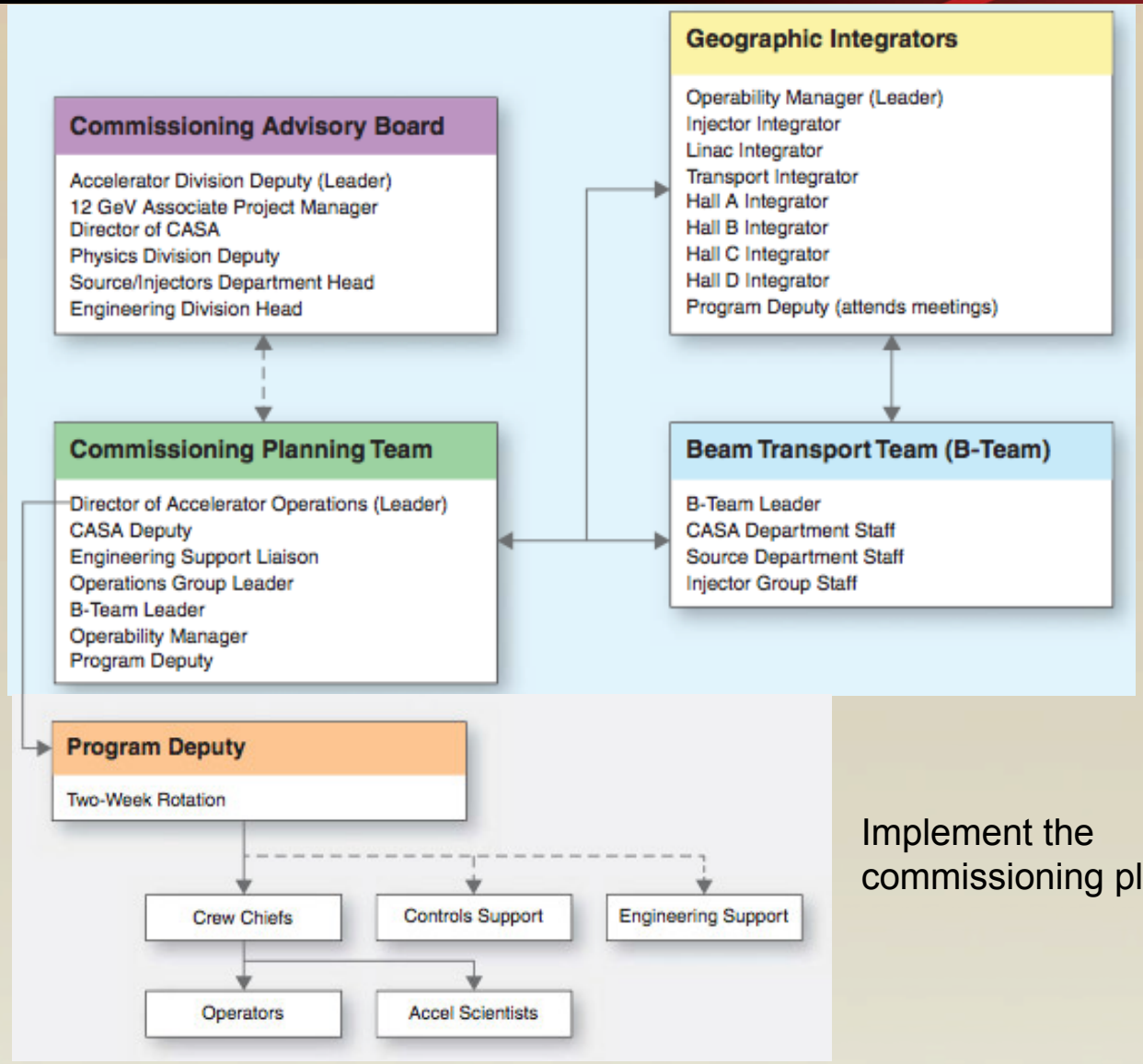
Both linacs on separate CHL lines on Dec 9 2013



Commissioning Structure

Review plan
Provide feedback

Develops the strategic plan



Ensure that beamline segments are ready for beam

Develops the detailed tactical plan

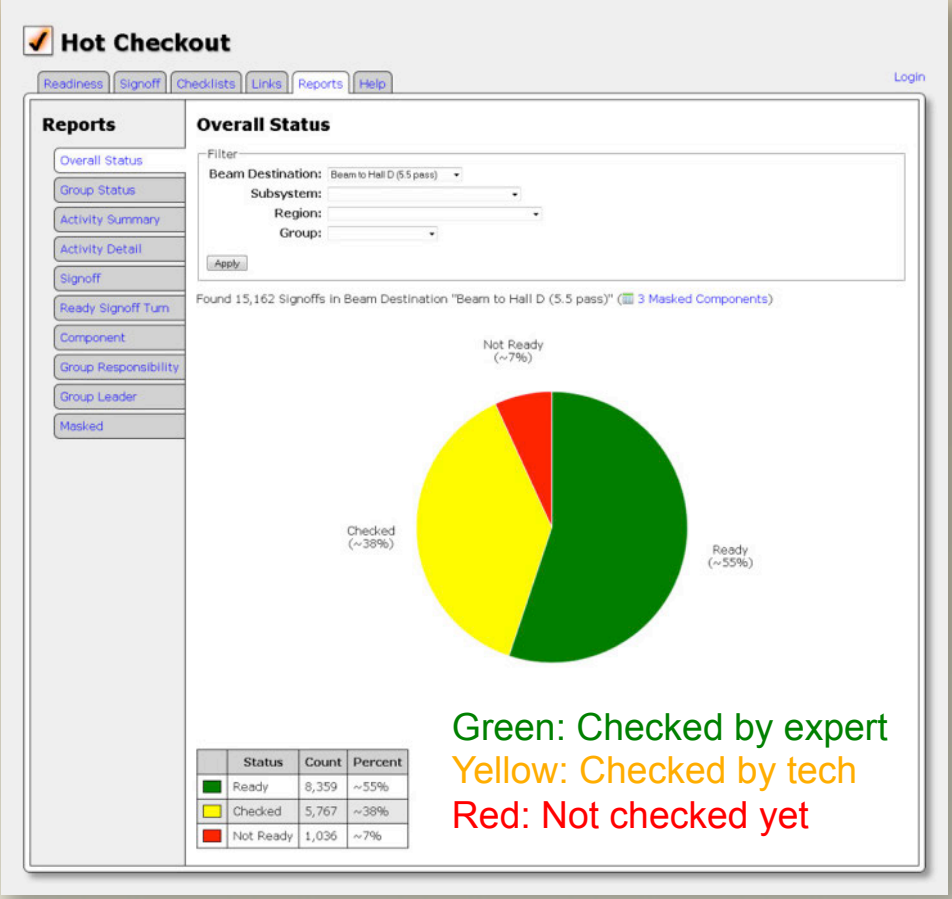
Implement the commissioning plan

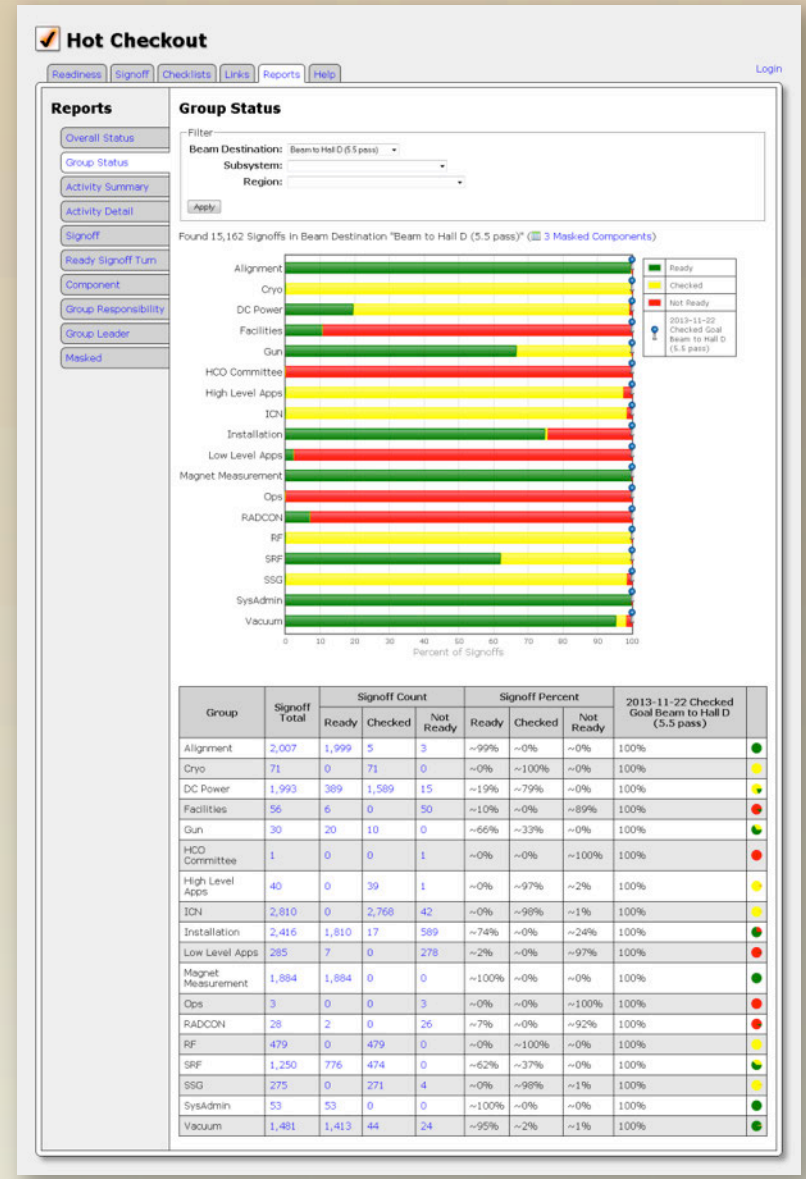
Hot Checkout / Readiness Tool

Web-based tool: captures readiness of all hardware for beam operations

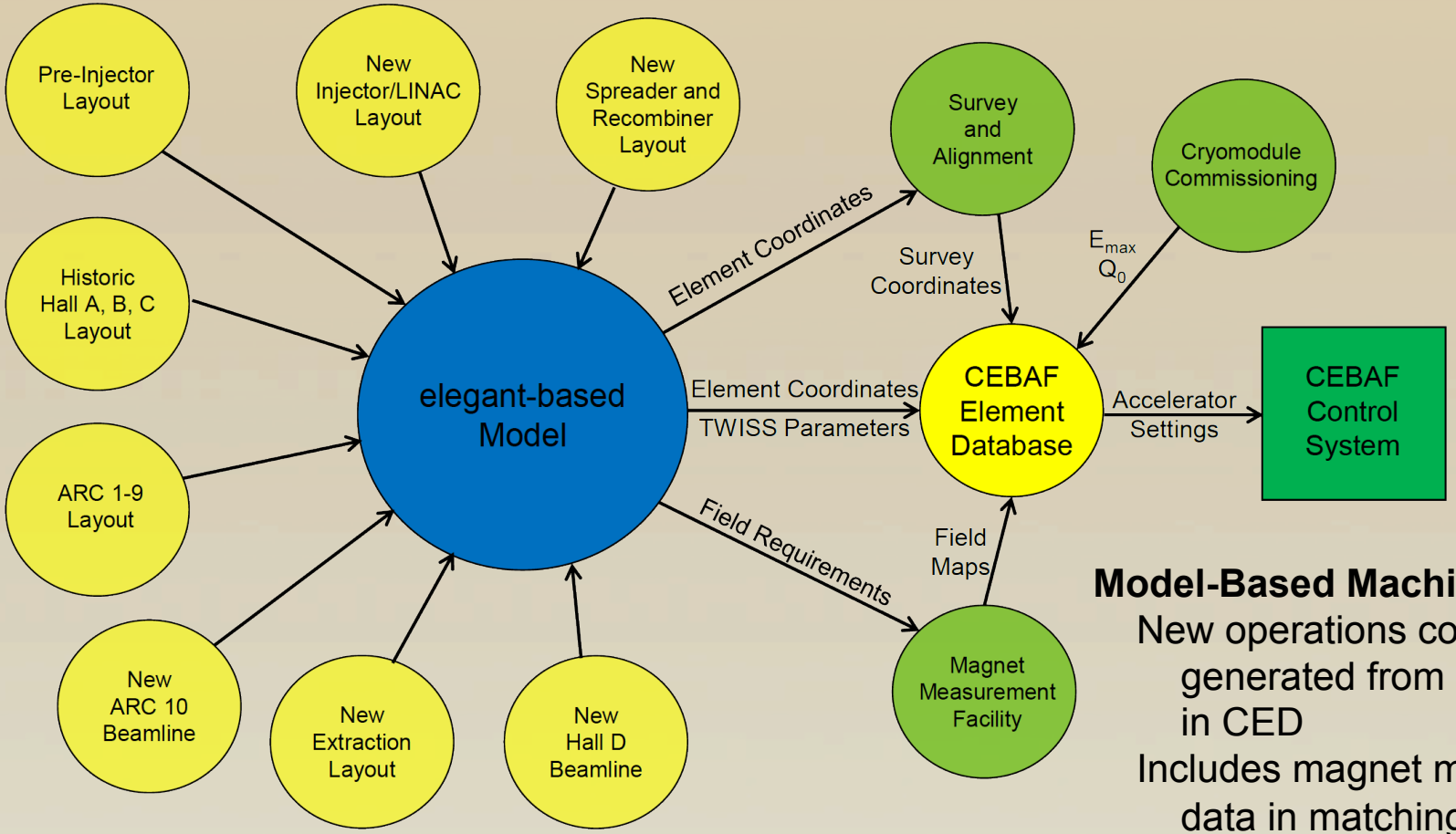
Over 15000 components in system for 5.5 pass to Hall D

Halls starting to use tool for their own checkout





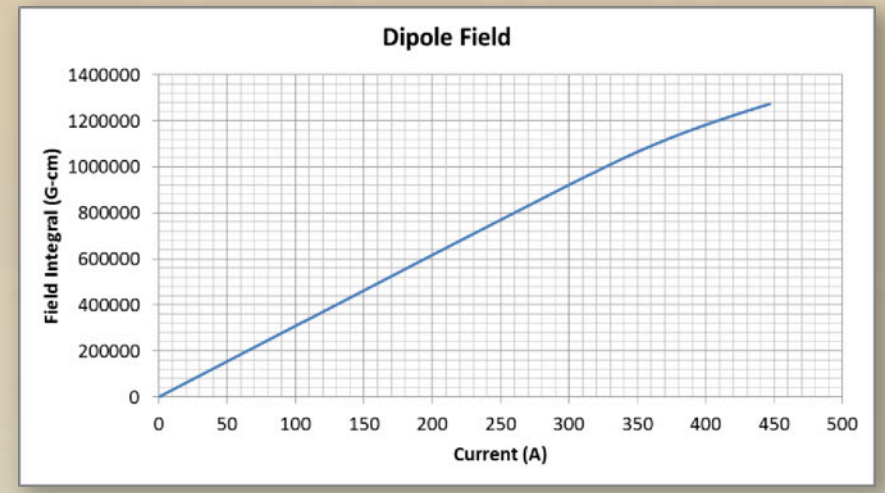
Model-Based Operations

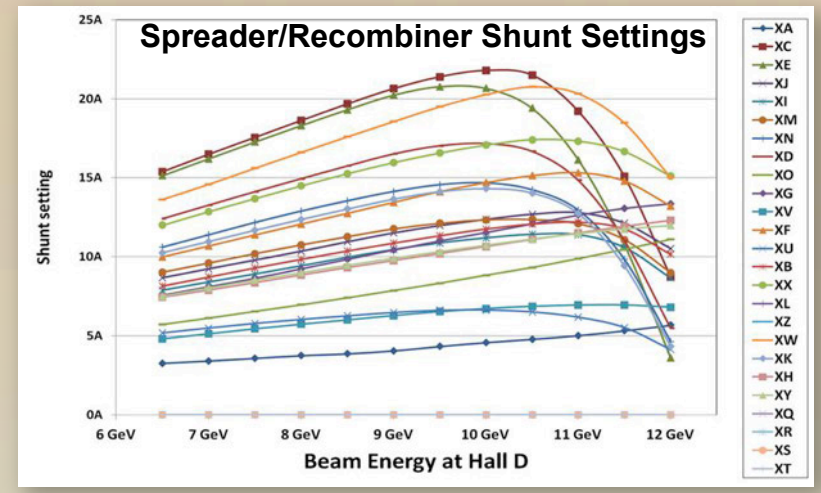


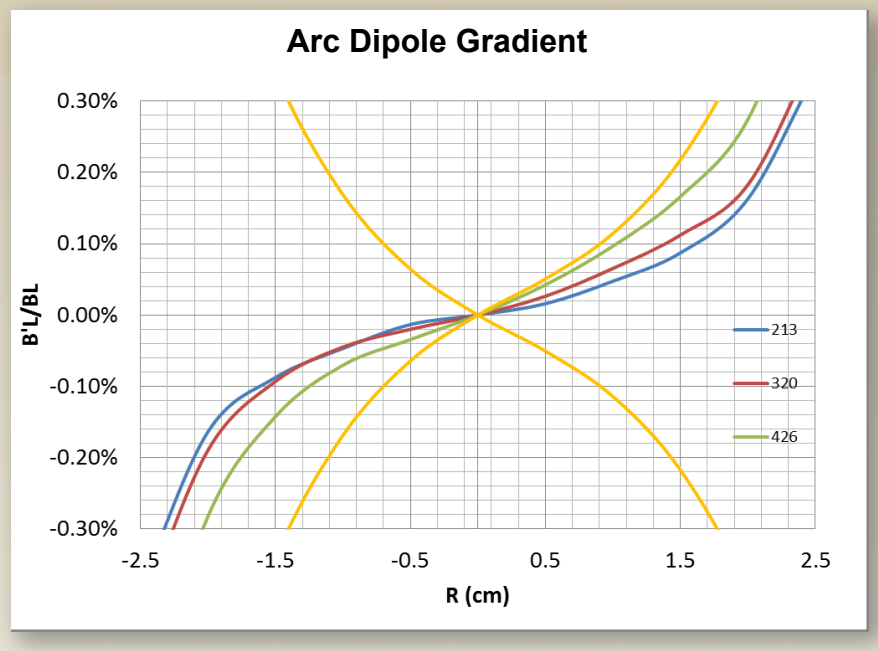
Model-Based Machine Setup

- New operations configurations generated from design model in CED
- Includes magnet measurement data in matching/optimization
- Applications generate elegant decks dynamically for matching, optics predictions
- Centralized lattice management

Magnetic Field Quality







Magnet Measurement Facility Data

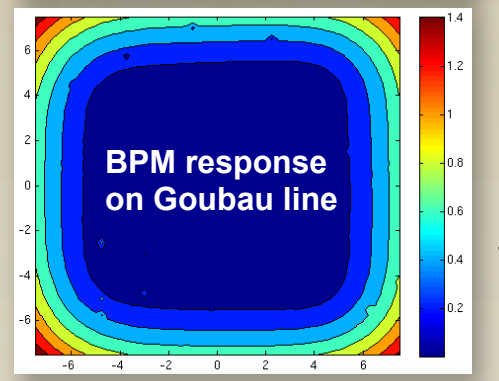
- All dipole and septa magnets measured
- All quad families measured
- Integrated dipole field, gradient, higher order multipole data

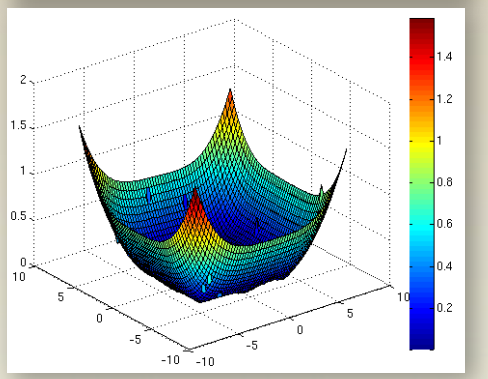
- Field data entered into CEBAF element database (CED)
- Control system uses magnet information from CED
- Much improved optics matching

Diagnostics for New Beamlines

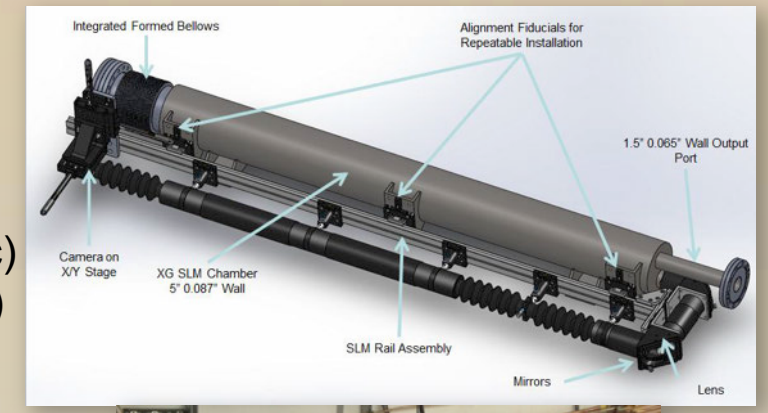
12 GeV Beam Diagnostics

- 62 antenna BPMs (arcs etc)
- **26 stripline BPMs (Hall D)**
- 2 cavity "nA" BPMs
- 6 dual-plane wire scanners
- 16 fluorescent viewers
- **3 synchrotron light monitors**





Synchrotron light monitors at high dispersion locations in arcs 1 and 2 now provide truly parasitic beam quality monitoring, including energy tails and slow modulations



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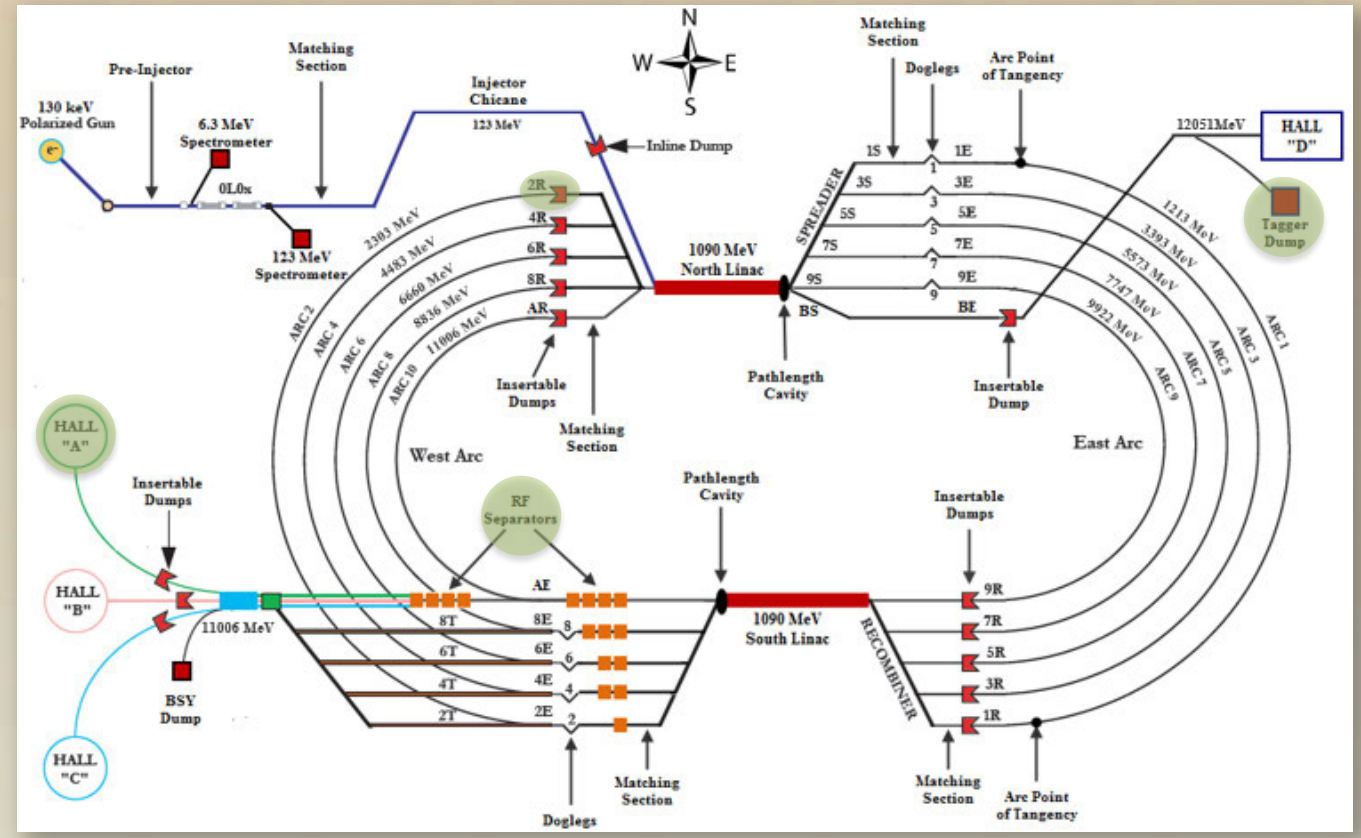
Commissioning Objectives



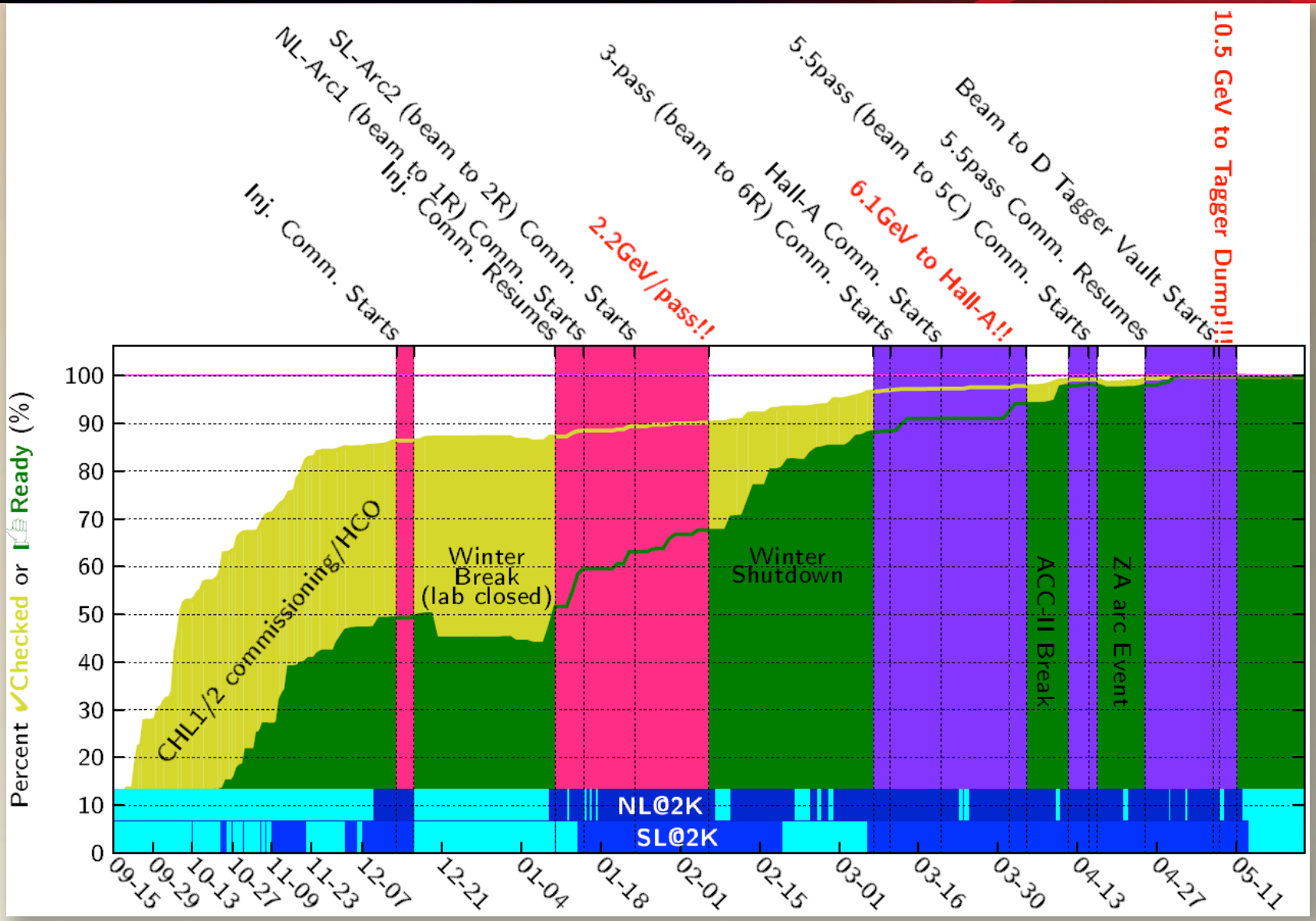
Main Goals for **November 2013-May 2014**

- Deliver 2.2 GeV beam to 2R dumplette
- Deliver >6 GeV CW beam to Hall A
- Deliver >10 GeV beam to Hall D

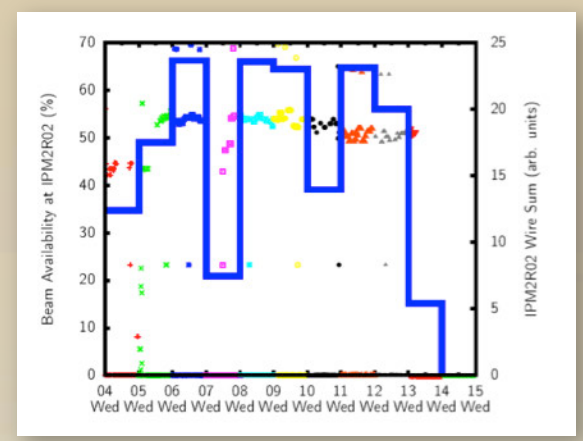
Main Goals for **November 2014-May 2015**

- Commission 750 MHz separators
- CW beam to multiple halls
- Three-beam CW beam program
- Measure/improve machine model

Commissioning Timeline

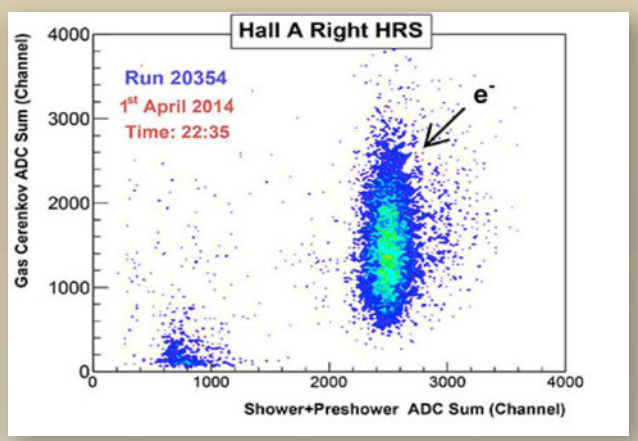


Commissioning Milestones



2.2 GeV availability for 8 hrs

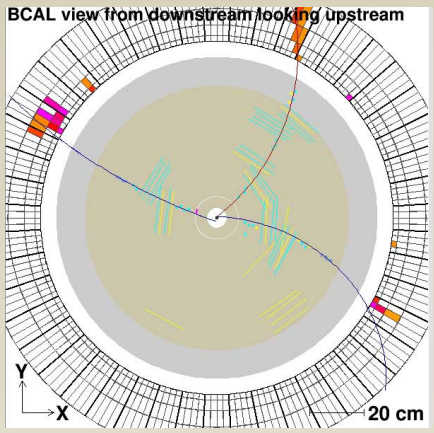
2.2 GeV beam on Arc 2 viewer



Hall A: first 6.1 GeV scattered e-

10.5 GeV to Hall D ramp

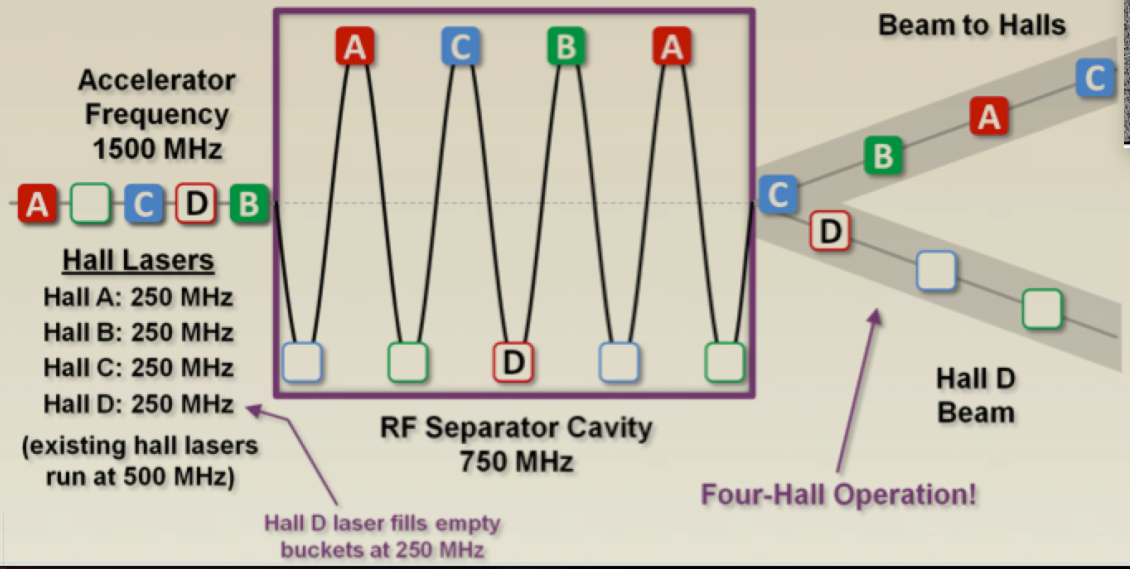
10.5 GeV to Hall D Tagger Dump



First Hall D GlueX events

2015 Commissioning Milestones

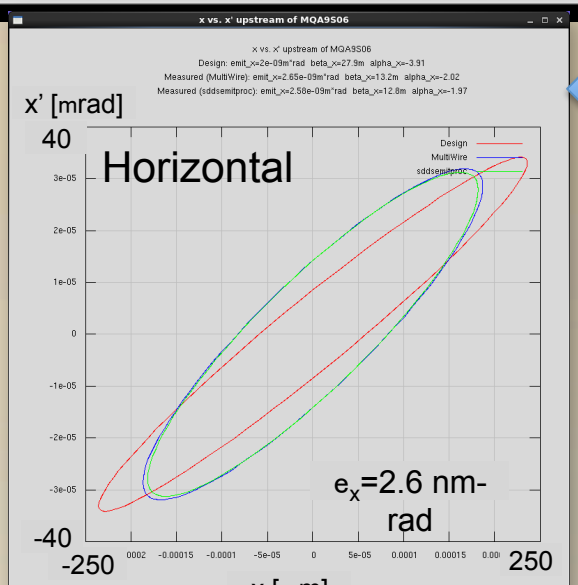
- FY15 Winter shutdown
  - Upgraded dogleg system
  - Installed 5th pass 750 MHz RF separators (to support 4-hall operations)
  - Installed 250 MHz drive lasers for polarized source
- FY15 Spring run
  - Commissioned 250 MHz drive laser system
  - Commissioned 750 MHz RF separators
  - **Simultaneous beam to Halls A and D on 5th pass**

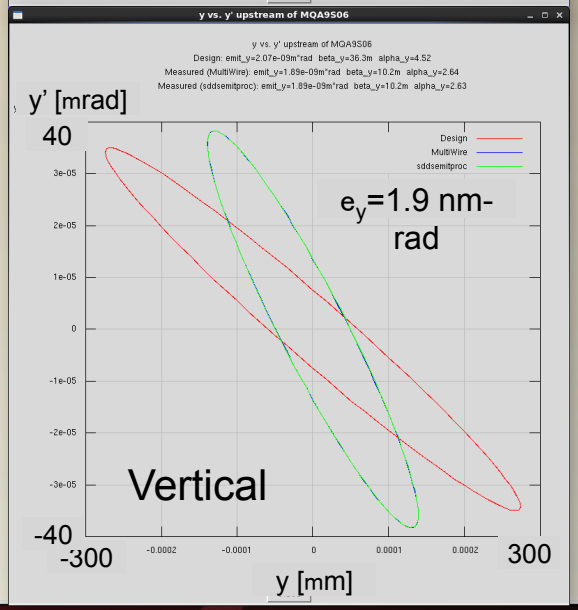


Meeting Beam Requirements

- Optimizing performance of SRF systems
  - Online **genetic algorithms** for **gradient/heat load optimization**
- Understanding synchrotron radiation effects
  - **Synchrotron radiation compensation coils** in higher-pass arcs
  - Design optics to **minimize transverse emittance growth**
- Model and matching improvements
  - Towards a **"model-driven machine"**, lower tuning deviation from design
  - Improve speed, reproducibility of transverse matching
  - LOCO: measure body gradients of spreader/arc/recombiner dipoles
  - RayTrace: measure phase space pseudo-ellipse evolution
- Other 12 GeV operational limitations
  - Pathlength control: **dogleg upgrade**
  - Tunnel air conditioning and environmental heat management

Model-Based Optics Rematching





Before match, as found

After match

All data plotted is the projected beam ellipse in (x,x') at start of an upstream scanned quad

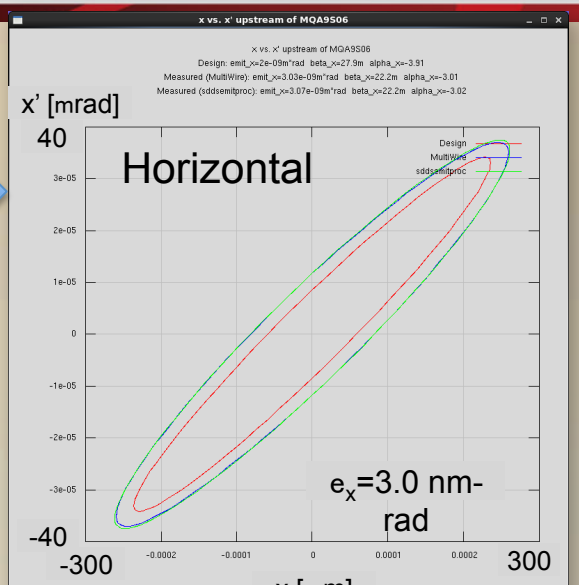
This data is for Arc 9 spreader

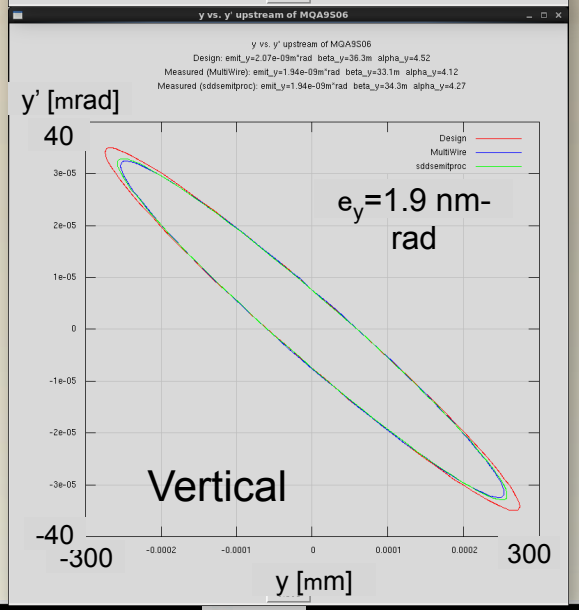
Blue and green ellipses are measurements

Red data is model prediction

Discrepancy in horizontal after match is only due to measured beam emittance being larger from expected design value

Faster, more reproducible optics matching through CEBAF





Optimizing SRF Performance

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

- Multiple paths to reach availability goals over time
  - Improve operations **cavity recovery processes**, post-trip retune time
  - Improve C20 trip models: maximize gradient, minimize trip rate
  - Continue C20➔C50 refurbishment program
  - In-situ He processing to improve gradients, reduce field emission

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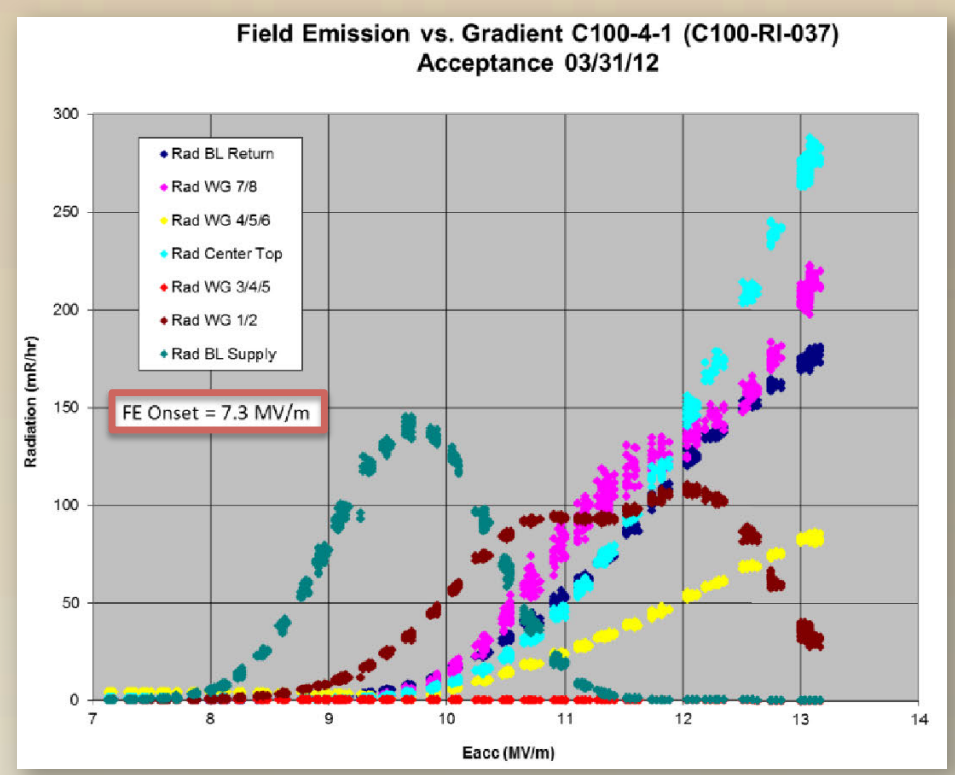
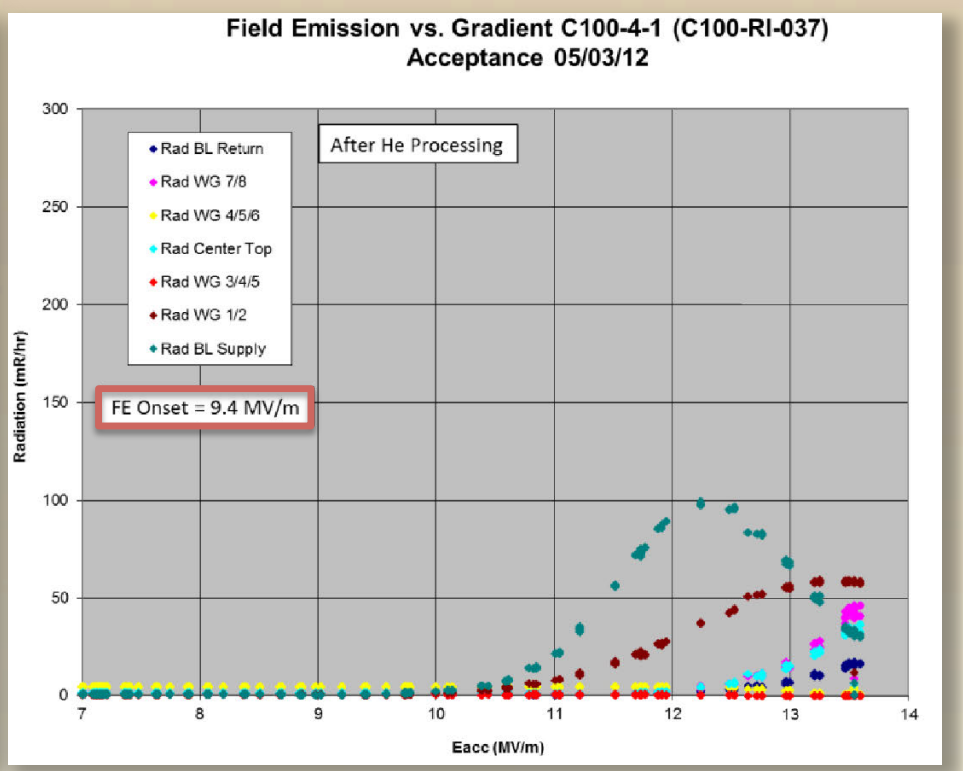
Cavity Helium Processing





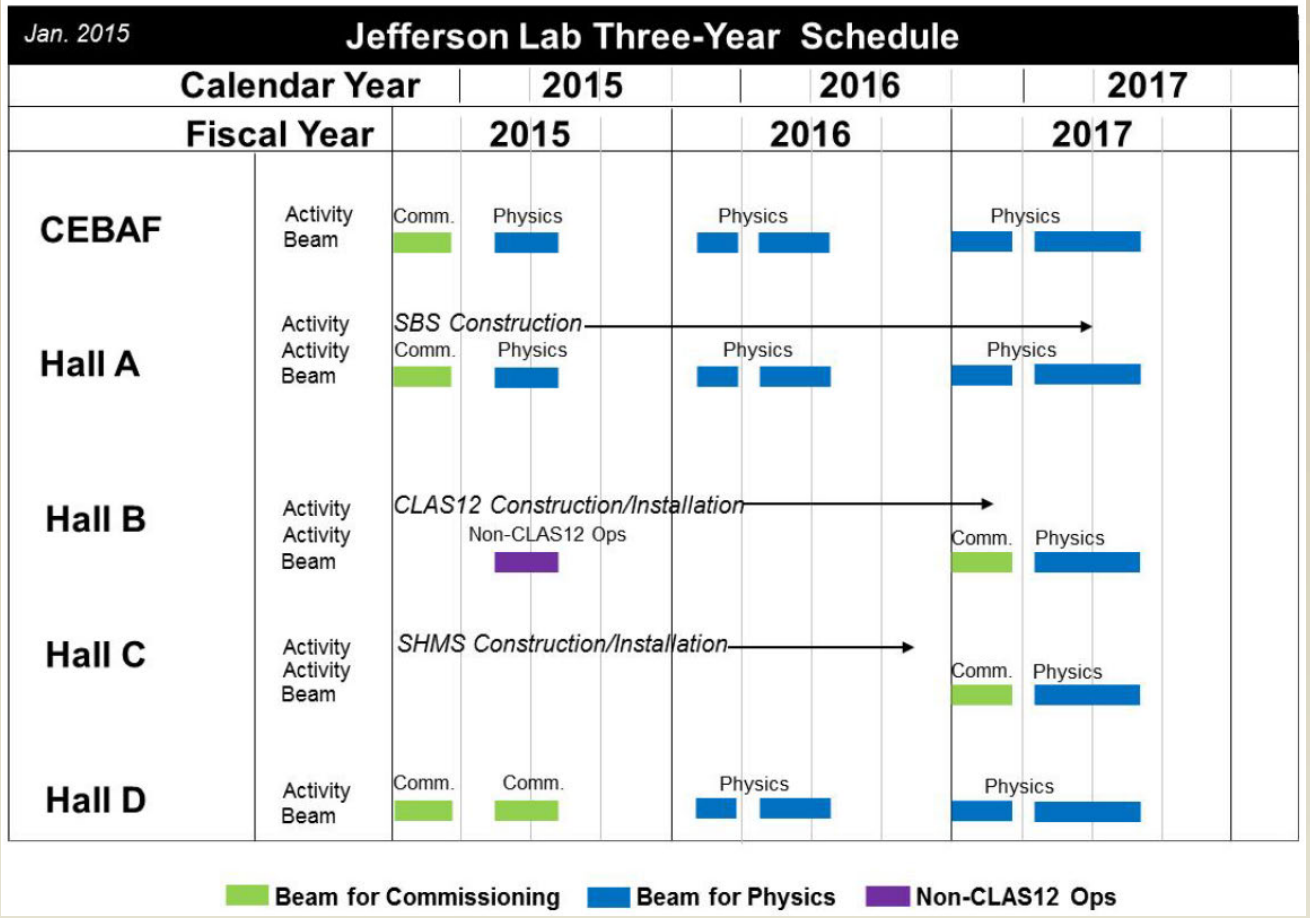
Helium processing of C100 cryomodules

- Introduce helium gas into cavity vacuum space
- Run RF to clean cavity surfaces
- Warm up and pump down to remove all residual gas
- **Improves high-field Q, reduces field emission, greatly reduces arcing at cold ceramic window**

Future plans are to routinely helium process some cryomodules every summer shutdown

Future Run Plans and Physics

- **Summer FY15:** Install AC, complete power distribution work, install C50 cryomodule, He process C100 cavities
- **Fall FY16:** Finalize optics, demonstrate full 12 GeV capability



Future 12 GeV Physics Program

Topic	Hall A	Hall B	Hall C	Hall D	Other	Total
The Hadron spectra as probes of QCD (GlueX and heavy baryon and meson spectroscopy)		1		3		4
The transverse structure of the hadrons (Elastic and transition Form Factors)	5	3	2	1		11
The longitudinal structure of the hadrons (Unpolarized and polarized parton distribution functions)	2	3	6			11
The 3D structure of the hadrons (Generalized Parton Distributions and Transverse Momentum Distributions)	5	9	7			21
Hadrons and cold nuclear matter (Medium modification of the nucleons, quark hadronization, N-N correlations, hypernuclear spectroscopy, few-body experiments)	6	3	7		1	17
Low-energy tests of the Standard Model and Fundamental Symmetries	3	1		1	1	6
TOTAL	21	20	22	5	2	70

At least a decade of productive physics with 12 GeV CEBAF

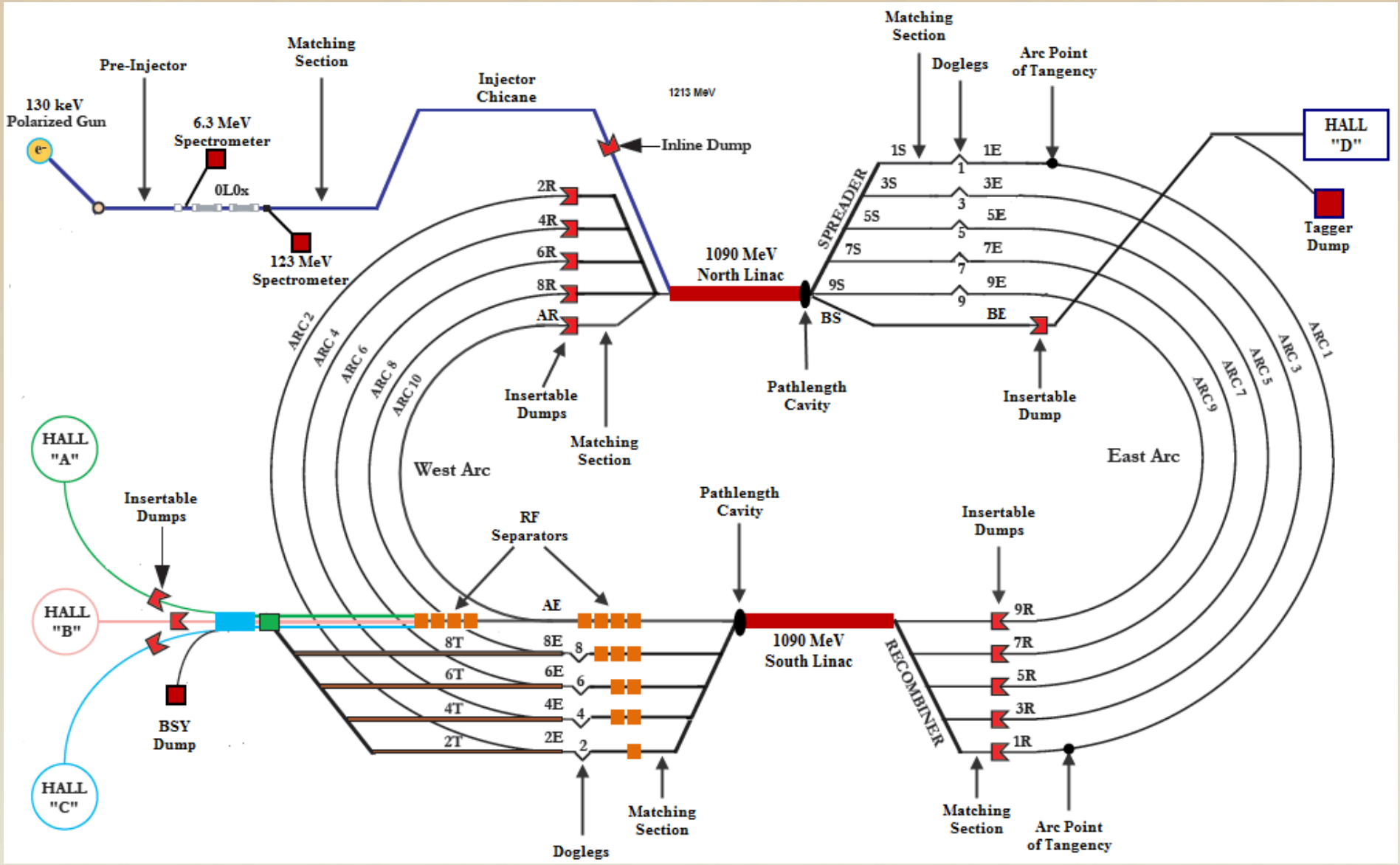
Acknowledgments

- This work is presented on behalf of Jefferson Laboratory staff, particularly members of the Operations and Beam Transport Teams

- Special thanks to M. Spata, Y. Roblin, A. Freyberger, F. Pilat, J. Benesch, M. Tiefenback, D. Turner, and M. McCaughan.

- And thanks to you, the audience, for your attention and interest in the CEBAF 12 GeV program!

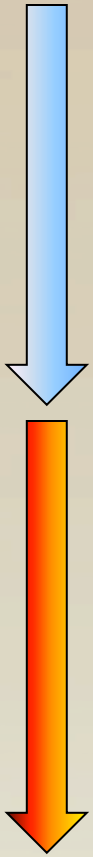
CEBAF Detail Schematic



Transverse Emittance Evolution

Region	σp/p [x10^{-3}]	σ_x [nm]	σ_y [nm]
Chicane	0.5	4.00	4.00
Arc 1	0.05	0.41	0.41
Arc 2	0.03	0.26	0.23
Arc 3	0.035	0.22	0.21
Arc 4	0.044	0.21	0.24
Arc 5	0.060	0.33	0.25
Arc 6	0.090	0.58	0.31
Arc 7	0.104	0.79	0.44
Arc 8	0.133	1.21	0.57
Arc 9	0.167	2.09	0.64
Arc 10	0.194	2.97	0.95
Hall D	0.18	2.70	1.03

12 GeV CEBAF has interesting non-equilibrium beam evolution



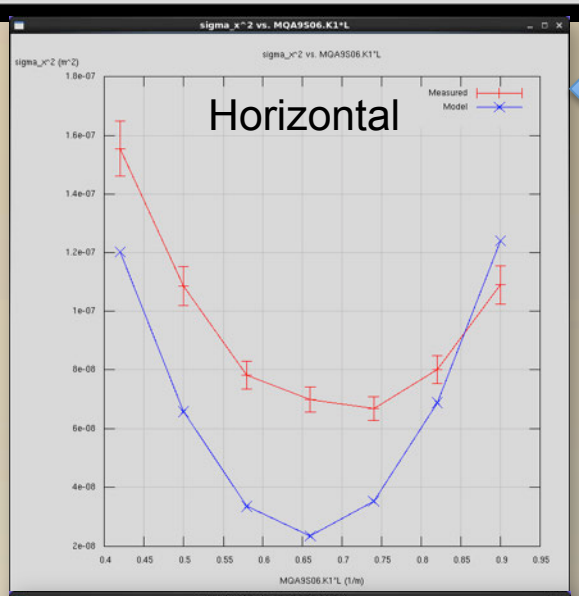
Adiabatic damping dominated

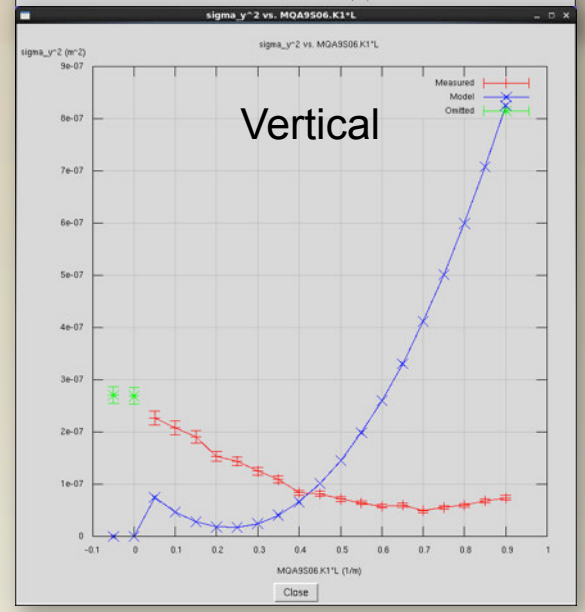
Arcs 6-10 with optics Reconfigured from FODO to DBA

Synchrotron radiation dominated

Emittances are geometric
All quantities are rms
Y. Roblin

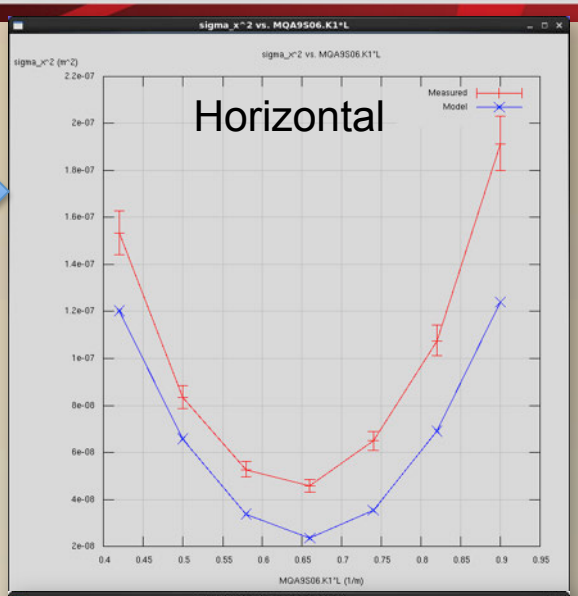
Model-Based Optics Rematch (raw)

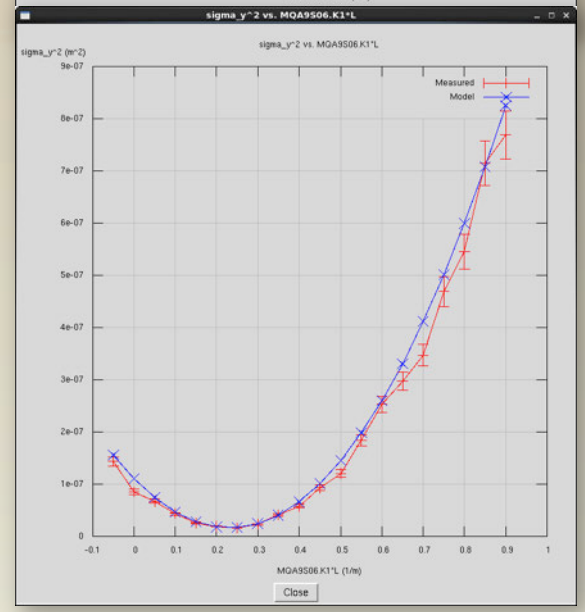




Before match, as found

After match





All data plotted is

(measured beam s_{rms})^2
vs
(set quadrupole KL)

Blue data is model prediction

Red data is measurement

Discrepancy in horizontal after match is only due to measured beam emittance being larger from expected design value